SBND and Short-Baseline Neutrino Program

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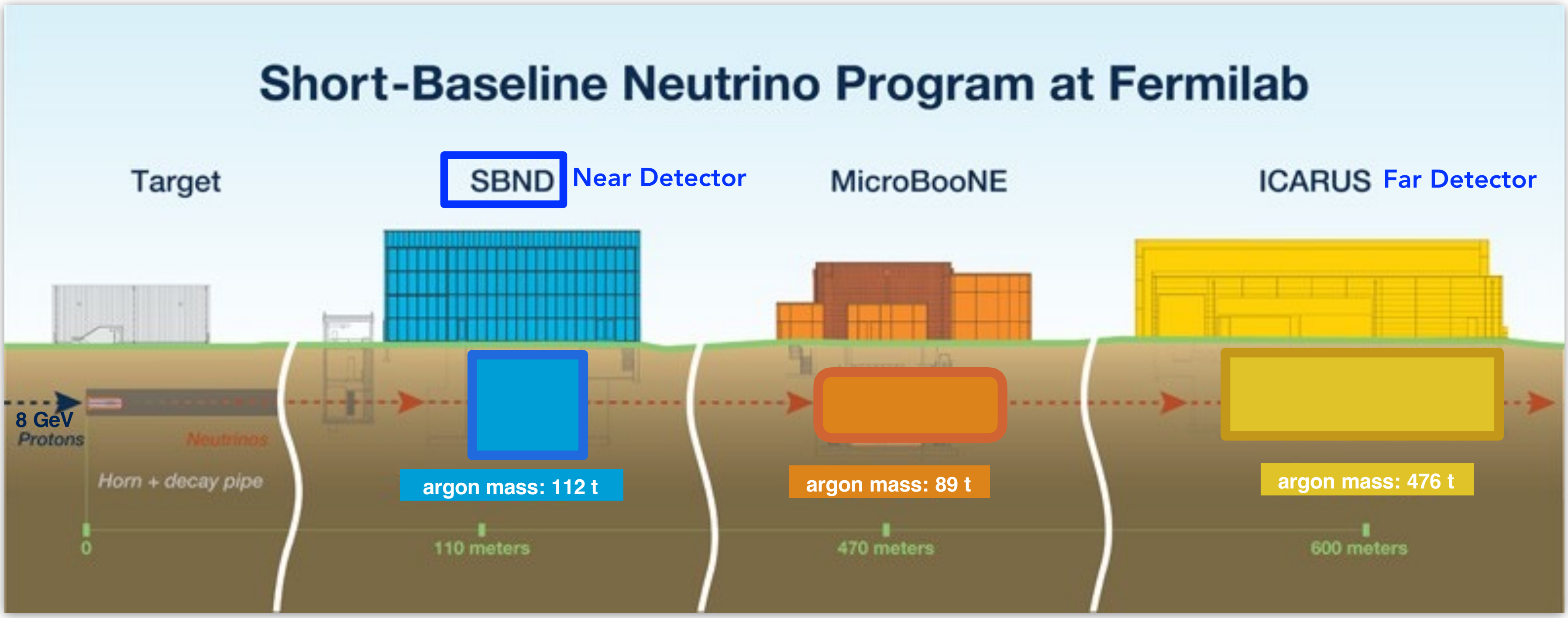
SHORT-BASELINE NEUTRINO PROGRAM



2015–2021
Large production of scientific results

2022–
Collecting data in final configuration

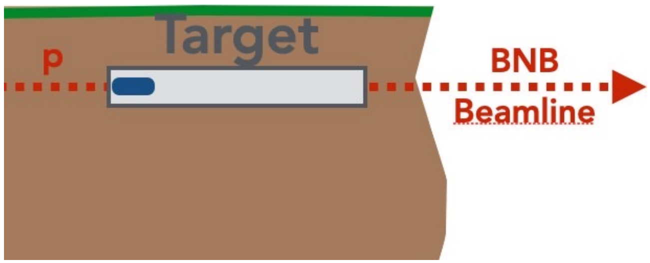
The Short Baseline Neutrino (SBN) Program at Fermilab consists of three LArTPC detectors, all in Fermilab's Booster Neutrino Beam (BNB) but at different baselines

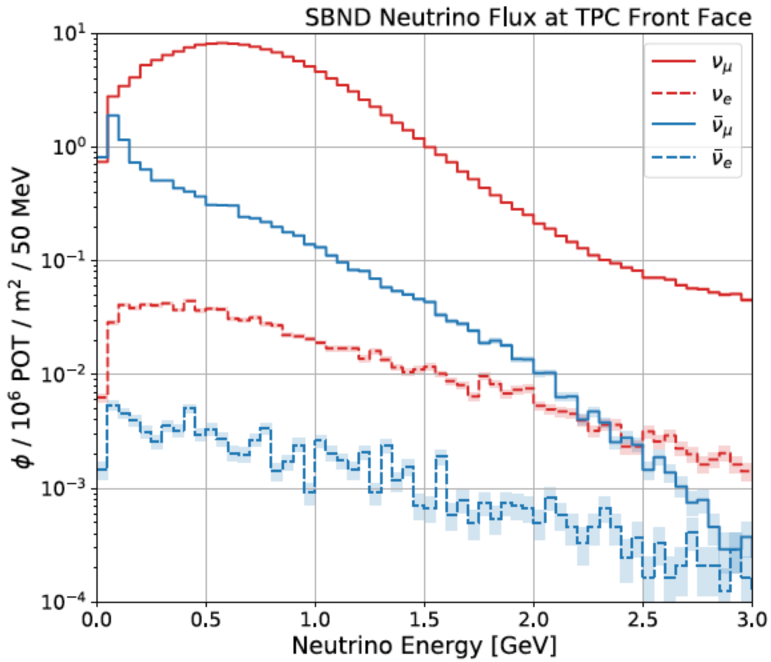
SBN Program aims to conclusively address the possibility of eV-scale sterile neutrino oscillations

