A NOVEL HIGH RATE READOUT SYSTEM FOR A HIGH EFFICIENCY COSMIC RAY VETO FOR THE MU2E EXPERIMENT

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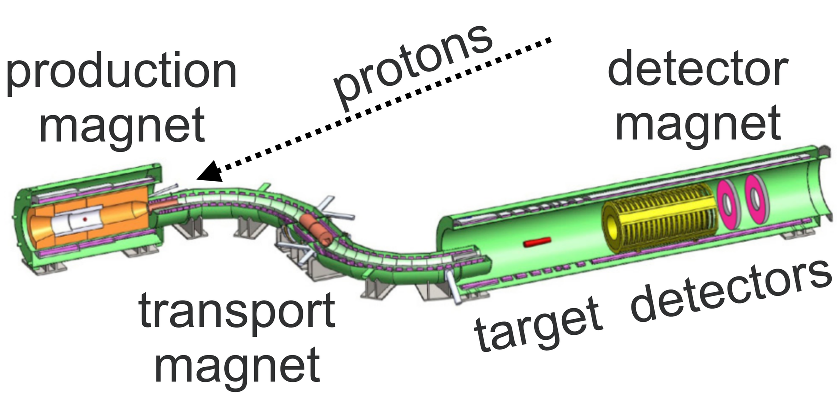
NuFact 2022, July 31 to August 6, 2022.

The mu2e Experiment

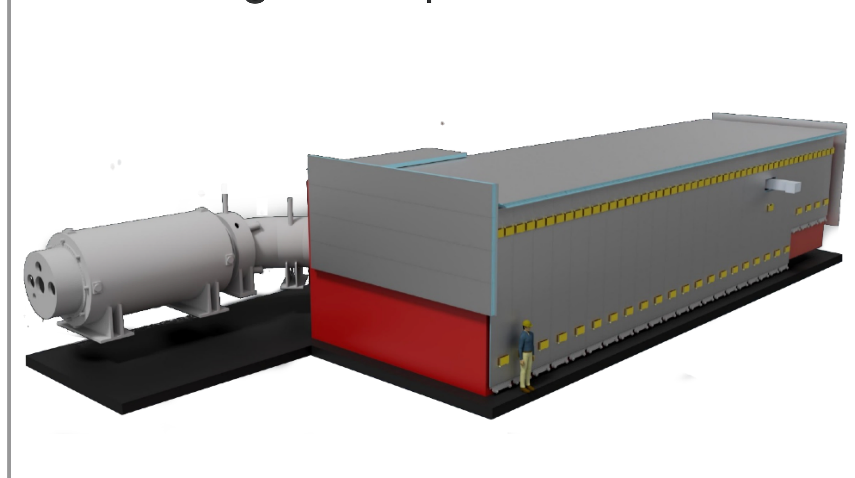
- $N\mu^- \rightarrow Ne^-$: Search for this charged lepton flavor violating decay with a single-event sensitivity of ~$2.5 \cdot 10^{-17}$.



- 15.000 cosmic rays pass through the detector every second, resulting in about one signature-like event per day.

