The Short Baseline Neutrino Program

Minerba Betancourt, Fermilab

Colombian Meeting on High Energy Physics 6th ComHEP

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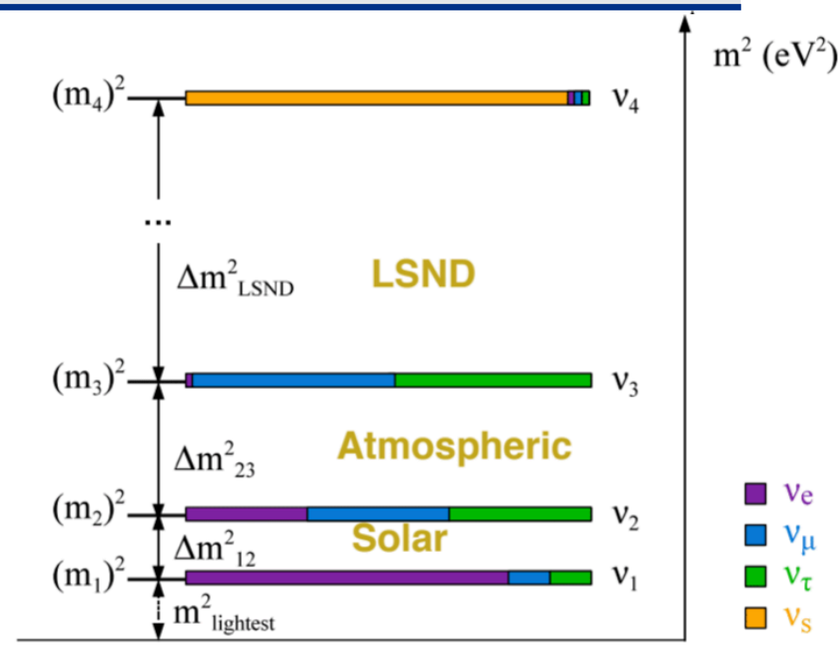
Short-Baseline Neutrino Anomalies

- Four anomalies have been observed in neutrino experiments at short baseline in the last 20 years
- These anomalies provided hints to indicate there is a fourth and non-weakly interacting (sterile) type of neutrino

Experiment	Type	Channel	Significance
LSND anomaly	DAR accelerator	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	3.8 σ
MiniBooNE anomaly	SBL accelerator	$\nu_\mu \rightarrow \nu_e$	4.5 σ
		$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	2.8 σ
GALLEX/SAGE	Source – e	ν_e disappearance	2.8 σ
Reactors anomaly	β decay	$\bar{\nu}_e$ disappearance	3.0 σ

- Each possibly explained by non standard sterile neutrino states driving oscillations at $\Delta m^2_{new} \approx 1$ eV^2 and small $\sin^2(2\theta_{new})$
- Is there any additional physics beyond the 3- flavor mixing neutrino oscillation?



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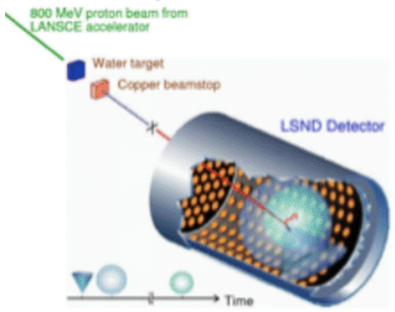
Sterile Neutrino Physics

Low energy $\bar{\nu}_\mu$ beam from a decay-at-rest pion beam (Los Alamos, 1993-1998)



LSND

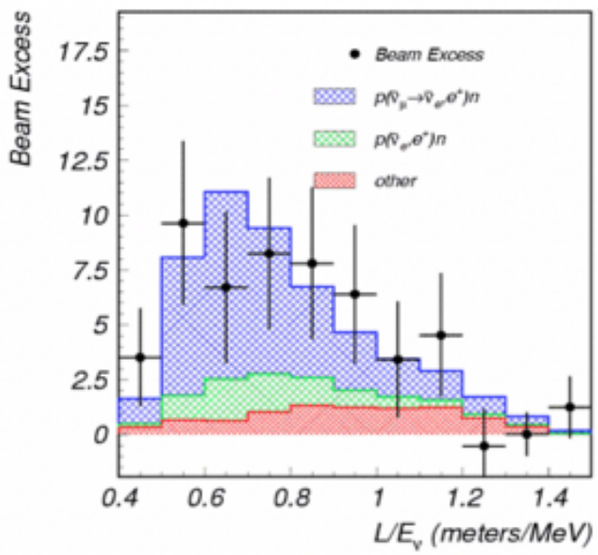
Baseline 30 m

E= [20 – 50] MeV

L/E ≈ 1 m/MeV

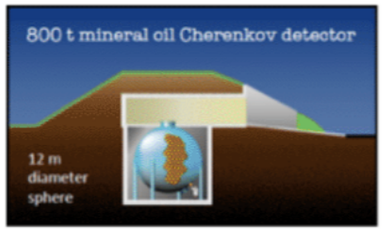
PRD 64 (2001) 112007

167 tons liquid scintillator



Decay in flight neutrino source (Booster Neutrino Beam - Fermilab)

L/E similar to LSND



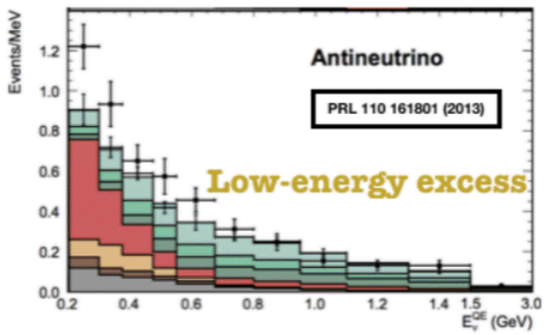
MiniBooNE

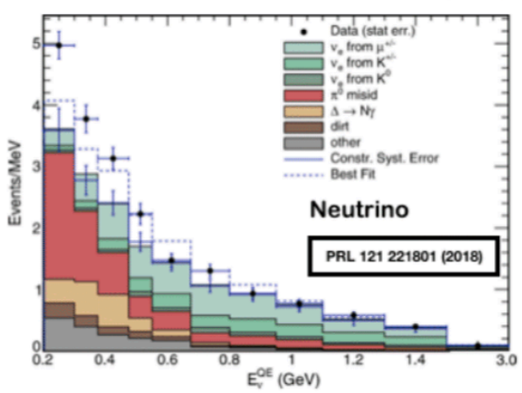
Baseline 540 m

E=[0 - 2] GeV

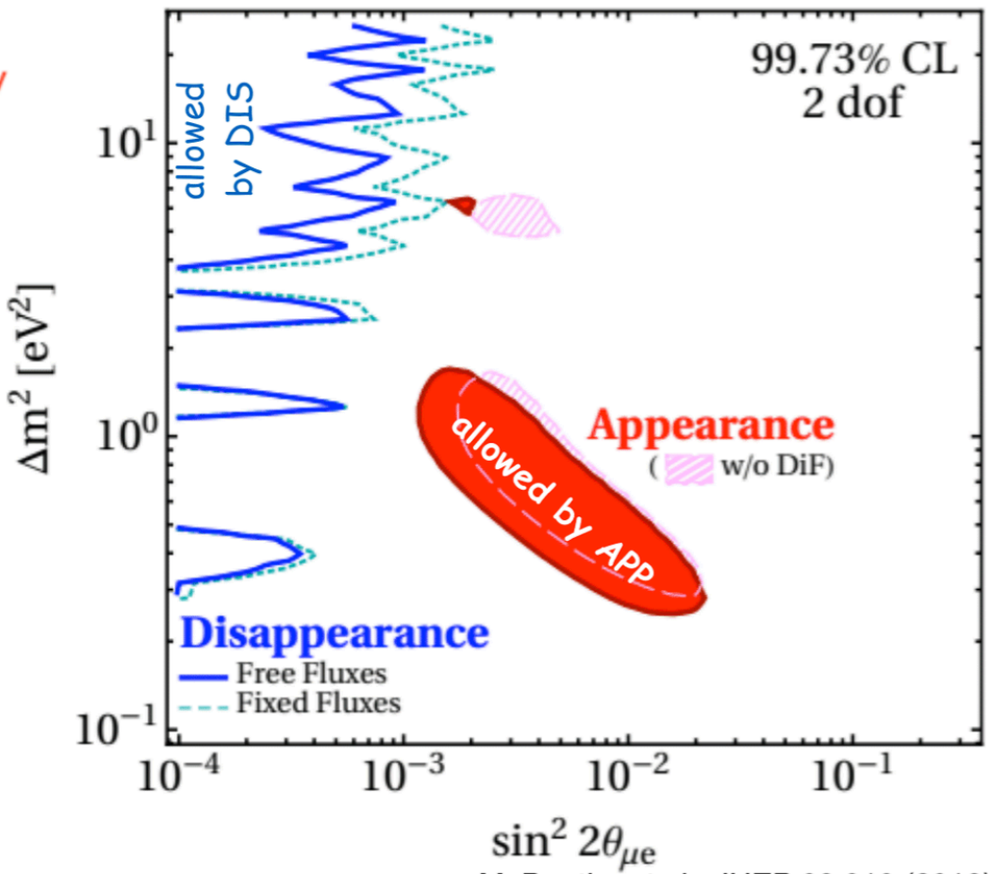
L/E ≈ 1 m/MeV

800 tons mineral oil





Tension between ν_e appearance and ν_μ disappearance results



M. Dentler et al., JHEP 08:010 (2018)

- Sterile neutrino scenario is far from understood:
  - No evidence in ν_μ disappearance experiments (IceCube, NOvA, MINOS/MINOS+)
  - No precise indication from recent $\bar{\nu}$ flux measurement at reactors
  - Planck data/Big Bang cosmology: at most one further flavor with m_{new}<0.24 eV

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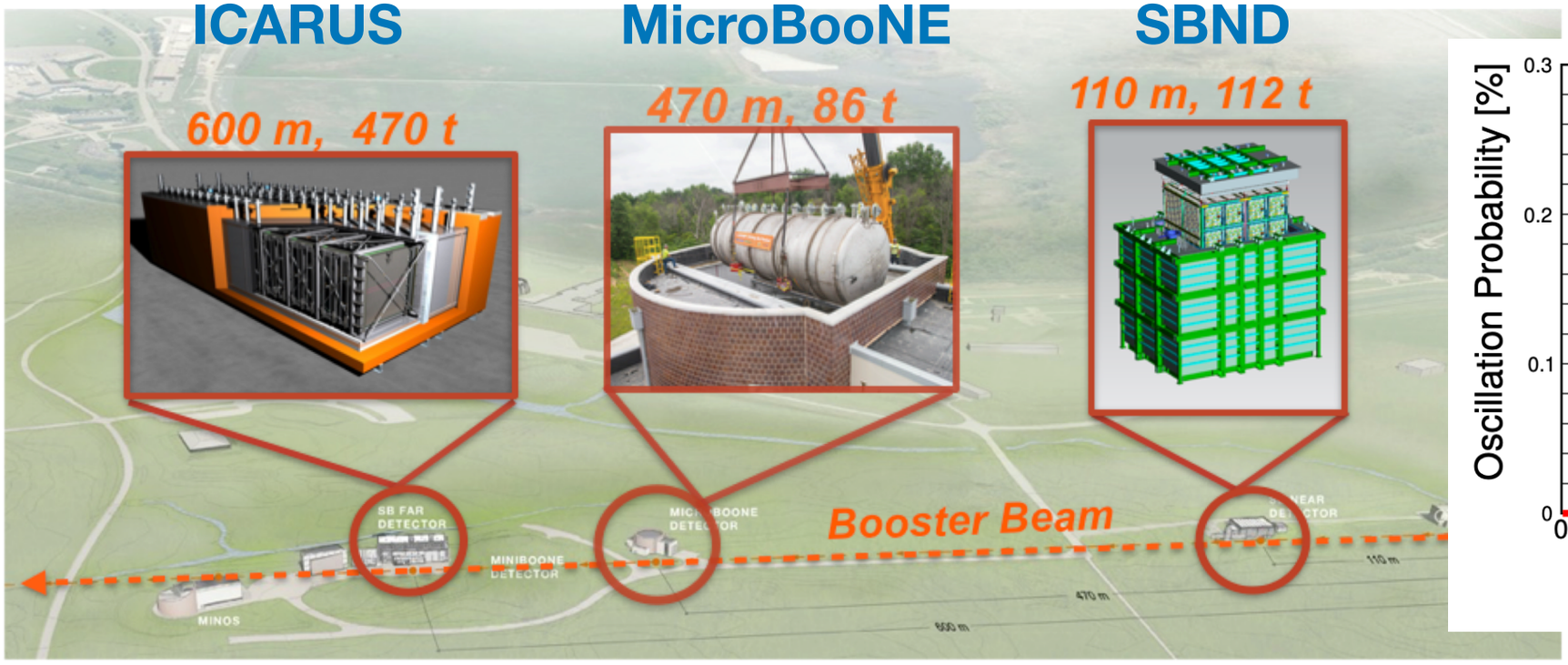
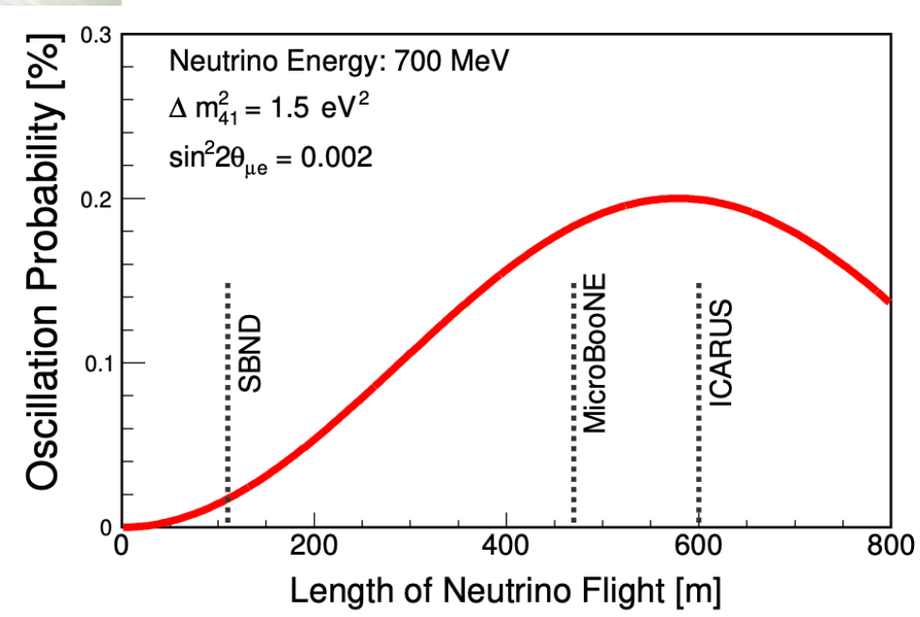
Short Baseline Program (SBN)

