Status of the Short Baseline Near Detector at Fermilab

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Brookhaven National Laboratory

SHORT-BASELINE SBND NEAR DETECTOR

Fermilab

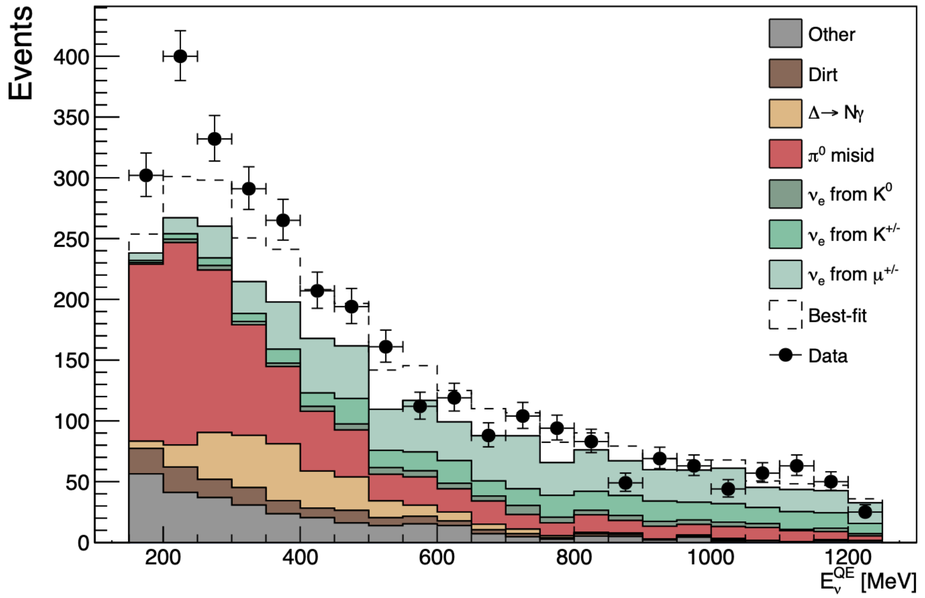
EPS-HEP July 27 2021

The Short Baseline Neutrino Program

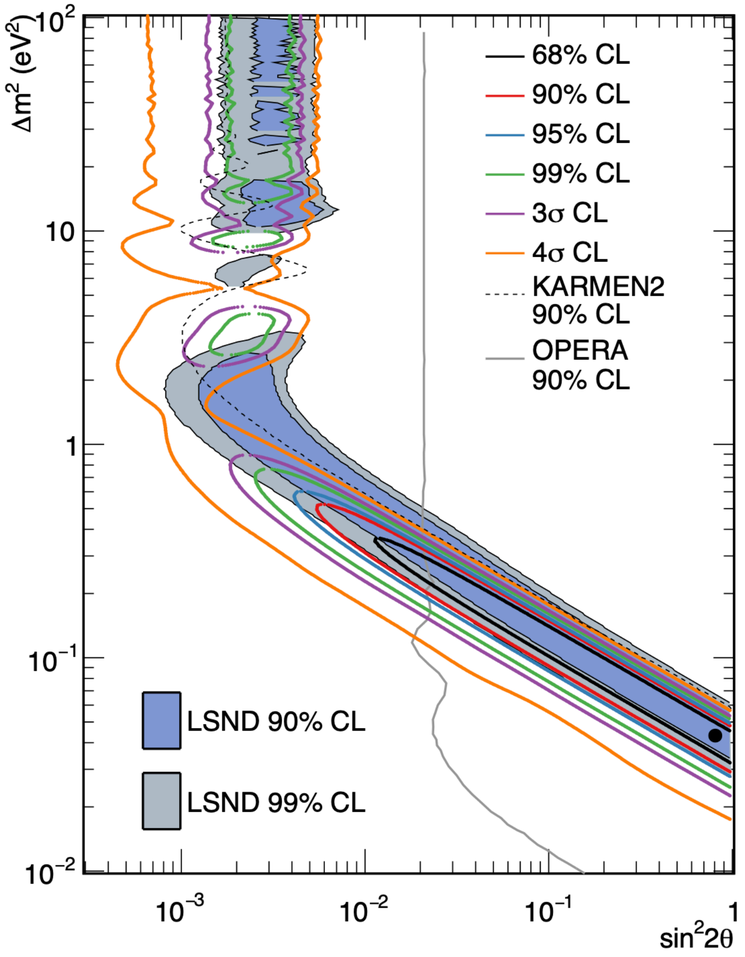
Main goal: address the anomalous results from past neutrino experiments (LSND, MiniBooNE), which could be explained by the possible existence of at least one **sterile neutrino**.

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

Phys. Rev. D 103, 052002 (2021)

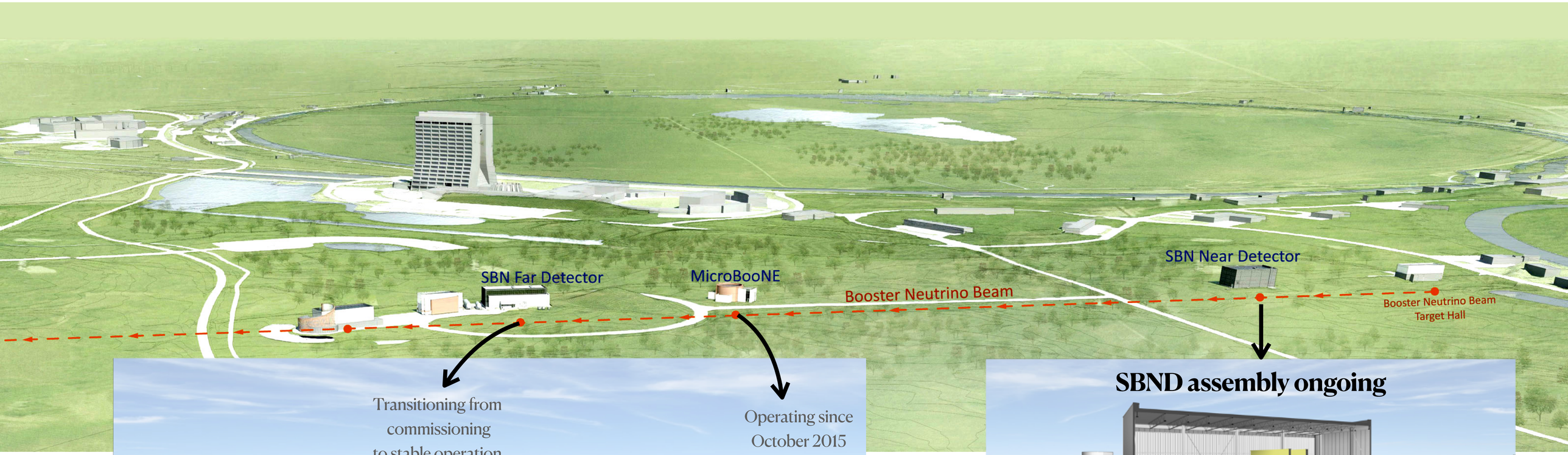


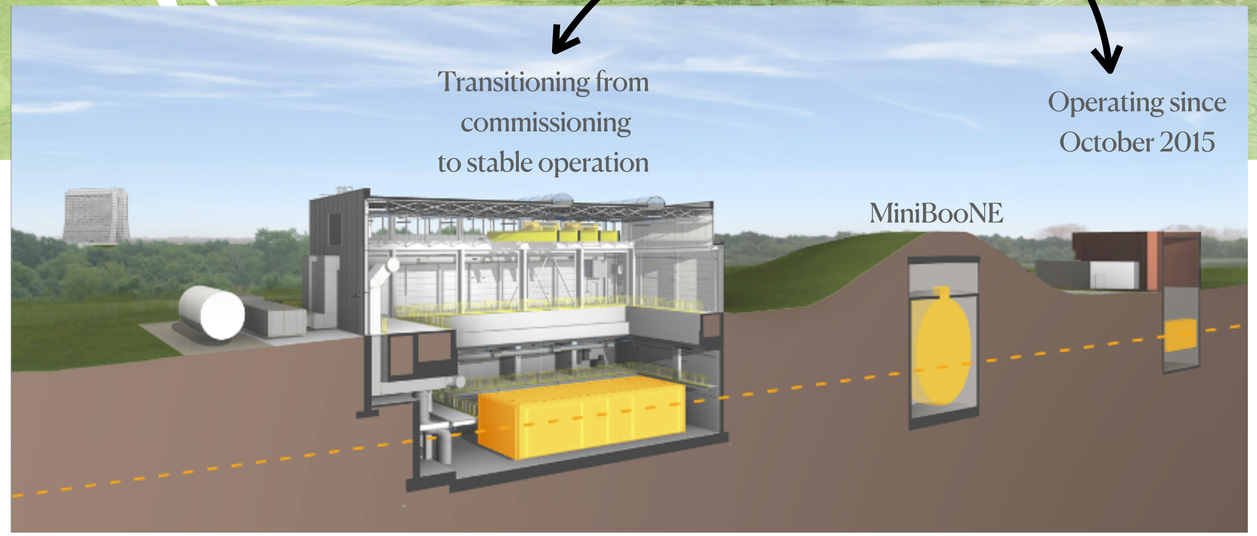
MiniBooNE's neutrino mode energy distribution. Best fit to neutrino mode data assuming 2-neutrino oscillations

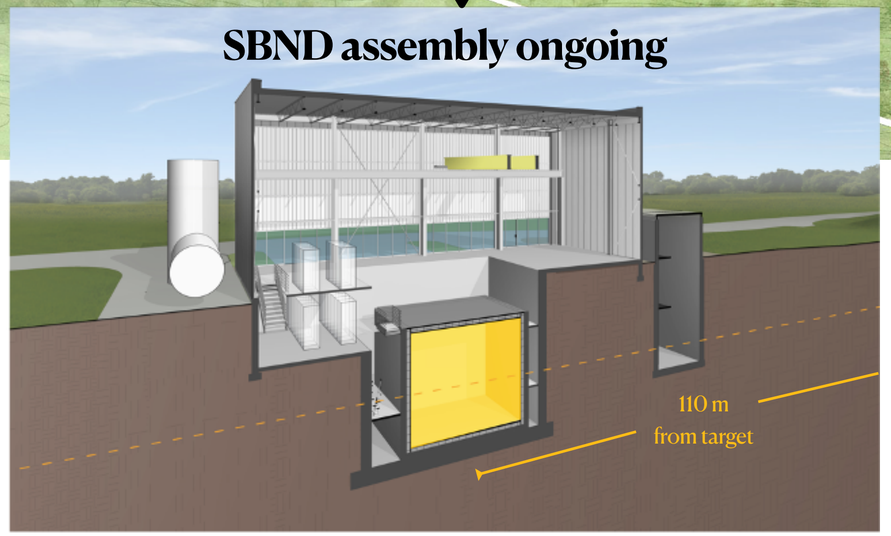


MiniBooNE's allowed regions for combined neutrino and antineutrino mode data assuming 2-neutrino oscillations.

