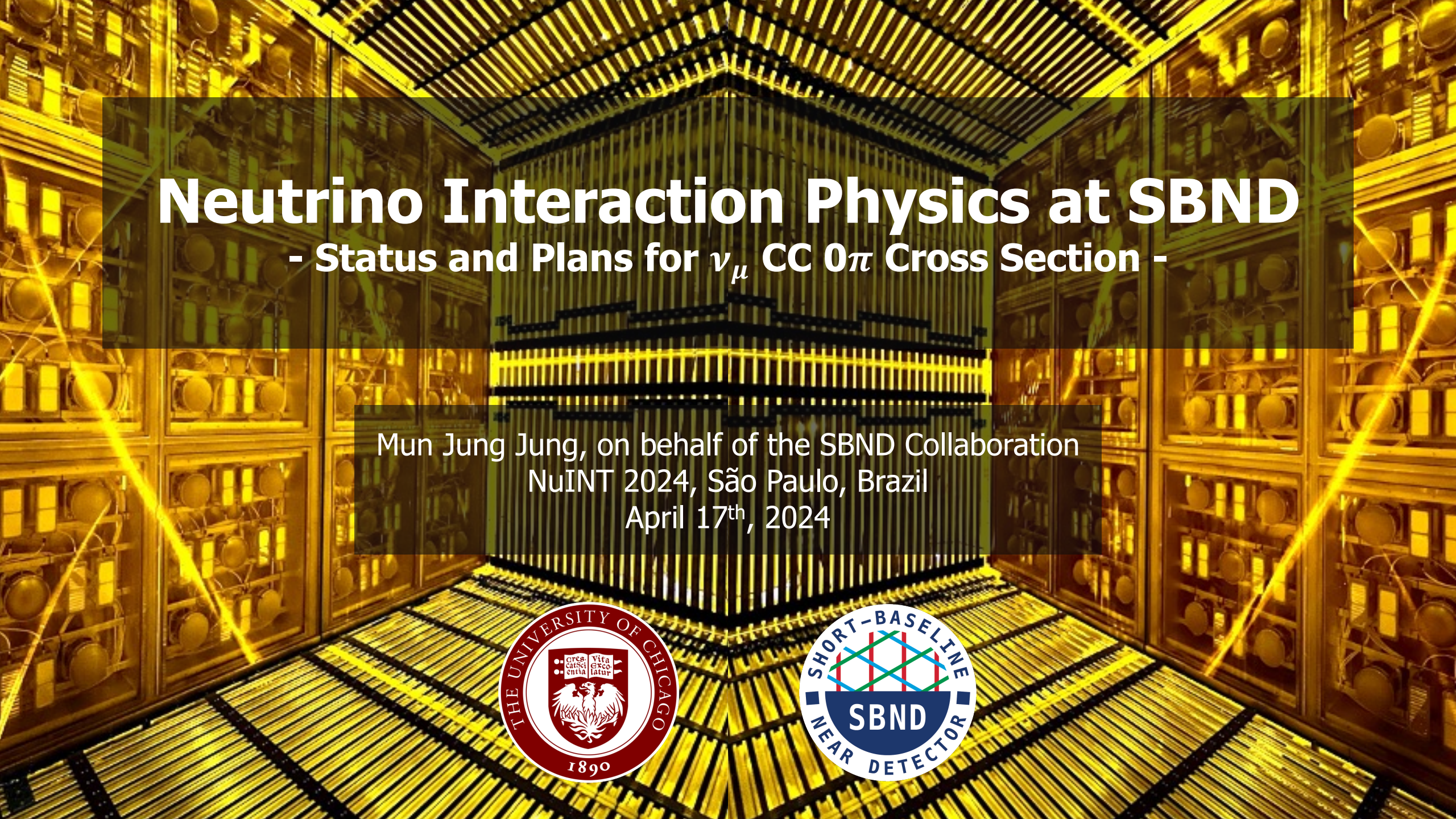


Neutrino Interaction Physics at SBND

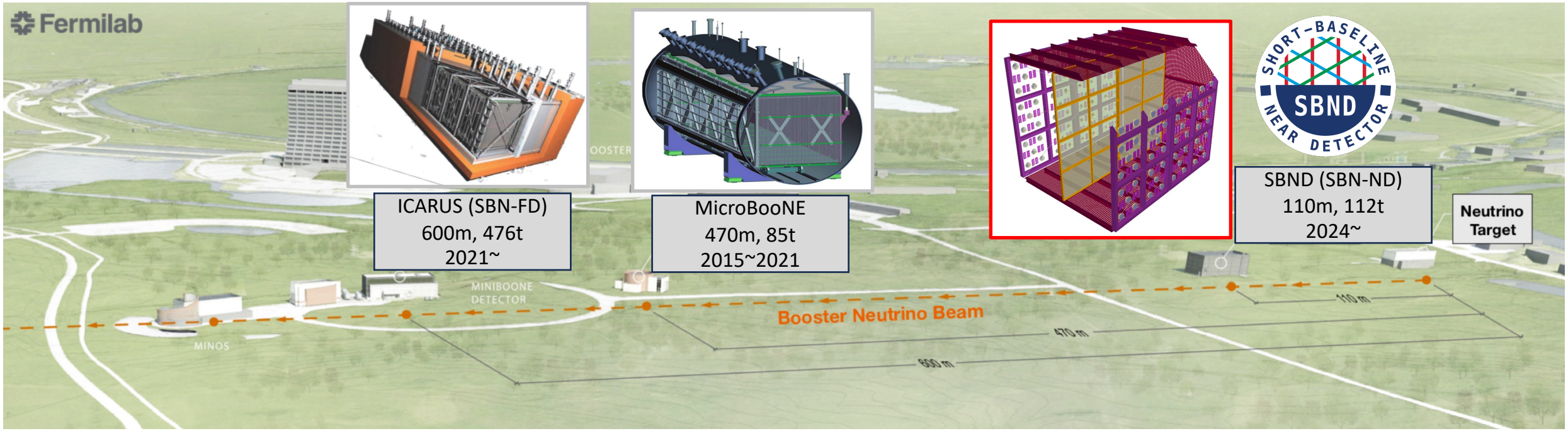
- Status and Plans for ν_μ CC 0π Cross Section -

Mun Jung Jung, on behalf of the SBND Collaboration

NuINT 2024, São Paulo, Brazil

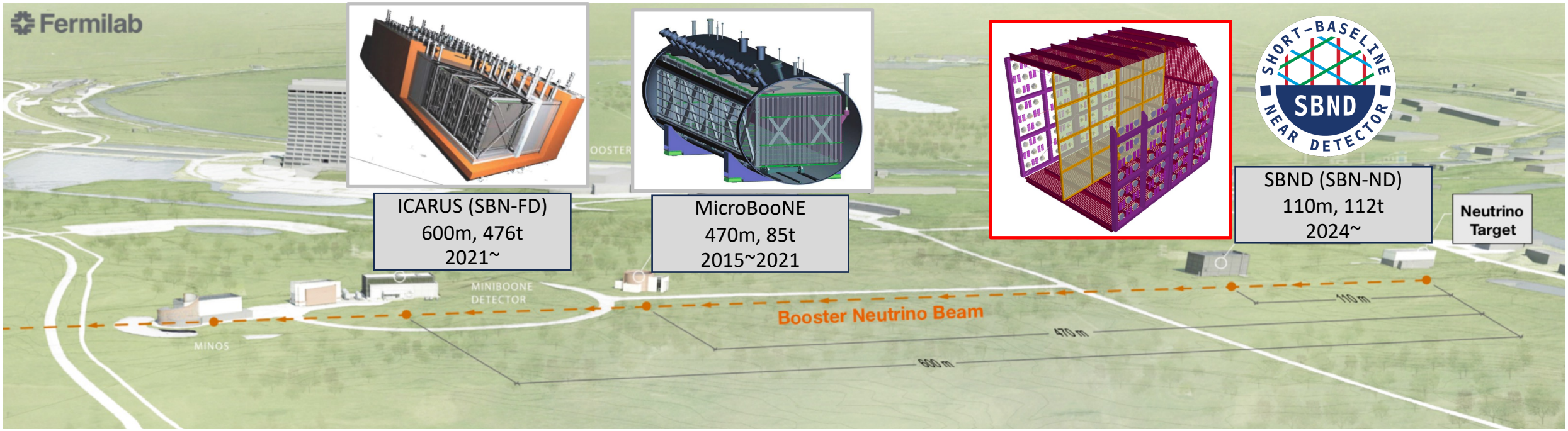
April 17th, 2024

The Short-Baseline Near Detector (SBND)



- SBND physics goals
  - measure neutrino-argon interaction cross sections at the few GeV neutrino energy range
  - contribute to oscillation analyses as part of the SBN program
  - search for new physics and study rare processes

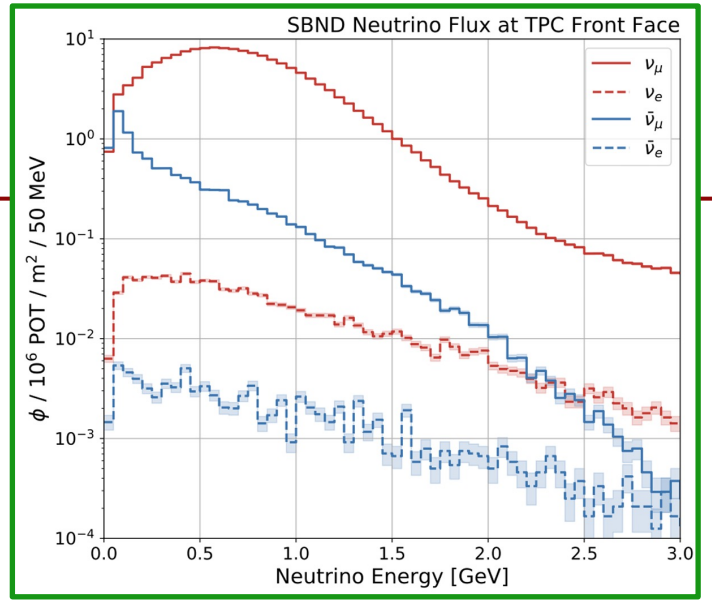
The Short-Baseline Near Detector (SBND)

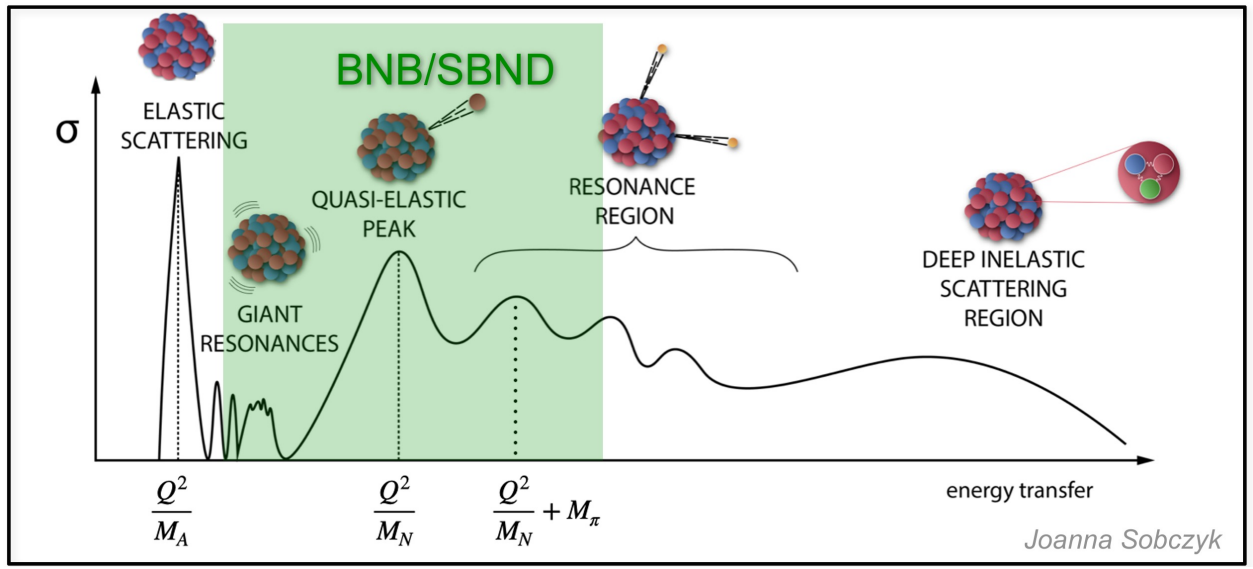


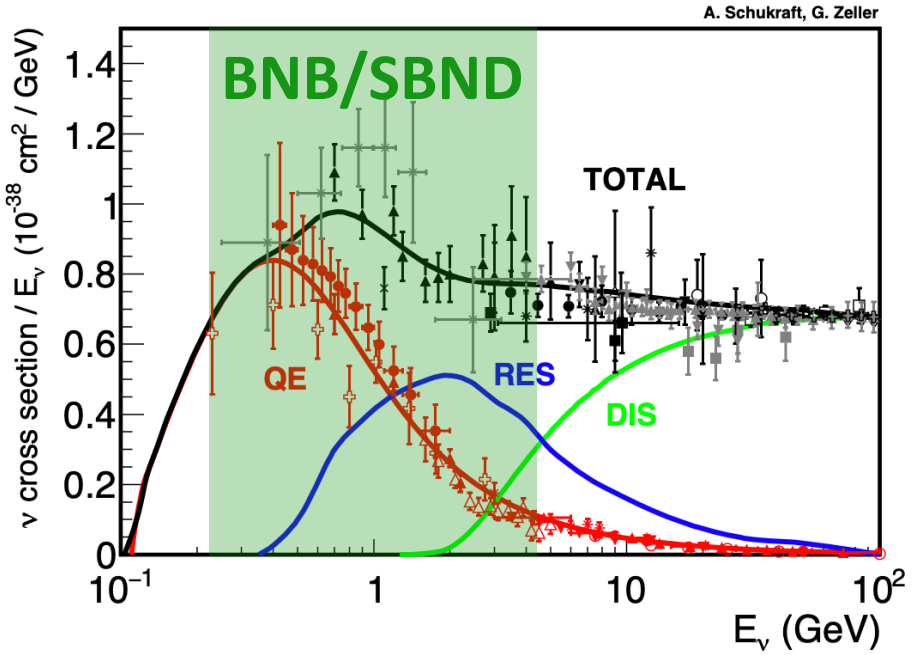
- SBND physics goals
  - measure neutrino-argon interaction cross sections at the few GeV neutrino energy range
    - contribute to oscillation analyses as part of the SBN program
    - search for new physics and study rare processes

