Development and Characterization of the Photon Detection System for DUNE Experiment

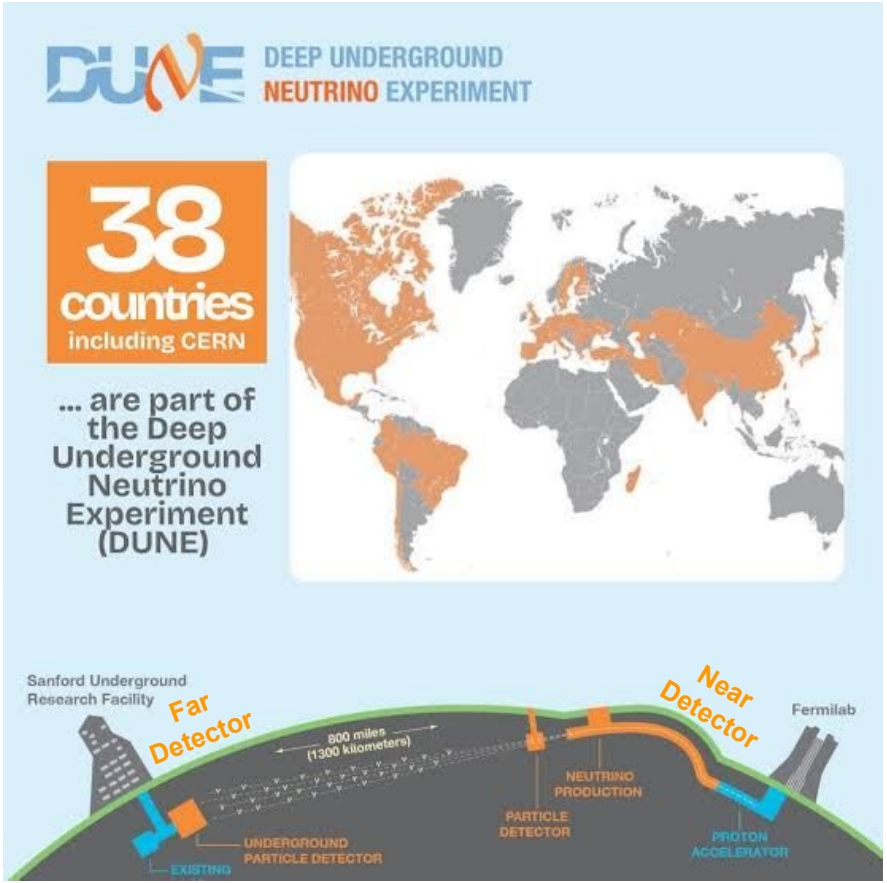
Maritza Delgado*
For the DUNE Collaboration

Seoul, 29 October 2026



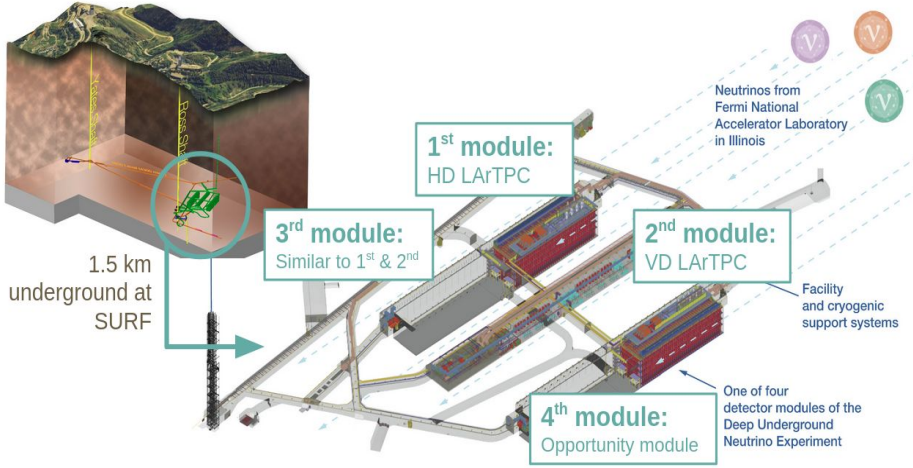
25th International Workshop on Next Generation Nucleon Decay and Neutrino Detectors (**NNN 2026**).

**maritza.delgadogonzalez@unimib.it*



THE DUNE EXPERIMENT

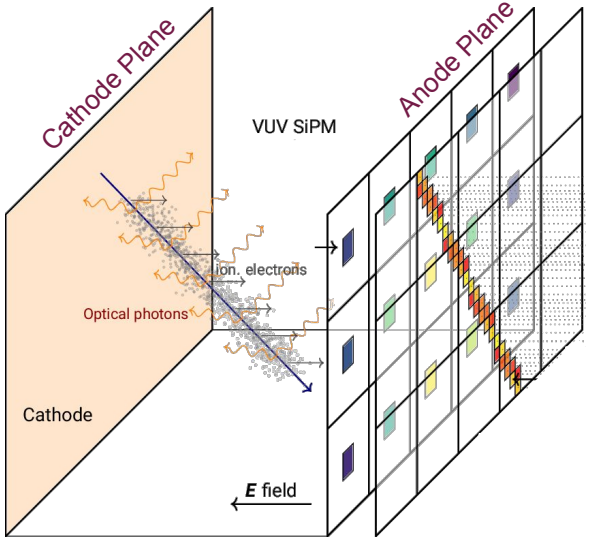
The Deep Underground Neutrino Experiment (DUNE) is a new generation long-baseline neutrino oscillation experiment.



More details in Rhiannon's talk tomorrow.

Photon detection in liquid argon

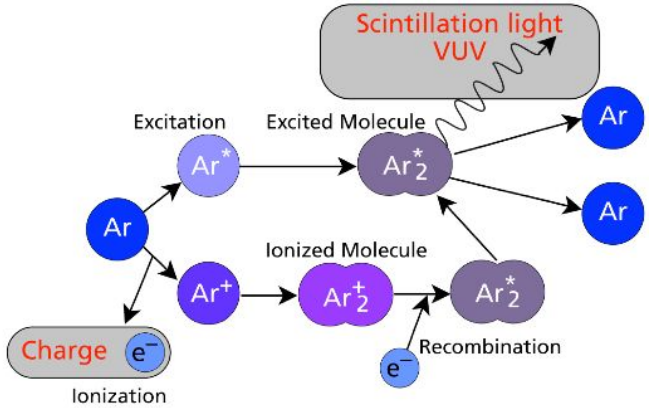
Example Horizontal drift



500V/cm drift field

Properties of LAr Scintillation light:

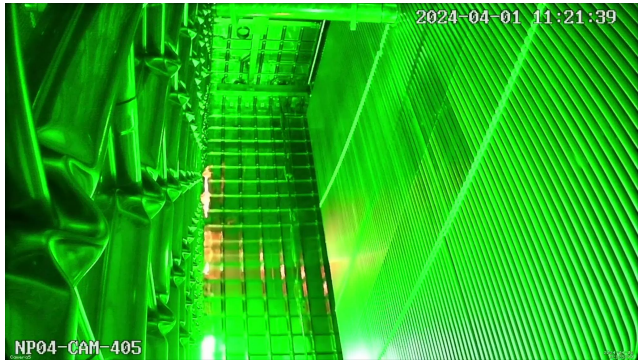
- LAr is a powerful scintillator
- Emission peak at 128 nm (VUV)
- Time profile: -Singlet state: 7 ns , -Triplet state: 1.5 μs
- Light yield (500 V/cm): 24000 ph/MeV
- Rayleigh Scattering length: ≈ 1 m



DUNE Photon Detection System (PDS)

Challenges

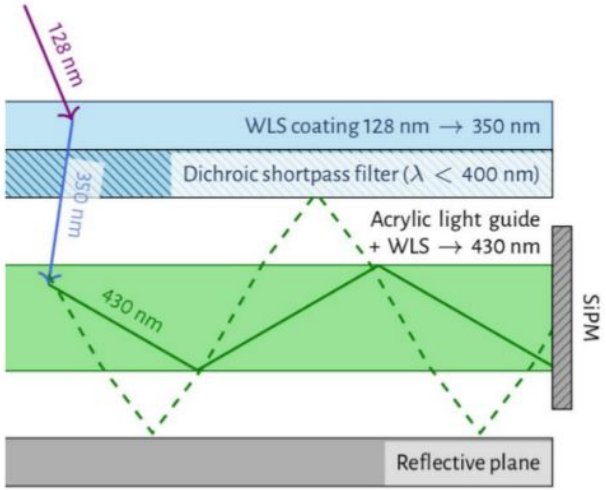
- The emitted photons at 128 nm (VUV):
- Difficult detection
- Easily absorbed by impurities
- LARGE detection area:
-Photosensors with small surfaces but high efficiency.