- Three argon Time Projection chambers (TPC) detectors at different baselines from Booster neutrino beam searching for sterile neutrino oscillations
  - Measuring both appearance and disappearance channels
- Measure neutrino cross sections on liquid argon
- Same detector technology and neutrino beamline: reducing systematic uncertainties to the % level
  - A detection technique providing an excellent neutrino identification to reduce the backgrounds





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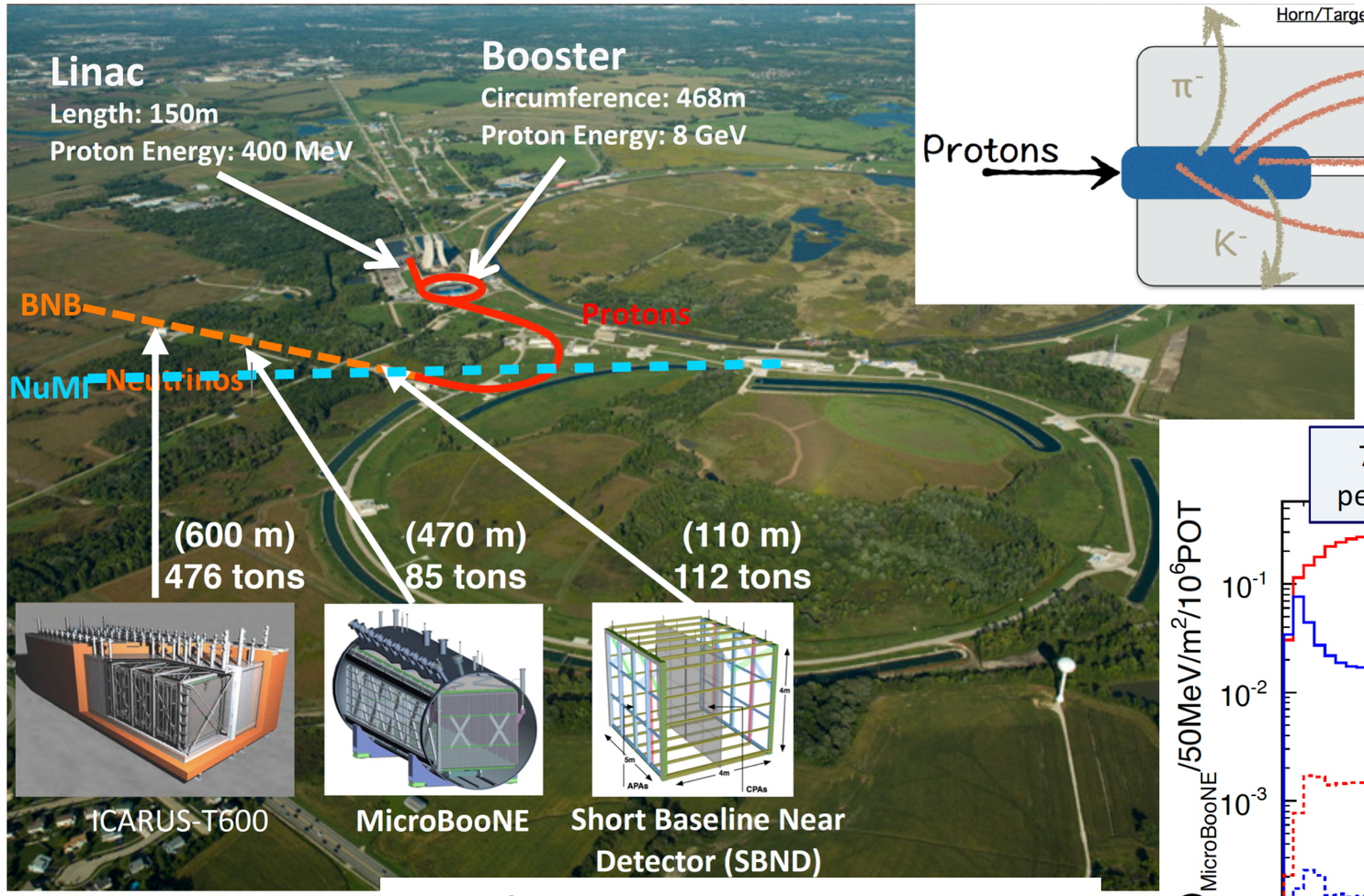
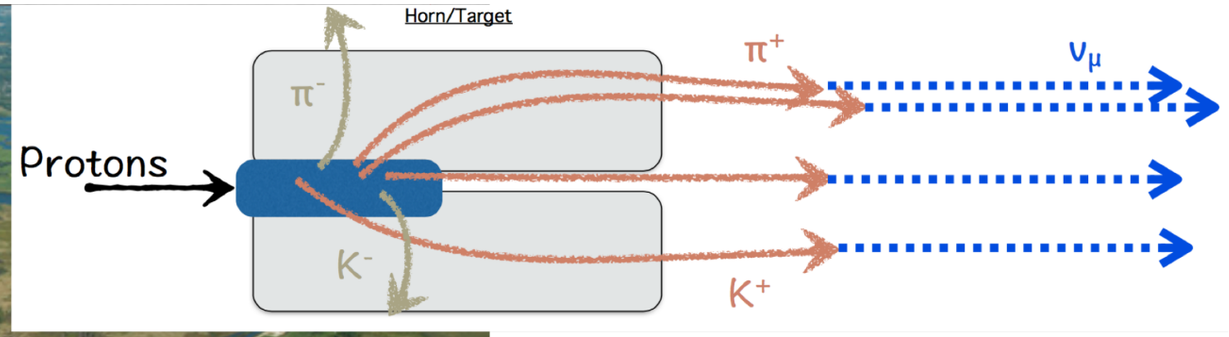
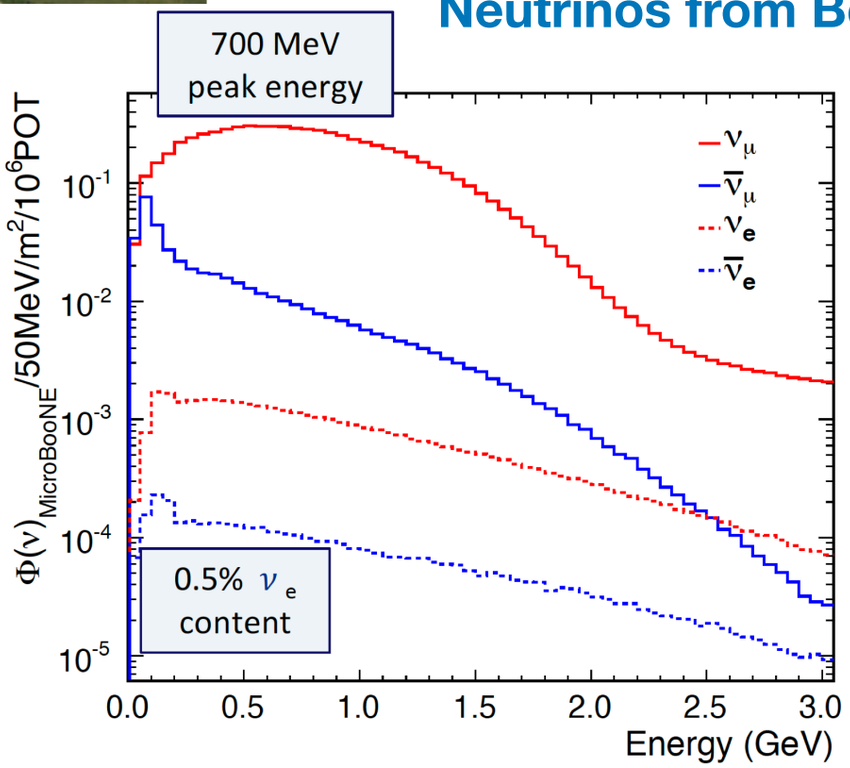
LArTPC facility on the Neutrino Beams at Fermilab

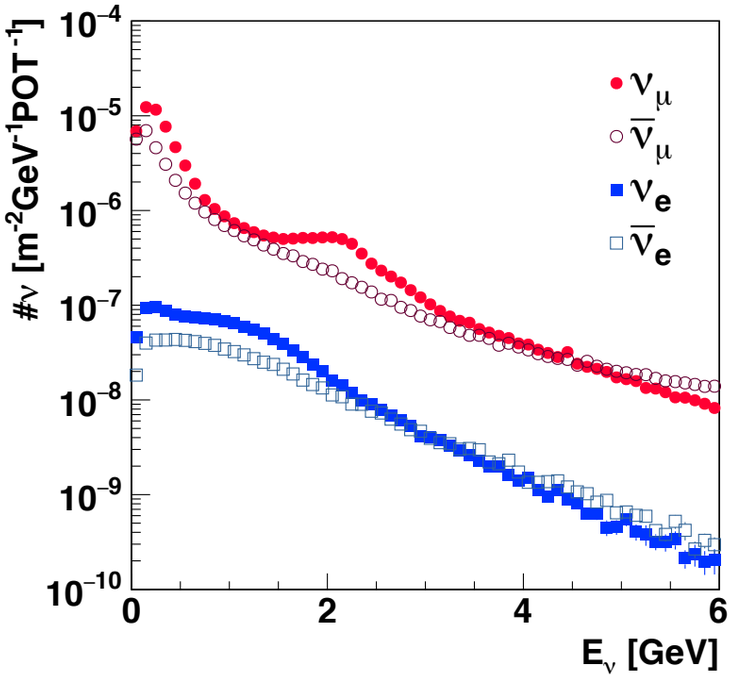




Neutrinos from Booster



Neutrinos from NuMI



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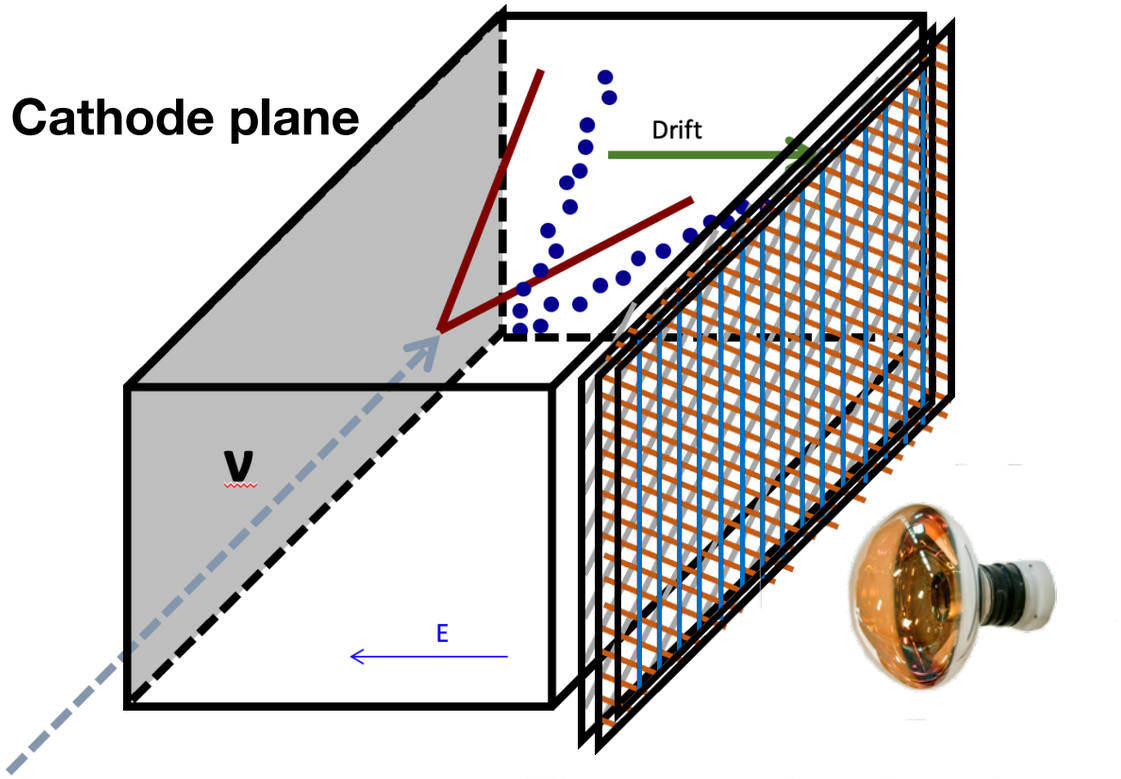
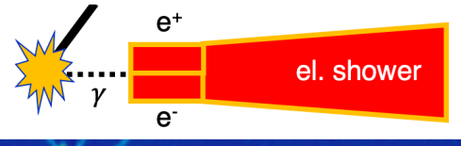
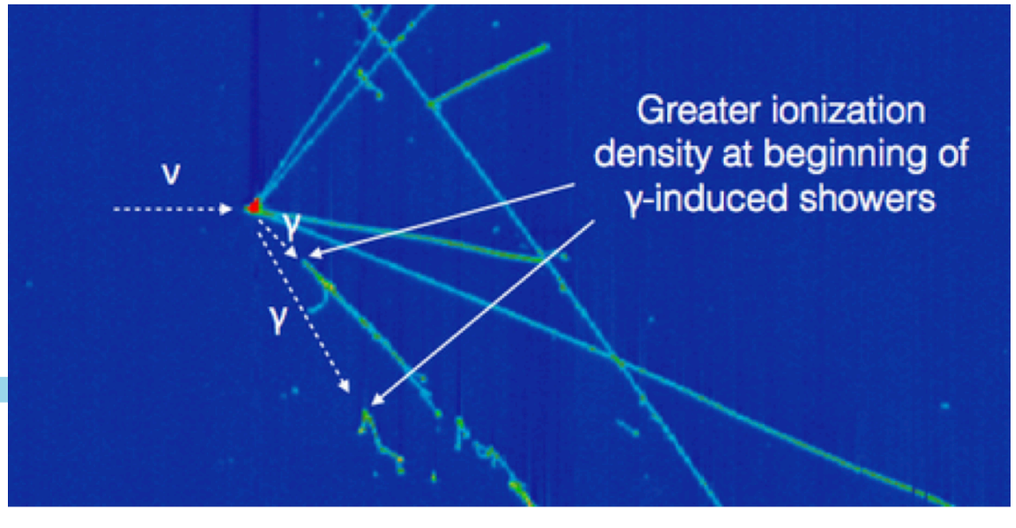
LArTPC: an ideal detector for ν physics

