Data Processing Electronics for Silicon Photomultipliers

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SkuTek Instrumentation
SkuTek.com

Outline

- The company and its capabilities.
- Customers.
- Products.
- Description of Phase II project.
- Deliverables.
- Plans.
  - Technical.
  - Non technical.
- Questions for the NP community.

The Company and Its Capabilities

We focus on data acquisition (DAQ) for nuclear physics, high energy physics, and particle astrophysics.

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

Our capabilities:

- Electronic design “top to bottom”: from the requirements, through schematic capture and board layout, all the way to prototyping, production, and support.
- Firmware development for Field Programmable Gate Arrays (FPGA).
- Algorithm implementation in the FPGA (VHDL, Verilog) and in embedded processors (python, C).
- Software development for embedded processors, with special focus on Embedded Linux.
- Algorithms for pulse processing.
- Development of nuclear radiation detector readout using vacuum or silicon photomultipliers.

Our Customers

- University of Rochester
- Houghton College
- The University of Tennessee Knoxville
- SFU Simon Fraser University — Engaging the World
- Université Laval
- Los Alamos National Laboratory
- Fermilab
- WIENER Plein & Baus, Corp. — Worldwide Industrial-electronic Nuclear-electronic Ressources
- Albert Einstein Center for Fundamental Physics — Universität Bern
- 上海交通大學 Shanghai Jiao Tong University

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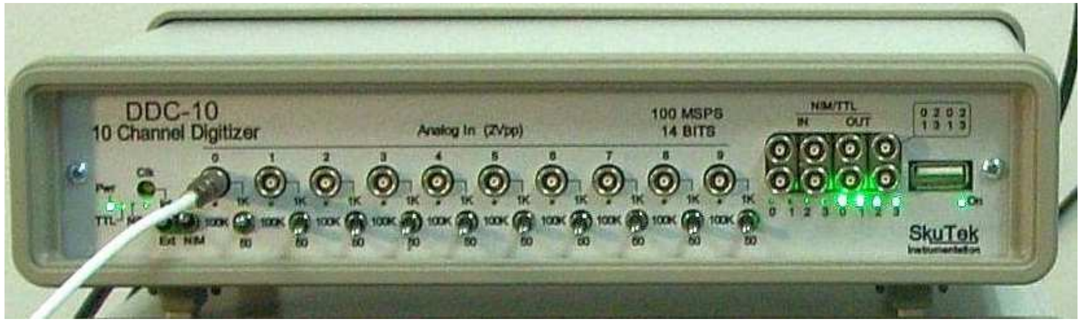
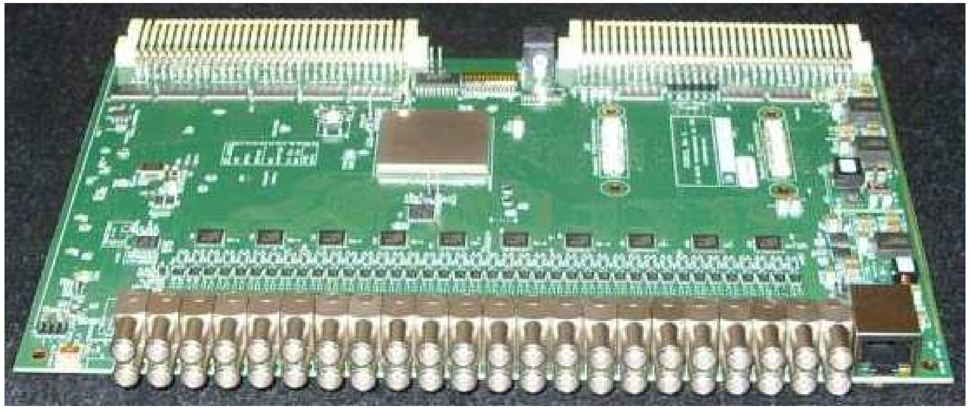
Our Products: VME Modules and Table Top Units

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 will develop 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 a small table-top units to systems with a larger 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 Year I Accomplishments

- We developed a unified Platform approach to all our products. The Platform consists of the digitizer hosting a Single Board Computer (either our MicroBone or the commercial BeagleBone), the FPGA firmware framework, and embedded software.
- Advanced the MicroBone Single Board Computer (SBC).
- Modified and streamlined the design of our FemtoDAQ miniature digital DAQ system.
- Developed two kinds of SiPM Carrier Board.
- Our SiPM carrier boards were used by pilot customers.
- Published a paper describing FemtoDAQ silicon photomultiplier applications.

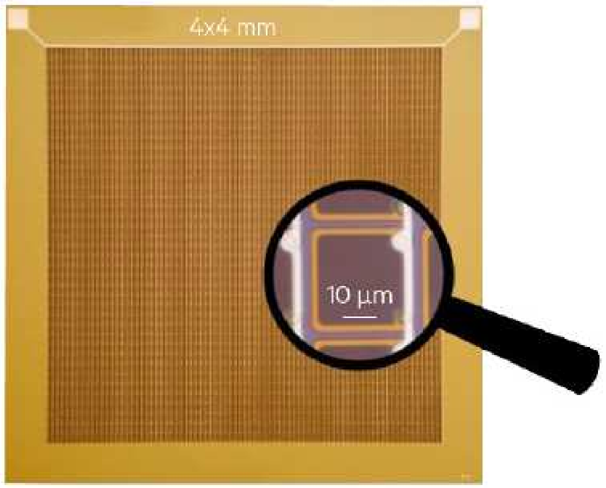
What Is the Silicon Photomultiplier (SiPM)?

<u>We do not make SiPMs</u>! We developed electronics for reading SiPMs. Let me explain what is SiPM.

