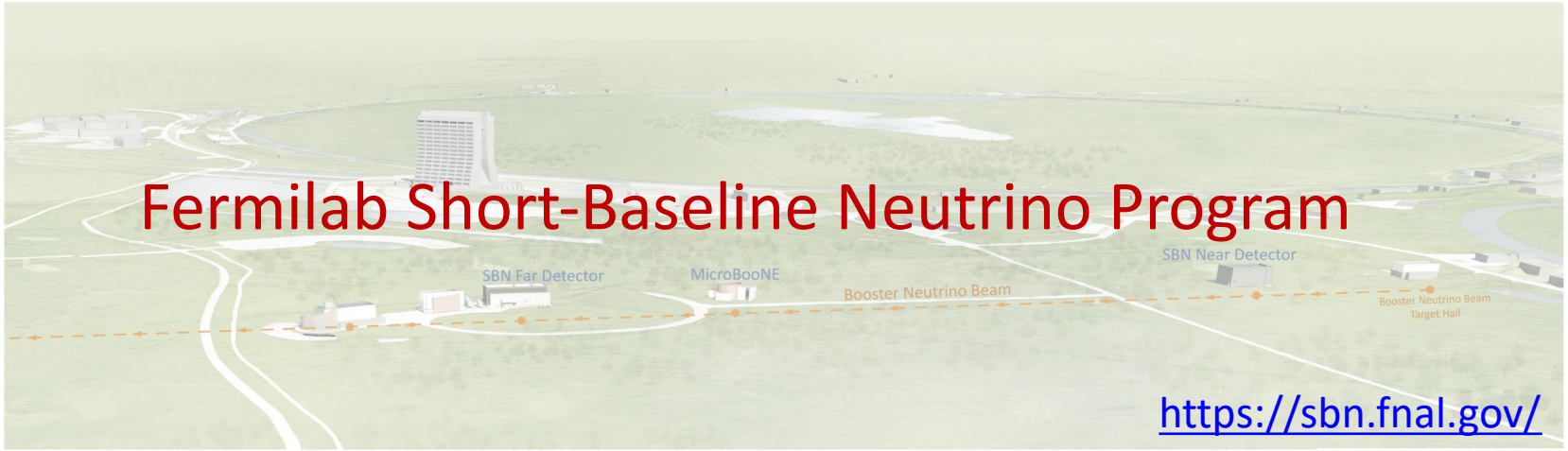


Fermilab Short-Baseline Neutrino Program

https://sbn.fnal.gov/

Robert J. Wilson
Colorado State University
for the SBN Program

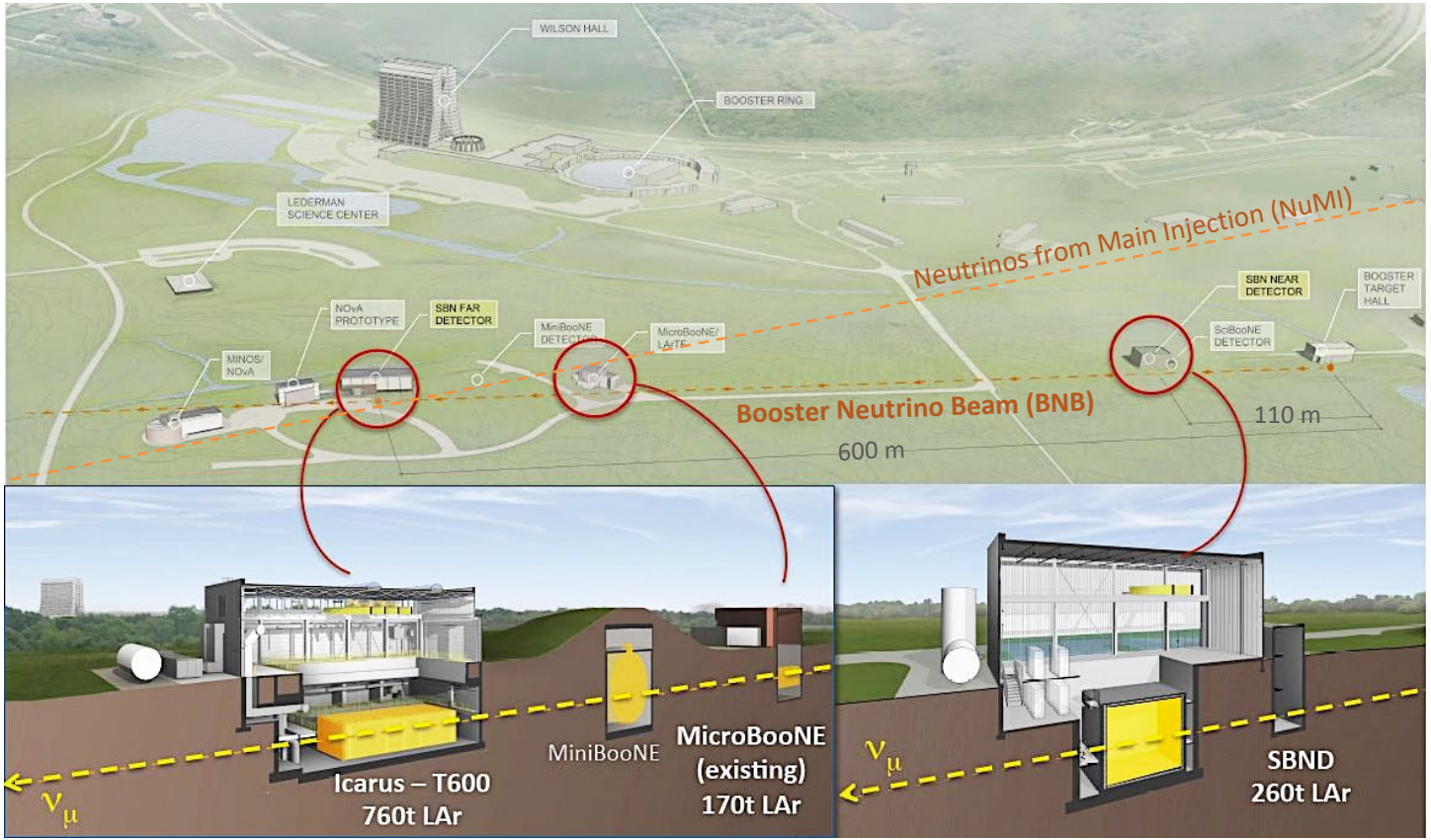
"Snowmass" Community Summer Study Workshop
University of Washington, Seattle
18 July 2022

