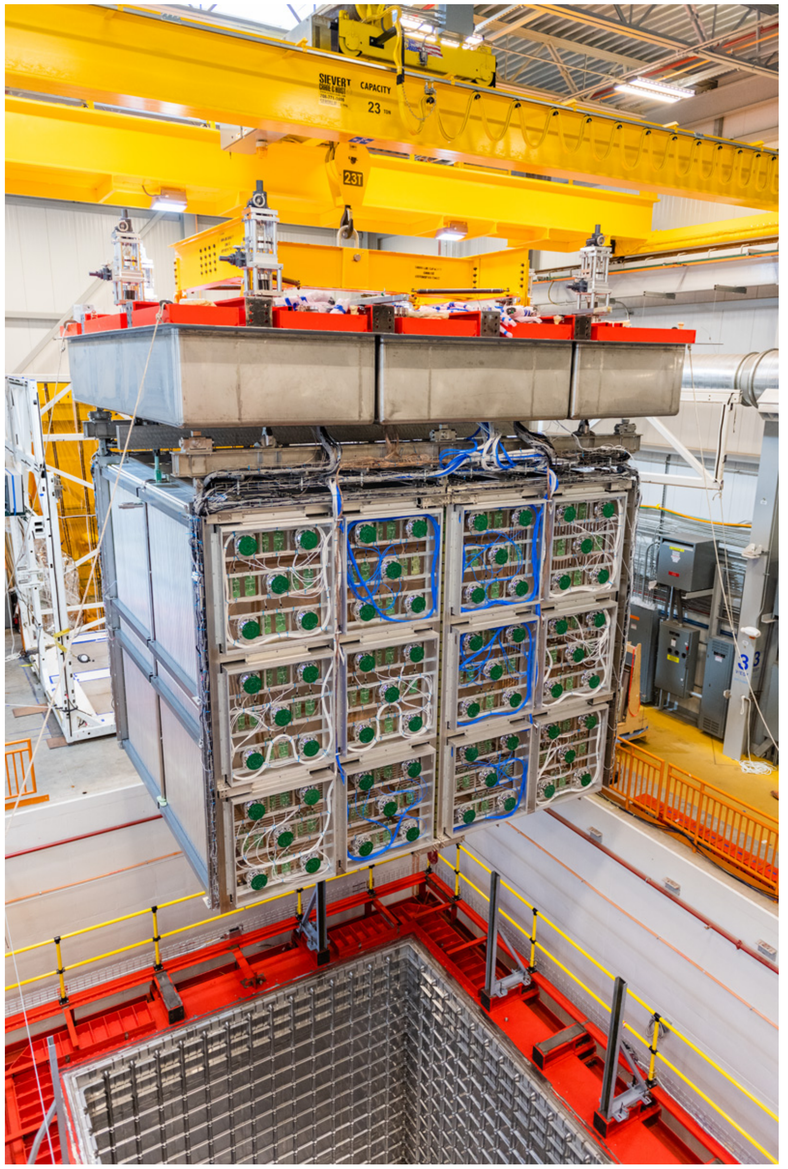
Status of the Short-Baseline Near Detector at Fermilab

Lynn Tung (on behalf of the SBND Collaboration)

Brookhaven Forum 2025
October 22nd, 2025



SHORT-BASELINE NEAR DETECTOR
SBND

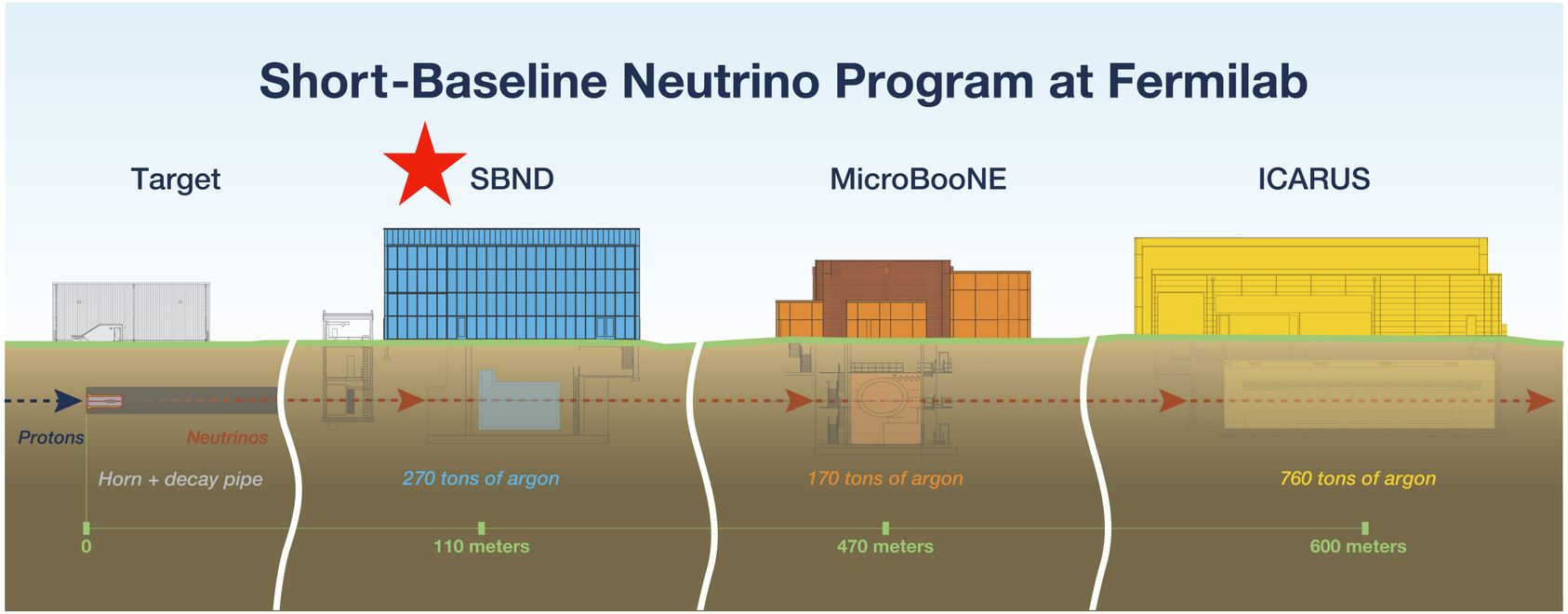
THE UNIVERSITY OF CHICAGO

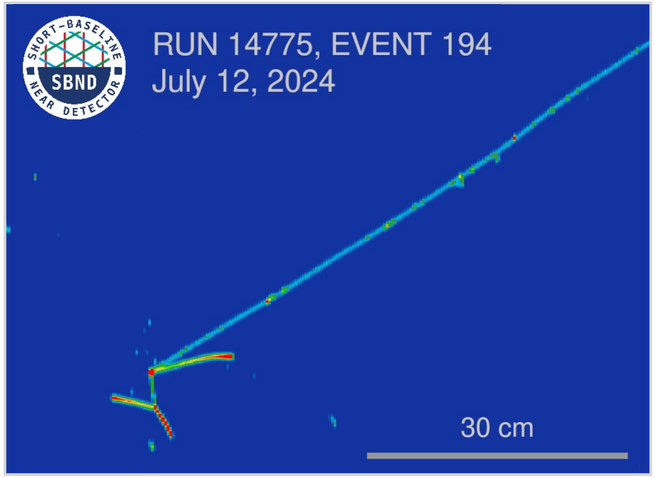
Talk Contents

- Physics Program and Detector Overview
- Detector Status and Calibration
- SBND Recent Results

Short-Baseline Neutrino Program

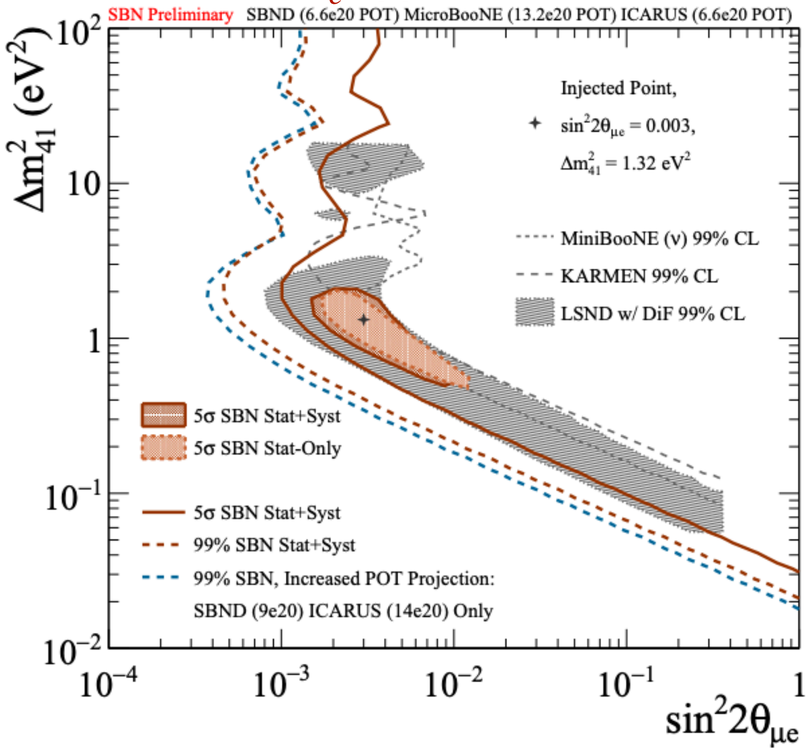
- SBN program comprises of multiple LArTPCs along the Booster Neutrino Beam (BNB) at Fermilab
- aims to resolve the anomalous Low Energy Excess at MiniBooNE via the search for eV-scale sterile neutrinos
- SBND has rich single-detector physics program, including ν-Ar measurements and searches for beyond the standard model physics



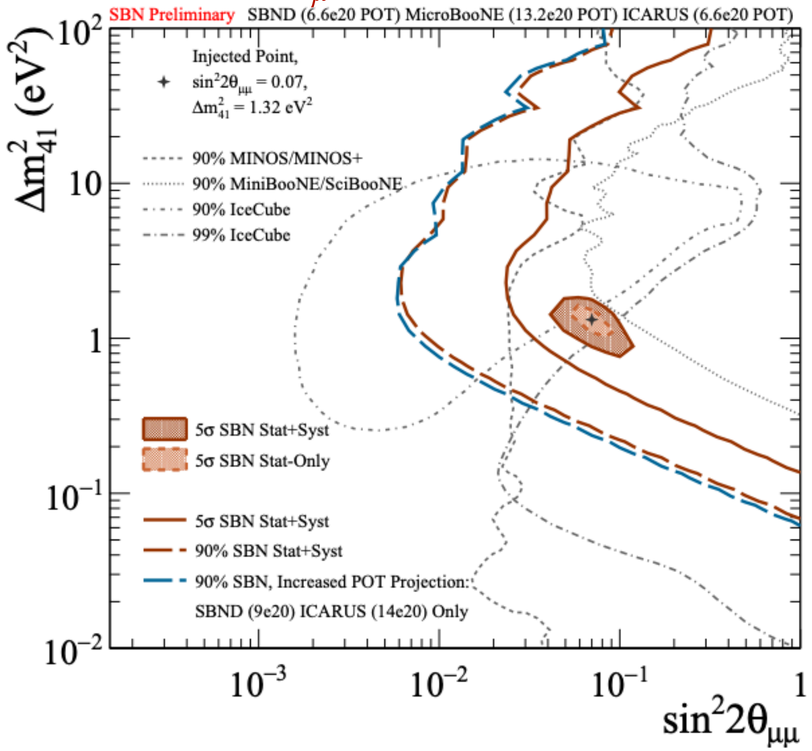


SBN Neutrino Oscillations

ν_e appearance



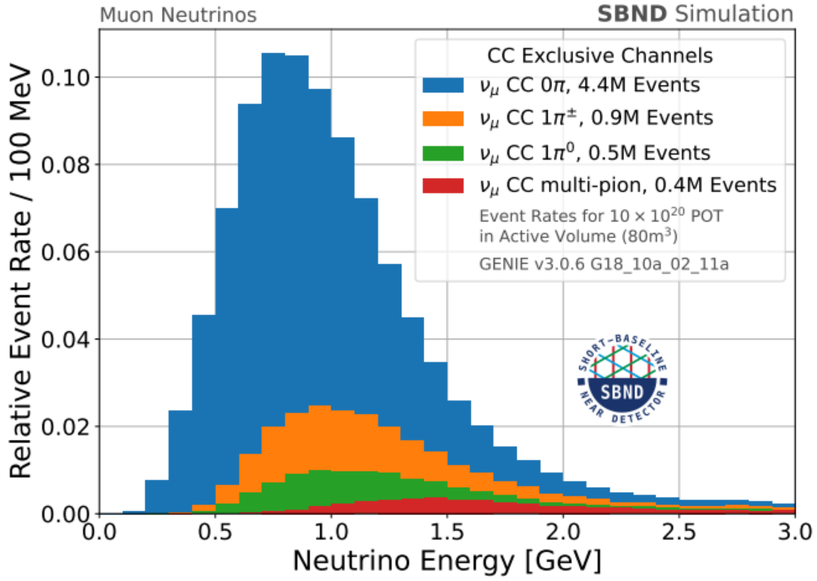
ν_μ disappearance

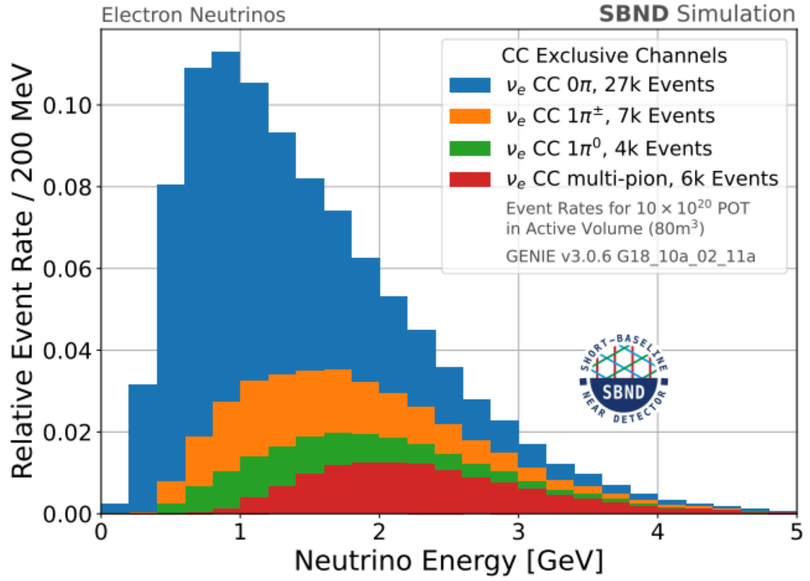


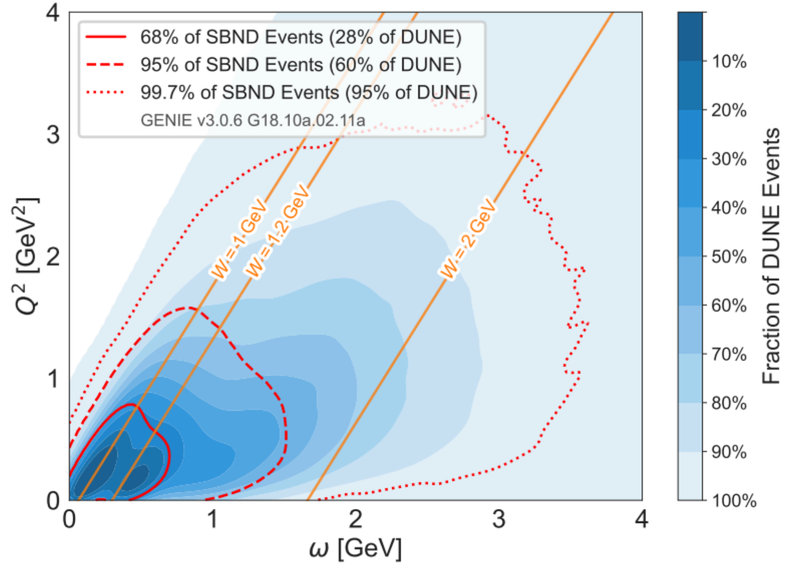
- will provide tight constraints of systematic uncertainties through high-precision measurements of the BNB flux and ν-Ar cross-sections
- analyses will include ν_μ disappearance **and** ν_e appearance, to conclusively address the sterile neutrino solution for short-baseline anomalies

