The ProtoDUNE experiment: past results and future plans

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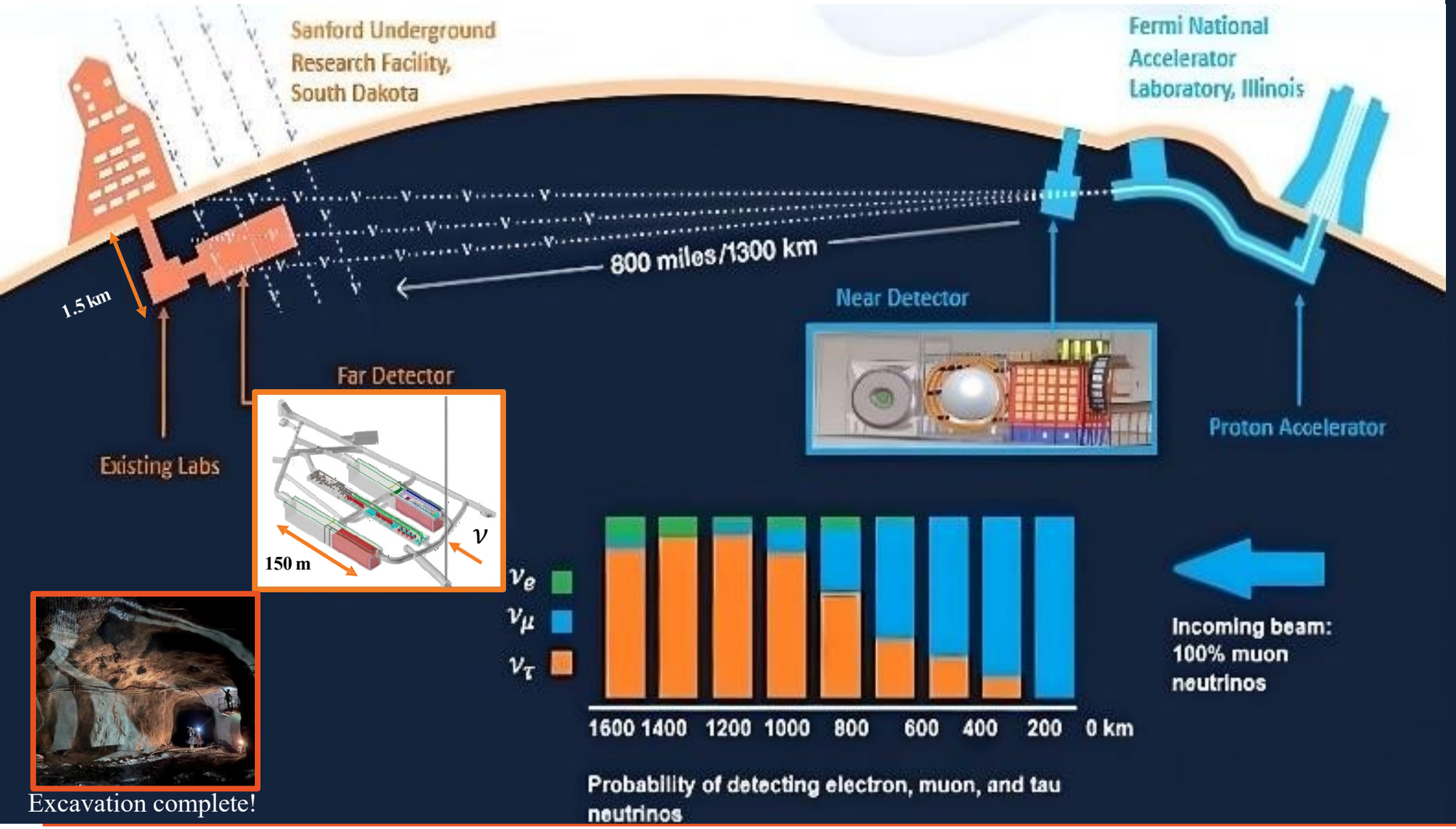
DPF-PHENO 2024

UNIVERSITY OF TORONTO

DUNE

DEEP UNDERGROUND NEUTRINO EXPERIMENT



Excavation complete!

- Next-generation neutrino experiment hosted in the United States.
- High-intensity neutrino beam, near detector complex at Fermilab.
- Underground Liquid Argon Time Projection Chamber (LArTPC) far detectors at SURF.
- Broad program of physics: precision neutrino oscillation measurements, MeV-scale neutrino physics, searches beyond the Standard Model.

ProtoDUNE

Prototypes of 2 DUNE far detector (FD) modules, located at CERN

Two LArTPC designs:

- Horizontal drift (HD) technology
- Vertical drift (VD) technology

- ProtoDUNE Horizontal drift is an 800t active mass TPC, making it the largest LArTPC constructed.
- ProtoDUNE successfully operated in 2018 and is preparing for its second run now (ProtoDUNE-II)

Figure: CERN Neutrino Platform.

