ProtoDUNE Single Phase

Liquid Argon Time Projection Chamber

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Deep Underground Neutrino Experiment

Some of DUNE’s goals:

- Search for the origin of matter
- Neutrino mass hierarchy

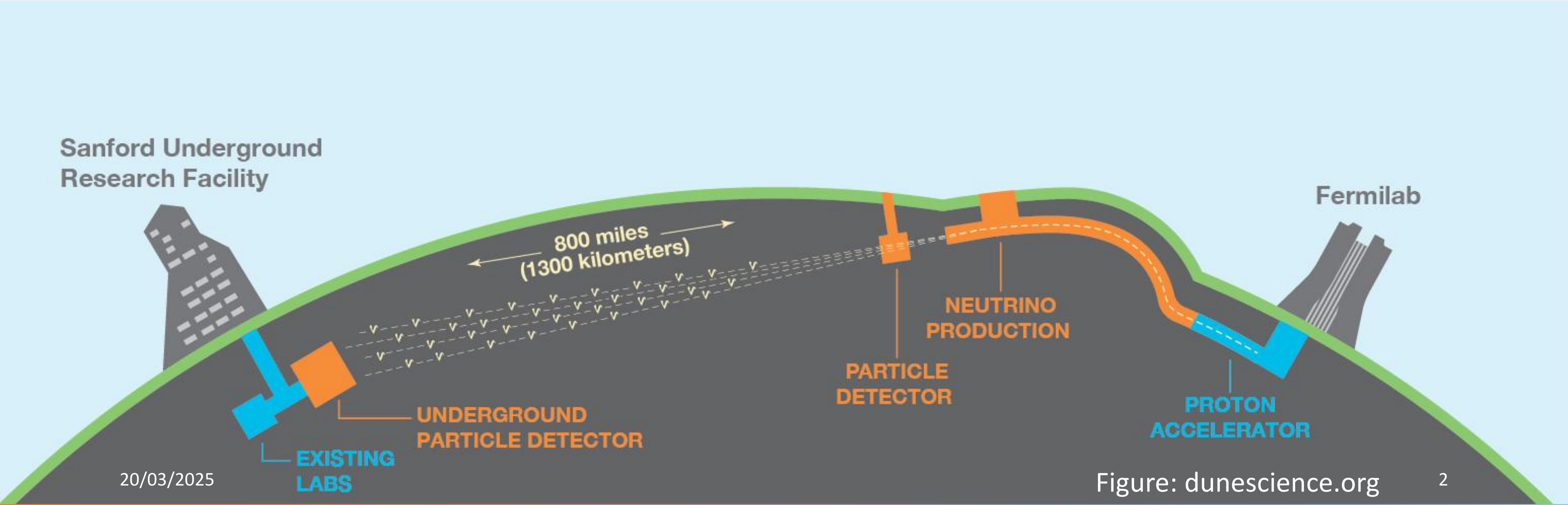

Figure: dunescience.org

ProtoDUNE Goals

Prototype at CERN for the far-detector module of DUNE

- Test the production and installation procedures of liquid argon time projection chamber (LArTPC) detector
  - 1:1 components
- Test long term operational stability

Acquisition of large samples of data

- Study the behaviour of charged hadrons, electrons, muons in LAr
- Measure cross section of interactions of charged particles in LAr

Real-world test bed for development of algorithms

CERN experiment

- Experiment at CERN Neutrino Platform (North Area)
- Exposed to tagged and momentum analyzed beam of charged particles with momentum 0.3-7 GeV/c

