SBND's Neutrino Interaction Cross Section Physics Status and Plans

2nd April 2024
2nd Short-Baseline Experiment-Theory Workshop
Santa Fe

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On behalf of the SBND Collaboration

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h.lay@lancaster.ac.uk

Me!

As I'm attending remotely, for those of you who don't know me:

- Originally from Warwickshire in the UK
- Currently a final year PhD student at Lancaster University writing my thesis on neutral current neutral pion production.
- Have been a member of the SBND collaboration for the last 3.5 years

(Not at the same time)

Outline

- **Introduction**

    The low-energy excess, the Fermilab Short-Baseline Neutrino program and the Short-Baseline Near Detector

- **Cross-Sections at SBND**

    Why cross-sections? And why SBND?

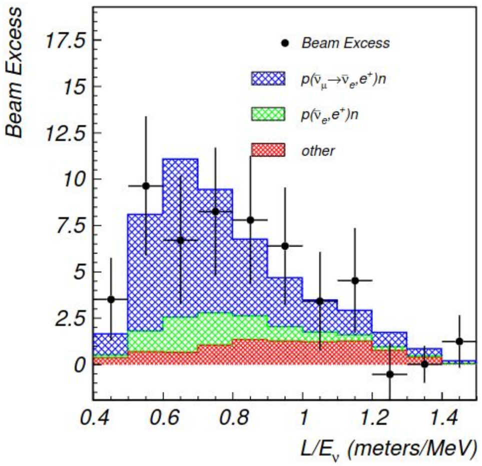
- **SBND Current Status**

    Where are we right now?

Introduction

Low Energy Excess

Phys. Rev. D 64 112007 (2001)



LSND saw a 3.8σ excess of $\bar{\nu}_e$ in a well understood decay-at-rest $\bar{\nu}_\mu$ beam.

Low Energy Excess

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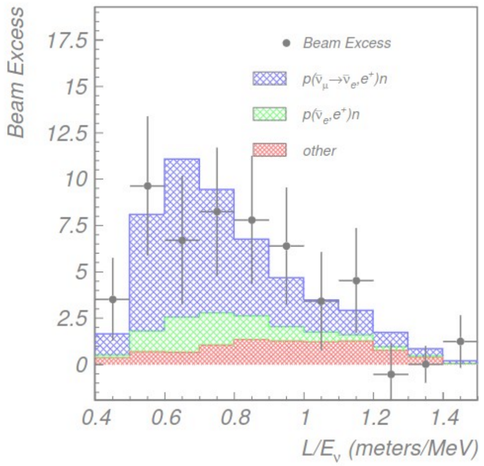

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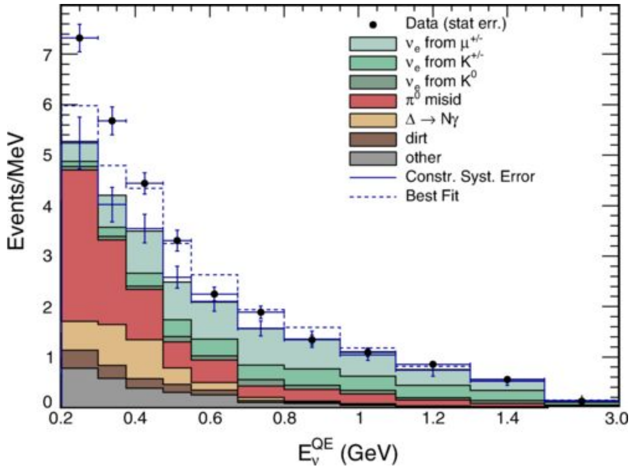
Phys. Rev. D 103 052002 (2021)

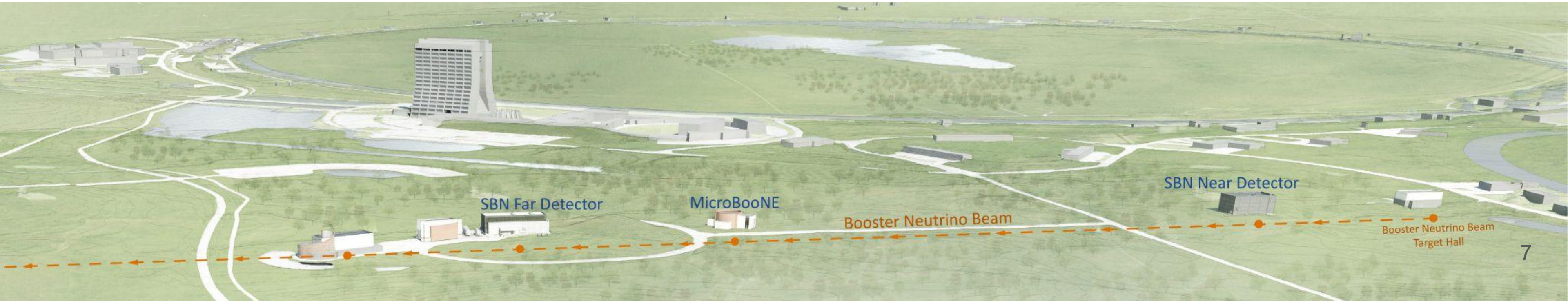


MiniBooNE then saw a 4.5σ/2.8σ excess of $\nu_e/\bar{\nu}_e$ in the Fermilab Booster Neutrino Beam.

Short Baseline Neutrino Program @ Fermilab

The Fermilab Short-Baseline Neutrino (SBN) Program was designed to investigate the LSND & MiniBooNE results with a world leading three detector experiment.

SBN consists of three LArTPCs situated on the Booster Neutrino Beam at Fermilab. Use of the same neutrino beam, target material and detector technology will enable us to restrict systematic uncertainties to the %-level.



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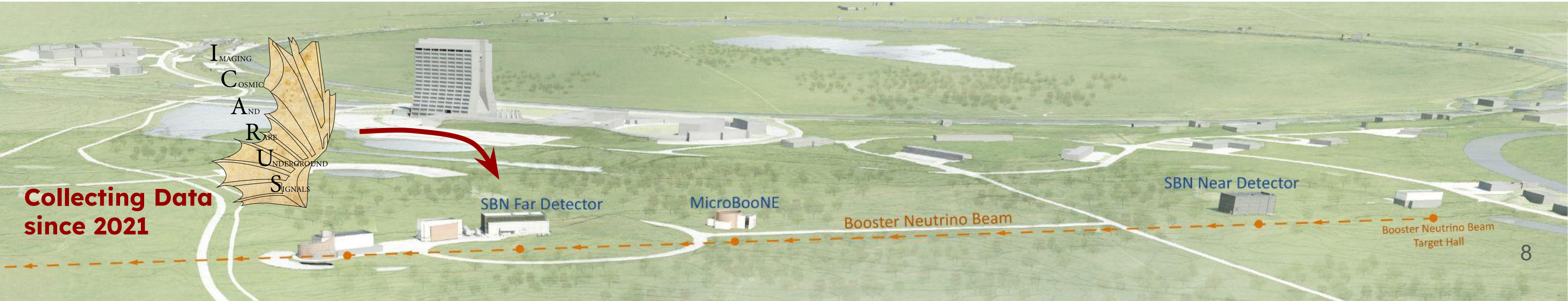

