

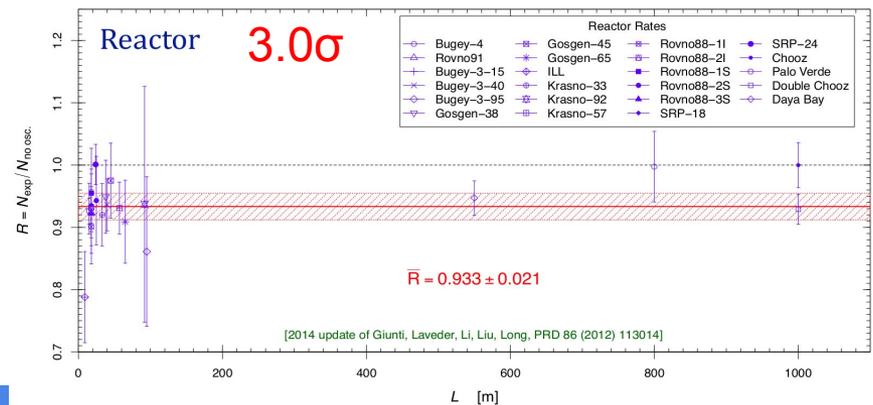
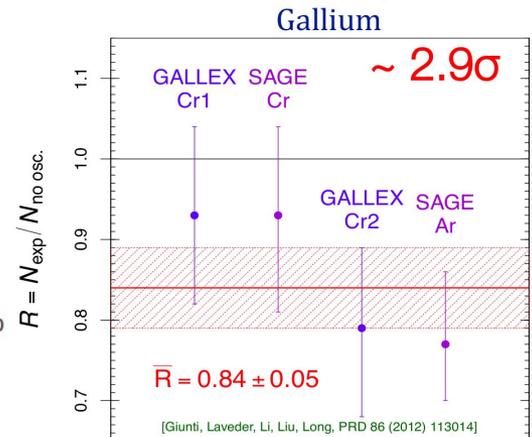
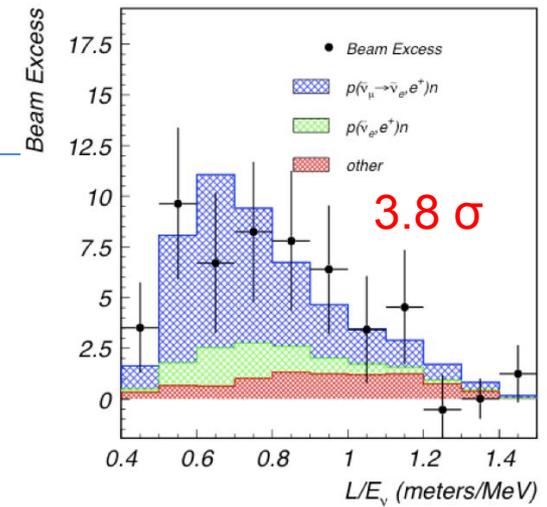
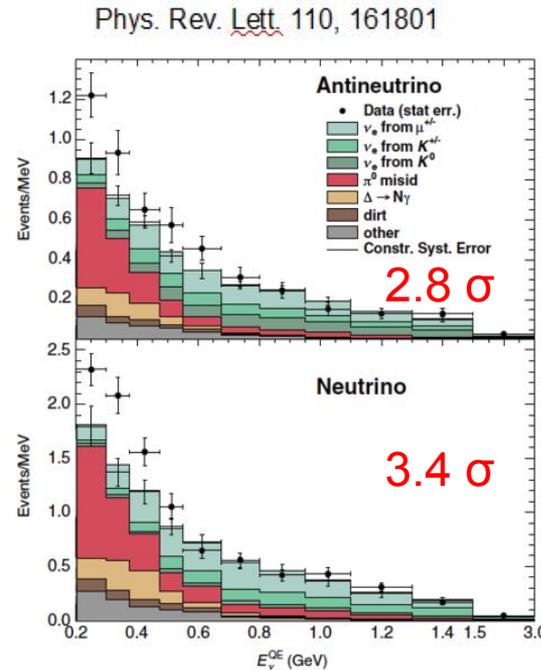
The Short Baseline Neutrino Program at Fermilab

Serhan Tufanli (Yale University)
for the
SBND, MicroBooNE and ICARUS collaborations

