DUNE

A next generation long-baseline neutrino oscillation experiment

Simon Peeters, on behalf of the DUNE collaboration

10th Symposium on large TPCs for low-energy rare event detection,
Paris 16/12/2021

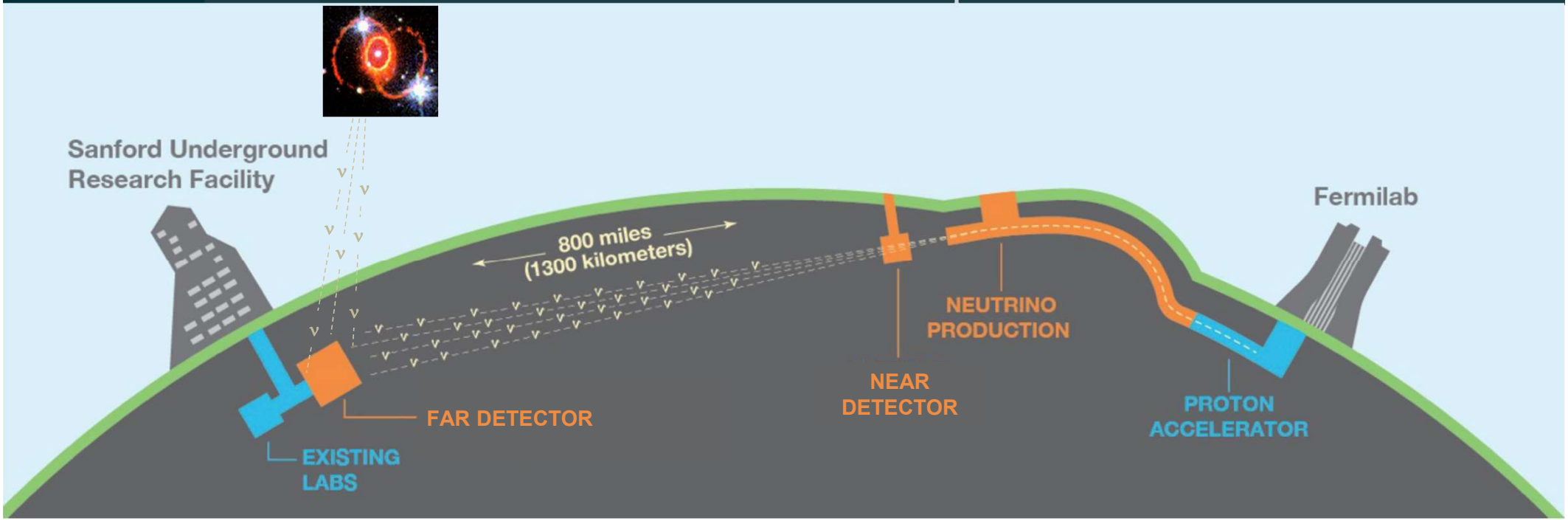
DUNE science collaboration

1350+ collaborators,
from 200+ institutions
and 30+ countries,
plus CERN

CERN, 2020

Online, 2021

DUNE: next generation long-baseline neutrino oscillation experiment



Unique design:

- High-intensity neutrino beam (1.2 MW, upgradable to 2.4 MW)
- 1,300 km baseline with an on-axis detector, providing a wide-band energy spectrum
- Four large-volume detector modules (17 ktonne), 1.5 km underground
- Multiple complementary systems in the near detector complex, providing unprecedented control of systematic uncertainties

Providing a rich neutrino physics programme:

- Neutrino oscillations: mass ordering, CP-violation, neutrino mixing parameters
- Neutrinos from core-collapse supernovae in our galaxy
- Nucleon decay
- Plus many other topics (neutrino interaction physics, atmospheric neutrinos, sterile neutrinos, WIMPS searches, etc.)

Long-baseline neutrino physics

$$P(\overline{\nu}_\mu \to \overline{\nu}_e) \simeq \sin^2\theta_{23}\sin^2 2\theta_{13}\,\frac{\sin^2(\Delta_{31}-aL)}{(\Delta_{31}-aL)^2}\Delta_{31}^2 + \sin 2\theta_{23}\sin 2\theta_{13}\sin 2\theta_{12} \times \frac{\sin(\Delta_{31}-aL)}{(\Delta_{31}-aL)}\Delta_{31} \times \frac{\sin(aL)}{(aL)}\Delta_{21}\cos(\Delta_{31}\pm\delta_{CP}) + \cos^2\theta_{23}\sin^2 2\theta_{12}\frac{\sin^2(aL)}{(aL)^2}\Delta_{21}^2$$

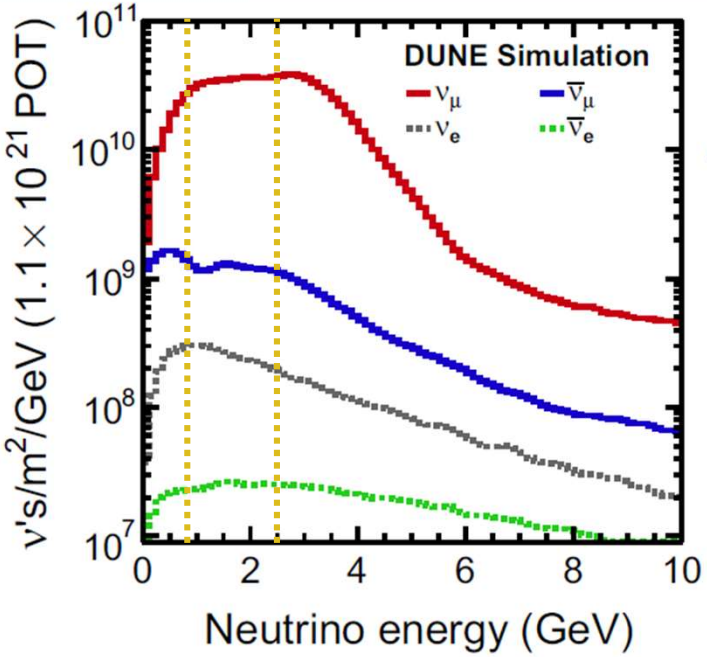
matter effects

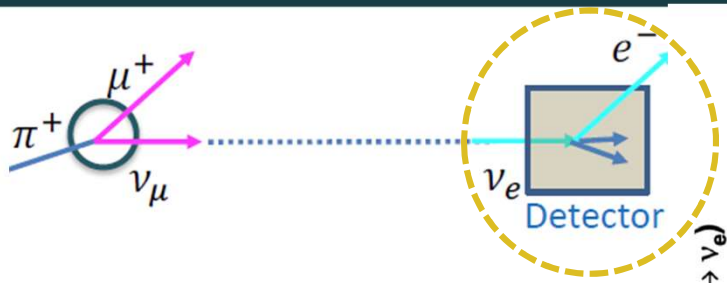
$$a = \pm\frac{G_F N_e}{\sqrt{2}} \approx \pm\frac{1}{3500\ \text{km}}\left(\frac{\rho}{3.0\ \text{g/cm}^3}\right)$$

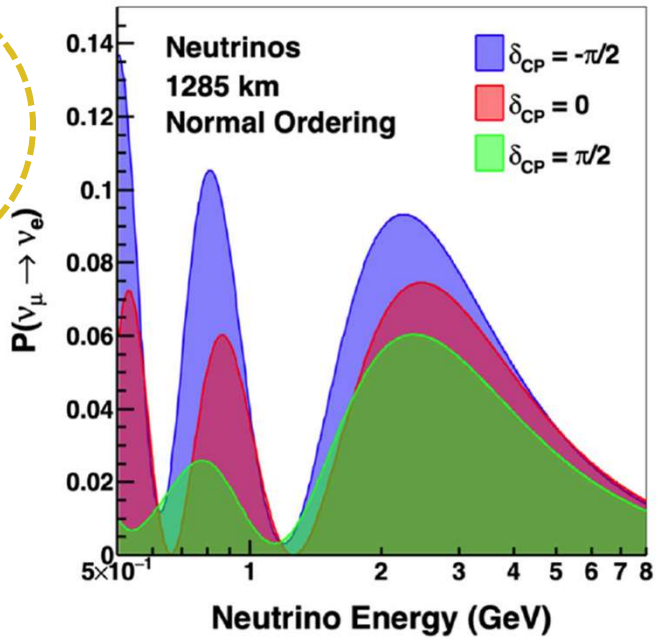
(+: neutrino, -: anti-neutrino)

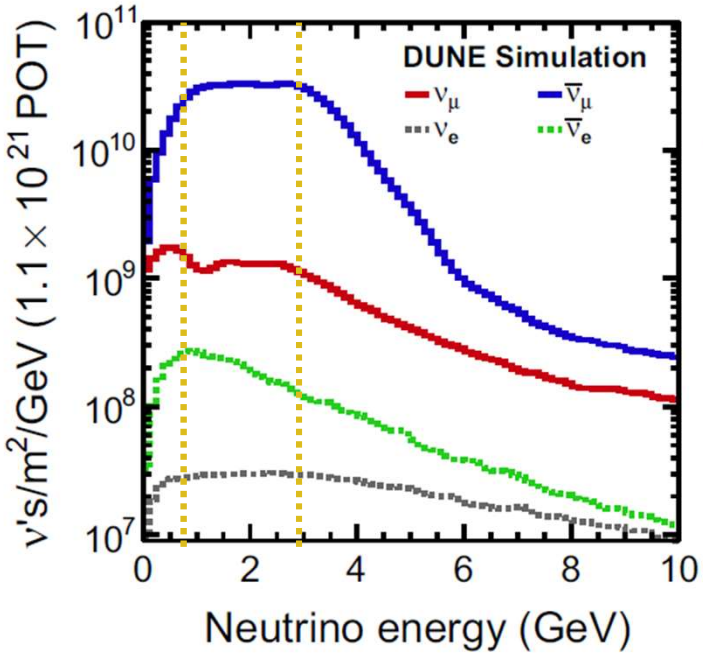
$$\Delta_{ij} = 1.267\,\Delta m^2_{ij} L/E_\nu$$