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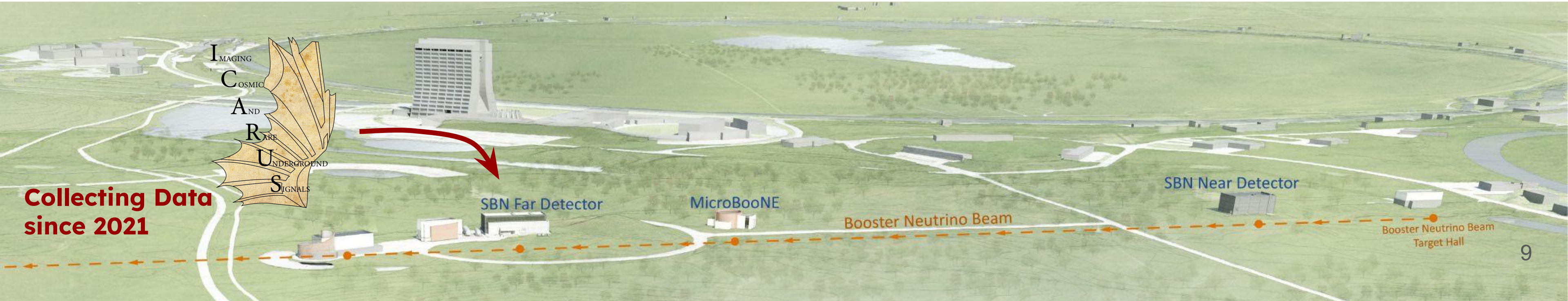
See Minerba's talk straight after this one, for ICARUS's own exciting cross-section program.



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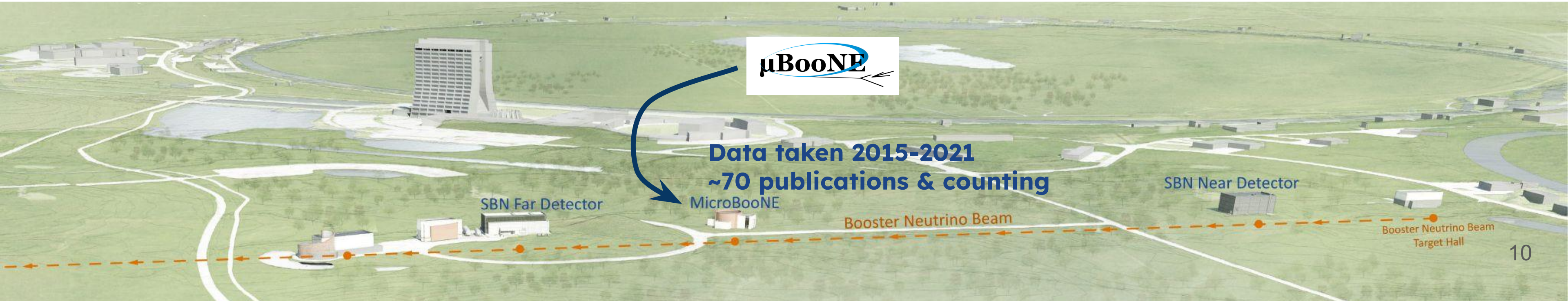

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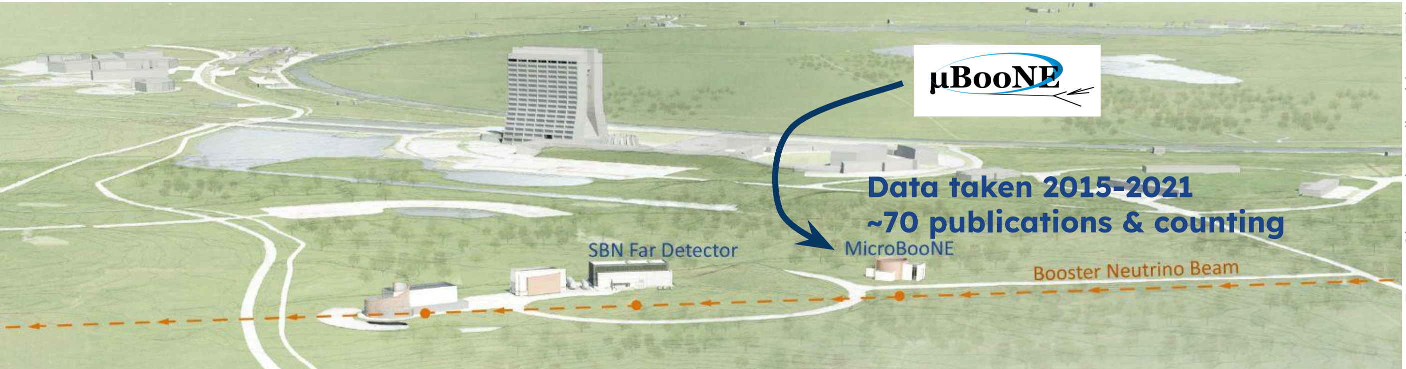
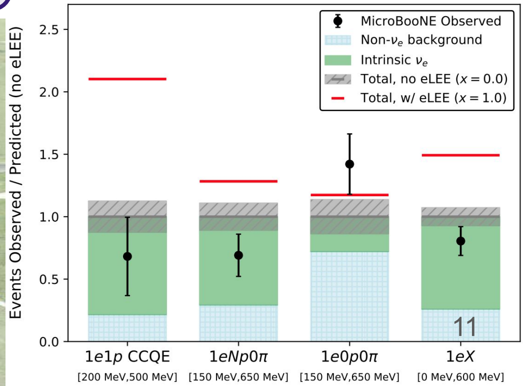
See Erin's talk from this morning for much more great detail on MicroBooNE's LEE results!



