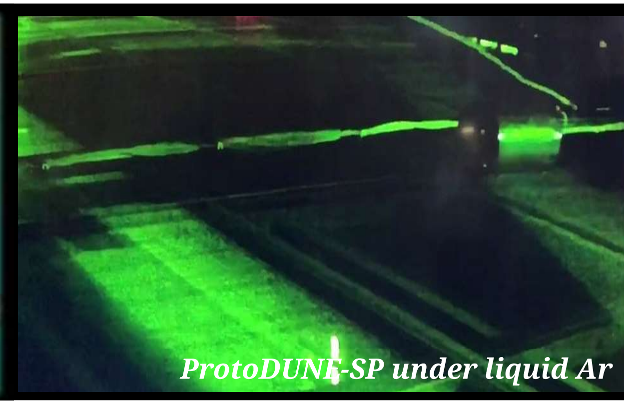
Status of the
Deep Underground Neutrino Experiment

Glenn Horton-Smith, Kansas State University, for the DUNE collaboration

Hilton Waikoloa Village

Dolphin Quest



ProtoDUNE-SP under liquid Ar

International Workshop on "Double Beta Decay and Underground Science"

Hawaii Island, United States – October 21-23, 2018

DUNE science

Primary goals:

- Neutrino oscillations, CP-violation, mass hierarchy
- Proton decay
- Supernova neutrinos

Rich ancillary program.

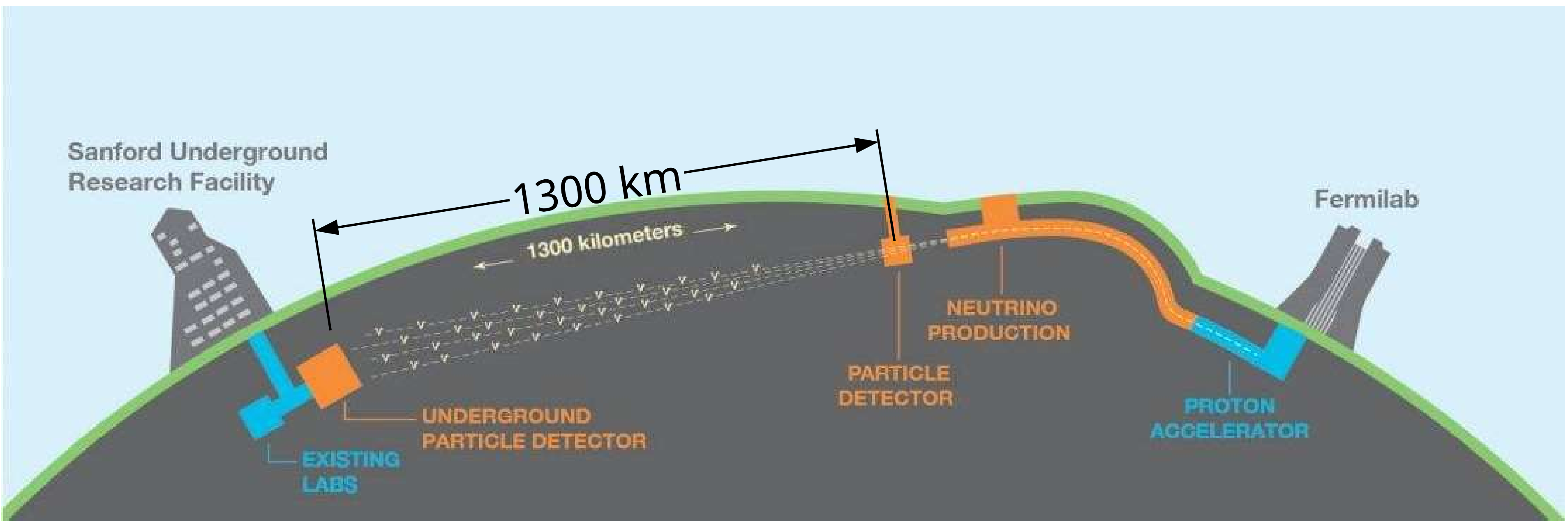
DUNE collaboration

- 1257 collaborators from 179 institutions in 32 countries
- 628 faculty/scientists, 198 postdocs, 110 engineers, 223 PhD students

Locations

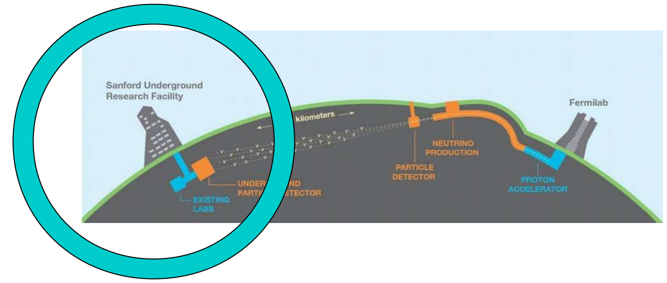
Far detector (FD) at SURF's 4850-foot level. (4300 mwe)
2×10 kt → 3×10 kt → 4×10 kt

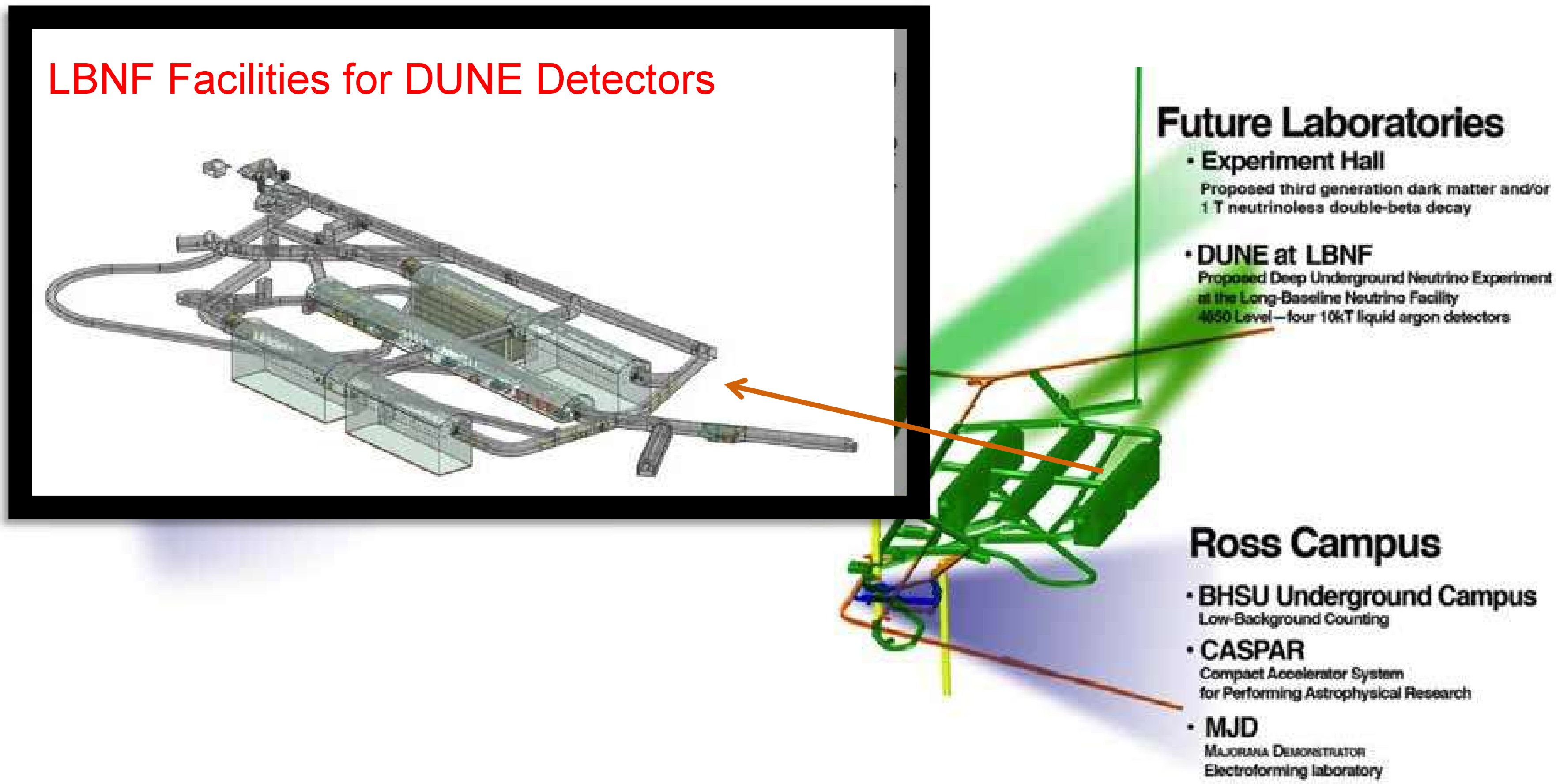
Near detector (ND) and neutrino beamline at Fermilab.
1.2 MW → → → 2.4 MW



SURF

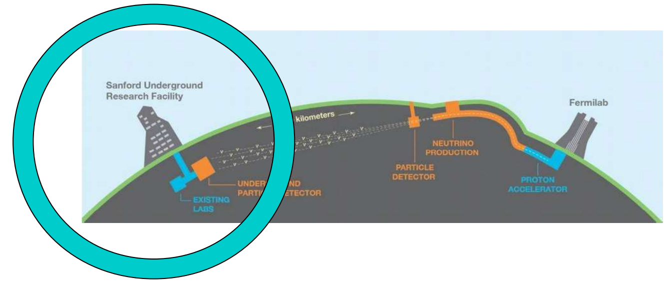
Sanford Underground Research Facility (Lead, SD)

