The Deep Underground Neutrino Experiment DUNE

Overview and Prospects in Germany

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Max-Planck-Institute for Physics

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MAX-PLANCK-INSTITUT FÜR PHYSIK

Overview

- The Physics Program and Facility / Detector Design Drivers
- LBNF and the DUNE Experiment
- The DUNE Near Detector - Possible German Participation

Disclaimer: I am not (yet?) a member of DUNE - but have been contributing to the near detector concept since 2016. As such, this is a “private” talk, all views & mistakes are my own.

The Physics Goals

… and Experimental Design Drivers

Key physics goals of next-generation long baseline neutrino experiments:

- Discover CP violation in the lepton sector
- Resolve the mass hierarchy
- Astrophysics with Neutrinos: Understanding supernova explosions
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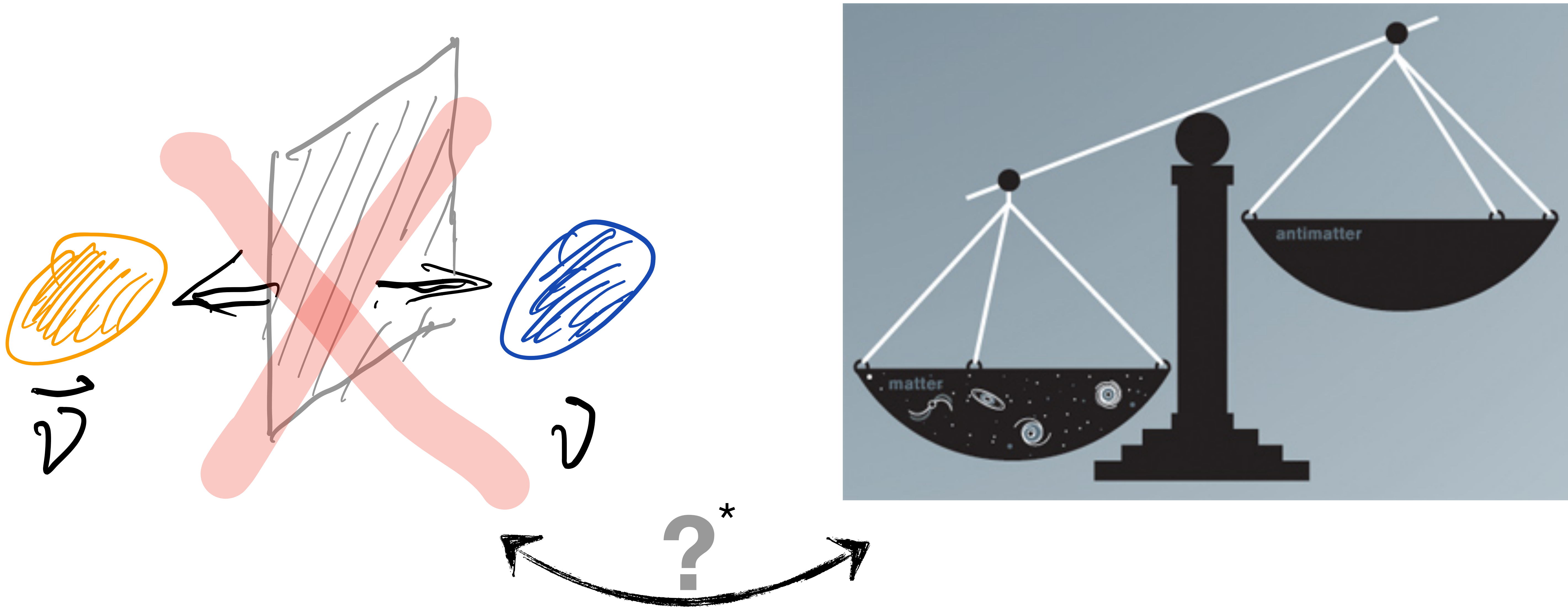

* N.B.: ν CPV no direct evidence for leptogenesis - still need a model connecting to high scales

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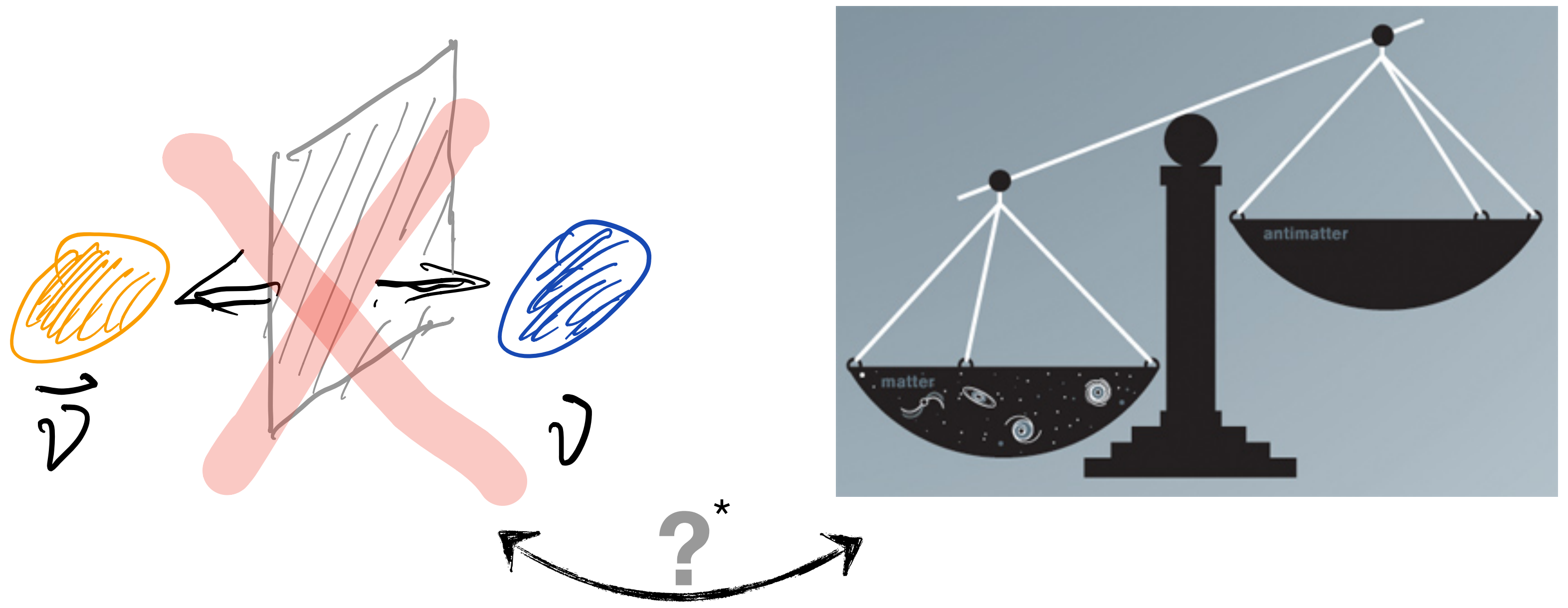

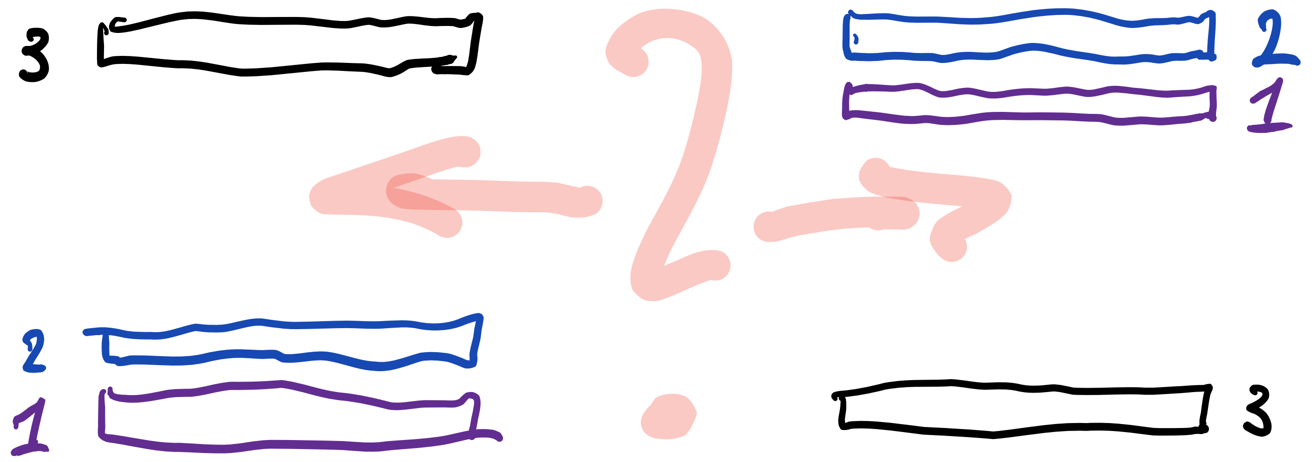

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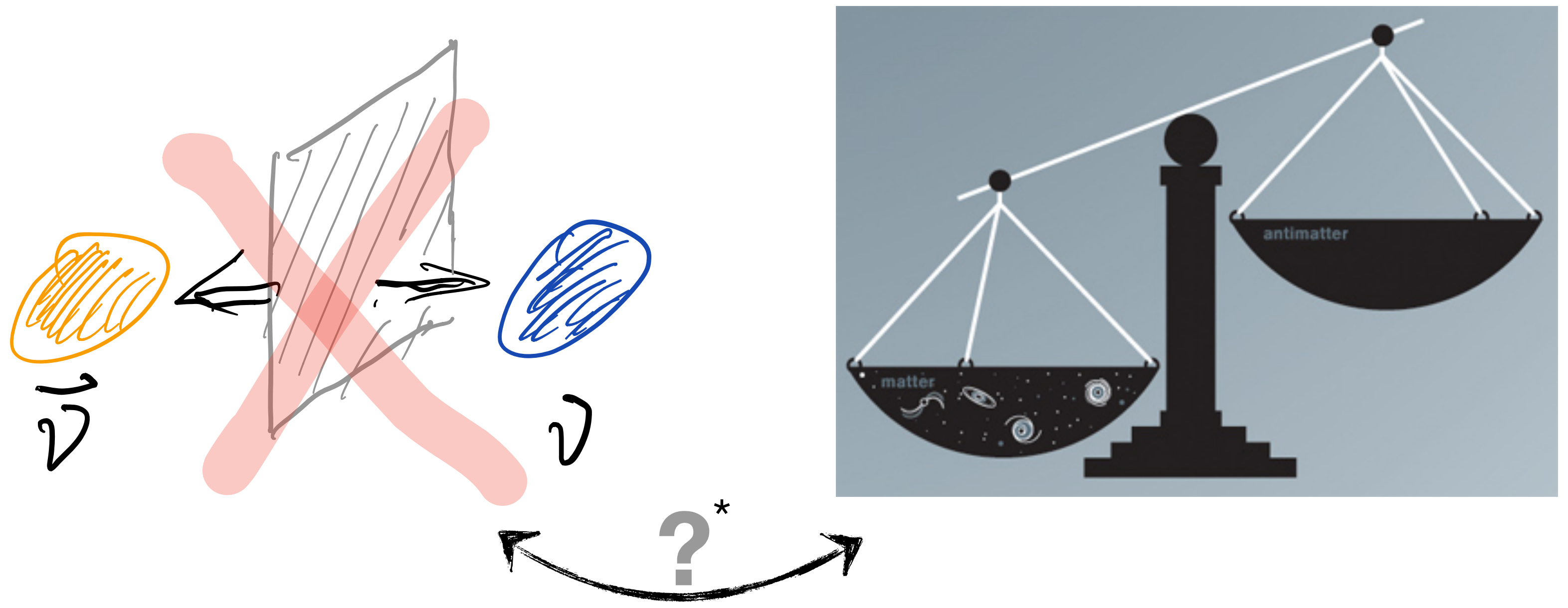

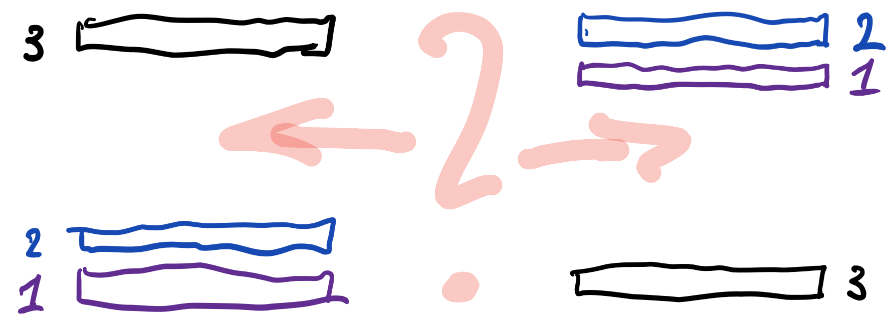

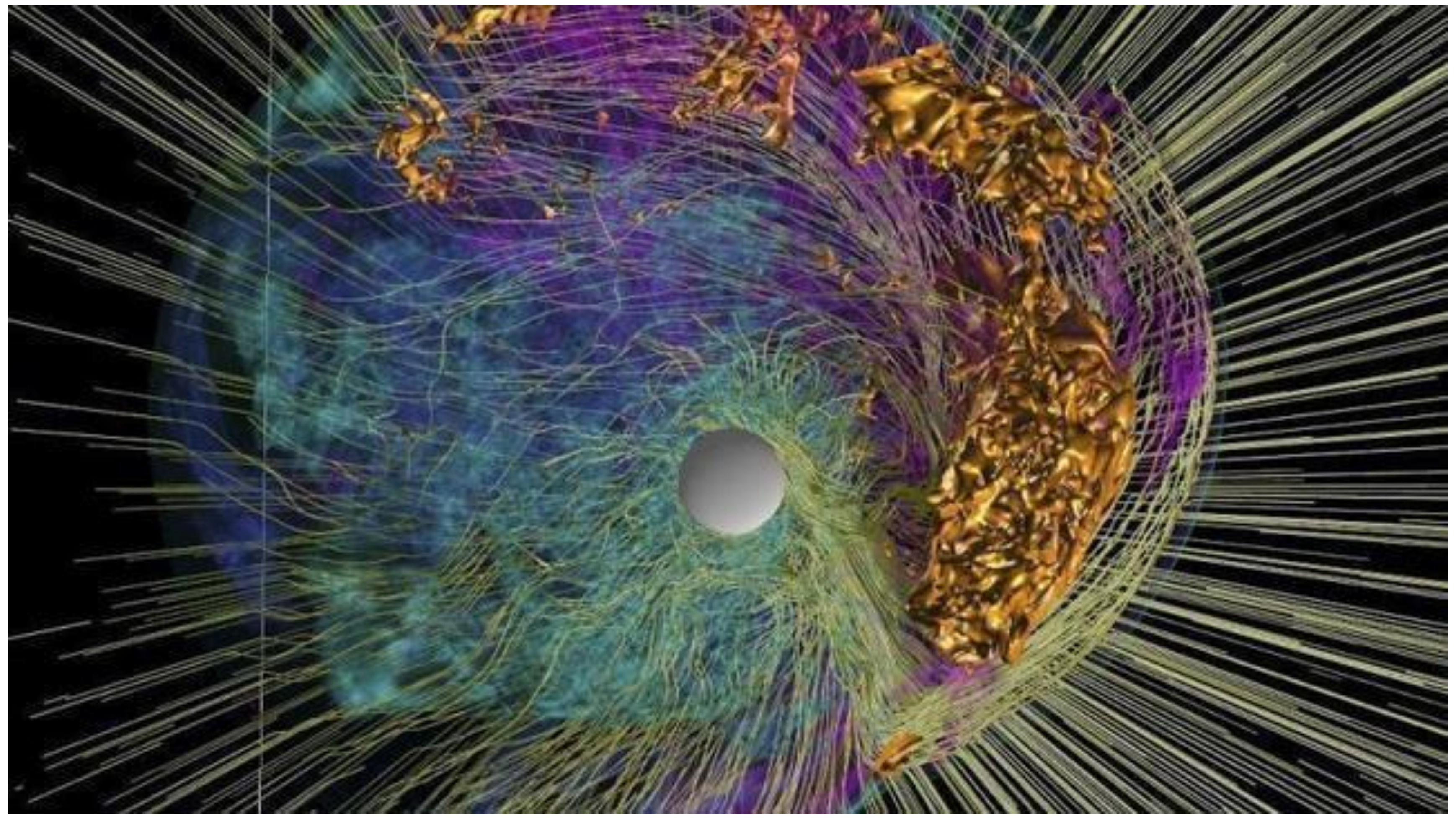

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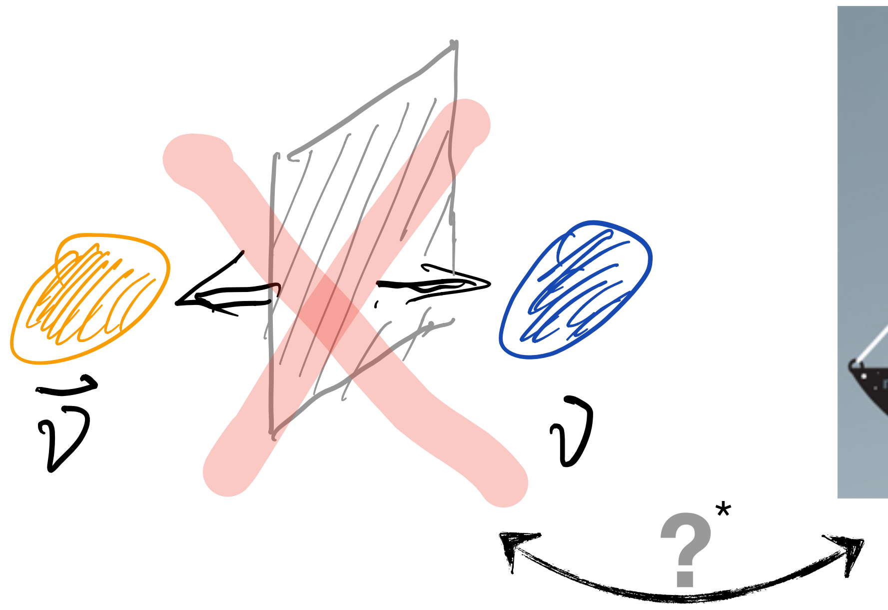

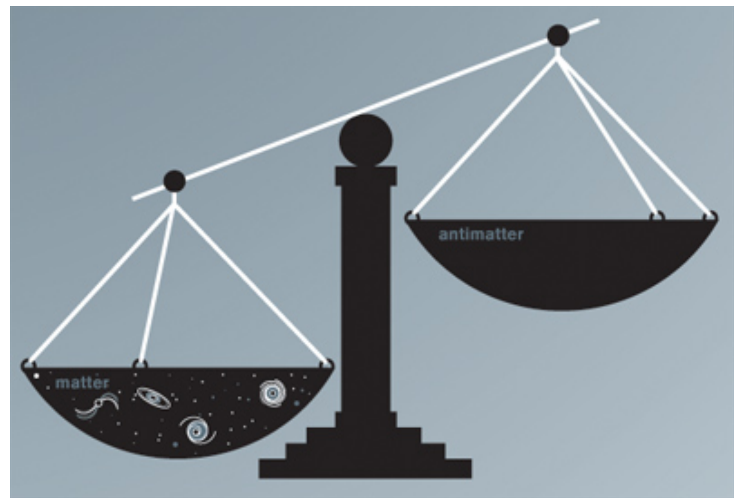

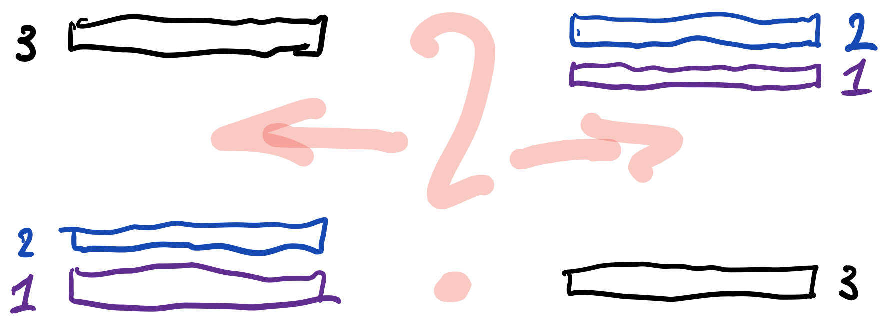

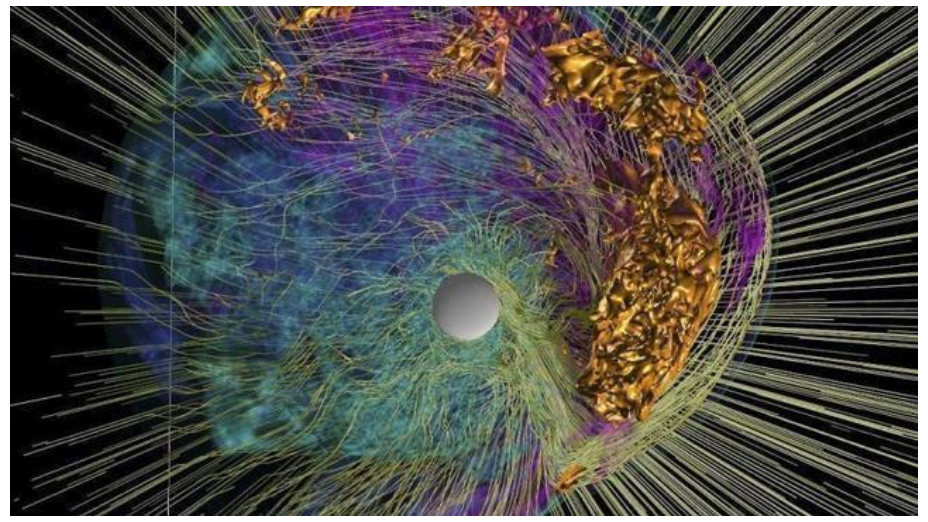

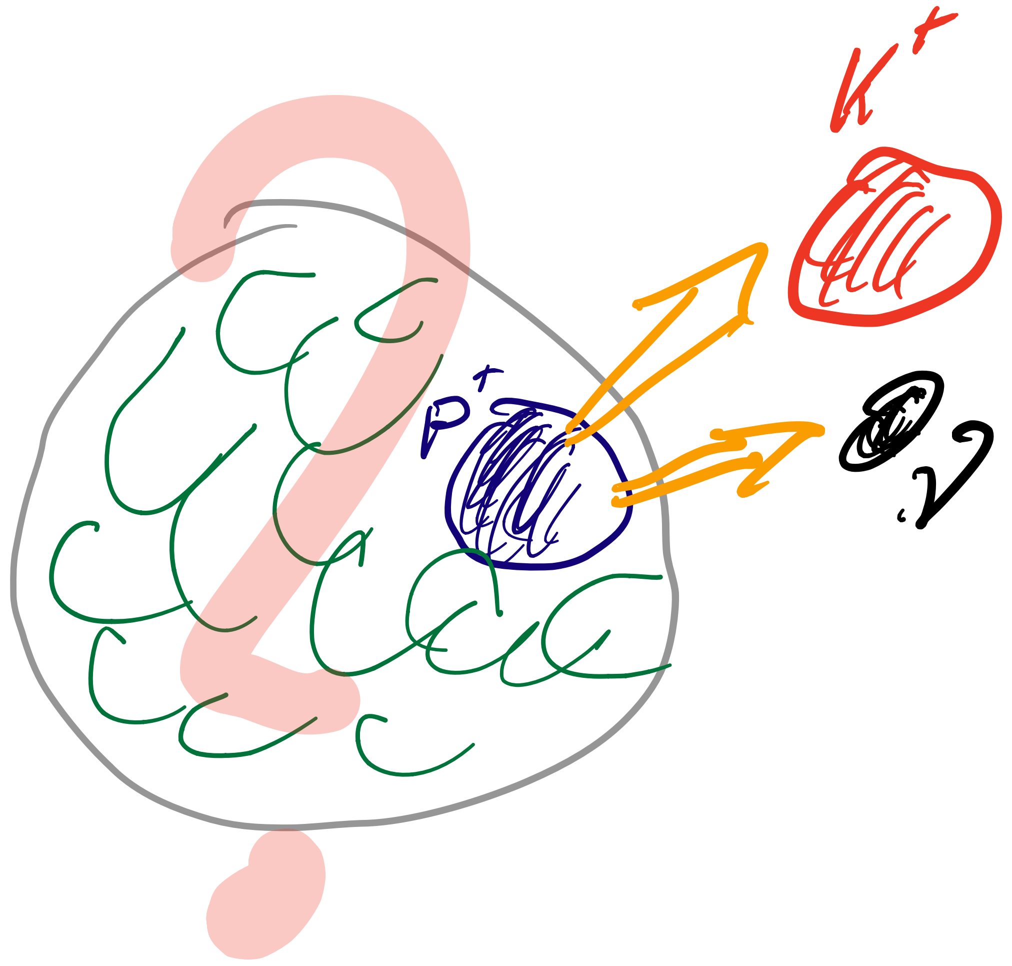

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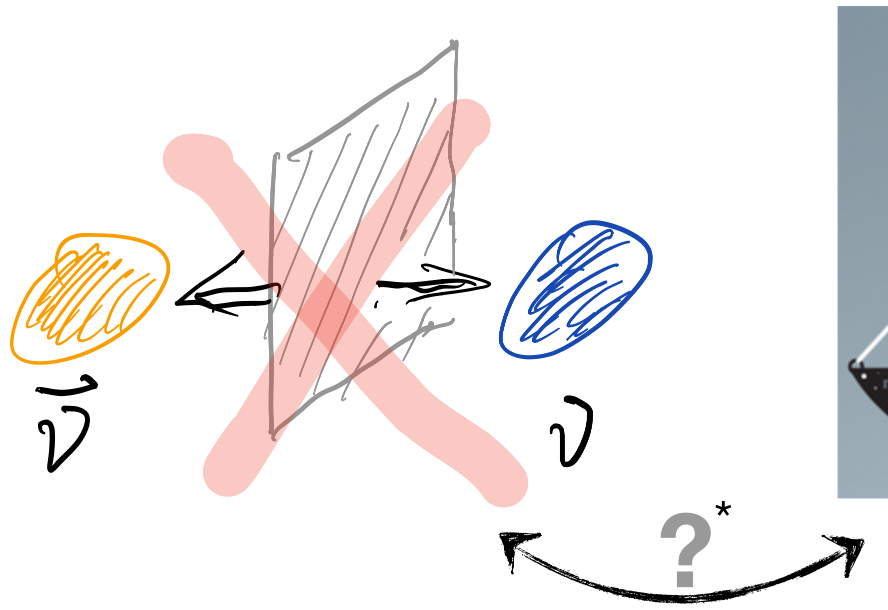

