

# Neutrino Physics with the Short- Baseline Near Detector at Fermilab

Thomas Wester, University of Chicago  
On behalf of the SBND collaboration

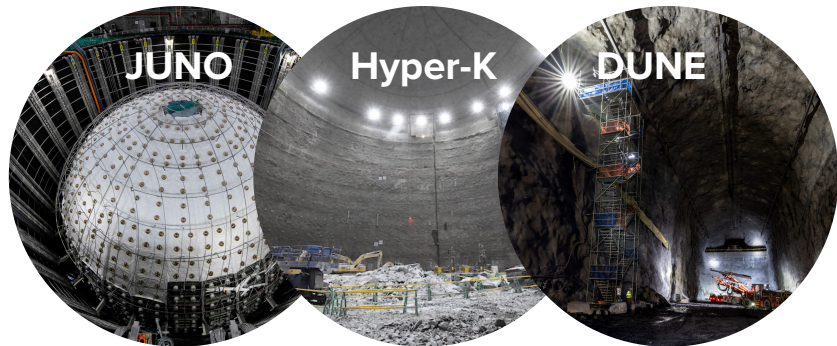
TAUP2025  
2025 August 28



# Neutrino Unknowns



Next-generation neutrino oscillation experiments coming online in the next 5 years!

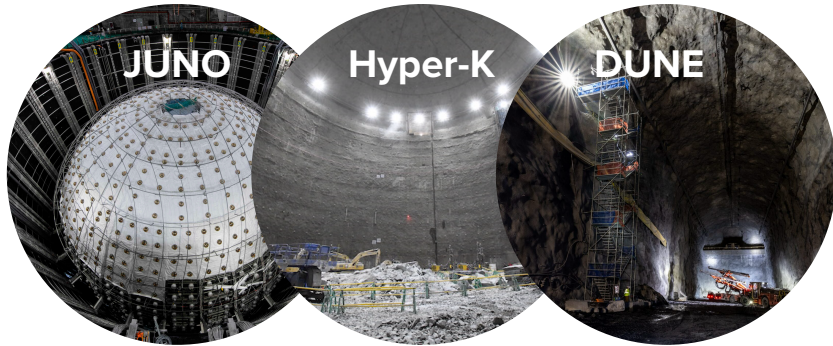




# Neutrino Unknowns

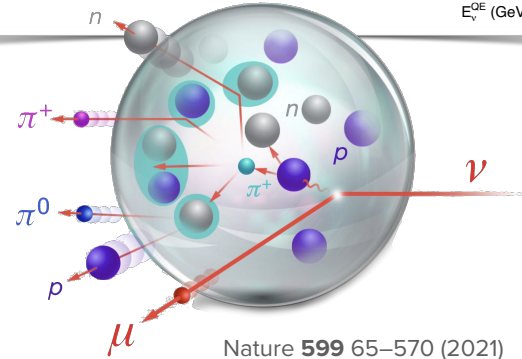
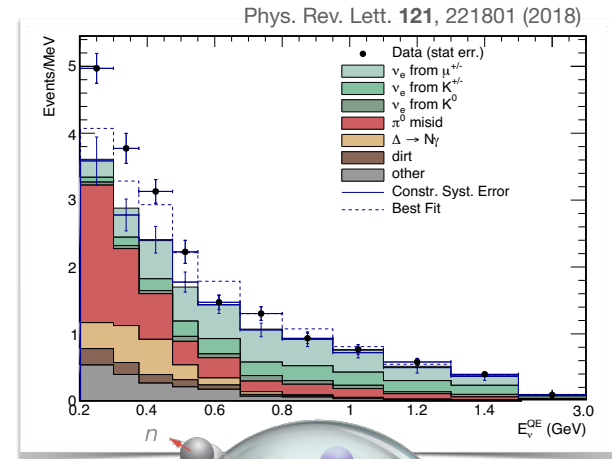


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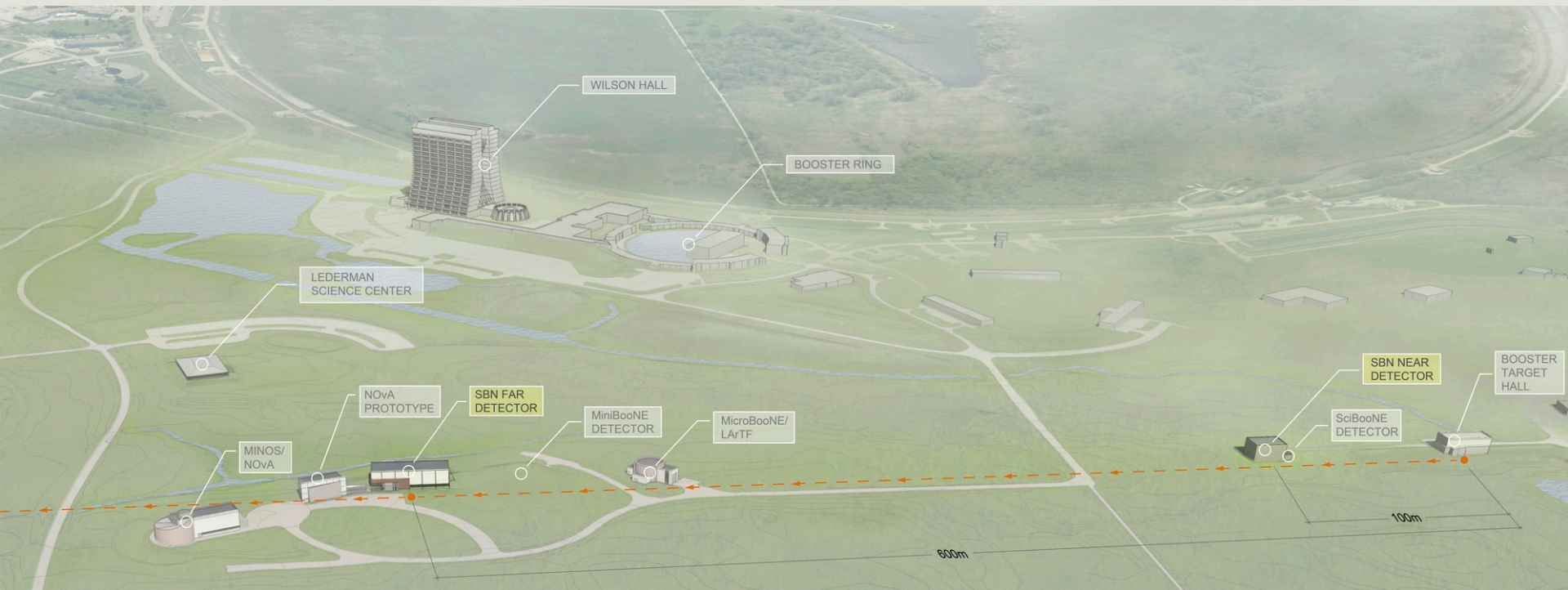


Big unknowns:

- Short-baseline anomalies — LSND & MiniBooNE
- Neutrino-nucleus interactions at the percent-level



# Short-Baseline Neutrino (SBN) Concept



[arXiv:1503.01520](https://arxiv.org/abs/1503.01520)

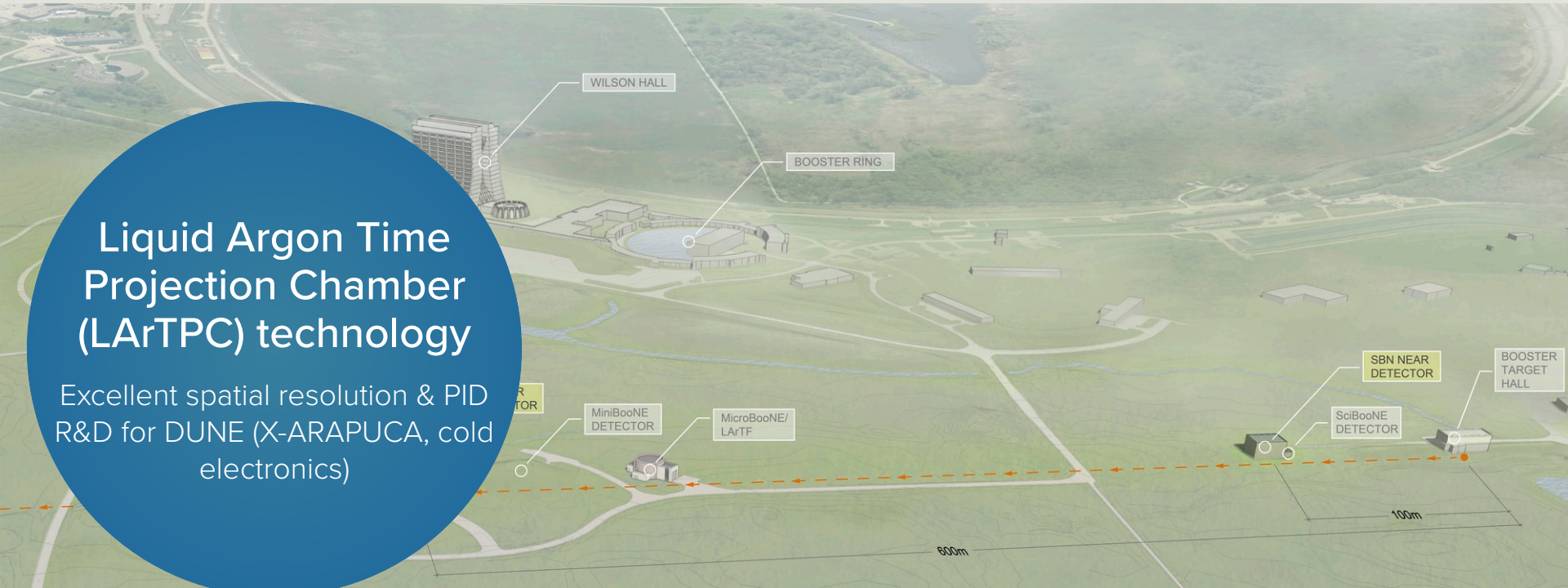
Annu. Rev. Nucl. Part. Sci. **69**, no. 1, pp. 363–387 (2019)



# Short-Baseline Neutrino (SBN) Concept

## Liquid Argon Time Projection Chamber (LArTPC) technology

Excellent spatial resolution & PID  
R&D for DUNE (X-ARAPUCA, cold electronics)



