



Short Baseline Neutrino

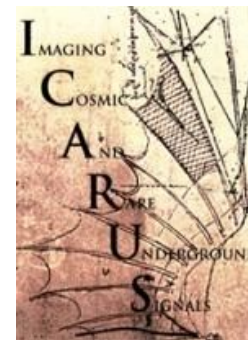
ICARUS + SBND

Short Baseline Neutrino Program

Anne Schukraft

NEUTRINO2022, Seoul

May 31, 2022

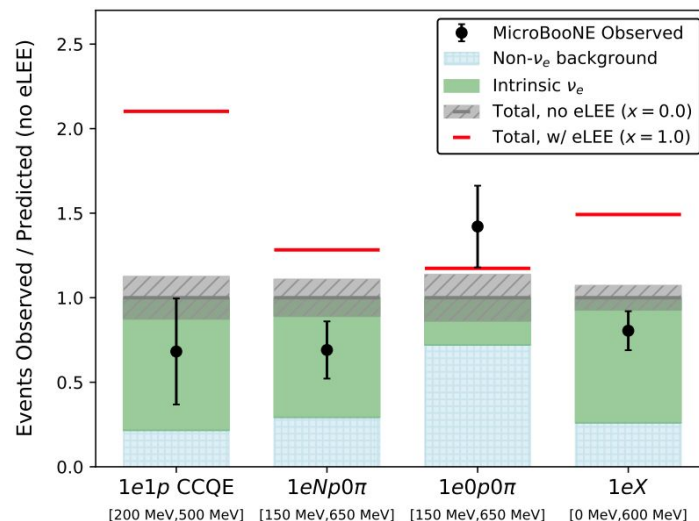


Sterile neutrino search beyond MicroBooNE

MicroBooNE presented results of their first analyses searching for an excess of low-energy electromagnetic events in single electron and single photon final states

-> see previous talk by H. Wei

- MicroBooNE finds no hints of an electromagnetic event excess
- MicroBooNE's result does not rule out the existence of sterile neutrinos



P. Abratenko et al, arXiv:2110.14054

Entering the next phase of accelerator-based short baseline oscillation searches requires

- **increased exposure through a larger far detector**
- **a near detector for systematics constraints**

Short Baseline Neutrino Program at Fermilab

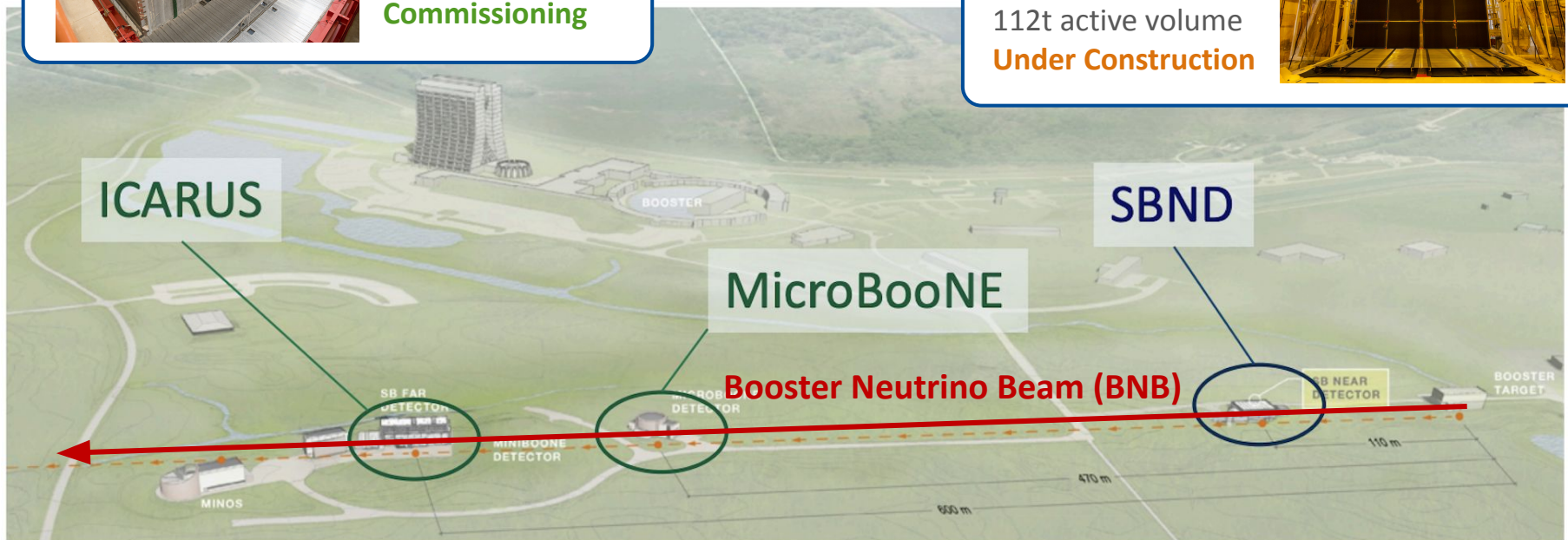
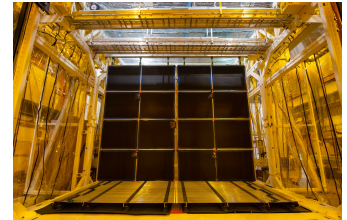


