Coordinating Panel for Advanced Detectors Workshop (CPAD 2024)

Monday, 18 November 2024 - Friday, 22 November 2024

Book of Abstracts

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Joint RDC 01 & 02 & 04 / 2

CosmoLink: Wireless Coincidence Detector Network

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CosmoLink is a compact coincidence detector designed for portable on-site muon flux measurement, featuring two scintillators coupled with wavelength shifting (WLS) fibers for efficient light guiding to Silicon photomultipliers (SiPMs). Each readout channel is equipped with a transimpedance preamp, discriminator, and peak hold circuit. A successful coincidence is digitized using an Analog to Digital Converter. Data, including coincidence counts and ADC values, is acquired using a low-cost microcontroller, with wireless transmission to a central server for collective data collection in shower experiments. Multiple detectors can be grouped in various geometries for broader cosmic ray studies, with inbuilt GPS and DMA supporting data synchronization across wide areas. The system is battery-powered, with options for solar or grid power, making it suitable for both small and large telescope arrays. Currently one prototype unit is being developed.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 5

Understanding the Response of a Qubit Chip Using Novel Materials in the G4CMP Simulation Toolkit.

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Understanding phonon kinematics and charge propagation in superconducting devices is crucial for minimizing correlated errors in superconducting qubits and conducting low-threshold dark matter searches. For nearly a decade, the Geant4 Condensed Matter Physics (G4CMP) package, has been limited to simulating charge and phonon transport in silicon and germanium materials. In this work, we have expanded the capabilities of G4CMP to include novel materials such as sapphire (Al_2O_3), Gallium Arsenide (GaAs), Lithium Fluoride (LiF), Calcium Tungstate ($CaWO_4$), and Calcium Fluoride (CaF_2). We demonstrate the use of this toolkit in generating phonon transport properties for these materials and compare the results with experimentally determined values where available. Additionally, we explore the performance of superconducting devices utilizing these materials.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 6

Developing A Qubit-Based Sensor For Low Energy Particle-like Dark Matter

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One of the challenges in exploring promising novel materials for dark matter searches is the detection of sub-eV energy excitations from light-dark matter interaction with a target material. Dark matter interaction can excite sub-eV optical phonon modes in polar materials like sapphire. We plan to utilize superconducting qubits on a sapphire substrate to study their response to energy deposition into the superconducting film and the substrate by irradiating them with photons and particles and also generating phonons in the chip. A fraction of the incident energy is expected to break Cooper pairs in the superconductor, releasing quasiparticles. As the quasiparticles tunnel across the Josephson junction, the charge parity of the qubit changes. The parity switching rate is proportional to the quasiparticle density in the qubit superconductor film and can be measured using standard qubit readout protocol. This presentation describes our ongoing attempt to build such a prototype detector.

Poster Session / 7

Searching for Light Dark Matter with Narrow-Gap Semiconductors: The SPLENDOR Experiment

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The SPLENDOR collaboration (Search for Particles of Light dark mattEr with Narrow-gap semiconDuctORs) is using novel narrow-bandgap single-crystal semiconductors as ionization detectors to search for low mass dark matter. We have developed a series of magnetic Zintl phase semiconductors with electronic bandgaps on the order of 1-100 meV, which will allow for sensitivities to fermionic dark matter with sub-MeV masses and bosonic dark matter with sub-eV masses. The materials are operated as ionization detectors, instrumented in a point contact geometry operated at mK temperatures, with the excited charge signal being read out with low-noise cryogenic HEMT based amplifiers. Our prototype charge amplifier has achieved sub-10 electron resolution and its performance is independent of detector material - offering utility to many other ionization based detection schemes. In this contribution, we will give an overview of the SPLENDOR project, discuss our recent progress, and give preliminary results from our first run with our $Eu_5In_2Sb_6$ based detector.

This presentation is on behalf of the SPLENDOR collaboration and is supported by the Laboratory Directed Research and Development program of Los Alamos National Laboratory.

RDC 06 - Gaseous Detectors Parallel Session / 8

Developing an ”ideal” gas TPC readout

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I will discuss a new collaboration between the University of Hawaii and Berkeley Lab dedicated to developing an “ideal” gaseous TPC readout technology based on integrated grid amplification and silicon pixel readout combined with ML/AI-capable frontend cluster discrimination.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 9

Low-Tc phonon-sensitive hafnium microwave kinetic inductance detectors for light dark matter searches

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Phonon-sensitive Microwave Kinetic Inductance Detectors (MKIDs) are scalable superconducting sensors enabling the next-generation low-mass dark matter direct search and neutrinoless double beta decay search. We have identified Hafnium (Hf) as a promising material to fabricate high-sensitivity MKID and developed the microfabrication process for low-Tc (140mK~200mK) resonators. Furthermore, since the Tc is lower than aluminum (Al) Tc, we designed Al phonon absorbers to collect phonons efficiently and couple them with Hf MKID via quasiparticle trapping to enhance sensitivity. Quasiparticle trapping solves the dilemma between the large inductor volume required by phonon collection efficiency and the small volume required by high kinetic inductance. This presentation will cover Hf MKID design and fabrication details, the measures to improve phonon collection efficiency, and results with x-ray calibration sources.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 10

Quantum Random Walk Simulator Using Ultrafast Optical Switches

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Quantum random walk processes have many intriguing applications in high energy physics including the simulation of parton shower evolution. We will present the design and initial results of a fiber loop time-bin quantum walk architecture using the hardware platform already in operation at the Fermilab Quantum Network in which the state of the photon is defined by its time-of-arrival. The fiber loop consists of an unbalanced Mach-Zehnder interferometer implemented using an ultrafast electro-optical switch. The input switch controls the photon path within the interferometer, while the output switch will direct the photon back into the interferometer or to single photon detectors to measure the probability distribution of arrival times. Depending on which path the photon takes each pass through the loop, its wave function will interfere on these optical switches similar to quantum interference on a beam splitter. This work is an important step towards utilizing real-world advantages of quantum information protocols to solve problems in high energy physics.

RDC 03 - Solid State Tracking Parallel Session / 11

Evidence of Charge Multiplication in Thin $25\mu\mathrm{m} \times 25\mu\mathrm{m}$ Pitch 3D Silicon Sensors

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Characterization measurements of $25\mu\text{m} \times 25\mu\text{m}$ pitch 3D silicon sensors are presented, for devices with active thickness of $150\mu\text{m}$. Evidence of charge multiplication caused by impact ionization below the breakdown voltage is observed. Small-pitch 3D silicon sensors have potential as high precision 4D tracking detectors that are also able to withstand radiation fluences beyond $10^{16}\text{n}_{\text{eq}}/\text{cm}^2$, for use at future facilities such as the High-Luminosity Large Hadron Collider, the Electron-Ion Collider, and the Future Circular Collider.
Characteristics of these devices are compared to those for similar sensors of pitch $50\mu\text{m} \times 50\mu\text{m}$, showing comparable charge collection at low voltage, and acceptable leakage current, depletion voltage, breakdown voltage, and capacitance despite the extremely small cell size. The unirradiated $25\mu\text{m} \times 25\mu\text{m}$ sensors exhibit charge multiplication above about 90 V reverse bias, while, as predicted, no multiplication is observed in the $50\mu\text{m} \times 50\mu\text{m}$ sensors below their breakdown voltage. The maximum gain observed below breakdown is 1.33.

RDC 04 - Readout and ASICs Parallel Session / 12

Design, Testing, and Results of the Multi-channel Fermilab CFD Readout ASIC

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We present the design and performance of the multi-channel Fermilab CFD ASIC (FCFD v1) developed for front-end readout of detectors with fast signals such as LGAD. The FCDF is a candidate readout ASIC for the barrel TOF detector of the ePIC experiment. It includes a specially designed discriminator that makes its response robust against amplitude variations of the signal. The application of the CFD directly in the readout ASIC promises to be more reliable and reduces the need for complicated and potentially time-dependent calibrations of precision timing detectors during their operation. We present measured performance of the FCFD v1 with multi-channel capability using LGAD signals from minimum-ionizing particles produced at the Fermilab testbeam facility. We demonstrate excellent timing performance for DC-LGADs with jitter below 10 ps and stability below 10 ps for signal sizes ranging from 7 to 60 fC. We also discuss measurements and design considerations for its use for AC-LGADs.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 13

High Energy Particle Detection with Large Area Superconducting Microwire Array

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We present the first detailed study of an 8-channel 2×2~mm^2 WSi superconducting microwire single photon detectors (SMSPD) array exposed to 120~GeV proton beam and 8~GeV electron and pion beam at the Fermilab Test Beam Facility. Recent advancement in the fabrication of large area SMSPDs make them an ideal sensors for dark matter detection and future accelerator-based experiments. The SMSPD detection efficiency was measured for the first time for protons, electrons, and pions, enabled by the use of a silicon tracking telescope that provided precise spatial resolution of 30~μm for 120~GeV protons and 130~μm for 8~GeV electrons and pions. Time resolution of 1.15~ns was measured for the first time for SMSPD with proton, electron, and pions. We will also present future plans and next steps of this exciting R&D program.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 14

Searching for axions and dark photons with superconducting nanowire single photon detectors (SNSPDs) in the BREAD experiment

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We present the progress towards a first stage dark photon BREAD (Broadband Reflector Experiment for Axion Detection) pilot experiment with a focus on SNSPDs. The BREAD experiment searches for axions and wave-like dark matter using a novel dish resonator which allows us to utilize state-of-the-art high-field solenoidal magnets. The axion target mass extends from ~[illegible]eV to eV, this large mass range makes it difficult to scale traditional resonator setups to the required volume. However, metallic surfaces in a high magnetic field dark matter axions can convert to photons regardless of axion mass. These photons can then be focused by a parabolic focusing reflector onto a low noise single photon counting detector. One of the single photon counting detectors that can be used for the BREAD experiment is superconducting nanowire single photon detectors (SNSPDs) that are sensitive to 0.1 to 1 eV axions and dark photons, due to its sensitivity to 1-10um photons.

RDC 07 Low-Background Detectors Parallel Session / 15

A Potential Method for the Production of Ice-XI for Low Mass Dark Matter Detection

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For nearly a century, dark matter has been a topic of excited debate and remains an area of active research. Currently, there are three main avenues of dark matter detection: direct detection, indirect detection for example of decay products, or production in particle accelerators. We focus on a specific material that could be used in the first of these. Ice-XI is a hydrogen-ordered phase of water ice that

forms at low temperatures. It is a particularly promising target for use in direct detection of light dark matter, specifically single phonon detection. We describe an attempt to make ice-XI employing minimal specialty equipment: using a KOH dopant and maintaining the sample at or below 72 K for several days via an LN2 bath in a vacuum chamber. The phase transition from ice-Ih to ice-XI is monitored through dielectric measurements of capacitors embedded in the ice samples.

Two week-long tests were performed using ice doped with 0.01 M and 0.05 M KOH. We observed no change in the 0.01 M test, but saw a slight increase in capacitance for the 0.05 M test. From previous studies, we expected the ice-XI phase transition to be accompanied by a rapid decrease in capacitance. Our results indicate that the phase transition did not occur in either test. However, some previous studies observed an initial slight increase before the main decrease in capacitance associated with the phase transition. Therefore, we suspect that this initial transition stage may have occurred in the 0.05 M test, and had the test been left to run longer, we may have observed the main stage of the transition as well.

While we were unsuccessful in documenting the transition, we believe the methodology to be sound. In future iterations of the experiment, we would either perform the test for longer time periods, or try some combination of higher KOH concentrations, colder temperatures, and/or smaller ice samples which could all accelerate the transition, making it more readily observable with our setup.

RDC 07 Low-Background Detectors Parallel Session / 16

High-purity CVD tungsten for use in low-background detectors

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Materials showing exceptionally low content of radioactive impurities and excellent mechanical properties (e.g., yield strength) are needed as structural and shielding materials in current and next-generation low-background detectors. Impurities of naturally occurring radionuclides Th-232, U-238, and their progeny, are typically required to be at or below the microBq/kg range, equating to concentrations in the parts per trillion (ppt) or parts per quadrillion (ppq) range. These levels can be several orders of magnitude lower than levels generally found in earth materials (i.e., soils and rocks) or in most commercially available materials. Such stringent radiopurity constraints pose a challenge in the sourcing and validation of materials, for which the most sensitive analytical methods are required. When sufficiently radiopure materials are not available off-the-shelf, new manufacturing methods are investigated and developed (e.g., ultra-pure copper electroforming).
Thanks to exceptional yield strength (750 MPa), high atomic number, and high density, tungsten has garnered interest as a potential structural and shielding material. Previous searches, however, have determined commercially available tungsten in the milliBq/kg range, from impurities of U-238 and its progeny, preventing the use of this material in low background studies.
In this work, we have investigated chemical vapor deposition (CVD) processes as a mean to produce tungsten material with sufficiently low content of Th-232 and U-238 impurities for use in ultra-sensitive detectors. To overcome challenges associated with measuring low-levels of Th-232 and U-238 in a tungsten matrix, a novel ICP-MS based analytical method was developed for tungsten assay. Detection limits of a few tens of ppq were obtained for both radionuclides. Produced samples of CVD tungsten were measured at levels ranging from single-digit ppt to less than a few tens of ppq of Th-232 and U-238, with a purification efficacy greater than three orders of magnitude compared to off-the-shelf tungsten. This work advances analytical chemistry capabilities for ultra-pure material validation, and paves the way for the use of ultra-pure tungsten in low-background detectors.

Joint RDC 03 & 11 Parallel Session / 18

Characterization of the response of Brookhaven AC-LGADs to proton and gamma irradiation

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Low-Gain Avalanche Detectors (LGADs) have excellent timing performance due to their incorporation of a doped layer tuned to provide moderate gain of about a factor 20. Classic LGADs have no-gain regions; addressing this has stimulated various novel designs. Due to their fill factor limitations, the classic LGAD's spatial resolution is limited to ~ 1mm. The AC-coupled LGAD (AC-LGAD) addresses this issue by eliminating the no-gain region and coupling the signal to the pads capacitively. Several types of AC-LGADs designed by Brookhaven National Laboratory had been irradiated by gamma rays and 400 MeV protons. Characterization methods, including those for IV, CV, inter-pad isolation, charge collection efficiency, and Transient Current Technique (TCT), are being developed at the University of New Mexico. Initial results will be presented.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 19

Photon detection based on microwave-optical quantum transducer

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Photon detection at radio frequencies (RF) plays an essential role in high-energy physics such as dark matter search. The detection of weak signal converted from dark matter in the presence of excess quantum and classical noise can be achieved by exploiting high-quality superconducting RF cavities in the presence of strong magnetic field. However, this is a nontrivial detection problem due to the weak energy of microwave photons and their vulnerability to thermal noise. One can gain advantage in sensing performance if the RF photons can be converted to high frequencies with larger energy and robustness against thermal noise. Quantum transduction, which faithfully converts photons from microwave to optical frequencies, has opened new horizons for quantum detection of weak RF signals. Here we propose and introduce a quantum-transduction-based on a three-dimensional electro-optic cavity system. The transducer enables high conversion efficiency between microwave and optical frequencies at low thermal noise condition. We also discuss the dark matter detection scheme in the presence of magnetic field based on our transducer. The proposed detection scheme can bring advantage to the sensor's performance by leveraging photon counting at optical bands.

Joint RDC 03 & 11 Parallel Session / 20

LGADs for the future Muon Collider Detectors

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The Muon Collider is a unique future energy frontier machine that will provide both energy reach and high precision within the same accelerator complex. Muon collider detectors are exposed to very large beam induced background (BIB) originating from muon decays. Precision timing 4D charged particle tracking is essential for mitigating out-of-time BIB effects. Forward muon tagging is a crucial tool for the physics program but challenging due to high occupancy and radiation dose, requiring a detector that is finely granular in space and time. In this talk I will describe the challenges, present specifications necessary to achieve the target performance, and discuss how LGAD based detectors can provide a solution for the challenges outlined above.

Joint RDC 03 & 11 Parallel Session / 21

Results for pixel and strip centimeter-scale AC-LGAD sensors with a 120 GeV proton beam

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We present the results of an extensive evaluation of strip and pixel AC-LGAD sensors tested with a 120 GeV proton beam, focusing on the influence of design parameters on the sensor temporal and spatial resolutions. Results show that reducing the thickness of pixel sensors significantly enhances their time resolution, with 20 µm-thick sensors achieving around 20 ps. Uniform performance is attainable with optimized sheet resistance, making these sensors ideal for future timing detectors. Conversely, 20 µm-thick strip sensors exhibit higher jitter than similar pixel sensors, negatively impacting time resolution, despite reduced Landau fluctuations with respect to the 50 µm-thick versions. Additionally, it is observed that a low resistivity in strip sensors limits signal size and time resolution, whereas higher resistivity improves performance. This study highlights the importance of tuning the n+ sheet resistance and suggests that further improvements should target specific applications like the Electron-Ion Collider or other future collider experiments. In addition, the detailed performance of four AC-LGADs sensor designs is reported as examples of possible candidates for specific detector applications. These advancements position AC-LGADs as promising candidates for future 4D tracking systems, pending the development of specialized readout electronics.

RDC 11 - Fast Timing Parallel Session / 22

Characterization of Low Gain Avalanche Detector Gain by Means of the Transient Current Technique

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Abstract

Low Gain Avalanche Detectors (LGADs) are silicon-based devices that can achieve good timing resolution due to their unique internal gain. LGADs are proposed for a wide range of fast-timing applications in high energy physics, nuclear physics, and other precision measurements of rare processes. The p-doped gain layer in an LGAD allows generation of a controlled avalanche of charge carriers, with a multiplication factor in the range 10-100. The gain is strongly dependent on the bias voltage, particularly for values close to breakdown voltage. In this study, the gain of LGADs is studied as a function of the bias voltage and as a function of the injected charge. Tests were performed with an infrared laser and a beta source to characterize the gain. Techniques developed in this study expand the characterization of LGAD performance from the case of minimum ionizing particles to the case of highly ionizing particles.

Acknowledgment

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RDC 01 - Noble Element Detectors Parallel Session / 23

Characterizing the Outgassing of Electronegative Impurities for nEXO

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nEXO is a 5 tonne liquid xenon (LXe) time projection chamber (TPC) that aims to detect neutrinoless double beta decay in ^{136}Xe with a projected 90% CL half-life sensitivity of 1.35x10^{28} yr. nEXO will be able to measure energy deposits from both ionization electrons and scintillation photons from events that occur inside the detector. To achieve the required 10 ms electron lifetime goal, it is important to understand how detector materials affect the chemical purity of LXe. This talk will overview nEXO's efforts to characterize the outgassing rates of different materials that are common in LXe TPCs as well as other candidate detector materials for nEXO.

RDC 09 - Calorimetry Parallel Session / 24

Scaling up the Scintillator Material for Large Calorimetry with a 3D-Projection Chamber

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Since the entry to the precision era for the nuclear and high-energy physics communities, excellent particle detection capability is highly demanded for each part of the detection system. A homogeneous EM-Calorimeter could provide excellent energy resolution for electrons and photons in a wide dynamic range allowing rapidity coverage, particle containment and granularity. However, concerns of high cost and radiation hardness in a severe radiation environment are often raised for large (tens of tons) calorimeters planned in future collider experiments such as the Electron-Ion Collider (EIC).
We propose a scalable 3D-projection calorimeter designed for the EIC's second detector, leveraging cost-effective scintillator materials with full 3D readout. This innovative detector provides fine granularity, tunable high light yield, fast timing, excellent scalability, and cost efficiency. Beyond EIC applications, this detector development may also find other applications in particle physics, nuclear physics, nonproliferation, and medical imaging instruments.
This presentation will detail the detector concept and key performance metrics.

RDC 02 - Photodetectors Parallel Session / 25

Development of UV-Sensitive GaN Single Photon Geiger-Mode Avalanche Photodiodes

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Silicon photomultipliers (SiPMs) have had a transformational impact on many important experiments in high-energy and astrophysics. However, the SiPM is intrinsically limited in its photoresponse below ~300 nm, a critical wavelength range for liquid noble scintillation detectors. An alternative to silicon for the fabrication of UV avalanche photodiodes (APDs) are the wide-bandgap III-N semiconductors AlGaN and GaN, which have a tunable direct bandgap energy and better sensitivity in the UV than Si detectors. With the commercial availability of high-quality native III-N substrates, we have successfully fabricated single GaN APDs and demonstrated enhanced UV sensitivity and Geiger-mode operation. Encouraged by these results, we improved our device design to reduce tunneling currents and device mesa edge breakdown, which we believe are the most significant contributors to the dark count rate near avalanche. We present measurements of our latest III-N APD devices with beveled mesas and a modified internal structure that lowered the dark current density 30,000 times.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 26

The Advanced Quantum Network at Fermilab and the Larger Chicagoland Area —Synergies with HEP Science

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We present the latest developments of the Fermilab and the Advanced Quantum Networks experiments. These operating quantum networks, with deployed infrastructure spanning the Chicagoland

metropolitan and beyond which include nodes at Fermilab, Northwestern University, The University of Illinois at Urbana-Champaign, Caltech, the Jet Propulsion Laboratory, and Argonne National Labs. The deployed network infrastructure and results includes links spanning more than 50 km, have achieved record quantum teleportation and entanglement swapping fidelities using time-bin photonics qubits with the existing fiber optics infrastructure. We will focus on new world-leading results on teleportation of entanglement protocol implementations with many implications to quantum communication and HEP science. We will discuss a program to increase the information rate and distances as well as to realize more complex protocols and how the existing network infrastructure including the classical backbone with a record timing synchronization below 3 ps can enable distributed sensing experiments with HEP applications.

RDC 11 - Fast Timing Parallel Session / 27

Time-resolved Intensity Interferometry for HEP Science with Ultrafast Quantum Sensors

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We present a proposal for a pathfinder experiment towards an ultra-precision time resolved intensity interferometry (TRII) system that will enhance the sensitivity of the current best telescopes. TRII measurements rely on the ability to time correlate the detection of photons from the same stellar source at two remote locations to better than 10 ps precision. Such unprecedented precision has not been accessible until the recent advent of ultrafast superconducting nanowire single photon detector (SNSPD) technology. Such a TRII system, equipped with these novel photon detectors, will enable HEP science measurements currently out of reach and help us understand the drivers for cosmic evolution. Enabled by the state-of-the-art SNSPD with tenths of picosecond-level timing resolution, the proposed TRII system will serve as a pathfinder towards the detection of gravitational waves from primordial black holes (PBHs) that can account for the observed dark matter in our Universe. The proposed approach has the potential to detect gravitational waves with lower frequencies compared to the existing LIGO and Virgo experiments and enables the observation of merger events in supermassive binary systems. The proposed pathfinder experiment is aimed to be deployed in Cerro Tololo Inter-American Observatory (CTIO) with an easily accessible baseline of 10 km.

RDC 04 - Readout and ASICs Parallel Session / 29

28nm sub-10ps TDC ASIC for 4D tracking - design and characterization

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4D trackers with ~10ps timing will be transformative at future collider experiments. Timing is crucial for reducing the combinatorial challenge of track reconstruction at extremely high pileup densities, it offers completely new handles to detect and trigger on long-lived particles (LLP), expands the reach to search for new phenomena, and enables particle-ID capabilities at low transverse momentum. At the Muon Collider, the timing information will be essential for reduction of the beam-induced background (BIB).
CERN's EP-R&D-WP5 survey has promoted the selection of 28nm CMOS node as the next step in microelectronics scaling for HEP designs. As one of the critical blocks necessary to enable 4D operation in trackers we present the design and characterization of a 4-channel sub-10ps Time-to-Digital Converter (TDC) ASIC in the 28nm node. The developed TDC is based on a novel 2D Vernier ring-oscillator structure with embedded sliding-scale technique for conversion linearity improvement that will simplify calibration of the TDCs, especially useful in high-channel count implementations such as 4D trackers.
The core of the TDC architecture is composed of differential voltage-controlled delay cells set at 50ps propagation delay and assembled in a 4-cell ring-oscillator with enable/disable function with programmable starting state. The ring-oscillator, enabled with a START trigger, coupled with a counter and a series of flip-flops sampling the state of the oscillator in correspondence of a STOP trigger performs a START-STOP time-interval quantization with 50ps time-steps and 1.6ns range. The feature of having the oscillator starting condition programmable, coupled with pseudo-random selection of the starting point at each measurement cycle, performs the sliding-scale function thus improving the conversion linearity beyond the limits set by mismatches between the delay cells of the ring-oscillator. To reach a sub-10ps resolution, the 50ps time-step of the previous structure is interpolated by a factor of 8 using a second ring-oscillator with delay cells set to 56.25ps propagation delay and enabled by a second STOP signal. Each step of the first ring-oscillator is sampled in correspondence of both rising and falling edges of the second ring-oscillator by a 2D array of flip-flops. This 2D Vernier structure reaches a resolution equal to the difference of propagation delays of cells in the two oscillators, i.e. 6.25ps. Both ring-oscillators implement the programmable starting state, i.e. sliding-scale, thus improving the linearity of the overall conversion.
Each ASIC channel receives one START and two STOP signals, simultaneously performing a 6.25ps and a 50ps measurements of the two time-intervals, for example a time-of-arrival (TOA) and a time-over-threshold (TOT) measurement. The 1.6ns measurement range of the prototype can easily be extended in future iterations by simple addition of a flip-flop to the counter.
Both the design and characterization of the 4-channle ASIC prototype will be presented at the workshop.

RDC 09 - Calorimetry Parallel Session / 30

5-D calorimeter design for optimal performance with AI/ML

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Many physics analyses use some form of AI/ML to identify physics objects such as jets and electrons and/or for whole event classification. However, such an approach has generally been taken a long time after the detector was designed and constructed. It is therefore relevant to question whether a proposed design of a future calorimeter is optimal for the application of AI/ML techniques. This paper raises a number of relevant related questions in areas such as granularity vs. confusion, ML online/offline compatibility, ML and on-detector logic, ML and timing, and cost constraints via ML. Possible related future research directions will be discussed.