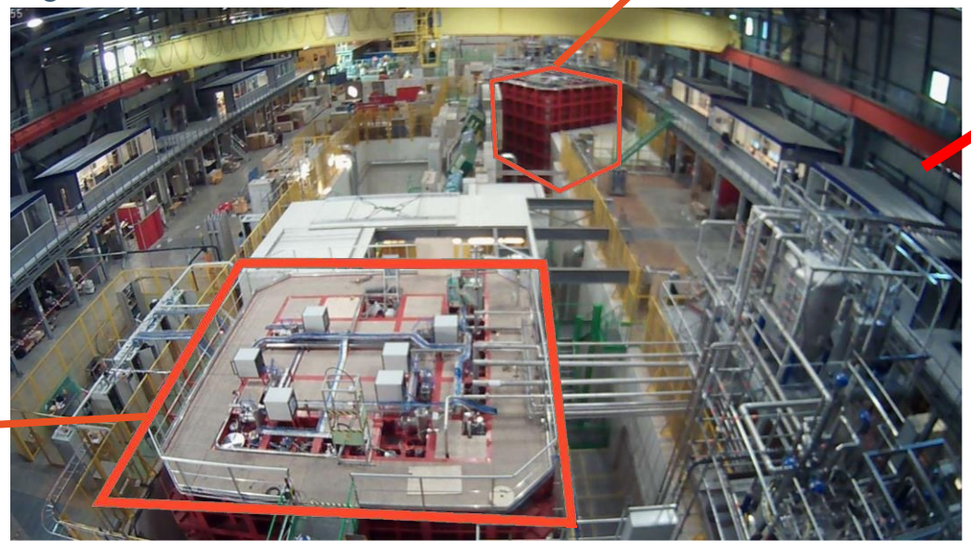
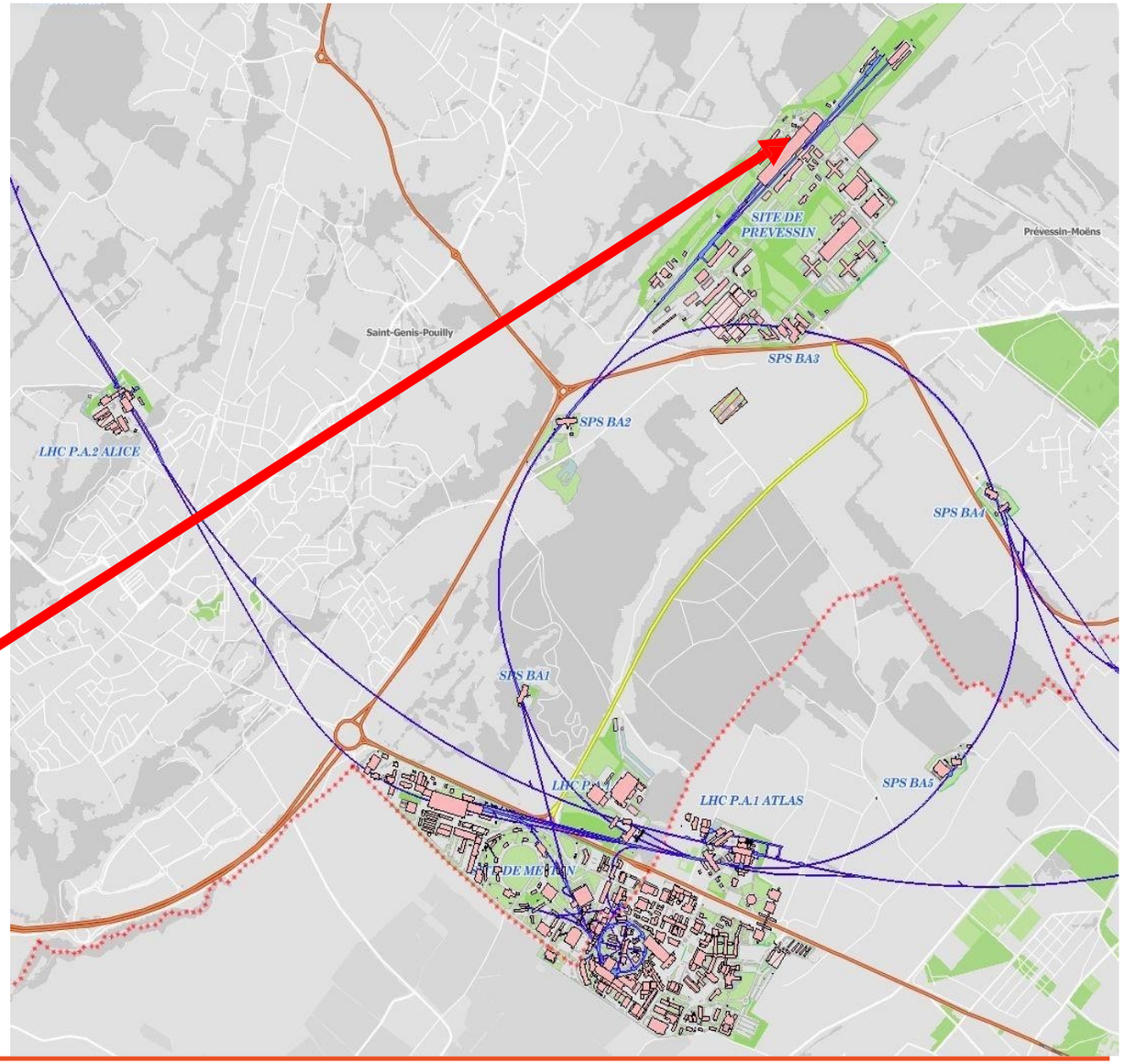


Figure: CERN.



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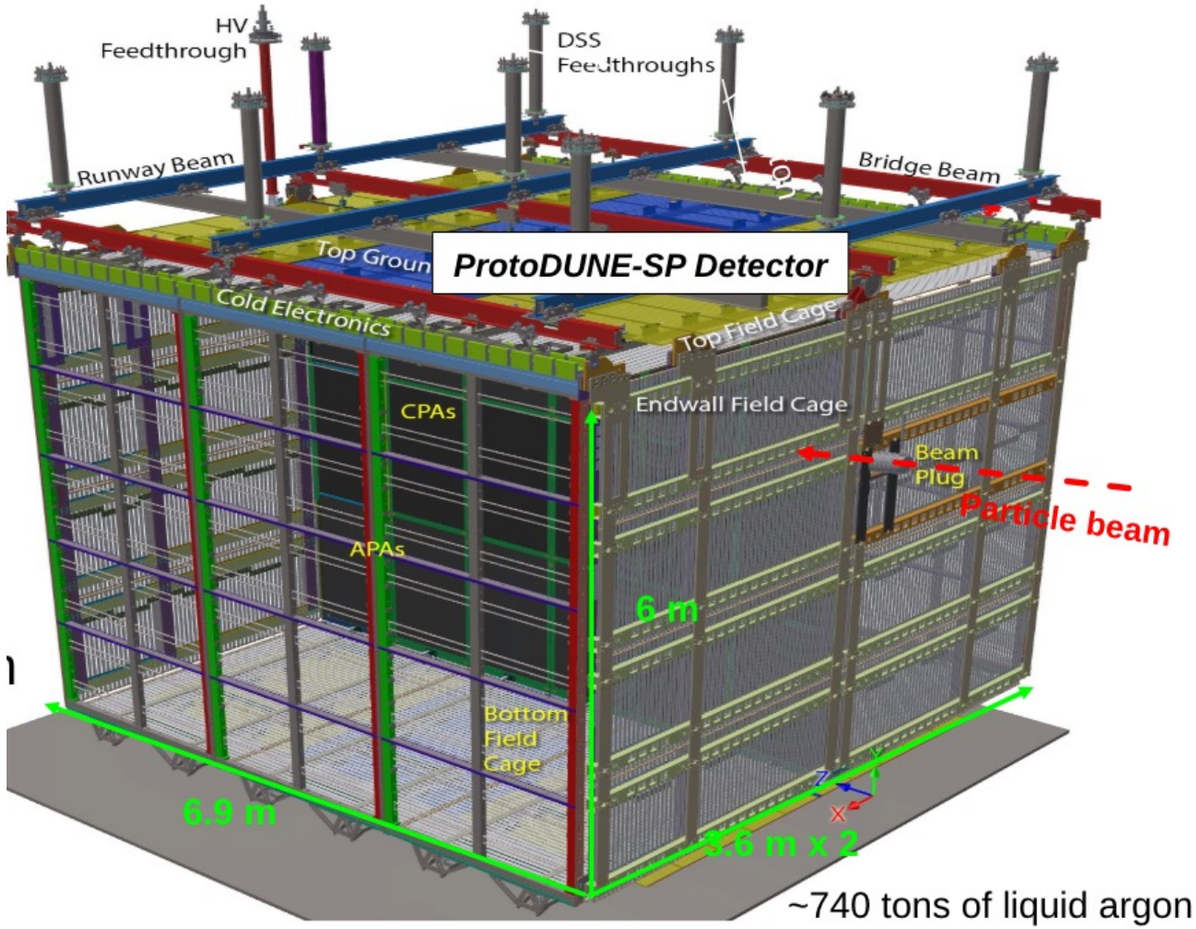
DUNE Prototype: Motivation

Large scale prototypes are mandatory for:
- Integration test with 1:1 components
- Assess the LArTPC technology performances

Detector physics:
- LArTPC detector physics
- Calorimetry with charged particles
- Evaluations of photon detectors in liquid argon

Ar-hadron interactions, EM shower, and Cosmic physics:
- Hadron-argon interactions with pions, protons, and kaons.
- Including total and exclusive cross sections
- dE/dx with charged particles, including electromagnetic showers.
- Michel electron energy reconstruction
- Seasonal variations of cosmic-ray muons



