Studying Neutrino-Nucleus Interactions at SBND

New Perspectives 2024

July 8, 2024

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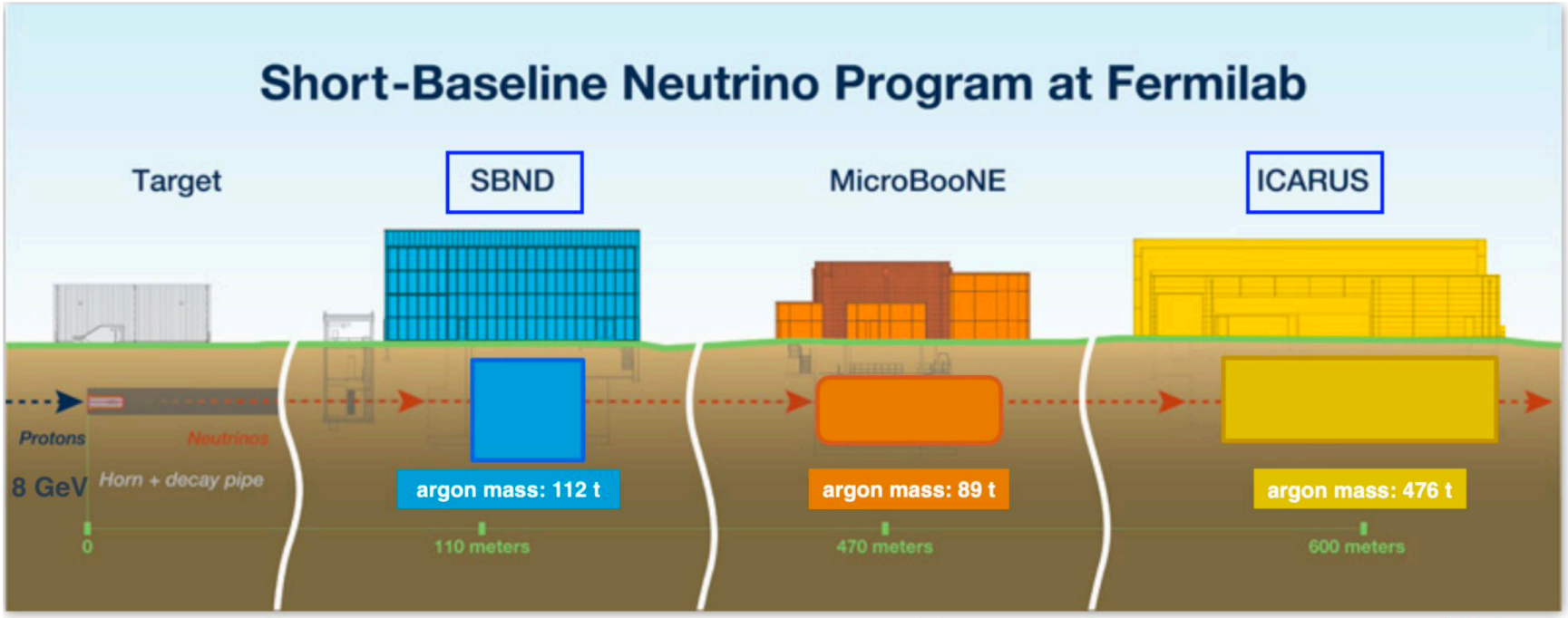
Short-Baseline Near Detector (SBND)



2015-2021
Large production of scientific results

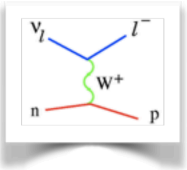
Beam composition:
ν_μ (93.6%)
$\bar{\nu}_\mu$ (5.9%)
ν_e+$\bar{\nu}_e$ (0.5%)

Mean ν_μ energy: ~0.8 GeV

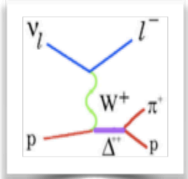
Short-Baseline Near Detector (SBND) - Cross Sections

- Booster Neutrino Beam (BNB) peaks at **0.8 GeV**
  - 93.6% ν_μ 5.9% $\bar{\nu}_\mu$ 0.5% $\nu_e + \bar{\nu}_e$
  - Probes various interaction modes with different final states

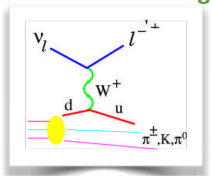
Quasi-elastic scattering (QE)

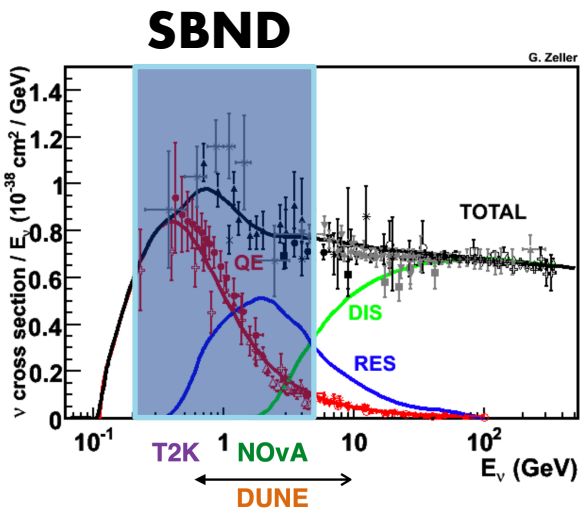


Resonance production (RES)



Deep Inelastic scattering (DIS)





J.A. Formaggio, G. Zeller, Reviews of Modern Physics, 84 (2012)

