The DUNE Experiment: Status & Prospects

Sowjanya Gollapinni (UTK)

(On behalf of DUNE Collaboration)

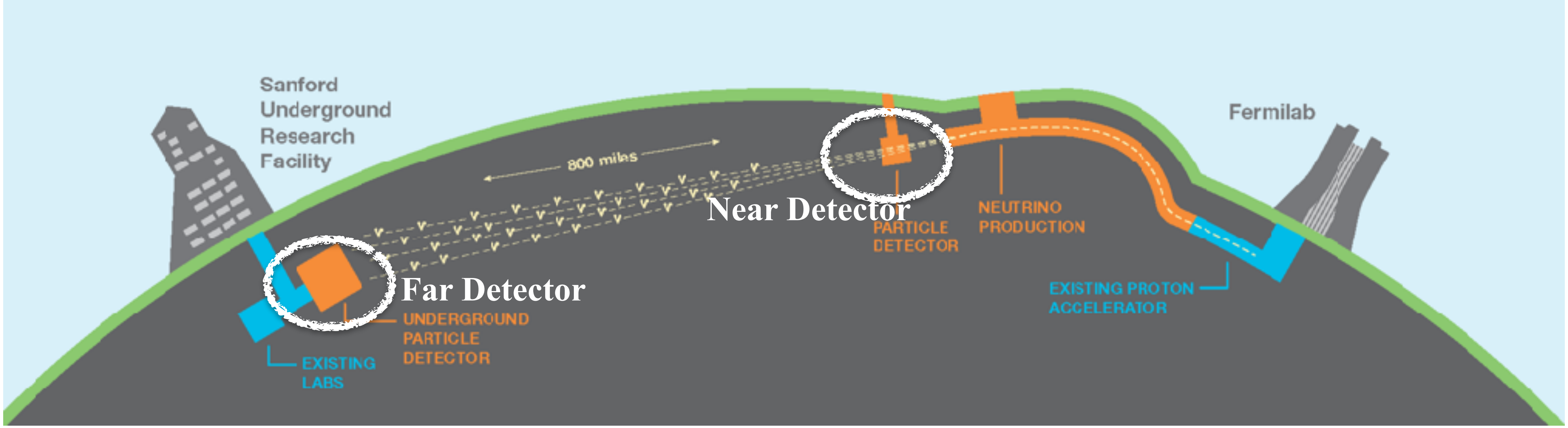
NuFact 2018, Aug. 16, 2018
Blacksburg, Virginia

The Deep Underground Neutrino Experiment

- MW-scale intensity neutrino beam from Fermilab to South Dakota over 1300 km
- Massive Liquid Argon Time Projection Chamber (LArTPC) as Far detector ~1 mile underground with 40 kilotons of fiducial mass
- Rich Physics program: Mass hierarchy, CP Violation, Supernovae physics, Nucleon Decay, New Physics etc.

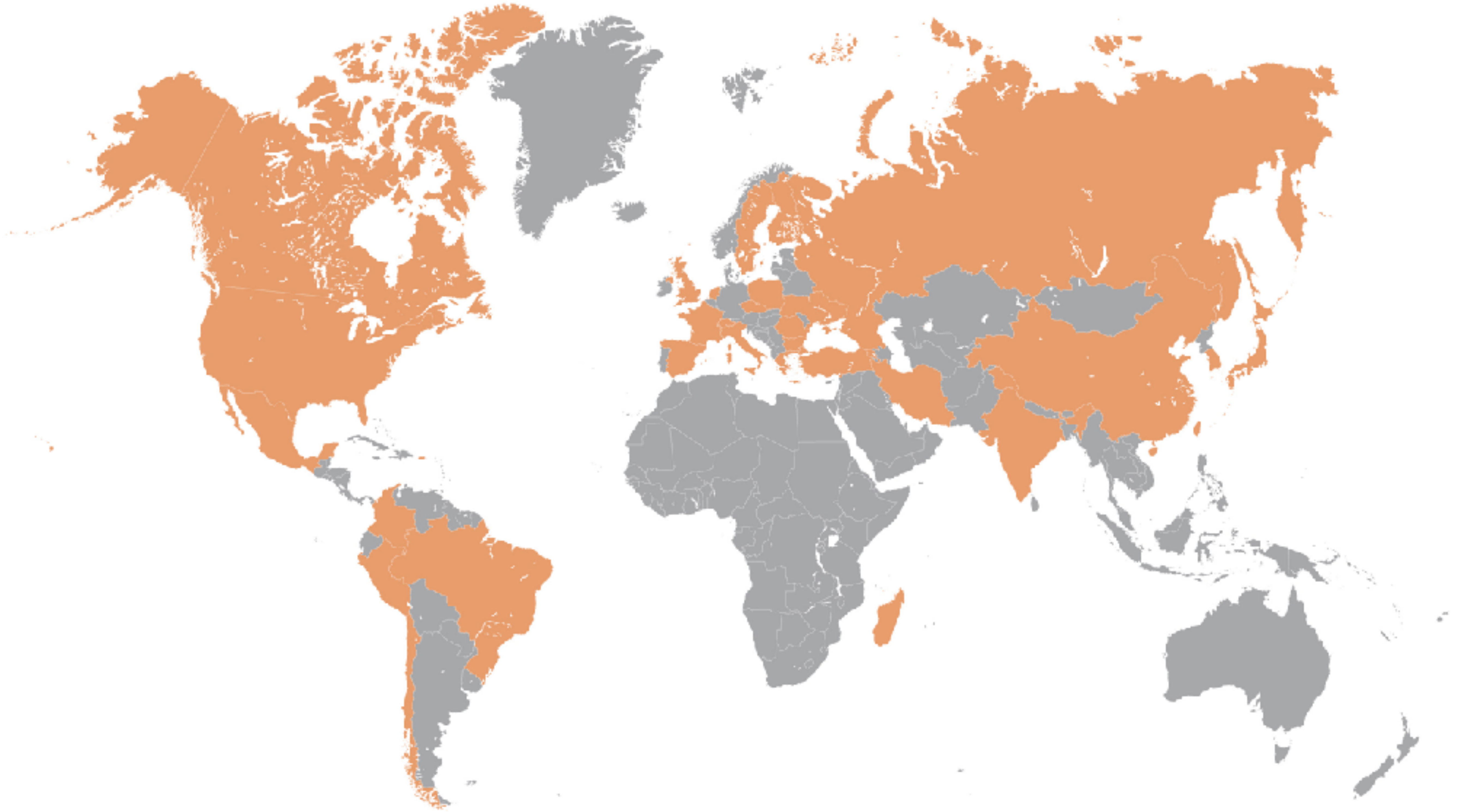
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

International
Mega Science Project



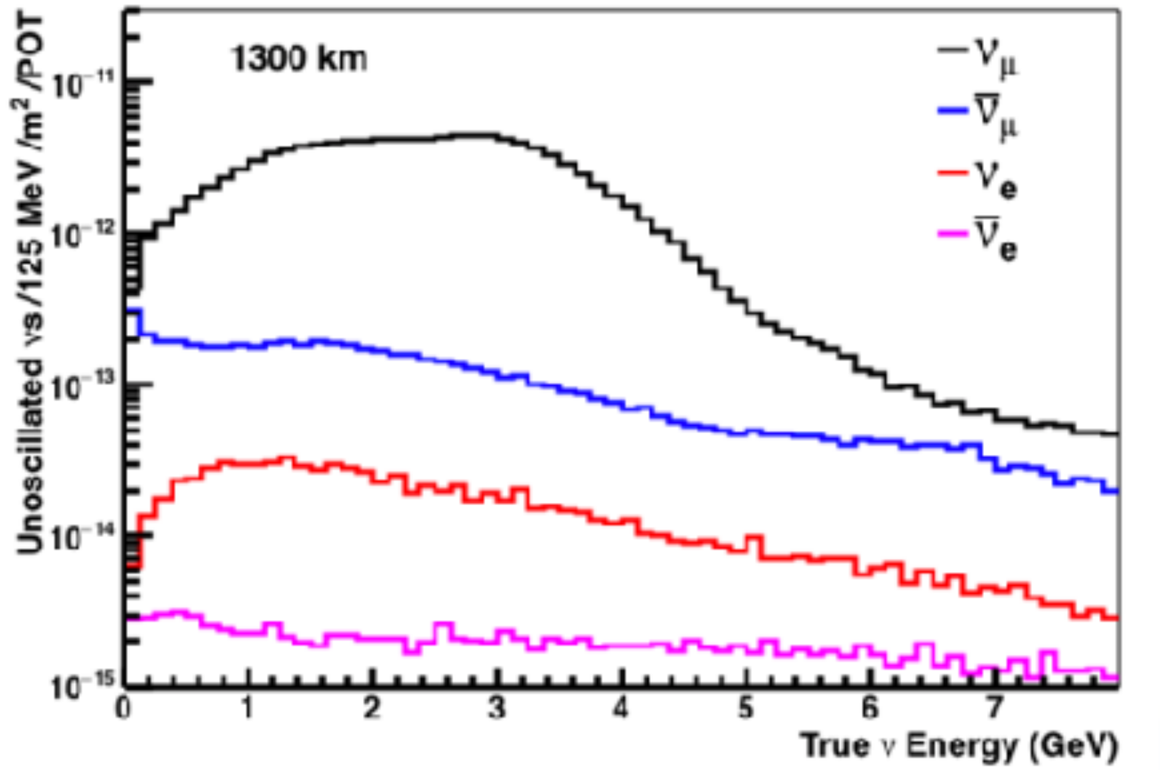
The DUNE Collaboration

1132 collaborators from 179 institutions in 32 countries

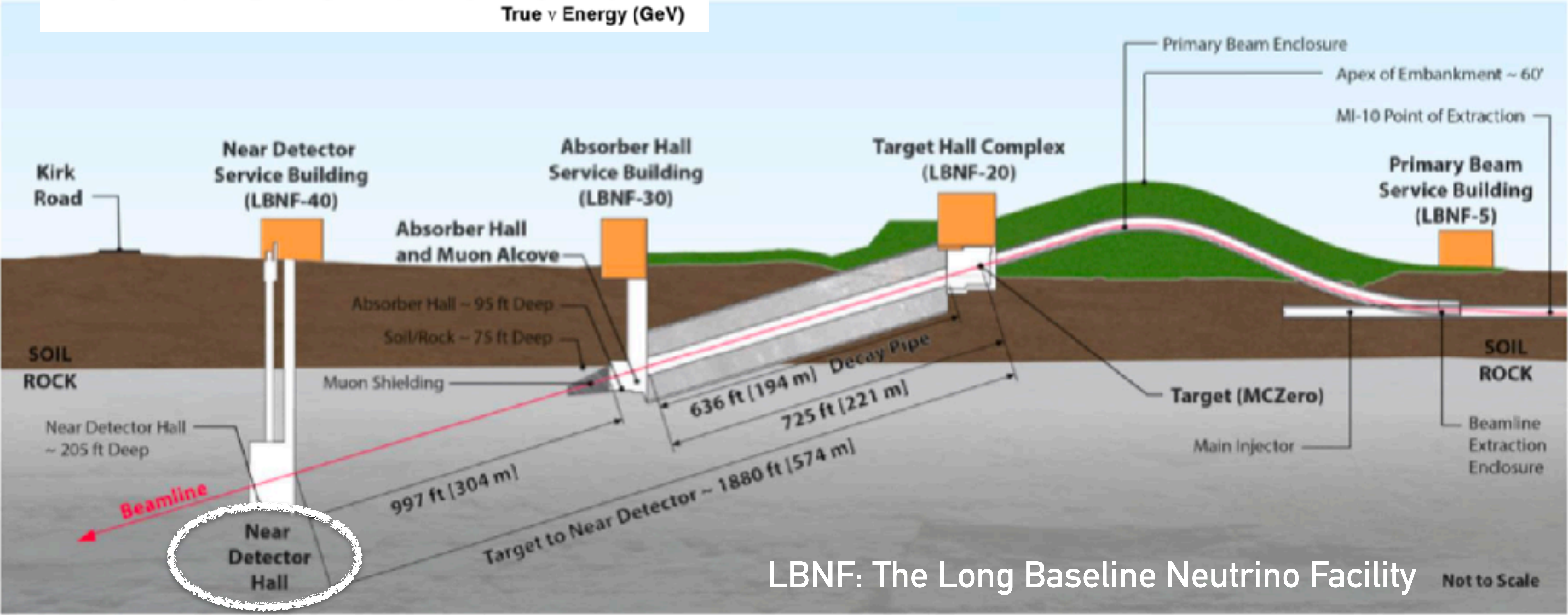


The collaboration is rapidly evolving and is becoming highly international

DUNE: The Neutrino Beam

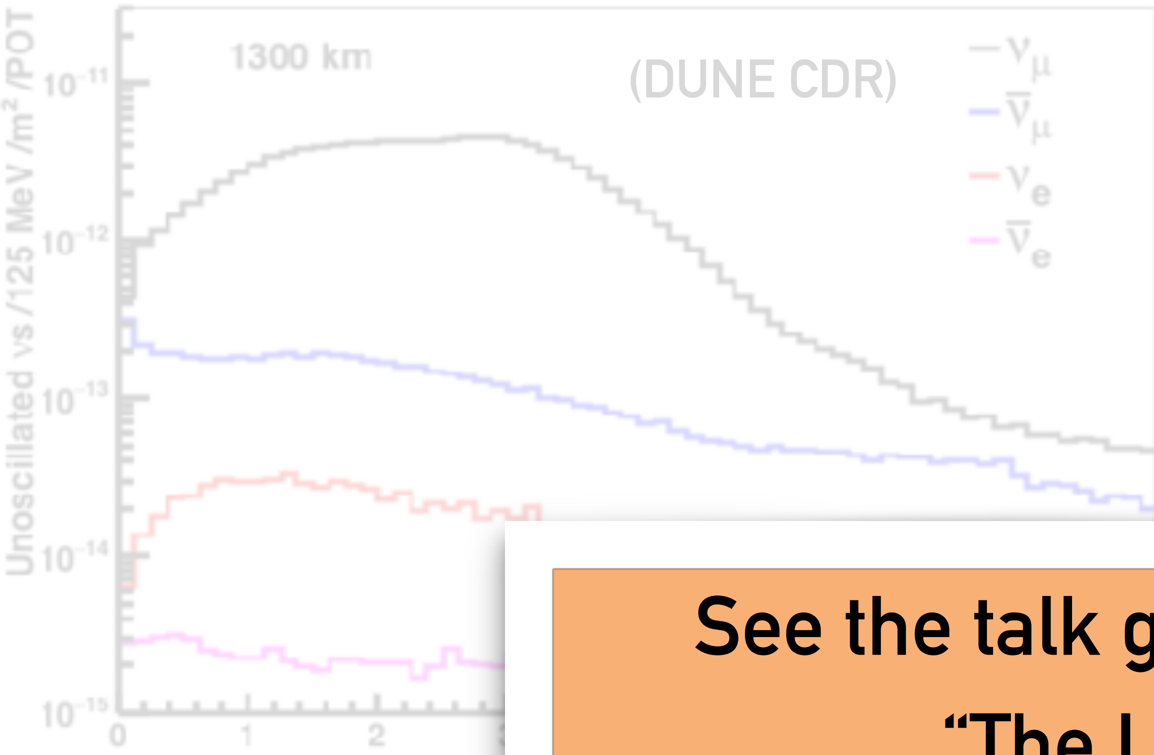


- 60–120 GeV protons from Fermilab's Main Injector
  - 1.2 MW beam power initially, upgradable to 2.4 MW power — compare to MINOS (<400 kW) and NOvA (600 - 700 kW)
- Achieving 1.2 MW beam power requires PIP II (proton improvement plan), a $0.5B upgrade — DOE CD-1 approval in Aug 2018!
- 200 m decay pipe at -5.8° pitch, angled at South Dakota



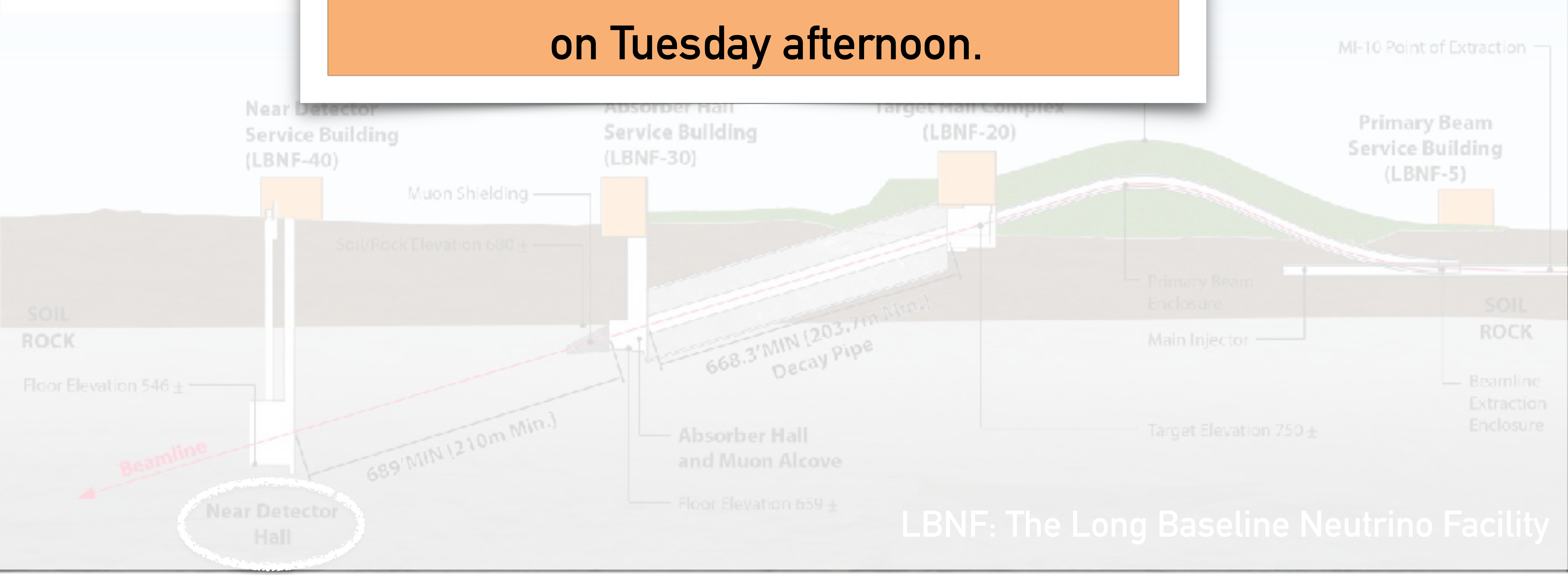
LBNF: The Long Baseline Neutrino Facility

DUNE: The Neutrino Beam



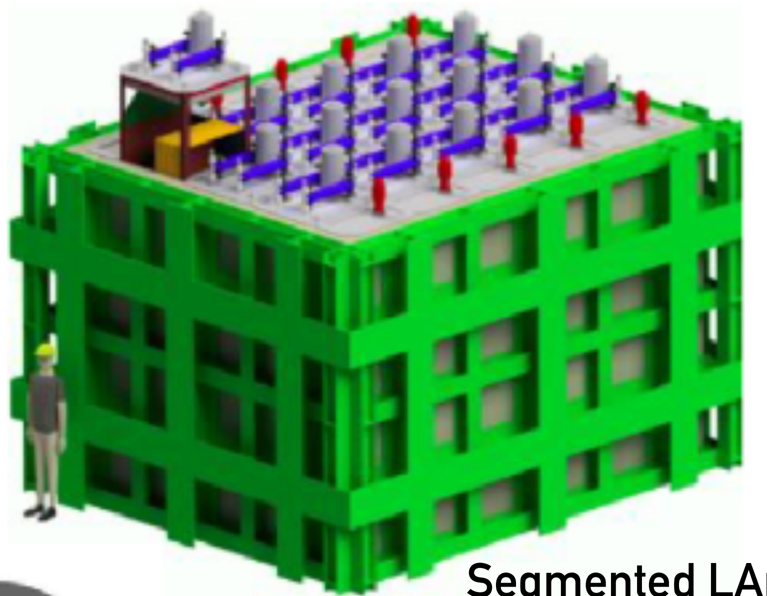
- 60–120 GeV protons from Fermilab's Main Injector (NuMI)
  - 1.2 MW beam power initially, upgradable to 2.4 MW power — compare to MINOS (<400 kW) and NOvA (600 - 700 kW)
- Achieving 1.2 MW beam power requires PIP II (proton improvement plan, $0.5B upgrade
- ...angled at South Dakota

See the talk given by Mary Bishai on "The LBNF Beamline" on Tuesday afternoon.