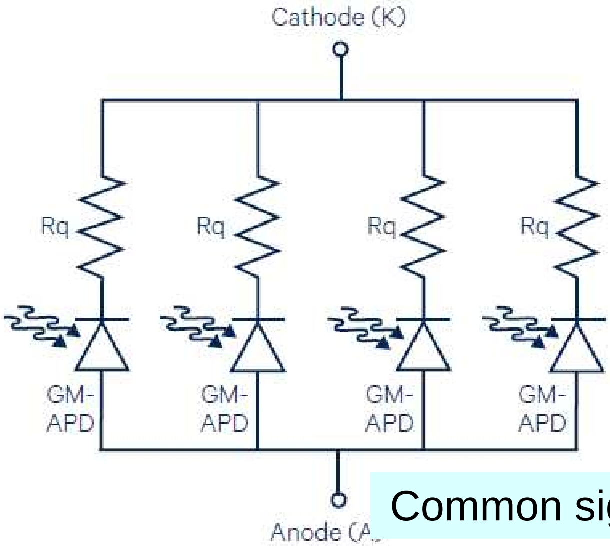
SiPM is an array of avalanche photodiodes (APD) operated in Geiger mode. Each APD cell is very small (~tens of μm). An impinging photon turns the APD “on”. The avalanche current causes a voltage drop in the quenching resistor Rq and the avalanche ends after a few nanoseconds.

- All cells add their currents together to a single output.
- The SiPM needs less than 100V to operate. (SensL devices need ~25V.)
- A typical amplification is a million, similar to a traditional phototube.
- Dark current pulse rate is very high, about 1 MHz from a few mm device.

Schematic (from First Sensor)

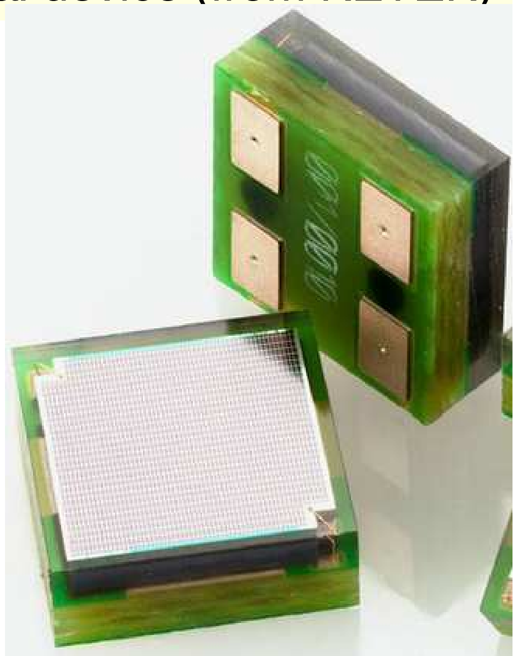


Connect to +bias.



Common signal

Actual device (from KETEK)

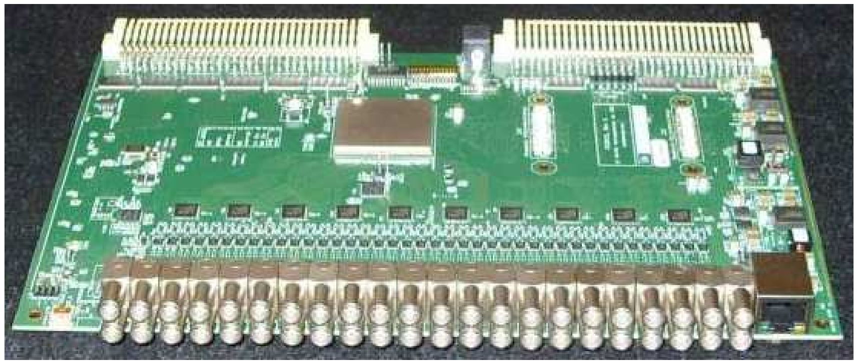


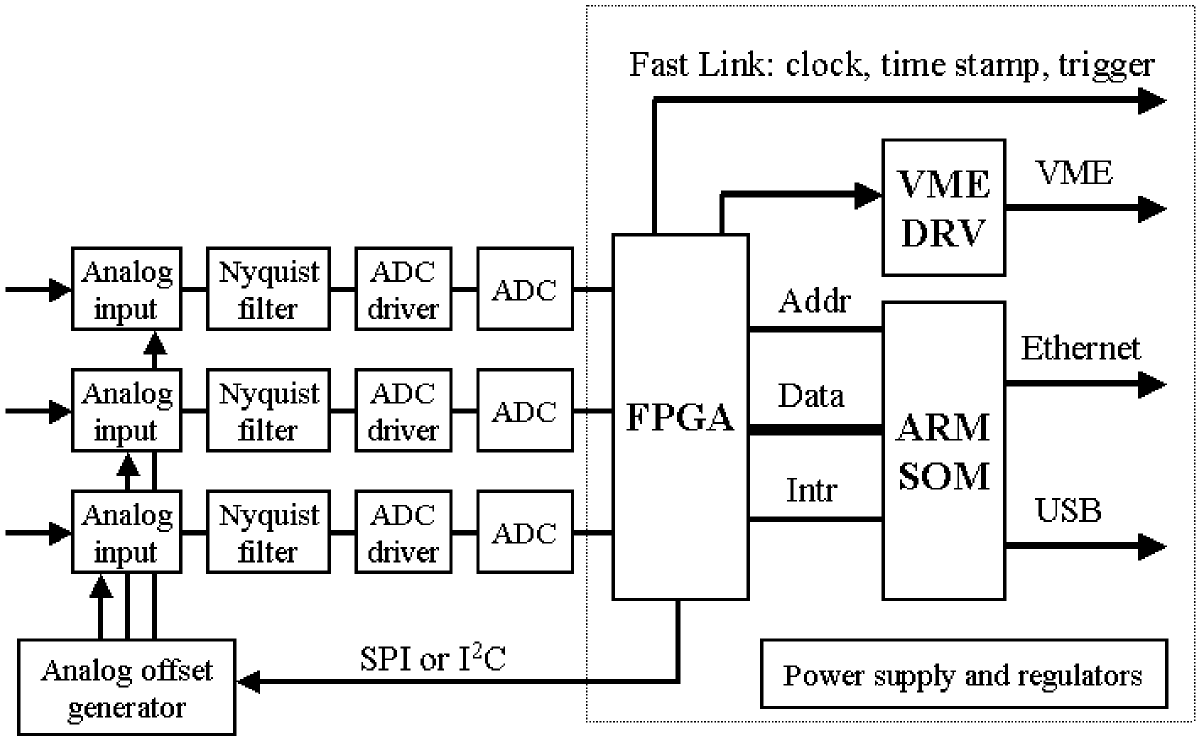
Platform Approach to Designing Our Electronics

- We adopted a “platform” approach to designing our electronics.
- All our digitizers are designed according to this block diagram.