ICARUS

600m baseline
470t active volume
Commissioning

SBND

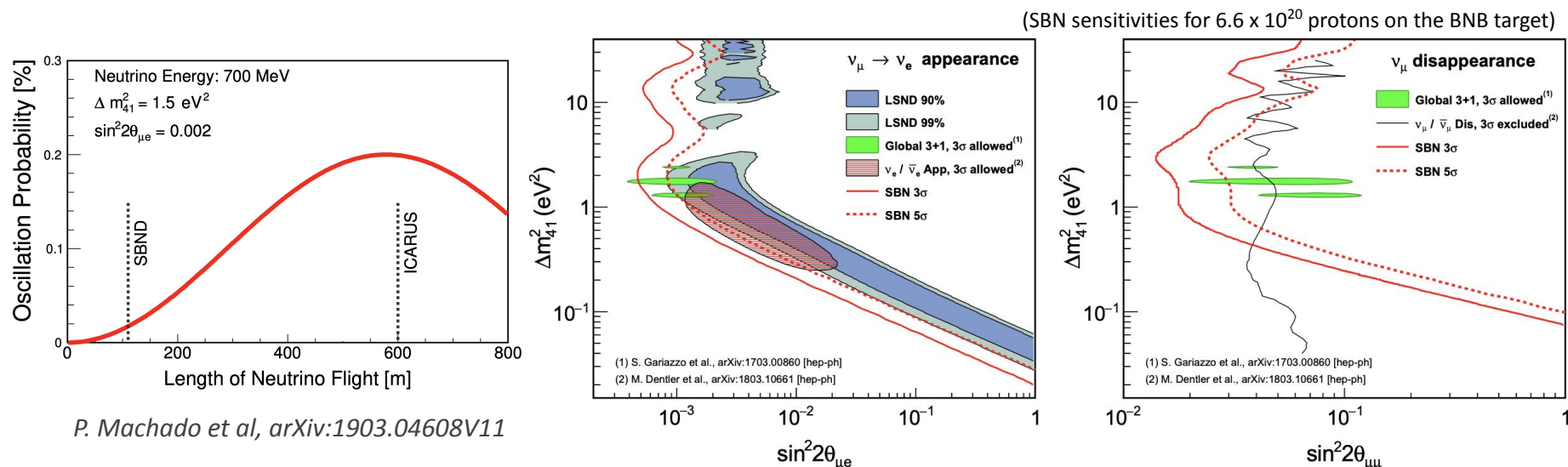
110m baseline
112t active volume
Under Construction



- Three detectors sampling the *same neutrino beam* at different distances
- *Same nuclear target* (Ar) and *detector technology* (LArTPC)
- reduces systematic uncertainties to the %-level

SBN Oscillation Sensitivity

- SBND + ICARUS will test the sterile neutrino hypothesis
 - can cover the parameter space favored by past anomalies with 5σ significance
- Observing neutrino flux at different distances from the beam target
- Effective systematics constraint through near detector (SBND) and same detector technology in near and far detector
- **Search for appearance of ν_e and disappearance of ν_μ within the same experiment**
 - current results show a 4.7σ tension between ν_e appearance and ν_μ disappearance channels



Alternative Explanations

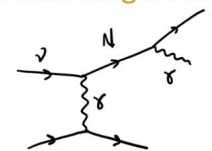
- There are many alternative models to explain the MiniBooNE excess that are not in tension with experimental results (including MicroBooNE)
- SBN can exploit these and other BSM scenarios using the strengths of each detector
SBND: proximity to beam target
ICARUS: observing the off-axis NuMI beam in addition to the BNB

Dark Neutrinos



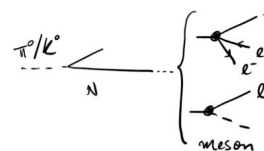
Light Z_D - Bertuzzo Jana Machado Zukanovich PRL 2018
 Bertuzzo Jana Machado Zukanovich PLB 2019
 Argüelles Hostert Tsai PRL 2019
 Heavy Z_D - Ballett Pascoli Ross-Lonergan PRD 2019
 Ballett Hostert Pascoli PRD 2020

