Reconstruction and identification of neutrino-induced events with electromagnetic activity in the final state at SBND

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Neutrino Cross-Section Physics

- Precise measurements of neutrino interaction cross-sections are critical for the next generation of neutrino experiments
- Interactions that produce electromagnetic activity are of particular interest due to their relevance to short-baseline electron neutrino appearance anomalies

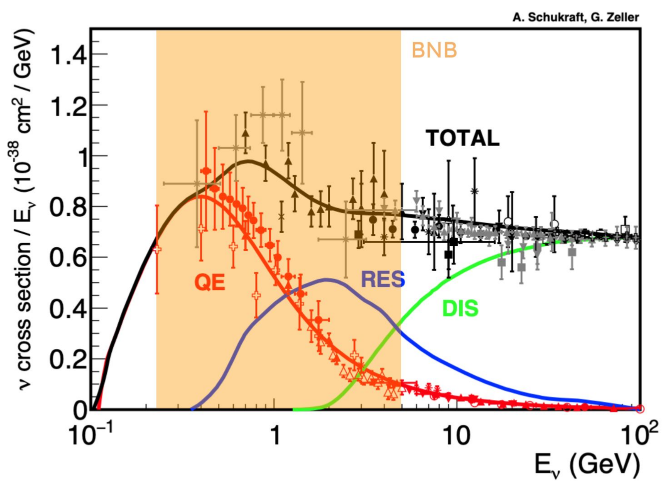


Figure 1: Contributions to the total charged current neutrino cross section [1].

Short-Baseline Near Detector

- 112-ton Liquid Argon Time Projection Chamber (LArTPC)
- Sophisticated Photon Detection System (PDS) and Cosmic Ray Taggers (CRTs) provide supplementary information for timing resolution, cosmic rejection, and light calorimetry
- Near detector for the Short-Baseline Neutrino program at Fermilab, located just 110m from the Booster Neutrino Beam (BNB) target
- Will record over 2 million neutrino interactions per year
- Rich single detector physics program of neutrino-argon cross-section measurements and beyond the standard model searches

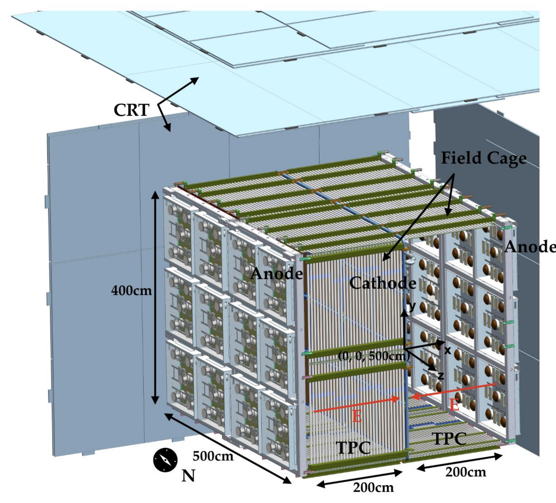
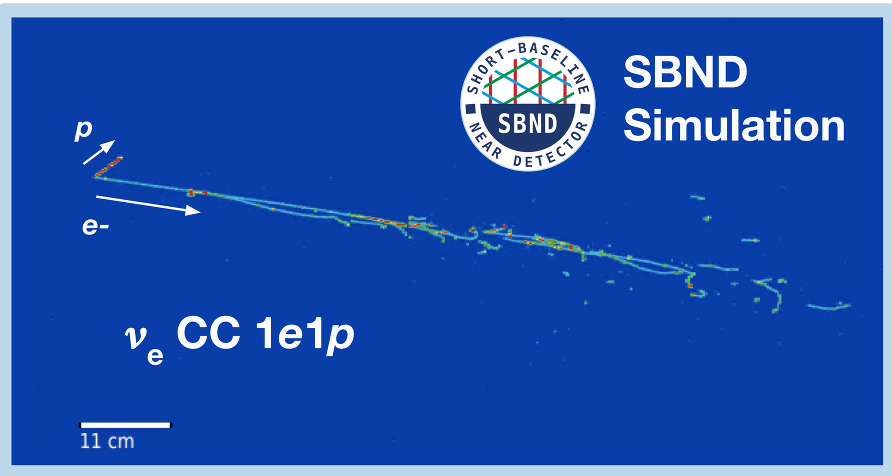


