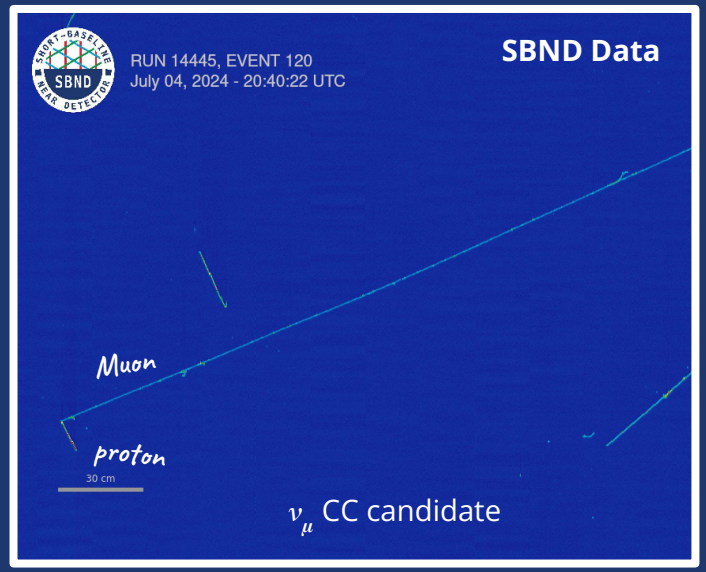
# Status of the Short-Baseline Near Detector at Fermilab

**Rodrigo Alvarez*,**

**on behalf of the SBND collaboration**

*rodrigo.alvarez@ciemat.es




Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

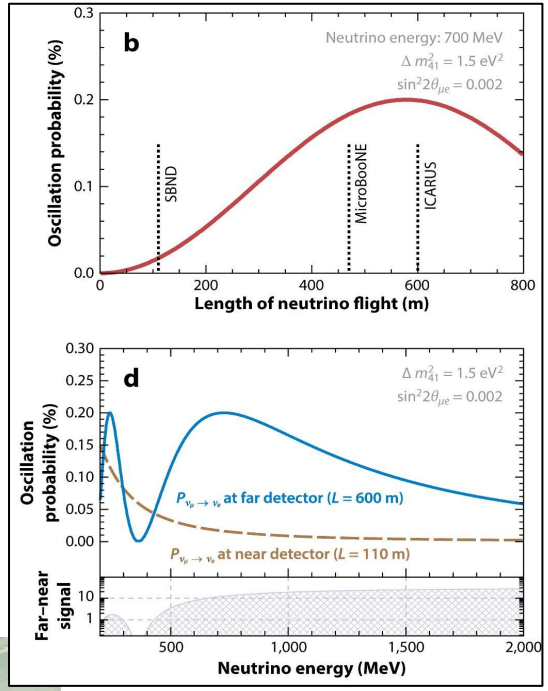
ICHEP 2024

# The SBN program

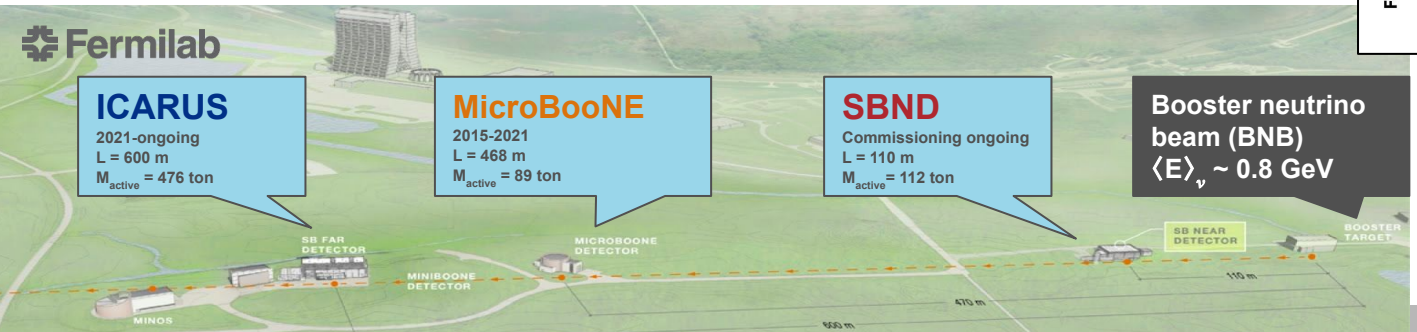
- Located in Fermilab (USA), consists of 3 LArTPC experiments along the booster neutrino beam (BNB):

  **ICARUS**, **MicroBooNE**, **SBND**

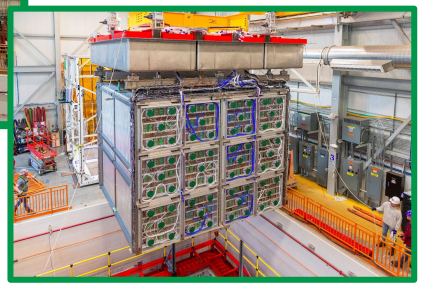
- Aims to resolve the electron-like event excess seen by LSND and MiniBooNE.
- Same neutrino beam and detector technology will constrain systematic uncertainties to the %-level.




[Annu. Rev. Nucl. Part. Sci.69:363-87]



# Detector status



TPC placed into the cryostat,

April 25, 2023

LAr filling completed March 2024

North and East CRT modules installed

April 2024

Ramp up to nominal TPC voltage

July 2024

# Detector status

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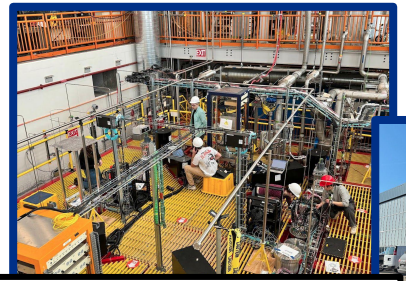
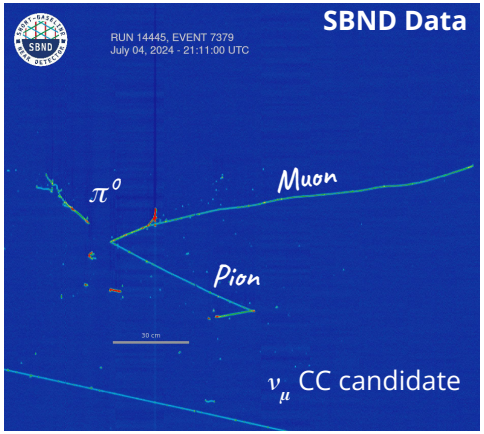
April 25, 2023



Started taking beam data at nominal voltage 2 weeks ago!