Neutrino Interactions @ SBND

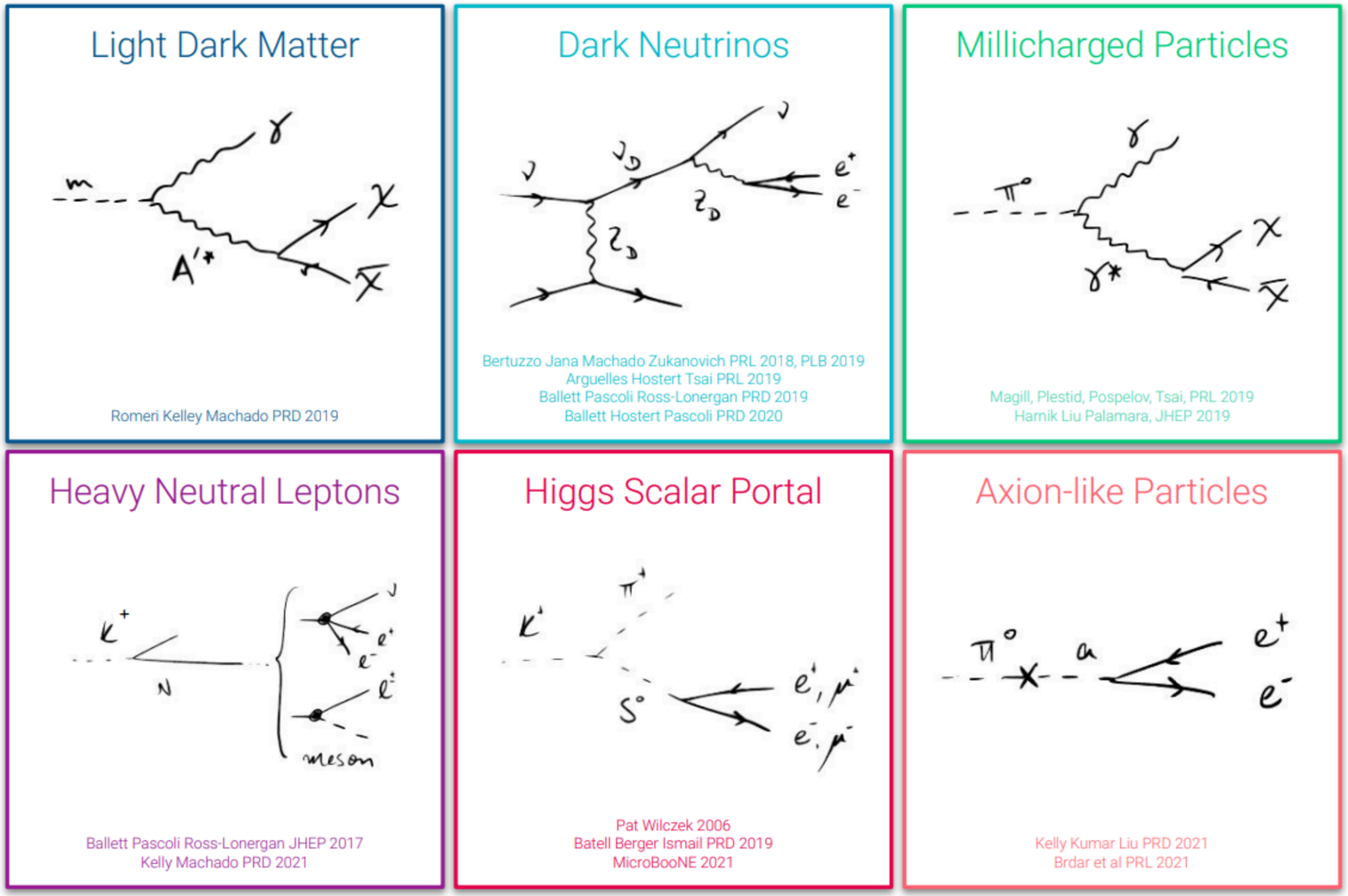
- SBND expects ~2 million ν_μ CC and 15k ν_e CC interactions per beam-year, with a total dataset of 10 million events (CC+NC)
- large statistics will allow precise, multi-dimensional cross-section measurements as well as measurements of rare channels
- substantial overlap with DUNE kinematic phase space







Beyond Standard Model Searches

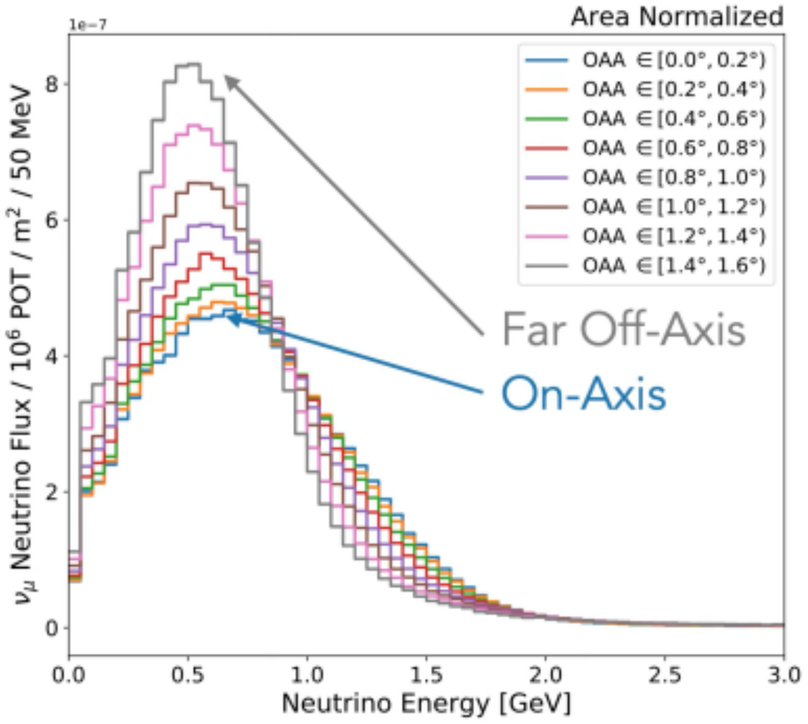


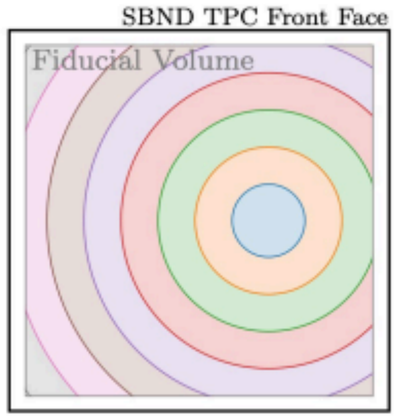
- opportunities to search for low-mass, low-coupling BSM particles
- competitive sensitivities to many dark-sector particles,
- ongoing efforts to carry out more model-independent approaches
- working closely with theorists to realize these searches
- for more details, check out the **next talk by L. Nguyen!**

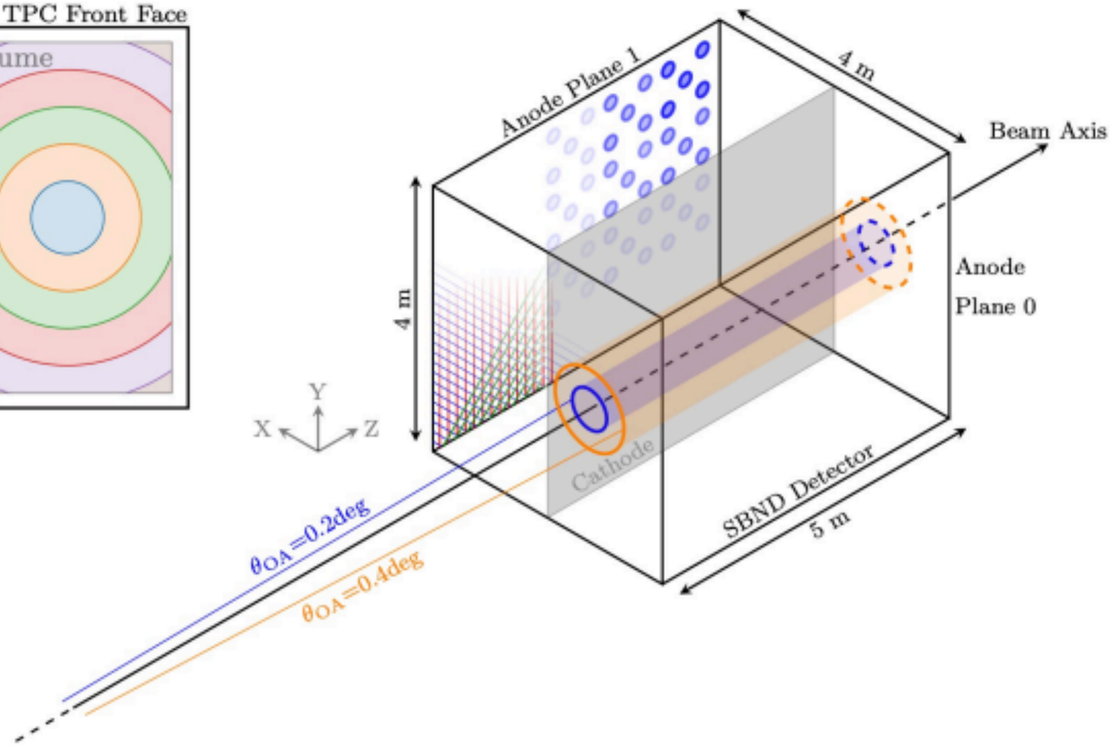
SBND PRISM

- **P**recision **R**eaction **I**ndependent **S**pectrum **M**easurement

- proximity to the beam and offset allows opportunities to study signals that vary as a function of neutrino energy or off-axis angle, and provides unique constraints of systematic uncertainties

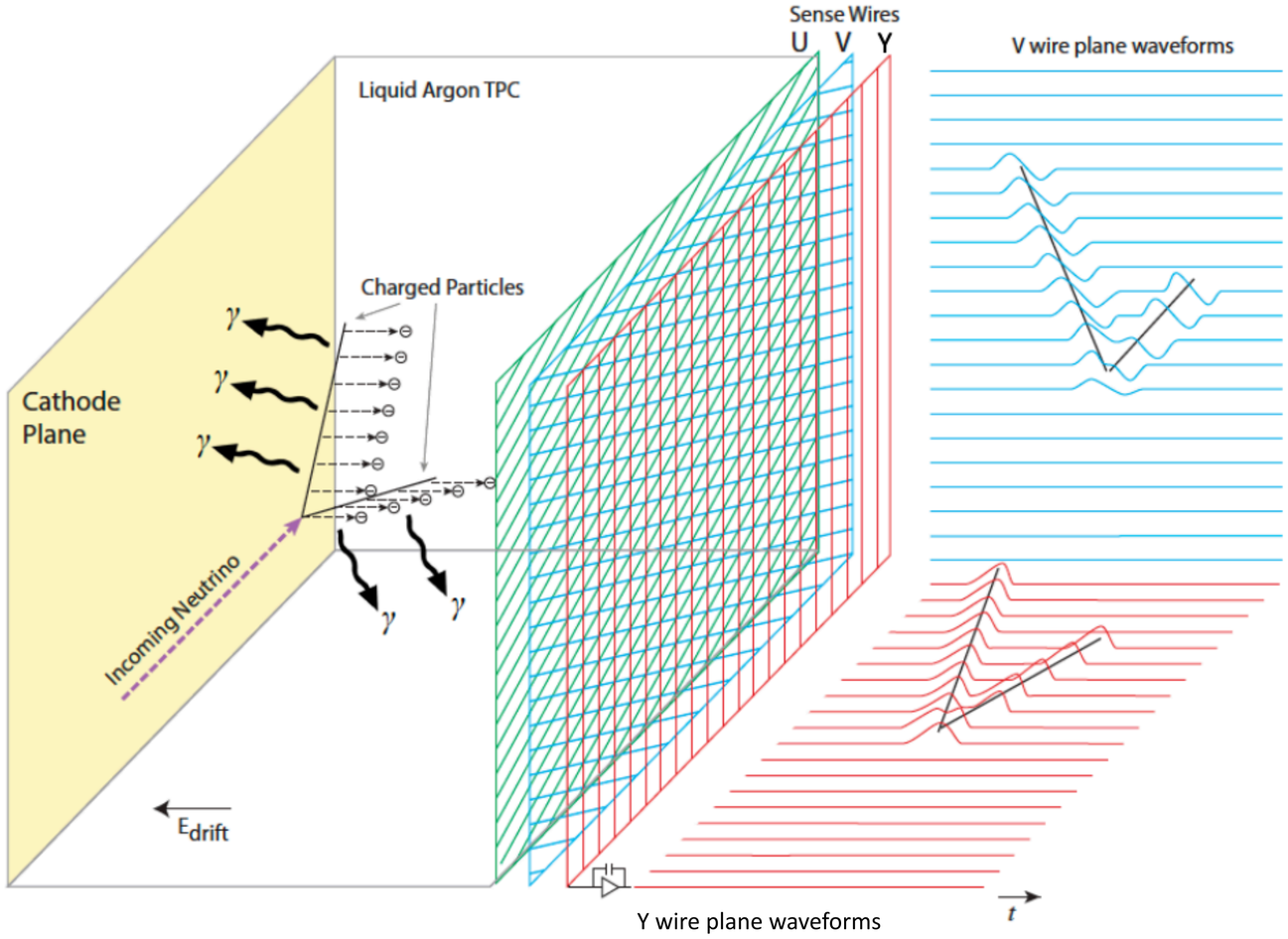




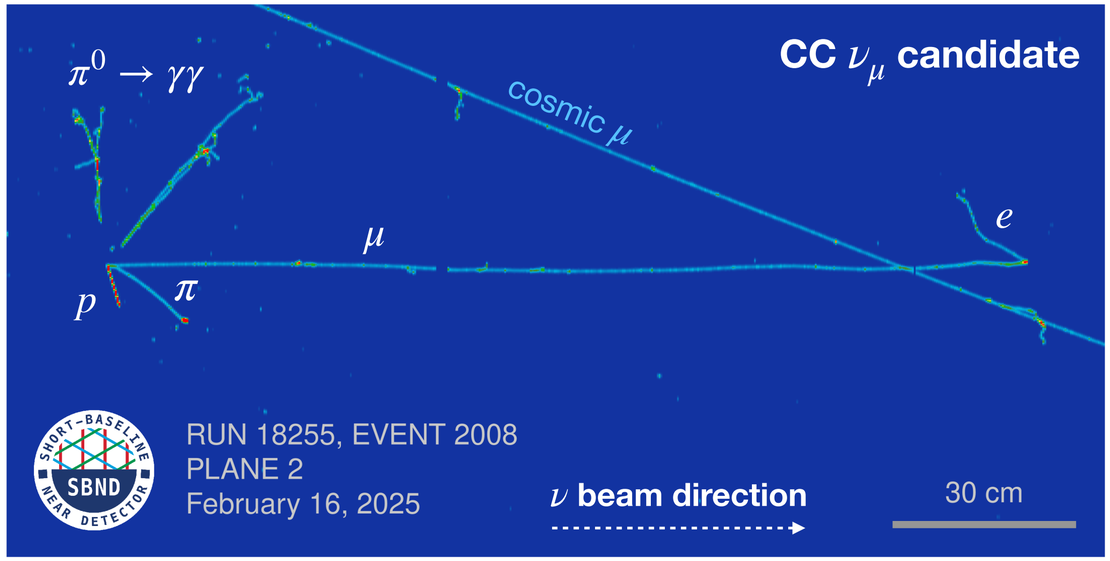


SBND Detector Status

Detecting Particles in a LArTPC

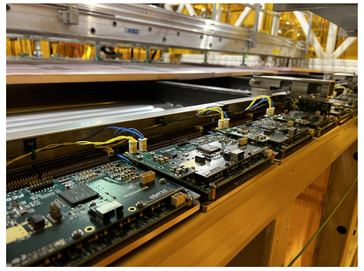


- Liquid Argon Time Projection Chambers (LArTPCs) are high spatial resolution O(mm), fully-active tracking calorimeters
- precise timing resolution via scintillation light
- excellent particle identification to resolve complex final states

