

The ADRIANO3 Triple Readout Calorimetric Technique

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For ADRIANO3 Project

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Rationale for ADRIANO3

- ❑ Neutron fluctuation of a hadronic shower responsible for up-to 20% of the energy measurement uncertainties
 - A triple readout calorimeter extends the event-by-event energy compensation of the dual-readout technique by also measuring the neutron component of the shower
- ❑ High-granularity helps in disentangling overlapping showers in a high-multiplicity event (e.g. hadron colliders)
 - A small-tile a-la CMS has enough granularity for events with $\sim 10^3$ particles
- ❑ Fast timing (<50 psec) provides:
 - TOF of slow particles
 - Disentangling of triggers in a high-collision rate accelerator
 - Discriminating low energy electrons vs pions (the showers start at different depths)

The ADRIANO3 Technique

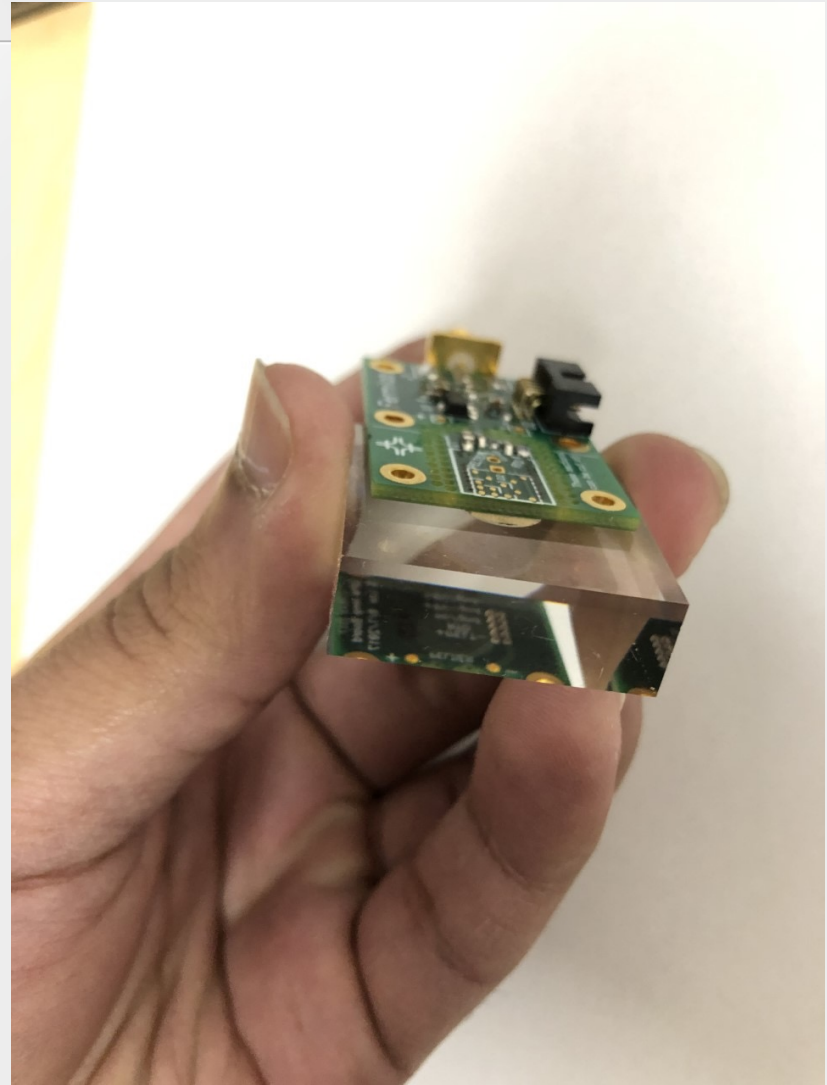
- High-granularity, **triple-readout** electromagnetic **and** hadronic calorimeter with fast timing
- Performance goals:
 - EM energy resolution: $\sigma(E)/E \sim 3\%/\sqrt{E}$
 - Hadronic energy resolution: $\sigma(E)/E < 25\%/\sqrt{E}$
 - Timing resolution: < 50 psec
- Relatively low cost

ADRIANO3 Active Components

- ❑ Cerenkov radiator: $3 \times 3 \times 2 \text{ cm}^3$ lead-glass tiles (typical size)
- ❑ Scintillator component: $3 \times 3 \times 0.5 \text{ cm}^3$ scintillating tiles (typical size)
- ❑ Neutron component: $1 \times 1 \times 0.5 \text{ cm}^3$ doped RPC
- ❑ Tiles readout: on-tile SiPMs
- ❑ RPC readout: pads

