Fermilab

2025-06-10

SBND Detector Status and First Results

Sungbin Oh[1], On Behalf of the SBND Collaboration at CIPANP 2025
1) Fermilab

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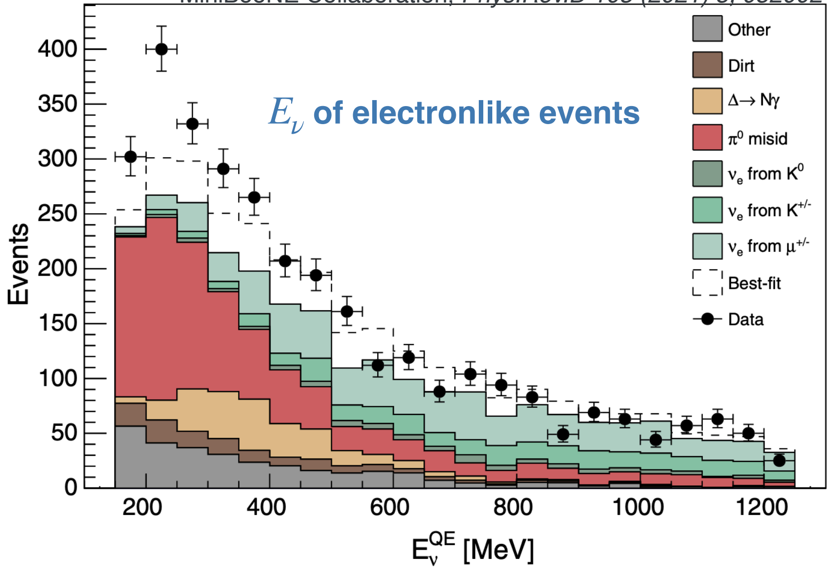
Short Baseline Neutrino (SBN) Program

Search for sterile neutrino with ~ eV mass scale

- The low energy excess in **electronlike** events reported by the LSND and the MiniBooNE experiments

MiniBooNE Collaboration, *Phys.Rev.D 103 (2021) 5, 052002*



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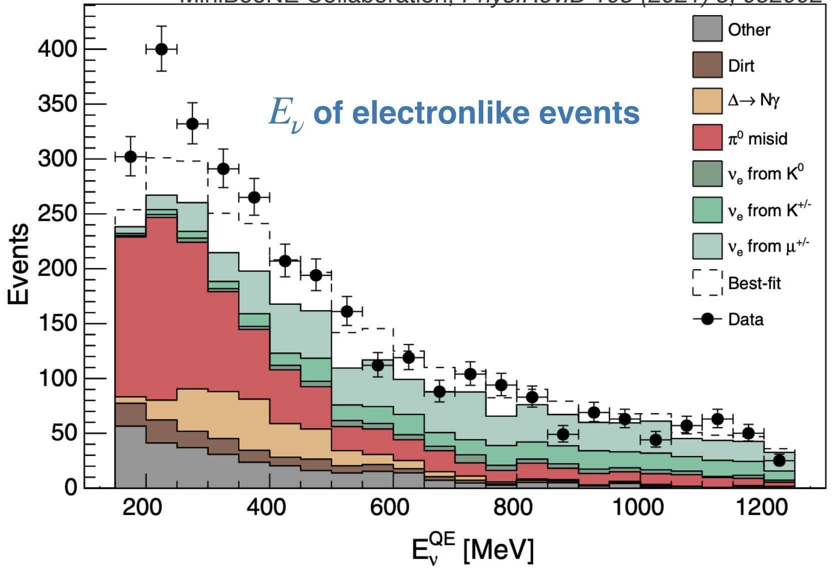

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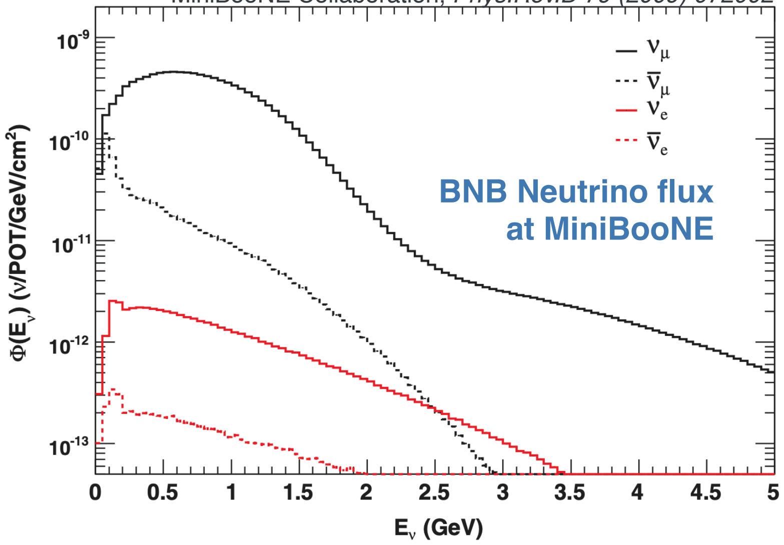

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  - $P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta_{\mu e} \sin^2(\Delta m^2_{41} L/E)$

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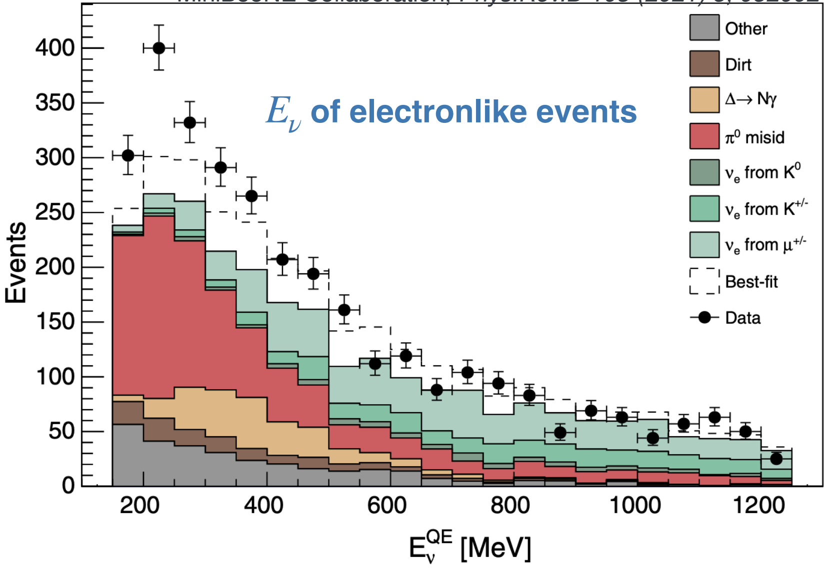

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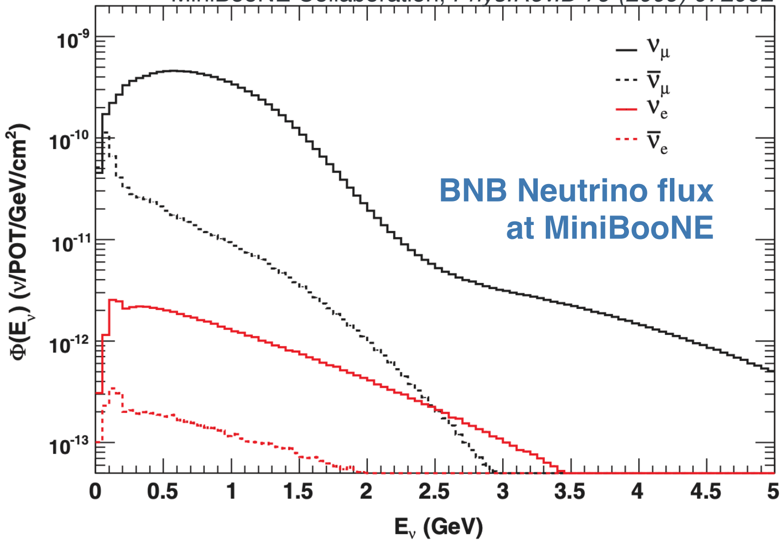

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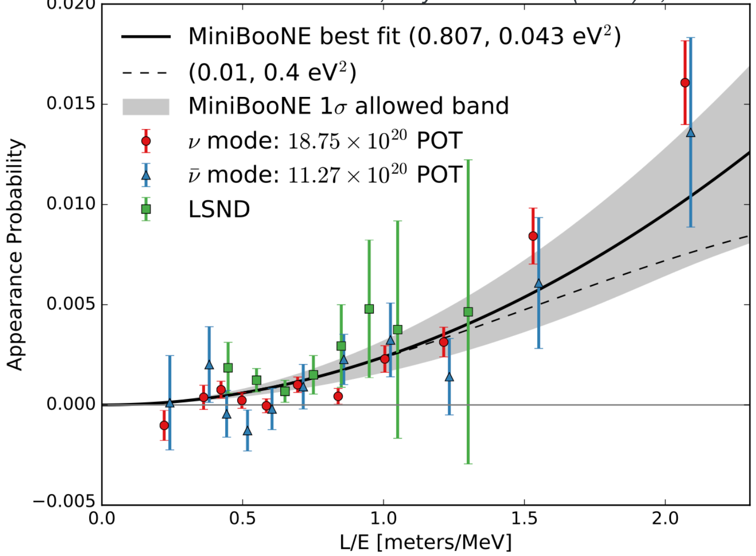

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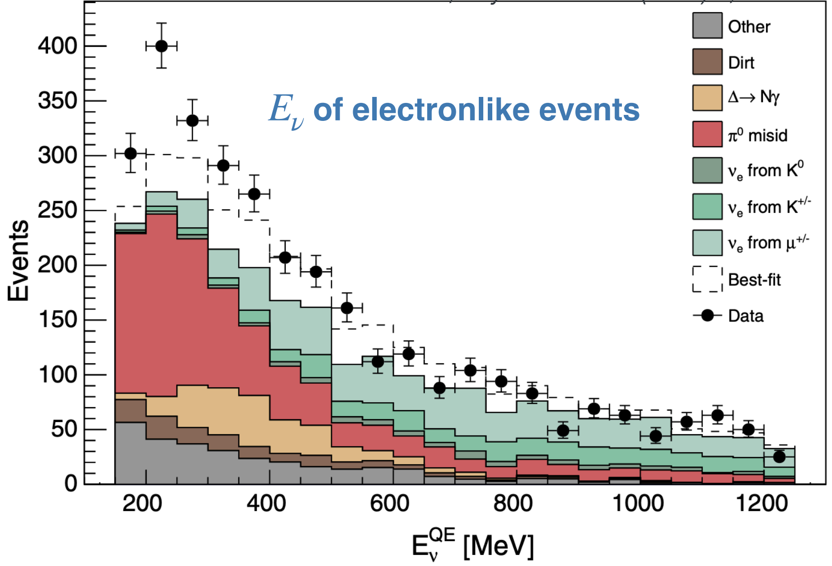

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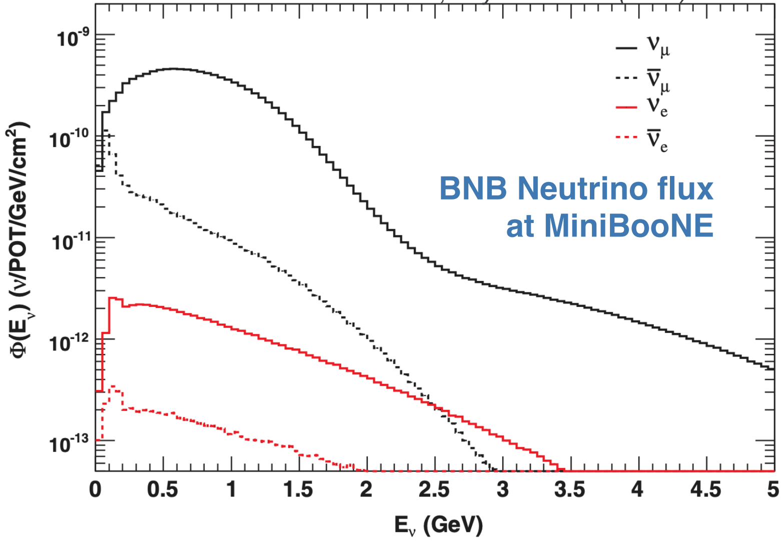

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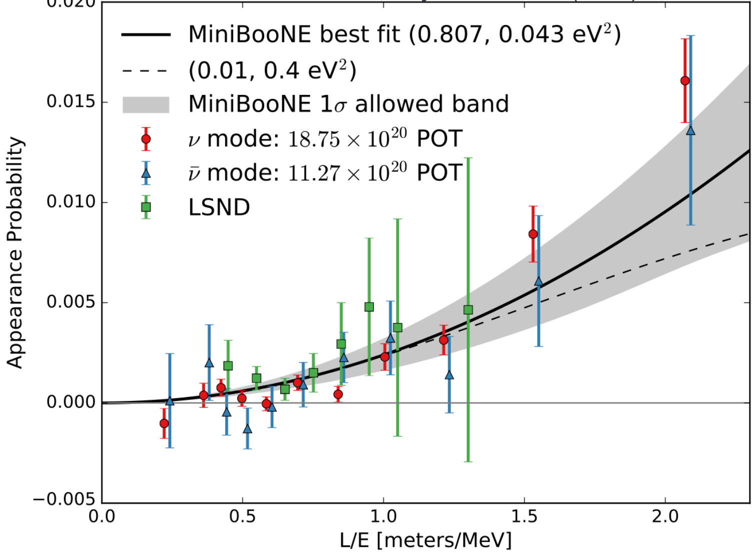

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- Is the low energy access coming from electrons or photons? → Improved detector technology!!!

