DUNE Photon Detector Review
Photosensor Baseline & Testing

V. Zutshi
for the DUNE Photon Detector Group

8/2/16

DUNE PD Photodetector Team

Has fabricated, commissioned and operated SiPM-based detectors (calorimetry, muon detection, tracking, ….) successfully:

- G. Blazey[1)], D. Boyden[1)], N. Buchanan[2)], A. Dyshkant[1)], M. Eads[1)], K. Francis[1)], L. Mualem[3)], D. Warner[2)], V. Zutshi[1)]
- In collaboration with: Z. Djurcic[4)], G. Drake[4)], S. Mufson[5)]

  1) Northern Illinois University

  2) Colorado State University

  3) California Institute of Technology

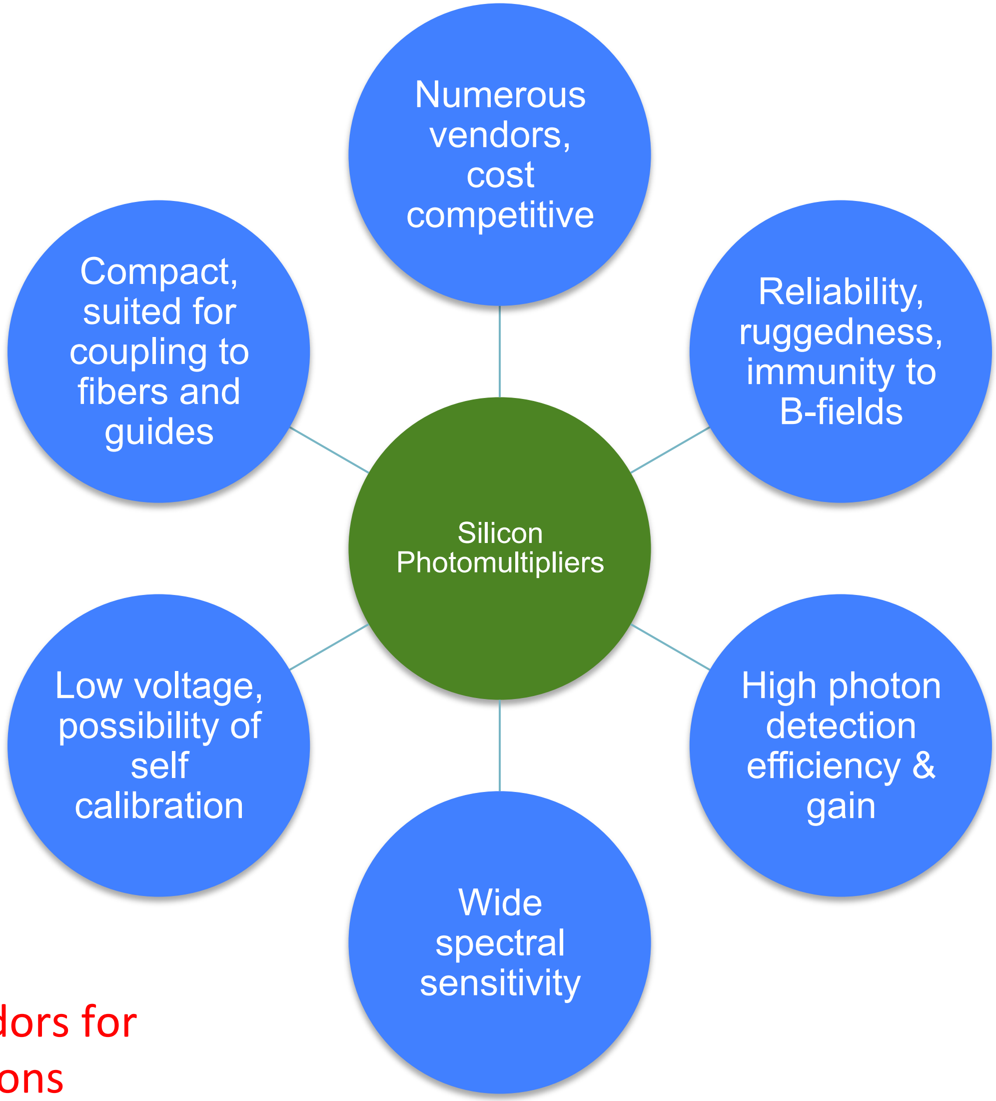
  4) Argonne National Laboratory

  5) Indiana University

Photosensors and proto-DUNE

- Both an opportunity and constraint
- Opportunity to validate baseline design and develop crisp photosensor requirements
- Constraints to some degree the resources that can be devoted to photosensor R&D which will however need to continue in parallel
  - Photosensor choice due to fast evolution of technology
  - Ganging schemes
- Based on testing carried out over 2014-15 SensL was deemed to appropriate for the proto-DUNE baseline choice