Transition Magnetic Moment



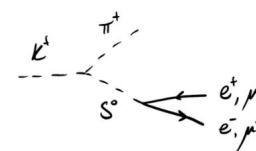
Gninenko PRL 2009
 Coloma Machado Soler Shoemaker PRL 2017
 Atkinson et al 2021
 Vergani et al PRD 2021

Heavy Neutral Leptons



Long list, ex.
 Ballett Pascoli Ross-Lonergan JHEP 2017
 Kelly Machado PRD 2021

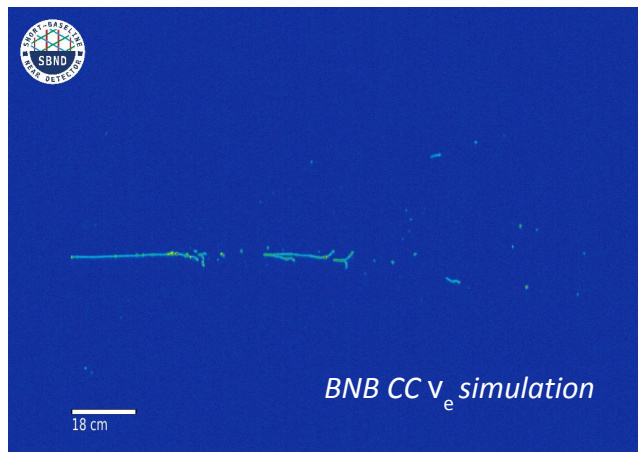
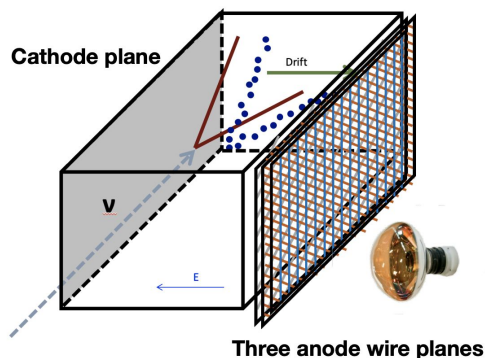
Higgs Portal Scalars



Pat Wilczek 2006
 Batelli Berger Ismail PRD 2019

Courtesy of P. Machado

not an exhaustive list



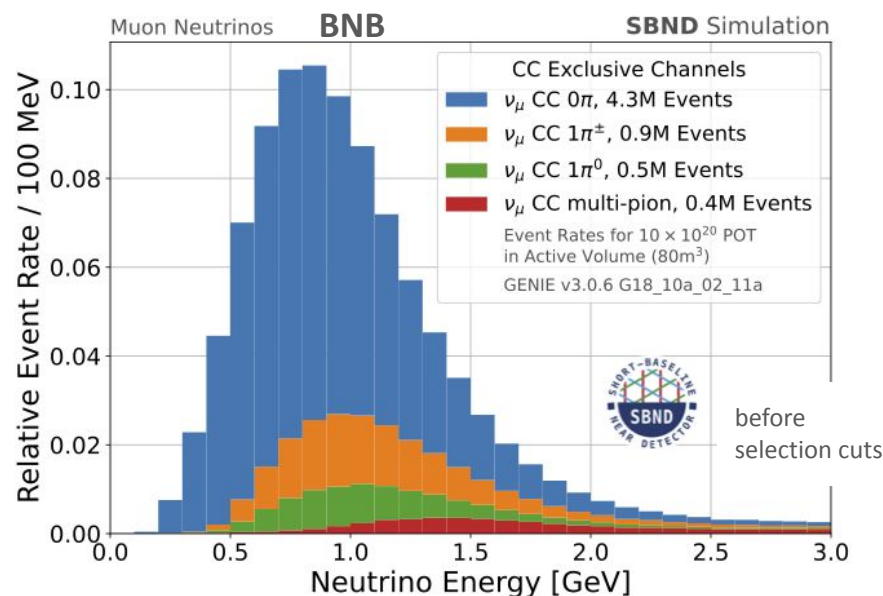
Investigating such models uses the unique capabilities of the LArTPC technology, with *high track and shower kinematic resolution, very good particle ID, calorimetric information on electro-magnetic & hadronic activity*