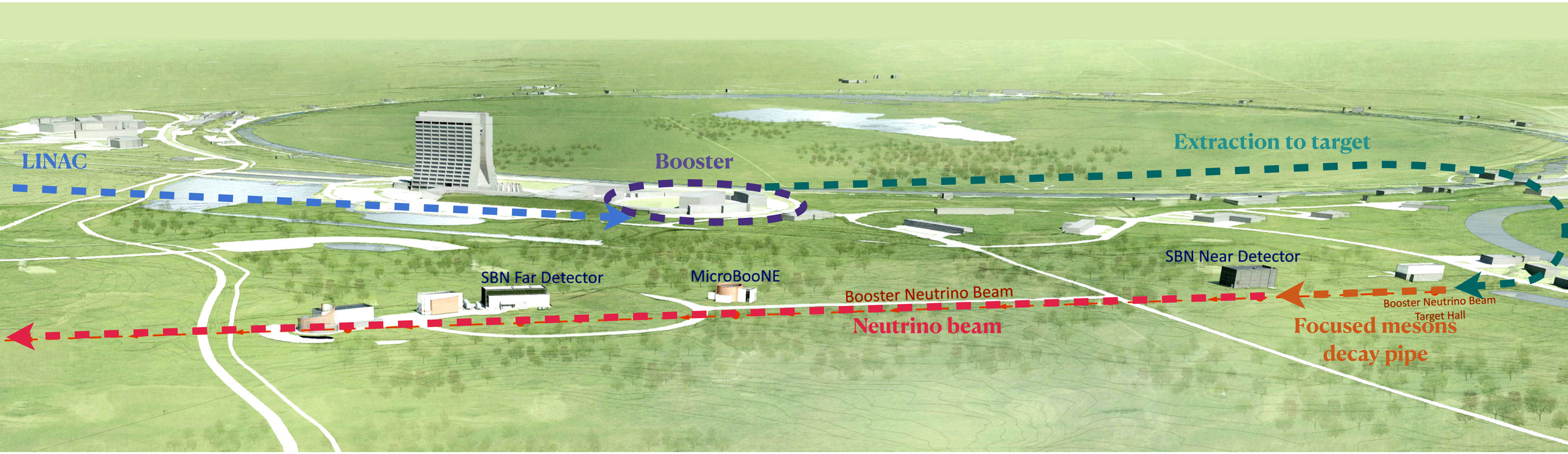
The Short Baseline Neutrino Program







The Short Baseline Neutrino Program

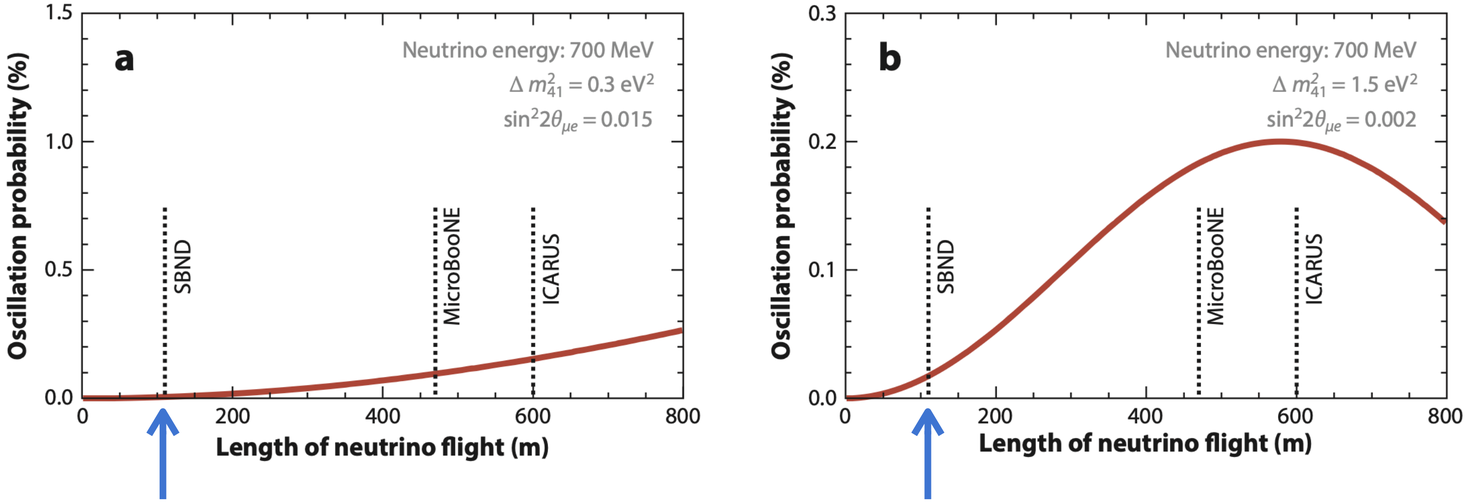


SBN **detectors** share the same nuclear target and similar technologies: liquid argon time projection chambers (TPCs). The detectors are strategically placed to look for neutrino oscillations at short baselines and low energy range along Fermilab's **Booster Neutrino Beam** (BNB), which provides a highly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

Being the closest to the neutrino production, SBND plays a special role on disentangling the sterile neutrino puzzle and discovery of new physics.

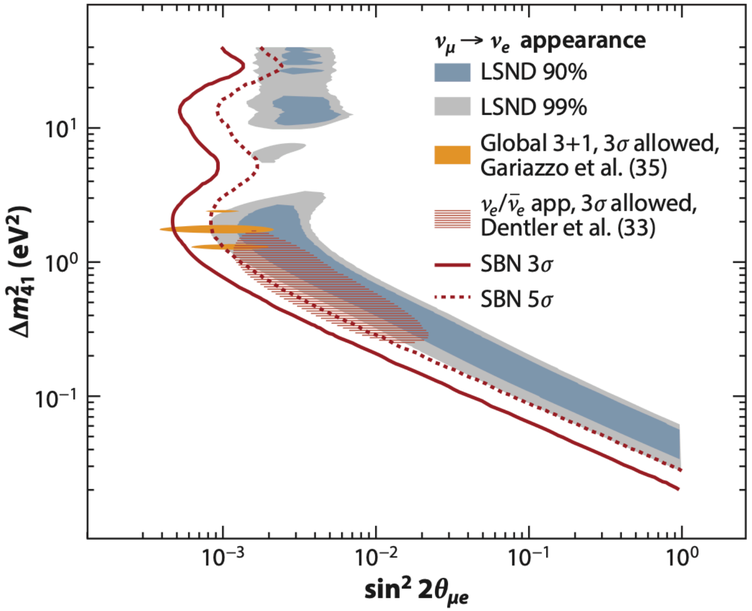
SBND Physics

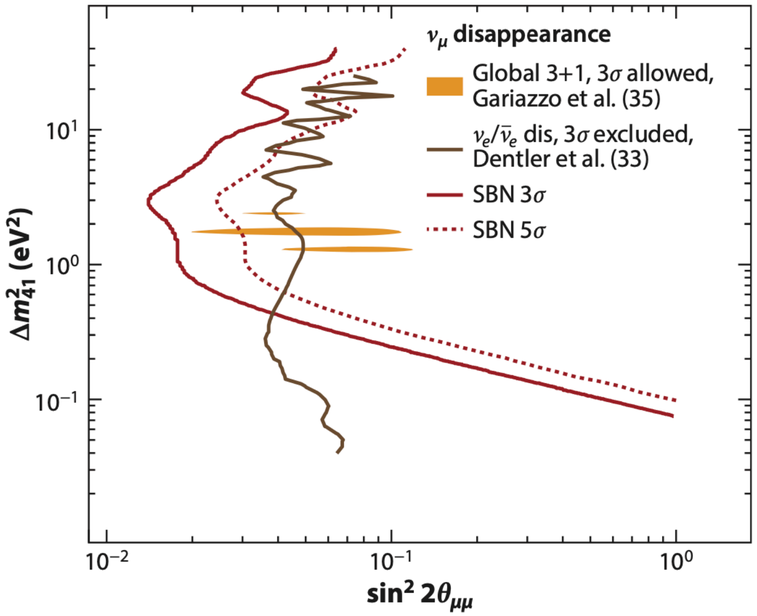
Sterile neutrino oscillations



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.

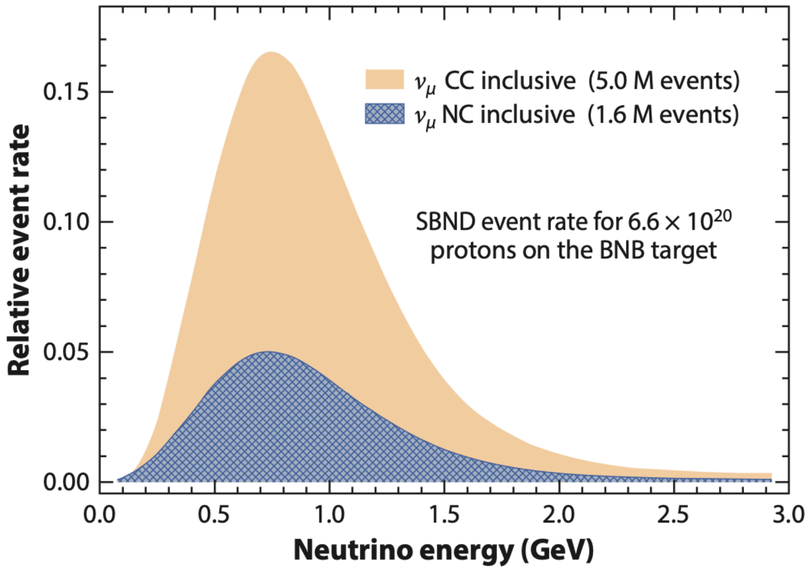


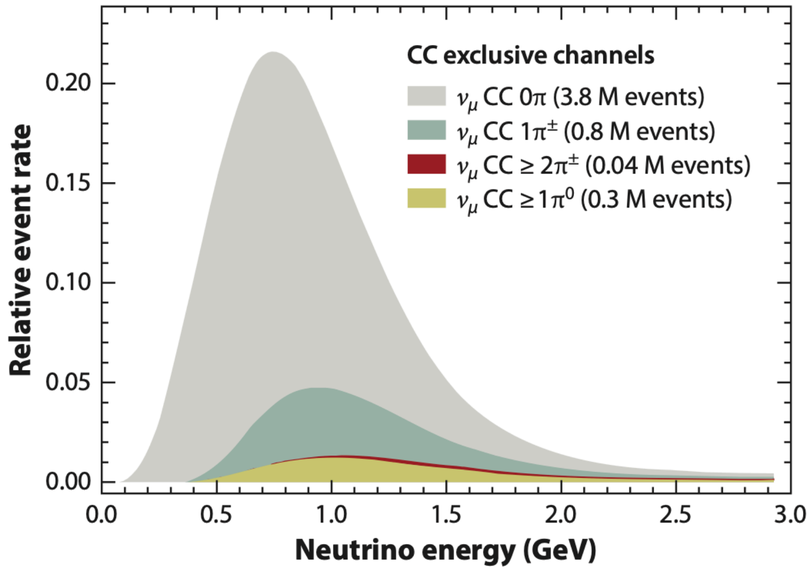


Annu. Rev. Nucl. Part. Sci. 2019 DOI 10.1146
(Reproduced from SBN Proposal assuming 6.6 E20 POT)