Phys. Rev. Lett. 128 241801



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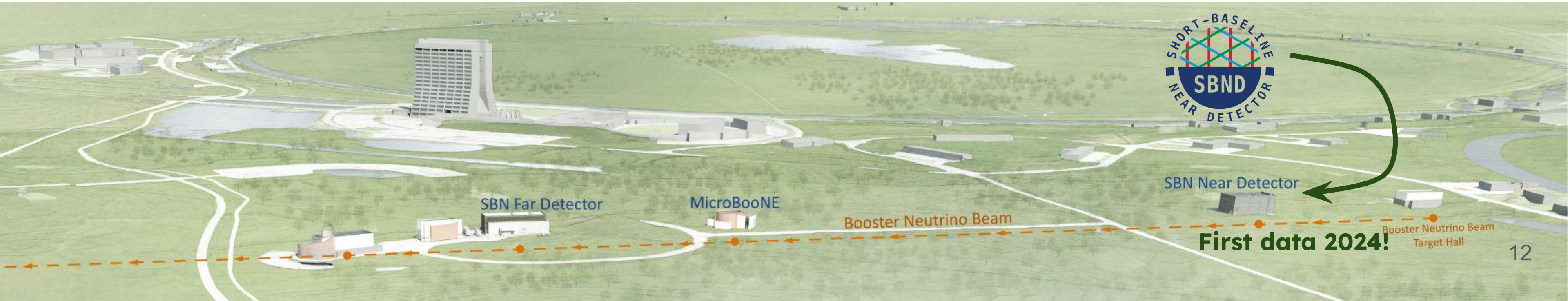
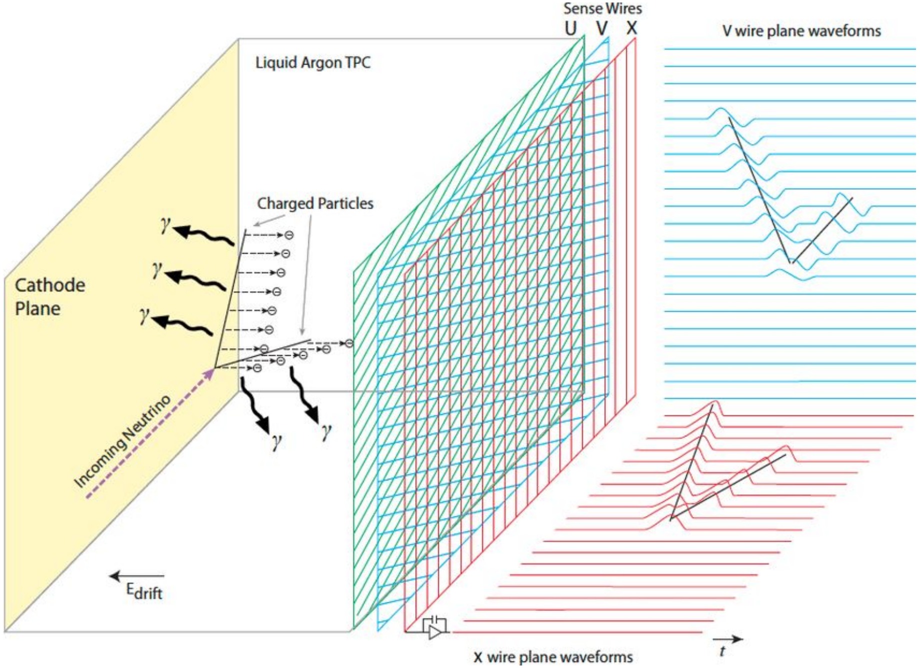
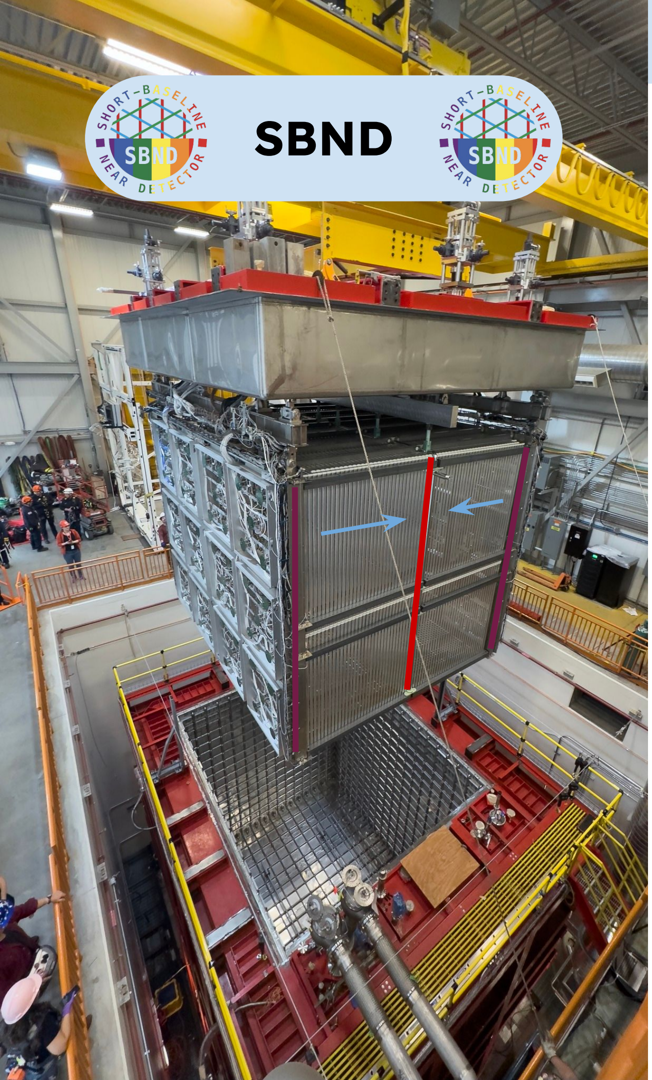
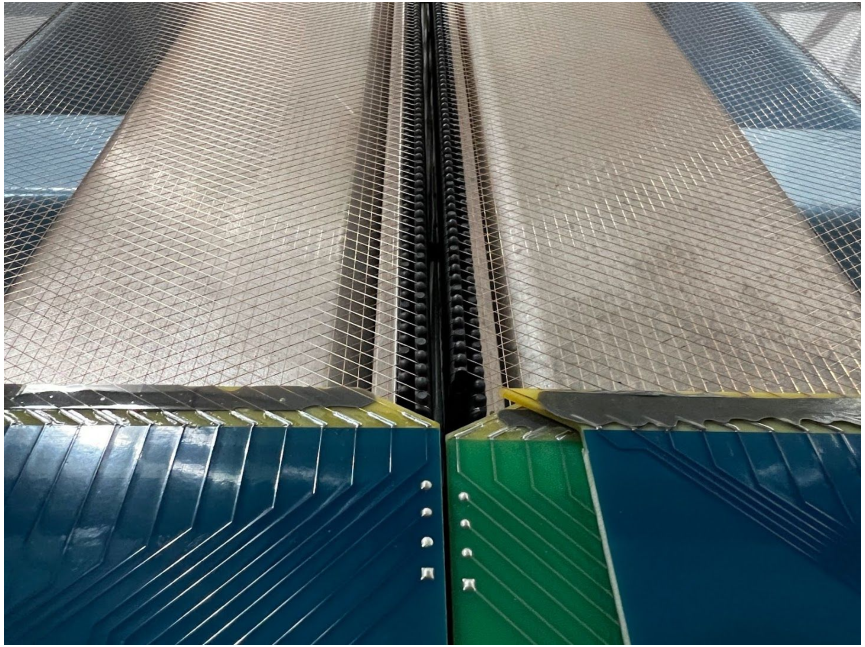