Common Platform Architecture

- VME is relevant only to VME units
- Fast Link is not provided in FemtoDAQ





Introducing the FemtoDAQ Digitizer

- FemtoDAQ is an entry level digitizer with two ADC channels, four digital I/Os, and a digitally controlled (10V to 90V) bias output for the SiPM.
- ADC channels digitize 14 bits @ 100 MHz.
- Ribbon cable connector is provided for powering an SiPM carrier board.
- Univ. of Rochester, Houghton College, Simon Frazer Univ., Laval University.

Four digital I/O

Two analog channels, 14 bits @ 100 MHz

Pin connector with 10V – 90V bias, power, and digital control for the SiPM carrier board.

Ethernet connector is in the back.

USB

Micro SD

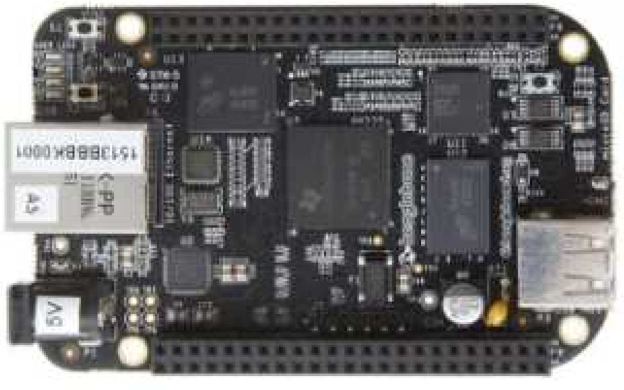
Development of the FemtoDAQ Digitizer

- Three hardware iterations, removing minor design flaws and improving performance.
- Improved both the GUI and the firmware (next slides).
- Implemented feedback from both the distributor Wiener USA and from the end users.

Commercial BeagleBone Black

Bias Generator, 10V up to 90V

2-channel Digitizer: 14 bits, 100 MHz

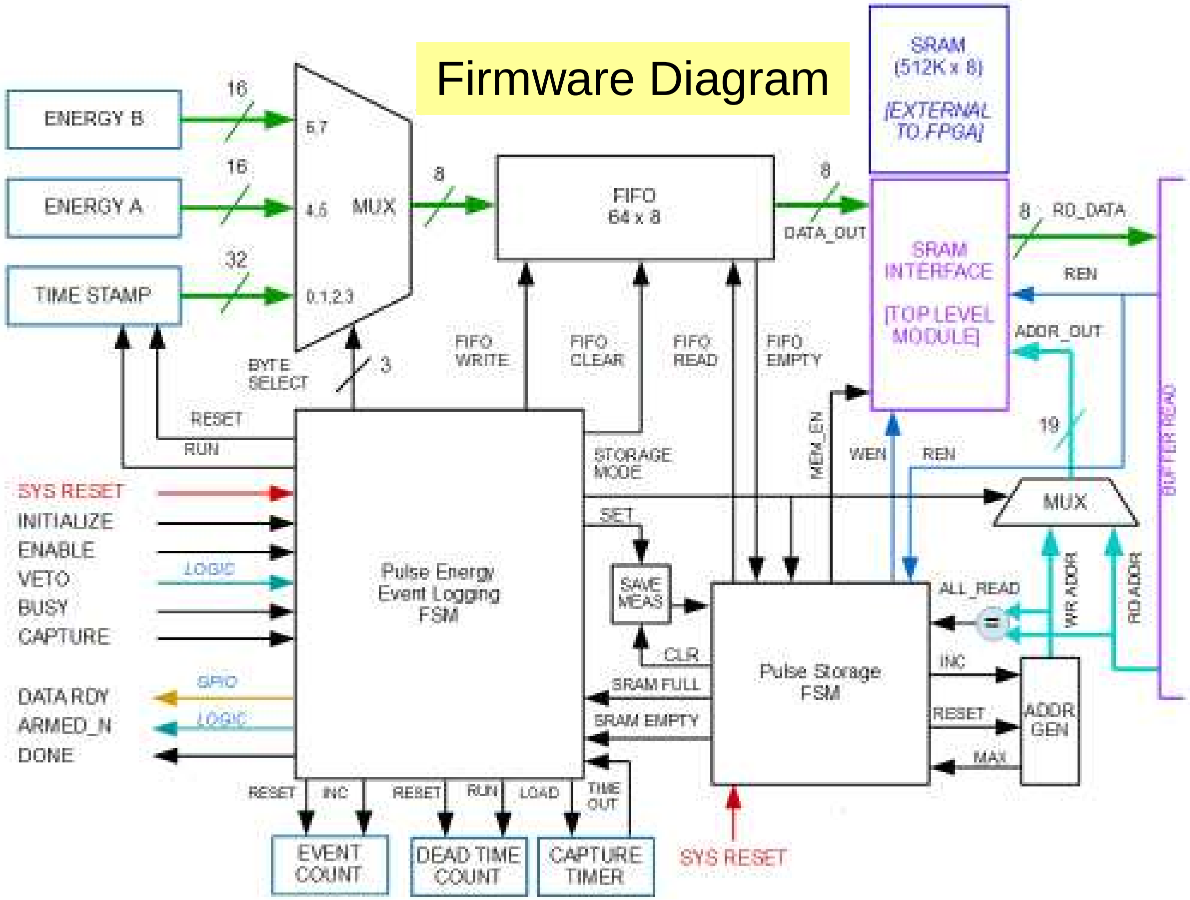


Event Logging Firmware for FemtoDAQ

Motivated by the ^{6}He measurement by the Houghton College group led by Professor Mark Yuly. Several thousand ^{6}He nuclei will be produced in OMEGA Laser shots at Univ. of Rochester Laboratory For Laser Energetics. The nuclei will decay with a half life 806.7 milliseconds. The decay events will be logged into FemtoDAQ memory. The software solution was not possible because Linux does not provide a real time response. We developed a firmware solution to log the events into on-board SRAM.

