AIDA innova

Advancement and Innovation for Detectors at Accelerators

WP9: Cryogenic Neutrino Detectors

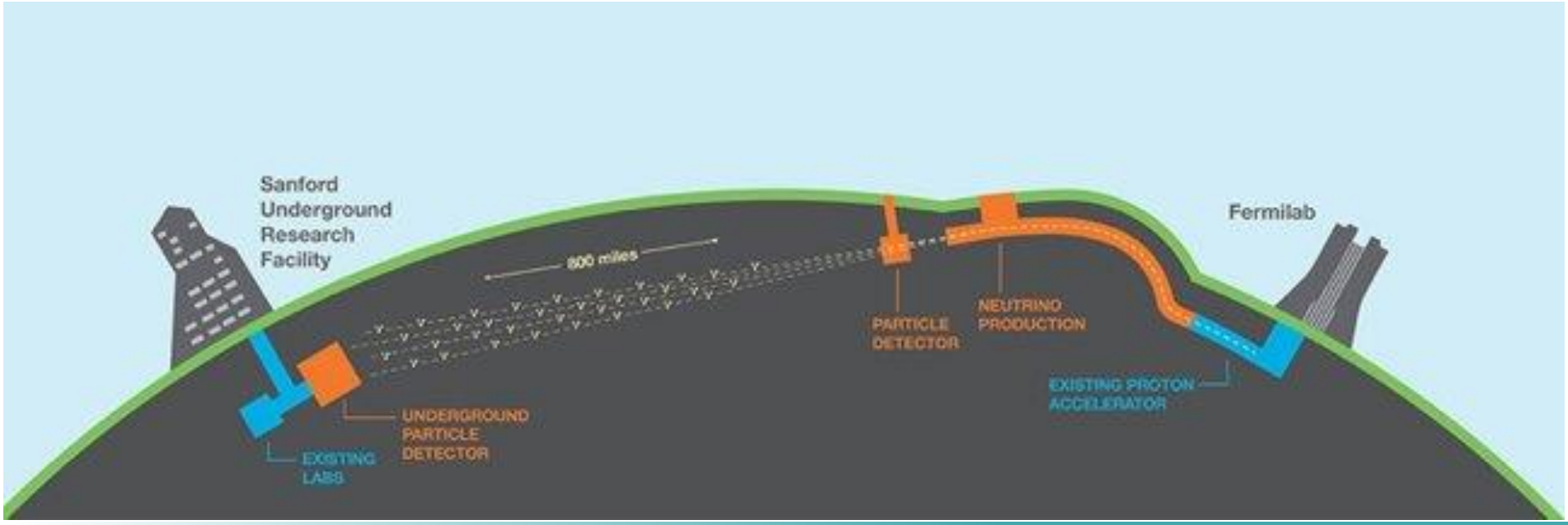
(3rd Annual Meeting)

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

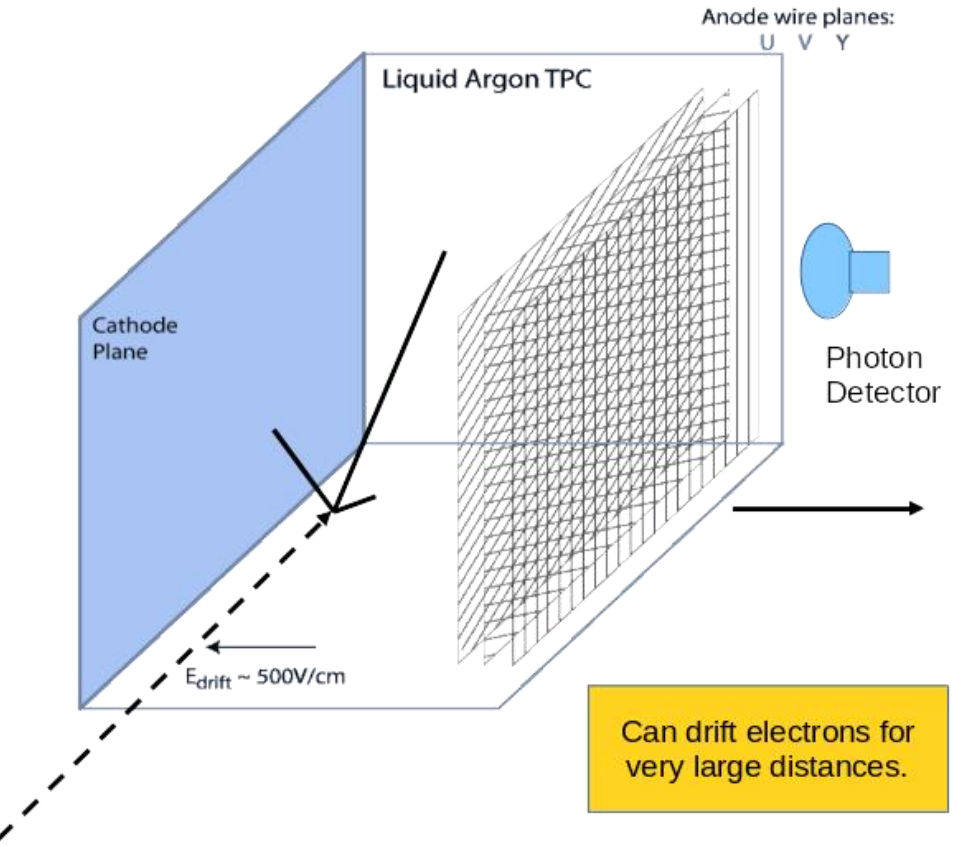
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

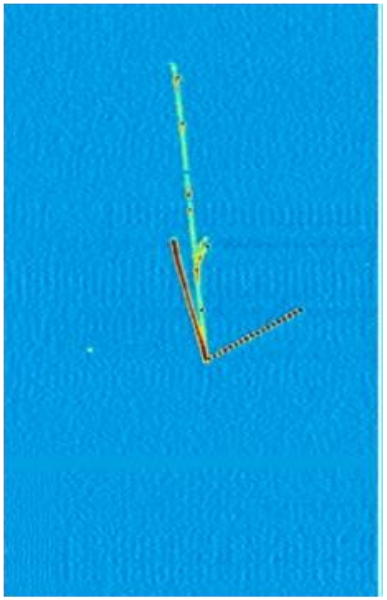
WP9: Cryogenic Detectors

- **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.



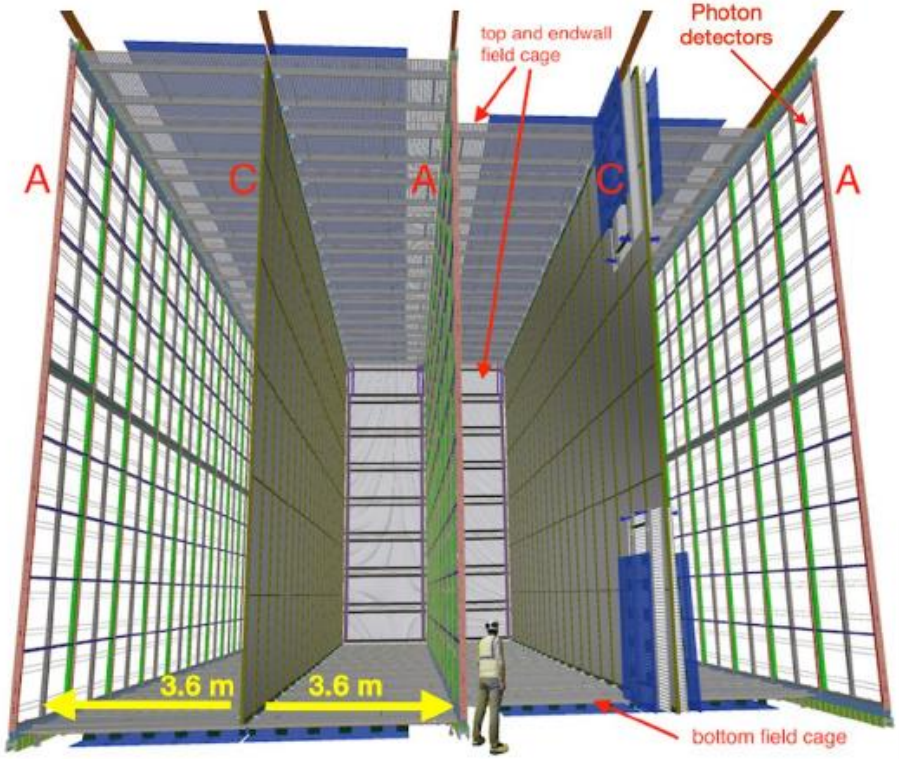
LArTPC operation (in a nutshell)