Cross Section Measurements in SBND + ICARUS

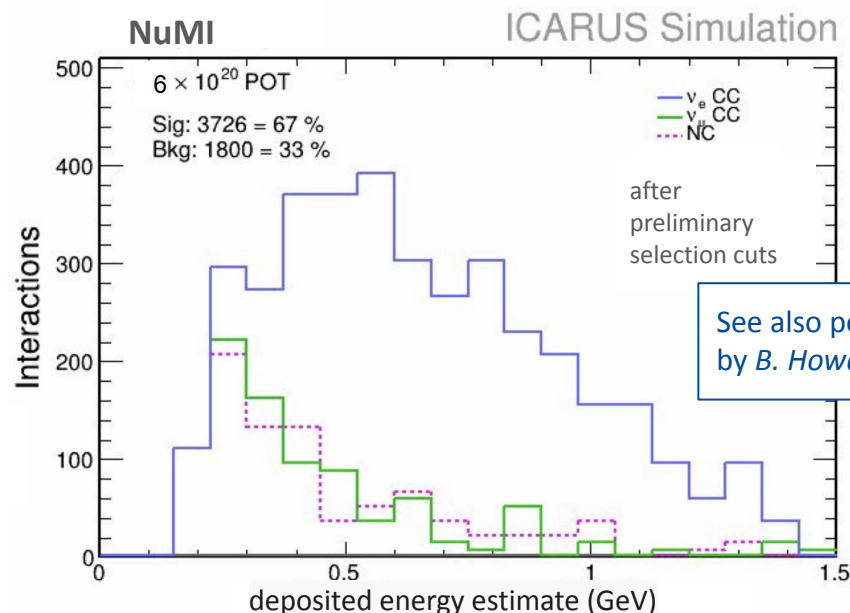
The unique imaging capabilities of LArTPCs enable precision cross section measurements

SBND will have the largest dataset of ν -Ar interactions and will do high-statistics measurements of many signatures and can observe rare channels

See also presentation by X. Lu



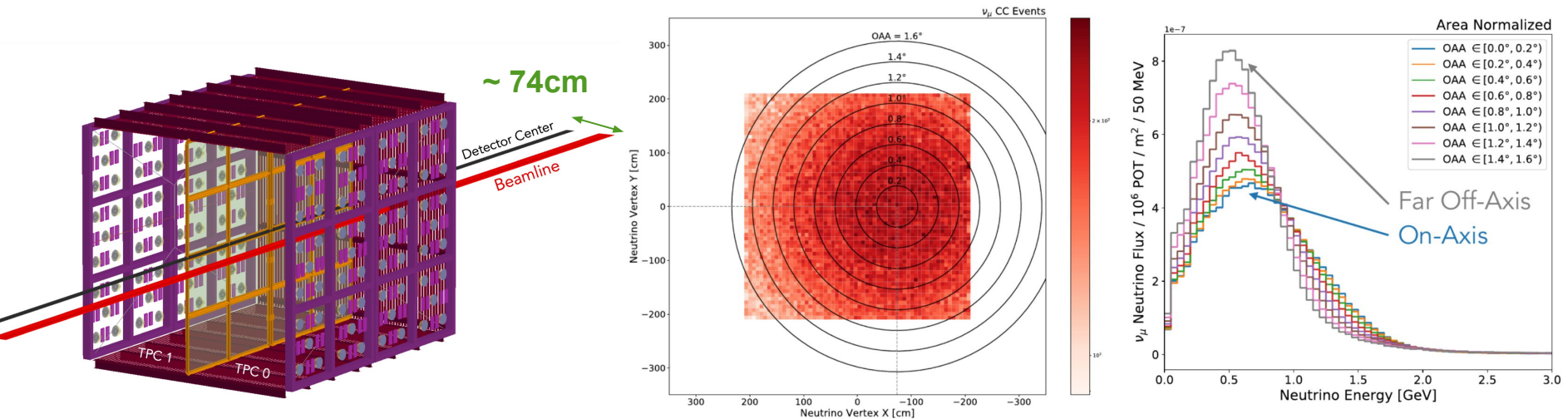
ICARUS can leverage its off-axis position in the NuMI beam and observe a ν_e enriched flux for ν_e -Ar measurements



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

Sampling multiple off-axis fluxes with the same detector

- With SBND being located very close to the beam target (110m) and slightly off-axis ($\sim 74\text{cm}$), the detector sees a different flux based on position within the detector
 - Similar to the DUNE-PRISM concept, but with a fixed detector