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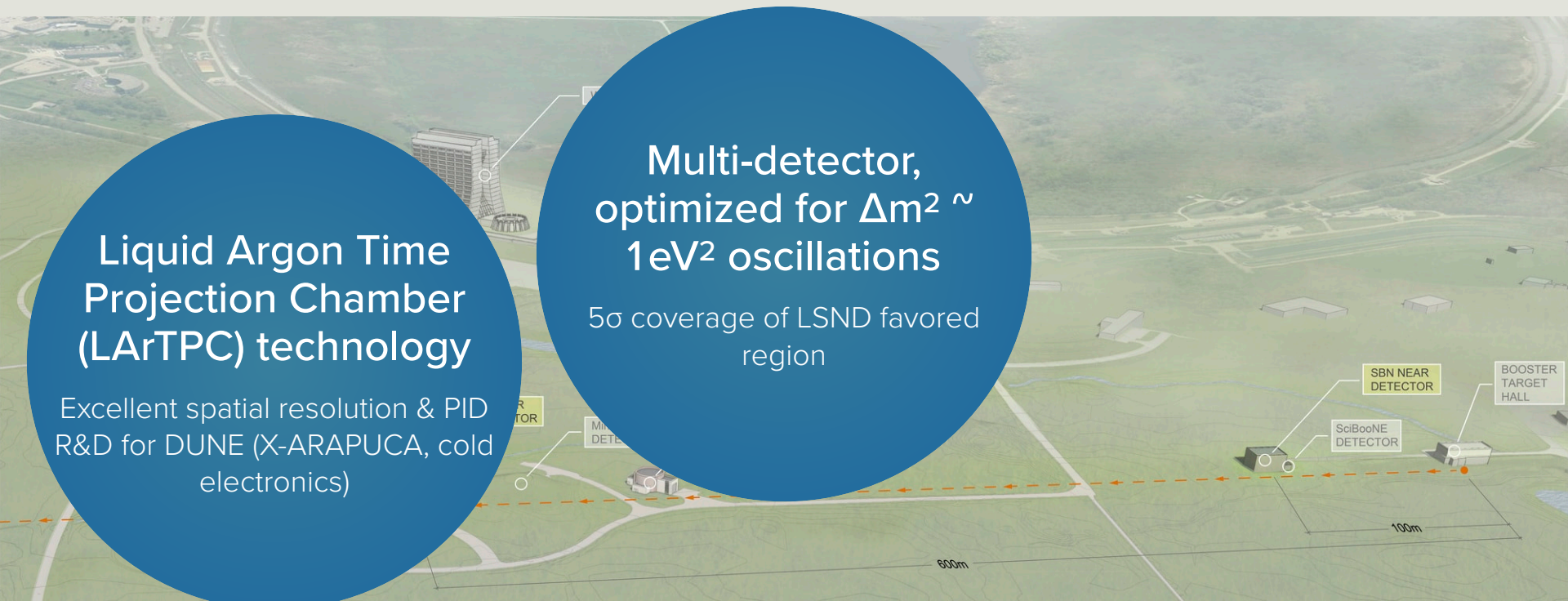
# Short-Baseline Neutrino (SBN) Concept

Liquid Argon Time  
Projection Chamber  
(LArTPC) technology

Excellent spatial resolution & PID  
R&D for DUNE (X-ARAPUCA, cold  
electronics)

Multi-detector,  
optimized for  $\Delta m^2 \sim$   
 $1 \text{eV}^2$  oscillations

$5\sigma$  coverage of LSND favored  
region





# Short-Baseline Neutrino (SBN) Concept

## Liquid Argon Time Projection Chamber (LArTPC) technology

Excellent spatial resolution & PID  
R&D for DUNE (X-ARAPUCA, cold electronics)

## Multi-detector, optimized for $\Delta m^2 \sim 1 \text{eV}^2$ oscillations

$5\sigma$  coverage of LSND favored region

## Broad physics program

Cross sections  
BSM signatures  
MeV physics  
Rare event searches  
Second beamline (NuMI)

# SBN Today





# SBN Today



**SBND**

112t, 2024—

**Booster Neutrino Beam**  
 $E_{\nu} \sim 800 \text{ MeV}$

**MicroBooNE**

89t, 2015—2020

**ICARUS**

476t, 2022—



# SBN Today



SBND

112t, 2024—

Booster Neutrino Beam  
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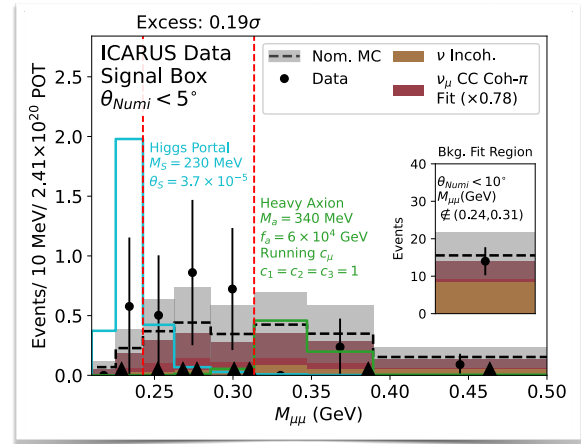
MicroBooNE

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ICARUS

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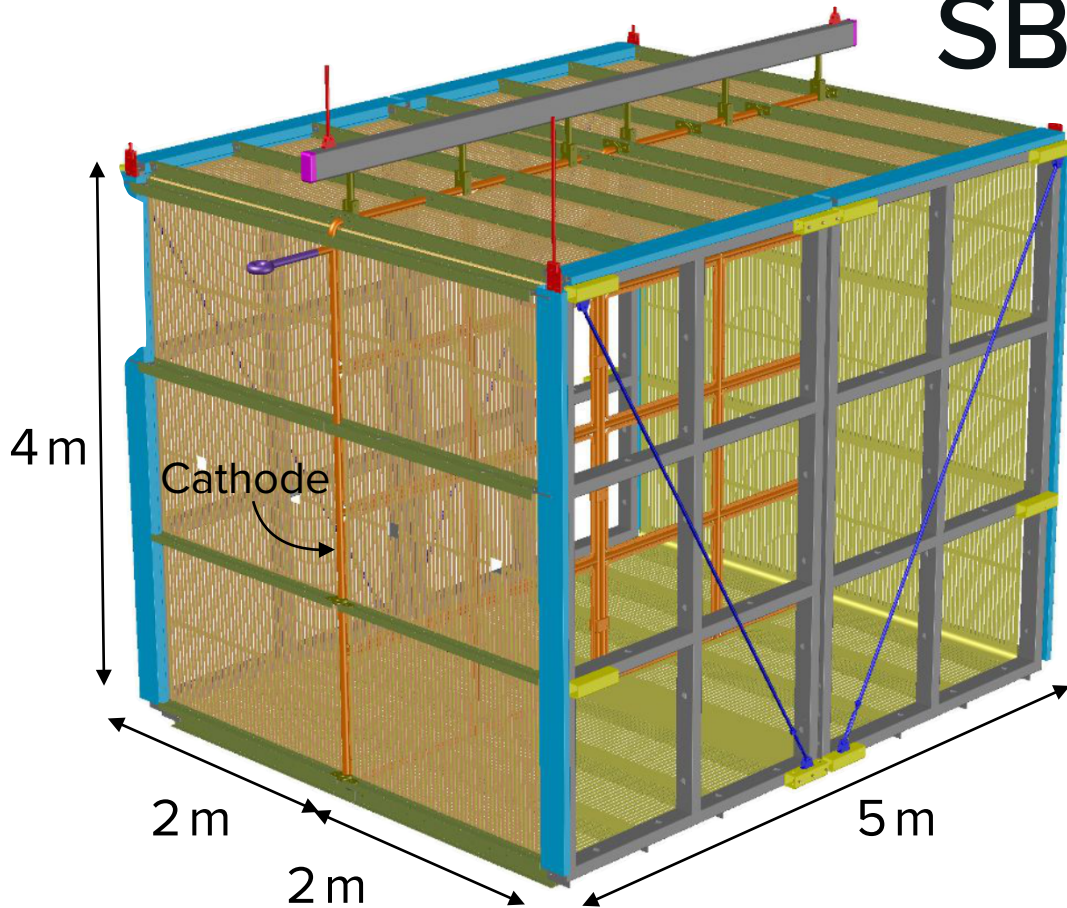
## ICARUS first physics results



Phys. Rev. Lett. **134**, 151801 (2025)

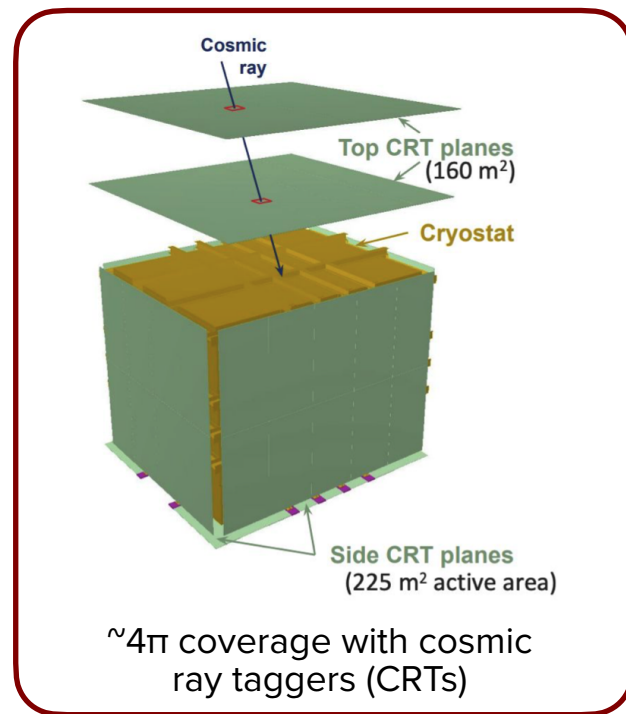
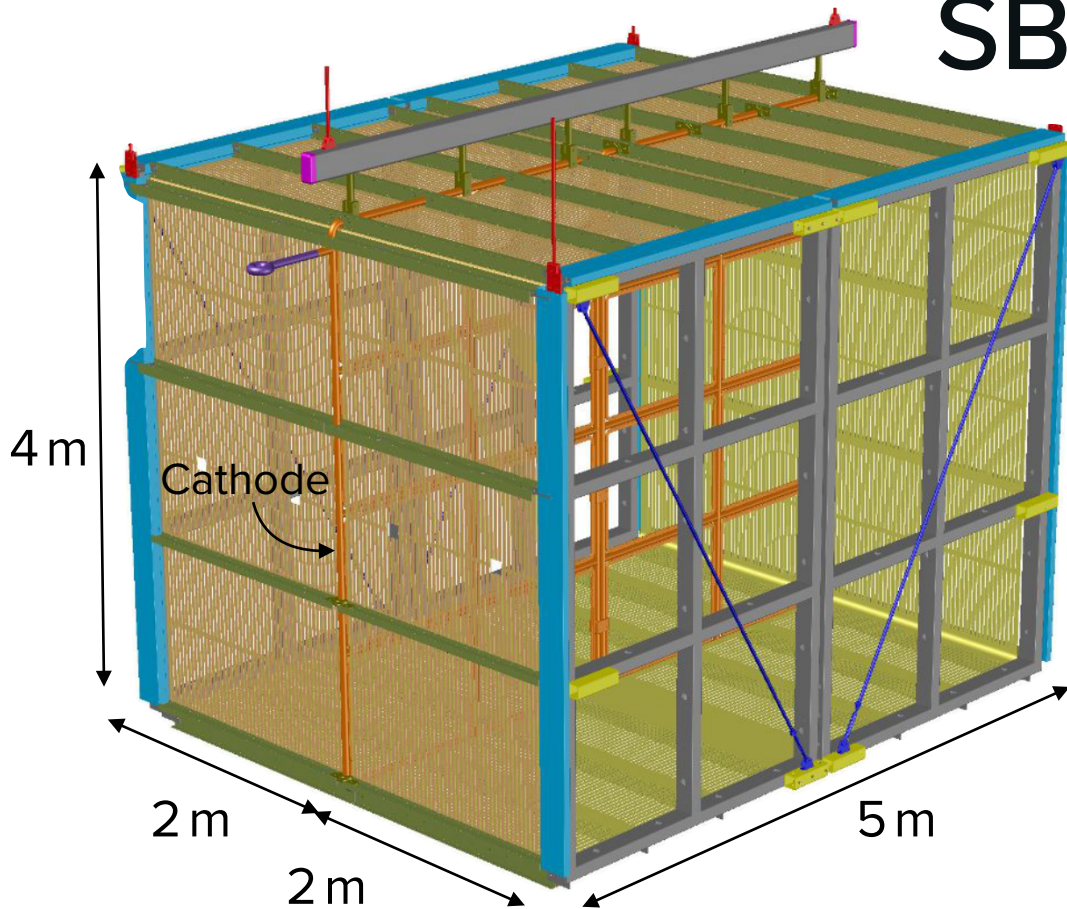