- Tracking device: precise 3D event topology with ~mm³ resolution for ionizing particle
- Powerful particle identification by dE/dx vs range
- Remarkable e/γ separation: calorimetric capabilities can distinguish e from γ at the shower start



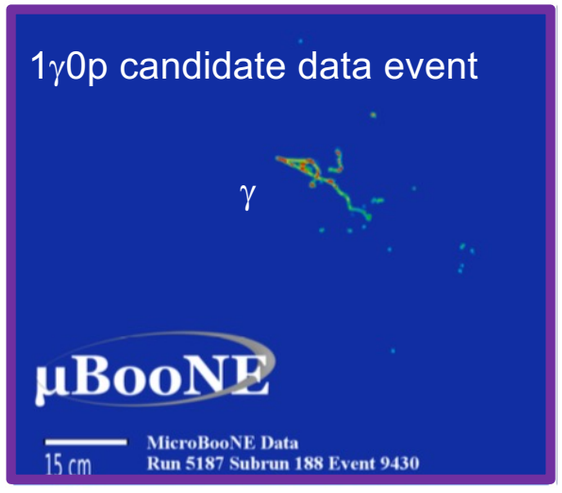
Three anode wire planes

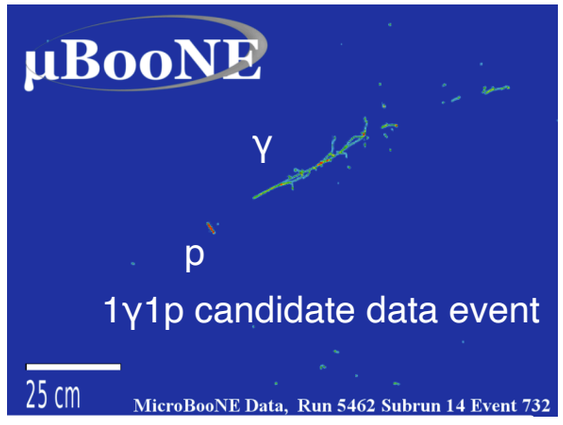


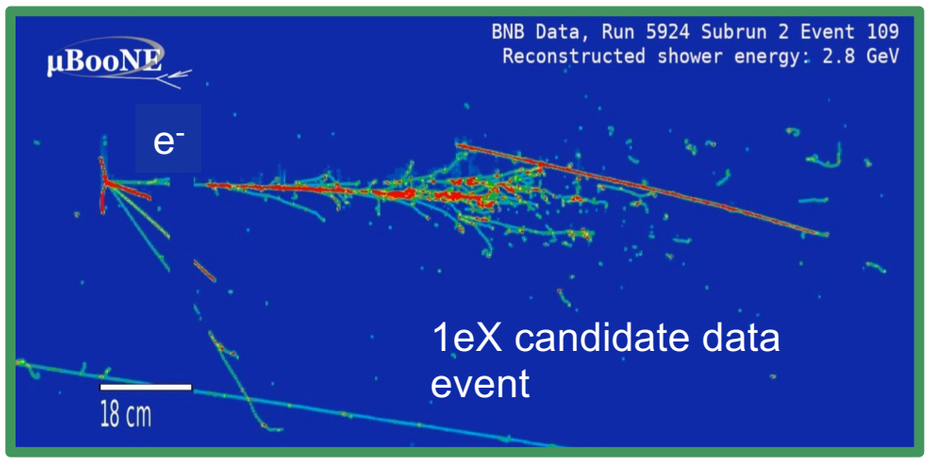


First Low-Energy Excess Search with MicroBooNE

- Four independent analyses
  - Single-photon analysis
    - NC Δ->Nγ hypothesis
    - 1γ0p, 1γ1p
  - Searches for a ν_e excess
    - Quasi-elastic kinematics (1e1p)
    - MiniBooNE-like final states (1eNp, 1e0p)
    - All ν_e final states (1eX)







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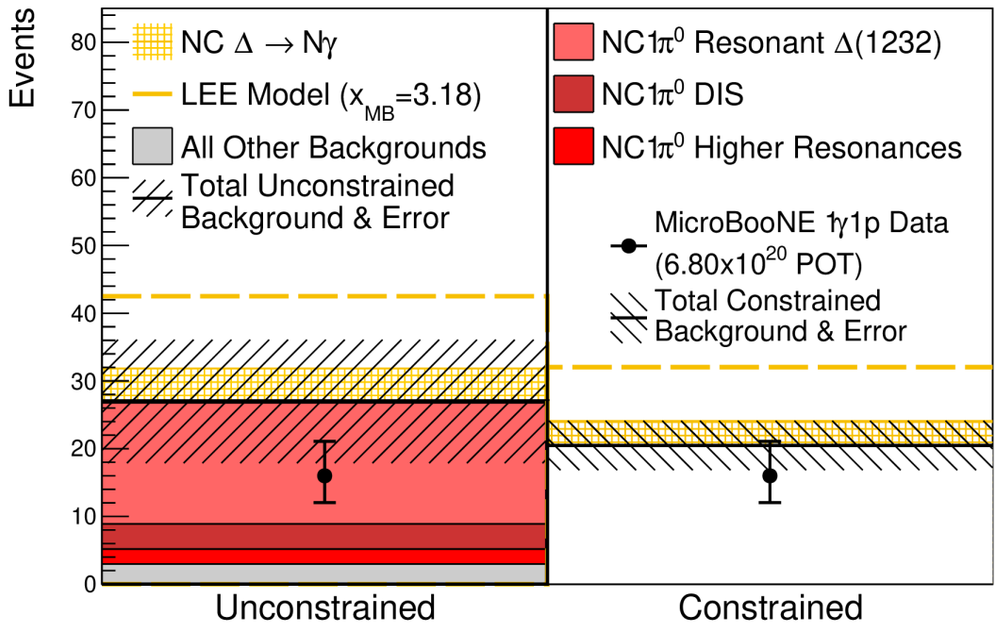
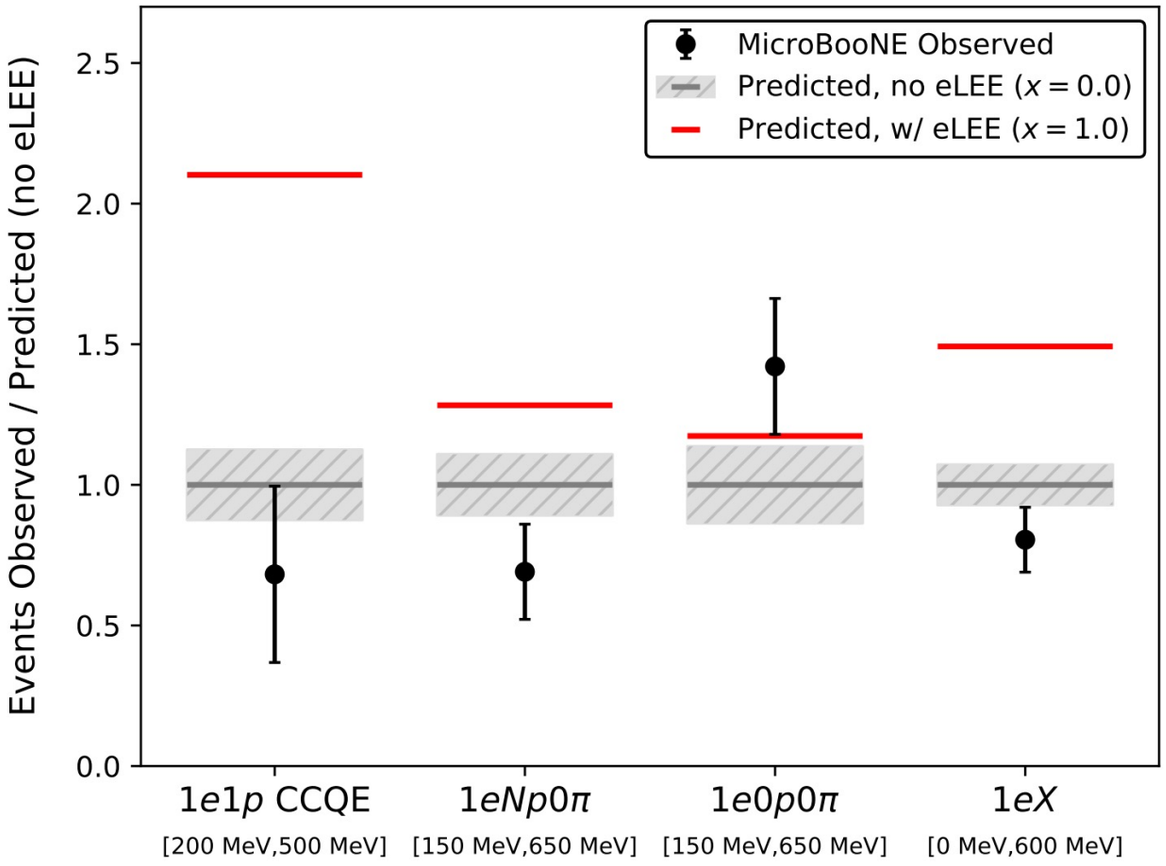
First Low-Energy Excess Search with MicroBooNE

- No evidence for an enhanced rate of single photons from NC Δ->Nγ decay above nominal MC predictions



https://arxiv.org/pdf/2110.14080.pdf, https://arxiv.org/pdf/2110.14065.pdf, https://arxiv.org/pdf/2110.13978.pdf

- Observe ν_e candidate events in agreement, or below, the predicted rates
- Reject the hypothesis that ν_e CC interactions are fully responsible for the MiniBooNE excess at > 97% C. L. in all analyses



https://arxiv.org/abs/2110.14054

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SBND and ICARUS Detectors

- Central cathode with 2 m drift regions
- 3 readout wire planes (2induction+collection)
  11263 TPC channels read out with amplification (ASIC) and digitization (commercial AD 7274) in cold
- 120 PMTs 8” hamamatsu, 192 X-ARAPUCA channels and TPB coated reflective foils embedded in cathode
- Cosmic ray tagger: scintillator strips read out by SiPMs

- 2 TPCs per module with central cathode, 1.5 m drift, E_D=0.5 kV/cm, Δt~1 ms
- 3 readout wire planes (2induction+collection) per TPC, ~54000 wires at 0, 60 degrees
- 360 PMTs 8”
- Cosmic ray tagger: scintillator strips read out by SiPMs