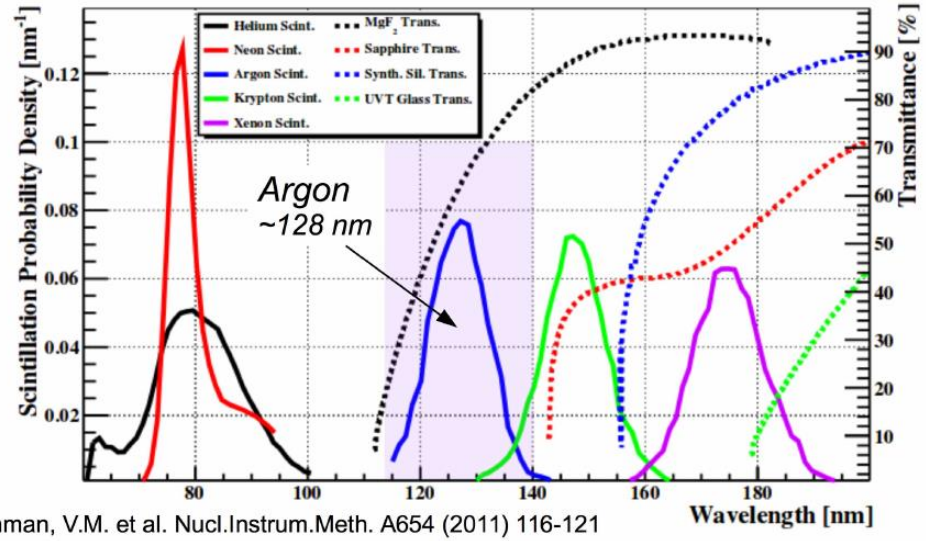
- Excellent position resolution + calorimetry and particle ID
- Ionization is primary signal.
- Scintillation light can provide additional information (timing, calorimetry, position)

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)

WP9: Cryogenic Detectors

DUNE (entering in a new phase !):

- Caverns excavation completed in January 2024:

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

- 2024 is the start of the construction phase for the DUNE far detectors (production starting of many components covered by WP9 in tasks 9.3 and 9.4)

- LAr availability for operating NP04 and NP02 at CERN with beam in 2024-2025

- SBND (at Fermilab) also filled (some aspects relevant to task 9.4)

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

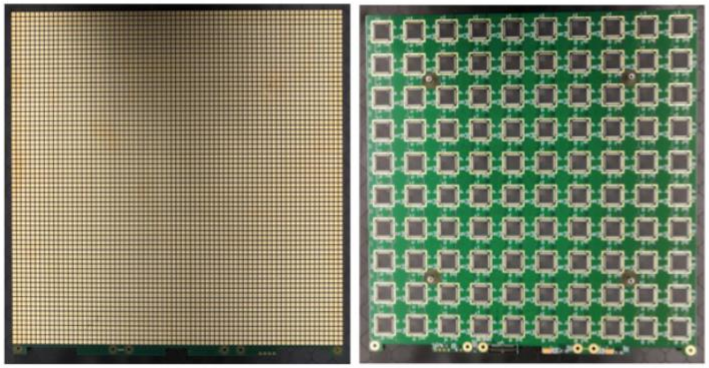
Intro to pixels

Idea: replace wires with pixel-pads

- Reconstruction less complicated
- Many more readout channels

LArPix

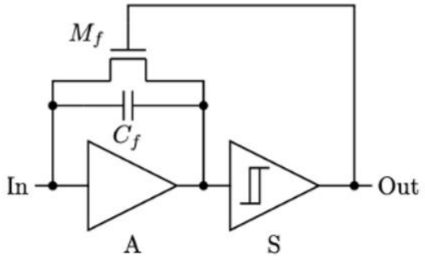
- Self triggered digitisation and readout
- Technology **demonstrated in ArgonCube**
- **Available now**
  - **Used for first prototypes**



32 cm by 32 cm anode PCB tile

Q-Pix

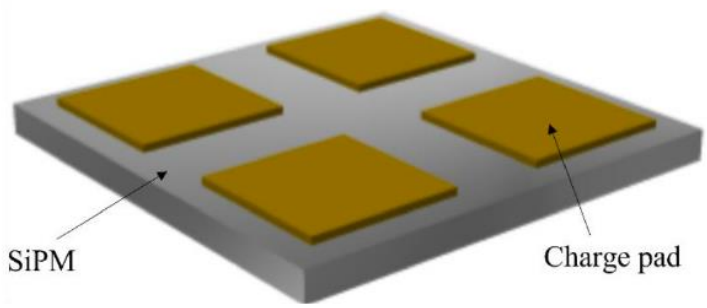
- Developed to **solve the data rate issue** of pixellated readouts
- **Electronic principle of least action**
- Saves time stamps instead of full waveforms



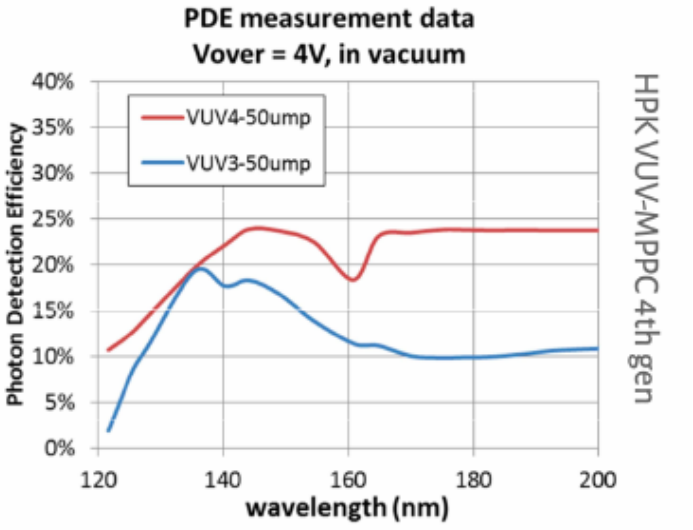
- Each channel integrates Charge Integrate Reset circuit
- Resets when charge > $\Delta Q/C_f$
- Measure reset times with embedded clock

SoLAr concept

- Collaboration between tasks.
- Idea to simultaneously readout charge and light.
  - Improve triggering and energy resolution
  - Improve backround rejection:
    - Pulse shape discrimination
    - directionality

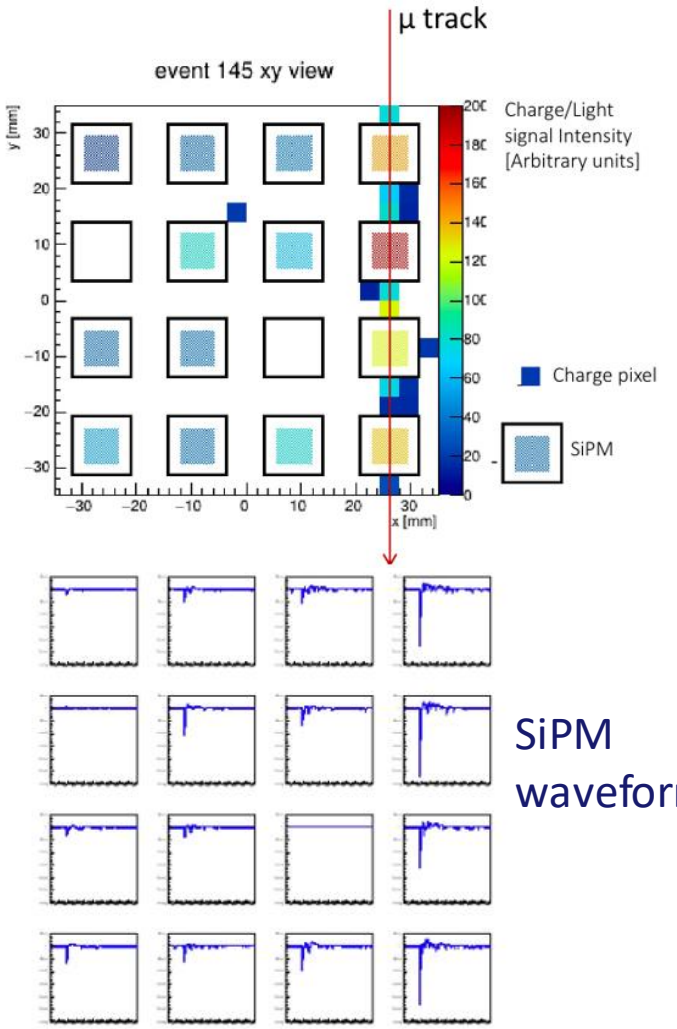


- New generation SiPMs:
  - Can detect photons at LAr scintillation wavelength
  - Hamamatsu 4th generation MPPC
  - FBK VUV-HD technology



