RUN 14737, EVENT 586
July 11, 2024

30 cm

SBND Cross-Section Program

Leo Aliaga (On behalf of the SBND Collaboration)

University of Texas at Arlington

September 19, 2024

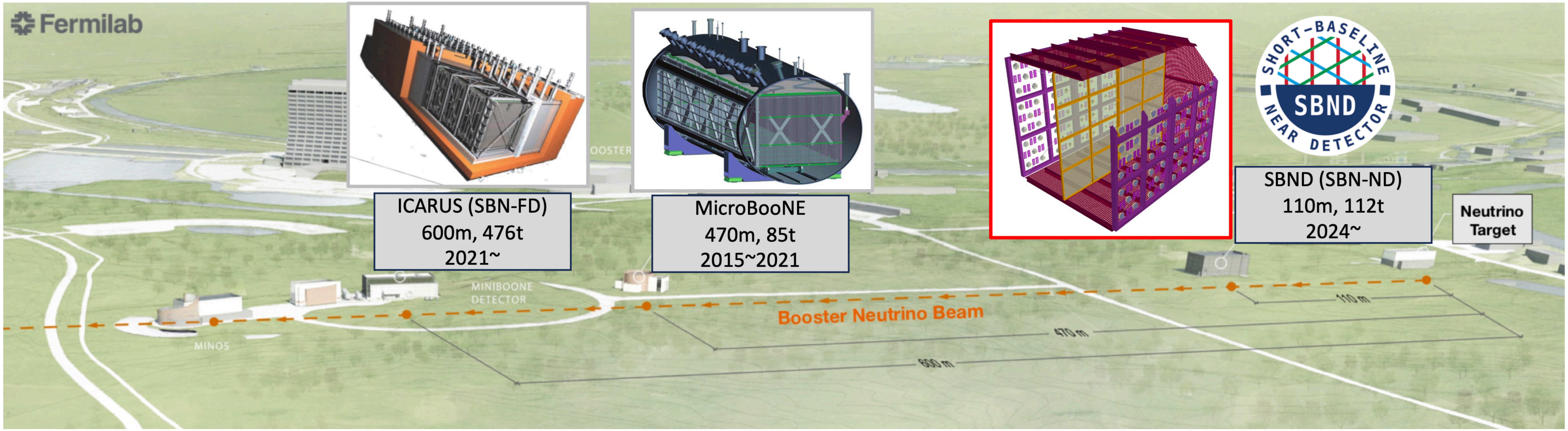
The 25th International Workhop on Neutrinos from Accelerators
NuFact-2024, Argonne National Lab
September 16-21, 2024

The Short Baseline Near Detector (SBND)

SBND Physics Goals

- Contribute to the oscillation program as a near detector in conjunction with ICARUS (FD)
- Measure neutrino-argon interaction cross sections in the few-GeV energy range
- Search for new physics and study rare processes

See more details in the SBND talk by Tereza Kroupova, WG 5



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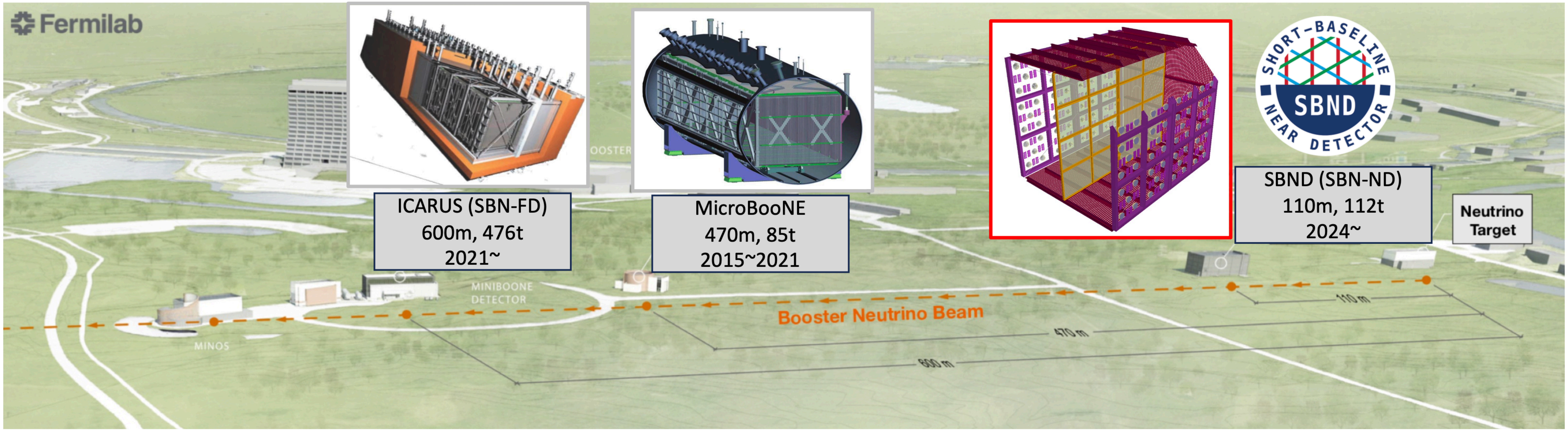
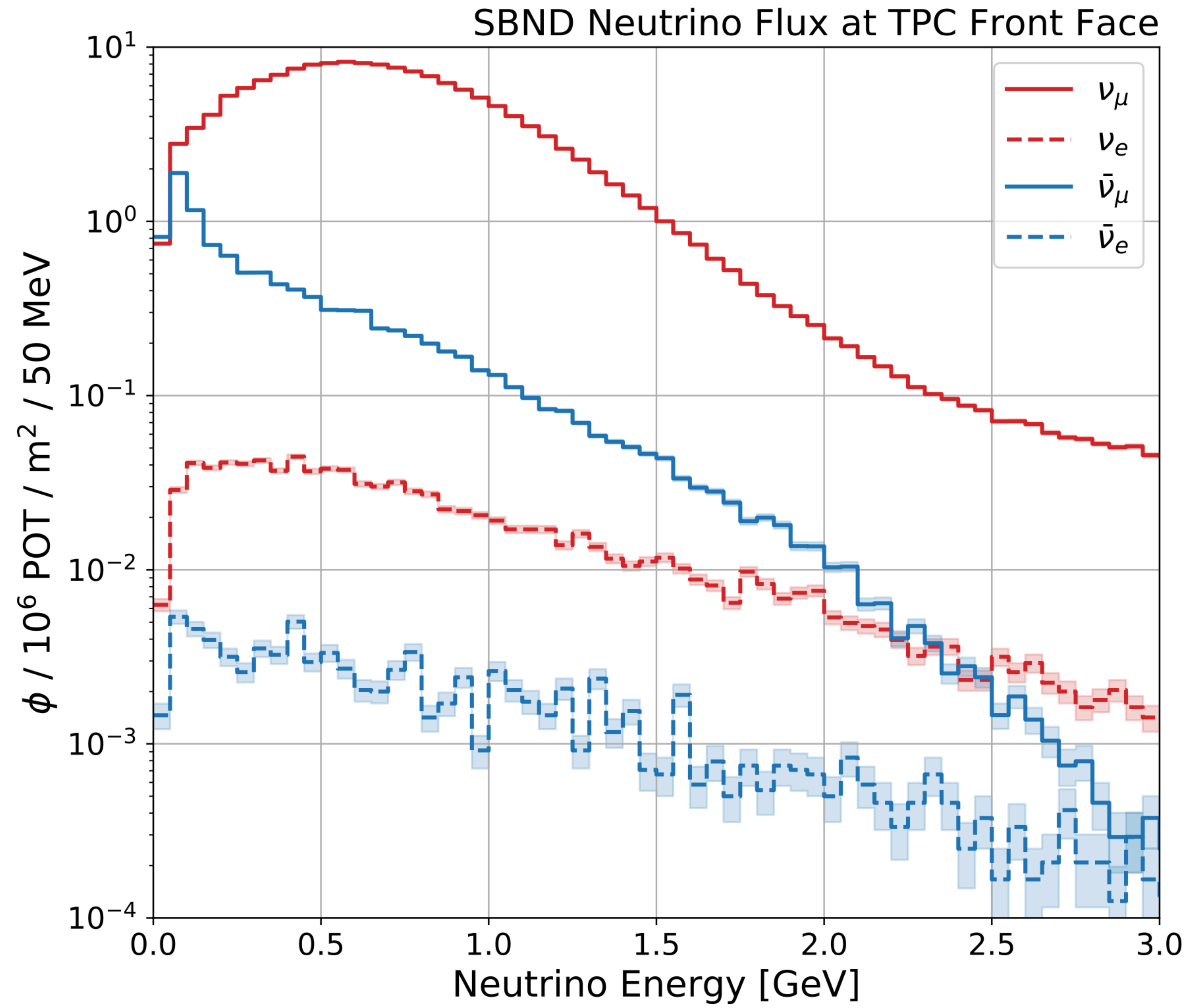
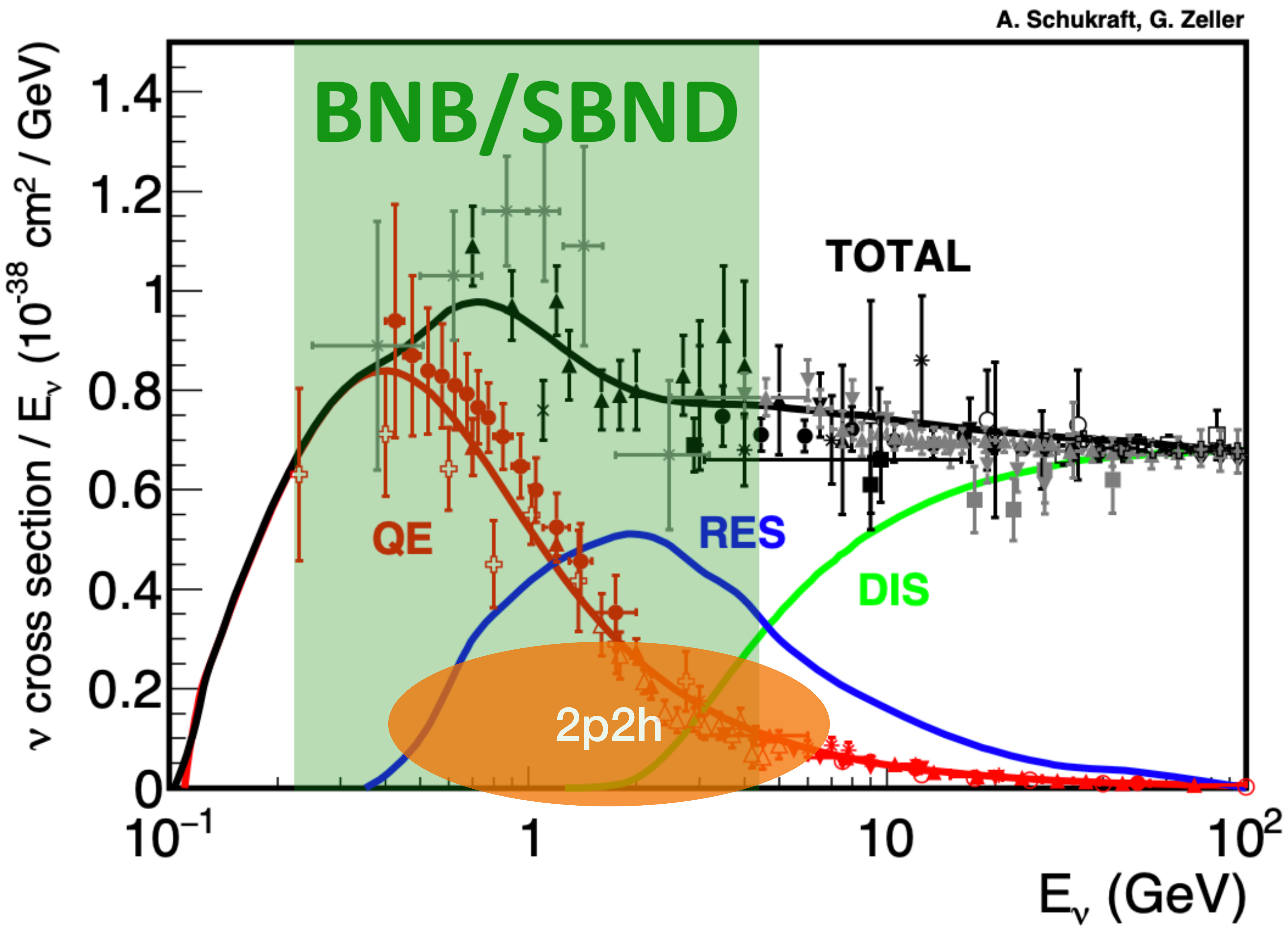


Neutrino Beam at SBND

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





Neutrino Interaction Measurements in SBND

High statistics and a robust control of systematics in SBND will allow a wide variety of neutrino interaction measurements

A quick sampler of what we are working on...

multi-dimensional differential measurements

- ν_μ CC inclusive
- ν_μCC Np0π
- ν_μCC Np1π^0
- ν_μCC Np1$\pi^\pm$
- ν_e CC inclusive
- NC Np0π
- NC Np 1π^0

measurement of rare processes

- ν_μ CC QE hyperon production (Λ^0, Σ^0, Σ^-)
- ν_μ CC inelastic K production ($K^+ + \Lambda^0$)
- NC Np1γ
- Neutrino–electron elastic scattering