# SBND Detector



- Active mass: 112 t
- Two drift volumes
- $E$ -field: 500 V/cm
- Baseline: 110 m  
~2 million  $\nu_\mu$  CC/year  
~15,000  $\nu_e$  CC/year

# SBND Detector



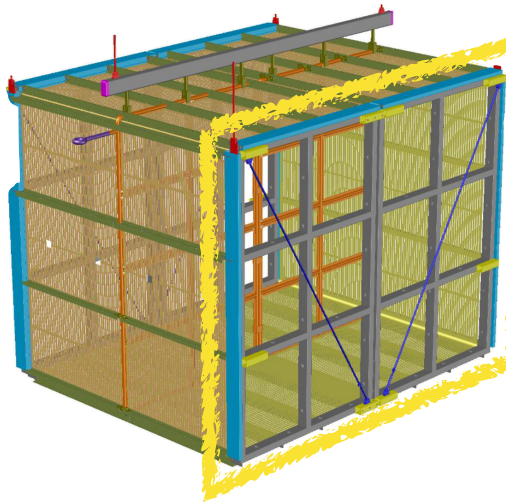


# SBND Detector



## TPC readout

- ~11,000 total wires
- 3 planes/TPC, 60° offsets
- Pre-amplification and digitization in LAr

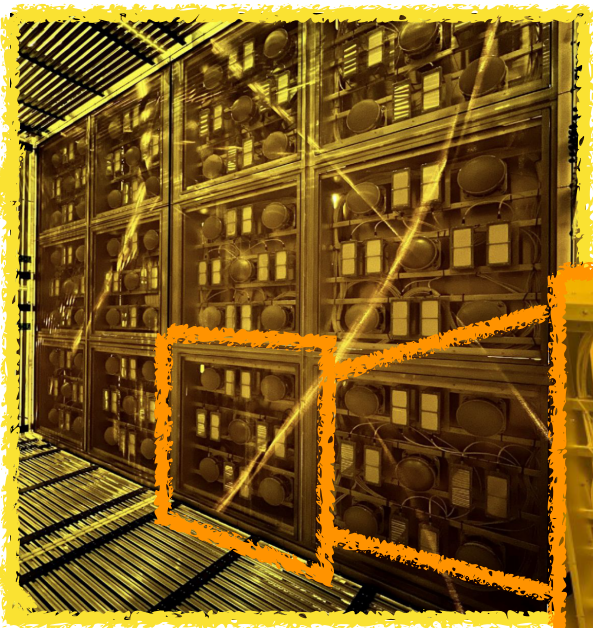
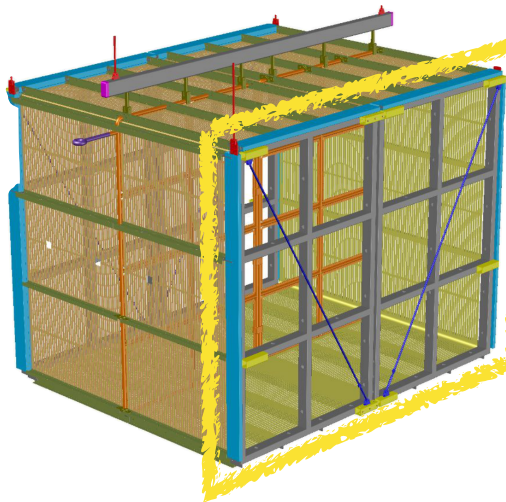


# SBND Detector



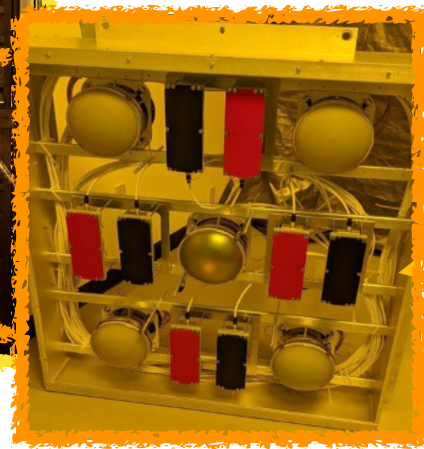
## TPC readout

- ~11,000 total wires
- 3 planes/TPC, 60° offsets
- Pre-amplification and digitization in LAr



## Photon detection system (PDS)

- 120 PMTs (60 per TPC)  
96 TPB-coated, 24 uncoated
- 192 X-ARAPUCAs (96 per TPC)  
96 PTP-coated, 96 uncoated
- TPB-coated foils on cathode





# Timeline

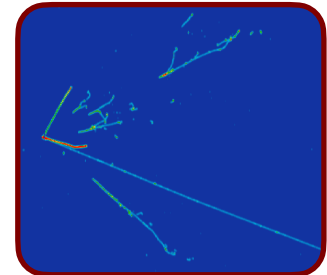


December 2022  
TPC assembly finished



March 2024  
LAr filling

July 2024  
HV ramp to -100 kV

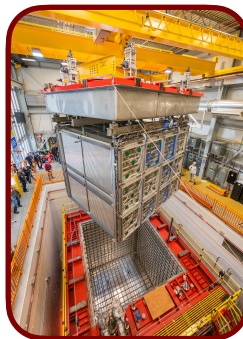


2022

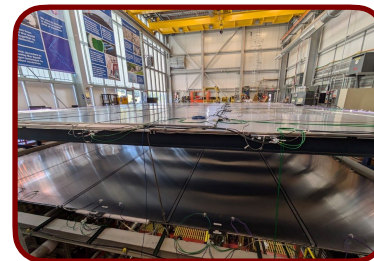
2023

2024

2025



April 2023  
TPC installed  
in cryostat



September 2024  
Final CRT panels installed



December 2024—  
July 2025  
Neutrino beam!  
“Run 1”