A pilot experiment will be performed at the SUNY Geneseo accelerator facility.

Firmware Diagram



What is logged:

Two energies A, B, and a time stamp.

Event logging added 4 clock cycles to the event handling (additional 40 ns).

Up to 64k events can be logged in a single laser shot.

How it will be used:

ΔE and E signals from the 6He decay will be logged with time stamps.

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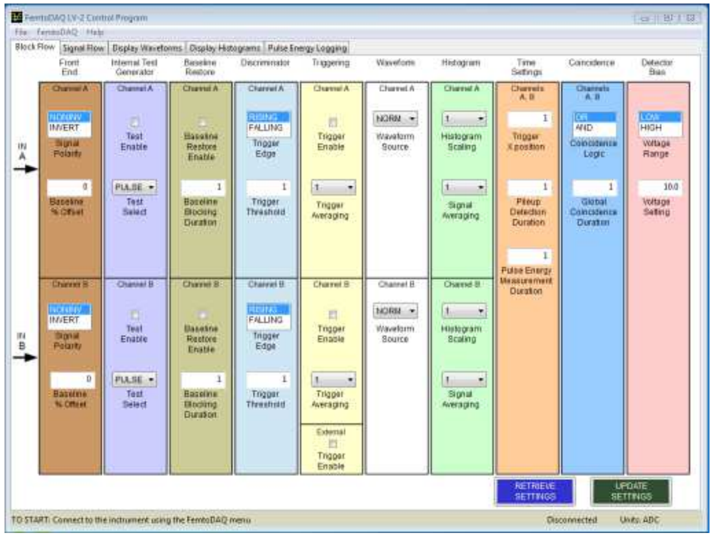
FemtoDAQ GUI and Software Features

Operating a digital DAQ instrument can be confusing. Lots of options and features are crammed into the Field Programmable Gate Array, where the user cannot put the scope probes or touch the hardware buttons. The user needs an intuitive way of using the device.

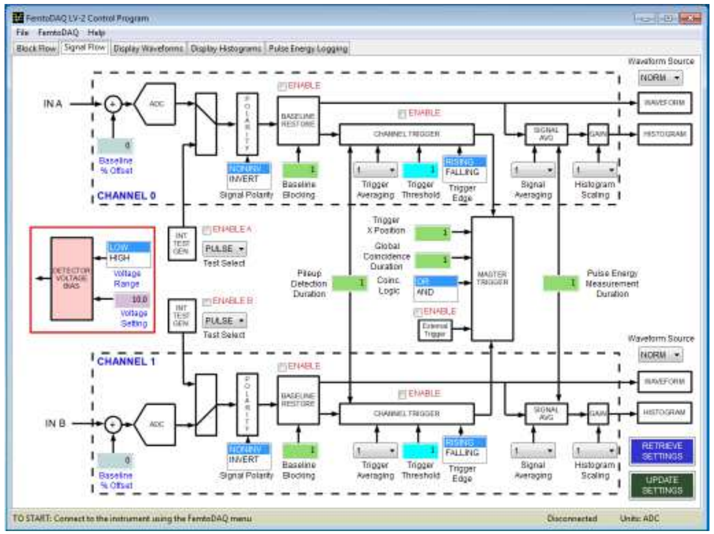
We developed two complementary ways to setup and operate the instrument.

- The “NIM bin display” caters to seasoned nuclear physicists who are used to NIM electronics.
- The “signal flow display” shows how the signal is processed and shaped inside the instrument.
- The pulses and histograms are shown in the oscilloscope-like windows.
- The data files can be written to disk: histograms, waveforms, event logging, or processed event files.