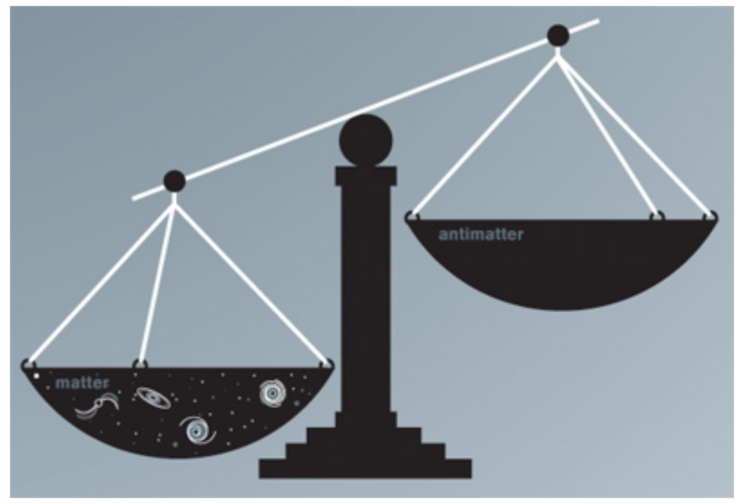

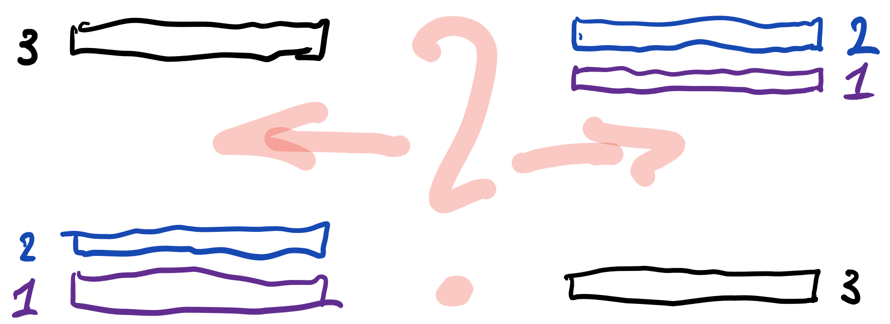

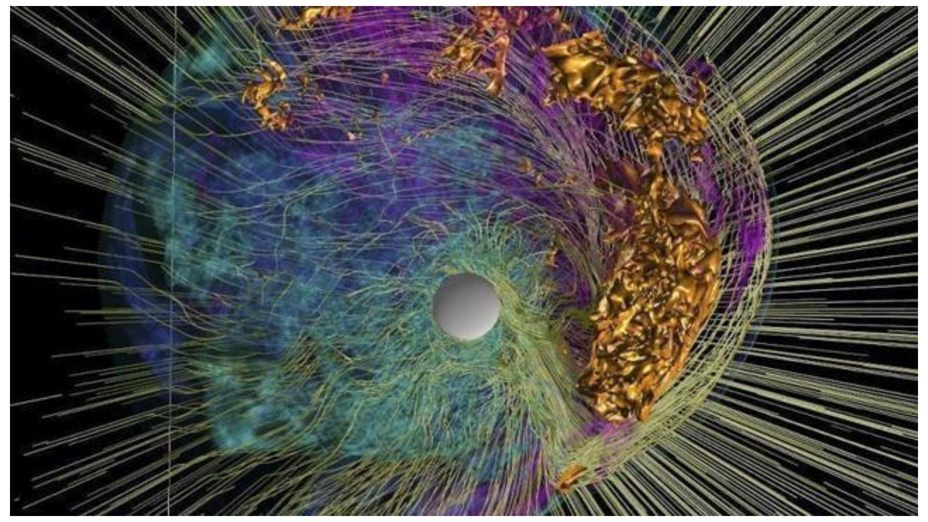

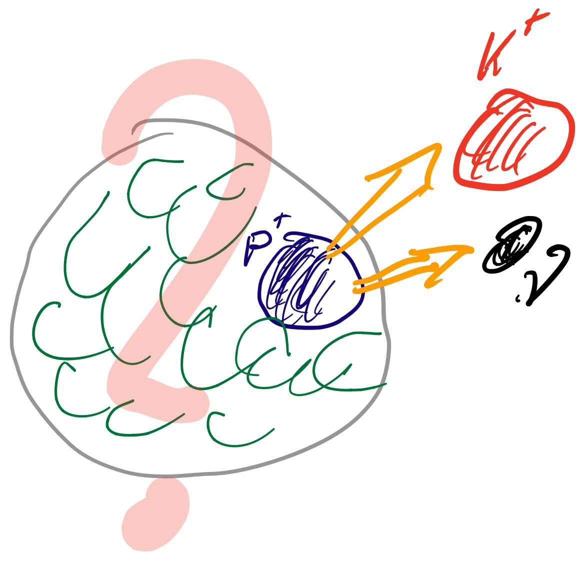

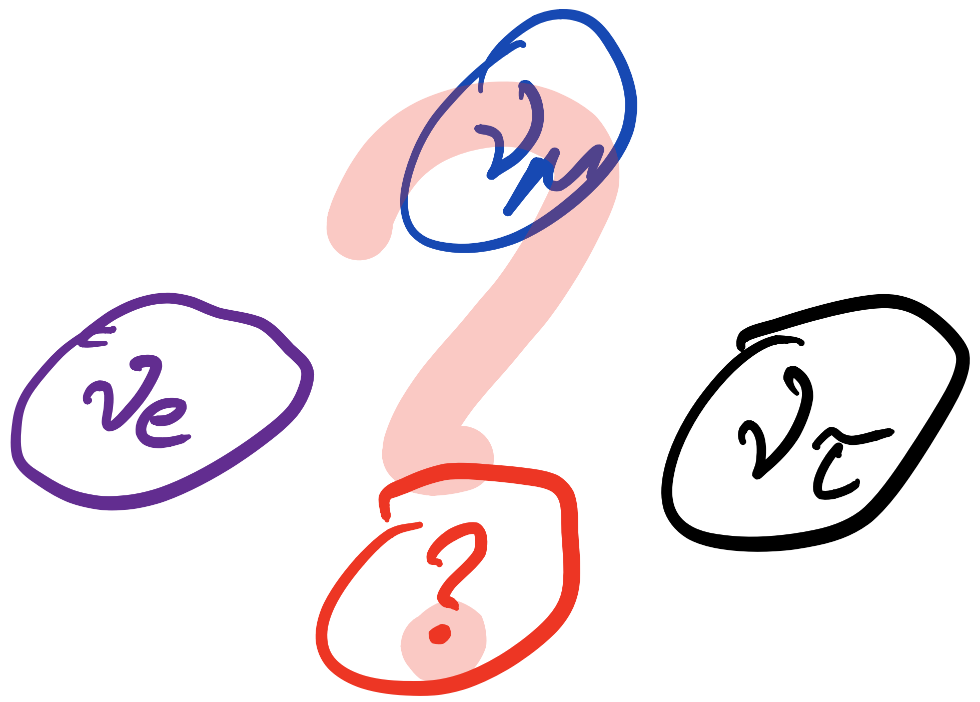

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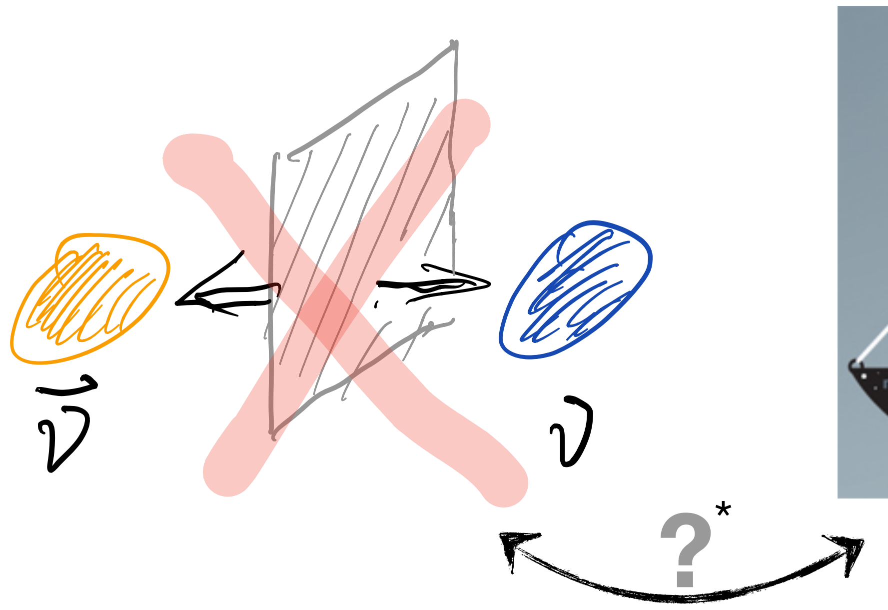
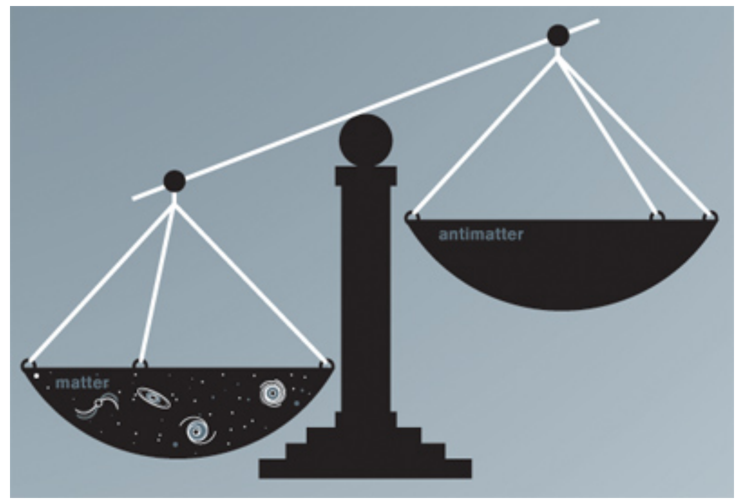
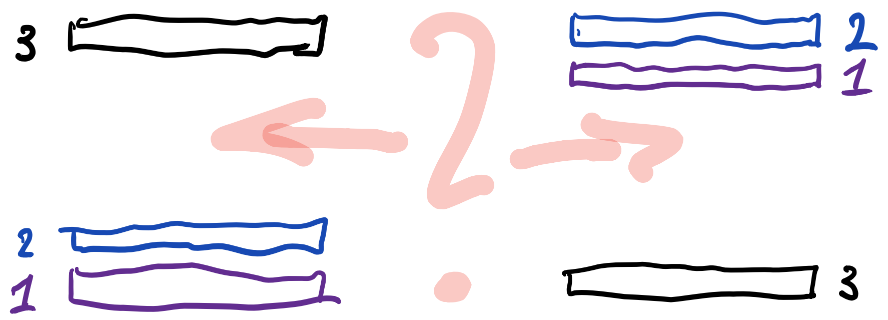
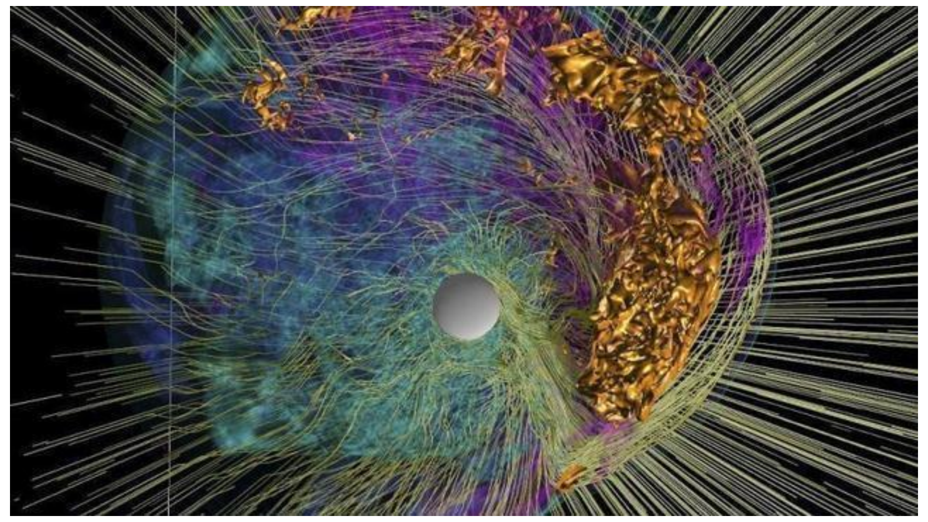
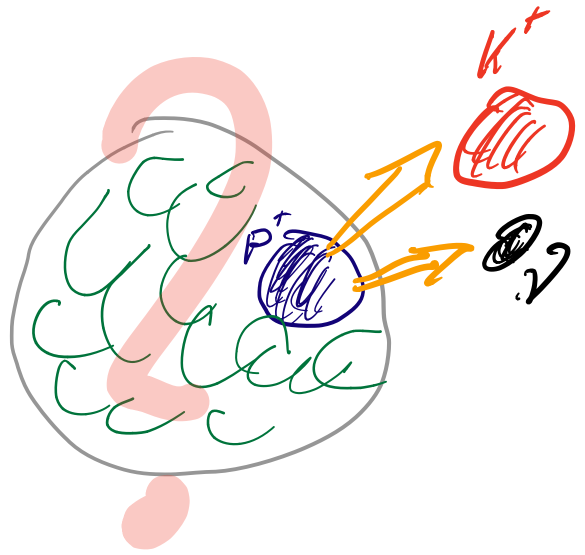




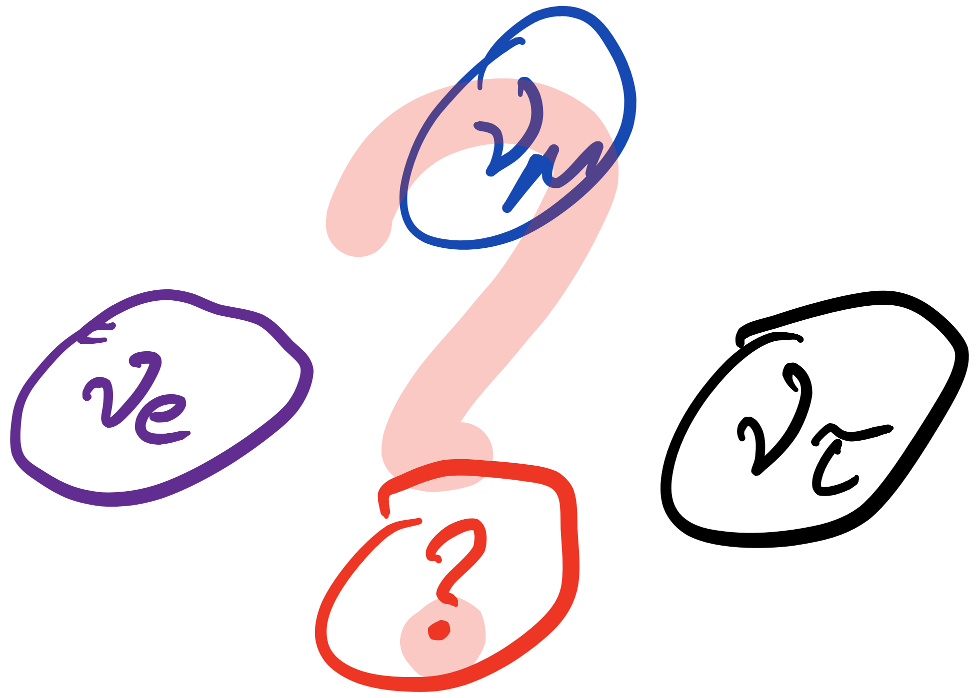






Requires:

- An intense neutrino and anti-neutrino beam, with near and far detectors for oscillation physics
- Large volume far detectors with low energy threshold
- Underground location for low backgrounds
- Long baseline (> ~ 500 km) to access mass hierarchy



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Designing a Long Baseline Experiment

… arriving at the DUNE Design

- Mass hierarchy sensitivity: ~ 1000 km baseline
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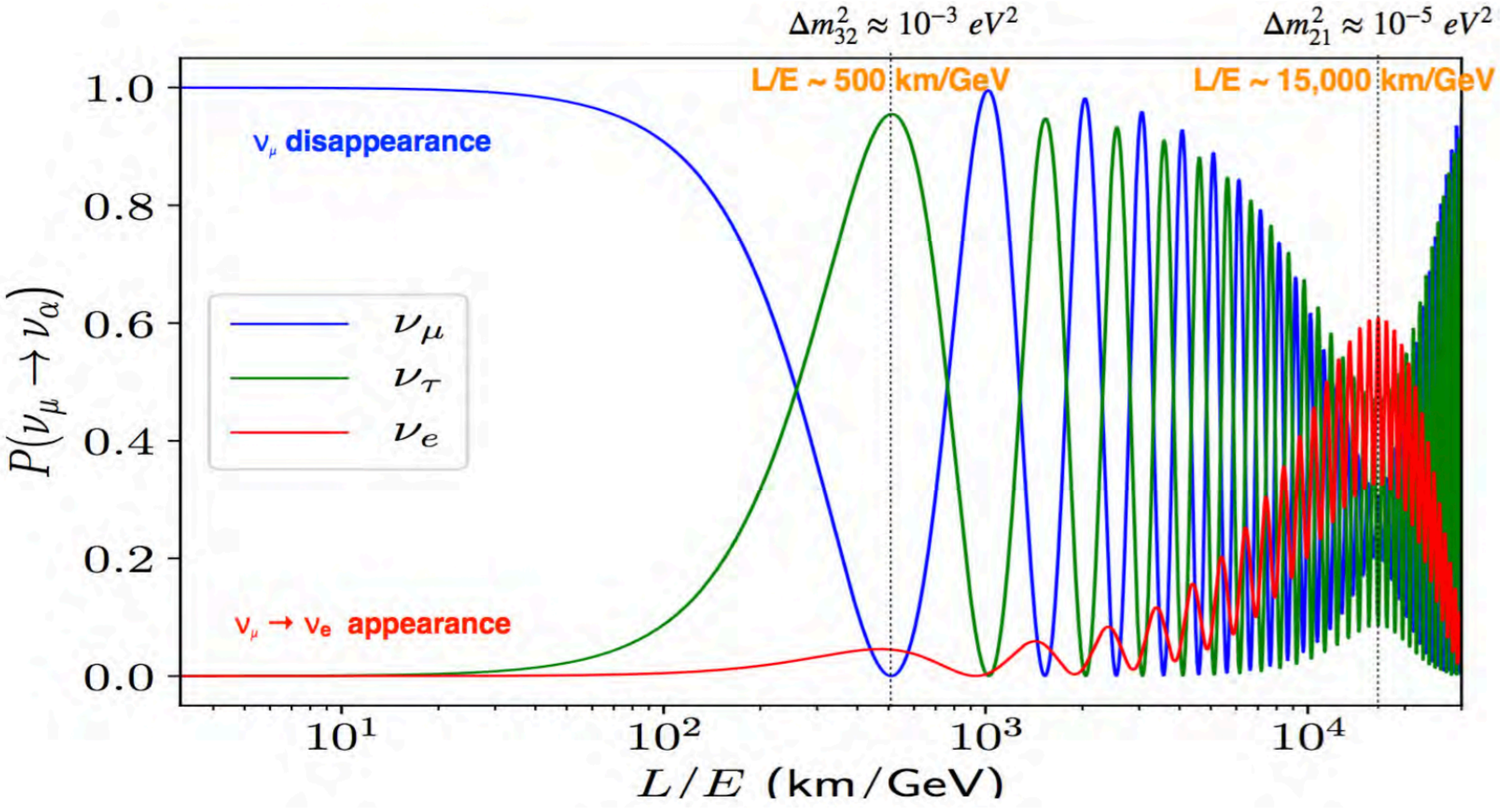
➯ ν energy ~ 2 GeV



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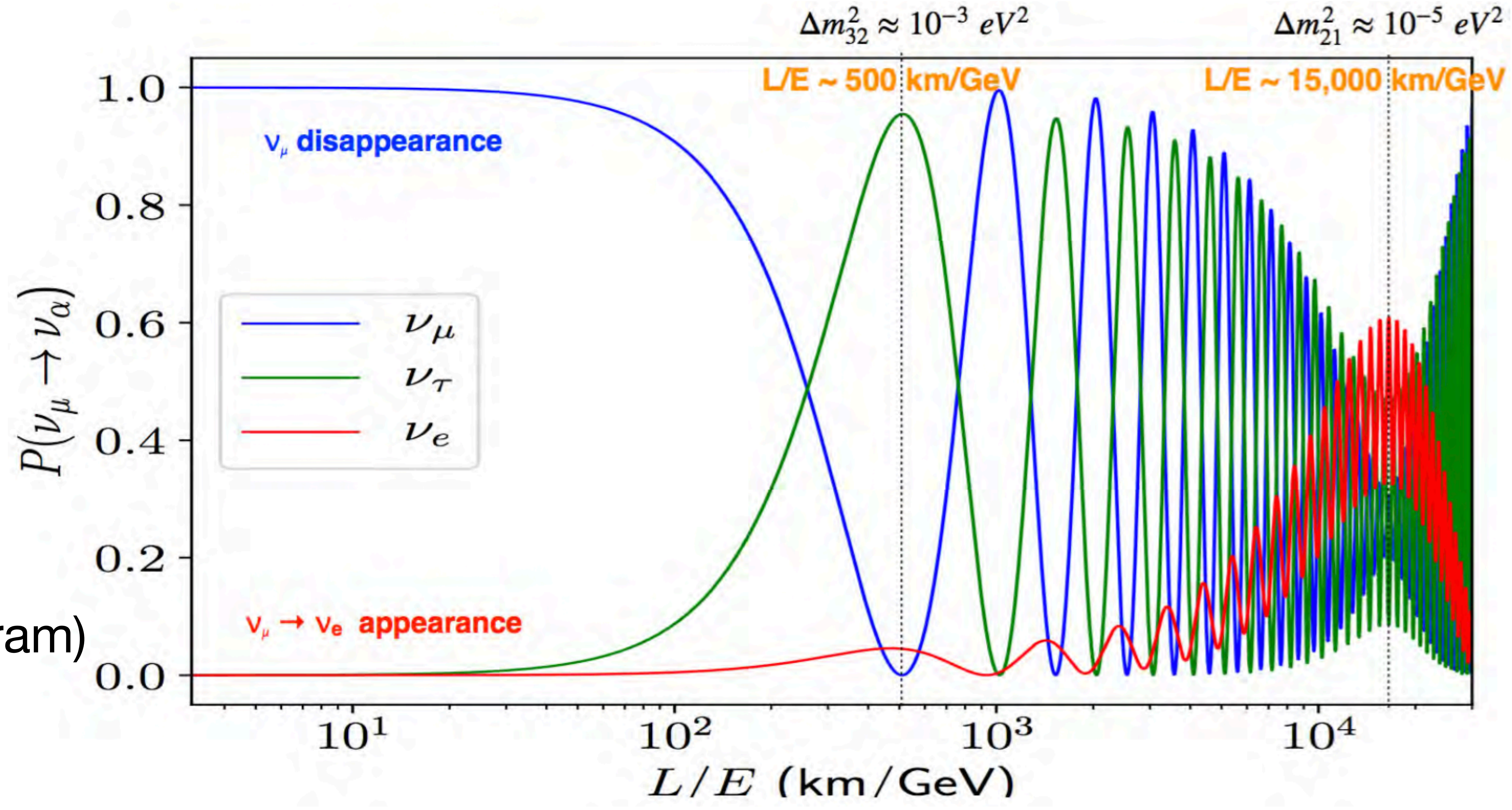
➯ On-axis beam (also broadens physics program)



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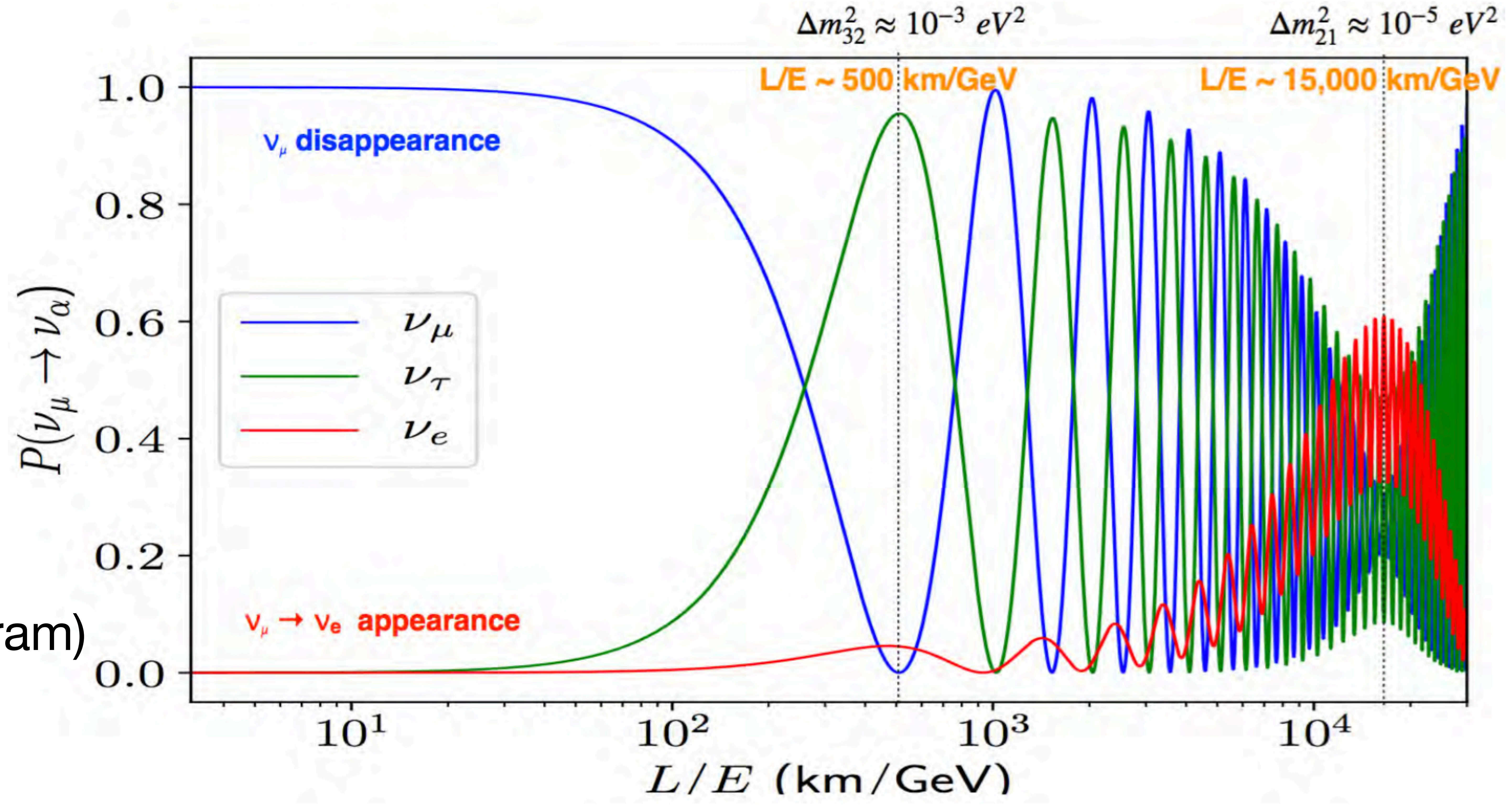

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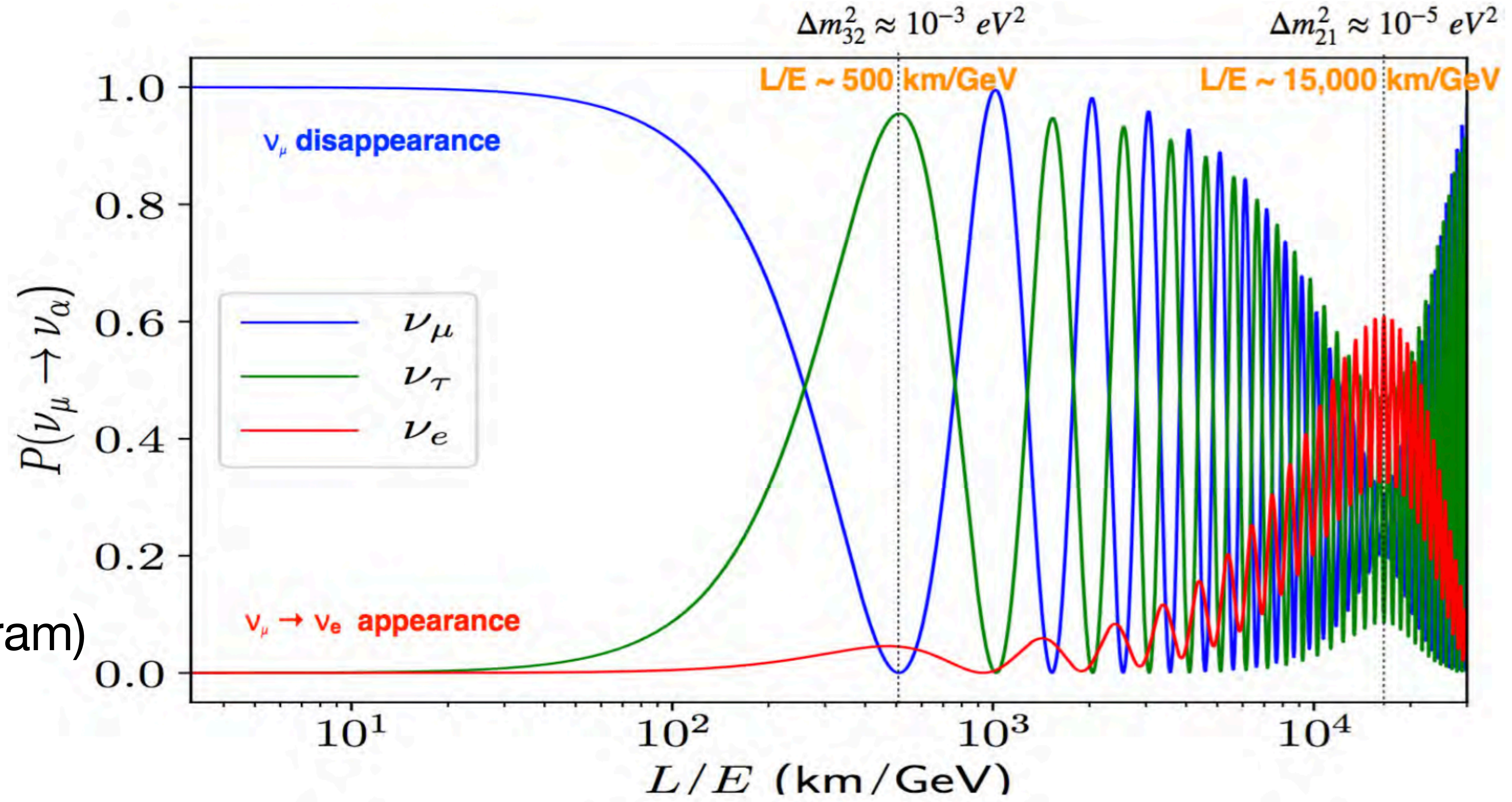
- A suitable location for the far detector - defines the precise choice of the baseline, sets other parameters



Here:

Sanford Underground Research Facility (SURF)

In the Homestake gold mine

➩ 1300 km, 2.6 GeV E_ν

LBNF / DUNE.

Overall Layout of the Facility.

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Neutrino beam

high-power proton accelerator

ν_μ / $\bar{\nu}_\mu$ selectable

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Near Detector

essential systematics control

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Overall Layout of the Facility.

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Large volume **Far Detector**
measure oscillated neutrino flux
astrophysics, nucleon decay

Near Detector
essential systematics control
high statisics ν physics progam

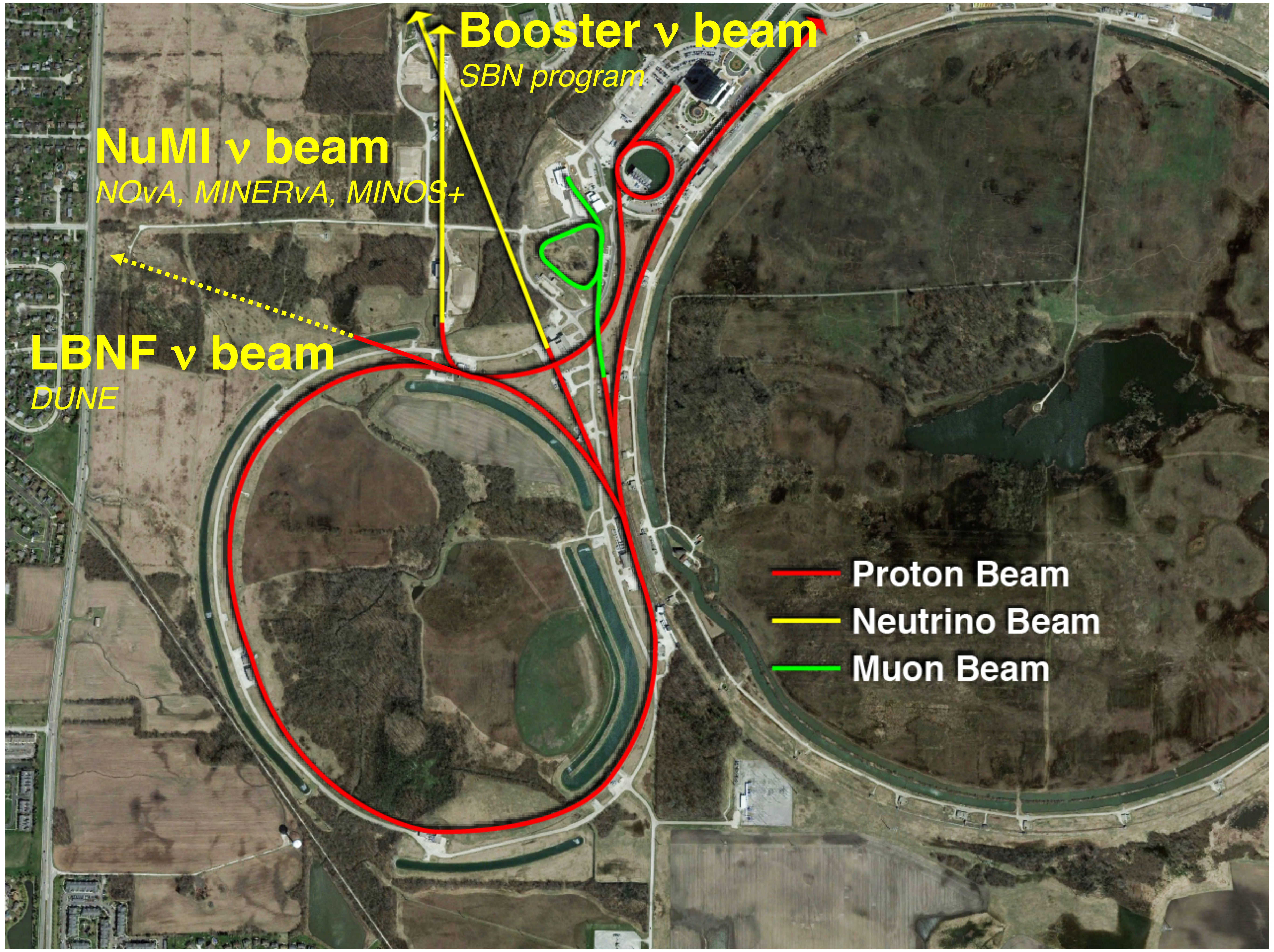
Neutrino beam
high-power proton accelerator
ν_μ / $\bar{\nu}_\mu$ selectable

Frank Simon (fsimon@mpp.mpg.de)

LBNF: The Beam

Making Neutrinos

- The Fermilab accelerator complex



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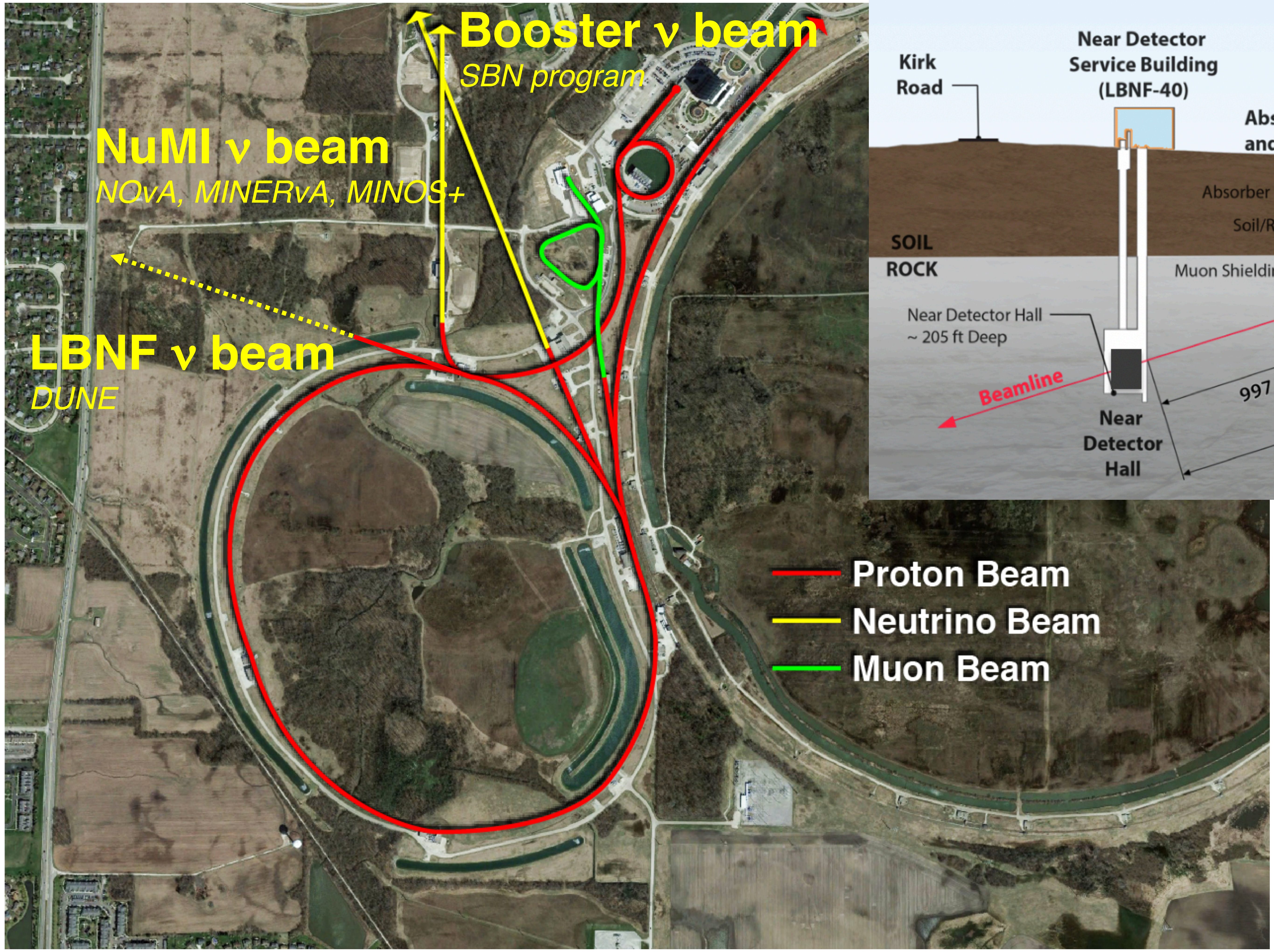

