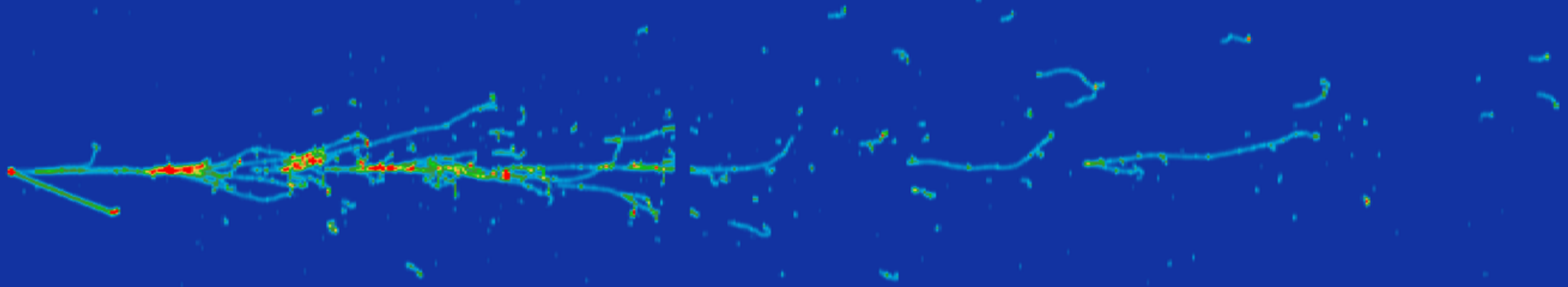
RUN 14729, EVENT 41
July 11, 2024

SBND: Precision Neutrino Physics and Beyond

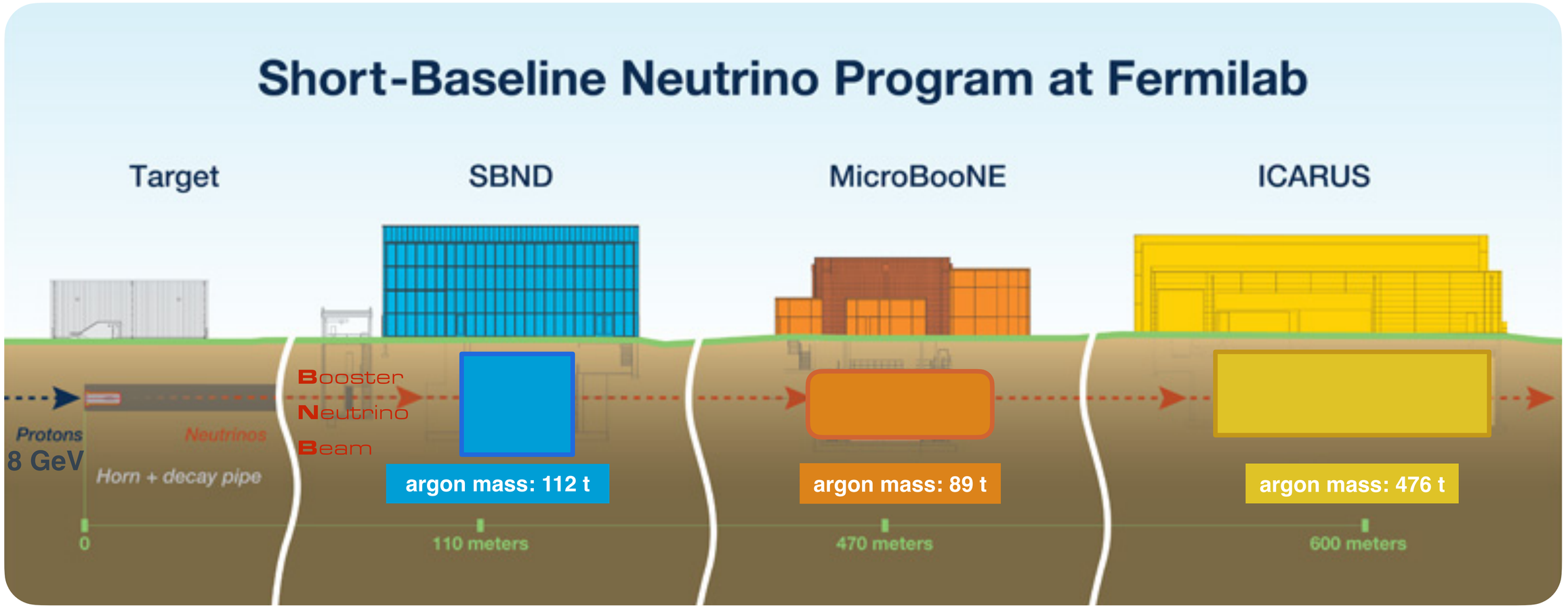


NNN26 Workshop – October 28th, 2026

Ornella Palamara – Fermilab

on behalf of the SBND Collaboration

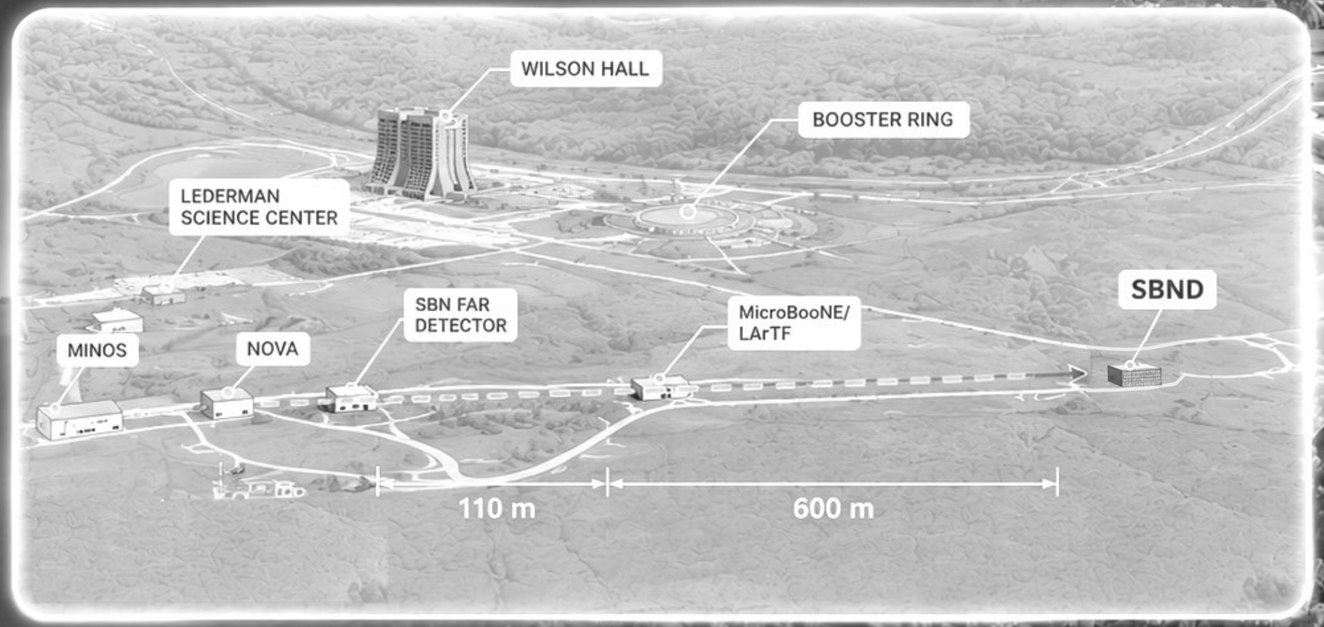
A Vision Focused on Neutrinos

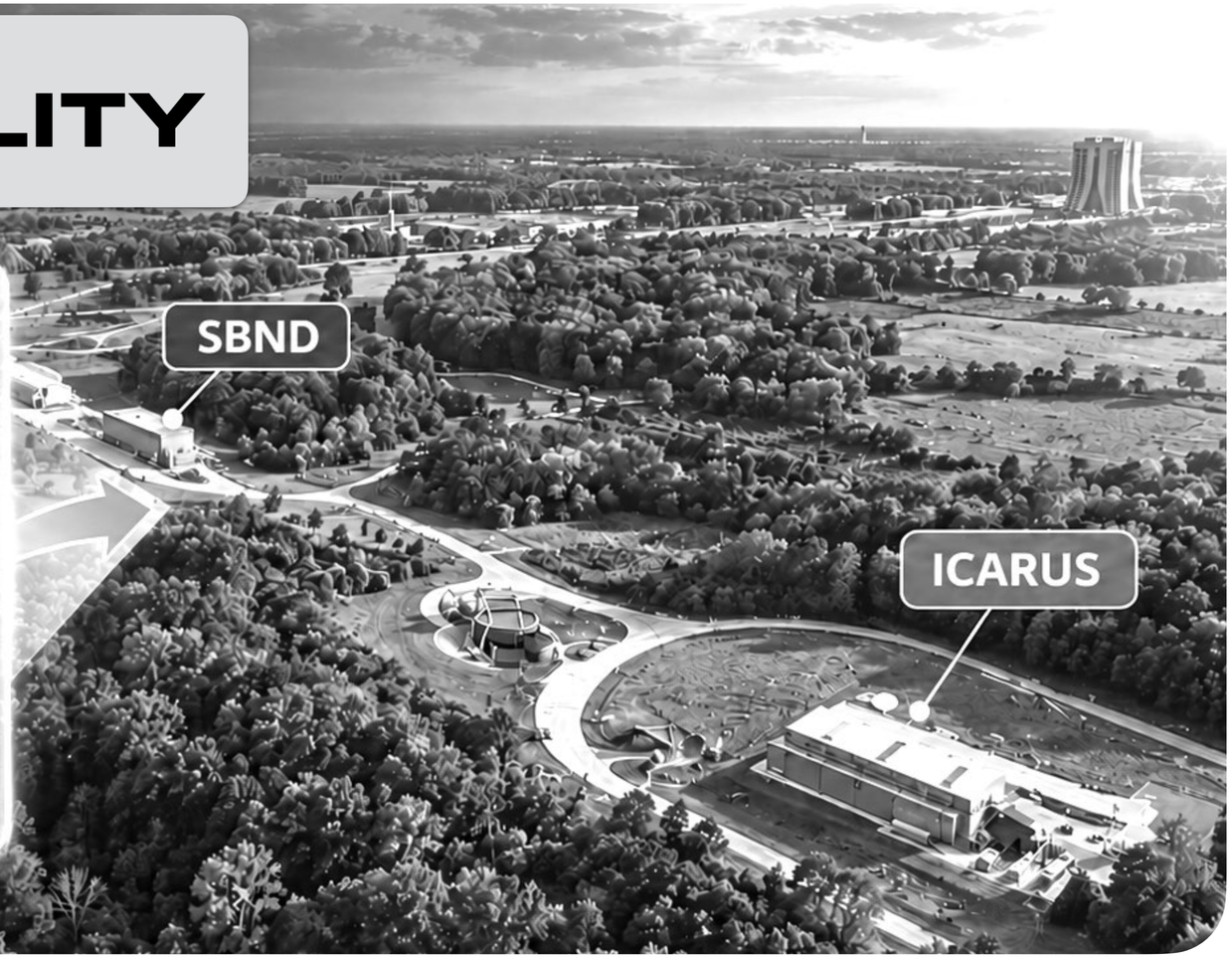


Short-Baseline Neutrino Oscillations
(ev-scale sterile neutrinos)

Neutrino Interactions

From vision to reality



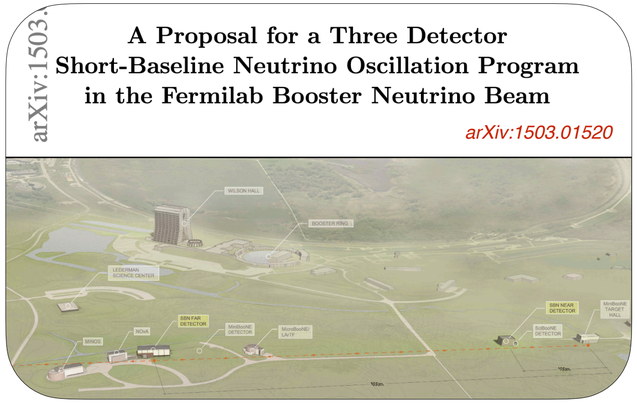


Original source images compiled and stylized using Claude

A DECADE IN THE MAKING

2014–15
The vision

The SBN program takes shape, with SBND proposed as near detector.



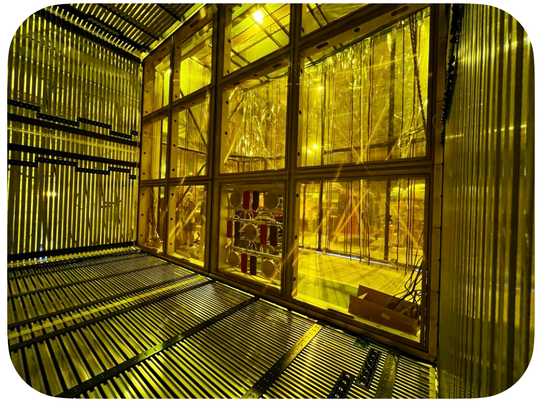
2016–21
Construction



A precision detector built from complex subsystems and contributions from institutions worldwide.

2021–23
Integration & Installation

Separately built systems come together as one instrument.