SBND


Sense Wires
U V X
V wire plane waveforms
Liquid Argon TPC
Charged Particles
Cathode
Plane
Incoming Neutrino
E_{drift}
X wire plane waveforms
t

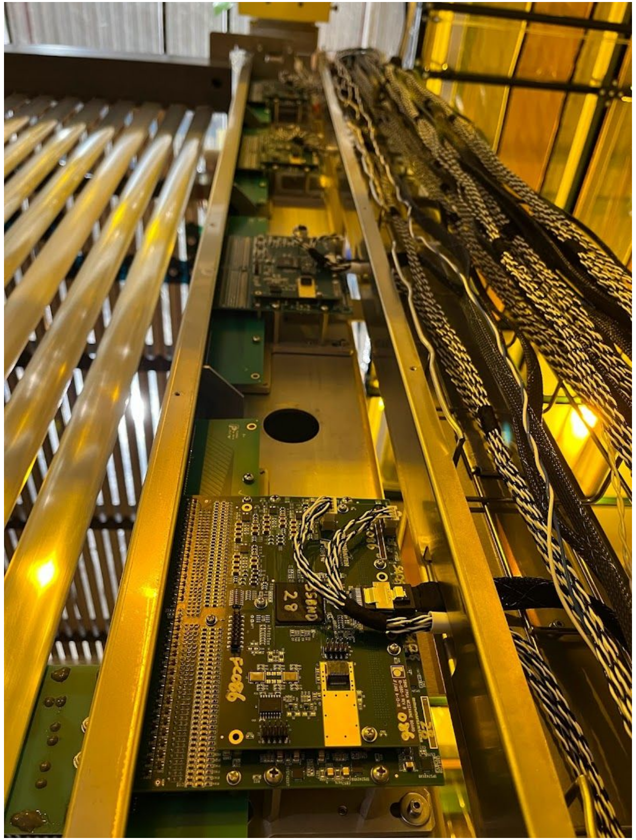


Two time projection chambers (TPCs) with a shared central cathode, opposing electric fields and readout anode planes either side.



Anodes

3 wire planes (0°, -60° and +60°)
3mm spacing
Total of 11,264 wires

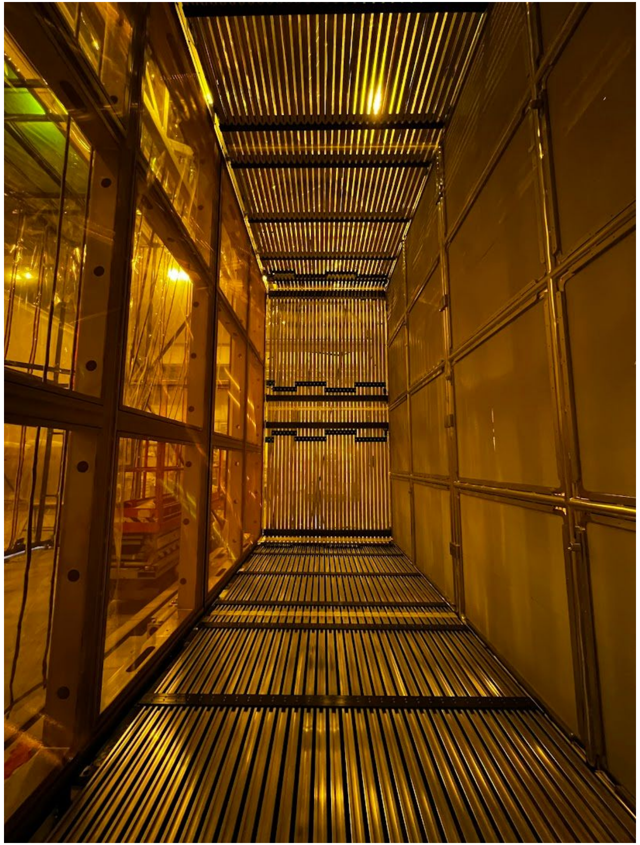


Cold Electronics

Shaping, amplification and digitisation of TPC waveforms takes place in the LAr to reduce noise.

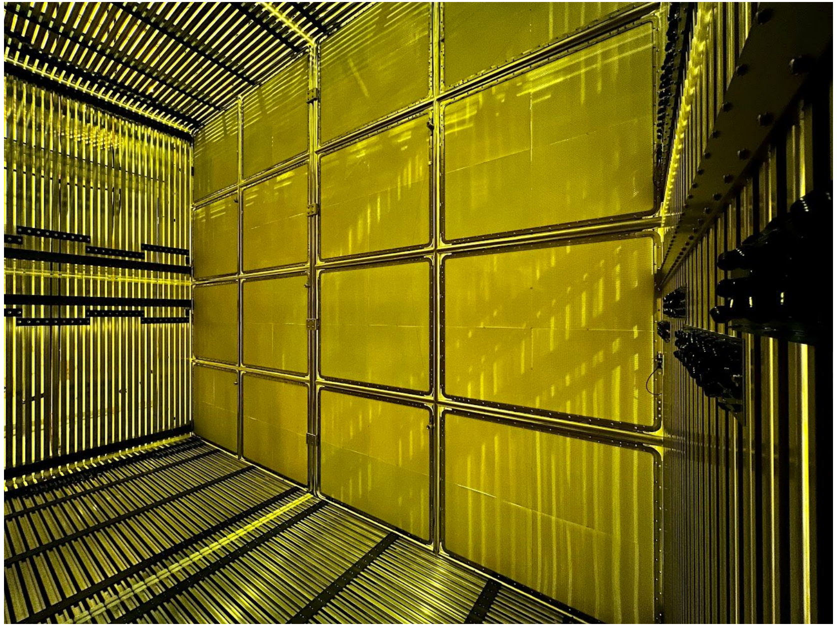
Field Cage

Surrounds each TPC to ensure consistent voltages steps establish the uniform 500V/cm electric field.



Cathode

As well as providing the -100kV bias to create electric field, the panels are TPB coated to shift reflected light from VUV to visible.

