DUNE: Status and Prospects

Georgia Karagiorgi, Columbia University
On behalf of the DUNE Collaboration

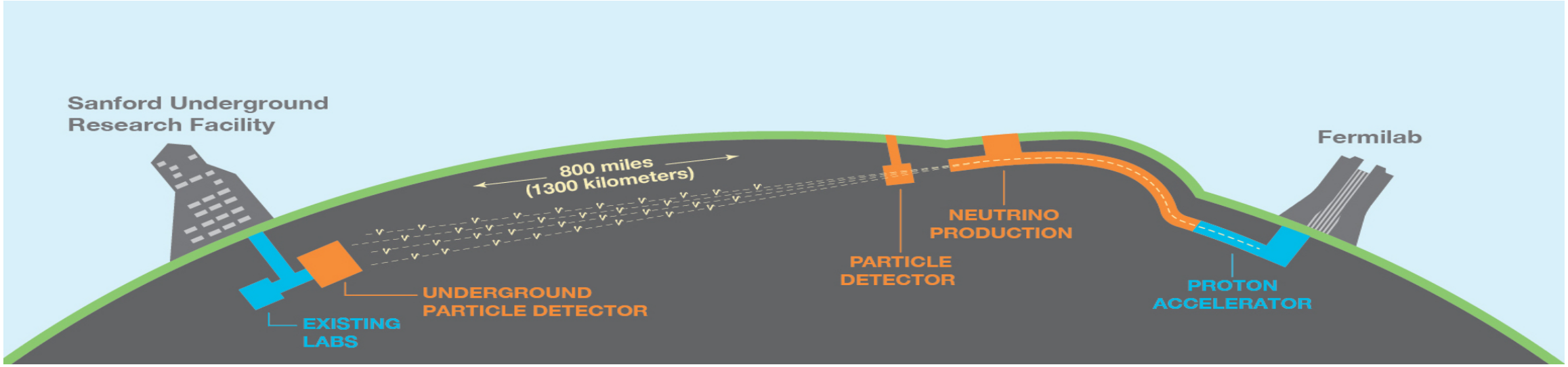
XIX International Workshop on Neutrino Telescopes
February 25, 2021

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

DUNE

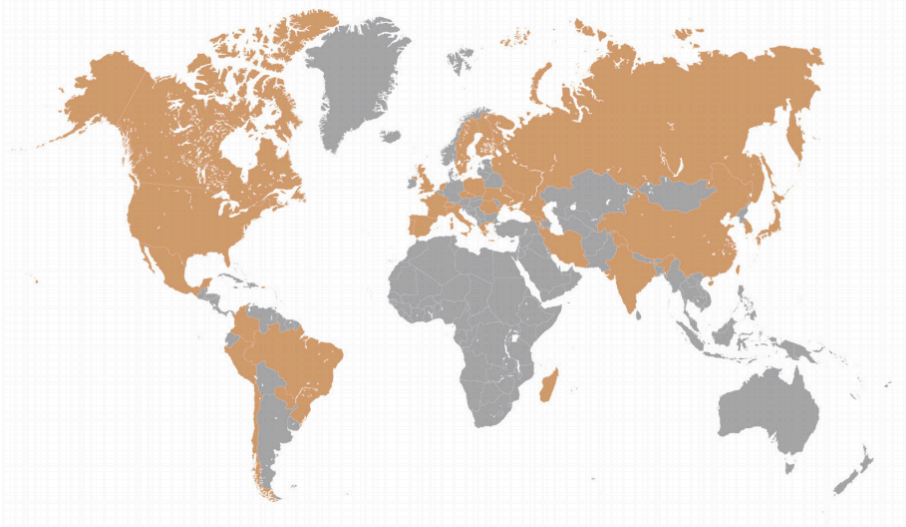
Deep Underground Neutrino Experiment

- **Long-baseline neutrino experiment:**
  - 1,300 km baseline
  - Neutrino and antineutrino beams
  - Large (70 kton) LArTPC far detector
    - 1.5 km underground
  - Near detector with LAr component
- **Primary physics goals:**
  - Three-neutrino oscillations: $\nu_\mu/\overline{\nu}_\mu$ disappearance, $\nu_e/\overline{\nu}_e$ appearance
    - δ_{CP}, θ_{23}
    - Neutrino mass ordering: normal/inverted
  - Supernova burst neutrinos
  - Beyond-Standard-Model physics: baryon number violation, sterile neutrinos, non-standard interactions, etc.



DUNE Collaboration

DUNE Virtual Collaboration Meeting
January 2021

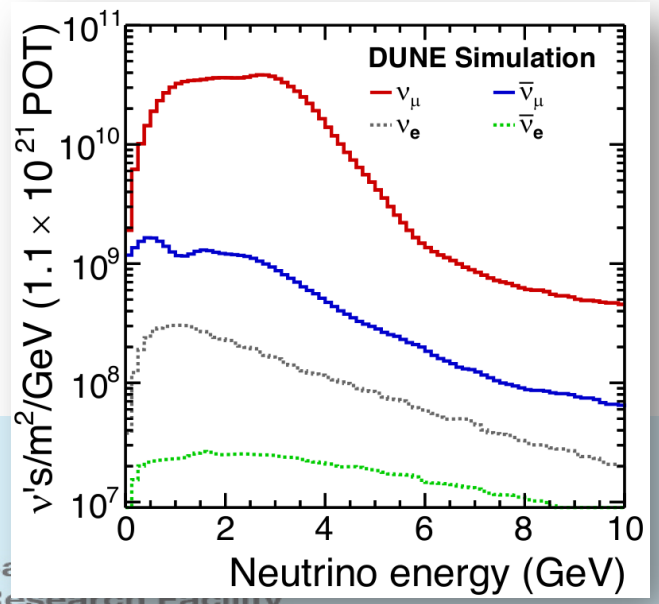


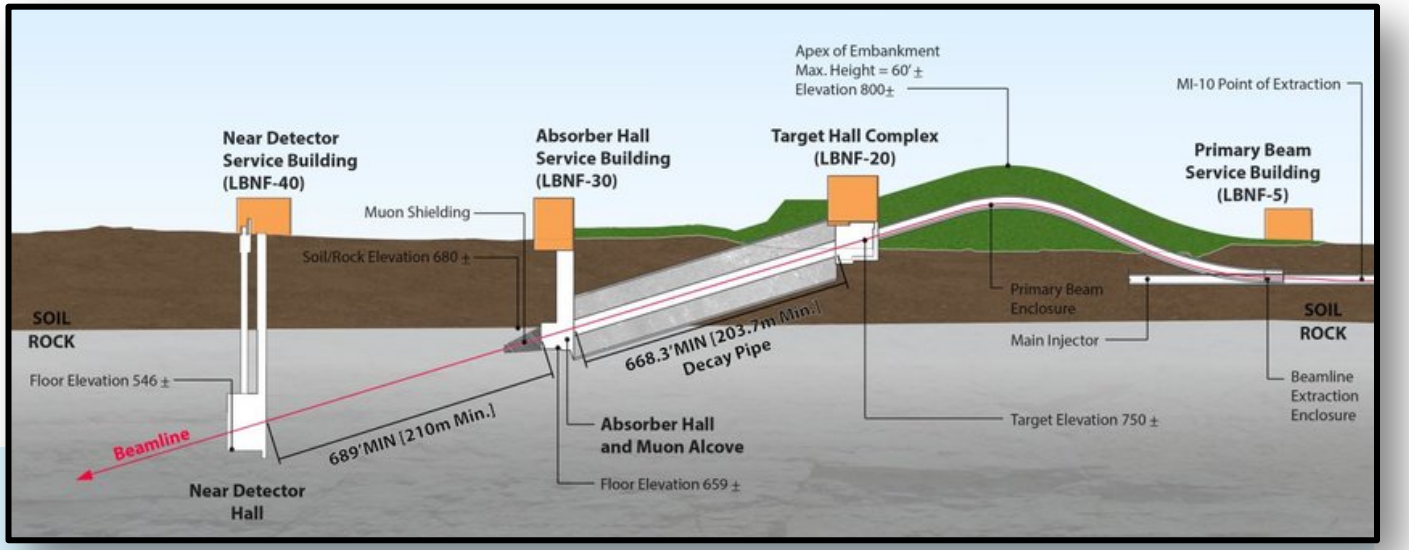
- 1298 collaborators
- 205 institutions
- 32 countries (plus CERN)

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

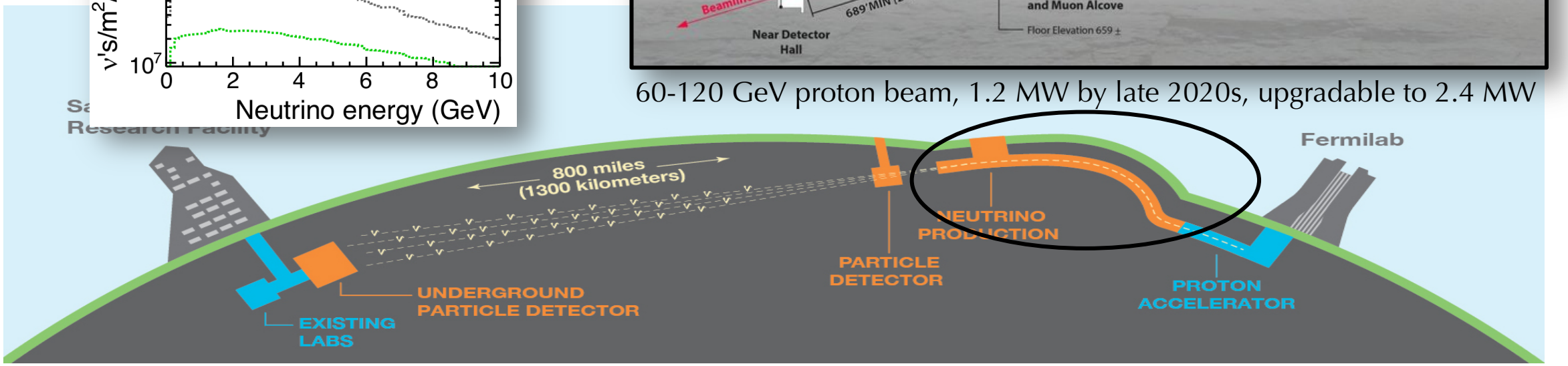
DUNE: Neutrino Beam

- DUNE's neutrino source: LBNF beam, from US Fermi National Lab (FNAL)



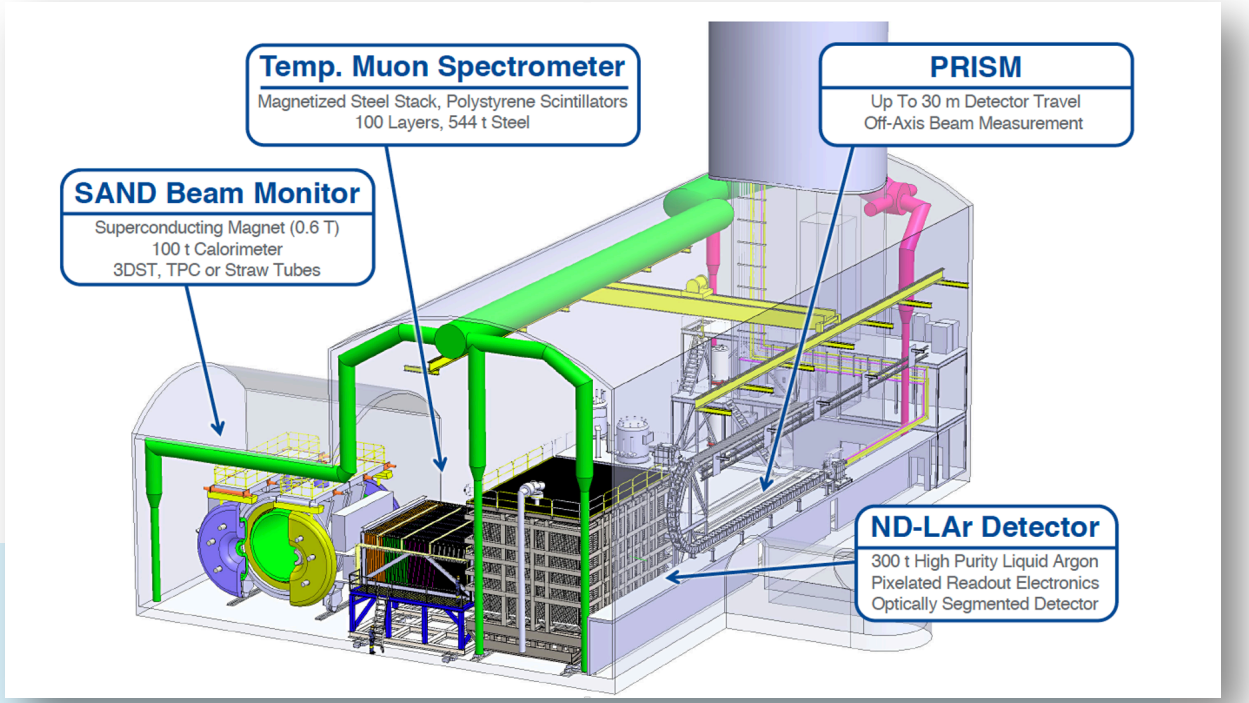


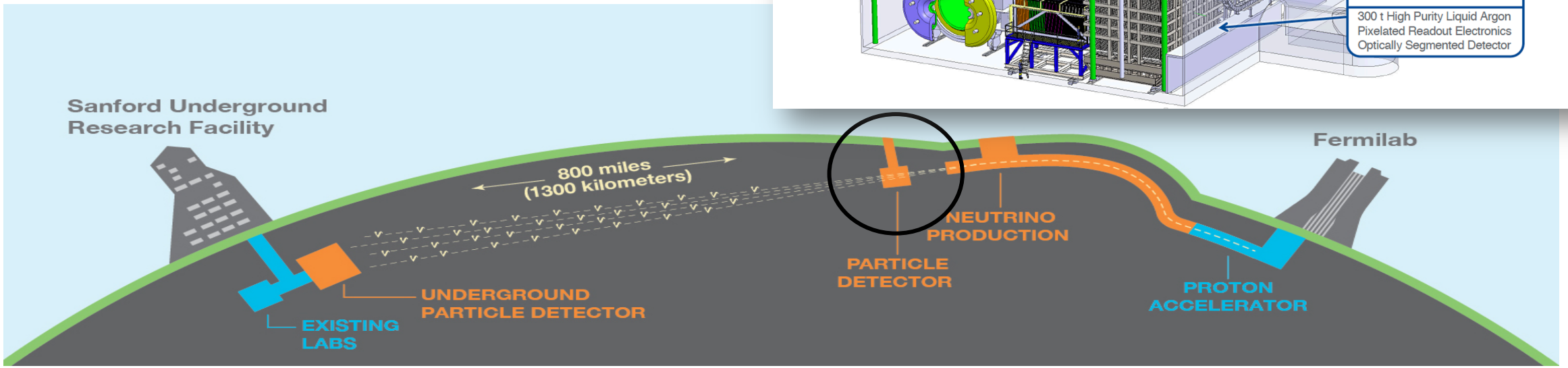
60-120 GeV proton beam, 1.2 MW by late 2020s, upgradable to 2.4 MW



DUNE: Near Detector (ND)

- **DUNE ND complex**
- Located 574 m from neutrino beam target
- Primary purpose: **characterization of neutrino beam** and **constraining of cross-section uncertainties** for long-baseline neutrino oscillation measurements