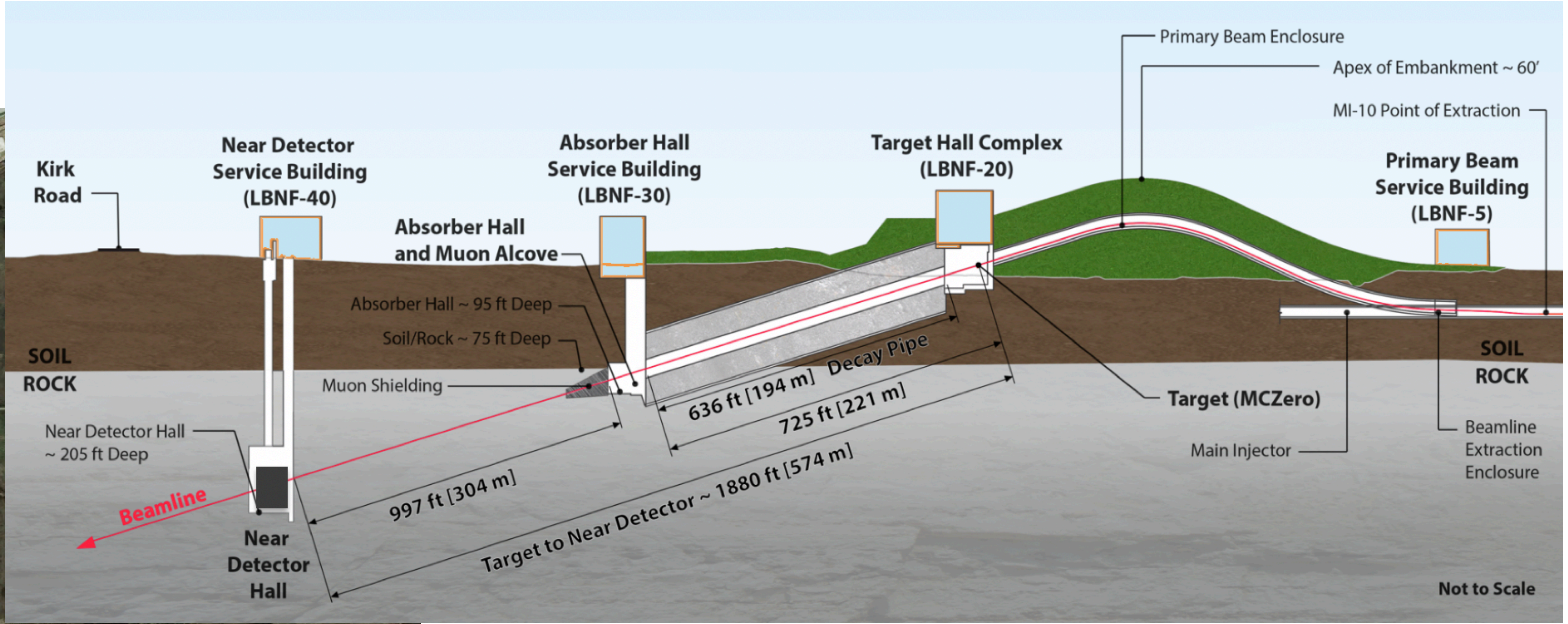

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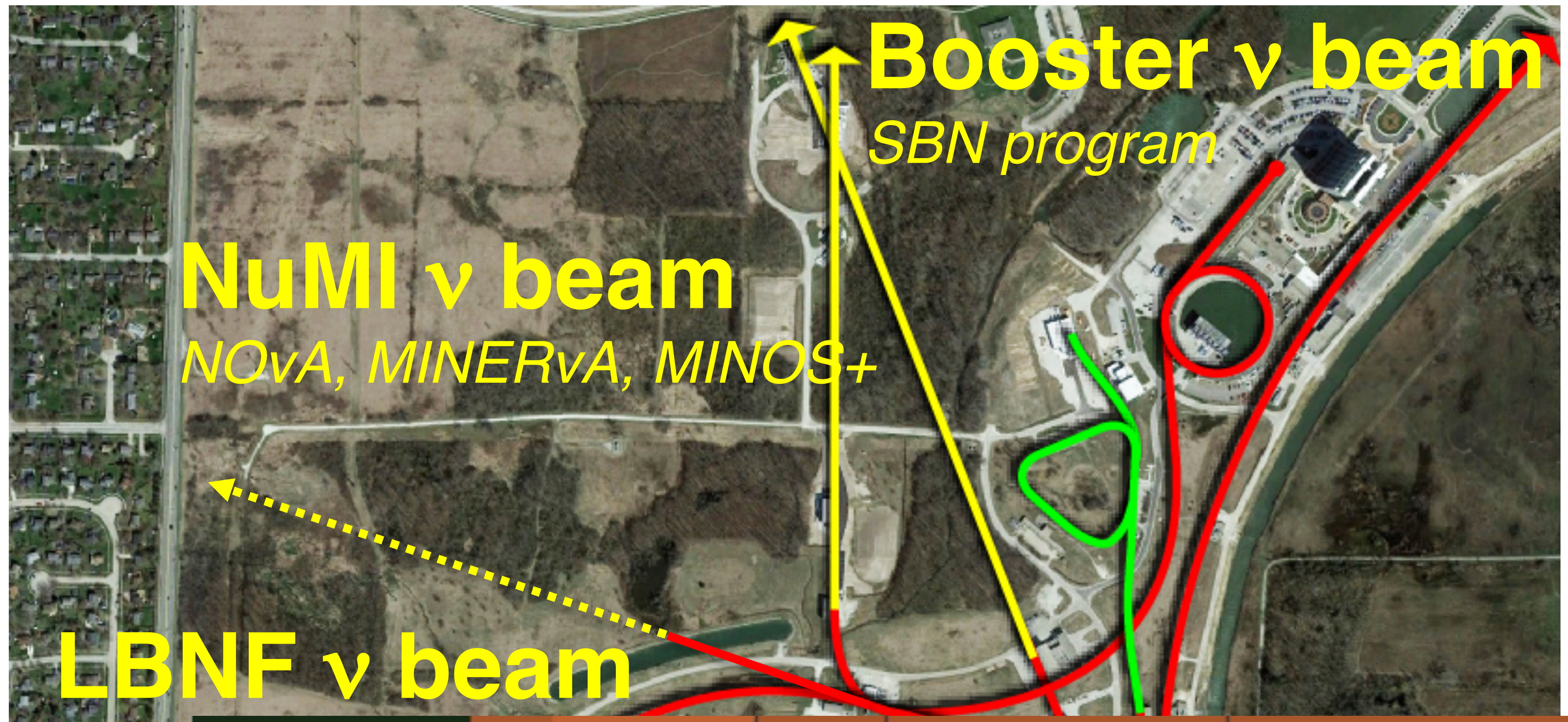
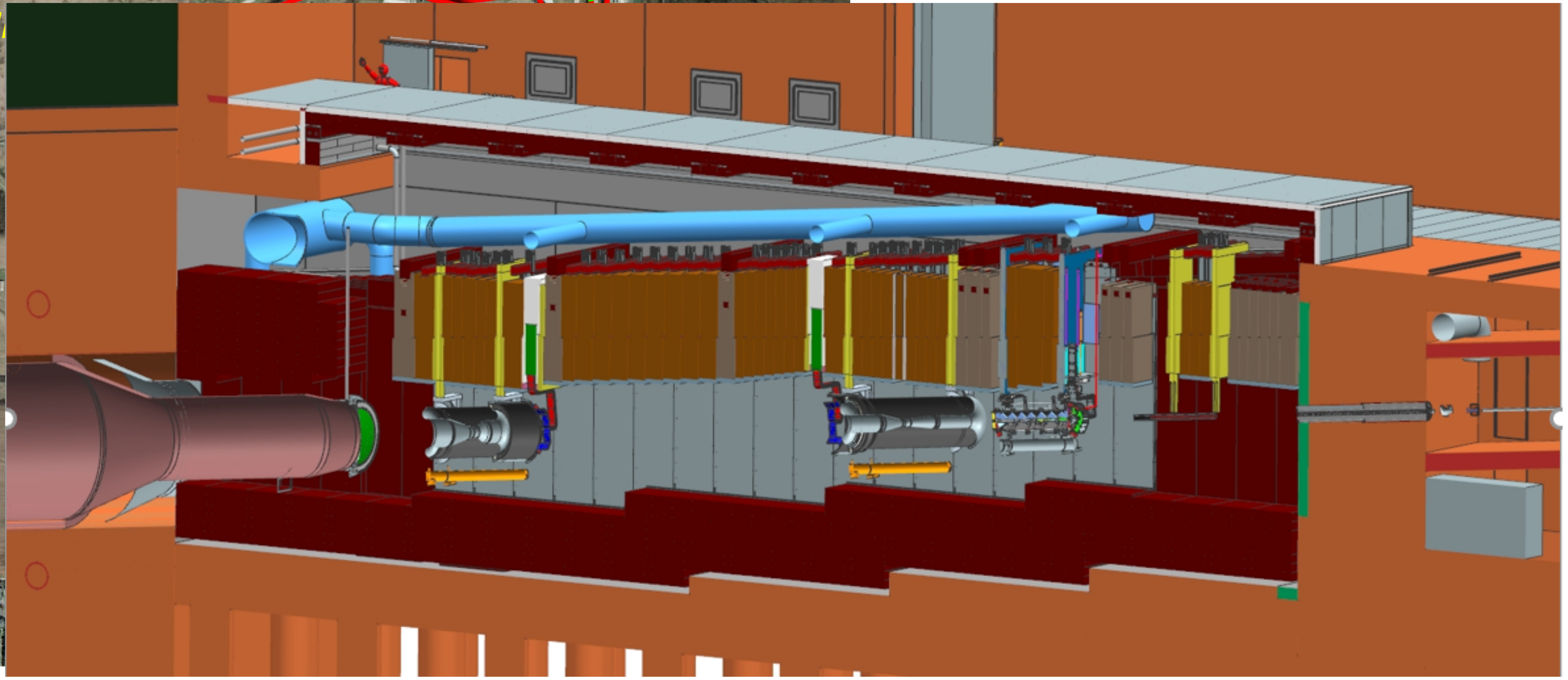
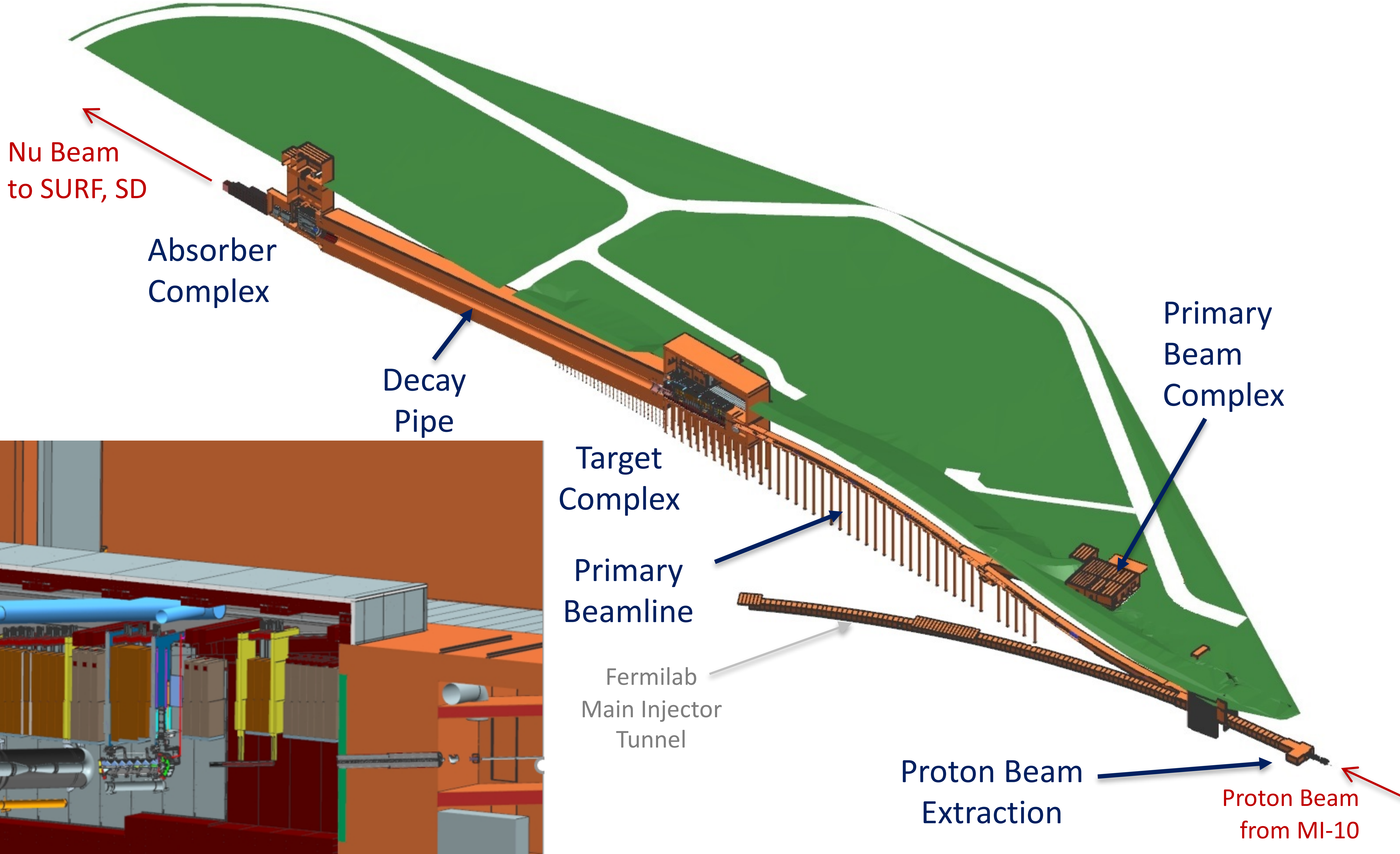
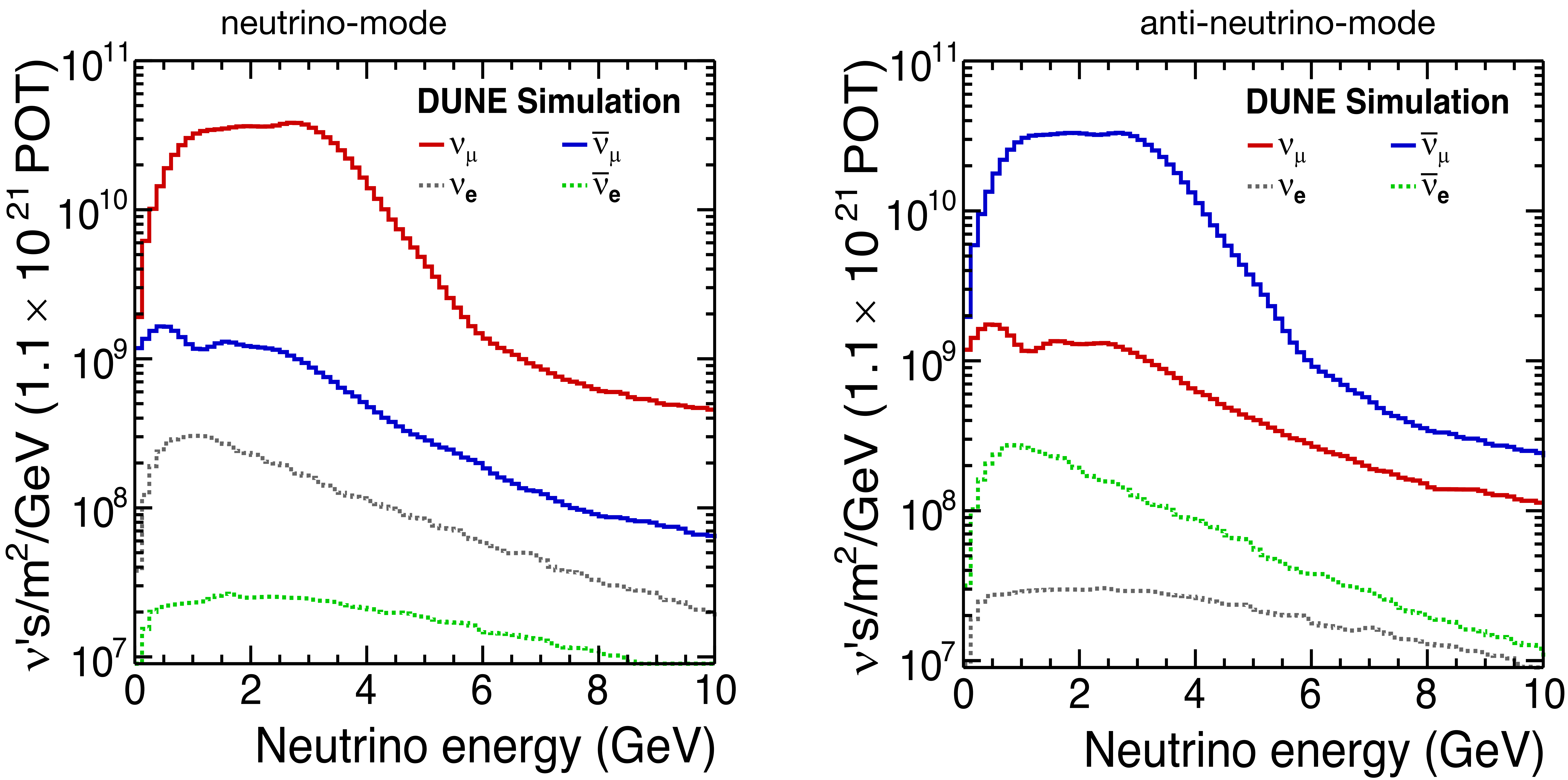






The LBNF Neutrino Beam

Energy Spectrum



DUNE Oscillation Measurements

The Main Observables

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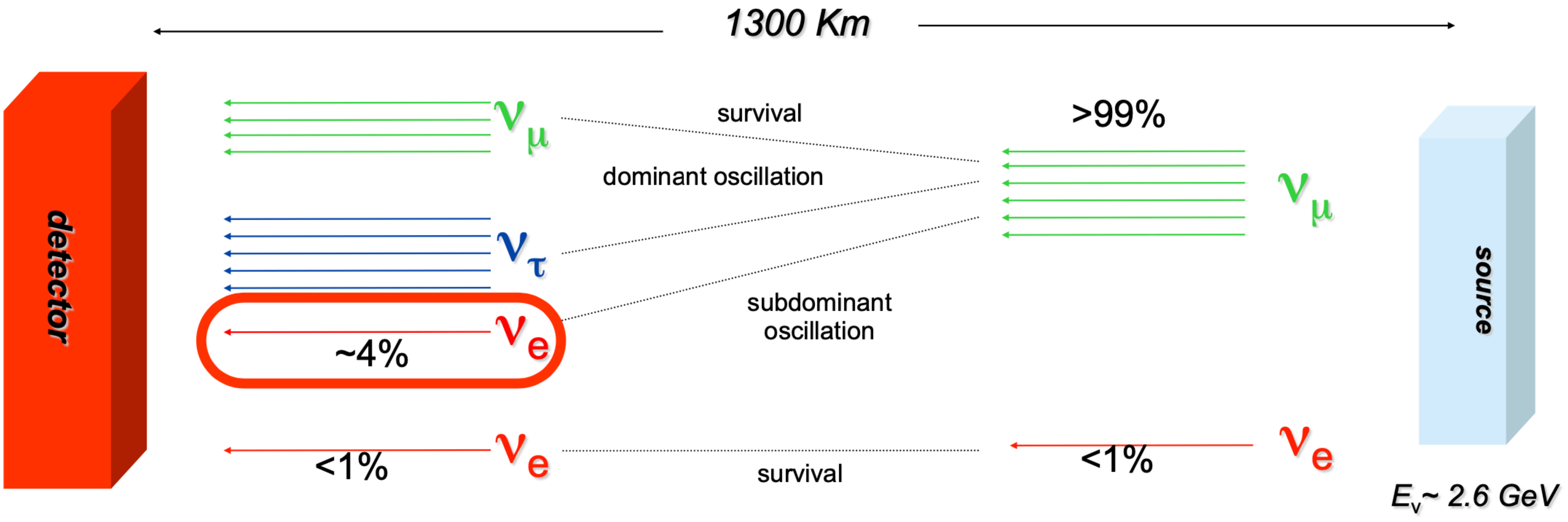

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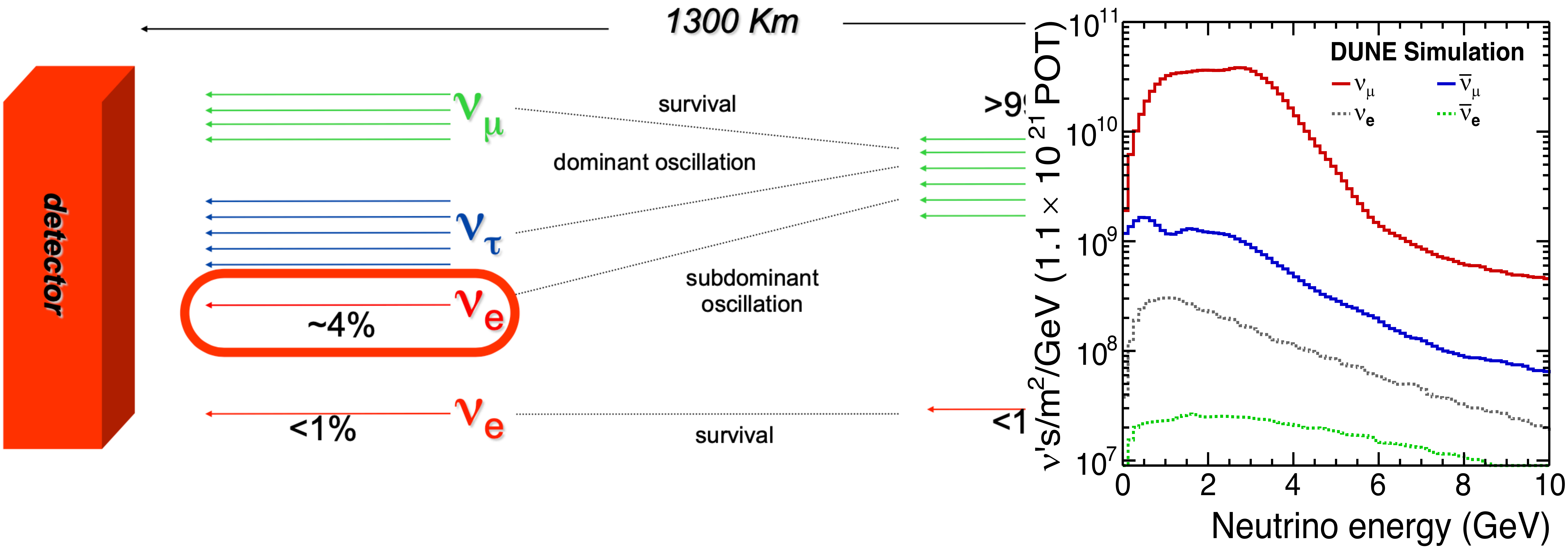

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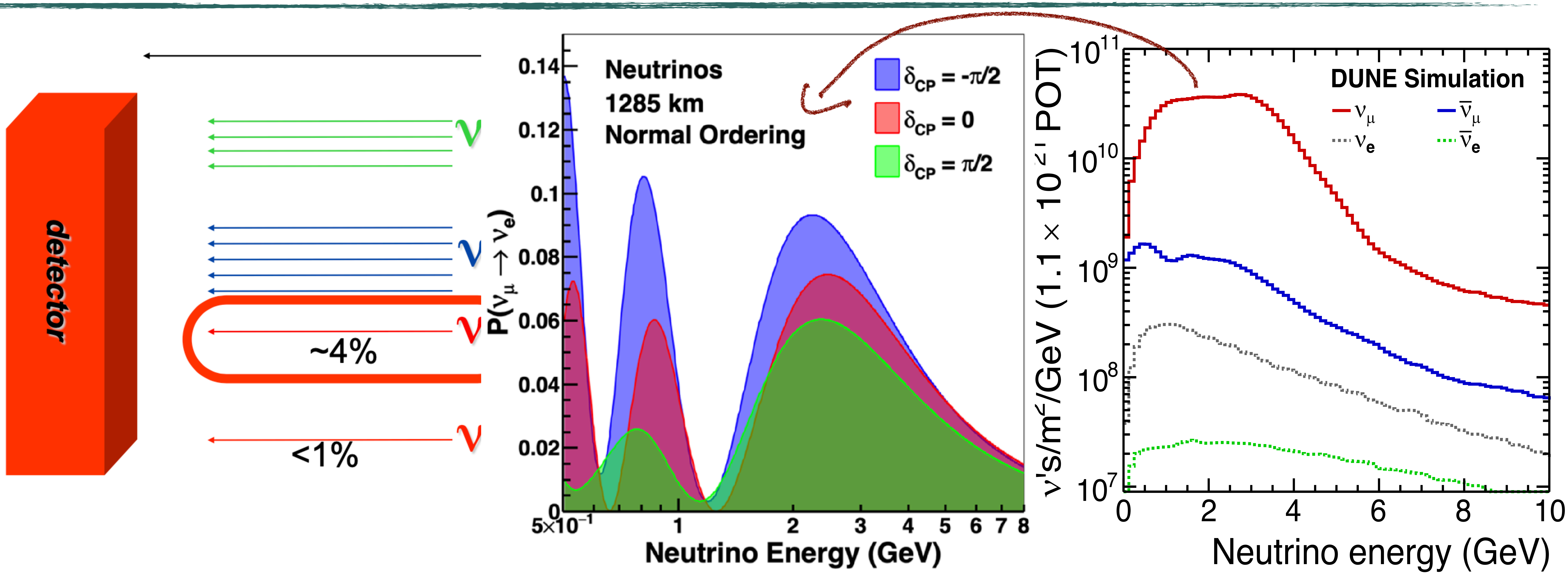

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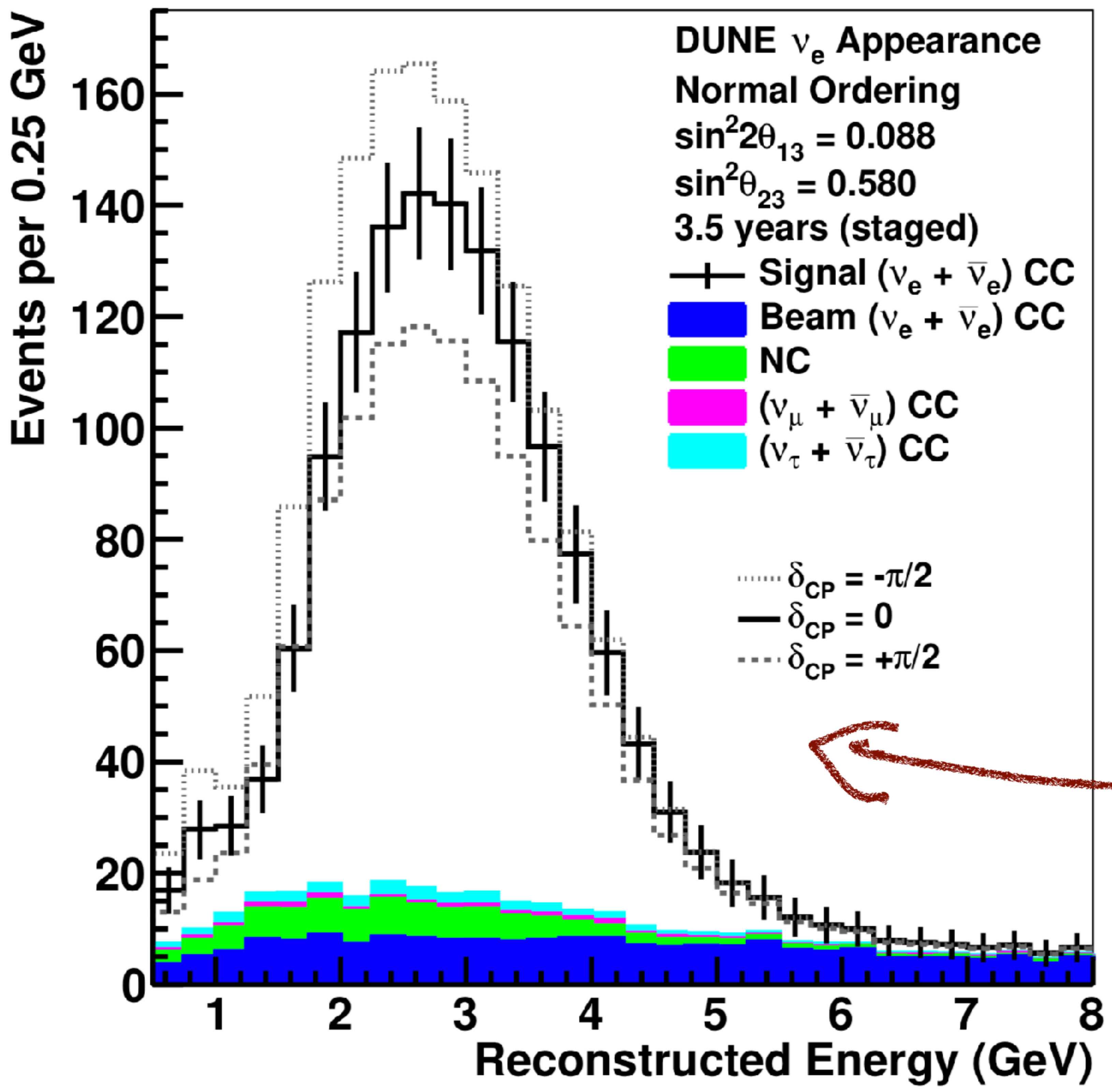

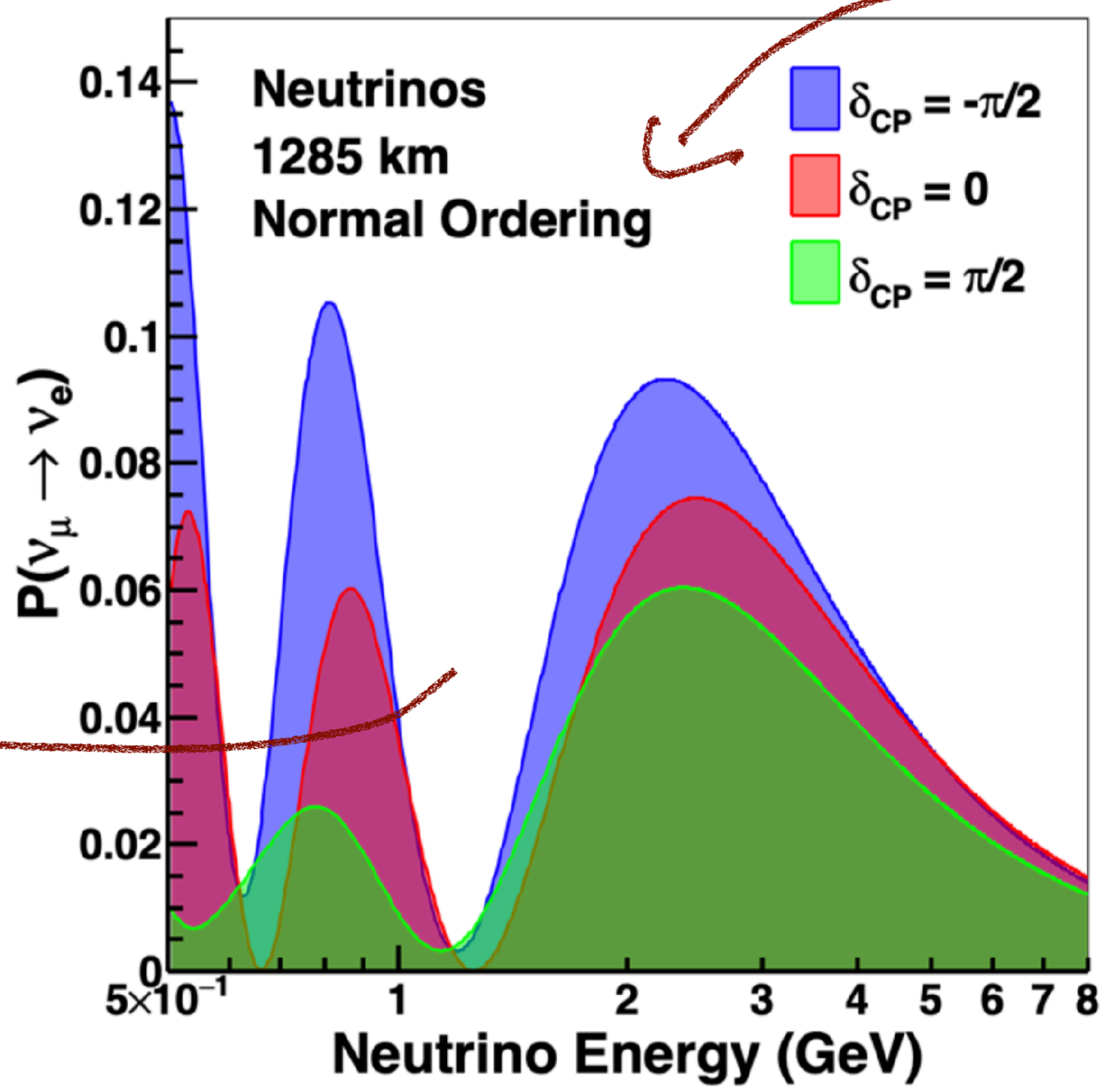

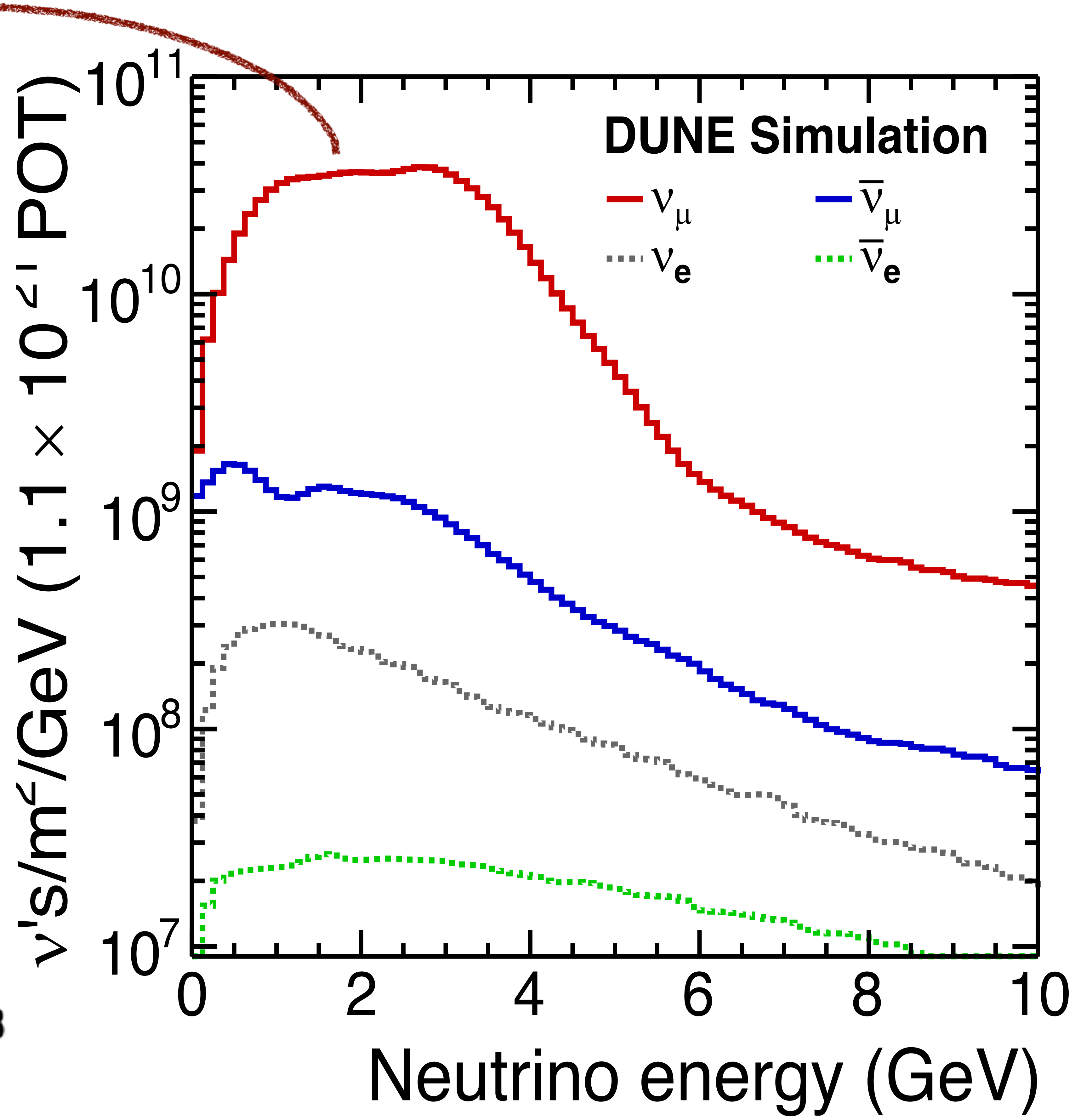

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- Crucial for the oscillation program:
  Accurate reconstruction of the neutrino energy and flavor, identification and rejection of background

