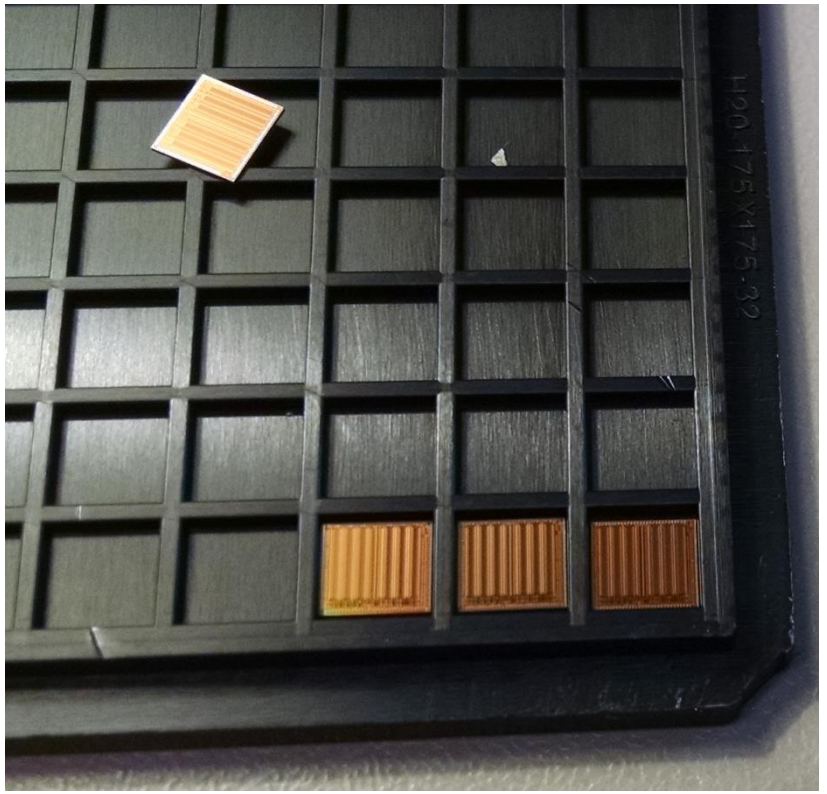
Waveform-sampling Integrated Circuits and Recent Applications at UChicago



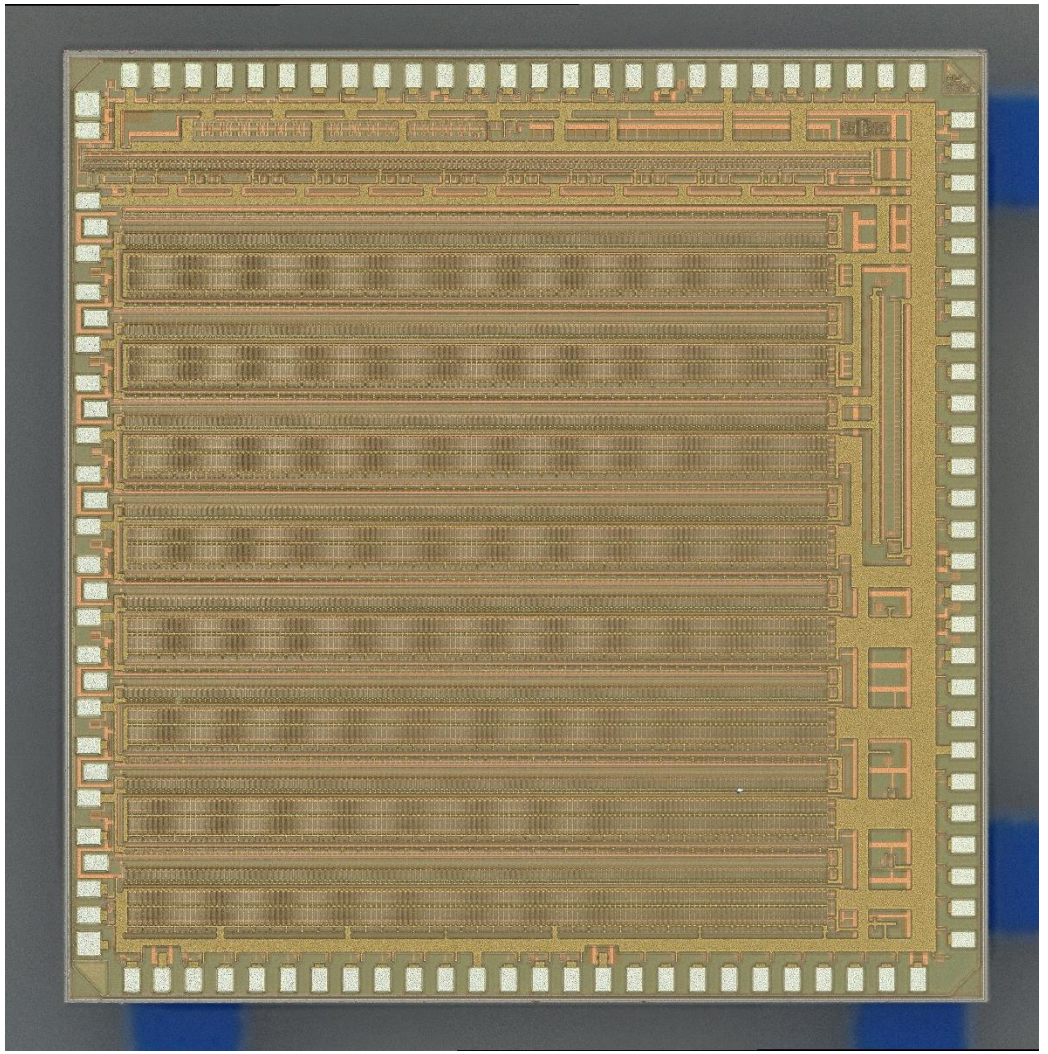
Eric Oberla
Senior Researcher 18-May 2022