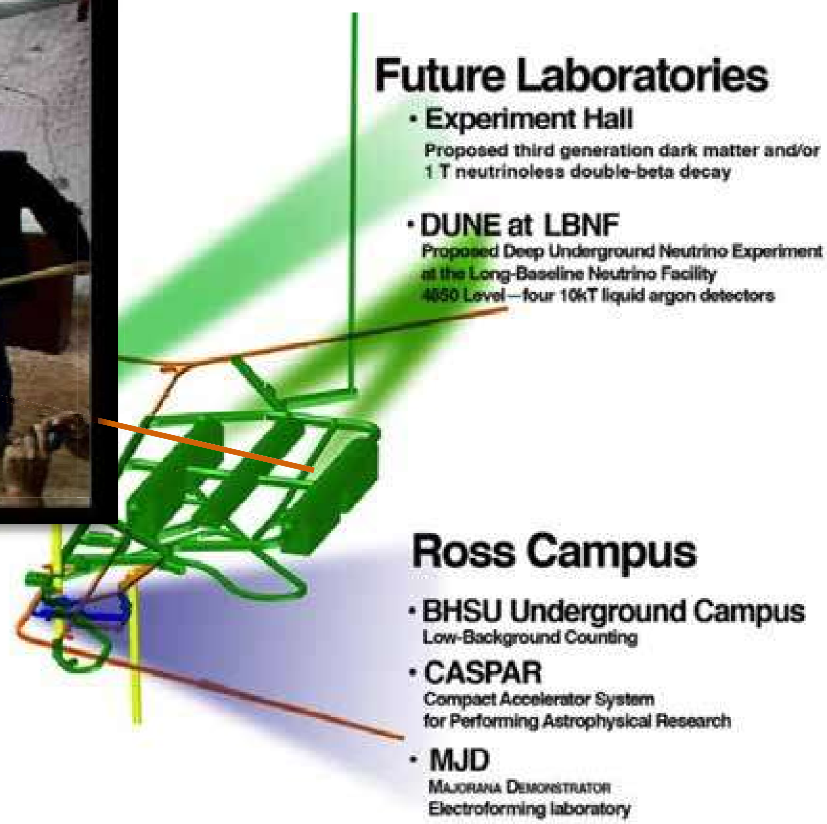




SURF

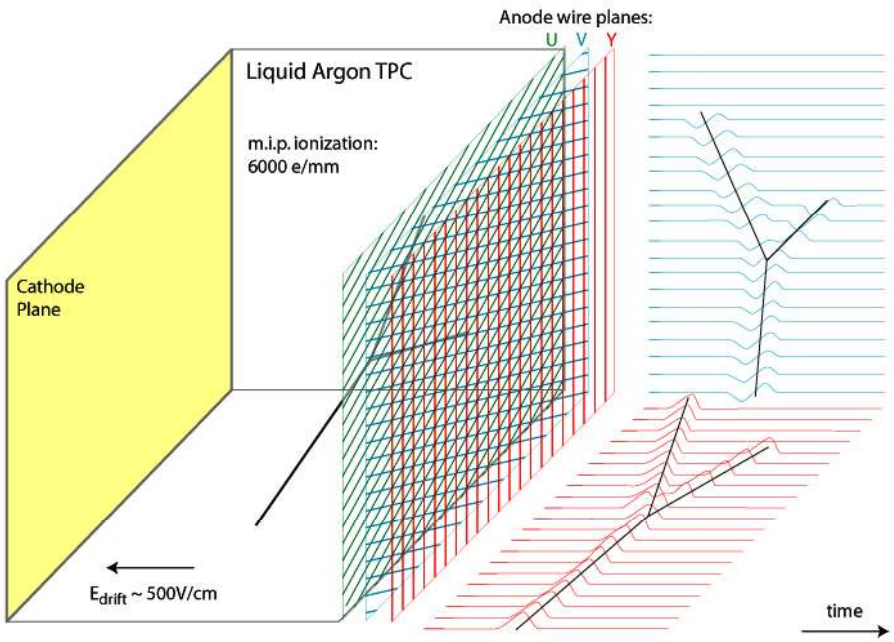
Sanford Underground Research Facility (Lead, SD)





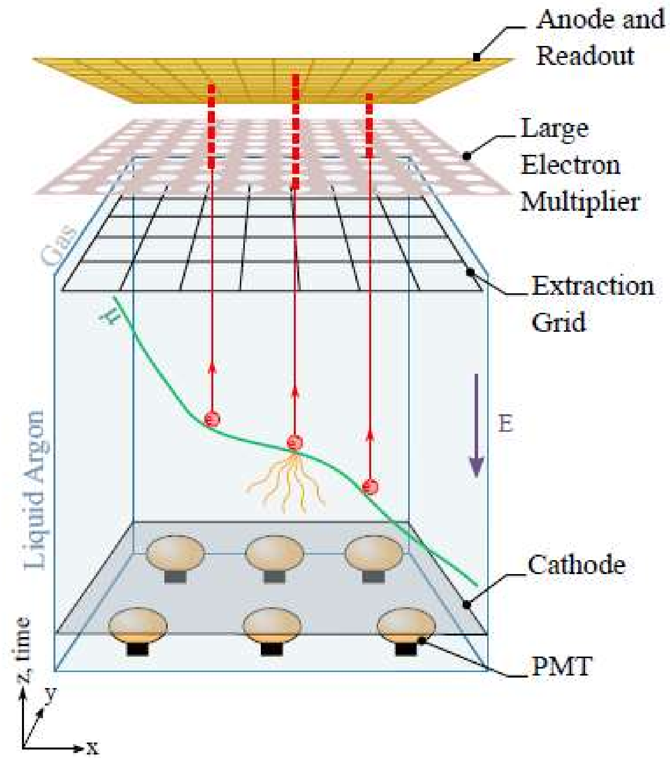
Liquid argon time projection chambers

Single Phase



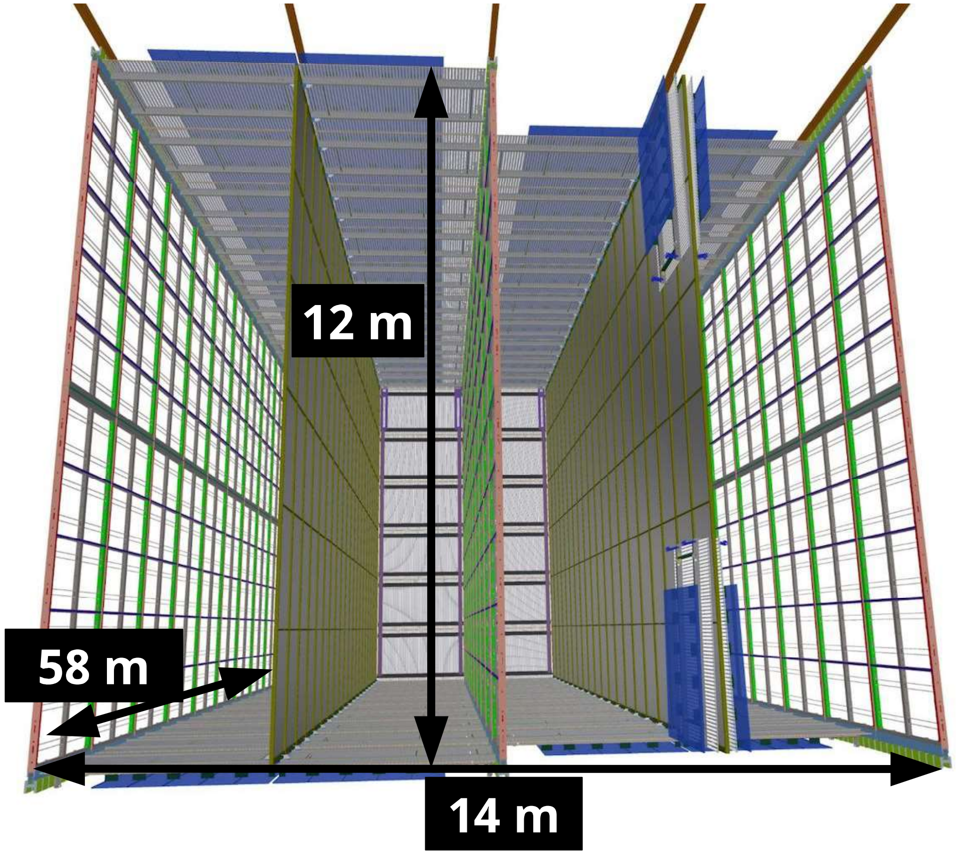
Animated by Bo Yu (BNL)
https://youtu.be/IH88L5nVvmY

Dual Phase

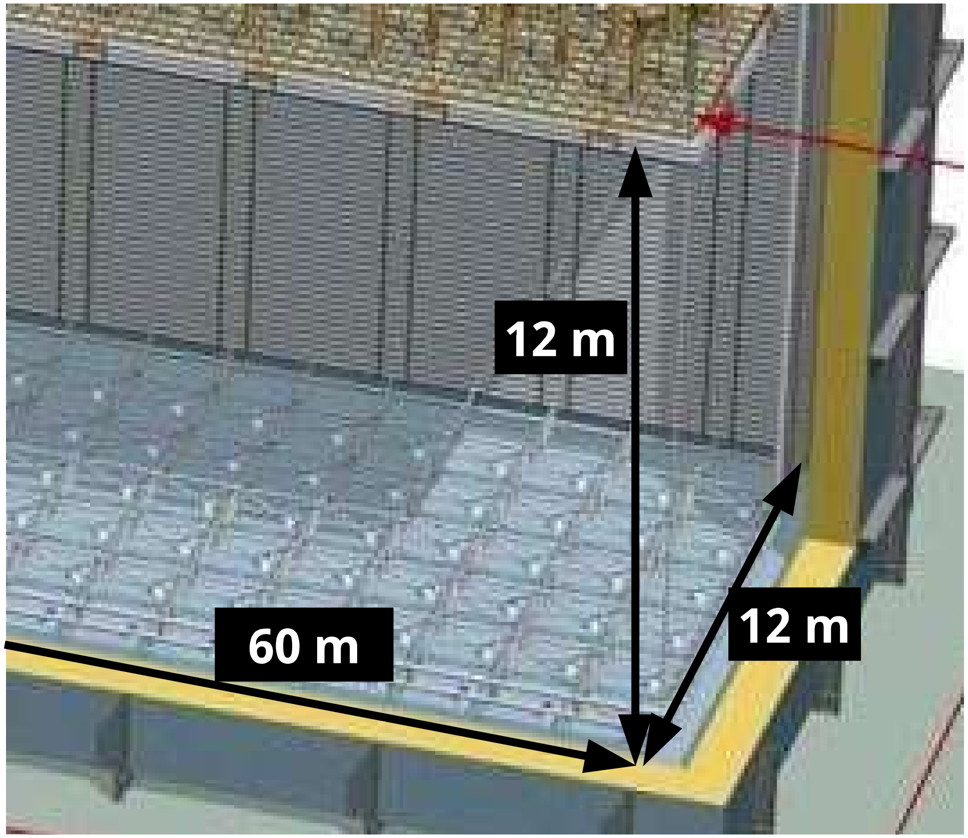


Far detector 10-kt modules

Single Phase



Dual Phase



Far detector 10-kt modules

Single Phase

IDR: arXiv:1807.10327

Active height	12 m
Active length	58 m
Maximum drift	3.5 m
Wire spacing	5 mm
Wire channels	384,000
Phot. det. ch.	6000