LArTPC

Charged particles ionize the liquid argon

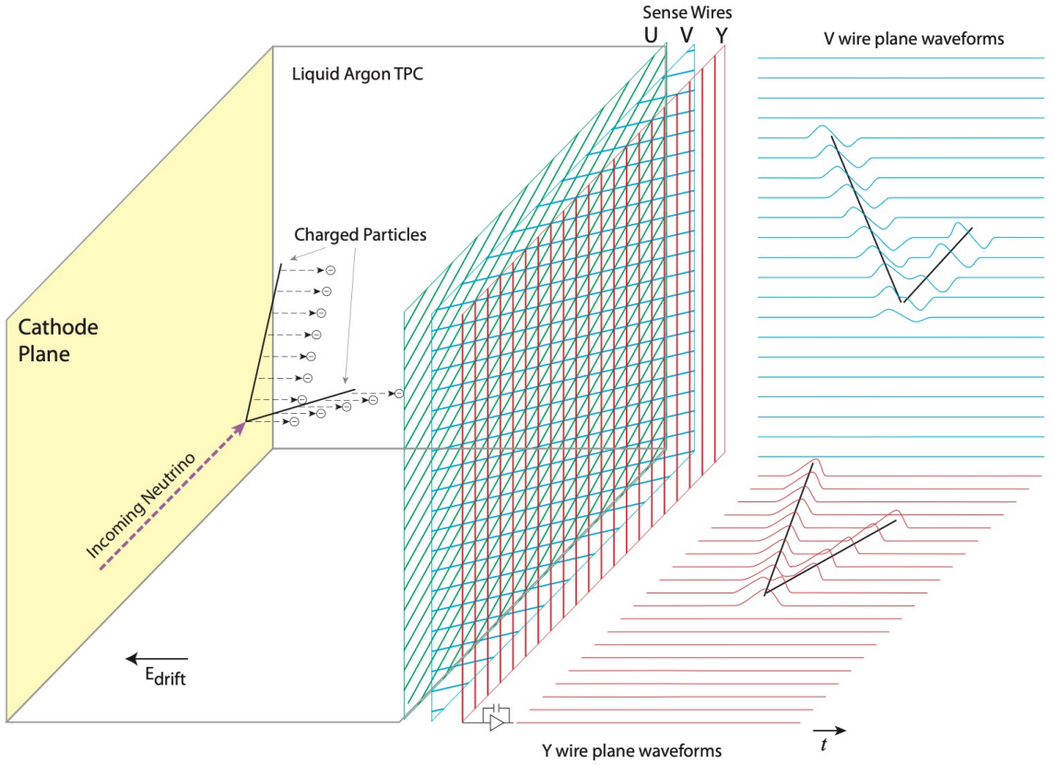
Produces a charge and light signal

Electric field at 500 V/m causes electrons to collect at the anode

3 planes at different angles resolves ambiguities

Induces a bipolar signal on first two wire planes (induction planes)

Induces a unipolar signal on third plane (collection plane)

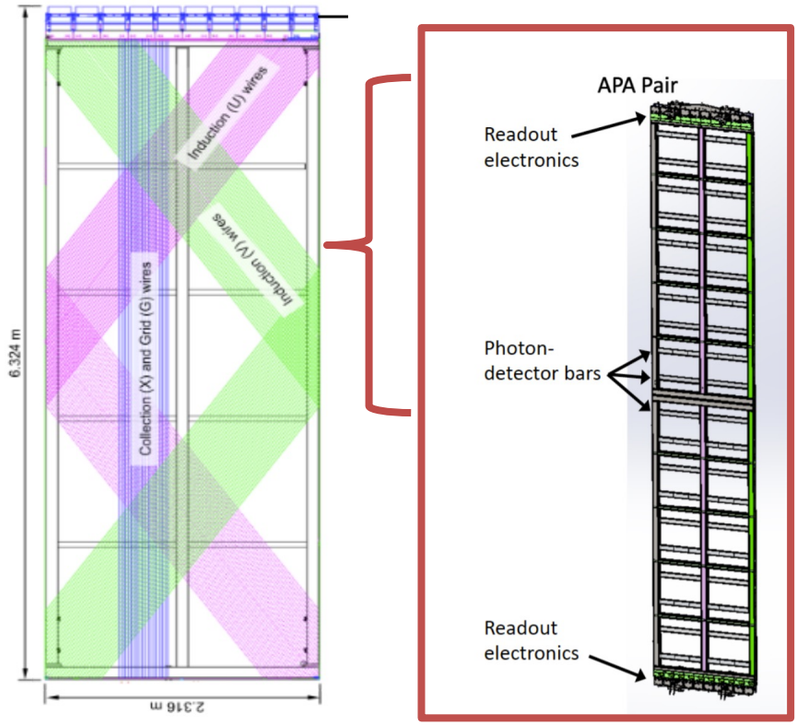


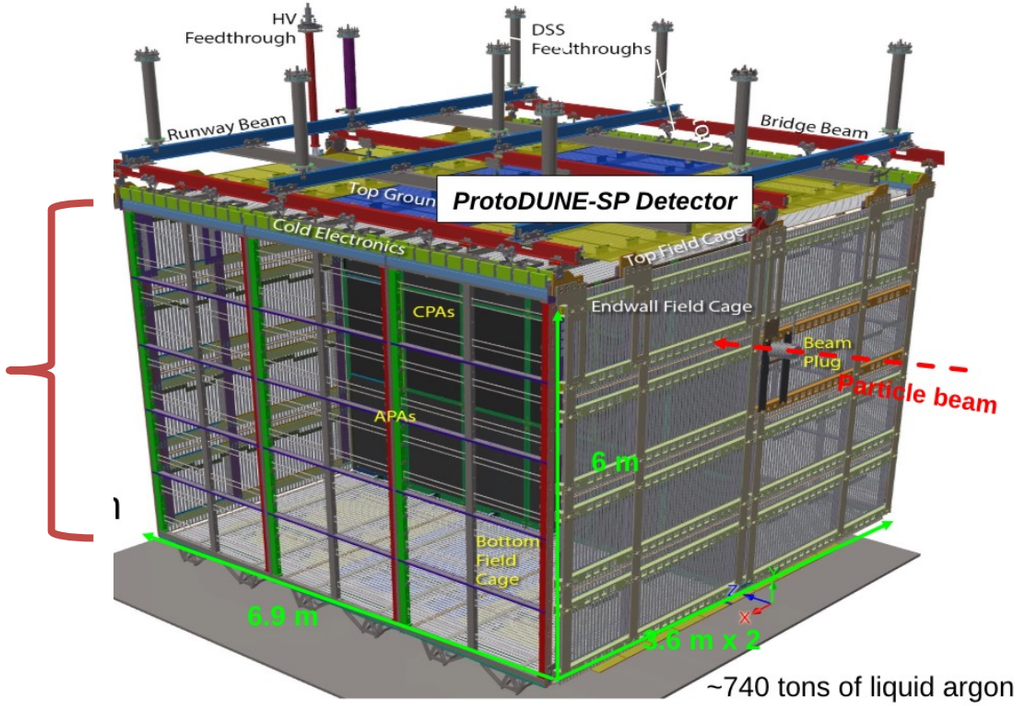
ProtoDUNE Single Phase (SP) detector

Anode module called APAs:
- Anode Plane Assembly
- Anode wire planes, electronics, and frame
- Light collection modules embedded behind anode
  - Several technologies tested in ProtoDUNE-I