Photodetector Choice



Not rated by vendors for cryogenic operations

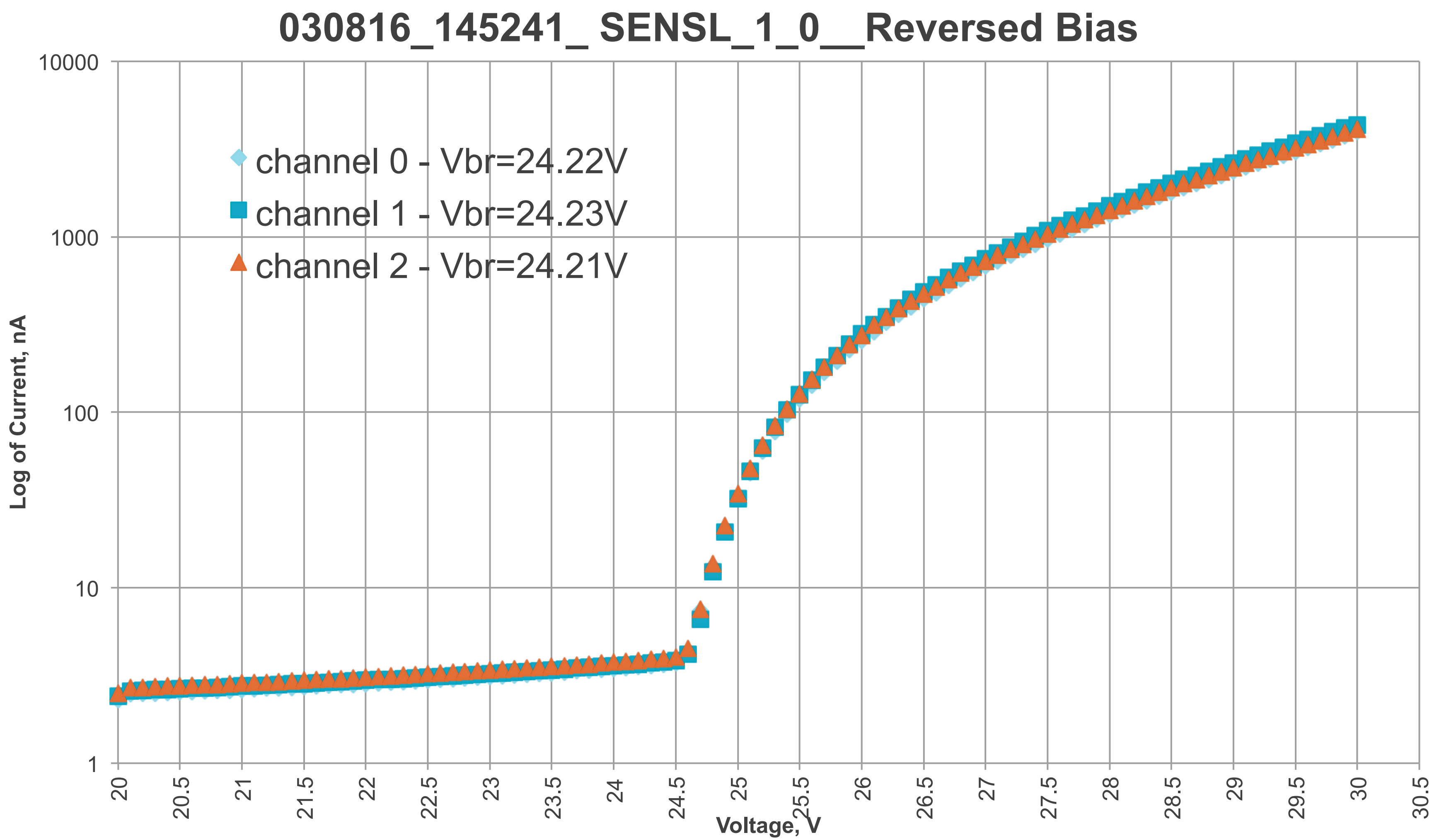
Device Specifications

- All values at 25^{o} C at overvoltage of 2.5V:
  1) 6mm x 6mm, 35 µm pixels
  2) Surface-mount packaging
  3) PDE > 30% (420 nm)
  4) Gain ≥ $3.0*10^{6}$
  5) Pulse rise time < 10 nsec
  6) Dark rate < 1.5 MHz @ 0.5 PE threshold
  7) X-talk (inter-pixel) < 10%
  8) Bias spread: ±0.25 V
  9) Temperature dependence ≤ 25 mV/^{o}C