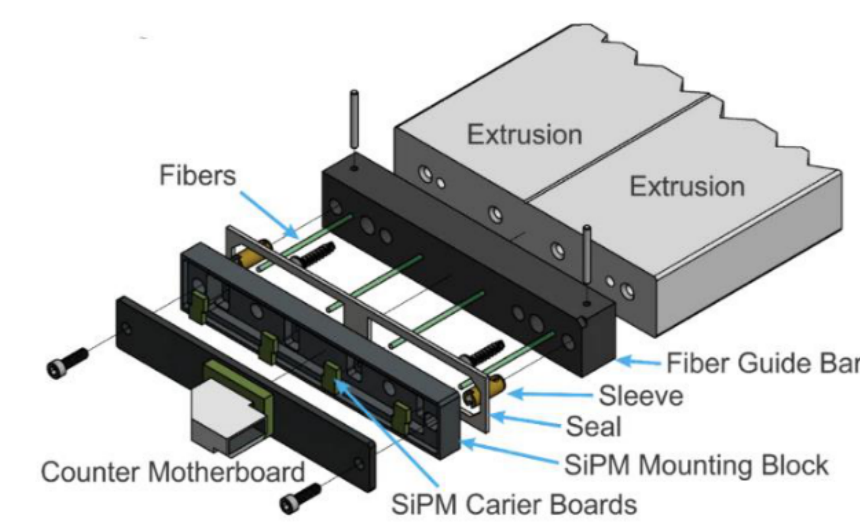
The Cosmic Ray Veto

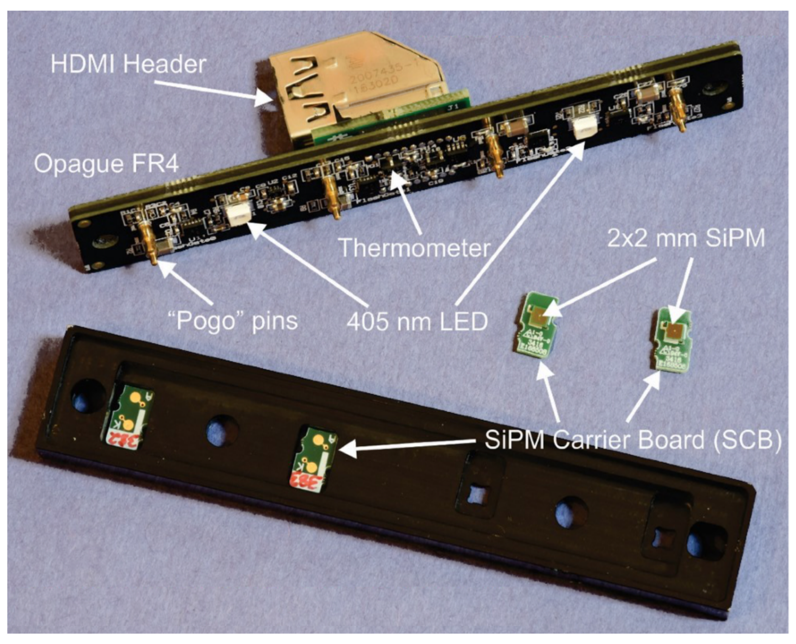
- The Cosmic Ray Veto (CRV) covers the experiment on all sides to give **>99.99% efficiency** for cosmic rays. It consists of 4 layers of extruded plastic scintillator with WLS fibers and SiPM photo-detectors. There are about 20 thousand SiPMs in the system covering 330 sq meters.



