Status of the Short Baseline Near Detector at Fermilab

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for the SBND Collaboration

Brookhaven National Laboratory

SHORT-BASELINE SBND NEAR DETECTOR

Fermilab

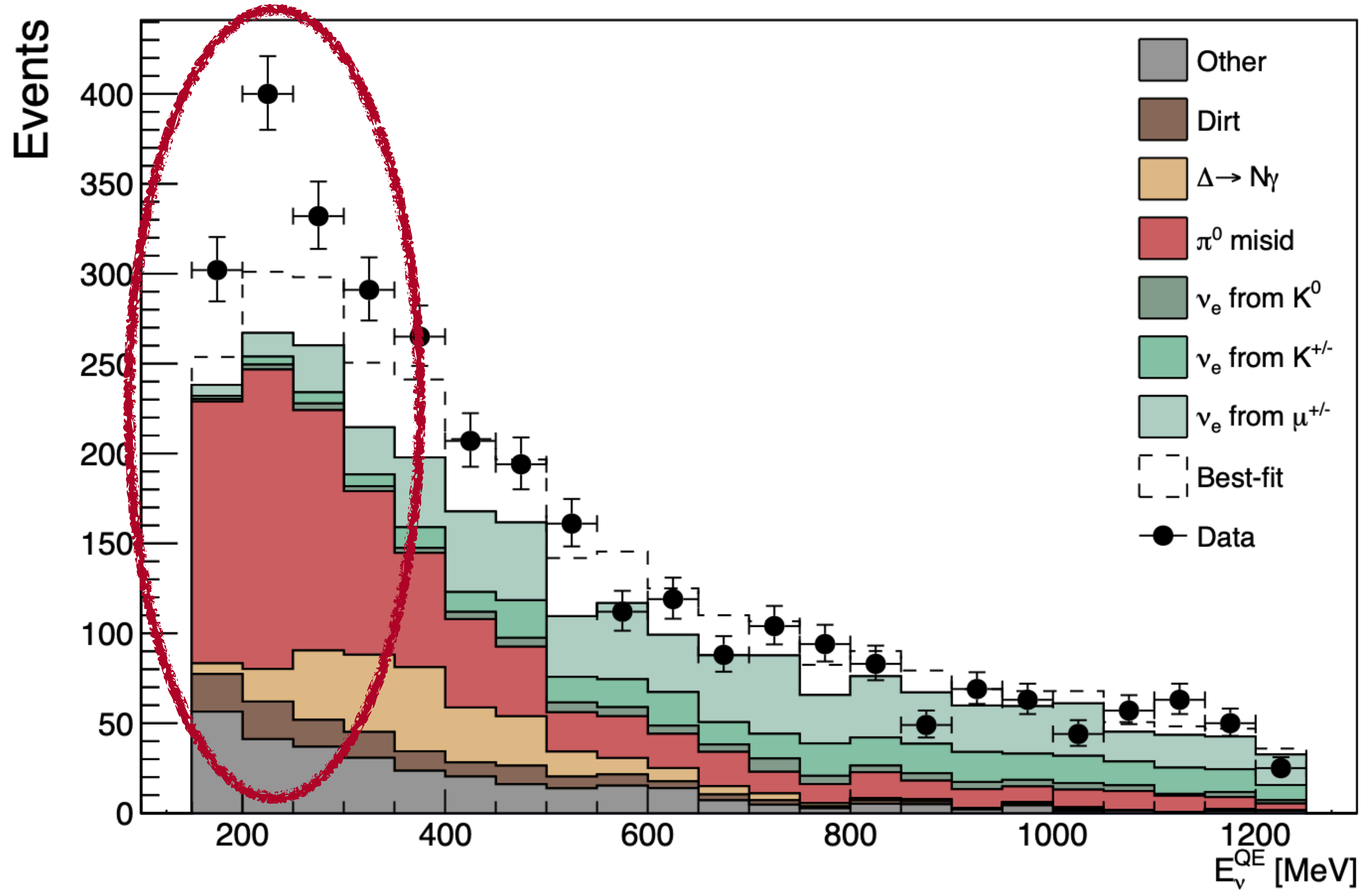
NuFACT August 22 2023

The Short Baseline Neutrino Program

Main goal: address the anomalous results from past neutrino experiments (LSND, MiniBooNE), which could be explained by the possible existence of at least one **sterile neutrino**.

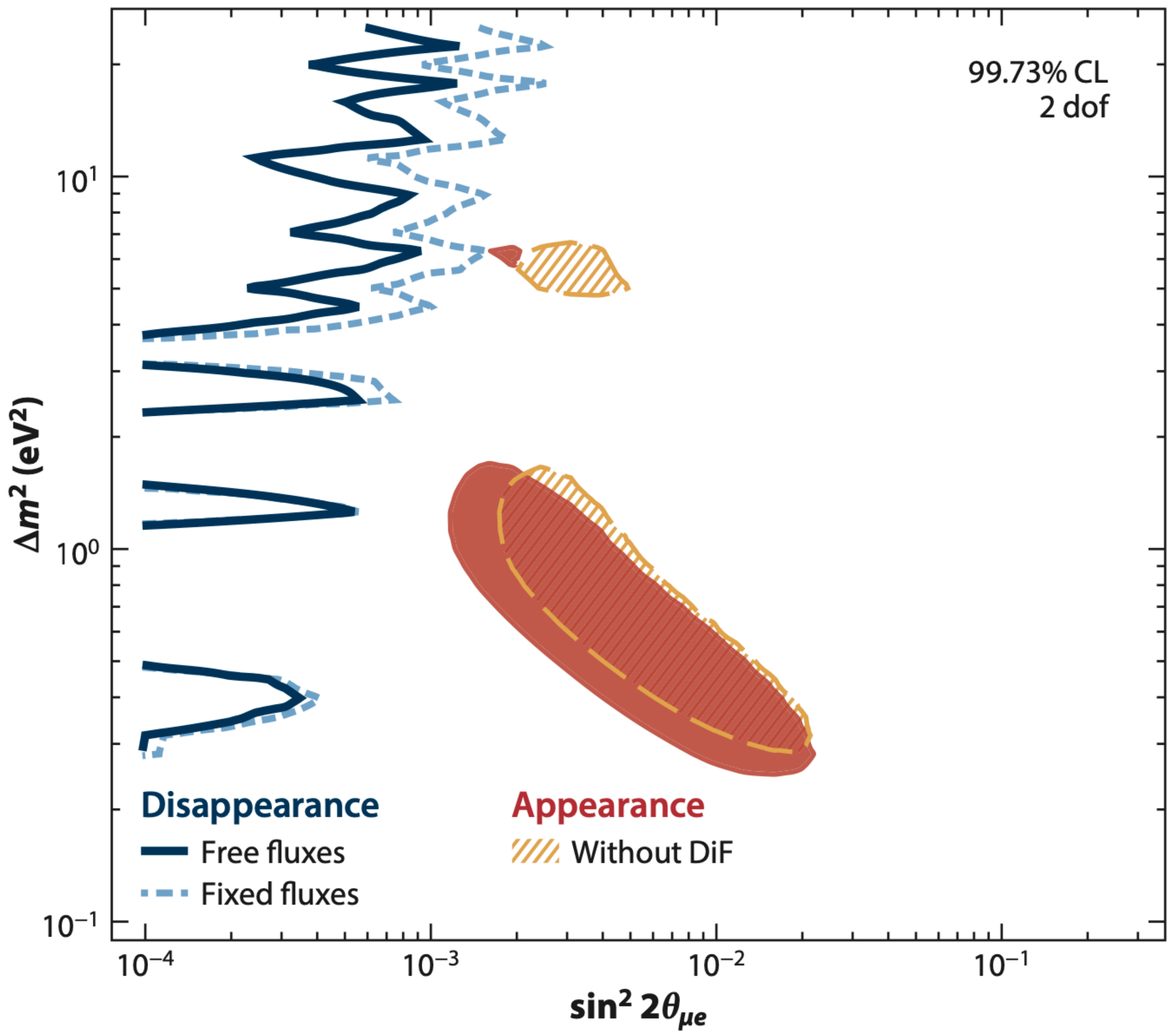
The Short Baseline Neutrino (SBN) Program will make precision measurements while providing a development platform for liquid argon time projection chambers (LArTPC) useful for future experiments (DUNE).

Phys. Rev. D 103, 052002 (2021)



MiniBooNE's neutrino mode energy distribution. Best fit to neutrino mode data assuming 2-neutrino oscillations

Figure adapted from JHEP 08, 010 (2018)



MiniBooNE's allowed oscillation parameter regions with simplified 2-neutrino oscillations model.

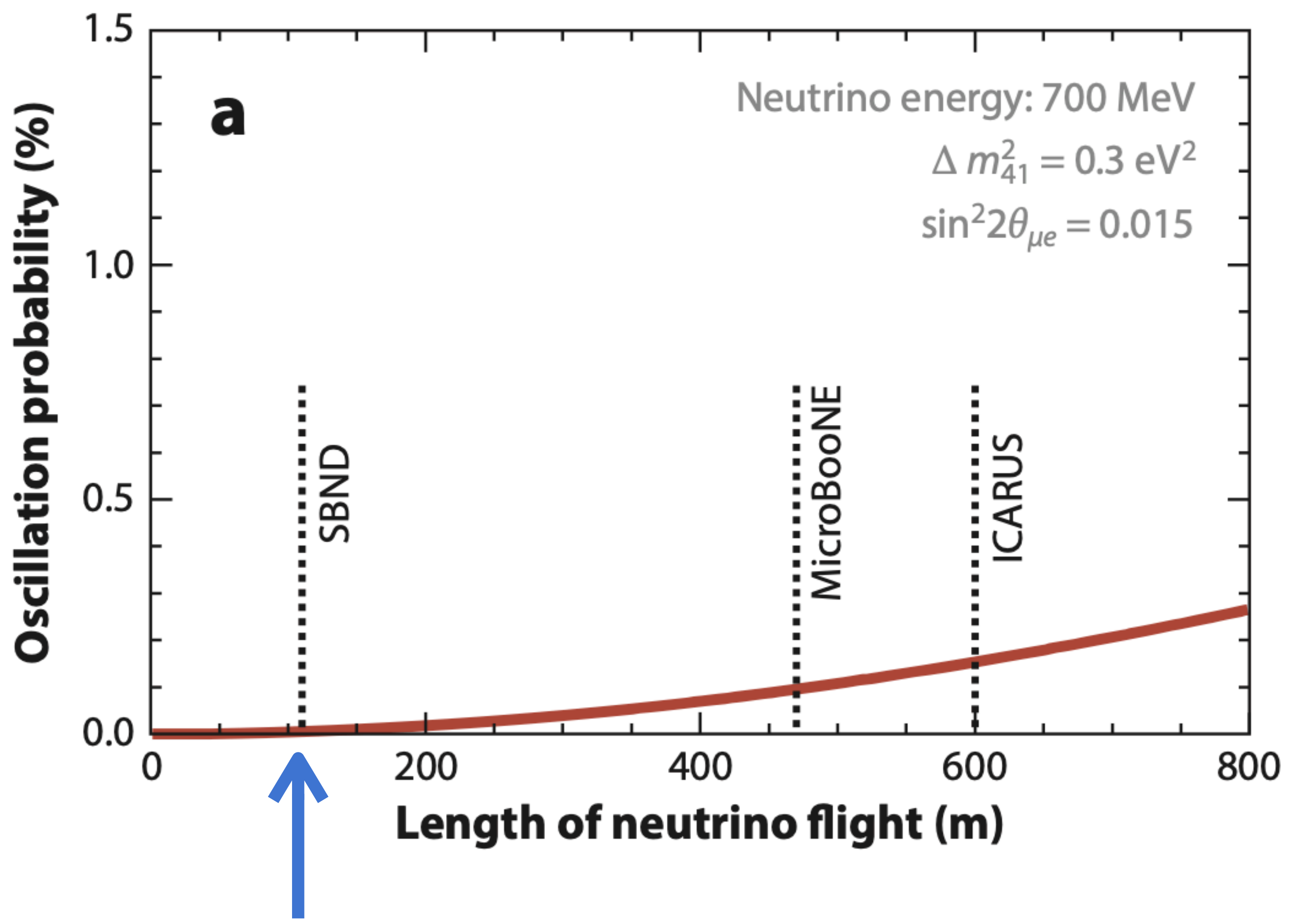
The Short Baseline Neutrino Program

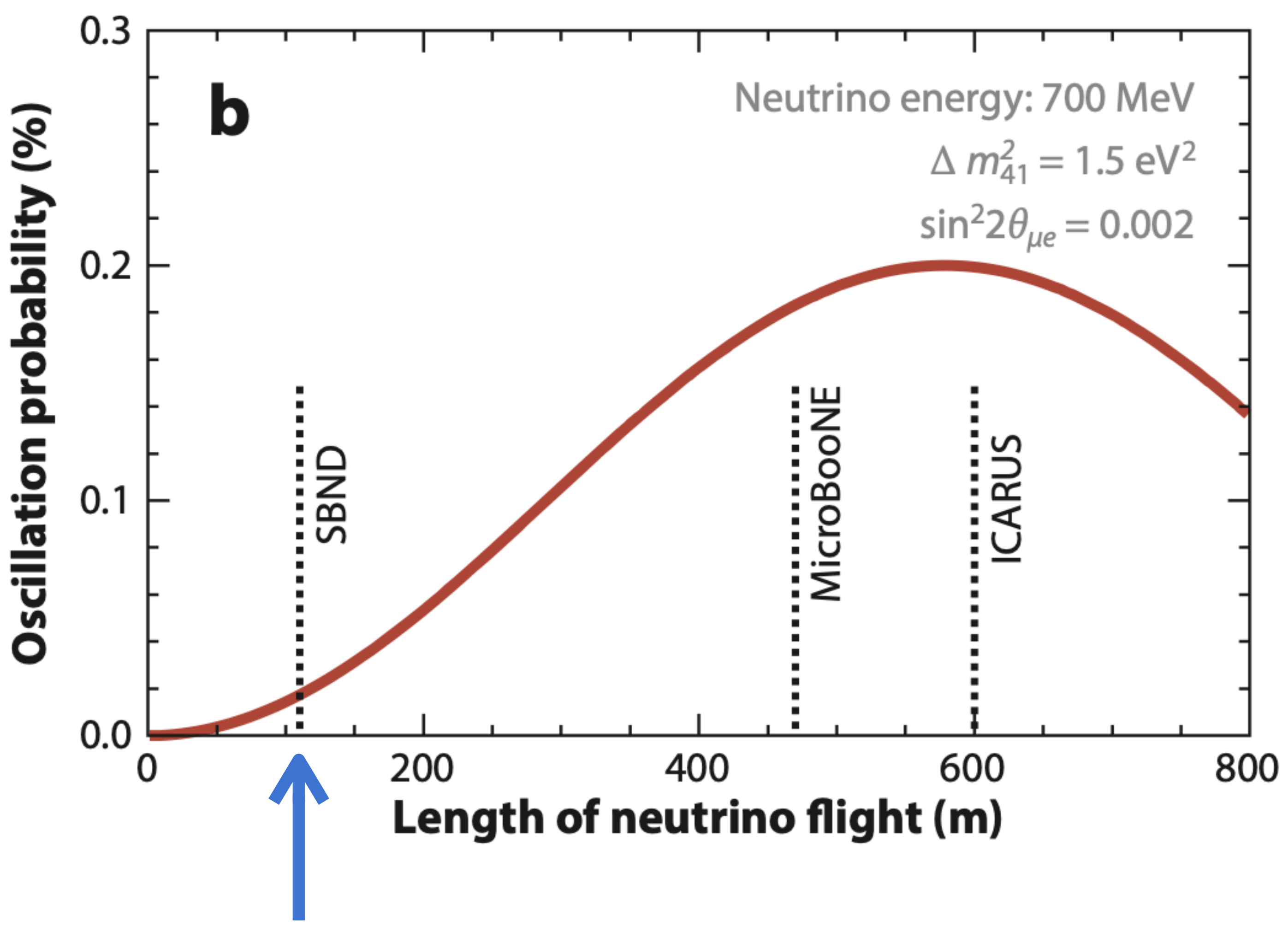
The 3 SBN detectors share the same nuclear target and similar technologies: liquid argon time projection chambers (LAr TPCs). The detectors are strategically placed to look for neutrino oscillations at short baselines and low energy range along Fermilab's **Booster Neutrino Beam** (BNB), which provides a highly pure source of either ν_μ or $\bar{\nu}_\mu$.

The Short Baseline Neutrino Program

SBND Physics

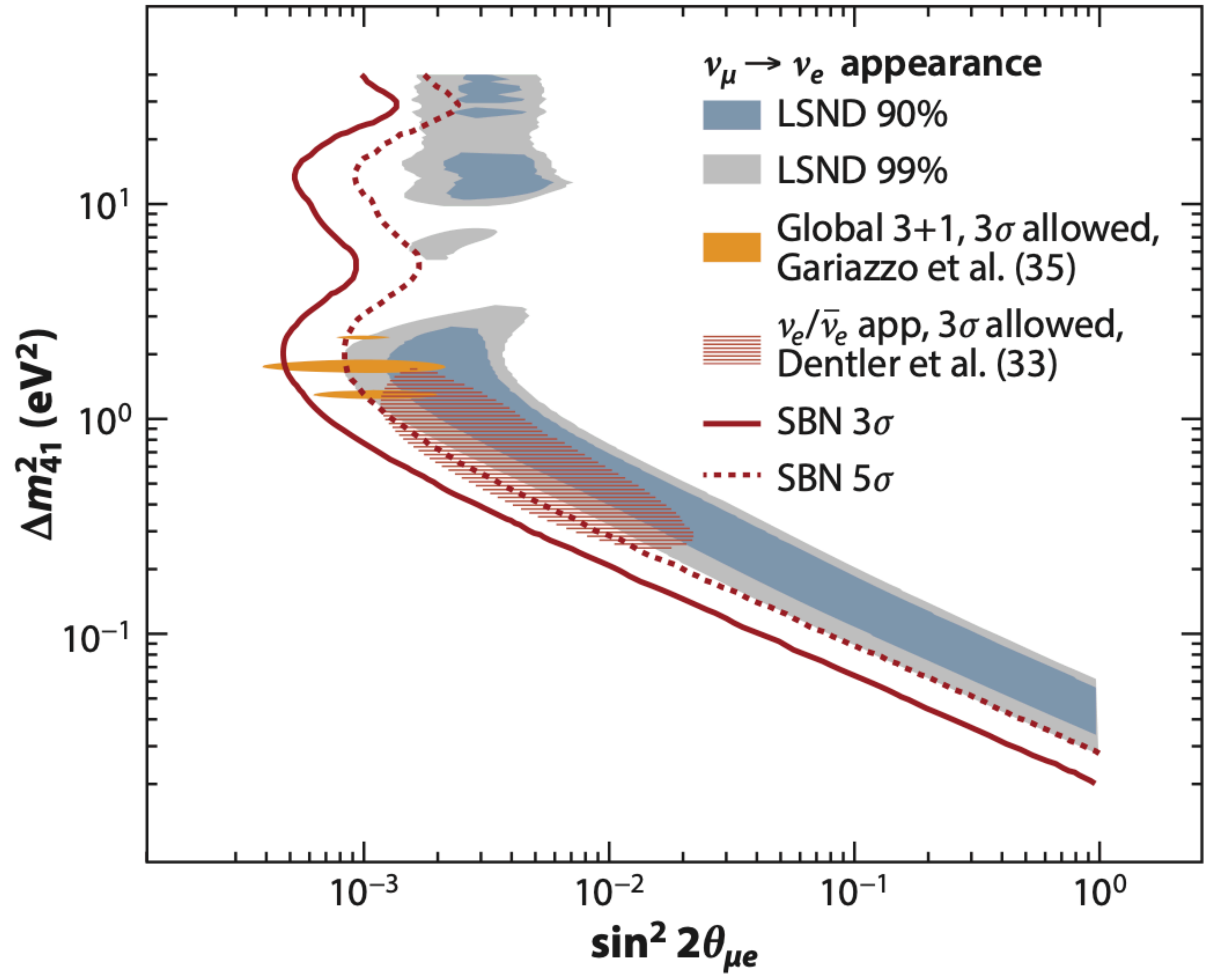
Short baseline oscillations

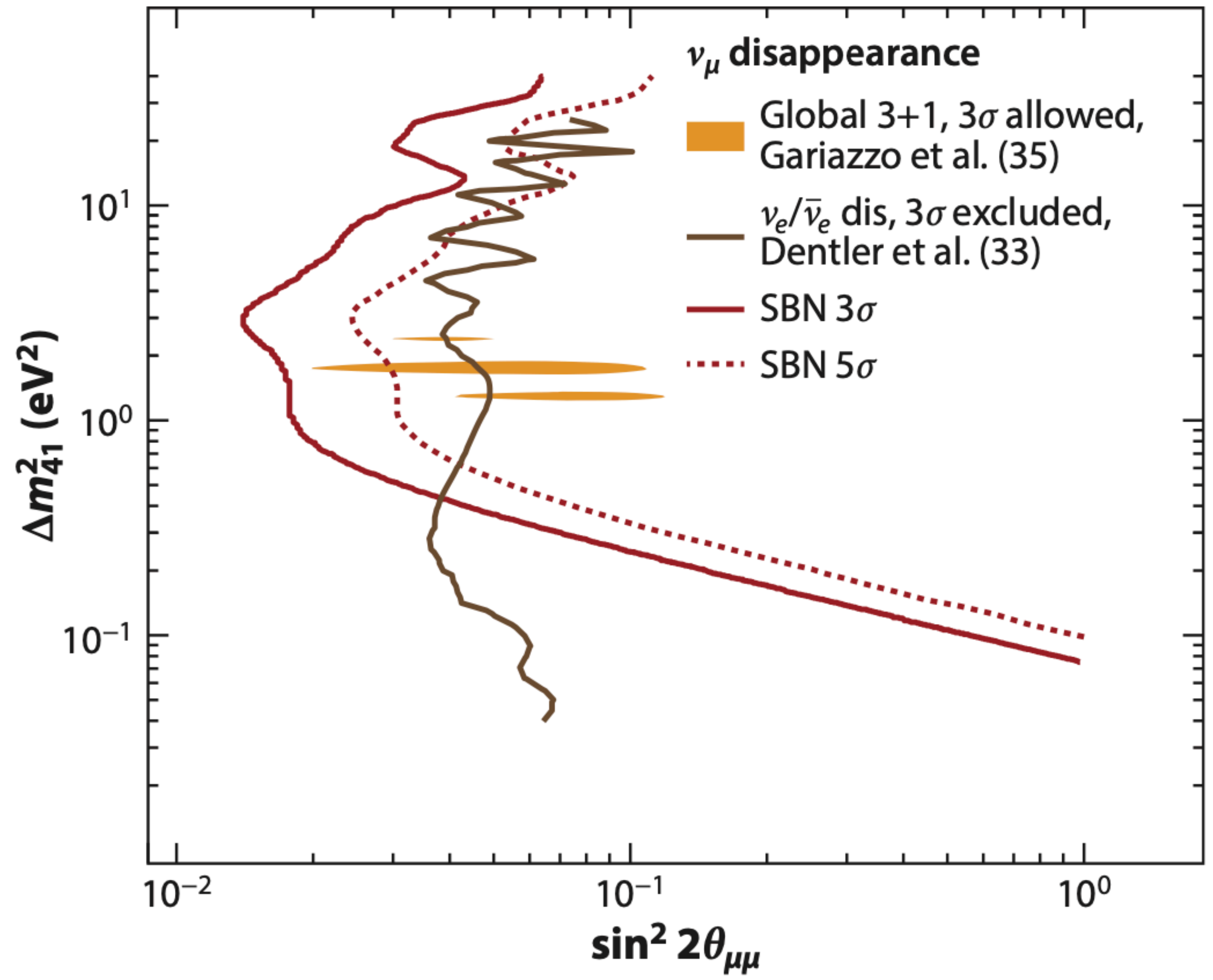




SBND will further constraint the intrinsic beam content by **measuring the unoscillated neutrino fluxes**, essential for performing simultaneous appearance and disappearance fits.

The near detector plays a fundamental role on answering whether the MiniBooNE **low energy excess** is intrinsic to the BNB or if it appears along the beamline.



