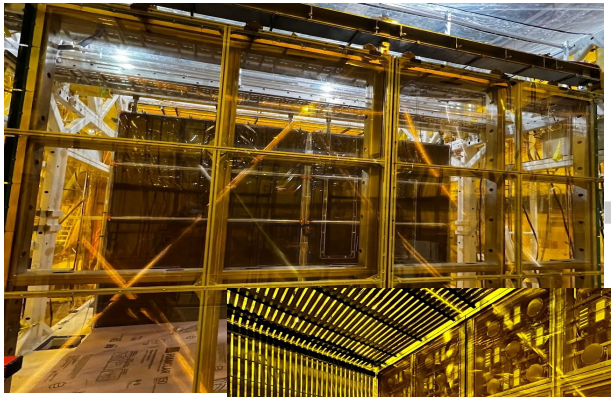
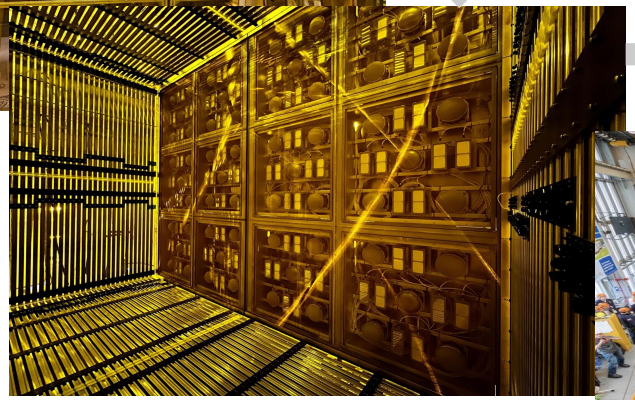
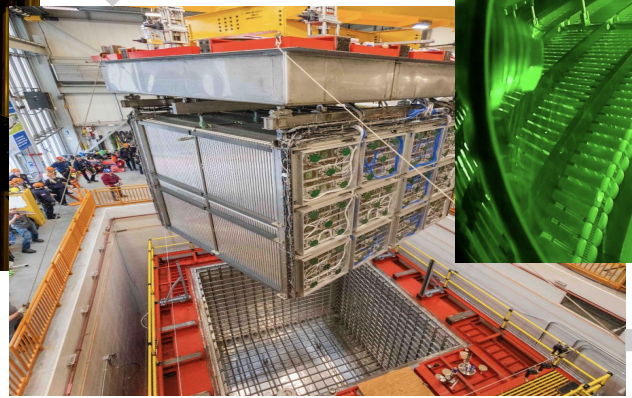
Status of the Short-Baseline Near Detector Experiment

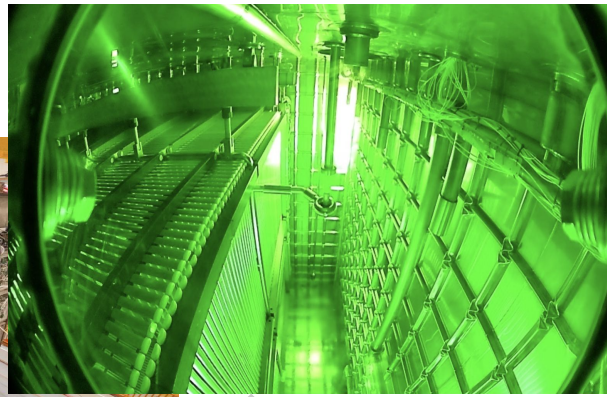
Fermilab 57th Annual Users Meeting - Inspirations from P5, July 10 2024

Daisy Kalra, Columbia University (*on behalf of the SBND Collaboration)*





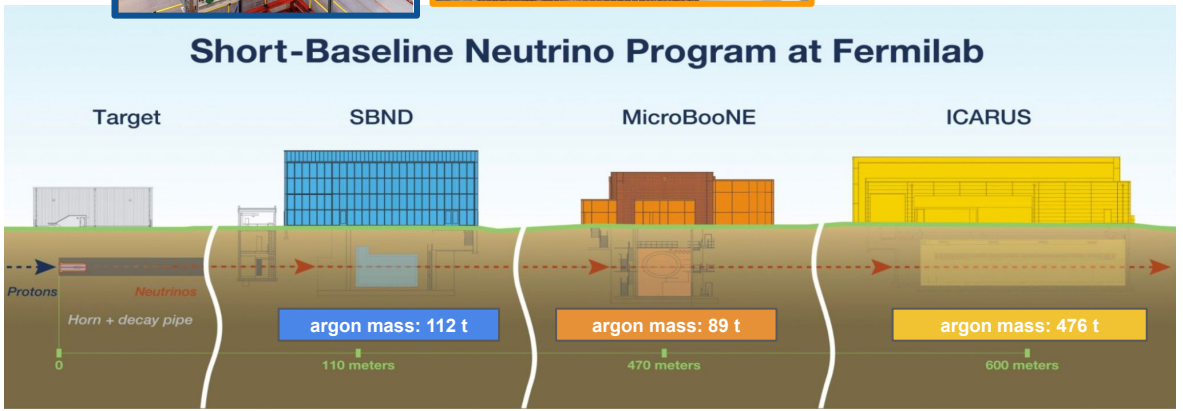




NEVIS LABORATORIES
COLUMBIA UNIVERSITY

The Fermilab Short-Baseline Neutrino (SBN) Program

- The Fermilab SBN program comprises three liquid argon time projection chamber (LArTPC) detectors



Collecting beam data since July 2024

Data collection period- 2015-2021

Collecting data since Oct. 2021

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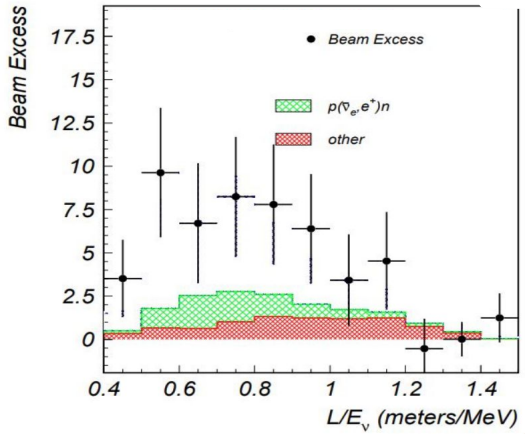
  Motivated from short-baseline neutrino anomalies seen by the **LSND** and **MiniBooNE** experiments

LSND (liquid scintillator detector)
Using antineutrinos from pion decay-at-rest, observed **3.8σ excess in $\bar{\nu}_e$**.