SensL SiPM Part Number: MicroFC-60035-SMT

- Will be part of the RFQ and purchase requisition

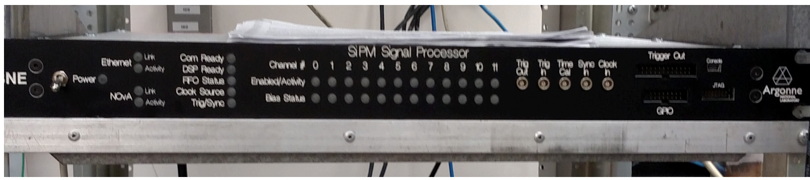
I-V Scan (room temperature)

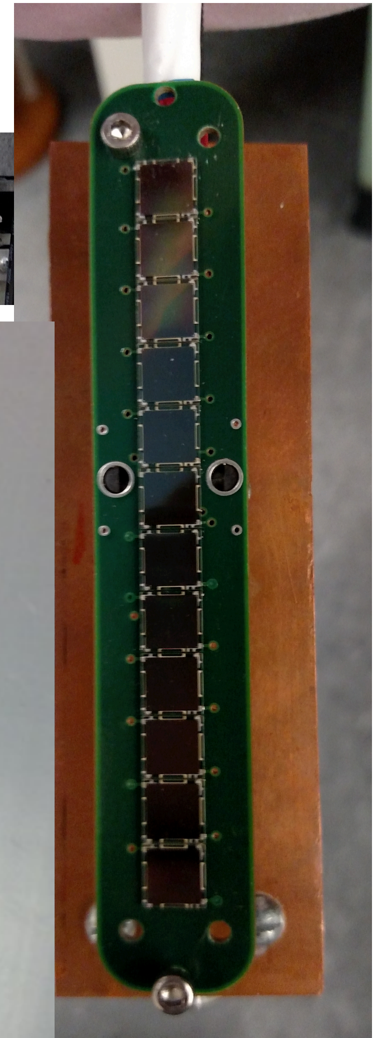


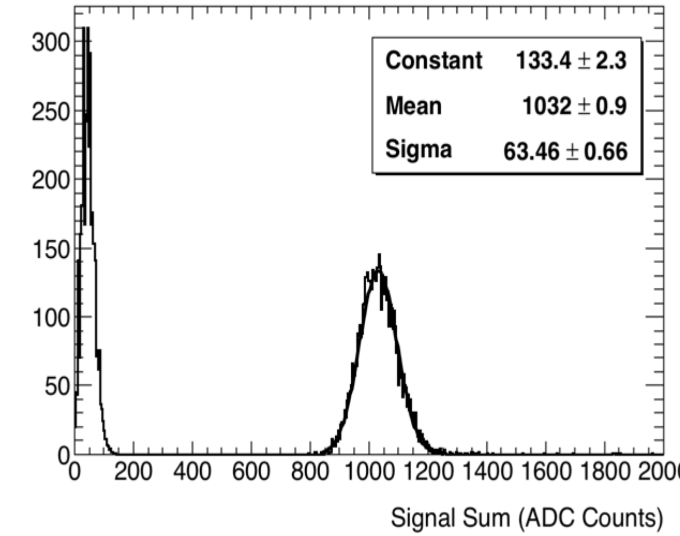
DEEP UNDERGROUND NEUTRINO EXPERIMENT

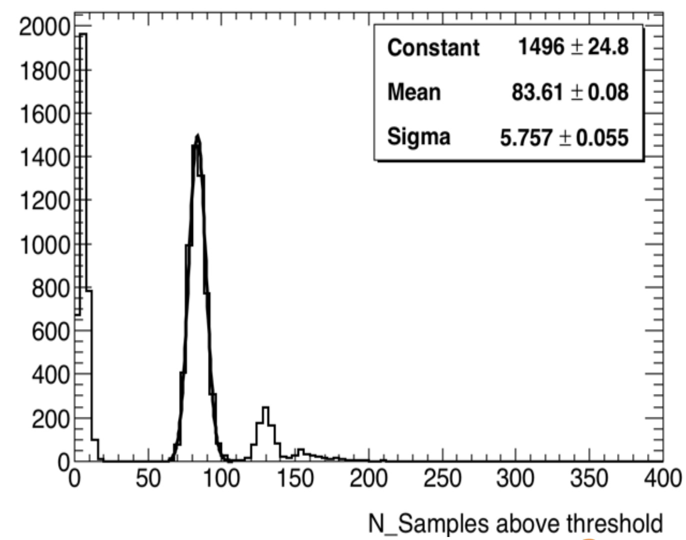
Test Components

SSP: waveform digitizer with 14-bit 150MSPS ADC (12 channels)