Kavli Institute
for Cosmological Physics
at The University of Chicago

ENRICO FERMI INSTITUTE

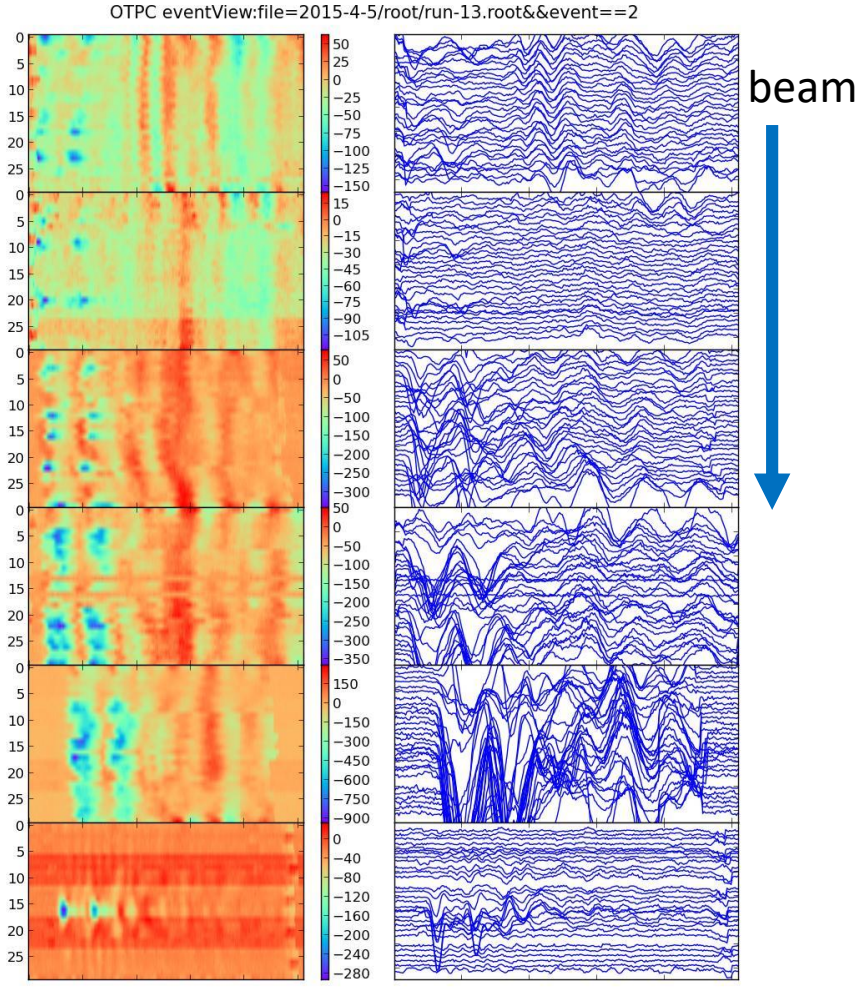
Outline : Chicago SCA waveform samplers

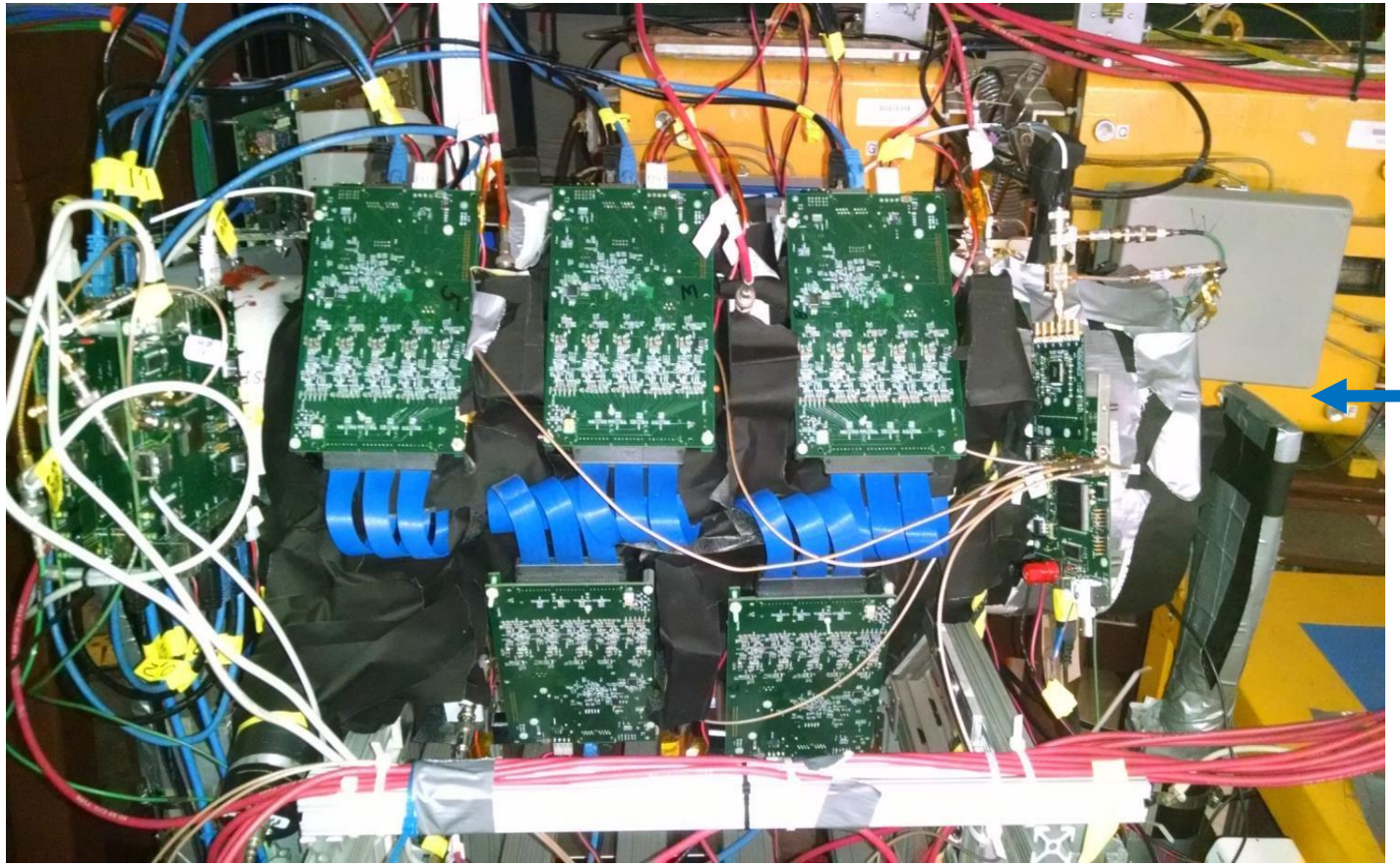
- New applications of PSEC4 ASIC [**10GSa/s waveform sampler** 0.13µm IBM/GF]
- PSEC4A ASIC and high-density readout applications [**10GSa/s waveform sampler** 0.13µm GF, double-buffering and longer record length]
- Future ASIC work → A robust 2GSa/s sampler + flexible trigger generation, an easy-to-use sampler for low-power system for remote detector installations [**0.18µm TSMC**]



A bit of history (from MCenter)

