Photosensors for the DUNE Photon Detector System

R. J. Wilson (Colorado State University)
V. Zutshi (Northern Illinois University)

for the DUNE Photon Detector Consortium

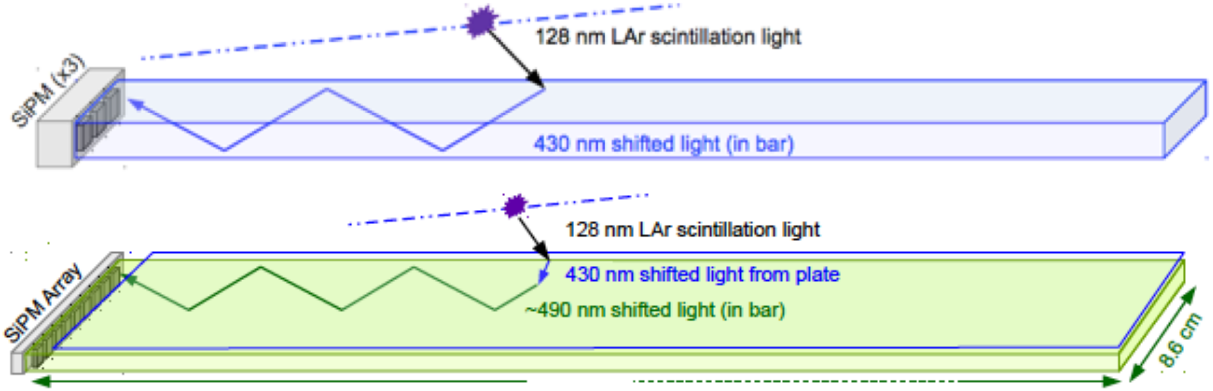
Outline

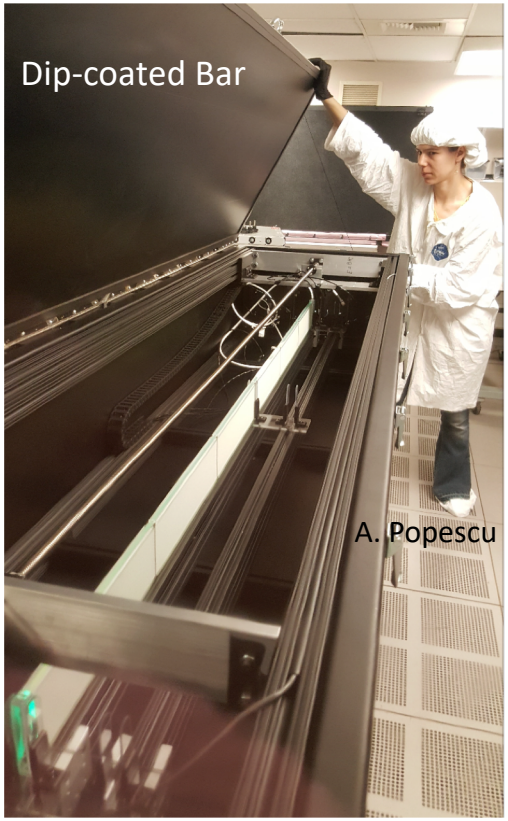
- DUNE Photon System in a nutshell
- Initial Photosensor Studies
- ProtoDUNE experience (Fall 2016 onwards)
- Key considerations
- First look at FBK 6x1 array

DUNE Photon Detector System

Three module types:

- **ARAPUCA ← goal**
- **Two light guide style ← alternative**





Two types of light guide bar modules

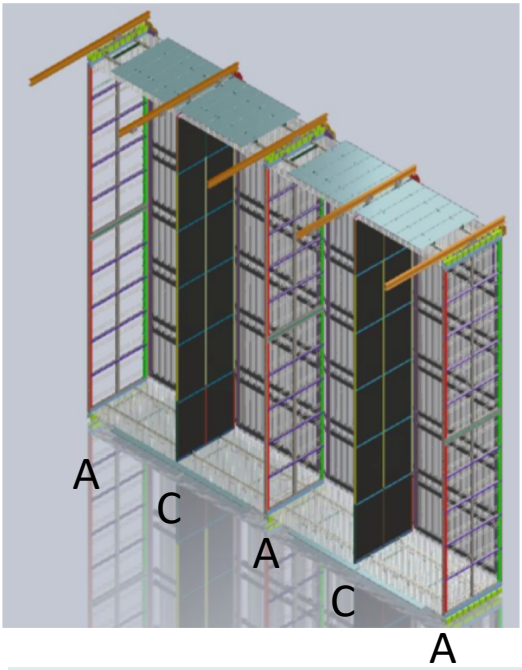
- Dip-coated in TPB
- Double-shift: Plates coated with TPB in close proximity to commercial bar doped w/ wavelength-shifter