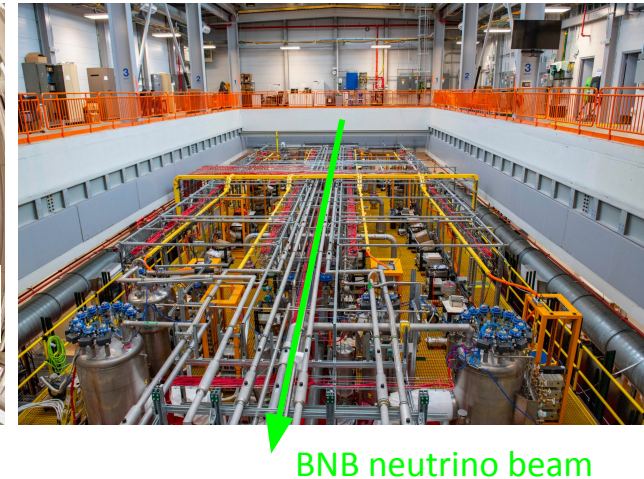
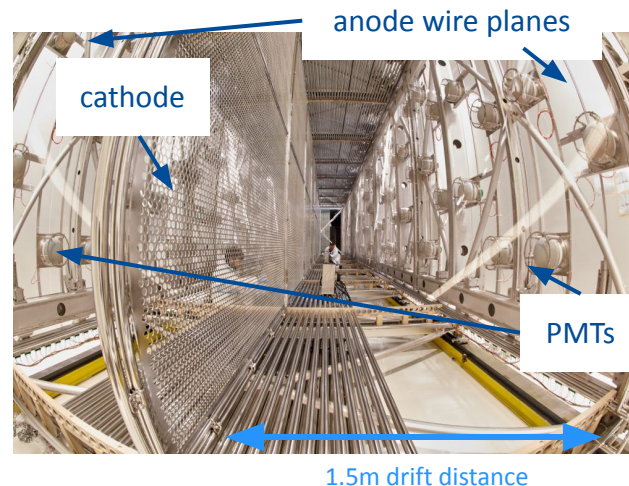
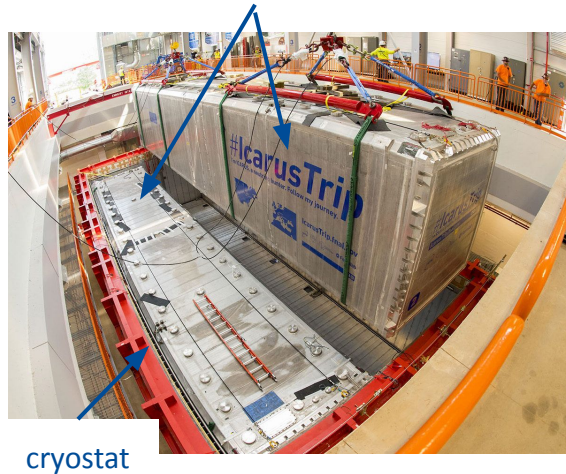
- Ongoing studies exploring physics potential of flux sampling
 - improve flux and cross section constraints in oscillation analysis
 - targeted cross section analyses with detector slices to constrain nuclear effects
 - reduced backgrounds for increasing off-axis angles
 - add capabilities for BSM searches

See poster **SBND-PRISM: Sampling Multiple Off-Axis Neutrino Fluxes**,
Beth Slater and Tereza Kroupova

