Status and Plans of DUNE

NuFACT2019

DaeGu, Korea

August 30, 2019

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for DUNE collaboration

Outline

- Introduction
- DUNE, a next generation ν experiment
- Physics Potential
- Status and Schedule
- Conclusions

A Perspective View

- Observation of The Top Quark
- Higgs-like Scalar Boson Discovery

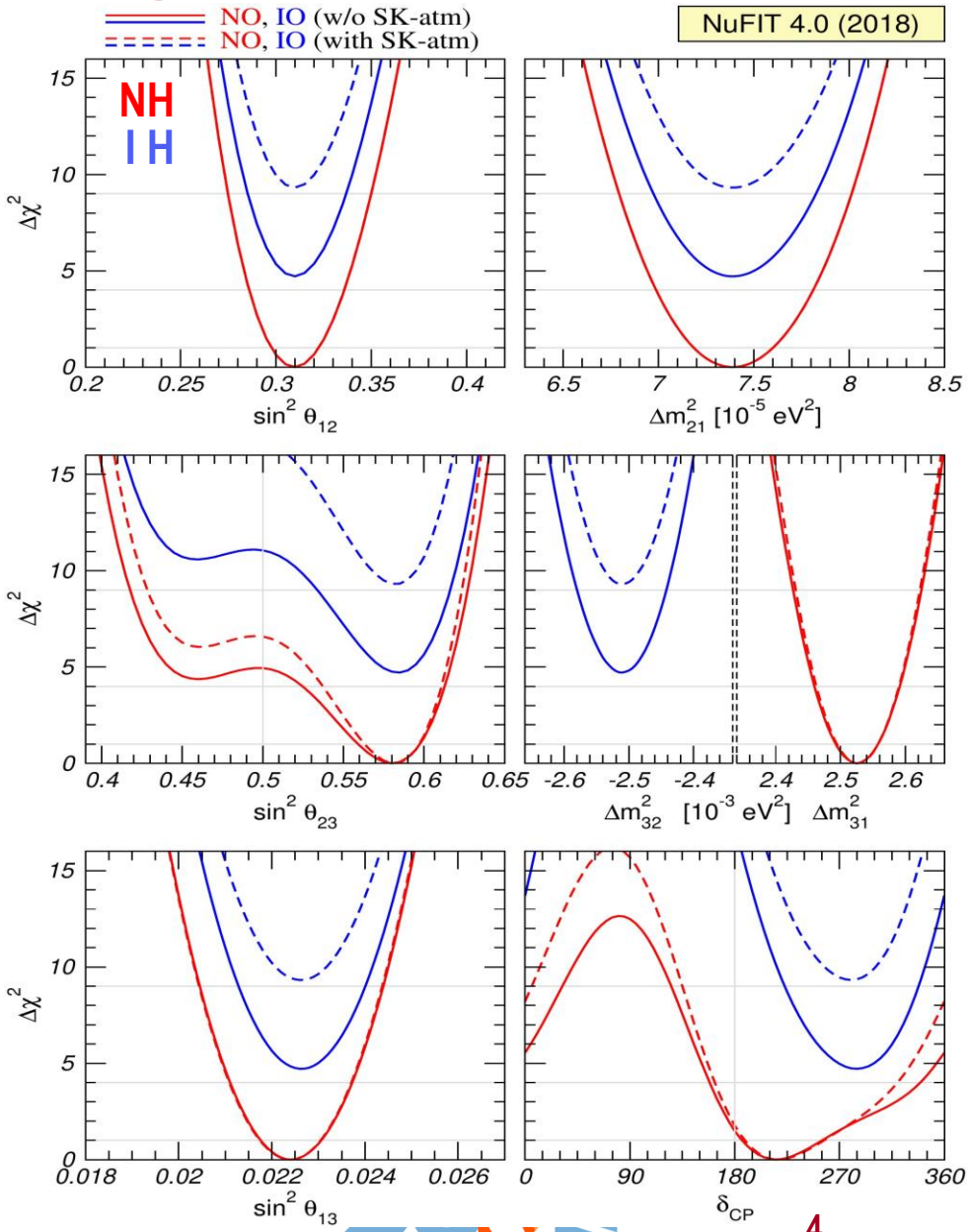
- Neutrino oscillation discovery

Physics Motivation

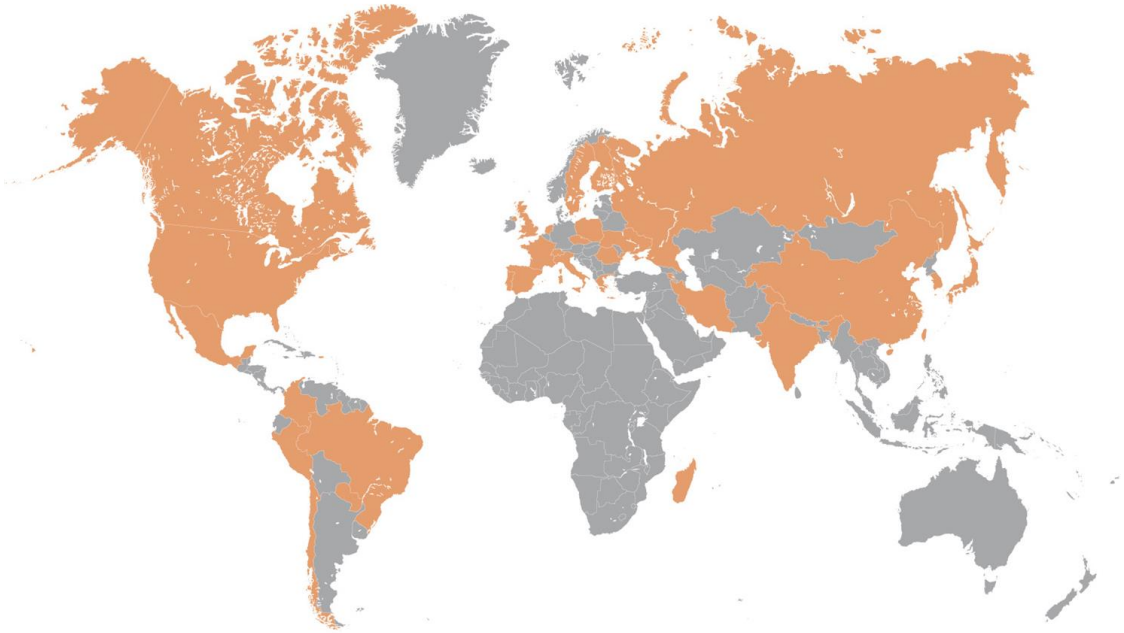
- The neutrino sector in the Standard Model needs a fix, so
  - Precision measurements of the oscillation parameters
    - Mixing angles and mass hierarchy
  - Studying the CPV and precisely measuring the CP phase
    - Do neutrinos and anti-neutrinos oscillate the same way?
- These could lead to a new symmetry
- The question of the grand unification
  - Energy scale of the unification and nucleon decay
- Understanding particles of astrophysical origin
  - Supernova, relic neutrinos, dark matter, etc
- These require high statistics samples
  - Large mass, large volume and highly capable (near and far!) detectors
  - High intensity neutrino beam facility with a long baseline

Current Understanding of 3ν Oscillation

- θ_{23} & ΔM^2_{23} measurements
  - Atm. ν: SK, IceCube, Km^{3}NET, etc
  - Long Baseline: K2K, MINOS, Opera, NOvA, etc
- θ_{12} & ΔM^2_{12} measurements
  - Solar ν: SNO, SK, Borexino, etc
  - Reactor: KamLAND
- θ_{13} measurements
  - Long Baseline: MINOS, T2K, NOvA, etc
  - Reactor: Daya Bay, RENO, Double Chooz



DEEP UNDERGROUND NEUTRINO EXPERIMENT



An international science collaboration

1106 collaborators from **184 institutions** in **31 countries**

Aug. 30, 2019

Status and Plans of DUNE

Jaehoon Yu

Deep Underground Neutrino Experiment (DUNE)

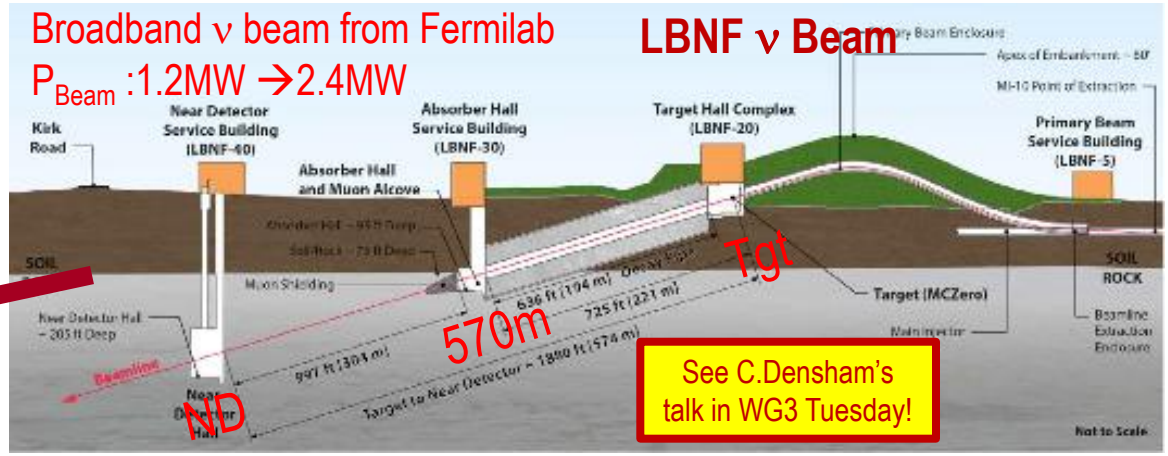
With the 2013 – 2014 strategic planning of the communities in the three regions, an effort of building a next generation international neutrino experiment is in progress

- Joint efforts of teams from all three regions – Americas, Europe and Asia – US flagship hosted by Fermilab
- LAr TPC ➔ Employ two technologies (SP/DP) within one experiment, systematic x-check
- LBNF (Long Baseline Neutrino Facility) far site facility construction approved by US DOE in Sept. 2016 ➔Ground breaking at the far site July 2017

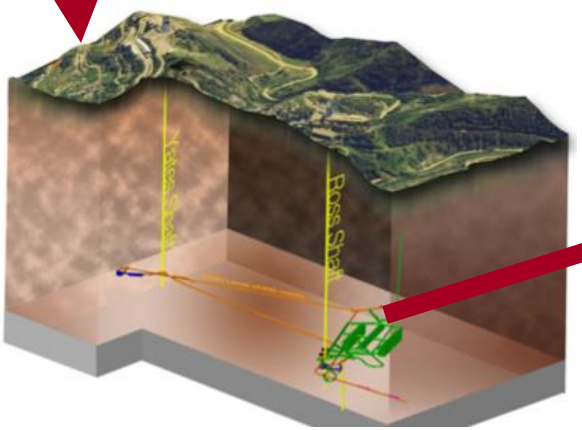
Anatomy of DUNE Experiment

Broadband ν beam from Fermilab

P_{Beam} :1.2MW →2.4MW

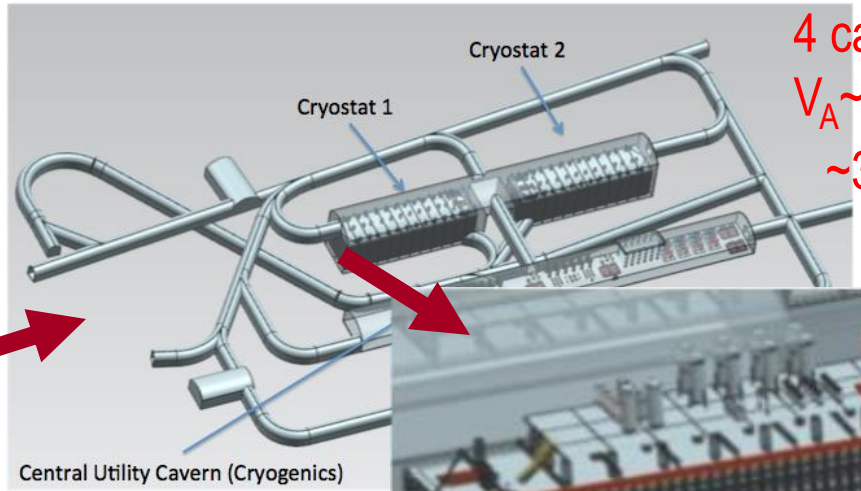


See C.Densham's talk in WG3 Tuesday!



