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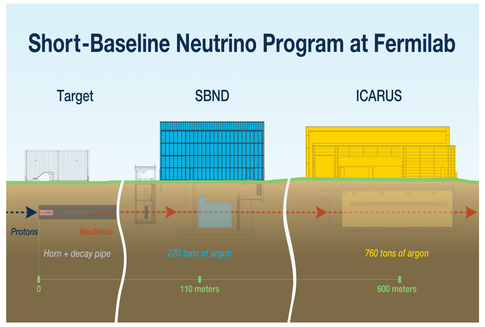
Progress toward Differential Cross-Section Measurements of Coherent Charged-Pion Production in Charged-Current Muon Neutrino Interactions on Argon with SBND

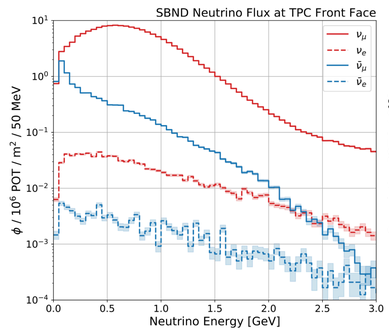
Sungbin Oh[1)] , On Behalf of the SBND Collaboration

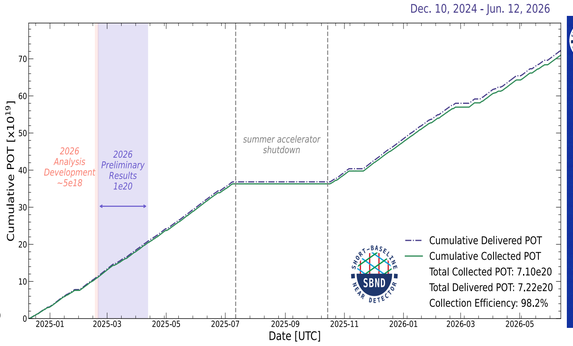
1) Fermi National Accelerator Laboratory

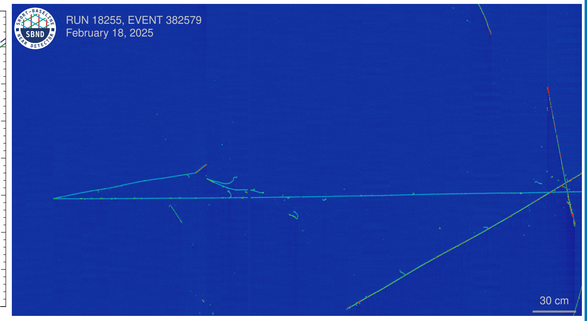
1. Short Baseline Neutrino (SBN) Program

- Two LArTPCs: SBND and ICARUS
- Booster Neutrino Beam: ν_μ dominant & detected $\bar{E}_\nu \approx 0.8$ GeV
- Physics
  - Understanding anomalous signals reported by the MiniBooNE and the LSND experiments [1]
  - **Precise cross-section measurements for ν-argon interactions**
  - Searches for physics beyond the standard model (BSM) i.e.) dark matters, heavy neutral leptons, ...
- SBND has already collected data more than 7.0×10^{20} POT
  - About 6 million ν–argon interactions have been recorded

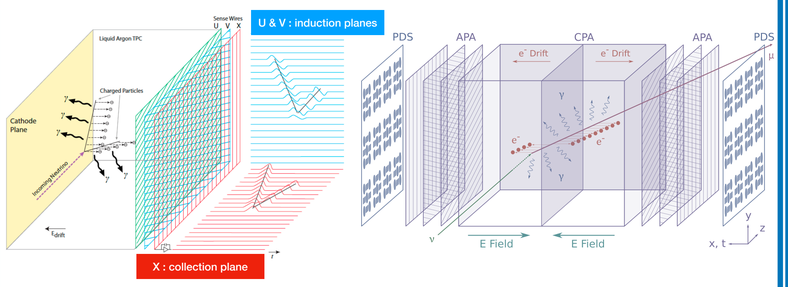








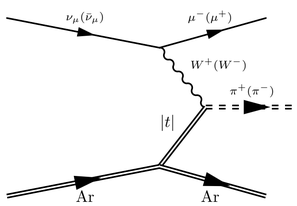
2. Short Baseline Near Detector (SBND)