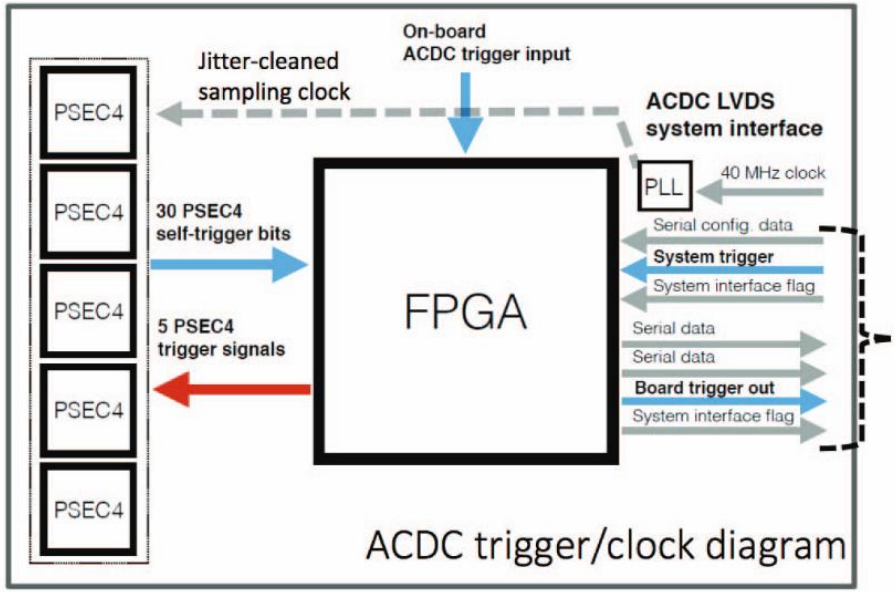
200 channel 10GSa/s PSEC4-based data acquisition system: the 40kg water Optical time-projection chamber w/ stripline-anode MCP-PMTs



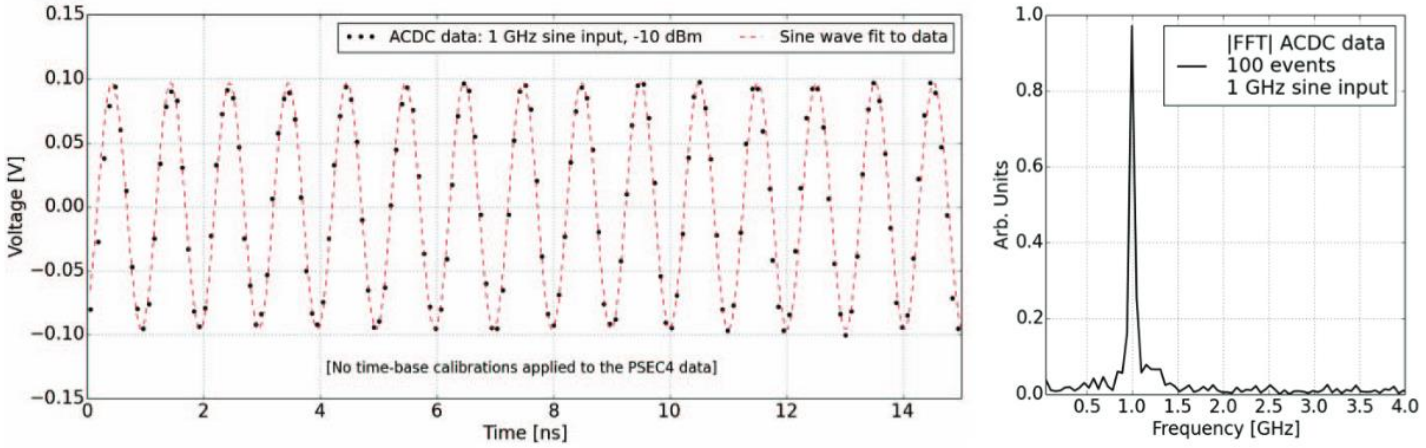


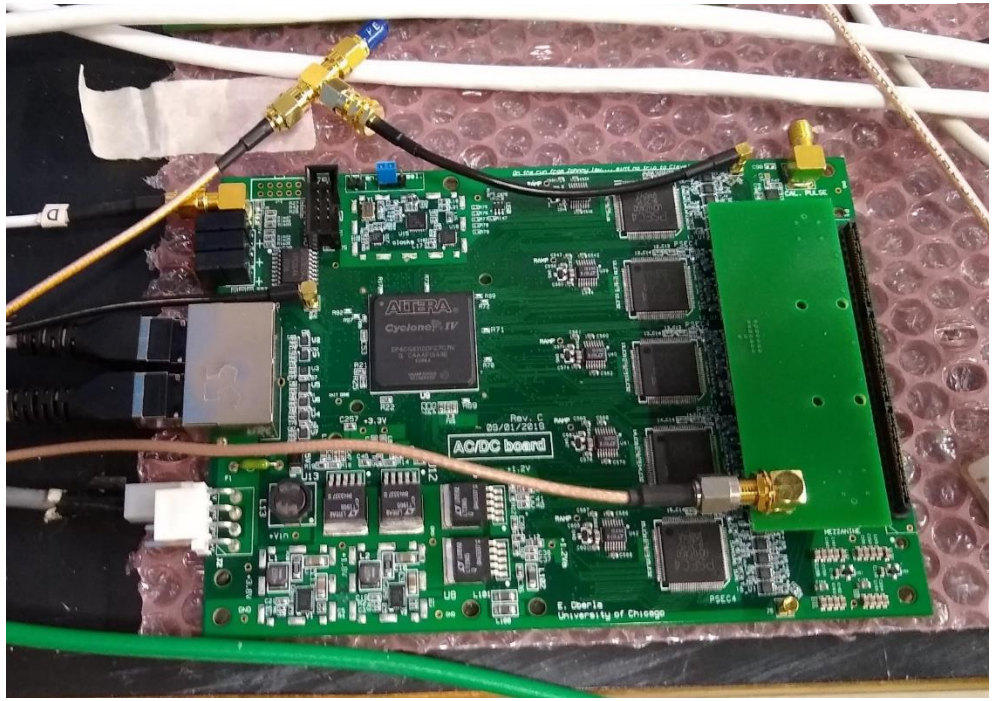
Ongoing work: PSEC4 for MTest TOF system using LAPPDs

- Updated 30channel DAQ (‘**ACDC**’) board from version used in previous OTPC – 60% power consumption reduction, individual per-channel trigger thresholds, inter-channel clocking skew < 5ps
- Full system time synchronization w/ White Rabbit
- Professional firmware development (J. Pastika)
- PSEC4-limited to 256 samples/channel
- Multi-stage trigger design using level-0 PSEC4 self-trigger bits, holding in analog memory until ‘beam’ trigger to digitize and push to disk



1GHz sine capture:

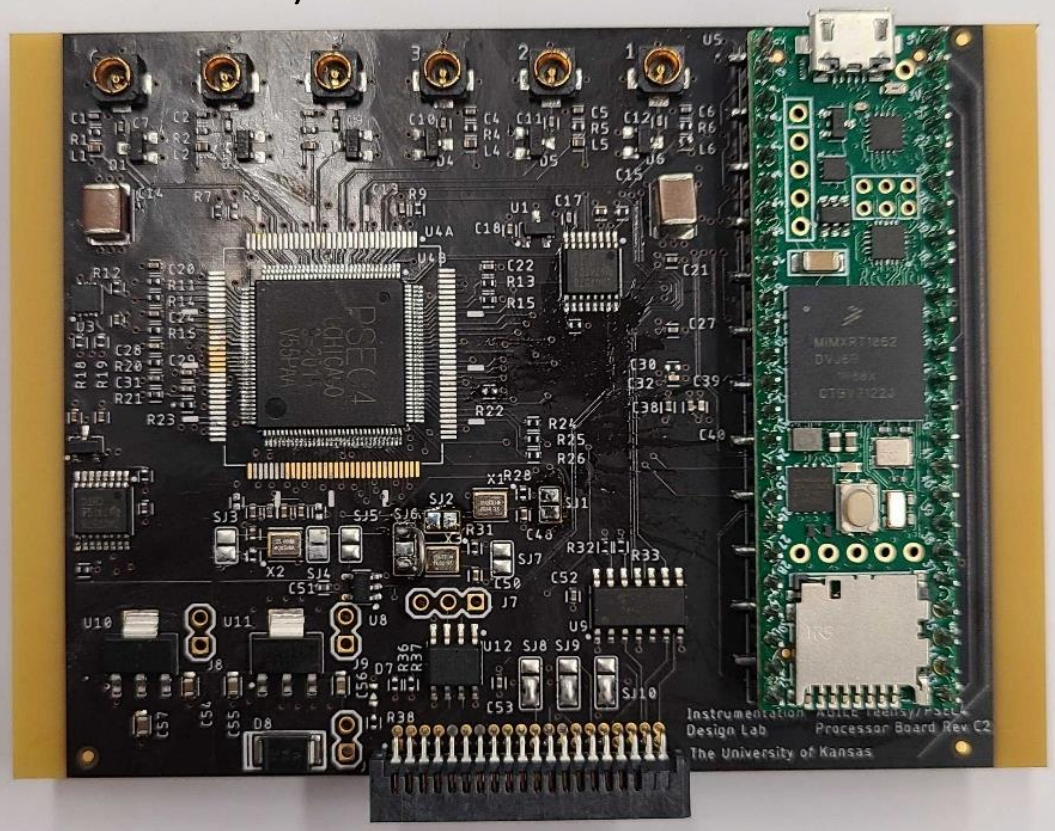




PSEC4 on a CubeSat : pulse-shape discrimination in space

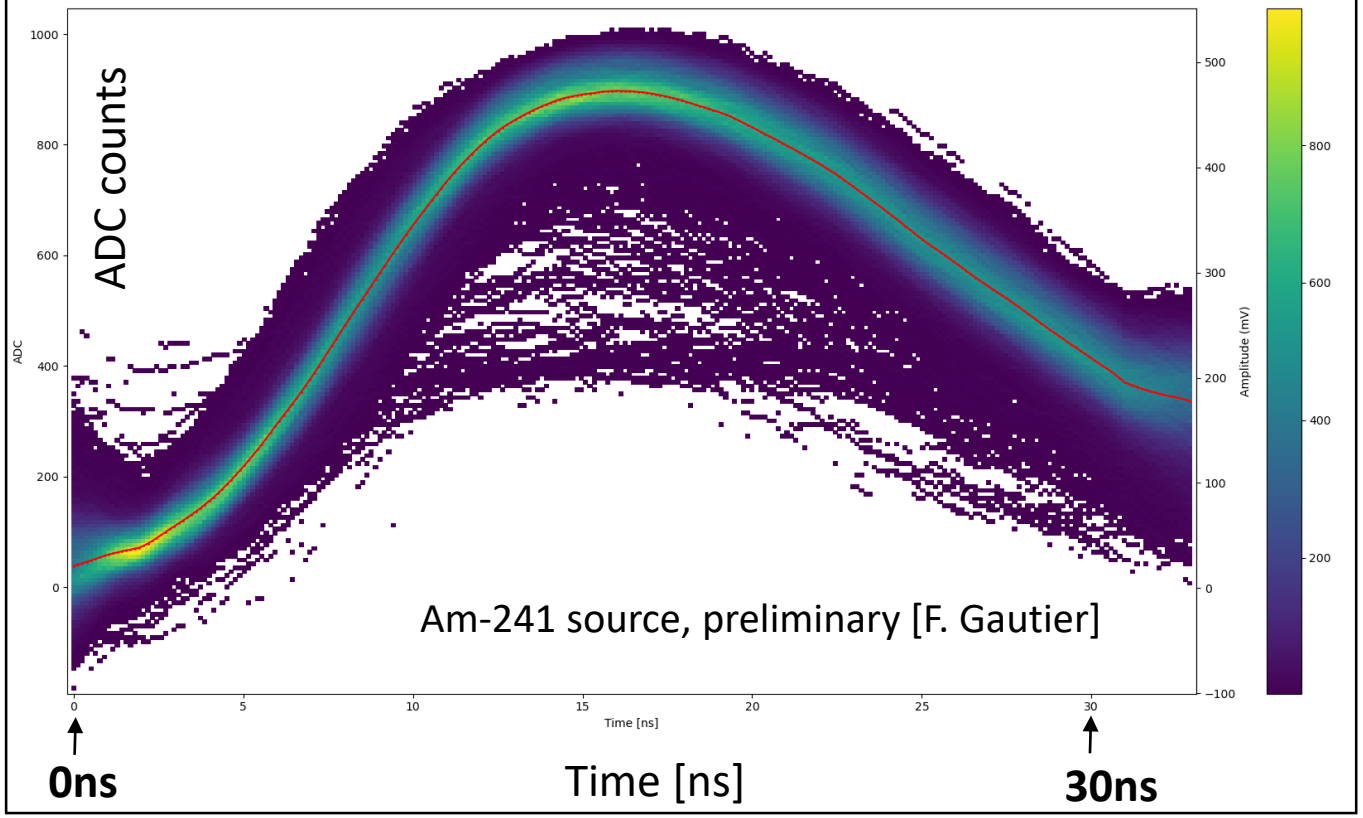
The AGILE (Advanced enerGetic Ion eLectron tElescope) payload uses multiple layers of fast silicon sensors and custom PSEC4 readout. The instrument is designed for real-time particle identification of a large variety of elements from H to Fe and spanning energies from 1 to 100 MeV per nucleon. Planned launch this year.