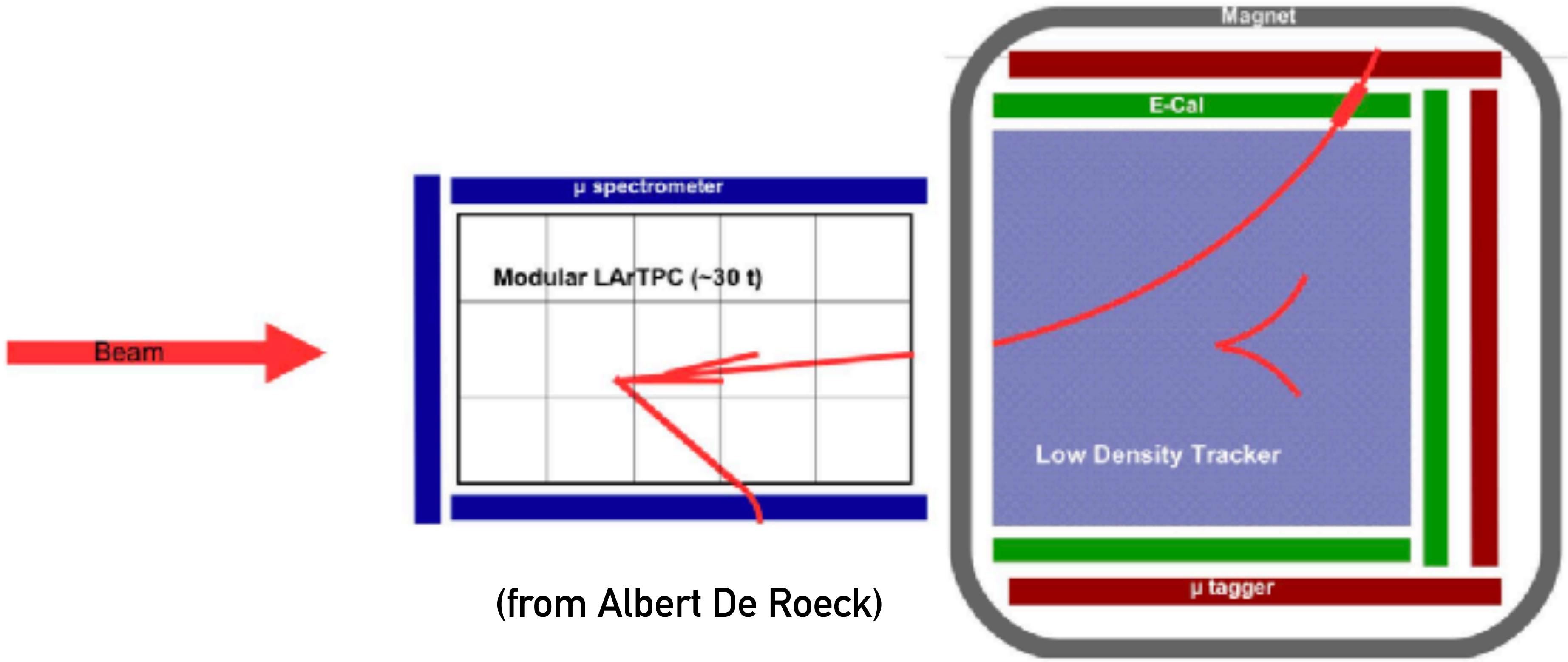


DUNE: A Hybrid Near Detector

- Near Detector (ND) will be located about 600 m from the target
- ND goals: constrain the systematic uncertainties for oscillations by measuring
  - "unoscillated" fluxes, neutrino-nucleus cross sections and likely detector physics
- Near detector conceptual design being finalized — will be composed of multiple systems
  - A highly segmented LArTPC (50 M ν_μCC events in 1 year; 15 k ν_eCC events in 5 years)
  - a magnetized multi-purpose tracker
  - A PRISM concept (movable detector) for off-axis measurements



Segmented LArTPC

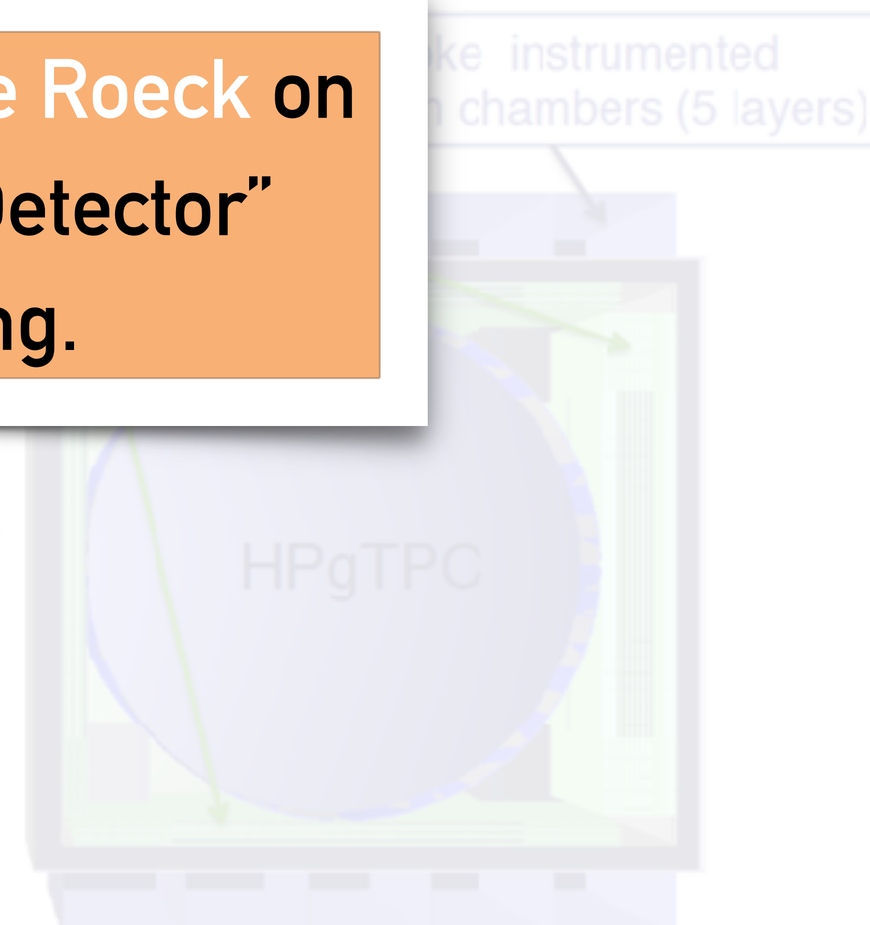


(from Albert De Roeck)

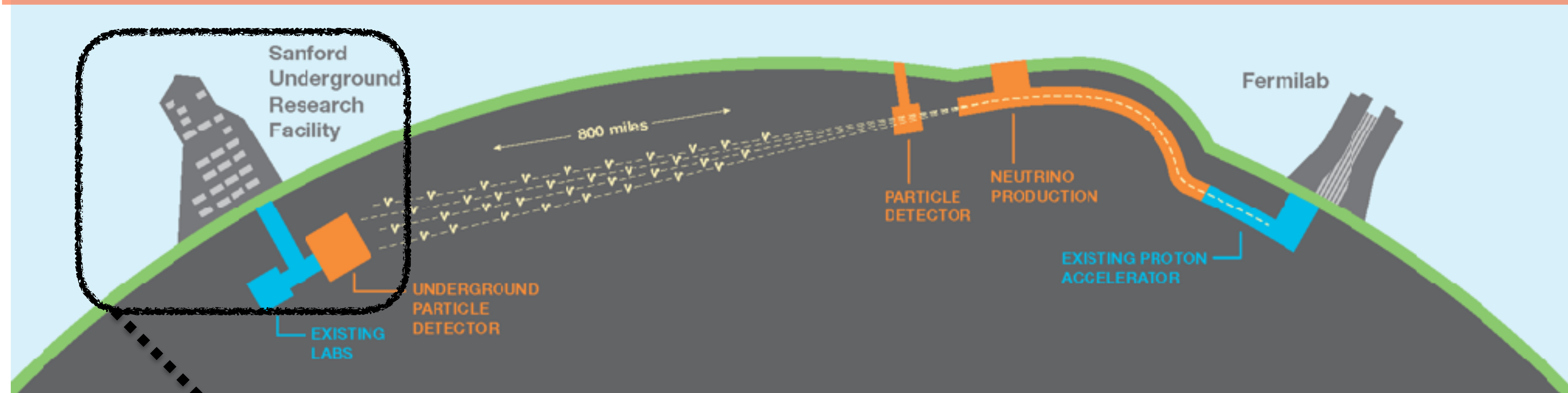
DUNE: The Near Detector

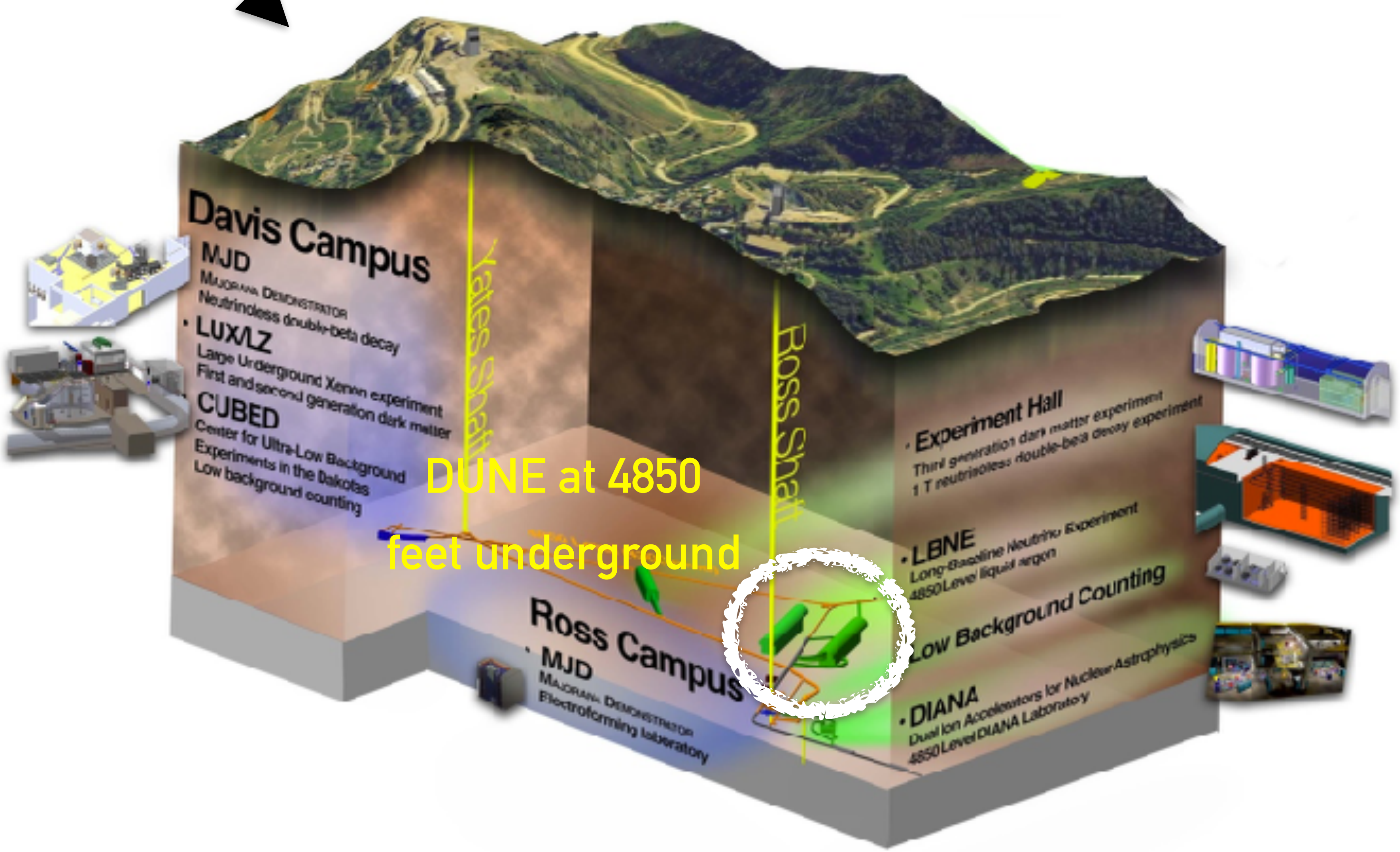
- Near Detector (ND) will be located about 600 m from the neutrino source
- ND goals: constrain the systematic uncertainties for oscillations by measuring
  - unoscillated fluxes, neutrino-nucleus cross sections and likely detector physics
- Near detector conceptual design being finalized
  — will be composed of multiple systems
  - A highly s
  - a magnet
  - A PRISM
- DUNE ND Con

See the talk given by Albert De Roeck on "Plans for the DUNE Near Detector" on Wednesday morning.



The DUNE Far Site (Sanford Lab)





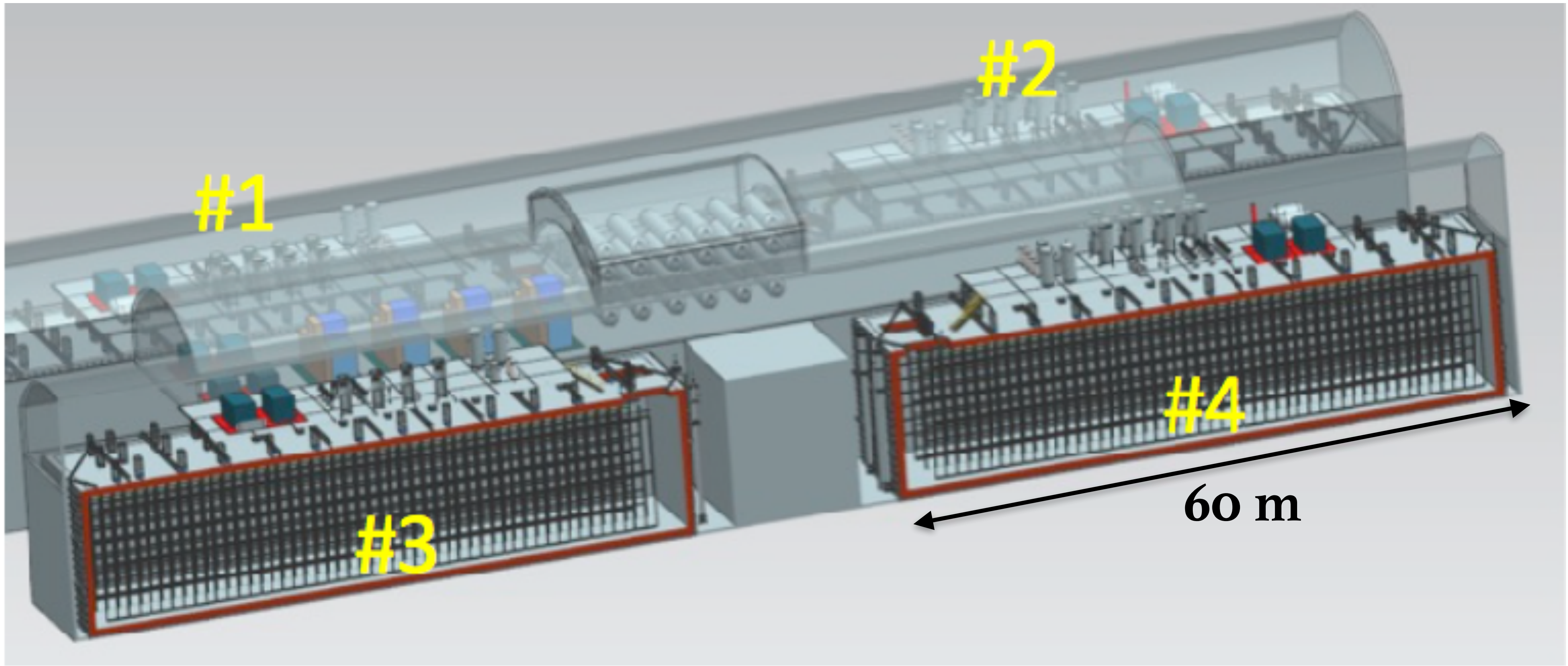
Sanford Underground

Research Facility

(Lead, South Dakota)

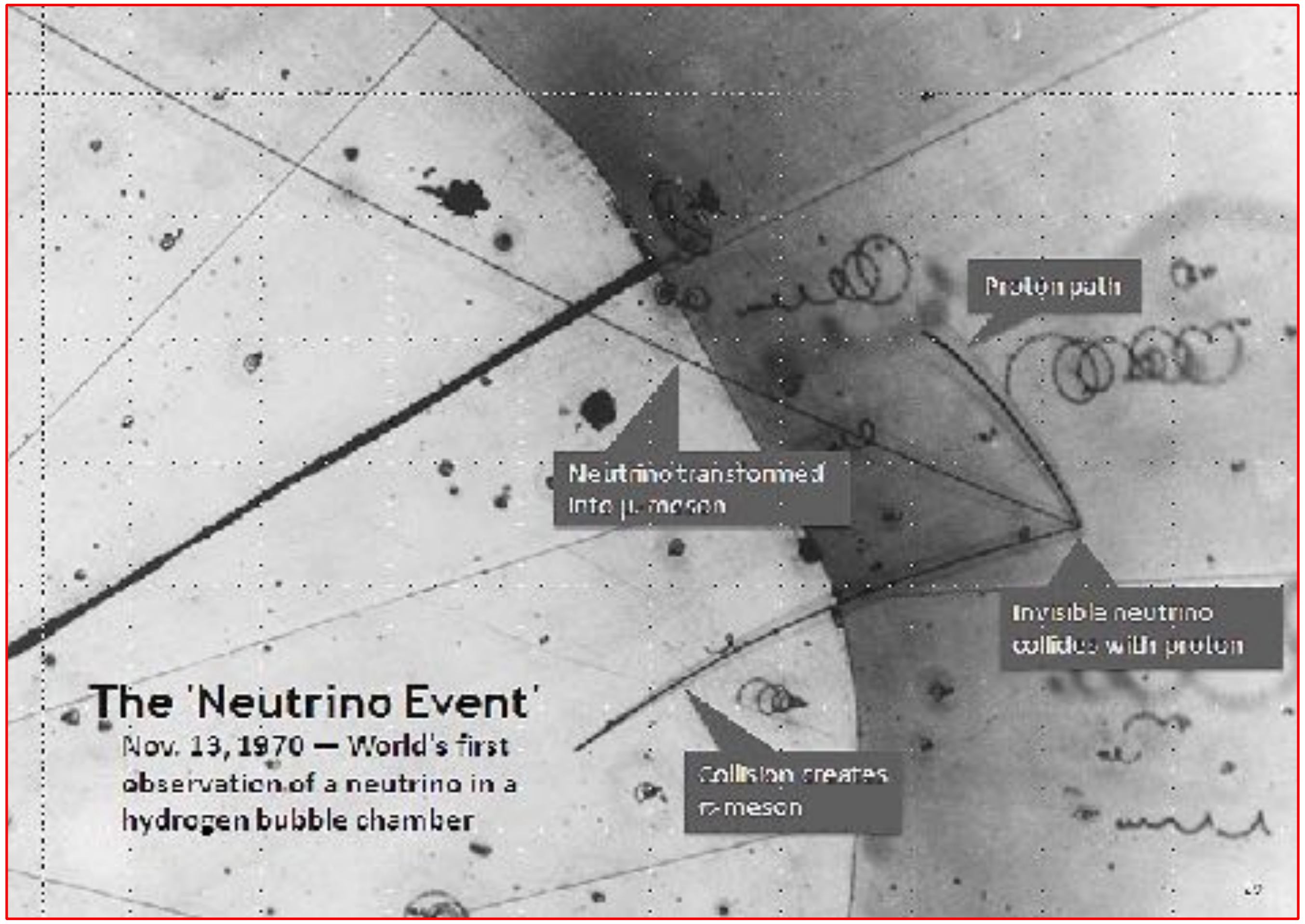
The DUNE Far Detector

- Four identical caverns for four independent Far detector modules, allows for staged approach to 40 kt
  - Plan to deploy first detector in 2024 with subsequent detectors deployed every 2 years after that
  - gives flexibility in detector technology & design
  - Similar (but not identical) 10 kt detector modules — all LArTPCs



Far detector design features

- A highly capable LArTPC
  - Argon makes an excellent target (dense, abundant, cheap etc.)
  - Fine granularity & excellent calorimetry
  - Can separate Signal (υ_e CC) from background (NC π^0)
  - Low energy thresholds
  - Technology allows for scalability → massive detectors



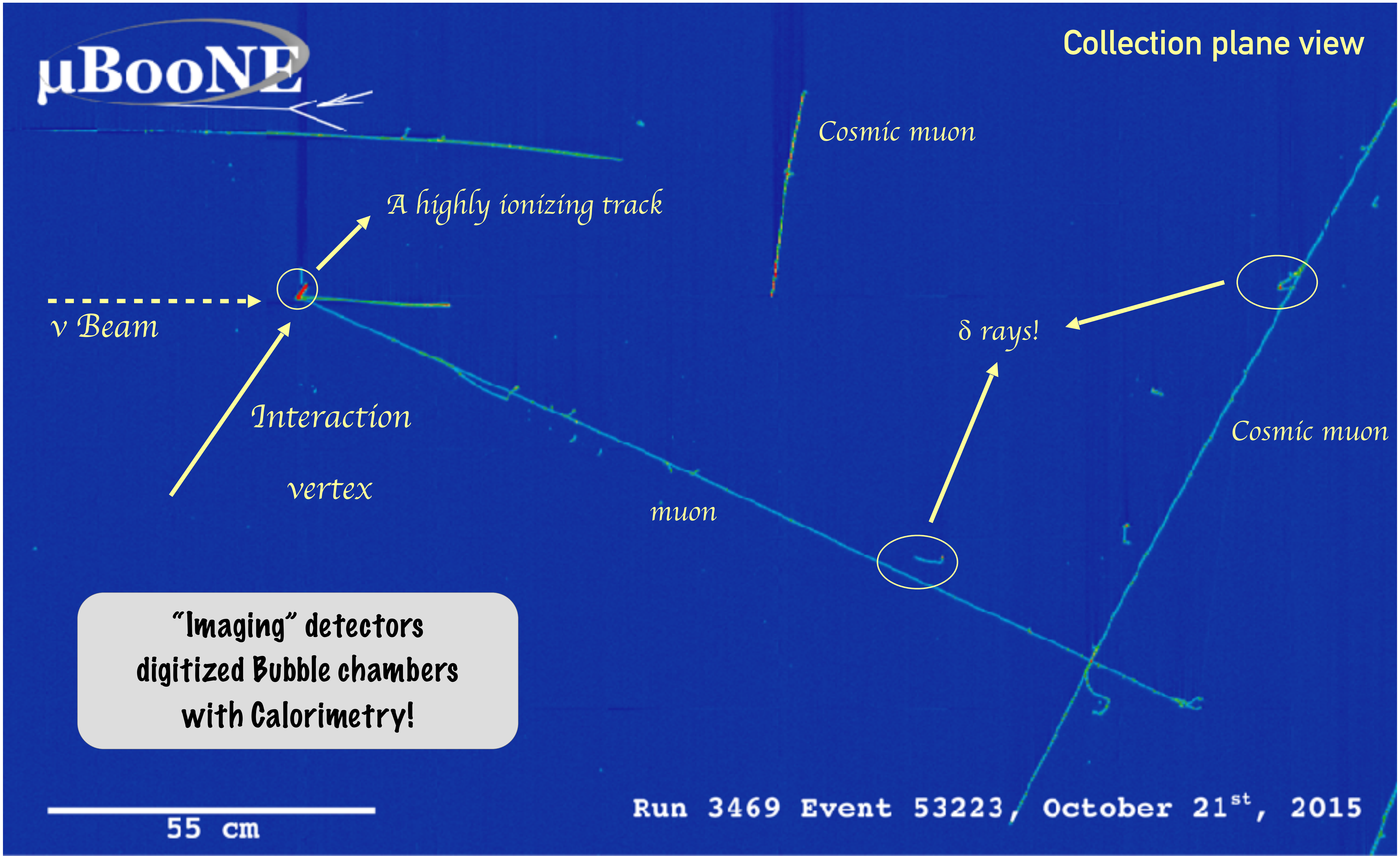
Bonus:

"bubble chamber" quality images

(high resolution — extract maximum information from every interaction)