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



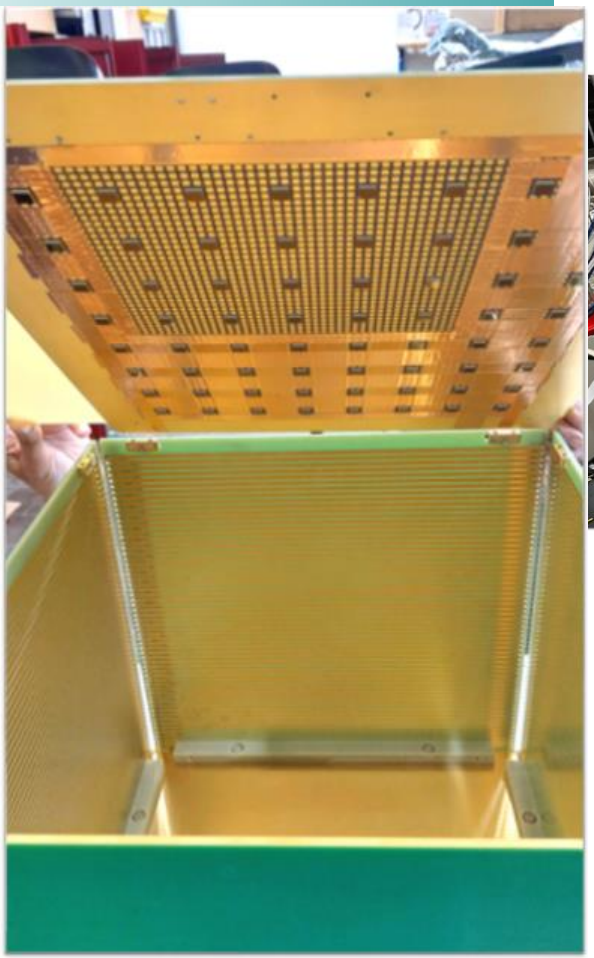
SiPM waveforms

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

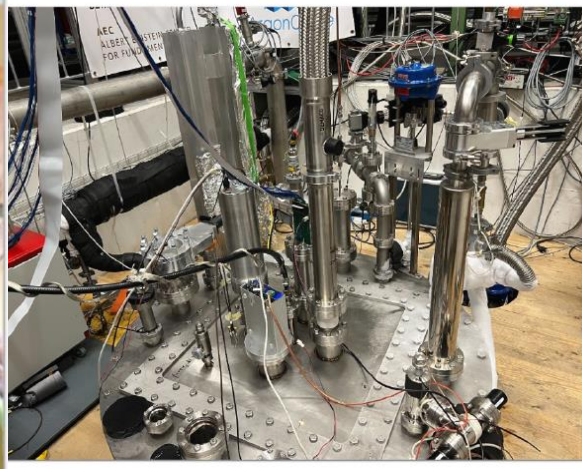
- V2 prototype (July 2023)
- 30x30x30 cm^3 volume
- 20 LArPix chips
- 64 Hamamatsu VUV SiPMS

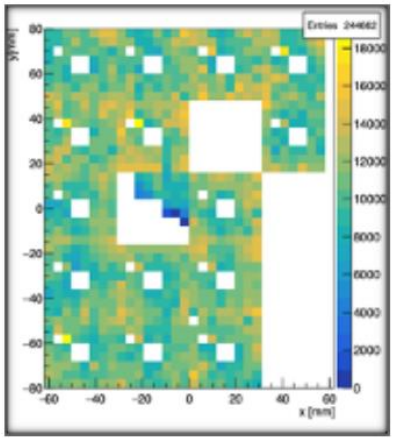
- 10 days of data taking
- Cosmic rays + ^{60}Co

- Partially Instrumented pixel tile



ArgonCube cryostat

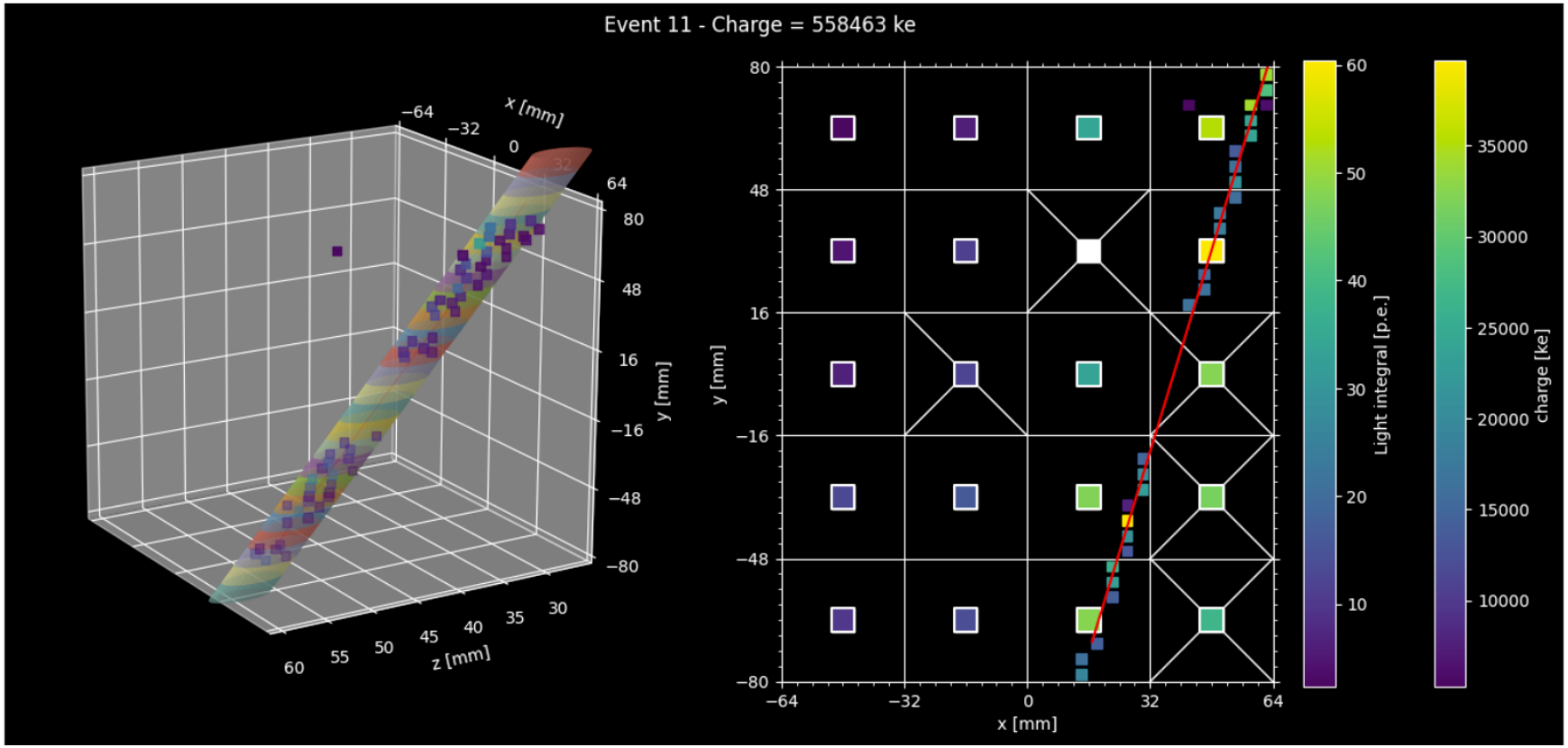




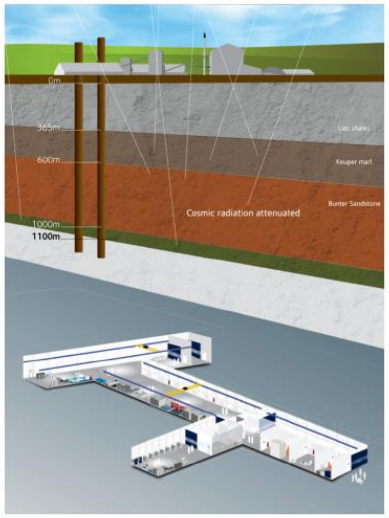
Hit map shows location of disabled pixels

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

Charge & light event display!