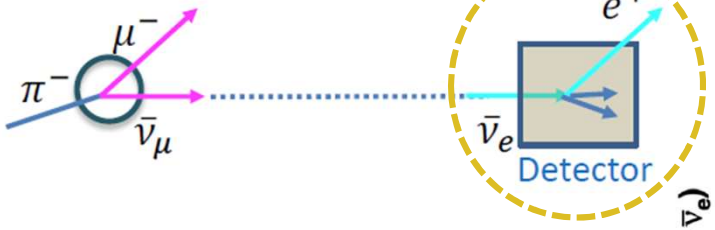
On-axis wide energy beam

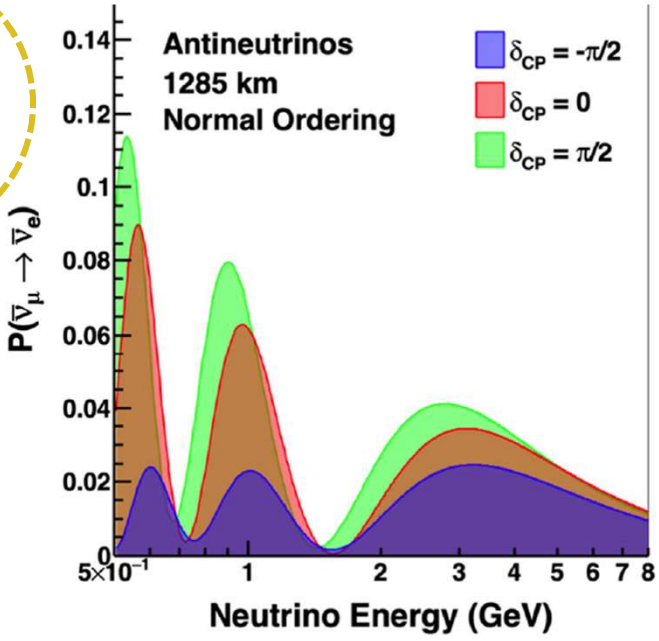












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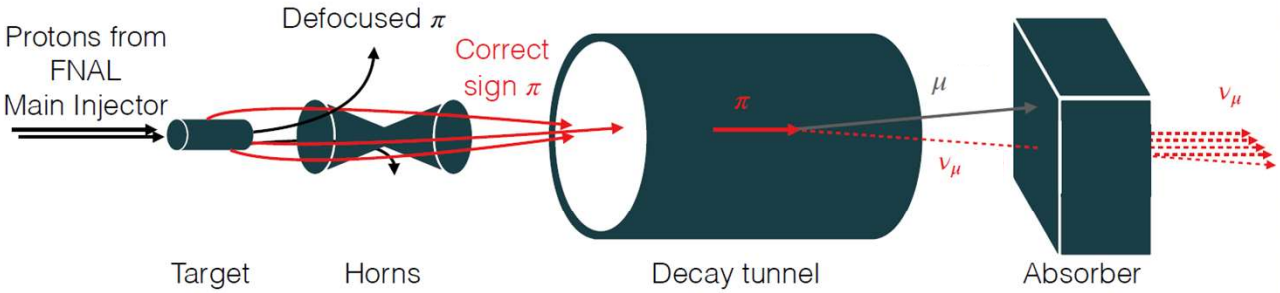
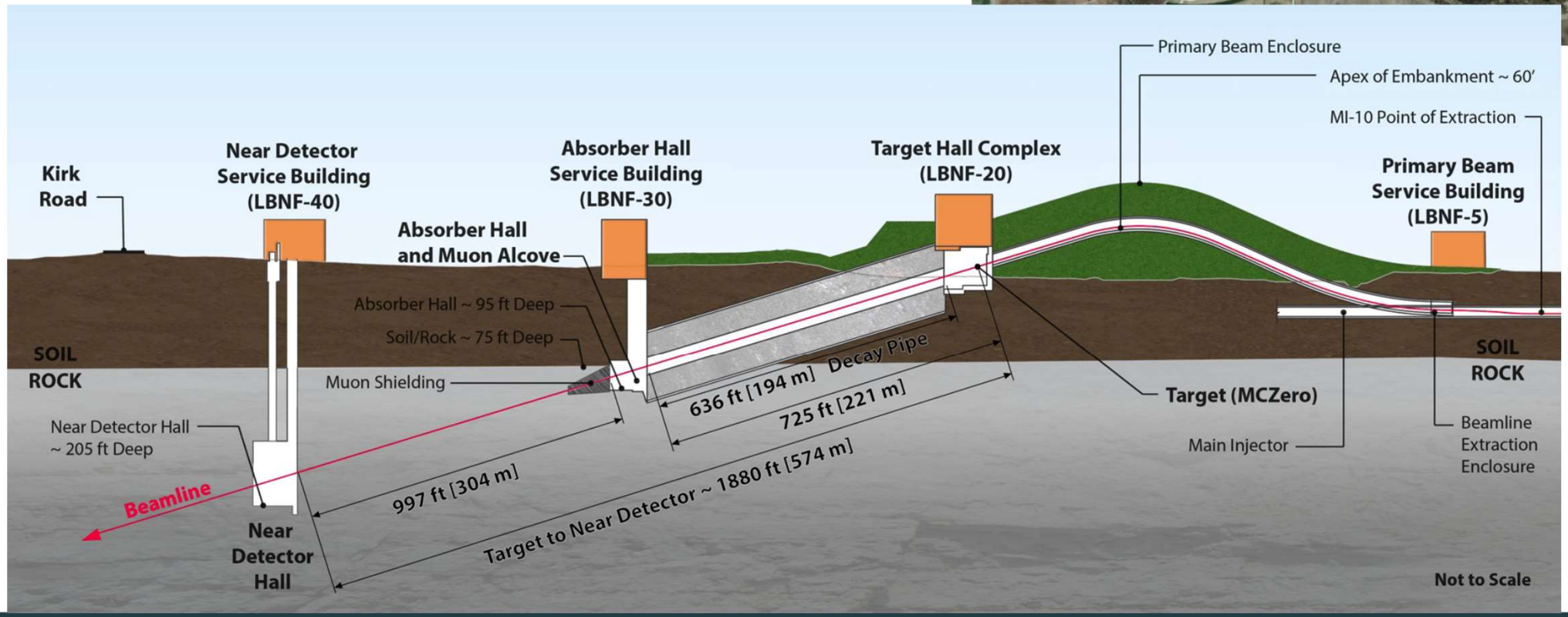
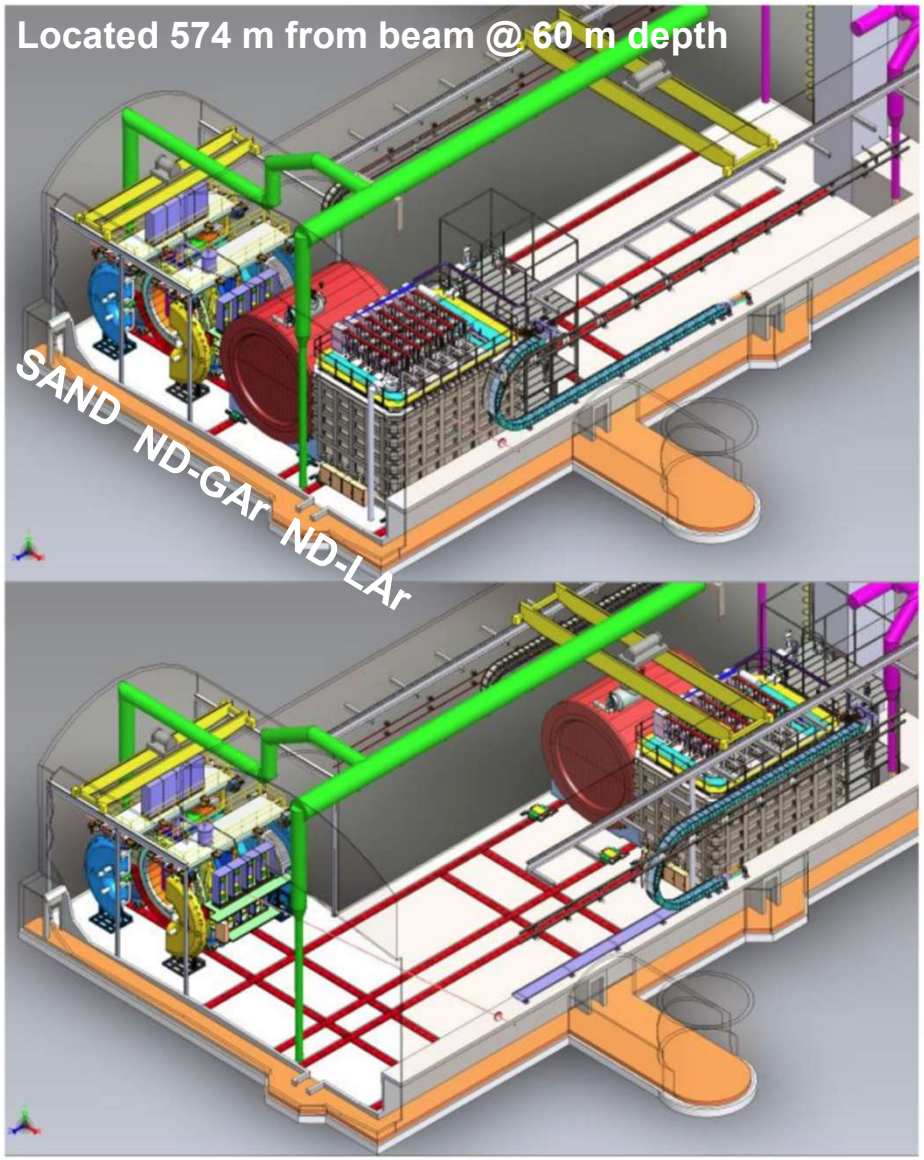
LBNF Beam at Fermilab