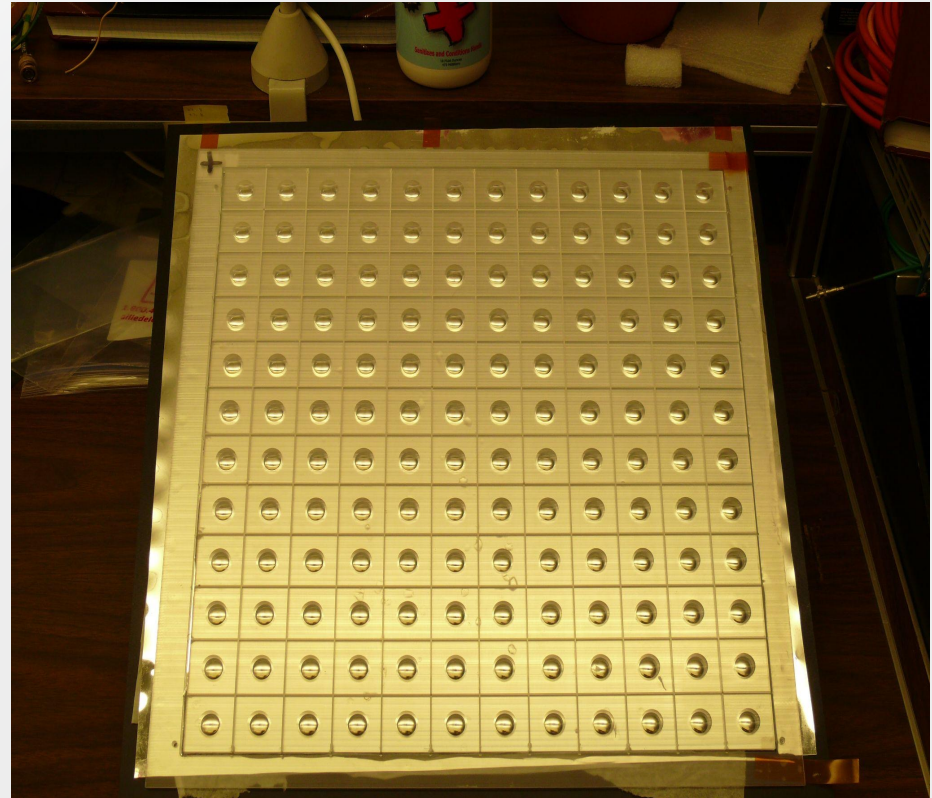
ADRIANO3 Lead Glass Tiles

- ❑ Mostly sensitive to the EM component of a hadronic shower
- ❑ Prompt Cerenkov signal from small tile has a single-channel timing resolution of 80 ps (for $> \sim 20$ pe)
- ❑ Active absorber for electromagnetic showers



ADRIANO3 Scintillating Tiles

- ❑ Sensitive to all charged component of a hadronic shower
- ❑ Also sensitive to neutrons thanks to high-H₂ content (too thin for high efficiency detection)
- ❑ Inherits from CALICE AHCAL/CMS HGC with SiPM-on-tile readout
- ❑ Tile wrapping replaced with tile coating



ADRIANO3 Thin Gd-Doped Glass RPC

- ❑ Sensitive to all the ionizing particles of the shower
- ❑ Capable of sustaining a particle rate up to 2 kHz/cm^2 (by the current state-of-the-art)
- ❑ Timing resolution of a few hundred psec per layer is achievable
- ❑ Glass doping with Gd would increase the triple-readout capability of ADRIANO3 by making the RPCs sensitive to neutrons



ADRIANO3 Perspectives

Lead-glass and scintillating components R&D in T1604 Collaboration

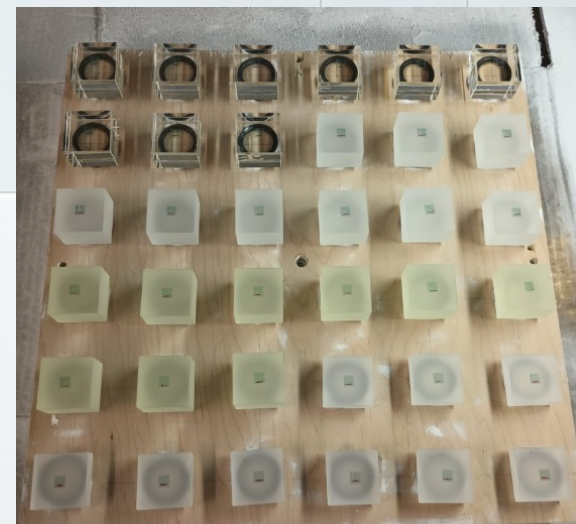
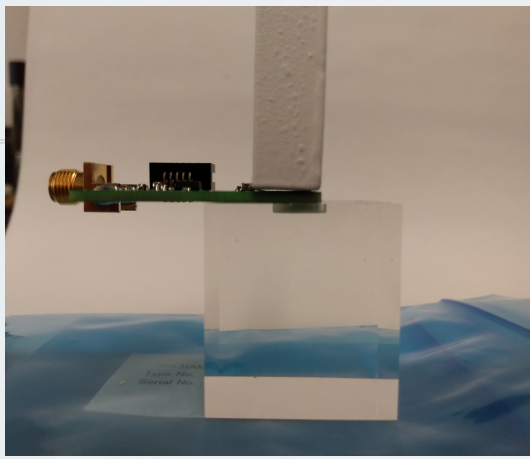
Thin-glass RPC R&D in T1041 Collaboration

Effort merged in a newly formed collaboration

- ❑ Under construction: 12 cm x 12 cm x 13 triple-layer prototype
- ❑ Integrate 2-3 hybrid RPCs at the first stage (not Gd-doped)
- ❑ Goal is to test it at Fermilab in Winter 2025
- ❑ ADRIANO3 project not yet funded: piggy-back on 1041 and 1604 activities
- ❑ Responded to DOE FOA 0003177 in Fall 2024

ADRIANO2 Highlights

- 1) Layout: alternating tiles of Pb-glass (Č) and scintillating plastics (S)
- 2) Tile size: $3 \times 3 \times 1 \text{ cm}^3$ for glass, $3 \times 3 \times 0.7 \text{ cm}^3$ for plastic (same as CMS)
- 3) SiPM-on-tile readout
- 4) High-granularity, dual-readout, integrally active, $<100 \text{ psec/cell}$ timing resolution
- 5) Č vs S used as PID at low energy experiments and for energy compensation at high energy



Tested Configurations over 3-years

- Three sizes
 - 3x3x1 cm³, 3x3x2 cm³, 3x3x3 cm³
- Six glasses:
 - SF57-HHT, ZF2, ZF6, ZF7, JGS1, HZPK7
- Three surface finish
 - Cut ground, sandblasted, polished
- Ten surface coating
 - BaSO₄, Teflon, Kevlar, Al sputtering , Al paint, ESR2000, Ag sputtering , Mo ALD, W ALD
- Two sensor interfaces
 - Dimple, no-dimple
- Three single sensors
 - Hamamatsu S13360, S14160 , Broadcom S466P014M (6x6 mm²)
- Two quadruple-sensors in active ganged mode
 - Hamamatsu S14160 (3x3 mm²), S14160 (4x4 mm²) S14160 (6x6 mm²), Broadcom S466P014M (6x6 mm²)