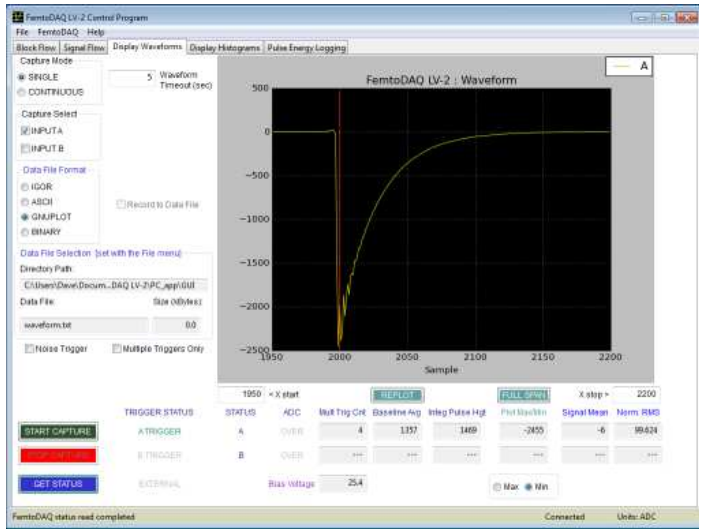
Simulated NIM bin with modules



Signal flow and pulse shaping view



Waveform and histogram display



Higher Density Digitizers

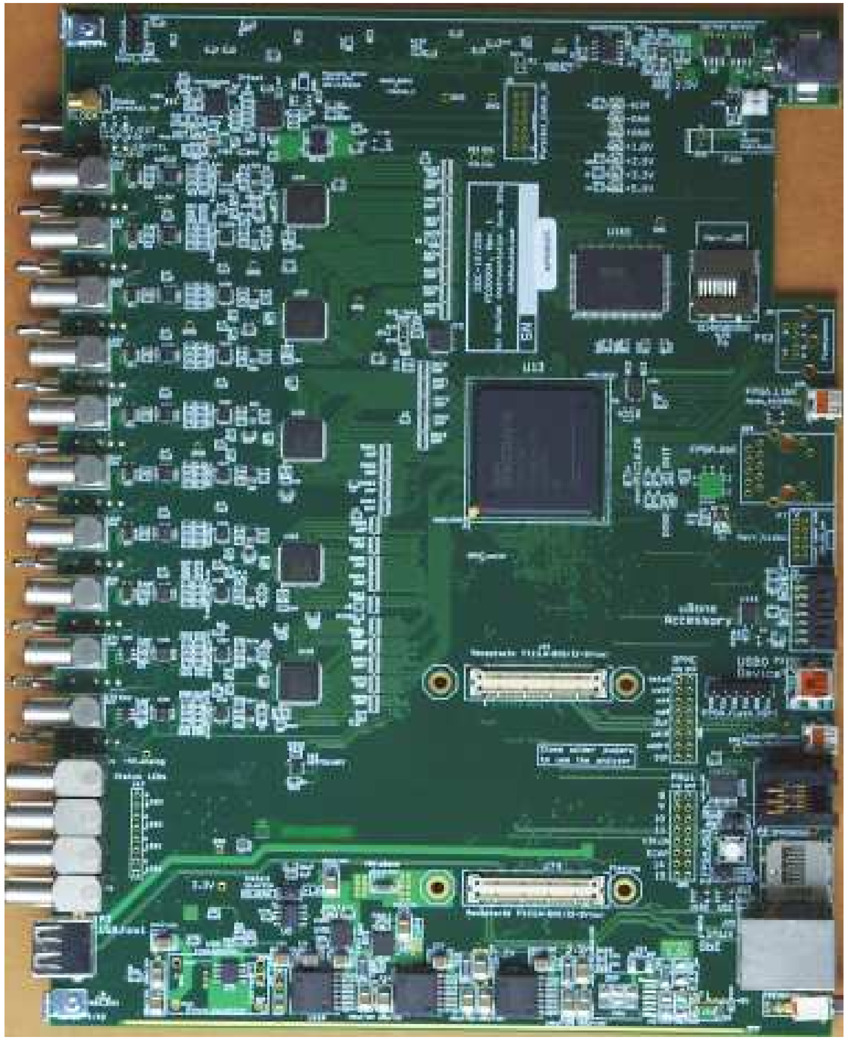
In addition to FemtoDAQ, we also work on higher density digitizers to be described on the 2nd day of this Exchange. Here I want to mention the 10-channel digitizer. In Year 2 it will be enhanced with the bias generator similar to the FemtoDAQ.

ADC clock (optional)

Ten inputs.
Input impedance:
50Ω, 1kΩ, or 100kΩ

4 * NIM in
4 * NIM out

USB #2



Bias generator will be here.

Ethernet #2 UDP

USB #1

RS-232

µSD

Ethernet #1 TCP/IP

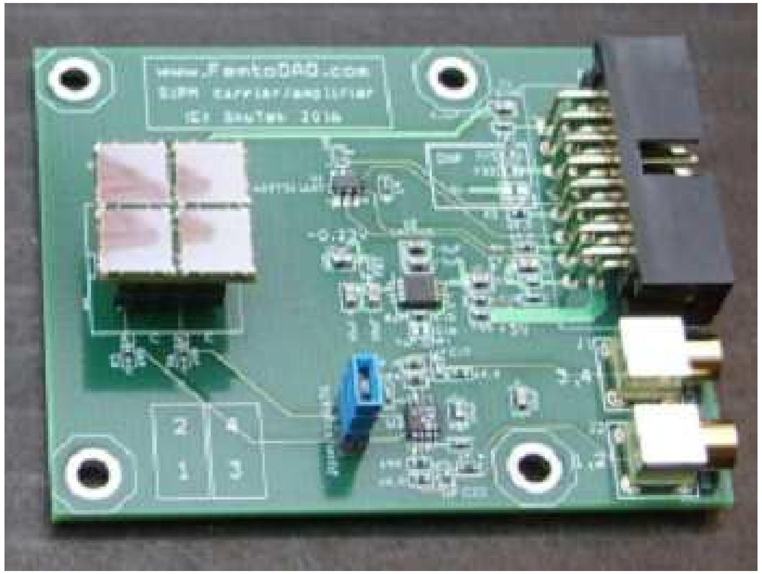
The SiPM Carrier Boards

The SiPM devices are too fragile to be used without a printed circuit board. We developed two SiPM Carrier Boards to utilize the 6x6 mm SiPMs, which are the most popular devices developed by SensL.