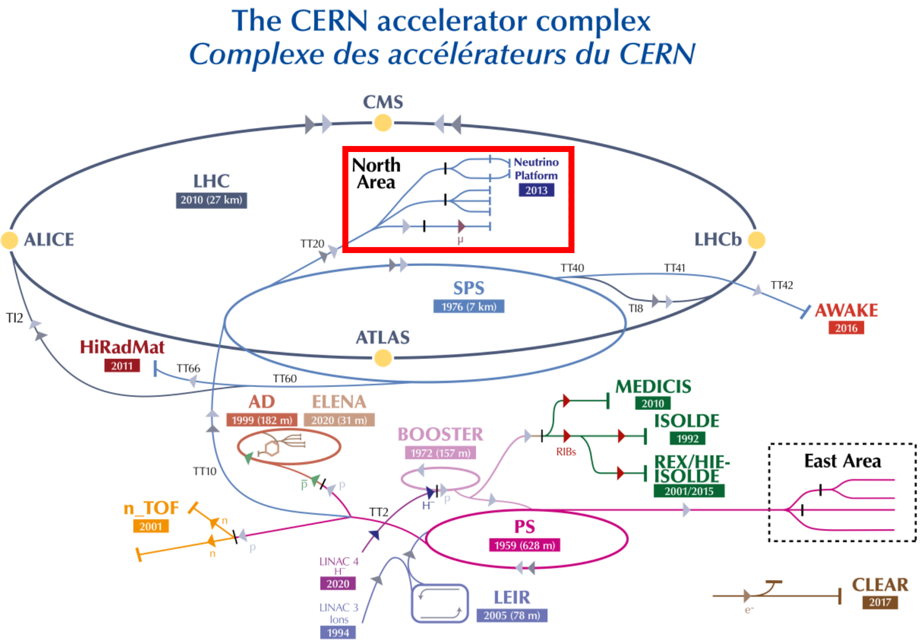

Figure: CERN

Figure: The DUNE Collaboration et al 2022 JINST 17 P01005

ProtoDUNE SP

Detector consists of these components:

- Time Projection Chamber (TPC)
- Cold Electronics (CE)
- Photon Detection System (PDS)
    - Triggering + calorimetry
- Cosmic Ray Tagger (CRT)