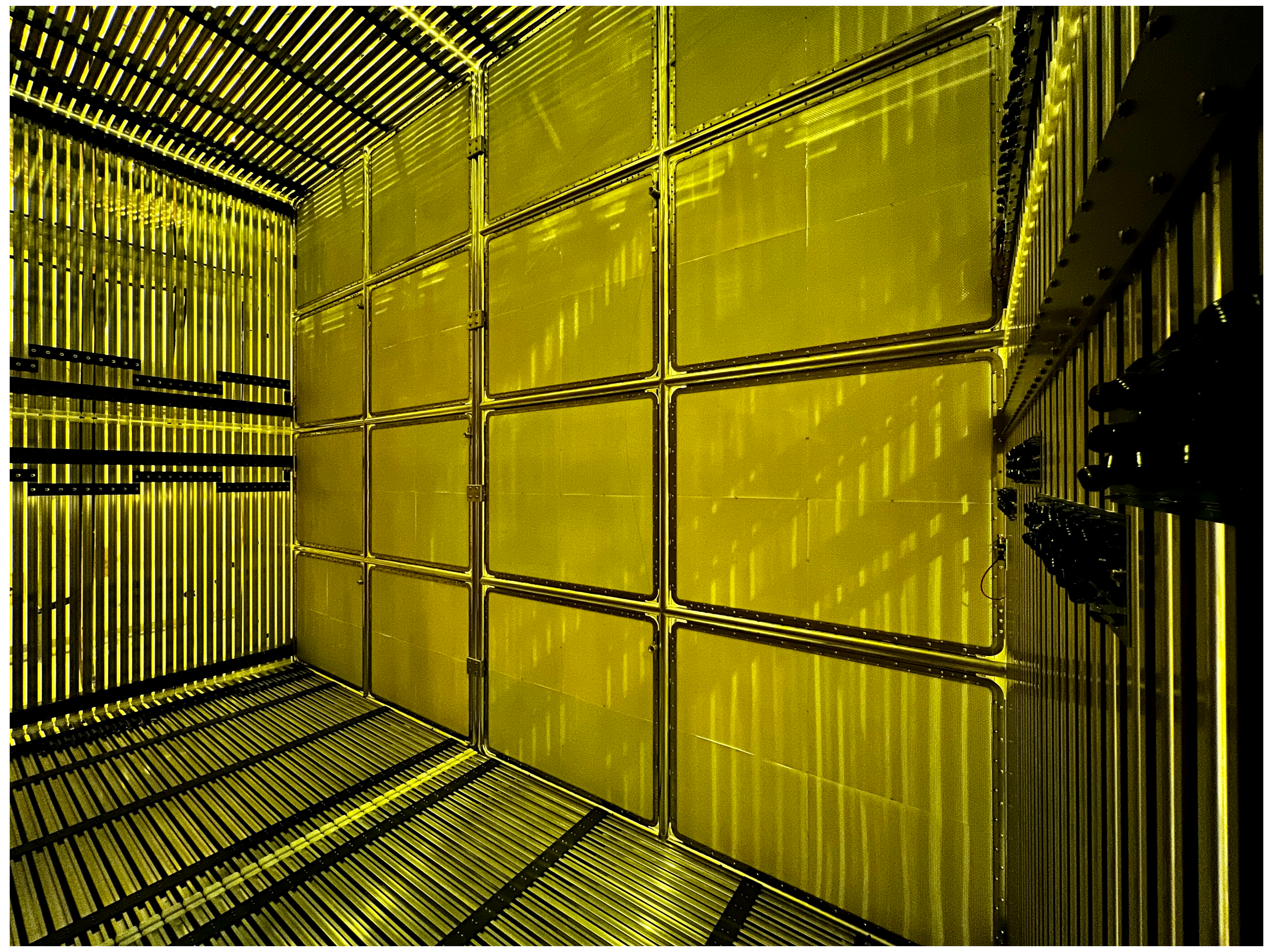


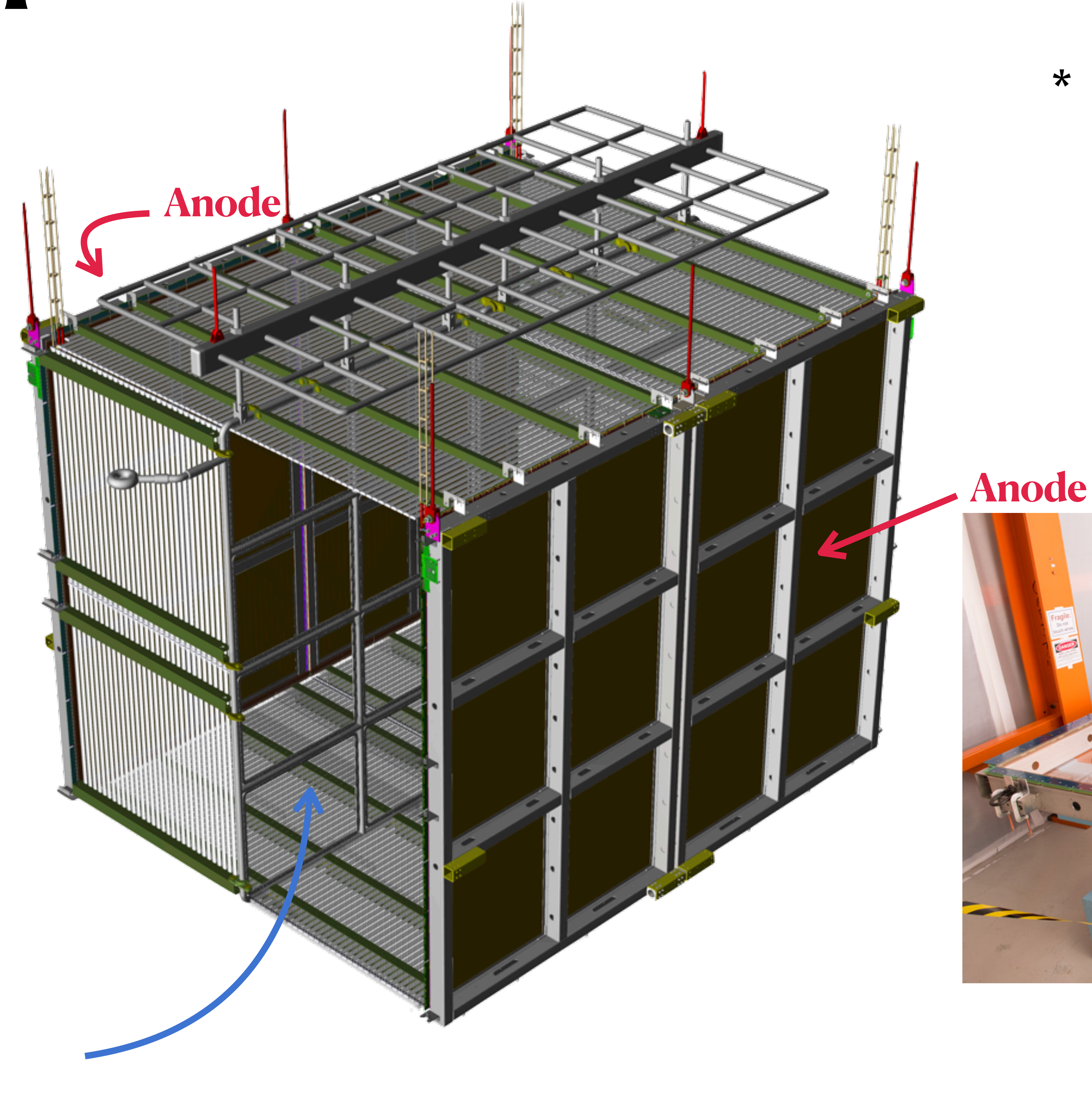
Annu. Rev. Nucl. Part. Sci. 2019 DOI 10.1146
(Reproduced from SBN Proposal assuming 6.6E20 POT)

Detector design

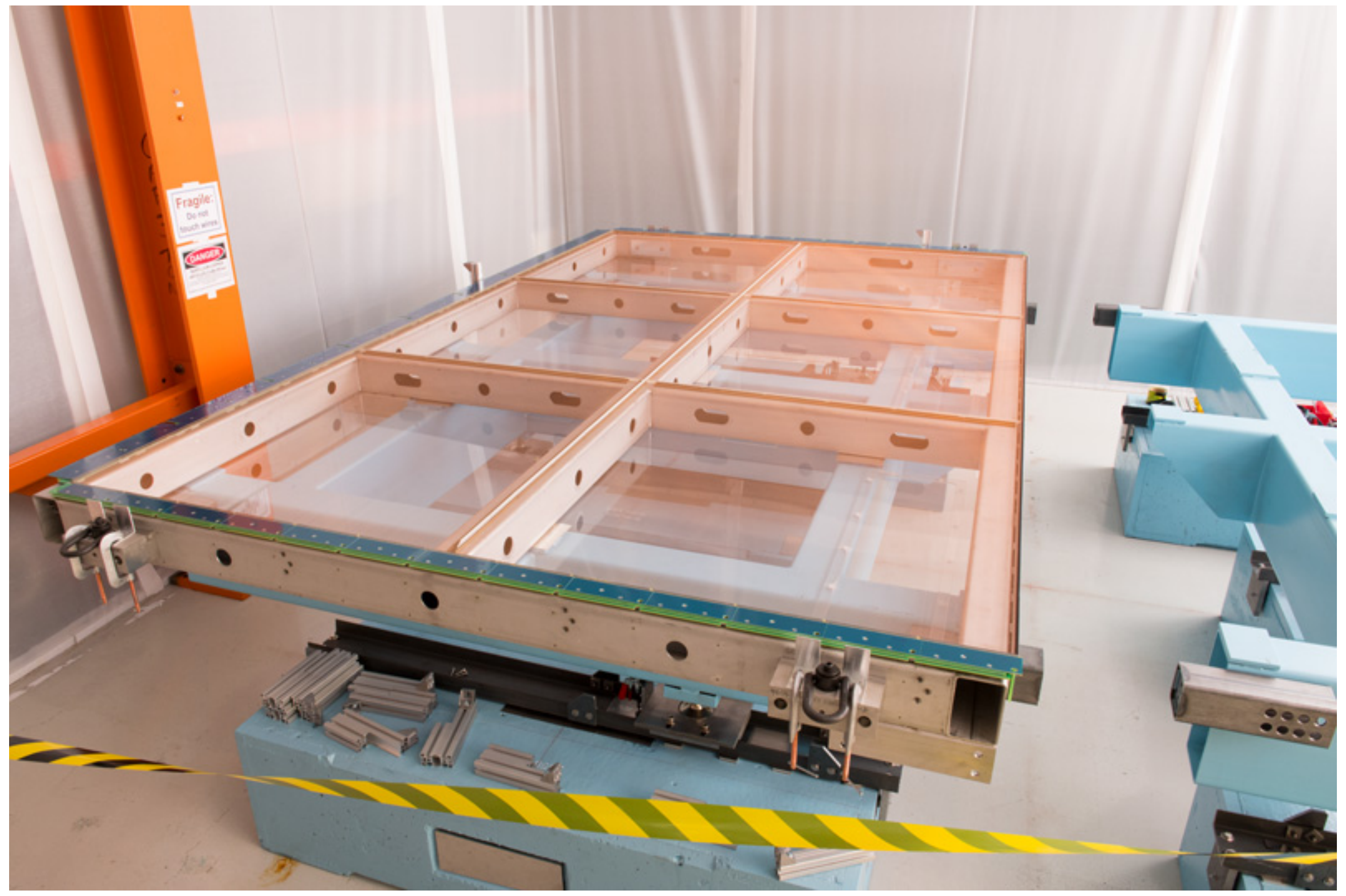
Time Projection Chamber

* One central cathode plane assembly (CPA)
  * Divides detector in two drift regions.
  * Foils coated with TPB wavelength shifter (WLS)





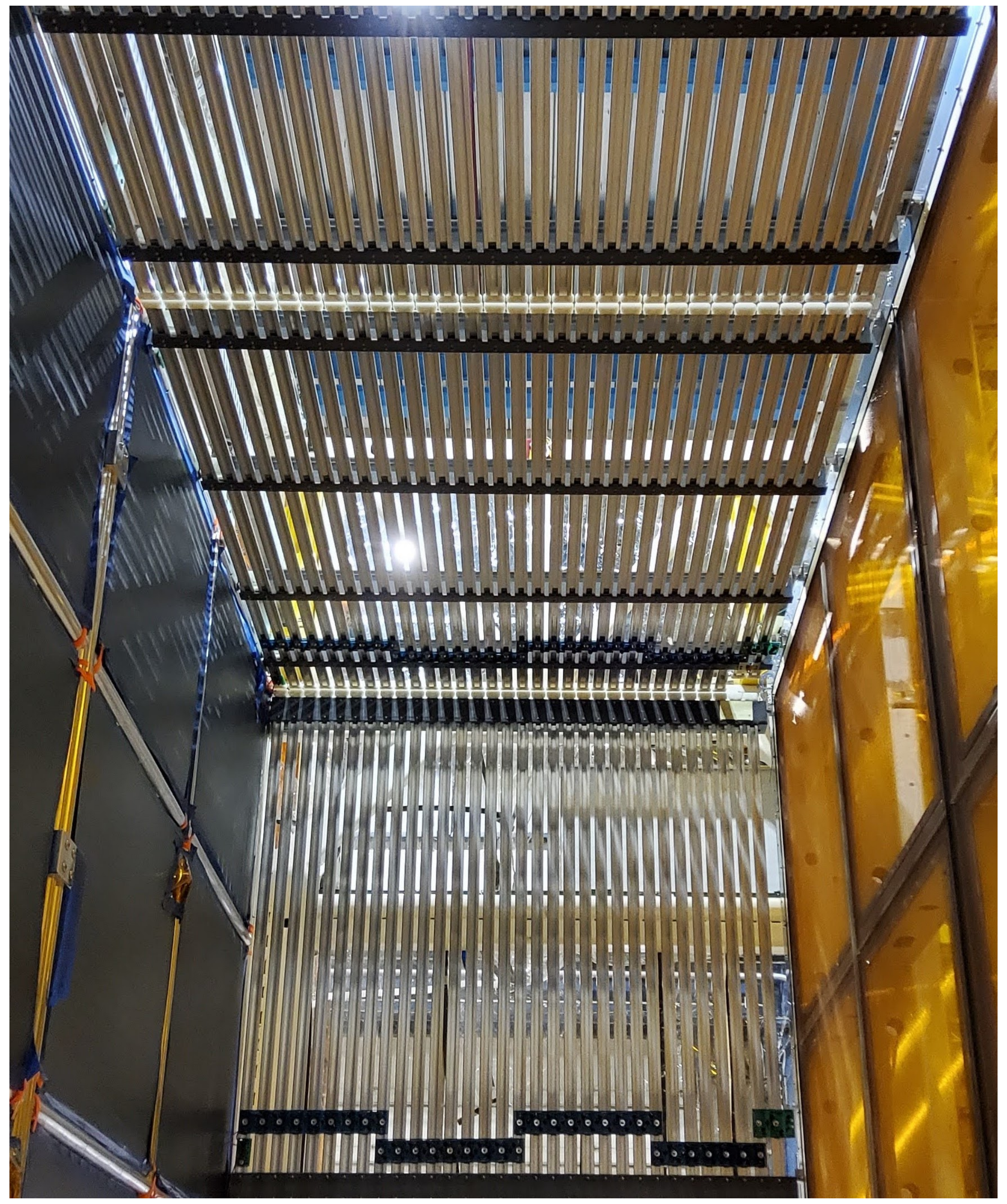
* Two anode plane assemblies (APAs)
  * 3 wire planes (vertical, +- 60 to the vertical)
  * Wire pitch and plane spacing = 3mm

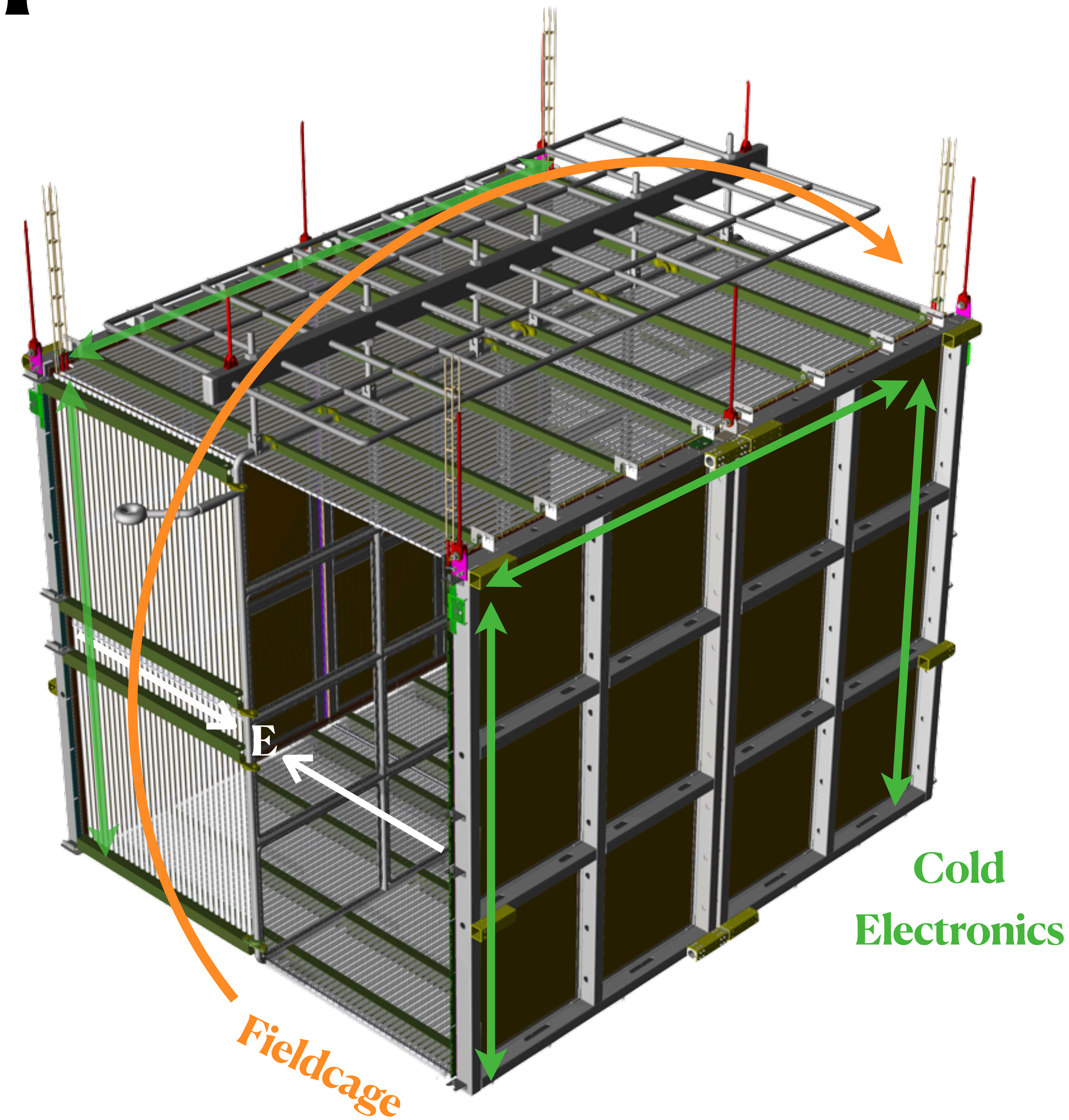


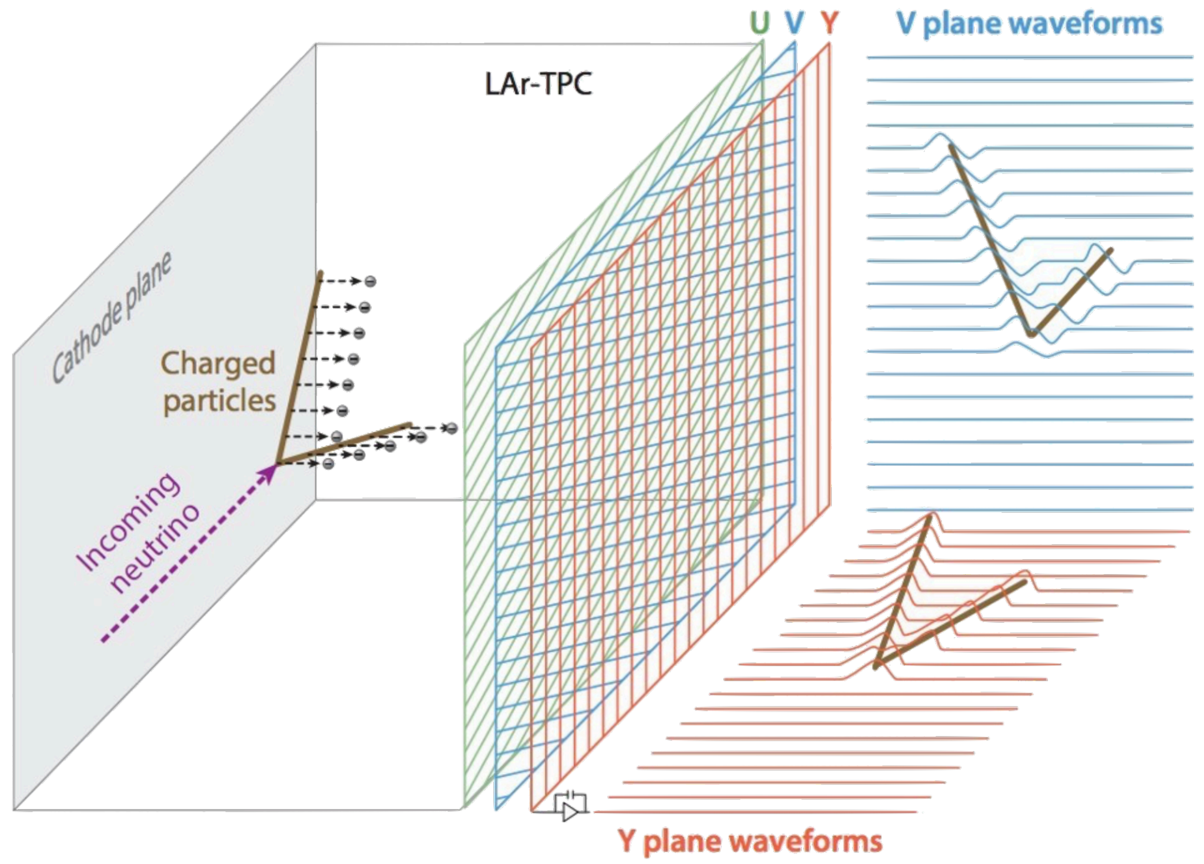
Detector design

Time Projection Chamber

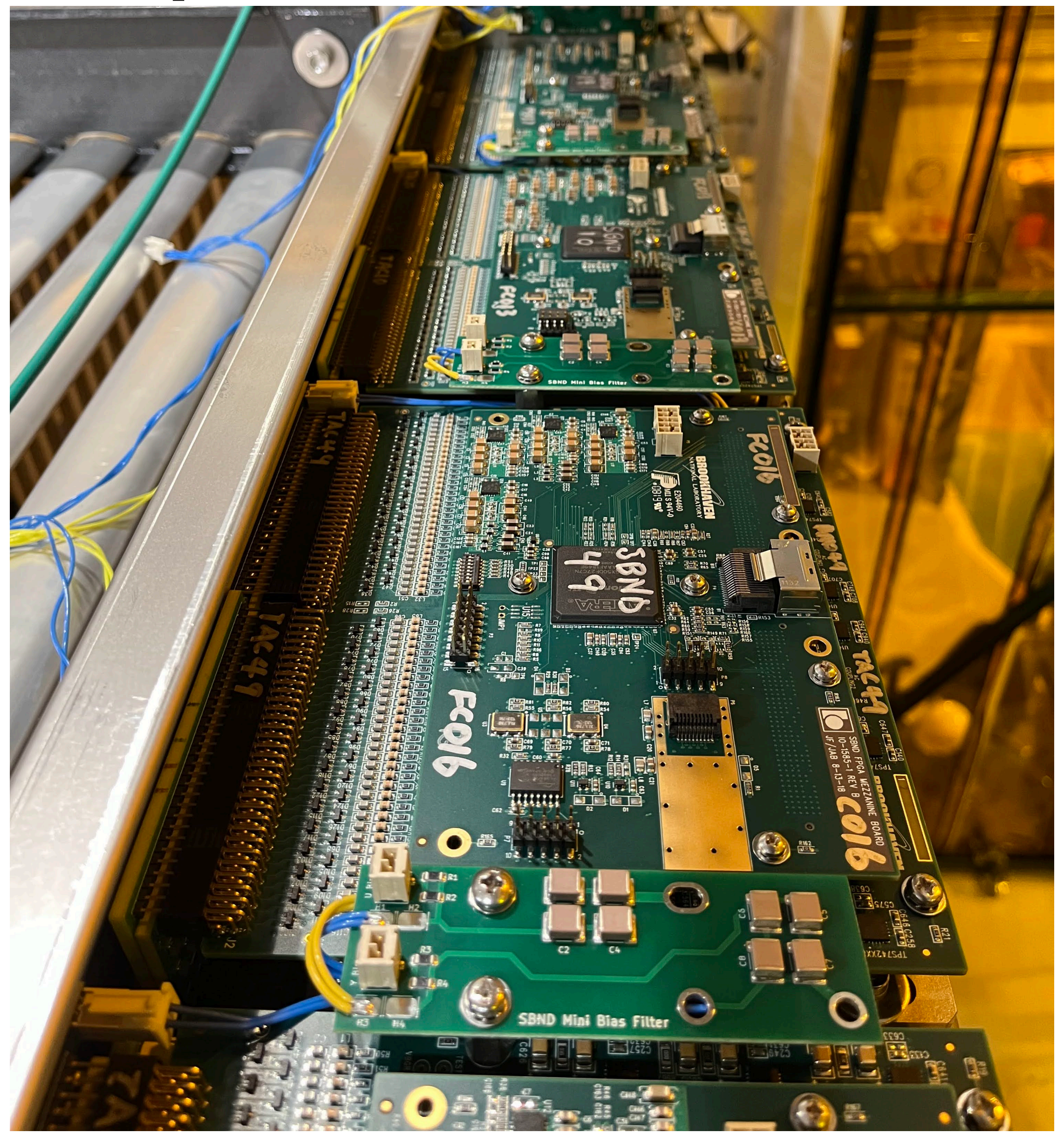
Field cage
maintains 500 V/cm drift field







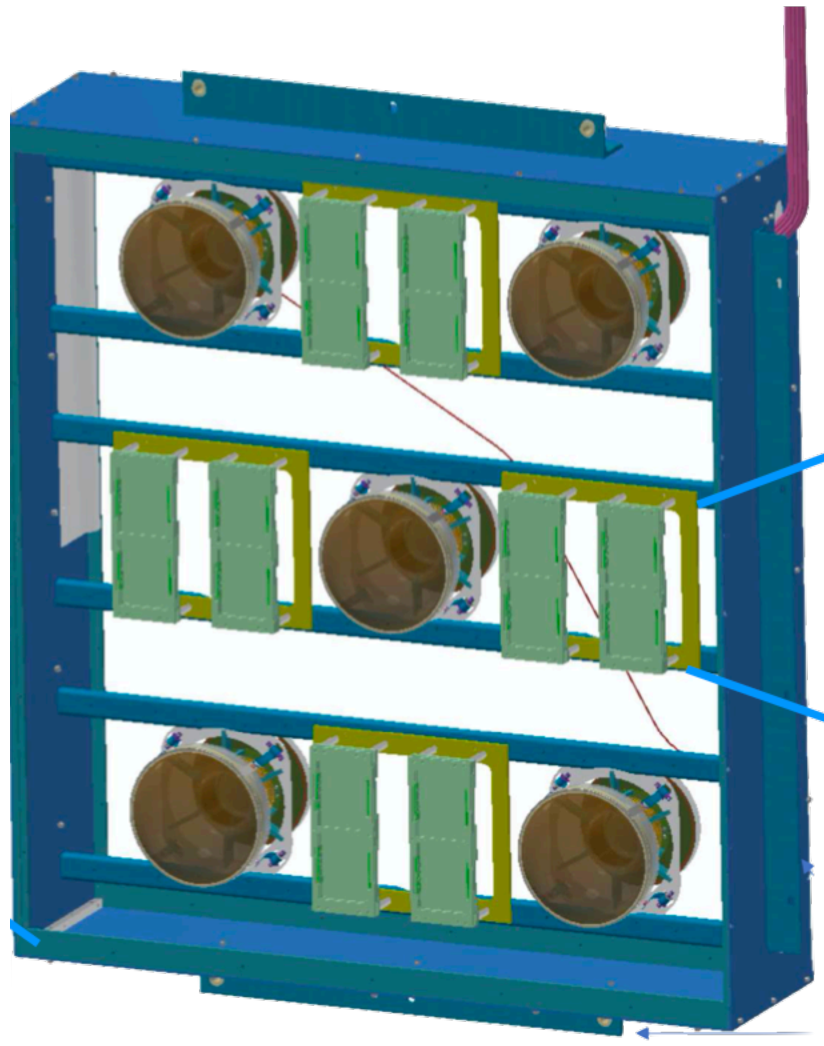
Cold electronics
optimises noise reduction