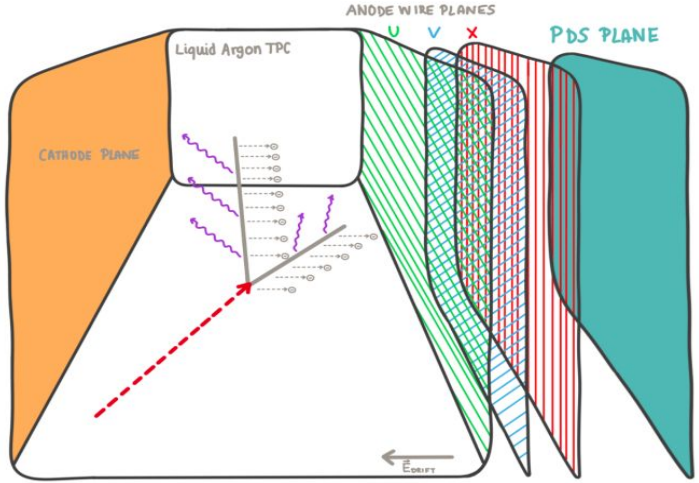

LAr filling completed March 2024

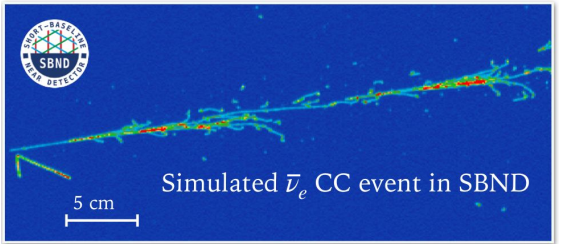
Ramp up to nominal TPC voltage

July 2024

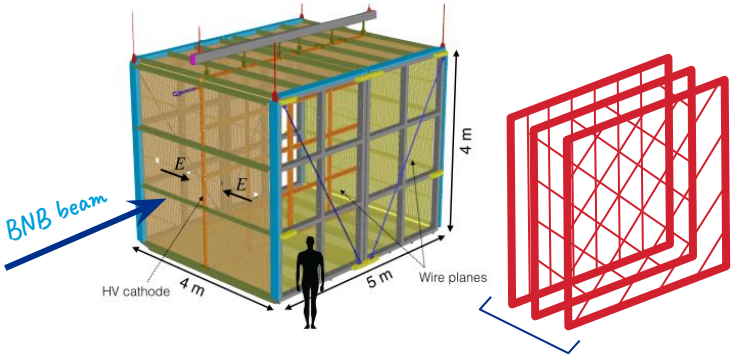
# LArTPCs working principle

- Charged particles produce ionization electrons and scintillation photons inside the TPC.
- Photon sensors measure the interaction time $t_0$ with ns precision.
- Electric field drifts $e^-$ towards anode plane.
- Wire planes(or other readouts) detect the $e^-$ producing 3D mm-level resolution images.



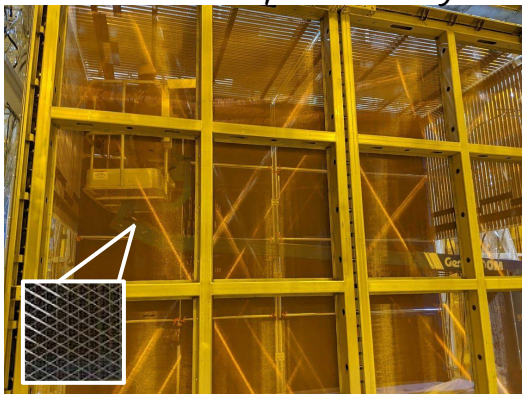
# SBND: the Short-Baseline Near Detector






3-mm wire pitch,
11,264 total wires

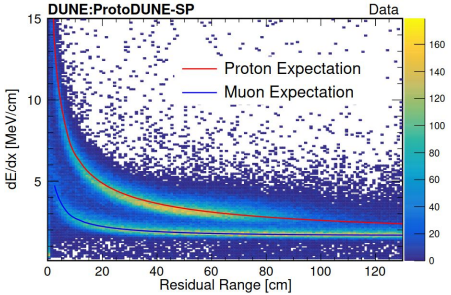
Anode plane assembly



TPC wires close-up

## 2 TPC volumes

- ➔ Cathode in the middle separates in two TPCs the active volume: 2x5x4 $m^3$ each
- ➔ mm level resolution of the event, precise calorimetry & particle ID (Bethe-Bloch equation)
- ➔ Continuous LAr purifying system to prevent charge (and light) loss (2m drift).