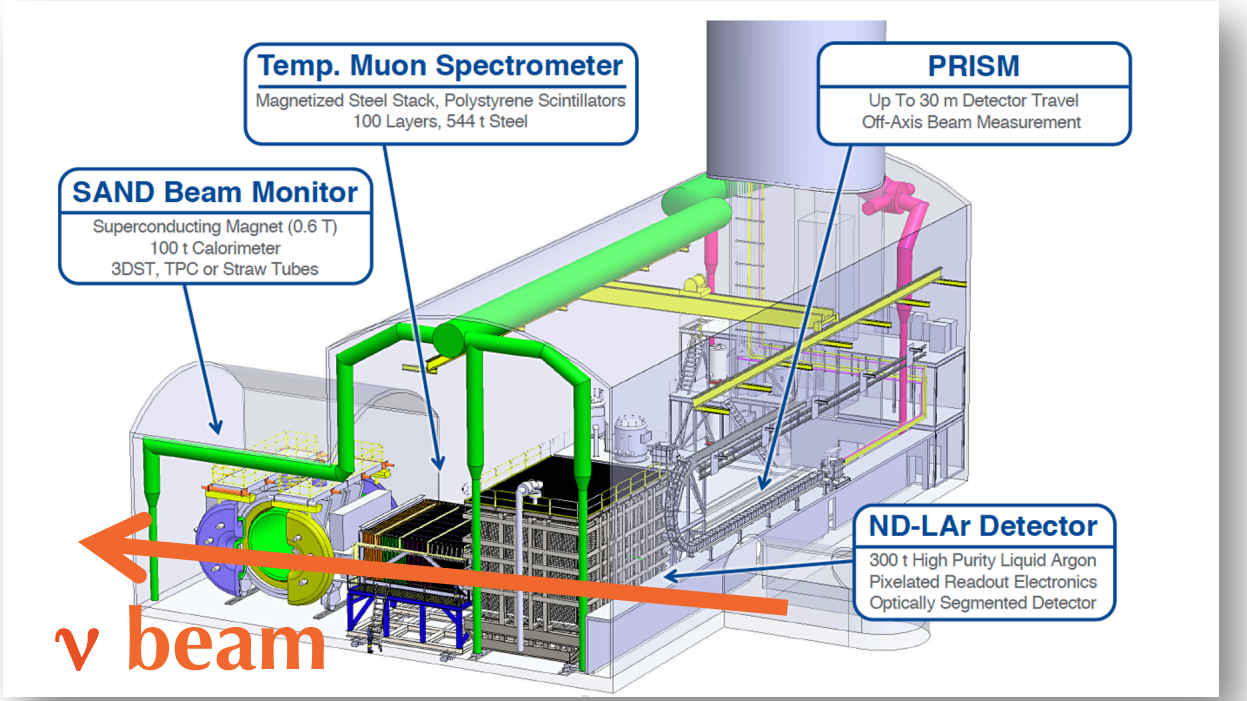


DUNE: Near Detector (ND)

- **DUNE ND complex**

  Multiple complementary systems:

  - **ND-LAr**: modular, pixelated LArTPC
    Primary target, similar to FD
  - **TMS → ND-GAr**: measures muons not captured by LArTPC → high-pressure GArTPC, surrounded by ECAL and magnet
    Muon spectrometer; nuclear interaction model constraints
  - **SAND**: tracker surrounded by ECAL and magnet
    On-axis beam spectrum/time-stability monitor

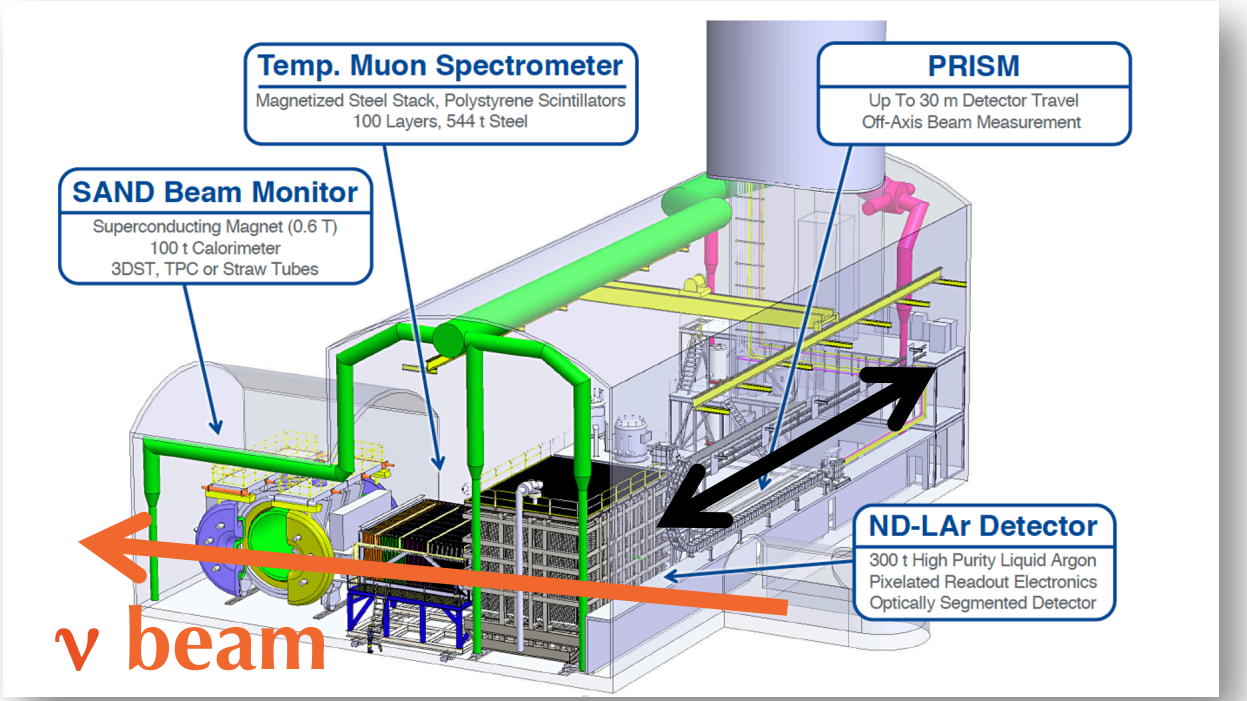


DUNE: Near Detector (ND)

- **DUNE ND complex**

  Multiple complementary systems:

  - **ND-LAr**: modular, pixelated LArTPC
    Primary target, similar to FD
  - **TMS → ND-GAr**: measures muons not captured by LArTPC → high-pressure GArTPC, surrounded by ECAL and magnet
    Muon spectrometer; nuclear interaction model constraints
  - **SAND**: tracker surrounded by ECAL and magnet
    On-axis beam spectrum/time-stability monitor

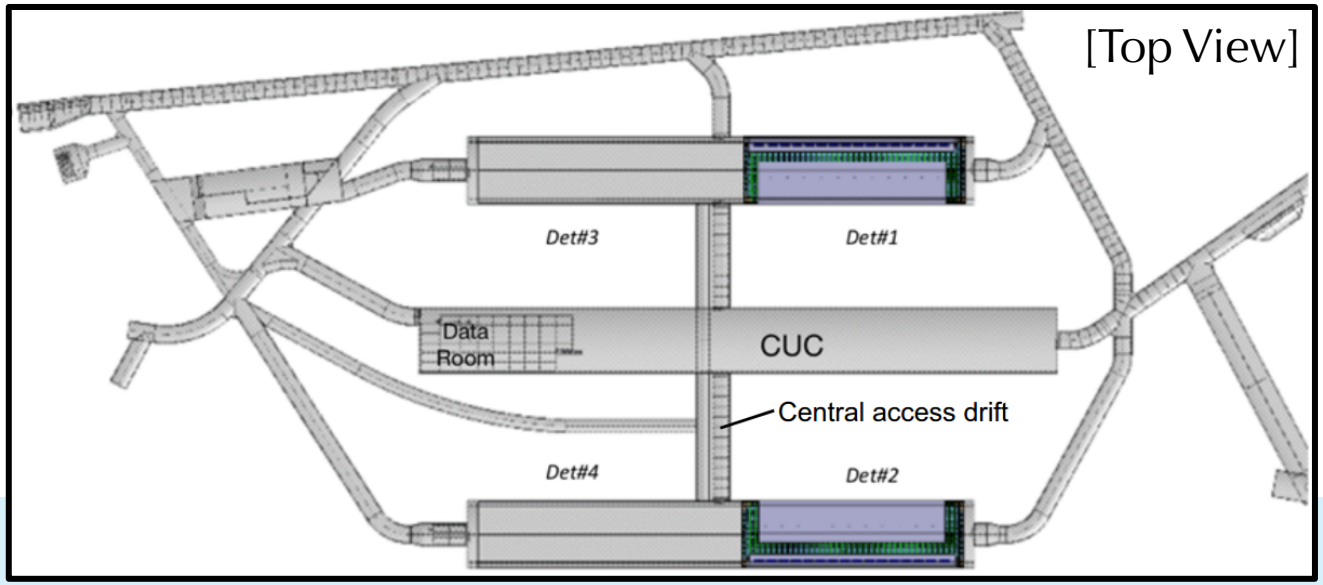


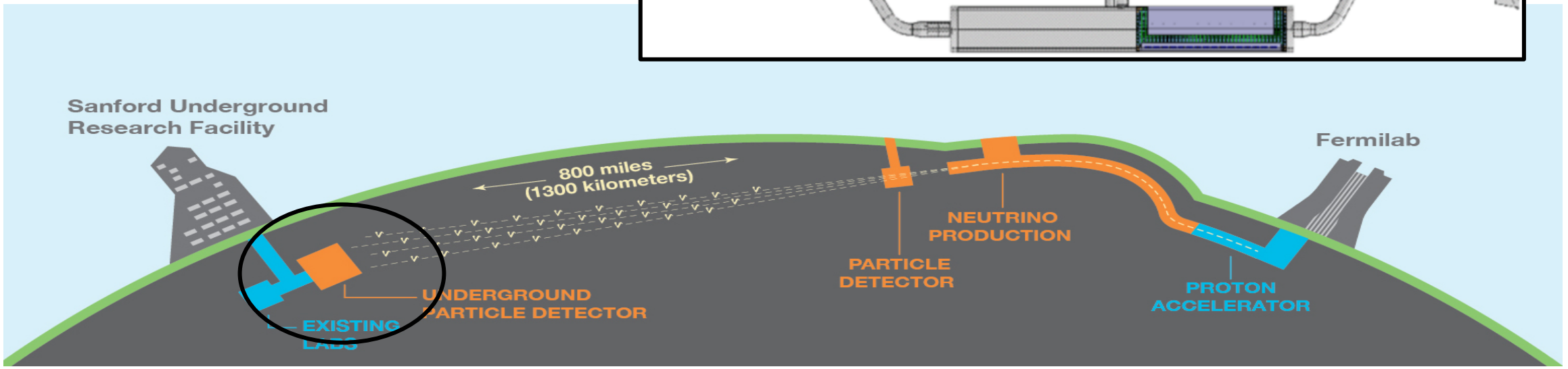
ND-LAr/TMS are **movable on/off-axis (PRISM)**

Probes different neutrino energies

DUNE: Far Detector (FD)

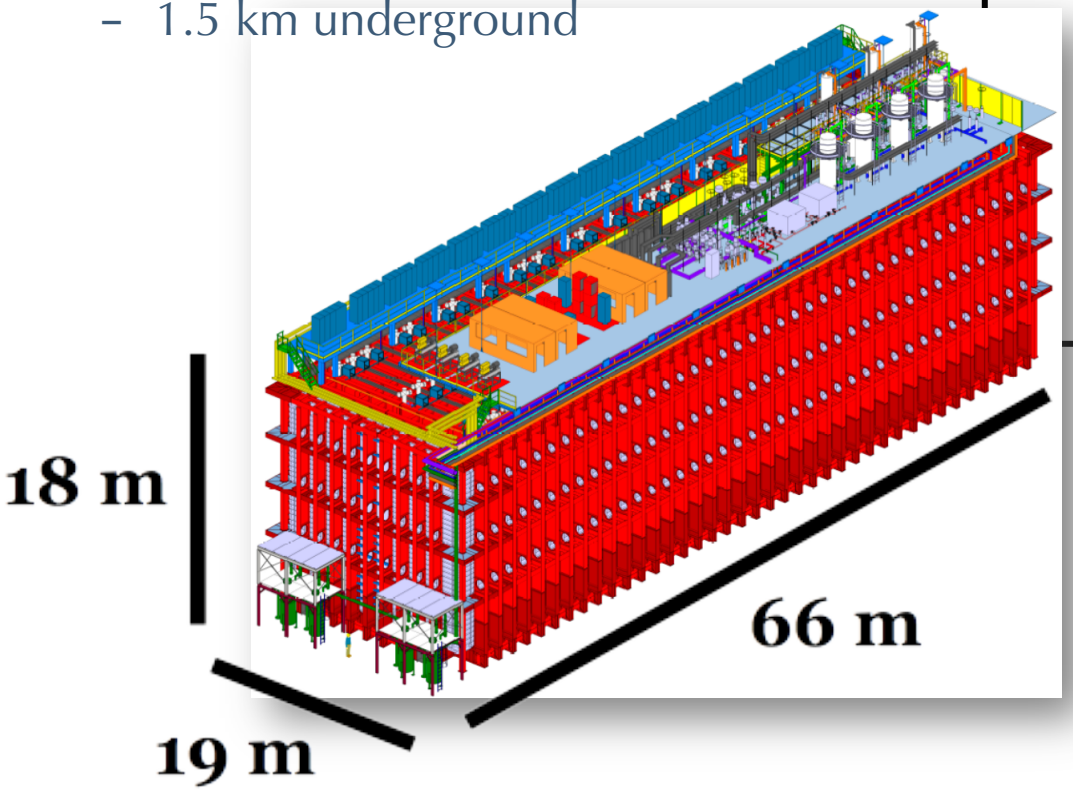
- **Four (4) LArTPC FD Modules, deployed in stages**
  - 17 kton each
  - 1.5 km underground

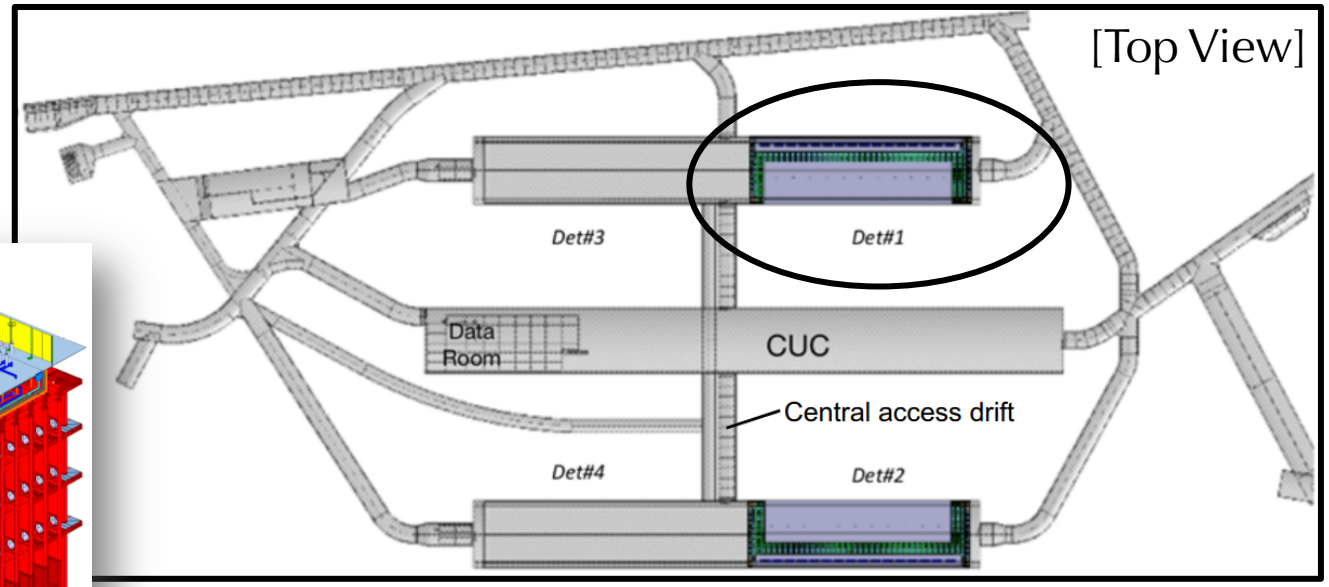




DUNE: Far Detector (FD)