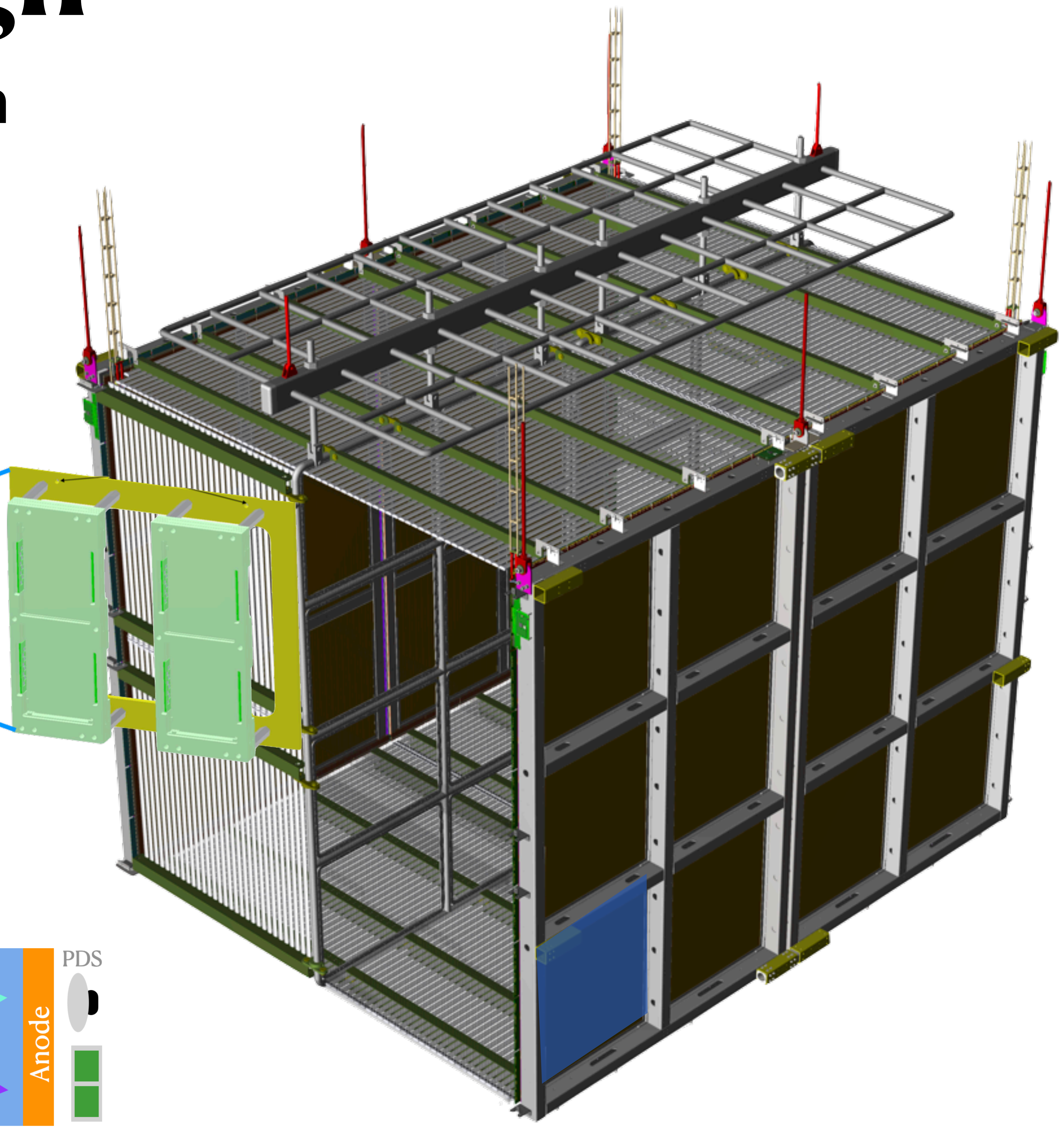


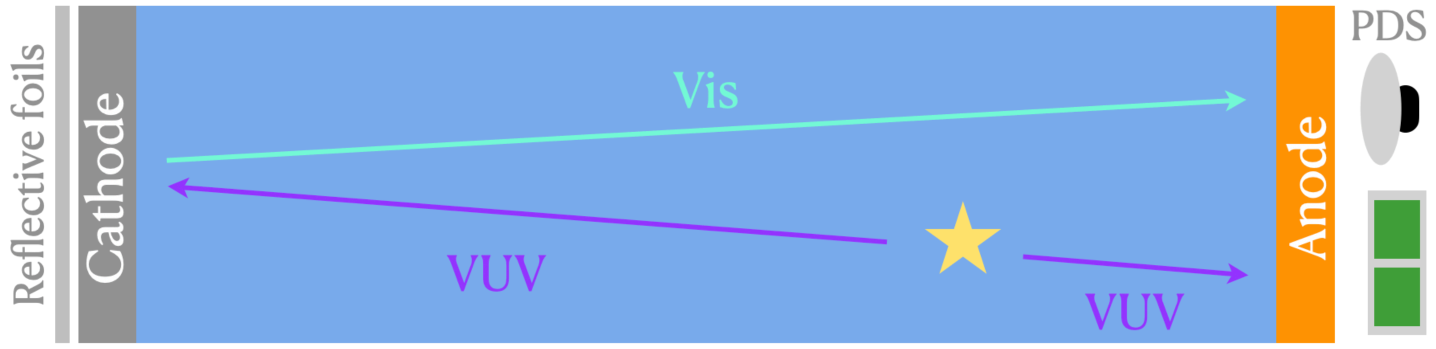
Detector design

Photon Detection System

Friday, WG6, A. Bhat
Signal Processing in SBND with WireCell





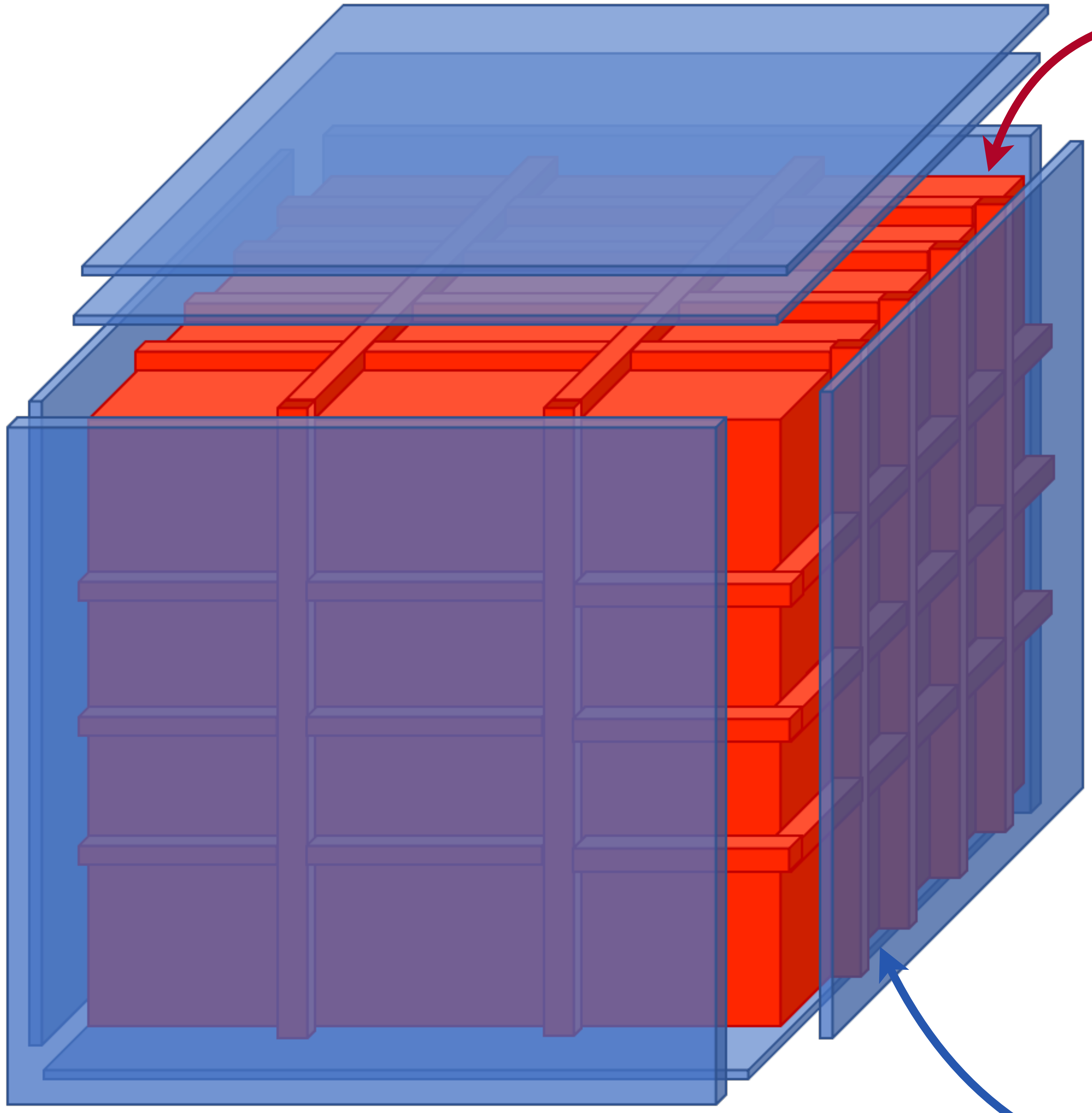


* Modular detection system behind APAs
* 24 photon detection system (PDS) modules
  * Photo Multiplier Tubes (PMTs) with nanosecond resolution
    * 92 coated PMTs with WLS
    * 24 uncoated
  * X-ARAPUCA
    * 196 photon traps, half with WLS

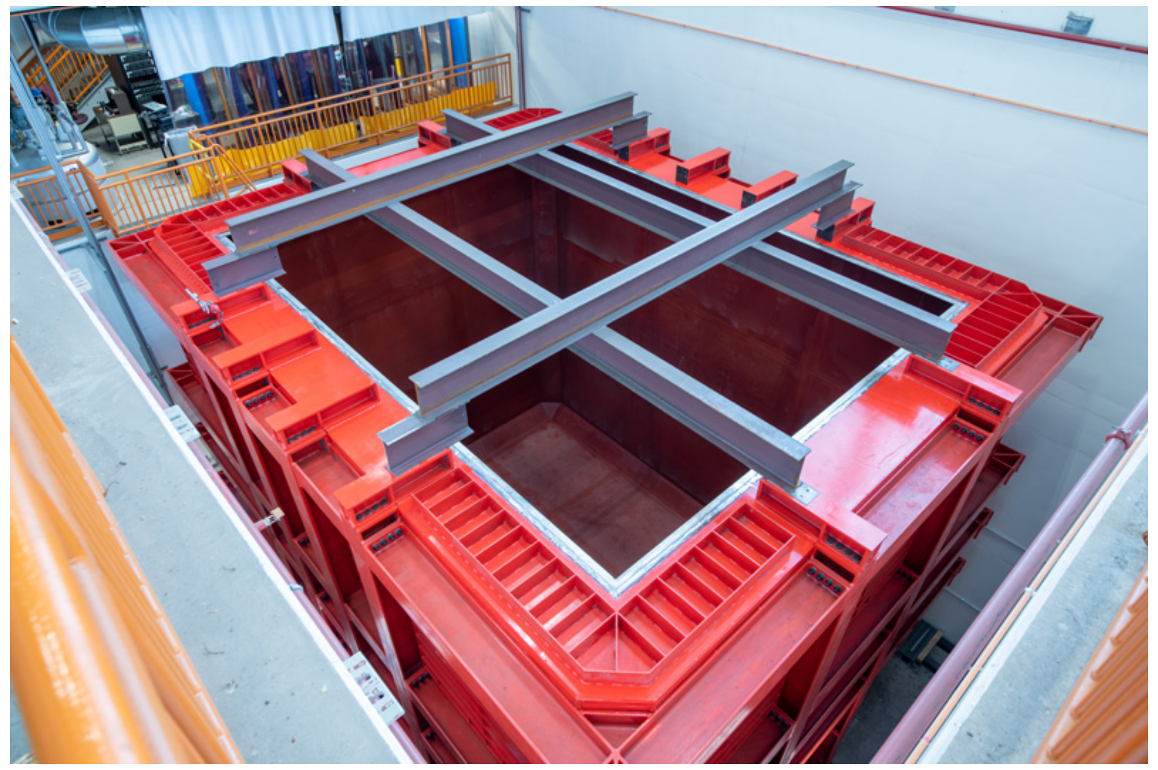
Detector design

Cosmic Ray Tagger

* Full detector coverage with planes of extruded scintillator strips that make up the cosmic ray tagger (CRT).
* Cosmic muons trigger the CRT before any other subsystem.
* Also useful for the search of exotic particles decaying outside the detector.
* Exiting particles can be identified by the CRT.



Cryostat vessel



CRT panels

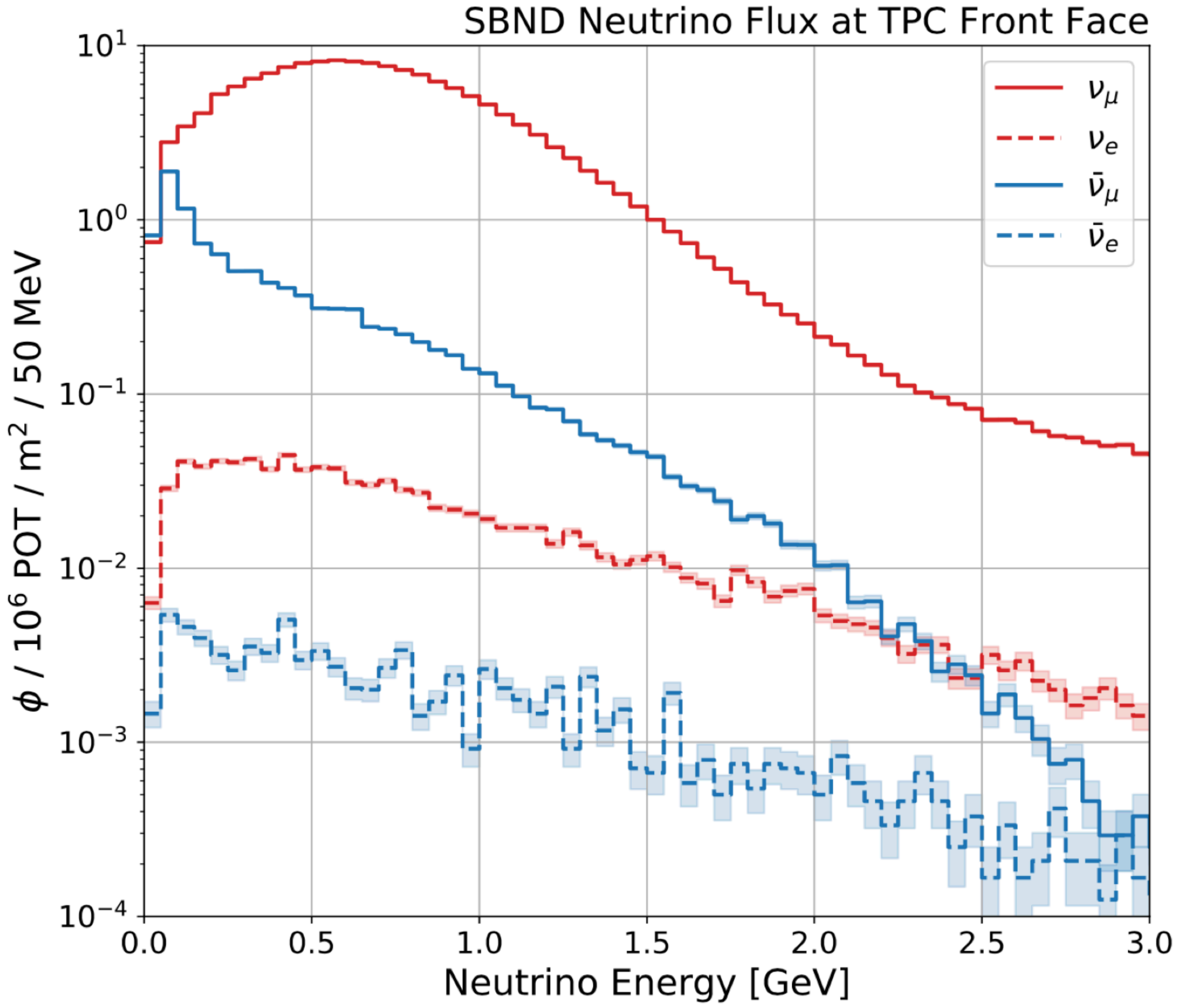
Booster Neutrino Beam (BNB)

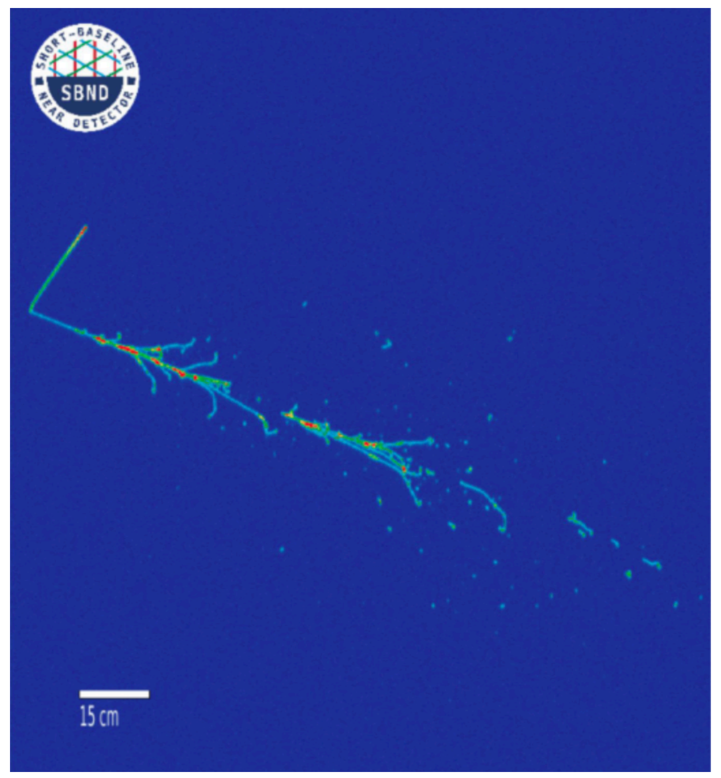
Neutrino Flux

Mean ν_μ energy is about 0.8 GeV

Beam composition:
ν_μ (93.6%)
$\bar{\nu}_\mu$ (5.9%)
$\nu_e + \bar{\nu}_e$ (0.5%)

Plan to collect data from 10×10^{20}–18×10^{20} protons on target (POT) from neutrino beam.

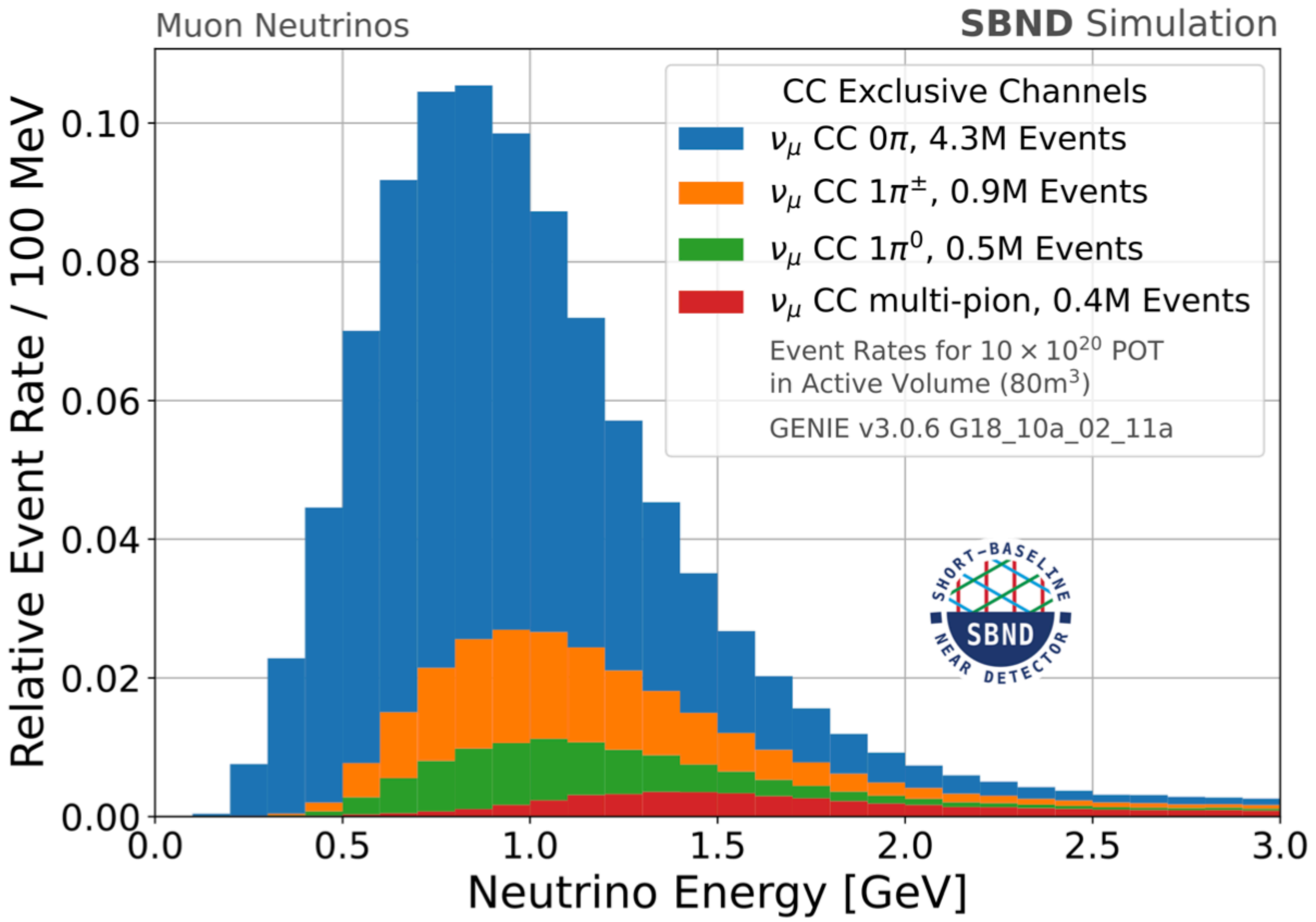


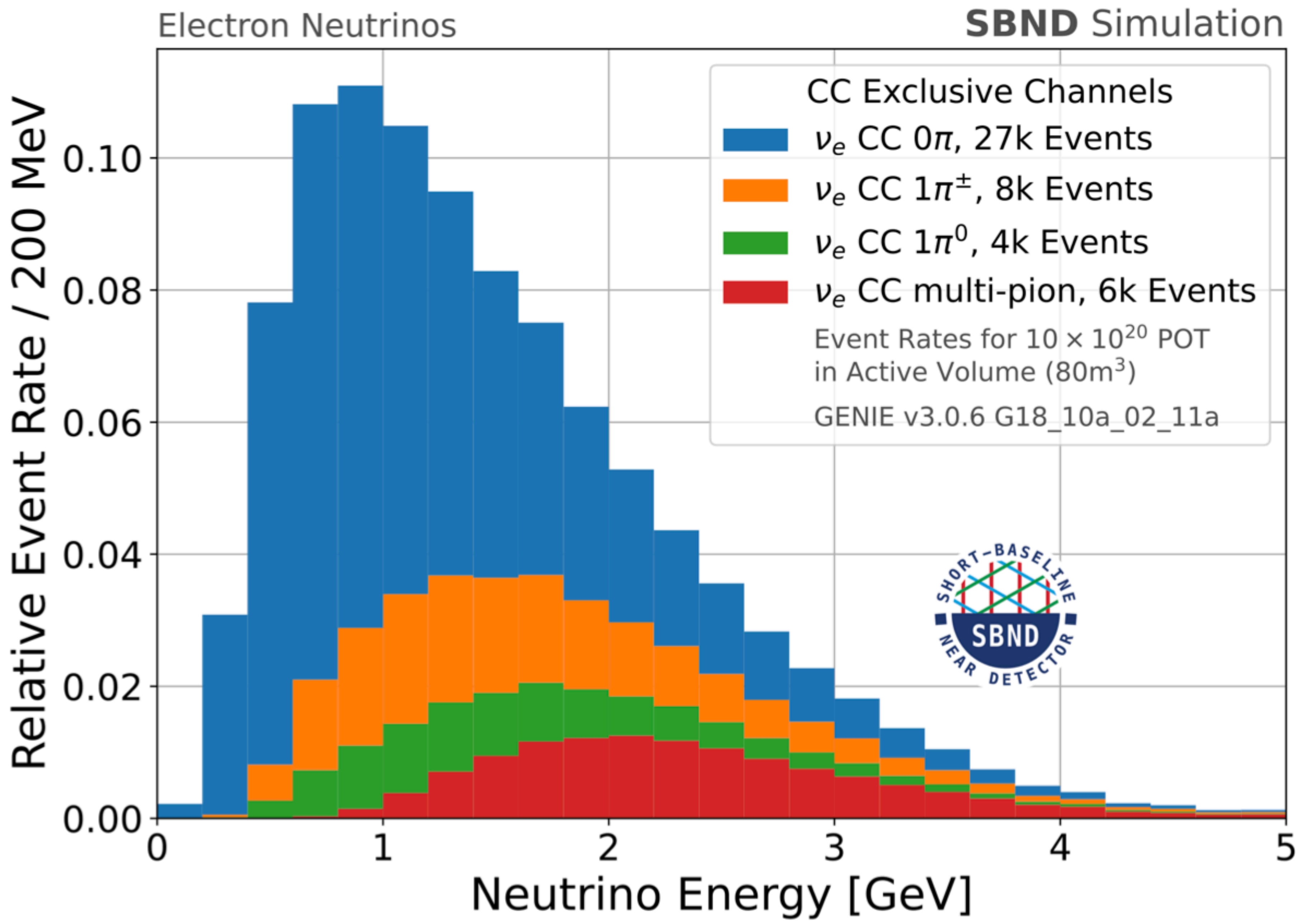


Simulated ν_e interaction in SBND

Neutrino flux

Cross section and interaction models





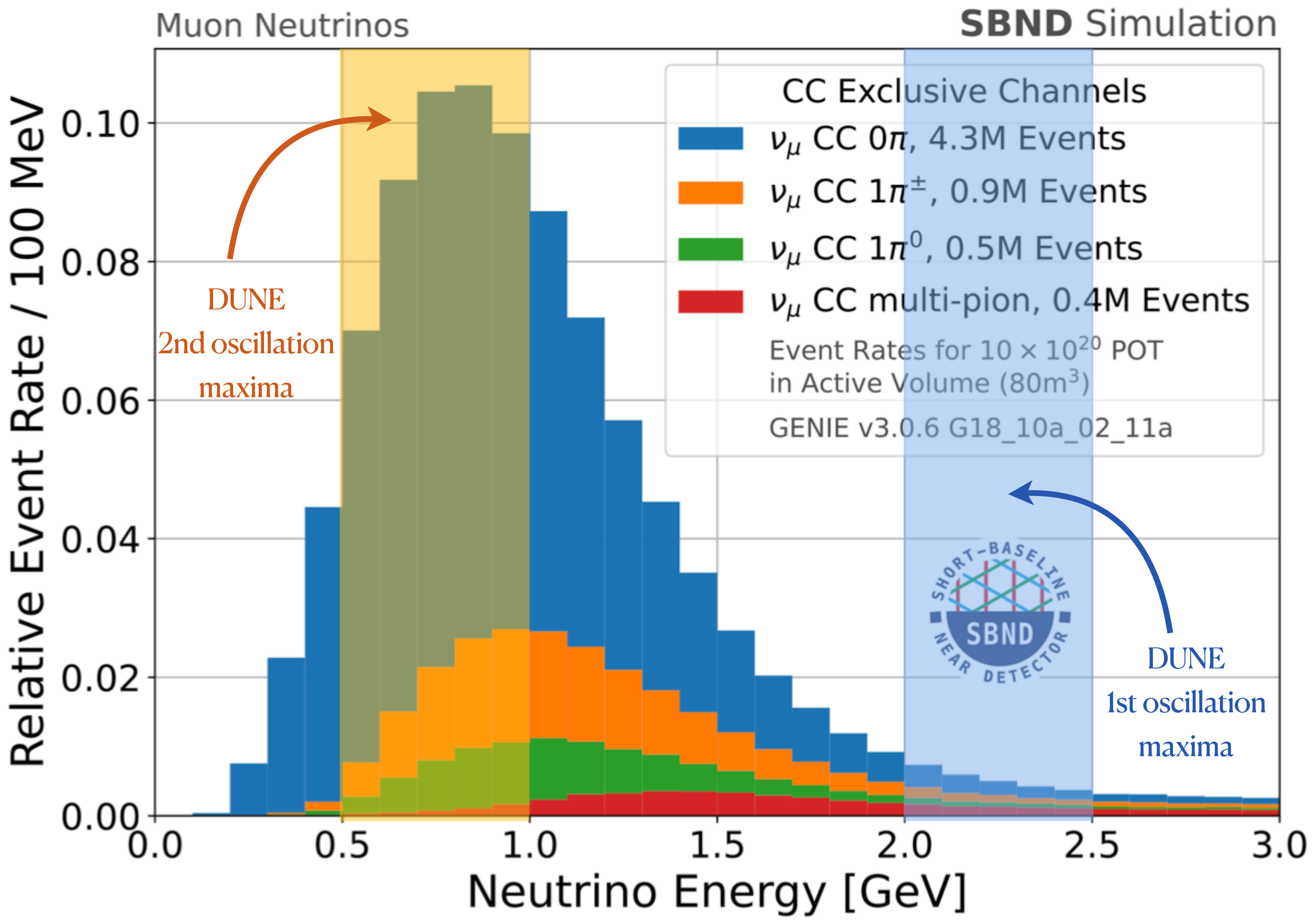
SBND will have the **largest statistics** of muon and electron neutrinos **than any previous LArTPC:**