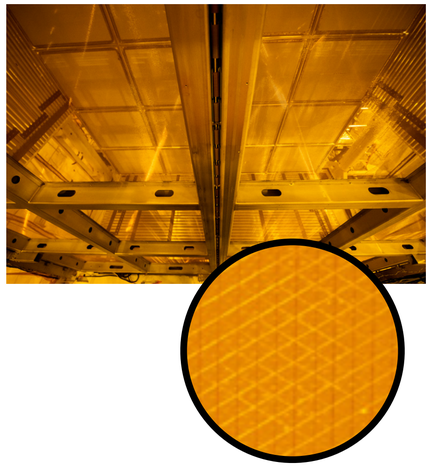


SBND Detector: LArTPC

SBND LArTPC size:
- 112 ton active mass
- 4x4x5 m^3 of active volume
- 2 drift volumes

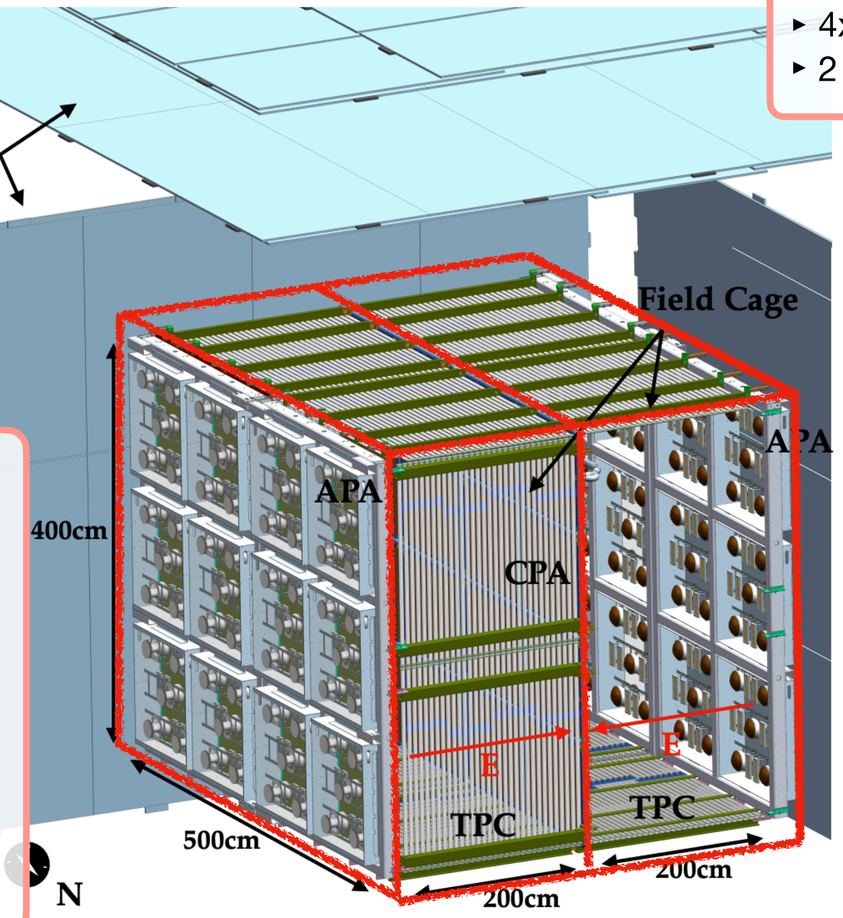


Cold Electronics
pre-amplify and digitize ionization electron signals signals at 89K

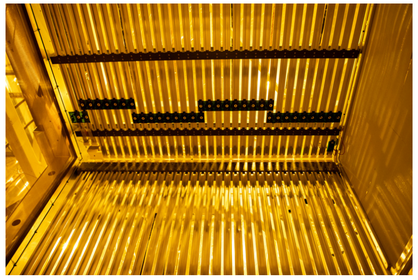


Anode Plane Assembly (APA)
on each side of the detector

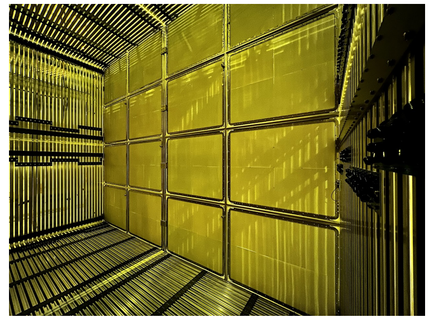
- 3 wire planes
- 11,264 total wires
- 3 mm wire spacing
- ±60˚ and vertical wire orientation



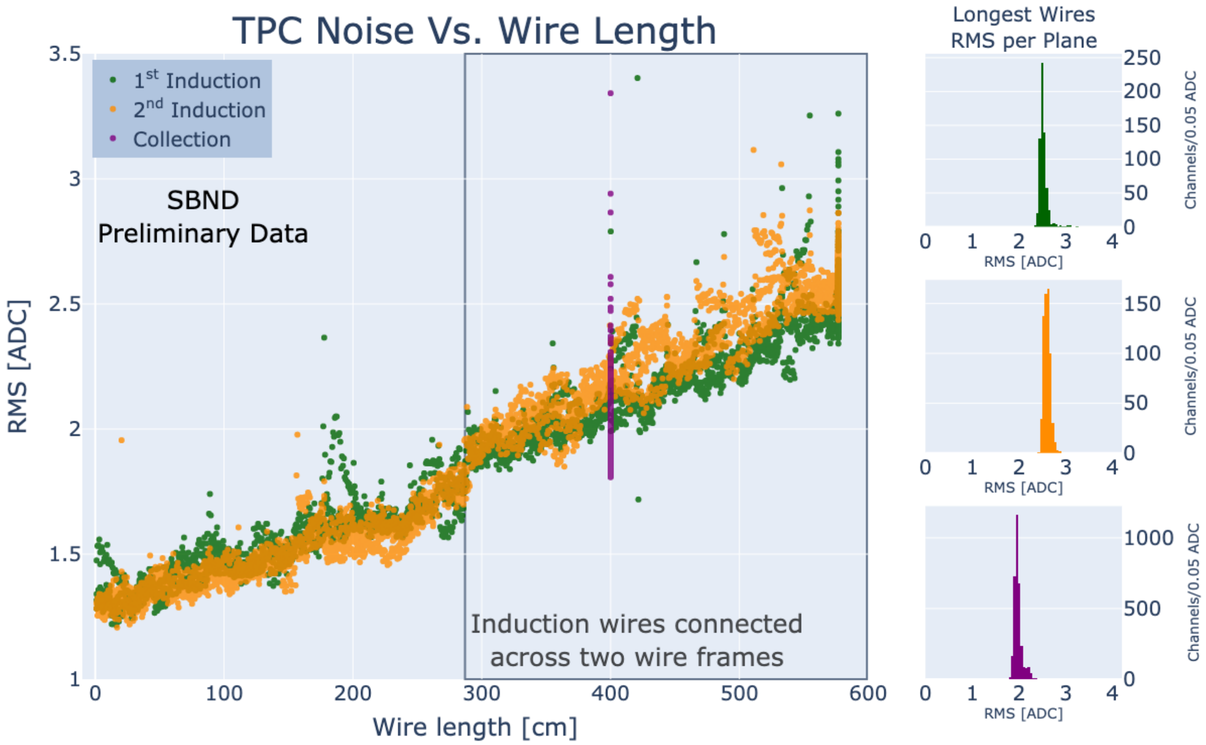
Field Cage
surrounds the TPC to provide a uniform 500 V/cm drift field

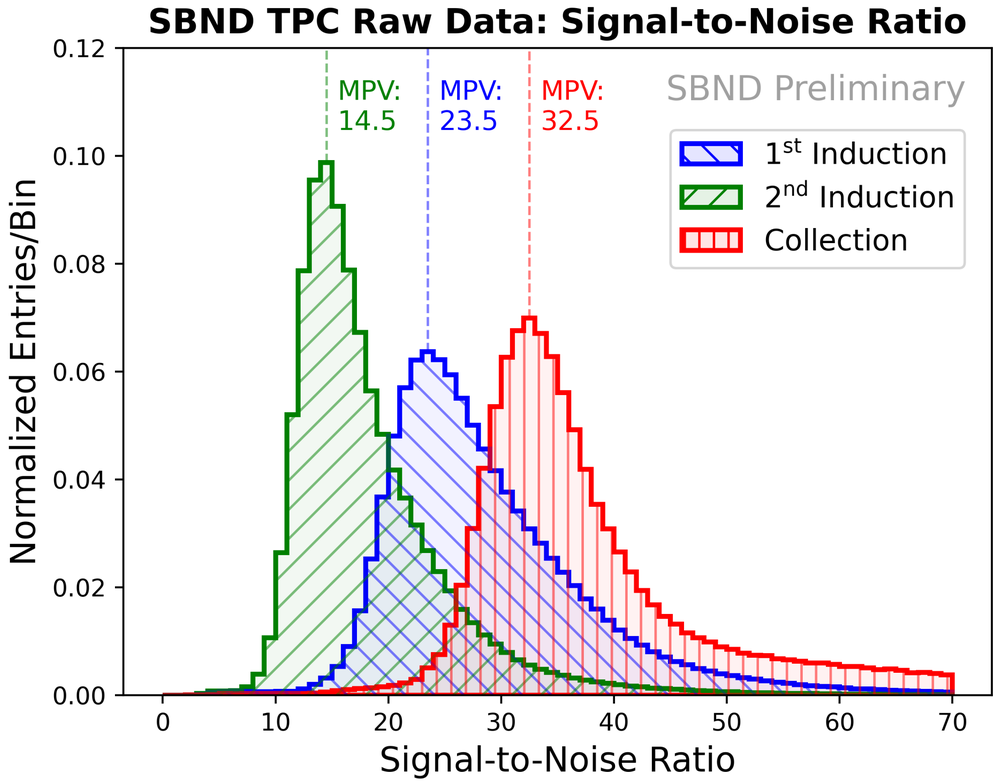


Cathode Plane Assembly (CPA)
splits detector into two drift volumes
- at -100kV
- 2 m drift distance
- drift time up to ~1.28 ms