RDC 09 - Calorimetry Parallel Session / 31

RADiCAL - Ultracompact, Fast-timing EM Calorimetry

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This project aims to advance the design of high-performance electromagnetic (EM) calorimeters for future particle physics experiments, particularly in high-luminosity environments with intense radiation and pileup conditions.The research builds on the RADiCAL (Radiation-hard and Compact) modular sampling calorimeter approach, which employs dense materials like LYSO:Ce scintillator plates interleaved with tungsten plates to minimize detector size while optimizing performance. The 14 mm x 14 mm x 135 mm modules—comparable in size to a human index finger—provide excellent timing and energy resolution, using specialized quartz capillaries filled with wavelength-shifting filaments to guide light to silicon photomultipliers (SiPMs).The primary objectives of this project are: to reduce the timing resolution to ≤ 10 ps for high-energy electrons and photons, important for their association with specific events produced in colliding-beam experiments and with decays-in-flight of long-lived particles; and to reduce the stochastic term in the energy resolution to ≤ 10%/√E, particularly important for the measurement of the energy of lower energy electrons and photons. These goals will be achieved by optimizing the RADiCAL structure with fast-response scintillators, efficient wavelength shifting capillaries, next-generation SiPMs, and advanced readout electronics. More broadly, the modular approach also enables the testing of advanced materials, photosensors and electronics, developed in collaboration with CPAD RDC and ECFA DRD groups. The versatility of RADiCAL modules offers the potential to distinguish EM showers from hadrons and beam-induced backgrounds, making them a valuable tool in a variety of detector environments, including future circular colliders (FCC-ee, FCC-hh) proposed for the European Laboratory for Particle Physics (CERN), the muon-collider proposed for Fermi National Accelerator Laboratory (Fermilab), and fixed target and forward-physics experiments.

RDC 01 - Noble Element Detectors Parallel Session / 32

Status of the CHILLAX Xenon-doped Liquid Argon Experiment

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Low-threshold, low-background noble liquid ionization detectors are desired for low-mass dark matter and Coherent Elastic Neutrino Nucleus Scattering (CEνNS) searches. Of the two primary noble

elements used for particle detection, argon and xenon, argon can yield higher energy nuclear recoils, but the electroluminescence light produced by Ar2 dimer is difficult to collect and the slow de-excitation process can cause a pileup of single-electron backgrounds. When liquid argon is sufficiently doped with xenon, the presence of xenon in the vapor can lead to electroluminescence emission from Xe*or ArXe*, which may have a higher yield, decay faster, and be collected more efficiently. The CHILLAX experiment at LLNL has demonstrated the highest xenon doping concentration in liquid argon, and is actively developing a dual-phase xenon-doped argon detector to demonstrate the benefits of xenon doping for low-energy sensitivities. In this talk, we will discuss the recent progress of the CHILLAX experiment, including a new record for the xenon concentration in liquid argon, a measurement of the gas xenon concentration, and other results.

RDC 01 - Noble Element Detectors Parallel Session / 33

Illuminating sub-GeV dark matter with liquid xenon TPCs

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Probing sub-GeV dark matter with liquid xenon TPCs is possible using the ionization-only signal. However, sensitivity with these detectors is currently hindered due to instrument backgrounds, delayed electron and photon emission. In this presentation, we show new data revealing the source of delayed emission. We discuss possible ways to mitigate this background for future experiments, and present sensitivity projections to sub-GeV dark matter candidates.

RDC 10 - Detector Mechanics Parallel Session / 34

Thermal testing for Tracking Detector Mechanics

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Tracking detectors under preparation for the High Luminosity LHC, and for next-generation Higgs factories, hadron and muon colliders, will require components and mechanical structures providing unprecedented strength-to-mass ratios, thermal conductivity, and radiation tolerance. The CMS outer tracker incorporates such mechanical components to enable state-of-the-art functionality, including the central-section flat-barrel plank support structures and pixel-strip module spacers. At UC Davis, we have carried out a suite of complementary measurements of the thermal, mechanical, and radiation damage tolerance properties of materials such as carbon foam, carbon fiber, thermally conductive epoxies, and high-k materials such as AlCF and AlN. The findings are relevant for the CMS HL-LHC outer tracker and future tracking detectors.

RDC 10 - Detector Mechanics Parallel Session / 35

Machine-Detector Interface at a 10 TeV Muon Collider

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A considerable challenge to the physics potential at a multi-TeV muon collider is the significant amount of beam-induced background (BIB) produced near the interaction region (IR), primarily from muons decaying along the straight section near the IR. BIB mitigation, therefore, is one of the primary drivers of the machine-detector interface (MDI) design. Several strategies have been developed to reduce the quantity of and modify the composition of the BIB, enhancing the ability to discern collision processes of interest from the background. These approaches include fine-tuning the collider lattice design while meeting beam dynamics requirements, incorporating dense shielding structures in the forward regions of the detector, and designing a finely segmented detector with 30-60 ps timing resolution. This presentation will review the dominant sources of BIB, key BIB mitigation strategies, the impact of the resulting BIB on the detector, and promising directions for future work in muon collider MDI optimization.

Joint RDC 03 & 07 & 08 / 36

Measurement of Lattice Quantum effects in phonon assisted solid state detectors

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Particle-induced crystalline defects are critical in various applications, from detecting dark matter and Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) to enhancing quantum computing devices. Defects within crystals can store energy, which directly influences particle interaction spectra and detection sensitivity. Furthermore, pre-existing defects can anneal over time, potentially manifesting as backgrounds in low-threshold detectors or causing decoherence in quantum computing devices, such as qubits. Despite the predicted effects of these defects, a deep understanding of their behavior has been elusive. This challenge stems from the need for detectors with unprecedented low-energy resolution (below 1 eV) and reliable sources of low-energy nuclear recoil to accurately study these defects.
We will present results from defect simulations in the most common detector crystals and introduce a novel method that utilizes activated nuclei in the lattice, where the recoiling nucleus serves as a source of low-energy nuclear recoils. Additionally, we will share our recent progress in achieving a $\sim$eV-scale threshold to facilitate these measurements.

Joint RDC 07 & 08 & 09 Parallel Session / 37

Low-Threshold Phonon-Mediated Detectors with Background Discrimination

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We developed a new generation of detectors that combine the Electron Recoil (ER) and Nuclear Recoil (NR) discrimination capability of SuperCDMS ionization and phonon (iZIP) detectors with the low-threshold capabilities of High-Voltage (HV) detectors. Both ionization and phonons are measured in a monolithic crystal divided between a large-volume (low-voltage) region and a small-volume (high-voltage) region, connected via a narrow channel. This restriction makes the two volumes thermally independent, while shaping the electric field allows carriers to pass through the channel.

We fabricated a prototype 100 g Si detector and demonstrated its discrimination performance. Here, we present our progress in achieving unprecedented thresholds and discuss our plans to use the detector for dark matter searches and low-energy (reactor) neutrino coherent scattering experiments.

RDC 09 - Calorimetry Parallel Session / 38

Geant4 simulations of sampling and homogeneous hadronic calorimeters with dual readout for future colliders

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Calorimeters with dual readout measure both scintillation and Cherenkov light produced in their active media. They offer improvements in energy resolution and, therefore, have become increasingly interesting due to the need for precision jet measurements at Higgs factories. We present GEANT4 simulations of single-particle responses in sampling and homogeneous calorimeters, and demonstrate the effect of inclusion of Cherenkov light in the reconstruction of energies.

RDC 04 - Readout and ASICs Parallel Session / 39

Embedded FPGA Developments for Machine Learning in Particle Detector Readout

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Embedded Field Programmable Gate Array (eFPGA) technology enables the integration of reconfigurable logic within an Application-Specific Integrated Circuit (ASIC). This methodology combines the low power consumption and efficiency of ASICs with the flexibility of FPGA configuration, making it particularly useful for machine learning applications in the data processing pipeline of future collider experiments. The open-source framework "FABulous" was used to integrate eFPGAs into a custom ASIC design, which was then fabricated and validated through testing. The potential of an eFPGA to function as a front-end readout chip was evaluated using data from simulations of high-energy particles traversing a silicon pixel sensor. A machine learning classifier, designed to reduce sensor data at the source, was synthesized and deployed onto the eFPGA. This proof-of-concept successfully replicated the expected algorithmic outcomes on the eFPGA with complete accuracy. We will present the performance results of our eFPGA implementation, share our lessons learned, and discuss our ongoing eFPGA R&D efforts, along with its future role in collider detector readout applications.

RDC 09 - Calorimetry Parallel Session / 40

First results from dual readout crystal calorimetry test beam with electrons at DESY

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The CalVision project seeks to develop high resolution calorimetry for future lepton colliders with state-of-the-art performance for both electromagnetic and hadronic signatures using the dual readout technique. We seek to improve the hadronic energy resolution of homogeneous scintillating calorimeters through the measurement and separation of the scintillation and Cherenkov light in hadronic showers. In April 2024, CalVision performed single-crystal tests using the electron test beam at DESY. Using a single delay line technique for waveform analysis, sufficient cerenkov light can be extracted to fully capitalize on the dual readout technique. This talk will present the results of PWO, BGO, BSO, PbF2, and two novel scintillating glasses.

RDC 05 - Trigger and DAQ Parallel Session / 41

Conceptual Design of the Data Acquisition System for the nEXO Experiment

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The Next Enriched Xenon Observatory (nEXO) experiment aims to search for Neutrinoless Double Beta Decay in liquid xenon. To meet the stringent scientific goals and requirements of the experiment, the nEXO Data Acquisition (DAQ) system is designed to handle high data rates, ensure precise timing, and support operations over a 10-year active measurement period at SNOLAB. The DAQ system collects and processes data from 3,840 charge channels and 7,680 photon channels. The architecture utilizes Commercial Off-The-Shelf (COTS) hardware to mitigate development risks and reduce costs. The DAQ hardware consists of a single, compact rack-mounted server equipped with a high-performance FPGA PCIe card for data and configuration links to front-end boards, lossless real-time data compression, and on-board multi-gigabyte data stream buffering. Precision Time Protocol (PTP) provides timing synchronization with an accuracy of less than 500 nanoseconds, ensuring relative clock alignment across the entire experiment for all subsystems with respect to the SNOLAB timing system. The software framework is based on the Maximum Integrated Data Acquisition System (MIDAS) DAQ, offering a web-based control interface and integrated support for various hardware components. Trigger logic in the FPGA PCIe card is implemented to filter events based on charge and photon signals, reducing the raw data bandwidth to manageable levels during physics data taking. We will present this DAQ conceptual design and discuss some of the critical requirements that are driving many design decisions in the DAQ firmware and software architecture.

RDC 06 - Gaseous Detectors Parallel Session / 42

Negative Ion Drift Studies in Low Pressure Gas Mixtures

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High fidelity measurements of low energy particle tracks are vital for physics applications where reconstructing directionality and event topology is required, such as in searches for dark matter, the Migdal effect, and new physics in CEvNS experiments. Low pressure negative ion drift (NID) time projection chambers (TPC) utilizing micro-pattern gas detectors (MPGDs) provide a unique and promising technology for such applications. The low diffusion and drift speeds in NID, combined with the high granularity and gas gains of MPGDs could lead to unprecedented 3D track reconstruction of low energy tracks.
Our group at UNM is currently constructing a small MPGD-based low pressure NID TPC to be used in a Migdal search. Measurements made with it will also inform the design for other rare searches that require larger volumes. This talk will discuss a variety of drift studies done in gases of interest for this search: He, Ar and CF_4, doped with either CS_2 or SF_6 as the NI component. We will also give a brief update on the status of the hardware development for this future detector.

RDC 09 - Calorimetry Parallel Session / 43

The SiD Digital ECal Based on Monolithic Active Pixel Sensors

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The Higgs physics goals of the future Higgs factories demand unprecedented precision. Monolithic Active Pixel Sensor (MAPS) technology applied to tracking and electromagnetic calorimetry (ECal) has excellent potential to achieve this precision. This technology offers high granularity, thin sensors, fast responses (<nsec), and small dead areas. Colliders with low duty cycles enable gaseous cooling for tracking and passive heat removal for calorimetry. This effort derives from the plans for the SiD concept originally conceived for the ILC.

A MAPS prototyping effort (NAPA-p1) led by SLAC in collaboration with CERN is aimed at the tracking requirements, with complementary application to the ECal requirements. The first MAPS prototype, designed in CMOS imaging 65 nm technology, is under test. The long-term objective is a wafer-scale sensor of area 5×20 cm^2. Small pixels significantly improve shower separation in the ECal. Detailed simulation of ECal performance confirms previous results, indicating electromagnetic energy resolution based on digital hit cluster counting provides better performance than the 13 mm^2 pixels SiD TDR analog design. Furthermore, two particle separation in the ECal is excellent down to the millimeter scale. Geant4 simulation results with optimized analysis based on machine learning has been studied to optimize these expectations. Simple thermal analysis suggests passive cooling is adequate for low duty cycle colliders.

RDC 04 - Readout and ASICs Parallel Session / 44

Automated and Holistic Co-design of Smart Readout ASICs with Embedded Machine Learning

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Extreme edge-AI systems, such as those in readout ASICs for radiation detection, must operate under stringent hardware constraints such a micron-level dimensions, sub-milliwatt power, and nanosecond-scale speed while providing clear accuracy advantages over traditional architectures. Finding ideal solutions means identifying optimal AI and ASIC design choices from a design space that has explosively expanded during the merger of these domains, creating non-trivial couplings which together act upon a small set of solutions as constraints tighten. It is impractical, if not impossible, to manually determine ideal choices among possibilities that easily exceed billions even in small-size problems. Existing methods to bridge this gap have leveraged theoretical understanding of hardware to create proxies for key metrics such as ASIC area and power and used them in neural architecture search. However, the assumptions made in computing such theoretical metrics are too idealized to provide sufficient guidance during the difficult search for a practical implementation. Meanwhile, theoretical estimates for many other crucial metrics (like delay) do not even exist and are similarly variable, dependent on parameters of the process design kit (PDK). To address these challenges, we employ intelligent search using multi-objective Bayesian optimization, integrating both neural network search and ASIC synthesis in the loop. This approach provides reliable feedback on the collective impact of all cross-domain design choices. We showcase the effectiveness of our approach by finding several Pareto-optimal design choices for effective and efficient neural networks that perform real-time feature extraction from input pulses within the individual pixels of a readout ASIC. The proposed optimization approach was used to realize a smart readout ASIC for segmented radiation detectors. The chip, which was designed in 65 nm CMOS technology, contains 23 independent sensing channels. Each channel features a low-noise analog front-end, single-ended to differential converter, ADC driver, high-speed 12-bit ADC, digital signal processor (DSP), and artificial neural network with on-chip weights for performing regression or classification tasks. The DSP was realized using a high-level synthesis design flow. Each channel contains 1.8 kb of on-chip memory and consumes approximately 14.3 mW at the nominal sampling rate of 25 MS/s.

RDC 02 - Photodetectors Parallel Session / 45

Advancements in Photon Detection for DUNE: Enhancing Neutrino Physics with Vertical Drift and APEX Systems

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The Deep Underground Neutrino Experiment (DUNE) seeks to address key questions in particle physics, including neutrino mass ordering, CP violation in the lepton sector, and searches for proton decay and supernova neutrinos. Central to these objectives is the Photon Detection System (PDS), which captures scintillation light for precise event timing, calorimetry, and triggering.

The DUNE horizontal drift (DUNE-HD) PDS uses X-ARAPUCA technology, with detectors positioned behind the transparent wired Anode Plane Assemblies (APA). In contrast, DUNE vertical drift (DUNE-VD) utilizes Charge Readout Planes (CRP) for charge detection, which have reduced transparency, requiring photon detectors to be placed on the cathode and behind the field cage. The

DUNE-VD features large X-ARAPUCA detectors in both locations, providing extensive optical coverage (~4π) and enhancing photon detection uniformity. The placement of detectors on the cathode was enabled by the pioneering development of Power-over-Fiber (PoF) and Signal-over-Fiber (SoF) technologies for liquid argon. These innovations provide essential electrical isolation and noise immunity, which are critical for the high-voltage cathode-mounted design. Successful validation of this approach through tests at CERN and Fermilab represents a significant milestone for the DUNE-VD project.

In DUNE's Phase II, the APEX (Aluminum Profiles with Embedded X-ARAPUCAs) concept is proposed for the third detector module. This innovative system leverages PoF and SoF technologies developed for DUNE-VD PDS, embedding photon detectors directly into the field cage profiles. This design ensures 100% coverage on four sides of the detector, achieving approximately 60% optical coverage overall. APEX is expected to significantly enhance light yield and uniformity. This increased light collection capability for MeV-scale energy deposits, along with improved energy reconstruction up to the GeV scale, positions APEX as a key component in helping DUNE achieve its long-term physics objectives. Promising results from simulations and prototypes at CERN support the potential of this approach.

RDC 07 Low-Background Detectors Parallel Session / 46

Sensitive radon assay for low background liquid xenon detectors

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nEXO plans to search for $0\nu\beta\beta$ decay of ^{136}Xe with a sensitivity of 1.35×10^{28} yrs using a liquid xenon time projection chamber. The experiment is expected to contain 5000 kg of xenon, and our goal is < 1.2 mBq ^{222}Rn in that system, responsible for 48% of the overall background budget. All xenon wetted components will be assayed to meet this goal, requiring sensitive Rn Assay instruments. I will discuss the performance of new Rn assay instruments built at SLAC that will be used to perform many of these assays.

RDC 11 - Fast Timing Parallel Session / 47

Impact of high deposited energy on Single Event Burnout in LGAD sensors

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Silicon sensors with gain such as LGADs (Low Gain Avalanche Diodes) are prime candidates for high resolution timing applications in High Energy Physics, Nuclear science, and other fields. Over the course of their lifetime, these sensors are required to withstand enormous amounts of radiation (>$10^{15} n_{eq}/cm^2$) while maintaining acceptable performances at hadron colliders. Particles interacting with highly biased sensors can produce irreversible damages known as Single Event Burnouts (SEBs).

Recent studies conducted using high energy protons or pions, i.e. minimum ionizing particles (MIPs), have shown that the probability of mortality caused by SEB for these sensors is proportional to the strength of the electric field generated locally by the particle interaction. Thus, the current expectation is that SEB events are more likely when a particle deposits a high amount of energy in the interaction with silicon. Protons and ions in the O(10 - 100) MeV energy range deposit a high amount of energy in silicon in their interaction, increasing the probability of SEBs with respect to a MIP produced at higher energy accelerators.

We exposed a variety of LGADs, pre-irradiated at the Rhode Island Nuclear Science Center up to $1.5\times10^{15} n_{eq}/cm^2$, to a high intensity beam of both non-MIP protons and ions produced at the BNL Tandem Van de Graaff accelerator. Results from this study allow us to strengthen our understanding of SEB and permanent radiation damages and parametrize SEB probability in interactions with high deposited energy.

RDC 03 - Solid State Tracking Parallel Session / 48

Scintillating quantum dots for ultrafast charged-particle detection

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We present a novel, blue-sky detector concept that aims to replace the relatively slow process of charge-drift in a semiconductor with light-collection from scintillating quantum dots (QDs) in order to achieve ultimate timing performance in a thin, low-mass material for future charged-particle detectors. Here we show measured detection performance using self-assembling InAs QDs inside of a 25 micron thickness GaAs semiconductor matrix grown via molecular beam epitaxy with an InGaAs photodiode monolithcally integrated for efficient light collection. We will discuss the current performance in light-collection and energy resolution relative to the theoretical optimum performance. Finally, we will outline proposed future research directions to investigate significant improvements in detector performance, ultimately approaching fundamental limits.

RDC 09 - Calorimetry Parallel Session / 49

Material Development and Prototype Study for Large-scale Liquid Detector

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Water-based Liquid Scintillator (WbLS) is an innovative material for constructing large-scale detectors in neutrino and dark matter research. The tunable light yield, enabled by an inline circulation system, allows for flexible detector optimization for different physics searches. With adequate photosensor coverage, detecting low-intensity light can reconstruct the momentum of energetic charged particles while enhancing sensitivity to low-energy events, thereby improving background suppression in kiloton-scale neutrino detectors. Adding metallic elements like Gadolinium further enhances

WbLS as a candidate for outer detectors optimized for neutron background tagging. A 30-ton WbLS demonstrator has been constructed at Brookhaven National Laboratory (BNL) to assess its stability, optical properties, and circulation process, providing valuable insights for designing large-scale detectors. Preliminary data and plans for investigating WbLS stability and performance will be discussed in this talk.

RDC 01 - Noble Element Detectors Parallel Session / 50

The Advanced Low- and High-Energy Calibration Techniques for the LZ Detector

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The LZ (LUX-ZEPLIN) collaboration operates a 7-tonne active mass, two-phase xenon TPC (Time Projection Chamber) surrounded by a multi-layer OD (Outer Detector) serving as an anti-coincidence veto, in order to find the elusive dark matter, at SURF (Sanford Underground Research Facility), the former location of the Homestake gold mine in the town of Lead, South Dakota. In service of the search for dark matter in the form of a WIMP (Weakly Interacting Massive Particle), a leading dark matter candidate, as well as axion-like particles, Boron-8 coherent neutrino scattering, supernova neutrinos, neutrinoless double-beta decay, and many other potential physics channels, LZ's scientists, engineers, and students must perform extensive calibrations in order to solidify a comprehensive understanding of the scintillation and ionization channels, for both nuclear recoils and electron recoils, both as possible signals and as backgrounds, across a wide range of energies, from sub-keV to MeV. I will provide a summary of the unique features and excellent performance of LZ's state-of-the-art calibration systems that have played key roles in enabling LZ's world-leading results across different searches. The comprehensive descriptions of the LZ calibration systems, and the Monte Carlo simulation efforts which support the results, will ideally serve as valuable references for future endeavors.

RDC 06 - Gaseous Detectors Parallel Session / 51

Design and construction of a novel energy-loss optical scintillation system (ELOSS) for heavy-ion particle identification

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A novel heavy-ion particle-identification (PID) device based on optical-readout energy-loss measurement (ELOSS) is presented. The device is designed to identify the atomic number of the reaction fragments that reach the focal–plane detector system of the S800 spectrograph at the Facility for Rare Isotope Beams (FRIB).
The new instrument consists of a large volume filled with xenon gas at pressures ranging from 400 to 800 Torr, surrounded by arrays of PhotoMultiplier Tubes (PMTs) for recording the prompt scintillation light emitted along the track of ions that traverse the detector. The number of scintillation photons captured by the optical readout is proportional to the energy deposited by the impinging particle, allowing identification of its atomic number (Z).
The ELOSS technology is expected to provide high-resolution ΔE measurements ($\leq 0.6\%\ \sigma$) at a high

counting rate (>50 kHz). In addition, it provides timing information (with a resolution < 150 ps σ) and a moderate localization capability (with a resolution <1 mm σ), compared to the lack of usable timing and space information of the conventional ionization chamber relying on drifting charges. The development of fast, accurate ΔE measurement techniques for present and future nuclear science facilities will have a high impact on the design and implementation of rare-isotope beam experiments at FRIB and their scientific outcome. As such, ELOSS also represents a prototype for the development of PID detector systems of other planned and future spectrometers, such as the High Rigidity Spectrometer (HRS) at FRIB.

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RDC 06 - Gaseous Detectors Parallel Session / 52

A High-Pressure Gaseous-Argon TPC R&D Effort for Neutrinos and Rare Events

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High pressure gaseous argon time projection chambers (HPgTPC) is crucial for many applications, including neutrino oscillation analyses, and rare event searches such as coherent elastic neutrino-nucleus scattering (CEvNS) and low-energy nuclear recoil detection. Current R&D efforts are focused on testing gas electron multipliers (GEMs) in high-pressure environments, which is critical for optimizing the performance and reliability of HPgTPC systems. Results may be particularly applicable for DUNE Phase II, where a HPgTPC will be placed in the near detector complex to address one of the significant sources of uncertainty in neutrino oscillation analysis: nuclear effects in argon at the neutrino interaction vertex. This talk will present updates on the GEM simulation studies, as well as progress on ongoing test stands aimed at benchmarking the performance of the GEMs and electronics for placement in a high-pressure gaseous argon environment.

RDC 01 - Noble Element Detectors Parallel Session / 53

Impact on Liquid Argon Scintillation from doping with a mixture of Isobutylene and Xenon

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Liquid argon detectors are widely used in neutrino physics and dark matter detection through the collection of ionization charge and/or scintillation light produced by particles interacting in the bulk liquid argon. The introduction of hydrocarbon-based photo-ionizing dopant into a liquid argon detector can extend its detection capabilities by lowering the energy threshold for charge collection and improving neutron detection efficiency through neutron capture on Hydrogen. These capabilities can be used for electron antineutrino detection via the inverse beta decay interaction, in-situ neutron flux measurements, and increased sensitivity to low-energy neutrinos produced by supernovae

in a detector such as DUNE. An experiment at the Fermilab Noble Liquid Test Facility (NLTF) was performed to understand whether the introduction of a cocktail consisting of Xenon and the photo-ionizing dopant isobutylene (C4H8) could provide a substantial number of free proton targets in a liquid argon volume while simultaneously preserving the scintillation light signal. The experiment ran in the summer of 2024 with different doping configurations at the ppm level studying the impact on the liquid argon scintillation light of isobutylene alone, xenon alone, and then a combination of isobutylene and xenon. This talk will present the results of the recent run along with the prospects for achieving doping concentrations that would be needed in a future liquid argon detector.