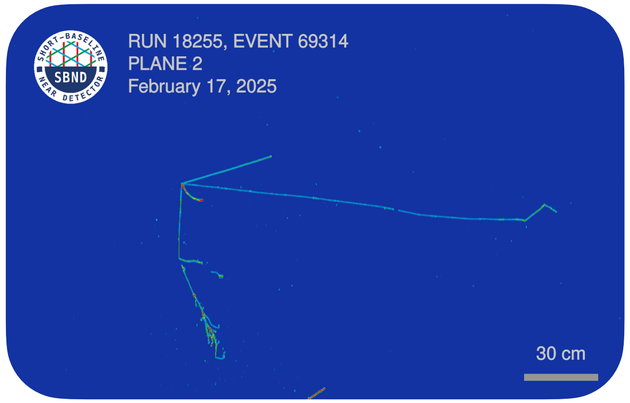
2024
Commissioning & First neutrinos



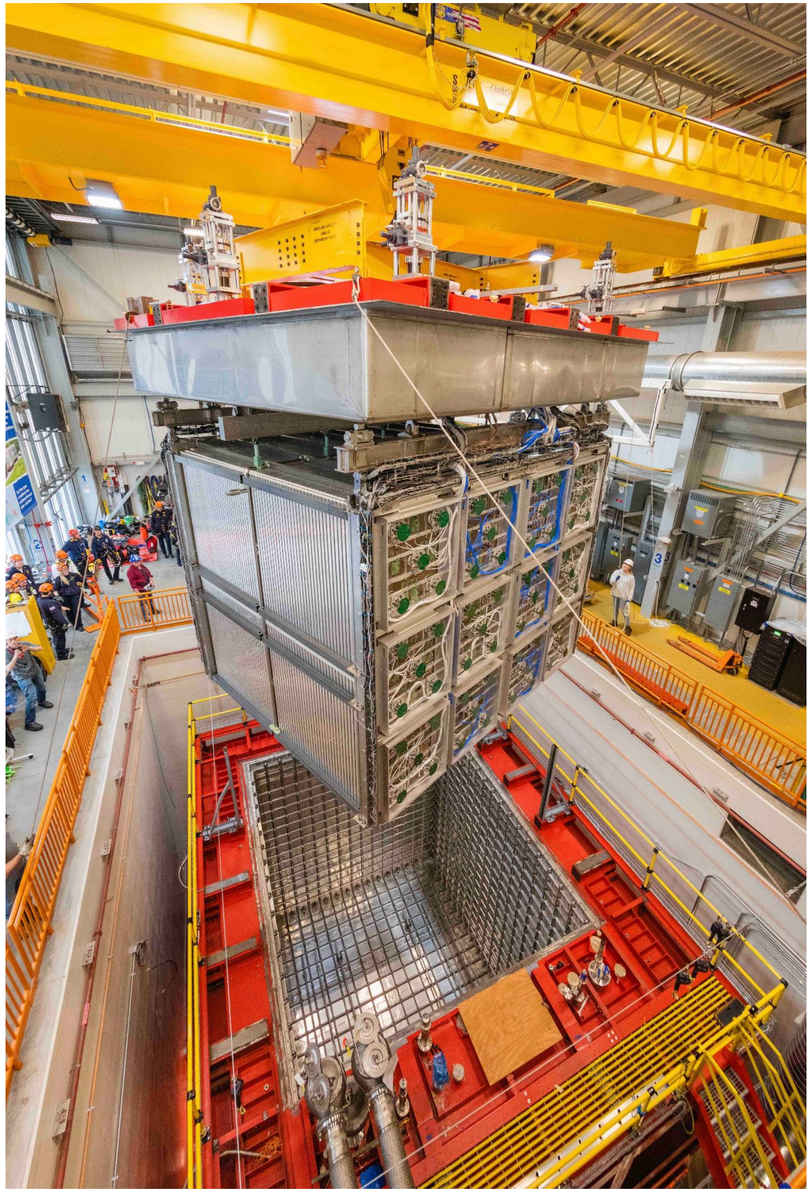
First neutrino interactions in July 2024, stable beam data from December.

2025–26
Toward physics

From a construction project to physics experiment.



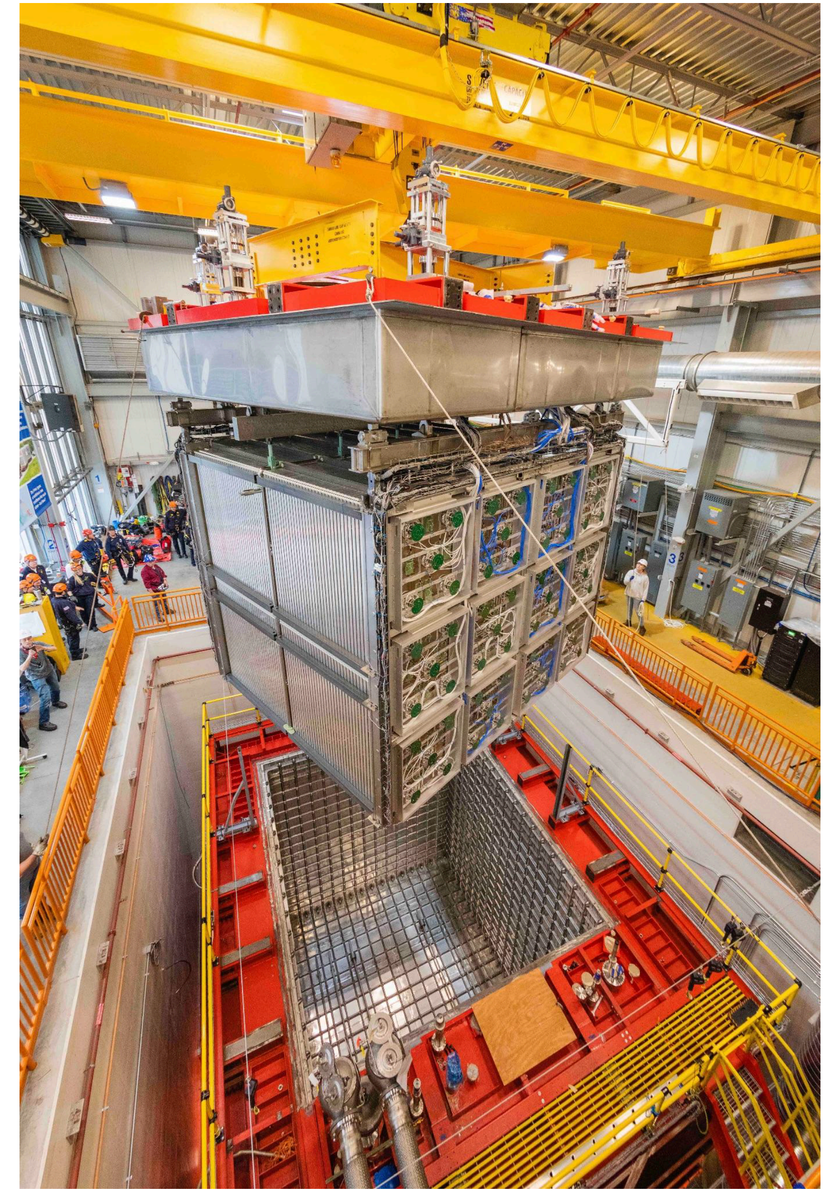
Thousands of Details – One Instrument

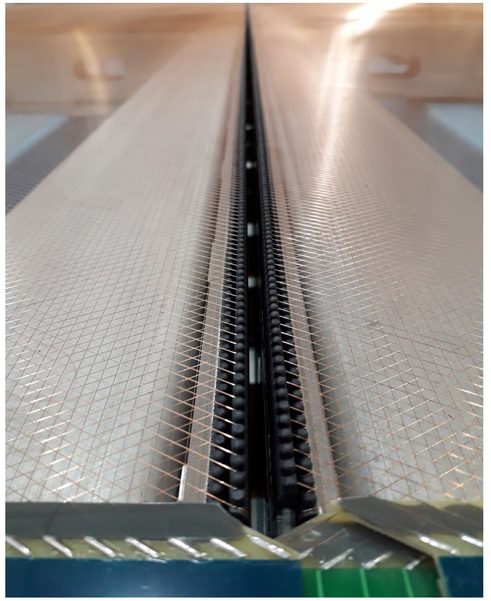


April 2023

Short-Baseline Near Detector (SBND): Design and Initial Performance
arXiv:2610.11782

Thousands of Details – One Instrument

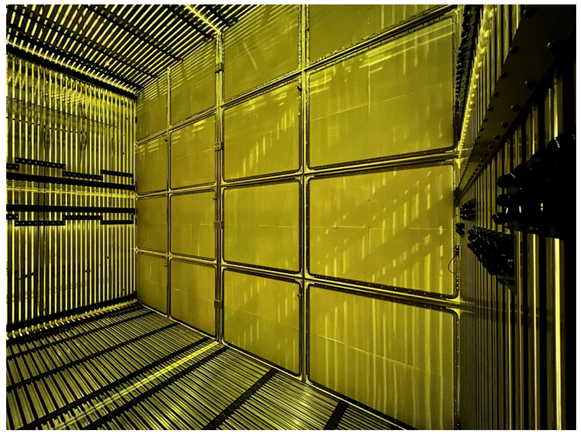




Wire planes with cold electronics

11,264 TPC readout channels

Cathode at -100 kV

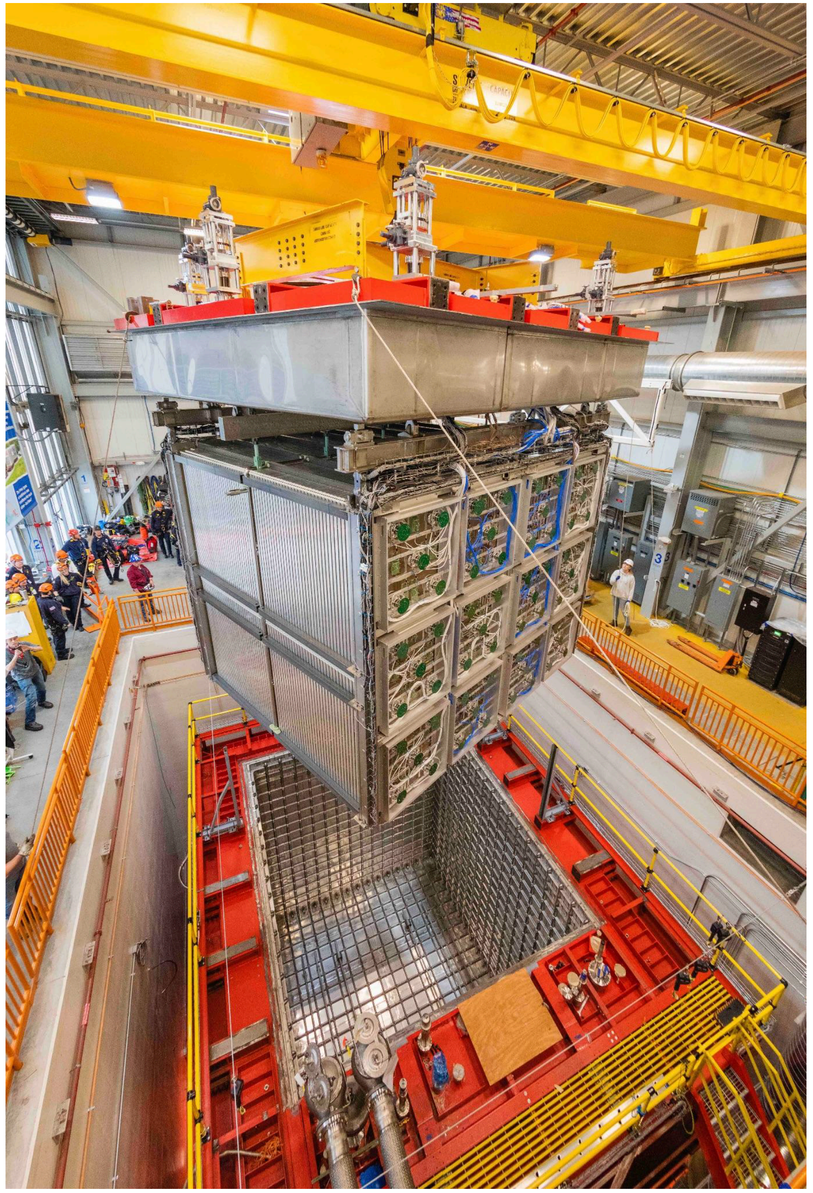


Field cage

4m x 4m x 5 m
Two Time Projection Chambers

Short-Baseline Near Detector (SBND): Design and Initial Performance
arXiv:2610.11782

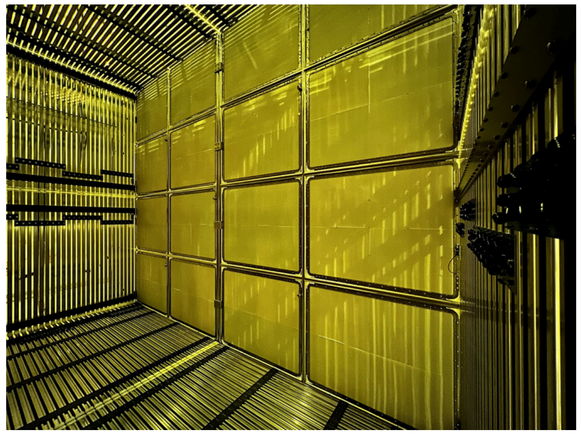
Thousands of Details – One Instrument



Photon Detection Systems

Production and installation of wavelength-shifting reflective light enhancers for the Short-Baseline Near Detector
JINST 21 P10008

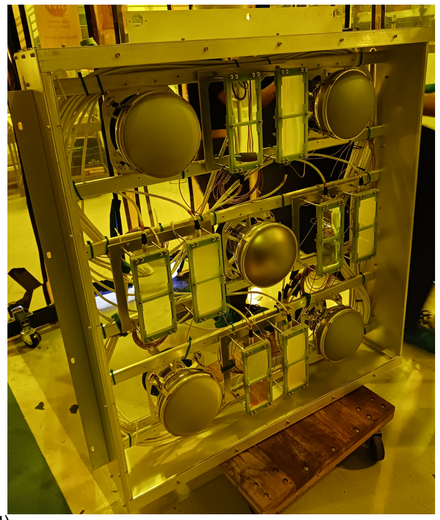
Wavelength-shifting Reflector foils on the Cathode



