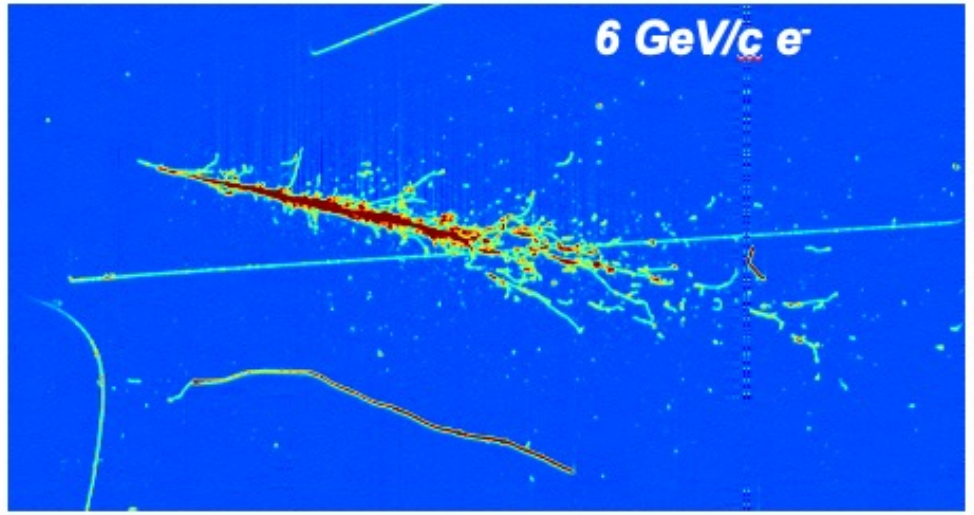
DUNE at LBNF



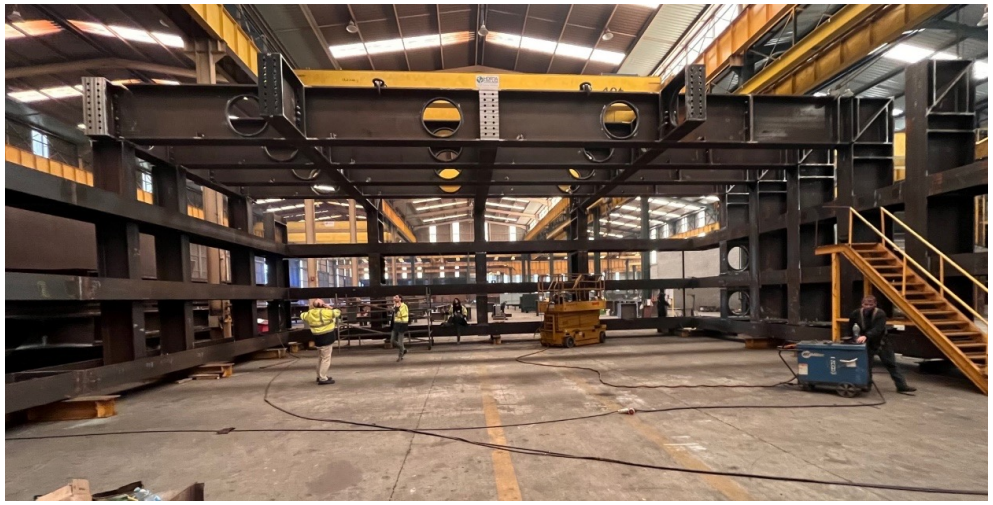
Christos Touramanis

University of Liverpool

On behalf of the DUNE Collaboration

XX International Workshop on Neutrino Telescopes

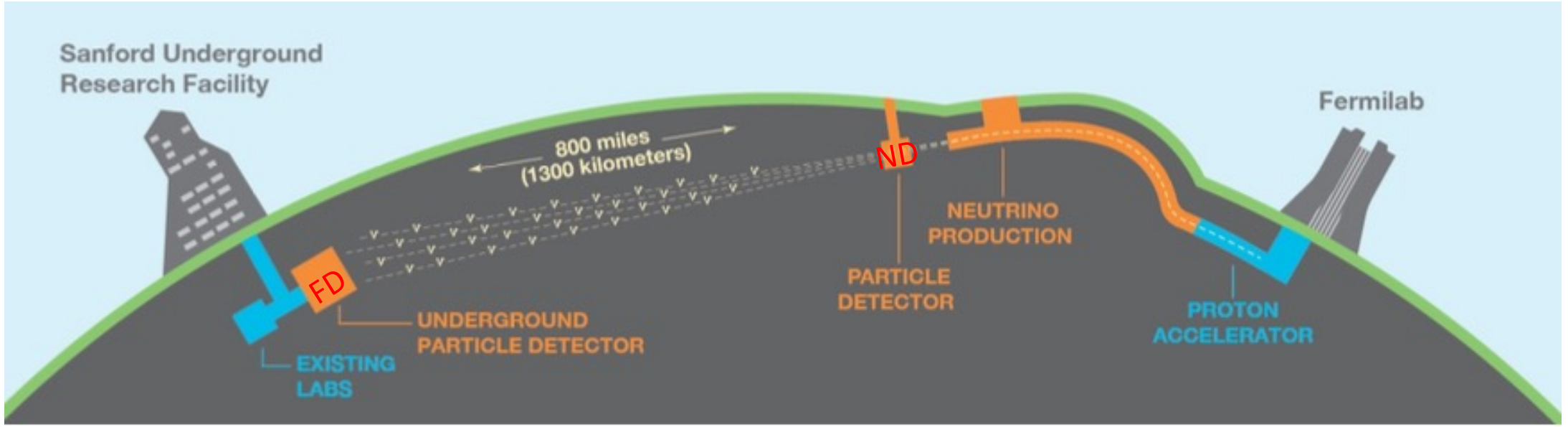
Venice, 26 October 2023



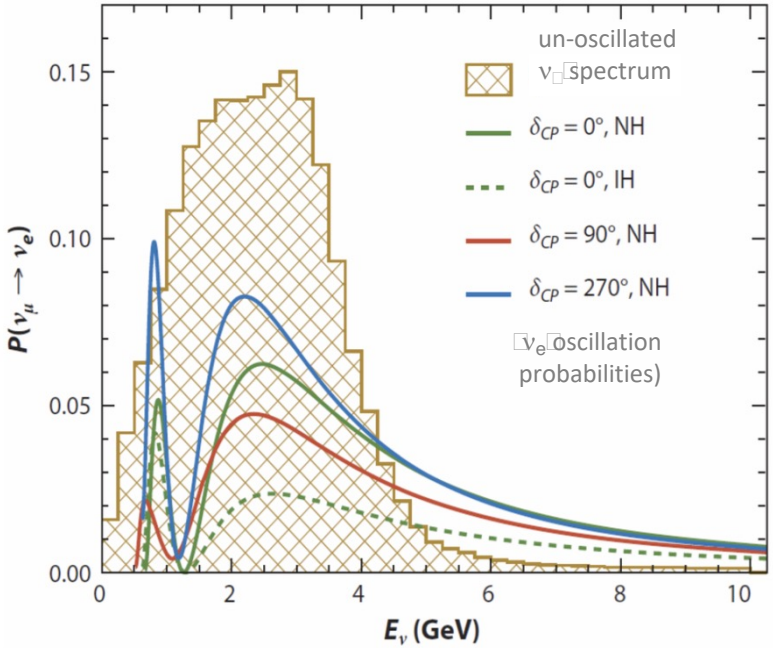
UNIVERSITY OF LIVERPOOL

DUNE

DUNE: the ultimate proton-driven long-baseline experiment

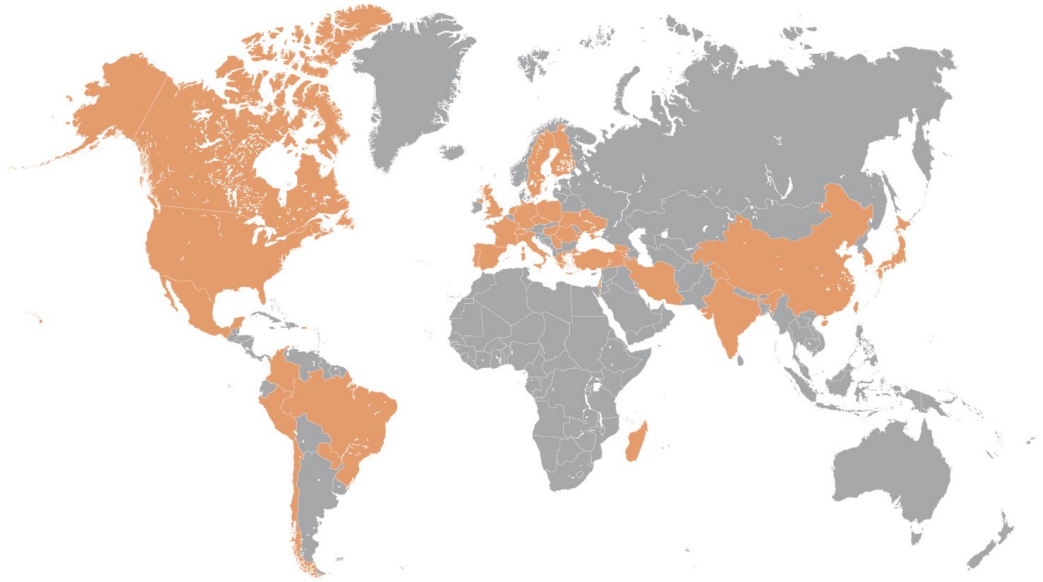


- *High precision measurements of neutrino mixing in a single experiment.*
- Determination of the neutrino mass ordering in the first few years.
- Observation and measurement of CP Violation in the neutrino sector.
- Test of the 3-neutrino paradigm (PMNS unitarity).
- Observatory for astrophysical neutrino sources (solar, atmospheric, supernova).
- Search for BSM physics.



DUNE: the Collaboration

- 1,450 collaborators
- 215 Institutes, including CERN
- 35 countries



January 2023 at CERN

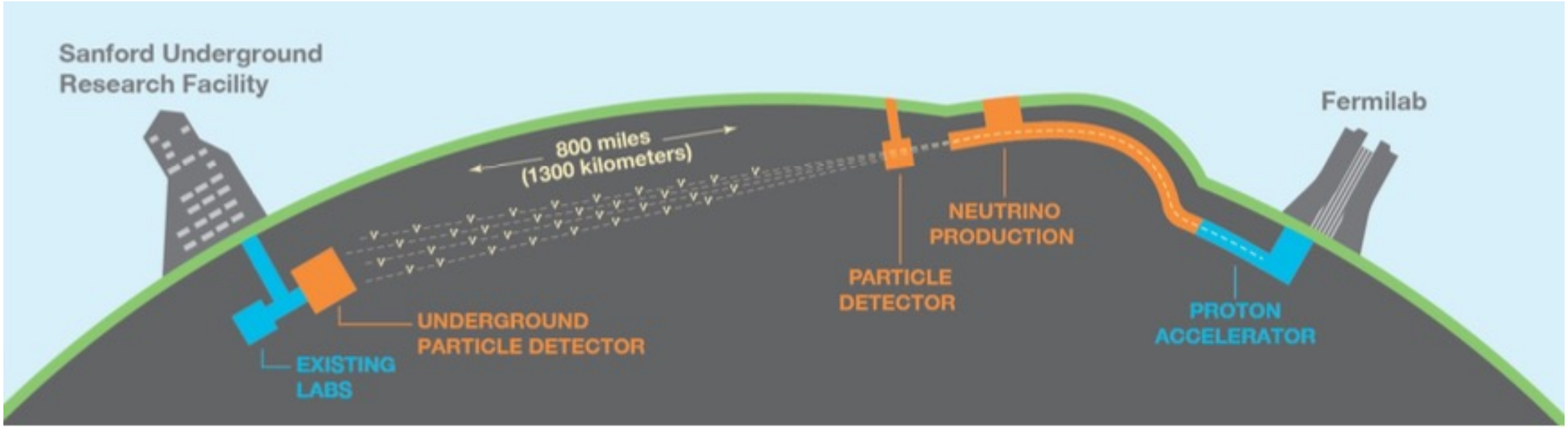
A long timeline already

- 2012: LAr TPC technology choice; large θ_{13}; LBNE reconfiguration (10kt on surface).
- 2013: European Strategy Update.