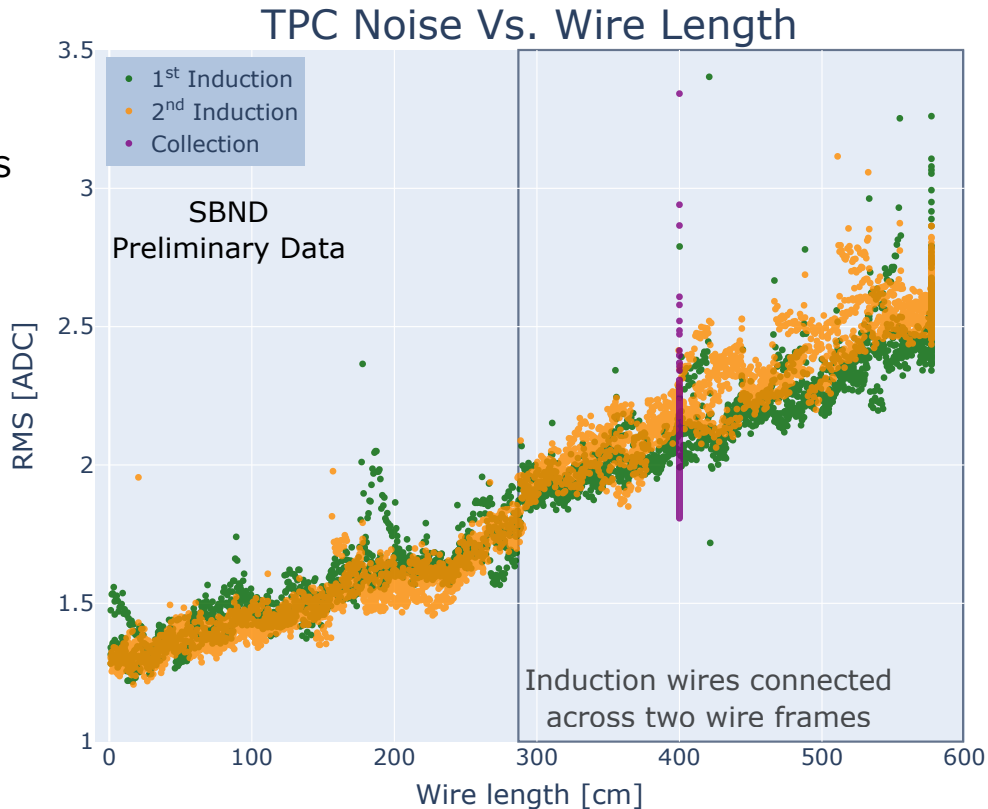
**SBND: Run 1**



# TPC Wire Noise



Wire noise: Close to intrinsic level, follows expected trend

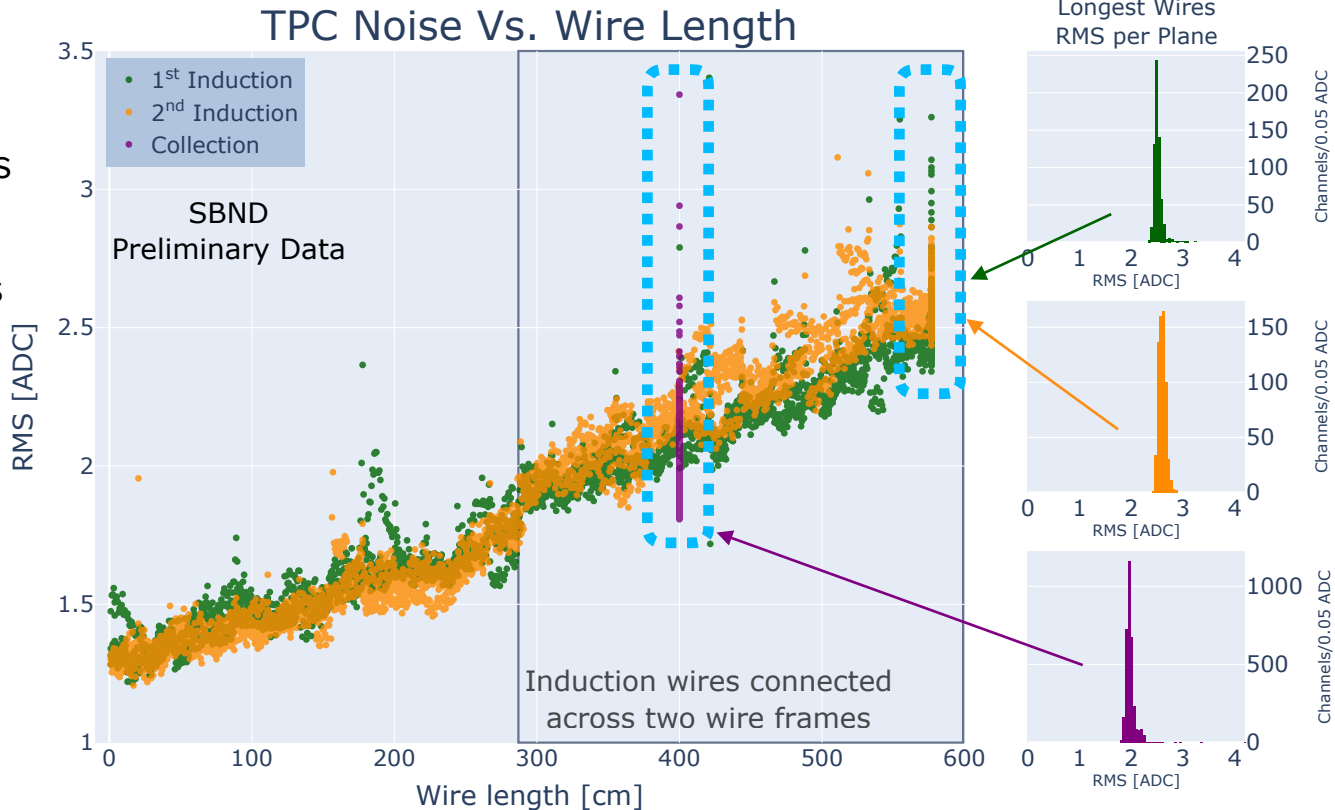


# TPC Wire Noise



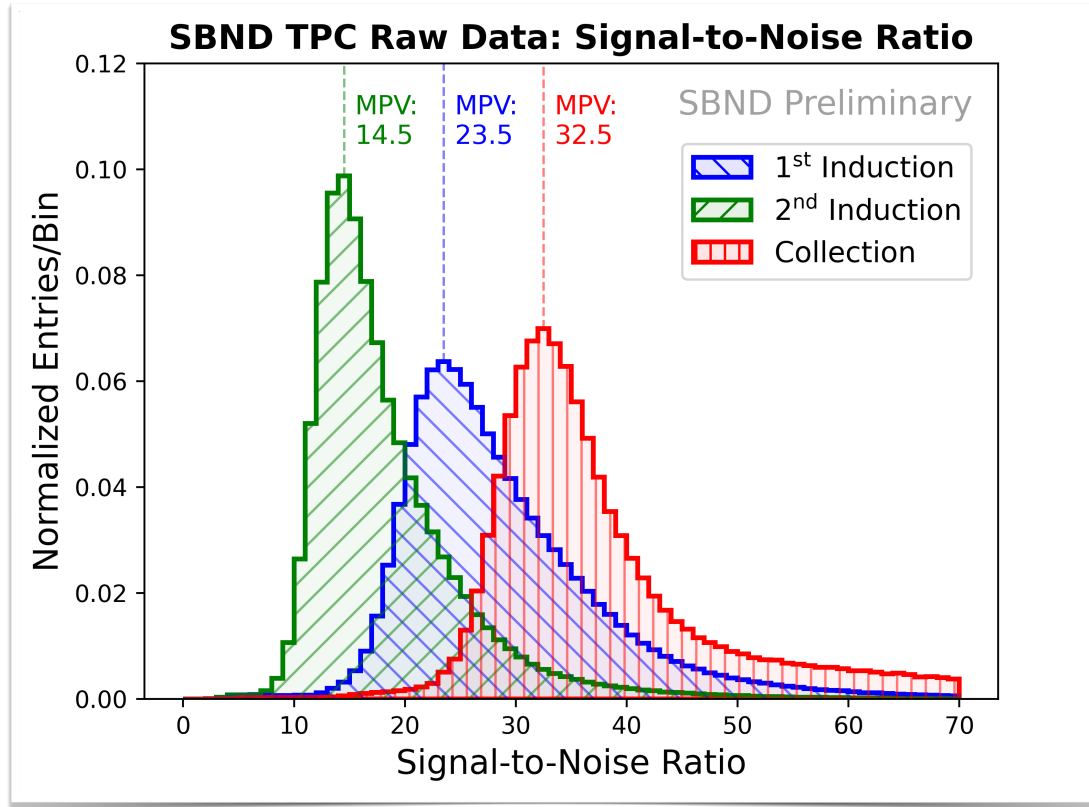
Wire noise: Close to intrinsic level, follows expected trend

RMS < 3 ADC counts across all planes

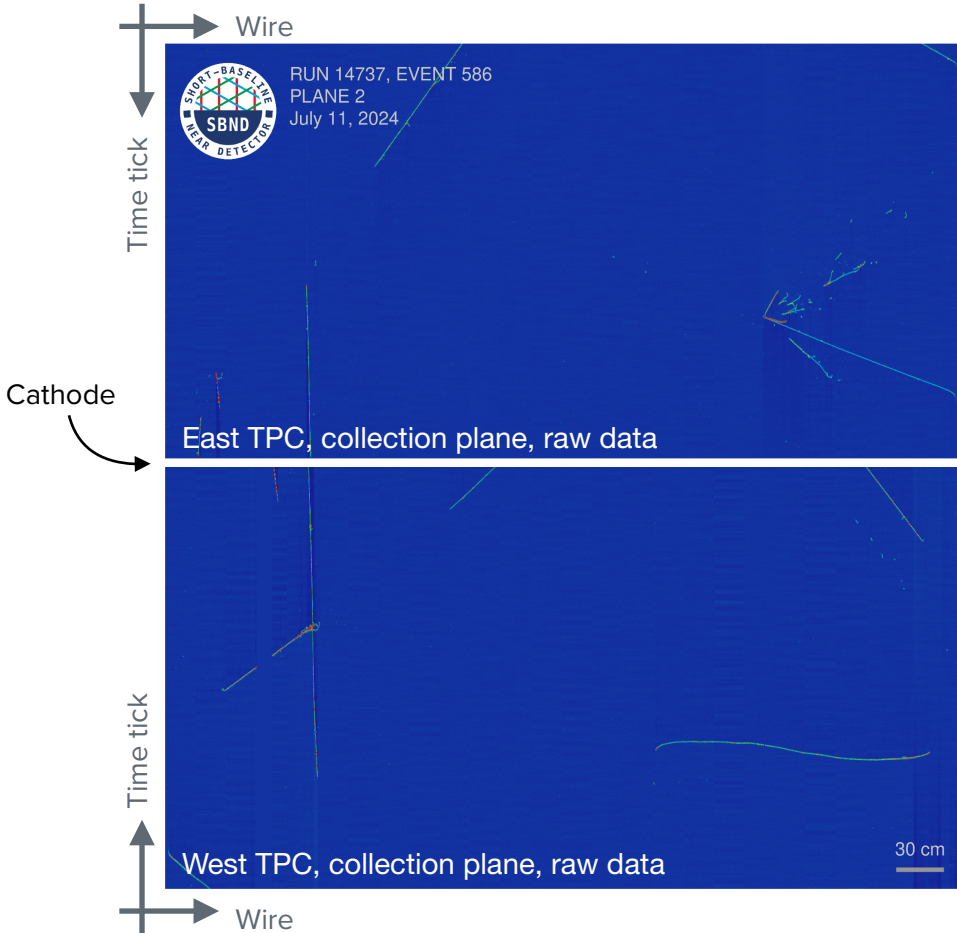




# Excellent signal-to-noise observed on all wire planes

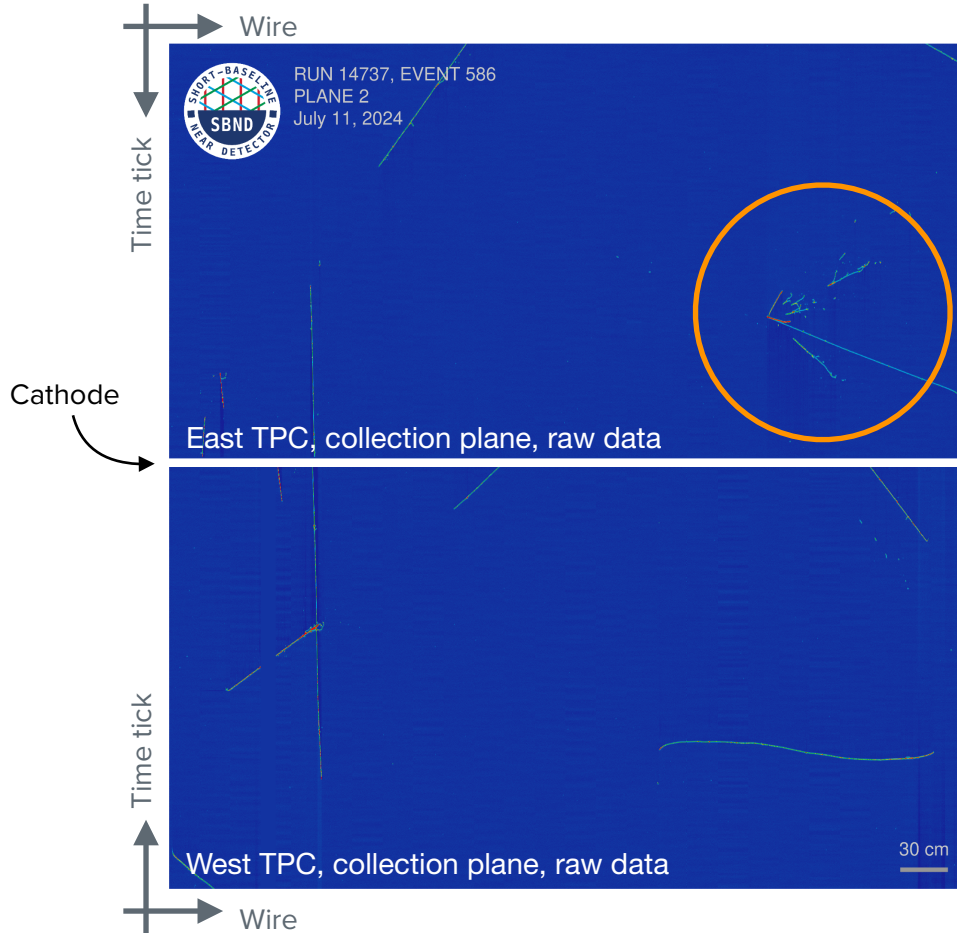


# Neutrinos in Data





# Neutrinos in Data



All planes with noise filtering

# Photon Detection System (PDS) & Cosmic Ray Tagger (CRT)



Both systems are functioning well! Exploring possibilities:



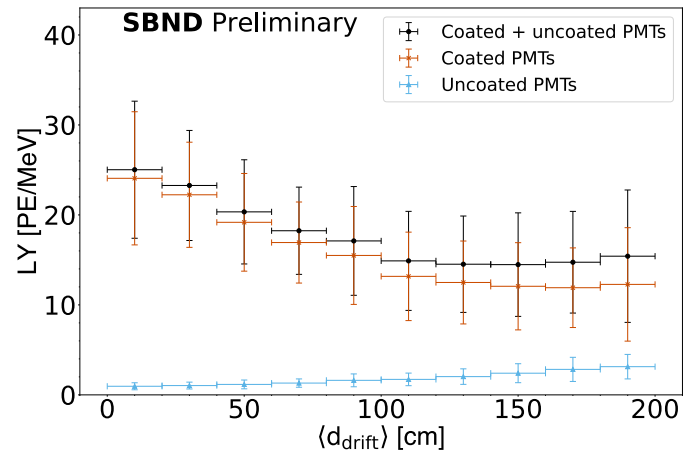
# Photon Detection System (PDS) & Cosmic Ray Tagger (CRT)



Both systems are functioning well! Exploring possibilities:

Spatial reconstruction using the combination of coated & uncoated PMTs

[Eur. Phys. J. C 84, 1046 \(2024\)](#)