MiniBooNE (mineral oil cherenkov detector)
Using neutrinos and antineutrinos from pion decay-in-flight beam, same L/E as LSND, observed **4.8σ excess in $\bar{\nu}_e$ and ν_e.**

$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$



PRD 64, 112007

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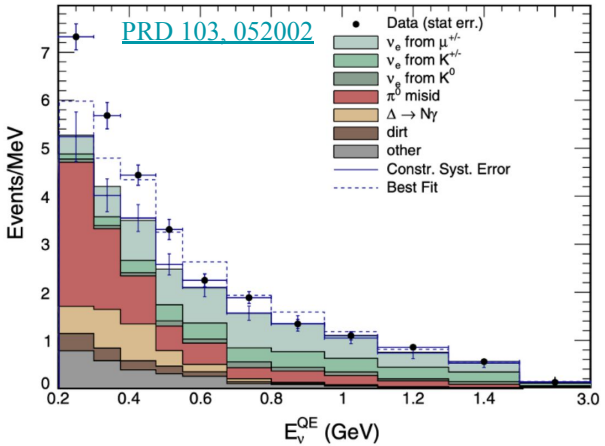

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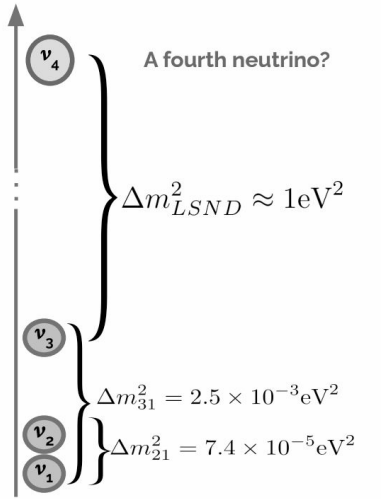
Short-baseline neutrino anomalies



- **These anomalies indicate a higher oscillation frequency than two others independently measured**!
  can not be accommodated within the standard three-neutrino picture.
- Minimal model (3+1) requires an additional heavier neutrino mass eigenstate (m_4) : **sterile neutrino**

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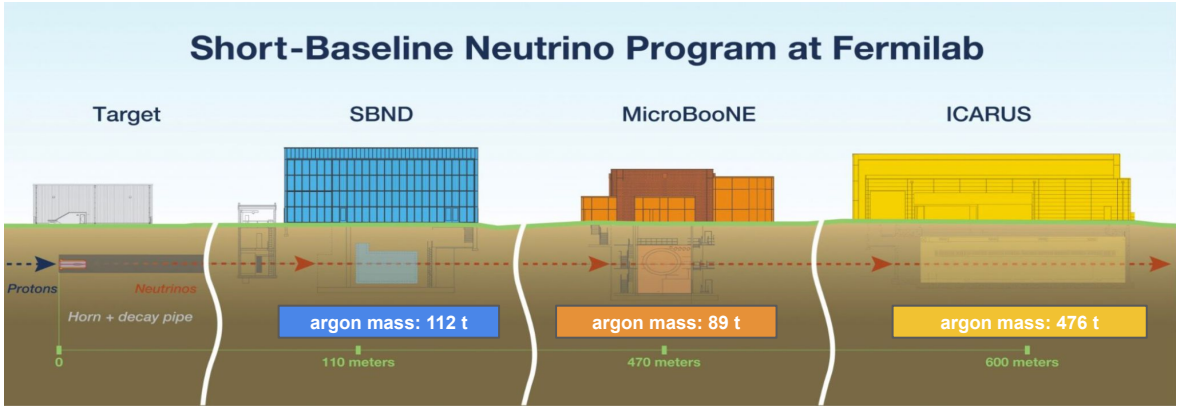
  (2) High-precision neutrino-argon cross section measurements
  (3) Search for beyond-the-Standard-Model (BSM) physics processes.

- The detector trio share the same primary neutrino beam, nuclear target and detector technology to reduce systematic uncertainties to the level of a few %.



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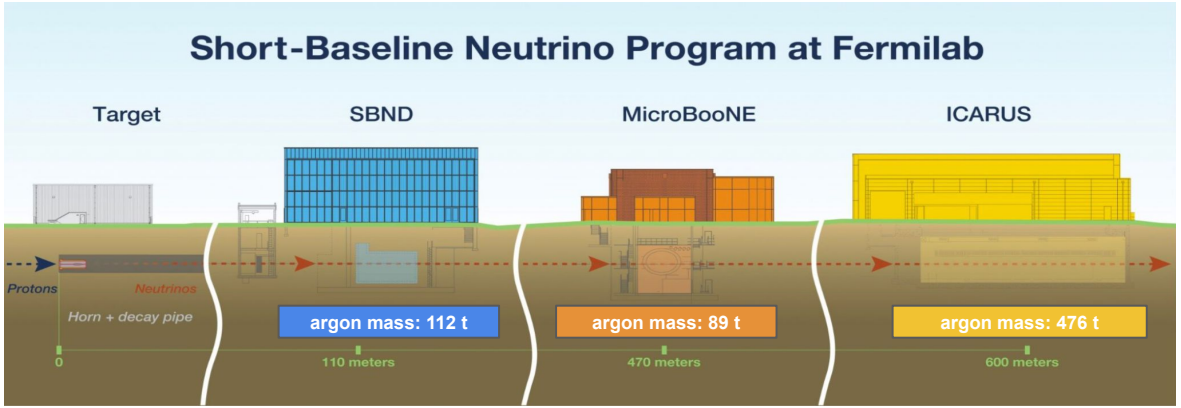
P5 Report, December 2023

The 2023 P5 report "Exploring the Quantum Universe" strongly endorses the science exploitation of the SBN program.



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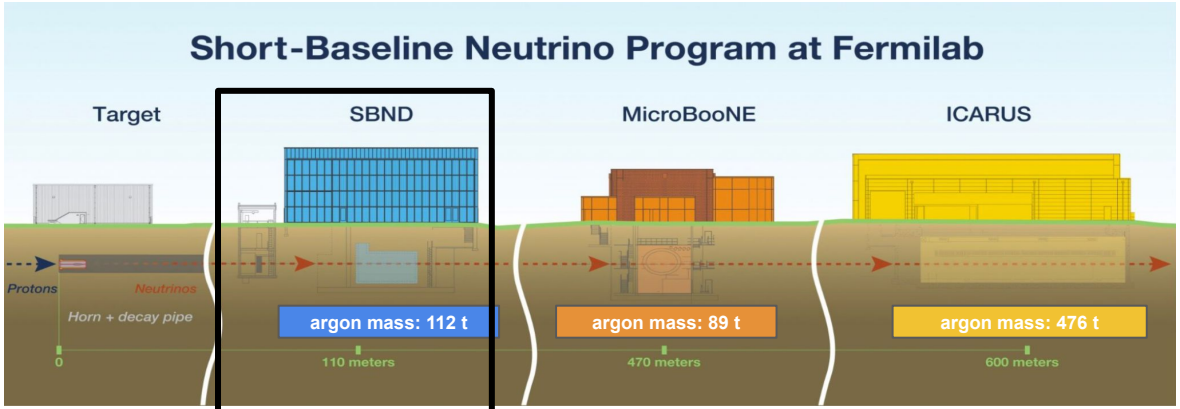

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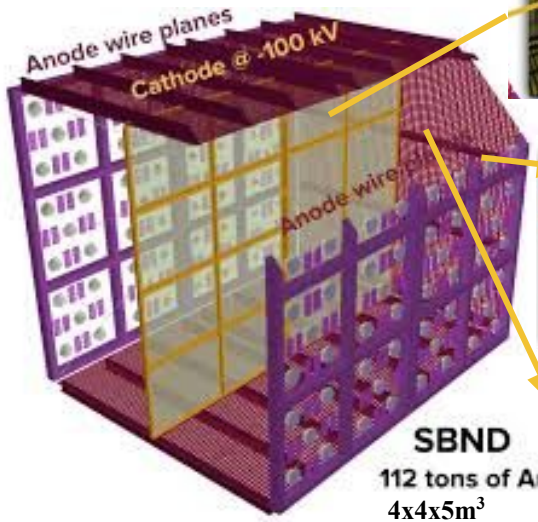
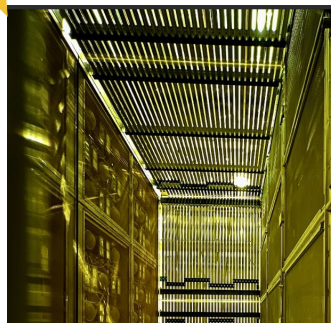