Measurements will provide inputs for theory, generators, and future experiments

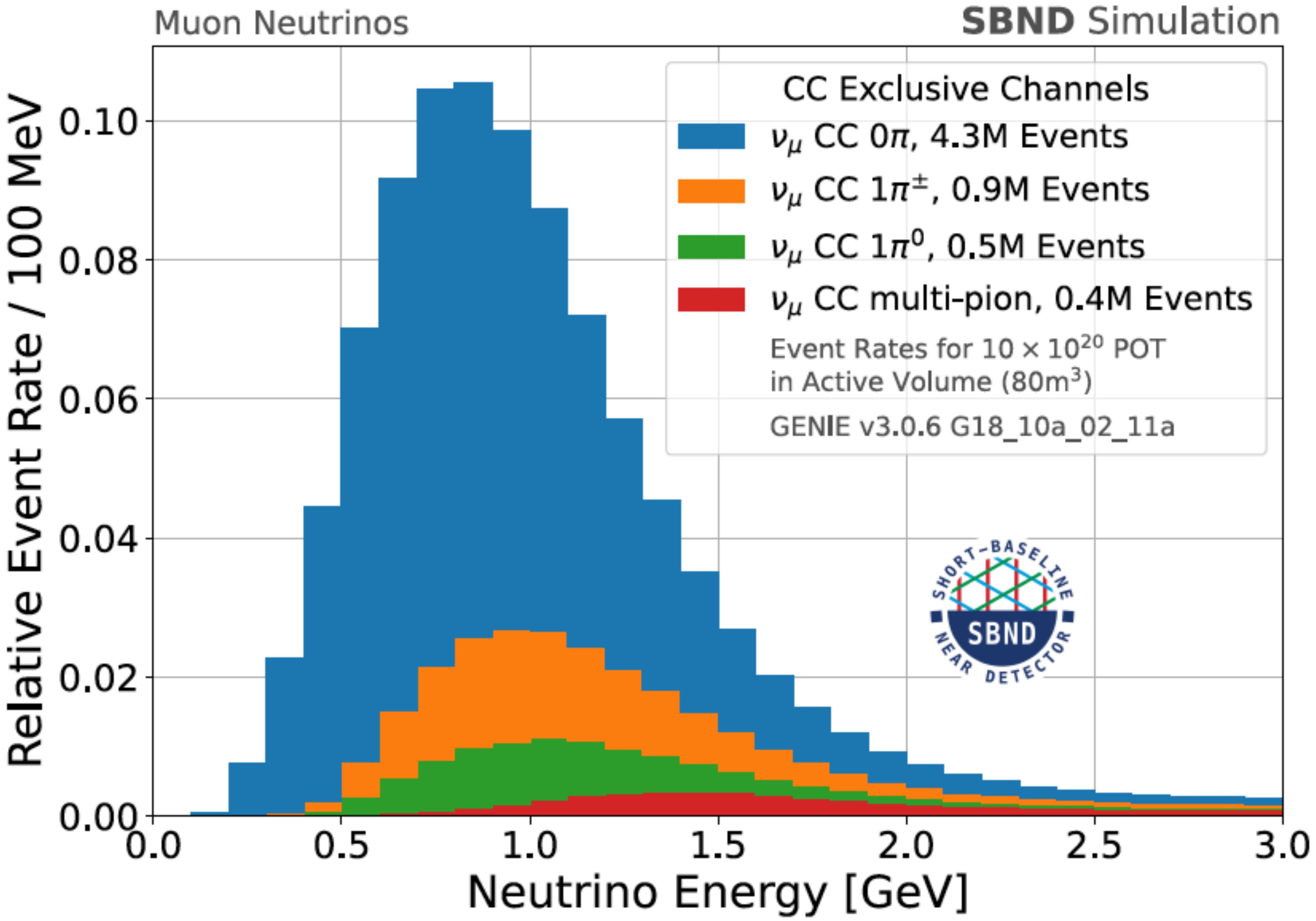
Capabilities of SBND

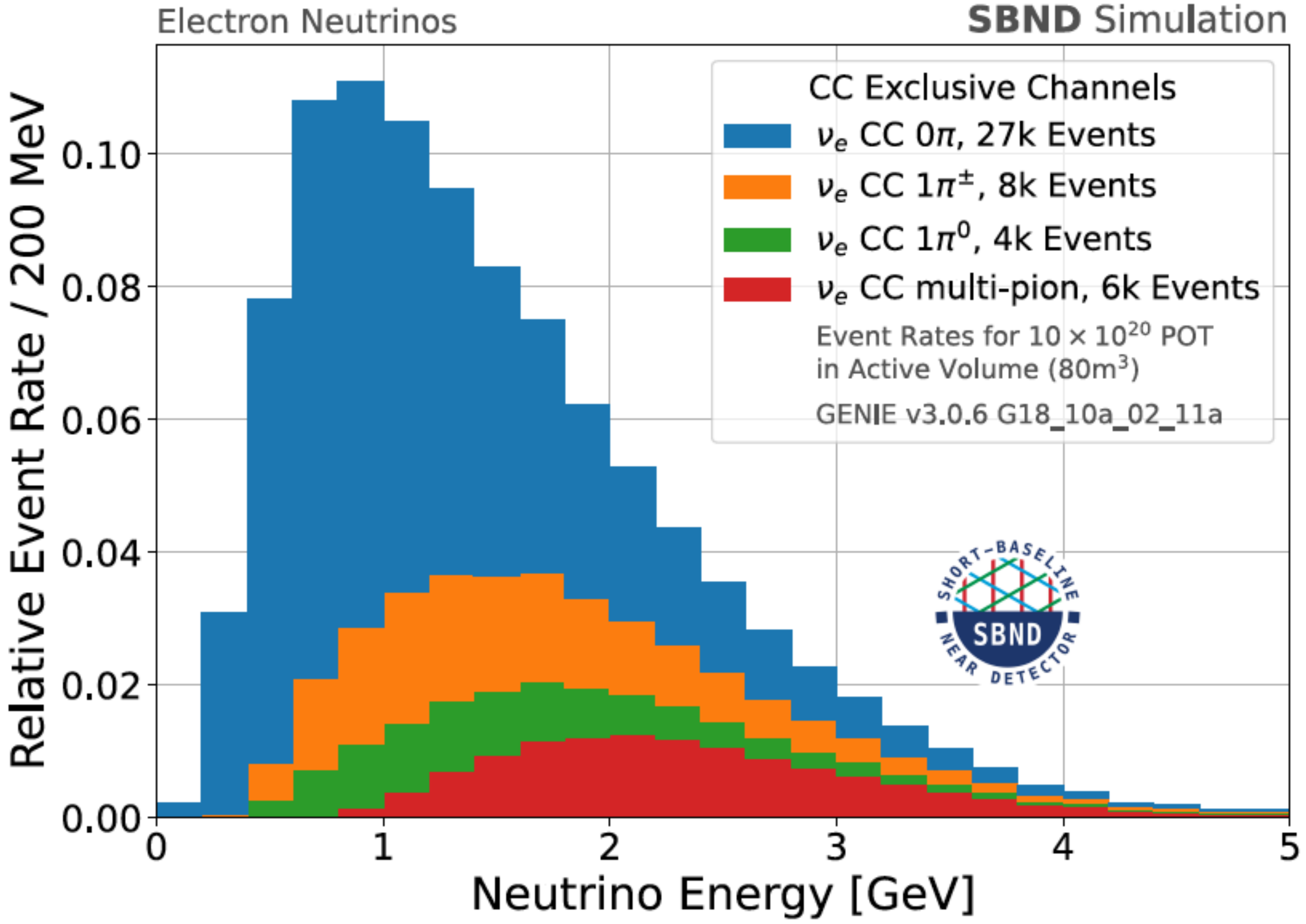
Neutrino Interactions in SBND

Precision studies of ν-Ar interactions

- *Unprecedented high event rate: **several thousand events/day** in SBND!*
- *Excellent reconstruction capabilities allowed by the LarTPC technology*

will enable a generational advance in the study of ν -Ar interactions in the GeV energy range.



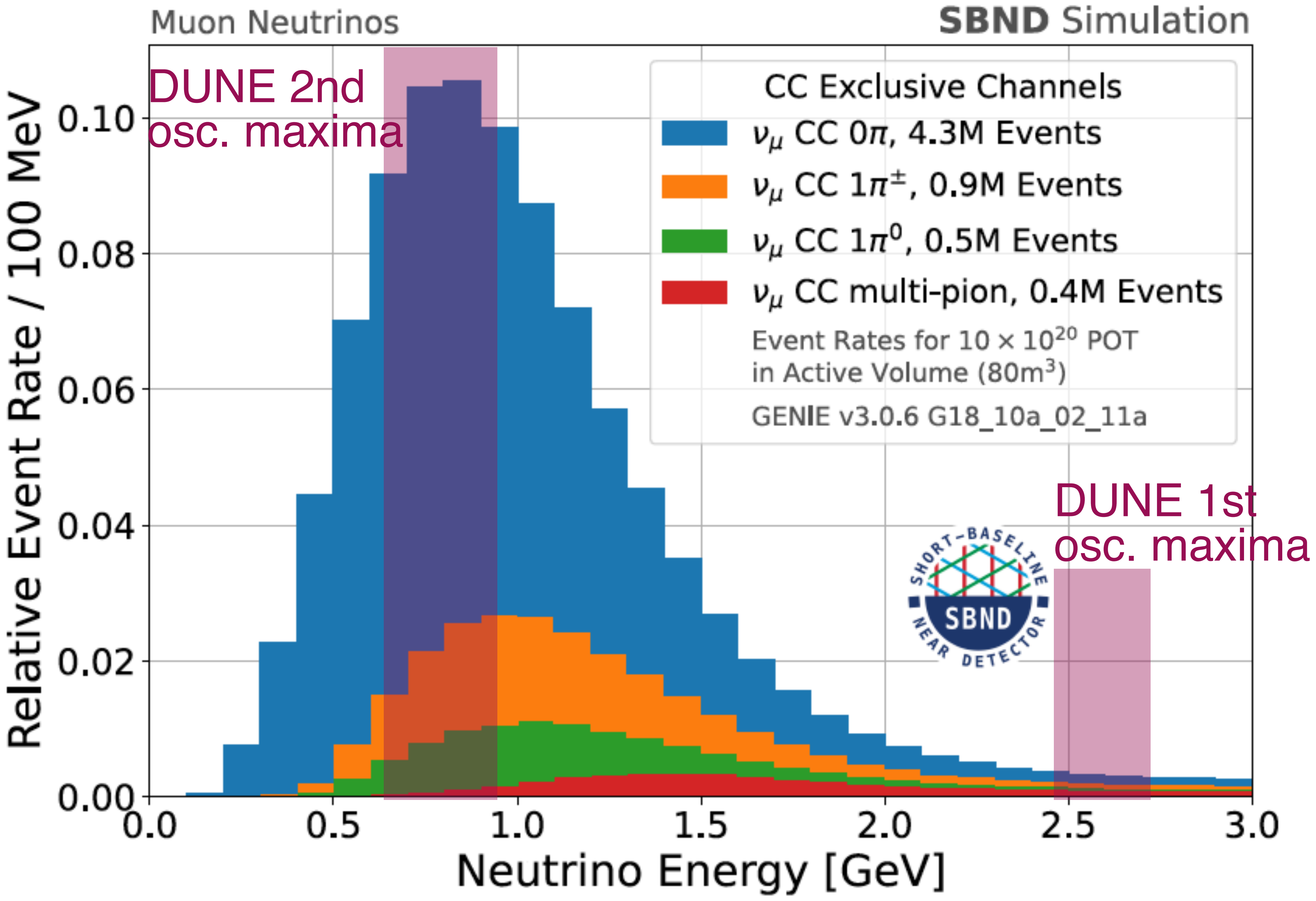


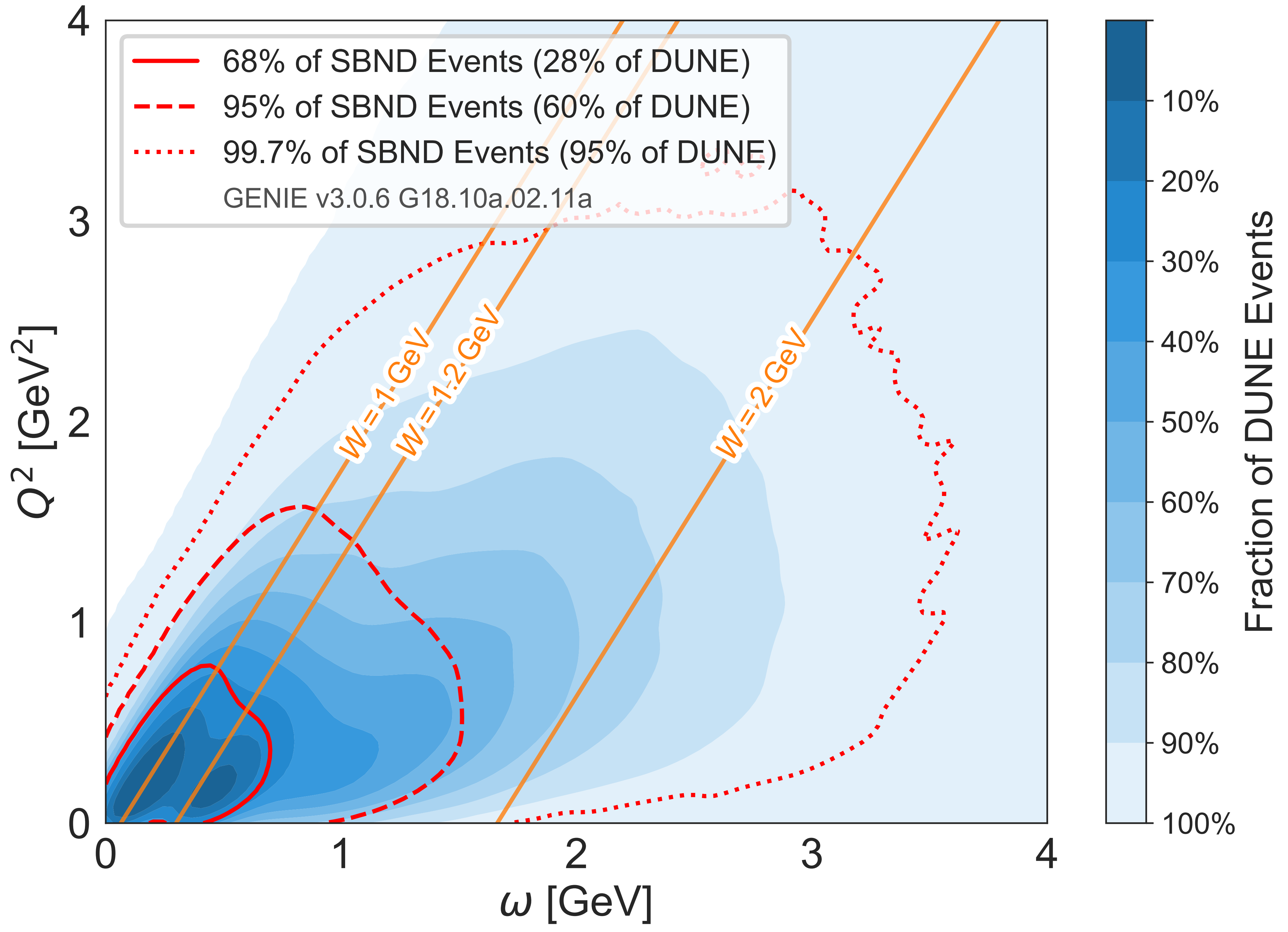
Neutrino Interactions in SBND

Moving into the era of **precise measurements** and **δ_{CP}** determination (**DUNE**), limited by systematics, model-associated uncertainties become very crucial.

Thanks to the high statistics with robust systematic uncertainties expected in SBND, it will inform the models used in the DUNE era.