# Photon Detection System (PDS) & Cosmic Ray Tagger (CRT)

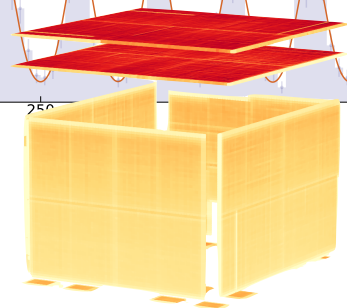
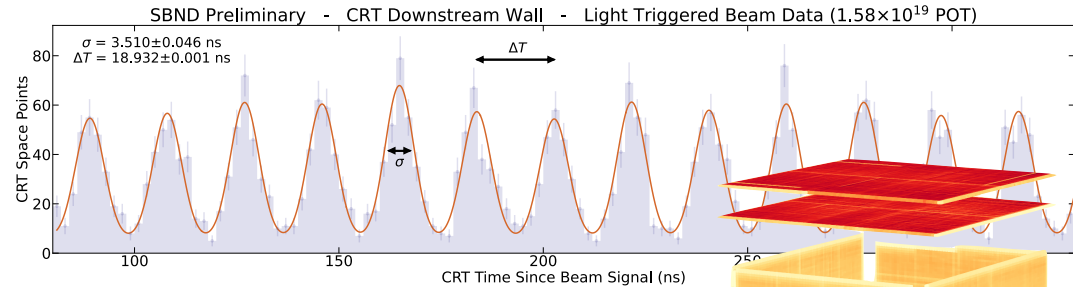
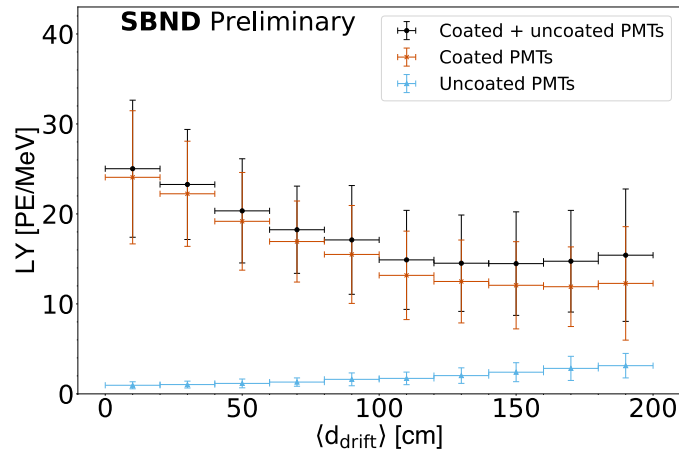


Both systems are functioning well! Exploring possibilities:

Spatial reconstruction using the combination of coated & uncoated PMTs

Few-ns timing resolution with CRT system too  
Sees the neutrino beam bunch structure

Eur. Phys. J. C 84, 1046 (2024)



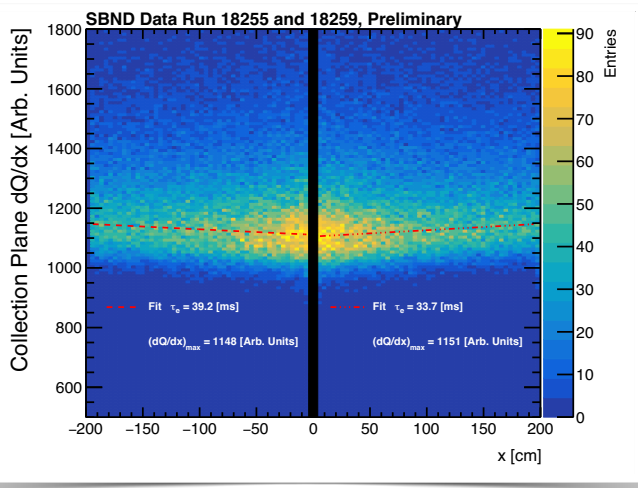
CRT hit rate data (Hz/cm<sup>2</sup>)



# SBND Calibrations



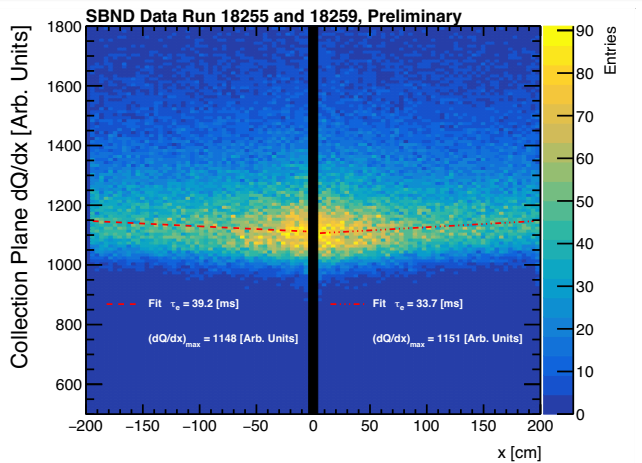
# SBND Calibrations



## Electron lifetime

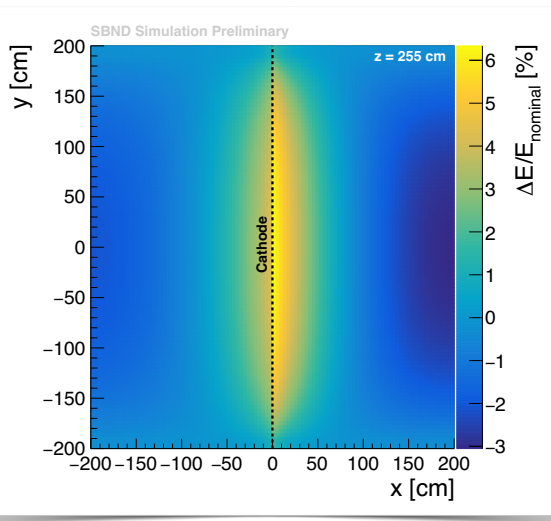
Preliminary measurement  
finds e-lifetime  $>10$  ms

# SBND Calibrations



## Electron lifetime

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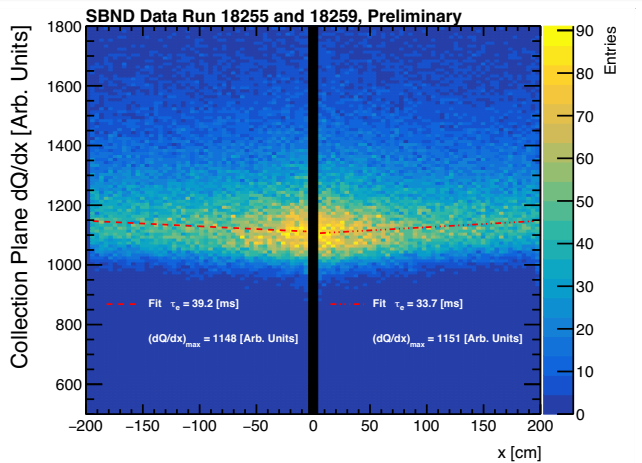


## Space charge effects

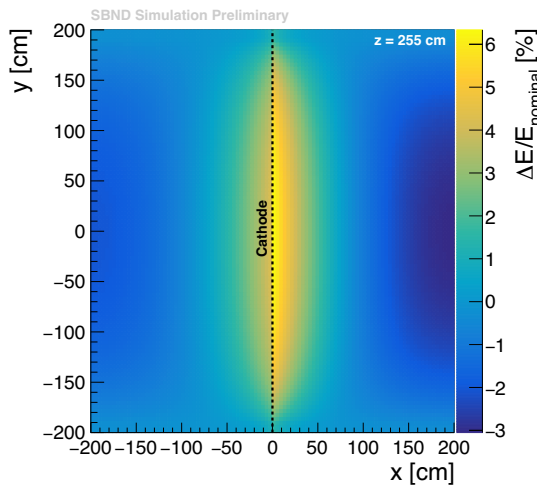
Well-characterized in both  
drift volumes



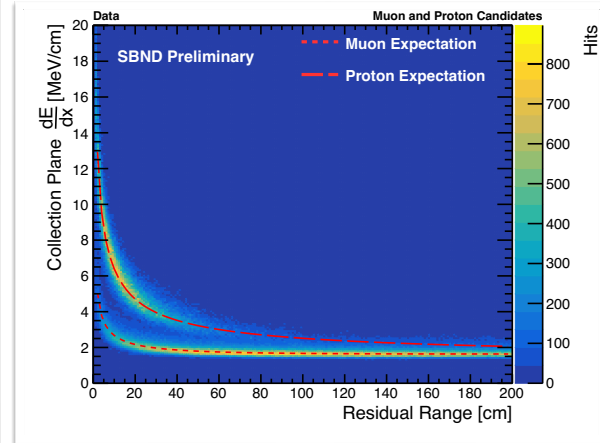
# SBND Calibrations



**Electron lifetime**  
Preliminary measurement  
finds e-lifetime >10 ms



**Space charge effects**  
Well-characterized in both  
drift volumes

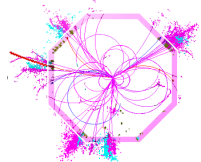


**TPC gain calibration**  
Data/MC agreement across  
a range of dE/dx

# Data Processing



SBN uses multiple, complementary approaches:



## PANDORA

2D clusters to 3D objects

Eur. Phys. J. C 78, 82 (2018)



## Wire-Cell

Tomographic 3D reconstruction

JINST 17 P01037 (2022)

## SPINE

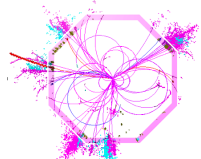
End-to-end machine learning  
reconstruction

NeurIPS #120 (2020)

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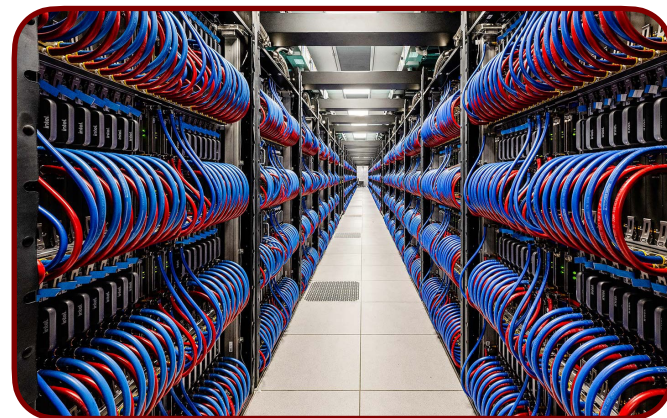
## Wire-Cell

Tomographic 3D reconstruction  
JINST 17 P01037 (2022)

## SPINE

End-to-end machine learning  
reconstruction

NeurIPS #120 (2020)



## Aurora at Argonne LCF

GPUs · Large-scale MC campaigns · Fast data  
storage & re-processing for multi-PB dataset

