AIDA innova

Advancement and Innovation for Detectors at Accelerators

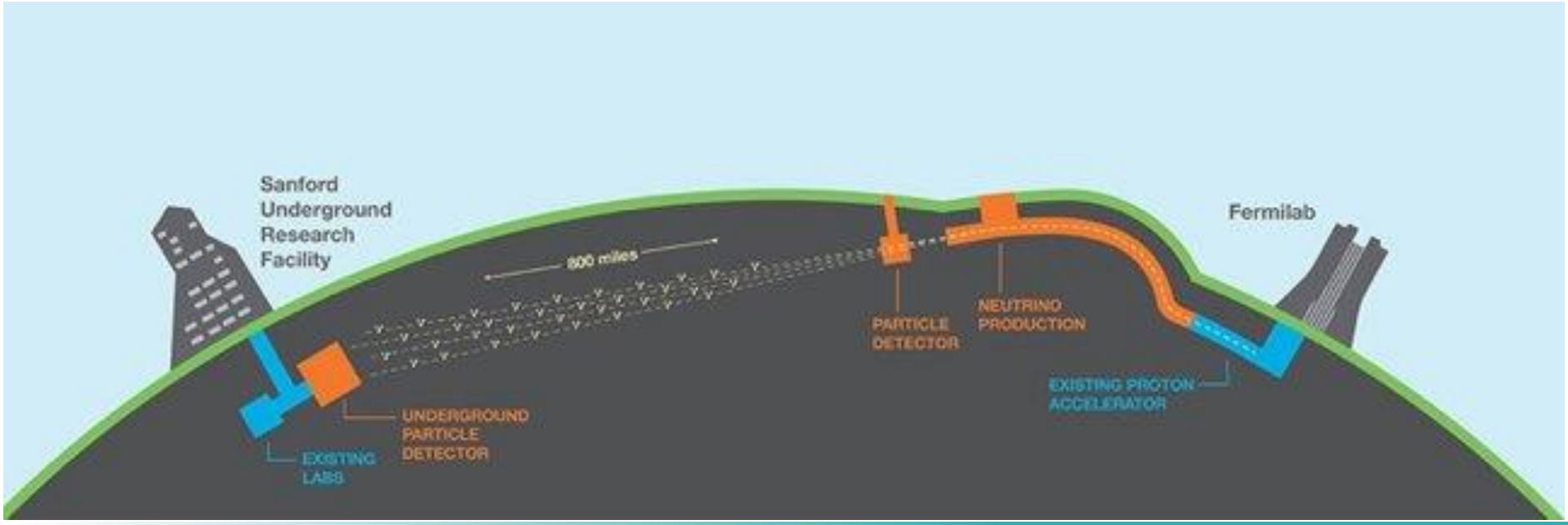
WP9: Cryogenic Neutrino Detectors
(2nd Annual Meeting)

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

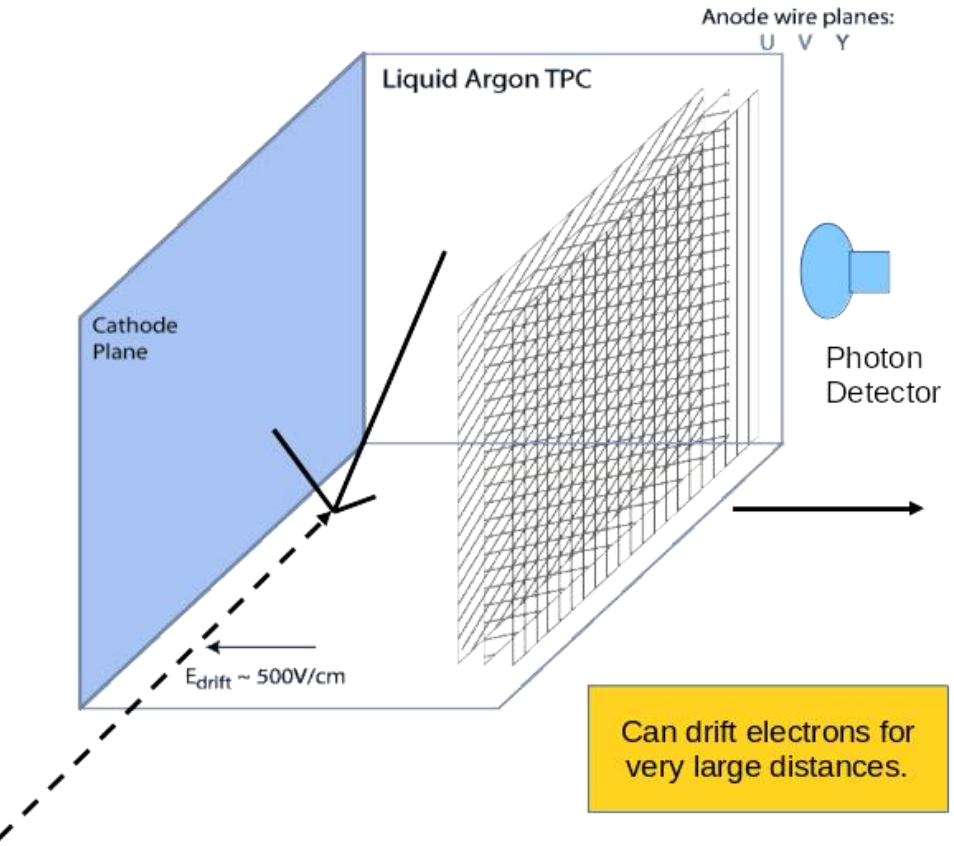
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

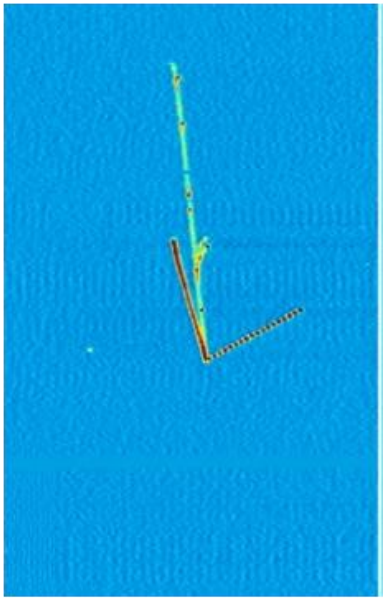
WP9: Cryogenic Detectors

- **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.



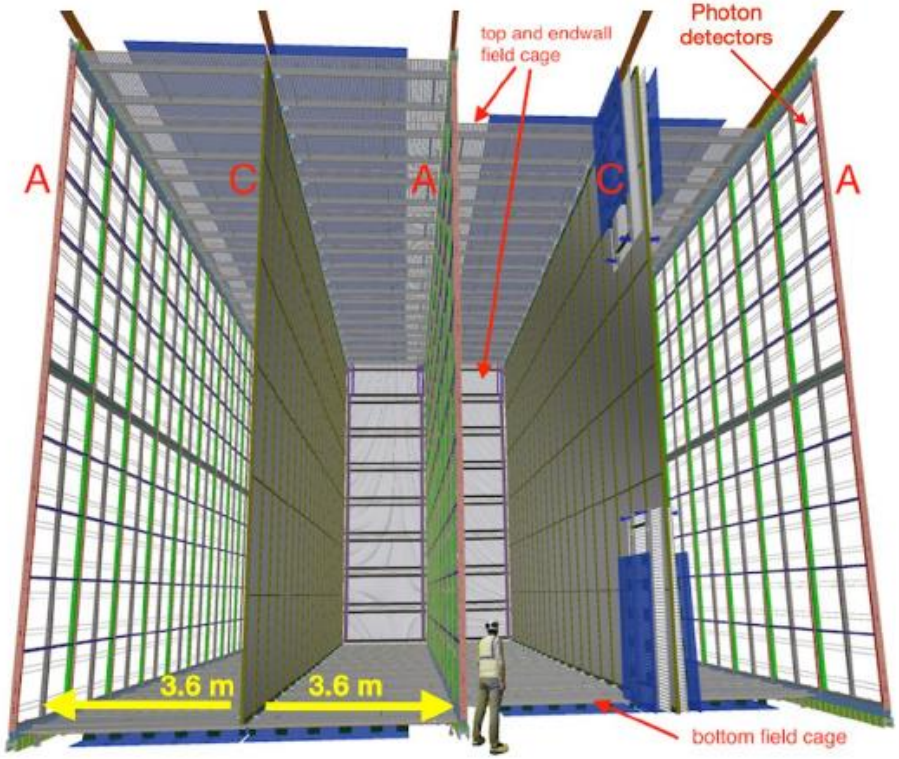
LArTPC operation (in a nutshell)





