CERN Neutrino Platform:
ProtoDUNE and DUNE programs at CERN

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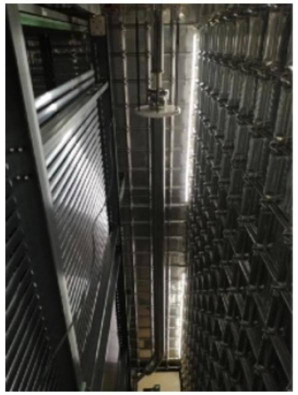
The CERN Neutrino Platform

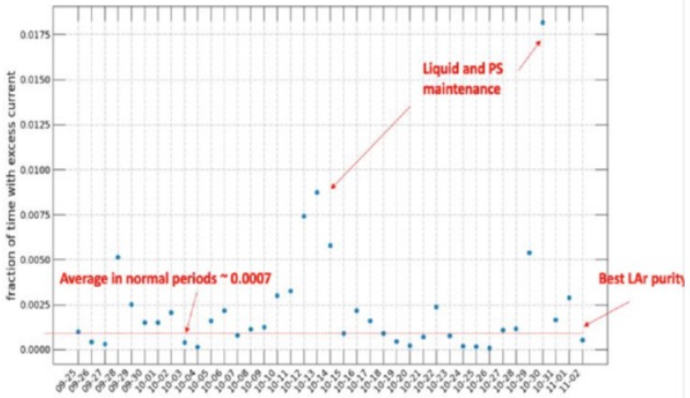
- It follows the mandate given by the *EU strategy* in 2013: "CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading long-baseline neutrino projects in the US and Japan." Confirmed in 2013 ES update.
- Main goal : compact the European groups around the projects of the future short and long Neutrino baselines.
- CERN as a facility for R&D on future technologies (HW and SW) and partner in several neutrino research programs.
- A new phase of the Neutrino Platform has been recently approved, including ProtoDUNE tests in 2023-2024 with Module-0 detector elements for DUNE Far-Detector-1 (HD) and Far-Detector-2 (VD).
- CERN will also provide infrastructures for DUNE, include the cryostats of FD-1 and FD-2.

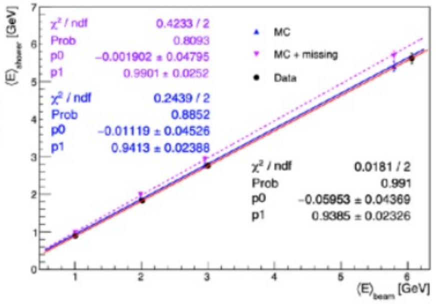
Neutrino Platform (cont.)

- Advances on LAr TPC detector technology for DUNE (2018-2022):
  - ✦ Finalized APA's configuration and components for the Horizontal Drift
    - ✦ Testbeam Sep-Nov 2018
    - ✦ Cosmic runs (Sep 2018 - Jul 2020)
    - ✦ Study of detector performance within or above specifications (signal-to-noise, stability and reliability of the cold electronics)
  - ✦ Development of technologies for Vertical Drift detector 2020-2023
  - ✦ Studied Xe doping (spring/summer 2020)
  - ✦ Achieved LAr Purity level above 20 ms lifetime
  - ✦ HV and drift field stability for Horizontal (-180 kV over 3.6 m) and Vertical (-300 kV over 6 m) Drifts ProtoDUNEs (until Mar 2022)
  - ✦ Trigger and readout
  - ✦ Development of large scale optical readout (ARIADNE)
  - ✦ Reconstruction and analyses:
    - ✦ Energy reconstruction of electrons
    - ✦ Hadron-LAr cross-section measurements

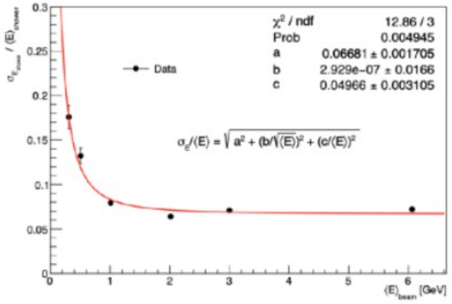
Detector Parameter	Specification	Goal	ProtoDUNE Performance
Electric Drift Field	> 250 V/cm	500 V/cm	500 V/cm *
Electron Lifetime *Impurity Concentration*	> 3 ms *(<100 ppt [O_2-equiv])*	10 ms *(<30 ppt [O_2-equiv])*	> ~30 ms in TPC ** *< 10 ppt*
TPC Electronics Noise	< 1000 e ENC	ALARA	550-650 e ENC (raw) 450-560 e ENC (cnr)***
TPC dead channels	< 1%	ALARA	0.2 % (of ~15,360 channels over 1.5 yr operation)
PhotoDetector Light Yield	> 0.5 Ph/MeV (at cathode plane - 3.6 m distance)		1.9 Ph/MeV ++ (at 3.3 m distance)
PhotoDetector Time Resolution	< 1μs	< 100 ns	14 ns ^^



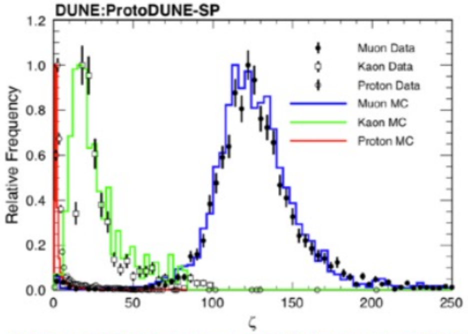




Reconstructed beam electron energy linearity

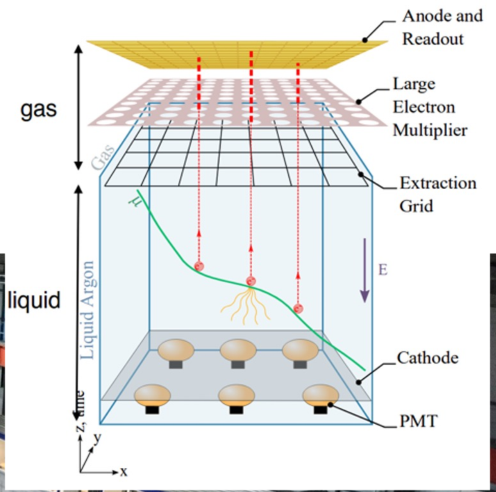


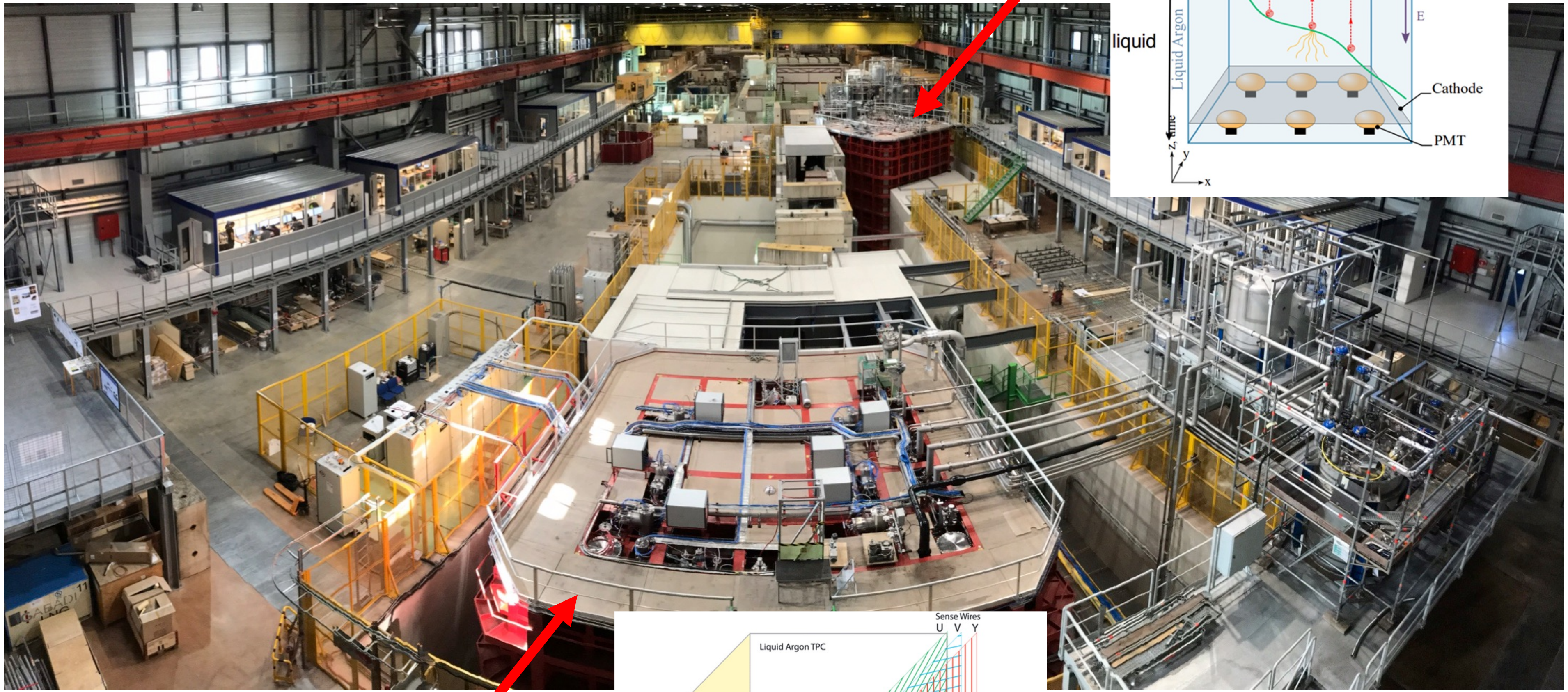
Reconstructed beam electron energy resolution