DUNE near detector



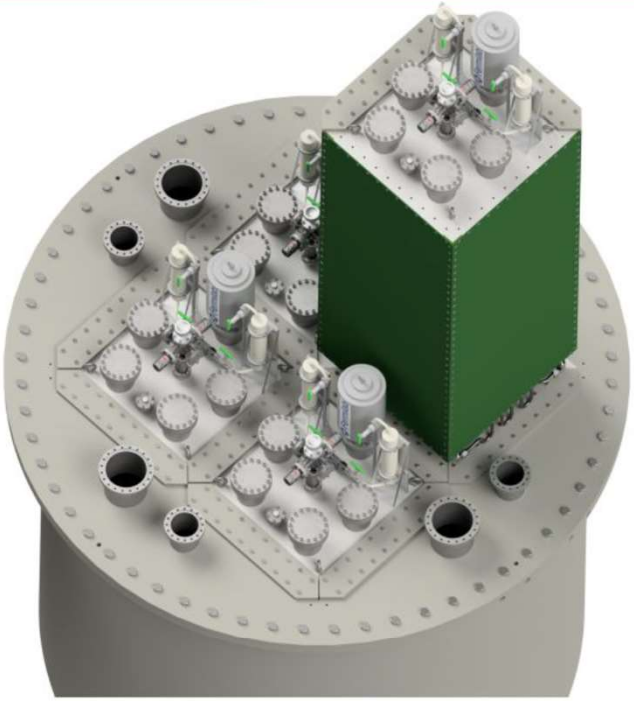
Multiple complimentary system:

- ND-LAr:
  Primary 50 tonne FV target, modular pixel readout
- ND-GAr:
  HP GAr TPC + 0.5 T magnet, measure muons escaping the LAr
- SAND:
  tracker surrounded by an ECAL and 0.6 T magnet, serves as on-axis beam monitor

DUNE-PRISM:
ND-Lar and ND-Gar can move 33 m to receive different beam fluxes, characterize the beam and constrain systematic uncertainties

See: the high pressure TPC, by Diego Gonzalez Diaz later in this session

ND-LAr

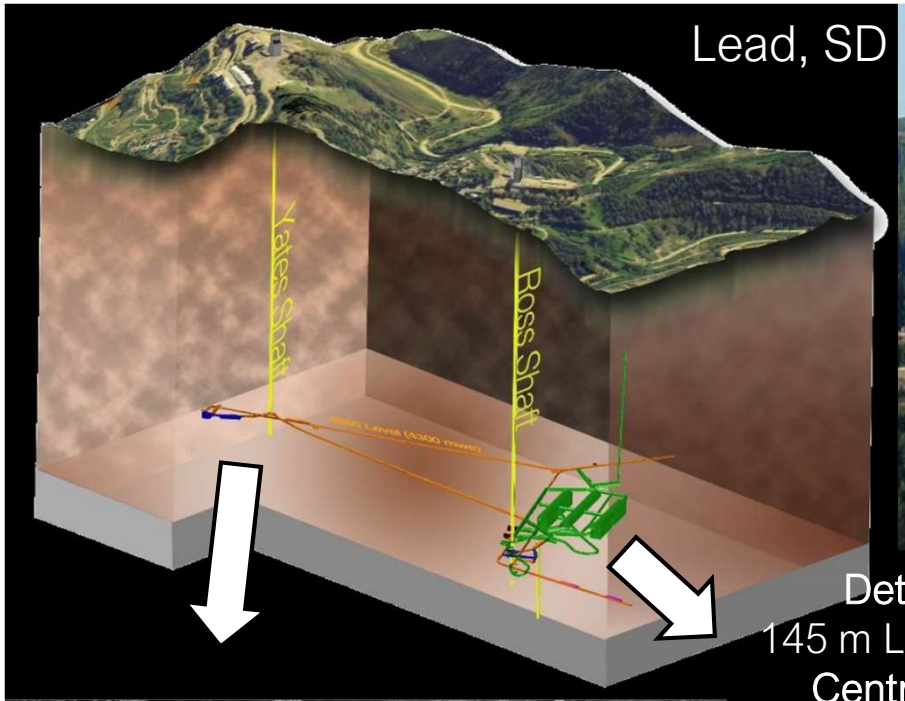


- Advanced Light Readout
- Pixel Charge Readout
- Resistive Field Cage
- Modular TPC Design

ArgonCube 2x2 demonstrator:
4 independent LArTPC modules
(0.7m x 0.7m x 1.4m per module)

Currently being tested at Fermilab,
testing in NuMi beam in 2022

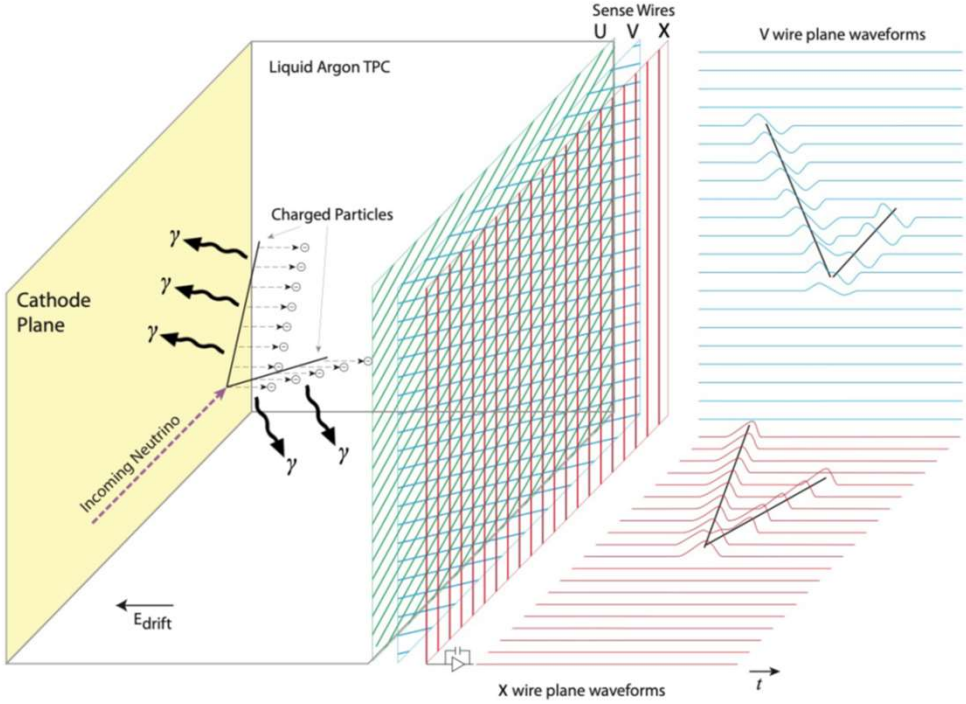
DUNE far detector

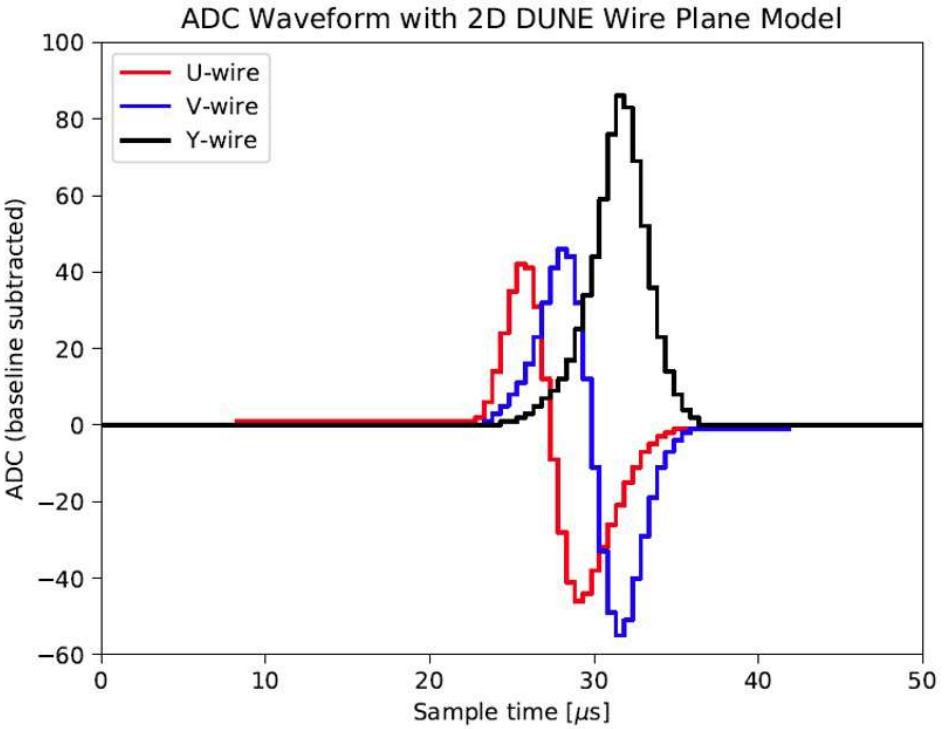


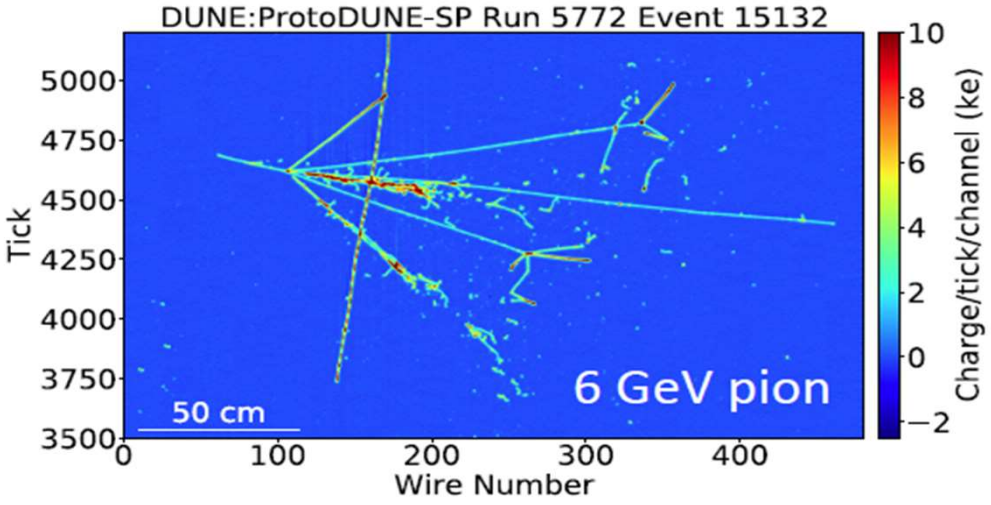
Sanford Underground Research Facility (sanfordlab.org)