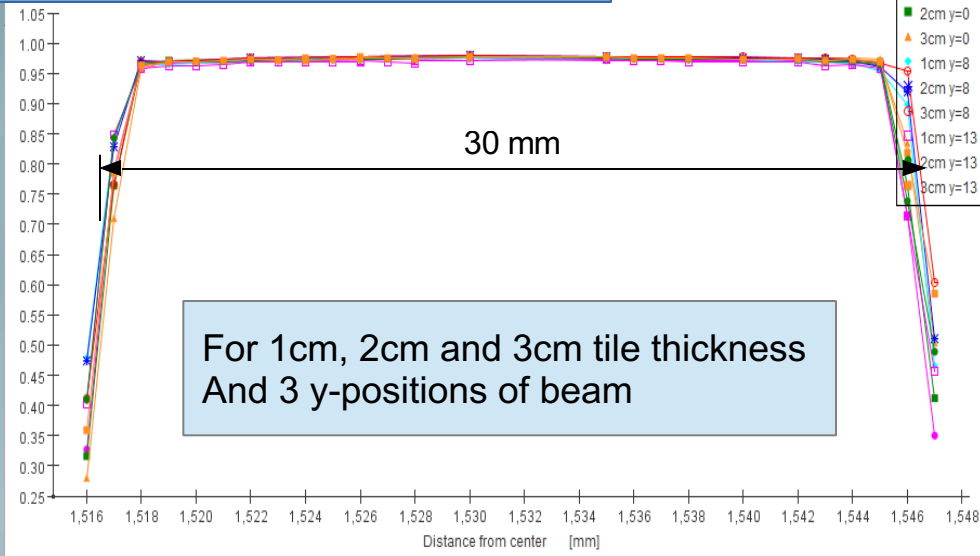
Total: 75 tiles tested

Energy resolution predicted (EM) < 2%/√(E)