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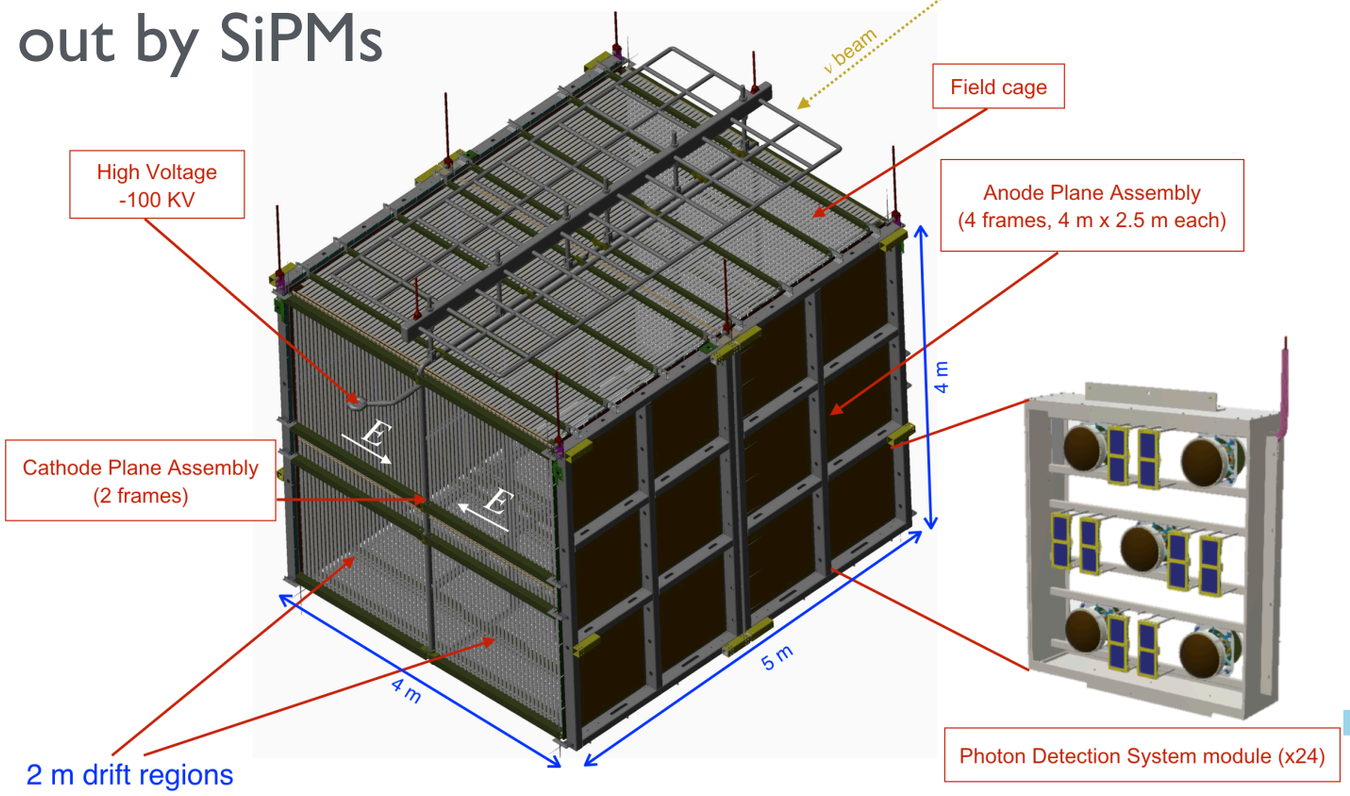
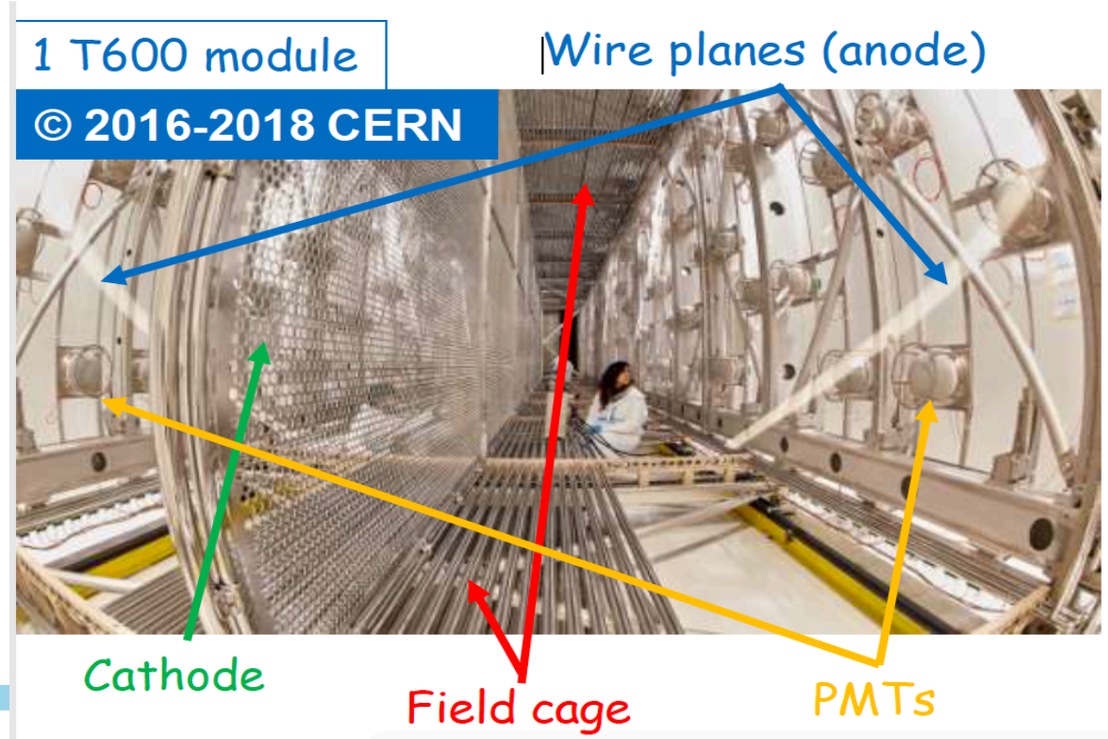
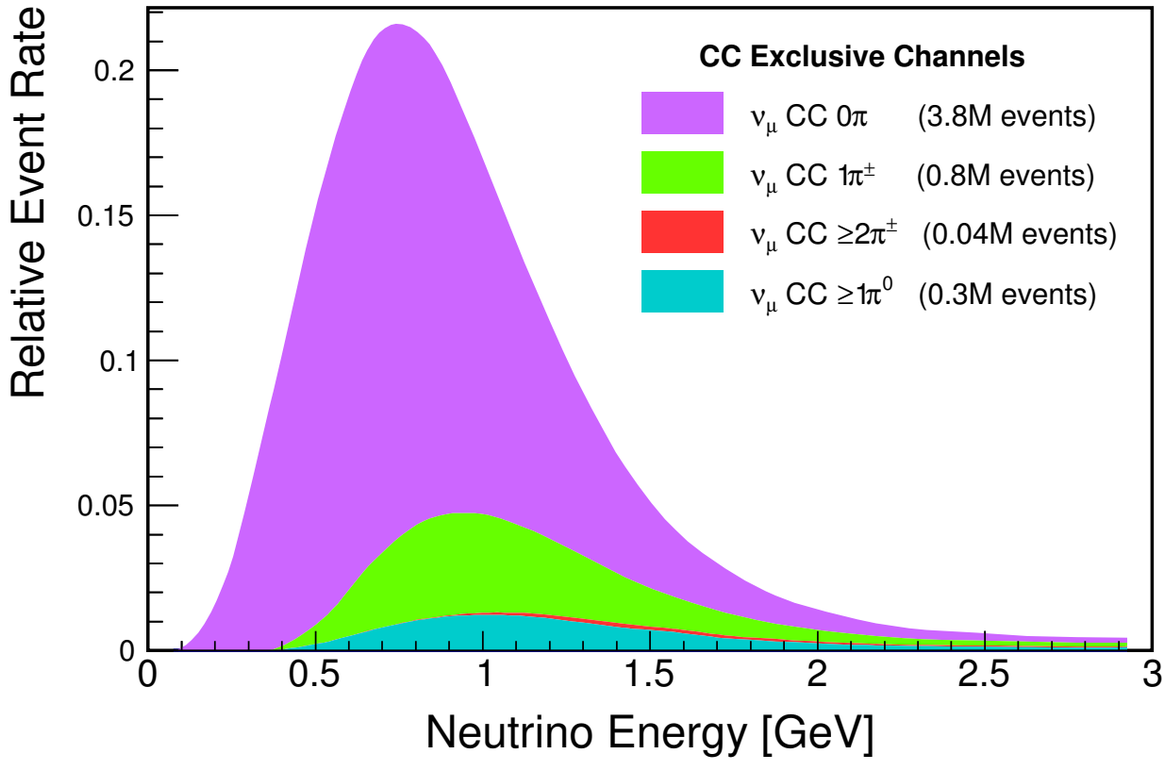




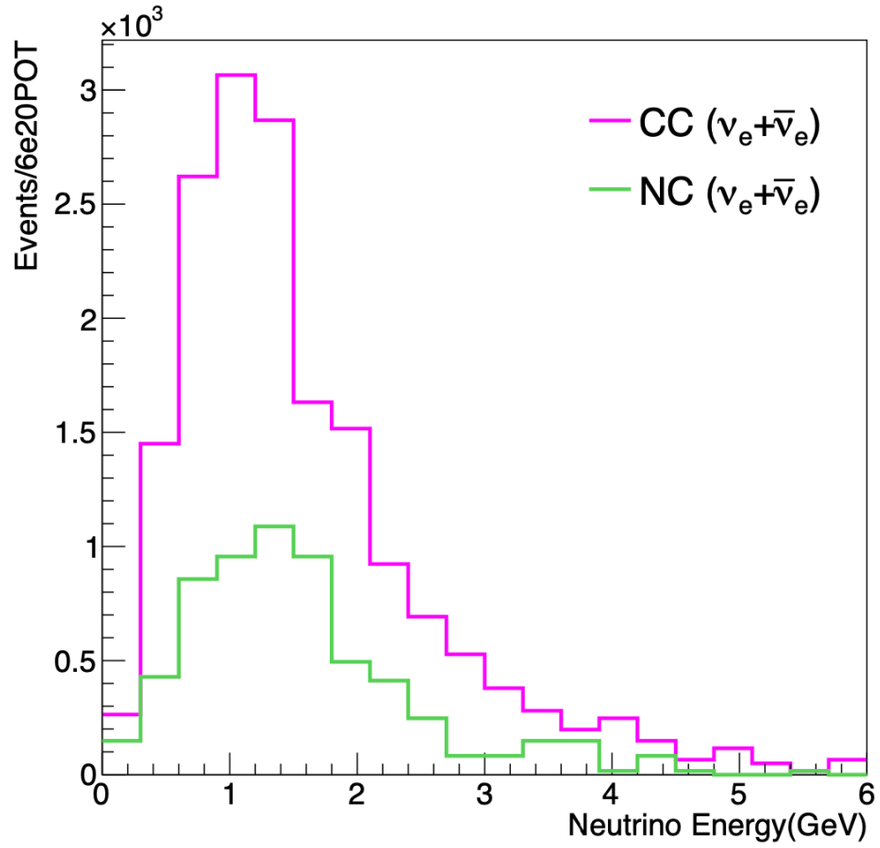
Neutrino Interactions at SBN

- High statistics precision measurements of neutrino argon cross sections in the DUNE energy range
  - SBND will have the word's highest statistics cross section measurements on argon
  - ICARUS will have high statistics electron neutrino cross section measurement

ν_μ from the Booster at SBND



ν_e from the NuMI off axis at ICARUS



- Rich BSM searches: Neutrino tridents, dark matter, Higgs portal, heavy neutral lepton, millicharged particles…

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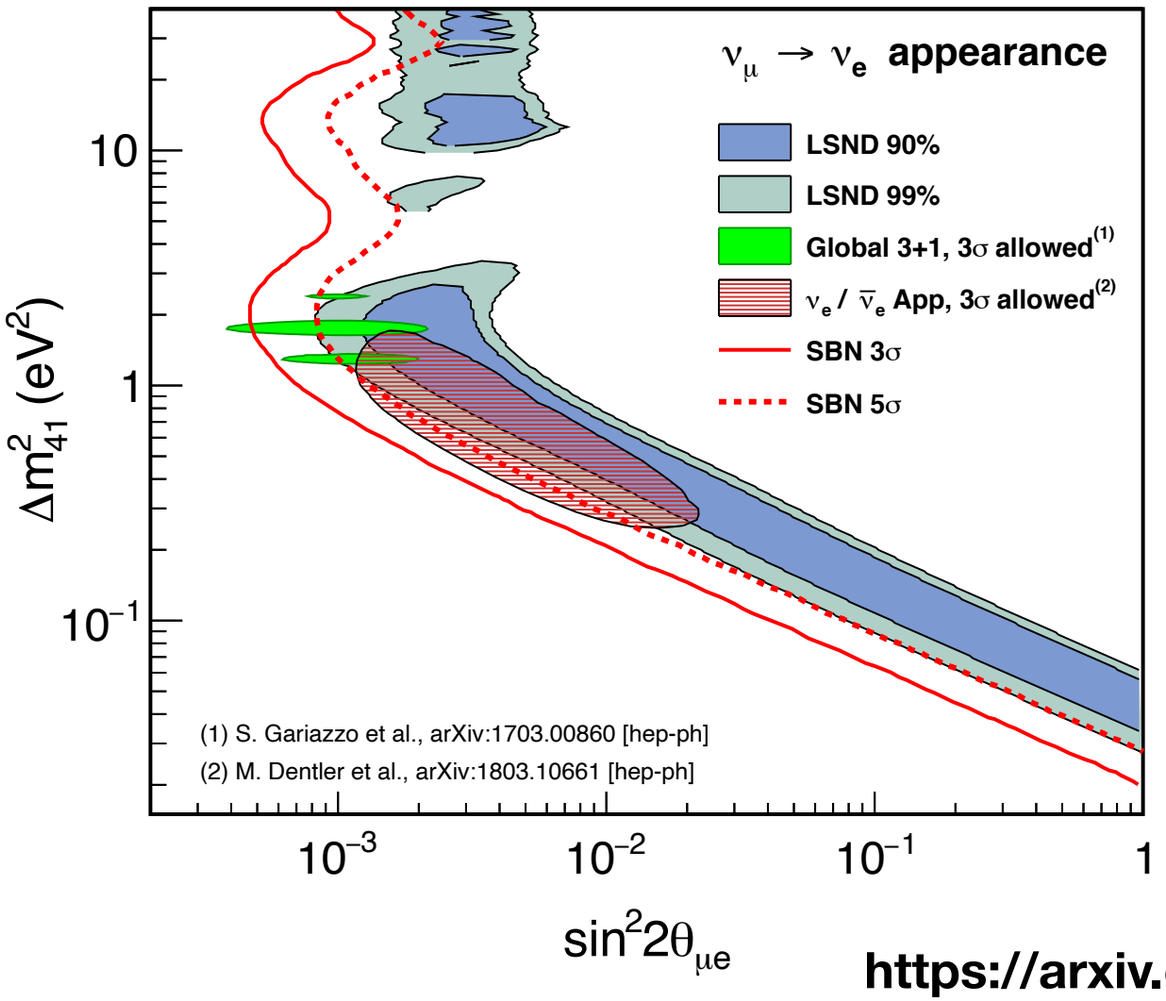
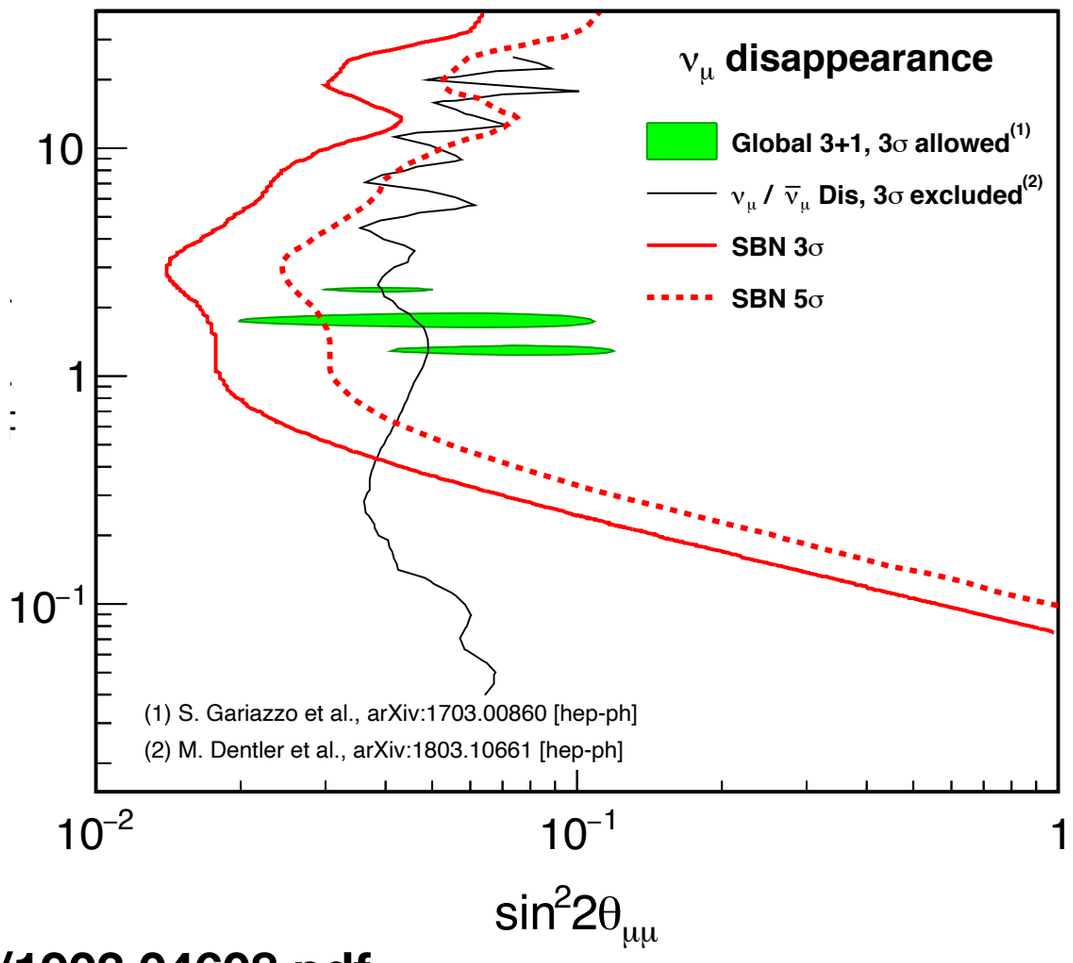
Sensitivity of SBN program