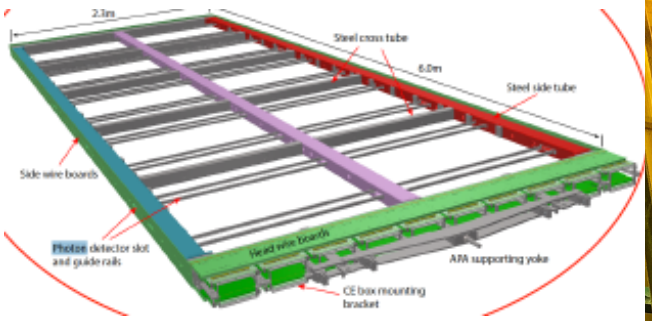
Each has 12 x 0.6 x 0.6 mm^2 SiPMs at one end – two ends being considered

DUNE Photon System

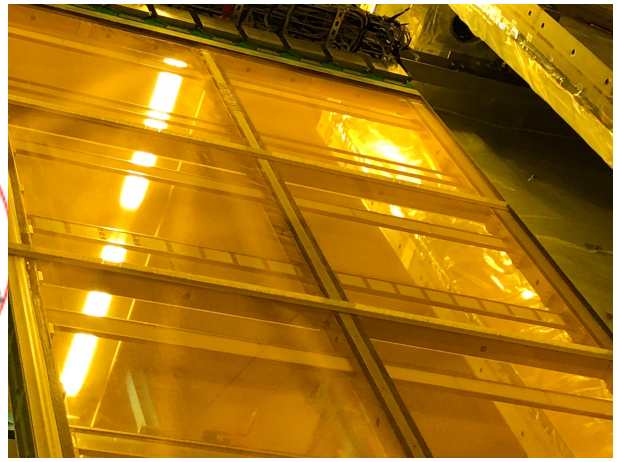
PD Modules are embedded in an Anode Plane Assembly (APA)

First full scale test in ProtoDUNE at CERN: Six full-scale APAs – ~Aug 2018





APA



APA in ProtoDUNE
- 3 types of photon detector modules visible

- The <u>first</u> 10 kt LAr Single-Phase LAr Far Detector has 150 APAs each with 10 PD modules
  - Ultimately there will be 4 x 10 kt – opportunities for new approaches later
- Light guide designs: **18,000**-36,000 (single or double-ended readout) SiPMs
- ARAPUCA: 144,000 - **288,000 SiPMs**
- ➔ **0.65-10.4 m^2 of active SiPM surface area**

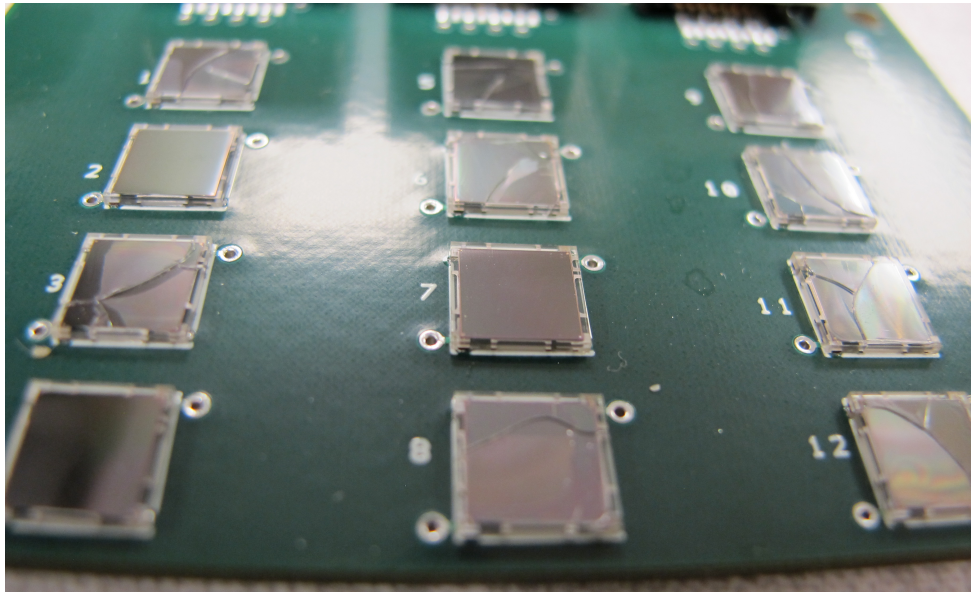
Initial Photosensor Studies

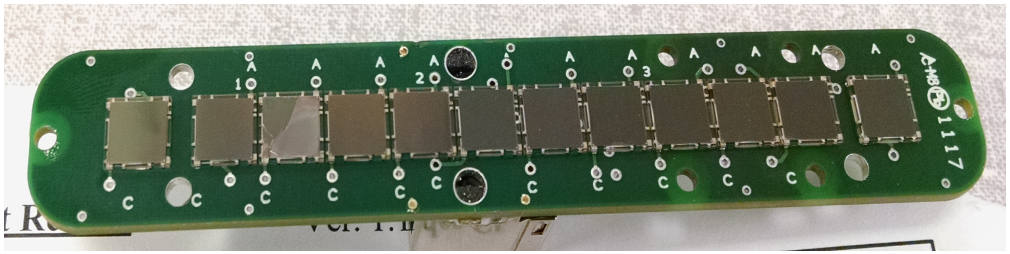
- Sustained photosensor R&D for DUNE carried out primarily at CSU, U. Hawaii and Indiana University
- Devices from a number of vendors tested especially Hamamatsu and SensL
- Afterpulsing issues (cryogenic temperatures) with Hamamatsu devices of that era were observed
- Also packaging was susceptible to cracking though not necessarily correlated with changes to electrical properties
- SensL devices did not show any anomalies physically or electrically
- SensL C-Series device chosen as the photosensor for ProtoDUNE

Preparation for ProtoDUNE – Lo Shock!

