OAK RIDGE National Laboratory

Instrumentation at ORNL highlight: Photon-to Digital readout development for light detection

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ORNL is managed by UT-Battelle, LLC for the US Department of Energy

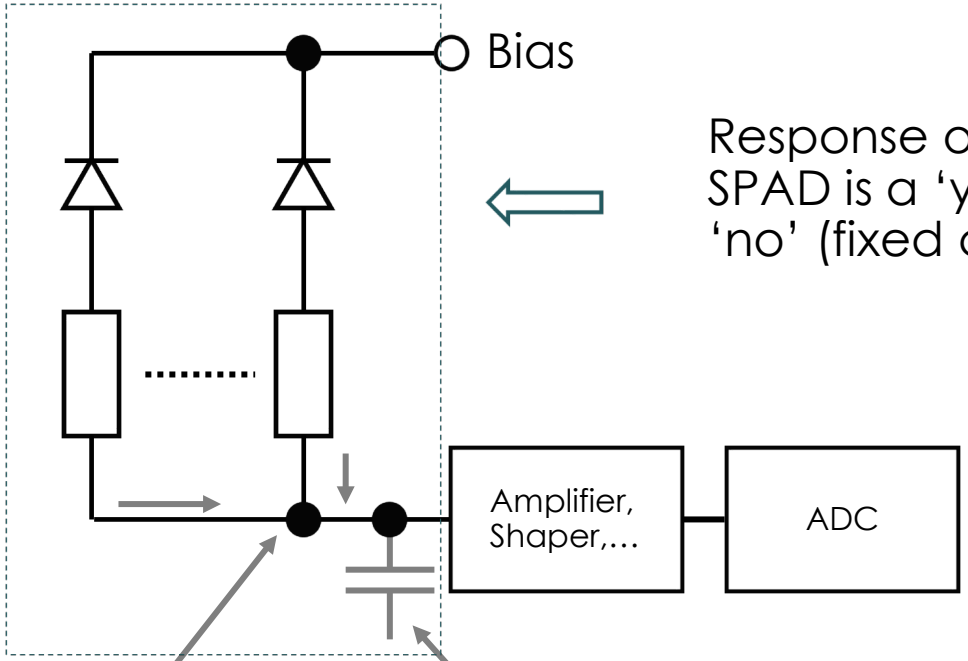
U.S. DEPARTMENT OF ENERGY

UNIVERSITÉ DE SHERBROOKE

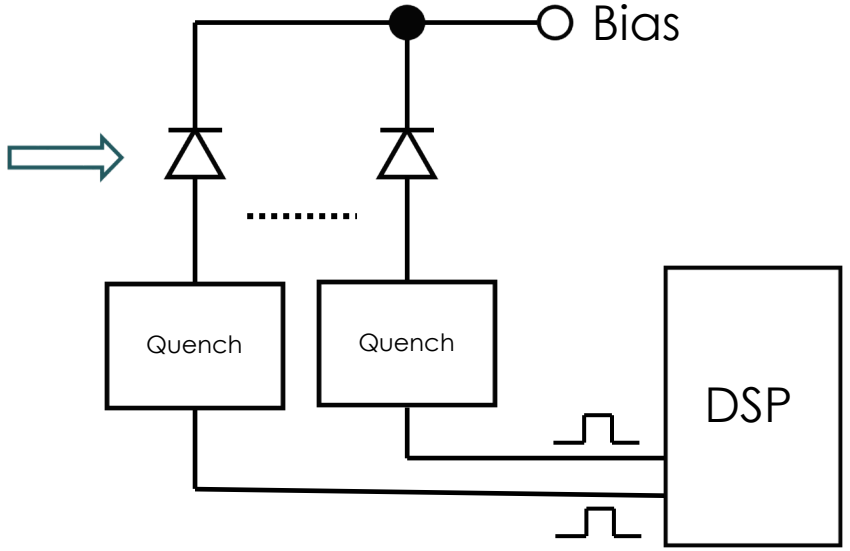
Instrumentation highlight

- Most institutions have state-of-the-art instrumentation research and facilities of some kind
- Highlighting a relevant effort may be more efficient in a limited time
- I believe this is an important R&D instrumentation program with a potential high-impact across the community.
- The idea is to build fully-digital, high-gain photon-to-digital converter systems.
- Collaboration with the Université de Sherbrooke.