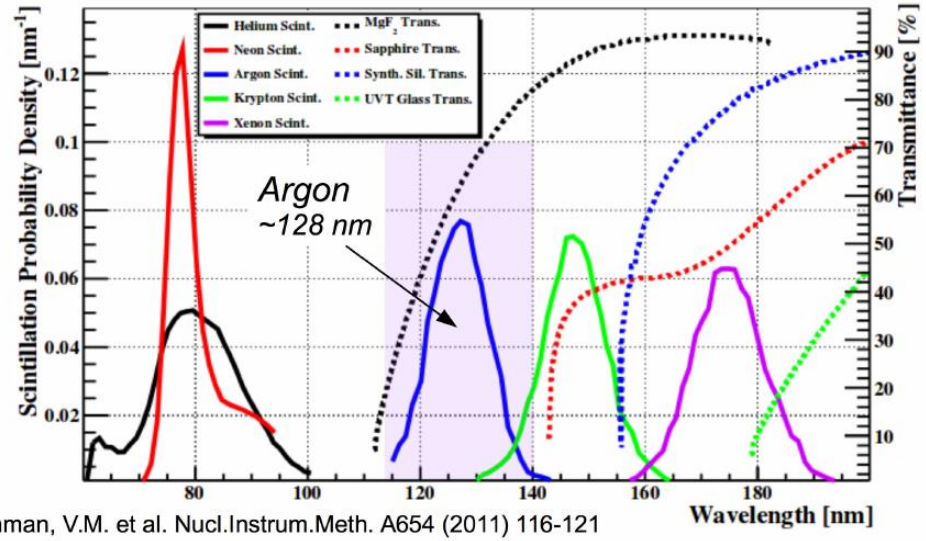
- Excellent position resolution + calorimetry and particle ID
- Ionization is primary signal.
- Scintillation light can provide additional information (timing, calorimetry, position)

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

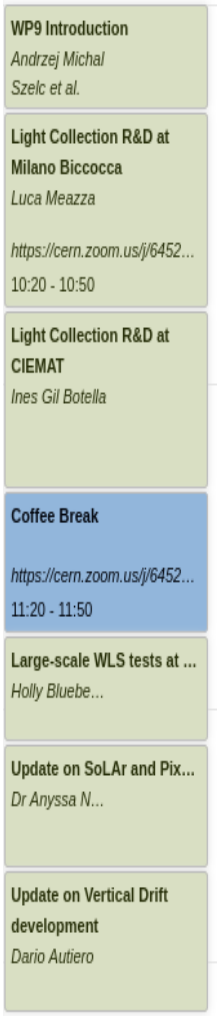
- Task 9.1: Coordination and Communication (CNRS-IP2I, Edinburgh)

- Task 9.2: Pixel Charge Readout (Manchester, 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)

Parallel Session yesterday



- 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, UBERN)

Talk by:
Anyssa Navrer-Agasson

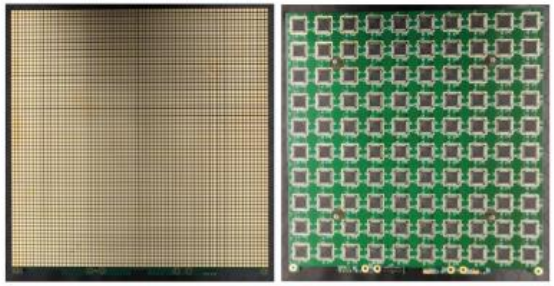
Intro to pixels

Idea: replace wires with pixel-pads

- Reconstruction less complicated
- Many more readout channels

LArPix

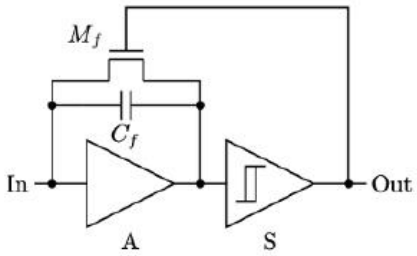
- Low power
- Self triggered digitisation and readout
- Technology **demonstrated in ArgonCube**
- **Available now**
  - **Used for first prototypes**



32 cm by 32 cm anode PCB tile

Q-Pix

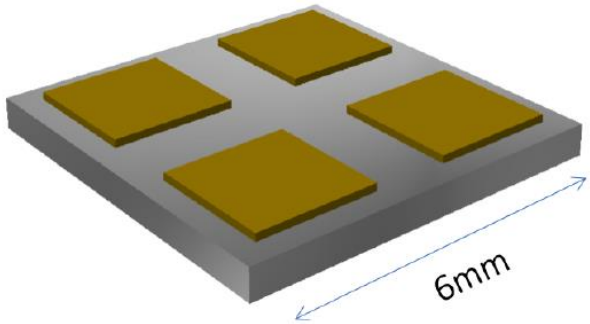
- Developed to **solve the data rate issue** of pixellated readouts
- **Electronic principle of least action**
- Saves time stamps instead of full waveforms



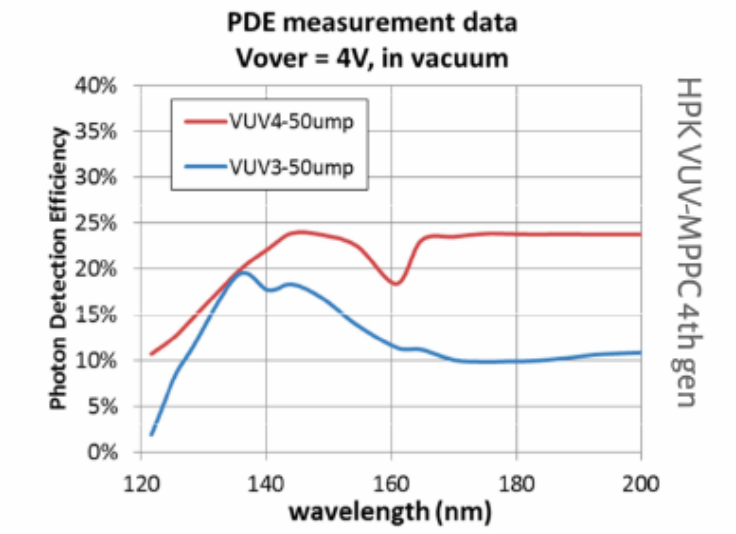
- Each channel integrates Charge Integrate Reset circuit
- Resets when charge > $\Delta Q/C_f$
- Measure reset times with embedded clock

SoLAr concept

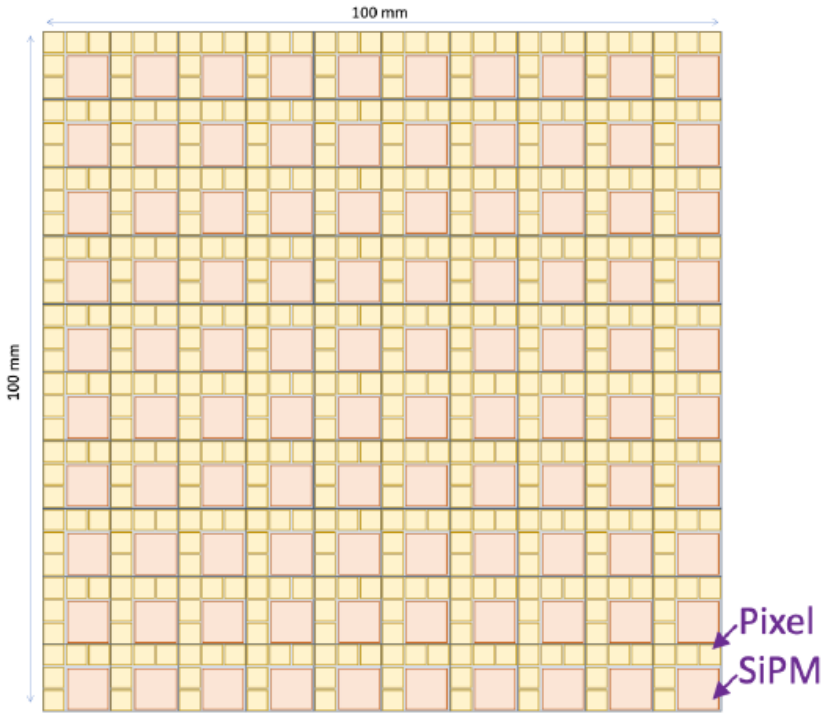
- Collaboration between tasks.
- Idea to simultaneously readout charge and light.

