DUNE: Status, progress and plans

Maritza Delgado “for the DUNE Collaboration"

February 17th, 2023

The international workshop on the origin of matter-antimatter asymmetry

CP2023

Outline of Talk

- Physics Motivation
- DUNE Neutrino Beam
- DUNE Near Detector Design
- DUNE Far Detector Design and Prototyping
- DUNE Plans and Installation Phases I and II
- Summary

Physics Motivation

What do we know about neutrino?

- Interact with matter via the weak force
- They oscillate in all 3 flavors
- The mixing angles (θ_{12}, θ_{23},θ_{13})
- Two mass differences (Δm^2_{21} and Δm^2_{31})

What do we not know about neutrino?

- CP violation in neutrino sector?
- What is the value of δ_{CP}?
- Neutrino mass hierarchy?
- Is the mixing angle θ_{23} maximum?
- Is sterile neutrinos existed?

The Deep Underground Neutrino Experiment

The Goals of DUNE Experiment

Measurements of the parameters:

-The charge parity (CP) phase,

-Determination of the neutrino mass ordering

-The mixing angle θ23 and the determination of the octant.

Neutron star and black hole formation. Ability to observe neutrinos from supernova events and perhaps watch formation of black holes in real time.

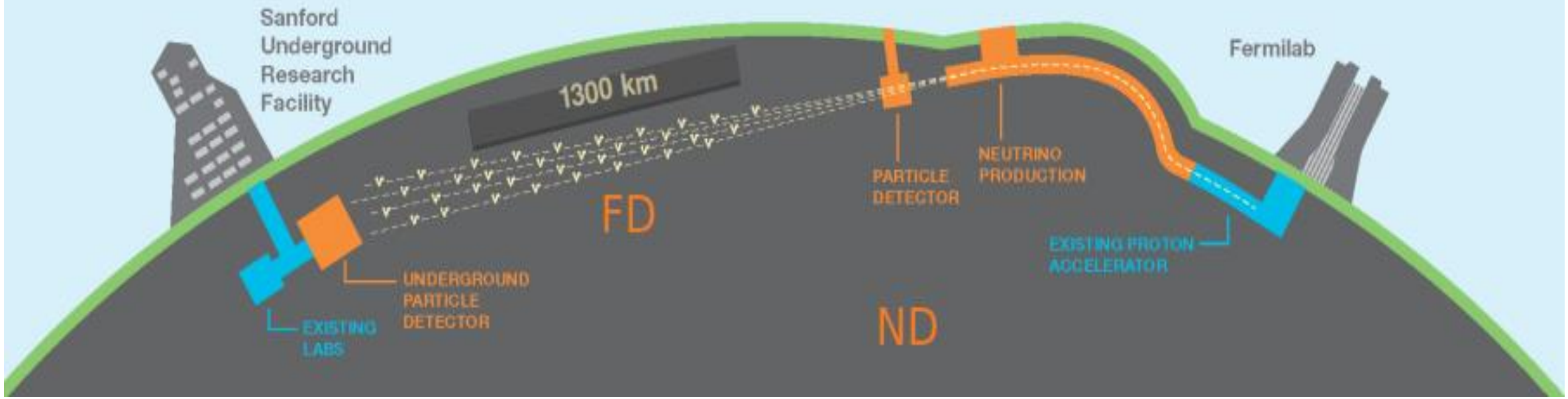
Unification of forces. Investigate proton decay, non standard interactions.

Atmospheric and Solar neutrinos.

DUNE collaboration

1400 collaborators from 200 institutions in 33 countries + CERN

The Deep Underground Neutrino Experiment (DUNE)



-Located at SURF's 1.5 km underground level with 1300 km baseline.

• A 70 kt total mass liquid argon far detector

•~1300 km, will be able to unambiguously determine the neutrino mass hierarchy and measure the value of δCP

- A high-intensity wide-band neutrino beam originating at FNAL (~ GeV energy range)

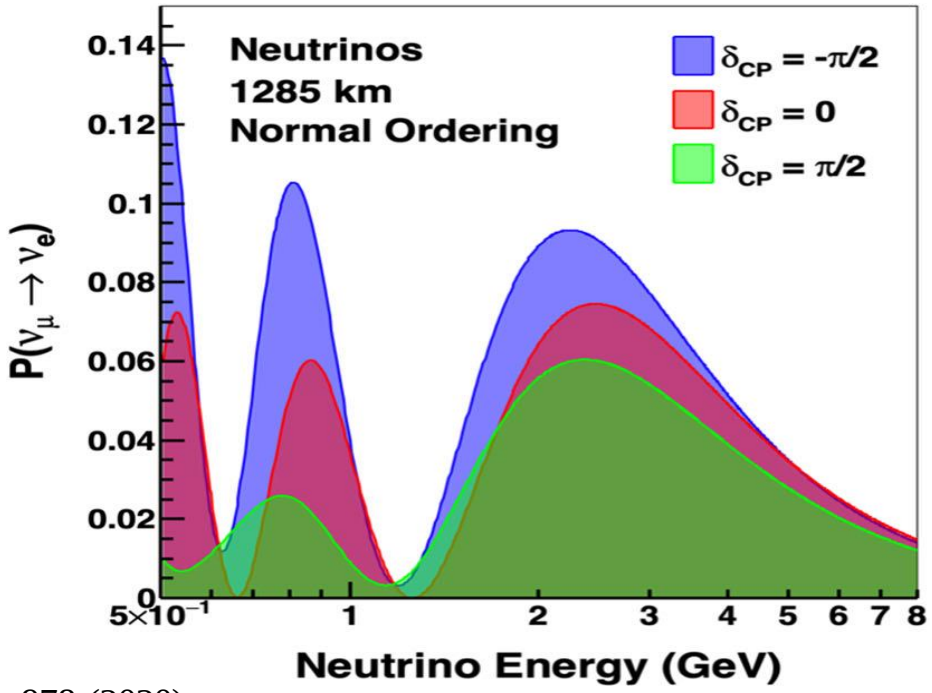
•Beam power:1.2 MW, upgradable to 2.4 MW .

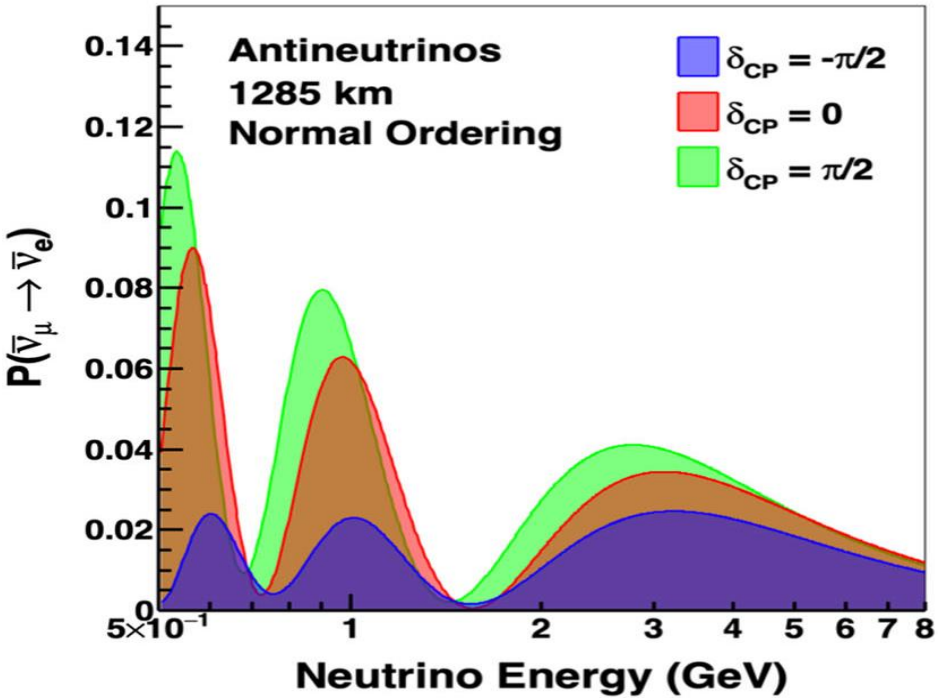
Physics:Neutrino Beam

- Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix-> The oscillation probability:

Appearance $$P(\nu_\mu \to \nu_e) = \sin^2 2\theta \sin^2(\frac{\Delta m^{2L}}{4E_\nu})$$

Disappearance $$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta \sin^2(\frac{\Delta m^{2L}}{4E_\nu})$$