We can cover a significant phase space of DUNE with SBND





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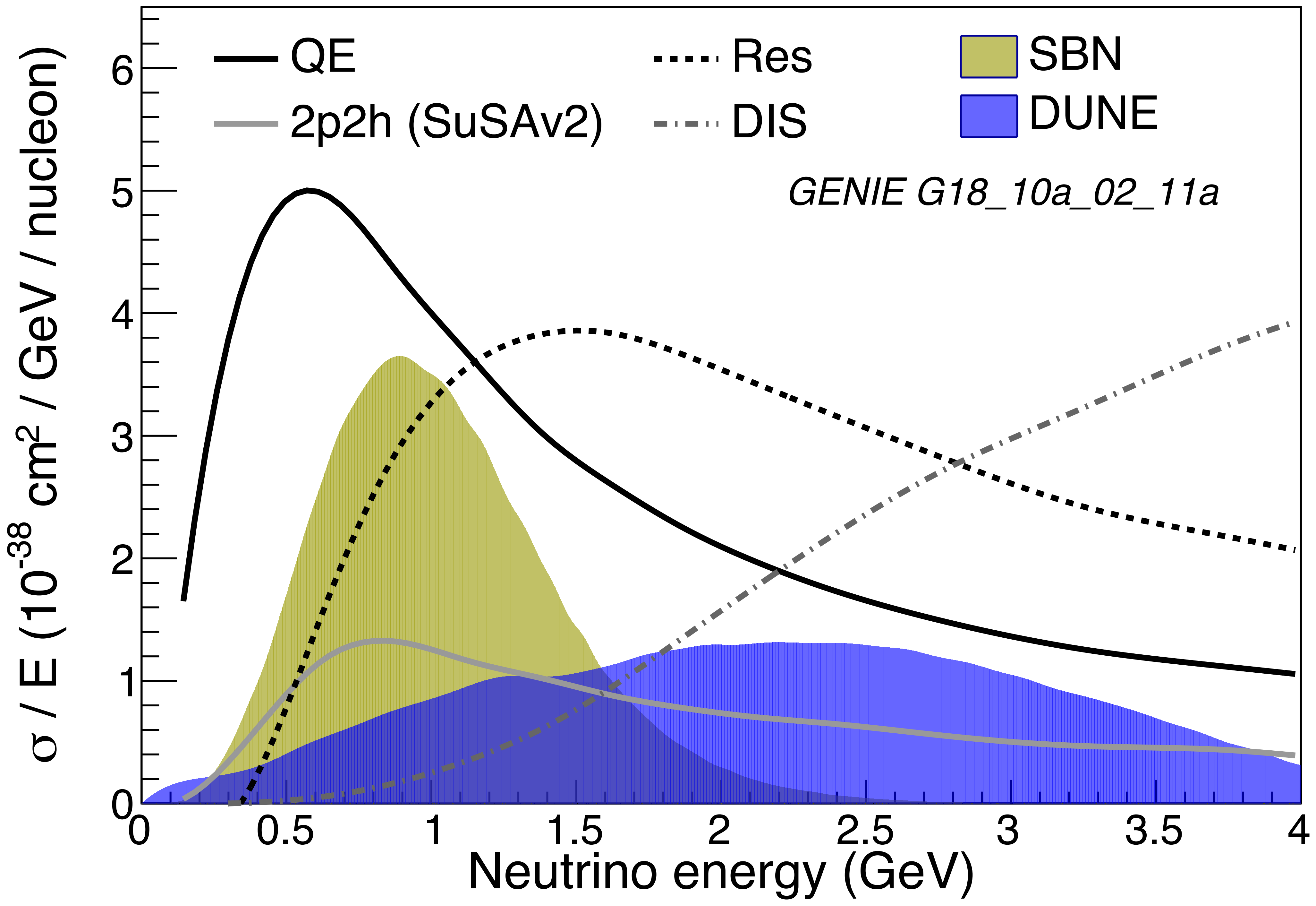
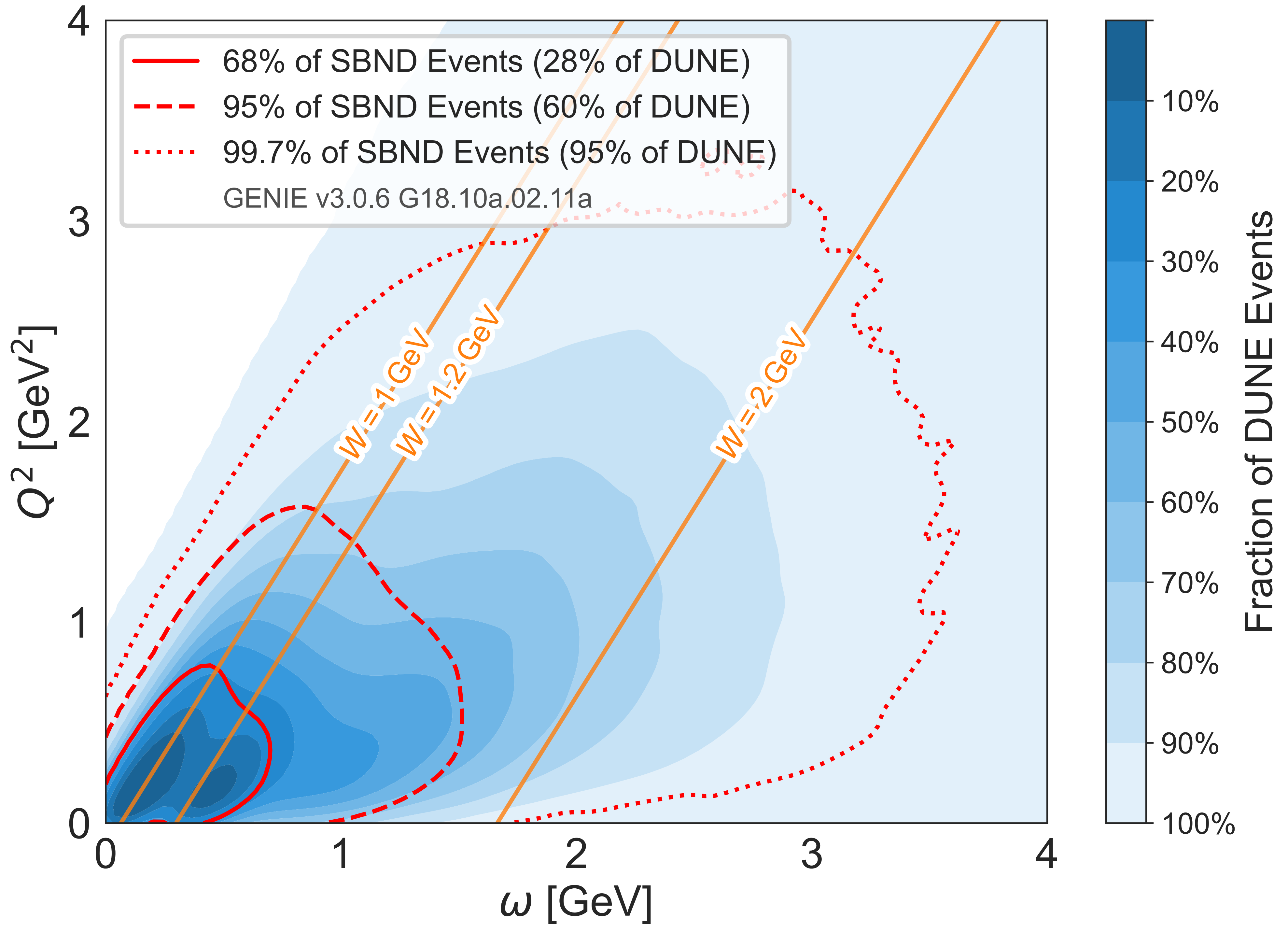
We can measure crucial systematics for DUNE





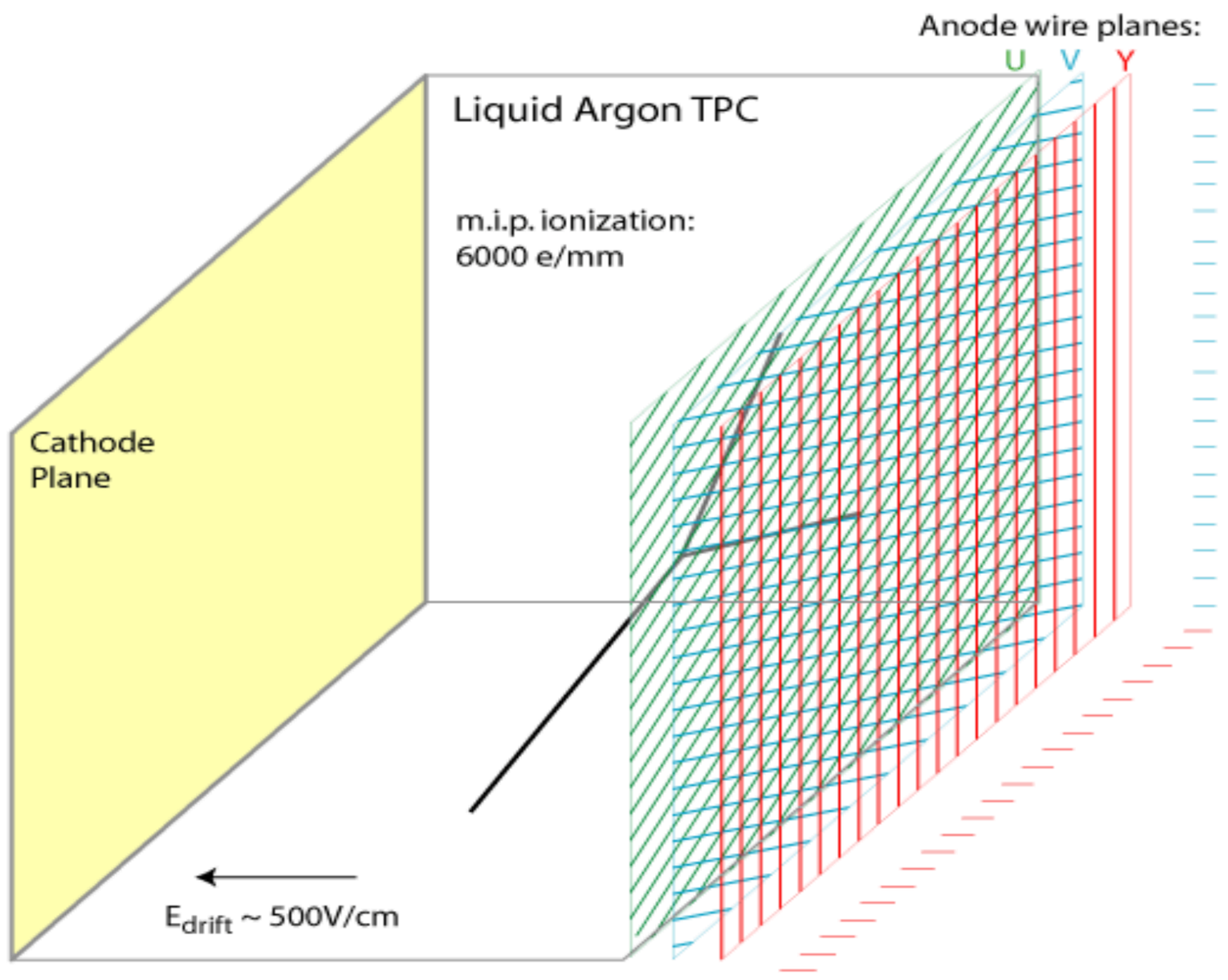
SBND Technology: TPC

See more details in the SBND talk by Tereza Kroupova, WG 5

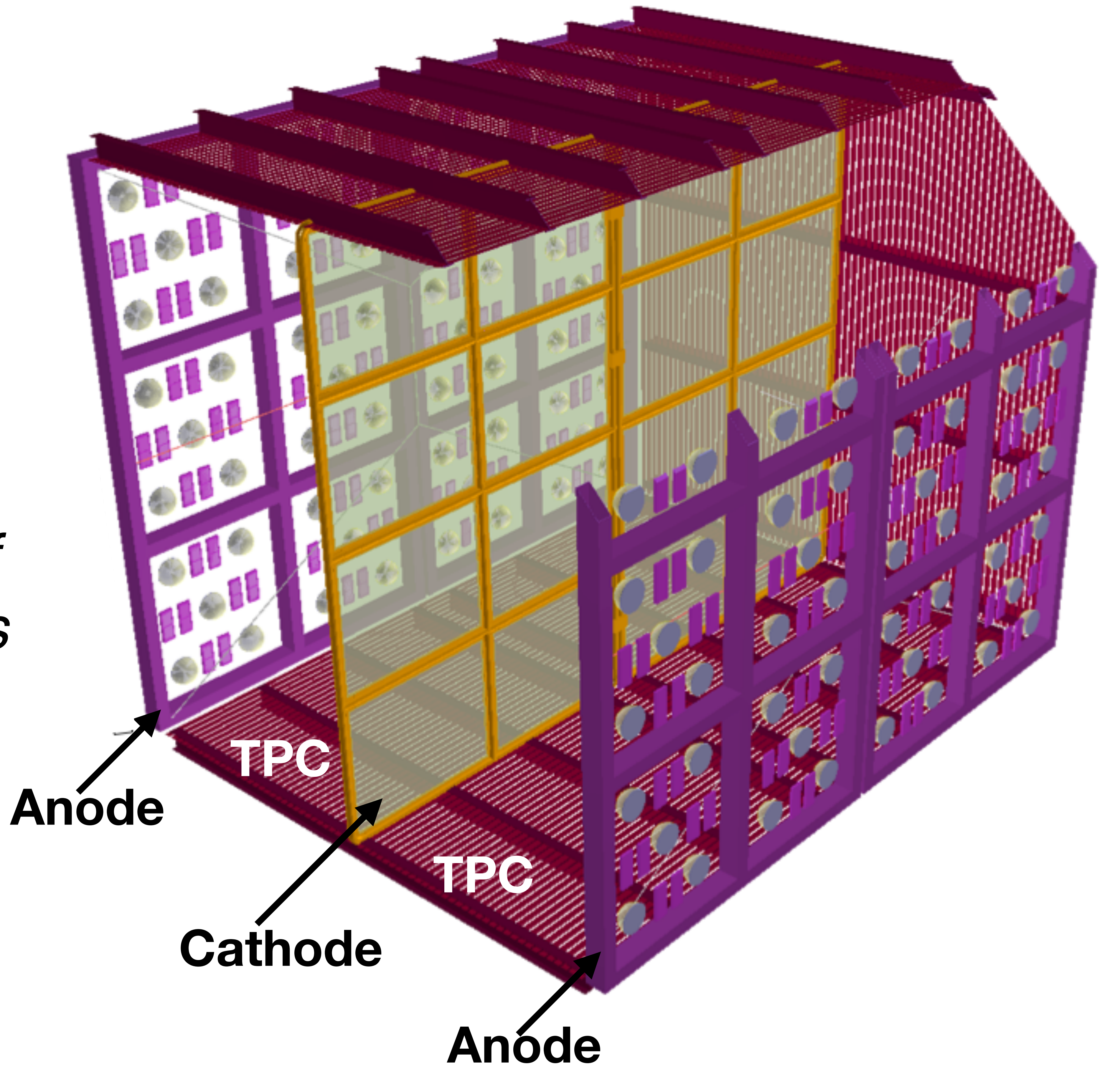
Large-mass LArTPC (112 ton active volume)

- 3D reconstruction with a mm position resolution
- Fine-granularity calorimetry
- Excellent particle identification with dE/dx information
- Low energy thresholds: few MeV

2 Time Projection Chambers total dimension: 4m x 4m x 5m



enable detailed reconstruction of complicated neutrino interactions



SBND Technology: PDS and CRT

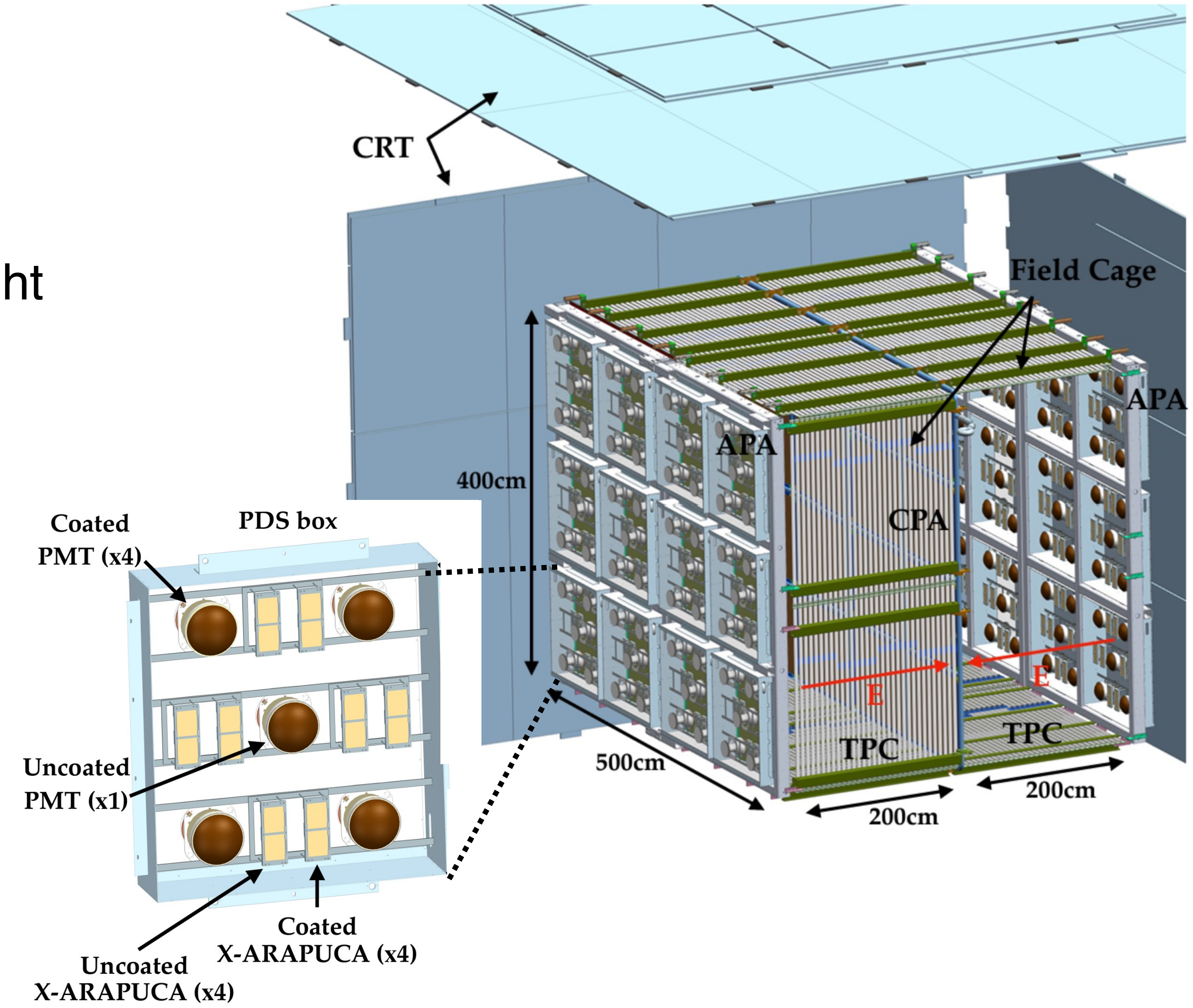
See more details in the SBND talk by Tereza Kroupova, WG 5

Photon Detection System (PDS)

- Novel technology of PMTs and X-Arapucas.
- Scintillation & reflected light => high and uniform light yield and excellent timing resolution.