- **Four (4) LArTPC FD Modules, deployed in stages**
  - 17 kton each
  - 1.5 km underground

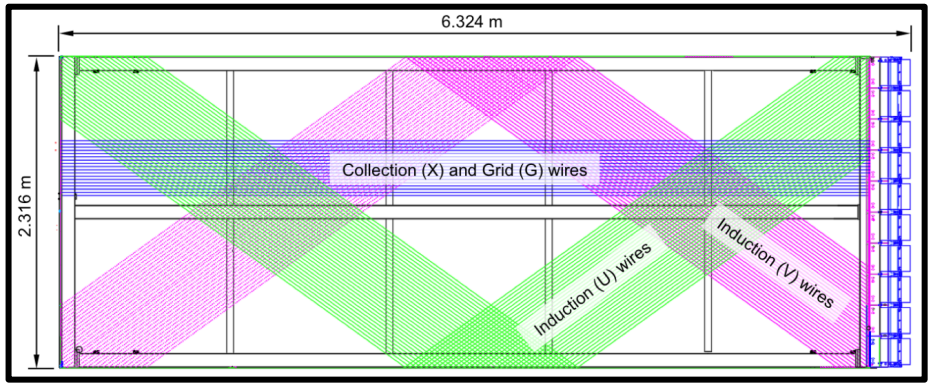




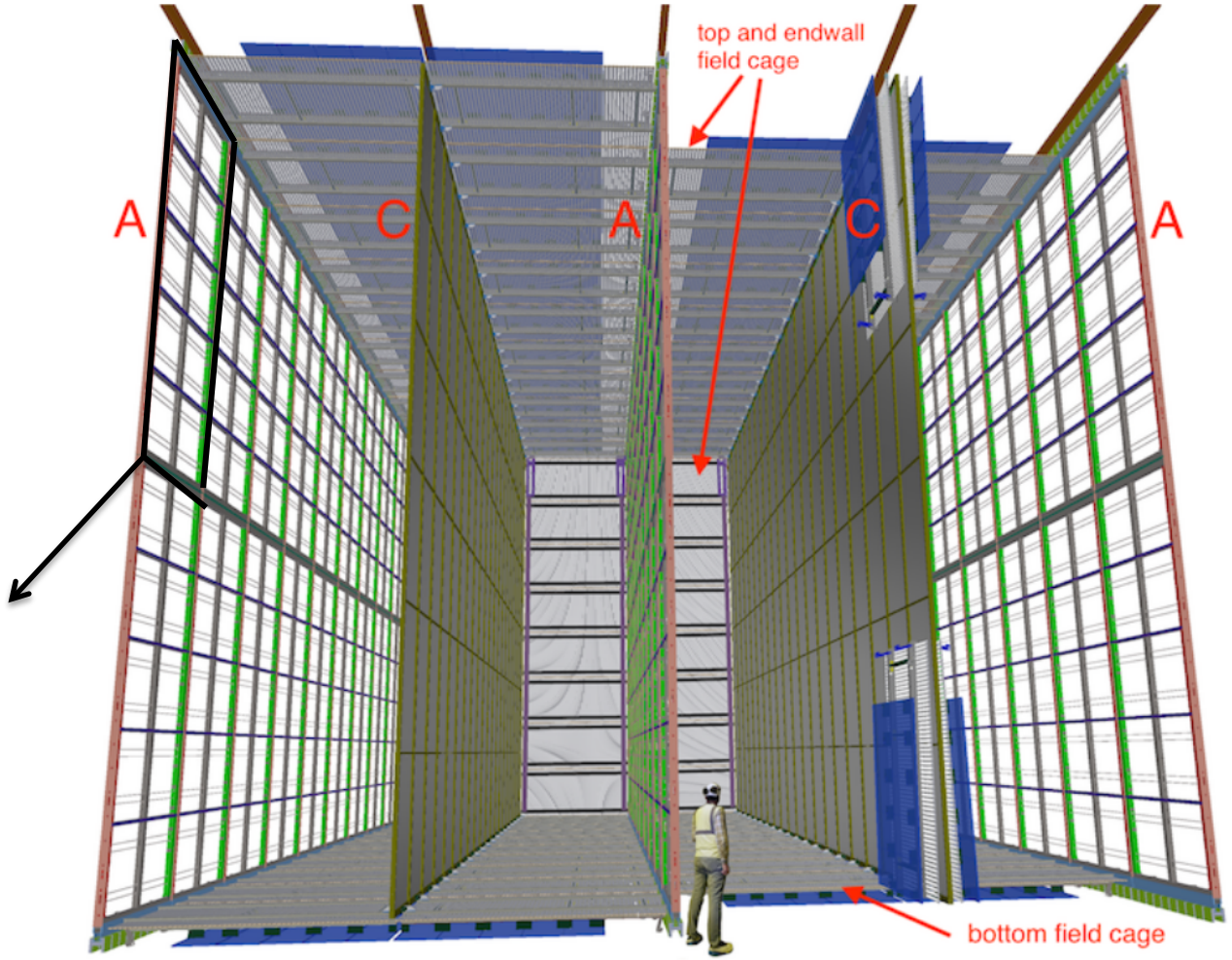
- Two far detector designs:
  Horizontal Drift and **Vertical Drift**
  (both employ liquid argon phase only)
- First detector module will be Horizontal Drift (HD)

DUNE FD HD LArTPC Module

- HD FD uses **modular drift cells** (scalability)
- Electric field: 500 V/cm, 3.6 m drift
- Suspended **Anode** and **Cathode Plane Assemblies** (APAs and CPAs)
- APA:
  - Wrapped induction wires, reducing number of readout channels, cabling complexity
  - Single plane of collection wires

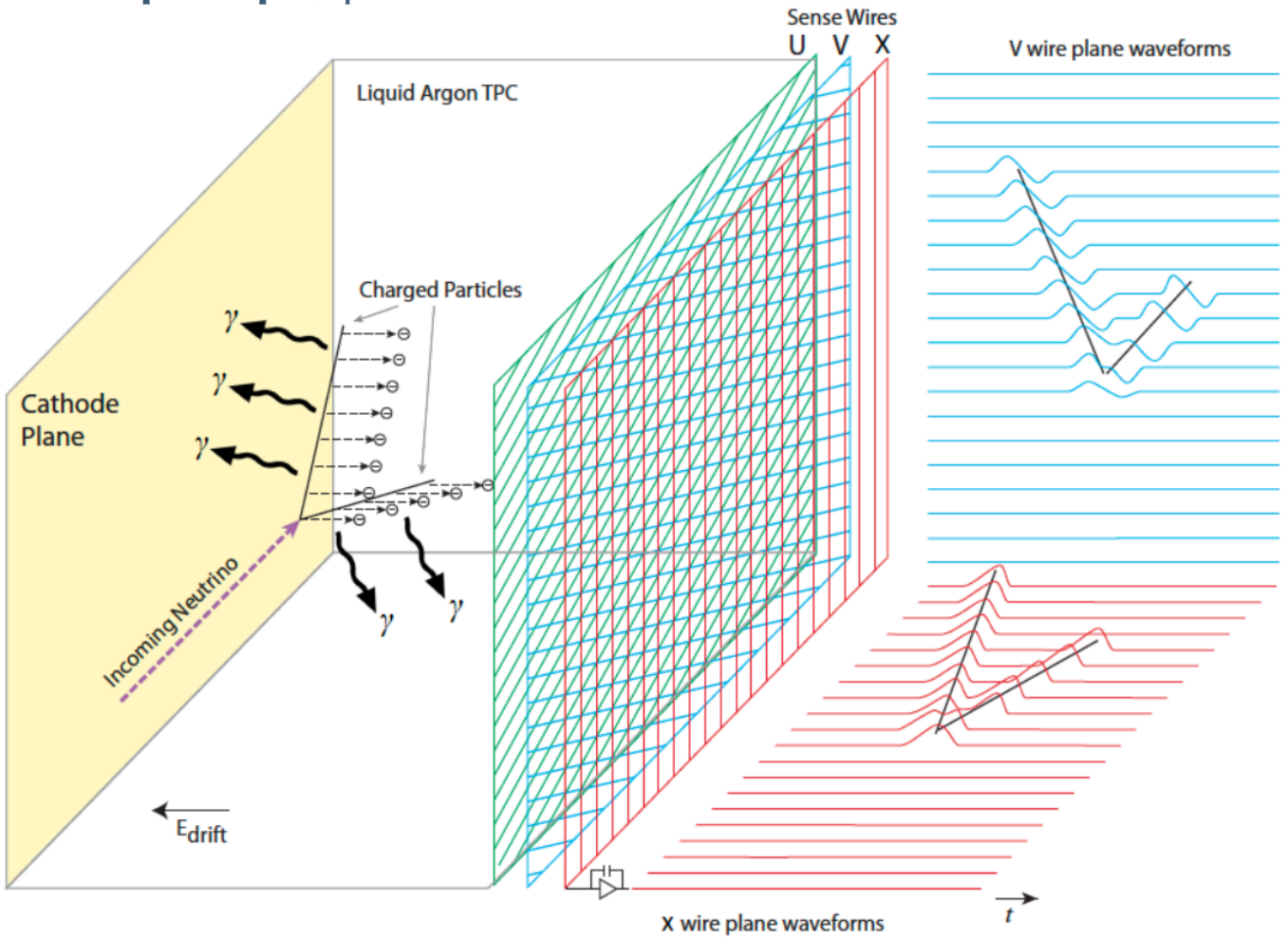


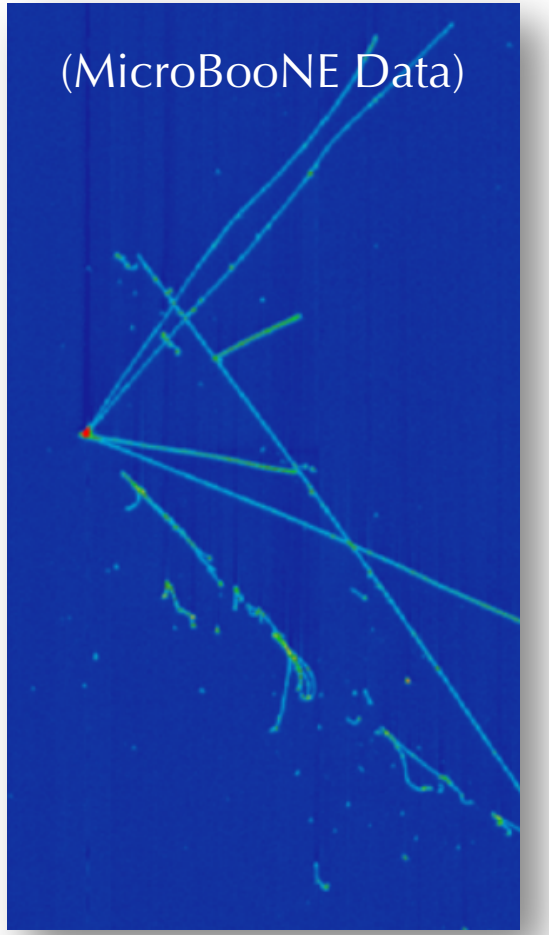
- **Photodetectors** also employed, providing timing and possibility of off-beam triggering



DUNE FD HD LArTPC Module

- **Detection principle**, per drift cell





3 images: one per wire plane provide stereoscopic 3D view of event

ProtoDUNEs at CERN

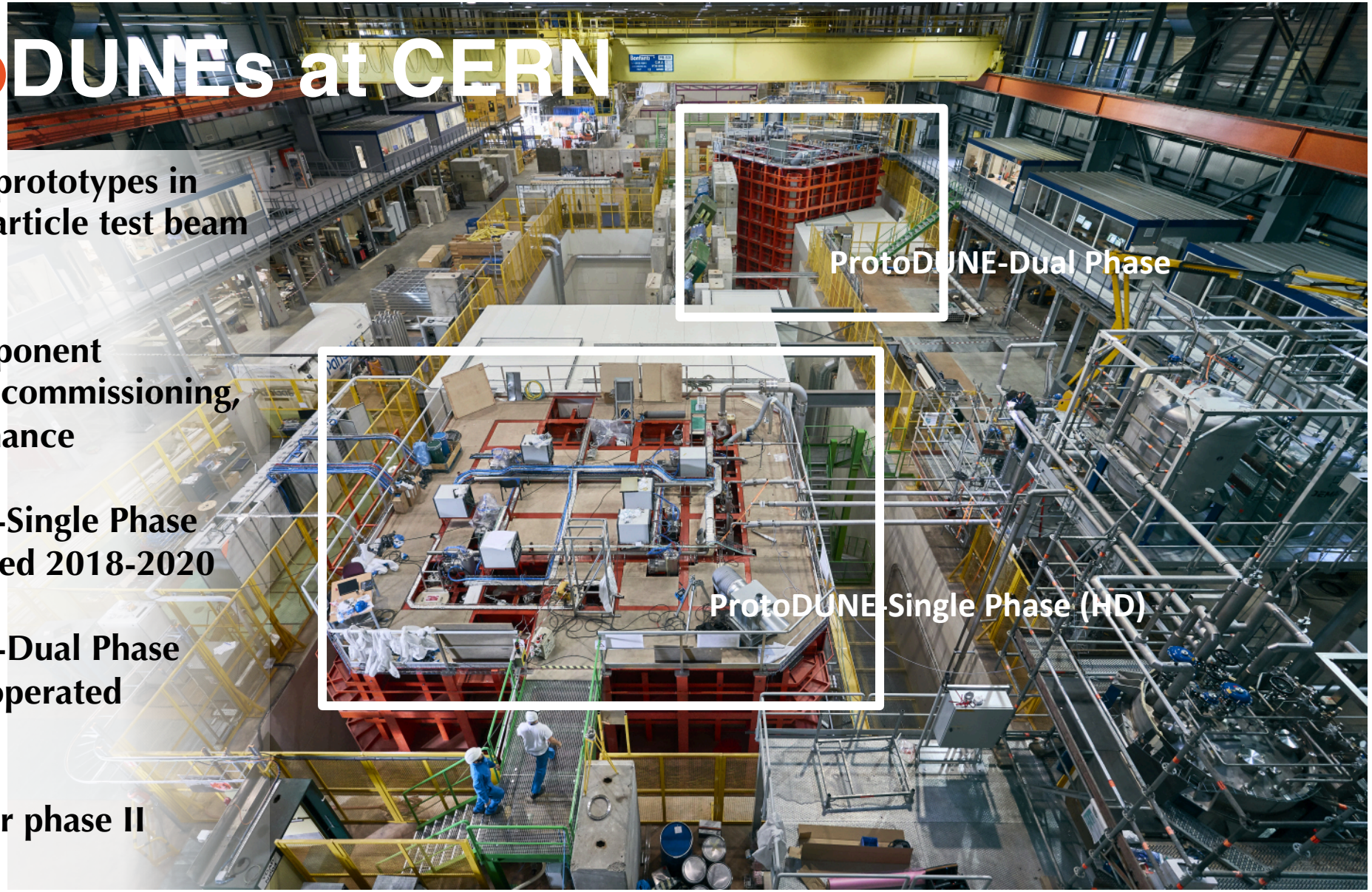
Two 1-kton prototypes in a charged particle test beam at CERN

