AIDA innova

Advancement and Innovation for Detectors at Accelerators

WP9: Cryogenic Neutrino Detectors

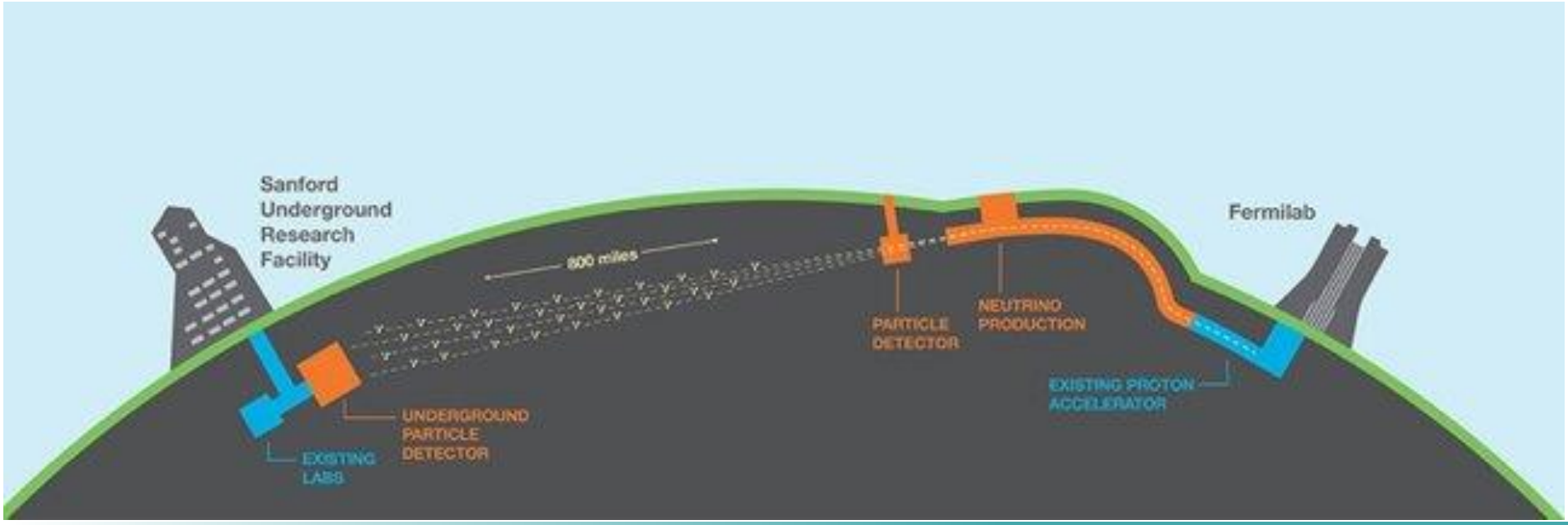
(4th Annual Meeting)

Dario Autiero (CNRS-IP2I) and Andrzej Szelc (Edinburgh)

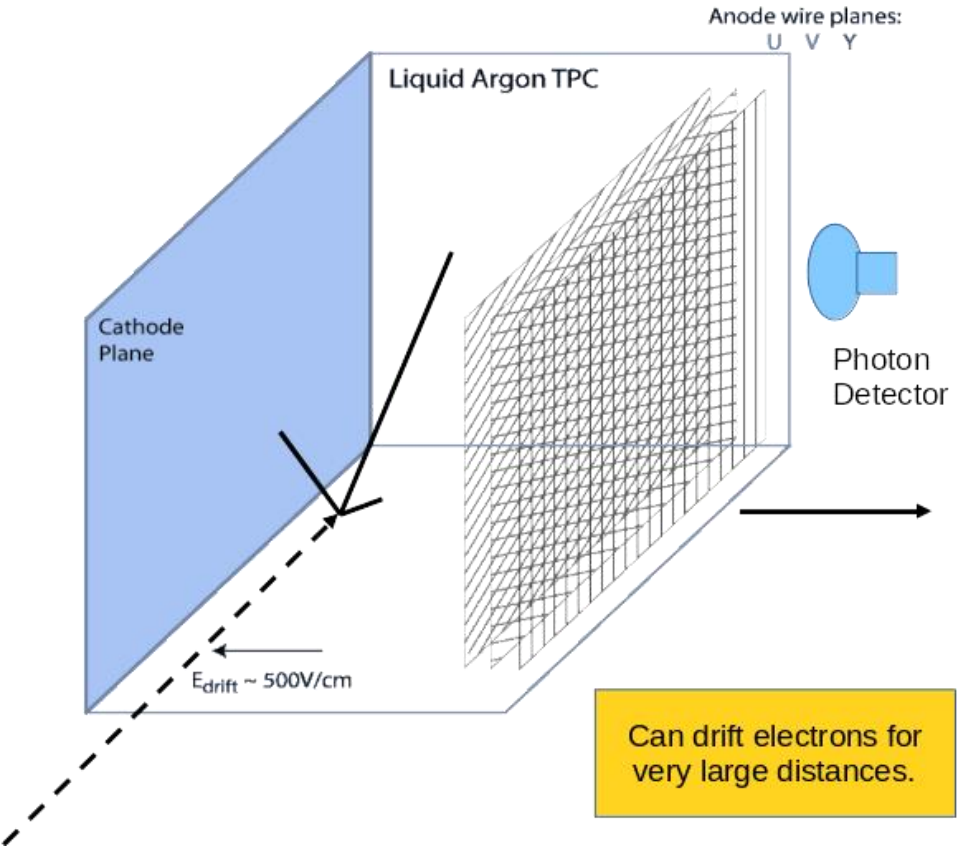
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

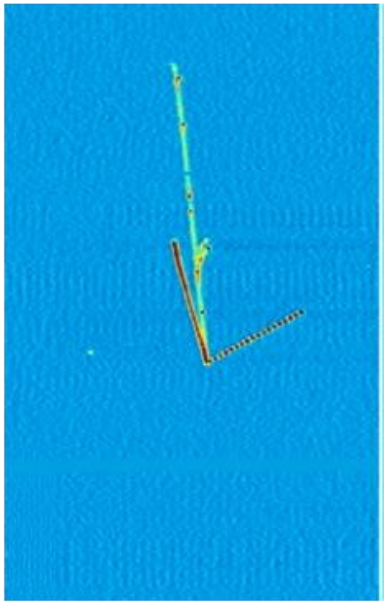
WP9: Cryogenic Detectors

- **WP9: Cryogenic neutrino detectors**
- Focus on innovative developments in large cryogenic detector readout:
  - Charge readout with pixels
  - Charge readout with vertical-drift detectors
  - Readout of scintillation light.
- Applications geared towards DUNE and large-scale DM detectors.



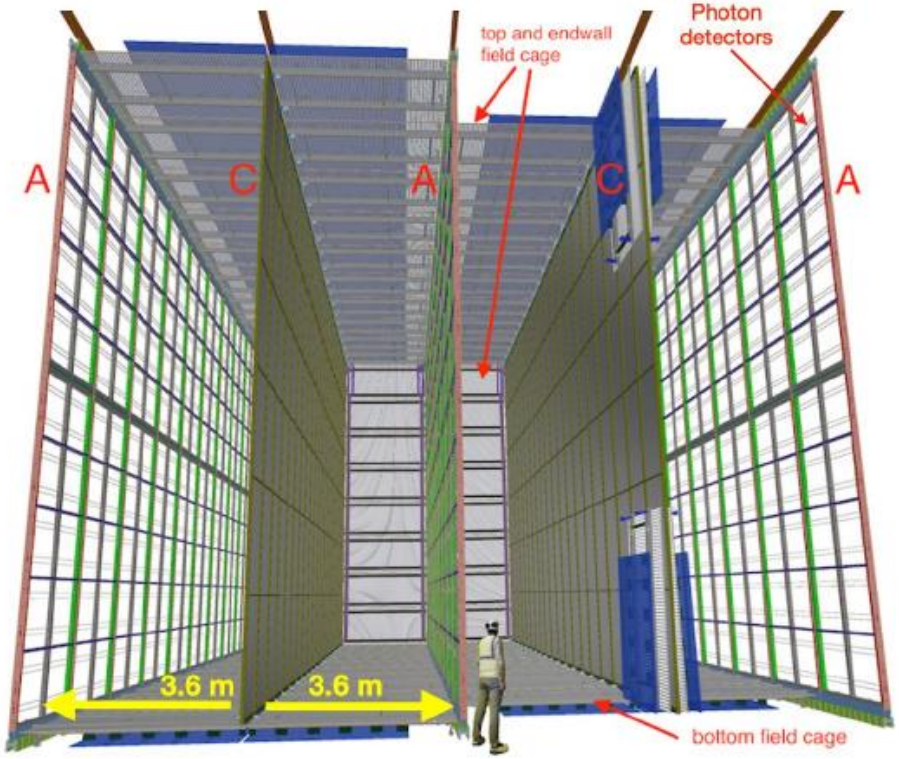
LArTPC operation (in a nutshell)





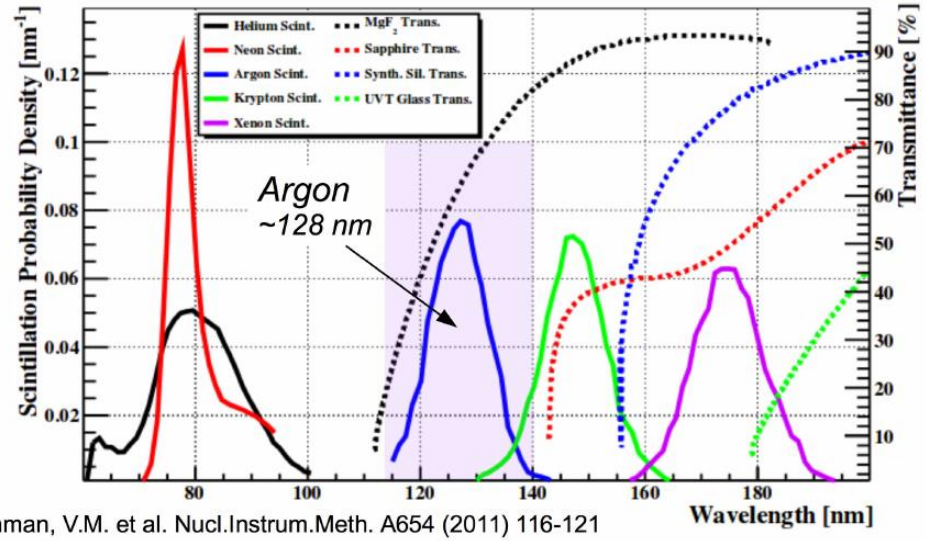
- Excellent position resolution + calorimetry and particle ID
- Ionization is primary signal.
- Scintillation light can provide additional information (timing, calorimetry, position)

Where is the catch(es)?



