Data Processing Electronics for Silicon Photomultipliers

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Outline

- The company and its capabilities.
- Customers.
- Products.
- Description of the Phase II project.
- Relevance to the NP program.
  - Our products are used at Fermilab, Oak Ridge, Los Alamos, MSU-NSCL, LZ Dark Matter Search. All these were funded by the DOE.
- Deliverables.
- Plans.
- Questions for the NP community.

The Company and Its Capabilities

- The team has grown over the last year. We hired two physicists and two software engineers (one of them part time).
- We also worked with several interns listed on the Acknowledgement page.

Our focus:

Data acquisition (DAQ) for nuclear physics, high energy physics, and particle astrophysics.

We use digital techniques to acquire and process signals from nuclear radiation detectors.

Our capabilities:

- Electronic design.
- Firmware development for Field Programmable Gate Arrays (FPGA).
- Software development for embedded processors, especially Embedded Linux.
- Algorithms for pulse processing.
- Algorithm implementation in the FPGA (VHDL, Verilog) and in embedded processors (python, C).
- Processing data from nuclear detectors of any kind.
- Development of detector assemblies using scintillators, PMTs, or SiPMs.

Our Customers

University of Rochester

Los Alamos National Laboratory

Fermilab

Houghton College

Wiener Plein & Baus, Corp.

The University of Tennessee Knoxville

Albert Einstein Center for Fundamental Physics

Universität Bern

SFU Simon Fraser University Engaging the World

Shanghai Jiao Tong University

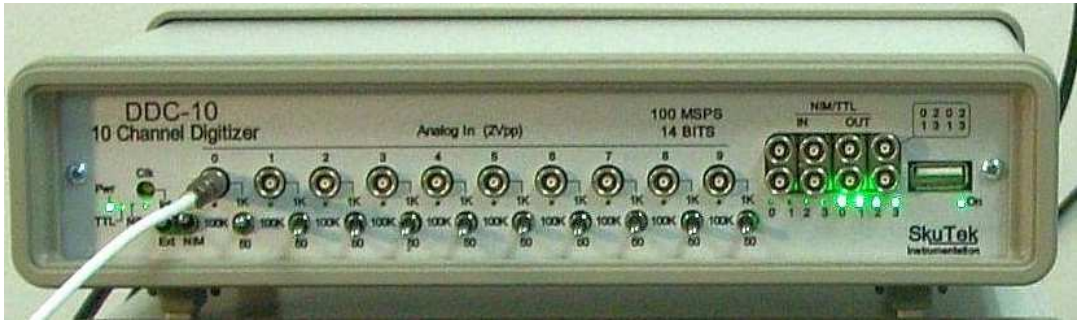
Université Laval

NSCL National Superconducting Cyclotron Laboratory

Augustana University

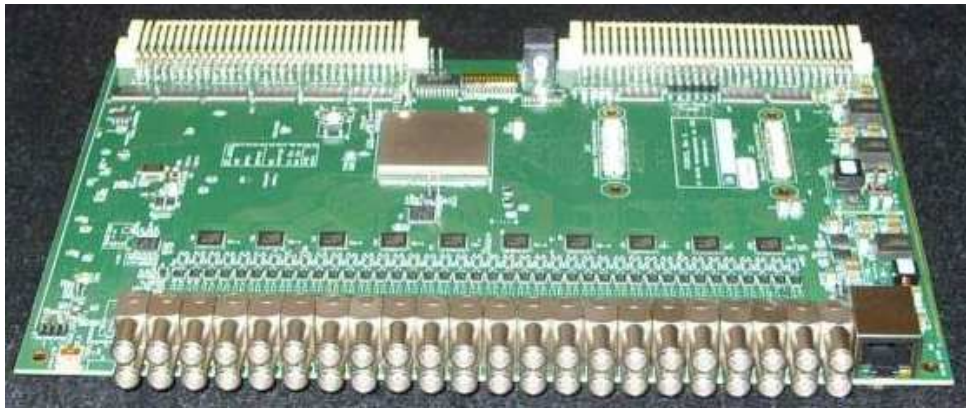
Our Products: VME Modules and Table Top Units

Standalone networked digitizer (10 channels)



Low cost networked digitizer (2 channels)

VME digitizer: 40 channels



VME trigger module

Description of Phase II Project

Problem or situation that is being addressed.