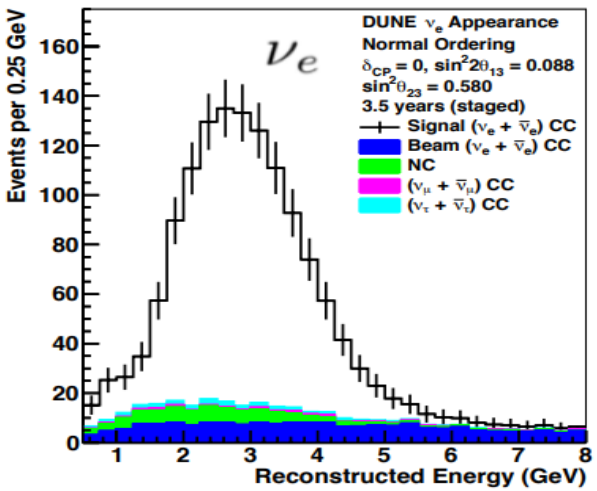


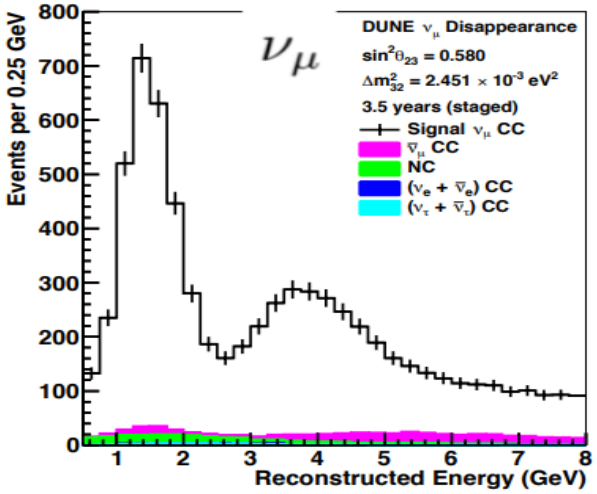


Eur. Phys. J. C80, 978 (2020)

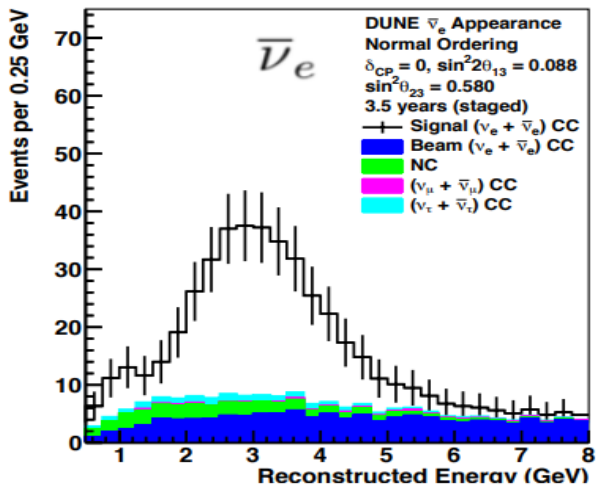
DUNE Oscillation Strategy

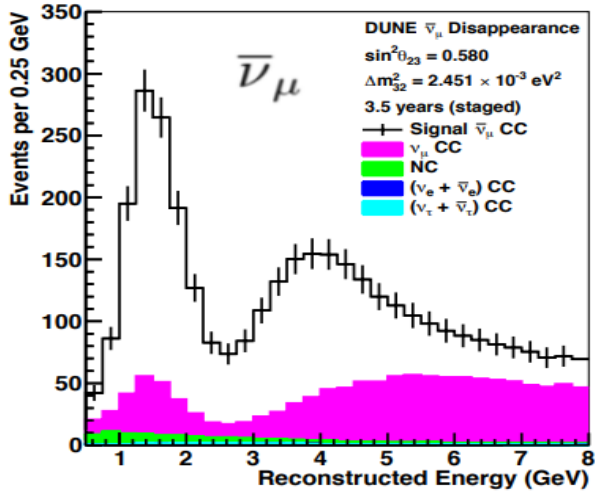
Neutrino Mode





Anti-neutrino Mode





The expected event rate:

Expected 1000 ve appearance events in ~7 years of equal running in neutrino and antineutrino mode.

Expected 10000 vμ disappearance events in ~7 years

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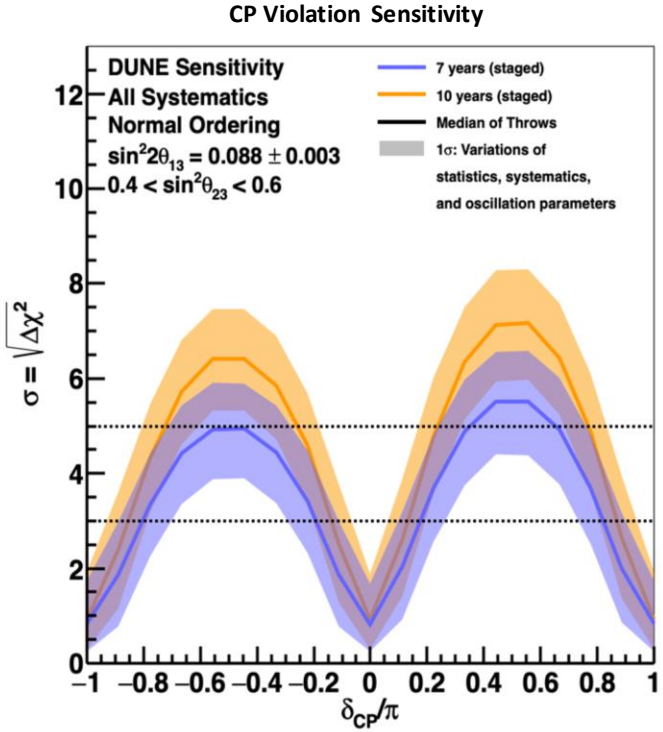
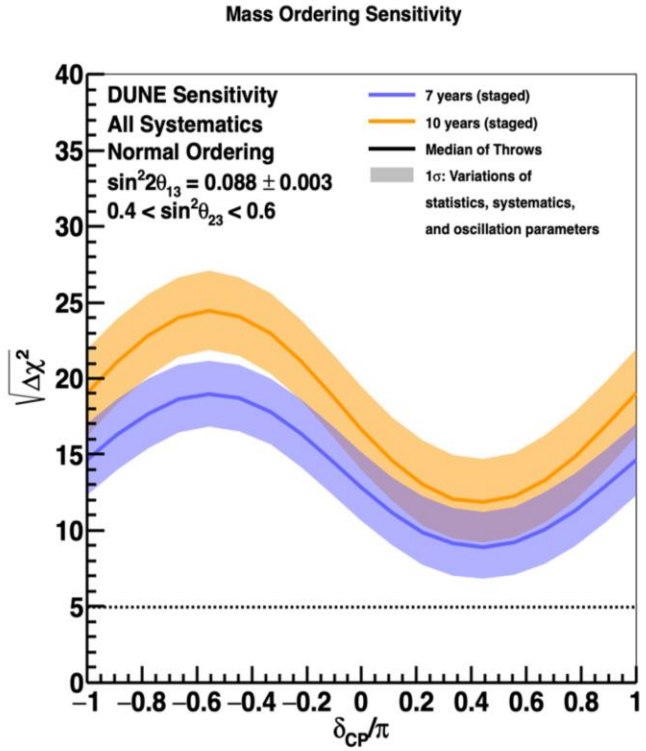
Physics:CPV and Mass Ordering

1300−km baseline establishes one of DUNE's key strengths:

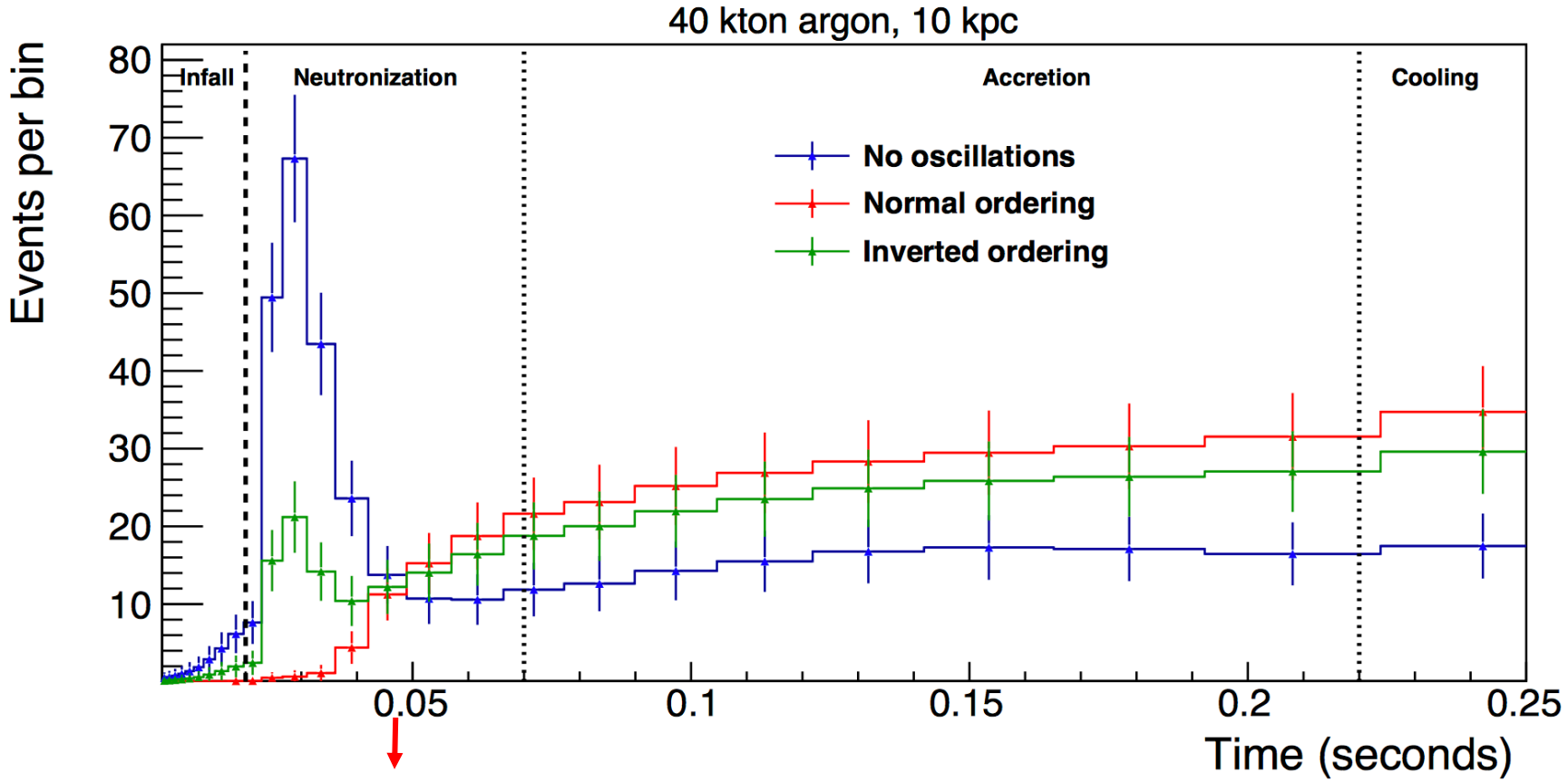




- $>5\sigma$ Significant CP violation discovery potential over a large range of possible true δCP values in 7-10 years of (staged) running .
- $> 5\sigma$ Definitive determination of neutrino mass hierarchy (normal or inverted) for all δ_{CP} .

Supernova Neutrino Burst and Solar Neutrinos

The DUNE experiment will be sensitive to neutrinos in the few tens of MeV range.



Neutronization: the initial neutrino burst in core collapse supernova, mostly ν_e

- Core-collapse SN is a system to search for new physics (Goldstone bosons, neutrino magnetic moments, dark photons, unparticles, and extra-dimensional gauge bosons).
- Energy-loss analysis using total energy of the emitted neutrinos and cooling rate.

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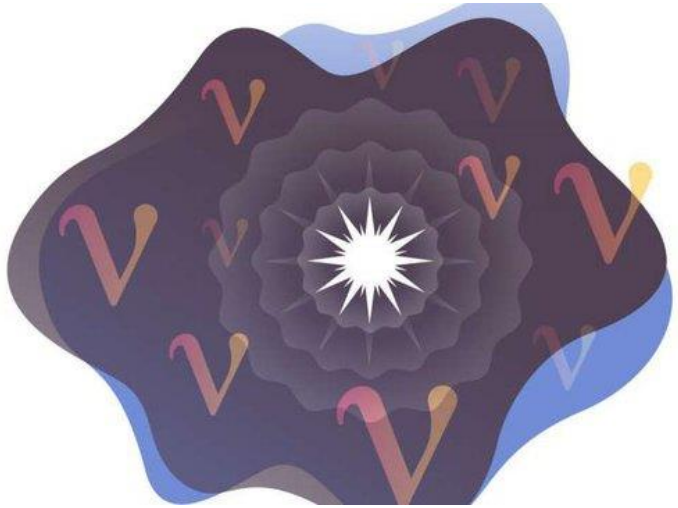
Beyond Standard Model (BSM) Physics

DUNE will be able to probe many potential BSM searches such as:

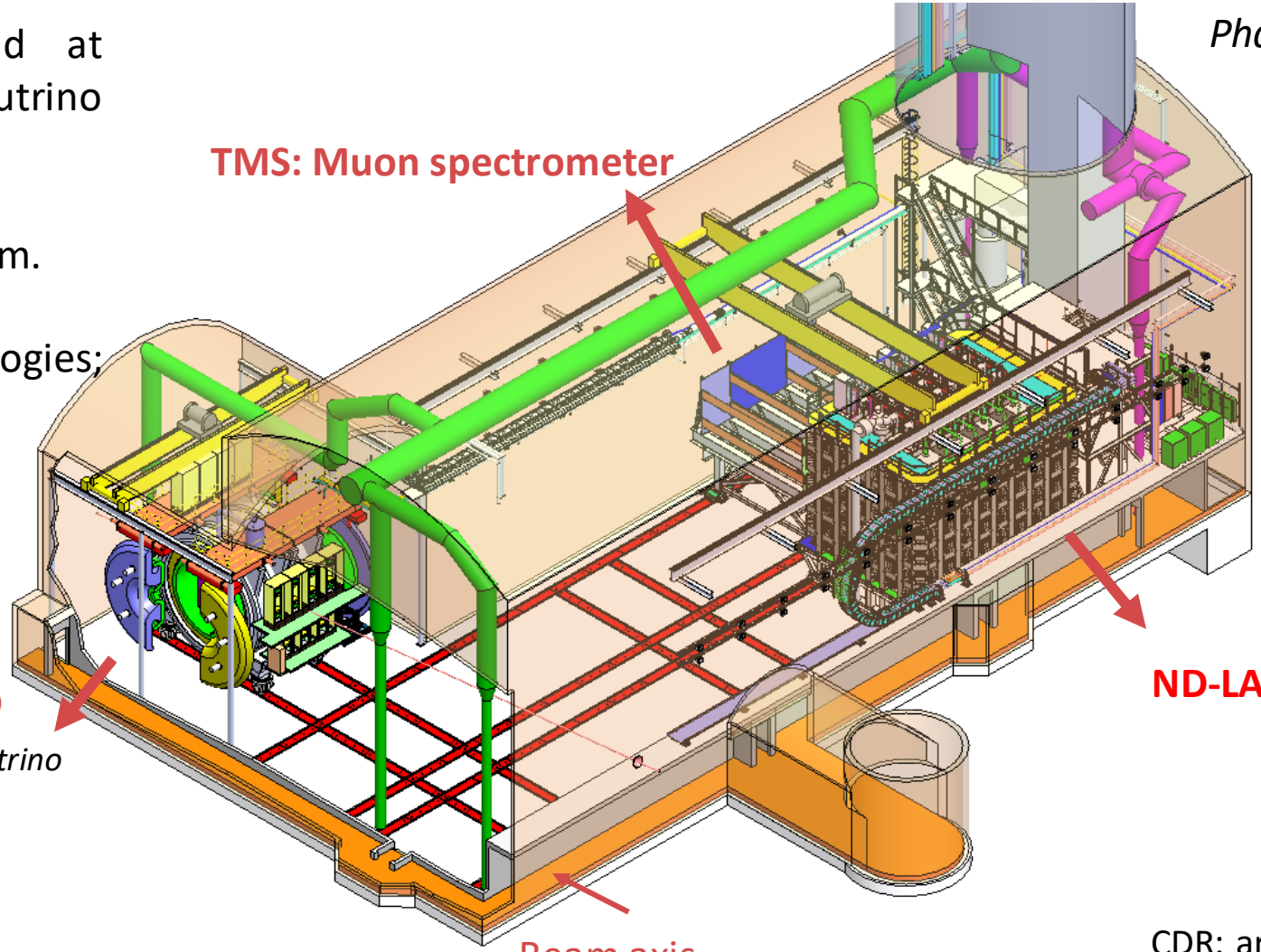
- Sterile neutrino mixing
- Proton decay
- Dark Matter (beam induced and cosmogenic origin)
- Heavy neutral leptons (HNL), neutrino trident production
- Non-standard interactions (NSIs)
- CPT symmetry violation