Immersed in a cryostat (1050 mbar) filled with LAr

Can measure particle tracks + energy

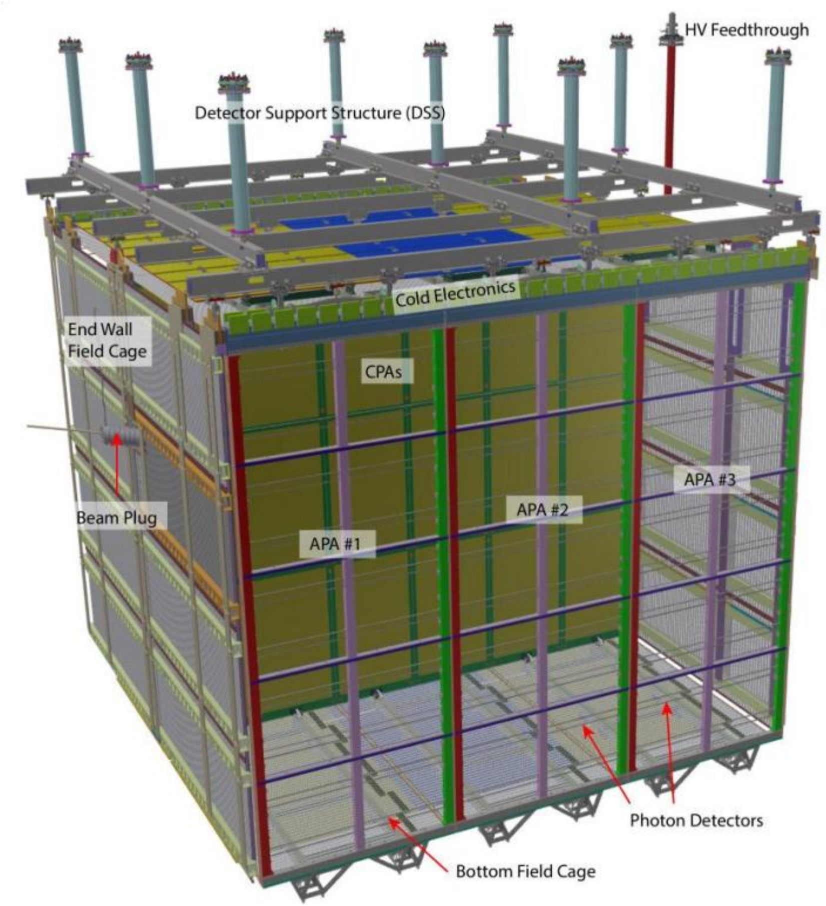

Figure: The DUNE Collaboration et al 2022 JINST 17 P01005

Time Projection Chamber

- Filled with liquid argon (LAr)
    - Noble gas
    - Produces scintillation light
        - $2.4 * 10^4$ vacuum ultraviolet γ/MeV (at Edrift 500 V/cm)
    - Challenge: purity of LAr
        - Electrons should be able to drift long enough to reach the APA's (3.6 m drift)
        - Drift time of electrons in pure Argon is long enough

TPC configuration	Anode-Cathode-Anode (2 active volumes)
TPC dimensions (active volumes)	6.086 (h) × 3.597 (w) × 7.045 (l) m^3
(instrumented volumes)	5.984 (h) × 3.597 (w) × 6.944 (l) m^3
Total active volume (nominal, at room T)	2 ×154 m^3
Total instrumented LAr mass (87.65 K)	419 t

Figure: B. Abi et al 2020 JINST 15 P12004

Charged particles from neutrino interaction ionize LAr

- Produces charge + scintillation light
- Charge drifts to anode planes
- Reconstruct 3D position of a particle with (x, y) information + drift time of the ionized electrons
- Use scintillation light to determine the time of the interaction

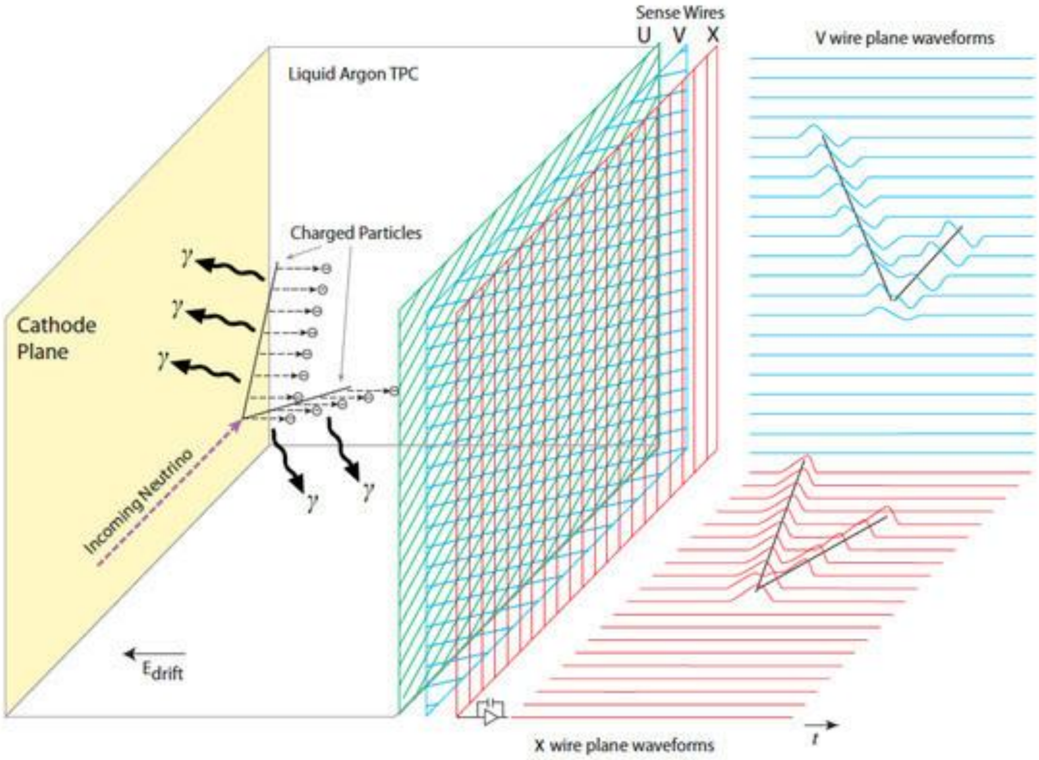

Figure: B. Abi et al, 2017, "The Single-Phase ProtoDUNE Technical Design Report"