In Nuclear Physics there is need for circuits (including firmware) and systems, for rapidly processing data from particle detectors such as gas detectors, scintillation counters, silicon drift chambers, silicon pixel and strip detectors, or silicon photomultipliers (SiPMs).

How this problem or situation is being addressed.

We are developing high-performance data acquisition electronics performing the SiPM readout. The electronics can be used either standalone, or as parts of large data acquisition systems.

The deliverables.

- The products will range from small table-top units to systems with a large number of channels.
- The table top units will serve small NP experiments, radiation detector development, or student labs teaching Nuclear Physics.
- Larger systems will serve experiments conducted at DOE facilities, e.g., Facility for Rare Isotope Beams (FRIB), which is a new national user facility for Nuclear Physics.

Phase II Accomplishments

- We developed a unified Platform approach to all our products. The Platform consists of a Single Board Computer (SBC), the FPGA firmware framework, and embedded software.
- Advanced the MicroBone Single Board Computer (SBC) which we developed earlier.
- Modified and streamlined the design of our Phase I FemtoDAQ miniature digital DAQ system.
- Developed two kinds of SiPM Carrier Boards.
- Our SiPM carrier boards were used by pilot customers: University of Tennessee at Knoxville and MSU - NSCL.
- Published a paper [1] describing FemtoDAQ silicon photomultiplier applications.
- Recently we ported the GUI and communication software from SSH to ZeroMQ.
- Improved the GUI.

1) W.Skulski, A.Ruben, S.BenZvi: *FemtoDAQ: A Low-Cost Digitizer for SiPM-Based Detector Studies and its Application to the HAWC Detector Upgrade*. IEEE Trans. on Nuc. Sci. 64, Issue: 7, July 2017. Page 1677.

Phase II Accomplishments

- We upgraded the communication protocol from SSH to ZeroMQ:
  - 8-fold increase of communication speed.
  - Several ZeroMQ communication topologies will enable building instrumentation clusters:
    - Point to point.
    - Broadcast.
    - Subscribe / receive.
  - ZeroMQ can be used for an instrument - agnostic communication infrastructure.
    - Under consideration at MSU - NSCL. (Ron Fox, LECM 2017 DAQ Workgroup.)
    - Recommended by CERN.

  - What is ZeroMQ? ZeroMQ is a networking library for exchanging messages among clusters, the cloud, and other multi-system environments.
  - Used by AT&T, Cisco, EA, Los Alamos Labs, NASA, Weta Digital, Zynga, Spotify, Samsung Electronics, Microsoft, and CERN. It is considered by MSU-NSCL (i.e., FRIB).
  - Programmer - friendly syntax. Easier than brute force TCP/IP programming.

Development of the FemtoDAQ Digitizer

- Completed several hardware iterations, removing minor design flaws and improving performance.
- Improved the GUI, communication software, and the firmware.
- Sold several units to pilot customers.
- Used at Univ. of Rochester, Houghton College, Simon Frazer Univ., Laval University.. (The list is growing!)
- We keep implementing the feedback from both the distributor Wiener USA and from the end users.