SBND also has a rich single-detector physics program including neutrino–argon cross section measurements and new and rare physics searches

Booster Neutrino Beam

High-intensity neutrino beam from 8 GeV proton beam on Be target





Neutrino flux at the SBND front face

Mean muon-neutrino energy: ~0.8 GeV

Beam composition:

ν_μ (93.6%)

$\overline{\nu}_\mu$ (5.9%)

ν_e+$\overline{\nu}_e$ (0.5%)

MicroBooNE and ICARUS also took data from an off-axis NuMI beam.

What makes the SBN Program Unique?

LAr Technology

Time Projection Chamber

Event **imaging**

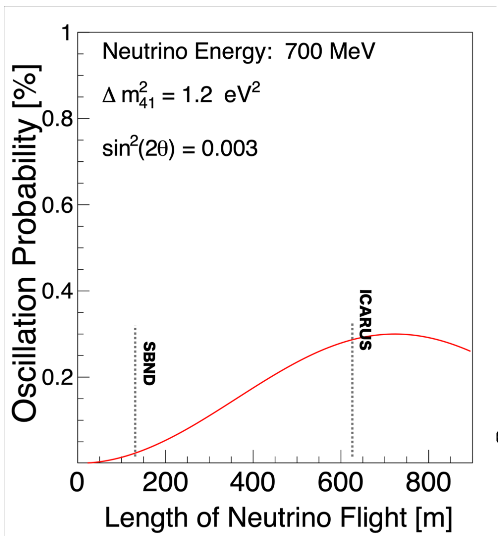
High-resolution **tracking**

Fine granularity **calorimetry** and

particle identification

Electron-γ separation

Low energy threshold



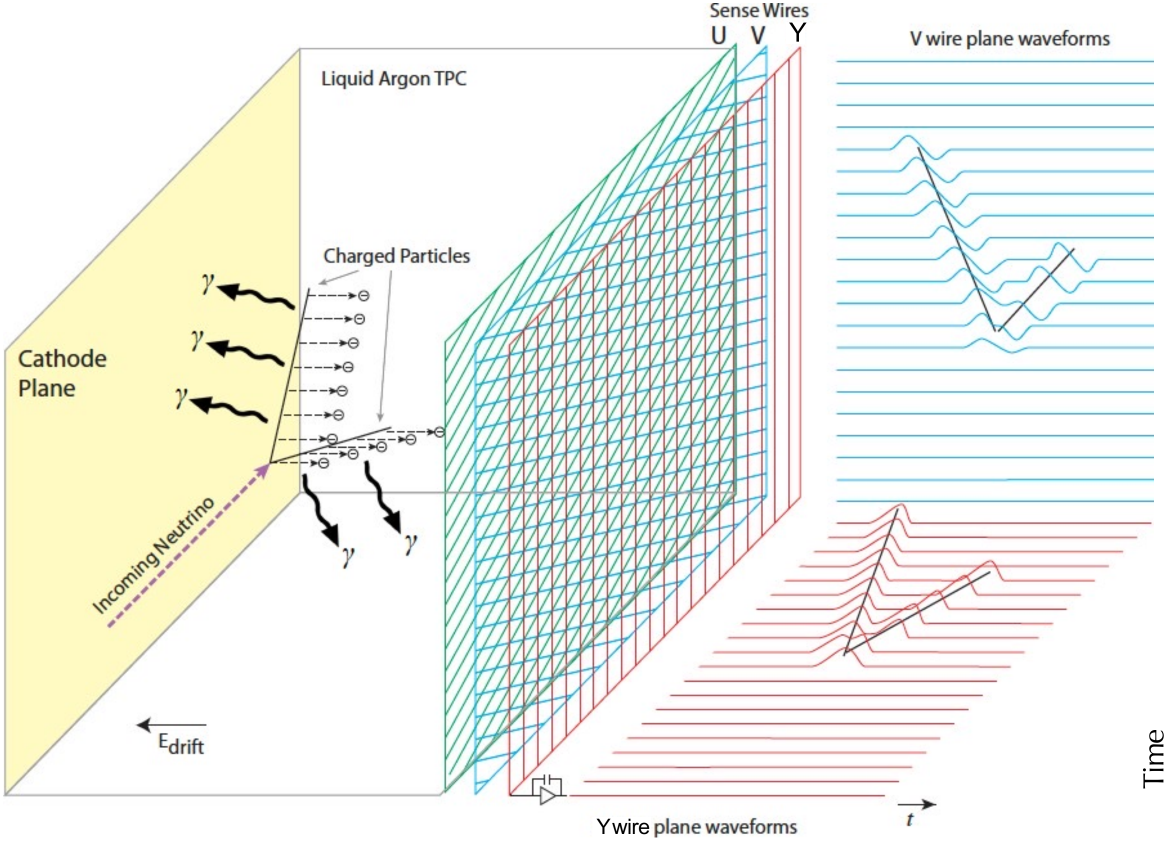
Near detector - SBND

Crucial for oscillation searches.
Sitting close to the neutrino source, SBND plays a **unique role.**
It sits before oscillations turn on @eV-scale → it characterizes the beam and **addresses the dominant systematic uncertainties**