PSEC4 + Teensy microcontroller flight board (no control FPGA!) << 0.25W



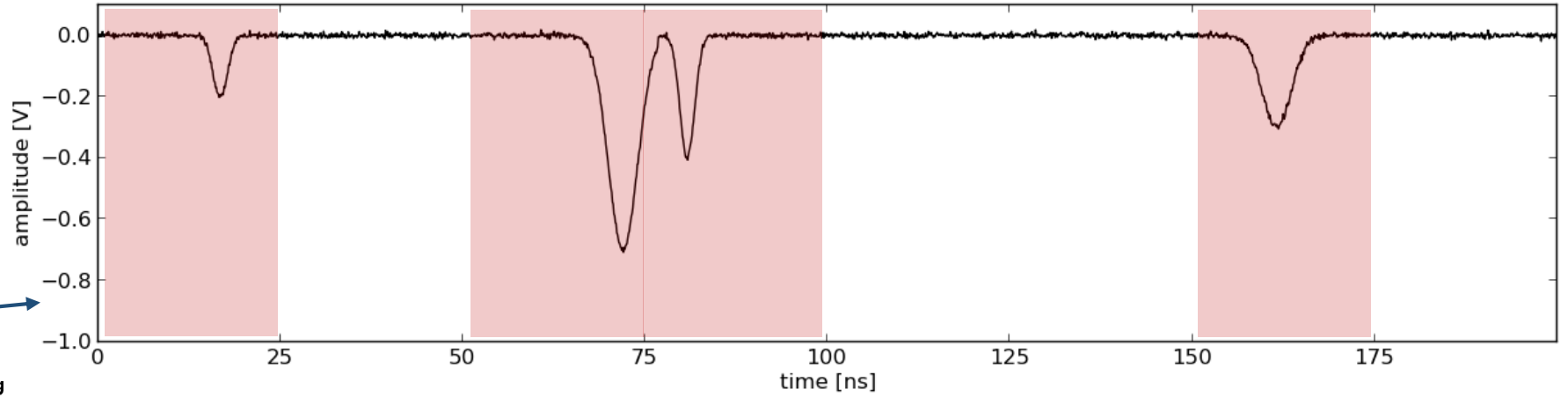
Work with KU / Goddard

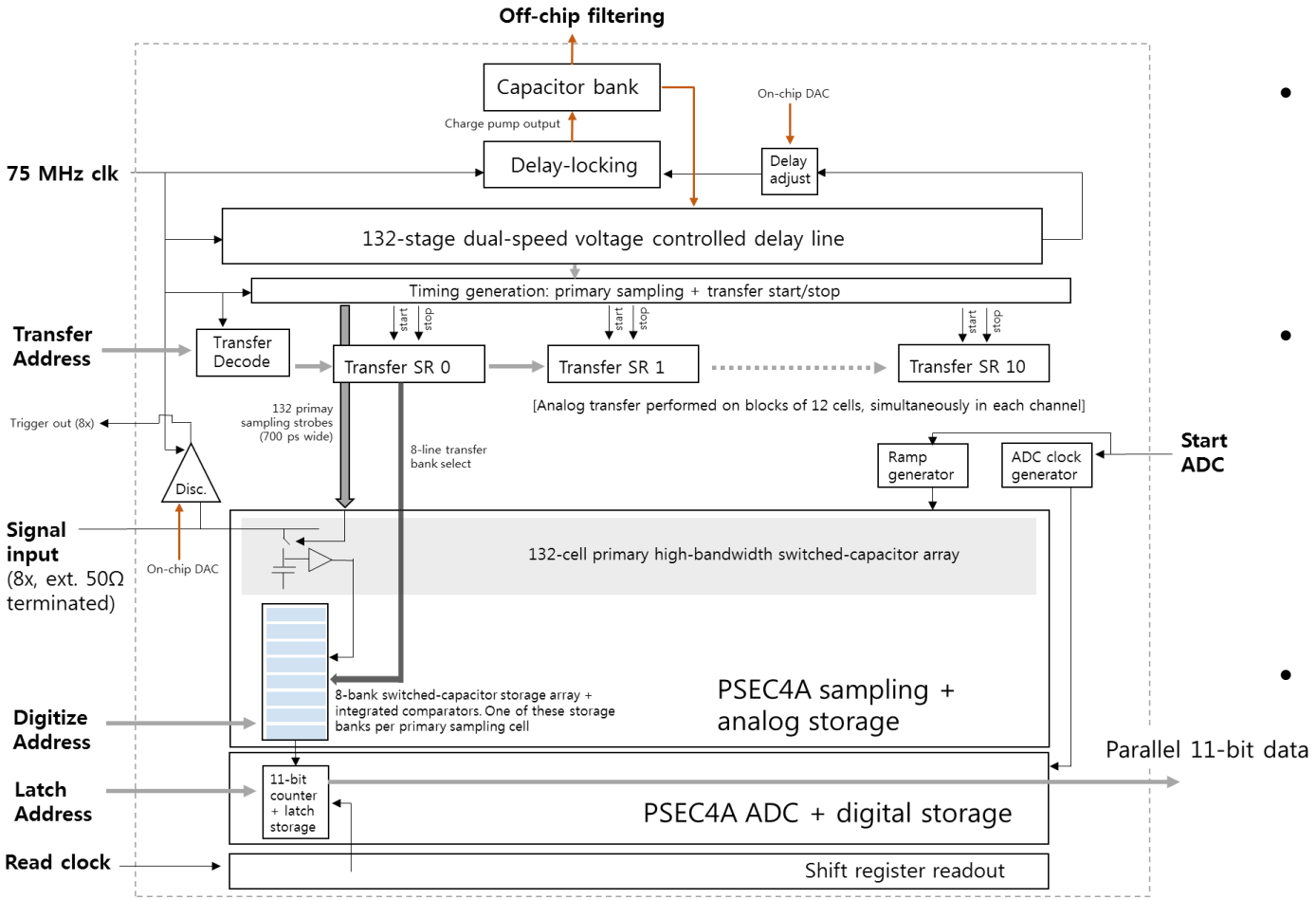
Overlapping of 9000 signals observed with AGILE instrument using an Americium 241 source placed on top a Si-detector. This charge signal is amplified by our FEE board and sampled by PSEC4 at7.7 GSa/s.