- Liquid Argon Time Projection Chamber (LArTPC)
  - Two electron drifting volumes share a central HV cathode plane
    - A field cage for uniform 500 V/cm E-field
  - Three readout wire planes for each TPC: one collection (vertical) and two induction (±60°) planes with 3 mm wire pitch
  - TPC cold electronics
    - Shaping, amplification and digitization in LAr (~ 87 K) for 11,264 wires
  - Photon detectors collect scintillation photons
    - Providing timing information with O(ns) resolution

3. Signal Definition

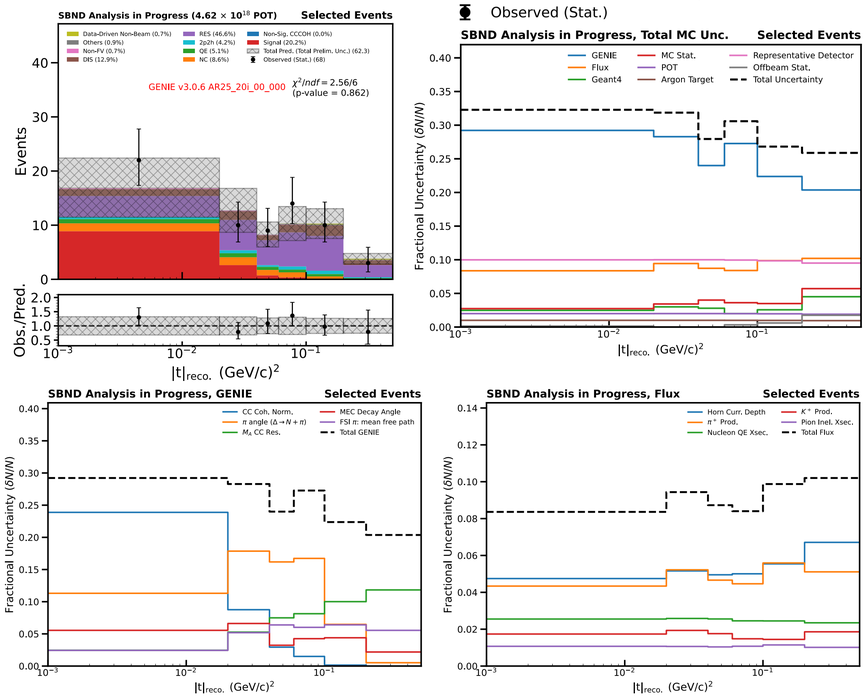
- Signal processes
  - $\nu_\mu + {}^{40}\mathrm{Ar} \rightarrow \mu^- + \pi^+ + {}^{40}\mathrm{Ar}$ and $\bar{\nu}_\mu + {}^{40}\mathrm{Ar} \rightarrow \mu^+ + \pi^- + {}^{40}\mathrm{Ar}$
  - Argon nucleus stays in its ground state
  - Final state topology is a clean two-track event



- The infinite target mass approximation
  - Four momentum transferred to argon nucleus: $|t| = \left[\sum_{\mu,\pi} p_i^{\perp}\right]^2 + \left[\sum_{\mu,\pi} (E_i - p_i^{\parallel})\right]^2$
  - Neutrino energy: $E_\nu = E_\mu + E_\pi \rightarrow$ **reliable neutrino energy estimate!**
- Truth-level signal definition
  - Exactly one muon with kinetic energy > 27 MeV
  - Exactly one charged pion with kinetic energy > 30 MeV
  - No proton with kinetic energy > 20 MeV
  - No neutron and no neutral pion at any energy

