The DUNE Photon Detection System

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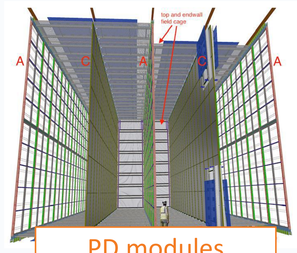
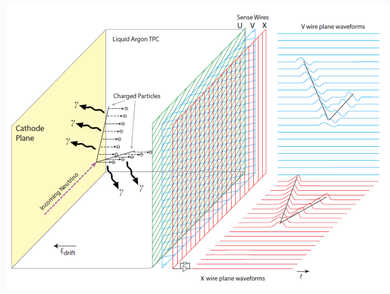
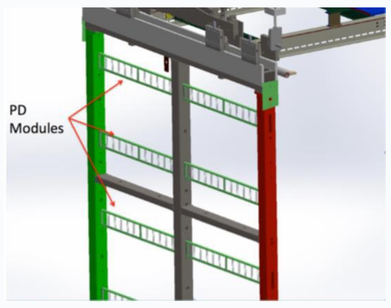
Single Phase DUNE Far Detector

- A 10 kilo tonne Single Phase LArTPC
- Read out the pattern of ionization with sub cm granularity
- Search from MeV to GeV scale neutrino interactions



PD modules Inside an APA





Photon Detection System

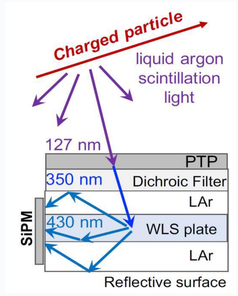
- Goals:
  - ✓Maximize the active volume
  - ✓Maximize the light yield
- Considerations:
  - ✓Constraint of the APA structure
  - ✓Cost effective: large area light collector minimizing photosensor coverage.

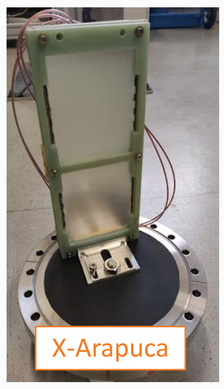
Light collectors: X-Arapuca

- The **X-ARAPUCA** design makes use of **total internal reflection and** highly reflective boxes to capture wavelength-shifted photons to improve detection efficiency.

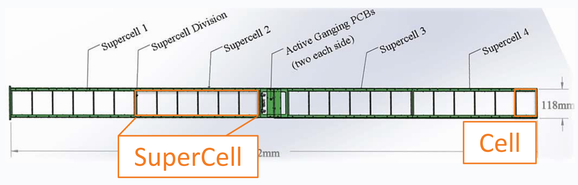
- Keys to an effective PD system in DUNE:
  - ✓**Efficient conversion** of VUV photons to captured photons.
  - ✓**High fraction** of captured photons incident on photosensors.
  - ✓**Efficient photosensors** for converting photons into electric signals.

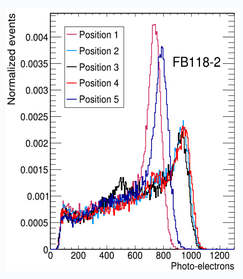
- **Supercell**: 6 **cells** 488 × 100 × 8 mm^3.
- **PD Module**: 4 supercells 2092 × 118 × 23 mm^3 (bars configuration).

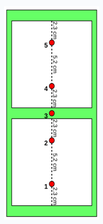


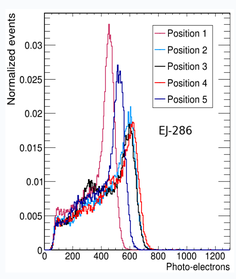


X-Arapuca

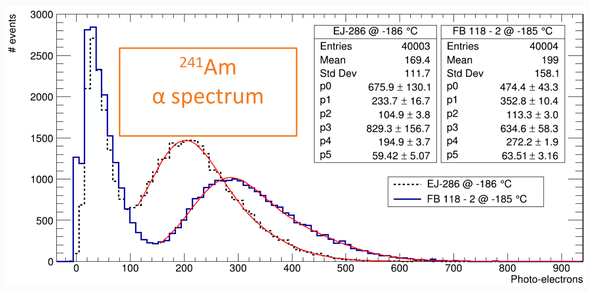








- **Supercell test**: 2-window supercell tested.
- Test on **light collection uniformity** and **efficiency**.