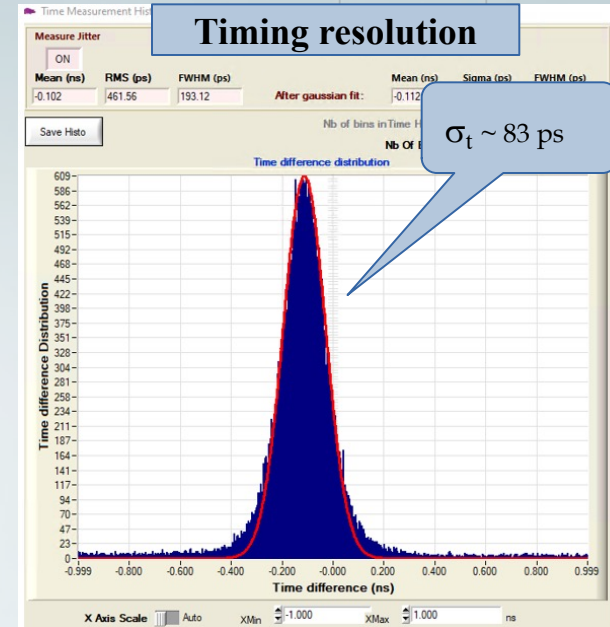
Timing resolution: ~80 psec/cell

ADRIANO2 performance

Efficiency vs beam position

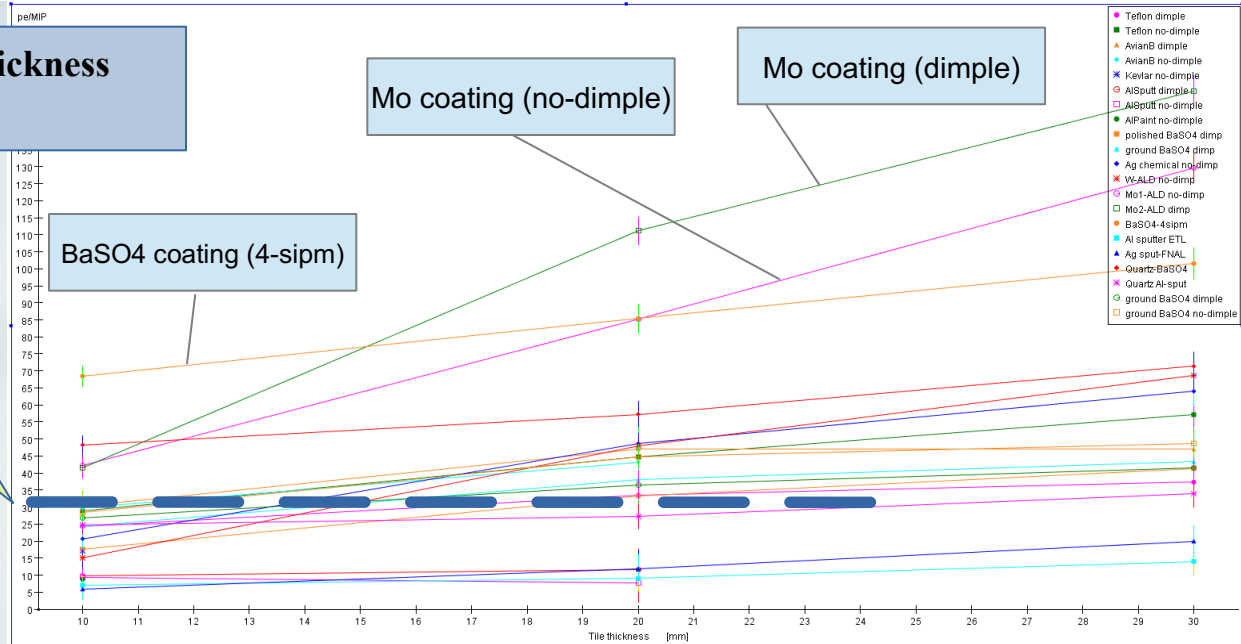


Timing resolution



Light Yield vs tile thickness

pe/MIP



$\sigma_E/E \sim 2\%/\sqrt{E}$ estimated
EM stochastic term

Thin-glass R&D in T1041 Collaboration

Inherits from the CALICE Digital Hadron Calorimeter

60 GeV π^+

The DHCAL prototype

Description

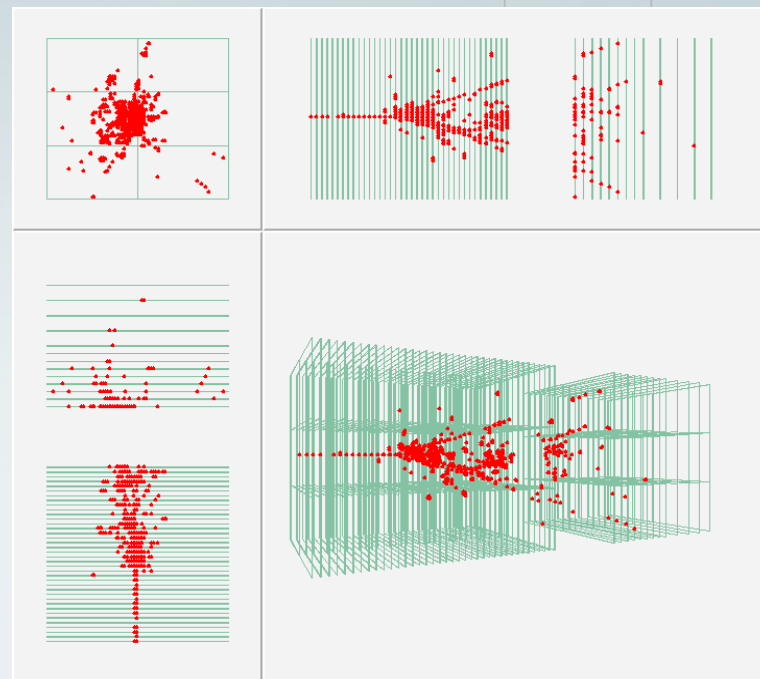
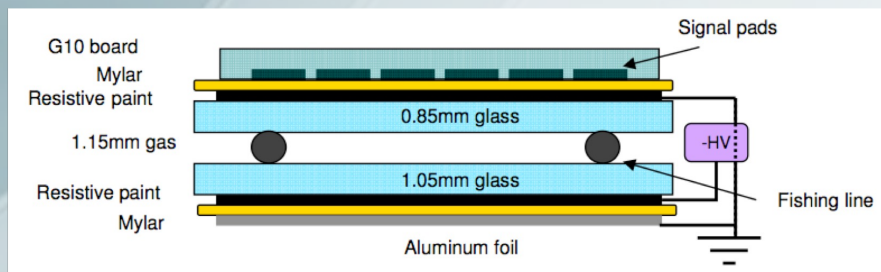
Hadronic sampling calorimeter

Designed for future electron-positron collider (ILC)

54 active layers ($\sim 1 \text{ m}^2$)

Resistive Plate Chambers (RPCs) with $1 \times 1 \text{ cm}^2$ pads

→ $\sim 500,000$ readout channels



Electronic readout

1 – bit (digital)

Tests at FNAL

with Iron absorber in 2010 – 2011
with no absorber in 2011

Tests at CERN

with Tungsten absorber in 2012₁₂

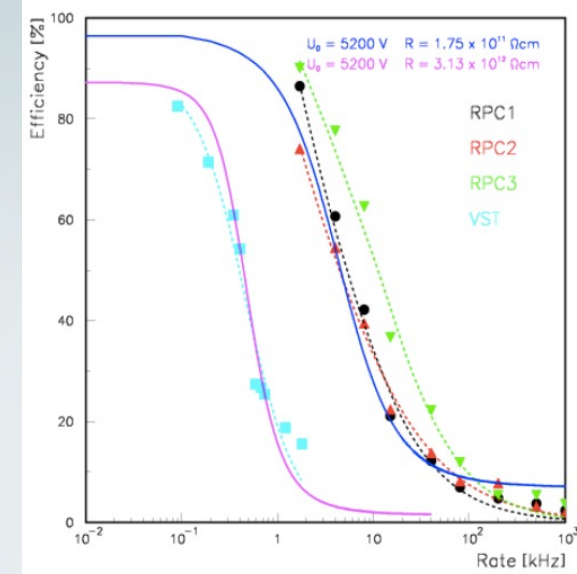


Development of semi-conductive glass and 1-glass RPCs

Semi-conductive glass: Co-operation with COE college (Iowa) and University of Iowa

Vanadium based glass

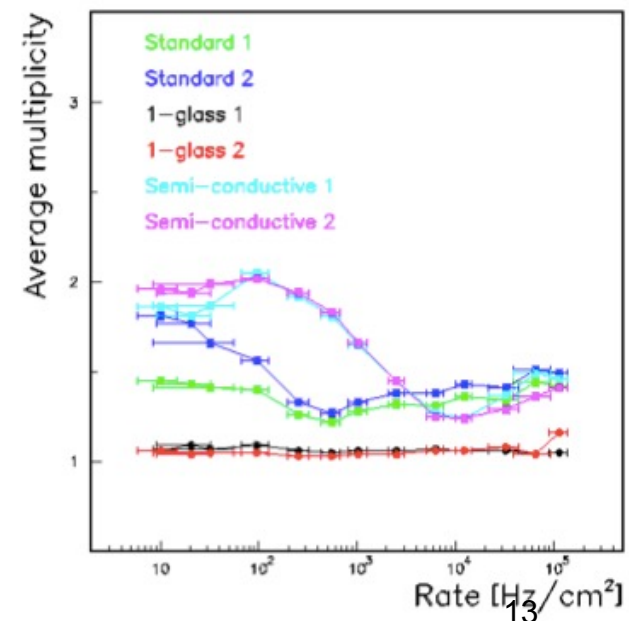
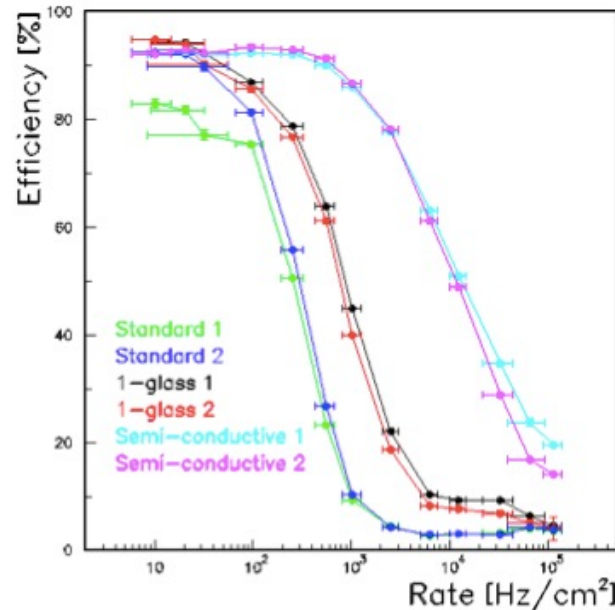
Resistivity tunable!