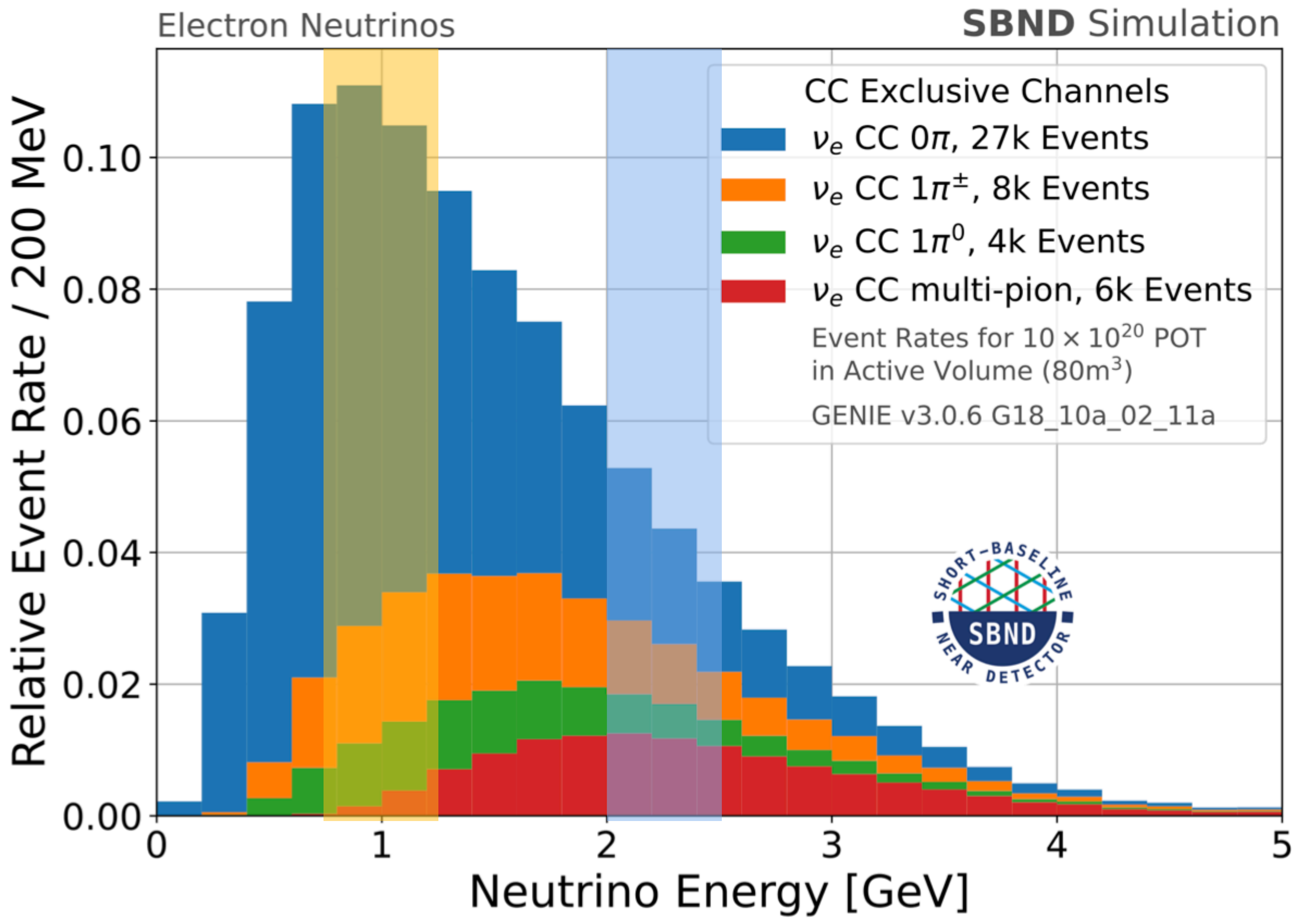
5M ν_μ and 12K ν_e $\sim$ per year.

The detector SBND will be capable of discerning a wide variety of final states.

Neutrino flux

Cross section and interaction models





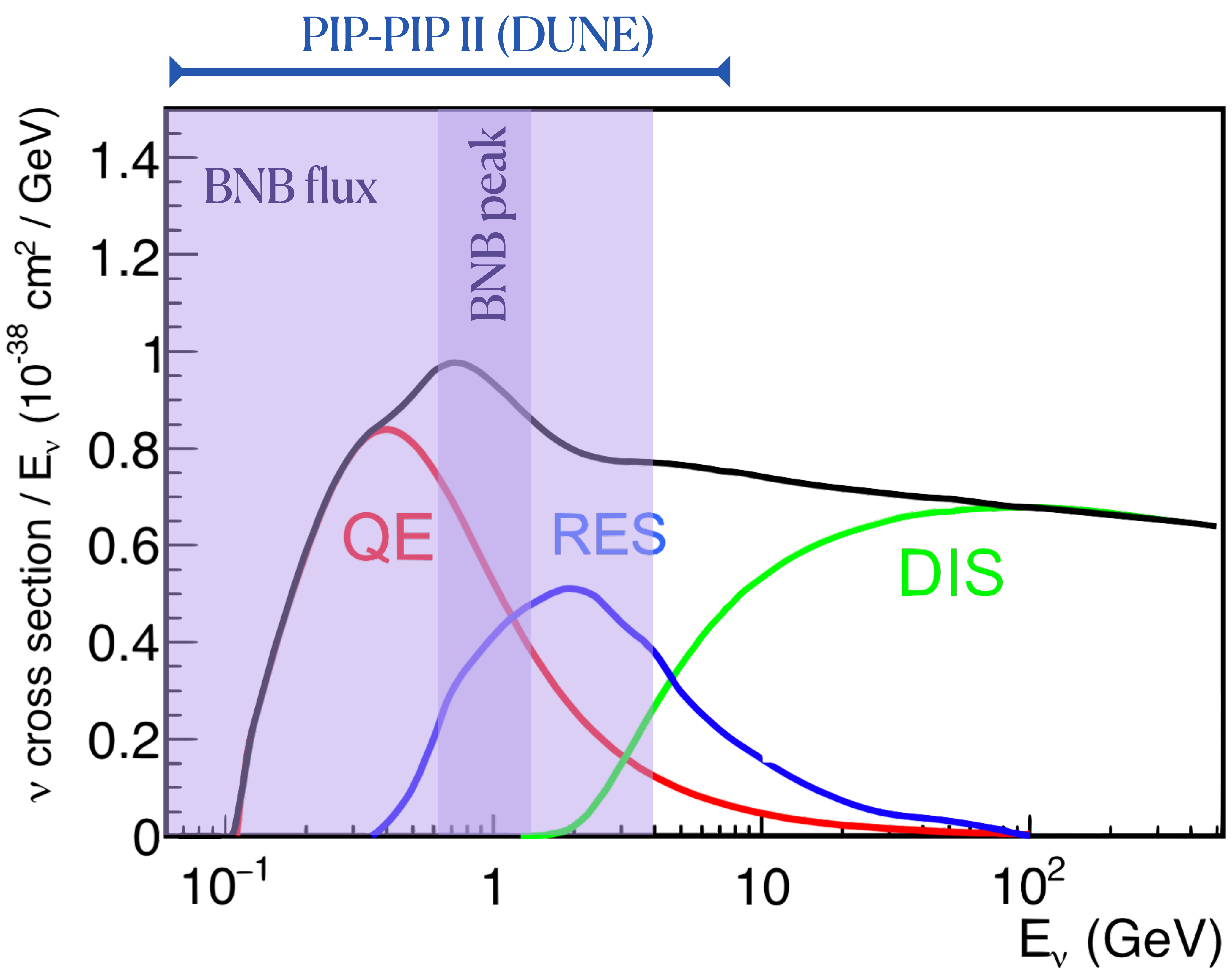
Specially relevant as BNB flux covers DUNE's first and second oscillation maxima.

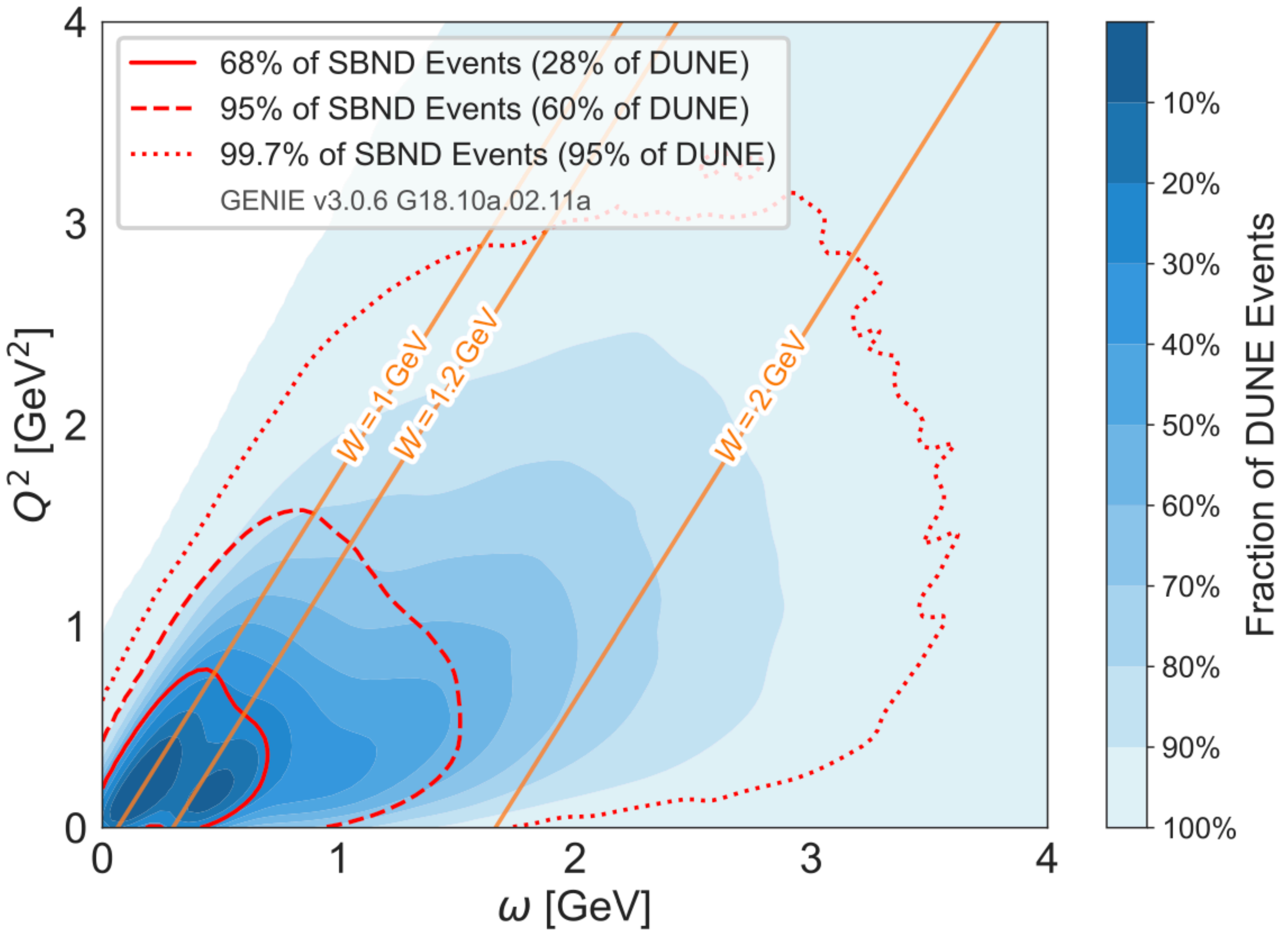
Neutrino flux

Cross section and interaction models

Friday, WG2, A. Furmanski
Neutrino Interaction Measurement Capabilities of the SBND Experiment

Poster, M. Jung
Neutrino-Nucleus Interaction with muon neutrino CC events



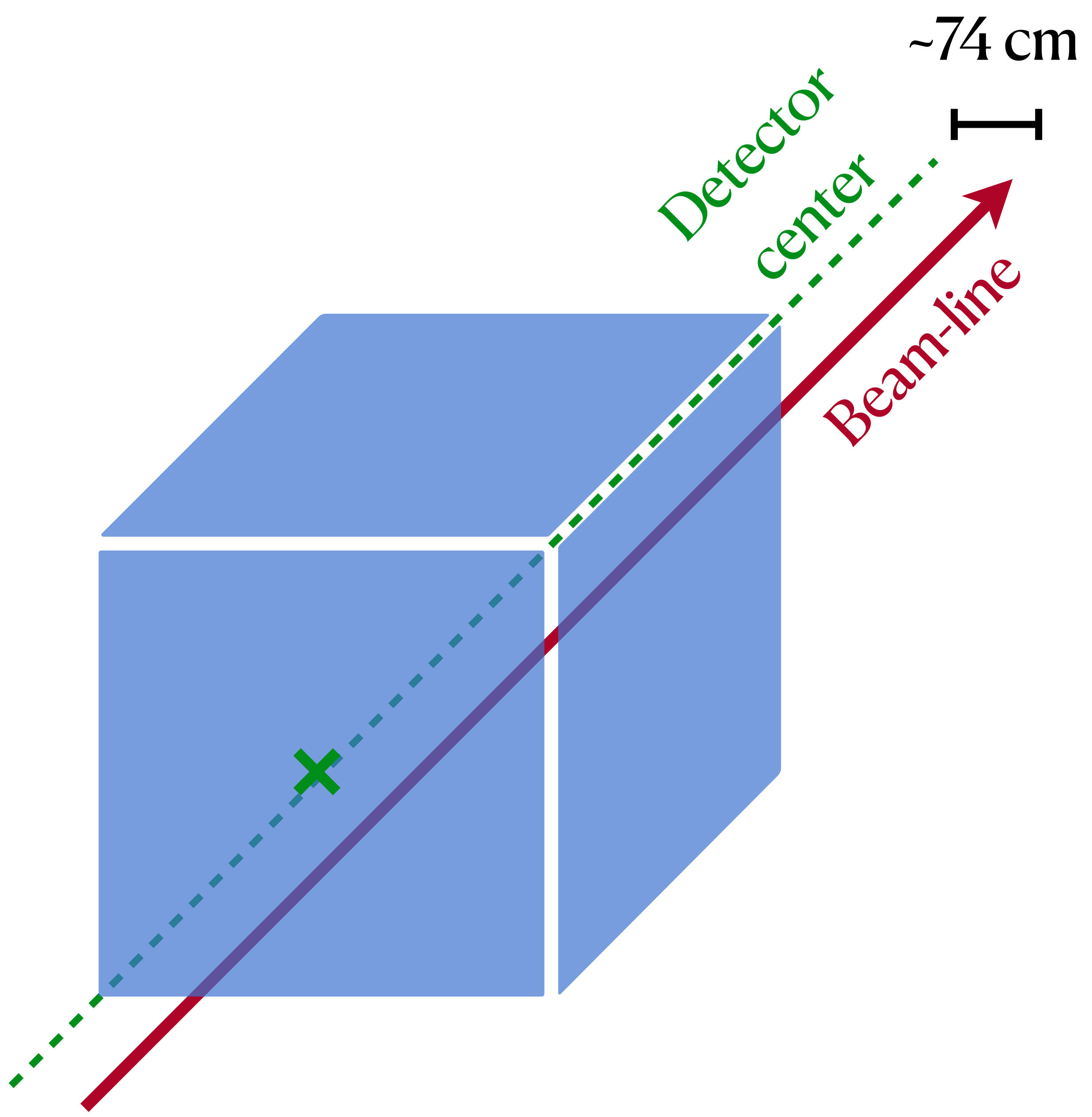


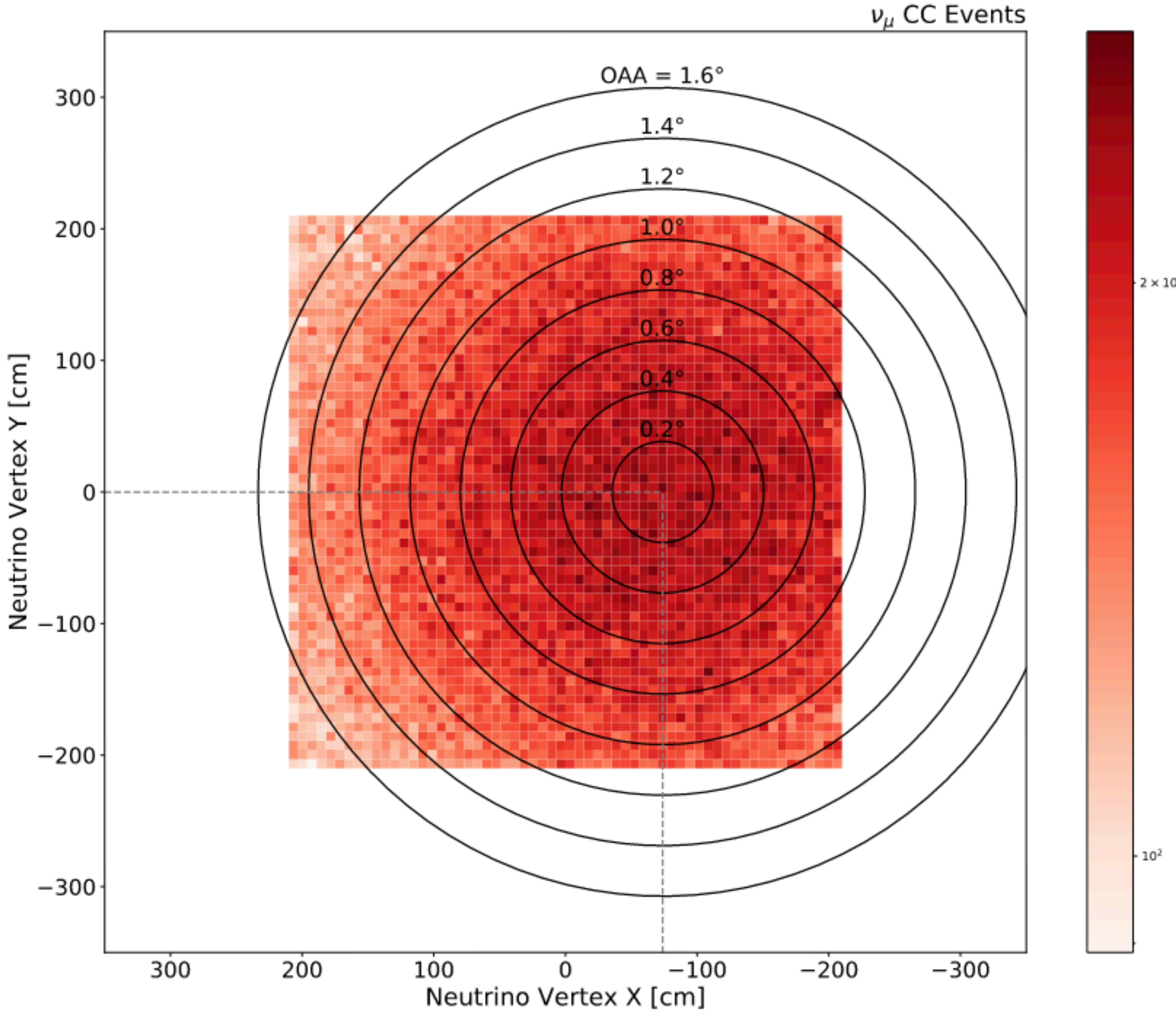
Measure nuclear effects and asses impact on final states and kinematics.
Perform precise cross-section measurements (for SBN program and long baseline).
Inform MC generators and discriminate between models (GENIE, GiBBU).

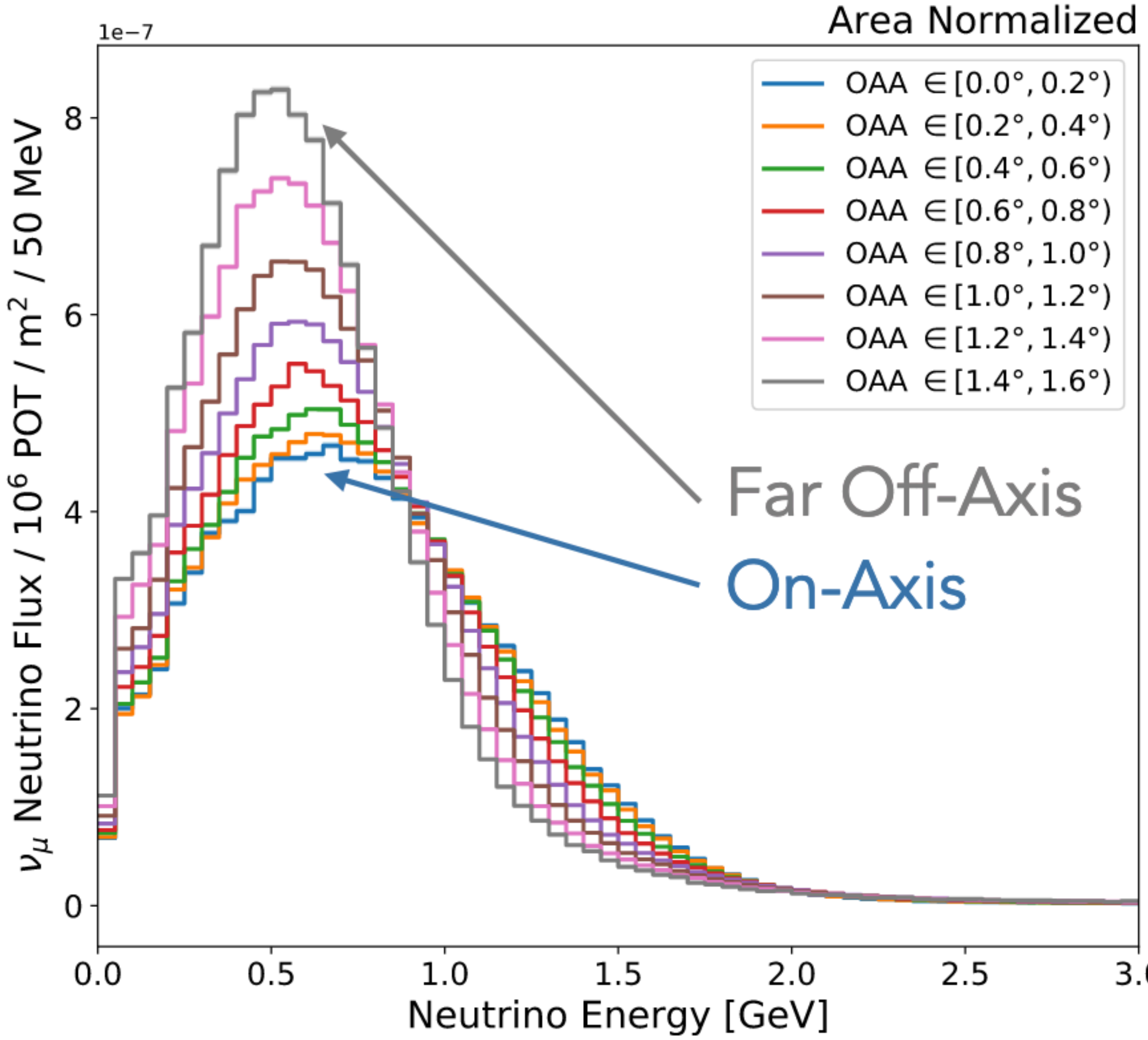
Off-beam axis

SBND is not perfectly aligned with the BNB line:
traversed by neutrinos coming from different angles wrt the beam axis

SBND PRISM







Neutrino energy distributions vary for different incoming off-axis angle, which correspond to the neutrino interaction vertex position.

Further off-axis fluxes have narrower distributions and peak at lower energies.