Proton PID (based on chi2 fit to proton dE/dx)

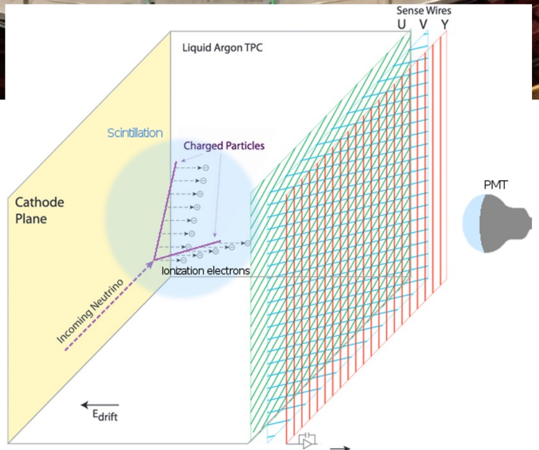
NP02: double phase
760 tons of liquid



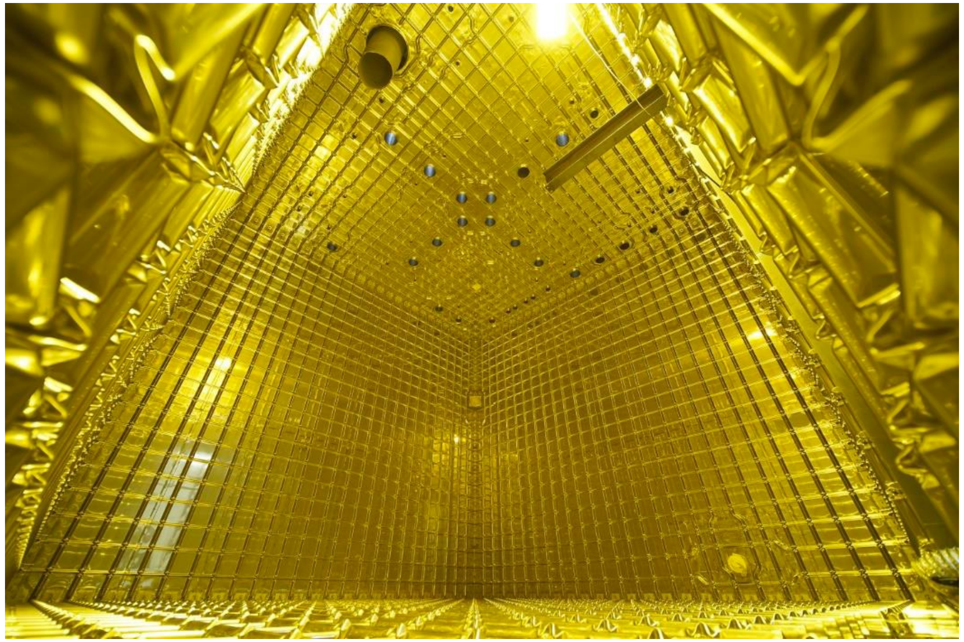


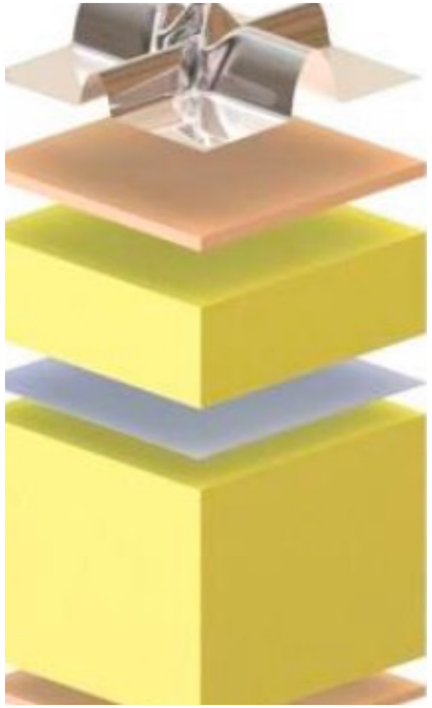
CERN Neutrino Platform: ProtoDUNE detectors in phase 1 set-up

NP04: single phase
760 tons of liquid



NP02, NP04: Membrane cryostat technology





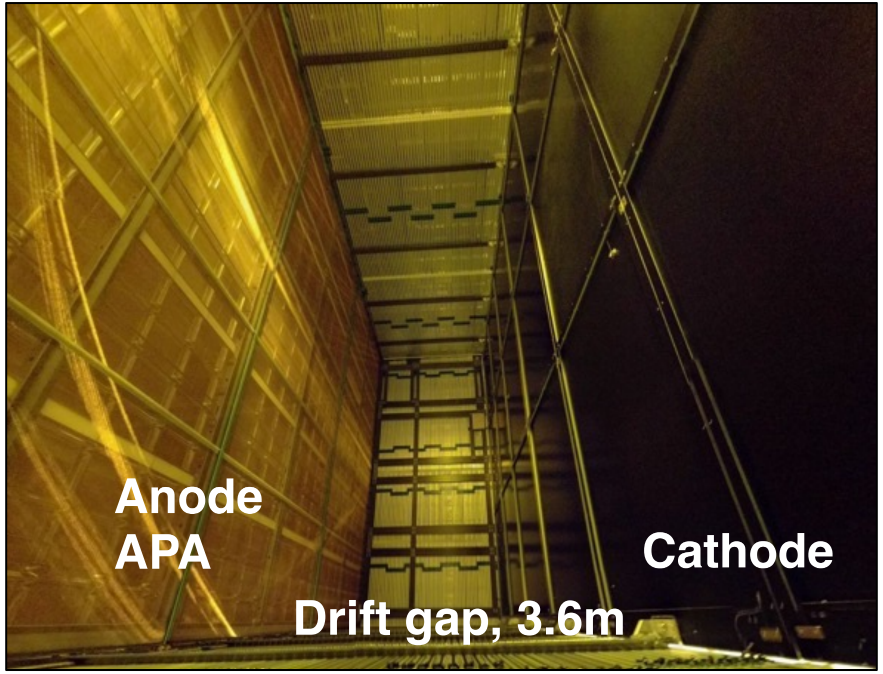
- Corrugated SS primary membrane in contact with LAr
- Plywood
- Insulation: reinforced polyurethane foam
- Secondary membrane for gas containment
- Insulation
- Plywood
- Outer vessel