The DUNE Near Detector

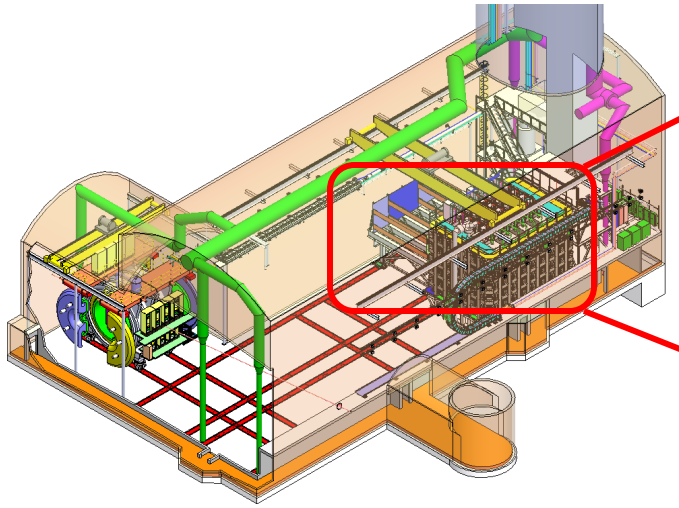
- Located 60 m underground at Fermilab; 574 m from neutrino beam target.
- Goals:
  -Characterize the neutrino Beam.
  -Measure with high precision.
- Comprises of multiple technologies; will be built in 2 phases.

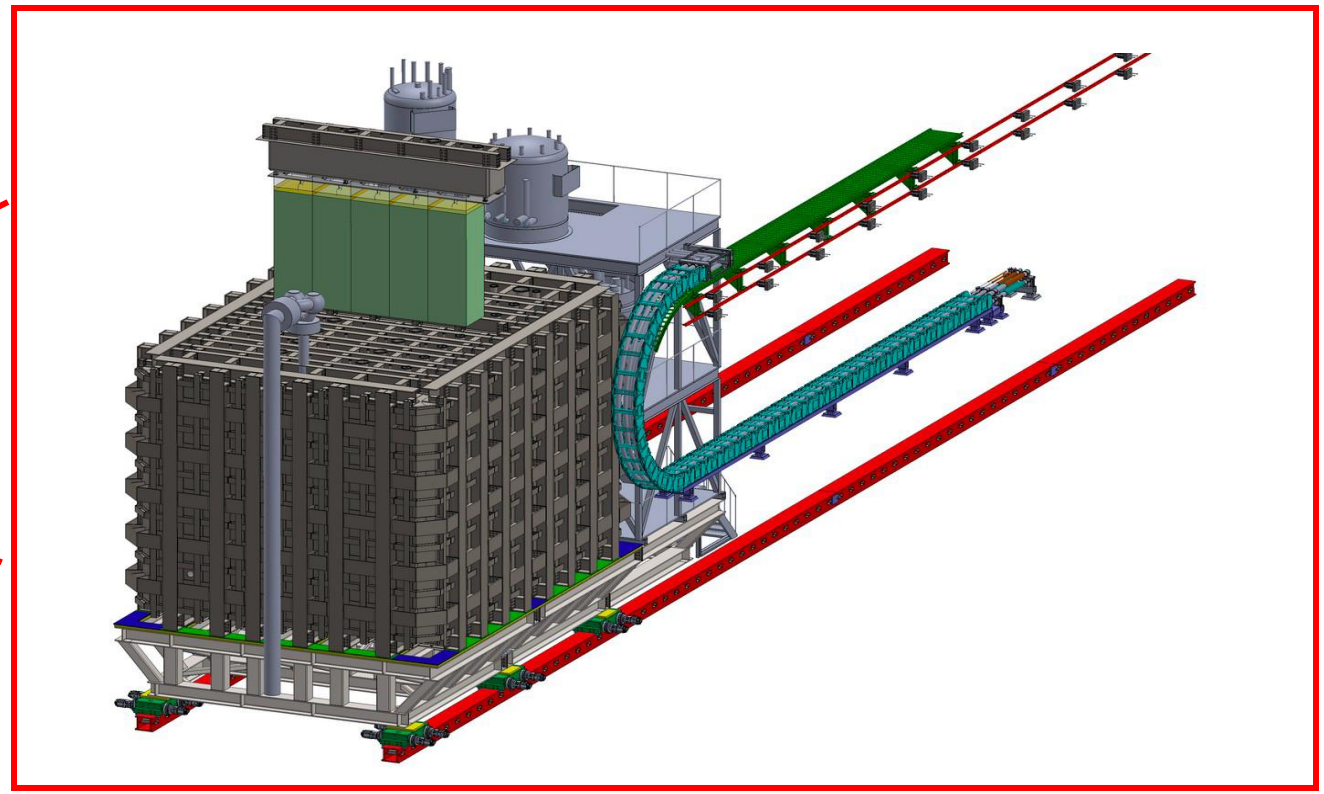
Phase 1 design



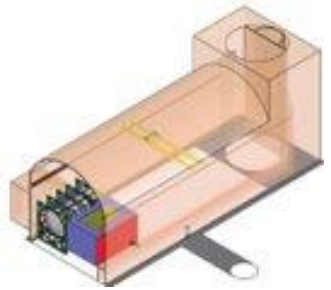
CDR: arXiv:2103.13910

The DUNE Near Detector

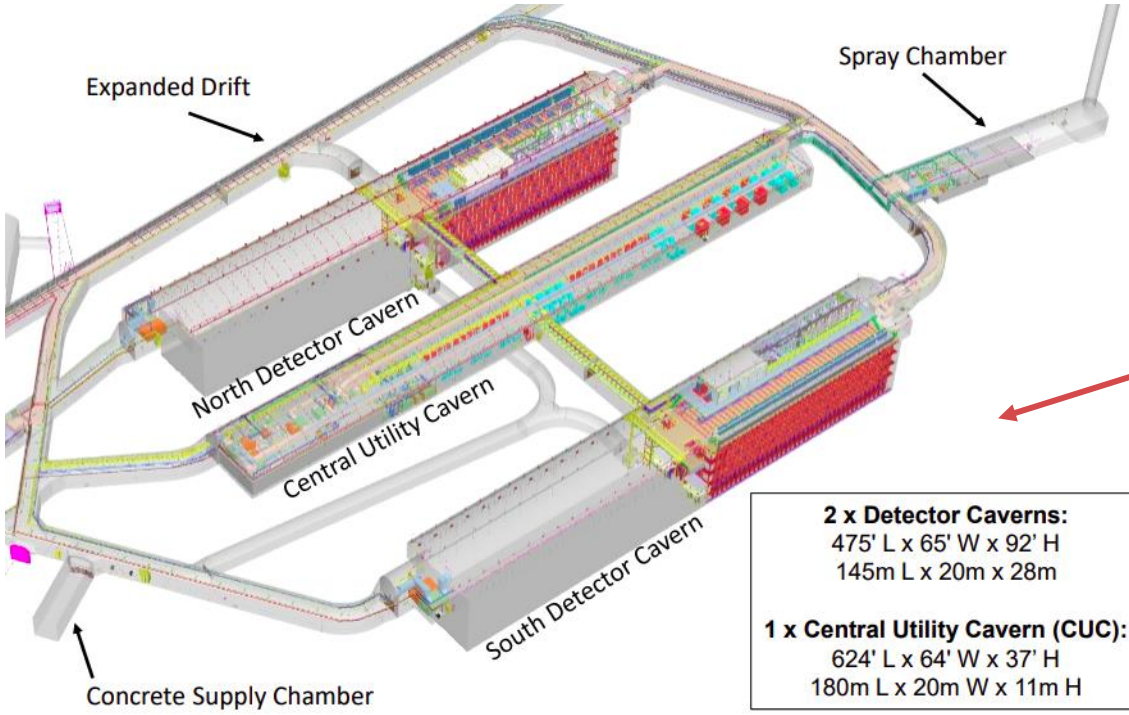




- ND-LAr and TMS systems can move off-axis up to 28.5 m to detect neutrinos at different production angles.
- Will help address uncertainties in ND to FD extrapolation.