- 2014:
  - P5 Report;
  - ICFA European Neutrino Meeting (APC, Paris);
  - LBNO-LBNE high level contacts; planning for Single Phase prototype at CERN;
  - Nigel Lockyer calls Neutrino Summit (July), launching new collaboration formation;
  - CERN Neutrino Platform official commencement.

- 2015: DUNE formed and named; DOE-CERN agreement for neutrino experiments.

DUNE / LBNF



DUNE The **International Collaboration** to design, construct, and operate suites of Near and Far Detectors, and to plan and deliver a unique science program.

LBNF The **Facility** comprising the Far and Near Sites (excavation, buildings, infrastructure) and the neutrino beamline.

PIP-II The improvement plan for the Fermilab accelerator complex to provide the proton beam for DUNE, and to enable future programs at Fermilab.

Funded by:

DOE LBNF/DUNE project, CERN, and 35 more countries.

DOE LBNF/DUNE project, CERN, Switzerland, Brazil, Poland.

DOE project, India, Italy, UK, France, Poland.

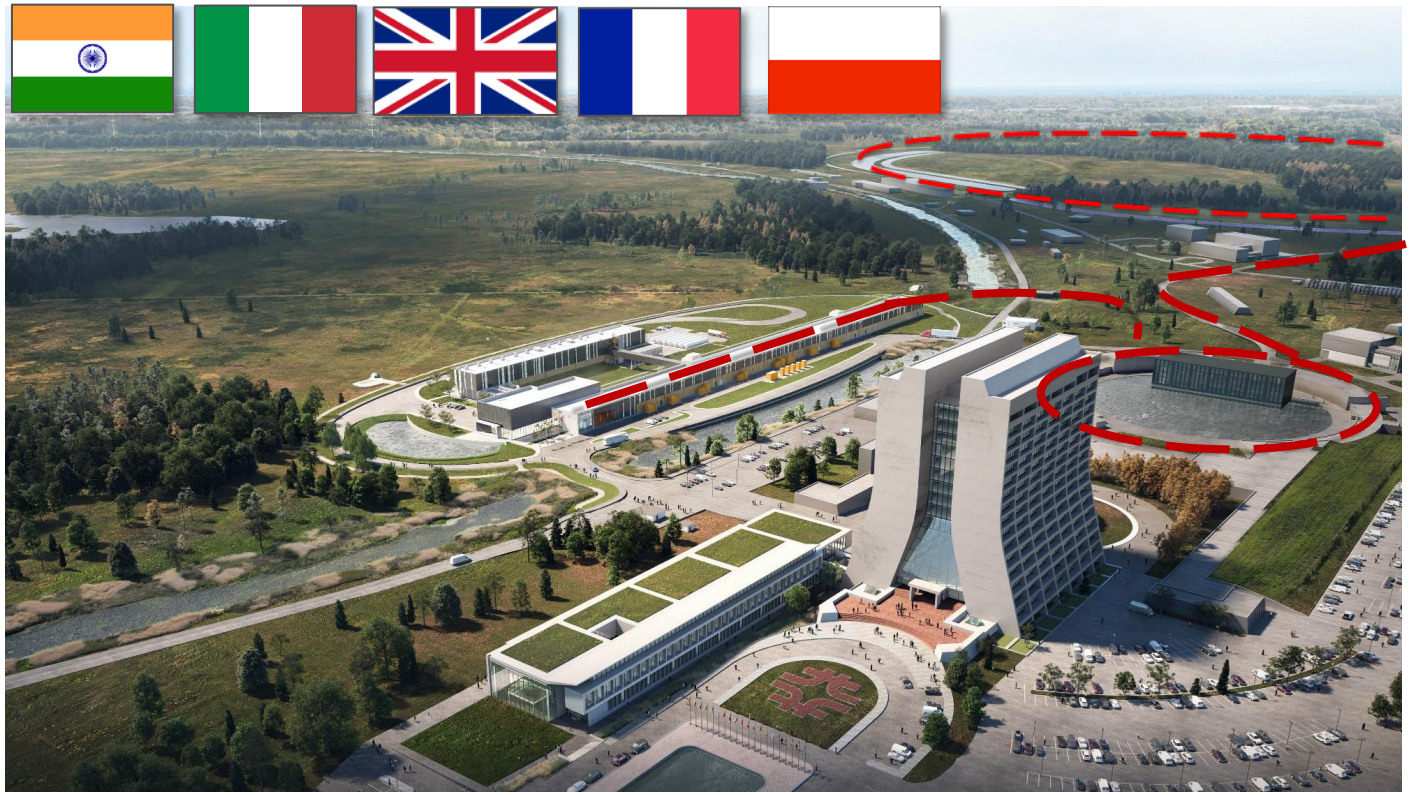
Current status and future plans in a nutshell

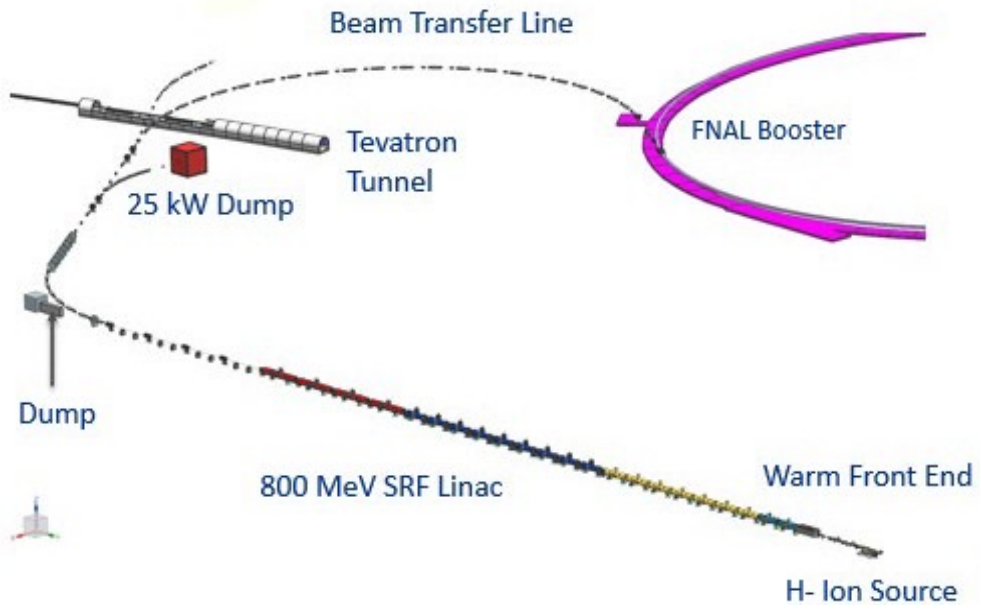
- LBNF is being delivered in its entirety.
- DUNE Phase I:
  - FD (approved): 2 x 17 kt (total) LAr TPCs: one Horizontal Drift, one Vertical Drift.
  - ND (baseline TBC and approved by 2025): NDLAr with TMS; DUNE-PRISM; SAND on-axis.
- PIP II: ongoing construction, first beam in 2031, reaching 1.2 MW by end 2032.

- Phase 2, as submitted to P5 (report due in early December):
  - DUNE ND plan: More Capable Near Detector (HPGAr TPC, magnet, calorimeter).
  - DUNE FD plan: FD3, FD4.
  - Fermilab plan: ACE: MIRT, Booster Replacement. Can provide up to 2.1 MW at DUNE start.

PIP-II

- New proton source for Fermilab : 800 MeV H^- SRF linac.
- 1.2 MW protons, upgradable to multi-MW, CW-compatible.
- Linac to Booster transfer line.
- Accelerator Complex upgrades.





Beam Schedule:

Fermilab beams stop end 2026

Beam commissioning: 2029-30

Beam to DUNE: Fall 2031, ~ 1 MW

1.2 MW by end 2032

Linac Scope

PIP2IT successfully demonstrated 17 MeV beam with parameters required for LBNF/DUNE operations