EPS Conference on High Energy Physics, 2017

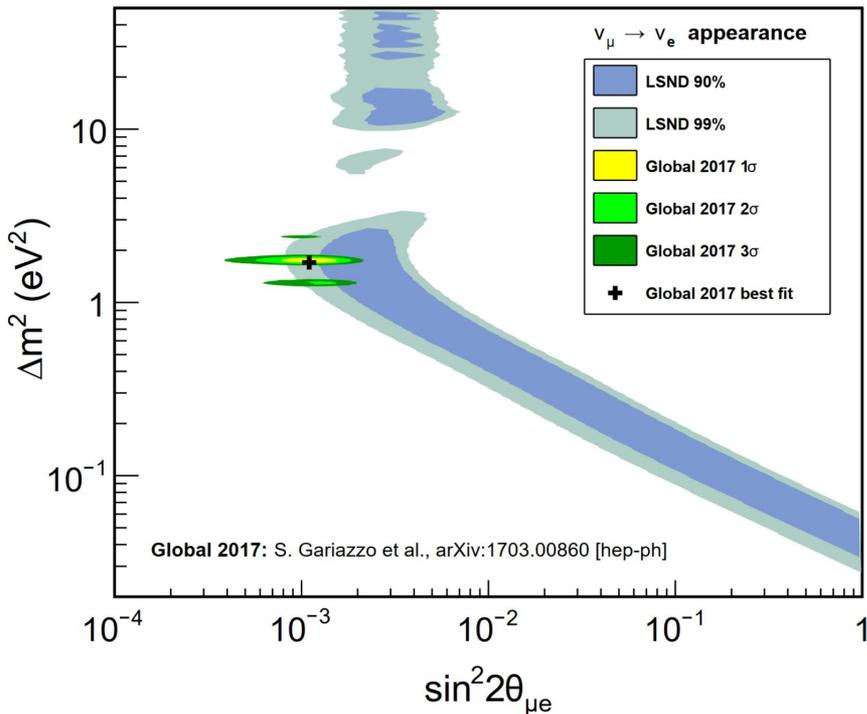
Neutrino anomalies

- Evidence for an low energy electron-like excess from neutrinos from particle accelerators (the “**LSND and Mini-BooNE anomalies**”)
- ν_e disappearance signal in the low energy anti-neutrinos from nuclear reactors (“**reactor anomaly**”) and from radioactive neutrino sources in the Gallium experiments (“**Gallium anomaly**”)



Why a Short-Baseline Neutrino Program is needed?

- Interpreted as oscillations involving sterile neutrinos with $\Delta m^2 \sim 1 \text{ eV}^2$ and an $L/E \sim 1 \text{ km/GeV}$
- New experimental efforts are needed to eventually solve the puzzle