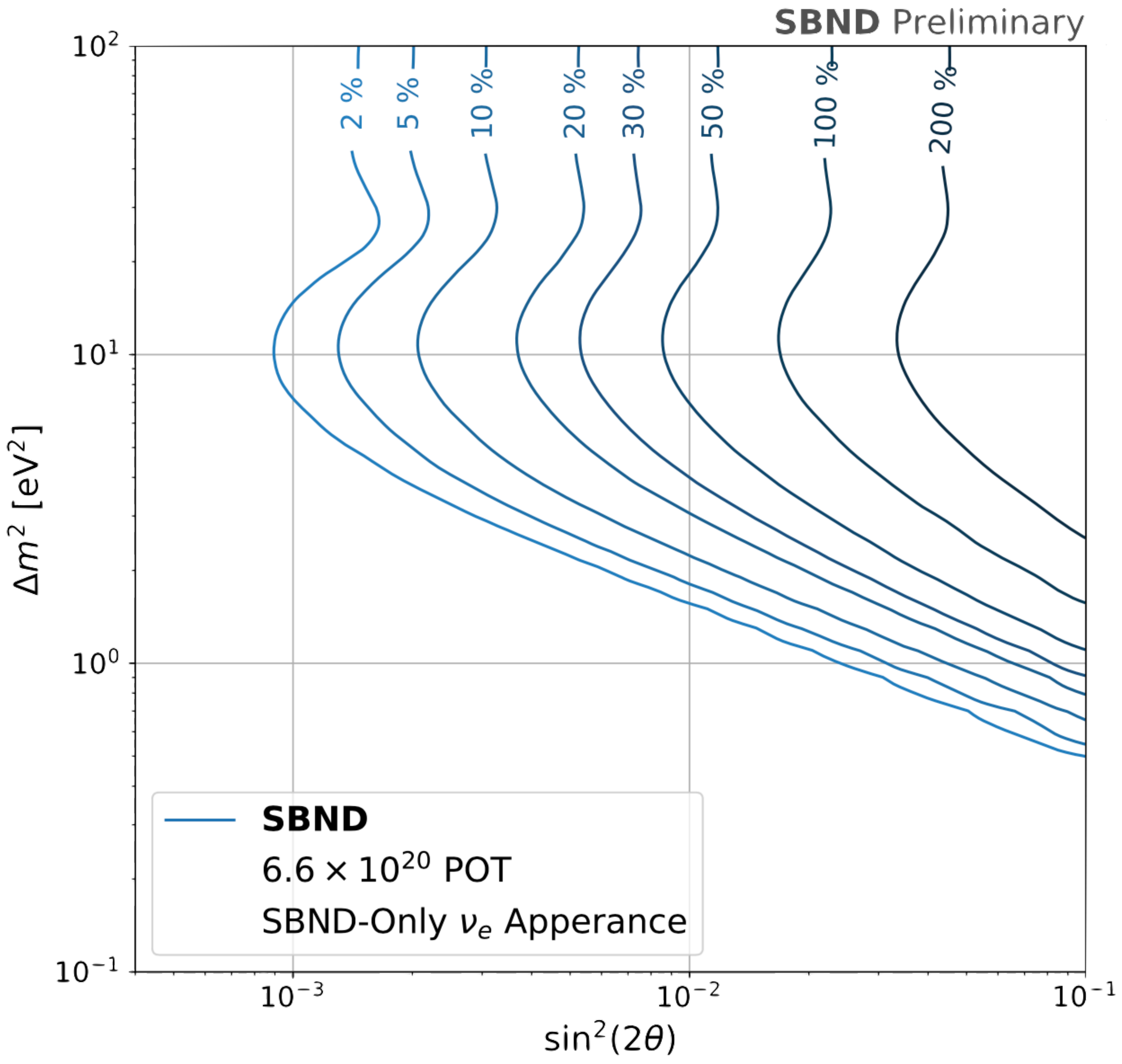
ν_μ and ν_e fluxes are affected by off-axis position (the later is less so).

SBND PRISM

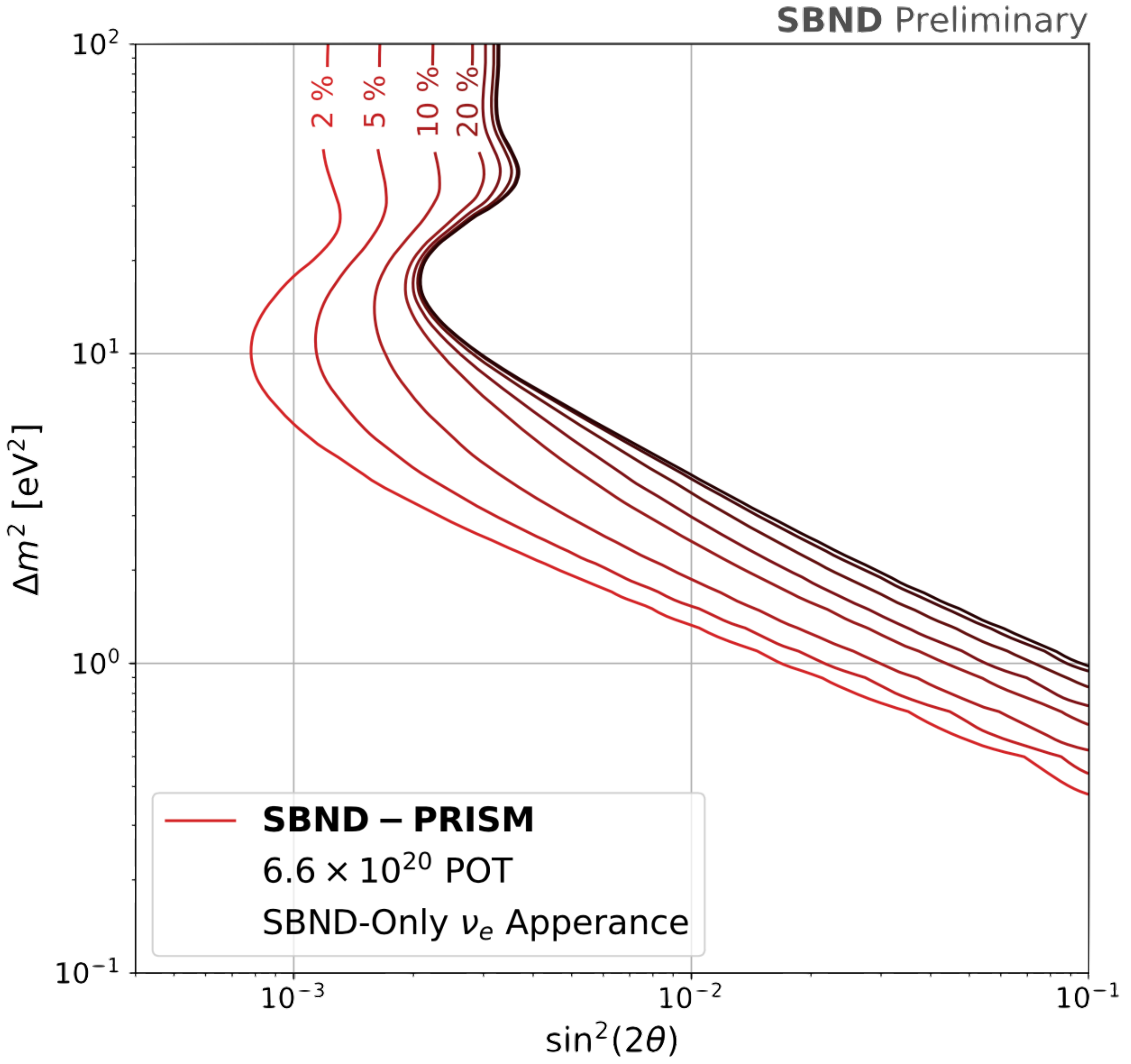
Precision Reaction Independent Spectrum Measurement[1] [1] nuPRISM

* Exploit muon neutrino and intrinsic electron neutrino off-axis flux differences —> improved sterile neutrino sensitivity
* Treat SBND as 8 sub detectors corresponding to different off-axis regions.
* Inflate cross-section uncertainty on cross-section model: SBND PRISM insensitive above 20%

SBND single detector



SBND PRISM sub-detectors concept

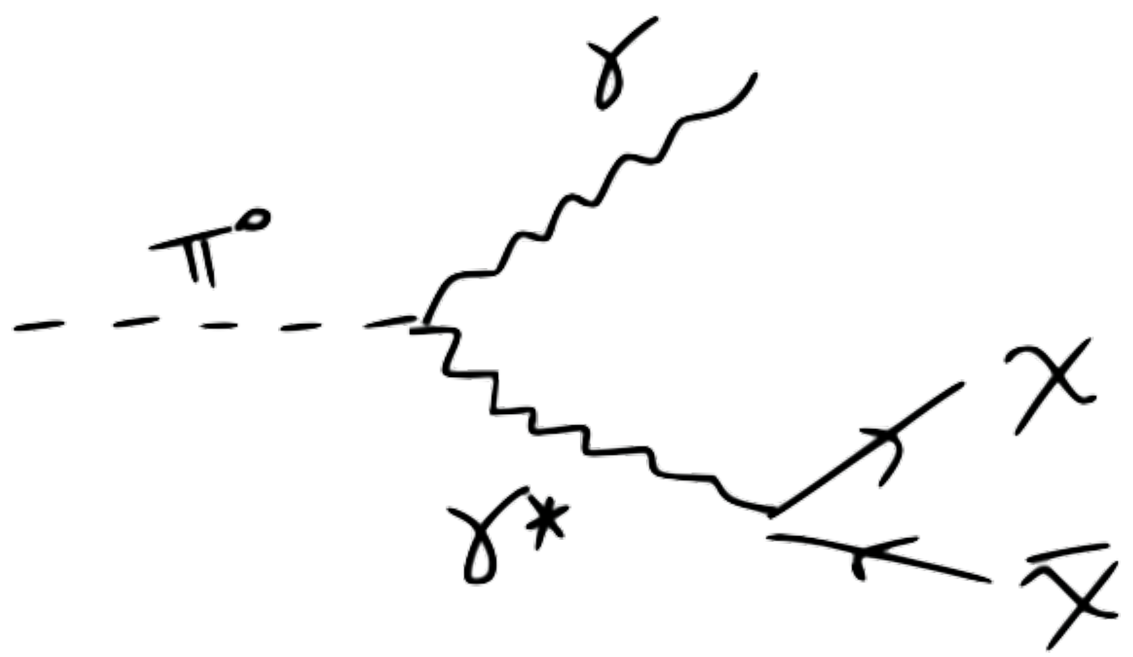


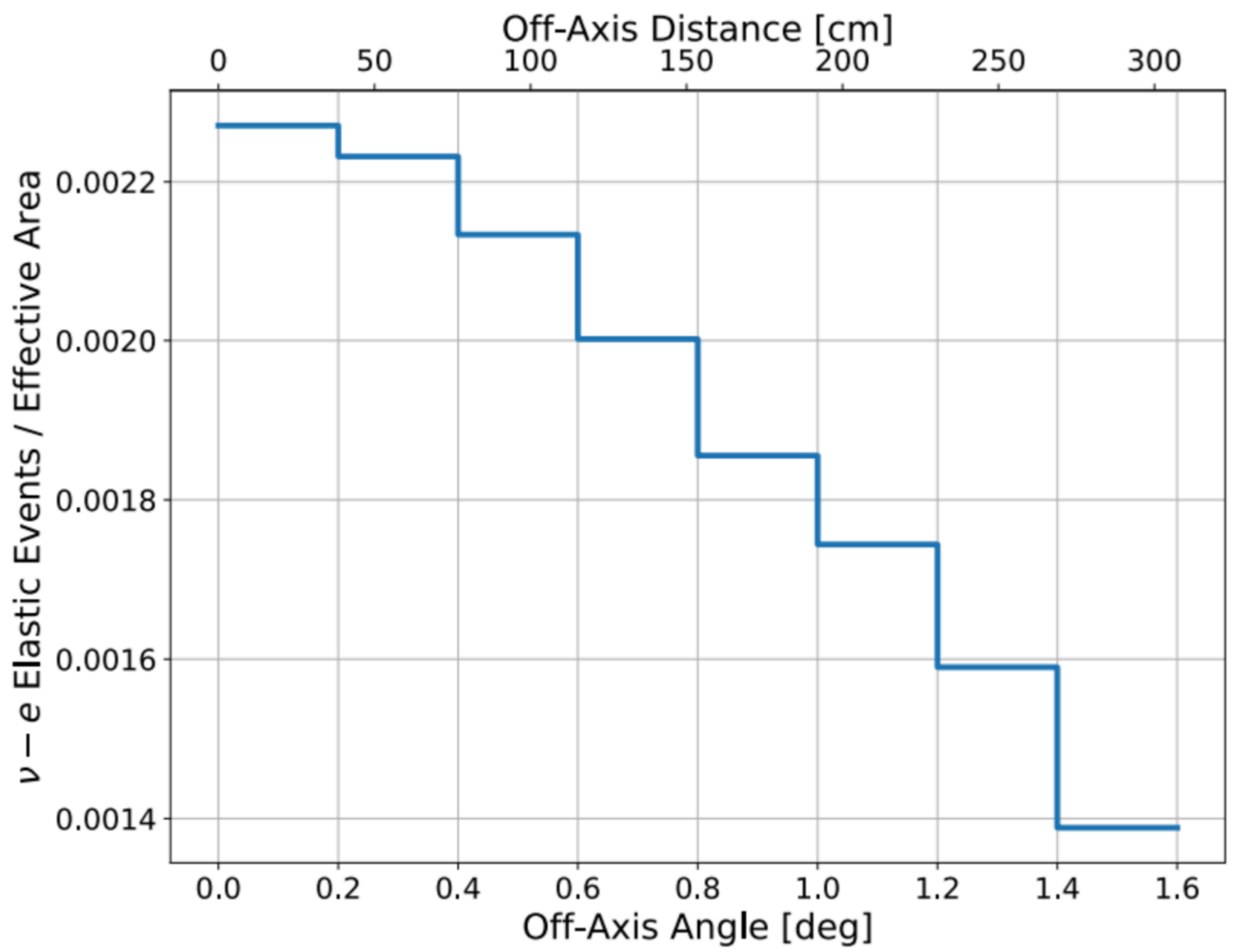
SBND PRISM

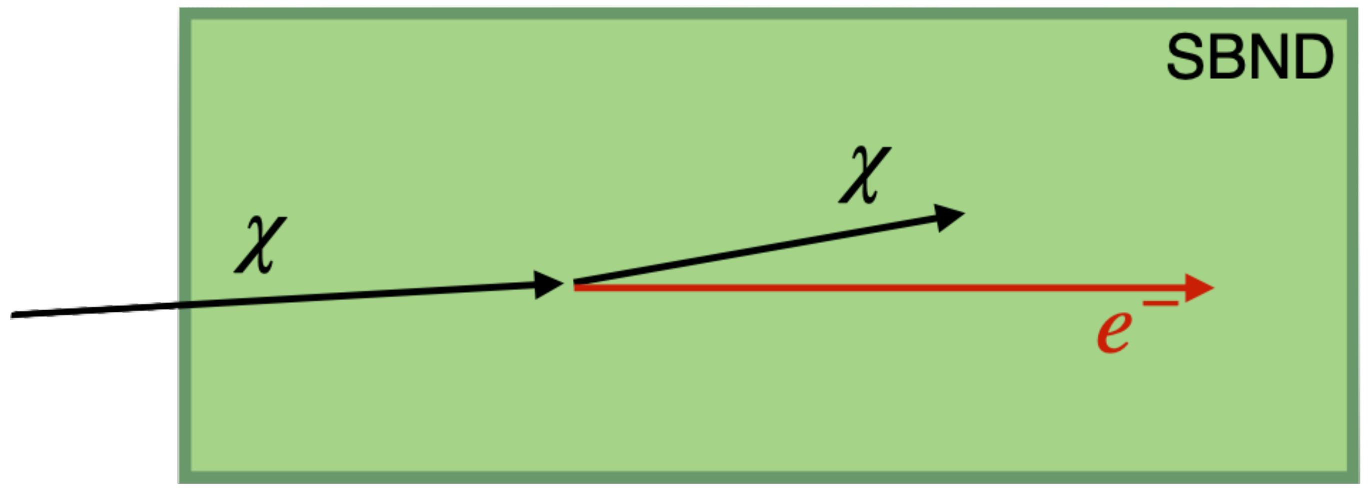
Precision Reduction Independent Spectrum Measurement[1]

[1] nuPRISM

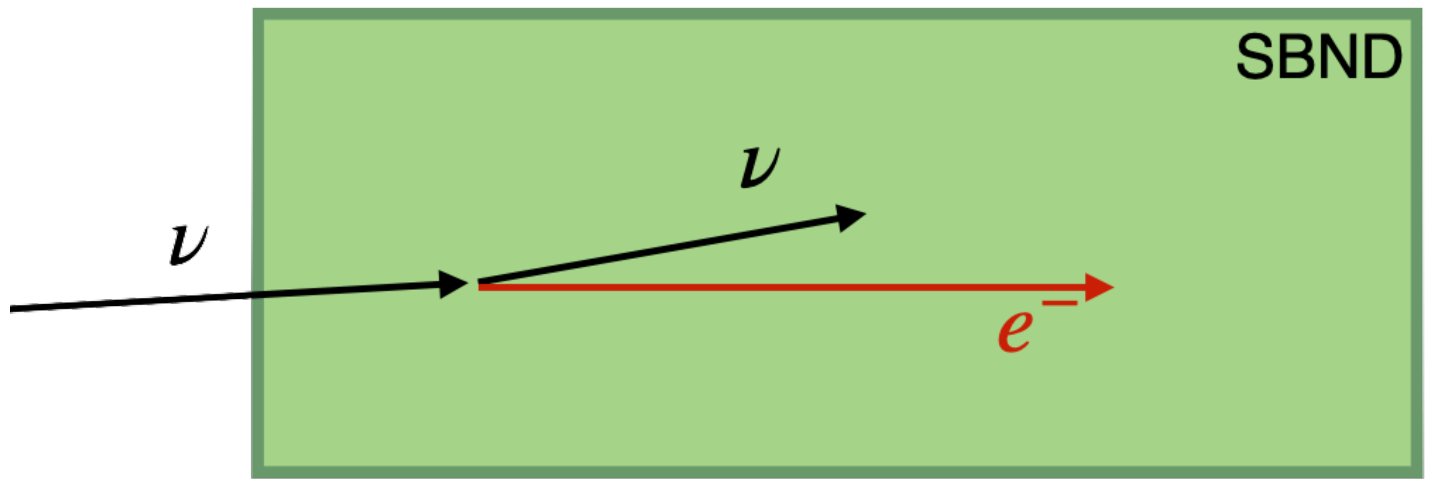
Light Dark Matter







Signal



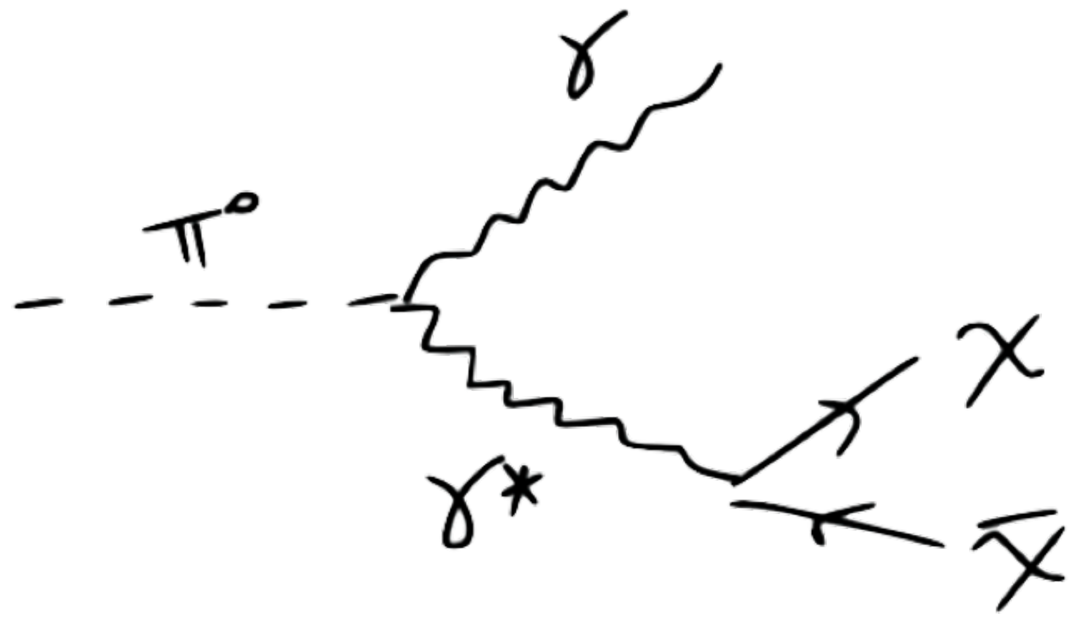
Background

Friday, WG5, X. Luo
Beyond the Standard Model Searches with SBND

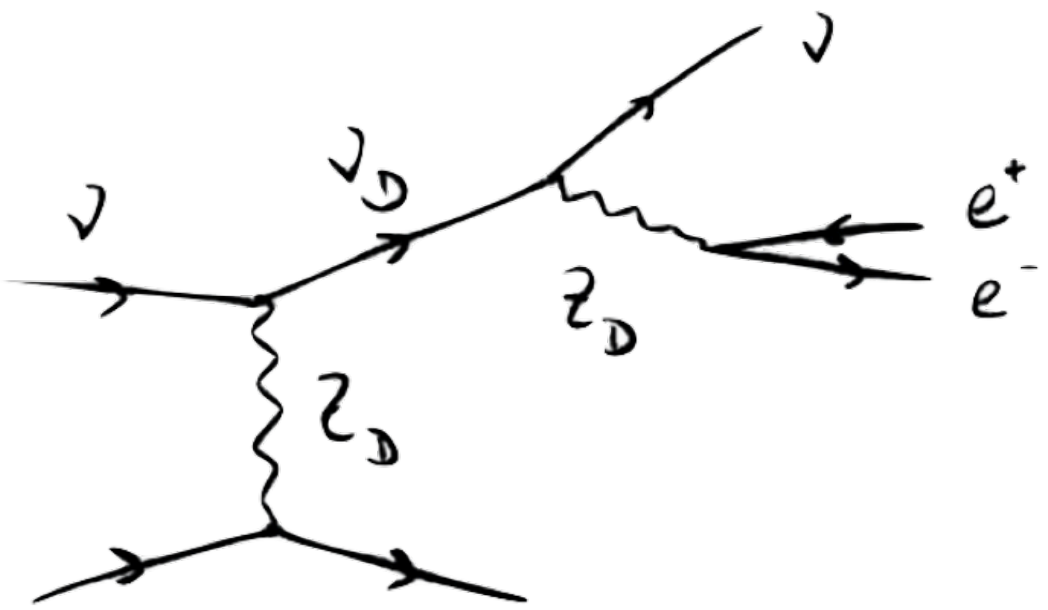
* Look for BSM particles from three body decay of neutral mesons (unfocused)
* Neutrino interactions from two body decay of charged mesons (focused).
* Going off-axis reduces the events that we'd like to reject

SBND other Beyond the Standard Model Searches

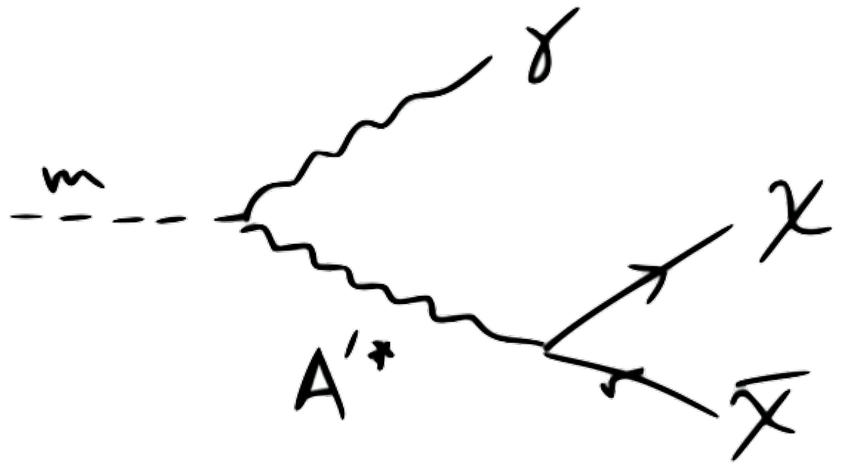
Light Dark Matter
[4]



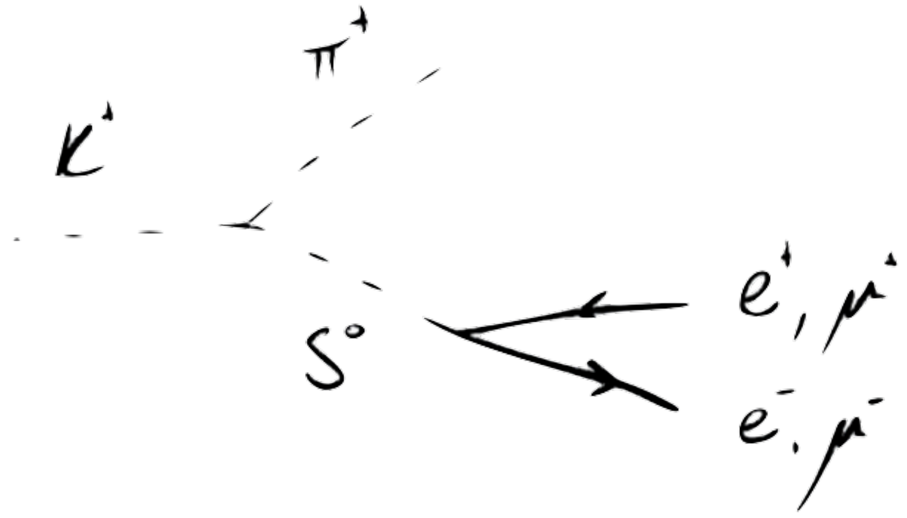
Dark Neutrinos
[1] [2] [3]



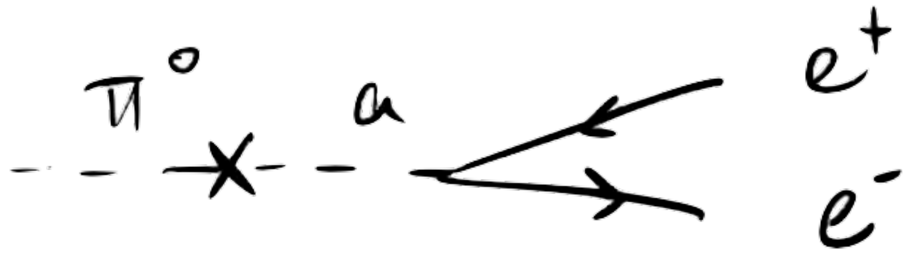
Milicharged Particles
[5] [6]



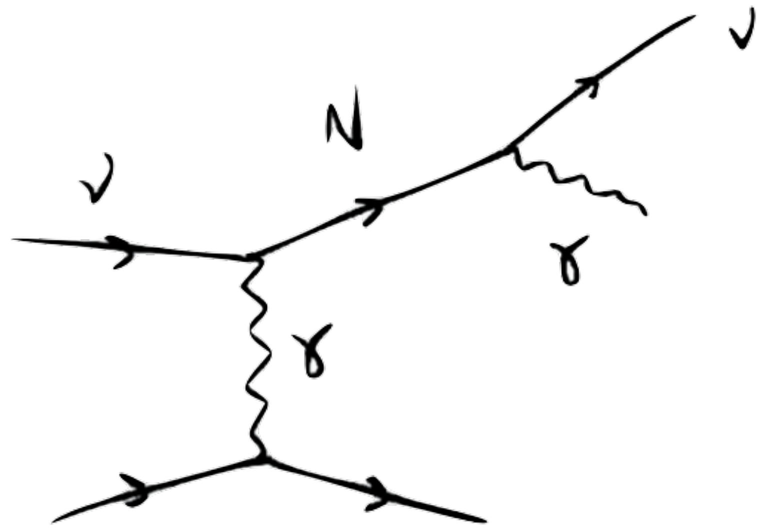
Higgs Portal Scalar
[15] [16] [17]



Axion-like Particles
[9] [10]



Transition Magnetic
[11] [12] [13] [14]