Tests were also done with commercial semi-conductive glass

Large (32 cm x 48 cm) 1-glass RPCs were made at Argonne and tested with cosmic rays and with particle beams.

Many advantages over 2-glass RPCs (higher rate capability, better position resolution, etc.)



Development of Hybrid RPCs

Probing a hybrid readout where part of the electron multiplication is transferred to a thin film of high secondary emission yield material coated on the readout pad with the purpose of reducing/removing gas flow and enabling the utilization of alternative gases.

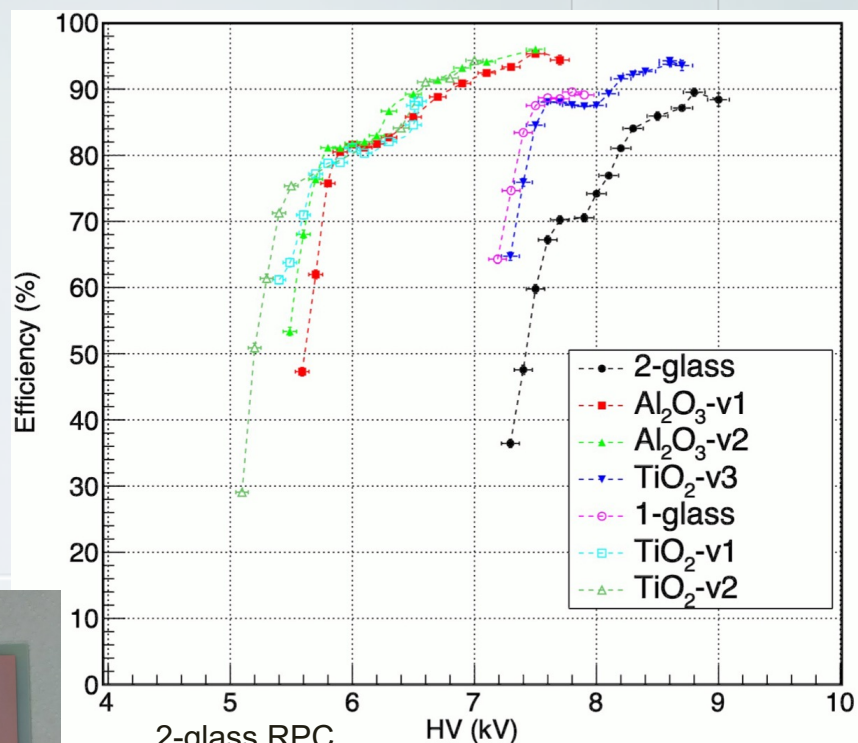
Built several 10 cm x 10 cm chambers with single pad readout.

Coating of Al_2O_3 made with magnetron sputtering.

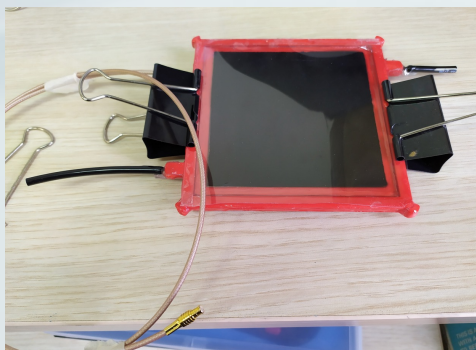
Coating of TiO_2 made with airbrushing after dissolving TiO_2 in ethanol.

RPCs obtain high efficiency at considerably lower high voltage settings.

➔ RPCs with functional anodes



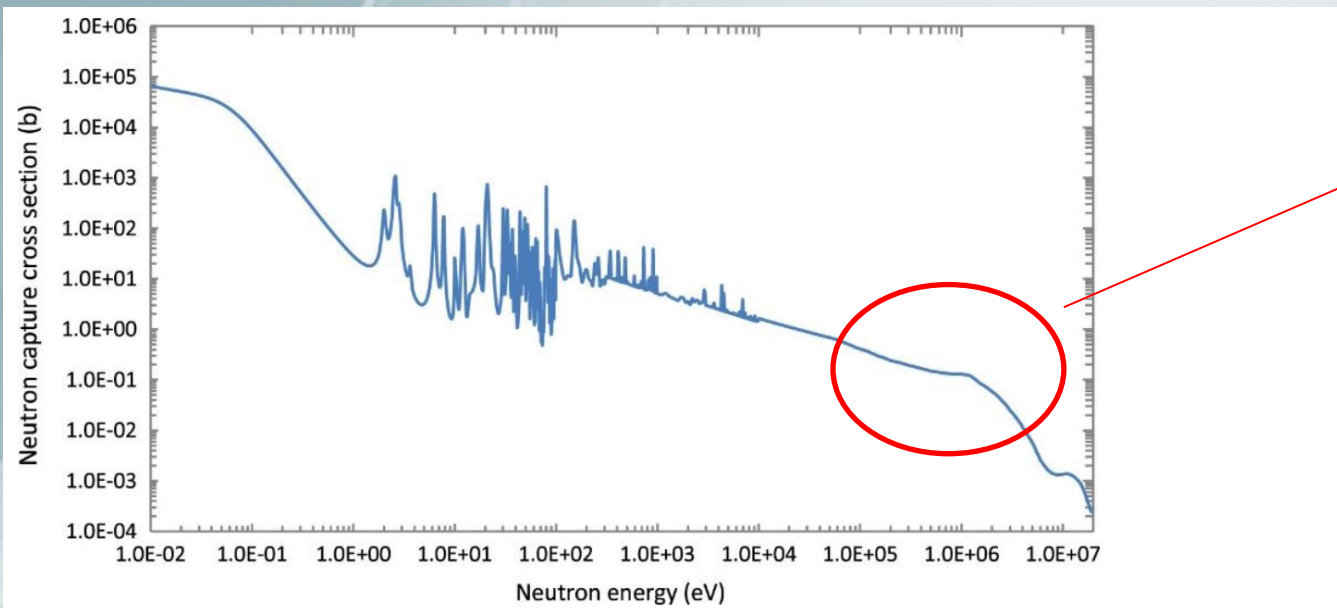
2-glass RPC
1-glass RPC
500 nm Al_2O_3 (v1)
350 nm Al_2O_3 (v2)
1 mg/cm² TiO_2 (v1)
0.5 mg/cm² TiO_2 (v2)
0.15 mg/cm² TiO_2 (v3)