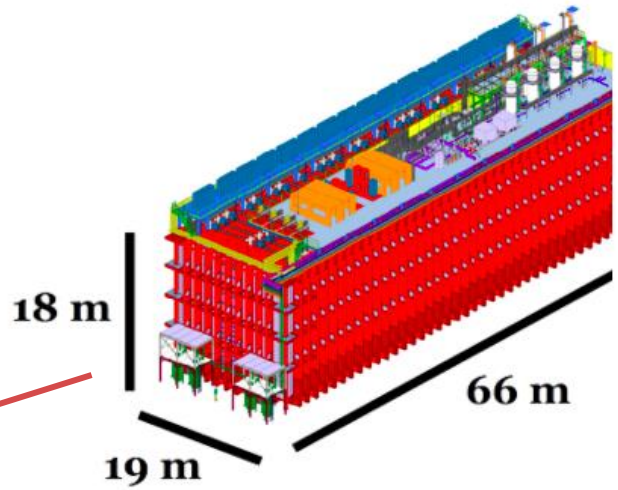


DUNE Far Detector



2 x Detector Caverns:
475' L x 65' W x 92' H
145m L x 20m x 28m

1 x Central Utility Cavern (CUC):
624' L x 64' W x 37' H
180m L x 20m W x 11m H



4 caverns,flexibility in design!!

Three DUNE FD modules will be Liquid Argon Time Projection Chamber (LArTPC)

- FD#1: Horizontal Drift (HD)
- FD#2: Vertical Drift (VD)
- FD#3: LAr technology TBD
- FD#4: Module of opportunity (R&D ongoing)

DUNE Caverns Excavation

Central Utility Cavern

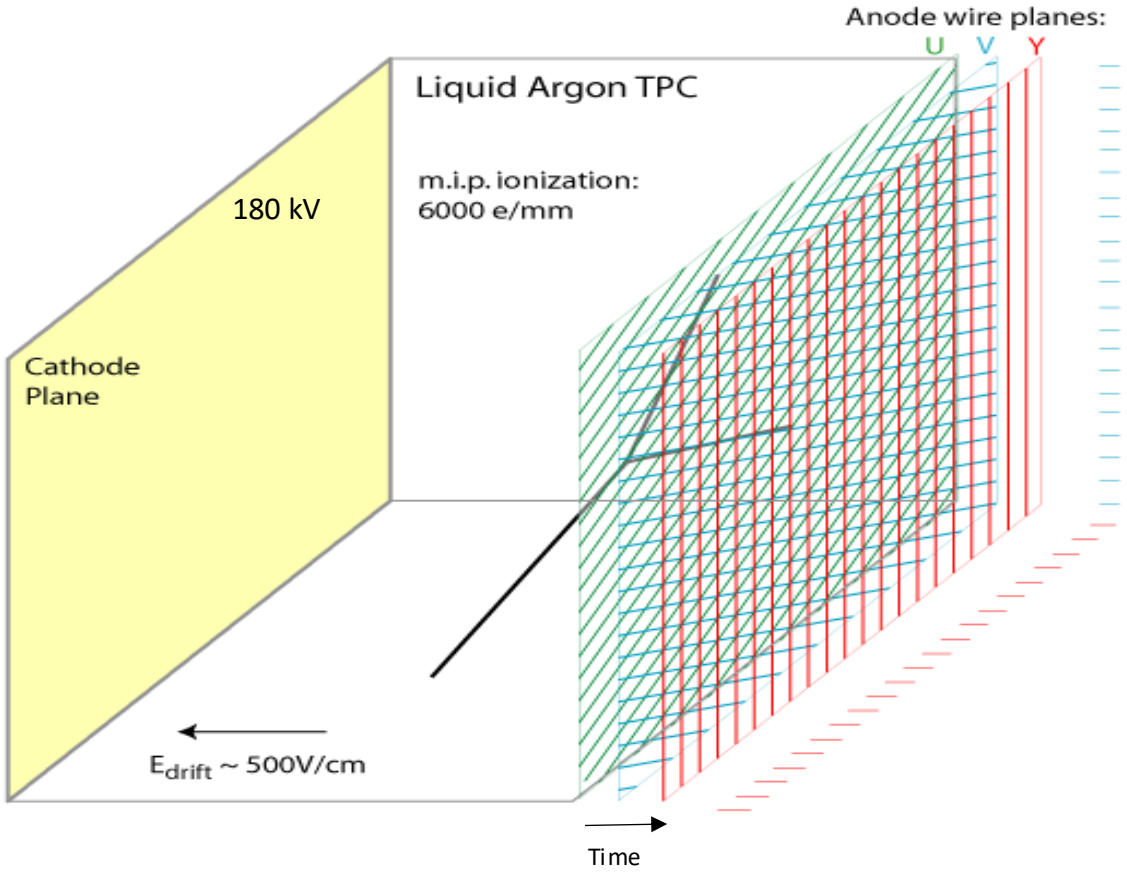
North Detector Cavern – West End

Drilling holes for blast charges in Central Utility Cavern (4850-36)

Installing CT Rock Bolts in Central Utility Cavern (4850-36)

-SURF far site excavation well underway
-North Cavern excavation began in May 2022
-Total excavated rock volume:50% as of January, 2023