Neutrino Interactions at SBND

- SBND covers a critical energy region in advancing our understanding of neutrino-nucleus interactions
  - Neutrino scattering on heavy targets like argon at the few-GeV neutrino energy range is complex

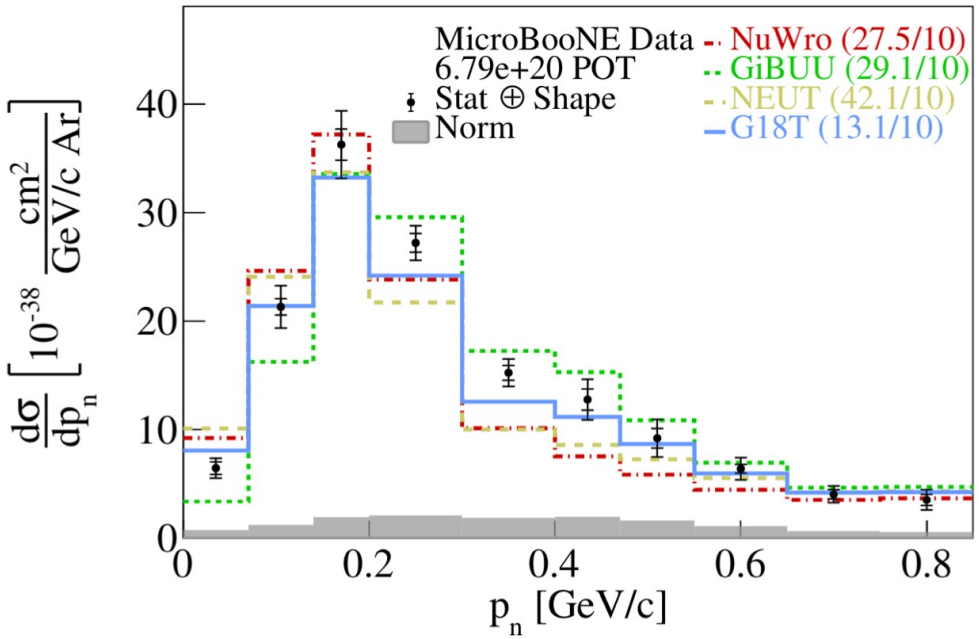




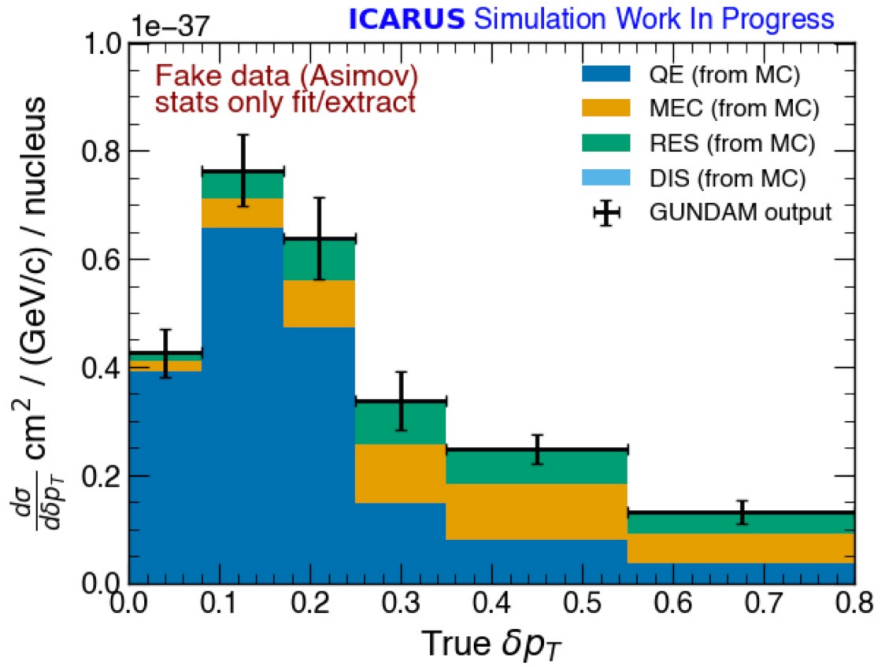


SBN ν_μ CC 0π Measurements

- Multiple neutrino-nucleus interaction measurements highlighted in previous talks
- SBND has unique capabilities to address the current challenges and decrease the statistical and systematic uncertainties on measurements



see Andrew Furmanski's talk earlier in this session

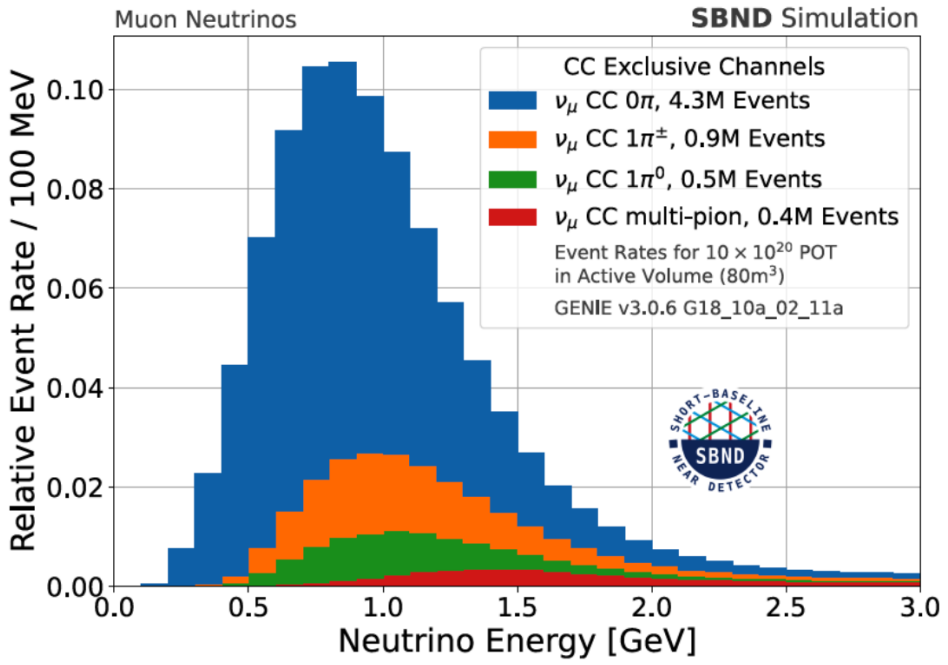


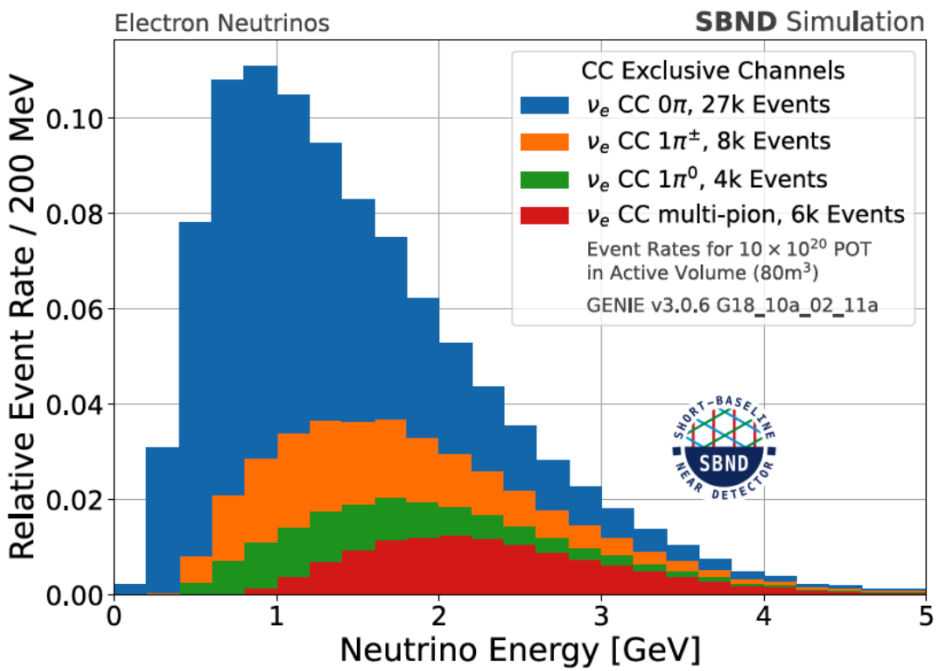
see Minerba Betancourt's talk earlier in this session

Capabilities of SBND

1. High-Statistics Dataset

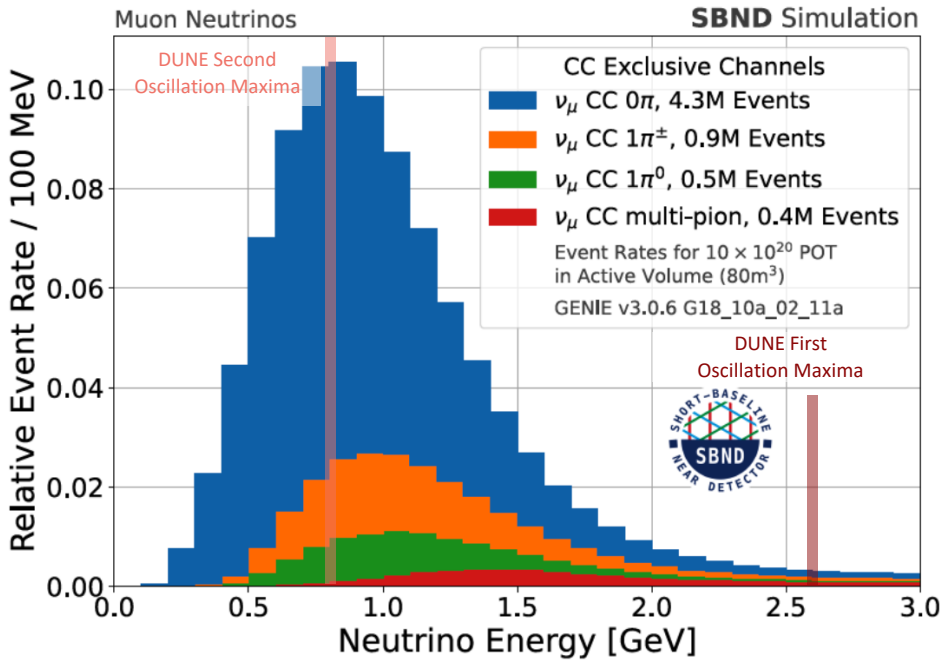
- SBND will collect the world's largest neutrino-argon interaction dataset
  - over 7000 neutrino interactions per day, 10-20 times more neutrino-argon scattering data than what is currently available over the lifetime of SBND
  - enable thorough investigation of the more dominant channels, as well as studies of rare processes
  - Will provide the neutrino theory/generator community and future experiments with essential input