PSEC4A

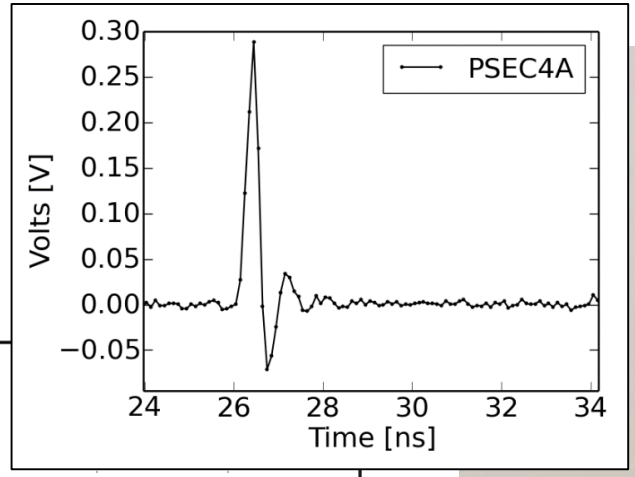
256 → 1052 samples/channel, written in addressable blocks to operate in multi-buffer mode

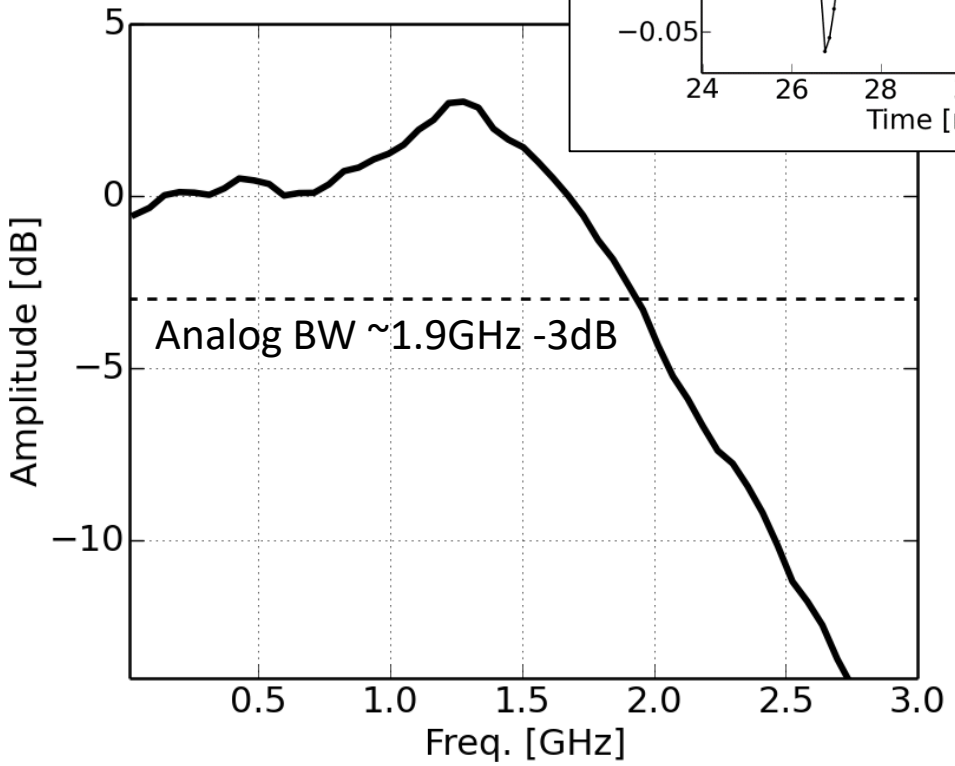


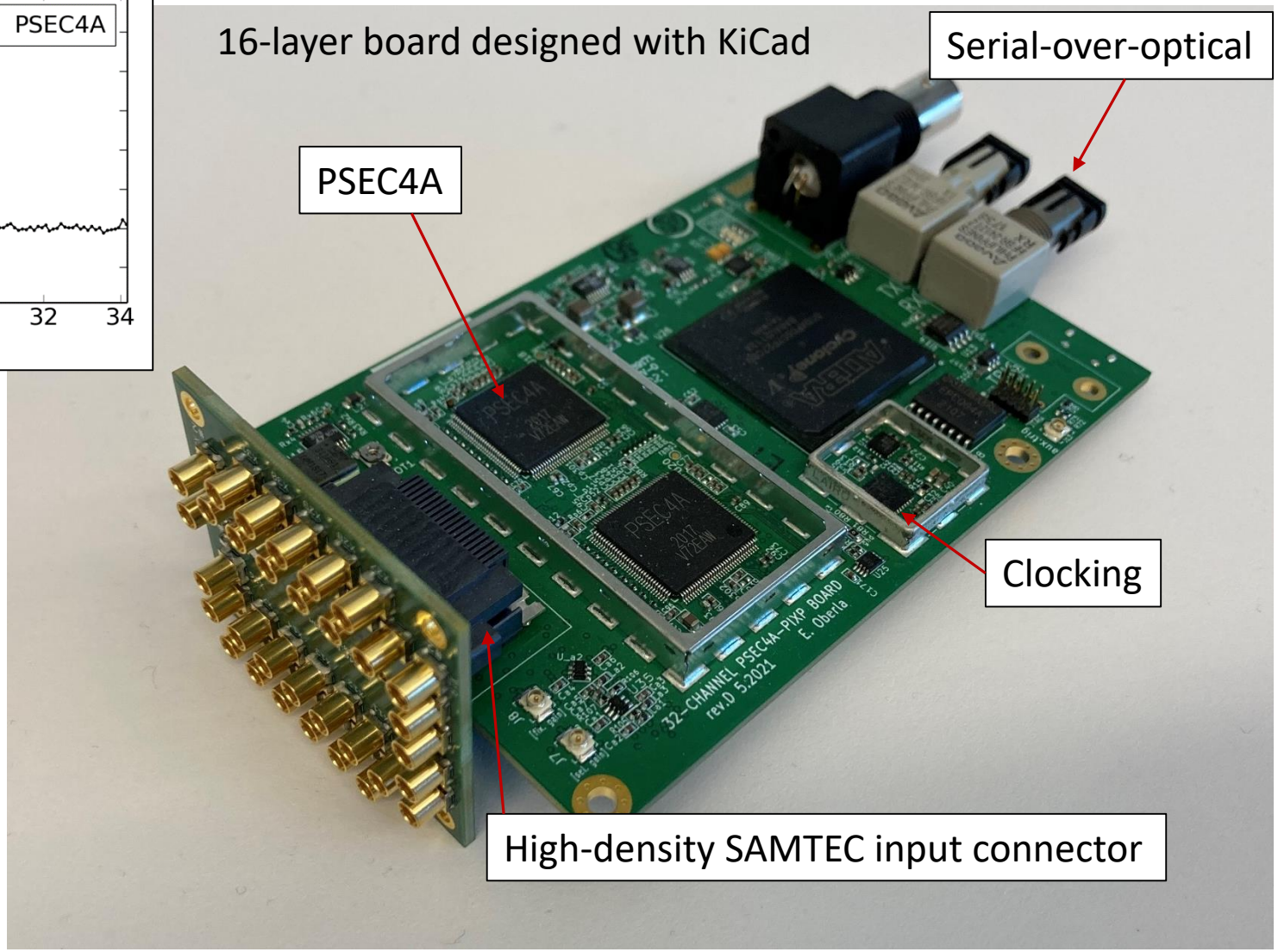


- The PSEC4A is based on a 132-sample primary switched capacitor array (SCA), which is driven by an voltage controlled delay line that feeds a timing generator circuit. At 10GSa/s operation, ~700 ps wide sampling strobes are generated for each primary cell.
- Each primary cell has a buffer amplifier and a closely integrated bank of 8 storage capacitors, which are addressable by the FPGA controller. The transfer window is hard-wired on chip to be 96-sampling intervals in duration. Blocks of 12 primary cells are transferred to the addressed storage cell simultaneously in all channels over a period of ~10 ns (when running at 10 Gsa/s).
- Digitized data are stored in a 4-bit serial latch that is included with each bit in the ADC counter, which saves the digital samples before the higher latency serial readout (~2 µs per 132 samples per channel