Cryoplant
2.5kW @ 2K

CDS

HWR
162.5 MHz

Single Spoke 1
SSR1 x (1 + 2)
325 MHz

Single Spoke 2
SSR2 x (1 + 7)
325 MHz

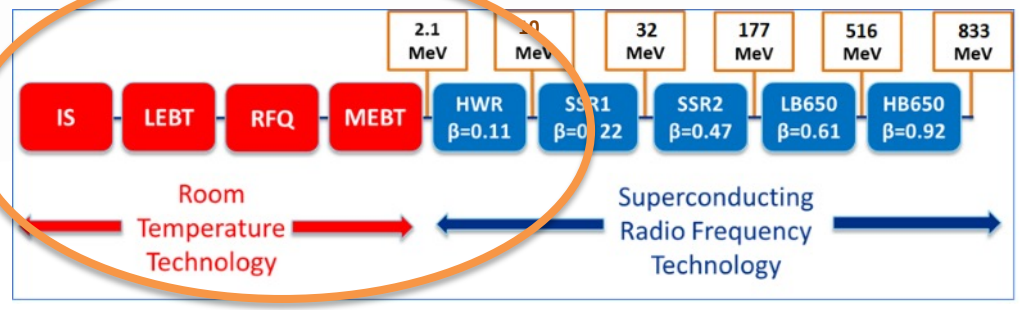
Elliptical
LB650 x (1 + 9)
650 MHz

Elliptical
HB650 x (1 + 4)
650 MHz

SRF technology

Room temperature technology

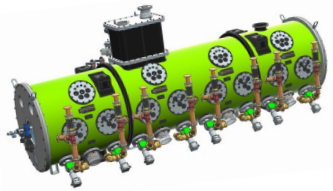
Tested at PIP2IT



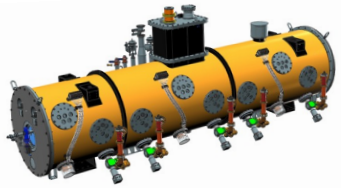
PIP-II technology map

SRF Cryomodules

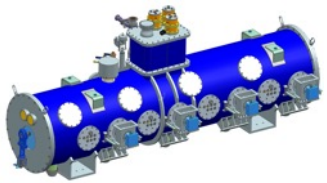
5.9 m



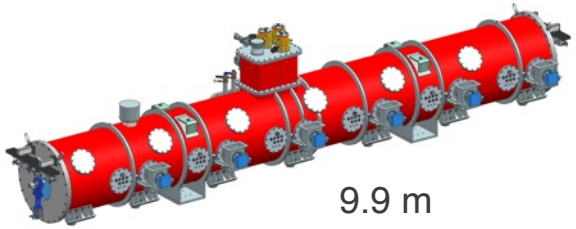
5.3 m



6.5 m



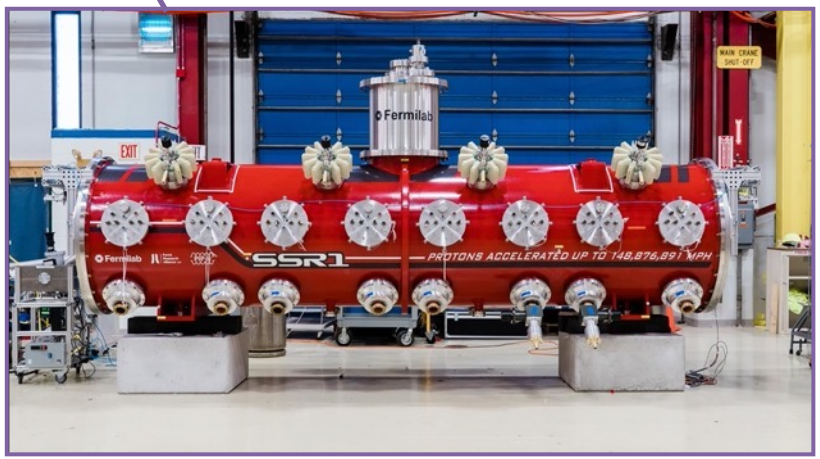
5.5 m

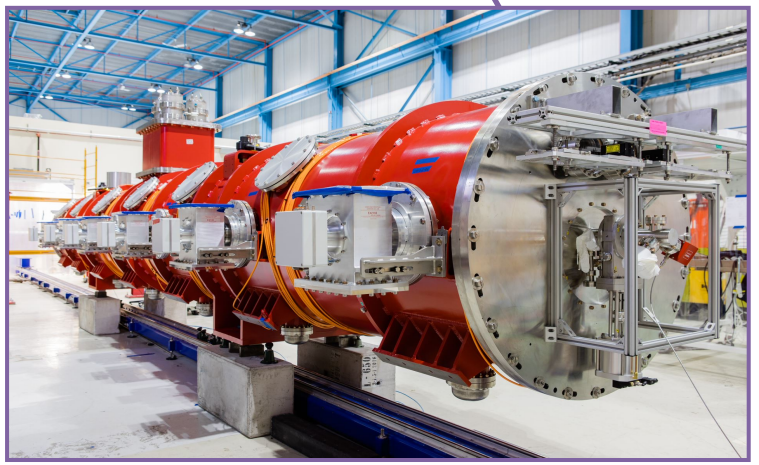


9.9 m

HWR ✓ SSR1 ✓ SSR2 ✓ LB650 ✓ HB650 ✓ (Cold testing in ongoing)

Pre-Production Cryomodules





✓ *Prototype designed* ✓ *Prototype built* ✓ *Prototypes validated*

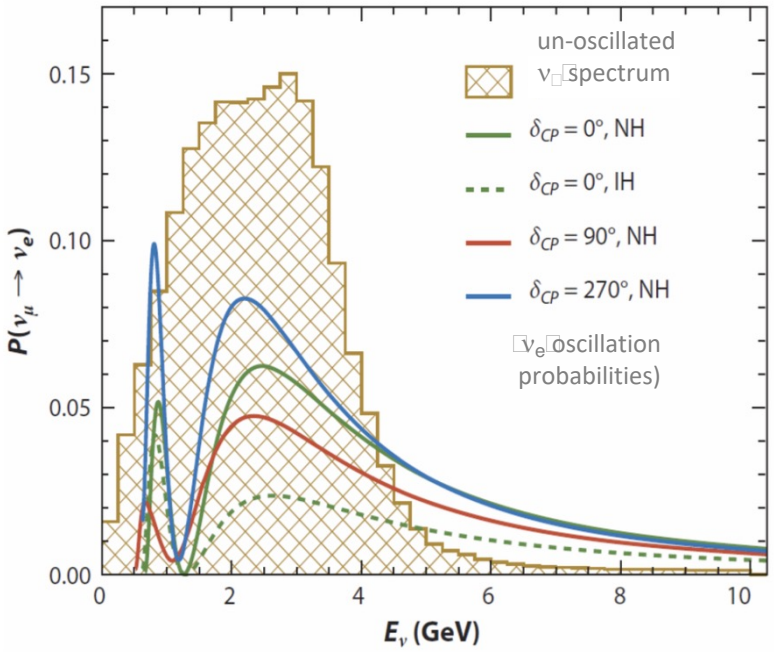
UNIVERSITY OF LIVERPOOL DUNE

Accelerator Complex Evolution

- ACE is proposed by Fermilab and considered by P5. It has two distinct steps:
- MIRT, the Main Injector Ramp and Targets:
  - Shortens MI cycle time with faster ramp time (now 1.33 s, PIP-II 1.2 s, MIRT 0.7 s).
  - Brings max. MI power from 1.2 MW to 2.14 MW.
  - Requires enhancements of the acceleration and magnet systems in the MI.
  - Must be accompanied by additional measures to improve Booster reliability.
  - Requires development of new target (and first horn) for higher power, faster pulsing.
  - It could allow to run DUNE with 2.1 MW in 2032.
- Booster Replacement: it is proposed that a project is established to *develop and deliver a Booster replacement accelerator*. This will be Fermilab future infrastructure, and also provide 2.4 MW to DUNE in parallel to other programs.

DUNE Oscillation physics

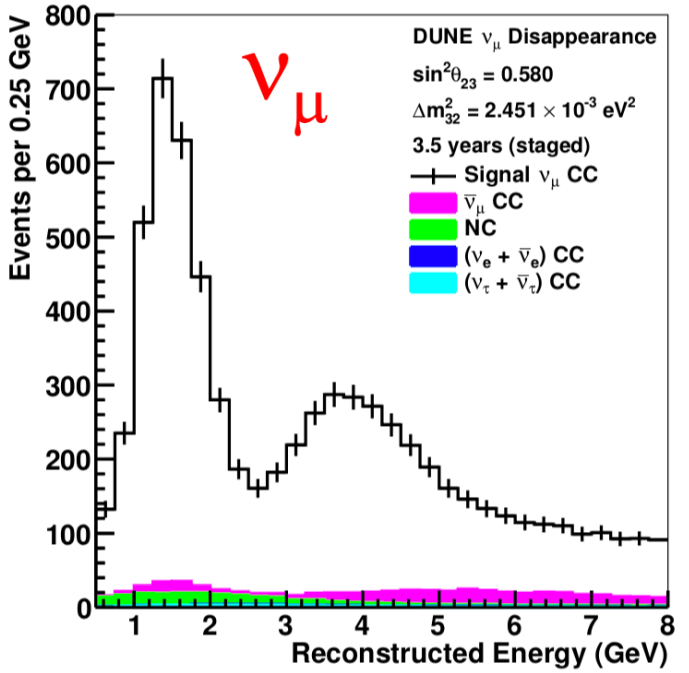
DUNE Collaboration, Eur. J. Phys. C80, 978 (2020)

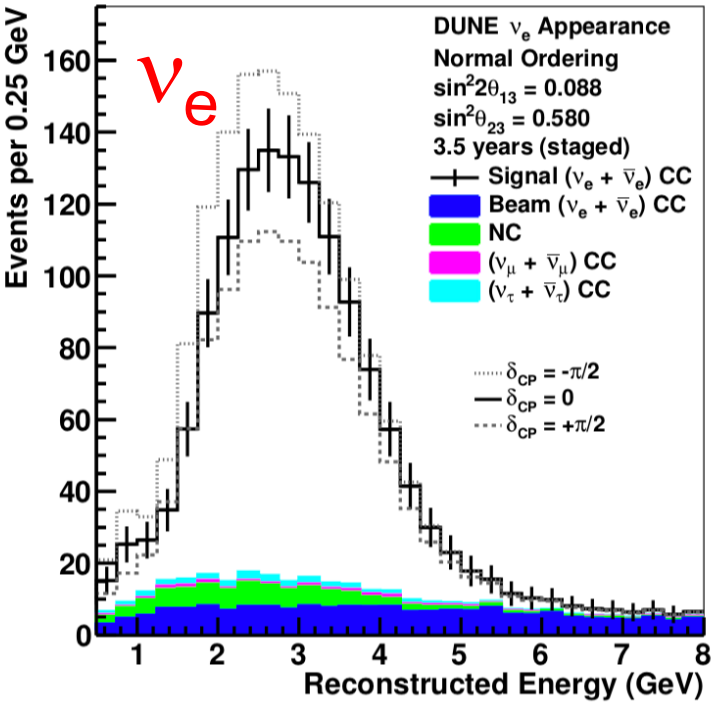


disappearance

$\nu_\mu \rightarrow \nu_e$

appearance





In year 1 alone, DUNE will collect ~150 oscillated ν_e events. This is aprox. the sum of T2K + NOvA.

- *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, depending on true MO, CP*

Determining Mass Ordering with DUNE Phase I using ν_e and anti-ν_e spectra.

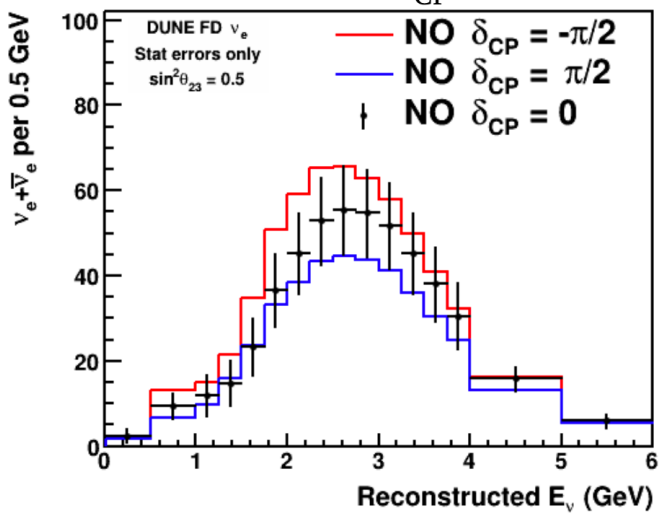
Data points show NO, $\delta_{CP} = 0$, $\sin^2\theta_{23} = 0.5$