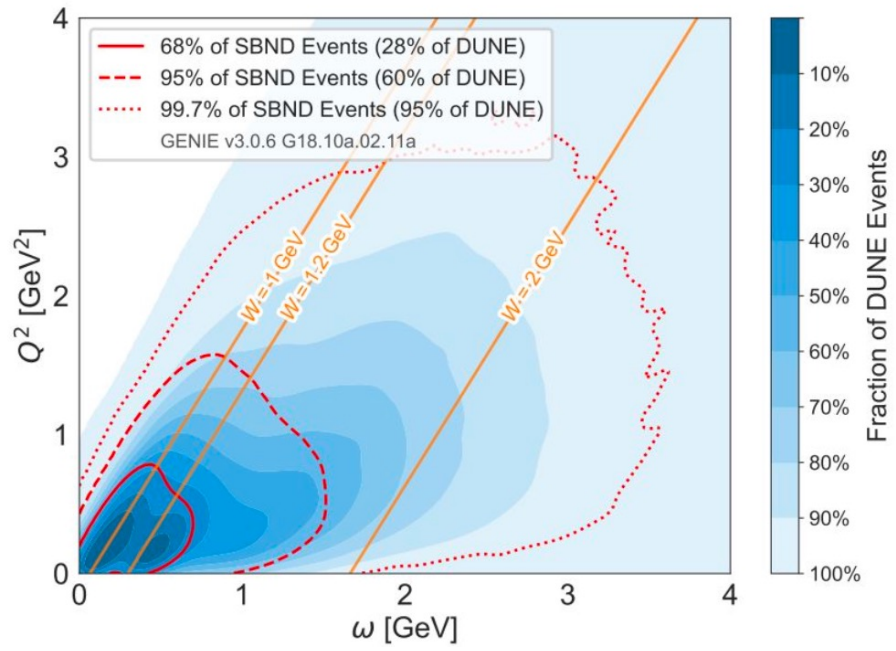




1. High-Statistics Dataset

- SBND interaction phase space has large overlap with the DUNE phase space
  - spans both first and second oscillation maxima
  - covers 95% of DUNE phase space with very high statistics

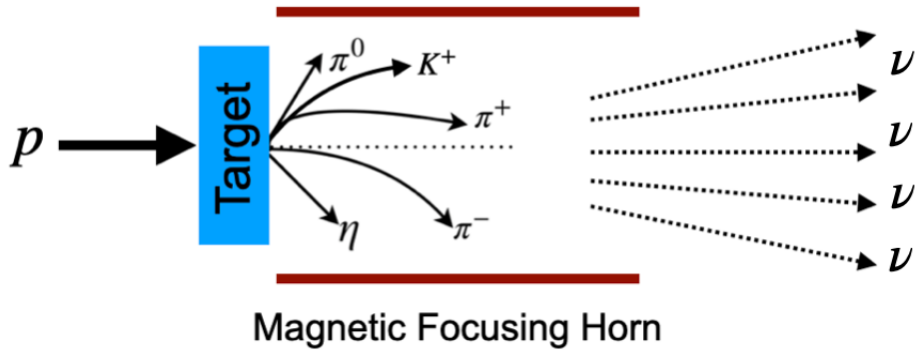




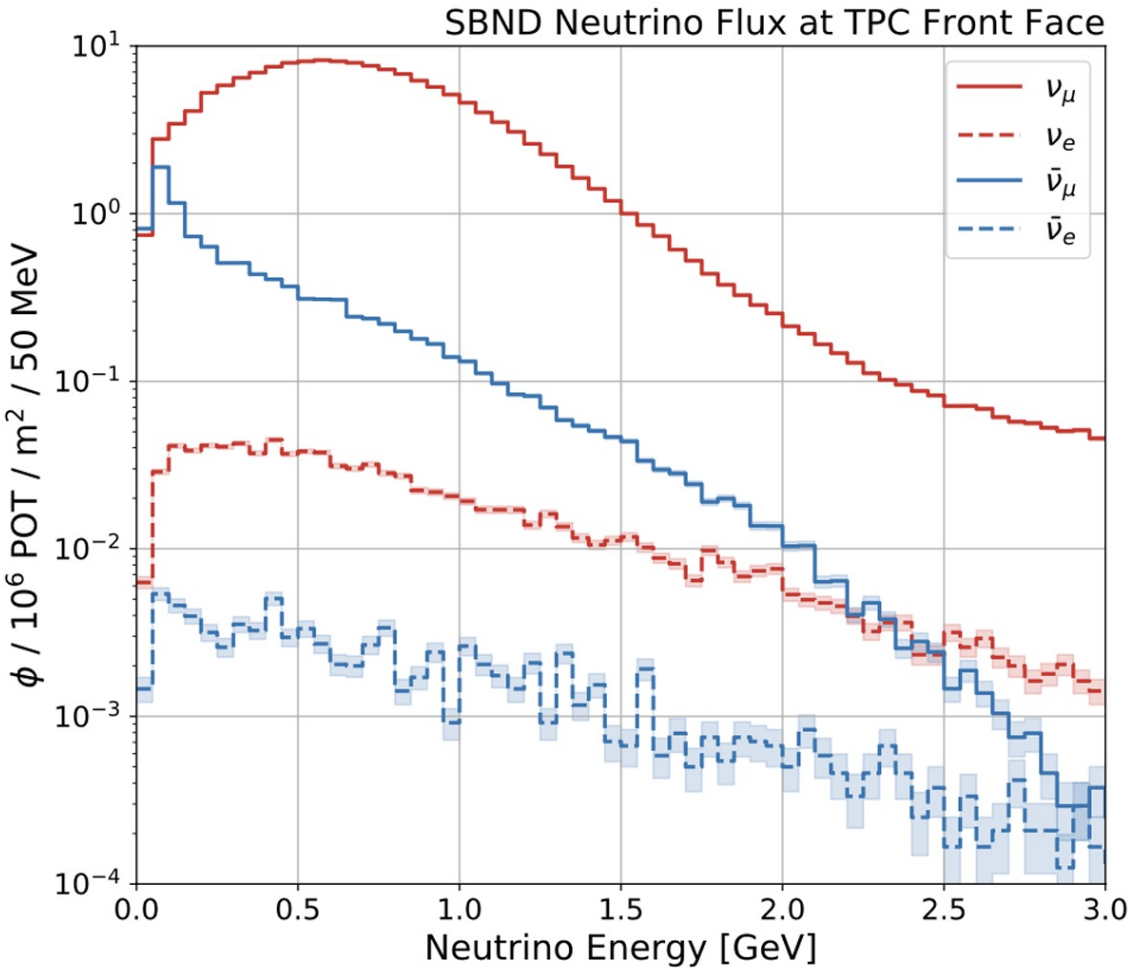
2. Off-axis Flux Effect (SBND-PRISM)

- Booster Neutrino Beam (BNB)
  - 8GeV proton on beryllium target
  - mean neutrino energy ~800 MeV
- Beam composition
  - 93.6% υ_μ
  - 5.9% $\overline{\upsilon_\mu}$
  - 0.5% $\upsilon_e + \overline{\upsilon_e}$

see Žarko Pavlović's talk for more on BNB

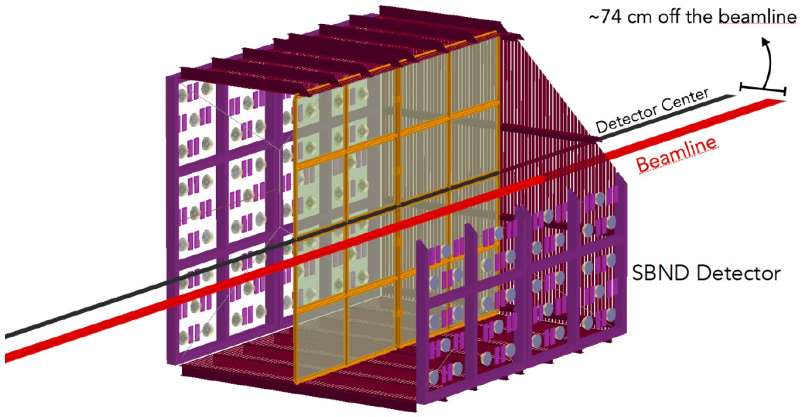


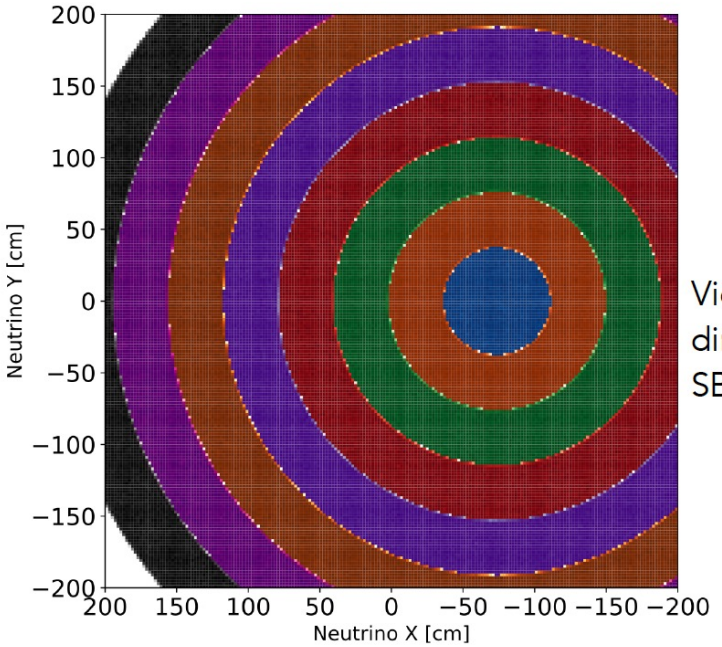
Magnetic Focusing Horn



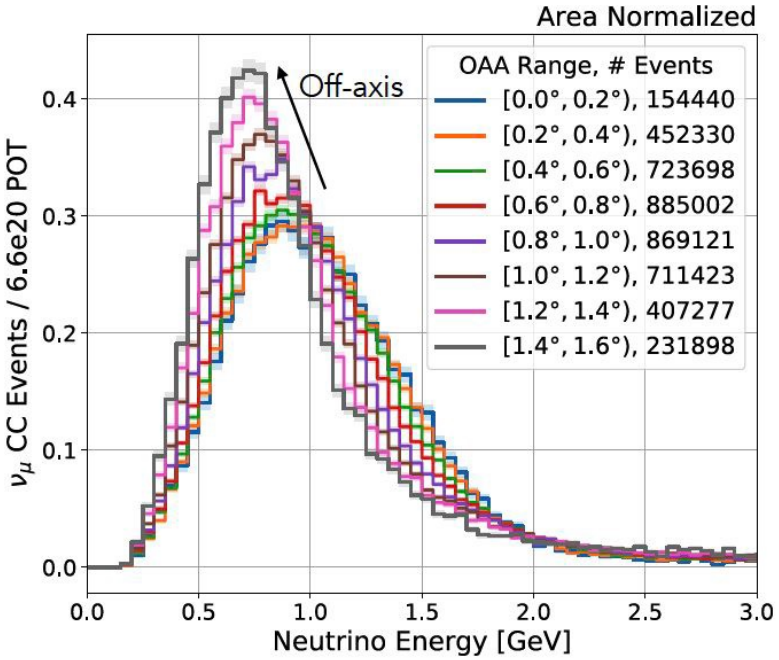
2. Off-axis Flux Effect (SBND-PRISM)

- Off-axis neutrino spectra differ from the on-axis spectrum
- SBND volume spans up to ~1.5 degrees off-axis
  - SBND is very close to the neutrino source, and sits slightly off-centered with respect to the BNB axis





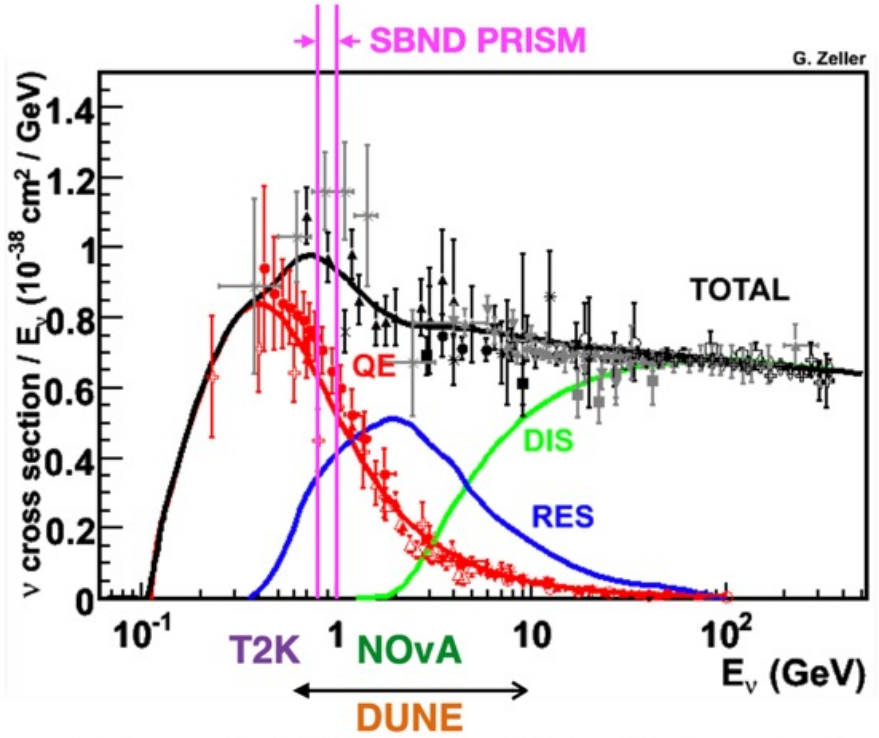
View from the beam direction
SBND Detector