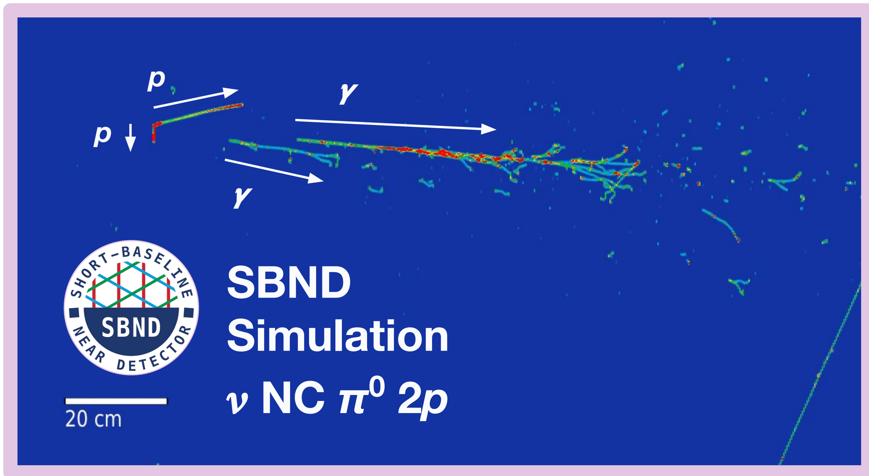
Figure 2: Schematic of the SBND Detector Systems [2].

Selection Procedure



~15,000 / year
ν_eCC Interactions

~100,000 / year
NC1π^0 Interactions



Pre-Selection
- Pandora Unambiguous Cosmic Removal
- Vertex in the Fiducial Volume

Cosmic Rejection → **Muon Rejection** → **Shower Selection** → **Charge-Light Hypothesis Cuts**

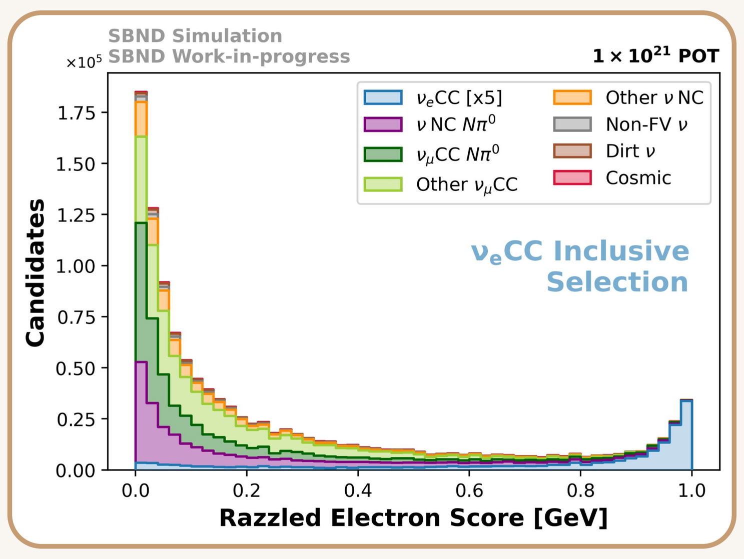


Figure 3: The Razzled Particle Identification BDT electron score distribution following the muon rejection stage for the ν_eCC inclusive channel.

Particle Identification is performed using a Multi-Class BDT called Razzled.

Razzled takes a combination of geometric and calorimetric inputs designed to isolate the defining features of muons, electrons, charged pions, photons, and protons.