Testing component installation, commissioning, and performance

ProtoDUNE-Single Phase (HD) operated 2018-2020

ProtoDUNE-Dual Phase (LAr+GAr) operated 2019-2020

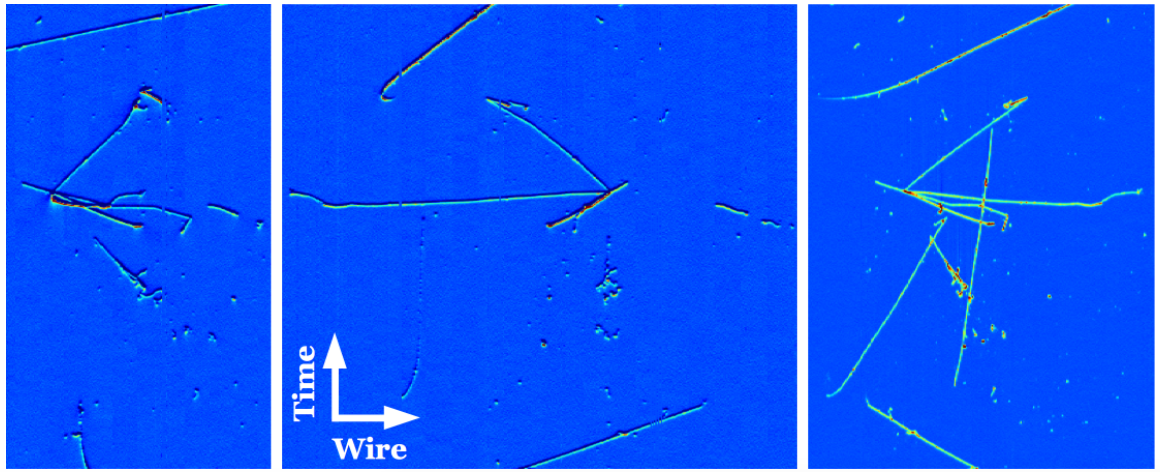
Preparing for phase II operations

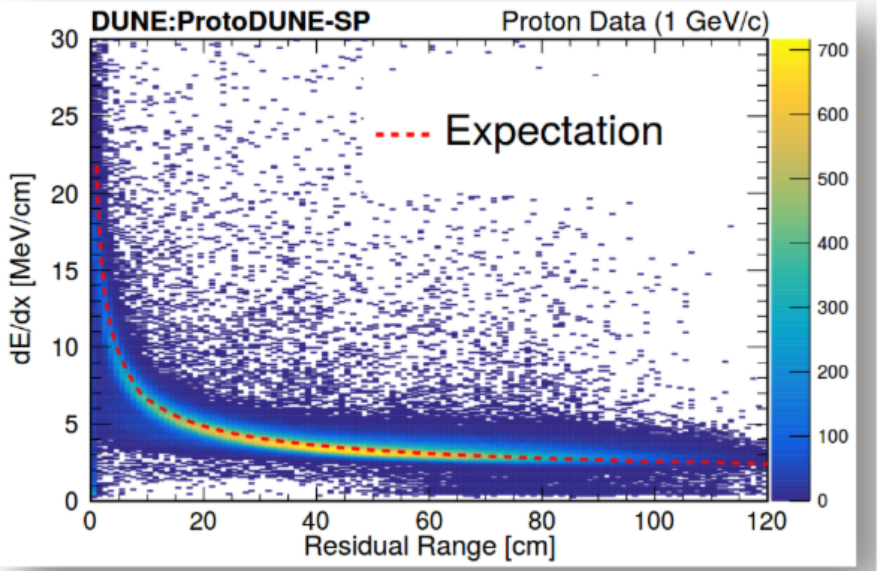


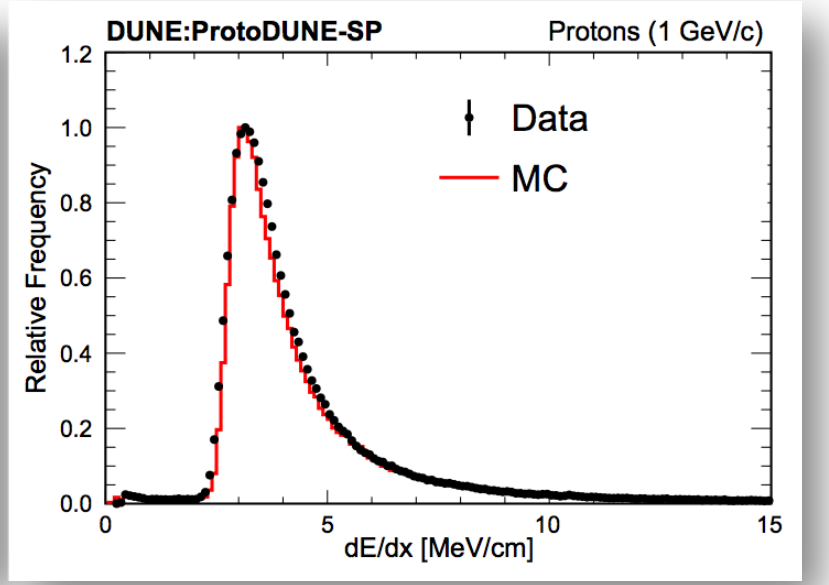
ProtoDUNE-Single Phase (HD) Results

- Low noise observed on all readout planes
- S/N ratio > 10 in all cases
  (> 40 for collection plane)
- **Stable running** since first operations began in 2018
- First results on ProtoDUNE-Single Phase (HD) performance:
  [JINST 15 (2020) 12, P12004]

First Event

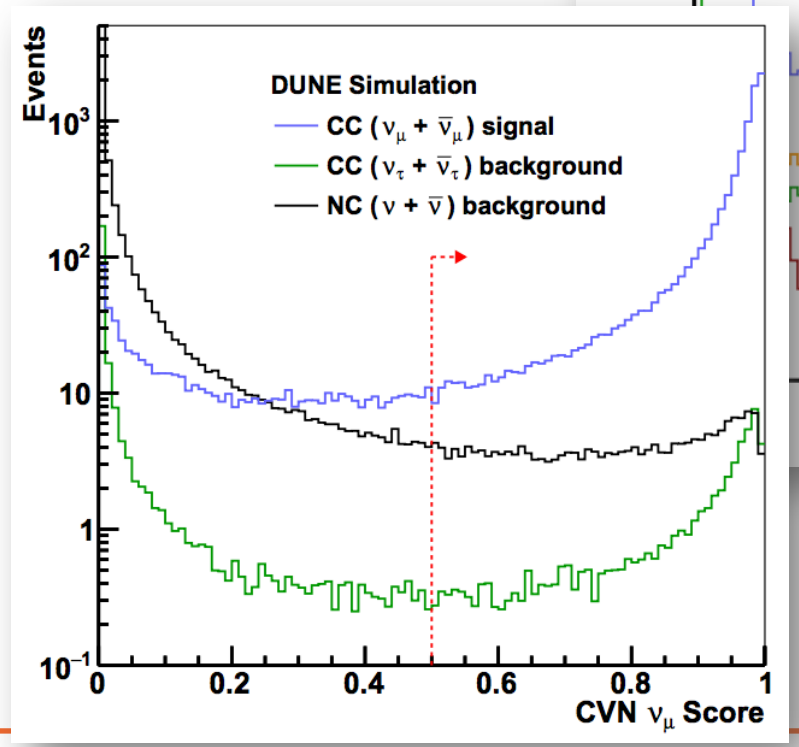


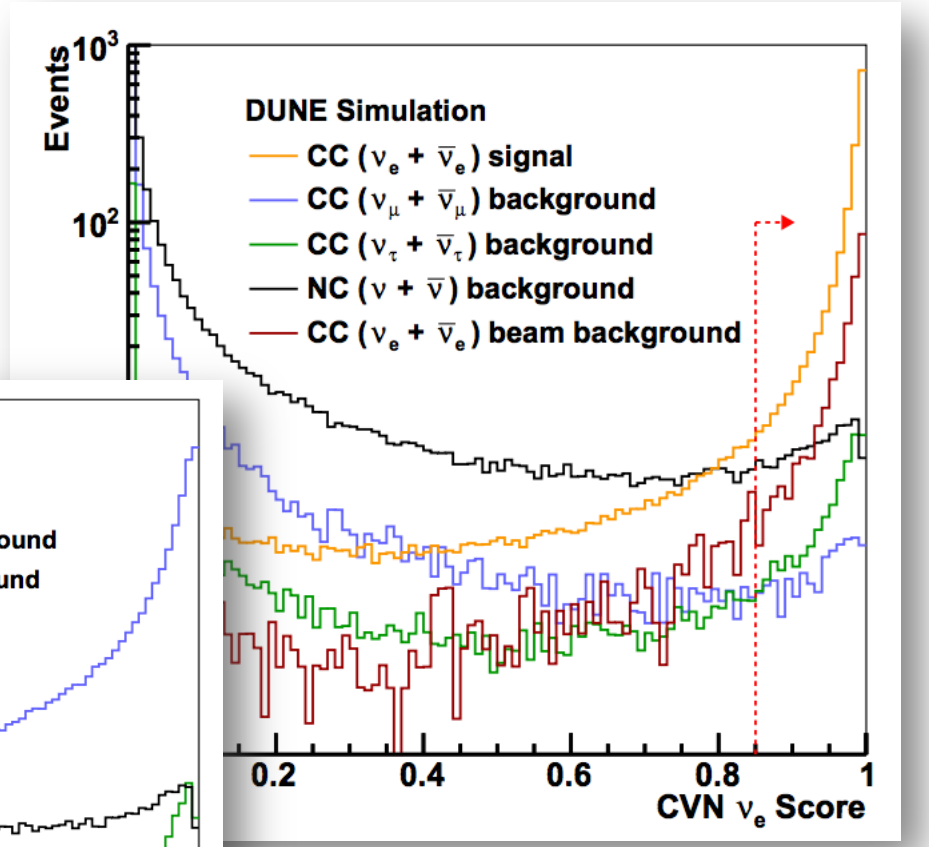




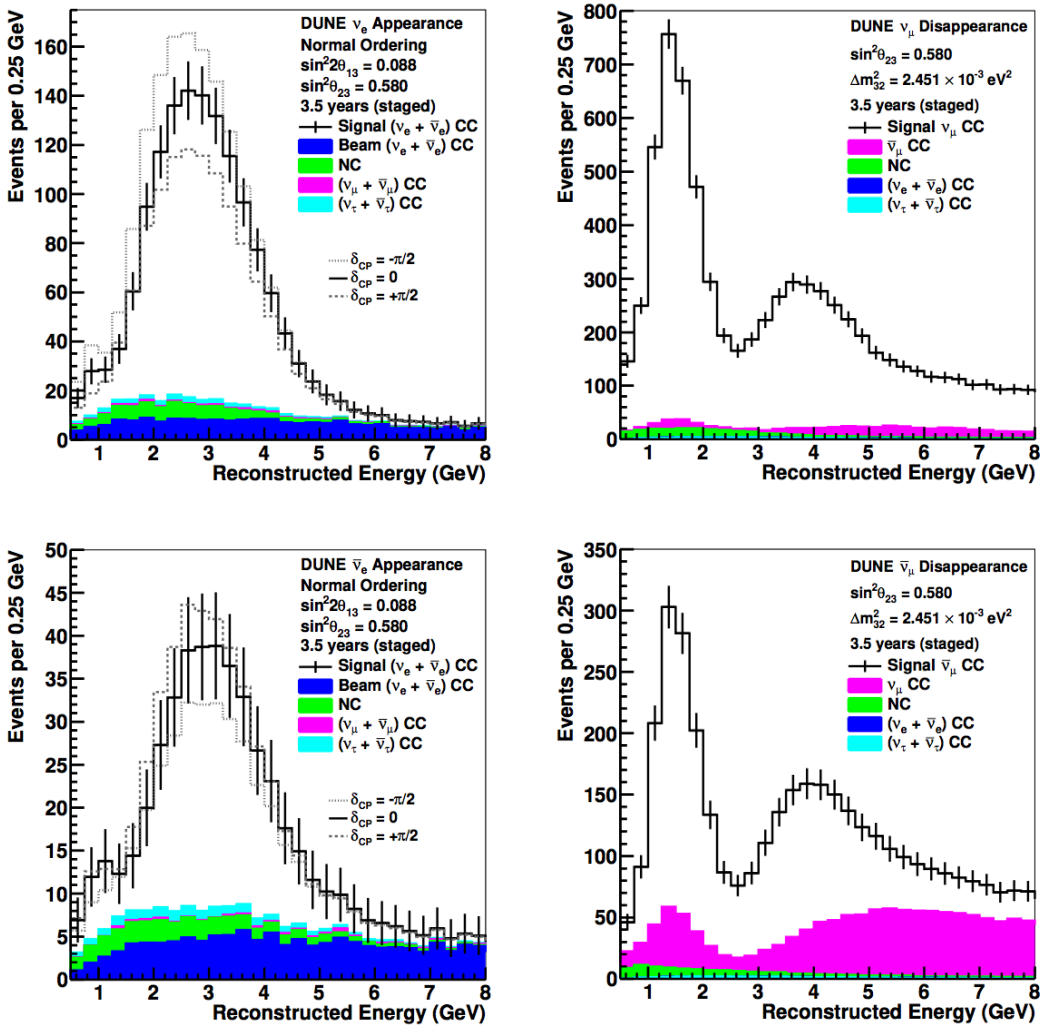
Neutrino Event Reconstruction/Selection

- Substantial progress in neutrino event reconstruction
- Machine learning/image analysis techniques lend themselves nicely to data processing/pattern recognition for reconstructing and identifying neutrino events in 3D
  - Use of convolutional neural networks (CNNs) for classifying events (images): 80-90% efficiency for both ν_μ and ν_e selections; low misidentification rates
  - PRD 102 (2020), 9, 092003