Dual Phase

IDR arXiv:1807.10340

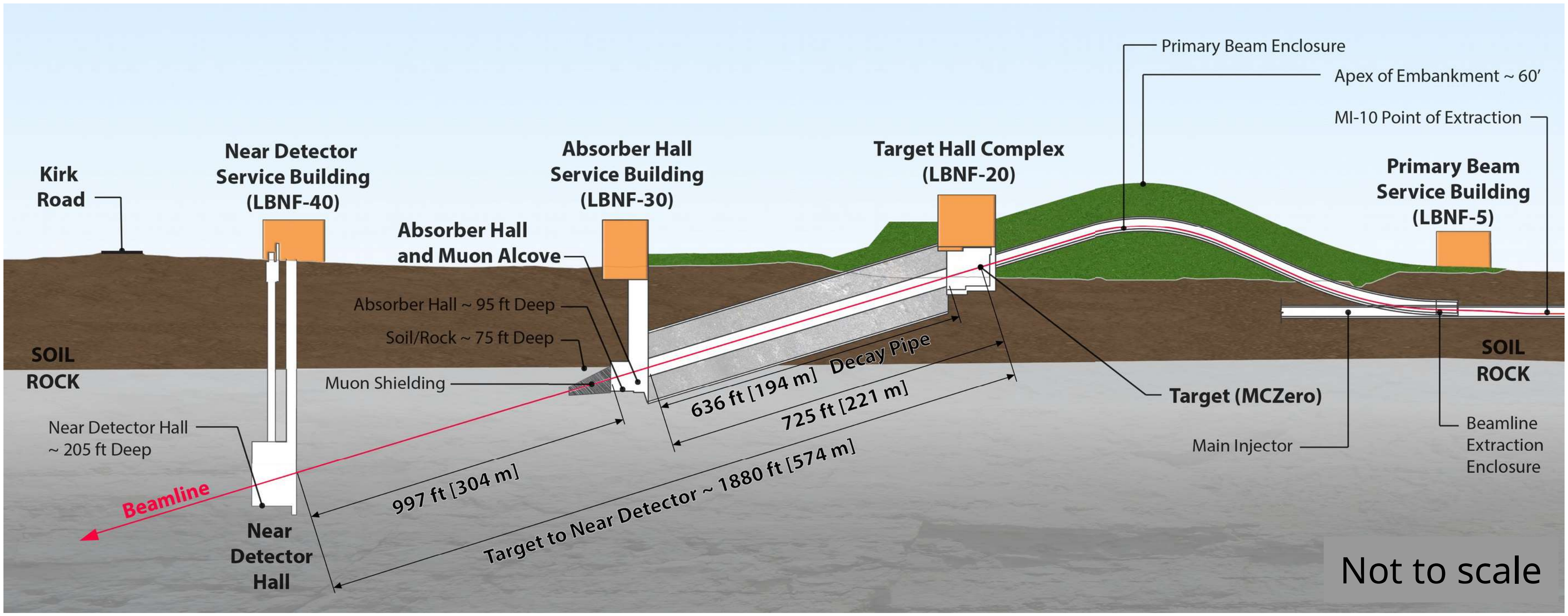
Active width	12 m
Active length	60 m
Maximum drift	12 m
CRP pixel size	3 mm
CRP channels	153,600
PMT channels	720

Design drift field: 500 V/cm

Electron drift speed at 500 V/cm: 1.6 mm/μs

LBNF beamline

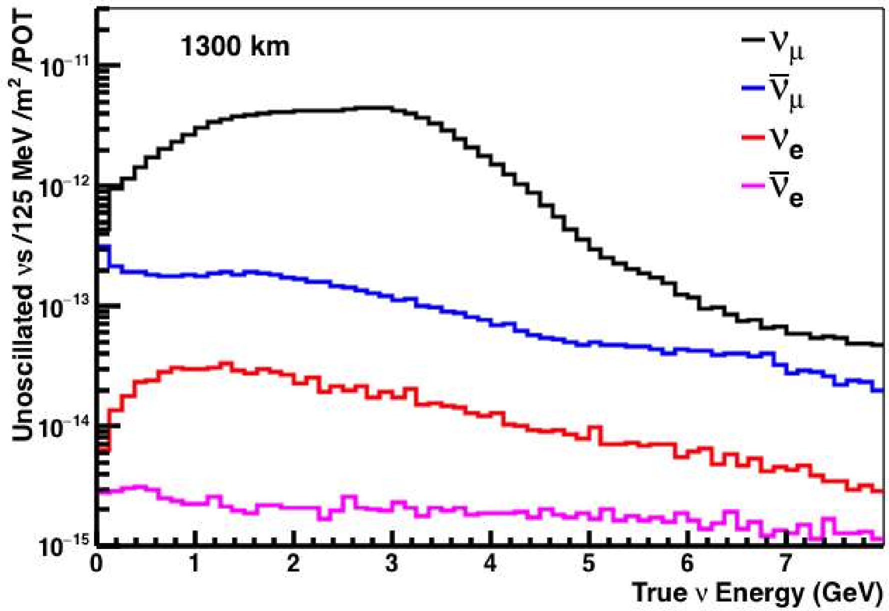
- Protons from Main Injector hit target. 101 mrad pitch to aim at FD in South Dakota. ~200 m decay pipe. ND hall at site boundary.

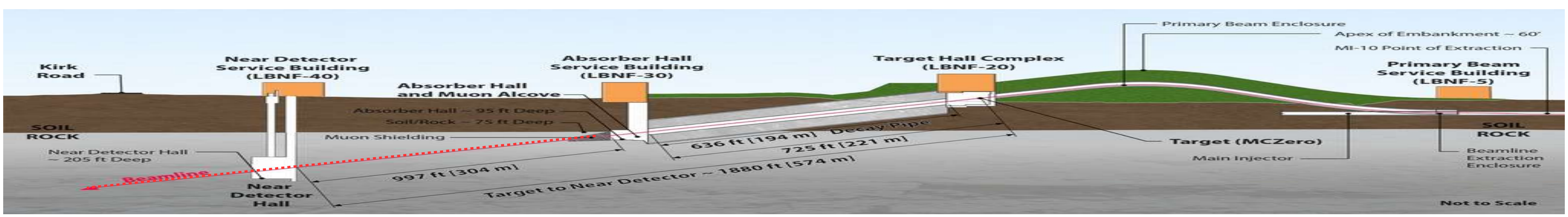


Neutrino beam

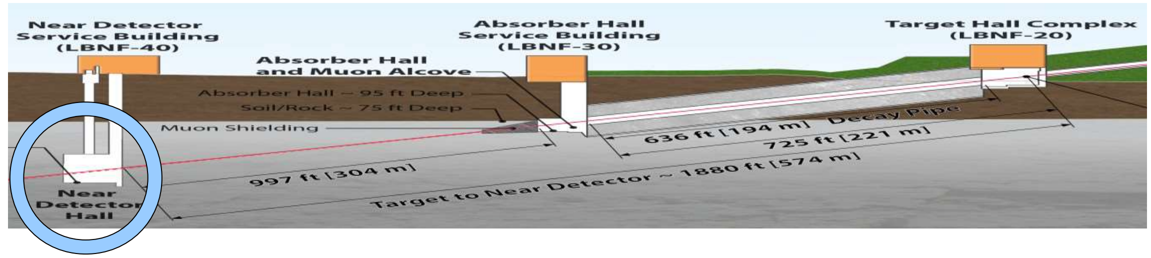
- 60-120 GeV proton beam at 1.2 MW ($\sim 10^{14}$ POT/s), upgradeable to 2.4 MW
- Horn-focused, wide-band neutrino beam optimized for CP violation sensitivity using genetic algorithm.
- Engineering design of 3-horn focusing system to optimized parameters in progress
- Neutrino and antineutrino modes

Unoscillated neutrino flux at 1300 km
(Conceptual Design Report Optimized Beam)

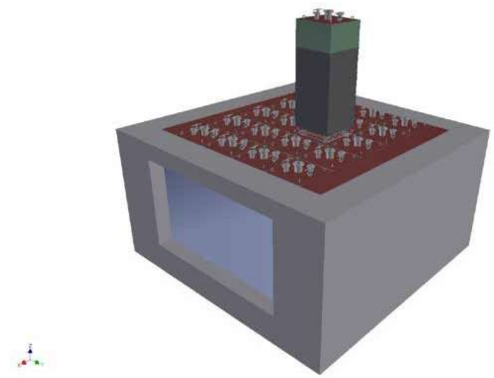


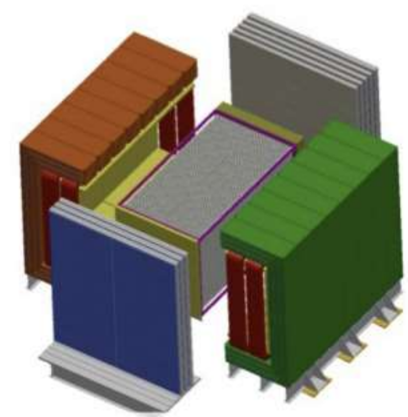


Near detector



- Constrain systematics for oscillation analysis: flux, cross-section, and detector uncertainties
- DUNE ND design concept near final
  - ND Conceptual Design Report (CDR) planned for 2019
- An integrated system of multiple detectors:
  - Segmented, pixel readout LAr TPC
  - Magnetized multi-purpose tracker
  - Electromagnetic calorimeter
  - Muon chambers
- Conceptual design preserves option to move ND for off-axis measurements
- >100 million interactions will enable a rich non-oscillation physics program



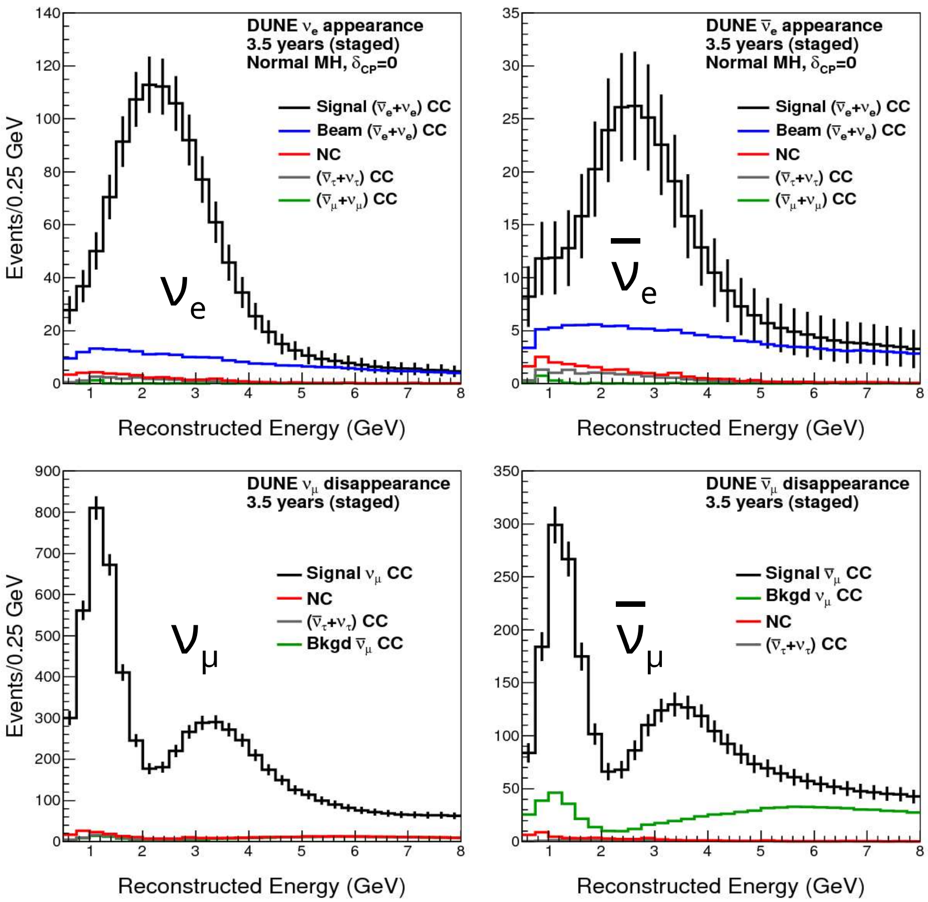


Neutrino oscillation measurements

- Spectra and intensity of ν_μ , $\bar{\nu}_\mu$, ν_e , $\bar{\nu}_e$, ν_τ , $\bar{\nu}_\tau$ with neutrino and antineutrino beam data.
- ν_μ , $\bar{\nu}_\mu$ disappearance.
- ν_e , $\bar{\nu}_e$, ν_τ , $\bar{\nu}_\tau$ appearance.
- Full set of neutrino oscillation parameters: mass ordering, δ_{CP}, and more.