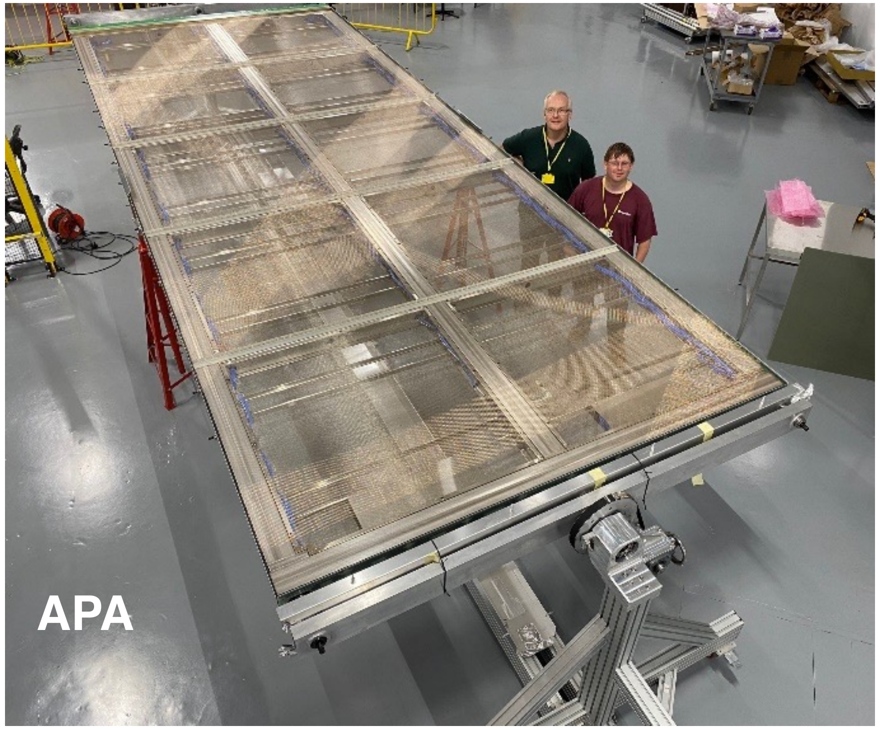
No vacuum, insulation purged with Ar

Concept developed for carrier ships. Developed for LAr in collaboration with industry (GTT)