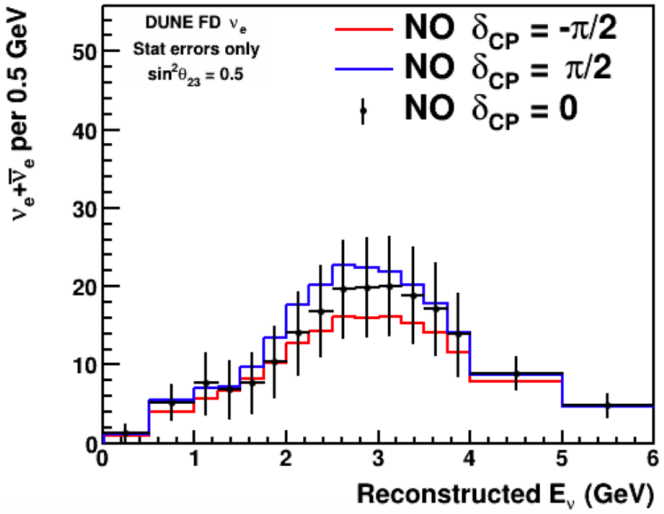
Neutrino mode

Phase I

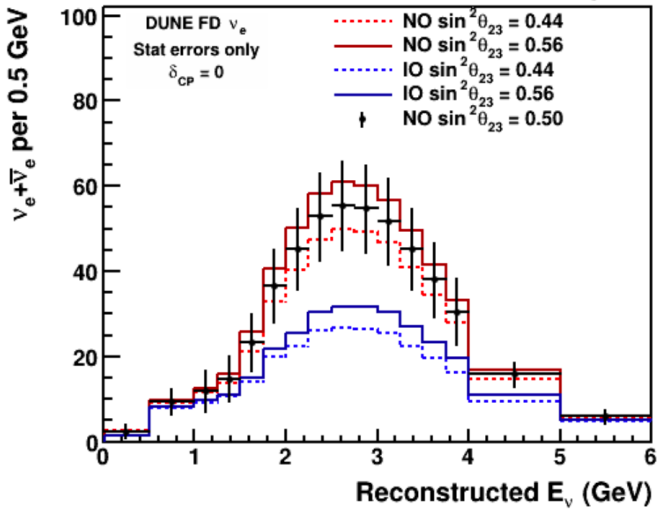
Antineutrino mode

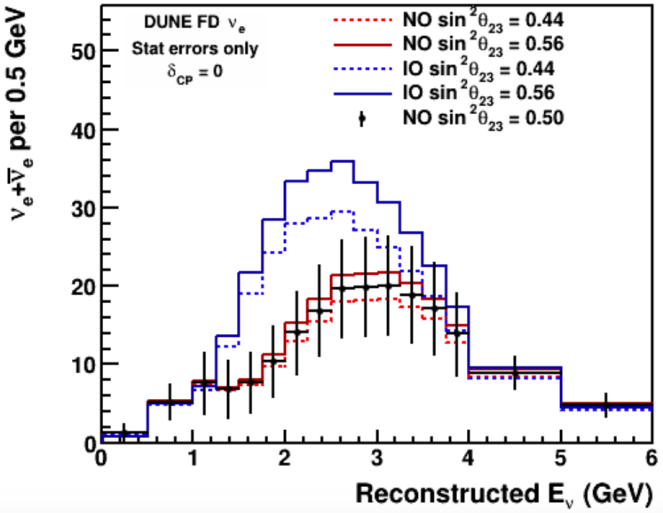
Varying δ_{CP}





Varying MO and $\sin^2\theta_{23}$





Measuring δ_{CP} and θ_{23} octant with DUNE Phase II using ν_e and anti-ν_e spectra.

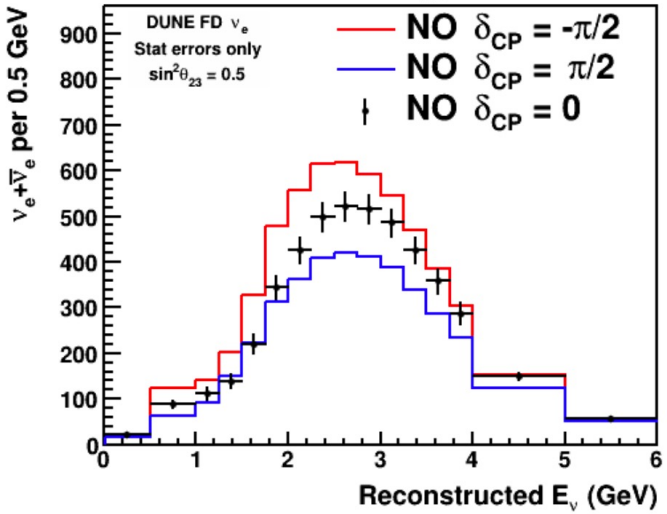
Data points show NO, $\delta_{CP} = 0$, $\sin^2\theta_{23} = 0.5$