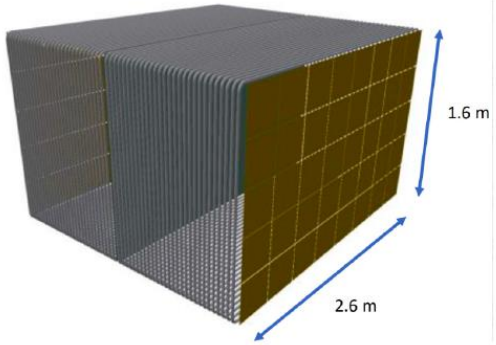
Towards a medium-scale demonstrator



- Planned in **Boulby Underground Laboratory (UK)**
  - 1 100 m rock overburden
- Proposal in preparation in synergy with dark matter (SOLAIRE)

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

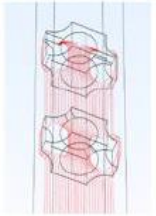
The DUNE 2nd FD module

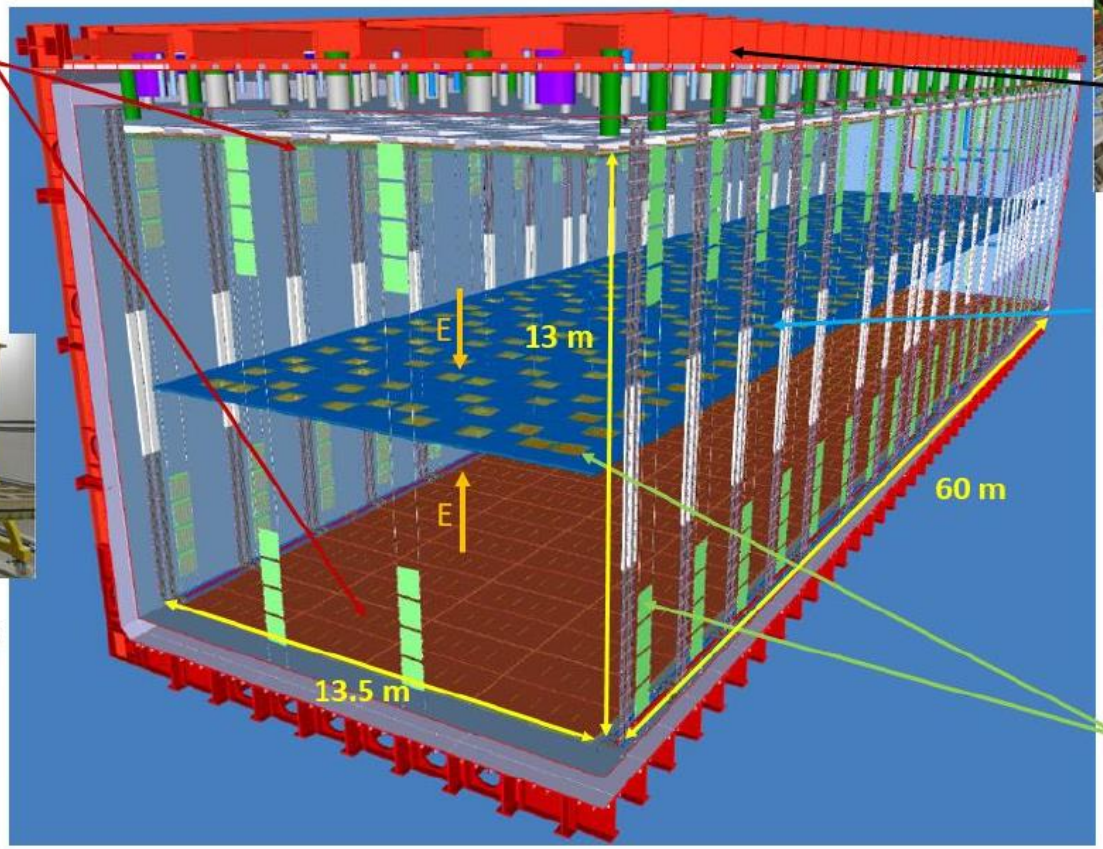
Vertical Drift: novel and optimized LAr TPC technology, anodes based on segmented perforated PCB

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

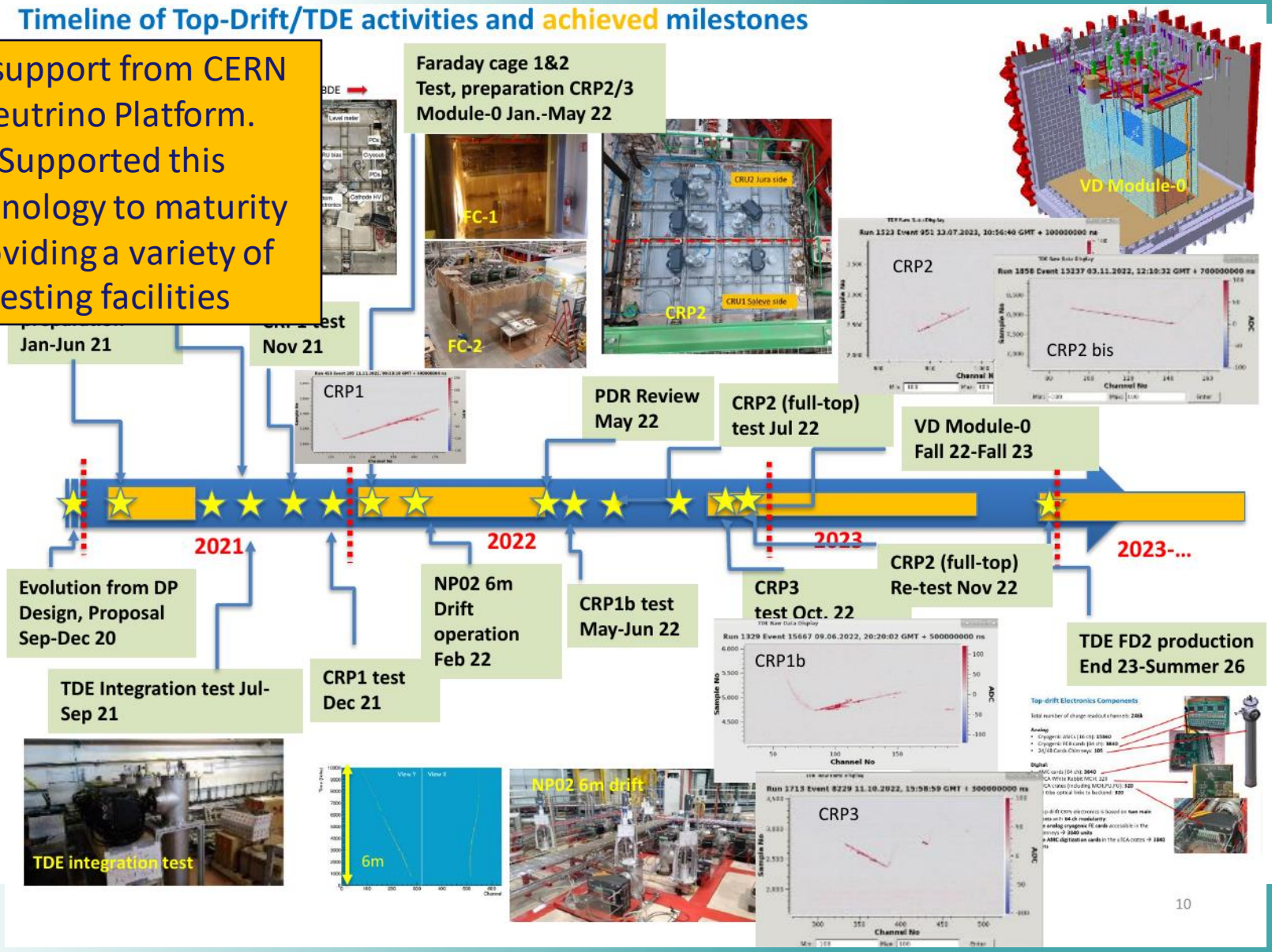
Cathode surface at -300 kV
→ E~500V/cm

1/40
Prototype in
NP02 cryostat
Module-0

UV photon detectors on cathode and cryostat walls

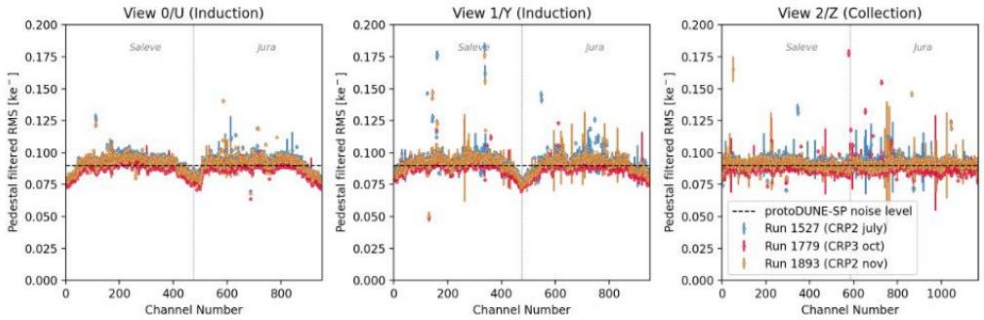
Significant R&D until 2021/22 !