Detector Caverns:
145 m L x 20 m W x 28 m H
Central Utility Cavern:
180 m L x 20 m W x 11 m H

LArTPC: Liquid Argon Time projection chamber







Far detector module I: HD

Charge Readout

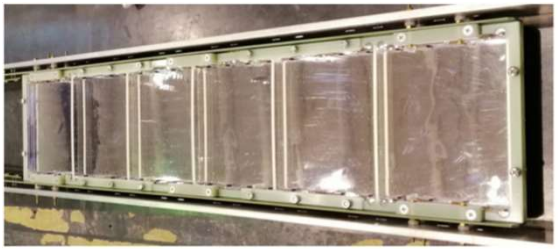
Alternated APA/CPA
(Anode and Cathode Plane Assemblies):

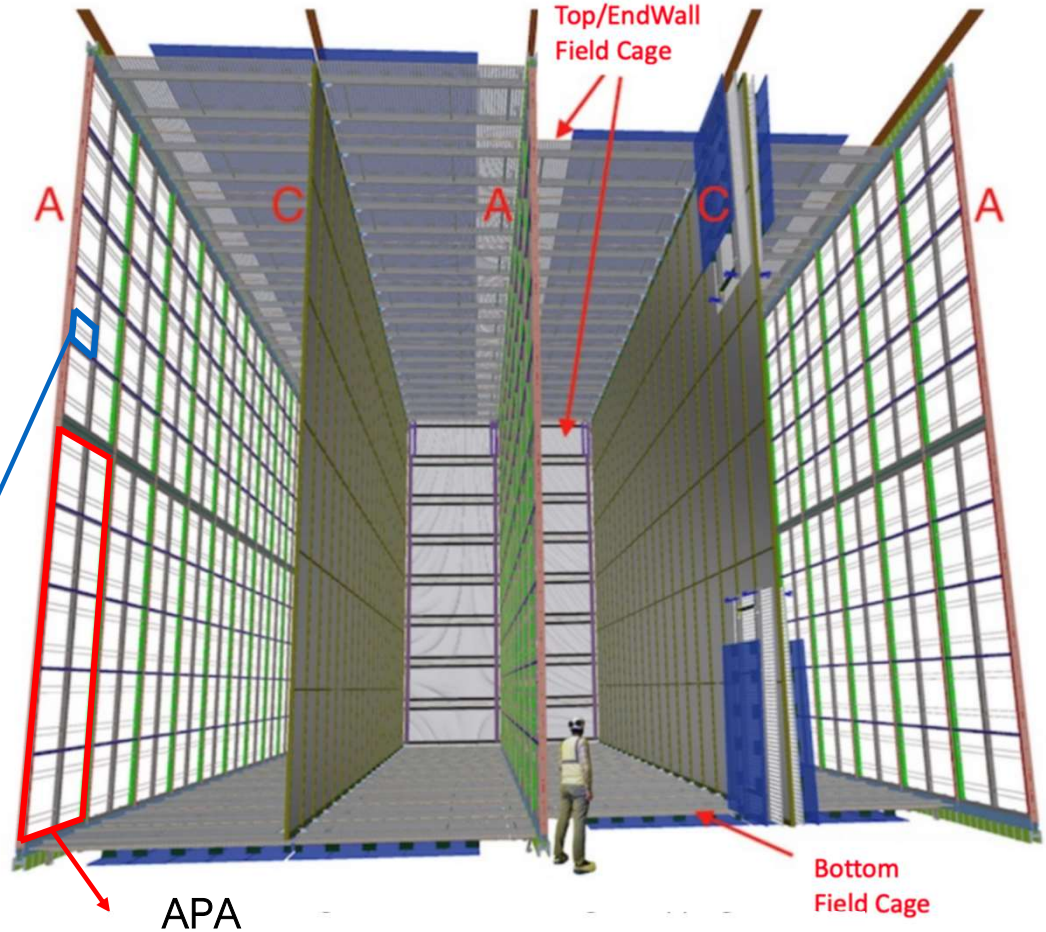
- Segmented: 4 drift volumes,
  Drift distance: 3.6 m
- Electric field = 500 V/cm
  (HV = -180 kV)
- Anode: 150 APAs, 4 wire planes each:
  Grid, 2x Induction, Collection
- High-resistivity CPAs
  to prevent fast discharge

Photon Detectors

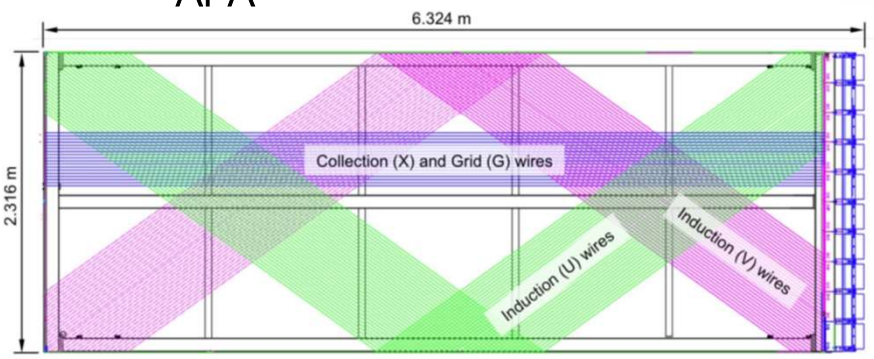
X-ARAPUCA light traps

X-ARAPUCA





APA

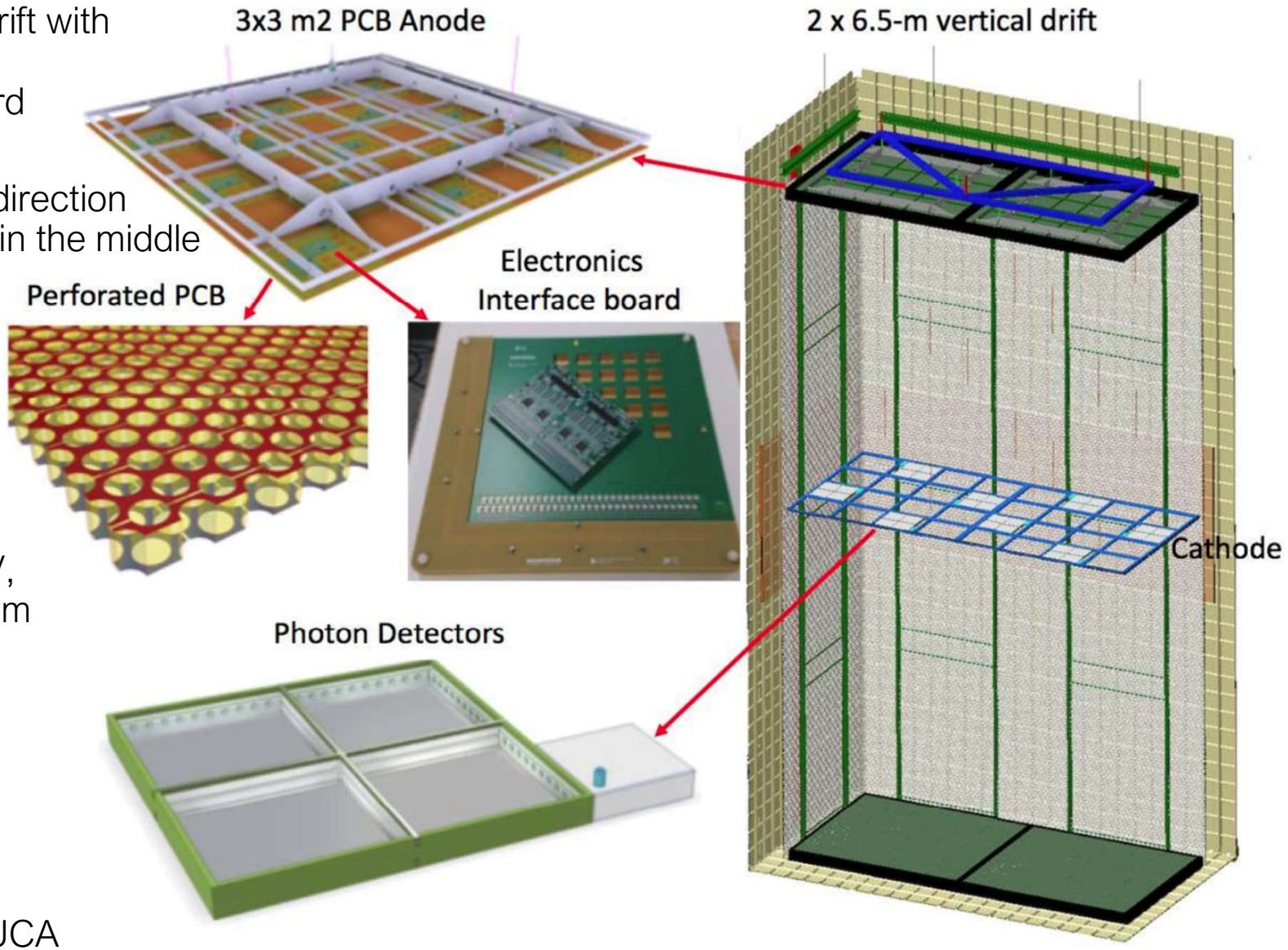


DUNE TDR, B. Abi et al 2020 JINST 15 T08010

Far detector module II: VD

Charge Readout

- 2 x 6.5 m vertical drift with horizontal Printed Circuit Board (PCB) anode
- Drift along vertical direction and cathode plane in the middle
- Readout on strips etched on PCBs
- Two induction and one collection readout
- Cathode at -300 kV, drift field of 450 V/cm