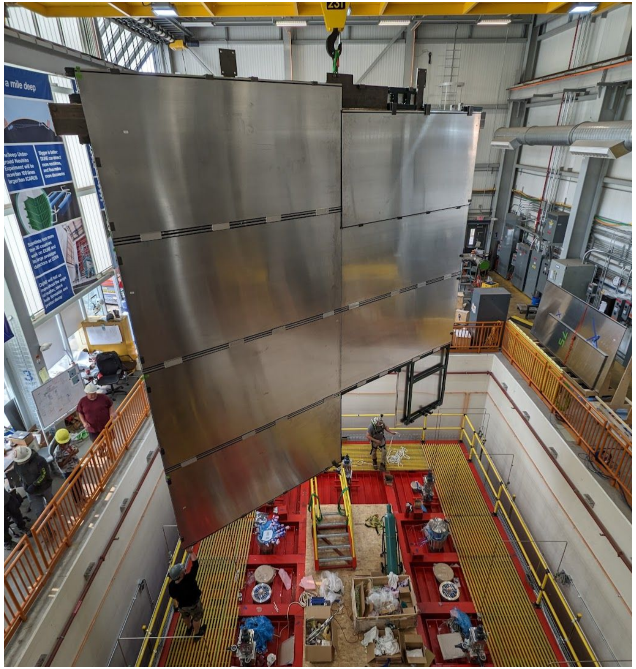


Photon Detection System (PDS)

A combination of 120 PMTs and 192 X-ARAPUCAs.
Sensitive to both the original VUV and the cathode-reflected visible light.

Cosmic Ray Taggers (CRTs)

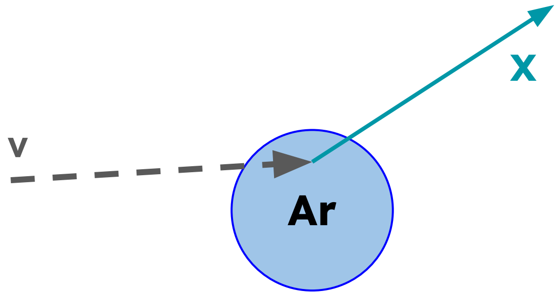
Cryostat surrounded with ~4π coverage of plastic scintillator for tagging incoming cosmic activity.



Cross-Sections at SBND

Why Cross-Section Physics?

- Neutrinos are the both the subject and the probe with which we are investigating the confusing picture of short-baseline physics.
- Understanding how they interact with our detectors is critical.



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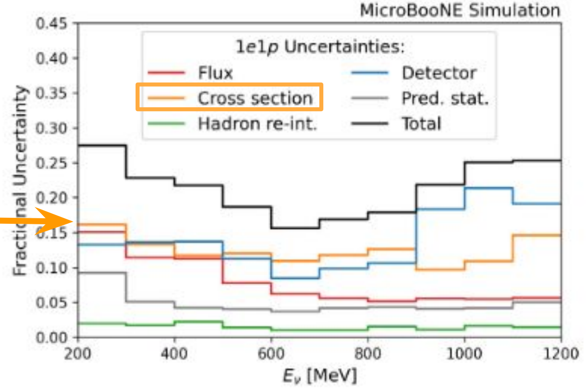
- Currently one of the largest systematic uncertainties faced by neutrino experiments.

Phys. Rev. D 105 112003 (2022)



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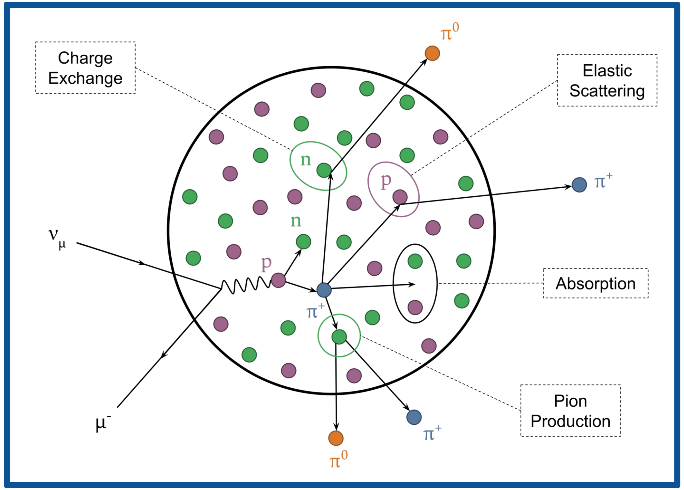
- Currently one of the largest systematic uncertainties faced by neutrino experiments.
- Complex nuclear targets (such as argon) mean that effects like multi-body correlations impact the primary interaction.
- Interaction products can also undergo further interaction in the nuclear medium before escaping the nucleus.



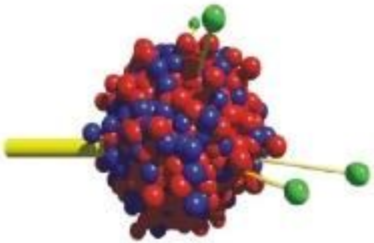
Why Cross-Section Physics?

- The complexity of the nuclear environment makes modelling and data comparisons difficult.

- SBND has the ability to use both GENIE & GiBUU as integrated event generators to make full event-by-event simulation predictions.
    - GENIE combines theoretical models with fits to global experimental data[1]
    - GiBUU transport theory based model[2]

Genie

UNIVERSAL NEUTRINO GENERATOR & GLOBAL FIT



GiBUU

[1] Nucl. Instrum. Meth. A 614 87

[2] Phys. Rev. C.94.035502 & arXiv: 2311.14286

Why SBND?

Vast statistics

High-precision detector

Flux sampling ability (PRISM)

Critical phase-space coverage

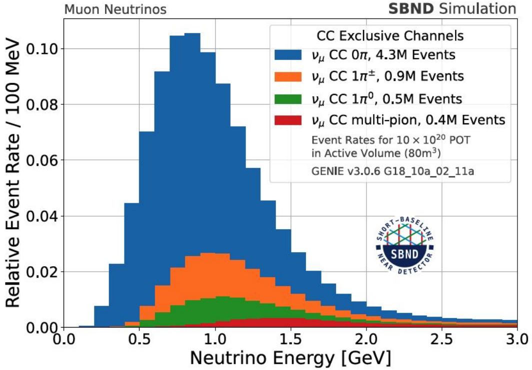
Vast Statistics

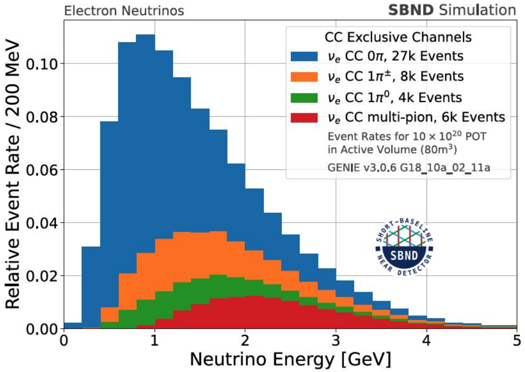
Thanks to its location only 110m from the BNB target, SBND will collect the largest ever dataset of neutrino-argon interactions (by an order of magnitude).