A neutrino event in the MicroBooNE LArTPC

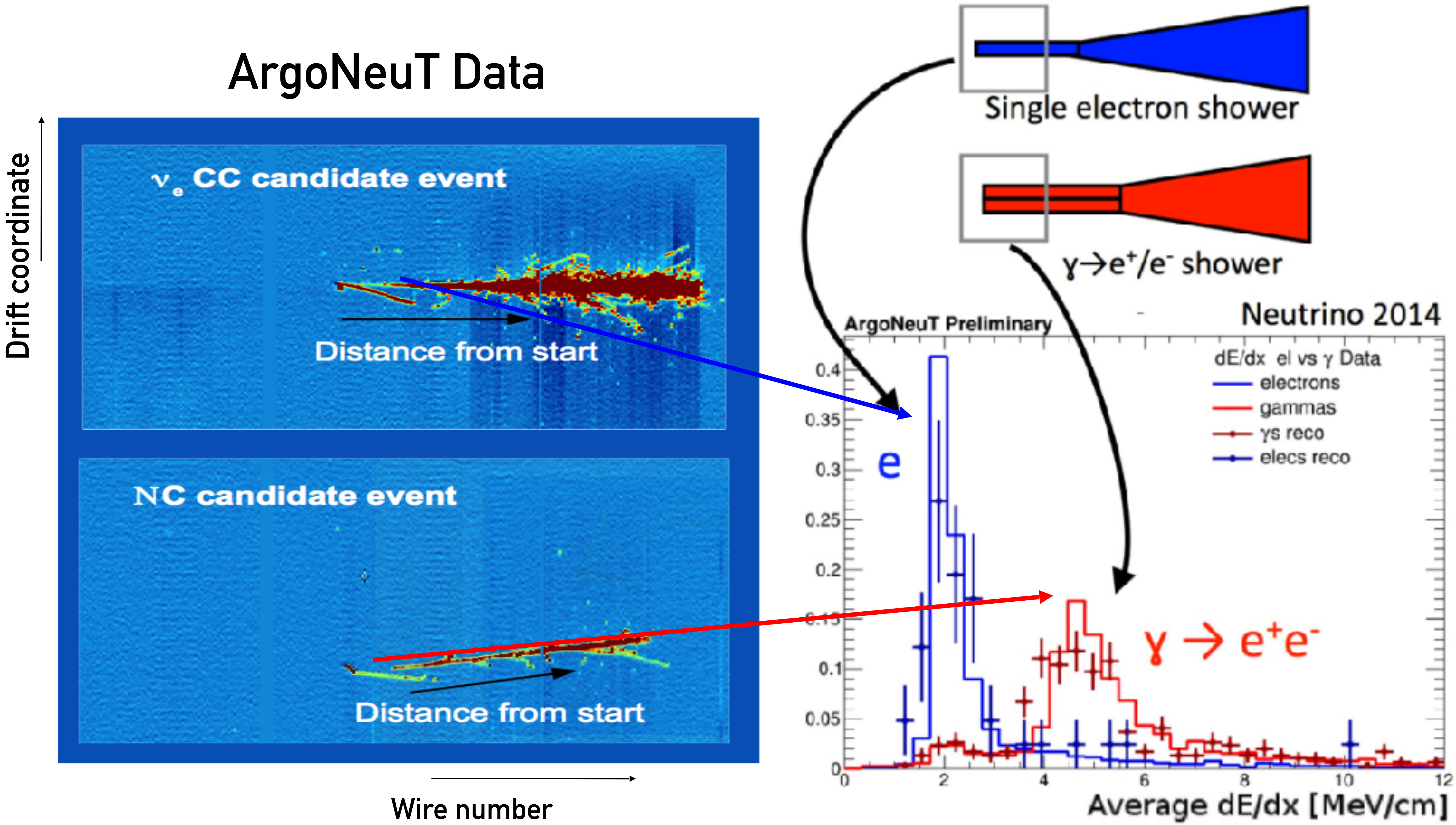
Time direction



Wire direction

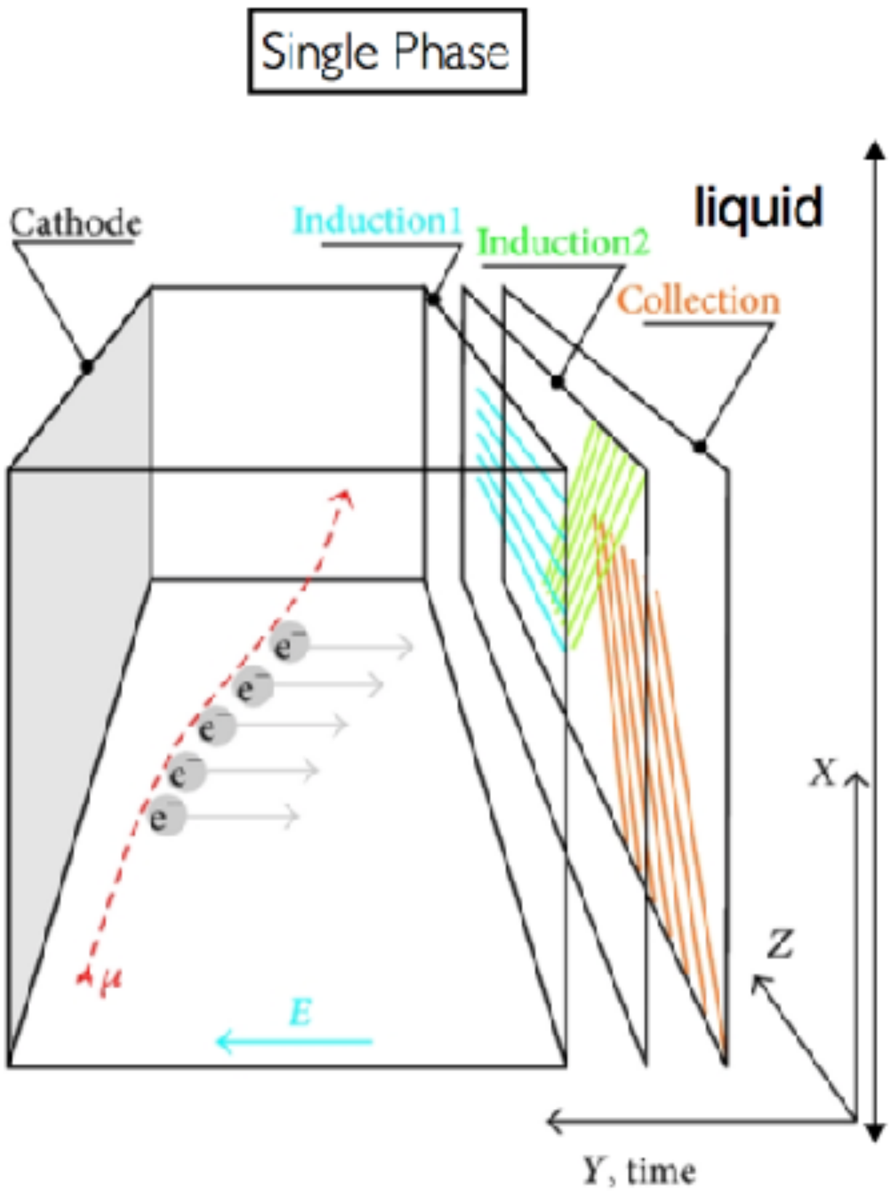
e/γ separation: Benefits of a LArTPC

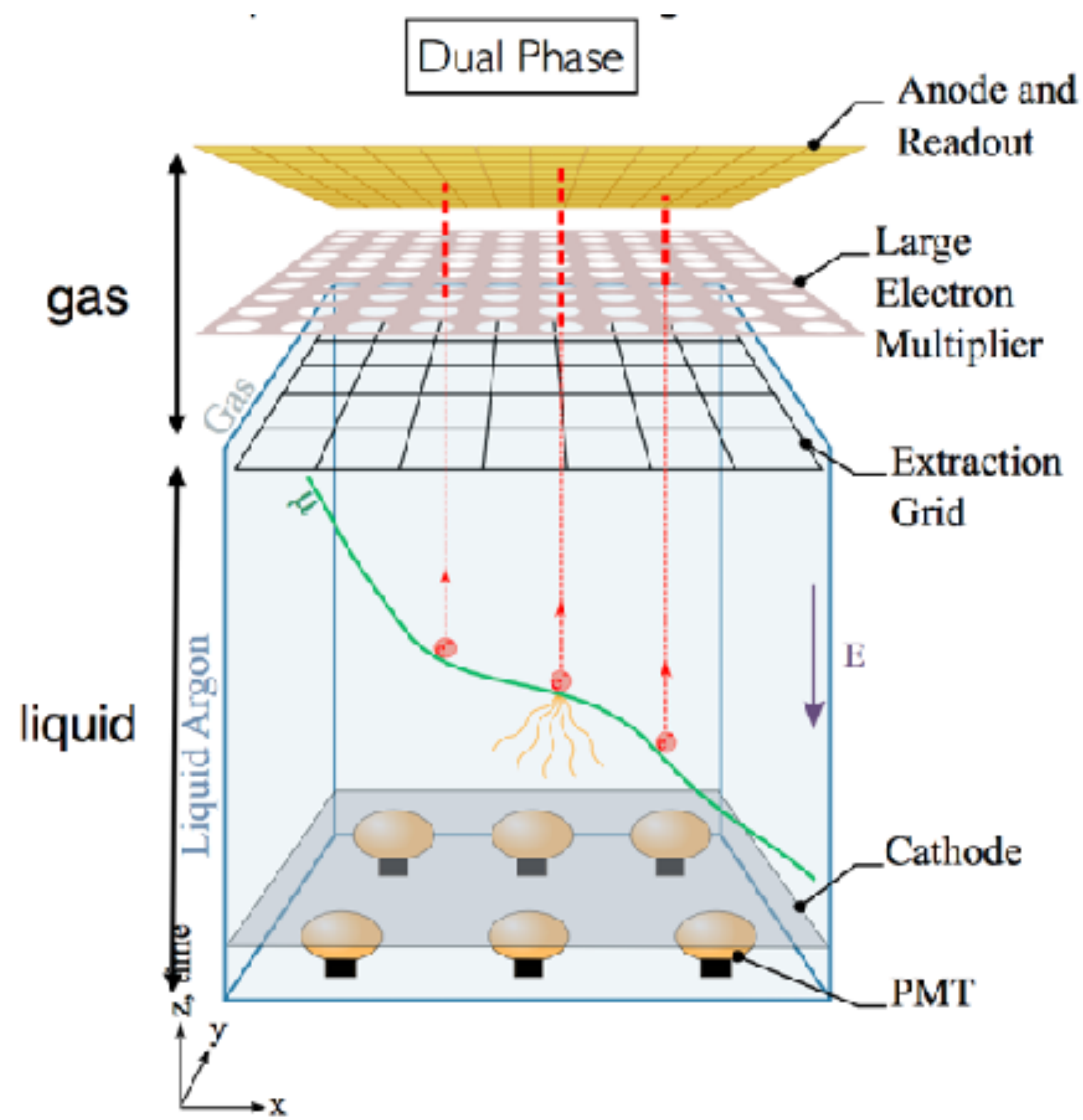
For ν_e Appearance searches, e/γ separation is critical
— Combine topology and charge information



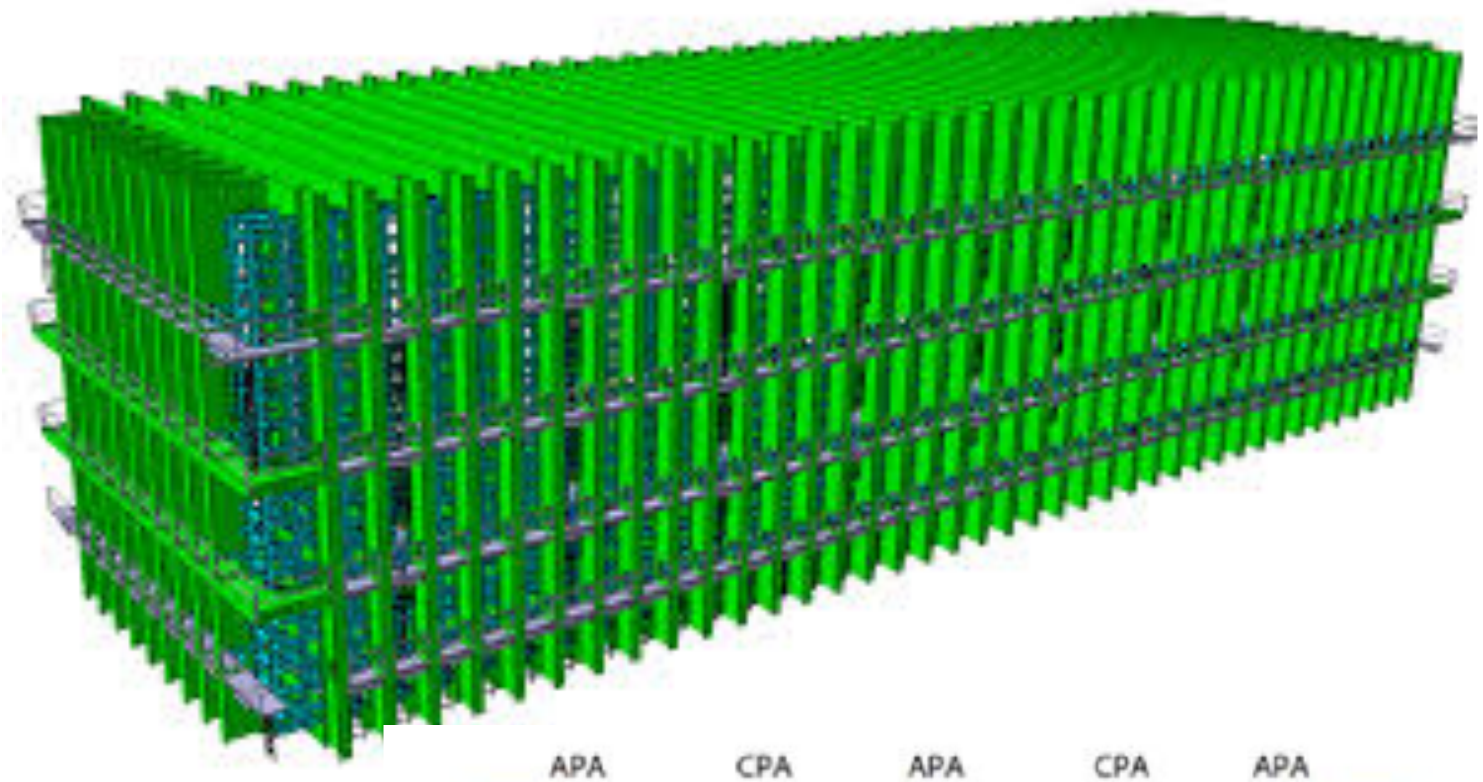
Far Detector Design(s)

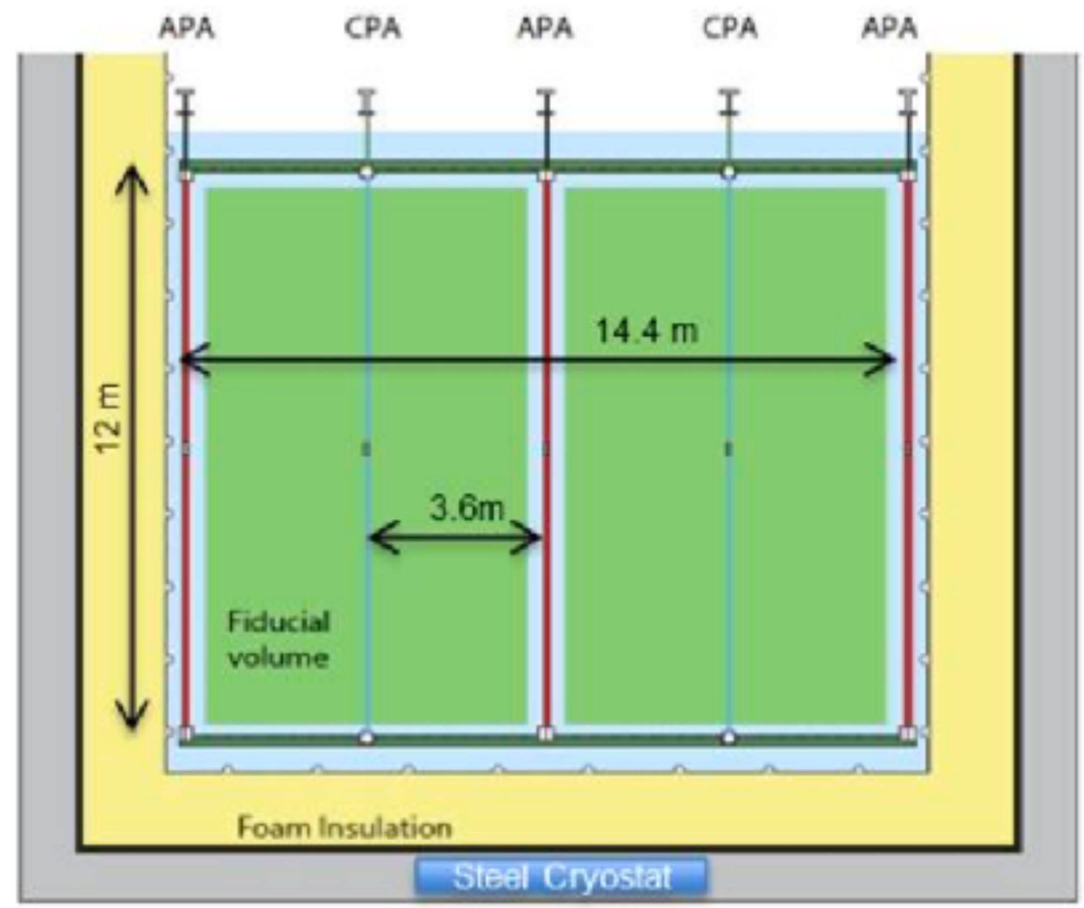
- Two designs under consideration
  - First 10 kt module will be a Single Phase (SP): drift and readout all in liquid phase
  - Second 10 kt module will be a Dual Phase (DP): drift in liquid; amplification and read out in gas





The Single-Phase Far Detector



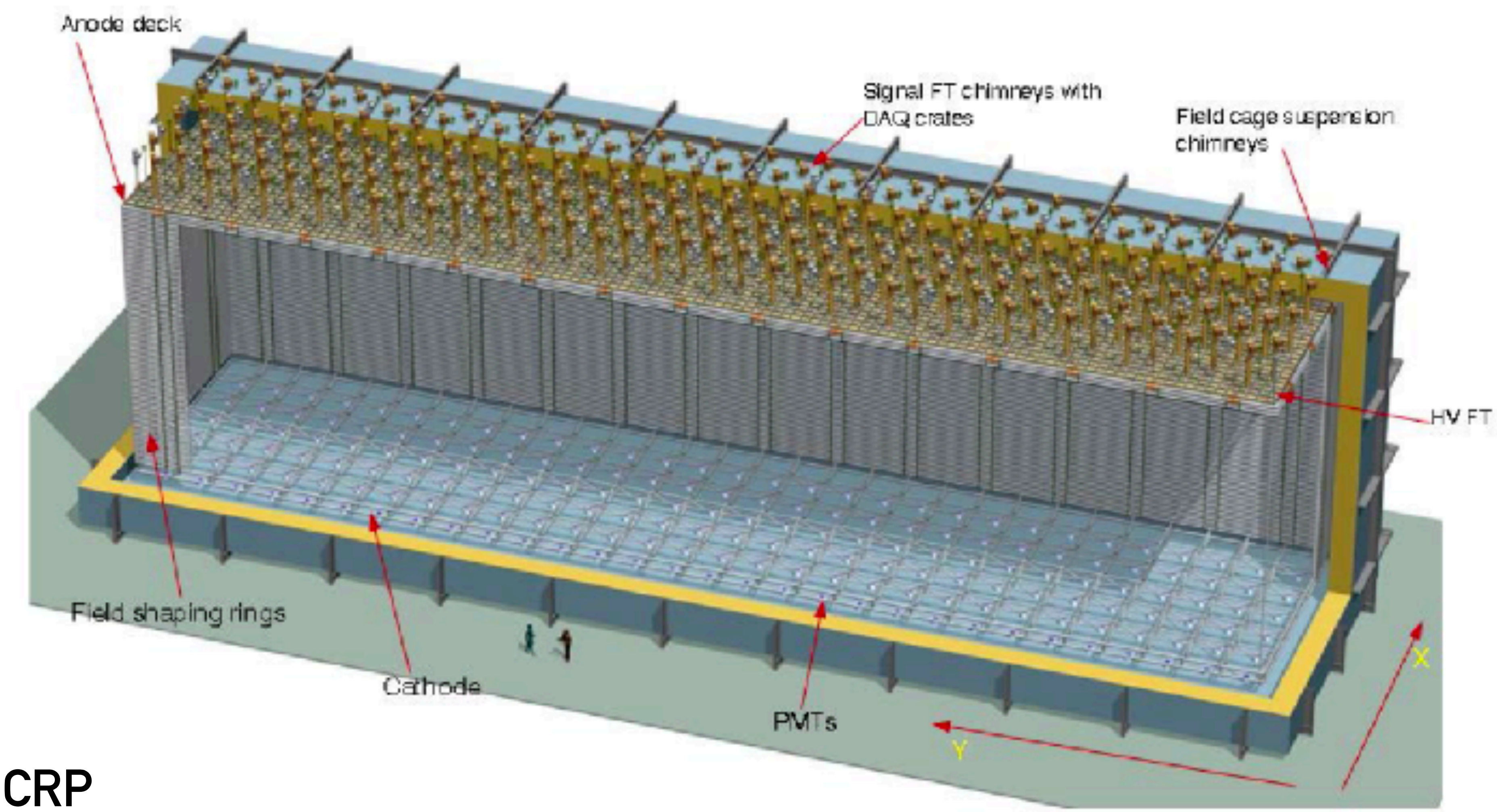


- 12 m x 14 m x 58 m active volume
- Cryostat has membrane design
- 150 APAs with 384,000 readout wires
- Each Anode-Cathode chamber has 3.5 m drift
- Cathode at 180 kV
- Anode planes have wrapped wires (readout on both sides)
- 6000 photon detection system (PDS) channels for light readout