Cathode module called CPAs:
- Cathode Plane Assembly
- Vcath = -180 kV

APA





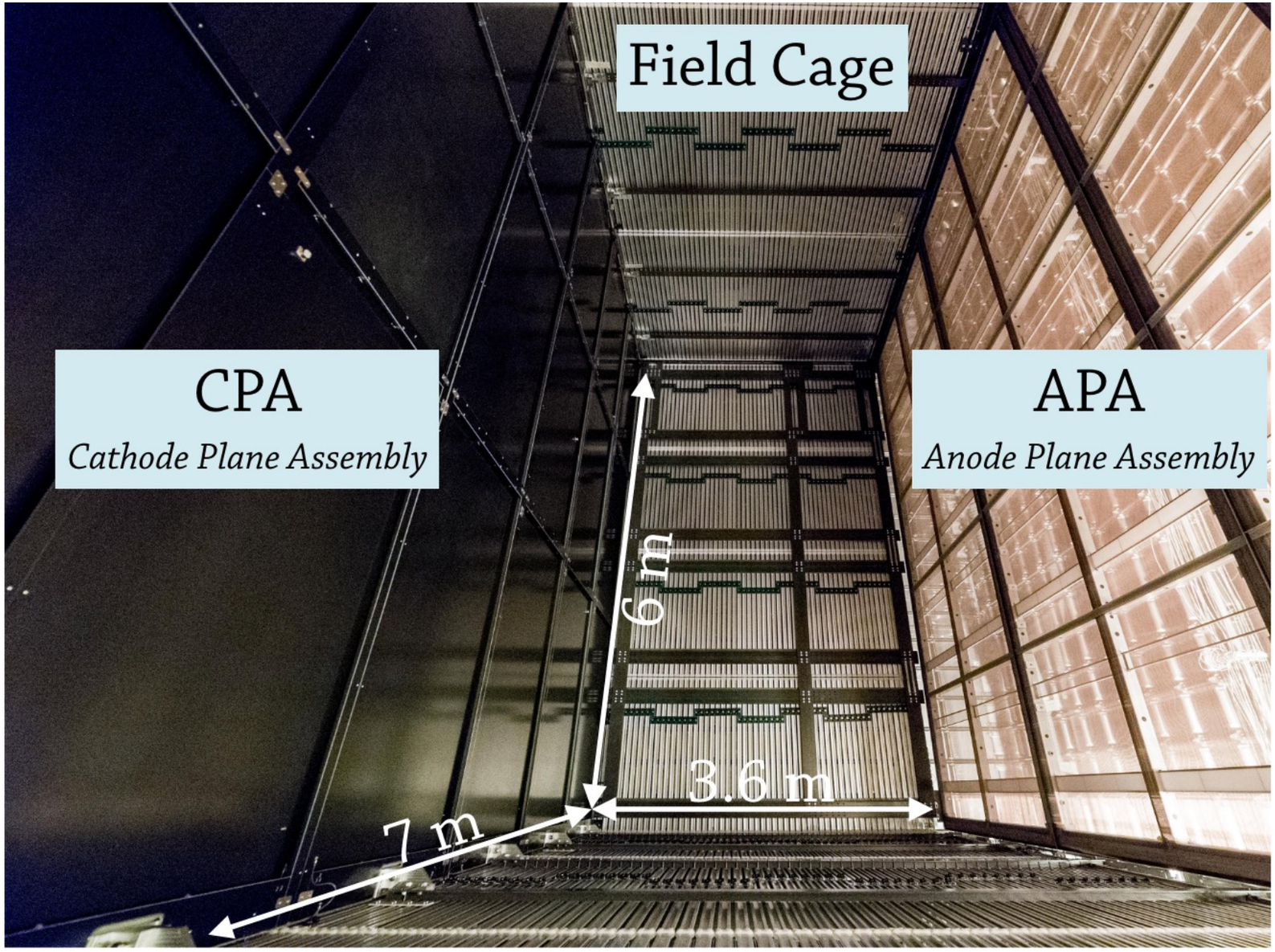
2 active volumes, 3.6 m drift each

APA – CPA – APA
6 APA and 6 CPA modules in ProtoDUNE-SP
(FD will have 150 APAs!)

Nominal drift field of 500 V/cm

https://iopscience.iop.org/article/10.1088/1748-0221/15/12/P12004

ProtoDUNE SP

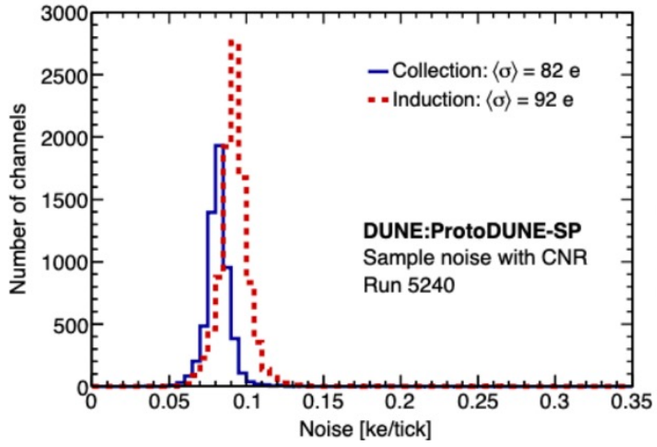


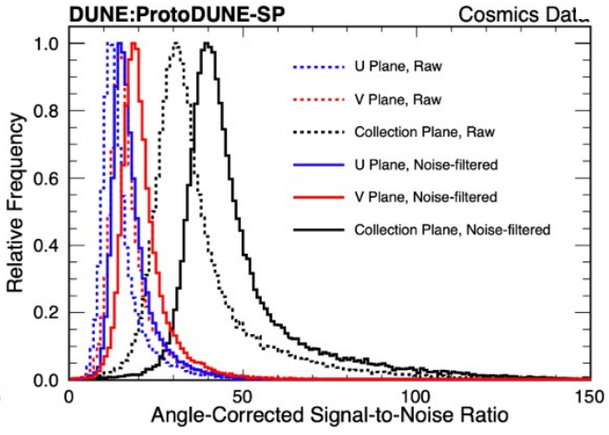
ProtoDUNE SP: Data

Oct.~Nov. 18: Beam data
- hadrons with momenta 0.3 ~ 7 GeV/c
- 4×10^6 triggered events
- H4-VLE beamline instrumented with ToF and Cherenkov counters for PID

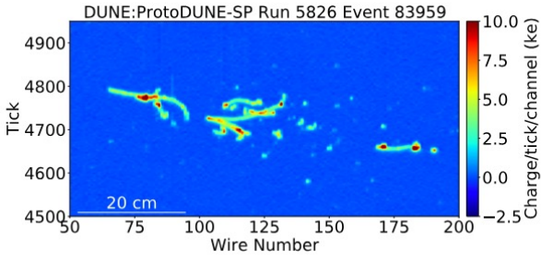
Nov. 18 ~ Jan. 20: Cosmic data
- Random and cosmic ray trigger
- Tests of detector performances & stability

Feb. 20 ~ Jul 20:
- LAr doped with 20 ppm Xe
- Test of light yield increase

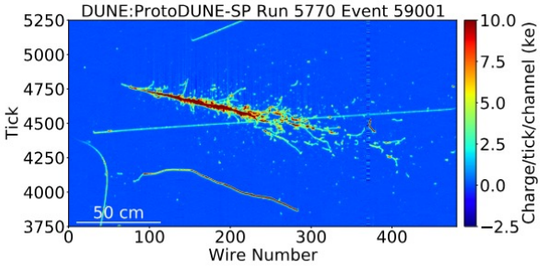




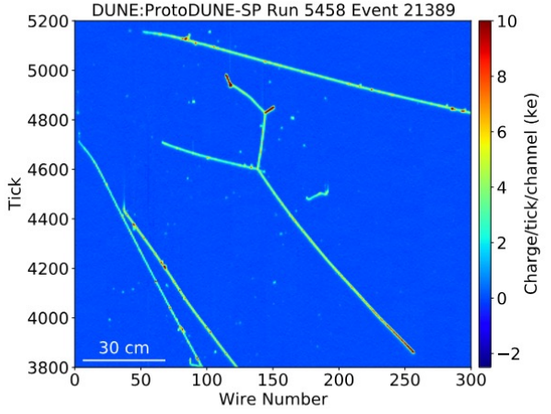
Selection of beam event displays



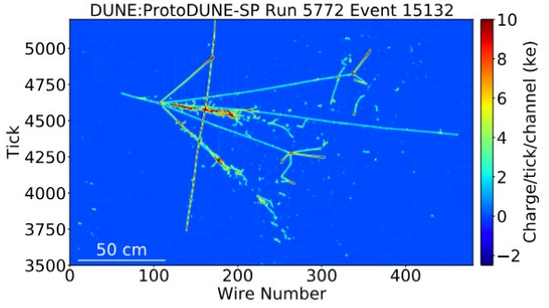
(a) A 0.5 GeV/c electron candidate.