From analog SiPM to PDC



Response of the SPAD is a ‘yes’ or ‘no’ (fixed charge



Analog current sum

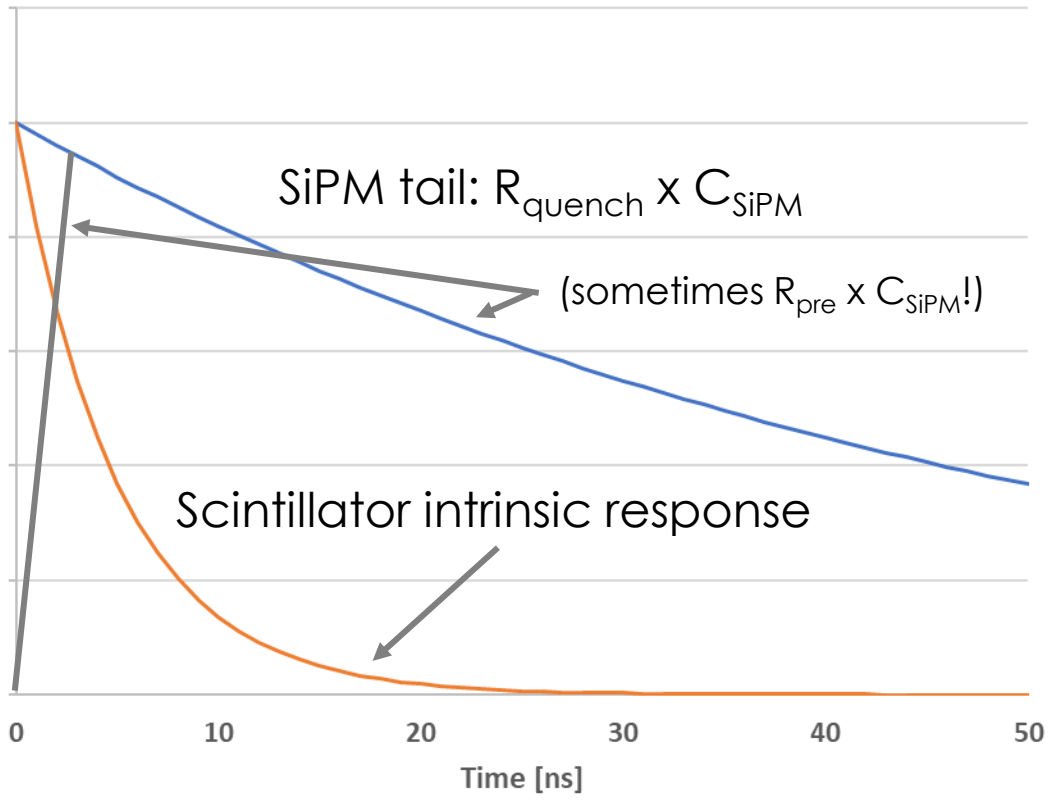
SiPM capacitance (=electronic noise)

The amplifier transforms charge into voltage and then BACK to digital

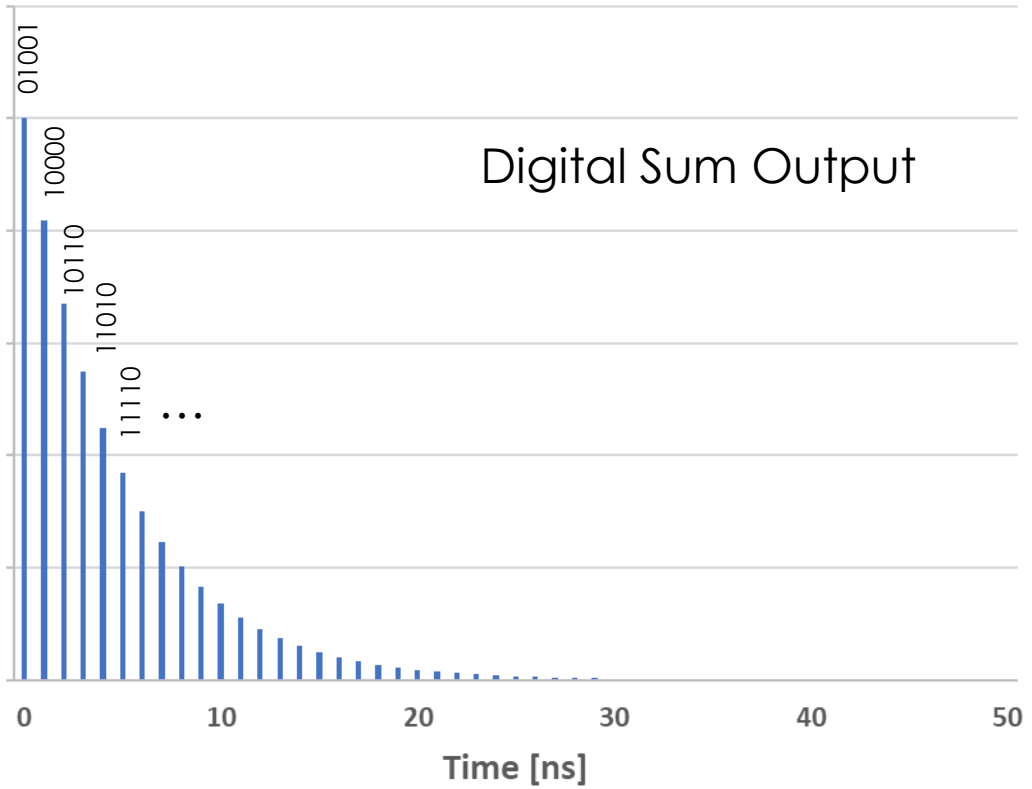
No D/A conversion. Everything stays digital