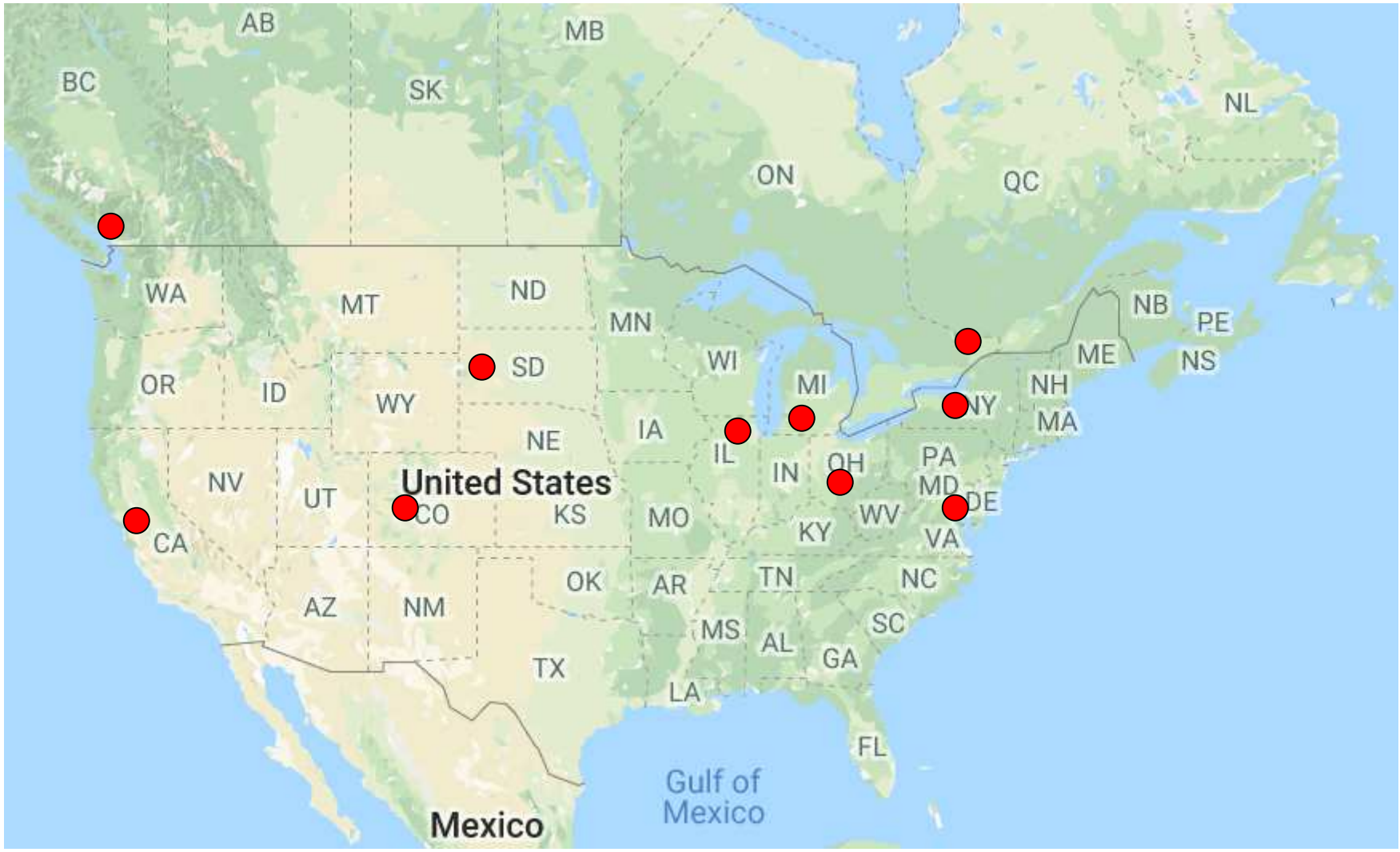
www.FemtoDAQ.com

Commercial BeagleBone Black

Bias Generator, 10V up to 90V

2-channel Digitizer: 14 bits, 100 MHz

FemtoDAQ Geography in North America

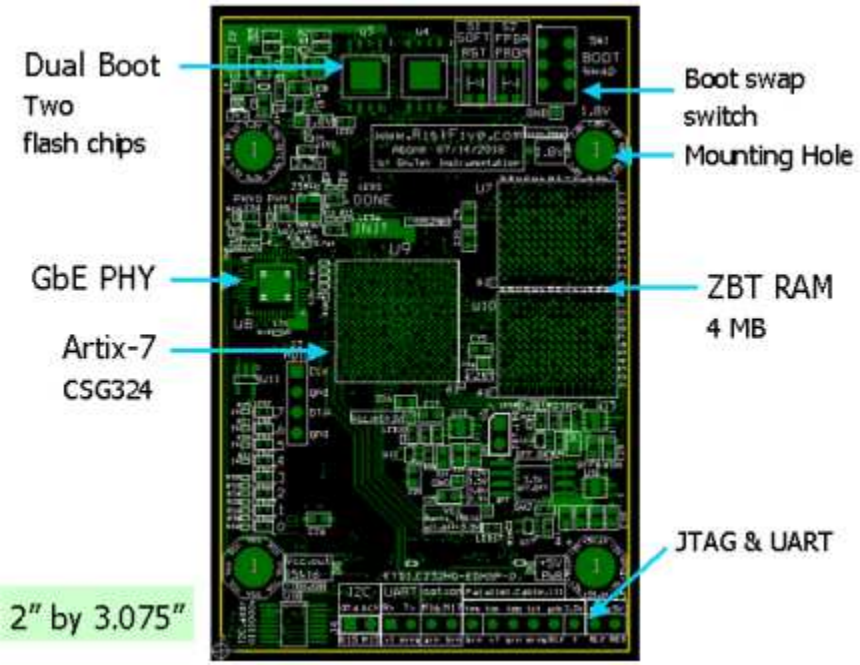


International sales: Germany and Israel

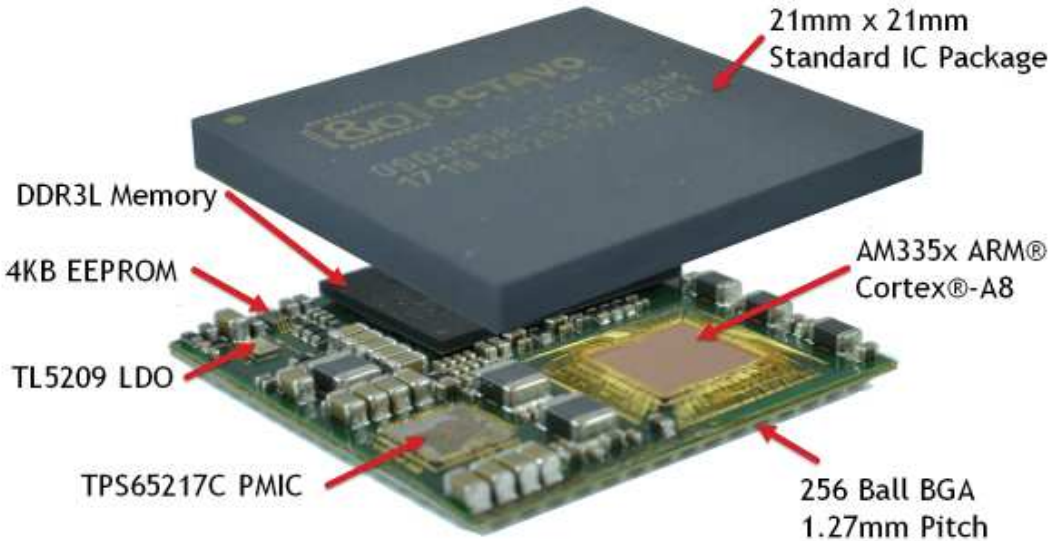
Future FemtoDAQ Design

- Replace the BeagleBone with the Octavo Systems hybrid chip OSD335x-SM.
- Simplify the design and remove the “good to have” features which proved inessential.
- Increase the waveform memory from 32 kB to 4 MB.
- Upgrade the FPGA to the Series-7 which is better compatible with our other projects.
- We developed the FPGA-On-Module (FOM) to make this task easier.
  - Visit the website RiskFive.com for details. You can use this FOM in your projects!

