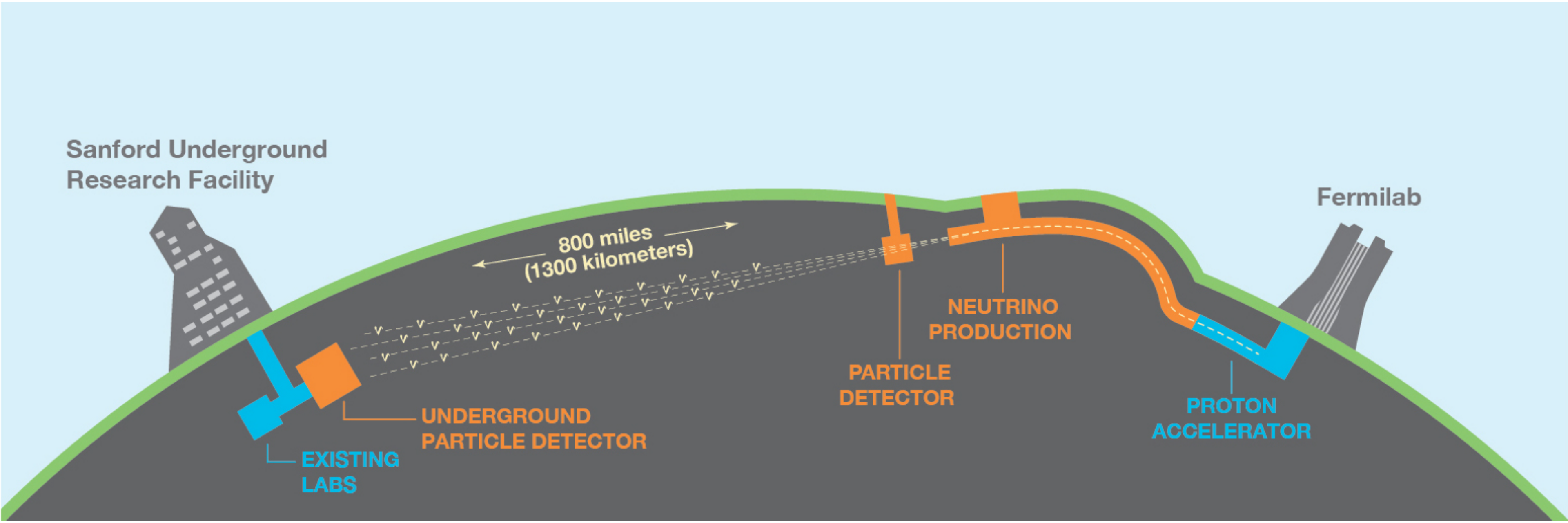

DUNE SP PDS: Photosensors

V. Zutshi, Northern Illinois University
for the Photosensor Working Group
11/13/18

DUNE SP PDS Photosensor Team

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

- N. Buchanan[1)], A. Dyshkant[2)], M. Eads[2)], K. Francis[2)], L. Patrizii[3)], F. Terranova[4)], R. Wilson[1)], J. Zalesak[5)], V. Zutshi[2)]
- In collaboration with: G. Cancelo[6)], L. Mualem[7)], D. Warner[1)]