Cathode Plane Assemblies (CPAs)

- 18 modules stacked to form 6 CPA columns
- Biased at -180 kV to provide 500 V/cm drift field
- Challenge: there is a lot of stored energy when the TPC is fully charged
  - Cathode needs to be constructed out of resistive materials
  - Need to prevent high-voltage discharge
  - FR4: fire-retardant fiberglass-epoxy composite material

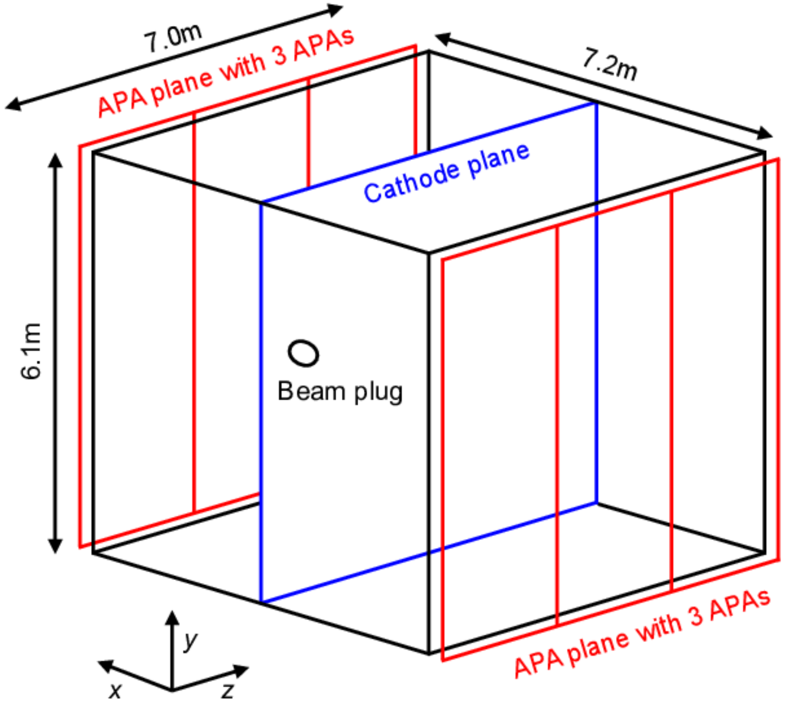

Figure: Abed et al, arXiv:2206.14521FERMILAB-PUB-22-488-AD-ESH-LBNF-ND-SCDCERN-EP-DRAFT-MISC-2022-007