Cosmic Ray Tagger (CRT)

- Cryostat surrounded by panels made of scintillator strips (detector on surface)
- Timing and position resolution allows for triggering on entering/exiting particles



Innovative Approaches

1. Revaluating BNB flux uncertainties

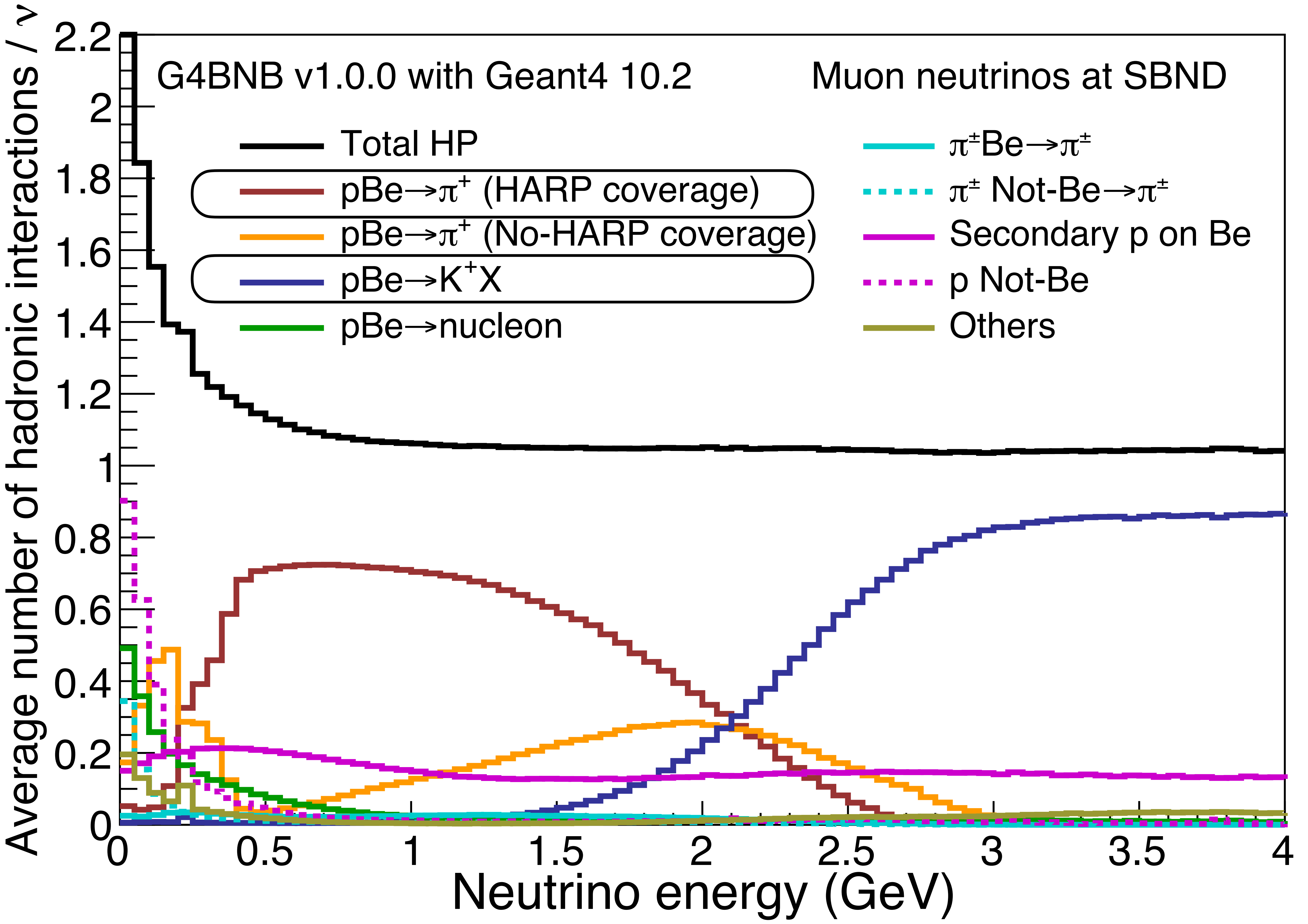
See more details in Josie Paton's poster

Neutrino flux uncertainty is the dominant factor in interaction measurements, making accurate flux calculations crucial for precise cross-section measurements at SBND

Development of G4BNB and reassessment of Flux Uncertainties

- G4BNB enables a complete record of hadronic interaction flux within a modern Geant4 framework
- We are constructing a new framework to calculate more precise flux uncertainties, incorporating current and future data

Currently, only the circled labels (p-Be → pions and kaons) have direct data coverage, provided by HARP data



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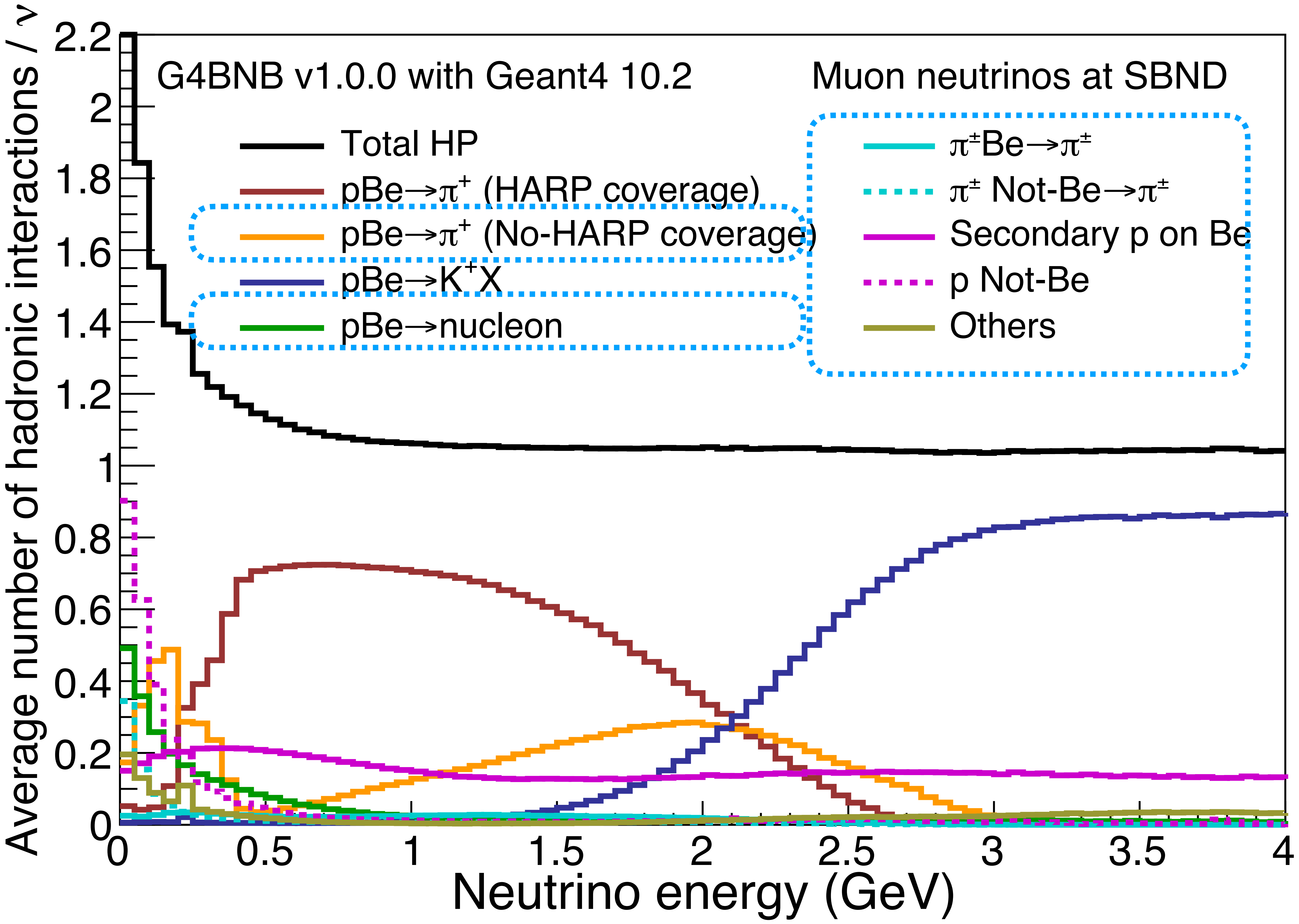
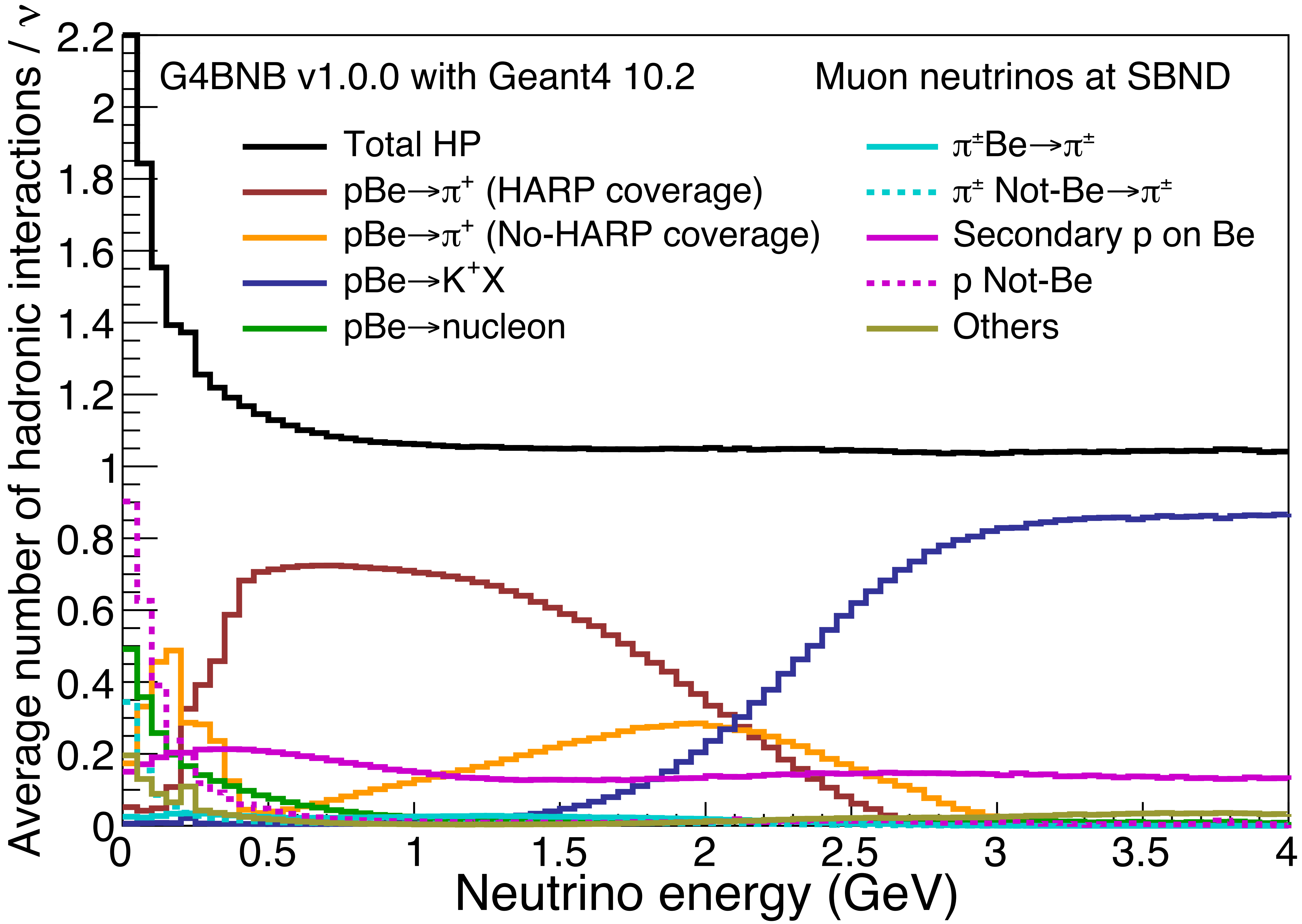
We are reevaluating the extension of data coverage, the account for secondary interactions and interactions outside the BNB Be target



Improvements through new HP data

Improvements in our flux uncerainties are possible by hadron production (HP) experiments

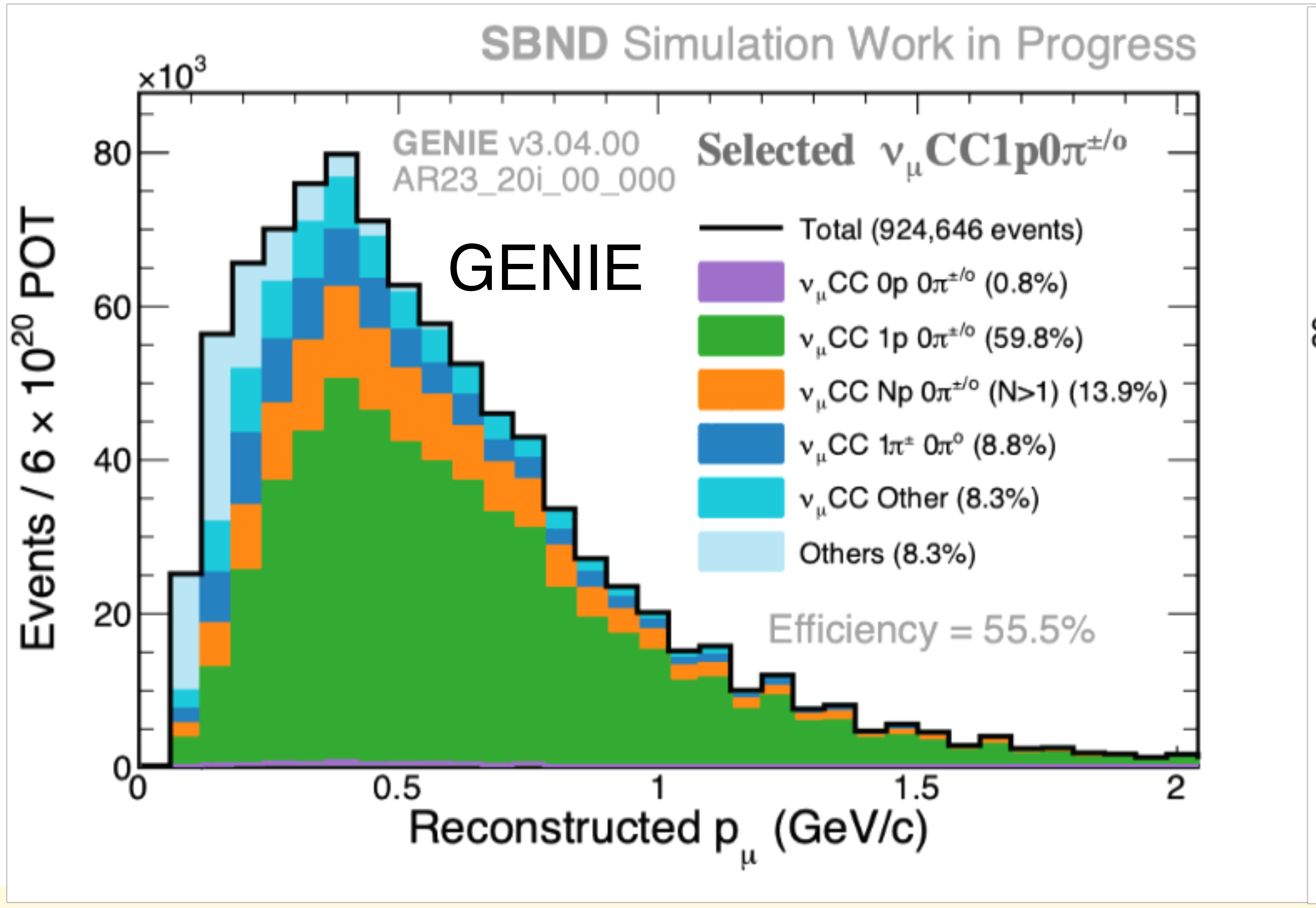
- **EMPHATIC (Fermilab)** has already collected HP data at energies ranging from 4 to 120 GeV, including Be, and plans to collect more.
  - SBND collaborators are actively working on analyzing this data
- **NA61/SHINE (CERN)** is proposing a new low-energy tertiary beam line at 1-20 GeV.
  - SBND collaborated with an addendum to this proposal to enhance the physics impact for our program

