



# Status of the Short-Baseline Near Detector at Fermilab



EPS-HEP 2025 – Marseille

RUN 18255, EVENT 2008

9<sup>th</sup> July 2025

PLANE 2

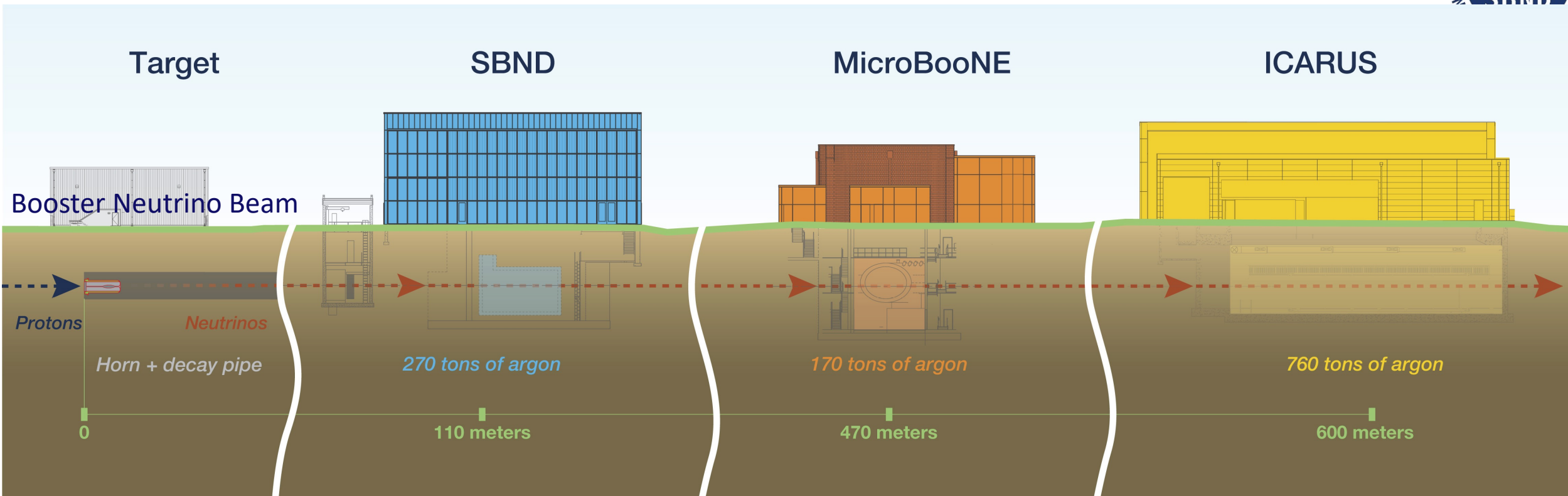
February 2025

Nicola McConkey, for the SBND collaboration

30 cm



# Short-Baseline Neutrino programme



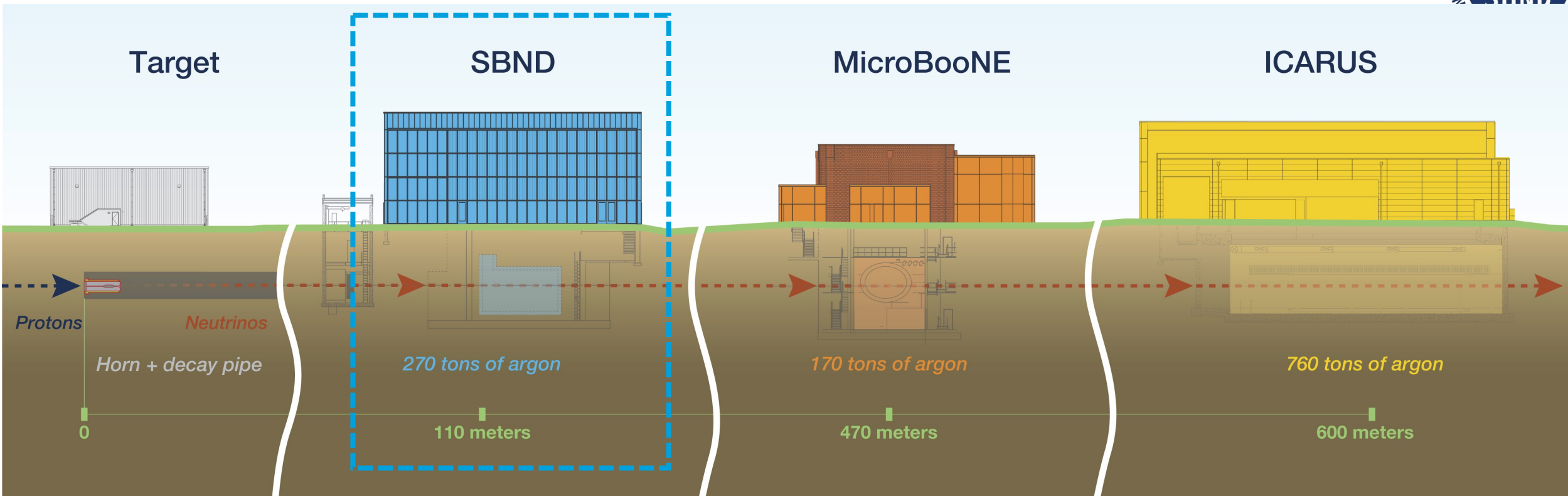
❑ Measures neutrino oscillations over 600m baseline

- Electron neutrino appearance
- Muon neutrino disappearance

❑ Search for eV-scale sterile neutrinos

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

# Short-Baseline Near Detector

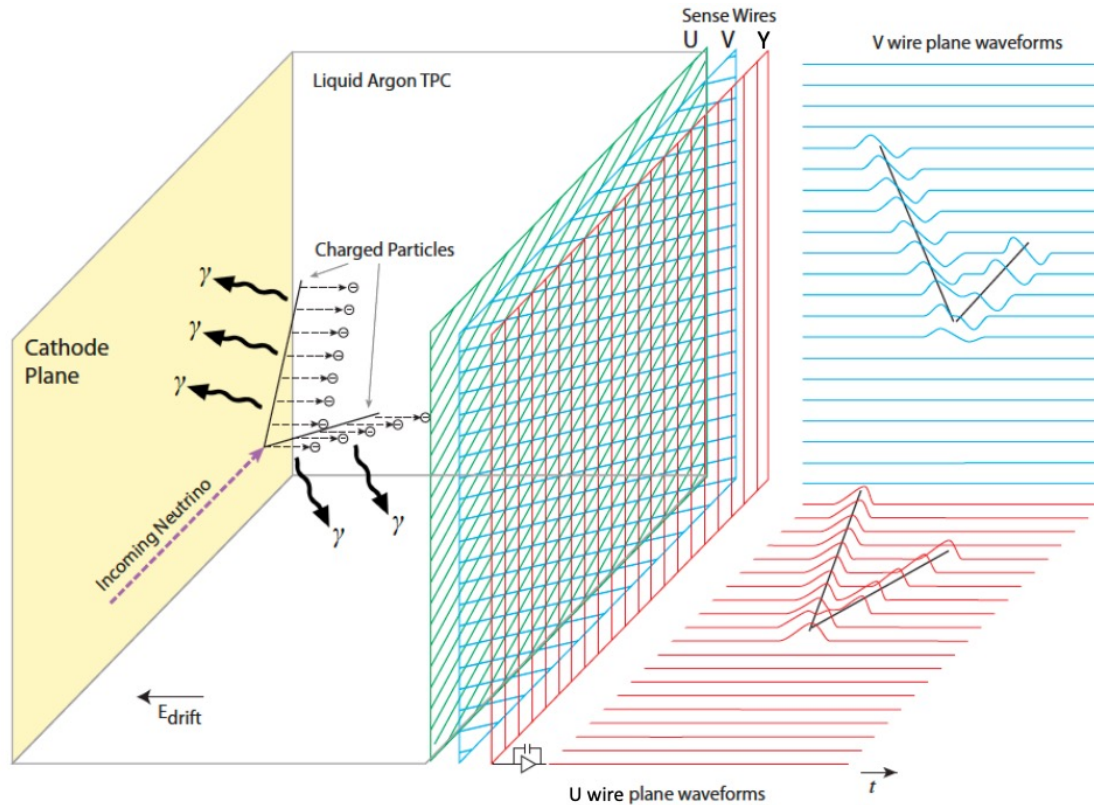


## SBND Physics goals

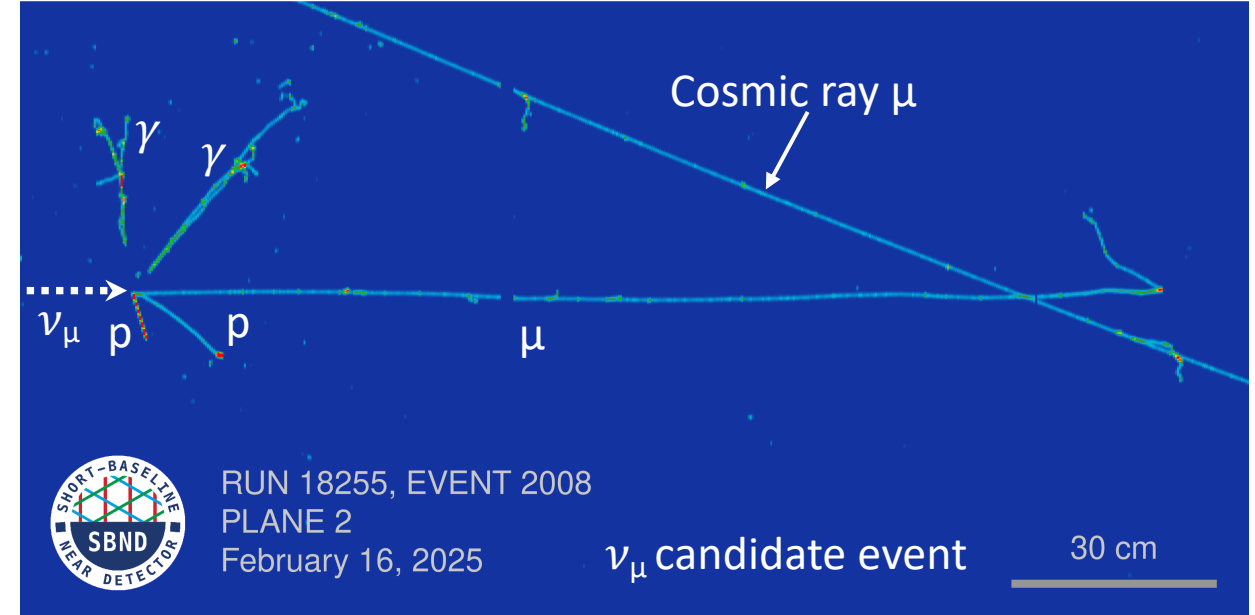
- ❑ Near detector for SBN oscillation measurements
- ❑ Neutrino interaction cross-section measurements
- ❑ Searches for Beyond Standard Model physics

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

# Liquid Argon Time Projection Chamber Operation



- ❑ Energy from particle interactions produce charge and light
  - Ionisation electrons are drifted to the readout plane
  - Scintillation photons are collected to give calorimetry and timing information
- ❑ Millimetre level 3D position information across entire detector volume