FOM: Artix-7 prototype with ZBT RAM
SkuTek design for Artix-7 development



Octavo Systems **OSD335x-SM** ($41)



The SiPM Carrier Boards

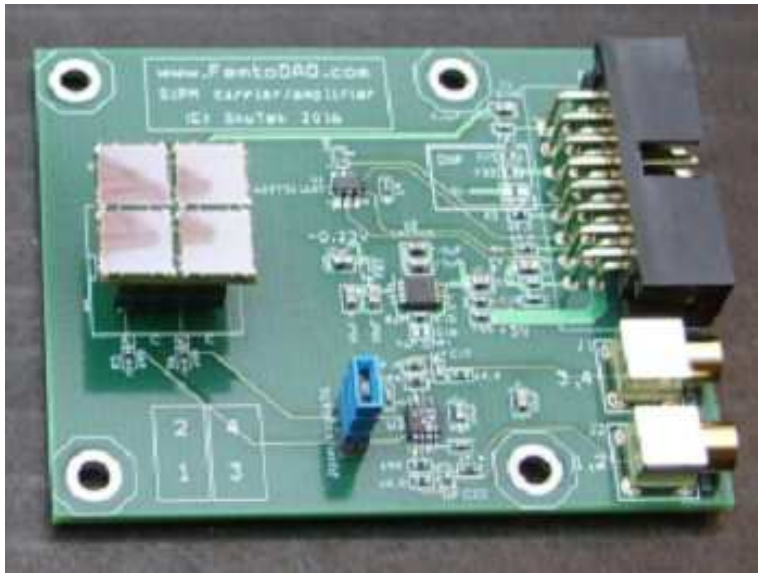
We developed two SiPM Carrier Boards to utilize the 6x6 mm SiPMs from SensL.

- Board A was used by Professor Segev BenZvi (Univ. of Rochester) for HAWC Trigger studies.
- Board B was used by Professor Robert Grzywacz in experiments at ORNL and MSU NSCL.

- Recently, more boards of each kind were purchased by MSU-NSCL.