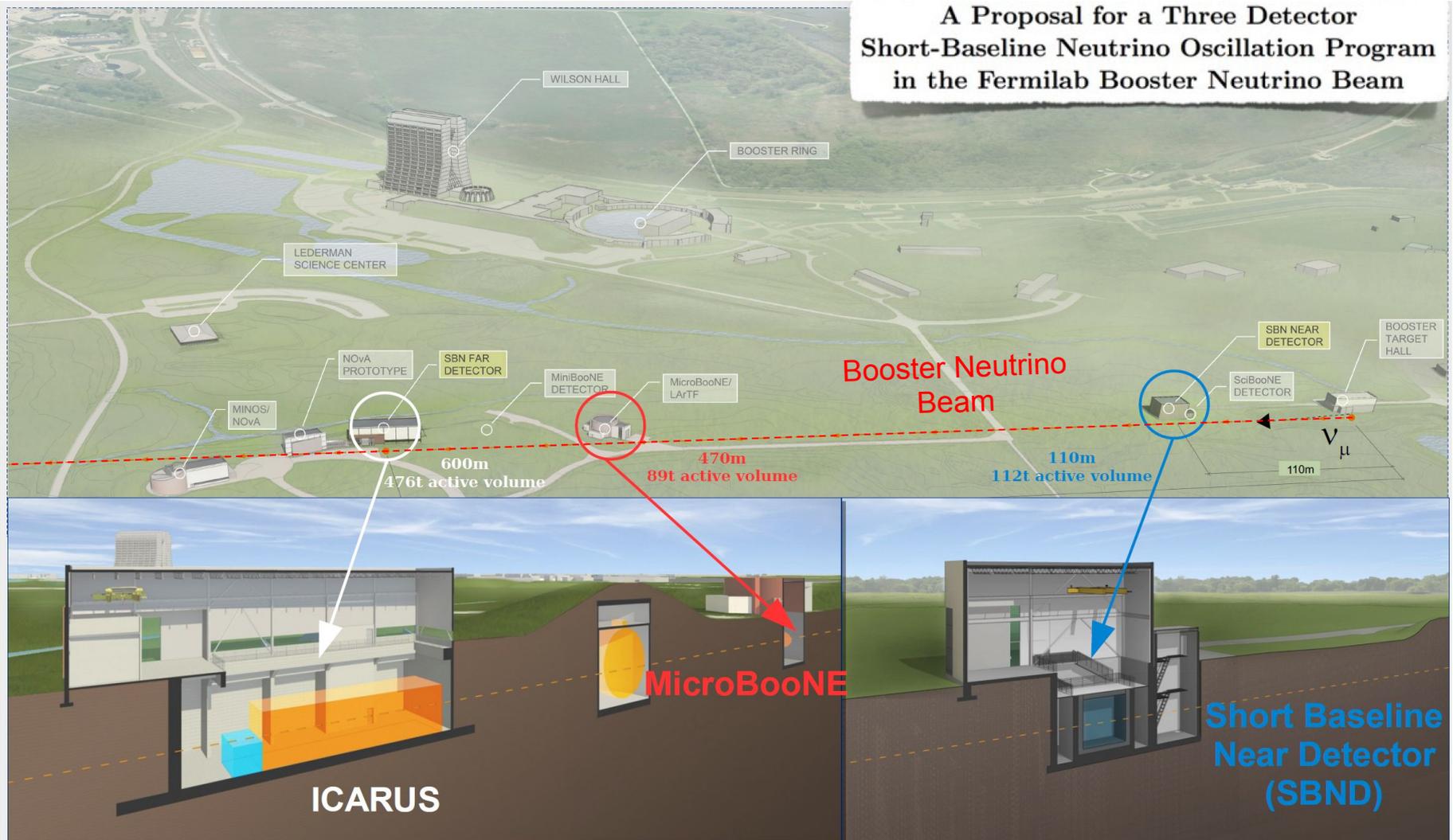
Experiment	Type	Channel	Significance
LSND	DAR	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ CC	3.8σ
MiniBooNE	SBL accelerator	$\nu_\mu \rightarrow \nu_e$ CC	3.4σ
MiniBooNE	SBL accelerator	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ CC	2.8σ
GALLEX/SAGE	Source - e capture	ν_e disappearance	2.8σ
Reactors	Beta-decay	$\bar{\nu}_e$ disappearance	3.0σ