LBNF Far Detector Site, SURF

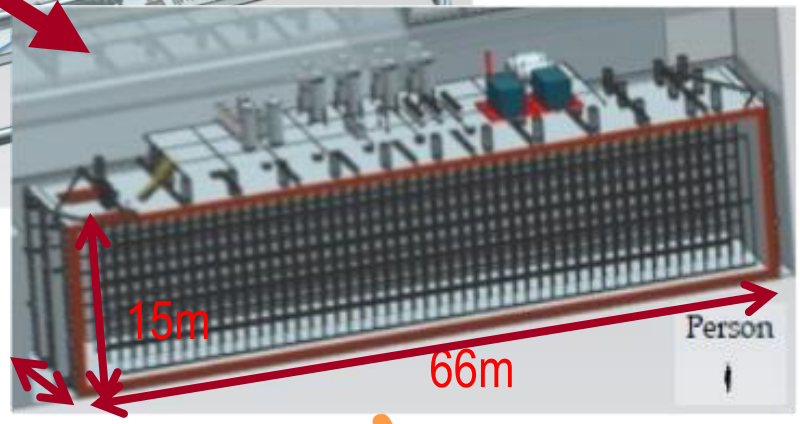
1500m underground



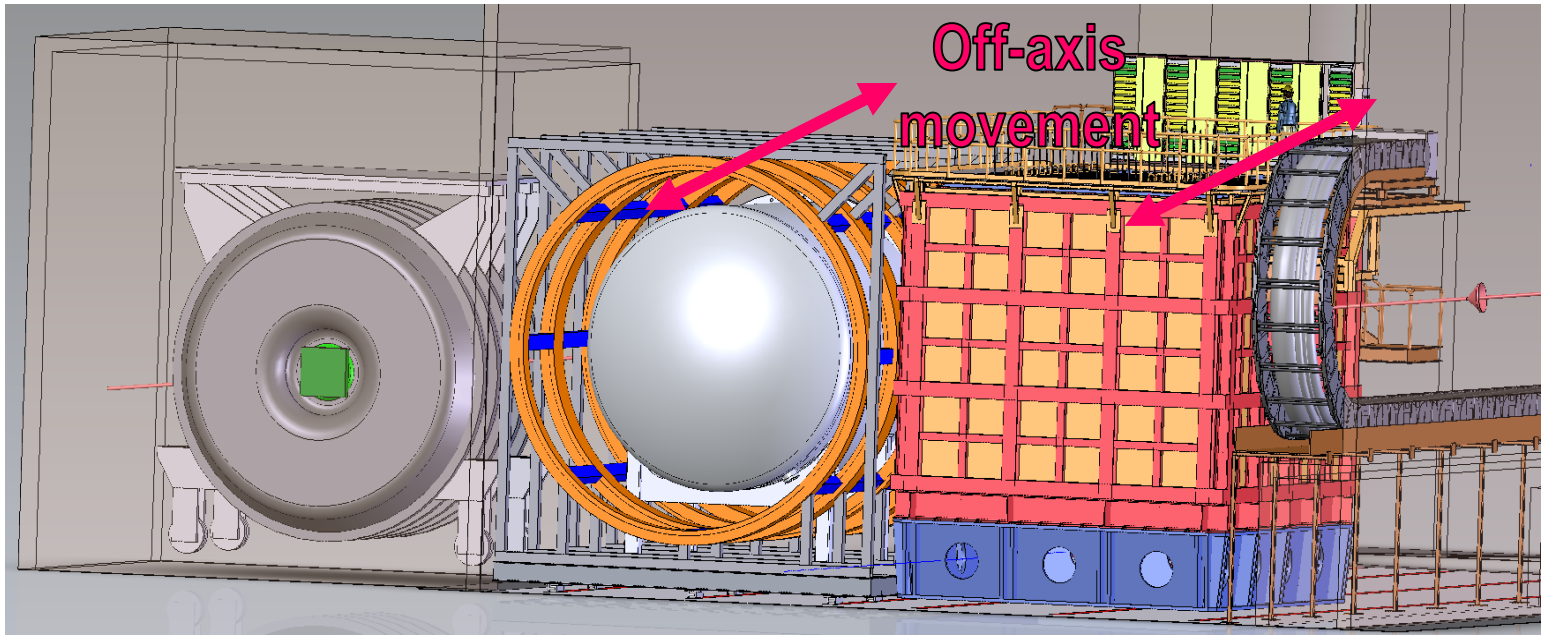
4 caverns w/ fiducial

V_A~ **10kt LAr** each

~30xICARUS



DUNE Near Detector Concept



beam direction

3D scint. tracker

GAr TPC w/ ECAL

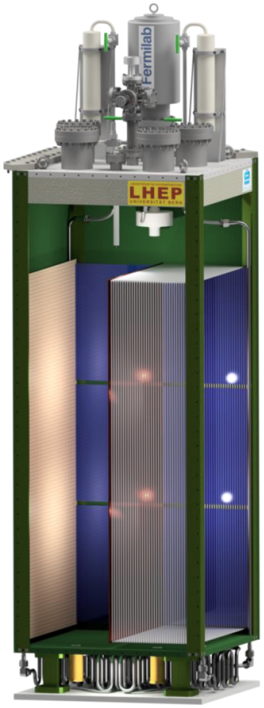
LAr TPC

- LAr TPC: Same technology as the FD; ν-Ar interactions (V_A=150t)
- Magnetized HPGAr TPC w/ ECAL: ν-Ar events with **low-threshold tracking;** p_μ measurements (V_A=1t)
- DUNE-PRISM: Off-axis ν spectrum for systematics
- 3DST (Fast on-axis beam monitoring, V_A=8t)+ECAL+Magnet