1) Colorado State University

2) Northern Illinois University

3) INFN, Bologna

4) INFN, Milano-Biccoca

5) Institute of Physics, Prague

6) Fermi National Accelerator Laboratory

7) Caltech

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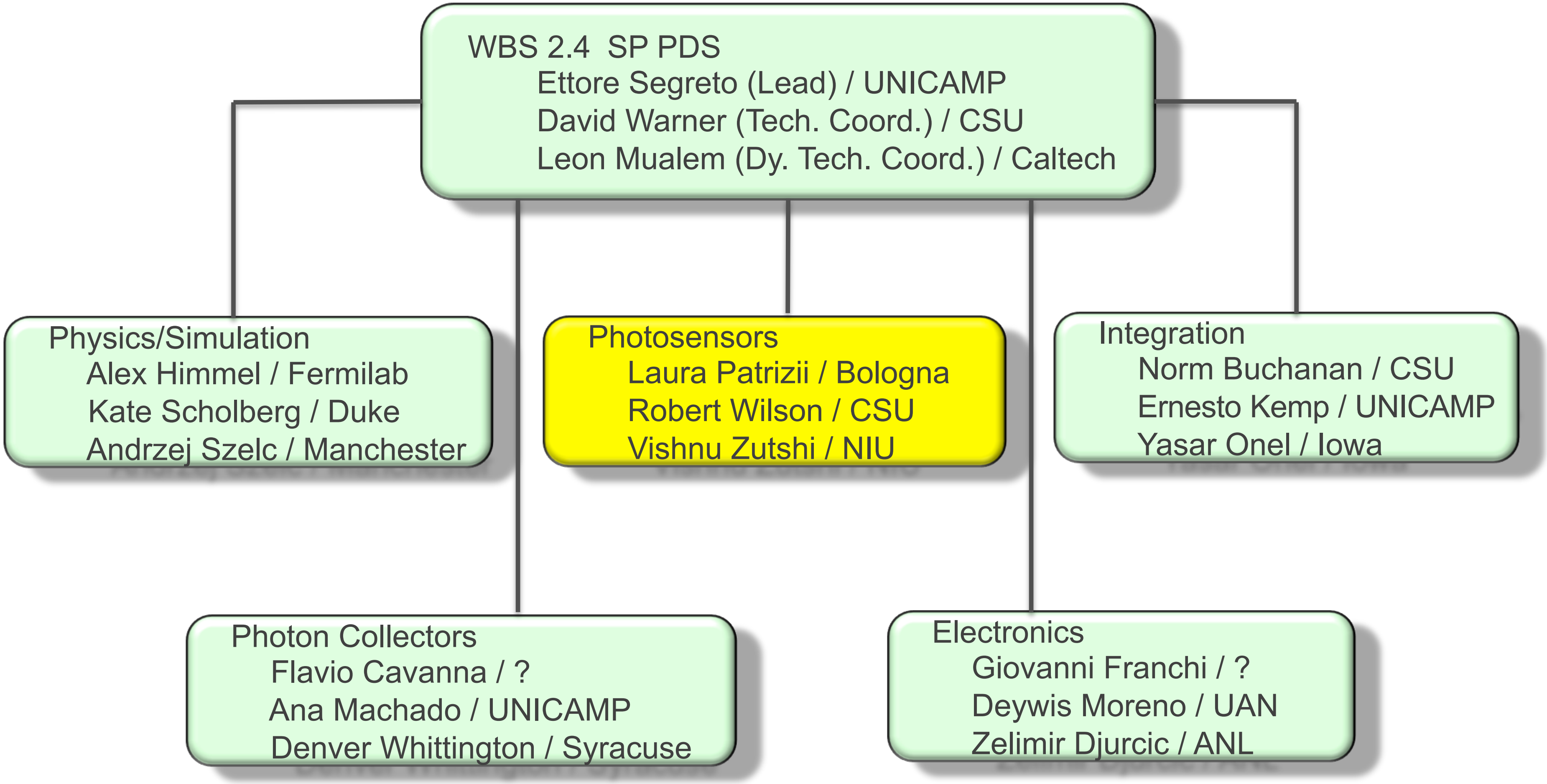
DUNE SP PDS Organization



Scope

Photosensors
Patrizii/Wilson/Zutshi

Photodetector Procurement
This task covers all aspects of the selection and evaluation of prototype photodetectors, and the procurement and testing of the production photodetectors.

Photodetector Quality Assurance Design and Fabrication
This task covers: (1) specifying the requirements for the photodetectors, including those required of the manufacturer, (2) determining the parameters to be tested upon receiving the photodetectors, (3) designing the test stand for photodetector testing, and (4) fabricating the test stand.

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Derived Requirements

- The DUNE SP PDS requirements are described in doc-db #6422
- The Photosensors must meet the following requirements:
  - ➢ It should be possible to actively gang upto 48 SiPMs per readout channel so as to allow for adequate photon system efficiency for detection and triggering of low energy neutrinos
  - ➢ The SiPM characteristics along with the associated FEE should allow for single photoelectron identification for detection of low energy neutrinos interacting close to the CPAs and for reliable calibration and threshold setting.
  - ➢ For a given threshold, the SiPM DCR should not dominate the background rate
  - ➢ The threshold needed for the above requirement should be less than the one needed to satisfy the overall efficiency requirement of the PD system

Derived Requirements

- The SiPMs and the associated FEE must provide a timing resolution no worse than 100 nsec
- The SiPM should be able to meet the above requirements and function within specifications for atleast 10 years in a LAr environment. It should be assumed that the sensor will see atleast 20 room temperature to LAr temperature cycles during this time.

As these requirements get translated into device specifications there will be trade-offs involved