Short-Baseline Near Detector (SBND): Design and Initial Performance
arXiv:2610.11782

Photon Detection Box (PMTs, X-Arapucas)

120 8”PMTs
192 X-ARAPUCAs



Scintillation Light in SBND: Simulation, Reconstruction, and Expected Performance of the Photon Detection System
Eur. Phys. J. C 84, 1046 (2024)

Thousands of Details – One Instrument

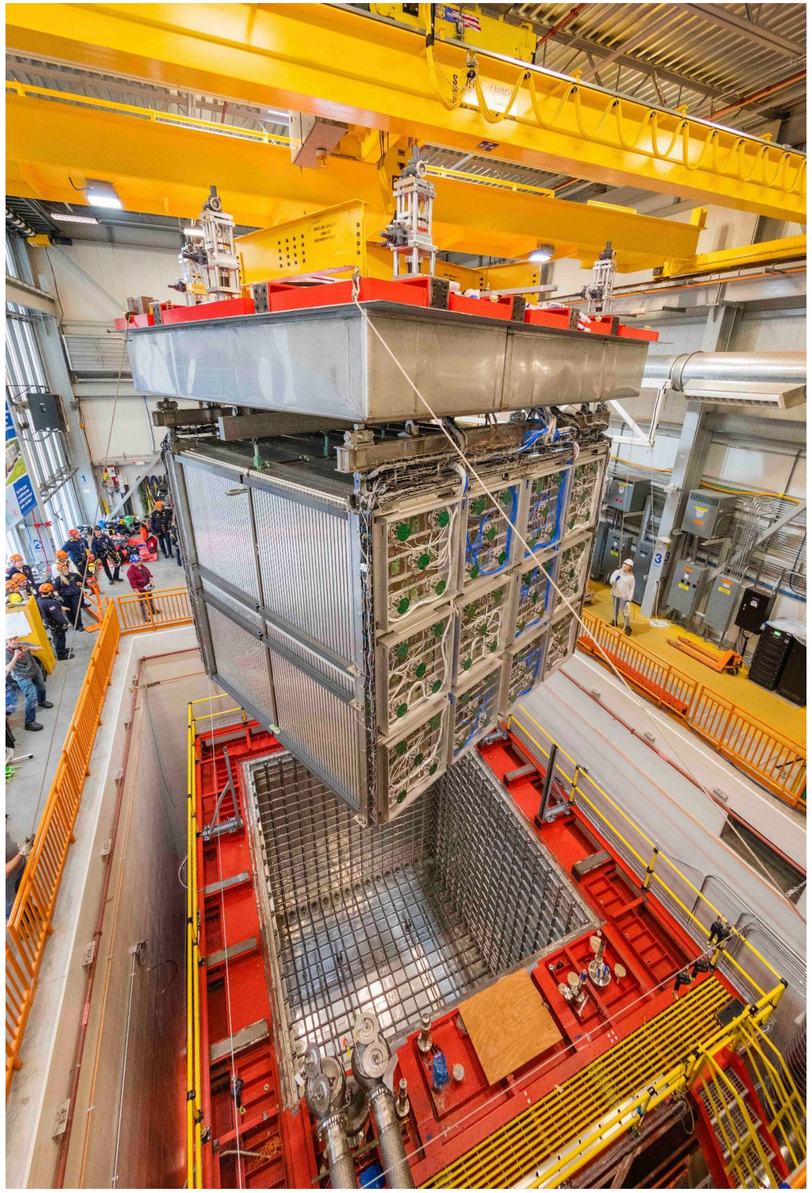


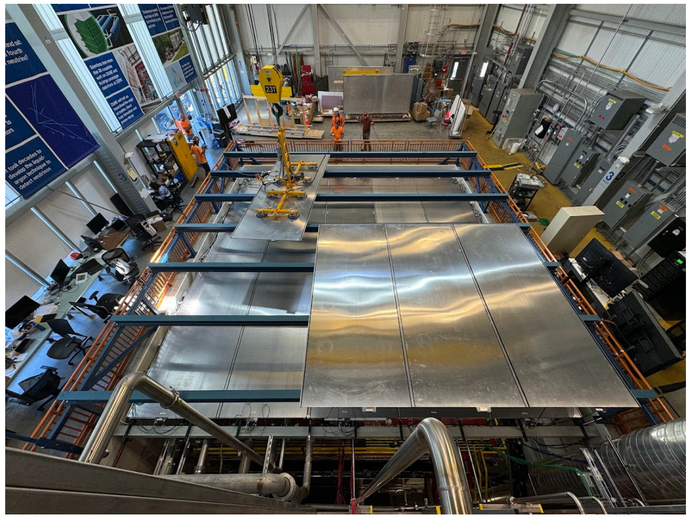
External

Cosmic Ray Tagger (CRT)

4π coverage

4,000 readout channels

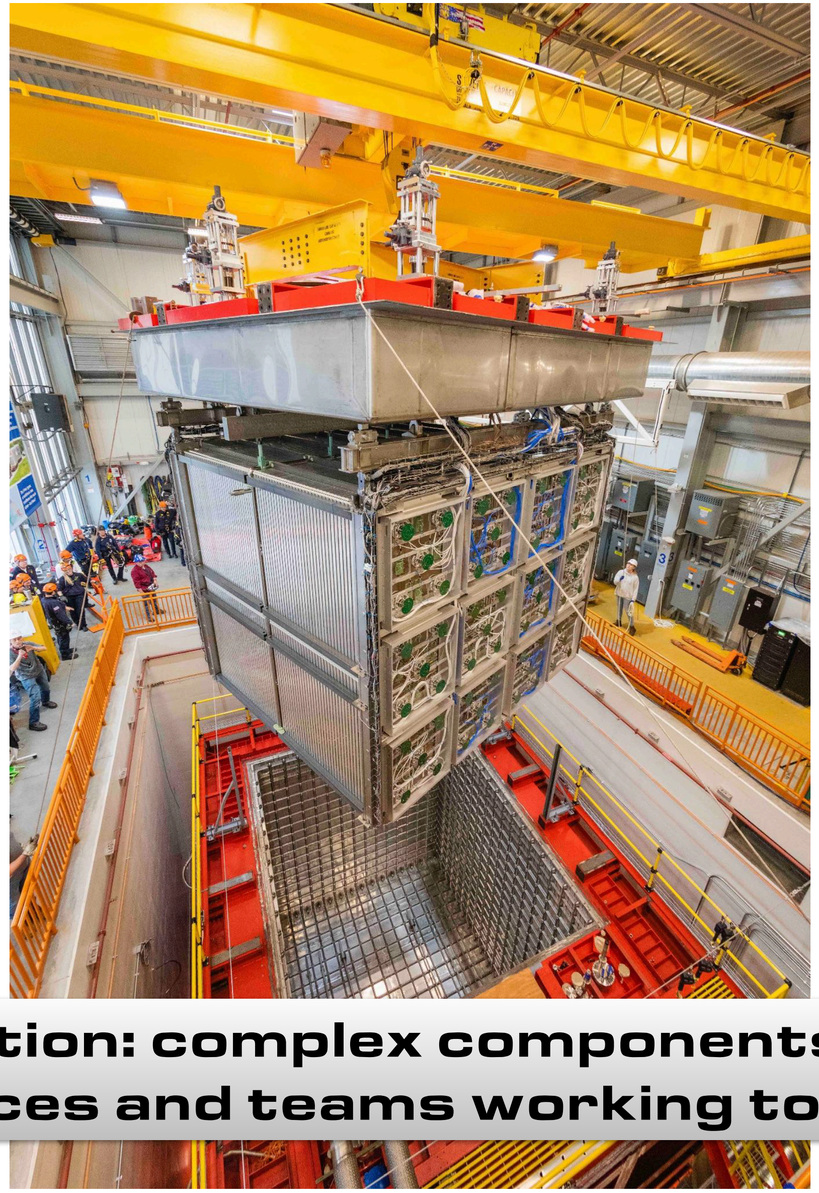


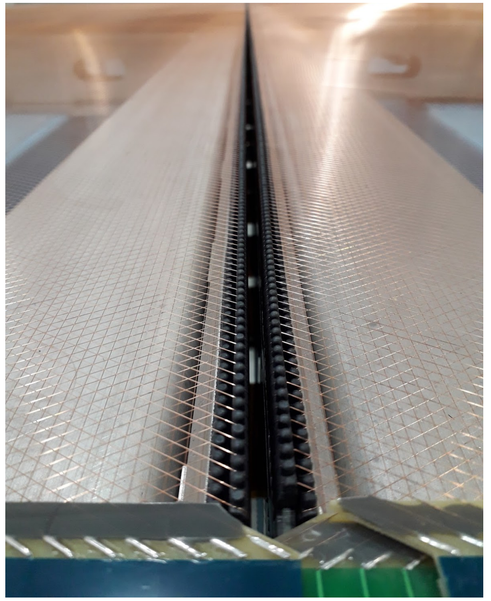


Short-Baseline Near Detector (SBND): Design and Initial Performance
arXiv:2610.11782

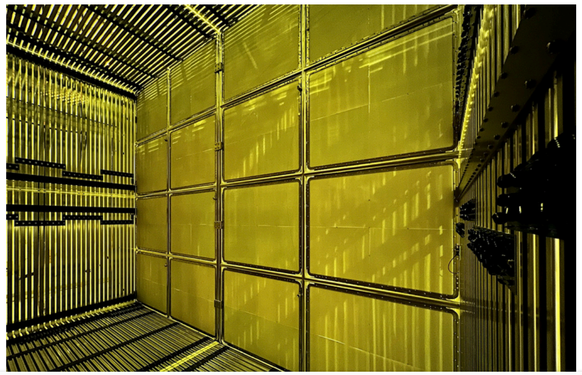
Thousands of Details – One Instrument

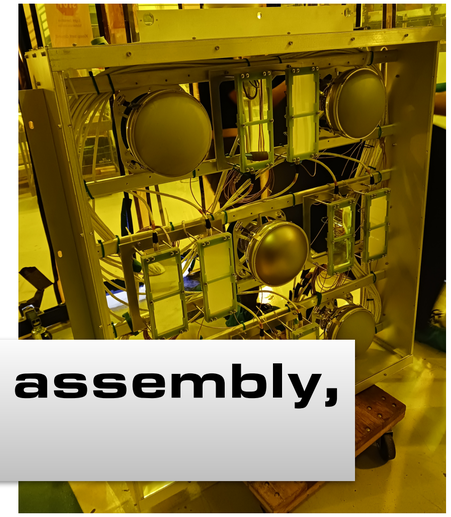






Cathode

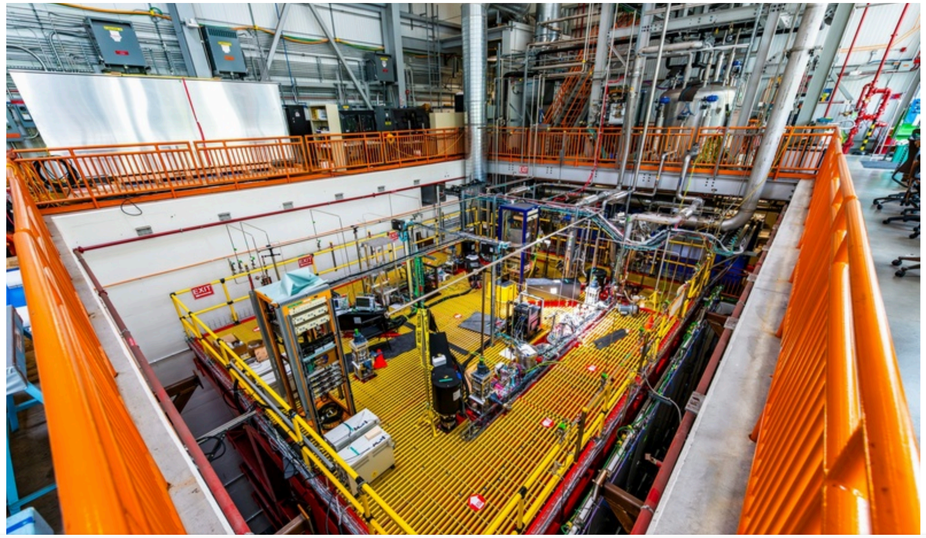




Engineering coordination: complex components, precision assembly, interfaces and teams working together.

Short-Baseline Near Detector (SBND): Design and Initial Performance
arXiv:2610.11782

One Precision Instrument

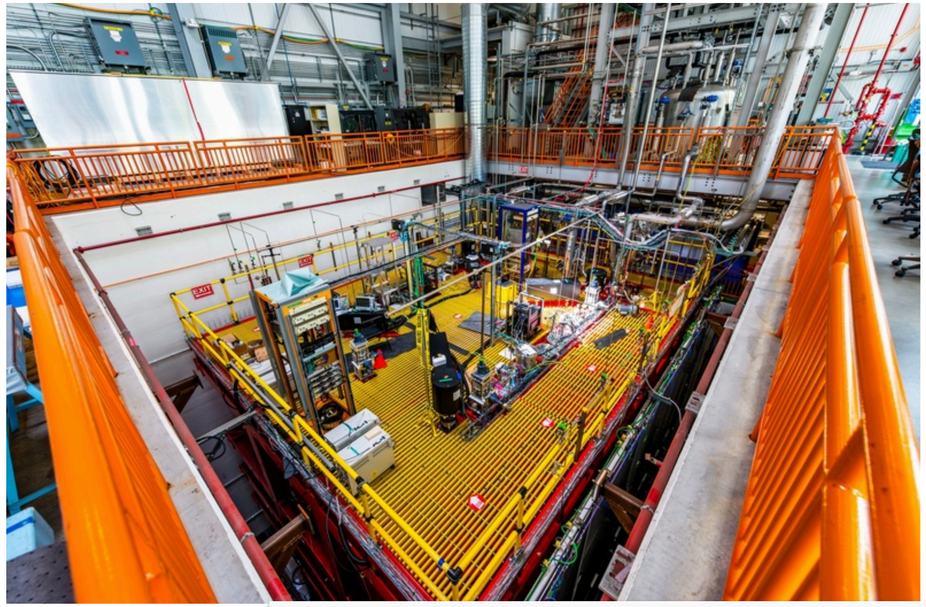




Integrating detector, cryogenics, electronics, readout, DAQ, trigger into one instrument.