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

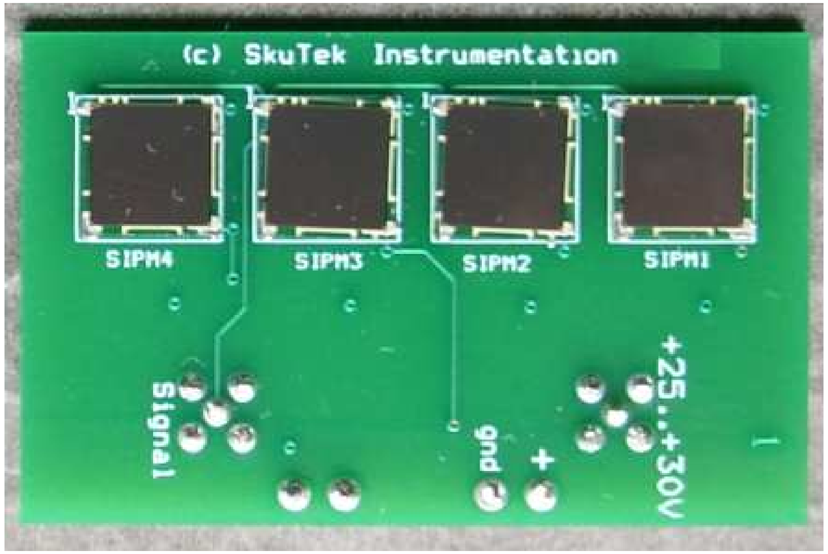
A

SiPM Carrier Board with amplification



B

SiPM Carrier Board w/o amplification

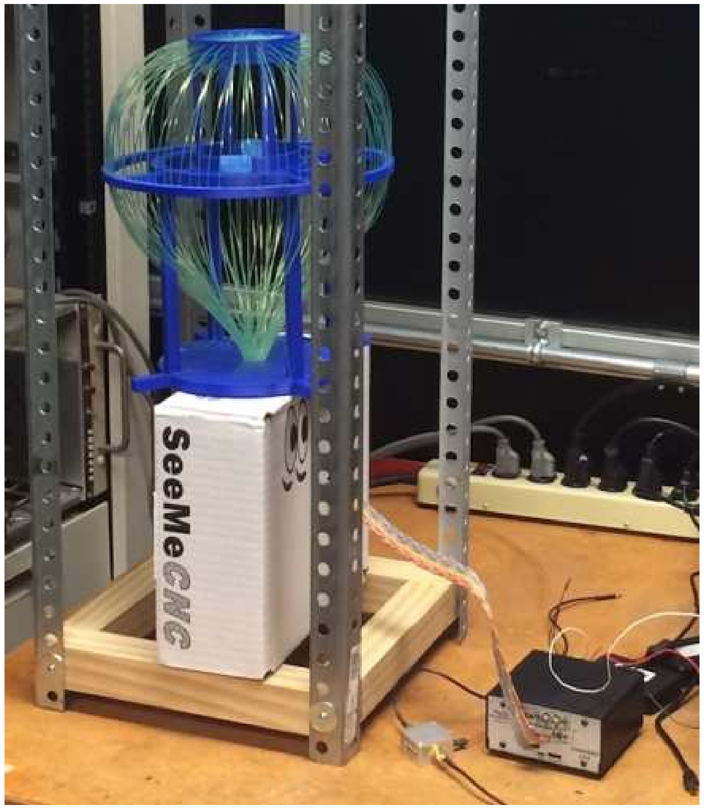


Customer Applications

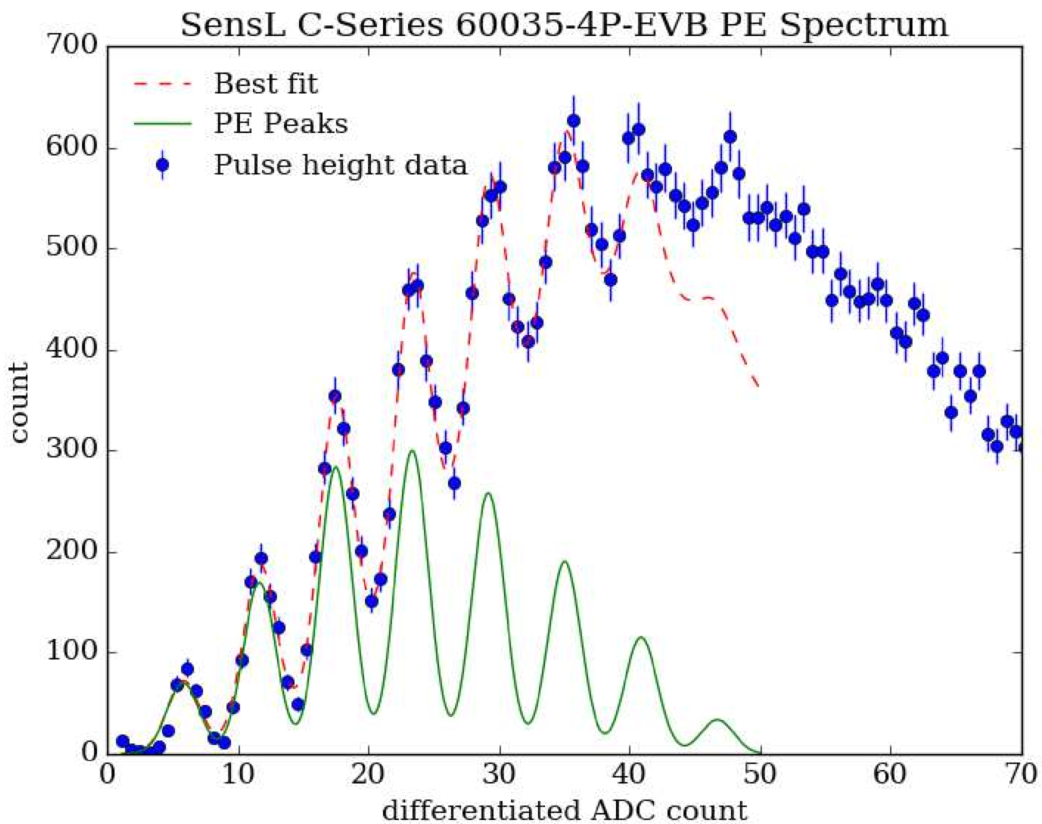
• Board A was used by our customer Professor Segev BenZvi (Univ. of Rochester) for HAWC Trigger studies.

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.

The wavelength shifting fiber collector for HAWC studies. The SiPM Carrier board is inside the white box. The FemtoDAQ is at the lower-right.



A single photoelectron spectrum collected with FemtoDAQ and the SiPM Carrier board.