Short-Baseline Neutrino (SBN) Program Science

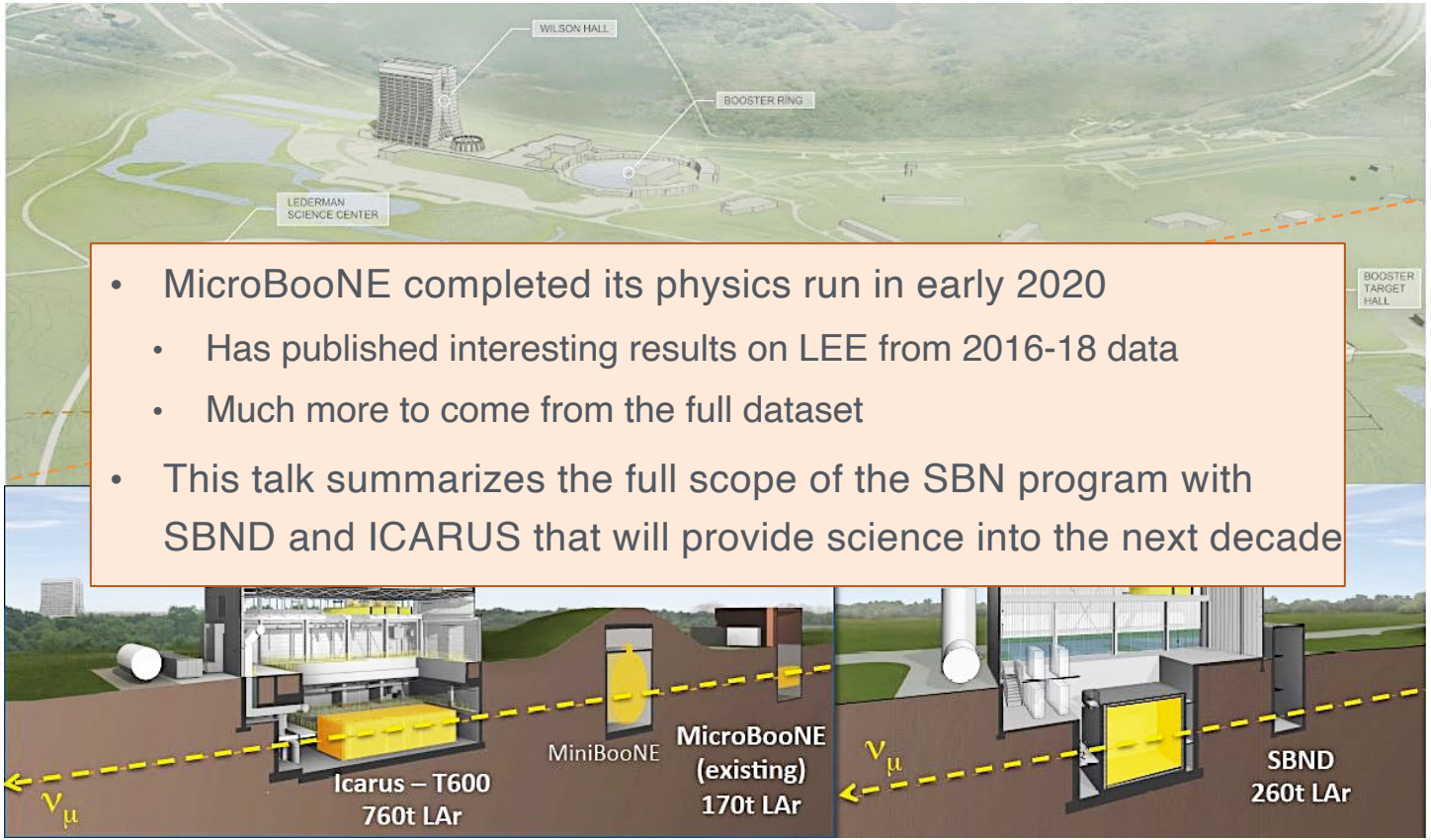
- Anomalous MiniBooNE Events
  - Investigate source(s) of low-energy excess (LEE) events observed by MiniBooNE using LArTPCs
- Search for Sterile Neutrinos
  - Discovery or definitive exclusion of 1 eV–scale sterile neutrino mass region motivated by LSND and MiniBooNE results
  - Provide verification or refutation of the Neutrino-4 experiment's* evidence for a 7.3 eV^2, large mixing angle, sterile neutrino
- Neutrino Interactions in Argon
  - Millions of ν_μ and tens of thousands of ν_e from two neutrino beams
- Search for Beyond Standard Model Physics
  - Higgs portal dark scalar, large extra dimension models, Lorentz/CPT symmetry violation, non-standard interactions, dark neutrino sectors, etc.

*Serebrov, A.P., *et al. Phys. Atom. Nuclei* **83,** 930–936 (2020)

SBN Complex at Fermilab

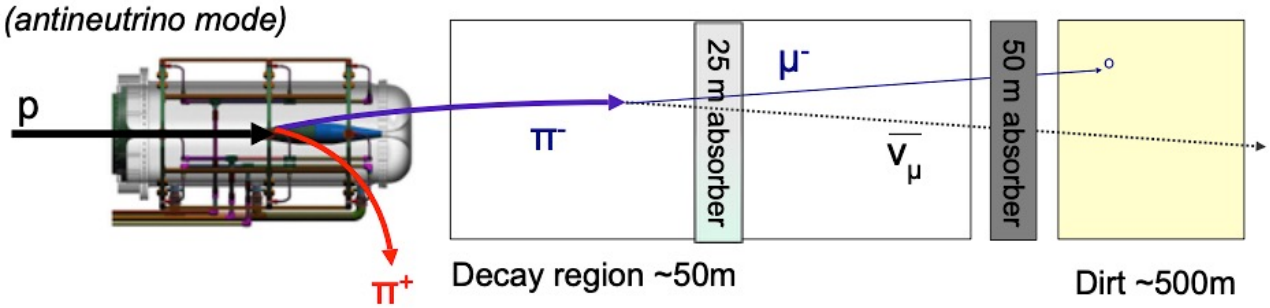


SBN Complex at Fermilab



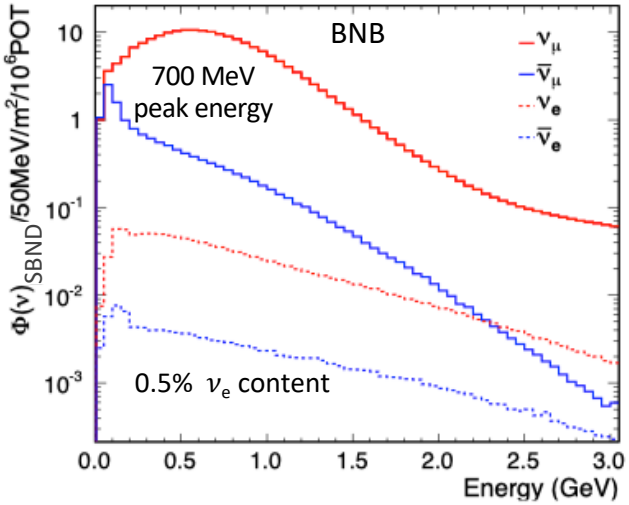
- MicroBooNE completed its physics run in early 2020
  - Has published interesting results on LEE from 2016-18 data
  - Much more to come from the full dataset
- This talk summarizes the full scope of the SBN program with SBND and ICARUS that will provide science into the next decade

Booster Neutrino Beam (BNB)

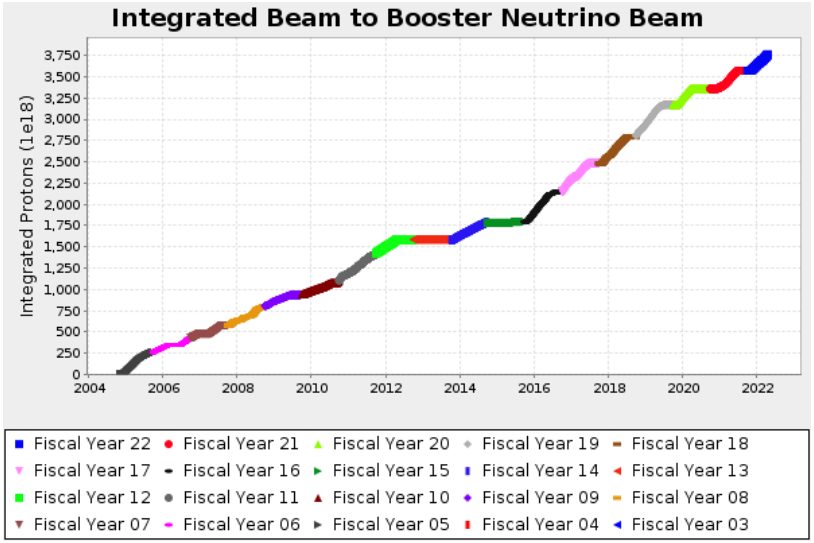


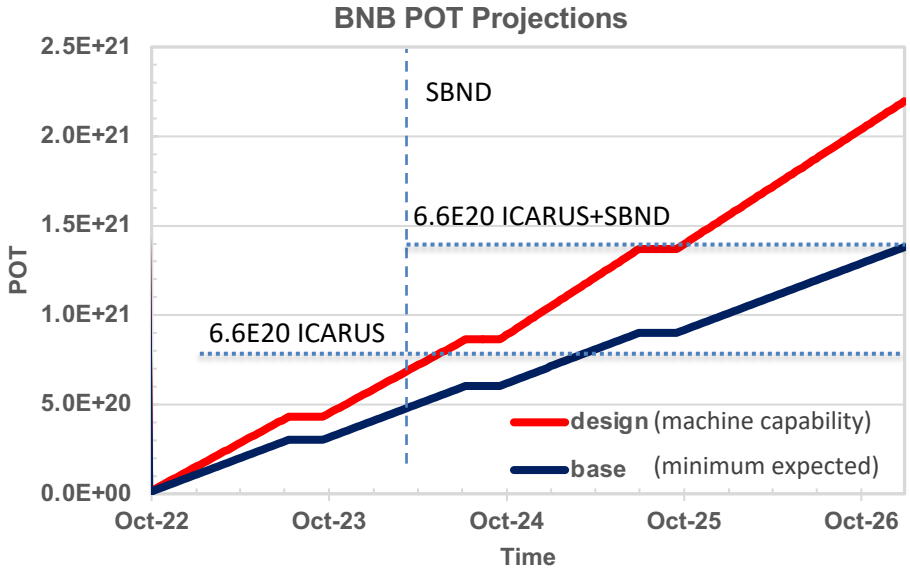
- 8 GeV protons from Booster
  - Beryllium target; horn pulsed at 170 kA
  - Up to 5 Hz and 5 x 10^{12} protons per pulse, 1.6 μs spill
- SBN Detector interaction rates
  - SBND: 0.25 Hz ν, 0.03 Hz cosmic
  - ICARUS: 0.03 Hz ν, 0.14 Hz cosmic

  (+ NuMI: 0.014 Hz ν, 0.08 Hz cosmic)