K. N. Abazajian et al. "Light Sterile Neutrinos: A Whitepaper", arXiv:1204.5379 [hep-ph], (2012)

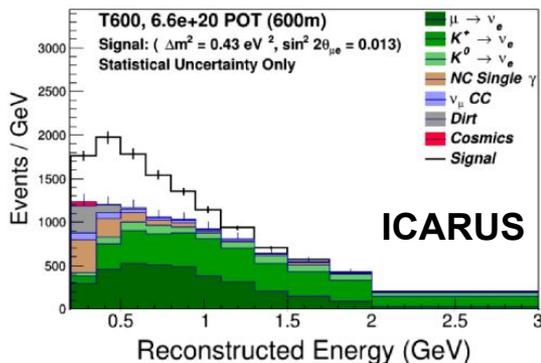
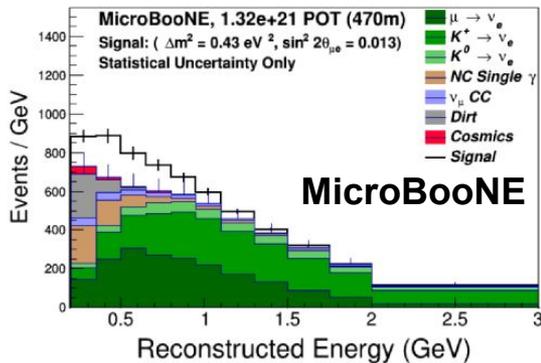
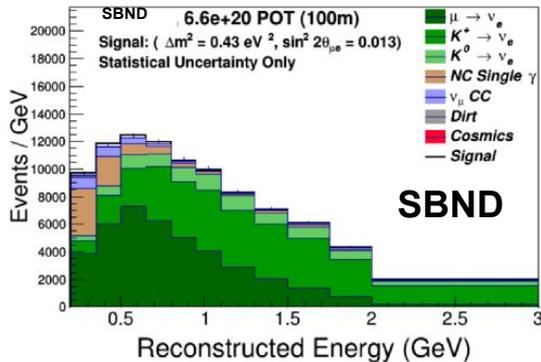
Radioactive neutrino sources	$\nu_e/\bar{\nu}_e$ dis.	100s of keV, 10s of cm
Nuclear reactor antineutrinos	$\bar{\nu}_e$ dis.	< 10 MeV, < 20 m
Stopped π beams	$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	~ 30 MeV, 30 m
Stopped K beams	$\nu_\mu \rightarrow \nu_e$	235.5 MeV, 160 m
Decay in flight π/K beams	$\nu_\mu \rightarrow \nu_e, \bar{\nu}_\mu \rightarrow \bar{\nu}_e$ $\nu_\mu/\bar{\nu}_\mu$ dis., $\nu_e/\bar{\nu}_e$ dis.	500 MeV – 2 GeV 100 m – 2000 m
Atmospheric neutrinos	$\nu_\mu/\bar{\nu}_\mu$ dis.	< 20 GeV, 15 – 130 km 100 GeV – 400 TeV, < 1.3×10^4 km
Cosmology	indirect N_s, m_ν	

Short Baseline Neutrino (SBN) program at Fermilab

- Three liquid argon time projection chamber (LArTPC) detectors in the Booster Neutrino Beam (BNB) at Fermilab.

