Towards a NCπ^0 Measurement in the Short-Baseline Near Detector

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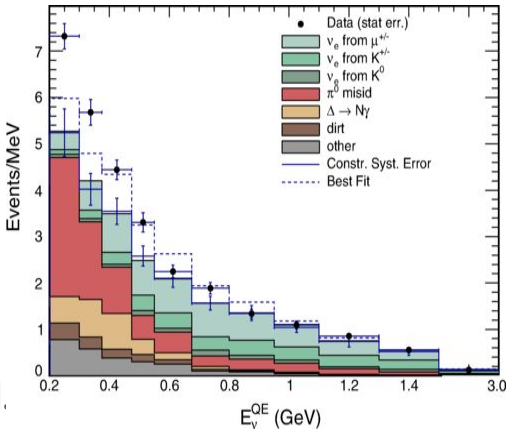
Short Baseline Neutrino Program @ Fermilab

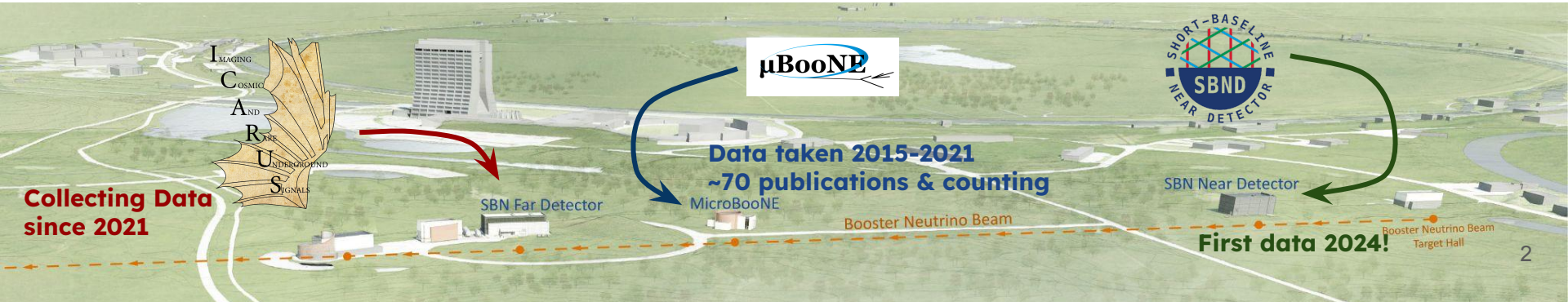
There is a long standing anomaly in electron neutrino appearance signatures over short baselines.

The Fermilab Short-Baseline Neutrino (SBN) Program was designed to investigate the LSND & MiniBooNE results with a world leading three detector experiment.

SBN consists of three LArTPCs situated on the Booster Neutrino Beam at Fermilab. Use of the same neutrino beam, target material and detector technology will enable us to restrict systematic uncertainties to the %-level.

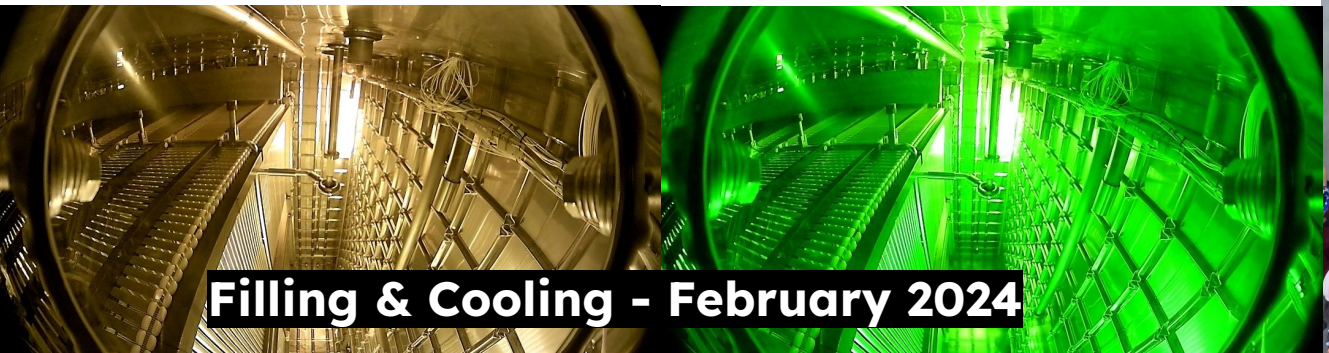
Phys. Rev. D 103 052002 (2021)