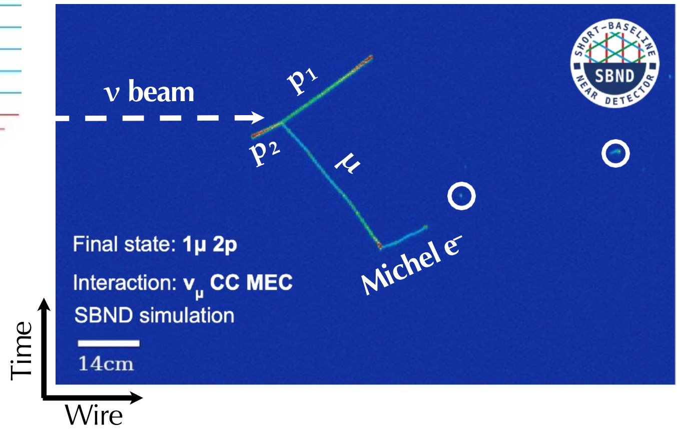
Far detector - ICARUS

Given its far location and large mass provides big exposure to oscillated neutrinos, allowing for a **high sensitivity oscillation search**

Detecting Neutrino Interactions with a LArTPC

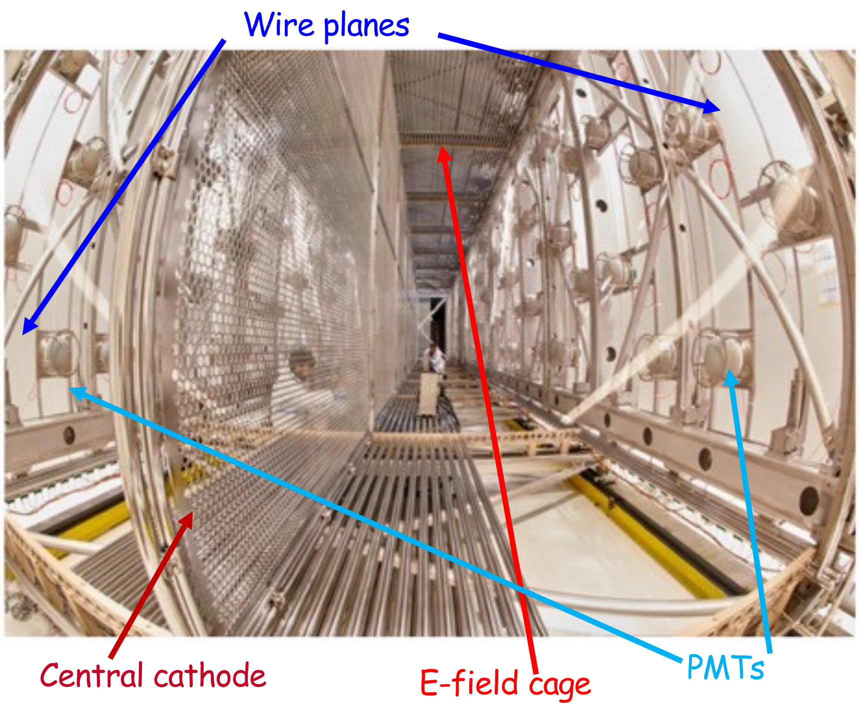


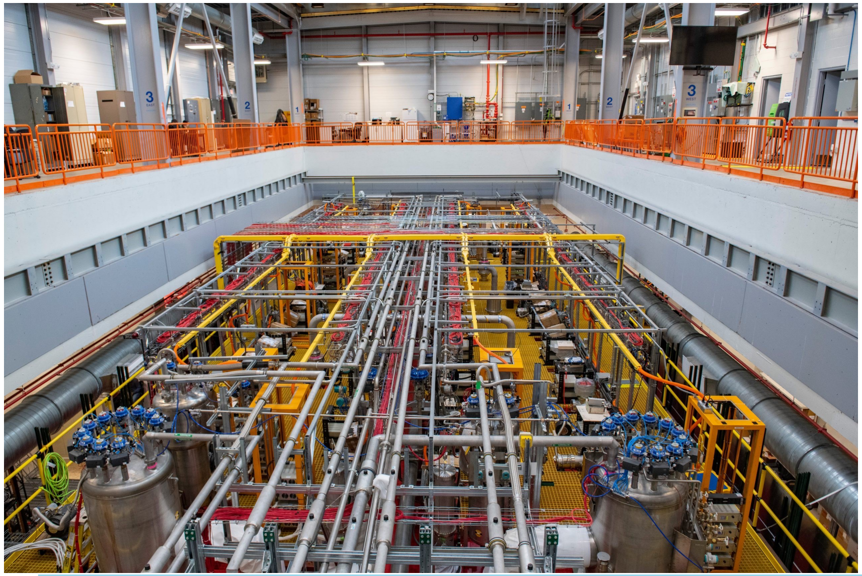
- LArTPCs are highly-capable, fully-active tracking calorimeters
- Precise timing information also available via scintillation light