System Response has no signal integrity issues

SiPM



PDC



Advantages

- Each SPAD has its own readout
  - Full control over each SPAD means improved efficiency and dead time management
    - Faulty SPAD can be turned off
    - Dark count effects can be mitigated via special coincidence algorithms
  - Always as good as single-photon timing
- No triggers = no power
- Never deal with output capacitance of SPADs.
  - Highest achievable SNR
  - No extra power needed in front-end when reading large areas
  - Signal integrity untouched by readout
- Extremely low power (watts/1000 cm^2) and very fast (tens ps) timing possible

Research at ORNL

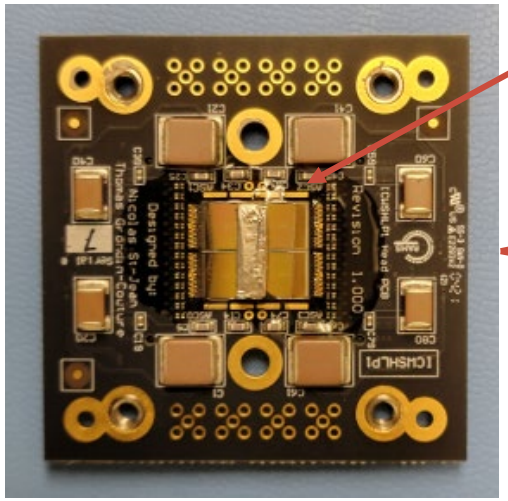
- The concept has been pursued by Philips for medical imaging applications
  - Not good at sharing
  - Not really 3D
- ORNL and UdeS R&D program targets many scientific fields (NNSA, NP, HEP)
  - Shared research
  - A path that is as versatile as possible: make devices that the community can just purchase.

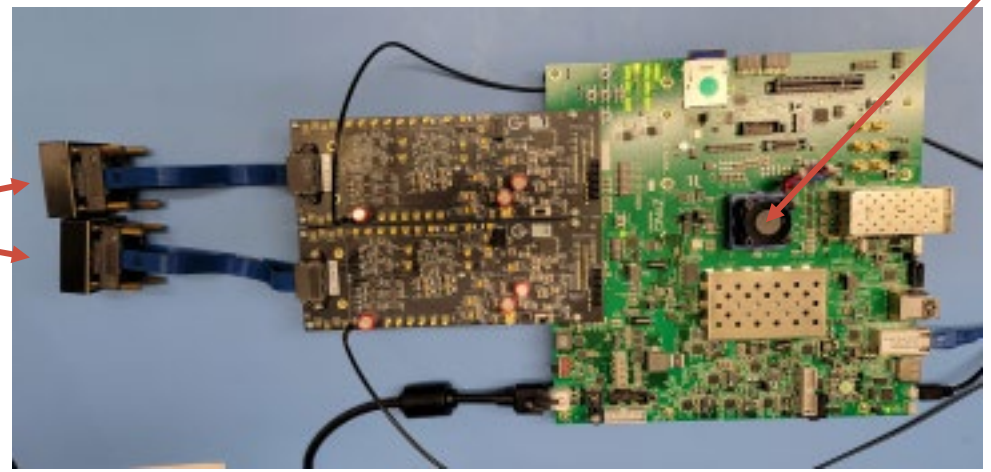
PDC Program

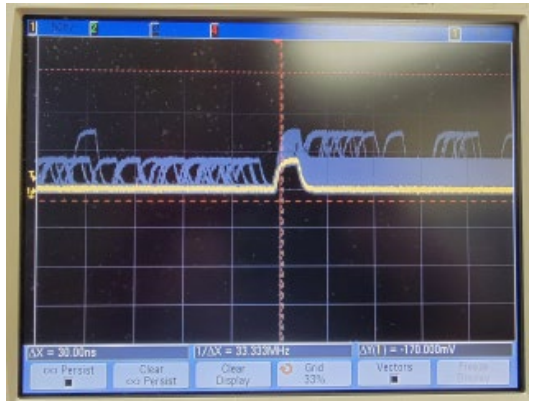
- To build a 3D-integrated PDC device that can be used in any application where light detection from any area size and light detector, with low power, high sensitivity is needed.
- Presently, we are demonstrating functionality of a 1D array of 61 SPADs coupled to 2D readout electronics (4096 SPAD readout)