The Cosmic Ray Veto Sensors

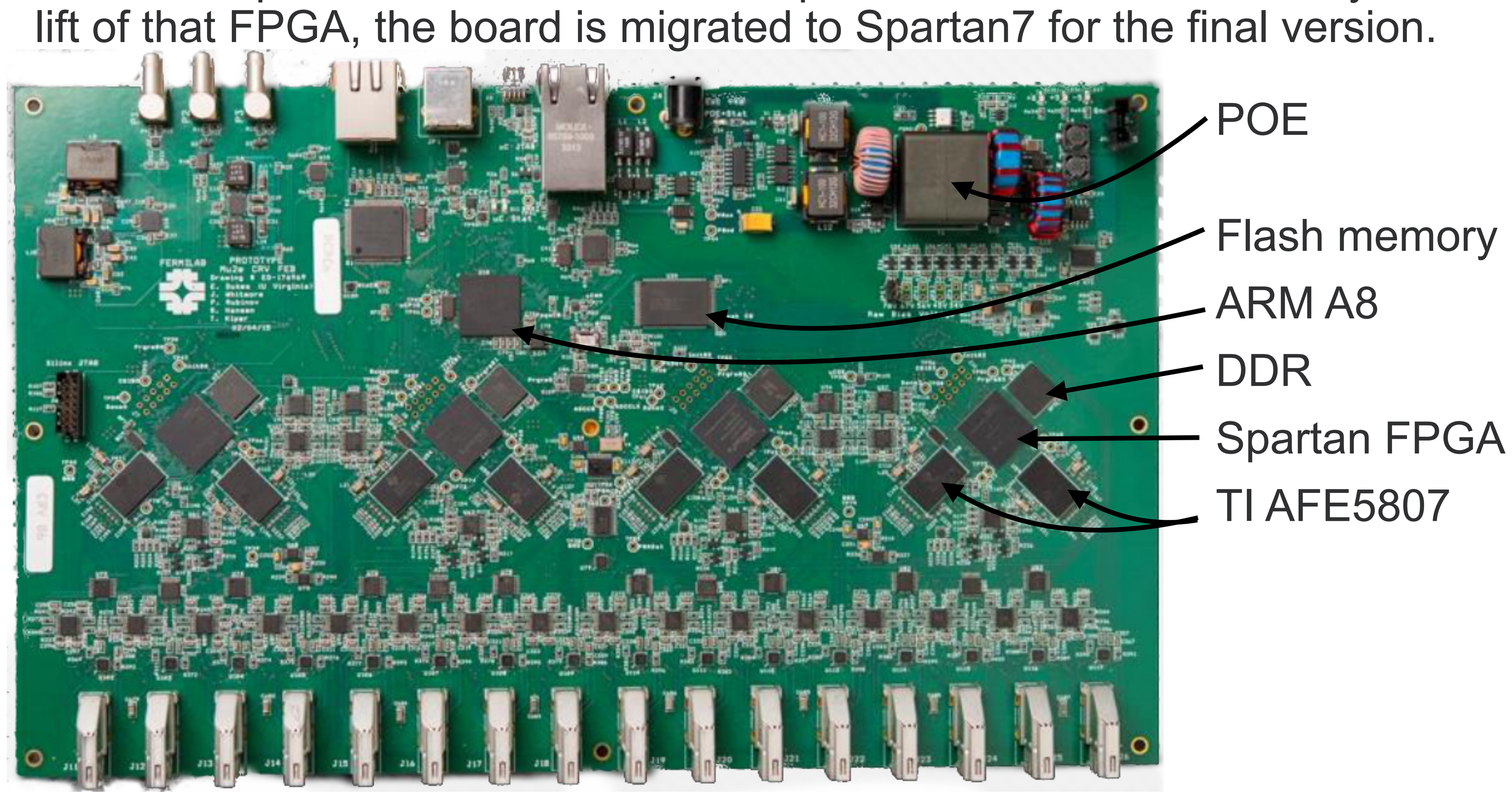
- The 4-channel counter mother board (CMB) contains LED flasher, bias filter, passive pole-zero and temperature sensor. Additional circuitry allows for a fast negative pulse to be applied to the SiPM bias, allowing for a temporary "blinding" of the SiPM. The SiPMs themselves are mounted on small carrier boards that make contact with spring loaded contacts, allowing for tight contact to the diamond polished fibers without crushing the SiPM.





The Front End Board

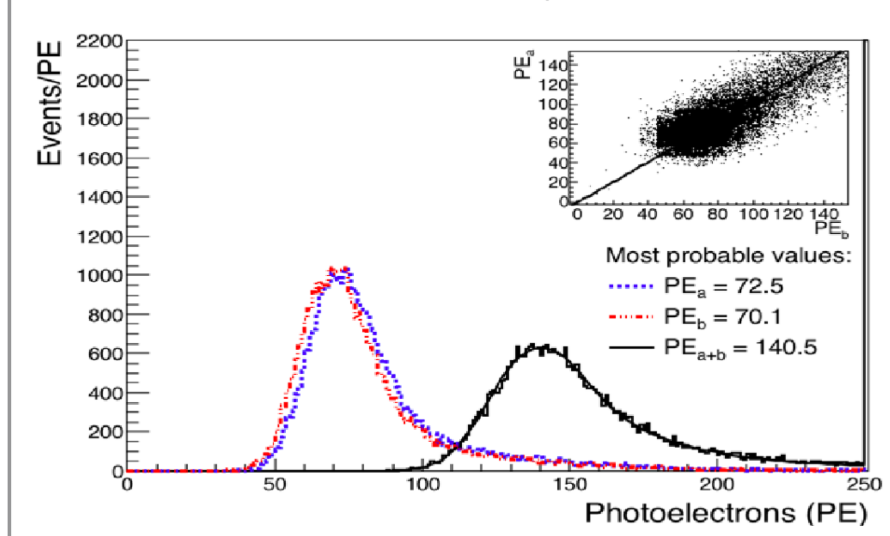
- The front end board (FEB) handles 64 channels (16 CMB, connected with HDMI cables). The digitizers are implemented as 4 identical sections, each having 2 x TI AFE5807 octal amplifier/digitizer chips running at 80 MSPS. The development boards used Xilinx Spartan6 FPGAs. Due to early end of lift of that FPGA, the board is migrated to Spartan7 for the final version.