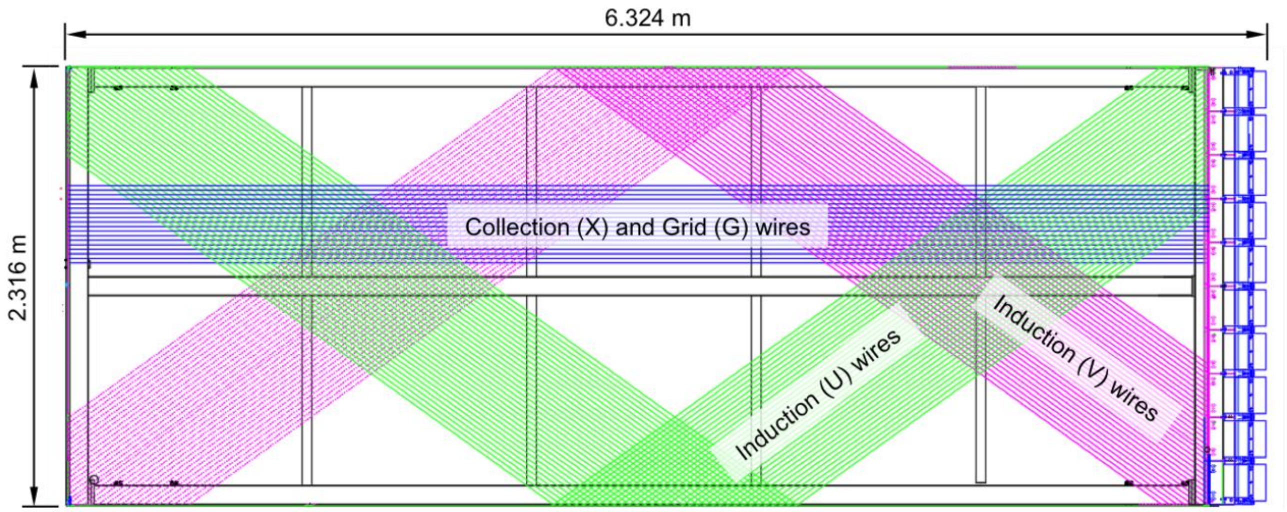

Figure: B. Abi et al 2020 JINST 15 P12004

APA’s & Photon Detectors

- Modular design
  - Can be easily scaled up

- Different wire angles
  - Each induction wire only crosses a collection wire once
  - To reduce reconstruction ambiguities
- Four layers of wires bonded on each side of the frame (X, G,
  - Biased at different potentials
  - Electrons collected on the X wires (pitch: 4.79 mm)
  - U, V: induction plane wires (pitch: 4.67 mm)
  - G: Grid plane wires (pitch: 4.79 mm)
    - Serve as an electric static discharge shield
    - Are not read out

APA layer	Bias voltage
Grid (G)	−665 V
Induction (U)	−370 V
Induction (V)	0 V
Collection (X)	820 V
Mesh (M)	0 V

Figure: The DUNE Collaboration et al 2022 JINST 17 P01005

Photon Detectors

Photon detectors embedded in APA's

- Cannot be placed outside the field cage
- 10 optical modules per APA
- Measure interaction times
- Independent measurement of the deposited energy