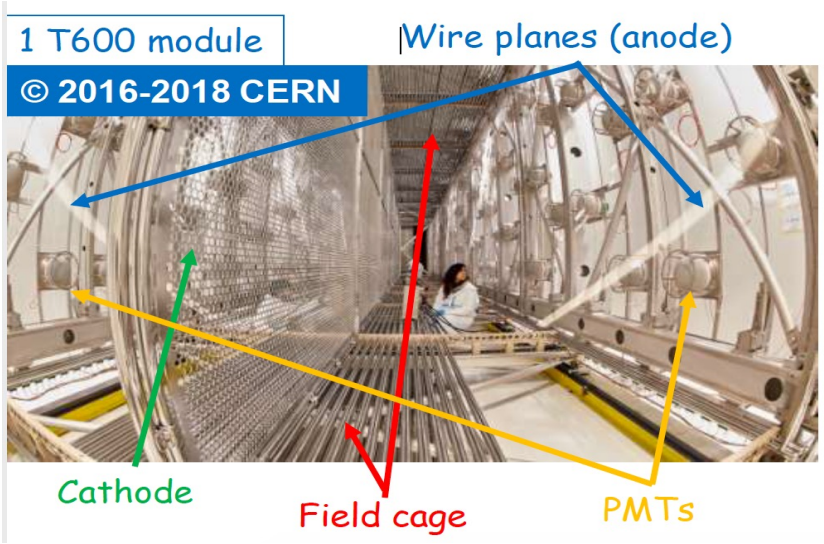
SBN Beam Projections





- Two-decades of neutrino production ⇒ a well understood beam that typically achieves near “design”
- SBN Proposal: 6.6 x 10^{20} POT
- BNB will operate until LBNF long-shutdown ~Jan. 2027 ⇒ with design POT delivery
  - ICARUS > 3X original SBN proposal
  - ICARUS+SBND > 2X original SBN proposal

SBN Far Detector: ICARUS-T600



- Two identical modules (T300) each is 19.6 x 3.6 x 3.9 m^3; total LAr mass 760 t; active mass 476 t
- Drift distance 1.5 m. Electric field 500 V/cm -> drift time ~1 ms
- 3 signal wire planes (2 induction + 1 collection); total 53,248 wires; new readout electronics
- Pitch and inter-plane distances: 3 mm; 400 ns sampling time
- New photon detector system – 360 TPB-coated PMTs
- New cosmic ray tagger – ~4π coverage, 1100 m^2 plastic scintillator

ICARUS-T600 at Fermilab

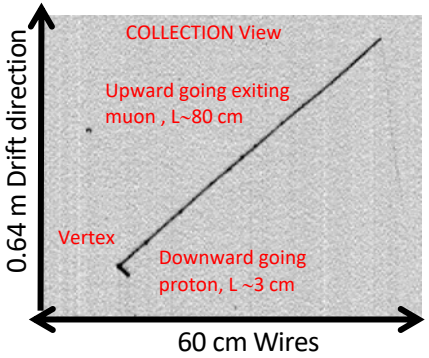
Aug. 2020: start of TPC/PMT operation

Dec. 2021: CRT installation complete

June 2022: overburden complete

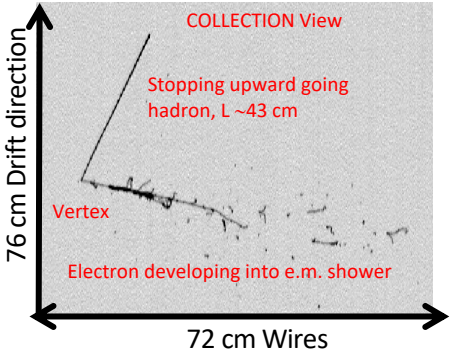
Steady data taking with BNB, NuMI beams since March 2021, in parallel with commissioning activities. Cosmics, ν_μ, and ν_e samples collected for trigger/calibration/reconstruction studies.

BNB CC QE muon neutrino candidate, E_{DEP} ~ 200 MeV

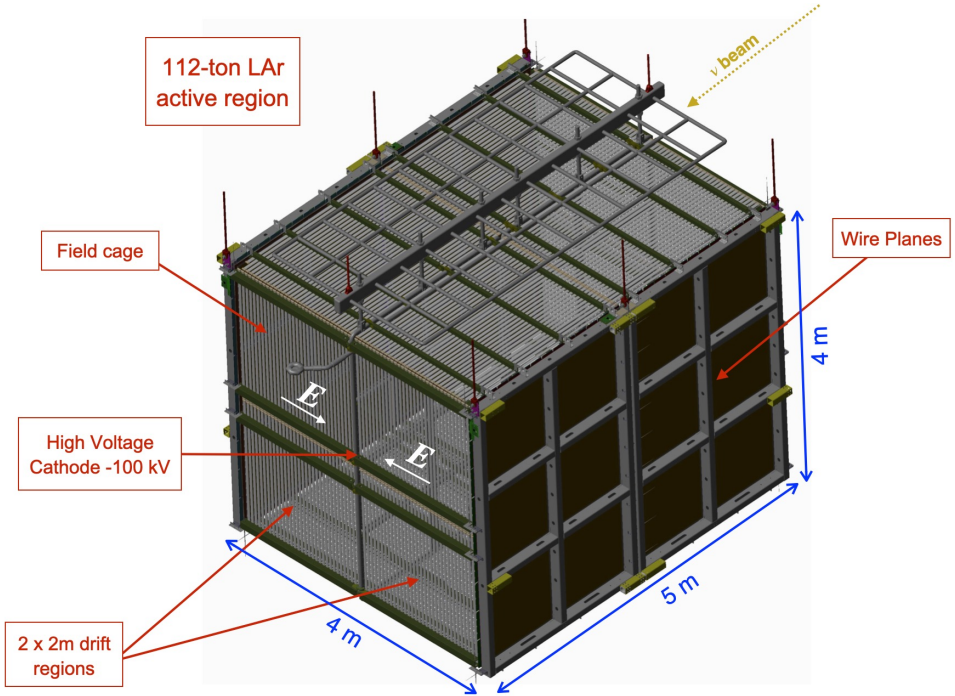


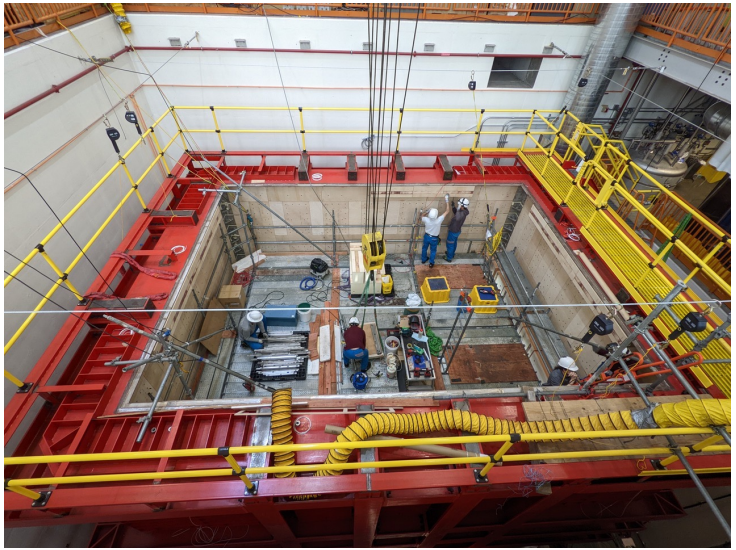
Data taking for Physics with BNB and NuMI beams 9 June 2022

Contained NuMI CC QE electron neutrino candidate, E_{DEP} ~ 800 MeV



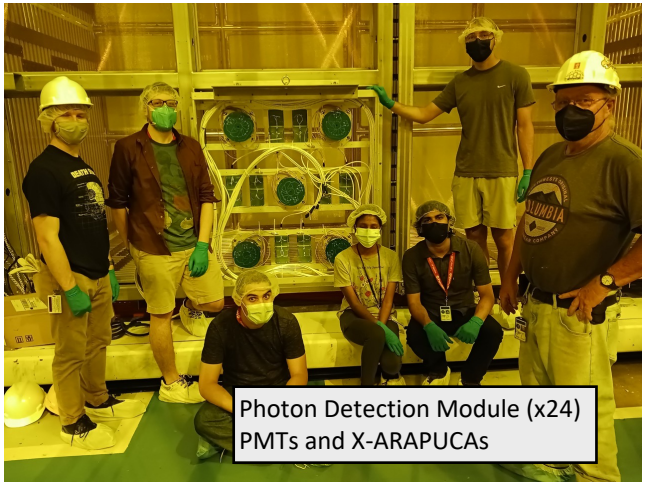
SBN Near Detector: SBND

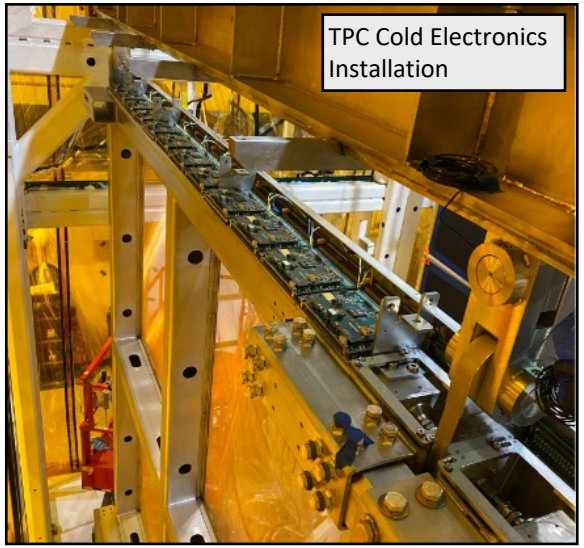




- Ground-up new detector – 4 m x 4m x 5m, 112 t active mass LAr
- Incorporating technology important for DUNE (cryostat, 2-m drift TPC, X-Arapuca photon detectors)