Goals of the PDS:

- Provide the timing information for an event.
- Improved energy reconstruction of the interaction
- Provide opportunities for the study of low-energy neutrino physics.
- Trigger for non beam events.

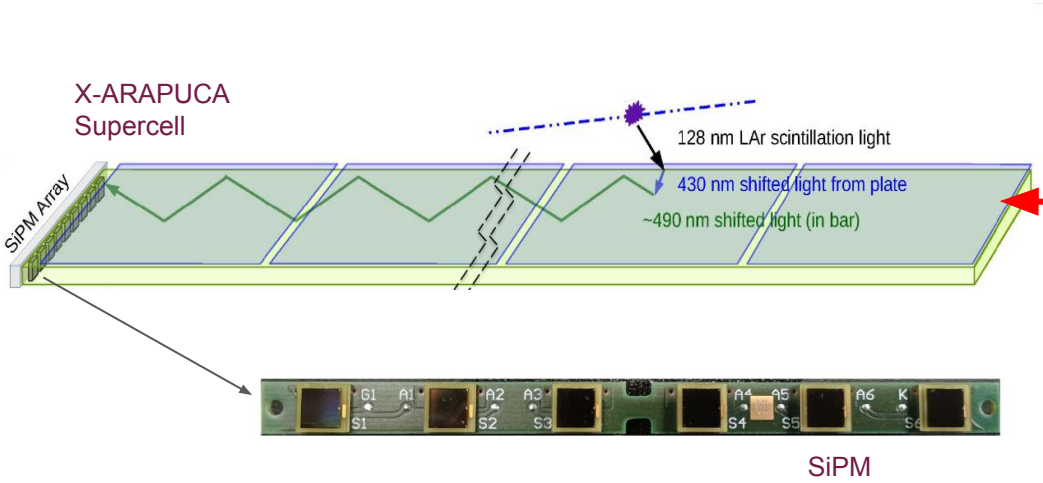
DUNE PHOTON DETECTION SYSTEM: X-ARAPUCA

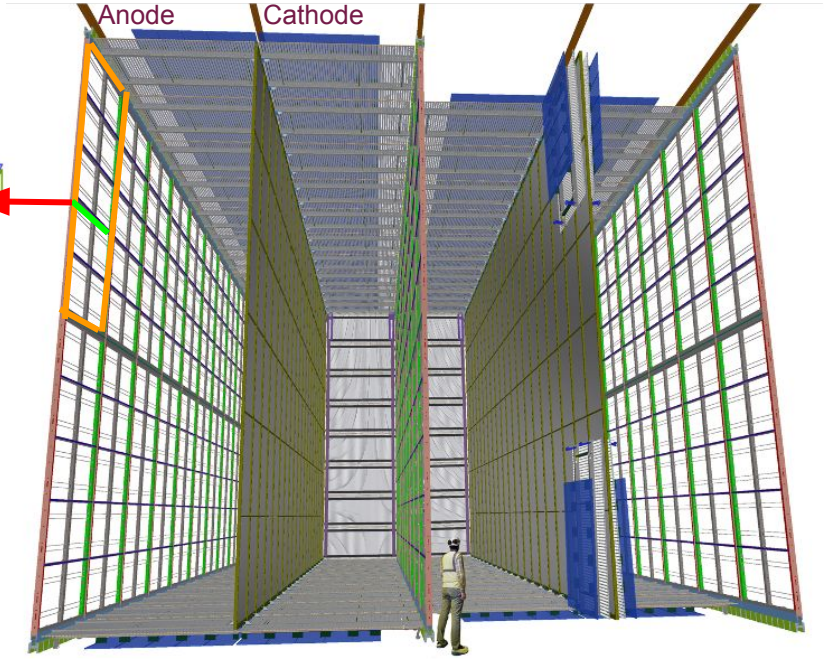


Photon trapping through(Brazil):

- Reflective box: Reflective internal surfaces.
- External wavelength shifter (PTP): Converts VUV light to 350 nm.
- Dichroic filter: Optical window with wavelength shifter coatings on both sides.
- Internal wavelength shifter (WLS): Converts light to 430 nm.
- SiPM: Photons are detected after reflection.

Photon Detection System for Horizontal Drift



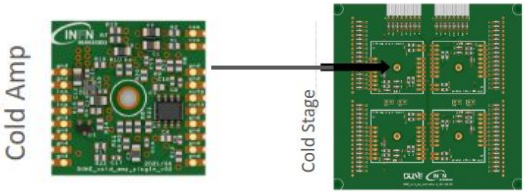


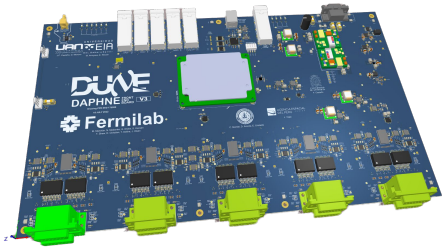
- 10 modules for Anode : 1500 in total
- 1 module : 4 supercell X-ARAPUCA (49 cm x 10 cm)

The Photon detection system will be installed within the anode planes.

Readout Electronics-Horizontal Drift

- 1 channel = 1 SuperCell (48 photon detectors:SiPMs)
  6 Passive ganging SiPMs
  8 Active ganging strips.
- Cold amplifier: Differential Signal
- Warm electronics: DAPHNE (Detector electronics from Acquiring PHotons from NEutrinos): Amplification, digitalization, sending to DAQ, etc.





DAPHNE

C. Brizzolari,et al, "Cryogenic front-end amplifier design for large SiPM arrays in the DUNE FD1-HD photon detection system"2022 JINST

Photon Detection System for Vertical Drift

MegaCell X-ARAPUCA :

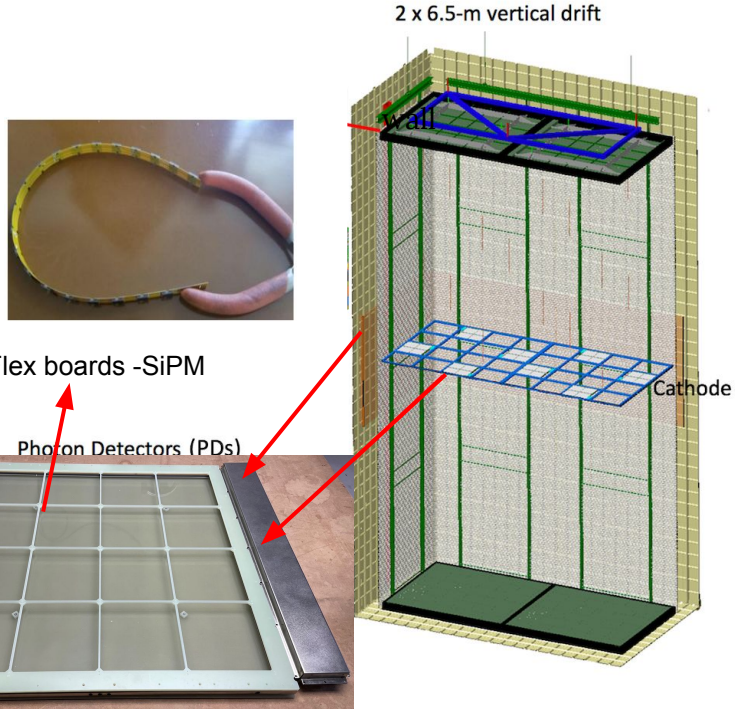
- 60 cm x 60 cm
- 160 SiPMs (each module):
  2 channels (80 SiPMs/channel)
  20 SiPMs on flex circuits

Walls:

- 352 Megacell X-ARAPUCA on the cryostat walls.
- Behind the field cage (70% transparent) on the four membrane walls.