See A. Bross's talk in WG1+2 Thursday!+ S.Kim's poster Monday

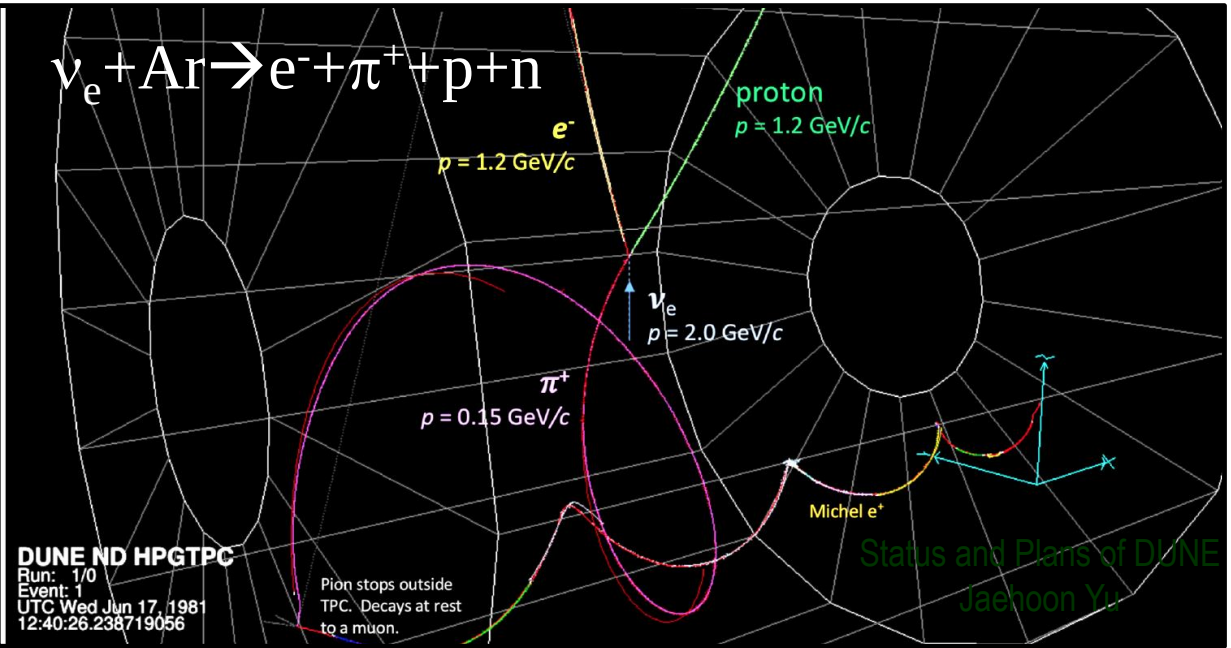
DUNE Near Detector Progress

ArgonCube (LAr TPC)
2-by-2 demonstrator in preparation

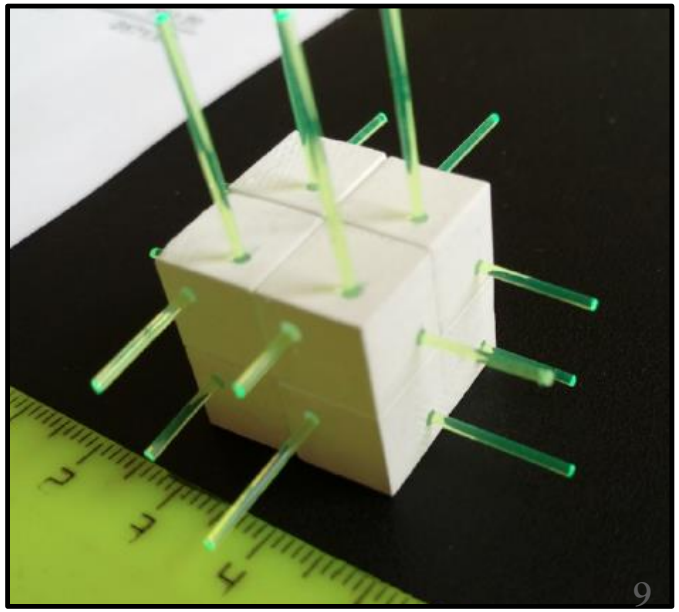


ArgonCube module
(0.7m × 0.7m × 1.8 m)
Pixelated readout

Simulated GAr TPC event with reconstruction

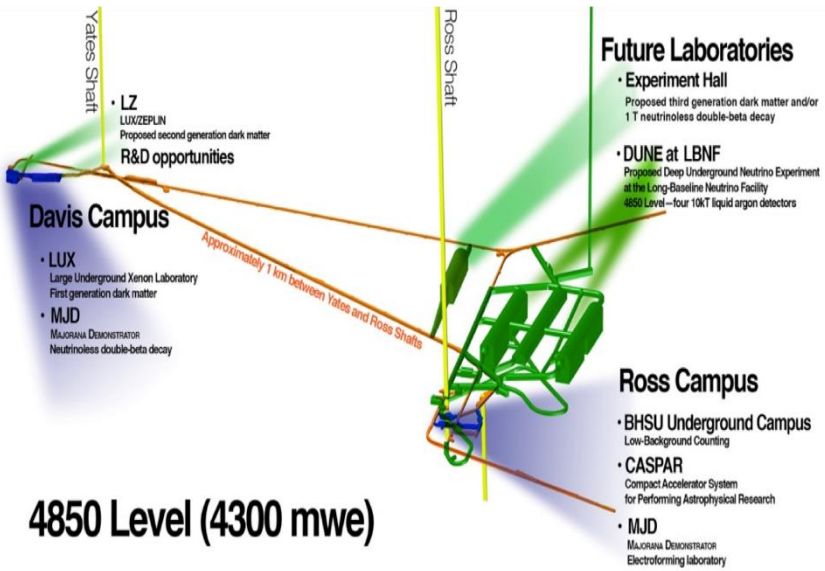


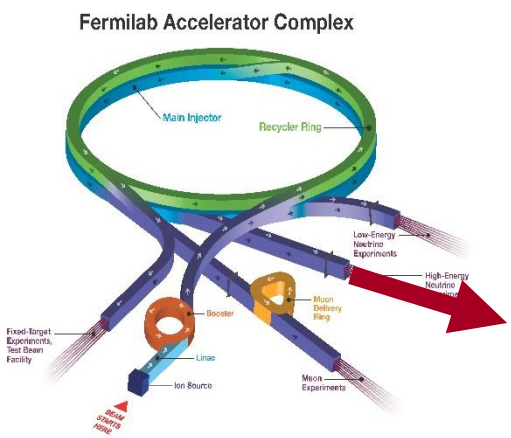
3DST detector elements

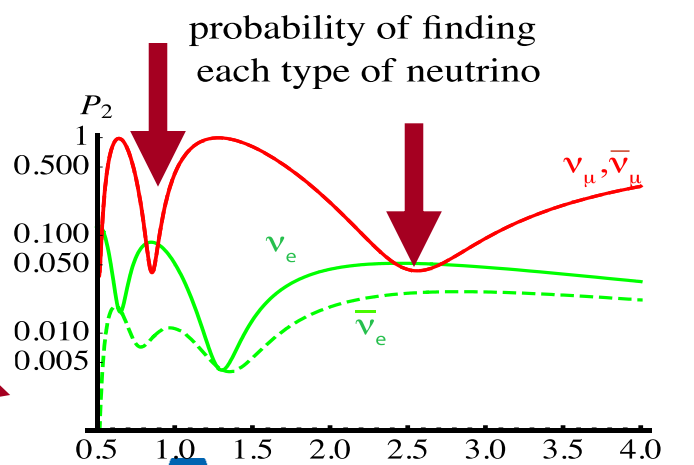


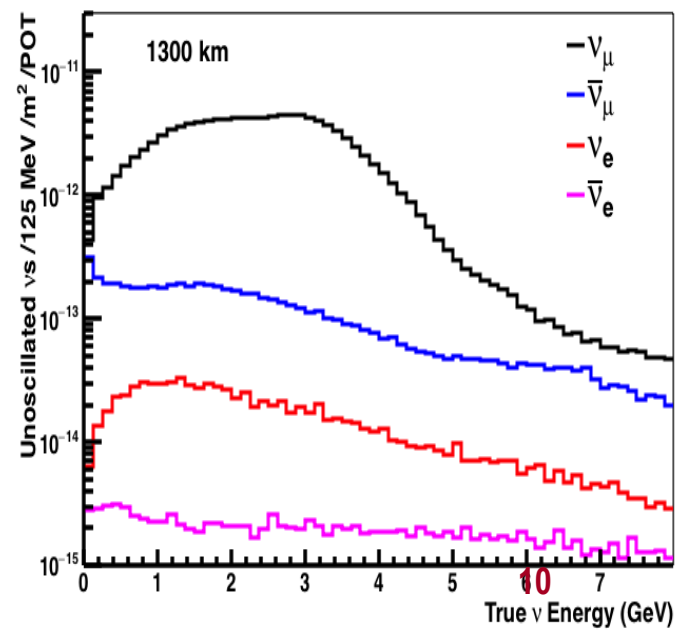
Long Baseline Neutrino Facility (LBNF)

- LBNF Consists of two elements
  - Far detector site: Sanford Underground Research Facility (SURF) in South Dakota
  - Neutrino Beam Line at Fermilab
    - E_p=60 – 120 GeV
    - 1.2MW upgradable to 2,4MW
    - Horn focused beam optimized for CPV studies ➔ Provides access to two oscillation maxima