- HD module has 150 APA modules.
- APA module is 6m x 2.5m and has ~3500 wires.
- APA production/installation challenging.

- Argon VUV light absorbed by most materials.
- APA geometry limits photon-detector size (PMTs not possible)
- Would like high light yield, but detector size means large number of channels needed



Gehman, V.M. et al. Nucl.Instrum.Meth. A654 (2011) 116-121

Work Packages and objectives

- Task 9.1: Coordination and Communication (CNRS-IP2I, Edinburgh)

- Task 9.2: Pixel Charge Readout (Manchester-> Imperial, Bern)
  - Optimized pixel tile pattern for the DUNE LAr far detector
  - Design and prototype for large scale tile-based anode plane

- Task 9.3: Vertical Drift Charge Readout (CNRS-IP2I, CNRS-IJCLab, CNRS-LAPP)
  - Novel Vertical Drift perforated anodes charge readout design evolving from the dual-phase charge readout stack
  - Development and tests of novel design of the Charge Readout Plane (CRP) integration surface of the Vertical Drift perforated anodes
  - Developments and tests of integrated cold electronics, new feedthrough chimneys design
  - Developments in associated digitization hardware and online data treatment

- Task 9.4: Light Readout (CIEMAT, INFN-MIB, Edinburgh)
  - Characterization of new photon detection methods, calibration devices and readout electronics
  - Implementation and characterization of a more efficient light collection system in NP02/ProtoDUNE phase II (Xe doping and Wave-Length Shifting (WLS) combined with reflective foils)
  - Dissemination of R&D results and NP02/ProtoDUNE II light-collection performance (web site)

WP9: Cryogenic Detectors

DUNE (has entered a new phase !):

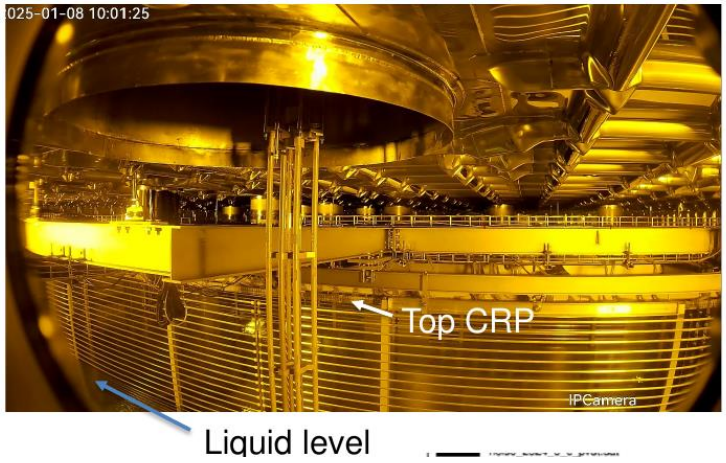
- Caverns excavation completed in January 2024:

https://news.fnal.gov/2024/02/excavation-of-colossal-caverns-for-fermilabs-dune-experiment-completed/

- Since 2024 we are in the construction phase for the DUNE far detectors (started the production of many of the components covered by WP9 in tasks 9.3 and 9.4)

- Successful run of ProtoDUNE-HD last summer, ProtoDUNE-VD filled in January 2025, and will take beam soon.

- SBND filled and taking data (relevant to parts of task 9.4)



Parallel Session yesterday

10:00

WP9 Introduction	*Andrzej Michal Szelc et al.*
Slovanka 117 , FZU	10:20 - 10:30
Status of SoLAr and Pixel R&D	*Dr Anyssa Navrer-Agasson*
Slovanka 117 , FZU	10:30 - 10:55

11:00

Coffee Break	
Kochanovska hall B, FZU	11:00 - 11:20
Vertical Drift development overview.	*Dario Autiero*
Slovanka 117 , FZU	11:20 - 11:45
Light Collection R&D at Milano Biccocca	*Carla Maria Cattadori*
Slovanka 117 , FZU	11:45 - 12:05

12:00

Large-scale WLS Development	*Andrzej Michal Szelc*
Slovanka 117 , FZU	12:05 - 12:25
Light Collection R&D at CIEMAT	*Ignacio Lopez De Rego*
Slovanka 117 , FZU	12:25 - 12:40

- Talks from all three tasks.
- Lots of impressive progress.
- Can only show a fraction/highlights - please look at talks for more details.

Pixels charge readout [T:9.2] (UNIMAN->Imperial, UBERN)

Talk by:
Anyssa Navrer-Agasson

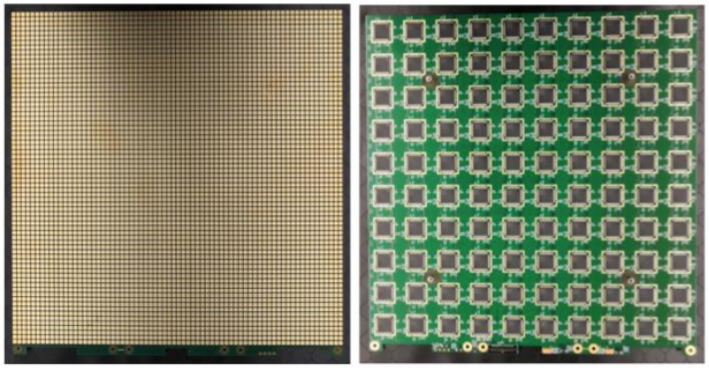
Intro to pixels

Idea: replace wires with pixel-pads

- Reconstruction less complicated
- Many more readout channels

LArPix

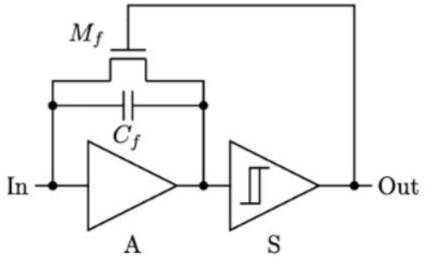
- Self triggered digitisation and readout
- Technology **demonstrated in ArgonCube**
- **Available now**
  - **Used for first prototypes**



32 cm by 32 cm anode PCB tile

Q-Pix

- Developed to **solve the data rate issue** of pixellated readouts
- **Electronic principle of least action**
- Saves time stamps instead of full waveforms

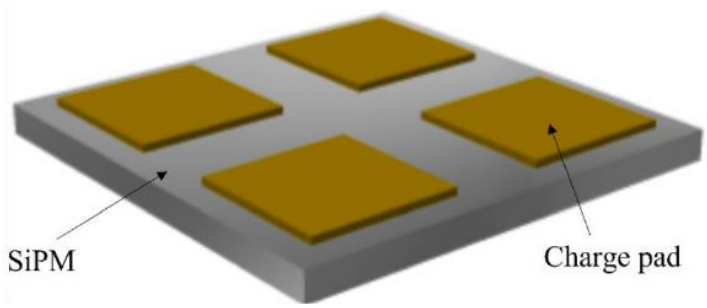


- Each channel integrates Charge Integrate Reset circuit
- Resets when charge > $\Delta Q/C_f$
- Measure reset times with embedded clock

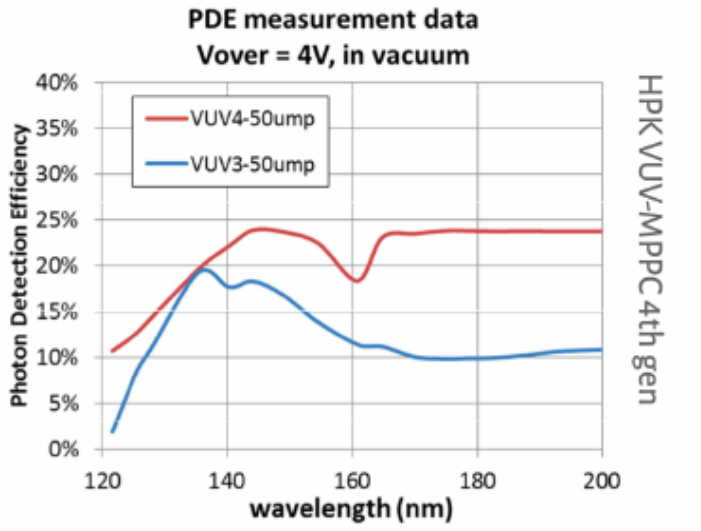
SoLAr concept

A method to simultaneously readout charge and light. In-built improvement of:

- triggering
- energy resolution
- background rejection:

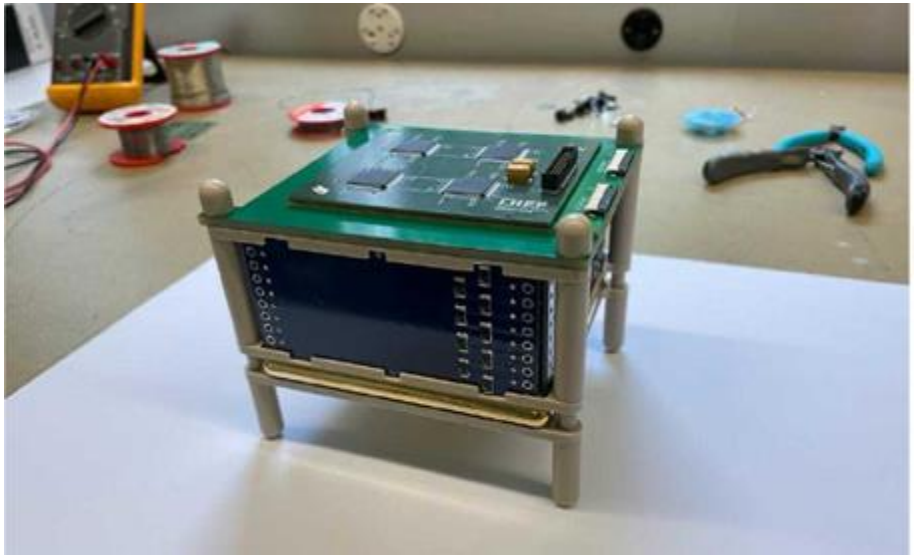


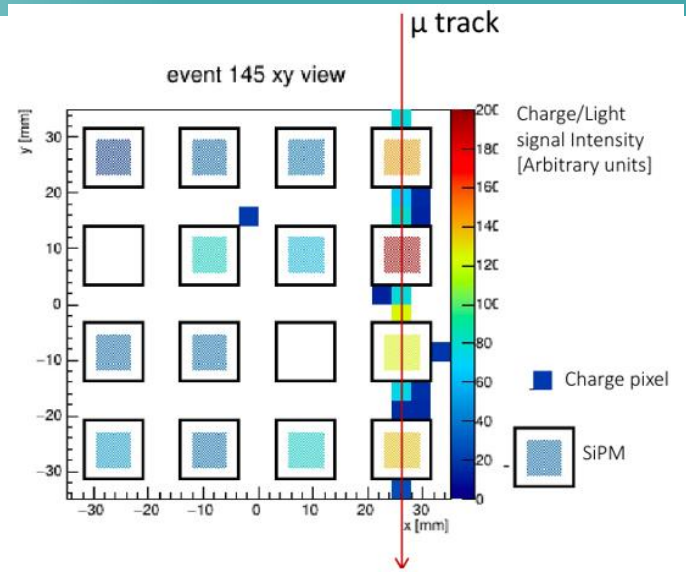
- New generation SiPMs needed:
  - Detect photons at LAr scintillation wavelength (VUV):
    - Hamamatsu 4th generation MPPC
    - FBK VUV-HD technology

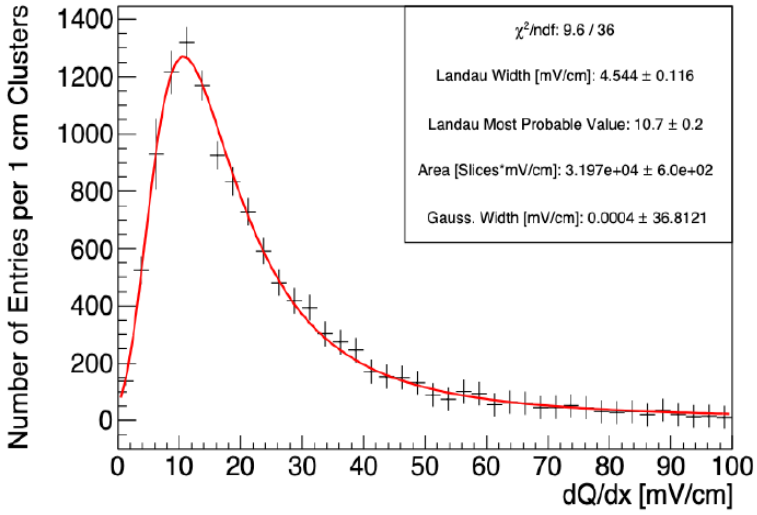


Pixels charge readout [T:9.2] (UNIMAN, UBERN)

- First SoLAr dual-pixel readout Protoype at Bern Oct 22
- Dimensions of the TPC: 12cmx10cmx5cm
- Active area of readout plane 7cmx7cm
- Drift distance ~5 cm







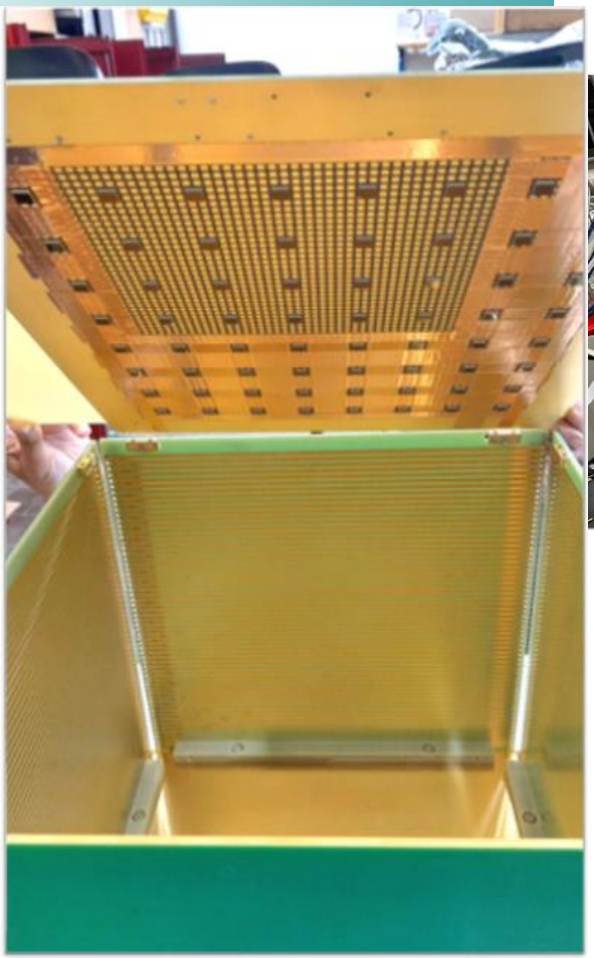
JINST 19 (2024) P11010

Pixels charge readout [T:9.2] (UNIMAN, UBERN)

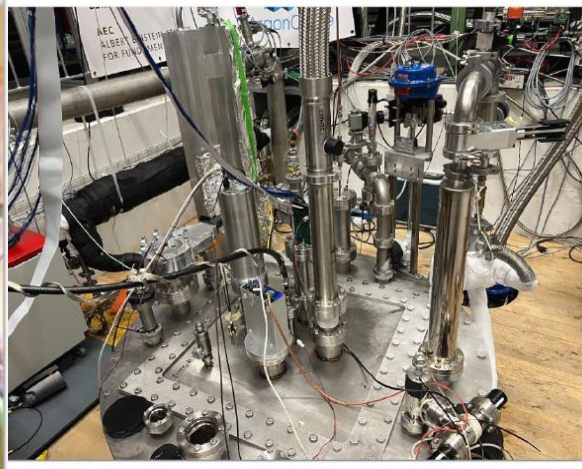
- V2 prototype (July 2023)
- 30x30x30 cm^3 volume
- 20 LArPix chips
- 64 Hamamatsu VUV SiPMS

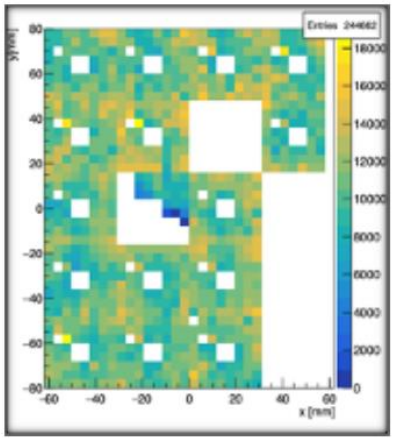
- 10 days of data taking
- Cosmic rays + ^{60}Co