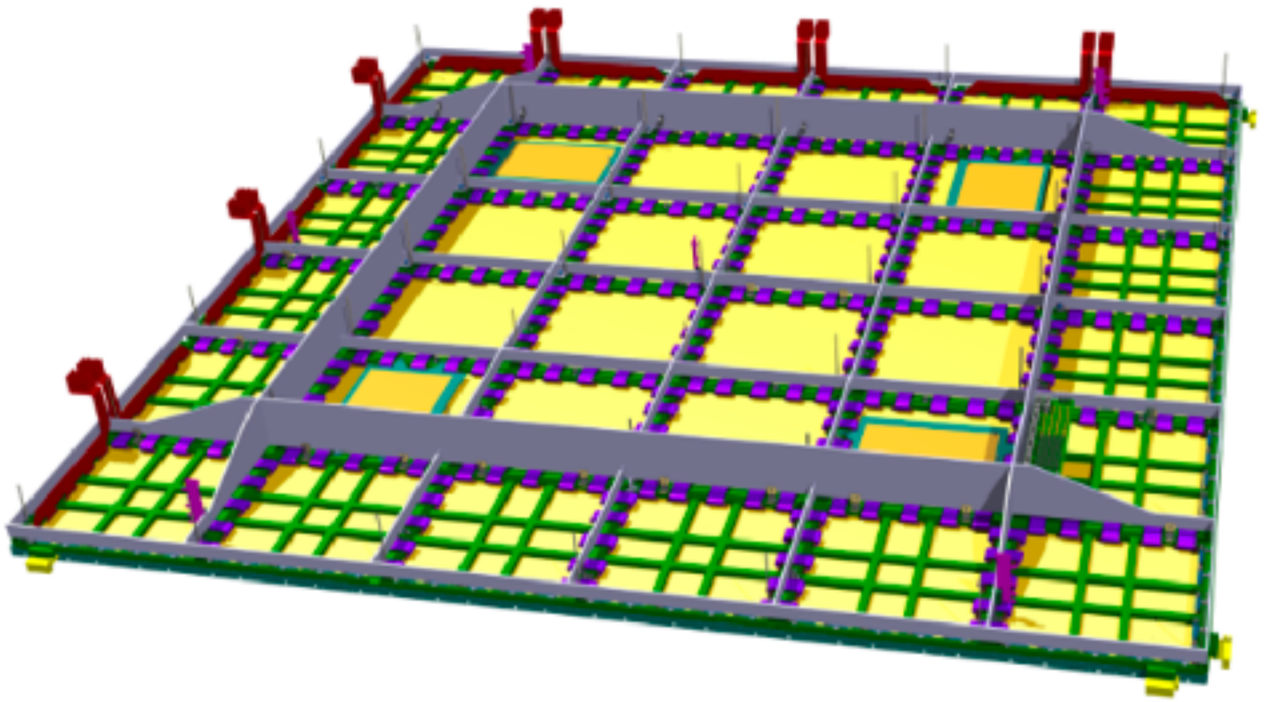
APA = Anode Plane Assembly

CPA = Cathode Plane Assembly

The Dual-Phase Far Detector



A 9 m^2 CRP



- 12 m x 12 m x 60 m active volume
- Larger drift at 12 m and higher fields
- Cathode at 600 kV
- 80 Charge Readout planes (CRP) with 153,600 channels
- 720 PMT Channels for light readout

DUNE Oscillation Physics:

ν_e Appearance & Matter Effects

- A ν_e appearance experiment (in matter) will be sensitive to rich physics (θ_{23}, θ_{13}, δ and matter effects)

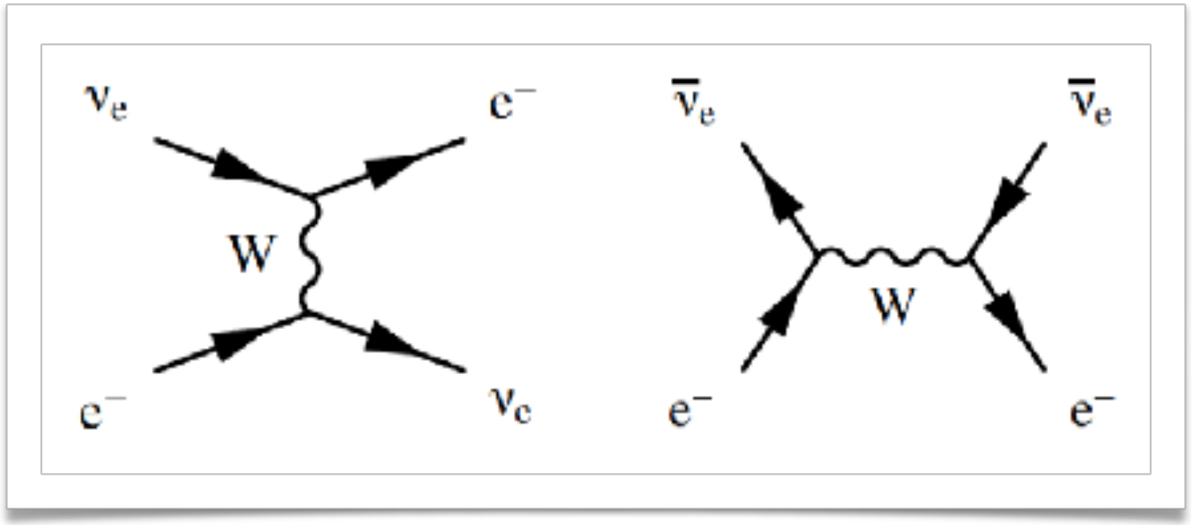
$$P(\nu_\mu \to \nu_e) \simeq \sin^2\theta_{23}\sin^2 2\theta_{13}\frac{\sin^2(\Delta_{31}-aL)}{(\Delta_{31}-aL)^2}\Delta_{31}^2 + \sin 2\theta_{23}\sin 2\theta_{13}\sin 2\theta_{12}\frac{\sin(\Delta_{31}-aL)}{(\Delta_{31}-aL)}\Delta_{31}\frac{\sin(aL)}{(aL)}\Delta_{21}\cos(\Delta_{31}+\delta_{CP}) + \cos^2\theta_{23}\sin^2 2\theta_{12}\frac{\sin^2(aL)}{(aL)^2}\Delta_{21}^2,$$

$$a = G_F N_e/\sqrt{2}$$

$$\Delta_{ij} = \frac{\Delta m_{ij}^2 L}{4E}$$

(For antineutrinos, a → -a and δ → -δ)

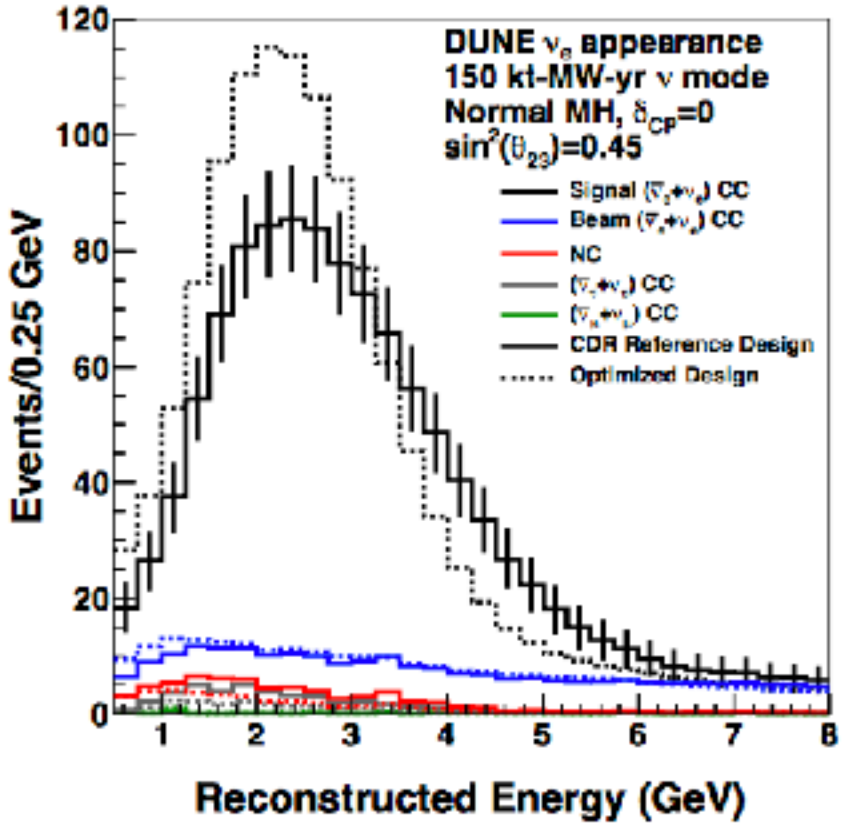
- Neutrinos travel through matter not anti-matter

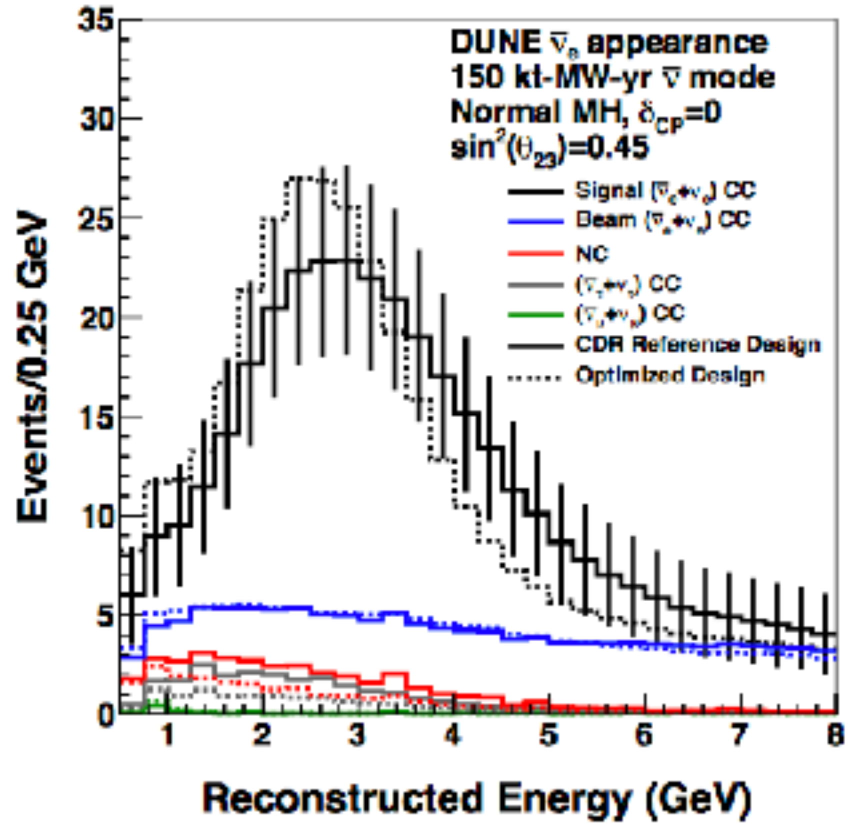


electron density in matter causes asymmetry through forward weak scattering = a hierarchy dependent effect

- Probe CPV by comparing neutrino and anti-neutrino oscillations

Expected Event Rates

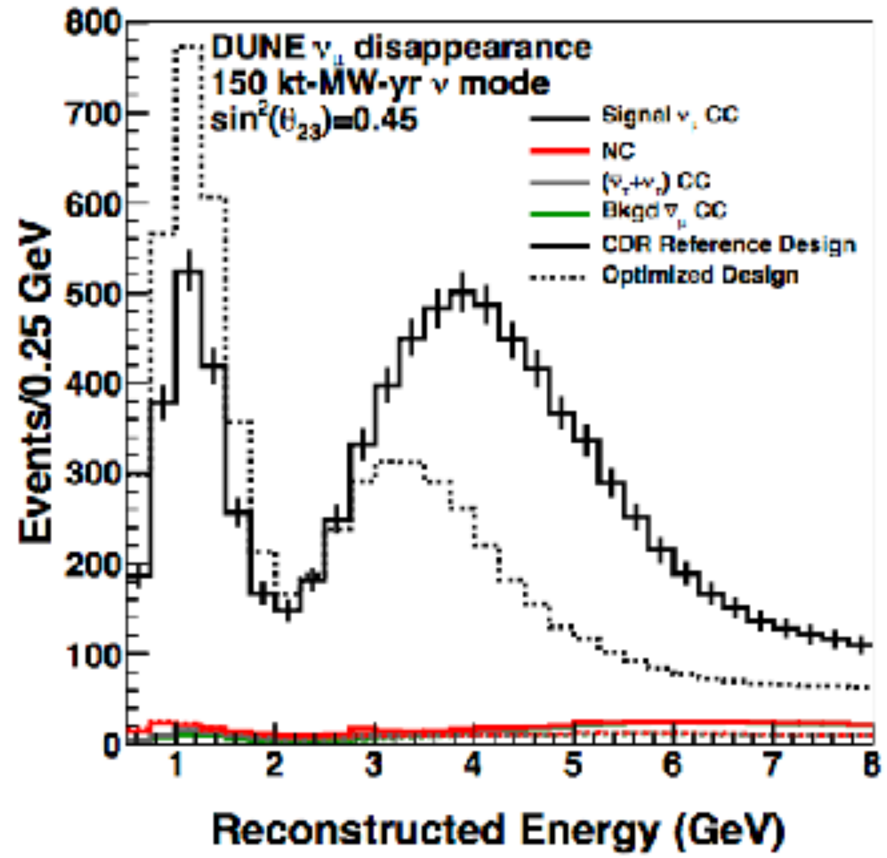


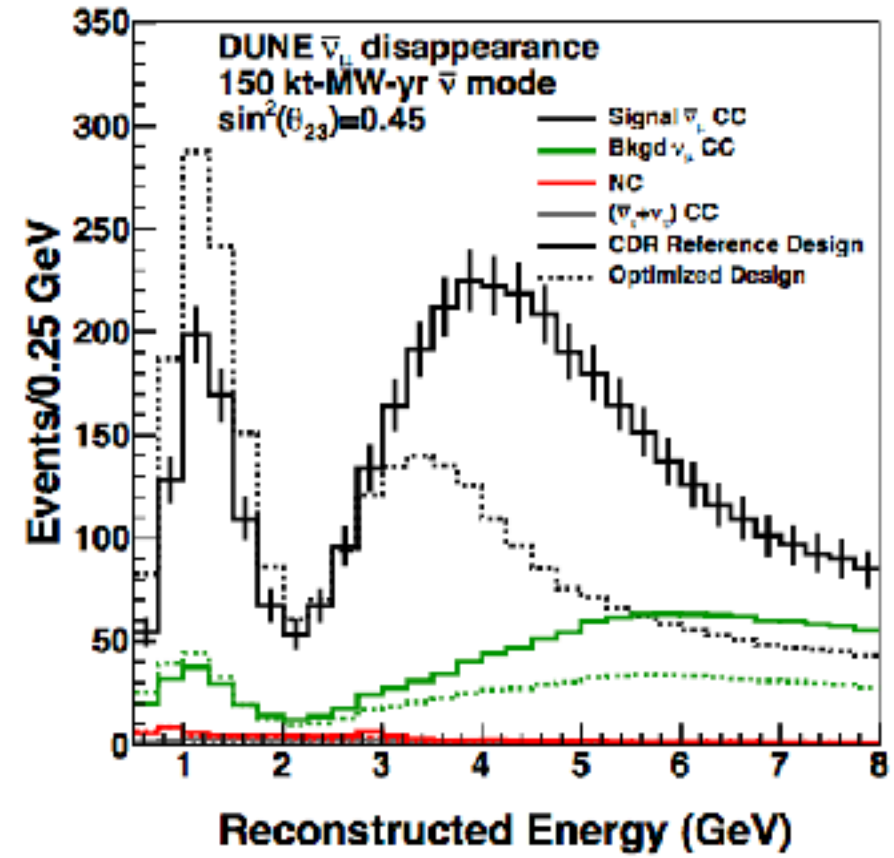


Electron-neutrino Appearance

(~1000 υ_e events with optimized beam)

Muon-neutrino Disappearance



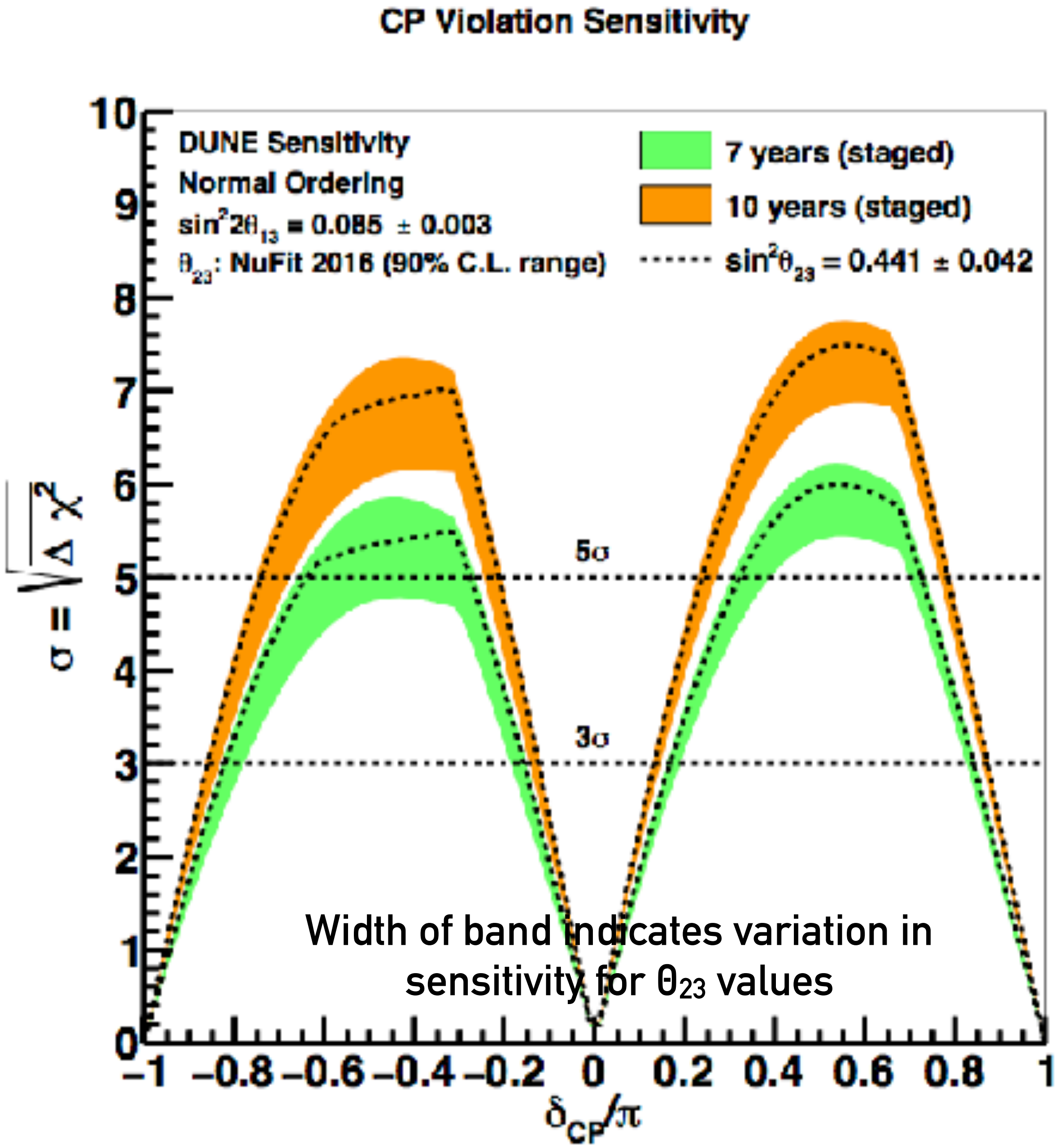


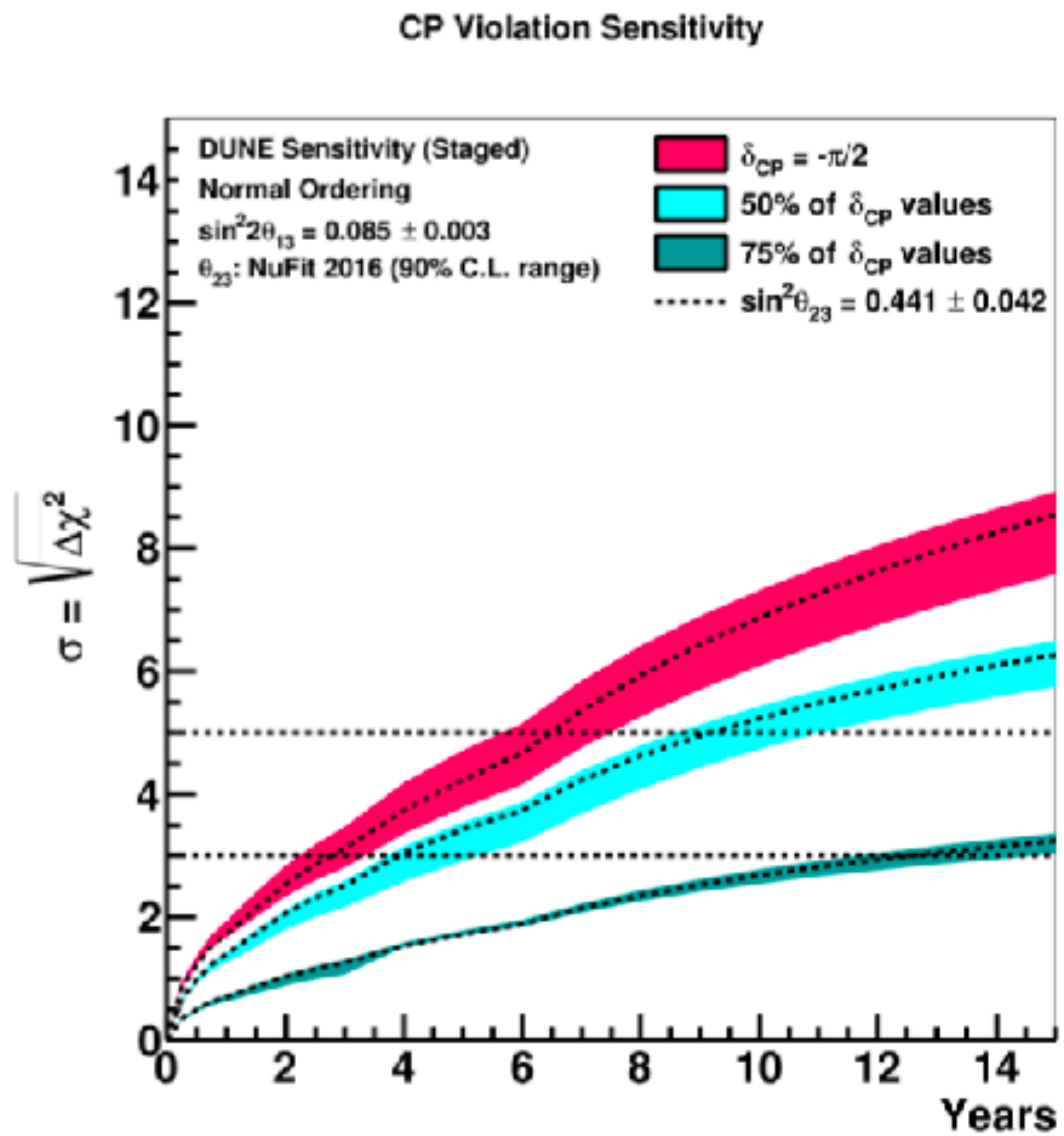
DUNE CDR
https://arxiv.org/pdf/1512.06148.pdf