Next Steps for ADRIANO3

→ RPCs with functional cathodes

Dope the cathode glass of one-glass RPCs with Gd to introduce the neutron capture functionality.



Region of
interest for
hadron
calorimetry

Fig. 2. Capture cross section as a function of neutron energy for natural Gd (IRDFF-1.0).

J. Dumazert et. al., "Gadolinium for neutron detection in current nuclear instrumentation research: A review", Nucl. Instrum. And Meth. A 882, 53, 2018.

Several R&D points to probe

Conclusions

- ❑ The ADRIANO3 **triple-readout** calorimeter technique has been proposed **for the first time**
- ❑ Gd-doped RPC glass is going to be explored
- ❑ High-granularity, triple-readout, and fast timing will benefit future experiments
- ❑ Experience and know-how of T1041 and T1604 are being merged; new funds are necessary for the full exploitation of the initial validation of the concept

Backup

RDC9 White Paper Signatories

- **ANL**
 - J. Elam, A. Mane, M. Zurek
- **Beykent University**
 - B. Bilki, M. Tosun
- **Fairfield University**
 - D. Winn
- **International Center for Elementary Particle Physics (ICEPP), The University of Tokyo**
 - W. Ootani
- **NIU**
 - C. Gatto, G.C. Blazey, S. Dyshkant, T.R. Fletcher, M.S. Figora, K. Francis, V. Zutshi
- **Fermilab**
 - V. Di Benedetto, J. Freeman, J. Hirschauer , S. Los , A. Mazzacane, D. Noonan, N.J. Pastika, E. Ramberg, M. Syphers
- **Shinshu University**
 - T. Takeshita
- **University of Iowa**
 - B. Bilki, Y. Onel, J. Wetzel, P. Debbin, M.I Miller
- **University of Kansas**
 - M. Murray, C. LeMahieu, J.D. Marquez, C. Royon, R.W. Young
- **University of Virginia**
 - D. Keller, J. Roberts, D. Seay

Distribution of Tasks and Overlap with Other RDCs

- Lead glass R&D, procurement and tests – Northern Illinois University - (RDC2)
- Scintillator R&D, procurement and tests – Northern Illinois University - (RDC2)
- Gd-doped glass development – University of Iowa (in collaboration with COE College)
- RPC R&D, construction and testing of RPCs with new glasses – University of Iowa – (RDC6)
- Development of readout electronics – Fermilab – (RDC4, RDC11)
- Detector integration and prototype construction – Northern Illinois University, University of Kansas – (RDC10)
- Beam tests coordination – University of Iowa, Fairfield University
- Design of the aFEE - collaboration with CERN's DRD6 and the *Laboratoire OMEGA Ecole Polytechnique-CNRS/IN2P3*.
- Design of dFEE - collaboration with Fermilab's Microelectronics Division.
- Data analysis and simulations – University of Iowa, Northern Illinois University, University of Virginia

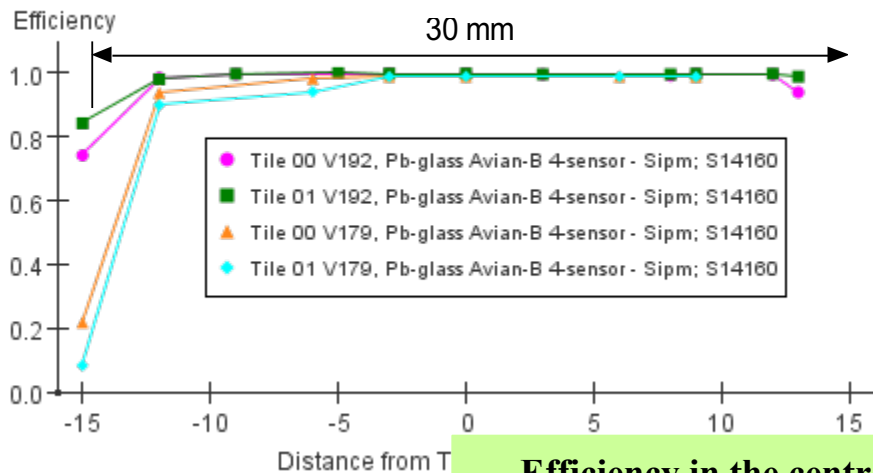
Projected Timeline

- Year 1: Construction of a small-scale prototype with lead-glass, scintillator and conventional/hybrid RPC components to validate the integration; start the R&D on Gd-doped glasses; start the R&D on electronics
- Year 2: System tests for the lead-glass + scintillator + electronics; tests of the RPCs with the new glasses
- Year 3: Integration of all the components to construct a small prototype with full ADRIANO3 functionality. Evaluation of design options for a dFEE ASIC via an FPGA-based prototype.
- Year 4: Performance projections for a collider size detector based on the outcomes of the beam tests. Test of the FEE ASIC chain.