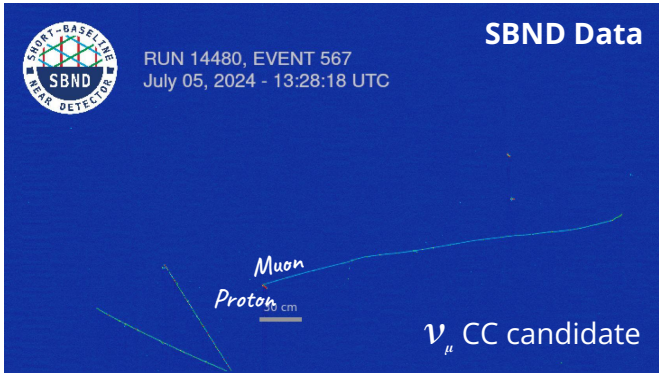


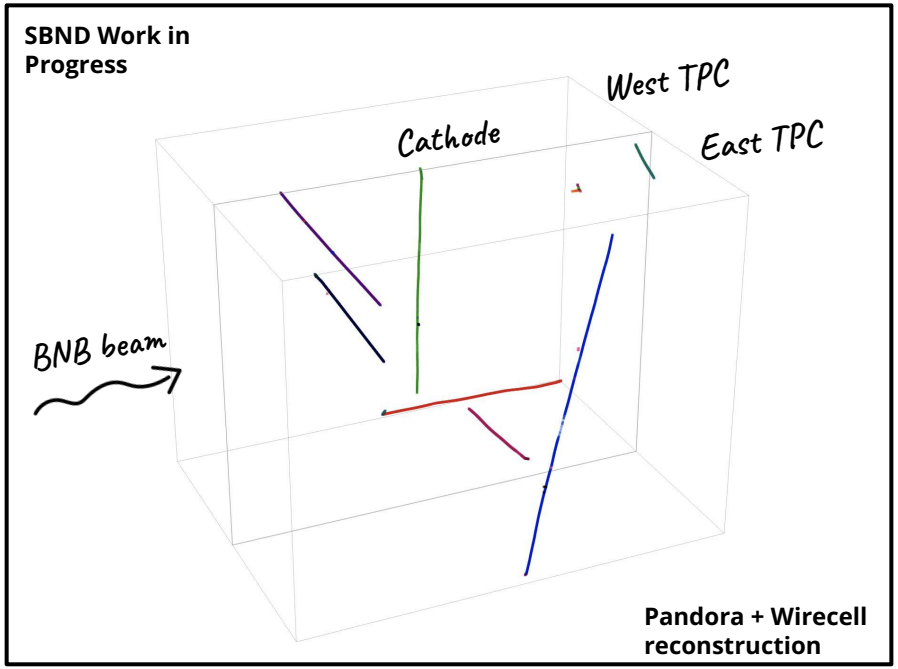

*B. Abi et al 2020 JINST 15 P12004*

- ➔ LAr filling completed in March.
- ➔ Commissioning efforts ongoing.
- ➔ Low TPC intrinsic noise ~2 ADC counts
- ➔ Detector has been operating at nominal drift field (100 kV) for the past few weeks!

# Early data: TPC reconstruction

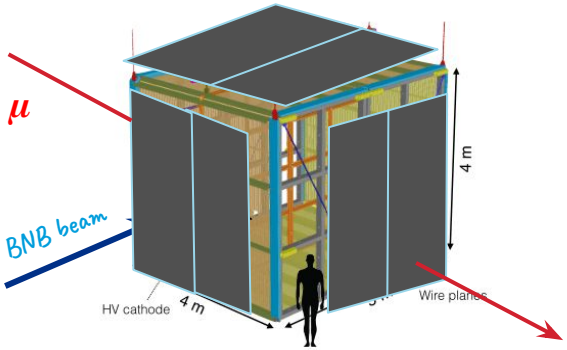
Example of the reconstruction workflow from the raw unfiltered signals…

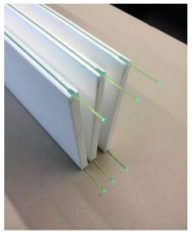


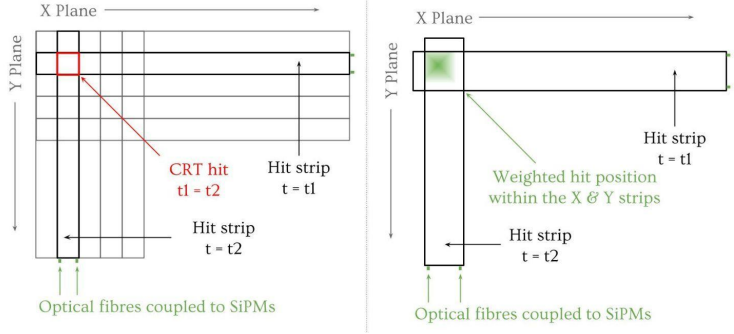

… to the 3D reconstructed objects after noise filtering and 2D-deconvolution

# SBND: the Short-Baseline Near Detector



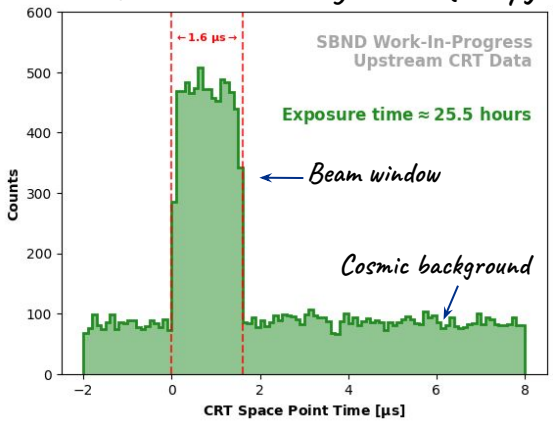
*CRT scintillator strip with wavelength shifting fibres in each side*




## Cosmic Ray Tagger system (CRT)

- ➔ **CRT walls surround the cryostat with ~4π coverage. They are composed of scintillator panels with SiPMs on the sides.**
- ➔ **Provides discrimination to backgrounds from cosmic rays.**
- ➔ **Precise timing (ns) and topology of the event allows for selection of calibration samples.**
- ➔ **All but top CRT planes installed and calibrated.**