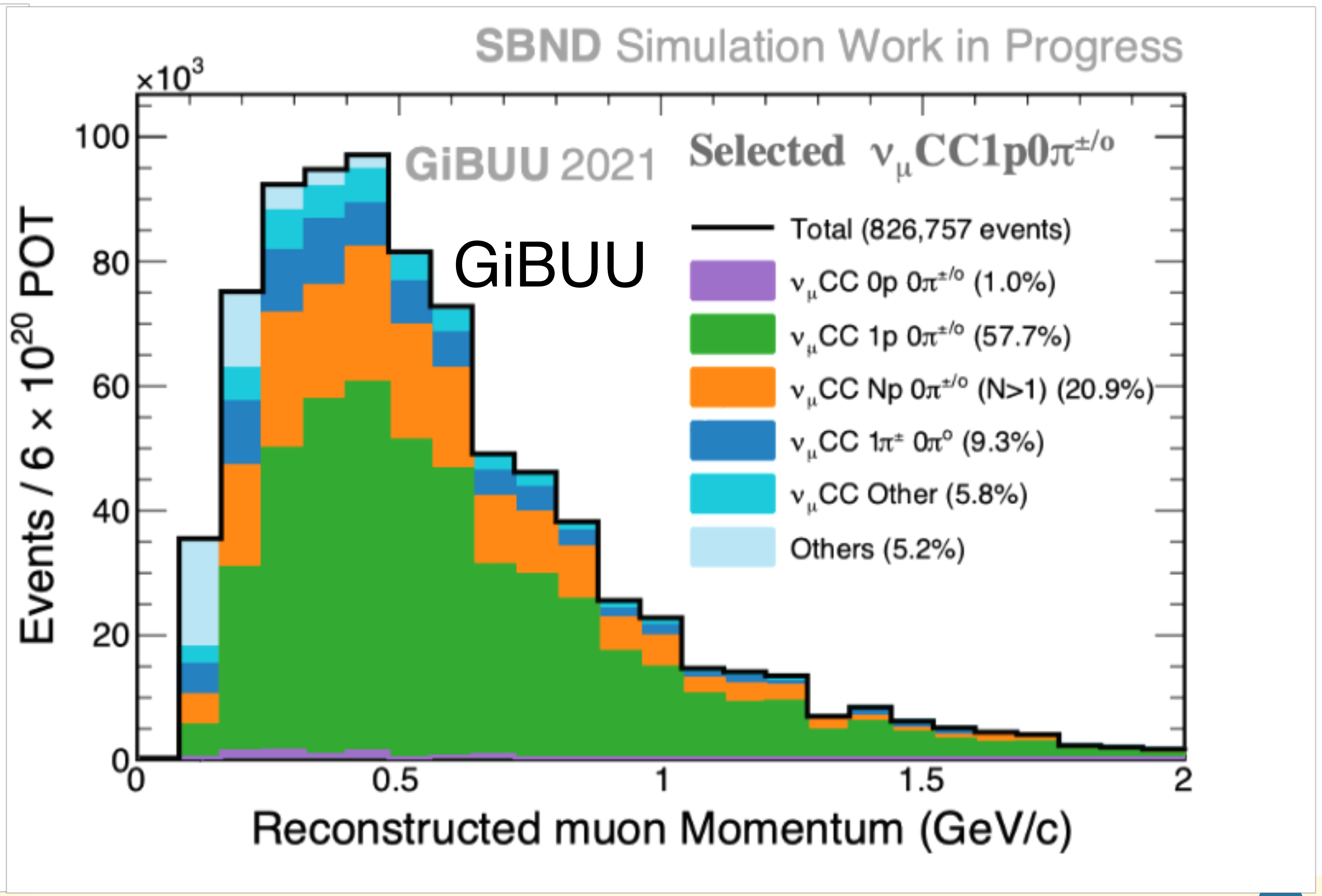


2. First implementation of GiBUU

SBND is the first neutrino LArTPC experiment incorporating GiBUU as an event-to-event generator

- It will provide a different physics approach to neutrino interactions, especially for FSI
- It provides invaluable insights for improving simulation corrections, including signal-to-background migrations (purity), efficiency, neutrino energy reconstruction, etc.





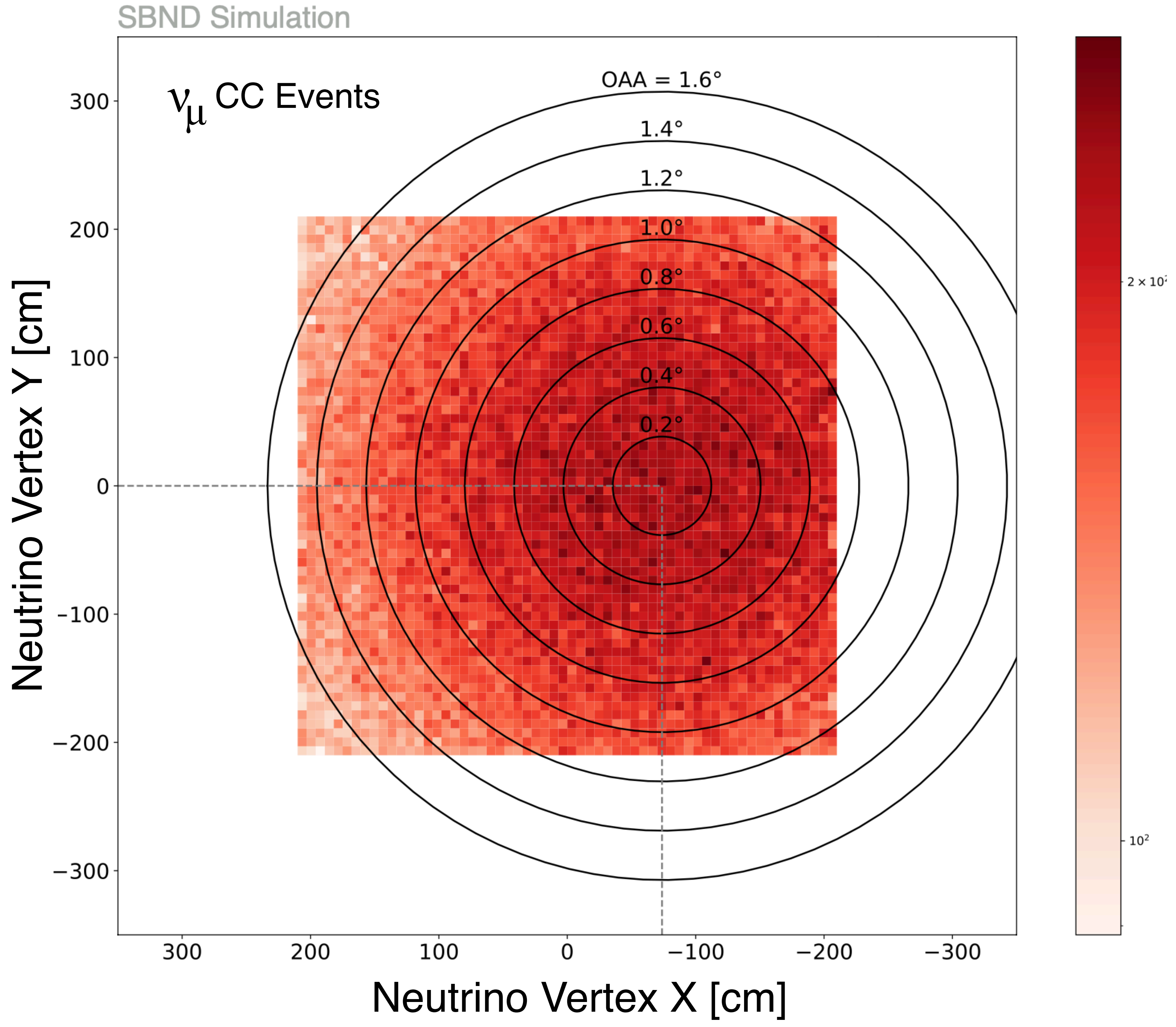
3. SBND PRISM

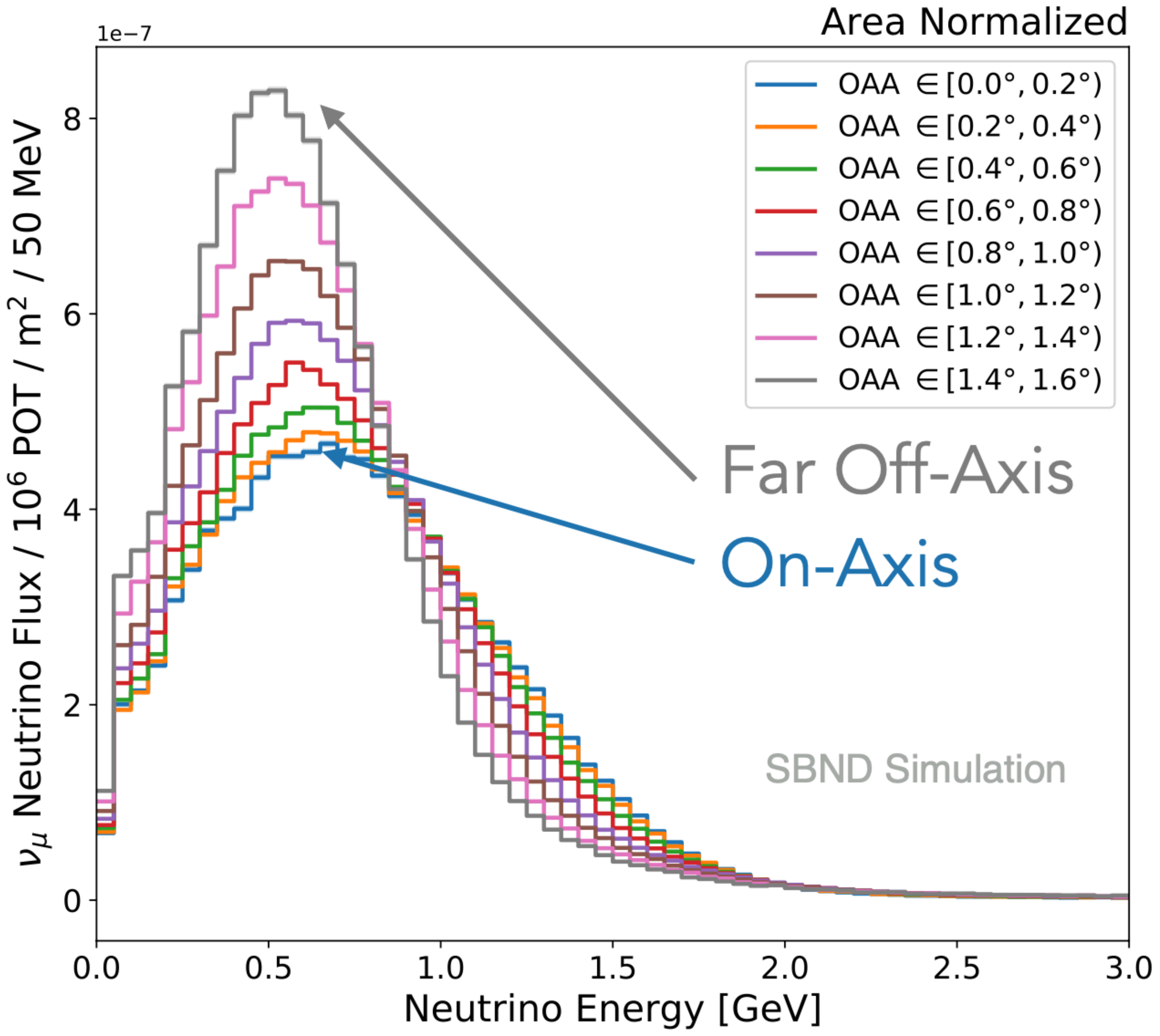
SBND detector is traversed by neutrinos coming from different angles with respect to the beam axis.