The ICARUS detector at FNAL

- Combined 2 modules, 2 TPCs per module with central cathode (1.5 m drift, E_D= 0.5 kV/cm);
- 3 readout wire planes per TPC at 0, ± 60^0, 3 mm pitch; (2Inductions+1 Collection)
- S/N > 10 for MIP tracks in Induction 2 and Collection planes;
- 360 photomultipliers, TPB coated, to detect the scintillation light produced in LAr;





2015-17: overhauling at CERN

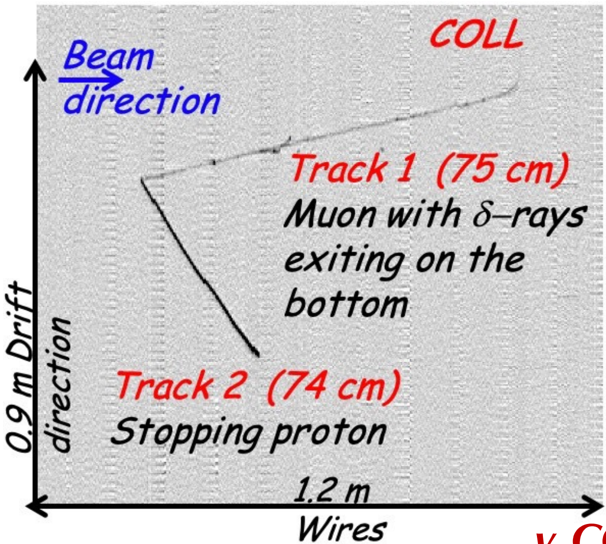
2018: transportation to FNAL and start of installation

2020: filling with LAr and start of commissioning

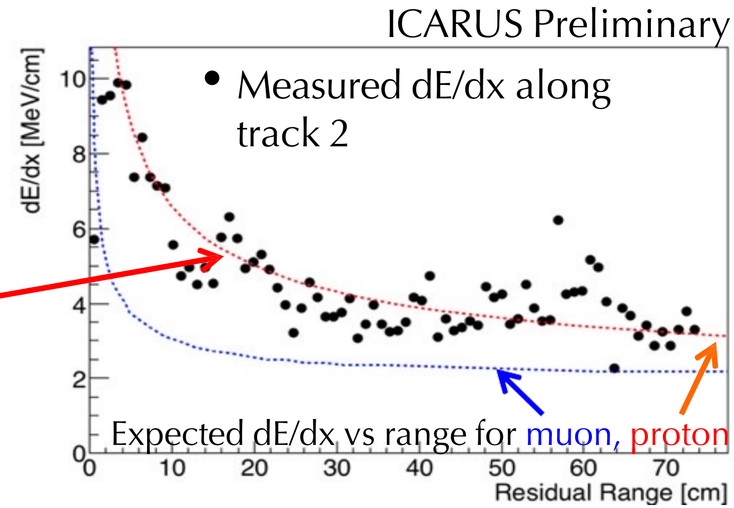
2022: start of physics data taking

Neutrino interactions at ICARUS

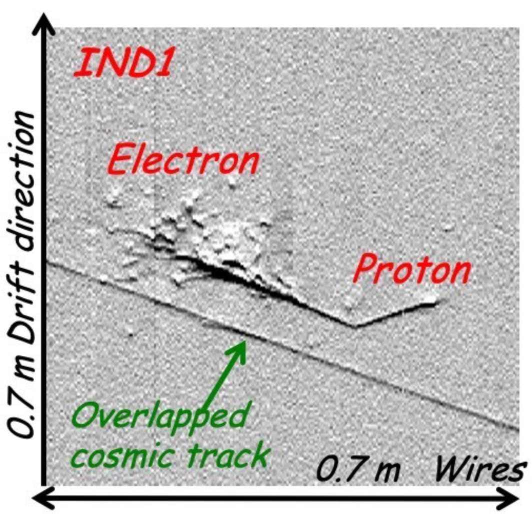
ν_μCC interaction from a BNB neutrino

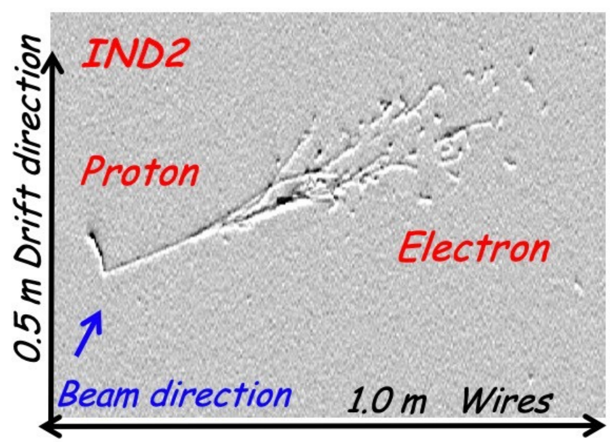


The study of dE/dx vs range confirms Track 2 is compatible with a proton (E_{DEP}~ 340 MeV)



ν_eCC interaction from a NuMI neutrino





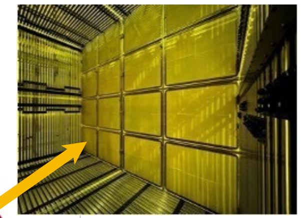
- QE ve CC event contained candidate, E_{DEP}~870 MeV:
  - ✓ proton candidate is upward going/stopping L= 13 cm;
  - ✓ e-shower is downward going.