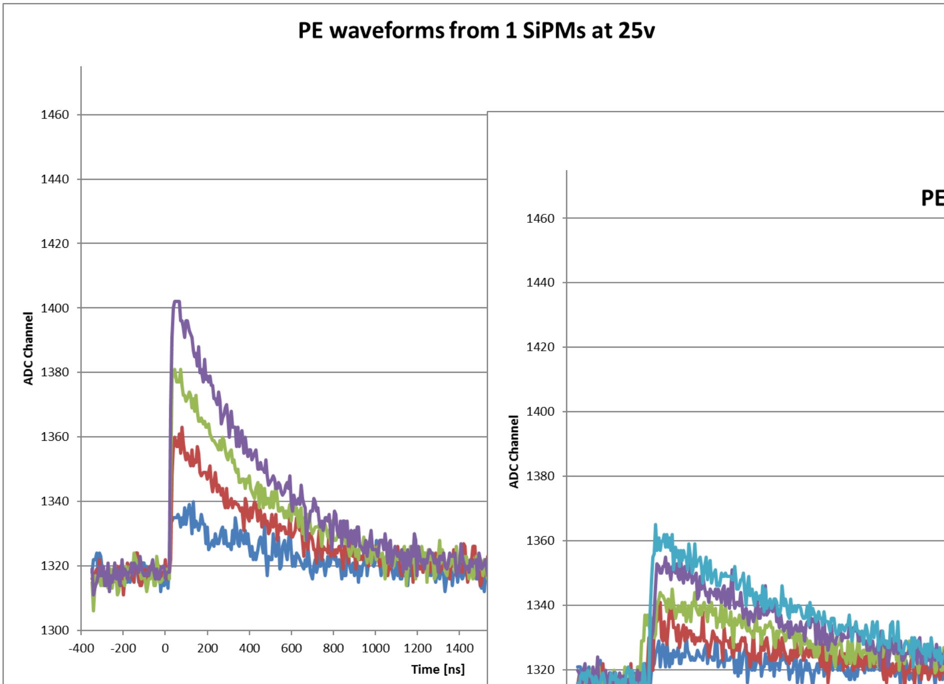


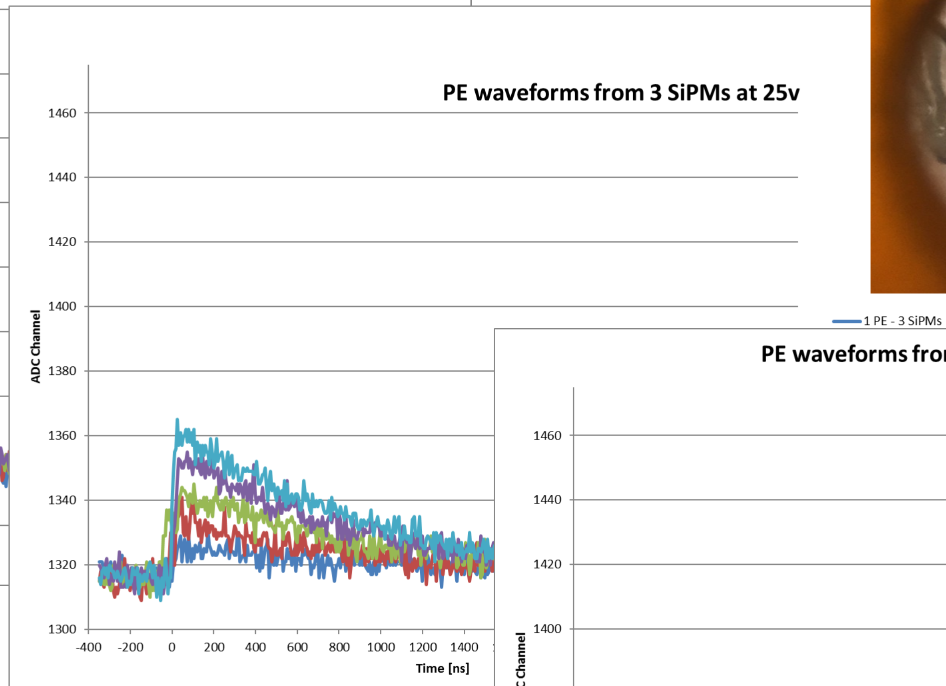
See Z. Djurcic's talk for details

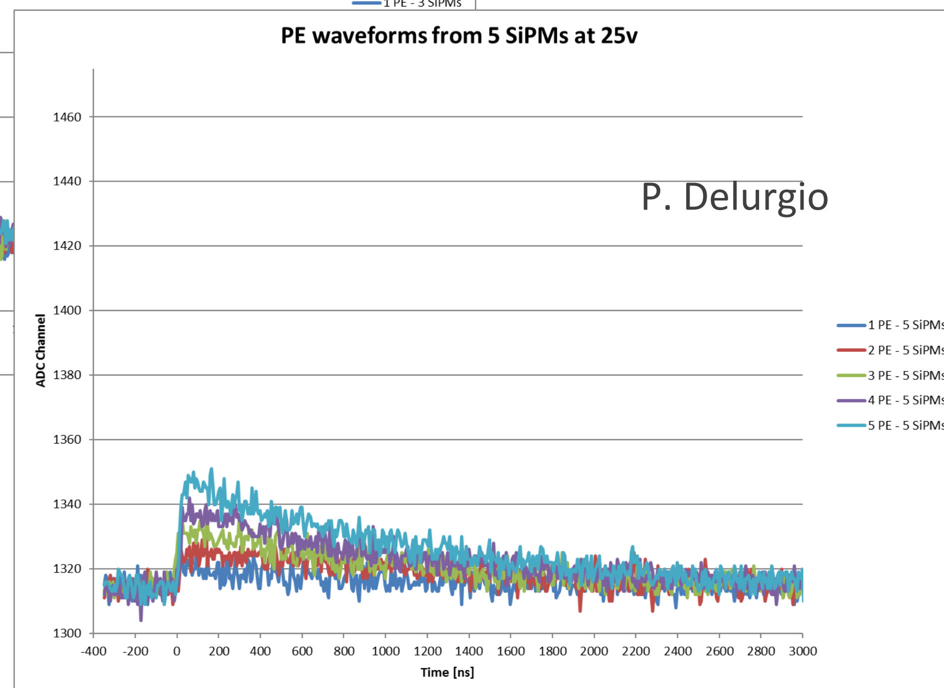
Ganging

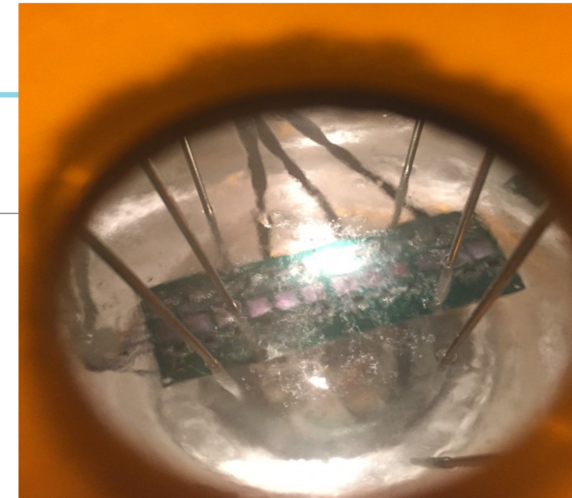
- To reduce both the number of cables penetrating the cryostat and the number of readout channels
- These desires need to be balanced with considerations related to performance and impact of failures
- Number of ganging schemes possible (passive, active, in-and-out of cryostat etc.)
- Most plausible solution for proto-DUNE given the schedule and cost constraints: passive, parallel ganging inside cryostat
- Studies carried out at ANL, IU and NIU using C-series SensL sensors dipped in LN_2 and connected to a SSP using a CAT6 PTFE cable (20-40 m)