Cathode :

- Each cathode :4 X-ARAPUCA Megacell double-faced
- Total: 320 double-sided on the cathode.



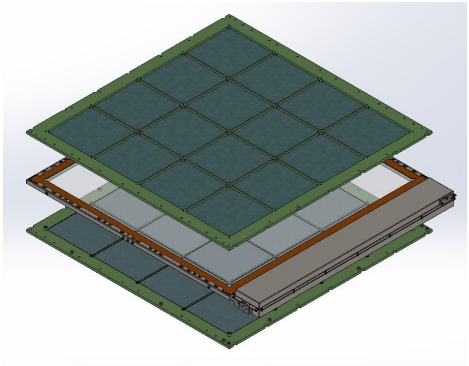
Readout Electronics-Vertical Drift

Innovate:

-Power over Fiber (PoF)

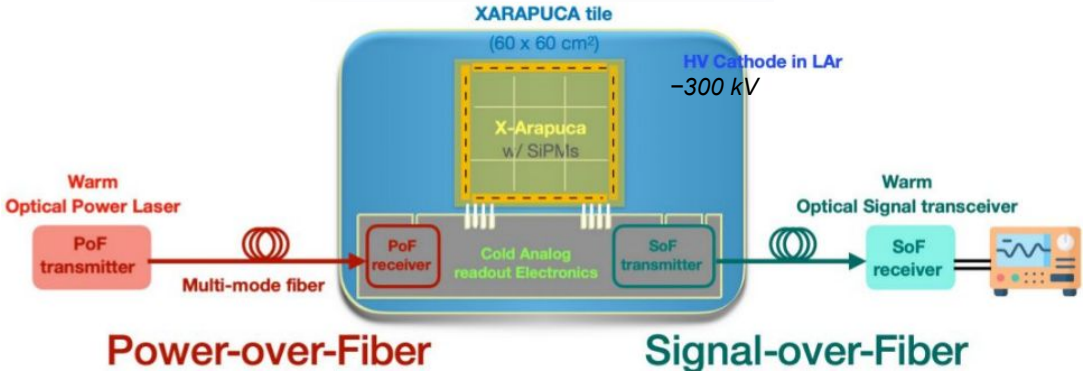
-Signal Over Fiber (SoF)

•Complete electrical isolation, noise immunity, park-free operation.



•PoF designed to power SiPMs without a conductor.
Based on GaAs laser system.

•The SoF system converts the analog signal into an optical signal.



M.A. Arroyave et al, “Characterization and novel application of power over fiber for electronics in a harsh environment”, 2024 JINST.

VUV SIPM-Silicon PhotoMultiplier

The SiPMs for DUNE: Two vendors:

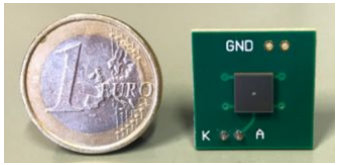
- Hamamatsu Photonics K.K (HPK) - Japan

HAMAMATSU
PHOTON IS OUR BUSINESS

- Fondazione Bruno Kessler (FBK) - Italy

FONDAZIONE
BRUNO KESSLER

- FD-Horizontal: ~300.000 SiPMs
- FD-Vertical: ~100.000 SiPMs





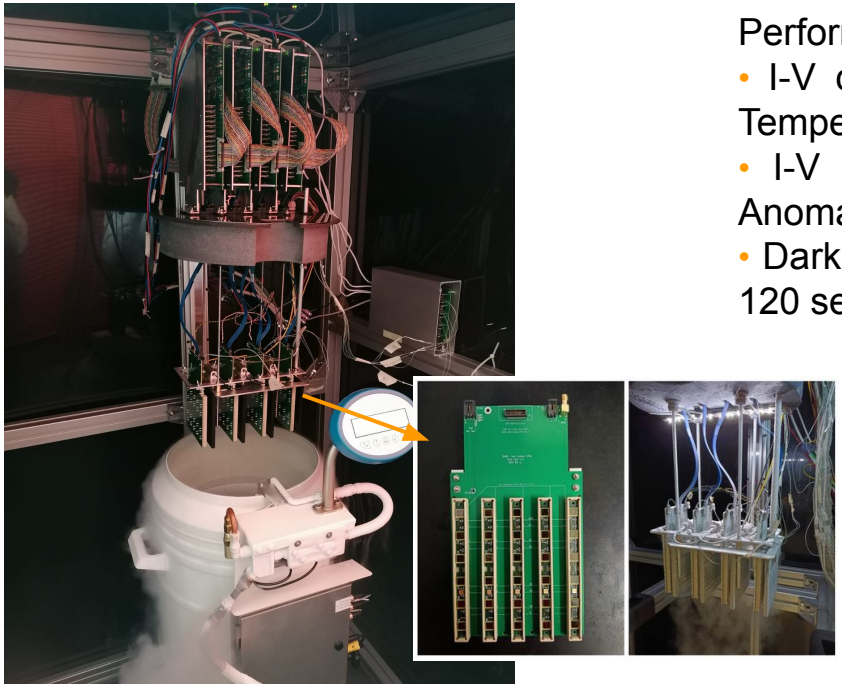
Requirements of DUNE:

Parameter	Value	Note
SiPM dimension	6x6 mm2	Compatible with the PDS module
Cell pitch	50-150 μm	As large as possible in the range allowed
PDE at nominal voltage(Vop)	>35% at 430 nm	At room temperature
Window material	Siliconic o epoxidic	Cryogenic
DCR	<200mHz/mm2 at Vop	At 77K
Breakdown voltage (Vbd) spread	<200mV(max-min)	Per group of 240 SiPM

M. Andreotti et al, "Cryogenic characterization of Hamamatsu HWB MPPCs for the DUNE photon detection system", 2024 JINST 19 T01007

SiPM Characterization:

Cryogenic Apparatus for Control Tests Upon SiPMs



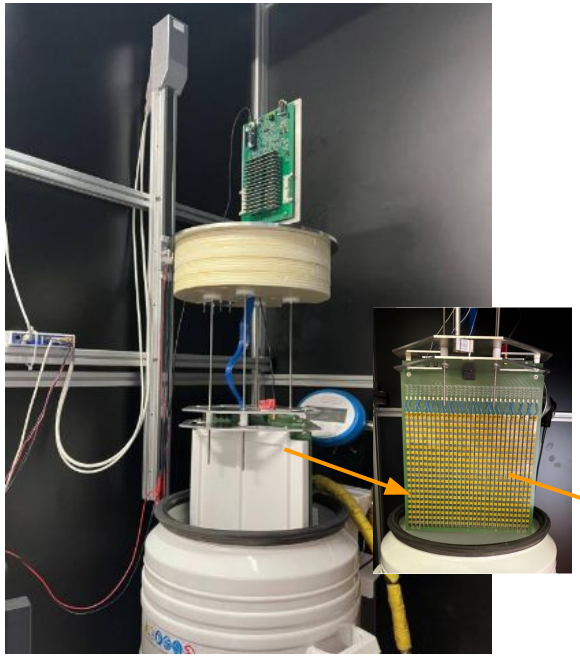
Performed tests:

- I-V curves at room temperature and Liquid Nitrogen Temperature Rq & Vbd.
- I-V extend at Vbd+9V of OV, without light Identify Anomalous IV curve.
- Dark Current Rate measurement with a time window of 120 seconds Identify Noisy SiPM.

- There are five CACTUS facilities in Europe: Bologna, Ferrara, Granada, Milano Bicocca and Prague.
- 70% of the total amount of SiPMs already tested!

SiPM Characterization:

Cryogenic Apparatus for Control Tests Upon SiPMs - Vertical Drift



Performed tests:

- I-V curves at room temperature and Liquid Nitrogen Temperature Rq & Vbd.
- I-V extend at Vbd+9V of OV, without light Identify Anomalous IV curve.