*BNB beam activity excess (early June data)*



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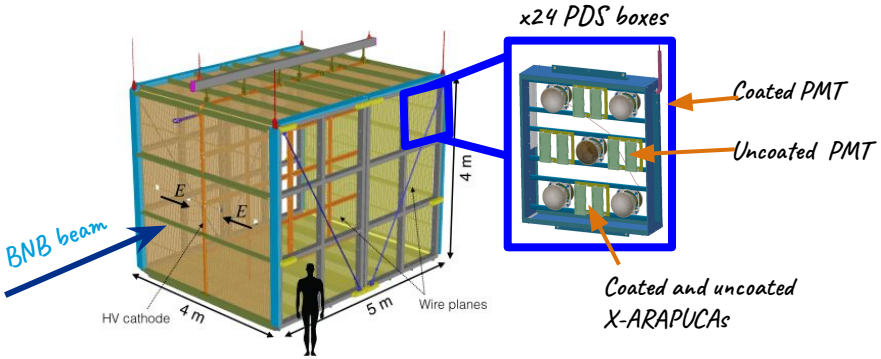
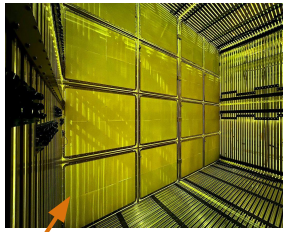
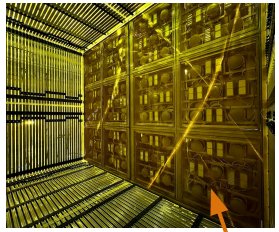


TPB coated foils in the cathode plane



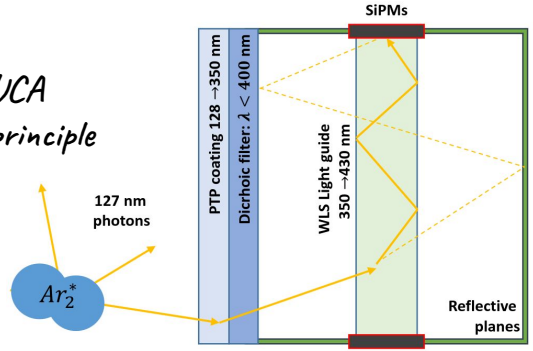
PDS sensors behind the wire planes

## Photon Detection system (PDS)

- ➔ Composed by 192 X-ARAPUCAs and 120 PMTs.
- ➔ Located behind the TPC wire planes.
- ➔ Provides triggering, particle ID, complementary energy reconstruction, background rejection…
- ➔ Early PMT Gain equalization performed.
- ➔ More details on SBND trigger system in [tomorrow's talk by Tereza Kroupova]!

➔ **Significant effort in R&D for future LAr experiments. 192 X-ARAPUCA sensors will be tested (DUNE-PDS).**

X-ARAPUCA working principle



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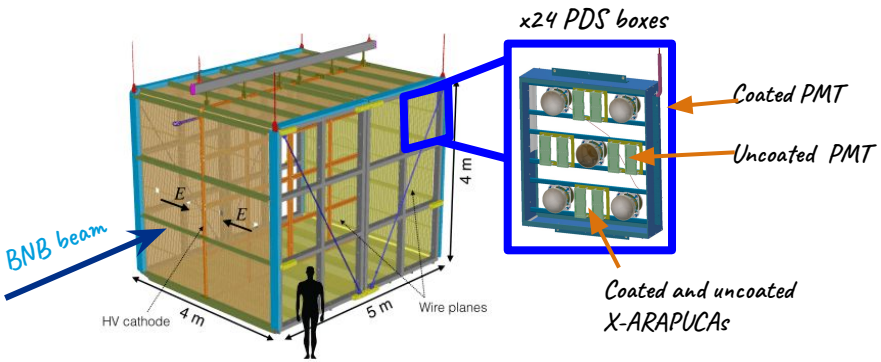


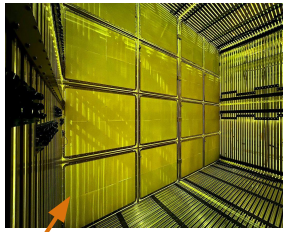

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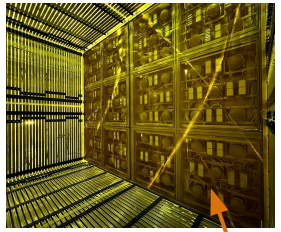

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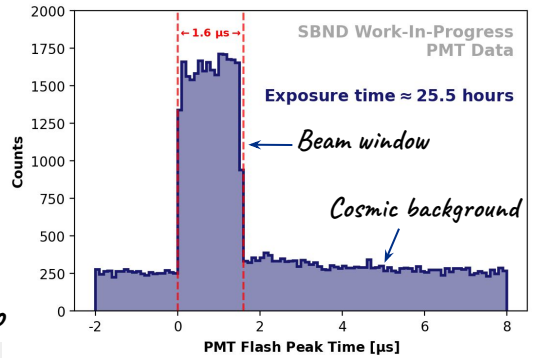
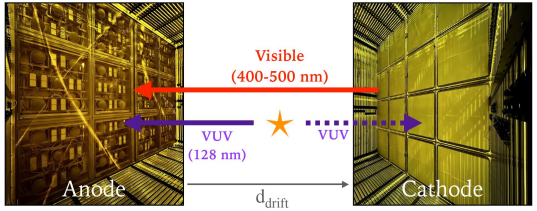
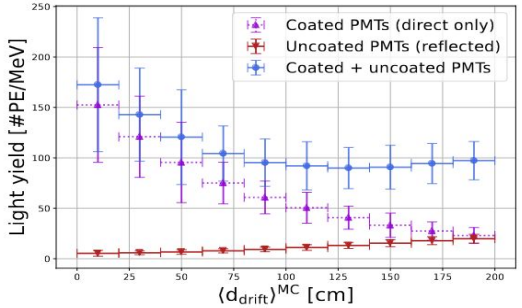
"Top-hat" plot, using only PDS signals info