The SBND Detector

LArTPC

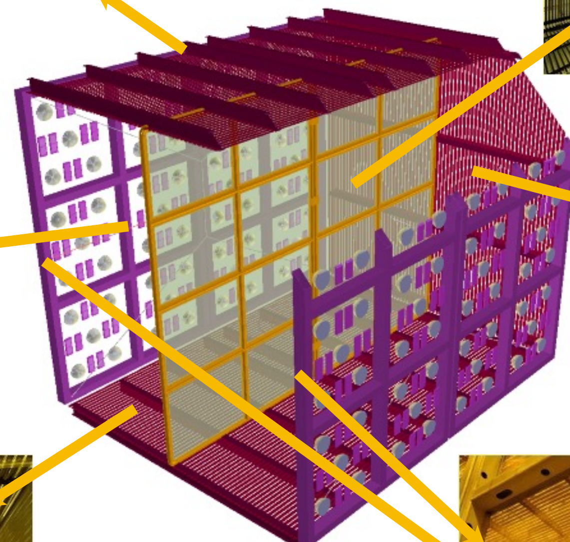
Active mass is 112 t
Active volume is 4×4×5 m^3

Cold Electronics (in LAr)
pre-amplify and digitize
TPC wire signals



Cathode Plane at –100 kV
divides the detector into two drift volumes

Drift distance is 2 m,
max. drift time is ~1.28 ms



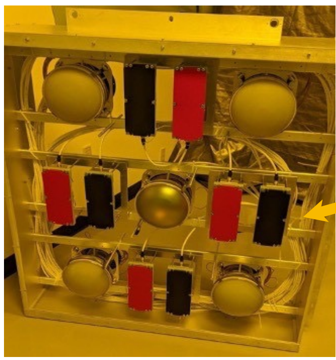
Field Cage wraps around the two TPCs to step down the voltage and ensure a uniform electric field of 500 V/cm

Anode Plane on either side, each with three wire planes with 3 mm wire spacing and different orientation per plane

Total of 11,260 wires

The SBND Detector

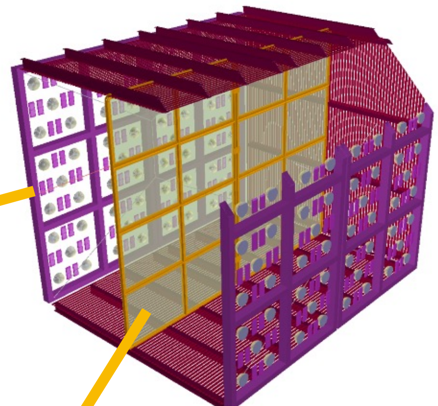
Photon Detection System



24 PDS Boxes
behind the anode wire planes

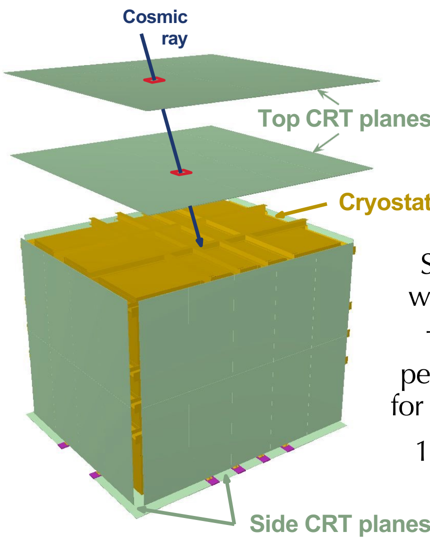
5×24 = **120 8″ PMTs**
80% TPB-coated,
20% uncoated

8×24 = **192 X-ARAPUCAs**
half with wavelength-shifting



Cathode Plane with
TPB-coated reflective foils
mounted behind mesh panels

Trigger System



(160 m² active area)

Scintillator strips
with SiPM readout

Two layers with
perpendicular strips
for accurate positions

142×32 channels

(225 m² active area)

Cosmic Ray Tagger

SBND Assembly & Installation

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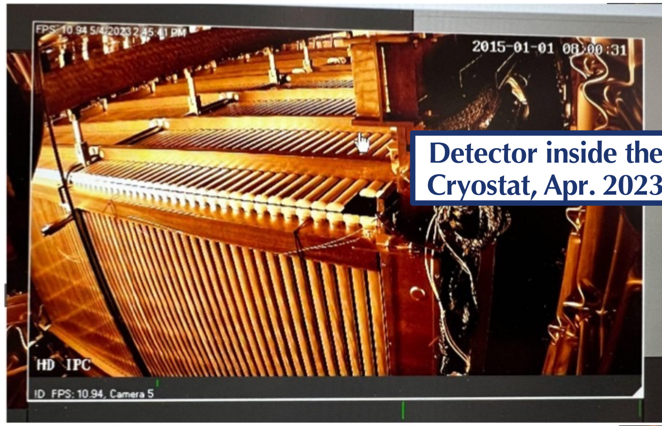
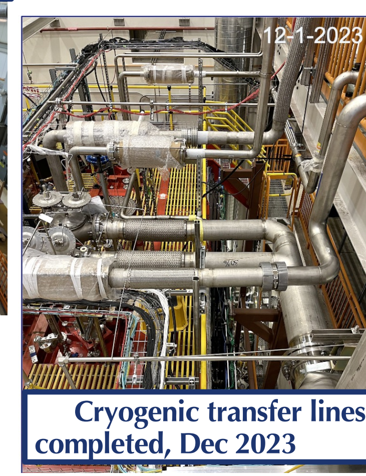