Cosmic Rejection is performed using a Boosted Decision Tree tool called CRUMBS.

CRUMBS harnesses the complementary cosmic rejection power of all three of SBND's detector subsystems: TPC, PDS, and CRT.

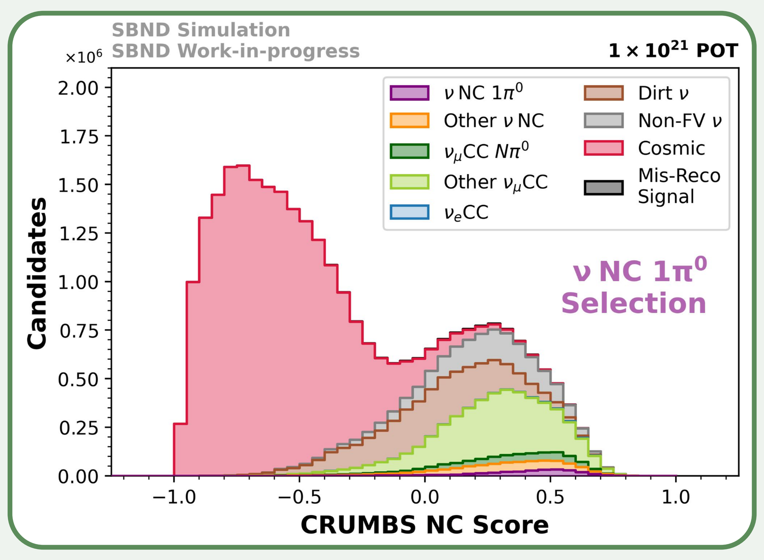


Figure 4: The CRUMBS cosmic rejection BDT score distribution for the NC 1π^0 selection candidates following the pre-selection stage. This variant of the CRUMBS score is optimised for neutral current selection efficiency.

Selection Results

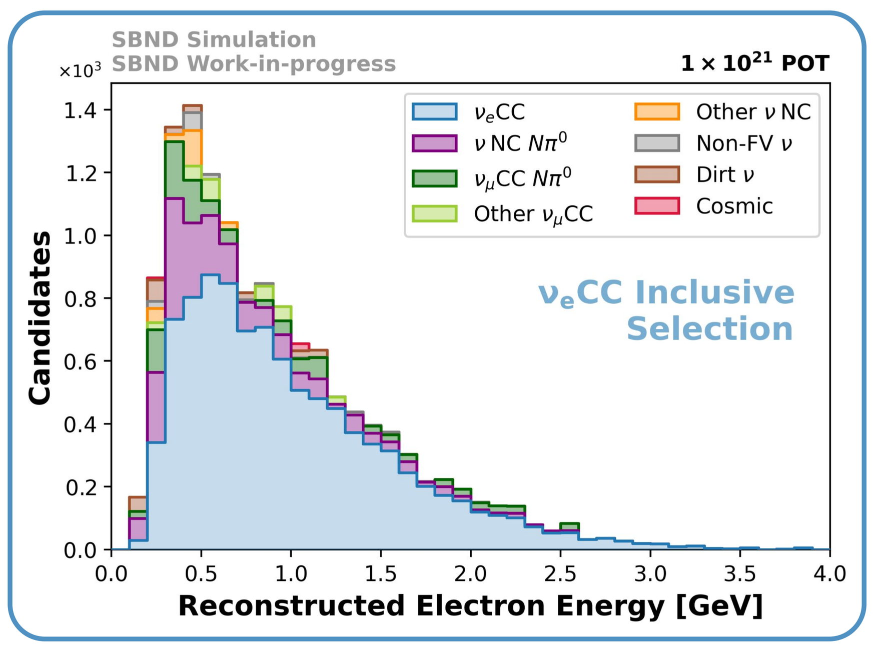


Figure 5: The reconstructed energy of the electron for all selected candidates in the ν_eCC inclusive channel.