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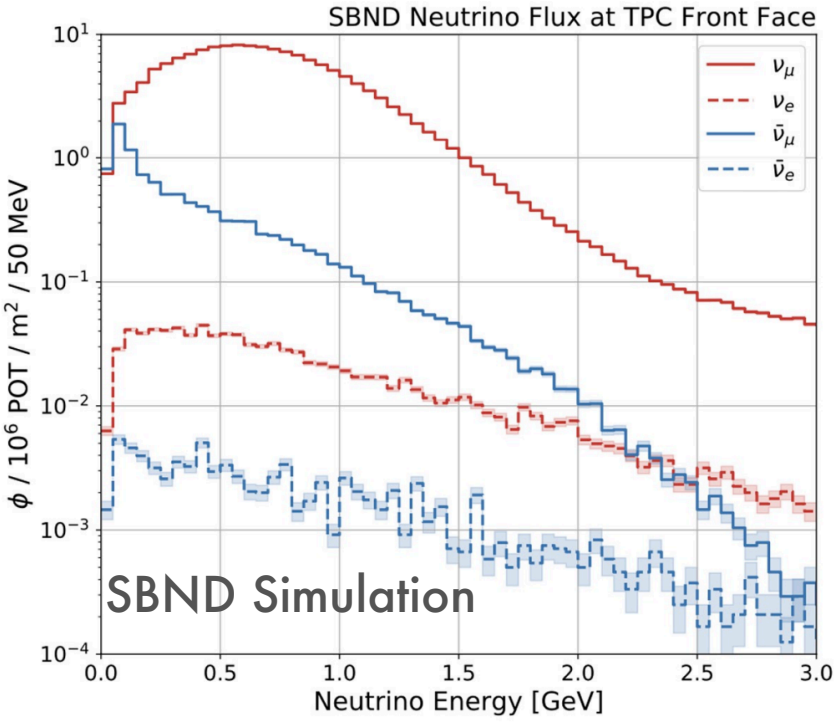
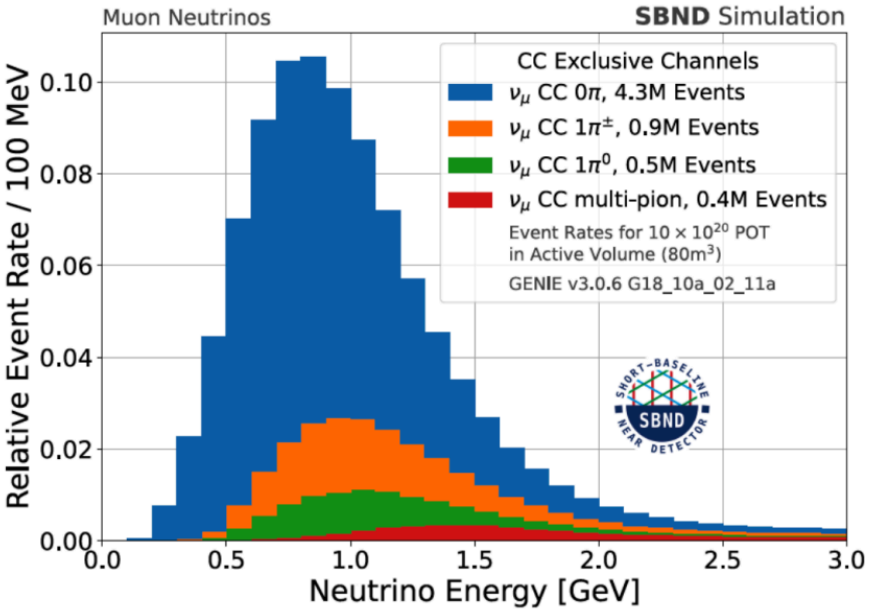
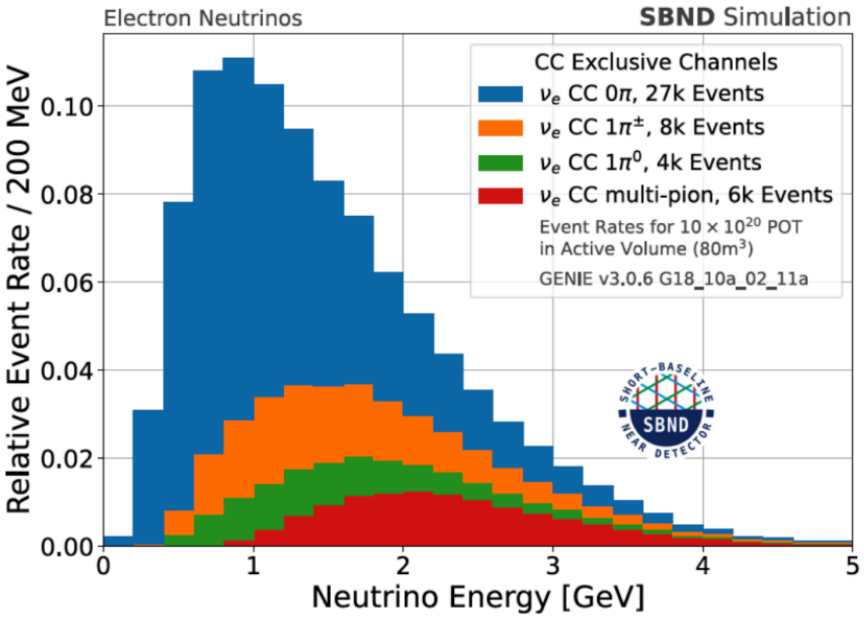


Short-Baseline Near Detector (SBND) - Cross Sections

- Booster Neutrino Beam (BNB) peaks at **0.8 GeV**
  - 93.6% ν_μ 5.9% $\bar{\nu}_\mu$ 0.5% $\nu_e + \bar{\nu}_e$
  - Probes various interaction modes with different final states
- Expect to see 2m ν_μ/yr (left) and 15k ν_e/yr (right)

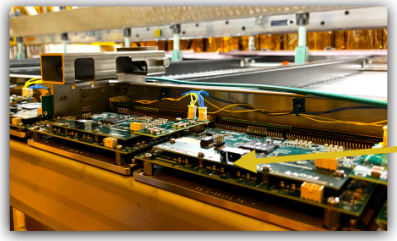




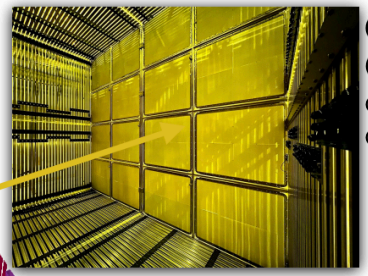
Short-Baseline Near Detector (SBND) - Detector