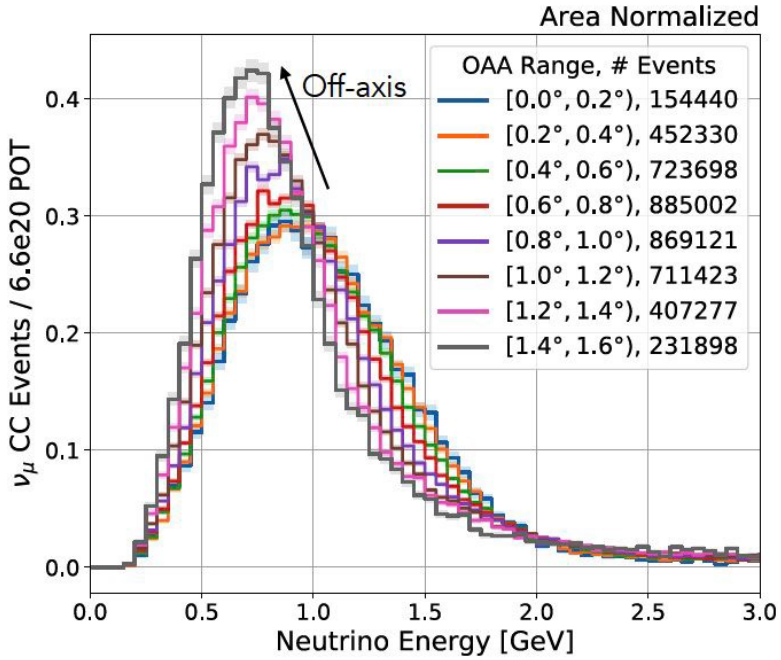


2. Off-axis Flux Effect (SBND-PRISM)

- Spectra peaks cover a narrow but interesting energy range
- Infer neutrino energy dependence by sampling different detector volumes
  - recent T2K analysis using both near detectors: Phys. Rev. D **108**, 112009
  - treat different volumes of SBND as different detectors

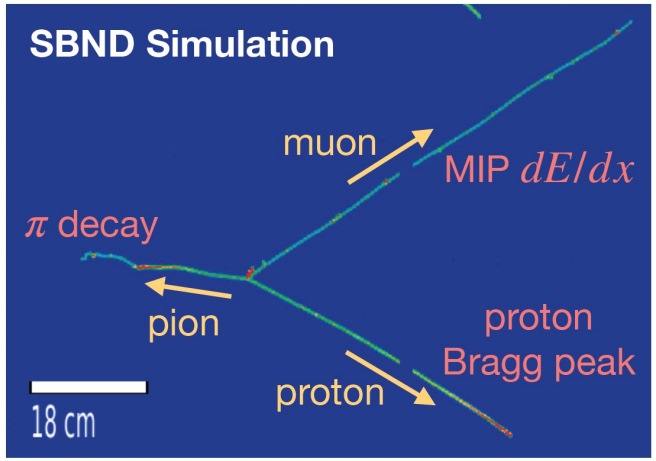
highlighted at Stephen Dolan's talk

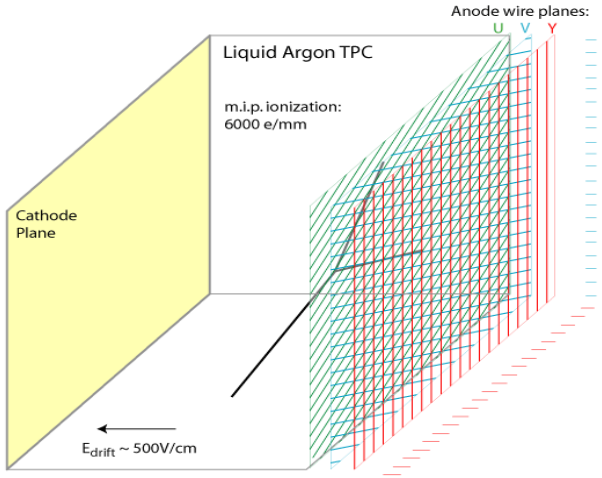


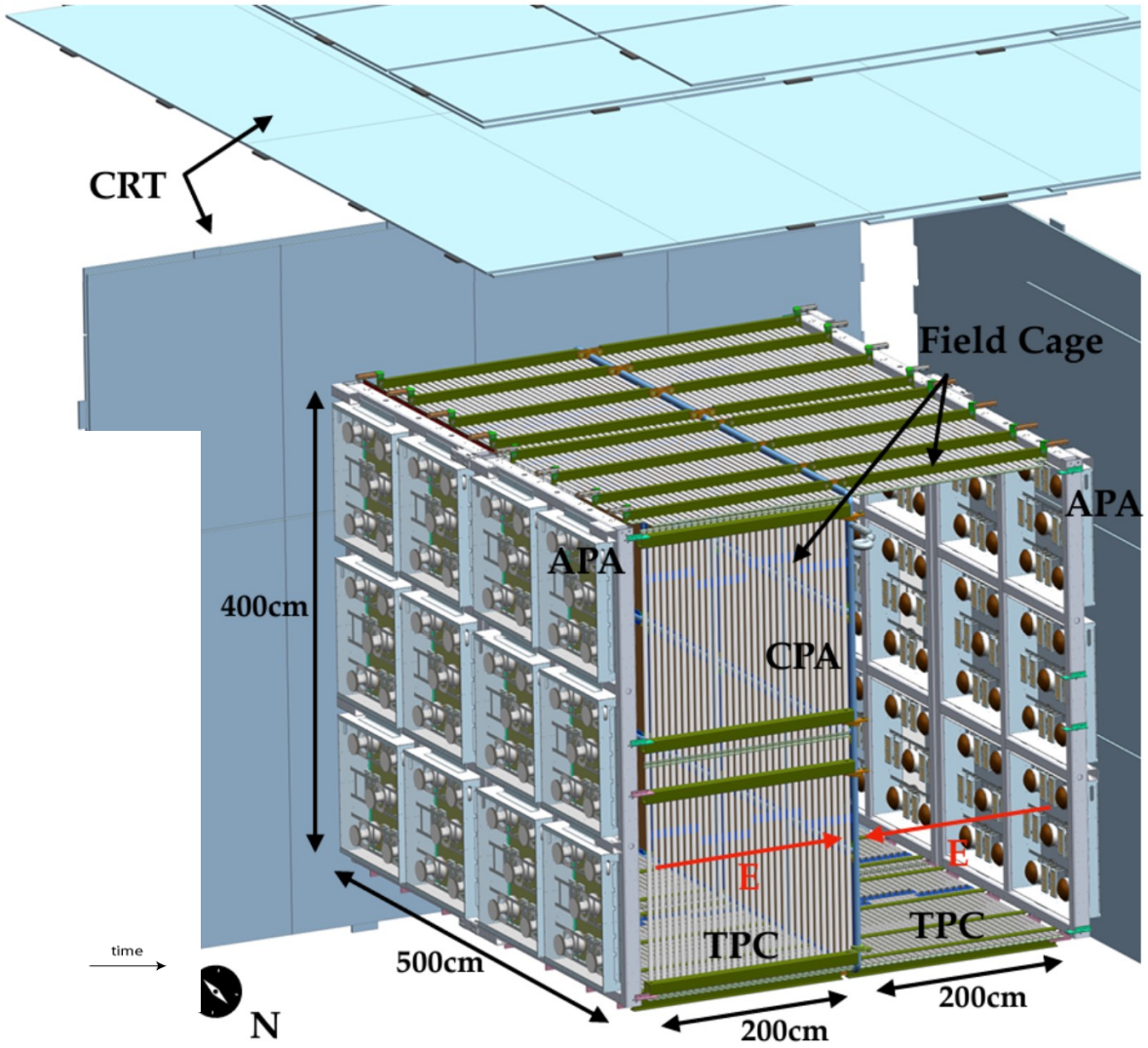


3. Detector Capabilities: TPC

- As fully active tracking calorimeters, LArTPCs enable detailed reconstruction of complicated neutrino interactions
  - resolve complicated final states with low reconstruction threshold
  - efficient particle identification