SBND Physics

Cross section and interaction models





SBND neutrino energy spectra for 6.6 E20 POT (1-2 years of running). Expected to record interactions from 10-16 E20 POT from the start of operations and before the accelerator's long shut down (January 2027)

Annu. Rev. Nucl. Part. Sci. 2019 DOI 10.1146

LArTPC detectors are designed for excellent particle identification and calorimetric energy reconstruction.

* Perform precise cross-section measurements
* Measure nuclear effects, asses impact on final states and kinematics
* Inform MC generators and discriminate between models

SBND will have the **largest statistics** of muon and electron neutrinos **than any previous LAr detector** and will be capable of discerning a wide variety of final states.

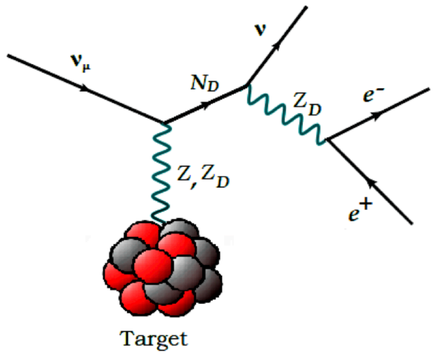
SBND Physics

Other analyses

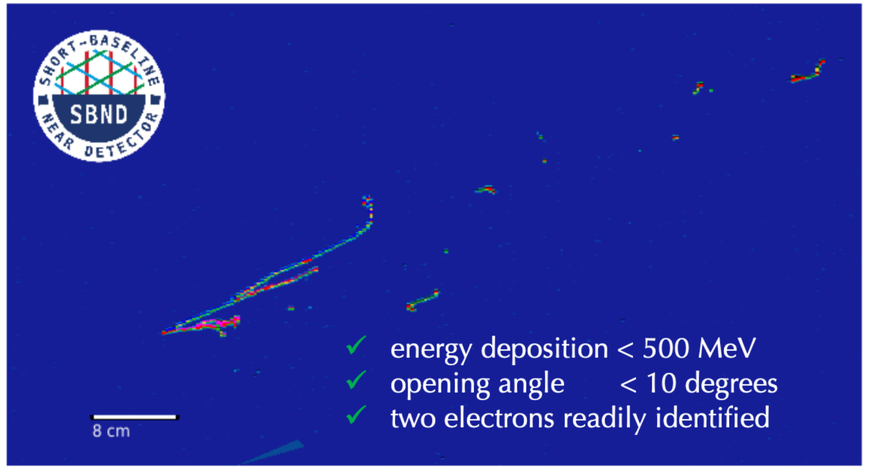
Beyond the standard model

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

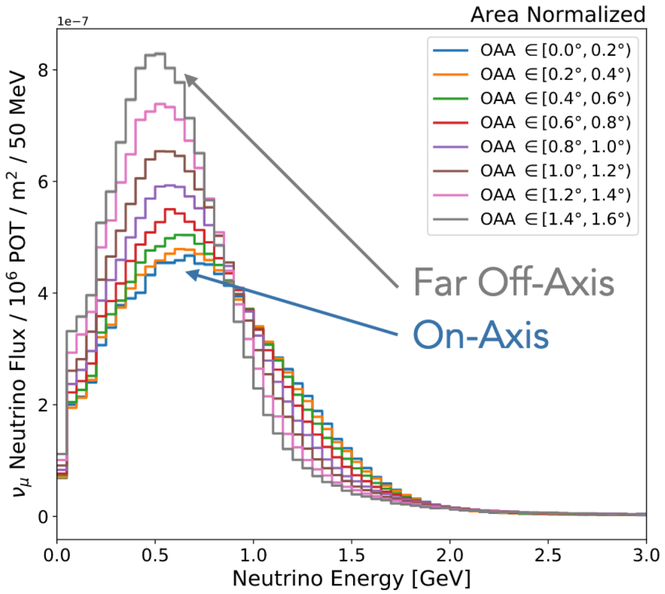
Sampling multiple off-axis fluxes with SBND-PRISM

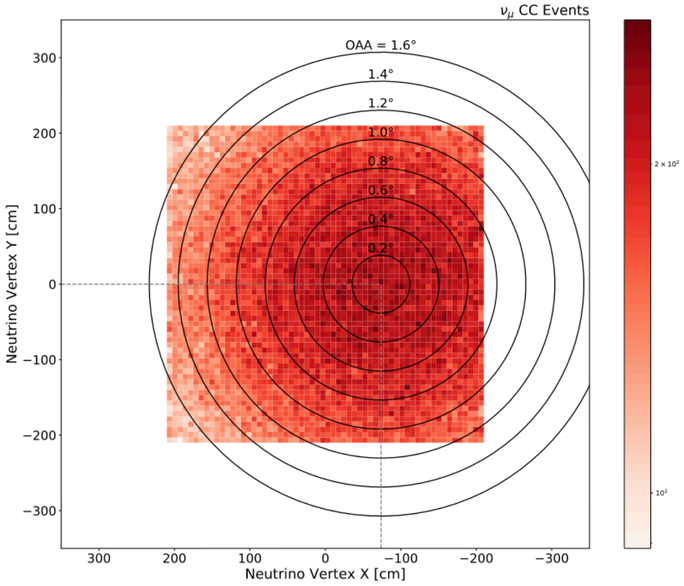


Machado et al.,
Phys. Rev. Lett. 121, 241801 (2018)



Dark neutrino implemented and available in GENIE v3.2
NuSTEC 2021 , de Icaza



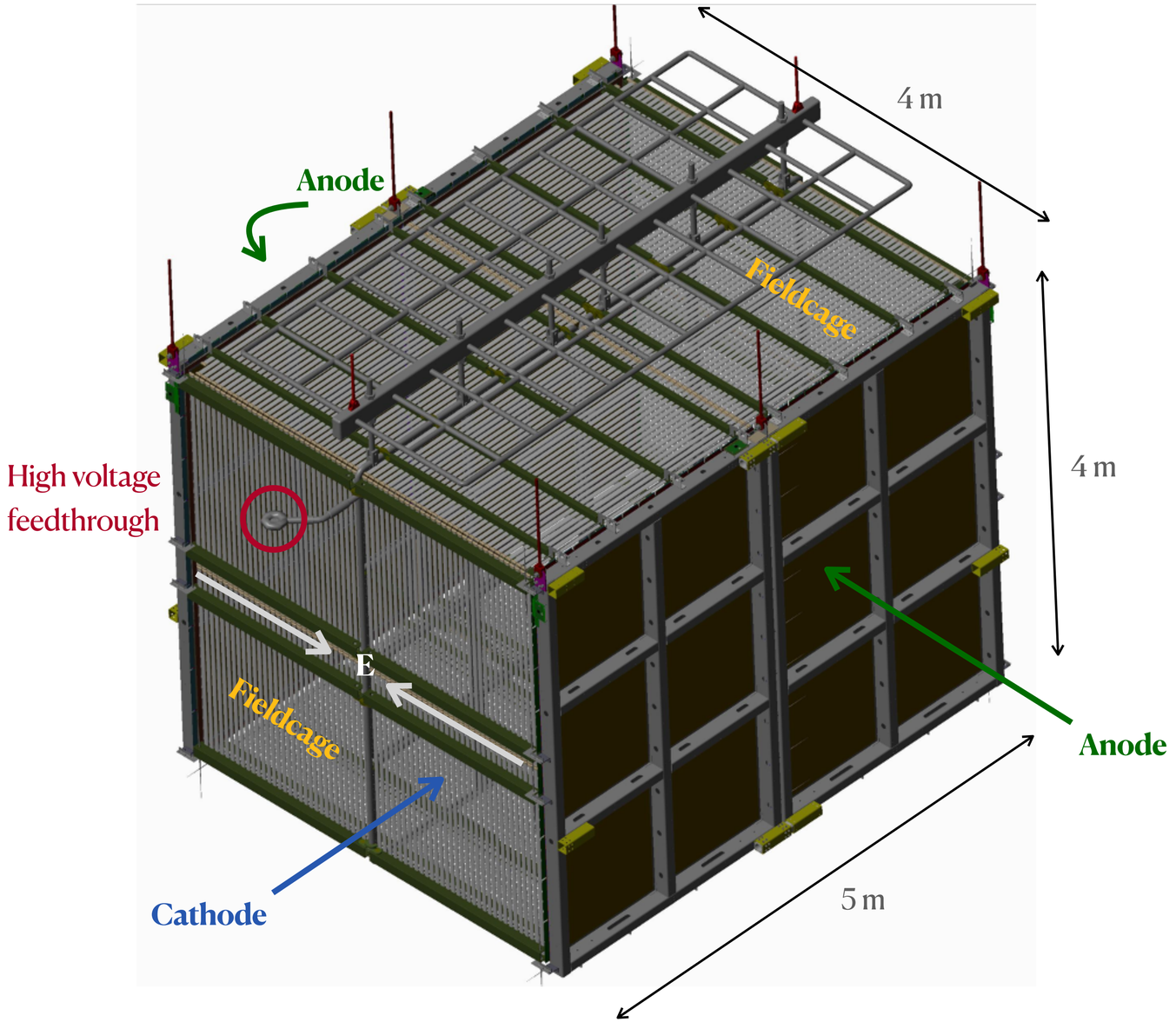


Neutrino flux at different off-axis positions.
Internal Document SBN-22130

Detector design

Time Projection Chamber

- Single phase LArTPC
- 112 tons active mass
- 5m x 4m x 4m active volume
- One central cathode plane assembly (CPA)
  - Divides detector in two drift windows
- Two anode plane assemblies (APAs)
  - 3 wire planes (vertical, +- 60 to the vertical)
  - Wire pitch and plane spacing = 3mm
- Field cage to maintain 500 V/cm drift field