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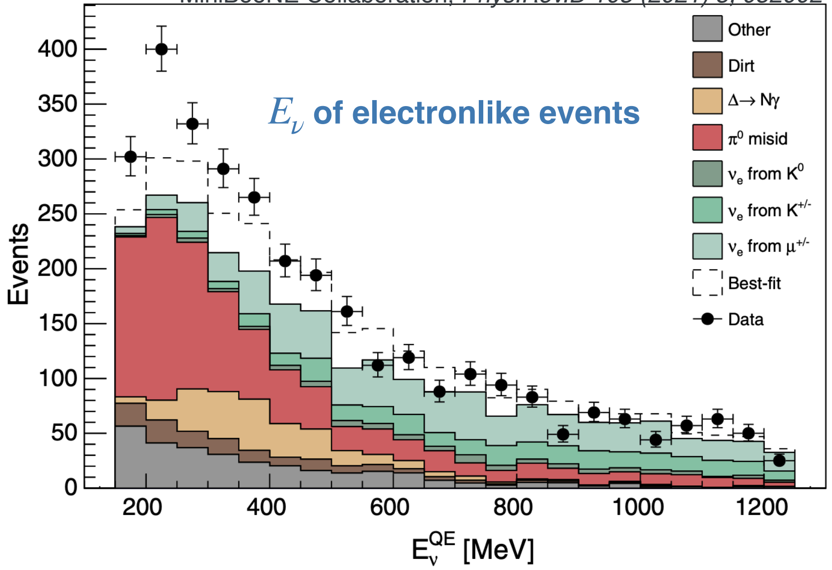

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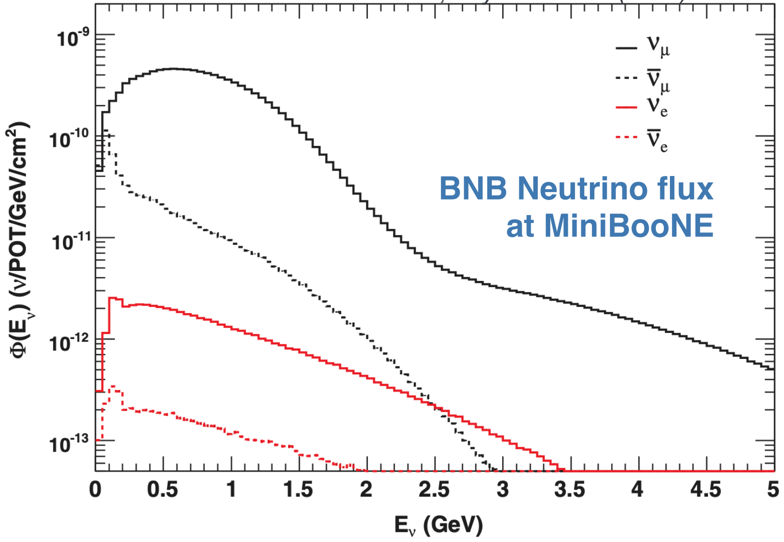

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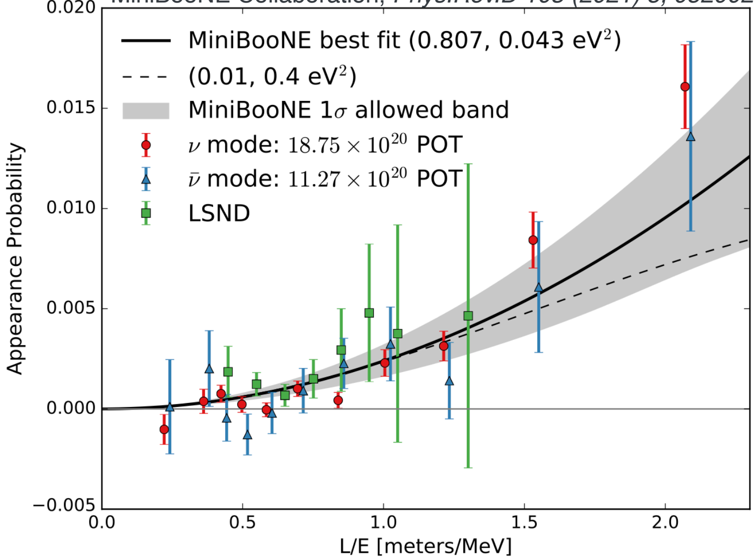

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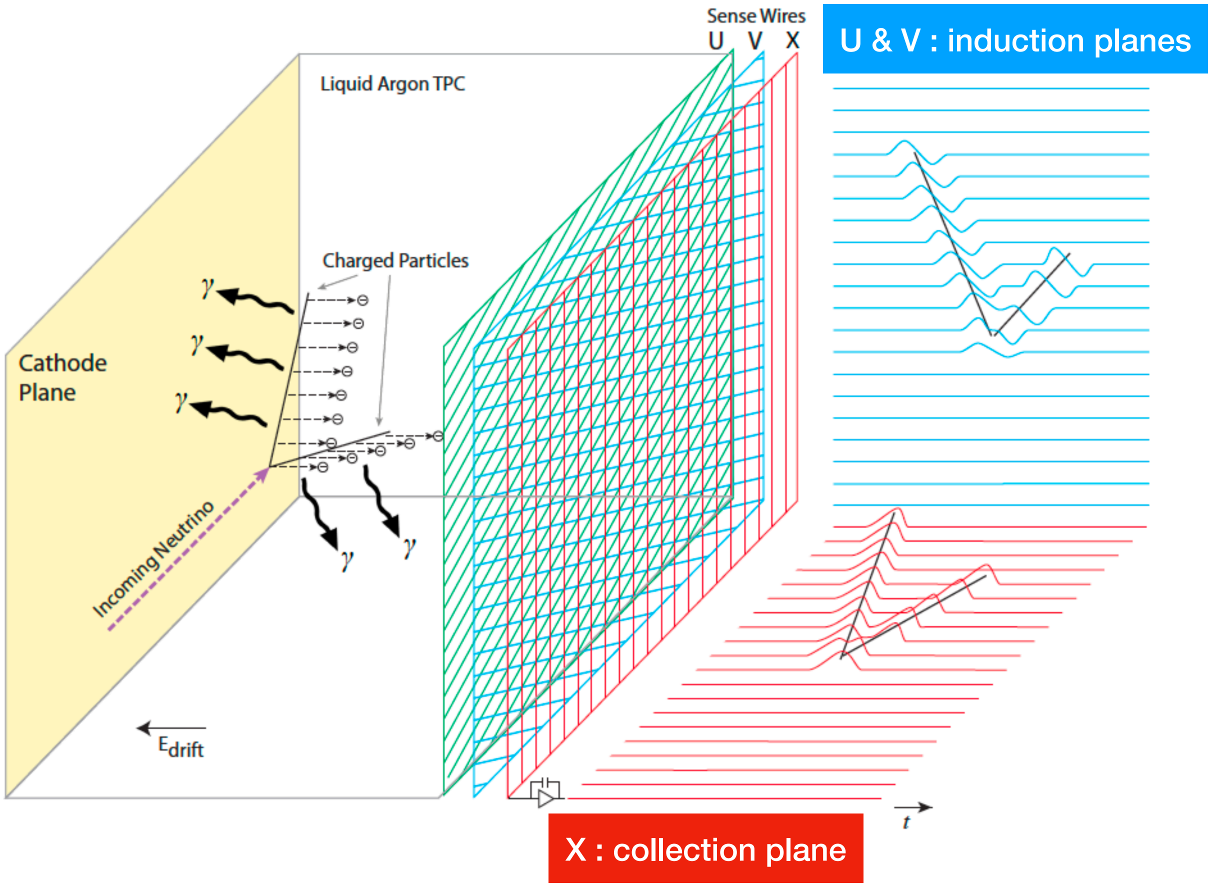
Use the same neutrino source with MiniBooNE: Booster Neutrino Beam (BNB) @ Fermilab

- Liquid argon time projection chamber (LArTPC) detector technology



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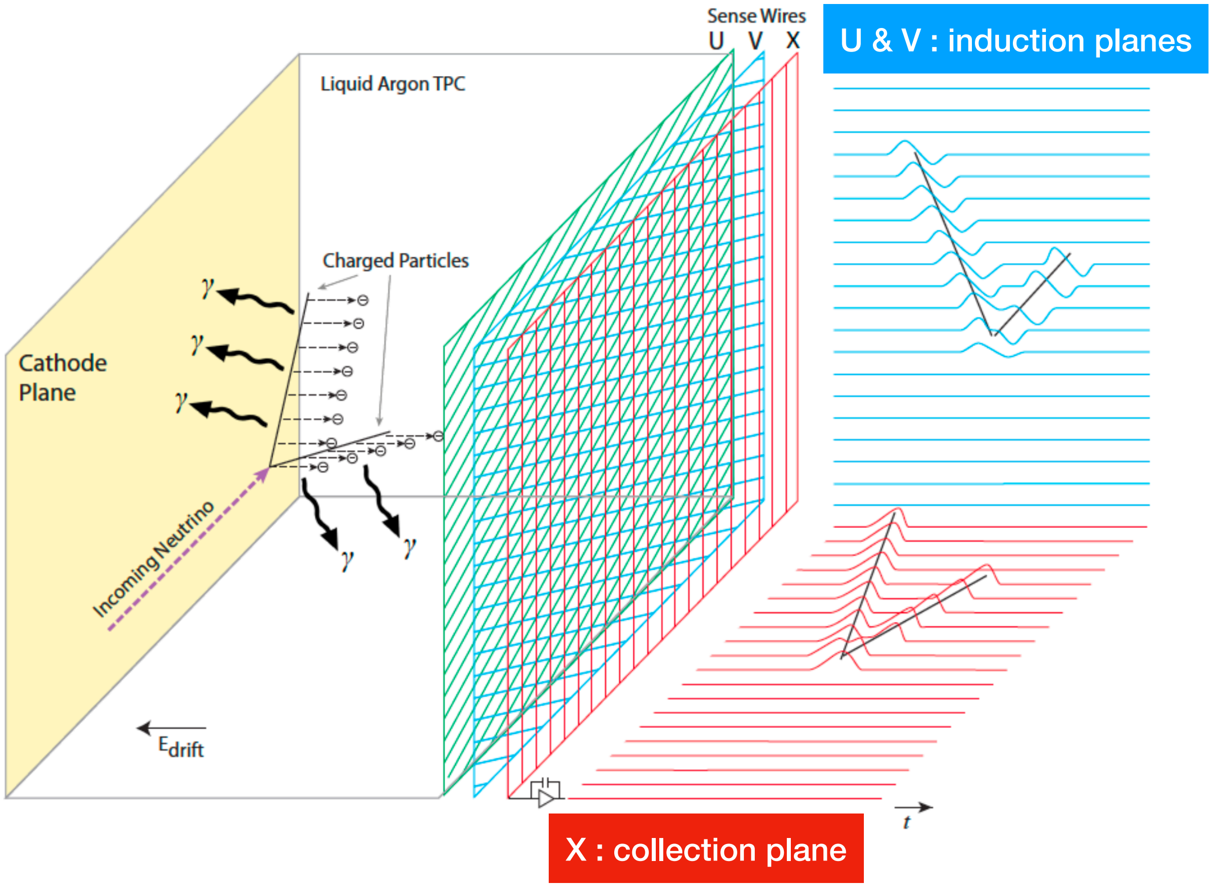

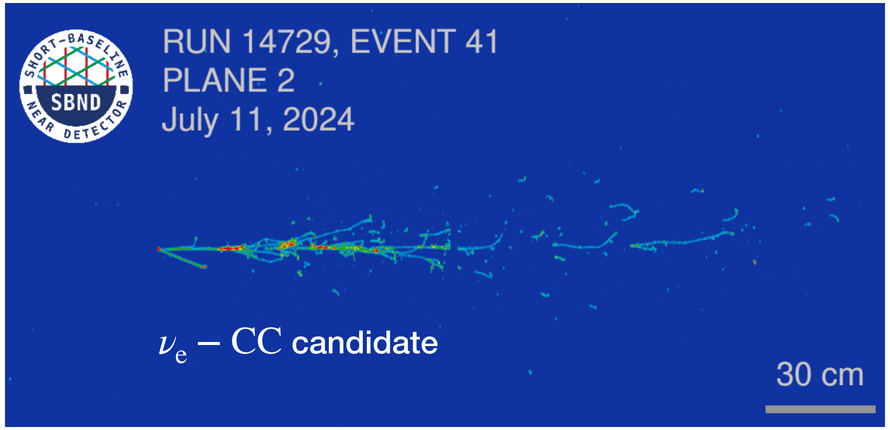

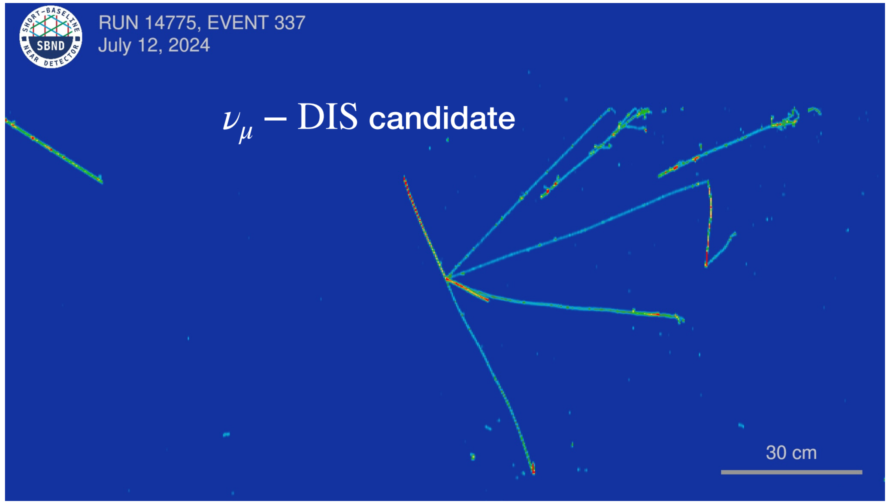

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	Active Mass (ton)	Baseline (m)	Operation
SBND	112	110	2024 -
MicroBooNE	89	470	2015 - 2021
ICARUS	476	600	2021 -

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- A wide physics program includes precise ν-Ar interaction studies and BSM searches (dark matter, HNLs)

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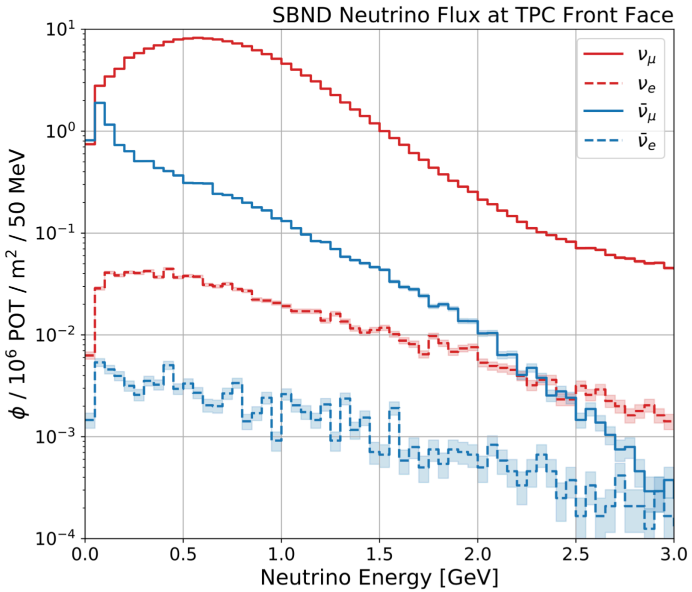
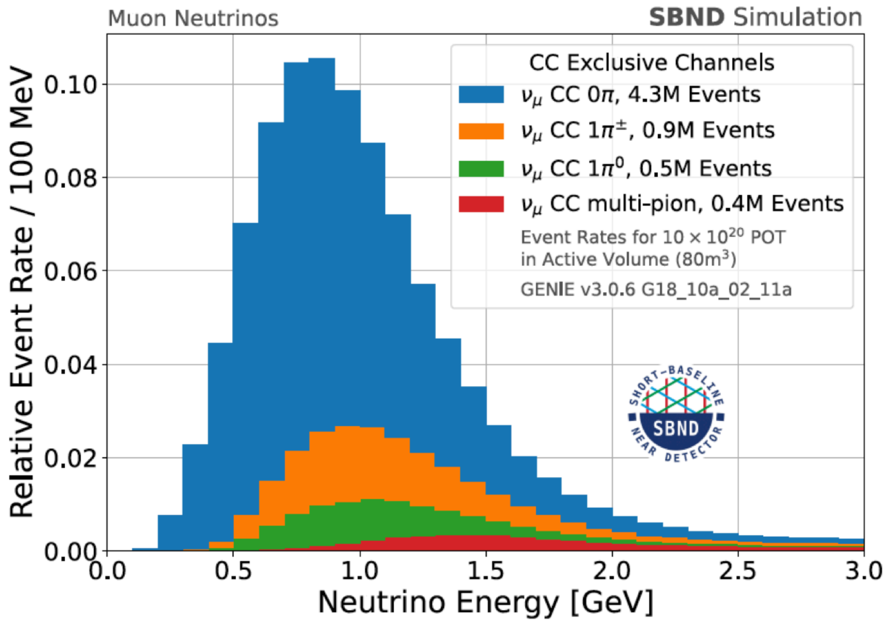
Short Baseline Neutrino Detector (SBND)