4-sipm/tile vs 1-sipm/tile performance

Efficiency vs position 4-sipm

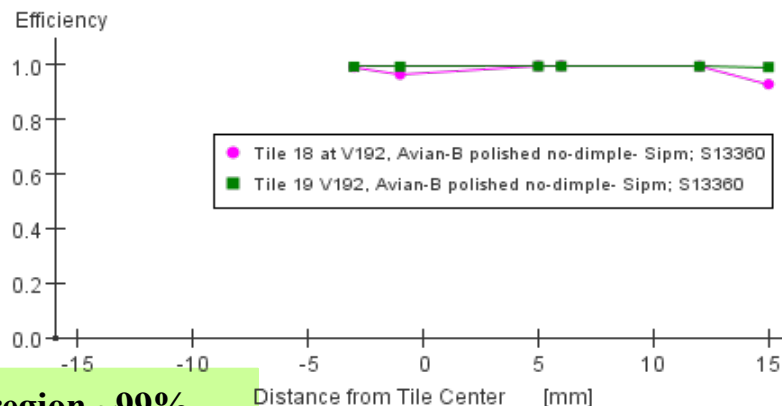
Efficiency vs Position 4-SiPM



Efficiency vs position 1-sipm

30 mm

Efficiency vs Position 1-SiPM

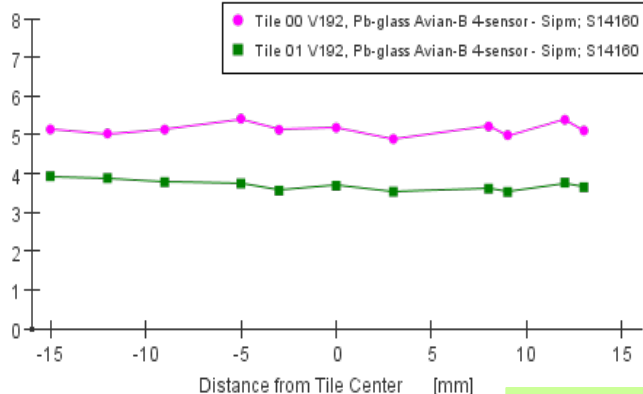


Efficiency in the central region ~99%
It starts dropping ~2 mm from tile edge

Light Yield vs position 4-sipm

pe/MeV

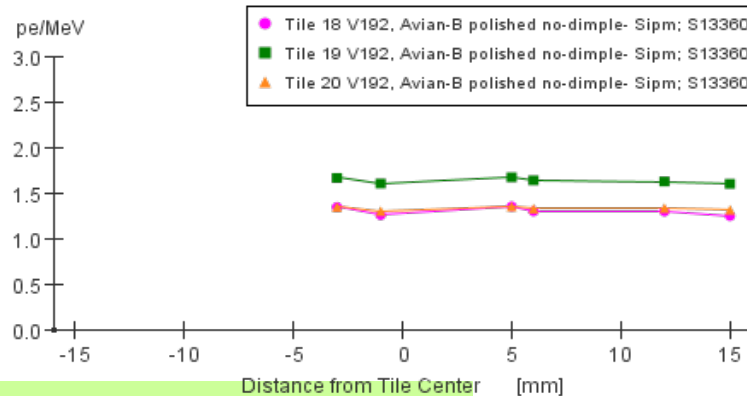
Light Yield vs Position 4-SiPM, pe/MeV



Light Yield vs position 1-sipm

pe/MeV

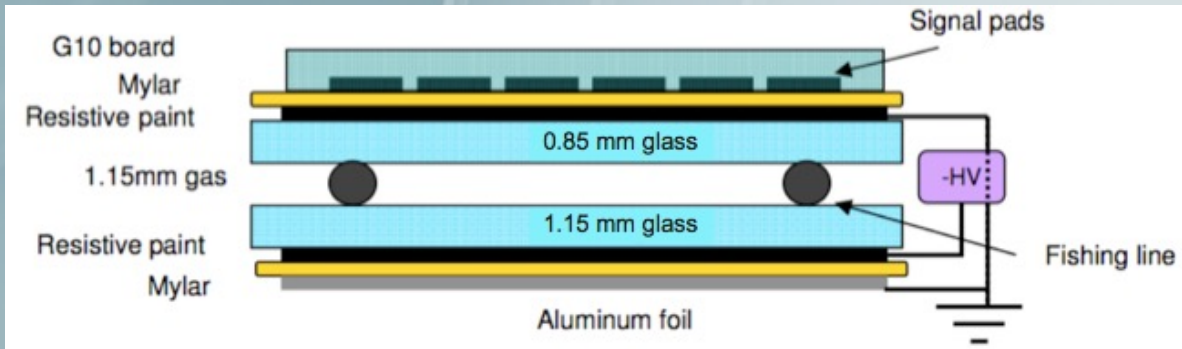
Light Yield vs Position 1-SiPM, pe/MeV



4-sipm L.Y. ~ 3x 1-sipm

Z. Sheemanto

Two-glass RPCs



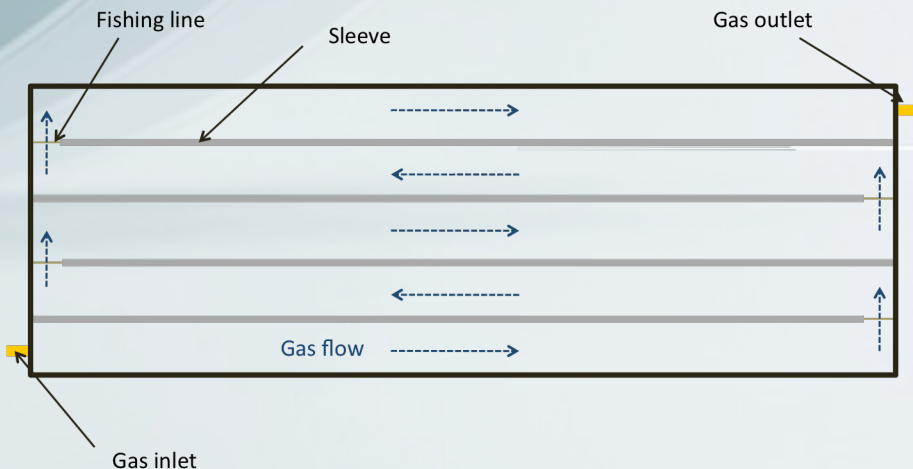
Gas: Tetrafluorethane (R134A) : Isobutane : Sulfurhexafluoride (SF_6) with the following ratios 94.5 : 5.0 : 0.5