Device Specifications

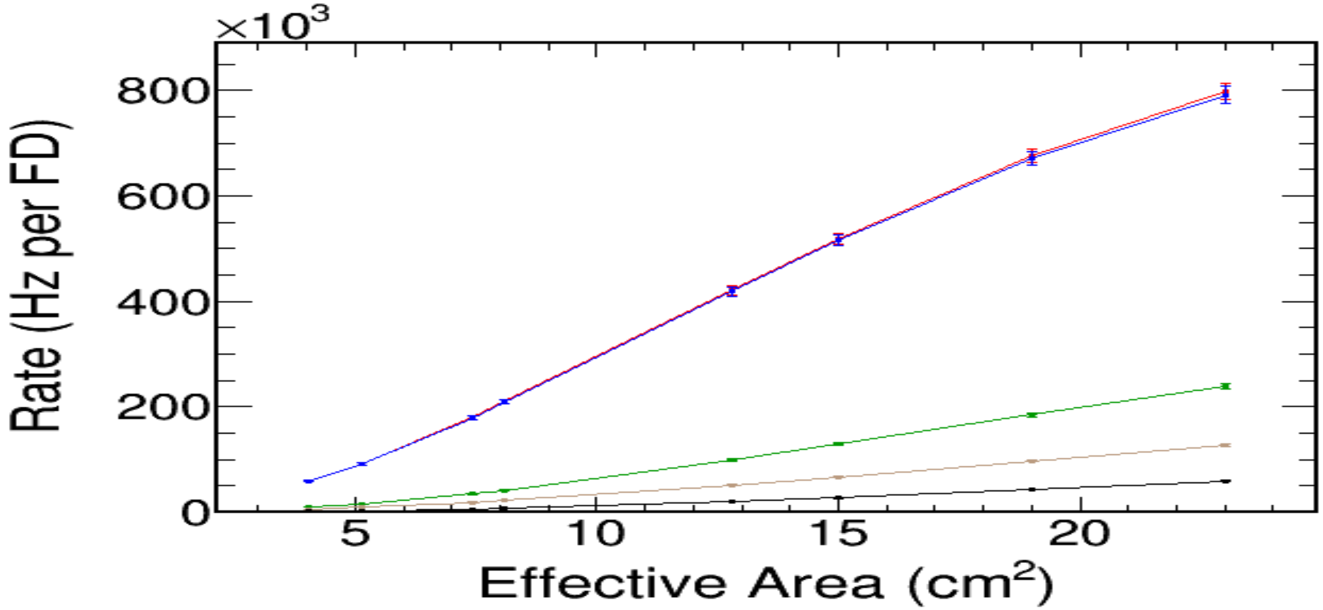
- Quantity
  - ~ 300 k devices for the 10 kT far detector module
  - The quantity required places constraints on the vendors that can be used
  - On the flip side the quantity required gives us some customization ability within budgetary constraints
  - The two vendors that can handle this scale of production and would be willing to carry out customization R&D: FBK & Hamamatsu
- Form factor
  - Will be driven largely by the mechanical design
  - 6mm x 6mm devices look most consistent with the current mechanical design

Device Specifications

- Dynamic range
  - ➢ Does not seem to be a stringent constraint
  - ➢ Very small correction with 25-30% occupancy
  - ➢ Assuming 20 PE/MeV and a few GeV going into one readout channel, even 100 micron pixel devices would be fine
  - ➢ 75 micron pixel size may be optimal
- Bias & bias dispersion
  - ➢ < 50 V (operating point, cold)
  - ➢ Ganging places constraints on operating voltage range of the devices
  - ➢ Within ± 0.1 V (rms) per batch (2-3k devices)
  - ➢ Within ± 1 V for the full production

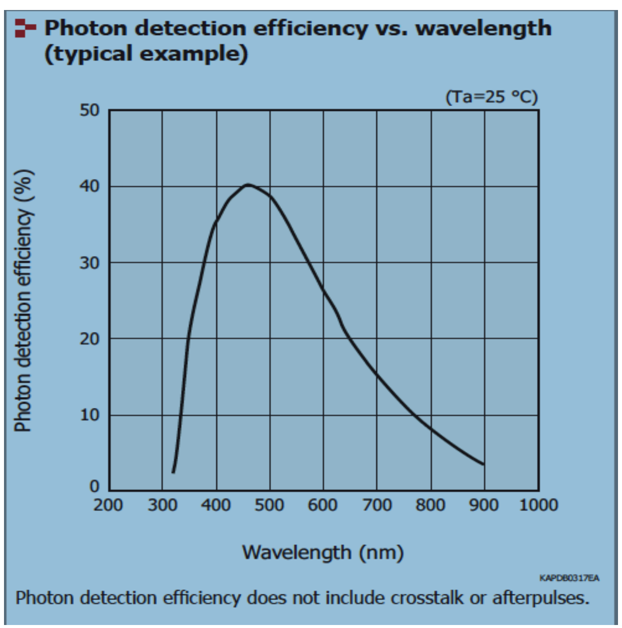
Device Specifications

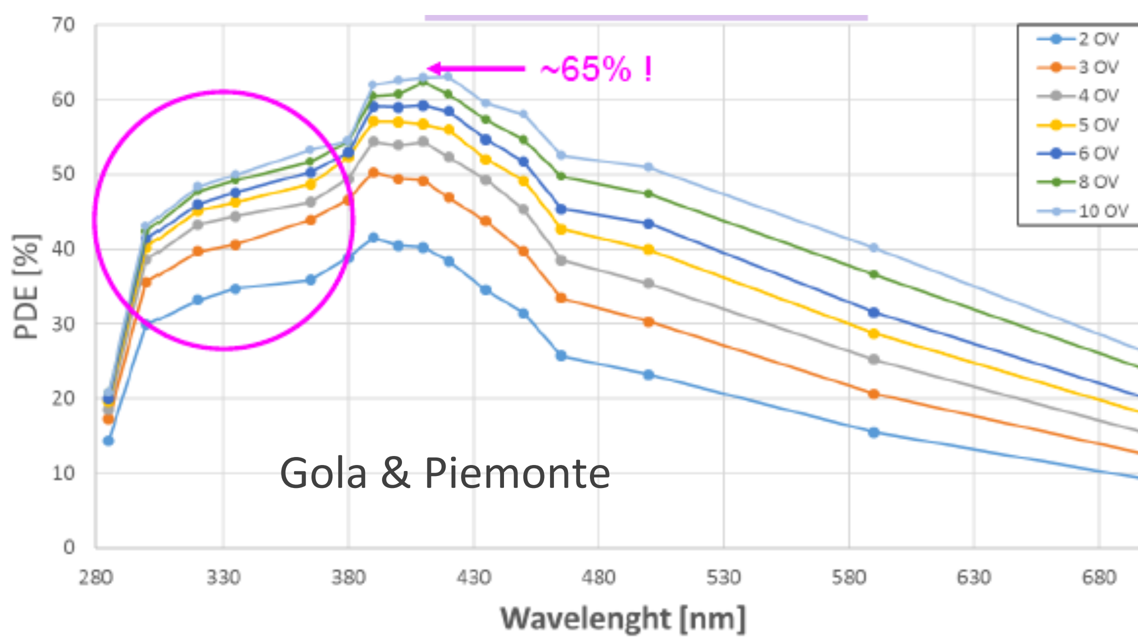
- DCR
  - Assuming ~1MHz for a 10kT detector, the background rate is roughly 200 Hz per readout channel
  - It makes sense to keep SiPM DCR < 100 Hz
  - DCR < 0.06 Hz/mm^2