Cathode plane at -100kV in the center, divides the detector into two drift volumes (2m drift region)

Anode plane on either side, each with three wire planes with 3mm wire spacing
Total of 11,260 wires
JINST 15 P06033



Field cage to ensure a uniform electric field of 500V/cm

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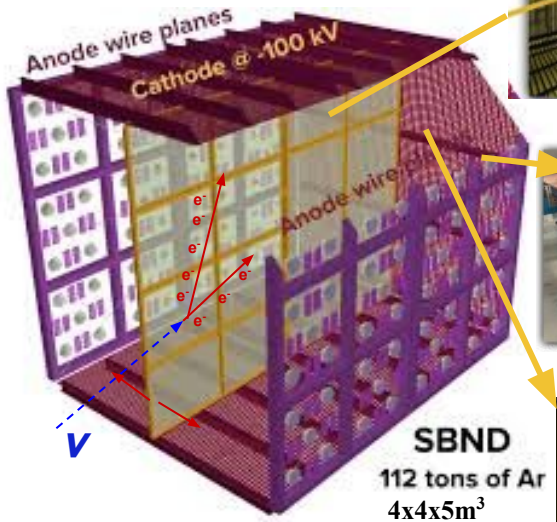

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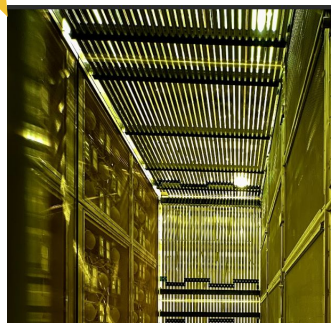

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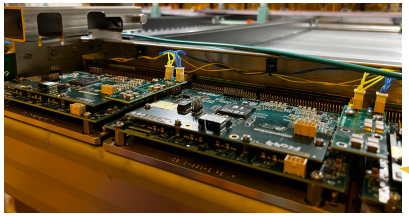
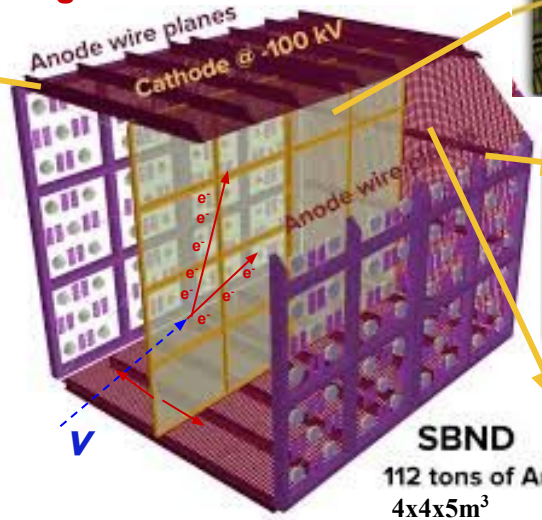


Cold electronics (in LAr)
Amplify and digitize **anode wire ionisation signals**.



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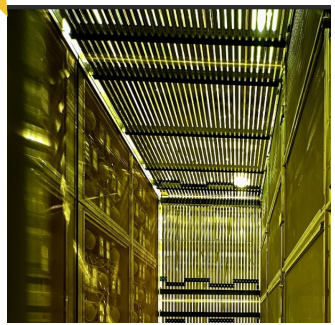

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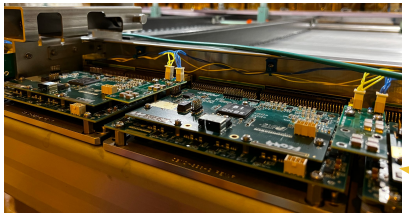

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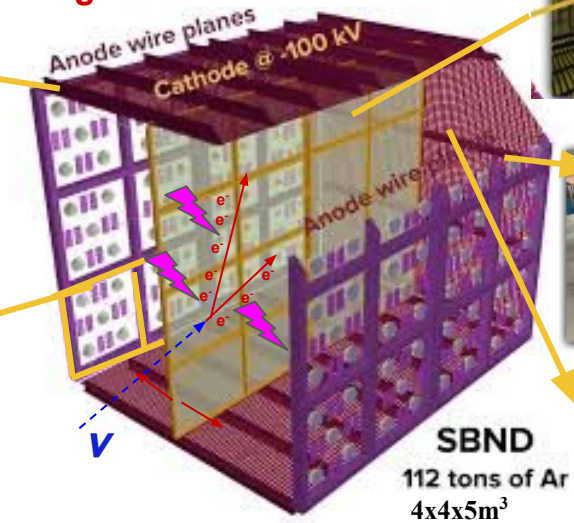

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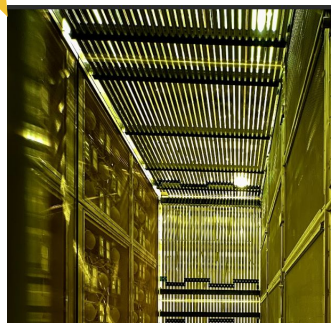
Photon Detection System to record the prompt **scintillation light**

120 PMTs
(80% TPB-coated, 20% uncoated)
192 X-ARAPUCAs

arXiv: 2406.07514(SBND Collaboration)

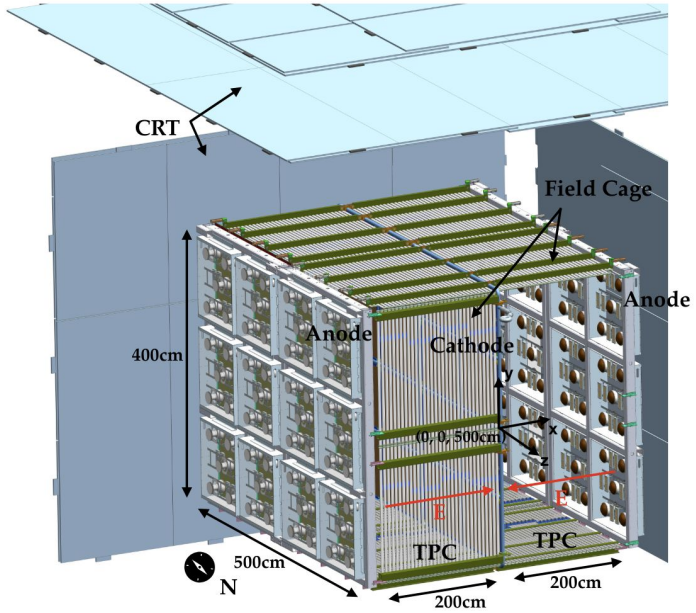


Field cage to ensure a uniform electric field of 500 V/cm

New technology to be demonstrated within SBND:
R&D for the next-generation DUNE experiment.