(b) A 6 GeV/c electron candidate.



(c) A 1 GeV/c pion candidate.



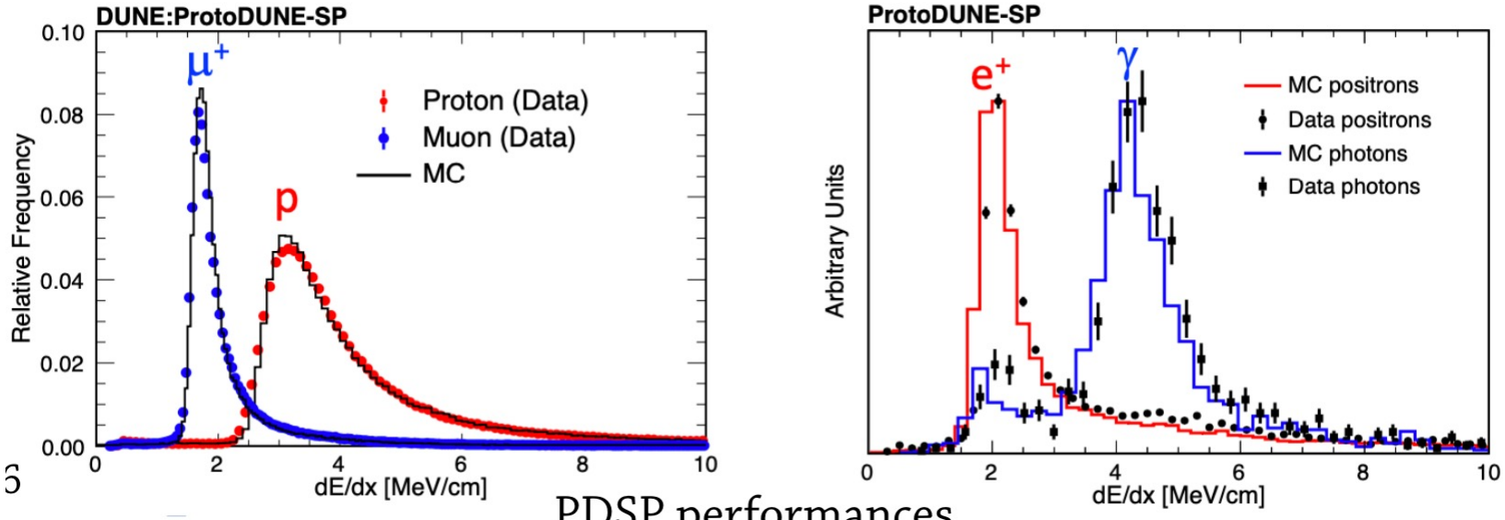
(d) A 6 GeV/c pion candidate.

https://iopscience.iop.org/article/10.1088/1748-0221/15/12/P12004

ProtoDUNE reconstruction and PID

3D reconstruction is handled by PANDORA, a multi-algorithm approach with pattern recognition:

- Separation of cosmic tracks from beam tracks
- Hierarchical reconstruction
- Reconstruction efficiency close to 100%
- Beam particle identification efficiency well above 80%



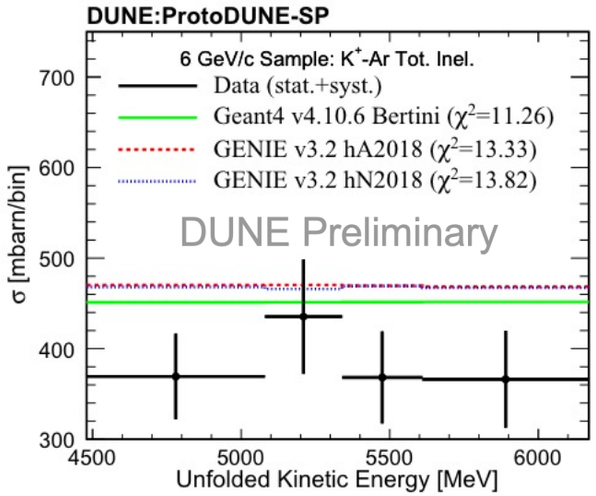
PDSP performances

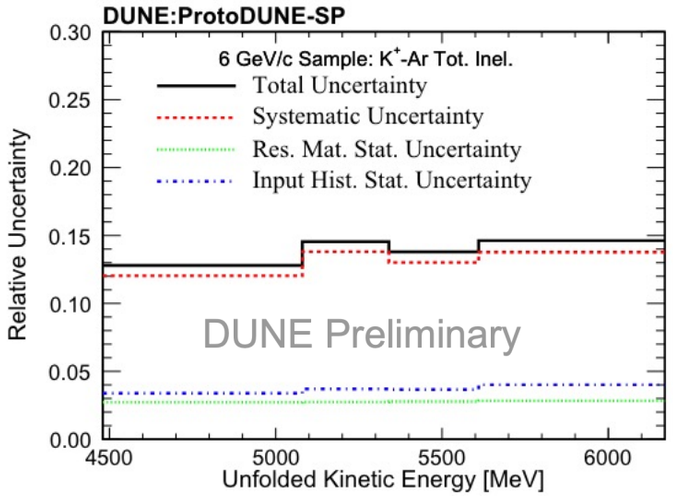
The excellent e/γ and μ/p separation is crucial for DUNE neutrino oscillation analysis

https://link.springer.com/article/10.1140/epjc/s10052-023-11733-2

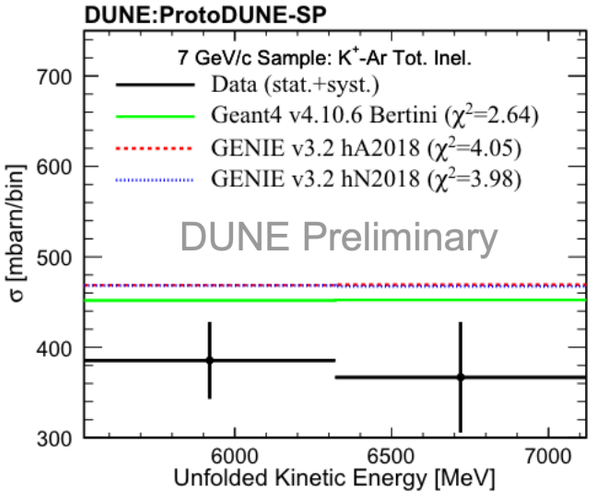
ProtoDUNE inclusive cross section results