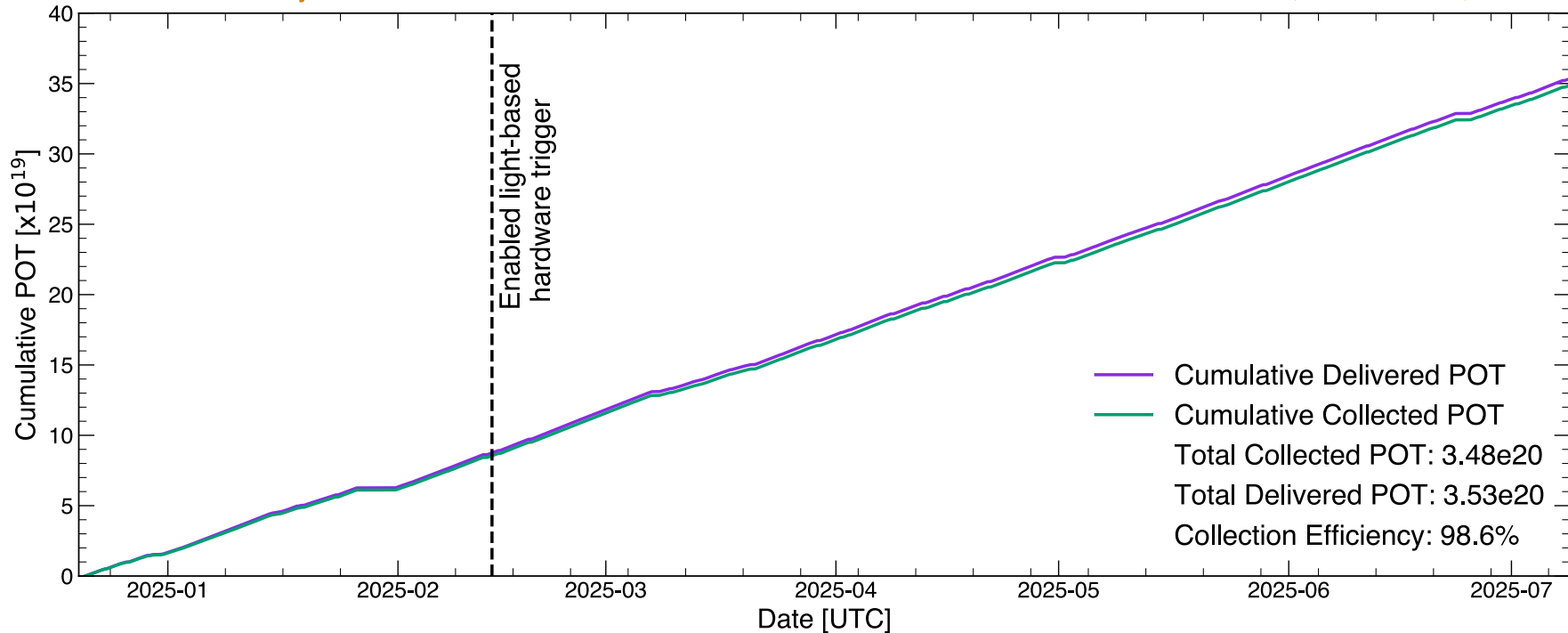


# Run 1 Complete!



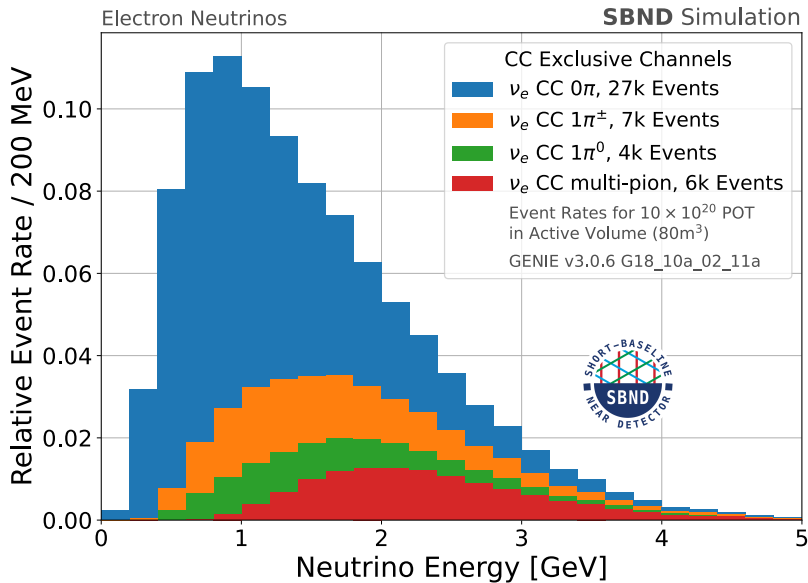
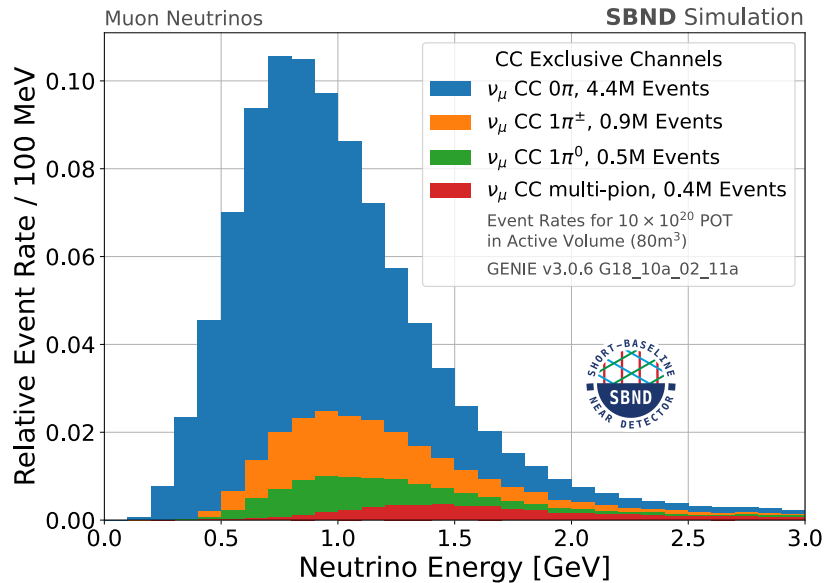
SBND Preliminary

Dec. 20, 2024 - Jul. 8, 2025



# **SBND Physics Potential**

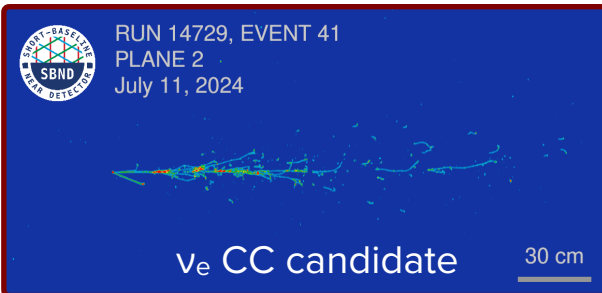
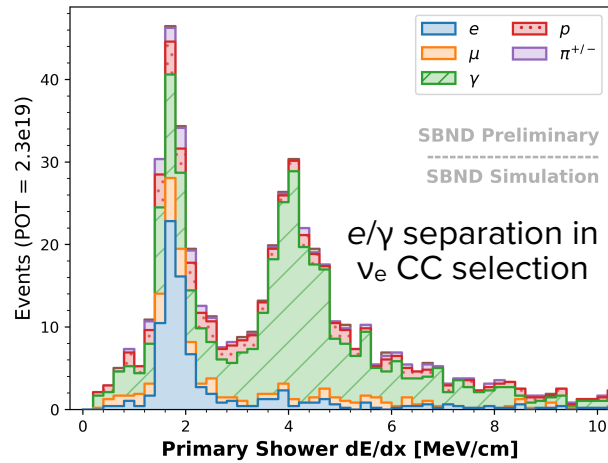
# Cross Section Measurements



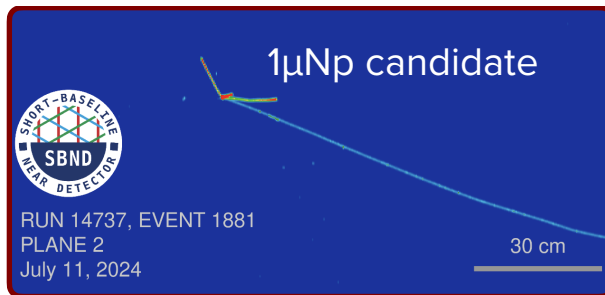
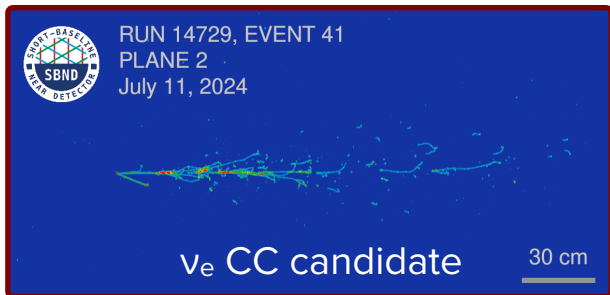
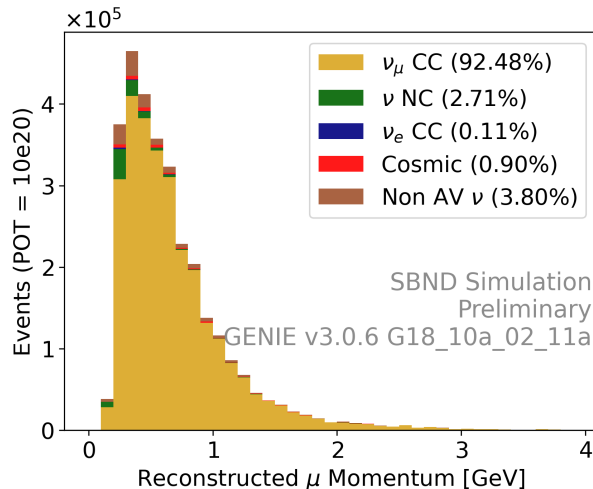
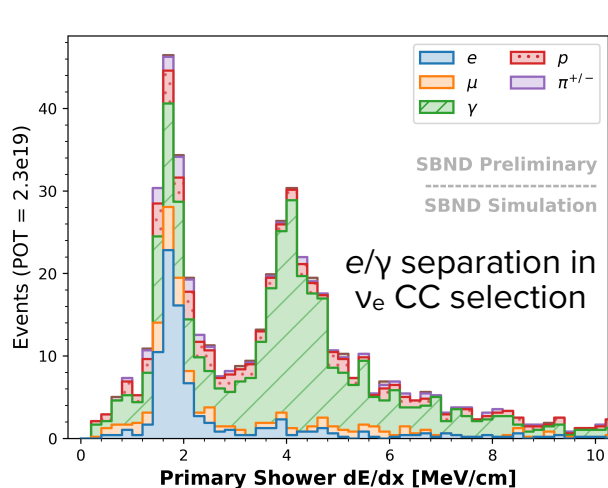
SBND expects  $\sim 6$  million  $\nu_\mu$  and 45,000  $\nu_e$  events in 3-year run  
 $\sim 2$  million  $\nu_\mu$  &  $\sim 15,000$   $\nu_e$  events already recorded!