Used for ProDUNEs, SBND, DUNE, DarkSide …

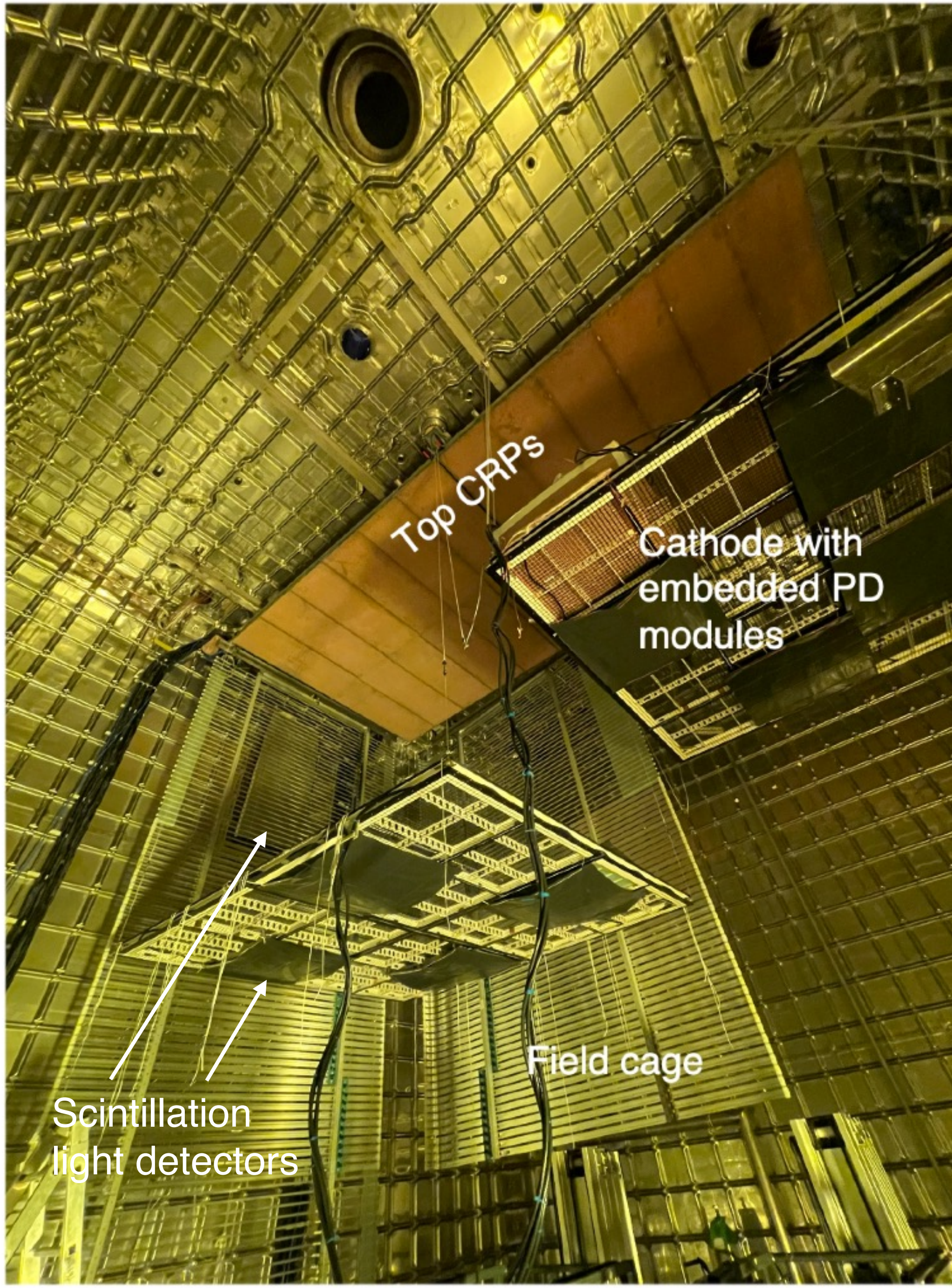
ProtoDUNE prototypes



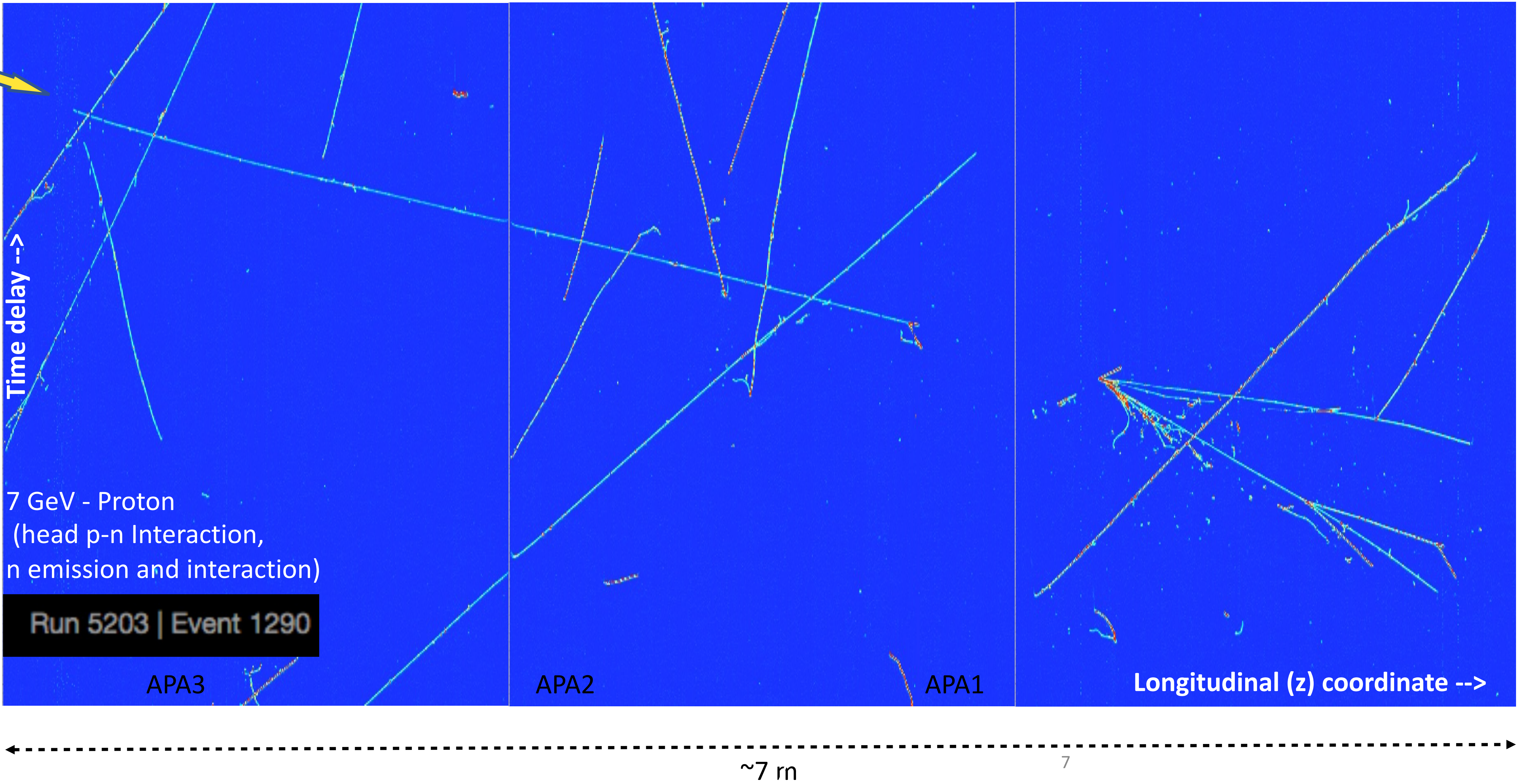


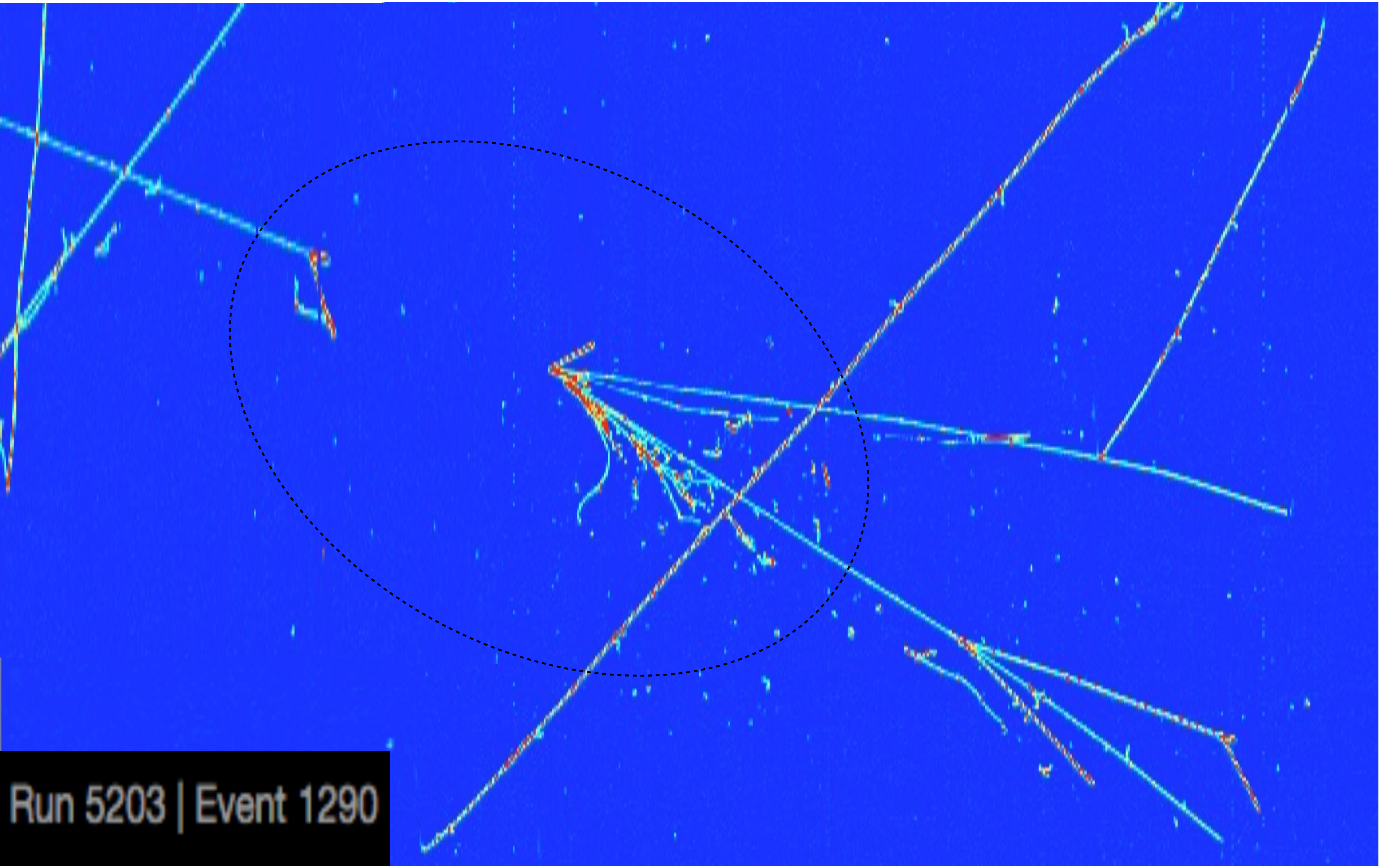
HD Design

VD Design



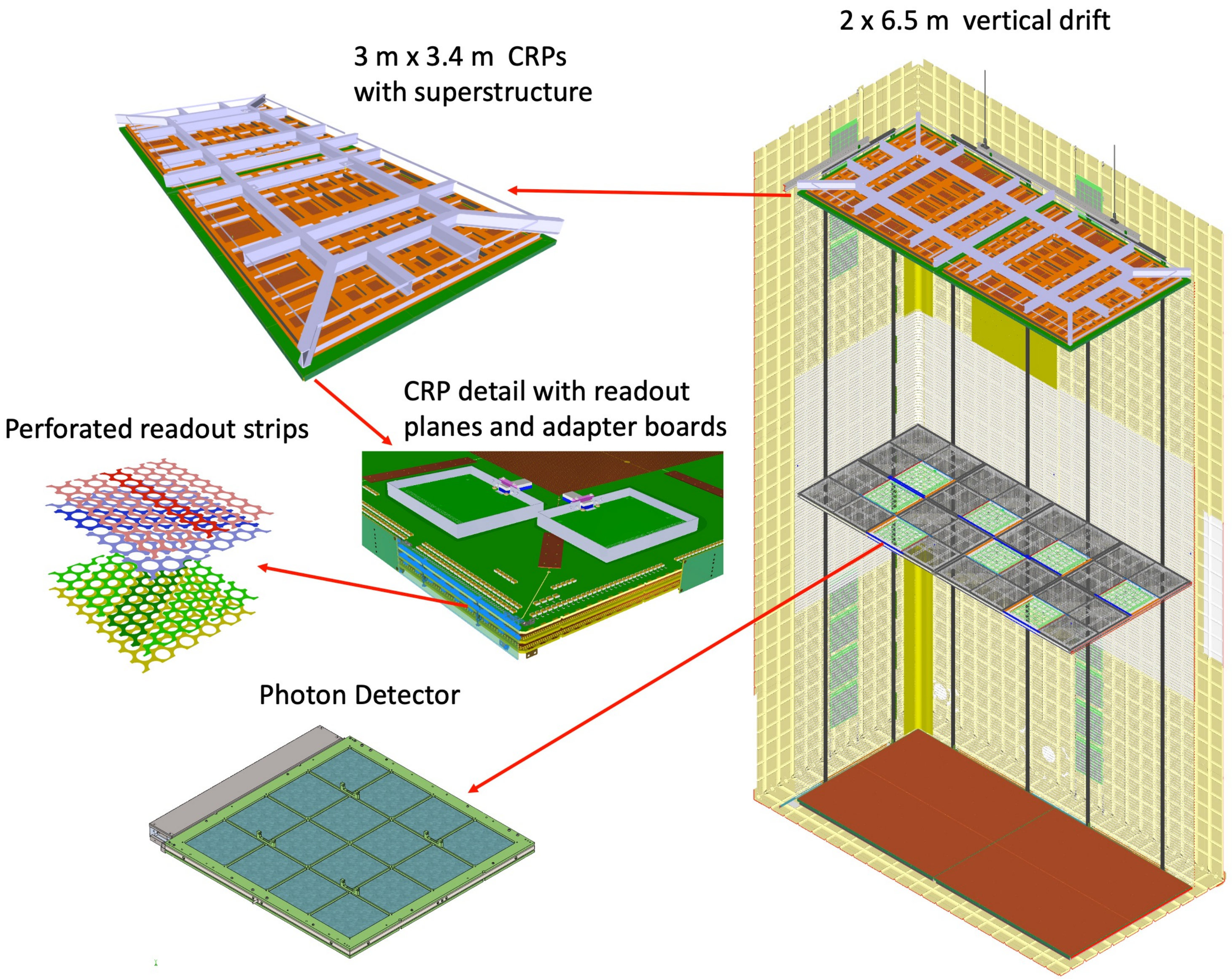
Event from ProtoDUNE-HD, with accidental cosmic ray activity