CRT provides 4π cosmic coverage (not shown)

TPC Cold electronics

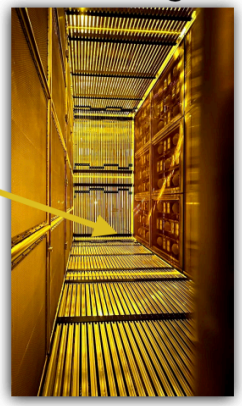


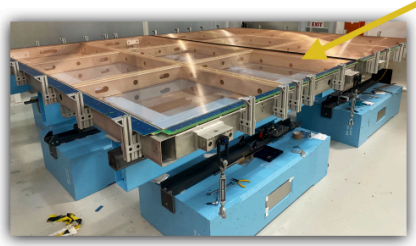
Two Time Projection Chambers
Total dimension: 4m x 4m x 5m



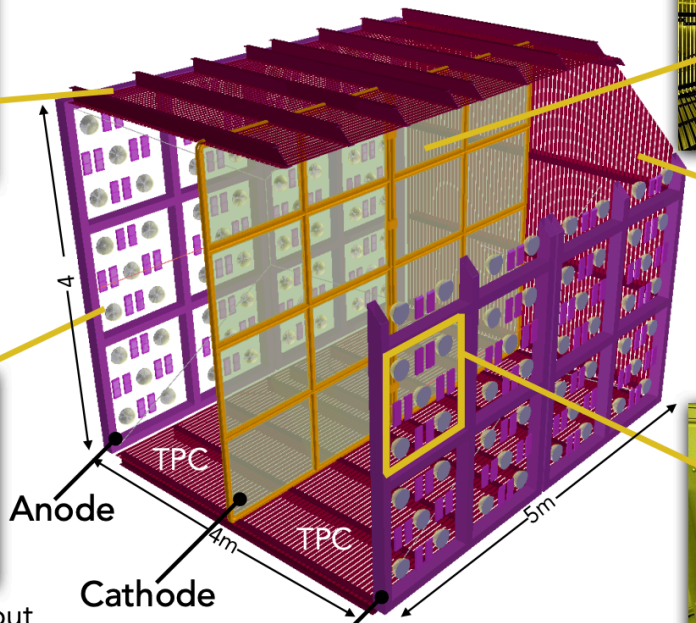
CPA - Cathode covered with TPB coated reflectors

Field Cage





APA - wire planes - 3 readout planes, ~11000 wires



Photon Detection Systems: 120 PMTs, 192 X-Arapucas

Detector components: Brazil, UK, Switzerland and US (NSF and DOE) Institutions
Cryostat and Cryogenics: CERN and FNAL (DOE)
Building and Infrastructures: FNAL (DOE)
Assembly and Installation: FNAL (DOE) and Collaboration Institutions

Credit - O. Palamara

First Data Analyses

L. Tung - ν_e CC inclusive

- 15k events produced/yr
- High stats cross section, important to understand intrinsic ν_e

M. Jung Jung - ν_μ CC $0\pi 1p$

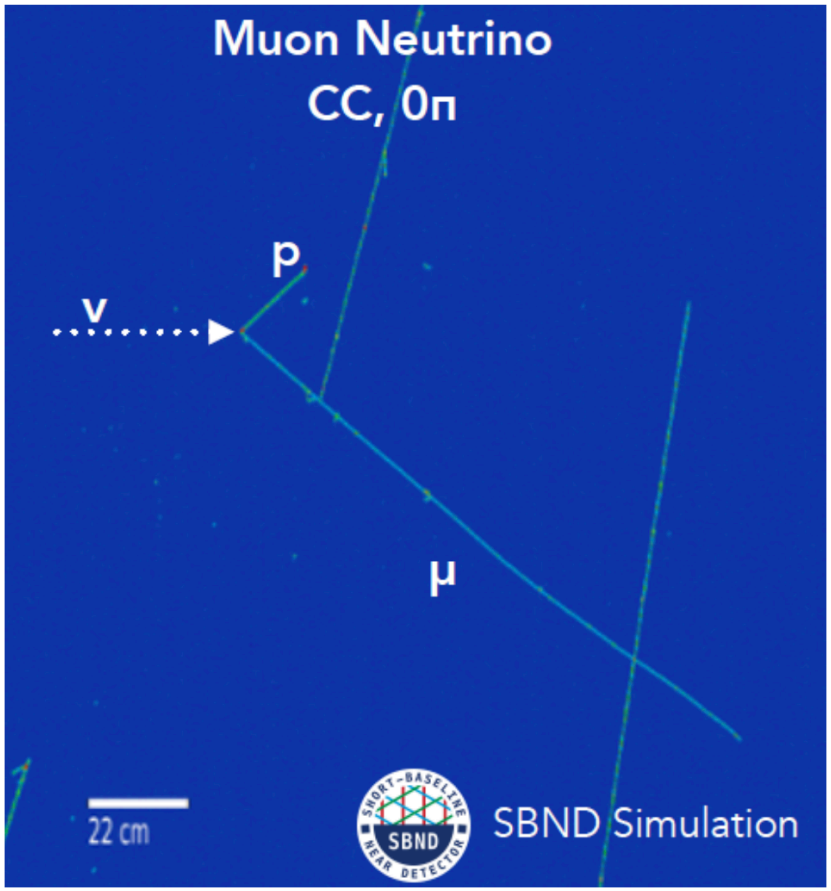
- 1.5m events produced/yr
- QE-like selection
- Explore nuclear effects using transverse kinematic imbalance (TKI) variables