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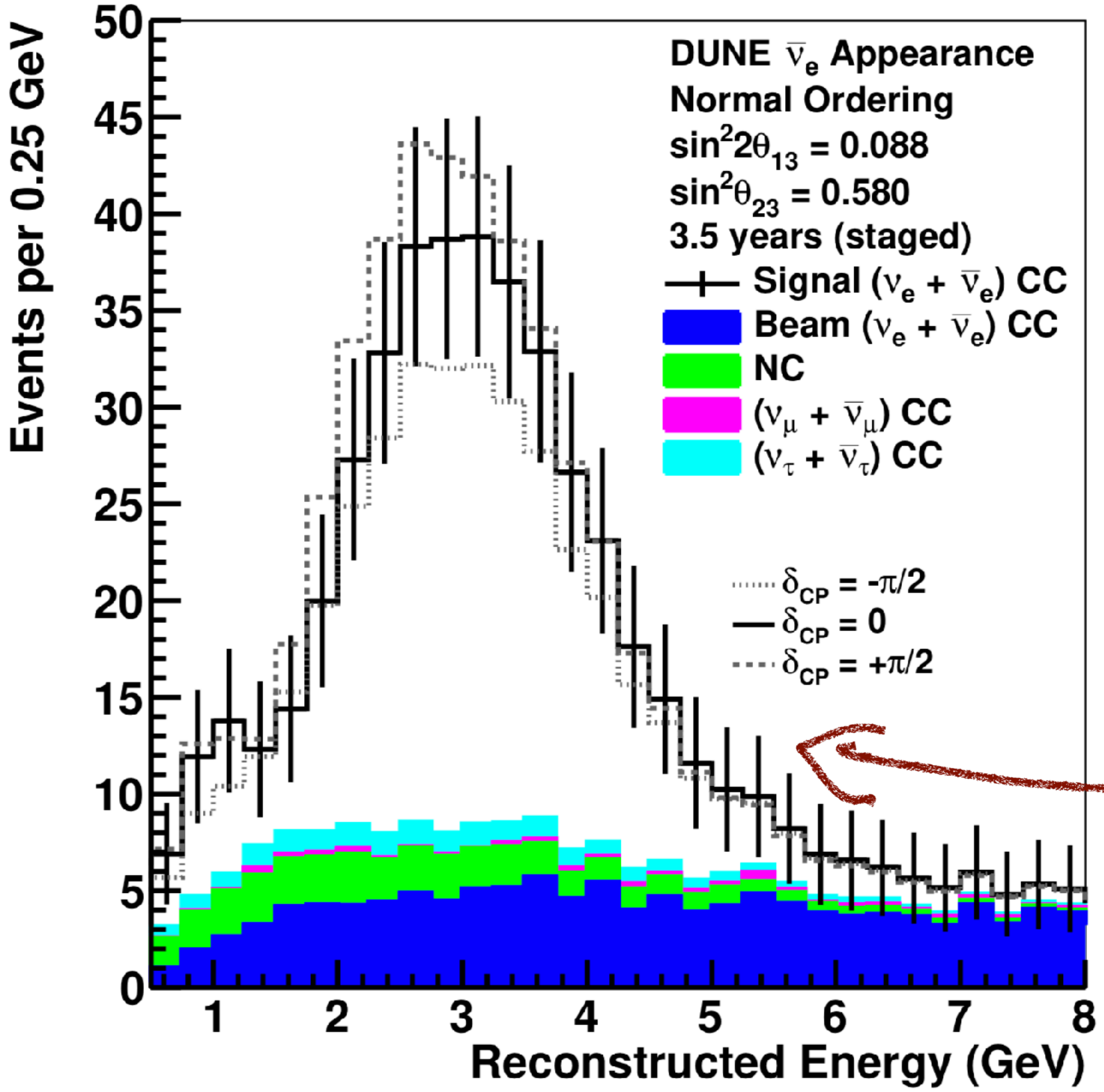

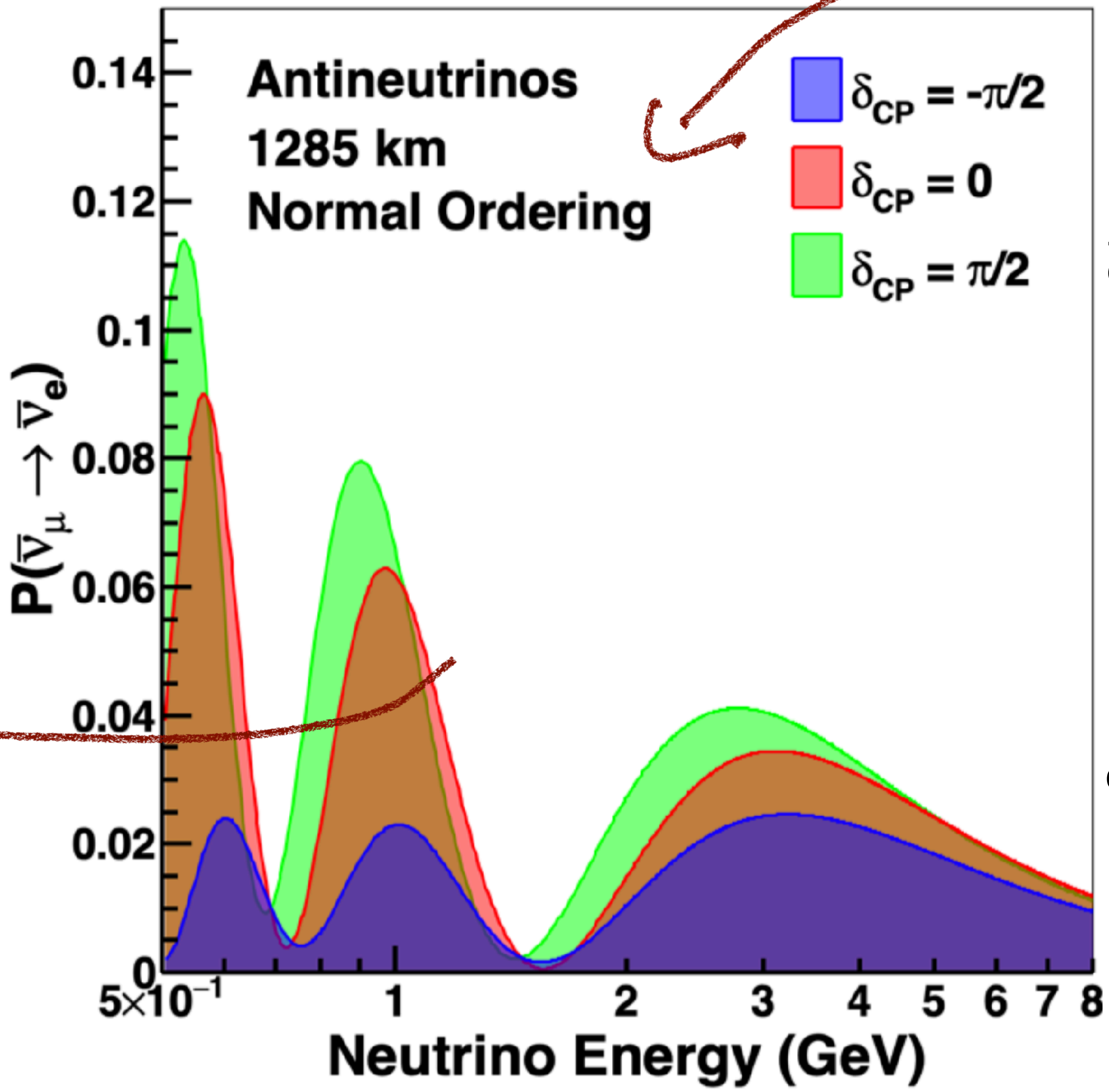

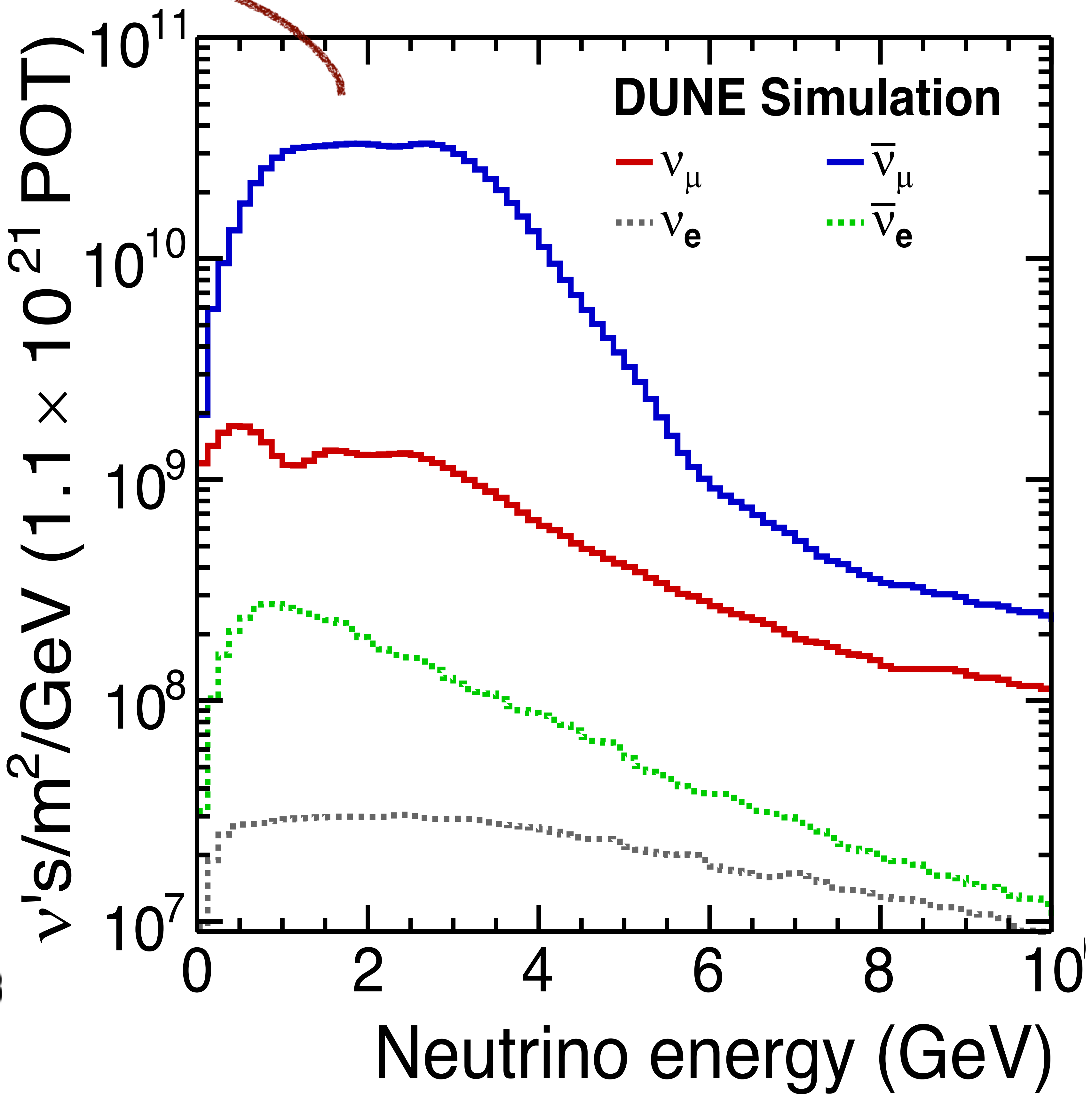

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Needs for the DUNE Detectors

Identification & Reconstruction of Event Classes

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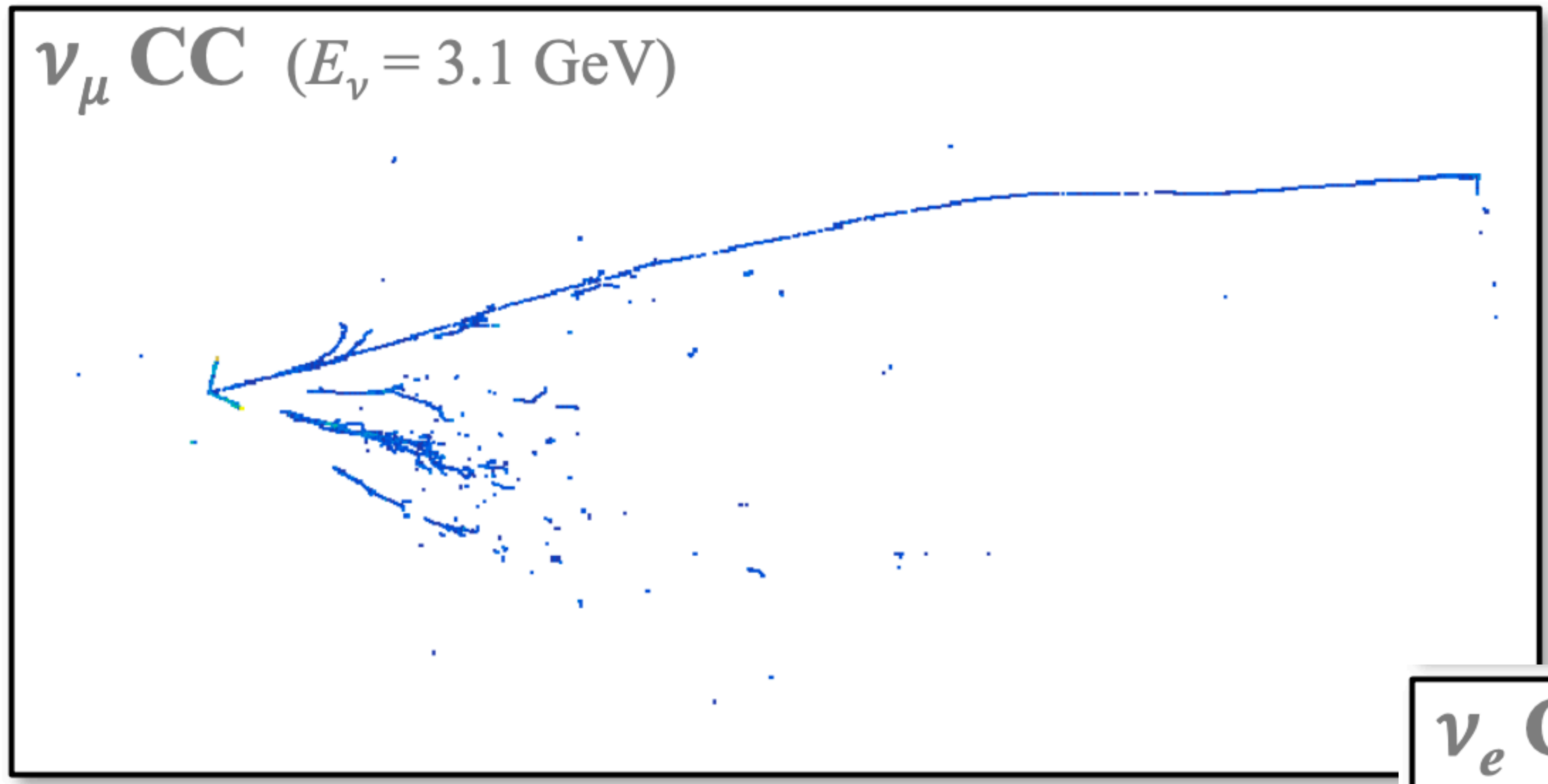
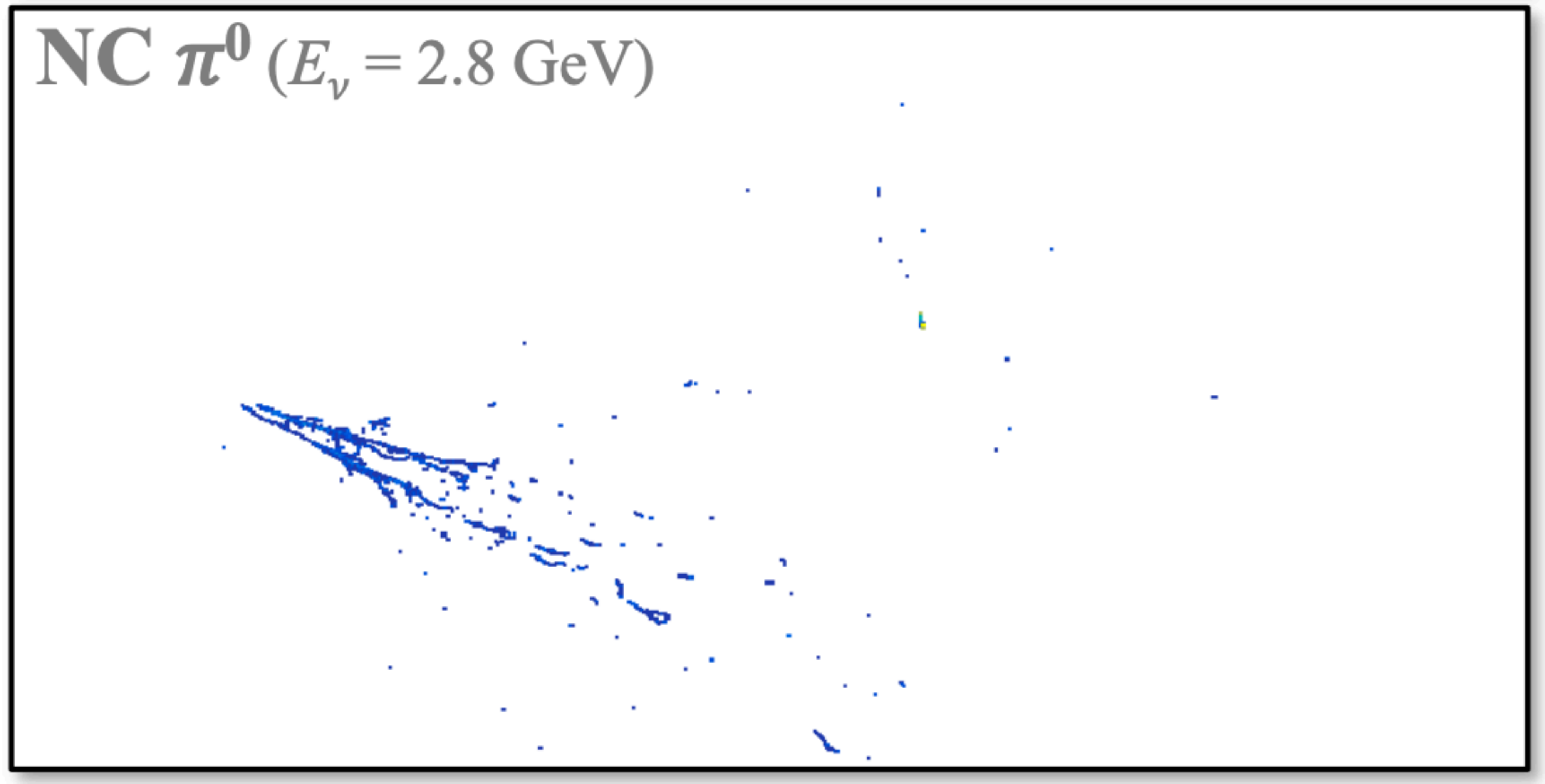
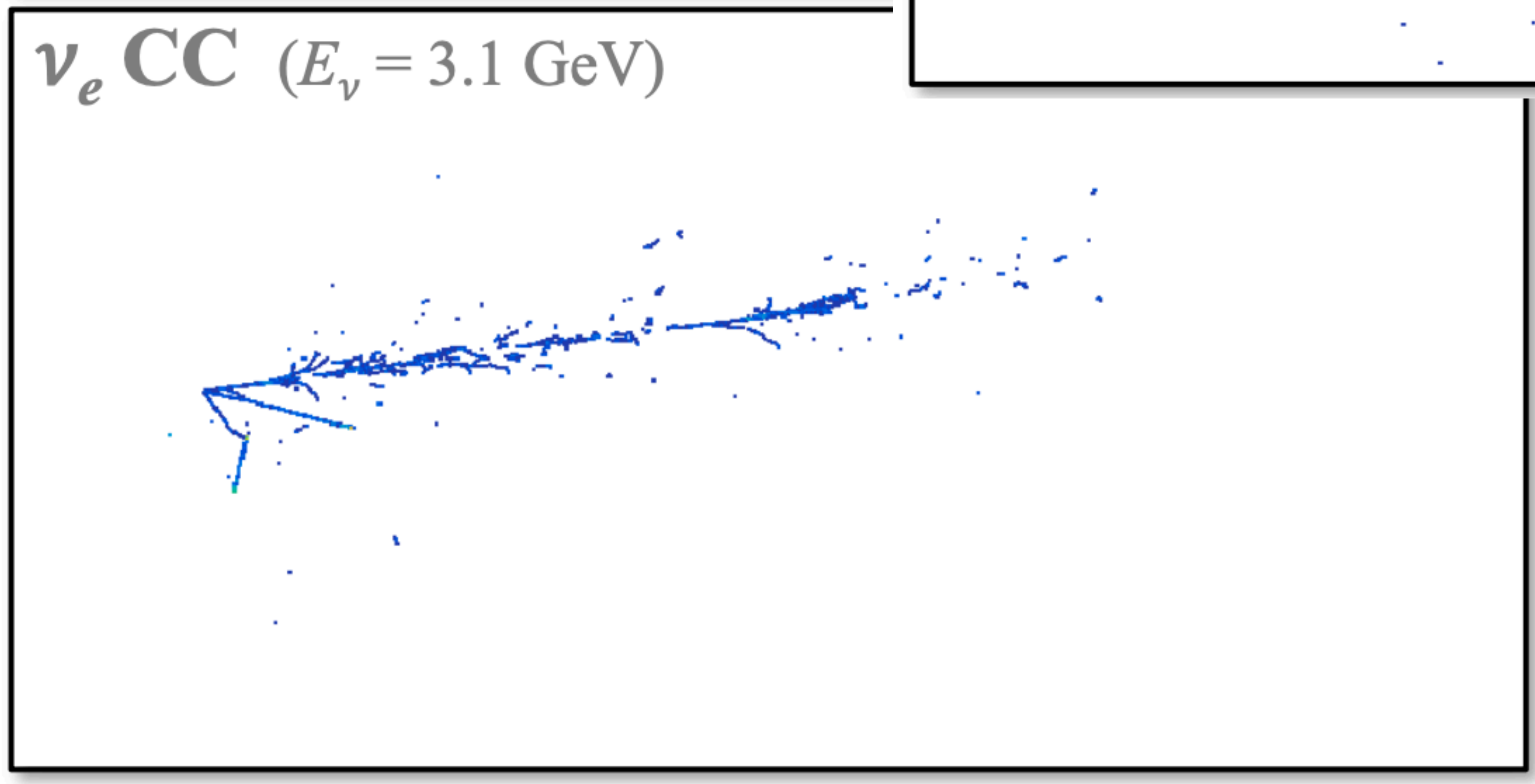


simulations





background!

- Precise energy measurement and classification of beam events
- Low energy threshold, and direction reconstruction for astrophysics events (SNs, …)

- Profits from highly granular information and comprehensive event reconstruction in liquid Ar TPCs

The DUNE Far Detectors

Large Volume, Deep Underground

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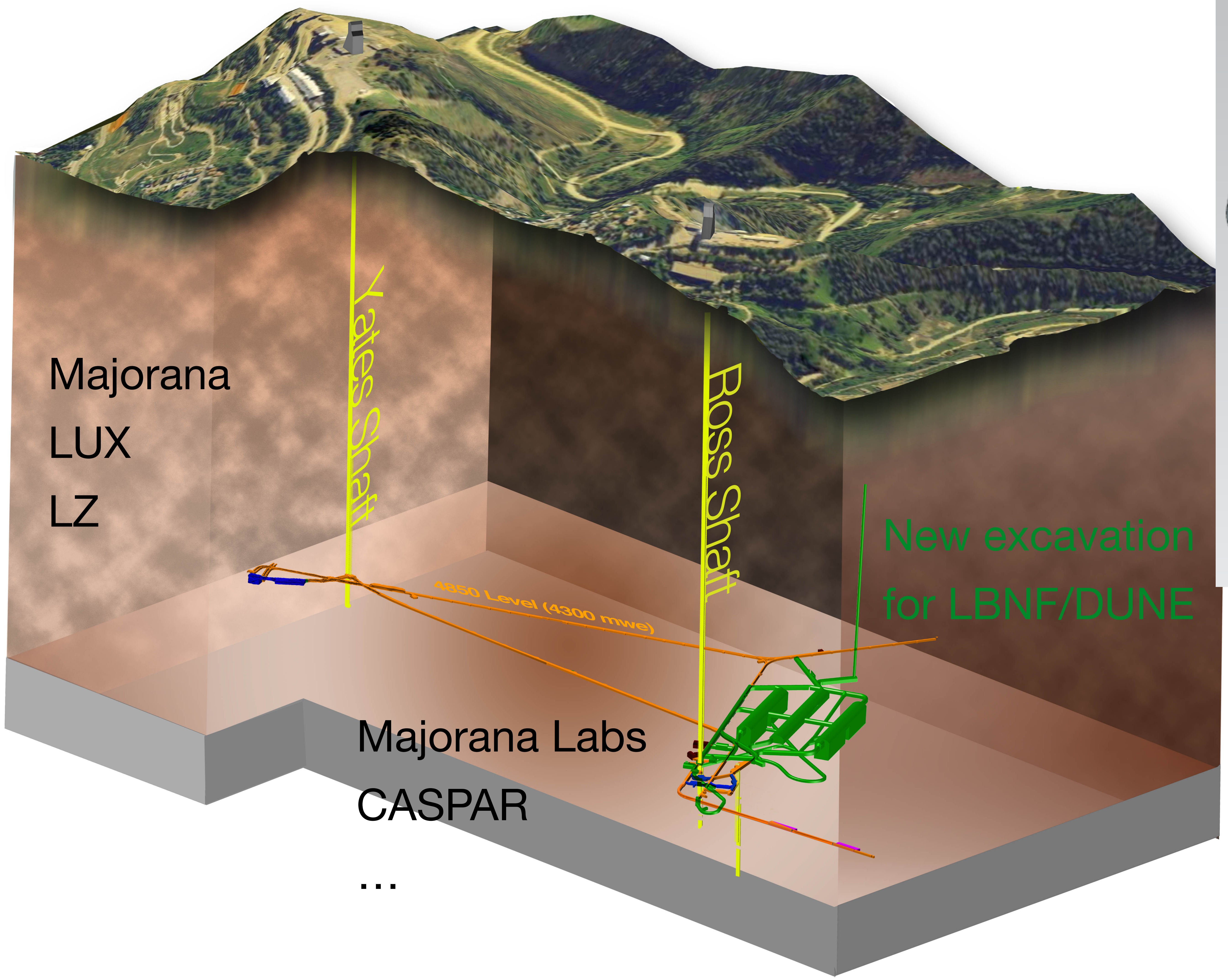
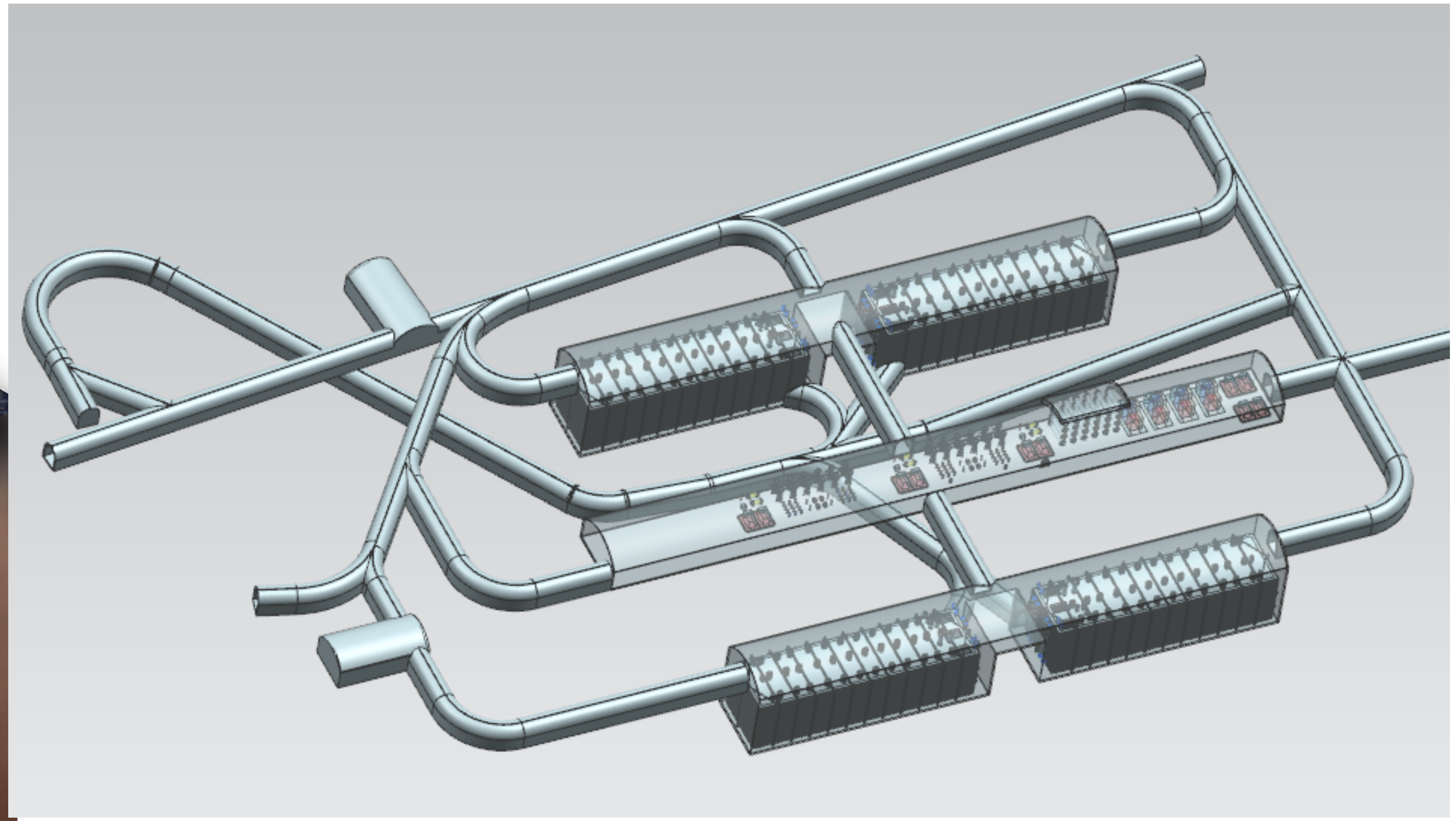