ICARUS Detector

2 LArTPC modules
Total of 760t LAr (467t active)

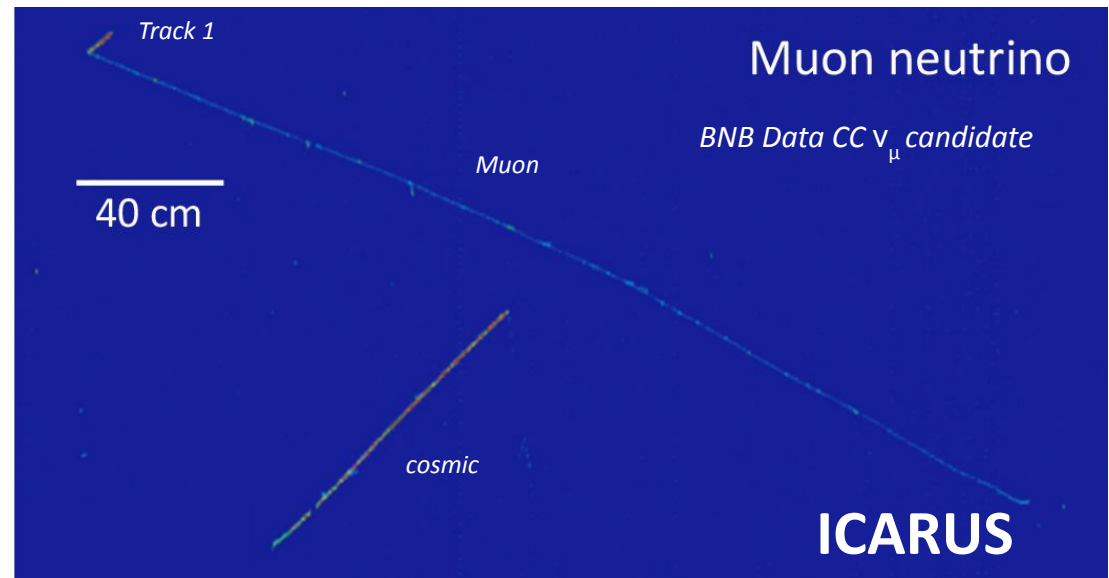
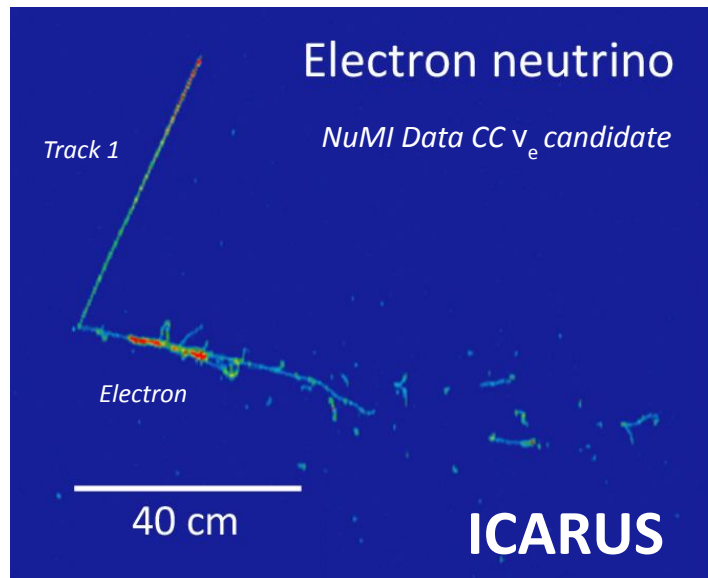
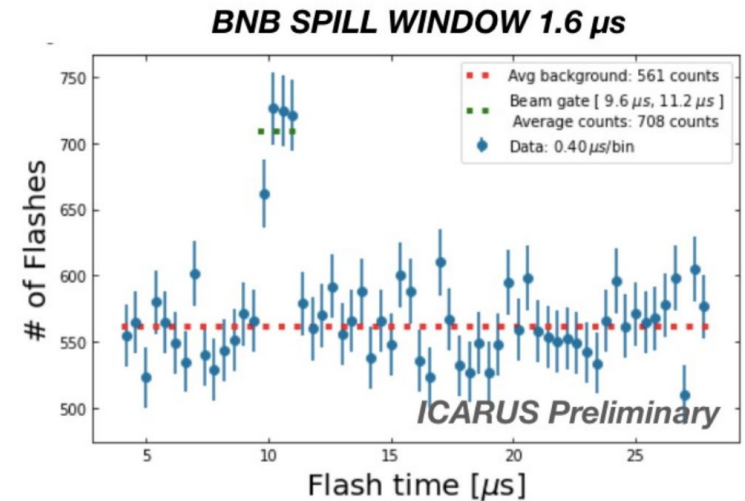
2 TPCs per module



- Originally deployed at LNGS
- refurbished@CERN and moved to FNAL for SBN
 - each module 19.6m x 3.6m x 3.9m
 - 3 readout wire planes per anode (2 induction, 1 collection)
 - 54000 wires
 - new TPC readout electronics
 - upgraded light collection system;
 - 360 8" PMTs
 - Just installed: Cosmic Tagger system & overburden for background reduction

ICARUS Commissioning Status

- ICARUS detector cooldown & filling started in February 2020
- Reached full electric drift field of -75kV in Fall 2020; PMTs turned on.
- Trigger Commissioning & Time-in with BNB and NuMI beams
- First neutrino data taken in June 2021
- Stable noise level; electron lifetime > 3ms
- Calibration campaign in process



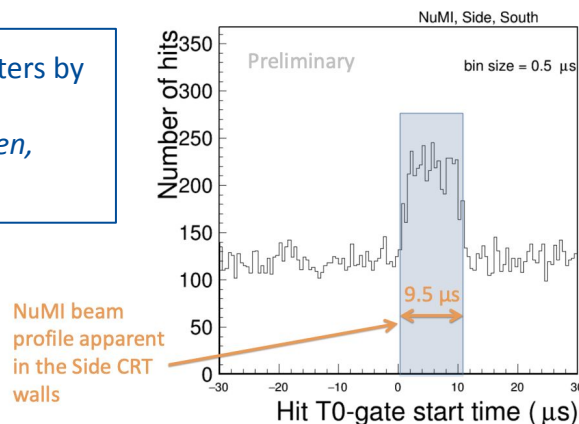
ICARUS Cosmic Tagger and Overburden Installation