Plenary session / 54

Scintillating Bubble Chambers for Rare Event Searches

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The Scintillating Bubble Chamber (SBC) collaboration is developing liquid-noble bubble chambers sensitive to sub-keV nuclear recoils. These detectors combine the excellent electron-recoil insensitivity inherent in bubble chambers with the ability to reconstruct energy based on the scintillation signal for further background suppression. The targeted nuclear recoil threshold of 100 eV is made possible by the high level of superheat attainable in noble liquids while remaining electron-recoil insensitive. In order to verify this reduced threshold, the SBC collaboration is building two functionally-identical 10 kg detectors. The first, SBC-LAr10, soon-to-be operational at Fermilab, will be used for engineering and calibration studies and has further potential in measurements of the coherent elastic neutrino-nucleus scattering on argon. The second detector, SBC-SNOLAB, for a low-background dark matter search will be operated underground at SNOLAB. An overview of scintillating liquid-noble bubble chambers and the physics potential of SBC-SNOLAB and SBC-LAr10 will be presented.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 55

Quantum Capacitance Detectors for Ultralight Dark Matter searches.

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QCDs, which are based on a charge qubit design, are the most sensitive far-infrared detectors in 1.5 THz regime. Apart from their current application in space telescopes for infrared spectroscopy, they have single-photon sensitivity that can be utilized to look for ultralight Dark Matter at the meV scale. This talk will give an overview of our work to characterize a QCD detector using a Black body source. Furthermore, we will discuss readout and optimization of these detectors to reduce the current dark count rate of 100 Hz, with the goal of reaching sensitivities needed for ultralight Dark Matter detection.

RDC 01 - Noble Element Detectors Parallel Session / 56

Reaching neutrino smog in noble liquid detectors and condensed matter aspects of dark matter searches

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Recent publications on solar neutrino detection in large dual-phase Xe detectors cite the absence of condensed matter physics models and use Bayesian analysis, like toy Monte-Carlo simulations and data-driven correction to account for delayed electron and photon emission and other detector physics effects. We tried to fill the gap and consider possible microscopic mechanisms of observed detector phenomena. We conclude that changes in low-energy background spectra with increased detector size are not due to changes in effects producing delayed electron and photon emission but are caused by changing electron extraction efficiency and suppression of low-energy events detection due to accumulation of unextracted charges on liquid-gas interface. The agreement of the current analysis with other measurements of Solar 7B neutrino flux does not validate the implicit assumptions made about detector physics which can lead to systematic uncertainties in the analysis results - up to missing interactions with dark matter particles. We formulate questions in condensed matter physics terms, describe experiments required to find answers, and discuss how unwanted effects can be suppressed or mitigated by changes in the detector design. In our opinion, the current uncertainties are the result of insufficient interactions between condensed matter and particle physics communities in the advanced detector development.
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-869463

Joint RDC 07 & 08 & 09 Parallel Session / 57

Toward sensitivity of radiopure NaI(Tl) to solar and reactor neutrinos and the possibility of neutrinos and ultra-light dark matter particles detection in the nano-explosive regime

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Only the hypotheses of direct energy depositions by particles as an explanation for seasonal background modulation observed by the DAMA-LIBRA collaboration were experimentally investigated in 20 years of history of this dark matter detection controversy. Alternatively, much lower energy nuclear recoils can trigger releases of energy stored in the material. The demonstration of optical control on energy accumulation and release processes in NaI(Tl) points to the feasibility of this alternative mechanism- the release of self-trapped electrons by low-energy nuclear recoils with subsequent recombination and luminescence. Importantly, these recoils cannot produce luminescence without stored energy/trapped electrons. Our experiments, Ice Cube, and other results indicate that long-living trapped electron states in NaI(Tl) can be selectively produced by exposure to UV light and to atmospheric muons. We discuss underlying condensed matter effects and suggest experiments required for testing the feasibility of nano-explosive detection of low-energy nuclear recoils in NaI(Tl).
By not taking into account the possibility of triggered releases of energy stored in NaI(Tl) we exclude from consideration interactions with ultra-light dark matter particles. This illustrates that model-independent search for dark matter particles requires exact, deterministic models of energy pass-ways in materials; using Bayesian techniques and making indirect and not pronounced assumptions about material properties can lead to biased analysis results and systematic errors.
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RDC 09 - Calorimetry Parallel Session / 58

The Barrel Imaging Calorimeter of the ePIC Detector

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The Barrel Imaging Calorimeter (BIC) of the ePIC detector is designed to meet the unique challenges presented by the physics of the Electron-Ion Collider. For energy measurements of showers, the BIC employs scintillating fibers aligned parallel to the beam axis, utilizing lead absorbers and silicon photomultipliers for readout. The challenging requirements for separating electrons from pions, among others, are met by interleaving the lead/SciFi portion of the detector with AstroPix MAPS silicon detectors capable of dE/dx measurement. This talk will discuss the design of the calorimeter, as well as some results from the R&D effort.

RDC 09 - Calorimetry Parallel Session / 59

Timing-imaging layers for 5D calorimeters and hadron identification at future high-luminosity colliders

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The LHCb experiment is planning its Upgrade II to align with the High-Luminosity LHC (HL-LHC) era, aiming to enhance its discovery potential through a combination of higher luminosity and increased detection efficiency for photons, π^0, electrons, and positrons. This powerful synergy promises to unlock new physics opportunities. Key to the success of this upgrade are three critical elements: high granularity, precise time resolution, and advanced feature extraction, supported by machine learning. This presentation will provide an overview of the ongoing R&D efforts for timing-imaging layers, focusing on their application in a 5D calorimeter, hadron identification at HL-LHC, and applications for experiments at future high-luminosity colliders.

Joint RDC 01 & 02 & 04 / 60

The Analog Photon Processor ASIC

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ull waveform digitization is an obvious solution for many particle physics detectors: Nyquist sampling ensures no information is lost, and extraction of important features can be postponed to later

offline analysis, or can even be done by a fast FPGA before storage to disk. For photon detectors used in large-scale neutrino physics, however, the dynamic ranges run from just single photons to perhaps a few thousand per channel, and we are interested only in the number of photons each sensor detected and their arrival times. I will describe here an "Analog Photon Processor" (APP) ASIC, being designed for the TSMC 65 nm process, that extracts the features necessary to do precision photon counting and time measurement, even in the case of multiple photons piled up on a single waveform. The APP does this by fast analog measurements, allowing system bandwidths to be increased and thus precision improved, while significantly reducing data volumes and cost. The APP will be particularly useful for future hybrid Cherenkov/scintillation detectors, such as the proposed Theia detector which is a candidate for DUNE's FD4 module.

Joint RDC 03 & 11 Parallel Session / 61

AstroPix for the Barrel Imaging Calorimeter in ePIC

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AstroPix is a high-voltage CMOS monolithic active pixel sensor (HVCMOS MAPS) originally developed for space-based missions, specifically for gamma-ray astrophysics. Its precise energy and position resolution, low noise, and low power consumption, combined with minimal dead material, meet the performance requirements for the Barrel Imaging Calorimeter (BIC) in the ePIC detector for the future Electron-Ion Collider. As a key component of the BIC, the 4 (+2) AstroPix imaging layers, interleaved with Pb/SciFi calorimeter layers, play a crucial role in position resolution, electron/pion separation, and shower profiling. This talk will provide an overview of AstroPix R&D, along with performance results from both bench and beam tests.

RDC 02 - Photodetectors Parallel Session / 62

EIC HRPPDs and their application in a proximity focusing RICH for the ePIC detector

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High Rate Picosecond Photodetectors (HRPPDs) are Micro-Channel Plate (MCP) based DC-coupled photosensors recently introduced by Incom, Inc. that have an active area of 104 mm by 104 mm, pixel pitch 3.25 mm and timing resolution on the order of 30-40 ps for a single photon detection. As such, these photosensors are very well suited for Ring Imaging CHerenkov (RICH) detectors that can also provide high resolution timing capability.

One of the emerging applications for this type of sensor is a proximity focusing RICH (pfRICH) in the backward endcap of the ePIC detector for the Electron-Ion Collider (EIC), which will be sited at Brookhaven National Laboratory. The pfRICH will cover an angular acceptance of $-3.5 < \eta < -1.5$, provide a positive kaon identification at a 3σ level up to ~7 GeV/c, and provide a timing reference of ~20 ps for the ePIC barrel and forward endcap Time of Flight subsystems.

Recently, a new version of HRPPDs has been developed that were substantially re-designed for use at the EIC, and a first batch of seven "EIC HRPPDs"was manufactured in early 2024. Results of a systematic evaluation of these first EIC HRPPD tiles, including gain and quantum efficiency (QE)

uniformity, timing resolution, and dark count rates (DCR) will be presented. Modeling results, illustrating the expected pfRICH performance in ePIC detector, will also be presented.

RDC 01 - Noble Element Detectors Parallel Session / 63

Charge Readout Planes for the DUNE Far Detector

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The DUNE far detector consists of liquid argon time-projection chambers (LArTPCs), which allow for kiloton-scale fiducial mass necessary for rare event searches and sub-centimeter spatial resolution required to image those events with high precision. In the vertical drift LArTPC detector, a horizontal cathode bisects the fiducial volume, creating two stacked drift volumes in which ionization electrons drift upwards and downwards towards anodes at either the top or bottom, respectively. The electrons are detected by 3m x 3.4m surface area charge-sensitive anodes called Charge Readout Planes (CRPs) built out of perforated PCB layers with conductive strips, enabling reconstruction in 3D. An international DUNE collaboration R&D program, which developed CRP prototypes and tested them in LAr, successfully demonstrated excellent performance of the CRP as large-scale, low-noise detectors. This talk will present the DUNE vertical drift detector, CRP design, results from prototype testing, and considerations for building and installing 160 CRP in the DUNE vertical drift TPC.

RDC 04 - Readout and ASICs Parallel Session / 64

Q-Pix: Latest status and R&D results for a scalable pixelated readout

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Q-Pix is an innovative approach for measuring ionization and, potentially, scintillation signals in large liquid argon Time Projection Chambers (LArTPCs). At its core is a self-triggering "Charge Integrate/Reset" circuit, where a charge-sensitive amplifier continuously integrates incoming current on a feedback capacitor. When the signal reaches a preset threshold, a 'reset'transition is initiated. The cycle then recommences, allowing continuous capture of detailed time and charge information. The original current can be reconstructed from the time between resets. Compared to traditional wire-based readout systems, a pixelated readout system offers the advantage of unambiguous 3D imaging in LArTPCs, reducing ambiguities in event reconstruction. This talk will present the latest status and R&D results from Q-Pix, including simulations, prototype detectors, ASIC development and testing, and lab infrastructure.

Poster Session / 65

Electron and Pion Response Benchmarks for the ePIC Barrel Imaging Calorimeter

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The Barrel Imaging Calorimeter (BIC), a subsystem of the Electron Ion Collider's ePIC detector, is a sampling calorimeter utilizing two technologies: scintillating fibers embedded in lead (Pb/ScFi), interleaved with AstroPix silicon sensors, providing the required energy and position resolutions and particle identification capabilities. A small Pb/ScFi calorimeter prototype, based upon a version of the GlueX Barrel Calorimeter with incorporated AstroPix sensors, has been tested in Summer 2024 at the Fermilab Test Beam Facility (FTBF) to benchmark the response to electrons and pions. Detailed simulations of the FTBF set up, necessary for performance benchmarking and BIC optimization studies, have been performed. The results from the beam test, together with the simulations, will be presented.

RDC 04 - Readout and ASICs Parallel Session / 66

Characterization of the MetaRock fast timing analog front end for future HEP experiments

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Detectors at future colliders will require timing precision on the order of 10 ps. Towards this goal, we' ve developed a low-power, high-speed prototype ASIC named MetaRock. MetaRock is an evolution of the Pebbles ASIC. As compared to its predecessor, MetaRock has improvements in the layout of the Pebbles analog front-end to reduce parasitic capacitances and enhance timing resolution. An on chip test bench consisting of a charge injection circuit and a second high-resolution (20 ps LSB) TDC are used for evaluating the performance of the AFE. Results are validated with an external high-resolution (4 ps LSB) TDC. We will present the AFE and testbed architecture and summarize the test results of the MetaRock prototype.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 67

First Measurements of Superconducting Quasiparticle-Amplifying Transmon (SQUAT) Sensors

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SQUATs are new quantum sensor using a qubit directly coupled to a feedline that are designed to detect THz photons or meV phonons. Incoming particles deposit energy in the qubit islands, generating quasiparticles, which can be detected as they tunnel across the qubit junction as a shift in the qubit parity state. These devices have several features which are especially beneficial for dark matter searches, including excellent energy sensitivity, bandwidth, multiplexability, and noise performance. Here we present measurements of SQUAT devices and demonstrate the potential of this new sensor.

RDC 09 - Calorimetry Parallel Session / 68

The ADRIANO3 Triple-Readout Calorimetric Technique

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Hadron calorimetry in collider experiments has long faced challenges due to significant fluctuations in the electromagnetic and neutral components of hadronic showers. To tackle these issues, a novel high-granularity, triple-readout calorimeter with fast timing capabilities—ADRIANO3—was developed. ADRIANO3 consists of a layered structure of heavy-glass tiles, plastic scintillator tiles, and thin resistive plate chambers, integrated into a single readout layer. The heavy-glass is primarily sensitive to the fast electromagnetic component of the shower above the Cherenkov threshold, while the plastic scintillator detects all ionizing particles, including neutrons to some extent. The resistive plate chambers, incorporating heavy gases and Gd-doped glass, are sensitive to both ionizing particles and neutrons. Small-scale prototypes of ADRIANO3's individual components were constructed and subjected to extensive testing in multiple beam test campaigns. This report covers the development of the ADRIANO3 concept and its components, the construction and testing of these prototypes, and presents current findings along with future research directions.

RDC 09 - Calorimetry Parallel Session / 69

Secondary Emission Calorimetry

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Electromagnetic calorimetry in high-radiation environments presents significant challenges, particularly in forward regions of lepton and hadron collider detectors. The conventional solution is to construct a sampling calorimeter using radiation-hard active media, though this often compromises energy resolution. To address this issue, we developed a novel approach: secondary emission calorimetry, which offers a radiation-hard, fast, robust, and cost-effective alternative. We built prototype secondary emission sensors and tested them in beam tests. In a secondary emission detector module, secondary emission electrons are produced from a cathode when charged hadrons or electromagnetic shower particles pass through the sampling module. These secondary emission electrons are then multiplied, much like photoelectrons in photomultiplier tubes. This report outlines the principles of secondary emission calorimetry, presents results from beam tests, and discusses Monte Carlo simulations with projections for large-scale secondary emission electromagnetic calorimeters.

Poster Session / 70

A lab scale time projection chamber (TPC) for testing the pixelated charge read out using the novel Q-Pix concept in gas and liquid argon environment

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We describe the design and operations of a lab scale time projection chamber (TPC) which is being developed to test the novel pixelated charge read out scheme, Q-Pix. The aim is to demonstrate the capability of the Q-Pix readout to reconstruct the particle tracks in ultra high pure (UHP) Argon (Ar) in both gas and liquid phase. The TPC is equipped with an Hamamatsu R8520 photo multiplier tube (PMT) below the cathode plane that allows the detection of the scintillation light. The front face of the PMT and the Teflon cylinder which holds the field cage is coated with TetraPhenyl Butadiene (TPB) that allows the detection of the VUV scintillation in Ar. For the testing and commissioning of the TPC we installed an alpha source (Am-241) and a gamma source (Co-60) near the field cages. This poster will present first data from the TPC in both gas and liquid argon and show how the performance of the purification system affects the lifetime of the slow component of the liquid Ar scintillation.

RDC 02 - Photodetectors Parallel Session / 71

Characterization of a novel vertical geometry amorphous selenium based photodetector with UV transparent window.

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This talk will present initial results from an amorphous selenium (aSe) vertical photodetector with VUV transparent graphene electrode. Our initial results provide proof that graphene can effectively be deposited on aSe and that a proper readout can be obtained with a thin metal electrode grown either below or above graphene. We observed a significant enhancement in the photoinduced signal strength when we increased the area of the top metal anode by depositing graphene. We will also present results from experiments that explored the transport properties of charge carriers inside aSe as a function of the applied electric field, temperature and nature of the metal electrode used to construct the device. Our results can pave the way towards the development of a novel photodetector design that can be incorporated in an integrated charge (Q) and light (L) sensor. Such a detector can result in the realization of pixelated Q+L sensor in large scale noble element TPC's.

RDC 02 - Photodetectors Parallel Session / 72

Engineering the electronic and optical properties of a-Se through Ge alloying for photodetection

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Amorphous selenium (a-Se) has recently gained interest as a low-cost, large-area photoconductor for high-energy physics applications, including liquid noble gas detectors. Its low leakage current, high absorption coefficient from the VUV to blue wavelengths, and ability to achieve impact ionization at low fields (~70 V/um) make it an ideal detector for low-light environments. It has also been shown to exhibit slight birefringence at room temperature, increasing under cryogenic conditions, and photo-induced angle-dependent transmission of near-infrared light when pumped with band region wavelengths, offering the potential for the directional detection of incident light. However, a-Se suffers from low carrier mobility and poor sensitivity to photon energies below 2 eV, limiting its application in high-speed detection and its versatility with various scintillators.

The alloying of a-Se has long been studied as a means to improve transport, increase stability, and tune optical properties. Previous works from this group and others demonstrate that alloying a-Se with tellurium (Te) reduces the band gap and increases sensitivity to long wavelengths, though mobility is further reduced. Alternatively, it has been shown that incorporating germanium (Ge) with a-Se can improve electron mobility while reducing charge trapping and altering the band gap; ternary alloys consisting of Ge-Se-Te allow for even more specific tuning of properties. Comprehensive studies on the effects of Ge concentration on optoelectronic properties are limited and primarily focus on applications in memory and switching, revealing a need for greater study of how we may optimize these alloys for photodetectors.

We propose to first explore the effects of Ge alloying, followed by a simulation-guided study of how Ge-Se-Te may be combined to create a high-sensitivity, fast-timing photodetector with photon incident angle detectability. In the work presented here, we discuss our preliminary findings on the co-deposition of Ge and a-Se by thermal evaporation. We explore the optoelectronic properties of GexSe1-x devices, including the optical band gap, carrier mobility, leakage, and responsivity. Preliminary evaluation from a pump-probe setup will delve into possibilities for directional detection of incident light from alloyed detectors. From this, we discuss the next steps in developing an optimized Ge-Se-Te photodetector and its potential for implementation in high-energy physics applications.

RDC 04 - Readout and ASICs Parallel Session / 73

Measurements of room temperature I-V characteristics in low threshold MOSFETs from the open source Skywater 130 nanometer Process Design Kit

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We present the room temperature I-V characterization of the MOSFETs embedded in a device fabricated from the open source Skywater 130 nanometer (SKY130) Process Design Kit (PDK). Using a vibration isolated device in a class 100 clean room we are able to obtain the output characteristics, transfer characteristics and gate capacitance of MOSFETs over a wide range of device sizes (lengths and widths). We validated the measurements against the PDK behavior at room temperature. The devices fabricated are aimed to be used as part of a cryogenic charge readout for liquid noble detectors. We will present plans for the next phase of I-V characterization as a function of temperature up to liquid argon temperatures. The aim of the cryo-measurements is to produce accurate cryo-models that are presently unavailable in the range of temperatures of interest. These measurements will to guide the optimization of the Sky130-Caravel chip for future detector applications and will contribute valuable data to the open-source Skywater community, fostering further advancements in this technology.

Joint RDC 01 & 02 & 04 / 74

Surface Plasmon enhanced piezoelectric voltage metal/ZnO thin film devices for UV photon detection

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This talk will present the investigation into the enhancement of the piezoelectric potential in a metal/ZnO thin film under surface plasmon resonance (SPR) conditions for the development of novel

piezo-plasmonic based UV photon detectors. Metal thin films are used in numerous high-tech applications, such as electronic devices, surface plasmon resonance sensors, and integrated photonic circuits because of their excellent electrical, optical and thermal properties. Similarly, ZnO is widely used in various applications because of its high refractive index, wide direct band gap, high thermal conductivity, and piezoelectric properties. To study the effect, COMSOL Multiphysics simulations are used for optimization structure of metal/ZnO layers for the sharpest SPR curve with maximum loss in reflectivity at resonance. The bias piezoelectric voltage was generated using a stress pin on the top ZnO layer and under SPR conditions the enhancement of this voltage signal was measured. Furthermore, for the detection of UV photons, a pump-probe experimental setup was used and at SPR angle, voltage signal was measured as function of intensity of pumped 240 nm UV light. This talk will present first results from prototype detectors designed to work in a cryogenic environment such as those found in liquid noble detectors

Poster Session / 75

Demonstration of a novel ZnO thin film-based Piezo Photonic Detector with in-device stress for cryogenic applications

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We propose a novel detection scheme that utilizes the piezo-pyroelectric properties of ZnO thin films. The aim is to realize a zero external bias vacuum ultraviolet (VUV) detector that can be used in liquid noble time projection chambers. We present initial results from our measurements that test our hypothesis that stress-induced in ZnO thin films through interface strain engineering can lead to an enhancement of the VUV photoinduced signals. We compare the signals from a bare ZnO detector in a vertical geometry to a detector with an additional silicon nitride layer that introduces the stress-induced piezo potential. In addition, we demonstrate the detector performance at cryogenic temperatures, and the results are discussed based on piezo- and pyro-electric potential induced in ZnO thin film. COMSOL simulations of the stress and temperature variation induced potential in bare Zno and in a ZnO/silicon nitride heterostructure will be used to optimize the device architecture. Through the optimization of the device architecture, we expect that the stress-induced potential can produce measurable signals under zero bias and low light conditions. Such a photodetector can have applications in rare event searches using liquid noble detectors, potentially for solar energy harvesting and the development of metamaterial broadband solar absorbers for near-perfect absorption in the UV to Visible wavelengths.

RDC 04 - Readout and ASICs Parallel Session / 76

Unique Pixel Detector Requirements in the Muon Collider Environment

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A muon collider is envisioned as one of the future high energy physics particle colliders and due to the short-lived nature of muons a challenging beam induced background (BIB) is driving many of the detector requirements. A Pixel detector at a muon collider will have to withstand a unique set of challenges created by the BIB and are an opportunity to be explored in an early detector R&D phase. The most prominent requirement is the need for full 4D tracking with O(30ps) timing precision to disentangle signal and BIB. But the presence of BIB has a more fundamental impact on traditional Pixel detector architectures. This presentation will compare the current state-of-the-art Pixel detector technology and where it falls short in the muon collider environment, hopefully inspiring potential new R&D directions.

Joint RDC 01 & 02 & 04 / 77

Can supermarket barcode scanner solve million-channel TPC readout problem?

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We present a free-space optical communication system that utilizes Light-Emitting Diodes (LEDs) and a mechanical streak camera to achieve wireless data transmission. This system addresses the scalability and reliability limitations of conventional wired and multiplexed readouts, offering significant advantages such as reduced single point of failure risk and immunity to electromagnetic interference. Remarkably, under optimal conditions, this system can simultaneously read out more than three million individual data channels, surpassing the capabilities of most existing wireless communication systems. Through a demonstration using consumer-grade optical and image sensor components, we have proven the viability of this innovative approach and showcased its exceptional time resolution and cost-effectiveness. This approach can potentially transform data transmission in experiments where a large number of sensors are distributed over a wide area, such as in liquid and gaseous TPCs of substantial volume.

RDC 04 - Readout and ASICs Parallel Session / 78

Cryogenic CMOS Amplifiers for Enhanced Sensitivity in the CMB-S4 Experiment

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The next-generation Cosmic Microwave Background Stage 4 (CMB-S4) survey aims to map the Cosmic Microwave Background with unprecedented sensitivity, probing key areas of fundamental physics such as inflation, exotic light relics, and dark energy. To meet these ambitious objectives, the experiment will deploy approximately 500,000 photon-noise-limited superconducting transition edge sensors (TES) across various large and small aperture telescopes. These TES will operate within cryogenic receivers, requiring multiplexing through low-temperature superconducting quantum interference device (SQUID)-based electronics. SQUID are ultra-sensitive detectors that measure faint magnetic fields, essential for capturing weak CMB signals from the early universe.

To optimize the cryogenic readout for the SQUIDs, the TID-ID Integrated Circuits group at SLAC National Lab has developed R&D amplifiers using state-of-the-art CMOS technologies, including 28 nm and 22 nm FDSOI. These mini-ASICs are engineered for deep cryogenic operation at 4 K, with potential performance at 1 K, allowing for direct interfacing with low-noise SQUIDs housed in cryocoolers. This integration significantly enhances the system's sensitivity by reducing noise and enabling more precise signal detection. By placing the readout electronics at cryogenic temperatures rather than room temperature, the system benefits from minimized cabling, improved signal-to-noise ratio (SNR), and a reduced thermal load on the cryostat. Supported by the LDRD program, these low-power, ultra-low-noise amplifiers, with simulated noise as low as 0.3 nV/√Hz, will be characterized in 2025, laying the groundwork for future System-on-Chip (SoC) ASIC developments tailored for extreme cryogenic environments.

Plenary session / 79

Transport Properties of an Amorphous Selenium-Based Charge Plus Light Sensor for Applications in Cryogenic Detectors

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Amorphous selenium (aSe), widely utilized in x-ray medical imaging, has emerged as a promising material for liquid noble detectors in particle physics. This work investigates the temperature and electric field-dependent charge transport properties of a novel aSe-based photo-sensor and its integration into a multimodal charge plus light sensor for use in pixelated liquid argon time projection chambers (LArTPCs). This work will present the design and fabrication of the first prototype, preliminary results from first tests, and showcase the sensor's response to low photon yields.