Detector inside the Cryostat, Apr. 2023


Cathode HV Feedthrough Installation, Jul. 2023


North CRT Wall Installation, May 2023

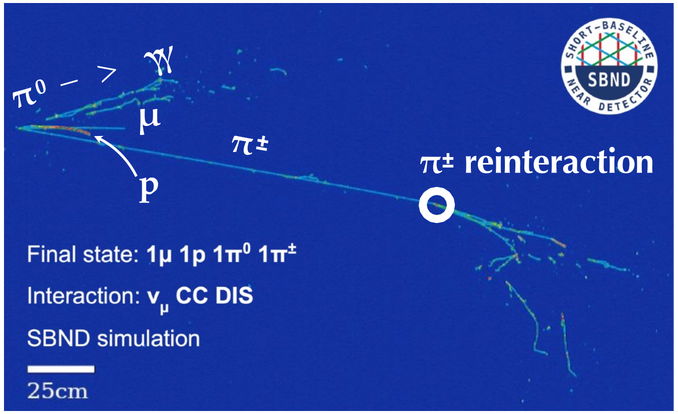


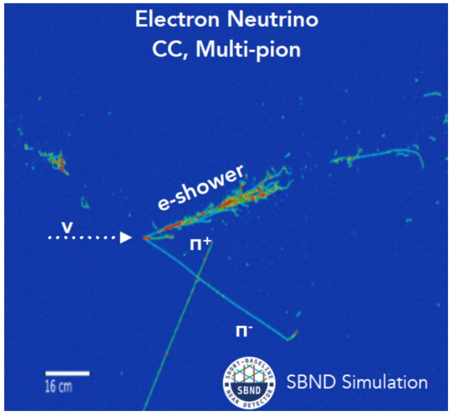
Cryogenic transfer lines completed, Dec 2023

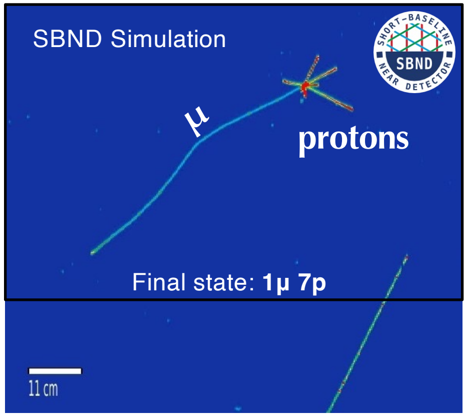
- Detector assembly and installation for all components inside the cryostat is complete, and the bottom and north CRT walls are installed.
- The the cabling for all systems from cryostat flanges to readout electronics racks, and in parallel with that on the final parts of cryogenics installation.
- The official end of installation on the 1^{st} of Dec 2023.
- Start LAr fill in January 2024, power up the detector in February and beginning of commissioning.
- First SBND Physics Run from April-July 2024. Expected data will match the MicroBooNE entire dataset.

Detecting Neutrino Interactions with SBND

- LArTPC capabilities enable low reconstruction thresholds and excellent particle identification for interactions in SBND
- Fine resolution also enables disentangling complex final states
- In comparable LArTPC detectors, isolated energy deposits can be identified down to O(100) keV — expect better from SBND (due to cold electronics)
  - Opportunity to study MeV-scale activity, e.g. from neutron scatters