With this dataset:

- Many channels will have enough statistics for double or even triple differential measurements.
- Measurements of rarer channels become possible.

CCν_μ ~2million / year

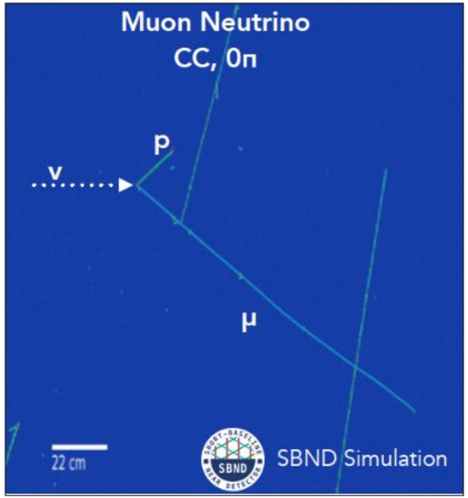


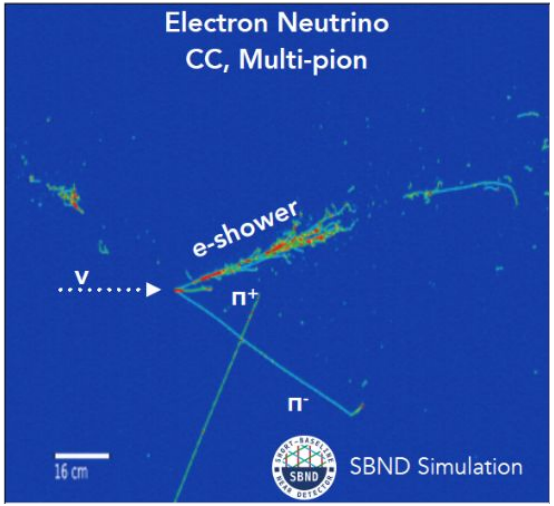


CCν_e ~15k / year

High-Precision Detector

- 3mm wire spacing allows for high-resolution imaging of complex final states.
- O(ns) timing resolution from PDS & CRT systems supplements TPC reconstruction.

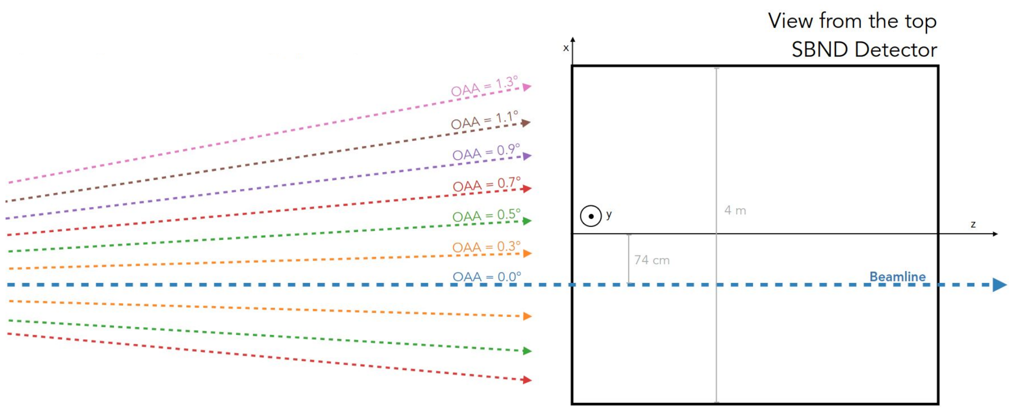


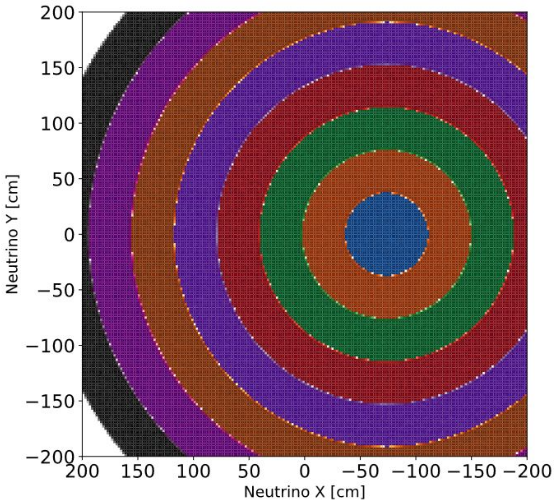


- Precision calorimetry allows for efficient particle identification.
- Low reconstruction thresholds.

SBND-PRISM

The BNB actually passes through SBND ~74cm from the centre.



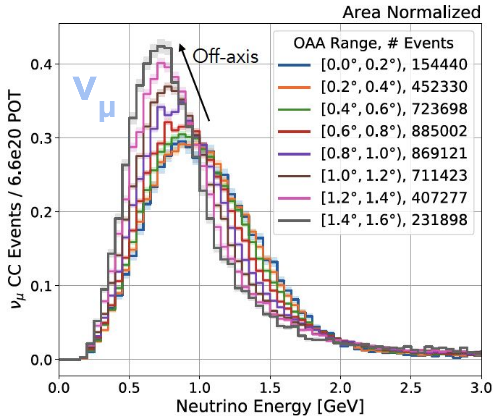


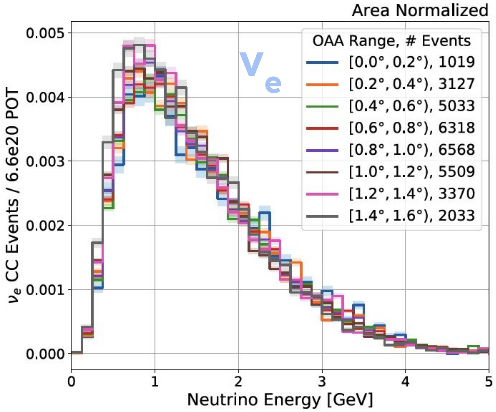
At a distance of 110m this allows SBND to access to off-axis angles of up to 1.6°.

SBND-PRISM

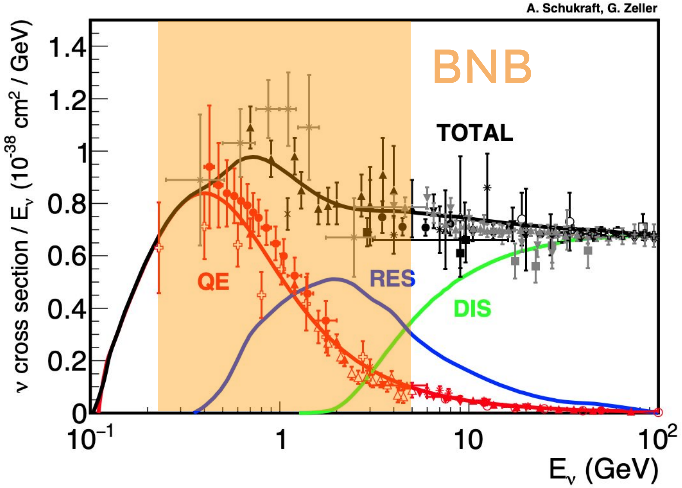
Due to the nature of the production mechanisms for ν_μ and ν_e (two-body vs. three-body) the resulting flux shape differences for each PRISM bin are far more pronounced for the ν_μ events.