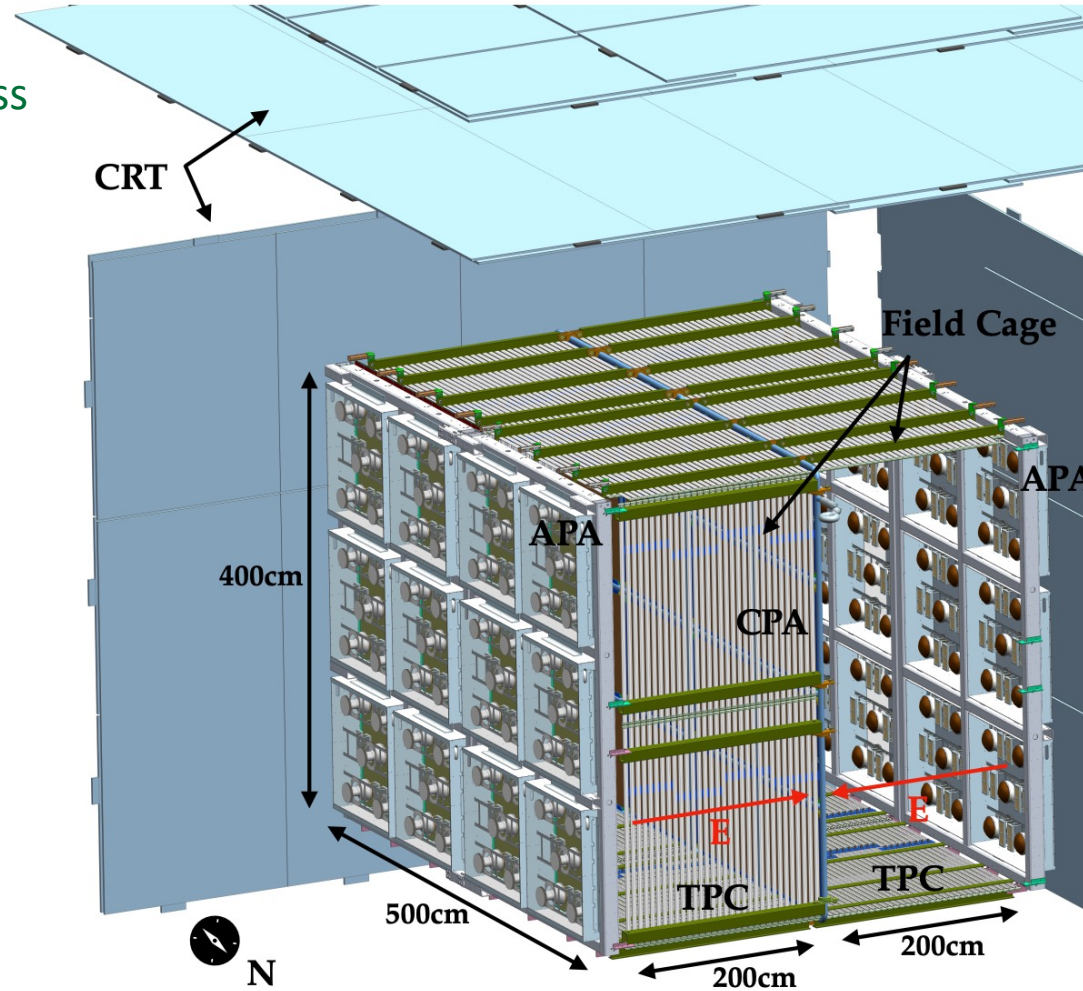


# SBND Detector Overview



## ❑ Liquid Ar TPC

- 112 ton active mass
- 4x4x5m active volume
- Two drift volumes

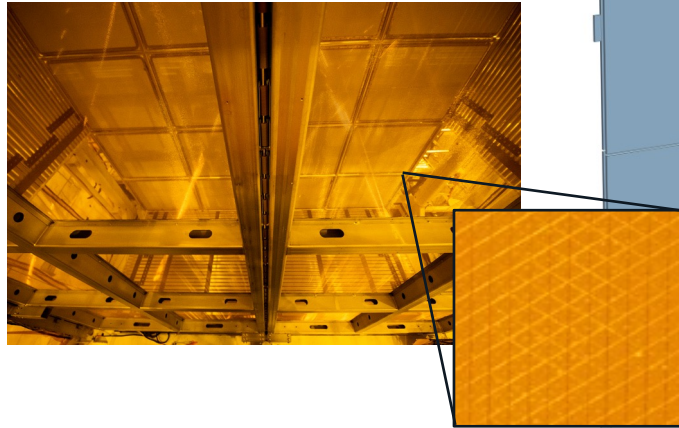


# SBND Detector Overview



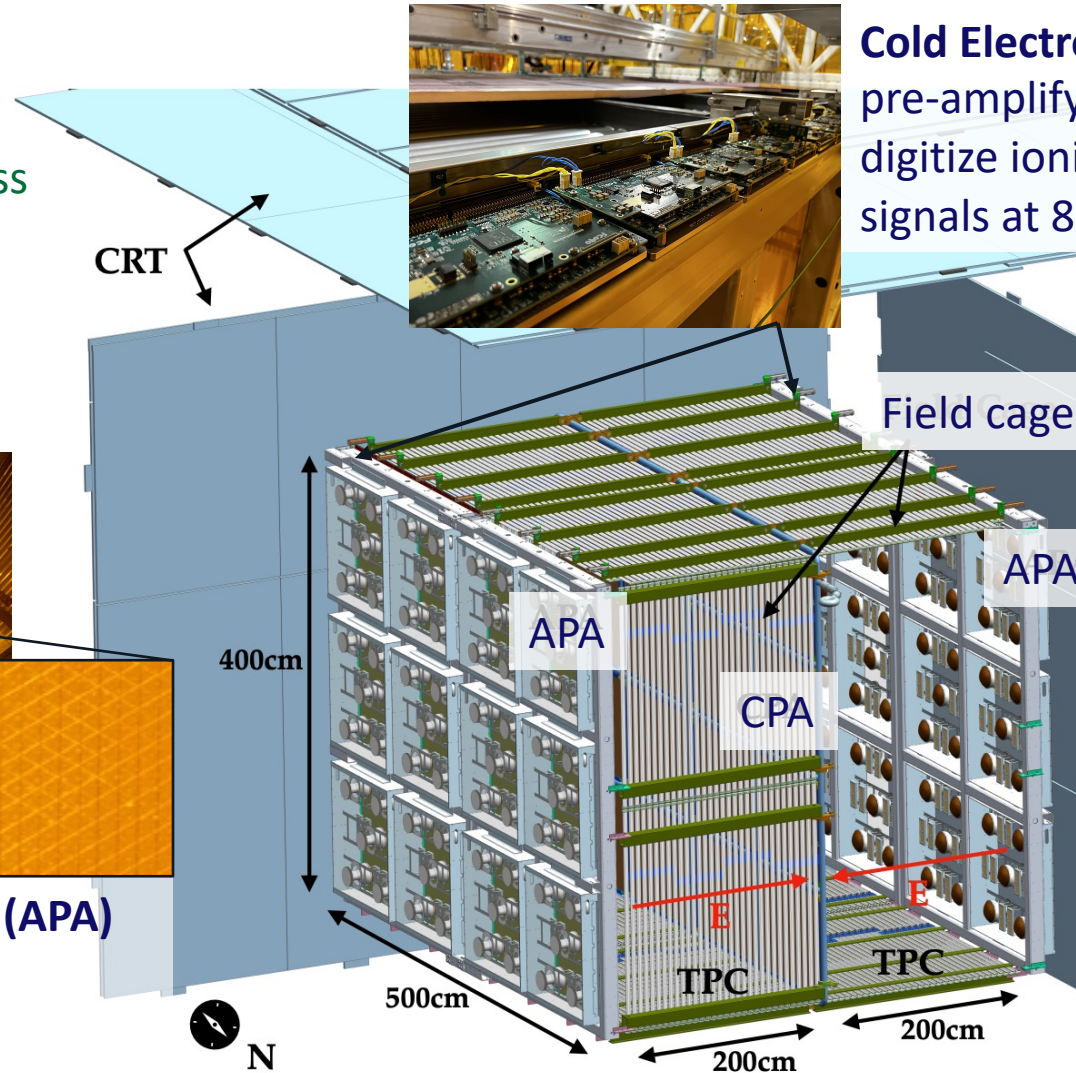
## ❑ Liquid Ar TPC

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- 4x4x5m active volume
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## 2 x Anode Plane Assembly (APA)

- 3 wire planes  $0, \pm 60^\circ$
- 3mm wire spacing
- 3mm wire plane spacing
- 11,264 wires per plane



**Cold Electronics**  
pre-amplify and  
digitize ionisation  
signals at 89K



**Field cage**  
ensures uniformity  
of 500V/cm E-field  
across drift region



**Cathode plane (CPA)**  
biased at -100kV

JINST 15 (2020) P06033  
[2002.08424]



# SBND Detector Overview

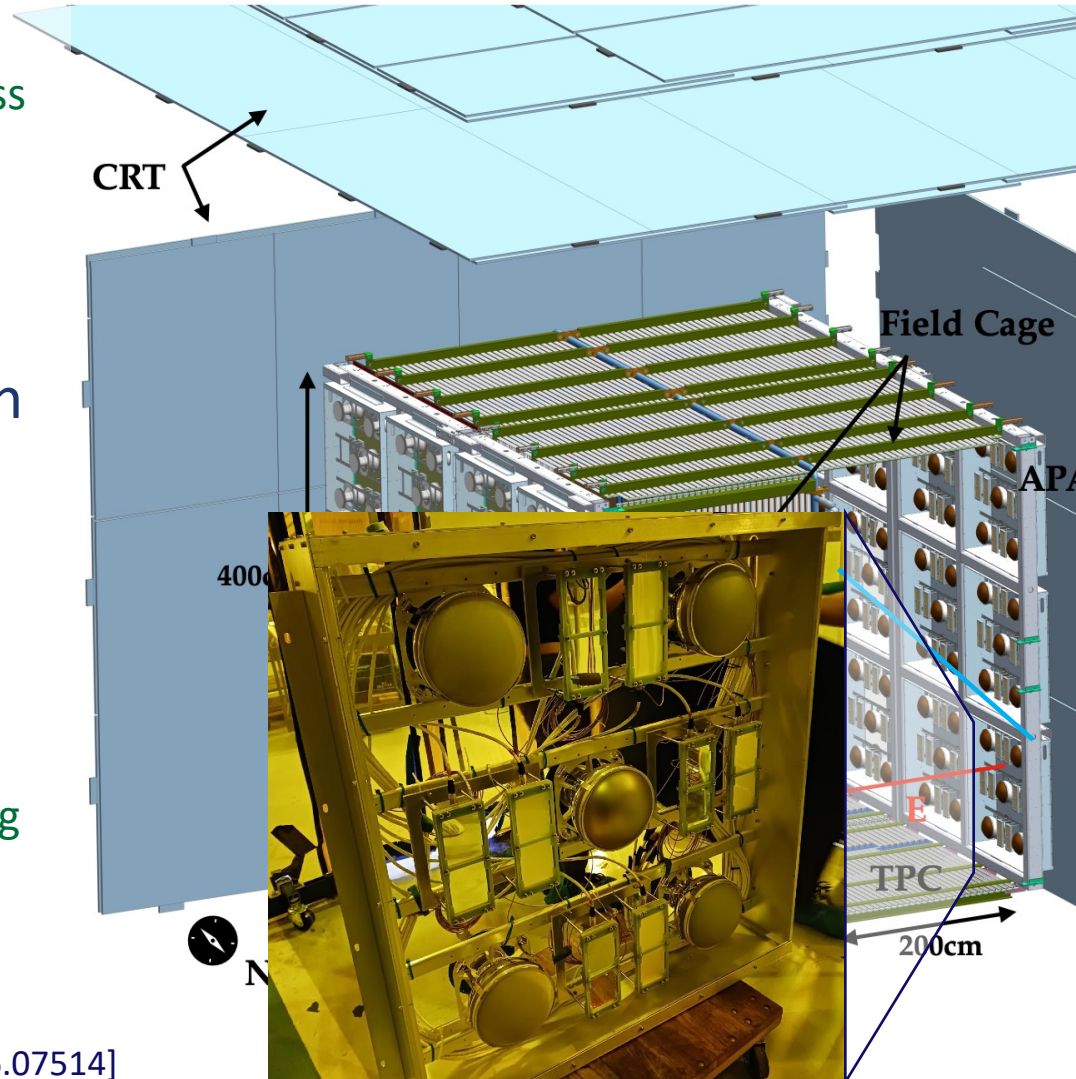


## □ LAr TPC

- 112 ton active mass
- 4x4x5m active volume
- Two drift volumes

## □ Photon Detection System

- 120 8" photomultiplier tubes
- 192 X-ARAPUCAs
- wavelength shifting reflective foils



**Wavelength shifting reflective foils** at cathode to increase uniformity of light yield



**Light detection system sensitive to VUV and visible light:**

- 80% of PMTs coated with wavelength shifter (TPB)
- 20% of PMTs uncoated
- 50% of X-ARAPUCAs VUV/visible sensitive

Eur. Phys. J. C 84 (2024) 1046 [2406.07514]



# SBND Detector Overview



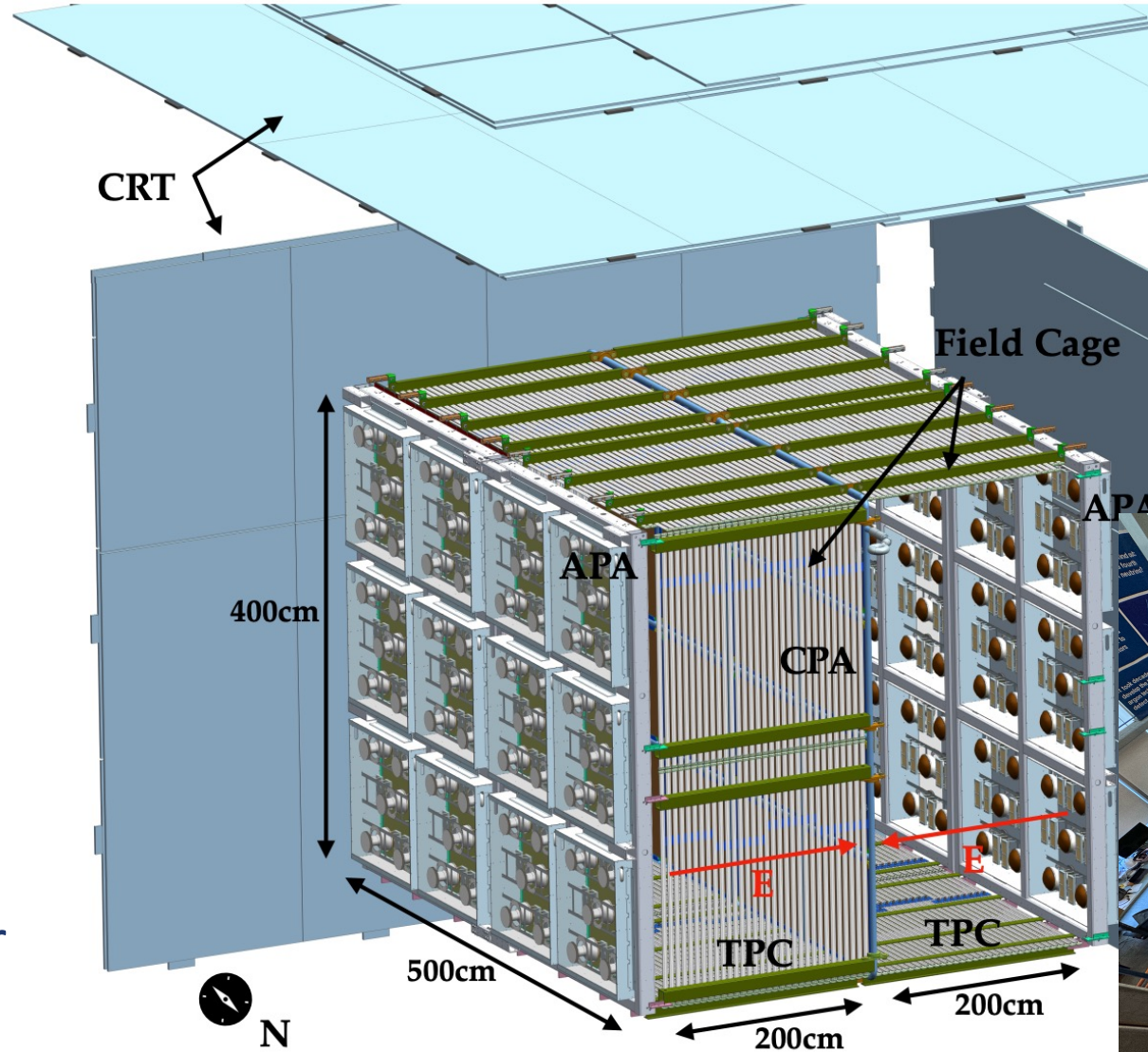
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## □ Photon Detection System