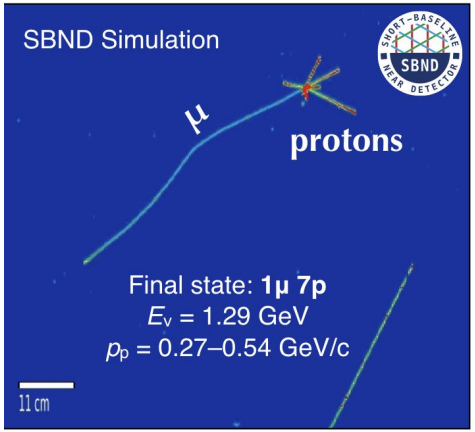
Cosmic Ray Tagger (CRT) for SBND

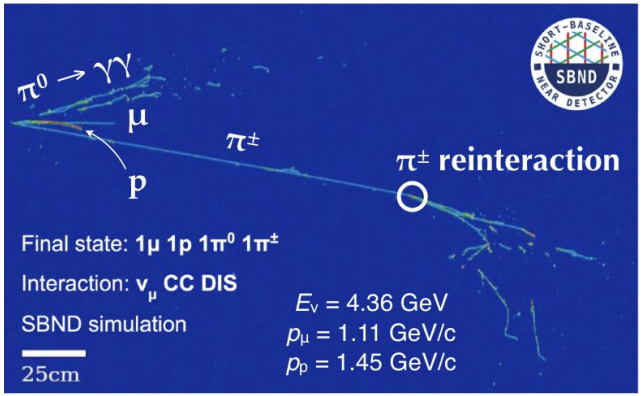
- SBND is not deep underground, but operated on-surface, therefore subject to a lot of random cosmogenic activity (background to many neutrino analyses).
- The SBND cryostat is surrounded by the CRT system (scintillator strips) → 4π coverage to tag cosmic activity.
- The CRT system helps remove cosmic ray tracks more efficiently using trajectory and timing of these particles as they traverse the detector walls.

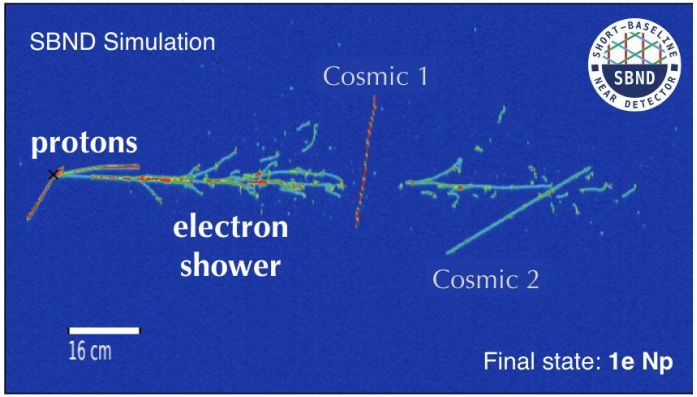


LArTPC Detector Capabilities

- 3D reconstruction with excellent, mm-scale resolution.
- Excellent particle identification.
- Disentangling complex final states.
- Low energy thresholds (demonstrated by previous LArTPC experiments)



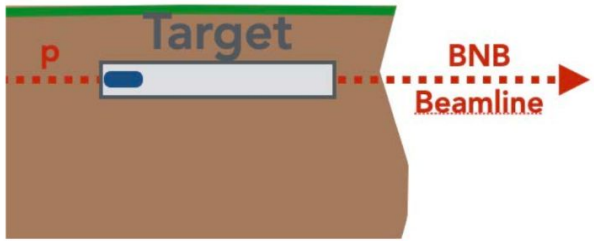


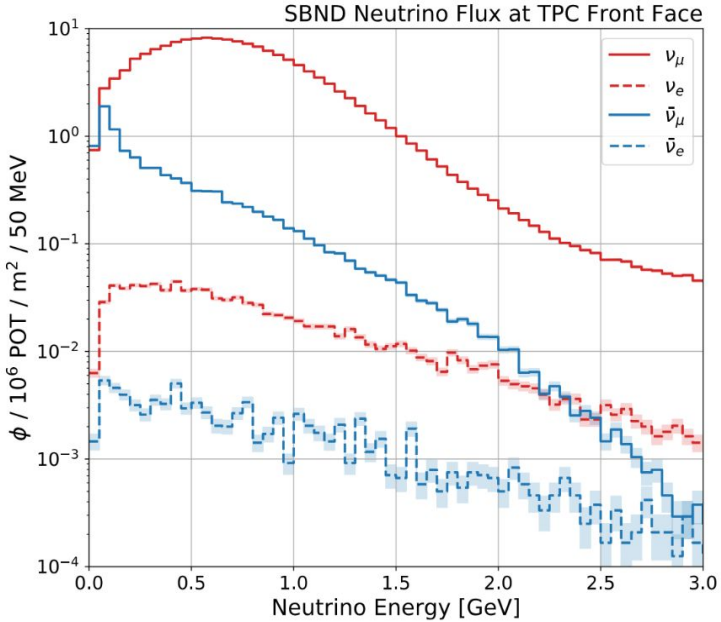


Neutrino Flux at SBND

Booster Neutrino Beamline (BNB) in Neutrino Running Mode

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%)

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

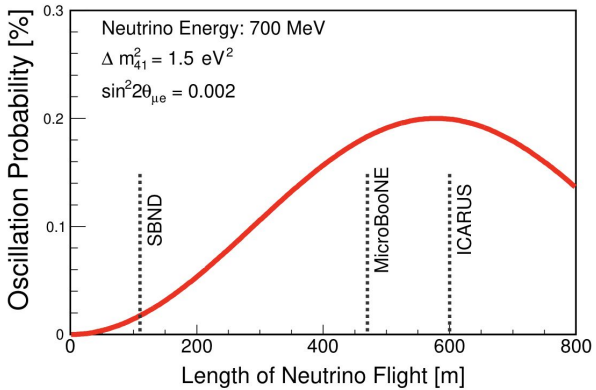
ν_e+$\bar{\nu}_e$ (0.5%)

SBND Physics

SBND Physics: (1) eV-Scale Sterile Neutrinos

arXiv:1903.04608

- SBND, together with MicroBooNE and ICARUS, aims to **definitively test the light sterile neutrino oscillation interpretation of the short-baseline neutrino anomalies.**



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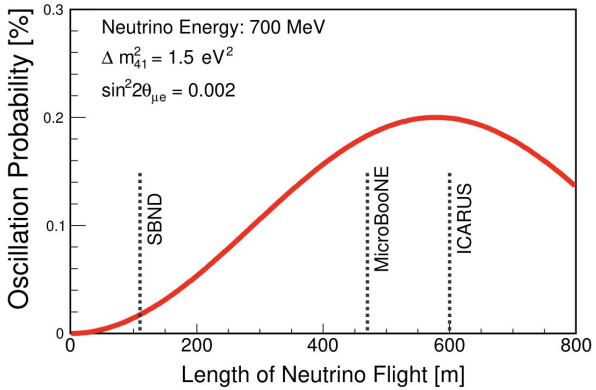
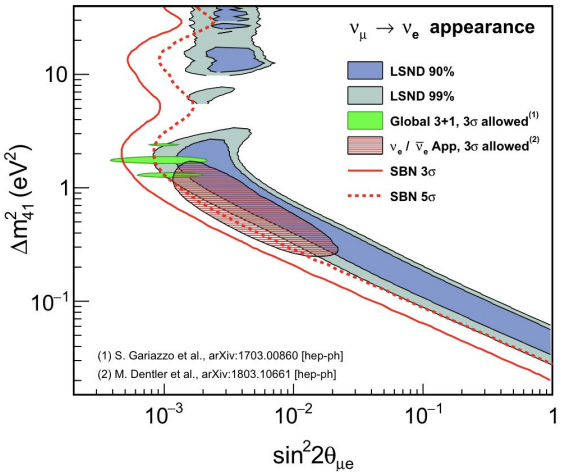
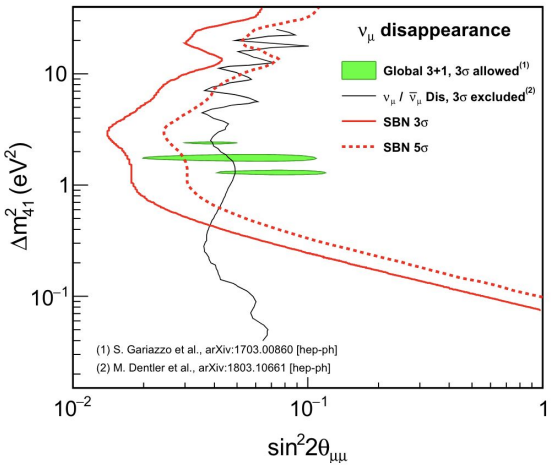