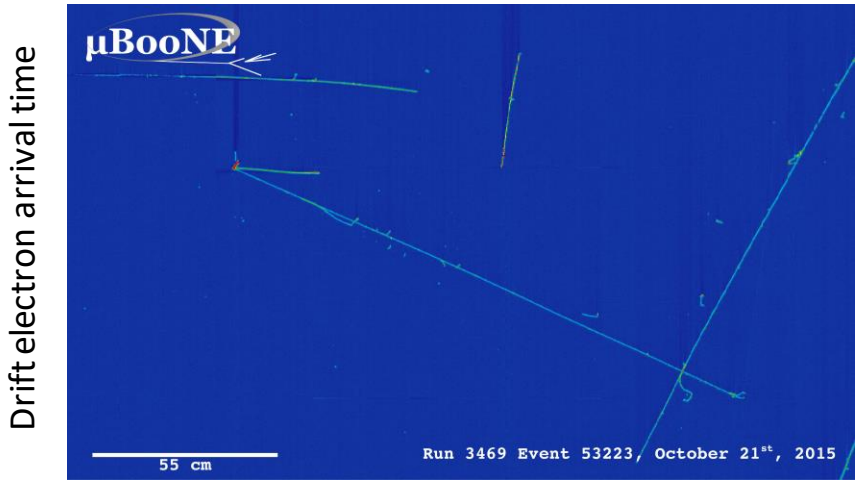
LArTPC Detector Concept



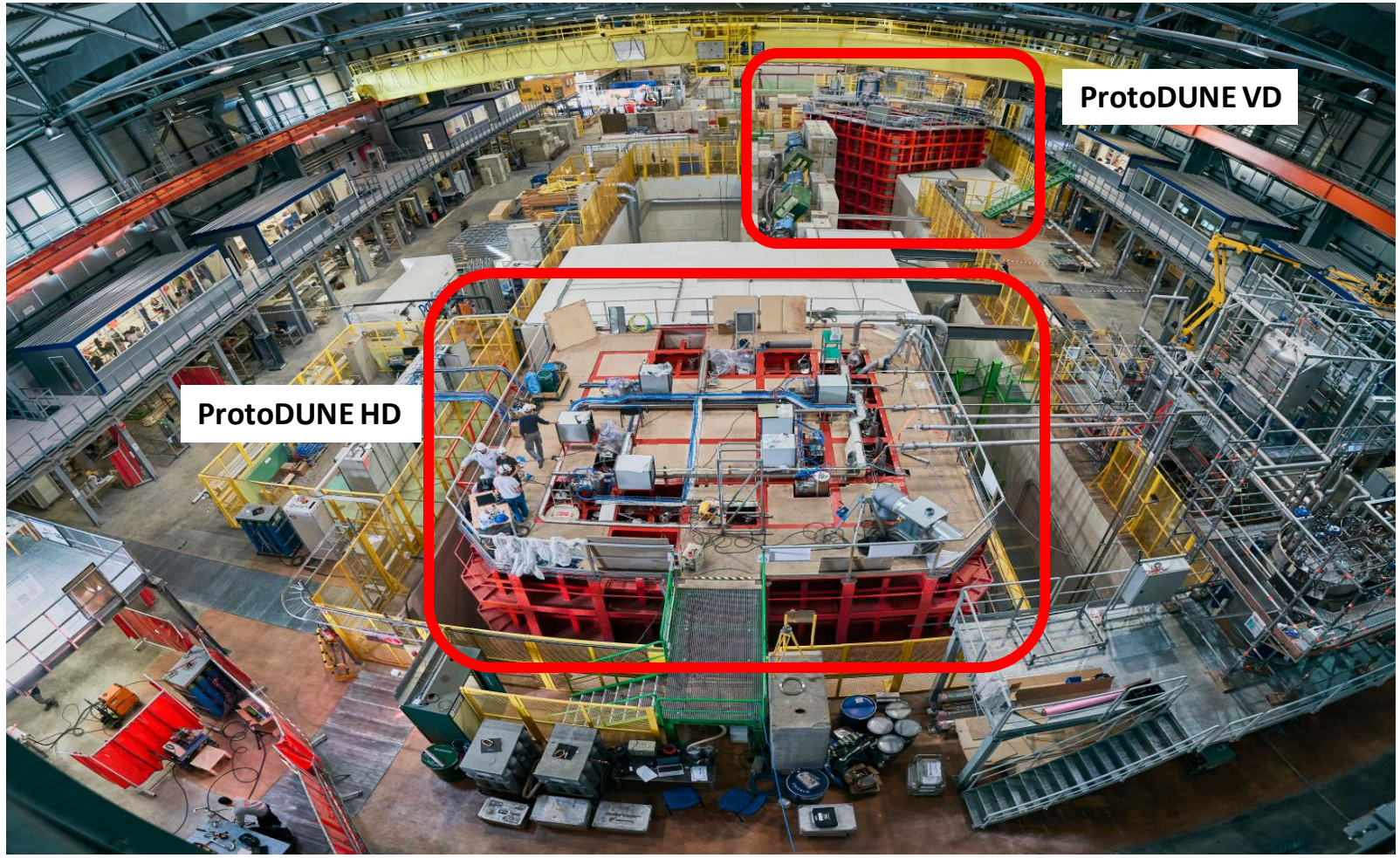
-Technology allows for scalability → massive detectors

- Argon makes an excellent target (dense, abundant, cheap etc.)
- Charged particles in LAr produce free ionization electrons and scintillation light (128nm)
- Time "zero" from scintillation photons.
- 3D reconstruction + Calorimetric measurements.

CCν_μ



DUNE Far Detector Prototyping



CERN Neutrino Platform EHN1

Two prototypes with 760 ton of liquid argon (~8x8x8 m^3)

Main Detector Elements include:
-Time Projection Chamber (TPC)
-Front-end cold electronics
-Photon Detector System
-Comic-Ray Tagger.

ProtoDUNE HD

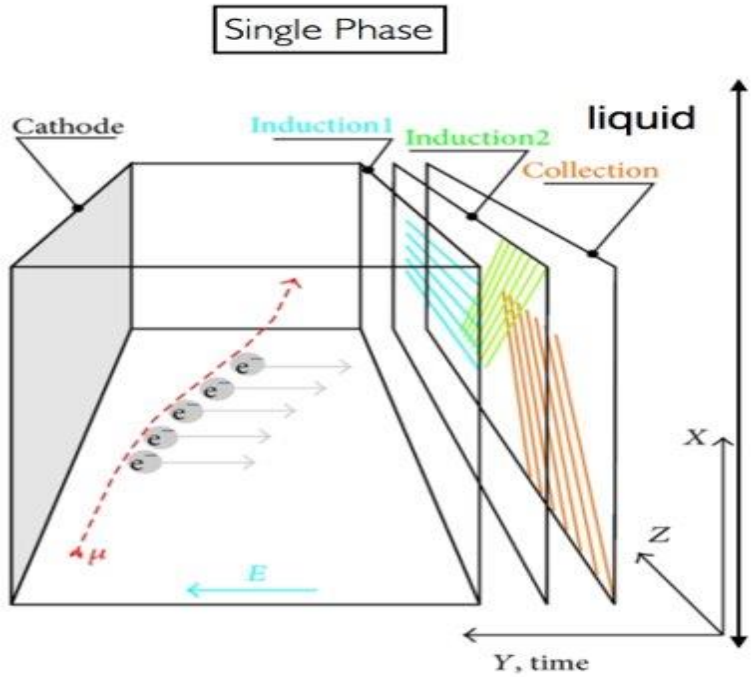
Module #1

-The active volume is 6 m high, 7 m wide and 7.2 m deep (along the drift direction).

-3.6 m horizontal drift

-Vertical anode wire planes

-Vertical resistive cathode



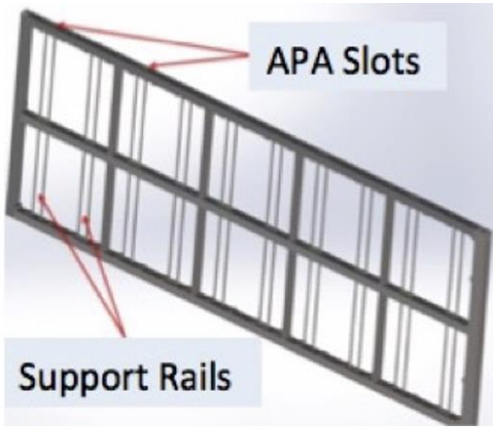
Anode Plane Assemblies (APA)
- 6 m high x 2.3 m wide

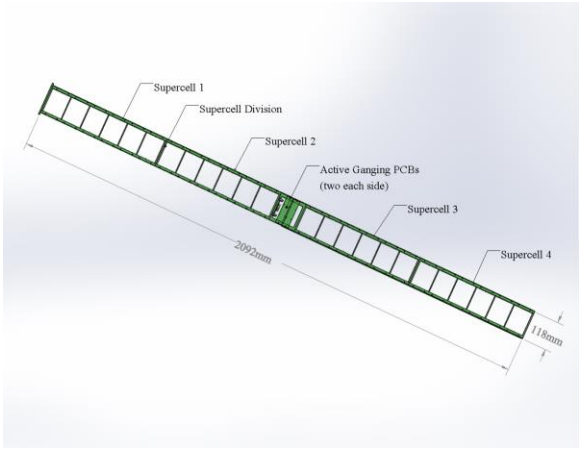
ProtoDUNE HD

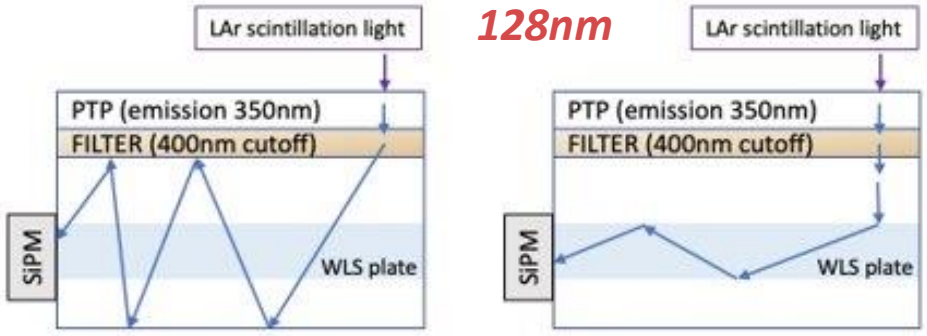
Photon detection system (PDS)

- 10 bars (209 cm x 12 cm x 2 cm) per APA, placed between the wire layers.
- Each bar contains 24 X-Arapuca cells, grouped into four supercells.
- The HD PDS will be composed of photondetector, photocollectors, readout electronics and calibration system.

X-Arapuca trap the light!!