CP Violation Sensitivity

- Sensitivities computed using GLOBES
- Assumes equal running in neutrino and antineutrino mode and staging
  - 75% of $\delta = -\pi/2$ at 5σ in 6.5 years
  - 50% of δ range at 5σ in 9 years
  - 75% of δ range at 3σ in 12.5 years

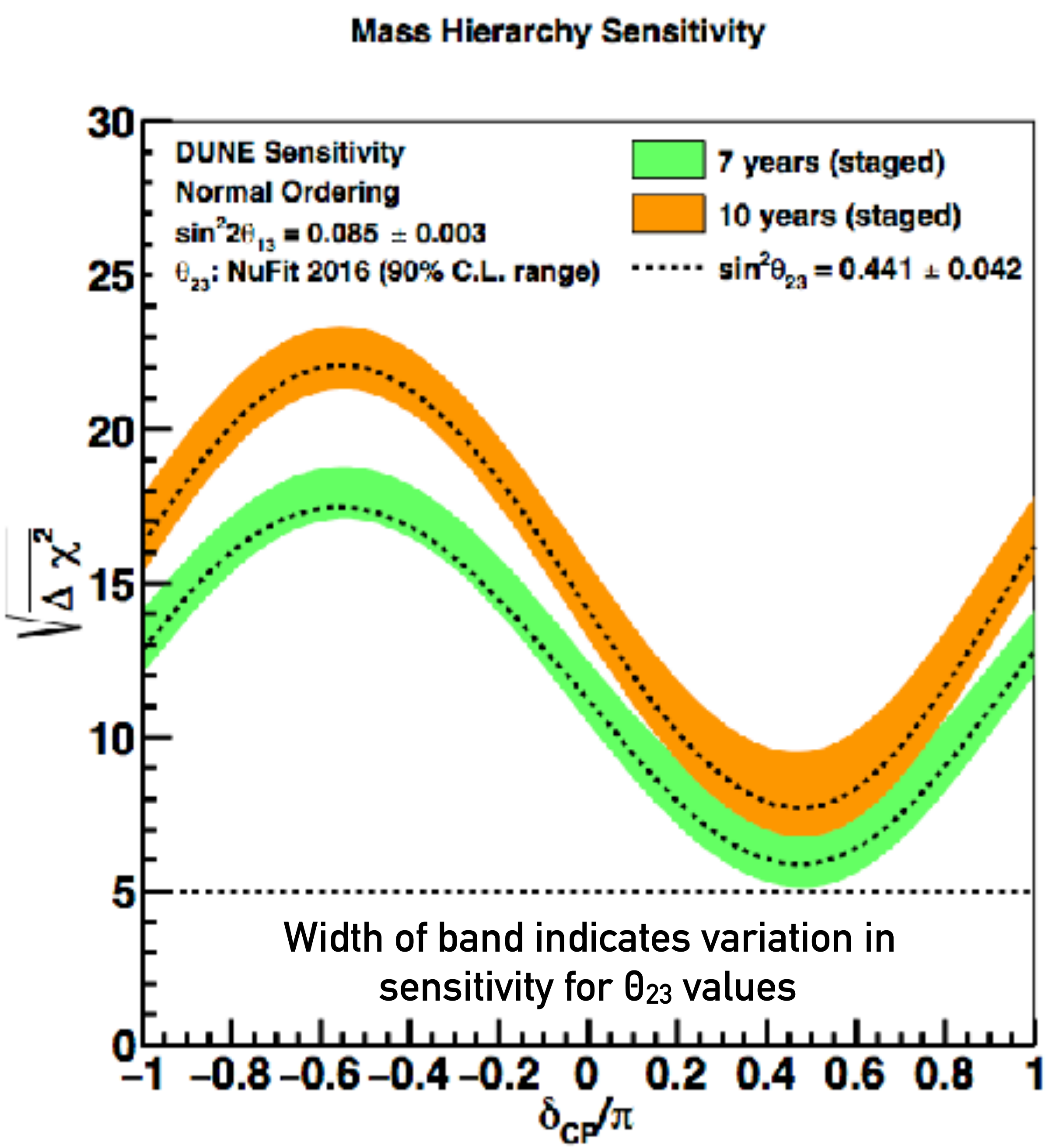
Significant milestones all through the beam program!

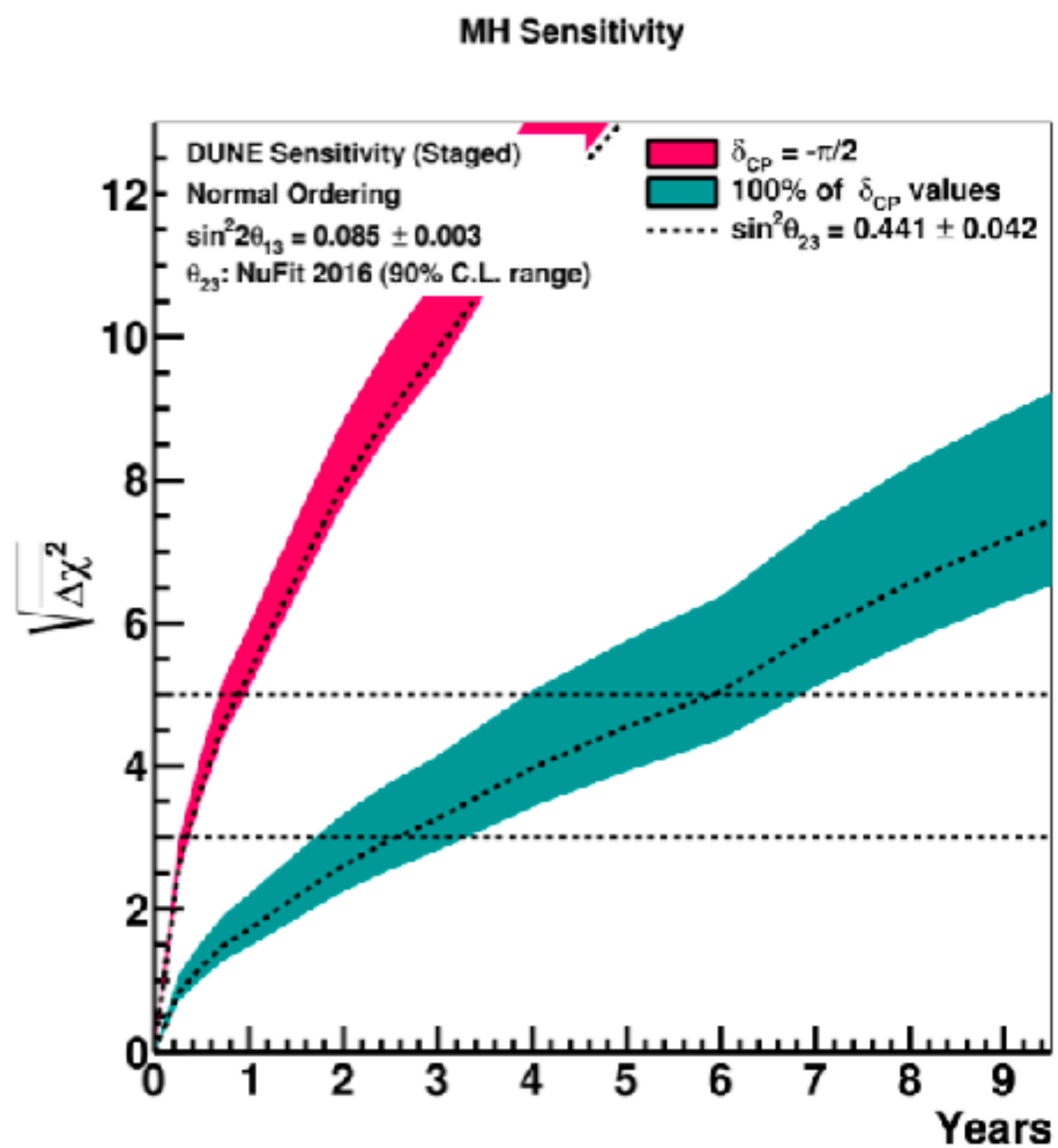




Mass Hierarchy Sensitivity

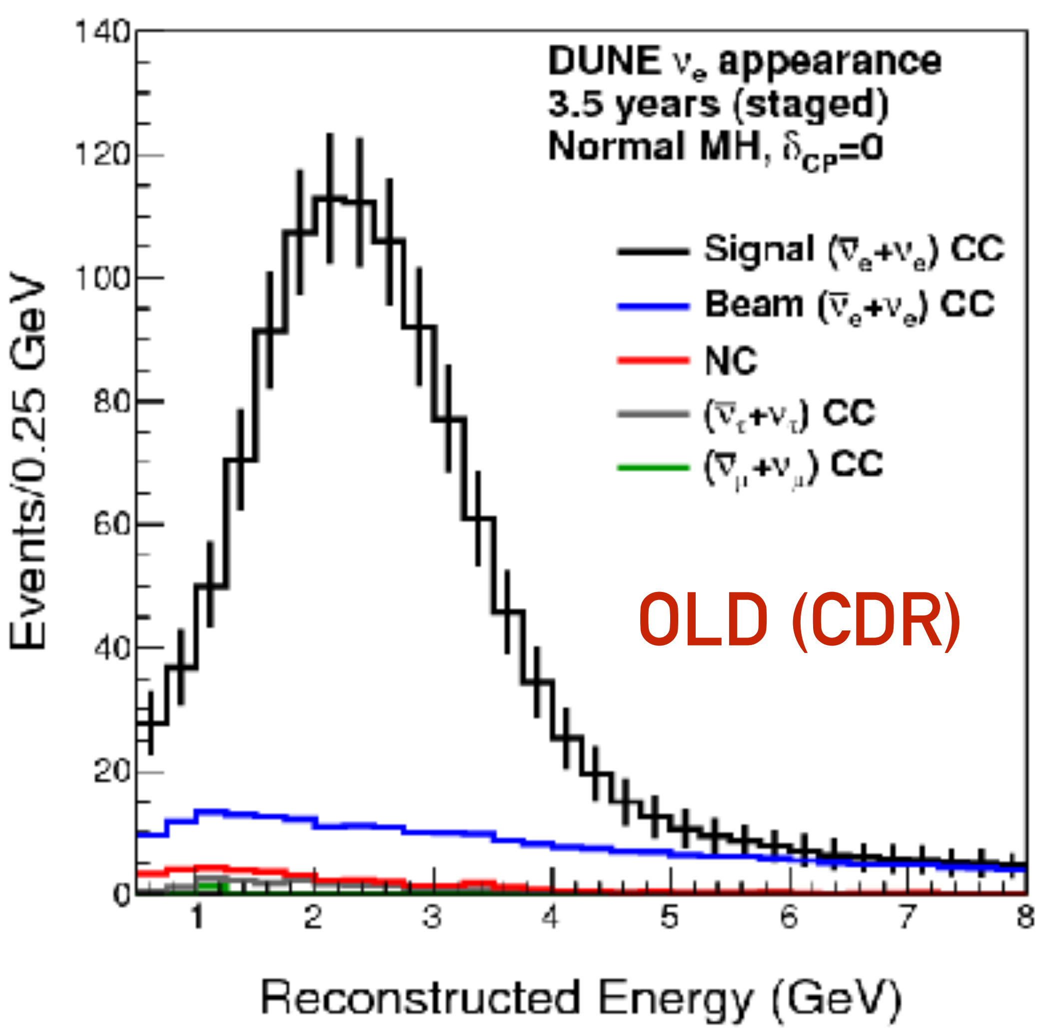
- Assumes equal running in neutrino and antineutrino mode and staging
- In 7 years,
  - definitive MH determination for the overwhelming majority of the δ_{CP} and $\sin^2\theta_{23}$ parameter space

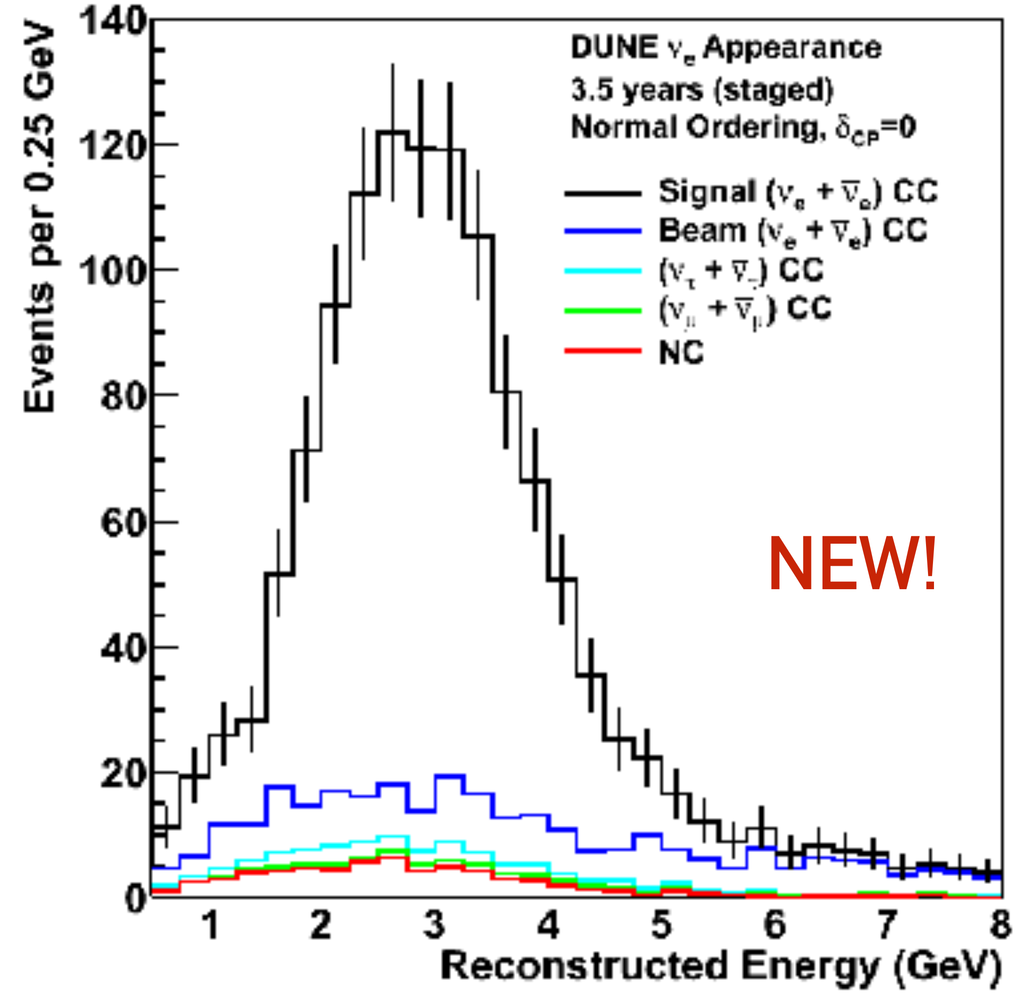




Improved Monte Carlo studies

- New sensitivity based on simulation using fully automated reconstruction and event selection exceeds CDR sensitivity
  - Convolutional Visual Network (CVN) selection techniques used for event categorization and υ_e selection
- Full update planned for TDR in 2019!



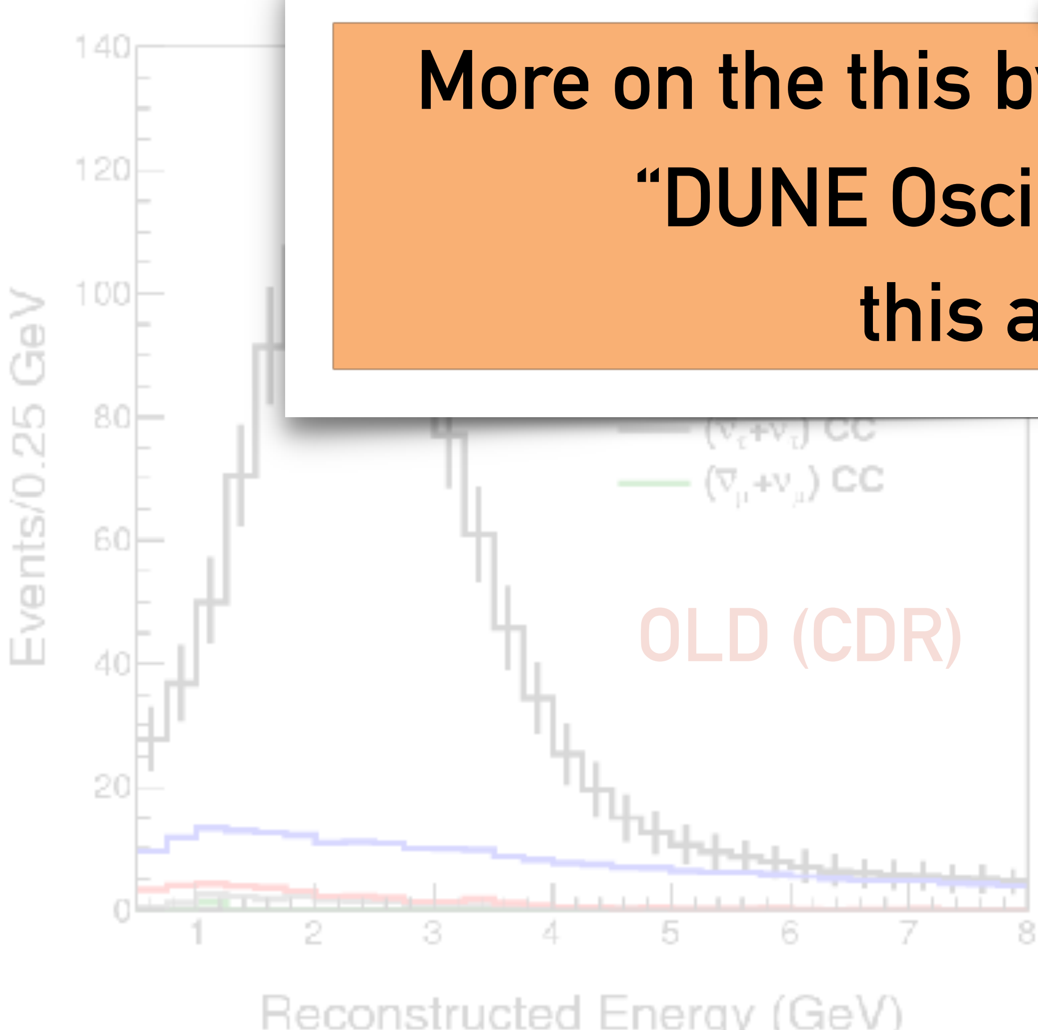


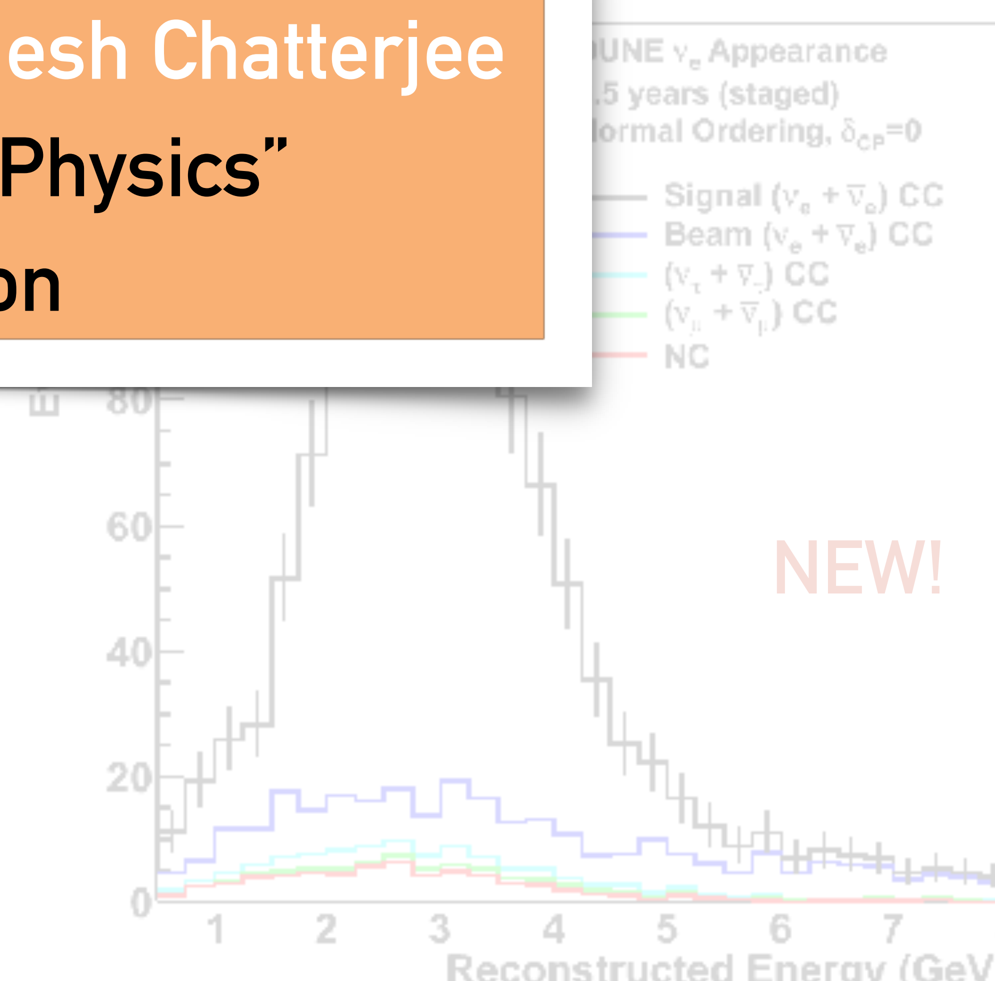
Improved Monte Carlo studies

- New sensitivity based on simulation using fully automated reconstruction and event selection exceeds CDR sensitivity
  - Convoluted Visual Network (CVN) selection techniques used for event categorization and υ_e selection

- Full update planned for TDR in 2019!