PSEC4A-PixP 32-ch high-density board



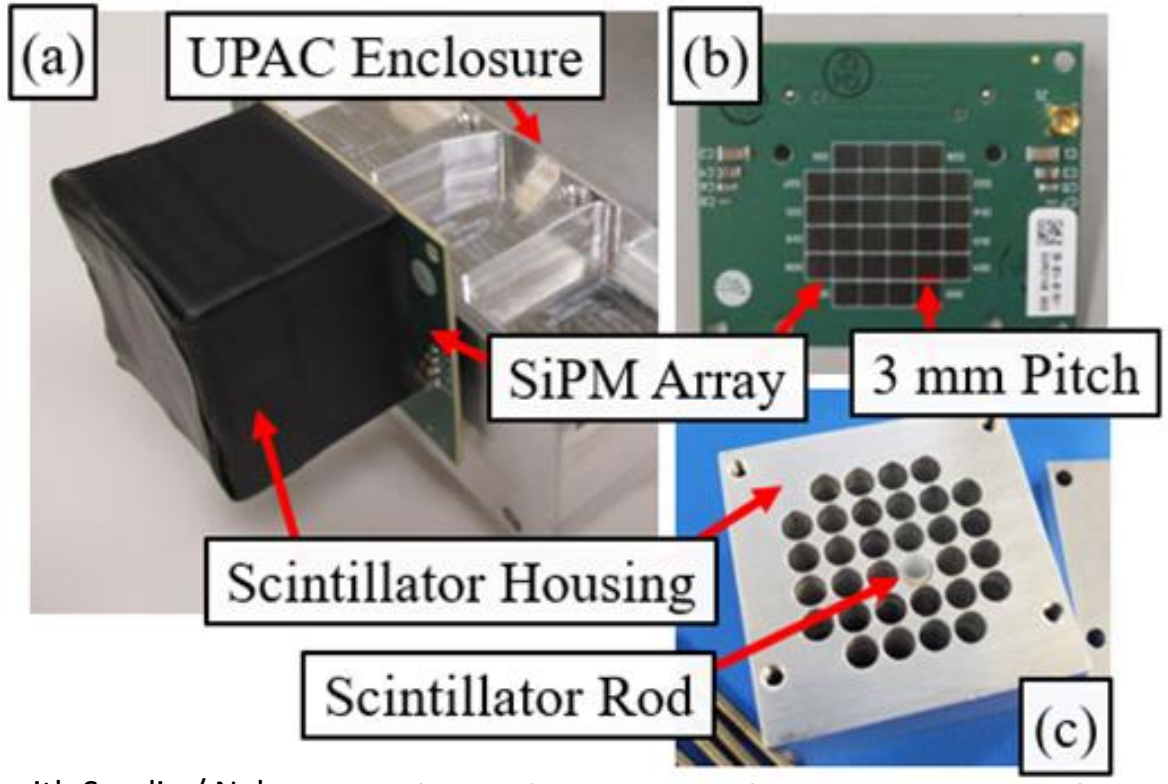




PSEC4A Application: Neutron Spectrometer

Plastic scintillator + high-density 9.25GSa/s PSEC4A waveform-capture neutron time-of-flight detector