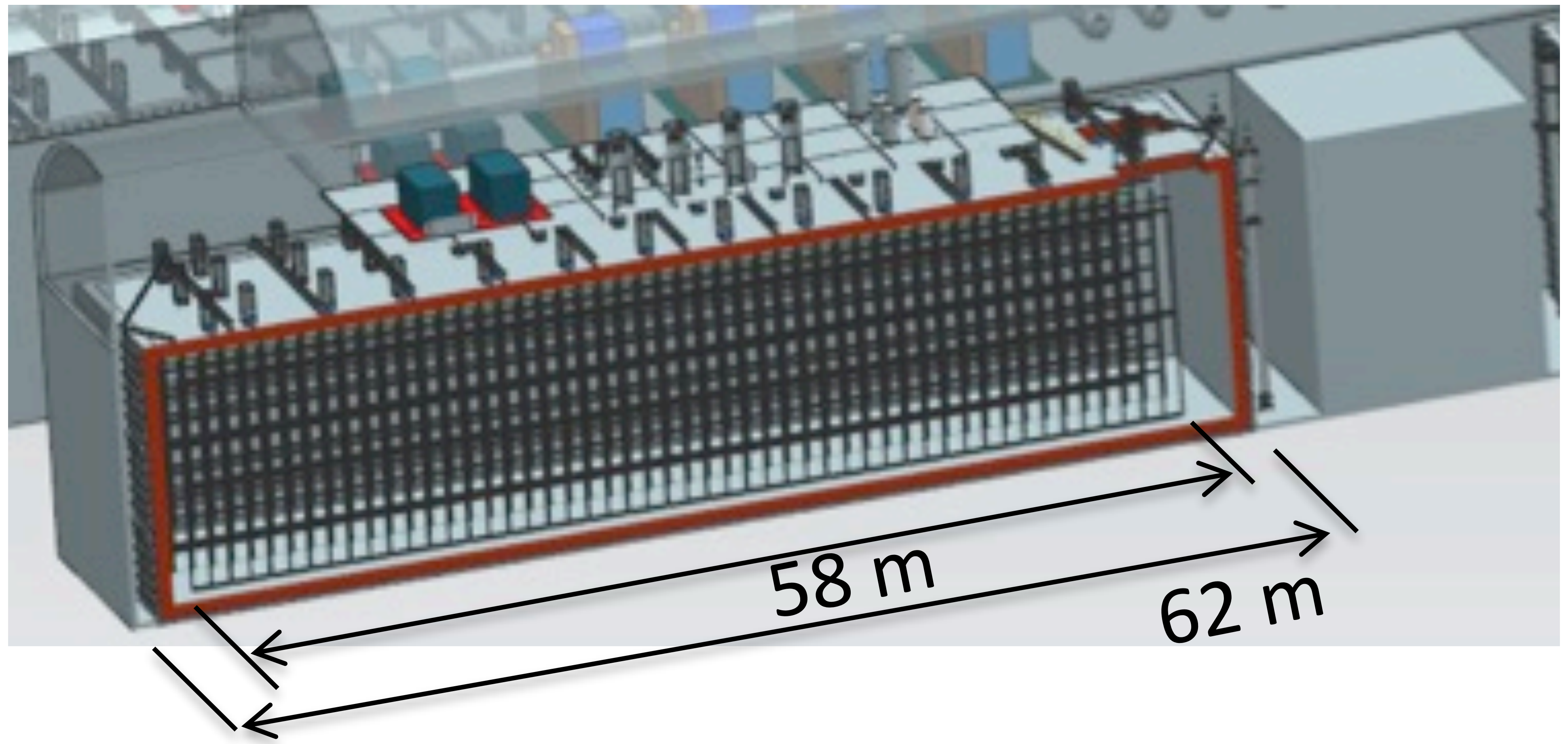


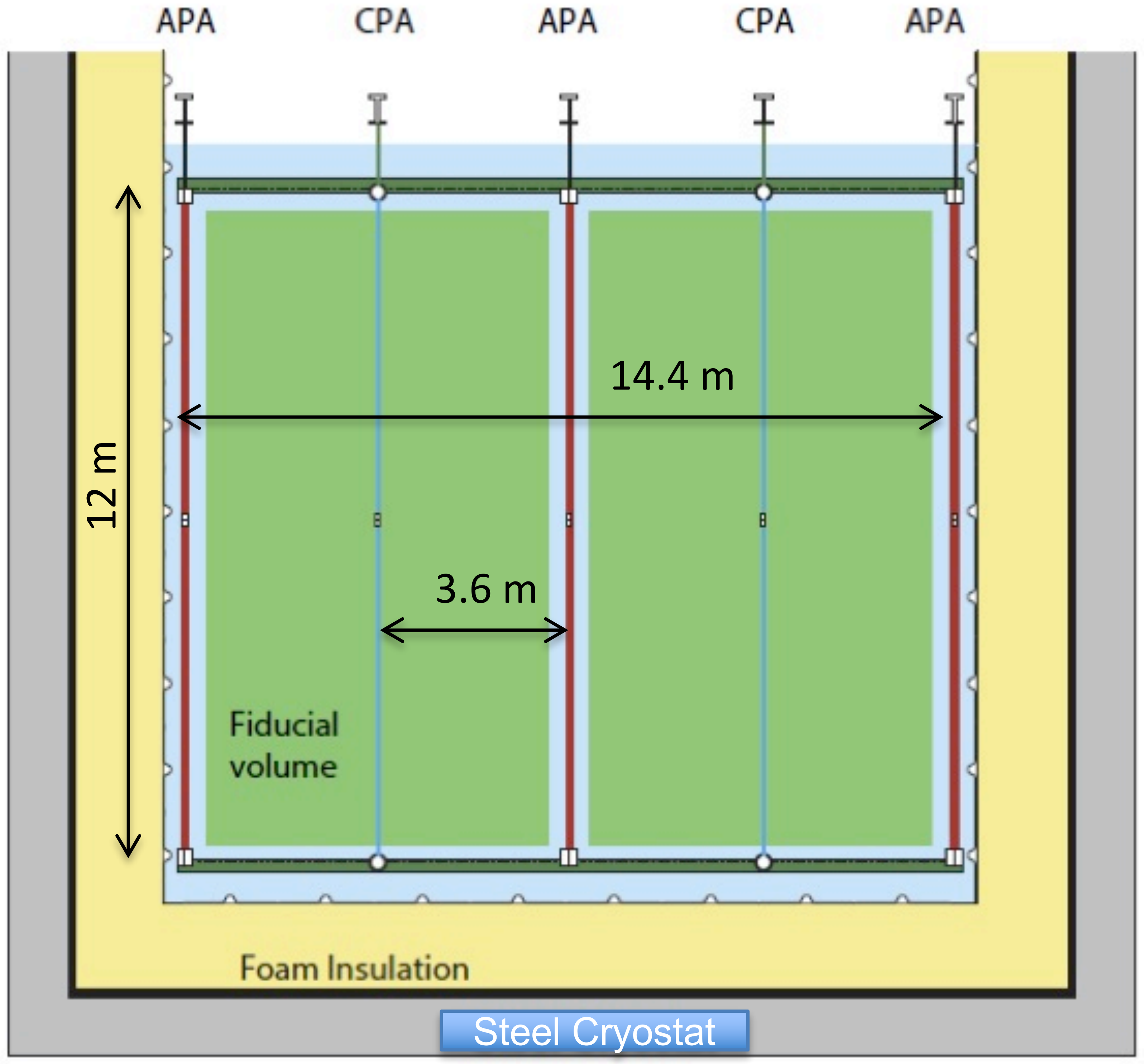
- 4 caverns, each for a 17 kT (10 kT fiducial) LAr cryostat ($15.1 \times 14 \times 62$ m^3)
  + central utility cavern, 4850 ft deep

The DUNE Far Detectors

Large Volume, Deep Underground

- Two single-phase LAr TPCs:





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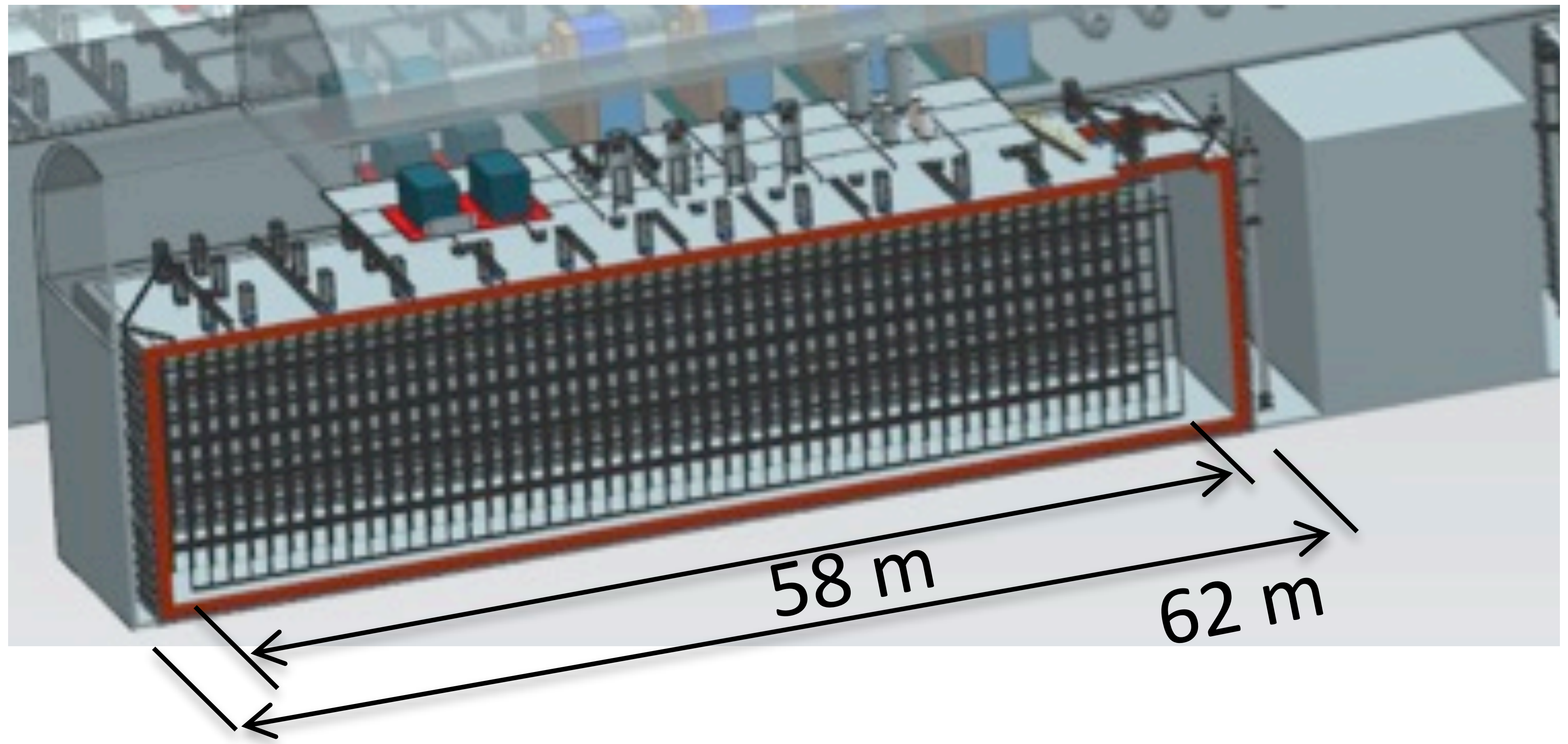

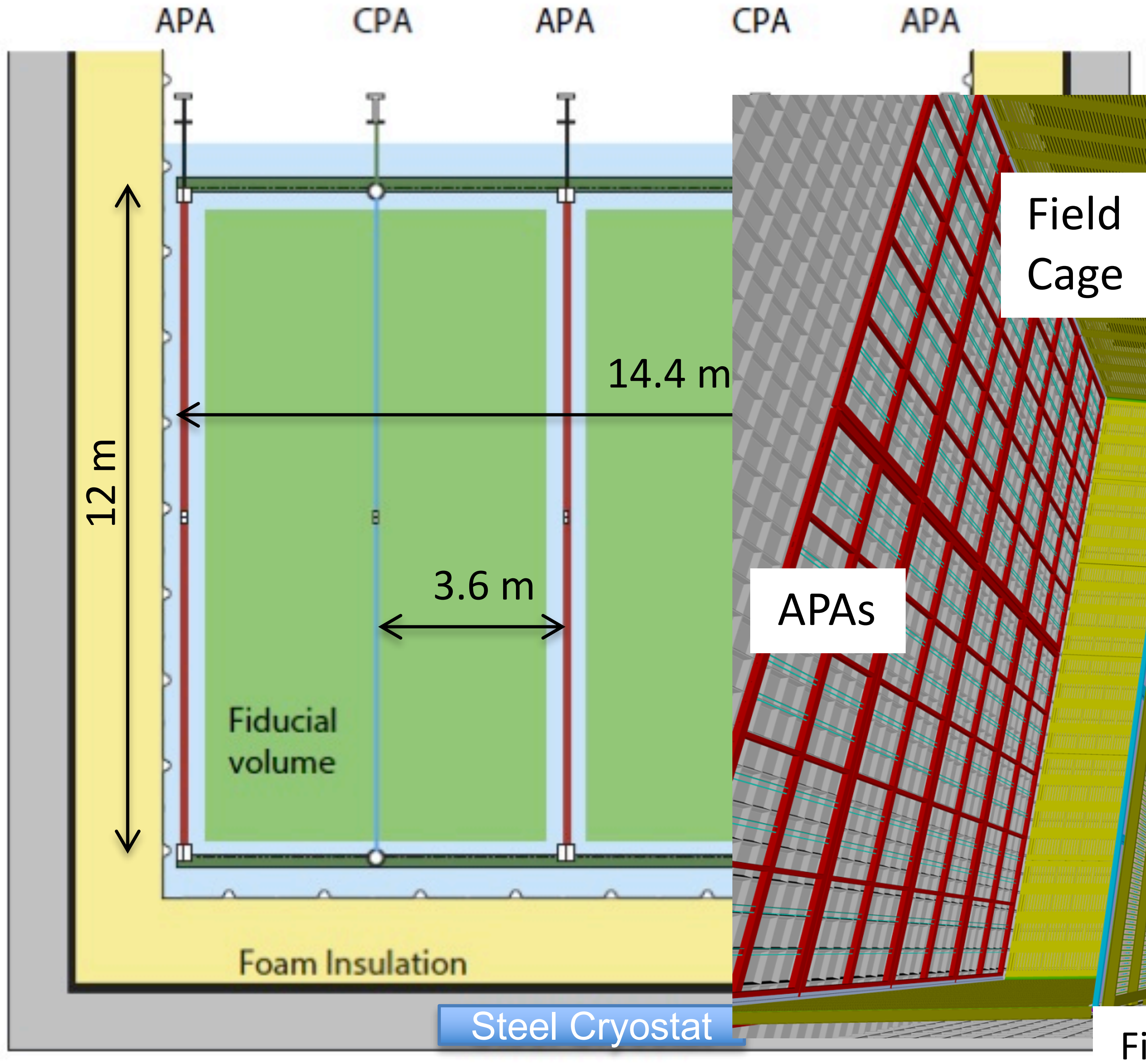

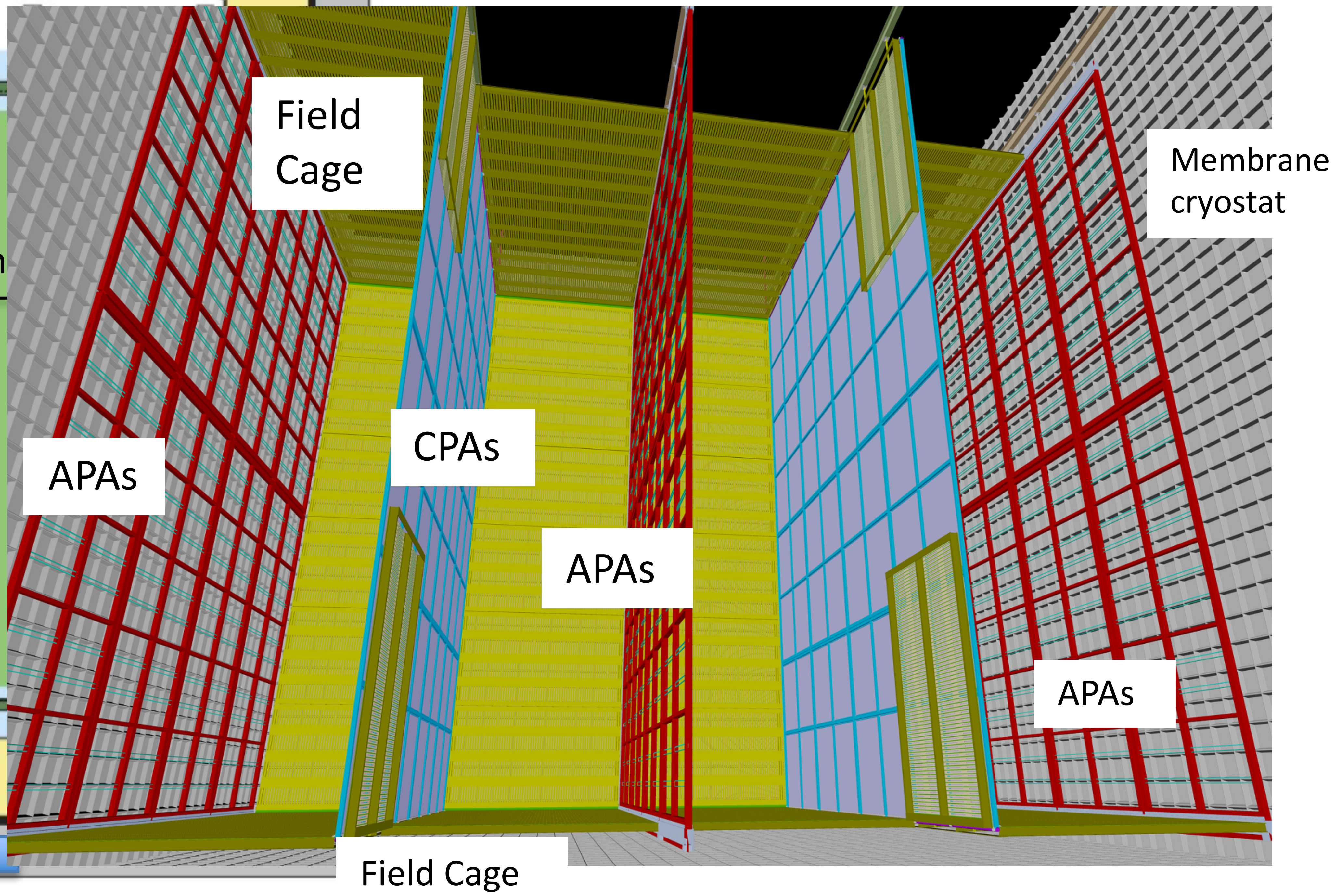

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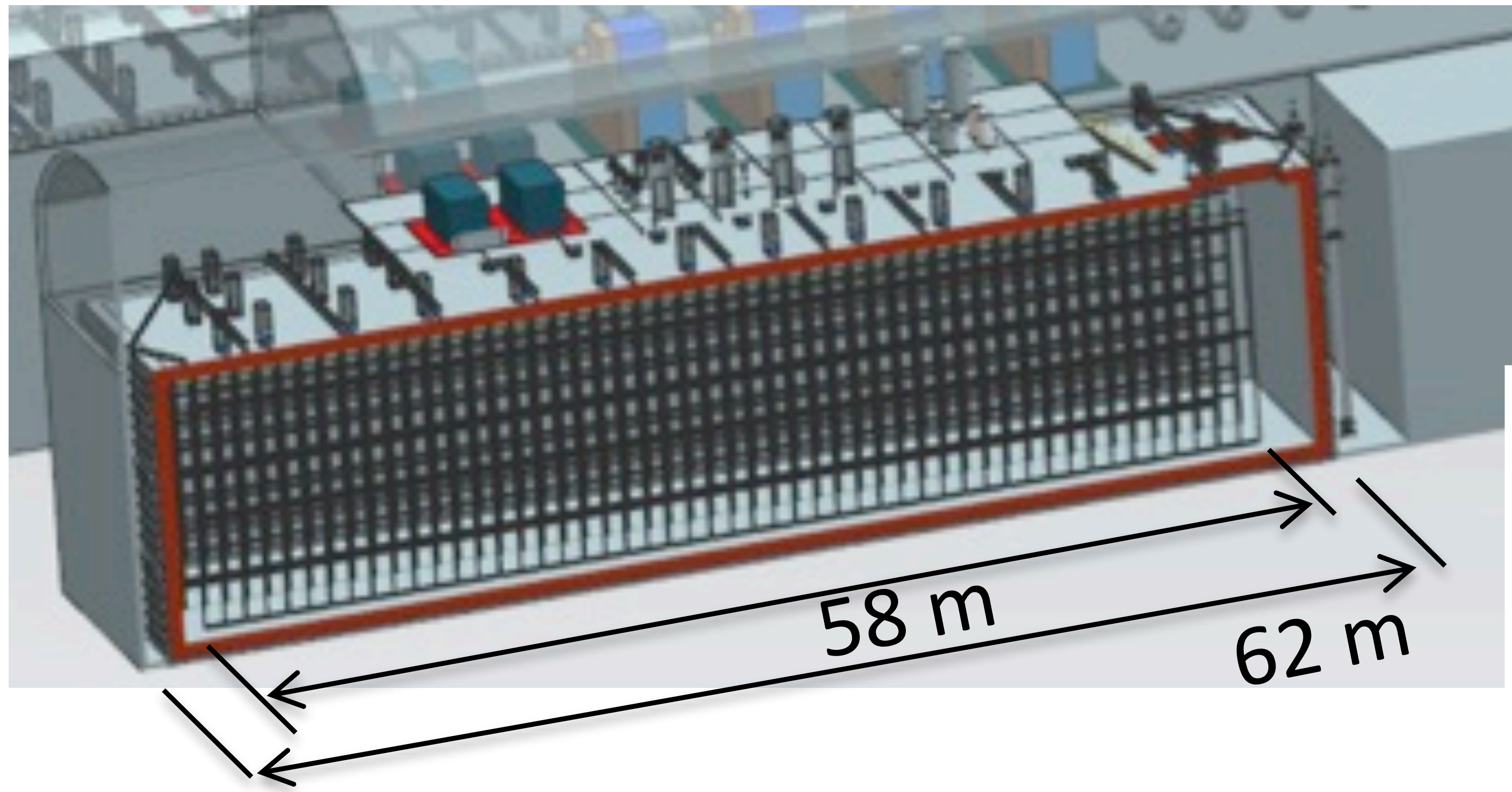

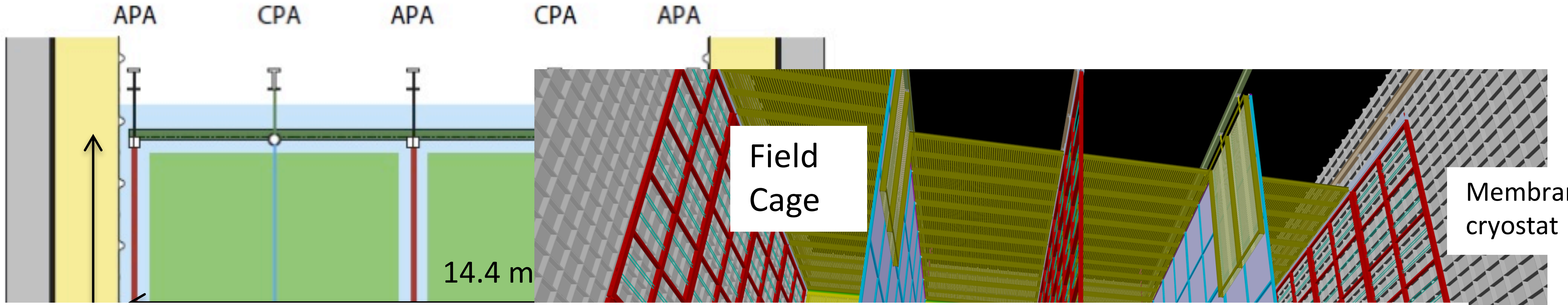

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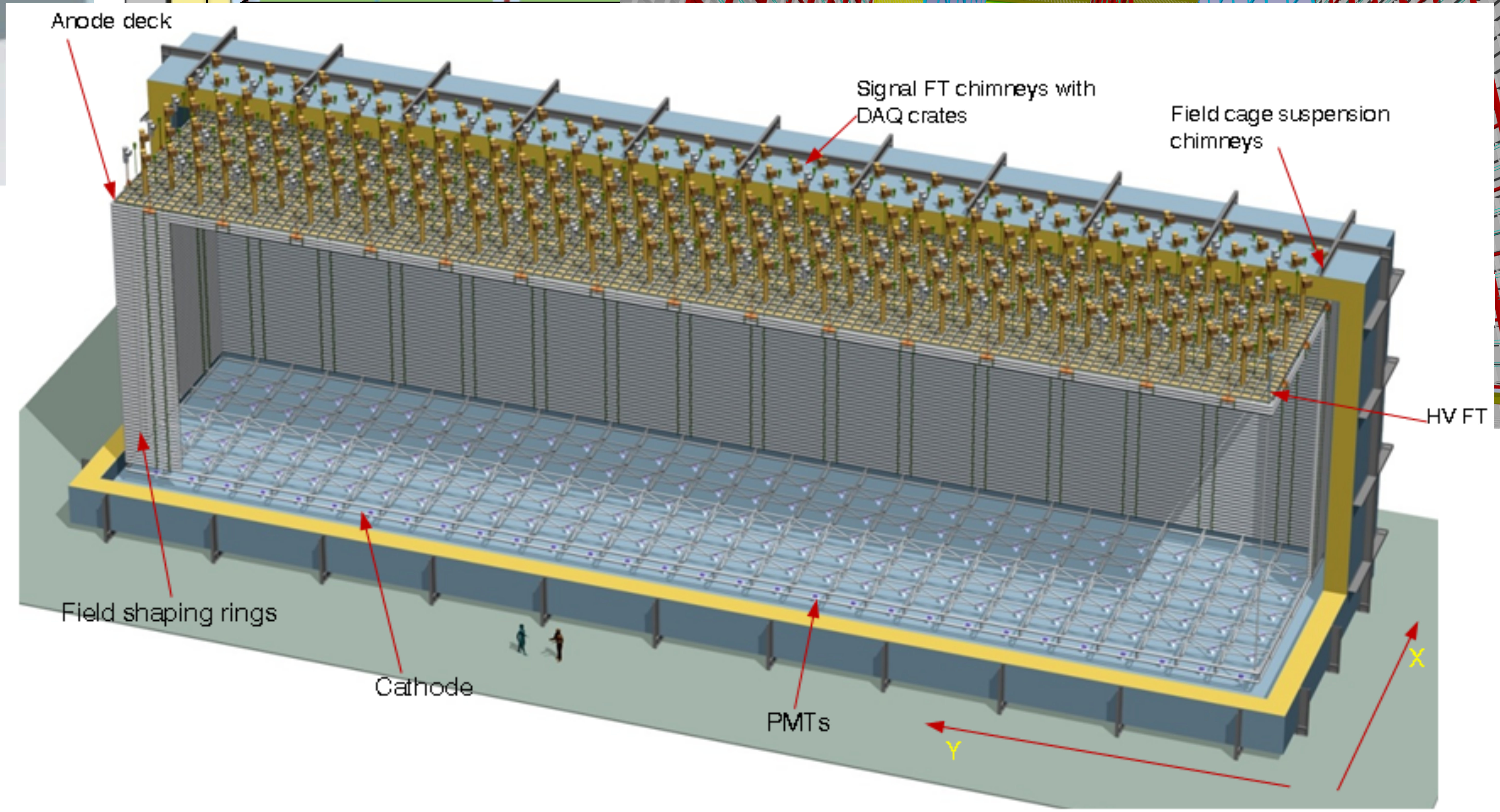

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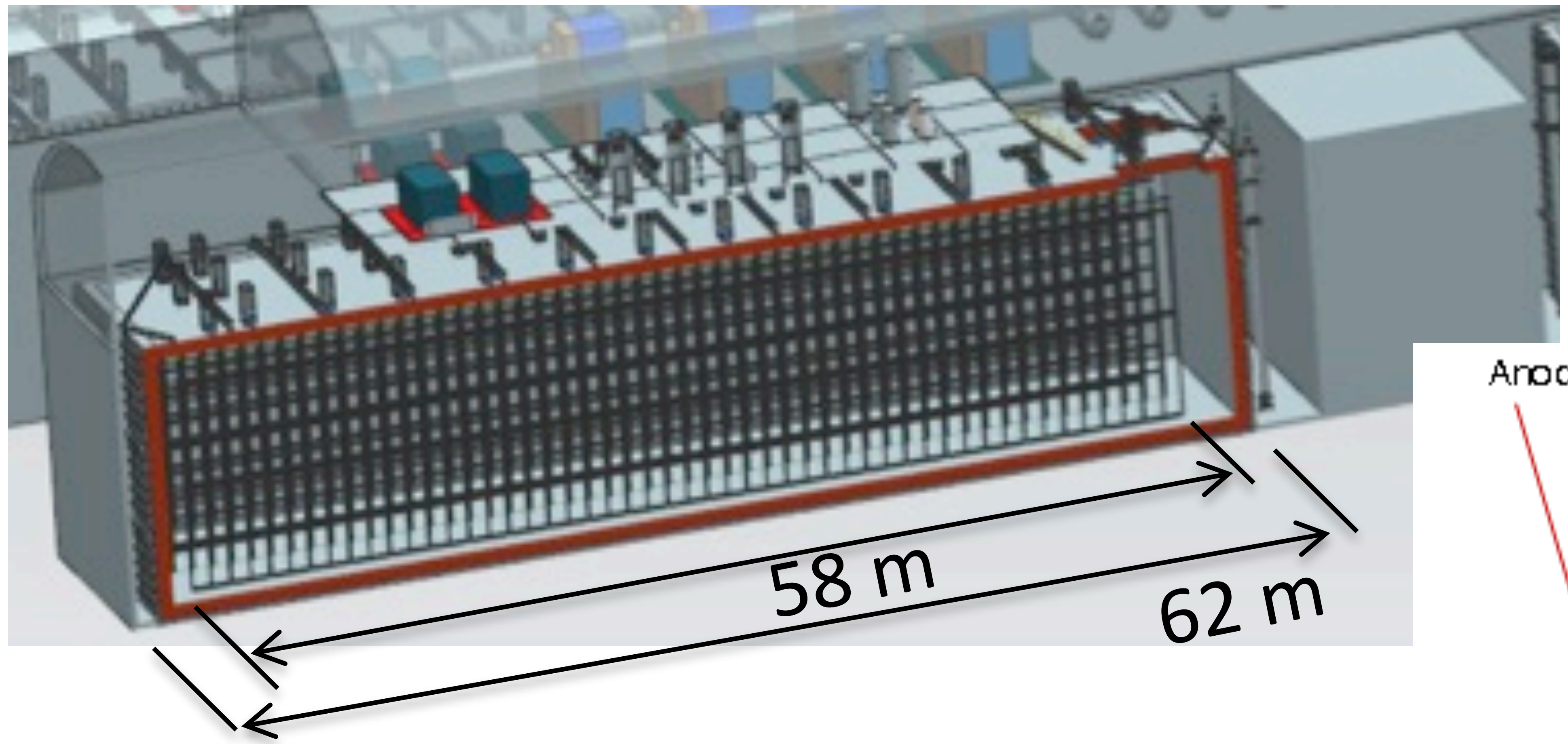
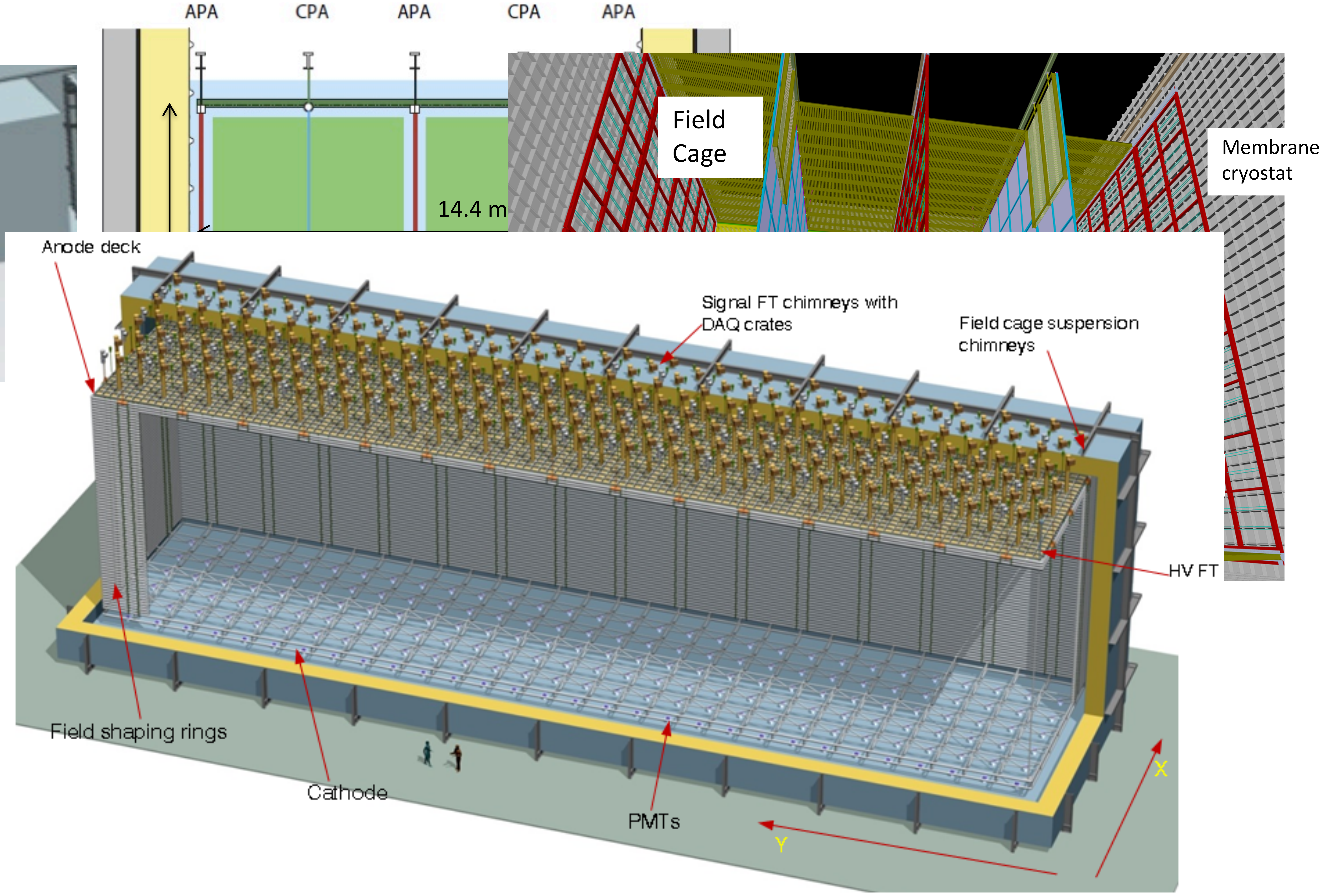