B. Carlson - ν_μ CC inclusive

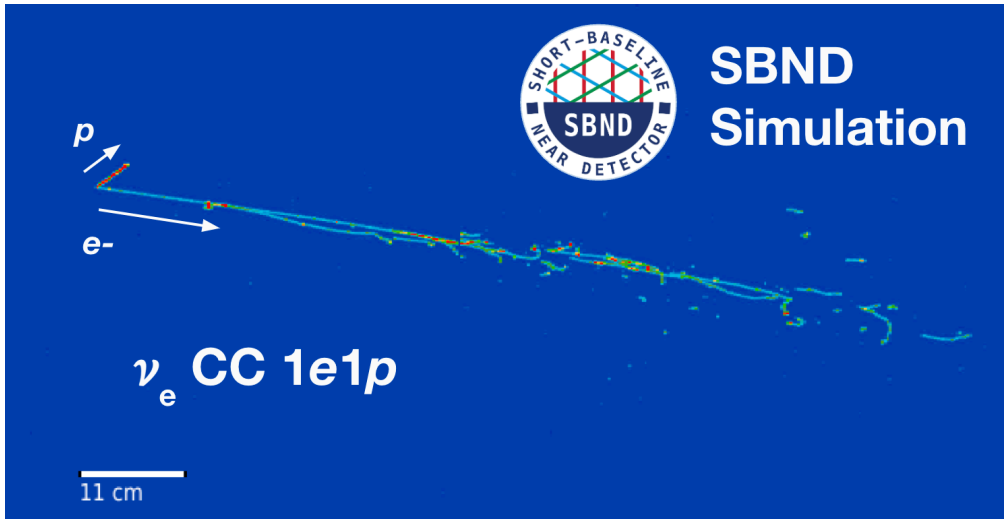
- 2m events produced/yr
- Benchmark detector performance, flux studies, neutrino-nucleus interaction model comparisons, least impacted by nuclear effects

Event Displays





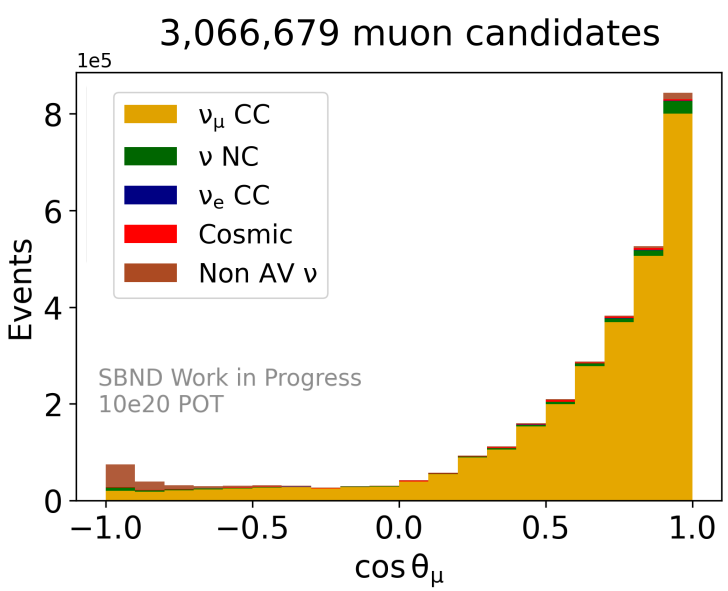
- Tracks - continuous
  - **muon, proton, pion**
- Showers - sparse and broad fragments
  - **electron, photon** (after pair producing)

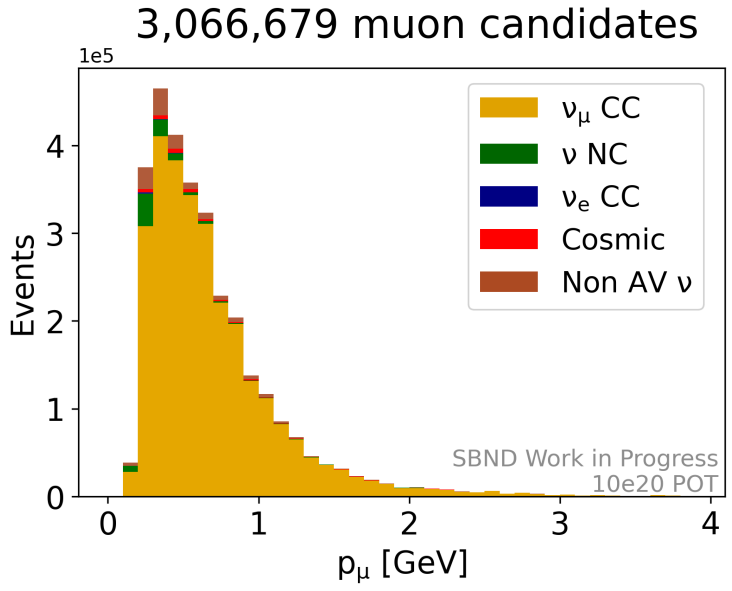


ν_μ CC Inclusive

- Efficiency is **50%** ν_μ CC events with **92%** purity (work in progress)

- Plenty of stats for a single or double differential cross section measurement





ν_e CC Inclusive

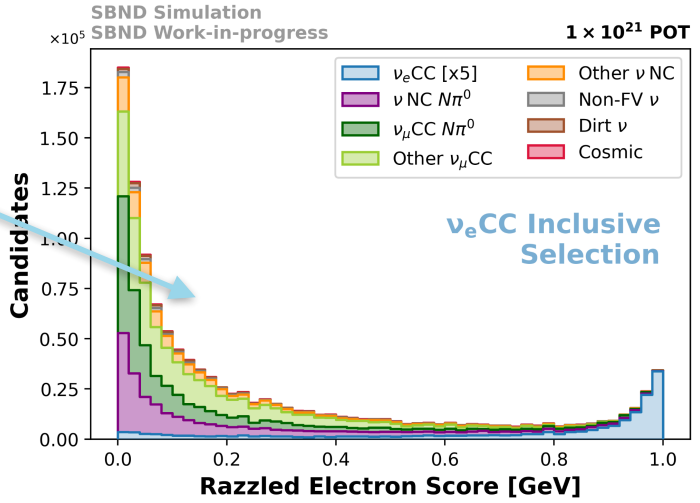
- Current efficiency **30.7%** ν_e CC events with **72.3%** purity
- Will select **13.5k** ν_e CC events for 1e21 POT
- Utilize CRUMBS BDT [1] to reject cosmics
- PID BDT [2] used to identify particle type