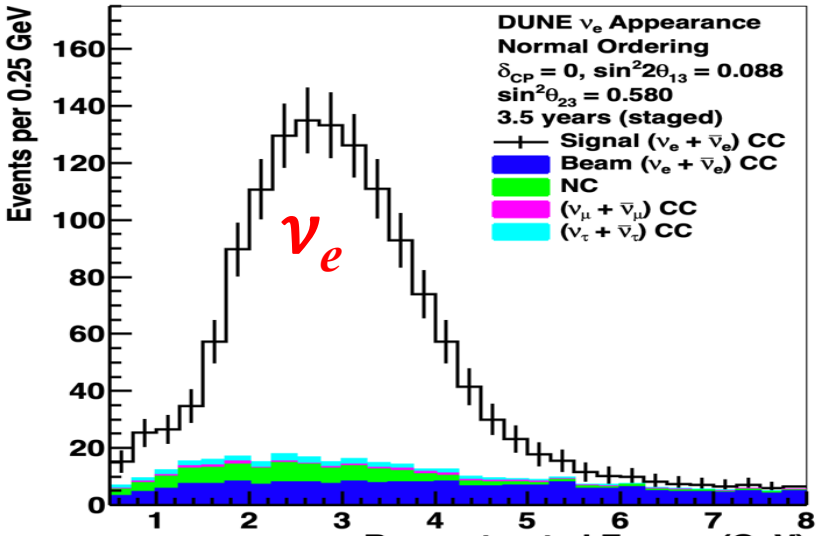


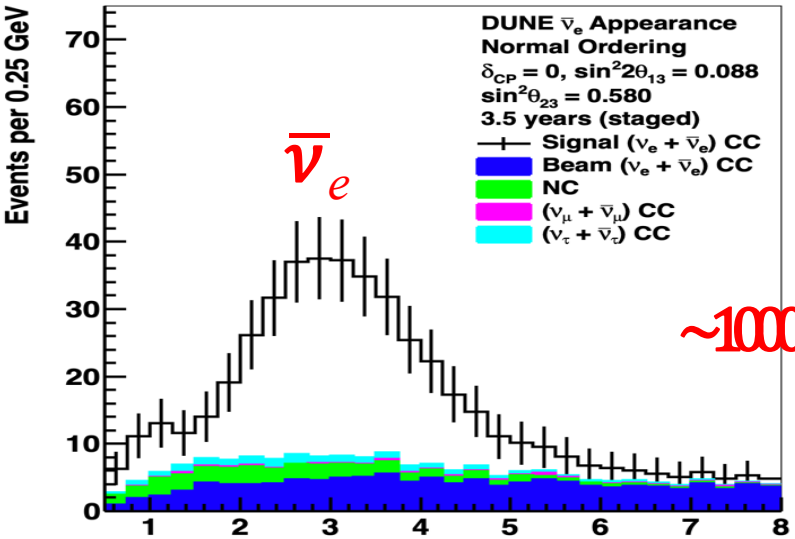




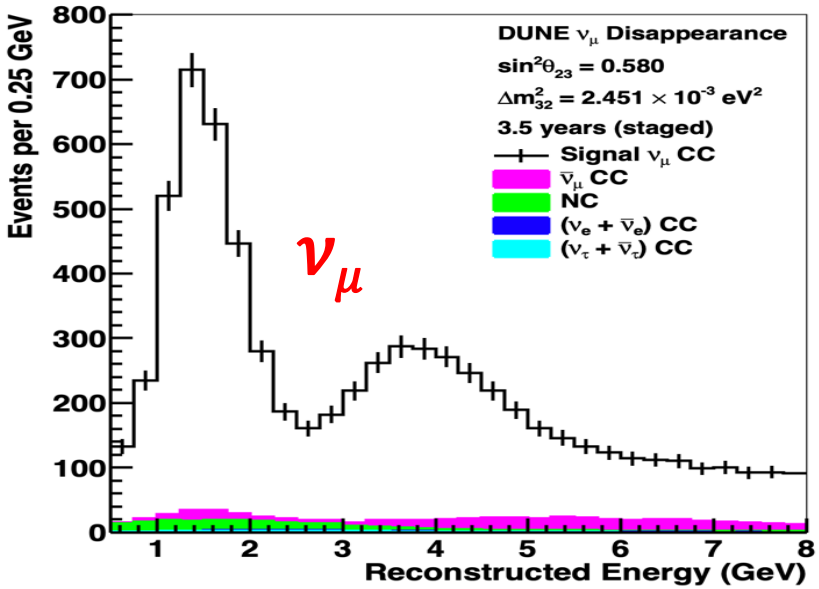


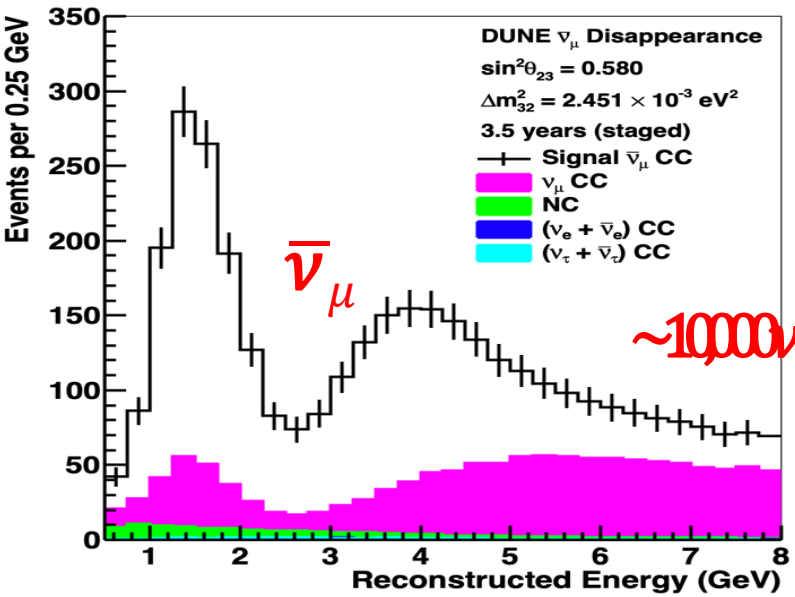
DUNE Oscillation Expectation – FD





$\sim 1000\, \nu_e / \bar{\nu}_e$



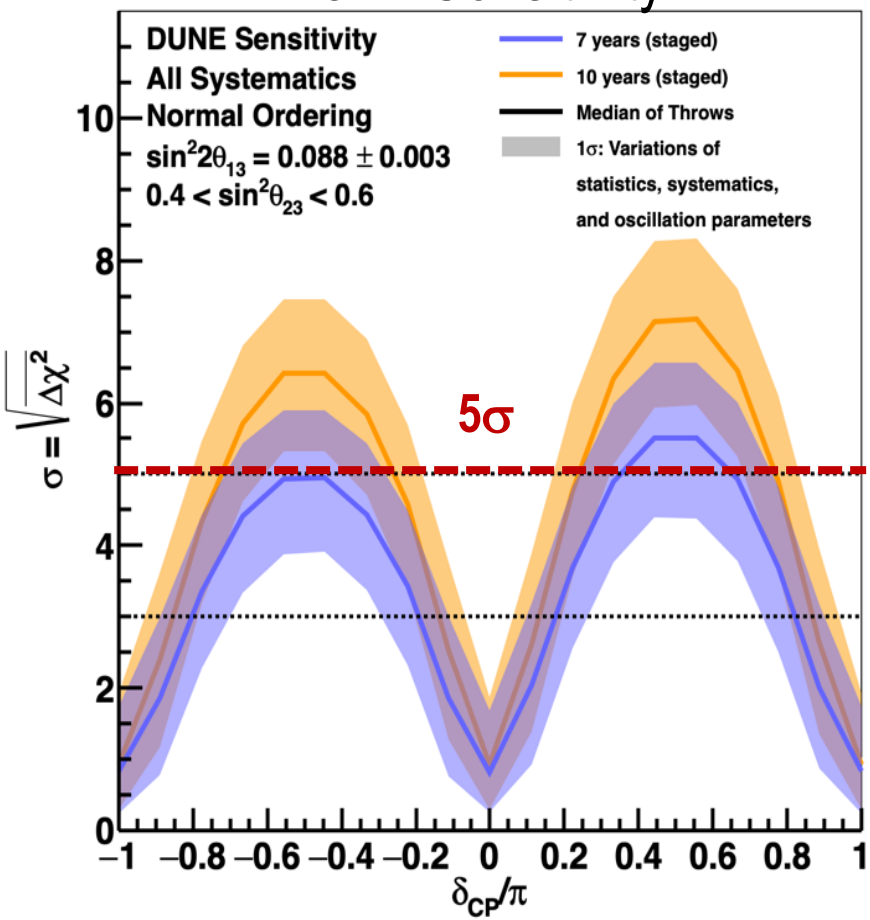


$\sim 10{,}000\, \nu_\mu / \bar{\nu}_\mu$

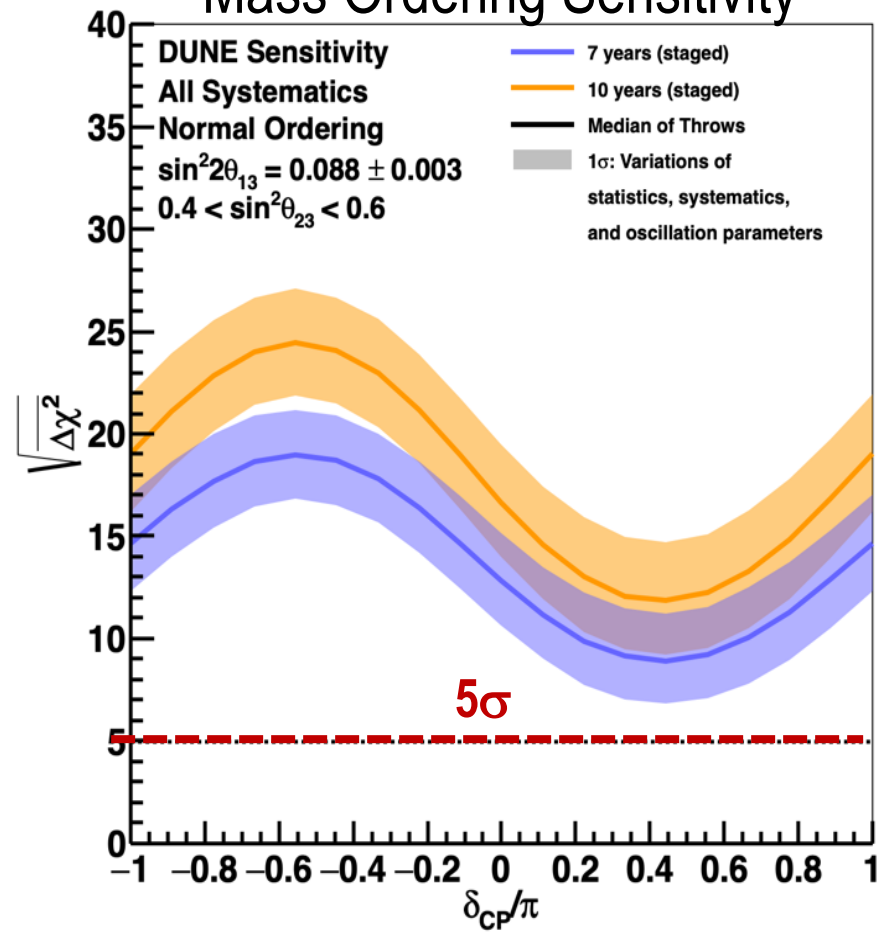
See S.Kim's talk in WG1 this afternoon!

CPV and ν Mass Ordering

*CP*v Sensitivity



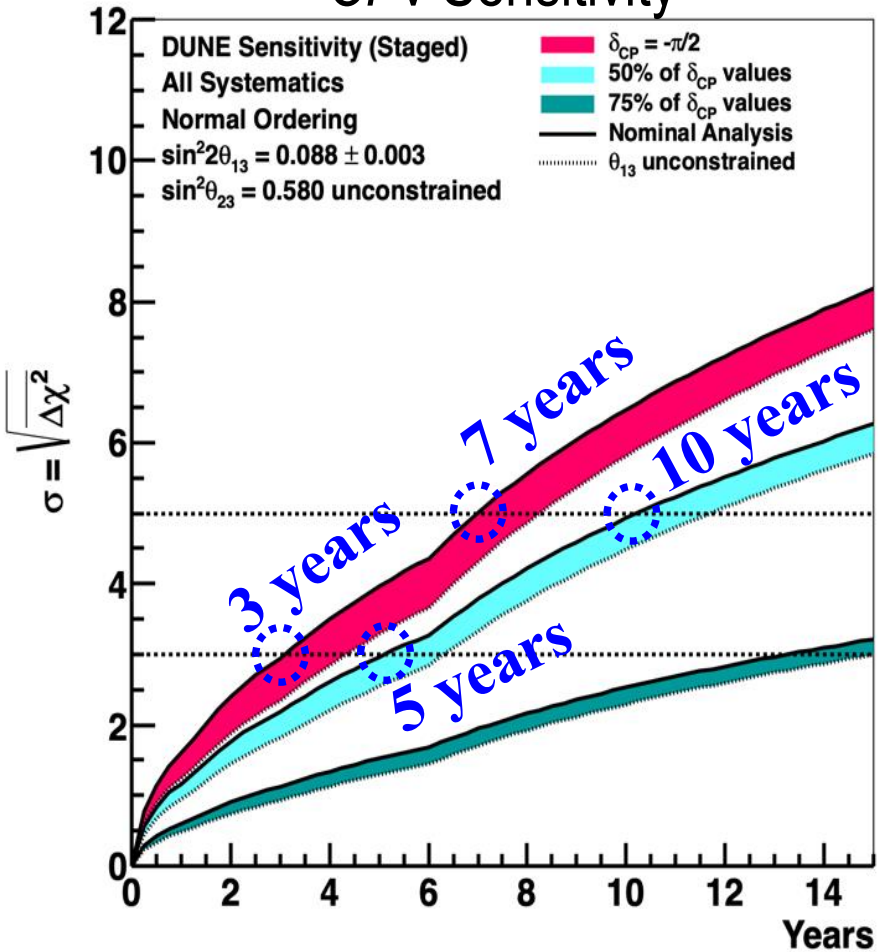
Mass Ordering Sensitivity



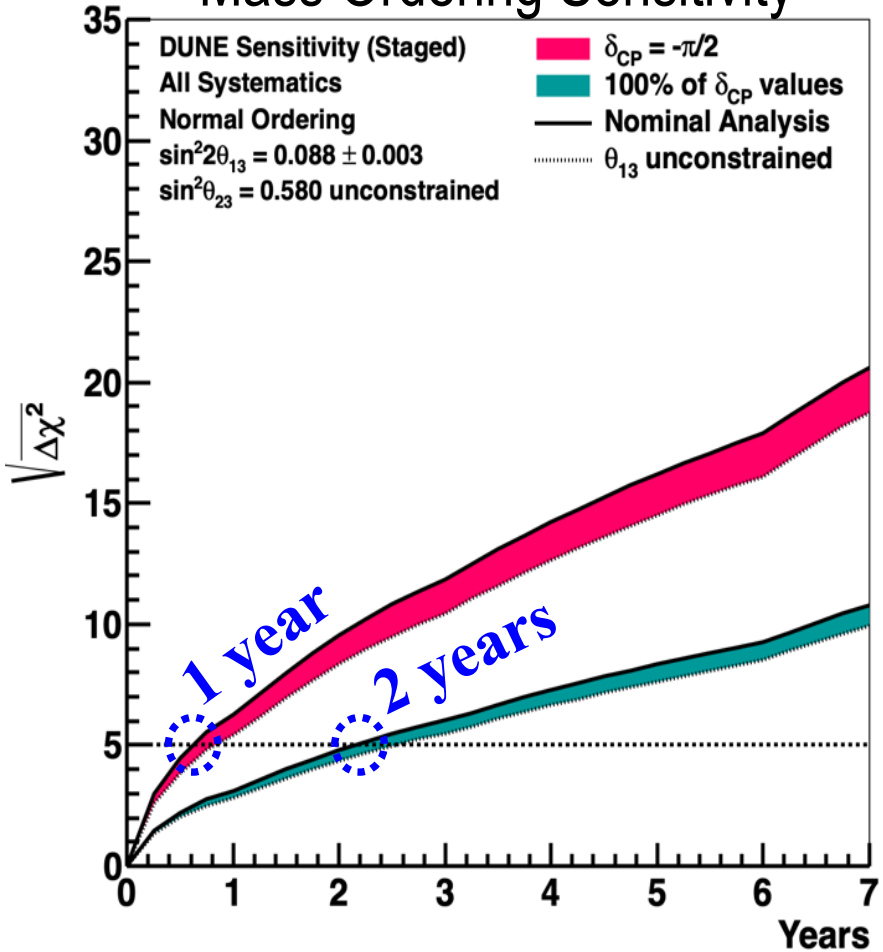
- >5σ CPv discovery over a wide range of δ_{CP}
- Definitive determination of mass ordering in all ranges of δ_{CP}