Concept: By utilizing a fixed detector (SBND), it samples multiple off-axis fluxes, providing unique insights into the neutrino spectrum

SBND unique features:

- Located just 110 meters from the neutrino source
- Not perfectly aligned with the neutrino beamline





Moving from on-axis to off-axis, the spectrum becomes narrower, and the peak shifts to lower energies

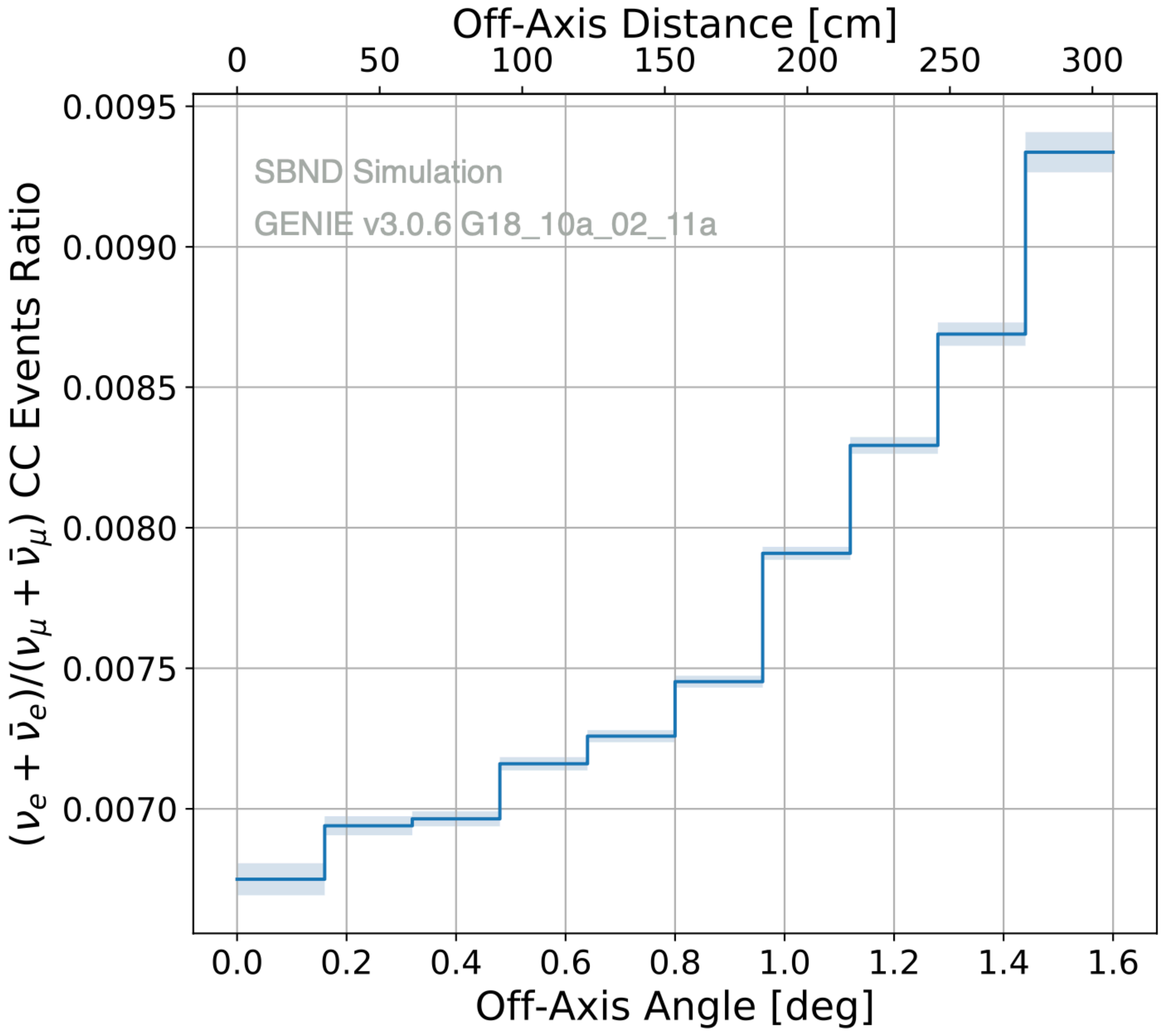
3. SBND PRISM: Impact on SBND cross sections

SBND PRISM will give us an invauable insight of the energy dependence of our cross-section measurements

Using SBND to explore topologies across different neutrino fluxes

- By treating different volumes of the SBND detector as separate detectors, we can explore neutrino topologies across varying fluxes.
- Key Points:
  - Each volume provides a distinct contribution from different interaction modes
  - Each volume also exhibits different energy dependencies

ν_e / ν_μ event rate is non-constant as a function of OAA

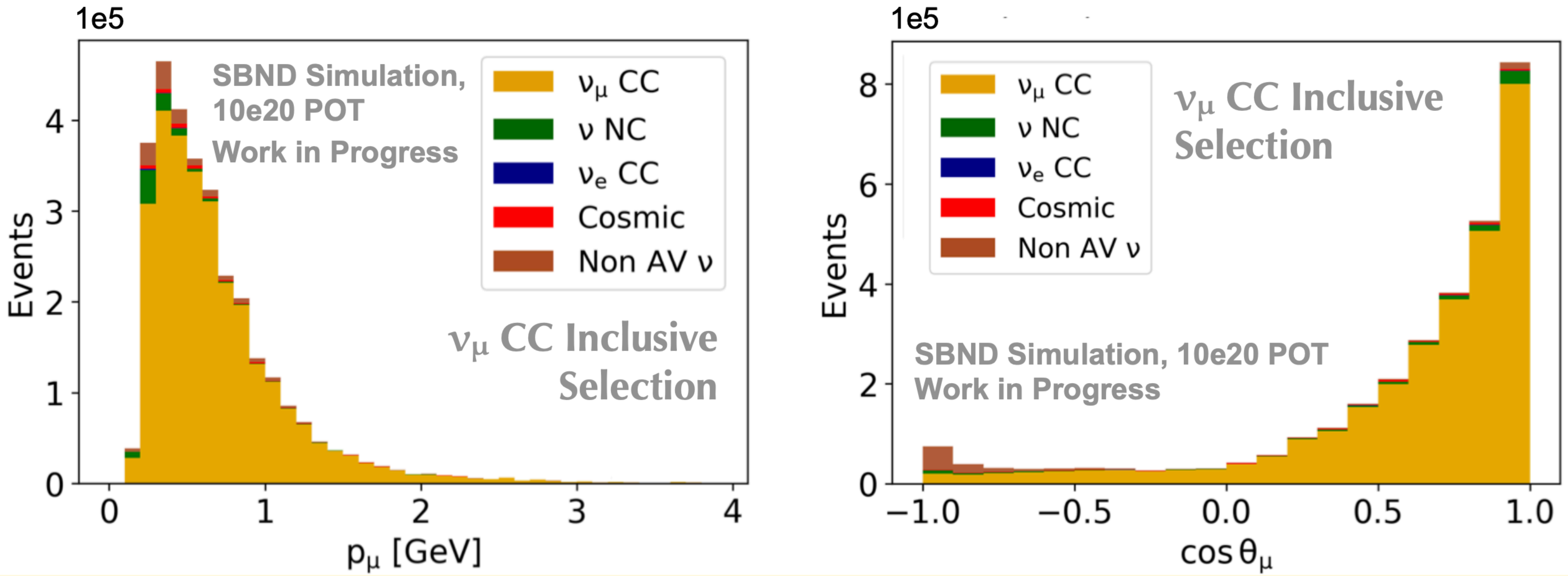


Cross-Section Physics at SBND

ν_μ CC Inclusive

The ν_μ CC inclusive analysis allows detailed study of muon kinematics with reduced uncertainties from FSI and statistics, leading to greater accuracy in comparisons with neutrino-argon interaction models

- This selection also aids in benchmarking detector performance and understanding the effects of the BNB flux
- The current selection achieves a highly pure sample of ν_μ CC interactions within the fiducial volume

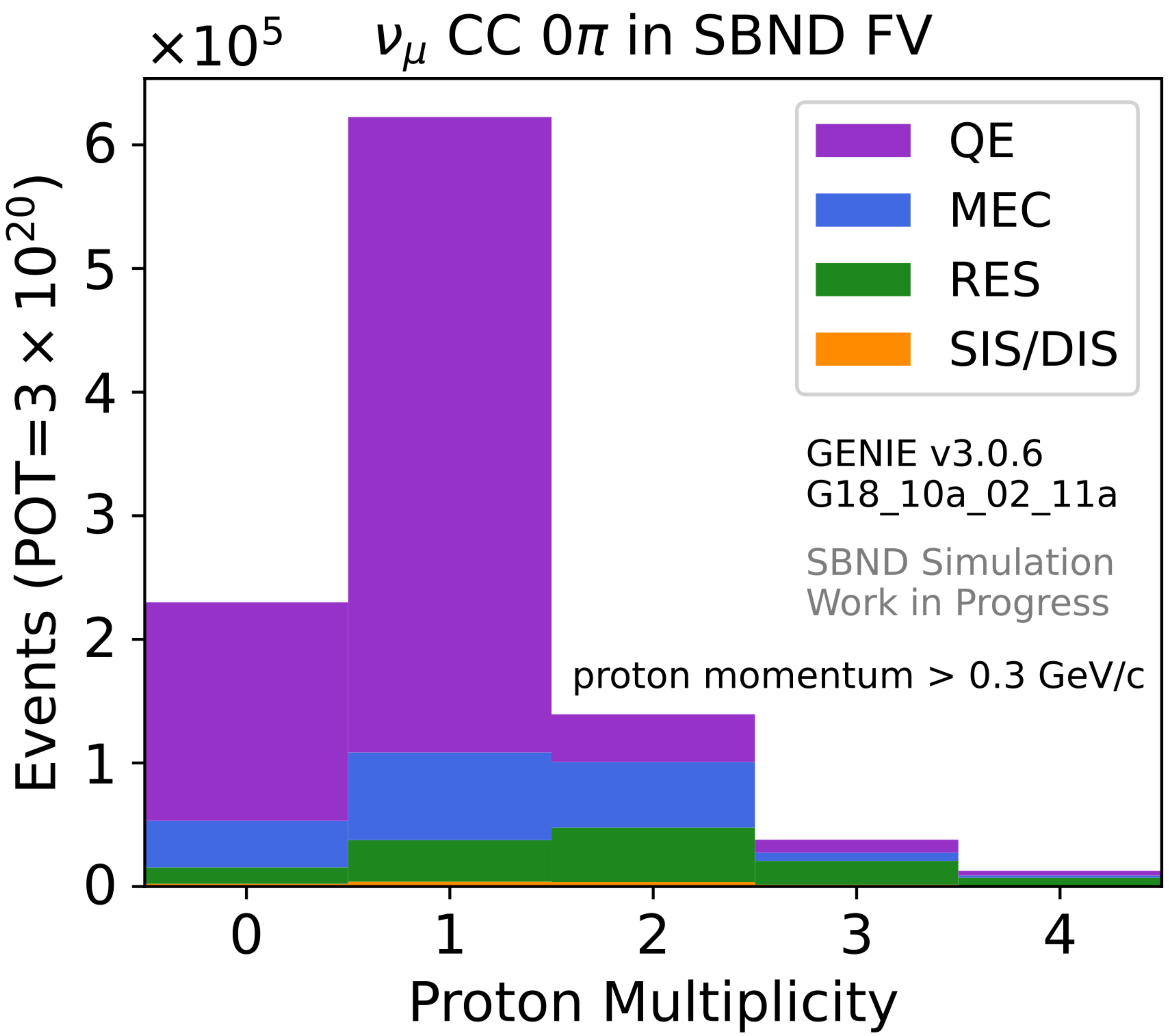


ν_μ CC, 0 π

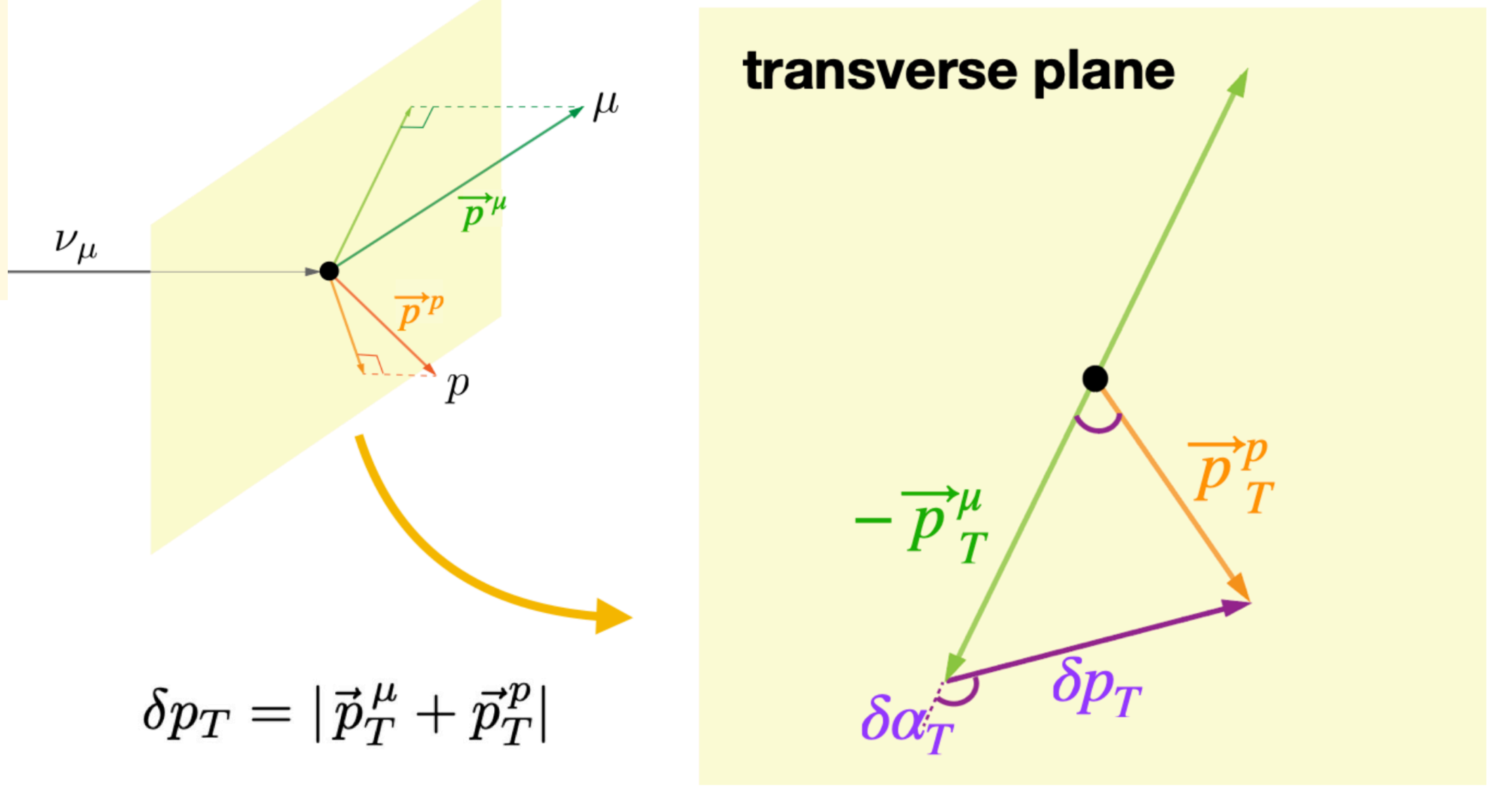
See more details in Moon Jung Jung's poster

SBND will make ν_μ CC 0π measurements with high-statistics and low reconstruction energy thresholds

- The focus is on specific ν_μ CC 0π **final state topologies** to study representative interaction modes
- For instance: QE is enhanced in the 1p channel