- The various tests have already started at the University of Milan-CACTUS facility

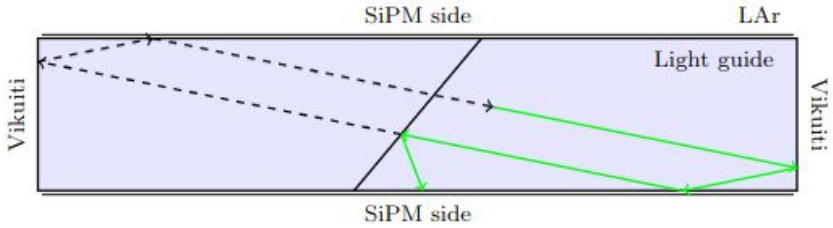


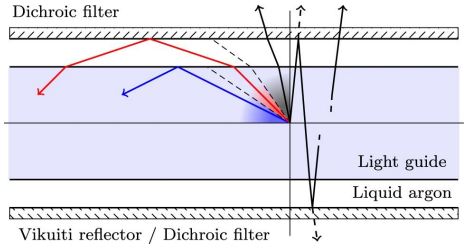
Optimization of the X-ARAPUCA

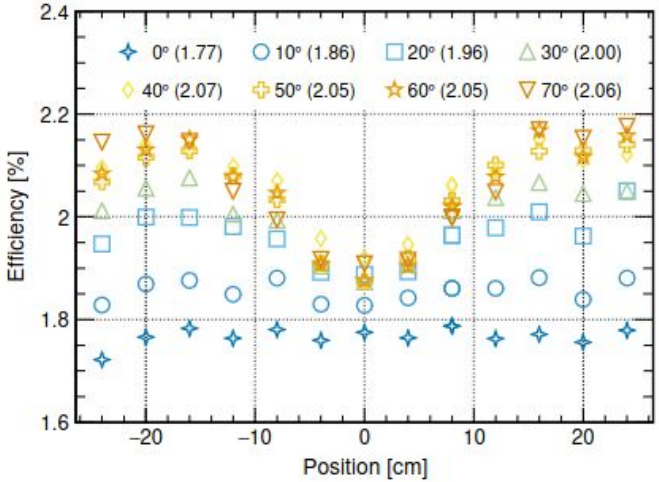
- The optimized X-ARAPUCA FD-HD design increases PDE from ~2.5% to ~4.6% (+84%):

- 40° angle cut with Vikuiti reflector to redirect trapped photons towards the SiPMs.

- Optical sealing and reduced gap: G10 spacers to minimize photon losses between SiPMs.



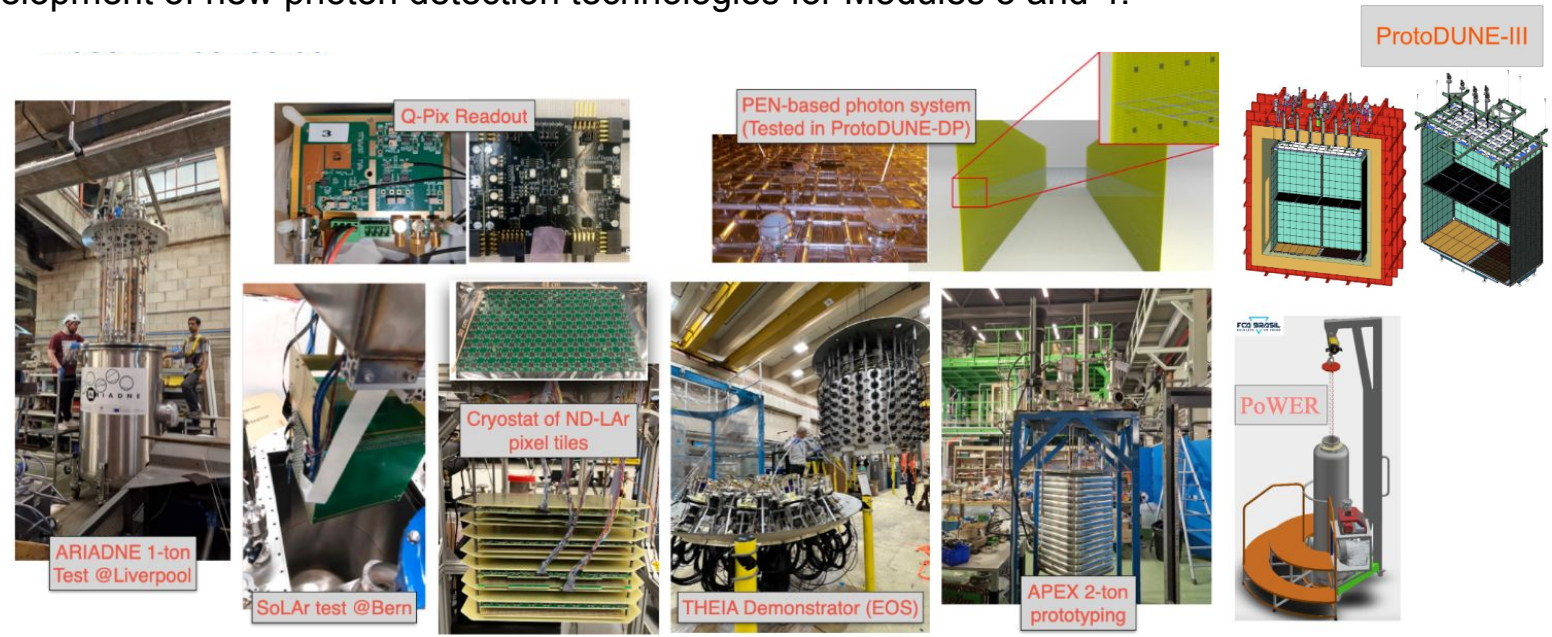




Bertolini, E., *et al.* Optimization of the X-Arapuca photon collection efficiency for the DUNE horizontal drift far detector. *Eur. Phys. J. C* **86**, 672 (2026).

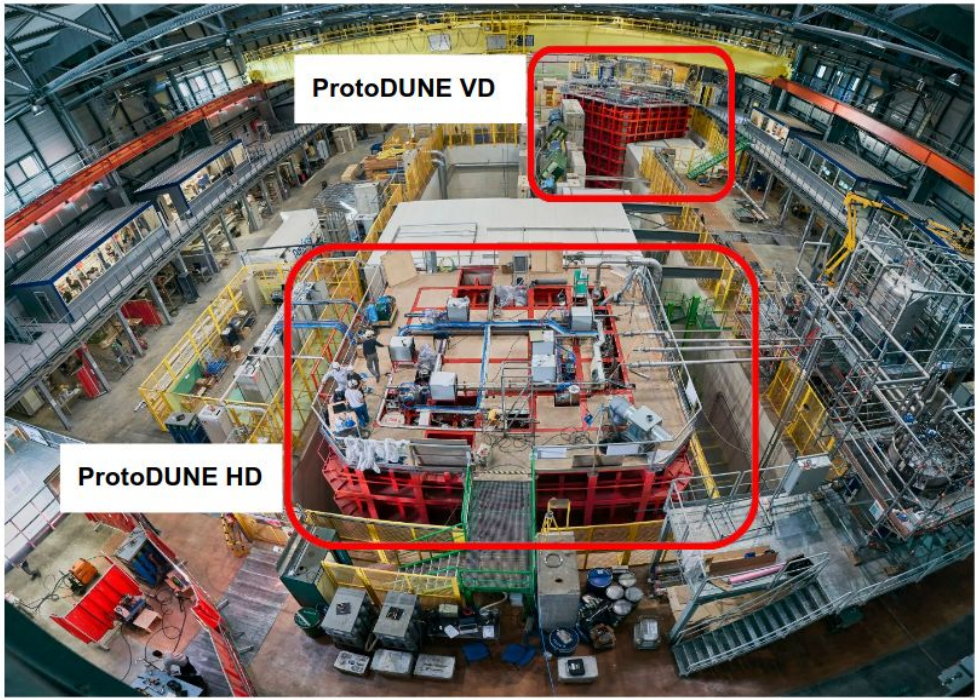
DUNE Phase II Photon Detection Technology

- Development of new photon detection technologies for Modules 3 and 4.



More details in Annysa's talk.

ProtoDUNE



CERN Neutrino Platform EHN1

- Two prototypes with 760 ton of liquid argon (~8x8x8 m3)

- Main Detector Elements include:

-Time Projection Chamber (LArTPC)
-Photon Detector System
-Front-end cold electronics
-Comic-Ray Tagger

ProtoDUNE

ProtoDUNE-HD

- Tested at CERN in 2024 (run II)
  -160 modules
- Massive dataset.
- PDS design - analysis ongoing.