- Test on **different WLS plates**:
  - ✓Commercial (Eljen 286) WLS plate, with measured PDE of 2.8%.
  - ✓**New WLS** bars (FB118-2, Acrylic matrix, higher efficiency) developed at MiB with PDE measured in same test stand 3.8%.

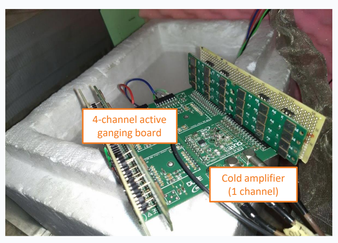
- **Supermodule test**
  - ✓2 supercells (half supermodule)
  - ✓Allow to test all the electrical boards for DUNE

- Coating and assembly infrastructure are being completed

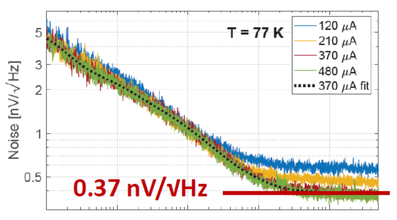
Test stand

Assembly infrastructure

Cold Electronics : Active Ganging

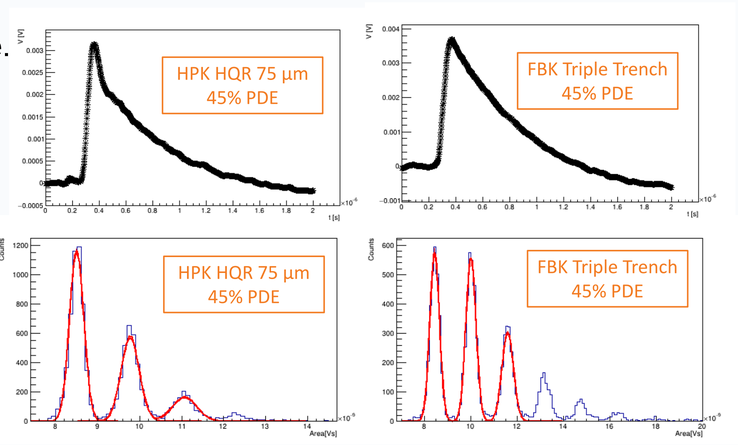


- Used to collect the **signals of 48 SiPMs** of a supercell into a **single readout channel**.
- Each channel reads out **48 6x6 mm² SiPMs** → 60 nF total input capacitance.
- 1 channel per SuperCell, 4 channels per module, **6000 channels in DUNE** (1st module).
- **Two-stage amplifier** - SiGe bipolar transistor + fully differential op-amp.
- **Low series noise** is required → SiGe input transistor gives **0.37 nV/√Hz** at cryo temperature.
- **Low power consumption** (2 mW/channel) to prevent boiling of LAr.



- Tested with **all candidate SiPMs for DUNE.**
- **Fast response**: <100 ns rise time.
- Dynamic range 2000 p.e.
- **Good S/N** ≈ 5-10 depending on SiPM type and overvoltage → Allows clear separation of photoelectron peaks (with 48 SiPMs in parallel).
- At 45% PDE:
  - ✓**HPK HQR 75 μm: 5.96** ;
  - ✓**FBK Triple Trech: 7.16**.

- Next → Integration of all the cold parts (SiPM+routing+cold amp+cable).



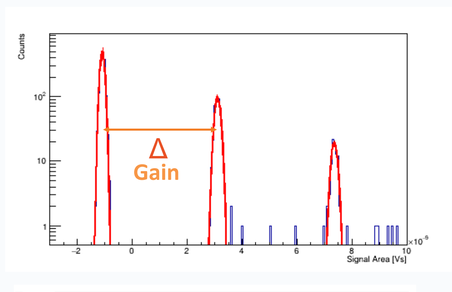
Photosensors : SiPMs

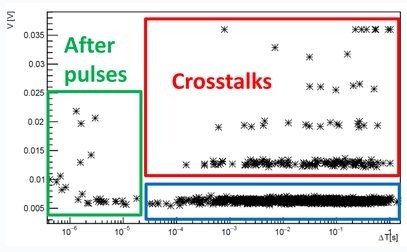
- **48 SiPMs** per Supercell
  - ✓6 SiPMs per PMB passively ganged
  - ✓8 PMB actively ganged