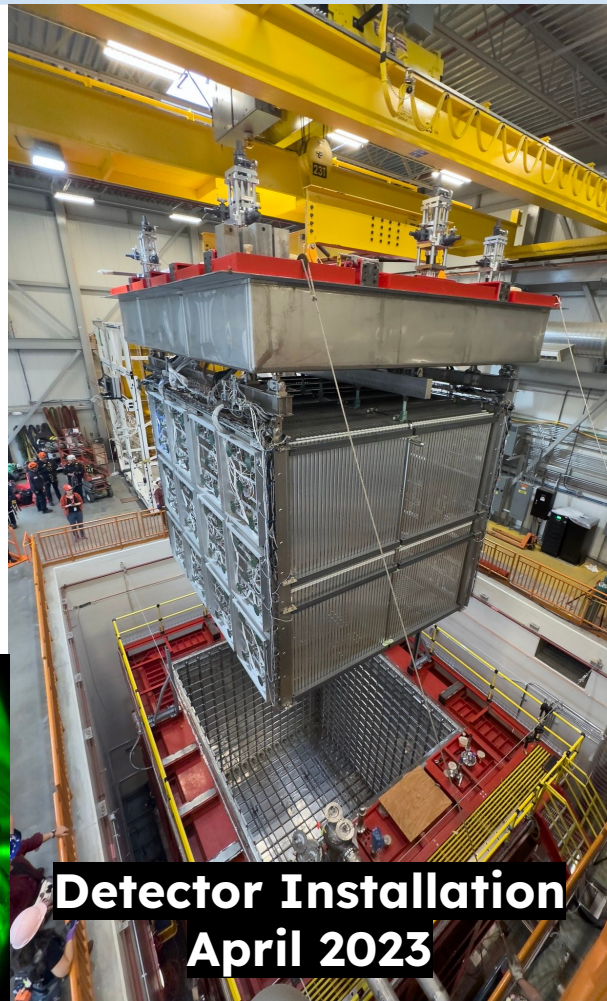




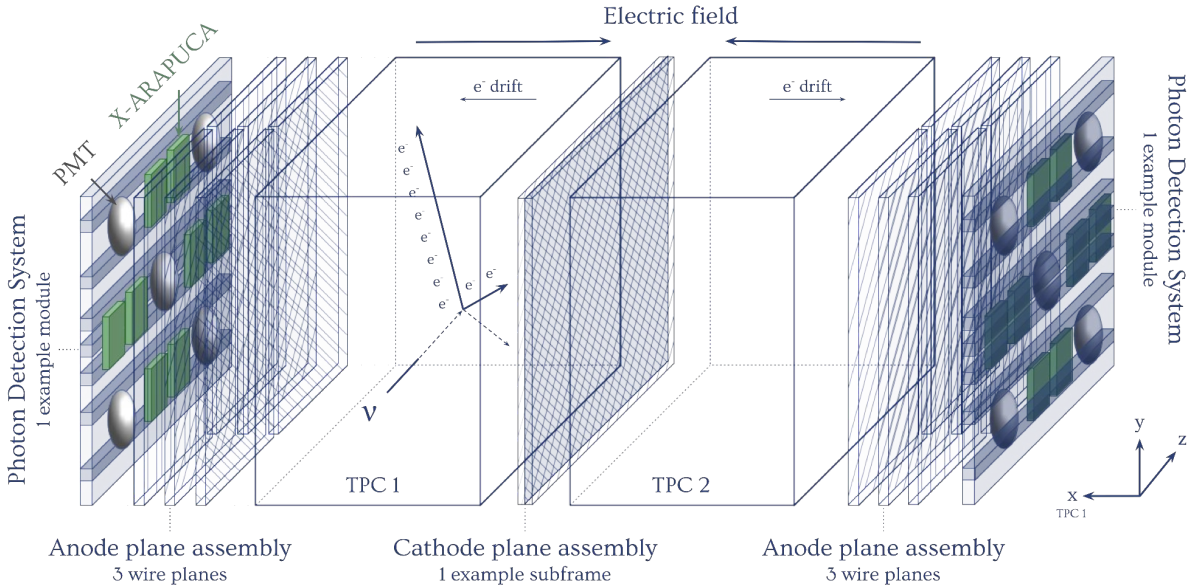
SBND

- Near Detector for the SBN program.
- Located 110m from the beam target.
- Will collect the largest ever dataset of neutrino-argon interactions.
- Broad physics program encompassing oscillations, BSM searches and neutrino interaction cross-sections.