- Searches for both ν_e disappearance and ν_μ appearance

ν_e appearance



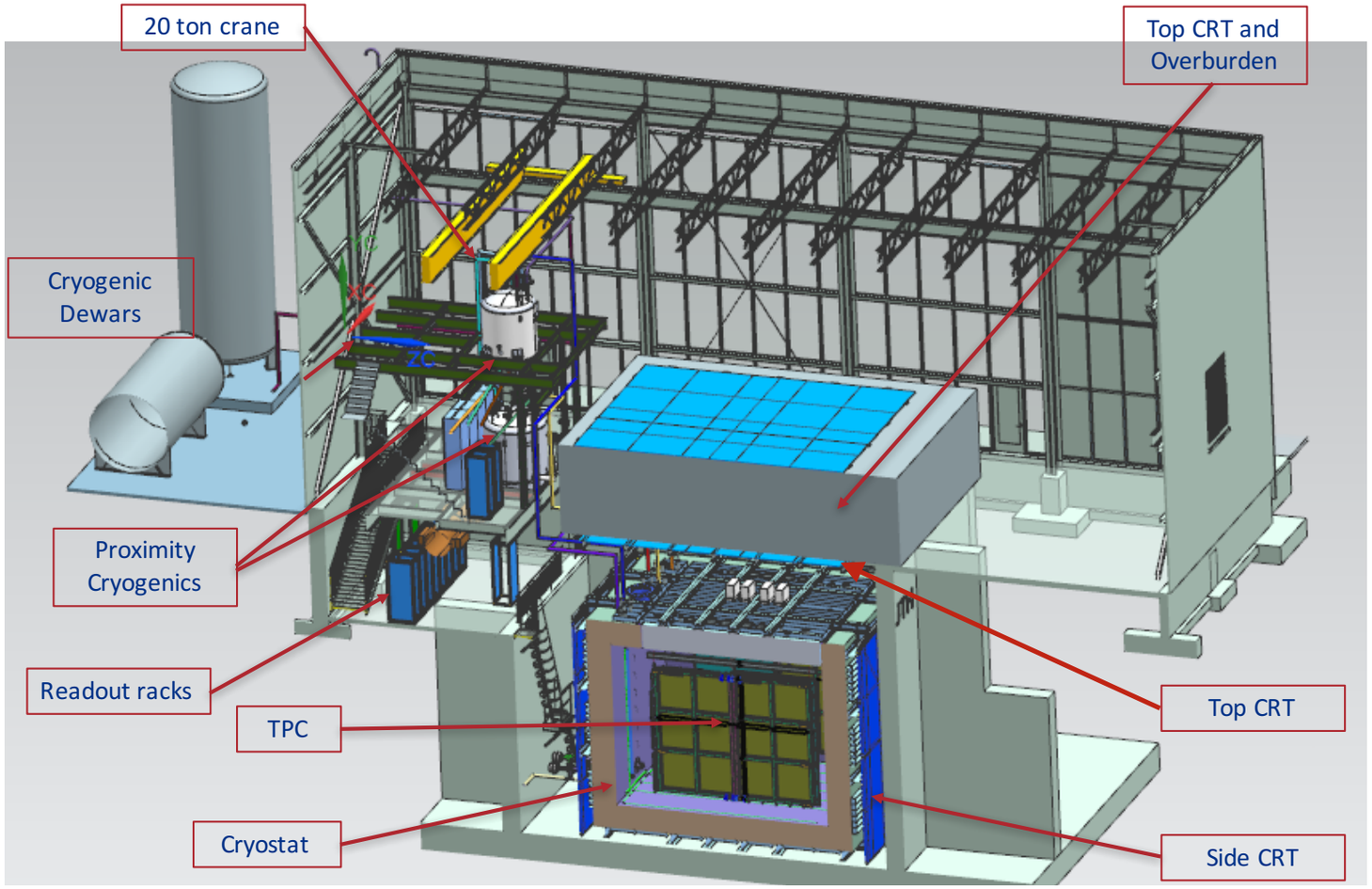
ν_μ disappearance

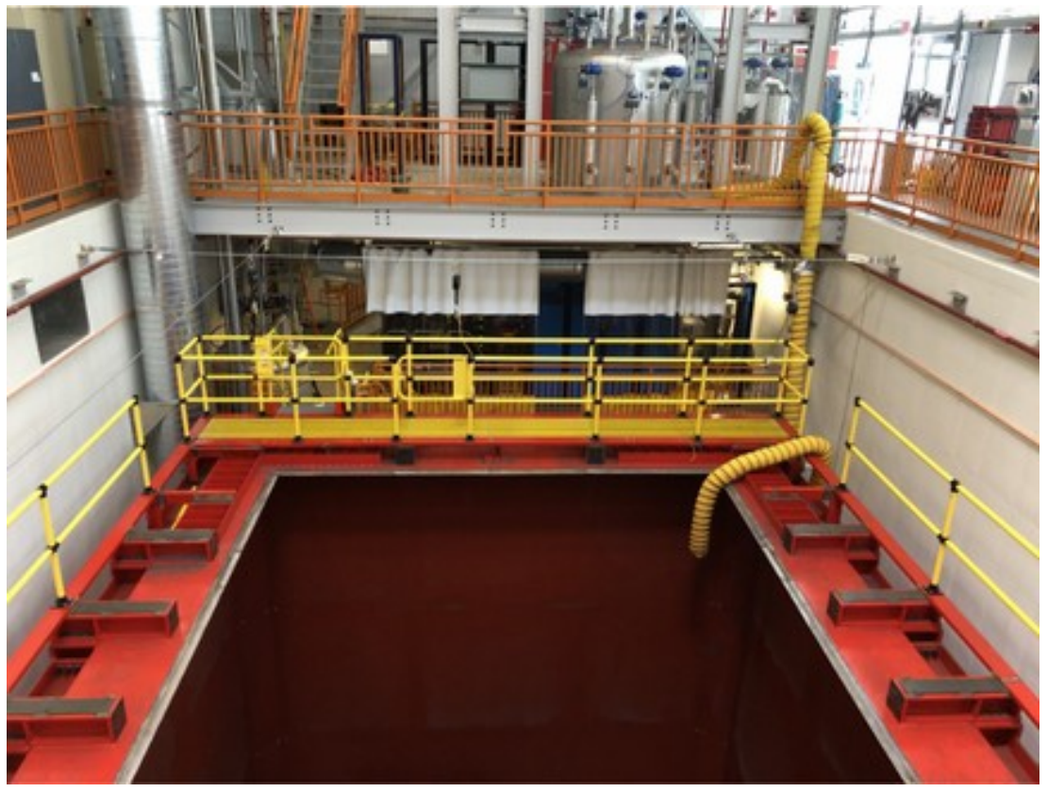


https://arxiv.org/pdf/1903.04608.pdf

- SBN cover much of the parameters allowed by past anomalies at >5σ significance

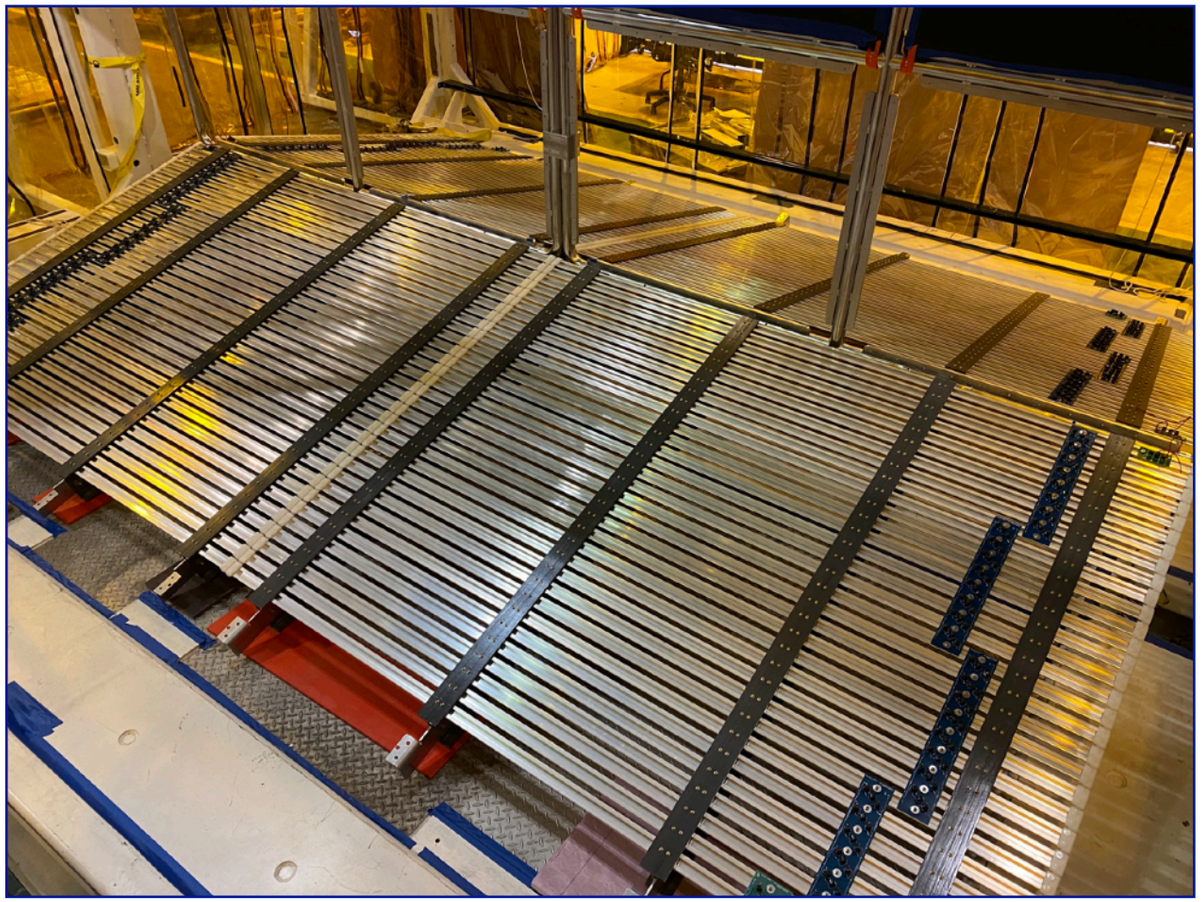
SBND Experiment

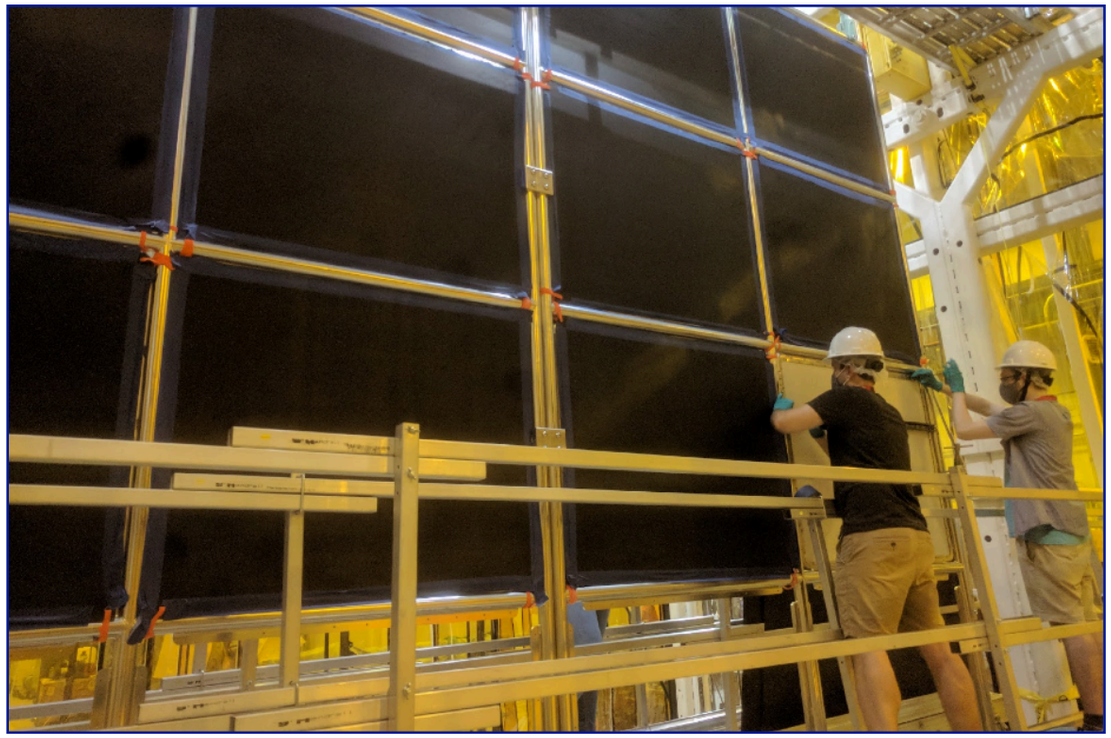




Status on SBND Construction

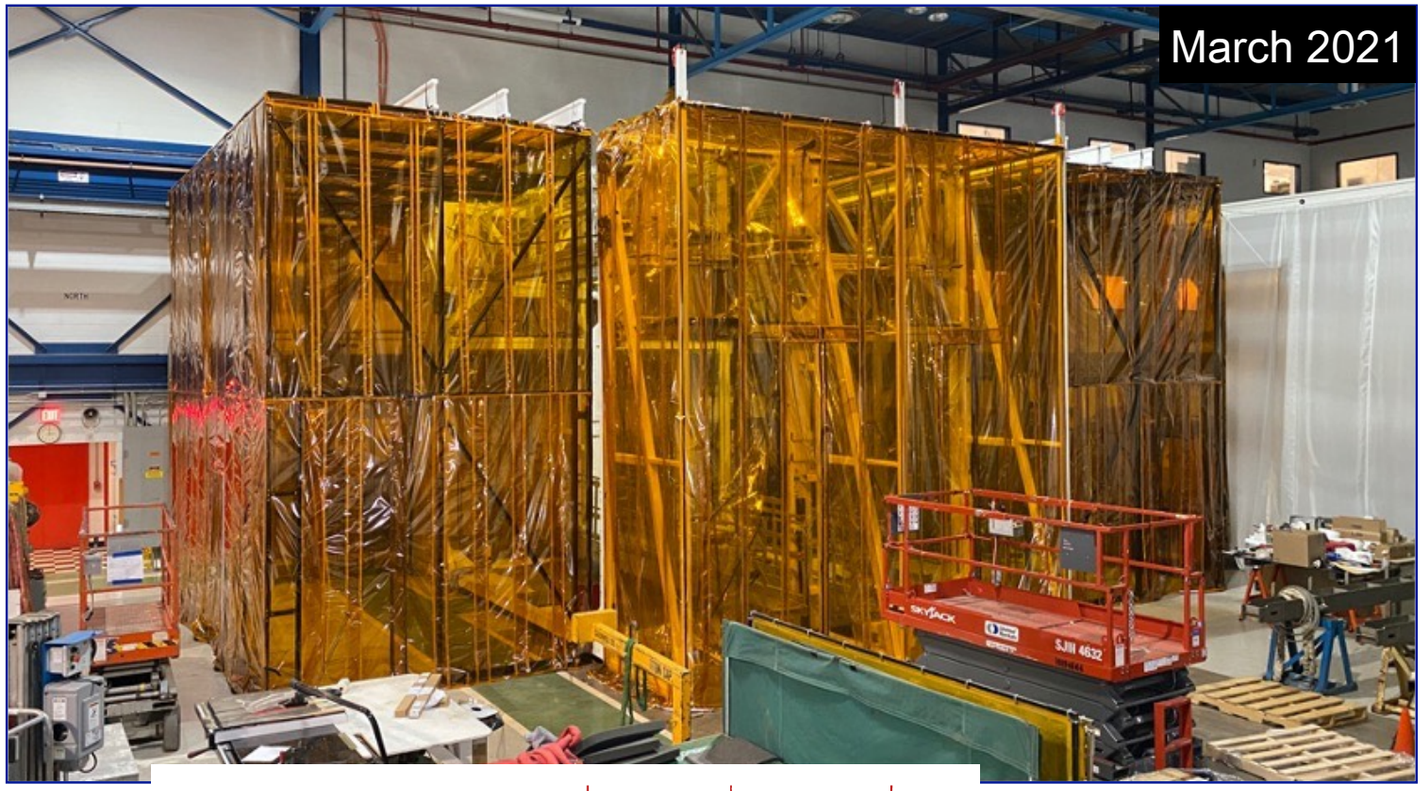
- Production of all TPC components and readout electronics is complete and components have been delivered to Fermilab
- TPC is being assembled, first TPC components installed in July 2021
  - Cathode plane assembly recently installed
  - Field cage bottom installed