- **192 SiPMs** per PD module
  - ✓4 electronics readout channels
  - ✓288,000 SiPMs in total

- **Two photosensor vendors** are being investigated: Hamamatsu (**HPK**) and **FBK**
  - ✓6 types (splits) of 6x6 mm² SiPMs developed specifically for DUNE: 4 from HPK (S13360 – LQR/HQR – 50/75 μm pitch) and 2 from FBK (NUV HD LF single/triple trench)

Low level specs	Value
Max nominal operating V	[50 V at cold]
Dark count rate (DCR)	<100 mHz/mm²
Correlated noise	<35%
Time resolution	<1 ms
Thermal cycles	>20
Recovery time	t ~ a few ms
PDE at 87 K	>35% at nominal OV
High level specs	**Value**
Dynamic range	1-2000 p.e.
S/N>4	Per supercell (48 SiPMs)
Trigger	1.5 p.e.





First selection procedure

- 25 SiPMs of each type **fully characterized** at single SiPM level:
  - ✓**IV curve** measurements at room T at 77 K;
  - ✓**gain**, **S/N** and **DCR** measured (77K) at OV to obtain 40%-45%-50% of PDE;
  - ✓20 **thermal cycles** with controlled cooling down and warming up;
  - ✓all measurements repeated after the thermal stresses.
- All splits **fulfill DUNE specifications**.

Final selection procedure

- **250 SiPMs per type** in the DUNE SiPM board tested at single SiPM level:
  - ✓**IV measurements** for all SiPMs at room T and 77K;
  - ✓20 thermal cycles with controlled cooling down and warming up;
  - ✓IV measurements repeated for all SiPMs and **complete characterization** for 5% sample per split.
- Test with **48 SiPM in active ganging** at different OV per each split: test of S/N and signal shape.
- **HPK HQR 75 μm** and **FBK Triple Trench** down selected.

HPK HQR 75 μm

PDE	Gain (10^6)	DCR (mHz/mm²)	Cross-talk	After pulse
40	3.73	57.54	6.62	0.86
45	4.59	64.97	8.97	1.10
50	5.44	66.32	10.96	1.30

FBK Triple Trench

PDE	Gain (10^6)	DCR (mHz/mm²)	Cross-talk	After pulse
40	4.73	80.79	13.76	2.85
45	6.01	86.33	15.67	3.25
50	8.21	93.35	40.50	4.05

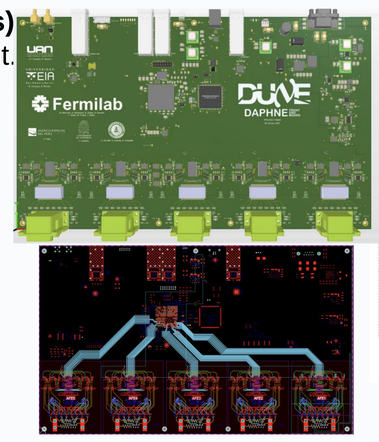
ProtoDUNE run II production

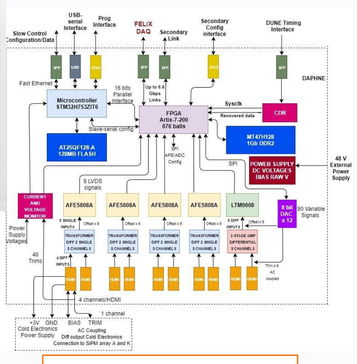
- 3000(+1000) SiPMs FBK and 3000(+1000) SiPMs Hamamatsu.
- **Dedicated test stand** for automatized IV curve and DCR measurements.

Warm Electronics : DAPHNE ASICs

- **DAPHNE (Detector electronics for Acquiring PHotons from NEutrinos)** design developed by the Mu2e redout.

- DAPHNE read-out boards:
  - ✓**40 channels** per module;
  - ✓**Artix 7 FPGA**;
  - ✓**14 bit ultrasound ADC**;
  - ✓Bias-Trim Voltage supply
  - ✓Cold Electronics power supply +3V
  - ✓Gigabit link up to **6.6 Gb/s to FELIXDAQ/full-mode** protocol
  - ✓DUNE **Timing interface**





DAPHNE Scheme