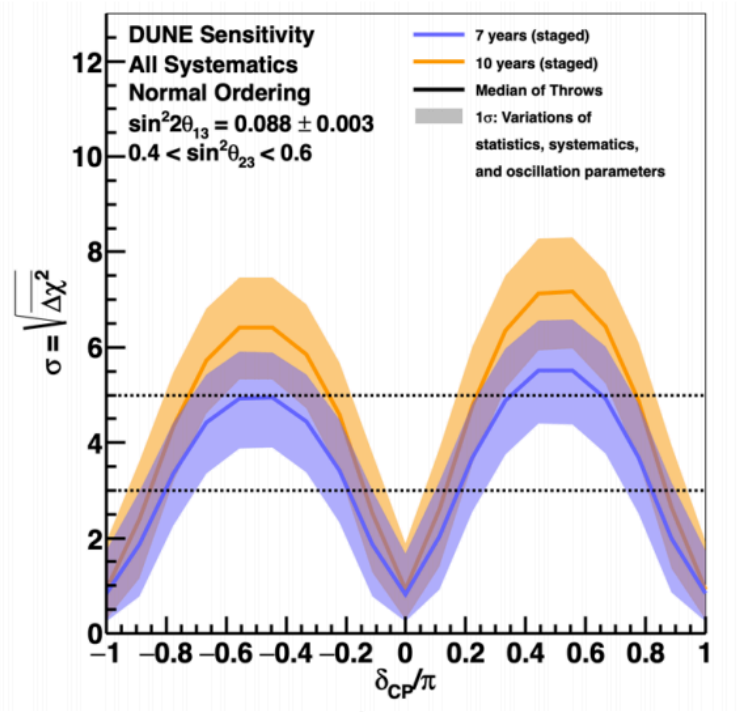
Physics Prospects: Neutrino Oscillations



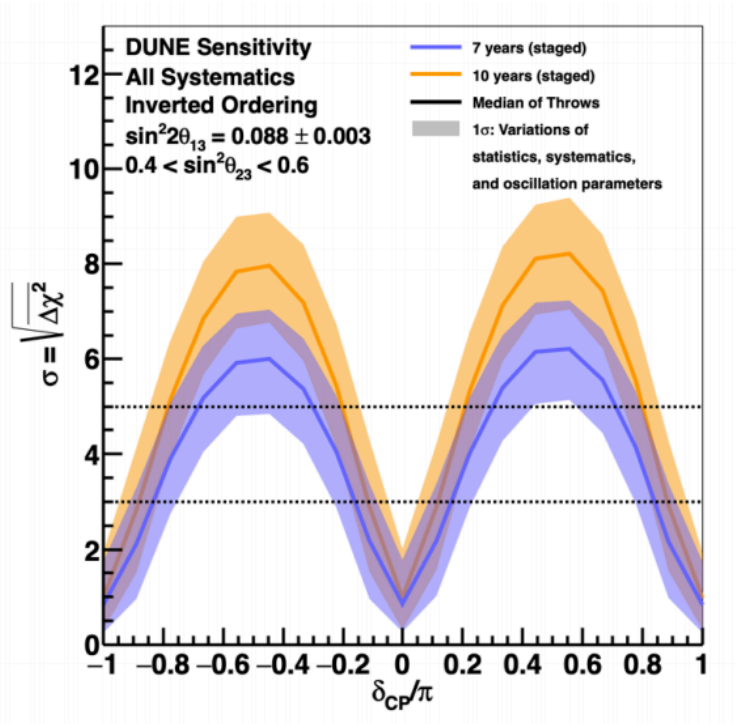
- Measurement and simultaneous fit over four components of FD data, with ND constraints
- Sensitivity assessment includes full FD systematics treatment (flux, cross-section, and detector)
- EPJC (2020) 10, 978

CP Violation Sensitivity

True Normal Ordering



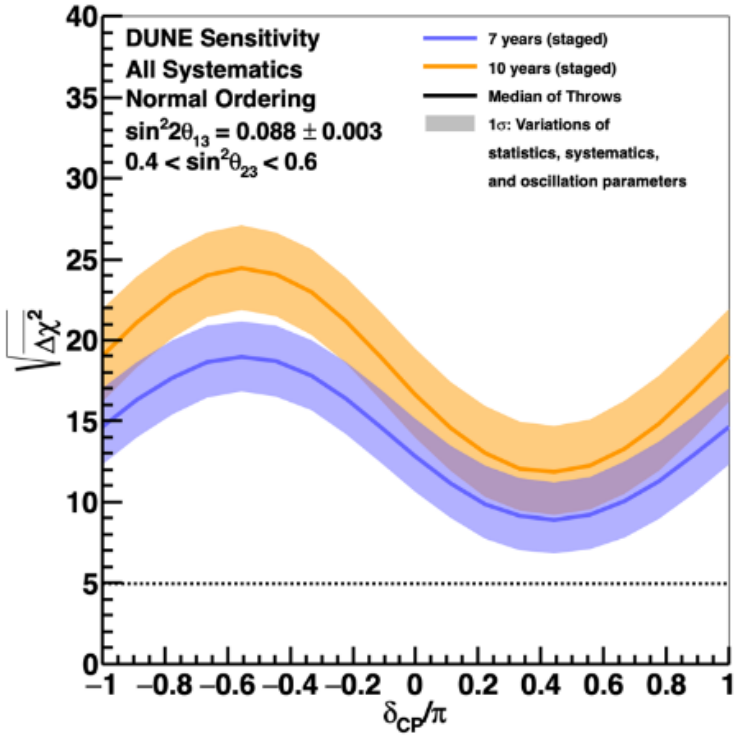
True Inverted Ordering



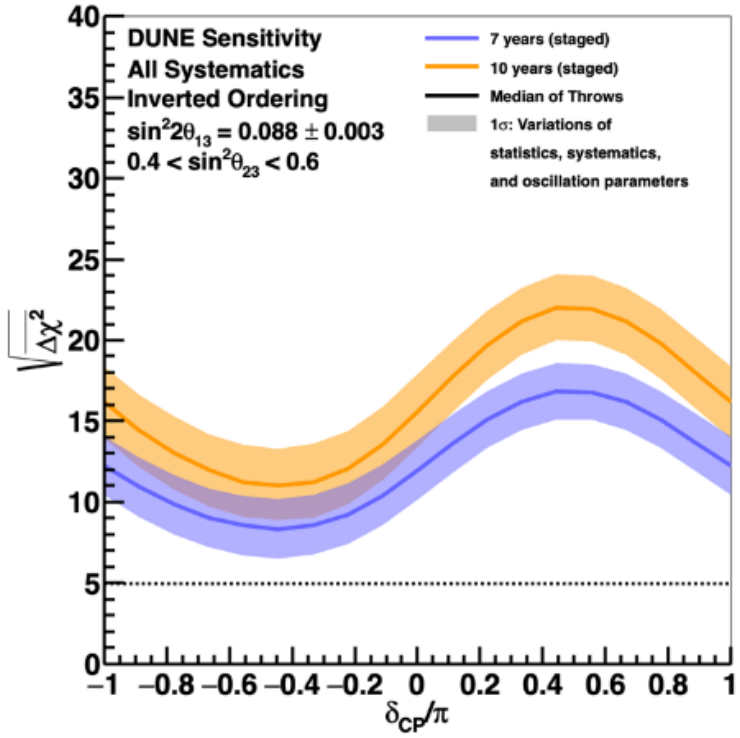
- Significant CP violation discovery potential over a large range of possible true δ_{CP} values in 7-10 years of (staged) running

Mass Hierarchy Sensitivity

True Normal Ordering



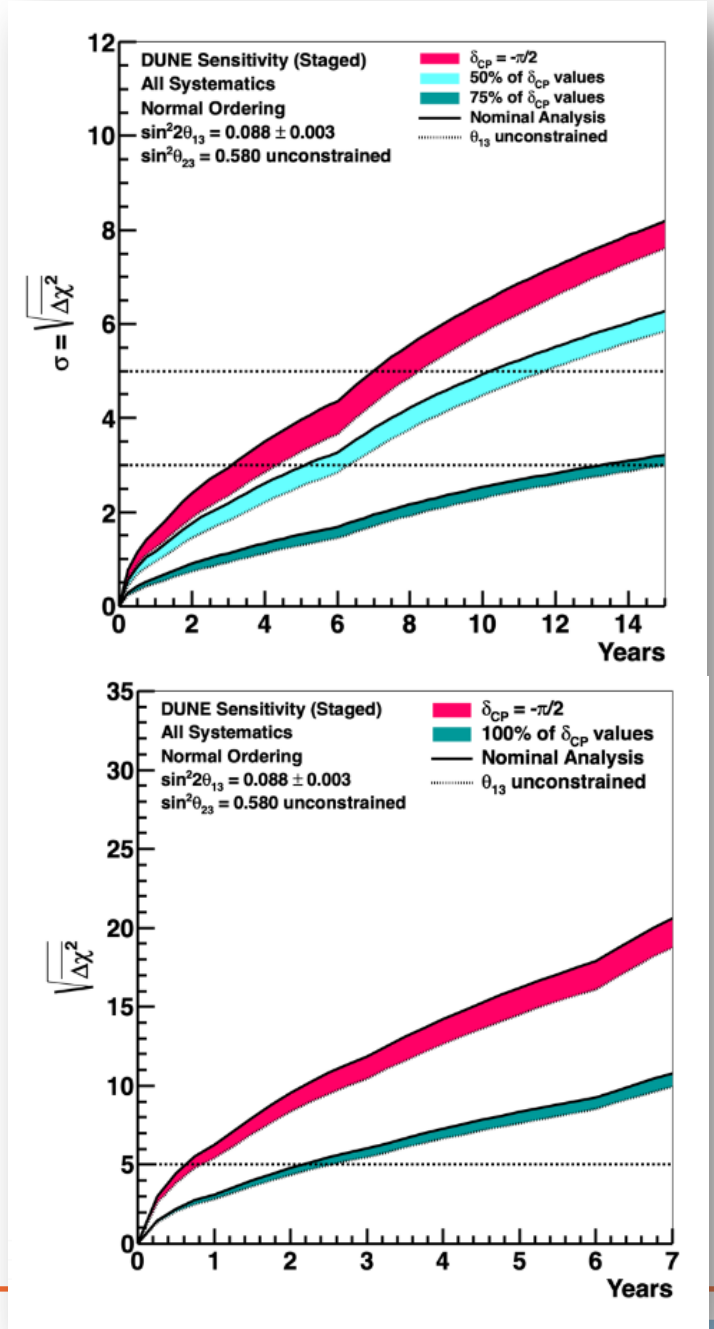
True Inverted Ordering



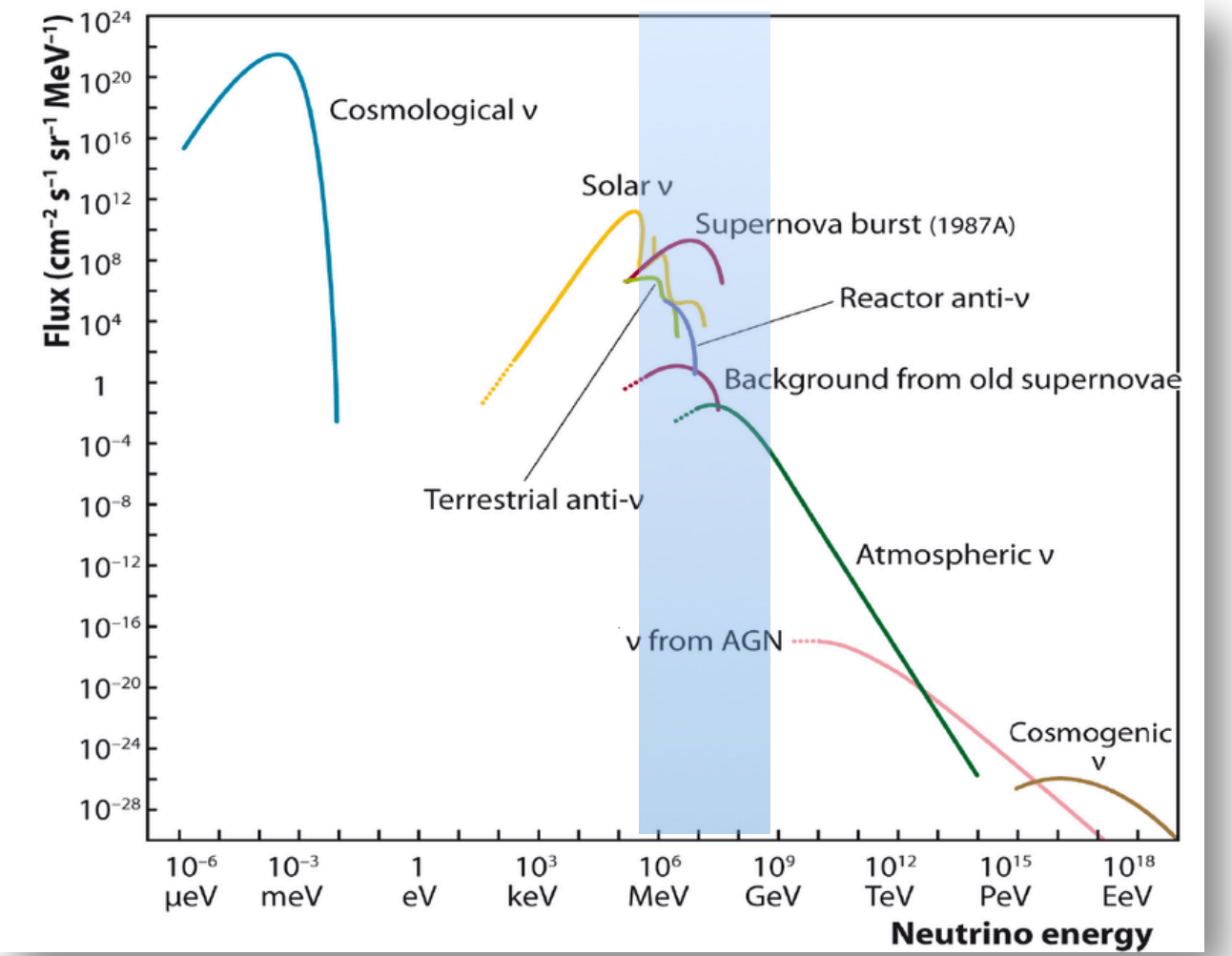
- Definitive determination of neutrino mass hierarchy (normal or inverted) for all possible parameters

Time-projected Sensitivity

- Assumes **nominal staging** as described in the DUNE Technical Design Report
- Width of each band represents sensitivity with and without reactor experiment constraints on θ_{13}
- **Unambiguous determination of mass hierarchy within the first 2-3 years**
- **Significant milestones throughout the beam physics program**
  - CPV discovery if true $\delta_{CP} = -\pi/2$ in ~7 years
  - CPV discovery for 50% of true δ_{CP} values in ~10 years



Beyond beam neutrinos: DUNE as "NeuTel"



- The DUNE FD will be sensitive to cosmic neutrinos from MeV to tens of GeV in energy
  - Stellar core-collapse supernova neutrinos
  - Solar neutrinos?