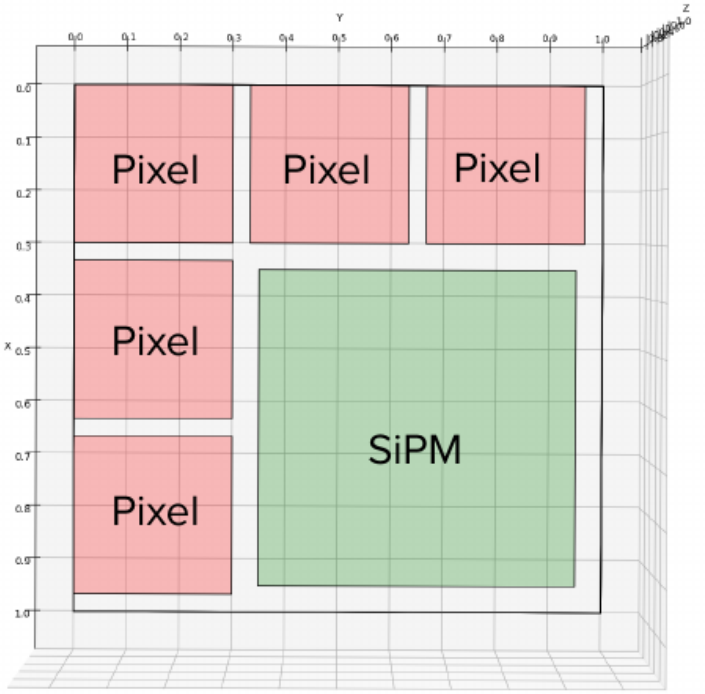


- New generation SiPMs:
  - Can detect photons at LAr scintillation wavelength
  - Hamamatsu 4th generation MPPC
  - FBK VUV-HD technology



Tile design

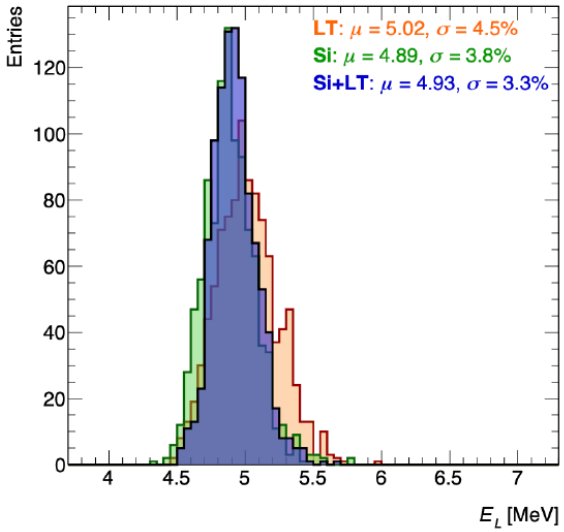




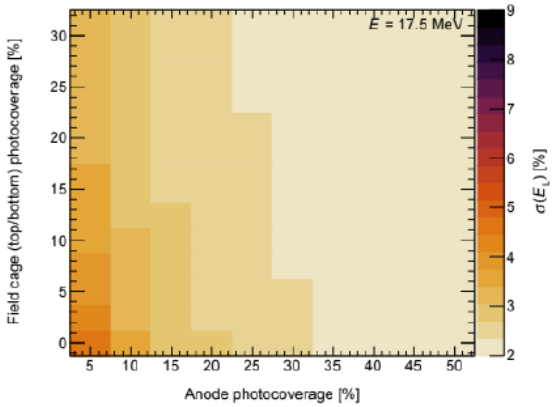
Milestone MS36
Pixels

Simulations and Sensitivities

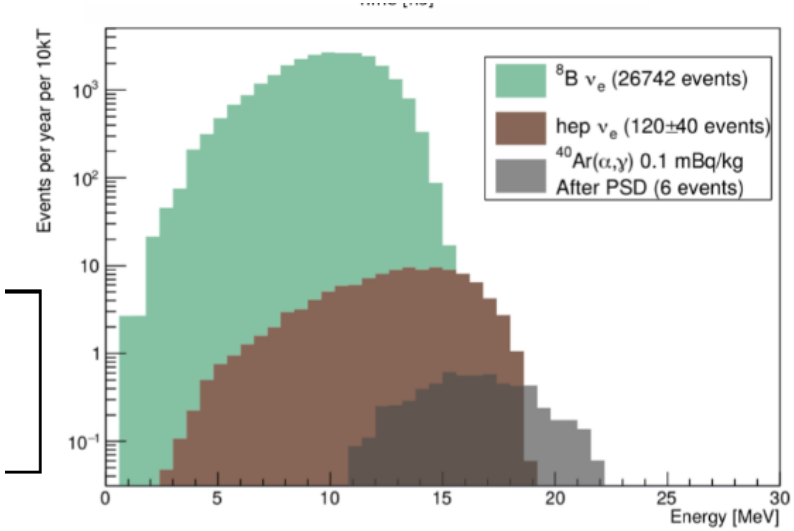
- Development of simulation is ongoing:



Energy resolution studies



Solar Neutrino background rejection

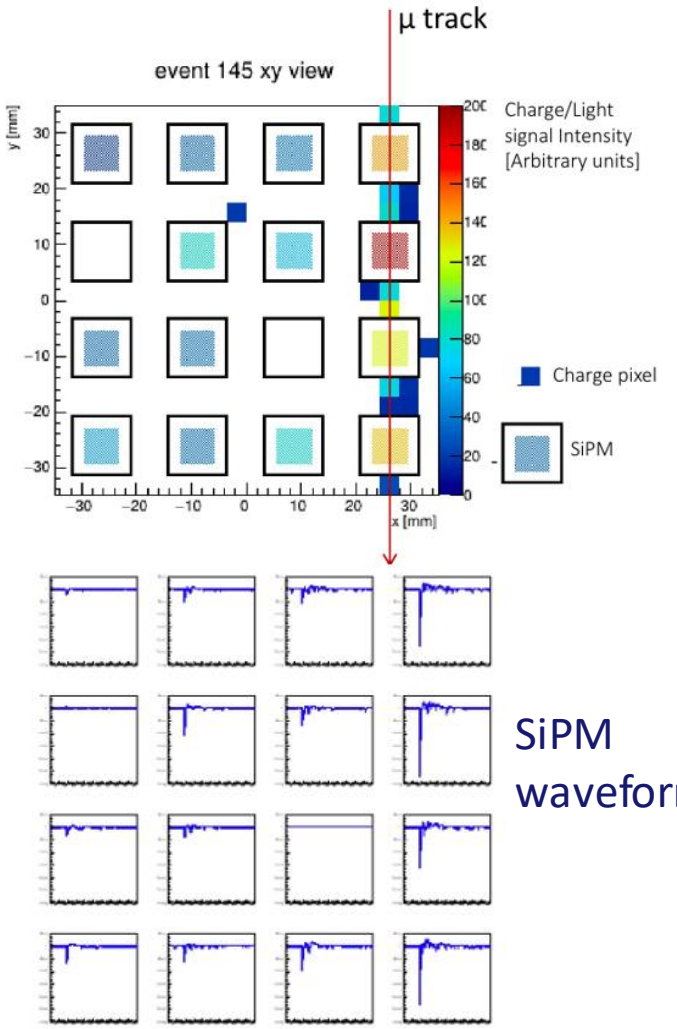


Study made with X-ARAPUCA detectors in a DUNE-sized module

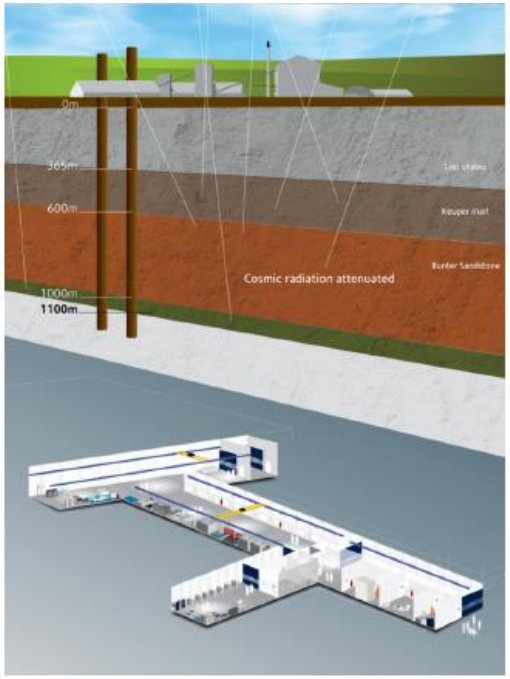
- Should perform even better with SoLAr design!