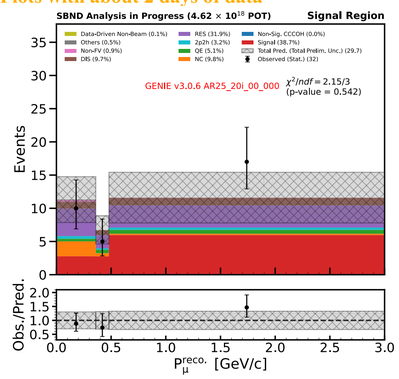
4. Event Selections

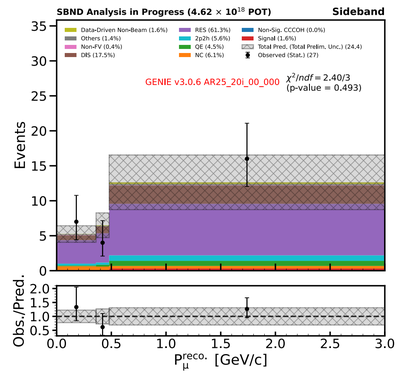
- Rejection of Non-Neutrino and Out-of-Volume Interactions
- Topology and multiplicity selection
  - Exactly **two track** objects and no showers (one muon and one charged pion)
- Kinematic and PID requirements
  - Utilizing calorimetry information to **veto protons**: check if there is proton-like Bragg peak
  - Among the two tracks, the longer track is assigned as muon candidate and the shorter track is assigned as charged pion candidate
  - Coherent interaction produces forward-going muons and charged pions
    - $\cos\theta_\mu > 0.7$, $\cos\theta_\pi > 0.5$, and $\cos\theta_{\mu\pi} > 0.5$
- Vertex activity cuts
  - To suppress neutrino interaction backgrounds with unreconstructed low-energy protons
  - Apply cut on electric charge sum of all hits inside a sphere centered at the reconstructed neutrino interaction vertex
    - For spheres with radii 1, 2, 3, and 4 cm
- Signal region and sideband
  - Signal region: $|t|_{\mathrm{reco}} < 0.04$ (GeV/c)^2
  - Sideband: $|t|_{\mathrm{reco}} > 0.06$ (GeV/c)^2

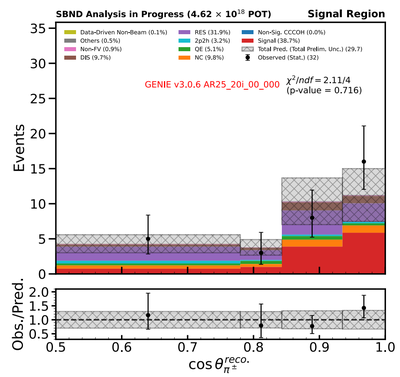


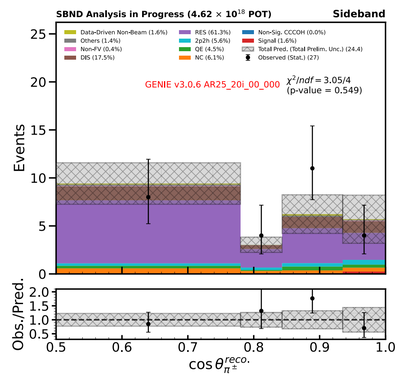
5. Event Rate Distributions

- In the signal region, signal efficiency is about 25% with about 39% signal purity
- **Plots with about 2 days of data**









6. Summary

- This analysis targets using the SBND Run 1 dataset (completed July 2025) data with 3.5×10^{20} POT
  - In the future, the full SBND dataset with about 10×10^{20} POT will be used
- Event selection for the charged current coherent charged pion production from ν_μ, $\bar{\nu}_\mu$ - Ar interactions is developed
  - Signal region and sideband are defined
  - Achieved about 25% signal efficiency with 39% purity in the signal region
- Event rate distribution comparison between MC simulation and data are presented with uncertainties
  - Cross-section measurements will be performed for muon and charged pion kinematic variables

Acknowledgements

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References

[1] MiniBooNE collaboration, Updated MiniBooNE neutrino oscillation results with increased data and new background studies, Phys. Rev. D 103 (2021) 052002 [2006.16883].