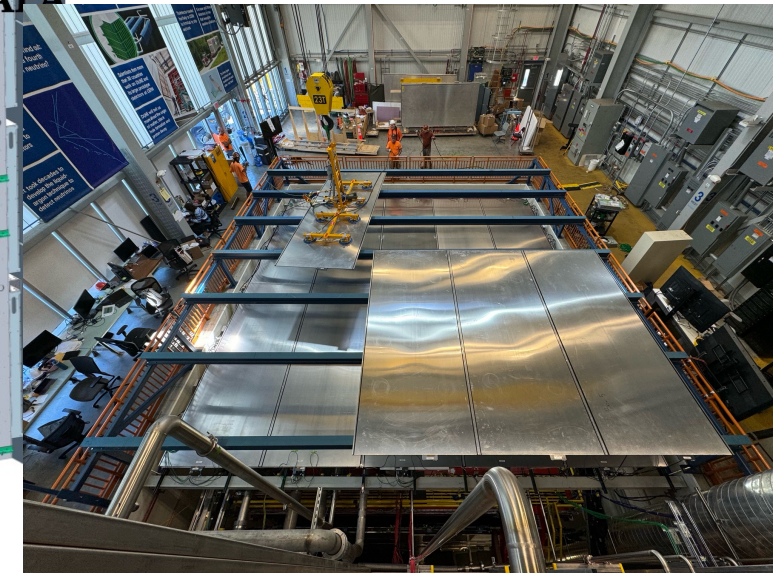
- 120 8" photomultiplier tubes
- 192 X-ARAPUCAs
- wavelength shifting reflective foils

## □ Cosmic Ray Tagger



**Seven taggers surrounding cryostat:** two top, four side, one bottom

- Two layers of perpendicular scintillator strips
- Tags entering and exiting particles with **ns timing** and **cm position resolution**





# SBND journey to operations



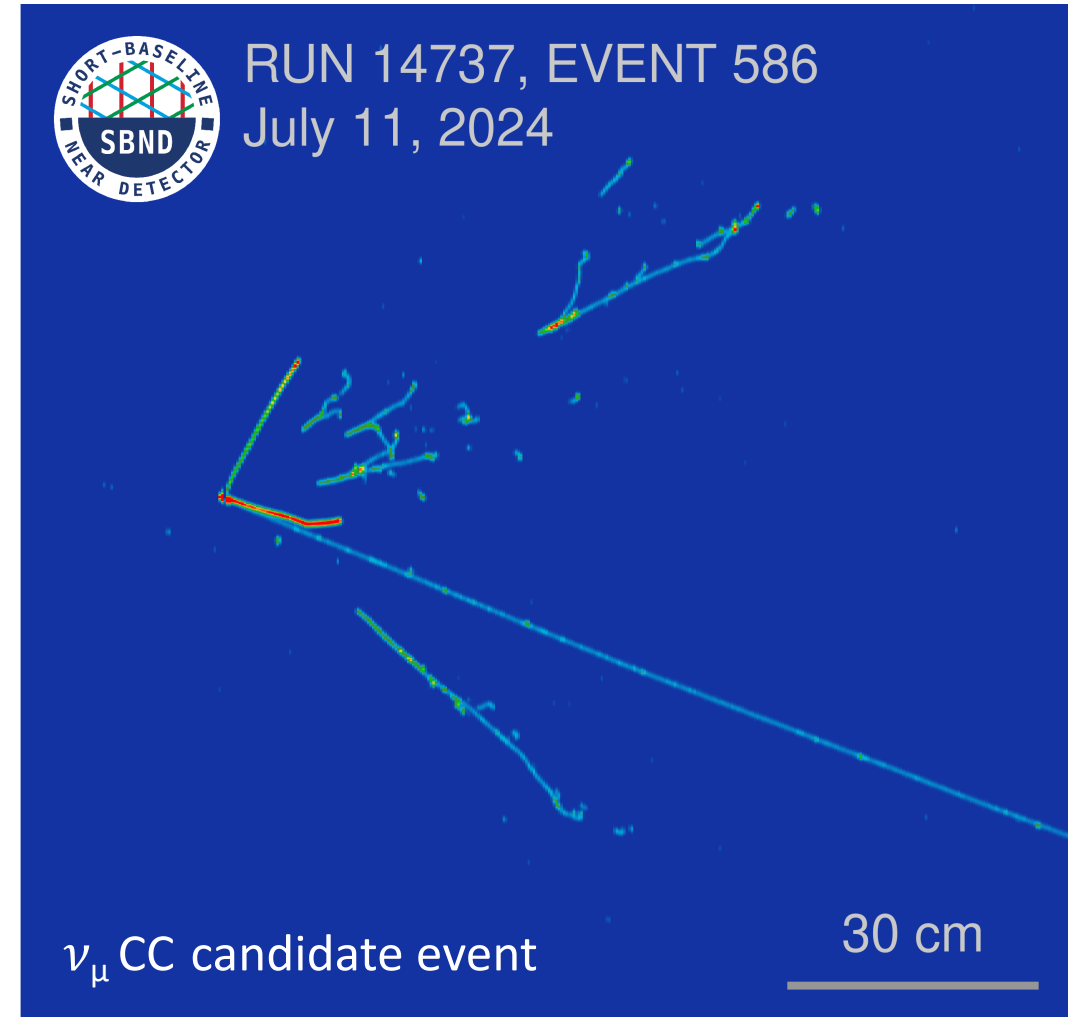
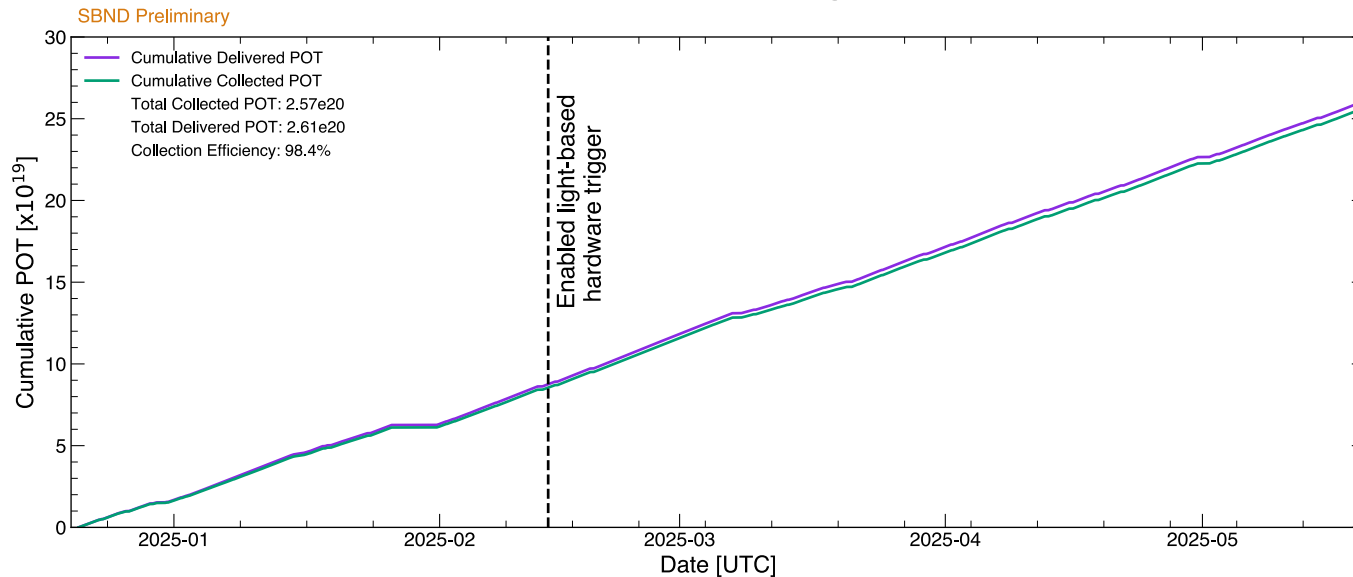


# Current status



- ❑ SBND is collecting neutrino data in the Booster Neutrino Beam at Fermilab
- ❑ Run 1 data collection ongoing!
  - 3.25e20 POT collected
  - **98.6% collection efficiency**

## SBND Cumulative POT through May 20, 2025





RUN 14729, EVENT 41  
PLANE 2  
July 11, 2024

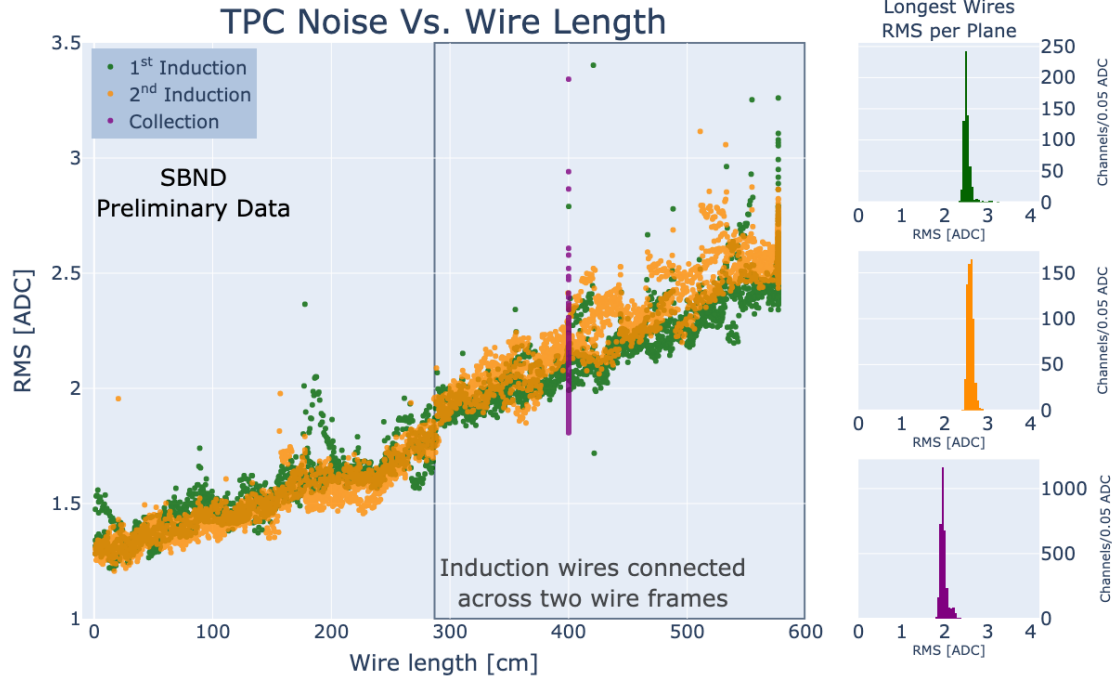
# SBND Detector Performance



30 cm



# TPC Noise Performance



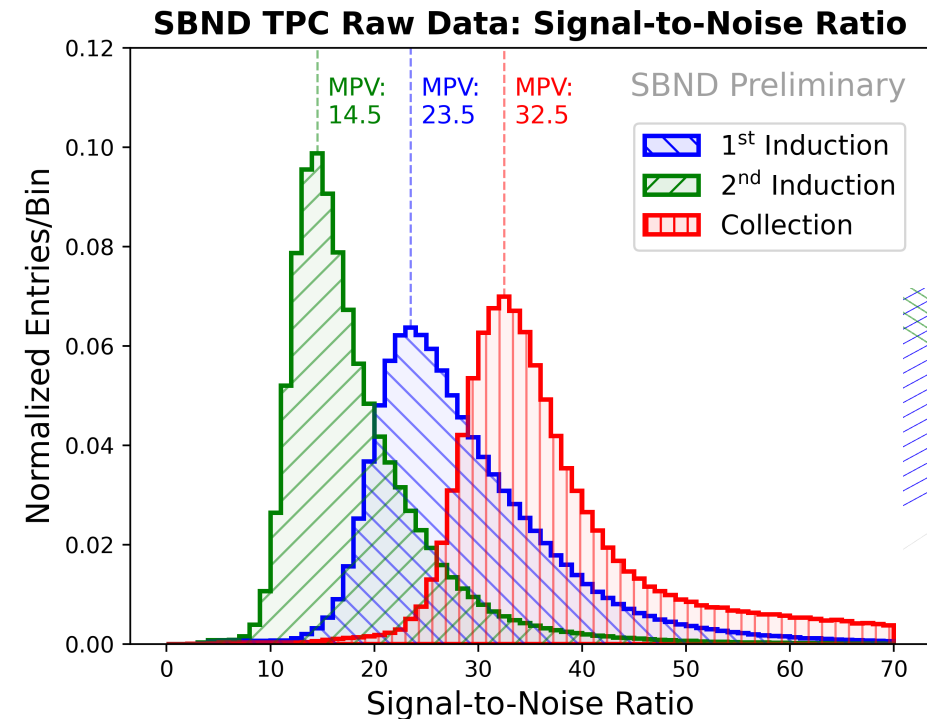
## Little to no sources of excess noise

- Noise dependent on wire length
- 4m wire has ~2ADC (~380ENC)