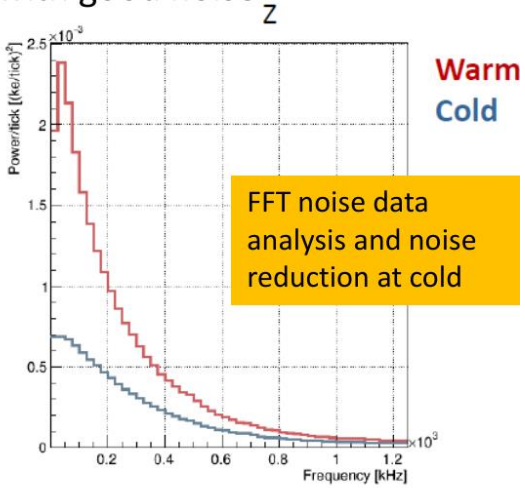
Big support from CERN Neutrino Platform. Supported this technology to maturity providing a variety of testing facilities

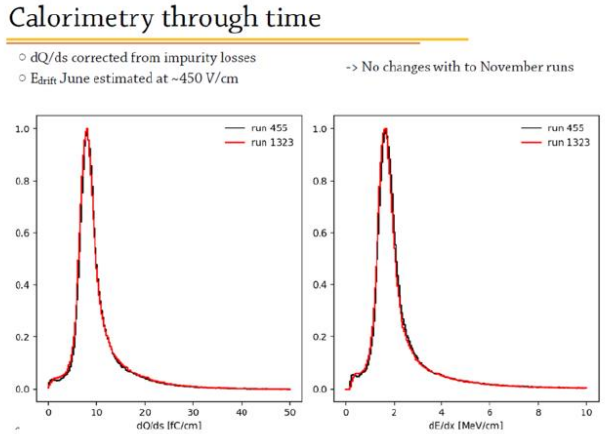


CRP Cold-box at CERN demonstrated performance

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

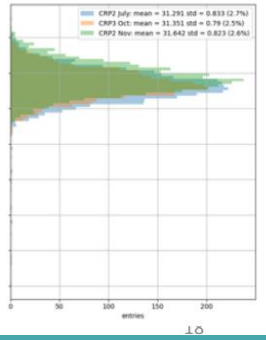






Stability of dE/dx response studied on **CRP1** October2021-June 2022

- 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):

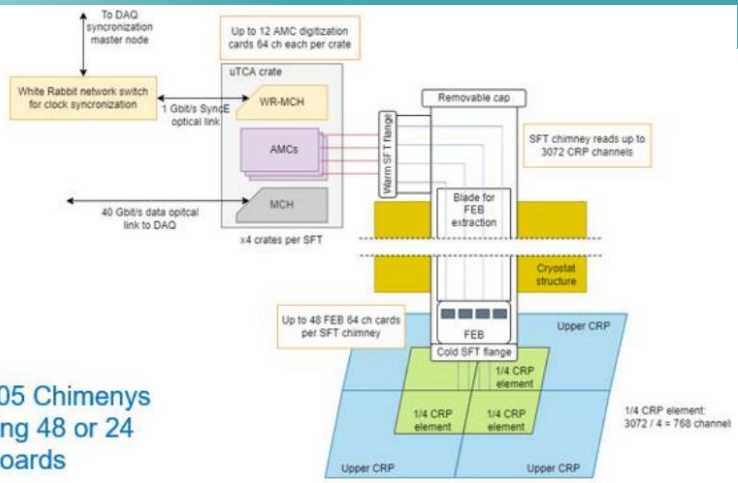
- 3840 cryogenic FE boards (64 channe with 15360 ASIC 16 channels amplifiers

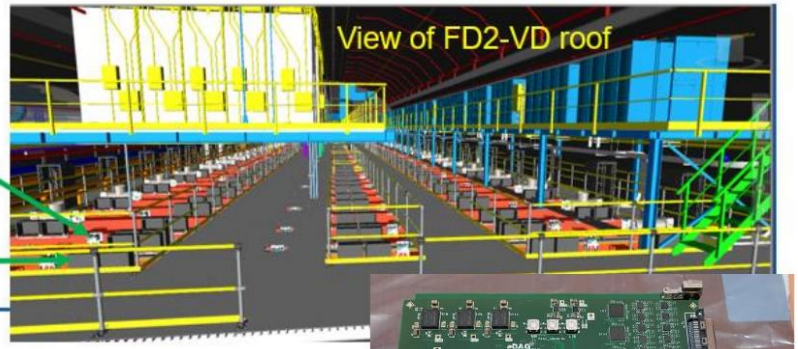
- 3840 AMC (64 channels)