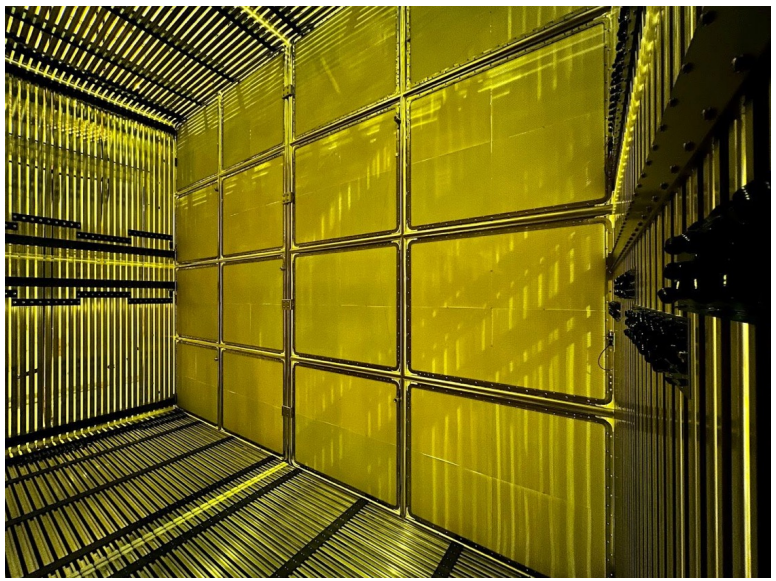


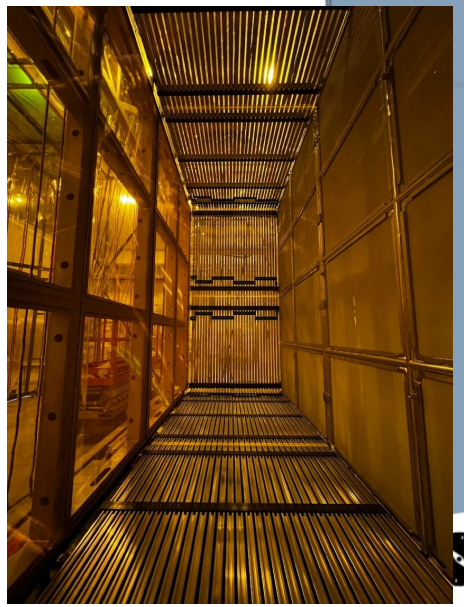


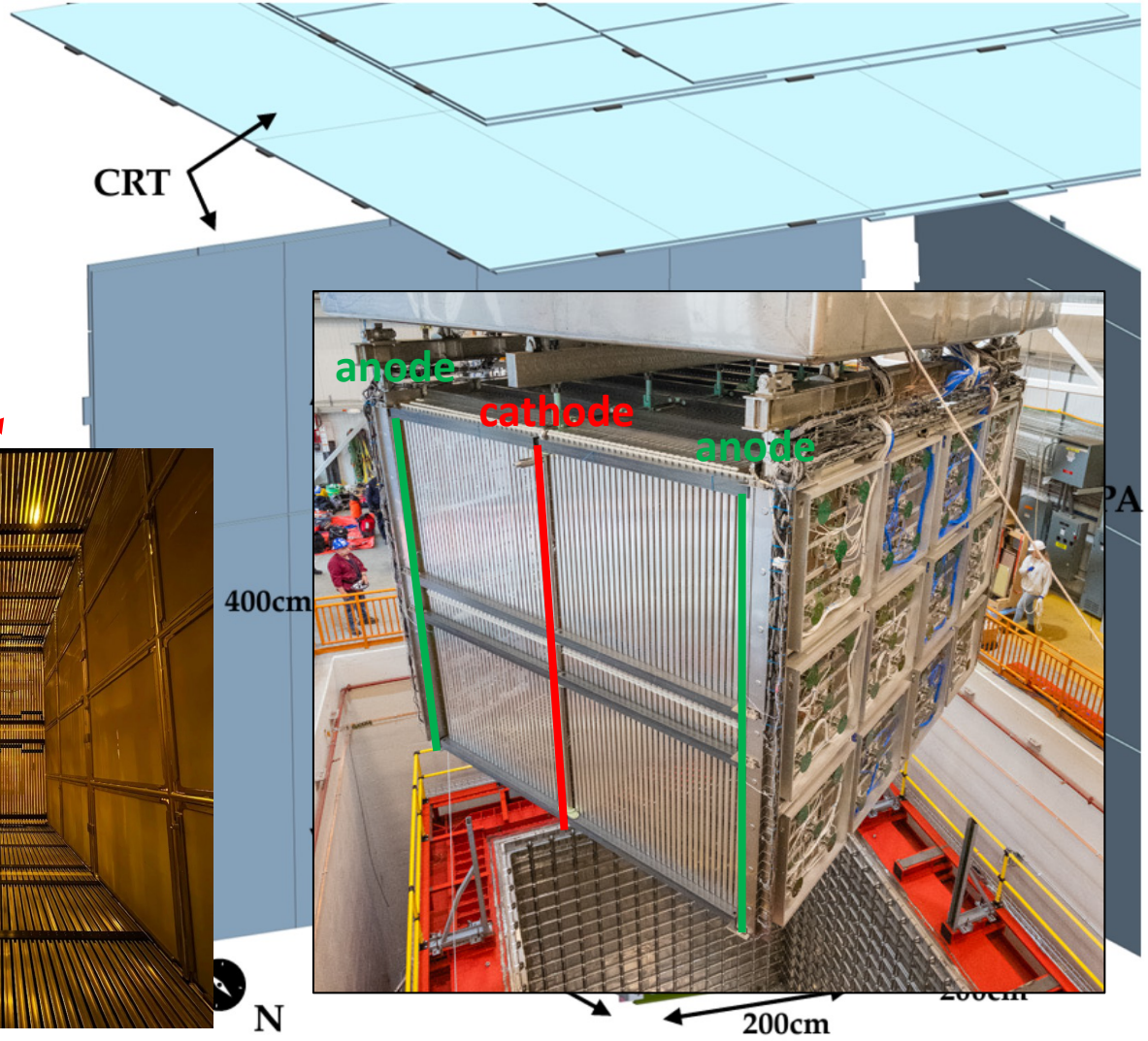


3. Detector Capabilities: TPC

- 2 TPCs with a shared central cathode and two anode readout planes
  - 3 wire planes, wire spacing 3mm
  - 500V/cm electric field provided by the shared central cathode and the field cage
  - TPB coated cathode panels shift light from VUV to visible range

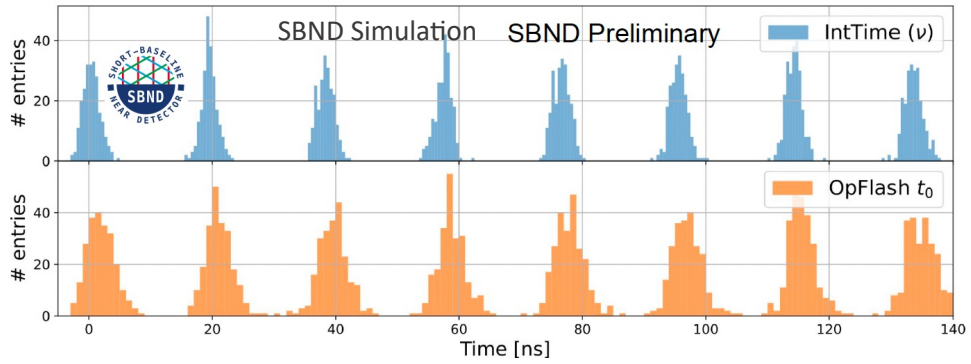


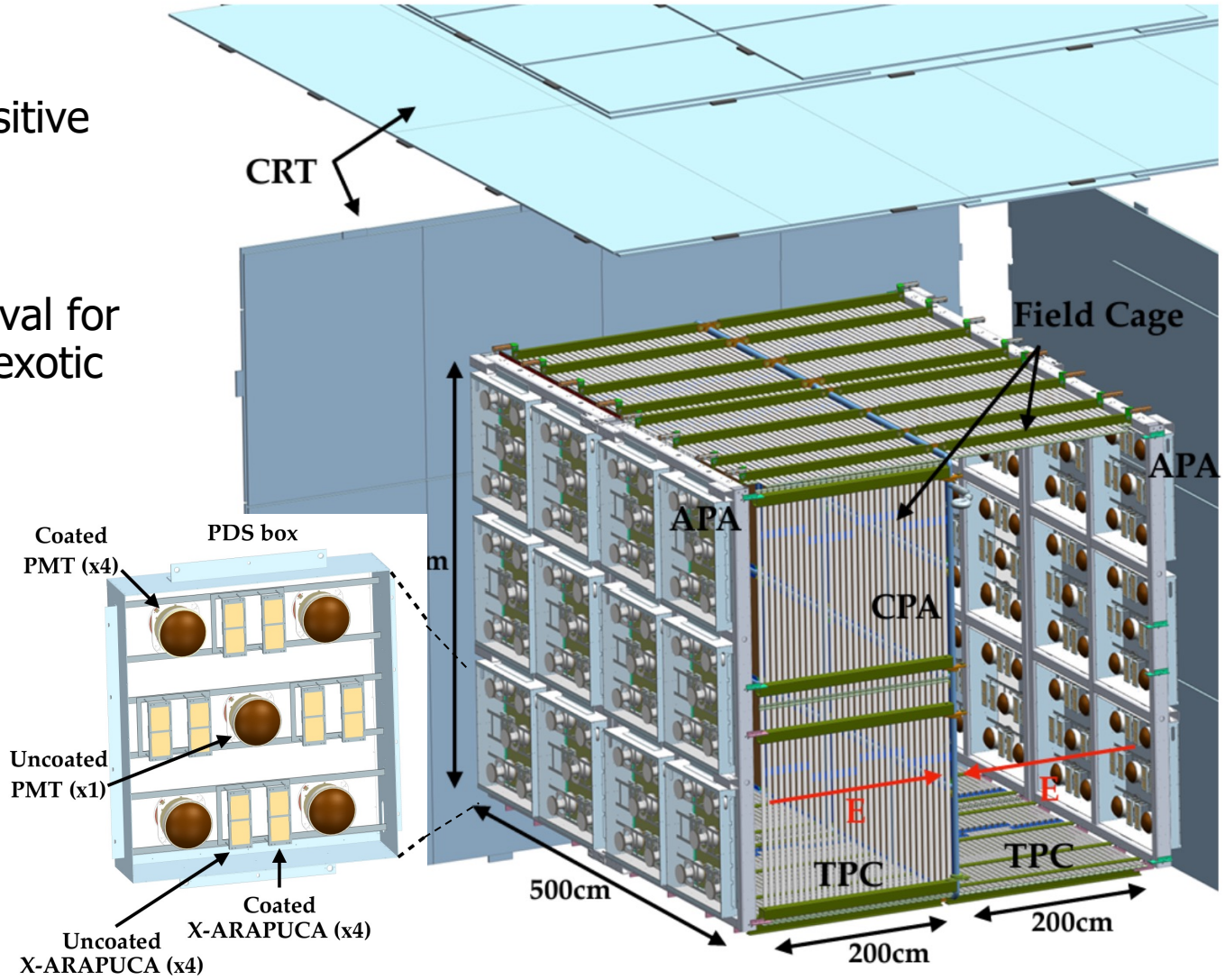




3. Detector Capabilities: PDS & CRT

- Photon detection system (PDS)
  - 312 total photon sensors: 120 PMTs (sensitive to both VUV and visible light) & 192 X-ARAPUCAs
  - ns timing resolution resolves the beam structure, providing efficient cosmic removal for neutrino analyses and beam removal for exotic searches
- Cosmic ray tagger (CRT)
  - 4π coverage to tag cosmic activity





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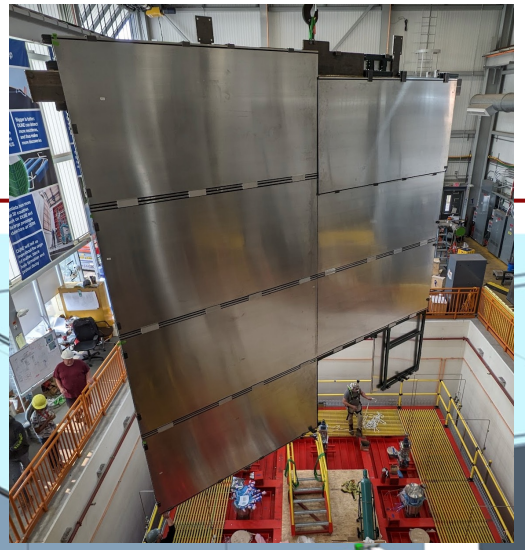
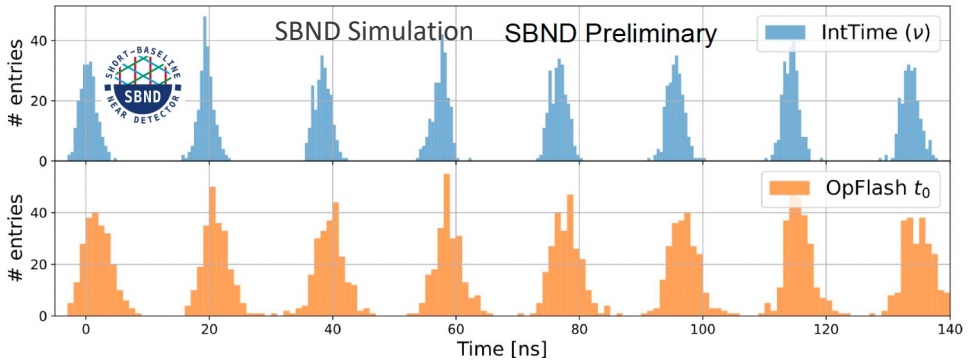
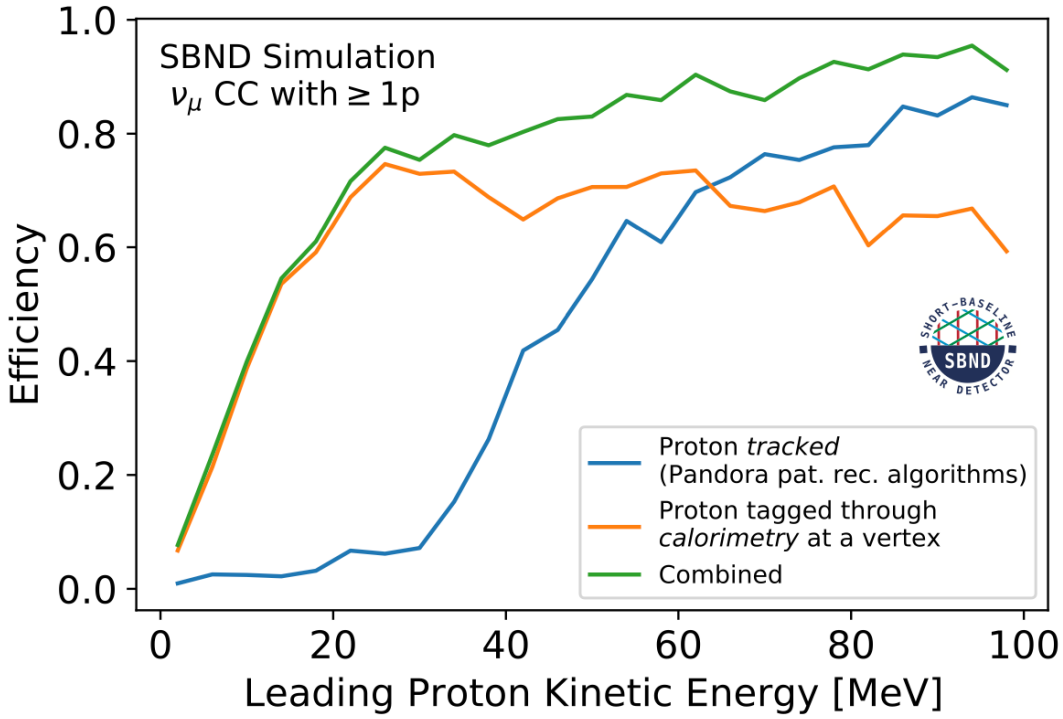




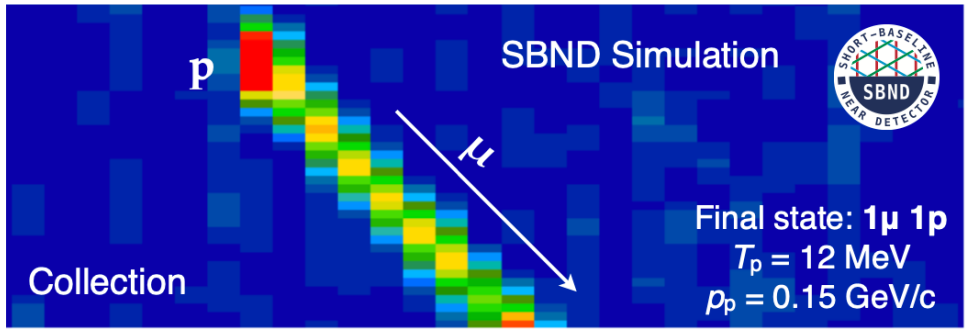
4. Reconstruction Capabilities

- SBND will use multiple advanced reconstruction software packages
  - Pandora is the standard reconstruction package for many LArTPC experiments
  - many complementary tools for specific tasks are being developed