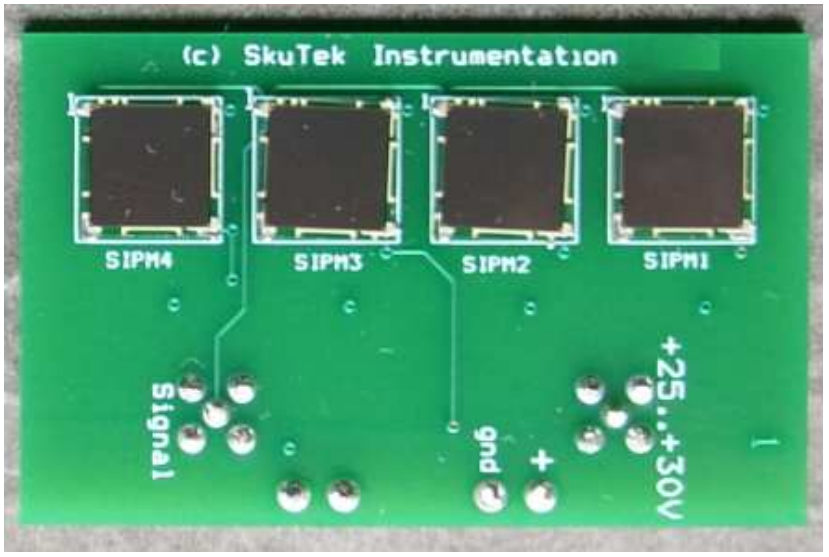
A

SiPM Carrier Board with amplification



B

SiPM Carrier Board w/o amplification

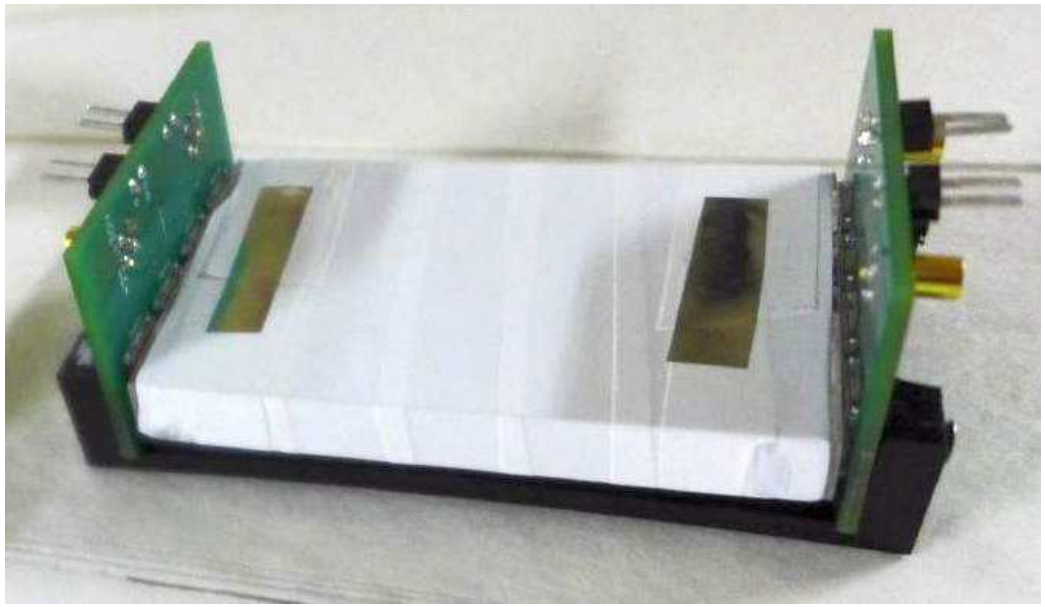


Customer Applications

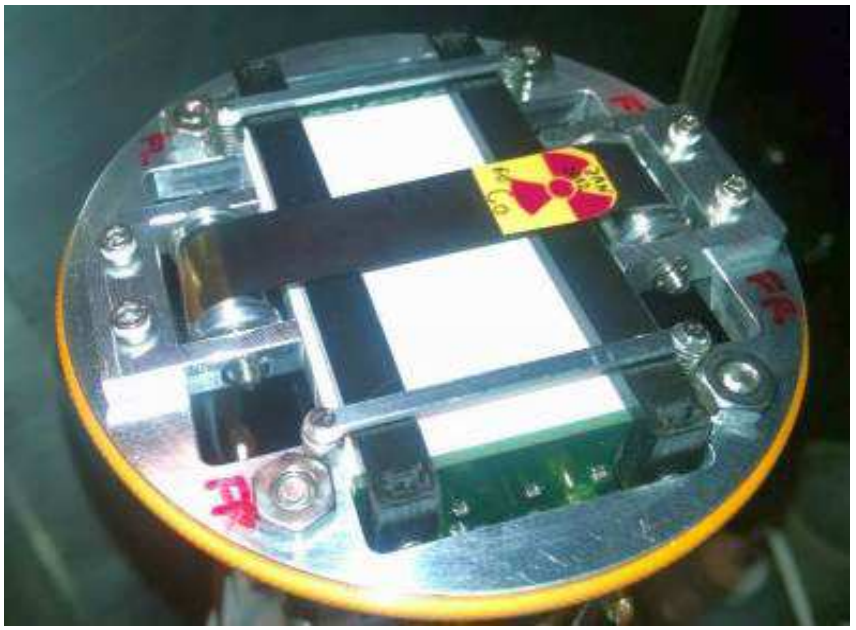
Board B was used by Professor Robert Grzywacz at ORNL and MSU NSCL. The group used a plastic scintillator and the SiPM arrays to measure beta particles and fast light ions.

Inspired by this success, MSU-NSCL ordered more such SiPM boards.

At ORNL the SiPM boards were used as a beta particle trigger for the VANDLE neutron array.



At NSCL the detector was used to measure light ion background in nuclear fragmentation.