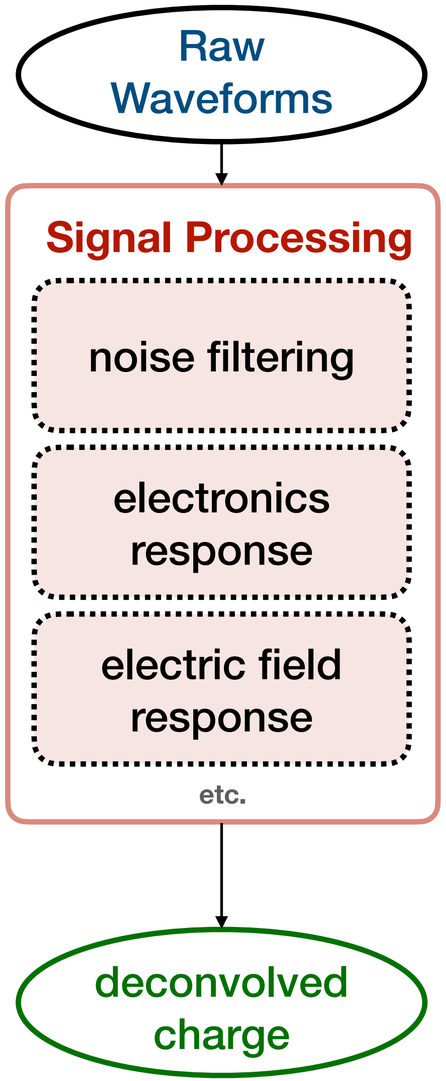
TPC Signal-to-Noise

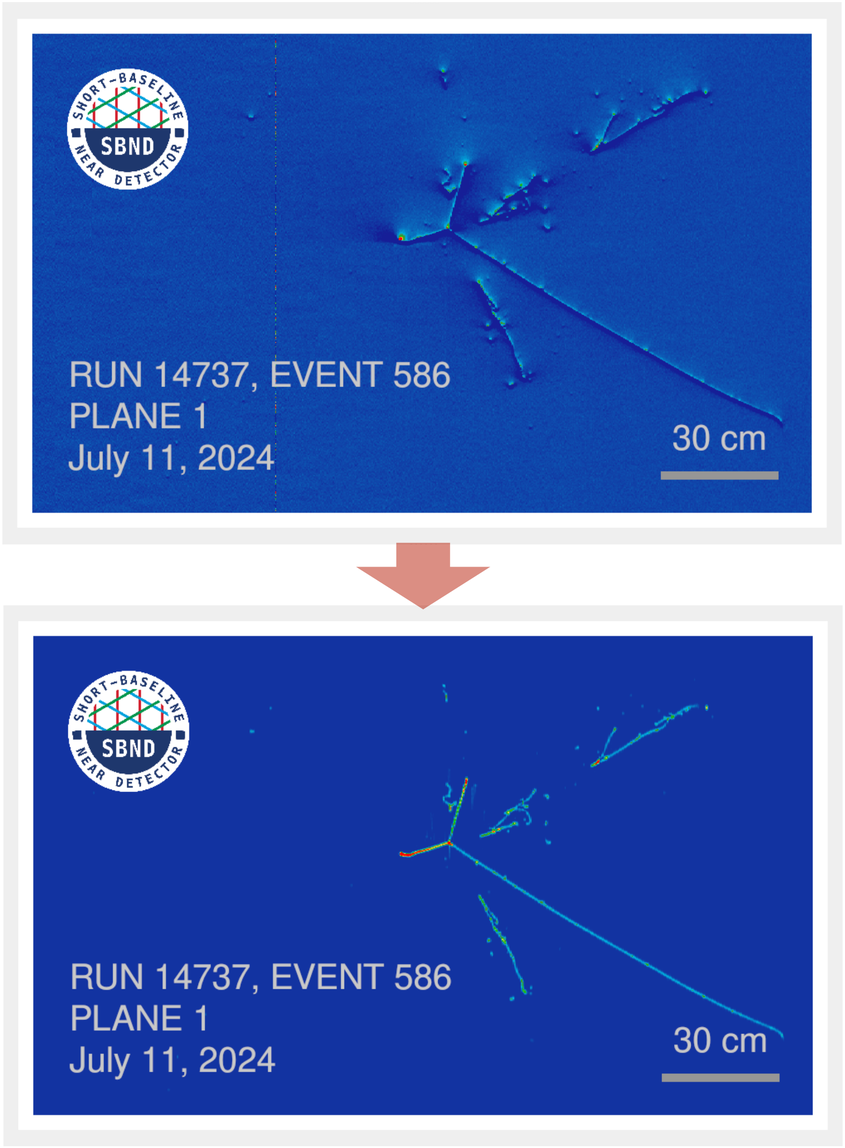




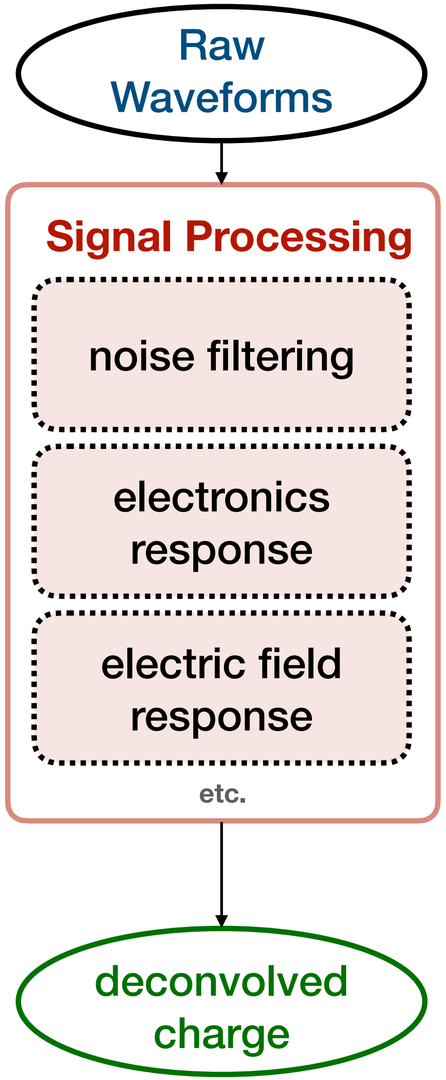
- TPC electronics noise main dependence on wire length, is close to the intrinsic floor
- even without any noise filtering, signal-to-noise is very high, comparable to previous LArTPCs *after* noise filtering

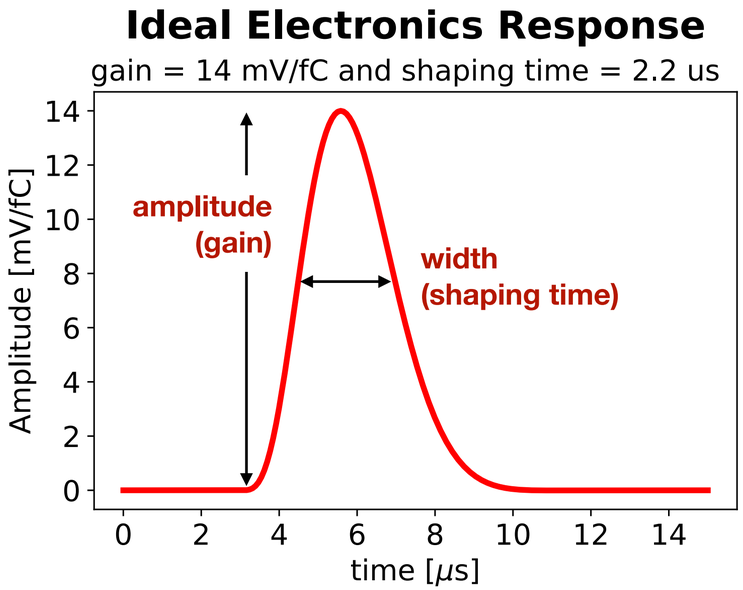
TPC Signal Formation & Processing

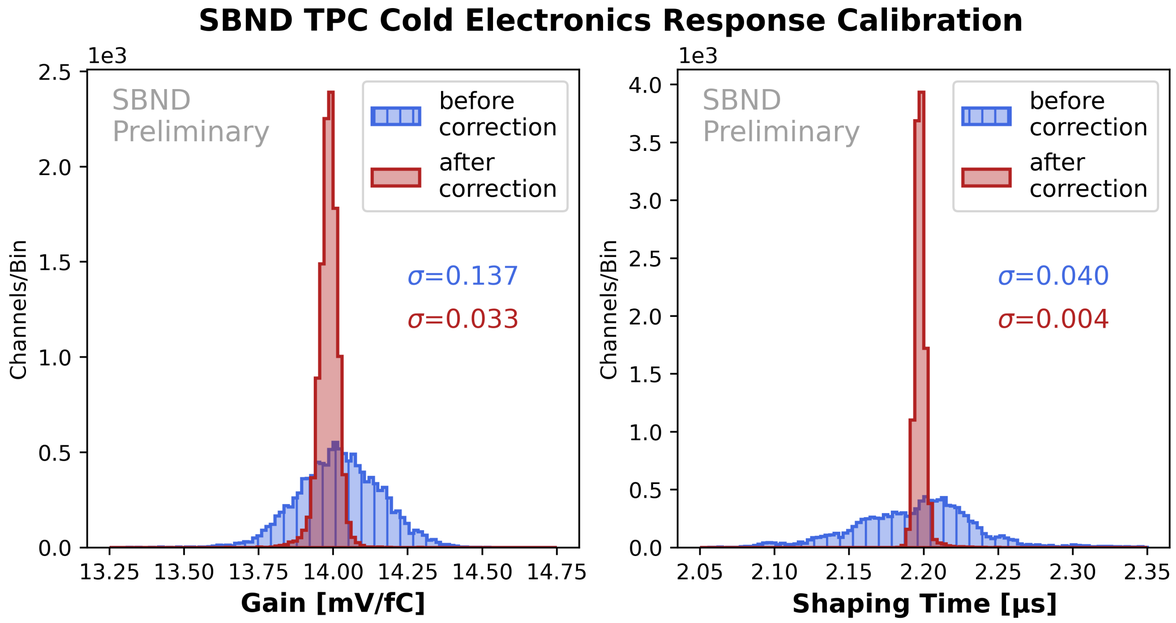




TPC Signal Formation & Processing



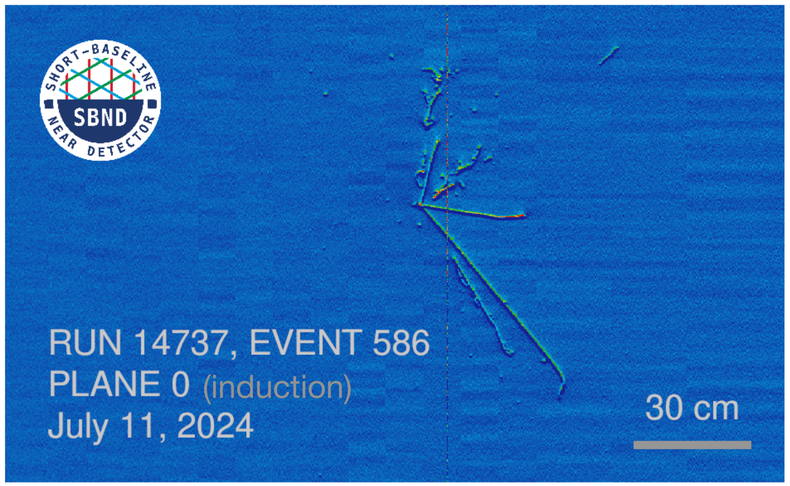


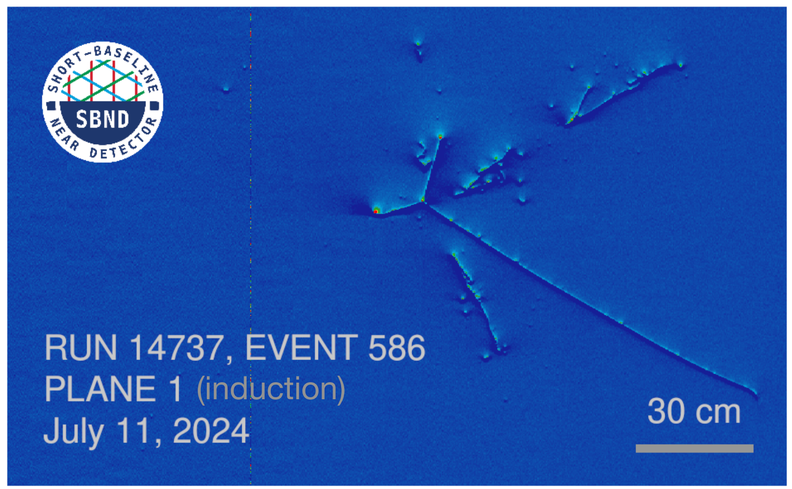


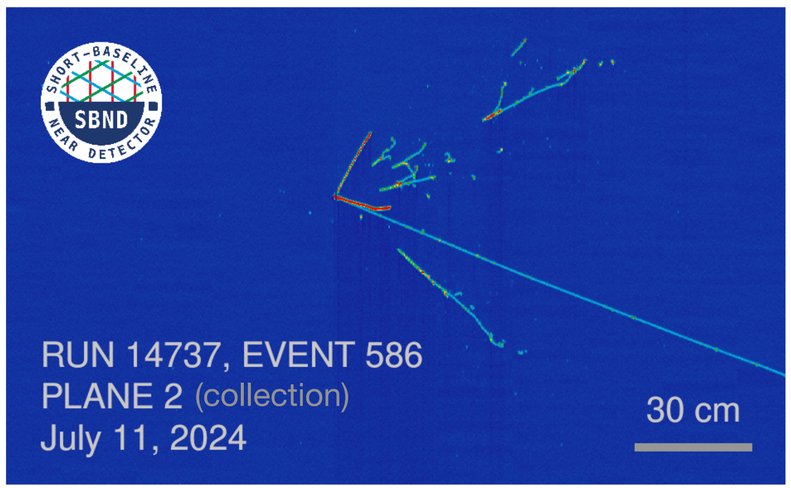
- cold electronics are responsible for amplifying and shaping signals for each wire
- clear improvement in response uniformity after corrections from internal calibration source
- have also validated our electric field response using cosmic muons, with good agreement between data and MC

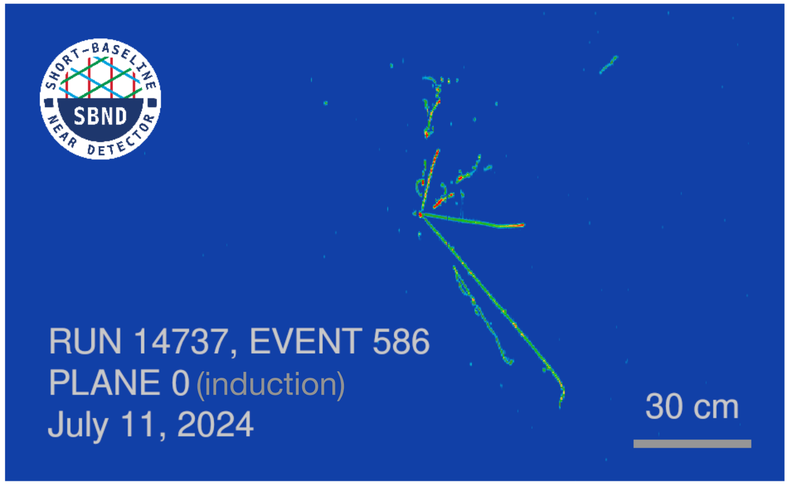
TPC Signal Processing

*same event, three 2D projections!