- One dual-phase LAr TPC:

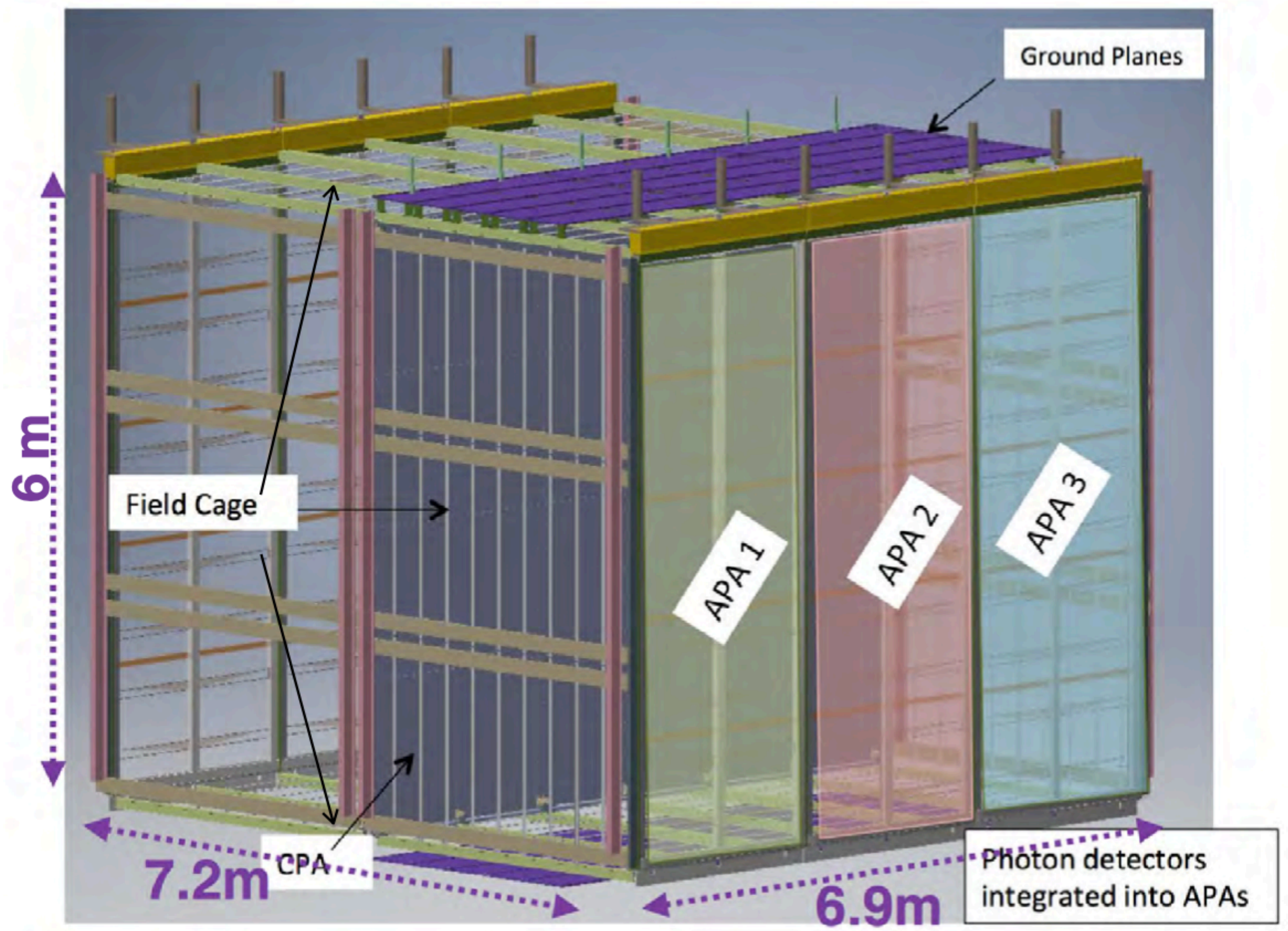


- + a fourth "module of opportunity"
  - technology to be decided

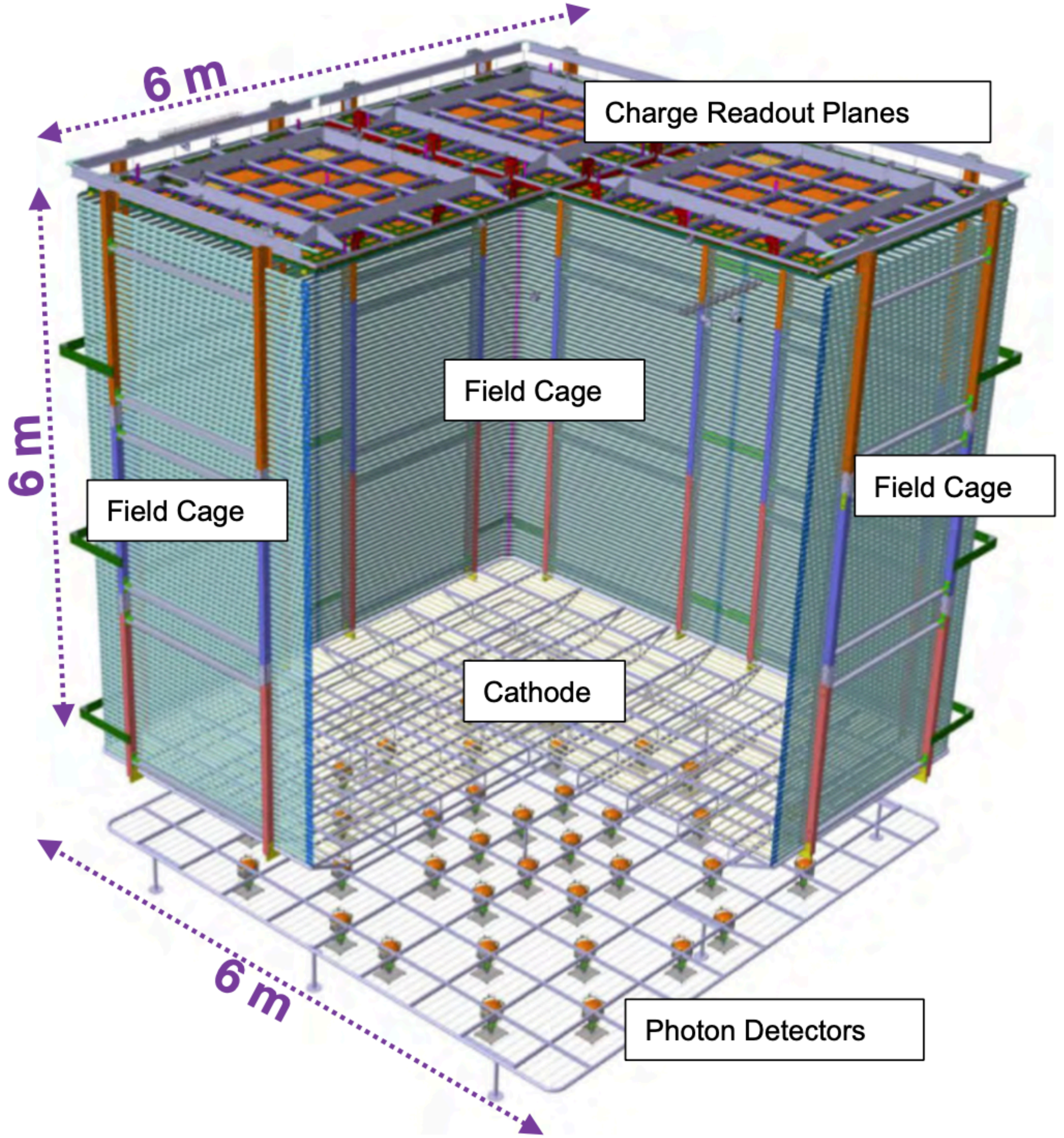
ProtoDUNE at CERN

Proving the Concept

Single Phase: 3.6 m horizontal drift

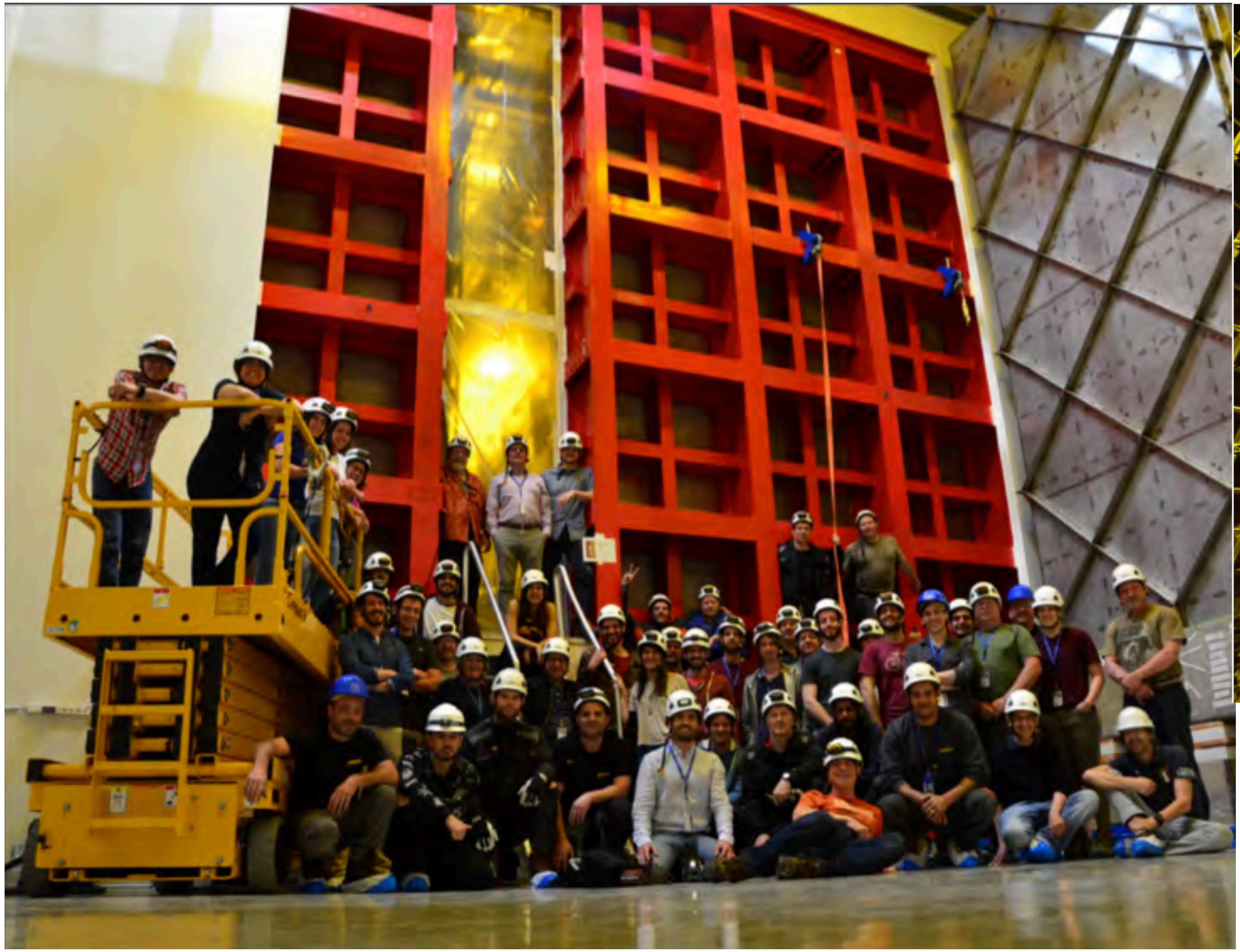


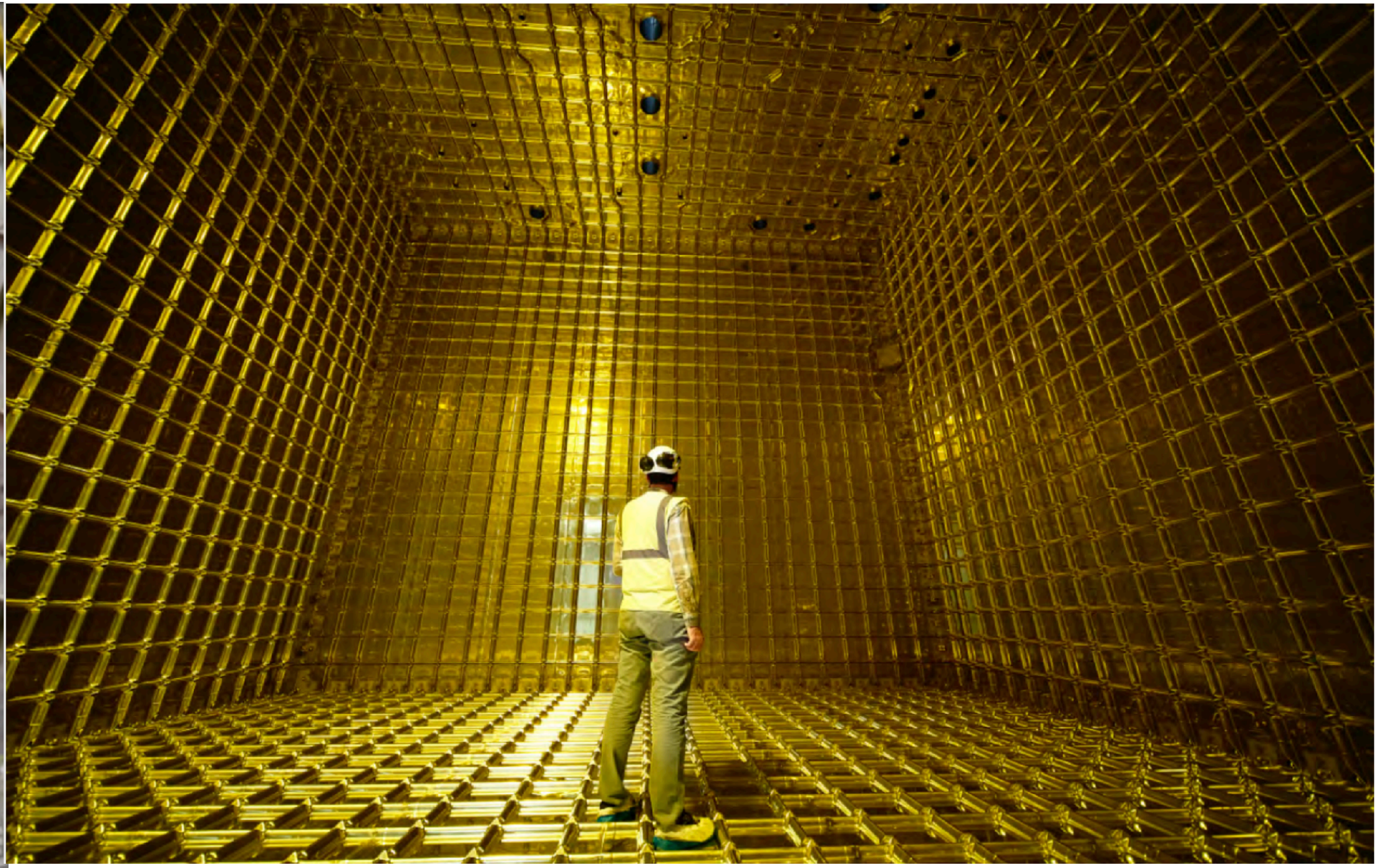
Dual Phase: 6 m vertical drift



ProtoDUNE at CERN

Proving the Concept

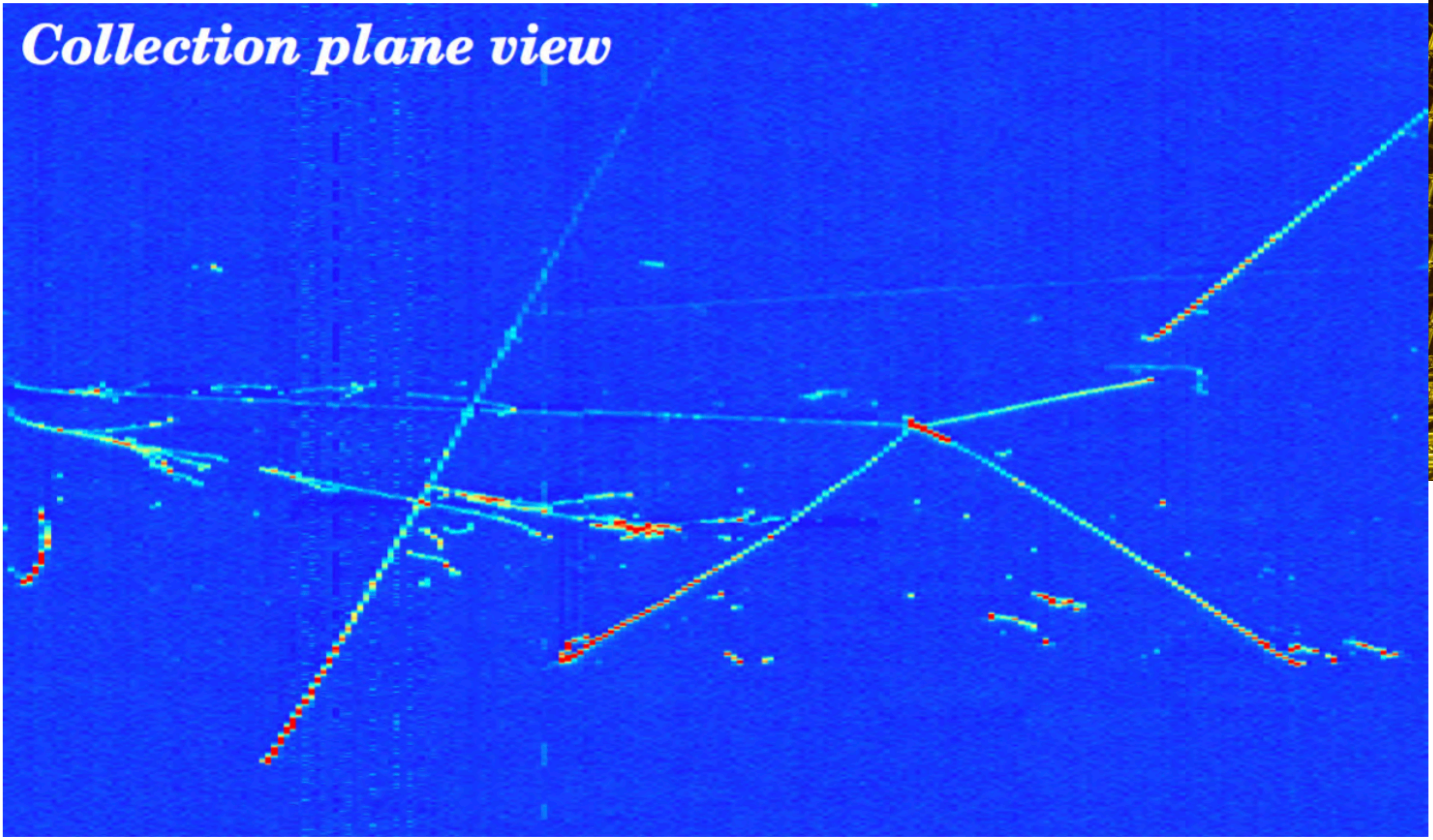


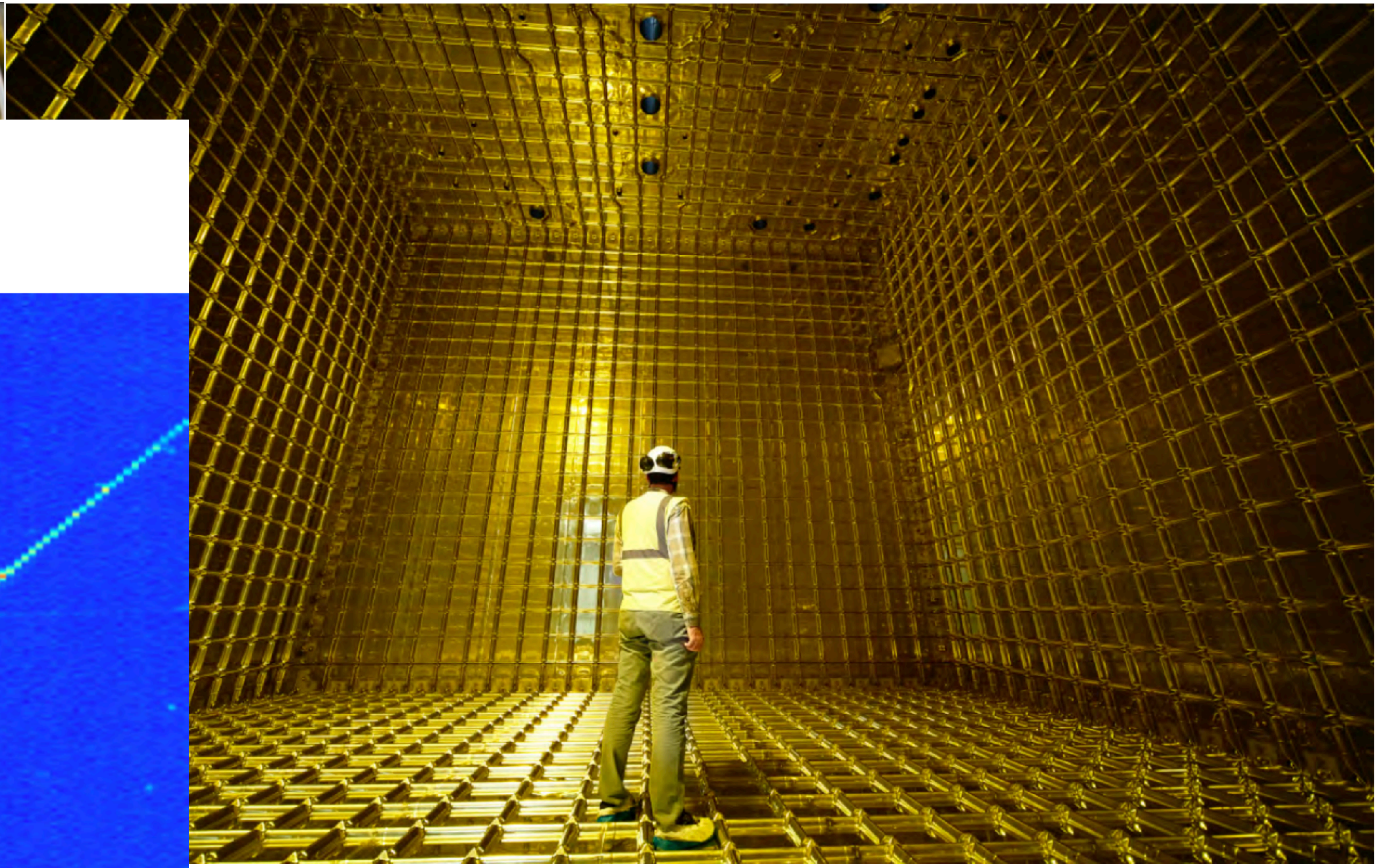


ProtoDUNE at CERN

Proving the Concept

2 EM showers and a pion interaction with 4 outcoming particles

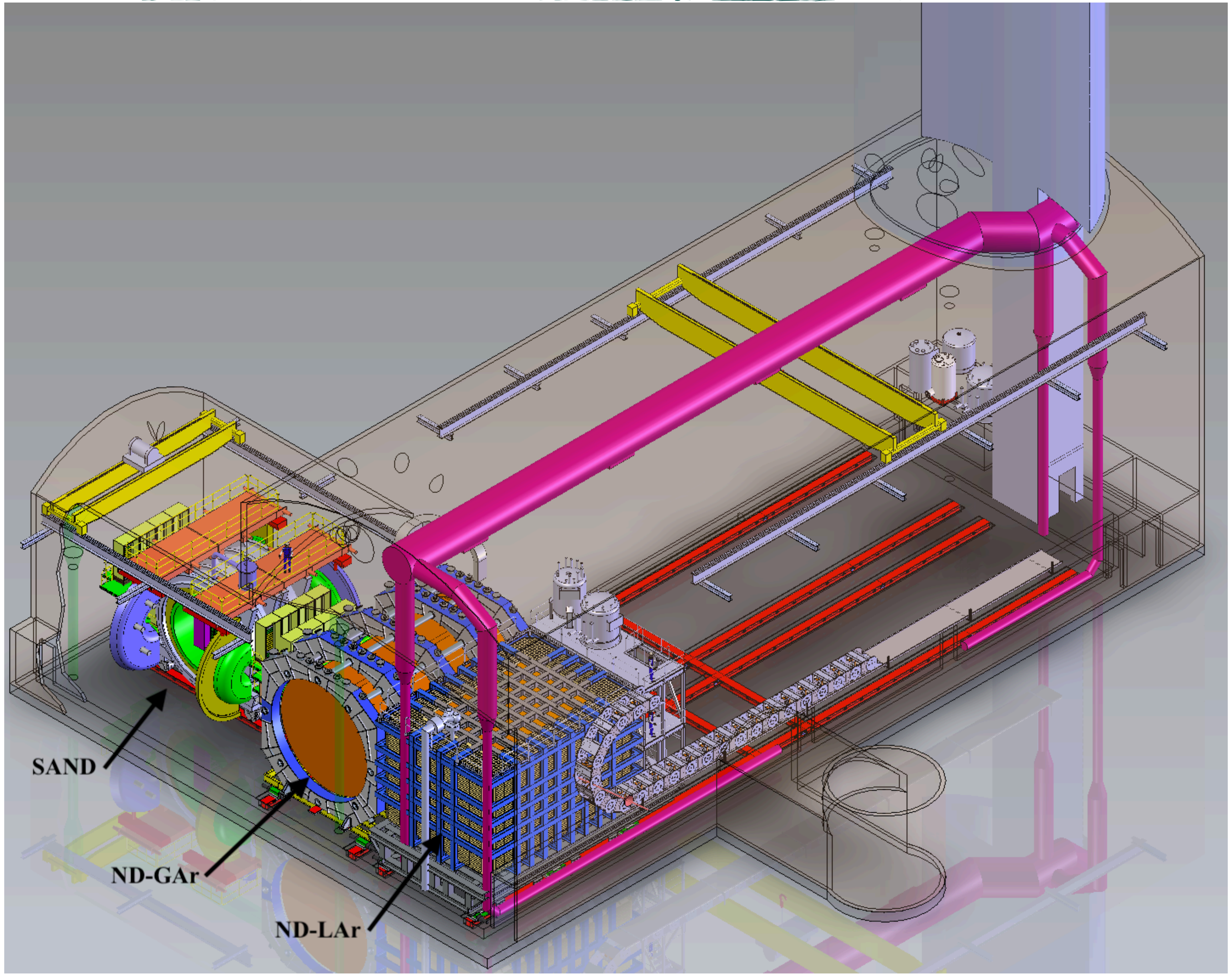




Successful operation of ProtoDUNE-SP with beam prior to LS2 at CERN

The DUNE Near Detector Complex

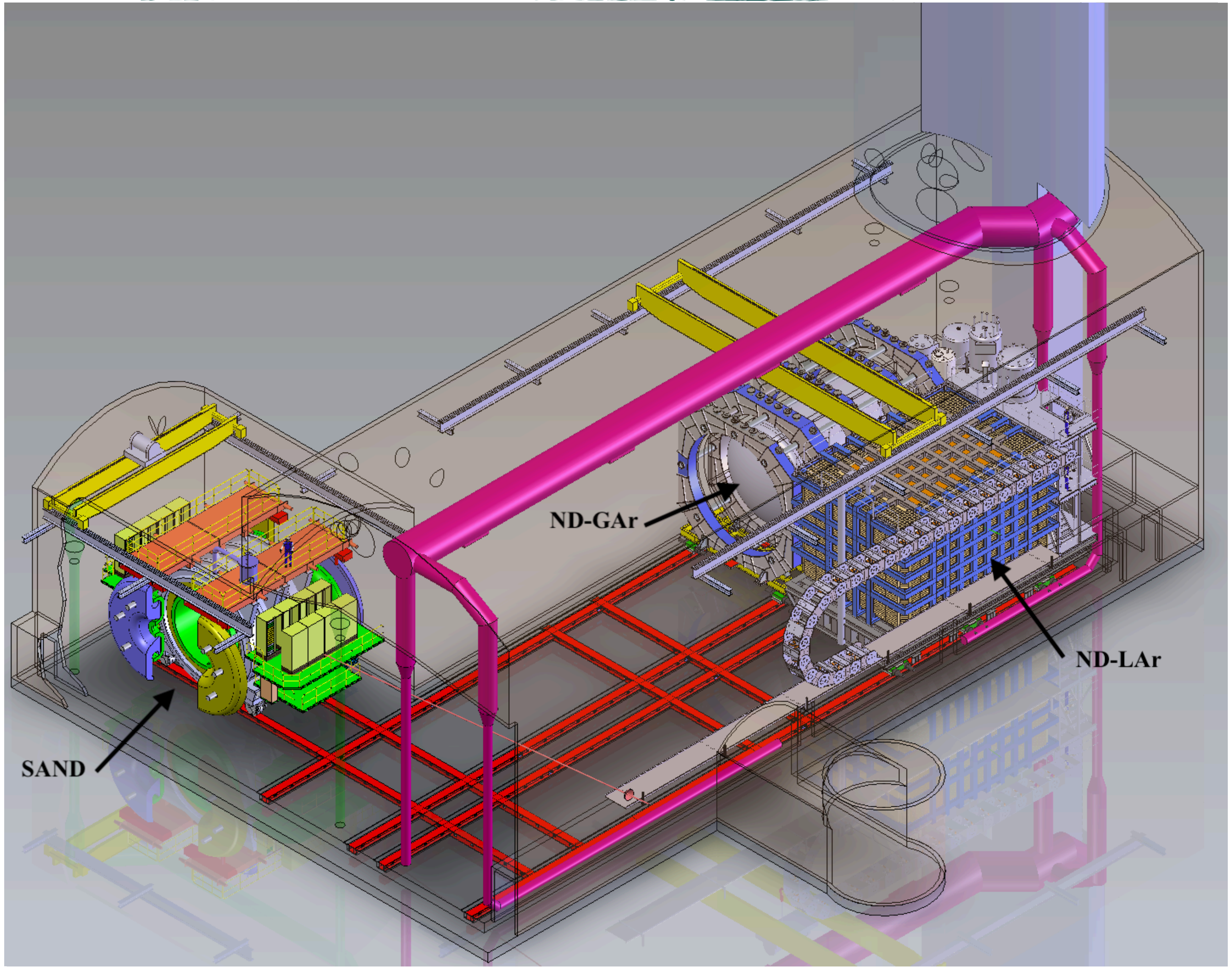
Understanding the Beam, Controlling Systematics



- A **liquid Ar TPC ND-LAr** with short drift length and pixelated readout
- A **Multi-Purpose Detector ND-GAr** with HPgTPC tracking + ECAL in a magnetic field
- An **on-axis beam monitor SAND** with tracking target (scintillator and / or gas), calorimetry and magnetic field

The DUNE Near Detector Complex

Understanding the Beam, Controlling Systematics



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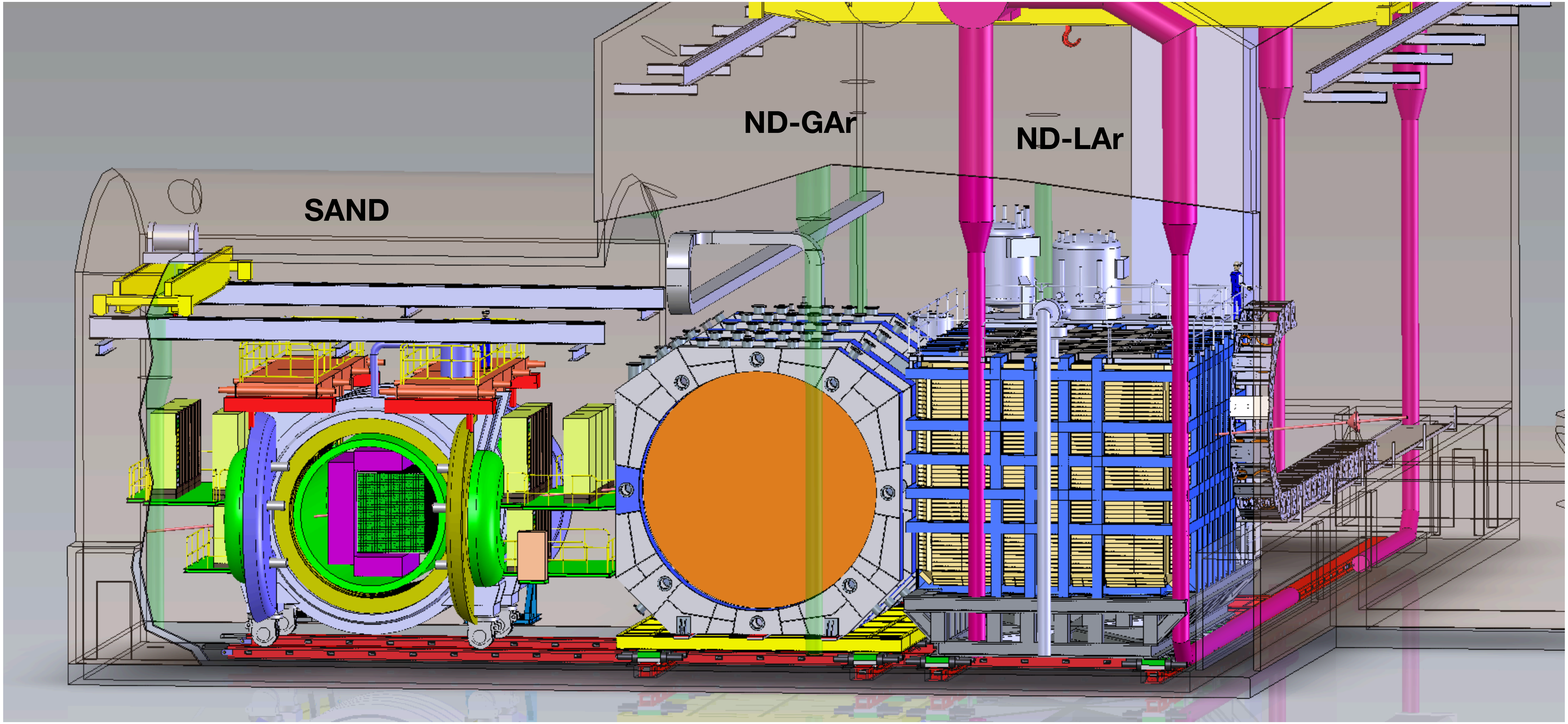
- ND-LAr and ND-GAr can move off-axis to measure at different energies / ν spectra: **DUNE-PRISM**
  - break cross section model degeneracies
  - linearly combine off-axis samples to construct arbitrary spectra: build FD-like oscillated spectra - reduction of model dependence