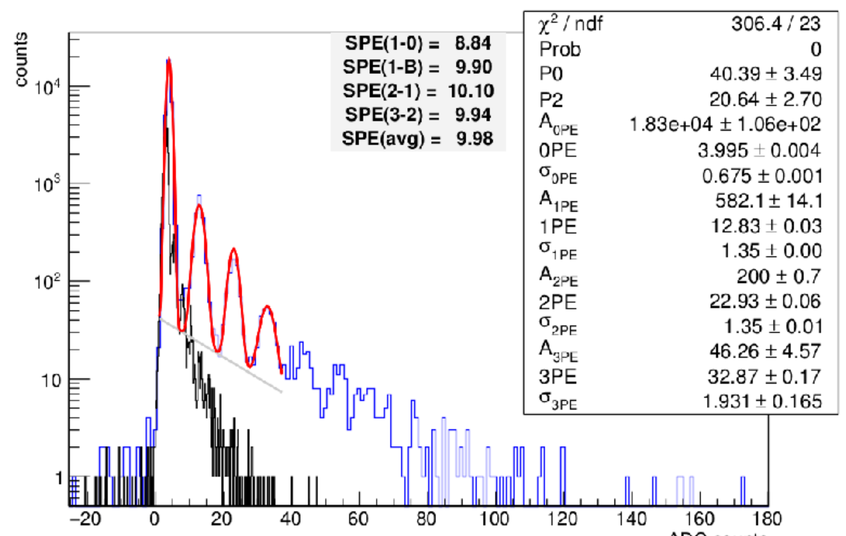
- Bias generation: A 9-stage CW is fed by a secondary winding on the 48V isolated DC-DC supply used to power the board. Used as a rail for 12bit DAC controlled pass elements that supply bulk bias voltage to 8 pairs of HDMI connectors as the detector bias. The low side of each SiPM is also connected to a bipolar 12bit DAC, with a swing of 8V to allow for wide range bias control for each individual channel. An analog switch matrix connecting a 4K resistor present on each DAC allows for precision current measurements of each diode, with 100pA precision and up to 1mAa.
- Additionally: 3 flexible logic inputs to allow for board synchronization, triggers and gates. An ARM A8 processor running at 200MHz eases housekeeping and control tasks and facilitates communications.