Short-Baseline Near Detector (SBND): Design and Initial Performance
arXiv:2610.11782

One Precision Instrument





Cool. Filling and purifying argon. Commission.

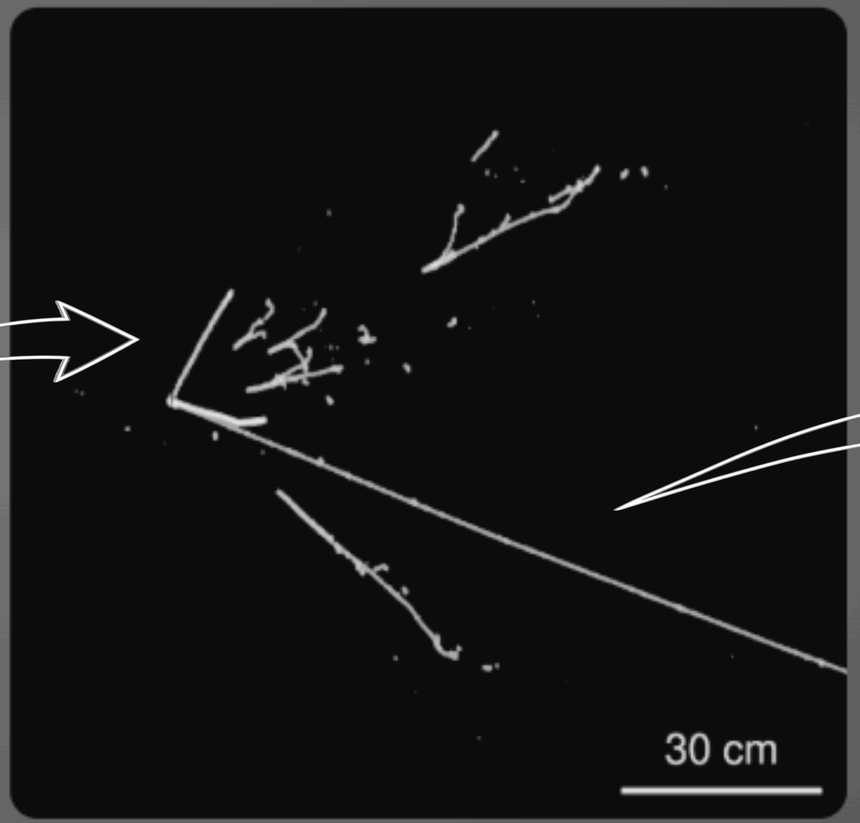


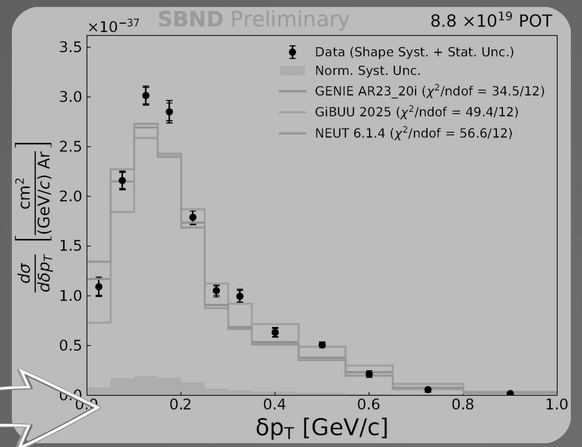
Excellent liquid argon purity achieved, electron lifetime exceeding 30 ms, 10 x the design requirement

Short-Baseline Near Detector (SBND): Design and Initial Performance
arXiv:2610.11782

The original vision becomes physics

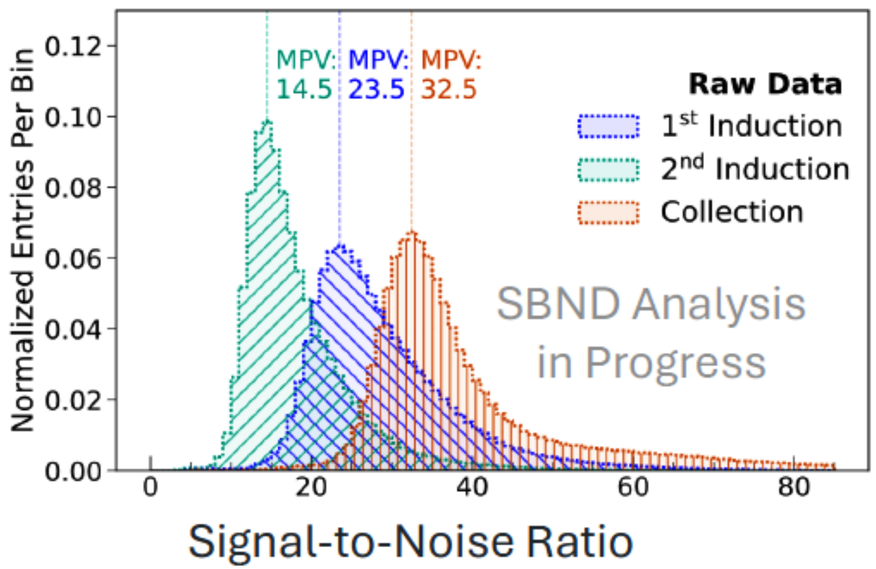




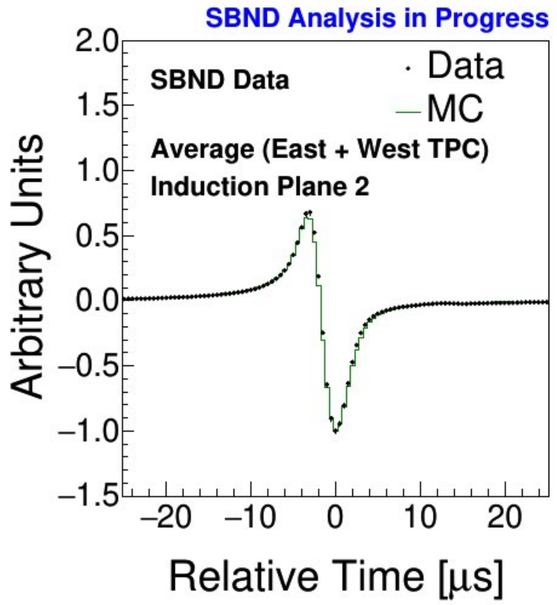


A Detector Ready for Physics

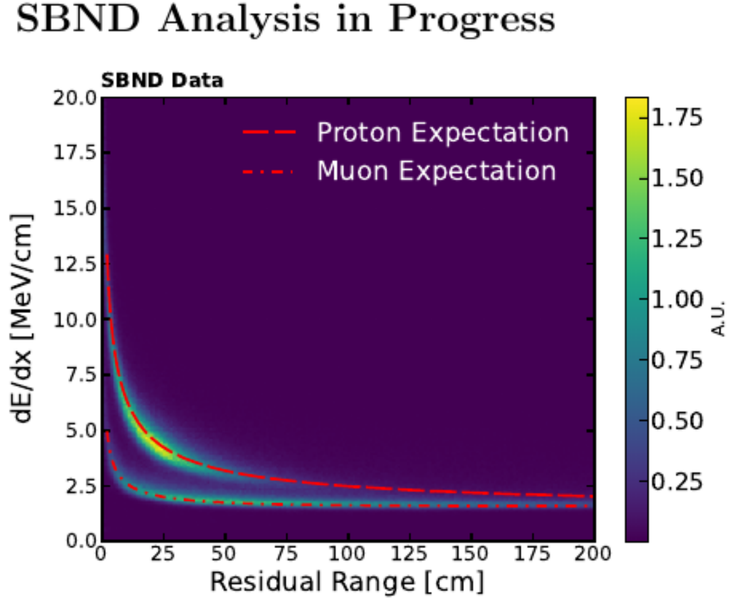
TPC cold electronics



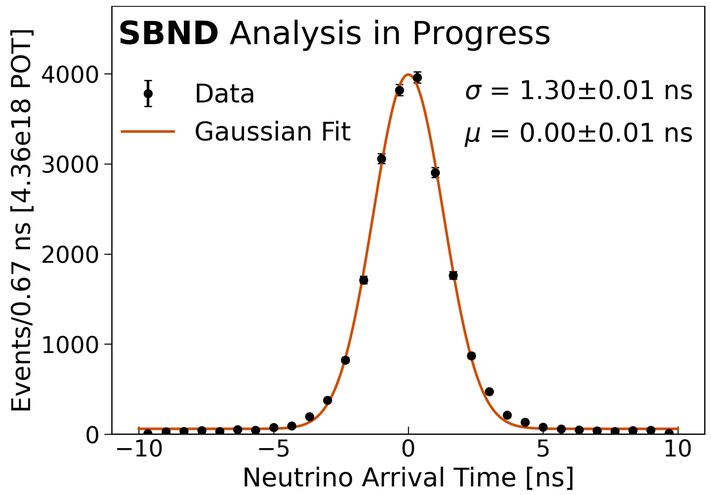
TPC Signal waveforms



Particle Identification



Neutrino Arrival Time



convoluted with the BNB bunch width, PMT timing <1 .3 ns

Photon Detection System: ns timing resolution

Enhanced Ionization Charge Identification in the Short-Baseline Neutrino Program Neutrino Detectors with Deep Neural Networks

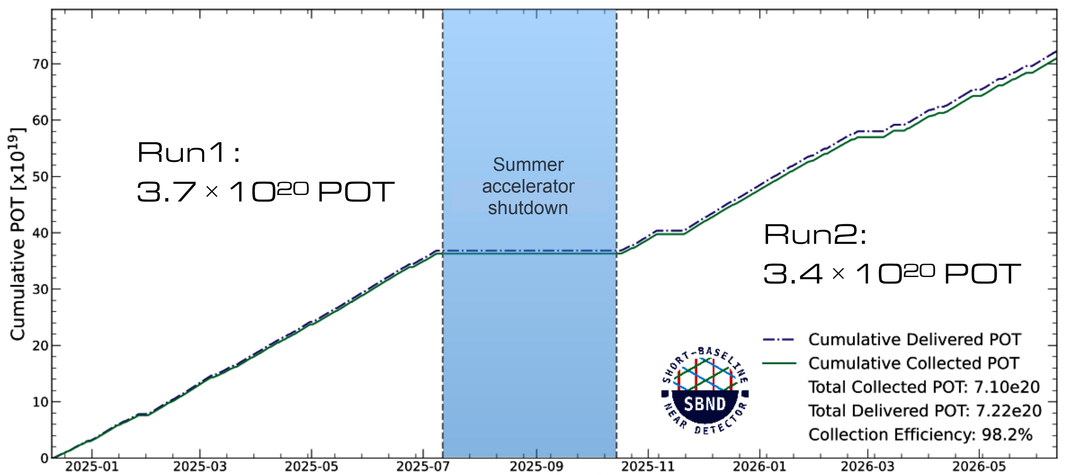
arXiv:2605.18861

Data-driven evaluation of detector systematics from cosmic muons. Few % level systematics on physics analyses.

Millions of ν-Ar Interactions

With its proximity to the neutrino source, SBND collects neutrino data with high event rate.

SBND Physics Data Taking



>7 x 10²⁰ POT collected, with >98% efficiency

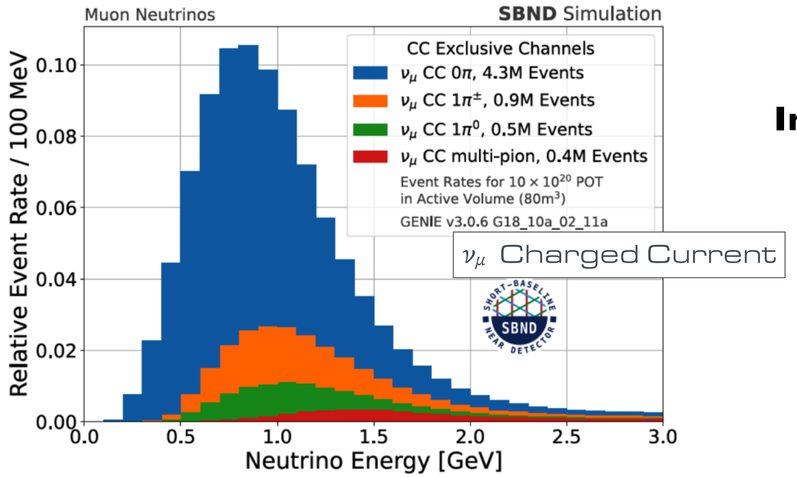
7 million neutrino interactions collected

[4M ν_μ CC, 30k ν_e CC]

World's largest ν-Ar data set

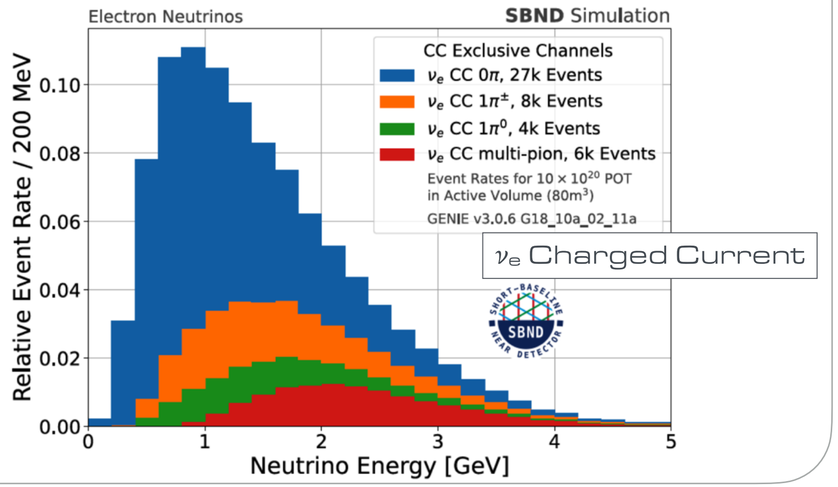
and growing...