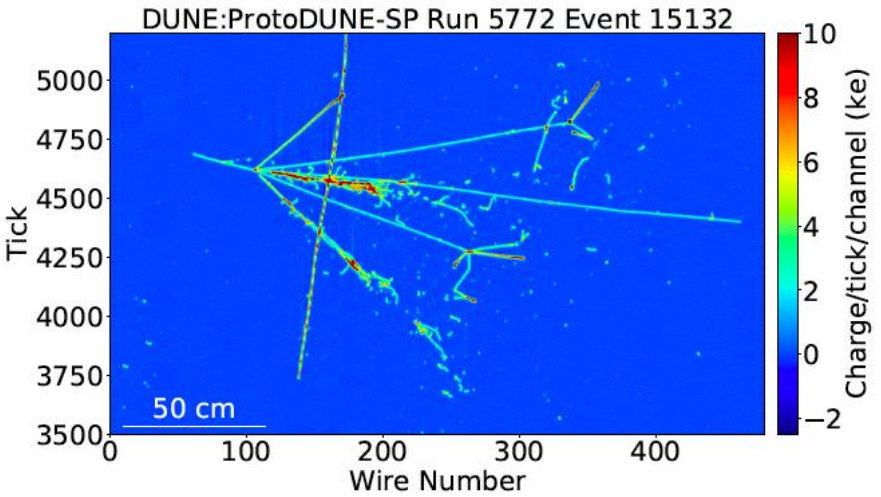






-Shift the VUV scintillation light

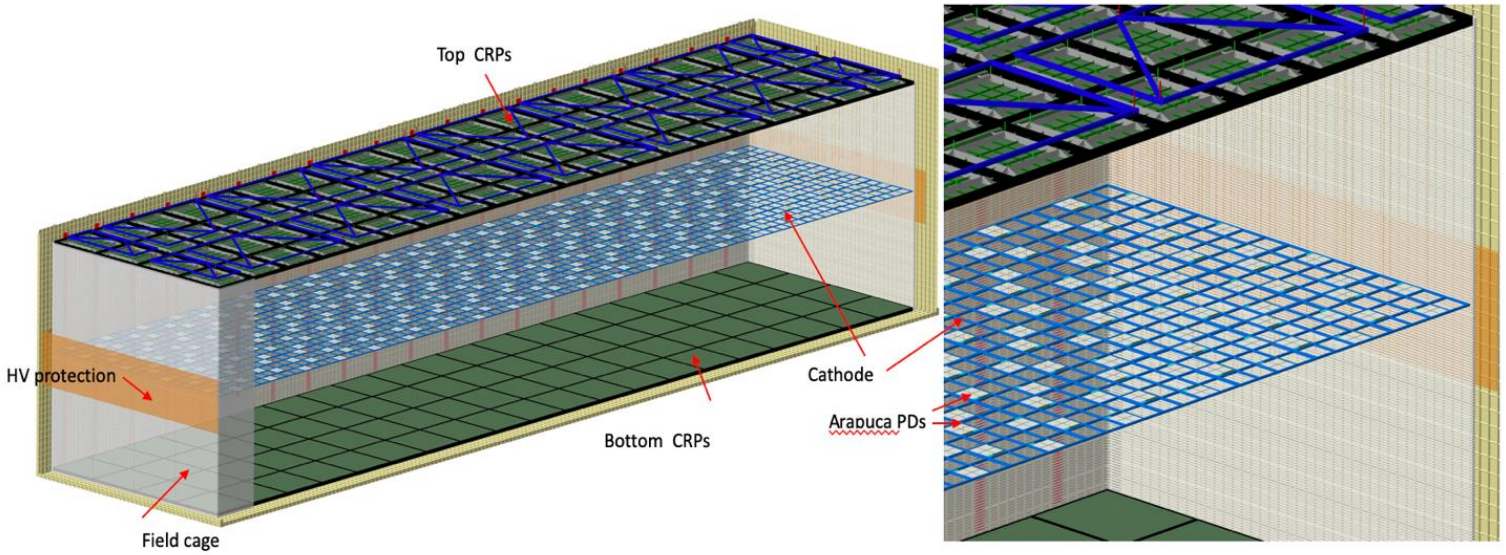
ProtoDUNE HD



-First Results published: JINST 15 (2020) 12, P12004.

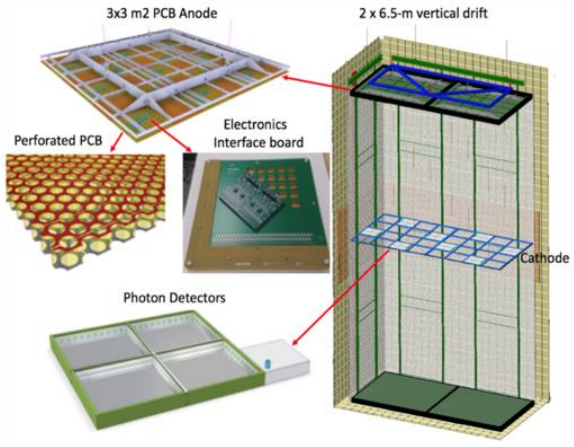
- More results to come soon, Stay tuned!

ProtoDUNE VD



Module #2 **NEW!**
-6.5 m vertical drift
-horizontal PCB anode readout (CRP)
-horizontal grid cathode
-photon detectors

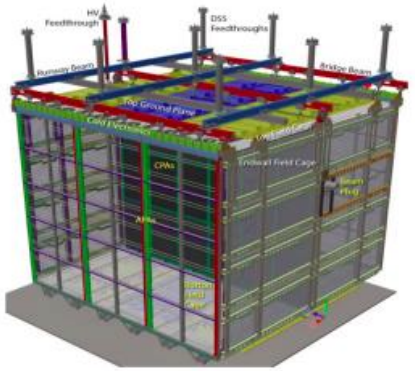
- Charge readout units at the top and bottom.
- Cathode in the middle
- Photon detectors integrated on cathode and on cryostat walls
- Designed to maximize active volume
- Perforated PCBs with segmented electrodes (strips) as readout units



ProtoDUNEs Design Evolution

Phase-II

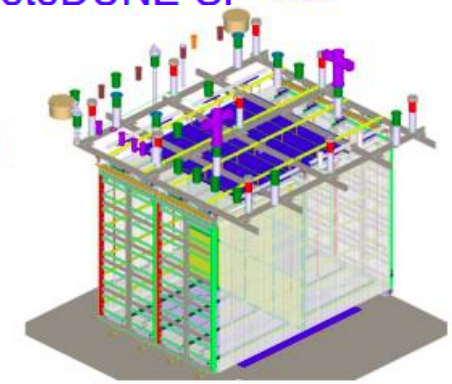
ProtoDUNE-SP (operated 2018-20)



Performance paper: JINST 15 (2020) P12004

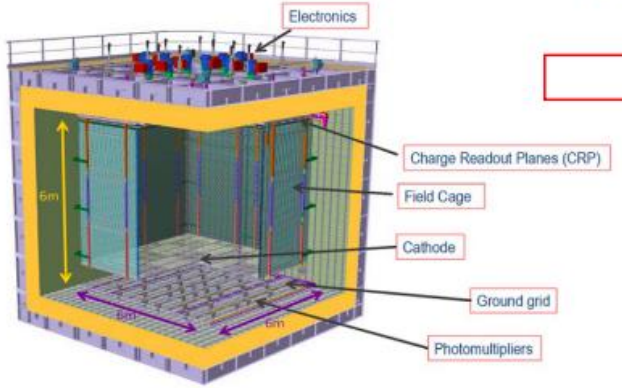
Detector paper: JINST 17 (2022) P01005

ProtoDUNE-SP-HD



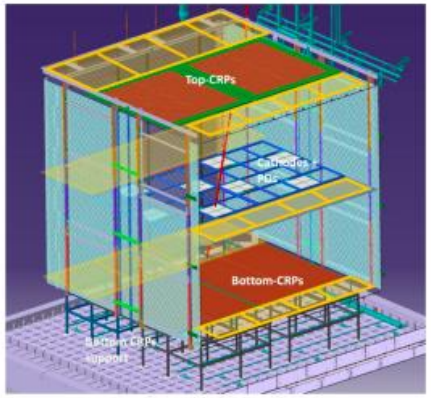
- Detector hardware near completion: Next step LAr fill

ProtoDUNE-DP (operated 2019-20)



Photon-detector paper: Eur. Phys. J. C 82 (2022) 7, 618

ProtoDUNE-SP-VD



Summary

- DUNE is a global project with more than 1000 scientist .
- Excellent sensitivity for measuring the CP violation phase and identifying the neutrino mass ordering.
- DUNE will precisely measure θ13, θ23, and Δm232
- DUNE is advancing rapidly
  - Far sight cavern > 50% excavated!
  - Beamline and near site finished 100% design
  - Both Near and Far detector prototyping is progressing successfully
- DUNE will have good sensitivity to the entire Milky Way, and possibly beyond, depending on the neutrino luminosity of the core-collapse supernova.