High Voltage: 6.3 kV (nominal)

Average efficiency: 96 %

Average pad multiplicity: 1.6

Gap size and gas flow uniformity is maintained via fishing line channels



1-glass RPCs

Offers many advantages

Pad multiplicity close to one

→ easier to calibrate

Better position resolution

→ if smaller pads are desired

Thinner

→ $t = t_{\text{chamber}} + t_{\text{readout}} = 2.4 + \sim 1.5 \text{ mm}$

→ saves on cost

Higher rate capability

→ roughly a factor of 2

Status

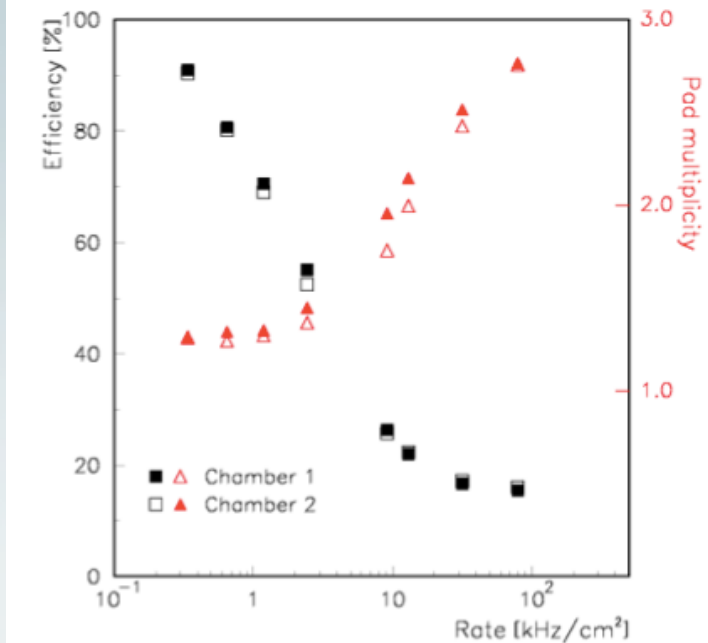
Built several large chambers

Tests with cosmic rays very successful

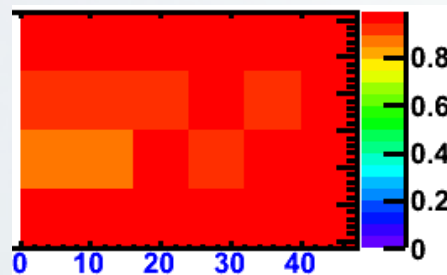
→ chambers ran for months without problems

Both efficiency and pad multiplicity look good

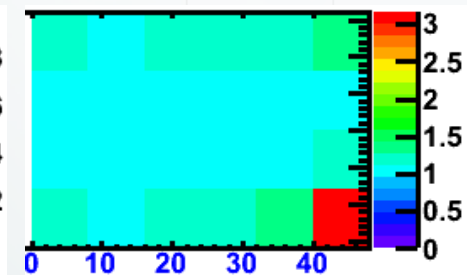
Good performance in the test beam



Efficiency

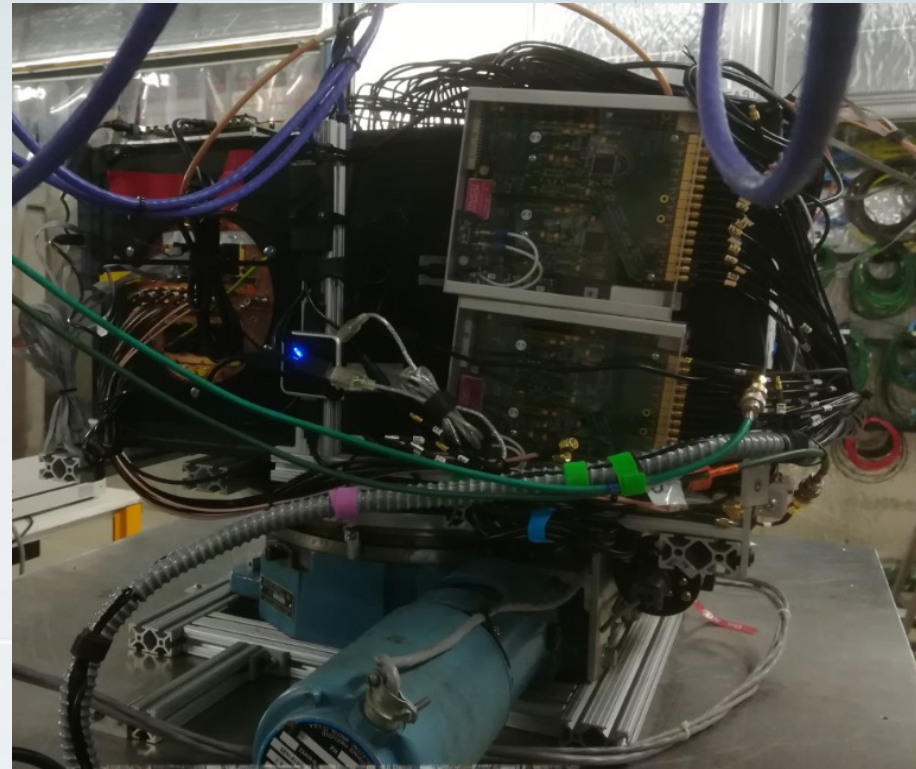


Pad multiplicity



ADRIANO2 R&D in T1604 Collaboration

- Currently in the beam at Fermilab: 7 layer, $\sim 5X_0$, 64 cells prototype, with Samic & petiroc readout (CAEN DT5550W)



xG. Blazey, A. Dychkant, M. Figora, T. Fletcher, C. Gatto, K. Francis, A. Liu, S. Los, M. Murray, E. Ramberg, C. Royon, M. Syphers, R. Young, V. Zutshi, C. Le Mahieu, J. Marquez, A. Mane, J. Elam, Z. Sheemanto

ANL, FNAL, KU, NIU, INFN, ETL

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