Ganging









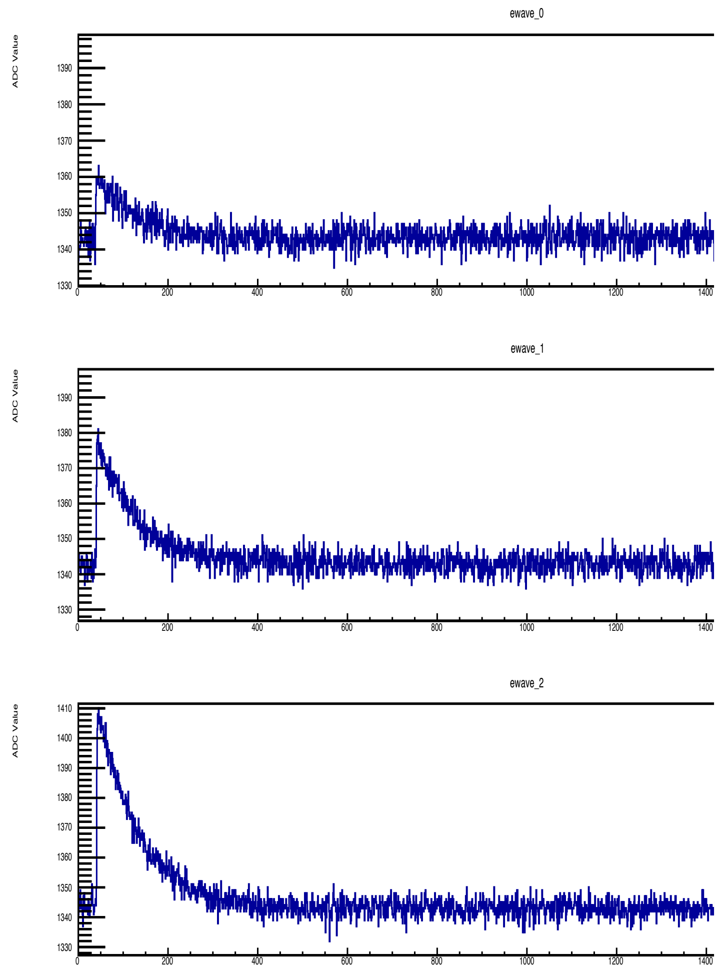
P. Delurgio

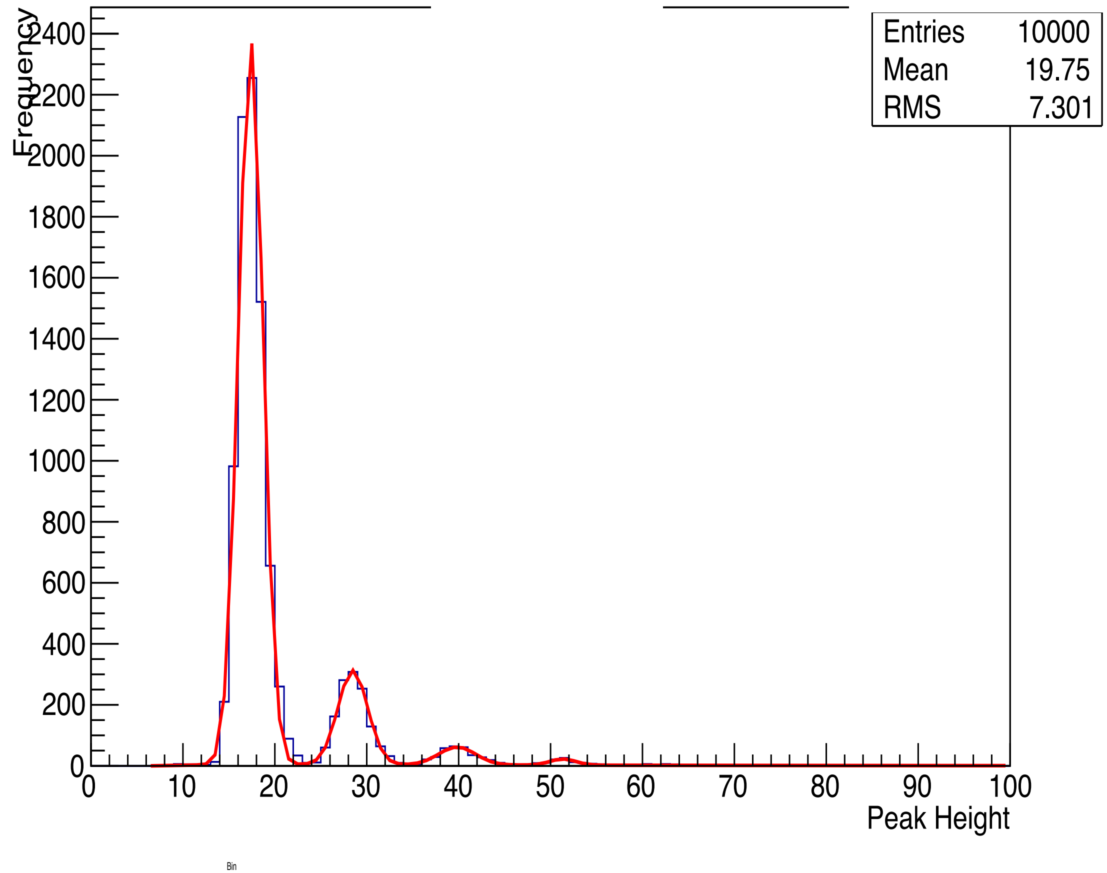
For the low-threshold mode the PD intends to run in, S/N considerations discourage passive ganging of more than 3 SiPMs inside detector