PDC “pilot” project (NA-22)

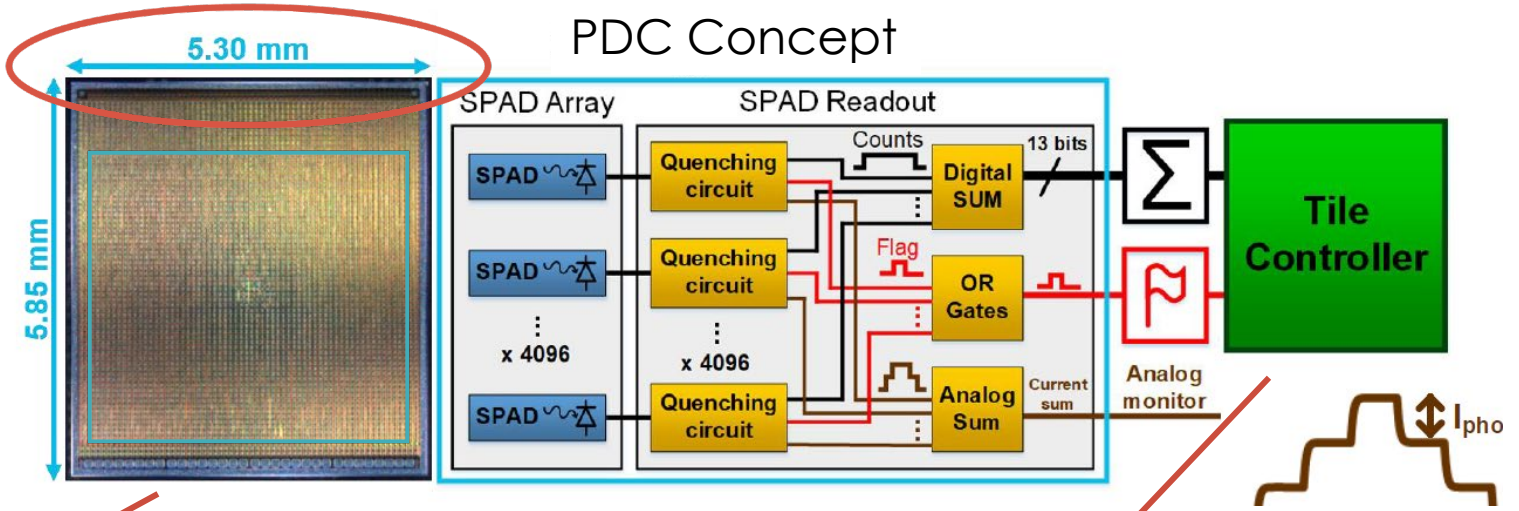
- 4096 readout channels ASIC with integrated row of 61 SPADs







PDC Concept



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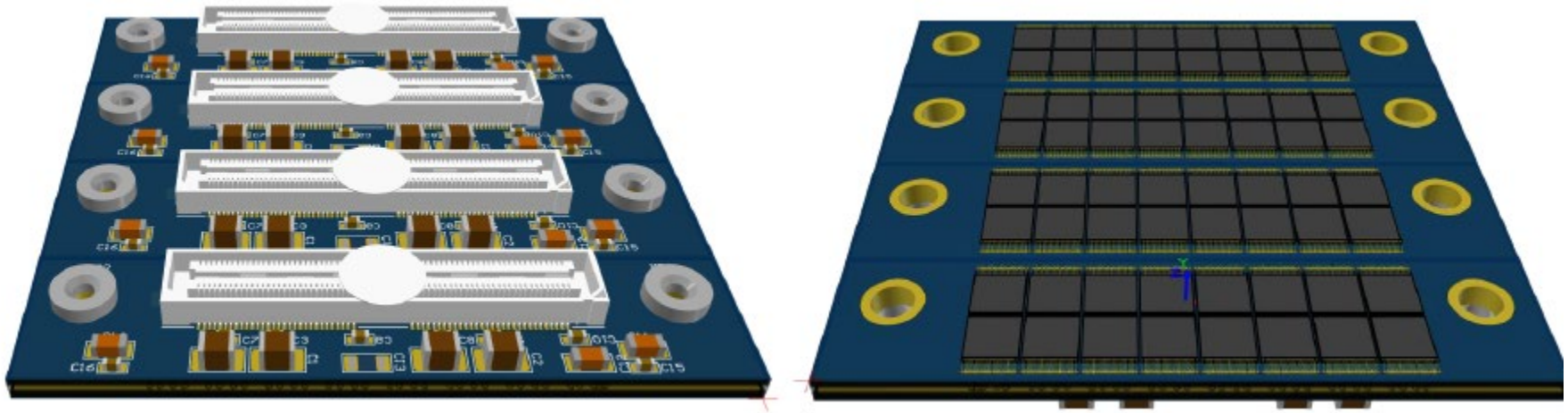
Deliverable