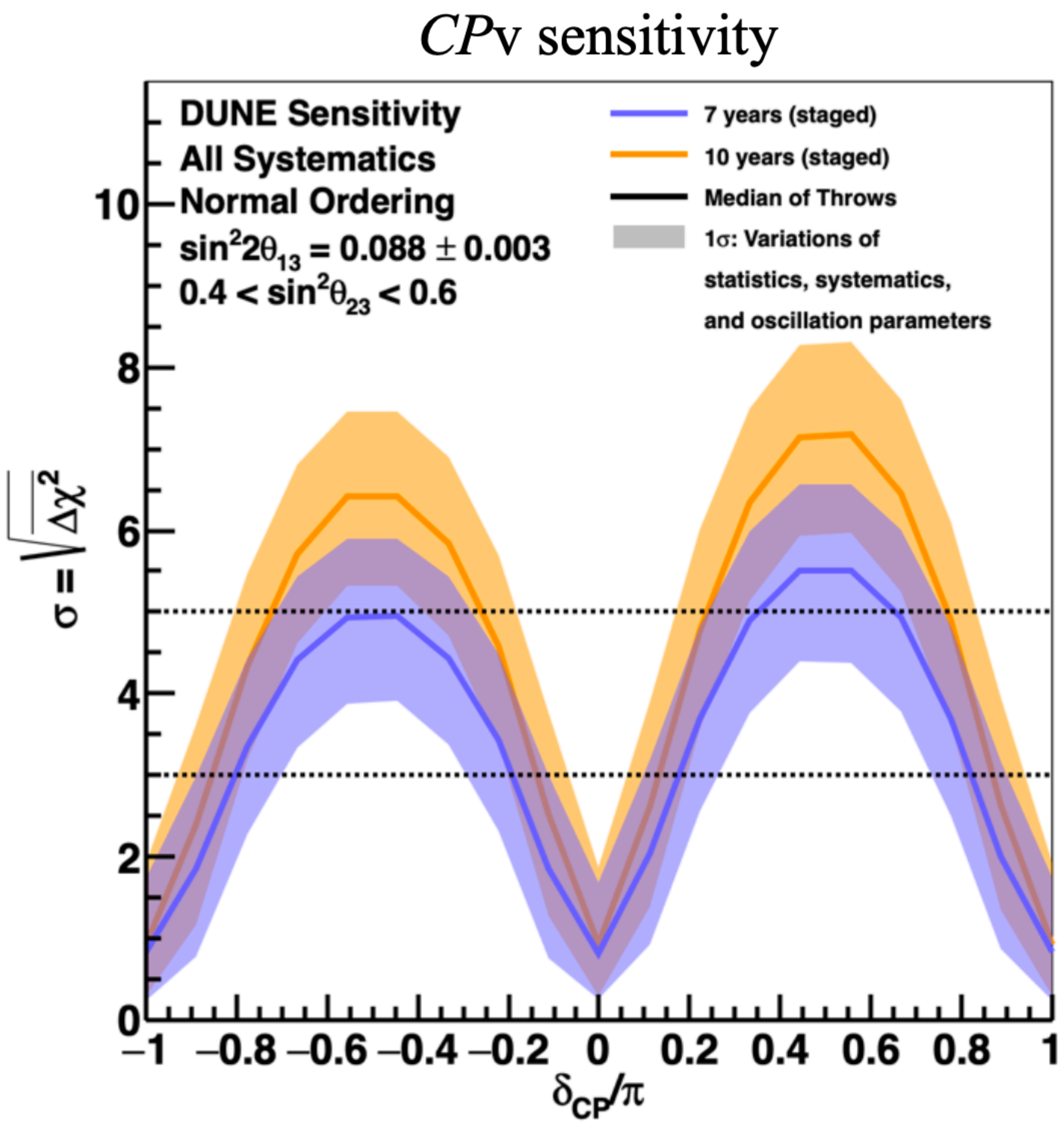
The DUNE Near Detector Complex

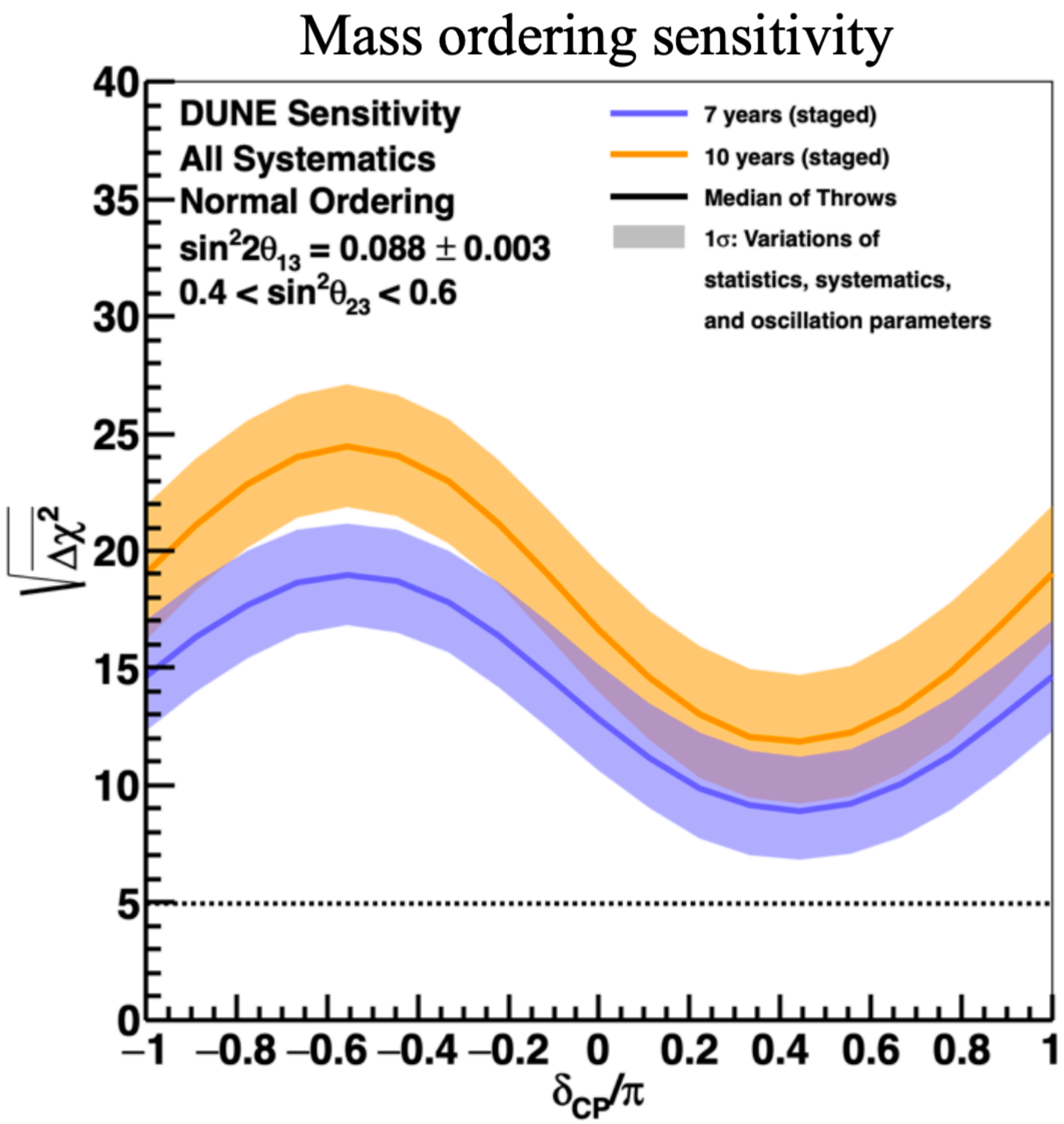
Understanding the Beam, Controlling Systematics



Expected Physics Performance

Selected Examples





Expected Physics Performance

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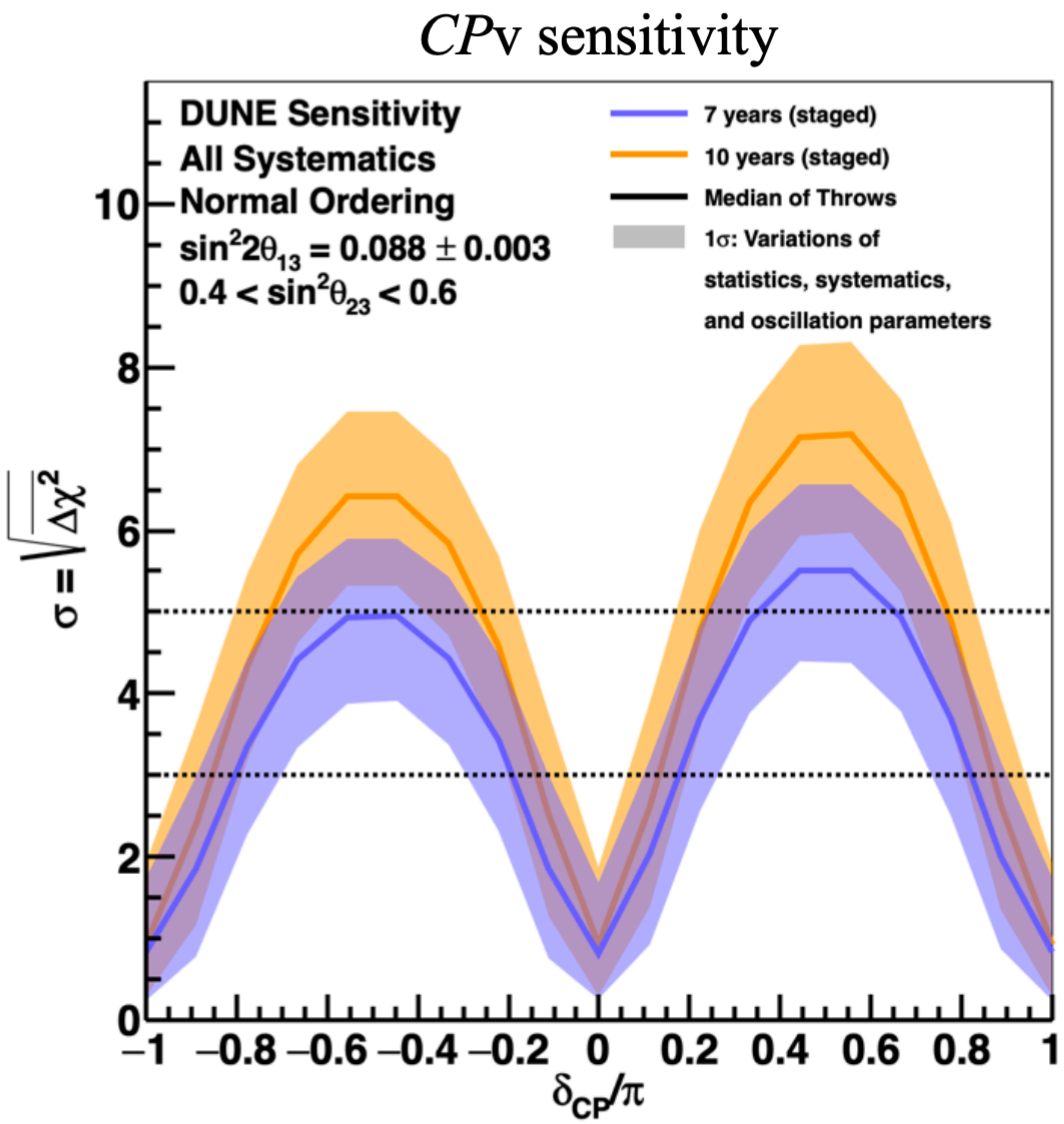
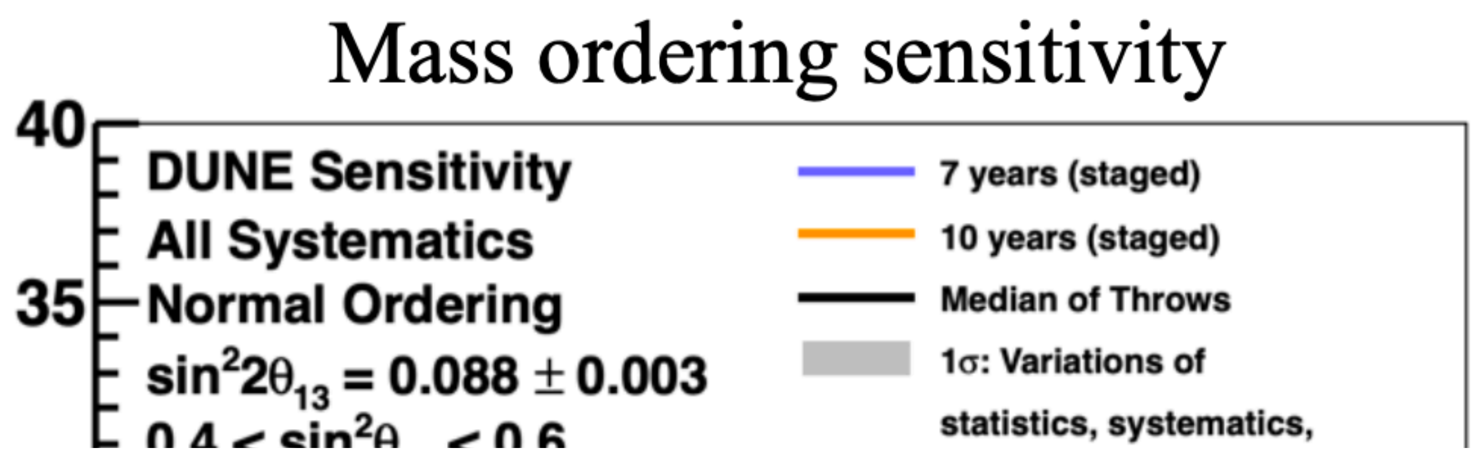
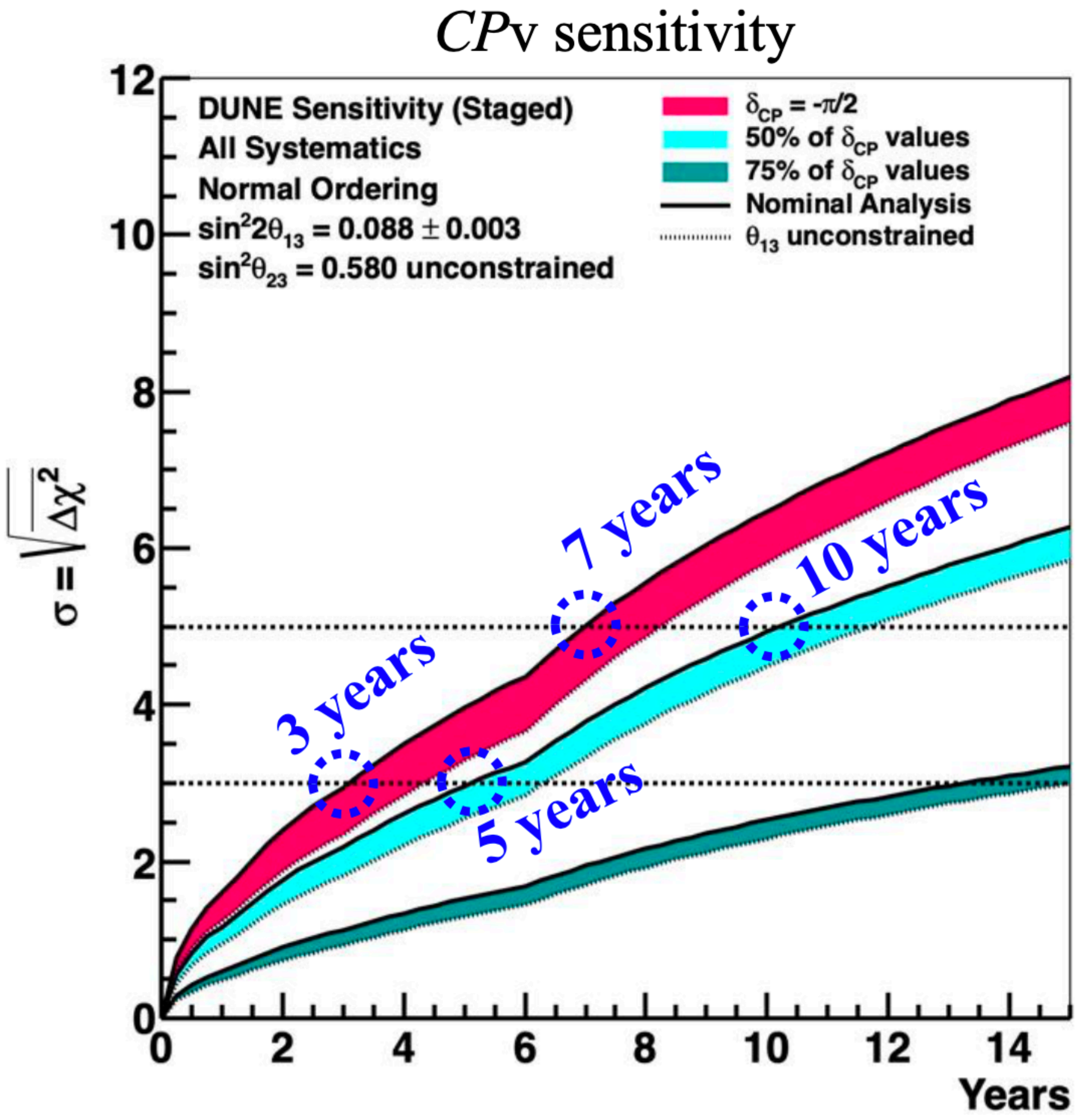
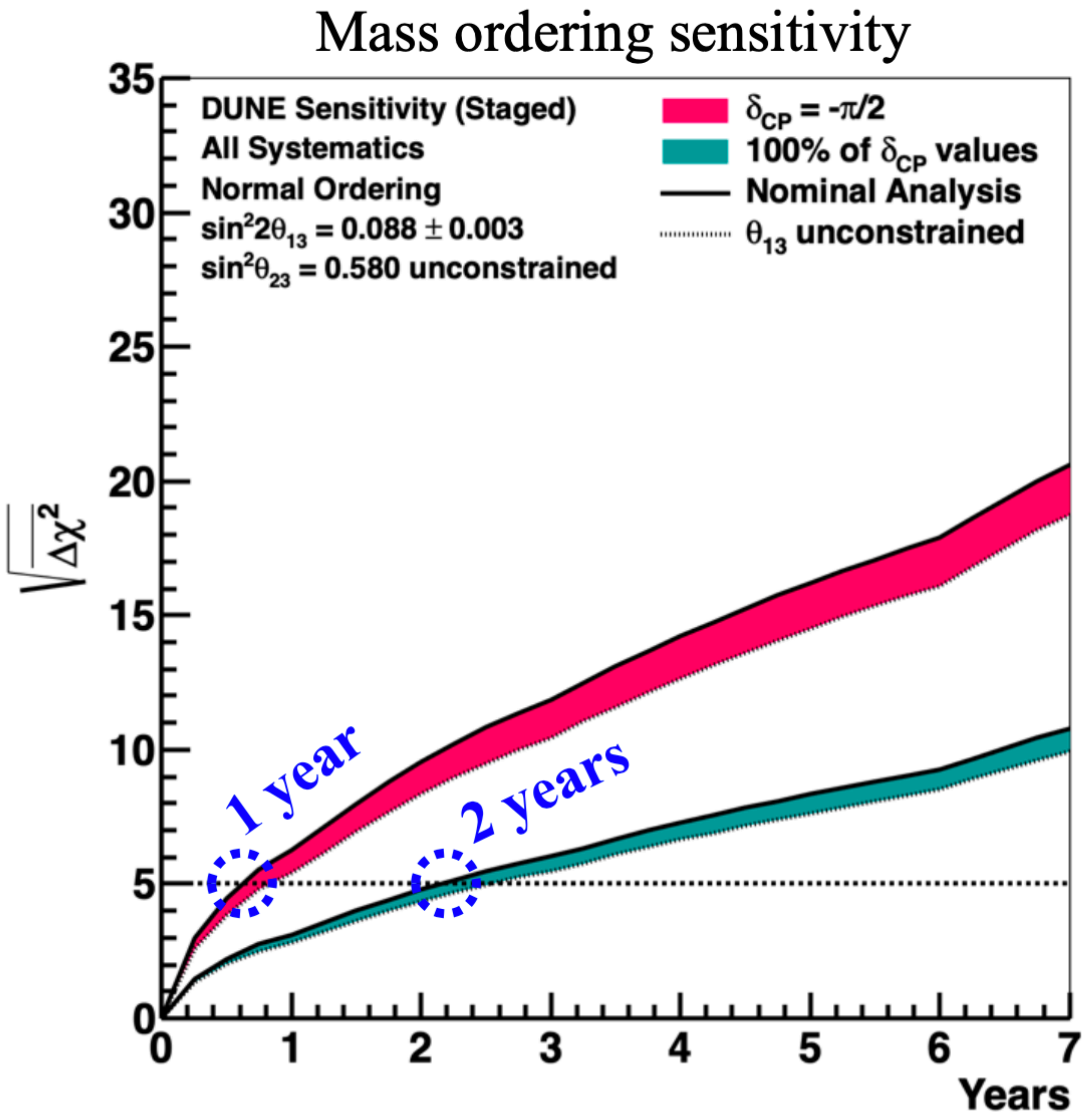




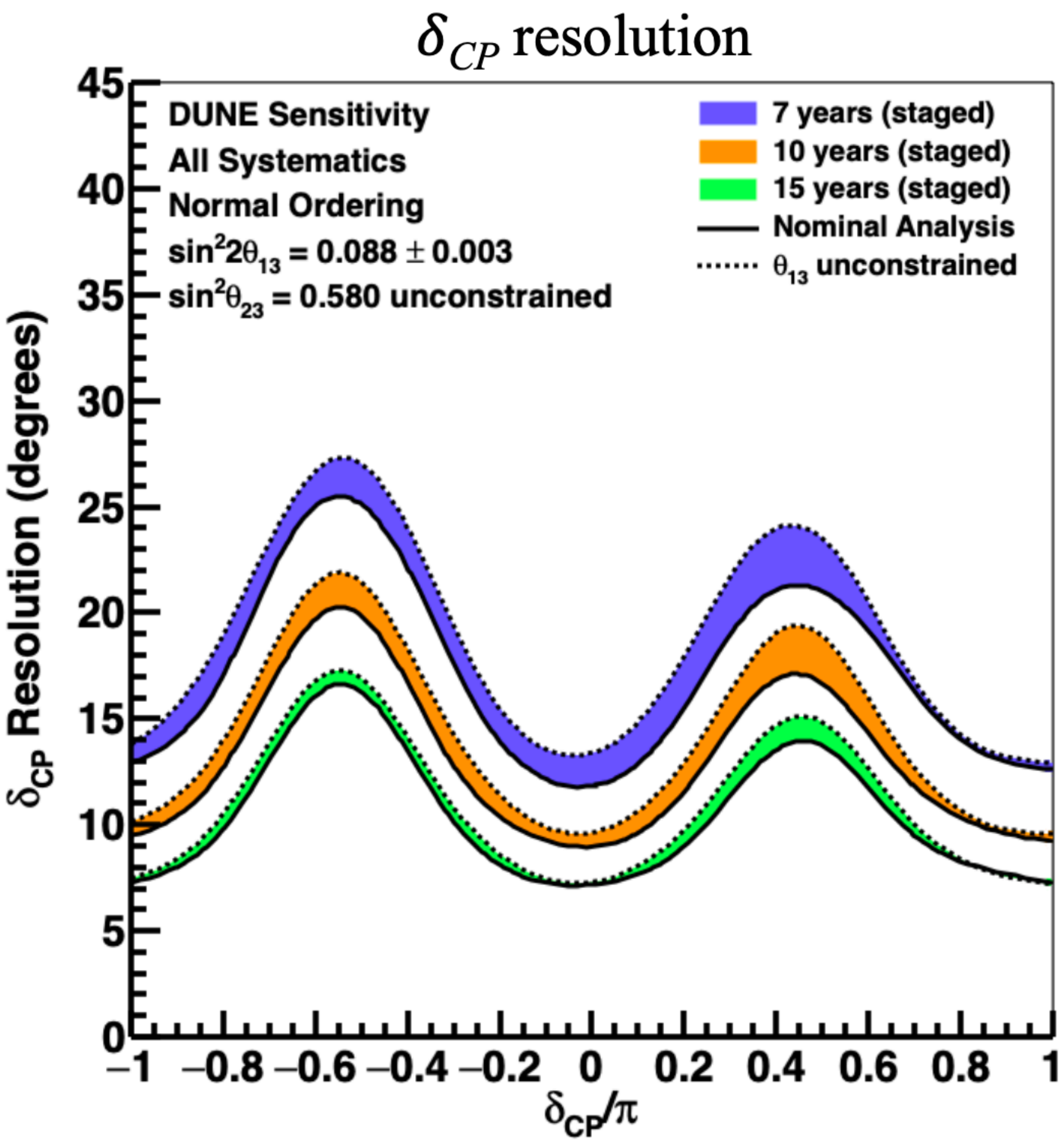




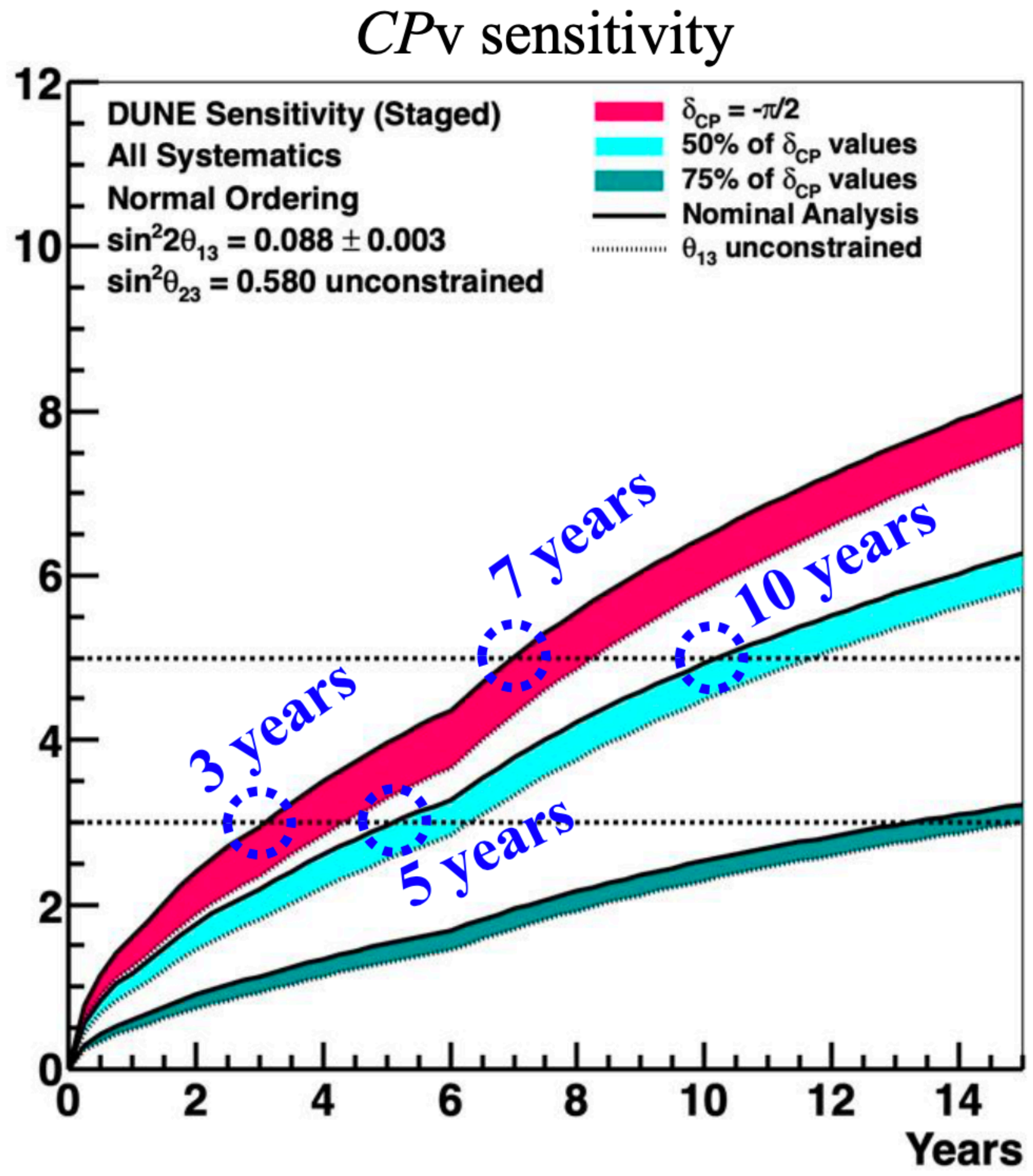
- Significant milestones throughout beam-physics program

Expected Physics Performance

Selected Examples



- Precise measurement of PMNS parameters



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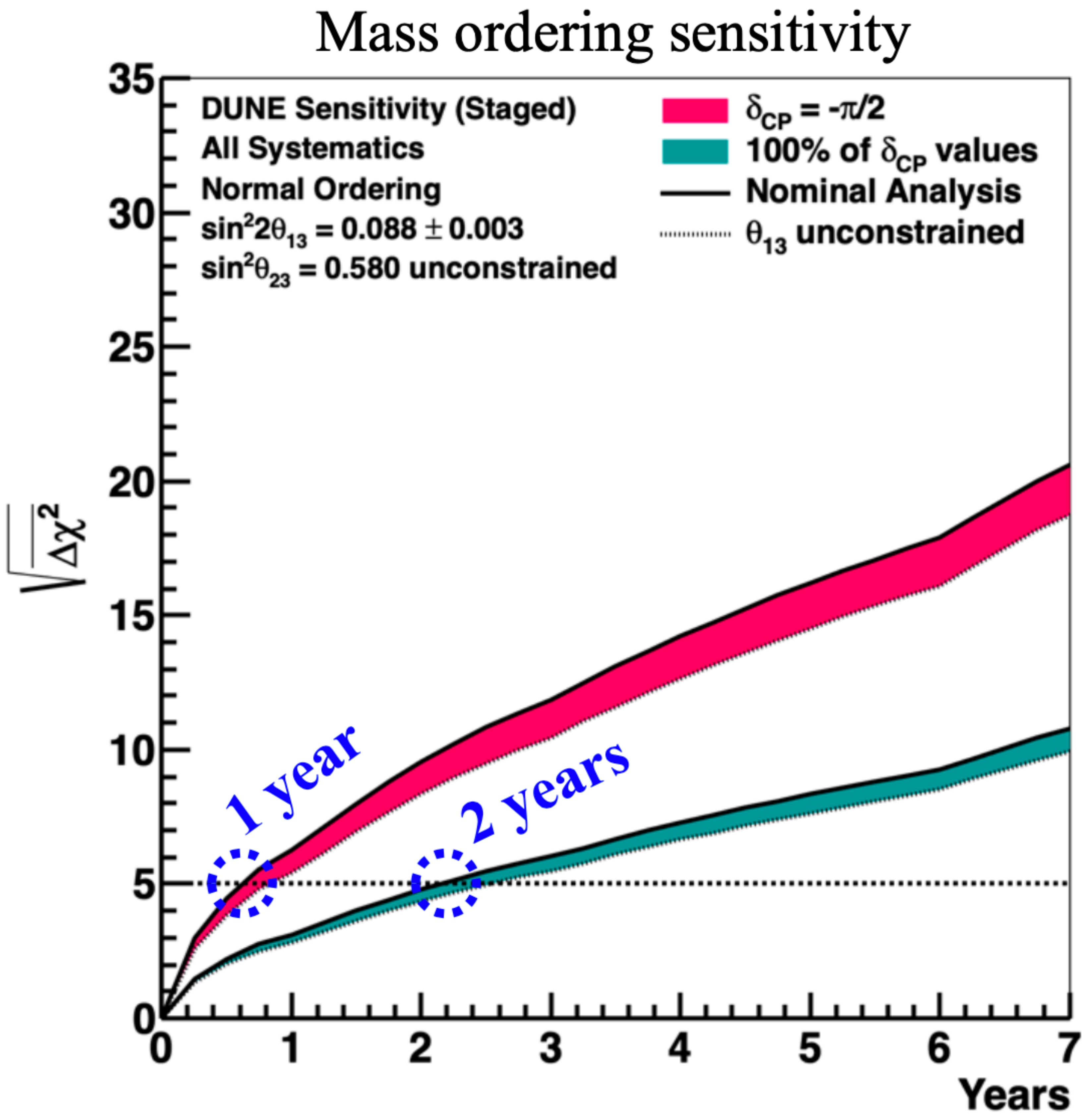

A Possible German Participation in DUNE

Applying Collider Detector Technology in the Near Detector & Beyond

MAX-PLANCK-INSTITUT FÜR PHYSIK

- The starting point: Essentially no German community in long baseline neutrino experiments
  But: Highly relevant expertise in the Collider community

  One example: Highly granular calorimeters - German “future collider” community a key driver, now also applied at LHC, what about neutrinos?