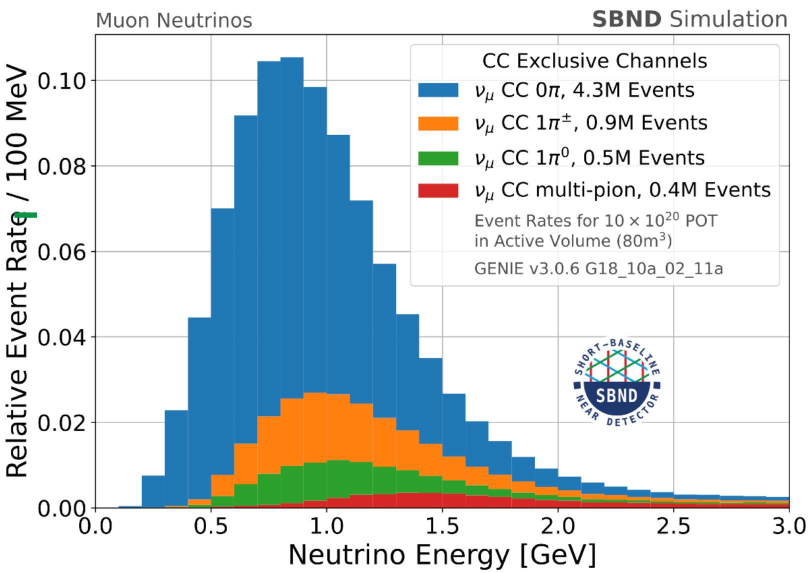


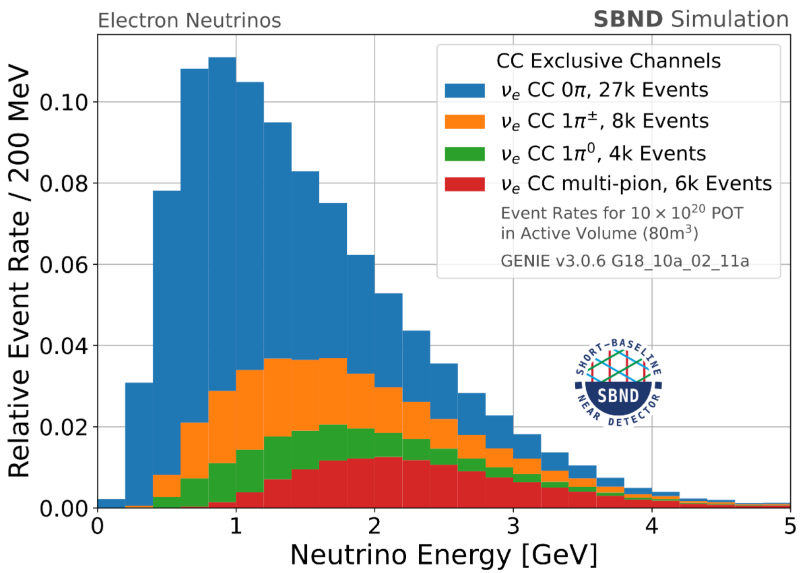
Neutrino Interaction Rates in SBND

- SBND expects approximately 2 million ν_μ CC and 15,000 ν_e CC interactions per year, and will collect beam neutrino data over the course of a ~3 year run
- Will record an order of magnitude more neutrino–argon interactions than currently available
- Enables a generational advance in the study of neutrino–argon interactions in the GeV energy range

  - For **more common channels**, SBND can make multi-dimensional differential measurements

  - For **rare channels**, SBND can make measurements that are limited in other existing experiments **(NC Np 1γ, Neutrino–electron elastic scattering, ν_μ-bar CCQE hyperon production, $K^+ + \Lambda^0$)**

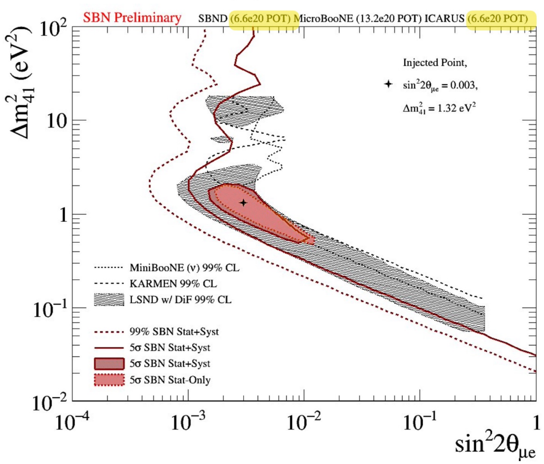




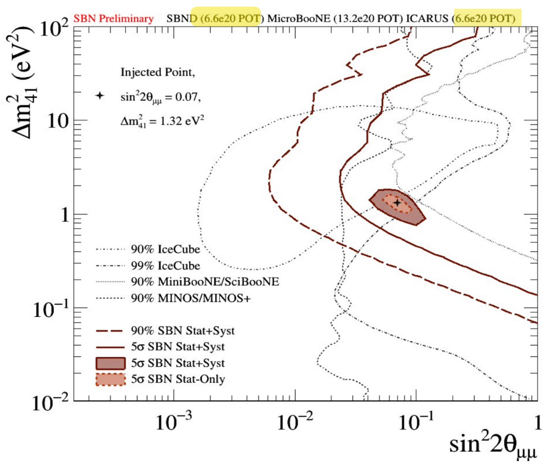
Sterile Neutrinos and Other BSM Physics in SBND

- SBND contributes to the SBN Program as the near detector, characterizing the beam before eV-scale oscillations set in and thus addressing dominant systematic uncertainties
  - SBN has a unique chance to jointly study ν_e appearance, ν_μ disappearance, and ν_e disappearance