Physics Prospects: Supernova Neutrinos

- Dominant interaction on argon:

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

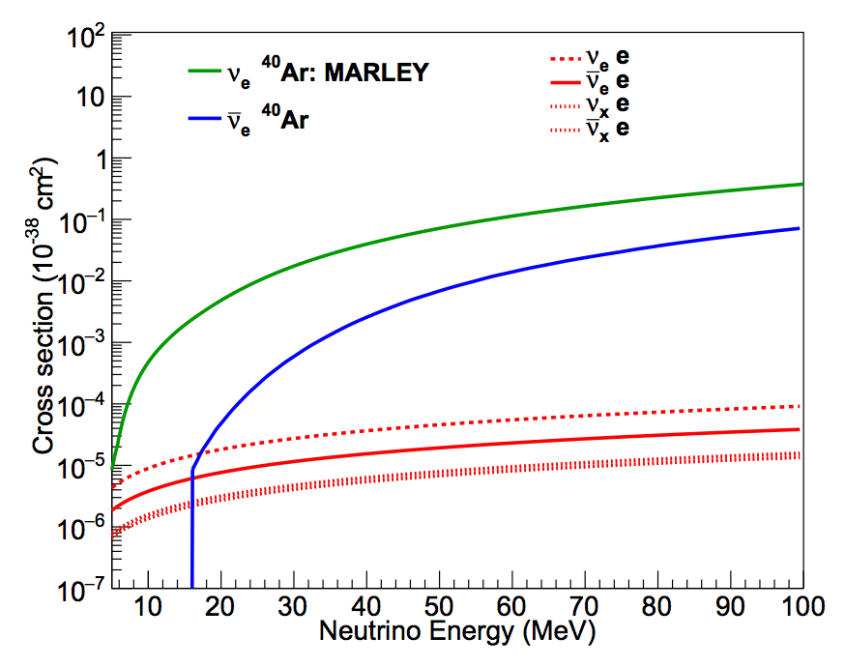
short electron track

nearby de-excitation gammas, Compton scattering

- Unique sensitivity to electron neutrinos from a supernova!

- In case of a **galactic supernova**, DUNE expects to observe up to thousands of neutrino interactions over the duration of the burst

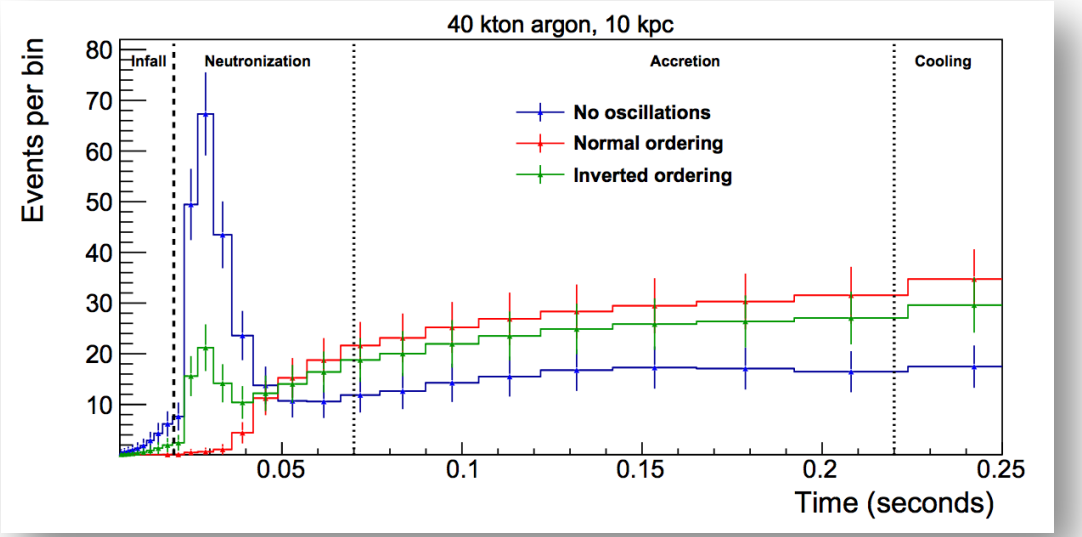
- arXiv:2008.06647

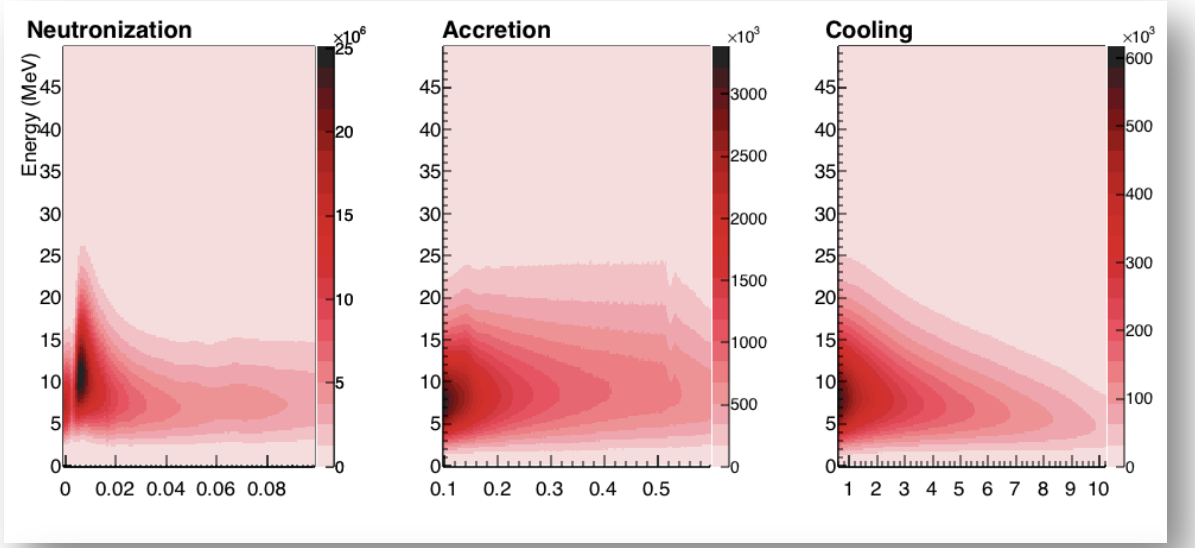


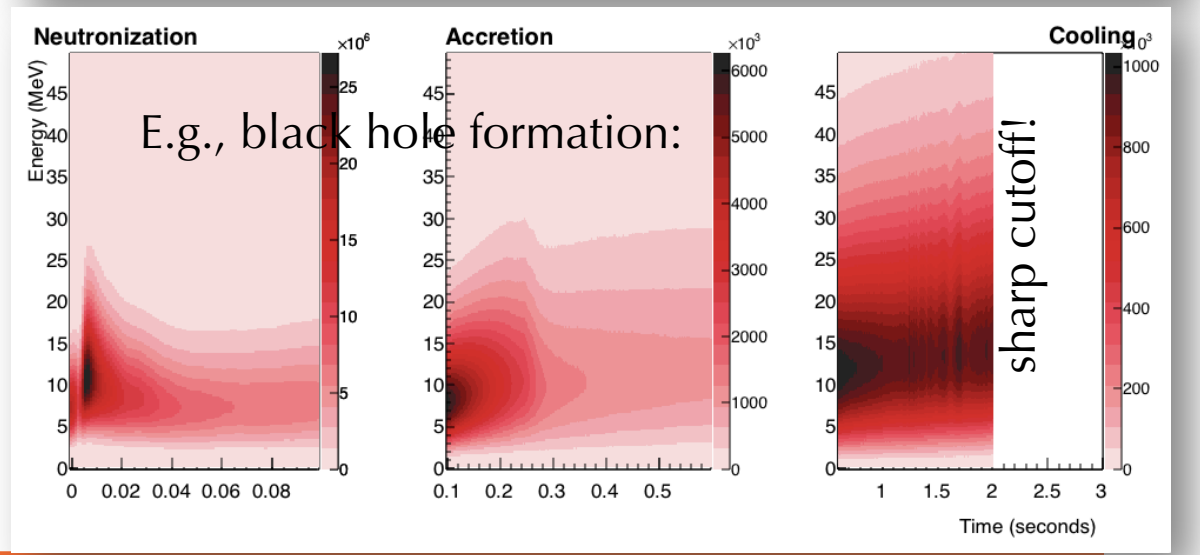
Channel	Liver-more	GKVM	Garching
$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	2744	3412	918
$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$	224	155	23
$\nu_X + e^- \rightarrow \nu_X + e^-$	341	206	142
Total	3309	3773	1083

Physics Prospects: Supernova Neutrinos

- Observed event rates access information on supernova physics/dynamics, e.g.:
  - Spectral parameter determination
  - Collective effects/shock wave
  - Strange star formation
  - Standing Accretion Shock Instability (SASI) oscillations
  - Neutrino trapping
- As well as on neutrino properties!

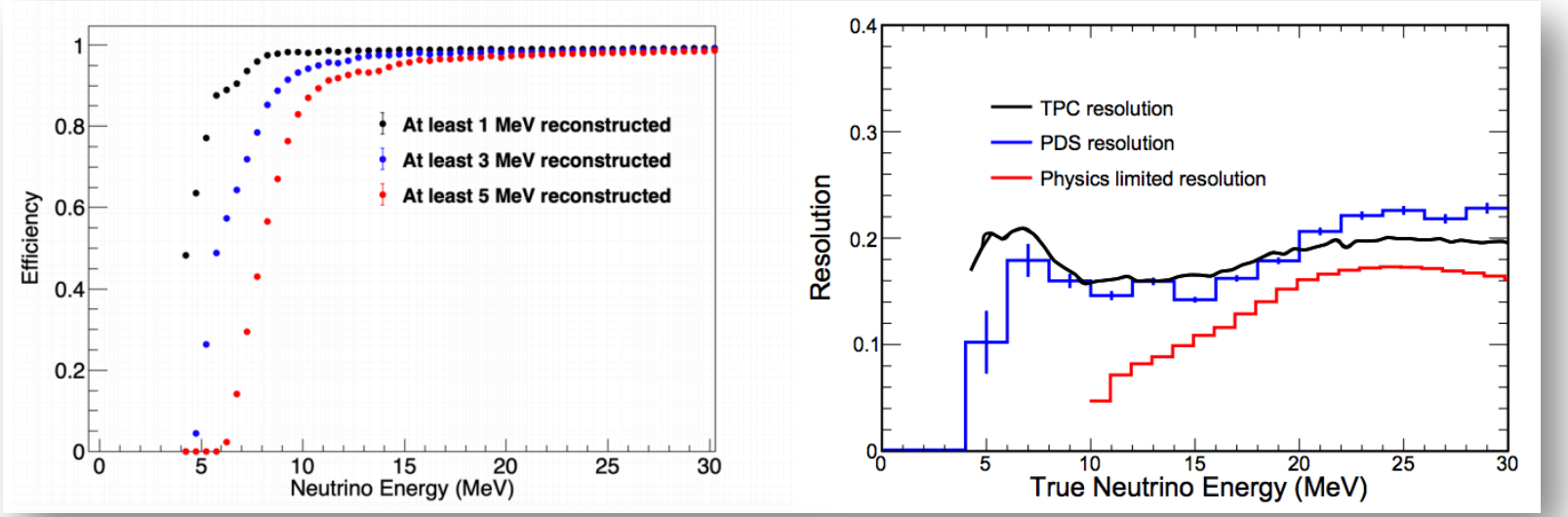


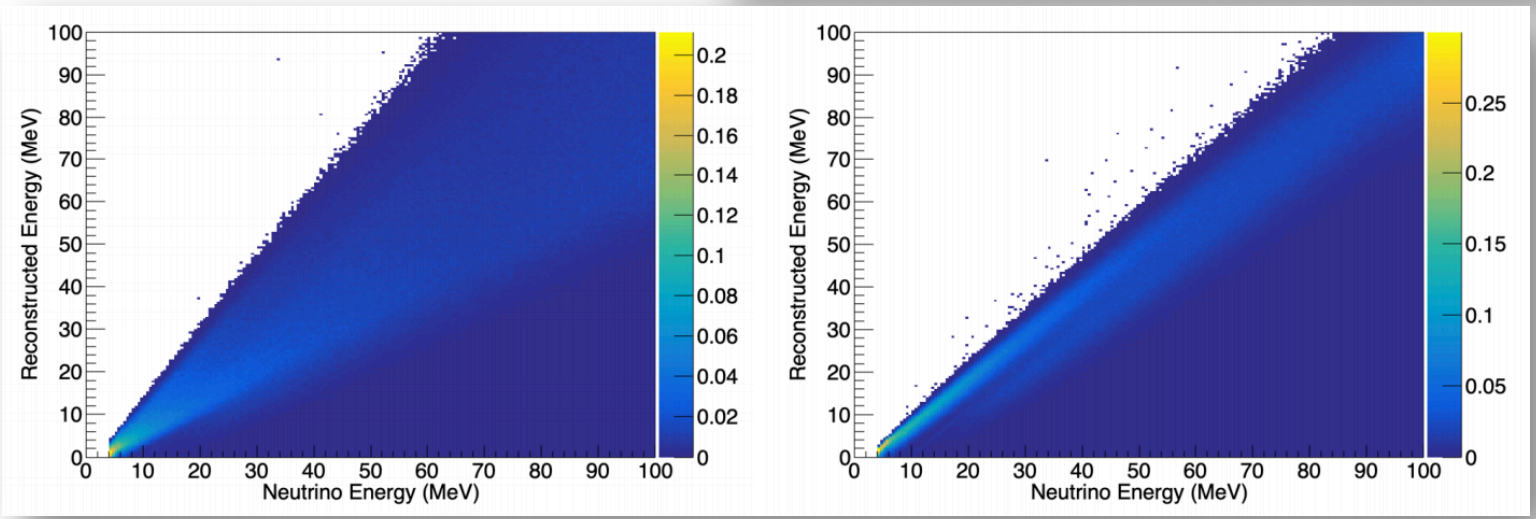




Physics Prospects: Supernova Neutrinos

- High reconstruction efficiency for supernova neutrino energy range, 15-20% energy resolution with both TPC and photodetectors





- Improvements in energy resolution with inclusion of light-based drift correction

Physics Prospects: Supernova Neutrinos

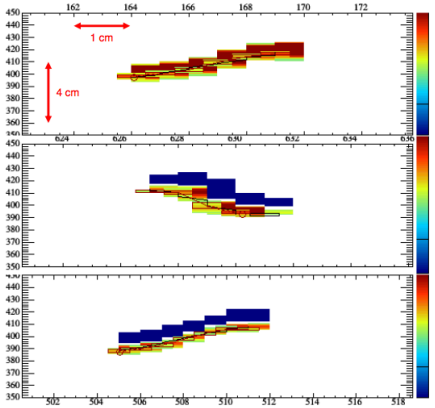
- **Supernova pointing:**

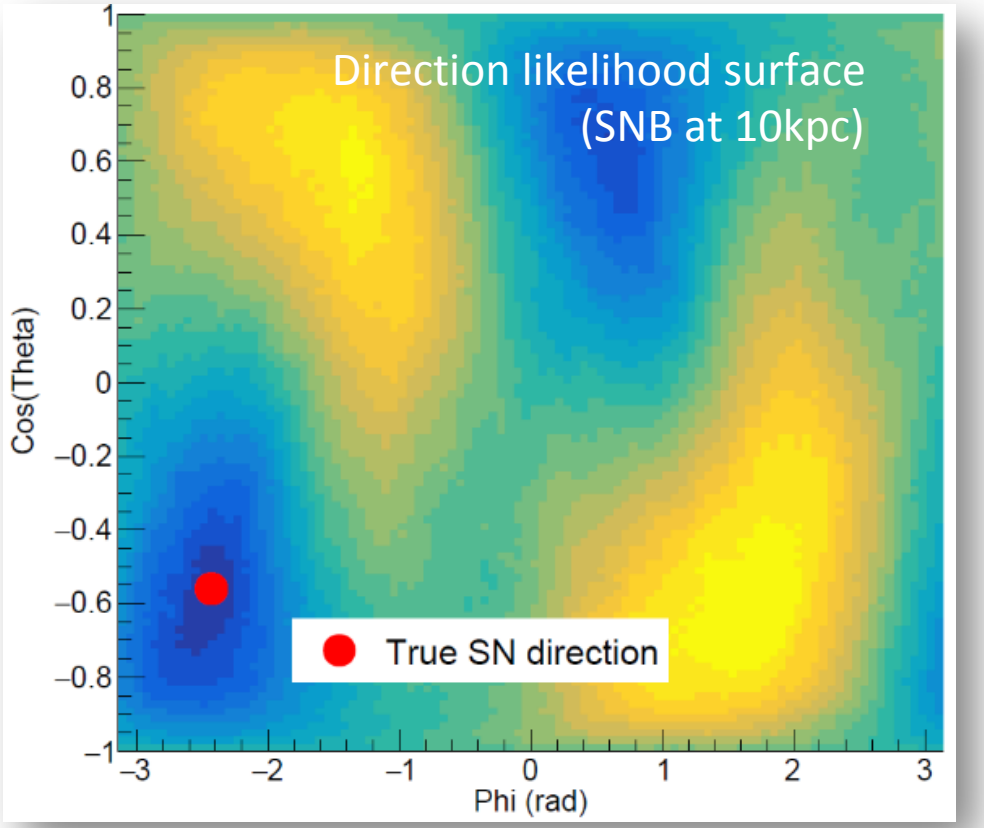
  neutrino-electron elastic scattering provides sensitivity to neutrino directionality