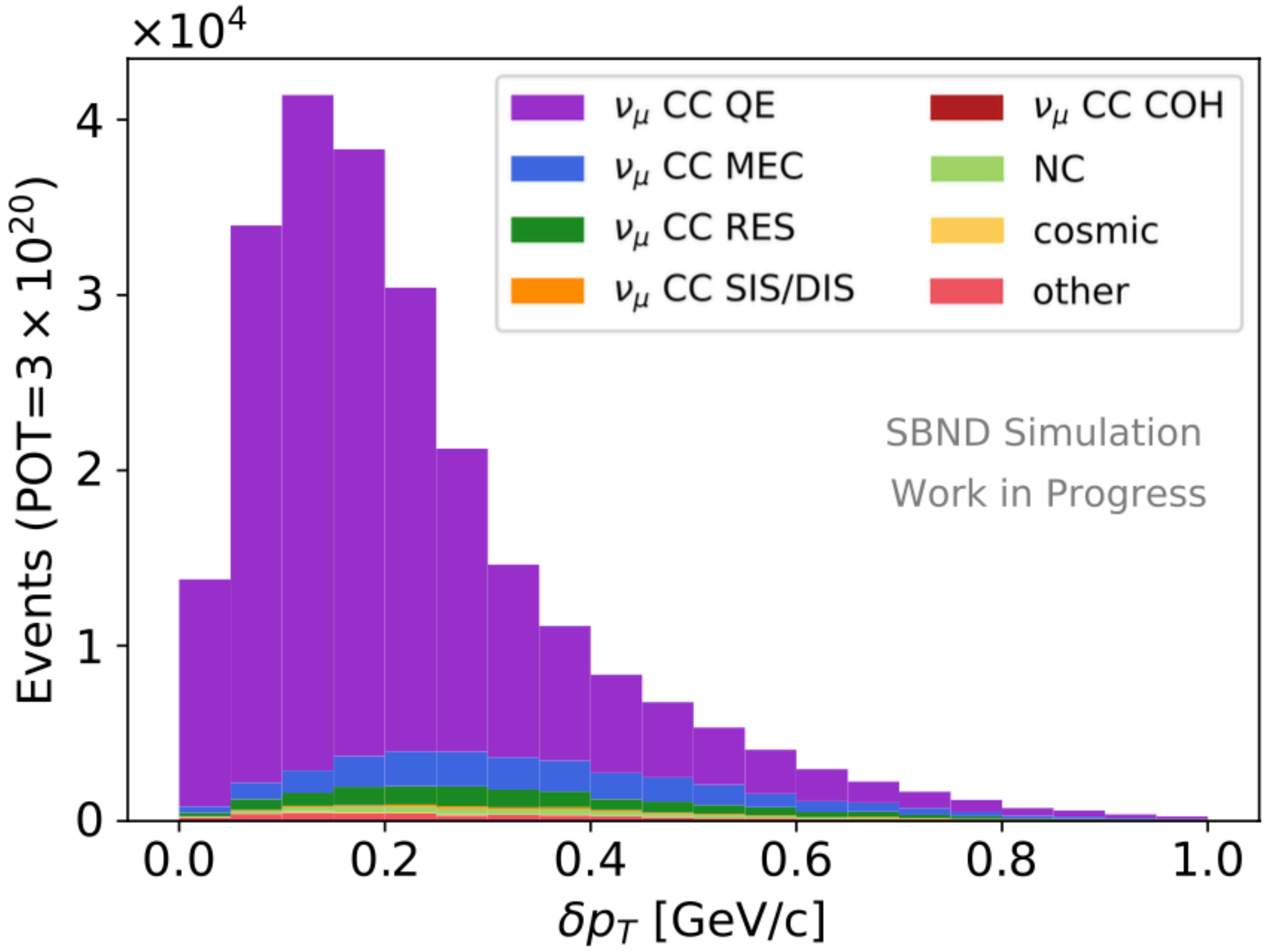


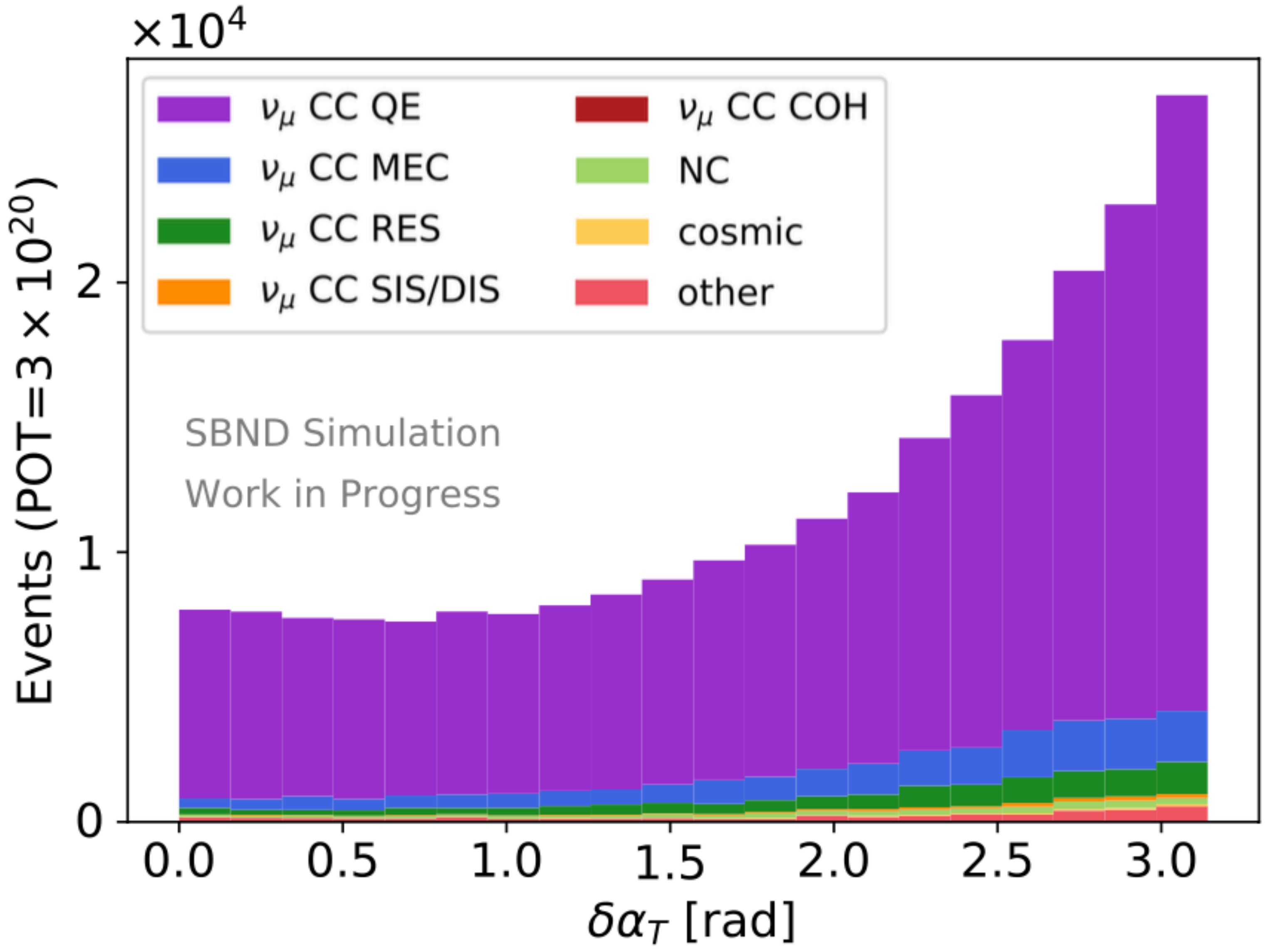
ν_μ CC, 1p 0 π

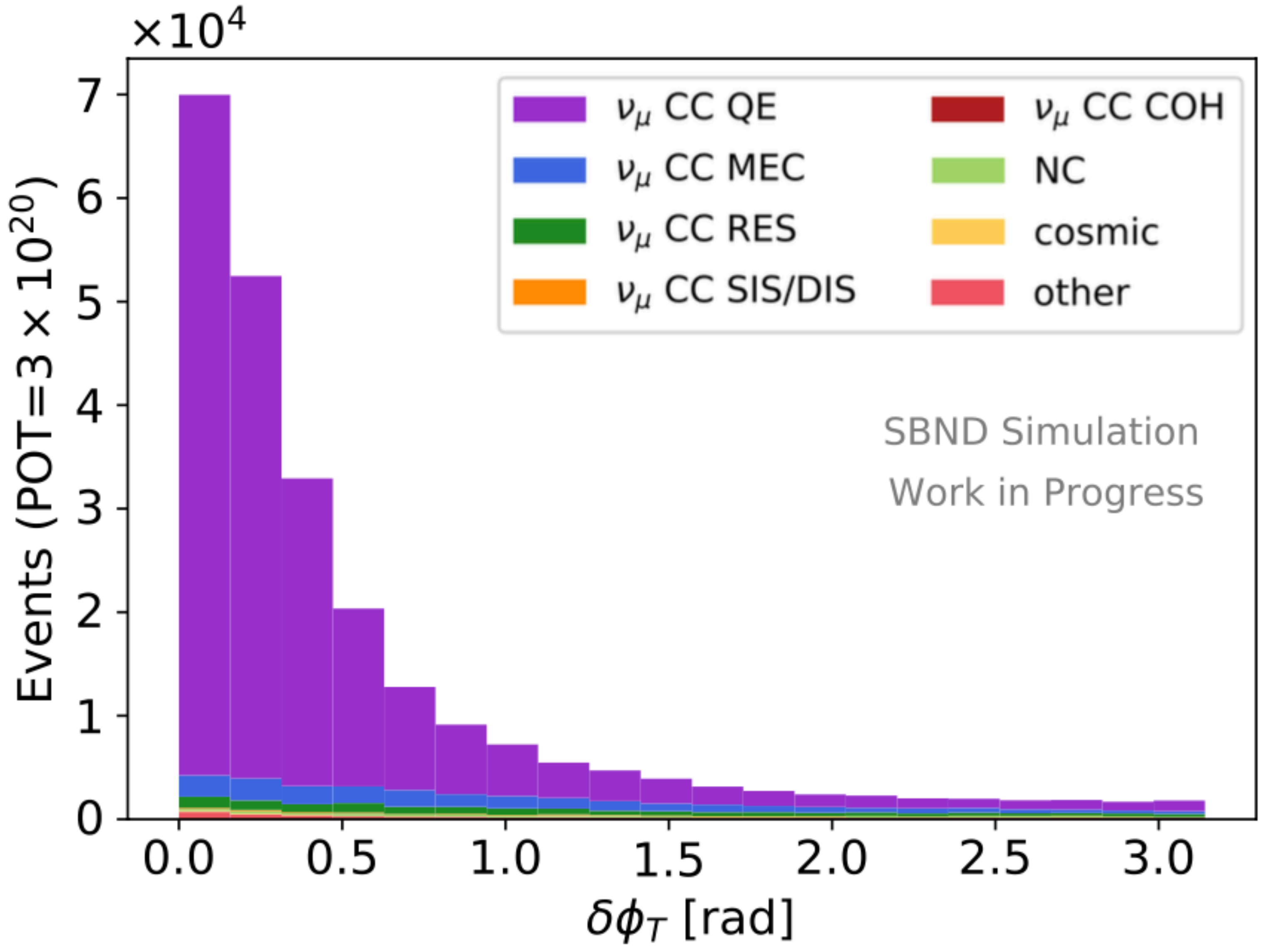


Probing Nuclear Effects with Transverse Kinematics Imbalance (TKI) variables

- 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







Commissioning and Data Collection

Post-LAr-Fill Commissioning

- *Completed in the spring, leading to the collection of an initial BNB neutrino dataset in early July*

Current Work

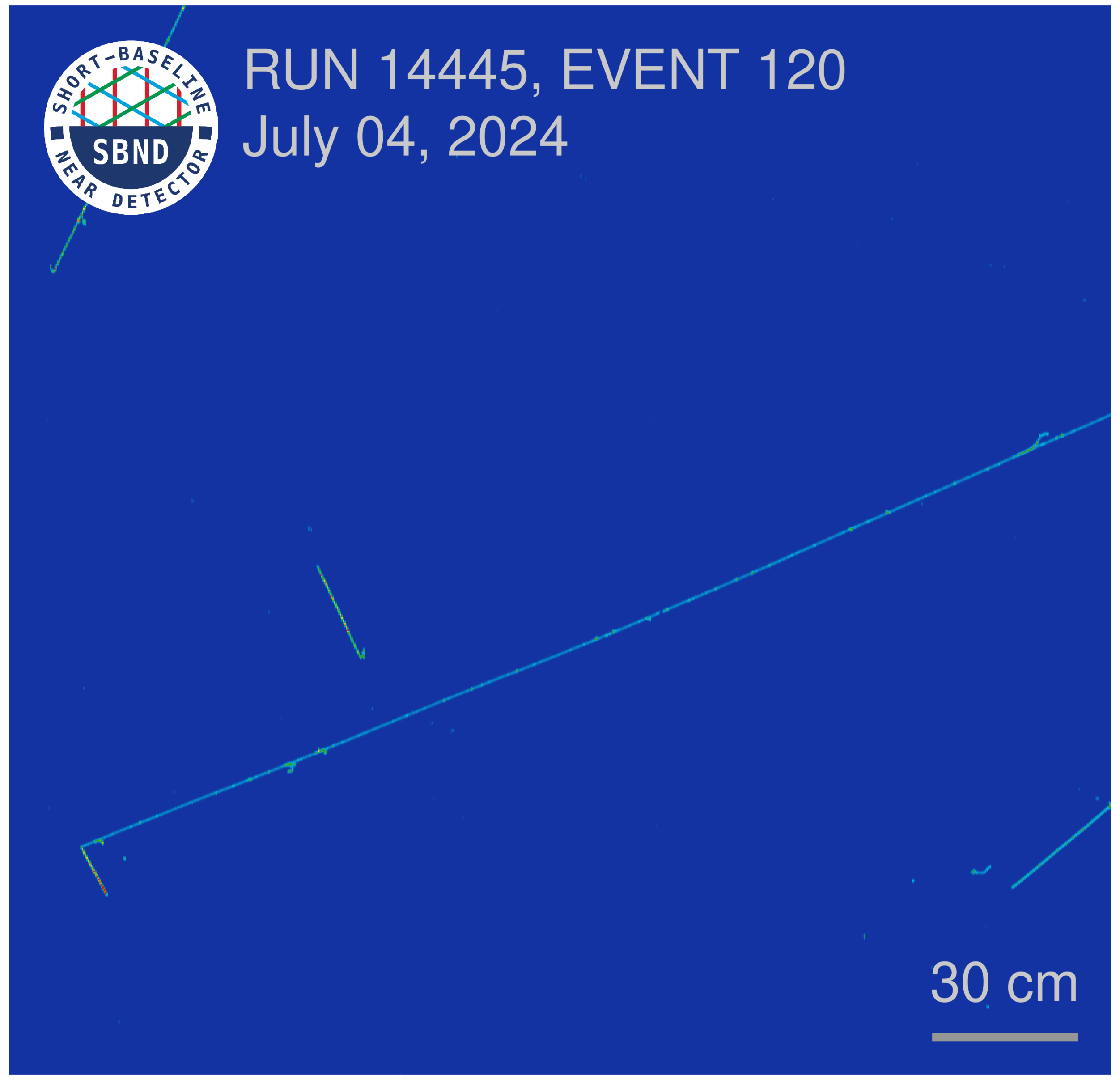
- *Installation and commissioning of the top CRT layers and X-ARAPUCA light detector readout*
- *Ongoing calibration of the detector*