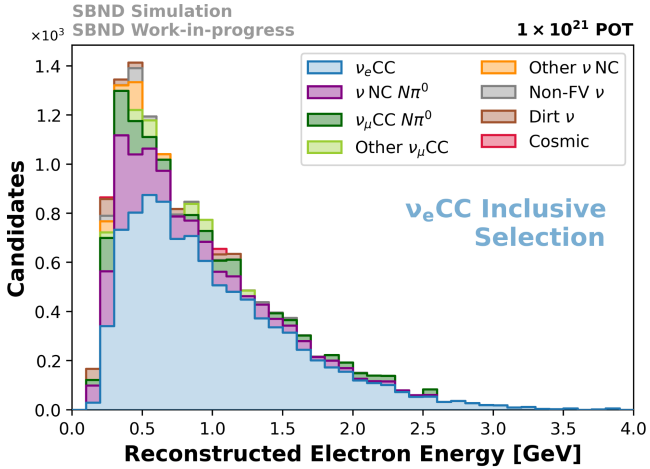
Pre-Selection
- reconstructed vertex within the FV + nu slice
- *primary shower energy must be at least **50 MeV***
- primary shower contained (end < 5 cm of edges)

Cosmic Removal
- use **CRUMBS** (cosmic removal BDT by Henry) to remove slices associated with cosmic rays

Muon Removal
- all tracks must be contained
- use Razzled (PID for tracks+showers BDT) to remove any slices with a muon

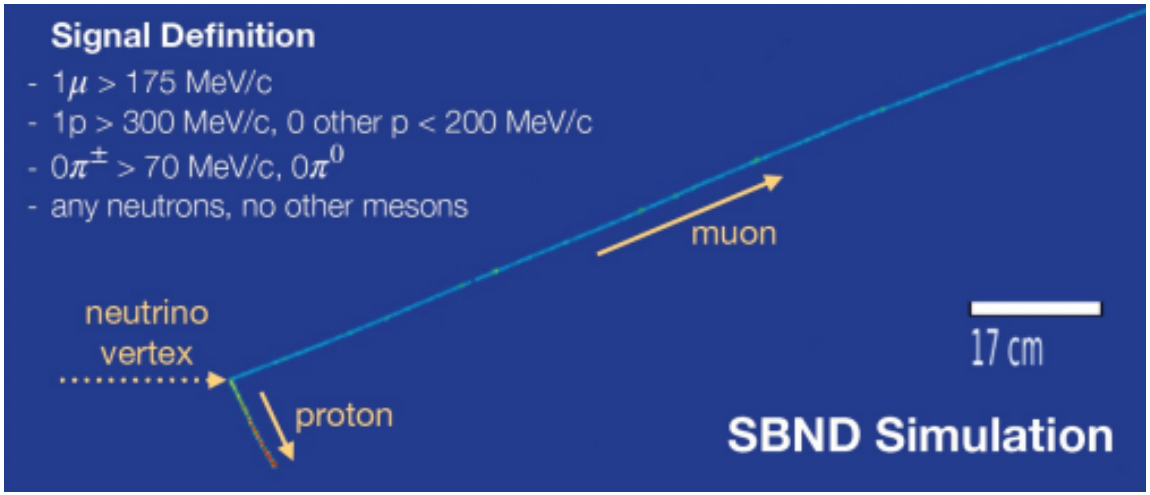
Electron Selection
- use Razzled electron score to select slices where the primary shower is an electron