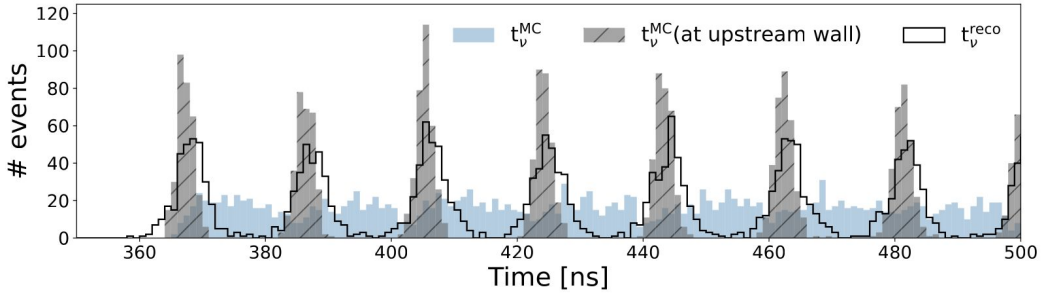


# SBND Photon Detection System

- Coated sensors can see both VUV (direct) and visible (reflected) light. Uncoated are sensitive to only vis light.
- Using only PDS information, we can estimate the 3D vertex of the interaction.
- Correcting for photons and neutrino ToF allows us to resolve the BNB bucket structure with O(ns) resolution -> key to search for BSM long lived particles.
- Paper describing simulation, reconstruction and the expected performance of the PDS out: [arxiv 2406.07514](arxiv 2406.07514) .

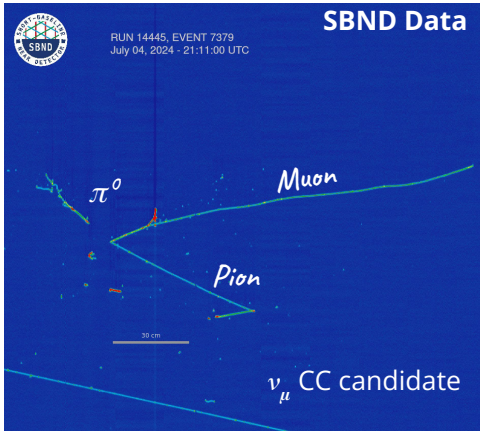


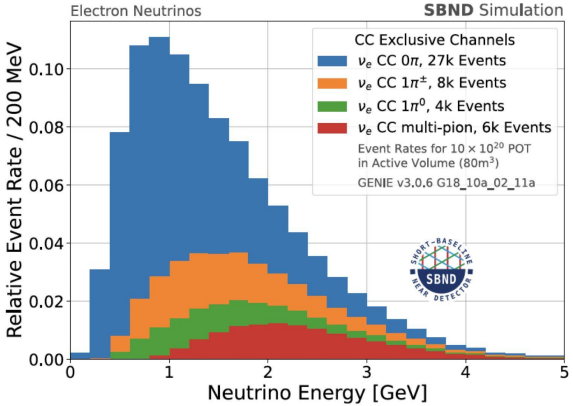



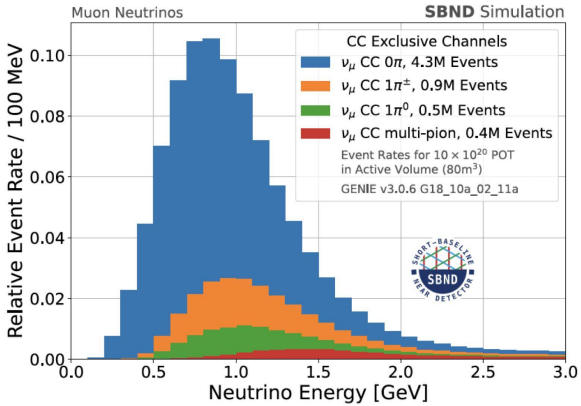



# Physics at SBND: $\nu$-argon cross section

- SBND total dataset for a expected exposure of 3-year/1e21 POT will have O(10M) neutrino events.
- More than 7k neutrino events per day!
- World leading statistics for many processes.
- Don't miss Rhiannon Jones poster this evening!