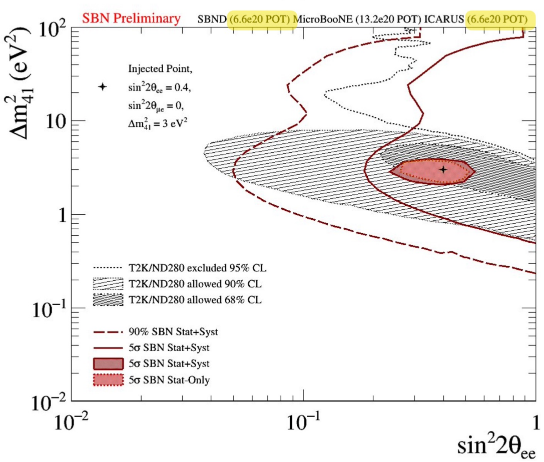
ν_e Appearance



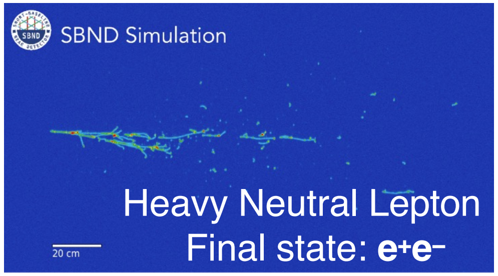
ν_μ Disappearance



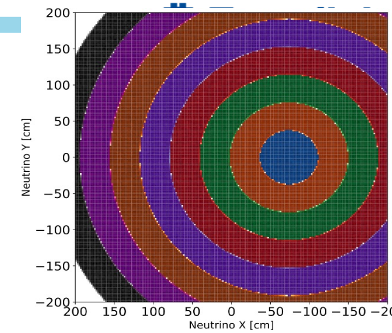
ν_e Disappearance



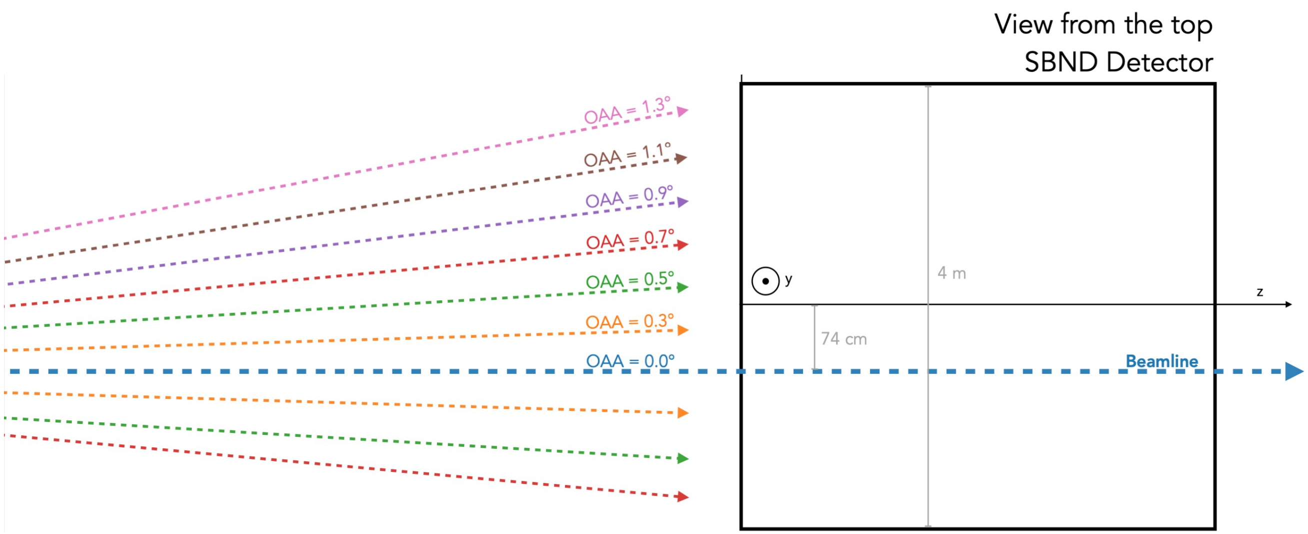
- In addition, SBND will pursue other possible explanations for the MiniBooNE low-energy excess anomaly as well as other beyond Standard Model physics scenarios



A Closer Look at the Booster Neutrino Beam
SBND-PRISM



- SBND is so close to BNB target that it sees neutrinos from a range of off-axis angles (OAAs)
  - Off-axis angles are calculated with respect to the BNB target position



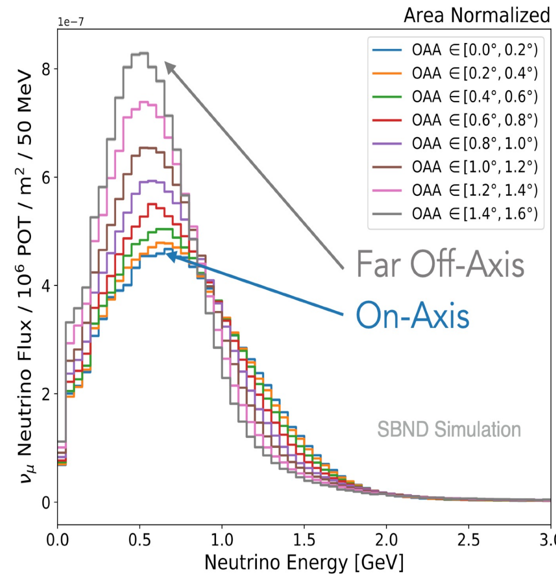


Figure courtesy of M. Del Tutto

- Allows SBND to leverage PRISM concept

SBND Simulation

Summary & Outlook

- Short-baseline neutrino program at Fermilab aims to definitely resolve the question of existence of an eV-scale sterile neutrinos using multiple detectors.
- SBND experiment finished the installation installation, and is ready for commissioning, and is on track to start operations in 2024. ICARUS continues taking data.
- The highly-capable LArTPC detector technology combined with SBND's close proximity to the BNB target and resulting high statistics will enable a wide variety of measurements.
- SBND-PRISM provides a unique opportunity to probe different neutrino fluxes within the same stationary detector.
- SBN received strong support from the P5 for the continued operation and research

Exploring the Quantum Universe

Recommendation 1

Not Rank-Ordered

In addition, we recommend continued support for the following ongoing experiments at the medium scale (project costs > $50M for DOE and > $4M for NSF), including completion of construction, operations, and research:

d. **NOvA**, **SBN**, **T2K**, and **IceCube** (*elucidate the mysteries of neutrinos*, section 3.1).

Science Experiments

Timeline	2024–2034	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
		Science Drivers						
LHC			P	P		P	P	
LZ, XENONnT				P				
NOvA/T2K		P				S		
SBN		P				S		

Lancaster University

Short Baseline Neutrino

Thank you!

SBND Collaboration Meeting, Sao Paolo, Brazil, December 2023