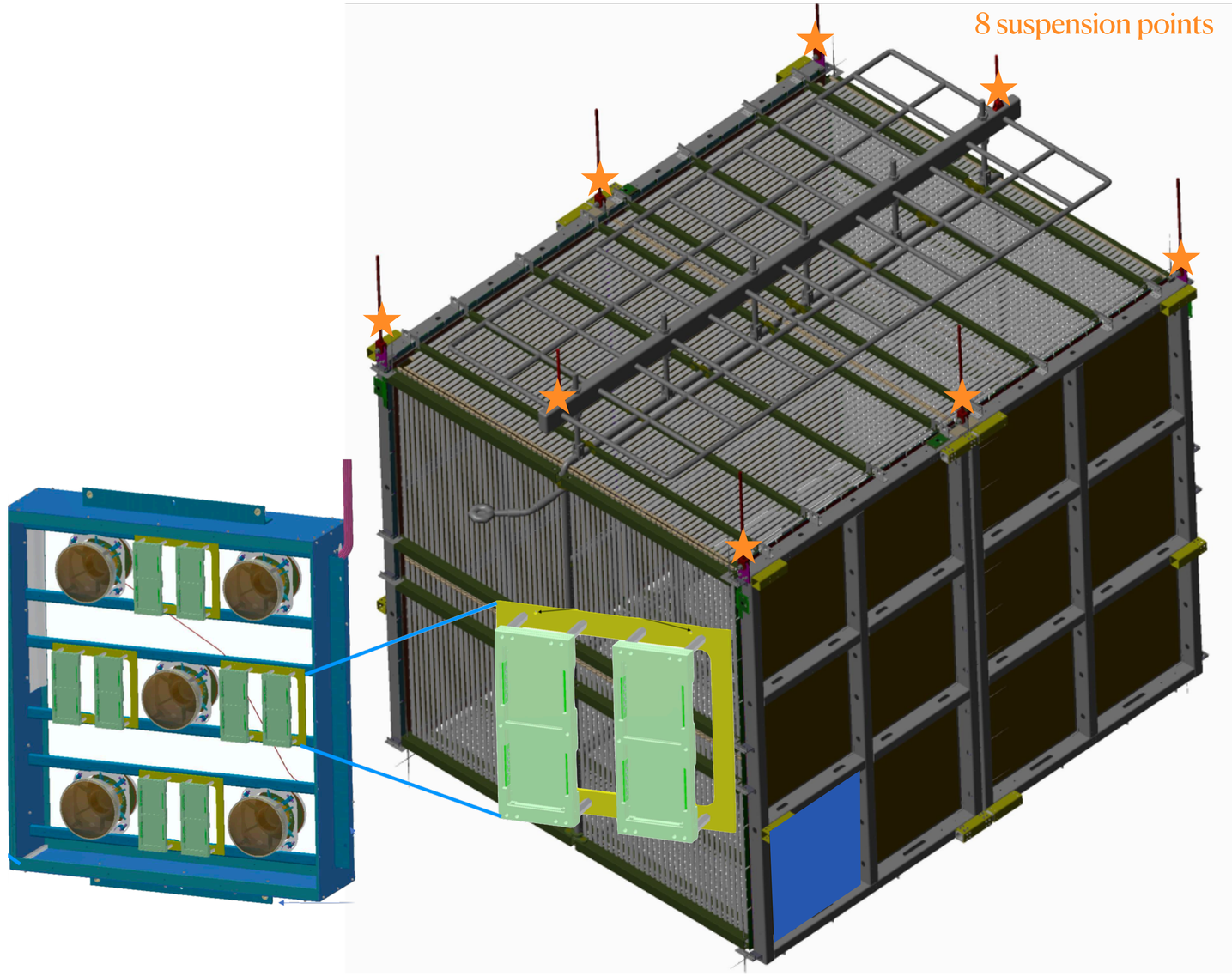
Detector design

Photon Detection System

- Modular detection system behind APAs
- 24 photon detection system (PDS) modules
  - 5 PMTs, 80% total with wavelength shifter (WLS)
  - 8 X-ARAPUCA photon traps instrumented with silicon photo-multipliers (SiPMs) , 50% with WLS
- Reflective foils behind CPA mesh.

Cosmic Ray Tagger

- Every side of the detector will be covered by planes of extruded scintillator strips
- Marginal background removal with overburden compared to beam background. No overburden planned.



Detector assembly

Status

Detector assembly ongoing at the Do assembly building (DAB)

- Assembly transport frame (**ATF**) build by the end of 2019. It will support and transport the detector assembly from DAB to it's final location, the SBN-ND building
- **Clean tent** build to protect components sensitive to UV and blue light and to keep assembly clean (2020/2021)

Assembly transport frame

Clean tent

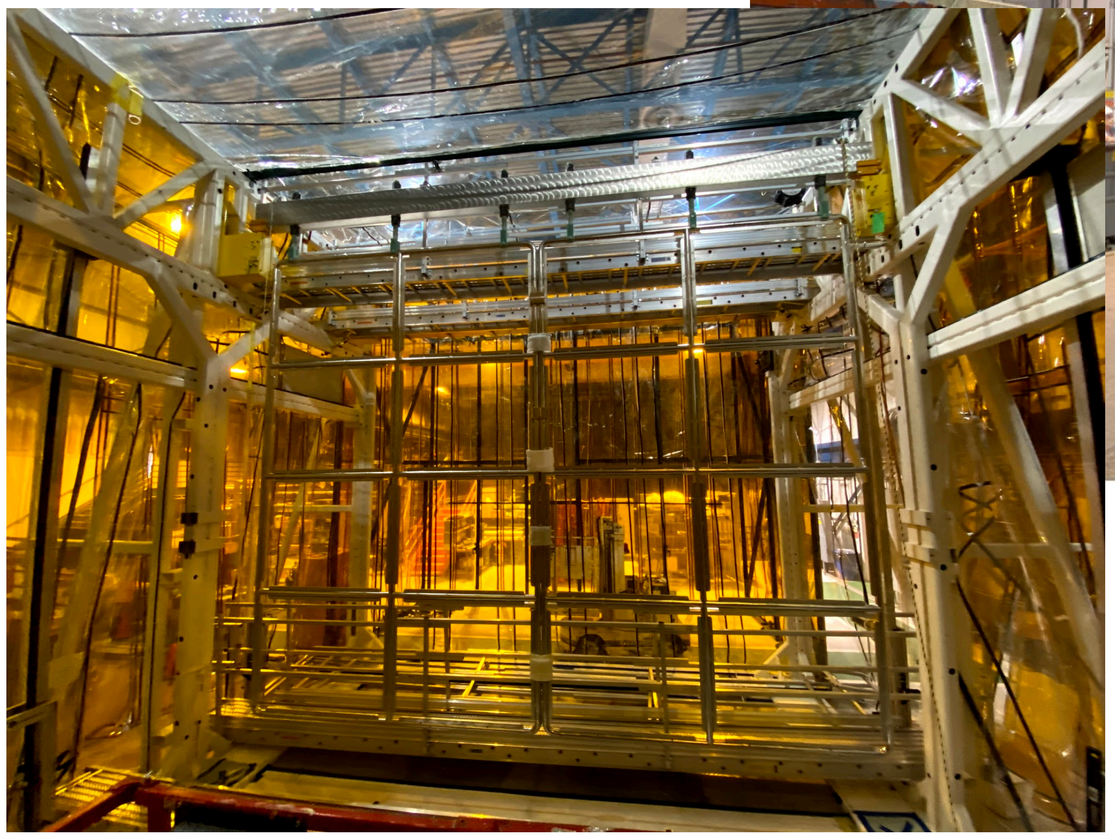
Detector assembly

Status

Assembly slowed down due to COVID restrictions but is ramping up.

- **CPA frame** installed 2 weeks ago
- CPA mesh panels currently being installed
- APA planes are already on-site, mechanically and electrically coupled
- Cold electronics (CE) on-site and tested ready for installation
- Field cage tests ongoing
- PMTs passed reception test at Fermilab
- X-ARAPUCA production ongoing