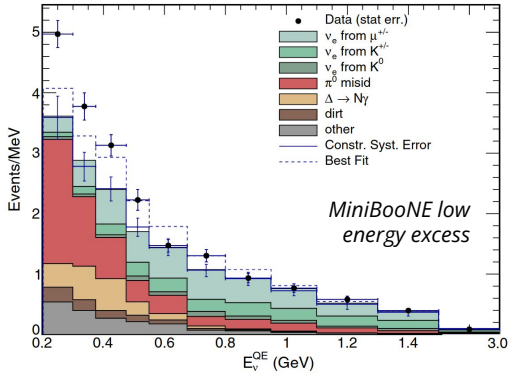



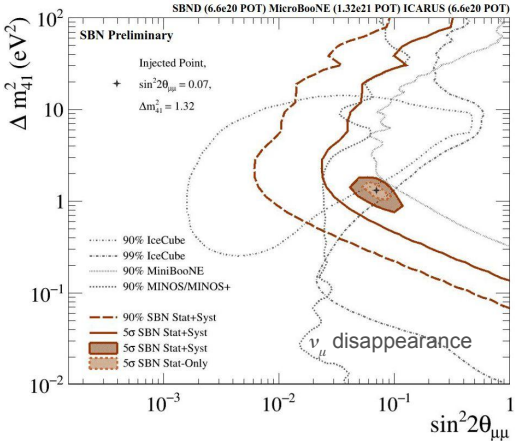
# Physics at SBND: sterile searches

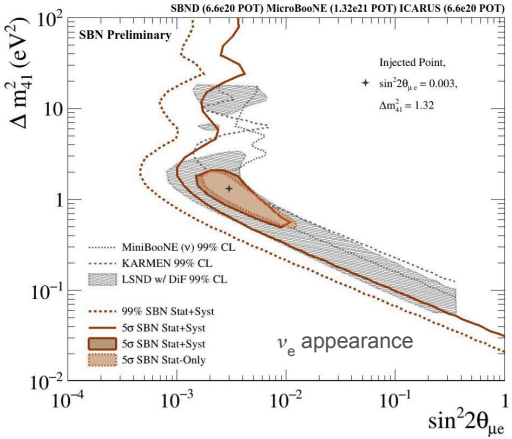
Phys. Rev. Lett. 121, 221801

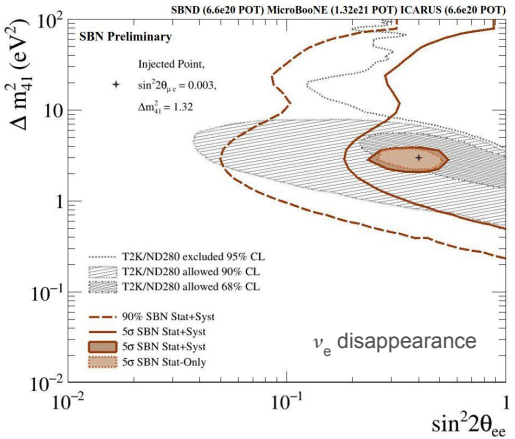
- Low energy excess in electron-like events reported by MiniBooNE and LSND collaborations.
- Could be explained by addition of light sterile extra neutrino flavours
- The SBN program will test this hypothesis in the eV scale.
- Near and far detectors -> further constrain systematic errors.
- Multiple detectors enables searches in both appearance and disappearance channels.




*Expected SBN-3 year sensitivity to a light sterile neutrino.*

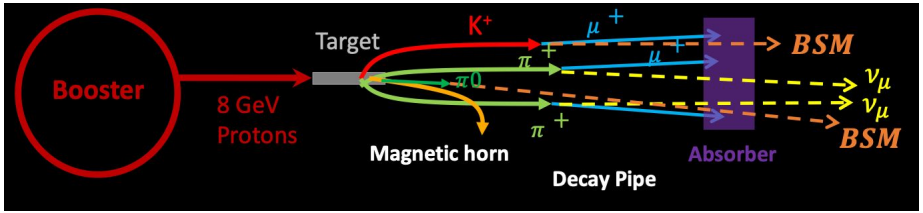


# Physics at SBND: more BSM searches

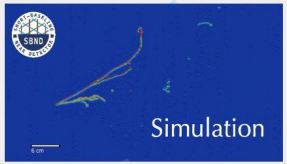
- The BNB can produce BSM particles from different sources: charged & neutral mesons, SM neutrinos, proton bremsstrahlung
- Broad BSM program:
  - Search for long lived particles between BNB buckets (no sm neutrino backgrounds).
  - Distinctive topologies can also be exploited.
- More details in Jiaoyang Li talk at the BSM session.




**Light Dark Matter**


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

**Dark Neutrinos**

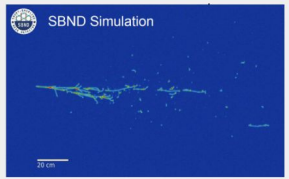



$e^+e^-$ pair with or without hadronic activity

**Millicharged Particles**

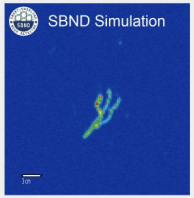

blips or faint tracks

**Heavy Neutral Leptons**



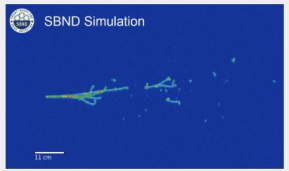

$e^+e^-$, $\mu^+\mu^-$, or $\mu^\pm\pi^\mp$ pair with no hadronic activity

**Higgs Portal Scalar**




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

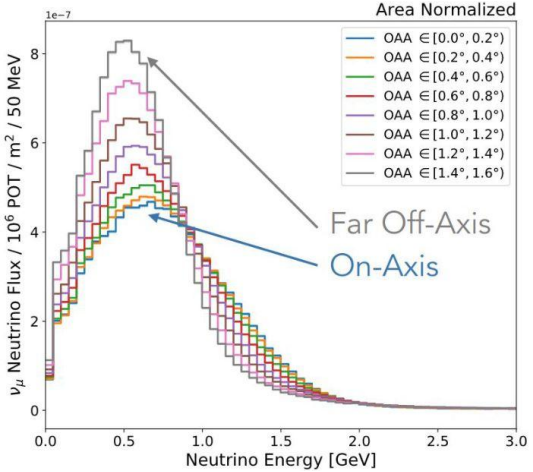
**Axion-Like Particles**

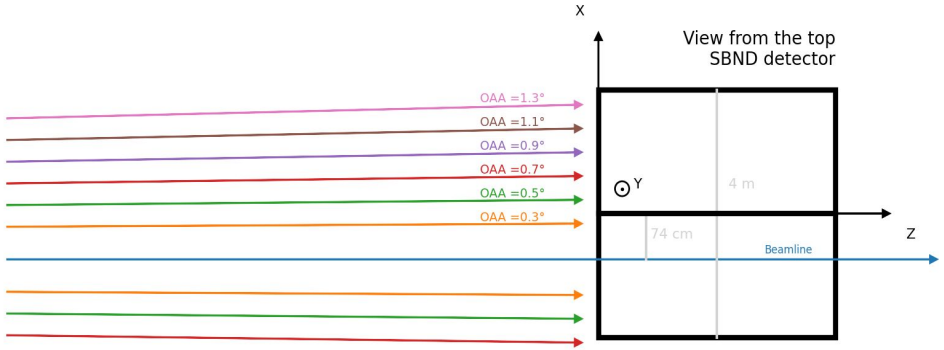



high-energy $e^+e^-$ or $\mu^+\mu^-$ pair

# Physics at SBND: PRISM

- ➔ SBND is sensitive to the angular dependence of the flux thanks to its proximity to the BNB target (110 m).
- ➔ Slicing the detector in angular sections, energy and total number of events vary.
- ➔ Only depends on the angle.
- ➔ Further constraints systematic uncertainties.