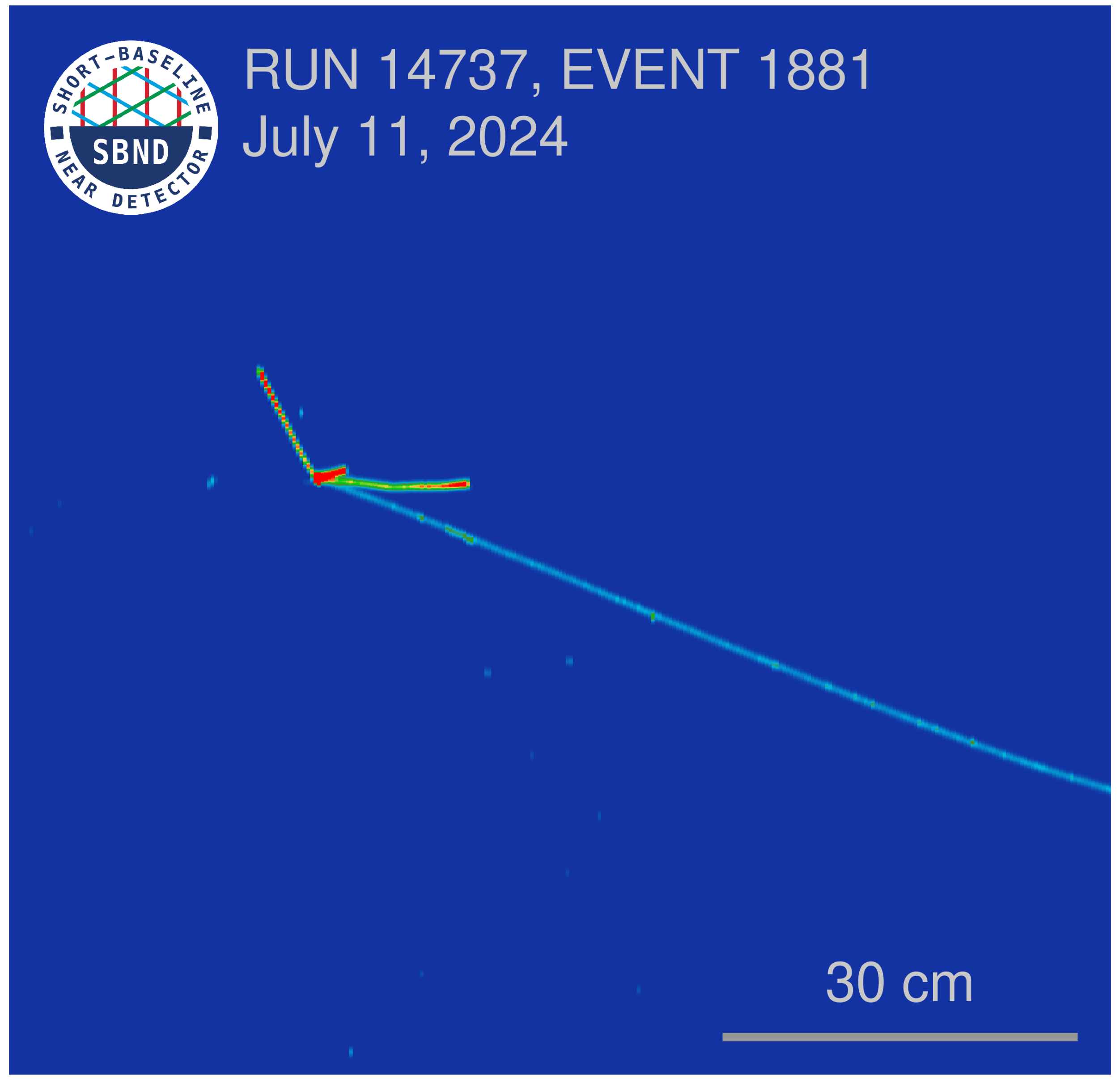
Performance Insights

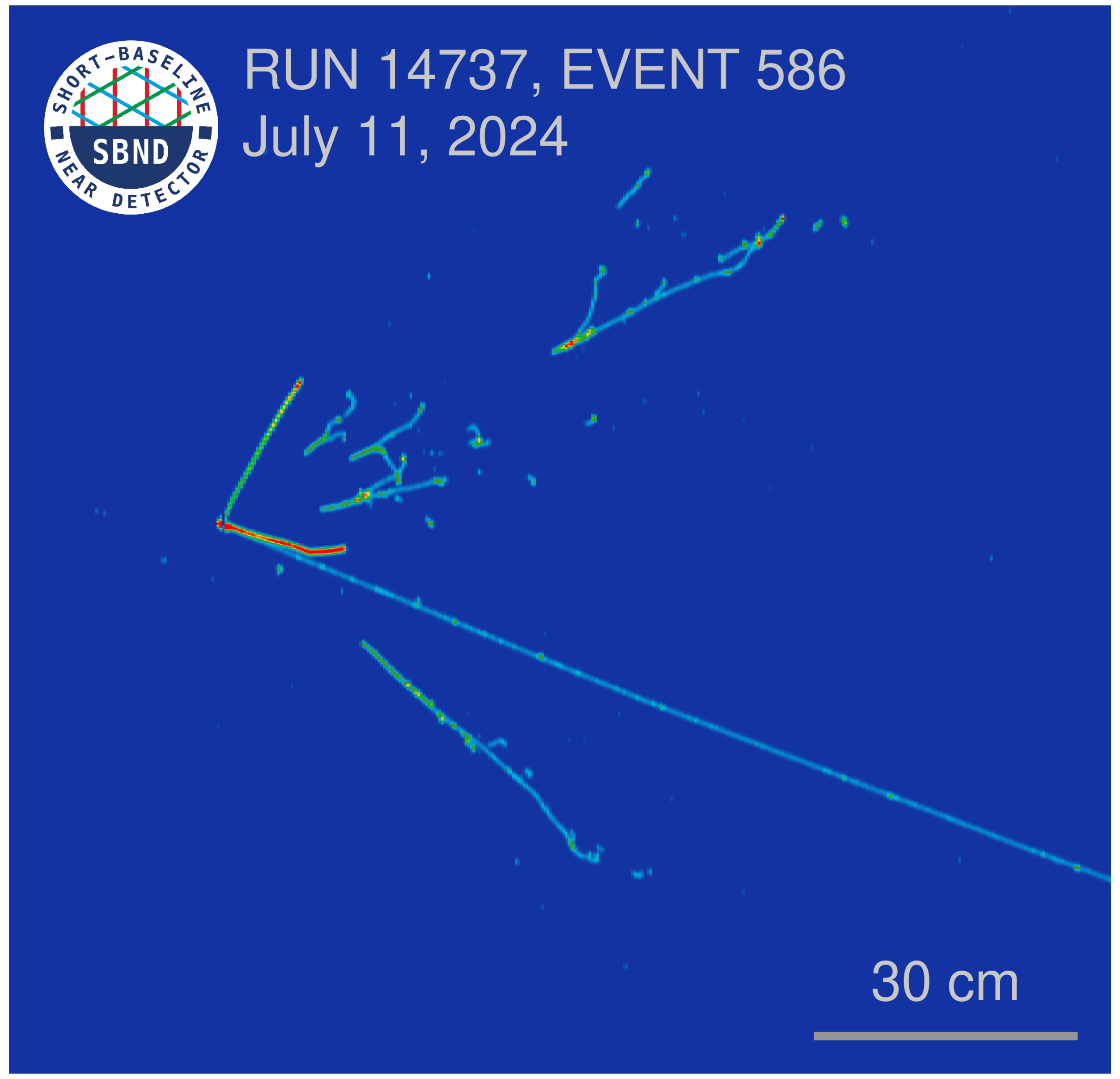
- *Initial assessments of reconstruction performance on collected data are promising*

Future Outlook

- *BNB beam is expected this Fall 2024*







Summary

- SBND's advanced LArTPC technology and proximity to the BNB target ensure high statistics and robust systematic uncertainties for diverse measurements

- Our innovative approches: SBND-PRISM, GiBUU integration as event generator, and improved flux uncertainty will enable unique and precise measurements

- Our cross-section program include:
  - *Multi-dimensional differential measurements in high-statistics channels.*
  - *World-first or leading measurements in rare neutrino interaction channels*
  - *Constraining neutrino interaction uncertainties for SBN oscillation searches and BSM studies*

- Reconstruction, selection, and analysis tools for cross-section measurements are well-developed in SBND simulation.

Stay tuned!

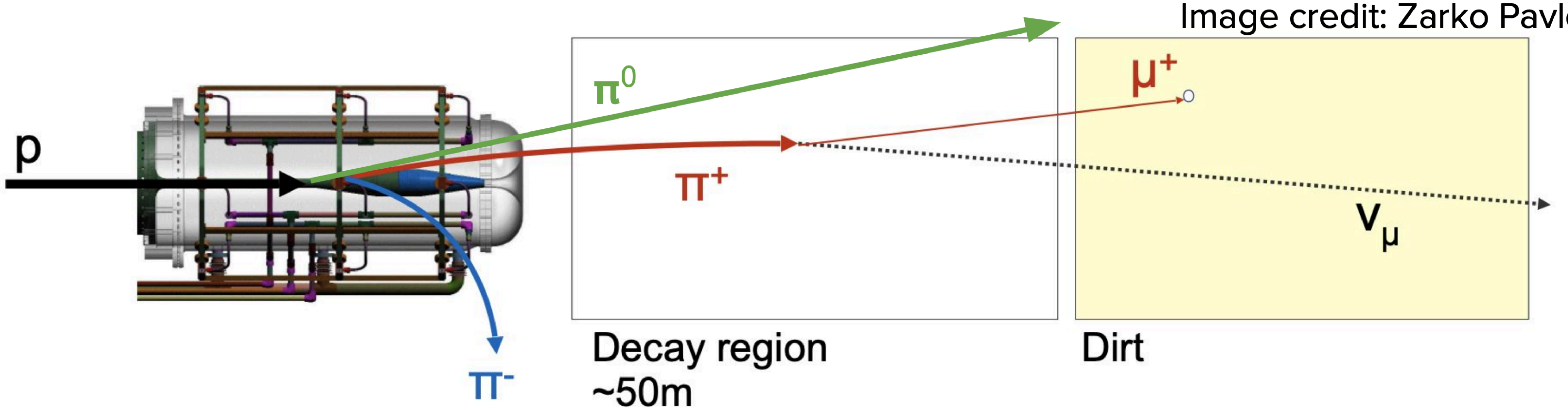

Thank you!
ROBERT
SBND Collaboration

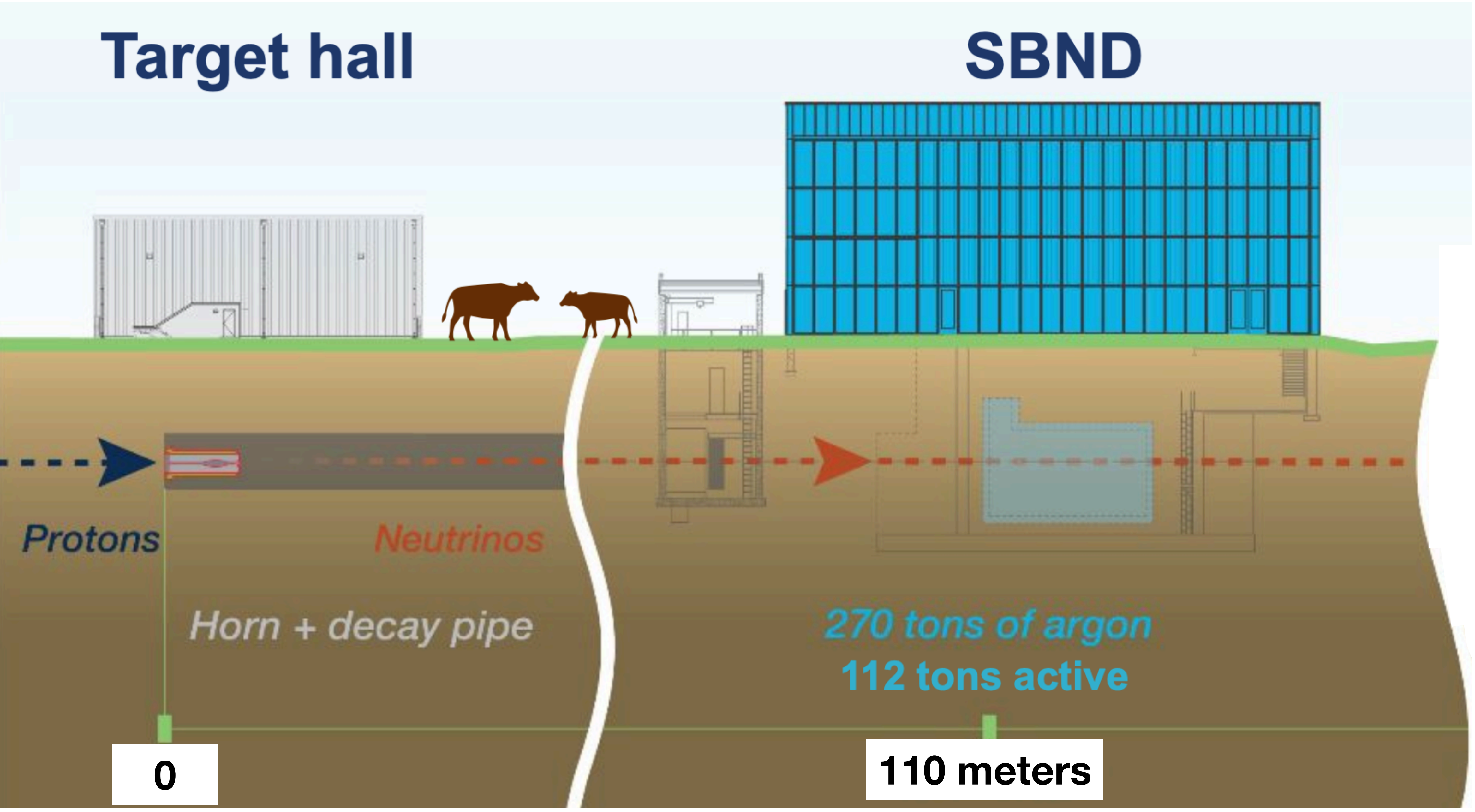
Backup

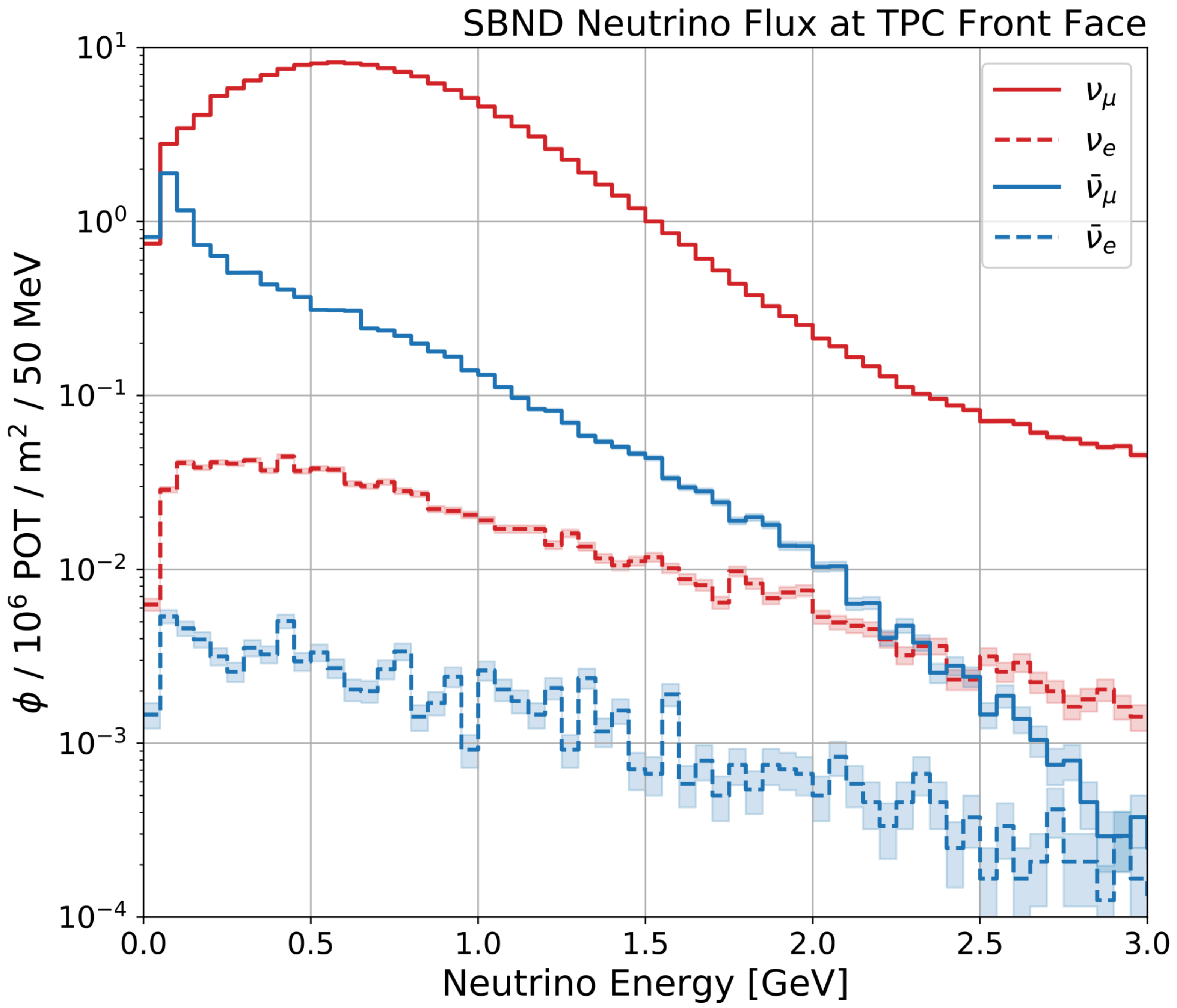
Booster Neutrino Beam (BNB)

- **8 GeV protons** from the Booster
- Beryllium **target**
- 1 Magnetic **horn**
- **Decay Pipe**: 50 m
- 25m steel **absorber**

Image credit: Zarko Pavlovic







ν_μ Charged-Current, Pionless Final States

To check with Shweta's plots