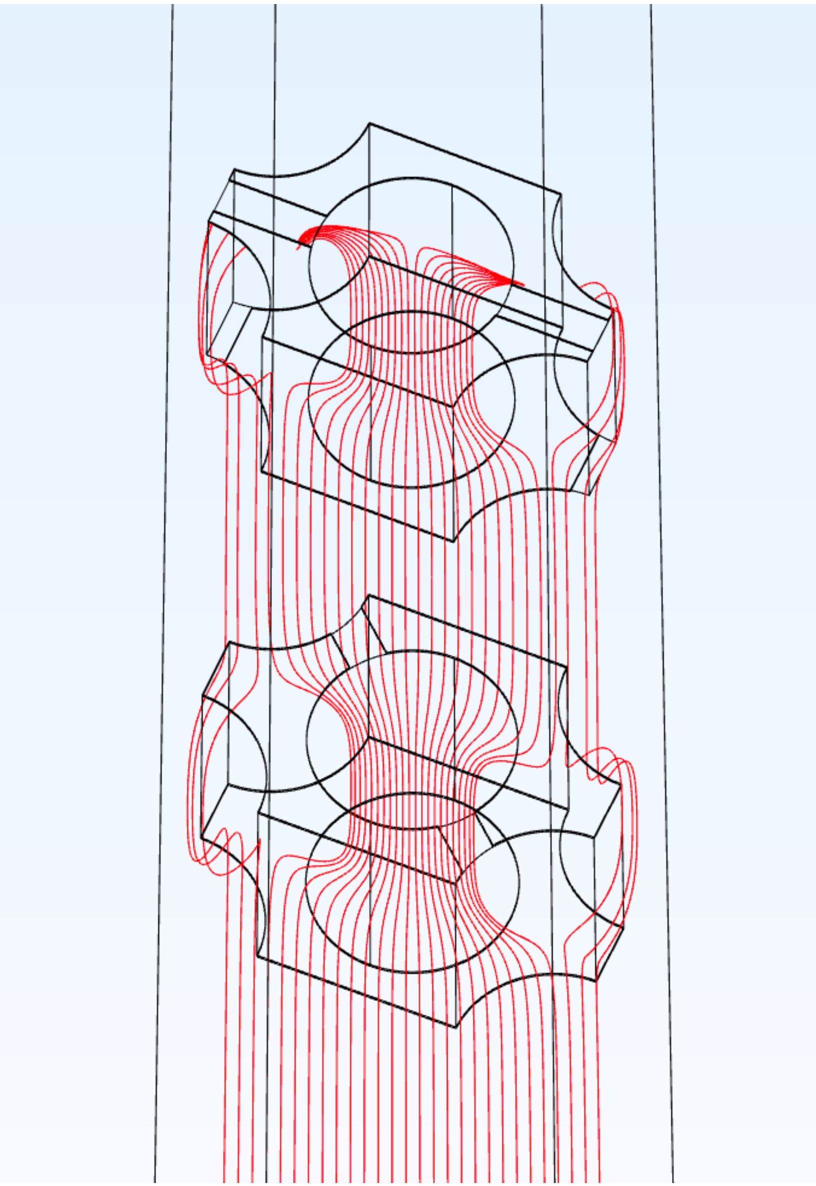


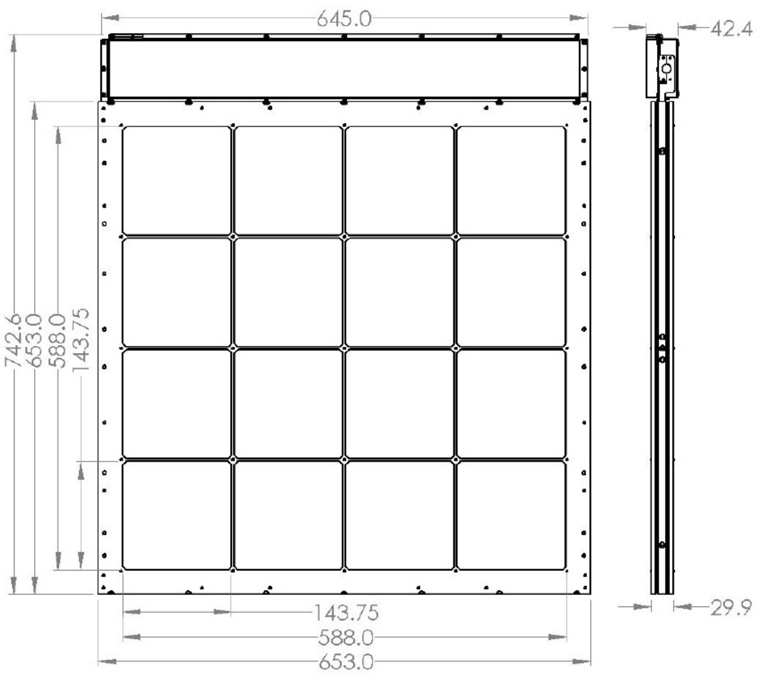


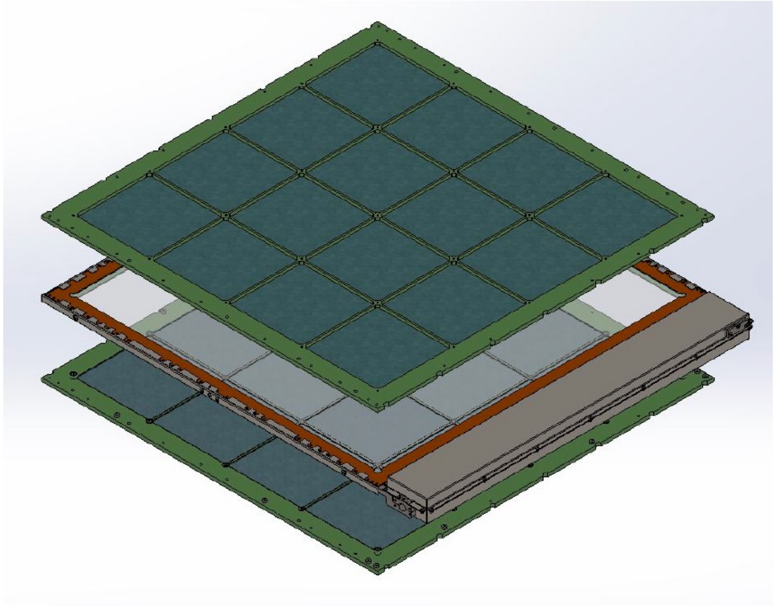
Zoom on the same event

DUNE FD-2 VD concept   (Vertical Drift far detector)









Detector for Ar scintillation light (UV light emitted by dimers formed at primary ionization):

- ARAPUCA detectors: acrylic detection plate, covered by wavelength shifter layers, acting as light guide (internal reflection), read out by silicon photomultipliers
- Complexity for DUNE FD2-VD: some modules are placed on the cathode, which is operated at -300 kV
    - Power for SiPM's bias and readout provided over optical fibers, connected to power converters
    - Similarly, readout uses signal converter and transmission via fibers

  These technologies are not new, but the is lack of experience for cryogenic applications and applications requiring very high reliability.

DAQ requirements

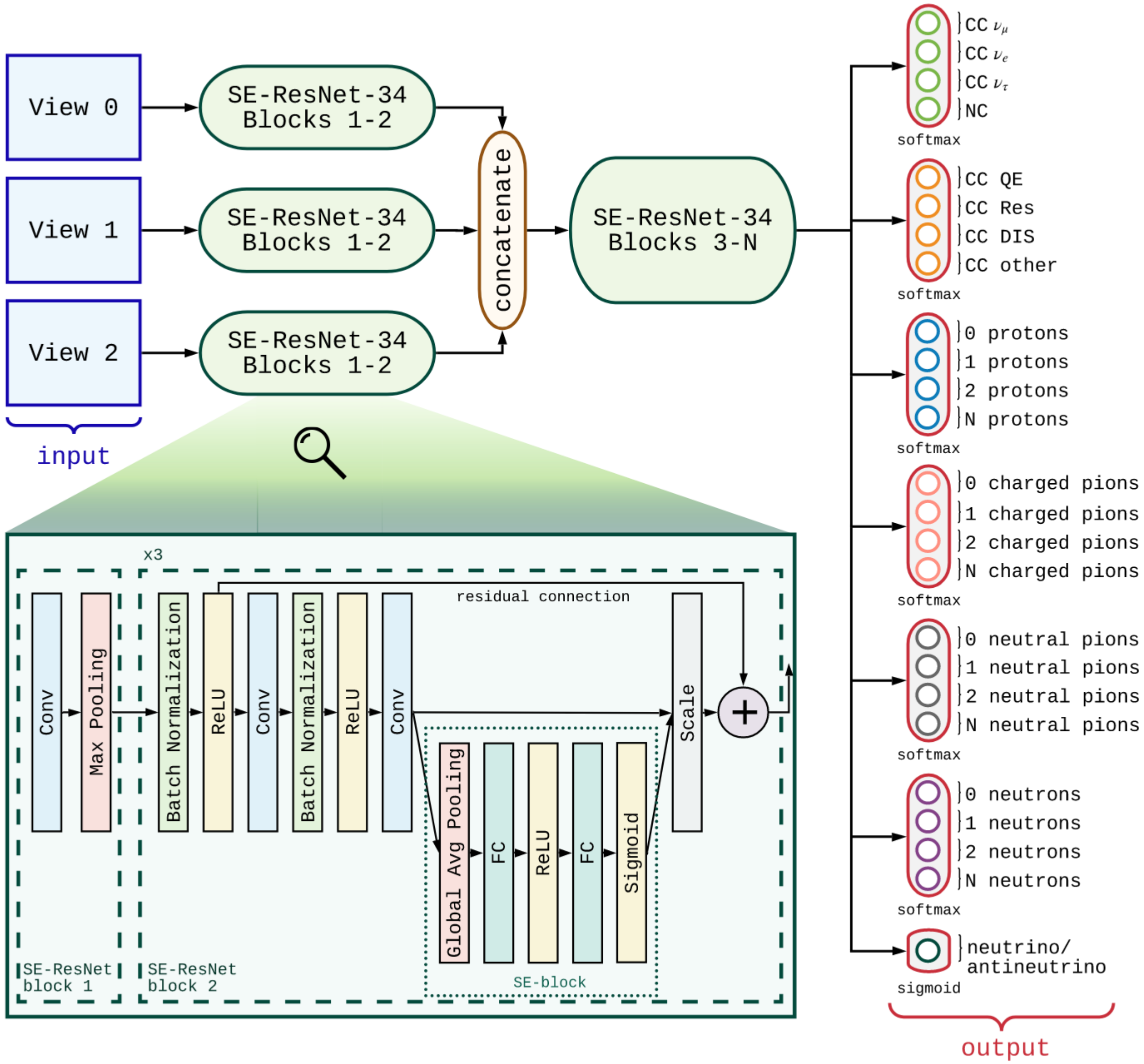
- Readout throughput: 1.8 TB/s per FD module
- 1.8 TB/s readout throughput
- 10 Gb/s average, 100 Gb/s peak storage throughput per FD module
- $\sim$30 PB per year data to tape