Proximity: 110 m from the BNB target

- High neutrino flux → high neutrino event rate → will record the world's largest ν-Ar scattering data
  - ~3 years of operation → ~6 million neutrino events





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- Off-axis neutrino flux inside the active volume
- Constrain ν flux and ν-argon interaction models as a near detector

NOνA: *Phys.Rev.D* 106 (2022) 3, 032004
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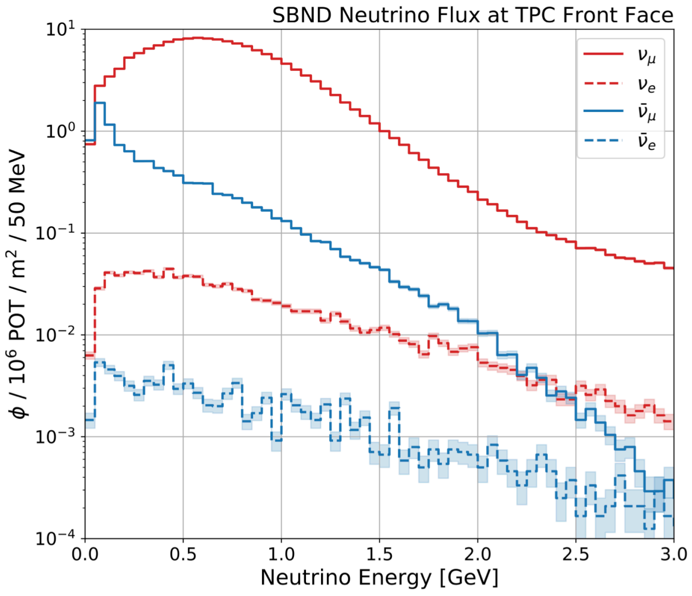

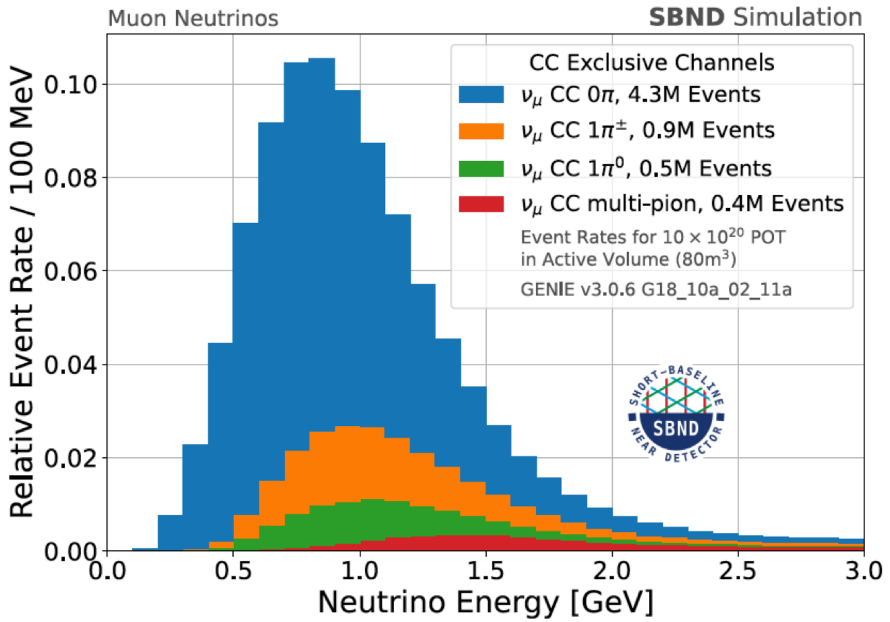

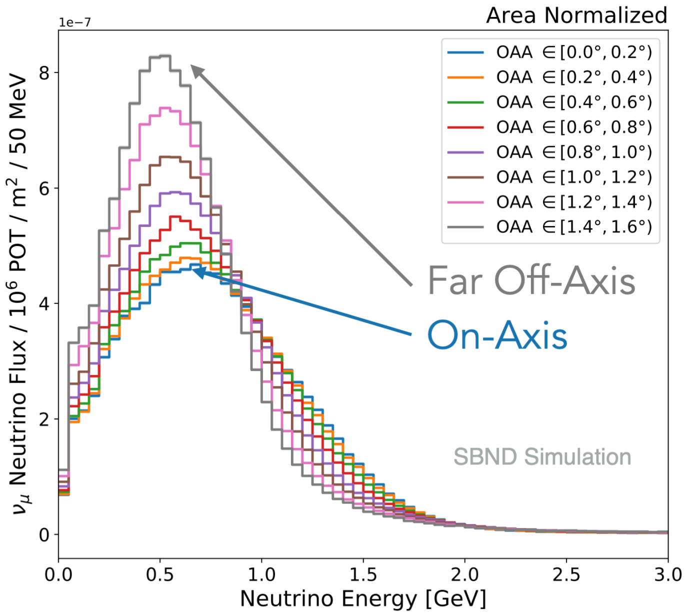

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- Off-axis neutrino flux inside the active volume
- Constrain ν flux and ν-argon interaction models as a near detector
- Excellent sensitivity to BSM particles as a beam dump experiment

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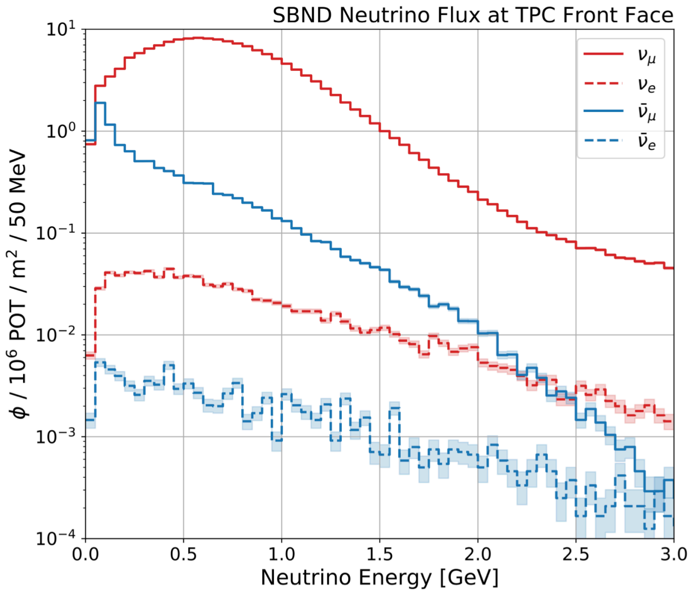

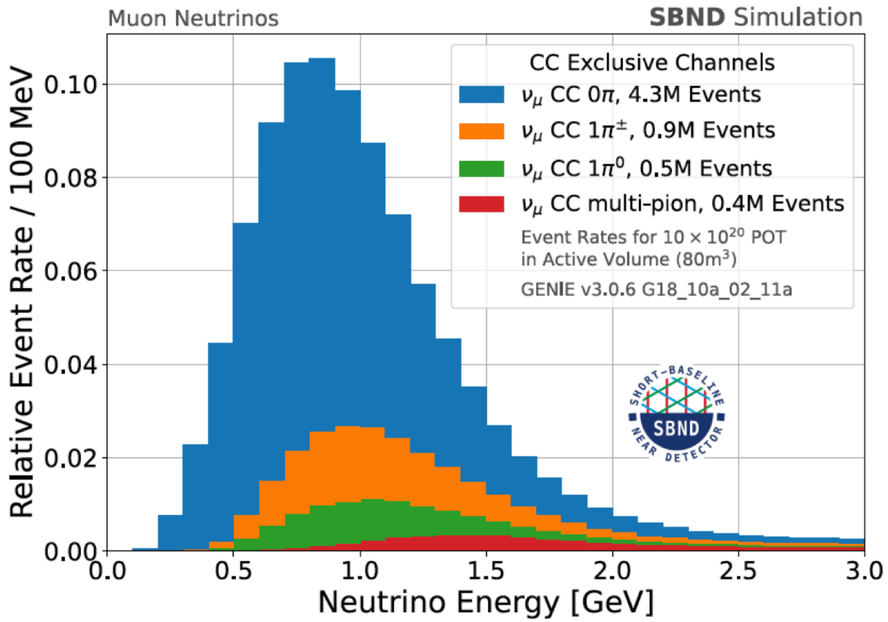

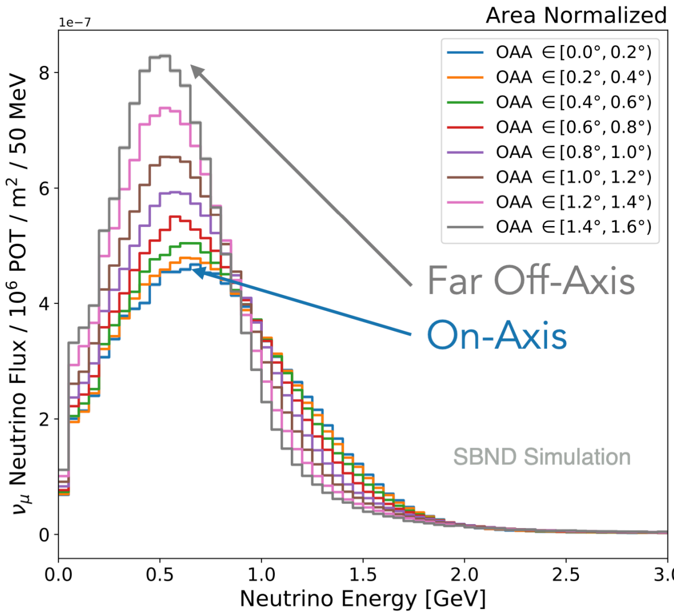

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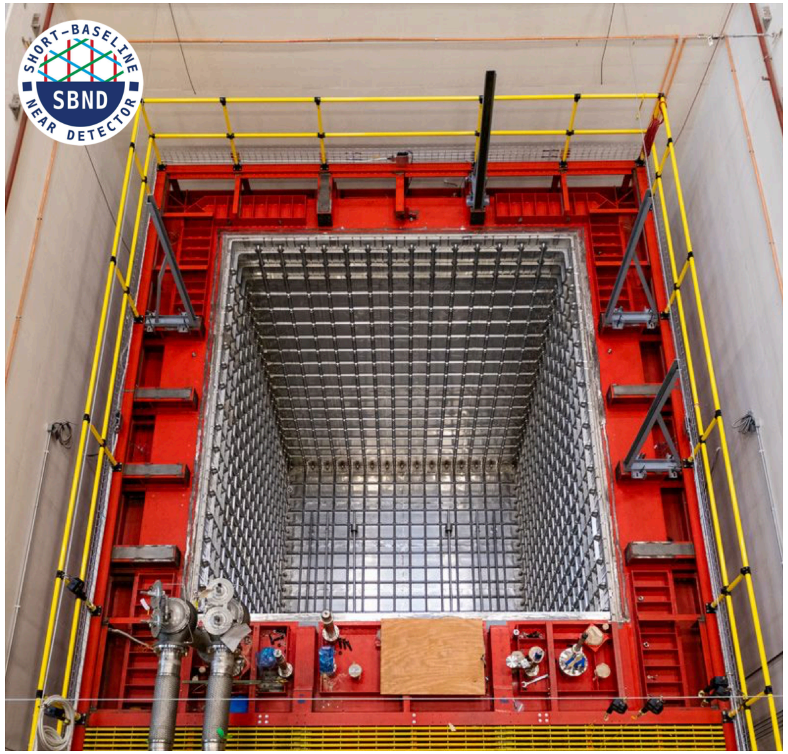
SBND: (1) Subsystems: (a) Cryostat and Cryogenics

Under 1 atm, argon boiling point is 87.3 K and freezing point is 83.8 K

- Utilize membrane cryostat which is an LNG industry technology: same with DUNE!



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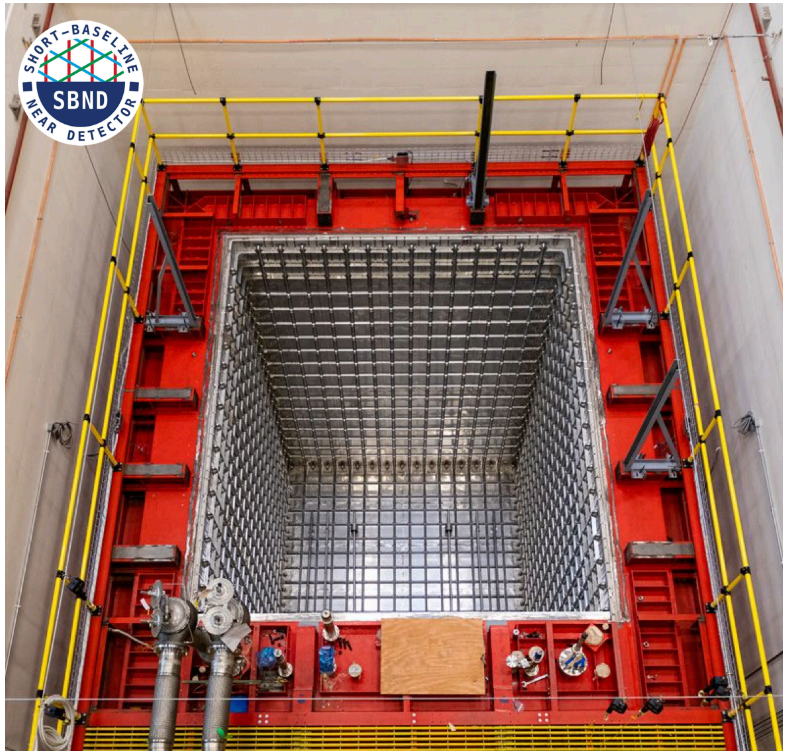