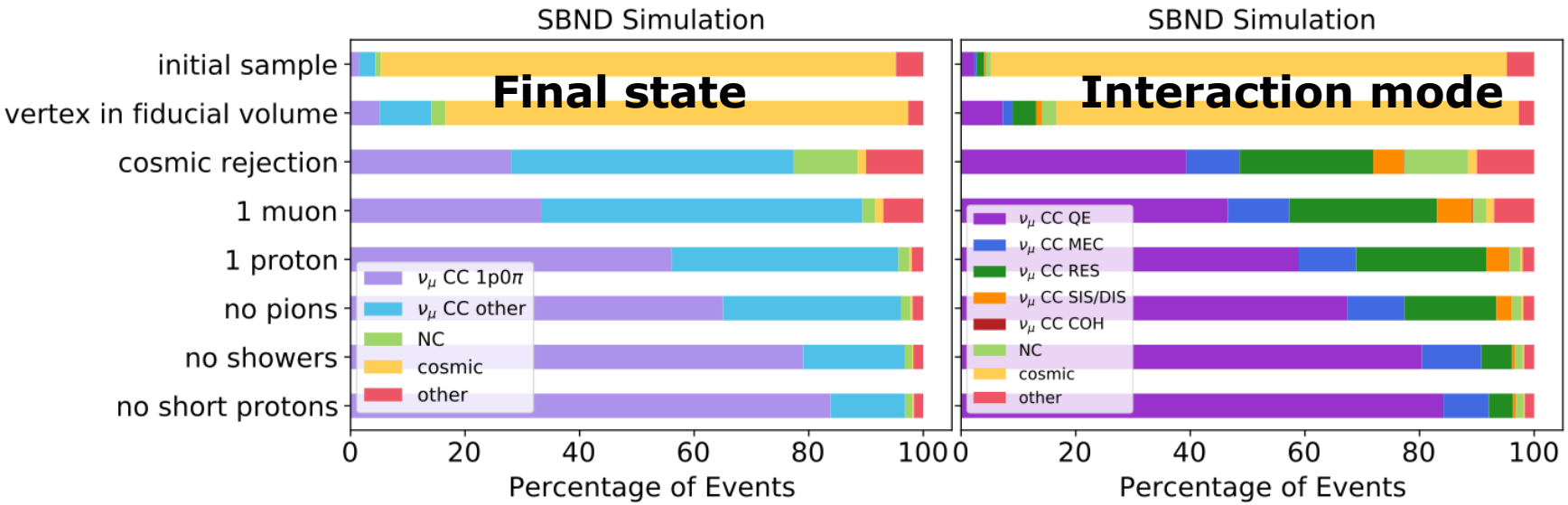




[1] H. Lay, APS April Meeting 2023
[2] E. Tyley, IOP 2021

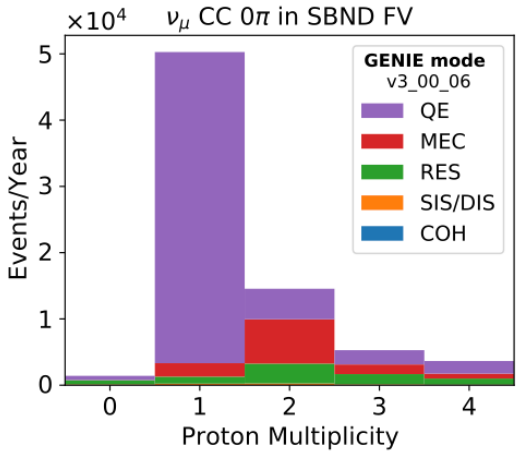
ν_μ CC $0\pi 1p$

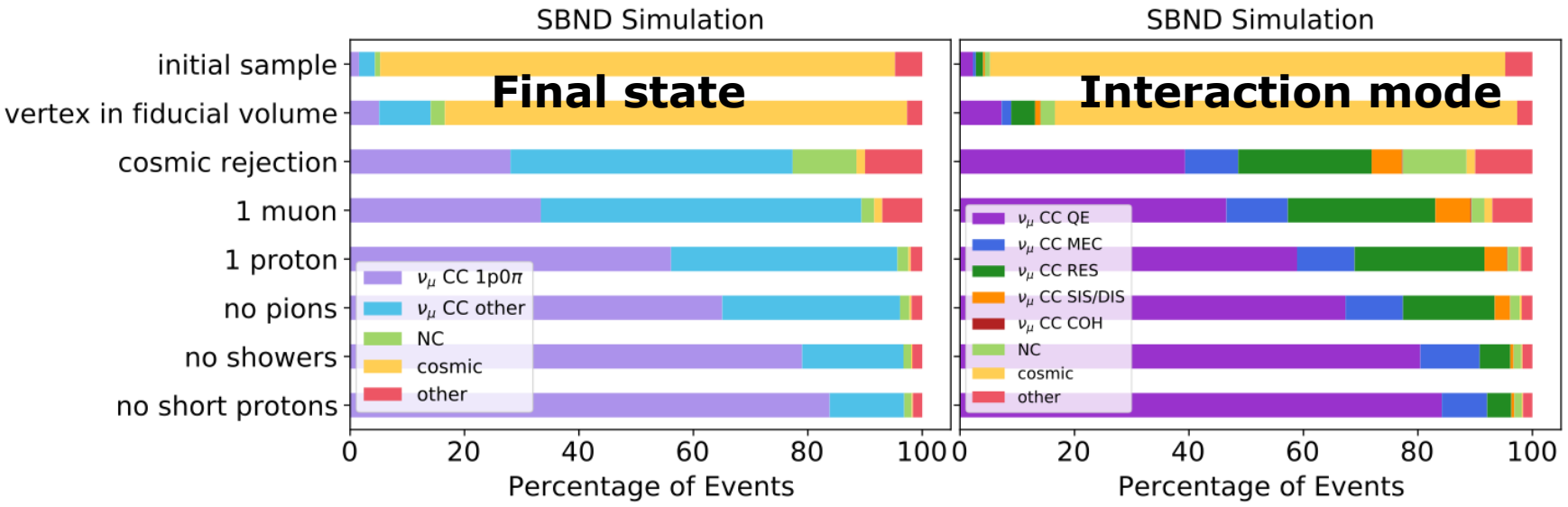




ν_μ CC 0π1p

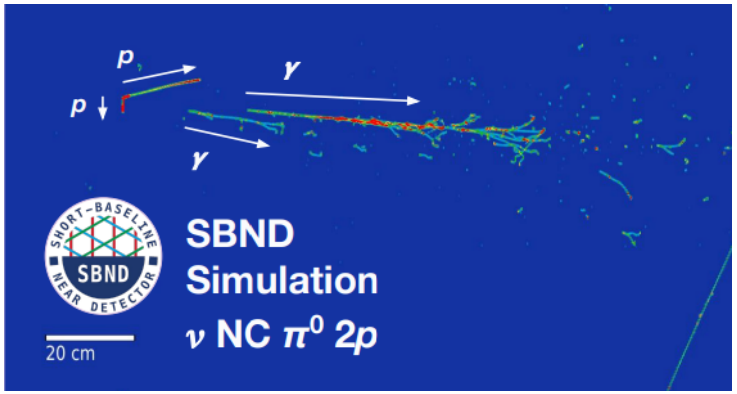
- 0π selection targets QE-like interactions (dominant interaction mode)
- Current efficiency **38%** events, over **600k** for 1e21 POT
- Proton identification can enhance QE-like interactions