RDC 02 - Photodetectors Parallel Session / 80

Measurements of Spectral Photon Sorting Using Dichroicons in Large Optical Neutrino Detectors

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Many neutrino detectors use photons as their primary event detection method, typically detecting numbers of photons and their arrival times. Photons also carry information about an event through their wavelength, polarization, and direction, but often little to none of this information is utilized. The "dichroicon," a Winston-style light cone comprised of dichroic filters, allows detectors to use the wavelength information encoded in photons. This talk will discuss measurements of the performance of the dichroicon in the CHESS detector, focusing on the dichroicon's scintillation and Cherenkov photon detection and separation efficiency. The results will include measurements from two types of dichroicons paired with water based and liquid scintillators exposed to radioactive and cosmogenic sources. In addition to the benchtop results, the talk will discuss the deployment of dichroicons in Eos, a 20-ton hybrid Cherenkov-scintillation detector. The Eos detector is a demonstrator for very large scale neutrino detectors, including Theia, and features the first deployment of 12 large-scale monolithic dichroicons. The talk will dicuss the ongoing measurements of the performance of dichroicons at Eos, as well as priliminary results that have so far shwon good data/MC agreement. The talk will also include predictions of the performance of dichroicons in future detectors like Theia. These results will include studies of the collection efficiency and discrimination between Cherenkov and scintillation light, new handles on particle ID, and novel reconstruction techniques that leverage the advantages of both Cherenkov and scintillation light.

RDC 09 - Calorimetry Parallel Session / 81

Neutron Capture in Liquid Argon for Calibration: Key Results from the DUNE-VD Prototype at CERN

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The Deep Underground Neutrino Experiment (DUNE) is a leading international project in neutrino science, aiming to address key questions in particle physics, including neutrino mass ordering, CP violation in the lepton sector, and searches for proton decay and supernova neutrinos. Neutron capture in argon releases a cascade of gamma rays, totaling 6.1 MeV, providing a "standard candle" for absolute energy scale calibration, which is critical for precision measurements. Additionally, neutrons pose a significant background challenge for the DUNE Far Detector in the low-energy range of a few MeV, where neutrons from the surrounding cavern can mimic neutrino interactions. Furthermore, neutrons frequently appear as final-state products in low-energy neutrino interactions with argon. Identifying the neutron capture signature in liquid argon is essential for DUNE's low-energy physics program.
DUNE's vertical drift (DUNE-VD) prototype employs X-ARAPUCA photon detectors and Charge Readout Planes (CRPs) for light and charge detection—systems that will also be used in the full-scale DUNE-VD module. During calibration efforts, a commercial neutron generator was used to introduce monoenergetic neutrons with an energy of 2.5 MeV into the detector. By combining light and charge information, neutron capture candidates are selected, and energy reconstruction is carried out. Results from the data collected using the pulsed neutron source in the DUNE-VD prototype will be presented at the conference.

Joint RDC 07 & 08 & 09 Parallel Session / 82

Project 8: Cyclotron Radiation for Neutrino Mass

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Project 8 aims to determine the neutrino mass by precisely measuring the electron kinetic energy near the tritium beta-decay endpoint.
Electrons are trapped in a magnetic field and emit radiation with a frequency related to their kinetic energy. This technique, pioneered by Project 8, is called Cyclotron Radiation Spectroscopy (CRES). Recently, Phase II was completed, illustrating a start-to-end analysis setting an upper limit on the neutrino mass. To advance to a competitive mass limit, Project 8 is pursuing resonant microwave cavities, boosting the signal-to-noise ratio while enabling larger volumes. The next demonstrator, the Cavity CRES Apparatus (CCA), is currently being constructed.

This talk presents the CCA progress and the model of the emitted signal and noise power entering the readout. Ultimately, quantum-limited readout is required, driving multiple R&D efforts, one of which is the development of TWPAs at high (~20GHz) and low (~500MHz) frequencies. These superconducting Josephson-based amplifiers offer a path towards high gain, broad bandwidth amplification with the required dynamic range.

RDC 07 Low-Background Detectors Parallel Session / 83

High-Radiopurity Structural Components Made by Chemical Vapor Deposition

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High-radiopurity structural materials are needed for a variety of high-energy physics experiments, particularly those involved in the search for dark matter or neutrinoless double beta decay in which background radiation from trace impurities can hide the desired signal. The structural material with the highest radiopurity currently available is electroformed copper, but its yield strength is only 12 ksi [1], which limits its utility as a structural material. In this project, using chemical vapor deposition (CVD) Ultramet fabricated articles made of tungsten—a material with very high yield strength and density—with extremely high levels of radiopurity such that the articles can be used for both shielding and structural applications.
Like electroplating, during which the voltage can be adjusted to preferentially deposit one metal instead of another, CVD process parameters can be adjusted such that one metal can be selectively deposited instead of others. CVD is also routinely used to manufacture freestanding structures with wall thicknesses up to several millimeters.
Thermodynamic analyses were performed on mixtures containing tungsten and a variety of undesirable impurities and decay chain progeny (e.g. uranium, thorium, radium, polonium, actinium, radon), and the predicted rejection ratios of the undesirable elements in the solid deposit ranged from roughly three orders of magnitude to over nine orders of magnitude. Similar calculations were performed for tantalum as the matrix rather than tungsten.
In parallel with the thermodynamic analyses, tungsten samples were fabricated by CVD and sent to Pacific Northwest National Laboratory, where an assay technique was developed using inductively coupled plasma mass spectrometry (ICP-MS) to quantify the concentrations of thorium and uranium in a tungsten matrix. Empirically, thorium and uranium levels as low as 80 parts per quadrillion (ppq) and 50 ppq, respectively, were measured.

1. N.R. Overman et al., "Majorana Electroformed Copper Mechanical Analysis,"Pacific Northwest National Laboratory, Richland, WA (April 2012).

RDC 06 - Gaseous Detectors Parallel Session / 84

A Straw Tracker for the FCC-ee

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We are working on R&D studies of a straw tracker that could be used as an inner tracker for the FCC-ee experiments. The straw tracker offers the advantage of a low material budget and a single-hit resolution of 100-120 microns per straw. With about 100 layers, the straw tracker will play a pivotal role in pattern recognition, particle identification, and long-lived particle searches. Straws with different radii can be used in different detector regions. We will present simulation and optimization studies for a straw tracker and its gas mixture using GEANT4 and Garfield simulation. We will also present test beam results with a prototype chamber.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 86

Deep-IR Sub-eV SNSPDs for Axion and Dark Matter Detection

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Superconducting nanowire single photon detectors (SNSPD) are ultra sensitive low noise detectors sensitive to single photons. By optimizing the material content of the superconducting thin film, it is possible to reduce the energy detection threshold far into the infrared. Such low threshold detectors are ideally suited for low mass dark matter and axion detection experiments such as the BREAD experiment, where detection sensitivity can be uniquely pushed far below the 1~eV scale. We will describe recent progress in SNSPD sensor R&D enabling detection of photons with wavelengths as large as 29 µm, enabling axion and dark photon detection down to masses as low as 0.04 eV, and next steps to potentially push the detection towards 50µm photons. We will also discuss challenges and potential solutions in deep-IR photon detection readout and antenna-coupled structures to enlarge the active area.

RDC 04 - Readout and ASICs Parallel Session / 87

Design, Testing and Performance of a sub-5ps RMS TDC ASIC in 22nm CMOS for LGAD and 4K readout.

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We present the design and performance of the DILVERT time-to-digital (TDC) readout chip developed for room temperature and 4K cryogenic operations. The chip simultaneously achieves very low power and picosecond timing resolution when operated in a cryogenic (4K) environment. It features configurable time bins and is an enabling technology for precision timing applications including 4D tracking and quantum communications. We present measurements using charge injection of LGAD signals and achieve time resolution consistent with the 3 ps design specification.

Joint RDC 03 & 11 Parallel Session / 88

Development of 3D-integrated detectors for high precision timing and position applications

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We present our progress towards the development of 3D-integrated sensing technology using advanced manufacturing techniques and collaboration with industry leaders. The aim of the project is to develop technology to enable large-scale particle detectors with 3D-integrated designs to simultaneously achieve 10 μm position resolution and 10 ps precision timing, with low-power consumption and high throughput rates. Our developments on the design and manufacturing of Low-Gain Avalanche Diodes (LGADs) devices in 12”foundry processes will be discussed, as well as the design of the ASIC techniques to meet various application needs for granularity, precision timing, and power. This research program leverages the unique combination of facilities and cross-disciplinary expertise of scientists and engineers at SLAC, FNAL, and LLNL and industrial partners. We show the current status of the project and future plans.

RDC 02 - Photodetectors Parallel Session / 89

Photon detection with nanoscale hybrids

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The sensitive element of a typical photon detector must perform several functions. It must absorb photons, transduce the photon energy into some excitation, and collect and possibly amplify those excitations. For example, in a silicon detector the photon is absorbed by the silicon crystal, giving rise to electron-hole pairs (excitations), which then must propagate to some collector and possibly be amplified along the way, for example via avalanche multiplication. All these steps are constrained by the properties of the one material: silicon. It is not possible to independently manipulate the absorption from the transduction, for example. In a nanoscale hybrid, multiple elements made of different materials are assembled into a nanoscale system, that is smaller than the wavelength of the target light, allowing each photon to interact coherently with the entire system. This makes it possible to have different, independently optimized elements responsible for absorption, transduction, and collection/amplification. This allows to achieve, for example, near 100% quantum efficiency within a desired band, with single-photon spectroscopic resolution inside the band. We will present the status of our effort to demonstrate such devices. We have developed theory and simulation for the operation of nanoscale hybrids. Our prototyping work involves carbon nanotubes, quantum dots, and transition metal dichalcogenides. We designed and produced integrated circuit passive and active substrates to support these nanomaterials and have developed integration methods using e-beam lithography as well as DNA-guided self-assembly.

RDC 01 - Noble Element Detectors Parallel Session / 90

CrystaLiZe: Dark Matter Detection and Beyond with Crystal Xenon

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We present the crystalline xenon time projection chamber (TPC), a promising novel technology for next-generation dark matter searches. Initial tests have established that it maintains many of the benefits of the liquid xenon TPC while also effectively excluding radon, the dominant background in currently-running xenon dark matter experiments such as LZ. This offers the potential for greatly improved sensitivity to dark matter through a crystal xenon upgrade to an existing experiment. This talk will discuss signal detection properties, radon exclusion performance, and progress towards a multi-kg demonstrator designed to establish its scalability.

RDC 09 - Calorimetry Parallel Session / 91

Performance of the H2GCROC ASIC in Hadronic Calorimetry

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The Forward Calorimeter (FoCal) is a new sub-detector for ALICE to be installed during CERN LS3, optimized for measurements in the forward region. FoCal-H, the hadronic calorimeter component of this upgrade, is designed as a scintillating-fiber calorimeter. Its front-end electronics are based on the H2GCROC ASIC, which was originally developed for the CMS HGCAL collaboration to read out SiPM signals. The ASIC has 72 channels and provides both energy and time information for the input signals. Key features like Time-over-Threshold (ToT) measurement and the current conveyor stage are important for efficient hadronic calorimeter readout.

In September, we tested the performance of H2GCROC with the FoCal-H prototype during a beam test at the SPS beamline. A fully customized hardware system based on the Xilinx KCU105 evaluation board, along with software built on the PySide framework, was used for the test. The results show that H2GCROC meets the demands of FoCal-H, confirming its capability for handling the front-end readout in the final detector.

RDC 04 - Readout and ASICs Parallel Session / 92

Front-end electronics of the High Granularity Electromagnetic Forward Calorimeter (FoCal-E) at ALICE

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FoCal, a high-granularity forward calorimeter, is one of the ALICE detector upgrade projects for Run 4 at the CERN LHC, scheduled to collect data starting in 2029, after the Long Shutdown 3. The calorimeter has two main subsystems: a highly granular silicon-tungsten electromagnetic calorimeter (FoCal-E), and a conventional sampling hadronic calorimeter (FoCal-H). FoCal is designed to cover a pseudo-rapidity between 3.4 and 5.8.

The electromagnetic calorimeter comprises 20 layers of tungsten absorbers interleaved with silicon detectors. Out of those active layers, 18 have a granularity of 1 cm2 and they consist of silicon pads

read out by the HGCROC, the read-out chip developed for the Compact Muon Solenoid (CMS) High Granularity Calorimeter. The read-out chip allows the measurement of the amplitude of the signal, together with the time-of-arrival and time-over-threshold.
The remaining 2 layers consist of high granularity 30x30 um2 monolithic sensors (ALPIDE) developed for the ALICE inner tracker.
The pad layers measure the shower energy and profile, while the pixel layers enable two-photon separation down to a few millimeters, to discriminate between isolated photons and merged showers of photon pairs generated by the decay of neutral pions. The total silicon sensor area for FoCal-E is about 12 m2 with about 150K individual pad channels and about 4 thousand pixel sensors.

In this contribution, we will discuss the development of the front-end electronics and the main results of the test beam campaigns, with a special focus on the electromagnetic calorimeter.

RDC 02 - Photodetectors Parallel Session / 93

Performance Evaluation of MCP-PMT with an Active Ion Barrier

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We present results from the performance characterization of MCP-PMTs with an active metal grid between the photocathode and the MCP. The active ion barrier grids are intended to prevent the positive ions generated inside the MCPs during the electron multiplication process from reaching the photocathode and thus, increase the lifetime of the MCP-PMT. The potential applied on the grid redirects the liberated positive ions toward the MCP. Our results demonstrate that the ion feedback rate, measured using the after-pulses generated by the ions, reduces with the applied potential on the grid. Our results also show that critical performance parameters such as the timing resolution, gain, and pulse height distributions are not impacted by the applied potential on the active ion barrier. We complement these results with simulation of the ion trajectories in a model MCP-PMT with active ion barrier grid and demonstrate how potential on the ion grid improves the timing resolution. Our simulations also provide a framework to identify the nature of ions that are generated inside the MCP. These observations, the first of their kind, provide essential data necessary to design new MCP-PMTs geometries with prolonged lifespans.

RDC 10 - Detector Mechanics Parallel Session / 94

Towards a Carbon-Fiber wire based drfit chamber

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We will present R&D towards an all/dominantly Carbon Fiber (CF) low mass multi-wire proportional chamber utilizing CF sense wires and optimized CF based support structures to hold them in place. Such a technology is an ideal match for the needs of future very light-weight tracking devices at a variety of particle physics experiments. A calculation of material budget between state-of-the-art gold-plated tungsten wires and CF wires of similar dimension show a drastic potential reduction of the radiation length X0 by a factor 10. The talk will highlight early results towards cutting-edge active sensing wire chambers providing the critical R&D for detectors at future colliders relying on transformational manufacturing techniques.

RDC 04 - Readout and ASICs Parallel Session / 95

Smart Pixels: Towards radiation hard ASIC with on-chip machine learning in 28nm CMOS

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We introduce a smart pixel prototype readout integrated circuit (ROIC) fabricated using a 28 nm bulk CMOS process, which integrates a machine learning (ML) algorithm for data filtering directly within the pixel region. This prototype serves as a proof-of-concept for a potential Phase III pixel detector upgrade of the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC). This chip, the second in a series of ROICs, employs a fully connected two-layer neural network (NN) to process data from a cluster of 256 pixels, identifying patterns corresponding to high-momentum particle tracks for selection and readout. The digital NN is embedded between the analog processing regions of the 256 pixels, maintaining the original pixel size. Its fully combinatorial digital logic circuit implementation minimizes power consumption, avoids clock distribution, and activates only upon receiving an input signal. The NN performs momentum classification based on cluster patterns, achieving a data rejection rate of 54.4% to 75.4% with a modest momentum threshold, opening up the possibility of using pixel information at 40 MHz for trigger purposes. The neural network NN) itself consumes around 300 μW. The overall power consumption per pixel, including analog and digital functions, is 6 μW, resulting in approximately 1 W/cm², within the permissible limits of the HL-LHC experiments. This presentation will showcase the preliminary testing results using Spacely, an open-source framework for post-silicon validation of analog, digital, and mixed-signal ASICs. Spacely maximizes hardware and software reuse, streamlining the testing process for small ASIC design teams in academia and research institutions.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 96

Searching for Sterile Neutrinos with Mechanical Quantum Sensors and CMOS Sensors

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We describe the proposed Quantum Invisible Particle Sensor (QuIPS) experiment, an optomechanical laser trap surrounded by active pixel detectors, that would allow for searching for heavy sterile neutrino masses in the 100s of keV to few MeV regime via weak nuclear decays. The experimental setup uses CMOS sensors to measure the direction of a beta particle emitted from a trapped nanosphere, and a scintillating detector to reconstruct its energy. When combined with the momentum impulse imparted to the trapped nanosphere, read out at the standard quantum limit, the full momenta of the weak nuclear decay products may be reconstructed: thus allowing for probing heavy sterile neutrinos and other BSM physics. This talk will present designs, simulations, recent progress, and projected sensitivities.

RDC 06 - Gaseous Detectors Parallel Session / 97

Experimental comparison of strip micromegas readouts in gaseous TPCs for directional recoil detection

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Imaging the detailed 3D topology of ionization in detectors is broadly desirable in nuclear and particle physics. Of particular interest is the directional detection of nuclear recoils from neutrinos or dark matter, which may prove critical for probing dark matter beneath the neutrino fog and affirming its galactic origin. Gaseous time projection chambers (TPCs) can provide the required low-energy directionality and in this context high-resolution x/y strip readouts are identified as the optimal balance between cost-efficiency and performance. We present an experimental comparative analysis of nine distinct x/y strip configurations with a Micromegas amplification stage. The VMM3a ASIC within the RD51 Scalable readout system (SRS) is used to read out individual strips, while the Micromegas avalanche charge is recorded with a pulse height analyzer system. These two complementary charge readout techniques are used with radioactive sources to characterize the gain, gain resolution, x/y charge sharing, and point resolution of each setup, in order to identify the optimal charge readout configuration. Additionally, we discuss how these results have informed the design of a 40L strip Micromegas TPC currently under development.

Joint RDC 03 & 07 & 08 / 98

Material properties of superconducting Hafnium films

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Hafnium (Hf) is a superconducting material that has been gaining popularity among the superconducting detector community –for e.g. TES bolometers (Rotermund et al. in prep), TES calorimeters (Lita et al. 2009, Safonova et al. 2024), optical and near-IR MKIDs (Zobrist et al. 2019, Coiffard et al.

2020), phonon-sensitive MKIDs (Li et al. in prep), STJ (STAR Cryoelectronics SBIR awarded 2022), and QPDs (Ramanathan et al. 2024). Hf is an attractive superconducting film for many reasons, including that its bulk critical temperature (Tc) is near 128 mK, the London penetration depth is estimated to be 20 nm [Kraft et al. 1998], and the surface kinetic inductance is high at around 15-20 pH/□ for a 125 nm film [Coiffard et al. 2020], thus making it well-matched to needs across many experiments.

Here we present a study of hafnium's material properties that lends itself to being a good superconductor across many detector efforts. We investigate empirical relations of critical temperature, normal resistance, internal quality factor, and how they in turn affect the kinetic inductance. We consider film properties such as the phases present through XRD measurements and how they are affected by film thickness and deposition temperature.

One key difference between past Hf detector efforts and our own, is our use of a heated sputter deposition. The heated sputter deposition has 2-fold consequences 1) it enables us to precisely tune Tc to our desired target value due to its linear dependence on deposition temperature and 2) it ensures that the Tc is robust against subsequent exposure to heat as long as the initial deposition temperature is not exceeded.

While Hf is an attractive superconductor for many detector applications, we observed that making reliable electrical contact requires a detailed understanding of the Hf interface. We discuss the challenges and solutions for the superconducting interfaces with films such as niobium, aluminum, and niobium nitride.

RDC 09 - Calorimetry Parallel Session / 99

Towards GPU Accelerated Full Simulation of Optical Calorimetry with Celeritas

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Dual readout calorimeters and noble gas time projection chambers require accurate modelling of Cerenkov photons to determine energy resolution and timing uncertainty of the detectors. Due to the high multiplicity of optical photons in a single event, fast parameterizations are often used to improve computational throughput at the cost of precision. Leveraging GPU hardware can make full optical photon simulations viable for characterizing detector response. The Celeritas Project is a GPU accelerated particle transport code optimized for High Performance Computing (HPC) systems. Currently Celeritas is capable of simulating electromagnetic showers and is currently being expanded to include optical photon physics, muon electromagnetic and decay physics, and neutron transport. In order to be easily integrated with existing Geant4 programs, Celeritas may be used as a drop-in replacement or as a target to off-load specified particle tracks to the GPU. Integration efforts into the CMS and Calvision software frameworks are currently proposed.

RDC 11 - Fast Timing Parallel Session / 100

Fast timing with μRWELL-PICOSEC detector technology

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The μRWELL-PICOSEC detector, which is based on Resistive Micro-Well (μRWELL) technology, is a novel concept for fast timing gaseous detectors that can provide timing resolution in the tens of picosecond range, making it ideal candidate for time-of-flight (TOF) technology for particle identification (PID) in particle physics experiments as well as for future medical instrumentation. The μRWELL-PICOSEC concept is based on a Cerenkov radiator that produces Cerenkov photons from high energetic charged particles, a photocathode layer that converts the Cerenkov photons into primary electrons, a μRWELL amplification layer that multiply the electrons through amplification in a CF4-based gas mixture and a pad-segmentation anode readout coupled with fast timing electronics to provide fast signal. Beam tests were carried out at the CERN SPS H4 beamline in summer 2023 and 2024. Preliminary results show timing performance of the order of 23 ps achievable with μRWELL-PICOSEC prototype. and position scan of the 100-pads of a multi-channel prototype was also performed to study time response uniformity of large area detector. In this talk, after a brief overview of the PICOSEC technology, we will present recent results with different single channel μRWELL-PICOSEC prototype designs and also the position scan results of the 100-pads large prototype to study timing response uniformity for large area μRWELL-PICOSEC detector. Finally, we will discuss the ongoing R&D effort to further improve the timing resolution and allow good position capabilities through charge sharing for large area.

Plenary session / 101

The Belle II Upgrade Program

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The Belle II experiment at the SuperKEKB e^+e^- collider started recording collision data in 2019, with the ultimate goal of collecting $50\ \mathrm{ab}^{-1}$. The wealth of physics results obtained with the current data sample of $424\ \mathrm{fb}^{-1}$ demonstrate excellent detector performance. The first years of running, however, also reveal novel challenges and opportunities for reliable and efficient detector operations with machine backgrounds extrapolated to full luminosity. In order to reach the target luminosity of $6 \times 10^{35}\ \mathrm{cm}^{-1}\mathrm{s}^{-1}$, an accelerator consolidation and upgrade shutdown is being studied for the timeframe of 2027-2028. Belle II is defining a detector upgrade program to make the various subdetectors more robust and performant even in the presence of high backgrounds, thereby facilitating the SuperKEKB running at high luminosity. This upgrade program includes the replacement of select readout electronics, upgrades of certain detector elements, and may also involve the substitution of entire detector sub-systems such as the vertex detector. A Conceptual Design Report is currently in preparation. This talk will cover the full range of proposed upgrade ideas and their development plans.

RDC 11 - Fast Timing Parallel Session / 102

Real-Time AI Triggering for Liquid Argon Time Projection Chambers

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Modern particle detectors, including liquid argon time projection chambers (LArTPCs), collect a vast amount of data, making it impractical to save everything for offline analysis. As a result, these experiments need to employ data down-selection techniques during data acquisition, referred to as triggering. In this talk, I will present ongoing efforts to provide real-time, intelligent, data-driven triggering for LArTPCs using hardware-accelerated AI algorithms. This approach can be adopted for various off-beam, rare physics searches with LArTPCs, for example the search for beyond-Standard Model (BSM) millicharged particles in SBND, or more broadly for BSM signals in a model-agnostic way, using anomaly detection. Drawing on studies that make use of simulated LArTPC data from the Short Baseline Near Detector (SBND) and the Public Dataset from the MicroBooNE LArTPC, I will discuss the overall performance of such approaches and their potential application in future LArTPC experiments.

RDC 01 - Noble Element Detectors Parallel Session / 103

Characterizing signal production in hydrogen-xenon gas mixtures

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Adding light dopant gasses like hydrogen to liquid xenon detectors is expected to improve their sensitivity to low-energy recoils—and consequently sub-GeV dark matter. HydroX is a multi-institution effort to explore the feasibility of this method for use in current and future liquid-xenon dark matter experiments, such as LZ. As part of this initiative, we have constructed a test stand at SLAC to measure the effect of hydrogen on scintillation and electron transport in gaseous xenon. In this talk, I will provide an overview of the test stand design, which includes a gaseous xenon time projection chamber and plumbing to enable hydrogen injection, circulation, and removal. I will present preliminary results and discuss plans for future studies.

RDC 11 - Fast Timing Parallel Session / 104

Advances in Neutrino Detector Technology from the ANNIE Experiment

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This talk highlights the latest contributions and significant milestones of the Accelerator Neutrino Neutron Interaction Experiment (ANNIE) in advancing neutrino detection technologies. ANNIE, located on the Booster Neutrino Beam (BNB) at Fermilab, serves as a research and development platform for cutting-edge detection techniques. It is the first neutrino experiment to utilize gadolinium (Gd)-loaded water, Large Area Picosecond Photodetectors (LAPPDs), and Water-based Liquid Scintillator (WbLS). We present the technological progress made by ANNIE in demonstrating the dual Cherenkov-scintillator hybrid detection system. In particular, we emphasize the successful deployment of SANDI, a 366 L WbLS volume, and the first deployment, integration, and operation of LAPPDs in a neutrino experiment.

RDC 05 - Trigger and DAQ Parallel Session / 105

Generic Back-End electronics for high-bandwidth detector readout

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To stream readout all the high-bandwidth detector in the High Energy Physics (HEP) and Nuclear Physics (NP) experiments is always a good wish but causes big challenge for the on-detector processing, data links and back-end electronics. The Front-End Link eXchange (FELIX) system is an interface between the detector and trigger readout electronics and commodity switched networks for the ATLAS experiment at CERN. The FELIX approach takes advantage of modern FPGAs and commodity computing to reduce the system complexity and effort needed to support data acquisition systems in comparison to previous designs. FELIX phase-I hardware (FLX-712) is based on the generic PCIe form factor with Kintex Ultrascale FPGA with support of PCIe Gen3. It has been widely adopted by other HEP and NP experiments - sPHENIX at RHIC, ProtoDUNE at CERN, CBM/RE21 at FAIR, test beam experiments at Fermilab and CERN. The recent development (FLX-182/FLX-155) are based on the Versal FPGA with support of PCIe Gen4/5 and 25Gb/s optical links. It has been and is going to be tested by several HEP and NP experiments - ePIC at EIC, sPHENIX at RHIC, LHCb at CERN, ALICE at CERN, CBM/RE21 at FAIR. In addition, CERN DRD7 (Electronics) collaboration has it as a hardware platform for adaptation from Front-End to Back-End with 100 GbE in one of Work Packages. This rapid improvement in the back-end electronics is a paradigm shift and enables triggerless readout of the future particle experiments that maximizes their discovery potential. The latest R&D progress of the Versal FPGA based FELIX development will be presented in this contribution.