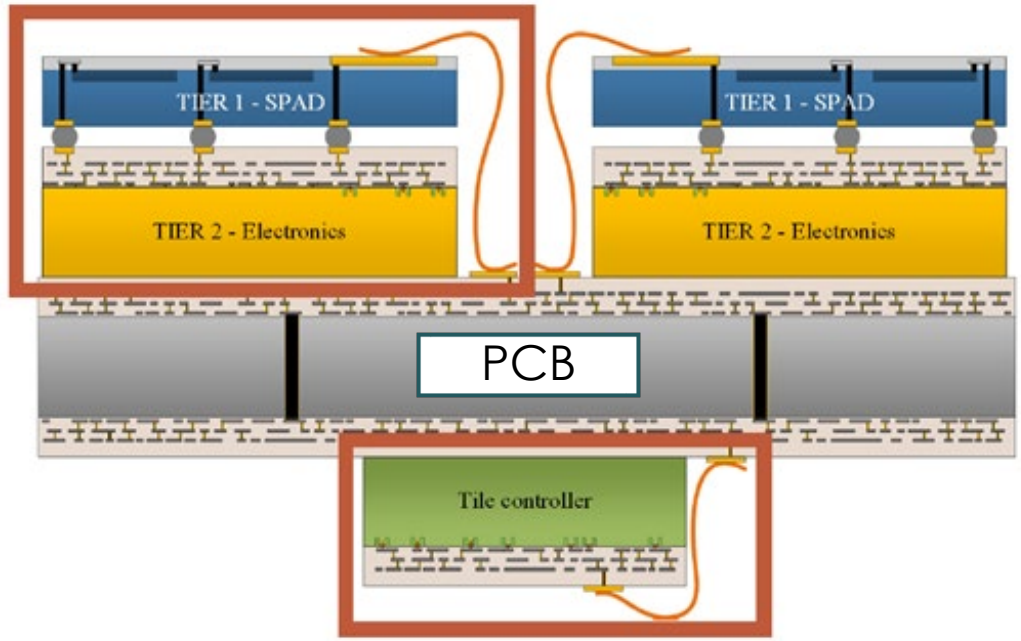
- Full 8x8 PDC tile (~50 x 50 mm) with FPGA tile controllers by end of FY22.



- Working on light detection with scintillator, designing ~170 ps TDC for timing resolution, ASIC tile controller.

Next steps

- The ultimate goal is to have 2D PDC arrays, 3D-connected to 2D readout electronics (3D integration). This is major effort that requires major investments.



Interested parties

- DOE-HEP has interest in our technology and has shown intent of funding 3D integration through its microelectronics portfolio.
- A follow-on effort with NA-22 will leverage an HEP-funded effort to
  - Co-develop 3D integration
  - Improve fill factor
  - Produce tile-able modules based on their 8x8 tile
- Interest from NP may open new funding avenues for high VUV sensitivity for liquified noble gases-based experiments (nEXO, DUNE, etc.)

Team (ORNL)

- Lorenzo Fabris, PI. ORNL Physics Division.

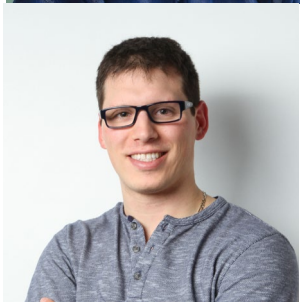
- Paul Hausladen. Project Scientist

Team (UdeS)

- Jean-François Pratte, UdeS PI,

- Serge Charlebois, UdeS co-PI

- Tommy Rossignol, UdeS CMOS circuit designer for SPAD readout. Firmware designer for tile controller (FPGA and ASIC full custom) for PDC readout.



- Nicolas Roy, UdeS CMOS circuit designer for SPAD readout. TDC and multilayers printed circuit board design for the tile controller. Procurement and local project management.