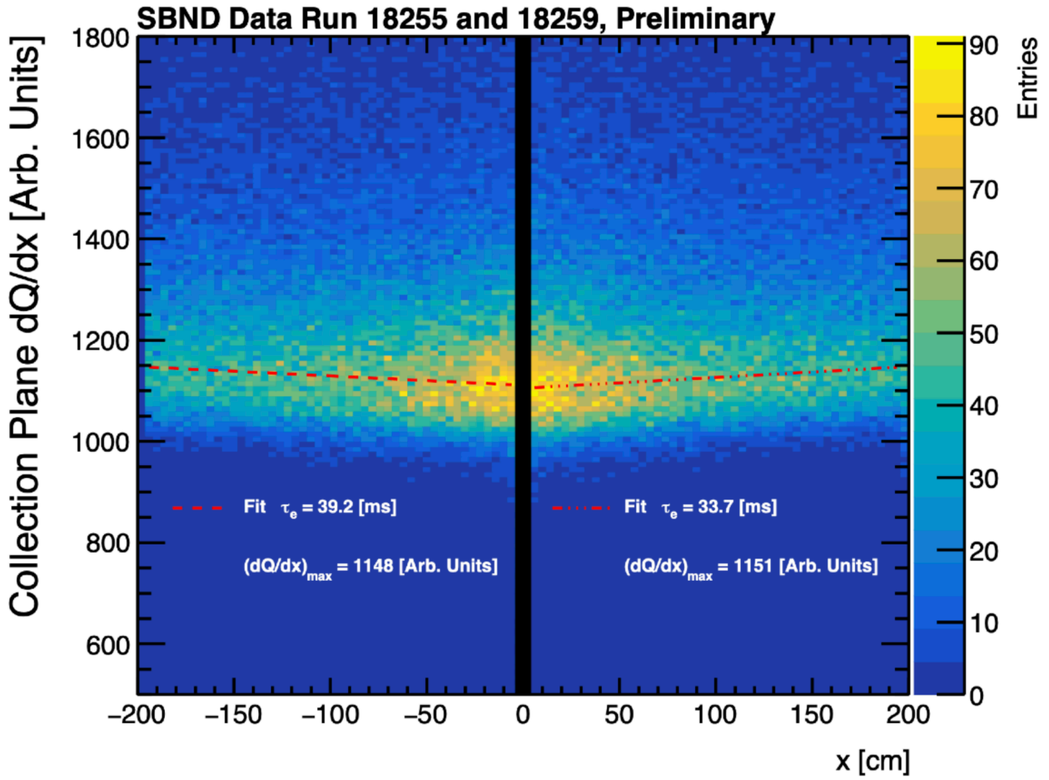


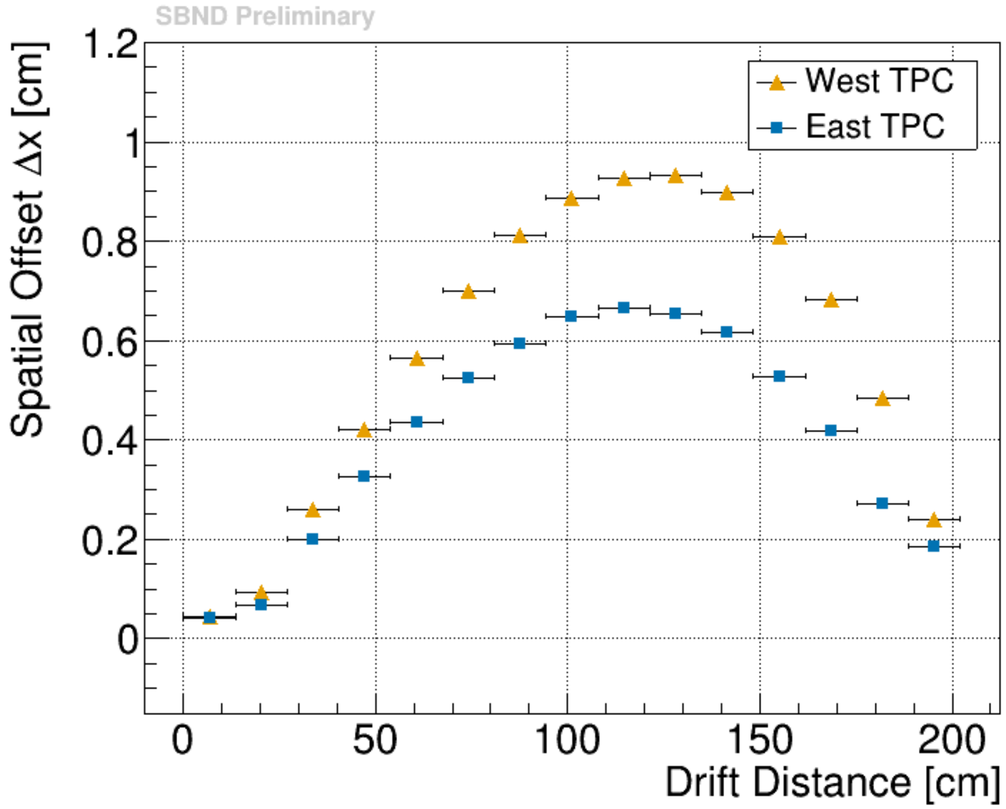






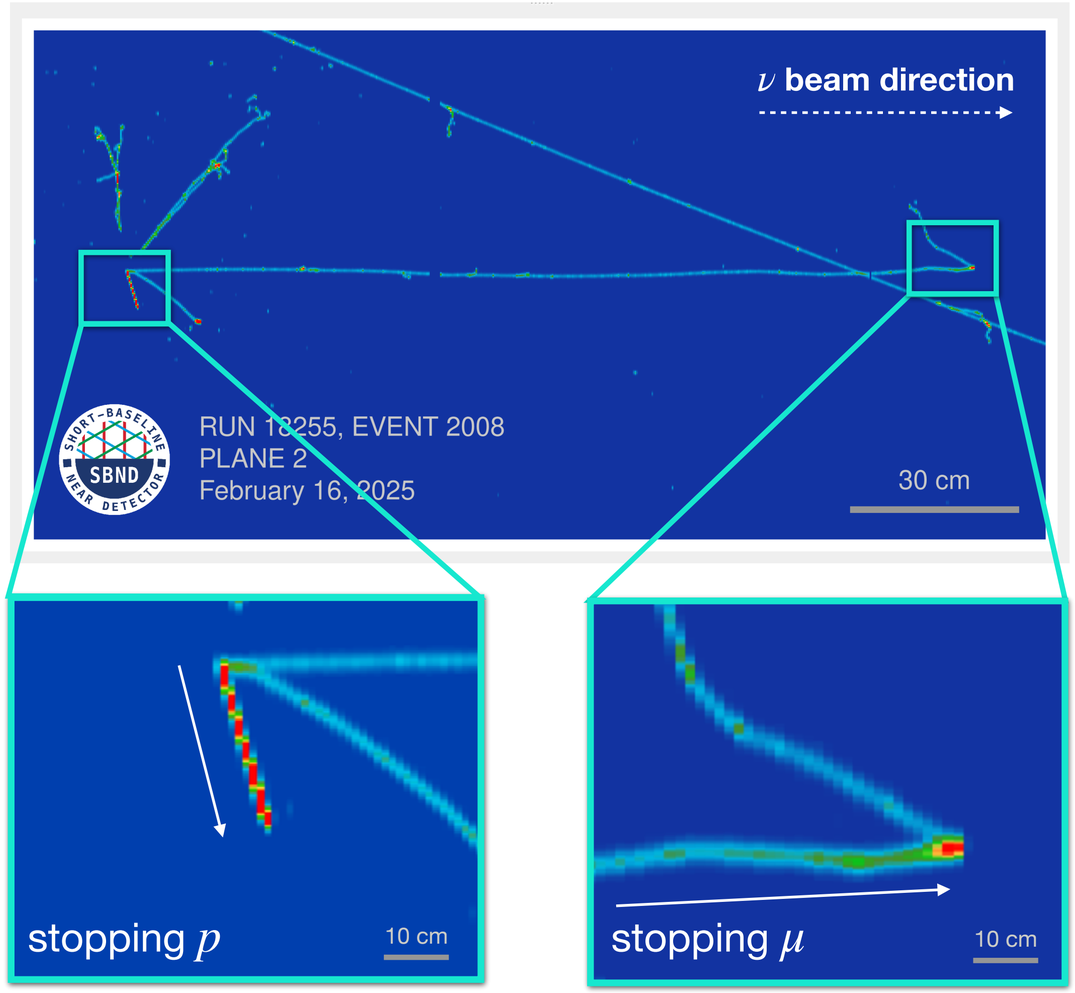
TPC Uniformity





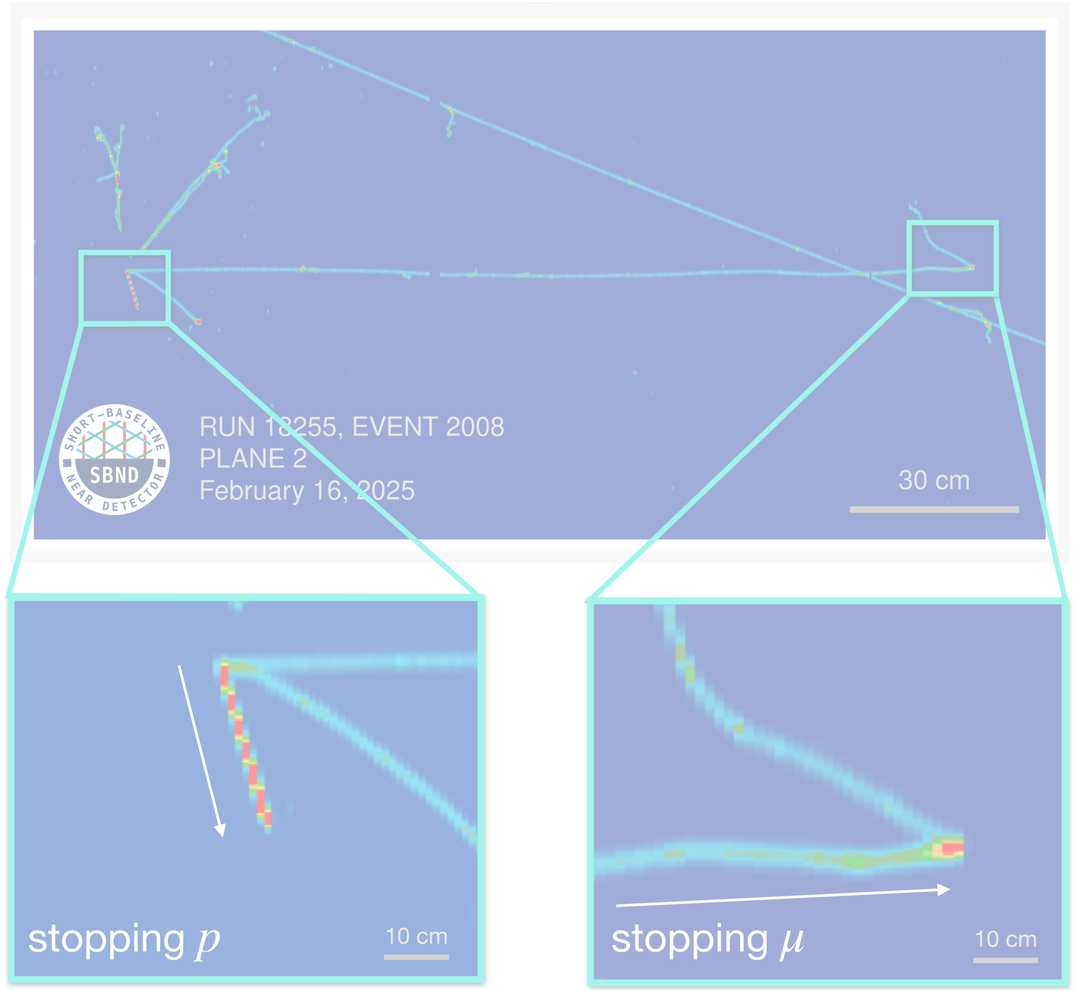
- **Argon Purity:** measured electron lifetime is consistently >30ms, well above the design value (3ms) and our maximum drift time (~1.3 ms)
- **Electric Field Uniformity**: space charge effects are <1 cm (<0.5% of detector dimensions)

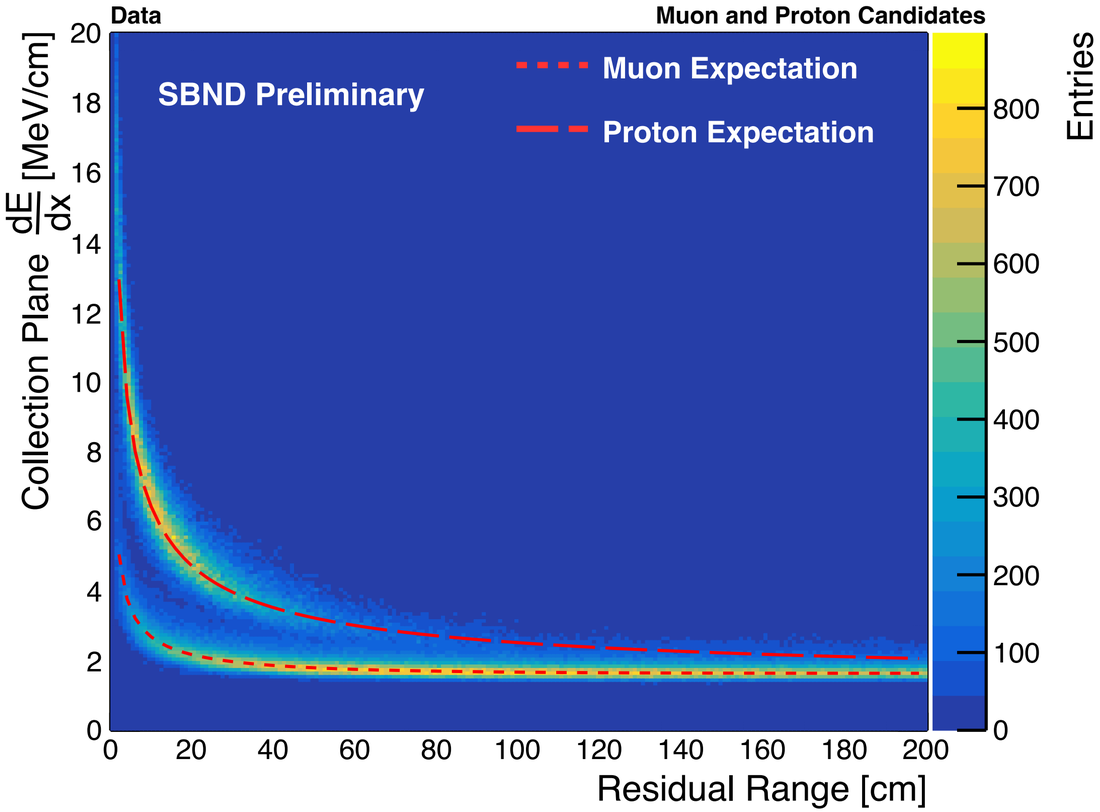
TPC Charge-scale Calibrations: dE/dx



- protons and muons have expected energy deposition per unit length (dE/dx) curves given by Landau-Vavilov theory
  - protons → more highly-ionizing
  - muons → more minimum-ionizing

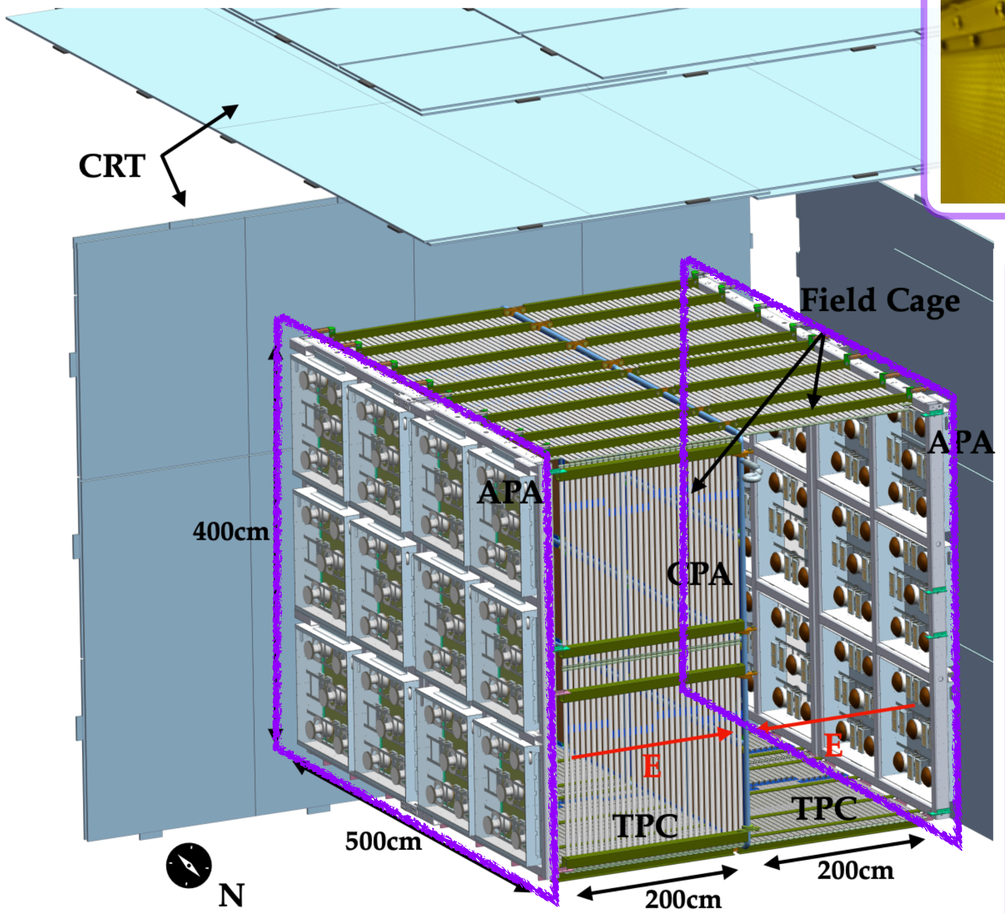
TPC Charge-scale Calibrations: dE/dx

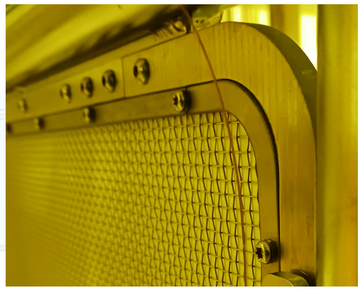




- muon and proton dE/dx show good agreement with the expected most probable value (MPV) from theory