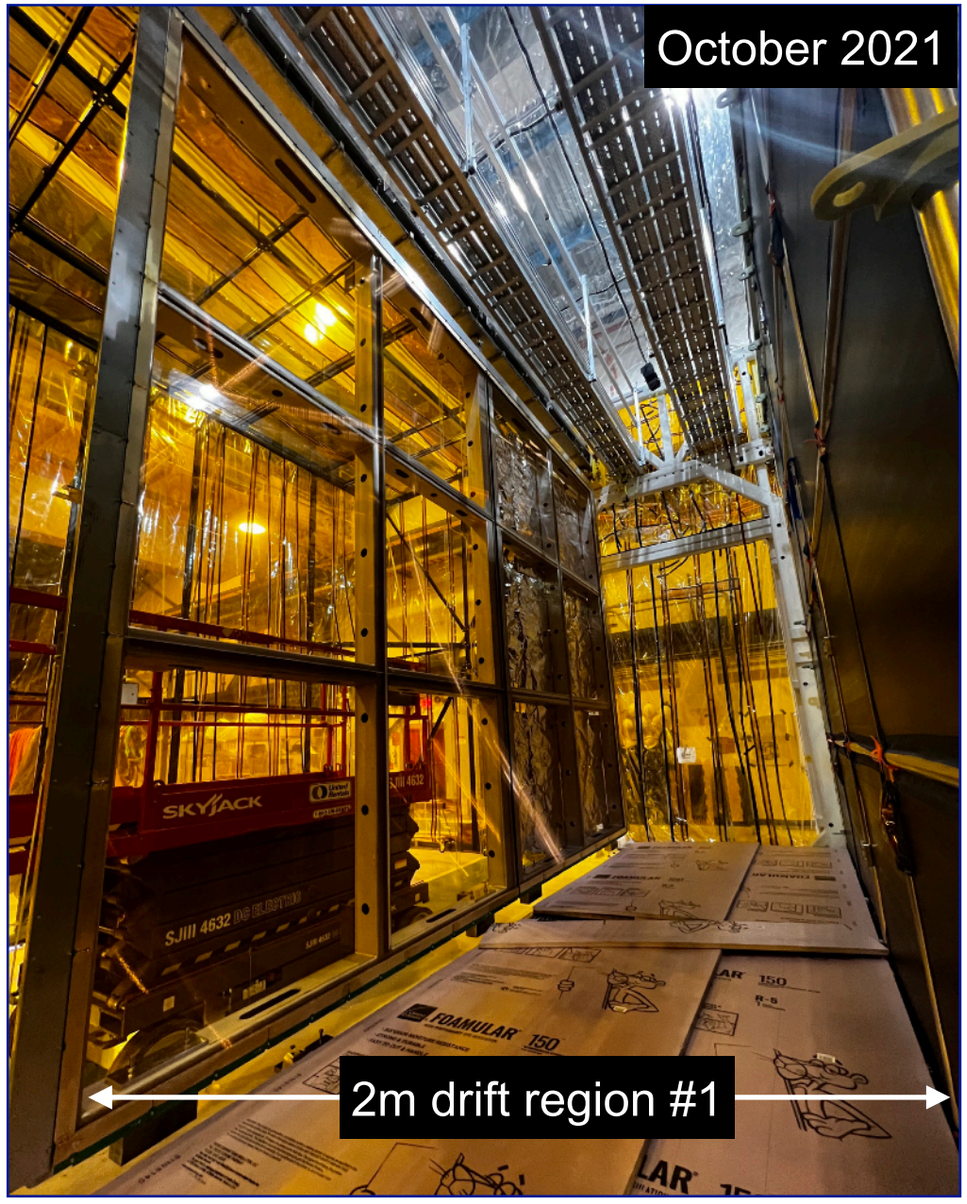


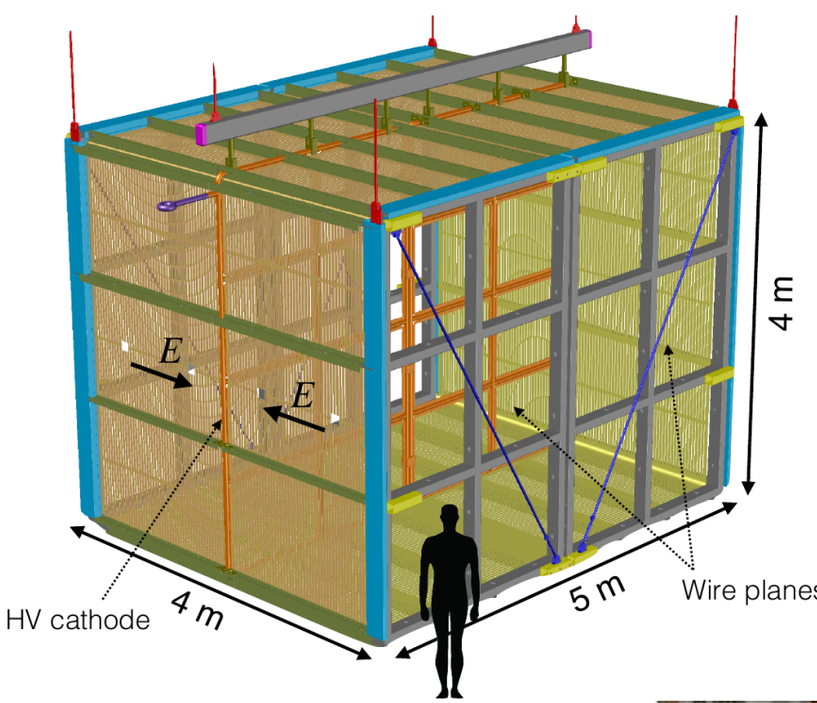


TPC Assembly

- First Anode plane successfully installed in October 2021







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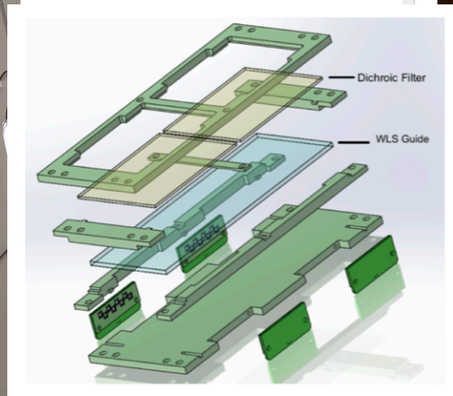
Photon Detectors and Cosmic Ray Tagger

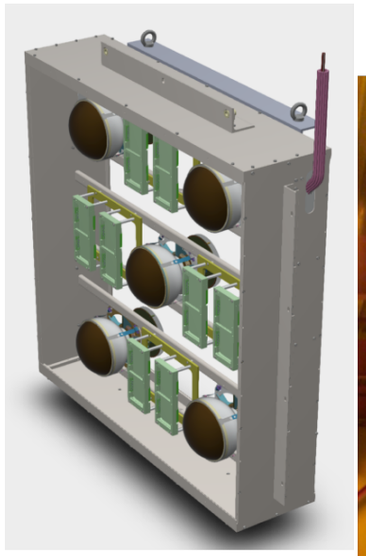
- All PMTs delivered to Fermilab. Stored in light protected room. Post-shipment reception tests completed
- All X-ARAPUCA modules delivered to Fermilab, clean tent ready for final assembly
- Photon detector calibration diffusers successfully installed on cathode plane
- Botton cosmic ray tagger installed in 2019

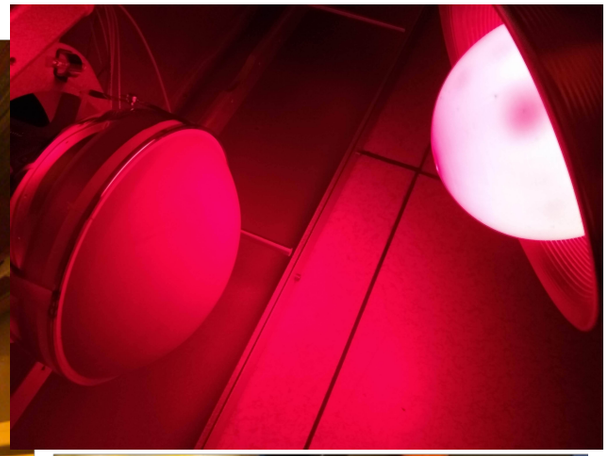
Bottom CRT

x-ARAPUCA



PMT





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Electronic Installation and DAQ

- Cold electronics and readout electronics ready for installation
- Installation of electronics components for detector readout and monitoring at SBND experimental hall is well underway
  - Racks, readout electronics, power supplies, ground impedance monitors, cabling, etc
  - All detector reader racks expected completed in early 2022

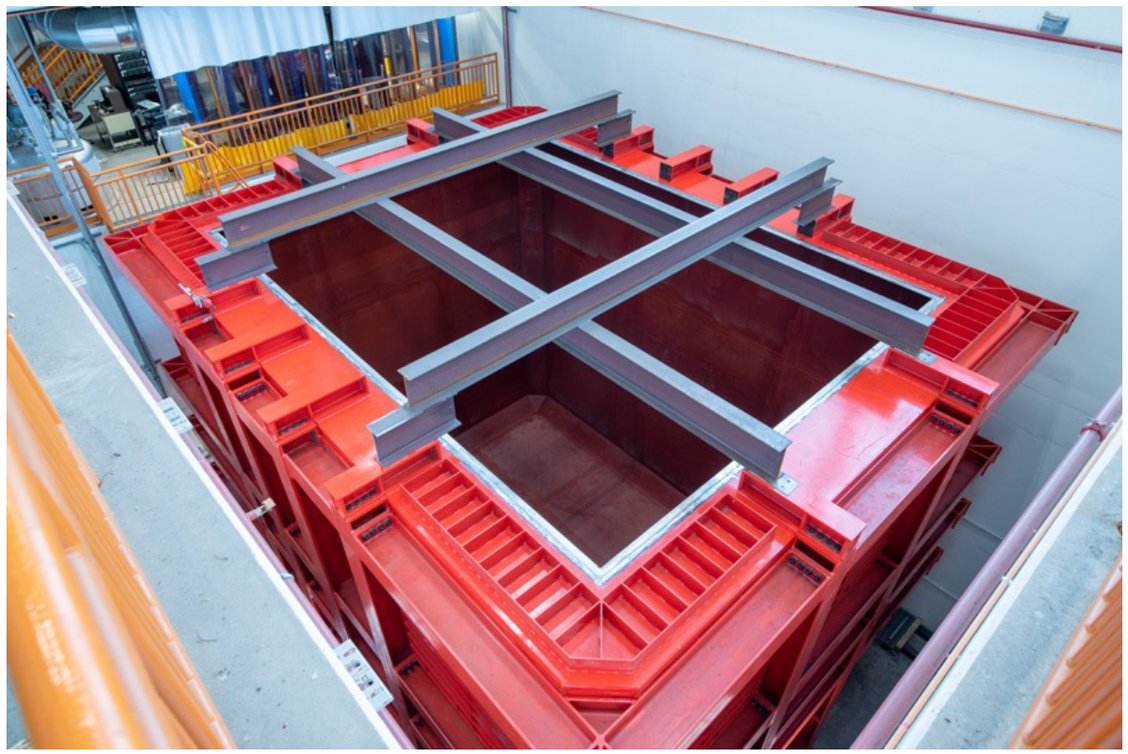
TPC readout

DAQ servers

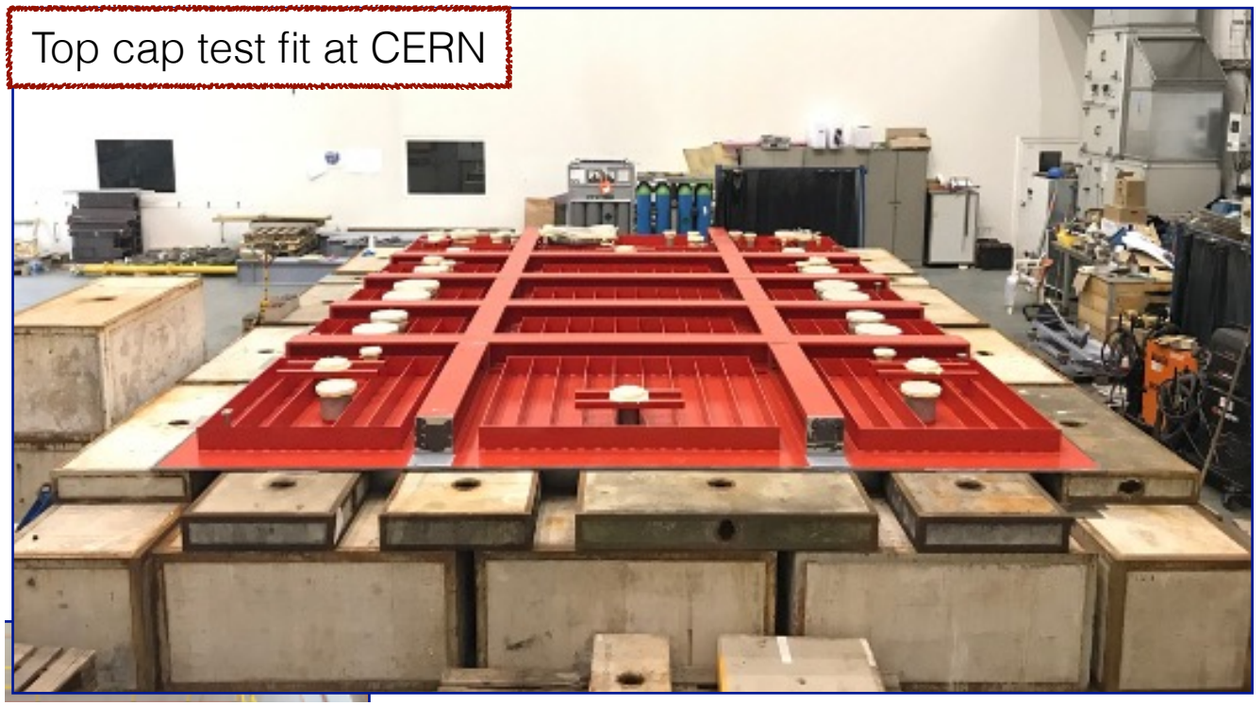
Trigger components

Cryostat and Cryogenics

- Warm outer vessel installed in the building
- Membrane cryostat material arrived at Fermilab in April 2021
- Cryostat top cap construction and test fit completed at CERN in May 2021
- External cryogenics installation progressing well at Fermilab