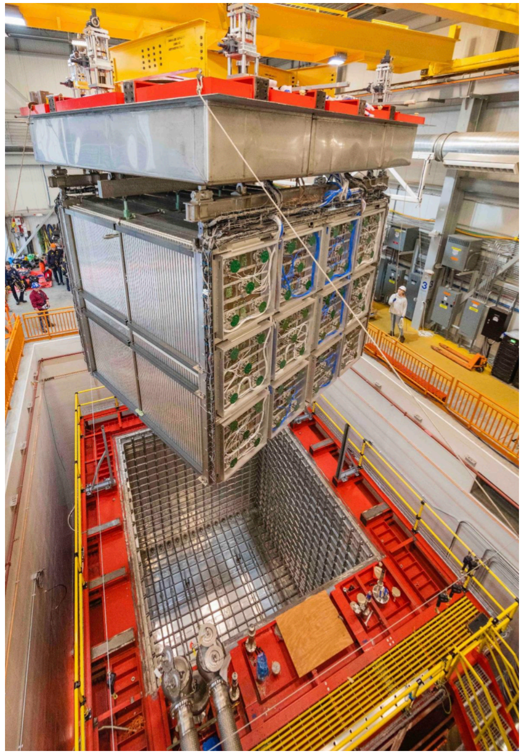

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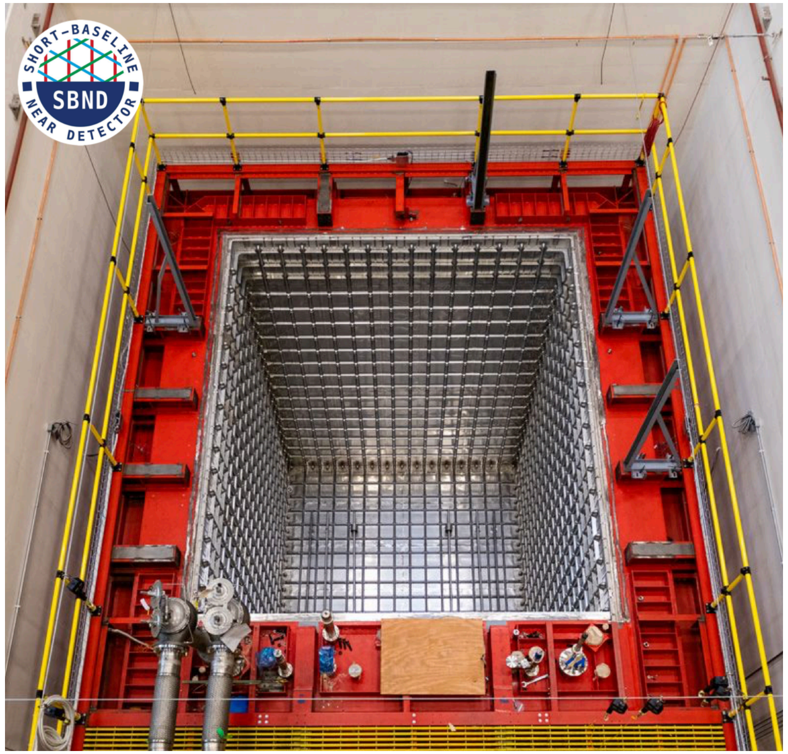
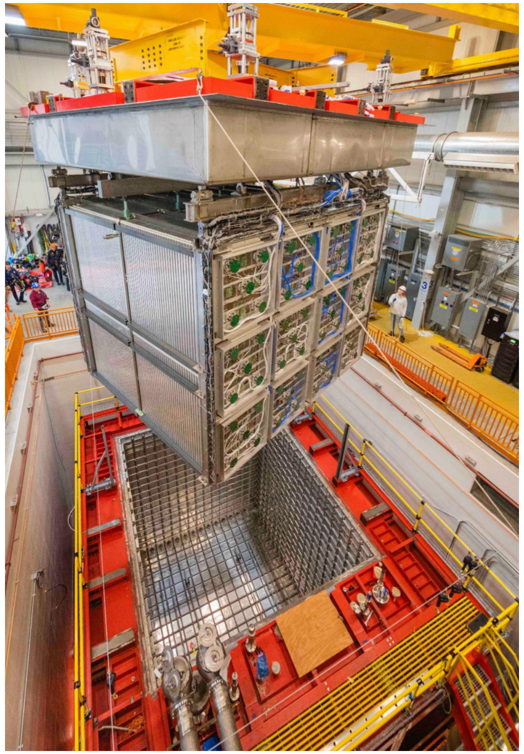
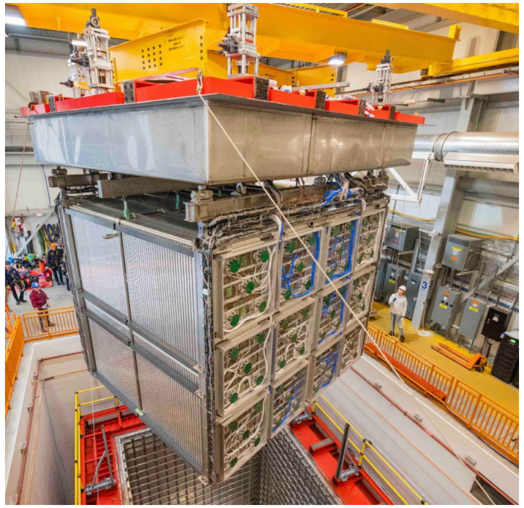
- A very successful collaboration between CERN and Fermilab engineers and physicists





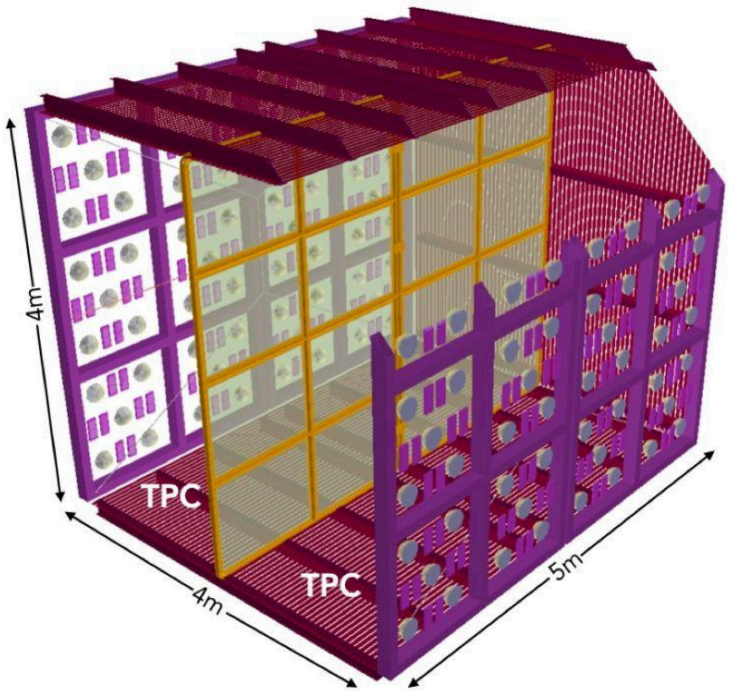
SBND: (1) Subsystems: (b) Time projection chamber (TPC)

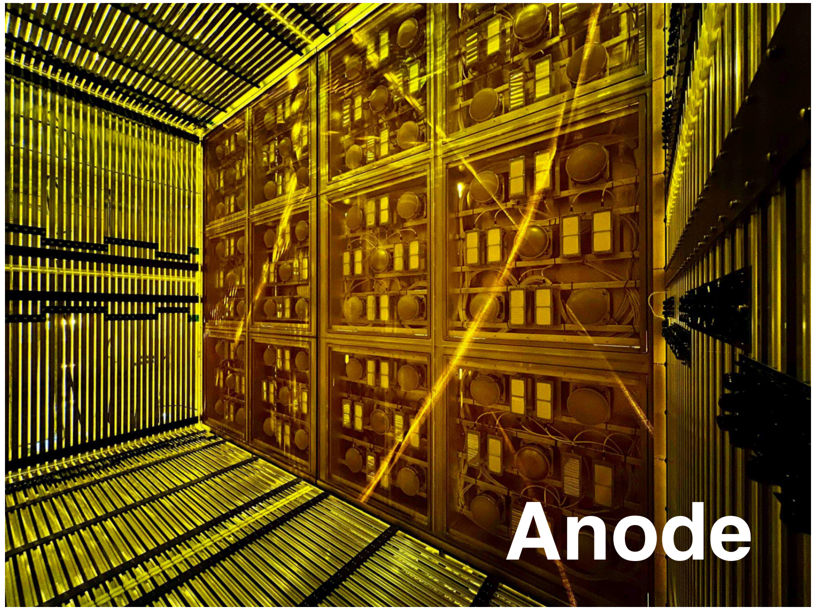


SBND: (1) Subsystems: (b) Time projection chamber (TPC)

Two electron drifting volumes share a central HV cathode plane

- A field cage for uniform 500 V/cm E-field
- Three readout wire planes for each TPC: one collection (vertical) and two induction ($\pm 60°$) with 3 mm pitch
- TPC cold electronics
  - Shaping, amplification and digitization in LAr (~ 87 K) for 11,264 wires





SBND: (1) Subsystems: (c) Photon detection system (PDS)

120 PMTs (Hamamatsu R5912-mod 8”) and 192 X-ARAPUCA devices

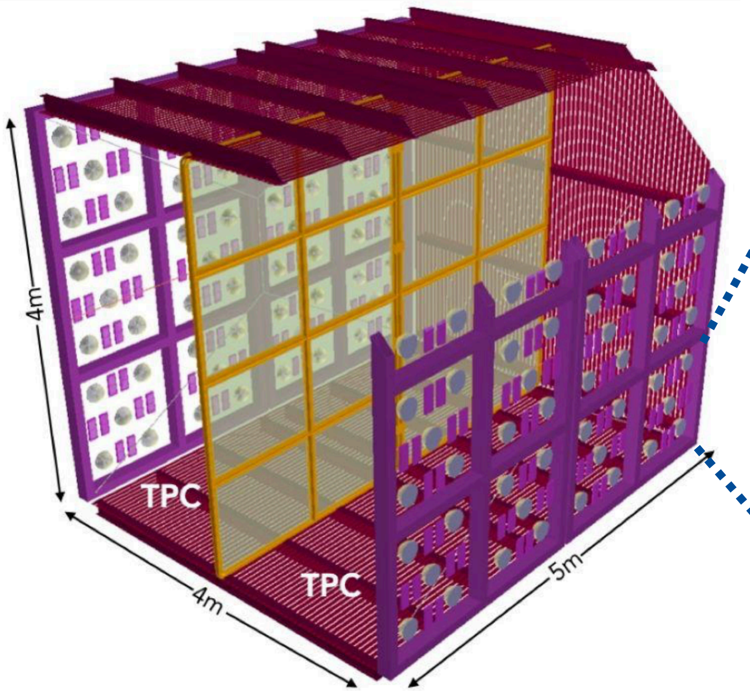
- Mixture of coated and uncoated devices

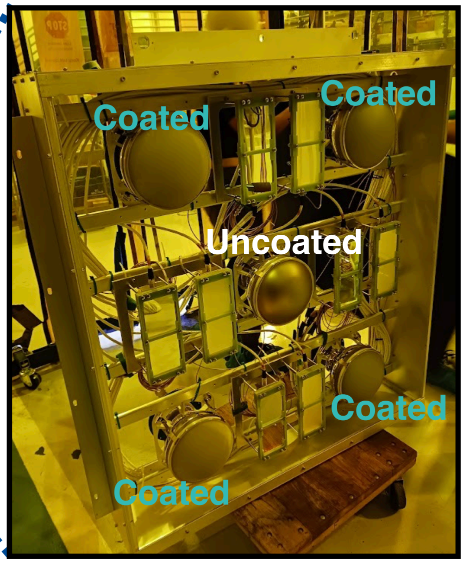
*Coated: for wavelength shifting of scintillating photons ($\lambda \sim 127$ nm) to photocathode sensible regions ($\lambda \sim 440$ nm)

Reflective foil panels coated with wavelength shifter embedded into the cathode plane

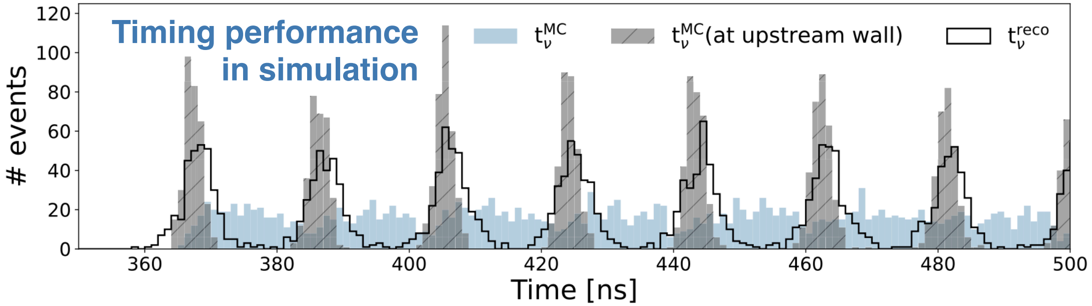
- Coated ones could collect direct VUV ($\lambda \sim 127$ nm), uncoated ones collect only wavelength shifted photons

Timing resolution is ~ O(1ns): essential for the trigger system





"Scintillation light in SBND: simulation, reconstruction, and expected performance of the photon detection system" *Eur.Phys.J.C* 84 (2024) 10, 1046