- 1700 SensL MicroFC-60035-SMT were purchased
- Same part number as was used in years of pre-ProtoDUNE studies
- After arrival, the devices were mounted on readout boards while observing all soldering and humidity constraints recommended by the vendor
- A very significant fraction (up to 50% in some cases) physically cracked on their first dipping into LN_2
  - cracking whether mounted or unmounted
- Rendered the devices non-functional
- Dipping procedures had not been modified

Preparation for ProtoDUNE – Lo Shock!





- Fraction of failures depended on specific board used but unmounted devices cracked too

Communication with SensL

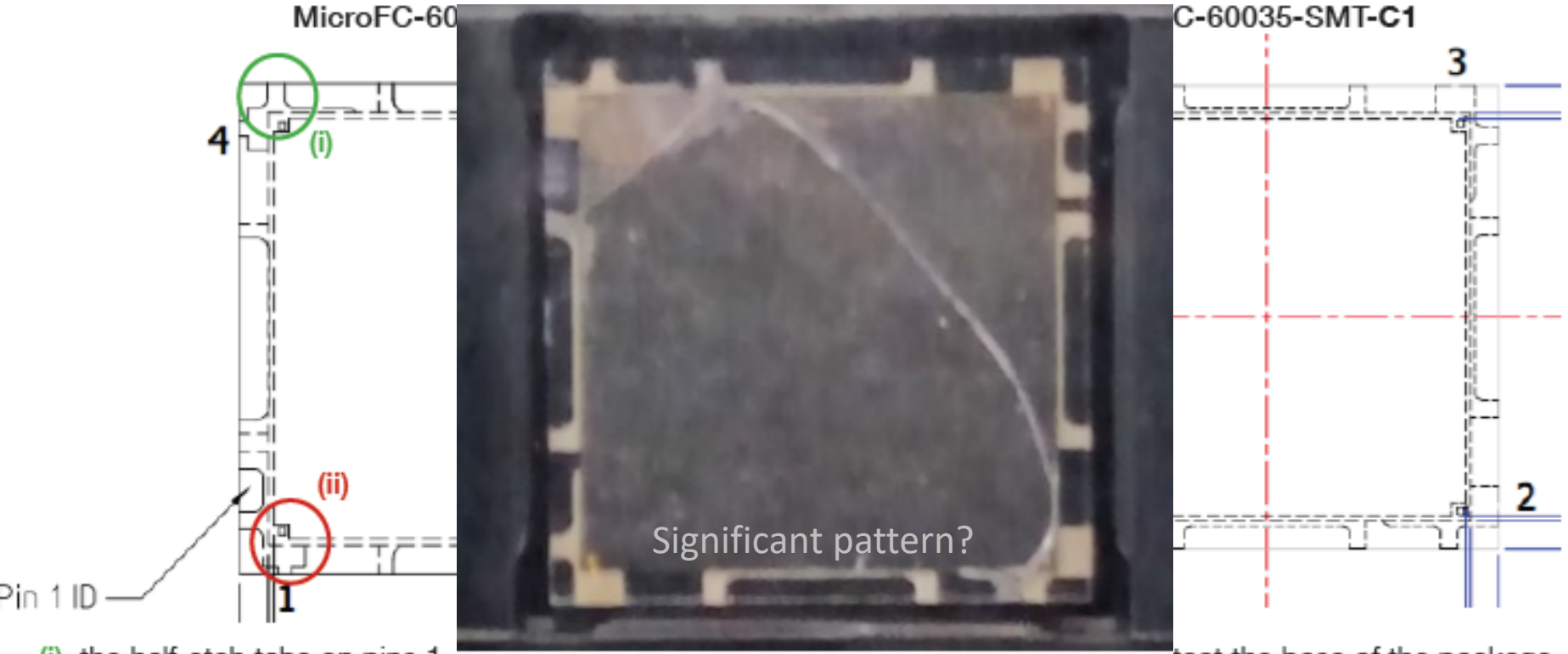
- "…a mold compound change…"
- No PCN issued regarding this to DUNE customers (CSU, IU, Hawaii) at that time
- Since operating outside the vendor operability range → no culpability or recourse
- Vendor declined to fabricate devices using the "old" mold compound and had only 500 pieces of the original version in stock – a problem for our plans
- Not completely clear that the "mold compound" was the (only) culprit
- Searches indicated a PCN had been issued on the location and specifics of the etch pads (DUNE customers were not notified about this either)

PRODUCT CHANGE NOTICE

C-Series MLP (SMT) Package - August 2016

sensL
sense light

APPENDIX



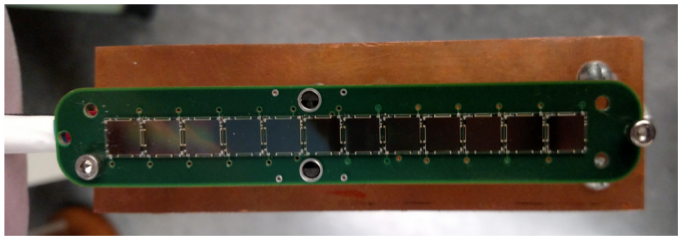
(i) the half-etch tabs on pins 1 - 4 have been relocated. The half-etch tabs do not contact the base of the package as there is package material underneath so there is no change to the package footprint or the recommended solder footprint.