ProtoDUNE-VD

- 16 Megacell were tested at CERN in 2025 and 2026.
- Doped with 7.48 kg of Xenon (10 ppm)
  Xenon doping improves both light yield and timing.



Plenty of data collected and data analysis in progress.

Summary

- The Photon Detection System (PDS) has a relevant role in DUNE physics.
- The Photon Detection System based on the X-ARAPUCA detectors.
- PDS technology will continue to be validated at CERN.
- New photon detection technologies are under development for DUNE Phase II (Modules 3 and 4).
- Physics analyses in preparation for DUNE

More results to come soon, Stay tuned!



Thank You!

The DUNE Collaboration Meeting
(Campinas,Brazil from Sep 21-25/2026)

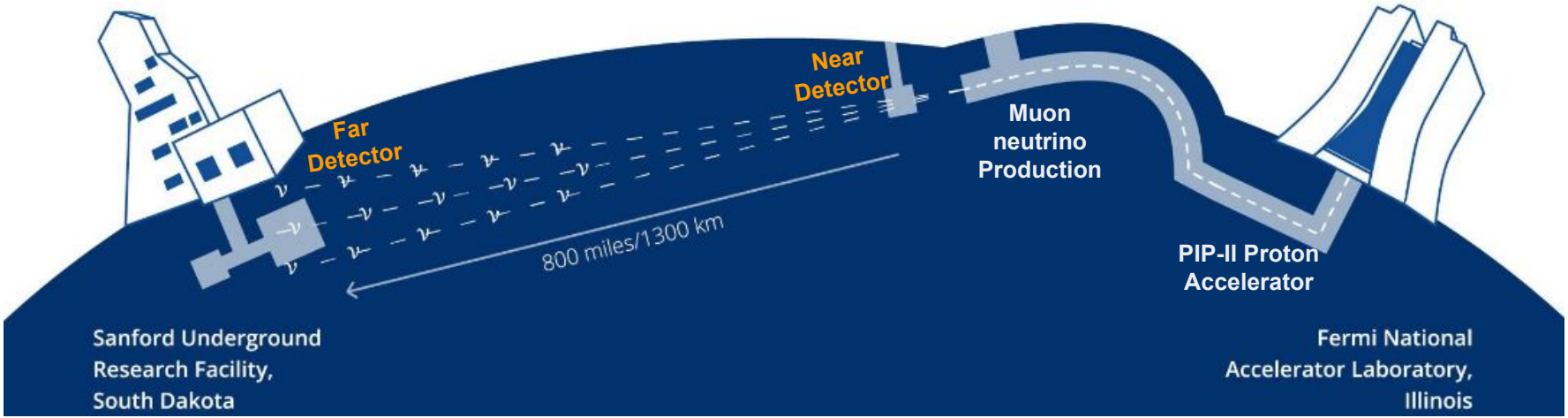
Backup slides

THE DUNE EXPERIMENT

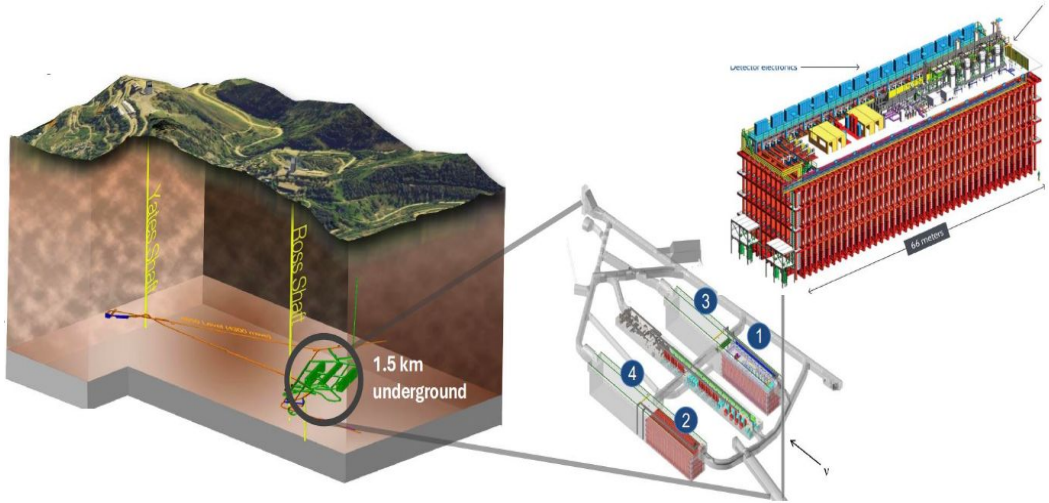
- Far Detector
Measurement of oscillated neutrinos.
Four 17kt LArTPC far detectors.

- Near Detector
Multiple detectors.
Cross-section measurements.

- Neutrino beam
1.2 MW beam power.
upgradeable up to 2.4 MW .

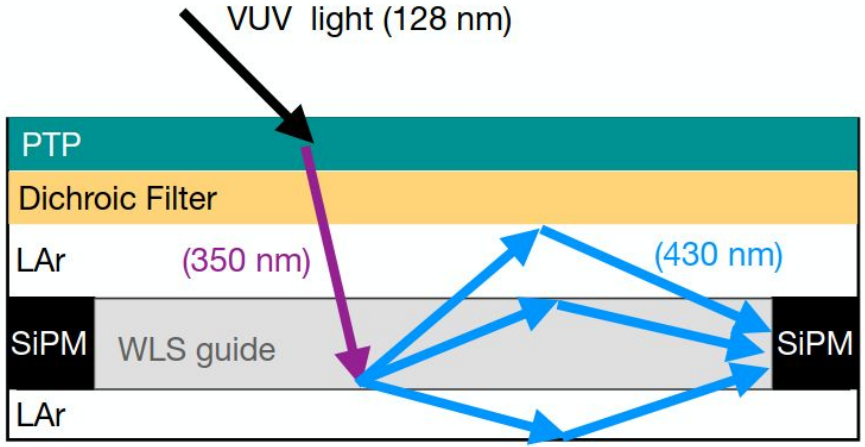


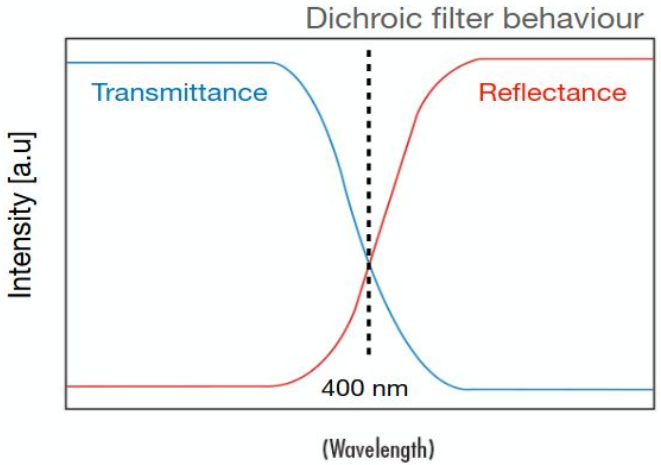
DUNE FAR DETECTOR



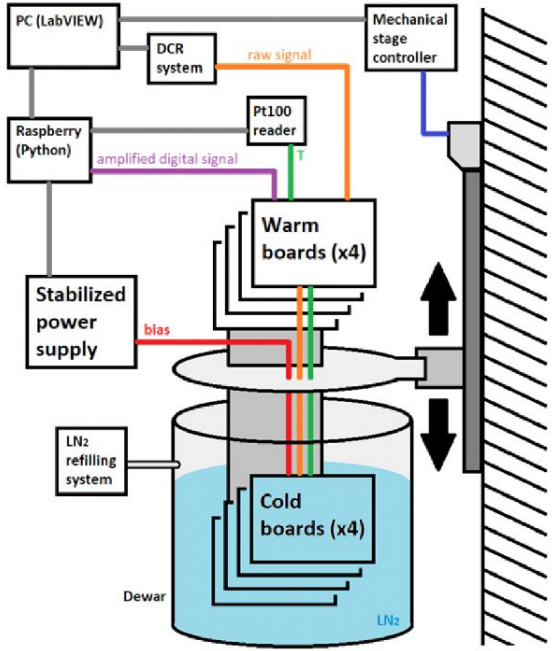
- Located 1.5 km underground in South Dakota.
- Each module:
  18.9 m (W) × 17.8 m (H) × 65.8 m (L)
  17.5 kton Liquid Argon
- Phase I: Design of FD-I and FD-II (1 , 2) has been finalized and component are under production.
- Phase-II: Discussion and R&D on the remaining modules (3,4) ongoing.