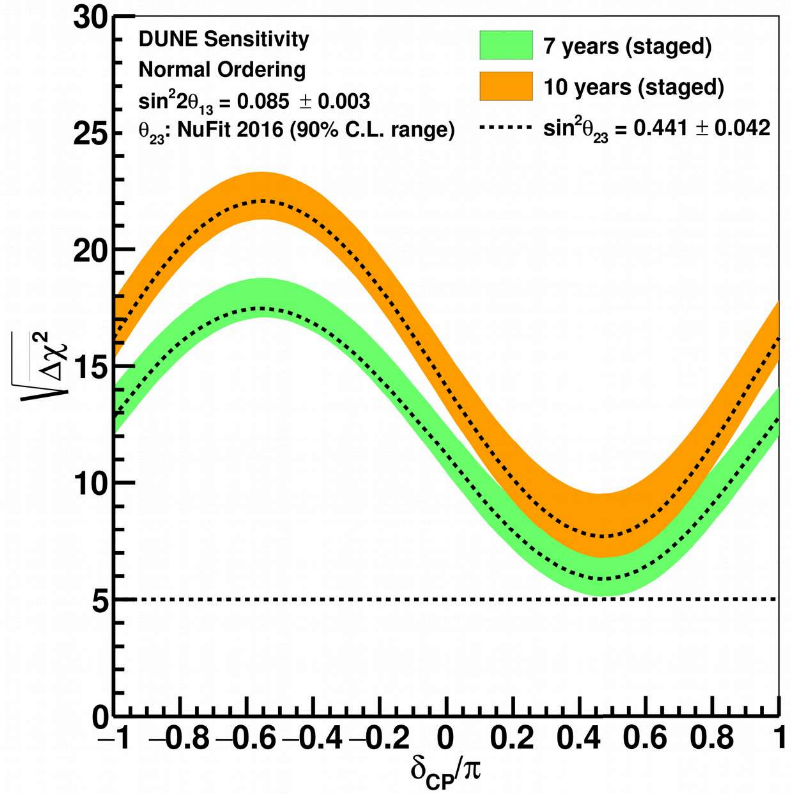
Oscillation Sensitivity Calculations

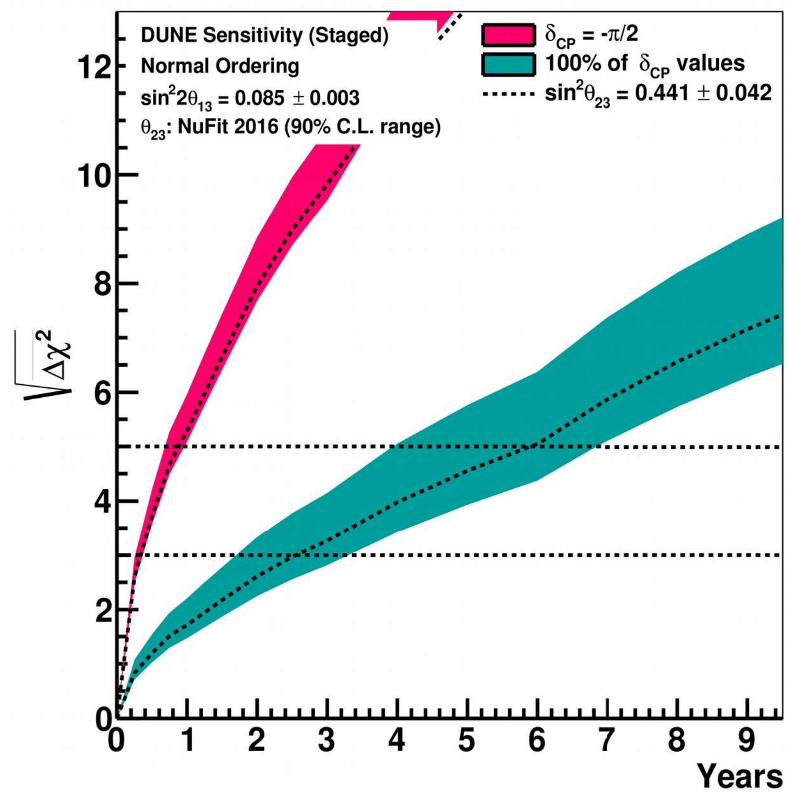
DUNE Conceptual Design Report (CDR) arXiv:1512.06148



- Reconstructed spectra based on GEANT4 beam simulation, GENIE event generator, and Fast MC using detector response parameterized at the single particle level
  - Efficiency tuned based on hand scans
- Order 1000 ν_e appearance events in ~7 years of equal running in neutrino and antineutrino mode
- Simultaneous fit to four spectra to extract oscillation parameters
- Systematics approximated using normalization uncertainties
- GLoBES configurations arXiv:1606.09550

Mass ordering sensitivity

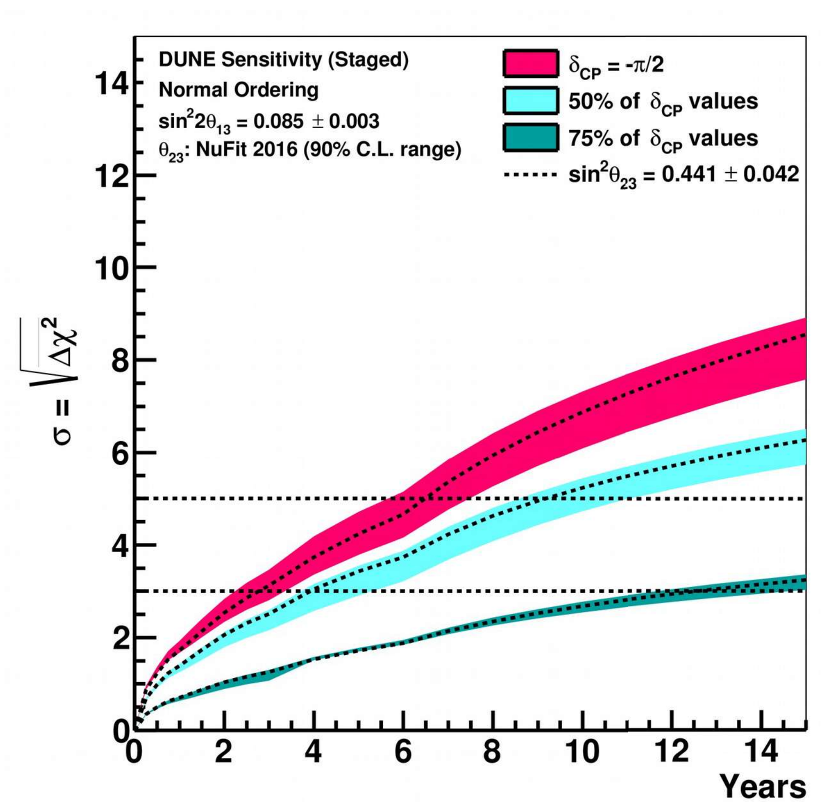




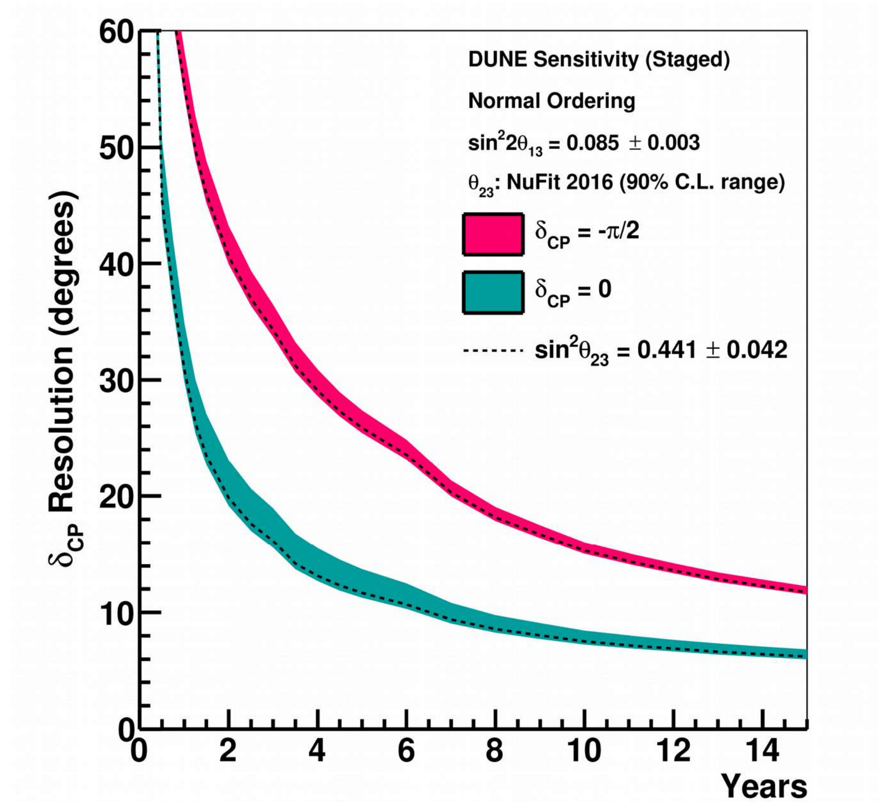
As function of unknown value of δ_{CP} for exposures of 7 and 10 years

As function of exposure for any δ_{CP} and for $\delta_{CP} = -\pi/2$.

CP violating phase



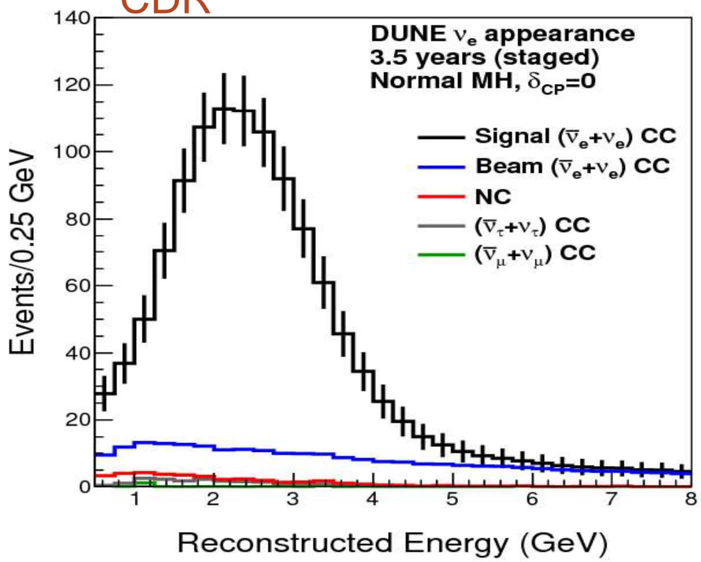
Significance ($\sqrt{\Delta\chi^2}$) as a function of exposure.