  4.5° pointing resolution is achievable

  Ongoing: understanding latency for online/semi-online directionality determination (+ trigger efficiency optimization studies)

10 MeV electron (Simultation+Reconstruction)

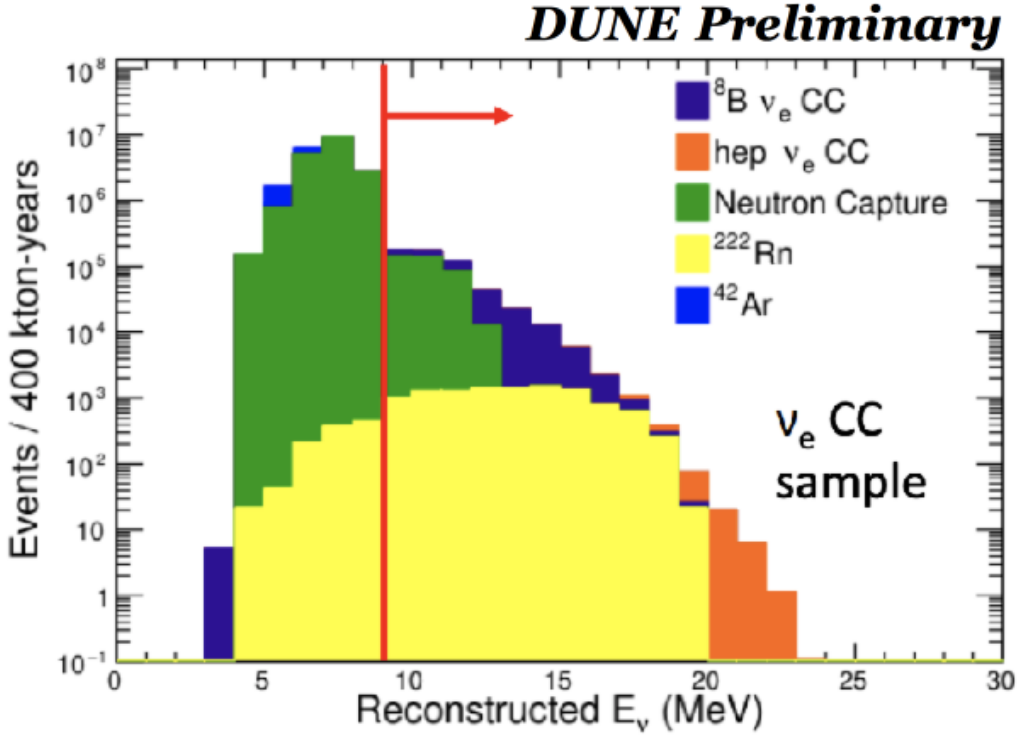




Study of pre-supernova neutrinos may also be possible

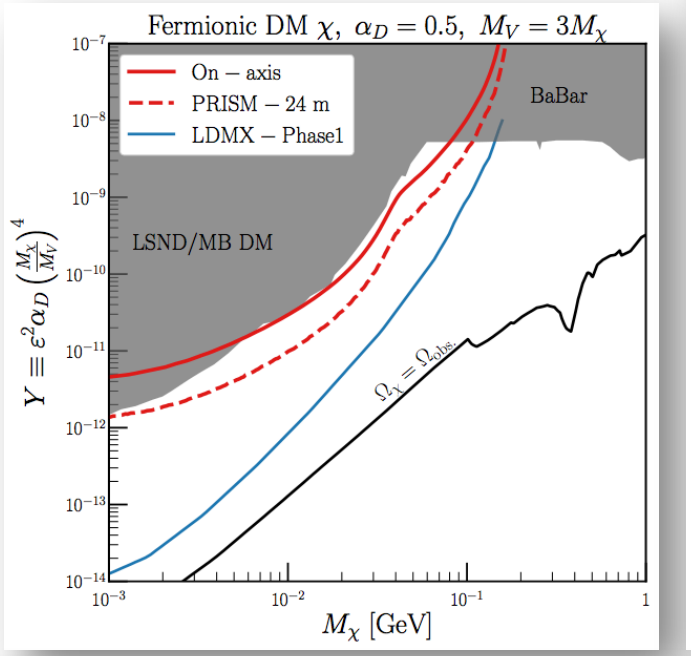
Physics Prospects: Solar Neutrinos

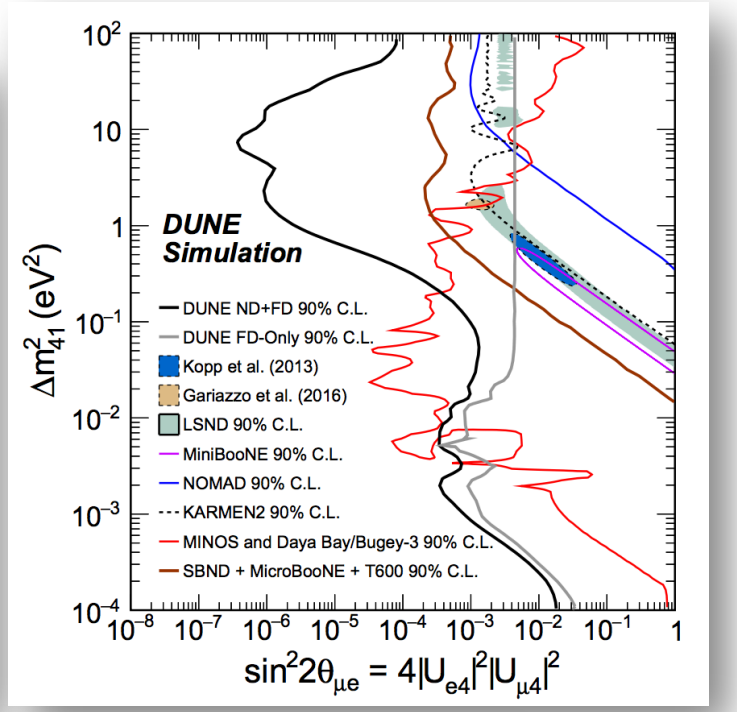
- Currently under investigation: sensitivity to solar neutrinos
  - ^{8}B solar neutrinos
  - hep solar neutrinos
- Unique capability of measuring solar neutrino energies event by event
- Background-limited
- A challenging measurement, but shows promise!

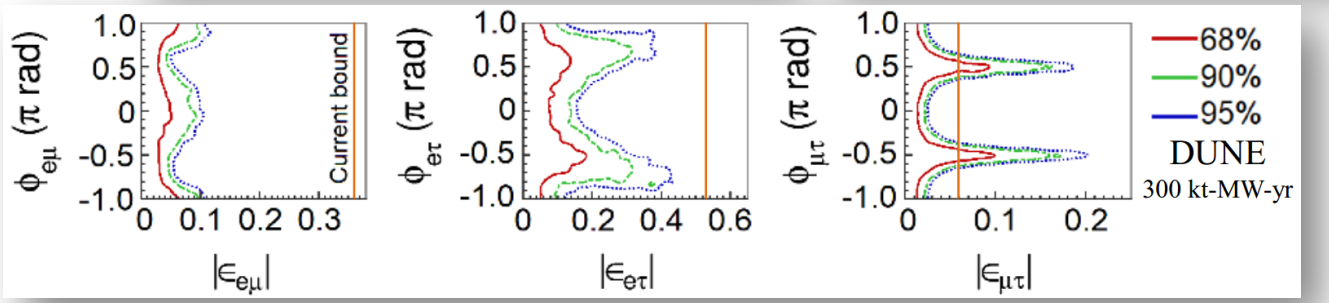


Physics Prospects: BSM Physics

- **Large catalog of Beyond-Standard-Model (BSM) searches**: baryon number violation, non-standard neutrino interactions, light sterile neutrinos, large extra dimensions, light dark matter, Lorenz violation…
  - arXiv:2008.12769

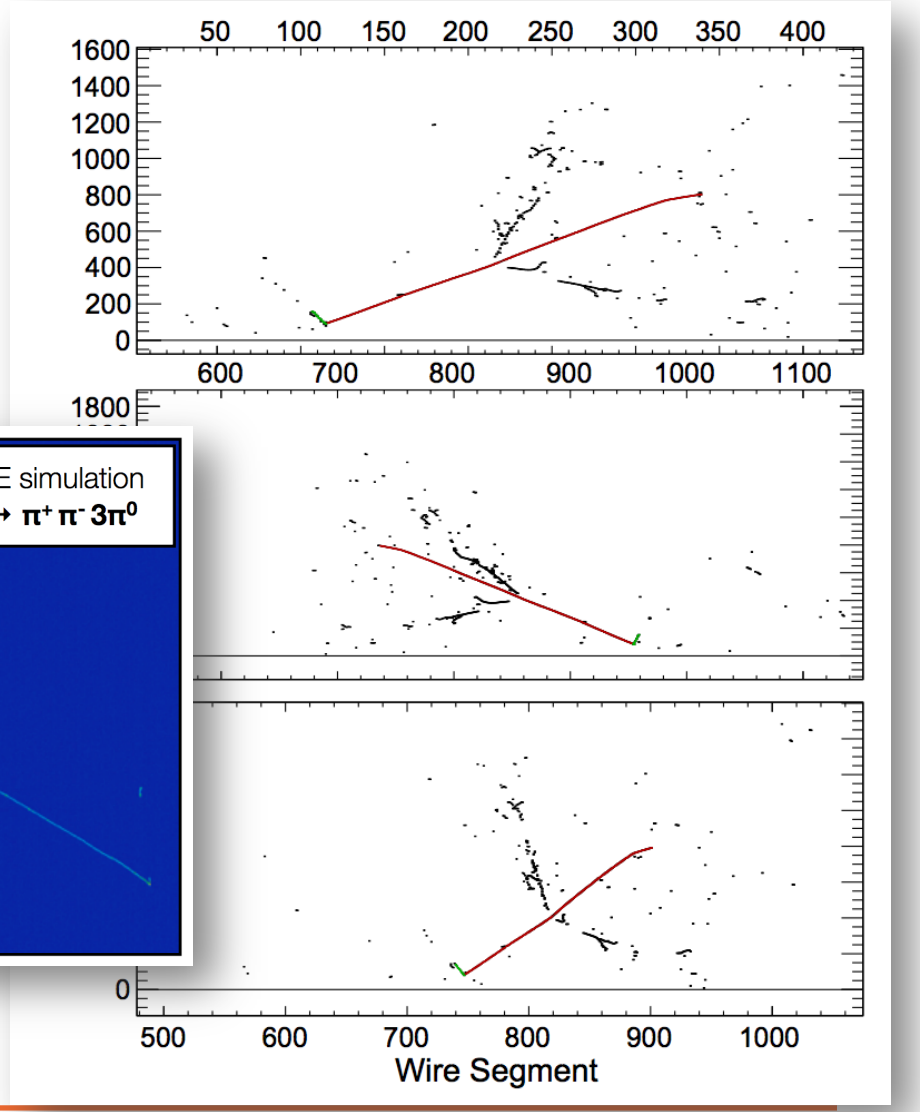


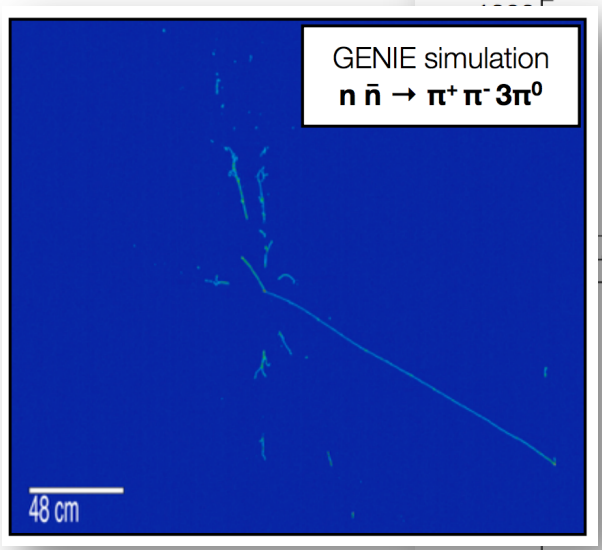




Physics Prospects: Rare Event Searches

- Key among BSM searches: **baryon number violation**
- Highlighted here: argon-nucleus-bound **neutron-antineutron oscillation**
  - $\Delta B = 2$ signature
  - Visually striking topology in a LArTPC
  - Projected sensitivity: $\tau_{free} > 5.53 \times 10^8$ s





Summary

- **DUNE will enable high-precision neutrino measurements in the next decade, and an exciting physics program**, encompassing:
  - CP violation measurement and neutrino mass ordering determination
  - **Studies of neutrinos from a galactic supernova burst, and potentially solar neutrinos**
  - Many BSM searches, including sterile neutrinos, baryon number violation, non-standard interactions, etc.
- **Excellent progress is being made on demonstrating detector technology and characterizing performance, toward realizing DUNE**
  - Technical Design Report for DUNE FD completed in early 2020
  - Conceptual Design Report for DUNE ND completed in 2020
  - Beam PIP-II construction ground broken in July 2020
  - Far detector site excavation continues
  - Detector cavern excavation contract awarded, will begin in 2021
  - ProtoDUNEs successfully operated at CERN with first R&D and physics results published → moving into phase II

Thank you!

Additional talks by DUNE collaborators at this conference:

- Richard Diurba — " Techniques developed calibrating ProtoDUNE-SP using a cosmic ray tagger"
- Yashwanth Bezawada — "Neutron generator calibration system for DUNE"
- Aleena Raquife — "Identification and reconstruction of Michel electrons in ProtoDUNE-SP"
- Janming Bian — "Results on physics performance of ProtoDUNE-SP"
- Mattia Fani — "Calibrating the world's largest LArTPC detector"
- Federico Battisti — "Physics potential with the DUNE ND-GAr detector"
- Junying Huang — "Simulation of low-energy neutron events at ProtoDUNE-SP"
- Tanaz Mohayai — "Capabilities of the DUNE Near Detector Complex"
- Olexiy Dvornikov — "Delta Rays: A Novel Calibration for the Deep Underground Neutrino Experiment (DUNE) for Low Energy Astrophysical Neutrinos"
- Heng-Ye Liao — "Measuring the proton-argon cross-section at ProtoDUNE-SP"

Thank you!