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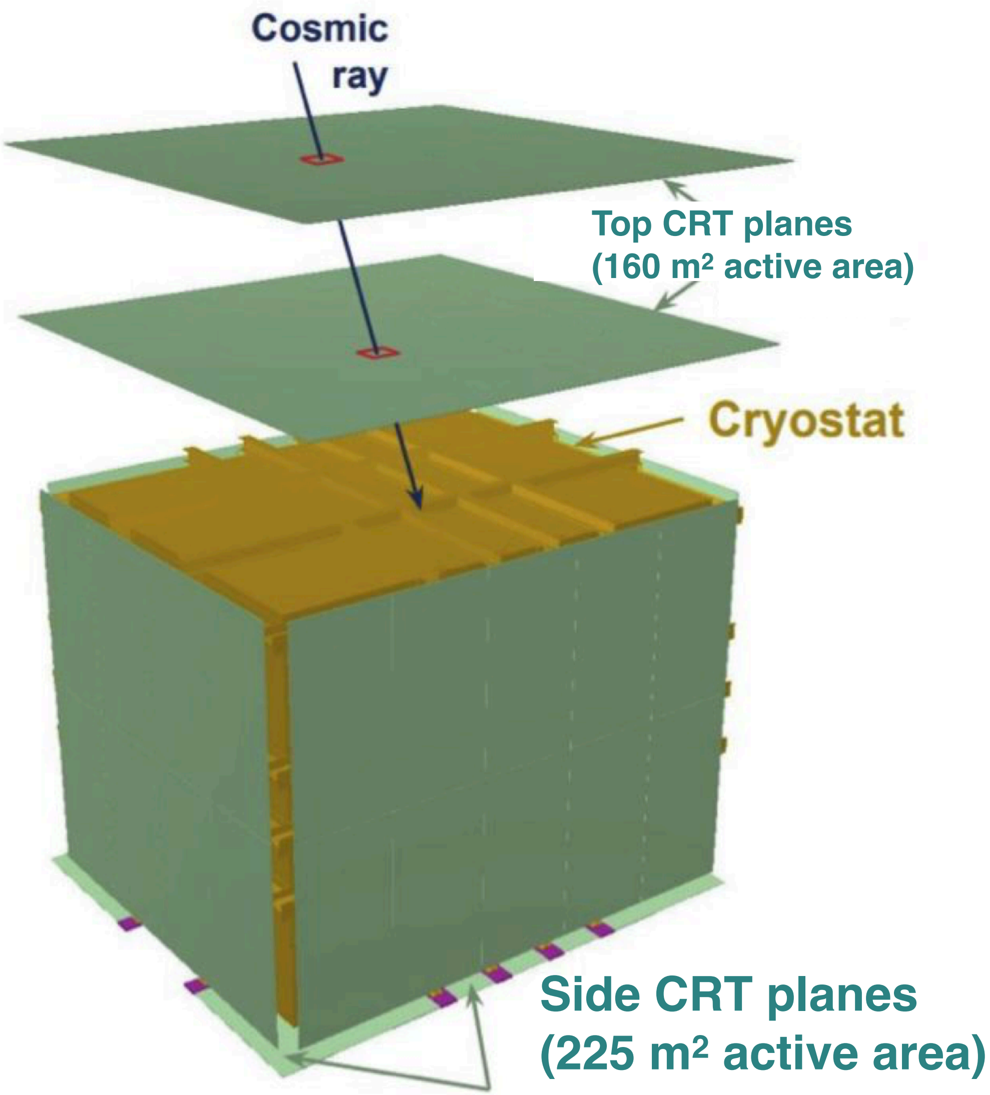
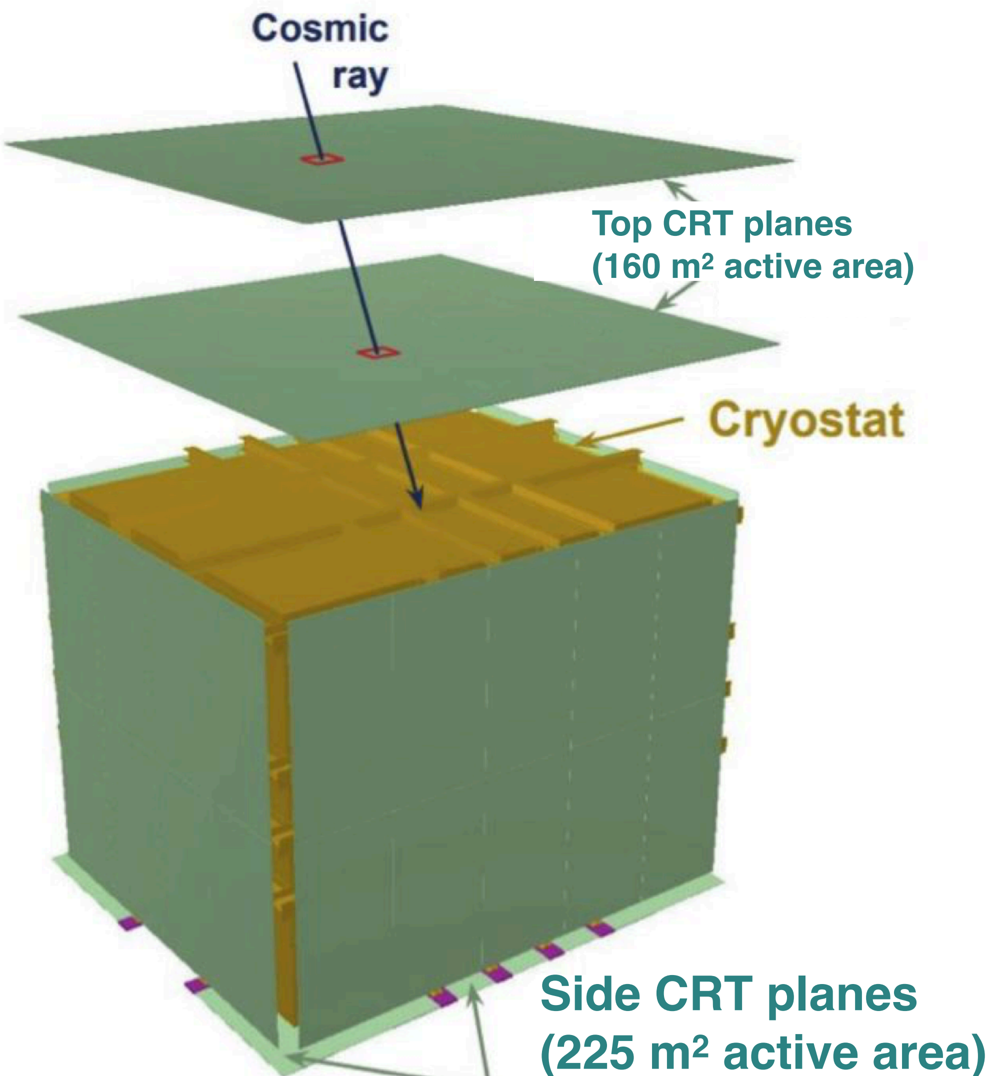


Cosmic ray tagger (CRT)

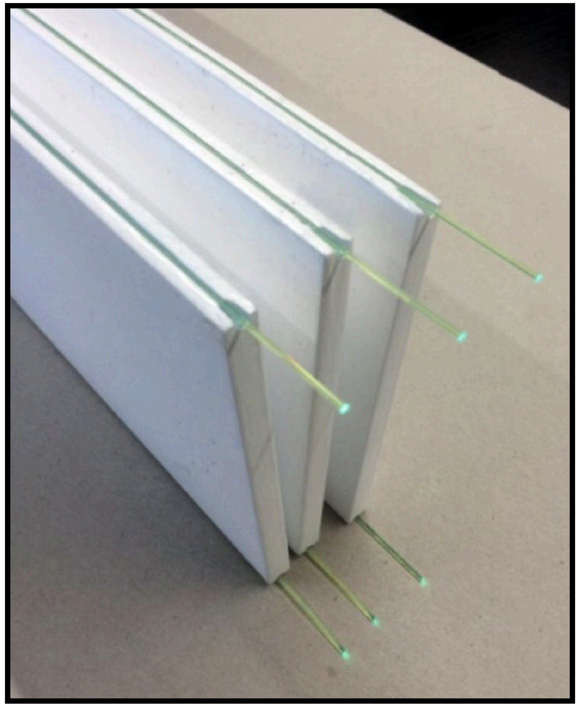
- Surrounds the SBND cryostat on all 6 sides

SBND: (1) Subsystems



Cosmic ray tagger (CRT)

- Surrounds the SBND cryostat on all 6 sides
- Built from 11.2 cm wide scintillator strips
  - Wavelength shift (WLS) fibers
  - Silicon photomultipliers (SiPMs) for light collection



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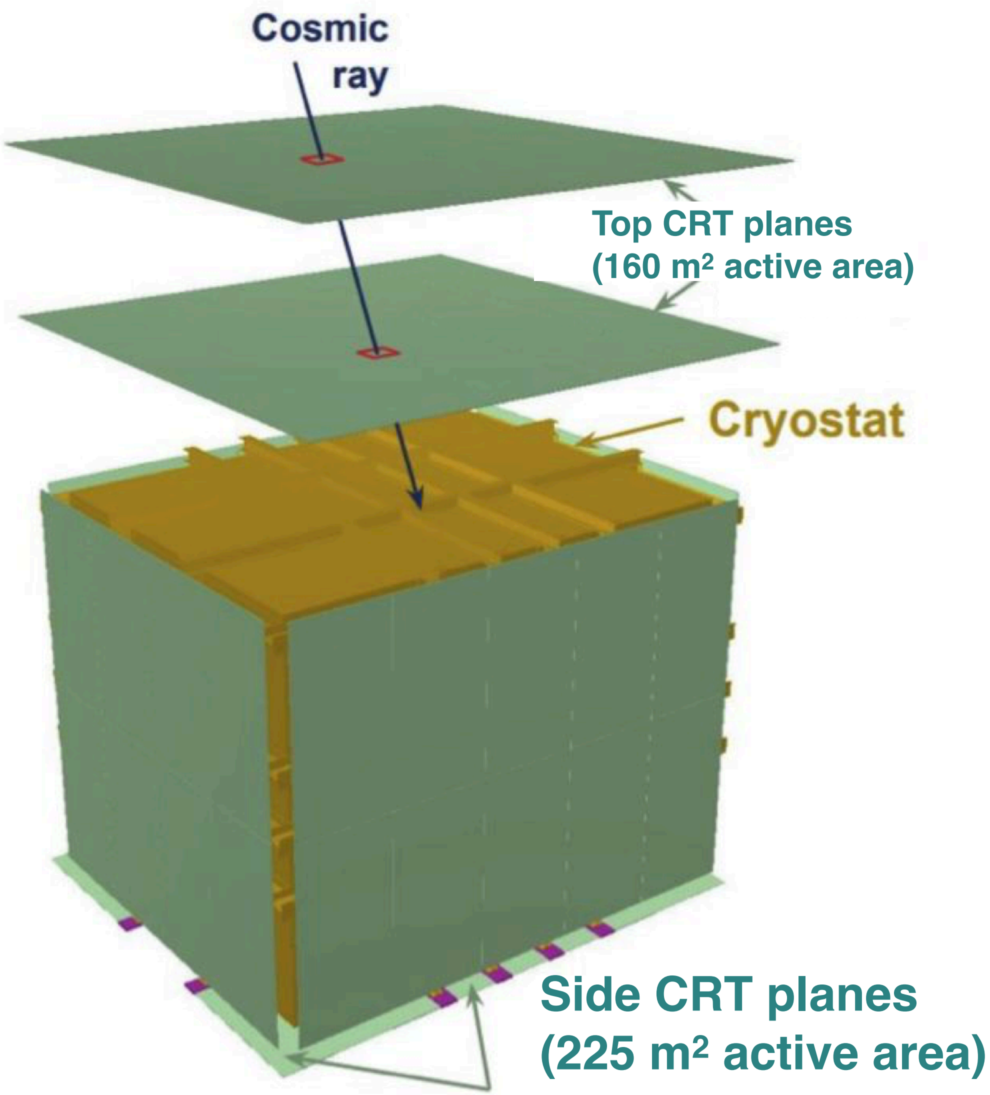

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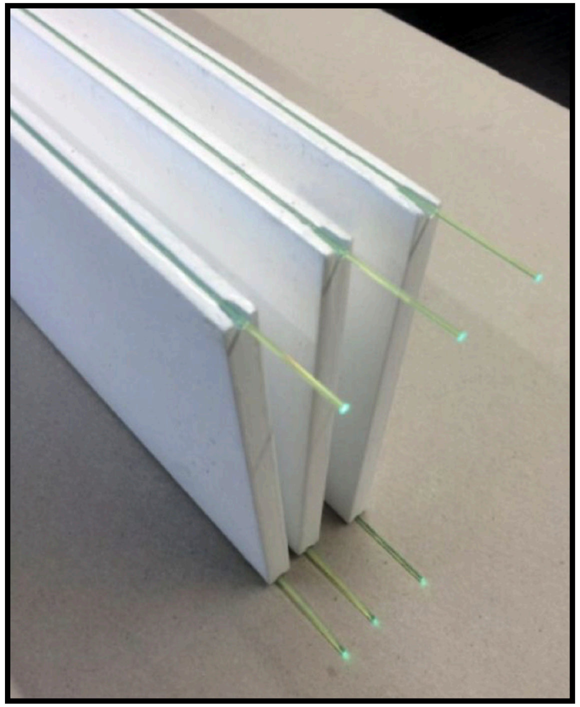
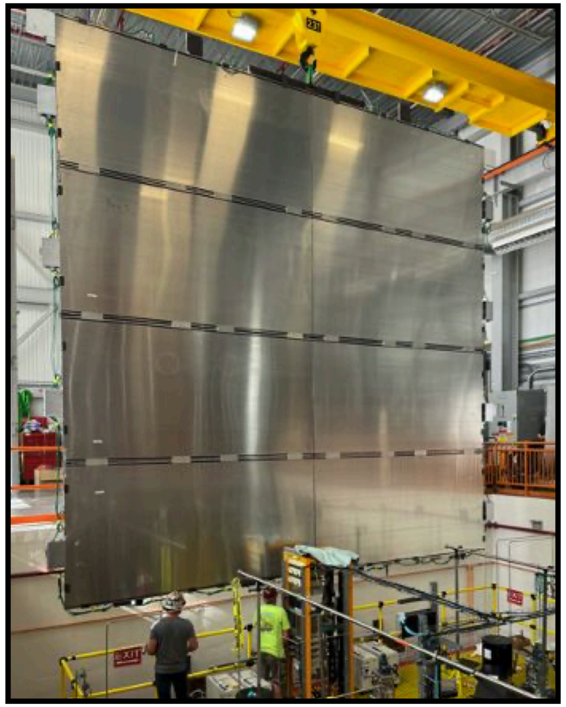




SBND: (2) Toward Operation

December 2022

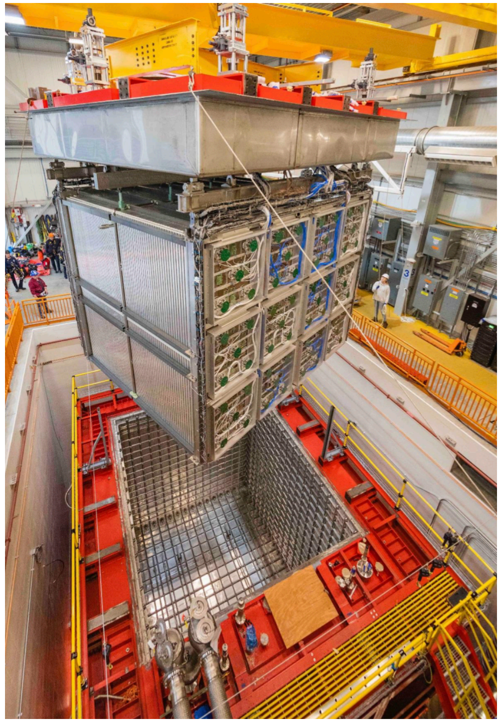
- Detector was fully assembled and moved to the detector hall (SBN-ND)

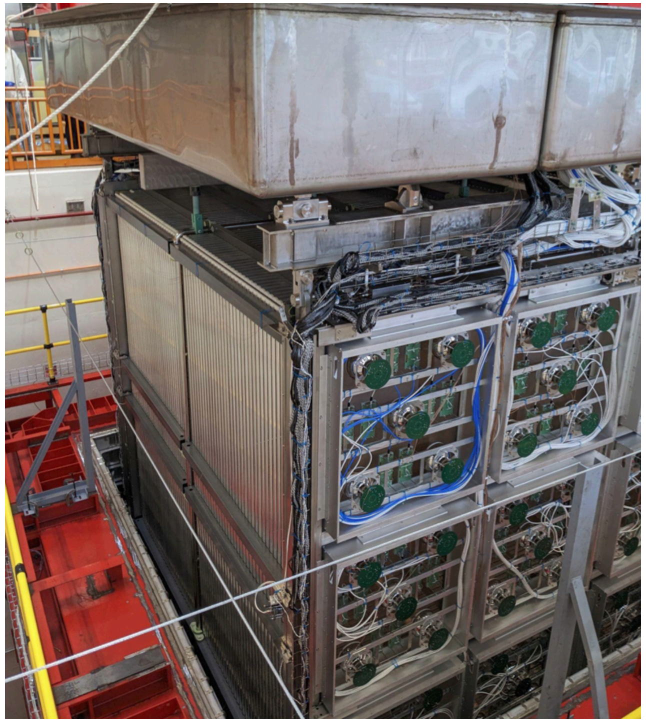
Dec. 2022
Fully assembled
Moved to the detector hall