The final selection for each channel results in:

Selection	Efficiency (%)	Purity (%)
ν_eCC Inclusive	30.7	72.3
NC1π^0	34.4	43.5

The largest background for each of these channels result from other classes of interactions that also produce electromagnetic activity.

For the NC1π^0 channel this comes from charged current π^0 production, whilst for the ν_eCC channel this comes from the neutral current channel itself.

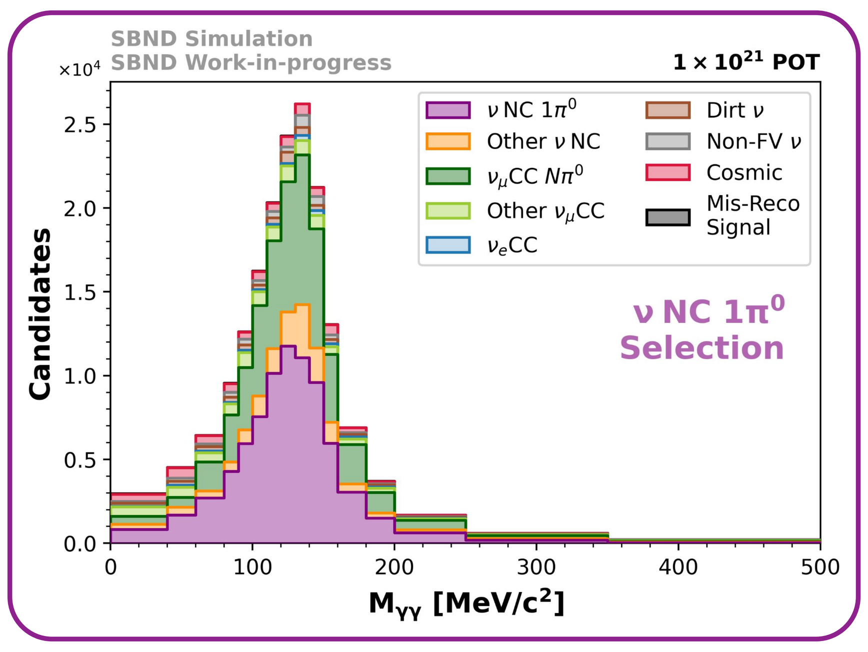


Figure 6: The diphoton invariant mass of all selected candidates for the NC1π^0 channel.

Light Calorimetry

SBND's Photon Detection System (PDS) is capable of measuring both visible and VUV light, and has a large number of photodetectors (312 total). The high photo-coverage allows us to implement **light-augmented reconstruction techniques.**

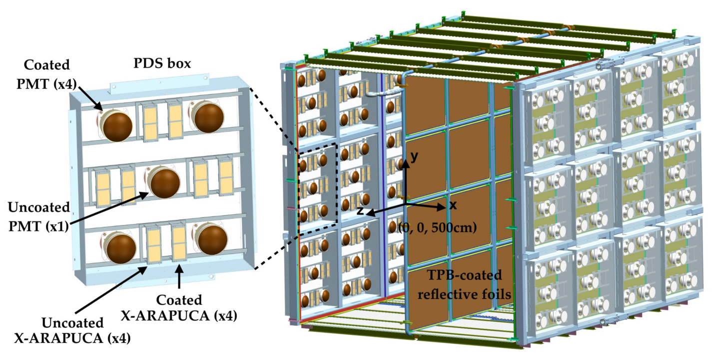


Figure 7. PMT and X-ARAPUCA arrangement in a PDS-box (left), together with a view of SBND's photon detection system (right) [2].