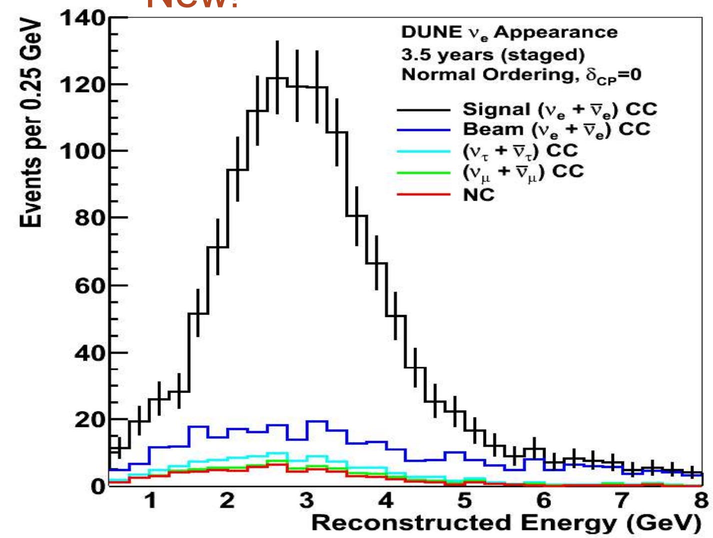
Expected δ_{CP} resolution (1 sigma) as a function of exposure.

New in 2018: Sensitivity using updated beam, full detector MC, fully automated event analysis

CDR



New!

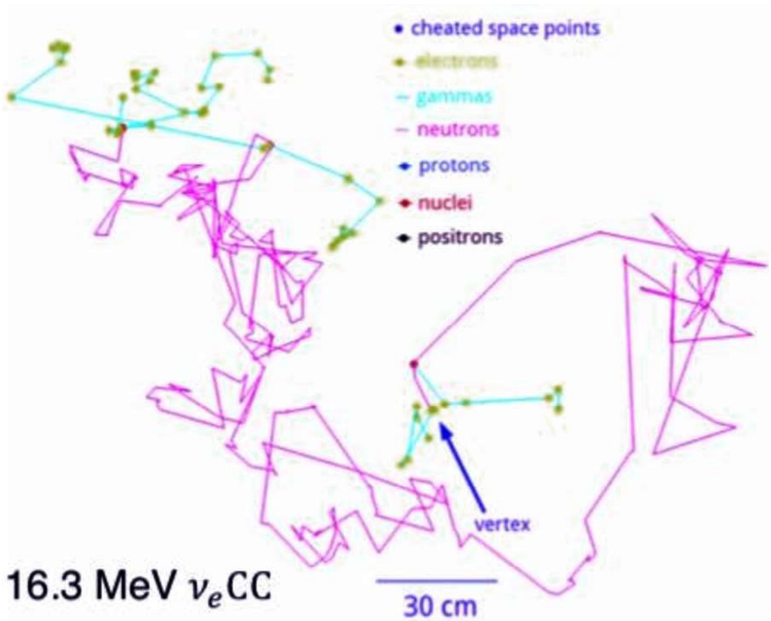


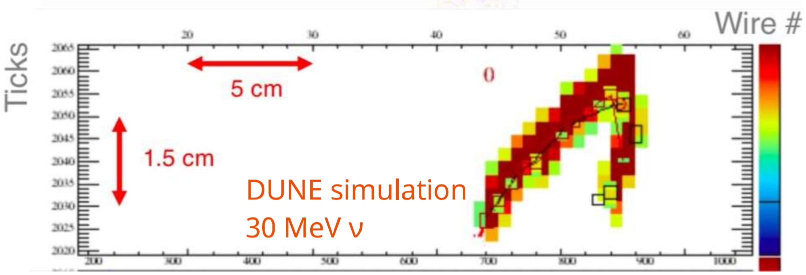
Sensitivity from MC-based analysis with automated reconstruction and event selection exceeds CDR sensitivity!

More details in Neutrino 2018 talk by Elizabeth Worcester, two posters.
Full update of sensitivity plots with detailed systematics planned for TDR in 2019.

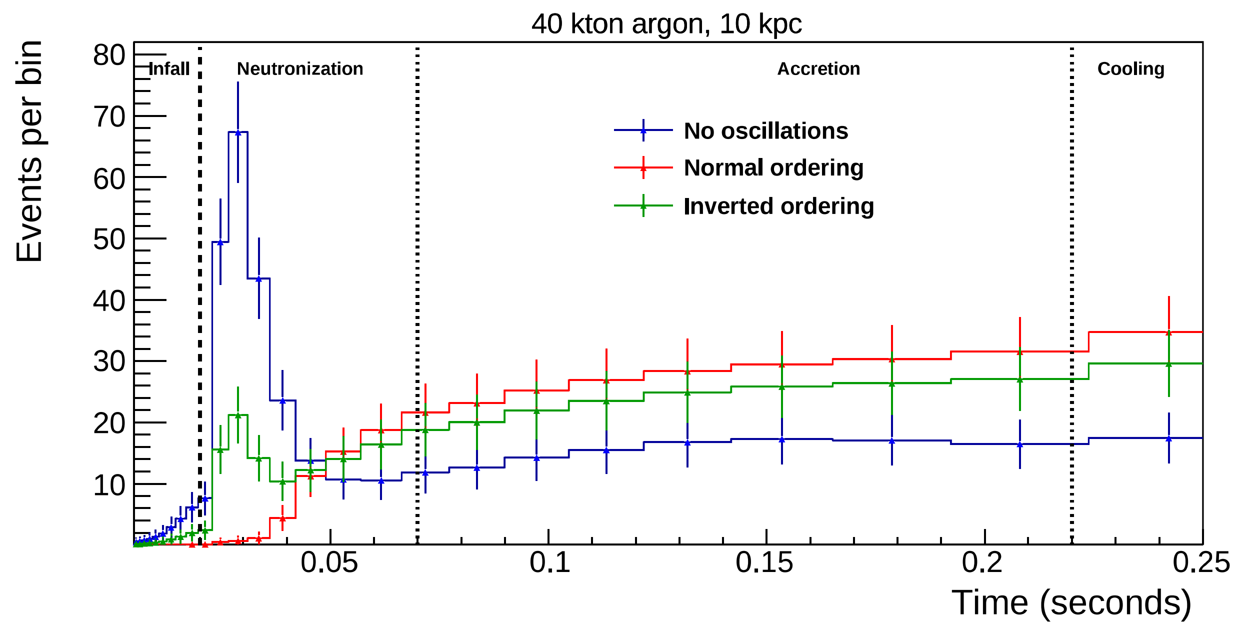
Supernova

MARLEY event generator: marleygen.org





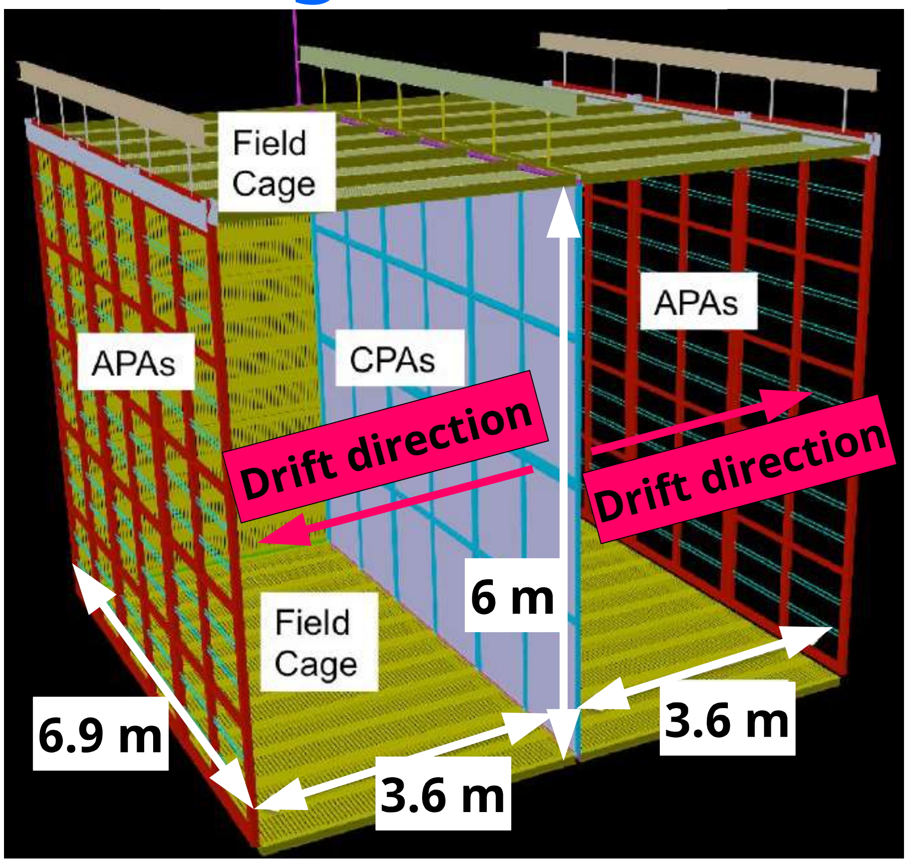
In LArTPC, SNB signal dominated by electron neutrinos: $\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$



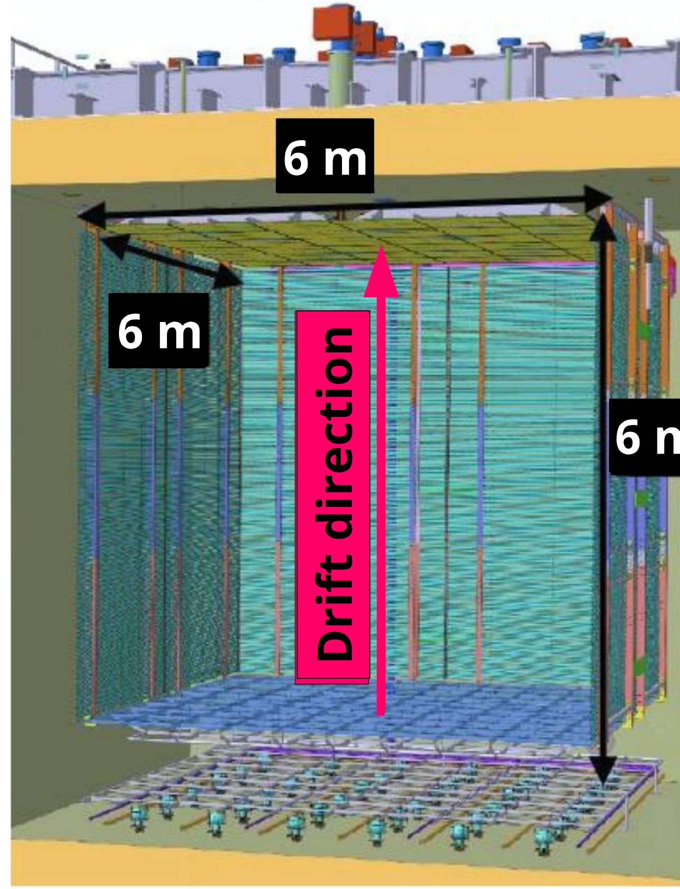
Measurement at early times tests mass ordering and SNB model

ProtoDUNEs

Single Phase



Dual Phase



CERN Neutrino Platform

Cryostat for ProtoDUNE-DP

Test-beam line

ProtoDUNE-SP cleanroom and cryostat

Test beam

- Tertiary beamline provides low energy particles in the momentum range of 0.4 to 12 GeV/c.
- Beamline fully instrumented for momentum selection, tracking, particle ID.
- Use for calibrating and verifying detector response to particles of known type and momentum.