Run3 has started on Oct. 1st, 2026



Neutrino Interactions

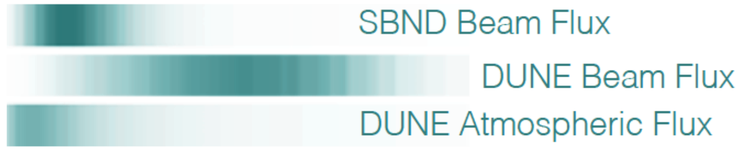
10 × 10²⁰ POT



Excellent detector performance, together with the scale of the dataset, provide a strong foundation for **precision neutrino measurements**.

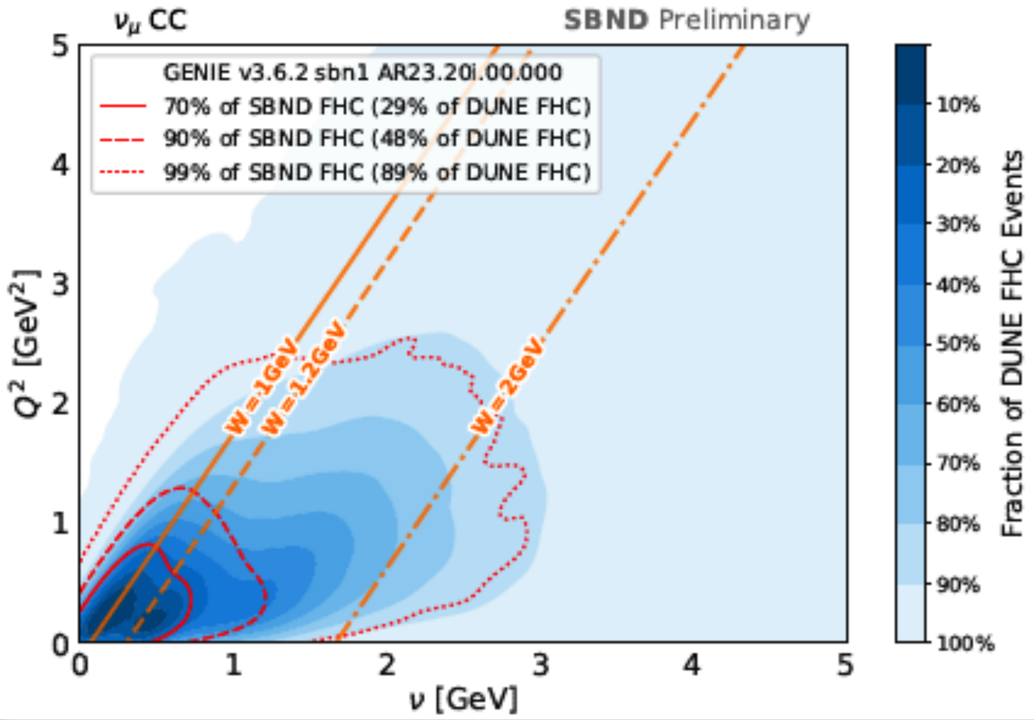
SBND Measurements: An Asset for DUNE

SBND's high statistics dataset spans the phase space relevant to DUNE



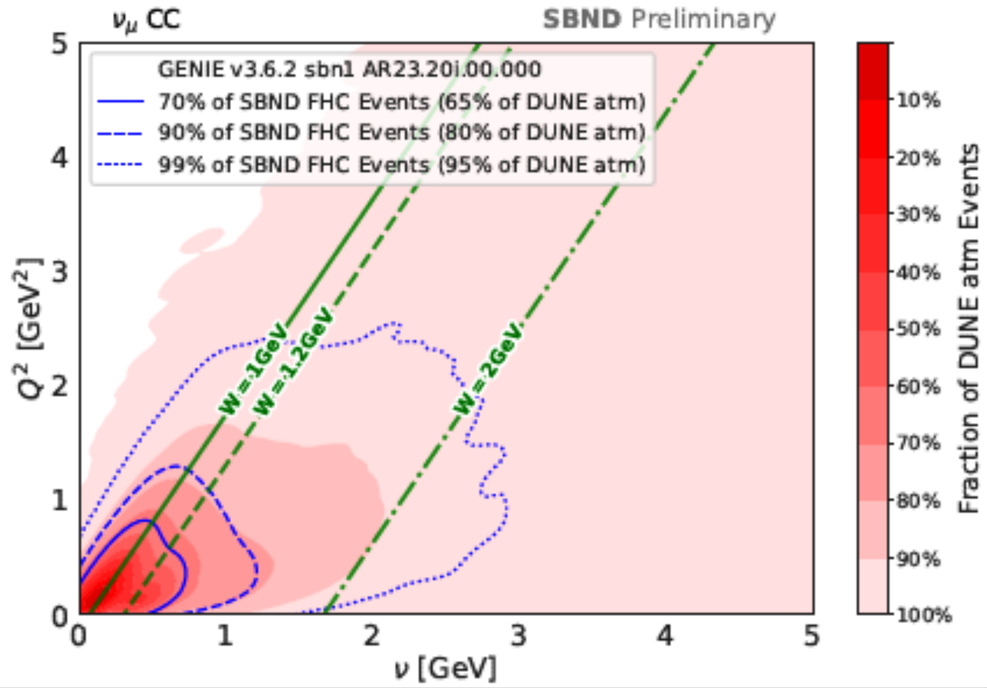
Kinematic coverage of charged-current ν_μ interactions in **DUNE** and **SBND**

DUNE CC ν_μ



Kinematic coverage of **DUNE atmospherics** and **SBND** charged-current ν_μ interactions

DUNE Atmospheric Flux



SBND's neutrino-interaction measurements can constrain interaction models and reduce uncertainties in DUNE measurements.

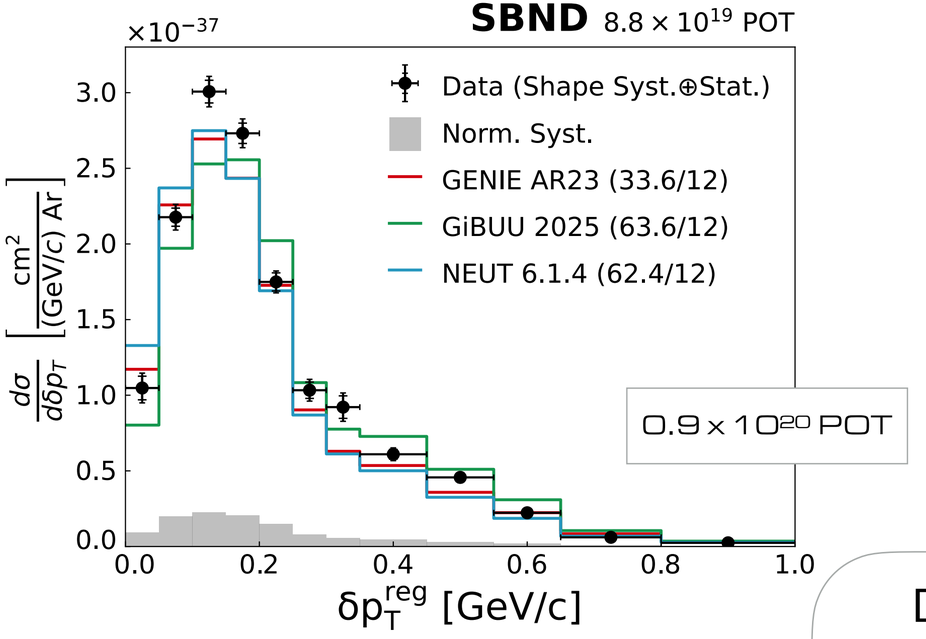
The Short-Baseline Near Detector at Fermilab: Input to the European Strategy for Particle Physics 2026 Update
inspirehep.net/literature/2906591

Turning Data into Physics

Transverse Kinematic Imbalance ν_μ **CC 1 proton 0 pions**

Differential cross section

SBND 8.8×10^{19} POT

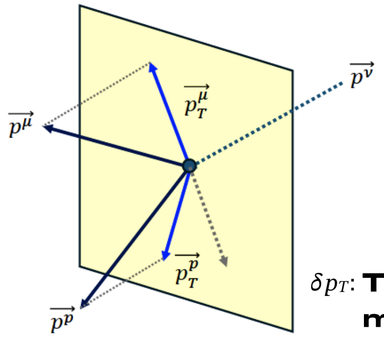


δp_T probes nuclear effects:

- Fermi motion shapes the peak
- FSI and multi-nucleon effects shape the tail

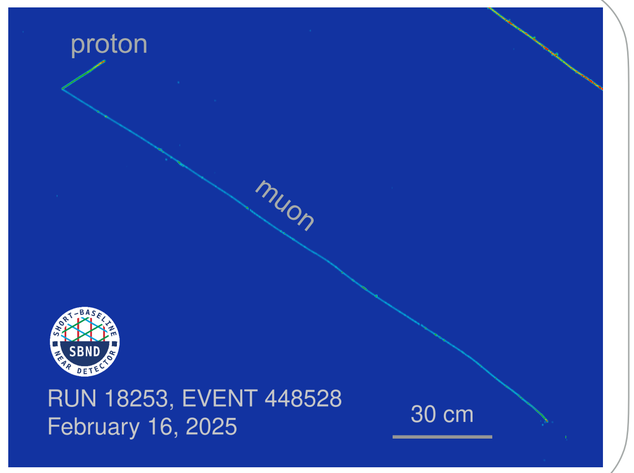
Current models do not fully describe the data

SBND data enable development and validation of interaction models for SBN and DUNE.



Quasi elastic dominated sample

δp_T: **Transverse momentum imbalance**, probing initial state Fermi motion



Data sample

60 days – 13k events

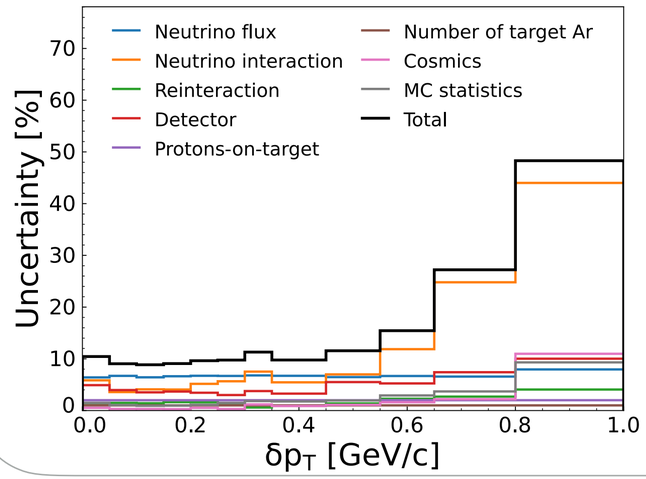
90% purity, 30% efficiency

Measurements of transverse kinematic imbalance in muon neutrino charged-current interactions on argon with a single proton and no pions in the final state with SBND

arXiv:coming tomorrow

Systematic Uncertainties

SBND Simulation



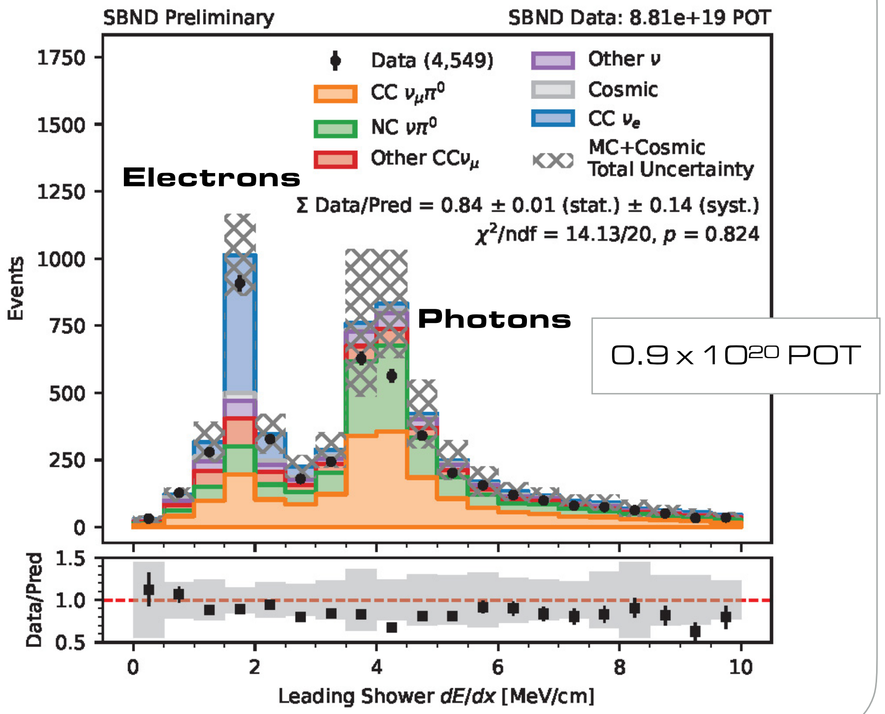
- Total ~8% at the peak (flux ~7%), interaction modeling in the tail
- **Detector systematics down to a few %**