X-ARAPUCA


VUV light (128 nm)
PTP
Dichroic Filter
LAr
(350 nm)
(430 nm)
SiPM
WLS guide
SiPM
LAr

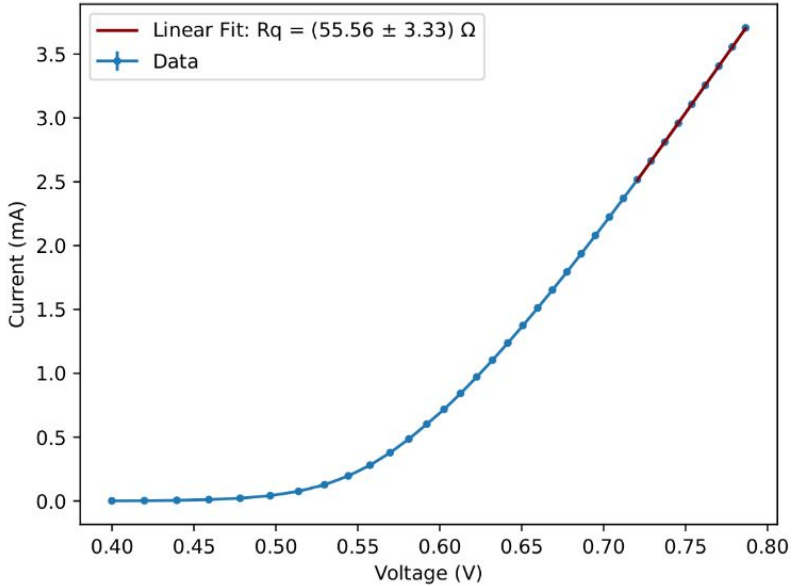

Dichroic filter behaviour
Transmittance
Reflectance
Intensity [a.u]
400 nm
(Wavelength)

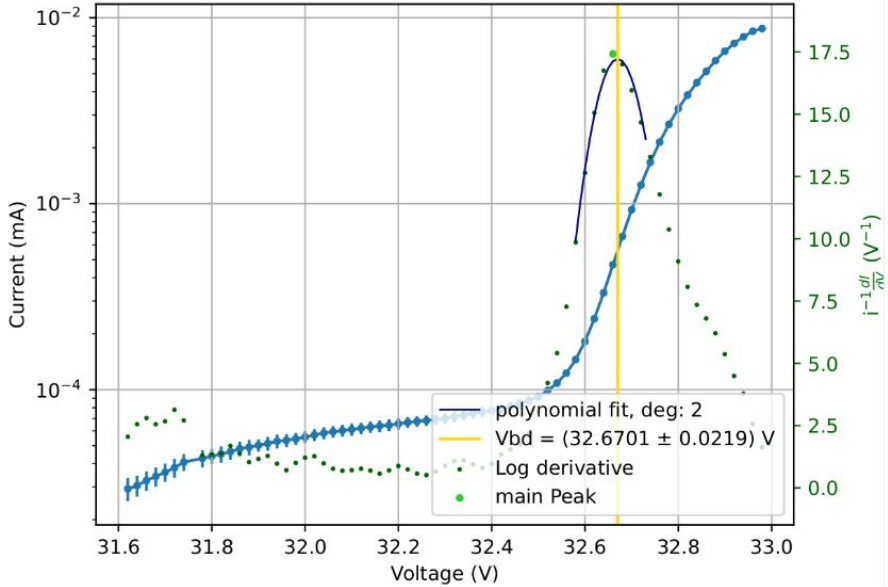
Cryogenic Apparatus for Control Tests Upon SiPMs



- Room temperature IV:

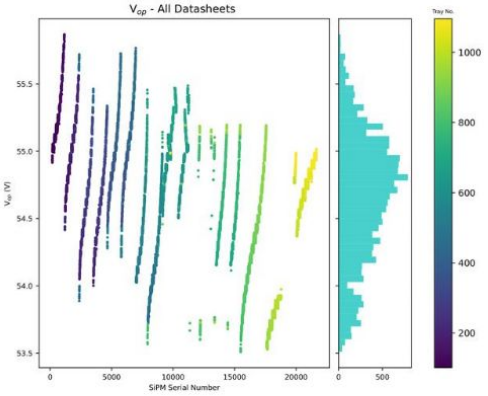
	Voltage range (V)	Current range	Step (mV)	Fit
Forward curve	0-1	[0.1-3.5]mA	20	Linear
Reverse curve	31.5-33.5	[10-500]nA	15	parabolic

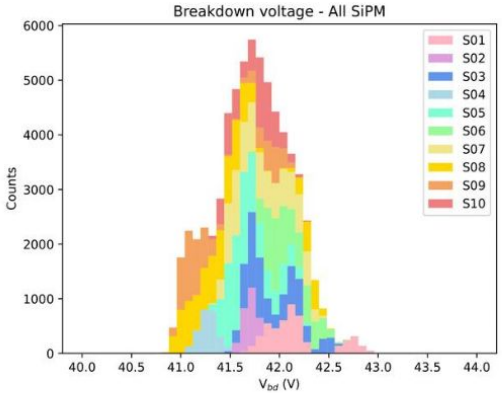


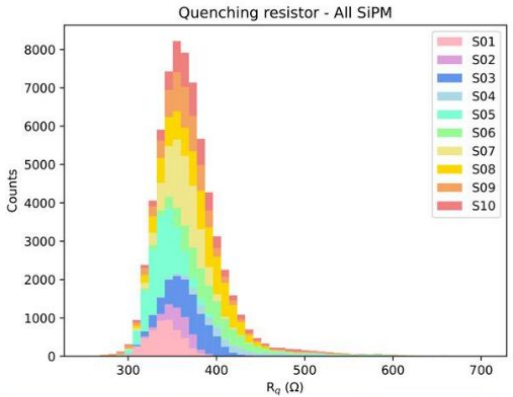


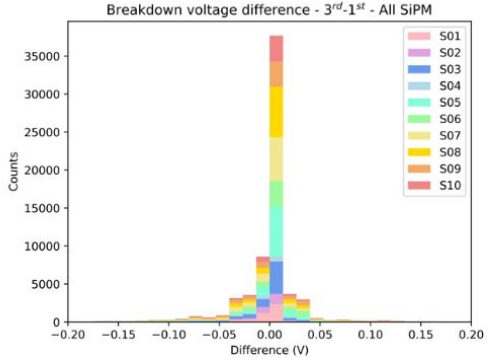
HPK sensors

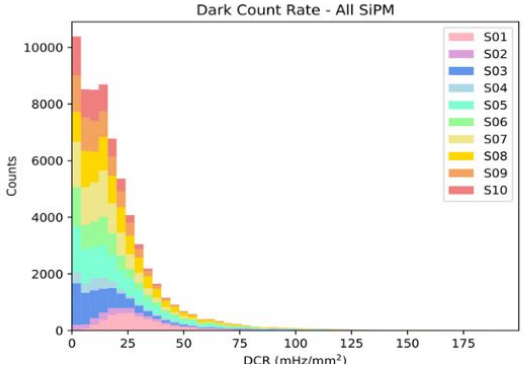
Failure rate ~0.05% at single SiPM level