Front End Board Performance

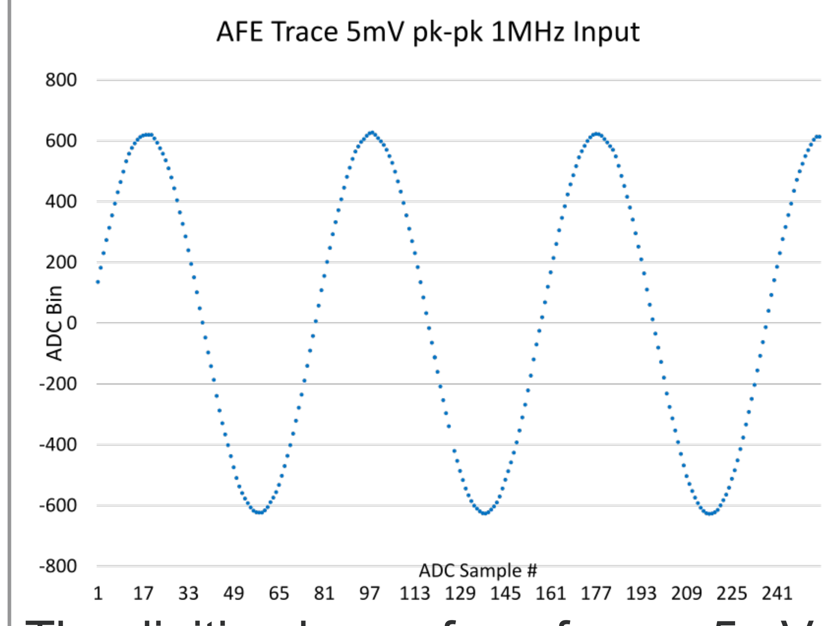
- The system has performed well in bench top testing and three test beams.
- Measured photoelectron yields have been found to be above the required thresholds necessary for 99.99% veto efficiency.



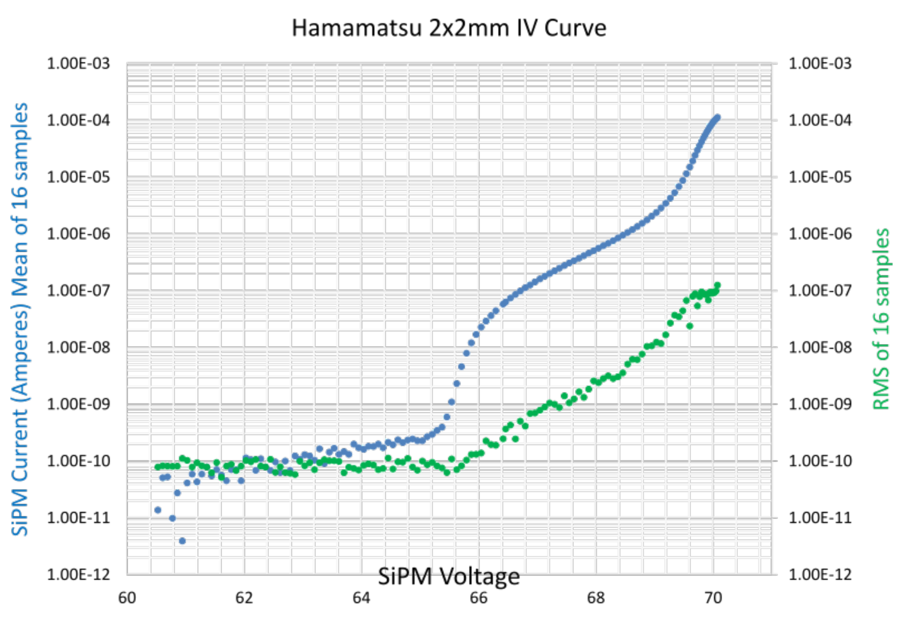
Photoelectron yield of di-counters from the 2017 test beam run.



A typical calibration spectrum. Black: below breakdown, blue: dark current.