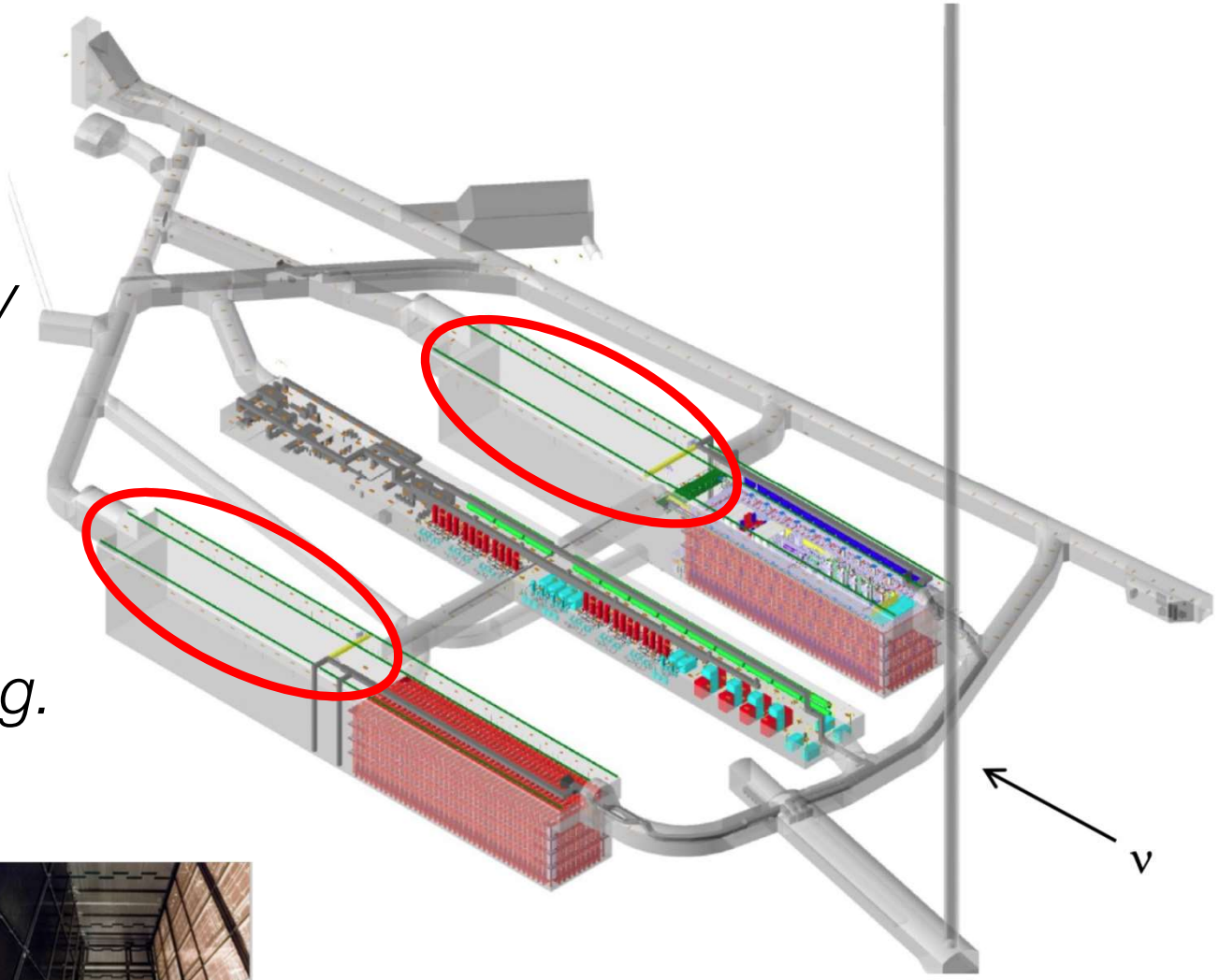
Photon Detection

- Based on X-ARAPUCA

Far detector modules III & IV

- Module 3 likely to follow module 2
- Module 4: *Module of Opportunity*

Workshops held to discuss range of concepts, *discussion are ongoing.*



https://www.bnl.gov/dmo2019/

Construction progress

Excavation work started.

ProtoDUNE

Two ~1 ktonne prototypes
(7.2 x 6.1 x 7.0 m)

Design validation of all components at full scale

Single-phase (SP), HD: 2018-20

- Charged particle beam + cosmic rays
- Event reconstruction, full analysis
- Neutron calibration, Xe doping, HV tests

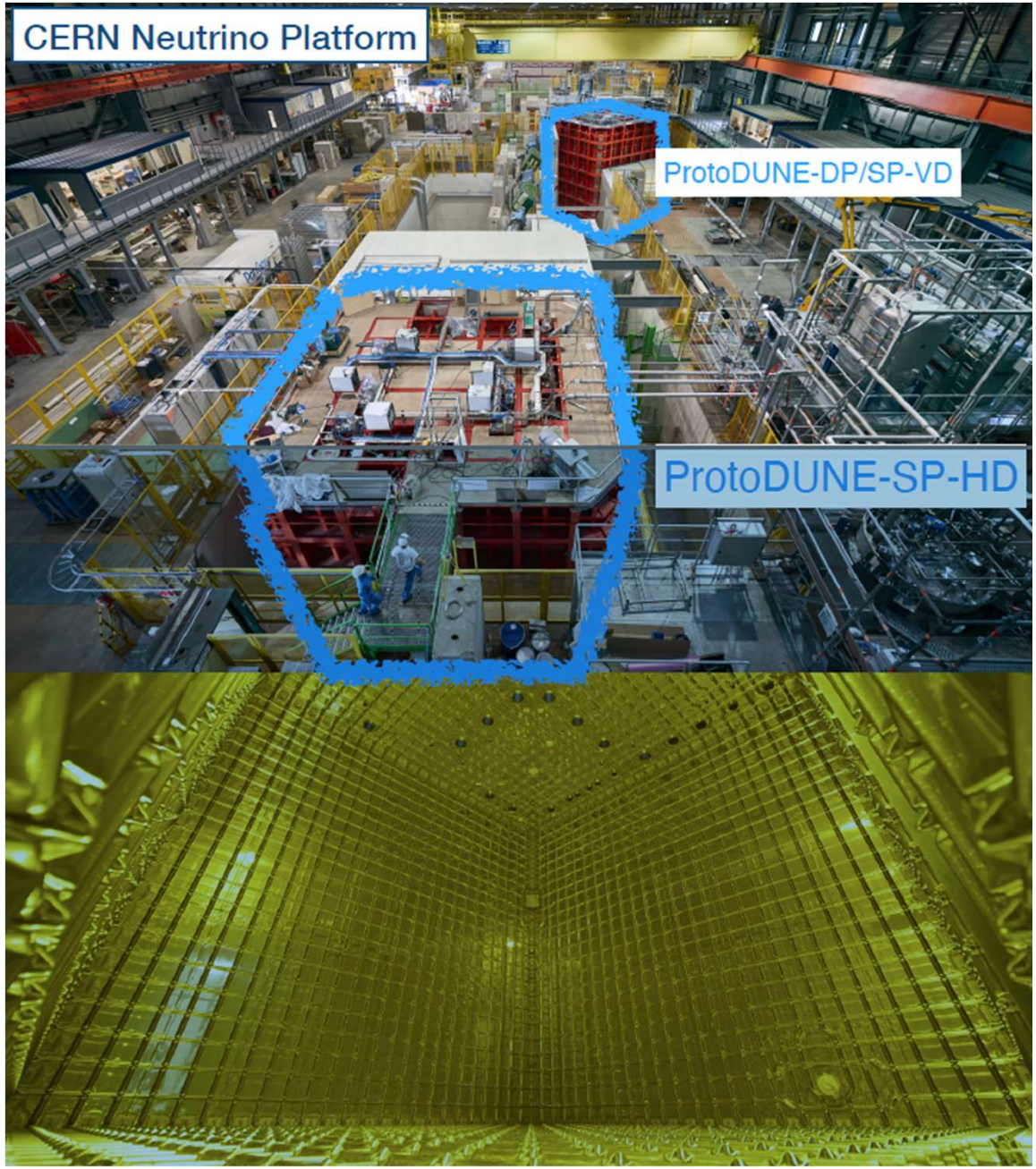
Phase-II starting in 2022

Dual-phase (DP): 2019-20
Signals produced in liquid and gas phases

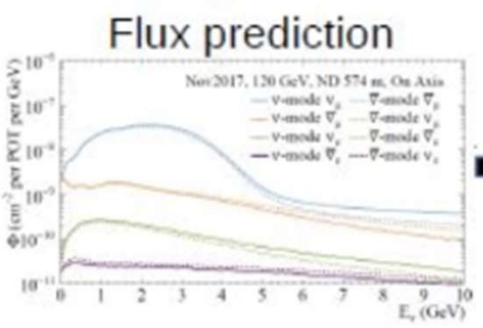
Evolved into SP-Vertical Drift

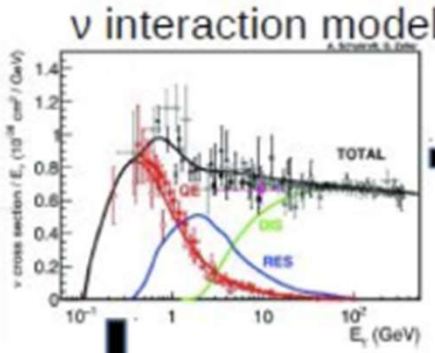
Starting in 2023

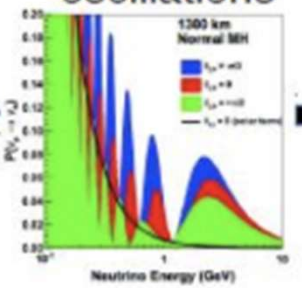
See Filippo Resnati's talk (next)