- Proton tracking threshold ~40 MeV by the standard pandora tracking using topology information

- Proton identification threshold can be pushed down to ~15 MeV by using calorimetry information (looking for large ionization deposits near the vertex)



SBND Status

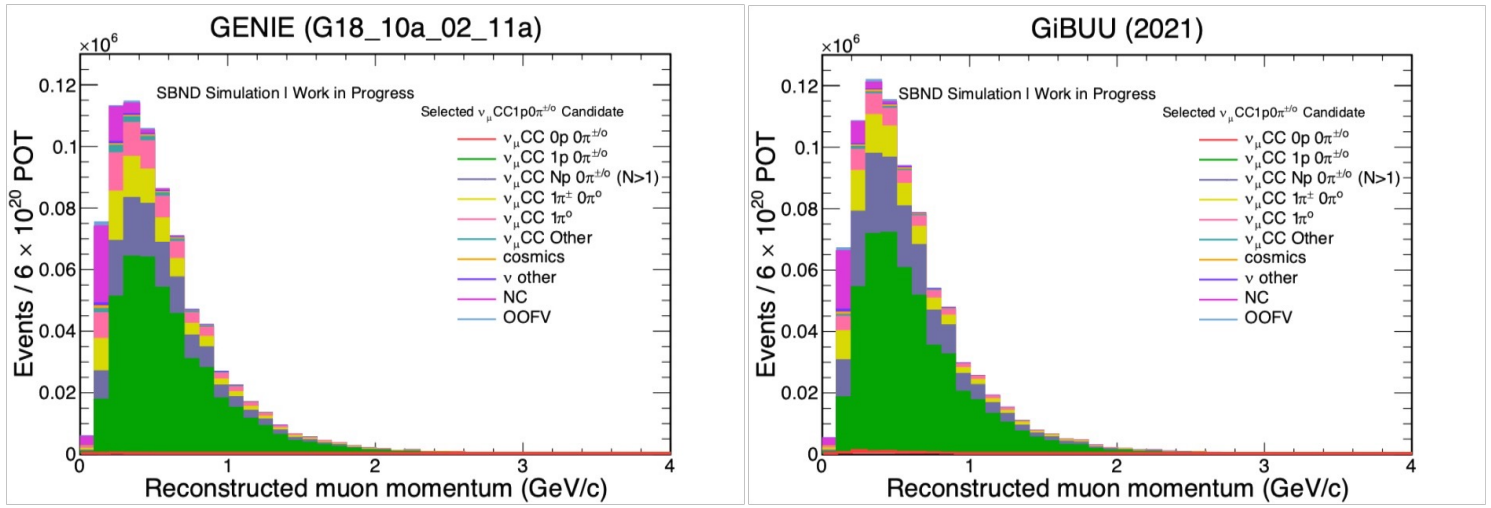
Now entering the commissioning & calibration phase

Stay tuned for updates at the summer conferences!

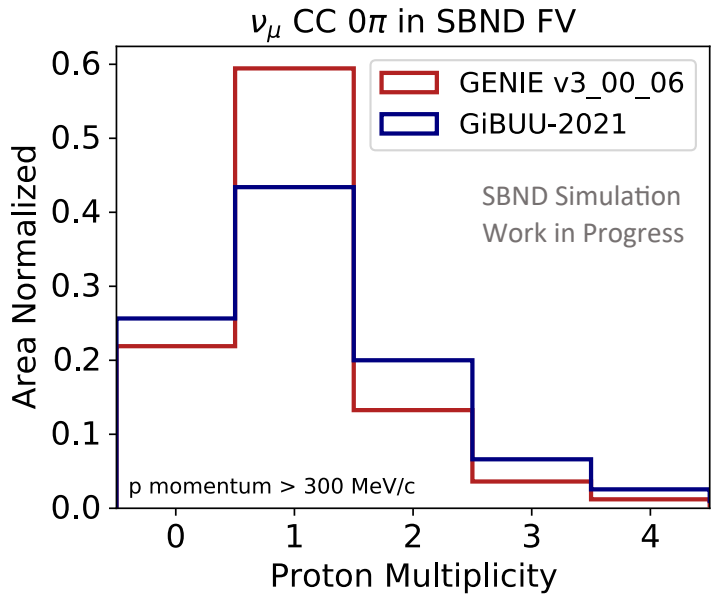
Cross Section Physics at SBND

Event Generators at SBND

- First experiment to use both GENIE and GiBUU as event-by-event generators with systematic uncertainties
- The two generators take different approaches
  - GENIE combines theoretical models with empirical data
  - GiBUU is based on the nuclear transport model

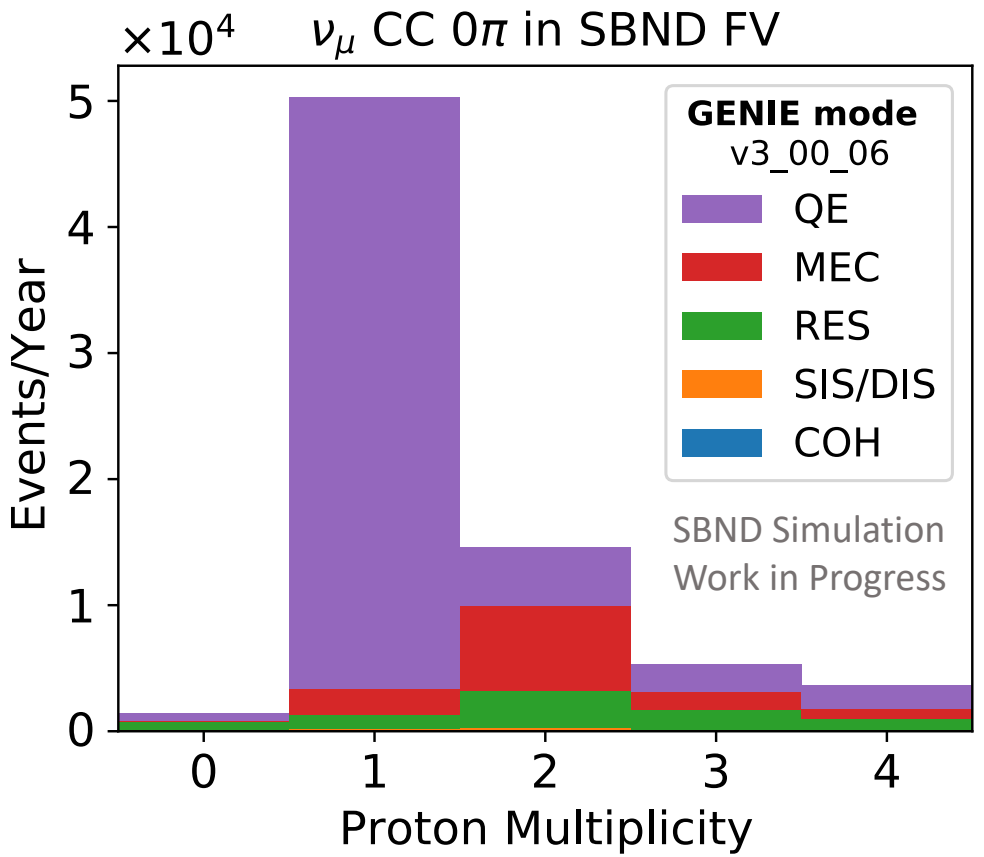


* the event selection and signal definition is different from the other plots shown in this presentation



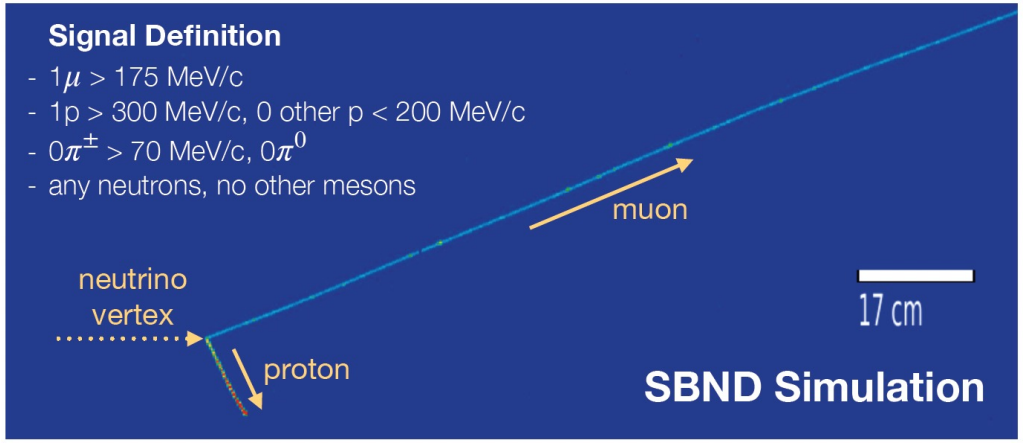
Towards ν_μ CC 0π Cross Section Measurements

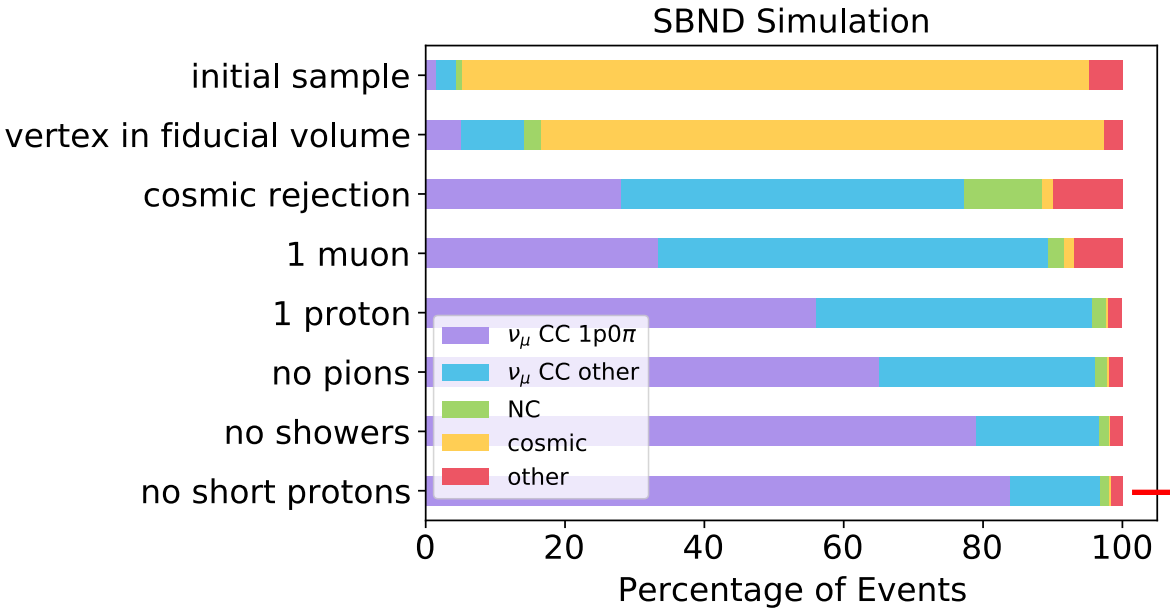
- SBND will make high-statistics cross section measurements with low reconstruction energy thresholds
- Target specific υ_μ CC 0π final state topologies to study the representative interaction modes
  - QE is enhanced in the 1p channel
  - MEC is enhanced in the 2p channel



ν_μ CC 1p0π

- Representative of the CC QE interaction mode
  - important exclusive channel for understanding multiple processes relevant to neutrino-nucleus scattering (FSI, nuclear effects)
- High-purity event selection is in place