## Without noise filtering SNR is very high

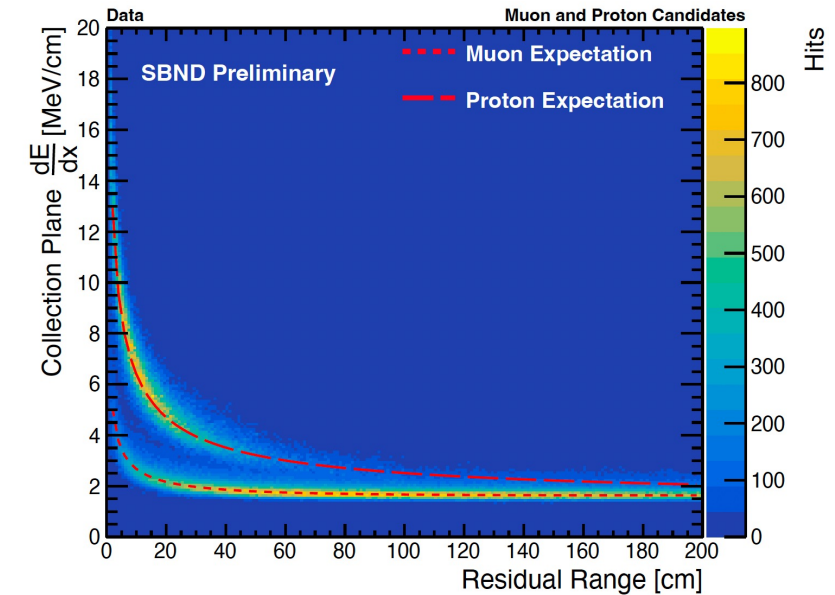
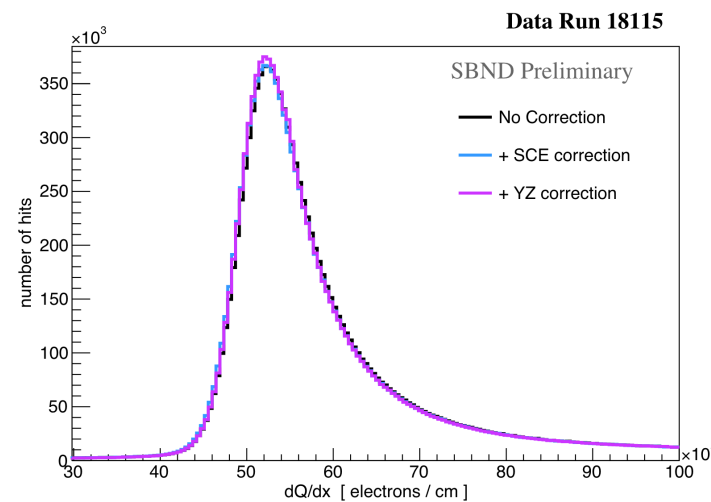
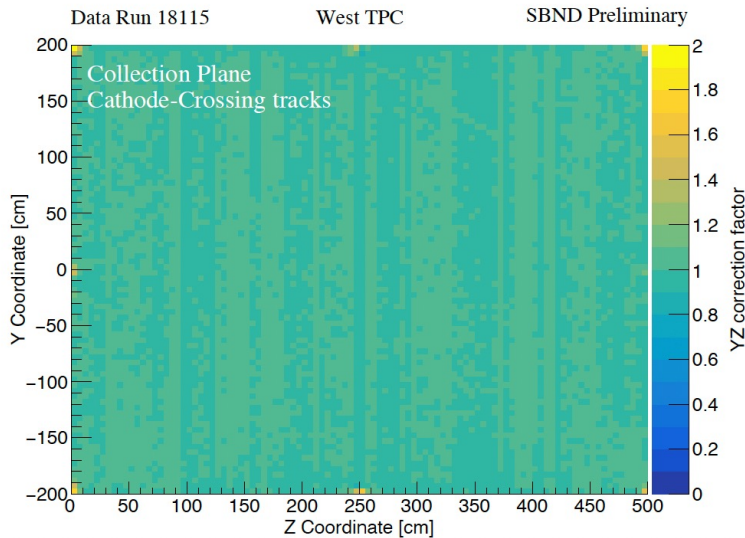
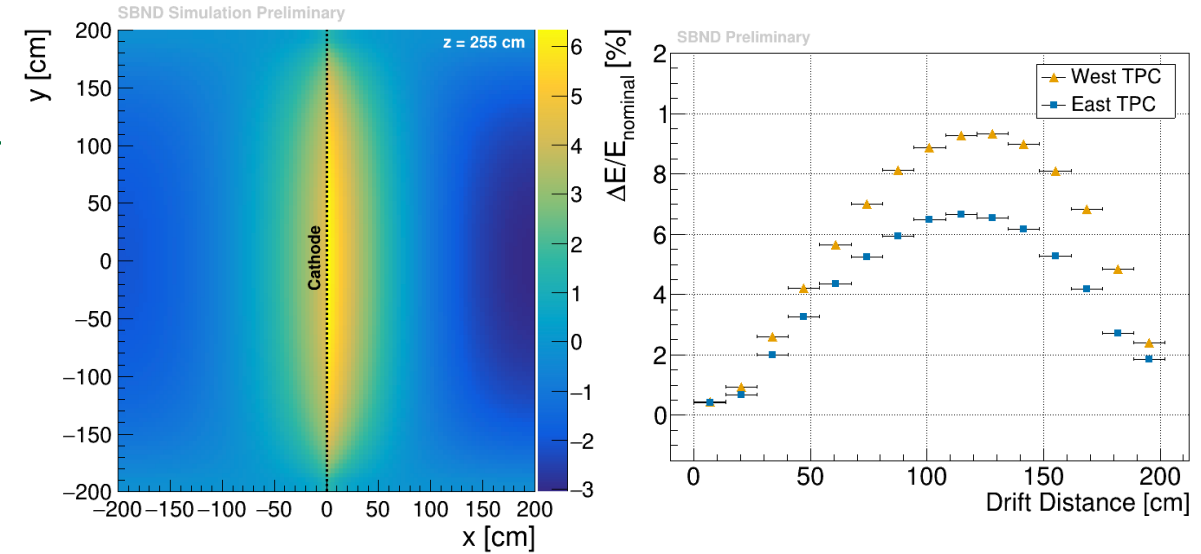
- Comparable to previous LArTPCs **after** noise filtering
  - Signal = wire waveform peak from cosmic ray muons
  - Noise = rms

## Signal processing (noise filtering, electronics response calibration, E field response) improves uniformity further

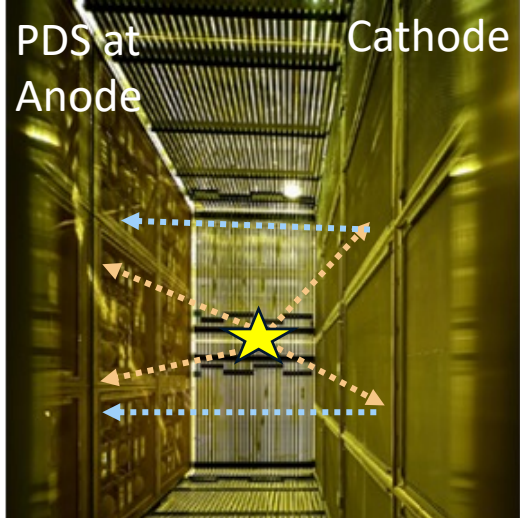


# TPC Calibration measurements

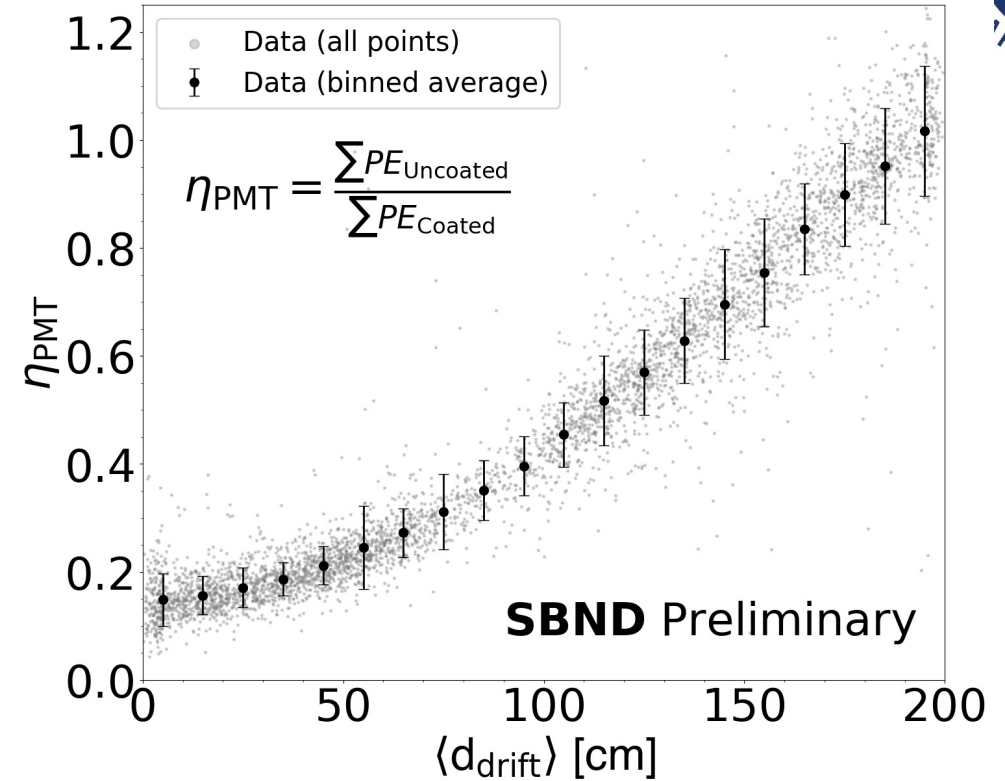
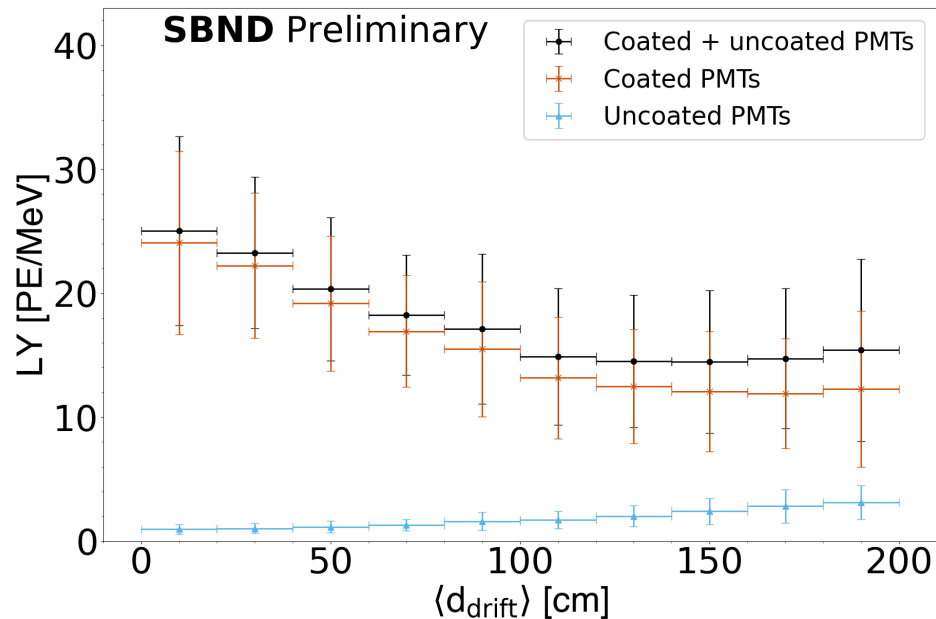
- ❑ TPC non-uniformities: Space charge
  - E-field distortions of up to 6%
  - Average space charge effects are <1cm across the detector
- ❑ TPC non-uniformities: YZ corrections (across wire planes)
- ❑ Charge-scale calibrations  $dE/dx$ 
  - muon and proton show good agreement with theoretical predictions
- ❑ Electron lifetime >10ms (8x max drift time)



# PDS Status



- ❑ Primary scintillation light is measured by coated PMTs
- ❑ VUV light reflected off cathode is wavelength shifted light is measured by uncoated PMTs
- ❑ Excellent timing resolution



- ❑ Light yield as a function of drift position for coated and uncoated PMTs

- ❑ Position reconstruction from light!