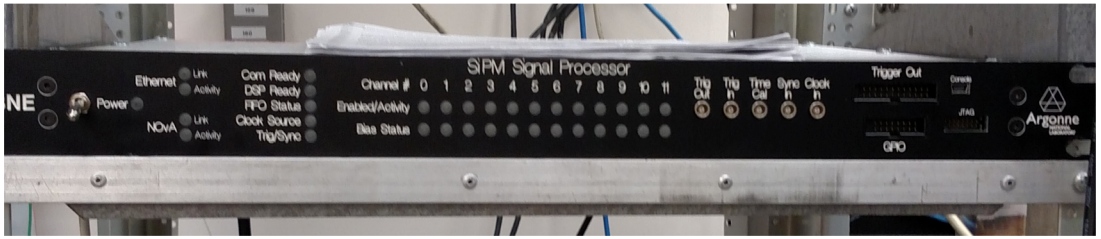
(ii) the pull in etch of the solder pads at the edge of the package has been changed to a flat edge. There is no change to the recommended solder footprint.

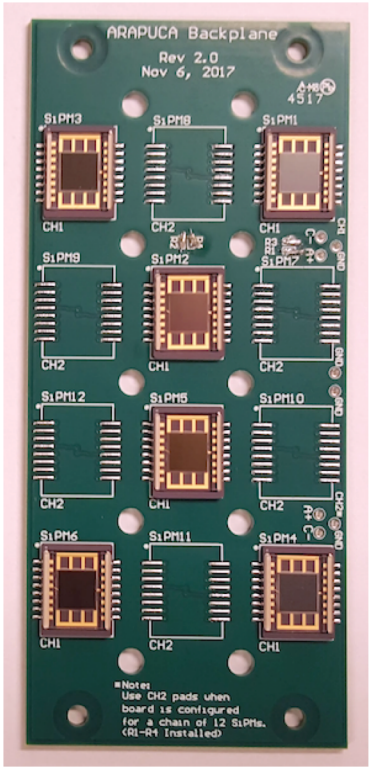
ProtoDUNE (and R&D) Readout

Two pcb configurations.

SSP: waveform digitizer with 14-bit 150 MSPS ADC (12 channels) by a collaborator (ANL)







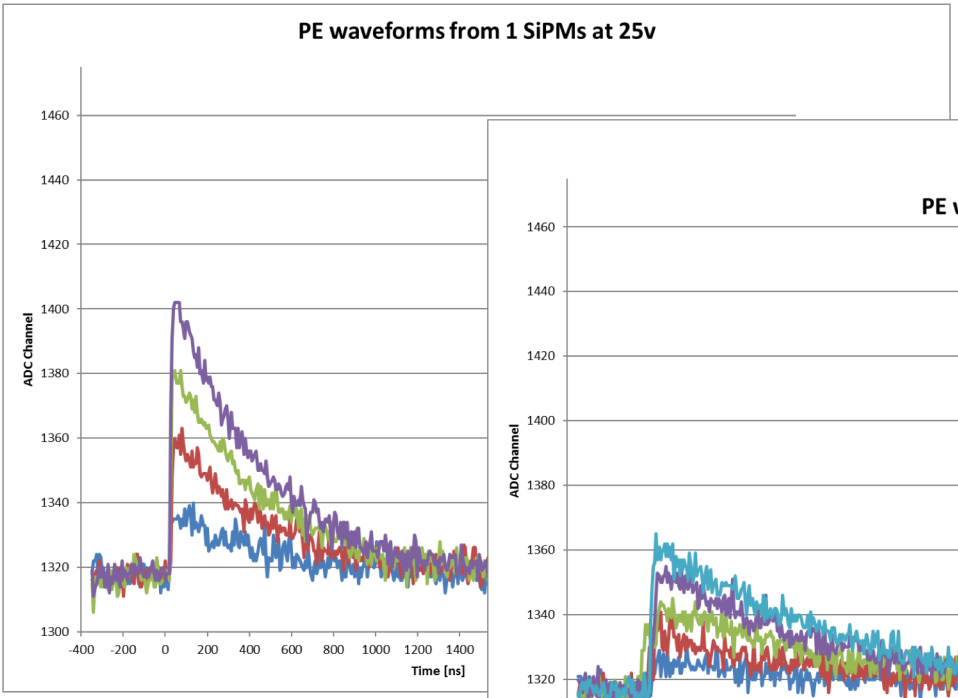
Not demonstrated that waveform is needed for DUNE → charge integration