Joint RDC 03 & 11 Parallel Session / 106

MAPS Silicon Vertex Tracker and AC-LGAD Time-of-Flight Detectors for the Electron-Ion Collider

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The Electron-Ion Collider (EIC) is a new flagship facility that will be built at Brookhaven National Laboratory to study properties of nuclear matter and the strong interactions through electron-proton and electron-ion collisions. High efficiency, high resolution vertexing, tracking and particle identification in a wide kinematic range are critical to fulfill the requirements of the EIC physics program. In this talk, we will describe the design and development of the silicon vertex tracker based on the most advanced Monolithic Active Pixel Sensor (MAPS) technology as well as the Time-of-Flight detectors based on the recently developed AC-coupled Low Gain Avalanche Diode (AC-LGAD) technology.

RDC 01 - Noble Element Detectors Parallel Session / 107

Self-compensating Light Calorimetry with Liquid Argon TPC for GeV Neutrino Physics

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Liquid Argon Time Projection Chamber (LArTPC) is an exceptional dual calorimeter capable of estimating the energy of incident particles through both the ionization charge and the scintillation light. This talk will show that due to the mechanisms of charge recombination and light generation involved in the energy dissipation in liquid argon, light calorimetry in LArTPCs is inherently self-compensating. The missing energy in the hadronic component is compensated for by the extra recombination luminescence compared to the electromagnetic component. Good compensation of the electron-to-hadron response ratio (e/h) around unity can be achieved across a broad range of drift electric fields from 0.2 to 1.8 kV/cm. This inherent self-compensation enhances the appeal of light calorimetry in LArTPCs, complementing the well-established charge calorimetry. Using GeV-neutrinos as a case study, we show that light calorimetry can yield an energy resolution comparable to the more sophisticated charge imaging calorimetry. The synergy between light and charge calorimetry offers a novel approach to evaluating and mitigating systematic uncertainties in energy measurements with LArTPCs.

RDC 06 - Gaseous Detectors Parallel Session / 108

Viability of GridPix TPC for the EIC second detector

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The possibility to realize a second detector at the IP8 position of Electron Ion Collider (EIC) is of great importance. It is aimed to provide complementarity and reference for the physics measurements of the future ePIC detector at the EIC with the possibility of extended physics measurements.
Time Projection Chamber (TPC) with GridPix readout is one of the most attractive options as it provides particle identification and high resolution tracking for the IP8 detector. The GridPIX technology is based on micromegas-style gain amplification. It is coupled with pixelated high-granular readout located below an etched aluminum mesh. providing amplification. This grid yields sufficient gain to provide good signal to noise ratio with more than 90% efficiency. Below the grid is an array of 55 by 55 µm pixels, providing high resolution measurement.
Using typical Argon-based mixtures, diffusion is most often sufficient and each electron from a cluster lands in a different hole. In this way, the GridPix detector technology promises a final realization of the long sought dream of cluster counting. Additionally, when coupled to a low diffusion gas, the GridPix technology will act as a high resolution tracker competitive with all-silicon systems.
I will present the concept and latest results on the GridPix TPC R&D for the EIC second detector.

RDC 04 - Readout and ASICs Parallel Session / 109

Autoencoders for At-Source Data Reduction and Anomaly Detection in High Energy Particle Detectors

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To address the challenges of future collider experiment environments, machine learning (ML) in readout electronics can be leveraged for smart detector designs, enabling intelligent inference and data reduction at-source. Autoencoders offer a variety of benefits for front-end readout; an on-sensor encoder can perform efficient lossy data compression while simultaneously providing a latent space representation that can be used for anomaly detection. Results are presented from low-latency and resource-efficient autoencoders for front-end data processing in a futuristic silicon pixel detector, enabling a readout scheme that can provide combined capabilities of off-detector data reduction and real-time sensor defect monitoring. Together these results highlight the multi-faceted utility of autoencoder-based front-end readout schemes, and motivate their consideration in advanced detector designs.

RDC 09 - Calorimetry Parallel Session / 110

Fermilab Program for Organic Scintillator

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Fermilab is one of the largest producers of organic scintillator in the world. Its scintillator has been used in a wide variety of applications including archeology, volcanology, mining exploration, agriculture, national security, as well as more traditional applications in HEP and Astro-particle physics. We will describe the scintillator extrusion facility and injection molding facility. We will discuss ongoing and near-term future projects for these facilities, including production of scintillating tiles for the CMS HGCAL HL-LHC upgrade.

Joint RDC 07 & 08 & 09 Parallel Session / 111

Status and Progress of the HeRALD Setup at Berkeley

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The HeRALD experiment is a dark matter direct detection experiment using superfluid He-4 as the target material. The advantages of helium as a dark matter target include its good kinematic matching with sub-GeV light dark matter, as well as the energy gain mechanism through quantum evaporation. Following the first demonstration of this novel dark matter detection technique at the UMass HeRALD setup, we aim to study the multi-channel coincidence calorimetric readout with Transition Edge Sensors at the Berkeley setup. In this talk, I will present recent progress at the Berkeley HeRALD setup.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 112

Receiver Noise In Axion Haloscopes

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Axions are a well-motivated dark matter candidate for solving the strong CP problem at the same time. Axion haloscope makes use of the conversion of axions to photons in a large magnetic field. To increase signal strength, many haloscopes make use of resonant enhancement and high gain amplifiers, while also taking measures to keep receiver noise as low as possible such as the use of dilution refrigerators and ultra low-noise electronics. We build the noise model based on the sources of noise found within a typical axion haloscope receiver chain, using the Axion Dark Matter eXperiment (ADMX) as a case study. We present examples of different noise calibration measurements at 1280~MHz using a hot load with ADMX during its most recent data taking run. The consistency between the measurements and the detailed model provide suggestions for future improvements within ADMX and other axion haloscopes to reach a lower noise temperature and to simplify the receiver chain design.

Joint RDC 03 & 11 Parallel Session / 113

Updates on charge sharing and radiation hardness of AC-LGADs for near-future Higgs factories and nuclear physics experiments

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Low Gain Avalanche Detectors (LGADs) are characterized by a fast rise time (~500ps) and extremely good time resolution(down to 17ps), and potential for a very high repetition rate with ~1 ns full charge collection. For the application of this technology to near future experiments such as e+e- Higgs factories, the ePIC detector at the Electron-Ion Collider, or smaller experiments (e.g., the PIONEER experiment), the intrinsic low granularity of LGADs and the large power consumption of readout chips for precise timing is problematic. AC-coupled LGADs, where the readout metal is AC-coupled through an insulating oxide layer, could solve both issues at the same time thanks to the 100% fill factor and charge-sharing capabilities. Charge sharing between electrodes allows a hit position resolution well below the pitch/sqrt(12) of standard segmented detectors. At the same time, it relaxes the channel density and power consumption requirement of readout chips.
Extensive characterization of AC-LGAD devices with both laser TCT and probe station (IV/CV) will be shown in this contribution, comparing the effect of various parameters among the readout electrode dimensions (strip/pad metal contact length and width, pitch) and sensor production details (manufacturer, N+ layer resistivity, dielectric capacitance, bulk thickness, doping of the gain layer). The data suggests that the length of the strip plays a dominant role in determining the extent of long-distance cross- talk and/or pick-up; on the other hand, the N+ layer resistivity influences the strength of the shared signal. We will also discuss our efforts at replicating the observed behavior of the sensors, including the capacitive and resistive circuitry on the fast readout boards used for sensor testing, in 2D and 3D TCAD simulations.
We will present the first results on AC-LGADs irradiated with 1 MeV reactor neutrons at JSI/Ljubljana to fluences on the order of 1e13 to 1e15 n/cm2. As observed in all silicon sensors, leakage currents and full depletion voltage points increase with irradiation. The radiation hardness of the gain layer, i.e. the electrical deactivation of Boron dopants, is determined by C-V measurements, showing the sensors to be radiation hard to lower fluences as relevant in e.g. the EIC, but degrading the gain at

1e15 n/cm2. Changes in the charge sharing profile across strips are observed in laser TCT measurements, indicating an increase of signal sharing potentially explained by degradation of the surface passivation, however not critically affecting sensor performance.
Finally, using a rotational stage in our laser TCT system we will show our initial investigation of charge sharing in AC-LGADs for hits incident on the sensor at an angle, to evaluate the effect of the tilted installation which is typical for silicon pixel and strip sensor modules in tracking detectors.

RDC 03 - Solid State Tracking Parallel Session / 114

Indium Phosphide sensors as a candidate material for future large-scale thin film detectors: device characterization and radiation hardness

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Thin film technology, as used in LCD displays and photovoltaics, could enable the fabrication of large-area, low-mass tracking detectors on flexible substrates, ultimately building towards roll-to-roll printing. Thin film detectors may also potentially incorporate electronic elements into a monolithic design, or involve the deposition of active sensor material onto a readout ASIC. Physical and chemical vapor deposition methods allow the fabrication of tracking sensors from many other semiconductors besides Silicon. Potential new material candidates for charged particle tracking and photon detection are identified by properties such as band gap, resistivity, charge carrier mobility and charge collection efficiency.
This presentation focuses on Indium Phosphide (InP), which stands out as having a significantly higher electron mobility (>4500 cm^2/Vs) than Si and has found use in optoelectronics and high-frequency electronics. Single-pad sensors and 5x5 pad arrays have been fabricated at Argonne National Laboratory on commercially available 350-µm thick InP:Fe wafers.
For single-pad sensors, we will summarize the initial characterization in the laboratory (IV, CV with uniformity assessment over the wafer; red laser TCT), as well as the results of test beams conducted with 120 GeV protons and focused X-ray beams. The reconstruction of hit position in 5x5-pad arrays in red laser TCT utilizing inter-pad cross-talk in addition to the main channel, is discussed.
To study of the radiation hardness of InP sensors, which is practically unknown compared to e.g. Si and diamond, a set of InP single-pad devices was irradiated with 1 MeV reactor neutrons at JSI/Ljubljana to the fluences of 1e13, 1e14, 1e15 and 1e16 n/cm^2. The sensors irradiated to 1e13 and 1e14 n/cm^2, as well as a non-irradiated reference, were tested with a Sr-90 beta source using a silicon LGAD reference as a trigger at different temperatures. Operation at lower temperature improves CCE and provides timing resolution down to < 25 ps. We find that excellent timing resolution is retained at a fluence of 1e13 n/cm^2. At 1e14 n/cm^2, increased degradation in collected signal charge and pulse amplitudes is observed, and higher bias voltages and lower temperatures are needed to reach 40 ps timing resolution. Rise time (and FWHM) for irradiated sensors decreases to 200 ps and below, but with a lower signal-to-noise ratio.
Our future plans for material modeling and simulation, as well as the next steps towards fabricating InP sensors by thin-film deposition methods, will be described.

RDC 01 - Noble Element Detectors Parallel Session / 115

Characterizing CRYO ASIC and Charge Readout in nEXO

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Neutrinoless double beta decay (0vbb) is a lepton-number-violating process that is forbidden in the Standard Model. The observation of 0vbb would imply that neutrinos are their own anti-particles, and provide an important step towards explaining the asymmetry of matter and anti-matter in the universe. nEXO is a proposed next-generation 0vbb experiment containing 5000 kg of isotopically enriched Xe-136 in a time projection chamber (TPC), detecting both ionization charge and scintillation light. Ionization electrons produced by charged particles drift along the electric field towards the anode where it is read out by arrays of crossed strips, deposited on 10 cm*10 cm dielectric tiles. The signal pre-processing, digitization and read-out steps are carried out at cryogenic temperatures by a follow-up novel System-on-Chip CRYO ASIC deployed on the back side of the tiles. nEXO requires a high precision of reconstruction of the electron energy to effectively discriminate signals from backgrounds. In this study, we focus on bench-top and cold tests at SLAC for the CRYO ASIC motherboard and the charge readout module prototype, and also the liquid xenon testing of the charge module prototype using a 28 kg LXe TPC at Stanford. These tests aim to characterize the noise and signal response performance of the charge module, and elucidate the reconstruction and physics potential of nEXO.

Joint RDC 01 & 02 & 04 / 116

Scintillation Imaging with Coded Aperture Masks

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Most noble liquid detectors employ scintillation light as either a timing signal for a TPC or as a calorimetric measurement, or both. Its relative amplitude and timing on multiple detectors can also be used to approximately locate an interaction.
Scintillation imaging goes a step further, introducing an optical system in front of finely segmented SiPM matrices. The objective is to build photographic cameras that capture images of the primary scintillation light.
In absence of a TPC, scintillation imaging alone can provide vertexing and tracking information, while combined it can enhance resolution and rate capability (which is a concern for near detectors located on powerful neutrino beams).
Both Xe and Ar scintillate in the VUV range, imposing stringent requirements on the optical system and SiPMs. Instead of using a set of lenses, a thin and compact camera with both deep and wide field of view can be created by using a coded aperture mask. This technique, already in use for X-ray and gamma photons, provides a reliable method of image formation at the cost of complex offline processing. The coded mask itself can further be made charge sensitive in order to obtain a combined charge and light detector.

The latest results from simulation and reconstruction of neutrino interactions in a LAr detector equipped with coded aperture cameras will be presented. A review of the applications, such as in DUNE/SAND, and the development status of key enabling technologies will also be included.

RDC 06 - Gaseous Detectors Parallel Session / 117

On Beyond Xenon: TPC gases and configurations for future neutrinoless double beta decay

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Scaling neutrinoless double beta decay experiments to the 100 ton or kiloton scale seems most plausible, at least from an instrumentation point of view, if we aim for a large TPC. However, the lack of a xenon supply chain is a bottleneck. In this talk, we will discuss possible alternatives TPC gases, including SeF6 efforts, and our efforts to identify alternative non-electronegative gases. We will suggest some novel TPC readouts and operating modes that might let us work around gain and drift problems in oddball gases.

Joint RDC 03 & 11 Parallel Session / 118

Developments of MAPS detectors for FCC-ee applications

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We will present the ongoing efforts on development of high precision low-power CMOS detectors for particle detection. Design efforts to produce MAPS sensors with a commercial foundry in the US, and characterization of prototypes of ARCADIA sensors will be shown. Efforts toward designing and producing MAPS with a commercial foundry in the US are pursued within our US-Japan consortium and we will present our current status, as well as our test beam characterization efforts on an ARCADIA technology demonstrator chip. ARCADIA chip has 25 µm2 pixels, and was developed as a test prototype by the INFN consortium of institutions as a candidate sensor for the FCC-ee vertex detector. We performed extensive characterization campaign of the ARCADIA chip with proton beams at the Fermilab Test Beam Facility (FTBF) and using infrared laser scans in laboratory. Results of these tests will be summarized, and we will present the status and plans of future developments of this technology.

RDC 10 - Detector Mechanics Parallel Session / 119

pfRICH cylindrical vessel outer shell effort for EIC ePIC experiment

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In this talk, we will discuss the design and engineering of the cylindrical vessel outer shell for the proximity-focusing Ring Imaging Cherenkov (pfRICH) detector at the Electron-Ion Collider (EIC). The pfRICH serves as a critical particle identification subsystem, providing momentum coverage of up to 7 GeV/c for pions, kaons, and protons in the backward region of the upcoming ePIC experiment at the EIC.
We will highlight our innovative construction methods for the cylindrical vessel, which is composed of a carbon fiber honeycomb sandwich structure. This design not only ensures a lightweight and robust enclosure but also maintains gas and light tightness, essential for the detector's performance. Key project phases will be discussed, including mandrel assembly and the integration of carbon-fiber composites. Additionally, we will address the fabrication of the two carbon fiber composite plastic (CFRP) rings that will secure the entire assembly, ensuring its structural integrity and performance in the EIC environment.

Joint RDC 03 & 11 Parallel Session / 120

Highlights of the US 4D Tracking Workshop

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4D Tracking is a major new technology that will be transformative for future colliders. 4-dimensional tracking with ultra-fast timing and very fine spatial resolution will be key to addressing the increasing complexity of events at hadron colliders (HL-LHC and FCC-hh) and suppressing the beam-induced backgrounds at muon colliders. Higgs factories (FCC-ee/ILC) will utilize timing layers with high granularity for ToF particle identification and long-lived particle searches.

With many efforts and ideas around 4D tracking in the US, we organized a first US workshop dedicated to bringing the US community interested in 4D tracking together to discuss the various efforts being pursued and discussing the formation of a collaboration to pursue 4D tracking detector R&D within the US.

In this presentation we will provide highlights of the workshop and summarize the main ideas it has generated and the next steps.

RDC 05 - Trigger and DAQ Parallel Session / 121

Empowering AI Implementation: The Versatile SLAC Neural Network Library (SNL) for FPGA

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SLAC has developed a library based framework that enables the deployment of machine learning (ML) models on Field Programmable Gate Arrays (FPGAs) located at the edge of the data chain, near the instrumentation. It's called the SLAC Neural Network Library (SNL), utilizes Xilinx's High-Level Synthesis (HLS) and offers an API inspired by Keras for TensorFlow. By adopting a streaming data approach, SNL optimizes the data flow between neural network layers, minimizing the need for buffering and achieving high frame rates with low latency, critical for real-time applications in experimental environments.
A key feature of SNL is its ability to re-load neural network weights and biases after training without the need for re-synthesis. This allows for rapid updates to the deployed models, enhancing adaptability and performance in dynamic environments. Additionally, the framework supports network quantization, which helps optimize the use of FPGA digital signal processing (DSP) and memory resources, crucial for maximizing efficiency in resource-constrained edge computing scenarios.

Joint RDC 03 & 11 Parallel Session / 122

The MAIA Detector for a 10 TeV Muon Collider

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Over the last few years, muon colliders have emerged as an exciting option for enabling access to the 10 TeV energy scale in the post-HL-LHC era; however, realizing this promise still requires significant research and development in both accelerator and detector technologies. Two potential designs for a 10 TeV center-of-mass energy muon collider detector are currently under study in both the US and internationally under the International Muon Collider Collaboration: MAIA (Muon Accelerator Instrumented Apparatus) and MUSIC (MUon Smasher for Interesting Collisions). Both designs are optimized to deal with the specific challenges of a muon collider, namely the large beam-induced background (BIB) from muons decaying in and around the detector. In this talk, I will give an overview of the proposed MAIA design, discuss how it addresses these challenges, present the latest results of new performance studies conducted over the past year using realistic simulations of the BIB, and talk about some of the outstanding challenges and next steps for this R&D effort.

RDC 02 - Photodetectors Parallel Session / 123

Development of Photon-to-Digital Converters - A 3D Integrated Digital Single-Photon Detector

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We develop 3D integrated photon-to-digital converters (PDC) aimed to replace PMTs and SiPMs in various radiation applications. In previous years we reported on a CMOS readout electronics designed for low power consumption in large area systems such as noble liquid dark matter or neutrino searches, or fast neutron spectroscopy. System integration of these PDCs has also been demonstrated. We also reported on the development of the SPAD technology optimized for precise timing and 3D integration onto the CMOS readout. We are proceeding with the bonding of functional SPAD wafers onto CMOS readout wafers to complete the first lot of 3D PDCs. We will report on their fabrication, on the CMOS readout operation, and on the SPAD performance.

RDC 06 - Gaseous Detectors Parallel Session / 124

MPGD Trackers in the ePIC Detector at the EIC

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The future Electron-Ion Collider (EIC) at Brookhaven National Laboratory will collide polarized electrons with polarized proton/ions. The electron –Proton / Ion Collider (ePIC) Experiment is the EIC general-purpose detector aiming at delivering the full physics program of the EIC. This unique environment imposes stringent requirements on the tracking system needed for the measurement of the scattered electron and charged particles produced in the collisions at the EIC. The central tracker of the ePIC detector has silicon layers for tracking and vertexing based on MAPS technology, which are complemented by large Micro-Pattern Gaseous Detector (MPGD) trackers in the barrel and in both the electron and hadron end cap regions. The MPGD layers provide fast timing (10-20 ns) and additional hit points (150 µm) for pattern recognition during track finding. Two MPGD technologies are used in ePIC central trackers: cylindrical Micromegas for the barrel inner tracker and planar thin-gap GEM-µRWELL hybrid detector for the barrel outer tracker and the end cap disks. In this talk, we will introduce these two technologies in the context of ePIC and we will discuss the ongoing R&D efforts to address the requirements. Finally, we will discuss the plans and timeline for the production and testing and commissioning of the MPGD trackers for the installation in the ePIC detector.

RDC 04 - Readout and ASICs Parallel Session / 125

Cryogenic front-end ASICs for low-noise readout of charge or light signals

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In this talk we will present CHARMS250 and CHARMS10, next-generation cryogenic front-end application specific integrated circuits (ASICs) designed in a 65 nm process for low-noise readout of charge or light signals generated within noble liquid time projection chambers (TPCs). Both ASICs are designed for operation at temperatures ranging from room temperature down to liquid nitrogen temperature, i.e., 77 K, with large capacitance detectors (up to hundreds of picofarads), with multiple channels of charge amplification stages with gain programmable in the range of ~ 4–25 mV/fC, pulse shaping filter stages with programmable pulse peaking time, and either direct readout or through single-ended or differential buffers. The design of CHARMS250 has evolved from the LArASIC chip, which was manufactured in a 180 nm process and has been selected as the first component in the 3-ASIC readout solution for Phase I of the Deep Underground Neutrino Experiment (DUNE). CHARMS250 provides shortest pulse peaking time of 250 ns, that is two times smaller than the shortest pulse peaking time provided by LArASIC, with the same power consumption as LArASIC, i.e., 6-11 mW per channel, depending on the choice of the output buffering, and a highly linear voltage readout for input charges up to 300 fC. On the other hand, CHARMS10 features a new front-end design that allows achieving shortest pulse peaking time of 10 ns, without degradation of the output linearity. Additionally, features such as local generation of bias voltages and extended digital assistance of analog functions provided over an I2C interface are included in both ASICs for improved robustness against process variability. Potential applications for CHARMS250 and CHARMS10 include light/charge readout of the Far Detector (FD) 3/4 in Phase II of DUNE, charge readout in the future circular lepton collider (FCC-ee), light readout in nEXO, and the silicon-based active target and liquid xenon calorimeters in PIONEER.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 126

Recent HeRALD Progress at UMass

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HeRALD (Helium Roton Apparatus for Light Dark Matter) searches for sub-GeV dark matter-nucleon scattering in a ^{4}He target. Phonons from an atomic recoil trigger the evaporation of ^{4}He atoms into the vacuum, which are then detected calorimetrically using a Transition Edge Sensor (TES) array. Here I will discuss recent R&D using a two-channel evaporation sensor. The multi-channel readout allows the construction of a coincidence requirement which may mitigate the ubiquitous Low Energy Excess (LEE) background.

RDC 09 - Calorimetry Parallel Session / 127

Automatization of LFHCal scintillating tile evaluation for the ePIC detector at the EIC

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The Longitudinally Segmented Forward Hadronic Calorimeter (LFHCal) is being designed for the ePIC detector at the Electron Ion Collider (EIC). One of its main motivations is to reconstruct jet energies with high precision in the $1.2 < \eta < 3.5$ rapidity range. The current design plans to use ~83k machined and ~480k injection molded scintillator tiles with silicon photomultipliers (SiPMs) coupled to them. During the construction, it is of critical importance to evaluate the quality of these tiles in terms of their photon yield and dimensional tolerances. Dimensional scans are particularly more important for machined tiles. In this talk I will present the customized set up to automatically scan the tiles with a Sr^{90} source to test for uniformity of photon production and an optical dimensional process for bulk characterization.

Poster Session / 128

A Feasible Production Strategy for Large Scale Cryogenic Readout Electronics in Giant LArTPCs

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Deep Underground Neutrino Experiment (DUNE) experiment aims to answer several fundamental questions about the universe such as why matter dominates antimatter and whether protons can decay. The four 10k-ton far detector (FD) modules built upon the LArTPC's superior particle tracking and energy calorimetry capabilities are crucial to fulfill the physics potential. While the Long Baseline Neutrino Facility (LBNF) is excavating underground space for FD modules, the current DUNE-US project scope (phase I) only includes two modules, the first LArTPC FD module utilizing modular multi-wire-plane anodes in a horizontal drift (HD) configuration and the second LArTPC FD module with Printed Circuit Board (PCB) anode planes in a vertical drift (VD) configuration. The third and fourth FD modules remain open in DUNE phase II for next generation LArTPC detectors with improved physics capabilities and cost-effective construction techniques. VD configuration with enhanced light coverage is the preferred solution under R&D. One of the key challenges is to readout enormous channels of charge and light signals with reliable and cost-effective construction techniques. It is expected that the integration density of readout electronics will significantly increase, the data throughput will be much higher, new power and data transmission schemes (such as signal over fiber and power over fiber in cryogenic temperatures) will be applied etc.
In this paper, we will first summarize the production strategy developed for charge readout electronics in FD1 and FD2 modules, analyze the capability of the existing cryogenic quality control test stands, discuss the lessons learned, and explore their potential capabilities to fulfill the production need of readout electronics in DUNE phase II.