SBND: (2) Toward Operation

April 2023

- Moved the detector into the cryostat





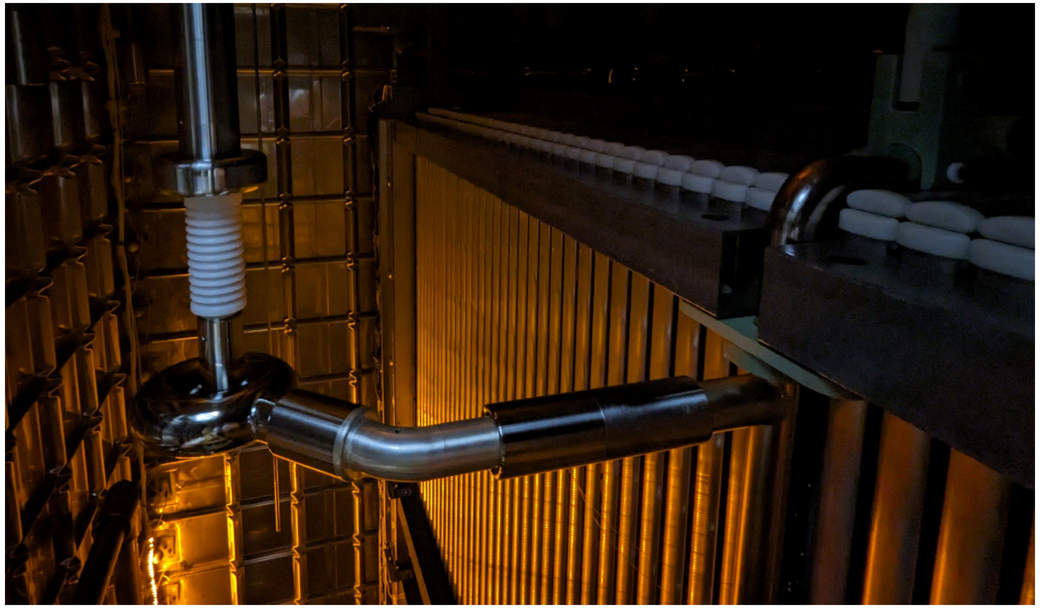
Dec. 2022
Fully assembled
Moved to the detector hall

April. 2023
Detector
inside cryostat

SBND: (2) Toward Operation

July 2023

- Cathode HV feedthrough installed



Dec. 2022
Fully assembled
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April. 2023
Detector
inside cryostat

July. 2023
Cathode HV
Feedthrough

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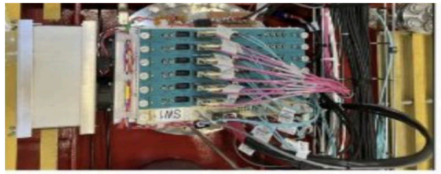
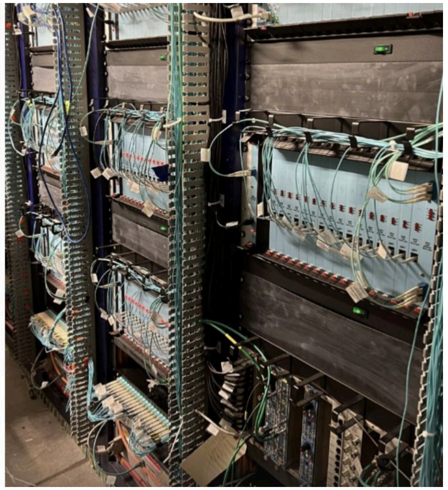
SBND: (2) Toward Operation

"Warm" commissioning

- Install cables
- TPC readout: front-end mother board to disk
- Install purity monitors
- Verify detector control systems .....





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Moved to the detector hall

April. 2023
Detector
inside cryostat

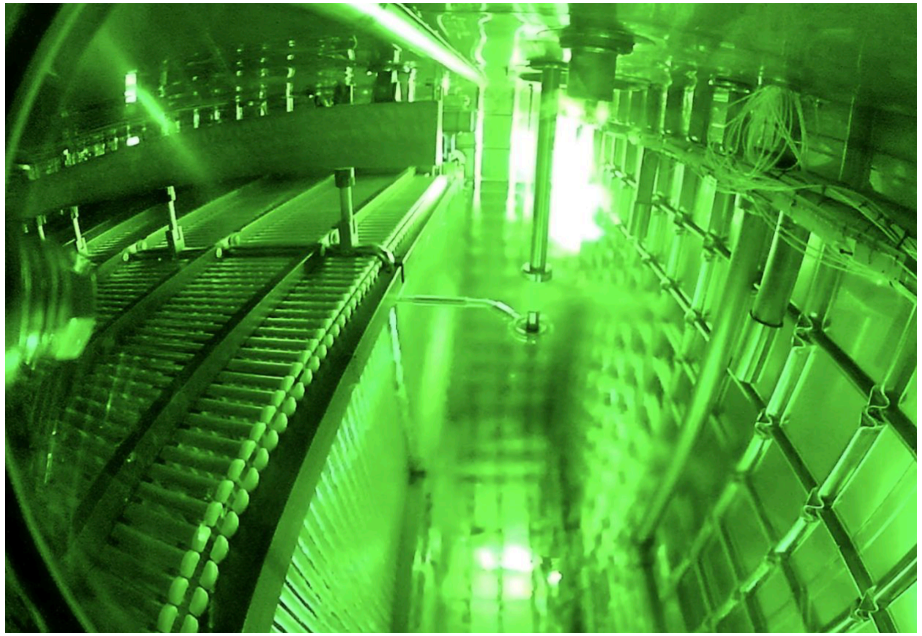
July. 2023
Cathode HV
Feedthrough

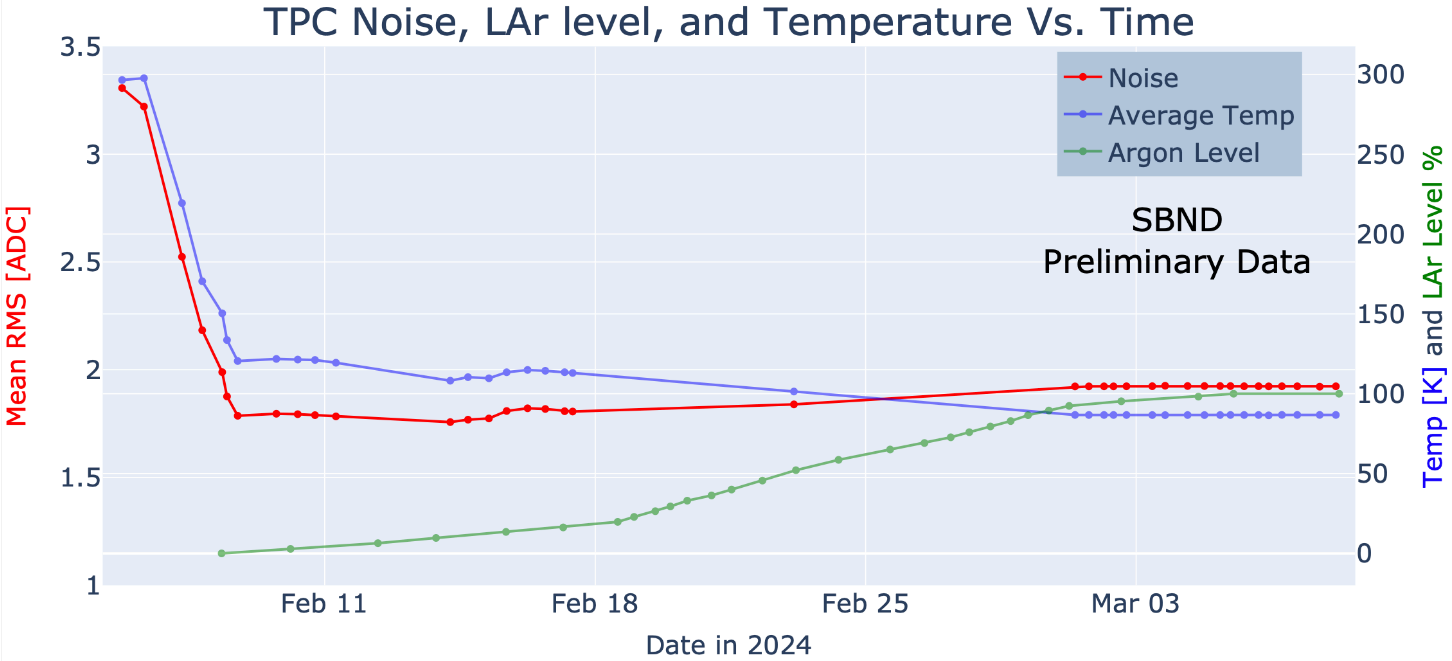
"Warm"
Commissioning

SBND: (2) Toward Operation

March 2024

- Filled with liquid argon





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Moved to the detector hall

April. 2023
Detector
inside cryostat

July. 2023
Cathode HV
Feedthrough

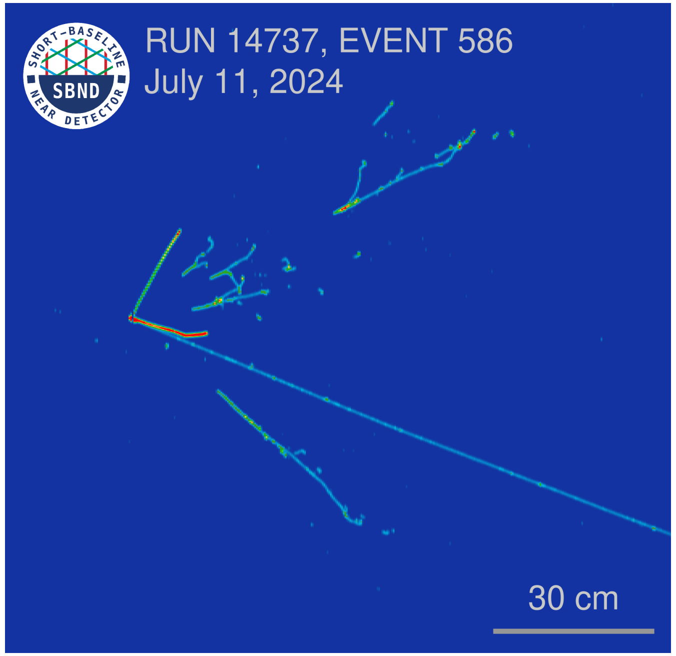
"Warm"
Commissioning

Mar. 2024
Filling LAr

SBND: (2) Toward Operation

July 2024

- Cathode voltage reached to the design target 100 kV



Dec. 2022 Fully assembled Moved to the detector hall

April 2023 Detector inside cryostat

July 2023 Cathode HV Feedthrough

"Warm" Commissioning

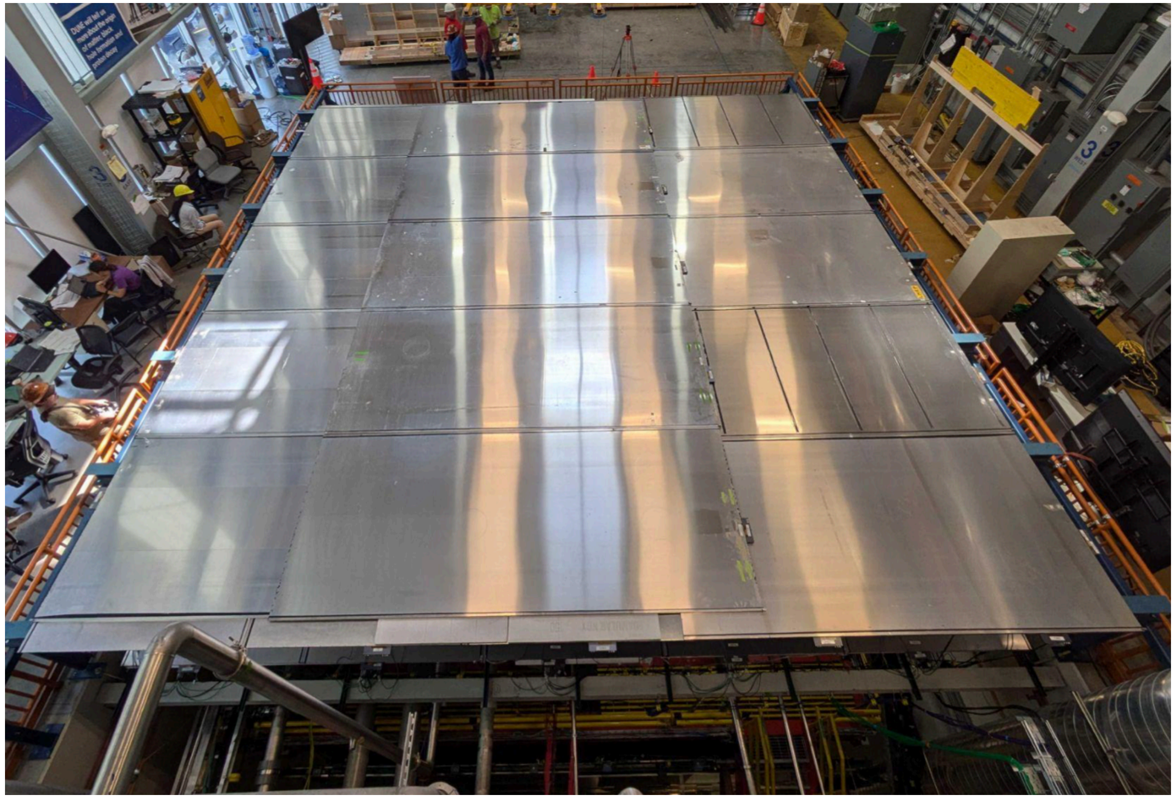
Mar. 2024 Filling LAr

July 2024 Cathode HV @ 100 kV

SBND: (2) Toward Operation

September 2024

- Installation of top CRT layers finished
- The last pice of the SBND!