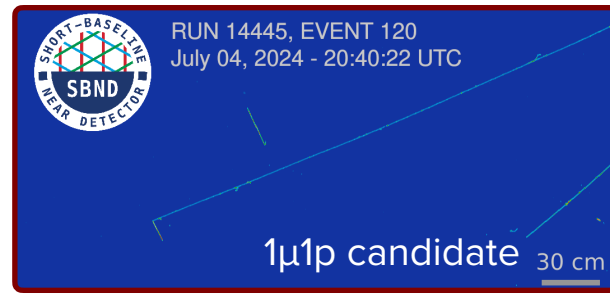
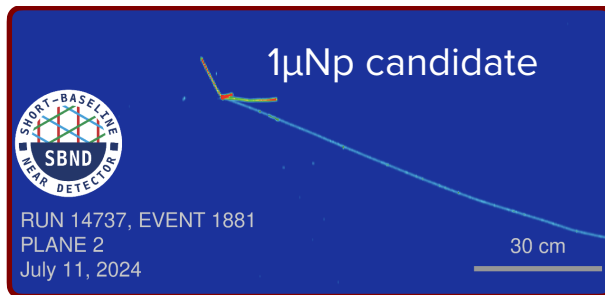
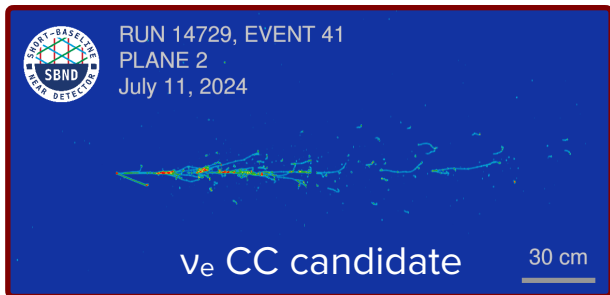
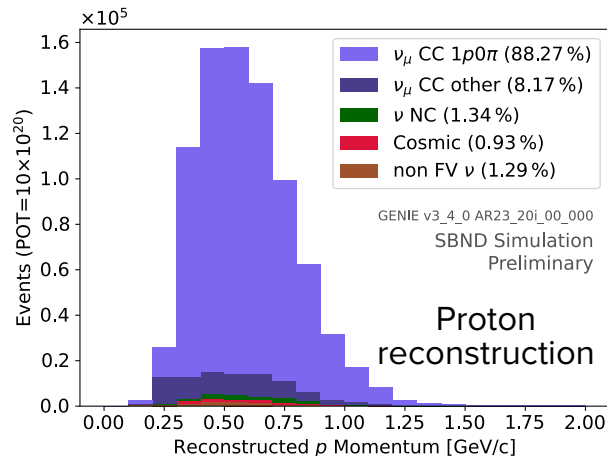
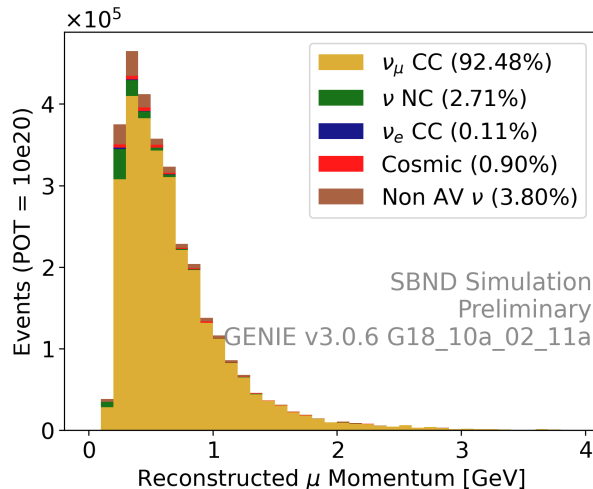
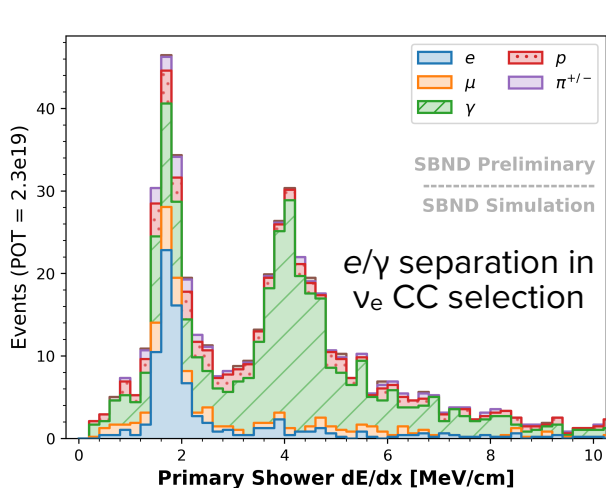
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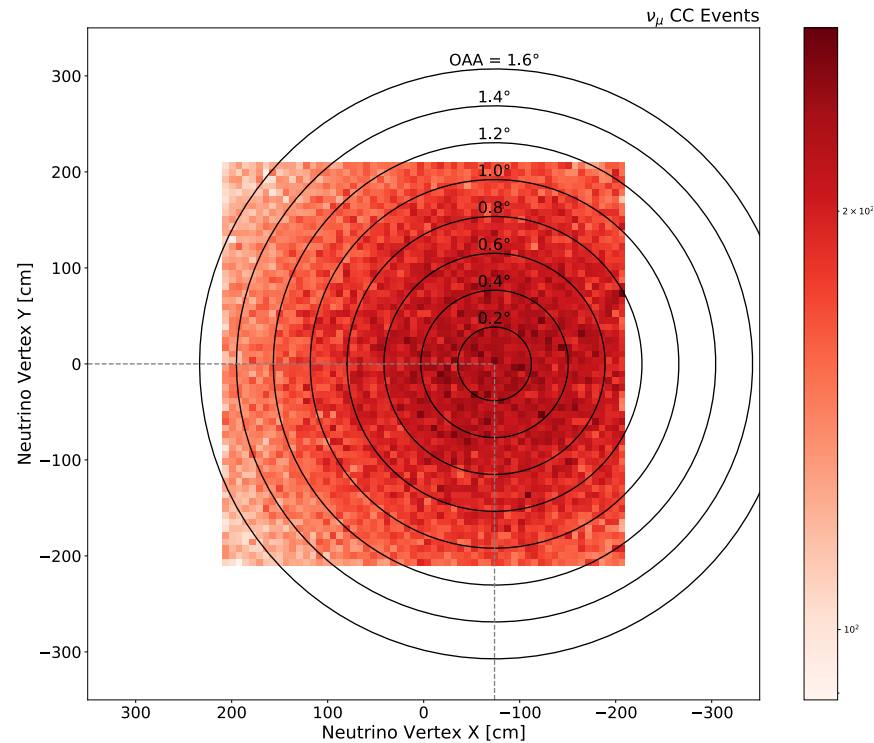
# Cross Section Measurements





# SBND-PRISM

Precision Reaction-Independent Spectrum Measurement



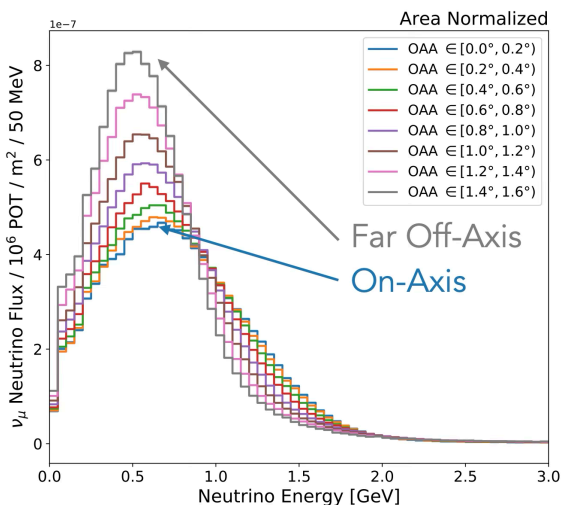
[arXiv:2504.00245](https://arxiv.org/abs/2504.00245)

# SBND-PRISM

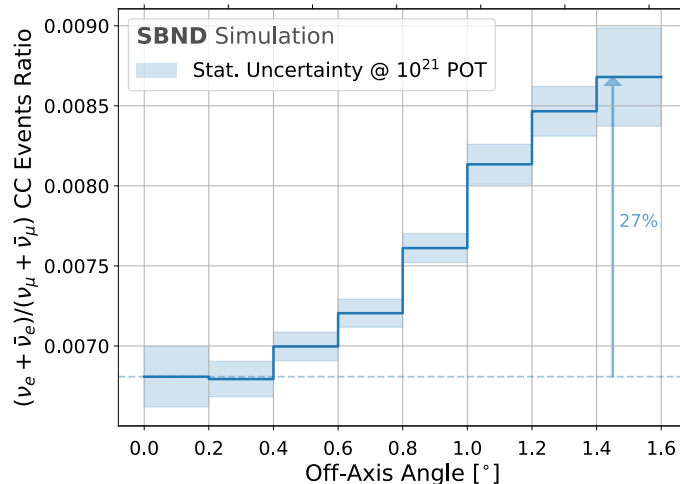
Precision Reaction-Independent Spectrum Measurement



PRISM enables flux characterization & background rejection due to changing  $\nu_\mu/\nu_e$  ratio

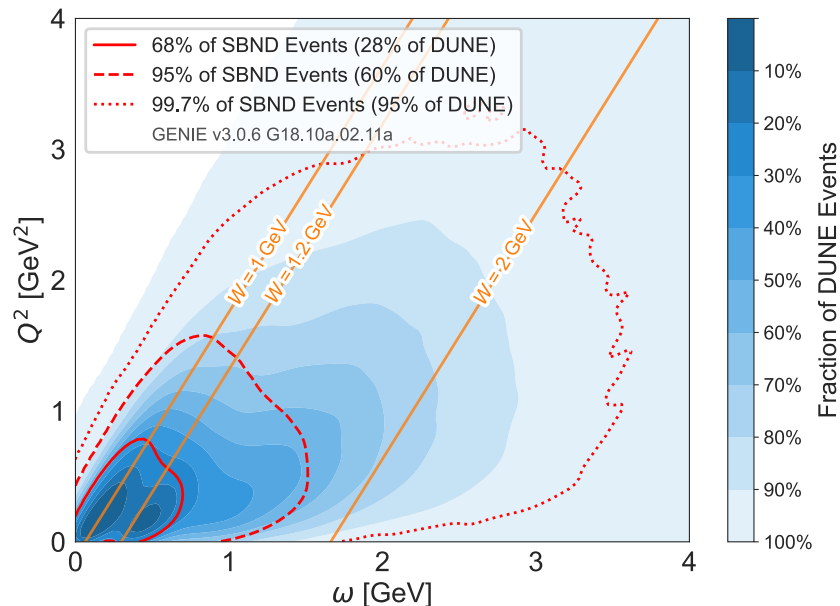
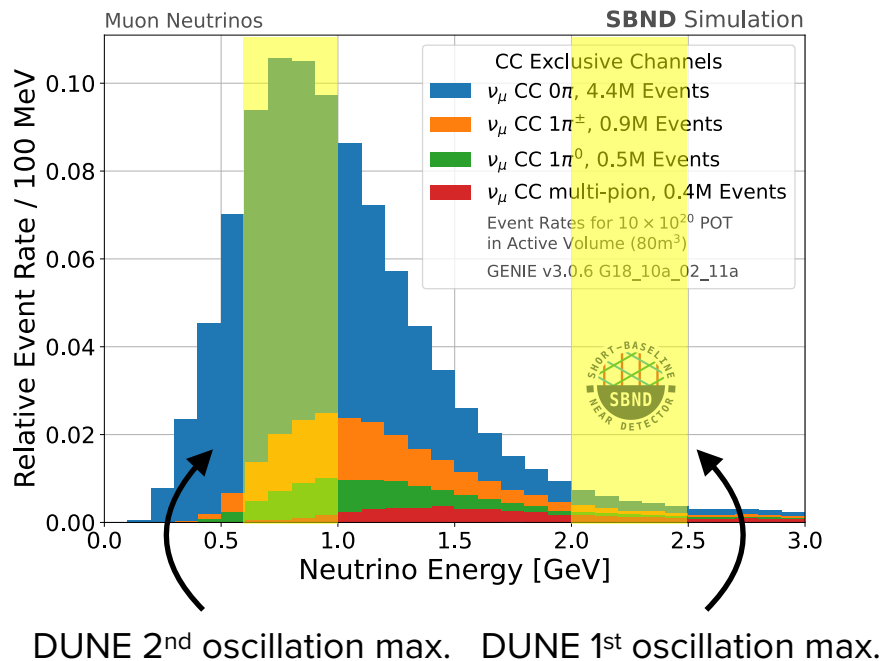