- SBND, together with MicroBooNE and ICARUS, aims to **definitively test the light sterile neutrino oscillation interpretation of the short-baseline neutrino anomalies.**
- **SBND will measure intrinsic ν_e and ν_μ components of BNB flux with high statistics before any *significant* oscillation happens, providing a powerful constraint on flux and cross-section.**
- ICARUS and MicroBooNE can search for deviations from the extrapolated predictions w.r.t SBND measurement.
- SBN will be providing world leading sensitivity to **ν_e appearance** and **ν_e and ν_μ disappearance at short-baselines.**



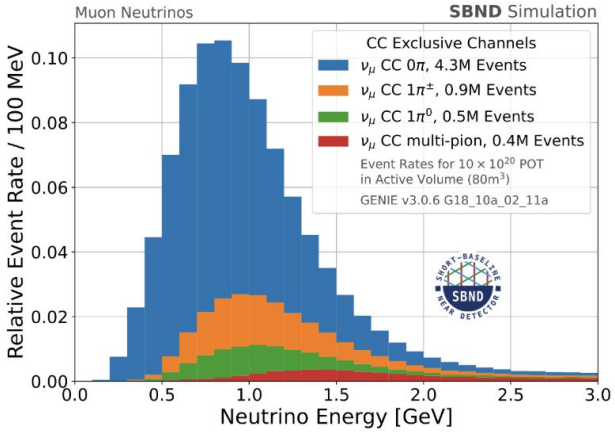


SBND Physics: (2) Cross Sections

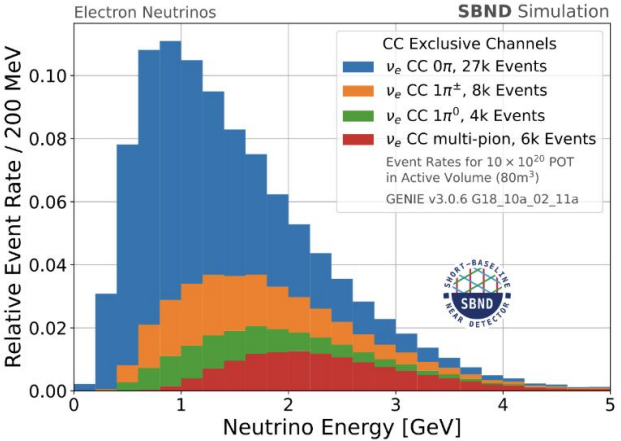
- Due to its close proximity to the target, **SBND will record the world's largest neutrino-argon interaction dataset** to study **neutrino-argon interactions in the GeV energy range.**

- **High statistics in SBND (~7000 neutrinos per day)** will allow a broad set of neutrino interaction measurements enabling **multi-dimensional differential measurements** and **searches for rare channels** (stat. limited in other existing experiments) e.g. hyperon production, ***ν***-e scattering on Ar, neutral current single-photon production, etc.

2M ν_μ CC events in an year



15k ν_e CC events in an year

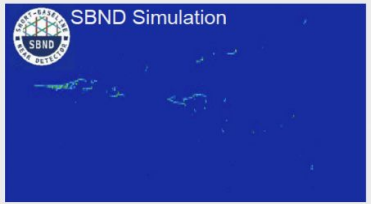


SBND Physics: (3) BSM

- Explore new BSM physics processes, including alternative solutions to short-baseline neutrino anomalies and other exotic physics processes.

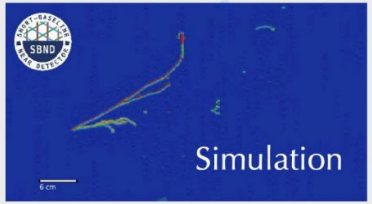
Thanks to high statistics that SBND will collect, high intensity beam, and LArTPC excellent particle identification capabilities.

Light Dark Matter



single e^- scattering or e^+e^- pair with no hadronic activity

Dark Neutrinos

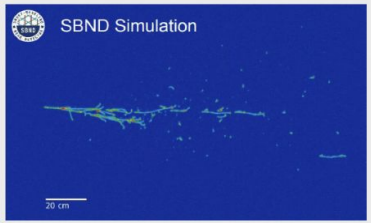


e^+e^- pair with or without hadronic activity

Millicharged Particles

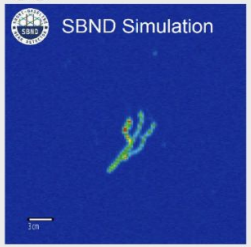
blips or faint tracks

Heavy Neutral Leptons



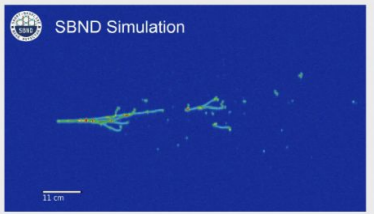
e^+e^-, $\mu^+\mu^-$, or $\mu^\pm\pi^\mp$ pair with no hadronic activity

Higgs Portal Scalar



e^+e^- or $\mu^+\mu^-$ pair with no hadronic activity

Axion-Like Particles



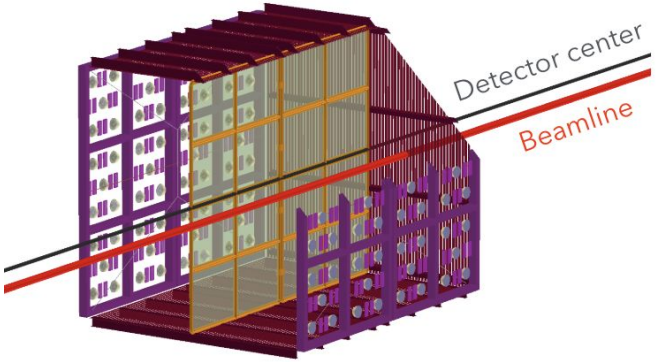
high-energy e^+e^- or $\mu^+\mu^-$ pair

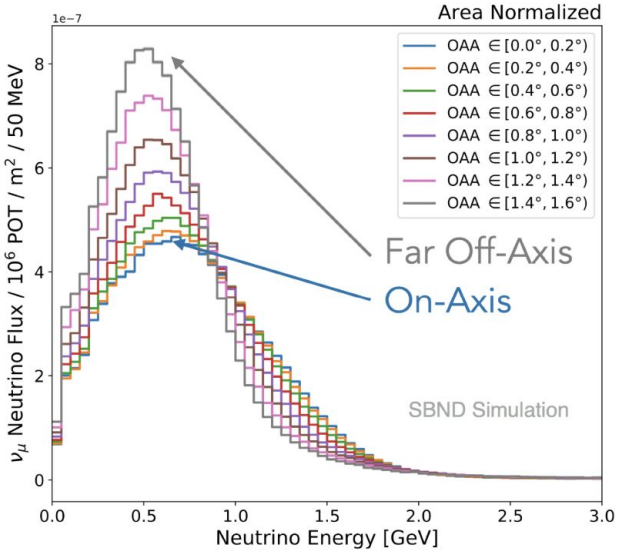
SBND Physics: (4) PRISM

Precision **R**eaction **I**ndependent **S**pectrum **M**easurement

- SBND is very close (110m) to the neutrino source and is ~75cm off-axis with the neutrino beamline.