Summary

- Technical milestones

  -Far and near detector prototyping and validation underway

  -ProtoDUNEs successfully operated at CERN with first results published

  -Far site civil construction to be complete in 2024 with far detector installation to follow-up

  -Near site and beamline are fully designed with a construction to proceed in parallel with far site activities.

- Plenty of opportunities for additional international participation.

More exciting developments to come in DUNE!

THANK YOU!

DUNE Collaboration Meeting, January 2023, CERN

BACKUP

Photon Detection System

X-ARAPUCA : A novel approach

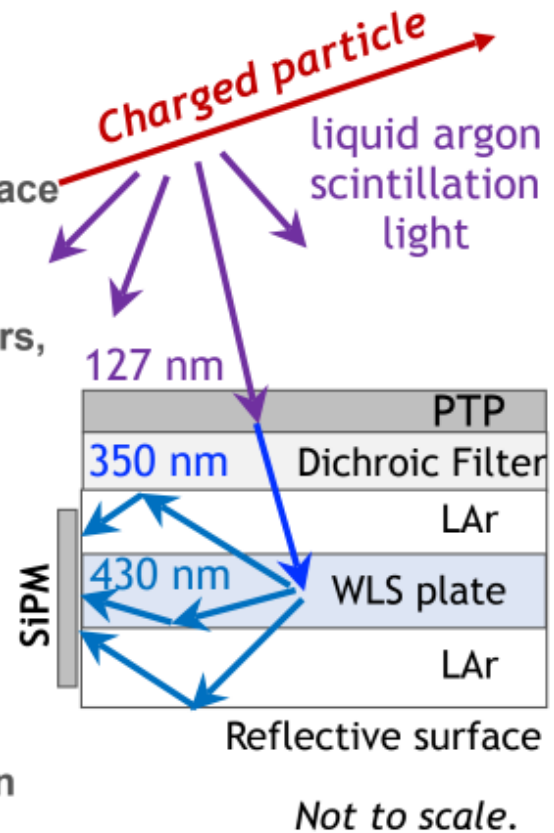
Flattened Box : Very highly reflective internal surface

Dichroic filter : Acceptance window of the device, deposited with 2 wavelength shifters, one on each side

External shifter : Converts LAr Scintillation light (pTP) to a wavelength 350 nm

Internal shifter : Converts light of wavelength 350 nm to a wavelength 430 nm

SIPM : Photons are detected after some reflection



Supernova Neutrino Burst and Solar Neutrinos

Infall → Neutronization → Accretion → Cooling

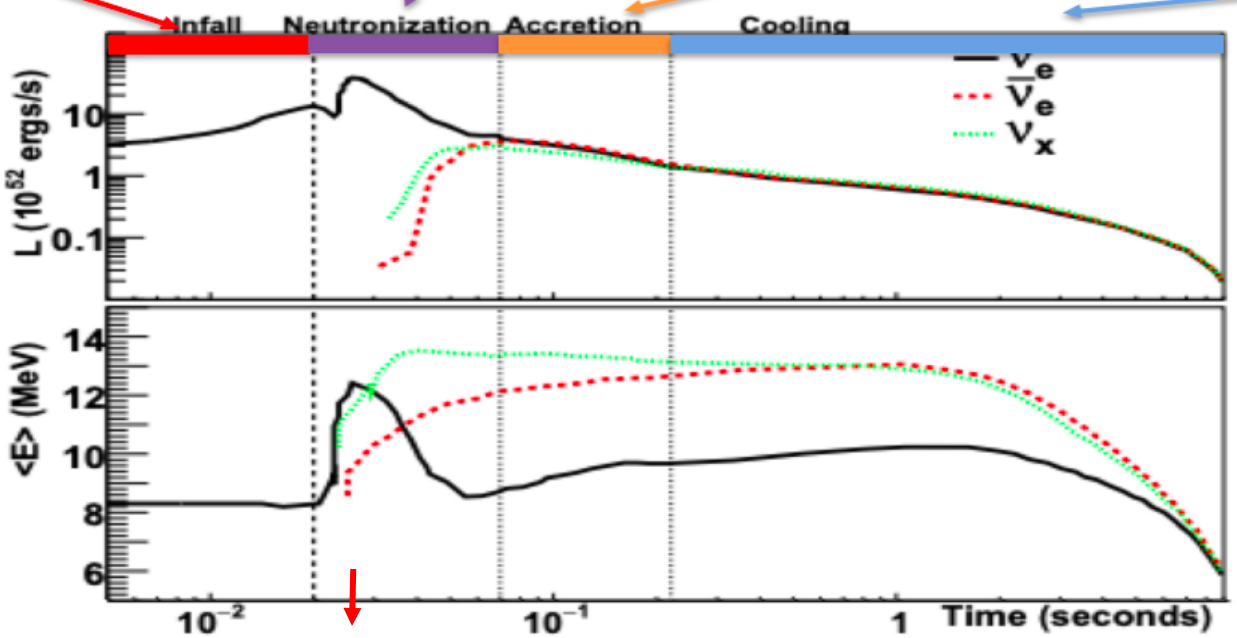
Core collapses, and a shock wave is formed. The medium is opaque even for neutrinos.

Primarily ν_e escape, as messengers of the shock front breaking.

(<1s) ν's powered by infalling matter.

(~10s) main part of the signal, the proto-neutron star sheds its trapped energy.

For a supernova at 10 kpc from Earth.



A lot of information about the supernova in this profile: flavor content and spectra of the ν's emitted change throughout these phases, and the supernova's evolution can be followed with the ν signal.

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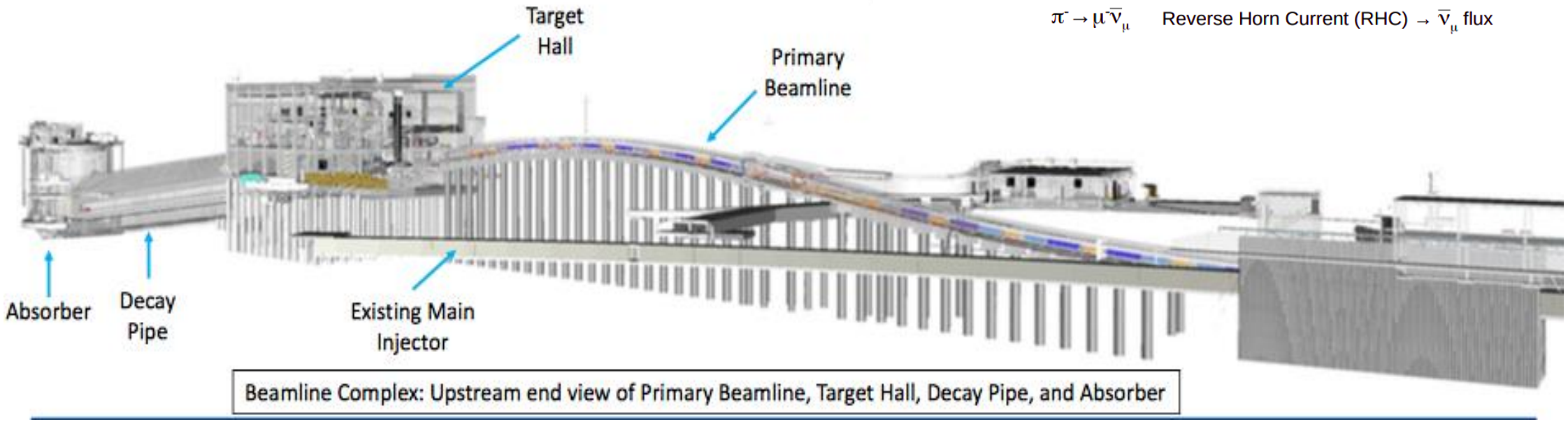
Neutrino Beam

$\pi^+ \rightarrow \mu^+\nu_\mu$ Forward Horn Current (FHC) → ν_μ flux

$\pi^- \rightarrow \mu^-\bar{\nu}_\mu$ Reverse Horn Current (RHC) → $\bar{\nu}_\mu$ flux



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

- The Proton Improvement Plan (PIP-II) will enable the world's most intense beam of neutrinos to DUNE.
- 1.2 MW beam intensity, upgradable to 2.4 MW.
- 100% final design completed on 28 Sep 2021.

Details published
Eur. Phys. J. C80, 978 (2020):
"Long-baseline neutrino oscillation physics potential of the DUNE experiment"