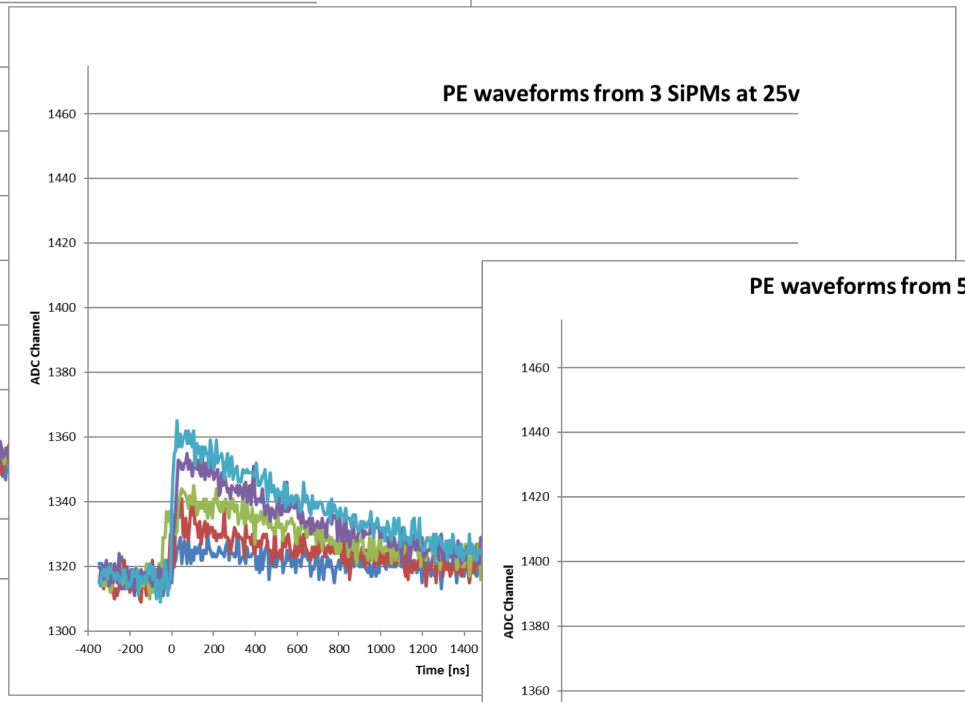
Signal Ganging

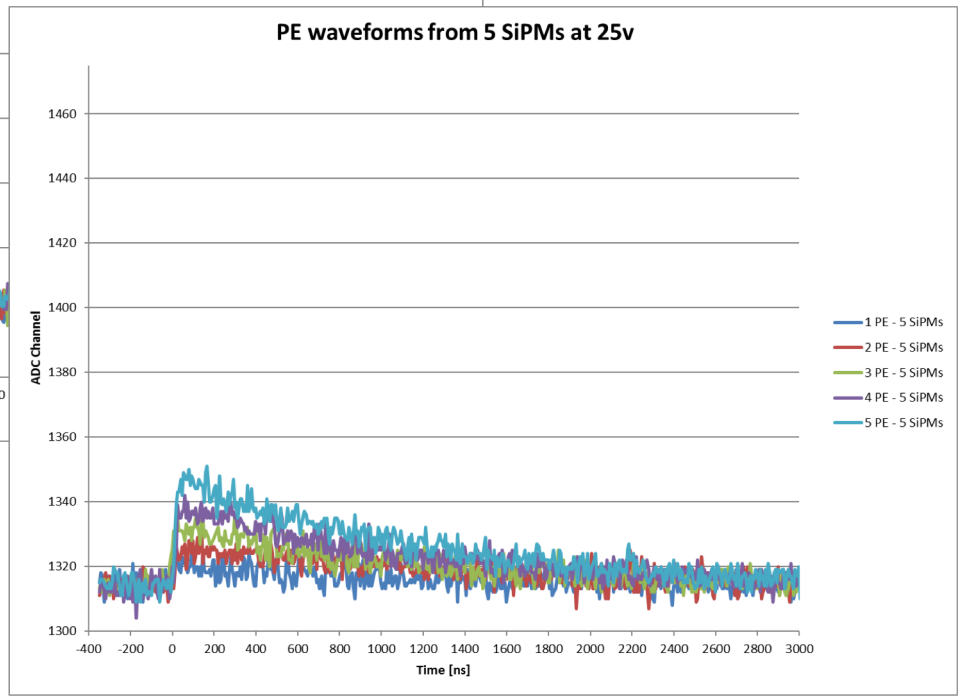
- Limitation on # electronics channels (cost) and cable runs (APA constraint) for DUNE
  → sensor ganging required for any of the collector options
- Passive and active summing under consideration
  - Active certainly required for ARAPUCA
- ProtoDUNE only uses passive ganging of sensors in parallel
- Passive ganging is simpler
  - Signal-to-noise issues with increasing level of ganging