Sensitivity vs Time

*CP*v Sensitivity



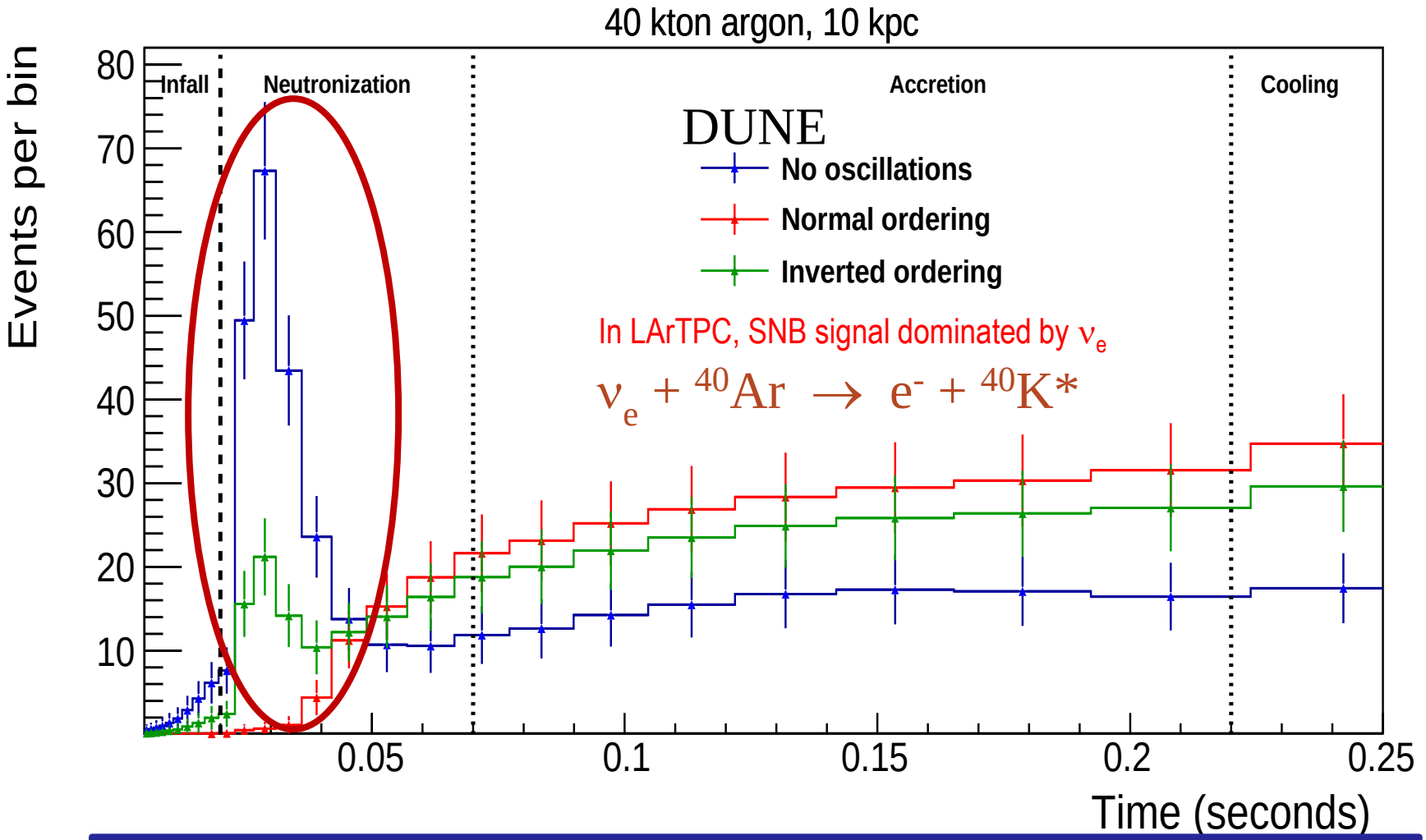
Mass Ordering Sensitivity



Significant milestones accomplished throughout beam-physics program

NuFit 4.0 (Nov 2018) best-fit parameters/uncertainties assumed, *JHEP* ***01*** *(2019) 106, www.nu-fit.org*

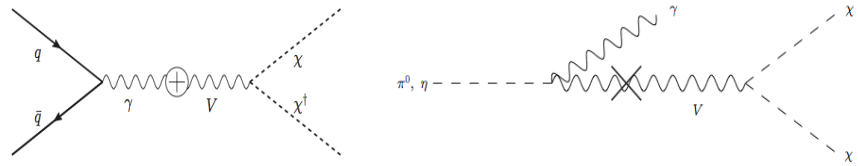
SNB Neutrinos



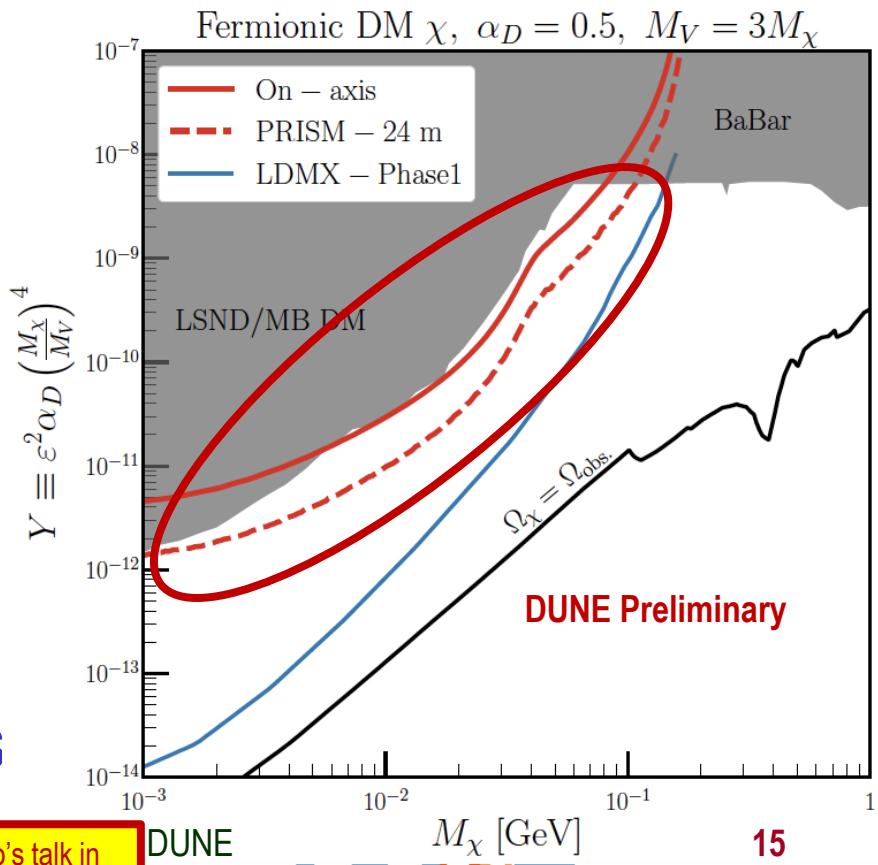
Observation of early time development yields sensitivity to neutrino mass ordering and details of SNB model.

BSM Physics at a ν Experiment?

- The high beam power, large detector mass + highly capable detectors make other BSM Physics viable
  - Low mass Dark Matter
  - Boosted Dark Matter
  - Sterile neutrinos
  - Non-standard Interactions, Non-Unitarity Mixing, CPT violation
  - Neutrino Trident
  - Large Extra Dimensions
  - Heavy Neutral Leptons
- Promote close collaborations between phenomenology community and experimentalists



Battell *et al.*, PRD80, 095024



https://arxiv.org/abs/1907.08311

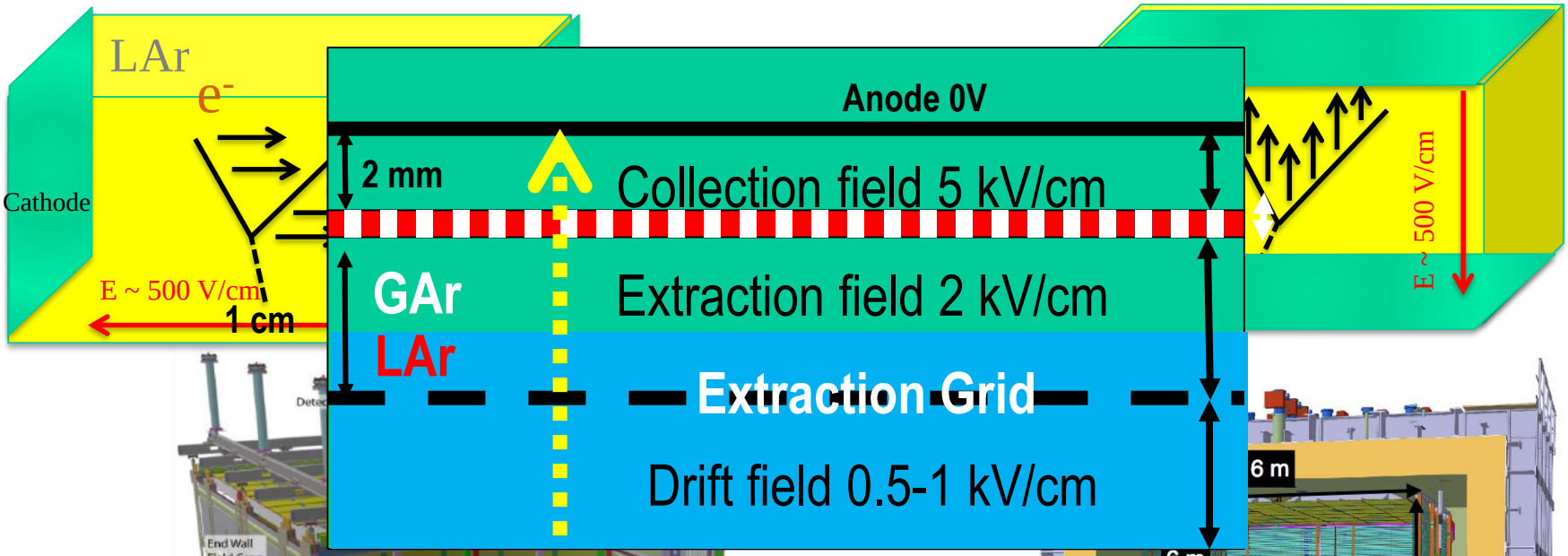
See K.Cho's talk in WG5 Thursday!

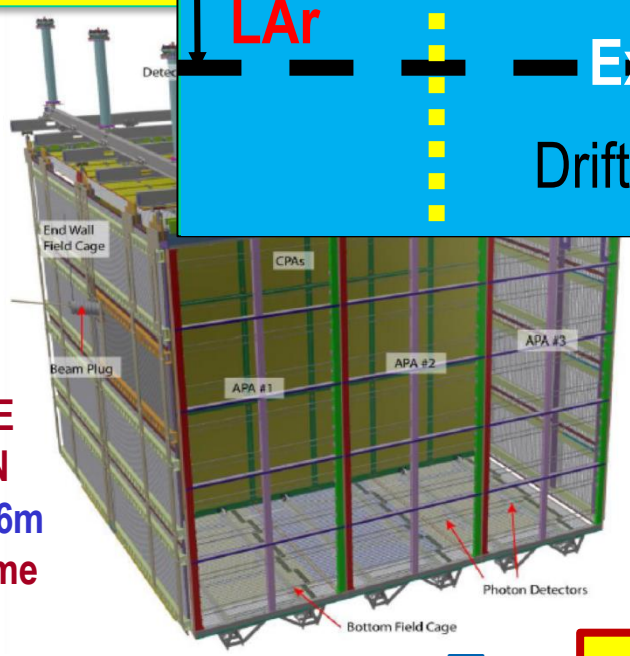
DUNE Single & Dual Phase Prototypes

Enabled by CERN Neutrino Platform

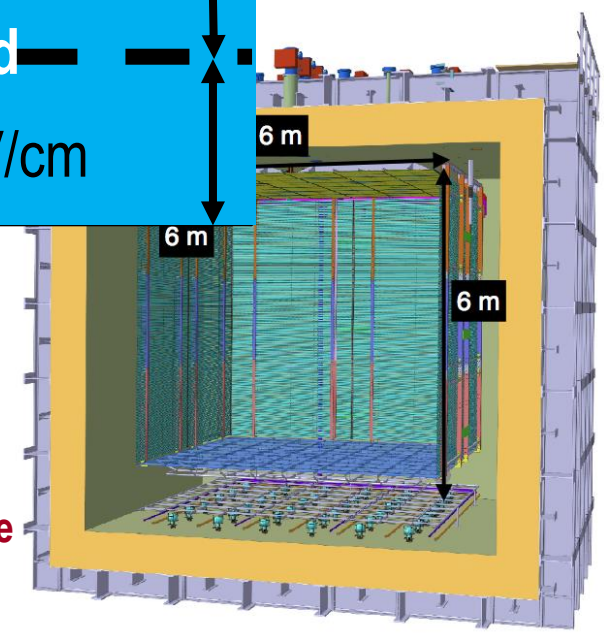
Single Phase:

Dual Phase:





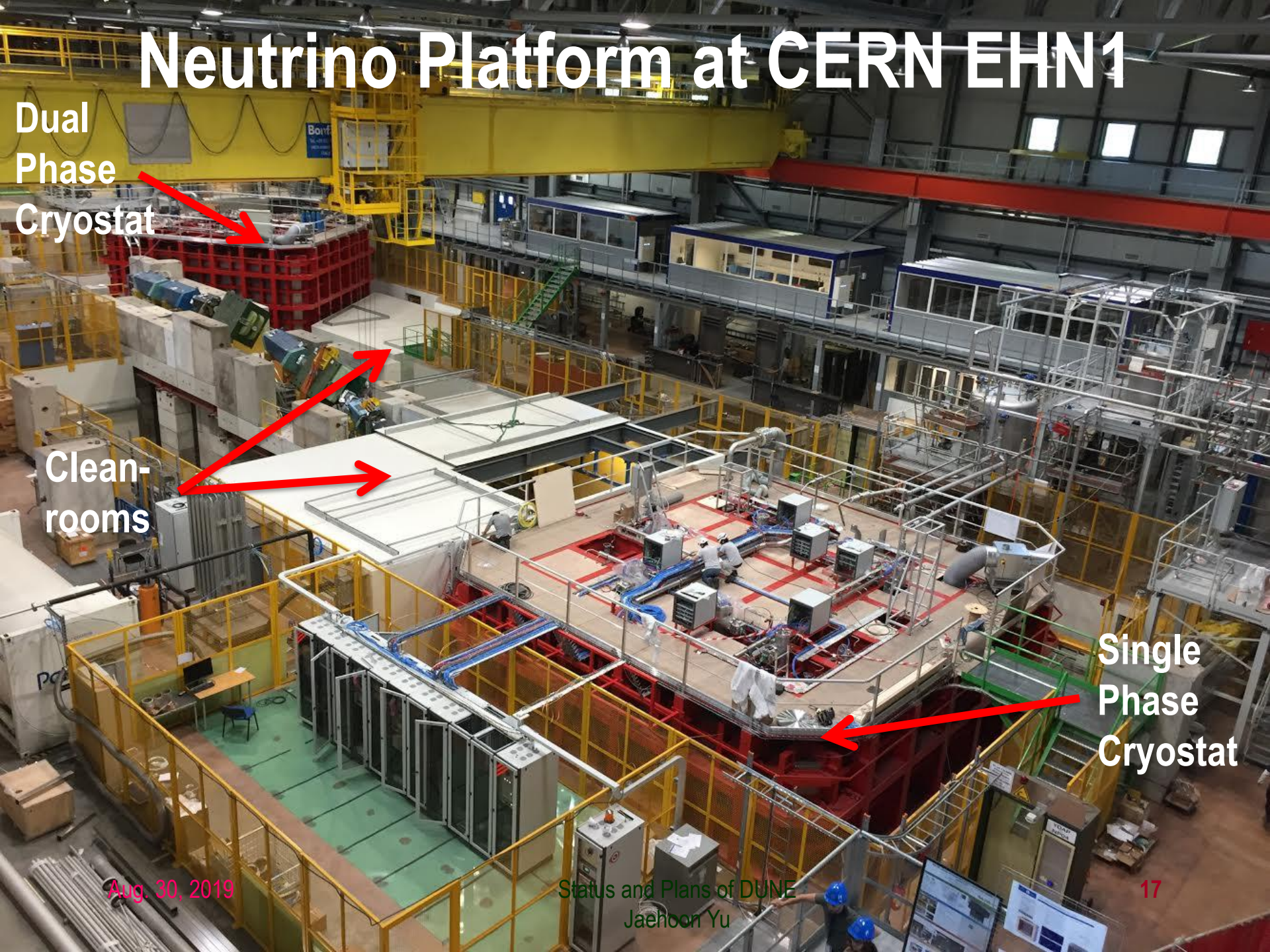
ProtoDUNE
SP@CERN
6.9mx7.2mx6m
Active volume