Short-Baseline Near Detector (SBND)

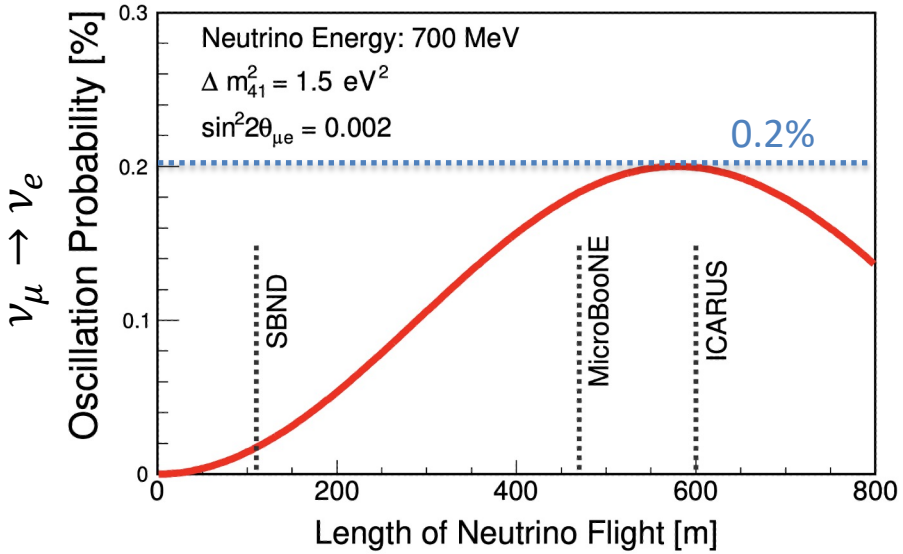




- Milestone: Installation complete and ready to fill in June 2023

SBN Oscillation Sensitivity

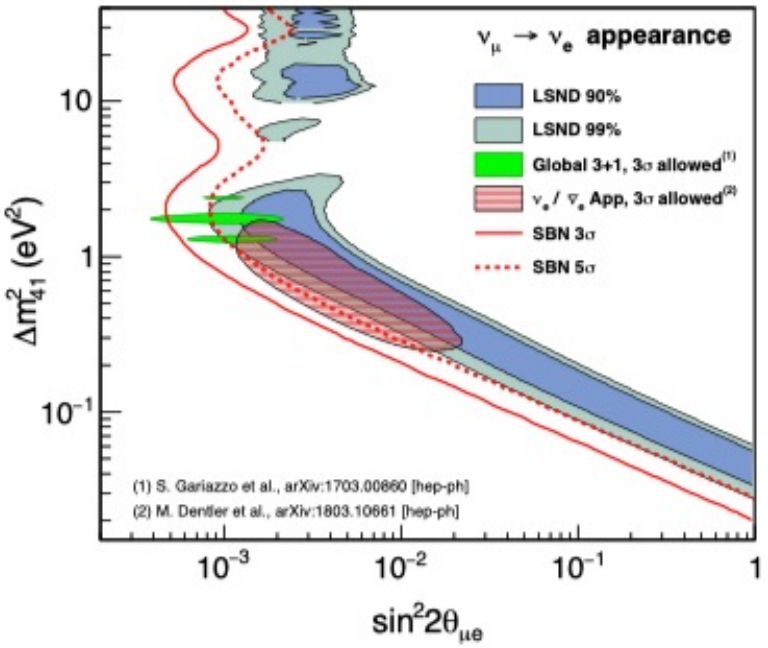
Example oscillation at BNB peak energy

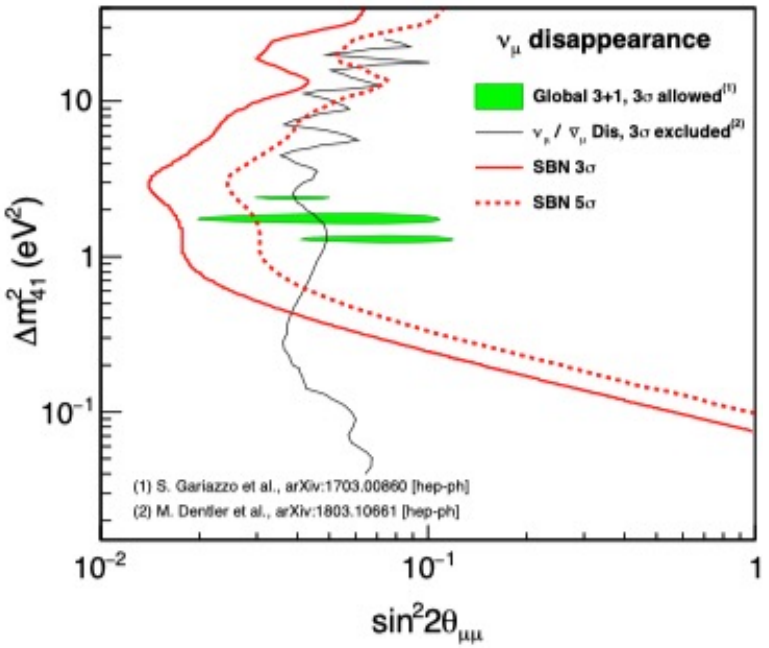


P. Machado et al., arXiv:1903.04608V11
https://doi.org/10.1146/annurev-nucl-101917-020949

- Multiple detectors using the same technology enables sensitive searches for ν_e appearance and ν_μ disappearance within the same experiment