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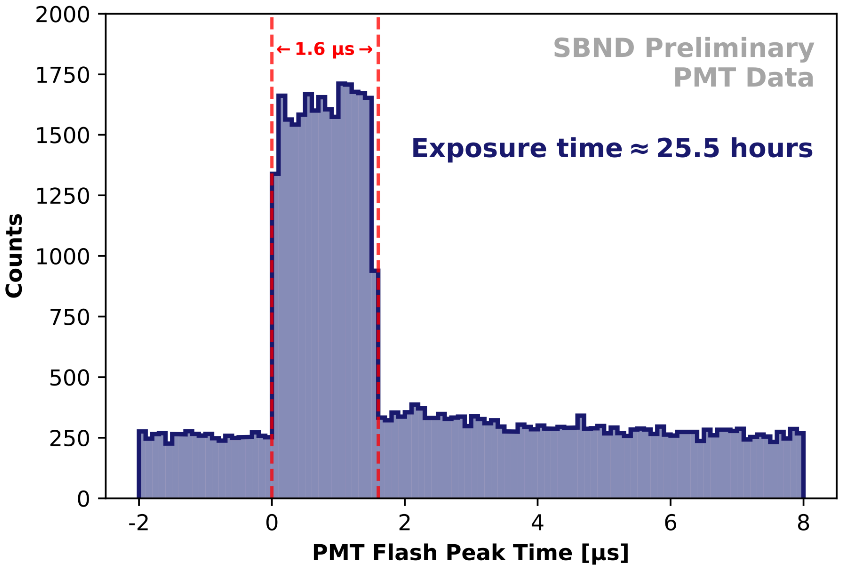
Cathode HV
@ 100 kV

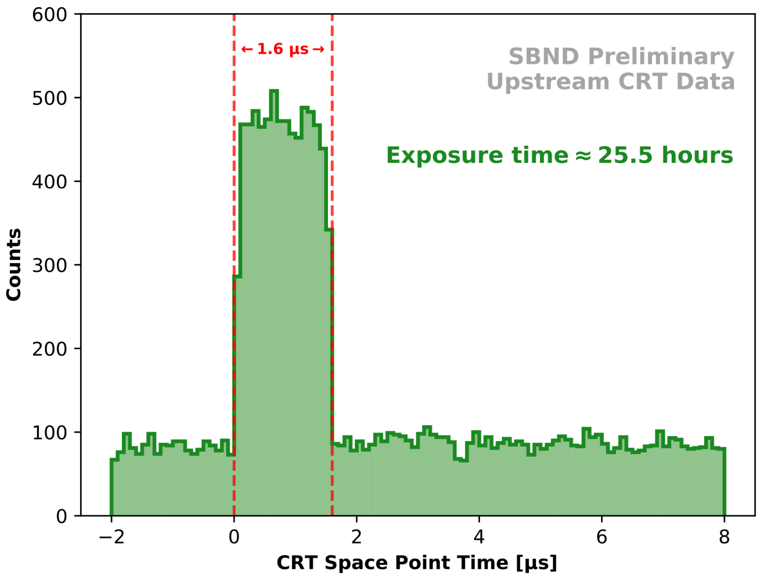
Sep. 2024
Top CRT layers
installed

SBND: (2) Toward Operation

February 2025

- Trigger menu for the Run1 is fixed
  - Includes trigger for BNB gate + light activity inside the TPC
  - BNB spill length (~ 1.6 μs) appears in PMT and CRT data
- Physics data taking is ongoing!!!





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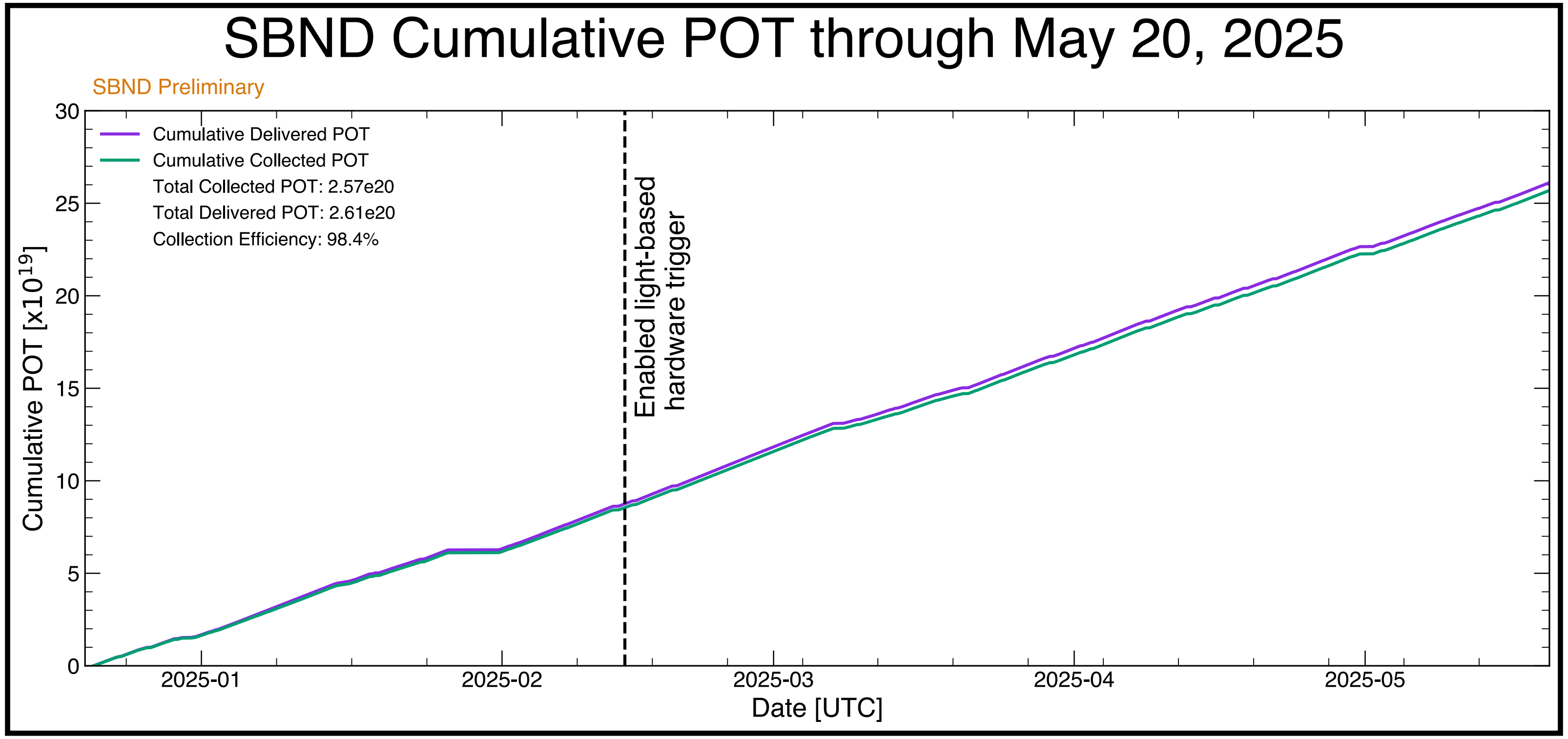
SBND: (3) DAQ Performance

Collected data and DAQ efficiency

- From 2024/12/20 to 2025/02/13, SBND had recorded zero bias data using BNB gates
- Since Feb. 13th 2025, SBND is recording data with light-based trigger and BNB gates
- Data recording efficiency is very high: 98.4%
- Collected 2.57×10^{20} POT as of 2025/05/20 → already more than 1M neutrino events!!!



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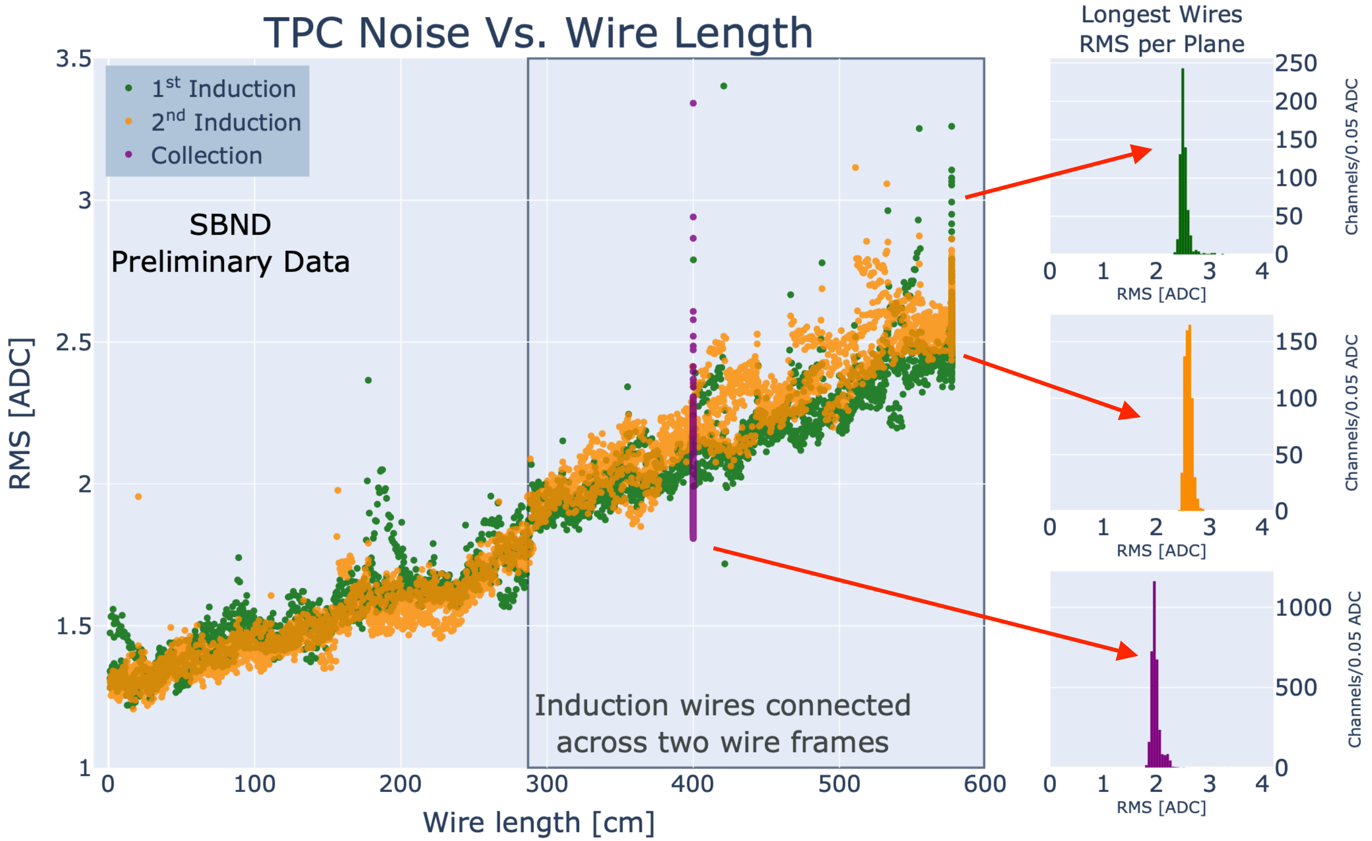
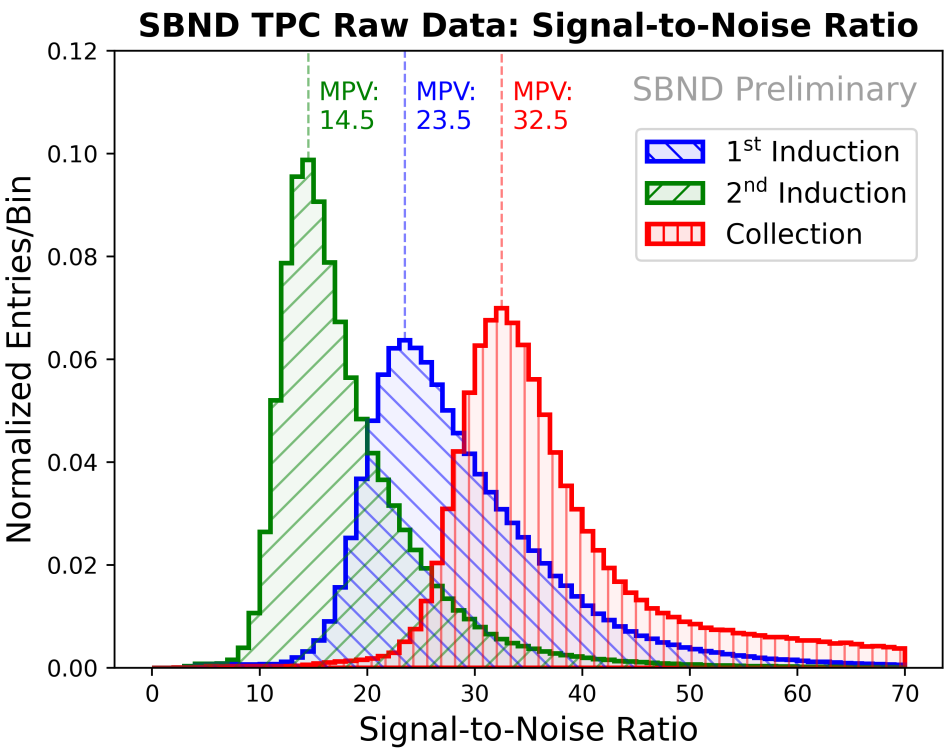
SBND: (4) TPC Performance

Noise

- For the longest (most noisy) wires, noise RMS is less than 3 ADCs in general
- Excellent signal to noise ratio in raw data: 32.5 for the collection plane





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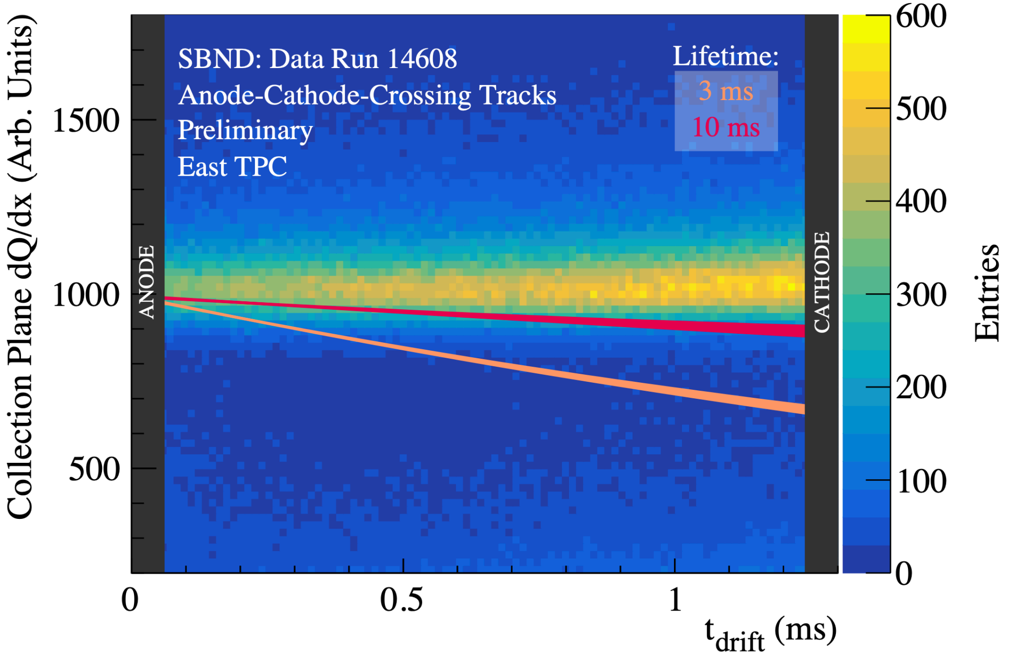
- Impurities inside liquid argon absorb drifting electrons: design electron lifetime goal is 3 ms
- Observed electron lifetime is longer than 10 ms