- This afternoon Gustavo will show a few slides on active ganging

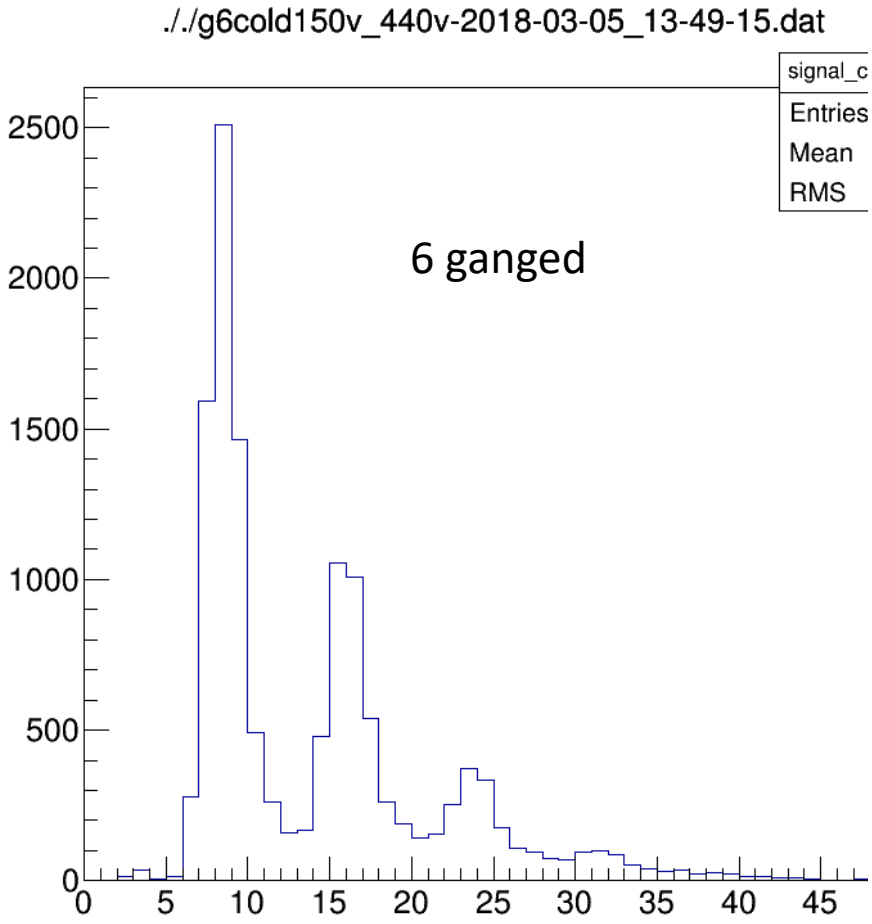
Passive Ganging SensL (~3 nF)

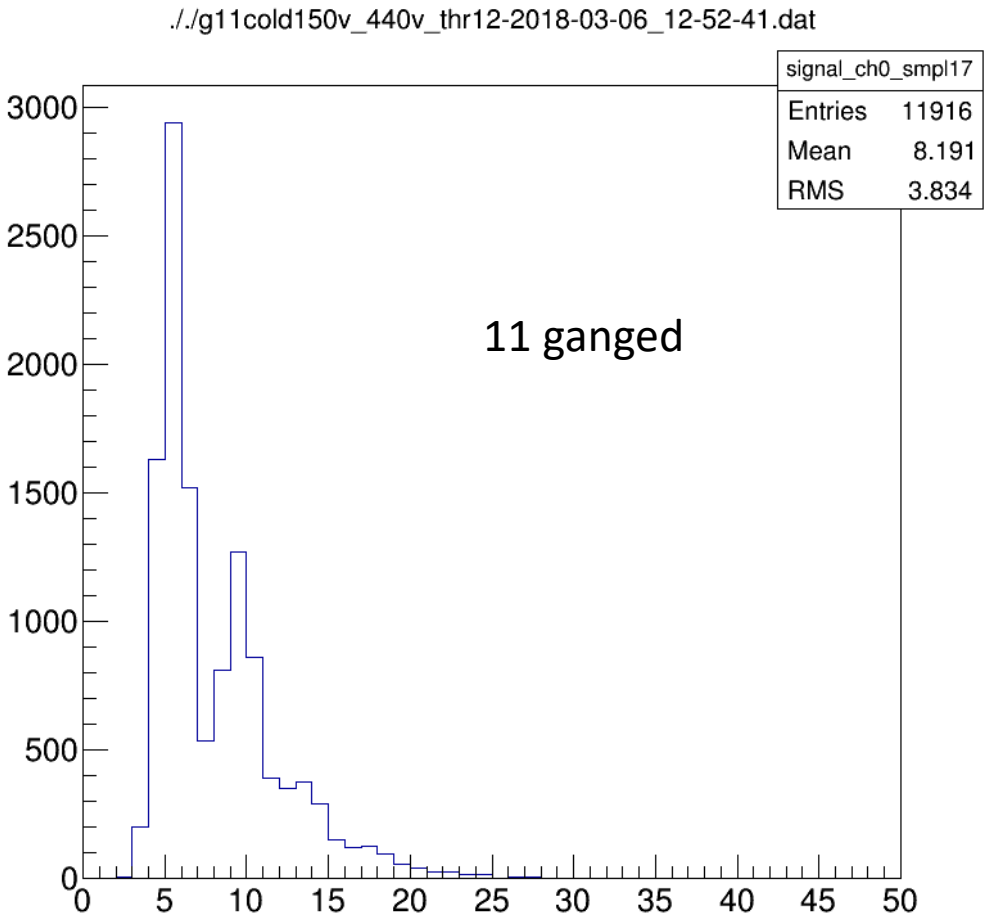






Passive Ganging Hamamatsu (~1 nF)