CPA frame attached to support beam and installed



CPA support beam

CPA frame

Detector assembly

Status

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- CPA frame installed 2 weeks ago
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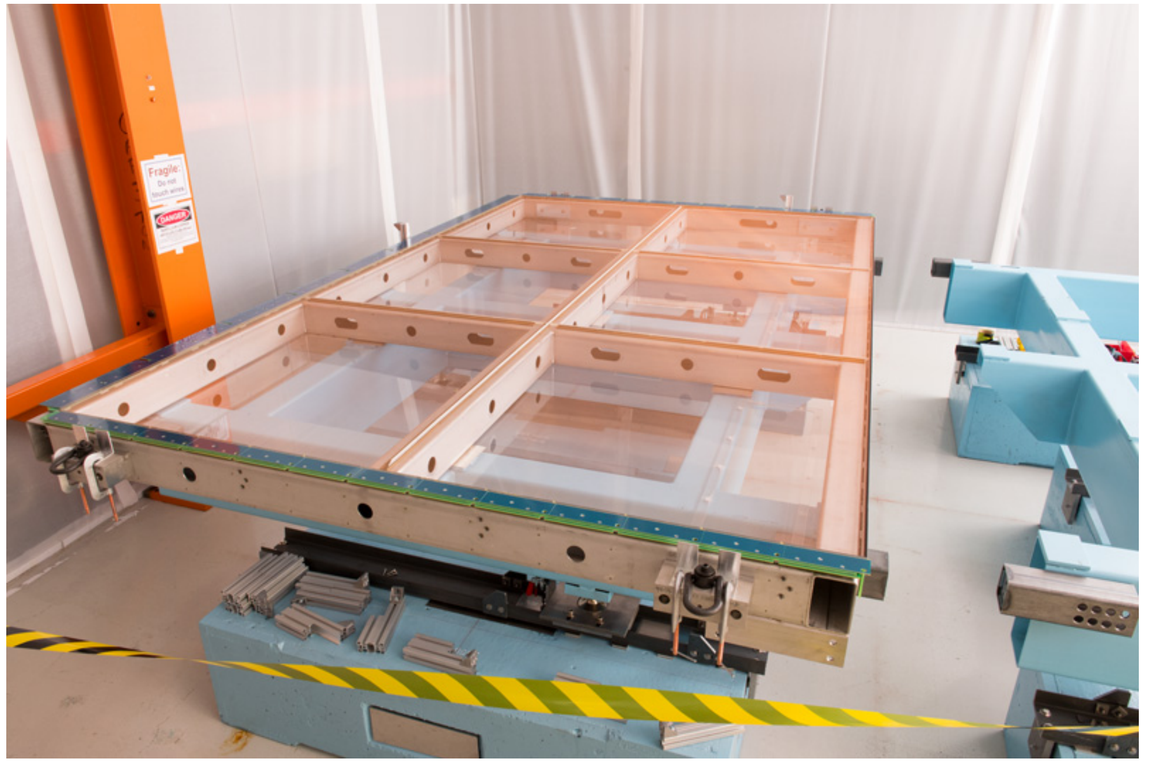
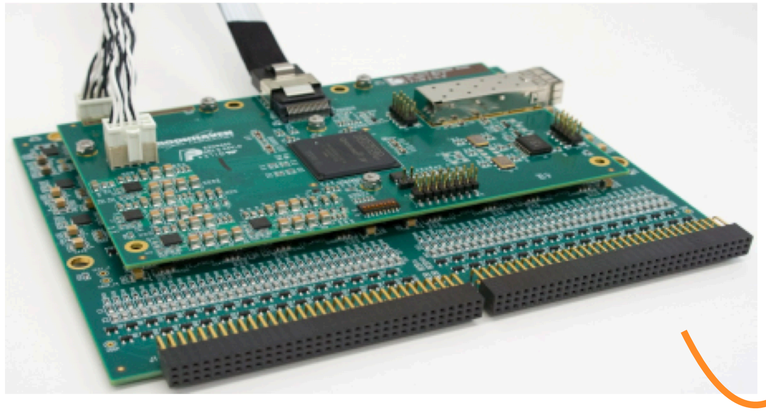
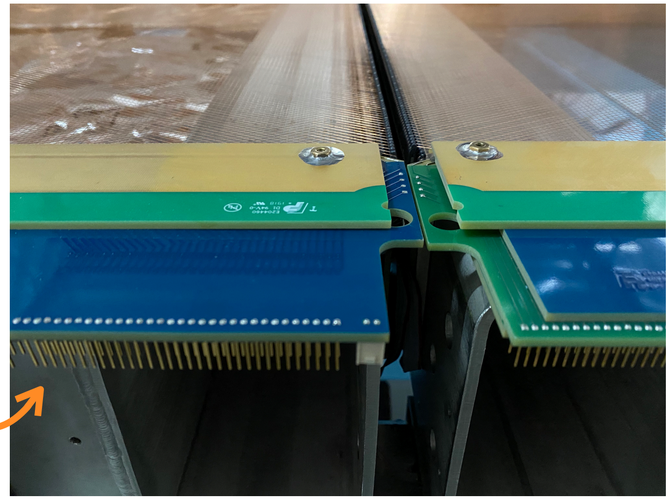
- **APA** planes are already on-site, mechanically and electrically coupled
- **Cold electronics (CE)** on-site and tested ready for installation
- **Field cage** tests ongoing
- PMTs passed reception test at Fermilab
- X-ARAPUCA production ongoing



One APA module



CE front end motherboard



APA joint

Detector assembly

Status

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- Cold electronics (CE) on-site and tested ready for installation
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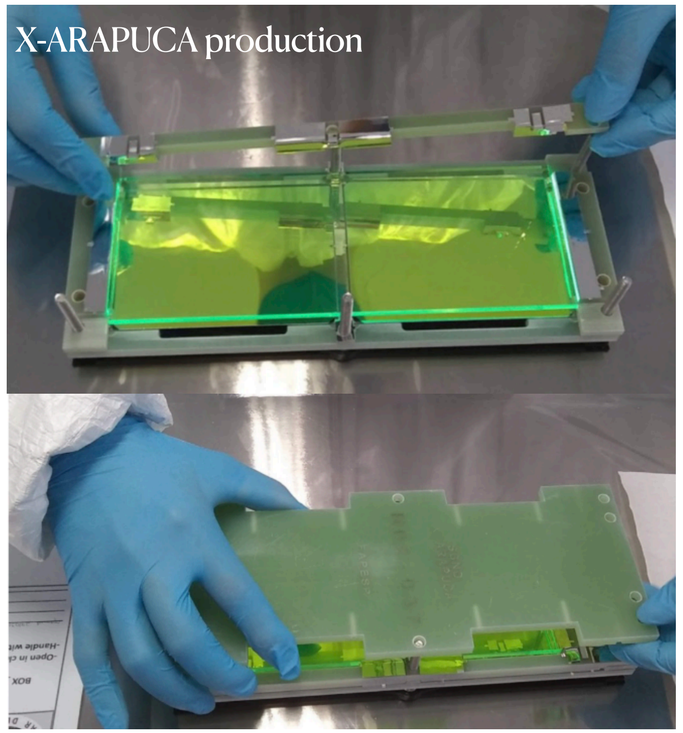
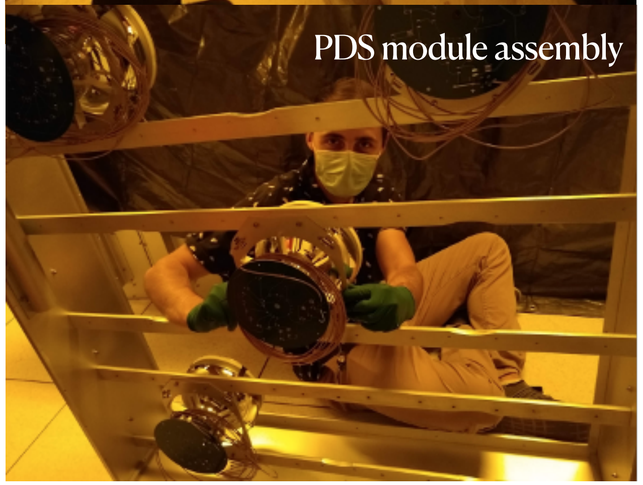
- **X-ARAPUCA production** ongoing