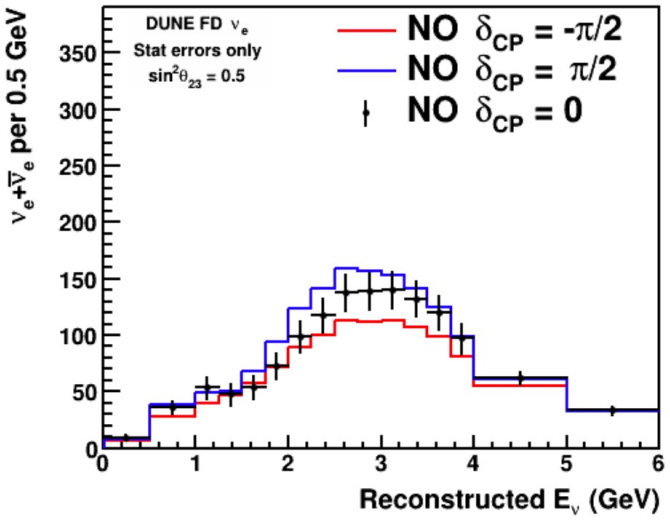
Neutrino mode

Phase II

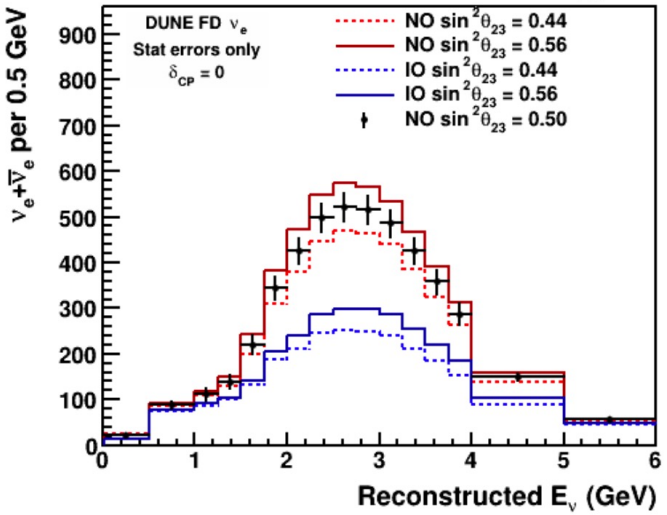
Antineutrino mode

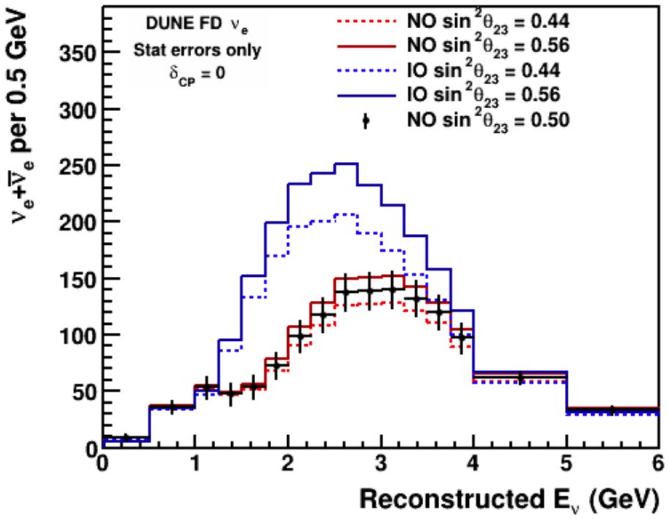
Varying δ_{CP}



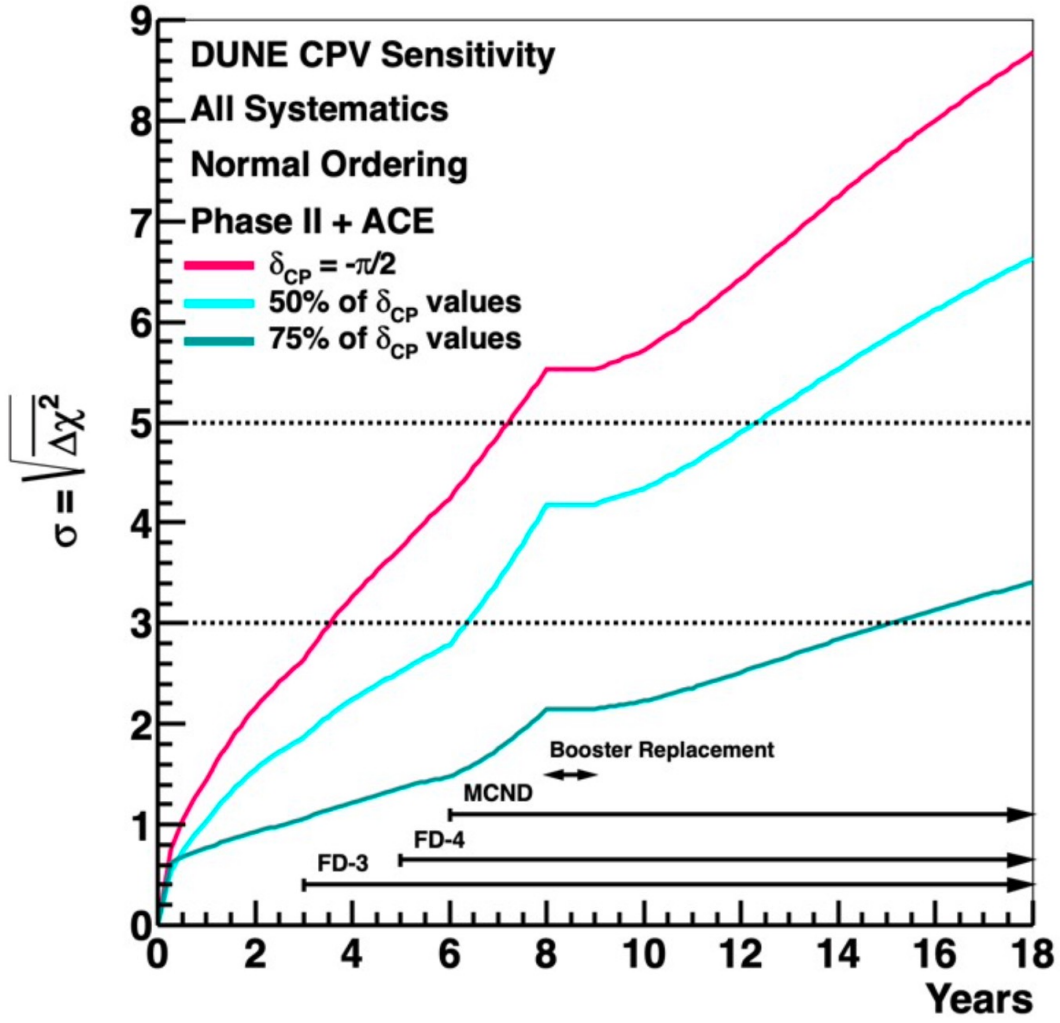


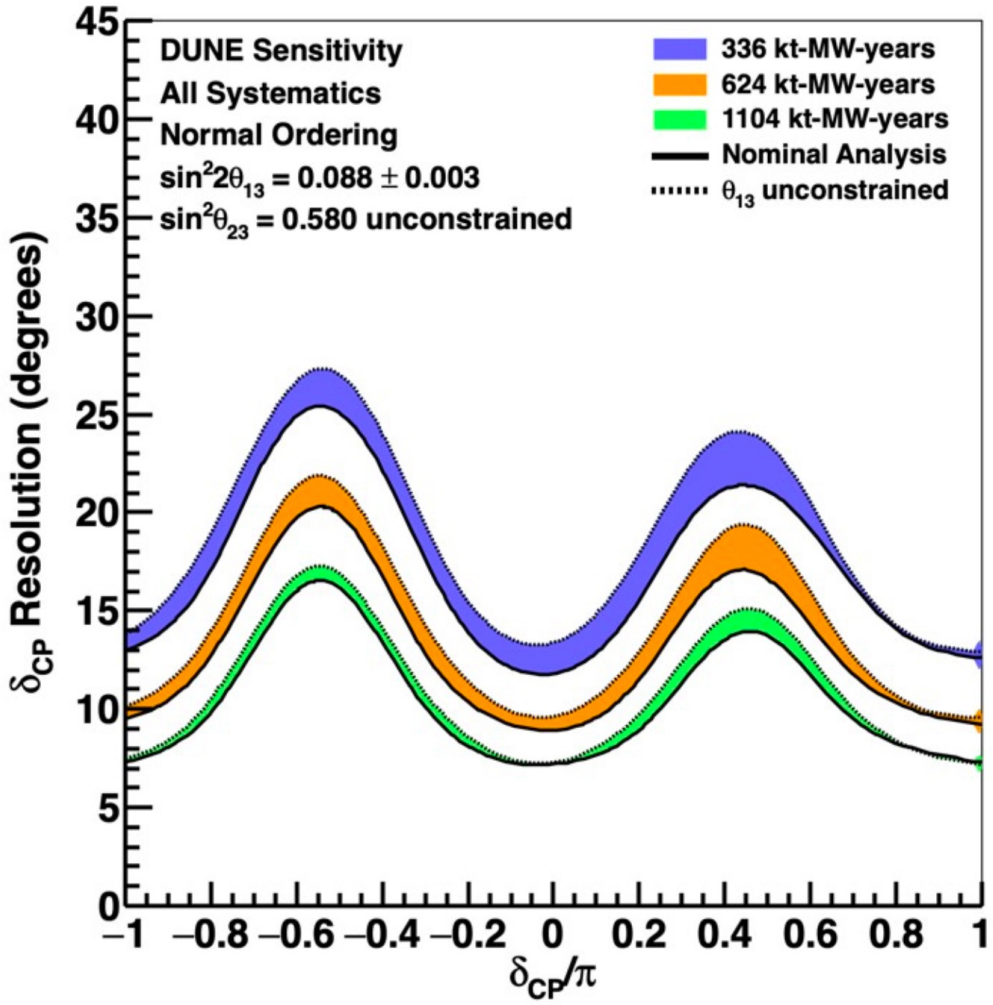
Varying MO and $\sin^2\theta_{23}$





Observation of CP Violation, measurement of θ_{CP}



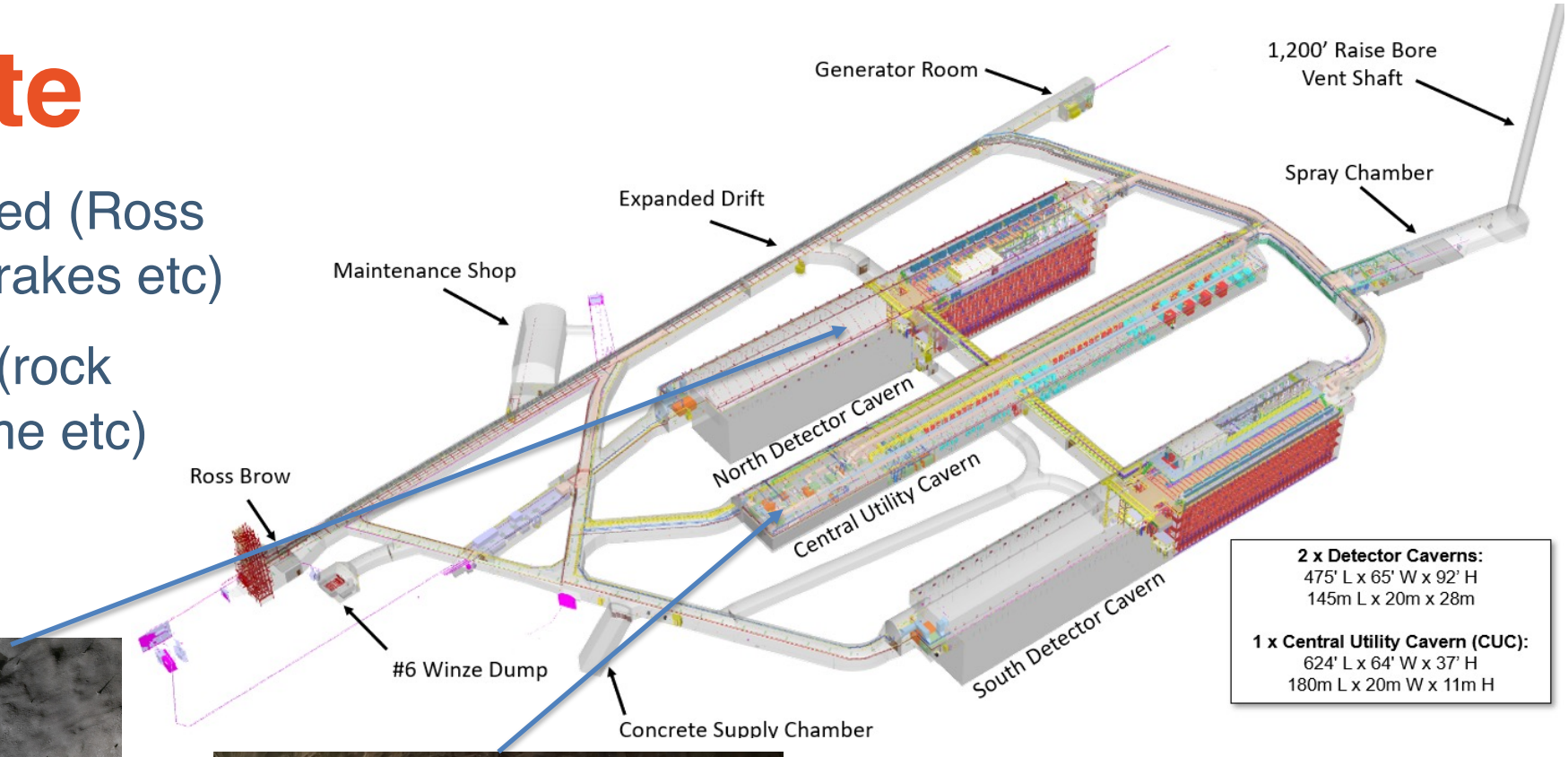


Extended physics capabilities of DUNE

- Broadband beam and calorimetric tracking in LAr allow to measure a large range of L/E in both the ND and FD, both with neutrinos and antineutrinos (sensitivity to steriles, CPT violation, NSI).
- Long baseline maximises sensitivity to matter-dependent new physics.
- Can measure parameters such as Δm^2_{32} with neutrinos and antineutrinos.
- Resolution on θ_{13} approaches that of Daya Bay for the full DUNE statistics.
- Sensitivity to low mass Z' from trident production cross section.
- 5σ sensitivity to solar hep flux in Phase I.
- LAr TPC can reconstruct tau decays and the LBNF beam has flux above the ν_τ production threshold. Can be further increased by moving the horns. Complementary to atmospheric ν_τ physics in ICECUBE.
- Supernova physics: unique sensitivity to ν_e; high statistics; time and energy resolution; pointing to ~5^O by separating elastic from CC using low-E de-excitation photons.
- ND sensitivity to Boosted Dark Matter from the beam; Heavy Neutral Leptons; …

LBNF Far Site

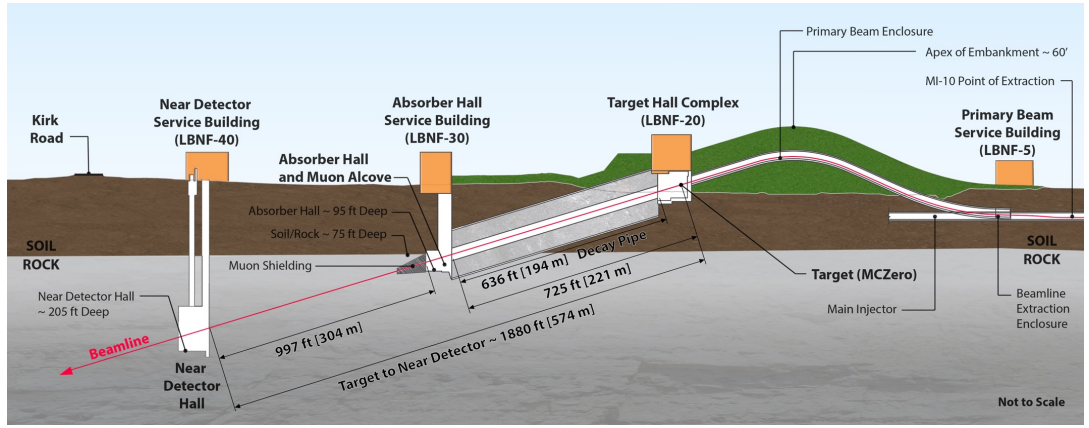
- Reliability Projects completed (Ross shaft, hoist motor, drives, brakes etc)
- Pre-Excavation completed (rock disposal systems, headframe etc)
- **Excavation 80% done!**



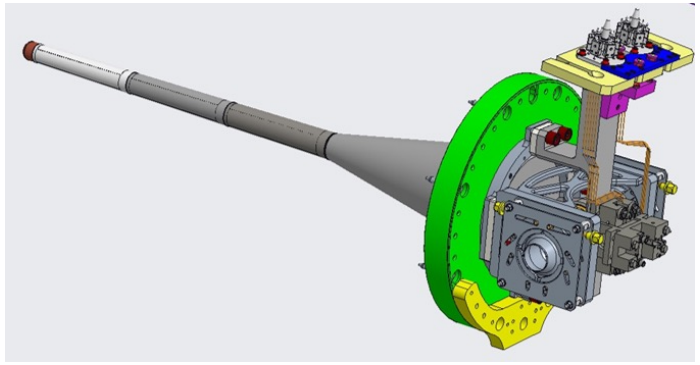
- Excavation complete: 2024
- Buildings & Infrastructure: end 2025
- First cryostat setup & installation starts winter 2024

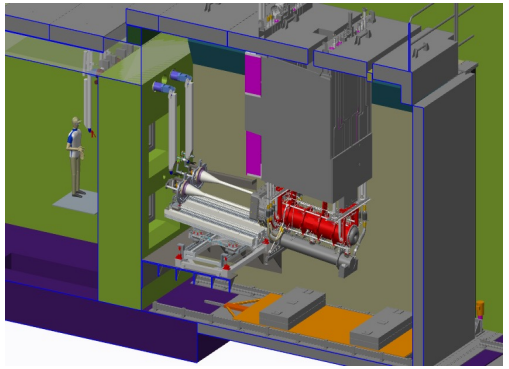
LBNF neutrino beamline

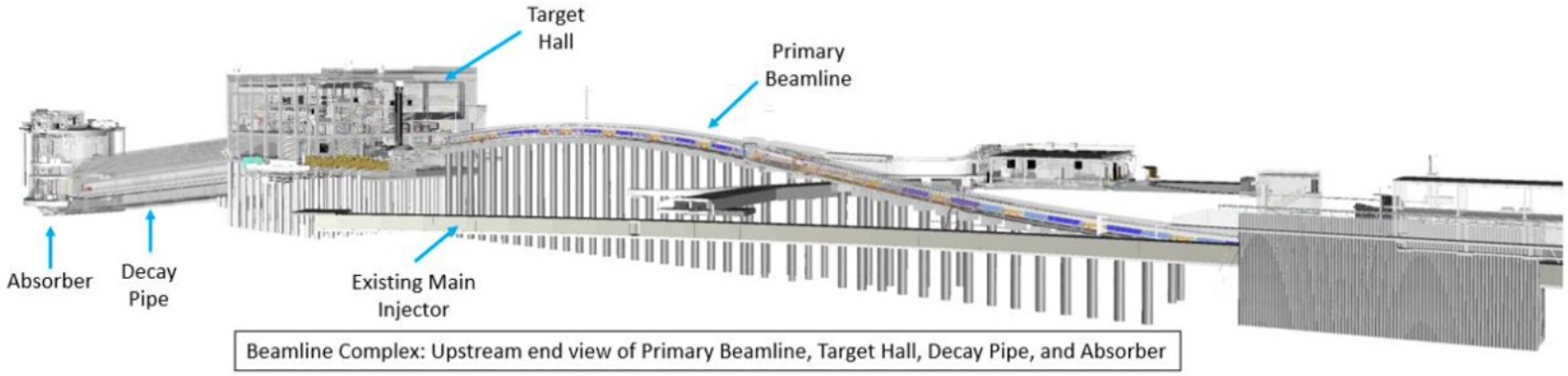
Beamline at 70% final design, on track.