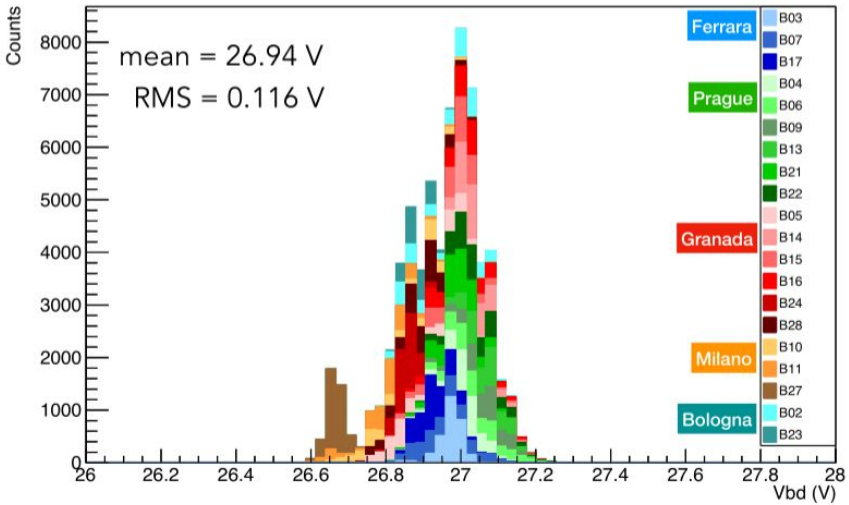




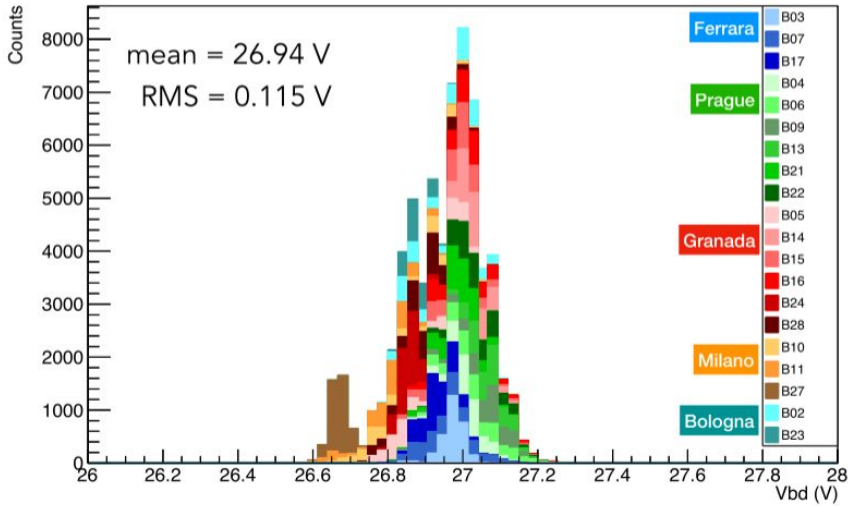
FBK Sensors

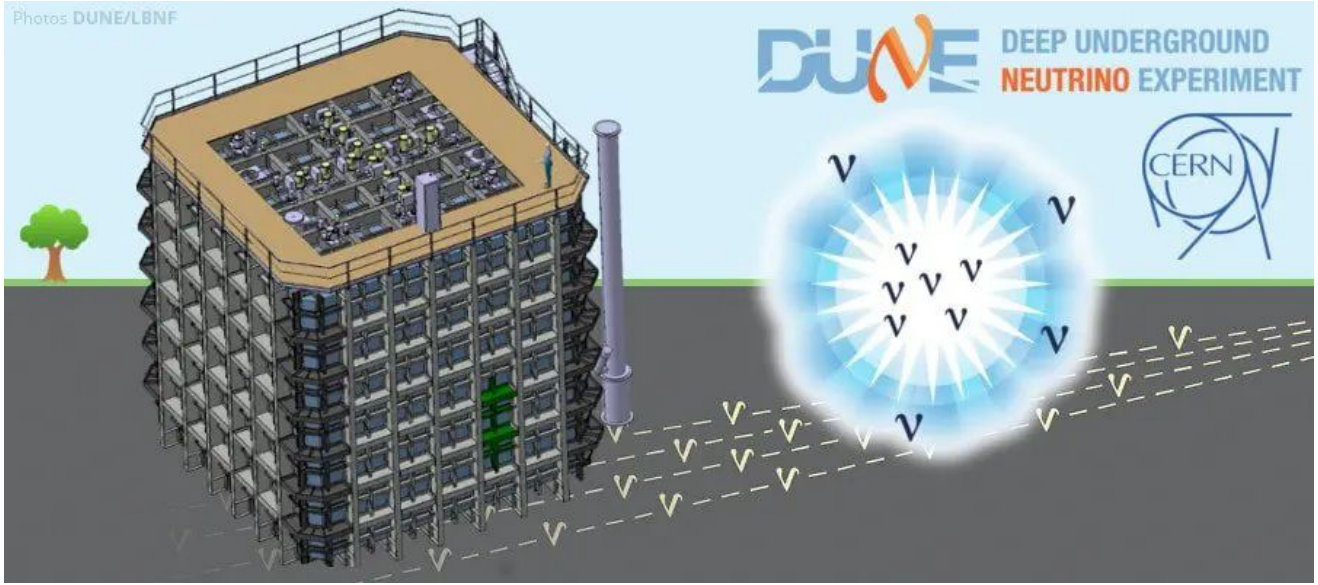
- Breakdown voltage (V_{bd}) before and after thermal cycles
- Almost no difference between 1st & 3rd cycle