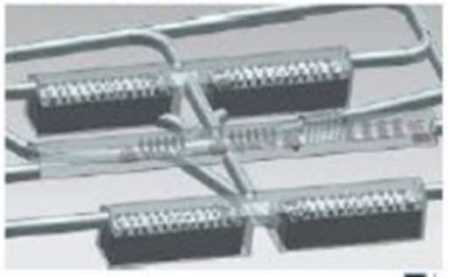


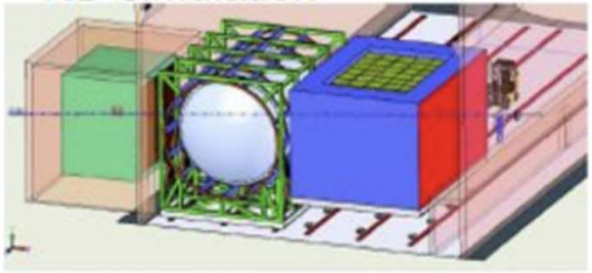
Oscillation analysis

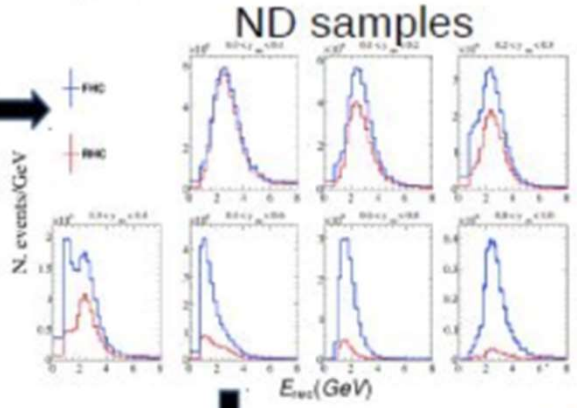


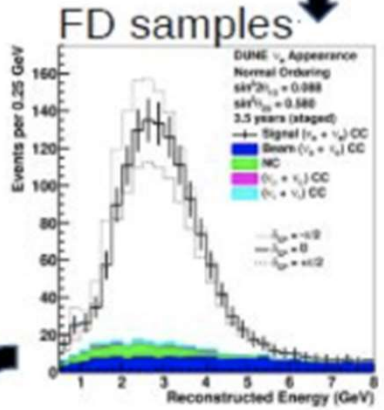


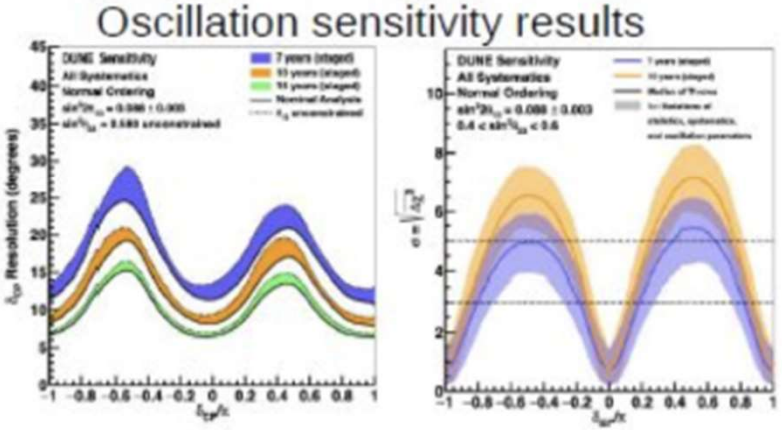


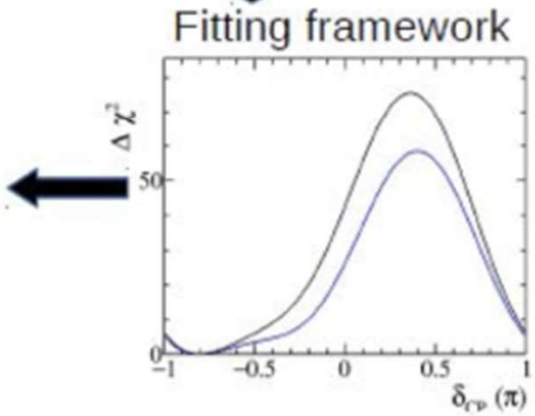


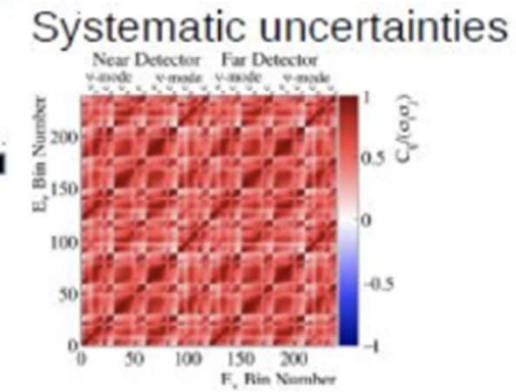












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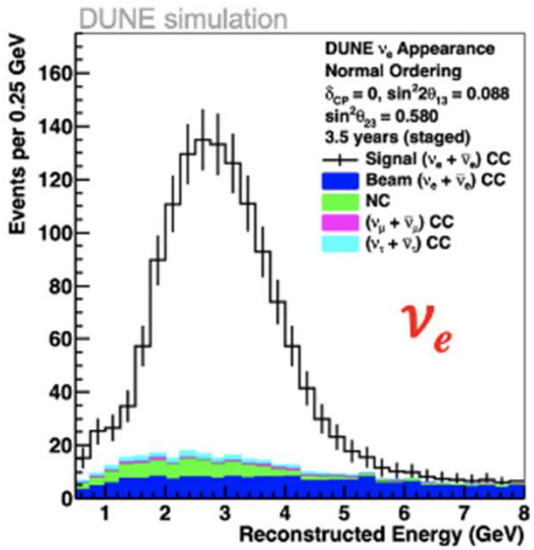
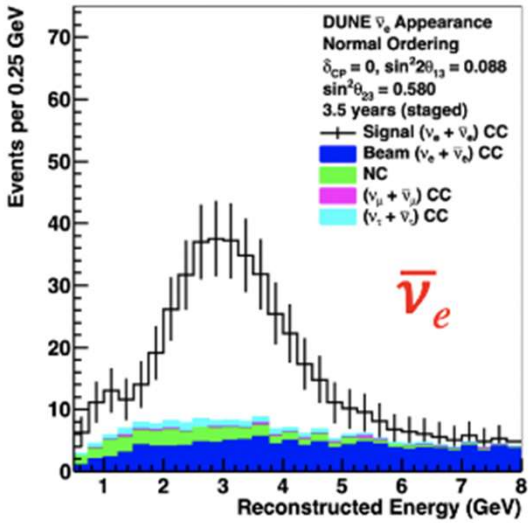
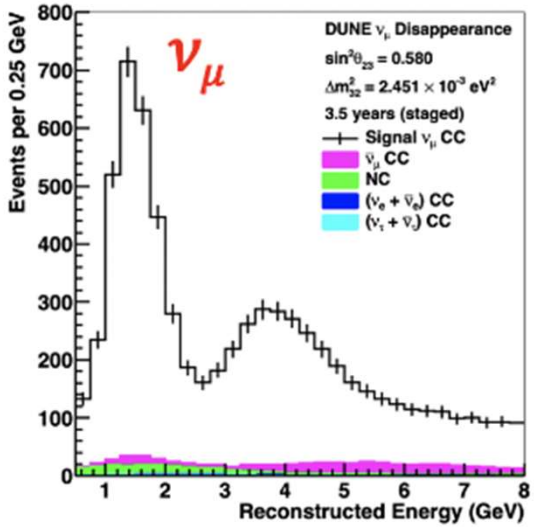
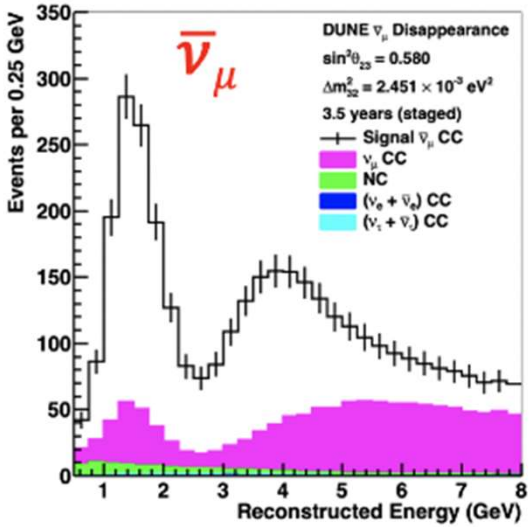
Far detector spectra