- $\eta_{\text{PMT}}$  is a proxy for drift position

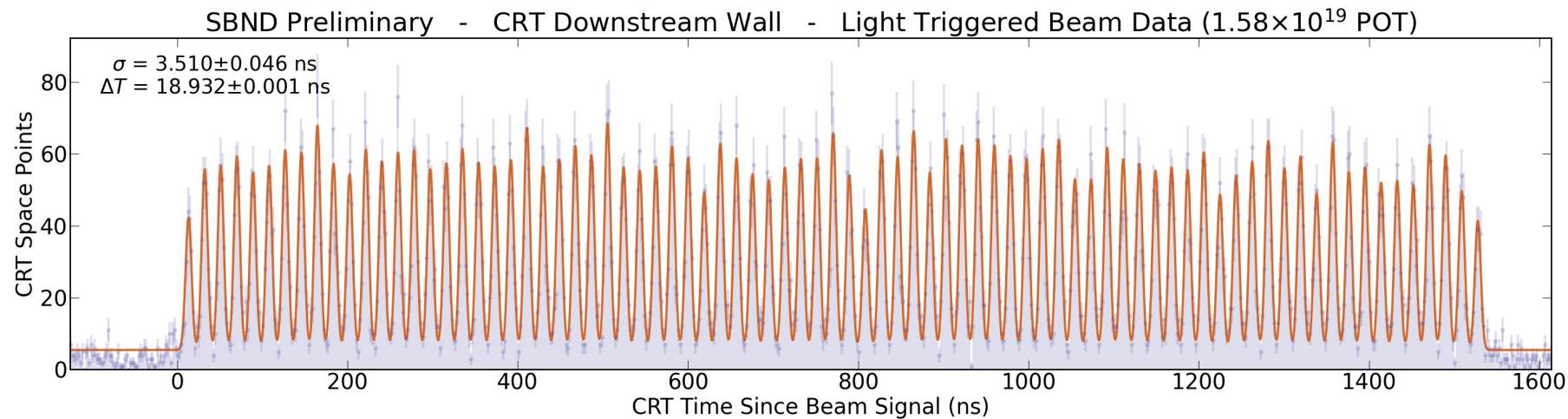
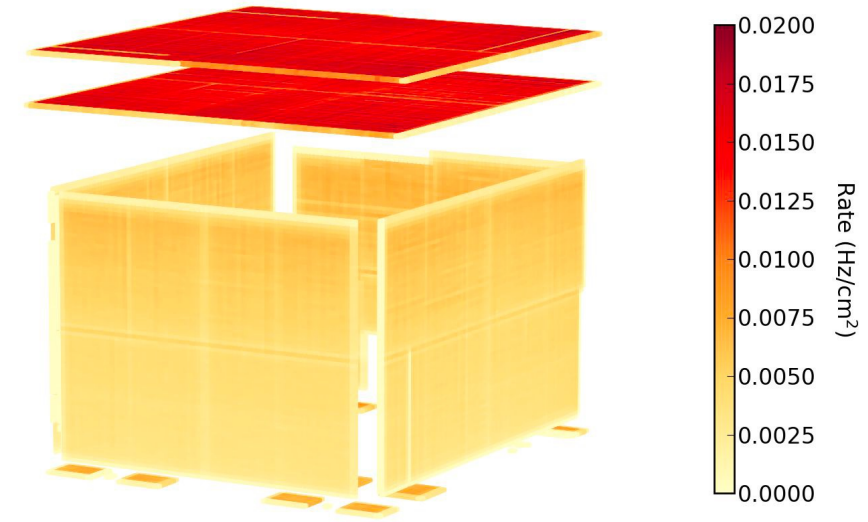
NEW!!



- ❑ Cosmic ray tagging is important for **background rejection** in many analyses, and for **calibration studies**
- ❑ **Nanosecond timing resolution** of CRT demonstrated in data – beam bucket structure



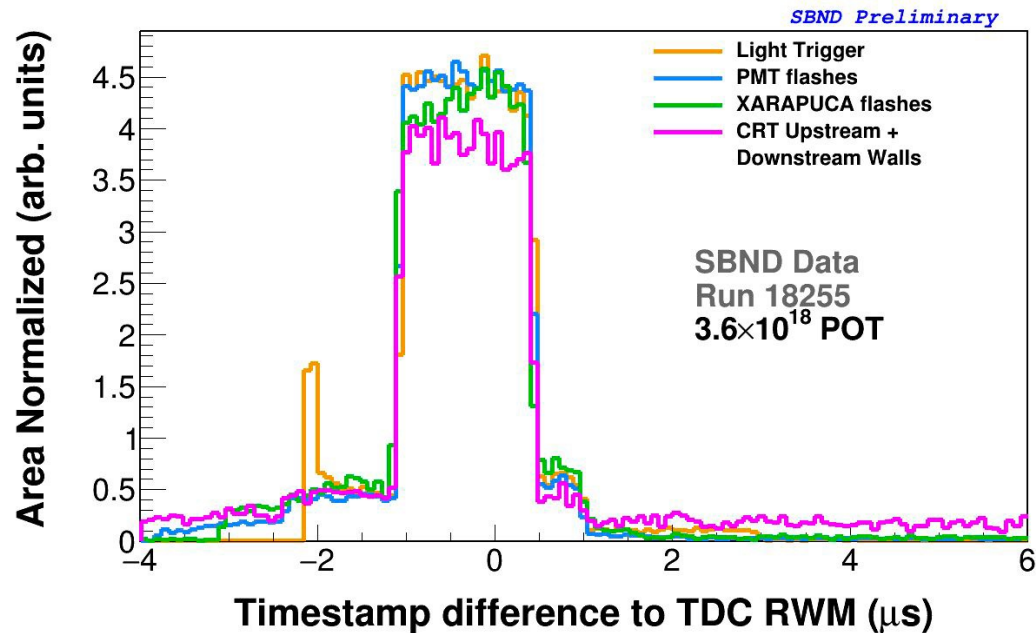
SBND Preliminary  
CRT Off-Beam Data



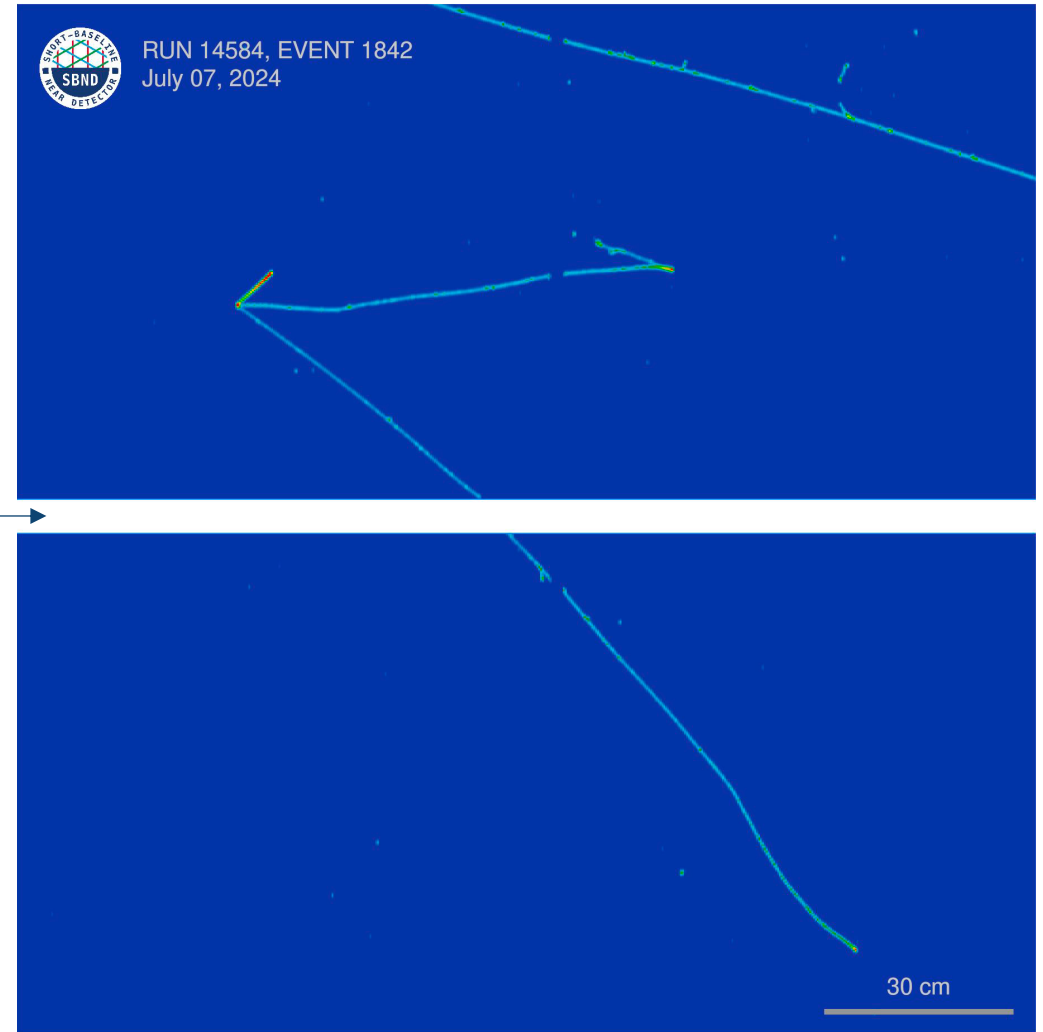
# Three complementary systems working together



- ❑ Synchronisation of PDS, CRT and trigger demonstrated by seeing beam activity concurrently
- ❑ TPC event displays consistent with in-time interactions



Cathode →





RUN 14548, EVENT 3455  
July 07, 2024

# SBND Physics

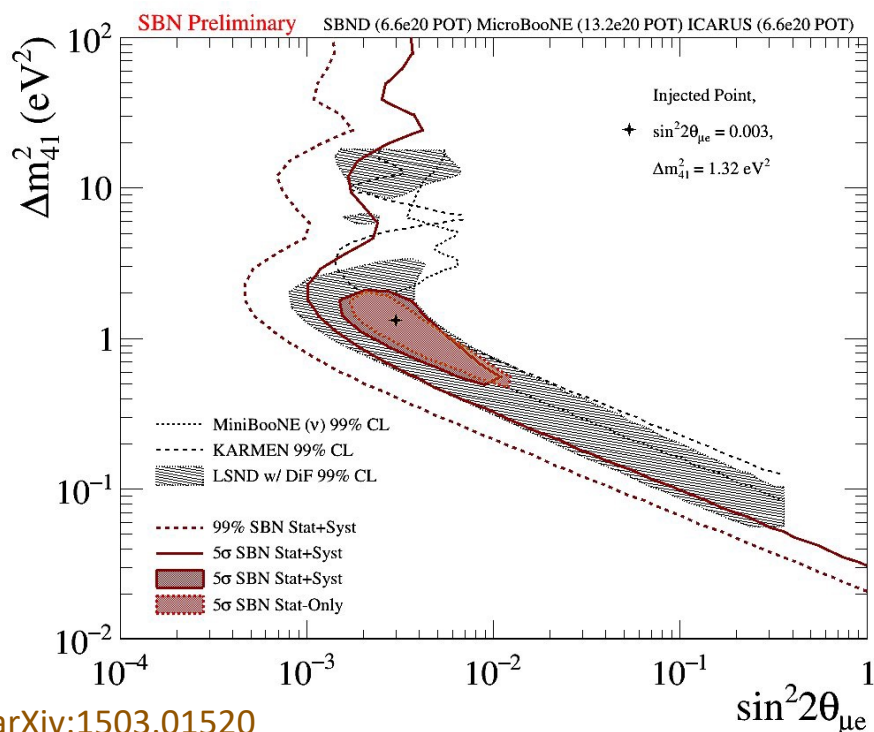
30 cm



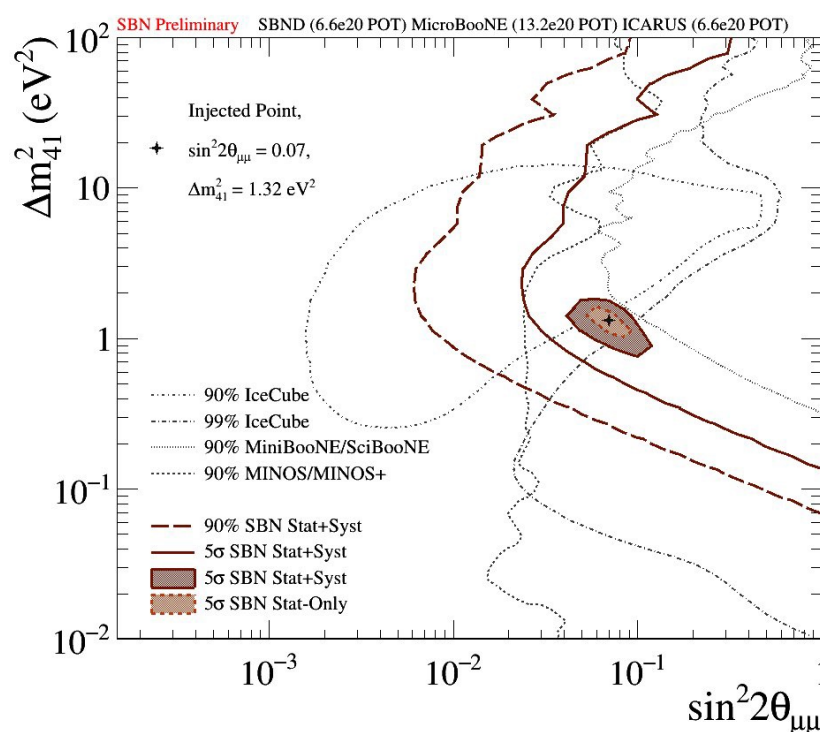
## ❑ Sterile neutrino searches at eV scale