- SBND can sample multiple off-axis fluxes with the same detector (leveraging the PRISM concept)
  - ➢ Access to event samples with different average energies → allows for better understanding of any energy dependent effects (e.g. cross-section, and potentially oscillations) in a single detector.





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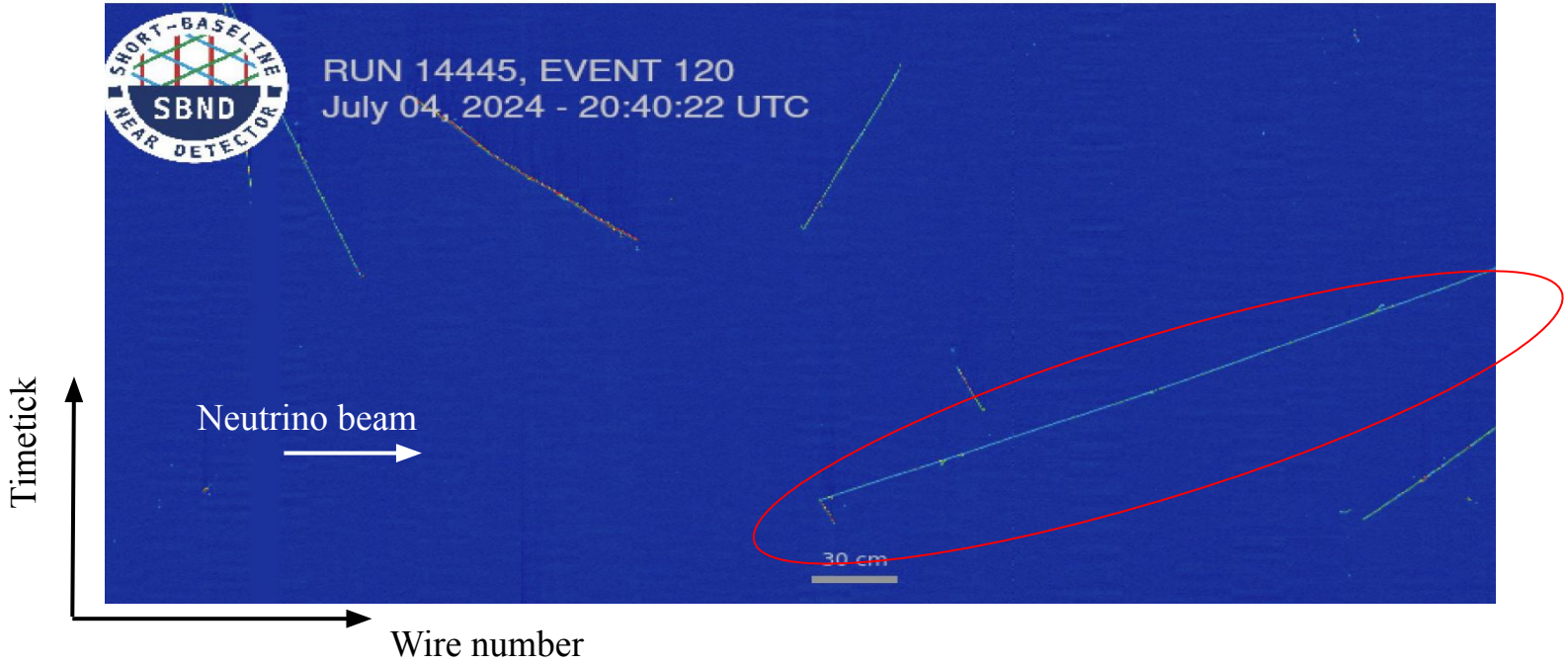
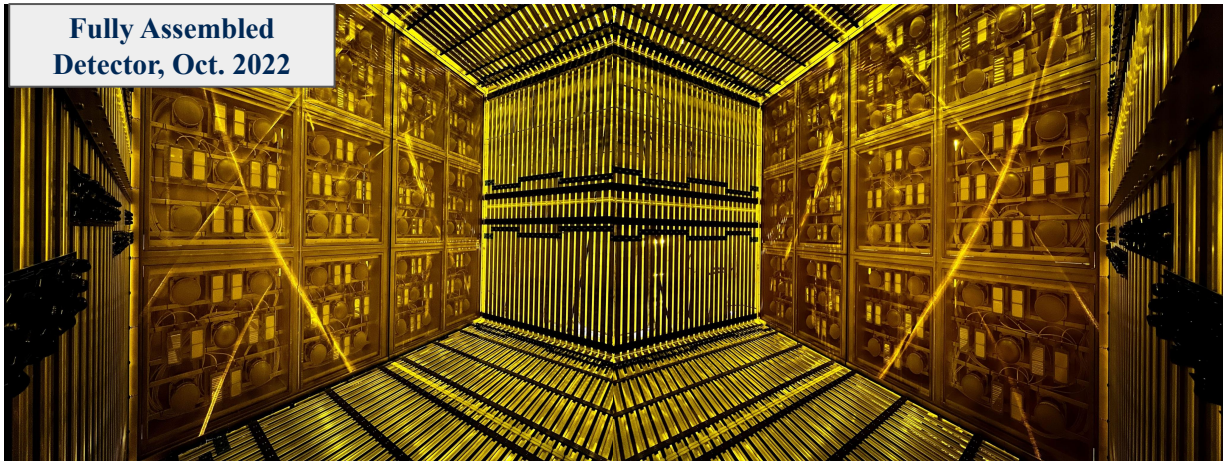


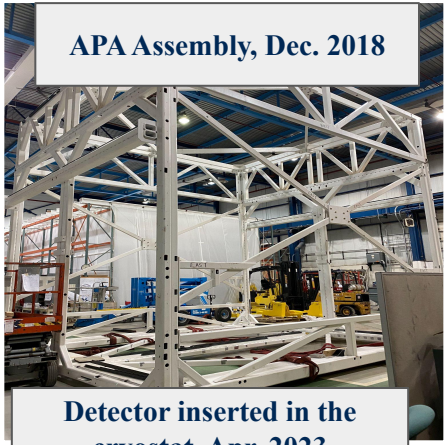
Reaching this milestone has been quite an exciting journey