- Following the completion of installation of the ICARUS detectors and start of operations, the experiment recently installed and commissioned a Cosmic Ray Tagger (CRT) on the outside of the cryostat, and a 2.8 m concrete overburden
- This is to reduce and tag abundant cosmic background events in a TPC operating on surface level
- *This completes all ICARUS installation*

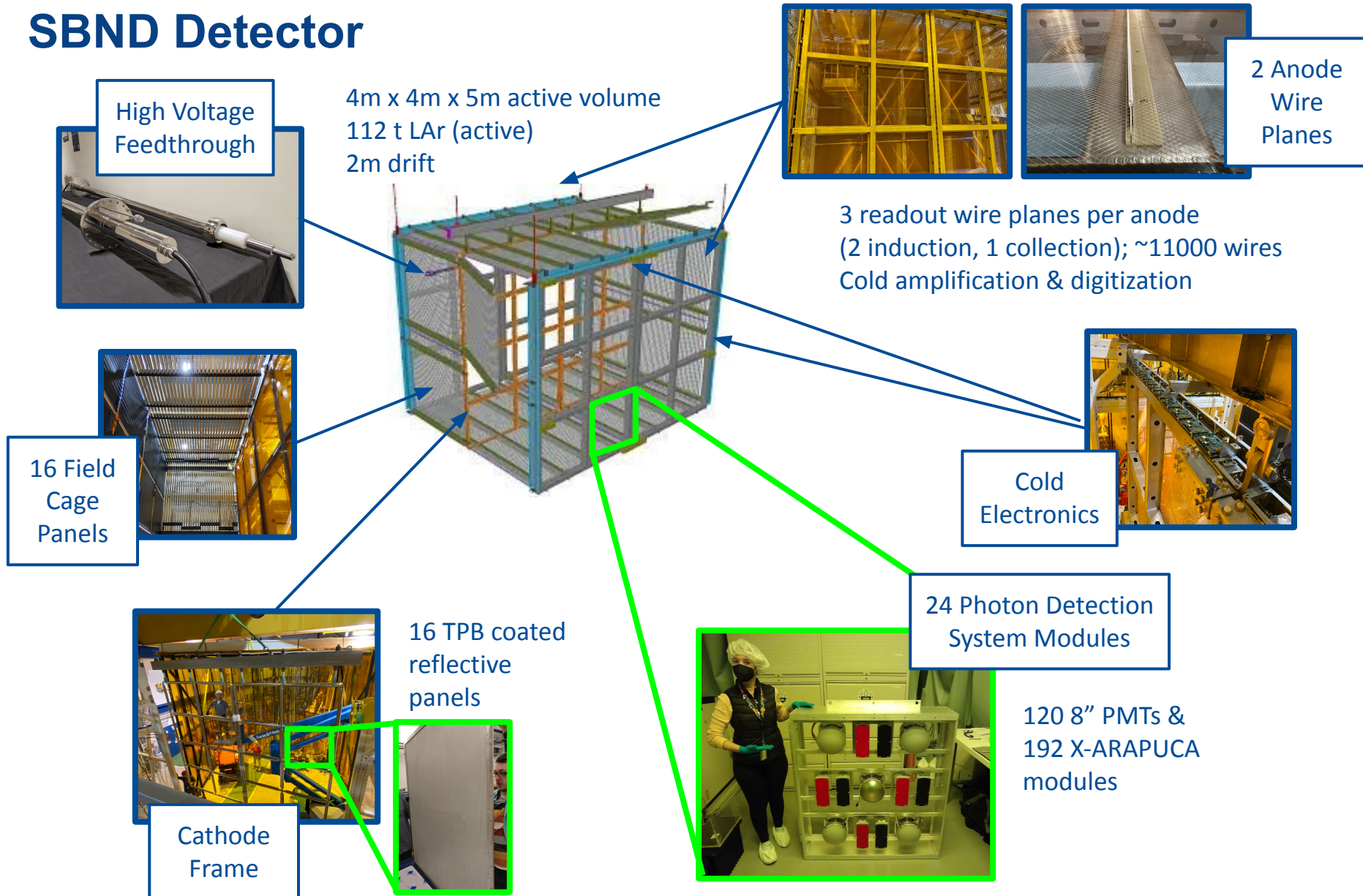
Side and Top CRT modules installed surrounding the ICARUS Cryostat.

See also posters by
F. Poppi,
A. Hegenstuen,
B. Behera



Second (of 3) concrete layers being installed above the ICARUS top CRT level.