- Partially Instrumented pixel tile



ArgonCube cryostat

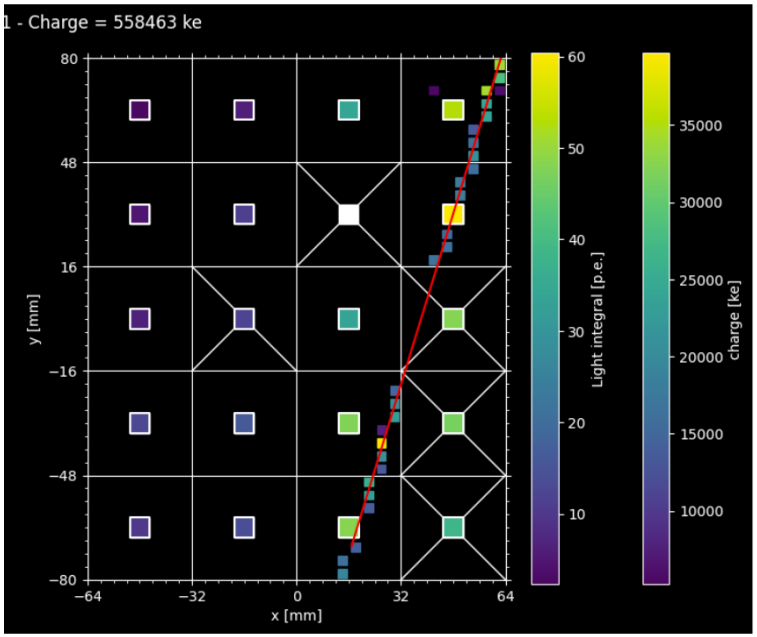




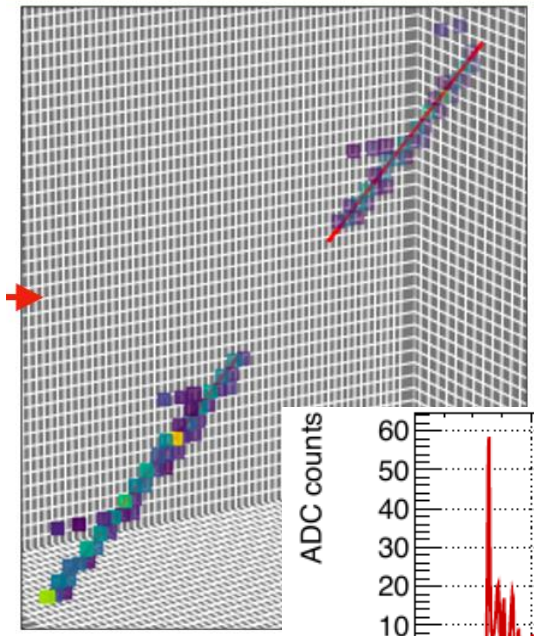
Hit map shows location of disabled pixels

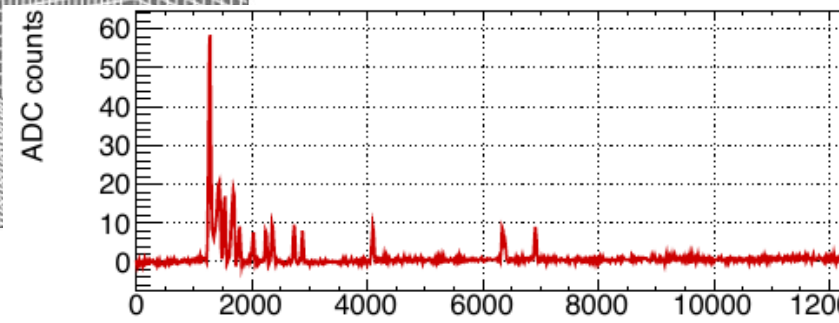
Pixels charge readout [T:9.2] (UNIMAN, UBERN)

Charge+light display



Tracking + light reconstruction



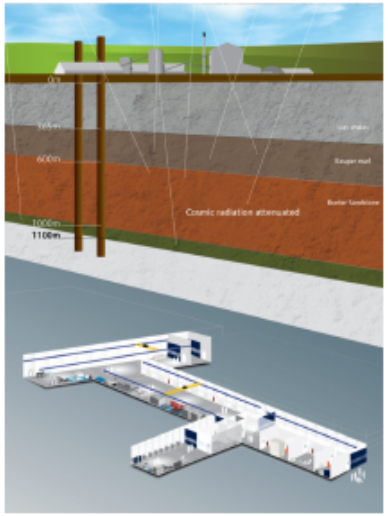


Established preliminary charge-light correlation.
Analysis being finalized.

Simulation for potential DUNE FD module advanced, using D9.1 - Large Scale Pixel Anode design.

Towards a medium-scale demonstrator

Next stage: operate a $\mathcal{O}$(10) ton detector underground



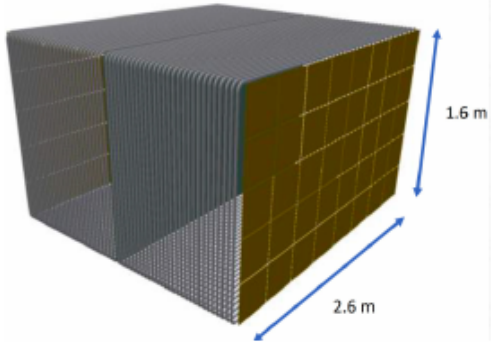
Boulby Laboratory (UK) a possible site. Other options being considered.

Science goals

- Validate SoLAr performance
- Observe ^{8}B flux with > 5 σ significance
- Estimate sensitivity to solar neutrinos for Module of Opportunity

Possible design:

- 1.6 x 2.6 x 2 m^3 (1 m drift length)
- 31 x 31 cm^2 tiles
- Light traps on 4 sides of the TPC



Also an opportunity to be part of a future ProtoDUNE run

- 10-ton scale prototype proposed for Boulby (proposal submitted in May 24).
- Not funded.

Vertical Drift charge readout [T: 9.3] (CNRS-IP2I, CNRS-IJCLab, LAPP)

Talk by
Dario Autiero

The DUNE VerticalDrift FD module

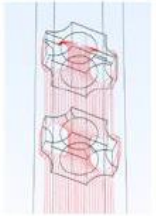
Vertical Drift: novel and optimized LAr TPC technology, anodes based on segmented perforated PCB

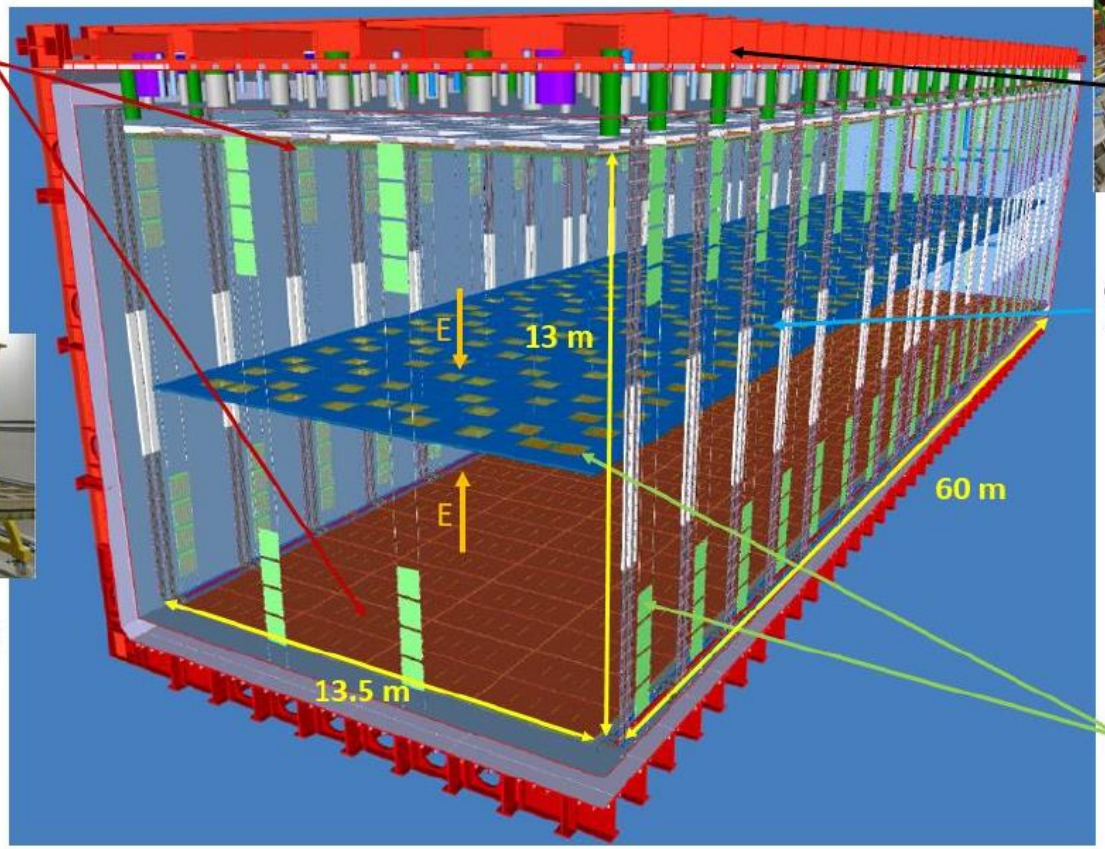
VD is now scheduled as the 1st DUNE FD to be installed.