RDC 06 - Gaseous Detectors Parallel Session / 129

High Precision Time Projection Chamber R&D for Future Circular e+e- Collider

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Circular Electron Positron Collider as a Higgs and high luminosity Z factory, the accelerator Technical Design Report has been released in the end of 2023. The baseline design of a detector concept consists of a large 3D tracking system, which is a high precision (about 100μm) spatial resolution Time Projection Chamber (TPC) detector as the main track embedded in a 3.0T solenoid field, especially for the accelerator operating at the high lumimorsity Tera-Z. TPC requires the longitudinal

time resolution (<100ns) and the physics goals require Particle Identification determine (PID) resolution (<3%).
In this talk, we will present the feasibility and progress of the high precision TPC technology for circular collider, even at Tera-Z. The fundamental parameters such as the spatial resolution, PID with the good separation power and the drift velocity were studied by the simulation and measurement using a TPC prototype with 500mm drift length. We will review the track reconstruction performance results and summarize the next steps towards TPC construction for CEPC physics and detector TDR, also some good inputs and contributions from Lepton Collider Time Projection Chamber international collaboration.

RDC 05 - Trigger and DAQ Parallel Session / 130

Towards FPGA-deployable real-time boosted top jet identification

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There is increasing interest in deploying sophisticated machine learning (ML) algorithms as part of the real-time data processing and filtering systems of high throughput physics facilities such as the future High Luminosity LHC (HL-LHC). To satisfy the strict latency and data processing constraints imposed by such facilities, ML algorithms can be deployed on FPGAs to perform real-time computation. Device manufacturers have recently introduced dedicated reprogrammable architectures that are highly optimized for low-latency real-time inference tasks that use common ML tools such as neural networks. In this talk, we will explore the use and benchmarking of Xilinx's "AI-Engine"architectures and the associated software development kit workflows for prototyping novel algorithms for FPGAs. Specifically, we present work towards deploying convolutional neural networks (CNNs) on the FPGAs planned for use in the ATLAS experiment's data filtering and acquisition upgrade to perform pattern recognition tasks to classify and select hadronic jets produced by moderately Lorentz-boosted top quarks. Using this CNN as a case study, we compare the hls4ml and Vitis-AI workflows for deploying these algorithms on FPGAs. We benchmark the latencies and resource usage across various candidate FPGA target devices, ML architectures, and AI-Engine usage.

RDC 09 - Calorimetry Parallel Session / 131

First Test Beam Results from the LFHCal Prototypes for the ePIC Detector at the EIC

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The Electron-Proton/Ion Collider (ePIC) detector will serve as the first experiment of the Electron Ion Collider (EIC) at Brookhaven National Laboratory, whose primary purpose is to perform comprehensive studies of nuclear structure via electron-ion and electron-proton collisions. In order to investigate the gluon saturation regime at small values of the momentum fraction \textit{x}, as well as to achieve 3-dimensional nucleon tomography, it is crucial to rigorously measure jets along the hadron-going (forward) direction of such collisions. One of the main motivations of LFHCal design is the precise energy reconstruction of jets of up to 250 GeV at forward rapidity ($1.2 < \eta < 3.5$) and the possibility for declustering within these jets inorder to investigate their substructure. The later will greatly benefit our understanding of hadronization in particular. The LFHCal is composed

of transversely-segmented 5 × 5 cm^2 scintillating plastic tiles – coupled to a SiPM – sandwiched between steel absorber layers along the longitudinal direction. During the Fall of 2023 and 2024, a series of beam tests of different types ($e^-, h^{\pm}, \mu^+$) and energies (1 - 15 GeV) took place at the CERN Proton Synchrotron T9 beam line. For these two test beam setups, two different read-out solutions were evaluated: a commercial digitizer (CAEN) and a solution based on the CMS H2GCROC. This contribution will include first results on the performance of both LFHCal beam test prototypes, focusing exclusively on the CAEN read-out solution.

Joint RDC 03 & 11 Parallel Session / 132

The Progress of Silicon Carbide Low Gain Avalanche Diodes (SiC LGADs)

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As a wide bandgap semiconductor material, silicon carbide (SiC) has been widely used in power devices due to its inherent advantages. In recent years, the use of SiC as a replacement for silicon in charged particle detectors for collider experiments has gained increasing attention. However, due to various limitations in SiC processing (such as ultra-low doping epitaxy and high energy ion implantation), fabricating devices with specific structures to meet the demands of charged particle detection remains highly challenging. The capability of future collider detectors to perform 4D tracking (time + position) has become a well-established requirement. Over the past decade, the silicon Low Gain Avalanche Detector (Si LGAD) has been extensively studied for its excellent timing performance and has demonstrated outstanding results in 4D tracking (delete this part). Owing to the unique properties of SiC, a SiC LGAD offers superior theoretical timing performance and operability at room temperature after irradiation compared to the Si LGAD, making it a promising alternative.

In this report, we will present the latest measurement results of the first successful SiC LGADs fabricated by the North Carolina State University, Lawrence Berkeley National Lab collaboration. These results include preliminary performance characterizations of both DC-LGAD's and AC-LGAD's using alpha particles and a ultra-violet transient current technique (UV-TCT), as well as a comparison of charge collection in SiC LGADs with different gain layer doping concentrations. These results provide strong evidence of low-gain carrier multiplication occurring in our SiC LGADs and offer preliminary validation of the ultrafast timing response.

RDC 04 - Readout and ASICs Parallel Session / 133

GAMPix - Electron Track Detection with a Dual Scale LArTPC System

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We report on progress with GAMPix (Grid-Activated Multi-scale Pixel readout), a novel charge readout system for TPCs. GAMPix is designed to enhance electron track reconstruction accuracy to the sub-millimeter level while ensuring high energy reconstruction accuracy with low power consumption. The GAMPix system uses coarse induction electrodes paired with pixel planes. Signals from the induction electrode activate the pixel plane and the analog front end of a new, rapidly power-cycled ASIC. By comparing diffusion-independent coarse signals with diffusion-affected pixel signals, GAMPix provides a powerful measurement of drift distance. This is particularly useful in situations like pile-up, where time-based depth determination is not possible. Our initial analysis suggests GAMPix shows significant promise for the DUNE Phase 2 modules. It could improve both low-energy performance (MeV scale) and energy resolution for GeV-scale interactions. Additionally, GAMPix meets the stringent requirements for GammaTPC, a proposed MeV gamma ray detector instrument concept based on LArTPC technology. We present findings from a small-scale demonstration and simulation results.

RDC 01 - Noble Element Detectors Parallel Session / 134

The Forward Liquid Argon Experiment at the Forward Physics Facility for High Energy Neutrino and Dark Matter Searches at LHC.

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The proposed Forward Physics Facility (FPF) is an underground cavern at zero degrees to IP1 with the space and infrastructure to support a suite of far-forward experiments at the Large Hadron Collider in the High Luminosity era (HL-LHC). The Forward Liquid Argon Experiment (FLArE) is a Liquid Argon Time Projection Chamber (LArTPC) based detector designed for very high-energy neutrinos and search of dark matter in FPF, 620 m from the ATLAS interaction point in the far-forward direction. With a fiducial mass of 10 ton, FLArE will detect millions of neutrinos at the highest energies ever detected from a human source and will also search for Dark Matter particles with world-leading sensitivity in the MeV to GeV mass range. The LArTPC technology used in FLArE is well-studied for neutrino and dark matter experiments, however the use at the LHC requires specific targeted R&D. It offers excellent spatial resolution and particle identification. In this talk, I will overview the physics reach, the preliminary design, the needed detector R&D, and the prospects for international sponsors.

Joint RDC 01 & 02 & 04 / 135

Performance of the Light Detection System in the ICARUS Detector at Fermilab.

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ICARUS is the largest Liquid Argon Time Projection Chamber (LArTPC) in operation and serves as the Far Detector of the Short Baseline Neutrino (SBN) program at Fermilab. It is exposed to both the booster neutrino
beam (BNB) and the off-axis flux from the NuMI beam at Fermilab. The ICARUS detector is in two identical cryogenic modules of ~300 tons each. The ICARUS scintillation light detection system with 180 TPB-coated
large-area Photo-Multiplier Tubes (PMTs) in each module, is crucial for triggering and event reconstruction. Due to its surface installation, the detector is exposed to a high flux of cosmic rays, necessitating precise timing to reject background events and align neutrino interactions with the accelerator beam time. This talk will provide details of the light detection system including its calibration for gain and time. The system has achieved superb stability and sub-nanosecond time resolution. The performance of the system in reconstructing the timing of neutrino interactions from the BNB and NuMI beams and rejection of cosmics by coincidence with a cosmic ray tagger will be discussed. Future work on neutrino reconstruction with the system independent of the TPC, and its use as a calorimetric tool for neutrino energy measurement will also be discussed.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 136

Particle Detection with SNSPDs

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We will present the latest test results of SNSPDs as particle sensors. The characteristics of SNSPDs as fast, highly efficient, and precise in time and position make them a potential detector technology meeting the requirements of accelerator-based experiments such as those at Jefferson Lab and the Electron-Ion Collider. We will discuss the R&D program to demonstrate the viability of superconducting nanowire particle detectors beyond the original concept as a single photon sensor. The discussion will focus on recent tests to understand the mechanism of particle detection and how to optimize sensor design. This includes the first tests of superconducting nanowire sensors with a 120 GeV proton beam and ongoing tests with radioactive sources.

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RDC 05 - Trigger and DAQ Parallel Session / 137

GPU Direct RDMA using SLAC's open source DMA engine

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To support larger bandwidth detector data, systems must be able to move the data directly to the processing elements with minimal software intervention. As an example, LCLS-II operation of the

ePixUHR 35K detector will generate data on the order of 250GB/s at 35kHz–far more than the existing CPU-based DAQ setup can handle. Using NVIDIA's GPUDirect RDMA technology, we implemented a low-latency and high-throughput data flow that allows acquired data to be compressed and processed on the GPU with minimal involvement of the CPU. Our test setup involves an AMD Kintex KCU1500 and an NVIDIA RTX A5000 GPU on the same PCIe root complex. RDMA allows the KCU1500's custom firmware to transfer data directly to the GPU, skipping the additional DMA transfer to main memory that would usually be required. We use CUDA device launchable graphs to initiate DMA transfers and process the incoming data. This allows the control flow and data processing to take place exclusively on the GPU, with the host processor taking a supervisory role. Confining control flow to the GPU using CUDA graphs resulted in a significant reduction in measured latency. This approach has the potential to support next-generation detectors required for future High Energy Physics experiments.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 138

Probing Sub-GeV Dark Matter with SPICE

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The search for dark matter has broadened to focus on a much wider class of candidates than in previous decades, including particle-like dark matter at the MeV-GeV mass scale. Lighter than traditional WIMPs, these particles deposit less energy in nuclear or electronic interactions; thus, discovering them will require low energy thresholds and cryogenic temperatures. In this talk, I will describe the progress of the SPICE experiment, part of the TESSERACT collaboration, to search for light dark matter using crystalline targets such as GaAs and Sapphire. I will detail specific thrusts of our ongoing R&D efforts: reducing low-energy backgrounds, improving energy resolution, developing transition-edge sensors, and conducting MeV-scale dark matter searches.

RDC 02 - Photodetectors Parallel Session / 139

Eos: Neutrino Detection Technology Demonstrator

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Based at UC Berkeley and LBNL, the Eos detector deploys a range of state-of-the-art detection technologies with the aim of simultaneously utilizing scintillation and Cherenkov photons in neutrino event reconstruction and analysis. New Hamamatsu 14688 PMTs have been measured to have a 450-ps transit-time spread. 12 dichroic light concentrators, which have the ability to spectrally sort photons, have been deployed. Data have been acquired with a variety of unique radioactive sources and a picosecond laser-driven optical system in a water target. With the first phase of data acquisition nearly completed, the 4-tonne capacity acrylic vessel will soon be filled with a water-based liquid scintillator. Eos was designed to have flexibility to test a variety of photodetectors, target materials, and readout technologies, and will continue operating for the next few years at Berkeley, before a possible move to a neutrino source.

RDC 02 - Photodetectors Parallel Session / 140

R&D of Power Over Fiber in harsh environments and its novel application for the DUNE FD-VD Photon Detection System

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The Deep Underground Neutrino Experiment (DUNE) is a next generation long-baseline neutrino experiment that will send an intense beam of neutrinos through two detector complexes: a near detector complex located at Fermilab (Chicago), and a far detector complex located ~1.5 km underground at Sanford Underground Research Facility (SURF) in South Dakota.

The DUNE far detector (FD) technology has been established for three out of four modules and will consist of liquid argon time projection chambers (LArTPCs), each holding about 17 kt of liquid argon. One of these modules will employ Horizontal Drift (FD-HD) technology, while another will use Vertical Drift (FD-VD) technology. The FD-VD module will vertically drift the ionized electrons from the cathode plane suspended at the mid-height of the active volume of the cryostat. To increase the photon detector coverage in FD-VD, photon detectors (X-ARAPUCAs) will be installed along the cathode plane besides those behind the field cage. Due to the high voltage (~300 kV) present at the cathode, conventional copper cables cannot be used to power the photon detectors. Therefore, Power-over-Fiber (PoF) technology will be deployed to power the photon detection system based on optical power transmission over optical fibers. This talk presents the R&D on different PoF components under harsh environments and its first-ever application in high energy physics detectors.

RDC 04 - Readout and ASICs Parallel Session / 142

PSD_CHIP: An ASIC for SiPM array readout

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PSD_CHIP is an ASIC developed jointly by UC Davis and LBNL for reading out SiPM arrays. Each channel of the chip, besides providing a fast trigger out pulse and a voltage level proportional to the total area of the pulse, also performs an analog pulse shape discrimination (PSD) function, based on a metric derived from partial and total integrals of the input pulse. A single PSD bit is sent out. The time windows for the two integrals are fully programmable in order to accommodate the decay times of various scintillators. The front end input is selectable for the polarity of the incoming pulse. Limited programmability for the gain is also provided to optimize the dynamic range for expected signal sizes. A 4-channel version of the chip was fabricated in the TSMC 180 nm process. The design and results from testing of the chip will be presented. This chip serves as the analog front-end of a larger design - the next version will also feature a digital back-end consisting of digitization and data processing blocks.

RDC 03 - Solid State Tracking Parallel Session / 143

Sensor co-design for Smartpixels

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As upcoming high energy physics experiments move towards higher energies and luminosities, there is a strong need to improve the measurement precision of tracking detectors. High-granularity pixel detectors are a feasible option and would enhance high-priority physics, especially signatures with heavy quark decays, but with the added cost of increased data rates. The objective of the Smartpixels project is to reduce the associated data volumes and unlock new capabilities by implementing neural networks on the detector hardware. To achieve this, we must understand the interdependence of algorithm and detector so that we can co-design them optimally. Previous work used filtering networks in the readout chips to predict the transverse momentum (pT) of incident particles and remove unimportant tracks with low pT. This work demonstrated signal efficiency and background rejection of about 93% and 25%, respectively, in simulation. The study has now expanded to assess network performance across various device parameters and test regression networks for predicting hit position and incident angle. This talk will cover ongoing work exploring how the pixel sensor pitch, radiation damage, and Lorentz drift (or its absence) affect the performance of the networks.

Joint RDC 03 & 07 & 08 / 144

Development of Near Quantum limited Kinetic Inductance Traveling-Wave Parametric Amplifiers Using Four-Wave Mixing

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We present the development of a kinetic-inductance traveling-wave parametric amplifier (KI-TWPA) based on NbTiN and TiN microstrip transmission lines optimized for sub-GHz and GHz frequency ranges. KI-TWPAs exploit nonlinear mixing processes enabled by the kinetic inductance of superconducting transmission lines, delivering wide instantaneous bandwidth, near quantum-limited noise performance, and high dynamic range. Our devices amplify signals via a four-wave mixing mechanism, achieving a tunable gain of up to 22 dB in the sub-GHz range. In the 4 to 8 GHz band, which is commonly used for cryogenic detector readout and superconducting qubits, the amplifier demonstrated a peak gain exceeding 20 dB, with amplifier-added noise as low as 0.5 to 1.5 photons. The device gain of the KI-TWPAs is tunable in that the gain can be adjusted based on the frequency of the pump tone. This feature makes the KI-TWPA suitable for applications where the signal frequency range needs to be changed, such as in dark matter experiments. Additionally, the higher frequency idler band of the KI-TWPA can be used instead of the signal band to search for dark matter candidates with a higher mass range. This dual-band operation can be achieved without making significant changes to the readout circuitry.

Joint RDC 01 & 02 & 04 / 145

High-performance Dichroic Filters for Large-Scale Neutrino Detector

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High performance dichroic filters (DFs) are key photon wavelength sorting devices for Cherenkov and scintillation light in water- and scintillator-based neutrino detectors. Future detectors will require large-area DFs at a low cost and with improved transmissivity and reflective properties. DFs are traditionally manufactured by various physical vapor deposition (PVD) techniques such as ion beam sputtering, electron beam and thermal evaporators with ion assistance. However they all have been subject to intrinsic drawbacks of poor large area uniformity, especially on curved surface, poor thickness control and high cost associated with vacuum technology and thickness monitoring tools. Atomic layer deposition (ALD) on the other hand has been well established for precise thickness control, excellent large area uniformity and conformity for coatings on complex surfaces, and low growth temperatures. Therefore it is well suited for optical coatings on large area glass tiles or temperature sensitive plastics, and on curved surfaces of Winston cones. In addition, a wide range of high quality dielectric materials (oxides, nitrides, fluorides, carbides, etc.) with high, medium and low refractive indexes are available by ALD, most of which can be deposited in a single ALD chamber thus complexity and production cost can be reduced. These merits provide an excellent solution to manufacturing various bandpass DFs requiring tight specs for multiple dielectric layer coatings and precise wavelength positioning and steepness. Other advantages of ALD coatings include defect free thus low optical loss, and super moisture/environmental resistance. Special ALD tools for handling large areas up to meter size, and multiple wafers up to hundreds/hour were demonstrated commercially. We present an update on a cost effective DF developed with ALD coating techniques for neutrino detector with a potential path for commercialization for mass production in collaboration with Raytum Photonics.

RDC 04 - Readout and ASICs Parallel Session / 146

LArPix Pixelated Charge Readout System

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LArPix is an end-to-end pixelated charge readout system for 3D imaging at the millimeter-scale in multi-tonne liquid argon time-projection chambers (LArTPCs). Leveraging large-scale commercial

fabrication techniques, the system is designed to be highly scalable and robust, enabling low-cost quick-turn system production at industry standard. The system is based on the LArPix ASIC, a cryo-compatible, low-power detector system-on-a-chip composed of 64 input channels. The analog front-end on each channel includes an integrating charge-sensitive amplifier, a tunable discriminator, and an 8-bit successive approximation register analog-to-digital converter. A digital core is shared across all ASIC channels, managing digital multiplexing and digital configuration and control. LArPix performance using prototype detectors at the 10^5 channel scale will be presented, and progress on design of 10^7-10^8 channel systems will be discussed.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 147

Large-format arrays of SNSPDs for time-resolved imaging and tracking

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We will present the latest results in scaling superconducting nanowire single photon detectors (SNSPDs) to large-format cameras, with as many as 400,000 pixels. We will discuss the future prospects for scaling these proof-of-concept results into practical cameras for time-resolved imaging in HEP applications, and discuss new concepts for using large-format SNSPD arrays for 4D tracking.

Joint RDC 03 & 11 Parallel Session / 148

LGAD gain suppression studies for the PIONEER experiment

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PIONEER is a recently approved, next-generation, rare-pion decay experimental program at the Paul Scherrer Institute (PSI) in Switzerland. The first phase of the experiment will focus on a measurement of the charged-pion branching ratio to electrons vs. muons Re/μ = Γ (π ⟶ eν(γ)) /Γ (π ⟶ μν(γ)). This is a test of lepton flavor universality to be performed at an order of magnitude greater sensitivity than any other experiment. At present, the SM prediction for Re/μ is known to 1 part in 10000, which is 15 times more precise than the current experimental result. An experiment reaching this theoretical accuracy will probe non-SM explanations of these anomalies through sensitivity to quantum effects of new particles up to the PeV mass scale.

After introducing the experimental strategy, we will focus on PIONEER's segmented stopping target (ATAR) which is a key enhancement over earlier experiments and crucial for achieving its precision goal in Re/μ . ATAR will define the pion stop fiducial region, and will suppress decay in flight and accidental positrons from earlier stopped pions*emphasized text* to allow the experiment to run at its

high beam rate of 300 kHz. It is indispensable for suppressing the dominant π-μ-e chain by more than six orders of magnitude to directly measure the tail of the π⟶ e+ν positrons in the calorimeter response.

ATAR is using an emerging detector technology called low gain avalanche diodes (LGADs). Our R&D program aims to develop this technology into a unique 5-D tracking device, featuring precision time information (0.2 ns time and 2ns pulse-pair resolution), precision 3-D tracking at the 100 μm scale and good energy resolution. Forty-eight individual LGAD strip sensors of 20x20 mm2 area and 120 μm thickness will be stacked with minimal dead material. A total of 4800 channels will be read-out with large dynamic range (several 100) and minimal cross talk.

Slow pions and muons in the PIONEER experiment generate large local energy deposition (*dE/dx*), where the LGAD gain is quenched by gain saturation, compromising the linearity of the sensor. In order to study, characterize and optimize the sensor behavior, we developed a test beam set-up at the UW CENPA Tandem accelerator. The response of sensors from several suppliers with differing properties is mapped as a function of energy and angle of incidence using protons of 1-8 MeV. We demonstrated the method in 2023 and significantly increased its scope and efficiency during 2024. These results and their impact will be discussed.

RDC 03 - Solid State Tracking Parallel Session / 149

Hybrid amorphous selenium / CMOS devices for MeV electron tracking

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We present the development of hybrid devices made from a thick ionization target layer of amorphous selenium (aSe) coupled to a silicon complementary metal-oxide-semiconductor (CMOS) active pixel array for charge readout. The CMOS pixels are instrumented to measure both the amplitude and time-of-arrival (TOA) of the charge signal for 3D tracking. The high spatial resolution in a solid-state target provides unparalleled rejection of backgrounds from natural radioactivity in the search for neutrinoless $\beta\beta$ decay and for solar neutrino spectroscopy with ^{82}Se. We summarize the current status of R&D, including results from the first CMOS sensors optimized for charge collection in aSe, and our plans to incorporate TOA and digital capabilities in the pixel.

RDC 07 Low-Background Detectors Parallel Session / 151

Nuclear/electronic recoil discrimination in silicon with CCDs

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We discovered event-by-event identification of nuclear recoils in silicon from the spatial correlation between the primary ionization event and the defect cluster left behind by the recoiling atom, later identified as a localized excess of leakage current under thermal stimulation. By irradiating a charge-coupled device (CCD) with an AmBe neutron source, we demonstrate full efficiency in the identification of nuclear recoils down to 90 keV, decreasing to 50% at 8 keV and reaching (6$\pm$2)% between 1.5 and 3.5 keV. Irradiation with a ^{24}Na γ-ray source does not result in any detectable defect clusters. This is the first realization of nuclear/electronic recoil discrimination in CCDs, a leading technology in direct searches for dark matter. We present our plans to extend the technique to

sub-keV nuclear recoils, which will greatly improve the sensitivity of the upcoming kg-scale CCD experiments to dark matter-nucleus interactions.

Plenary session / 152

Novel Light Detectors for MeV-Scale Directional Dark Matter Detectors

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The search for sub-GeV dark matter requires novel detector development due to the small expected ionization signal and large backgrounds, many of which still need to be well-modeled. For this reason, to unambiguously detect dark matter, a detector must be able to determine the directionality of the incoming particles so that the daily modulation of the rate can be used to confirm a dark matter signal. This can be accomplished by combining anisotropic scintillating crystals, such as trans-Stilbene, as a detector medium, with an optically-sensitive Skipper CCD as a readout. This is the basis of my proposed work for the GIRA fellowship. I will be working on the development of an above-ground prototype of the detector including characterization of the Skipper-CCDs and determining relevant backgrounds. This will lead to an initial underground data run and preliminary exclusion rates. I will discuss the connections between this and my work on a second light dark matter experiment based at MIT, which will use Quantum Dots as the detector medium and Silicon Nanowire Single Photon Detectors (SNSPDs) as the readout.

RDC 04 - Readout and ASICs Parallel Session / 153

Low-Power, High-Bandwidth Photonic Communication for Readout Integrated Circuits

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Silicon photonics is a game-changing readout technology for detectors, including those required for next-generation collider experiments, combining extremely high throughput and low power with immunity to crosstalk and a low heat load for cryogenic detectors. We will present early results from a Lab-Directed Research & Development program which aims to demonstrate a practical Silicon-Photonic readout with 20 Gb/s/channel bandwidth of a pixel detector readout integrated circuit, including the design of CMOS ring drivers and a high-speed FPGA readout solution, and we will show early results from implementing the link with commercial optical hardware. We will also show high-speed data modulation (+10Gb/s) at 4K deep cryogenics with 100fJ/b energy-efficiencies, and also resonance tuning capabilities using phase-change materials.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 154

Development of on-chip spectrometer Microwave Kinetic Inductance Detector arrays as a technology for mm-wave Line Intensity Mapping

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Line Intensity Mapping (LIM) is an emerging cosmological survey technique that measures the integrated emission of certain atomic and molecular lines with high throughput and low spatial and spectral resolution to quickly map large volumes of the large scale structure distribution in our universe. Mm-wave LIM would measure the redshifted emission from CO/[CII] using established survey techniques developed by CMB experiments. This presentation will discuss progress of a mm-wave LIM detector development program focused on Microwave Kinetic Inductance Detector (MKID) arrays with on-chip filter banks and feedhorn-based optical coupling. It will describe the cosmological goals of LIM at mm-wavelengths and the staged R&D approach, and will discuss the current status of technology development where a small array, called the SPT Summertime Line Intensity Mapper (SLIM), will be deployed for summer observations on the South Pole Telescope.