- SBN covers most parameter regions favoured by previous measurements at **5 $\sigma$  confidence level**
- **Complementary measurements in different modes** important for interpreting sterile neutrino oscillations

$\nu_e$  appearance



$\nu_\mu$  disappearance



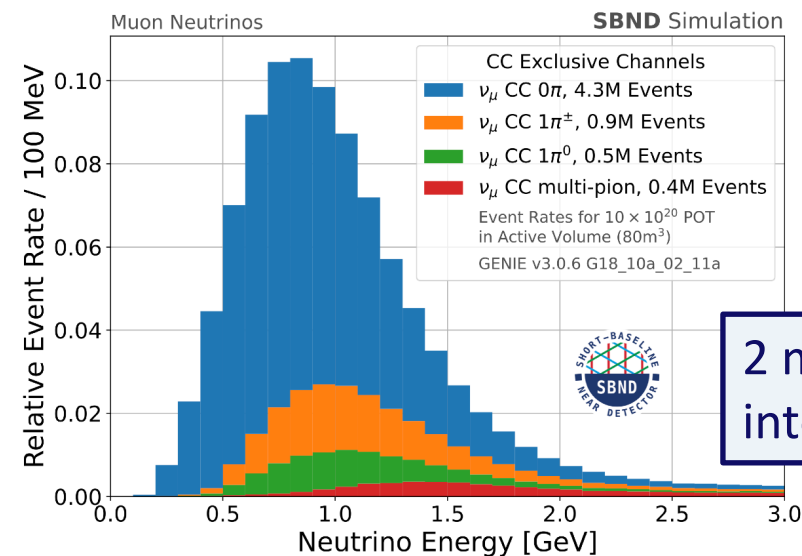
## ❑ Near detector data is essential for performing a **broad, definitive test of the light sterile neutrino hypothesis**

- Flux and cross-section constraints
- Detector similarities help to constrain systematic uncertainties to %-level

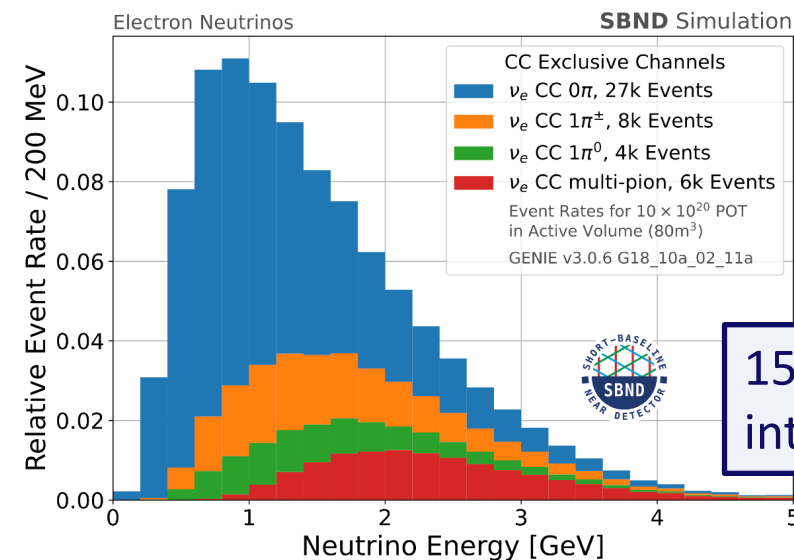
# SBND Interaction physics



- ❑ SBND is an ideal place to study neutrino interaction physics!
  - SBND already has the highest statistics sample of  $\nu$ -Ar data
  - SBND expects a data set 20-30x larger than current global neutrino-argon dataset
- ❑ Will measure  $\sim 10\text{M}$  neutrinos over expected data taking
  - Muon neutrino beam peak energy  $\sim 0.8\text{GeV}$
  - Electron neutrino contamination at 0.5% level
- ❑ Study **nuclear effects in neutrino interactions** on argon nuclei with unprecedented precision
  - High interaction rate and LAr TPC technology allows precision measurements of exclusive event topologies
  - Much needed testing and validation of nuclear interaction models
- ❑ Big impact for future LAr experiments



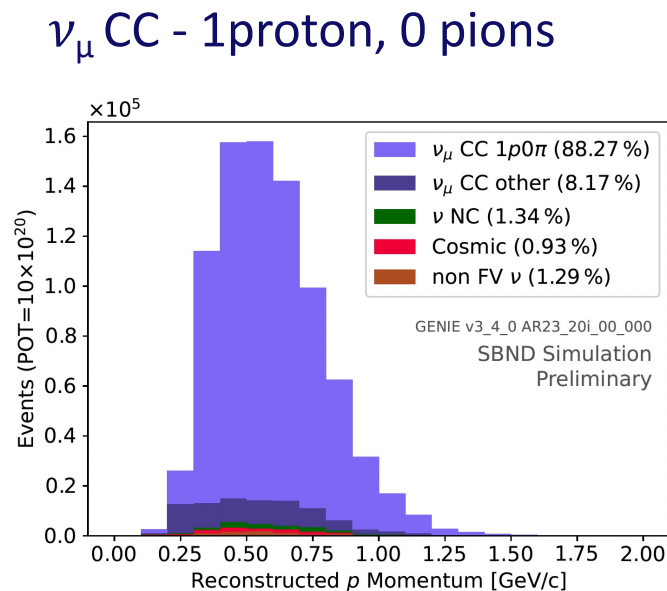
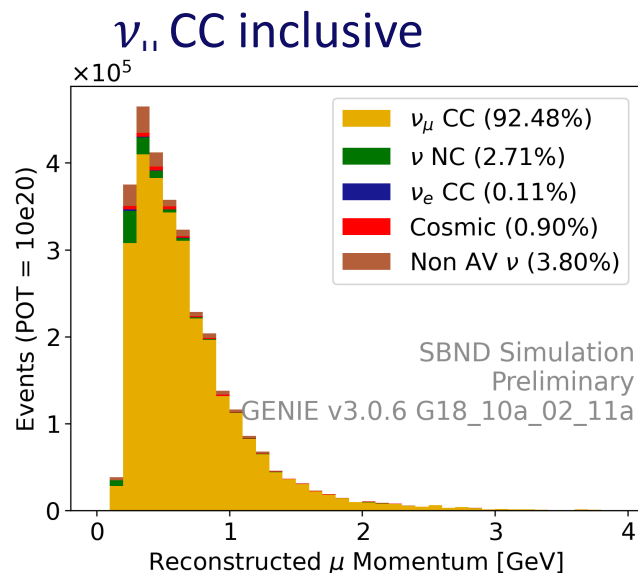
2 million  $\nu_\mu$  CC interactions per year



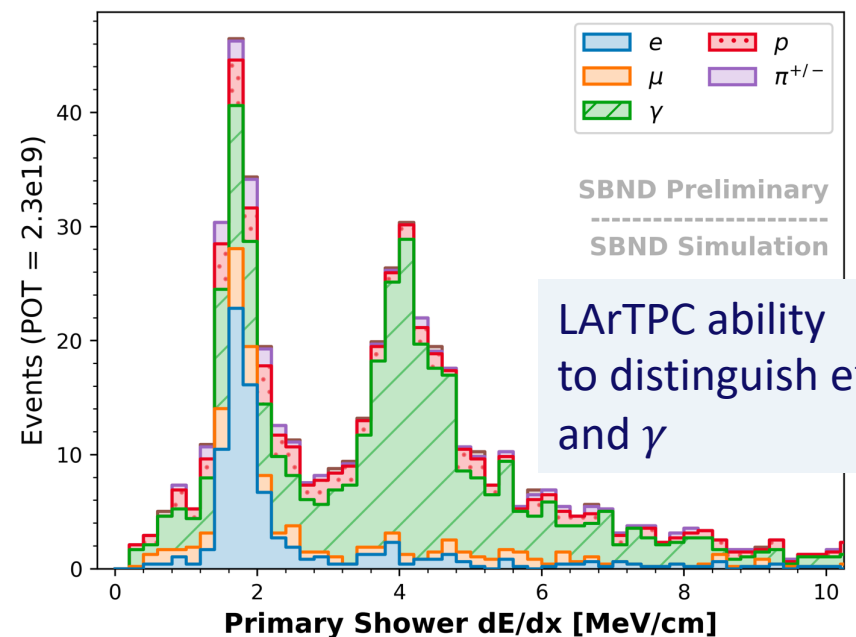
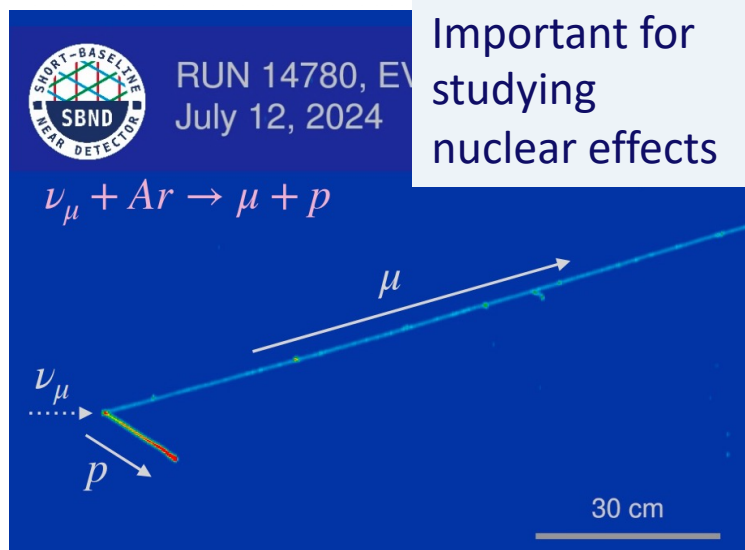
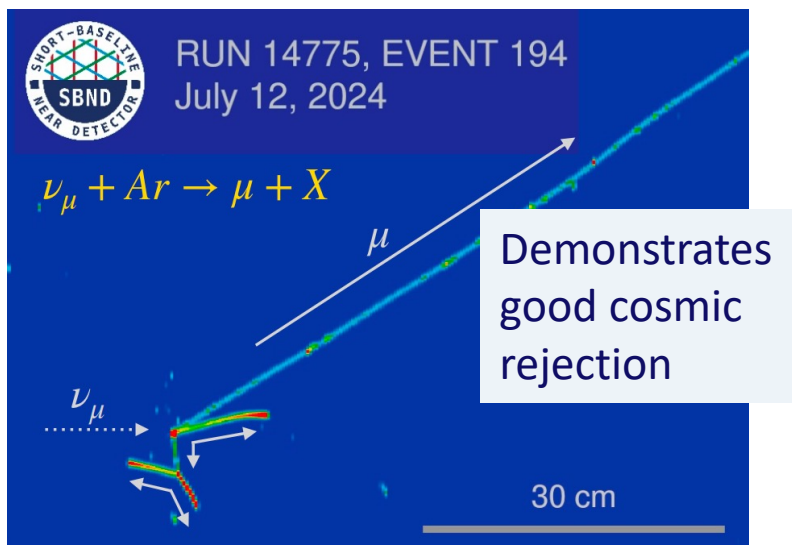
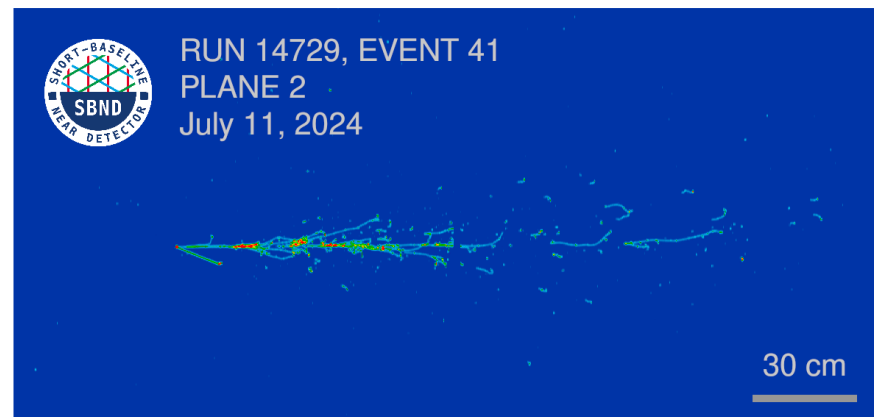
15,000  $\nu_e$  CC interactions per year



# (Selected) First Cross-section measurements



$\nu_e$  CC inclusive



# Many cross-section analyses in progress



## Ongoing analyses

- ☐  $\nu_\mu$  CC inclusive
- ☐  $\nu_\mu$  CC  $1p0\pi$
- ☐  $\nu_e$  CC inclusive
- ☐ NC  $1\pi^0\pi^\pm$
- ☐ Coherent pion production
- ☐  $\nu_\mu$  CC  $1\pi^\pm$
- ☐ Resonance production of Eta mesons