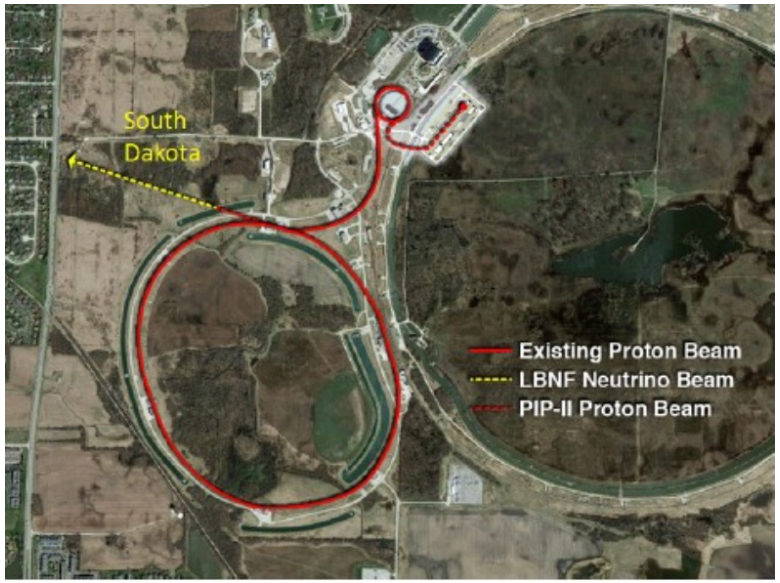
Target design & 2 first units; remote handling (UK)







Beamline Complex: Upstream end view of Primary Beamline, Target Hall, Decay Pipe, and Absorber

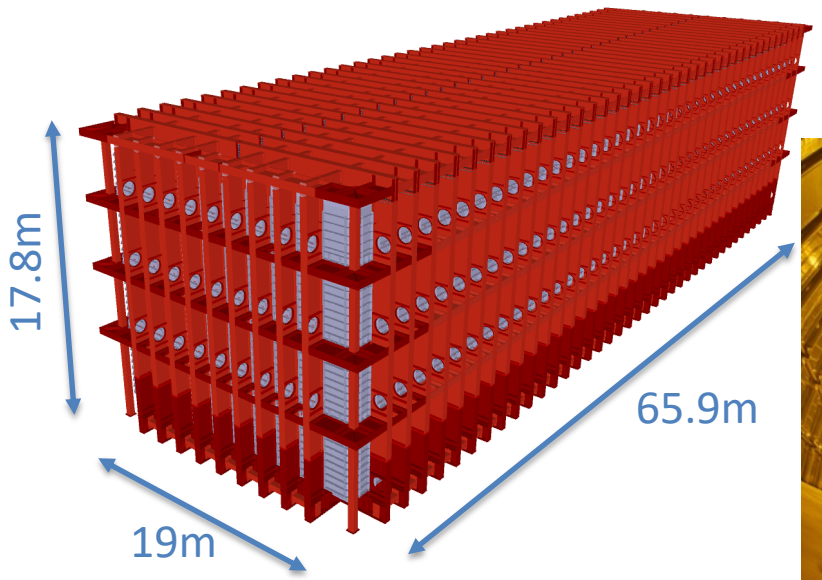


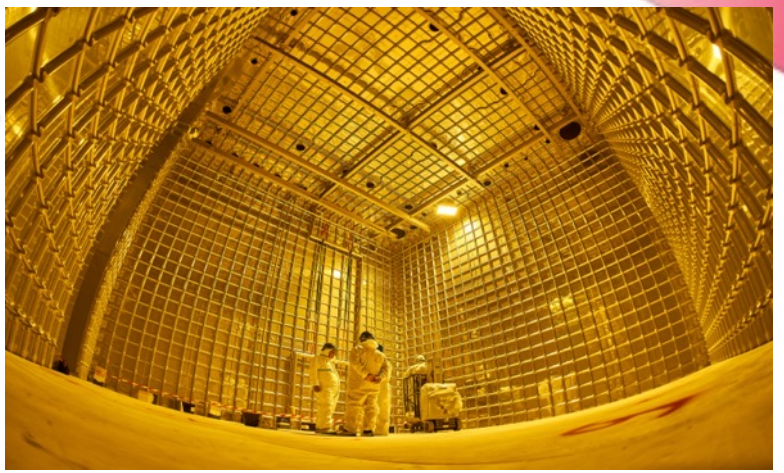
Far Detectors

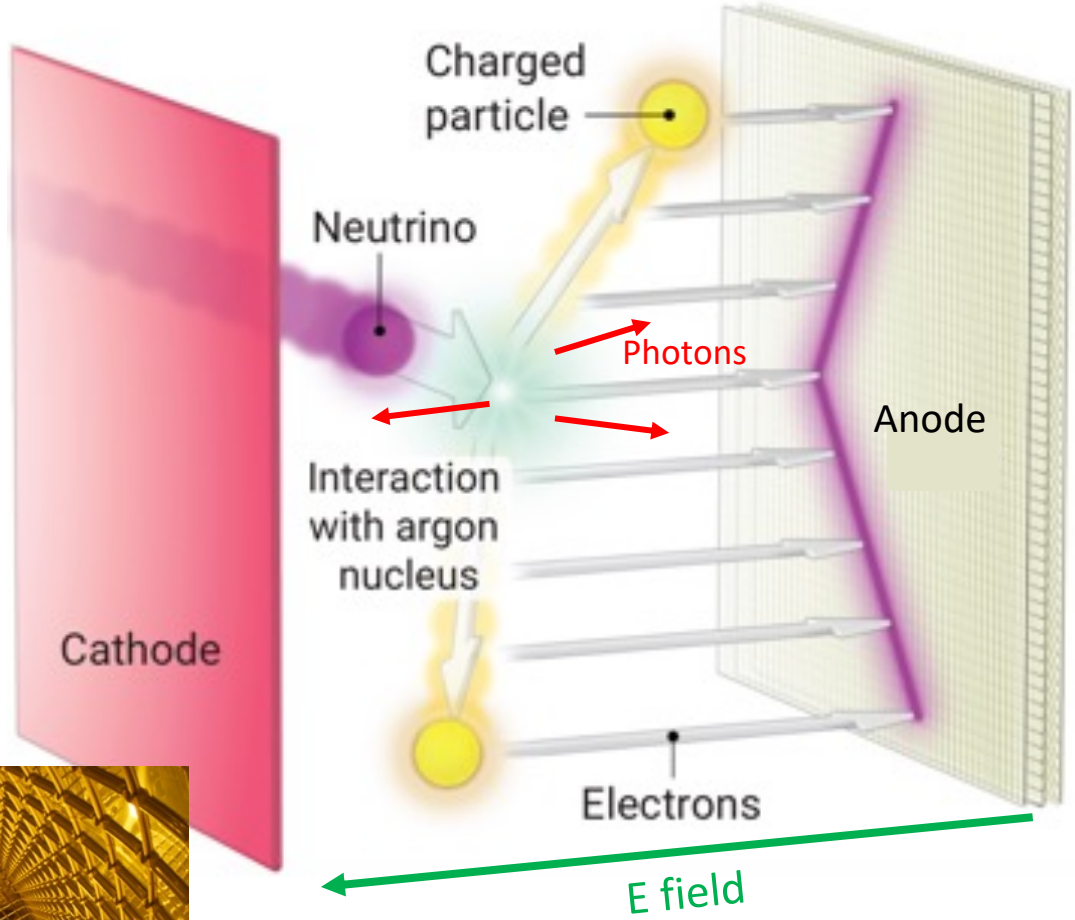
- 2 (max 4) LAr TPCs, 17 kt Argon total (10 kt fiducial) each one:
  - Horizontal (charge) Drift
  - Vertical (charge) Drift

Each membrane cryostat has internal volume :