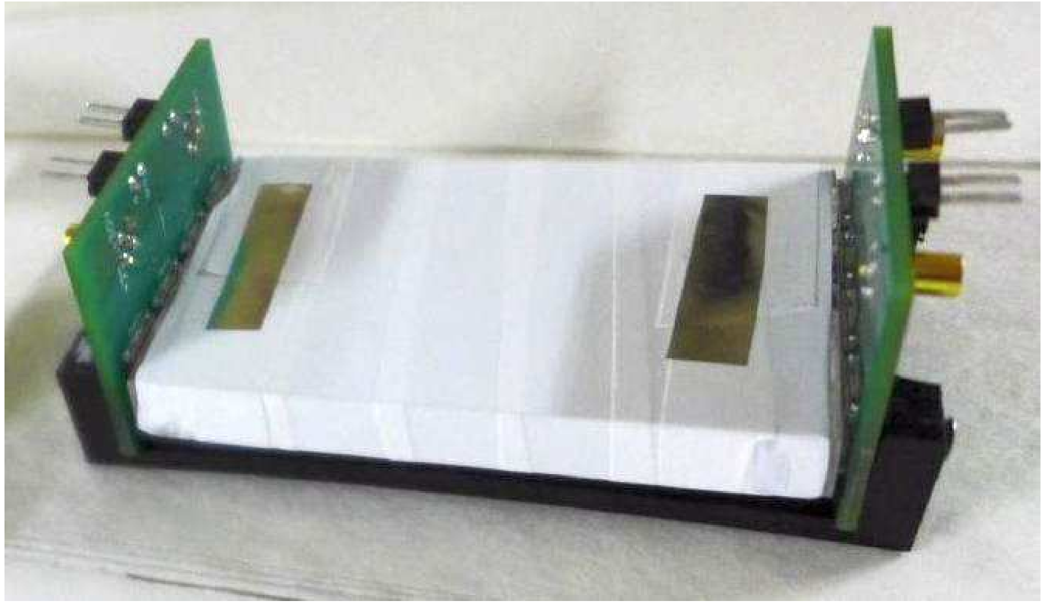
Customer Applications

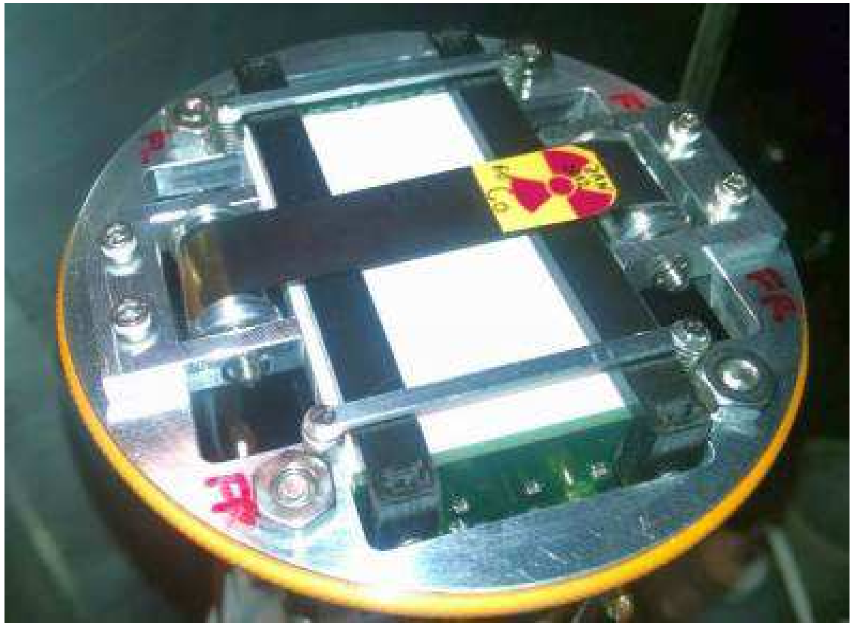
Board B was used by Professor Robert Grzywacz in experments at ORNL and MSU NSCL. The group used a plastic scintillator and the SiPM arrays to measure beta particles and fast light ions. The detectors performed flawlessly [1].

[1] Robert Grzywacz, private communication.

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.