LAr TPCs produce large amount of data
Zero-suppression would be useful, but it is critical for the physics goal:

- Somewhat easier for “high energy” beam neutrino interactions
- Difficult for supernova and solar neutrino measurements

- Besides, supernova events require $\sim$100 s continuous readout, compared to ~ 5 ms for other types of events.

Non-classic event reconstruction: Event identification in the DUNE far detector with a Convolutional Neural Network



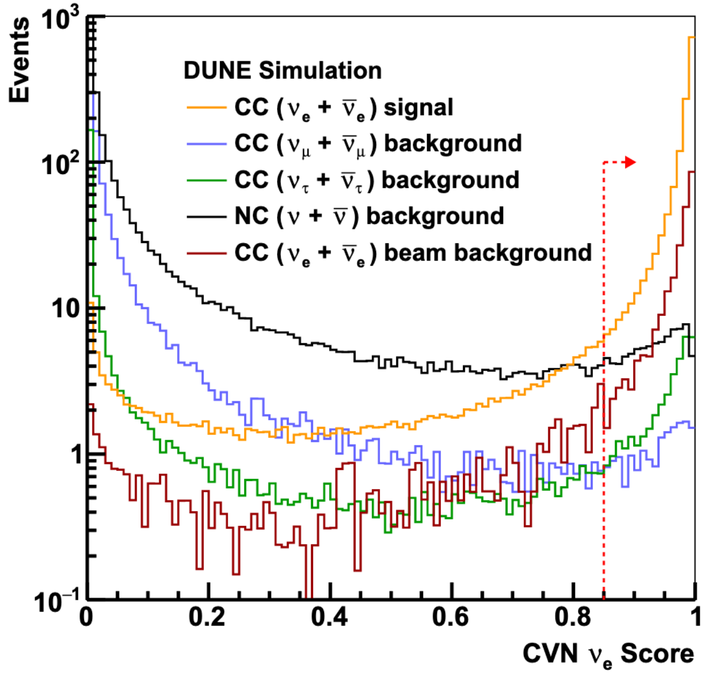
«Images» from each readout view are analised in a CVN, which labels them as

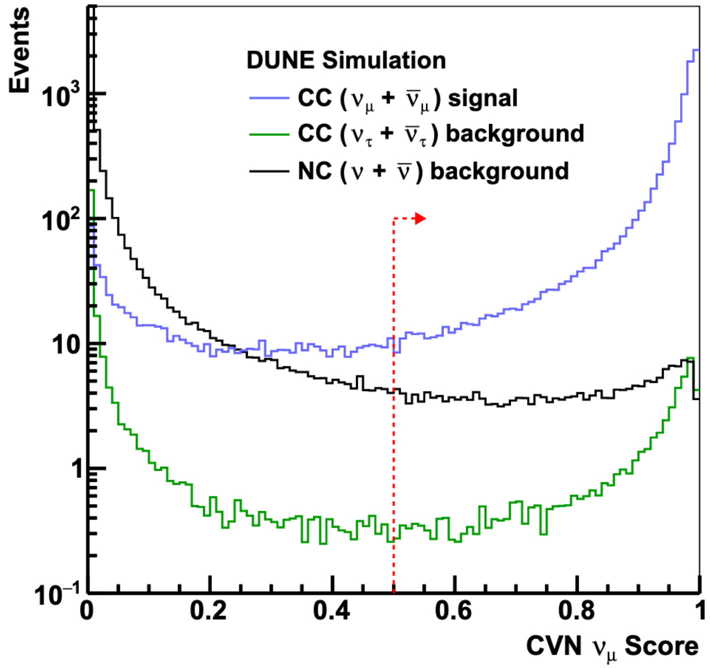
- Charged-current ν_e event
- Charged-current ν_μ event
- Charged-current ν_τ event
- Neutral-current ν event

(neutrino or antineutrino).

The classifier is trained on MonteCarlo data.

Effciency and purity values of about 90% are obtained for ν_e and ν_μ .



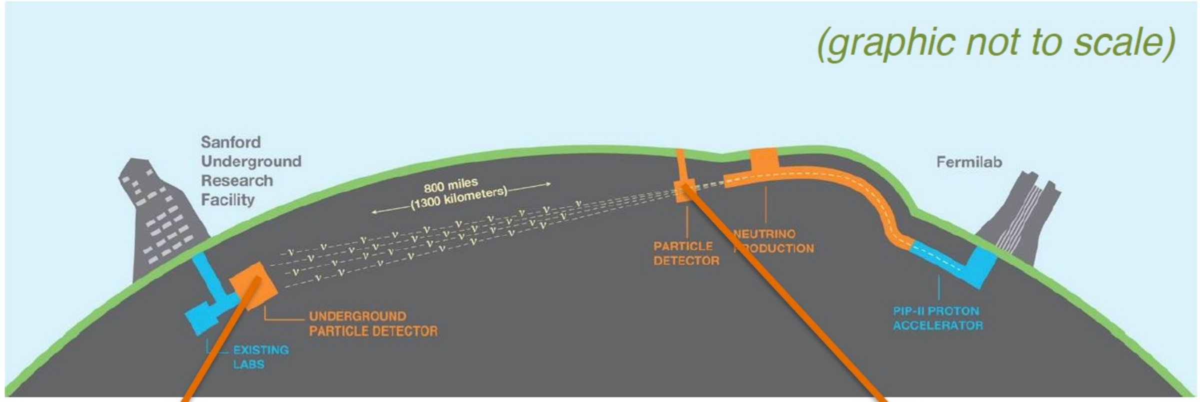


Also *classic* reconstruction, and *hybrid approaches* are followed

https://doi.org/10.1103/PhysRevD.102.092003

Near and Far Detectors in a Nutshell

LAr TPCs at both the near and far sites



DUNE

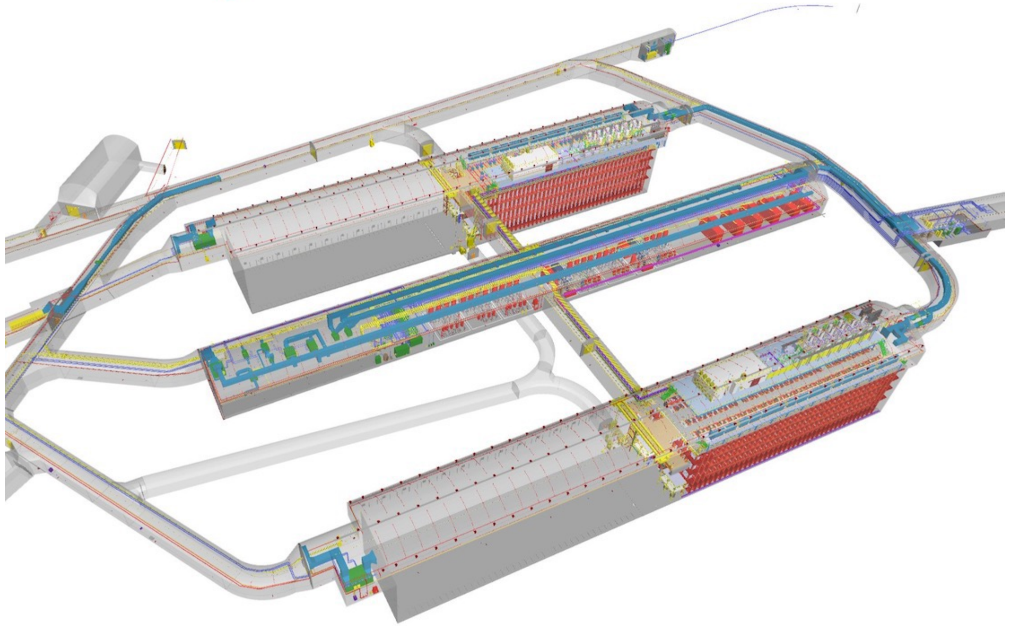
Data collection expected to start in 2030