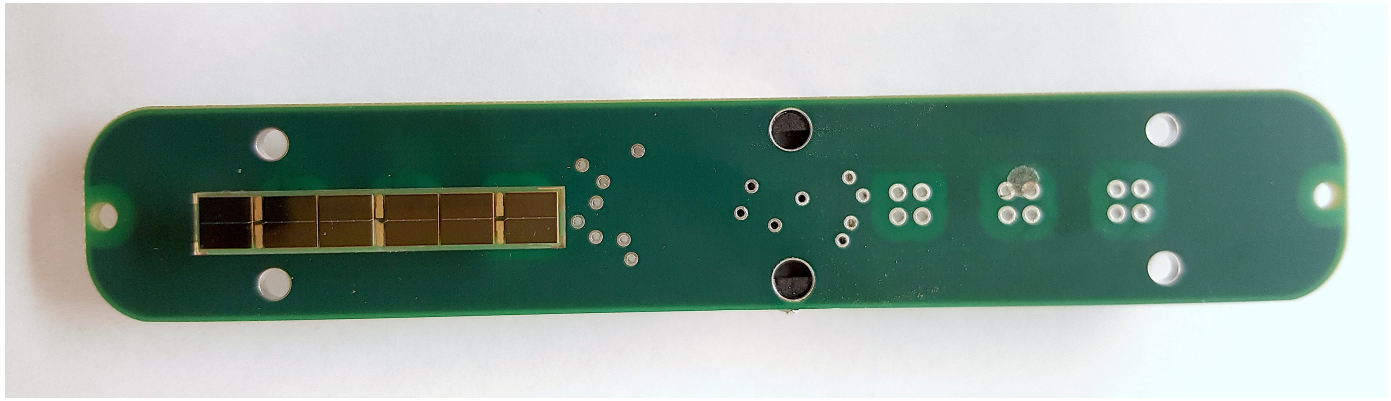
Key Considerations

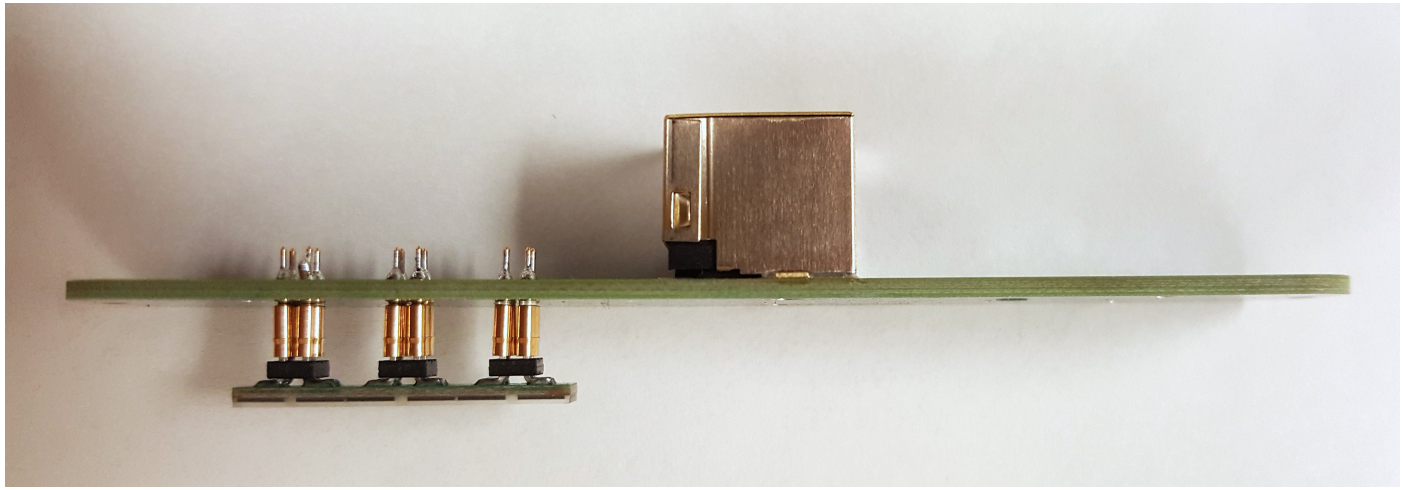
- Cryogenic reliability and performance of candidate SiPMs
  - Mechanical stability
  - Well-behaved electrical characteristics
  - Long-term stability
  - We will implement tests to ascertain these but need vendor to certify this application as a valid use of their product and commitments to maintaining the same process and materials for some “reasonable” period i.e. evaluation and production order at minimum
- Cryogenic reliability and performance of candidate SiPM mounted in clusters