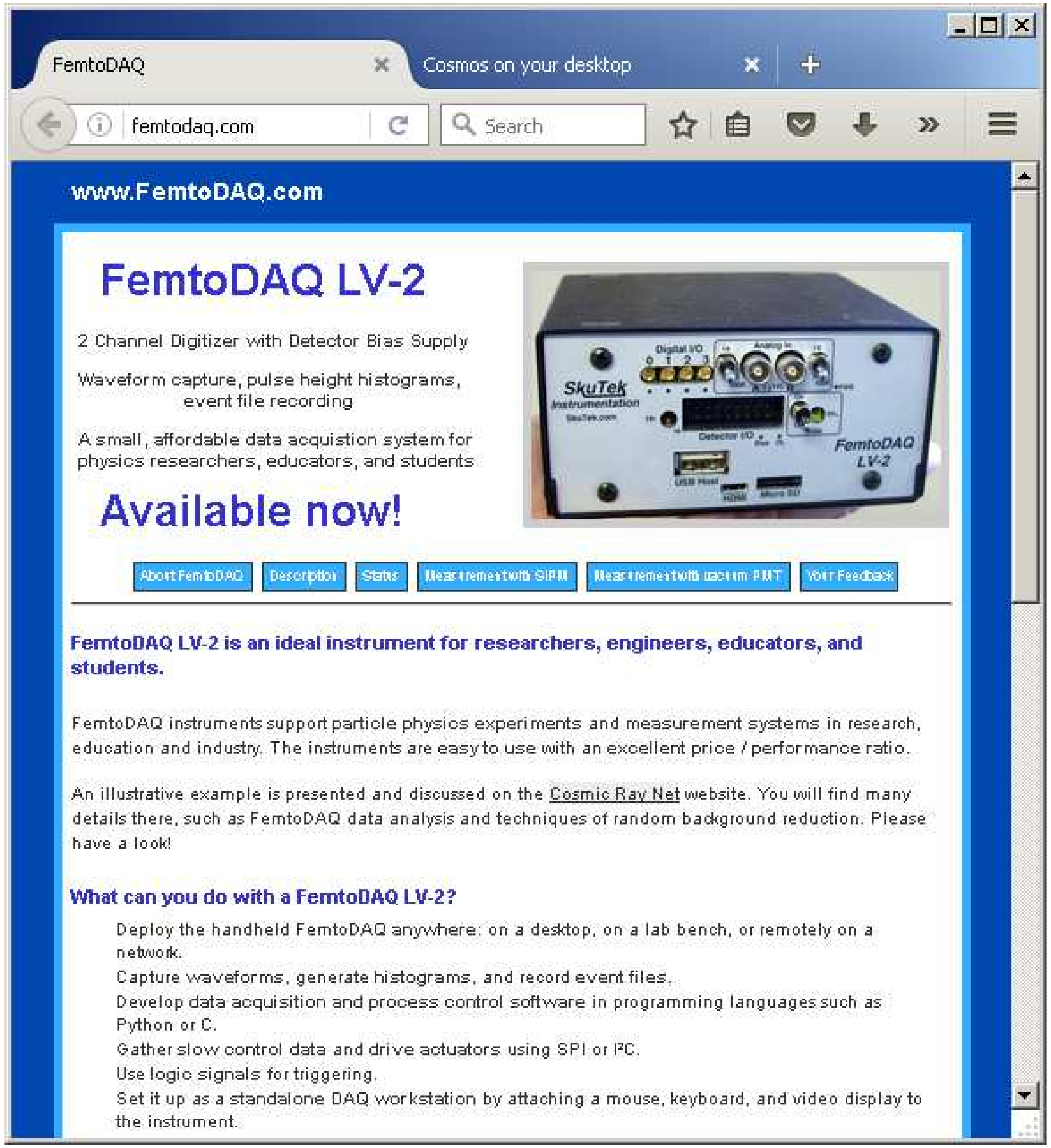


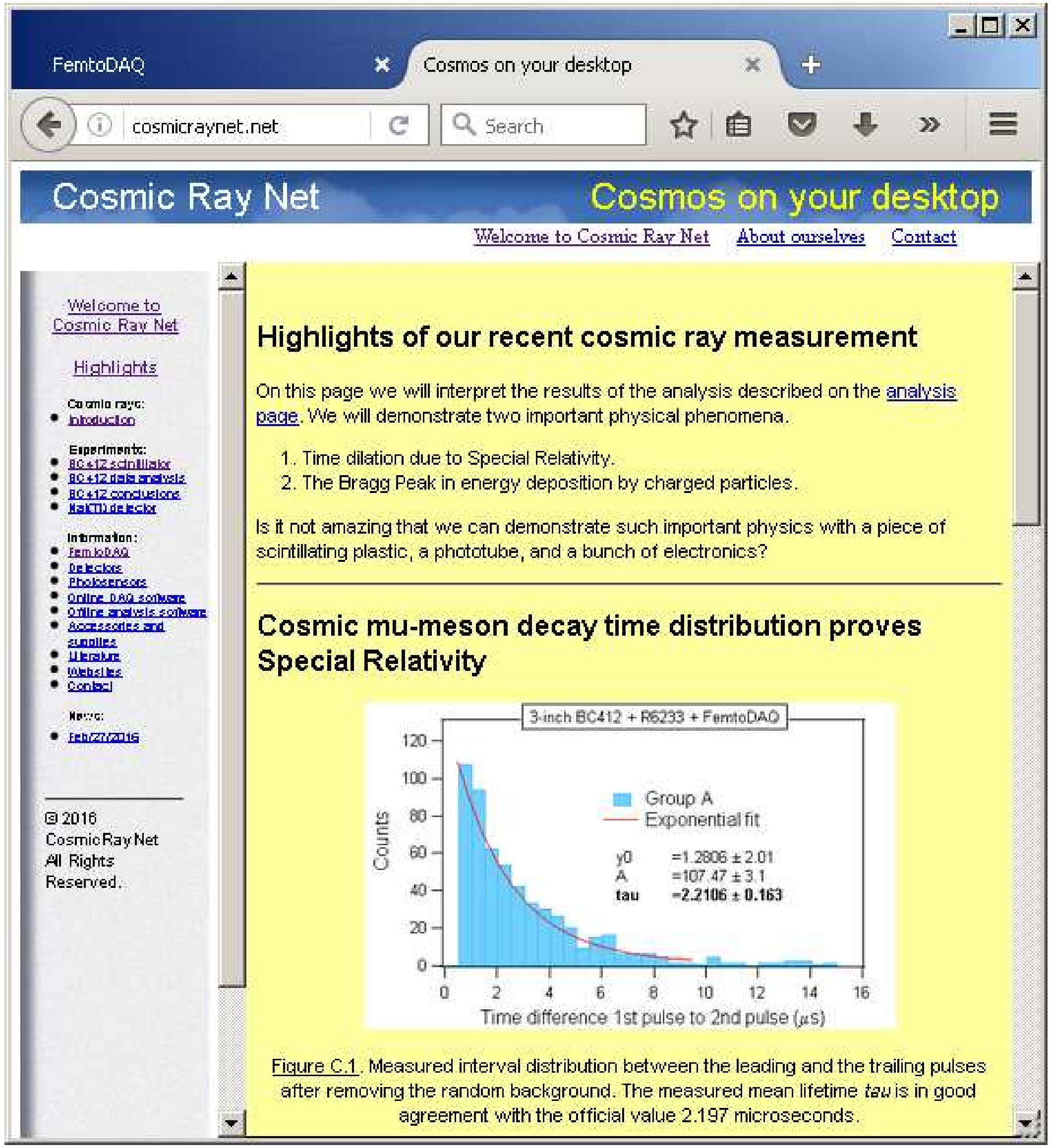
More Information

Dual channel FemtoDAQ with Silicon Photomultiplier control: an entry-level, low cost, easy to use DAQ.

Instrument: **FemtoDAQ.com**

Example application: **CosmicRayNet.net**





Future plans

- Develop a high density digitizer with 64 channels per unit and bias output (10V - 90V).
- Add the same bias output to our 10-channel table top digitizer.
- Develop more kinds of the SiPM Carrier Boards.
- Develop SiPM “demonstrator” experiments for schools, small labs, and colleges.
- Engage students and interns in our work.
  - This Summer we worked with an extremely talented intern!
- Solicit input and suggestions from the community. Extremely important…
  - The PI participates in FRIB DAQ Working Group which is an excellent venue for learning the needs of the Low Energy Community.
  - Last week the PI presented our work at the LEC Meeting at ANL:

    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 the SiPM devices?
- What kinds of carrier boards and SiPM modules do you need for your detectors?
- Do you need digitizers, SiPM amplifier boards, SiPM signal shapers, etc.
- Development of any kind of SiPM - related electronics is a fair game for us.
- An issue of practical importance are connectors for high density devices.
    - What kind of connectors would you prefer for your detector?
    - Coax is good but expensive. Ribbon cables are cheap but low performance.
- If you need something, please talk to us!

Acknowledgements

Joanna Klima, Gregory Kick, Sean Fallon

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Thank you for your attention.