- 105 Chimenys hosting 48 or 24 FE boards

- 320 WR-MCH

- 320 µTCA systems with 40 Gbit/s MCH





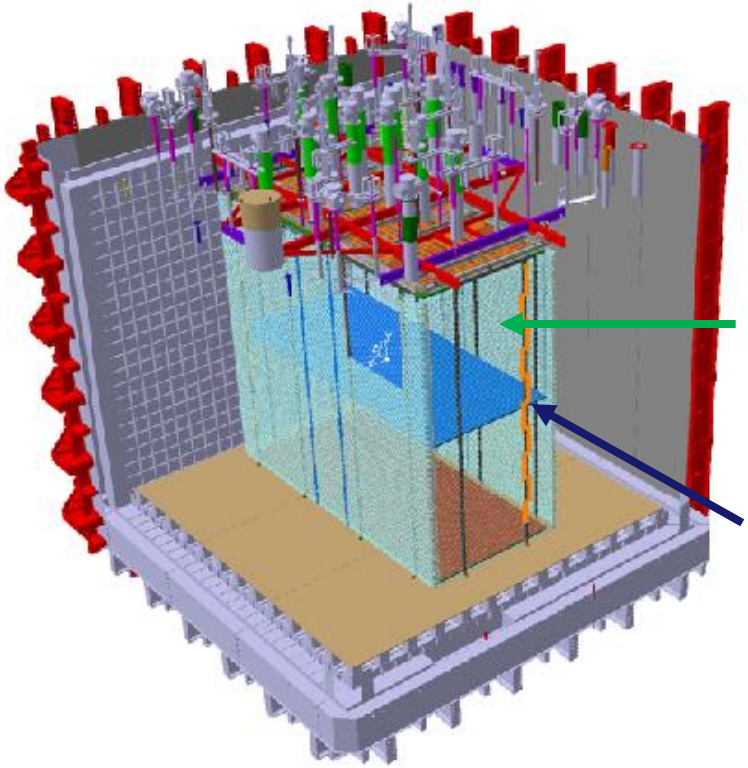
4 16.10.23

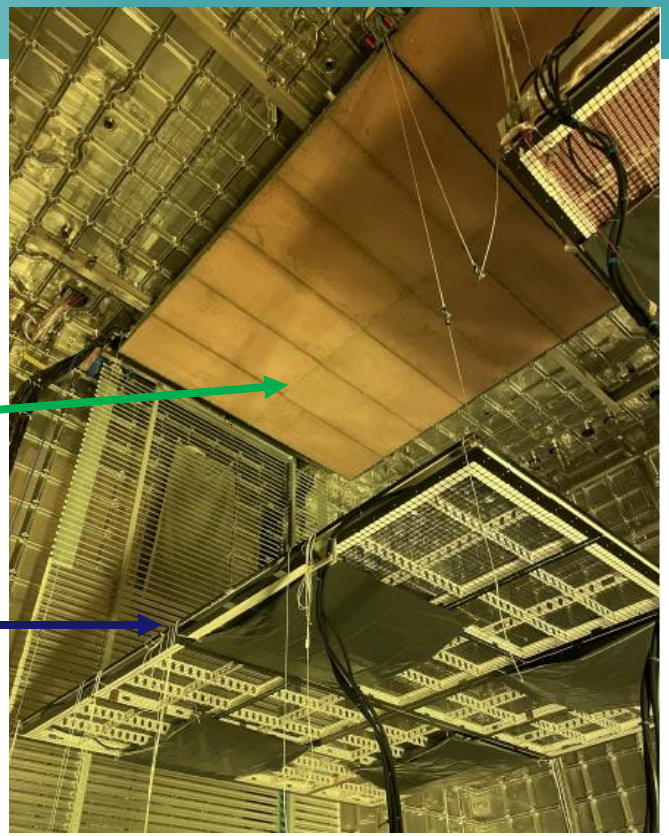
Setting up for production activities for FD2 (going to regime in 2024)

- Cryogenic ASICs produced with AMS
- AMC boards and microTCA crates (June 2024)
- Frond End boards (September 2024)
- Chimneys (September 2024)
- CRP structures (September 2024)

19

Module-0 (ProtoDUNE-VD)





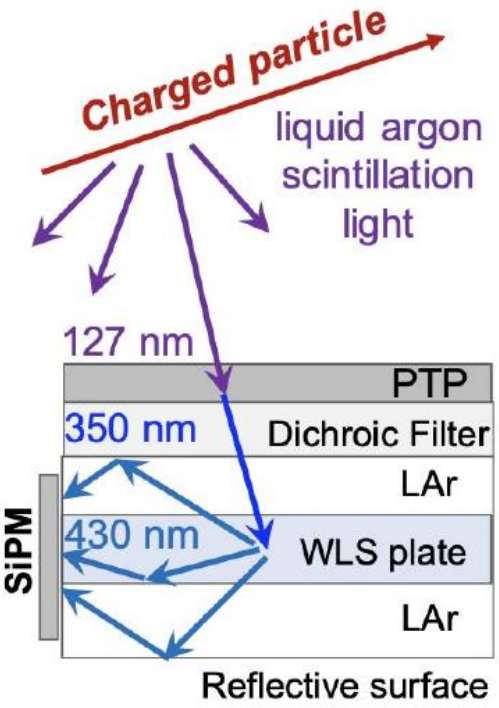
- Module-0/ProtoDUNE Vertical Drift: last Vertical Drift integration exercise before 2nd DUNE FD module construction -> completed in June 2023
- Detector will be filled (fall 2024, due lack of LAr) - main applications for reconstruction studies/development of cosmic and charged beam.

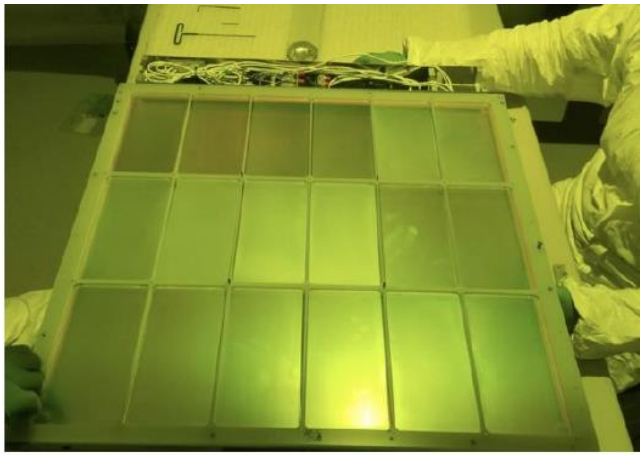
Light Readout [T:9.4] (CIEMAT, INFN-MIB, UEDIN)

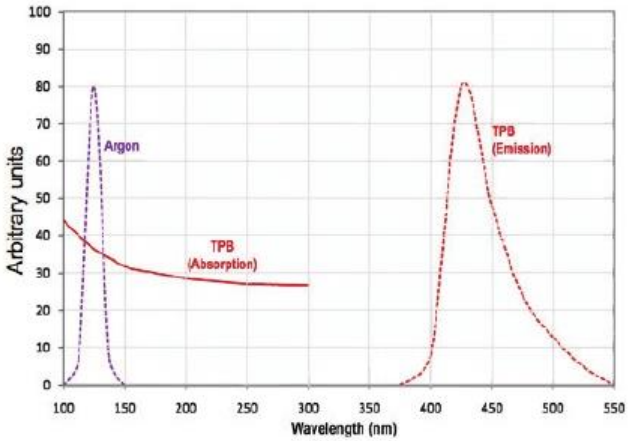
Talks by:
Carla Cattadori
Clara Cuesta
Andrzej Szelc

Common solutions in LAr Light Readout

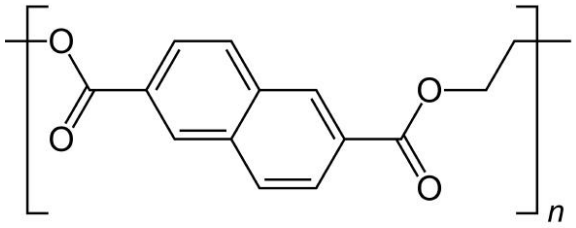
Ideas:
- Use light collectors (trapping photons)
- Use wavelength-shifters to transform light to visible







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



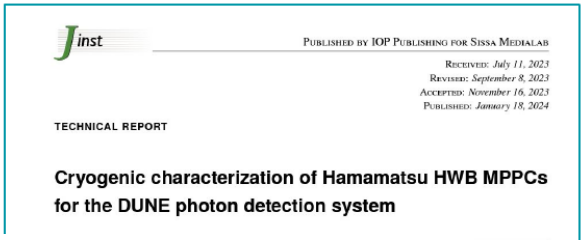
Above: PEN molecule; below: PEN sheets

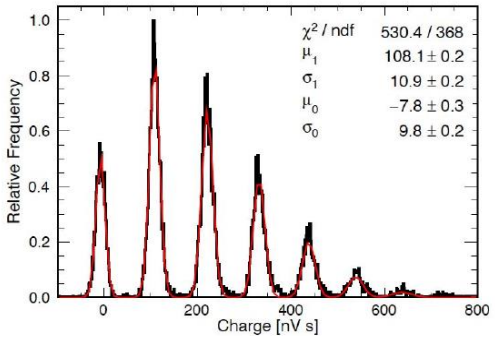
Assembly and tests of ProtoDUNE X-ARAPUCAS

CIEMAT main activities on light readout R&D

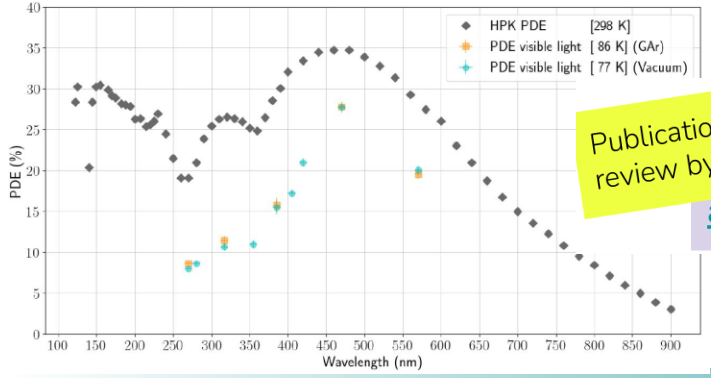
JINST 19 (2024) T01007

1. SiPMs
2. DUNE HD X-ARAPUCA photon detection efficiency (PDE)
3. SBND X-ARAPUCA PDE
4. DUNE VD X-ARAPUCA PDE
5. ProtoDUNE-VD
6. DAPHNE electronics