Device Specifications

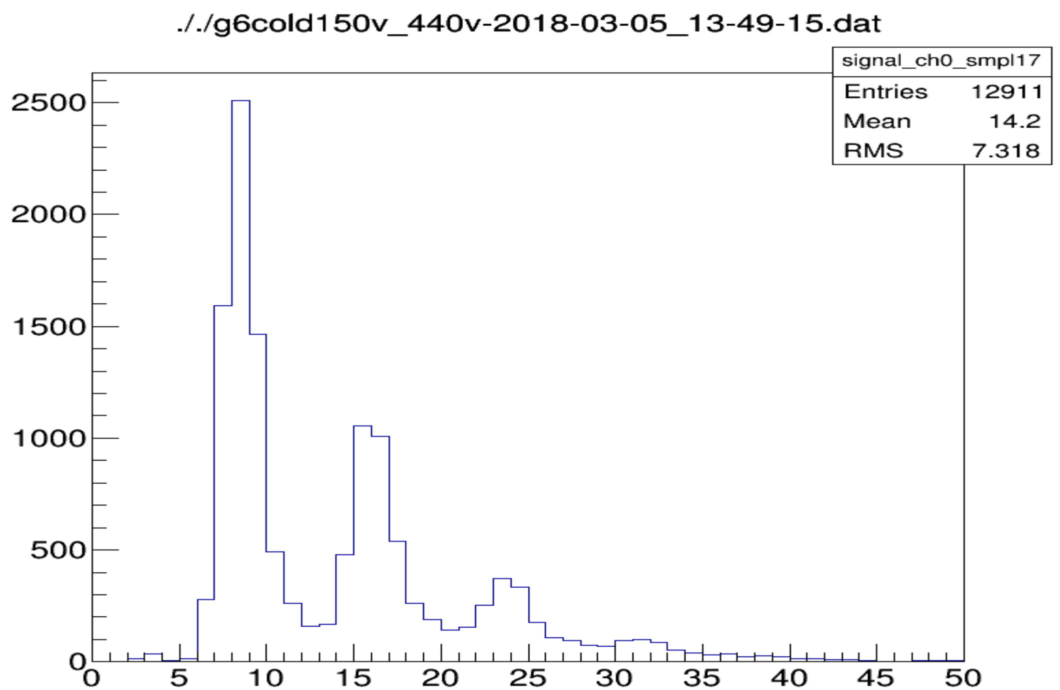
- PDE
  - > 35% at nominal (+2-3 V) operating voltage
  - Broad maxima in the 400-520 nm range