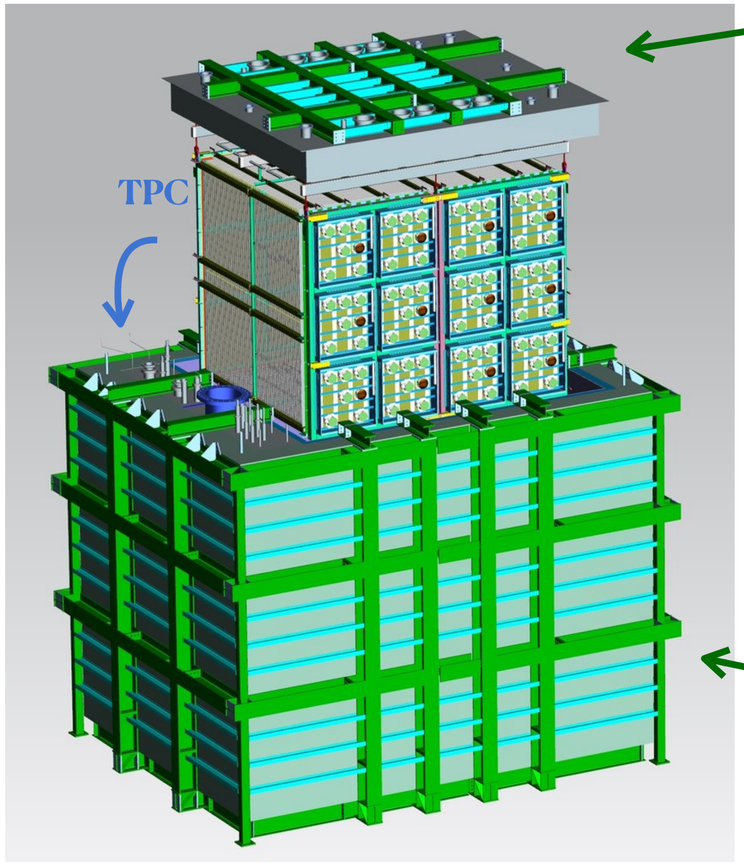




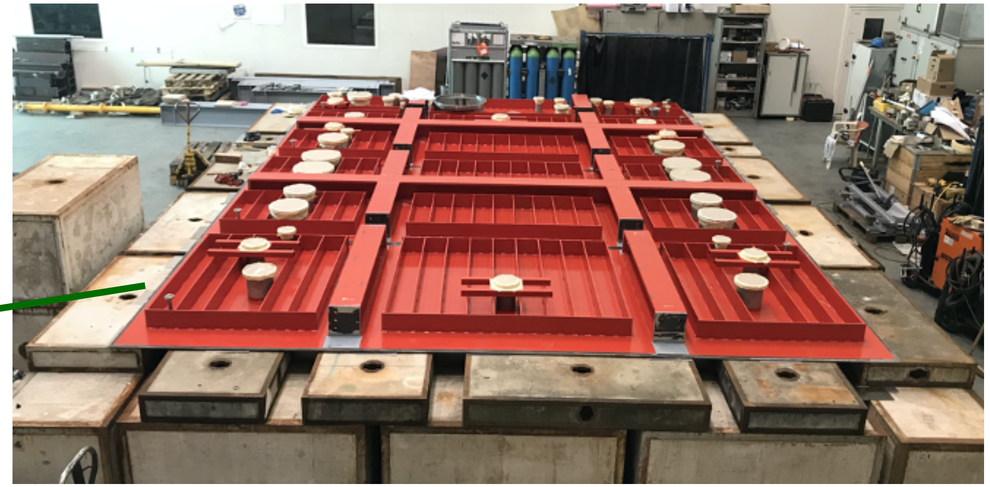
Detector installation

Status

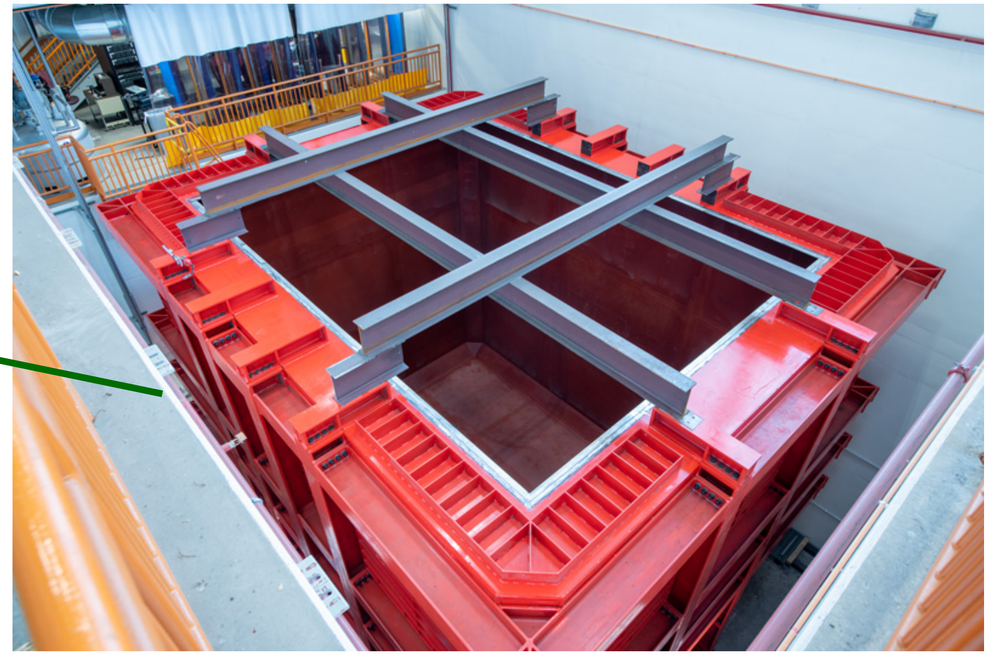
- **Warm outer vessel** already installed in the SBN-ND building.
- **Cryogenics** installation ongoing
- Installation of cryostat membrane starting this August, all the materials on-site
- Fabrication of cryostat top at CERN completed. It'll be shipped to Fermilab by the end of summer.



Cryostat top



Warm vessel



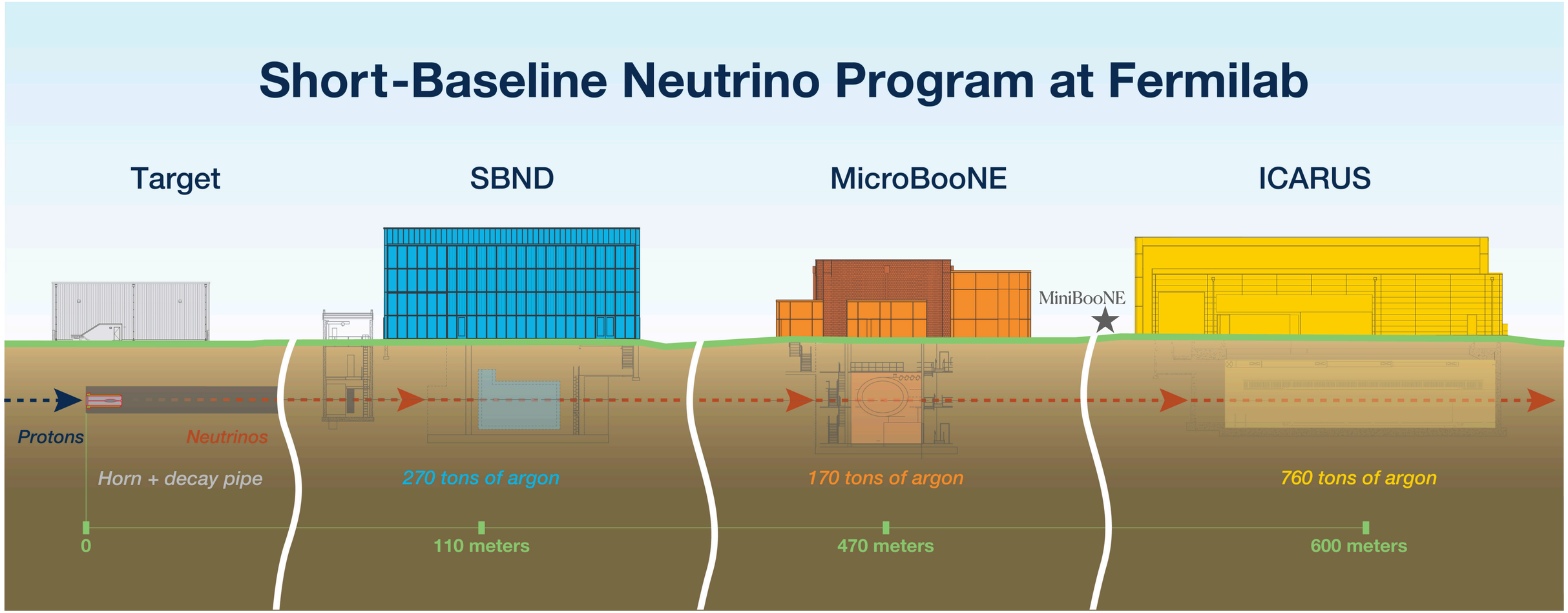
Summary

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 flux for sterile neutrino searches
- The detector will record the largest sample of neutrino-Argon interactions than any past or present experiment.
- It will provide precise cross-section measurements and inform MC generators.
- SBND will be ready for cold commissioning by the end of 2022

Backup

Short-Baseline Neutrino Program at Fermilab



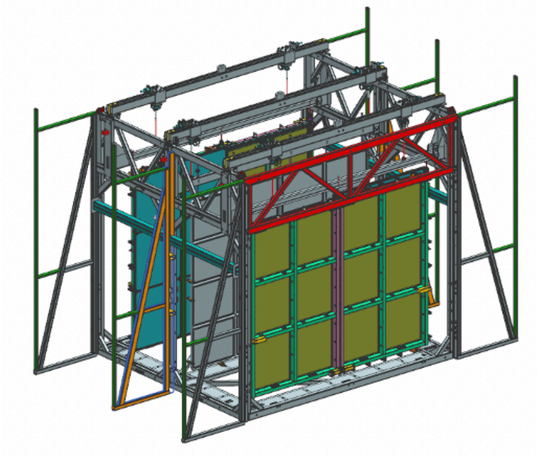
Detector assembly ongoing

Operating since October 2015

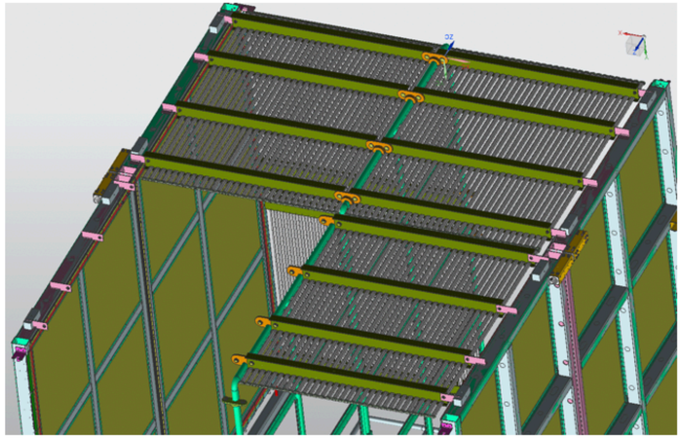
Transitioning from commissioning to stable operation