Light sensors: silicon photo-multipliers

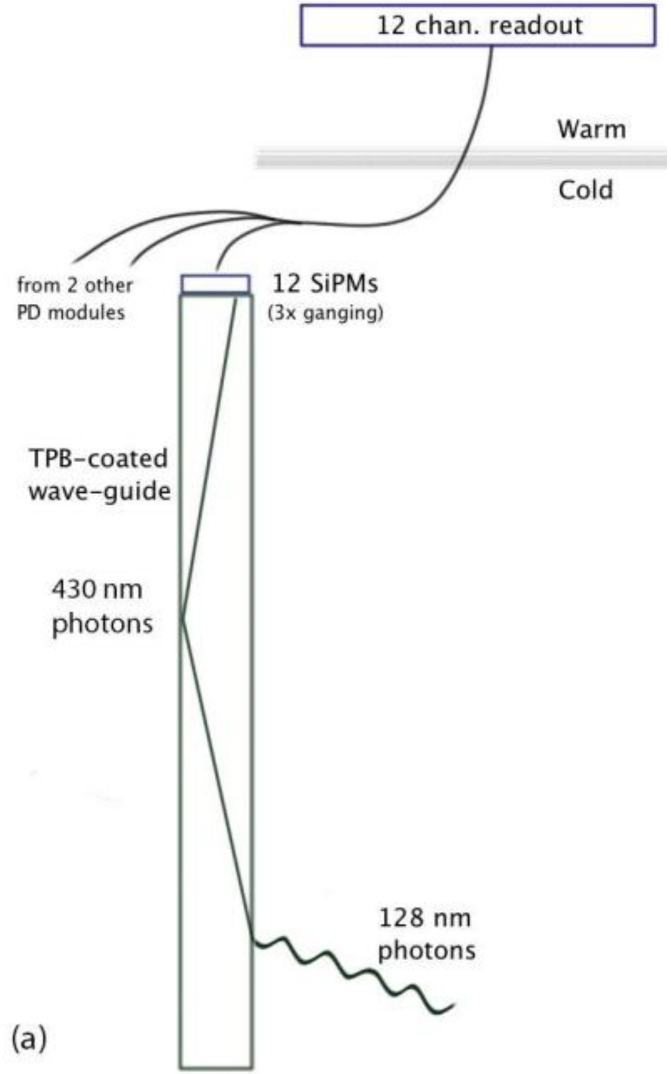

Figure: B. Abi et al 2020 JINST 15 P12004

Cryogenic Readout Electronics (CE)

- Mounted directly on the APAs
  - Reduces noise and channel capacitance
- 20 Front-end motherboards
  - Amplify, shape, digitize signals
    - Amplification and pulse shaping done by ASICs
    - Digitizing by ADCs
  - Transmit signals to warm interface electronics

- Signals from each APA wire are read out with a rate of 500 ns

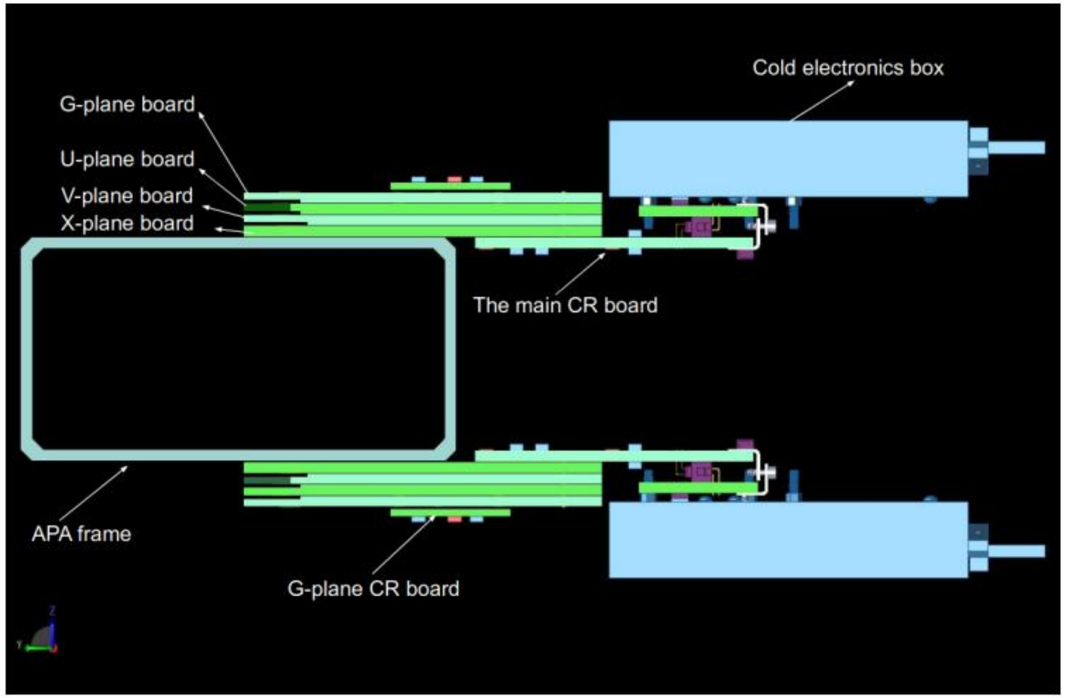

Figure: The DUNE Collaboration et al 2022 JINST 17 P01005

ProtoDUNE-SP Performance

Table: B. Abi et al 2020 JINST 15 P12004

Plane	Peak signal-to-noise ratio			
	Raw Data		After noise filtering	
	MPV	Average	MPV	Average
Collection	30.9	38.3	40.3	48.7
U	12.1	15.6	15.1	18.2
V	14.9	18.7	18.6	21.2