Unprecedented precision from just 12% of the data – details at the Fermilab Wine and cheese on October 30th

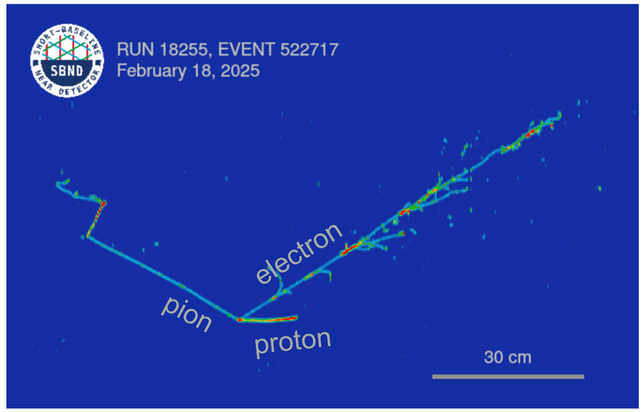
Turning Data into Physics

Inclusive ν_e CC Cross Section

Electron-gamma separation



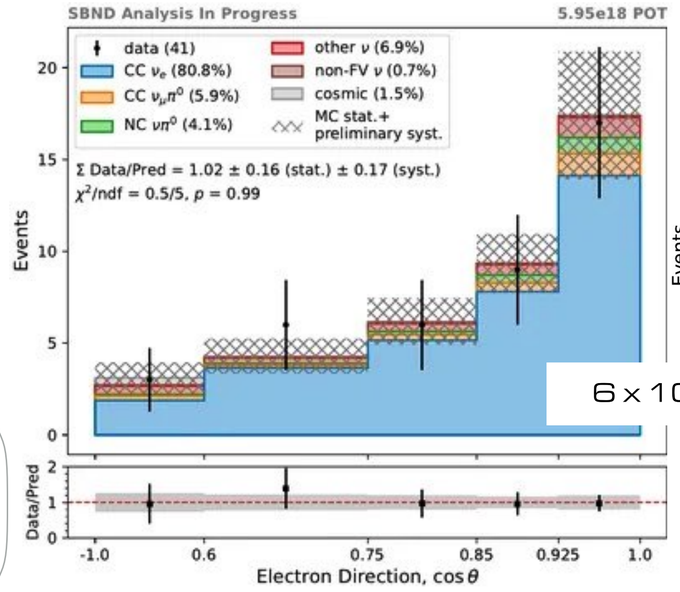
0.9 x 10^{20} POT

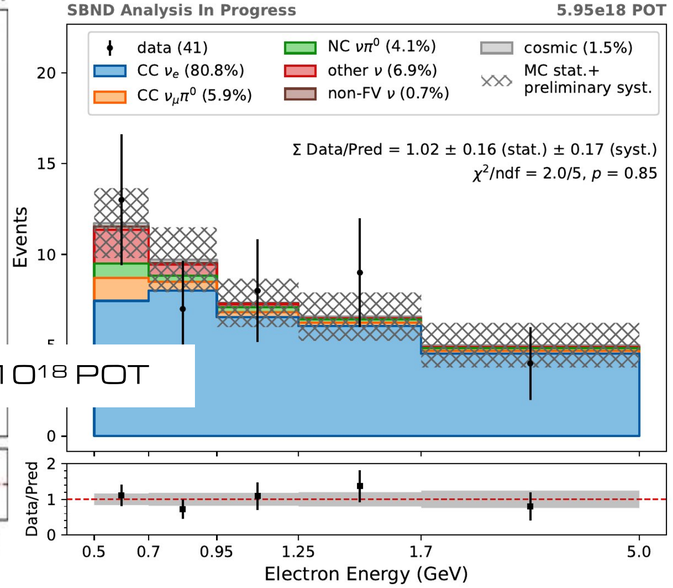


>500 MeV e.m. shower

Relevant to the energy range of DUNE oscillation measurements

Differential cross sections





6 x 10^{18} POT

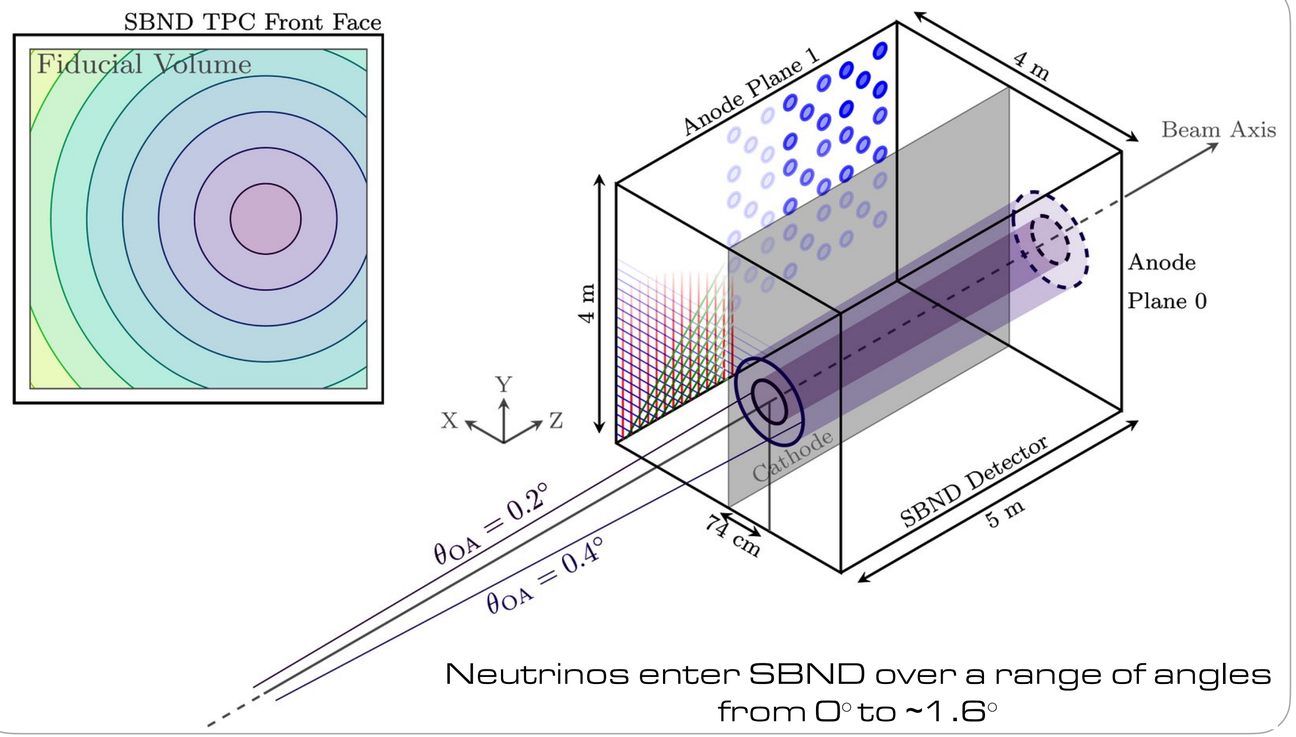
Results from 60 days of data will be presented at the Fermilab Wine and Cheese on November 20th.

Data sample

2 days – 41 events

81% purity, 26% efficiency

SBND-PRISM: Extending the Physics Reach



Neutrinos enter SBND over a range of angles from 0° to ~1.6°

"PRISM" technique:

sample variations in the neutrino flux as a function of angle

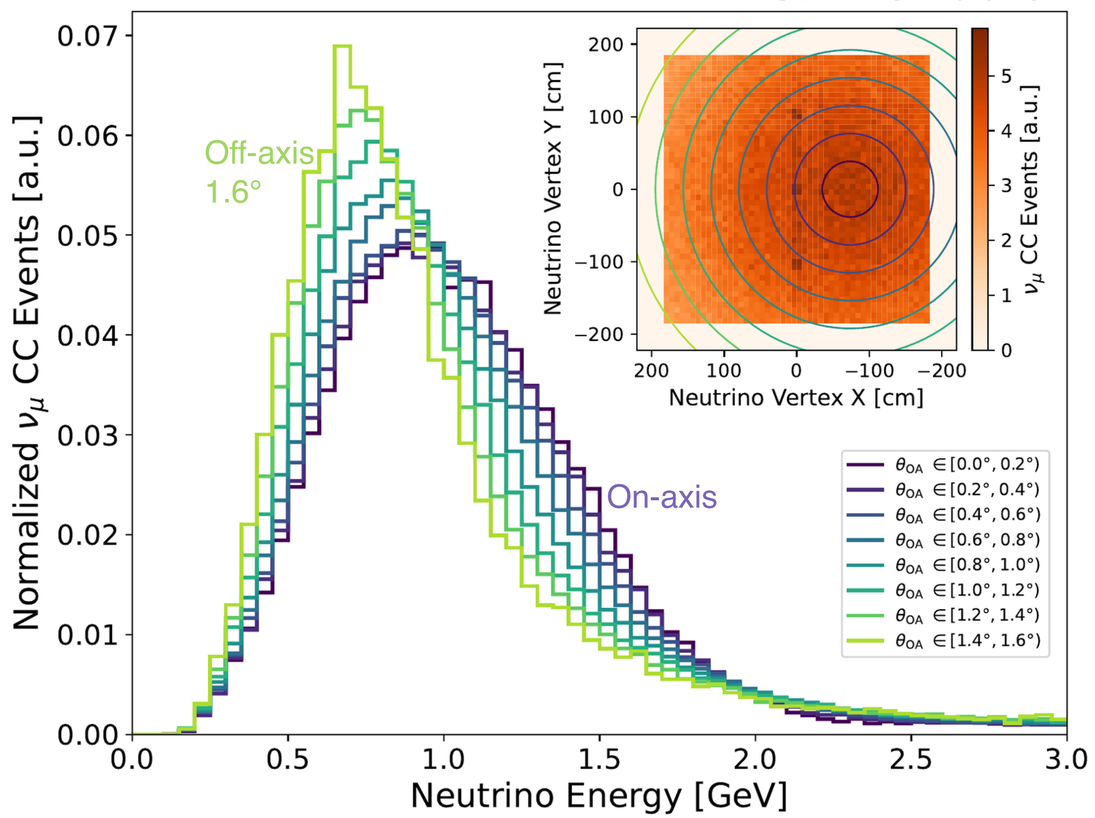
Exploited to expand the

physics potential of SBND

Sampling off-axis neutrino fluxes with the short-baseline near detector

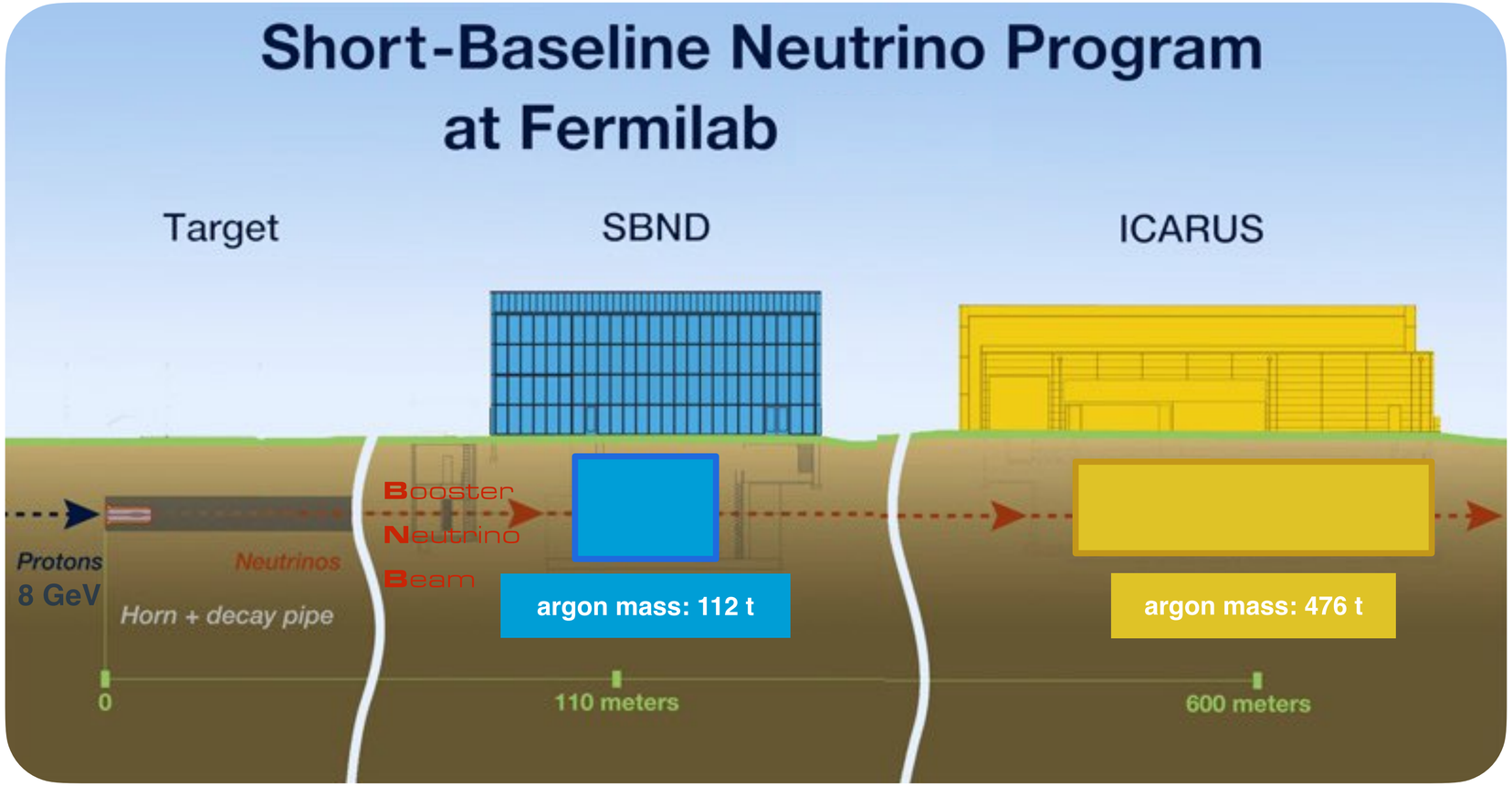
Phys. Rev. D 113, 072007 (2026)

ν_μ CC event distributions at different off-axis angles



SBND's proximity to the beam target provides a high neutrino flux, while its spatial extent offers access to **multiple neutrino spectra within the same detector**.