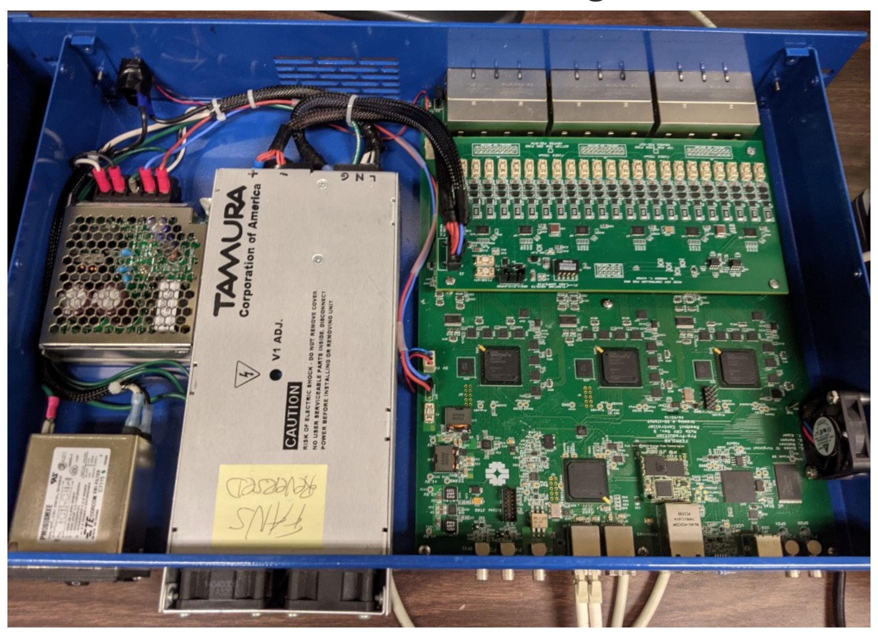
The digitized waveform from a 5mV (corresponding to ½ p.e.) (p-p) sine wave illustrates the excellent analog performance of the FEB.



The bias voltage and current measurement system of the FEB is adequate for IV characterization, rivaling commercial test equipment.

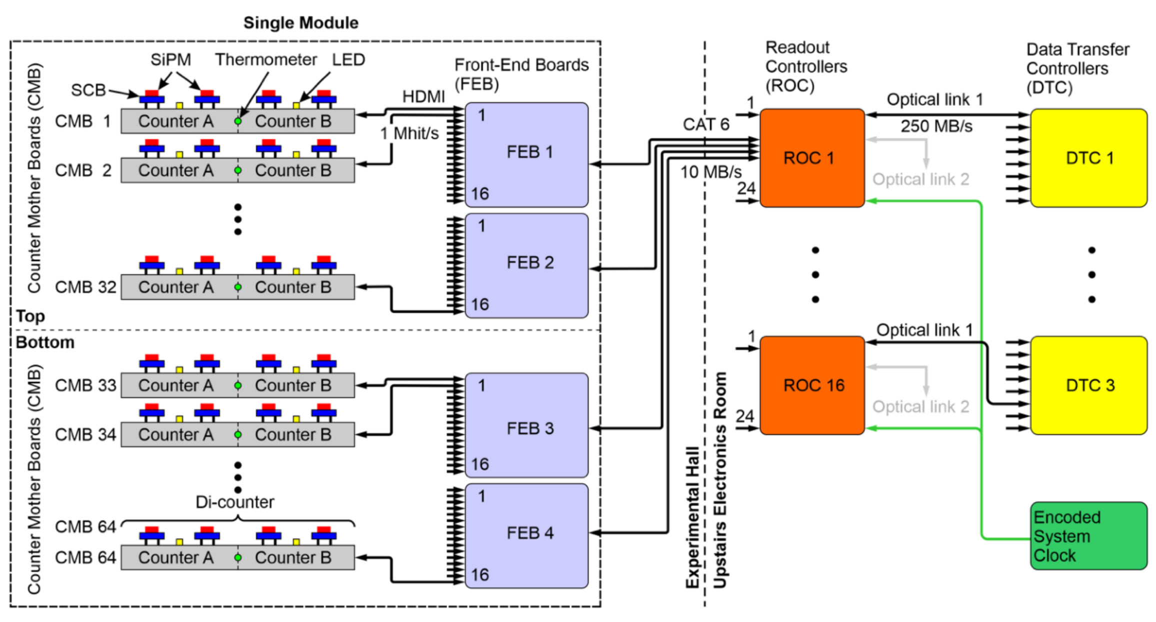
The Readout Controller

- The readout controller (ROC) connects to up to 24 FEBs and to the TDAQ system via 3.125 GBPS optical data-link and a punched 40 MHz LVDS reference clock for timing.



System Overview

- The Mu2e Cosmic Ray Veto DAQ is a triggered system with pull architecture. Waveforms of zero-suppressed events are stored in FEB's paged DDR RAM .



System Performance

- Vertical slice tests from FEB to DTC. The data request time is dominated by the FEB with the largest occupancy.