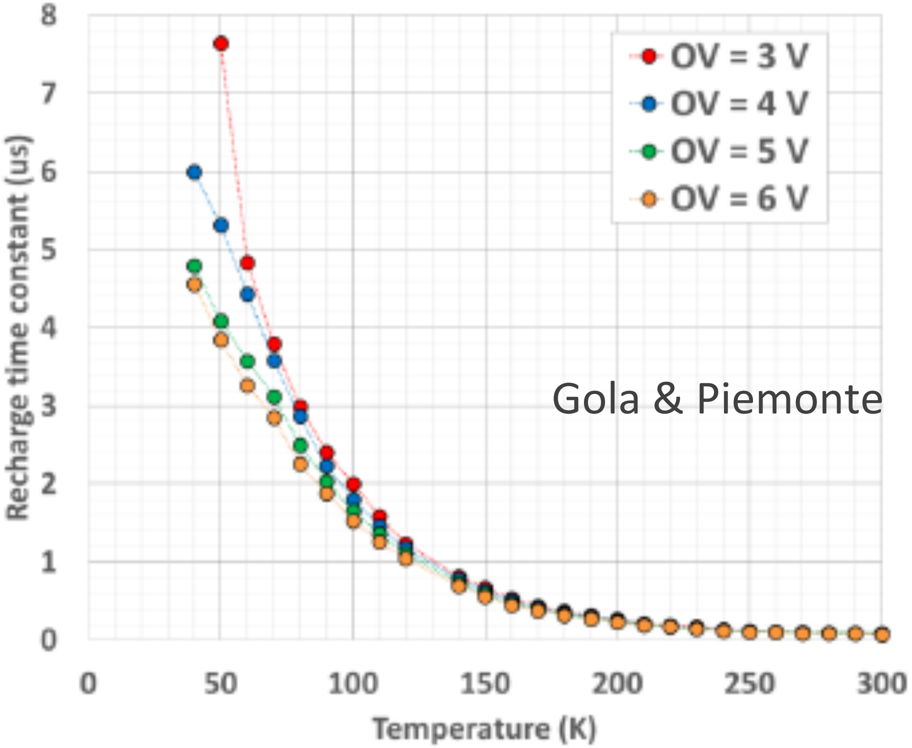
Device Specifications

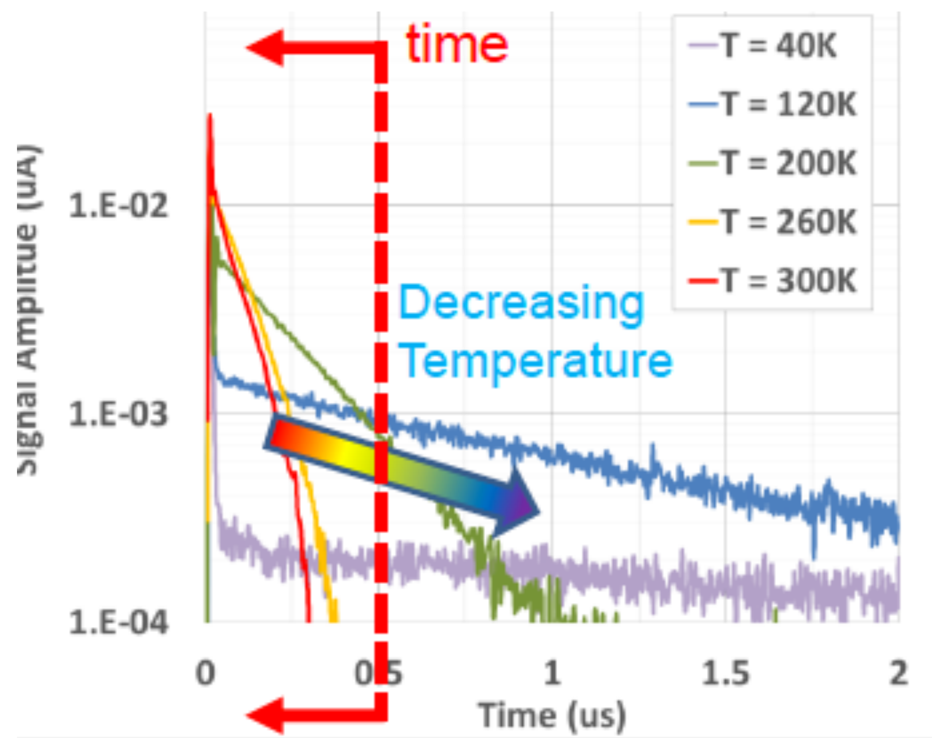
- Terminal capacitance
  - Passive parallel ganging imposes constraints
  - Currently 6-fold passive ganging being considered
  - Requires < 0.03 nF/mm^2 (aiming for S/N ~ 5)