Sensitivity Plots Based on SBN Proposal



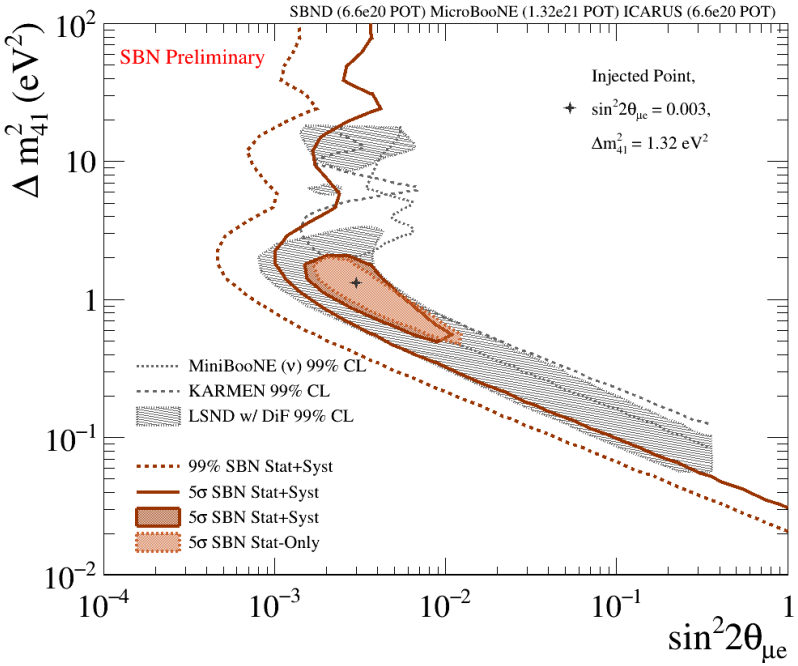


P. Machado, O. Palamara D. Schmitz, arXiv:1903.04608V11
https://doi.org/10.1146/annurev-nucl-101917-020949

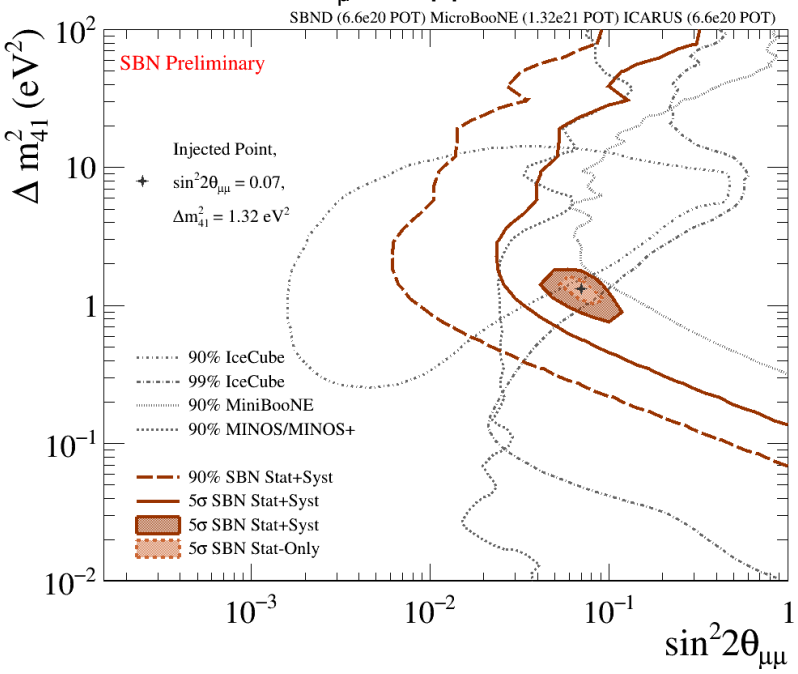
SBN Oscillation Sensitivity - Update

SBN Preliminary – as-built detector size/position, more realistic systematics, etc. – work in progress

SBN ν_e appearance



SBN ν_μ disappearance

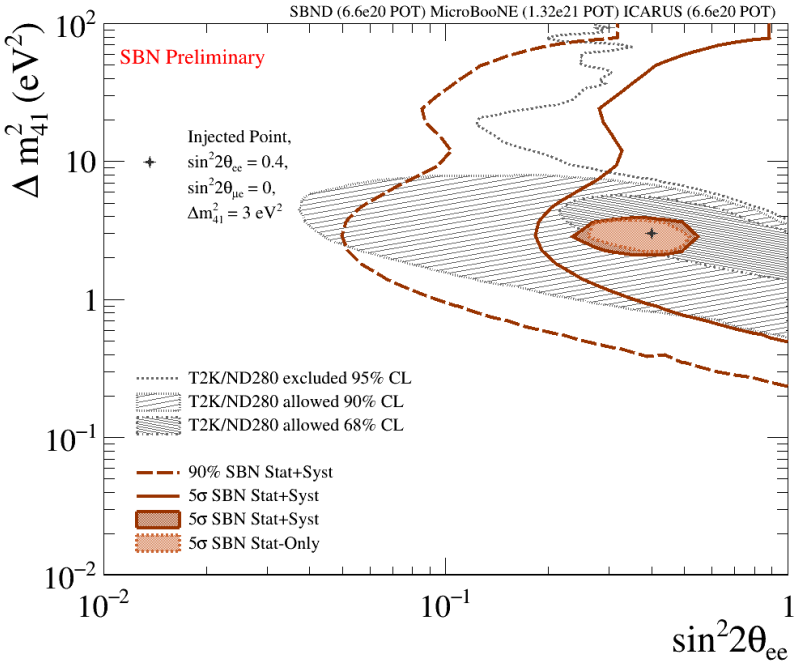


- SBN sensitivities for 6.6 x 10^{20} protons on the BNB target; will be updated to the larger dataset

SBN Oscillation Sensitivity - NEW

Direct probe of $\sin^2 2\theta_{ee}$ using a neutrino beam rather than lower energy (MeV) reactor antineutrinos

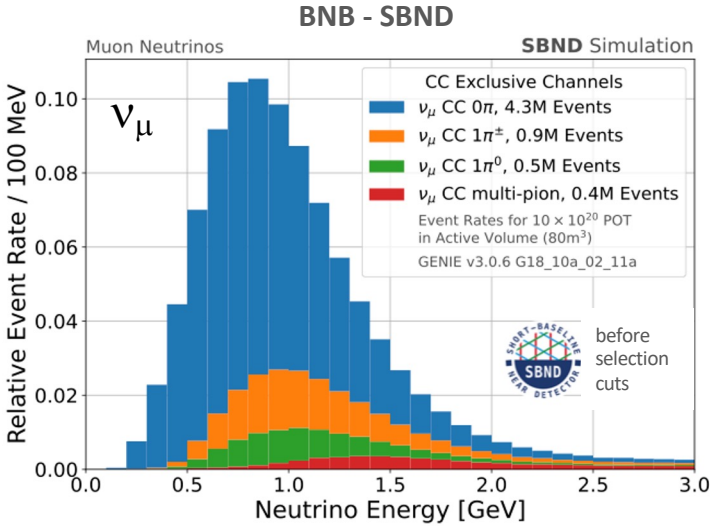
SBN ν_e disappearance



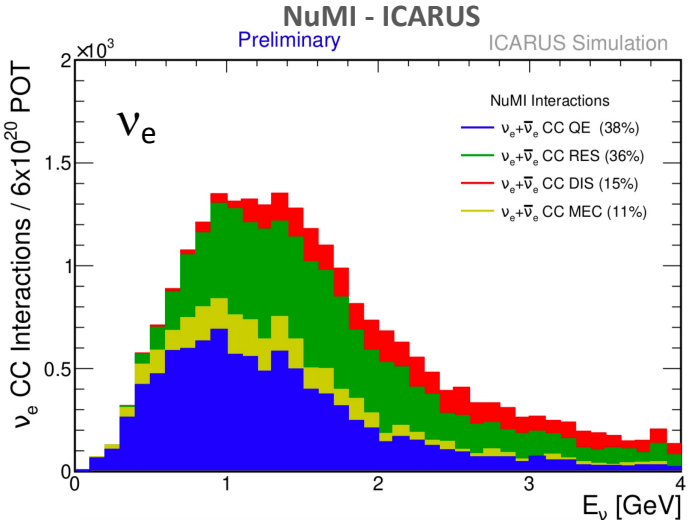
- ~35,000 intrinsic. ν_e at SBND for 6.6 x 10^{20} BNB POT
- ICARUS will use ν_e disappearance from NuMI as part of Neutrino-4 signal investigation

Cross Section Measurements

SBND High-statistics measurements of many signatures and can observe rare channels such as heavy baryons (Λ^0, Σ^+), NC coherent single photon production, etc.



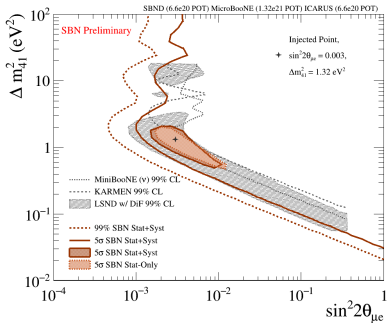
ICARUS can leverage its off-axis position in the NuMI beam and observe a ν_e enriched flux for ν_e-Ar measurements

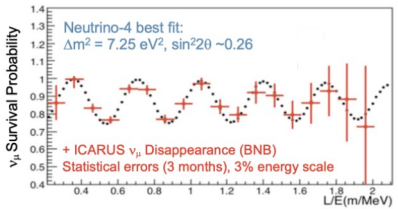


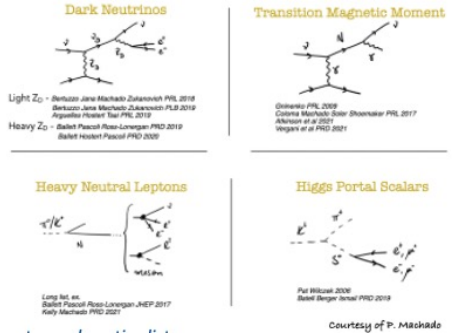
SBN cross section measurements will inform cross section theory & generator work, and lay groundwork to lower the systematic uncertainties for current and future high-precision experiments such as DUNE.