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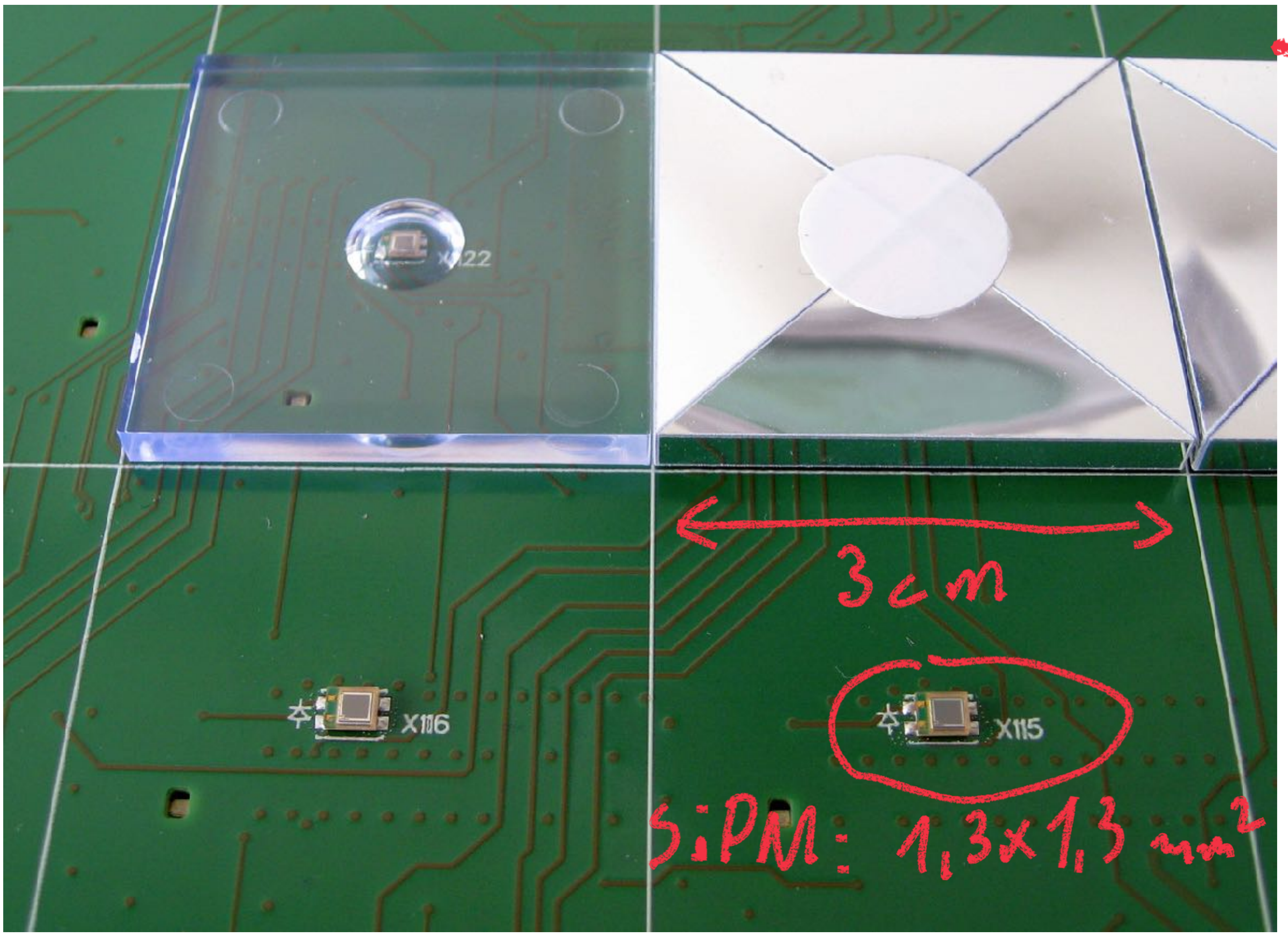
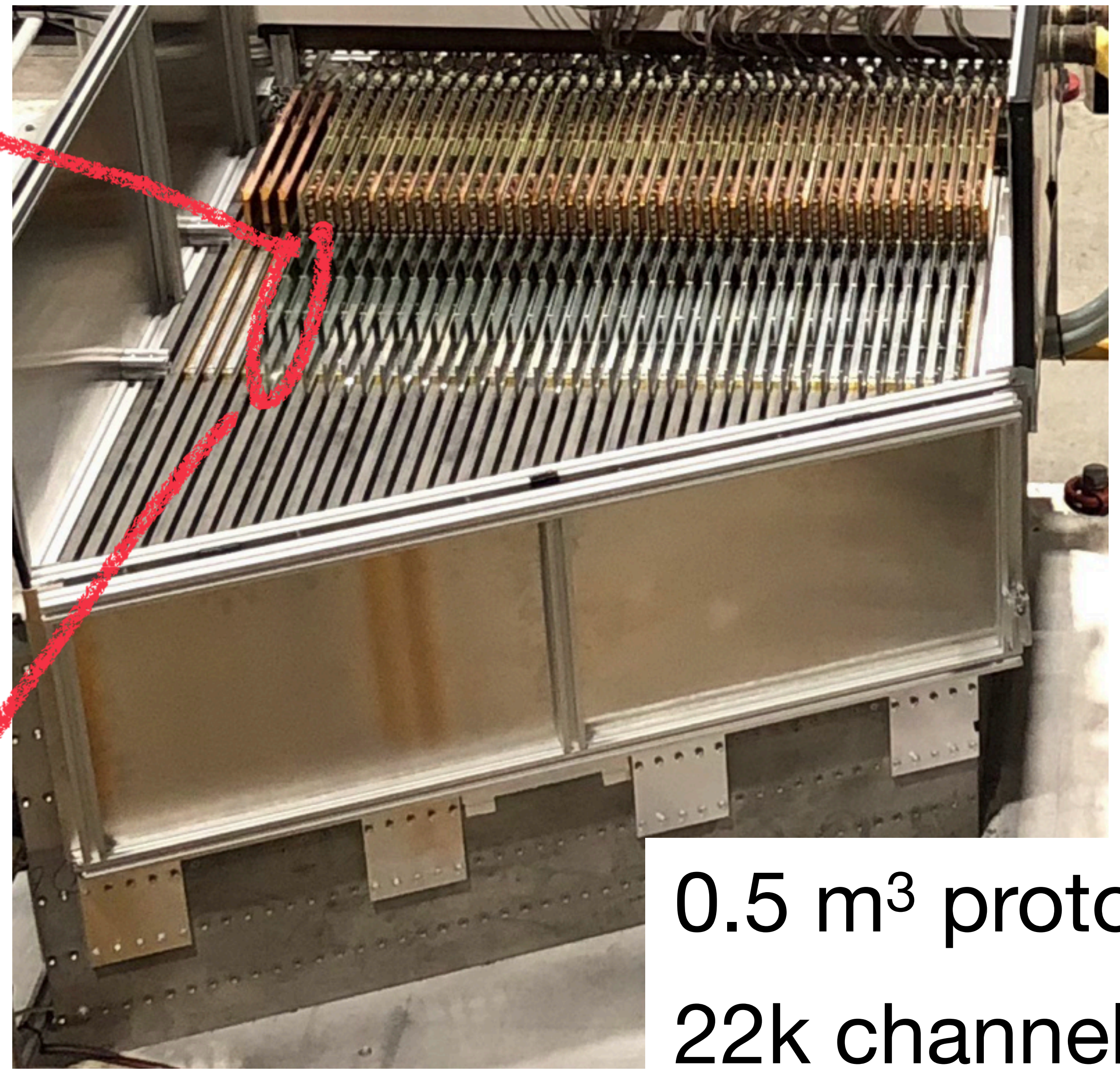
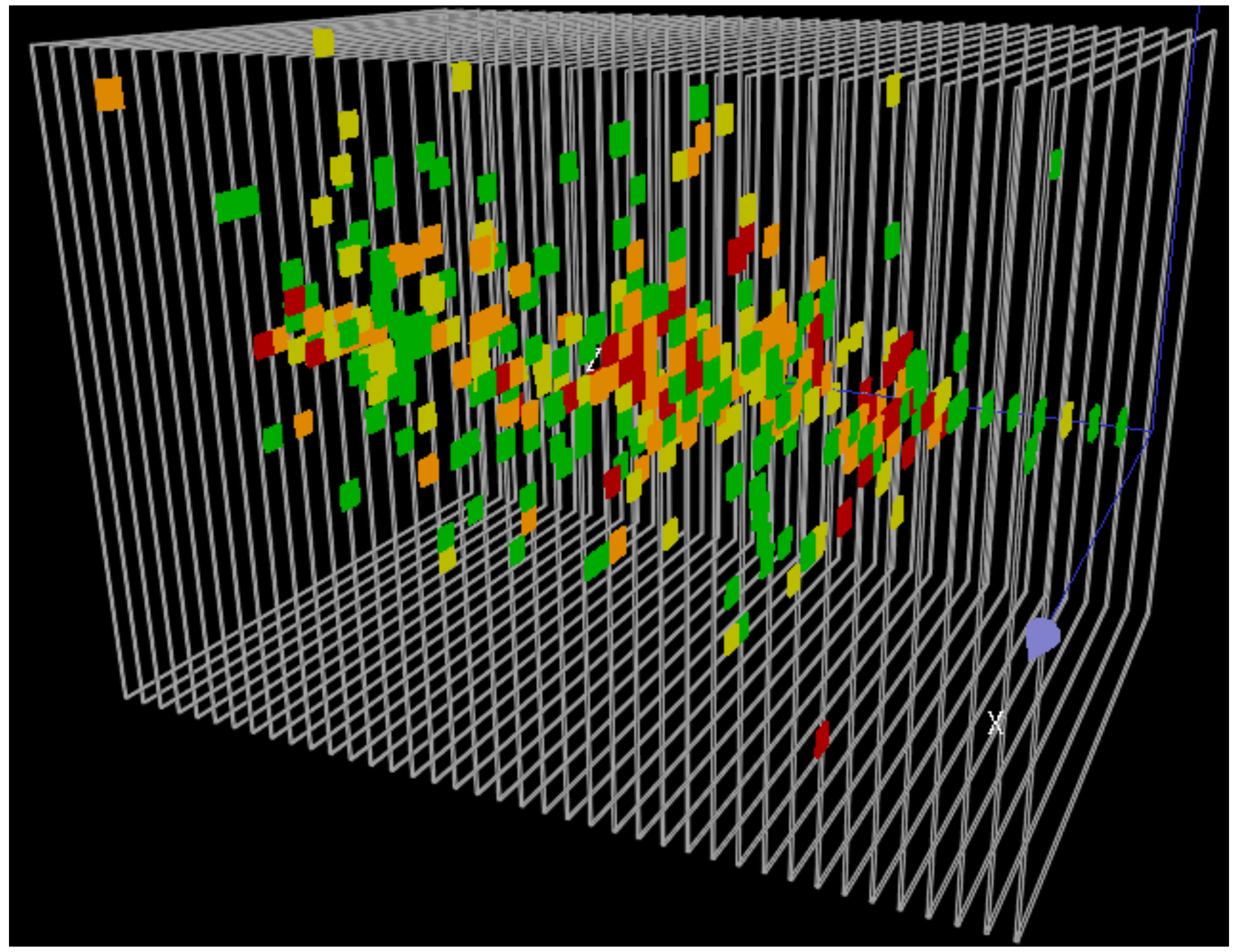
- The CALICE Analog Hadron Calorimeter: **SiPM-on-tile** technology





0.5 m³ prototype
22k channels

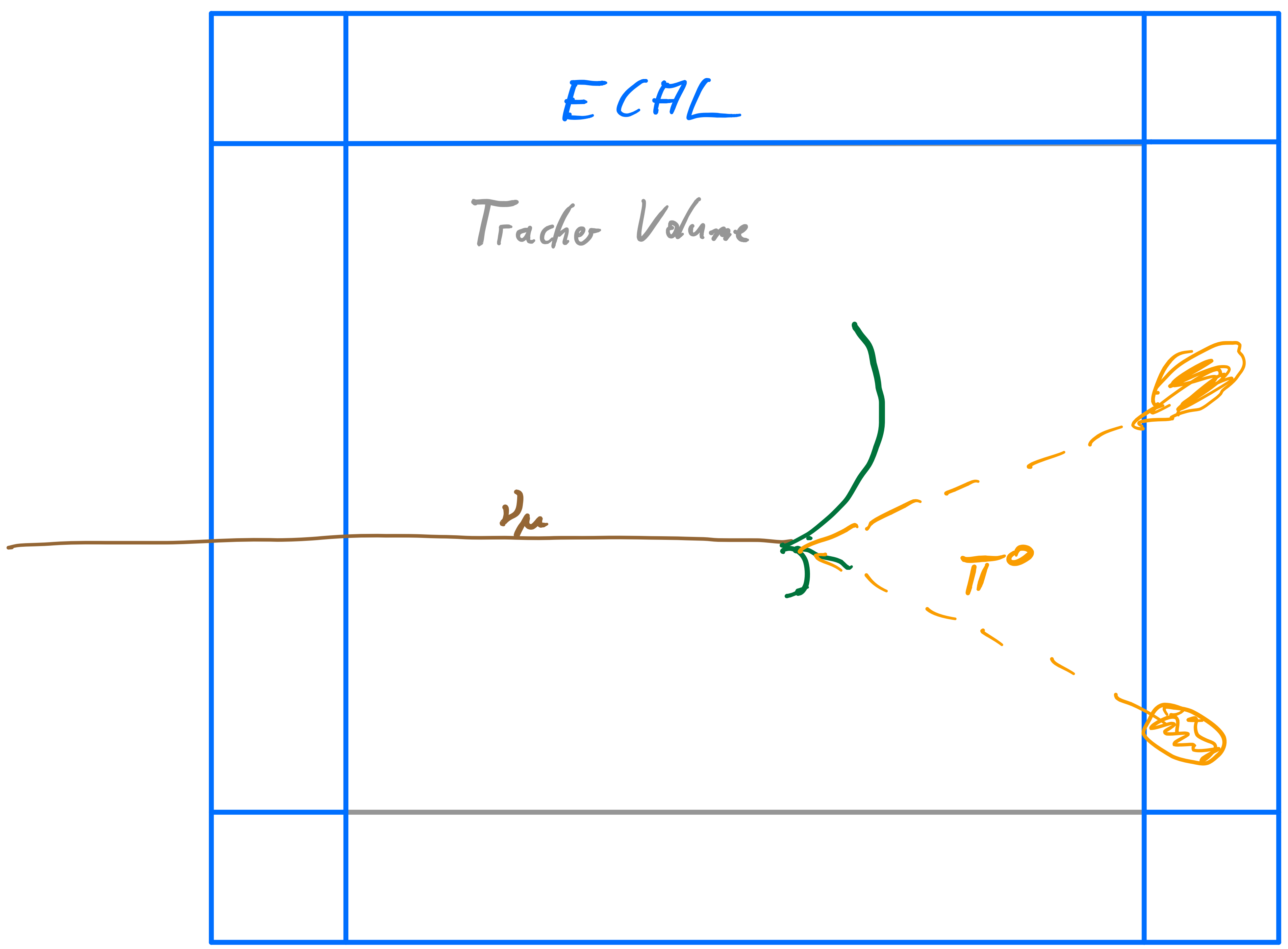


5D reconstruction particle showers in detectors

Near Detector Possibilities with a highly capable ECAL

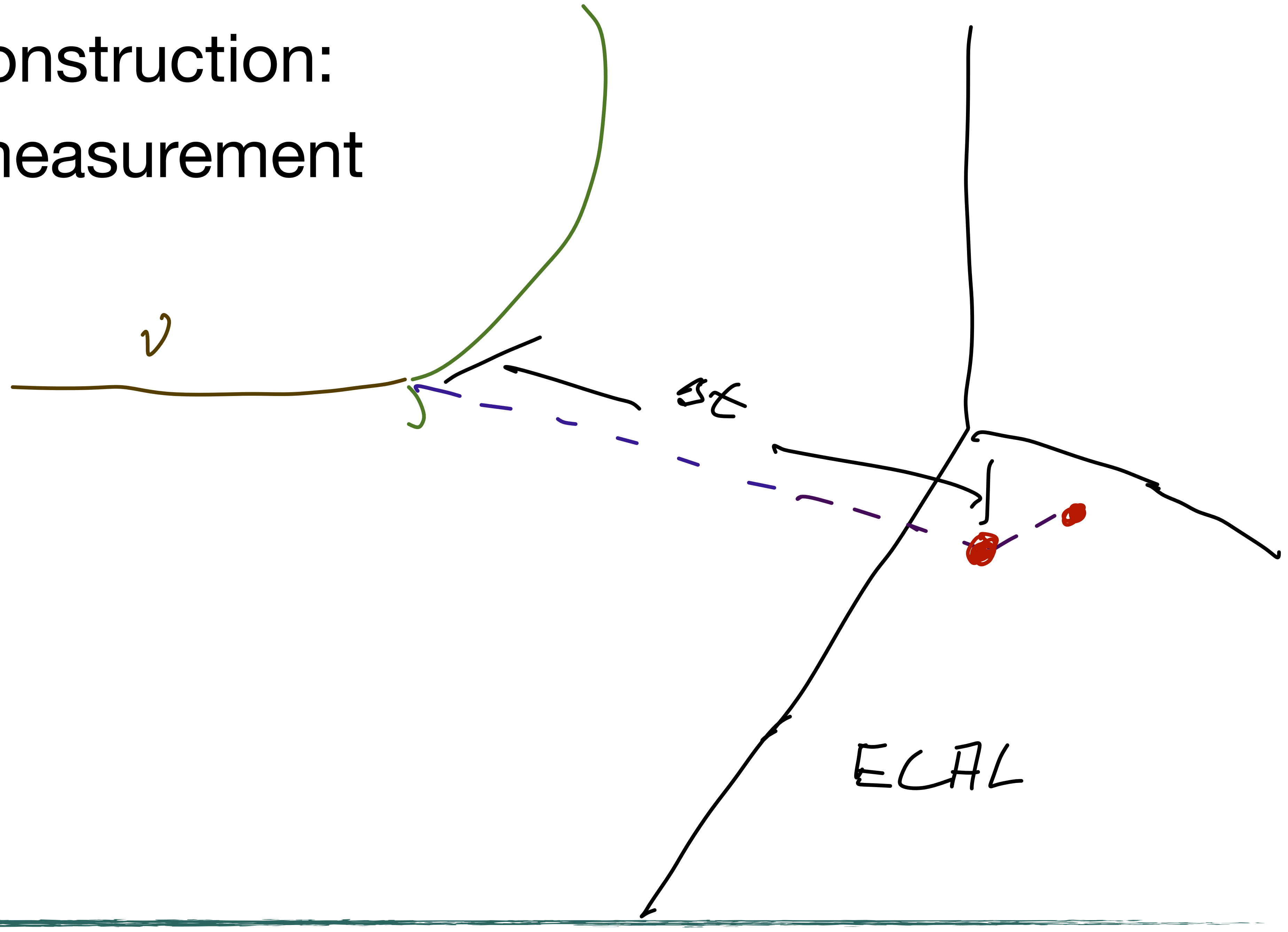
Still under Study

- One of the components of the DUNE Near Detector System: ND-GAr, with a low-density tracker and electromagnetic calorimetry in a magnetic field



Highly granular calorimetry:

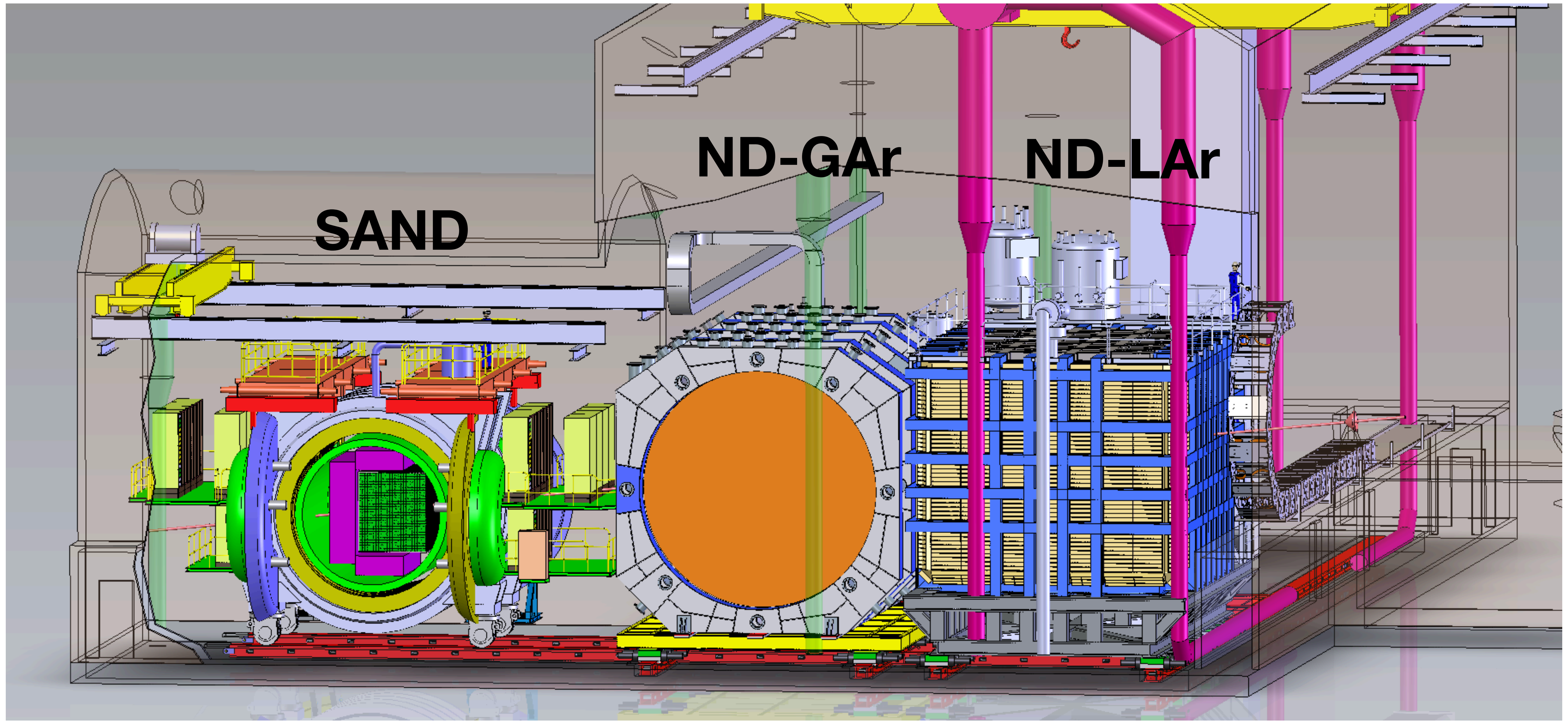
- Good energy and pointing resolution for photons: π^0 reconstruction, constraining key backgrounds
- Muon tracking and ID
- Potential for neutron reconstruction: time of flight as energy measurement



The DUNE ND-GAr

With a Highly Granular Calorimeter

MAX-PLANCK-INSTITUT FÜR PHYSIK

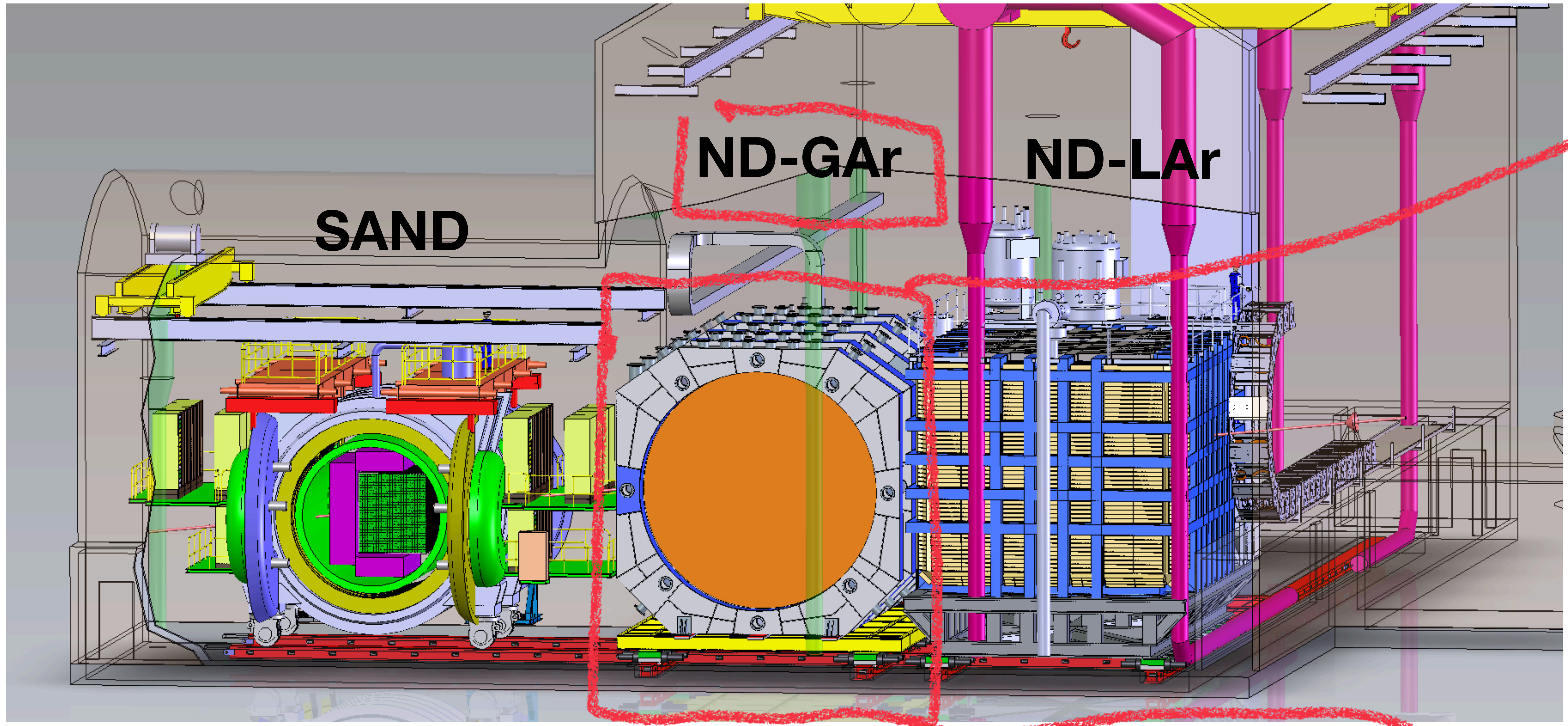


- Developing an ambitious calorimeter concept, with *O* 2M channels, combining SiPM-on-Tile and scintillator strips

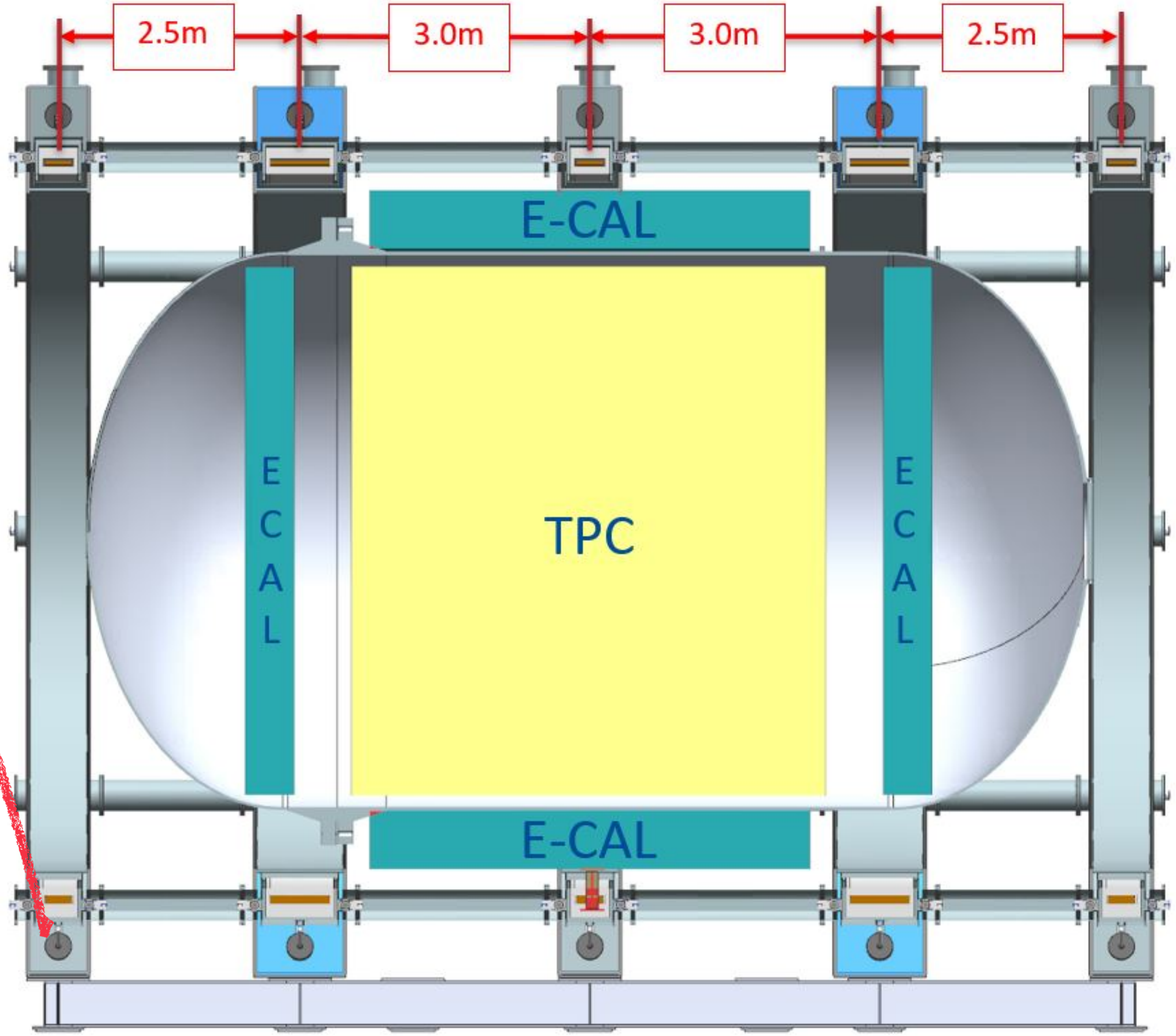
The DUNE ND-GAr

With a Highly Granular Calorimeter

MAX-PLANCK-INSTITUT FÜR PHYSIK



- Developing an ambitious calorimeter concept, with *O* 2M channels, combining SiPM-on-Tile and scintillator strips
  - Builds on key expertise in Germany:
    - SiPM-on-tile technology
    - Overall detector concept, integration, reconstruction
    - ASICs and front-end electronics
    - DAQ   …



Towards a Project

Strategic Discussions & Concrete Plans in Germany

- First ideas for detector concept developed in 2016
- Discussions in community beginning in 2017 and 2018 - also in a series of workshops in context of Update of European Strategy for Particle Physics
  - Workshop “The Future of Neutrino Physics - A German Perspective on Topics, Opportunities and Challenges “ (02/2017, Heidelberg) supporting coordinated participation in a long baseline experiment (DUNE or HyperK)
  - Strategieworkshop “Teilchenphysik” (05/2018, Bonn): “Eine sichtbare Beteiligung deutscher Gruppen an long-baseline Experimenten, insbesondere bei LBNF/DUNE, wird mit Nachdruck unterstützt.“
  - European Strategy for Particle Physics (06/2020): “Europe, and CERN through the Neutrino Platform, should continue to support long baseline experiments in Japan and the United States. In particular, they should continue to collaborate with the United States and other international partners towards the successful implementation of the Long-Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE).
- BMBF-funded R&D project on scintillator technology, bringing together collider and neutrino - motivated activities in FP 2018 - 2021
- Now: developing application for next FP, still primarily focusing on R&D, as foundation for construction project and official step towards DUNE - with a broad community of ~ 17 PIs, 11 Institutes

Conclusions

- DUNE has a broad, exciting physics program:
  - CP violation and mass ordering in long baseline oscillations
  - Supernova and solar neutrinos
  - A wide range of SM measurements and BSM searches

- Highly capable detectors
  - Liquid Argon TPCs as far detectors - with technology successfully demonstrated by ProtoDUNE at CERN
  - A Near Detector Complex with different systems to characterise the beam, control systematics, and perform neutrino physics measurements - still in the process of being fully defined

- A fully international project - with key contributions from all regions
  - German participation under discussion - focusing on opportunities in the Near Detector, and long-term perspectives in alternative far detector technologies