SBND Detector



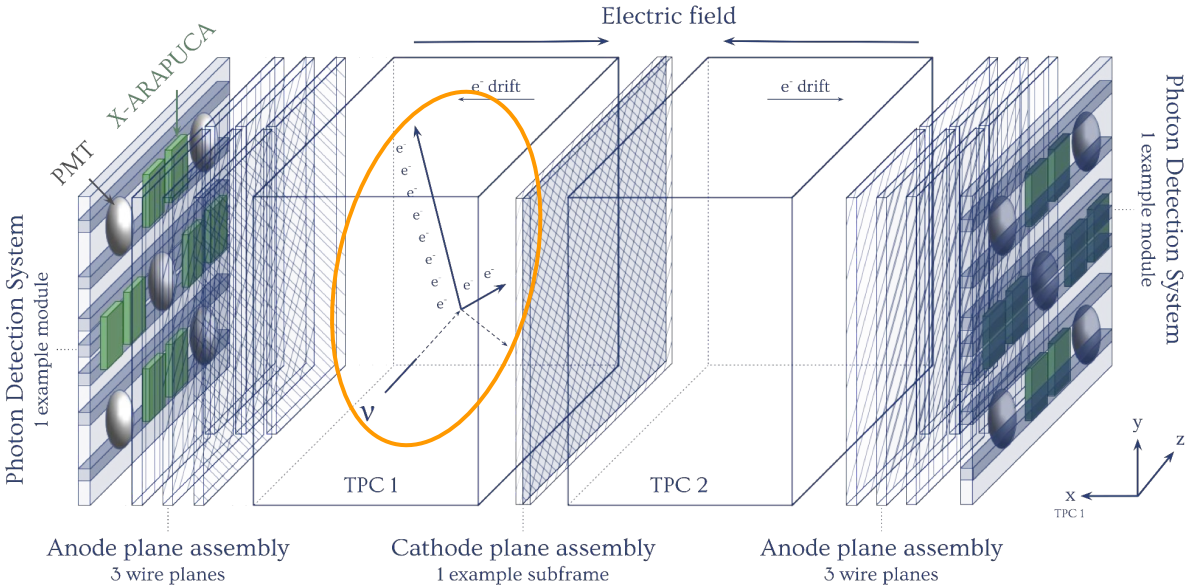
SBND TPC

Neutrino interaction produces (charged) particles.

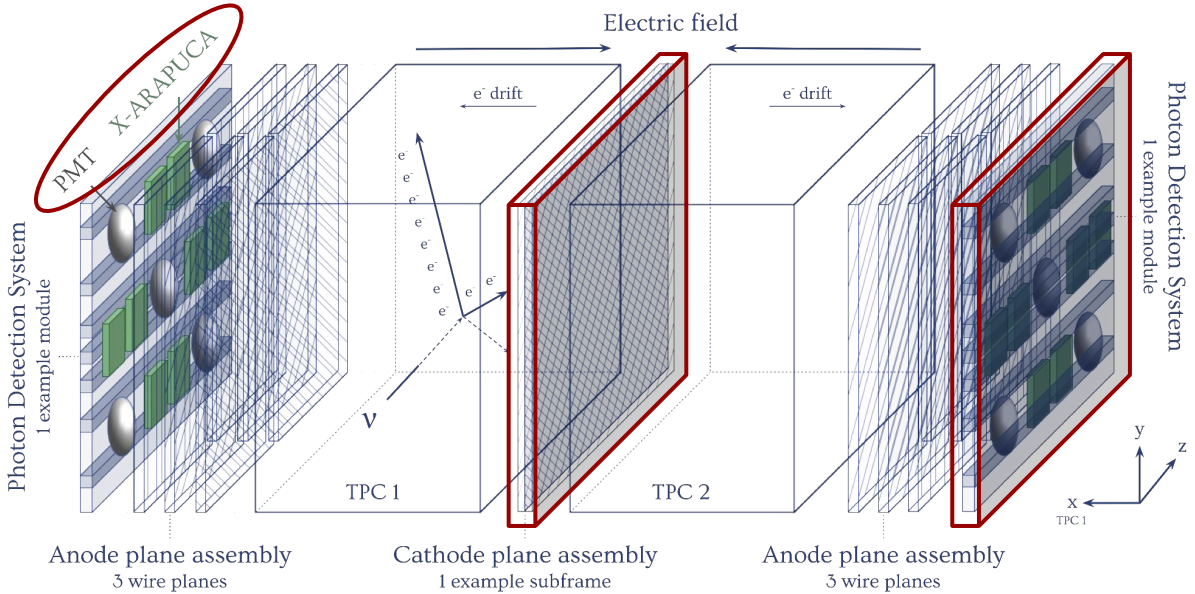
Charged particles ionise & scintillate in the argon.

Ionisation electrons drift to anode wire readout planes.

3D images formed from 3 x 2D projections.