Top and bottom anode charge readout surfaces:

Made of 80+80 Charge Readout Plane units
3x3.375 m^2
Each unit: 2 stacked layers of segmented perforated PCBs

Strips 5 mm
Holes 2.4 mm





µTCA charge readout

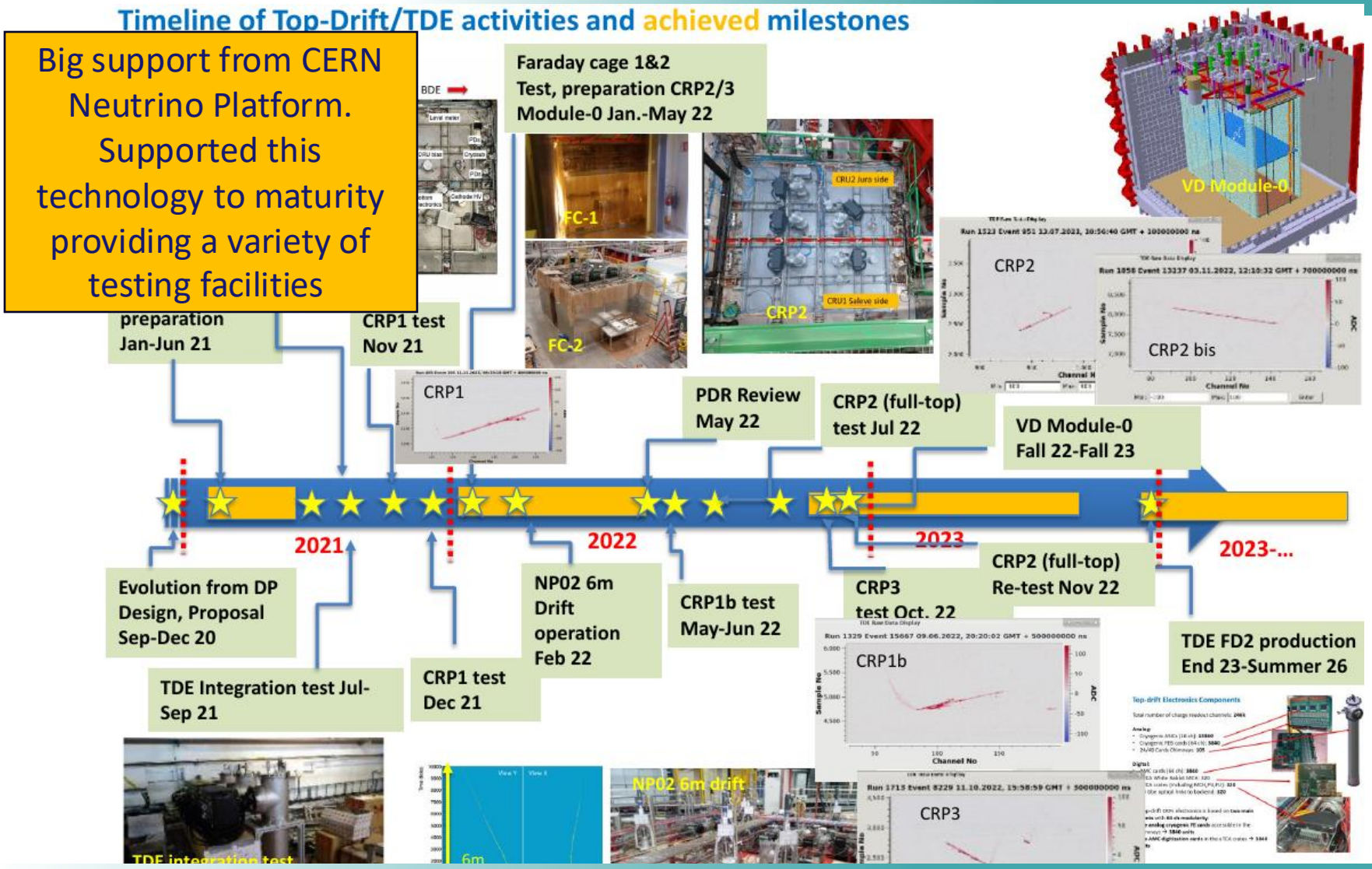
Cathode surface at -300 kV
→ E~500V/cm

1/40 Prototype in NP02 cryostat Module-0

UV photon detectors on cathode and cryostat walls

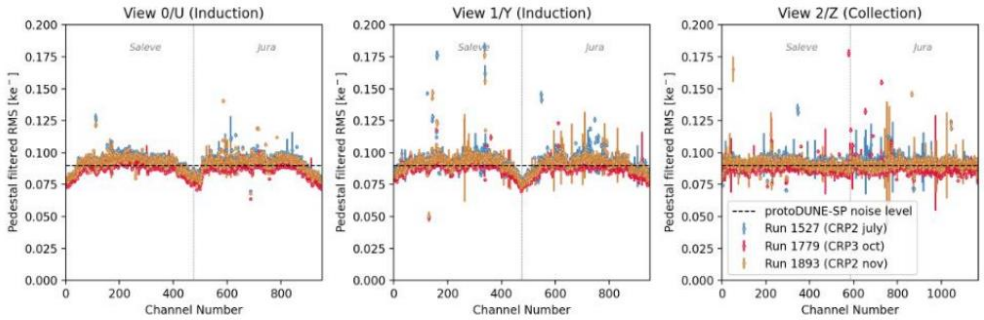
Intense Activity of R&D and tests

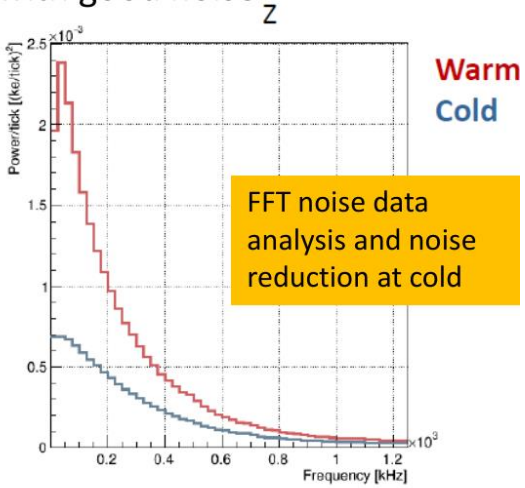
Big support from CERN Neutrino Platform. Supported this technology to maturity providing a variety of testing facilities



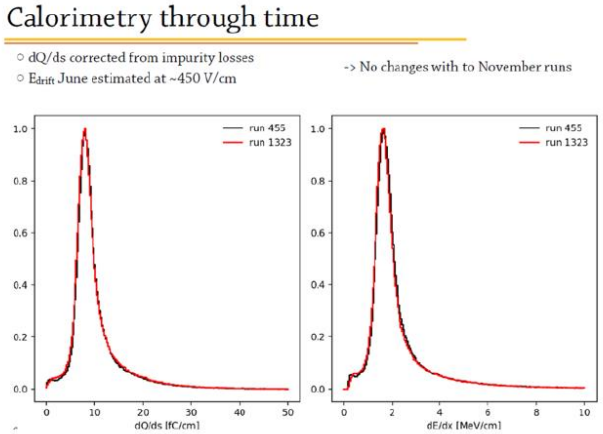
CRP Cold-box at CERN demonstrated performance

Reliable and stable operation during the full CRP Cold-Box runs with good noise performance



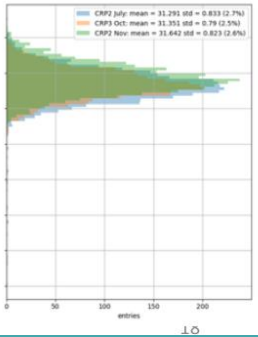


FFT noise data analysis and noise reduction at cold



Stability of dE/dx response studied on **CRP1** October2021-June 2022

- Large cosmic data samples (~M events per test) collected in stable operation. Systematic investigation of external coherent noise sources (PD, instrumentation)
- Remarkable reproducibility of calibration data taken for CRP2/3/2 (1%) with 2.5% response spread among different channels
- Signals reproducibility confirmed in physical response to cosmic tracks (dQ/dx) from offline analysis of CRP data



Switching mode to production

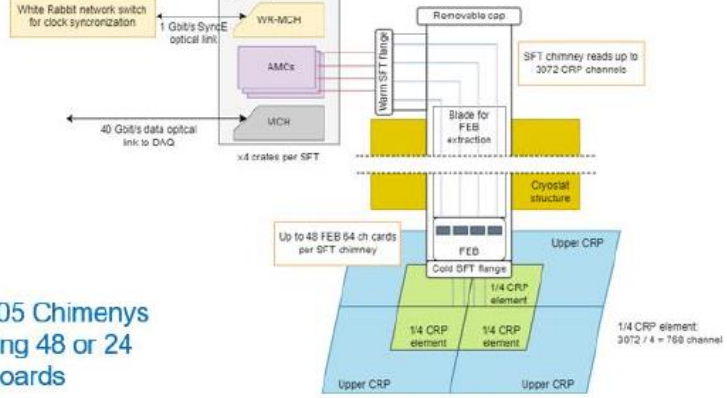
Readout System for the top-drift volume of FD2-VD
80 CRP, 3072 channels/CRP, 246k total channels

Elements needed to be installed on FD2-VD (production 2024-2026):

- 3840 cryogenic FE boards (64 channe with 15360 ASIC 16 channels amplifiers

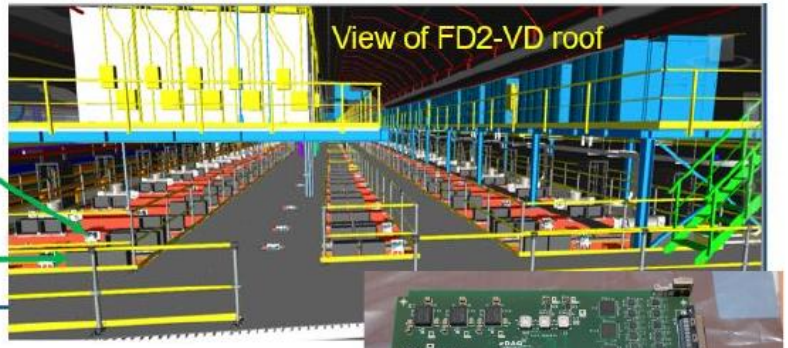
- 3840 AMC (64 channels)