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

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



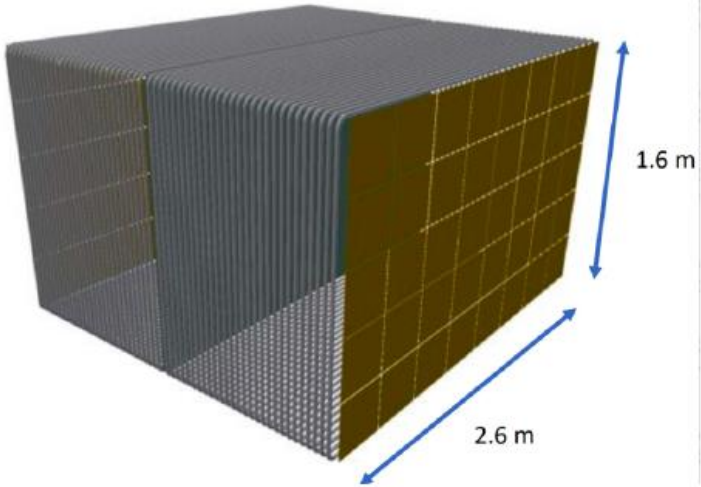
Towards a medium-scale demonstrator



- Planned in **Boulby Underground Laboratory (UK)**
  - 1 100 m rock overburden

Science goals

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



- 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

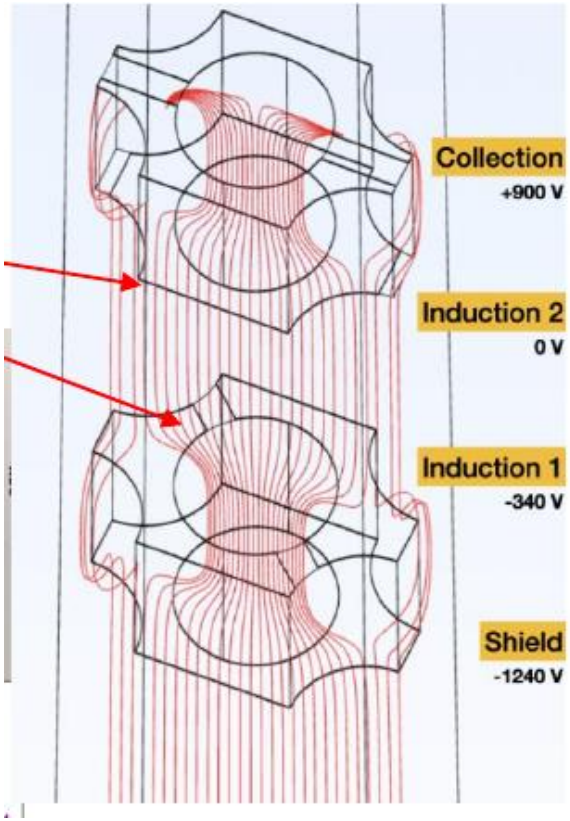
Vertical Drift charge readout [T: 9.3] (CNRS-IP2I, CNRS-IJCLab, LAPP)

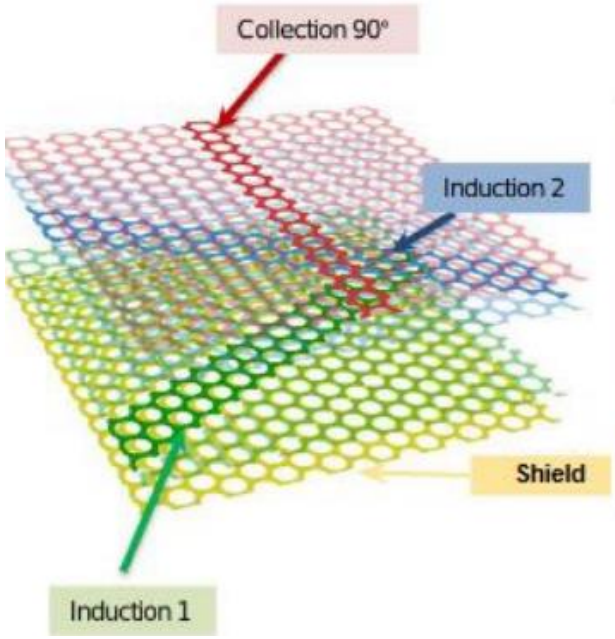
Talk by
Dario Autiero

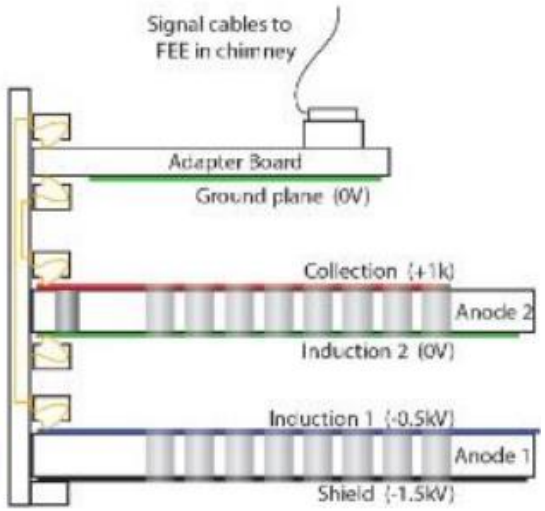
How vertical drift works

Idea: replace wires with perforated PCB boards

- Reconstruction similar to wires (multiple planes)
- Similar number of readout channels







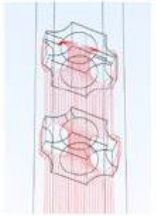
How it fits in the DUNE 2nd FD module

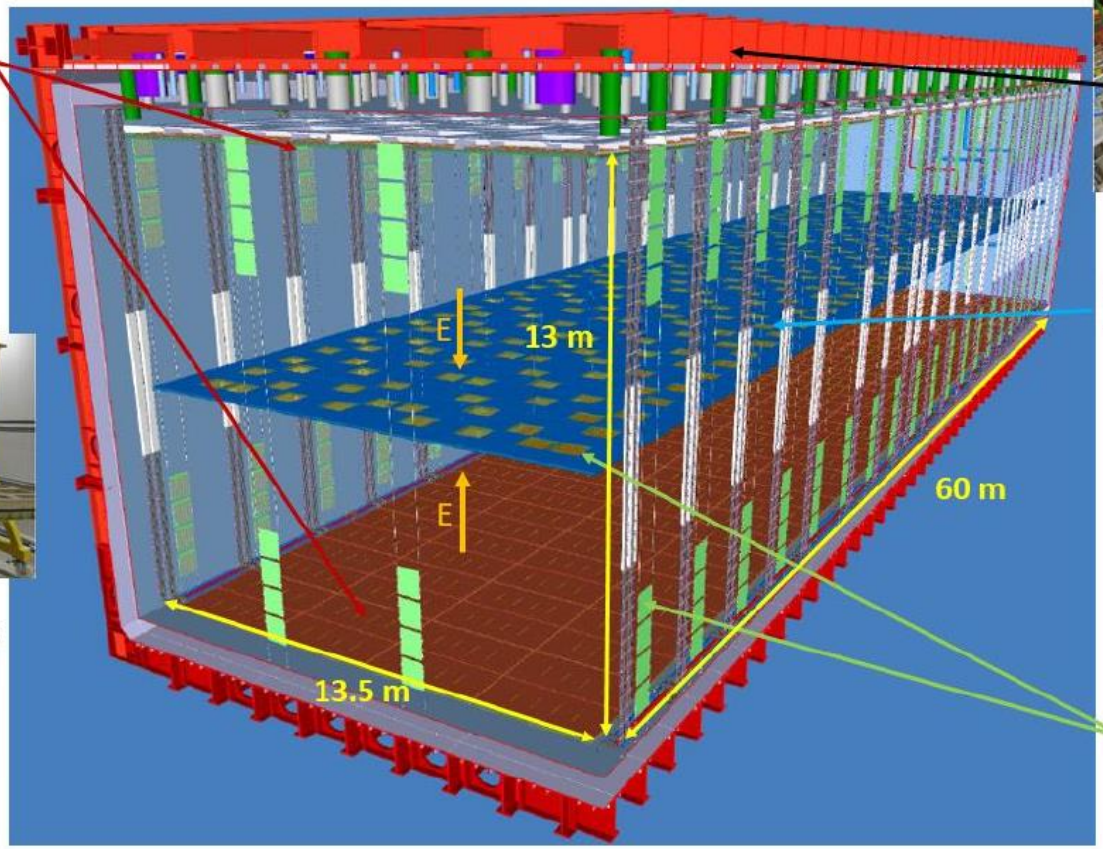
Vertical Drift: novel and optimized LAr TPC technology, anodes based on segmented perforated PCB

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

Lots of activity carried on in 2021/22 !

Timeline of Top-Drift/TDE activities and achieved milestones

CDR Review
Jun 21

TDE components preparation
Jan-Jun 21

TDE Integration test Jul-Sep 21

Evolution from DP Design, Proposal
Sep-Dec 20

CRP1 test
Nov 21

CRP1 test
Dec 21

Faraday cage 1&2
Test, preparation CRP2/3
Module-0 Jan.-May 22

NP02 6m Drift operation
Feb 22

PDR Review
May 22

CRP1b test
May-Jun 22

CRP2 (full-top) test Jul 22

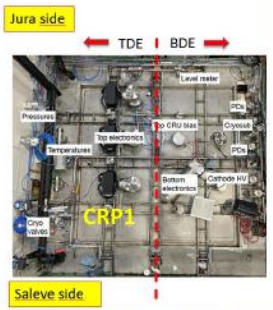
CRP3 test Oct. 22

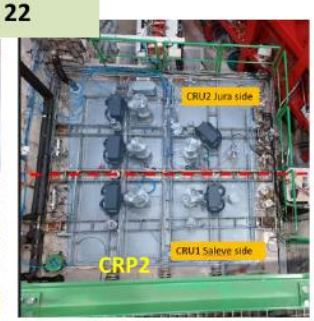
VD Module-0
Fall 22-Fall 23

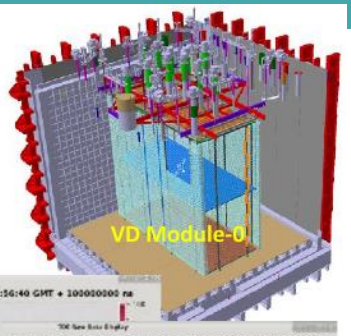
CRP2 (full-top) Re-test Nov 22

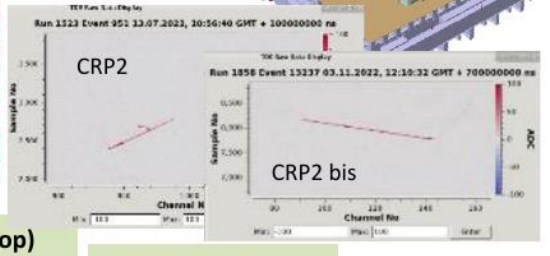
TDE FD2 production
End 23-Summer 26

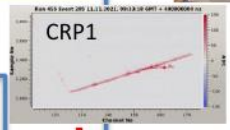
2021 2022 2023 2023-...