ProtoDUNEs use same basic designs and components as planned for DUNE

- Mechanical design: cryostat type, detector supports
- High voltage systems: drift HV supply, cathode plane(s), field cage, …
- Anode wire planes (SP) / charge readout plane (DP)
- Photon detectors
- Detector cryogenic instrumentation
- Electronics and DAQ

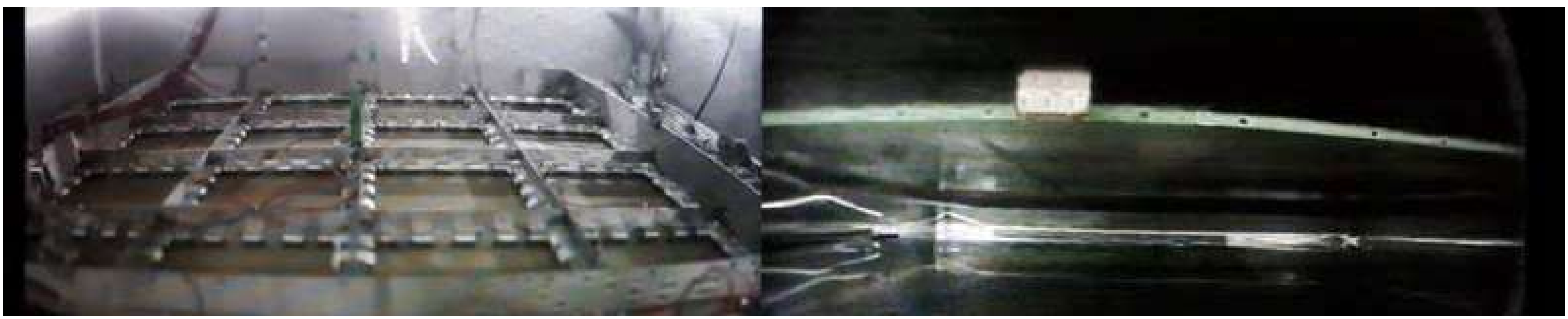
ProtoDUNE-DP field cage fully assembled, tested to 150 kV in air