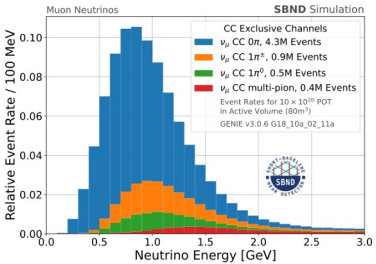
ICARUS/SBN Outlook

- ICARUS operated well in commissioning mode and has begun first physics run
- SBND is on track for operation in late 2023
- ICARUS will reach nominal dataset by mid-2024 and ICARUS+SBND by late 2025
  - 2-3X higher statistics by 2027
- The SBN program will provide a broad spectrum of neutrino and BSM physics and in-depth experience with LArTPC technology and analysis through to the start of DUNE program



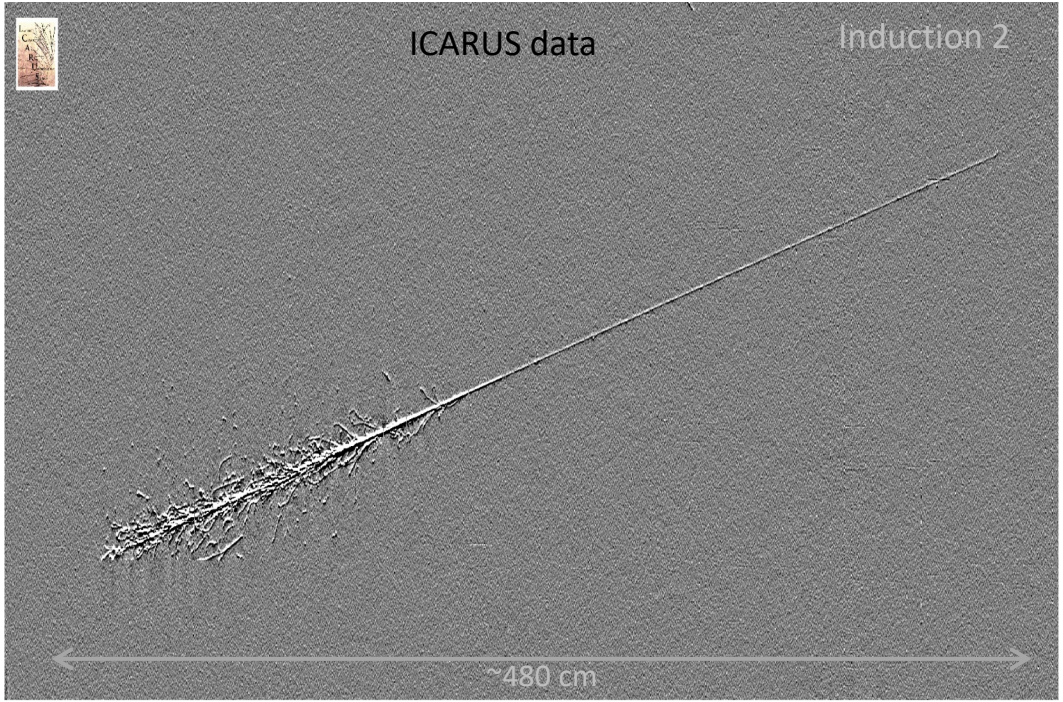






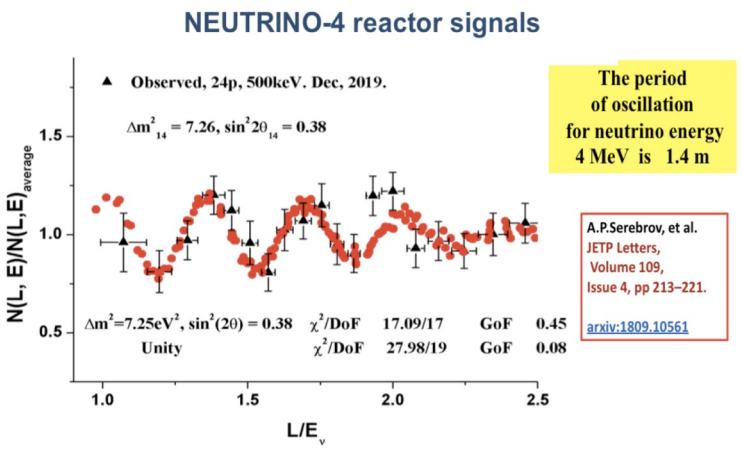
Thank you

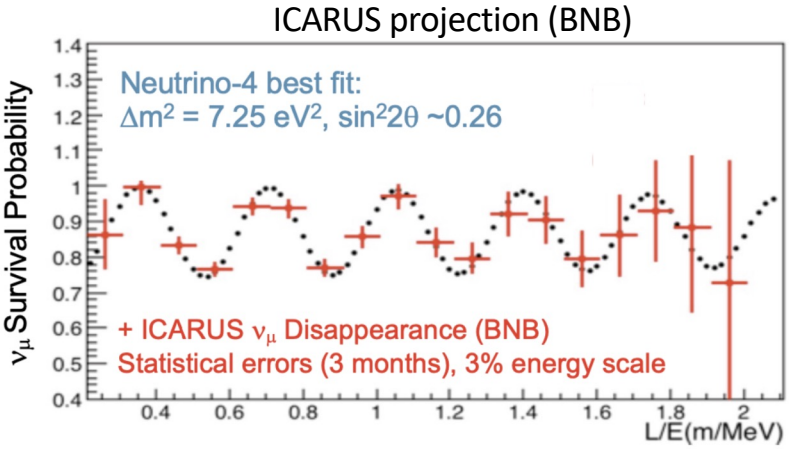
- Questions?



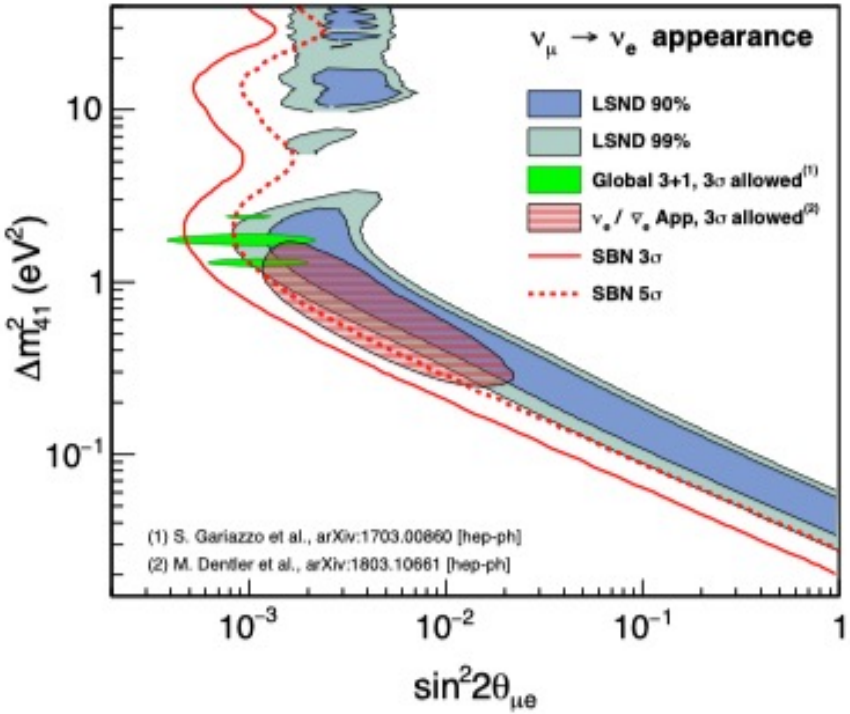
Search for Neutrino-4 Oscillation signal with ICARUS

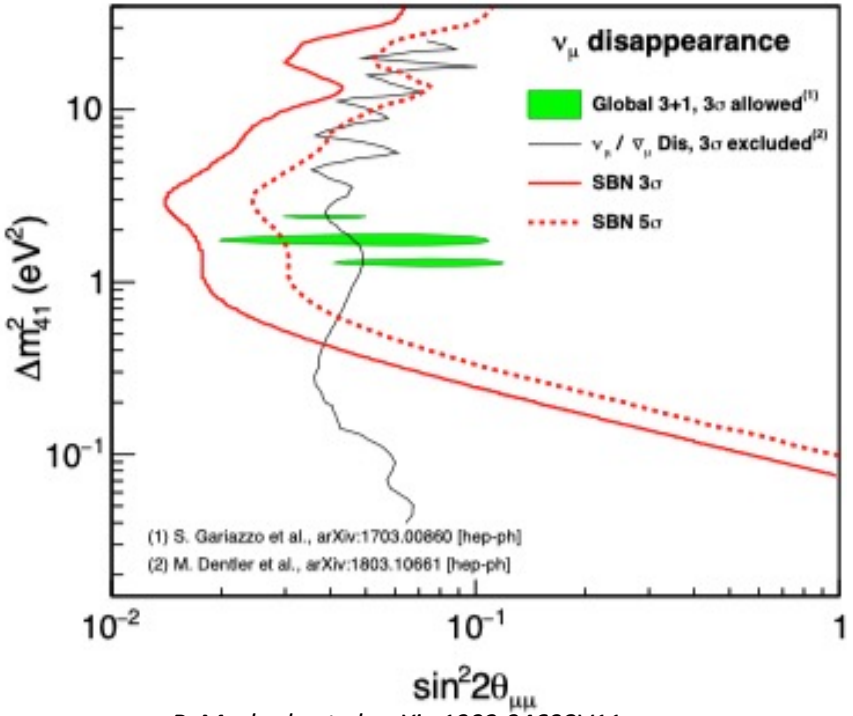
- The Neutrino-4 collaboration claim a reactor neutrino disappearance signal with a clear modulation with L/E ~1-3 m/MeV
- ICARUS has sensitivity to this parameter space as a single-detector and is planning an oscillation analysis investigating the Neutrino-4 signal using data taken in the coming year (prior SBND operations)
- ICARUS will do analyses in two independent channels using different neutrino beams
  - ν_μ disappearance using the BNB
  - ν_e disappearance using NuMI