- 105 Chimenys hosting 48 or 24 FE boards



- 320 WR-MCH

- 320 µTCA systems with 40 Gbit/s MCH



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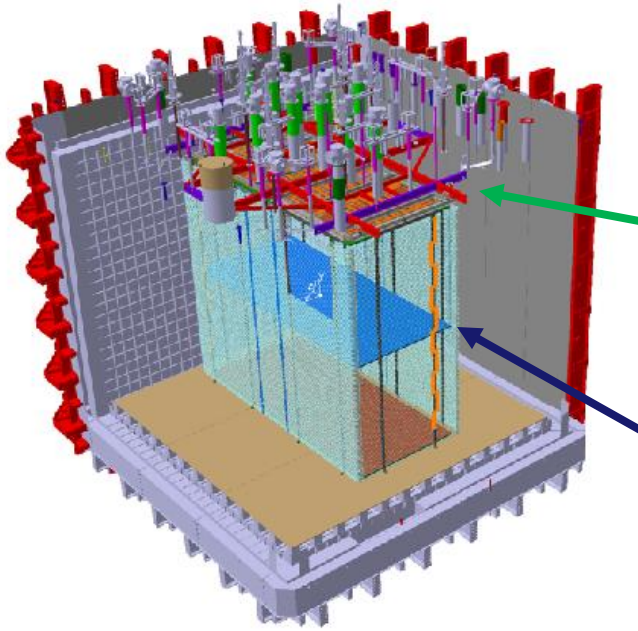
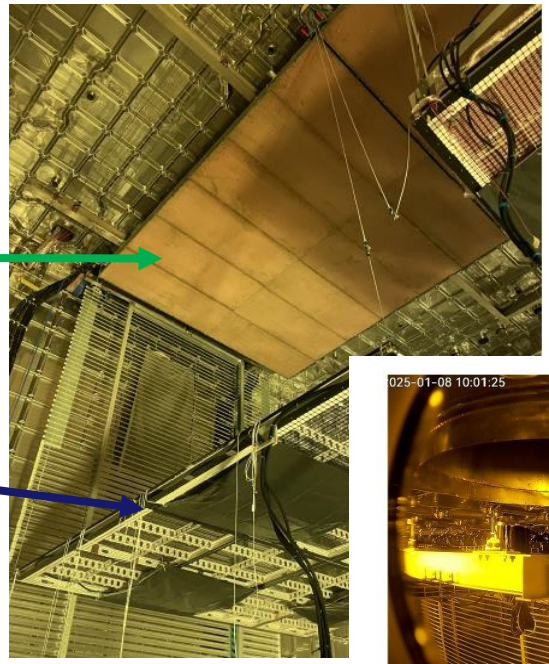
Production activities for FD-VD in progress (started in 2024)

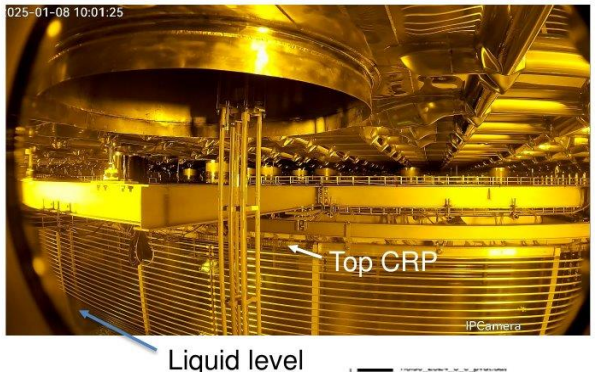
- Cryogenic ASICs production completion with AMS
- AMC boards and microTCA crates
- Frond End analog boards
- Chimneys
- CRP structures

22

Module-0 (ProtoDUNE-VD)







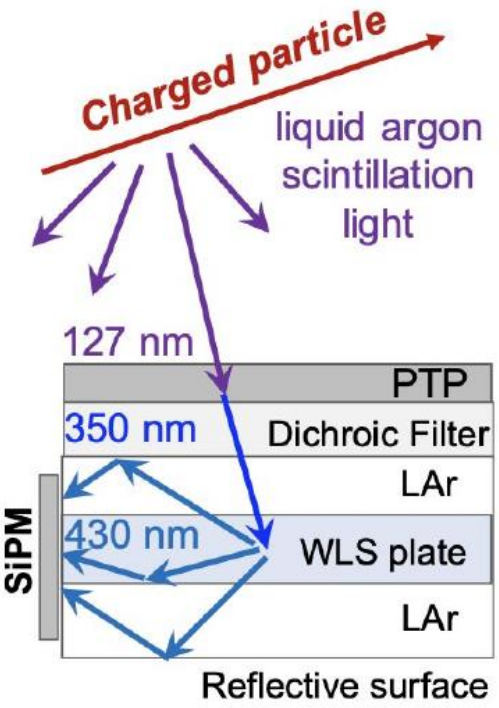
- Module-0/ProtoDUNE Vertical Drift: last Vertical Drift integration exercise before 2nd DUNE FD module construction -> completed in June 2023
- Detector has been filled (end of 2024), will take beam later this year.
- Main applications for reconstruction studies/development of cosmic and charged beam.

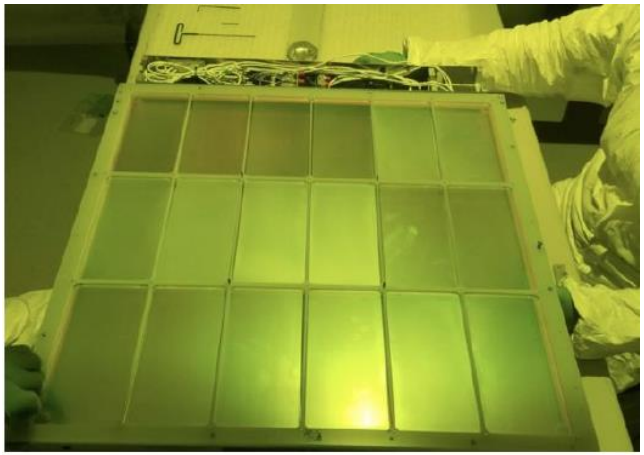
Light Readout [T:9.4] (CIEMAT, INFN-MIB, UEDIN)

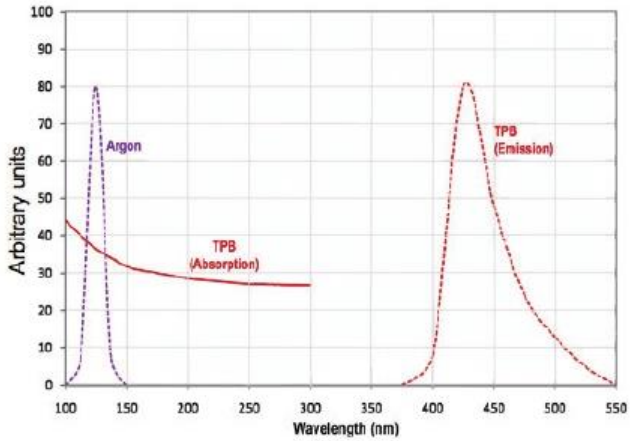
Talks by:
Carla Cattadori
Ignacio Lopez de Rego
Andrzej Szelc

Common solutions in LAr Light Readout

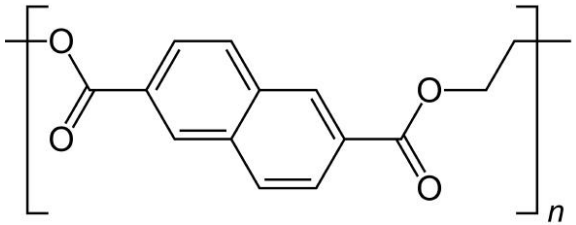
Ideas:
- Use light collectors (trapping photons)
- Use wavelength-shifters to transform light to visible





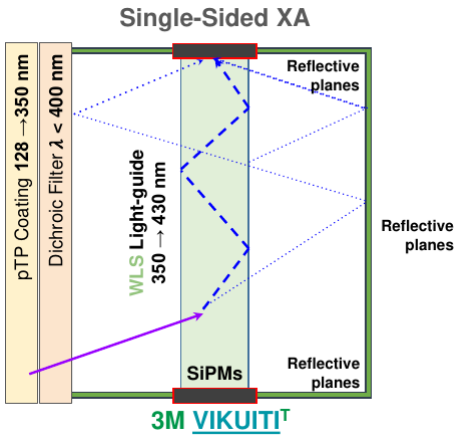


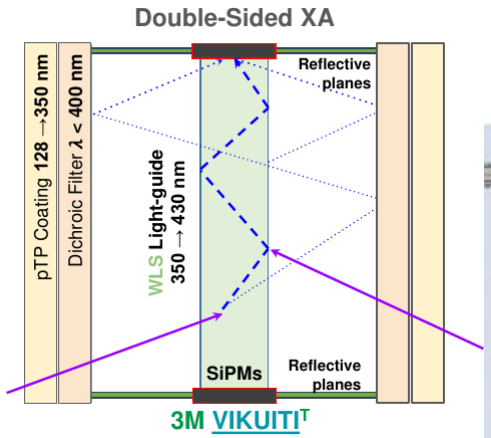
TPB emission and absorption spectra and argon scintillation peak [1]