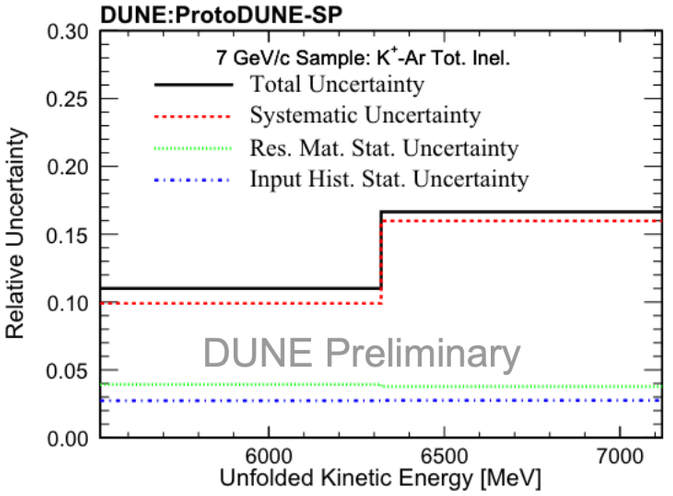
Kaon-Argon inelastic total cross-section and uncertainty





6 GeV beam





7 GeV beam

"First Measurement of the Total Inelastic Cross Section of Positively-Charged Kaons 2 on Argon at Energies Between 5.0 and 7.5 GeV" – The DUNE Collaboration

ProtoDUNE-SP Summary

Summary of ProtoDUNE-SP performance meeting/exceeding DUNE specifications

Detector parameter	*ProtoDUNE-SP performance*	*DUNE specification*
Average drift electric field	500 V/cm	250 V/cm (min) 500 V/cm (nominal)
LAr e-lifetime	> 20 ms	> 3 ms
TPC+CE Noise Signal-to-noise ⟨SNR⟩	(C) 550 e, (I) 650 e ENC (raw) (C) 48.7, (I) 21.2 (w/CNR)	< 1000 e ENC
CE dead channels	0.2%	< 1%
PDS light yield	1.9 photons/MeV (@ 3.3 m distance)	> 0.5 photons/MeV (@ cathode distance — 3.6 m)
PDS time resolution	14 ns	< 100 ns

https://iopscience.iop.org/article/10.1088/1748-0221/15/12/P12004

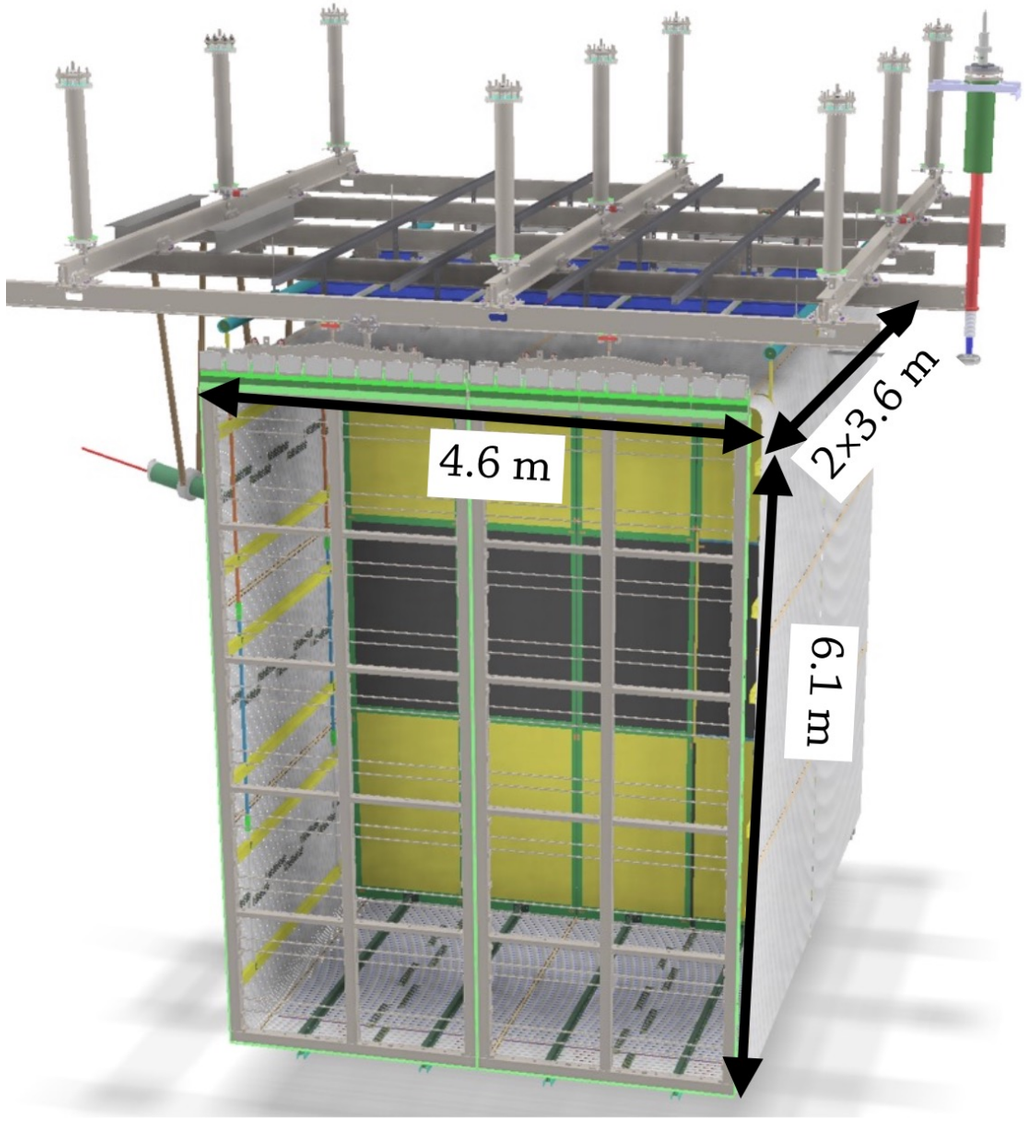
ProtoDUNE HD Plans

Improved HD design:

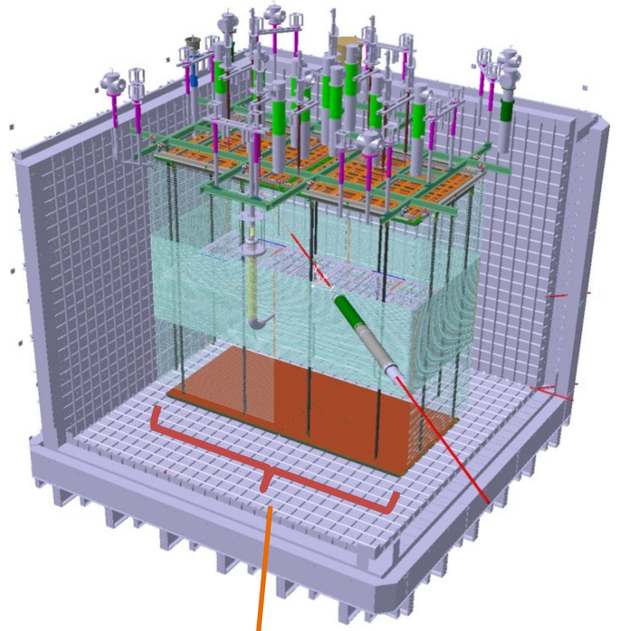
- Updated APA, CPA and cold electronics designs
- 4 APAs to match the field cage-cryostat distance of the FD module
- 2 APAs upside down with the electronics at the bottom
- Light collection modules: X-ARAPUCA technology chosen
- Test new calibration systems
  - Neutron source, laser, 207Bi sources, temperature sensors along the APAs

Beam time approved by CERN
Running at $\pm$1 GeV:

- Negative polarity data not collected at ProtoDUNE-SP
- Perform inclusive, exclusive and differential cross sections of hadrons on argon
  - π^-, π^+, proton