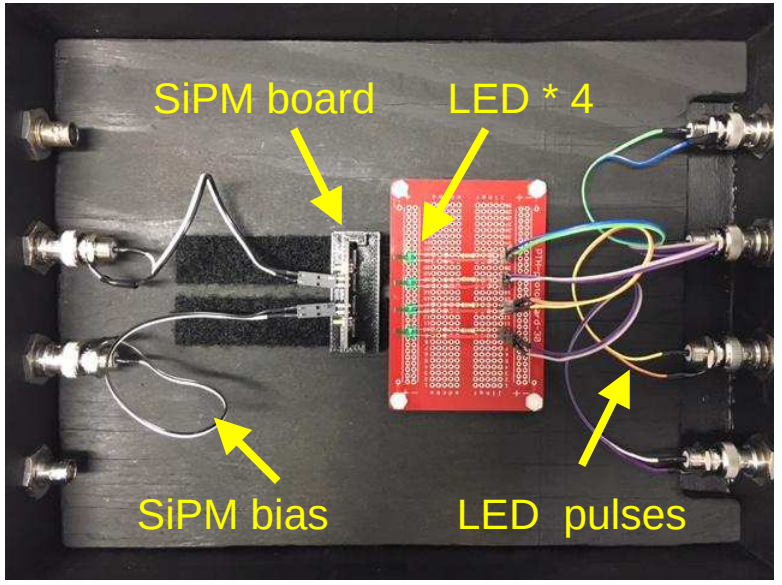
SiPM Test Box

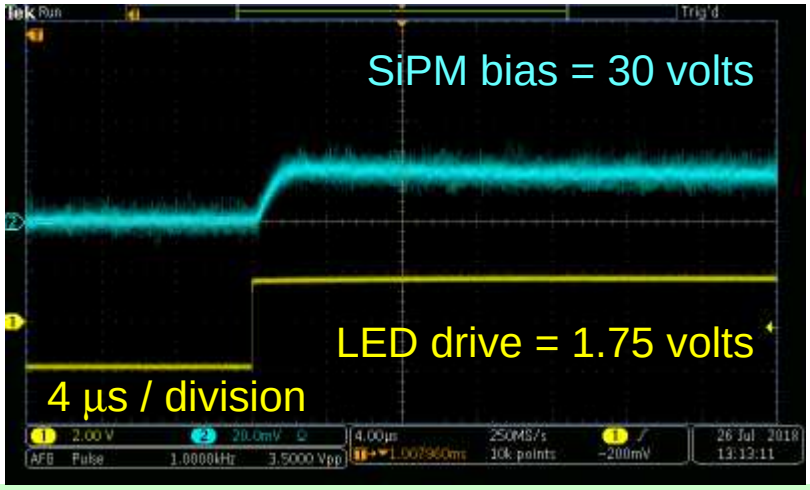
Our Summer intern Brian Kroetz developed a light - tight box for testing SiPMs.

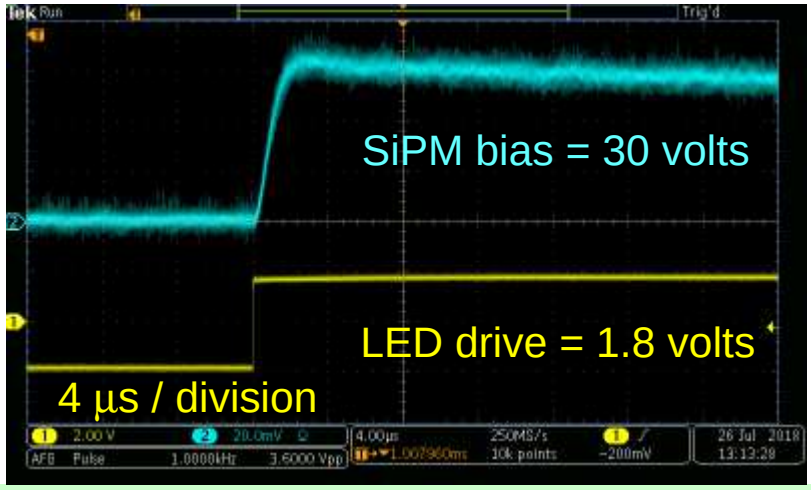
Wooden box from Target

Painted black, BNC mounted

Inside the box







Future Plans

- Develop a high density digitizer with 64 channels per unit.
  - This development has been delayed pending the completion of the 32-channel digitizer for LZ and the 40-channel digitizer for Nuclear Physics. We plan to share the digital portion of these digitizer across the entire product line.
- Add the SiPM bias output 10 V - 90 V to our 10-channel table top digitizer.
  - The design has been completed. The board production is pending.
- Develop more kinds of the SiPM Carrier Boards.
- Develop an SiPM “demonstrator” experiment for schools, small labs, and colleges.
  - The low cost light tight box will help achieve this goal.
- Engage students and interns in our work.
  - Four interns are listed on the Acknowledgements page.
- Solicit input and suggestions from the community. Extremely important…
  - Our new hire David Miller is attending the 2018 LEC Meeting at MSU-NSCL.

    www.phy.ornl.gov/fribdaq/ -- Workshops. Follow the last link on that page.