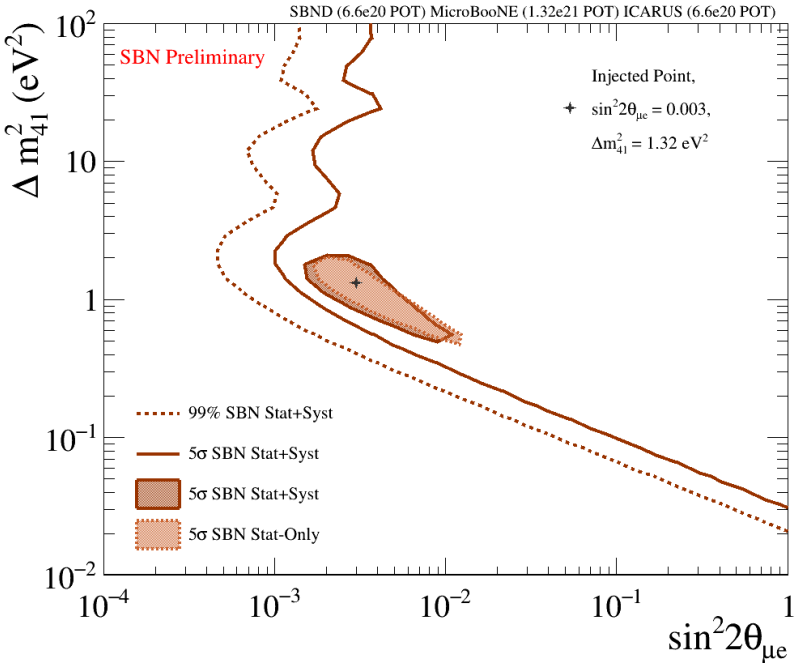
Previous Sensitivity Plots w/ LSND and

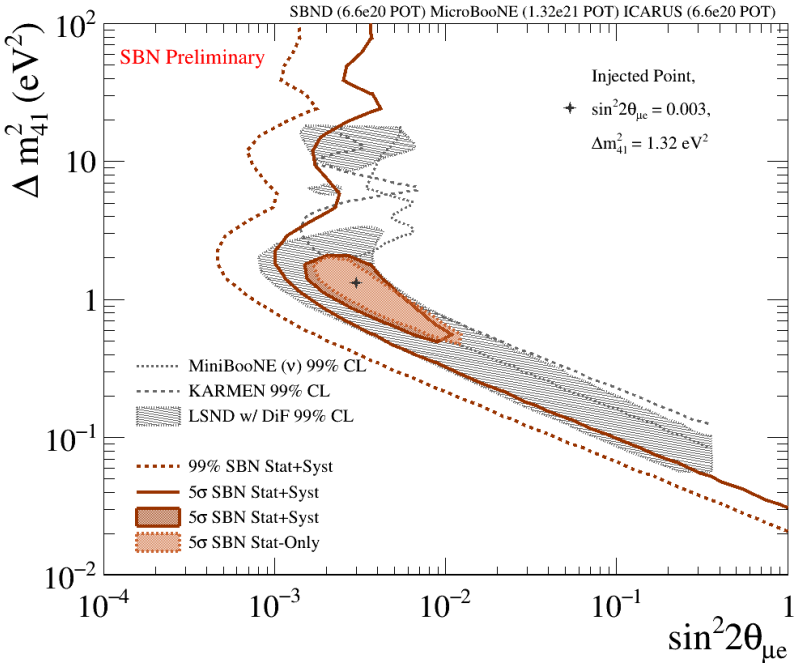




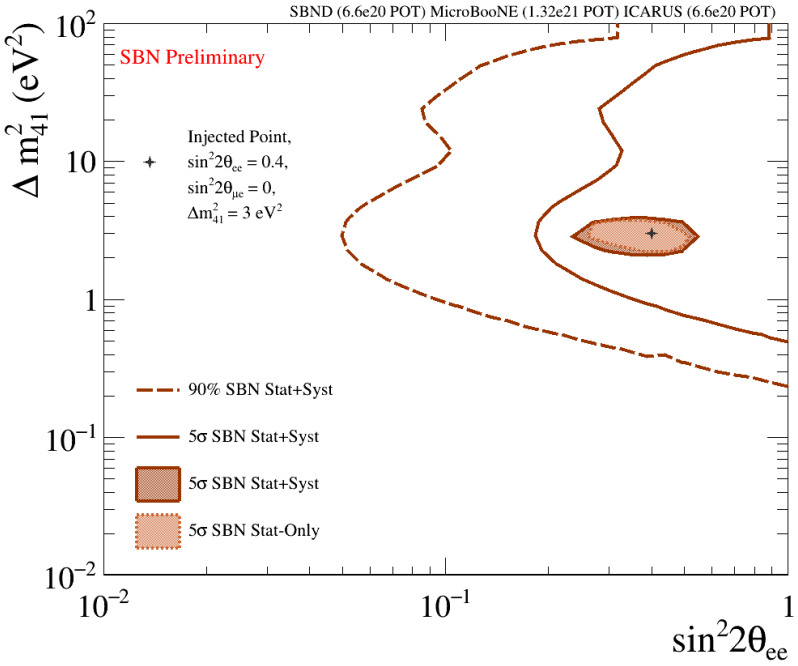
P. Machado et al, arXiv:1903.04608V11
https://doi.org/10.1146/annurev-nucl-101917-020949

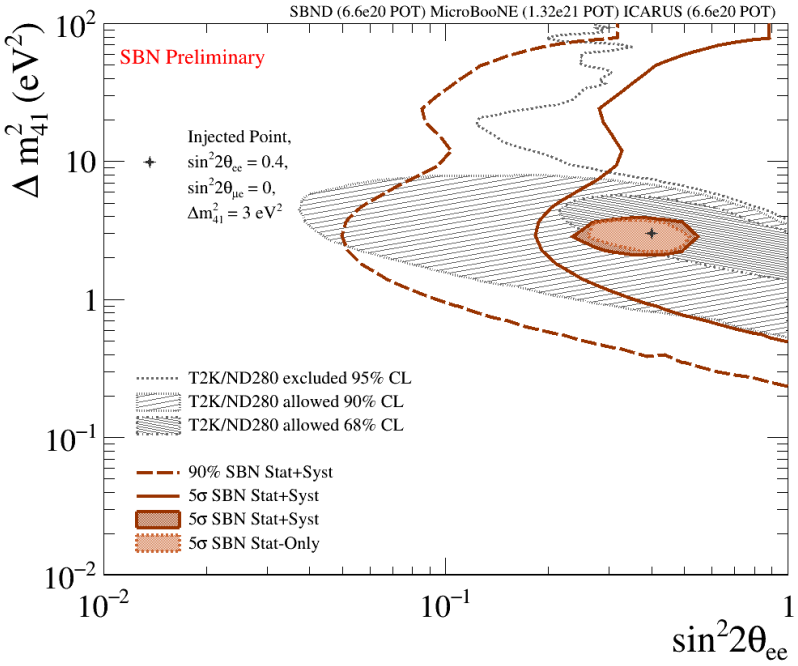
Updated Sensitivity Plots – ν_e appearance