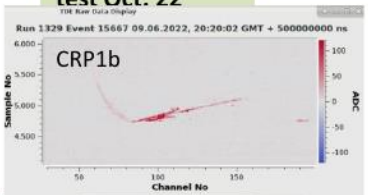


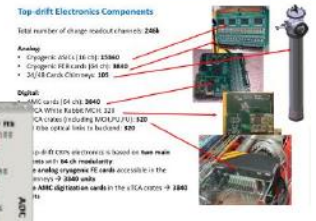


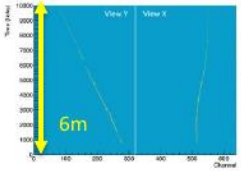


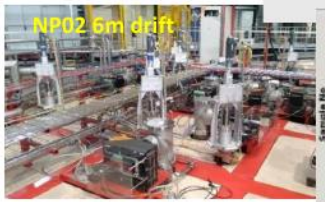


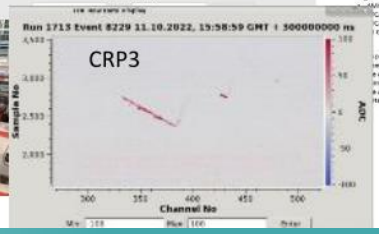












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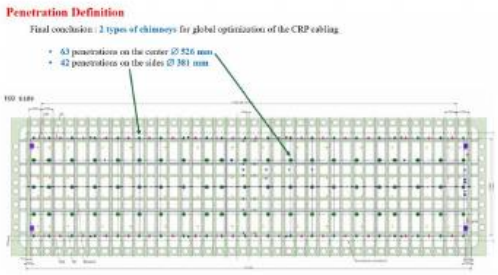
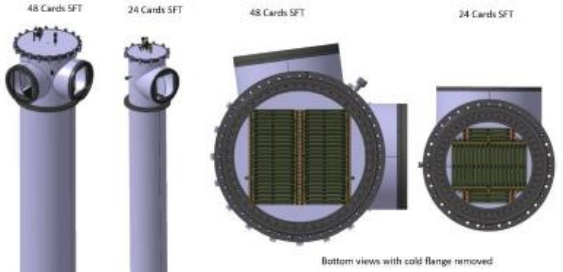
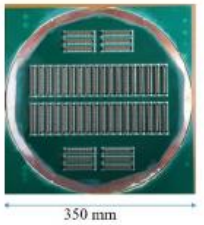
Top-drift Electronics (TDE) and chimneys development

Large Chimneys for FD2 (parralel testing path to cold-box and Module-0)







- Large progress on prototyping activities for 24 cards SFT and flanges
- Progress on thermal simulations and design optimization
- Testing program of 24 chimneys prototype in parallel to Module-0 in 2023 (NP02 cryostat roof has already 10 cards chimneys)
- Production and test of 48 cards prototype foreseen as well in 2023

Milestone MS37 (Chimneys)

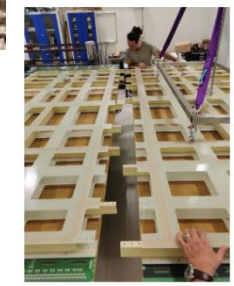
Top drift CRPs readout based on completely accessible electronics:

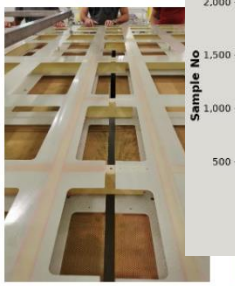
- Top Drift Electronics (TDE) subsystems:
  - Analog FE cryogenic electronics: Cryogenic ASICs and Front-End cards at the bottom of the chimneys
  - Digital FE electronics on cryostat roof: AMC digitization cards + uTCA systems, timing distribution system

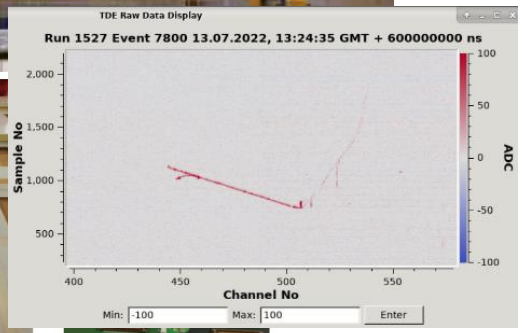
→ **TDE electronics successfully validated with top-drift CRPs in 2021/22**

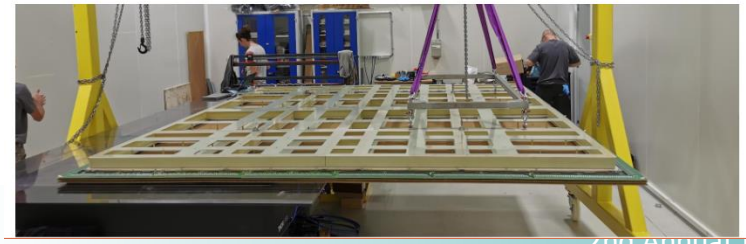
Milestone MS39 (Digitization)

CRP development



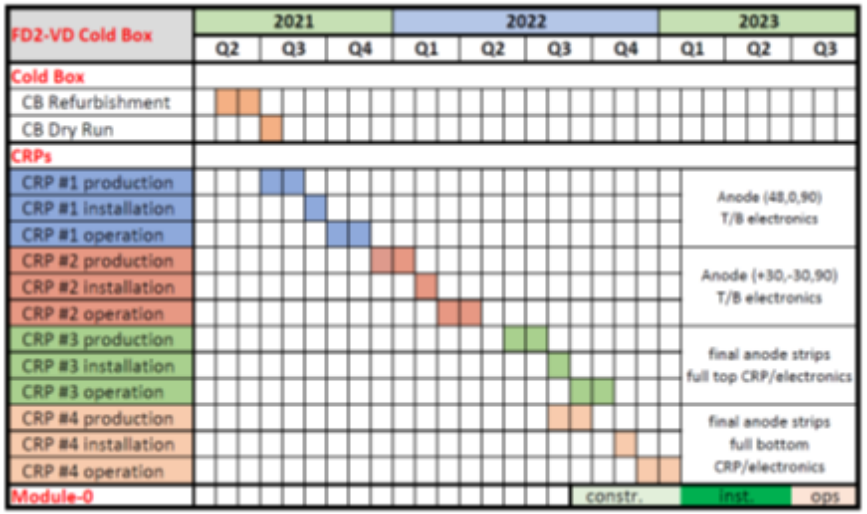






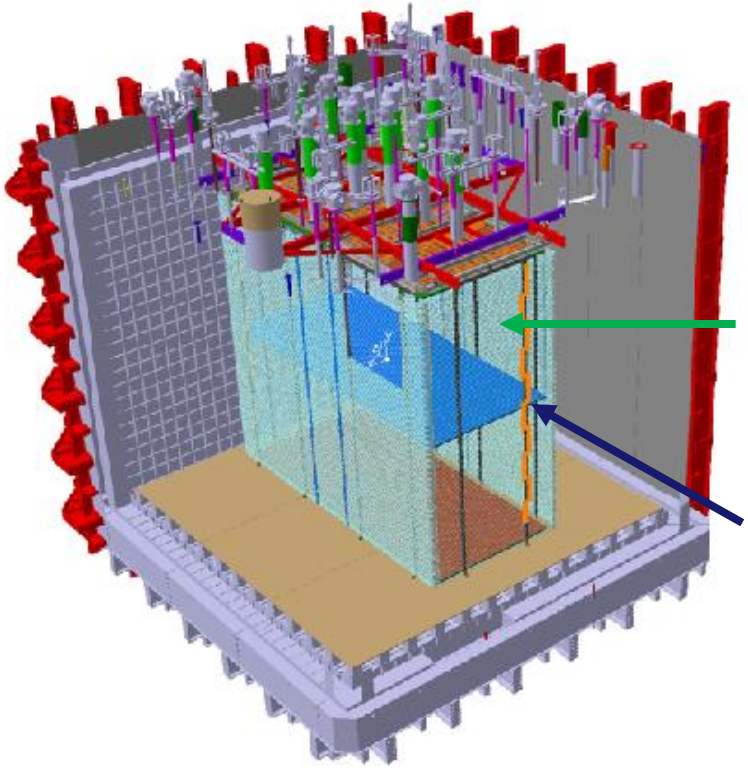
Vertical Drift Charge Readout Planes (CRP) with perforated anodes successfully constructed and tested with TDE electronics at the CERN Neutrino Platform with an intensive test program:

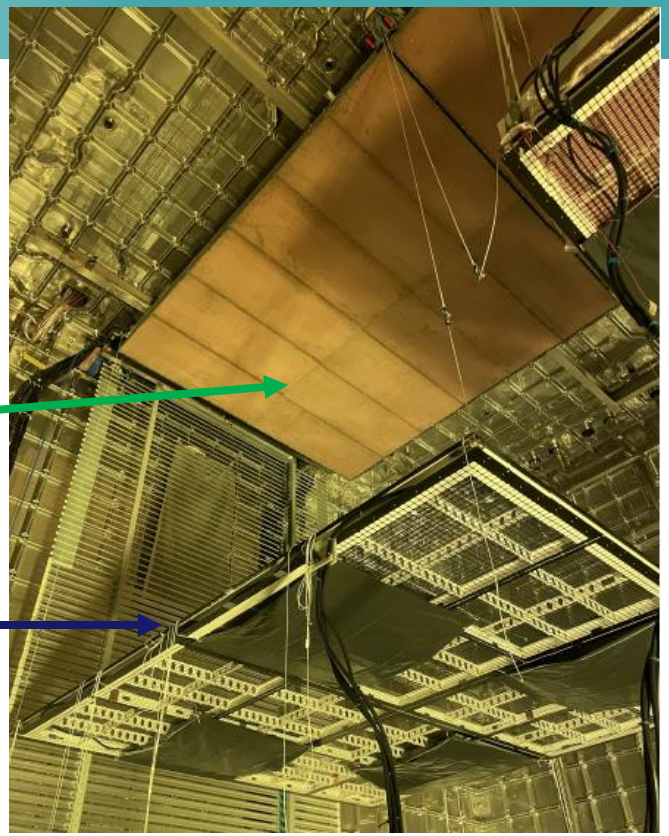
- First Vertical Drift CRP tested in 2021
- Continuation of the program in 2022 (sticking to original schedule): characterization and validation of two final design top-drift CRP (CRP2 and CRP3)



Milestone MS38 (CRP)

Module-0 (ProtoDUNE-VD)





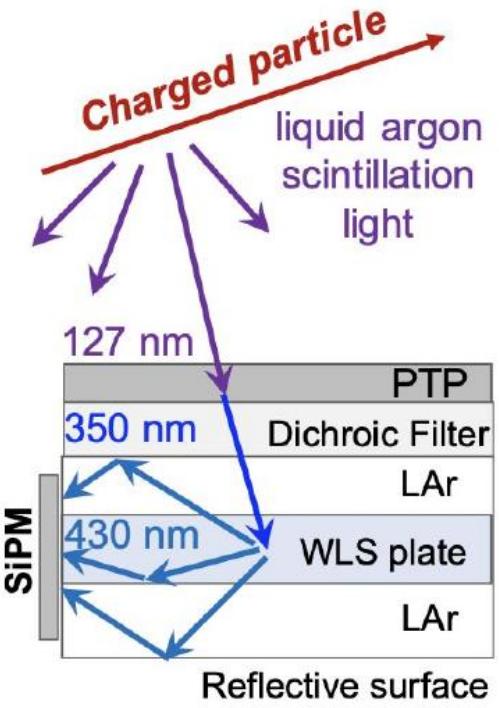
- Module-0/ProtoDUNE Vertical Drift: last Vertical Drift integration exercise before 2nd DUNE FD module construction
- Two top-drift CRP, validated in 2022 in the cold-box TPC tests installed at the beginning of 2023 in the NP02 cryostat (formerly ProtoDUNE dual-phase).

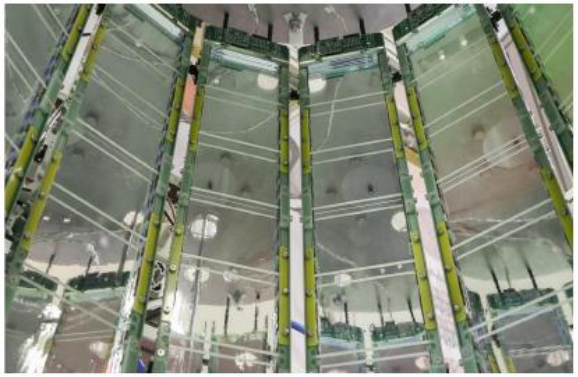
Light Readout [T:9.4] (CIEMAT, INFN-MIB, UEDIN)

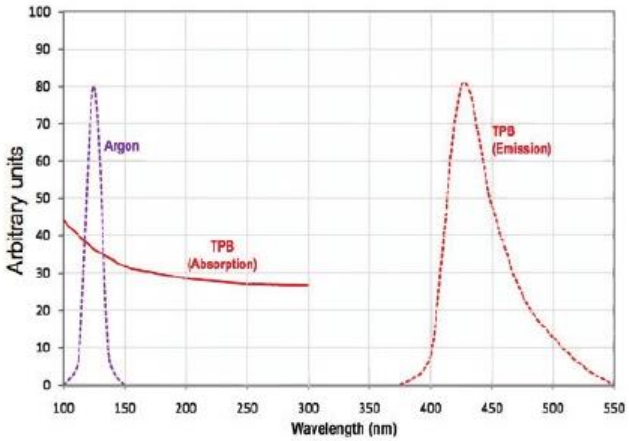
Talks by:
Luca Meazza
Ines Gil Botella
Holly Parkinson

Common solutions in LAr Light Readout

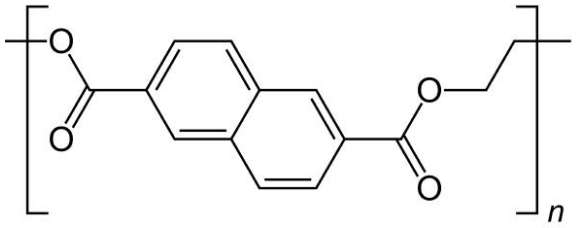
Ideas:
- Use light collectors (trapping photons)
- Use wavelength-shifters to transform light to visible





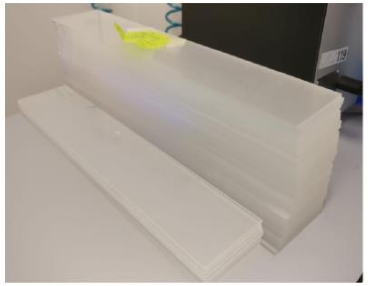


TPB emission and absorption spectra and argon scintillation peak [1]



Above: PEN molecule; below: PEN sheets

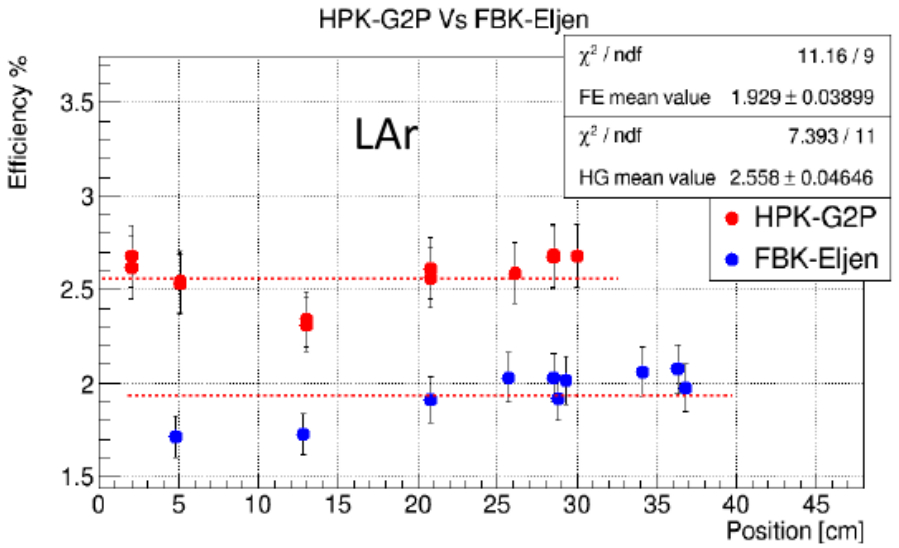
X-ARAPUCA WLS bar selection

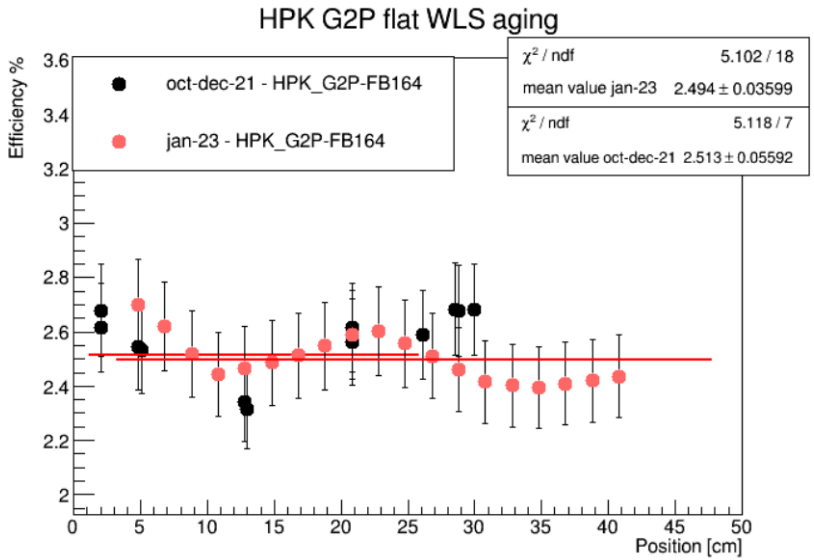


- 90 x WLS slabs for pDUNE FD1-PDS: 480 x 93 mm^2 x 4mm thick

  Laser cut (external industrial partner) and edge polishing procedures to cut out the casted plates in tiles defined and validated.