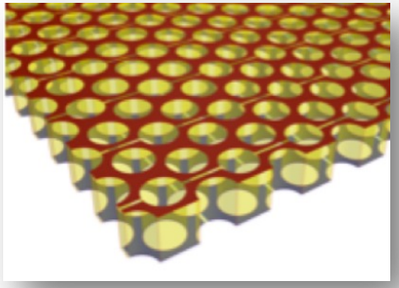


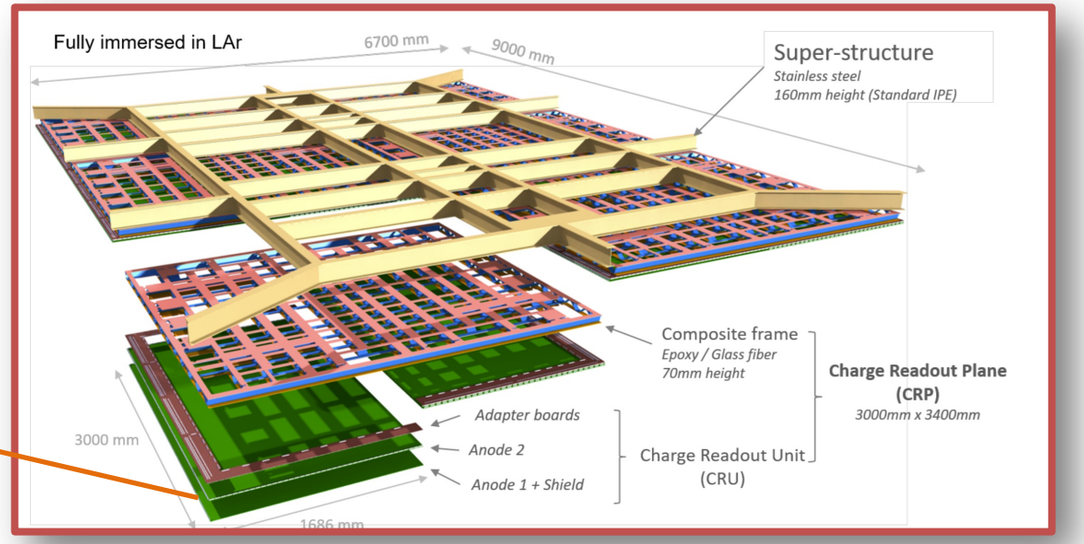
ProtoDUNE VD - CRP



Vertical drift technology:

- Charge readout plane (CRP) house the anode planes, electronics, and frame.
- Dimensions 3 x 3.4 m^2
- Anode of drilled PCBs with etched strips
  - More robust than wires
- 3 anode planes at varying angles {-30˚,+30˚, +90˚} wrt. beam
- X-ARAPUCA embedded in cathode

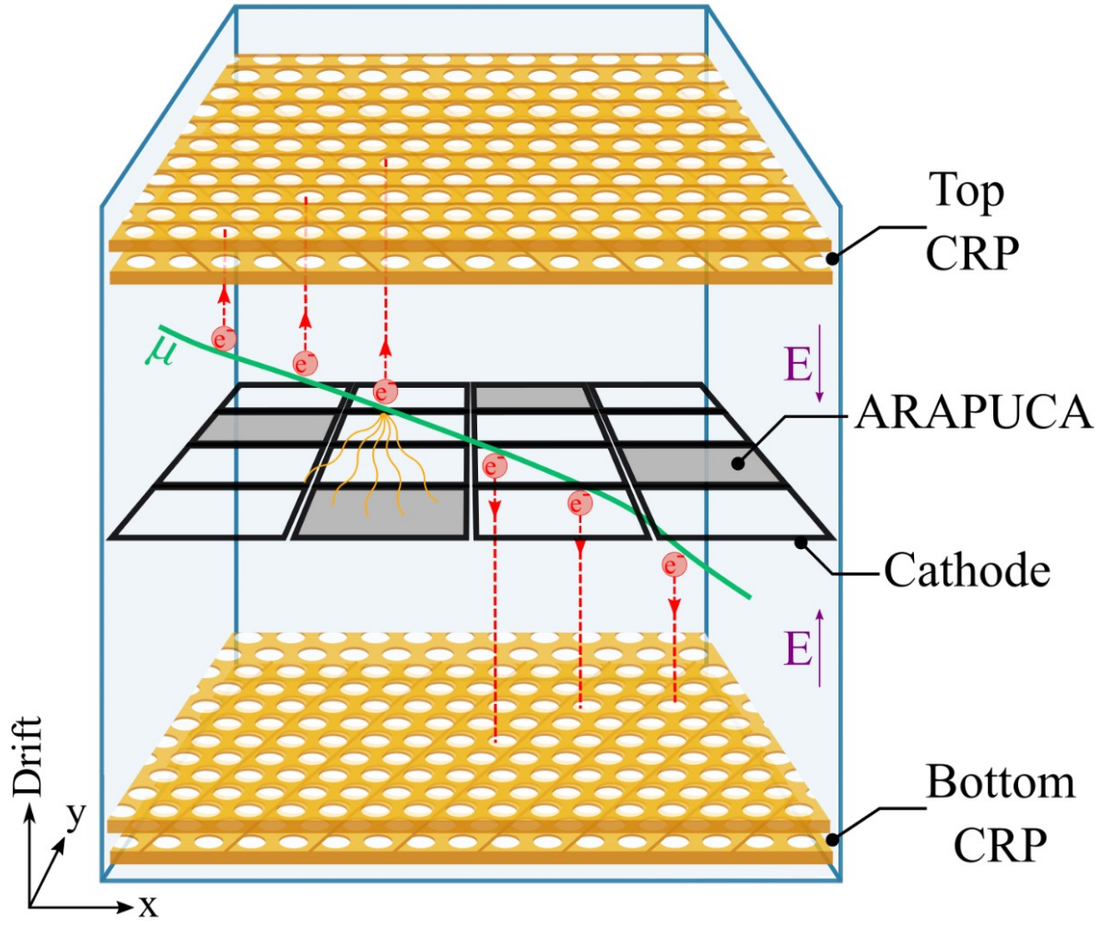




ProtoDUNE VD

- Very low electronic noise
- 2 top CRPs + 2 bottom CRPs (FD will have 2 x 80 CRPs!)
- 2x3m drift distance (compared to 2x6m drift distance in FD