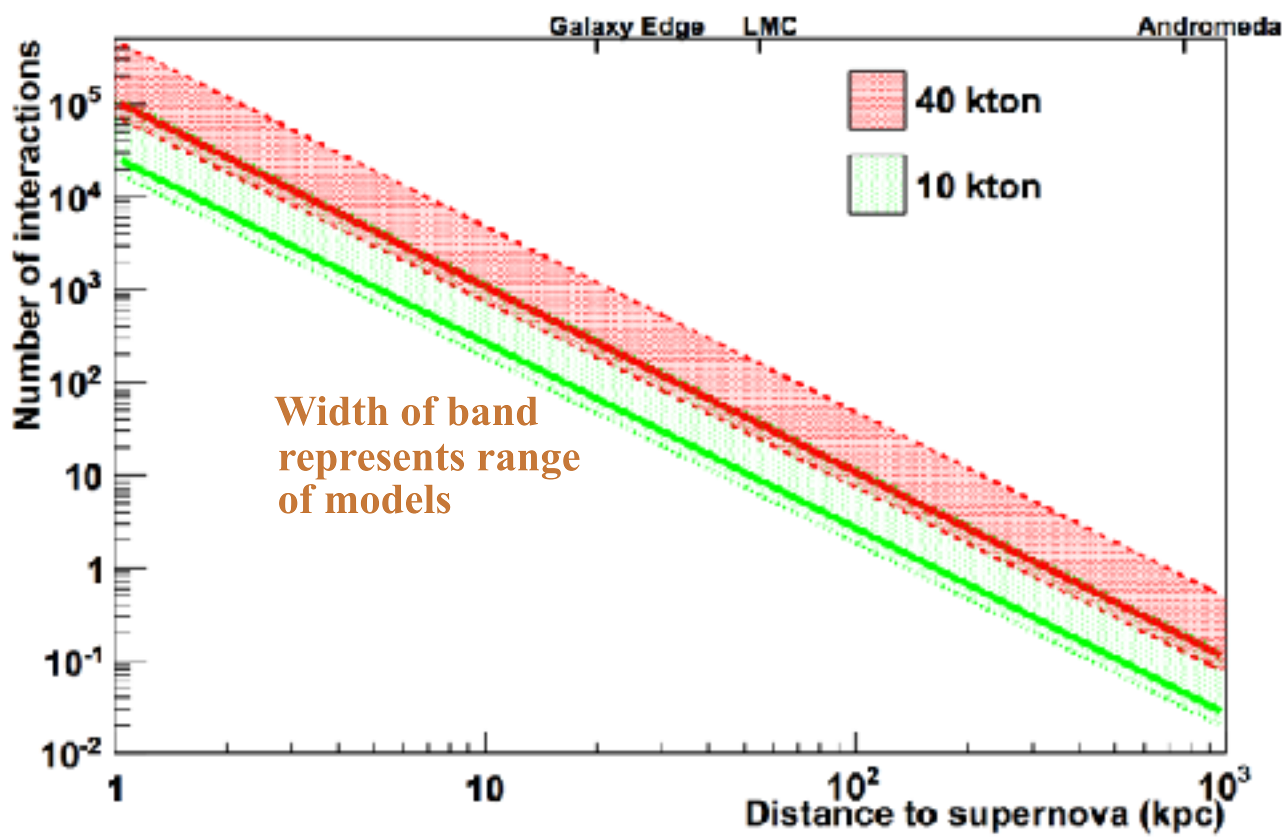
More on the this by Animesh Chatterjee
“DUNE Oscillation Physics”
this afternoon

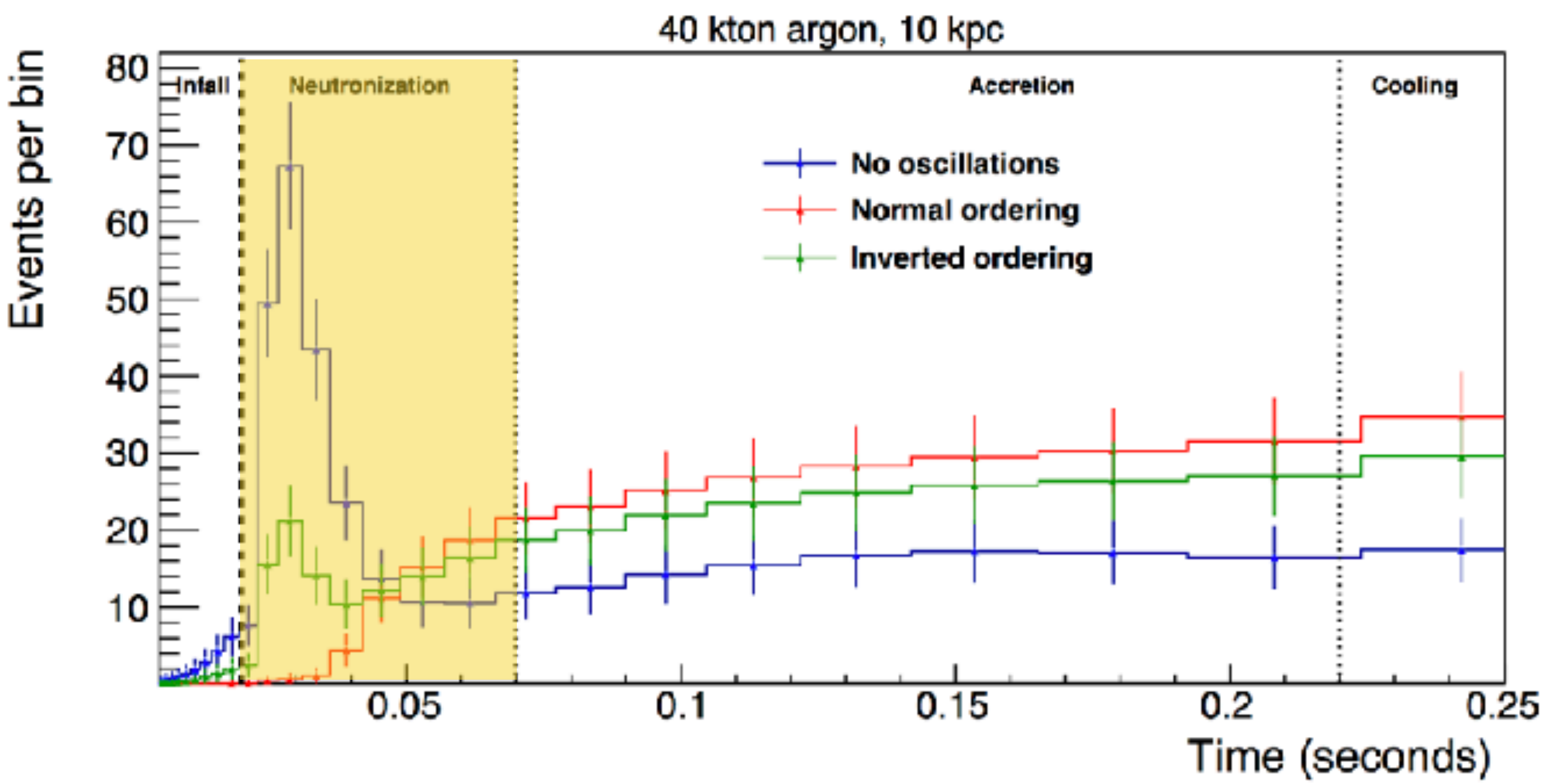




DUNE Supernovae Physics

- LArTPCs posses unique capability to detect SN electron neutrinos: CC ν_e capture of SN neutrinos on Ar: $\nu_e + Ar^{40}(18) \rightarrow K^{40}(19) + e^-$
- Detection requires sensitivity to low energy gammas (<50 MeV) and electrons



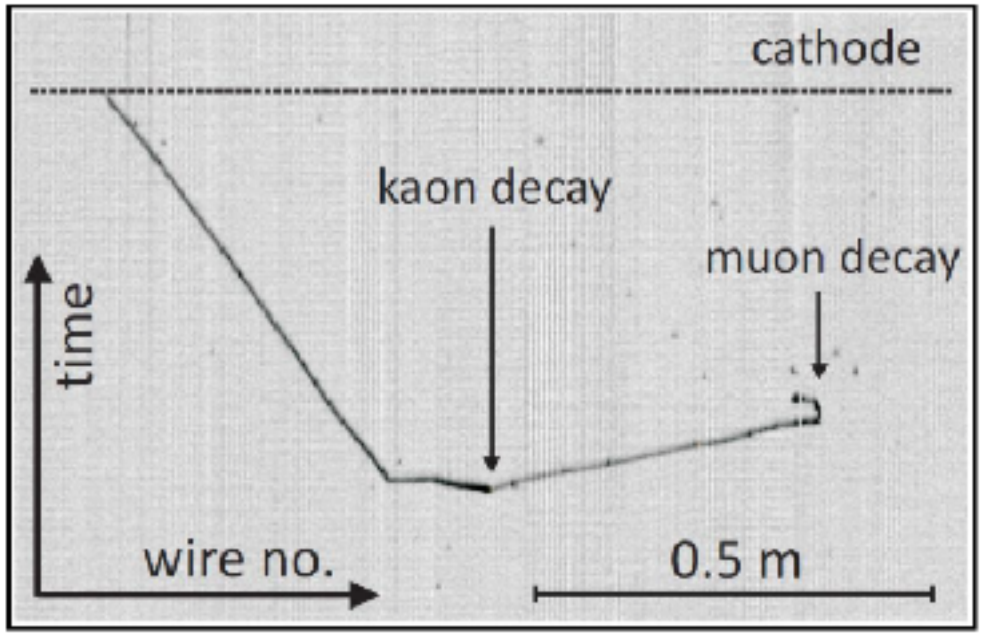


Early development of the signal is sensitive to neutrino mass ordering

Other Physics Searches

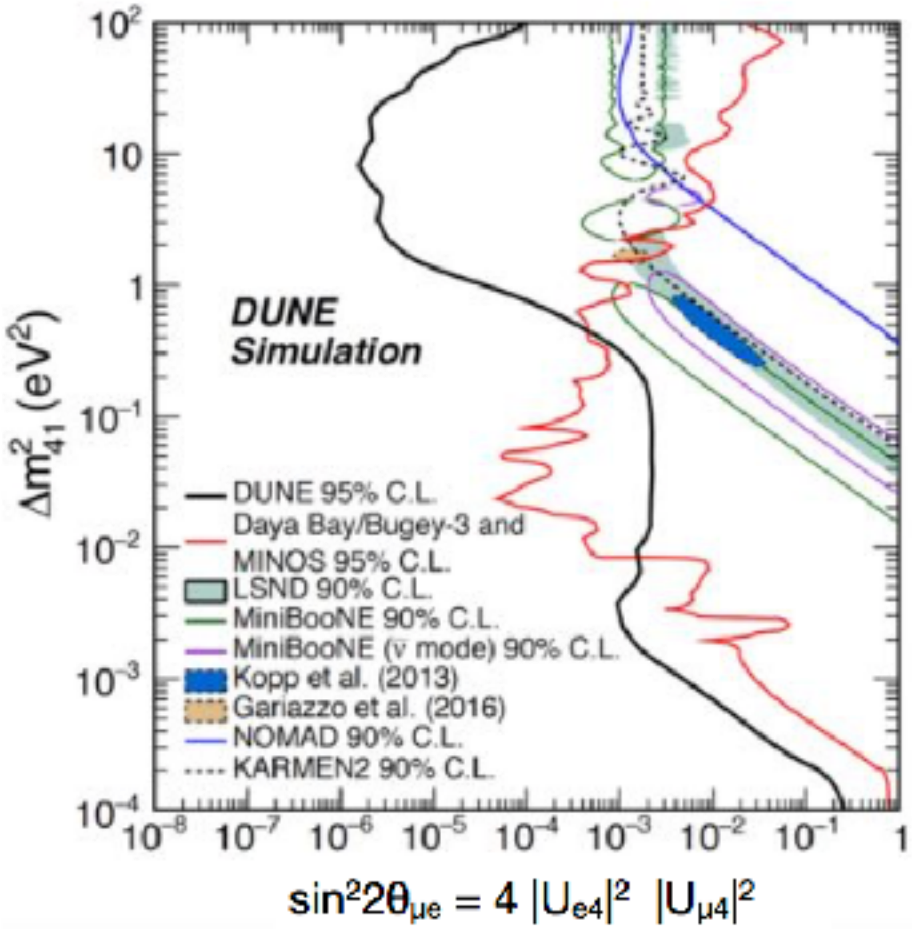
- Baryon Number non-conservation: nucleon decay and neutron-antineutron oscillations
  - Some GUT models explicitly break the baryon number symmetry predicting proton decay
  - proton lifetime is too long $\tau > 10^{33}$ years
  - But, huge detector, large exposure (20+ year program) — watch many protons for a single decay

ICARUS collab., Adv. HEP, vol. 2013, 260820 (2013)

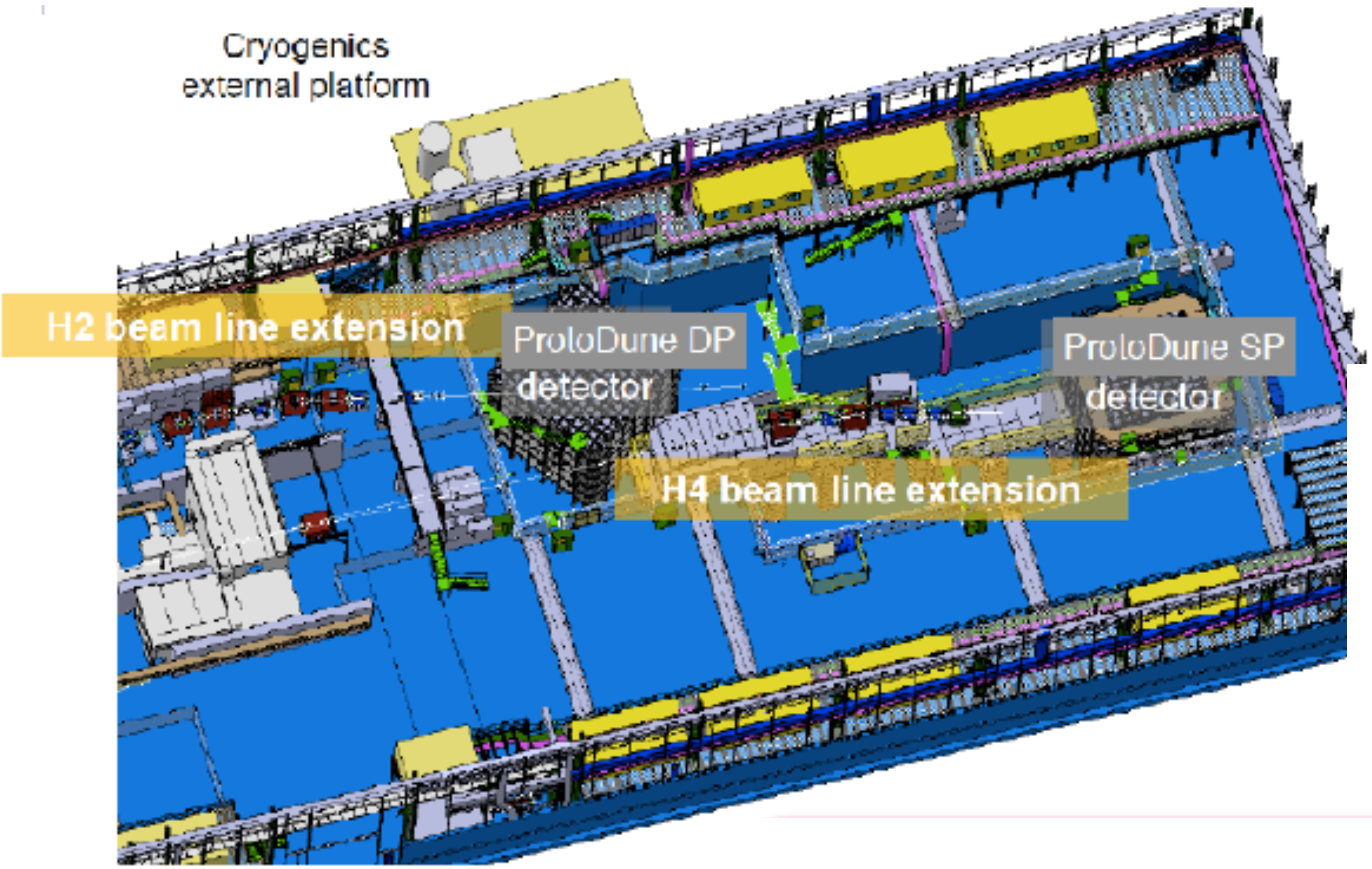


- Many Beyond the Standard Model searches possible at DUNE
  - Dark Matter
  - Sterile Neutrinos
  - Large Extra Dimensions
  - Non-standard Interactions
  - ….

(ν_eCC appearance at Near detector)



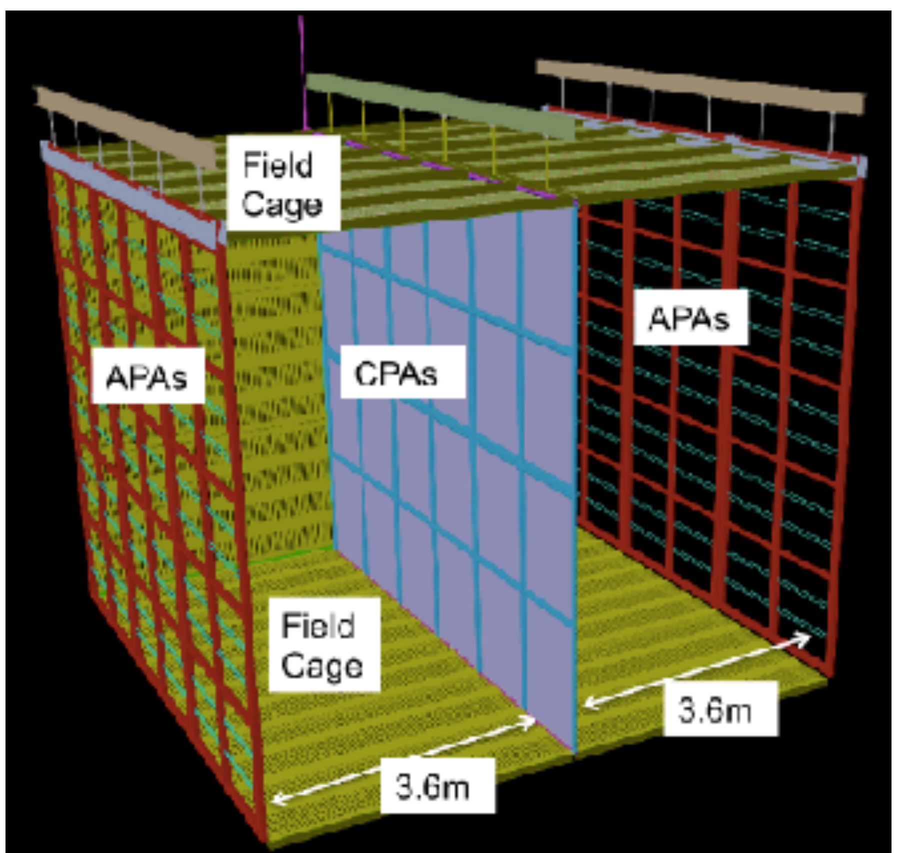
DUNE Prototypes @ CERN



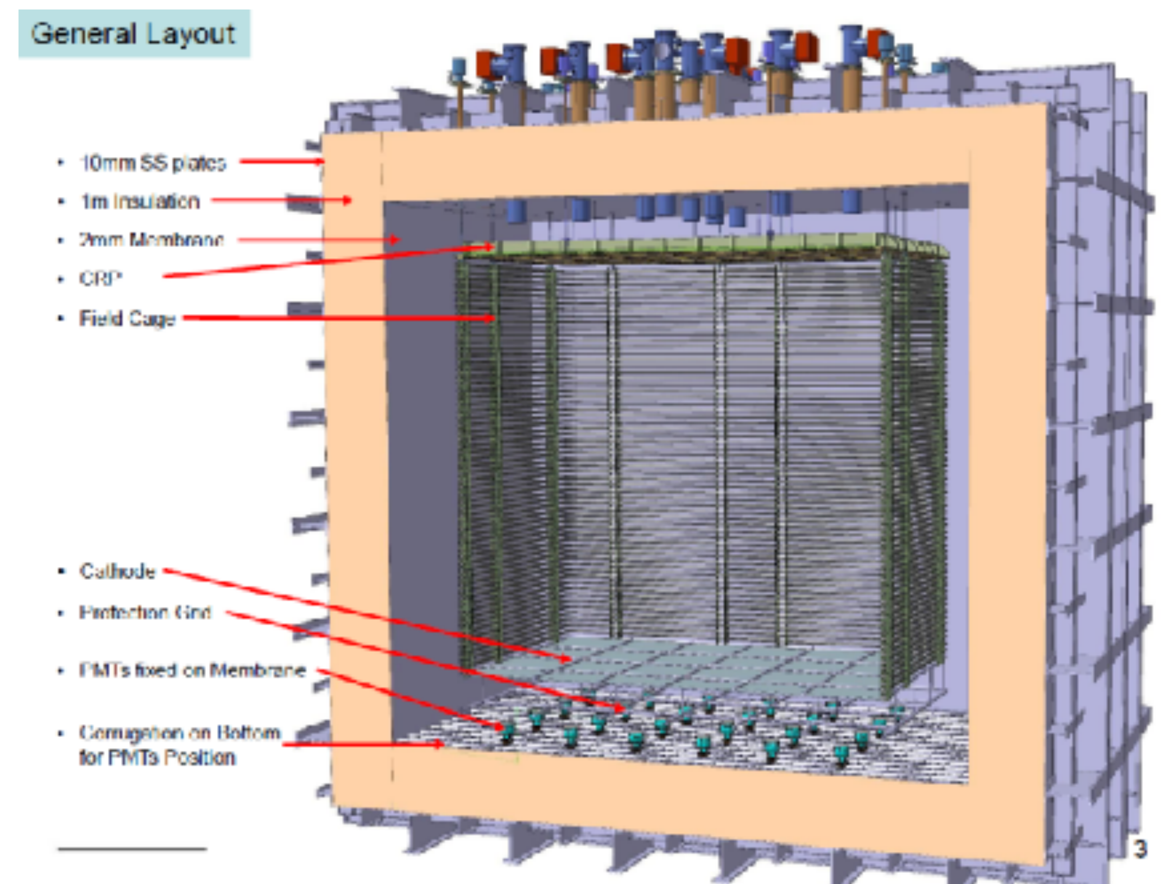
ProtoDUNE goals:

- Design validation, Operation & Performance
- Test beam data to understand detector response & Particle ID