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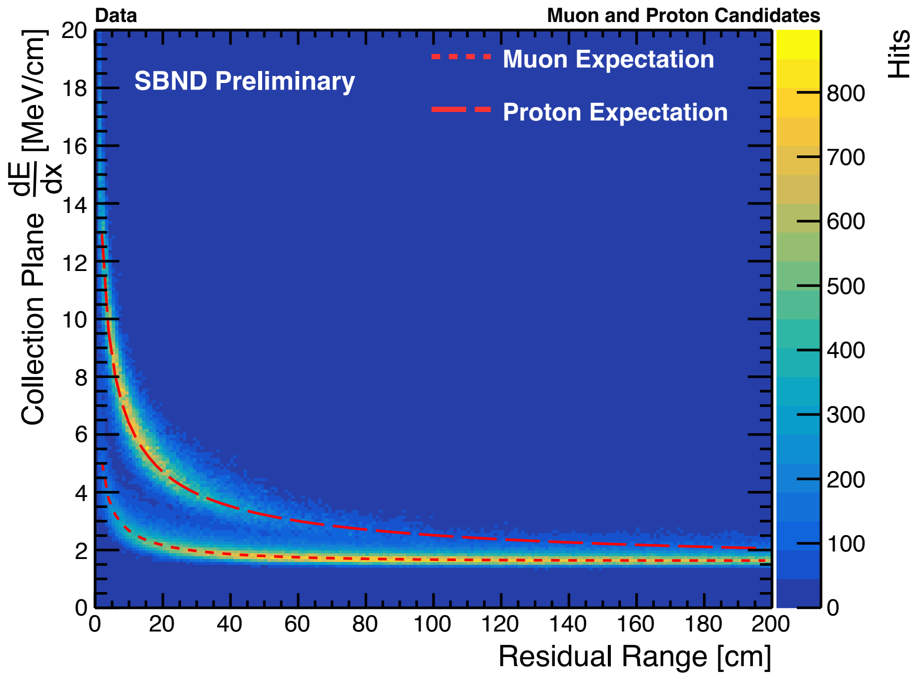
Calorimetry

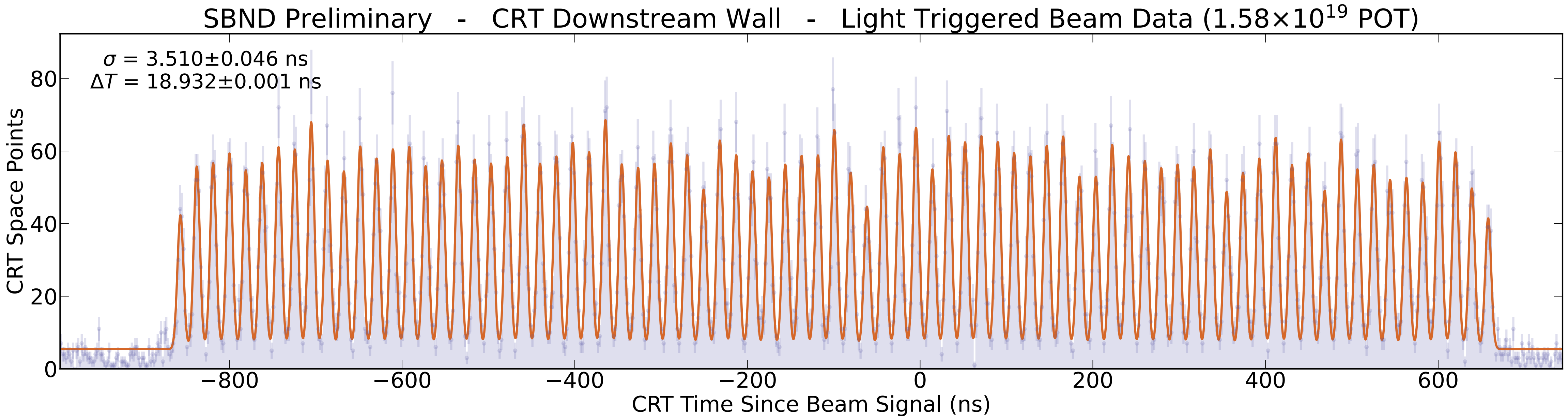
- Measured energy deposition per unit length (dE/dx) for muon and proton candidate tracks show good agreement with the most probable value (MPV) curve expected by the Landau-Vavilov theory



SBND: (4) Timing Performance

Reproduction of the BNB spill structure

- For a spill (~1.6 μs), there are 81 proton bunches
  - Bunch spacing (ΔT_{bunch}): 18.936 ns, bunch width (σ_{bunch}): 1.308 ns
- Using BNB gate plus light trigger and CRT timing information
  - Reproduced ΔT_{bunch} very well with 18.931 ns and all 81 bunches
  - Measured bunch width of 3.510 ns indicates that CRT has about 3.3 ns timing resolution



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Summary

The SBN and SBND offer world class physics program

- Search for sterile neutrino with ~ eV scale mass
- Precise ν-Ar interaction studies
- BSM searches: dark matter, heavy neutral leptons, ...

SBND finished its commissioning at Summer 2024

- DAQ is stable: physics run since December 2024
- TPC: electron lifetime longer than the goal and good calorimetry performance with low noise level
- TPC, PDS and CRT are well integrated as a single detector: SBND!!!

First physics run of SBND is ongoing

- Since the last December, already more than 1 M neutrino events are recorded as of May 20th
- Physics results are coming soon. Stay tuned!

Thank you!!

The SBND Collaboration

updated May 2025

Including both scientific and technical personnel

*Spokespeople

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Queen Mary University, UK: Y. Dabburi, N. McConkey
Rutgers University: K. Lin, A. Mastbaum
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Tufts University: O. Alterkait, Z. Imani, T. Wongjirad
Virginia Tech: C. Mariani, G. Moreno-Granados, P. Roy
University of Warwick: A. Chappell, X. Lu, J. Marshall, A. Wilkinson

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Fermilab

FermiFORWARD

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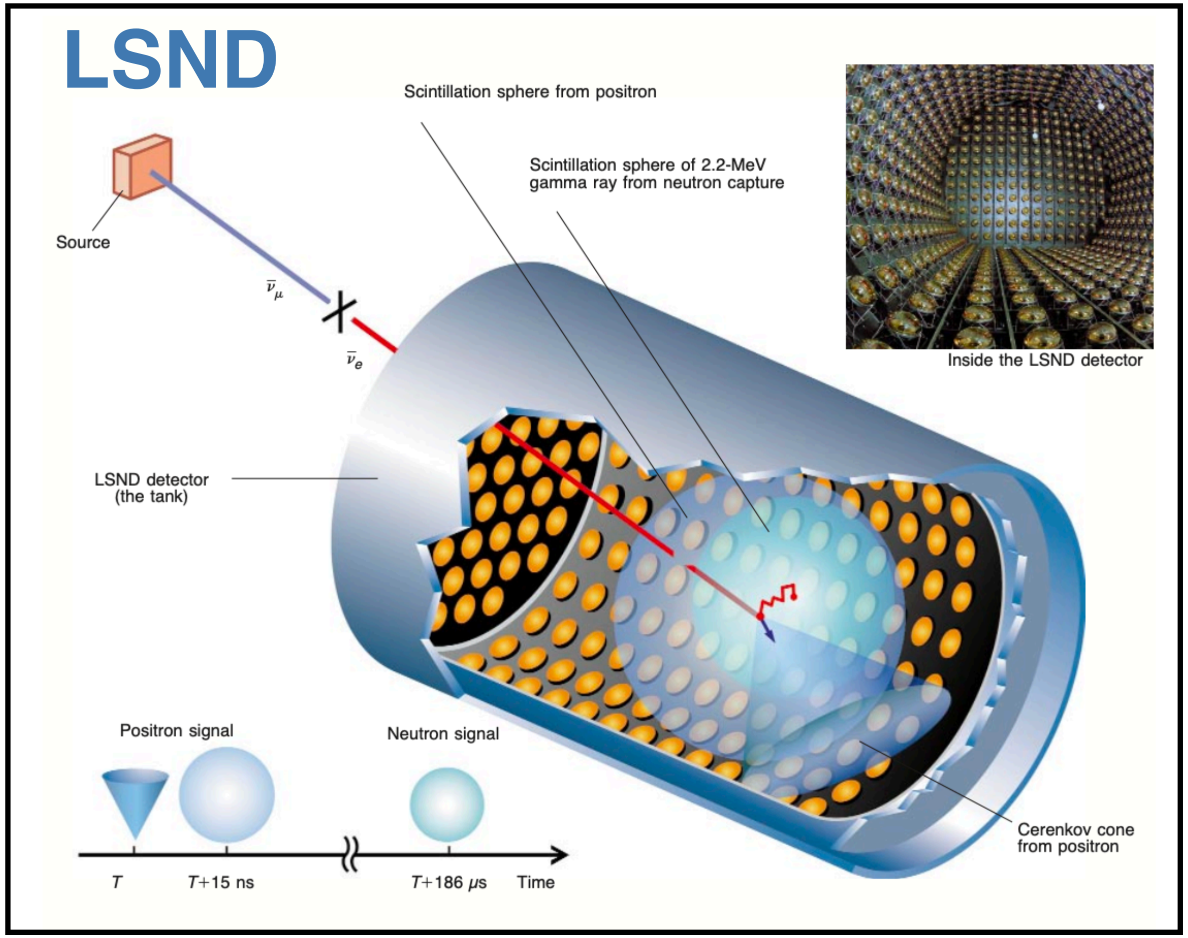
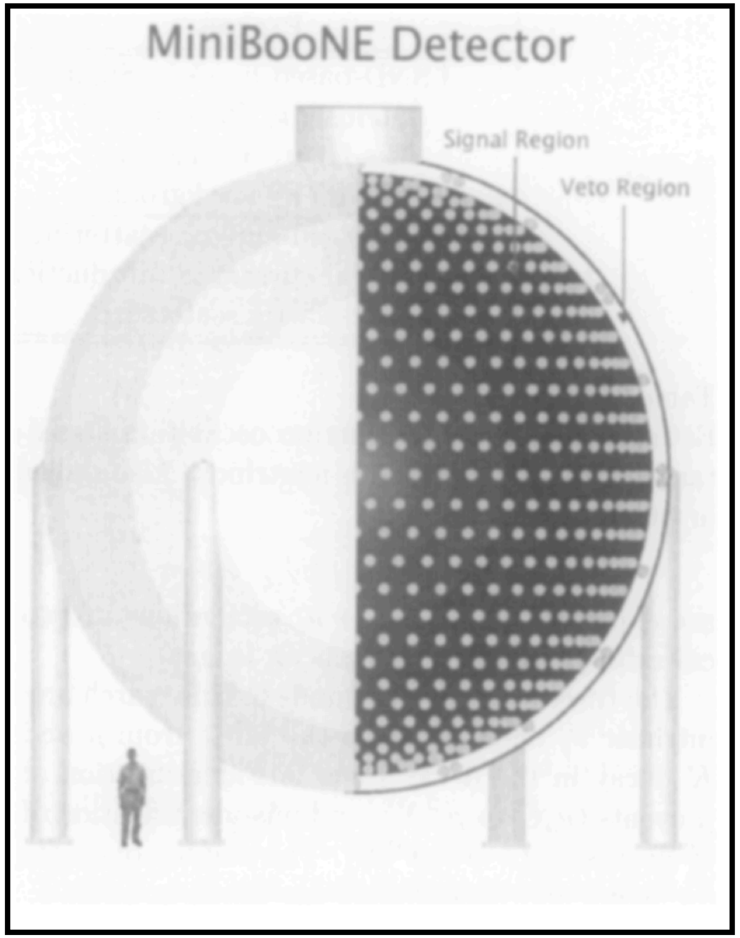
LSND and MiniBooNE

- Both detectors are filled with mineral oil as scintillating material, and ~ 1k PMTs for light detection





3 + 1 SBN Oscillation

There could be

- ν_e (dis)appearance, ν_μ disappearance

$$U_{3+1} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} \\ U_{s1} & U_{s2} & U_{s3} & U_{s4} \end{bmatrix}$$

$$\sin^2(2\theta_{\mu\mu}) = 4(1 - |U_{\mu 4}|^2)|U_{\mu 4}|^2,$$
$$\sin^2(2\theta_{ee}) = 4(1 - |U_{e4}|^2)|U_{e4}|^2,$$
$$\sin^2(2\theta_{e\mu}) = 4|U_{e4}|^2|U_{\mu 4}|^2,$$

$$P(\nu_\mu \to \nu_e) = \sin^2 2\theta_{\mu e}\sin^2(\Delta m^2_{41} L/E),$$
$$P(\nu_e \to \nu_e) = 1 - \sin^2 2\theta_{ee}\sin^2(\Delta m^2_{41} L/E)$$
$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{\mu\mu}\sin^2(\Delta m^2_{41} L/E)$$

Booster Beam: Bunch Structure

Spills with 5 Hz rate

- A spill is about 1.6 μs long
- A spill consists of 81 bunches (protons packet)
  - A bunch consists of ~ 5×10^{10} protons
  - With 18.936 $\pm$ 0.001 ns spacing: 81 x 18.936 = 1533.816 ns ~ 1.53 μs
  - With 1.308 $\pm$ 0.001 ns width
- Injection energy: 400 MeV
- Extraction energy:8 GeV

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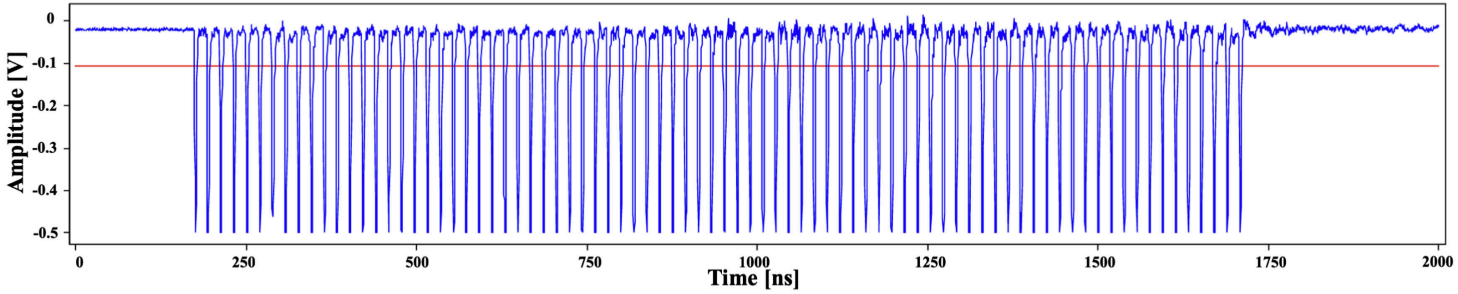

FIG. 2. Trace of a single BNB RWM waveform showing the BNB ns substructure. The red line shows the discriminator threshold used by the oscilloscope. The waveform sample frequency is 2 GHz. The vertical axis is the induced charge on the RWM in volts. Each BNB proton pulse is composed of 81 bunches spaced at $\Delta = 18.936 \pm 0.001$ ns. The average bunch width is $\langle \sigma_{\rm BNB} \rangle = 1.308 \pm 0.001$ ns. The RWM time structure shown in this figure is obtained through the instruments and methods described in [16].

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Booster Neutrino Beam (BNB) Structure

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