Friday, WG5, X. Luo
Beyond the Standard Model Searches with SBND

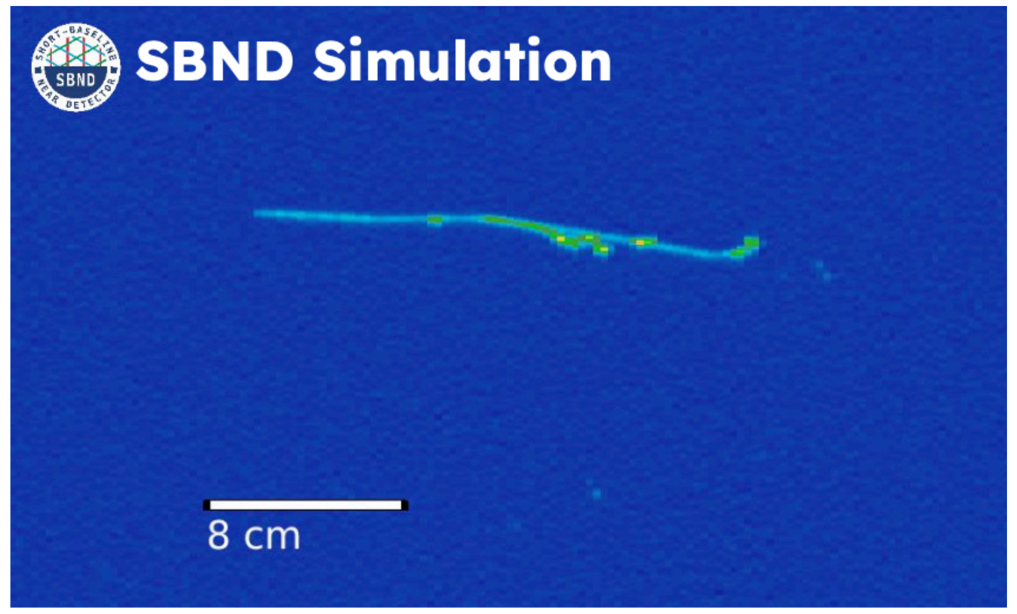
Alternative explanations to MiniBooNE's excess, and other BSM models:

Modifications to neutrino oscillations and new states

Diagram credit: Pedro Machado

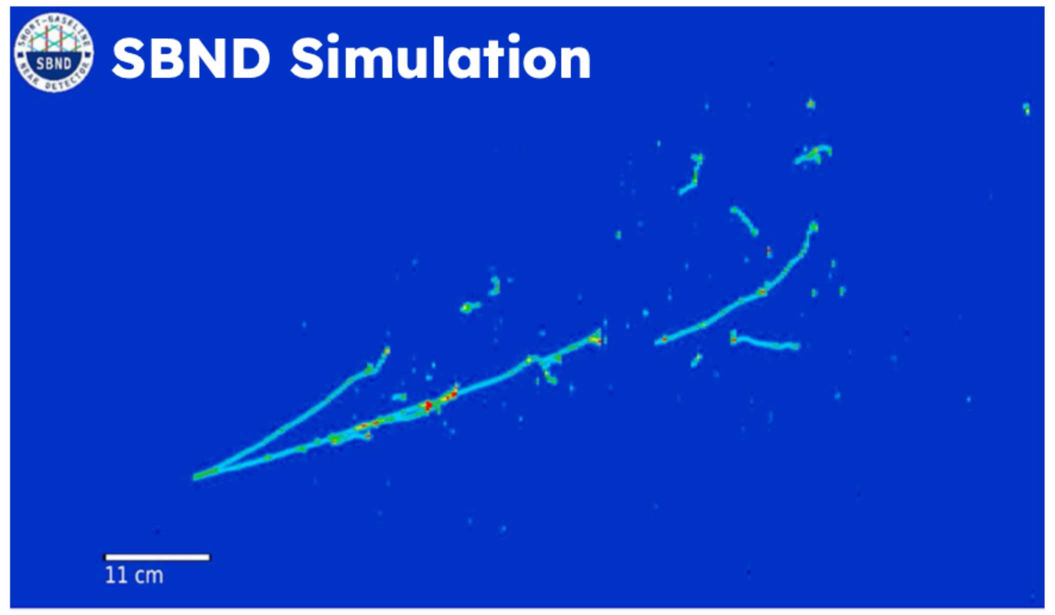
SBND other Beyond the Standard Model Searches

Light Dark Matter



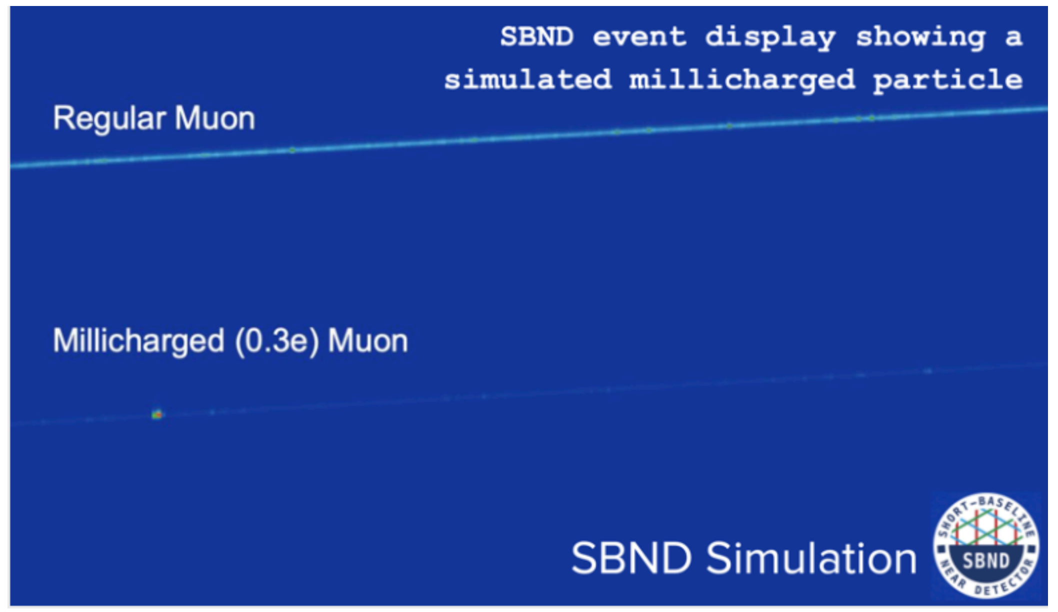
electron scattering

Dark Neutrinos



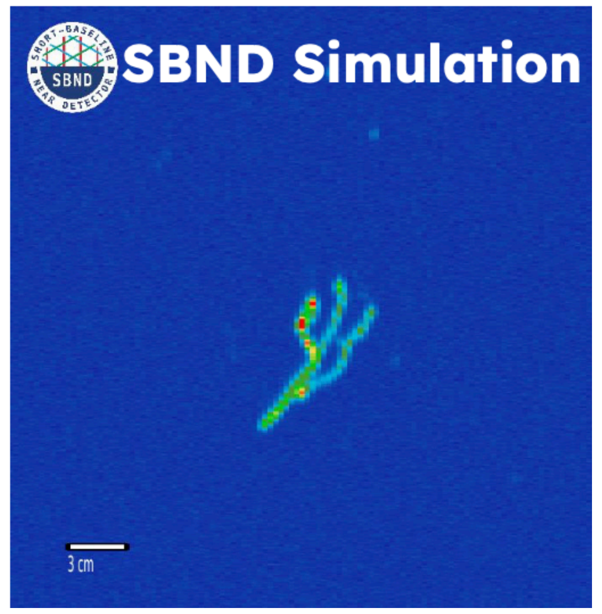
e^-e^+ pair with or without hadronic activity

Milicharged Particles



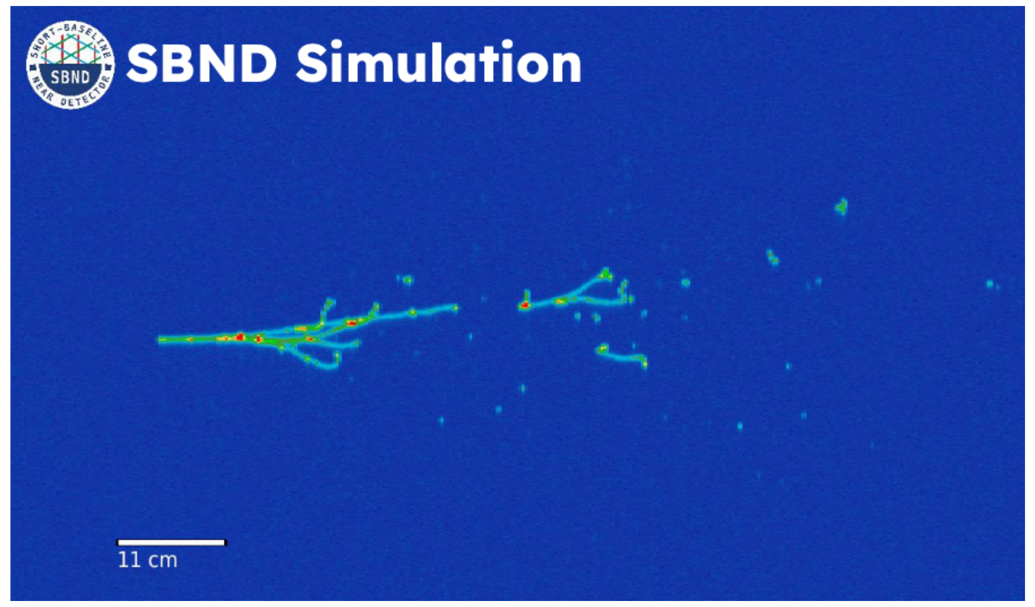
blips

Higgs Portal Scalar



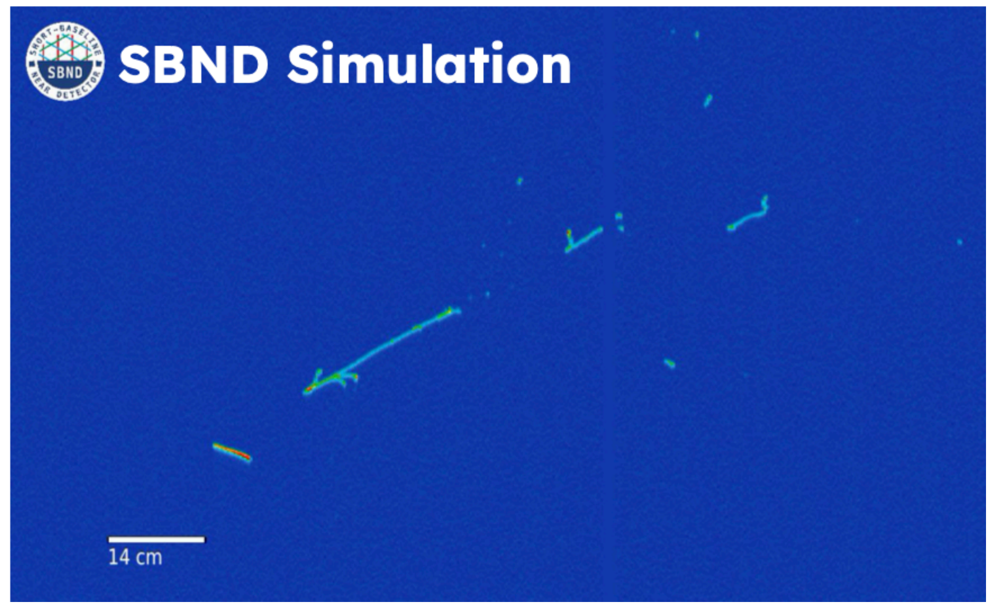
e^-e^+or $\mu^-\mu^+$ without hadronic activity

Axion-like Particles



high energy e^-e^+or $\mu^-\mu^+$

Transition Magnetic



γ shower and hadronic activity

Friday, WG5, X. Luo
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Modifications to neutrino oscillations and new states

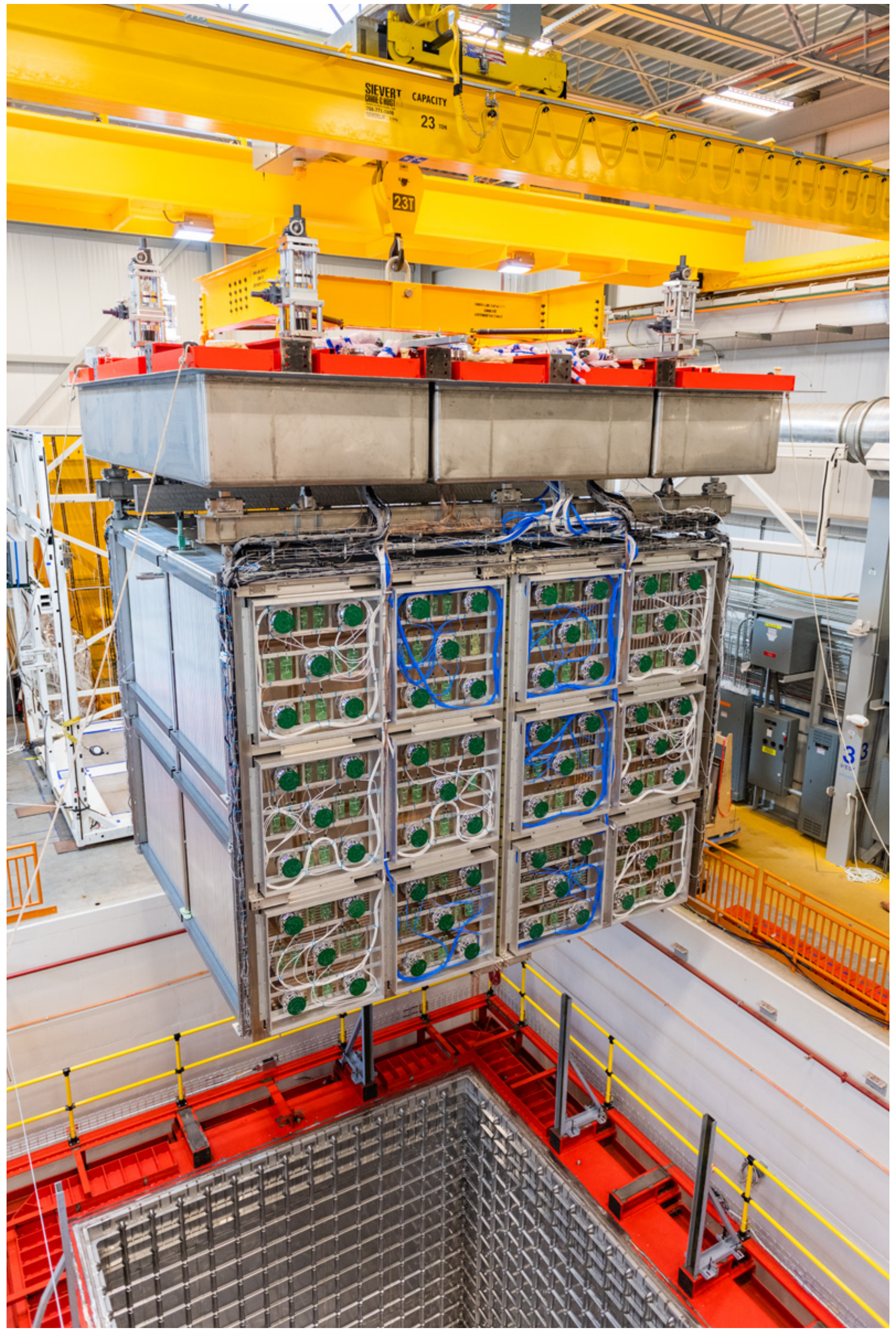
SBND status

Detector move

Assembly transported from D0 building to the SBN-ND building.

December 2022

SBND status



Detector move

Assembly transported from D0 building to the SBN-ND building.

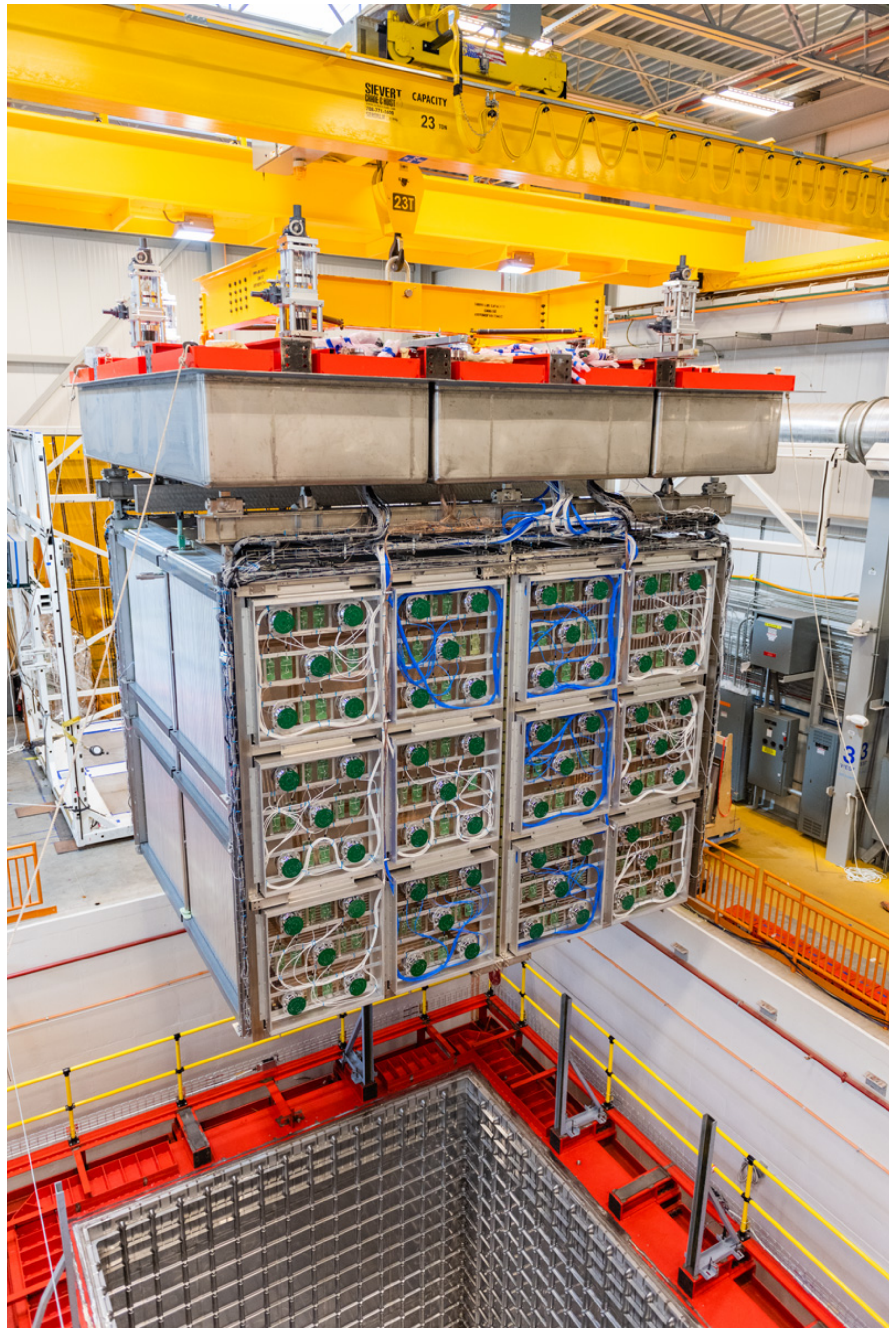
December 2022

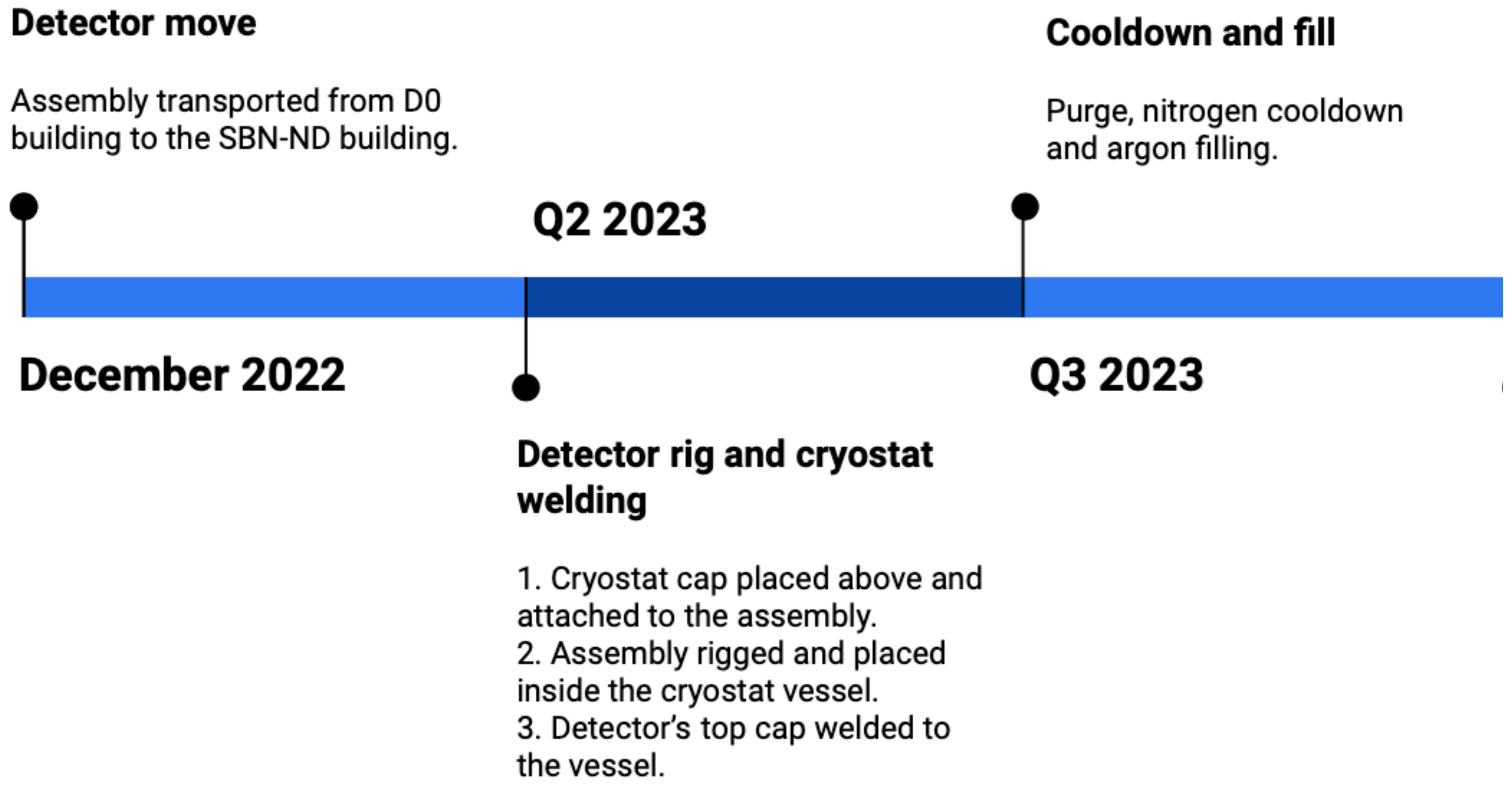
Q2 2023

Detector rig and cryostat welding

1. Cryostat cap placed above and attached to the assembly.
2. Assembly rigged and placed inside the cryostat vessel.
3. Detector's top cap welded to the vessel.

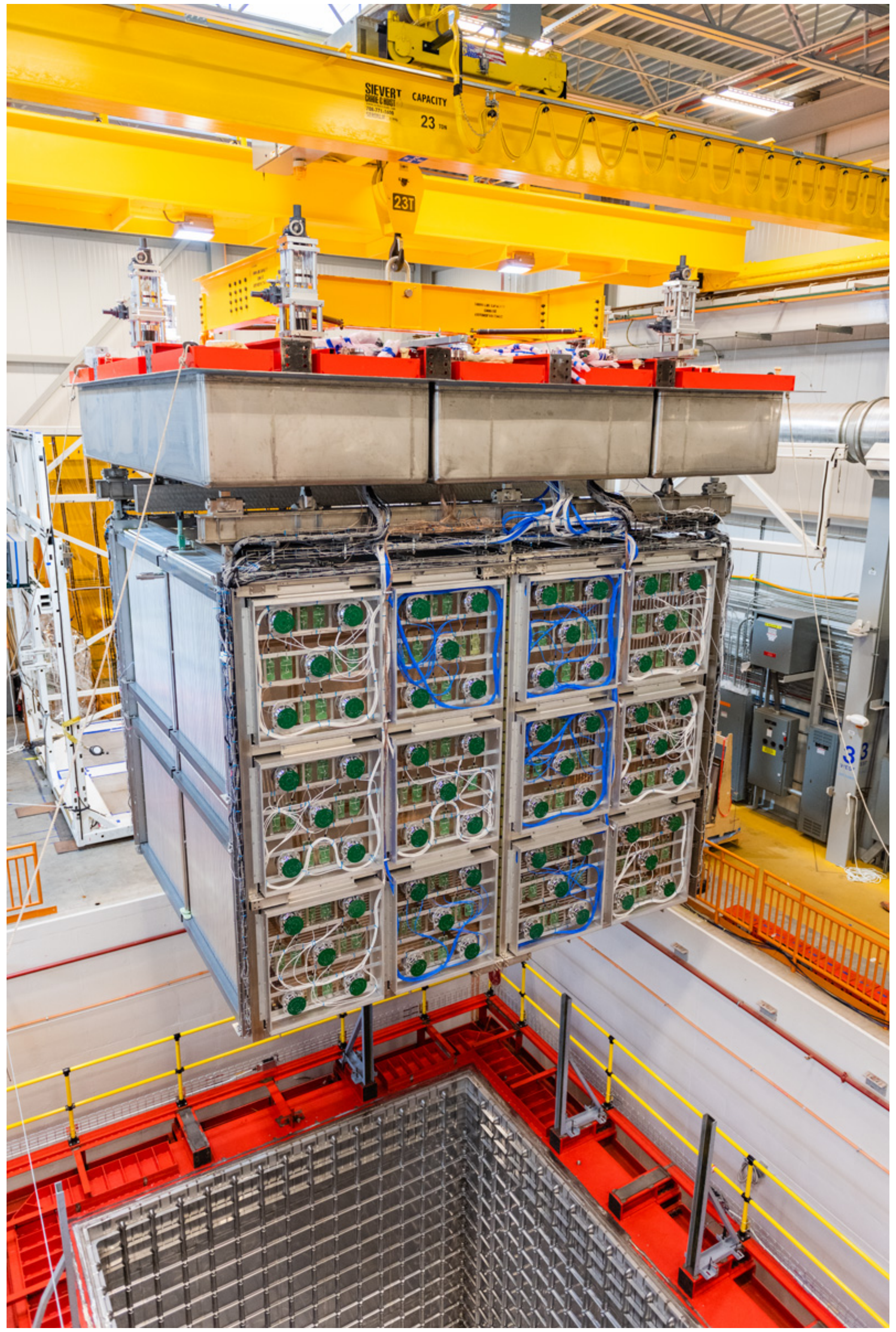
SBND status





* Single phase liquid argon projection chamber (LArTPC)
* 112 tons active mass, 5m x 4m x 4m active volume

SBND status



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Q3 2023

Cooldown and fill

Purge, nitrogen cooldown and argon filling.

Q4 2023

Commissioning

Ready for commissioning and finalise cosmic ray tagger (CRT) installation.