Baseline (for proto-DUNE)

- Silicon Photomultiplier readout (12 per paddle)
- Bring analog signals out with cables
  - Conservative approach with the most viability with the current infrastructure
- Gang 3 sensors in parallel
- CAT6 PTFE cable
  - Fine from the point-of-view of LAr contamination
  - Twisted pairs to reduce pickup over long lengths
  - Significantly reduced cable volume, number of connectors and cost over single twisted pair cables
- Waveform digitizer FEE for flexibility

Baseline Performance

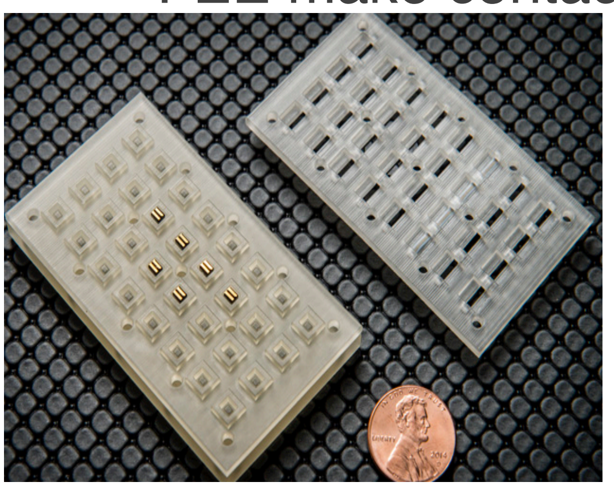


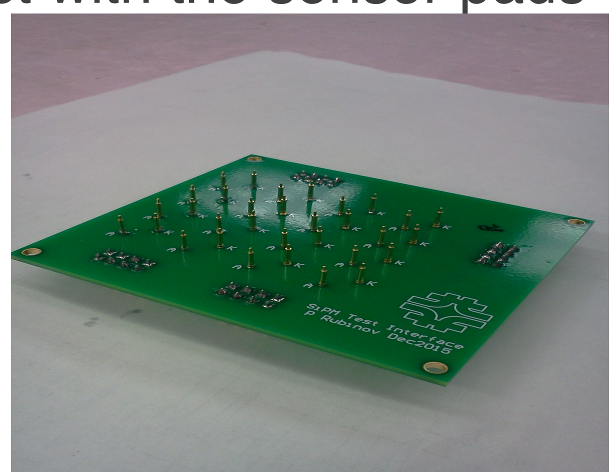


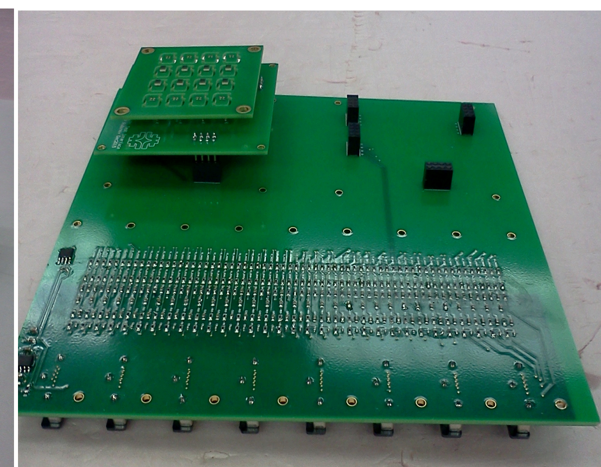
SSP output using CAT6 cable connected to the "ganged" SiPM board