ProtoDUNE-DP charge readout plane

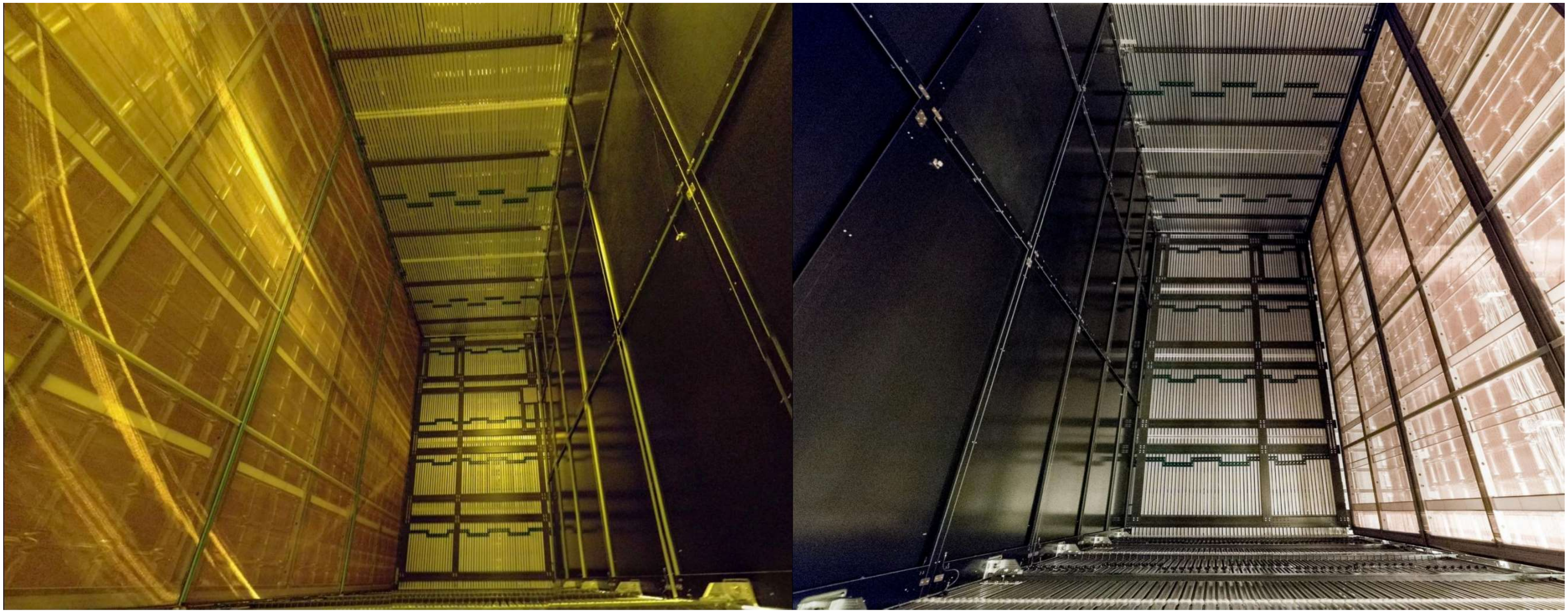
CRP #1 under construction

CRP #1 assembled

CRP #1 over LAr in cold box



ProtoDUNE-SP complete TPC: cathode, field cage, anode plane arrays

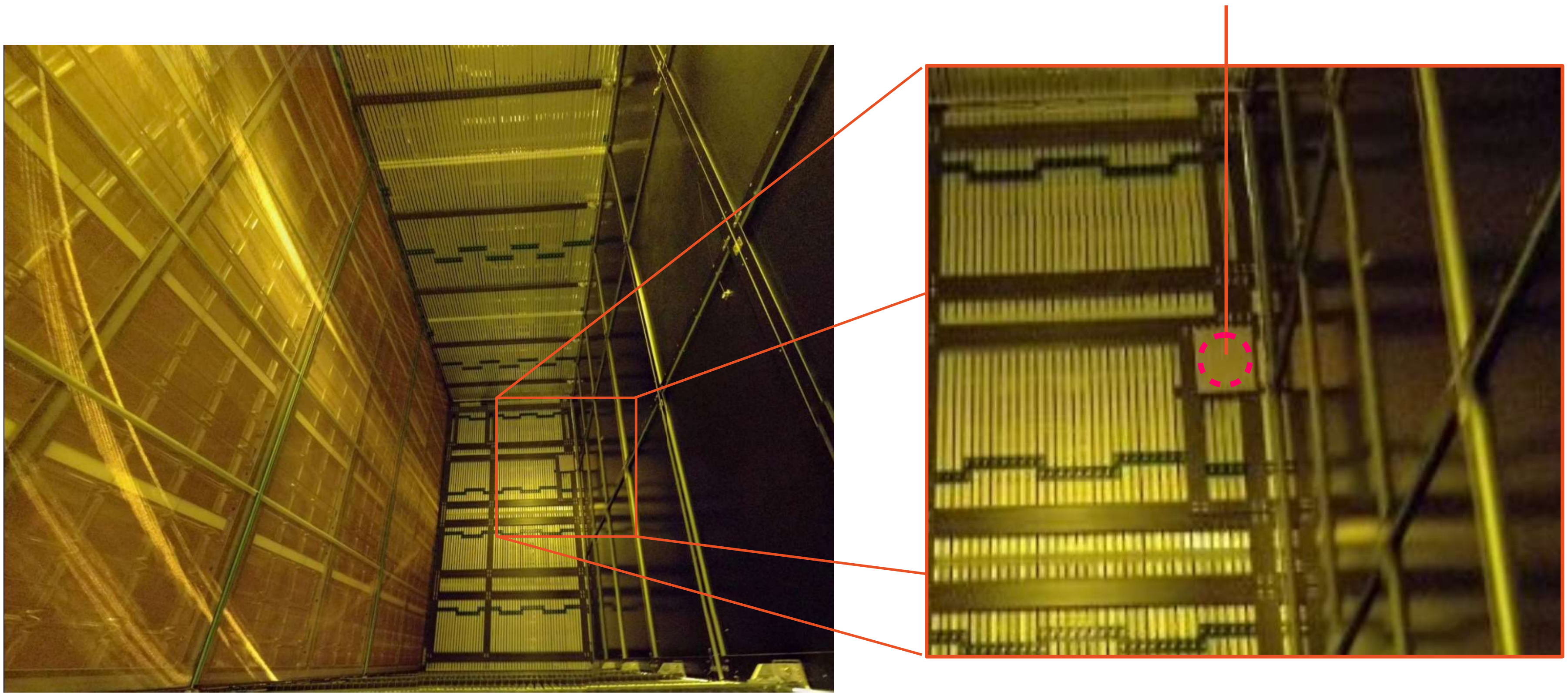


Looking from “upstream” towards test-beam

“Beam right” side

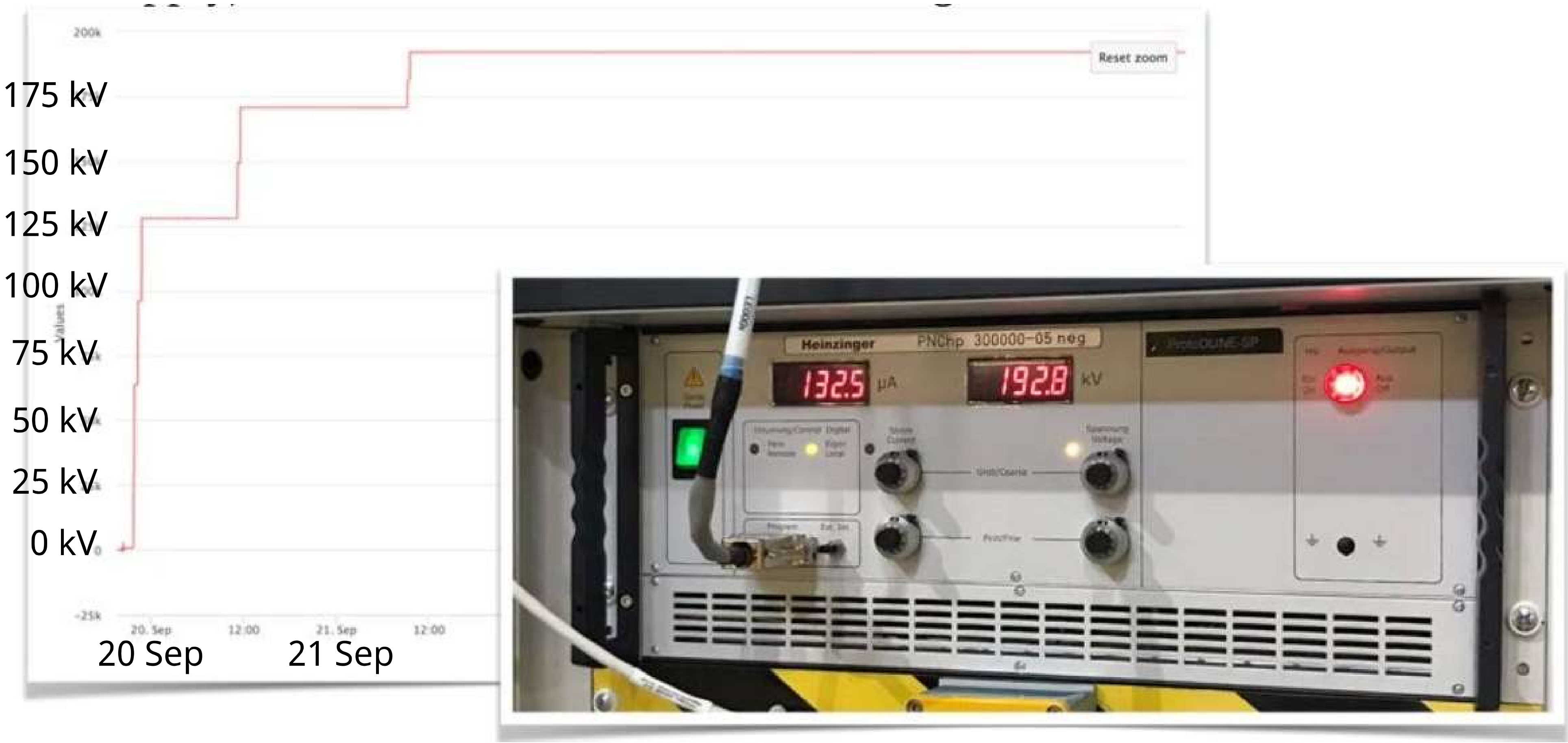
”Beam left” side

Test beam enters ProtoDUNE-SP here

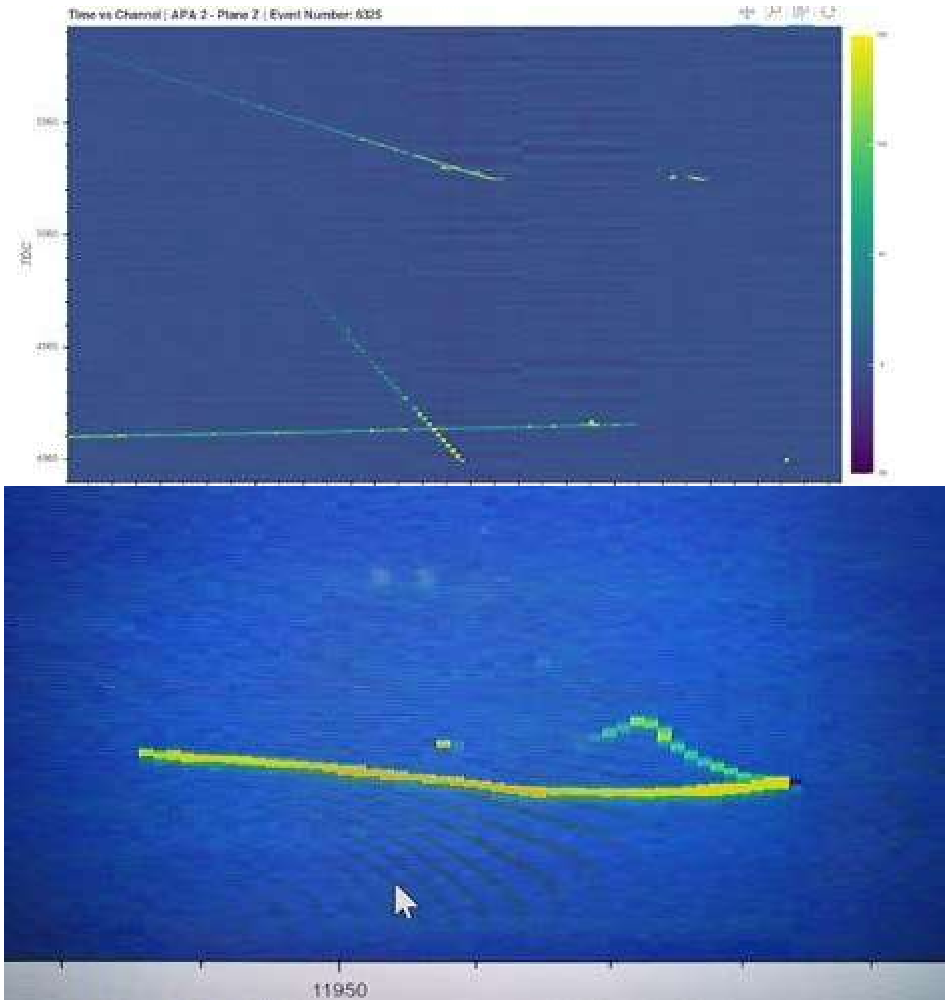


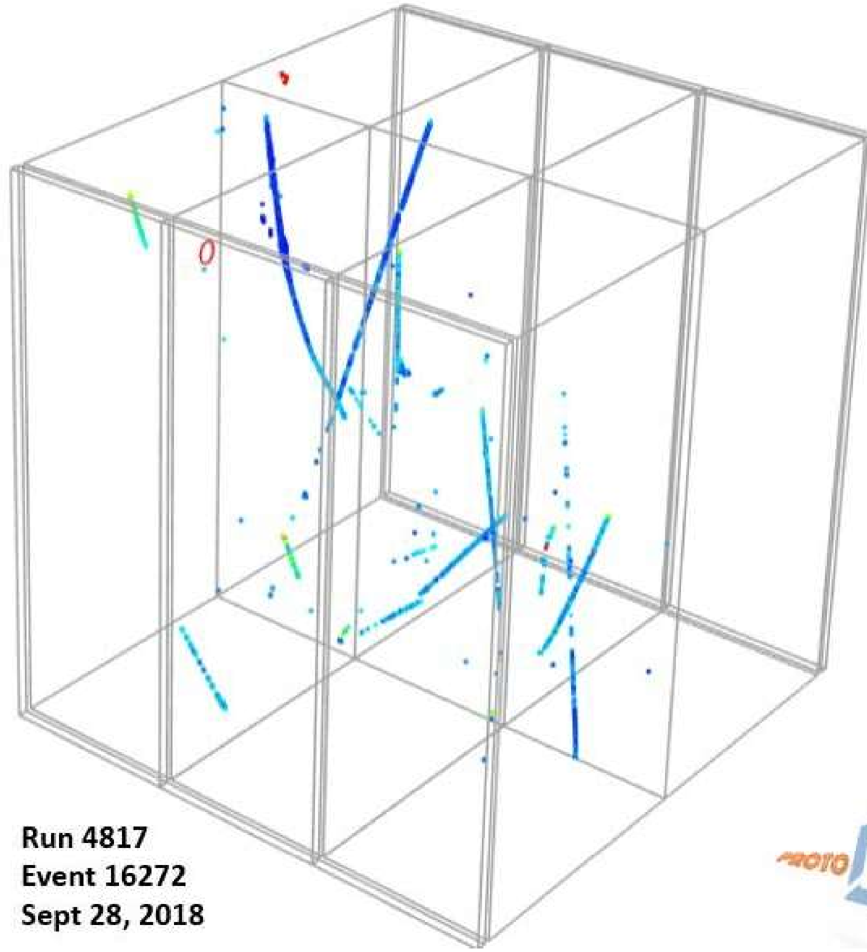
- Scattering and energy loss reduced by beam “window” through cryostat insulation and “plug” in LAr outside TPC.