2024

Physics

Detector fully operational and ready for physics run.

* Single phase liquid argon projection chamber (LArTPC)
* 112 tons active mass, 5m x 4m x 4m active volume

Summary

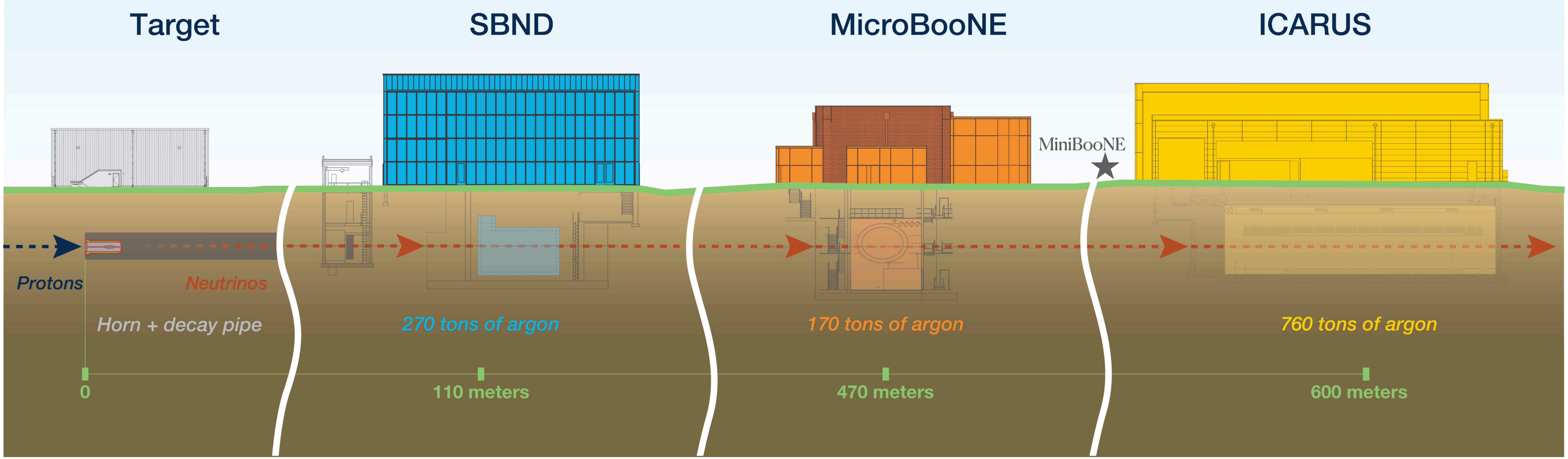
The Short Baseline Neutrino program at Fermilab has sterile neutrino oscillations, new physics searches and technology development as main goals

* The Short Baseline Near Detector, SBND, will constrain the unoscillated BNB flux.
* SBND will look for sterile neutrinos and perform other beyond the standard model searches.
* The detector will record the largest sample of neutrino-Argon interactions than any past or present experiment.
* The detector will be ready for cold commissioning by the end of this year.