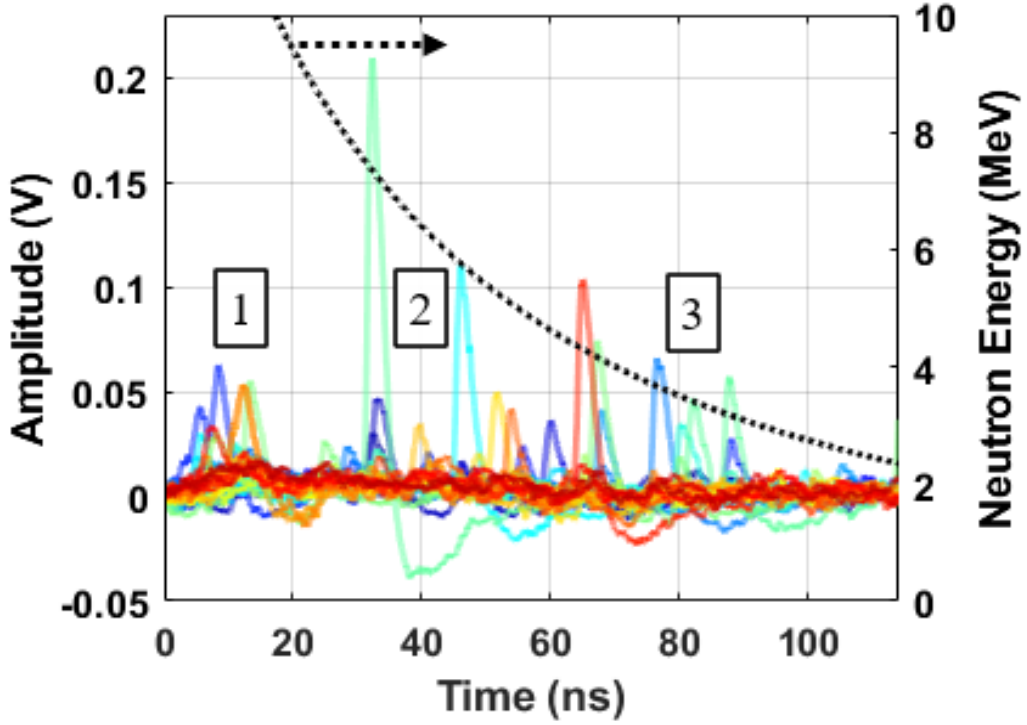
UPAC: Ultrafast Pixel Array Camera



Work with Sandia / Nalu

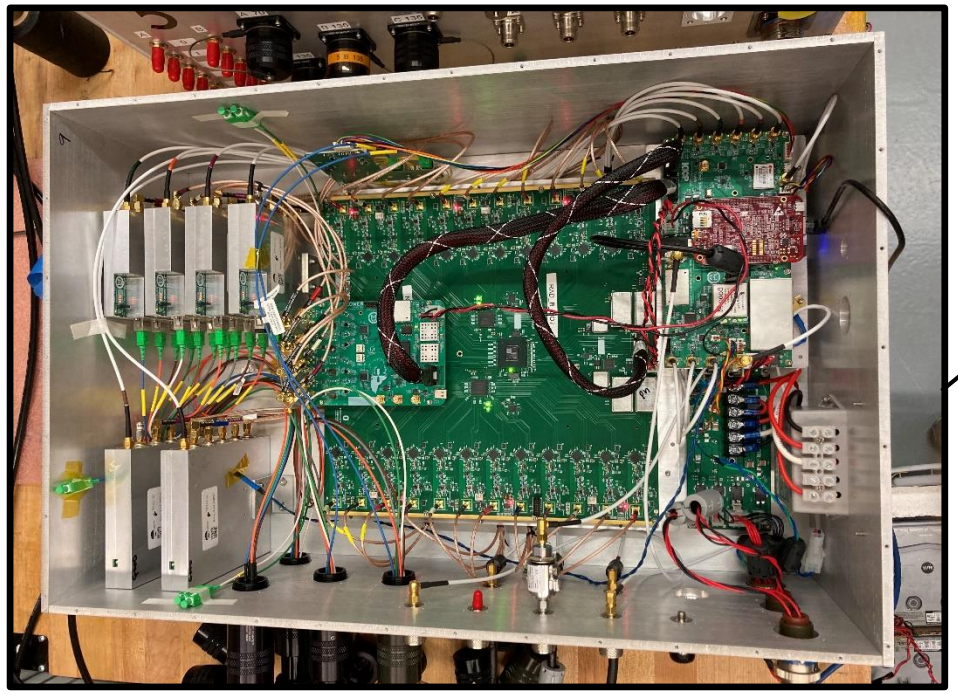
Submitted to RSI: Q. Looker, EJO, J. Porter *et al*

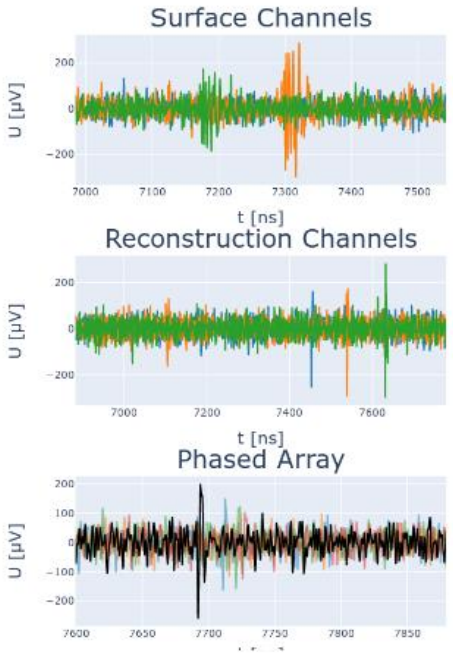
Example neutron detector data. Unique colors represent independent detector channels. Region 1 shows the baseline recovery from the photon flash and what are likely associated after-pulses in the SiPMs. Region 2 indicates the arrival of energetic neutrons. Region 3 shows a cluster of similar neutron interactions around 2-3 MeV.



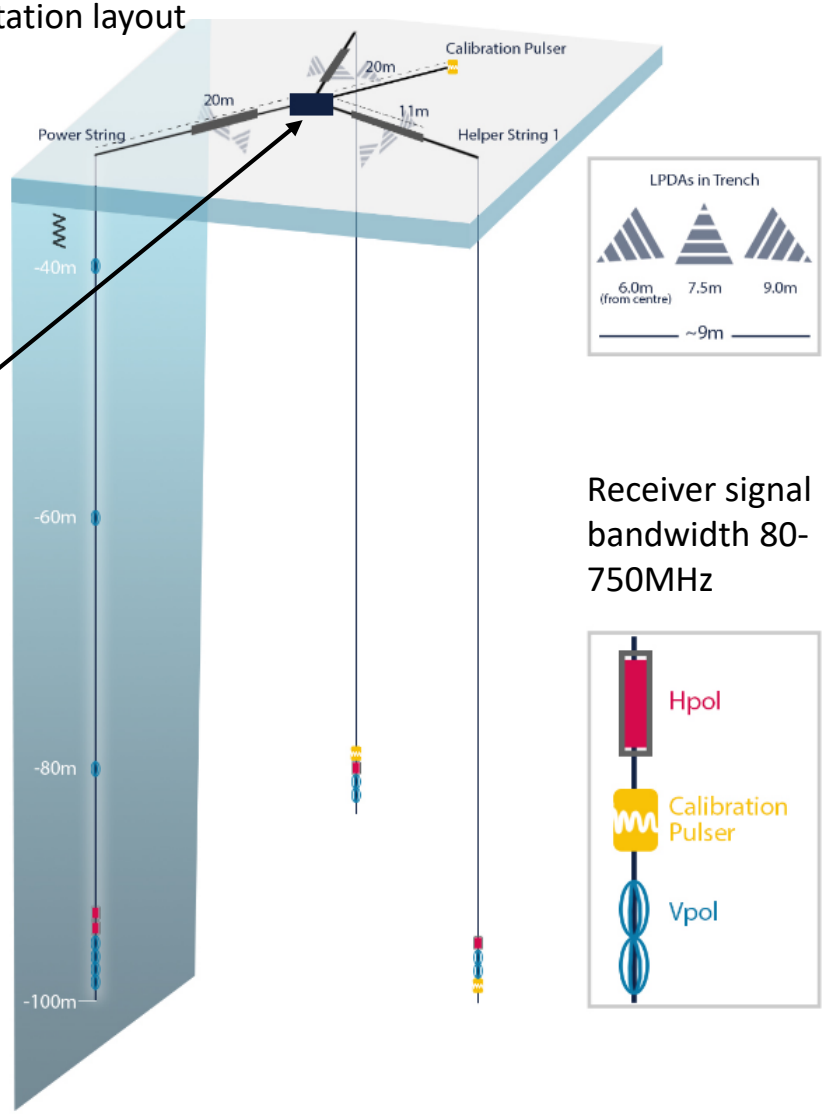
Upcoming work: robust ‘slow’ sampler in 180nm TSMC, as a part of TerraDAQ

- Essentially a translation + upgrades of the PSEC4A design to TSMC 180nm, funded with an internal seed grant here at KICP. Primary application of this chip is remote astro-particle radio detectors (e.g. future RNO-G & IceCube gen2 radio) as a part of TerraDAQ: a low-power fully integrated DAQ and trigger.
- Targeting 500MSa/s to 2 GSa/s sampling range. Investigating fully-synchronous sampling vs. delay-line timing generation
- Multi-event buffering, ~1µs buffer depth, ease-of-use and ease-of-calibration are major goals





Radio Neutrino Observatory in Greenland (RNO-G) station layout



Receiver signal bandwidth 80-750MHz