Cryogenic Performance Requirements

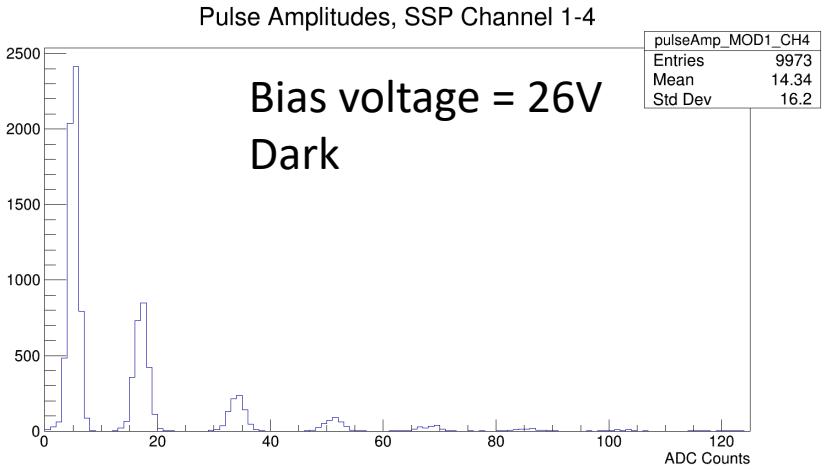
- A formal set of requirements has not yet been established
  - The following is an informal set based on operating experience with current prototypes
- Assume 6 mm x 6 mm individual device size for now
- *Preliminary* characteristics for operation at -186 °C @ and 3V bias:
  - Breakdown spread tbd (minimize to facilitate ganging)
  - DCR < 15 Hz @ 0.5 PE
  - Gain > $5*10^5$
  - X-talk < 5%
  - Afterpulsing: low (< 5%?)
  - PDE >= 30% (450 – 550 nm)
  - Dynamic range is not a big concern (75 or 100 micron pixels should be fine)
  - Bias voltage – may be a concern for active ganging (series) schemes

First Look at FBK 6x1

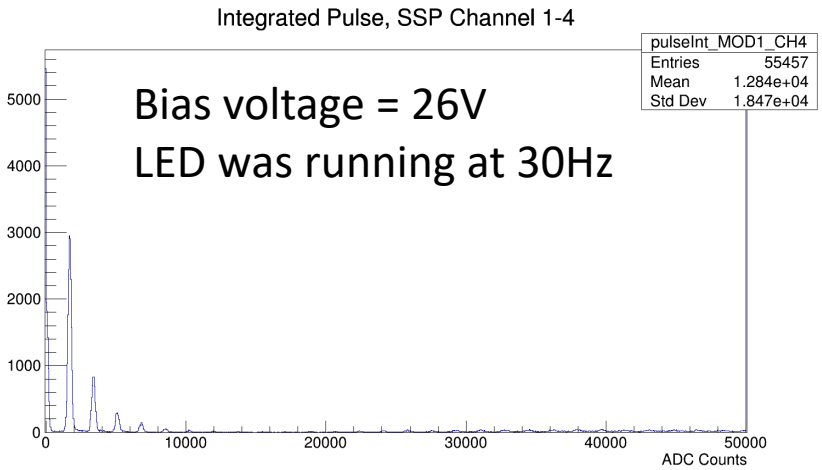


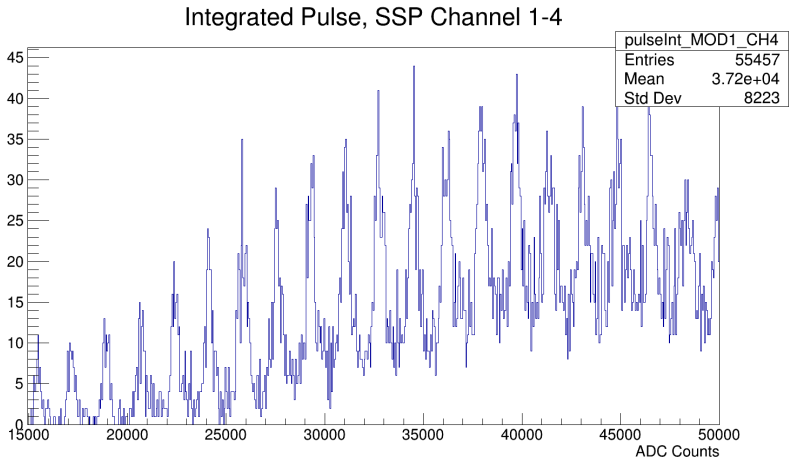


LED Illumination



Testing & Plots: A. Christensen





Summary

- DUNE will need ~1-10 m^2 of SiPM
- Need a cost effective device that meets performance specs
- Devices must operate at LAr temperature for >10 years
- Current focus is on the first 10 kt DUNE Single-Phase Far Detector – Technical Design Report planned for 2019
  - A second 10 kt module will use standard large area PMTs
  - Third and Fourth modules are currently entirely open with respect to technology choices
- We are very interested to explore ways to partner with FBK