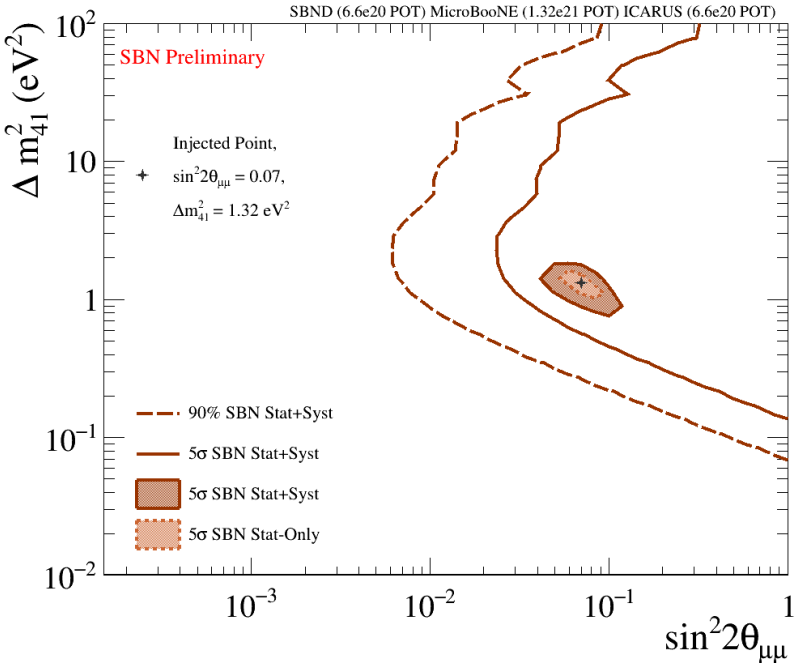


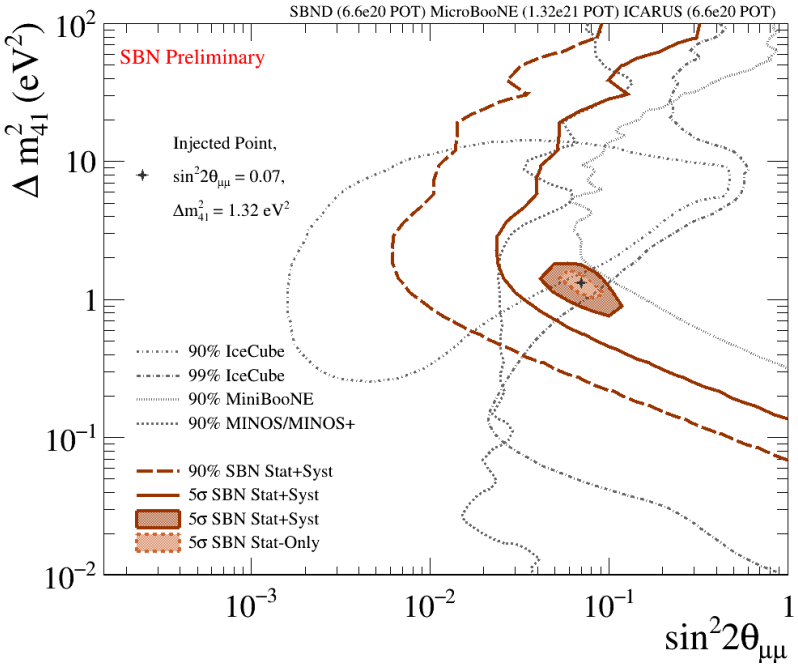
Updated Sensitivity Plots – ν_e disappearance





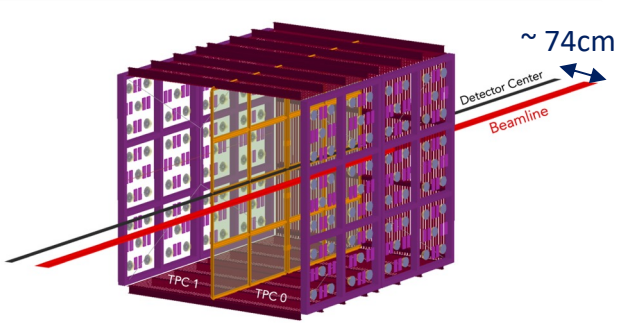
Updated Sensitivity – ν_μ disappearance

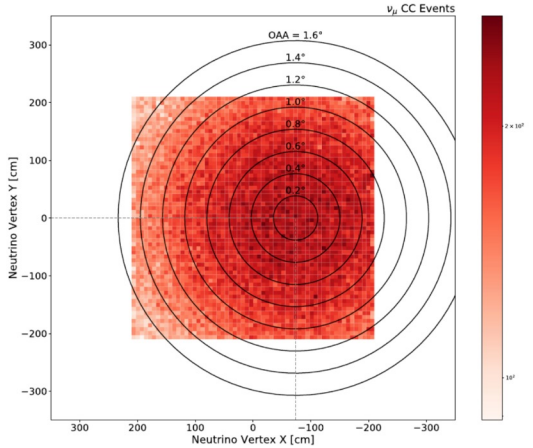


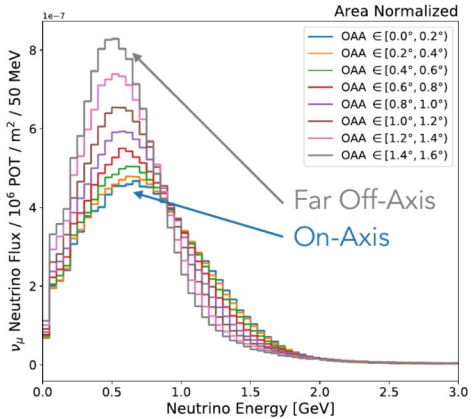


SBND: Sampling multiple off-axis fluxes with the same detector

- SBND is located very close to the beam target (110 m) and slightly off-axis (~74 cm), so the detector sees a different flux based on position within the detector
  - Similar to the DUNE-PRISM concept, but with a fixed detector





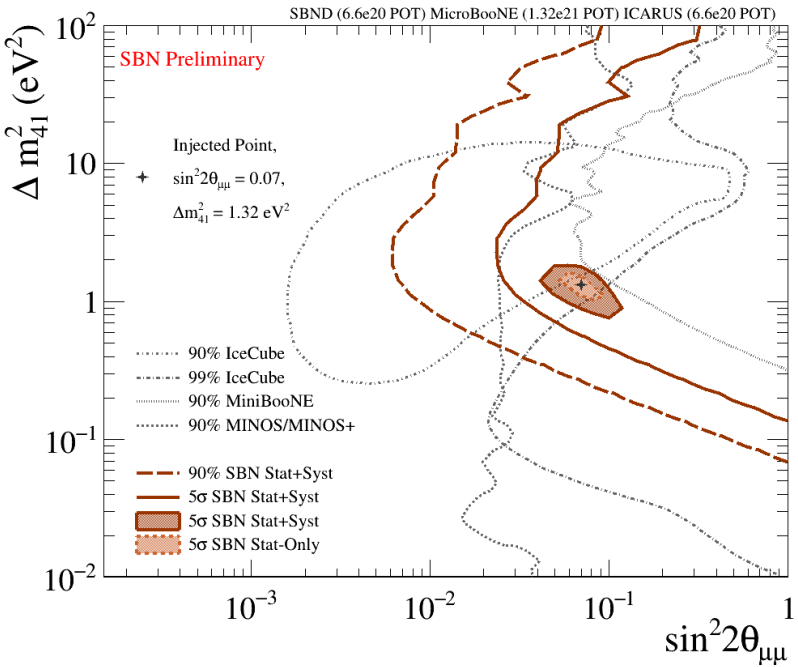


- Ongoing studies exploring physics potential of flux sampling
  - improve flux and cross section constraints in oscillation analysis
  - targeted cross section analyses with detector slices to constrain nuclear effects
  - reduced backgrounds for increasing off-axis angles
  - add capabilities for BSM searches

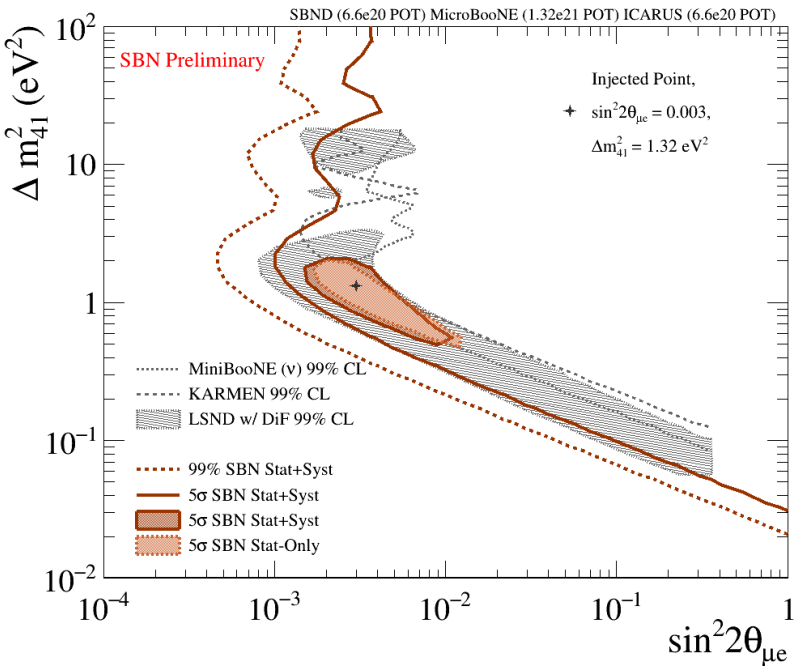
SBN Oscillation Sensitivity - Update

SBN Preliminary – Includes more realistic systematics, detector positions etc. – work in progress

SBN ν_μ disappearance



SBN ν_e appearance



SBN sensitivities for 6.6 x 10^{20} protons on the BNB target