Beam and cosmics data planned for late 2024-25
Use argon from protoDUNE HD



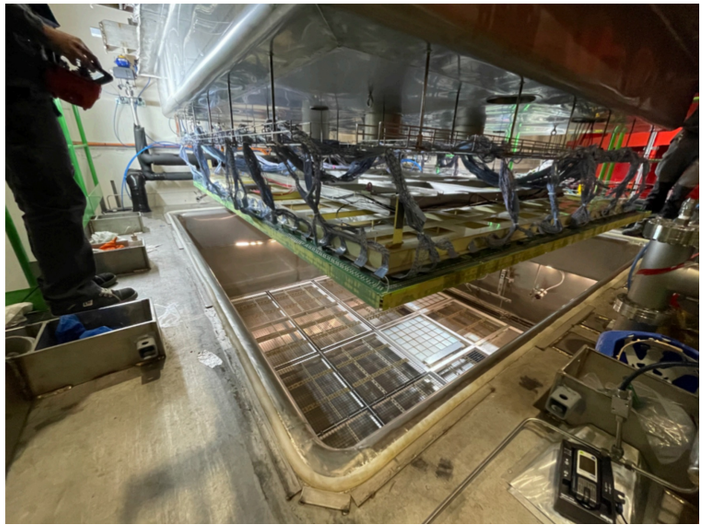
VD-Coldbox

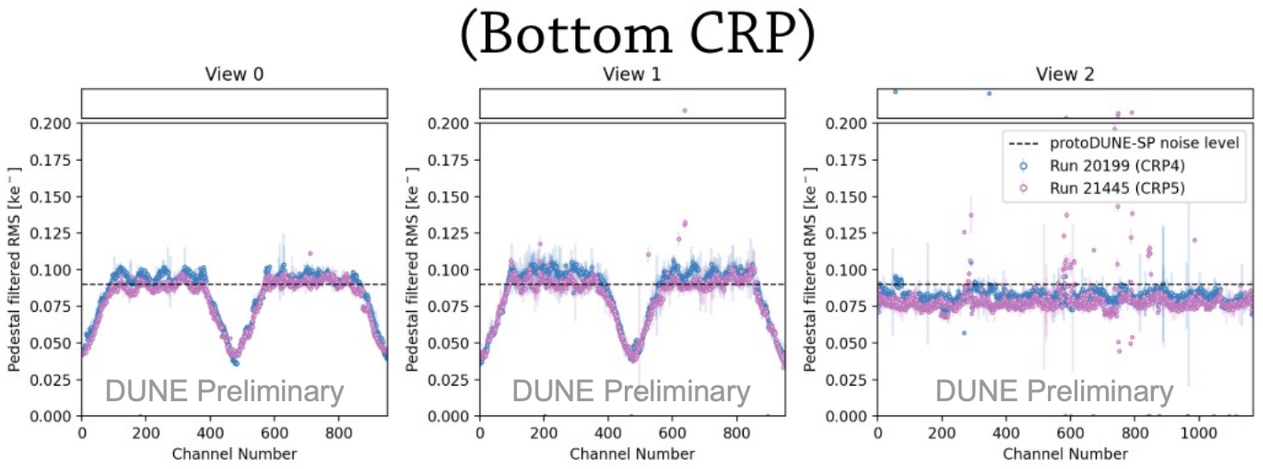
The Coldbox is a small TPC collecting cosmics data to test CRP and X-ARAPUCA instrumentation

23cm drift length

Noise:
- Coherent noise filtered
- Bridge-shape due to the noise being proportional to the strip length
- Bottom CRPs measured noise at the same level of protoDUNE-SP
- Top CRPs to be tested, expects similar noise levels

Uniformity:
- Very uniform dQ/dx across the bottom CRPs
- Less than 1% of channels unresponsive or too noisy





Summary

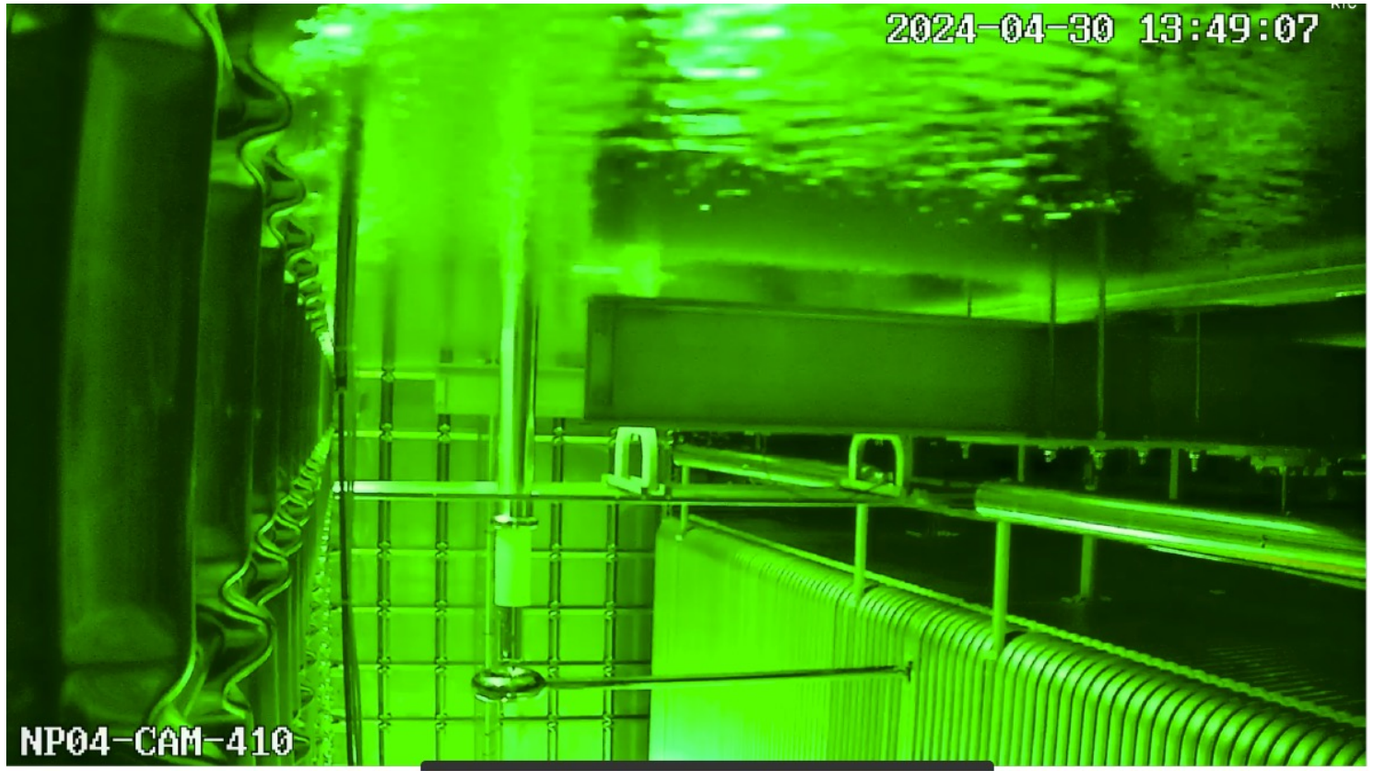
DUNE is expected to start data taking with a neutrino beam with 2 far detector modules in ~2032

- HD and VD LArTPC modules
- Both technologies are being thoroughly tested at CERN with the protoDUNEs:
  - Engineering
  - Performances
  - Reconstruction algorithms
  - Energy scale, Resolution
  - LAr physics
  - Hadron-Argon cross sections
- Proved the feasibility of achieving vital technical requirements for the DUNE Far Detector Horizontal Drift module

A new round of data is about to start, stay tuned!

END

Thanks for your time!!!



ProtoDUNE HD filled with LAr!

Inside ProtoDUNE VD

References

FDR

https://edms.cern.ch/ui/#!master/navigator/document?D:101190518:101190518: subDocs

Trigger and Data AcQuisition Overview

https://indico.fnal.gov/event/57752/contributions/260312/

First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform:

https://iopscience.iop.org/article/10.1088/1748-0221/15/12/P12004

Reconstruction of interactions in the ProtoDUNE-SP detector with Pandora:
https://link.springer.com/article/10.1140/epjc/s10052-023-11733-2

(Confusing) history of ProtoDUNE names

Originally protoDUNE single phase (SP) and dual phase (DP) were tested in the 2018 protoDUNE run.

ProtoDUNE DP had issues:

- A short between high voltage extender and field cage
  - Non-uniform drift field
  - Reduced active volume
- Non-flat liquid argon surface
  - Can cause discharges

But the vertical drift design aspect was successful.

For protoDUNE-II the second run in 2024, both HD and VD are single phase LArTPCs, and have been named to differentiate the horizontal vs vertical drift direction technologies.

If you see protoDUNE SP, it has been upgraded to **protoDUNE HD**.
And protoDUNE DP has been redesigned into a single phase **protoDUNE VD**.