ProtoDUNE
DP@CERN
6mx6mx6m
Active volume

See J. Bian's talk in WG1+2 Thursday + J. Thompson Poster Monday

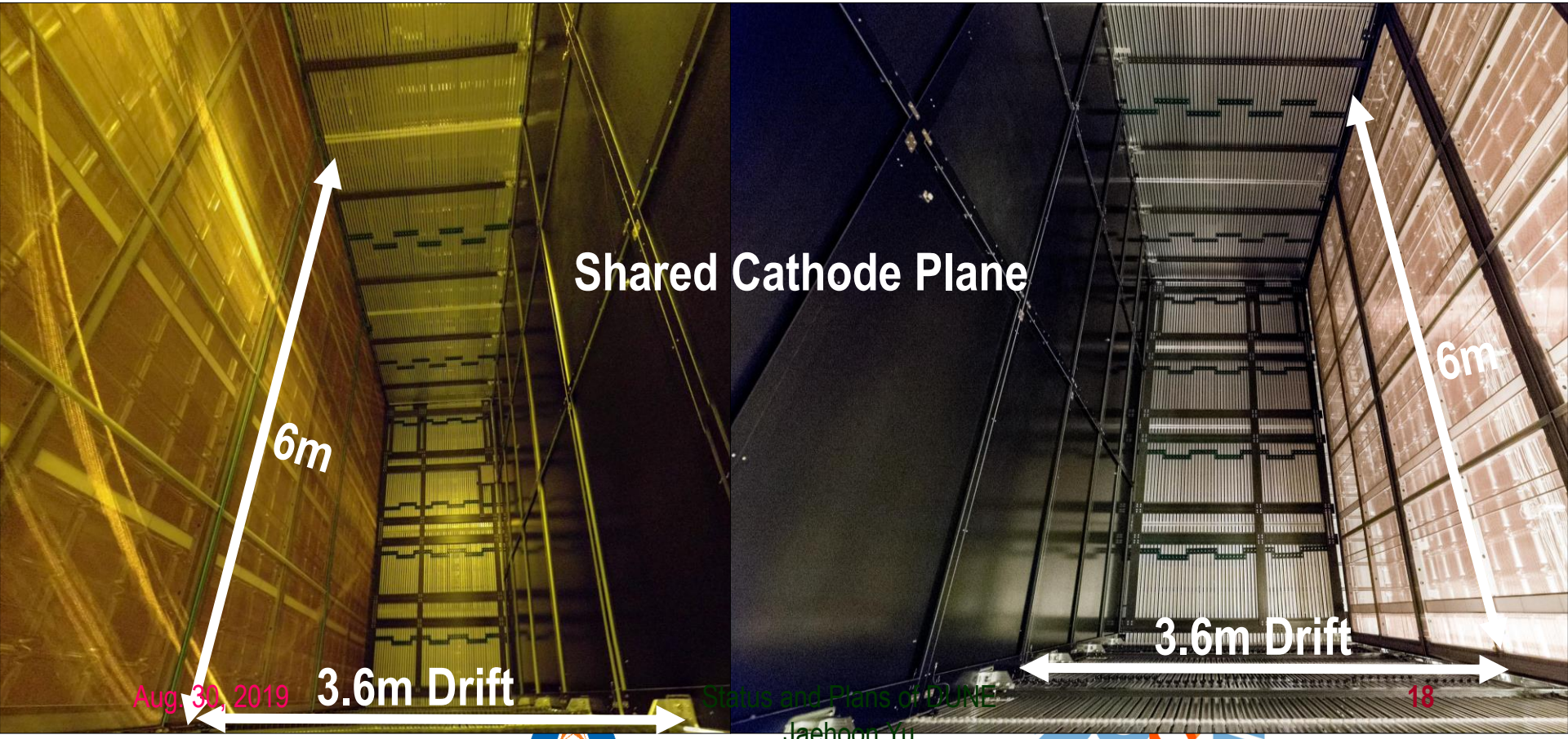
Neutrino Platform at CERN EHN1



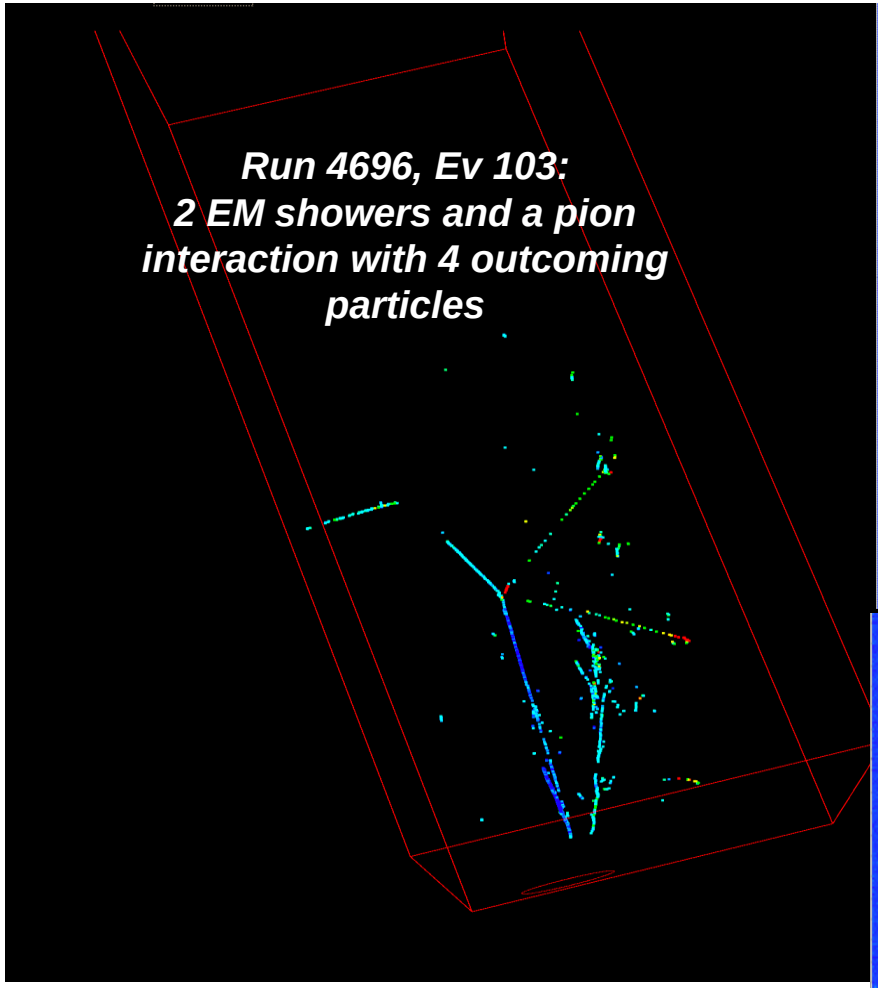
Status of ProtoDUNE Single Phase

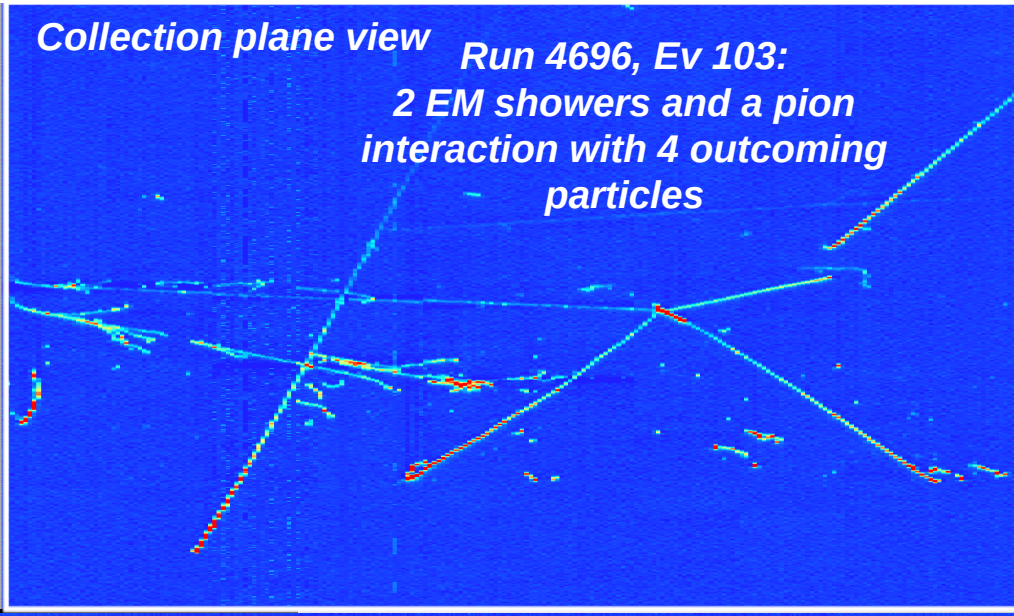
- Detector completed and the cryostat shut end of June, 2018
  - LAr filling completed on Sept. 13, 2018
  - TPC's activated and taking data since Sept. 21, 2018
    - Observed cosmic tracks as soon as the TPC turned on close to the operational HV
    - LAr purity is **~6ms**, **99.7%** of the channels alive!, gain **uniform within 5%** across
  - Beam data taking stopped on Nov. 15, 2018 ➔ data analyses ongoing
  - Cosmic data taking continues throughout the 2 year CERN beam shutdown ➔ PD2 planned

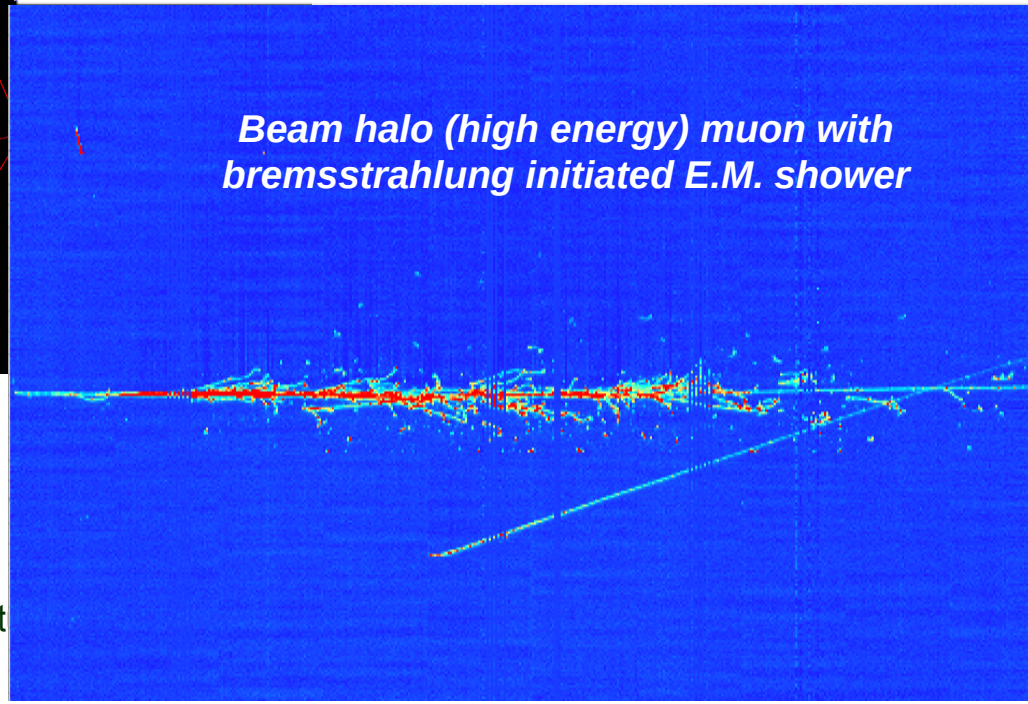
See J. Bian's talk in WG1+2 Thursday + J. Thompson Poster Monday