Device Specifications

- Quenching resistor
  - Poly-silicone or metal type
  - Value and variation





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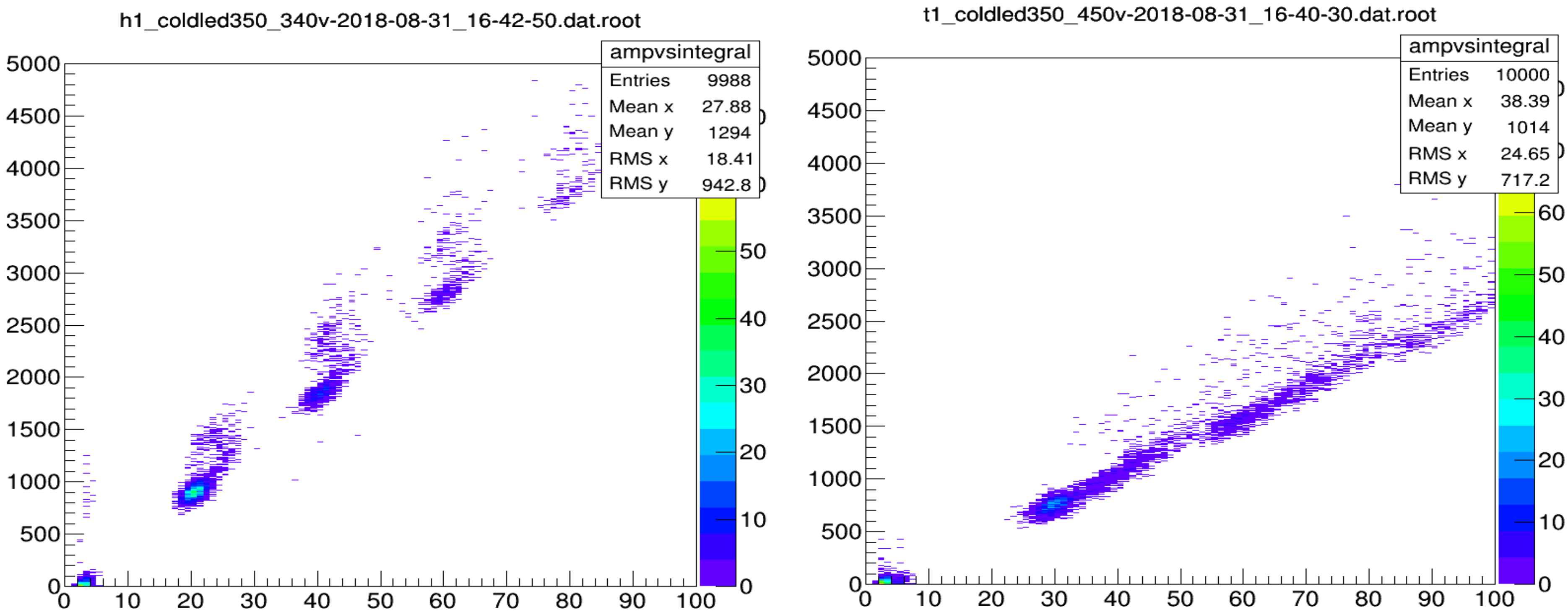
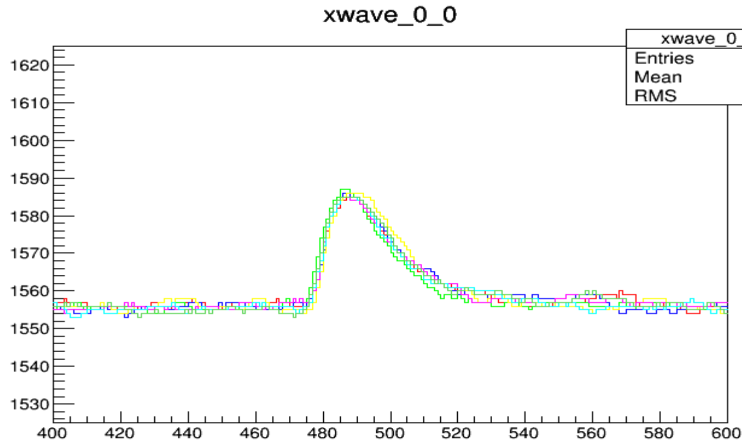
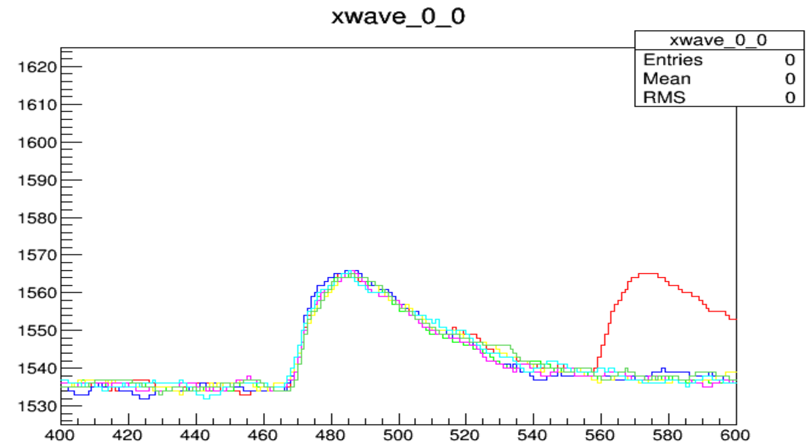
Device Specifications

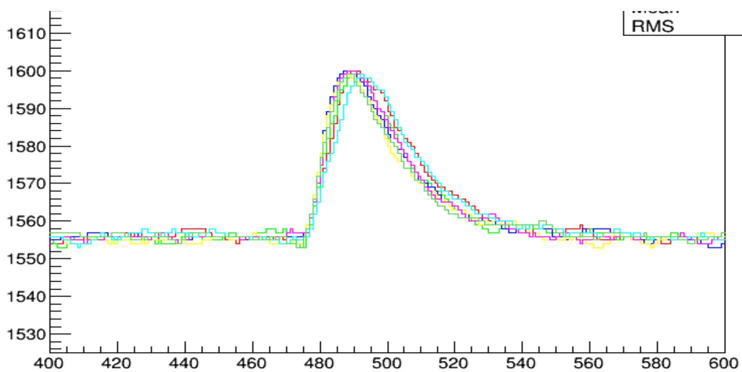
- X-talk & after-pulsing
  - Devices with trench technology
  - < 15% at nominal operating voltage