SBND PDS



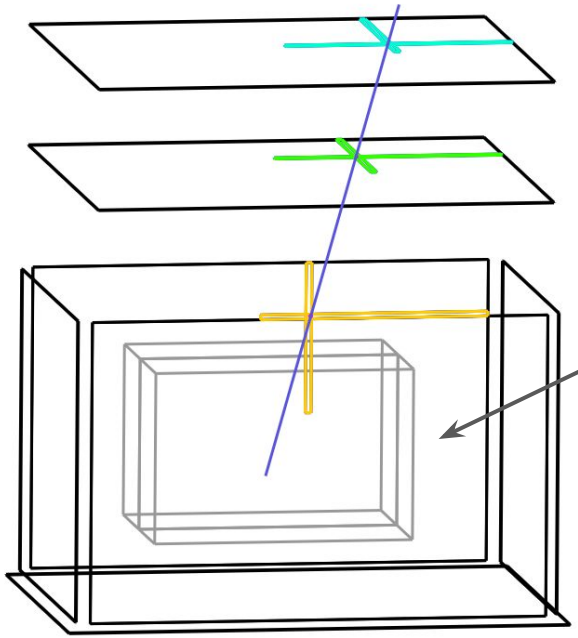
Scintillation light recorded by unique Photon Detection System (PDS).

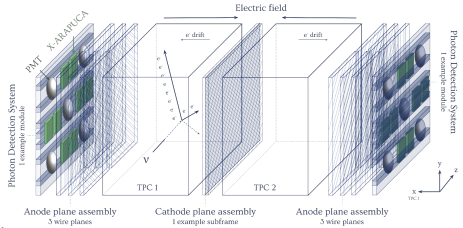
PDS consists of 120 traditional PMTs & 196 X-ARAPUCA light trap devices.

Nanosecond timing resolution critical to beam triggering and cosmic background rejection.

Cathode coated with wavelength reflecting foil to improve light collection efficiency.

SBND CRT



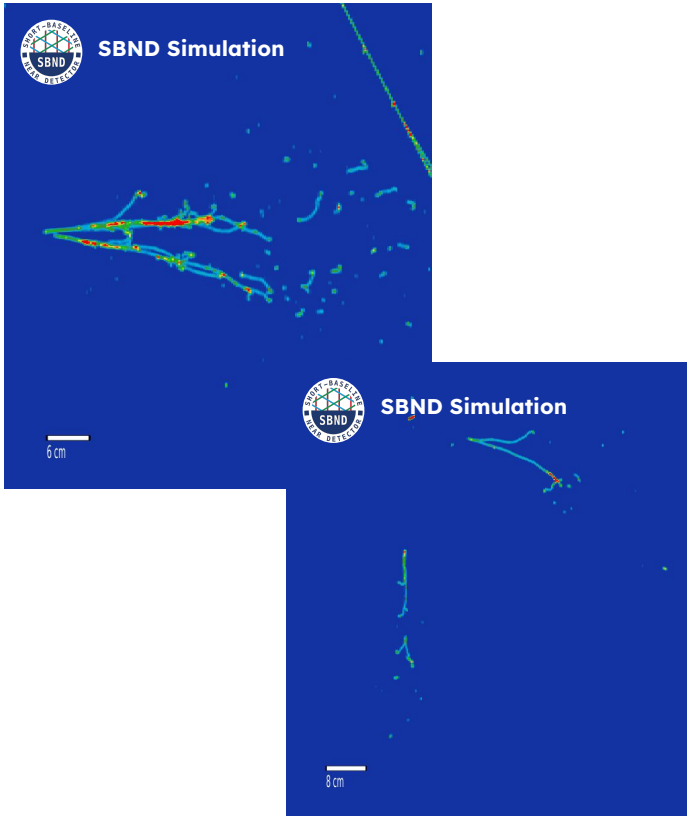


Cryostat surrounded with plastic scintillator panels to form a cosmic ray tagger (CRT) system.

Tags particles entering, exiting or passing through the detector with nanosecond precision.

NCπ^0

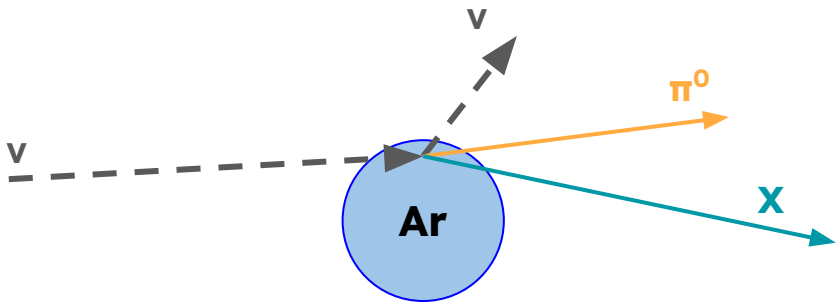
- Characterised by the two photons from the $\pi^0 \rightarrow \gamma\gamma$ decay.
- Important background in any LEE-like searches looking for electromagnetic shower signals.
- Measurements of single pion production required to better constrain models.
- Resonance production dominates at BNB energies with some coherent and deep inelastic scattering events too.