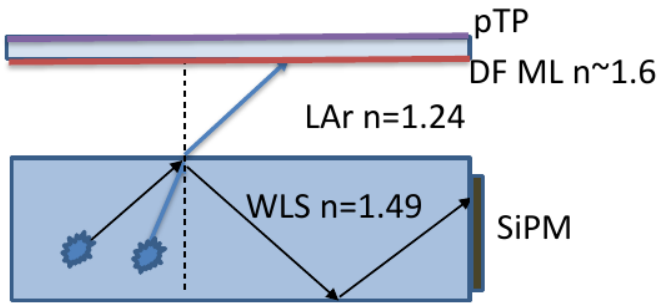
- **20** x WLS slabs for the pDUNE FD2-PDS: 607 x 607 mm^2 x 4mm thick casted in one week





Milestone MS40
SiPM testing and large WLS surfaces

Dichroic filter tests

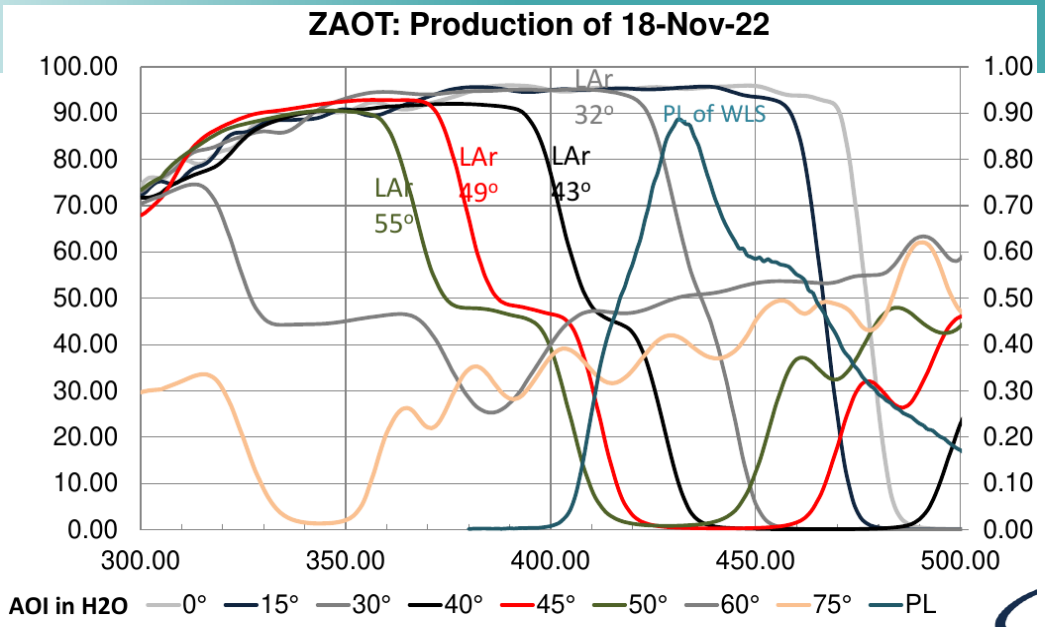


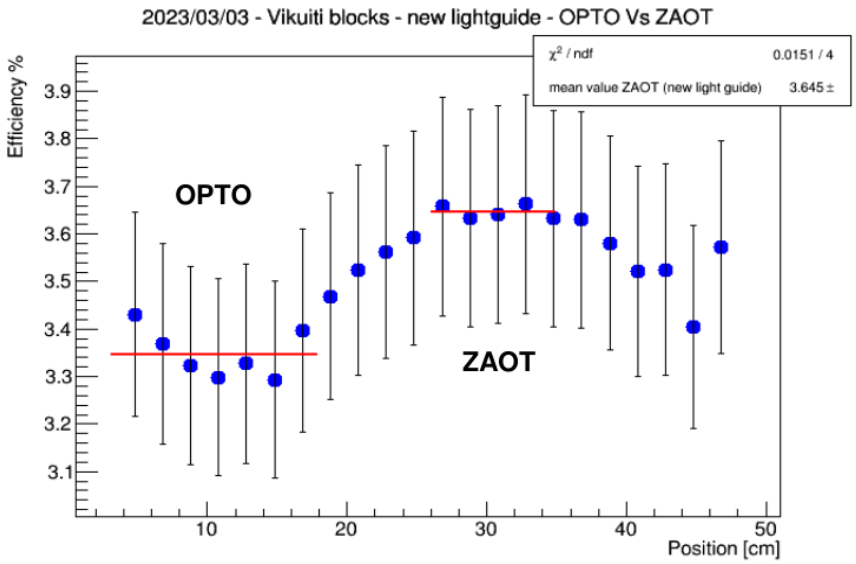
ZAOT (our industrial partner) substrate

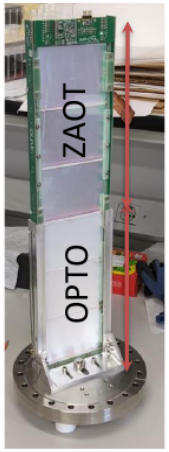
- Borofloat 33 Optical Glass

OPTO (BL component) Substrate

- B270

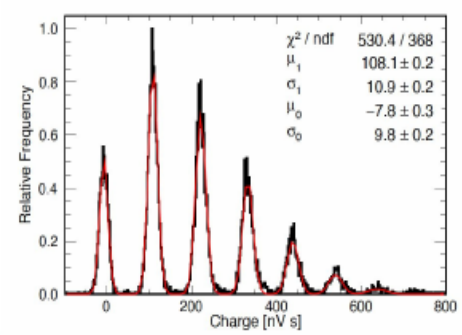


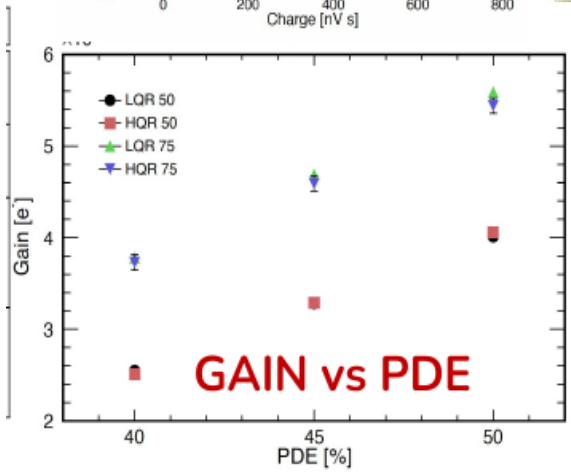




Assembly and tests of ProtoDUNE X-ARAPUCAS

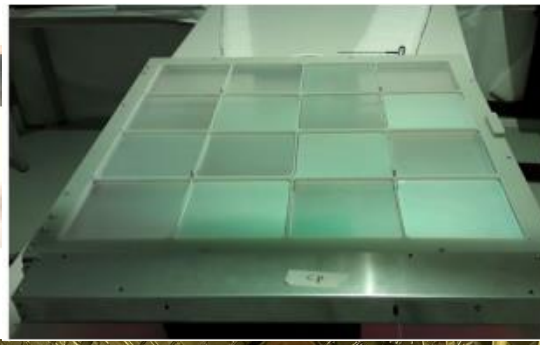
- HPK SiPM characterization:

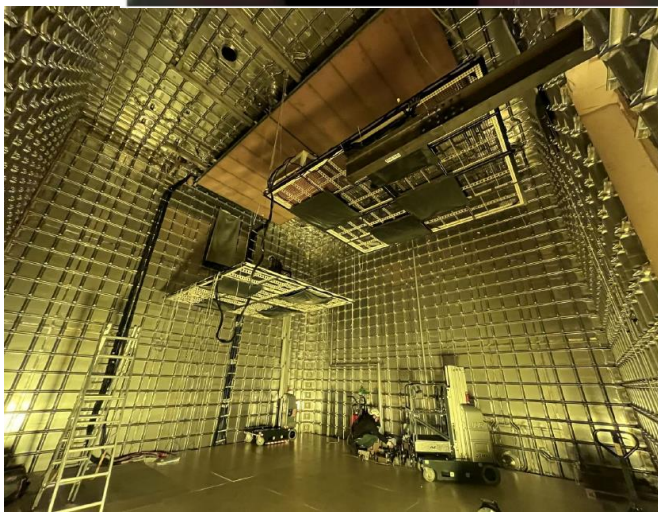




Assembly and testing 74 (out of 160) X-ARAPUCAs at CIEMAT prior to their installation in ProtoDUNE at CERN