SBND Detector: Photon Detection System



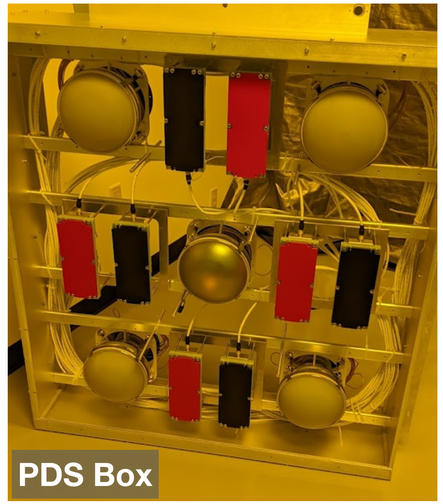


cathode with **TPB-reflective** foils to increase light detection/ light yield

Photon Detection System

120 8” Photo-Multiplier Tubes (operating)

192 X-ARAPUCAs (commissioning)



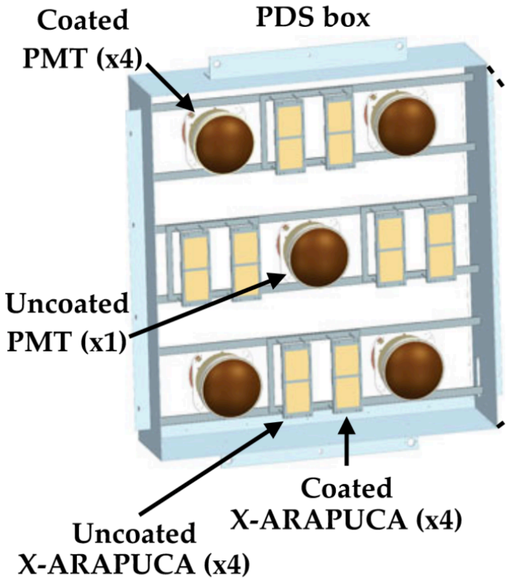
PMTs:
- 80% TPB-coated
- 20% uncoated

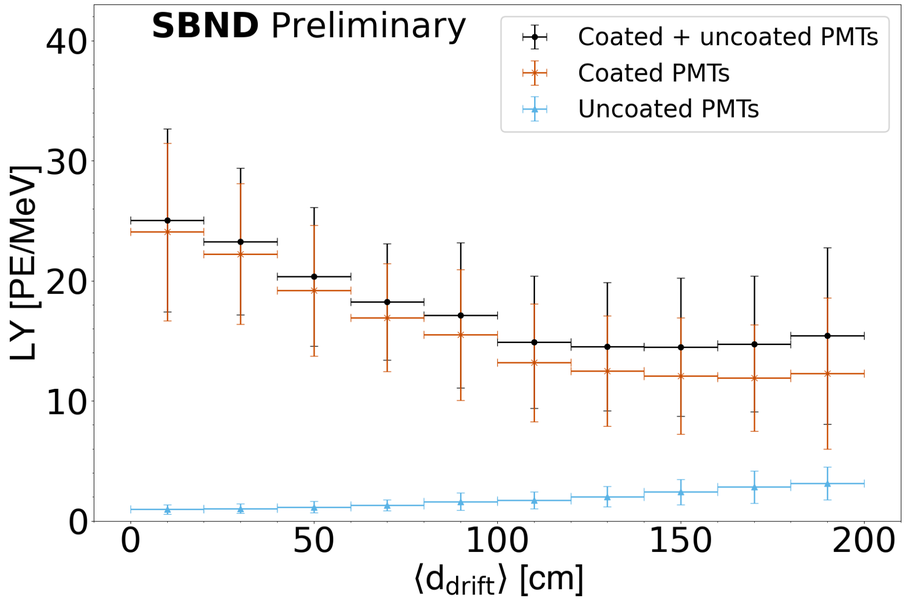
X-ARAPUCAs
- 50% w/ λ-shifting

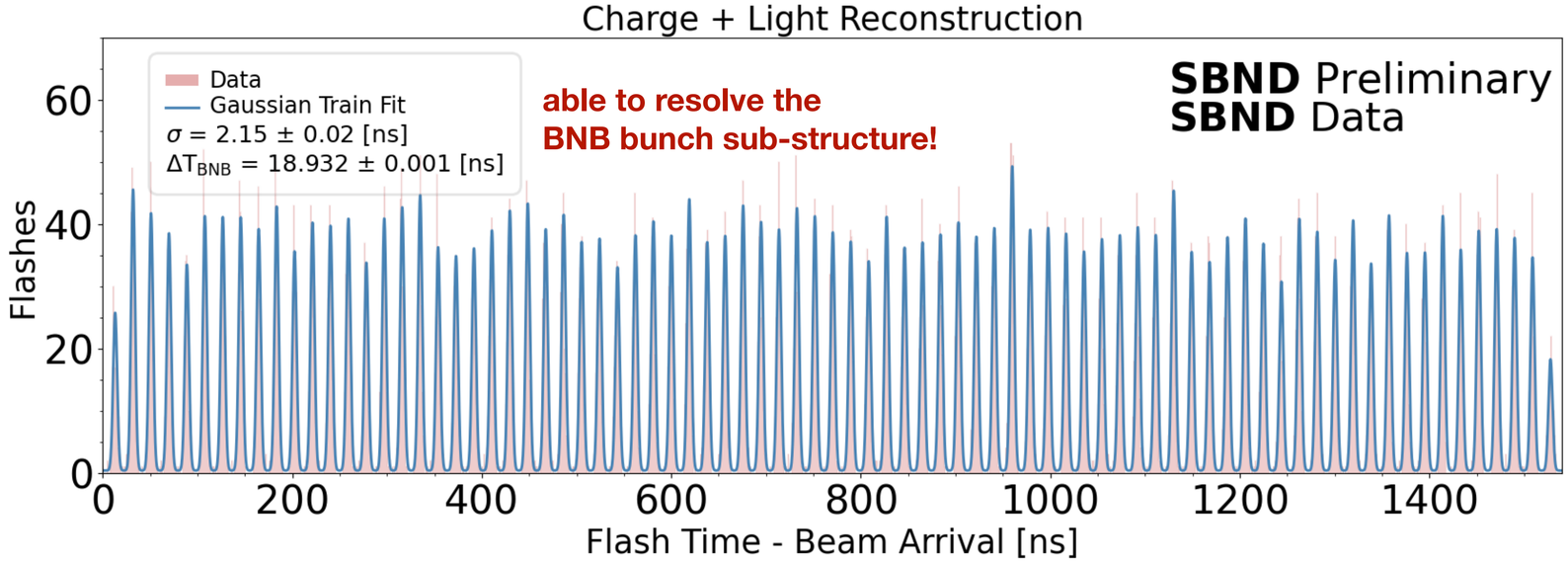
SBND Collaboration, Euro. Phys. J. C **84**, 10 (2024)

PDS Calibrations

- have characterized many properties of the PMTs, including:
  - channel-by-channel single electron response (SER) and deconvolution
  - total light yield is >15 PE/MeV
- PMT reconstruction capabilities:
  - 3D position reconstruction
  - timing resolution O(2 ns)
  - calorimetry with light
- X-ARAPUCAs are currently being commissioned!



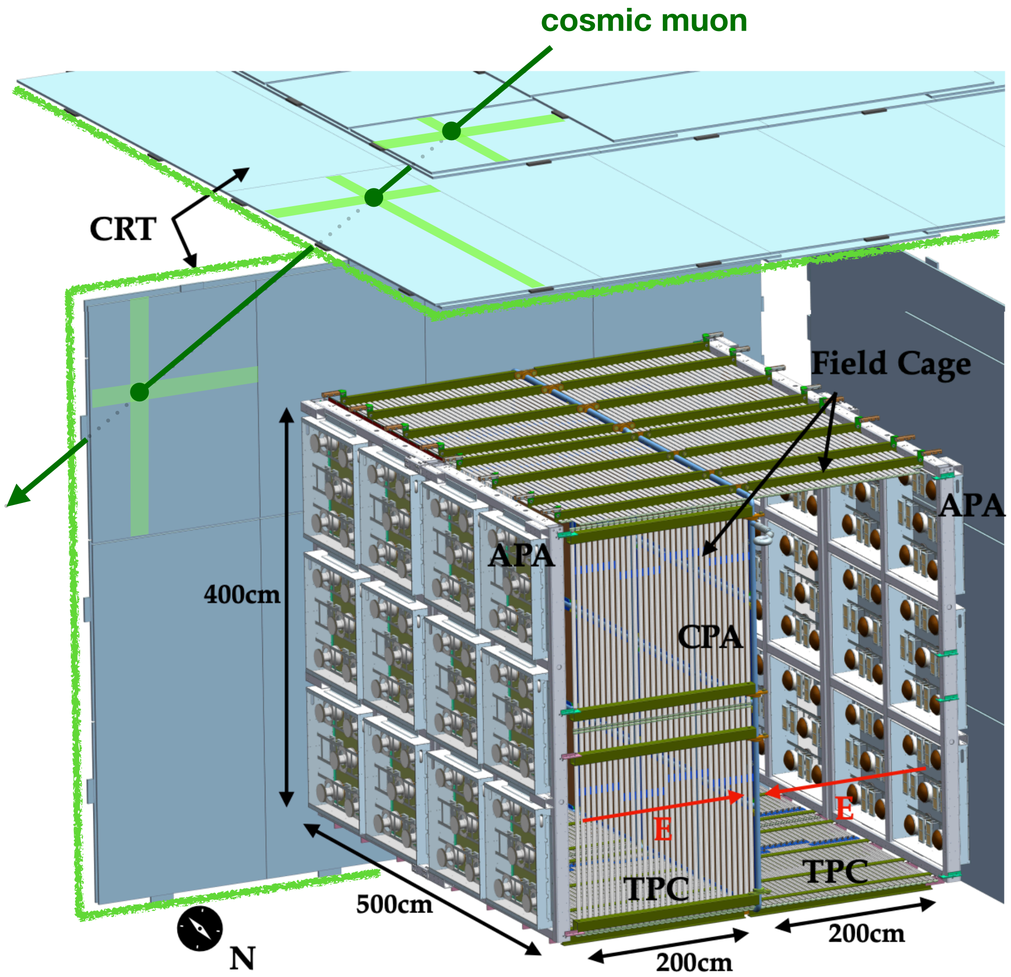




SBND Detector: Cosmic Ray Tagger


CRT Top installation (Summer 2024)

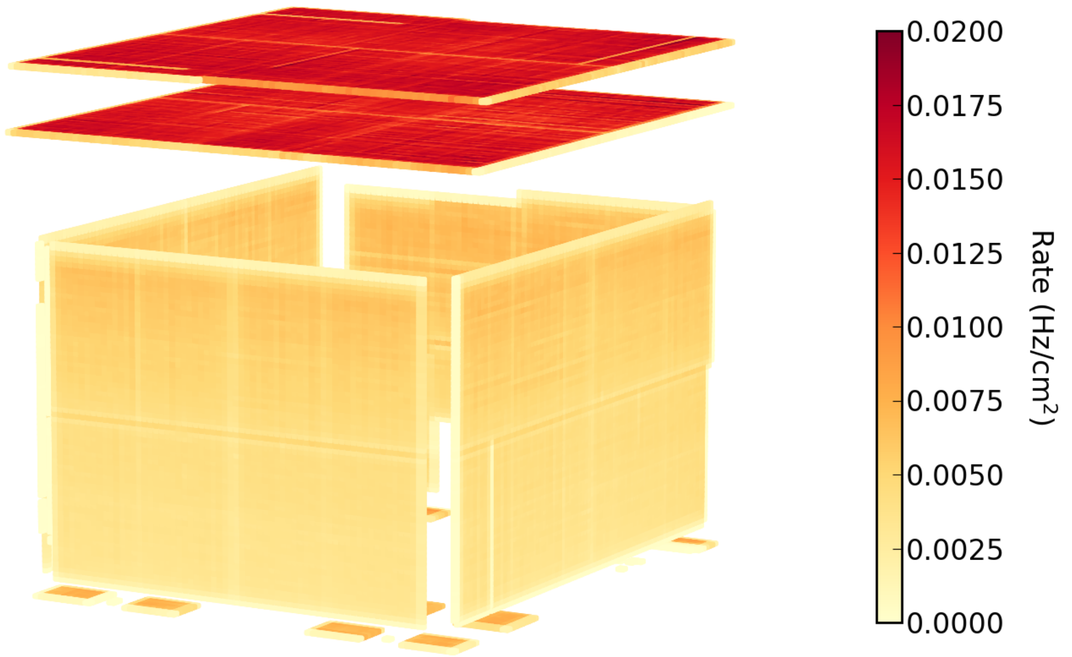
- seven taggers: two top, four side, and one bottom
- each tagger = two layers of perpendicular scintillator strips
- can tag entering and exiting particles with accurate timing and position resolution