Quality Control (Procedure)

- Warm Testing (NIU)
  - Done immediately after receipt of sensors and before mounting them on the carrier boards
  - Minimizes chances of mounting bad SiPMs on the boards
  - Sensors put into custom 3-d printed “waffle packs” (allow for electrical contact and part tracking before mounting)
  - Pogo pins mounted on a passive board which connects to the FEE make contact with the sensor pads







Device Testing

- Measurements:
  - Forward and reverse bias I-V curves
  - Break- down voltage
  - Dark current and dark count rate
  - Gain and gain resolution
  - X-talk
  - Response
  - Bias dependence of above

Quality Control (Procedure)

- I-V curves, dark spectra and LED response recorded for each sensor in these warm measurements
- Comparison of breakdown, gain, x-talk etc. to device specifications
- A few % kept aside
- Mounting of SiPMs on Mounting Boards (CSU)
  - Tested waffle-packs along with their travellers shipped to Fort Collins
  - Sensors are baked-out and mounted in-house
  - Database maintained
  - Visual and electrical inspection
  - Populated carrier boards are shipped back to DeKalb for cold testing

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Quality Control (Procedure)

- Cold Testing (NIU/Caltech)
  - SiPMs fired up warm to do quick live check
  - Testing in LN_2 with CAT6 PTFE cable connected to a SSP
  - Dark and LED measurements (note that on the board the devices are ganged in 4 groups of three)
  - Ship certain number of boards to Caltech for x-check
  - Tested SiPM boards are shipped to CSU for installation
- Installation on PD module (CSU)
  - SiPM board interfaced with PD assembly and warm live check performed followed by scan of PD using VUV light source
  - Module dipped in LN_2 and SiPMs readout
  - Warm VUV scan of modules
- Shipment to CERN

Quality Control (Acceptance)

- Stage 1 (SiPMs ready for mounting): sensors pass warm live check and exhibit parameters consistent with specs
- Stage 2 (SiPM boards ready for cold testing): stuffed boards pass visual inspection and connectivity tests
- Stage 3 (SiPM boards ready for module assembly): All 4 channels on the SiPM board deliver required performance
- Stage 4 (module assembly ready to go cold): warm live check and VUV scan after assembly successful
- Stage 5 (module ready to ship to CERN): readout of sensors with module in LN_2 followed by warm scan ok
- Stage 6 (module ready for installation in proto-DUNE): warm live check of sensors on receipt of modules checks out

Schedule

- Design modifications to warm tester: Sept., 2016
- Fabrication of warm tester complete: Oct., 2016
- Warm testing starts: mid-Oct., 2016
- Tested waffle-packs shipped to CSU: mid-Nov., 2016
- Stuffed SiPM Boards shipped from CSU: mid-Dec., 2016
- Cold-tested SiPM boards shipped to CSU: mid-March, 2017
- Installation on PD modules commences: April, 2017

Risks

4 - NO -- risk does not impact FS-CF	1 (Low)	**FD-089**	**Photon detector SiPMs are not qualified for cryogenic use**	The PD system reference read out device SiPM's are not rated for cryogenic temperatures. If they are found to have quality problems at cryogenic temperatures, then cryogenic PMT's will have to be used instead at extra cost.

- See talk by S. Mufson
- Another long-term testing stand being setup at Caltech

Environmental, Safety, & Health

- In consultation with safety personnel at home institutions
- SiPM operation
  - SiPM operating voltages vary by vendor (generally within 20 - 80 V)
  - Devices of most interest to us will be in the 20-30 V range
  - Operation of SiPMs will follow Fermilab ES&H Manual (FESHM) standards for electrical equipment operation.
- QC SiPM testing jig
  - Hazards are minimum (Soldering, epoxy, etc.)
- LN_2 handling
  - Standard safety procedures (gloves, safety glasses etc.)
  - Volume of LN_2 in SiPM testing is not big enough for ODH issues

Summary

- proto-DUNE operation will be a key input in the validation of the current baseline and for continued photosensor R&D for the DUNE detectors
- For proto-DUNE the baseline design for DUNE PD photosensor readout has been specified and tested in installations at several institutions
- SensL MicroFC-60035-SMT ganged in parallel in groups of 3 read out with CAT6 PTFE cable going to a SSP
- A plan for quality control of the photosensors has been developed along with a specification of institutional responsibilities