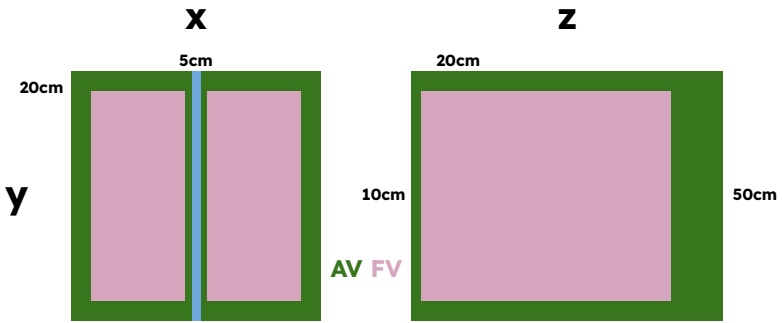


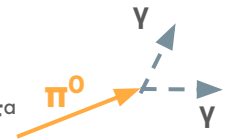
Signal Definition

NC $1\pi^0$ Inclusive

- NCν interaction
- within FV
- $1\pi^0 \rightarrow \gamma\gamma^*$
- X
  - No $\mu^{\pm}$, $e^{\pm}$, π^0
  - Any other combination of nucleons & mesons





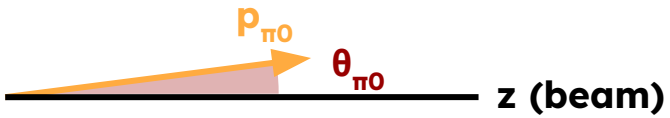


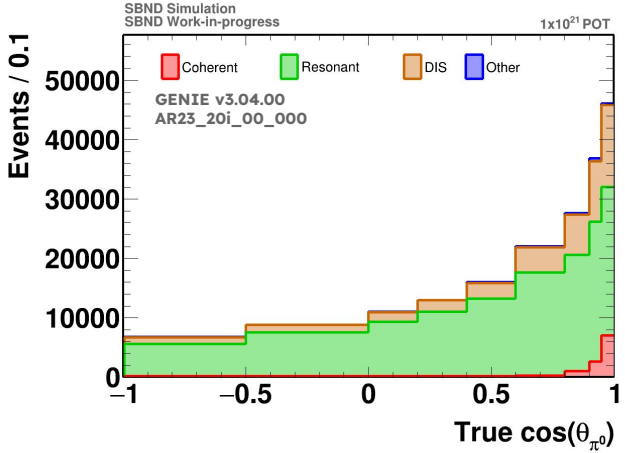
*$\pi^0 \rightarrow \gamma\gamma$ has a 98.8% BF[a]
Only other non-negligible is $e^+e^-\gamma$

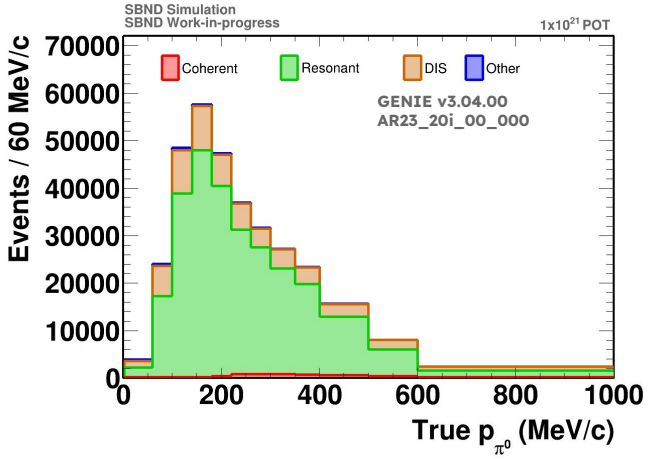
[a] R.L. Workman *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2022**, 083C01 (2022).

True Distributions

- Two key observable kinematics
  - Pion momentum
  - Pion direction with respect to the z-axis (beam direction - great proxy for neutrino direction).
  - The latter shows a heightened coherent contribution at forward boosted angles.