TPC assembly

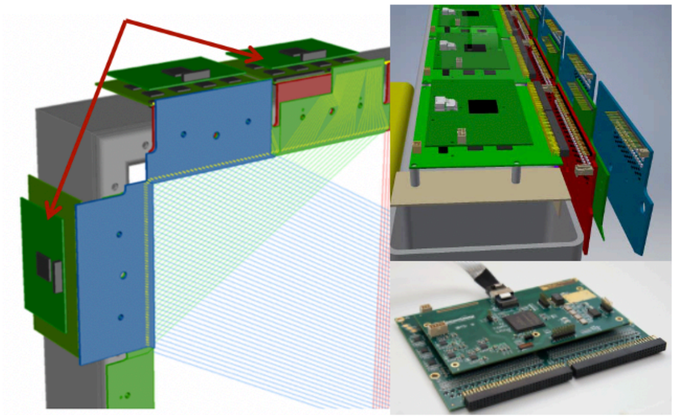
1) Install APAs and CPA



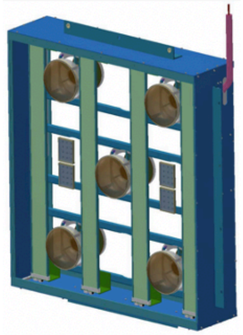
2) Install Field cage



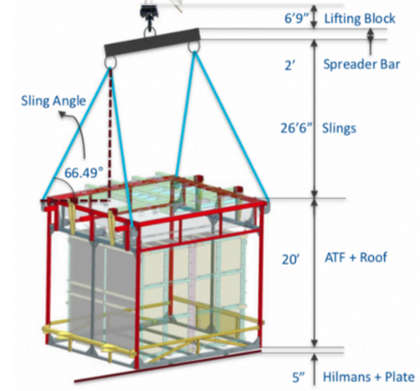
3) Install cold electronics



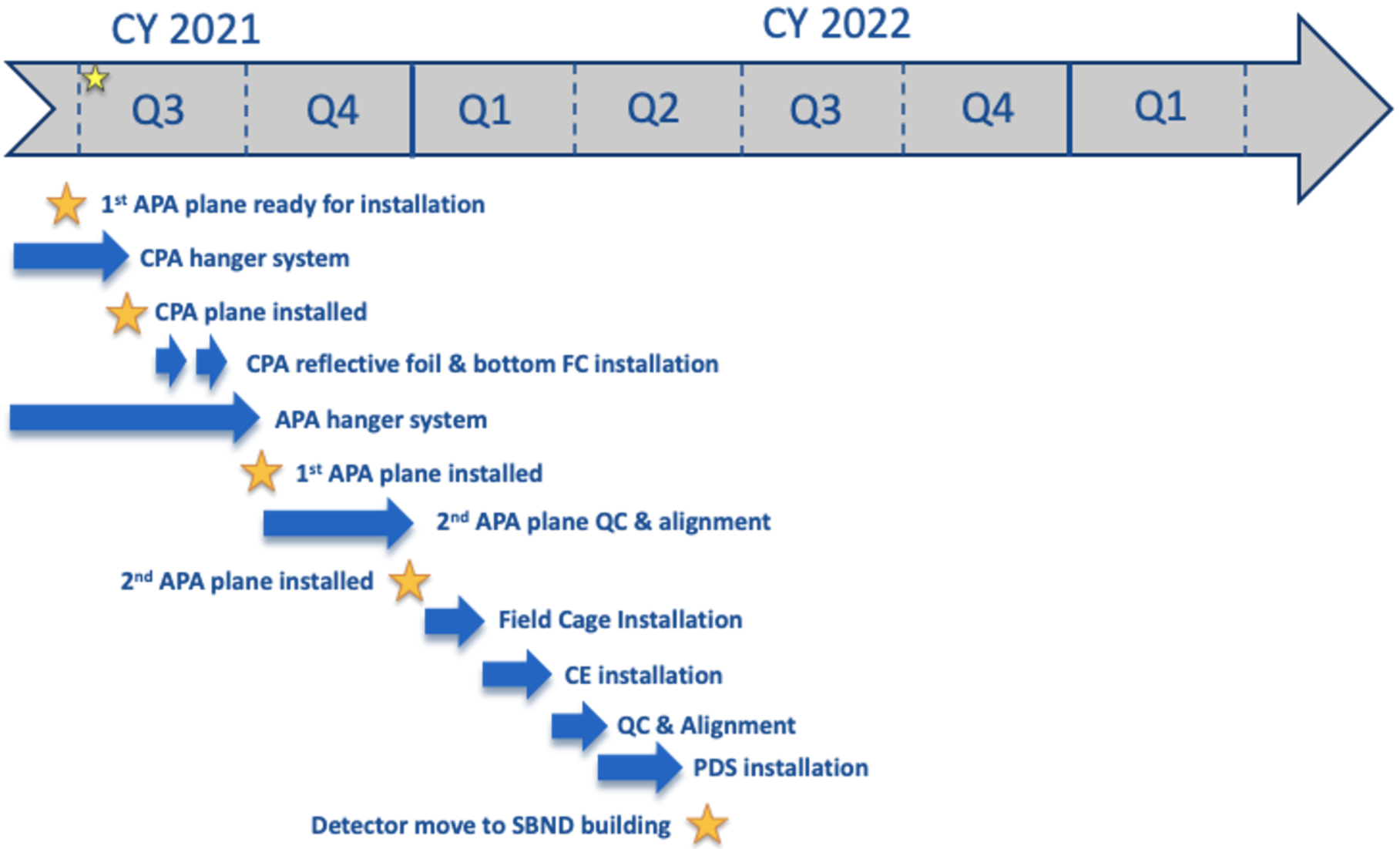
4) Install photon detection system



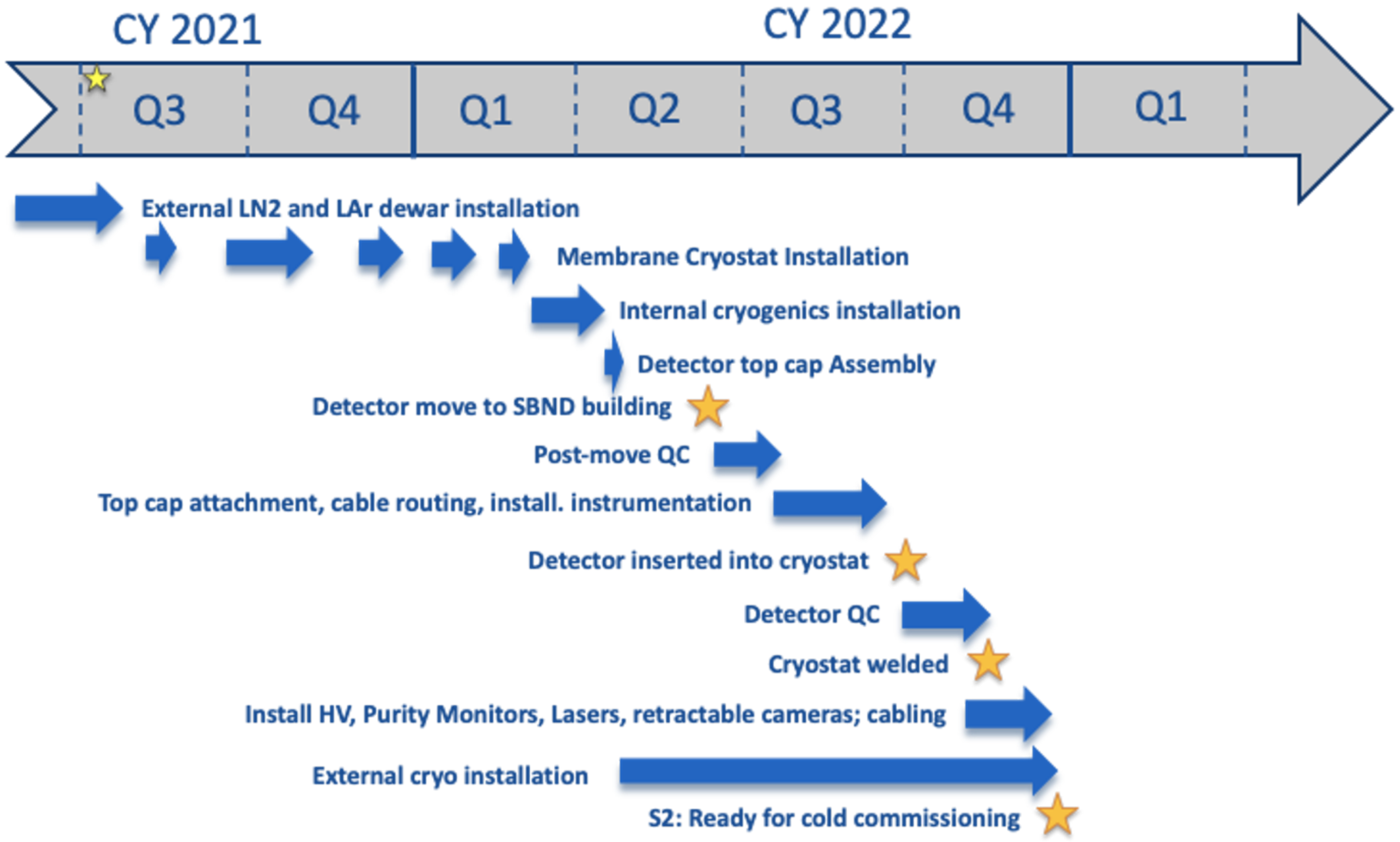
5) Move to SBN-ND detector hall!