RDC 09 - Calorimetry Parallel Session / 155

A Micromachined Radiation-Resistant Dense High Rate Calorimeter Sensor Prototype Using Secondary Emission

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A Micromachined Radiation-Resistant Dense High Rate Calorimeter Sensor Prototype Using Secondary Emission

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We present a prototype of a 20 stage stack assembly 3.8 cm diameter active area x 2.6 cm deep stack of proximity-focused micromachined 0.65 mm thick CuBe(1%) sheets serving as dynode-like secondary emission sensors, separated by a drift distance of 0.6 mm between sheets by ceramic spacers. The stack has a density of ~25-30% of the density of CuBe. Baseline operation is in a modest vacuum ~10^-4 Torr, 4-5 orders of magnitude higher than that needed in cesiated PMT, with the stack voltages provided by in-vacuum wire wound high vacuum resistor chain. A full COMSOL simulation using custom secondary emission subroutines is in reasonable agreement with the device tested. We discuss tests with gamma, beta and neutron sources, cosmic muons and 100 GeV pion MIPs. The pulse risetime is <10ns, and gain is ~few x 10^5. At -4,400 V in a ~0.3T B-field from a bar magnet at orthogonal directions, the response was < 2% changed. We posit that full scale MEMs stack calorimeter tests may demonstrate that the response to the low energy components (neutron knock-ons, ion fragments, spallation) at low incident kinetic energies in hadronic showers will result in enhanced signals, since the secondary emission yield follows dE/dx. For charged particle velocities beta~0.03 the yield is ~200x to that of MIPs at beta~1. This enhancement may compensate hadronic energy resolution effects that are lost in scintillators in part due to Fano factor suppression in high dE/dx low energy ion fragments, and de-emphasize the response to e-m components. We discuss prospects for using tungsten and other dense metal micromachined sheet dynodes.

Poster Session / 156

Novel Toxic Gases as Detection Media in TPCs

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Time Projection Chambers (TPCs) use various chemical species as detection media, depending on the specific application, the required sensitivities, and the types of particles being measured. Xenon is useful but of limited availability, and non-xenon double beta decay TPCs may need to choose unfamiliar, probably toxic, gases. We aim to design and build a cylindrical proportional counter that works as a test bed for sulfur-bearing compounds, like H_2S and C_4H_4S, and then experiment with selenium-bearing compounds like H_2Se and C_4H_4Se that could be used as gain gases in detectors for future double beta decay searches. These gases have been selected as they have been shown to exhibit electropositive behavior in numerical calculations. The proposed setup is unique because it is designed to have the highly toxic and corrosive gases mentioned above as its operating media, and it can also operate at elevated temperatures. Calibration will be achieved using an iron-55 X-ray source. Later upgrades to the setup will also enable the determination of drift velocities. These measurements will allow us to determine the mobility of the gas and assess its effectiveness as a drift gas in radiation detection. The results obtained on a steam run will be discussed, and the prospects of moving on to the gases of interest will follow to look for other suitable gas mixtures. The results from this project will be applied to further studies on other promising gain gases for future dark matter detection and double beta decay experiments.

RDC 10 - Detector Mechanics Parallel Session / 157

Dynamic Phonon Modelling in Silica for Simulating Substrate Backgrounds in the BeEST Experiment

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The BeEST experiment searches for physics beyond the standard model (BSM) in the neutrino sector by utilizing the electron capture (EC) decay of 7Be. The 7Be is embedded in superconducting tunnel junction (STJ) sensors such that the low-energy (eV-scale) decay products are detected with high energy resolution and efficiency. Modelling of low-energy backgrounds is crucial to understanding potential beyond standard model (BSM) physics, including low-energy phonon and quasiparticle generation within the superconductors. In this talk, modelling methods for phonon dynamics in cryogenic silica are described in detail for use with G4CMP. Phonon properties calculated include scattering parameters, isotopic scattering rate, anharmonic decay rate, fractional phonon density of states based on phonon modes, etc. Beyond the BeEST experiment, accurate modelling of phonon dynamics is of significant importance for simulating the impact of radiation on quantum sensing regimes.

The BeEST experiment is funded in part by the Gordon and Betty Moore Foundation (10.37807/GBMF11571), the DOE-SC Office of Nuclear Physics under Award Numbers DE-SC0021245 and DE-FG02-93ER40789, and the LLNL Laboratory Directed Research and Development program through Grants No. 19-FS-027 and No. 20-LW-006. TRIUMF receives federal funding via a contribution agreement with the National Research Council of Canada. The theoretical work was performed as part of the European Metrology Programme for Innovation and Research (EMPIR) Projects No. 17FUN02 MetroMMC and No. 20FUN09 PrimA-LTD. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52- 07NA27344.

RDC 02 - Photodetectors Parallel Session / 158

Monolithic Single Photon Detector for Dark Matter Search Experiments

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Silicon photo-multipliers (SiPM) are widely used as light detectors for the next generation of experiments dedicated to high energy physics. Compared to the traditional photomultiplier tubes (PMTs), the SiPM offers several advantages such as excellent single-photon resolution, low power consumption, low sensitivity to magnetic fields, small dimension. However, for the multi-ton noble liquid detectors commercially available SiPM are not suitable for large coverage due to higher cost and additional packaging material. In this talk, we present our considerations on developing a new class of monolithic active single-photon detectors with integrated readout electronics for scintillation light detection in the next generation experiments.

RDC 09 - Calorimetry Parallel Session / 159

Upgrade of the CMS Electromagnetic Calorimeter for the High-Luminosity LHC

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The High Luminosity upgrade of the LHC (HL-LHC) at CERN will provide unprecedented instantaneous and integrated luminosities of around 5 x 10^34 cm-2 s-1 and 3000/fb, respectively. The expected average of 140 to 200 collisions per bunch-crossing (pileup) represents a severe challenge for the detectors. In the barrel region of the CMS electromagnetic calorimeter (ECAL), the lead tungstate crystals and avalanche photodiodes (APDs) will operate at a lower temperature with respect to the present and the entire readout and trigger electronics will be replaced.

Each of the 61,200 ECAL barrel crystals will be read out by two custom ASICs providing signal amplification with two gains, ADC with 160 MHz sampling rate, and lossless data compression for the transmission of all channel data to the off-detector electronics. Trigger primitive generation by updated reconstruction algorithms as well as data acquisition will be implemented on powerful FPGA processors boards. The upgrade of the ECAL electronics will allow to maintain the excellent energy resolution of the detector and, in addition, to greatly improve the time resolution of electrons and photons above 10 GeV, down to a few tens of picoseconds.

This talk will present the design and status of the individual components of the upgraded ECAL barrel detector, and the results of energy and time resolution measurements obtained with the latest ECAL readout electronics prototypes using electron beams with energies of up to 250 GeV at the CERN SPS.

RDC 07 Low-Background Detectors Parallel Session / 160

Measuring, mitigating, and removing cosmogenic tritium in silicon

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Long-lived radioactive isotopes produced by cosmogenic activation can be a major source of background for rare event searches such as dark matter and neutrinoless double beta decay. In this talk I will present recent efforts to measure and mitigate cosmogenic tritium production in silicon devices including measurements of the production rate, efforts to reduce exposure through shielding, and novel techniques to remove cosmogenic tritium from silicon substrates.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 161

Recent Results and Advances of GigaBREAD: Broadband Reflector Experiment for Axion Detection

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We report R&D progress, as well as the first axion-like particle search results with BREAD - a novel dish antenna for broadband ~μeV-eV wave-dark matter detection, which allows to utilize state-of-the-art high-field solenoidal magnets. Axions are converted non-resonantly to photons on a cylindrical metallic wall parallel to an external magnetic field. These photons are then focused using a novel reflector geometry onto a state-of-the-art high-sensitive photon detector. We recently demonstrated [PRL 128 (2022) 131801] that this concept using a conversion area in a solenoidal magnet has the potential to discover QCD axions spanning multiple decades in mass range. In this talk we present progress on the first BREAD pilot experiment in the range of 10GHz in a 4T magnetic field, called GigaBREAD. While other dish antenna experiments have constrained dark photons, this is likely the first dish antenna apparatus constraining axion-like dark matter. We also discuss upscaling to larger, cryogenic and magnetized versions and advanced detectors.

Joint RDC 01 & 02 & 04 / 162

Overview of the design, instrumentation, and calibration plan of the Scintillating Bubble Chamber (SBC-LAr10).

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The Scintillating Bubble Chamber (SBC) collaboration is developing liquid-noble bubble chambers to detect sub-keV nuclear recoils, allowing the search for low-mass (GeV-scale) dark matter and coherent elastic neutrino-nucleus scattering from low-energy (MeV-scale) neutrinos. The scintillating bubble chamber detectors benefit from the energy reconstruction that the scintillation signal gives in addition to the superior electron-recoil insensitivity that bubble chambers naturally provide. The SBC-LAr10 was recently installed at Fermilab in the MINOS tunnel, which is located 100 meters underground. It will be operational soon. A summary of the SBC-LAr10's thermo-mechanical design will be given, which will include the pressure, thermal, and process control details. This talk will provide an overview of the components of the data acquisition system, including bubble imaging, scintillation detection, and acoustic detection. The primary objective of the SBC-LAr10 chamber is the calibration of nuclear and electron recoil responses. The presentation will cover the plan for carrying out these calibrations.

Poster Session / 163

Towards THz Axion Detection: Characterization of Waveguides for Cryogenic Quantum Device Calibration

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The axion is a leading dark matter candidate which also addresses the Strong CP problem in the Standard Model, but its detection remains challenging due to its extremely weak predicted electromagnetic signals. Superconducting qubits offer a promising solution. Superconducting Quasiparticle-Amplifying Transmons (SQUATs) are designed to be sensitive to single THz (meV) photons by detecting tunneling events through readout of the qubit transition frequency. A key challenge in calibrating these detectors is delivering THz photons into cryogenic environments, as traditional fiber optics absorb THz radiation. To address this, we conducted warm testing of circular copper waveguides to characterize their coupling and transmission properties. Here, we present the findings from our initial tests and outline the readiness of our system for low-temperature operation. If successful, broadband THz photon detection using quantum sensors could mark a major step forward in experimental searches for axions, laying the foundation for future experiments like BREAD and opening new pathways for low-mass dark matter searches.

Joint RDC 03 & 07 & 08 / 164

Non-equilibrium energy accumulation as a source of backgrounds in low threshold detectors

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Quantum fluctuations or equilibrium thermal fluctuations cannot explain the single photons and small light pulses coming out of the scintillator detector in between interactions with external particles or residual radioactivity events. The processes of energy accumulation and delayed release may explain these effects. Similar arguments can be built for other detectors, including solid-state low-temperature detectors. Two-level Systems (TLS) can be present and participate in such excessive energy accumulation, interact with each other and other energy-bearing states and defects, and be involved in energy releases. Still, it is the processes of energy accumulation and release that

are essential for excess and delayed backgrounds in detectors, and the same process should lead to quantum errors and decoherence in qubits. As such a process was not considered in previous extensive studies of material sources of non-thermal noise and decoherence, joint research efforts in high-energy physics, material science, and quantum information science would be beneficial.
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Poster Session / 165

A novel sub-eV particle detection scheme using magnetic metrology of superconducting thin films using NV Centers

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We propose a novel particle detection mechanism that utilizes the ability of nitrogen-vacancy centers (NV) in diamond thin films to investigate nanoscale magnetic phenomena on superconducting thin films. Energy deposited by a particle either directly in the superconductor or in an absorber, causes a thin layer of superconductor on the diamond film, to transition to normal state. The transition to normal state is detected through variation in the optically detected magnetic resonance spectra of NV centers. Initial results from our simulation show that the energy threshold for particle detection is in the sub electron volt regime and an optimization of the absorber, superconductor, the thin film geometry, and the implementation of the magnetic resonance spectroscopy can lead to good spatial and energy resolution. Here we will show the results from our simulation including optimization of detector performance. We will present the next phase of the project that aims to build and test an diamond - superconductor heterostructure based detector in a controlled laboratory environment. Our detection scheme can be thought of as an optically read out transition edge sensor (TES) that may result in lower noise and thresholds. Since pico Tesla magnetometry using NV centers and particle detection using TES has already been demonstrated with on-chip integration, we believe coupling these two technologies will lead to particle detection down to the meV range, which is crucial for advancing particle physics and exploring Beyond Standard Model (BSM) phenomena, including potential dark matter interactions. On-chip integration would allow for the development of compact, high-sensitivity detectors with direct applications in both particle physics and fundamental research.

Joint RDC 07 & 08 & 09 Parallel Session / 166

Status of Commissioning and R&D for the Ricochet Experiment

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Coherent elastic neutrino-nucleus scattering (CEνNS) offers a valuable approach to searching for physics beyond the Standard Model. The Ricochet experiment aims to perform a precision measurement of the CEνNS spectrum at the Institut Laue–Langevin nuclear reactor with cryogenic solid-state detectors. The experiment plans to employ an array of cryogenic thermal detectors, each with a mass of around 30 g and an energy threshold of below 100 eV. Additionally, the detectors will be able to differentiate between nuclear and electron recoils, as neutrinos interact via nuclear recoils, and electron recoils from gammas constitute the largest background component in the experiment.

To achieve these requirements, two types of cryogenic-based detectors have been investigated: germanium ionization and phonon detectors using Neutron Transmutation Doped (NTD) thermometers, and superconductor-based detectors using Transition Edge Sensor (TES) thermometers. The NTD germanium detectors are being commissioned at the ILL and will form the bulk of phase 1 detectors. The TES-based detectors are currently in the R&D phase. The TES-based detector is exploring potential target materials, including zinc, aluminum, and tin. Superconductors can potentially provide pulse-shape particle identification as the interplay between broken Cooper Pairs and phonons is different for electron and nuclear recoils.

In this presentation, I will provide an update on the Ricochet experiment and the ongoing development of the TES-based detector.

Plenary session / 167

The sPHENIX TPC

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The central component of the sPHENIX tracking system is the "compact" (2 meter length, 80 cm outer radius) Time Projection Chamber (TPC). This TPC operates in the continuous readout mode with a low Ion BackFlow (IBF) in a similar style to that pioneered by the ALICE TPC. In contrast to many prior TPC devices, this TPC emphasizes position and momentum resolution over the measurement of specific ionization (dE/dx) and features a number of unique design features in keeping with this priority. This presentation will give an overview of the device, summarize the struggles and eventual success of the TPC in the 2023 and 2024 running periods, and discuss the outlook for future running.

RDC 06 - Gaseous Detectors Parallel Session / 168

Calibration Systems for the sPHENIX TPC

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The sPHENIX experiment completed construction at Brookhaven National Lab's RHIC facility in 2023 and has now completed its first full year of data taking, with a physics program that will probe the nature of QGP through jet, upsilon and open heavy flavor final states over a broad range of pT. The experiment's Time Projection Chamber covers |\eta|<1.1 and full azimuth, and serves as its main tracking detector for particle identification and momentum resolution. The readout plane uses quadruple-GEMs for amplification and to mitigate ion backflow, but the detector also includes a suite of calibration systems to monitor and correct distortions due to space charge, as well as other static and time-varying effects. This talk will review the distortion correction scheme as well as the design and status of its components, focusing on the two independent laser systems: The high-rate diffuse laser flash which illuminates a test pattern on the TPC's central membrane, and the steerable 'direct' laser system which is designed to inject tracks at known trajectories.

RDC 03 - Solid State Tracking Parallel Session / 169

From Physics to Detectors at FCCee

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The physics drivers of experiments at FCCee motivate detector specifications that exceed the current state-of-the-art. Realizing the full scientific potential of FCCee will require new and cross-cutting technological development. This talk will present the status of FCCee physics targets, detector designs, and next steps in the context of CPAD R&D areas and synergistic progress for future Higgs factories.

Plenary session / 170

Quantum Acoustic Devices for Low-Threshold Dark Matter Detection

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The absence of a conclusive direct detection of conventional, GeV-scale dark matter has recently increased focus on low-threshold detector technologies capable of sensing light (sub-GeV) and ultra-light dark matter candidates. Many such technologies rely on athermal phonon sensing, in which meV-scale phonons from a DM scatter are sensed via their ability to break Cooper pairs in superconducting films. While detectors based on such pairbreaking sensors are highly advantageous and scalable, their sensor threshold is ultimately limited by the energy needed to break a Cooper pair, 2Δ. In this work, we present the qubit-coupled hBAR, a novel detector architecture for single phonon detection at the O(10μeV) scale that does not share this limitation. This architecture, composed of a superconducting qubit piezoelectrically coupled to a high-overtone bulk acoustic resonator, was originally developed in the context of the quantum acoustics community and has a sensor threshold ultimately limited by thermal noise. In this talk, we present a discussion of the design and expected performance of this architecture in phonon sensing, and briefly highlight the rare physics candidates that may be probed with this architecture.

RDC 04 - Readout and ASICs Parallel Session / 171

A 10GHz Low-Jitter Cryogenic PLL For Quantum Applications in 22nm

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Quantum computing (QC) applications require the manipulation and readout of thousands or even millions of quantum bits (qubits) to execute quantum algorithms. Utility-scale quantum systems rely

on classical control and readout cryo-electronics, which must be tightly integrated with the qubits in the same environment. This integration reduces the connections between the cryogenic plane and room temperature, lowering the latency of the control loop necessary for implementing error correction algorithms. A major challenge in developing large-scale, practical quantum computers is the complexity of interconnects between milli-kelvin qubits housed in dilution refrigerators and room-temperature (RT) controllers.

The ROADS project focuses on innovating qubit readout through multiplexing and data conversion. A popular readout scheme combines RF reflectometry with frequency domain multiplexing, where many qubits share a single RF transmission line, each tuned to a unique resonant frequency for parallel readout. However, ROADS is advancing toward direct-to-digital conversion, which requires wide bandwidth and high linearity. This involves generating and acquiring high-speed, high-accuracy, low-noise signals at cryogenic temperatures (CT), particularly the clock signals generated by a cryogenic phase-locked loop (PLL).

Designing a cryo-CMOS PLL for QC applications presents several challenges. First, low phase noise (PN) and low reference spurs (SREF) are essential to avoid limiting qubit control fidelity. Second, the PLL must function at CT, where transistor parameters differ significantly from RT, and no mature device models exist. For instance, the threshold voltage of transistors increases by ≈150 mV, and carrier mobility can double at CT. While ON-resistance of a transmission gate decreases when the input voltage is near the supply or ground level, it can increase by two orders of magnitude when the input is near the middle of the supply voltage, posing issues in sampling circuits. Additionally, transistors exhibit poorer matching at CT, degrading the linearity of analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and current sources. Low power consumption (Pdc) is also crucial, given the limited cooling power of cryogenic refrigerators and the need to control more qubits.

This abstract presents a 10GHz low-jitter cryogenic PLL fabricated in GF 22nm FDX process, capable of operating at 4.2 K. To meet the challenges of cryogenic operation, an analog PLL architecture is employed to maintain high performance from 300 K to 4.2 K. A charge-pump type II PLL architecture was designed and implemented, comprising key sub-blocks such as the phase and frequency detector (PFD), charge pump, low-pass filter (LPF), LCVCO, and clock divider. The VCO frequency is integrated into a phase shift, which feeds back into the PFD. To compensate for temperature variations and reduce periodic disturbances, the PLL features programmable charge pump current and LPF bandwidth settings. A binary-controlled MOM capacitor array broadens the VCO tuning range, ensuring optimal loop parameters with good phase noise performance and loop stability. Phase noise and jitter measurements are currently underway and will be presented at the Workshop.

RDC 05 - Trigger and DAQ Parallel Session / 172

Caribou: A versatile data acquisition system for silicon pixel detector prototyping

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Caribou is a versatile data acquisition system used in multiple collaborative frame-works (CERN EP R&D, RD50/DRD3, AIDAinnova) for both bench-top and test-beam qualification of novel silicon pixel detector prototypes. The system is built around a common hardware, firmware and software base shared across different projects, thereby drastically reducing the development effort and cost. The current version consists of a custom Control and Readout (CaR) board and a commercial Xilinx Zynq 7000 series System-on-Chip (SoC) platform. The CaR board provides a hardware environment featuring various services such as powering, slow-control and high-speed data links that can be used by the target detector prototype. The SoC platform is based on a ZC706 evaluation board running a fully featured Yocto-based Linux distribution (Poky) and a custom data acquisition software (Peary).

Migration to a Zynq UltraScale+ architecture is ongoing and a new hardware version is under development which aims to replace the evaluation board with a commercial System-on-Module (SoM) and combine the CaR board and SoM into a fully integrated hardware platform, while also adding new features and improving the capabilities of the system. This talk describes the current Caribou system architecture, its capabilities, examples of projects where it is used, and the foreseen system upgrade.

RDC 04 - Readout and ASICs Parallel Session / 173

Tackling particle tracking problems using CMOS-based simulated Ising machines

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In future high energy physics (HEP) experiments, proposed approaches to tracking the spatiotemporal information of charged particle trajectories on layers of detectors require FPGA clusters to process hit information and compute track parameters. For example, track triggering for the HL-LHC project requires processing of data volumes estimated up to 30 Tbits/s using 15K input combinatorics that define the track trigger decision within O(10µs) latency. This project aims to conduct a feasibility study on mapping the tracking problem to a custom-designed quadratic unconstrained binary optimization (QUBO) solver ASIC while also exploring track reconstruction time-to-solution, task energy/area efficiency and implementation scalability.

Joint RDC 03 & 07 & 08 / 174

TWPA and JPA

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Parametric amplifiers continue to be vital components in solid state quantum readout at cryogenic temperatures. Various flavors of parametric amplifiers are carving their place in a number of different readout architectures. Josephson junction (JJ) based amplifiers are the natural progression when these readout architectures are at deep cryogenic temperatures. Josephson traveling wave parametric amplifiers (JTWPA) and Josephson parametric amplifiers (JPA) are the two main contenders of JJ based amplifiers. These types are further divided into current pumped and flux pumped operating modes. Current pumped designs require a directional coupler at the input to combine the signal tone

with the pump tone. Whereas a flux pump designs mutually couples the pump tone over the entire amplifier as the signal tone travels through it. JTWPAs have a wider bandwidth than their JPA counterparts. The JTWPA acts as a non-linear transmission line which requires dispersion engineering. The JPAs are narrowband amplifiers, but can be tuned to a desired frequency.

We have designed flux pumped JTWPA and JPA devices with MIT-LL's SFQ5ee process. The JTWPA was designed to operates from 4-12 GHz at 6dB of power gain. Our JPA's are designed to operate at 7.5 GHz with 20db of power gain. We will report on the status of the integration and assembly of the devices to a PCB and shielding cavity, which are currently underway. We are working closely with Fermilab's LOUD facility to integrate the experiments in existing test stands.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 175

Simulation Tools to Estimate Energy Thresholds of Superconducting Qubit-based Athermal Phonon Detectors

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Recent experimental probes have demonstrated that ambient high-energy radiation can produce phonon-mediated quasiparticle poisoning in superconducting qubit arrays, leading to spatiotemporally correlated errors. This has garnered interest in understanding the potential sensitivity of such arrays to small in-substrate energy depositions characteristic of low-mass, sub-GeV dark matter scatters. In this talk we will discuss a set of simulation tools useful for modeling such energy depositions and the subsequent detector response. Using these tools, we will then present estimates of the efficacy with which superconducting qubit arrays can act as low-threshold phonon-mediated detectors of particle impacts in the attached substrate. In particular, we explore the energy resolution and threshold of qubits operated in an energy relaxation sensing scheme akin to that used in recent studies of radiation-induced correlated errors.

RDC 09 - Calorimetry Parallel Session / 176

First Test Beam Results from the ePIC LFHCal Prototype utilizing the HGCROC Digitization

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The Longitudinal Forward Hadronic Calorimeter (LFHCal) is a sampling hadronic calorimeter which will cover the forward (hadron-going) region from $1.2 < \eta < 3.5$ in the ePIC detector at the EIC. The physics goals of the EIC demand strong jet reconstruction performance in this region to investigate small momentum-fraction x phenomena. To achieve this, the LFHCal is constructed from alternating layers of steel plate and 5x5 cm scintillator tiles directly coupled to an SiPM, enabling fine segmentation in both the transverse and longitudinal shower measurement. A prototype LHFCal module was tested at the CERN Proton-Synchrotron T9 beam line in September of 2024 with electrons, muons, and hadrons spanning energies of 1 to 15 GeV. During the test beam, two different digitization schemes were utilized, one being a commercial CAEN product and the other based

on the HGCROC readout designed for the CMS experiment. This contribution will present the first results from the HGCROC readout electronics.

RDC 11 - Fast Timing Parallel Session / 177

Ultra-fast and low-noise silicon photomultiplier for next generation HEP detectors

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High energy physics (HEP) experiments require high-performance detectors to advance the energy, luminosity, and cosmology frontiers. Photomultiplier tubes (PMTs) have been extensively used to detect scintillation light. In recent years, silicon photomultipliers (SiPMs), an array of single photon avalanche diodes (SPADs), have become preferable as a solid-state alternative to PMTs due to their invulnerability to magnetic fields, compactness, low operating voltage, robustness, and lower cost. Furthermore, SiPMs implemented in a standard CMOS process, as opposed to a dedicated optical process, allow the optical sensor to be coupled on the same chip with the readout electronics. This results in a compact, low-cost, and low-bias voltage SiPM detector. However, SiPMs tend to rapidly degrade in high irradiation environments, making them unsuitable for some collider experiments, particularly given the trend towards higher luminosities and therefore higher irradiation levels. One of the major challenges of SiPM in such high-radiation environments is their noise performance. In addition, CMOS detectors have been developed for precision position measurements in HEP due to their compactness and spatial granularity. In recent years, developments have focused on sub-100 ps photon timing and direct particle detection.
To address the demands for timing precision and improved noise performance, the proposed project plans to develop an ultra-fast, low-cost, compact, scalable, and low-noise SiPM detector with integrated readout electronics. This idea involves integrating innovative perimeter field gates into SPADs within commercial CMOS processes to create perimeter-gated SPADs. Preliminary work has shown that the field modulating gate reduces the noise (dark count) of regular SPADs and SPAD-based SiPM detectors. To improve the timing resolution, we will design new front-end readout circuits at the pixel level and high-resolution time-to-digital converters (TDCs) at the system level. Detector performance will be optimized by pursuing a "chiplet"approach in which the SiPM devices and matched readout circuits are fabricated on separate dies using different, carefully selected fabrication processes and then integrated within the same package.
As a result of this research, we expect to create a new class of SiPM detectors that provides an order-of-magnitude improvement in key performance metrics, namely timing resolution and noise. In summary, the proposed novel scalable SiPM detectors will provide noise and timing resolutions far beyond what is currently available, allowing them to be used not only in HEP experiments that will be exposed to high radiation levels, but also in other applications such as long-term space missions.