ProtoDUNE-SP at full voltage

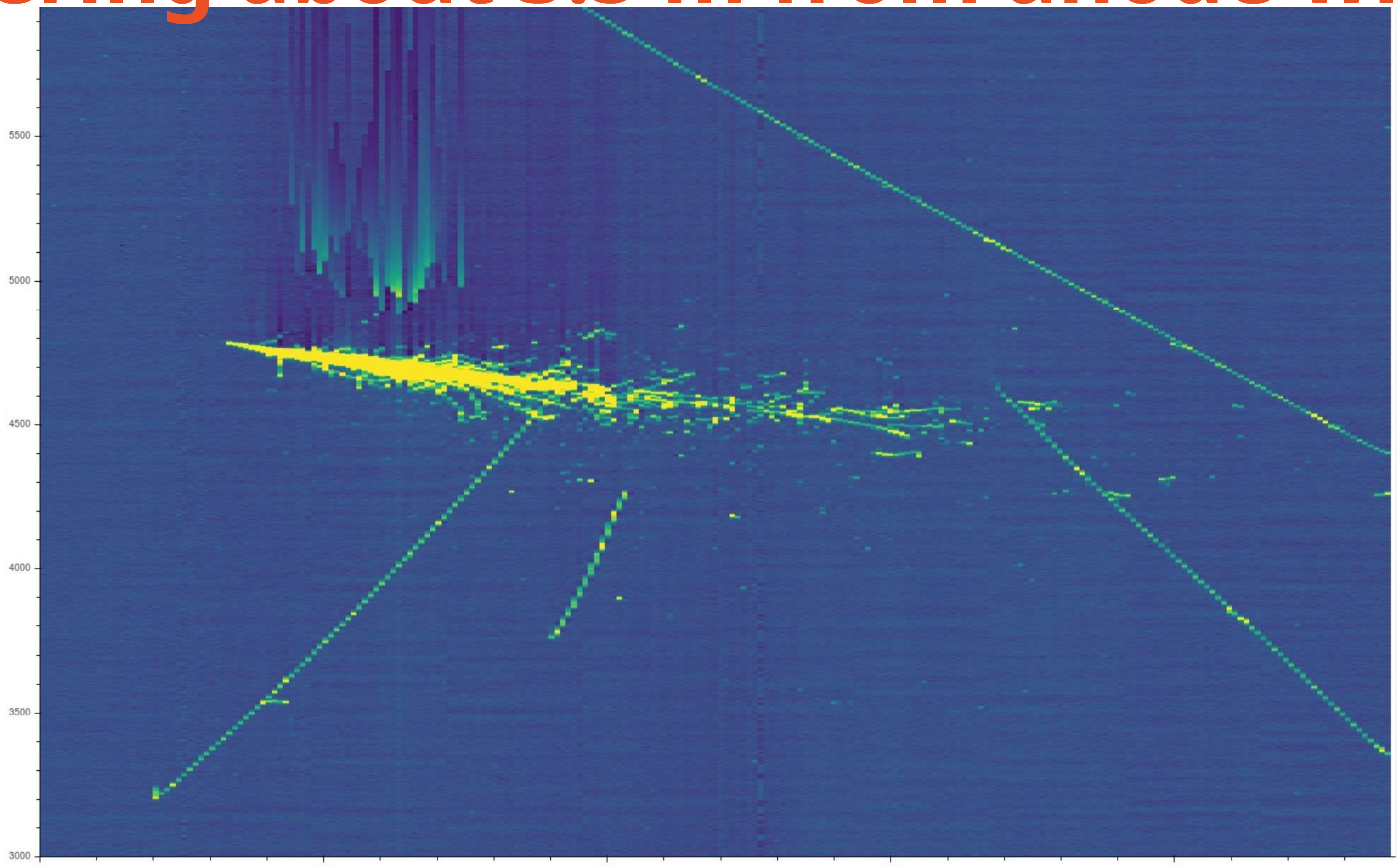


ProtoDUNE-SP taking data – cosmics



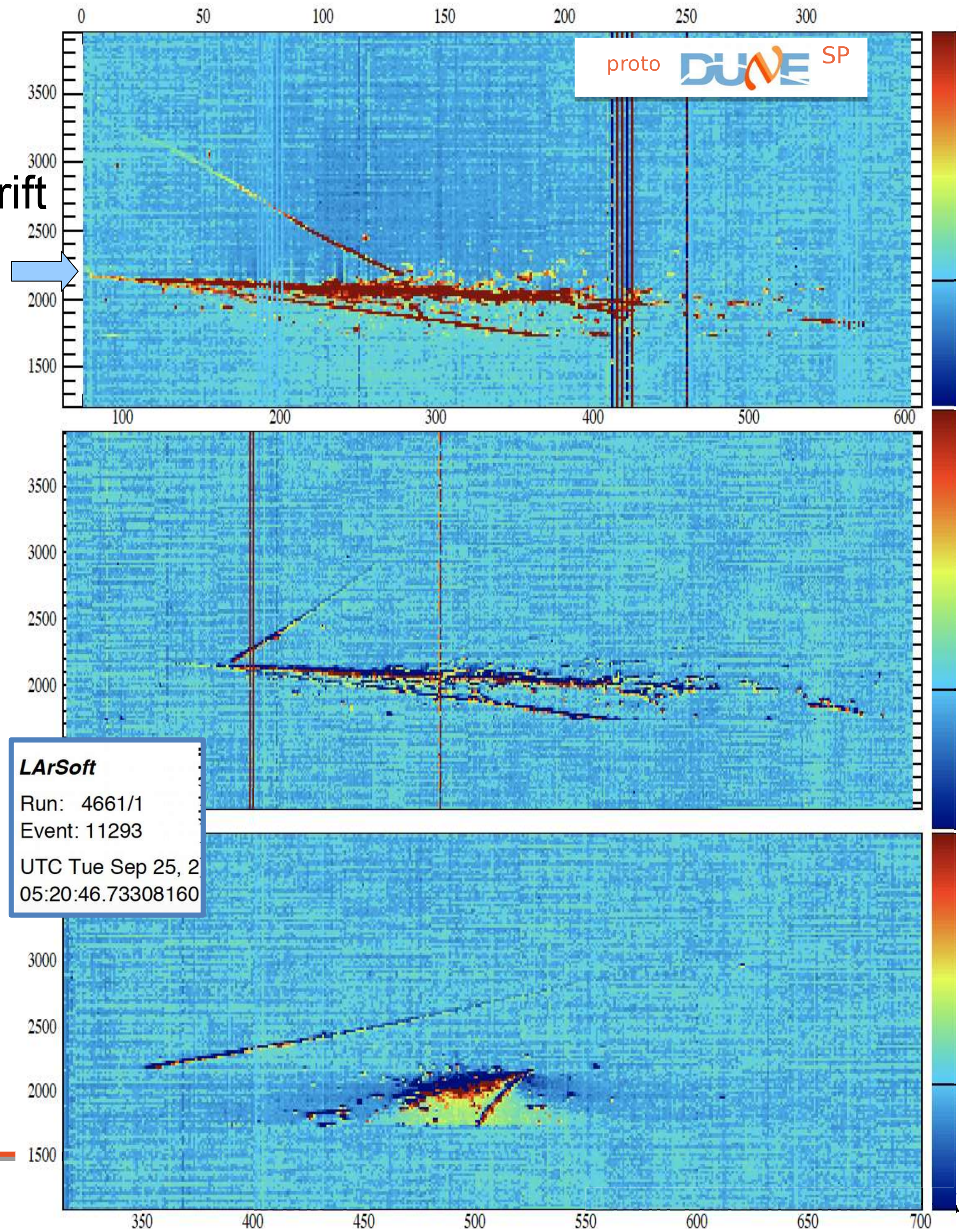


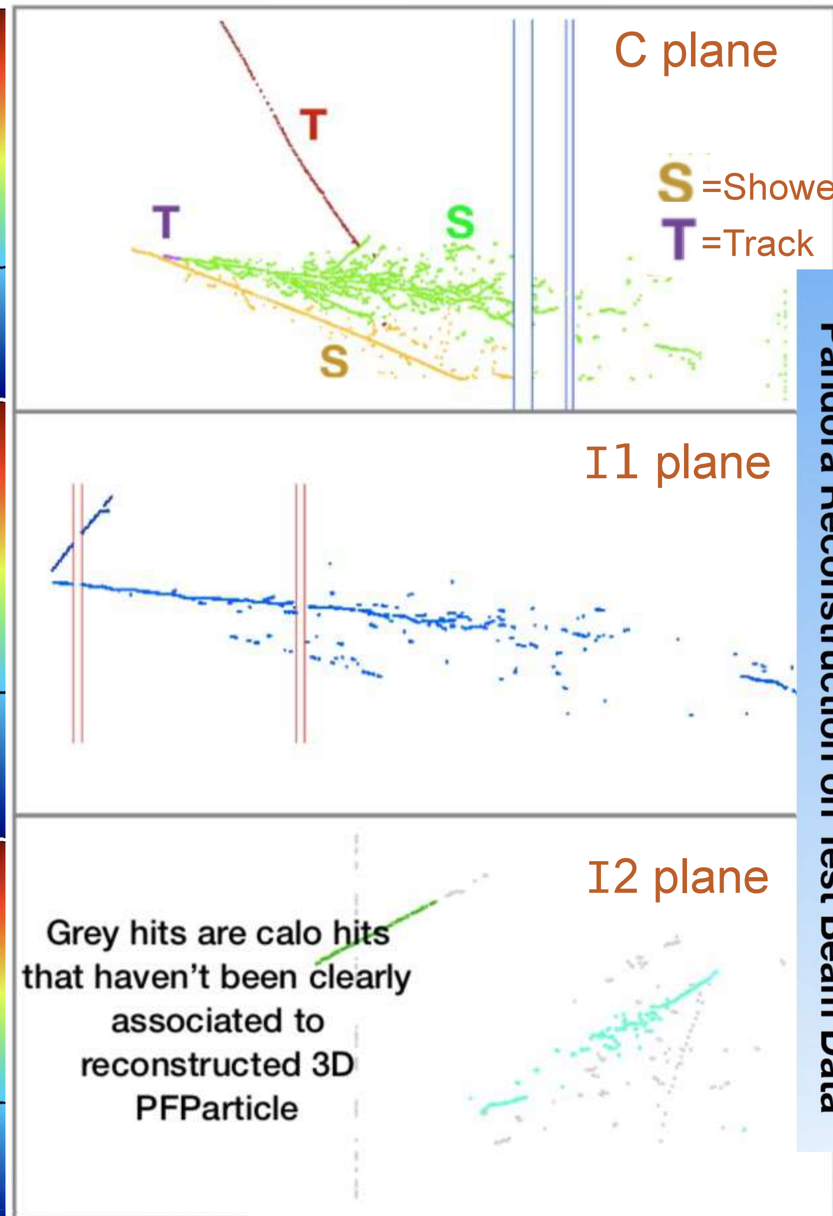
ProtoDUNE-SP taking data – test beam entering about 3.5 m from anode wires



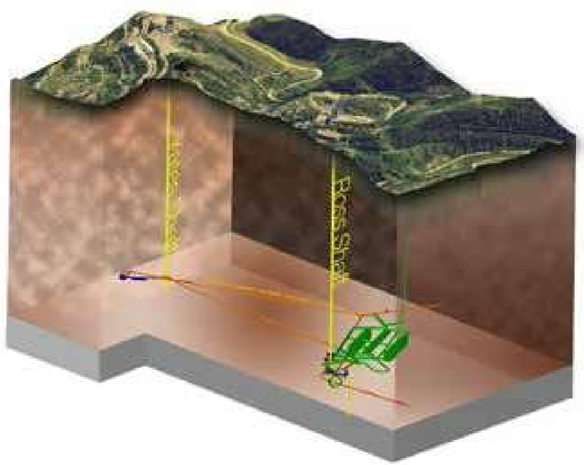
Pandora Reconstruction on Test Beam Data

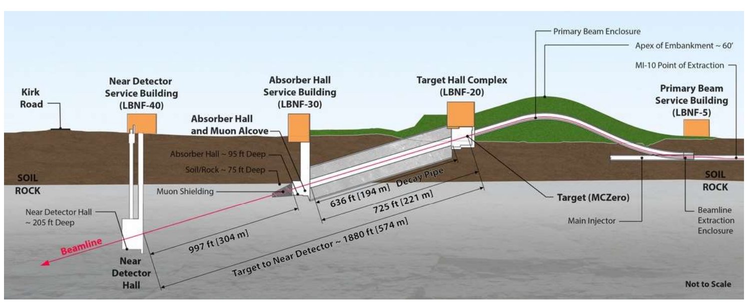
3.5 m drift
2.2 ms





DUNE general timeline





Physics data as soon as 1st module complete
- Atmospheric ν
- SNB and solar ν
- Proton Decay
- Detector calibration

2018: ProtoDUNEs at CERN

↓

2019: Technical Design Report

↓

2019: Far site primary excavation begins

↓

2022: First module installation begins

↓

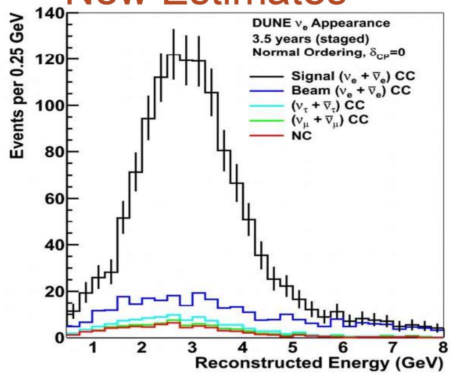
2026: Neutrino beam available

Acknowledgments

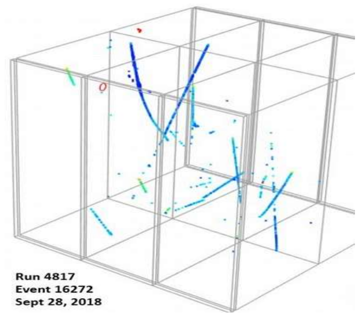
- DUNE would not be possible without the support of agencies and institutions in US, EU, and Worldwide.
- The partnership of the CERN Neutrino Platform and the CERN [TE-CRG, EN-EA, BE-BI, EP-DT-DI and TI] contributions are an integral and fundamental part of the ProtoDUNE effort.
- Fermilab’s role as the host for DUNE near and far detectors, beamline, and LBNF, is of course critical.
- Not to mention the dedication, skills and enthusiasm of the many DUNE Collaborators.

Summary

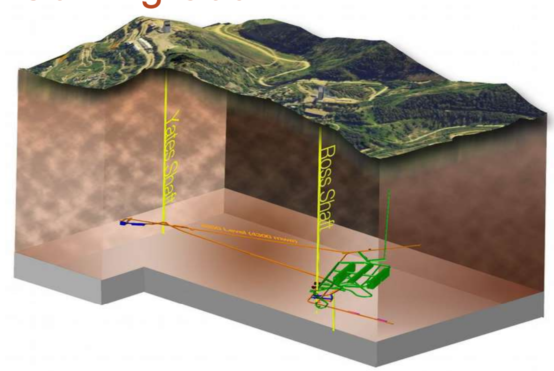
New Estimates



ProtoDUNE



Coming Soon…



- LBNF/DUNE: rapid progress to mega neutrino physics facility
- New oscillation sensitivity estimate using full detector MC and reconstruction chain more realistic than CDR
- ProtoDUNEs: construction→data taking, step up ladder to 40 kt
- Look for DUNE Technical Design Report and protoDUNE SP and DP results in 2019!
- Expect first DUNE FD data in ~2024