Q + L: Energy Reconstruction with Charge and Light

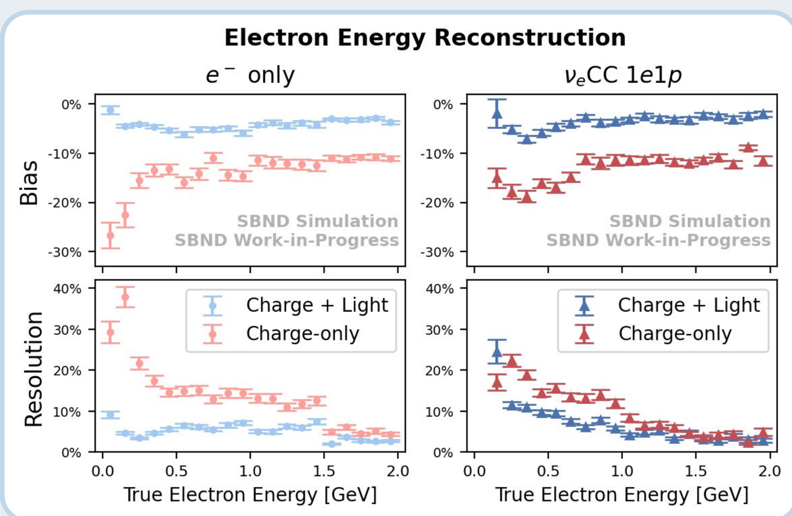


Figure 8: The electron energy reconstruction performance for a single simulated electron (left) and the electron from an electron neutrino charged-current interaction with a single proton (right). **Compared to the traditional charge-only method, the incorporation of light information improves both the bias and resolution of the energy reconstruction.**

Light information can recover missing energy from reconstruction effects such as mis-clustering and missing charge [3].

$$E_{\text{vis}}^{\text{tot}} = (Q + L) \cdot W_{\text{ph}}$$

electron only

$$E_{Q+L}^{e^-} = E_{\text{vis}}^{\text{tot}}$$

electron from *1e1p*

$$E_{Q+L}^{e^-} = E_{\text{vis}}^{\text{tot}} - E_{\text{range}}^{p}$$

Q → L: Charge-Light Hypothesis

A hypothesis for the amount of scintillation light that can be produced from the reconstructed charge.

A large difference between the hypothesis L_Q and measured light L may indicate:

1. **Poorly reconstructed neutrino interactions**
2. **Non-coincident cosmic backgrounds**

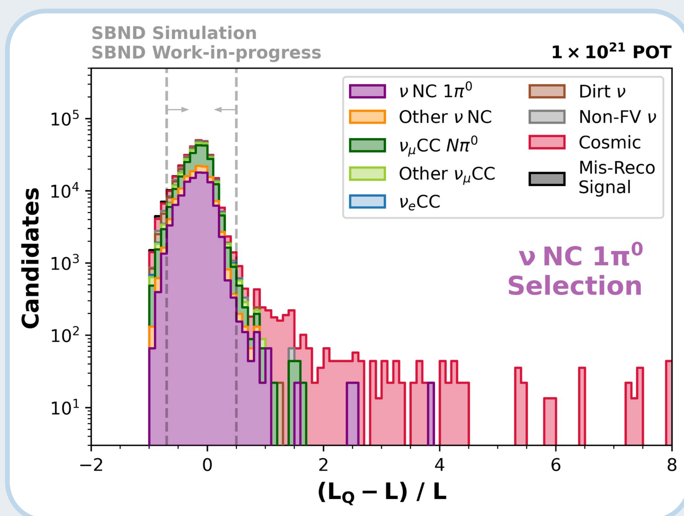


Figure 9: The distribution of the fractional difference between hypothesized L_Q and measured light L following the photon selection stage of the NC 1π^0 selection.

References

[1] J. A. Formaggio and G. P. Zeller. *From eV to EeV: Neutrino cross sections across energy scales*. Rev. Mod. Phys. 84 (3 Sept. 2012)
[2] P. Abratenko et. al. (SBND Collaboration). *Scintillation Light in SBND: Simulation, Reconstruction, and Expected Performance of the Photon Detection System.* arXiv 2406.07514
[3] W. Foreman et al. (LArIAT Collaboration). *Calorimetry for low-energy electrons using charge and light in liquid argon.* Phys. Rev. D 101, 012010 (22 January 2020)

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