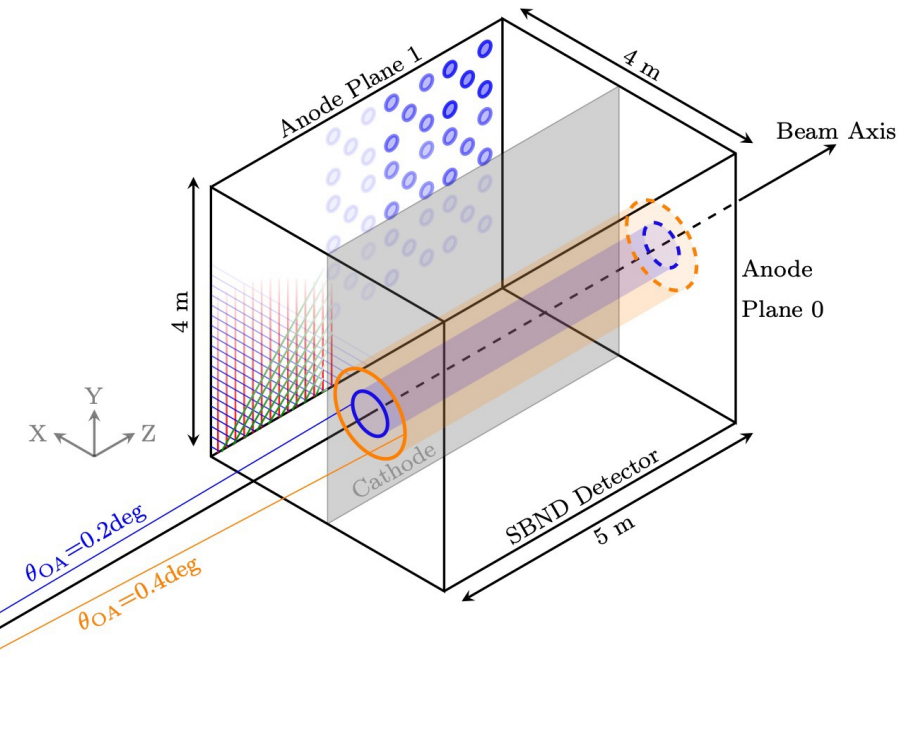
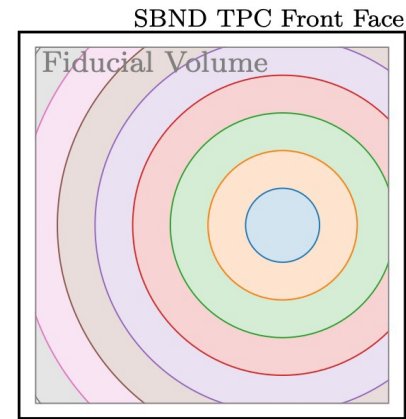
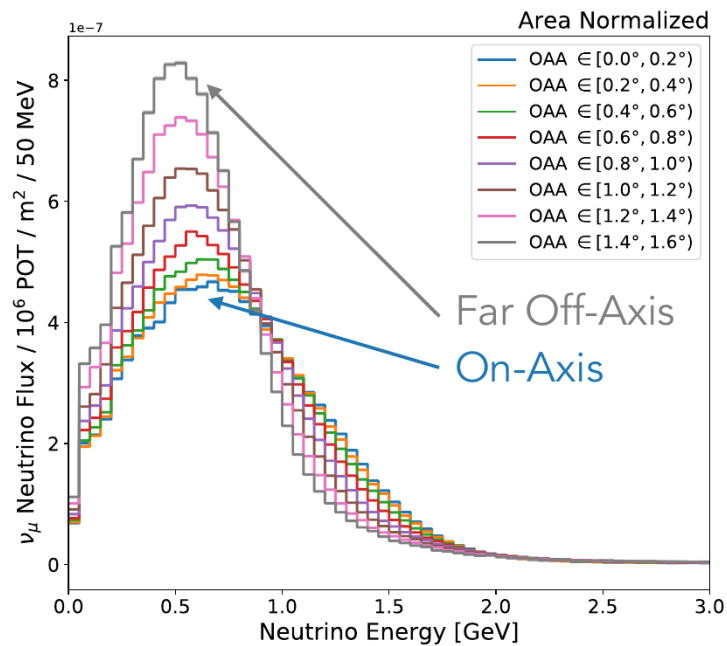
Previewed here

## Also in progress

- ☐  $\nu_\mu$  CC  $2p0\pi$
- ☐  $\nu_\mu$  CC  $\pi^0$
- ☐  $\nu_\mu$  CC Shallow Inelastic Scattering
- ☐  $\nu_\mu$  CC QE hyperon production
- ☐ Cluster production (deuterium, tritons, alphas)
- ☐ Neutrino-electron elastic scattering
- ☐  $\mu$  decay at rest

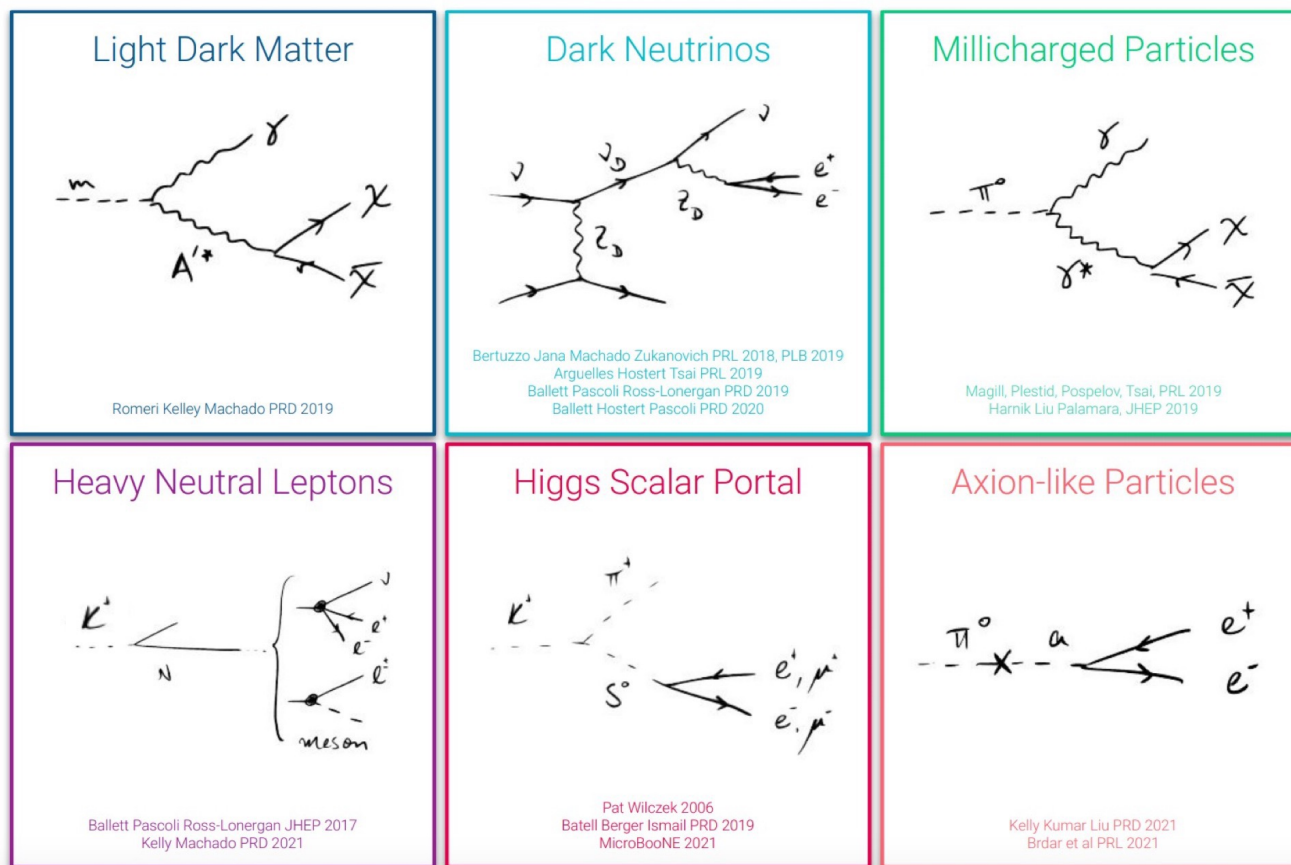
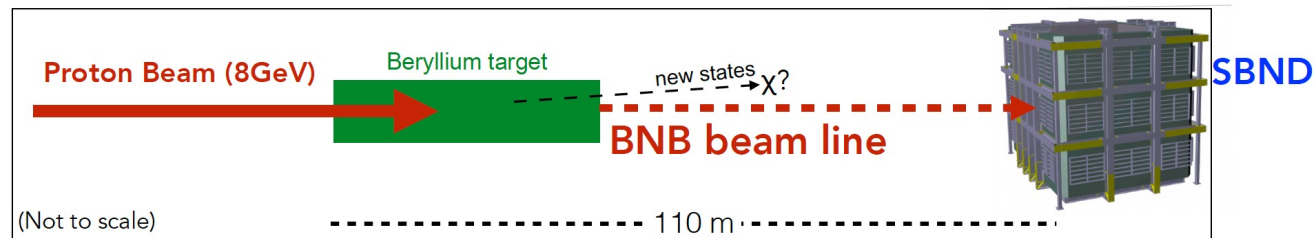
...and many more to come

- ❑ SBND sees neutrinos from a range of off-axis angles (OAAs) coming from the BNB target ( $0^\circ - 1.6^\circ$ )
- ❑ Precision Reaction Independent Spectrum Measurement (PRISM)
- ❑ Explore changing  $\nu_\mu$  spectrum



# SBND Beyond Standard Model physics

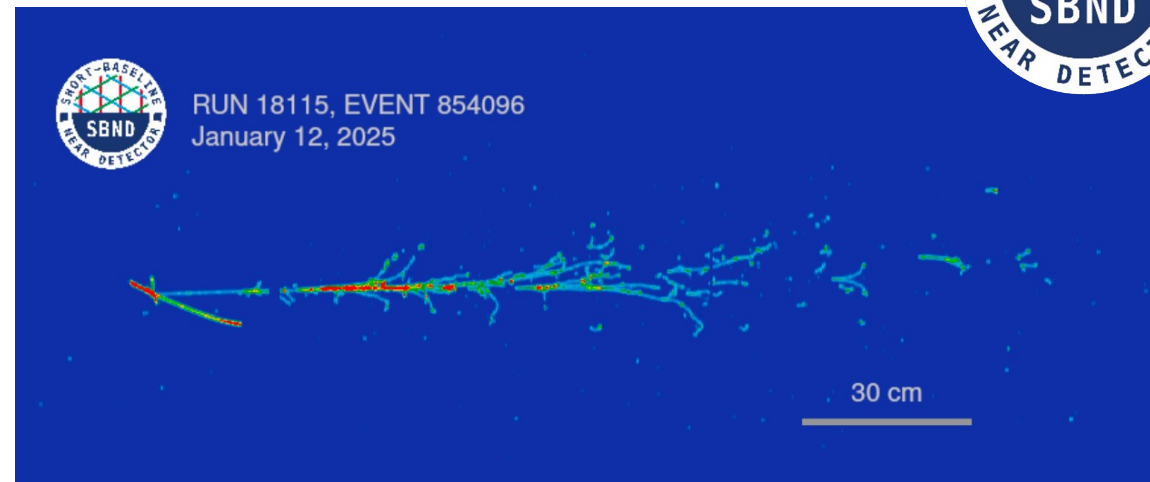
- ❑ Large mass precision detector close to beam target
  - High intensity neutrino beam
  - High intensity proton beam
- ❑ Ideal opportunity to search for **low-mass, low-coupling** BSM particles
- ❑ **Advanced timing reconstruction** facilitates separation of massive long lived particles from neutrinos based on **time of flight**
- ❑ Actively engaged with the **theory community** to fully exploit the physics opportunities





# Summary

- ❑ SBND has been stably collecting physics quality neutrino data since December 2024
  - Largest data set of neutrino-Argon interactions!
- ❑ SBND detector systems are performing very well
- ❑ Broad physics programme
  - Near detector constraints for the SBN programme
  - Neutrino cross-section measurements
  - Beyond standard model searches
- ❑ Forthcoming papers:
  - SBND-PRISM paper
  - SBND detector paper
- ❑ Stay tuned for our first neutrino physics results!