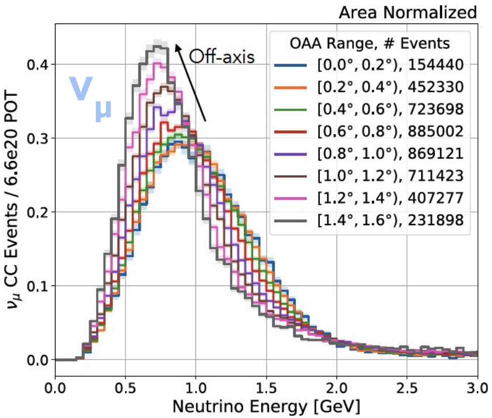
This will allow SBND cross-section measurements to access the interplay between neutrino energy and final state kinematics, performing the same (differential) measurements in different PRISM bins.

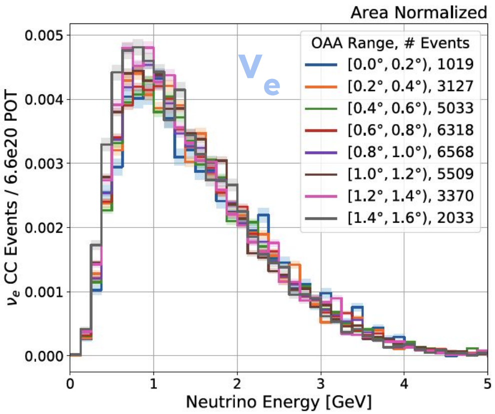




SBND-PRISM



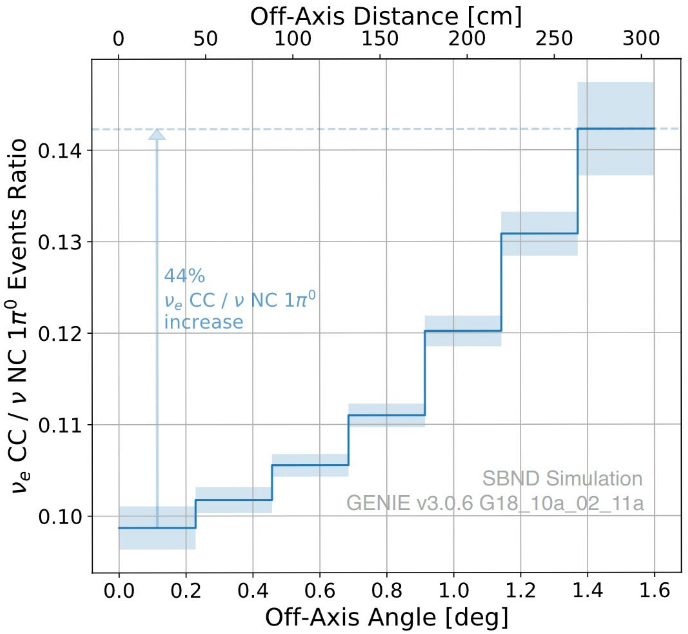




The more off-axis PRISM bins receive smaller contributions from non-QE processes whilst the central bins are more enhanced in MEC, RES and DIS events. Again this will allow analyses to further isolate important model discrepancies.

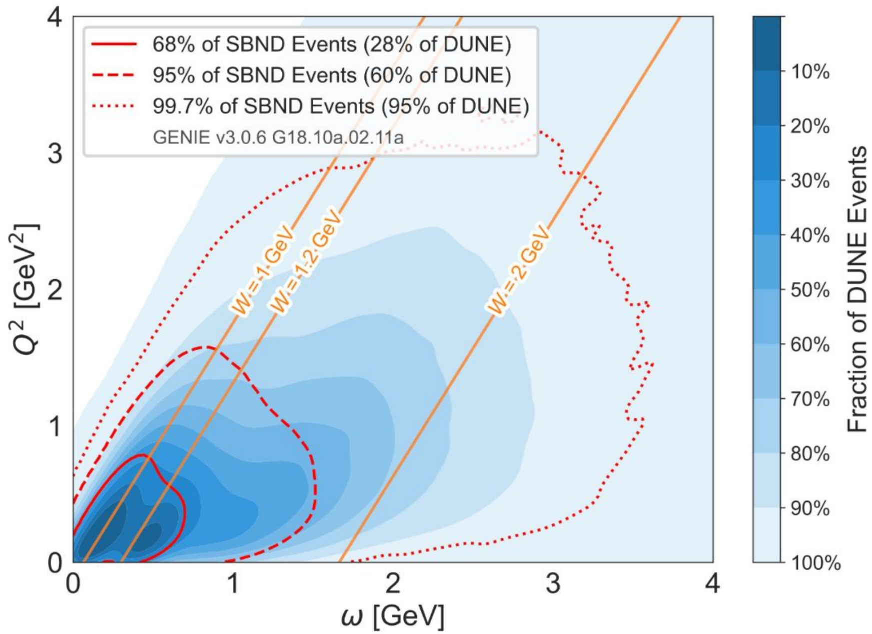
SBND-PRISM

The differences can also be exploited in decreasing backgrounds at increasing angles (e.g. NCπ^0 in CCν_e measurements).



See Pedro's talk tomorrow at 4pm for more on how SBND-PRISM can be used towards our physics goals.

Critical Phase Space Coverage



DUNE kinematic coverage is represented with the blue 2D histogram.
SBND kinematic coverage is shown with 3 contours, representing 68%, 95%, and 99.7% of all SBND data.

The cross-section measurements made by SBND will not just be of relevance to the Short-Baseline community but are more broadly important in constraining interaction systematics for other experimental programs, such as DUNE.