- Vertical-Drift large X-ARAPUCA installation

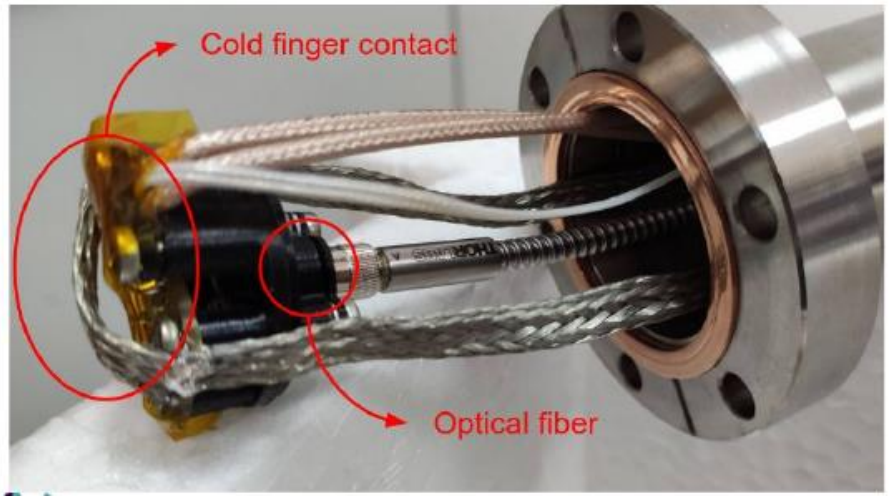


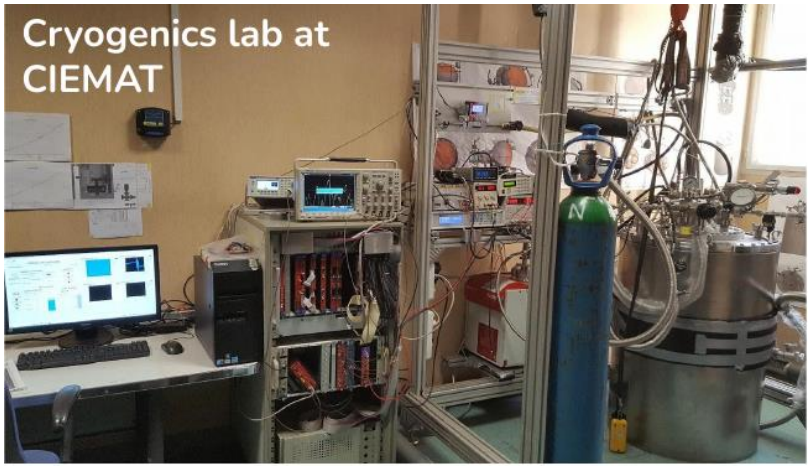


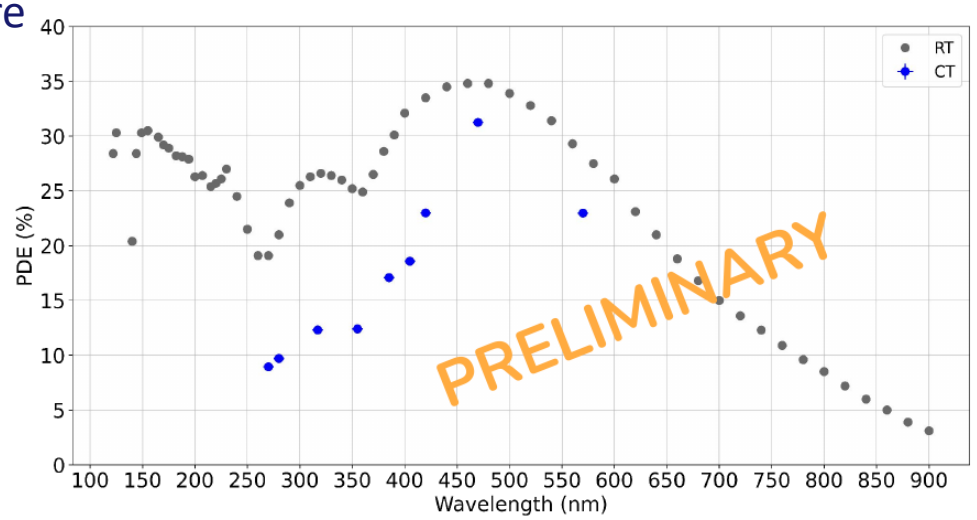
Milestone MS40
SiPM testing

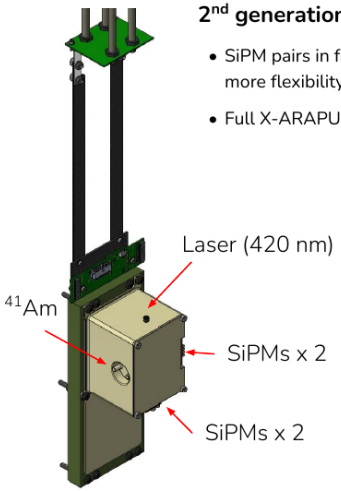
Photon detection R&D (including in cryo setups)

VUV SiPM characterization at LN2 temperature









SBND X-ARAPUCA

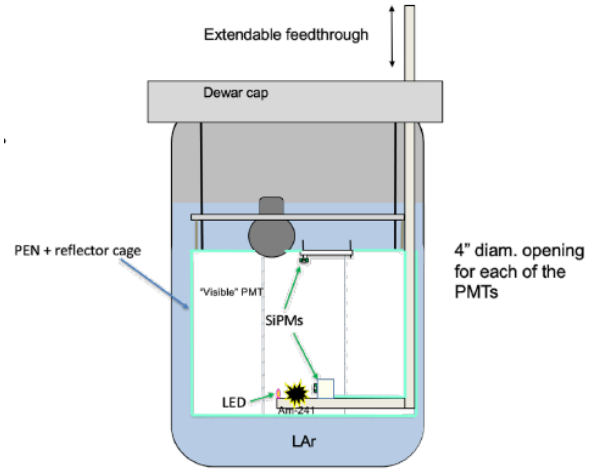
2nd generation calibration box

- SiPM pairs in front of each light source to minimize angular uncertainties. Also more flexibility for triggers.
- Full X-ARAPUCA window coverage to eliminate shadowing effects.

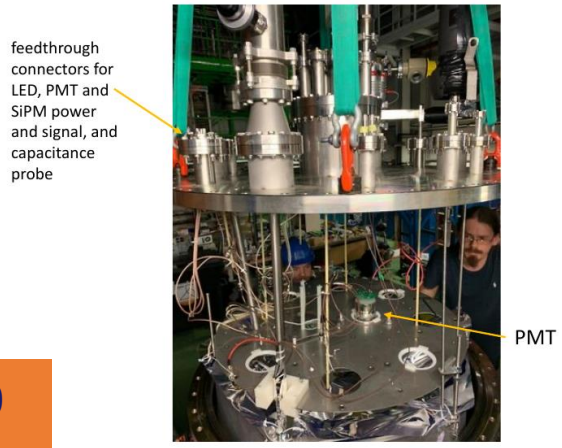
4 X-ARAPUCA configurations tested		
SiPMs	WLS Bar	Filter
SensL	Eljen 286	pTP coated 400 nm cutoff
SensL	Eljen 280	450 nm cutoff (only visible light)
HPK	Glass to power (blue)	pTP coated 400 nm cutoff
HPK	Glass to power (green)	450 nm cutoff (only visible light)

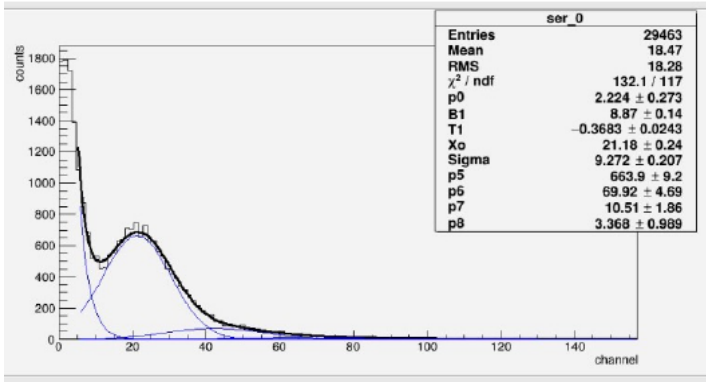
Large-scale WLS test

- a dedicated test has been performed at the CERN neutrino platform test facility to measure the performance of large-area PEN sheets as a WLS
- 19 days of data acquired in January – February 2023
- Data quality is good and analysis is ongoing
- Stay tuned for results soon



Schematic of experimental setup





Milestone MS40
Large-scale WLS

Milestones and Deliverables

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

Conclusions

- Lots of work ongoing .
- New prototypes will be operational soon – lots of exciting data to analyze.
- New ideas/collaboration formed with help from AIDAInnova
- Milestones mostly on track (slight delays on reporting)