Order 1,000 appearance events in 7 years

Order 10,000 disappearance events in 7 years

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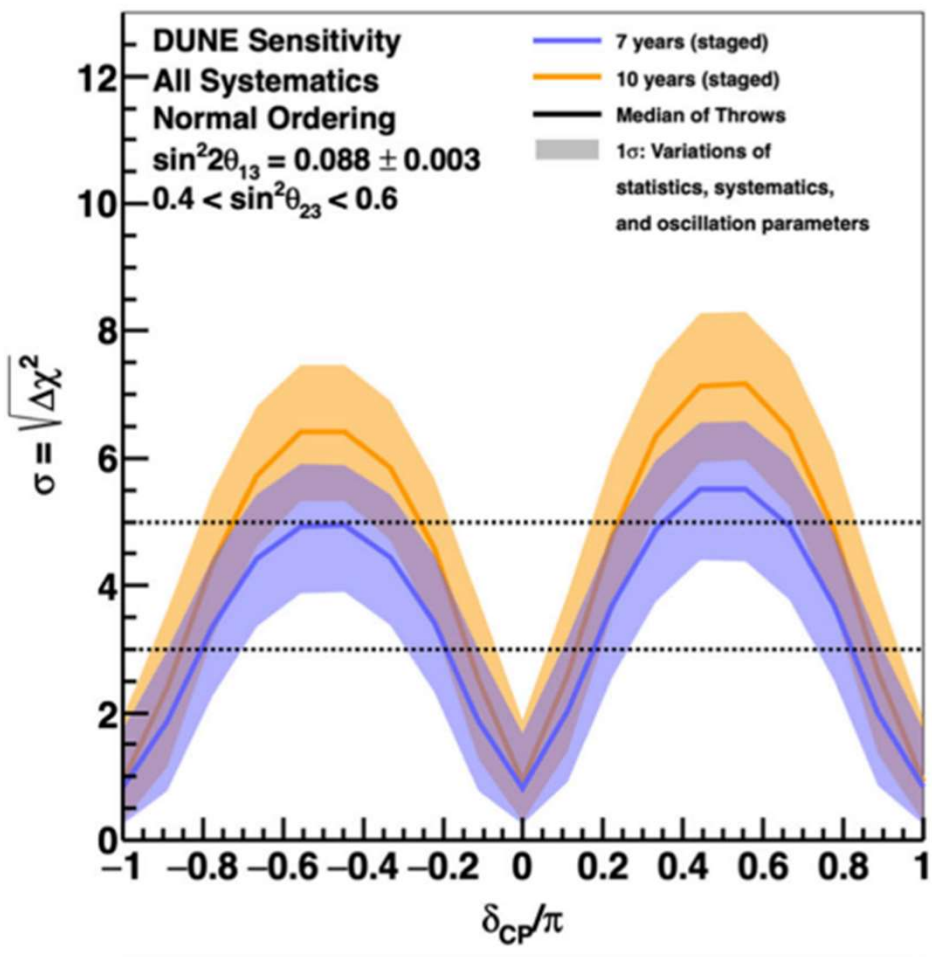
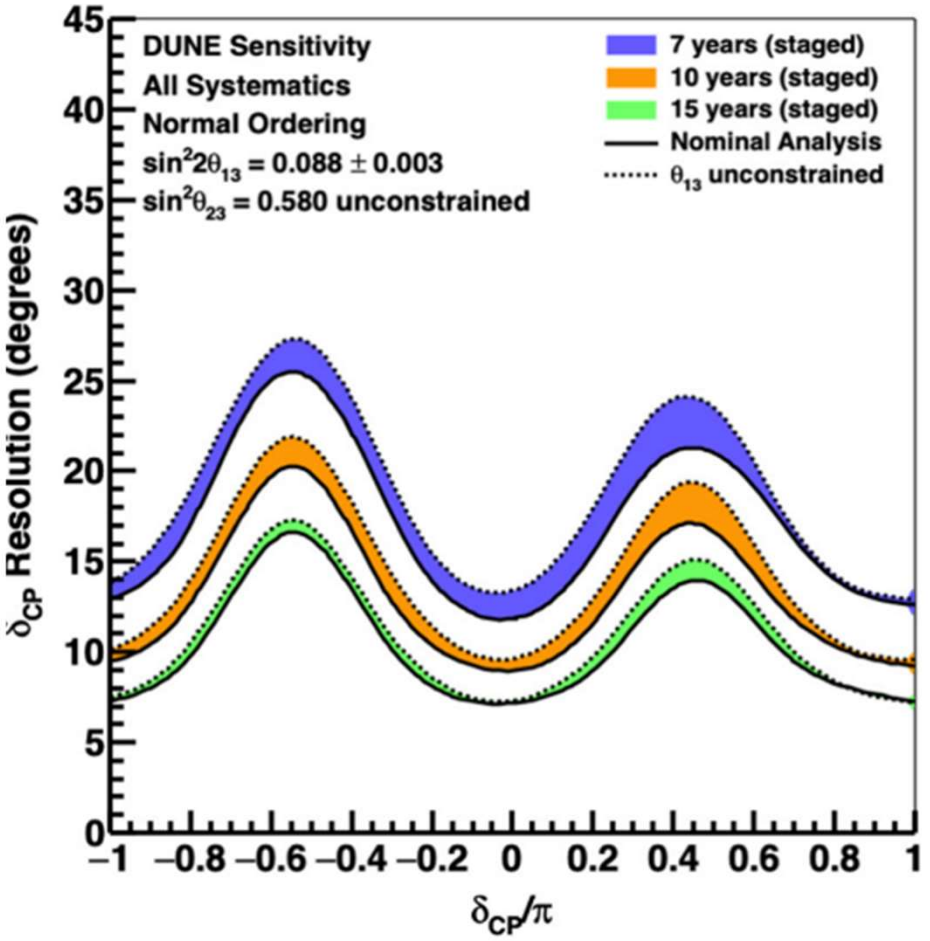
CP-phase sensitivity





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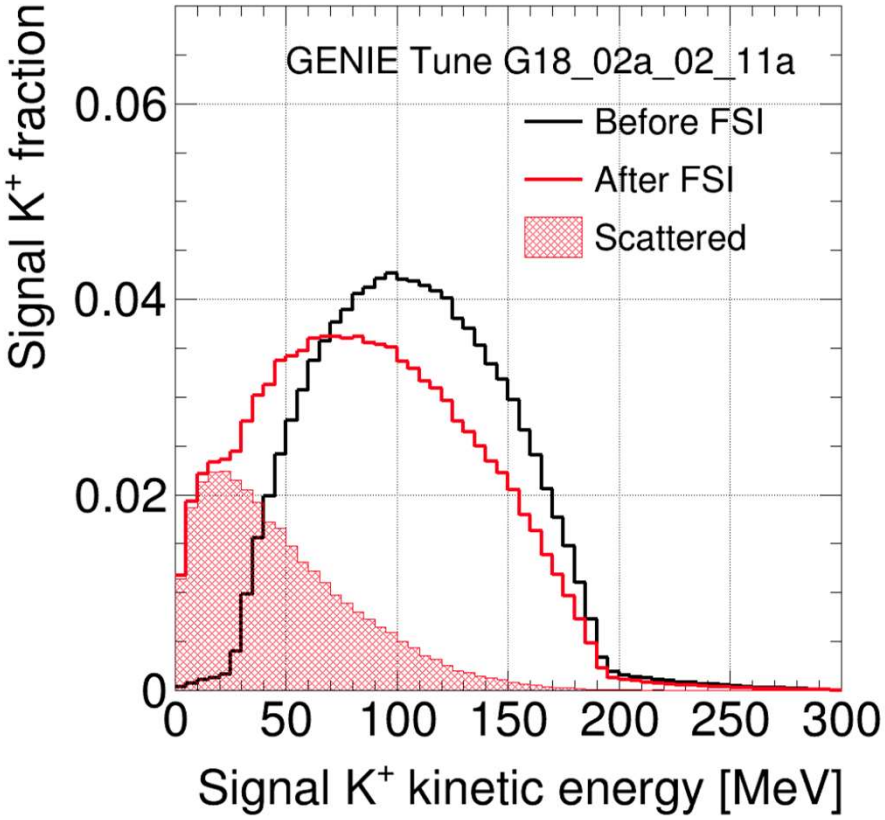
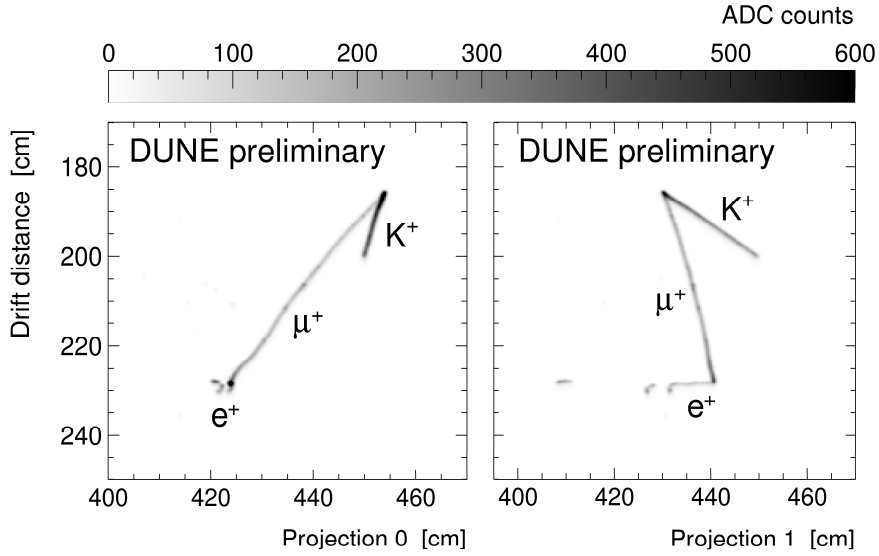
Unambiguous determination of neutrino mass ordering within first few years.
Significant milestones throughout the beam physics programme.