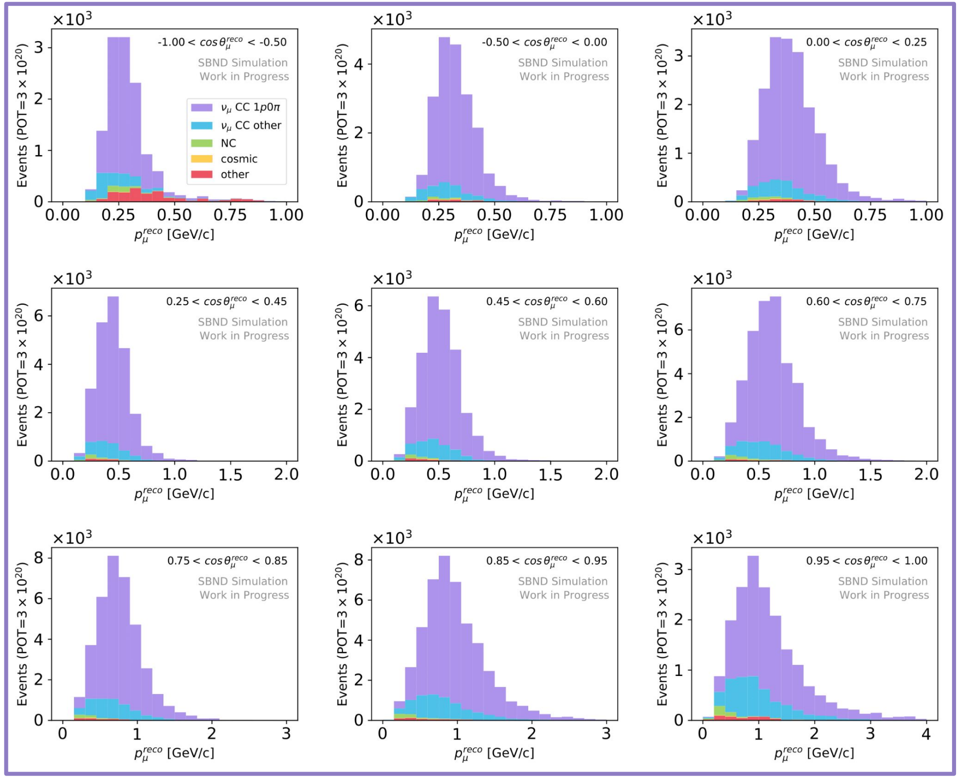
SBND will cover a large fraction of the DUNE kinematic phase space with significant statistics on the same target material.

Ongoing Work

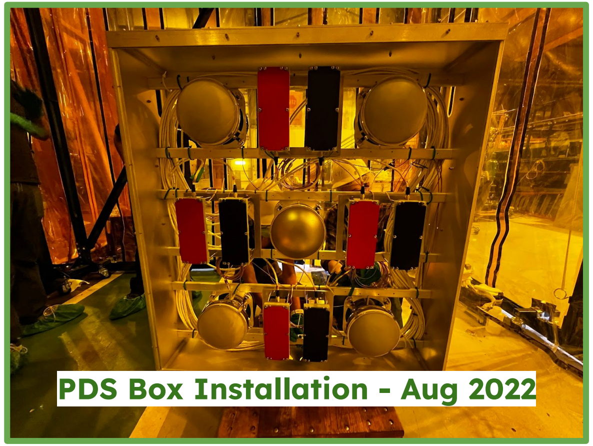
Lots of work has gone into preparing Monte Carlo selections in advance of first data.

This includes:

- First data efforts: CCν_μ Inclusive, CCν_μ0π, CCν_e Inclusive
- Longer term projects include NC1π^0, CCν_μ1π, Λ-production, ...



SBND Current Status


PDS Box Installation - Aug 2022


TPC Completion - Oct 2022


Detector Move - Dec 2022


Detector Installation - April 2023


1st CRT Wall Installation - May 2023

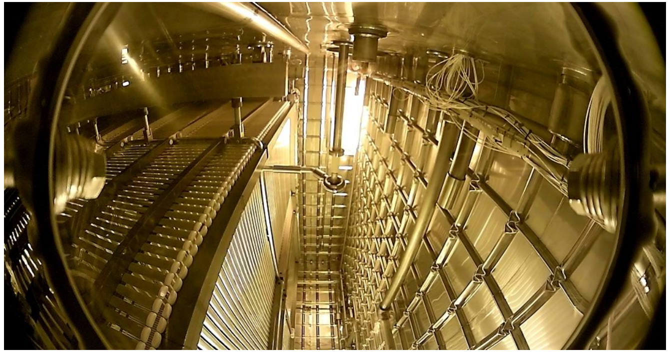

Argon Fill - February 2024

SBND Commissioning

Over the last couple of months:

- The SBND cryostat has been cooled and filled with LAr.
- The cold detector components are being switched on and operated.
- Cold commissioning has begun - first PMT voltage settings, first TPC noise measurements, etc
- We're excited to take our first data this year, and begin utilising the unique capabilities of SBND!

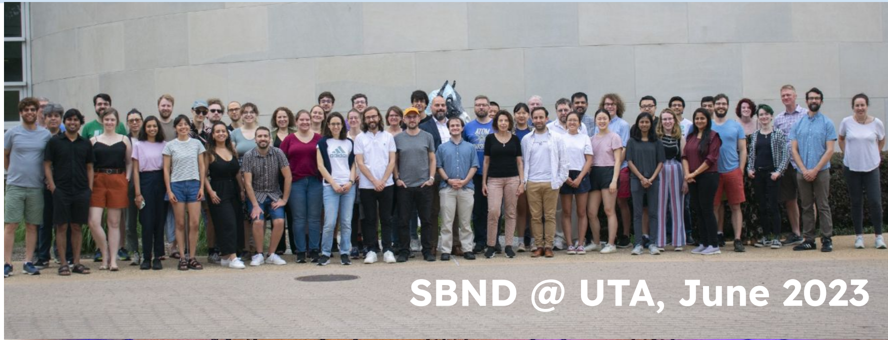
Supraja will talk tomorrow at 4:30pm about another exciting aspect of our physics program, BSM searches!



Filling & Cooling - February 2024

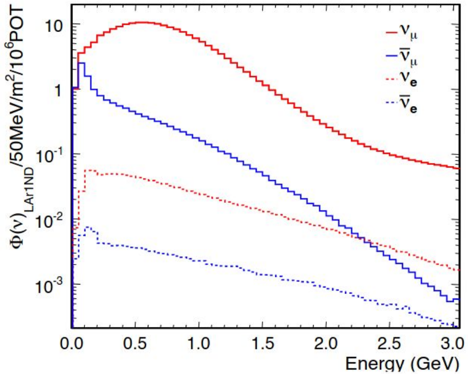
Summary… Thanks!

- SBND will collect a world leading dataset of neutrino-argon interactions from which a rich program of interaction cross-sections can develop.
- The unique capabilities of SBND lend themselves to advancing LArTPC reconstruction and analysis techniques.
- A huge amount of preparation has gone in to ensure we are ready for the first SBND data, which is now on our doorstep!
- Our beautiful detector is now ready to go, stay tuned for the first SBND results!



BACKUP

Booster Neutrino Beam



BNB Flux @ SBND