Far Site

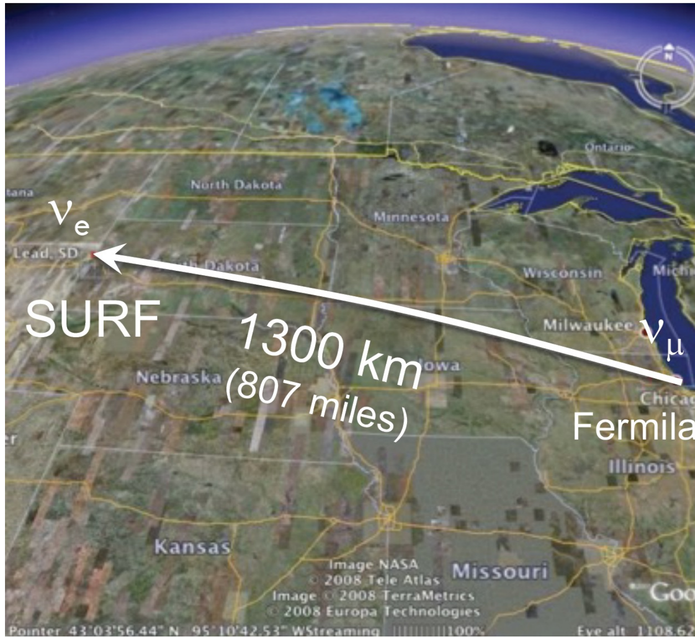
- *1300km from the proton source*
- *very large LAr TPCs (each 17 ktons)*
- *underground in South Dakota*

Near Site

- *550m from proton source*
- *on-site at Fermilab*
- *both stationary & moveable detectors*

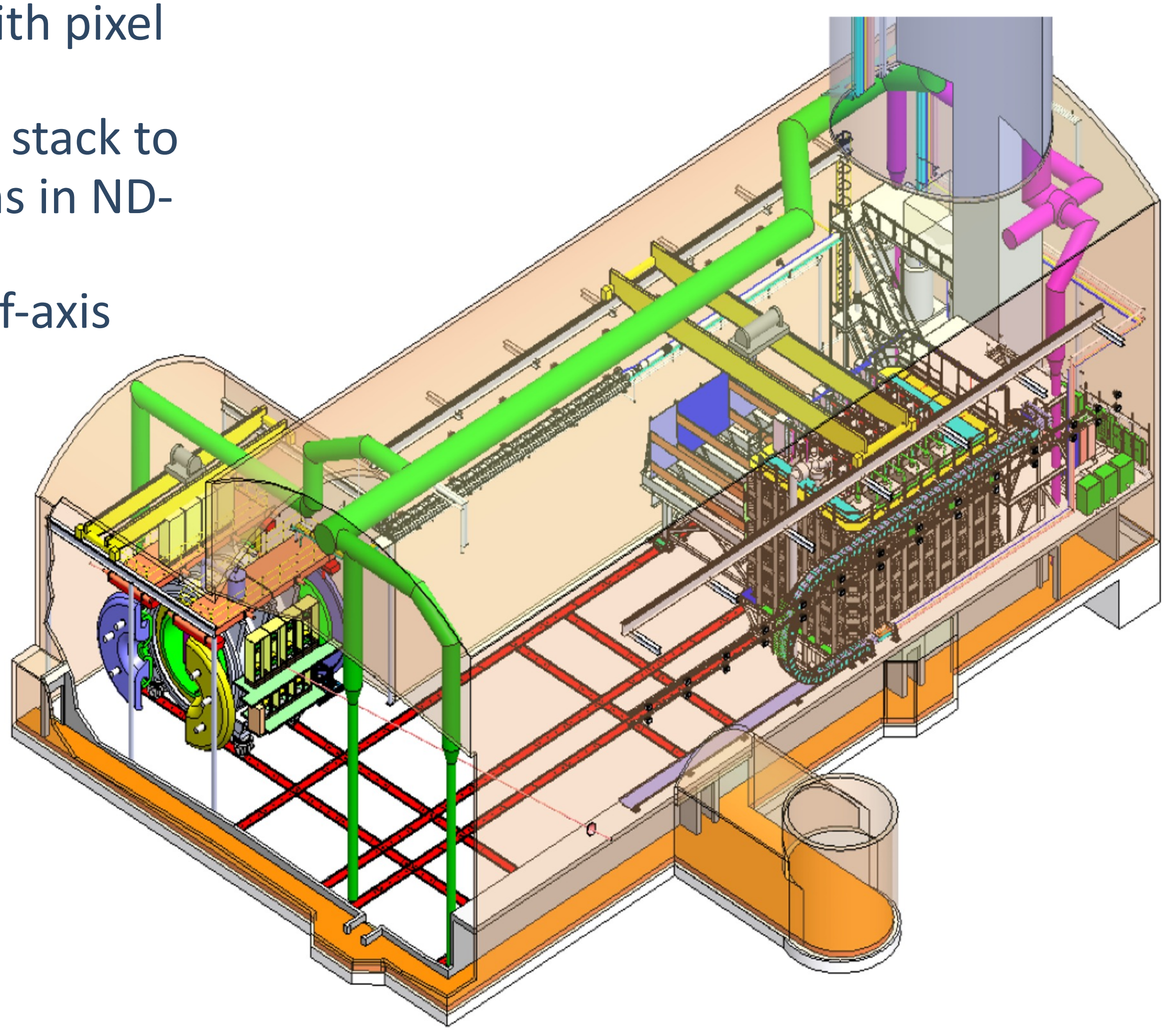


Phase-1: 2 far detectors
Phase-2: 4 far detectors



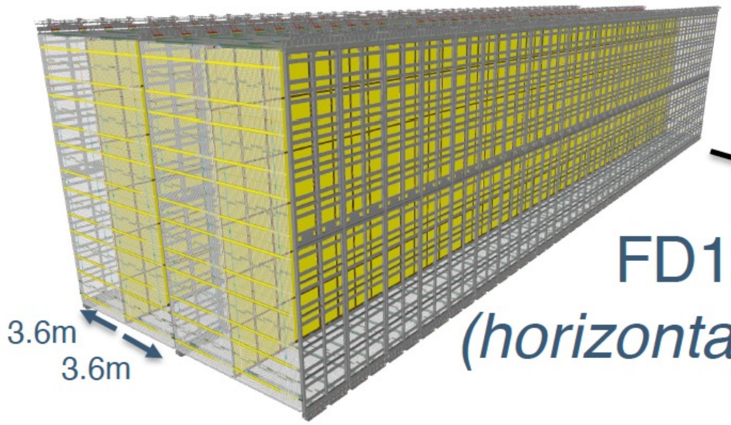
•Phase 1 Near Detector:

- ND-LAr +TMS with DUNE-PRISM: moveable LArTPC system
  - ND-LAr: 7x5 array of modular 1x1x3 m^3 LArTPCs with pixel readout
  - TMS: Muon spectrometer: magnetized steel range stack to measure μ momentum/sign from ν_μ CC interactions in ND-LAr
  - DUNE-PRISM: ND-LAr + TMS move up to 28.5 m off-axis
- SAND: Multi-purpose on-axis magnetized detector
  - KLOE SC solenoid and Calorimeter
  - GRAIN: Optical LAr target
  - STT: STraw tube tracker system



DUNE Far Detectors (Phase I)