Additional talks by DUNE collaborators at this conference:

Thursday:

- Richard Diurba
- Yashwanth Bezawada
- Aleena Raquife

Friday:

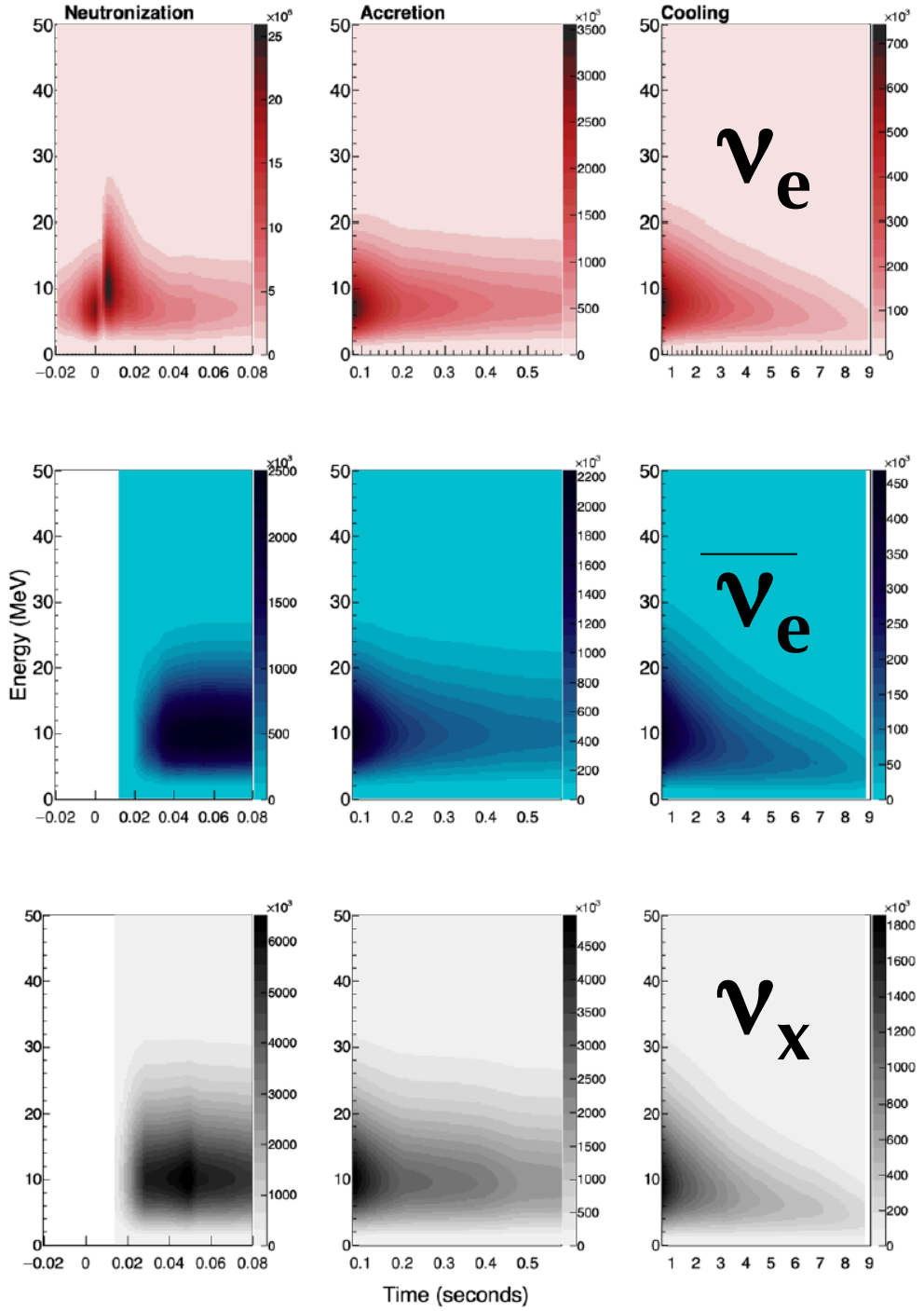
- Janming Bian
- Mattia Fani
- Federico Battisti
- Junying Huang

- Tanaz Mohayai, “Capabilities of DUNE Near Detector Complex”
- Olexiy Dvornikov, “Delta Rays: A Novel Calibration for the Deep Underground Neutrino Experiment (DUNE) for Low Energy Astrophysical Neutrinos”
- Heng-Ye Liao, “Measuring the proton-argon cross-section at ProtoDUNE-SP”

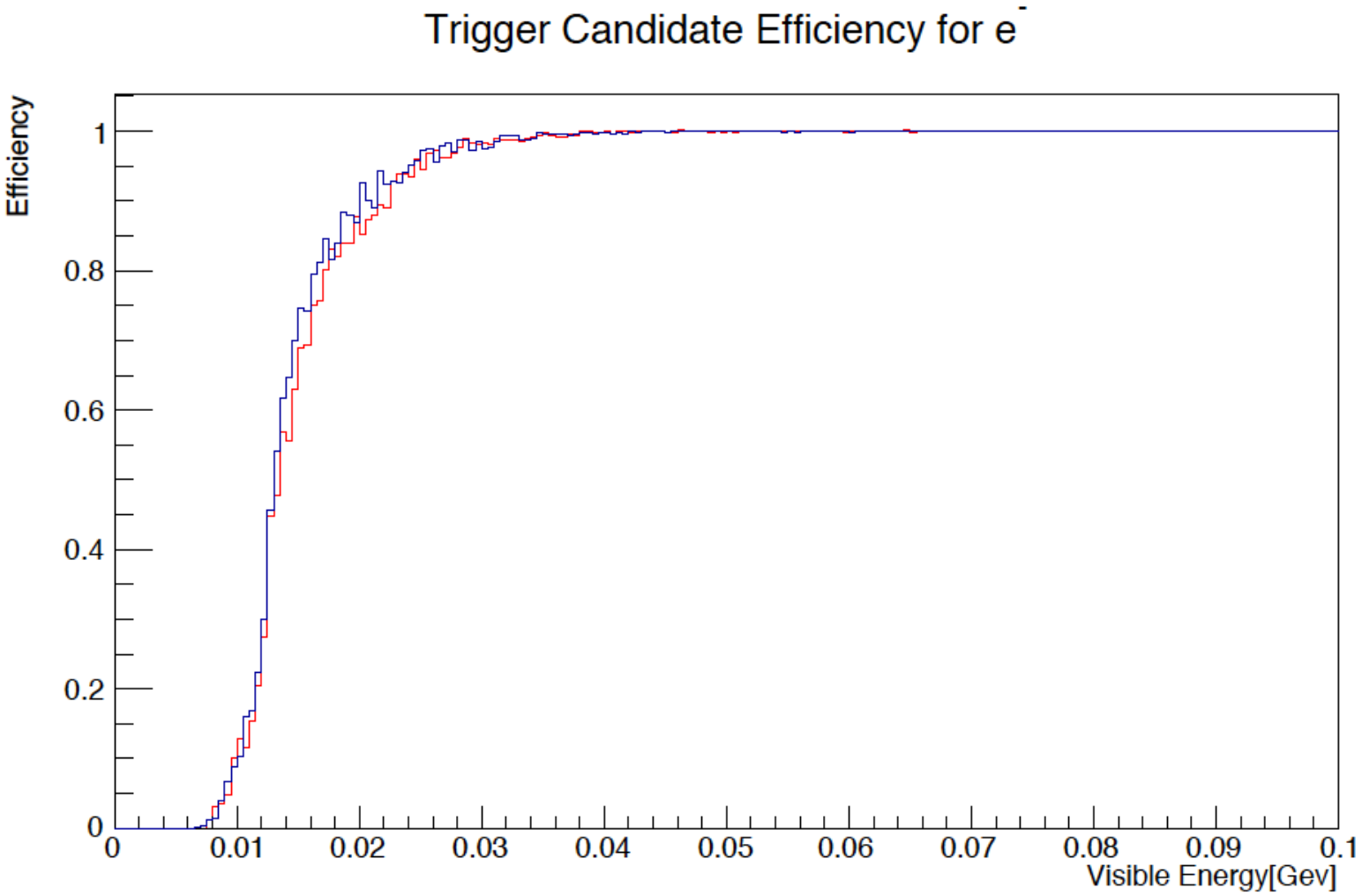
Backup Slides

- **Garching electron-capture supernova model**

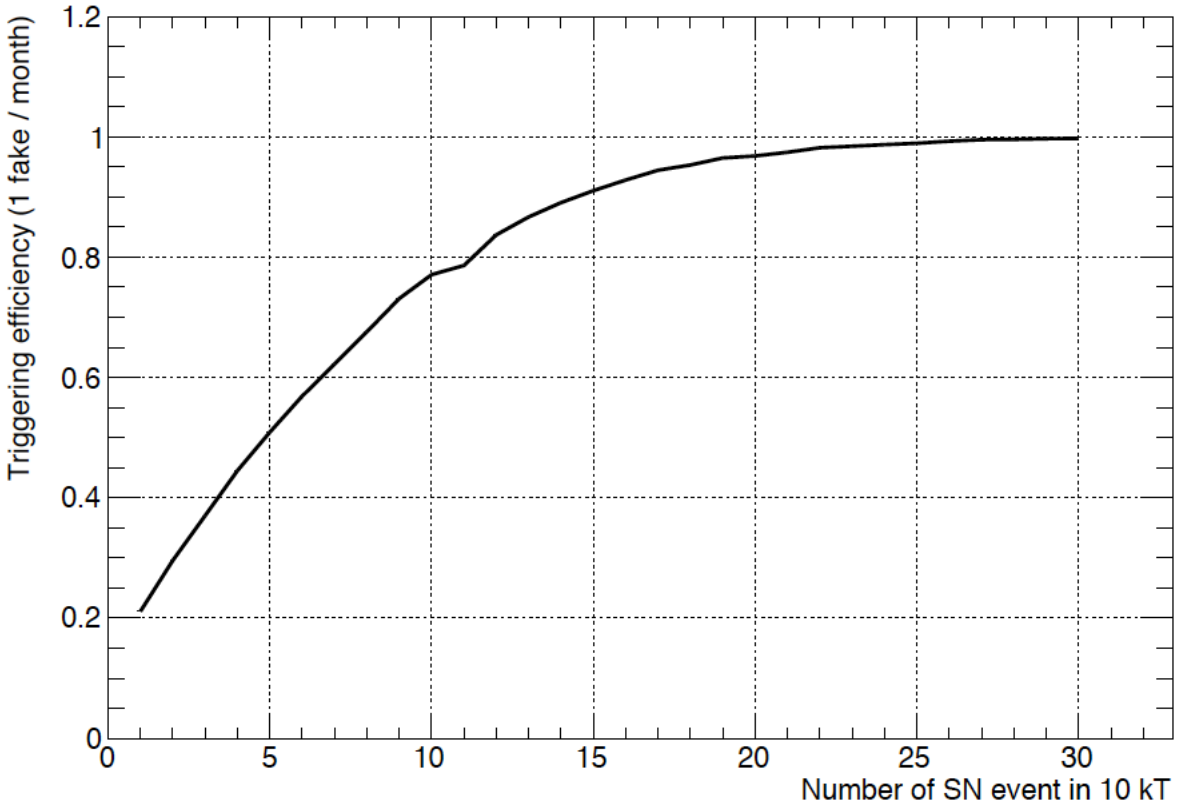
- Core bounce at t=0



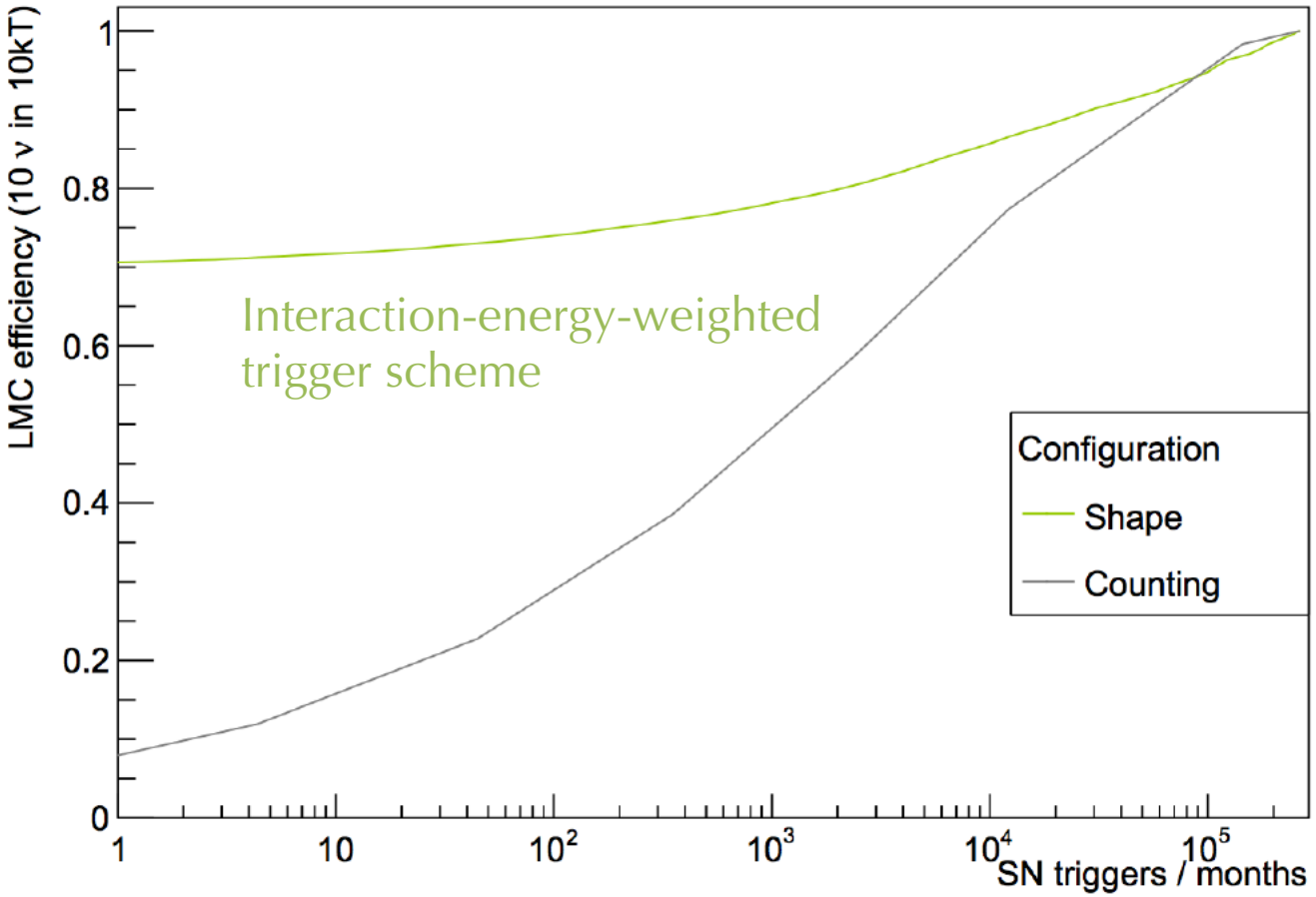
- TPC-based trigger efficiency on individual neutrino interactions
- Horizontal Drift module



- **TPC-based trigger efficiency for a supernova burst (multiple neutrino interactions)**
- **Horizontal Drift module**



- **TPC-based trigger efficiency for a supernova burst (multiple neutrino interactions)**
- **Horizontal Drift module**



- **Supernova pinched-thermal flux parameter determination**