감사합니다

Backup

Short-Baseline Neutrino Program at Fermilab

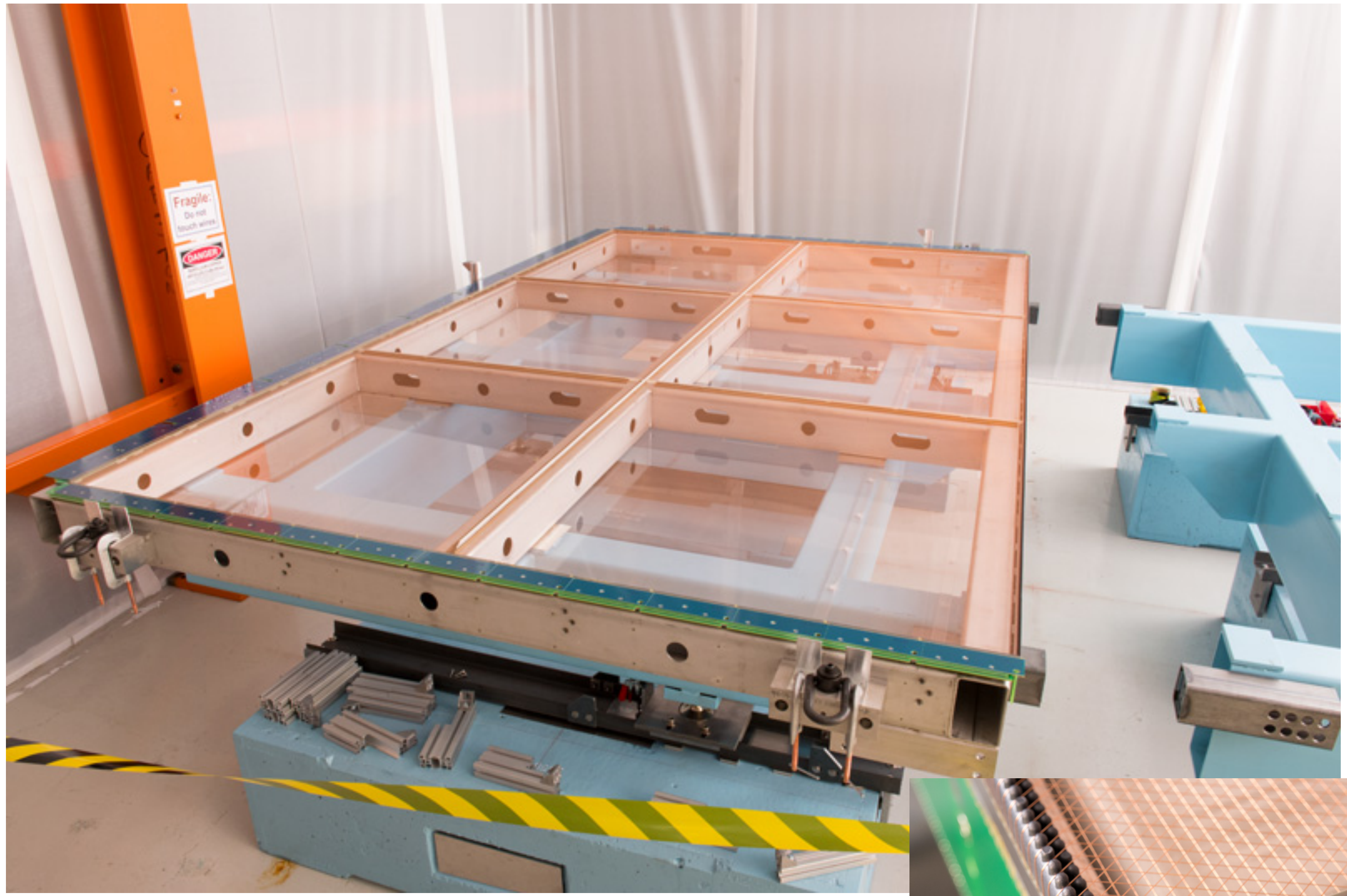


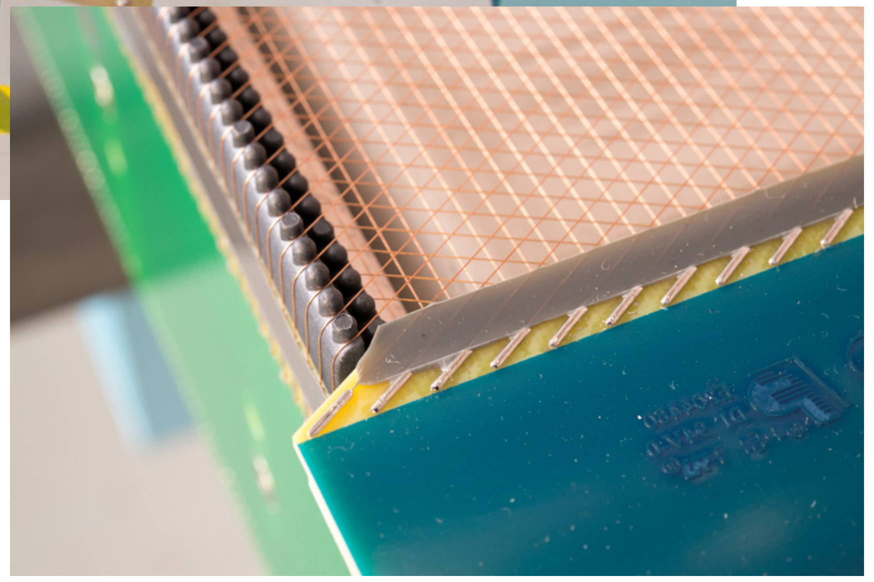
In transition to commissioning

Decommissioned 2021

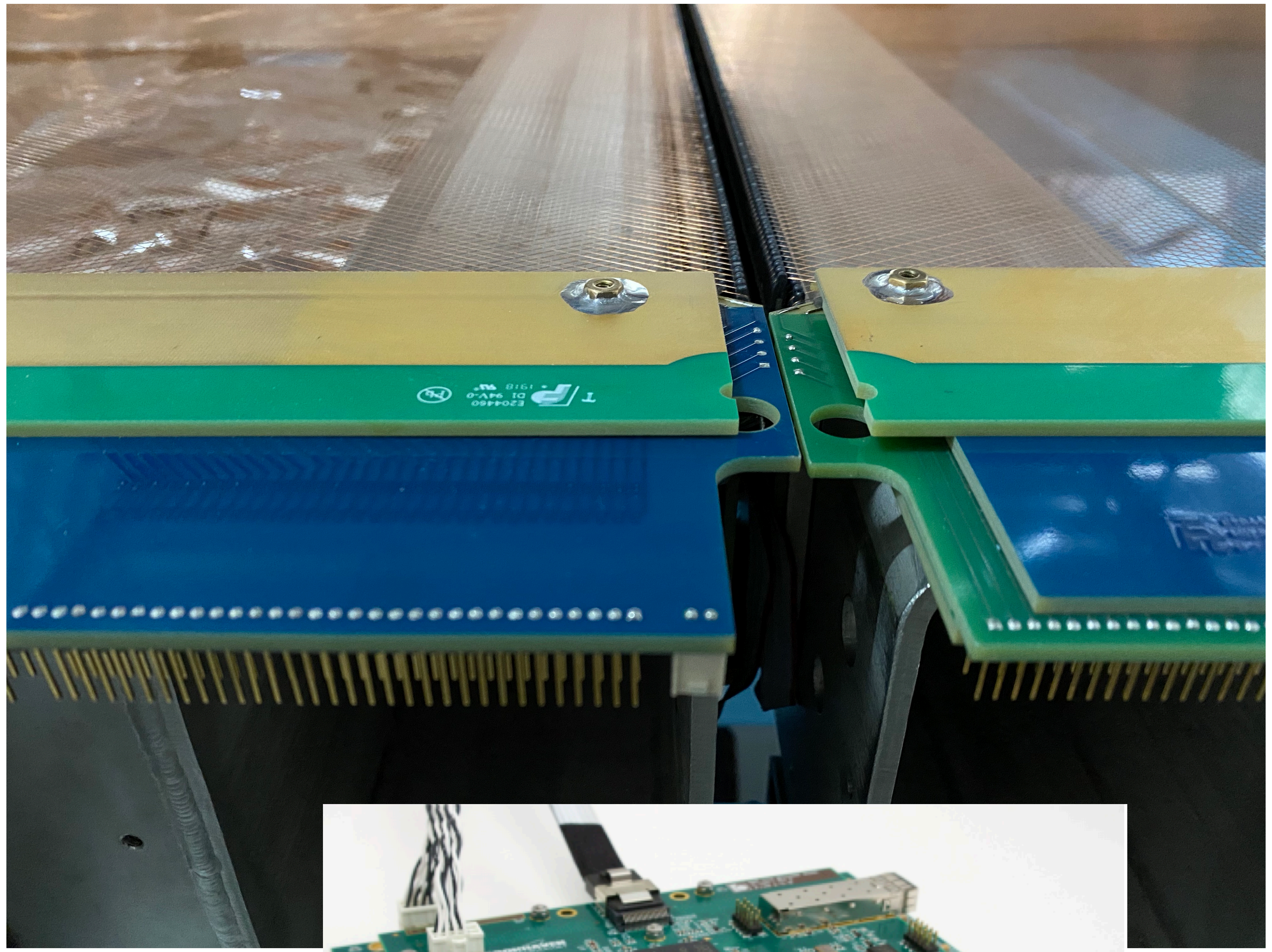
Stable physics operation

Detector assembly





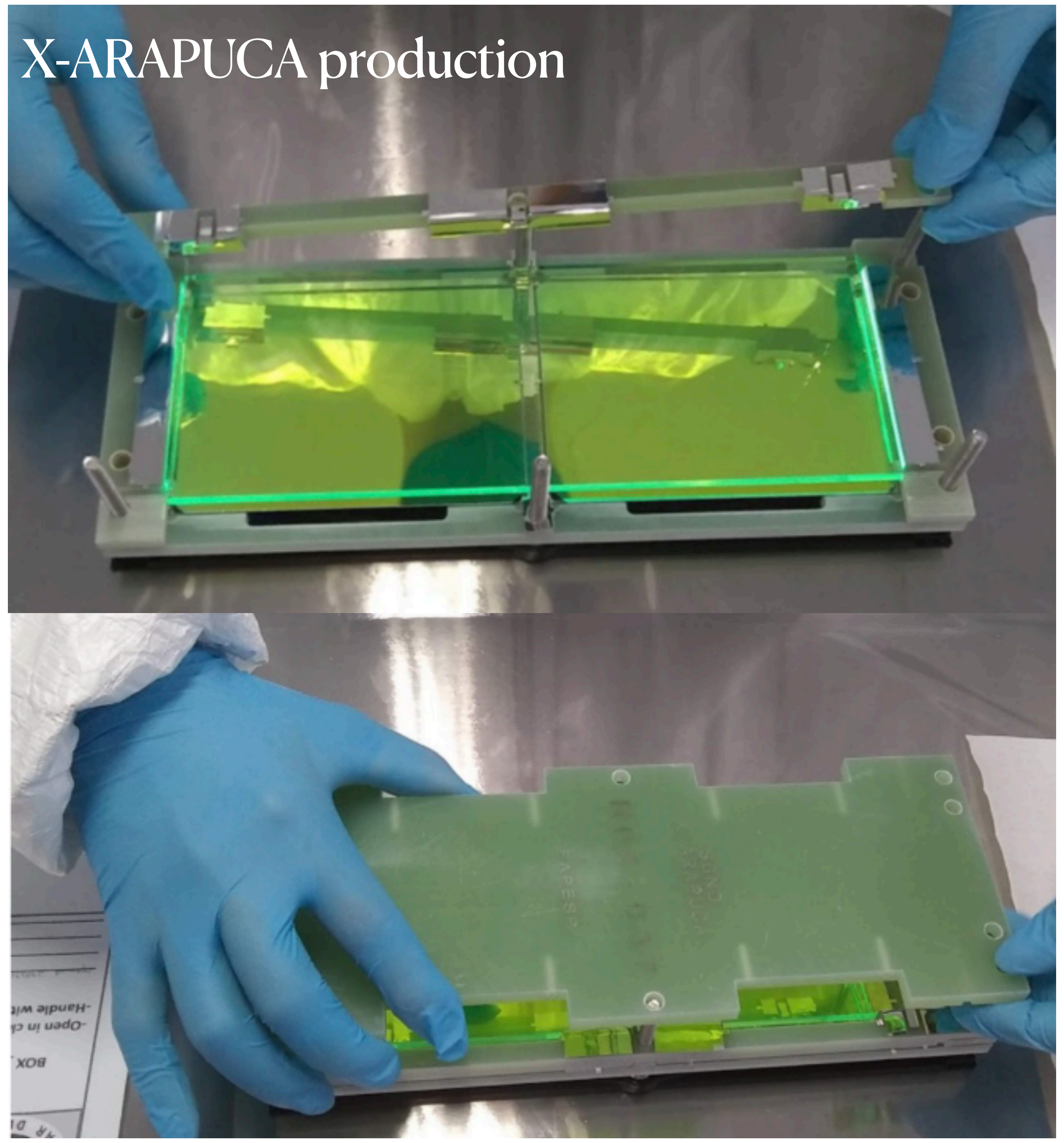
One APA module



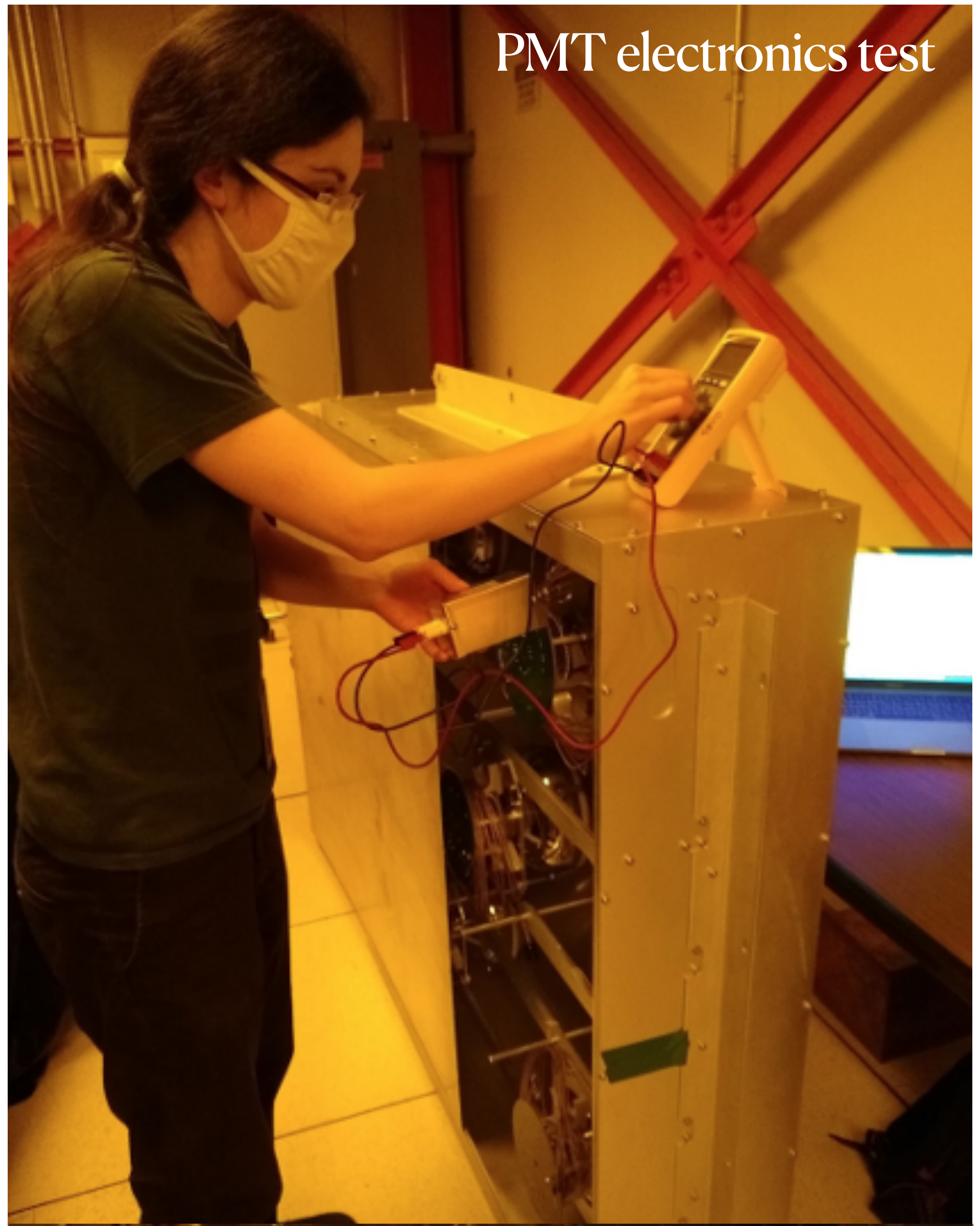
APA joint

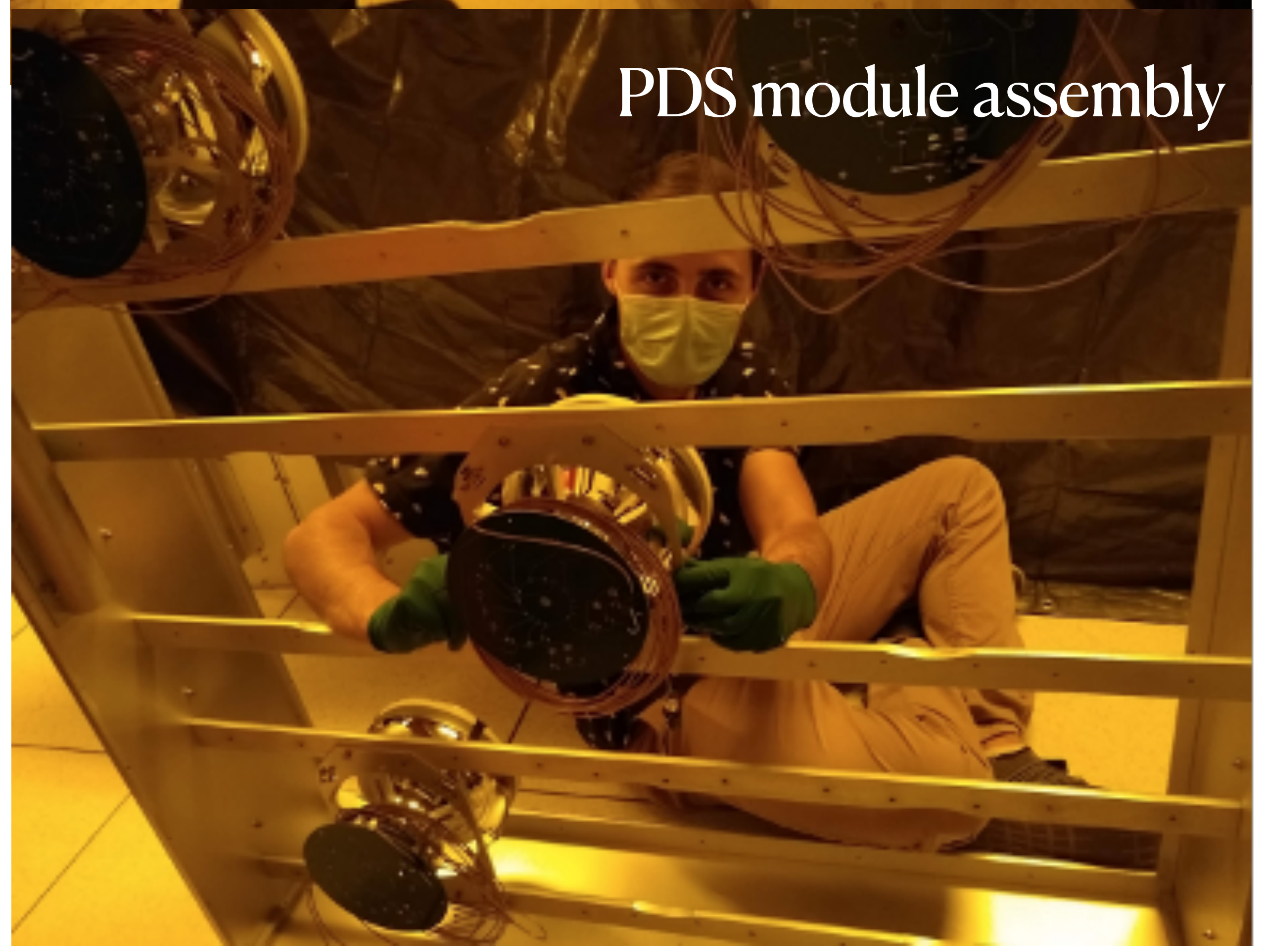
CE front end motherboard

Detector assembly

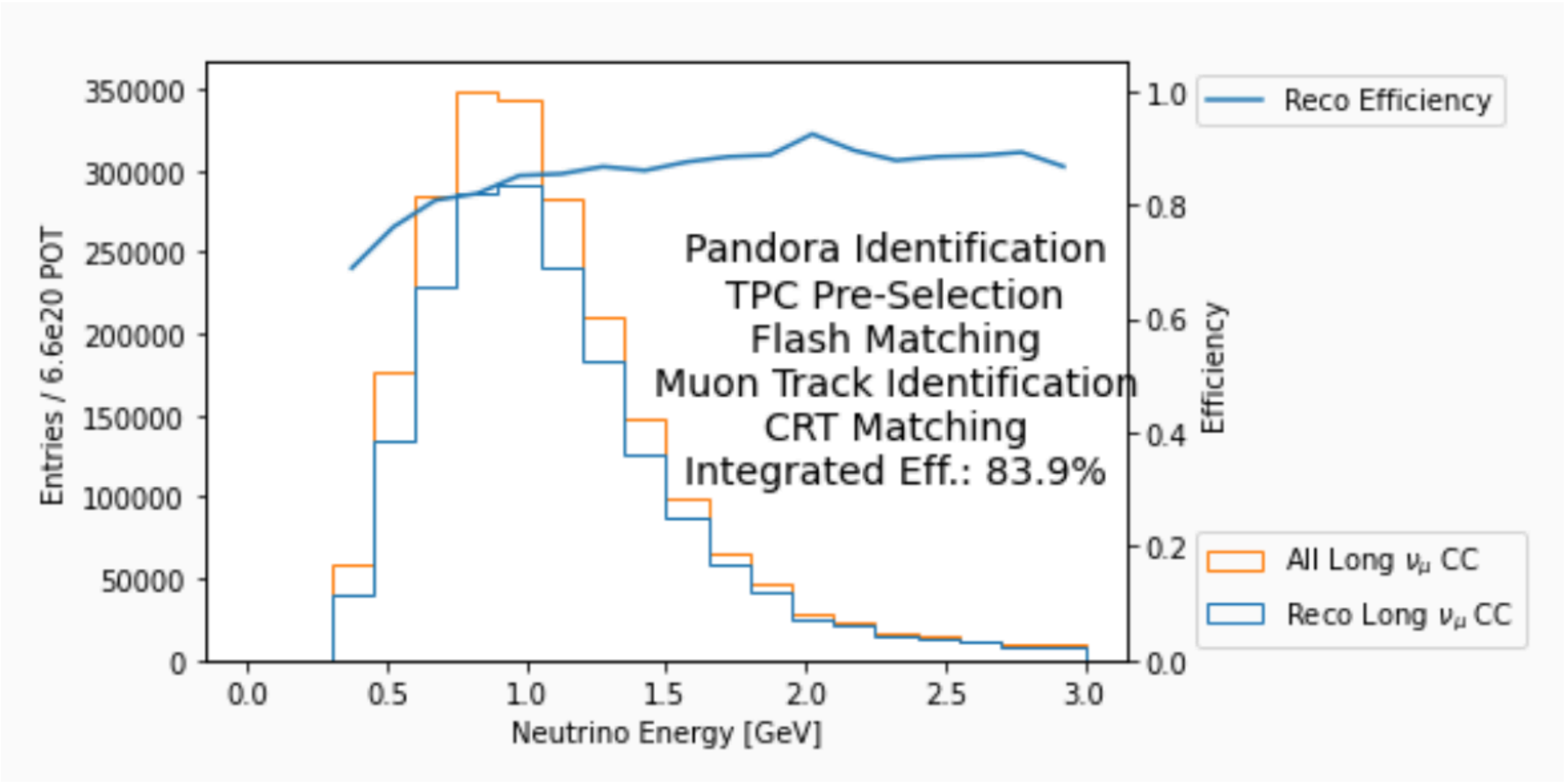

X-ARAPUCA production


PMT physical inspection

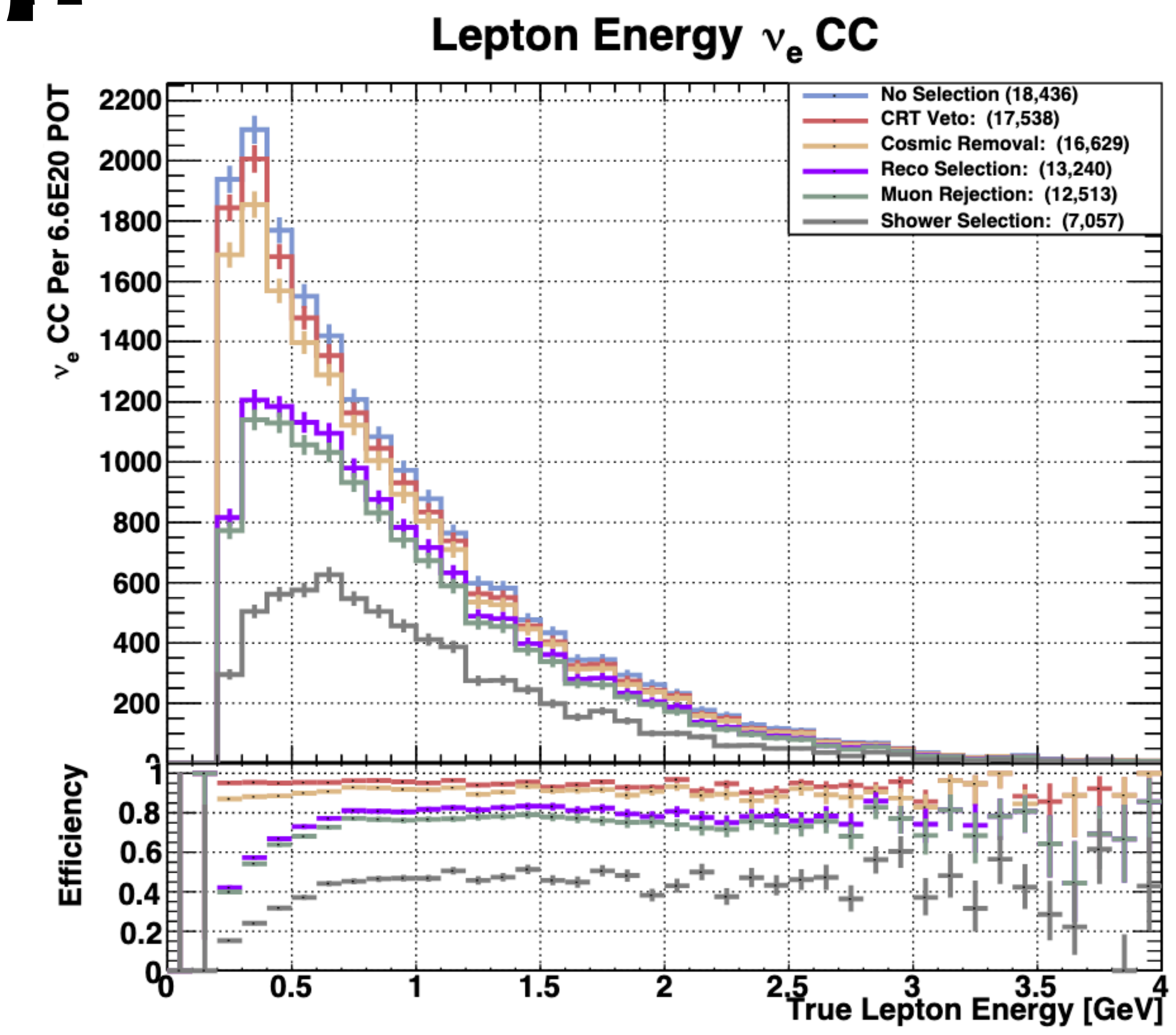

PMT electronics test


PDS module assembly

Event Selection



84 % muon neutrino selection efficiency
Internal Document SBN-21438, Gary Putnam



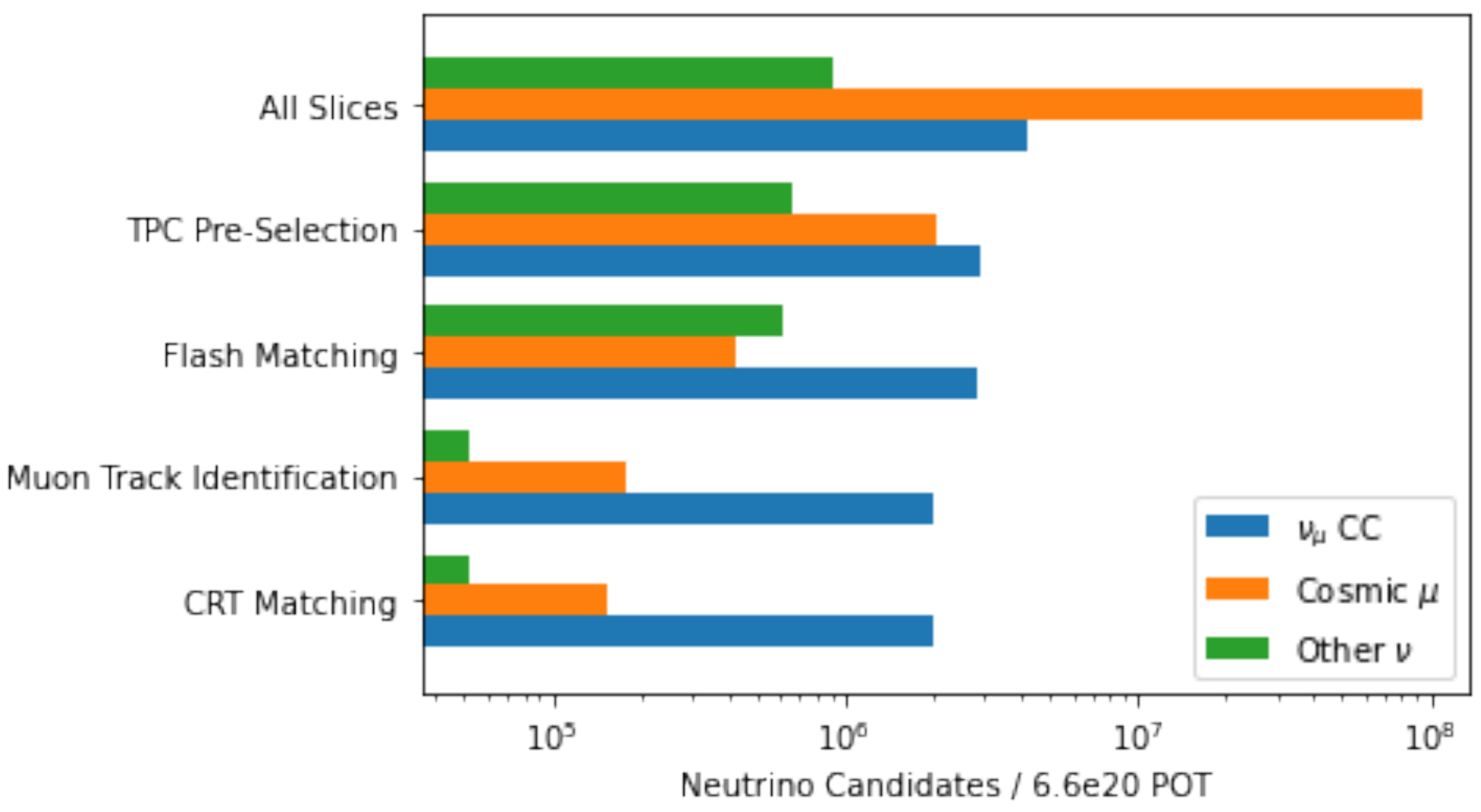
47 % electron neutrino selection efficiency
Internal Document SBN-21423, Edward Tyley

* Requires to not be tagged as clear cosmic (by Pandora)
* Passes CRT veto
* High flash match score
* In detector's fiducial volume
* Track and shower characteristics to muon or electron neutrino CC interactions (inclusive)

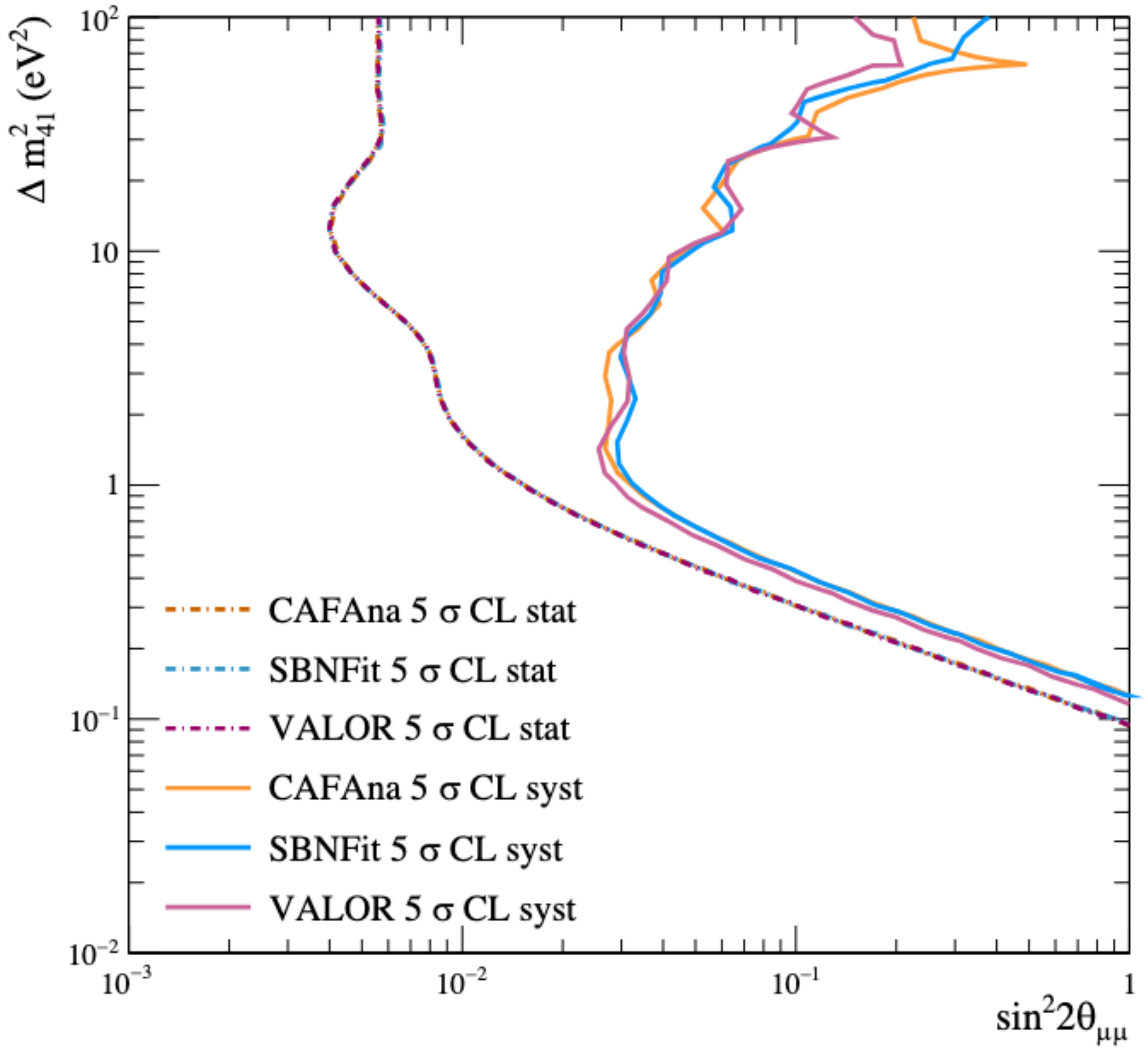
Tools

Reconstruction, selection and analysis tools

Sophisticated techniques and reliable tools are implemented in SBND to achieve our physics goals.



Bar-chart showing the selection flow for muon neutrino CC interactions. This specific analysis uses CAFs and upROOT. Internal Document SBN-22676

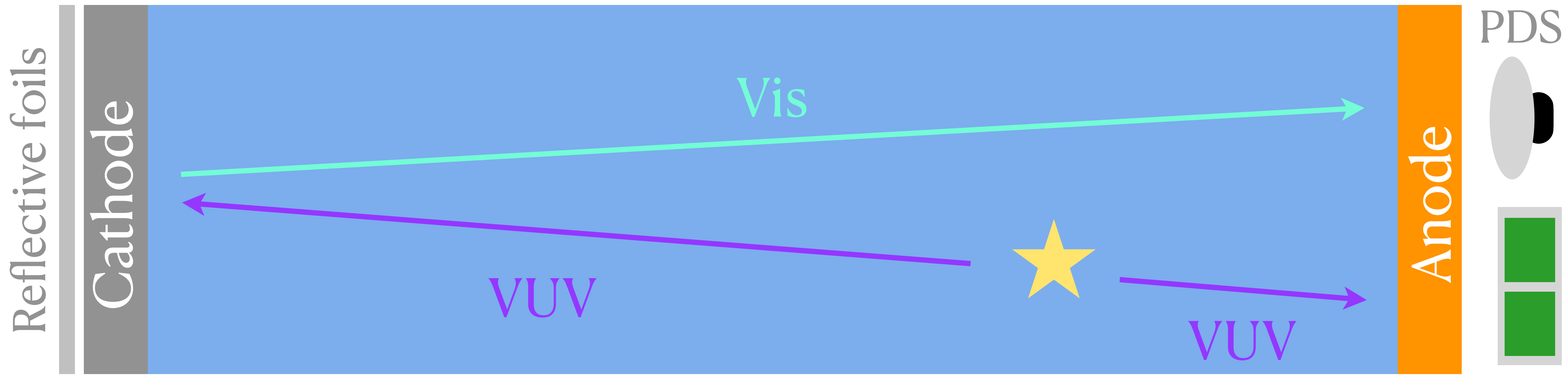


SBN 5 sigma exclusion sensitivities with 3 different fitters. Internal Document SBN-20166

* Simulation: GENIE and CORSIKA.
* Reconstruction: Pandora multi algorithm pattern recognition (other machine learning algorithms in development).
* Event selection: Uses Common Analysis Files (CAFs), and CAFAna or other open source software.
* Oscillation fits: CAFAna (NOvA and DUNE), VALOR(T2K) and SBNfit (MicroBooNE).

Detector design

Photon Detection System

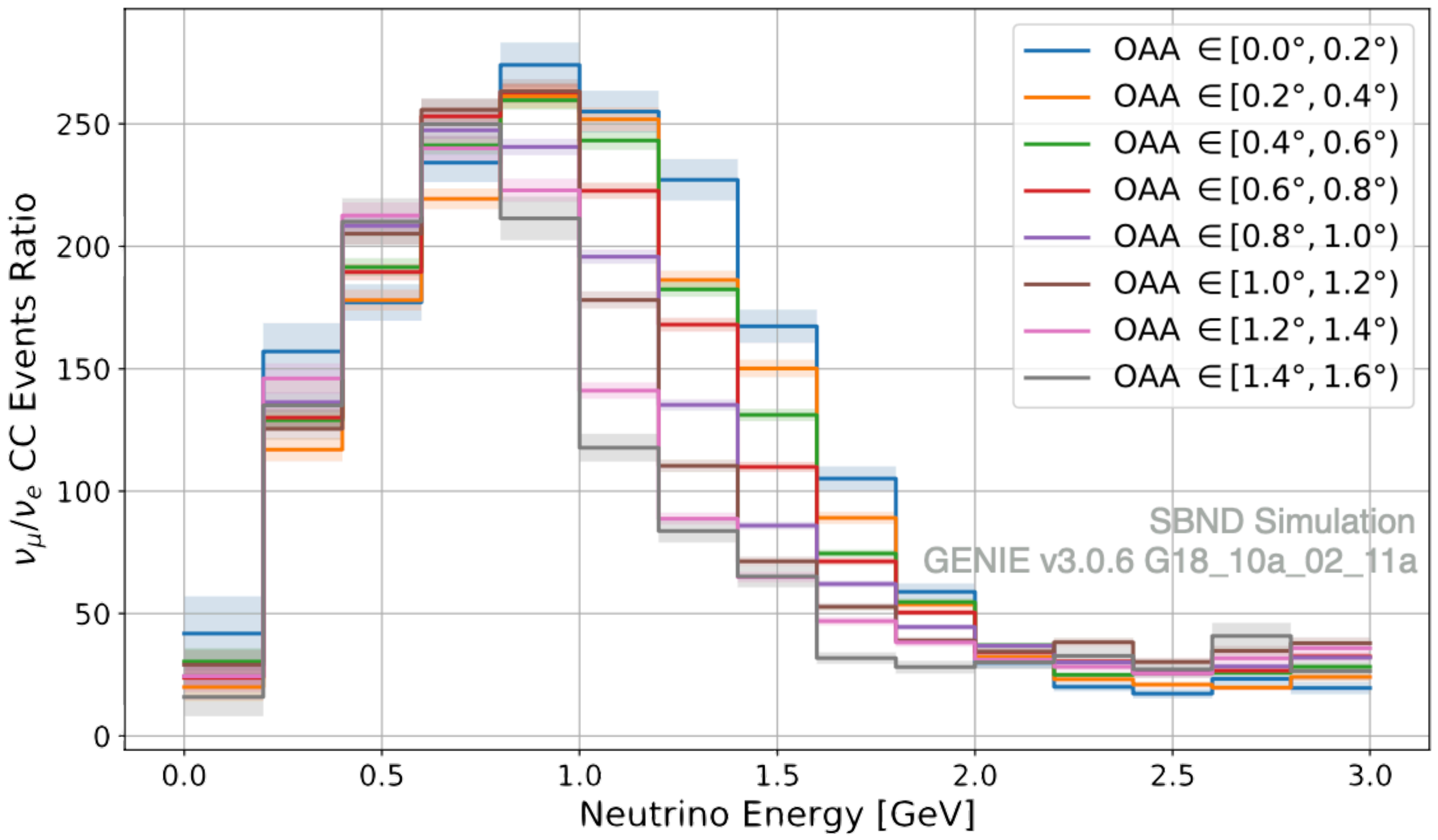


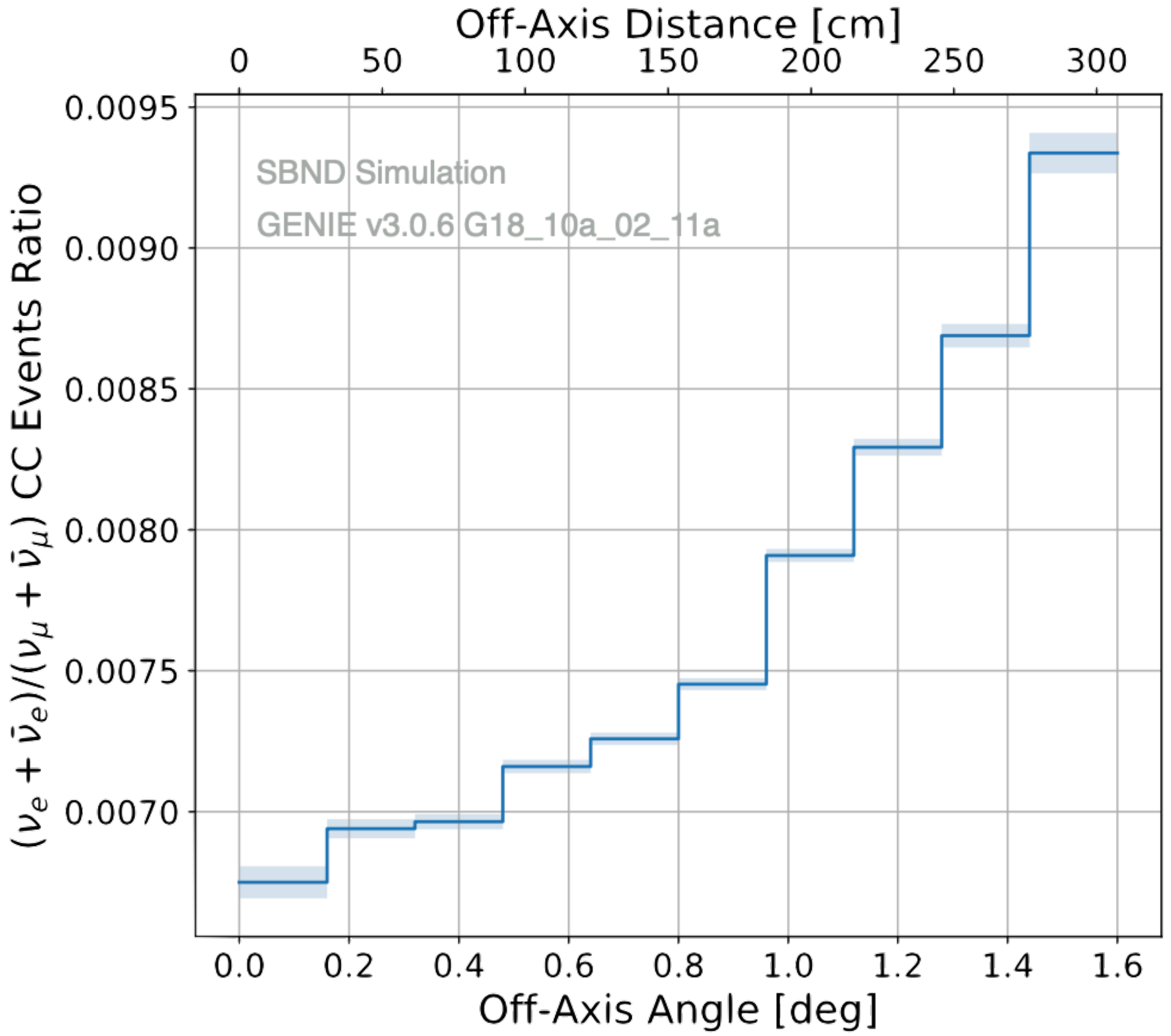
* Modular detection system behind APAs
* 24 photon detection system (PDS) modules
  * PMTs
    * 92 coated PMTs with WLS
    * 24 uncoated
  * X-ARAPUCA
    * 196 photon traps, half with WLS
* Reflective foils behind CPA mesh

Precision Reaction Independent Spectrum Measurement: sample different off-axis fluxes with a single fixed detector.

Application to the whole SBN program

* Interaction model constraints
* Background constraints
* Neutrino oscillations
* BSM searches
* Cross Section energy dependence
* Muon-to-Electron Neutrino Cross Section



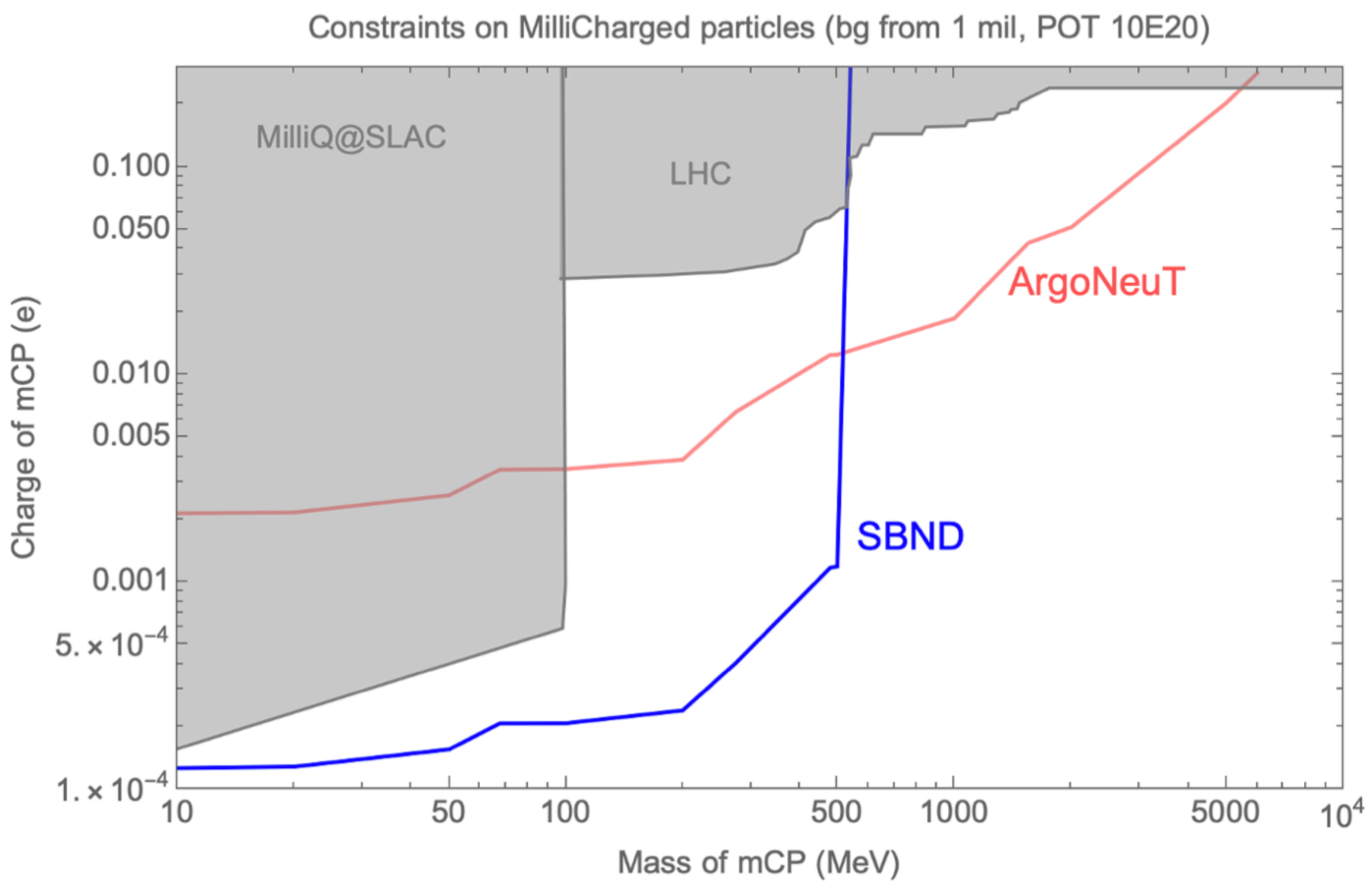


BSM searches

Beyond the standard model

- * New states: heavy neutrinos, neutrino tridents, dark matter, dark neutrinos
- * Modifications to neutrino oscillations: Lorentz and CPT violation, decaying sterile neutrinos, large extra dimensions.

- **Millicharged particles**: hypothetical new particles with fractional charge.
- Neutral mesons produced from proton collisions with the target could decay into millicharged particles.
- Millicharged particles will produce low-energy depositions (small hits or faint tracks) that point back to the target.
- **SBND could provide a promising new search for millicharged particles.**



Preliminary results from simulation

Argoneut method: R. Acciarri et al., PRL124 131801 (2020)