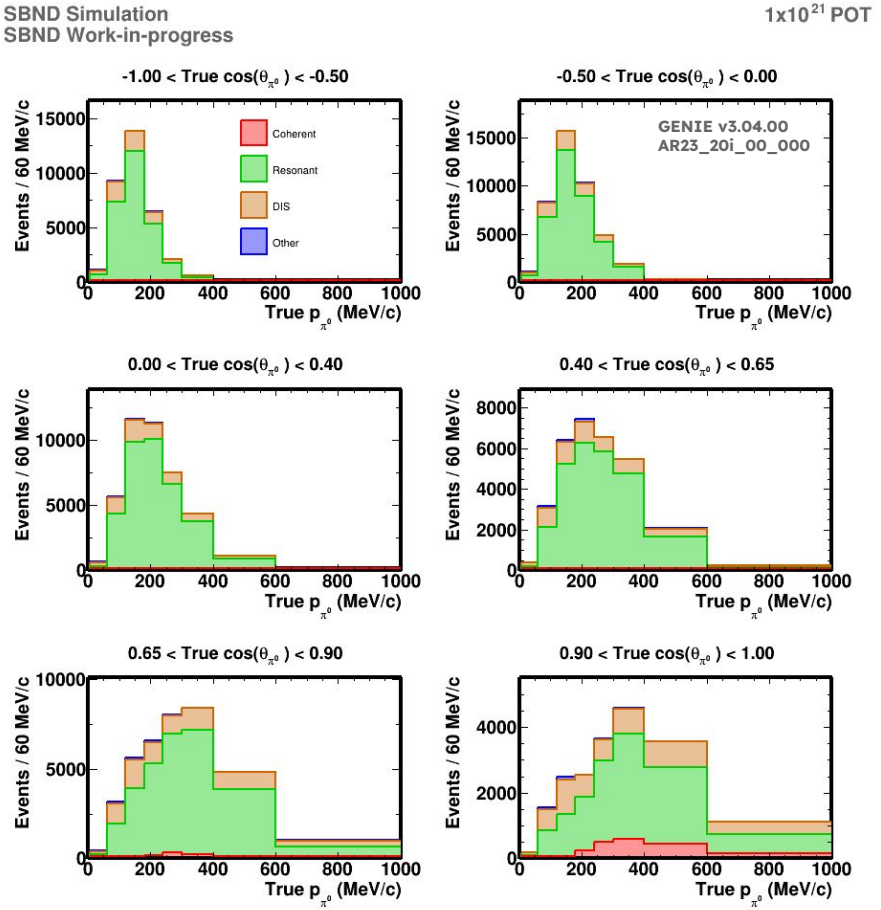




Double Differential

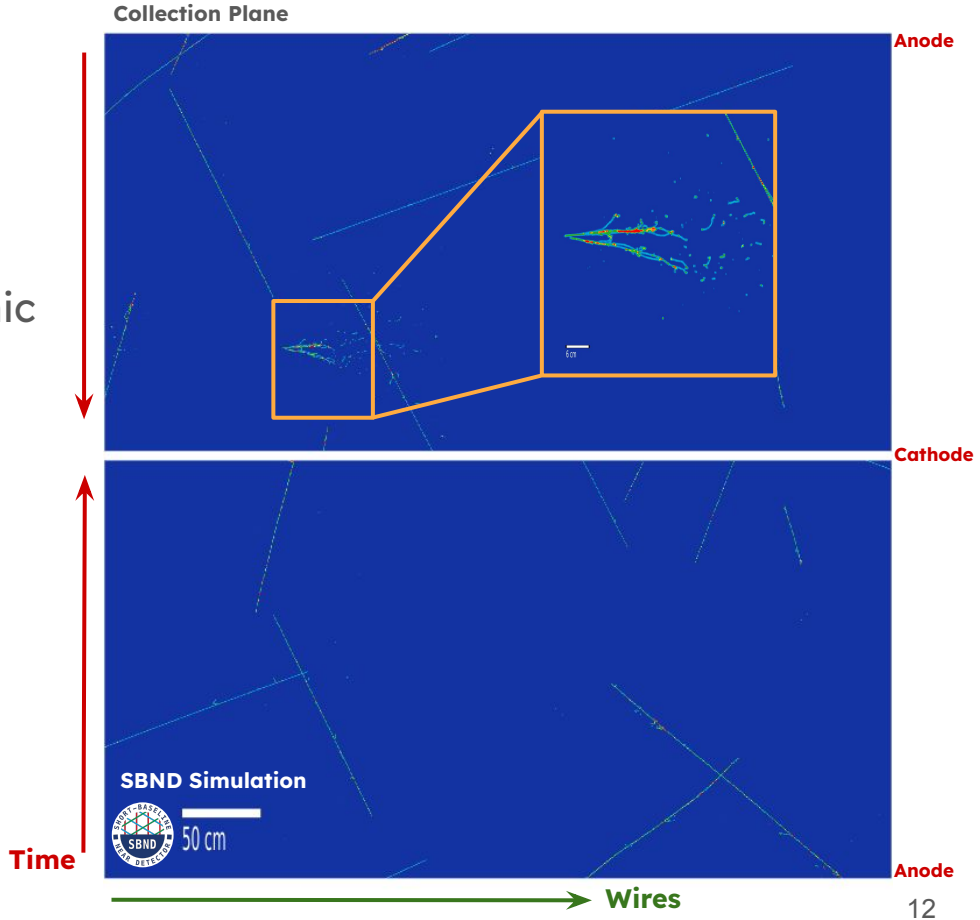
Thanks to its huge exposure, SBND will be able to make higher precision measurements of many channels.