Questions for the NP community

- What kind of electronics do you need to efficiently utilize SiPM devices?
  - Digitizers, amplifier boards, shapers, etc.
- What kind of SiPM boards / modules do you need from us?
  - Modules with amplification provide better signals, but they need power.
  - “Passive” modules do not need power, but the signals will be weaker.

More information:

2-channel instrument: **FemtoDAQ.com**

Example application: **CosmicRayNet.net**

FPGA-On-Module: **RiskFive.com**

Acknowledgements

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Brian Kroetz.

Special thanks to Michelle Shinn and Manouchehr Farkhondeh

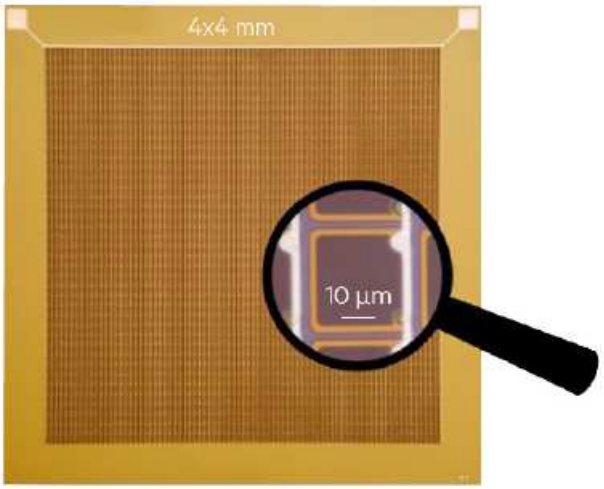
Backup slides

What Is the Silicon Photomultiplier (SiPM)?

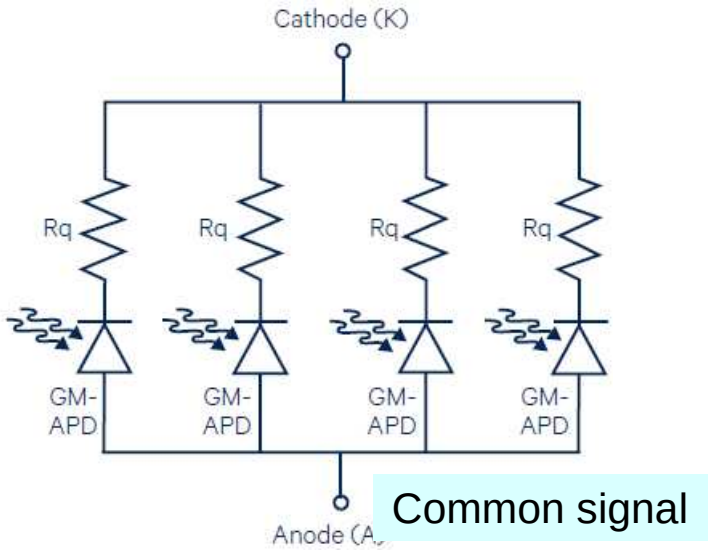
SiPM is an array of avalanche photodiodes (APD) operated in Geiger mode. Each APD cell is very small (~tens of μm). An impinging photon turns the APD “on”. The avalanche current causes a voltage drop in the quenching resistor Rq and the avalanche ends after a few nanoseconds.

- All cells add their currents together to a single output.
- The SiPM needs less than 100V to operate. (SensL devices need between 25 V and 30 V.)
- A typical amplification is a million, similar to a vacuum PMT.
- Dark pulse rate is very high, about 1 MHz from a typical device.

Schematic (from First Sensor)



Connect to +bias.



Common signal

Actual device (from KETEK)