Two Detectors. One Oscillation Program



Near and **far** detectors **complementary**.

SBND measures the neutrino beam with high statistics before significant oscillations are expected.

ICARUS measures the same beam further along the flight path, where oscillation effects could develop.

Comparison of SBND/ICARUS measurements could signal neutrino oscillations.

Systematic control at the % level is critical.

Dual LArTPCs: Systematics Cancel, Reach Grows

Single Detector Analysis

ICARUS has completed a single detector ν_μ disappearance analysis [arXiv:2603.22557v1].

Joint Analysis

ICARUS alone
17-18%
Flux and cross-section uncertainties

→

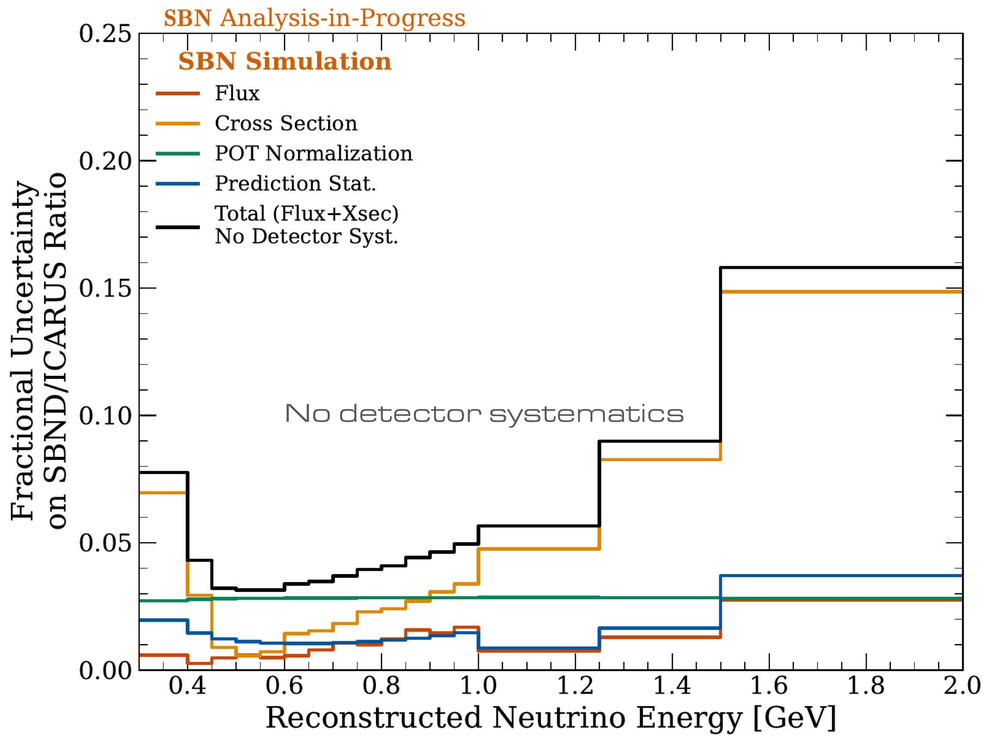
ICARUS + SBND
A few percent
Near the flux peak

SBND has constrained detector uncertainties directly with data to **few % level**.

The Impact

Adding SBND can improve sensitivity **by an order of magnitude** by constraining the event rate close to the source.

Fractional uncertainties on SBND/ICARUS ratio



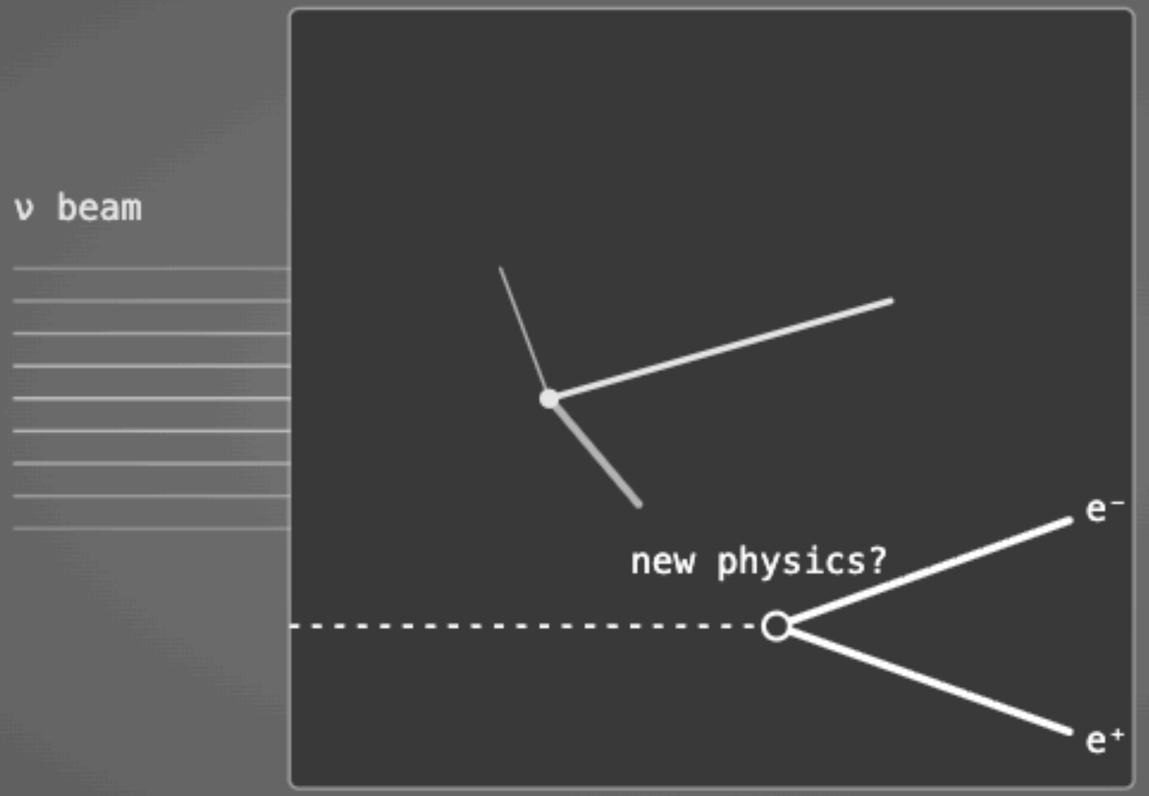
Common physics uncertainties largely canceled, shifting the focus to detector-specific effects.

NEXT STEPS

Underway — First **joint ν_μ disappearance analysis**, expected in early 2027

Next
- ν_e appearance
- NC disappearance
- SBND-PRISM constraints

From Neutrinos to New Physics

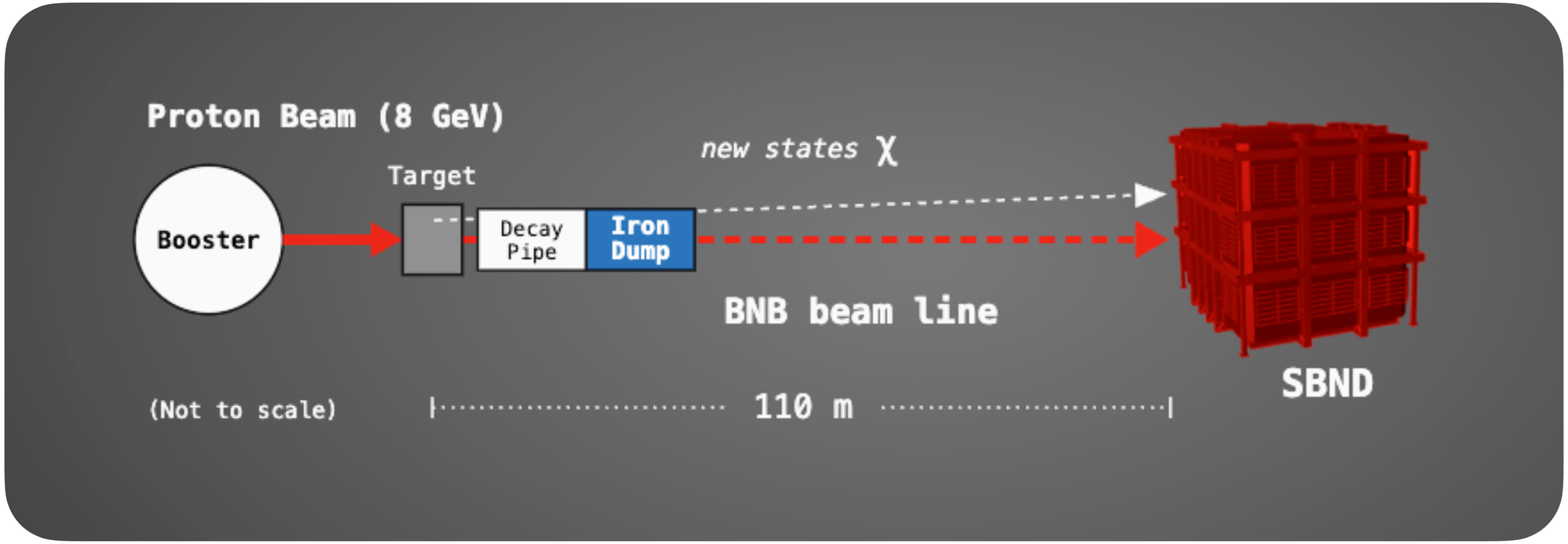


The Science Evolved: Expanded Physics Program

Alternative explanations of the short-baseline anomalies and other Beyond Standard Model scenarios.

Many ideas for new physics searches beyond the original goals came within reach in neutrino experiments.

SBND is ideally suited to these searches: proximity to the target, large mass, excellent LArTPC imaging and particle identification, and precise timing resolution.



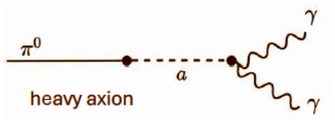
New particles produced at the target or beam dump (via meson decay, mixing with neutral meson,…) can decay in SBND, yielding diverse final-state topologies.

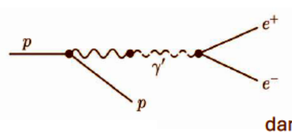
The Short-Baseline Neutrino Program at Fermilab, Annu. Rev. Nucl. Part. Sci. 69 363-387 (2019)

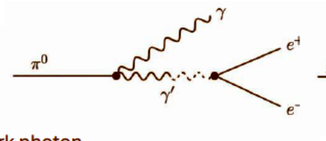
Looking Beyond the Standard Model

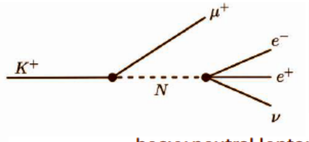
SBND enables searches for **dark sector particles** and **alternative explanations of short-baseline anomalies at sub-GeV scale**.

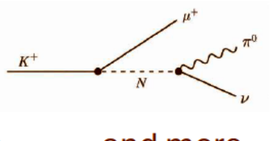
Searches span a broad range of models, from specific theoretical scenarios to model-independent analyses, with distinct experimental signatures.





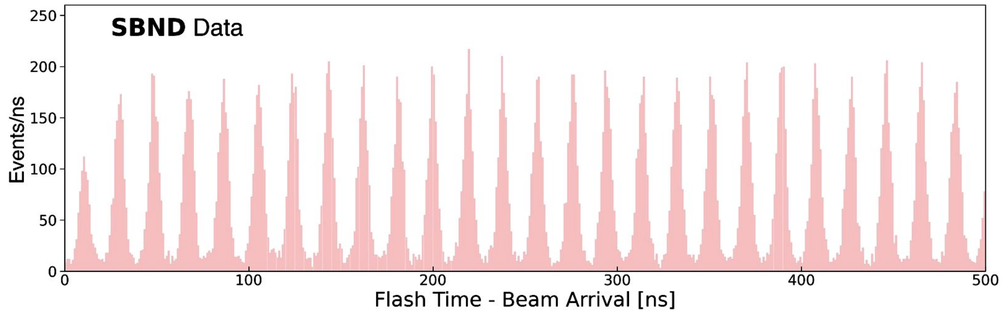






and more...