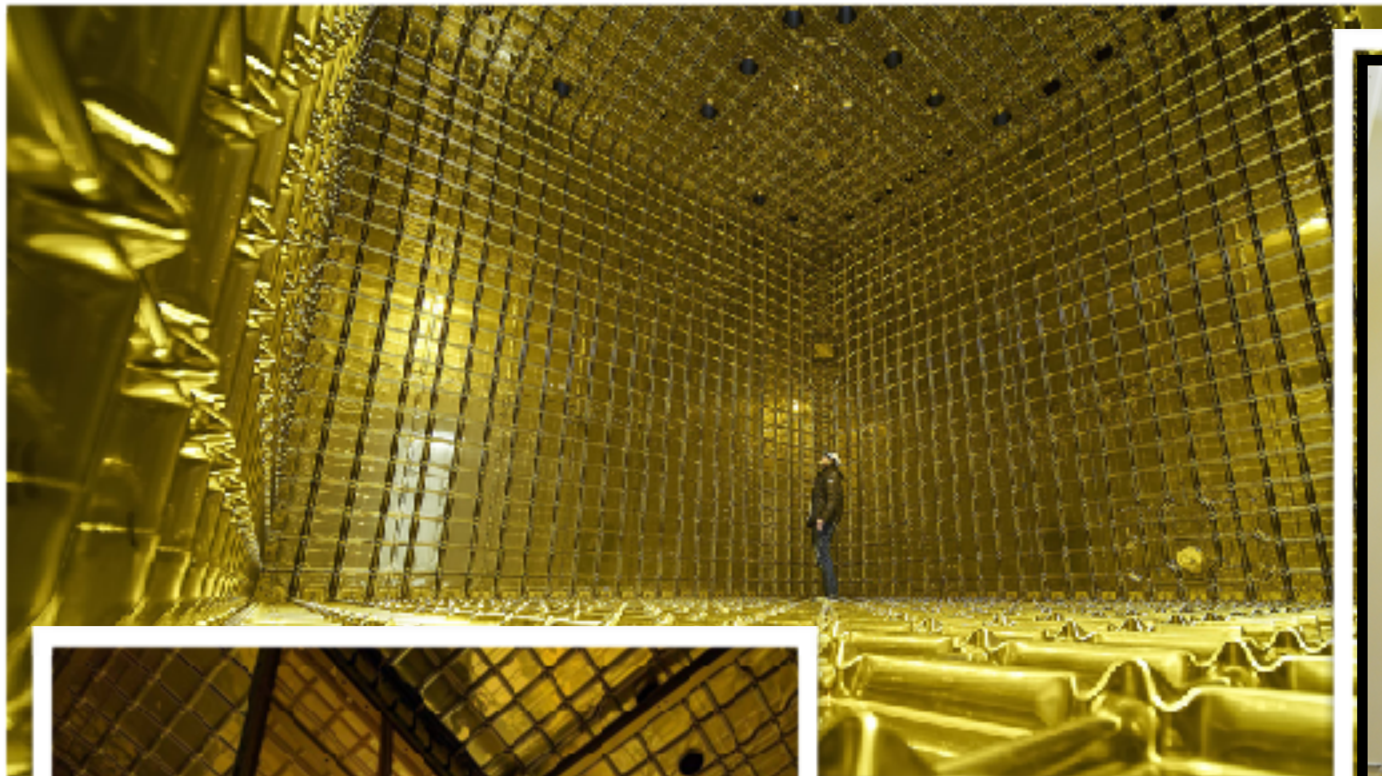
ProtoDUNE-SP 6 x 7 x 7 m^3

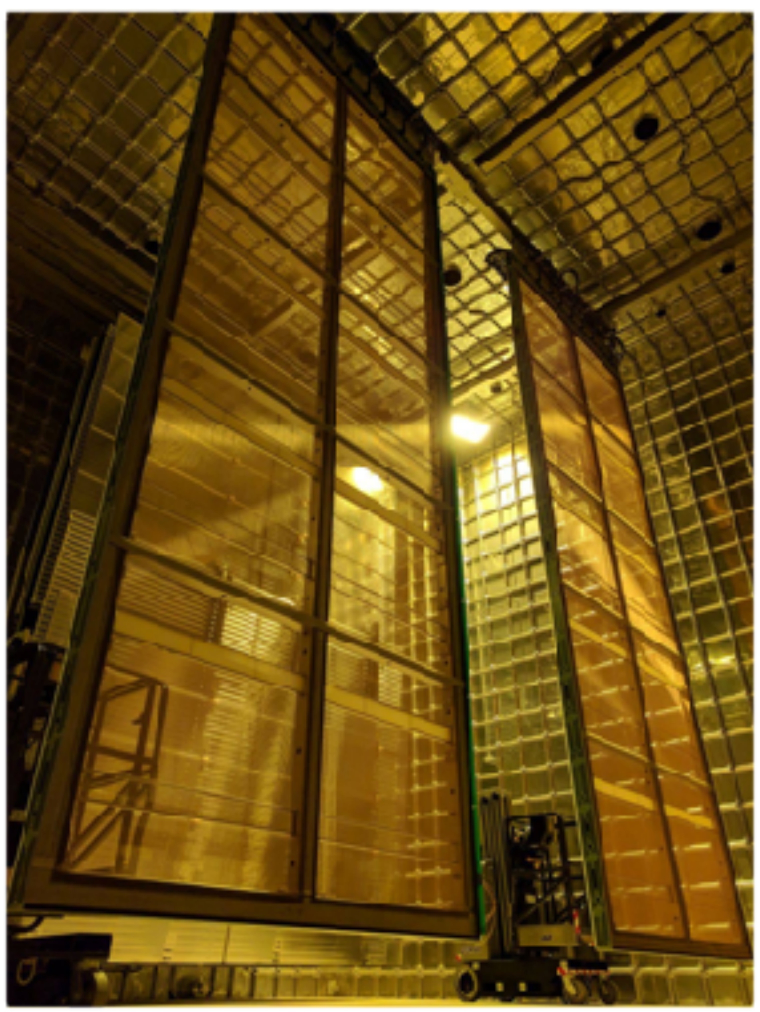


ProtoDUNE-DP 6 x 6 x 6 m^3



ProtoDUNE-SP Status

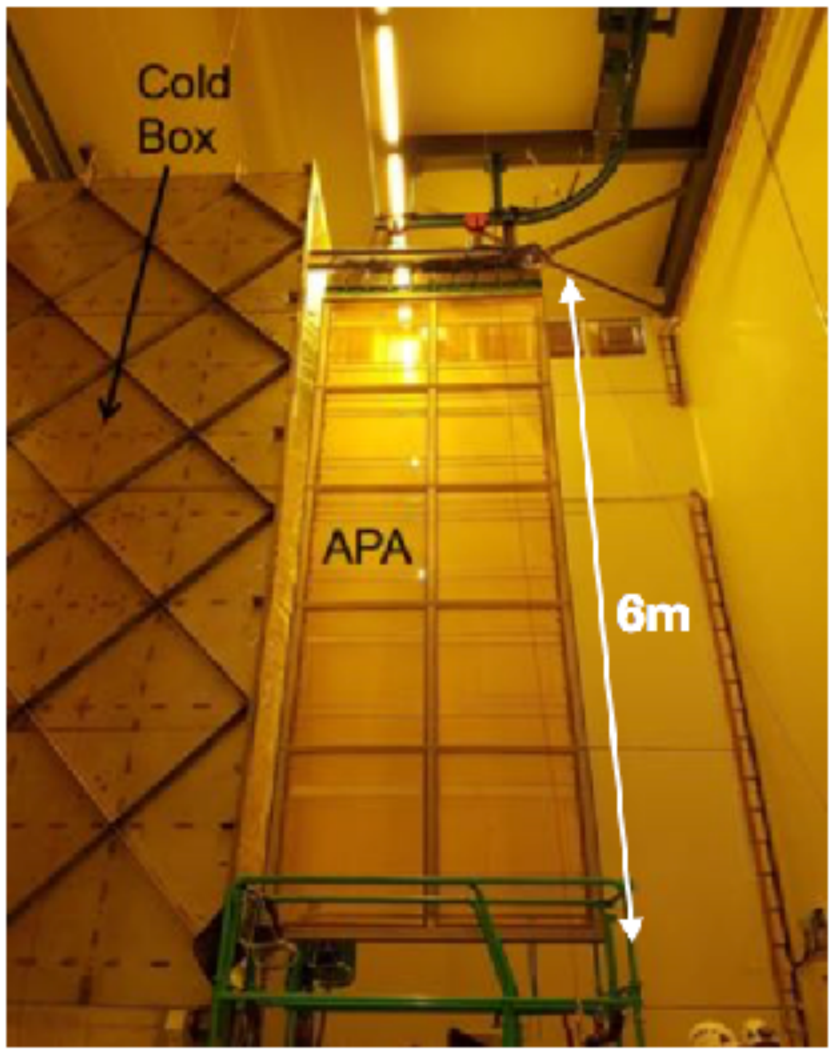


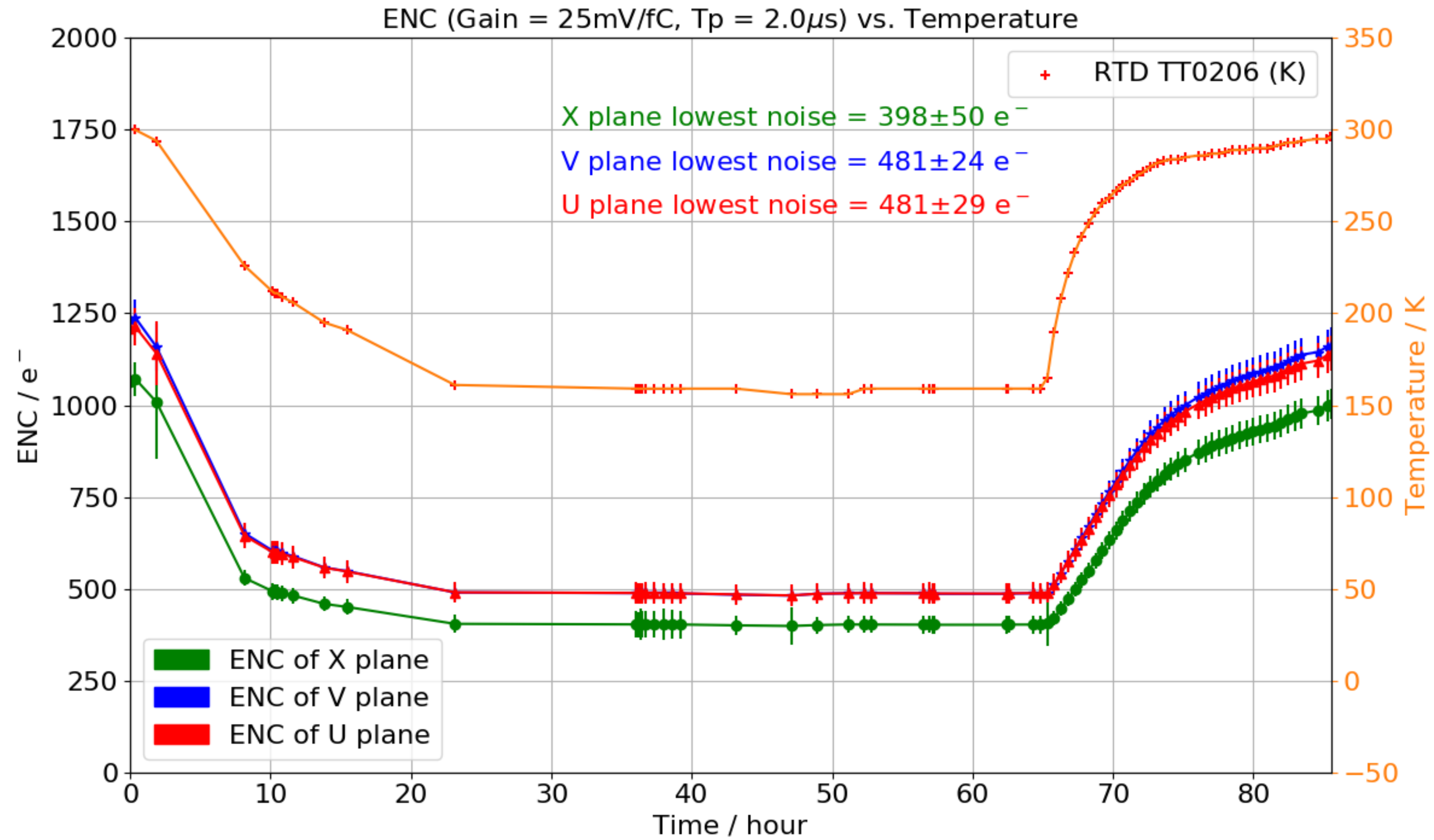


- ProtoDUNE-SP construction complete!
- Commissioning in progress

ProtoDUNE-SP Cold Box Results

Allows testing of assembled APA and electronics before installation into protoDUNE cryostat

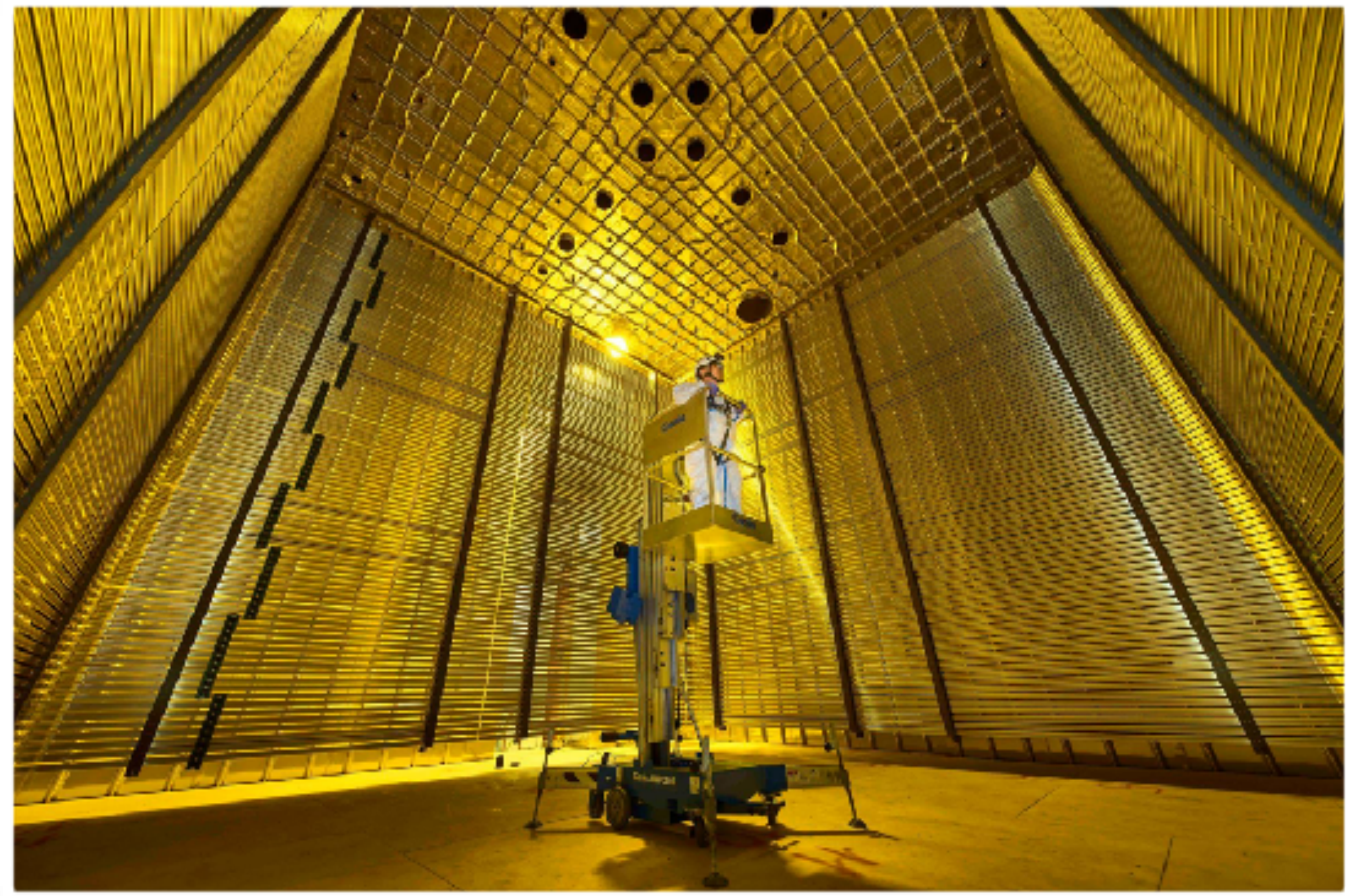


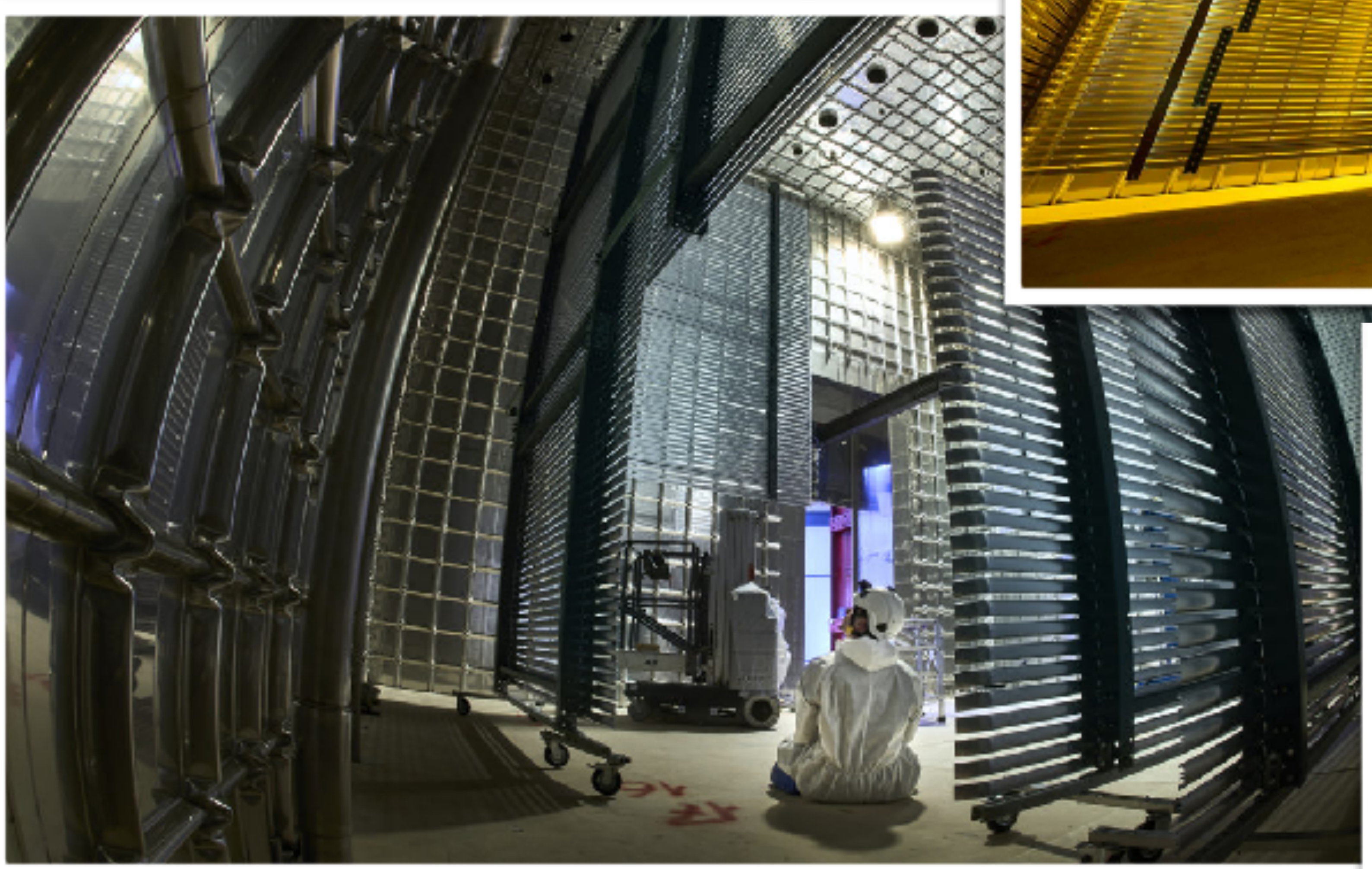


Promising results of APA wire noise in cold box

ProtoDUNE Dual Phase Status

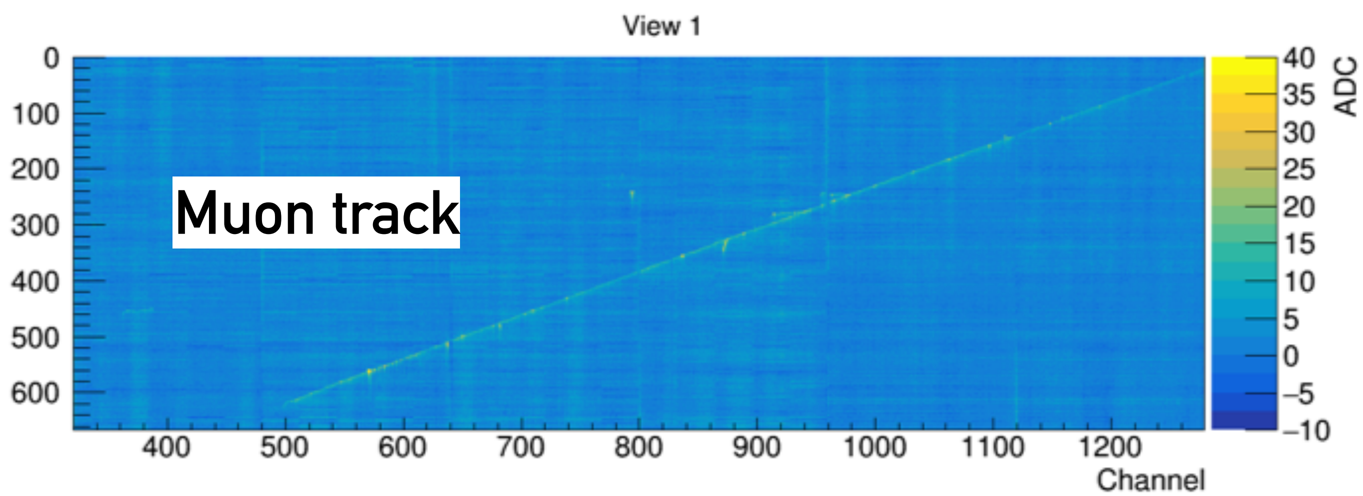
- ProtoDUNE-DP Field Cage complete in April 2018
- Successful HV tests at 150 kV!
- Collaborators hard at work — aim to finish installation in Fall 2018