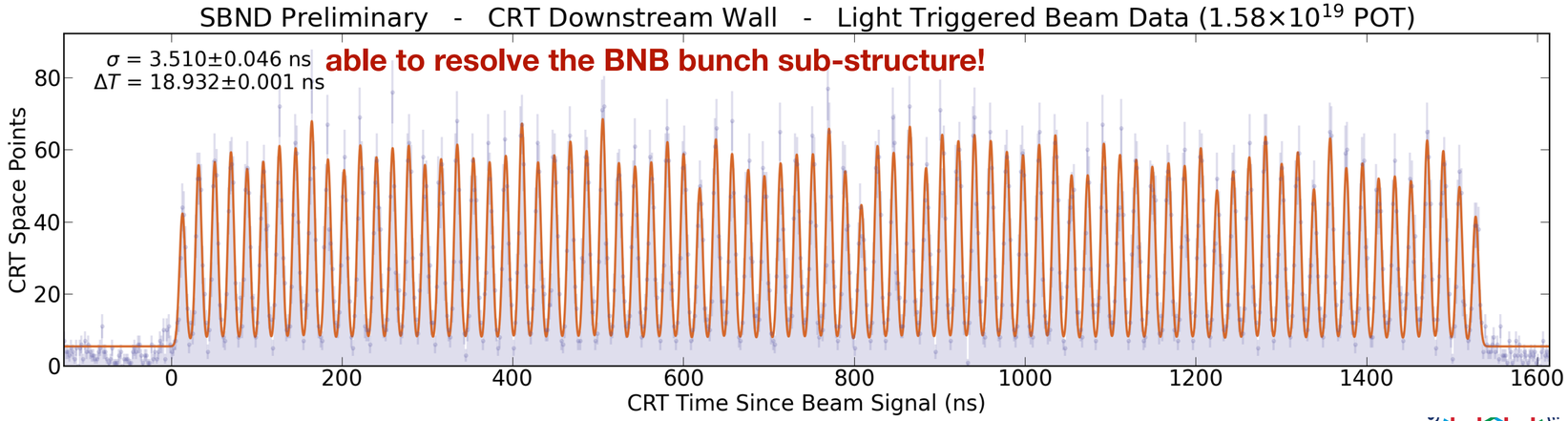


*north, east, bottom CRT panels not pictured

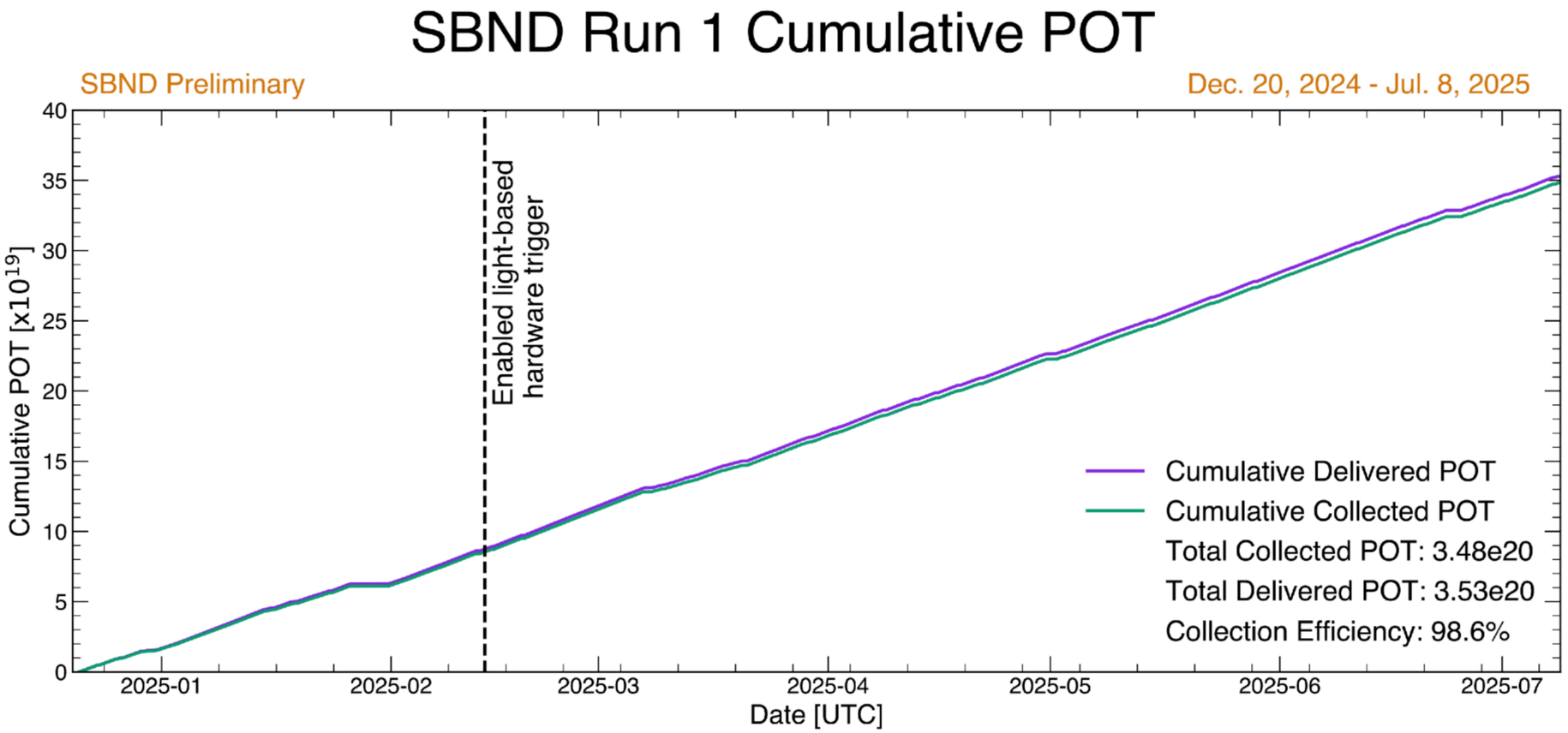
CRT Capabilities

- CRT SiPM voltages tuned to ensure uniformity across modules
- CRT has been essential in calibrating all other detector subsystems!
  - provides both time and spatial position for through-going muons
  - ~nanosecond timing resolution
- can measure cosmic rate
- can use as *background veto* for neutrino analyses





SBND Operations

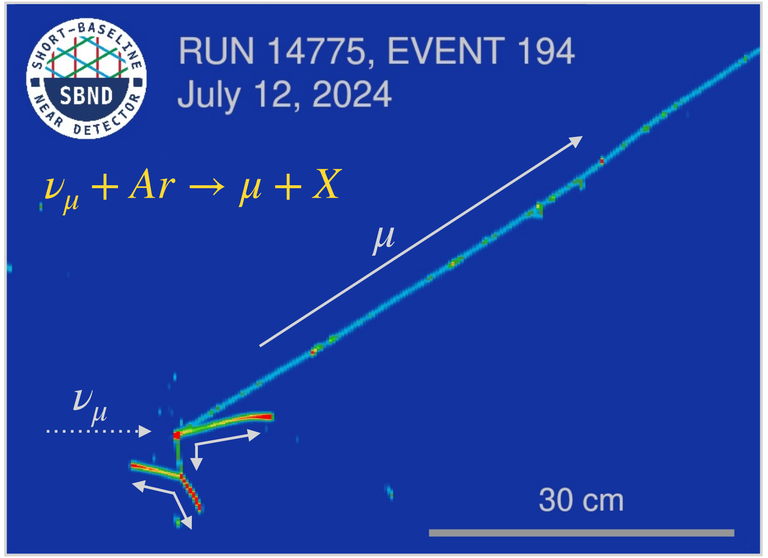


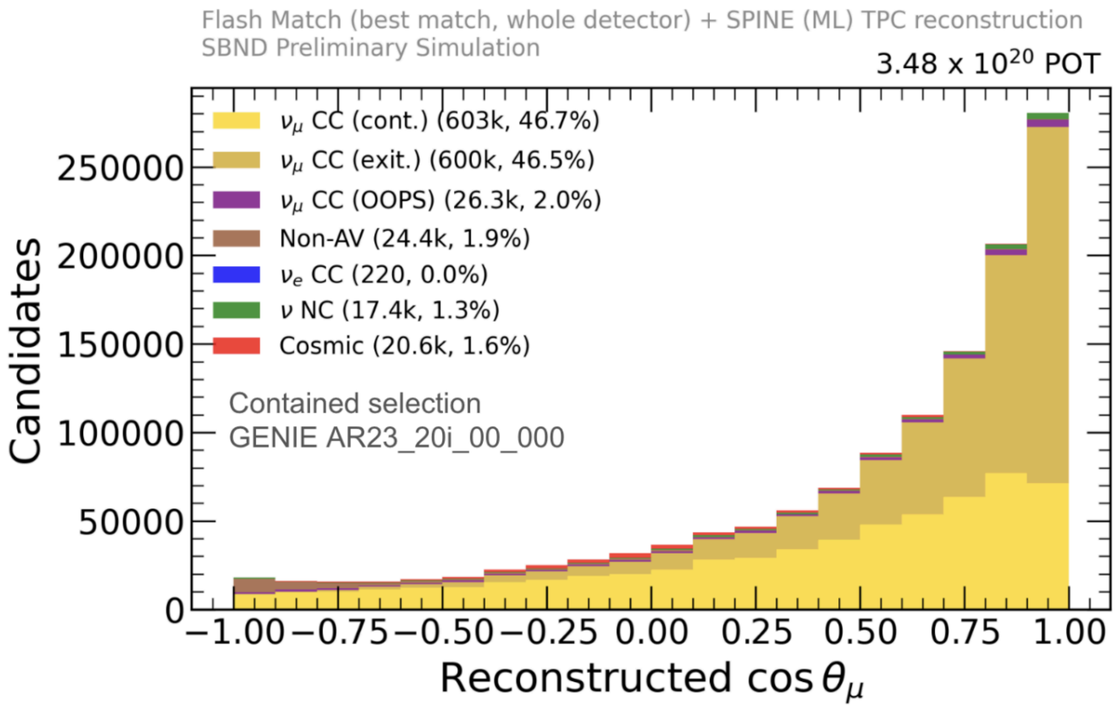
- collecting physics quality data between December 2024-July 2025, approximately nearly 3 million neutrino interactions already in the Run1 dataset (3.5e20 POT)!
- currently taking data for Run2!

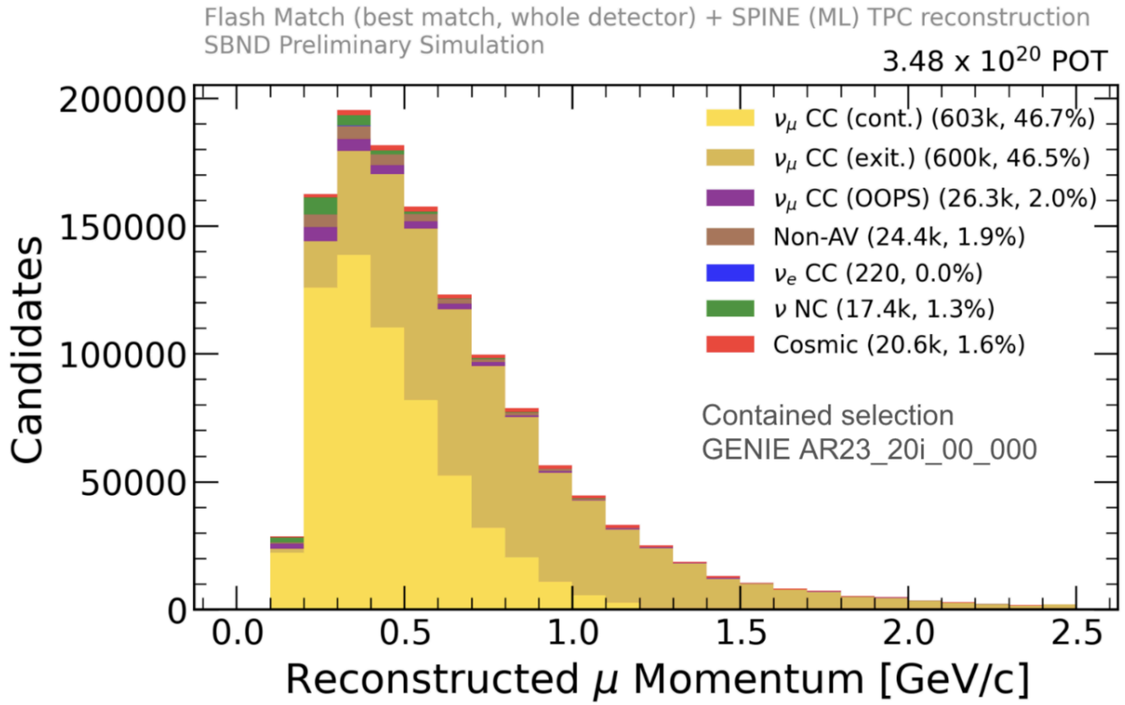
Preliminary Results from First Analyses

ν_μCC Inclusive

- both high efficiency and purity at selecting ν_μ events, expect half a million selected events in just the Run1 dataset
- multi-dimension cross-section in muon kinematics with low model dependency