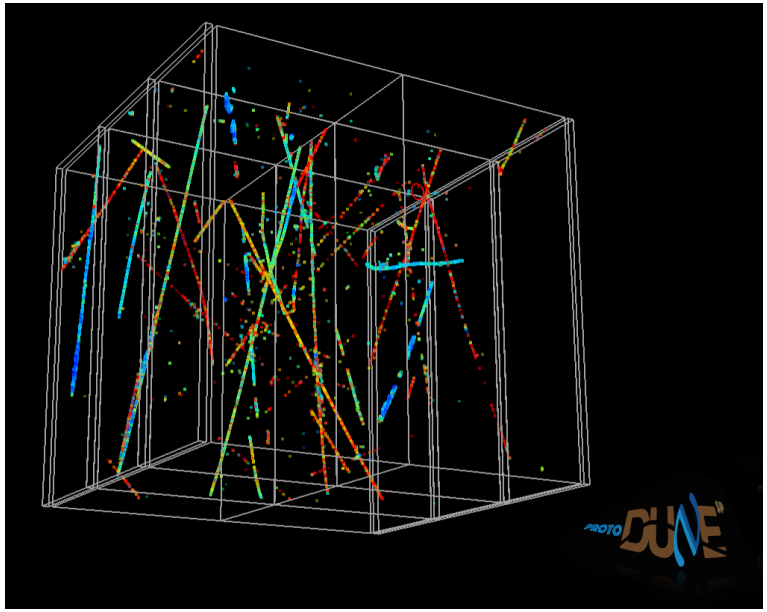
ProtoDUNE SP Beam Pile-up and Halo



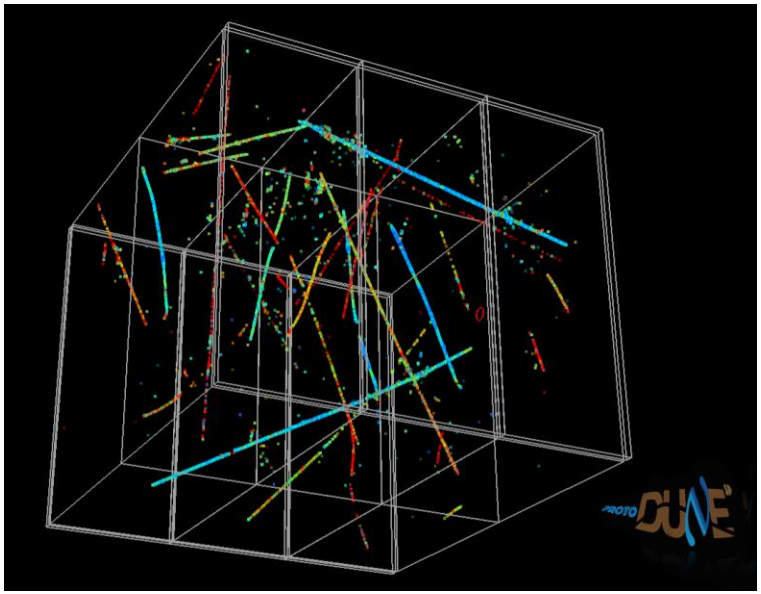


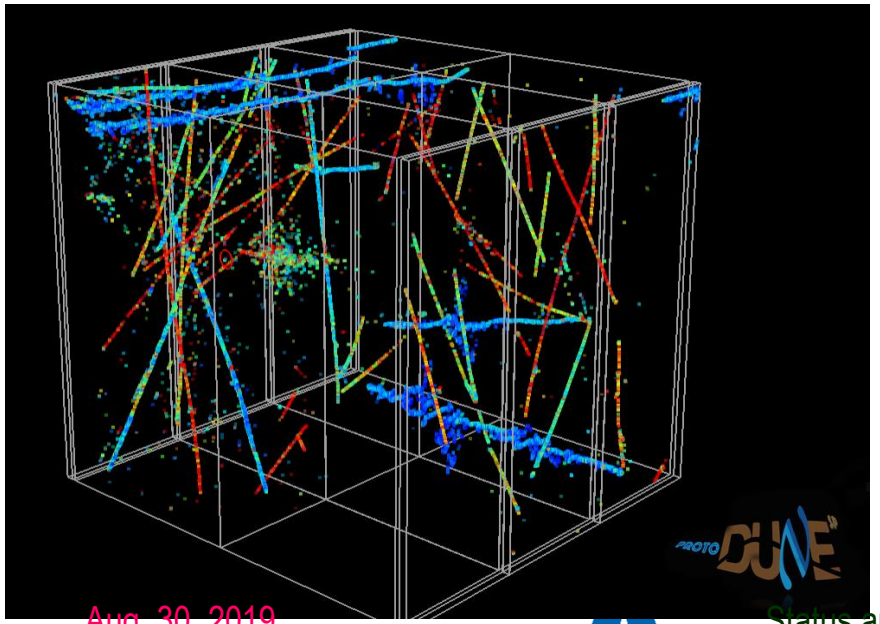


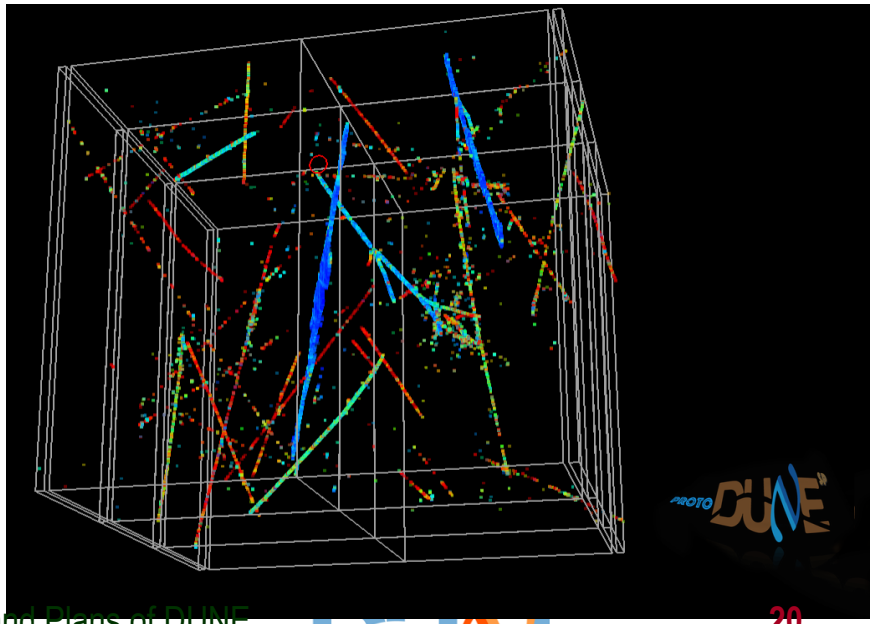
ProtoDUNE SP Cosmic Ray+Beam



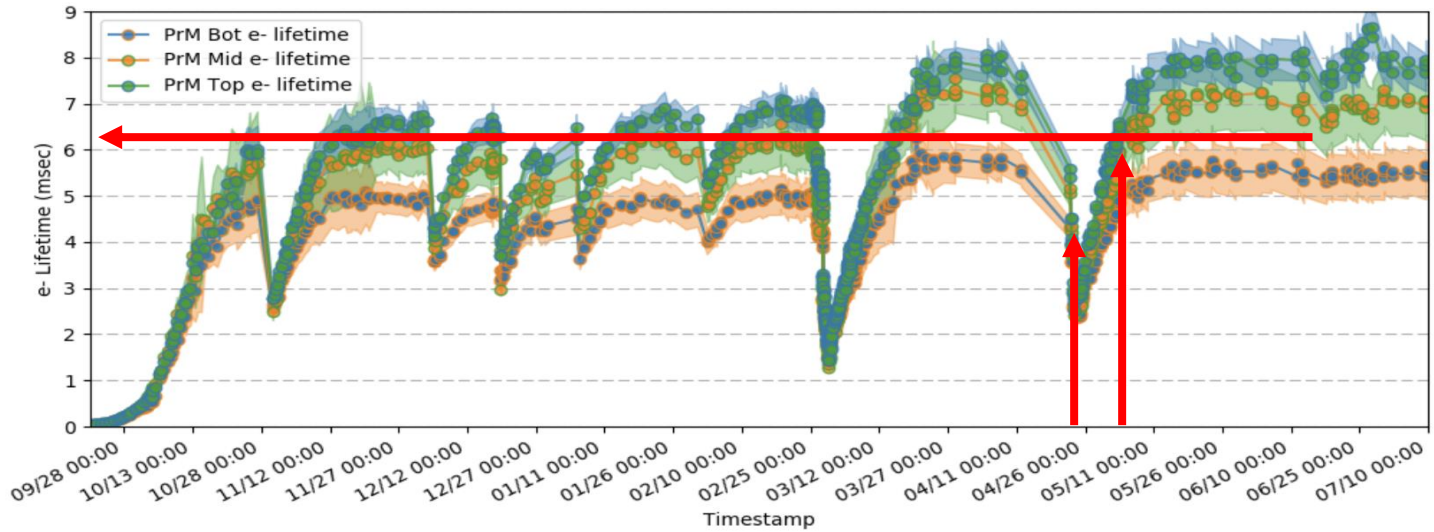
3D cosmic ray and beam events







ProtoDUNE SP LAr Purity & dE/dx



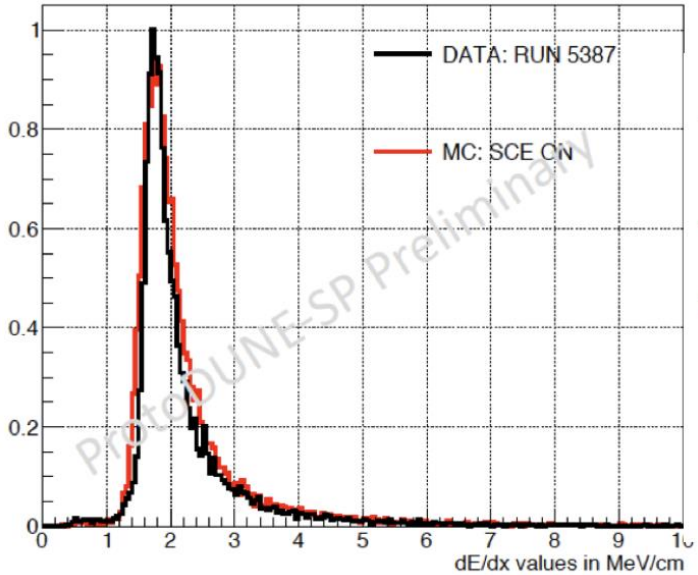
Purity>6ms

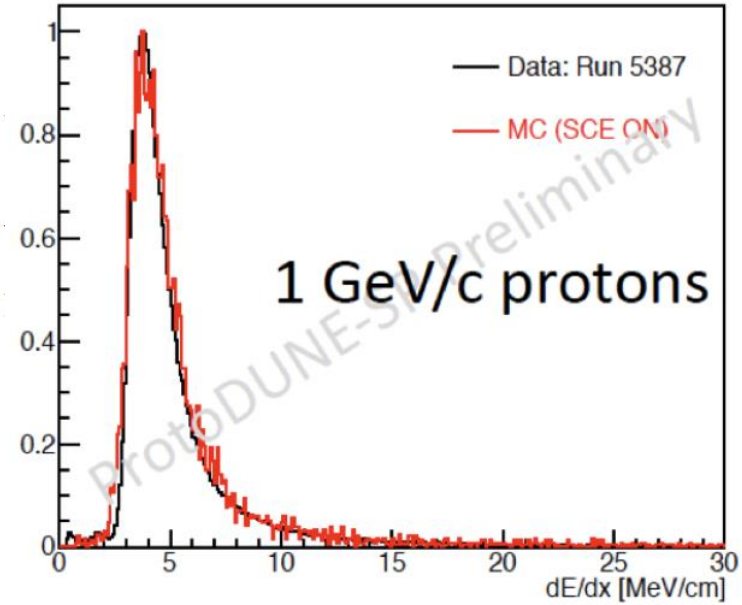
Reach high purity within 2-3 weeks

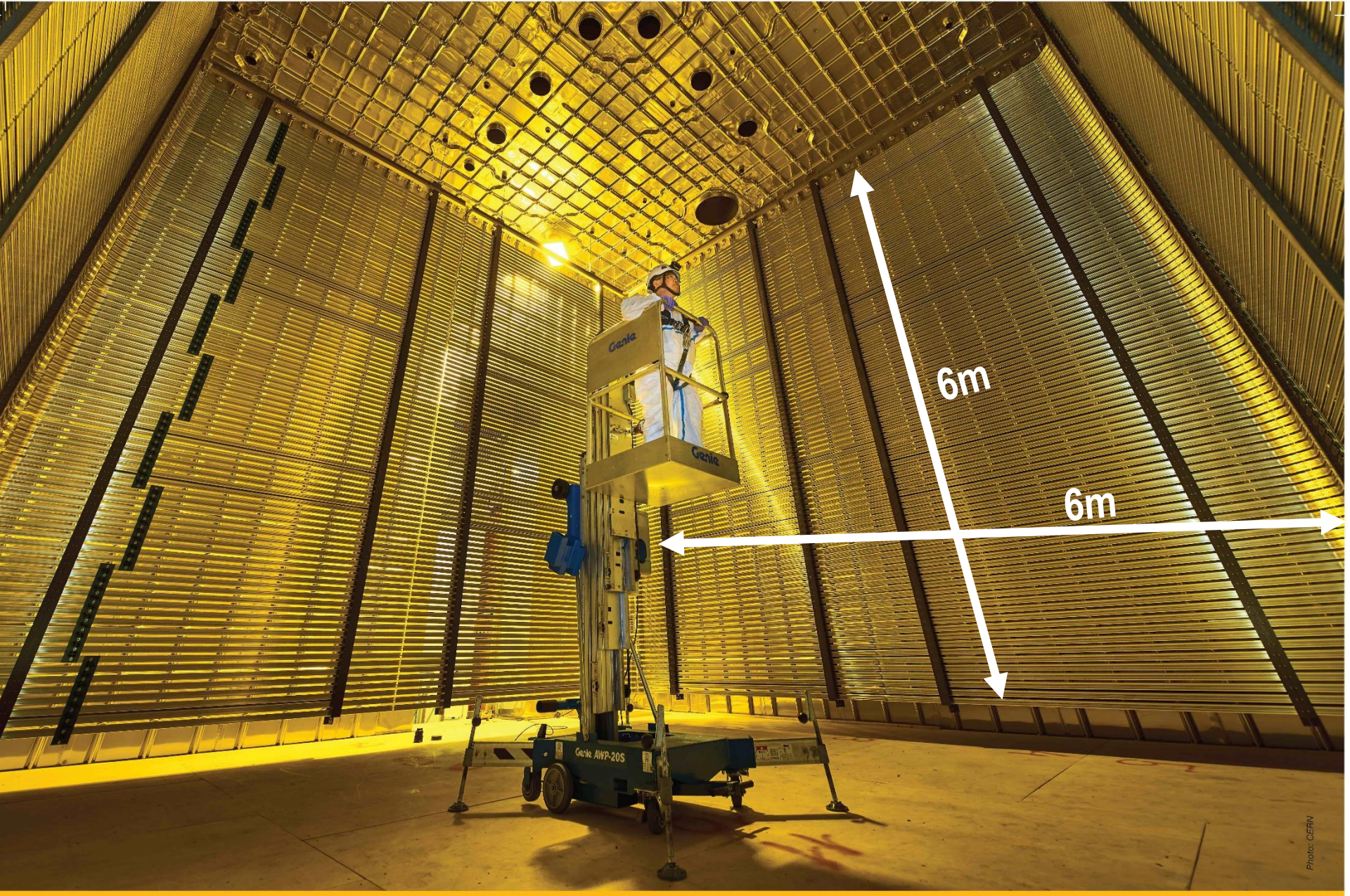
See J. Bian's talk in WG1+2 Thursday

ProtoDUNE on surface ➔ space charge effect must be understood and corrected for
Use stopping μ for absolute dE/dX

Use the absolute dE/dX on beam protons







Prototype detector for the Deep Underground Neutrino Experiment

Fermilab U.S. DEPARTMENT OF ENERGY

DUNE – Financial Supports?

- DUNE – Strong US DOE support for
  - LBNF – SURF facility cavern excavation ongoing
  - Detector prototype and technical design efforts continue
- CERN
  - Constructed Neutrino Platform in North area extension
  - Built 2 ProtoDUNE cryostats & agreed to build the 1st 10kt DUNE Cryostat
- UK provides an $88M construction grant for DUNE
- Other countries already making/ working on contributions
- US Congress has been providing funds at the optimal funding profile in the past two years & this year!
  - US currently spending >$100M/yr

DUNE Planning Milestones

- ✓July 2017: DUNE Far Site Ground breaking
  - Start of the two DUNE FD cavern construction
- ✓2018 – 2022: ProtoDUNE SP and DP at CERN
- ✓Late 2019: DUNE FD TDR approved
- Early 2020: DUNE International project baseline
  - Finalize various milestones, including the LBNF
- Aug. 2024 – May 2025: 1st 10 kt FD Installation
- Aug. 2025 – May 2026: 2nd 10 kt FD Installation
- ~2027: ND/LBNF beam Ready

Conclusions!

- The neutrino sector in SM needs to be modified
- Precise understanding of neutrino oscillation phenomena and CPV in lepton sector are essential
- Large scalable DUNE prototypes taking data since 2018 ➔ Data analyses ongoing
- DUNE garners strong financial commitments from US, UK, CERN and other participating countries ➔ FD site civil construction ongoing
- DUNE FD TDR and ND TDR reviews to complete end of 2019 and 2020, respectively
- Two 10kt V_A FD's target to complete by May 2026