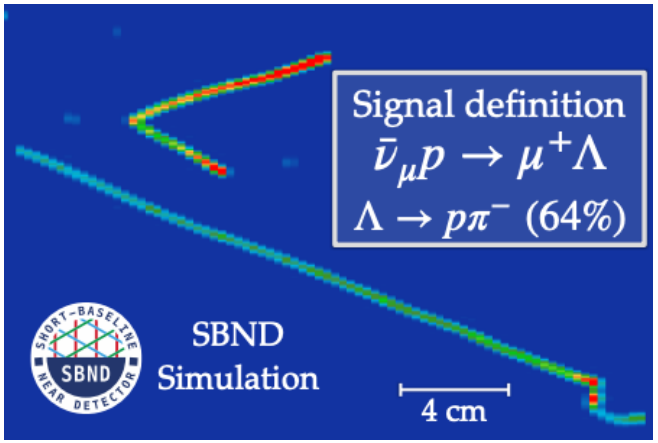
Future Analyses

H. Lay - NCπ^0

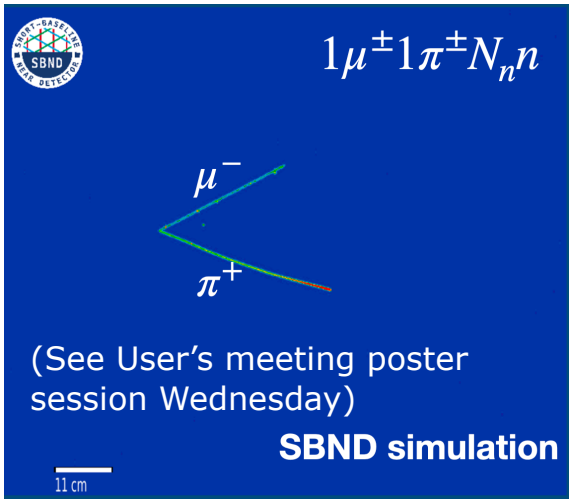


Many more analyses on the horizon!

F. Nicolas - **Hyperon**



L. Pelegrina Gutiérrez - ν_μCC $\pi^\pm$



Conclusion

- SBND is able to successfully select various neutrino channels to perform cross section analyses
- The high stats of SBND will allow us to search exclusive and low intensity channels
- LArTPCs enable good calorimetry with fine spatial resolution
- SBND is powered up to **100 kV** as of **July 3, 2024**
- Stay tuned for future SBND cross section analyses!
  - **L. Tung** - ν_e CC inclusive
  - **M. Jung Jung** - ν_μ CC 0π
  - **B. Carlson** - ν_μ CC inclusive
  - **H. Lay** - NC π^0
  - **L. Pelegrina** - ν_μ CC $\pi^\pm$
  - **F. Nicolas** - Hyperon

Thanks!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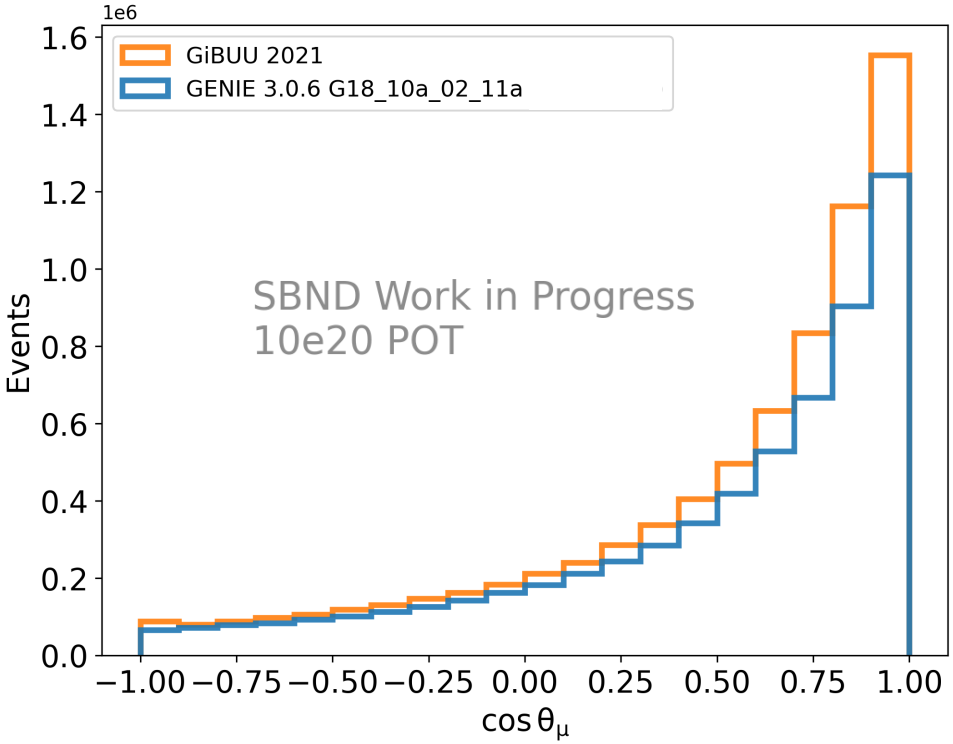
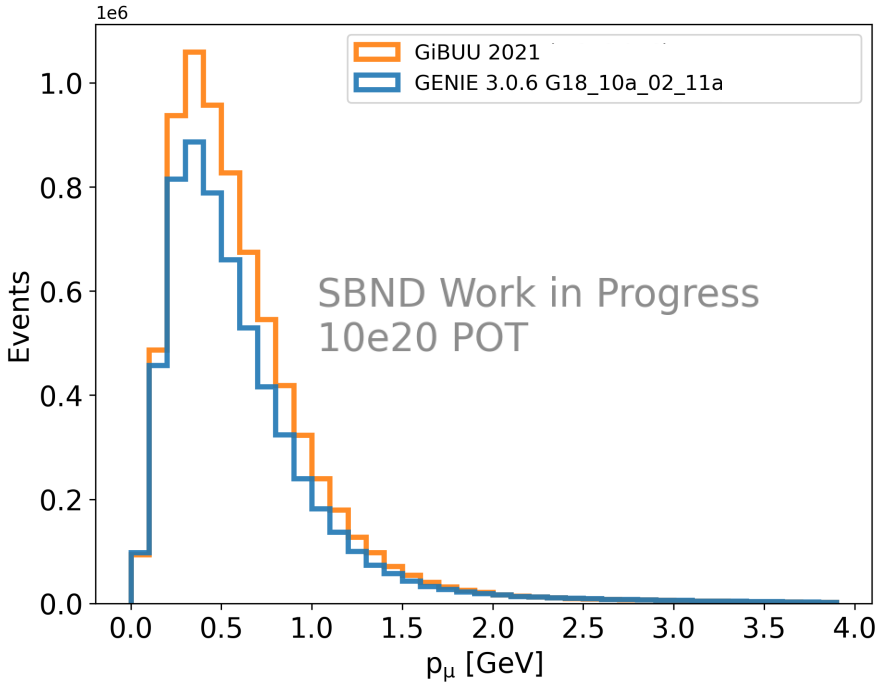
QUEEN