This includes more differential measurements becoming feasible. In the case of NCπ^0, a double differential measurement will be possible.



Selection

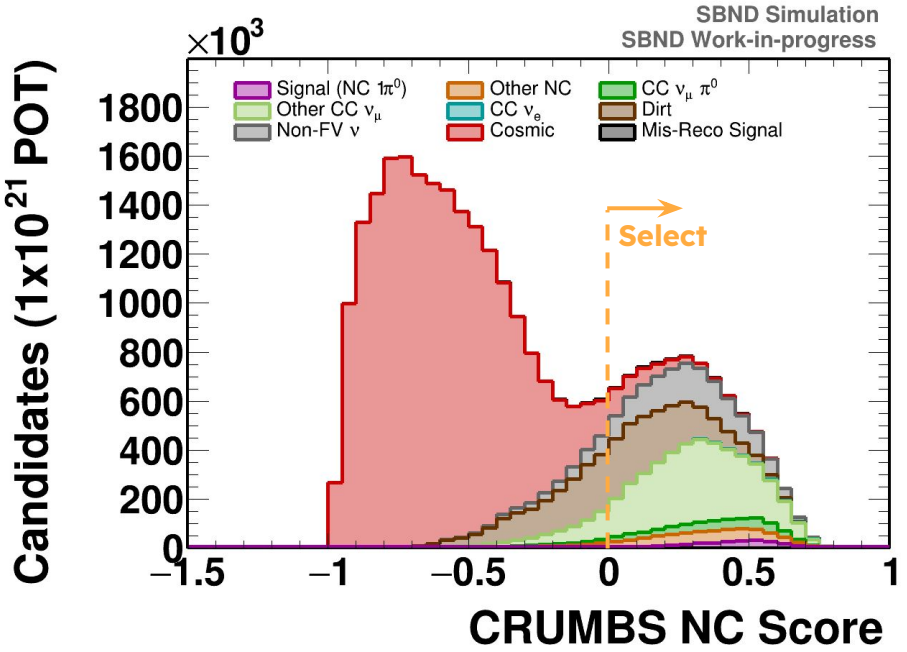
- Unfortunately we do not just see just nice isolated neutrino events.
- Each readout will also contain ~5 cosmic muons .
- The first stage of the Pandora pattern recognition groups distinct areas of activity in the detector into “slices”[1].
- Some clearly cosmic slices are immediately removed by the reconstruction, the remaining slices form the base unit of the selection.



[1] Eur. Phys. J. C 78 (2018) 1, 82

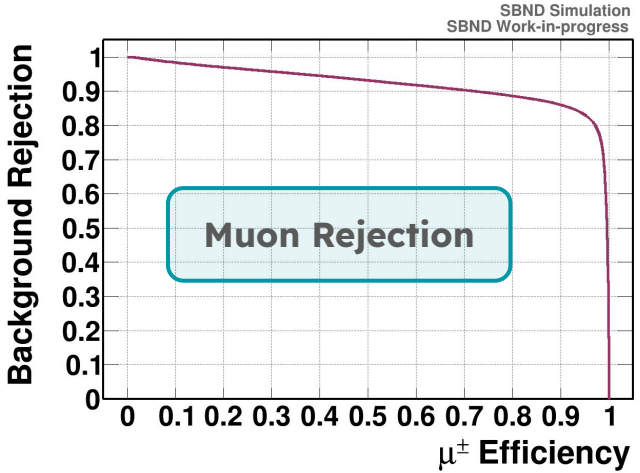
Cosmic Rejection

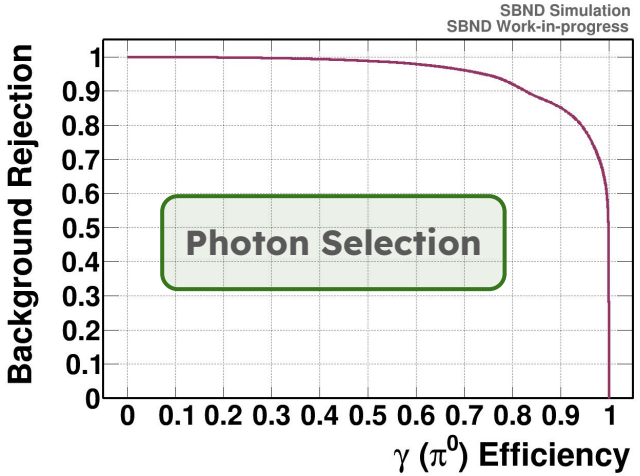
- We then reject the dominant cosmic activity using a tool I developed called CRUMBS.
- CRUMBS is a BDT that harnesses the complementary cosmic rejection power of the different detector subsystems.
- There are separate variants trained on CCν_μ, CCν_e and NC signals.