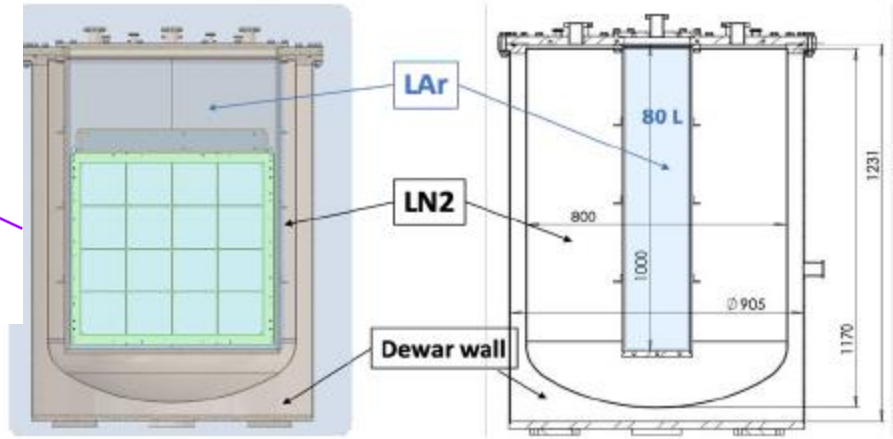
Above: PEN molecule; below: PEN sheets

Tests of ProtoDUNE X-ARAPUCAS





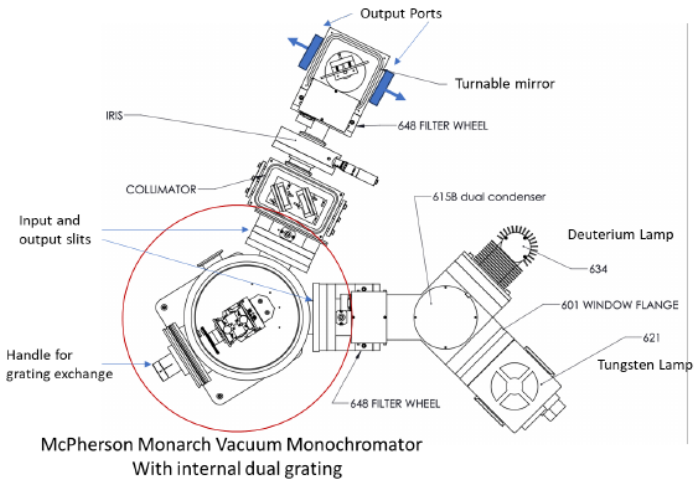
Dedicated cryostat for VD X-A tests.



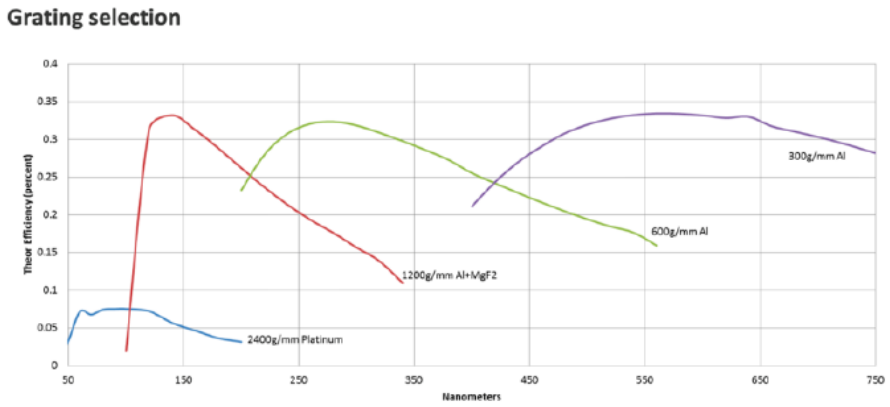
	Dichroic Filter		Non-Dichroic Filter		
	Single-Sided	Double-Sided	Single-Sided	Double-Sided	Single-Sided
OV	1. DF-XA	2. DF-XA-DS	3. noDF-XA	4. noDF-XA-DS	5. noDF-XA_24mg
4.5	(3.7 ± 0.3) %	(4.0 ± 0.4) %	(4.5 ± 0.4) %	(4.5 ± 0.4) %	(4.3 ± 0.4) %

- Conclusions:
  - **Compatible performance** of **single vs. double-sided XA** configs.
  - **Improvement 18% (single-sided)** & **11% (double-sided)** when **removing dichroic filters** due to non-ideal entrance transmittance and shifting cut-off for different angles.

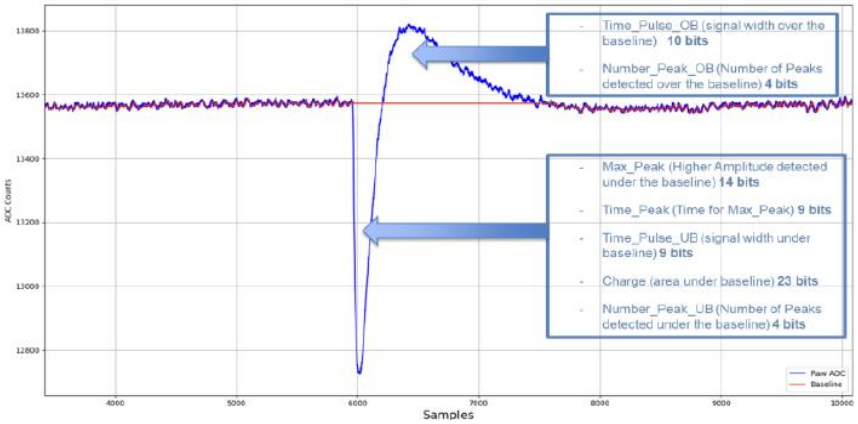
Light trigger and new monochromator



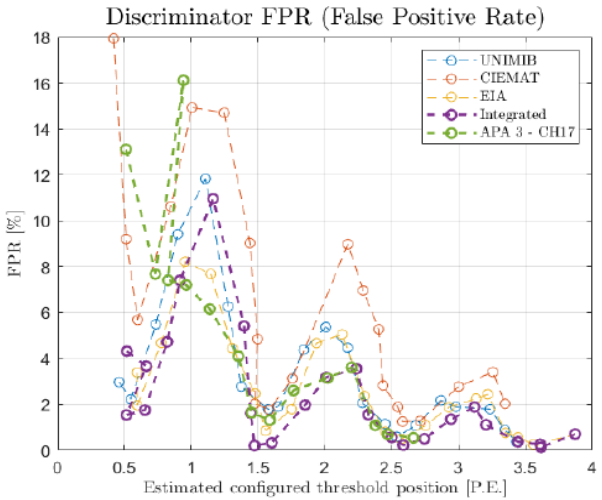
McPherson Monarch Vacuum Monochromator
With internal dual grating



Wide range of wavelengths available. First tests in progress.



First scintillation light triggers algorithms developed and tested in ProtoDUNE-HD

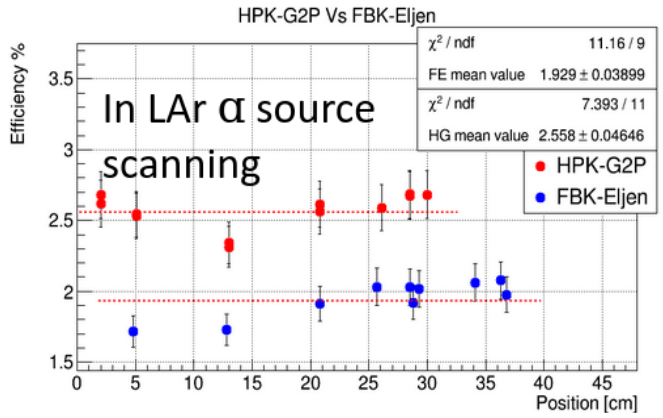


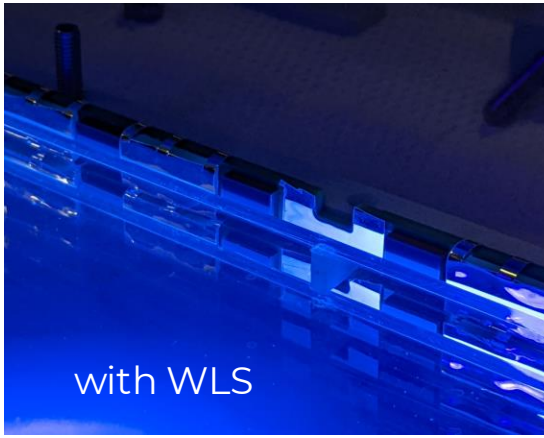
Campaign to improve X-Arapuca efficiency

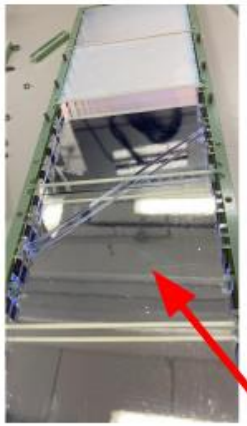
New WLS – lightguide material
New optical sealing
Modified bar geometry.

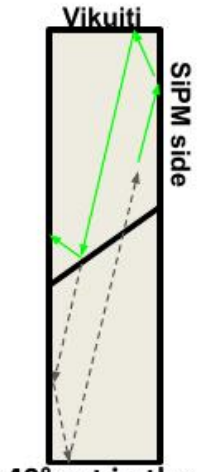
Result modified PDE from
2% -> 4.5%

Applied also to HD detectors.