ν_μ CC Inclusive

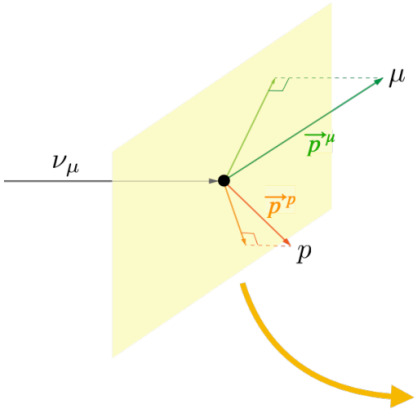
- Measure lepton kinematics from resulting CC interactions
- GiBUU (orange) and GENIE (blue) generators predict differing event rates and shapes
- Differing QE modeling largely drives these differences

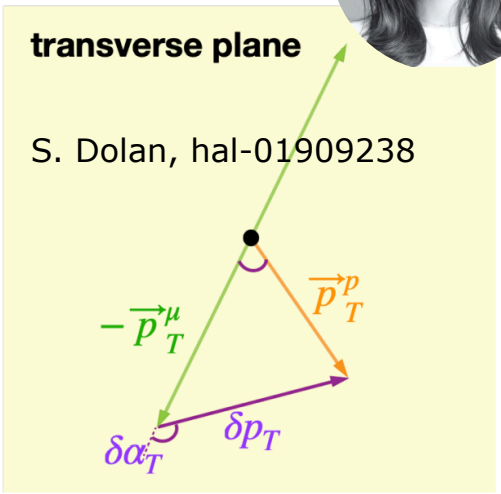




ν_μ CC 0π1p

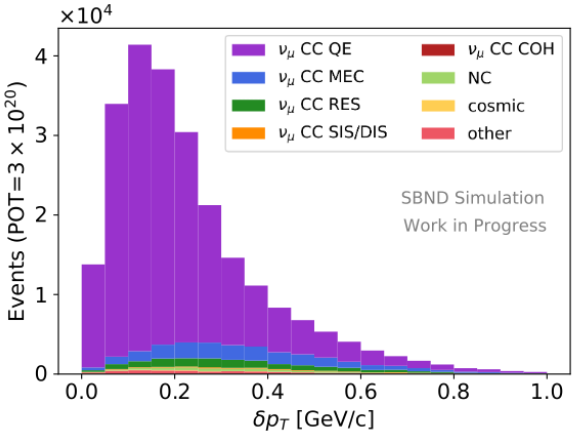
- Differential variables δp_T, $\delta \alpha_T$, $\delta \phi_T$ further probe **nuclear effects**
- Can perform differential cross sections in these variables or use them to further isolate QE-like events
- Used to study final state interactions, nucleon-nucleon correlations, and fermi motion

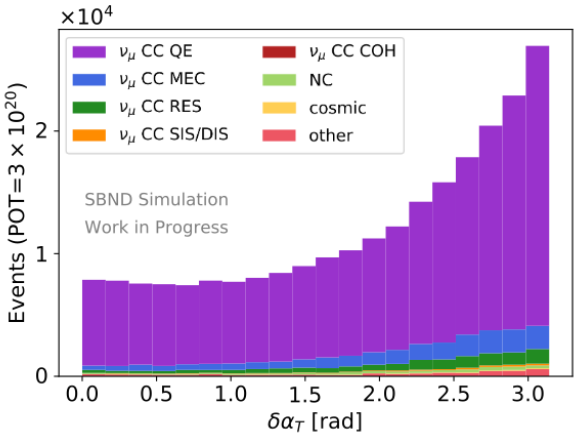


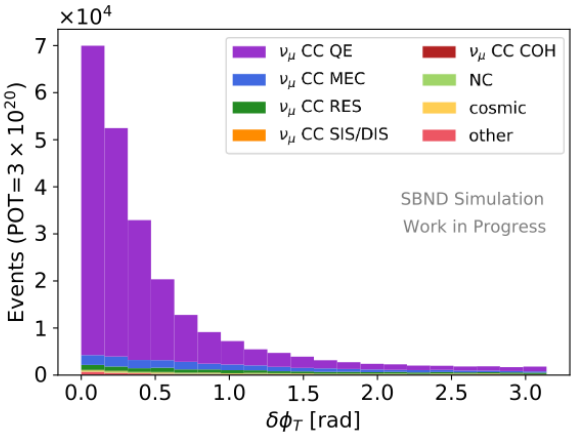


$$\delta p_T = |\vec{p}^{\,\mu}_T + \vec{p}^{\,p}_T|$$

$$\delta\phi_T = \cos^{-1}\left(\frac{-\vec{p}^{\,\mu}_T \cdot \vec{p}^{\,p}_T}{|\vec{p}^{\,\mu}_T||\vec{p}^{\,p}_T|}\right) \qquad \delta\alpha_T = \cos^{-1}\left(\frac{-\vec{p}^{\,\mu}_T \cdot \delta\vec{p}_T}{|\vec{p}^{\,\mu}_T||\delta\vec{p}_T|}\right)$$







ν_μ CC Inclusive