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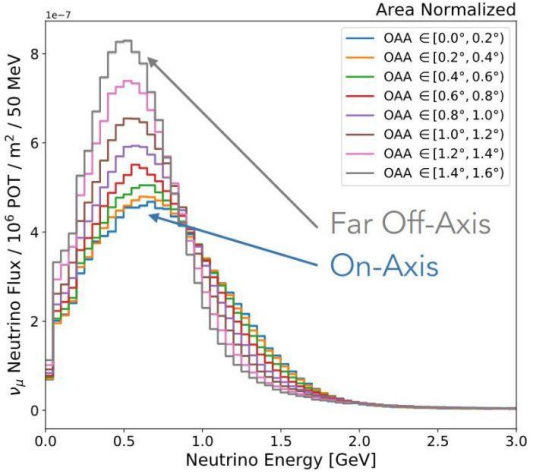
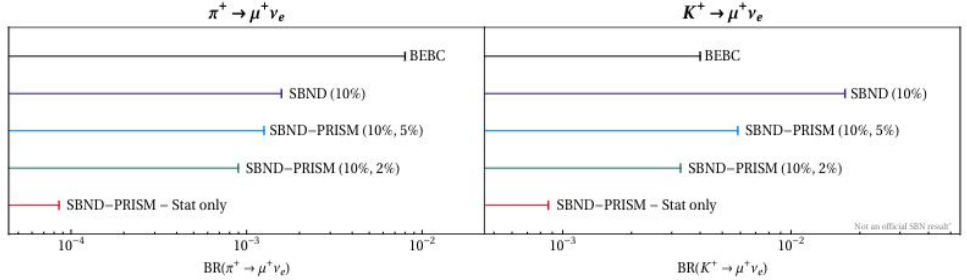
- ➔ Slicing the detector in angular sections, energy and total number of events vary.
- ➔ Only depends on the angle.
- ➔ Further constraints systematic uncertainties.
- ➔ Exploiting this feature, SBND might be able to test lepton flavor violation (P. Machado et al).

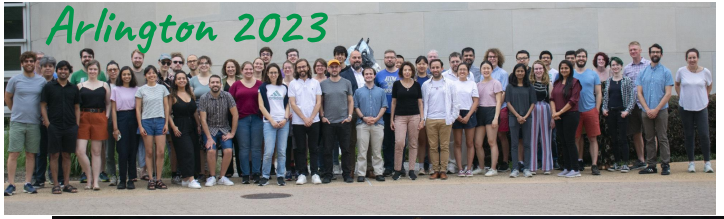



arxiv 2405.00777



# Summary

- SBND detector has been filled with LAr and is already taking data, commission efforts ongoing.
- SBND will take millions of neutrino interactions in the following years. World-leading statistics for many neutrino-argon processes and a rich physics program.
- As a part of the SBN program, it will explore the LSND and MiniBooNE anomalies parameter space with ~5 sigma.
- We expect physics quality data runs to start in fall 2024, as the BNB re-starts operations.
- Stay tuned for exciting results in the coming years!






*Thank you for your attention!*

*Děkujeme za pozornost!*

# Backup

# More installation milestones

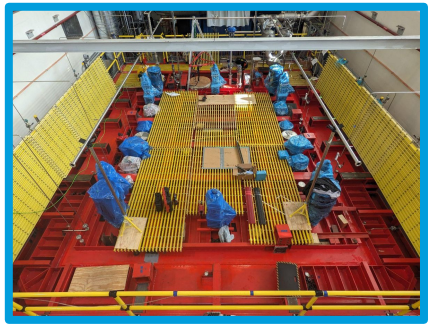
TPC moved to SBN-ND
December 1, 2022

Detector placed into the cryostat,

April 25, 2023

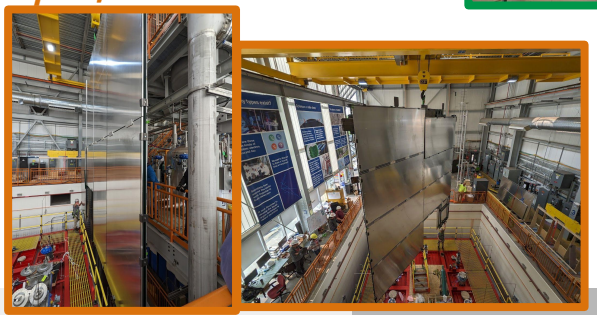
HV feedthrough installed and cryostat closed

July 20, 2023



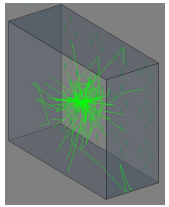
First CRT wall installed

May 18, 2023



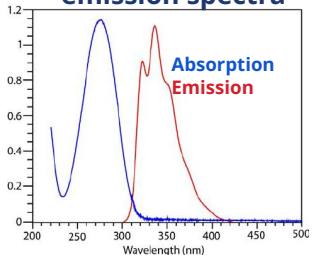
# Light production in SBND

## VUV Light



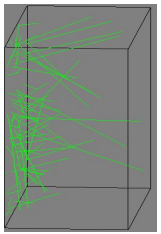
- Directly produced in LAr volume
- Rayleigh scattering length ~1 m
- TPB & P-Terphenyl (pTP) coating of PDS sensors