Goal: noise level should be well below signals from charged particles

-> Succeeded

Table: B. Abi et al 2020 JINST 15 P12004

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

ProtoDUNE performs better than DUNE specifications

References

- Abi, B., Abud, A. A., Acciarri, R., Acero, M. A., Adamov, G., Adamowski, M., ... & Chen, M. (2020). First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform. *Journal of instrumentation*, *15*(12), P12004.
- Abi, B., Acciarri, R., Acero, M. A., Adamowski, M., Adams, C., Adams, D. L., ... & Dale, D. (2017). The single-phase ProtoDUNE technical design report. *arXiv preprint arXiv:1706.07081*.
- Abud, A. A., Abi, B., Acciarri, R., Acero, M. A., Adames, M. R., Adamov, G., ... & Calcutt, J. (2022). Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC. *Journal of Instrumentation*, *17*(01), P01005.
- https://lbnf-dune.fnal.gov/about/science-goals/
- https://www.dunescience.org/

Backup Slide(s)

ProtoDUNE Performance

- Spatial distortions due to space-charge

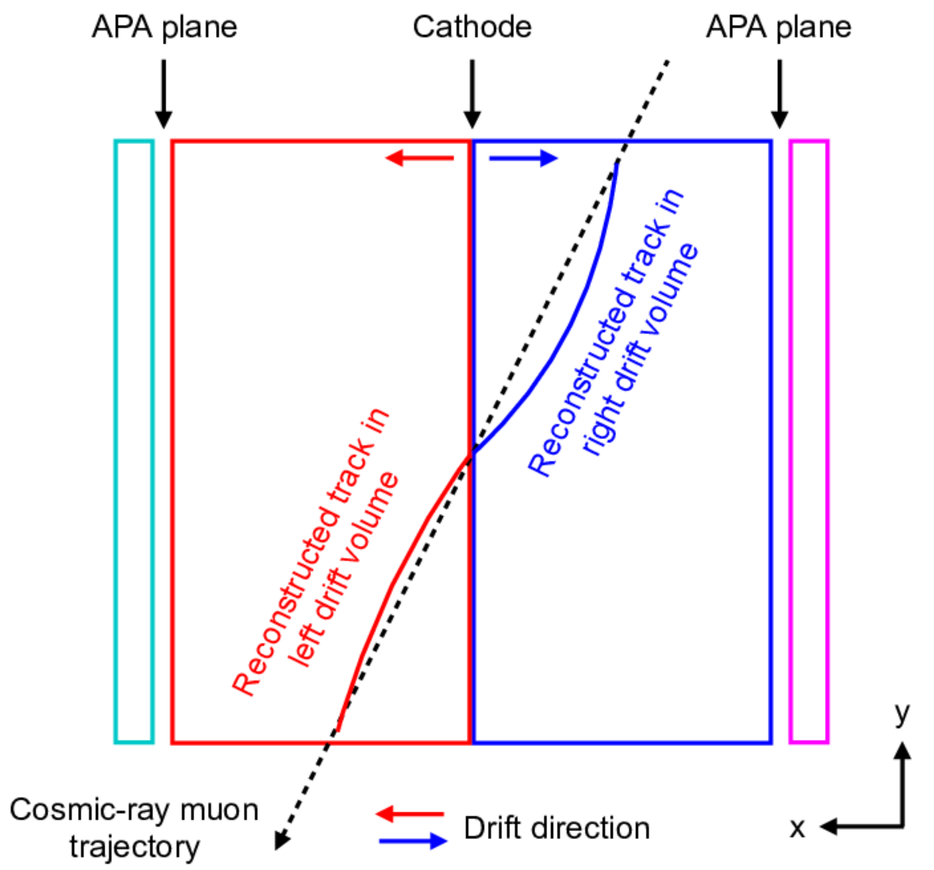

Figure: Abed et al, arXiv:2206.14521FERMILAB-PUB-22-488-AD-ESH-LBNF-ND-SCDCERN-EP-DRAFT-MISC-2022-007