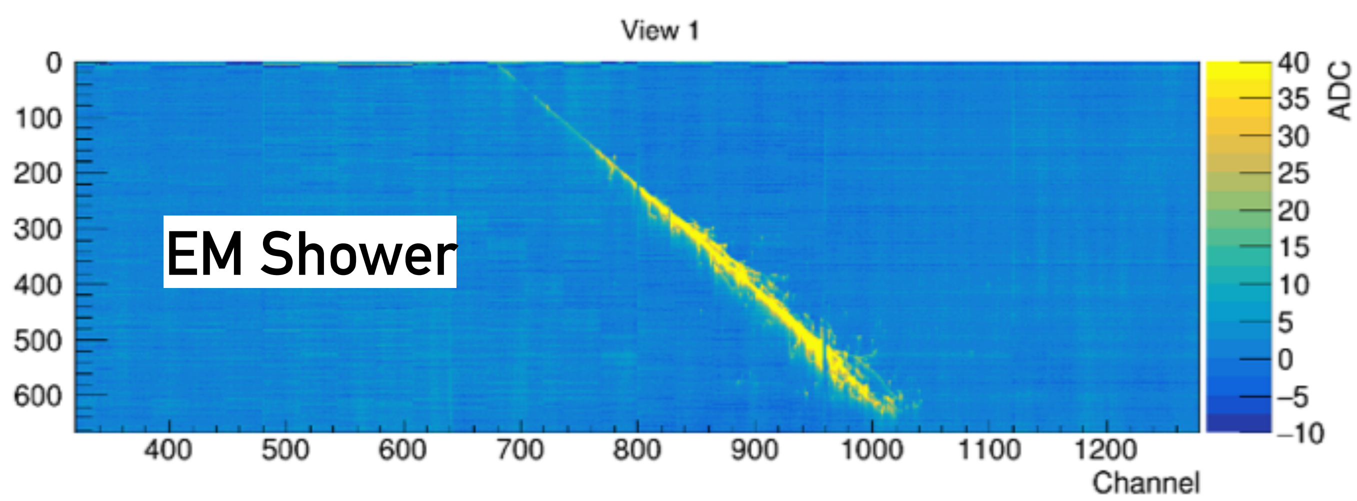


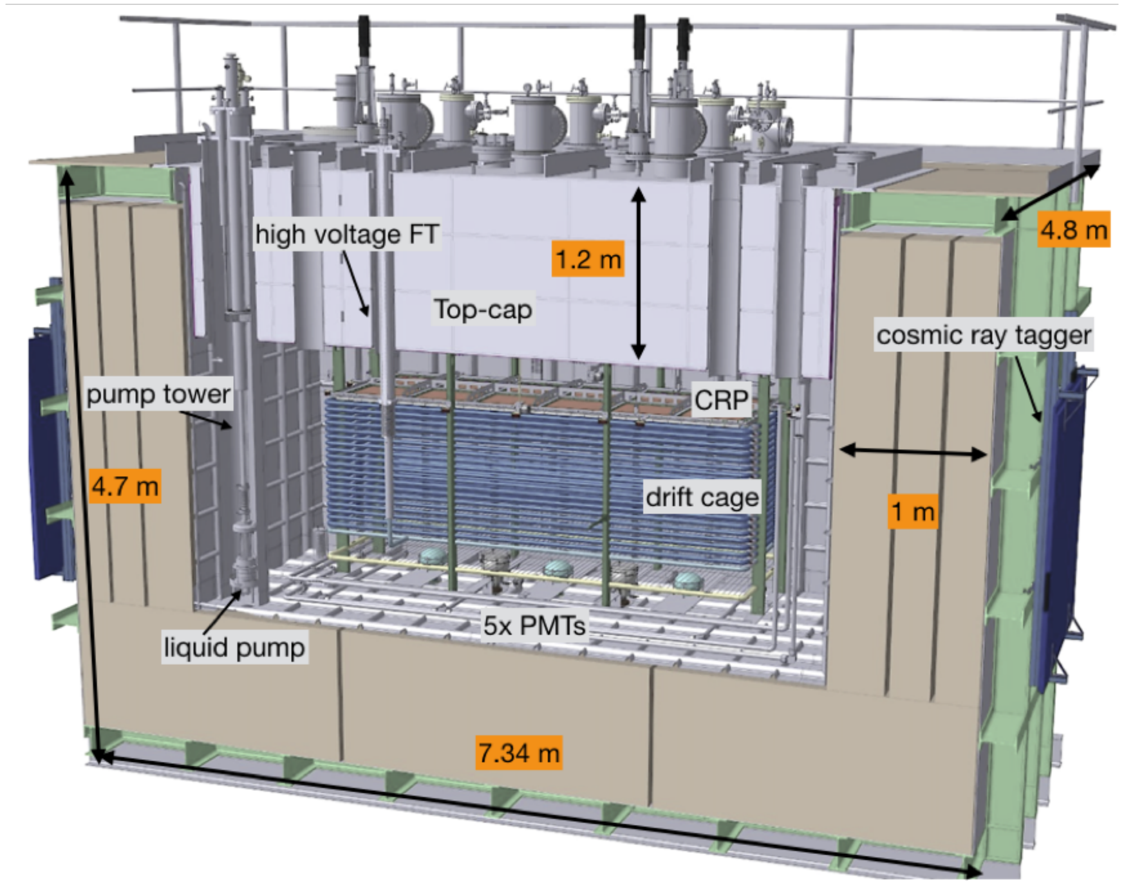


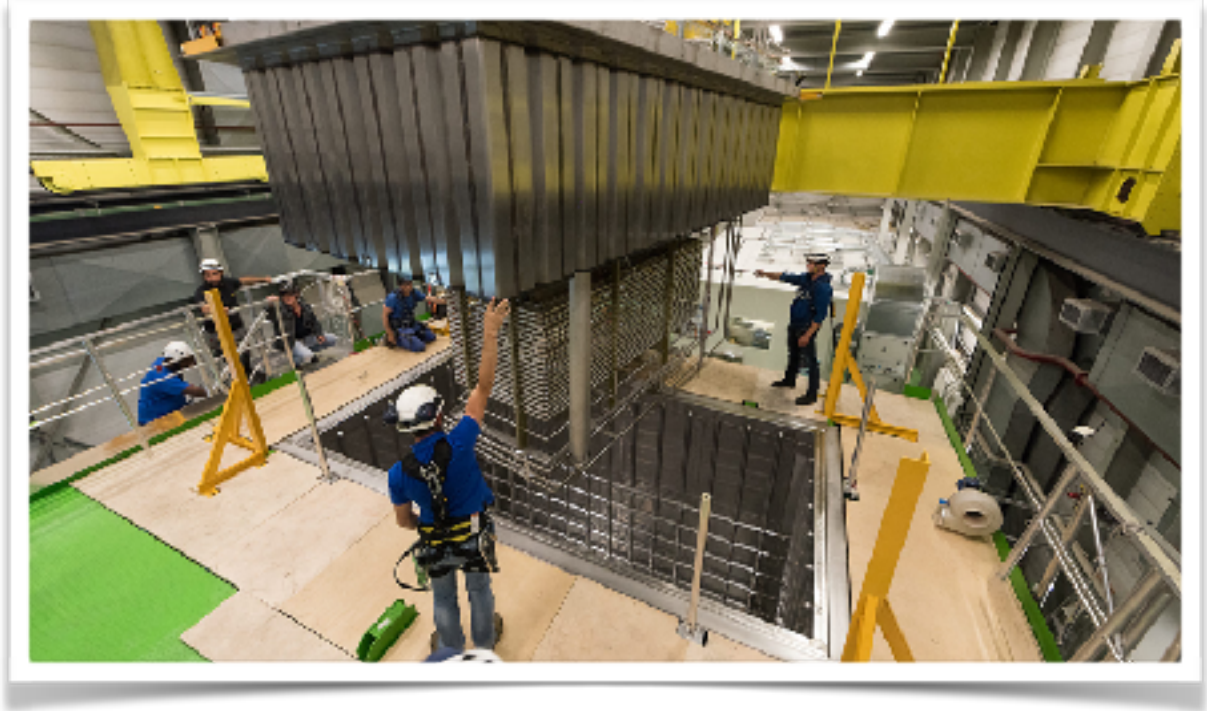
3x1x1 *Dual Phase Prototype*

- **Successful demonstration of Dual-Phase technology**
- **Operated at CERN between June and November 2017**



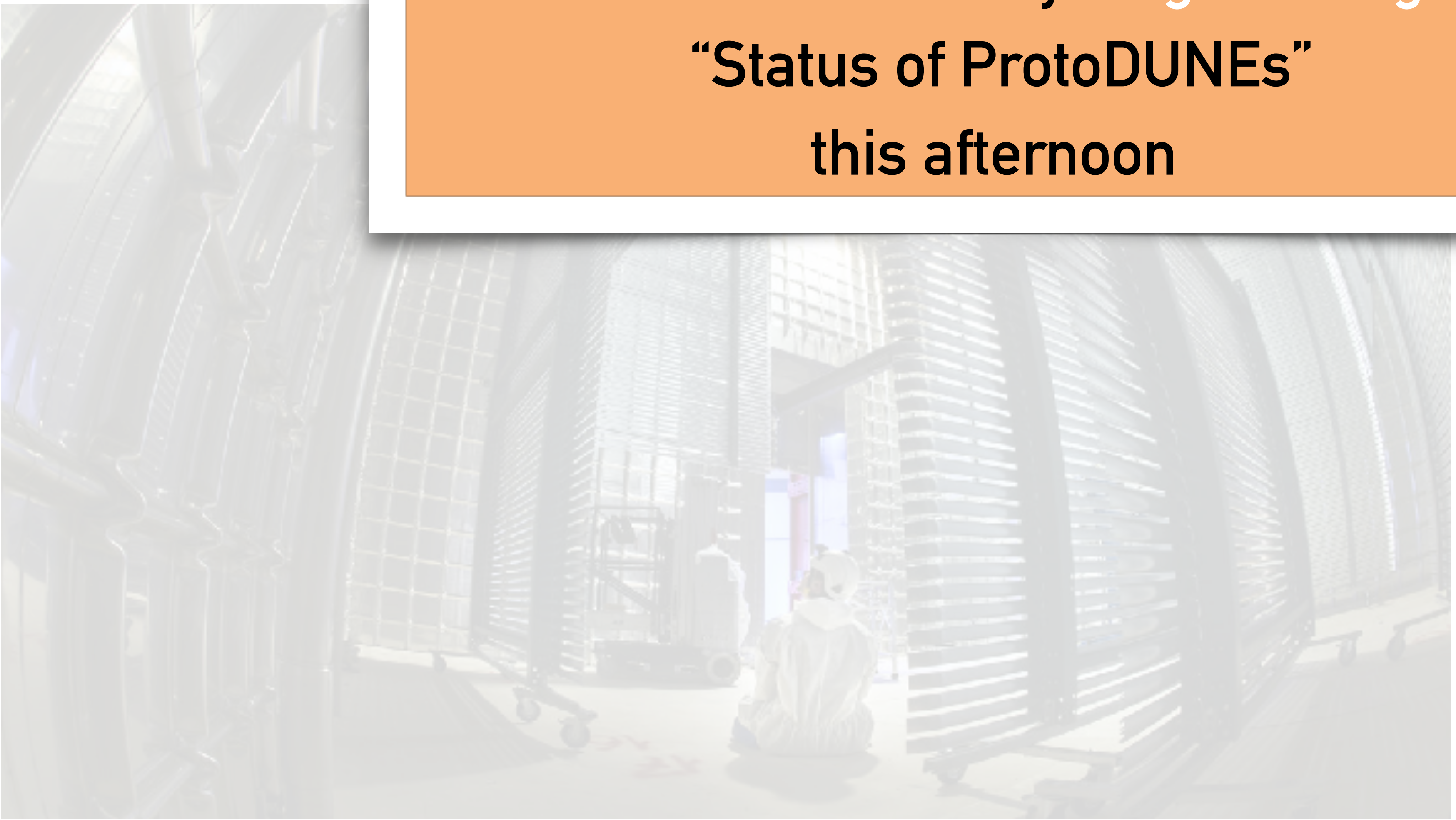






ProtoDUNE Dual Phase

- ProtoDUNE DP Field Cage complete in April 2018
- Successful HV tests at 150 kV!



More on the this by Jingbo Wang

"Status of ProtoDUNEs"

this afternoon

DUNE Timeline

2018: ProtoDUNEs at CERN

2019:

- Technical Design Report (TDR)
- Far Site Primary Excavation
- CD-2 DOE review

2022: First Module Installation Begins

2024: Physics data Begins

2026: Neutrino Beam available

June 2018: ProtoDUNE-SP installation complete

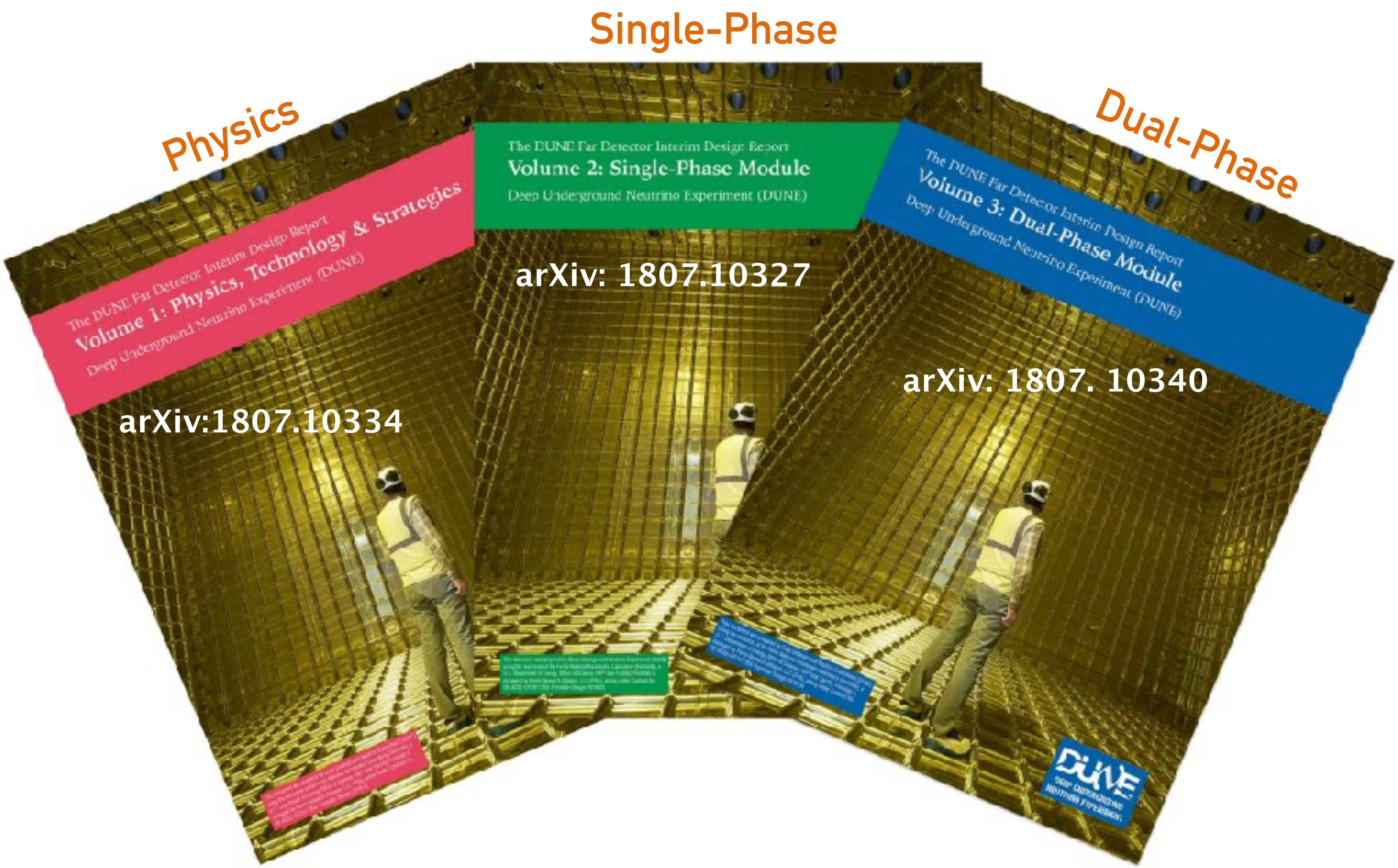
Aug 2018: ProtoDUNE-SP LAr filling

Sep — Nov 2018: ProtoDUNE-SP test beam

Fall 2018: ProtoDUNE-DP installation complete

DUNE Interim Design Reports (IDRs)

A significant milestone for DUNE — July 2018

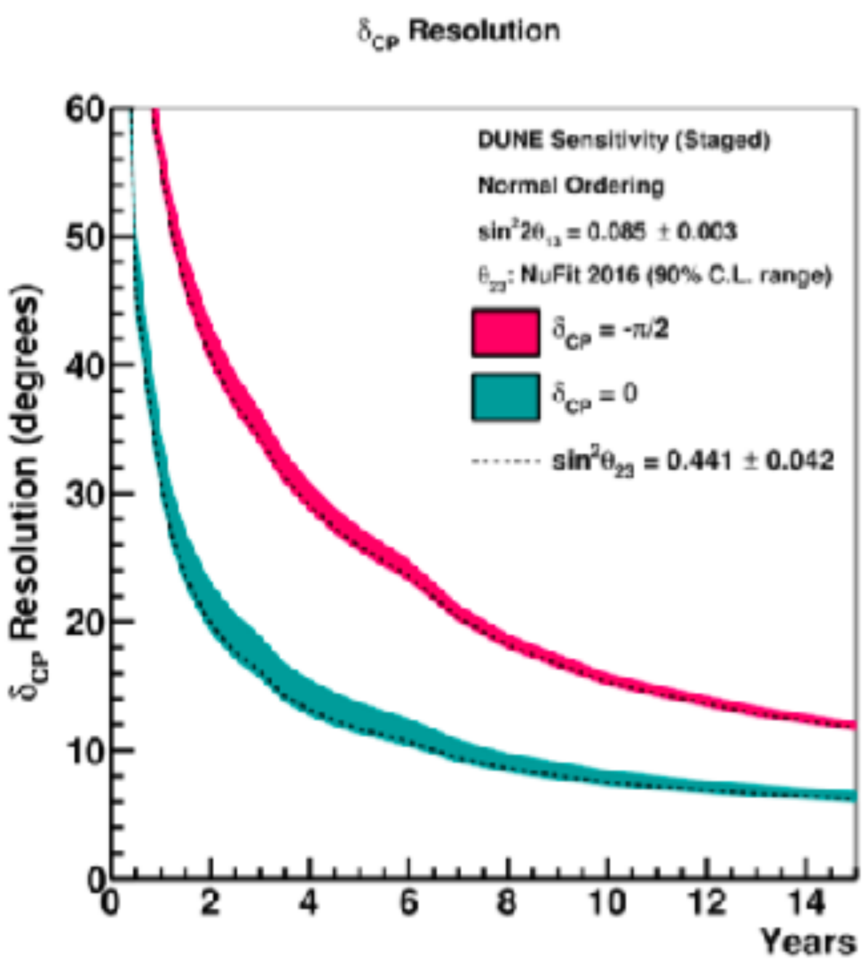


Exciting Physics Ahead with DUNE

Thank you for your attention!

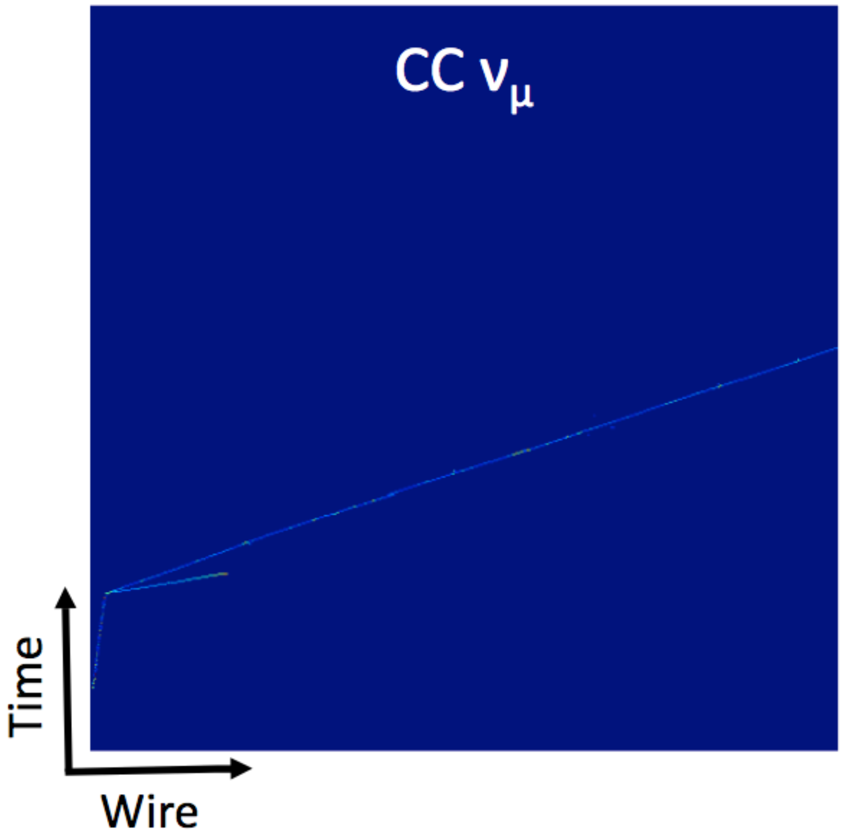
EXTRAS

Oscillation Resolution & Milestones



Physics milestone	Exposure (kt · MW · year)	Exposure (years)
1° θ_{23} resolution ($\theta_{23} = 42^\circ$)	29	1
CPV at 3σ ($\delta_{CP} = -\pi/2$)	77	3
MH at 5σ (worst point)	209	6
10° δ_{CP} resolution ($\delta_{CP} = 0$)	252	6.5
CPV at 5σ ($\delta_{CP} = -\pi/2$)	253	6.5
CPV at 5σ 50% of δ_{CP}	483	9
CPV at 3σ 75% of δ_{CP}	775	12.5
Reactor θ_{13} resolution ($\sin^2 2\theta_{13} = 0.084 \pm 0.003$)	857	13.5

CVN Event Selection & Efficiency



- Training performed on sets of 500 x 500 DUNE MC images
- Event selection performed by applying cuts on ν_e CC-like and ν_μCC-like CVN classifiers

- ν_e CC-like cut chosen by optimizing CPV sensitivity
- CVN ν_e event selection efficiency similar to that from CDR Fast MC