~28'500 m^3, ~17'500 tons of LAr

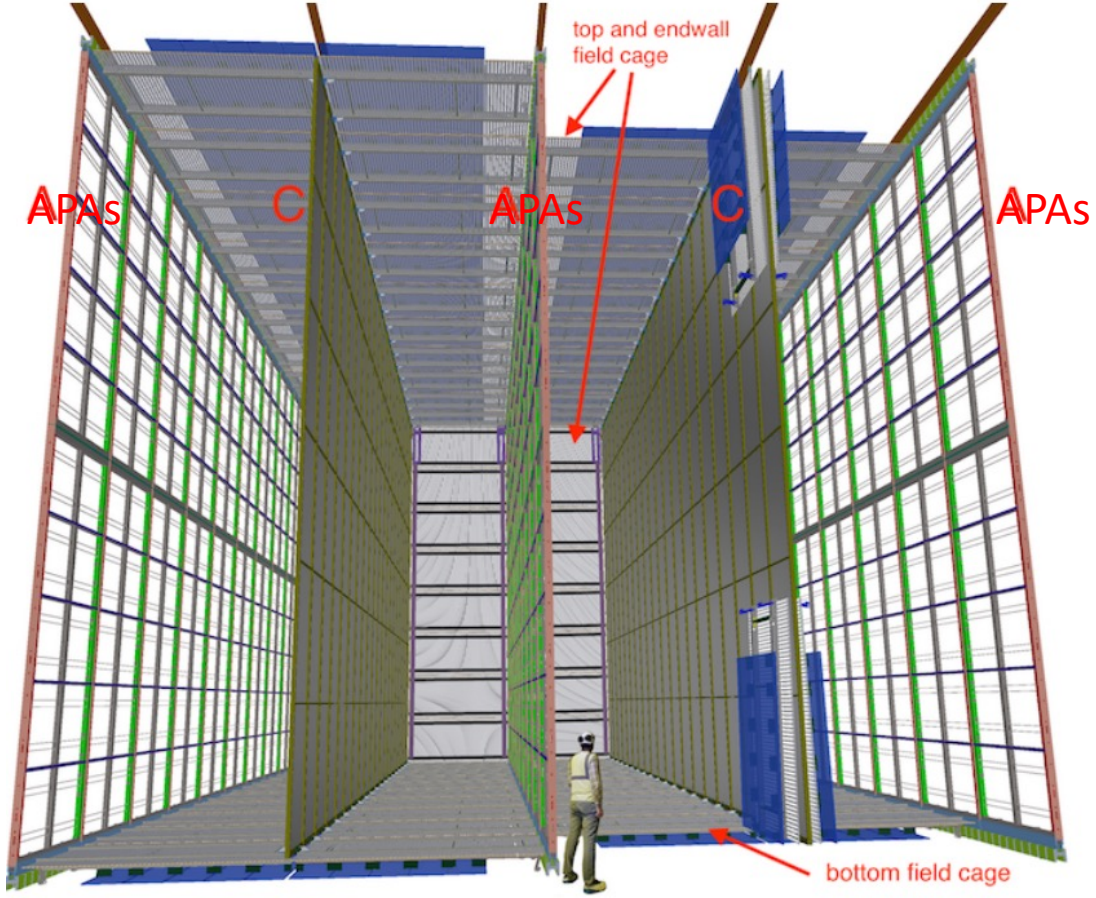






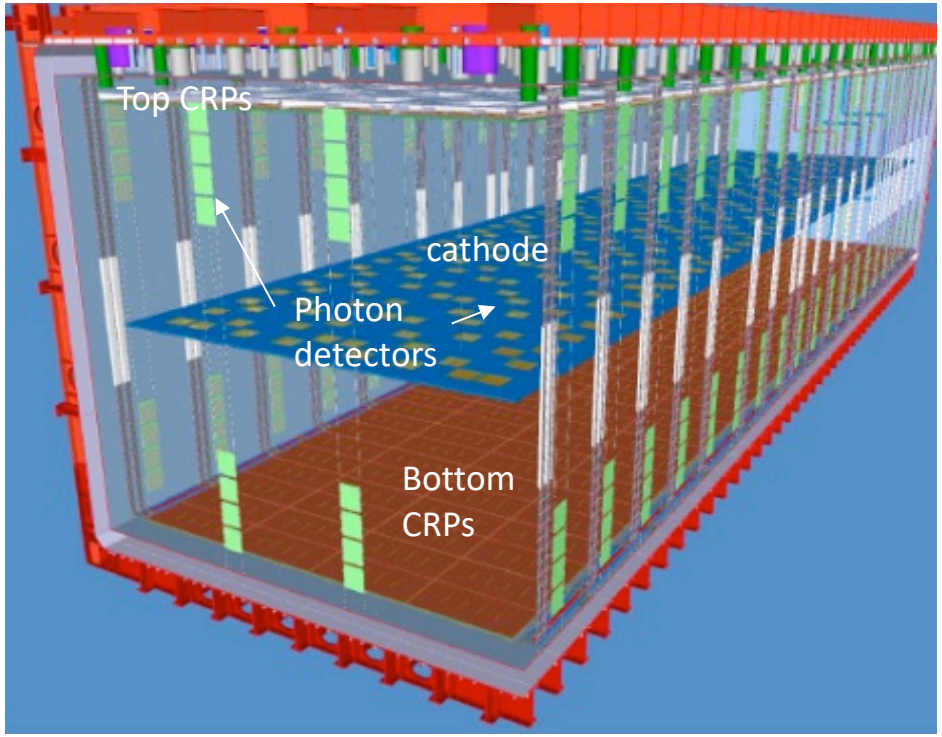
ProtoDUNE cryostat
Same technology
1/25 of FD module

Horizontal Drift



- APA : based on a wire chamber technology
- Drift length ~ 350 cm -> ~ 180 KV on cathode
- ~ 9800 m^3 = ~ 13'661 tons of active LAr

Vertical Drift

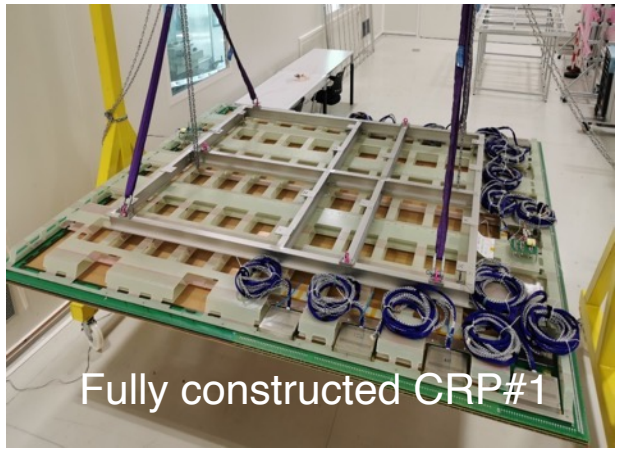


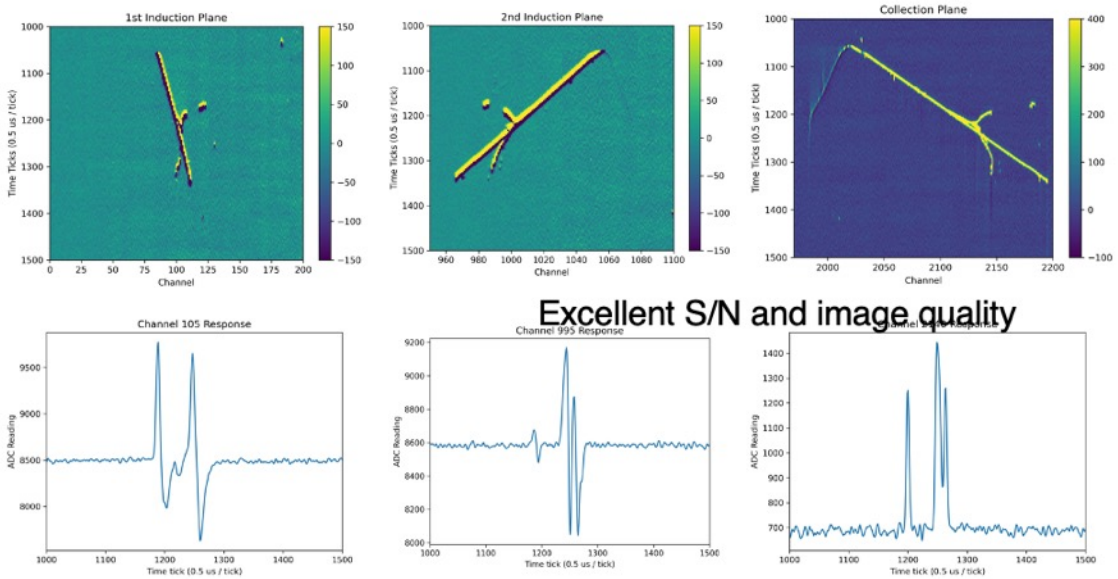
- CRP : based on perforated PCB technology
- Drift length ~ 640 cm -> ~ 300 KV on cathode
- Photon detectors on the cathode at 300 KV
- ~ 10180 m^3 = ~ 14'190 tons of active LAr

NP02 (VD), NP04 (HD) @ CERN NP

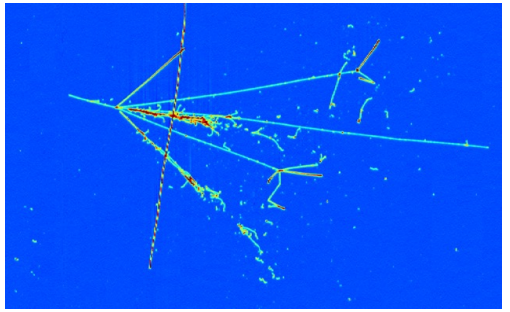
- 2 mostly identical cryostats
- 700 ton LAr each one
- 2 dedicated beamlines
- NP04 construction time:
  - August 2016 start warm structure
  - August 2018 LAr filling
- HD TPC:
  - 410 tons active volume (ICARUS 475)
  - 3.6 m drift (MicroBooNE 2.6)
- VD TPC: 300 kV across 6 m drift demonstrated stable over long periods

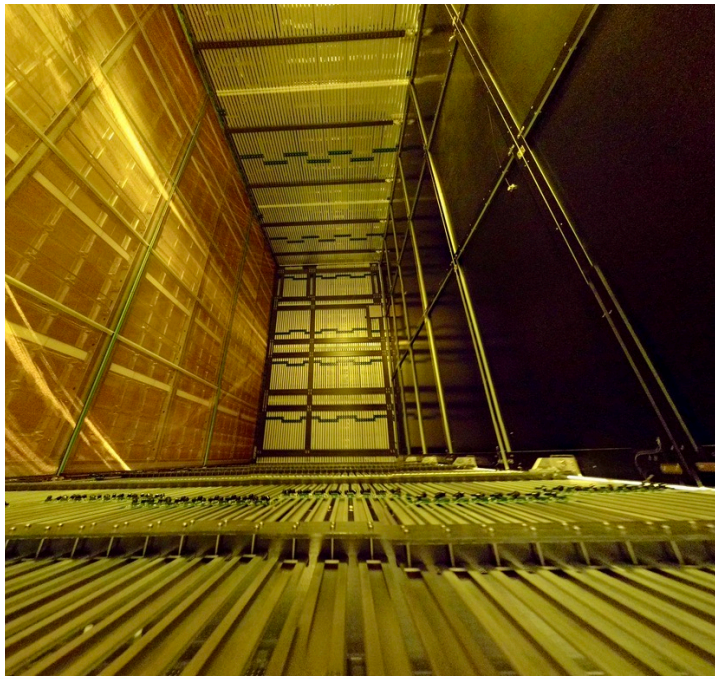
Vertical Drift





Horizontal Drift



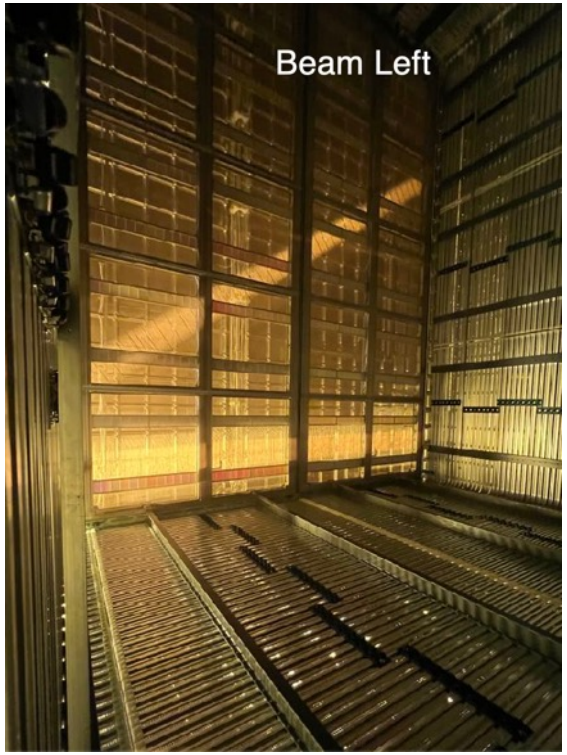


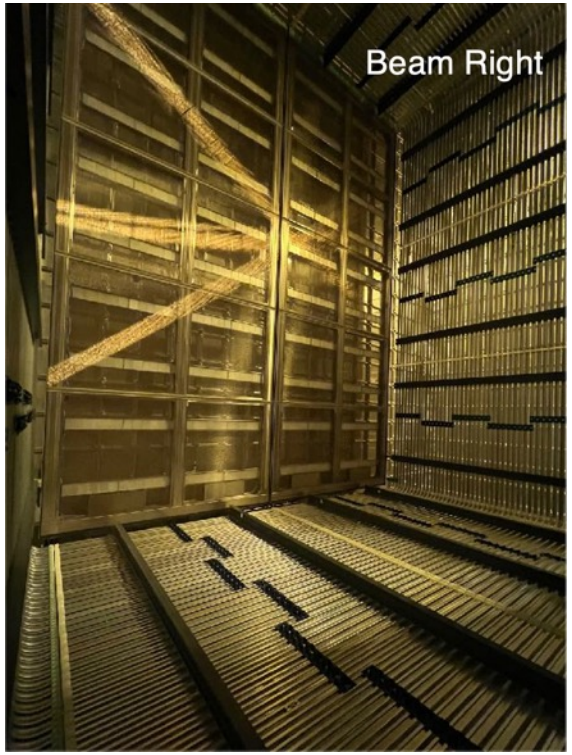
Detector Parameter	Specification	Goal	ProtoDUNE Performance
Electric Drift Field	> 250 V/cm	500 V/cm	500 V/cm *
Electron Lifetime *Impurity Concentration*	> 3 ms *(<100 ppt [O_2-equiv])*	10 ms *(<30 ppt [O_2-equiv])*	> ~30 ms in TPC ** *< 10 ppt*
TPC Electronics Noise	< 1000 e ENC	ALARA	550-650 e ENC (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 ^^

* 99.5% uptime. ** in TPC EF=500 V/cm, in PurMon EF=20 V/cm - (< 10 ppt [O_2-equiv] during beam run).
*** coherent noise removed. ++ from extrapolation based on actual ARAPUCA data. ^^ two pulse separation.