SBND Detector



SBND Construction Status

- SBND is about to complete the construction of the TPC
 - Both wire planes and the cathode were installed into the Assembly Transport Frame in 2021
 - Field Cage modules and Cold Electronics installed in end of 2021 & 2022
 - Photon Detection System will be installed this summer

Dec 2019



Empty Assembly Transport Frame

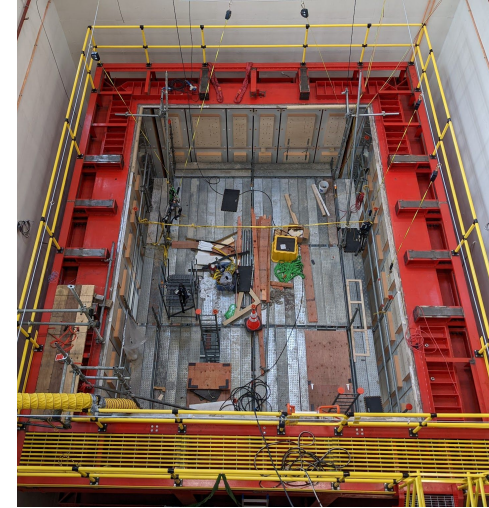
May 2022



Assembly tent with TPC inside



Cathode and Field Cage



Membrane Cryostat installation in progress

- Cryostat steel support structure completed in Nov 2019; Membrane cryostat installation in progress right now
- The detector will be transported to its final position in the BNB beamline end of 2022, and start commissioning in 2023

Summary

- **ICARUS** commissioning is completing and ICARUS is preparing to *start its Physics Run*
- **SBND** *Installation progressing very well* - expected to start operating the detector next year
- **SBN** experiments working together on software tools & analyses and preparing for a wealth of physics analyses in *oscillations, cross sections and BSM* - *see posters!*

ICARUS posters @NEUTRINO2022

- Investigating Short-Baseline Neutrino Anomalies with ICARUS, *Justin Mueller*
- Understanding the NuMI Neutrino Flux at ICARUS, *Dan Cherdack et al.*
- Neutrino-Argon Cross-Section Measurements Using the NuMI Neutrino Beam at ICARUS, *Bruce Howard et al.*
- The Top Cosmic Ray Tagger of the SBN Far Detector at Fermilab, *Francesco Poppi*
- Data analysis in the ICARUS (SBN FD) Cosmic Ray Tagging system, *Anna Heggsetuen*
- Cosmogenic background rejection at the ICARUS, *Biswaranjan Behera*

SBND posters @NEUTRINO2022

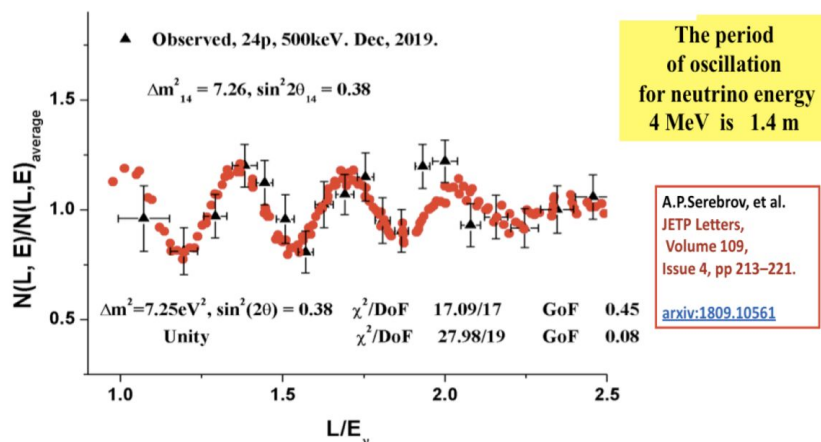
- Simulation and reconstruction of scintillation light with X-ARAPUCA photodetectors in SBND, *Rodrigo Alvarez Garrote*
- Cosmic Background Rejection in SBND with Multiple Detector Systems - The CRUMBS Tool, *Henry Lay*
- SBND-PRISM: Sampling Multiple Off-Axis Neutrino Fluxes, *Beth Slater and Tereza Kroupova*
- Analysis Capabilities of High-Statistics V-Ar Interaction Exclusive Channel with Protons and no Pions at SBND, *Mun Jung*
- Event Selection Tools Targeting Single-Photon Events in The Short-Baseline Near Detector, *Keng Lin*

Backups

Search for Neutrino-4 Oscillation signal with ICARUS

- The Neutrino-4 collaboration claimed a reactor neutrino disappearance signal with a clear modulation with $L/E \sim 1\text{-}3\text{m/MeV}$
- 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 to the start of 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

NEUTRINO-4 reactor signals



ICARUS projection