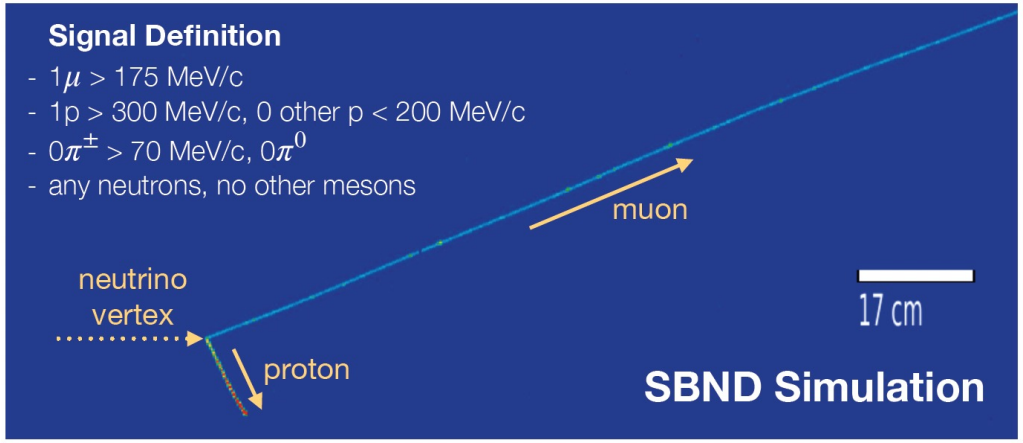


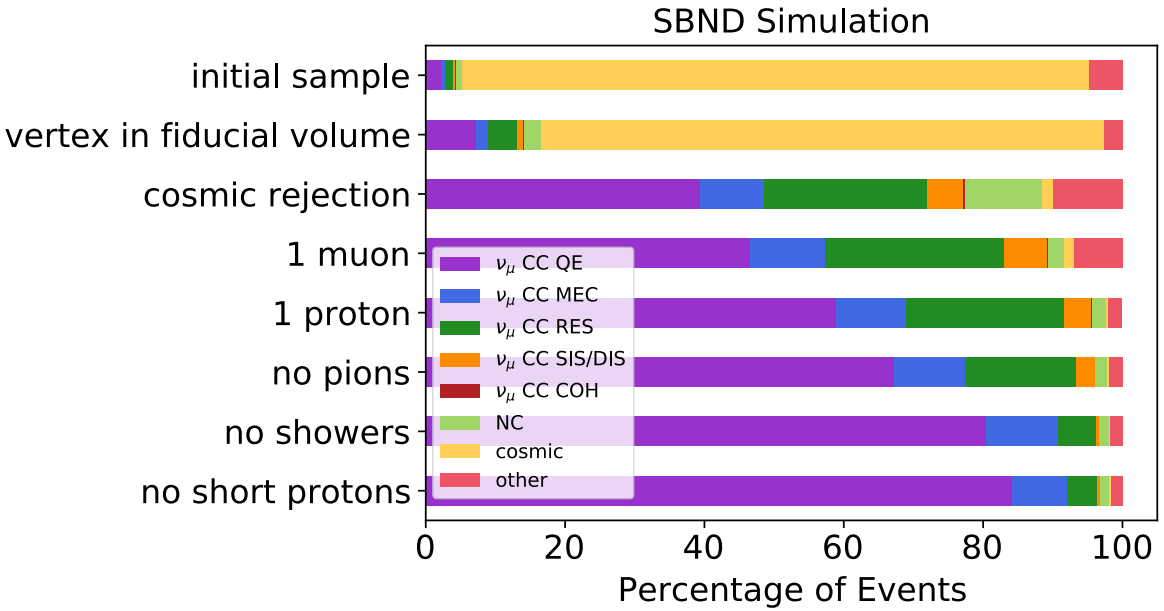
- Early data will have enough statistic for double-differential measurements
- Full dataset will enable N-differential measurements for a full survey of interaction phase space

→ selection efficiency 38%, over 200k events/year!

ν_μ CC 1p0π

- Representative of the CC QE interaction mode
  - important exclusive channel for understanding multiple processes relevant to neutrino-nucleus scattering (FSI, nuclear effects)
- High-purity event selection is in place

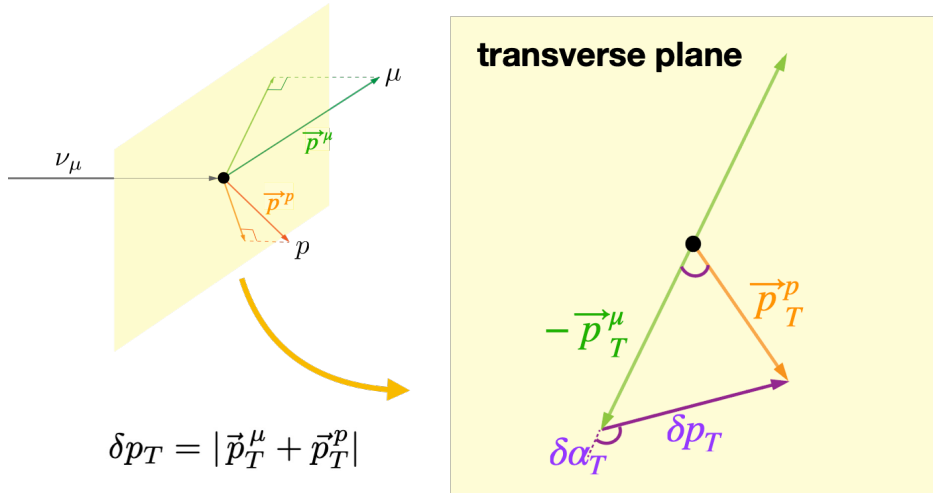


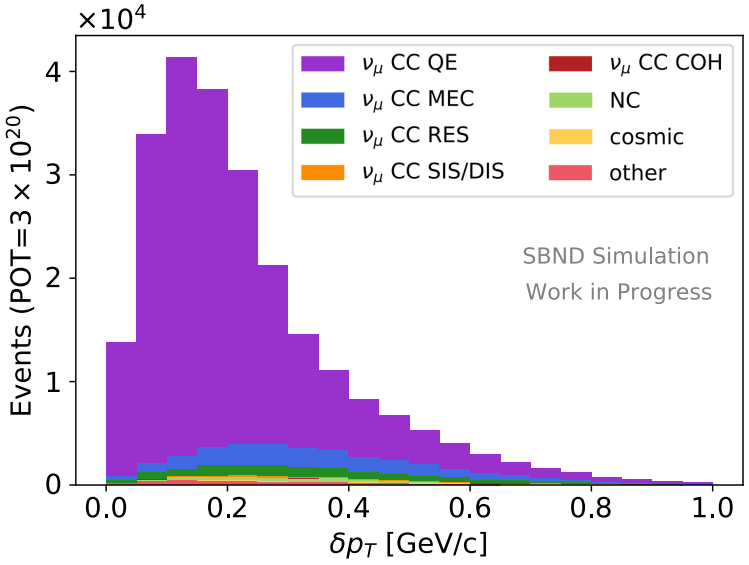


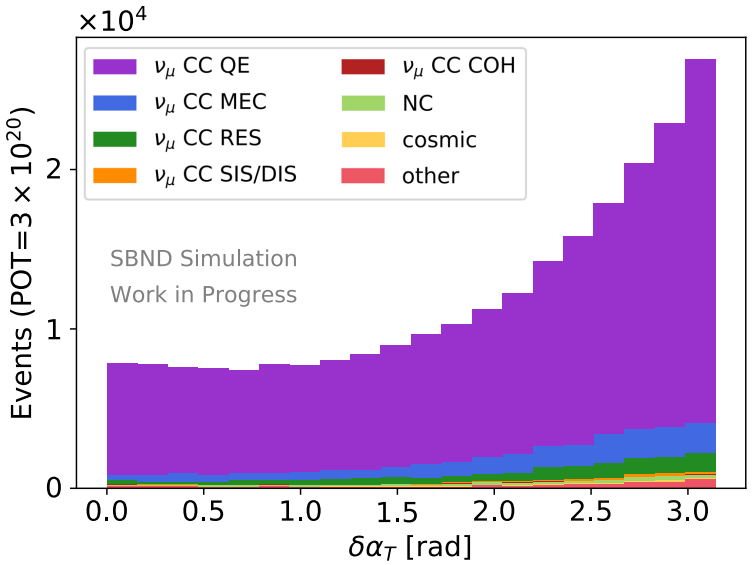
- Early data will have enough statistic for double-differential measurements
- Full dataset will enable N-differential measurements for a full survey of interaction phase space

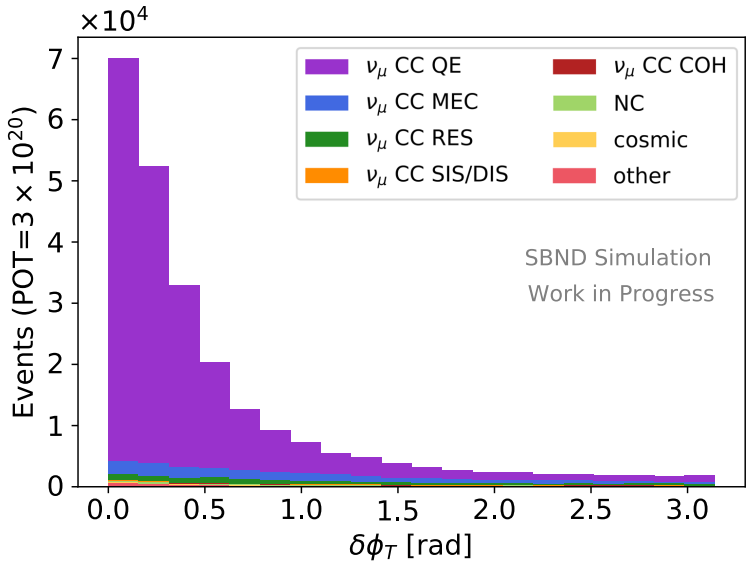
ν_μ CC 1p0π

- Kinematics on the plane transverse to the neutrino direction are useful probes of nuclear effects
  - transverse kinematic imbalance (TKI), implies background interactions or nuclear effects