Journey to Data Taking: Detector Assembly



Journey to Data Taking: Detector Assembly to Commissioning

APA Assembly, Dec. 2018



Fully Assembled Detector, Oct. 2022

Towards commissioning: Installing cables

Detector inside the Cryostat, Apr. 2023

Detector inserted in the cryostat, Apr. 2023

Cathode HV Feedthrough Installation, Jul. 2023

Towards commissioning: Purity monitors

Journey to Data Taking: Detector Assembly to Commissioning

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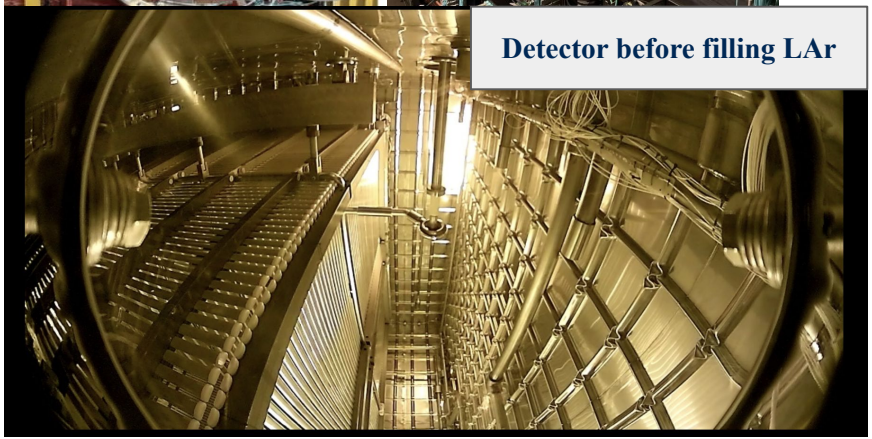
Fully Commissioned Detector, Dec. 2023



Detector before filling LAr

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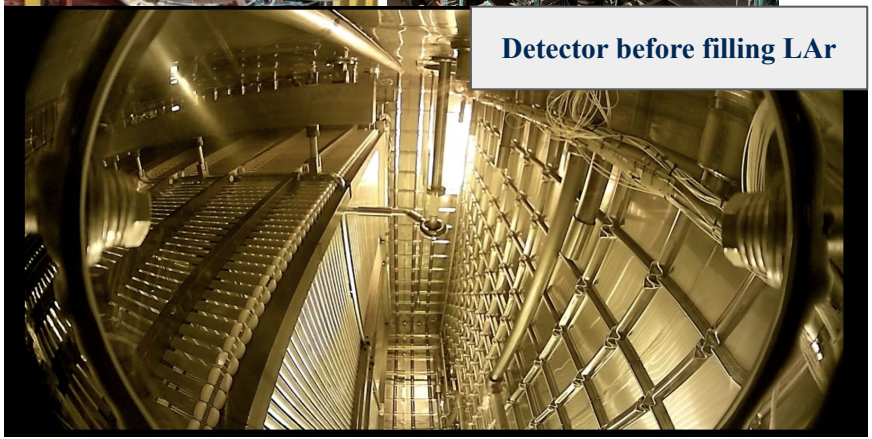
Fully Commissioned Detector, Dec. 2023



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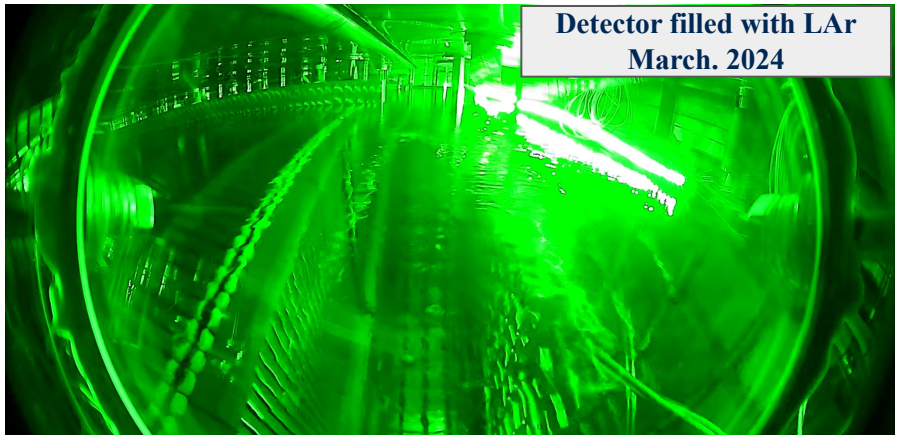
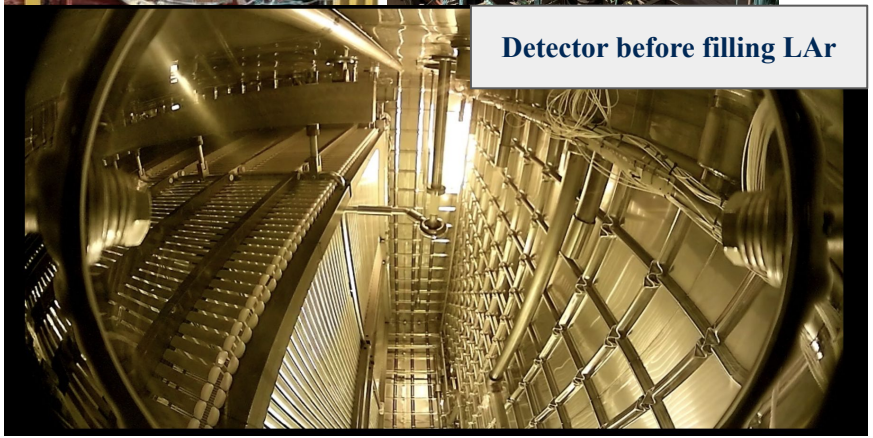


Detector filled with LAr March. 2024

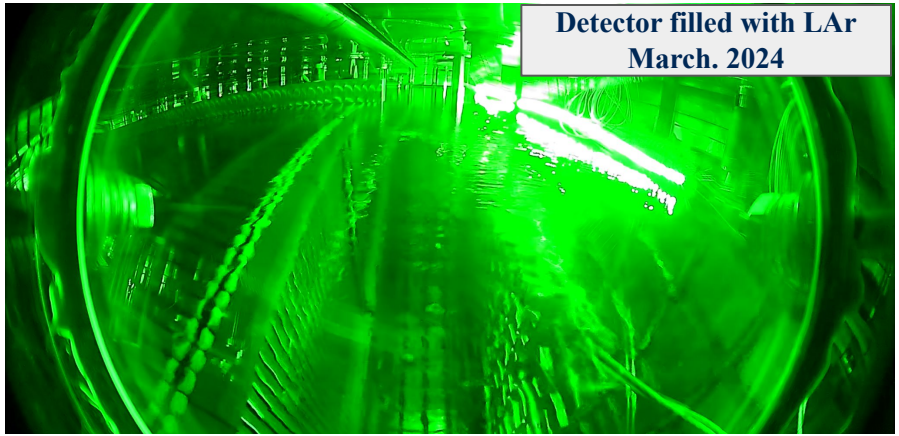
Journey to Data Taking: Detector Assembly to Commissioning

Fully Commissioned Detector, Dec. 2023

All the detector subsystems were powered ON in March 2024!