**pTP absorption & emission spectra**



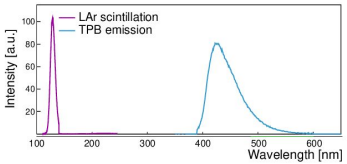

*Nuclear Science Symposium (pp. 2228-2233), 2008*

## Visible Light



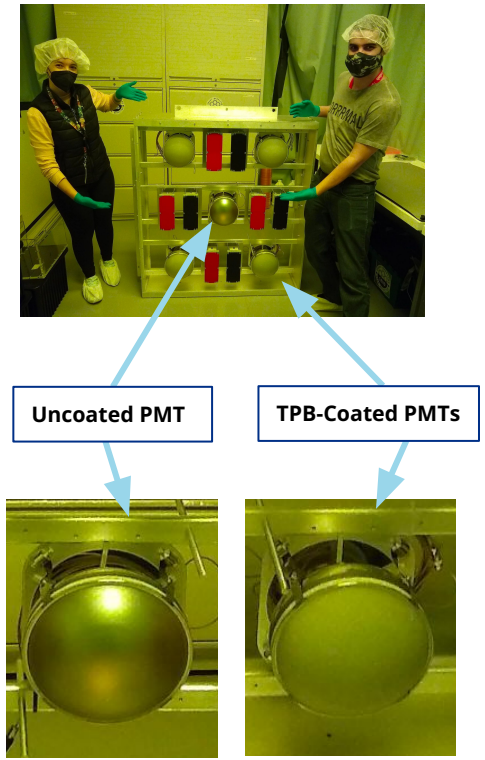
- Re-emitted by TPB foils in the cathode plane
- Rayleigh scattering length ~20 m

**TPB emission spectra**




*Eur.Phys.J.C 82 (2022) 5, 442*

# PDS: Photomultiplier Tubes




*Left & right: uncoated and coated PMTs installed in PDS Box*

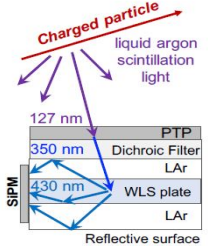
- ➔ 120 total 8” Hamamatsu R5912 PMTs
  - ◆ 96 TPB coated PMTs (VUV +visible light)
  - ◆ 24 uncoated PMTs (visible only)
- ➔ 500 MHz CAEN readout.
- ➔ PMT system already tested and characterized by CCM experiment
- ➔ Used for trigger building.

# PDS: X-ARAPUCAs

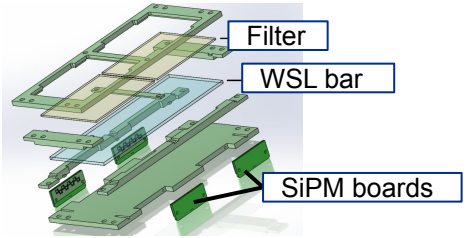

| SiPMs | WLS Bar | Filter | Modules in SBND |
|---|---|---|---|
| **SensL** MICROFC-30050-SMT | Eljen 286 | pTP coated 400 nm cutoff | 88 |
| **SensL** MICROFC-30050-SMT | Eljen 280 | 450 nm cutoff | 88 |
| **HPK** 6050-VE | Glass to power B. | pTP coated 400 nm cutoff | 6 |
| **HPK-VE** 6050-VE | Glass to power G. | 450 nm cutoff | 6 |
| **HPK** 6050-HS (↓bias,↑PDE) | Glass to power B. | pTP coated 400 nm cutoff | 2 |
| **HPK-HS** 6050-HS (↓bias,↑PDE) | Glass to power G. | 450 nm cutoff | 2 |

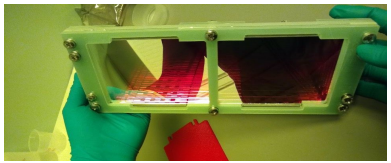
*SBND X-ARAPAPUCA configurations*

- ➔ **New scalable technology under development.**
- ➔ **Photons get trapped inside the module, increasing collection area. Side SiPMs collect the photons.**
- ➔ **Cut-offs allow for light source discrimination (450nm filter lets only visible light through)**
- ➔ **CAEN readouts: 12-bit / 62.5 MHz**
- ➔ **Important R&D for future experiments (DUNE PDS is only X-ARAPUCA based).**



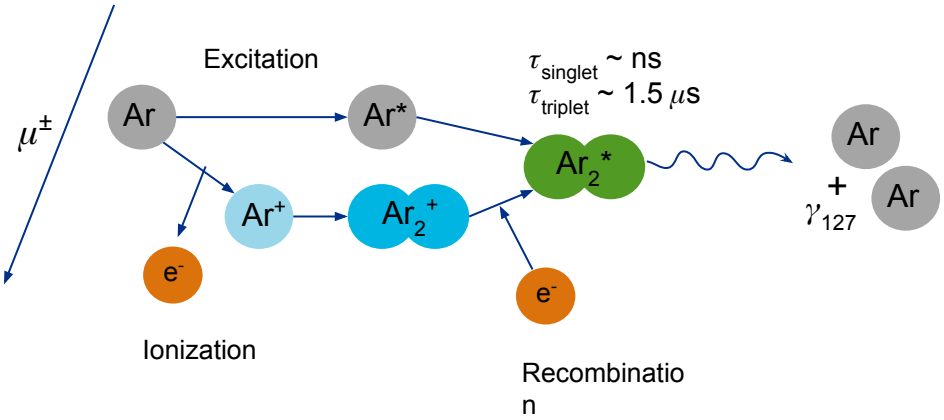

*X-ARAPUCA operating principle. Nucl. Instrum. Meth. A, 985 (2021)*

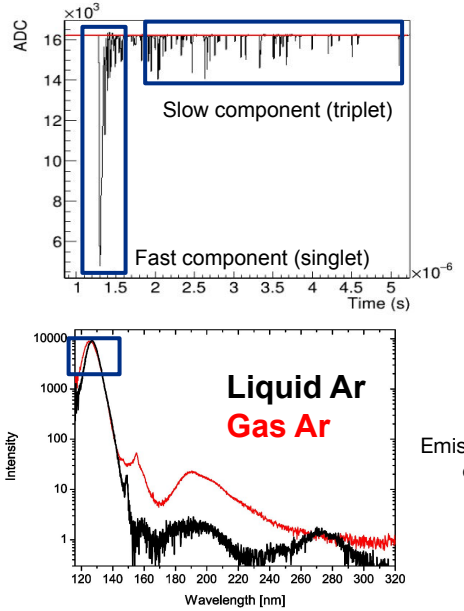


*Left: SBND X-ARAPUCA mechanical scheme. Right: mounted module*

# Liquid argon scintillation light




Emission spectra of argon

*EPL (2010)*, *91*(6), 62002