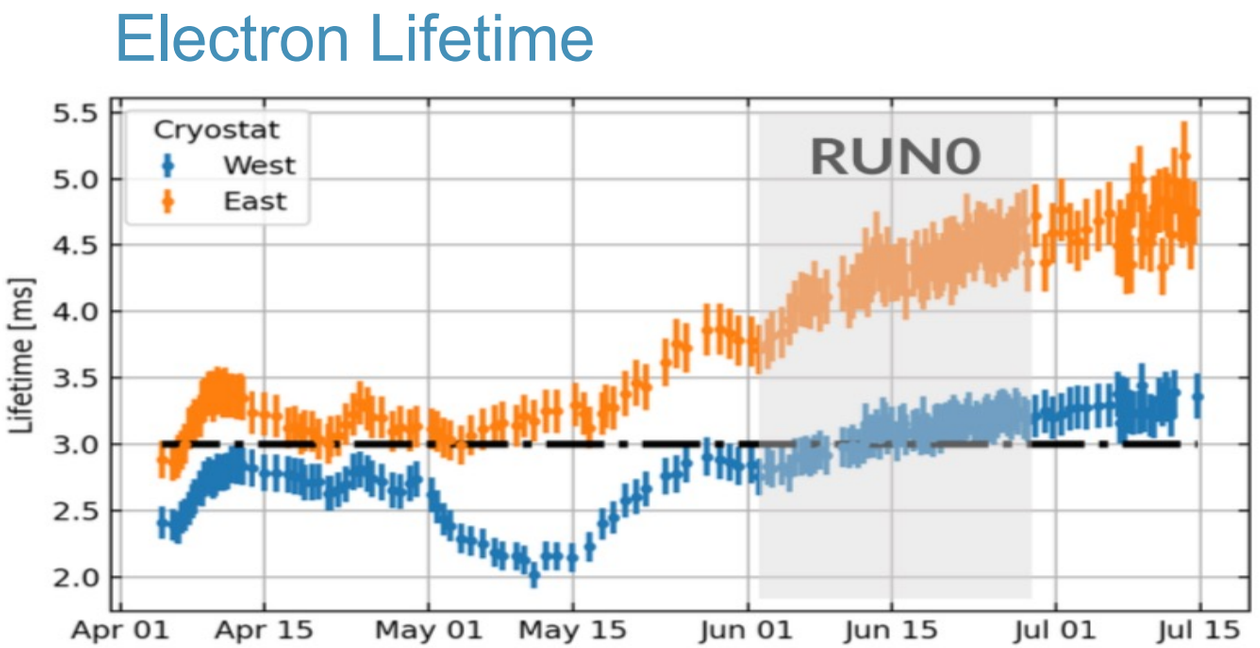
Top cap test fit at CERN



External cryogenics dewars at FNAL

ICARUS at FNAL

- Several technology improvements were introduced, aiming to further improve the achieved performance ICARUS previous runs: new cold vessels, improvement of the cathode planarity, higher performance read-out electronics and upgrade of the PMT system
- ICARUS began commissioning in 2020, collecting first neutrino data in June 2021
- Stable noise levels (S/N>10), good electron lifetime



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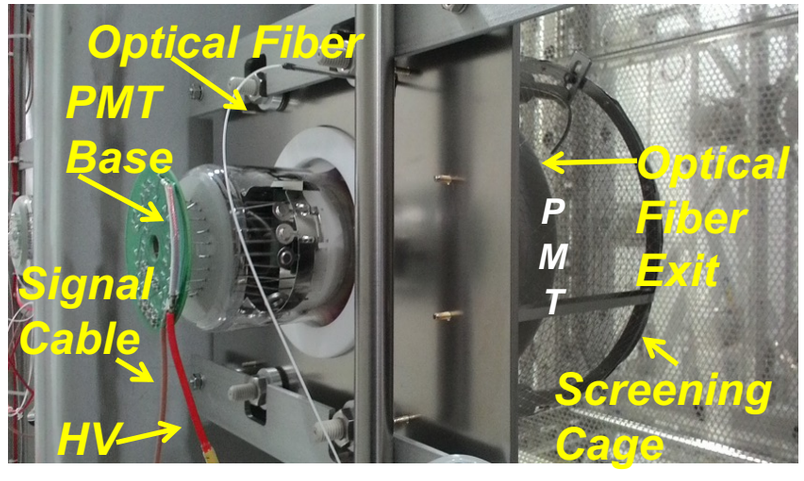
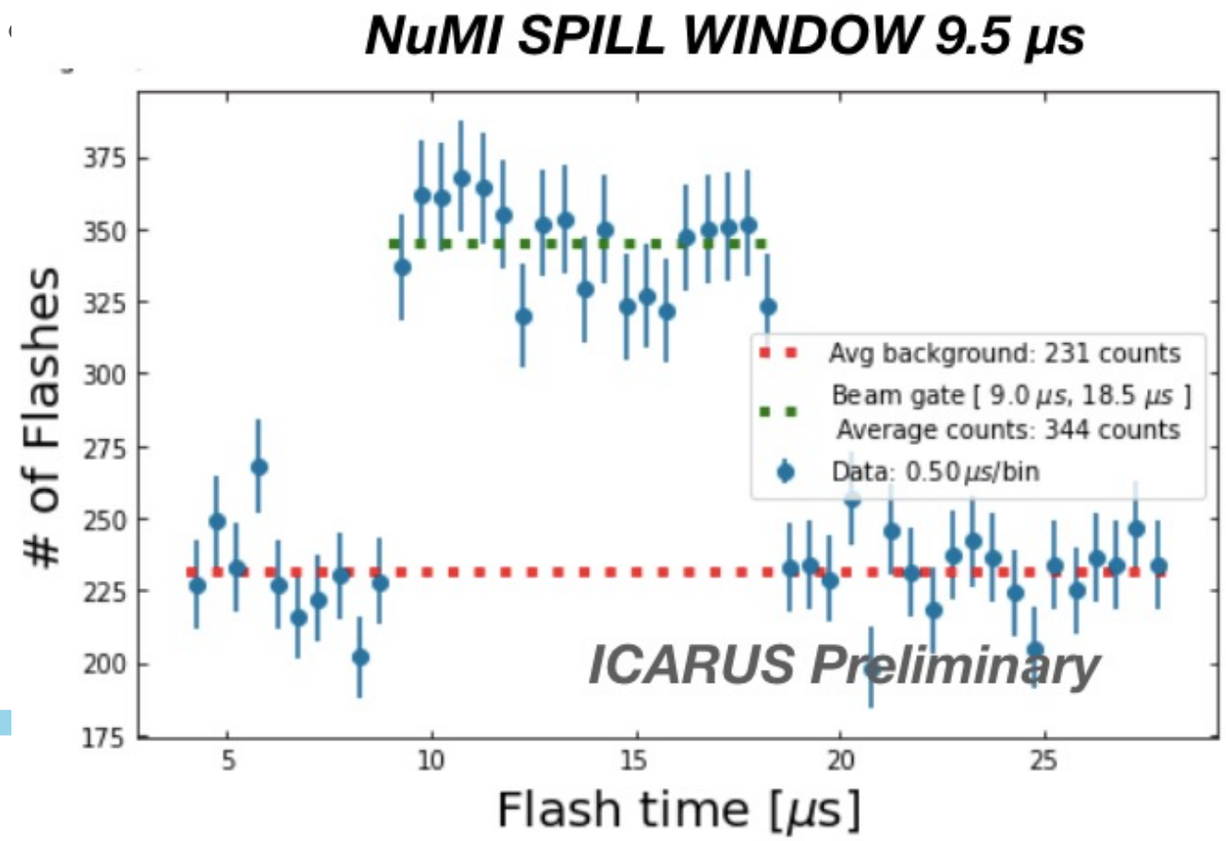
Light Collection System Upgrade (PMT)

- ICARUS at SBN has 360 PMTs 8” (5% photocathode coverage of TPC wire area, 15 phe/MeV) that provides:
  - Precisely identify the time of occurrence of any ionizing event in TPC with ns resolution
  - Localize events with <50 cm spatial resolution
  - Give event topology for selection purposes
    - Sensitivity to low energy events (~100 MeV)
- The system was completed in 2019
- Commissioning of the system started in 2020





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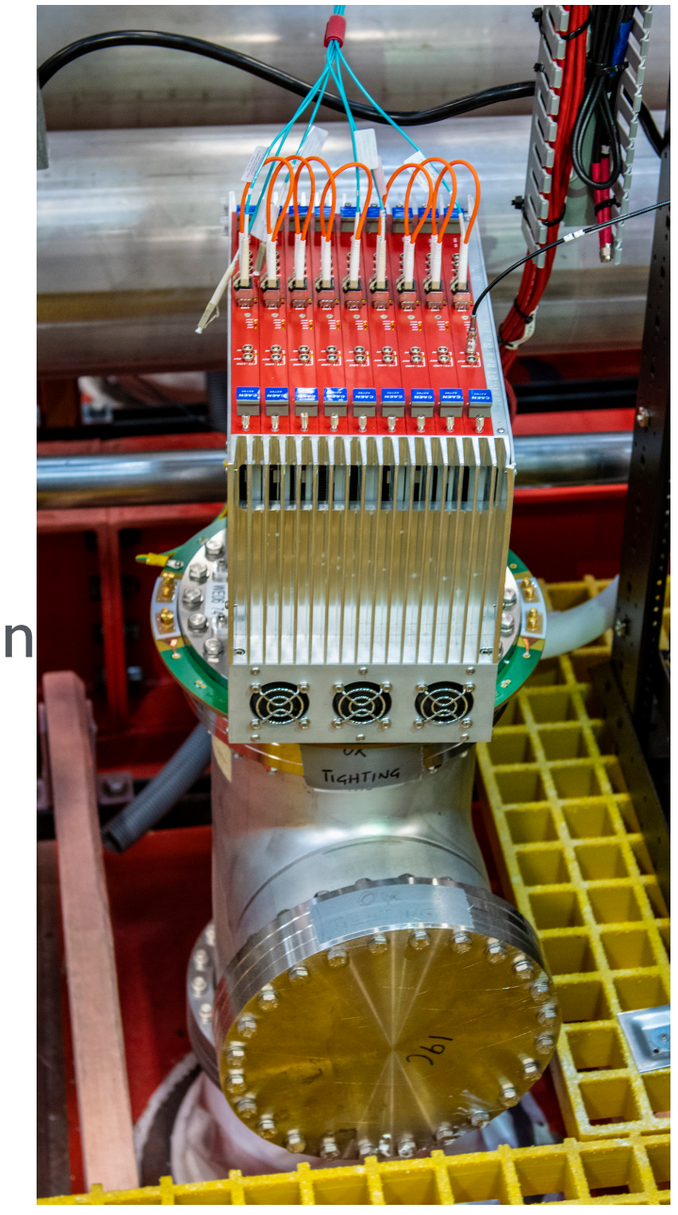
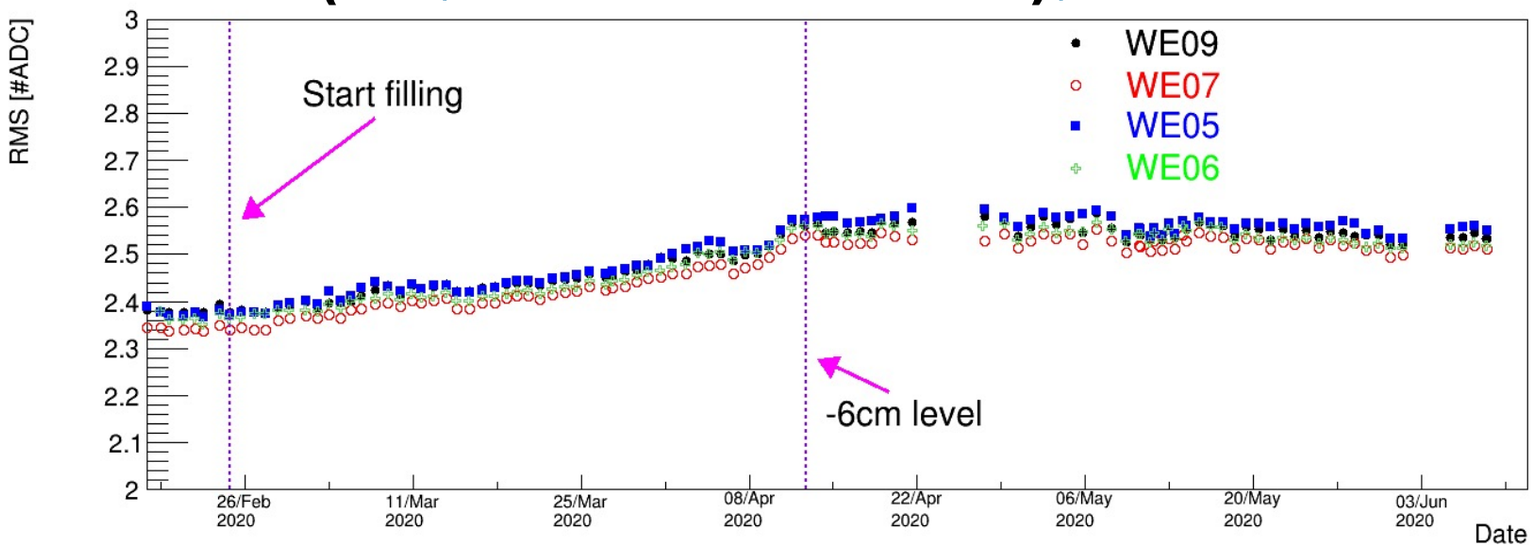
TPC Readout Electronics Upgrade