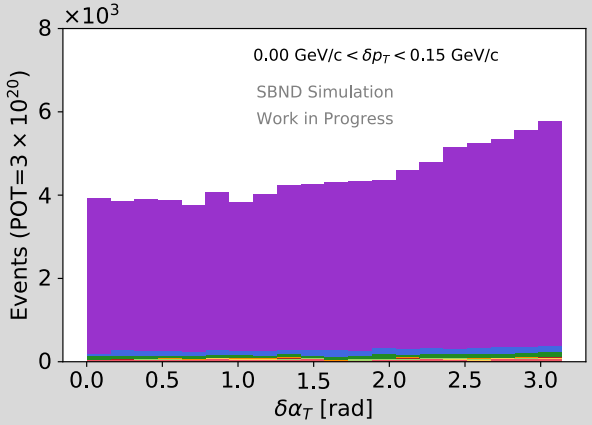


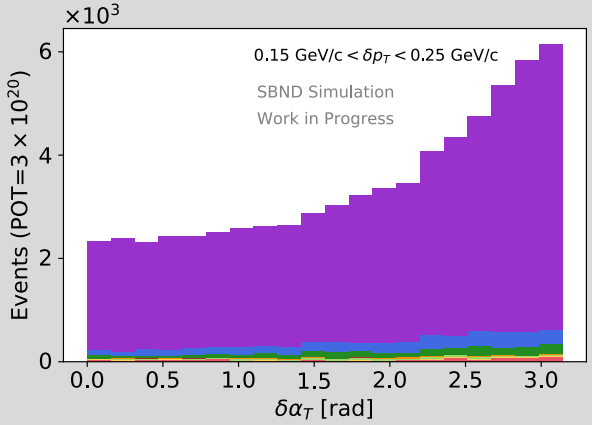


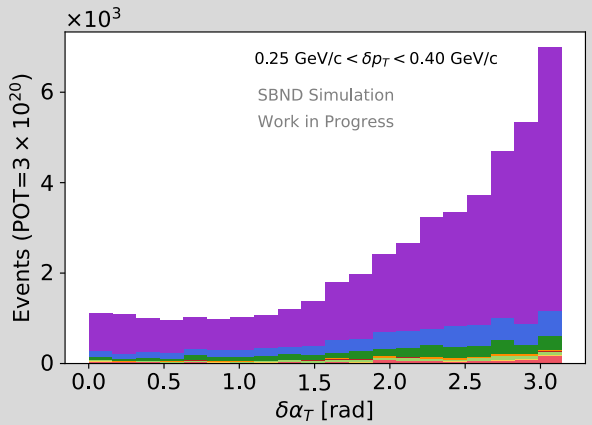


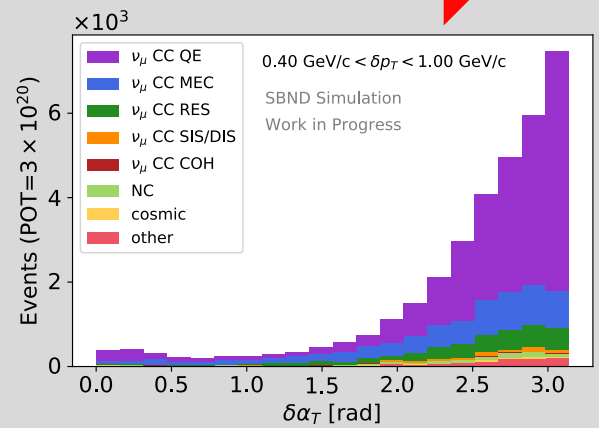
ν_μ CC 1p0π

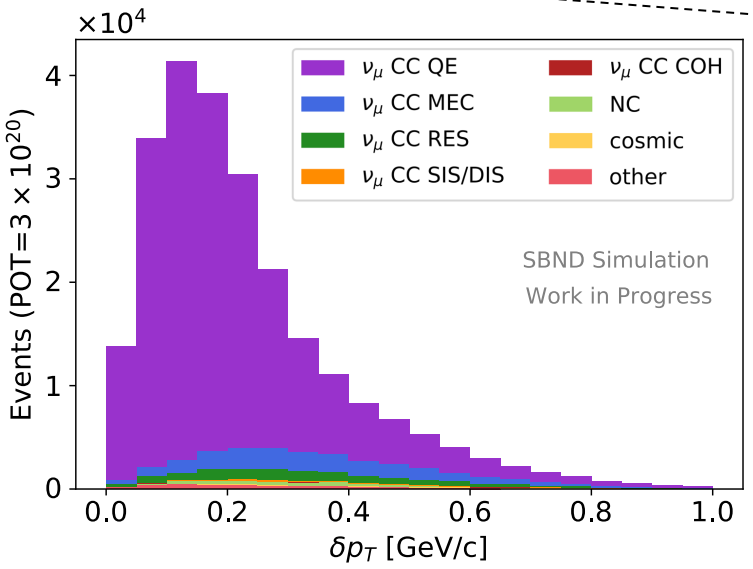
nuclear effects

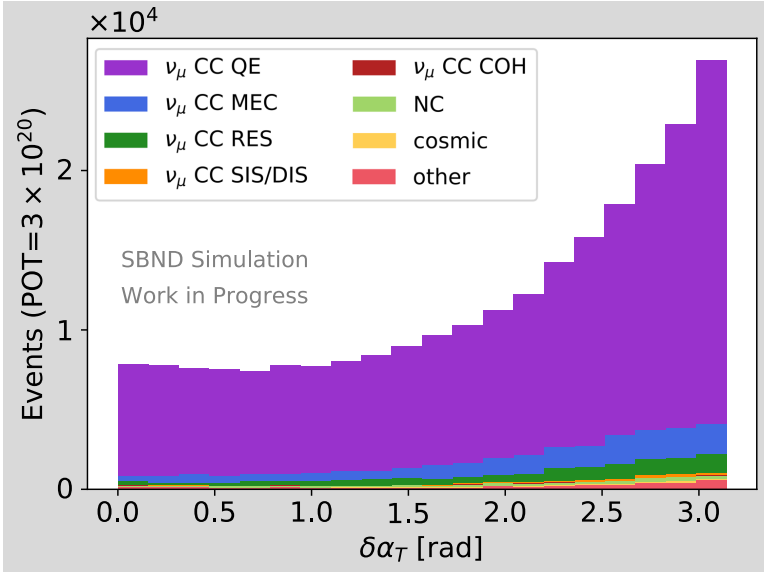


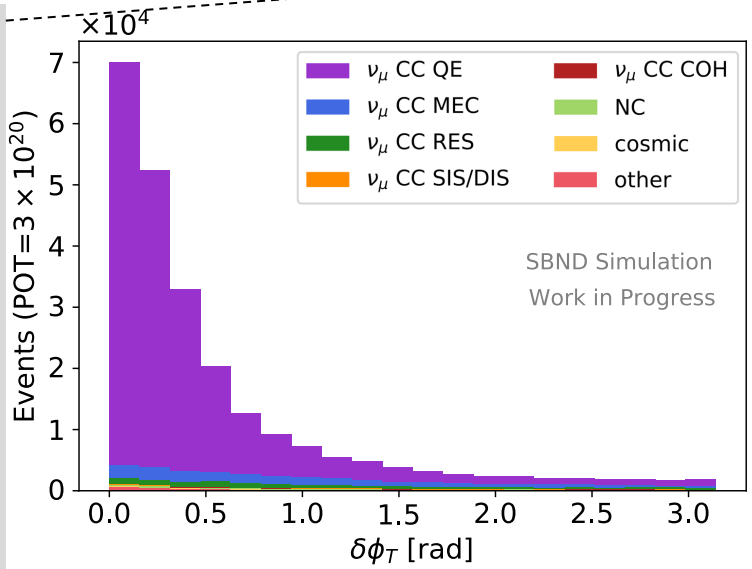












Summary

- Neutrino interaction measurements are a key part of the SBND physics program
- SBND has unique capabilities to enable excellent cross section measurements
  - will collect an order of magnitude more neutrino-argon scattering data than what is currently available
  - unique detector, reconstruction, and analysis capabilities will decrease the systematic uncertainties
  - uses both GENIE and GiBUU as event-by-event generators
- SBND has a rich cross section program
  - active analysis work targeting the more dominant final state topologies for early data
    - υ_μ CC inclusive (μ + X), υ_μ 1p0π (μ + p), υ_e CC inclusive (e + X)
  - long list of other topologies to shortly follow
    - υ_μ Np0π (μ + Np), N > 1, NC 1π^0 (π^0+ Np), υ_μ CC 1π^0 (μ + π^0 + Np), ...
- SBND data is near – stay tuned!

Thank you!

SBND Collaboration Meeting
December 2023

262 Total Collaborators

210 Scientific Collaborators
(faculty/scientists, postdocs, PhD students)

40 Institutions

5 Brazilian Universities
CERN
1 Spanish University, 1 National Laboratory
1 Swiss University
8 UK Universities, 1 National Laboratory
18 US Universities, 4 National Laboratories

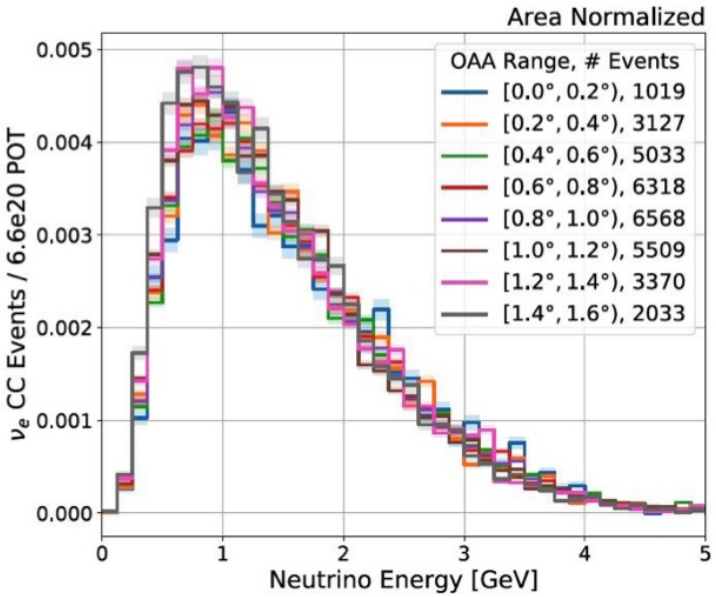
Additional Slides

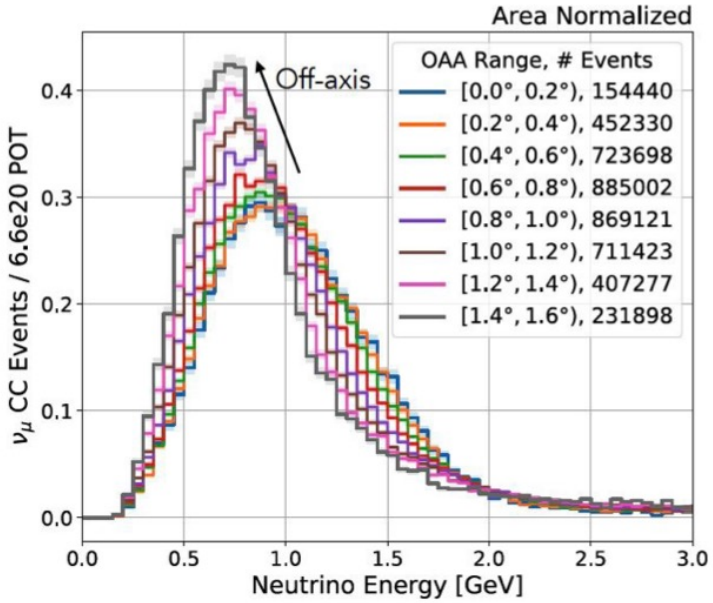
Off-axis Flux Effect (SBND-PRISM)

- υ_μ and υ_e flux has different off-axis effect due to the production mechanisms
  - enable analyses such as υ_μ/υ_e cross section measurements and study of lepton mass effects

$$\mu^+ \rightarrow \nu_e + \bar{\nu}_\mu + e^+$$
$$K^+ \rightarrow \nu_e + e^+ + \pi^0$$
$$K_L^0 \rightarrow \nu_e + e^+ + \pi^-$$

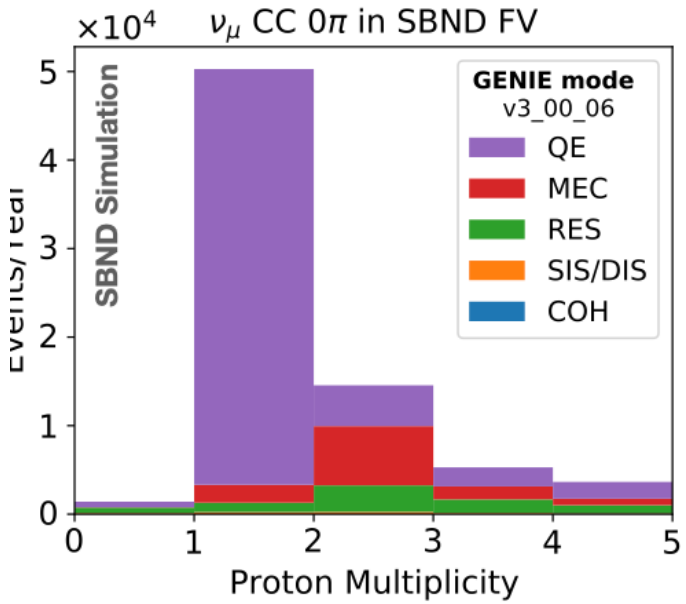
$$\pi^+ \rightarrow \nu_\mu + \mu^+$$
$$K^+ \rightarrow \nu_\mu + \mu^+$$

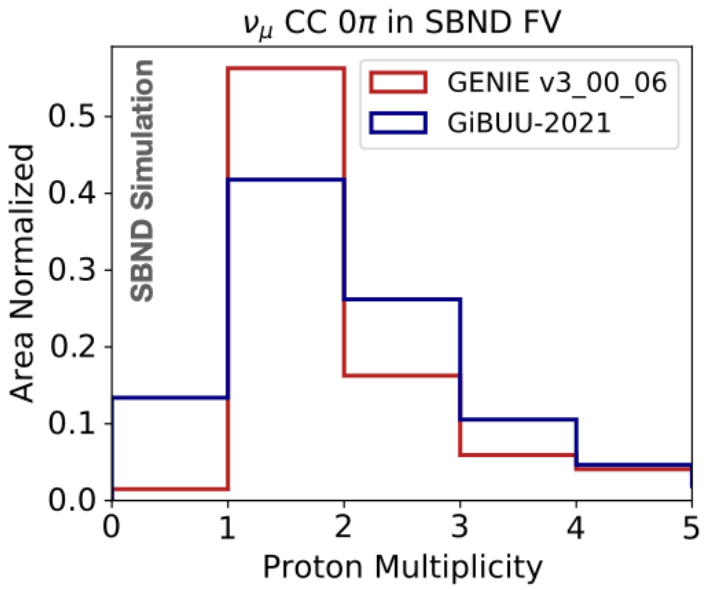


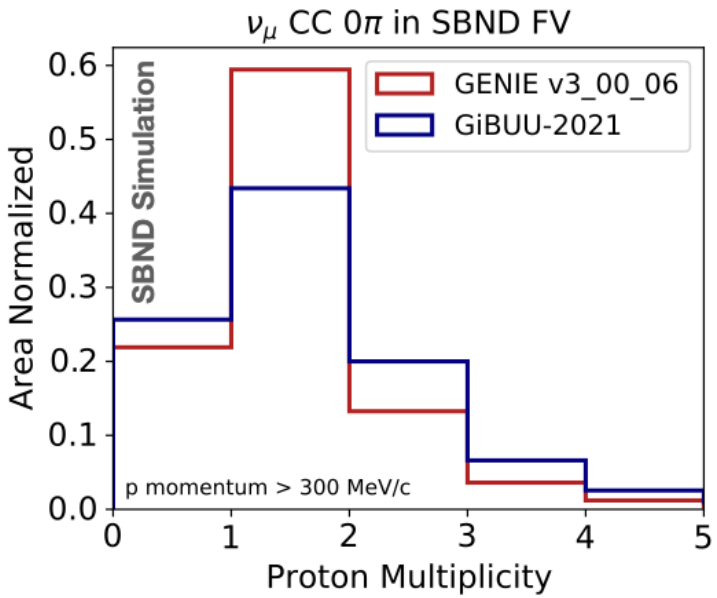


Proton Multiplicity Prediction

- GENIE `v3_00_6 G18_10a_02_11a`
- GiBUU-2021







Neutrino Energy Reconstruction

- Select QE-like sample by requiring low momentum imbalance
  - rejects non-QE interaction events that undergo large nuclear effects
  - with this additional selection, we obtain a sample with QE purity 95%, 1p0pi purity 93%
- Candidate for an exclusive channel approach to υ_μ disappearance oscillation search
  - neutrino energy reconstruction is important, even for multi-detector searches