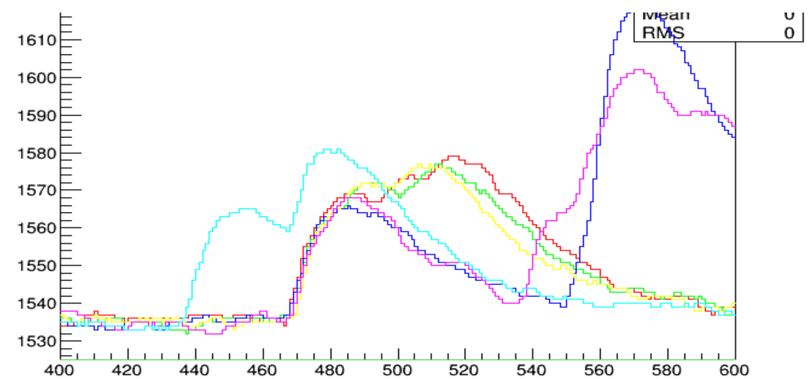


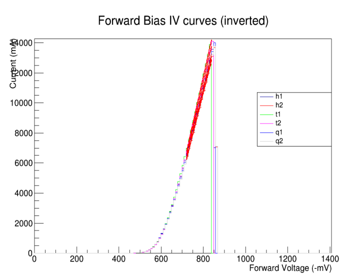
Device Specifications

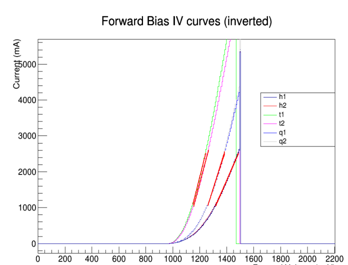












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Device Specifications (Summary)

- Will be part of the RFQ and purchase requisition

Ongoing testing

Interfaces

Internal Interfaces	
Interface	Descriptions
Photodetector to Hoverboard	
Photodetector to ARRAPUCA module	
Photodetector to summing electonics board	
External Interfaces	
Photodetector to LAr	

Interfaces are documented and actively managed

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SiPMs in Noble Liquids

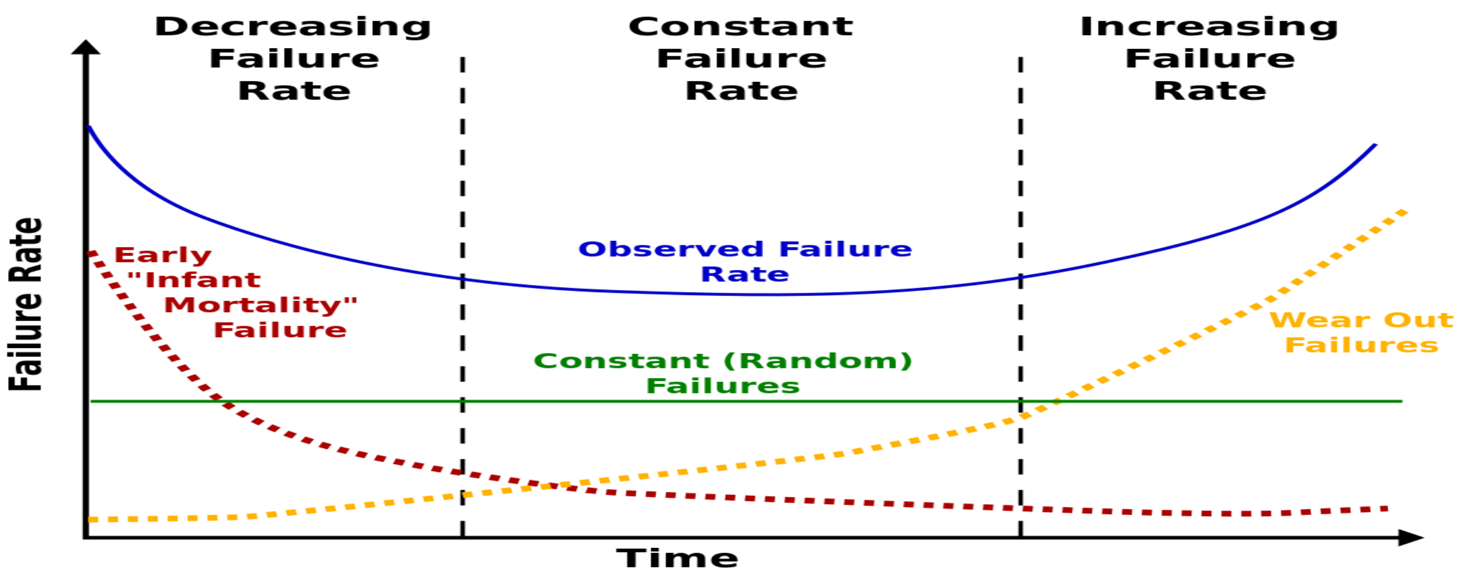
- Relatively young field
- Some experiments/installations one can hope to learn from:
  - GERDA (LAr veto shield, running)
  - MEG II (commissioning)
  - Darkside, nEXO etc. (at various stages of preparation)
- Observations:
  - have generally worked rather closely with the SiPM vendors (there is an implicit customization)
  - pre-protoDUNE state of mind
  - in principle do not have the accessibility and longevity constraints we have