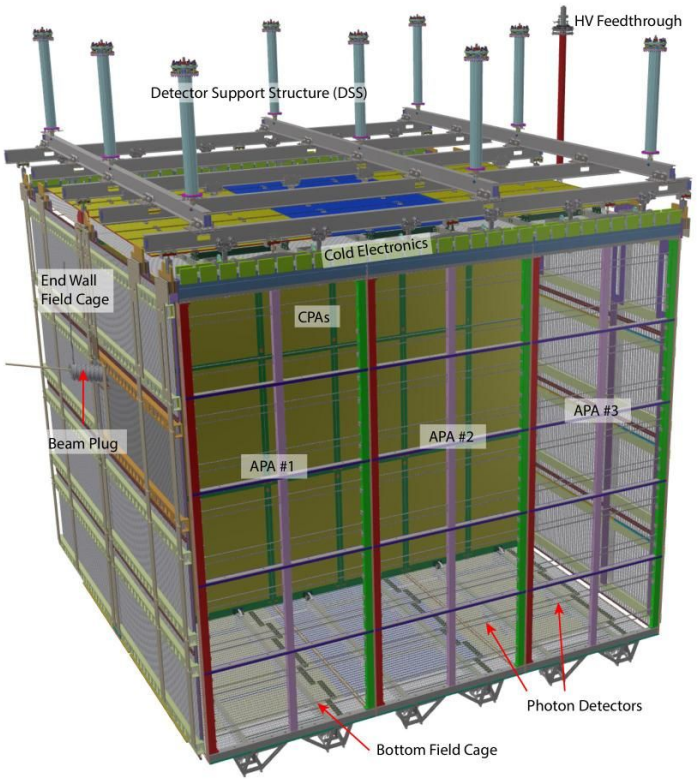
@LN2 Temperature, 1rd cycle

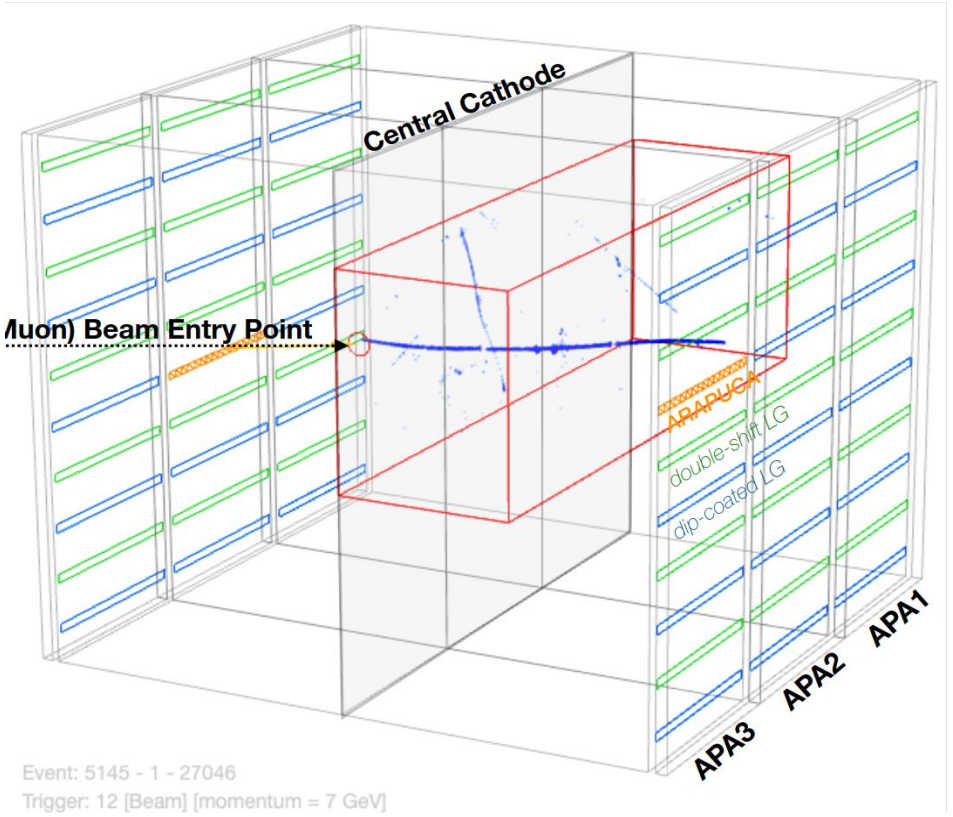


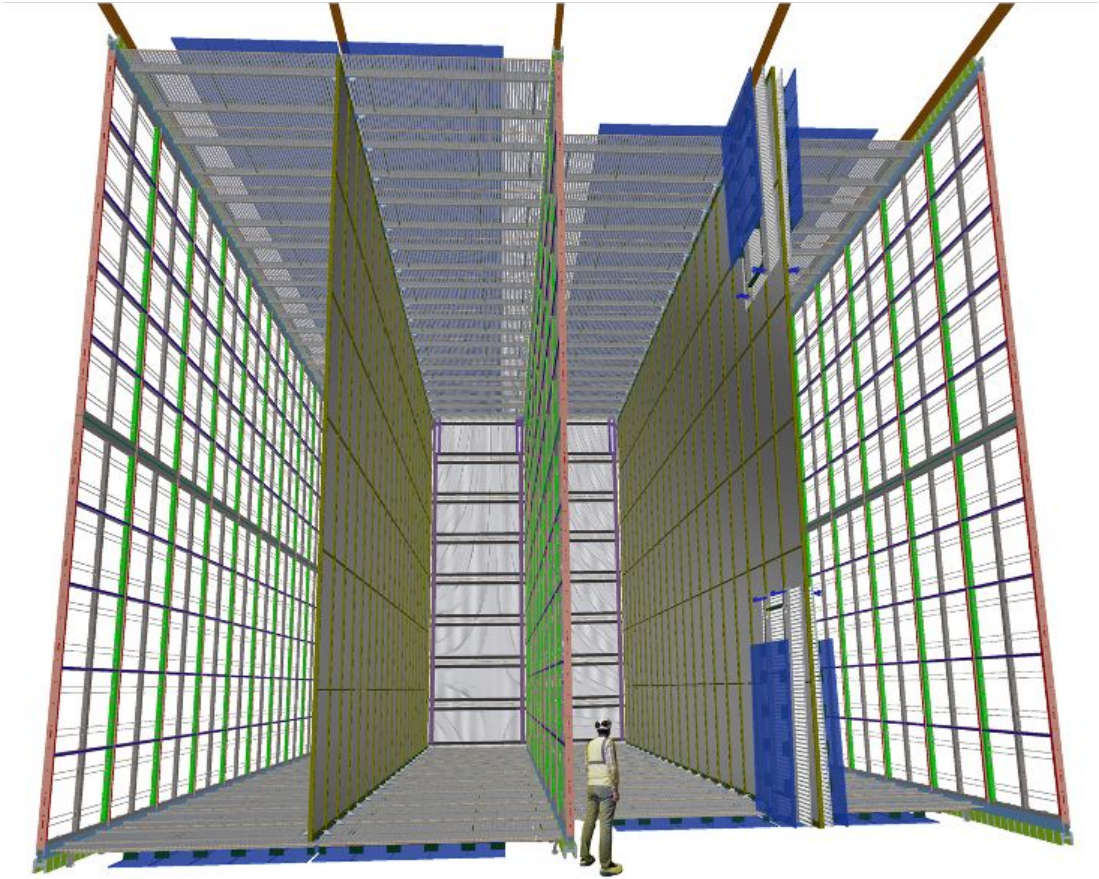
@LN2 Temperature, 3rd cycle

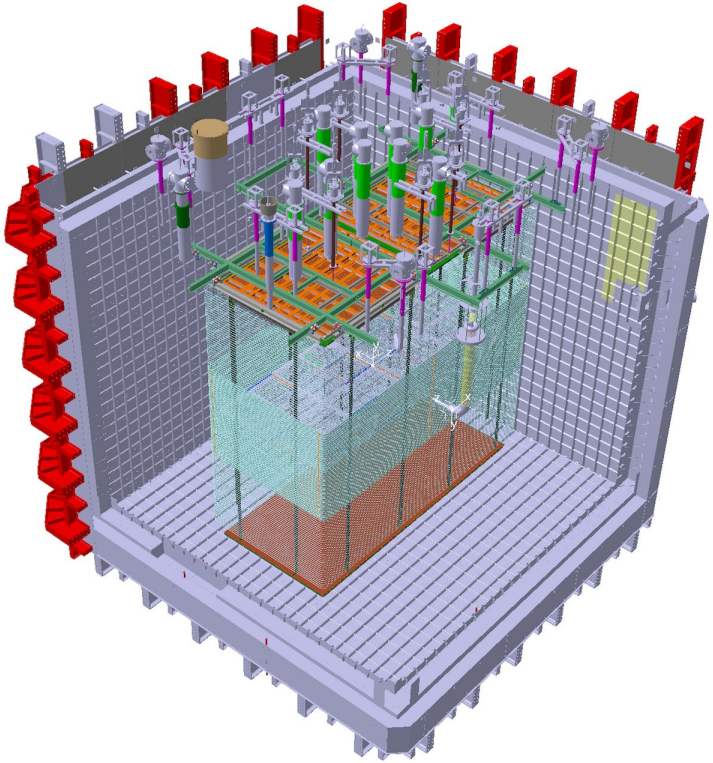



Photos DUNE/LBNF
DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT
CERN

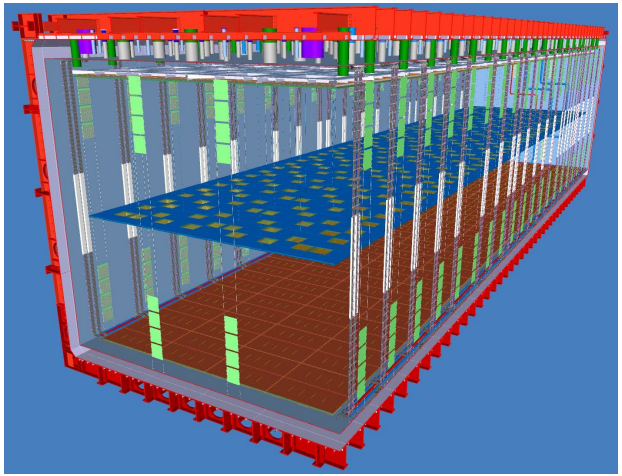

HV Feedthrough
Detector Support Structure (DSS)
Cold Electronics
End Wall
Field Cage
CPAs
Beam Plug
APA #1
APA #2
APA #3
Photon Detectors
Bottom Field Cage


Central Cathode
Muon) Beam Entry Point
ARAPUCA
double-shift LG
dip-coated LG
APA3
APA2
APA1
Event: 5145 - 1 - 27046
Trigger: 12 [Beam] [momentum = 7 GeV]









DUNE Phase II Photon Detection Technology

- Development of new photon detection technologies for Modules 3 and 4.
- **Main goals**: improve signal-to-noise ratio, spatial resolution, light yield, and response uniformity, while reducing external backgrounds.
- **Photon readout optimization:** APEX, POWER, and ARIADNE.
- **Integrated light and charge detection:** SoLAr, LightPix, and Q-Pix-LILAr.