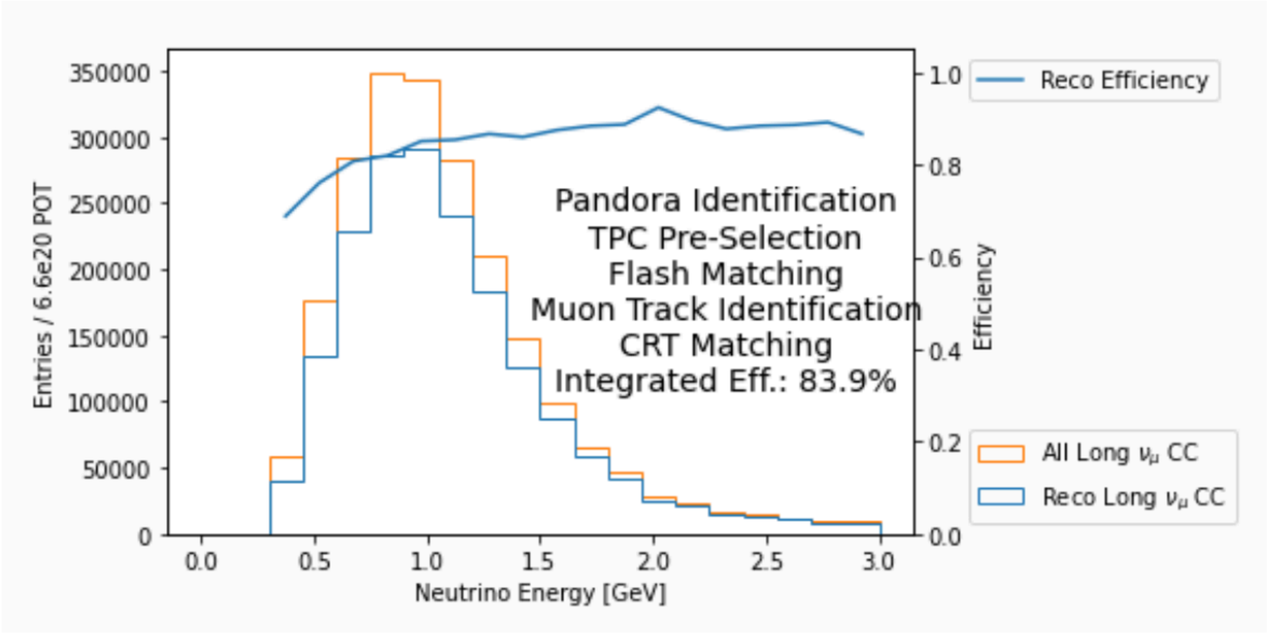
Assembly timeline



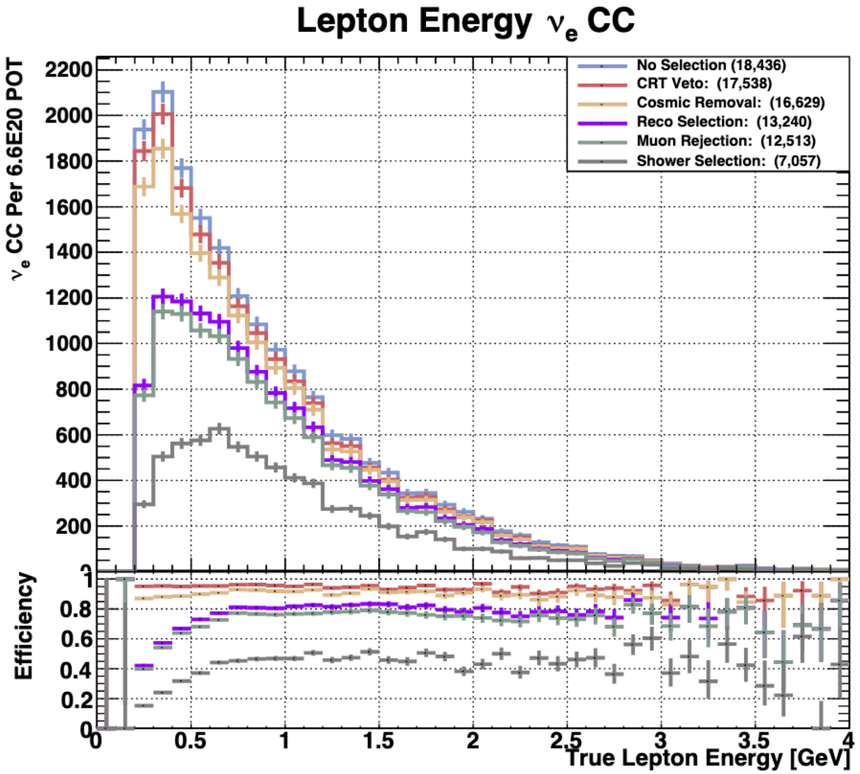
Installation timeline



Event Selection



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

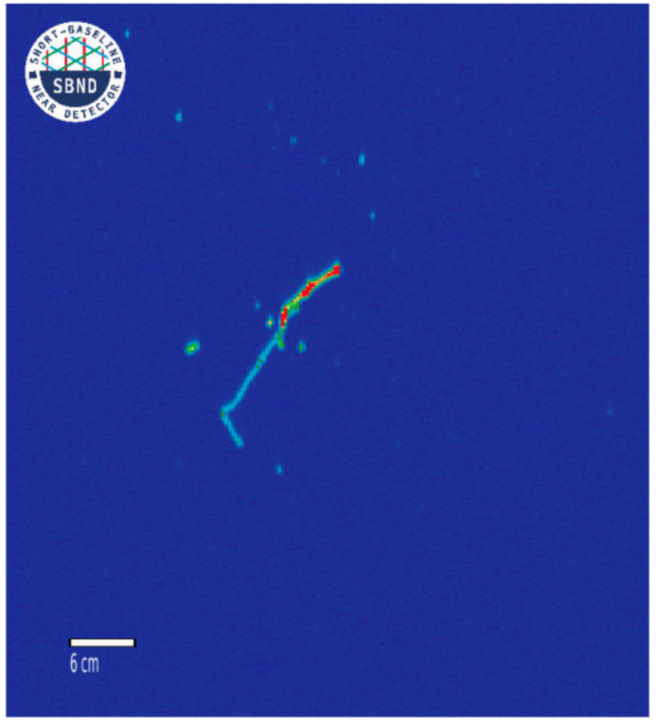


47 % electron neutrino selection efficiency
Internal Document SBN-21423, Edward Tyley

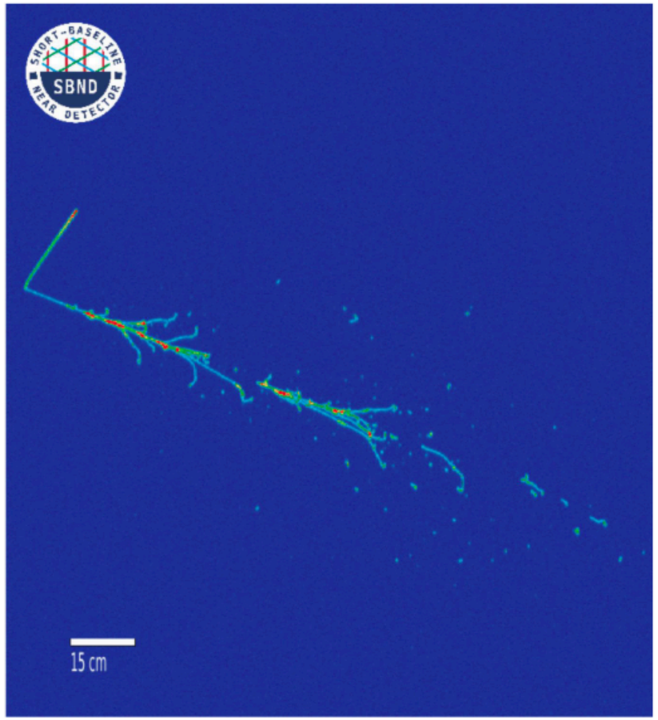
* Requires to not be tagged as clear cosmic (by Pandora)
* Passes CRT veto
* High flash match score

* In detector's fiducial volume
* Track and shower characteristics to muon or electron neutrino CC interactions (inclusive)

Pandora reconstruction



Example low energy shower

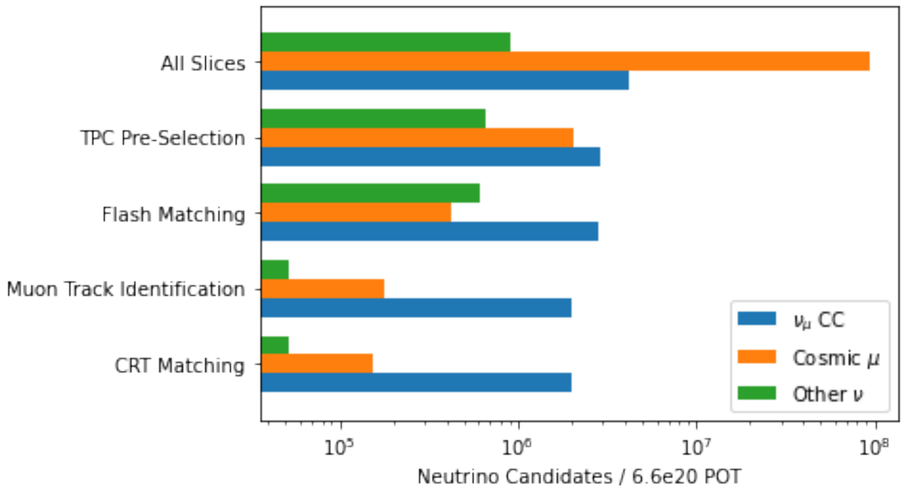


Example high energy shower

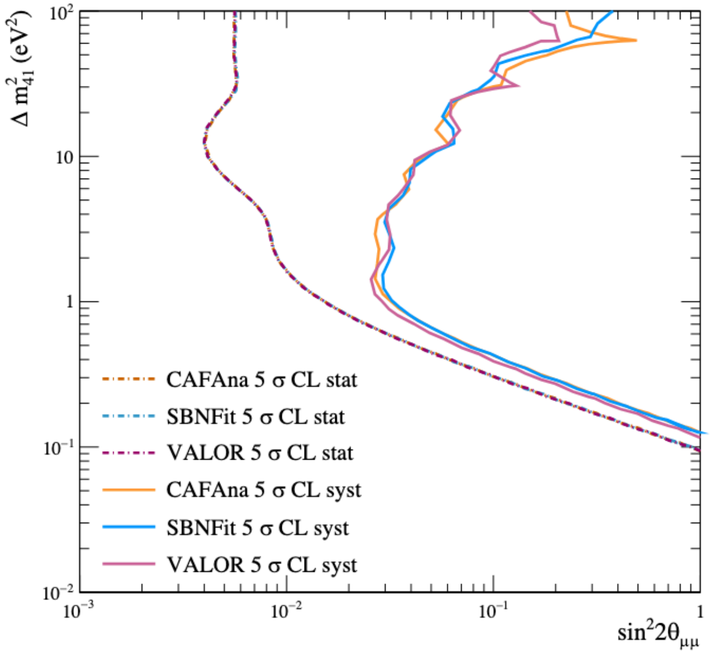
Tools

Reconstruction, selection and analysis tools

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



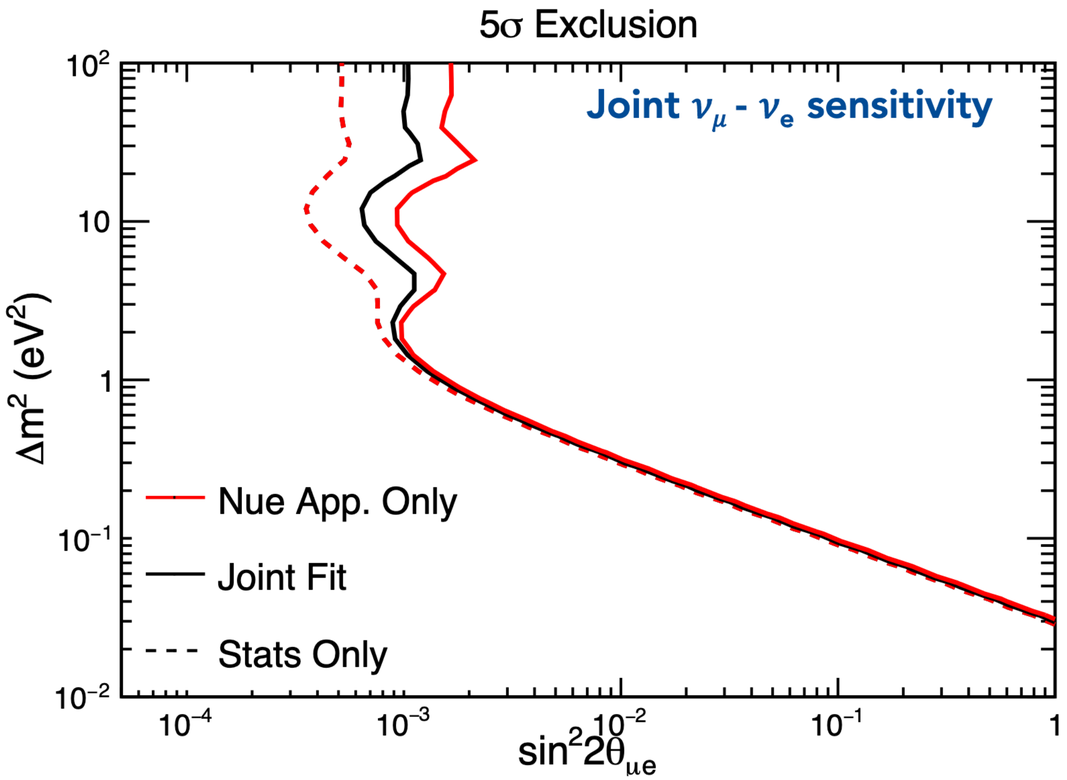
Bar-chart showing the selection flow for muon neutrino CC interactions. This specific analysis uses CAFs and upROOT. Internal Document SBN-22676



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).

Overburden


5σ Exclusion
Joint ν_μ - ν_e sensitivity
Nue App. Only
Joint Fit
Stats Only
Δm^2 (eV^2)
$\sin^2 2\theta_{\mu e}$
10^2
10
1
10^{-1}
10^{-2}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1