Investigating the bunch structure

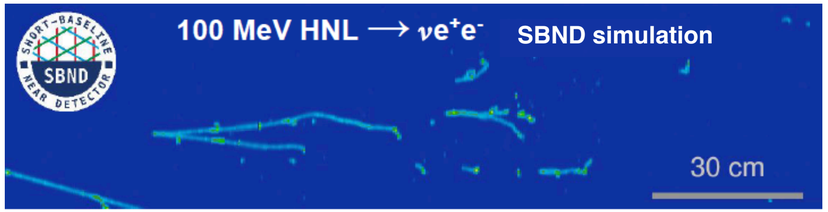


ns-level timing in the photon detector system to resolve the BNB bunch structure:

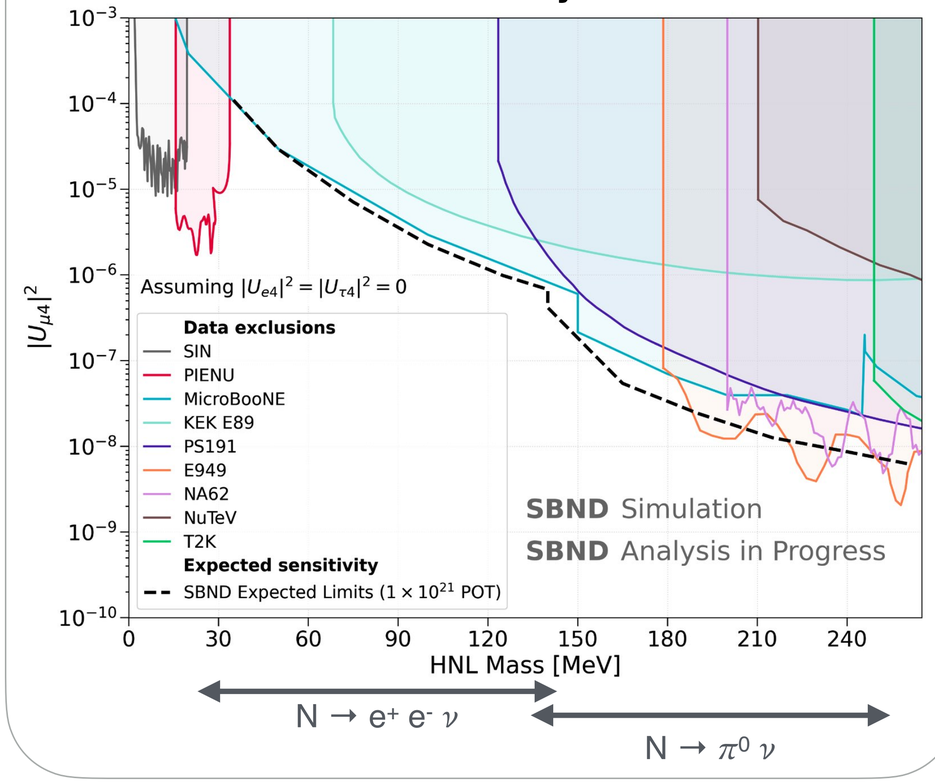
1.6 μs proton spill.

81 bunches. ~1.3 ns wide spaced at ~19 ns.

Opens the possibility to search for **massive long-lived particles arriving between the neutrino bunches**



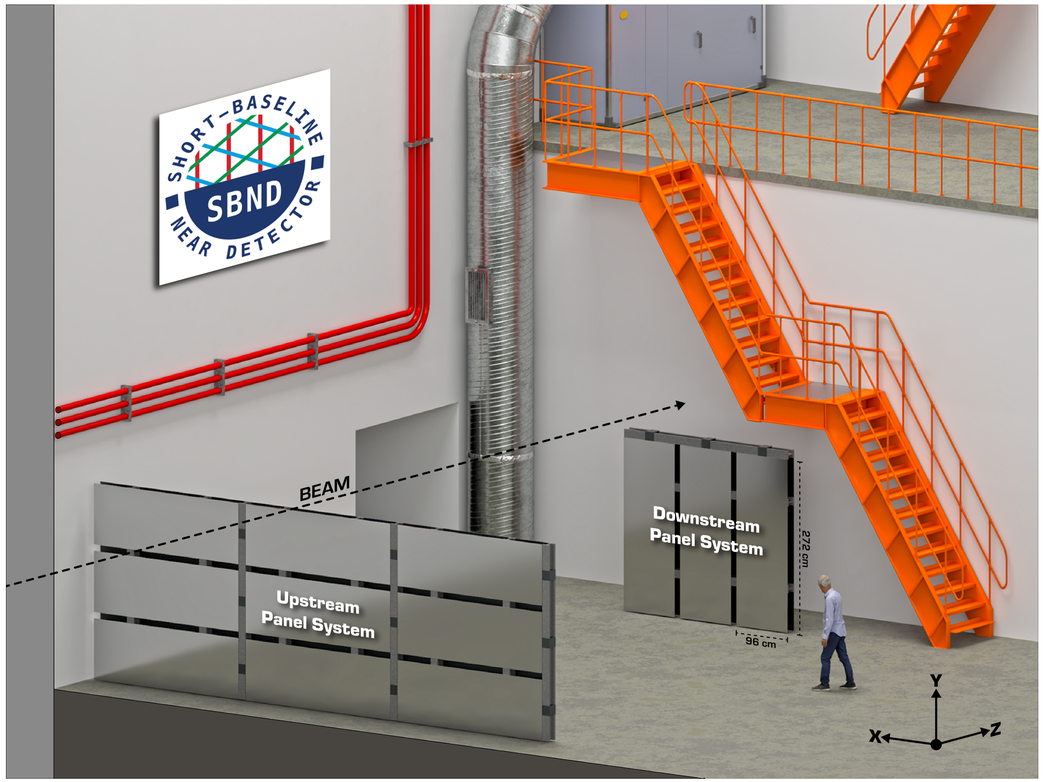
Sensitivity to HNL



Access to unexplored parameter space with complementary signatures

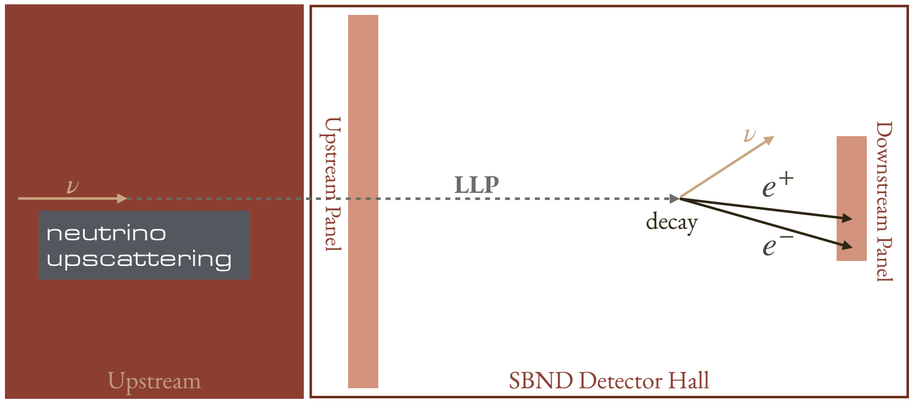
SBN BSM generator, MeVPrtl, arXiv:2605.11321

Search for Long-Lived Particles using the CRT



CRT Beam Telescope

2.95×10^{20} POT



Signal: LLP produced in surrounding material and decaying at macroscopic distance in the CRT panels, providing coverage for meter-scale decay lengths.

Upstream panel used as veto against neutrino-induced background.

Two hits consistent with an **electron-positron pair** in the **downstream panel.**

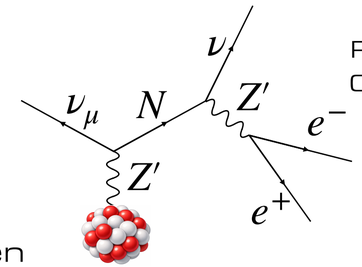
→ Removes 99.86% of background.

Signal purity of the sample is still only 2%: further reductions via BDT, using timing, spatial and calorimetric information from the CRT.

ν-nucleus production of LLP

Model proposed as source of the MiniBooNE anomalous excess [PRL 121, 241801 (2019); PRD 99, 071701 (2019)].

SM neutrinos up-scatter to heavy sterile neutrinos via Z' exchange, then decay into collimated **e+e- pairs**.



Benchmark point:
$m_N = 400$ MeV, $m_{Z'} = 1.25$ GeV

Re-weighted for 6 decay lengths: 0.3 – 100 m

Signal generated using DarkNews [Comput.Phys.Commun. 297 (2024) 109075]

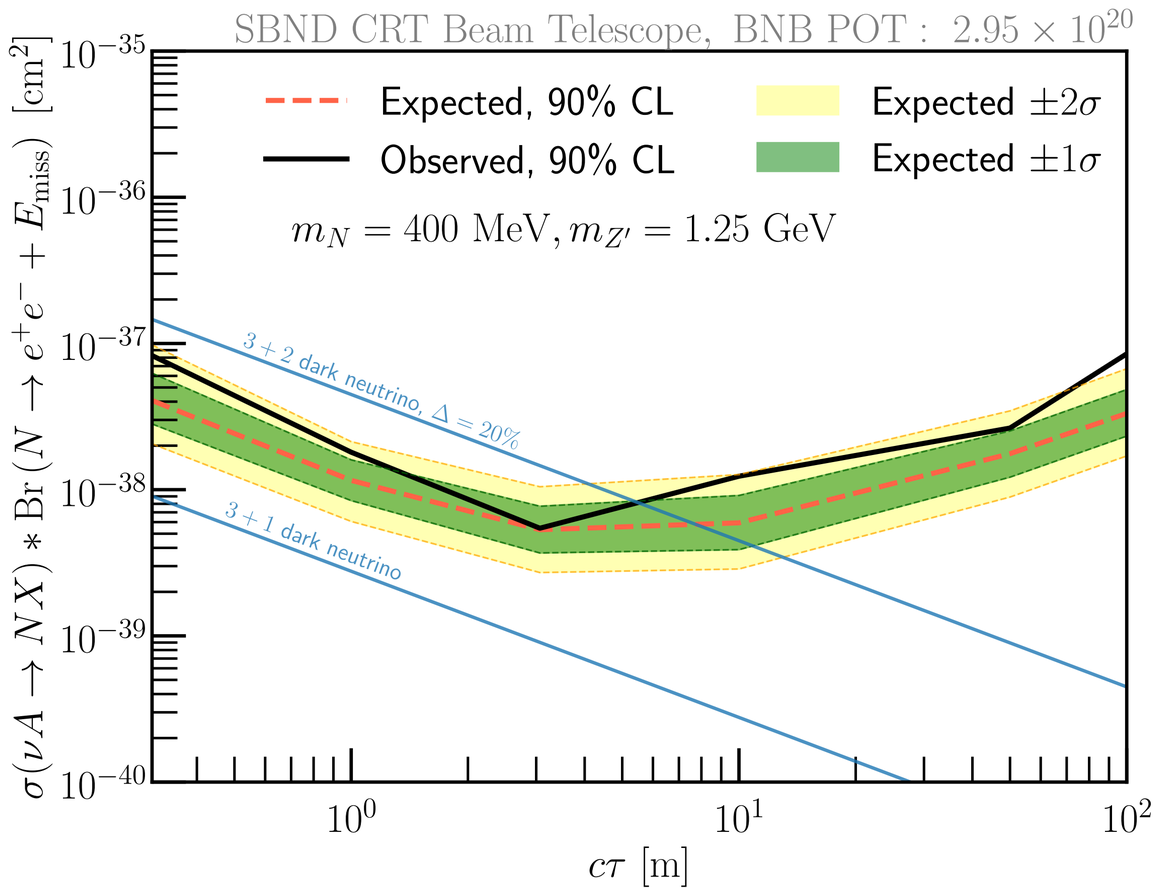
Neutrino background using GENIE

Search for Long-Lived Particles using the CRT

Model-agnostic approach

Parameter space:
Effective production cross section
(production cross section x decay branching ratio)
vs
decay length

90% confidence limits



for meter-scale decay lengths (0.3-100 cm)

No significant excess observed above expected background

Dark -neutrino model benchmark *

- 3+1 : The minimal scenario is beyond the sensitivity of this search.
- 3+2: The heavier dark neutrino decays into the lighter one and brings the resulting benchmark within SBND CRT reach.

Search for Neutrino-Produced Long-Lived Particles Using the SBND Cosmic Ray Tagger Beam Telescope

arXiv:2610.37555 *TODAY!!*

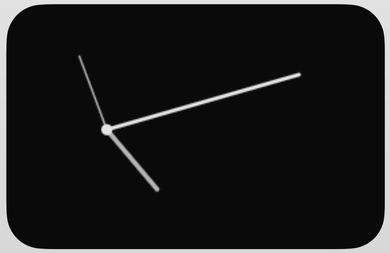
First BSM result with SBND data

* Benchmark parameters: m_N=400 MeV, $m_{Z'}$=1.25 GeV; the 3+2 scenario assumes a relative mass splitting $\Delta \approx 20\%$.

One Experiment. An Expanding Scientific Reach

From a scientific vision to new opportunities for discovery.

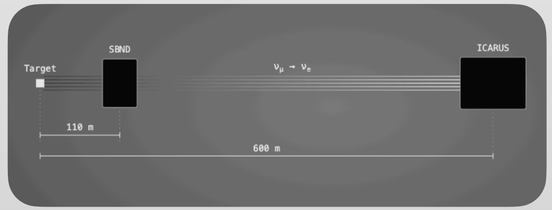
The world's largest dataset of neutrino interactions on argon.



Neutrino interactions

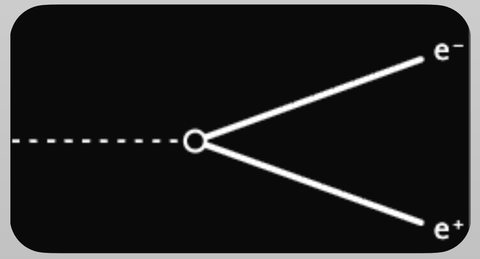
Precision measurements





Neutrino oscillations

The SBN program



Beyond the Standard Model

New physics opportunities

From **precision neutrino physics** to **new searches for physics beyond the Standard Model**.