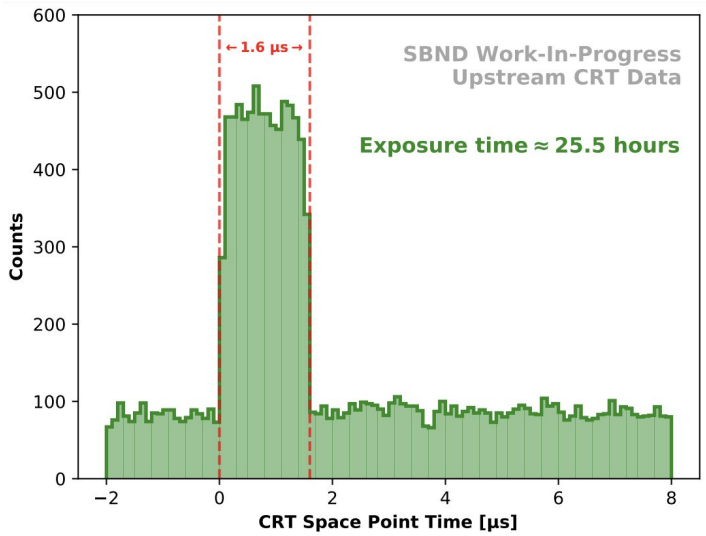
Detector before filling LAr

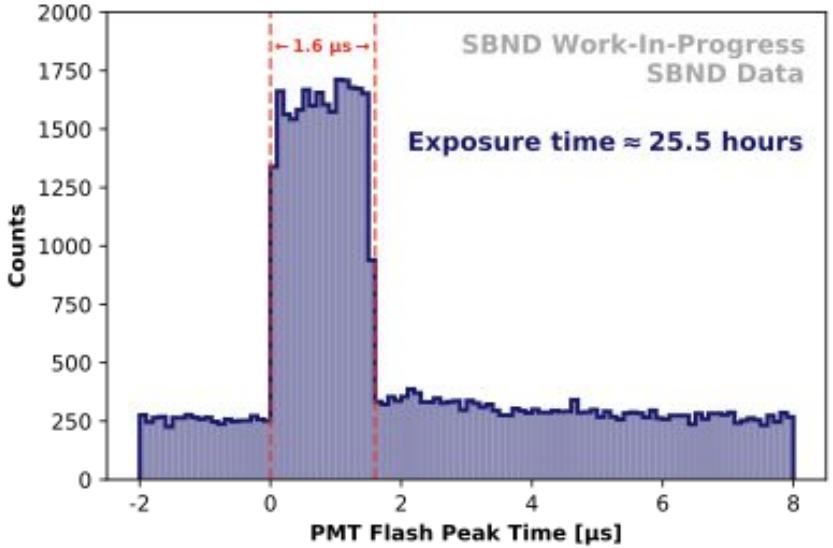


Detector filled with LAr March. 2024

Journey to Data Taking: Successful Commissioning

- **Successful demonstration of SBND commissioning using CRT and PMT data**
  → clear peaks in CRT and PMT data from the neutrino beam
  - ➢ **1.6μs wide peak reflecting the duration of the BNB spill**





Journey to Data Taking: Ramping up cathode HV

- The cathode HV was gradually increased in steps, with stability monitored over several hours.

March 2024

During first ramp-up, instabilities were observed in the drift HV system, stopped the ramp for investigation.
Determined that discharges were occurring in bottom part of field cage module (in one of the TPCs)

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June 28 - July 03, 2024

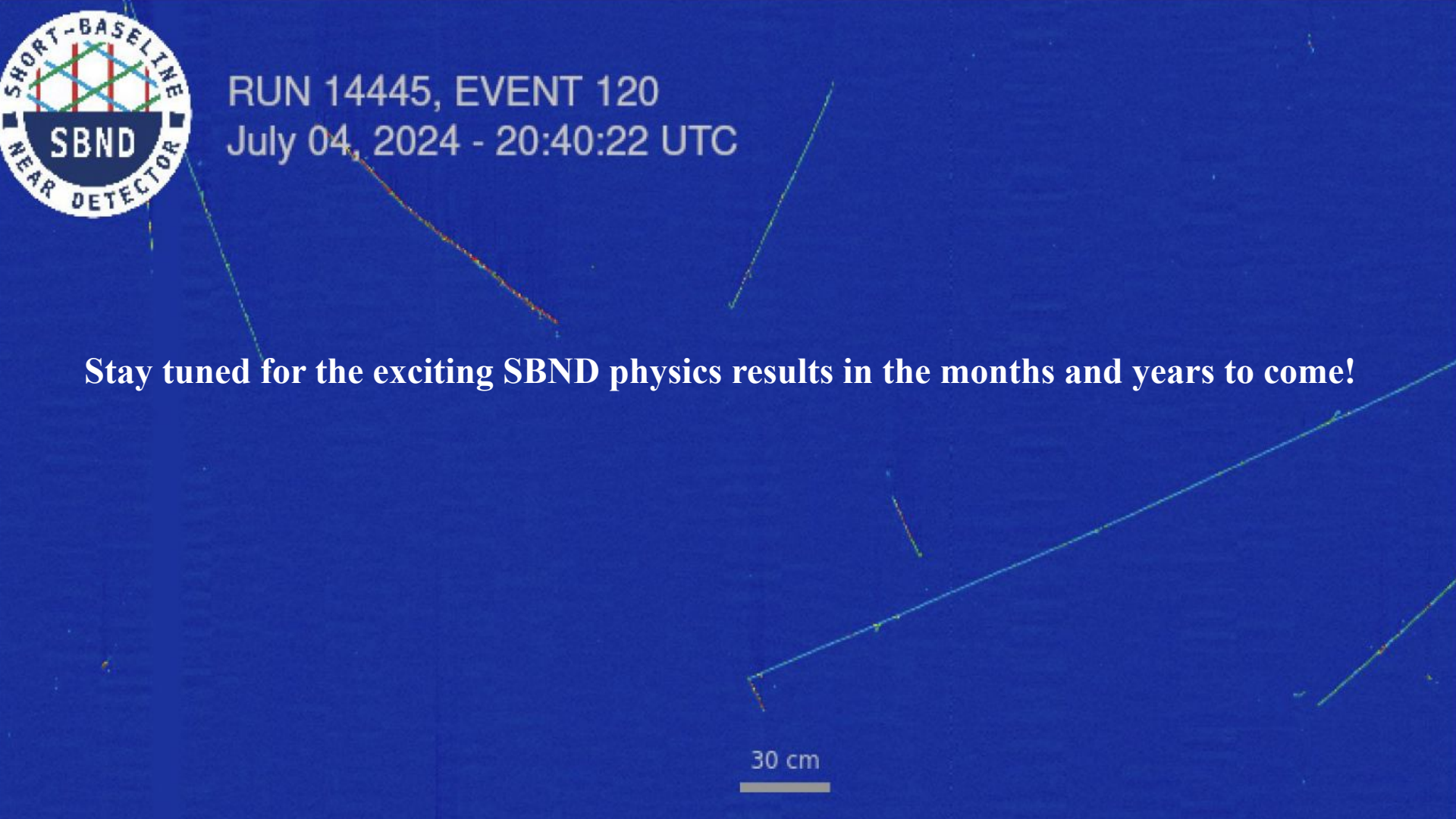
Ramped up cathode to the design target of 100kV.

Journey to Data Taking: Fully Operational

- **Ramped up cathode HV to the design target 100kV on July 3, 2024!**
  The cathode HV was gradually increased in steps, with stability monitored over several hours.

- The plan is to take beam data until the July 12 (beam summer shutdown)

ROC-West, Wilson Hall. July 3rd, 2024



Stay tuned for the exciting SBND physics results in the months and years to come!

Thank you!