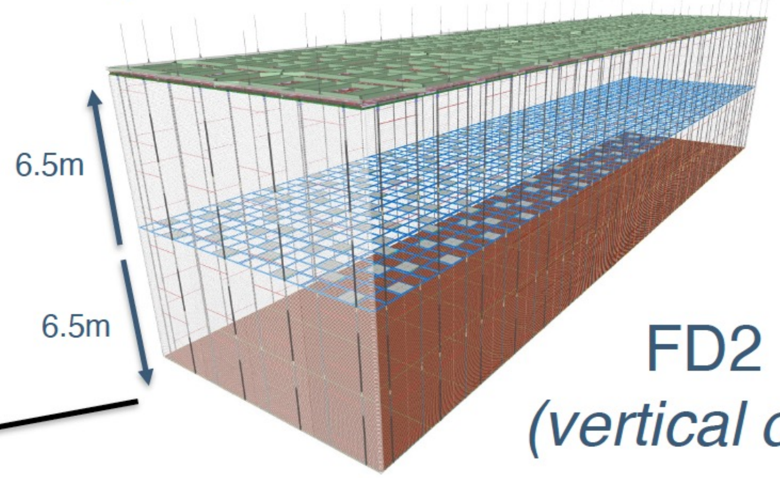
- Phase 1 will include caverns for 4 detector modules in South Dakota and 2 far detector modules, each 17 kton of LAr, the largest LAr TPCs ever constructed.
  - *FD1: horizontal drift (ala ICARUS, MicroBooNE)*
  - *FD2: vertical drift (capitalizing on protoDUNEs)*



APA
Anode Plane Assemblies

FD1
(horizontal drift)

- *cryostat installation starts in 2024*



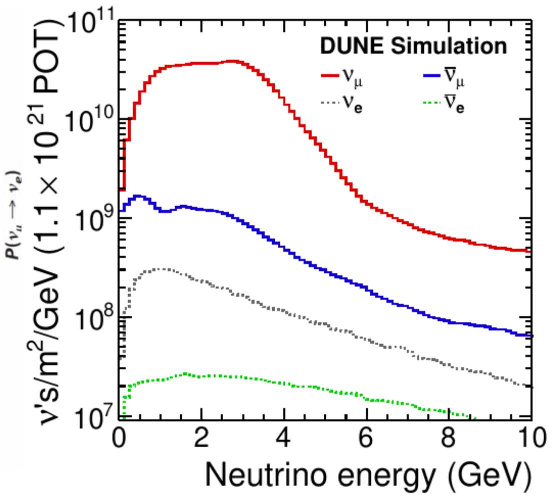
FD2
(vertical drift)

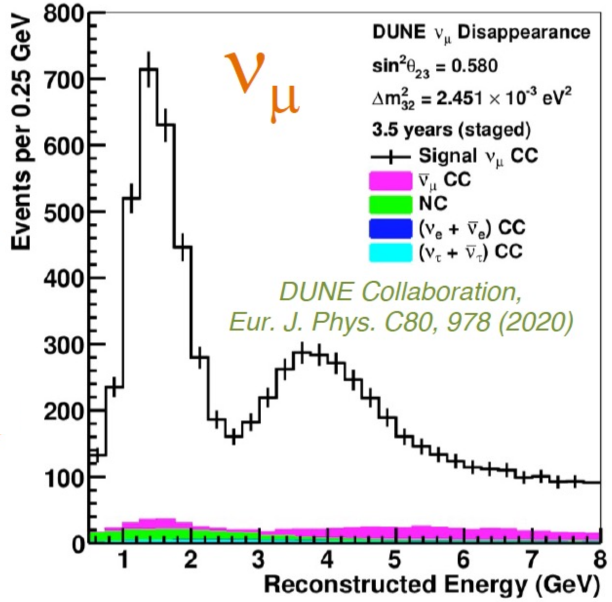
CRP
Charge Readout Planes

- Order of magnitude more mass than has been deployed up to now from all LAr TPCs

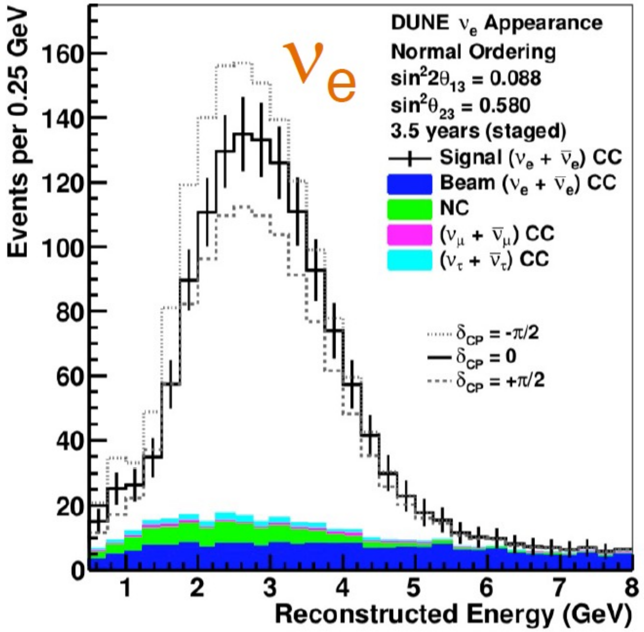
Beam Physics with the Far Detectors

- DUNE is unique in that we can unambiguously distinguish the MO, CPV and do not require inputs from other experiments.





- Phase II is critical!



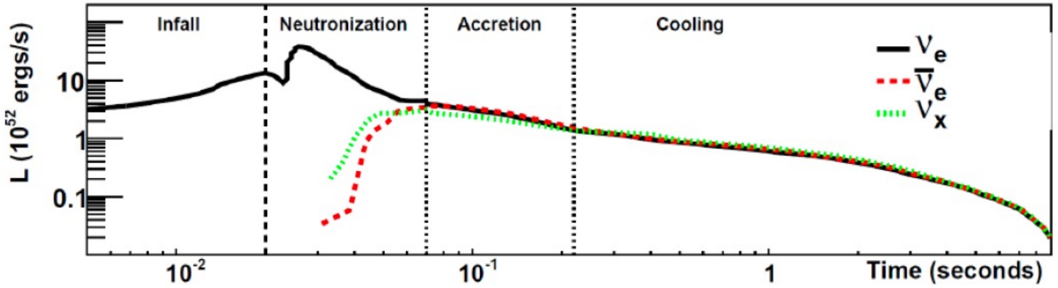
- When beam turns on, the DUNE far detectors will collect ~150 oscillated ν_e events in the first year alone. This is larger than each of the current NOvA, T2K ν_e data sets. We immediately hit the ground running.

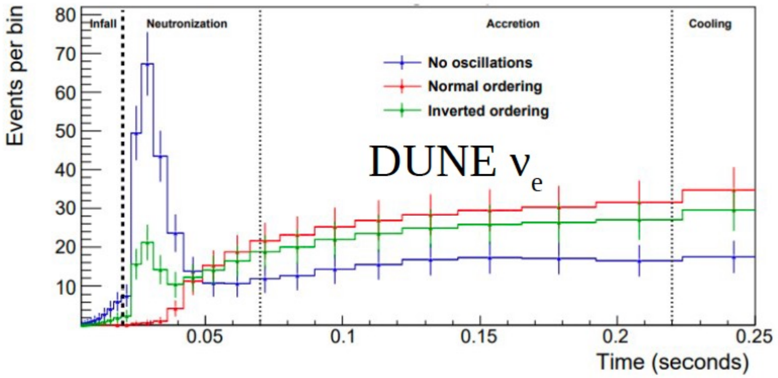
- assuming a beam ramp-up to 1.2 MW, 2 FDs, normal ordering, δ_{CP}=0

- expected range is 70-180 ν_e events in FHC, depends on true MO, CP

Supernova physics: unique sensitivity to electron neutrinos

10 kpc supernova burst





	ν_e	$\bar{\nu}_e$	ν_x
DUNE	89%	4%	7%
SK[1]	10%	87%	3%
JUNO[2]	1%	72%	27%

[1]Super-Kamiokande, *Astropart. Phys.* **81** 39-48 (2016)
[2]Lu, Li, and Zhou, *Phys Rev. D* **94** 023006 (2016)

- Time (and energy) profile of the flux is rich in supernova astrophysics
- Flux contains ν_e and $\bar{\nu}_e$ as well as a component of the other flavors (ν_x) – DUNE has **unique sensitivity to ν_e** component
- Phase I: O(100s) events per FD module for galactic SNB
- Phase II: Reach extends reach beyond the Milky Way
- Enhancements to LArTPC design in Phase II could greatly extend low energy science (see talk by Mary Bishai)