RESULTS

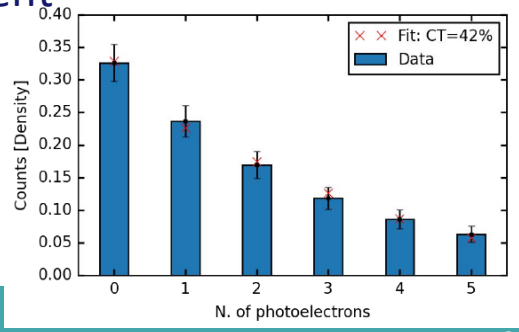


Publication under review by NIM-A

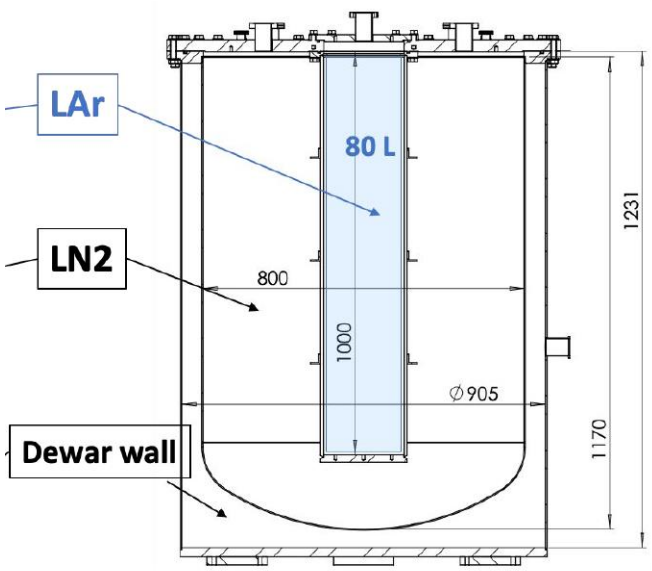
arXiv: 2402.01584

Measurement of PDE of SBND X-ARAPUCAS

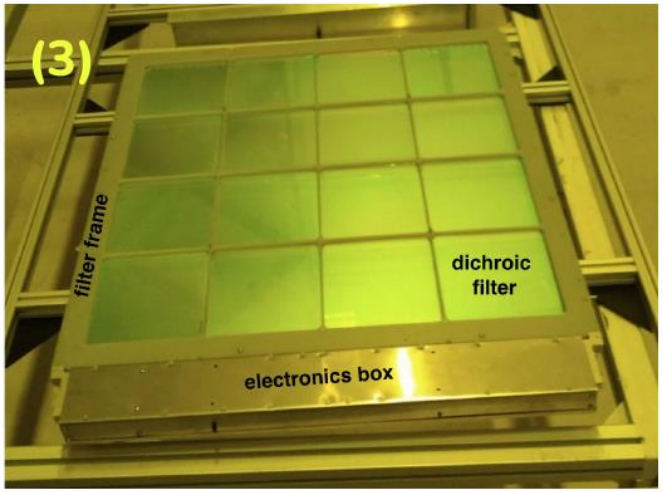
SensL pTP X-ARAPUCA, OV 6 [V]



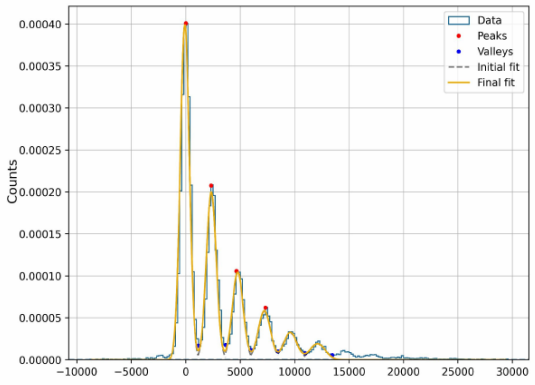
ProtoDUNE-VD R&D and PDE measurements



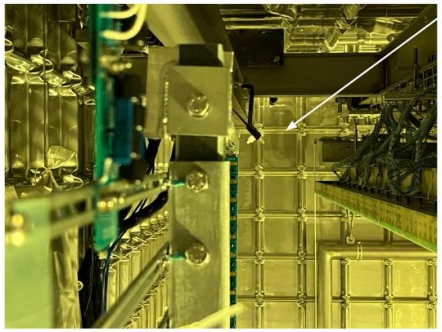
cathode X-ARAPUCA

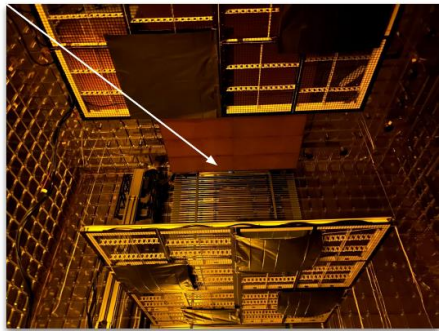


XA - Channel 0

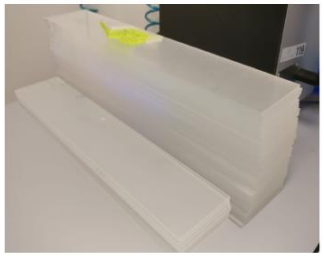


LED illuminated **fiber** pointing towards cathode X-ARAPUCAs





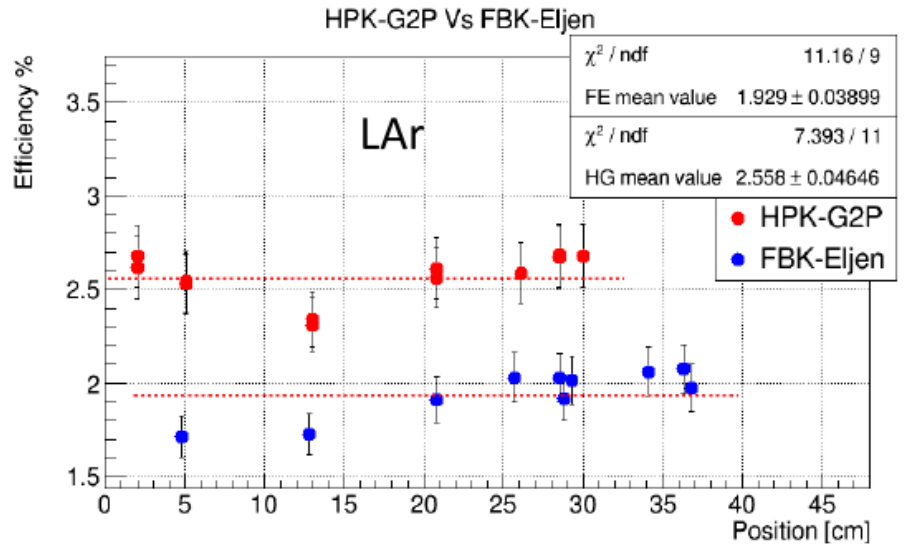
X-ARAPUCA WLS bar selection

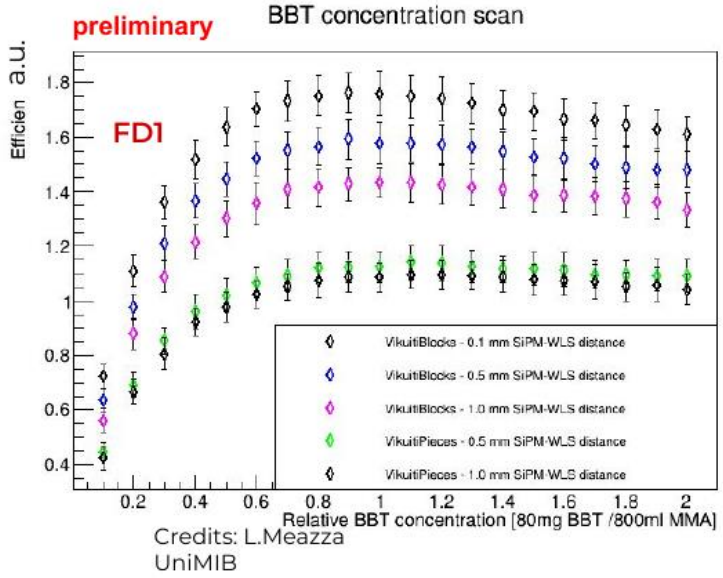


- 90 x slabs for pDUNE FD1-PDS: 480 x 93 mm^2 x 4mm thick
- ~ 60 WLS SBND 202 x 77 mm2

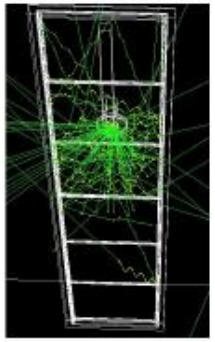
Laser cut (external industrial partner) and edge polishing procedures to cut out the casted plates in tiles defined and validated.