RDC 04 - Readout and ASICs Parallel Session / 178

Wavelength and Polarization Multiplexed Silicon Photonic ICs for Parallelized Fiber Optic Readout

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Silicon photonics provides a scalable platform for fiber optic communication applied to detector readout because it shares the same manufacturing processes and hardening efforts as mature Si CMOS electronics. Single mode fiber links are far superior to multimode fiber optics or electrical cabling, primarily due to the potential for much higher aggregate bandwidth. High spectral efficiency results in large bandwidths enabled by the various degrees of parallelism that are only available in single mode fiber, including wavelength, polarization, and phase multiplexing. Optical multiplexing is especially advantageous compared to electrical multiplexing, as it eliminates the need for rad hard, high-speed circuits for on-detector data concentration, which are a major challenge and a single point of failure.

An overview of Silicon photonic links will be presented, with potential system-level improvements to detector readout chains. Previous results will be highlighted that demonstrate high-speed performance and radiation hardness to high total ionizing dose (TID) levels. A ring resonator modulator (RRM) that was highly doped for improved radiation hardness and low temperature operation was radiation and cryogenically tested. Additionally, a polarization controller and optical receiver was demonstrated to show polarization management, and the potential for bidirectional signaling on a single fiber or a doubling in channel count in unidirectional readout.

Experimental results on a new transmitter PIC will be shown –with 8 λ x 25 Gbps RRMs on the same waveguide, using the same RRM as a previous irradiation result. The wirebonded and fiber attached part has an electro-optic bandwidth of 20 GHz and a total fiber -fiber insertion loss of 6.5 dB. Previous hardness measurements indicate operation at a TID of 1 Grad and temperatures above 77 K.

Poster Session / 179

Enabling large arrays of transition-edge sensors for high-energy physics with multiplexed microwave readout

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The scalability of sub-Kelvin superconducting sensors is generally limited by their associated superconducting readout electronics, motivating multiplexing schemes which reduce the system complexity, cost, and thermal load on the refrigerator. Microwave SQUID multiplexing, which naturally

has access to ~100x the operation bandwidth of alternative schemes, is a compelling candidate for future advanced readout. It combines the inherent frequency-division multiplexing capability of kinetic inductance detectors with the ability to independently optimize the sensor array, enabling broad compatibility with a variety of TES and MMC sensors. Here, we report on two directions of technology development advancing microwave SQUID readout for HEP applications.

First, we summarize a demonstration of the largest TES multiplexing factor to date, implemented with TES bolometers suitable for mm-wave observatories probing inflationary physics and constraining light relics via the cosmic microwave background. By doubling the bandwidth of previous implementations, this development increases the multiplexing factor from 910 to 1,820. We further show that the channel yield, electrical crosstalk, and readout noise are consistent with the needs of ground-based cosmic microwave background telescopes.

Second, we describe new work to develop a microwave SQUID multiplexer for sub-eV threshold TES calorimeters suitable for direct detection searches for keV - GeV mass dark matter. A unique challenge with any readout scheme of such sensors is the avoidance of sub-fW parasitic power dissipated in the TESs, which can saturate them. We report on efforts to model, measure, and mitigate the sources of parasitic leakage in microwave SQUID readout as a first step to developing a scaling path towards a future experiment with thousands of TES sensors.

RDC 06 - Gaseous Detectors Parallel Session / 180

The sPHENIX TPC Readout System

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The sPHENIX TPC is a double-sided, GEM-based, gaseous drift detector covering full azimuth and |η| < 1.1. The TPC is instrumented with 624 Front End Electronics (FEE) Cards which perform analogue/digital conversion, pulse shaping, and zero suppression. The FEE cards use 8 SAMPA v5 ASIC chips with shaping time of 80 ns, digitization rate of 20 MHz, and 10-bit adc ouptut for 256 pads each. The data/timing distribution and routing to/from the FEEs is done using a system of FrontEnd LInk eXchange (FELIX) cards. The FEE and FELIX cards along with the back-end servers (Event Buffer and Data Compression or EBDCs) constitute the TPC Data Acquisition (DAQ) system. The TPC DAQ operates in a unique hybrid trigger-streaming mode which reached 30 % of its full streaming rate during sPHENIX proton-proton data taking - 3 times its goal. This talk will present an overview of the TPC Readout System including a summary of its use during the sPHENIX Run '23 and '24 periods including as well as outlook for future Run '25.

RDC 09 - Calorimetry Parallel Session / 181

Testing a SiPM-on-tile calorimeter prototype with 200 GeV pp collisions at RHIC

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We present results from a parasitic test of a SiPM-on-tile calorimeter prototype conducted during the 2024 proton-proton (pp) run at the Relativistic Heavy Ion Collider (RHIC), with a center-of-mass energy of 200 GeV. The prototype, measuring 20 x 20 cm² and comprising 400 channels, serves as a critical testbed for the design of the Electron-Ion Collider's (EIC) Zero-Degree Calorimeter (η > 6)

and Calorimeter Insert (3.0 < η < 4.0). This marks the first commissioning, operation, and calibration of a SiPM-on-tile calorimeter in a hadron collider environment. The study evaluates the prototype's performance under realistic collider conditions, including effects of radiation-induced degradation, Minimum Ionizing Particle (MIP) response, and high-energy particle shower reconstruction in three dimensions. We detail the experimental setup, operational challenges, performance metrics, and insights drawn from both data and simulations. These findings will guide the ongoing development of the ePIC detector system.

RDC 01 - Noble Element Detectors Parallel Session / 182

Recent results and future plans of XeBrA

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The Liquid Xenon Time-Projection Chamber (LXe TPC) is a prominent technology for direct dark matter and neutrinoless double-beta decay searches. The next generation of LXe TPCs aims to increase their drift lengths while maintaining high operational electric fields in the hundreds of volts per centimeter. To achieve this goal, we need to gain a clearer understanding of how various engineered factors impact the risk of electrostatic discharge (ESD) when scaling up LXe TPCs. To explore this, we utilized the Xenon Breakdown Apparatus (XeBrA), a 5-liter spark chamber equipped with adjustable large-area electrodes and transparent viewports. This setup allows us to study the dominant factors contributing to ESD, such as pressure, stressed electrode area, or surface finish. In addition, we employ a system of two high-frame rate cameras to investigate the origin mechanism of ESD. In this talk, I will summarize the main results from our last data-acquisition campaign and discuss future run plans.

RDC 04 - Readout and ASICs Parallel Session / 183

An Ultra-Low-Voltage, 16-Channel Current DAC ASIC in 22nm FDSOI for Cryogenic SQUID Biasing

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In this work, we present a sixteen-channel, ultra low-voltage (≤ 0.1 V analog supply) current DAC designed in 22nm FDSOI technology for biasing SQUIDs. The ASIC integrates eight 6-bit DACs and eight 8-bit DACs, programmed through a simple serial interface. It operates effectively across a wide temperature range, from 300K to 4K, by using the back-gate bias to counteract threshold voltage variations across temperature. The DACs output current range is 0.25 mA and 1.25 mA for the 6-bit and 8-bit DACs, respectively. Measurement results at both cryo and room temperature demonstrate excellent performance, with DNL below 0.5 LSB for the 8-bit DAC and below 0.25 LSB for the 6-bit DAC.

Poster Session / 184

Progress on Superconducting Bolometers for the RICOCHET Experiment

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The RICOCHET experiment located at the research reactor at ILL in Grenoble, France is a Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) observatory that aims to detect reactor neutrinos through low-energy nuclear recoils. RICOCHET has been comissioned and operated at ILL since the first half of 2024 with a small array of Ge detectors with heat and charge readouts. We focus on the development of the complementary detector array (Q-Array) under active R&D, which uses superconducting crystals (Zn, Al, and Sn) of around ~50 grams as the recoil target and Manganese-doped Al Transition-Edge-Sensors (TESes) for bolometric readout. We present and discuss the detector data and a corresponding cascade model for particle interactions in bulk superconductors. The cascade model provides physical insights towards understanding the data and achieving Particle identification (PID) for nuclear and electron recoil events in a bulk superconductor.

Poster Session / 185

ePIC LFHCAL Testbeam Module Production

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Oak Ridge National Lab (ORNL)'s Electron-Proton/Ion Collider (ePIC) group works on the production and testing of the ePIC LFHCalorimeter. This calorimeter is longitudinally segmented, containing 62,424 read out channels; it will be located in the forward going direction of ePIC. Each module of the calorimeter consists of 65 layer assemblies, made of 8 scintillator tiles placed over a Silicon Photomultiplier (SiPM) flexible PCB board. Over the summer one of these modules was constructed, with most of the process being done in-house with the exception of the production of the materials. The completed module was then sent to CERN's PS beamline for testing, which took place from August 28 to September 11, 2024.
Each SiPM board was individually tested using a LED inside a dark box so that we could fit their Single Photon Spectrums (SPS). The script used to do this reads multiple files of data, compiles them into a single data frame, and then fits them using a multi-gaussian function. Fits that produce either too small of a Poisson distribution or too large of a standard deviation will then be discarded as these fits are either just electronic noise or not have distinctive enough peaks to read. The gain of the fits that pass this filter are then collected and grouped together by their respective channel. These groups are then fitted to a linear regression model to get the gain of the SiPM channel as a function of the over voltage used. This allows us to calibrate the ADC to the number of photons detected in a single event. While fitting the SPSs we began cosmics testing, for which we stacked 8 layer assemblies together and let them collect MIPS. This allowed us to see what was the most common ADC the readout unit collected, then we could translate that to the number of photo-electro using the gain that was found from the SPSs.

RDC 07 Low-Background Detectors Parallel Session / 186

First year of LEGEND-200 and a brief overview of LEGEND-1000

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The discovery of Neutrinoless double beta decay (0νββ) would have profound implicaBons for neutrino physics and cosmology. It would provide unambiguous evidence for the Majorana nature of neutrinos, lepton number non-conservaBon and shed light into the absolute neutrino mass scale. The Large Enriched Germanium Experiment for Neutrinoless ββ decay (LEGEND) searches for 0νββ in the 76Ge isotope. The first phase of the experiment, LEGEND-200 has been acquiring stable data with 142 kg of enriched germanium detectors over the last year. This talk will discuss the first year of physics data from LEGEND-200. We will also present a brief overview of the second phase of the experiment, LEGEND-1000.
This work is supported by the U.S. DOE and the NSF, the LANL, ORNL and LBNL LDRD programs; the European ERC and Horizon programs; the German DFG, BMBF, and MPG; the Italian INFN; the Polish NCN and MNiSW; the Czech MEYS; the Slovak SRDA; the Swiss SNF; the UK STFC; the Canadian NSERC and CFI; the LNGS, SNOLAB, and SURF faciliBes.

RDC 02 - Photodetectors Parallel Session / 187

The Theia Neutrino Detector: Concept and Development

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Water-based Liquid Scintillator (WbLS) shows promise as a detector medium offering the advantages of both pure water detectors and conventional liquid scintillator. With the capability of measuring and distinguishing both Cherenkov and scintillation light, it could use the former to measure track direction and particle species while the latter allows a low energy threshold and excellent energy resolution.

Theia is a proposed detector at the 25+ kton scale that would use these capabilities for a broad program of neutrino physics and BSM searches spanning energies from hundreds of keV to a few GeV, including determination of the neutrino mass hierarchy, measurement of the neutrino CP-violating phase, and searches for neutrinoless double beta decay and proton decay. If deployed as a far detector module for the DUNE project, it would also complement the liquid argon program by providing a way to disentangle flux and cross section systematics through interactions on a different nuclear target. I will present the Theia concept, current R&D efforts with WbLS, and the ongoing studies aiming to demonstrate Theia's suitability as DUNE far detector 4.

Poster Session / 188

Analysis and Grading of Phase-2 CMS Outer Tracker Module Test Performance

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The Outer Tracker (OT) of the CMS experiment provides information about the trajectory of charged particles produced in proton-proton collisions at the LHC. During the High Luminosity LHC (HL-LHC) upgrade, scheduled for the late 2020s, the entire tracker will be replaced with new modules that will interface with the Level-1 Trigger for the first time ever at the LHC. Module production is distributed across several facilities around the world, necessitating coordinated standards of quality assessment and control. This poster focuses on the development of POTATO (Phase-II Outer Tracker Analyzer of Test Outputs), a C++ software which provides a standardized procedure for analyzing and grading test results of the new OT modules.

Poster Session / 189

LFHCAL Test Modules

Author: Cordney Nash[None]

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This work with the Relativistic Nuclear Physics Group at Oak Ridge National Laboratory (ORNL) focuses on testing and characterizing Silicon Photon Multipliers (SiPMs) for the Longitudinal Forward Hadron Calorimeter (LFHCAL). Using a waveform generator, multiple LEDs and a DAQ software tested the calorimeters components which will play a key role in the Electron-Ion Collider (EIC) experiment. The SiPM boards were later tested at CERN.

Plenary session / 190

Remarks from the Physics and Astronomy Department Head

Plenary session / 191

Remarks from the ORNL Physics Division Director

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Plenary session / 192

Remarks from TN State Representative Sam McKenzie

Plenary session / 193

Welcome from the Local Organizers and Workshop Logistics

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Plenary session / 194

CPAD 2024 Activities Recap

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Plenary session / 195

ECFA DRD Overview

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Plenary session / 196

DOE Detector R&D Overview

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Plenary session / 197

TPC@50: Past

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TPC@50: Present

Plenary session / 199

TPC@50: Future

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TPC@50: Keynote Dave Nygren

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Plenary session / 201

Developing Novel Low-Threshold, Phonon-Mediated Qubit Sensors

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Particle interactions in a superconducting qubit chip generate non-equilibrium quasiparticles that can tunnel across the Josephson junction and can be detected as an error (or treated as a signal) in the qubit. Large energy deposits, such as those from ionizing radiation, can cause such errors (our signals) across multiple qubits on the same chip and are correlated in space and time. We present recent results on the correlation between radiation flux and the stability of qubit gate charge from measurements of an array of weakly charge-sensitive superconducting qubits in a low background environment at NEXUS. We propose a continuation of this study by running two new devices in a similar low background environment: an array of tantalum transmon qubits and a SQUAT device from SLAC, which are less and more sensitive to charge noise and radiation environments, respectively. Results from these studies will be input into qubit response simulations and will inform design choices for new sub-eV superconducting quantum sensors for particle detection.

Poster Session / 202

Data Quality Monitoring for the HL-LHC Upgrade to the CMS Outer Tracker

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The CMS detector will upgrade its tracking detector in preparation for the High Luminosity Large Hadron Collider (HL-LHC). The Phase-2 outer tracker layout will consist of 6 barrel layers in the center and 5 endcap layers. These will be composed of two different types of double-sensor modules, capable of reading out hits compatible with charged particles with transverse momentum above 2 GeV ("stubs"). Stubs are used in the back-end Level 1 track-finding system to form tracks that will be considered by the Level-1 trigger to select interesting events. An important part of this update is ensuring the tracker and the stub building step work correctly, which is where Data Quality Monitoring (DQM) comes in. Currently, there is no automated system to measure the performance of stub reconstruction. This talk focuses on the software development to ensure that we can monitor the performance of stub reconstruction, making use of Monte Carlo truth information.

Plenary session / 203

Ian Shipsey Memorial

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Plenary session / 205

DPF Insturmentation Award

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Plenary session / 207

CPAD Closeout

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Poster Session / 208

Containerization of the Burn in Box Software for the CMS Outer Tracker Upgrade

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The construction of modules for the Phase 2 Outer Tracker upgrade is underway. Due to the large number required, there will be many sites participating in this process. In order to facilitate smooth assembly and testing of these modules, a consistent environment is required across all of these sites. The sites will use a burn in box to stress and test the modules that require multiple, cutting edge, in progress software. To ensure ease of use for and consistency across the sites, we are developing a series of docker images for use. These will be automatically tested to ensure correctness and will pull changes from the relevant repositories to stay up to date.

RDC 09 - Calorimetry Parallel Session / 209

Discussion

Plenary session / 210

Higgs Factory PED R&D Status and Planning

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Plenary session / 211

DUNE Phase-II Detector R&D Status and Planning

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Plenary session / 212

CMB-S4 Detector Status and Planning

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Plenary session / 213

G3 Dark Matter Detector R&D Status and Planning

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Plenary session / 214

Muon Collider PED Status and Planning

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Plenary session / 215

Neuromorphic Computing for Scientific Applications

Author: Catherine Schuman[1]

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Neuromorphic computing is a popular technology for the future of computing where inspiration from biological brain is used to motivate new hardware, software, and algorithm design. In this talk, I will overview the field of neuromorphic computing and give an introduction to spiking neural networks. I will present several examples of real-world applications of FPGA-based neuromorphic systems for scientific applications, as well as discuss opportunities for future custom-chip neuromorphic systems for high energy physics applications.

Poster Session / 216

Commissioning of the C-Rack: CMS Outer Tracker Modules Testing using Cosmic Rays

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The Cosmic Rack (C-Rack) is an essential component of the CMS High-Luminosity LHC (HL-LHC) upgrade at CERN. Designed to test 2S modules and validate the Tracker Integration workflow, the C-Rack trigger system utilizes a scintillator and photomultiplier tube (PMT) setup with cosmic rays as the particle source. This poster presents the commissioning and calibration results of the scintillator-PMT system. In addition to generating the required trigger signal, the system also offers the capability to locate particle hits within the scintillator.

Poster Session / 217

Novel Temperature Sensing with Silicon Shards in the Nab Experiment

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The Nab experiment at the Spallation Neutron Source aims to measure the electron-neutrino correlation coefficient 'a' and the Fierz interference term 'b,' utilizing pixelated silicon detectors to test CKM matrix unitarity. Accurate temperature monitoring is crucial for ensuring that the detectors meet the required temperature stability to achieve precision goals. In this context, the focus is on a broken silicon diode detector shard. A copper plate was designed for mounting to a closed-cycle refrigerator to measure the voltage needed for current flow under forward bias conditions. The objective is to establish a correlation between forward bias voltage and temperature by varying the temperature on the shard and recording the corresponding voltages at which current flows. The effectiveness of this technique for temperature measurement will be evaluated. Should the detector shard prove effective as a temperature sensor, it would provide evidence that the Nab experiment can perform in situ temperature measurements by forward biasing the detector.

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 218

RDC-8 Overview, Coordination and Progress

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RDC-8 Coordinators (Kathiwada and Suzuki) will give overview of the coordination activities

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 219

RDC-8 Coherent subgroup overview

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RDC-8 Coherent subgroup overview

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 220

RDC-8 AMP,INT,NMR,OptMech subgroup overview

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RDC-8 AMP,INT,NMR,OptMech subgroup overview

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 221

RDC-8 Pair breaking sensor subgroup overview

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RDC-8 Pair breaking sensor subgroup overview

Joint RDC 03 & 07 & 08 / 222

RDC-3,4,7,8 Combined Session - Materials for Quantum Sensors

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Joint RDC 03 & 07 & 08 / 223

RDC - 3,4,7,8 Discussion Session - Common Need

Discussion to identify common R&D theme, technology gap, availability

For example,
* Low background material R&D
* Low background test facility
* Parametric amplifier
* Microfabrication capability/ access

Joint RDC 07 & 08 & 09 Parallel Session / 224

RDC 7,8,9 - Combined session discussion session

Discussion session to identify common R&D thread and gap in technology

Poster Session / 225

Large area, thick, highly pixelated silicon detectors for the Nab Experiment

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The Nab experiment, currently taking data at the Spallation Neutron Source, uses an unpolarized neutron beam to precisely measure two of the free neutron beta decay correlation parameters to probe physics beyond the Standard Model. The electron-neutrino correlation coefficient, a, will give us access to investigate CKM unitarity, and the Fierz interference term, b, will enable us to put bounds on the existence of scalar and tensor currents in the weak interaction. The Nab experiment uses two large area, thick, highly pixelated silicon detectors at either end of a 7 m tall magnetic spectrometer to measure the electron energy and the proton time of flight, which can be used to construct nearly the full phase space of neutron decay, and make determinations of a and b. This poster will focus on the detectors' characteristics, operation, and systematic effects that are considered.

Poster Session / 226

Detecting Charged-Current Neutrino-Nucleus Interactions on Oxygen in a Heavy Water Cherenkov Detector

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At Oak Ridge National Laboratory (ORNL), the COHERENT collaboration has built a heavy water Cherenkov detector to measure the neutrino flux coming from the Spallation Neutron Source (SNS) via the scattering of neutrinos on deuterium nuclei, with the primary aim of improving the precision of past and future CEvNS measurements. Detector construction was completed and measurements began in the summer of 2023. Although this heavy water Cherenkov detector was built primarily to measure the SNS neutrino flux, it can also be used to measure the cross section of neutrino-nucleus charged-current interactions on oxygen nuclei. Charged-current neutrino-oxygen reactions produce electrons that emit Cherenkov radiation within the detector. The SNS is the most powerful pulsed source of accelerator-based neutrinos in the world, which produces electron neutrinos in a similar energy range to supernova neutrinos. Thus the measurement of this charged-current neutrino reaction in oxygen can improve supernova neutrino detection. This neutrino-oxygen interaction has also never been experimentally measured in this energy range, and thus its measurement can be a test of nuclear models. This presentation describes methodology for detecting and measuring the cross section and event rate of this charged-current interaction between electron neutrinos and oxygen nuclei.

RDC 06 - Gaseous Detectors Parallel Session / 227

Strategic R&D on gaseous detectors within DRD1 Work Packages

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The DRD1 Collaboration aims at promoting the development and applications of gaseous detectors and is organised according to the General Strategic Recommendations outlined in the ECFA Detector R&D Roadmap Document. The Strategic R&D is organised in Work Packages that consolidate the activities of institutes with shared research interests in specific areas, including applications, performance challenges, material and detector technologies. The contribution will discuss the status of the DRD1 collaboration and Work Packages focusing on the ongoing and planned R&D activities.

RDC 09 - Calorimetry Parallel Session / 228

RDC9 Introduction

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Joint RDC 03 & 11 Parallel Session / 229

RDC3/11: Discussion (LGAD)

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Joint RDC 03 & 11 Parallel Session / 231

RDC3/4: Discussion (MAPs/Integration)

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Plenary session / 232

DPF Instrumentation Award

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Plenary session / 233

DPF Instrumentation Award

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Poster Session / 235

The QUAntum LImited PHotons In the Dark Experiment with far infrared photon counting

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QUAntum LImited PHotons In the Dark Experiment (QUALIPHIDE) utilizes novel receivers and detectors operating in the microwave to far infrared to search of Hidden Photons (HP). HPs are a candidate for wave like dark matter. Searches with quantum sensing techniques enables exploring new phase space for both HPs and axion like particles. The first version of QUALIPHIDE was done in the microwave with traveling wave parametric amplifiers. Now, we are probing deeper than standard quantum limit searches by using photon counting. This new iteration of QUALIPHIDE will operate in 8-16 THz (~50 meV hidden photon masses), with expected sensitivity of kinetic mixing

~10^-12. Our work focuses on the sensors, as we enable their reach with mHz dark count rates, and eventually towards operation at ~1 THz.

Plenary session / 236

Discussion

RDC 08 - Quantum and Superconducting Sensors Parallel Session / 237

Discussion prep

RDC 04 - Readout and ASICs Parallel Session / 238

The Role of Young University Undergraduates gudied by national lab experts

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Submitted

RDC 04 - Readout and ASICs Parallel Session / 239

Design of an 8 Channel 40 GS/sec 20 mW/Channel Waveform Sampling ASIC in 65 nm CMOS

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RDC 04 - Readout and ASICs Parallel Session / 240

Design and Implementation for the Digital Block of PSEC5.

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RDC 11 - Fast Timing Parallel Session / 241

A Modular Test System for the PSEC5 40 GS/s waveform-sampling ASIC

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Poster Session / 242

Modifications to HV Chain in sPHENIX TPC Readout Modules

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The sPHENIX detector at RHIC is a heavy ion experiment that aims to further investigate the microscopic nature of the QGP through precision measurements of jets, the upsilon, and open heavy flavor probes over a broad pT range. The Time Projection Chamber (TPC) is the main tracking detector in the experiment with a rapidity range of $|\eta|<1.1$ and full azimuthal coverage. Amplification in the TPC is performed using an array of quadruple-stacked gas electron multiplier (GEM) modules to amplify signals from the chamber for precise tracking measurements. The GEM foils and transfer gaps are energized through resistor chains that distribute high voltage across the entire stack. Sparking events within the GEMs will sometimes lead to changes in the effective resistance that reduce the gain of affected modules and limit TPC performance. Initial attempts to restore proper voltages to these modules proved challenging due to the placement of the HV cards in the magnet bore of the detector. To simplify this process, the HV chain of each module was modified by rerouting the resistors on the GEM HV cards to breakout boxes located in separate racks away from the detector that use replaceable resistor cards. Here we present the design, testing, and implementation of the TPC breakout boxes as well as future upgrades to further improve the system in the next run of sPHENIX.

RDC 10 - Detector Mechanics Parallel Session / 243

RDC10 Mechanics - News

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RDC 10 - Detector Mechanics Parallel Session / 244

RDC10 - Funding, Facilities, DRD8, AOB

Additional discussion time