Nucleon decay



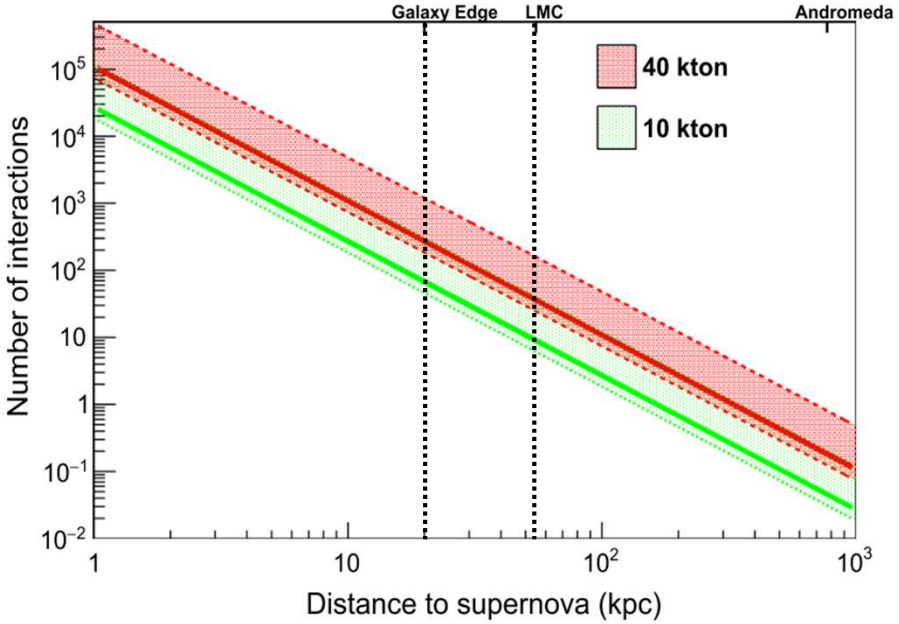
Backgrounds: Atmospheric neutrinos



https://doi.org/10.22323/1.390.0226

DUNE will be competitive for favoured SUSY decay channel:
$\tau(p \rightarrow \bar{\nu}K) > 1.3 \times 10^{34}$ yrs @ 90 % CL after 400 kt · yrs

Supernova neutrinos



In case of a galactic supernova, DUNE expects to observe up to thousands of neutrino interactions

Unique sensitivity to electron neutrinos

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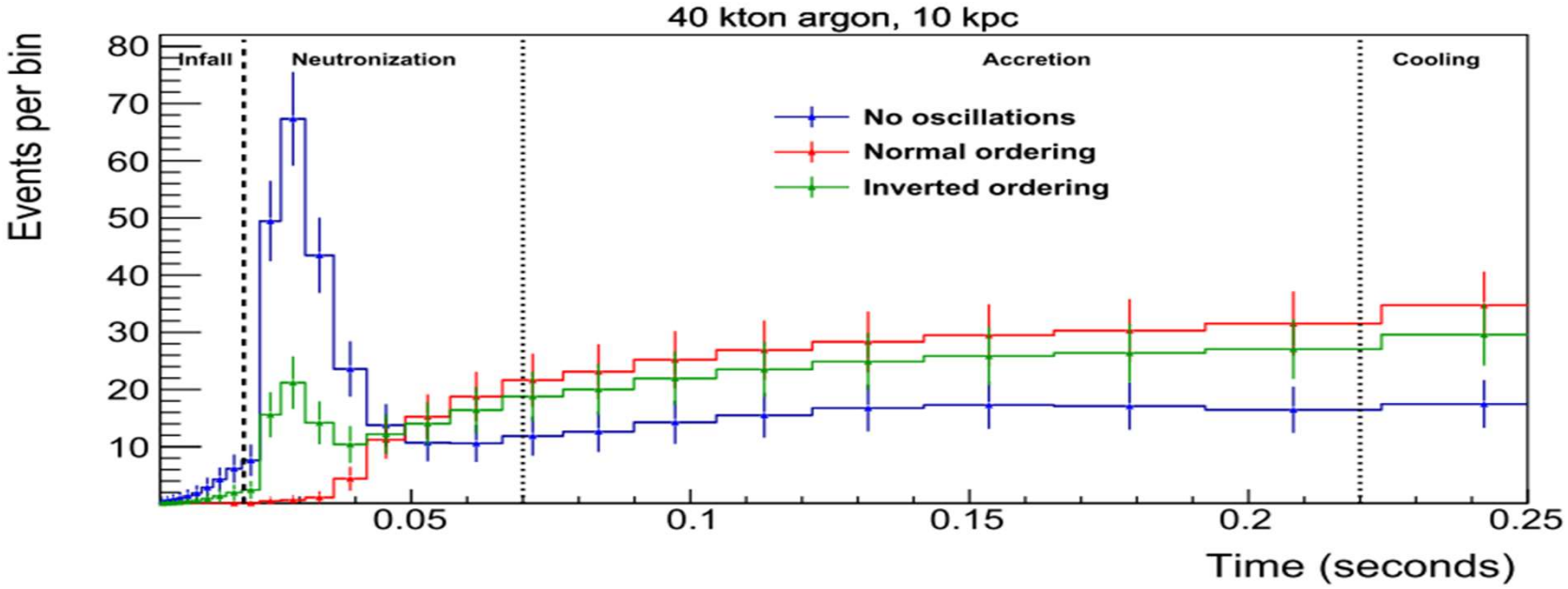
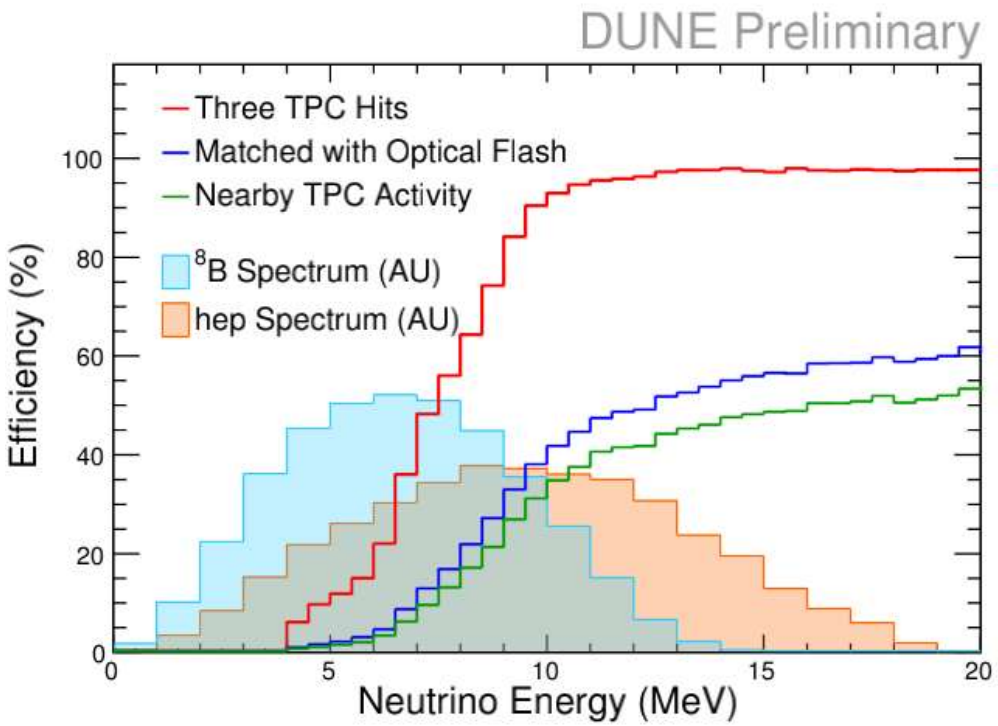
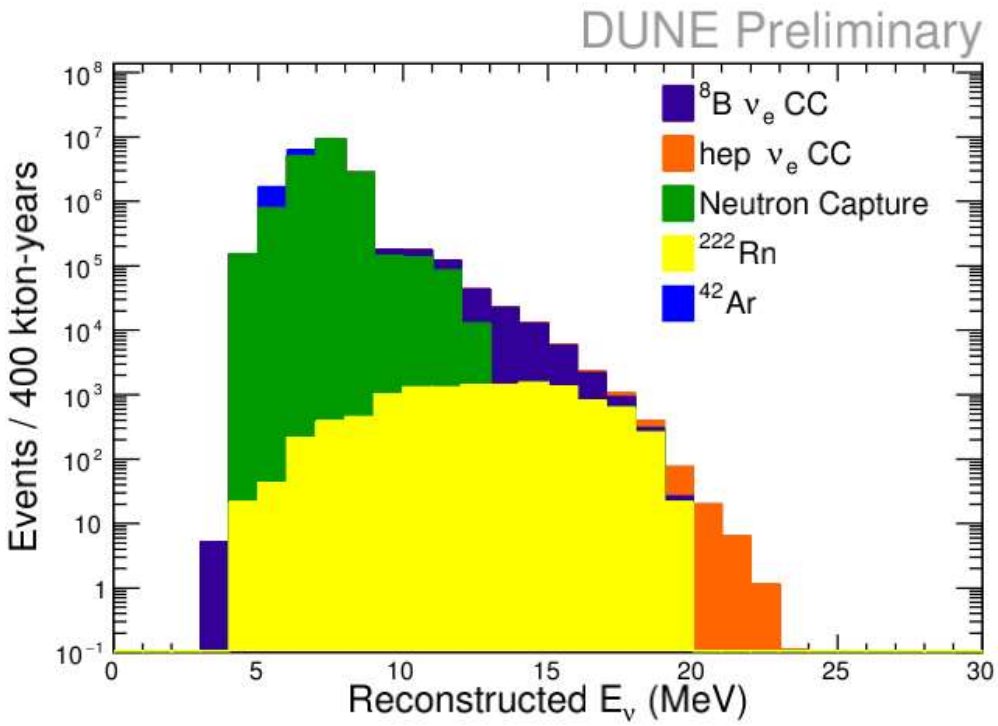


Solar neutrinos





DUNE can potentially observe solar neutrinos, giving access to the observation of hep neutrinos.

Summary

- DUNE will provide a rich physics programme:
  it will measure neutrino oscillations providing insights on matter/antimatter imbalance in the Universe and other open questions in physics (BSM, neutrino astrophysics).
- DUNE far detector site under construction; excavation ongoing.
- Detector technologies defined for far detector modules 1 and 2.
- Prototyping efforts underway at CERN with test beam runs planned in 2022-2023.
- First DUNE far detector installation in mid-2020s with first neutrino beam data in late 2020s.