Particle Identification

- Having removed the cosmic & out of FV backgrounds, particle identification is needed to isolate NC1π^0 interactions.
- A series of cuts reject slices with clear muons (CCν_μ) and select slices with two clear photons.
- This is done using a multi-class BDT tool called Razzled which looks at geometric & calorimetric variables.

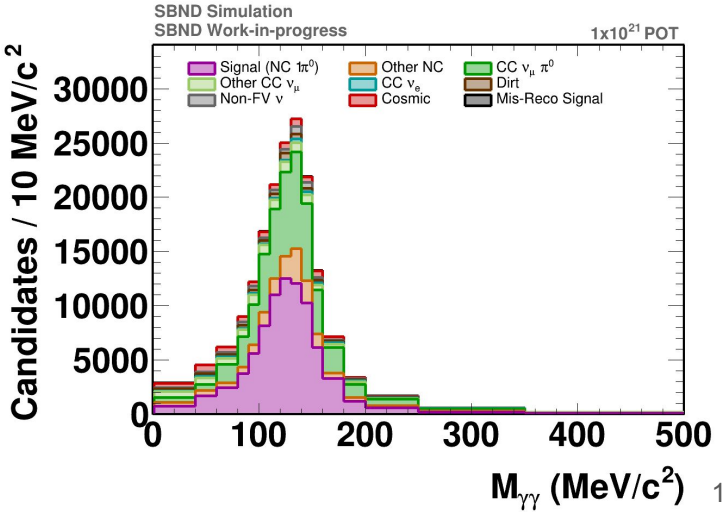




Final Selection

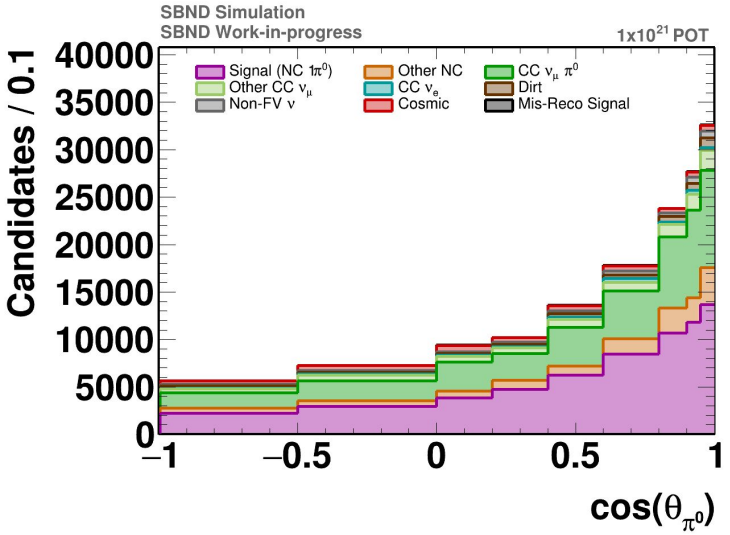
Efficiency (%)	Purity (%)	Eff * Pur (%)
36.18	44.35	16.04

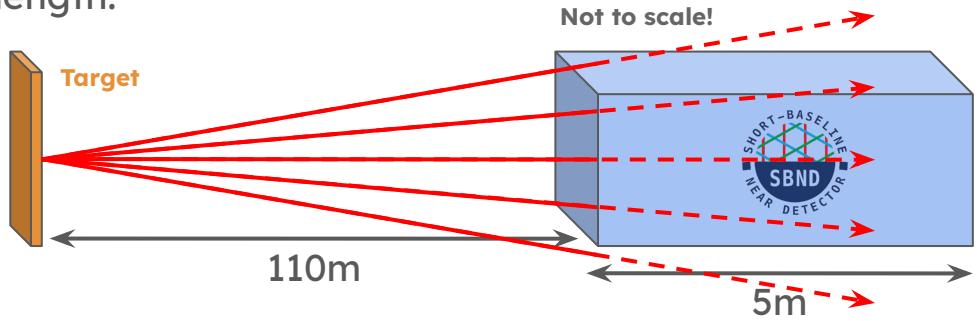
Final selection includes some cuts on the quality of the PDS-TPC matching & a containment cut to help reduce CCν_μ backgrounds in the inclusive sample.



Extracting a Cross Section

- Apply kinematic fitting with invariant mass constraint to improve kinematic observables.
- Extract MC cross-section
  - Apply efficiency and purity corrections.
  - Normalise for flux & targets, accounting for flux spread along detector length.
  - Systematics studies ongoing





Conclusions

- Monte Carlo selection of challenging NCπ^0 channel demonstrating good performance.
- Exercising cross-section extraction and systematics tools in advance of first data.
- SBND is commissioning now! Stay tuned for exciting results coming soon!


SBND @ Arlington, June 2023


SBND @ São Paulo, Dec 2023