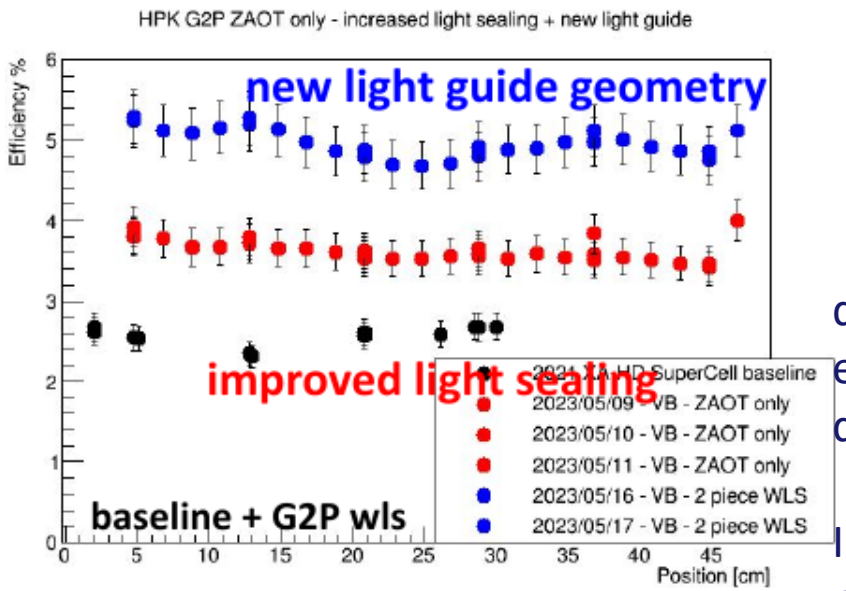








40° cut in the middle with Vikuiti applied

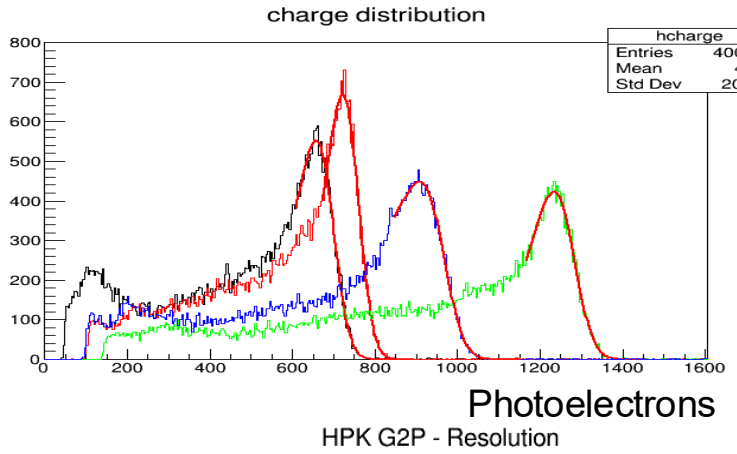


detection efficiency doubled!

Improved resolution.

X-ARAPUCA WLS bar selection

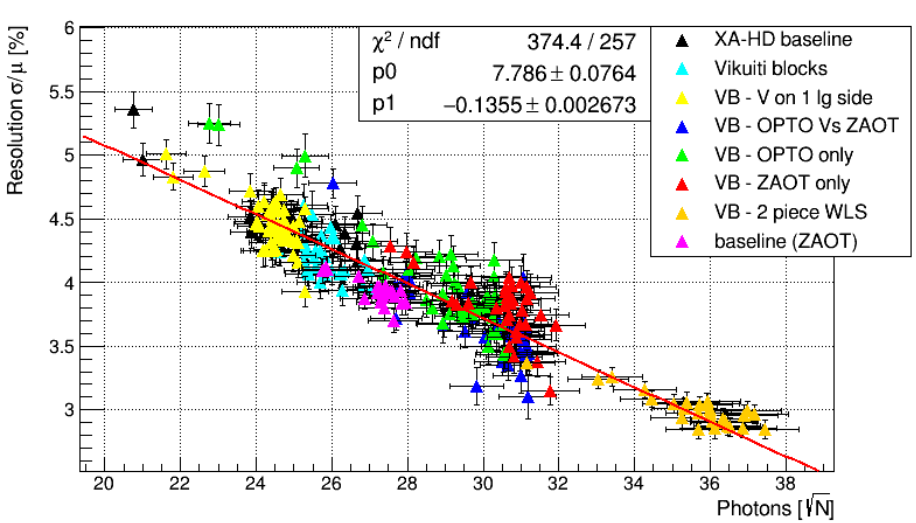
— **DUNE FD1 XA** baseline design
— p-DUNE WLS no optical sealing, ZAOT DF
— p-DUNE WLS w. optical sealing, ZAOT DF
— WLS with cut & optical sealing, ZAOT DF



In parallel, tests of PEN as WLS for future large-scale applications.

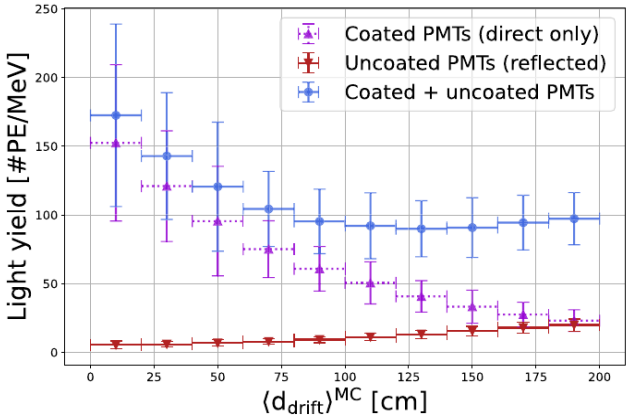
First tests show
~ 44% of the XA BL design (pTP & Blue WLS)

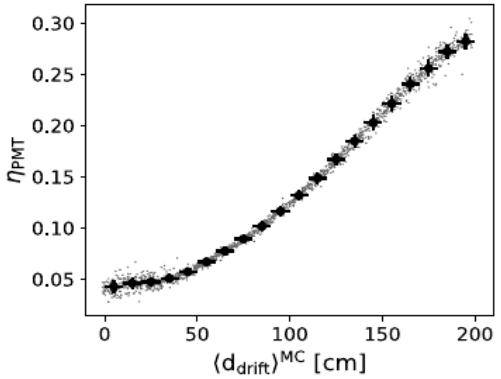
consistent with other measurements.



Large-scale WLS for neutrino detectors

- SBND @ FNAL is running. Equipped with 38² m of TPB-coated foils. Mature simulation and reconstruction allows development of new applications – demonstrated drift position reconstruction.
- PMT calibration enabled PMT setup. First glance shows WLS working.
- In parallel – test @CERN, 4m² of PEN.
- Tested stability on week-time scale. Efficiency ~47% of TPB.





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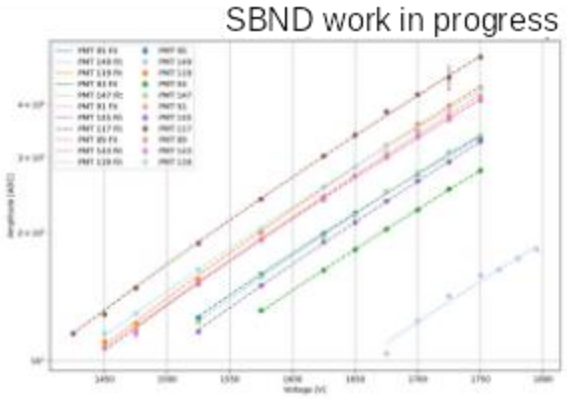

ArXiv:2411.17934

Deliverables/Milestones

Milestones

MS #	Milestone Name	Lead beneficiary	Due Date (in months)	Means of verification
MS36	Pixel optimisation	40 - UNIMAN	23	Report (Task 9.2)
MS37	Status report on chimneys	8 - CNRS	22	Report (Task 9.3)
MS38	Status report on CRPs	8 - CNRS	23	Report (Task 9.3)
MS39	Status report on digitisation	8 - CNRS	33	Report (Task 9.3)
MS40	Large-scale WLS surfaces and SiPMs Tested	21 - INFN	22	Report (Task 9.4)

Deliverables

D #	Deliverable Name	Lead beneficiary	Type	Due Date (in months)
D9.1	Large-scale Pixel Anode	40 - UNIMAN	Report	44
D9.2	Vertical Drift chimneys, digitisation, CRPs	8 - CNRS	Report	46
D9.3	R&D in LAr optical readout	29 - CIEMAT	Report	45

Foreseen detector developments successfully completed – excellent results from various tests are having an impact on the final detector configuration for DUNE

Switching to production mode.

New collaborations enabled by AIDAInnova

All WP 9 milestones completed. Deliverables 9.1 and 9.2 completed.
9.3 extended until end of May.

Conclusions

- AIDAInnova activities have resulted in excellent progress in developing cryogenic neutrino detectors.
- Milestones completed. Final deliverable due end of May (extended)
- New ideas/collaboration formed thanks to AIDAInnova
- Highlights of the WP:
  - New concept of combined pixel charge + light readout
  - Fully developed and tested design of the VD readout for the DUNE FD module.
  - Facilities and extensive tests of the various flavours of the DUNE light detectors.
  - 2x Improved DUNE Light Detection efficiency.
  - Demonstration of light-only drift position reconstruction.
- We learned a lot and achieved a lot.