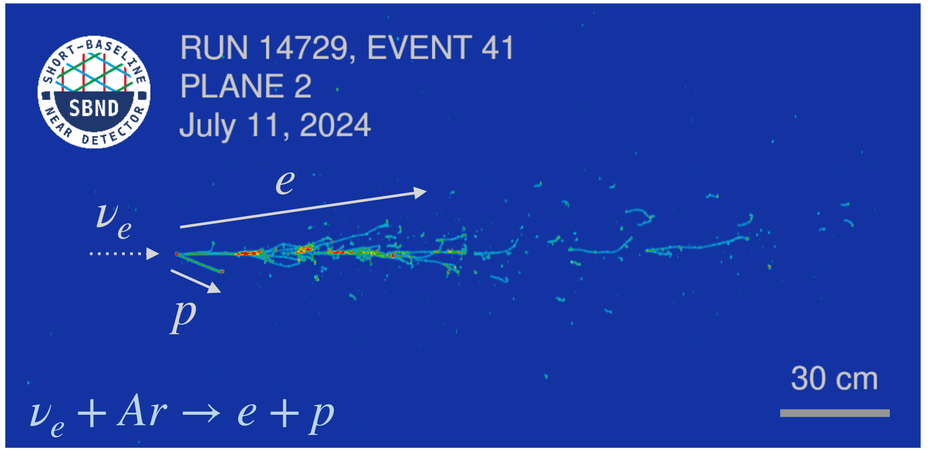


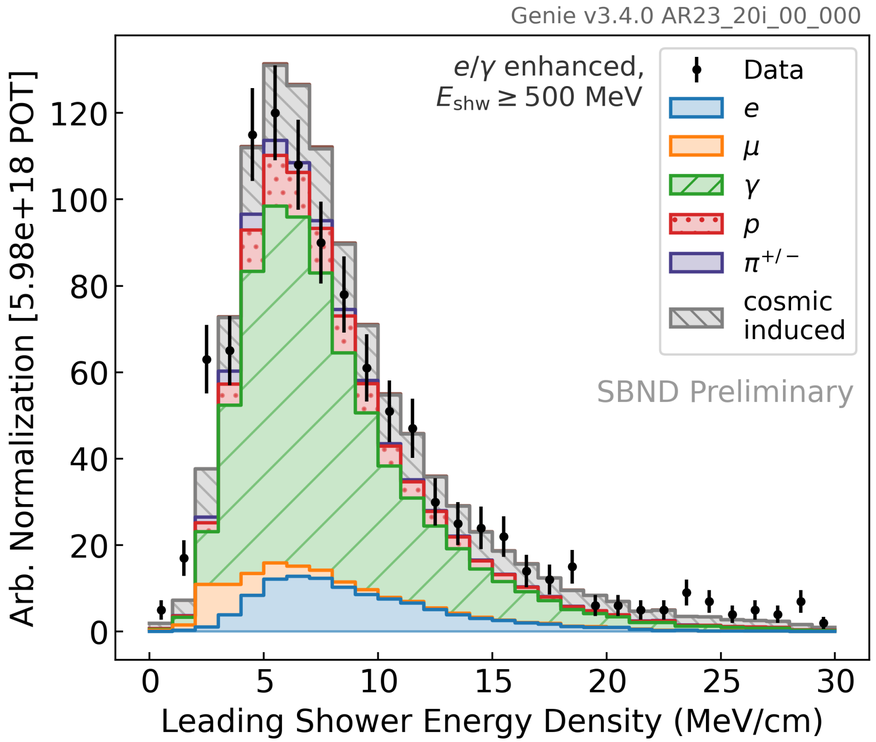


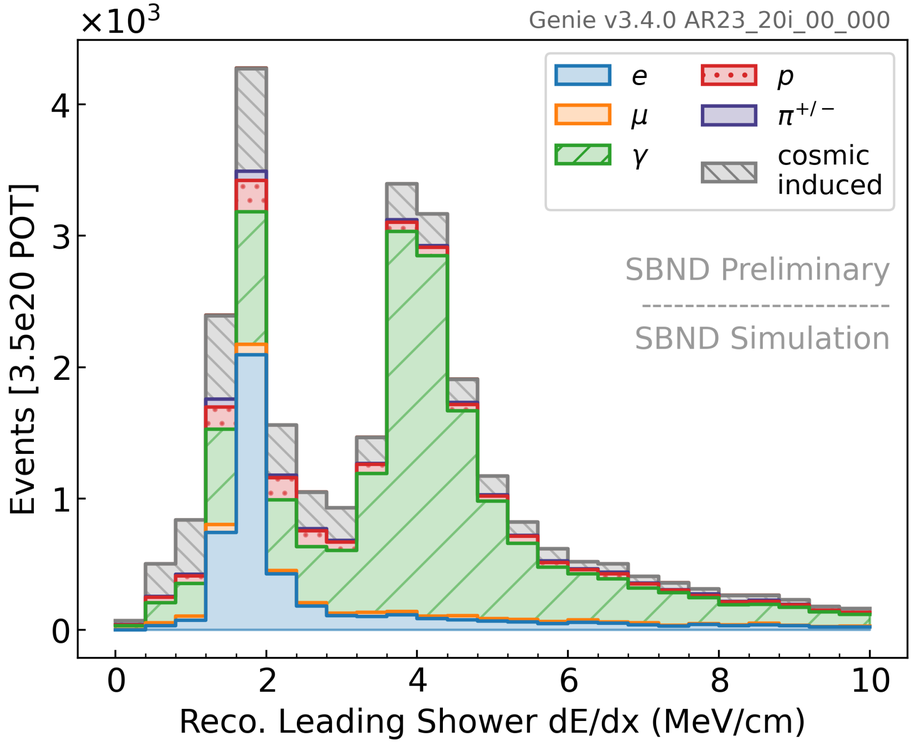


ν_eCC Inclusive

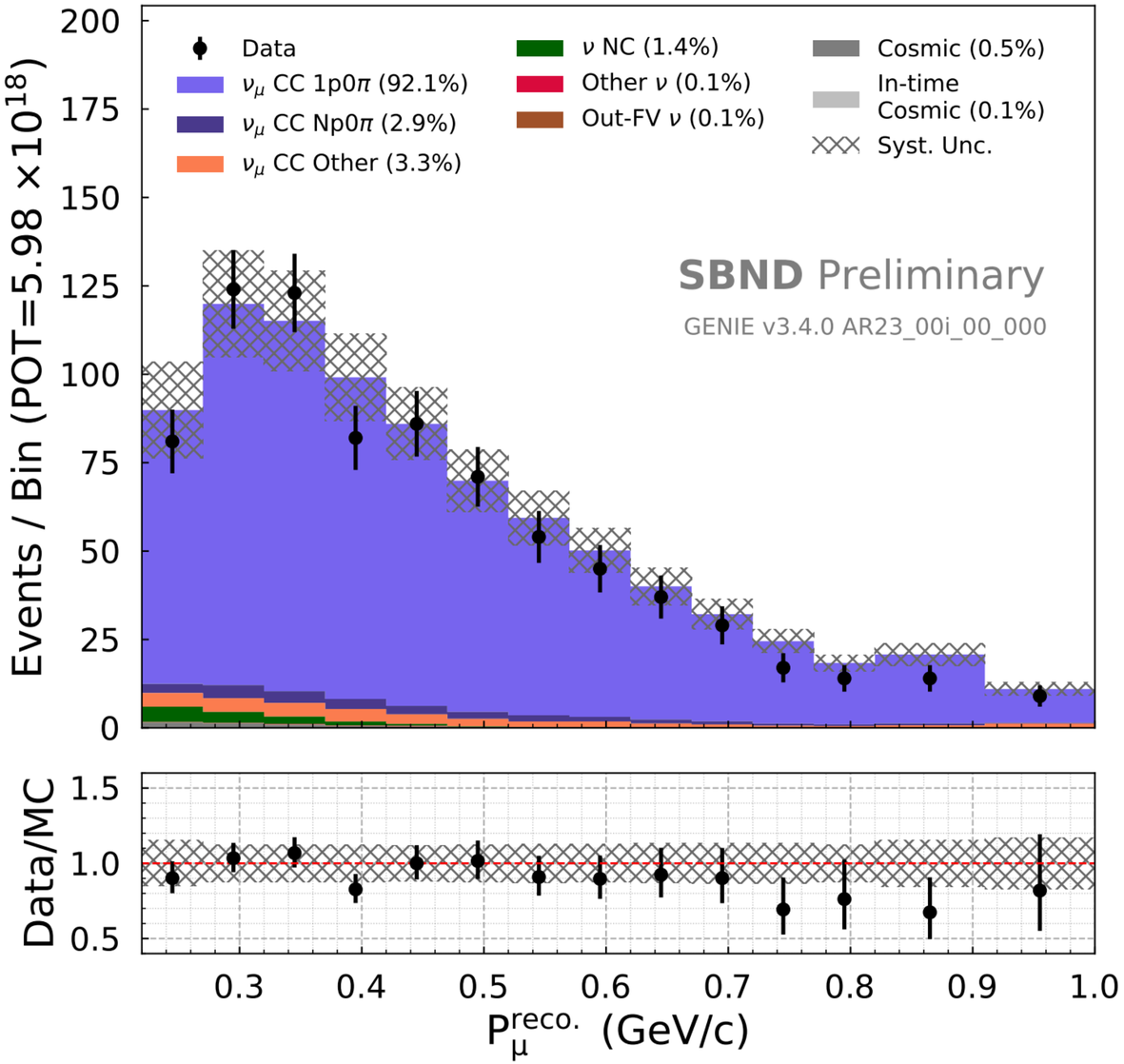
- differential cross-section measurement in electron kinematics, expect thousands of selected ν_e events in the Run1 dataset
- demonstrate good characterization of electromagnetic activity and e/γ separation, crucial for oscillation studies



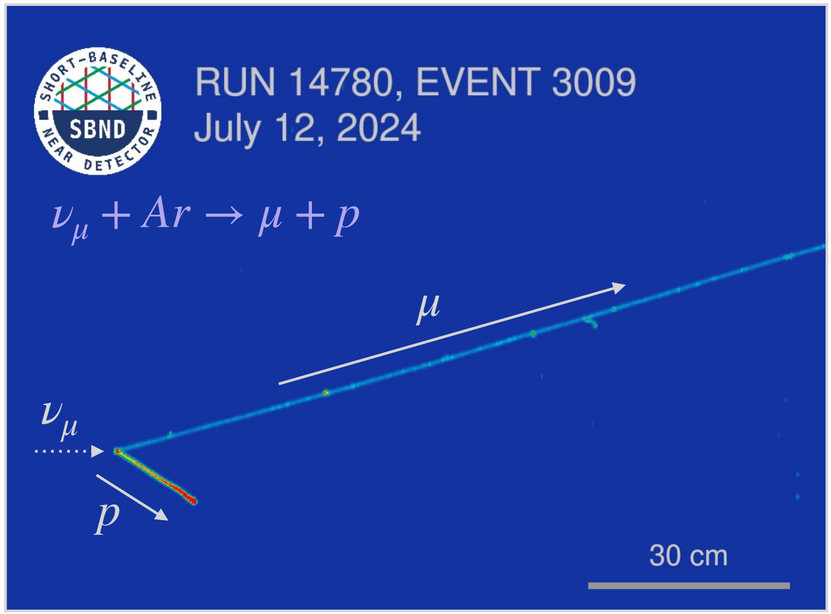




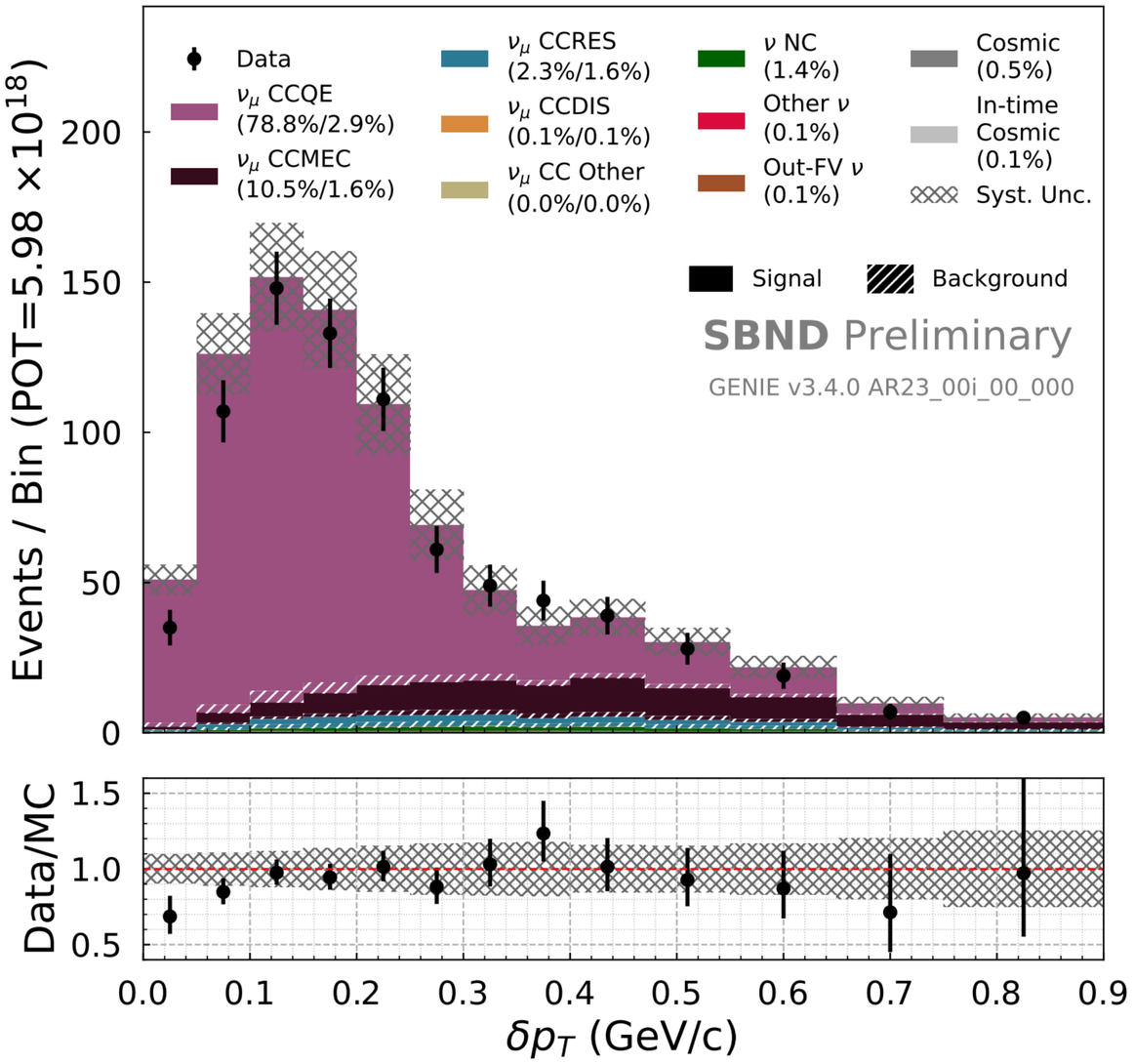
ν_μ $1\mu 1p0\pi$ exclusive channel



- analysis is in advanced stages, including systematic uncertainties and unfolding
- representative final state for charged-current quasielastic (CCQE) scattering



ν_μ $1\mu 1p 0\pi$ exclusive channel



- transverse kinematic imbalance (TKI) variables provide sensitive probes of nuclear effects

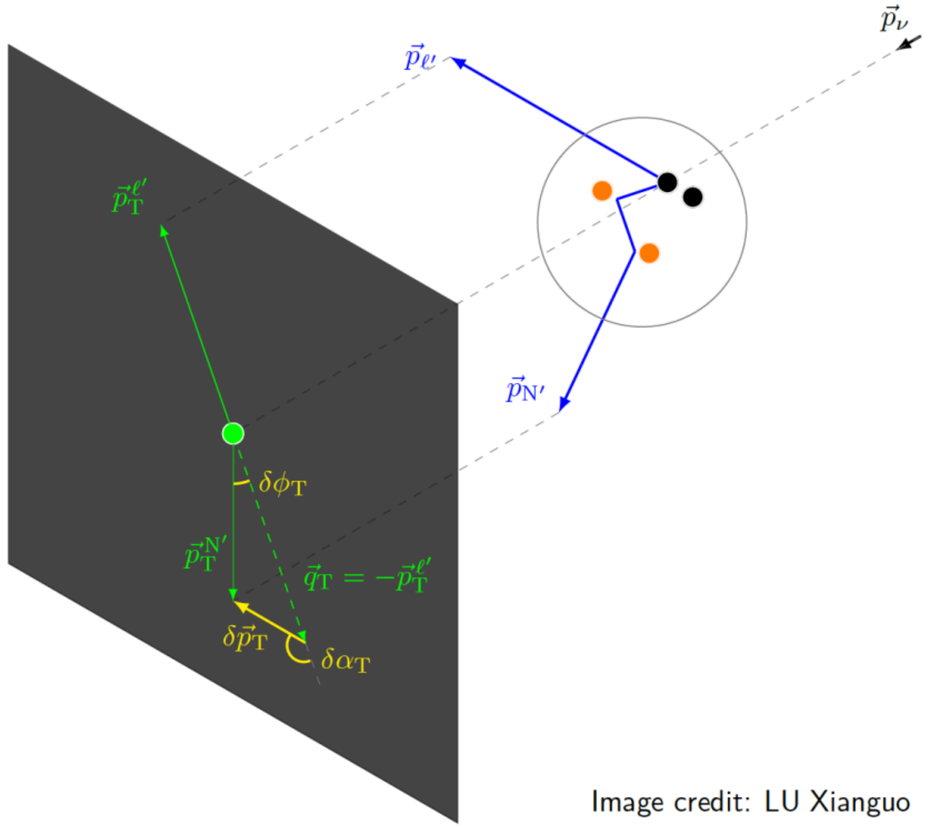


Image credit: LU Xianguo

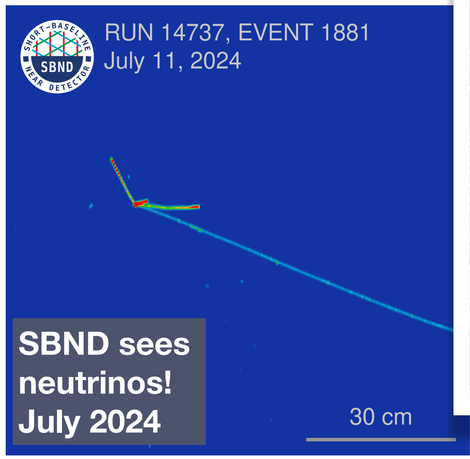
Summary + Outlook

- SBND is fully operational, with 3.5e20 POT of neutrino data collected since December 2024!
- detector studies and calibrations already show great detector performance
- several preliminary neutrino physics analyses ongoing, with many more to come
- stay tuned for physics results in the near future!


Detector Assembly, Dec 2018-Sep 2022


Detector Move, Dec 2022


Detector Into Cryostat, April 2023



SBND sees neutrinos! July 2024


SBND June CM Sheffield, June 2025