~200 MeV peak shift



~27% change in flavor ratio

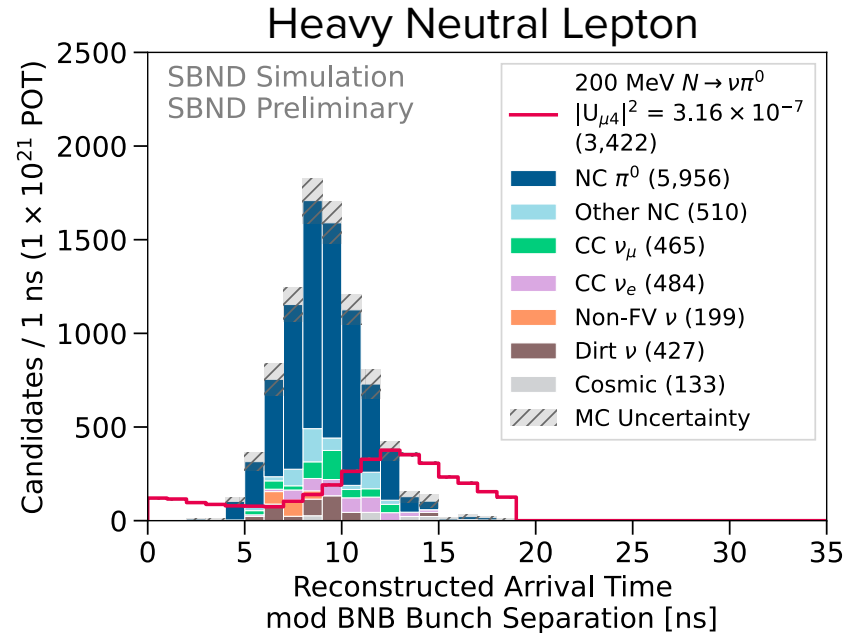
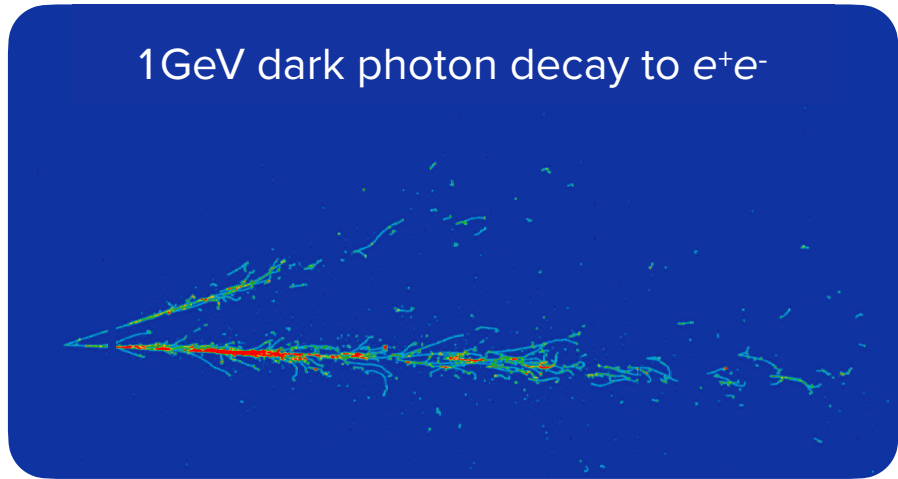
# SBND probes DUNE energies relevant for oscillations with good phase-space coverage



# Beyond Standard Model (BSM)



SBND expects competitive sensitivity to many BSM scenarios thanks to intense beam, precision timing & excellent PID



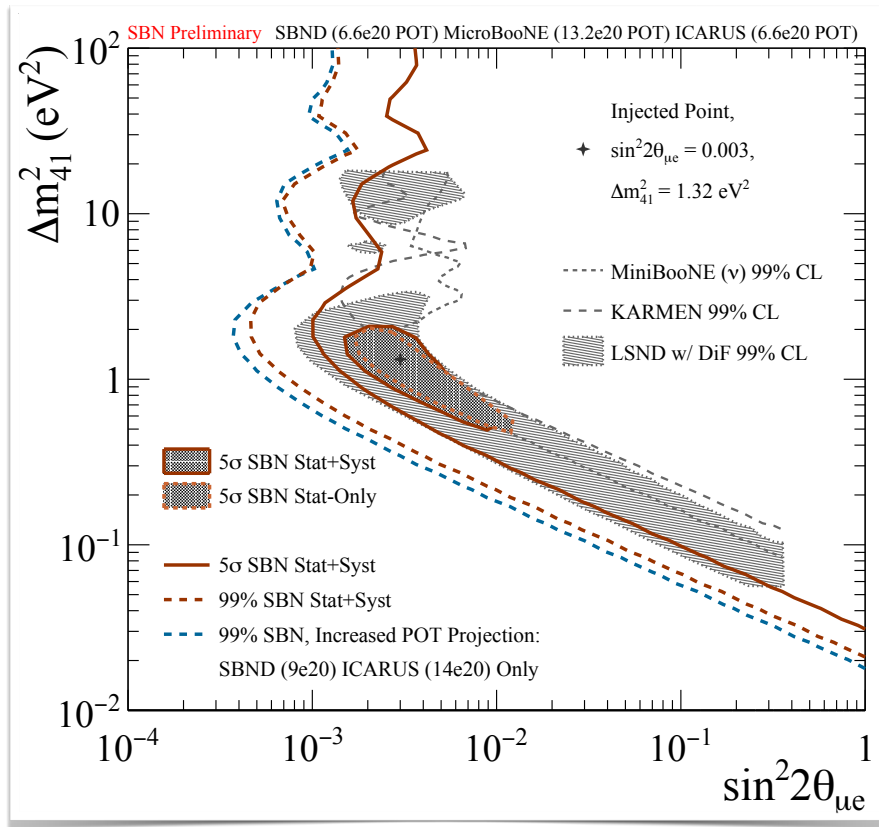


# $\nu_e$ Appearance with SBN



Combination of SBN experiments cover LSND/MiniBooNE favored parameter space for sterile 3+1 oscillations

SBND provides critical flux & cross section constraint necessary to reach the full potential of SBN program



# Summary

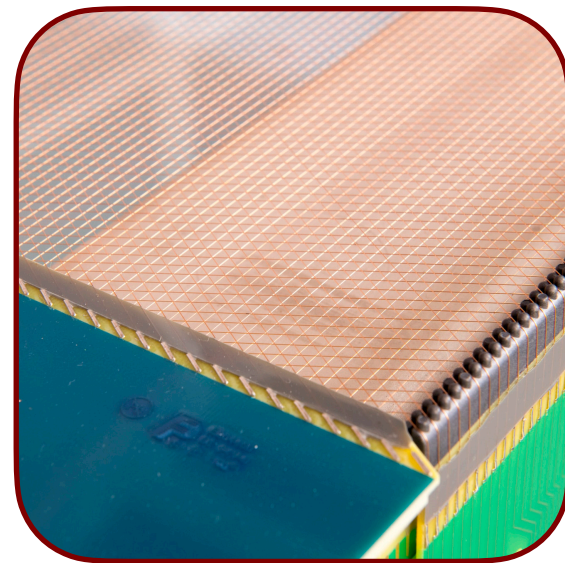
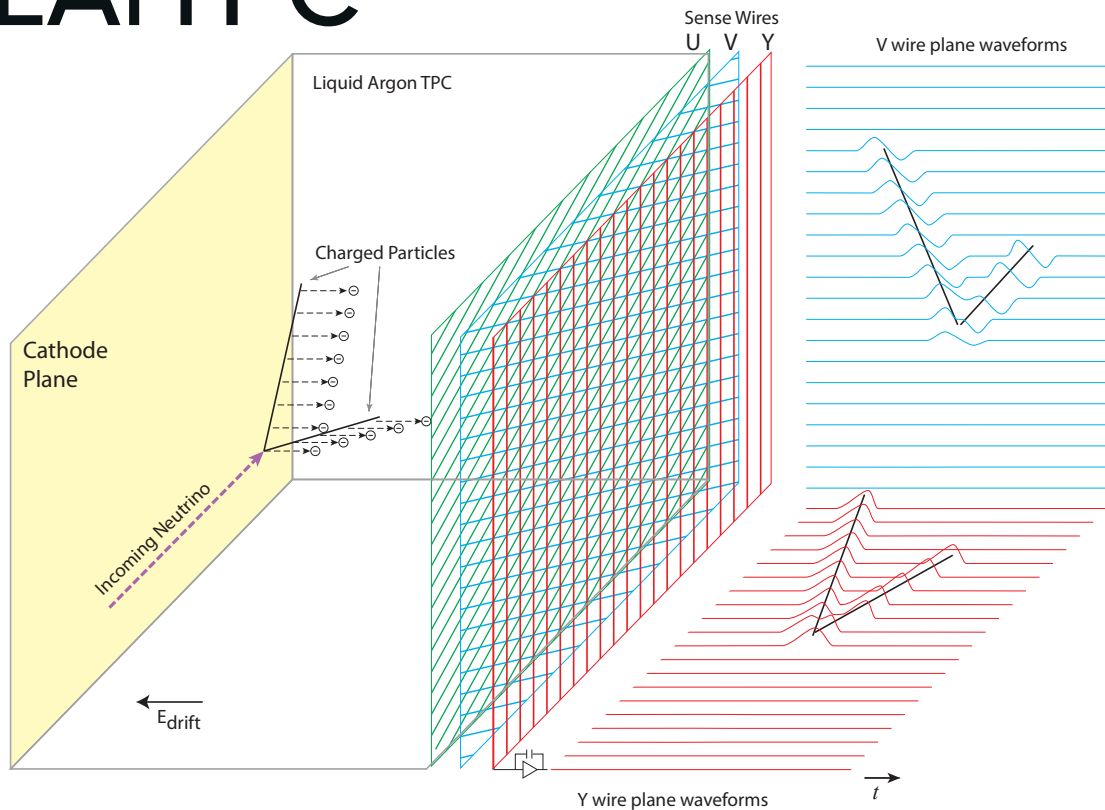


- SBND has collected the world's largest neutrino-argon interaction data set in its first run
- Excellent detector performance, well-understood calibrations
- Analysis tools & infrastructure are ready

Look forward to first results very soon!

Extra

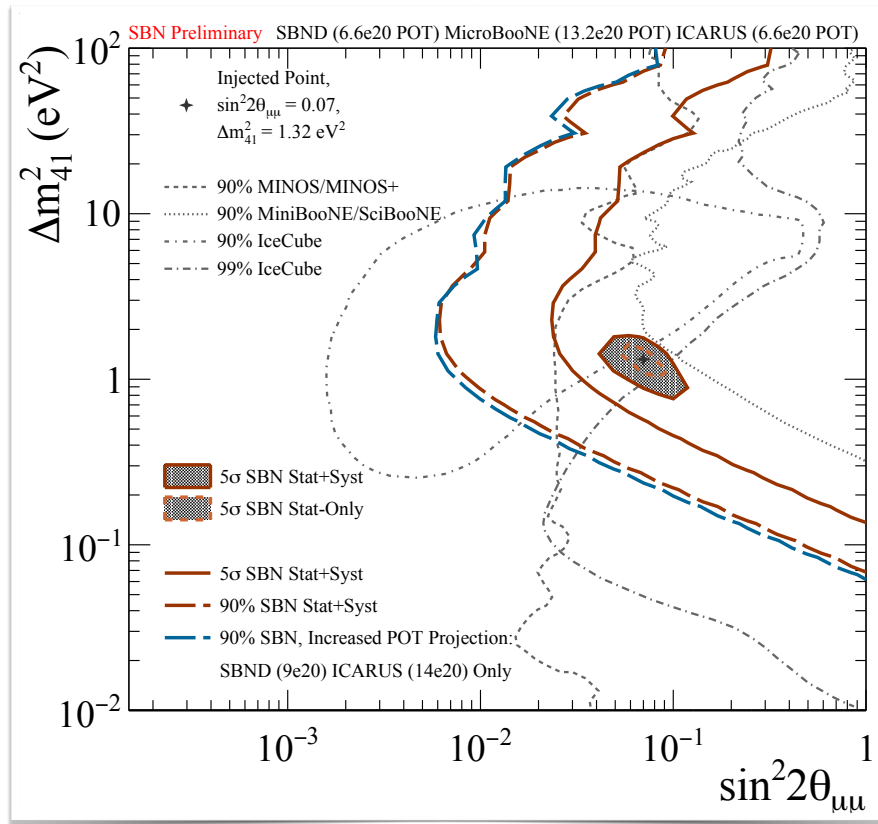
# LArTPC



Wire planes in SBND, 3 mm pitch



# $\nu_\mu$ Disappearance with SBN



# e-lifetime Stability



e-lifetime > 10 ms maintained throughout Run 1 (3 ms design)