- **20** x slabs for the **Module-0** of **FD2-PDS**: 607 x 607 mm^2 x 4 mm thick casted in one week
- **10** x slabs in 2023 for the **Module-1** & PDE test stands 607 x 607 mm2 x 5.5 mm

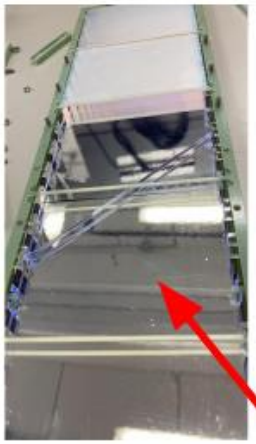


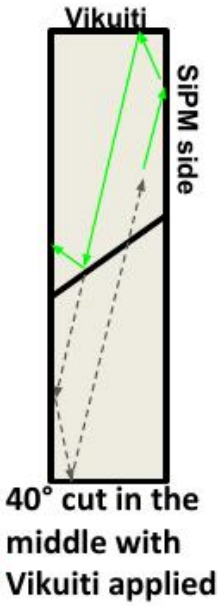


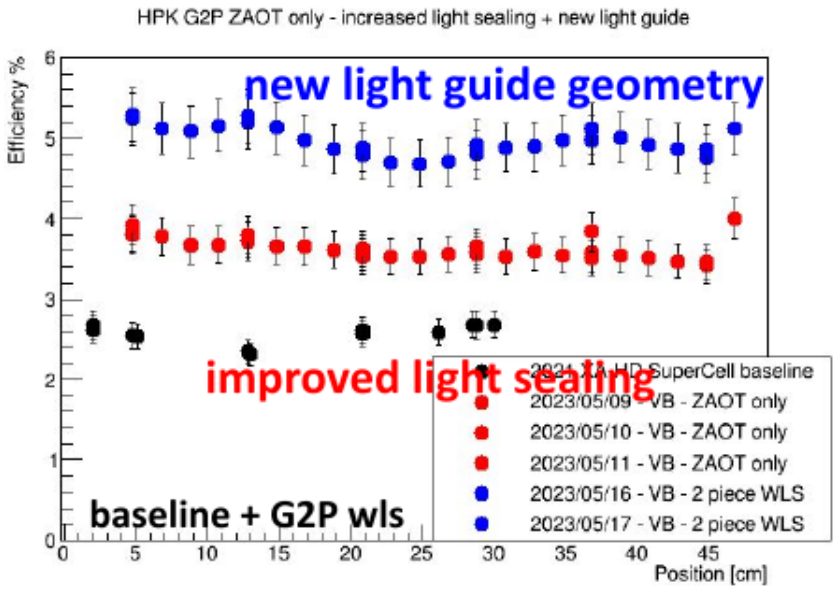
Improved coupling via flex-circuits & spring-loaded mechanism.
Chromophore concentration optimized



New WLS bar Geometry





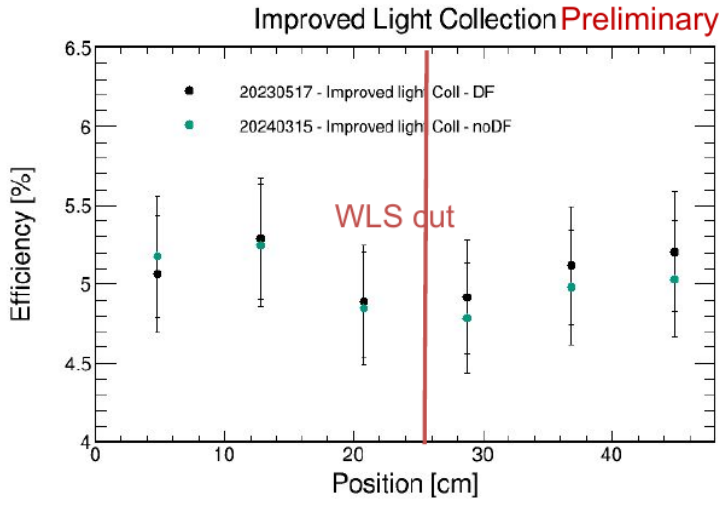


detection efficiency doubled!

Improved resolution.

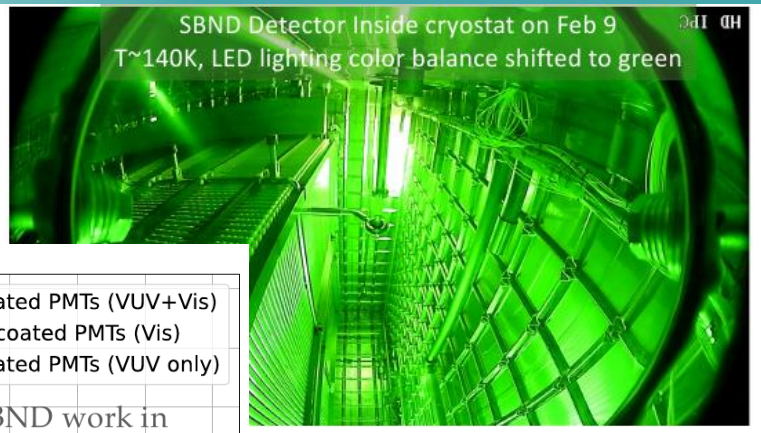
In New Geometry, removal of dichroic filters does affect efficiency.

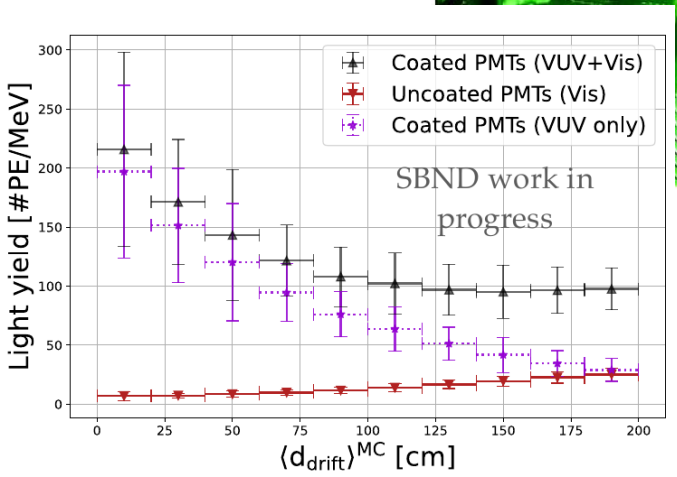
Big reduction in cost and production complexity.

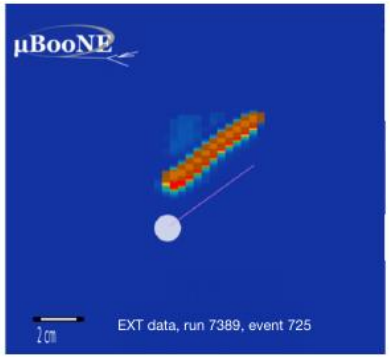


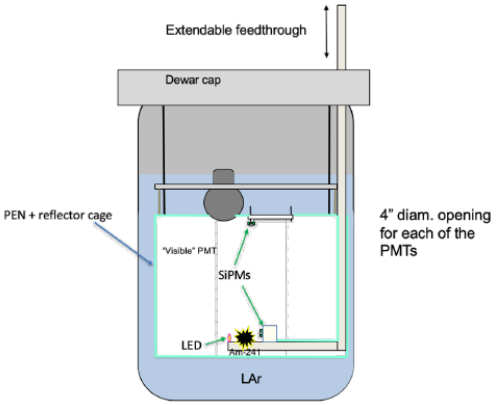
Large-scale WLS for neutrino detectors

- SBND @ FNAL, getting ready to run. Equipped with 38^2 m of TPB-coated foils.
- Preparing for first measurements of LY (protons, muons) and PMT calibration.
- In parallel – test @CERN, $4m^2$ of PEN.
- Data quality is good and analysis is ongoing
- Stay tuned for results soon









Schematic of experimental setup

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 fantastic progress.
- New ideas/collaboration formed thanks to AIDAInnova
- Transitioning from R&D phase to production:
  - DUNE cavern excavation completed!
  - ProtoDUNEs have LAr to run in spring and fall
  - SBND @ FNAL filled, and in commissioning.
- Expecting lots of exciting results.
- Milestones completed (slight delays on reporting) - looking forward to deliverables.