Reside outside the cryostat

- New TPC readout electronics
  - A front-end based on analogue low noise/charge sensitive pre-amplifier
  - More compact layout: both analog+digital electronics in a single flange
  - Lower noise ~1200 e- equivalent (~20% S/N improvement w.r.t LNGS)
  - Shorter shaping time ~1.5 μs matching e- transit time between wire planes providing a better hit position separation
-



TPC Noise (coherent noise removed)



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New Cosmic Ray Tagging System (CRT)

- CRT surrounds the cryostat with two layers of plastic scintillators (~1100 m^2)
- Provides spatial and timing coordinates of the track entry point
- Few ns time resolution allows measuring direction of incoming/ outgoing particle propagation via time of flight
- Three subsystems providing ~95% tagging efficiency:
  - Bottom, side and top CRT
- Finalizing the installation of the top CRT

Side CRT: installed

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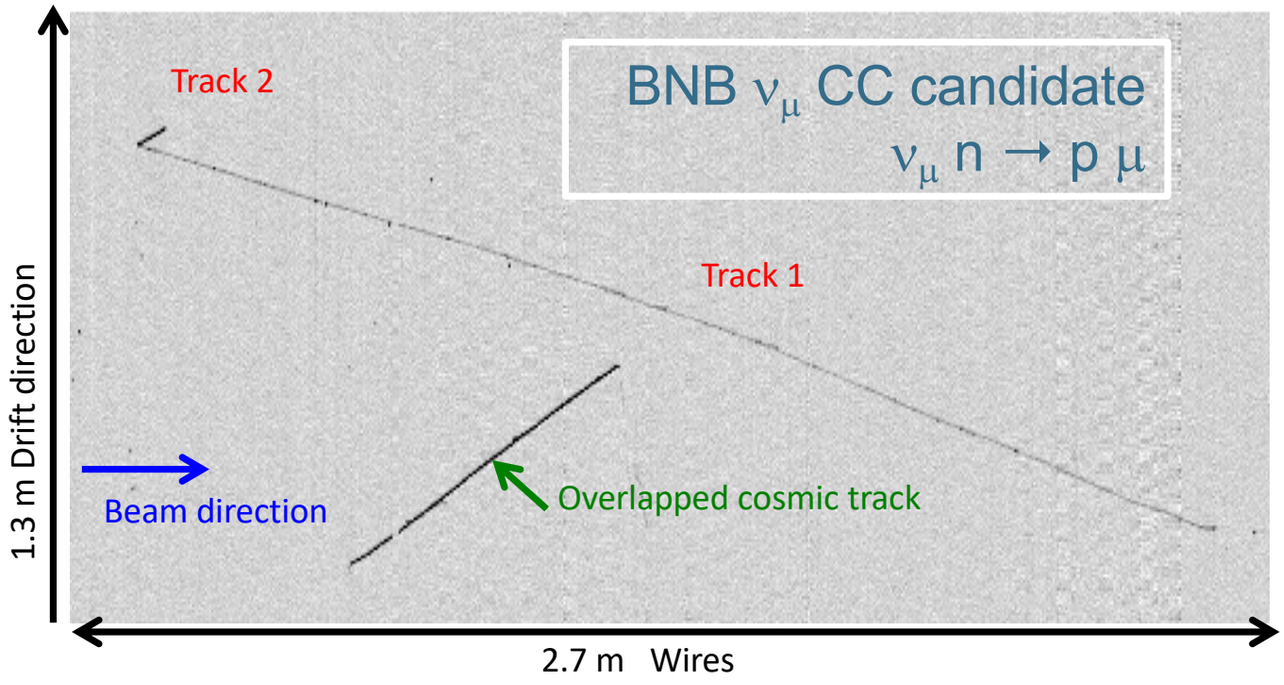
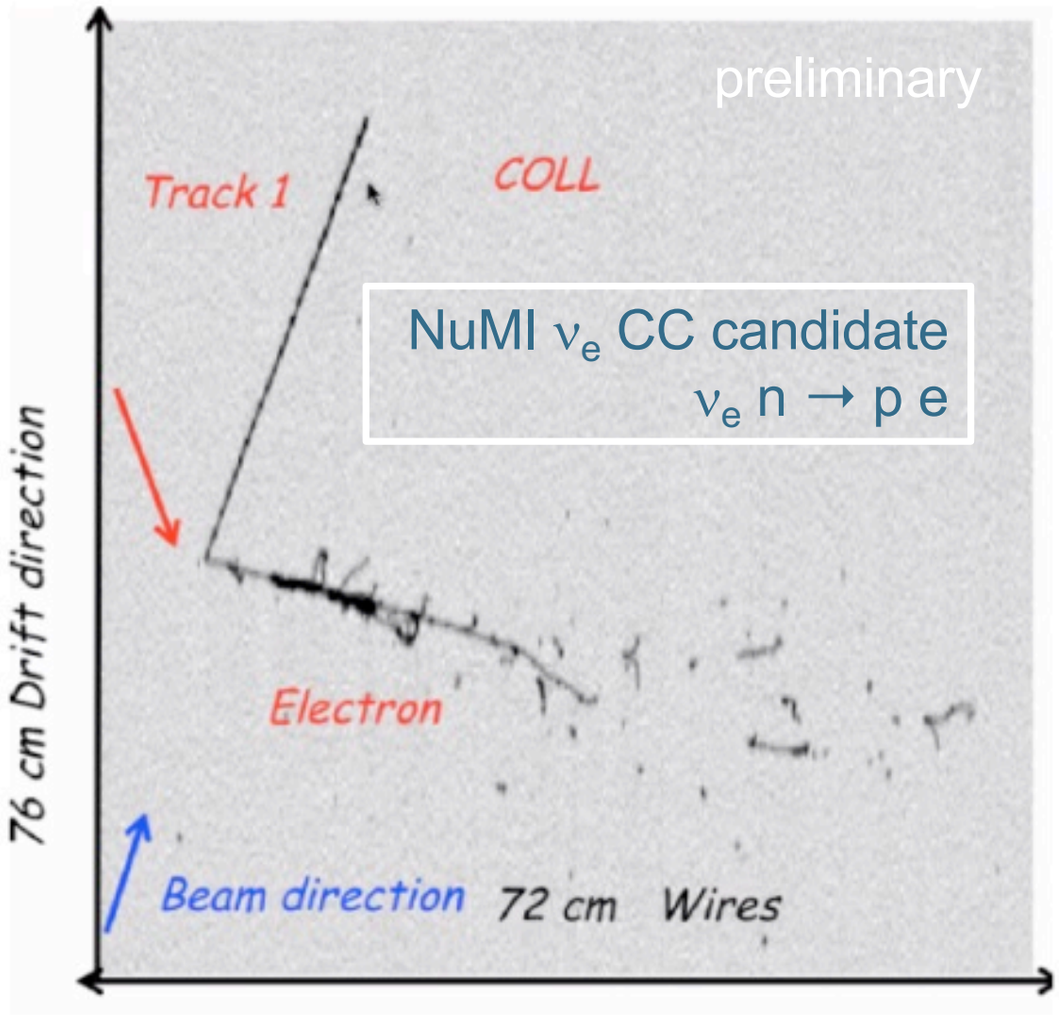
ICARUS Commissioning Status

- ICARUS started to take neutrino data from Booster (2.8×10^{19} POT) and NuMI (5.2×10^{19} POT) this past June 2021

Muon Neutrino



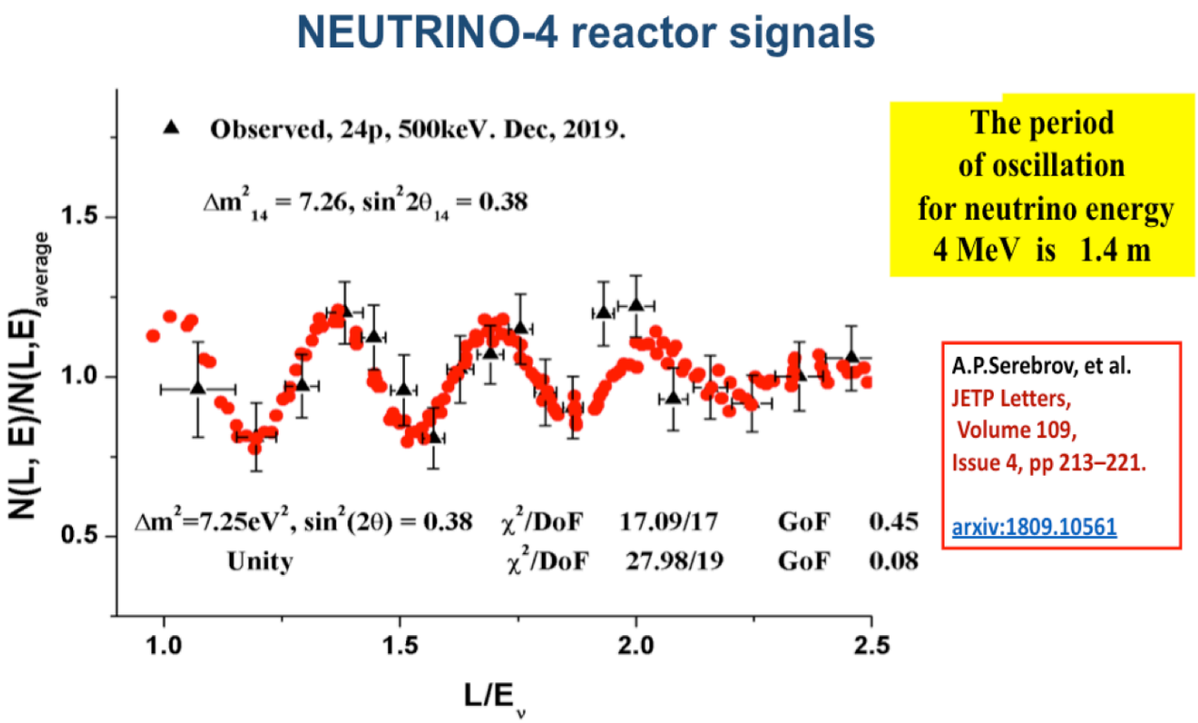
Electron Neutrino



- Final stages of the trigger system are being implemented and tested this fall
- Commissioning of full cosmic ray tagger and installation of the overburden is scheduled in early 2022
- Collecting neutrino data from Booster and NuMI neutrino beams

Search for Neutrino-4 Oscillation Signal

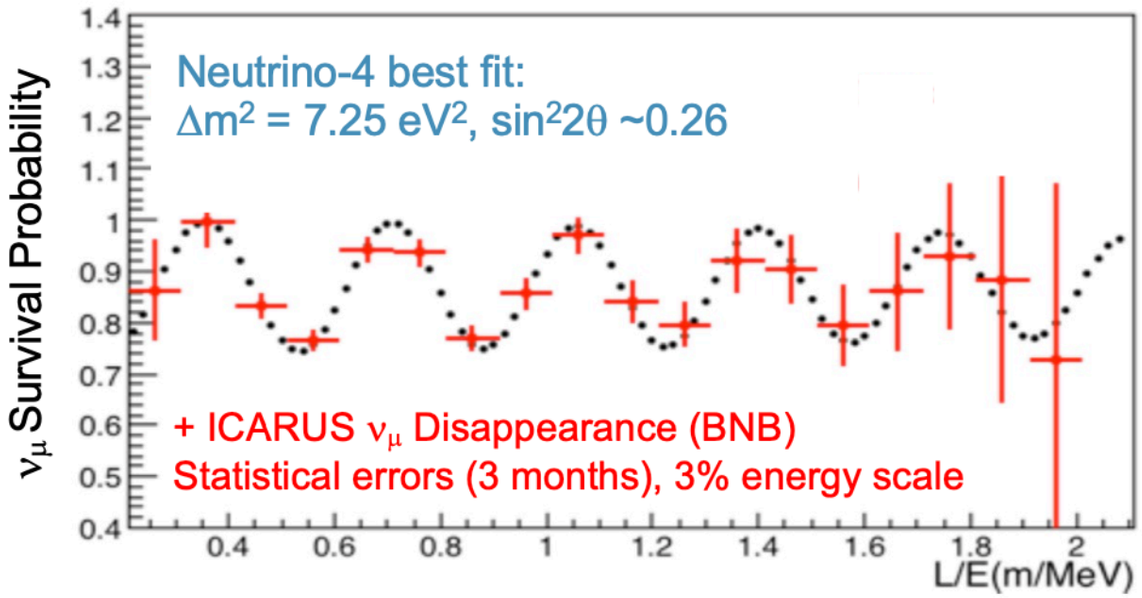
- The Neutrino-4 collaboration claimed a reactor neutrino disappearance signal with a clear modulation with L/E ~1-3m/MeV
- ICARUS will perform a single-detector oscillation analyses using data taken in the coming year (before SBND data is available)



The period of oscillation for neutrino energy 4 MeV is 1.4 m

A.P.Serebrov, et al.
JETP Letters,
Volume 109,
Issue 4, pp 213–221.

arxiv:1809.10561



- ICARUS will be able to test this oscillation hypothesis in the same L/E range in two independent channels with different beams
  - Disappearance of ν_μ using Booster beam
  - Disappearance of ν_e using NuMI beam

Summary

- The SBN detectors will perform a world-leading search for eV-scale sterile neutrino by looking at both appearance and disappearance channels
- Rich physics program of neutrino-argon scattering measurements and BSM physics
- SBND construction is well on its way, all the components ready for assembly and installation
  - SBND installation in progress, expect commissioning in 2023
- After an extensive refurbishing, ICARUS installation at FNAL in the SBN far site has been completed
- Commissioning of ICARUS at Fermilab in progress and getting ready to start the physics data taken
- The SBN oscillation program will begin when SBND will be operational
- Many opportunities to join the collaboration and participate with installation, commissioning and data analysis