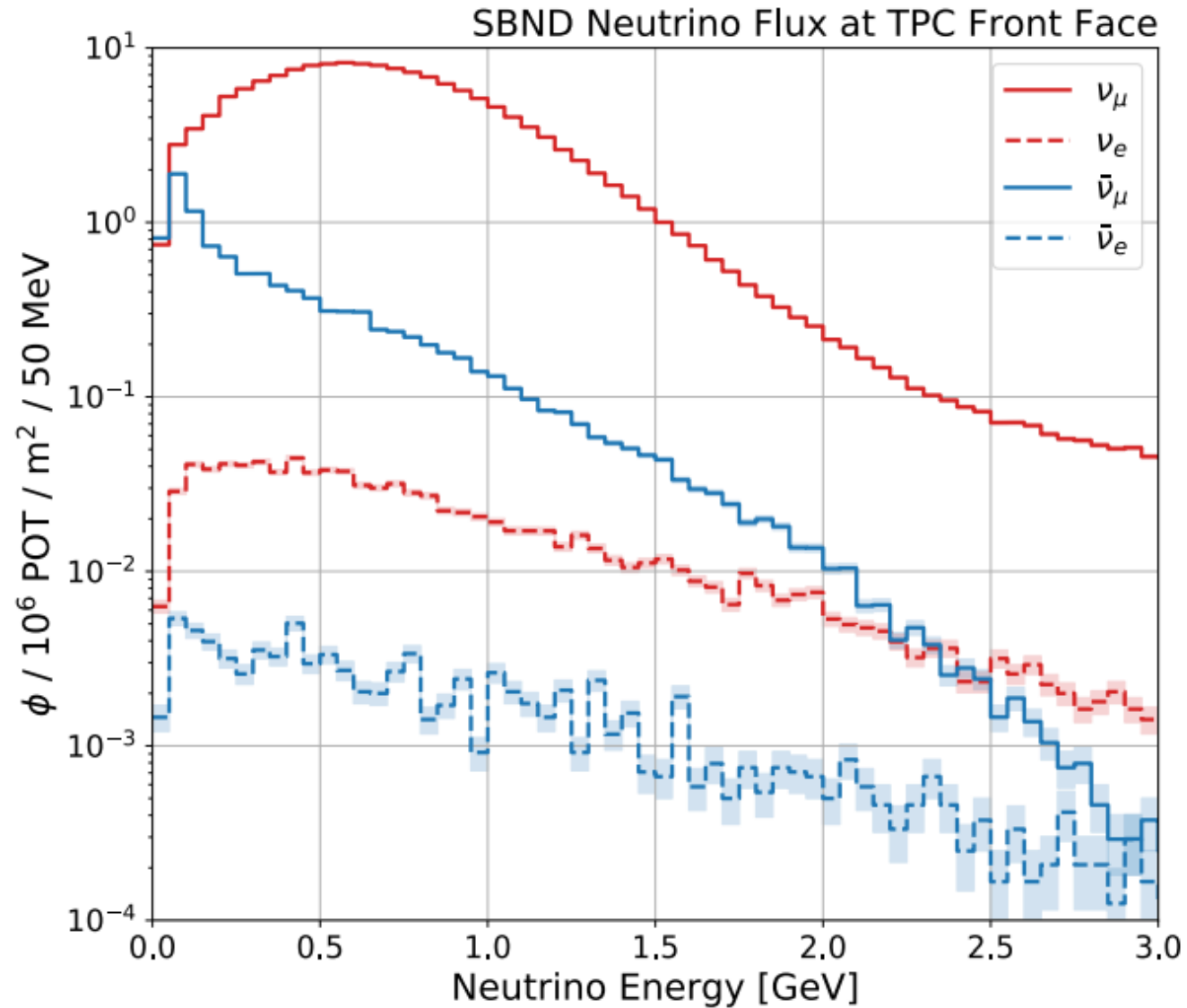




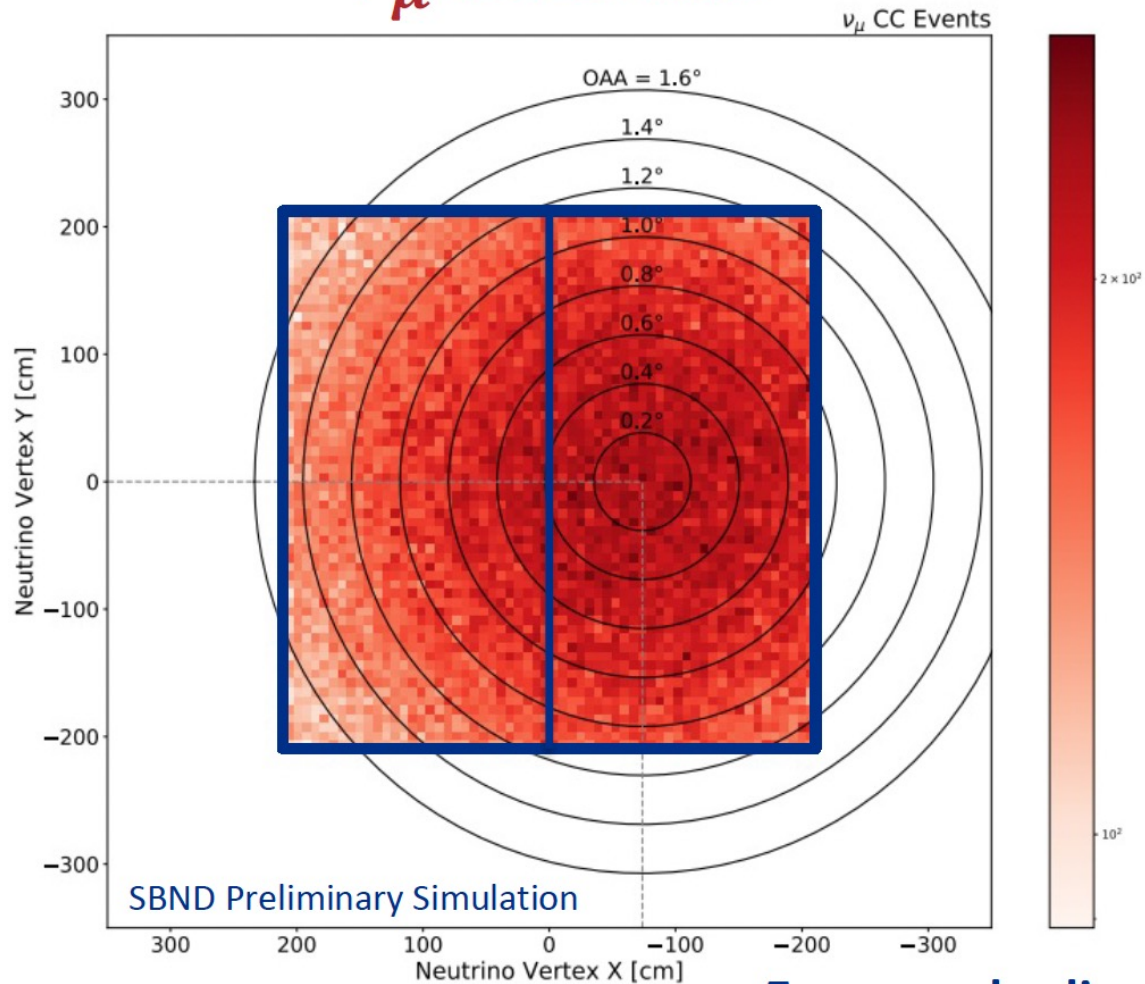


# Backup

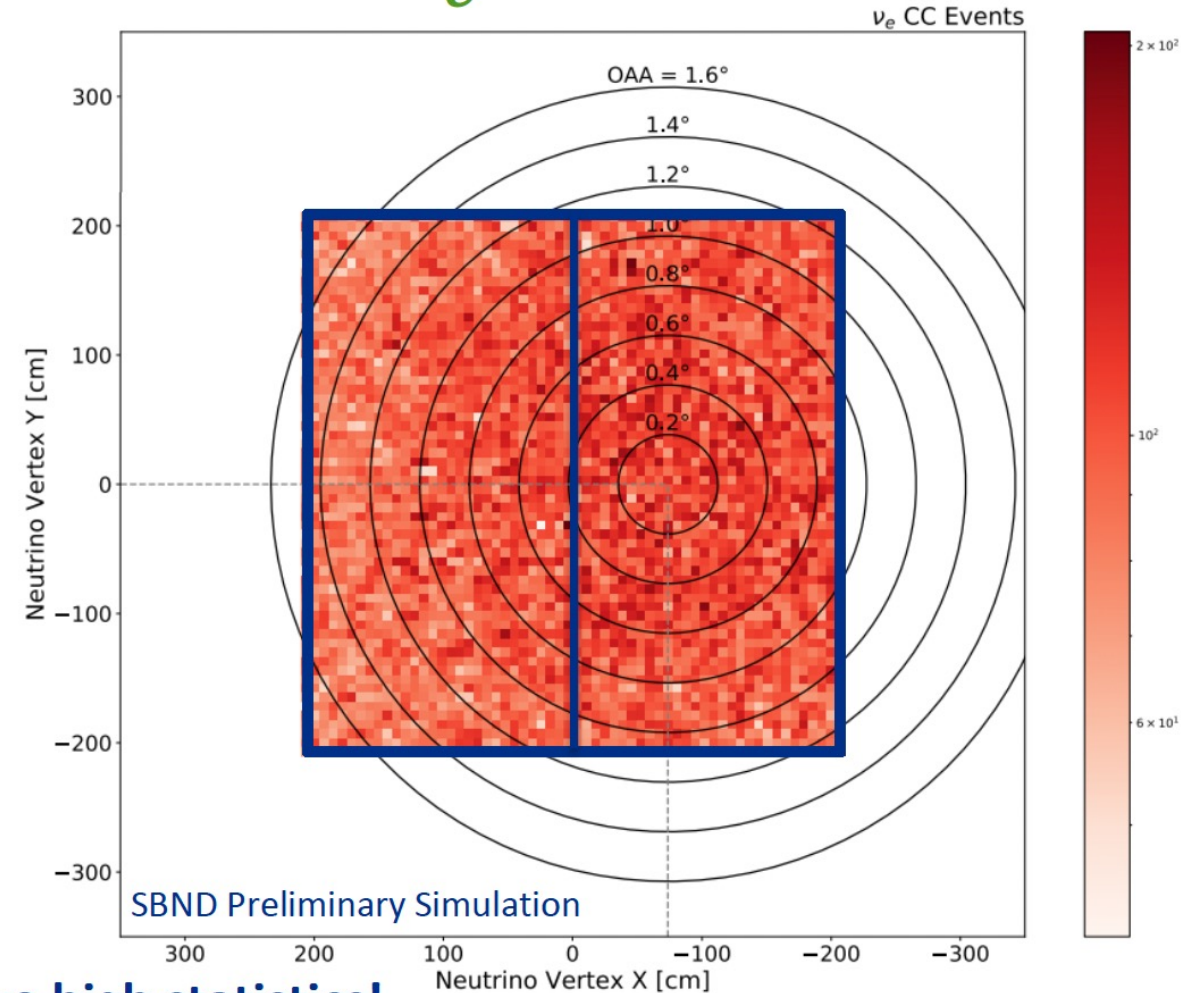
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## $\nu_\mu$ CC events

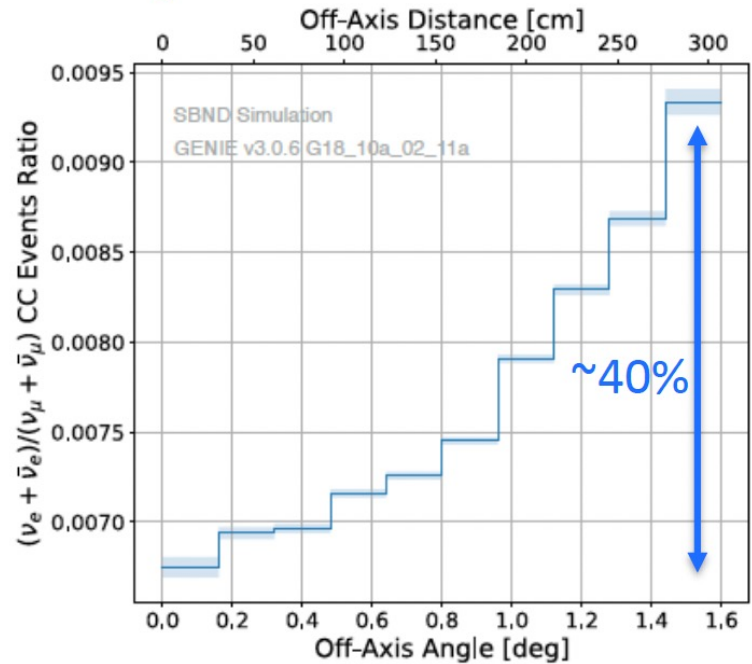


## $\nu_e$ CC events



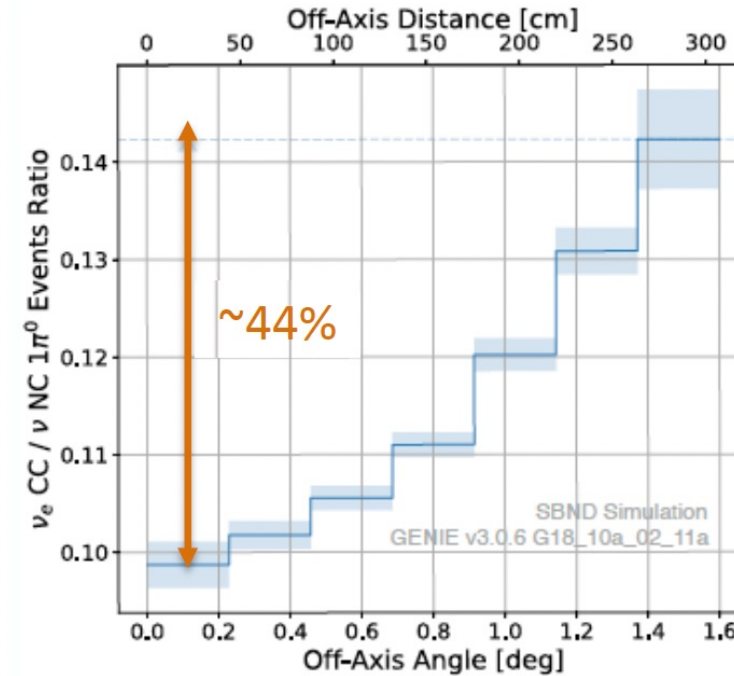
**Every angle slices have high statistics!**

## $\nu_\mu$ to $\nu_e$ cross section



- $\nu_\mu$  to  $\nu_e$  cross section ratio increases going more off-axis  $\rightarrow$  measure  $\nu_e/\nu_\mu$  cross section.
- Can study lepton mass effects & lepton flavour universality ([Phys. Rev. D 110, 035031](#))

## $\nu_e$ CC VS $\nu$ NC $1\pi^0$



- $\nu$ -neutral current with  $\pi^0$  can mimic  $\nu_e$  signal.
  - Important source of background!
- Going off-axis can reduce this background!