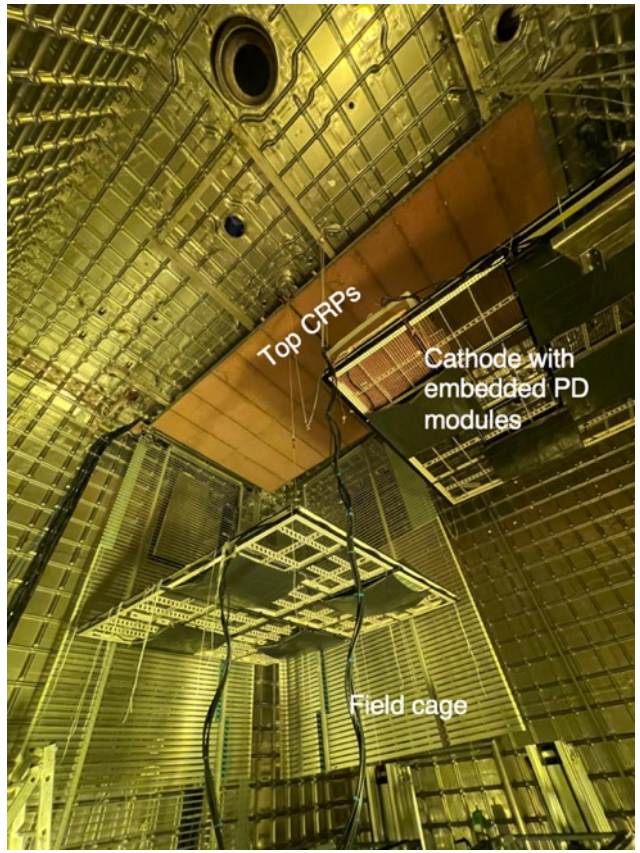
Module 0s for HD and VD at CERN Ready to fill

Horizontal Drift (NP04)





Vertical Drift (NP02)



Far Detector construction

Cryostats

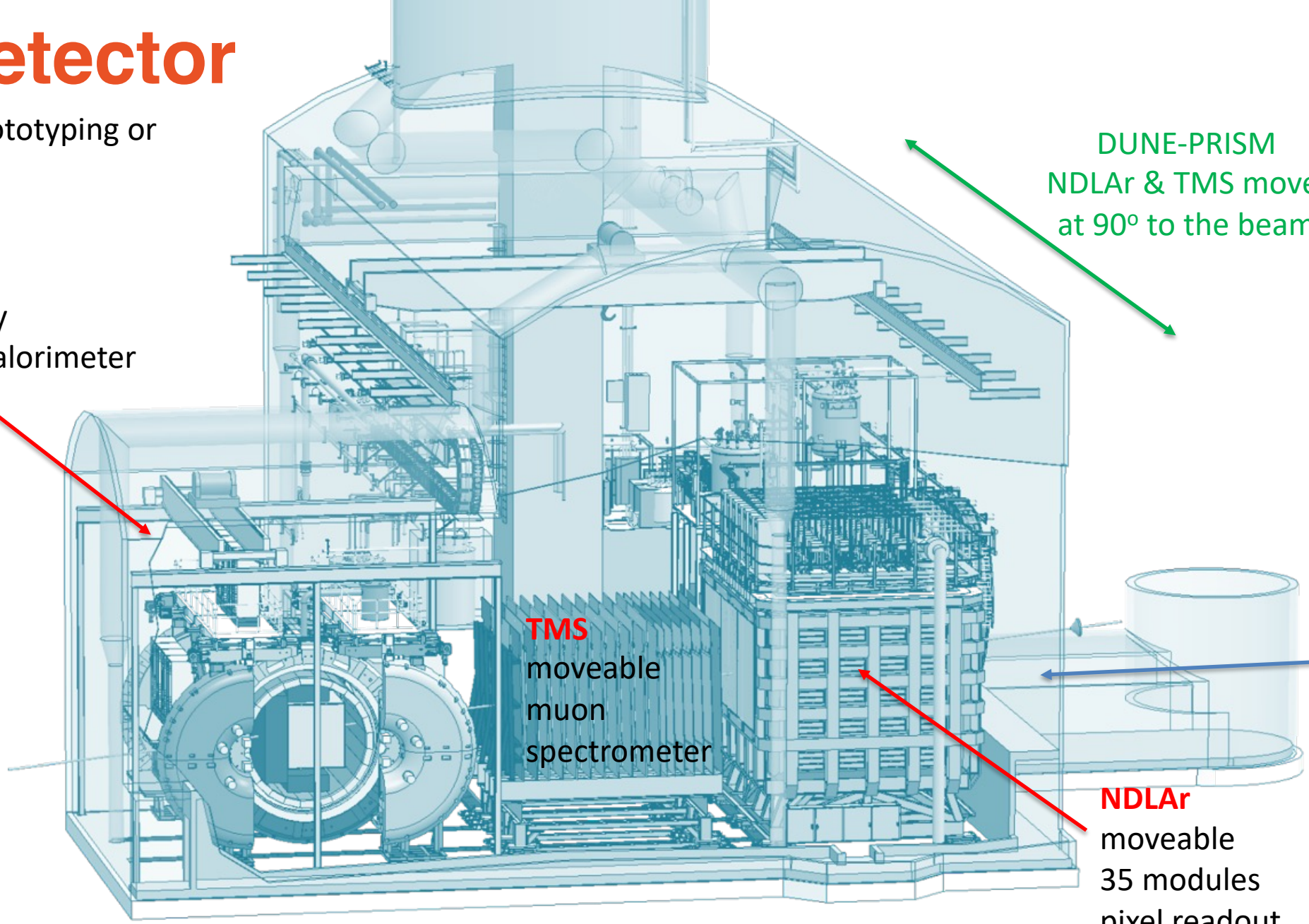
HD: APAs

VD: CRPs

Near Detector

All systems in prototyping or preparation

SAND
on-axis, stationary
KLOE magnet & calorimeter
Straw Tubes
GRAIN: 1 ton LAr



DUNE-PRISM
NDLAr & TMS move
at 90° to the beam

TMS
moveable
muon
spectrometer

neutrino
beam

NDLAr
moveable
35 modules
pixel readout

The future

- First Far Detector ready taking data: 2029: Start of non- beam physics.
- Second Far Detector taking Data: 2030

- Near Detector taking data: 2031
- Beam on: 2031: Main physics program starts: Oscillations, MO, CPV

- Phase II: MCND, FD3, FD4, >2 MW proton beam, to come online in the next decade

Thank you for your attention

Other DUNE talks at NEUTEL 2023

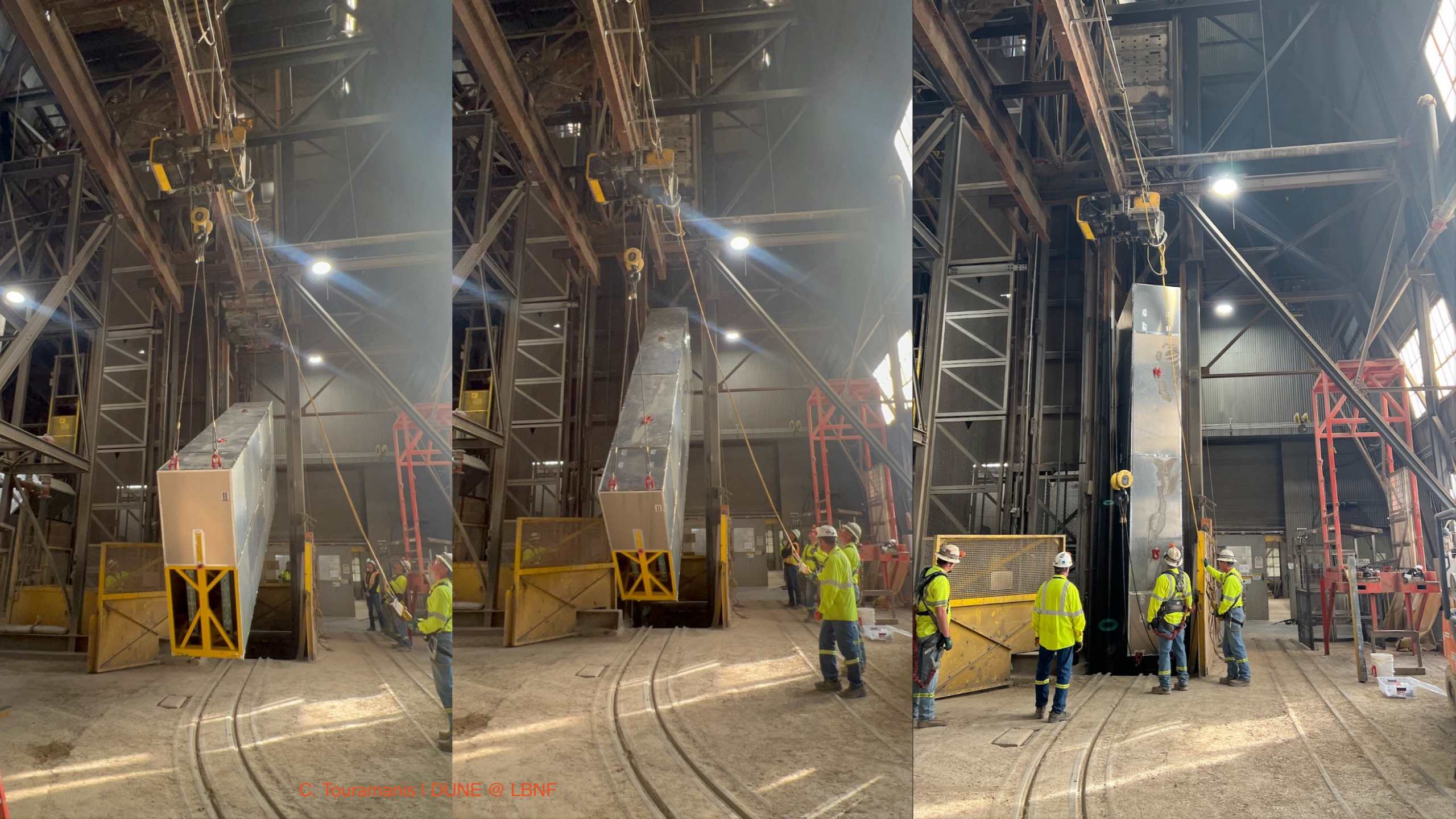
- Valentina Cicero: Imaging Neutrino interactions with Liquid Argon scintillation light at the DUNE Near Detector Complex. (24/10)

- Richard Diurba: Overview of the 2 x 2 Demonstrator: A Pixel-Based LArTPC Prototype for the DUNE Near Detector. (24/10)

- Giulia Brunetti: The photo-detection system and double calorimetry in DUNE. (24/10)

- Pablo Barham Alzás: Supernova detection and triggering with the DUNE Far Detector. (26/10)

Taking the first DUNE APAs 1 mile underground at SURF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