Risk Mitigation

- Typically the sensors are rated for operation down to -40 C
- This means that changes in the production process could have unforeseen consequences at LAr or LN_2 temperatures since they are in principle outside the range of applicability of the devices as tested by vendors
- Possible paths:
  - ➢ Reliability engineering
  - ➢ Process control
  - ➢ Vendor and collaboration testing

Reliability

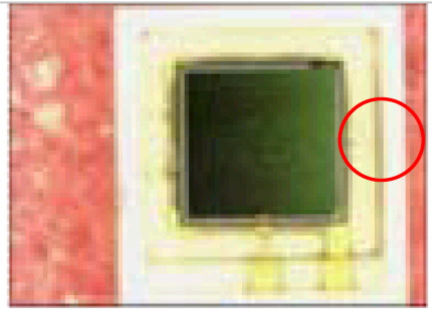
- Probability that system will function as required under the target operating and environmental conditions
- Empirical testing/cycling
- Physics of failure
- Number of quantitative tools available for extrapolation based

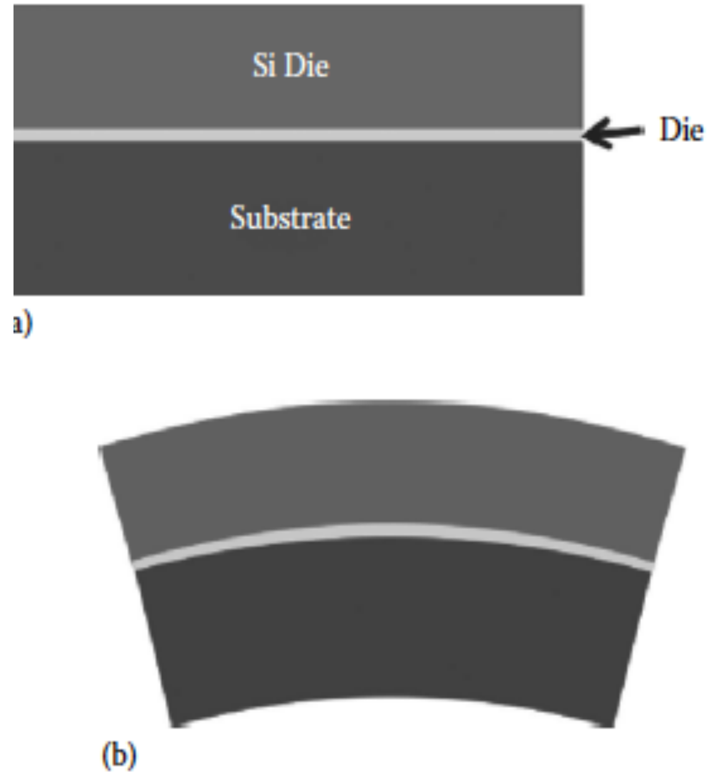


Packaging at Low Temperatures

- Provides protection to the die, a means of connecting electrically and thermally to the die
- Primary issues are changes in material properties and stressed induced due to differential CTEs
- In general:
  - ➢ increased modulus of elasticity for metals and polymers
  - ➢ decreased elongation(brittleness)
  - ➢ CTE decreases
  - ➢ phase transitions in metals, particularly solders

Die Attach



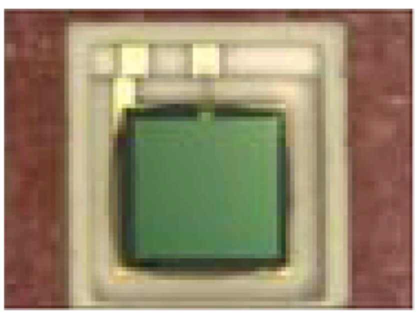


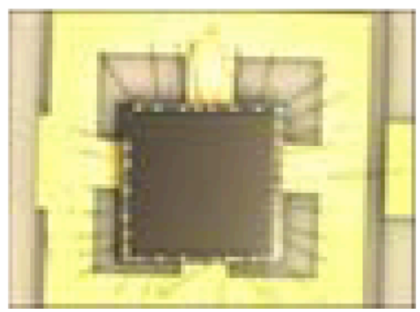
Epoxy resin
w/ conductive adhesive glue

cracked at 1cycle
conductivity: good > 20cycles

Silicone resin
w/ conductive adhesive glue

small crack at 10cycles
minor detachment at 20 cycles
conductivity: good > 20cycles





bare
w/ conductive adhesive glue

no visible damage: at > 20cycles
conductivity: good at > 20cycles

bare
w/o conductive adhesive glue

no visible damage: at > 20cycles
conductivity: good at > 20cycles

Not the Only Interface

- “packaging” in this sense; a collection of materials and interfaces
- Ideally you want to specify the system with minimal CTE mismatch with substances that will not undergo any drastic transformation
- Interfaces of interest to us:
  - die-to-substrate
  - substrate-to-potting mold
  - potting mold-to-encapsulation
  - solder joints to everything else

Proto-DUNE Observations

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Quality Assurance

- Vendor specs
- Vendor testing

Quality Control (Procedure)

- Test suite
- Device characterization

Quality Control (Acceptance)

- Test suite
- Device characterization

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

Schedule

Risks

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