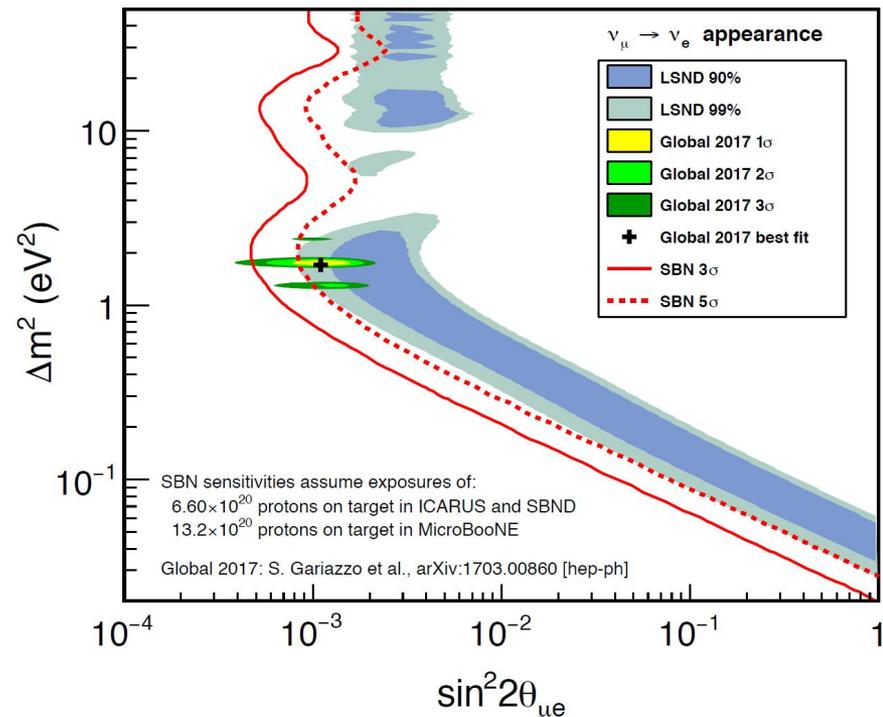


Search for sterile neutrinos: $\nu_\mu \rightsquigarrow \nu_e$ appearance

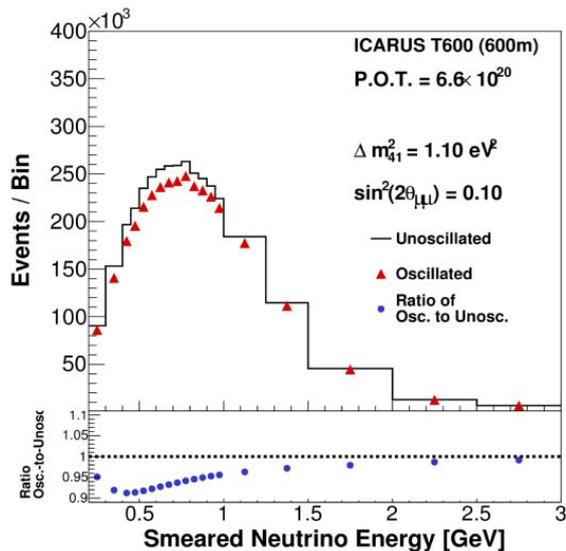
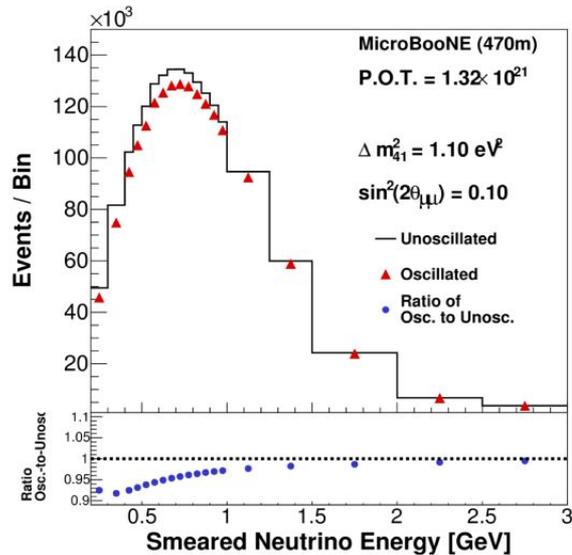


<http://arxiv.org/abs/1503.01520>

- A large mass far detector and a near detector of the same technology reduces both statistical and systematic uncertainties
- SBN detectors enable 5σ coverage the 99% C.L. allowed region of the LSND signal and global best fit values

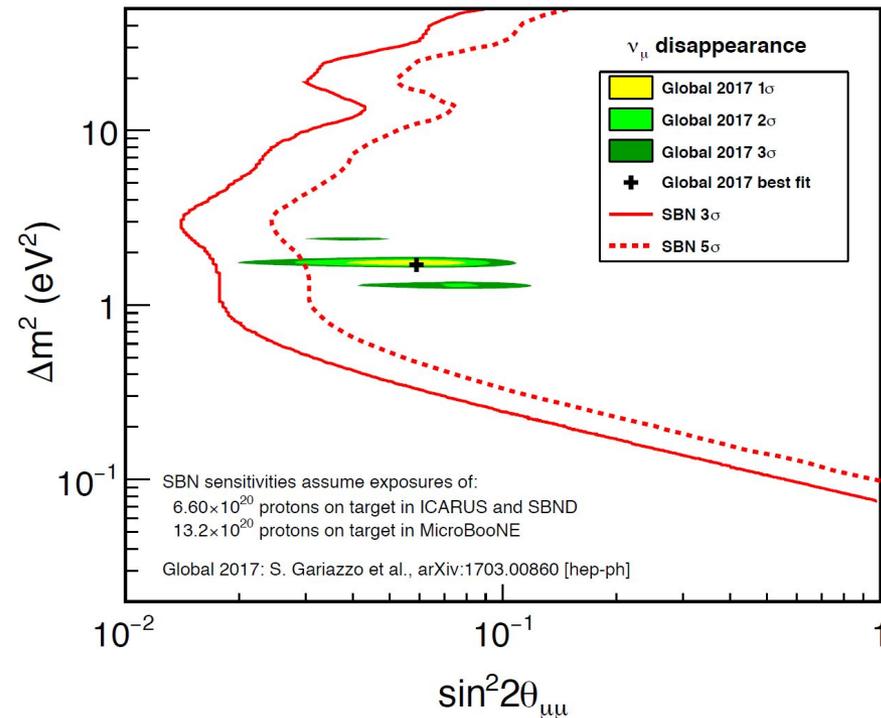


Search for sterile neutrinos: ν_μ disappearance



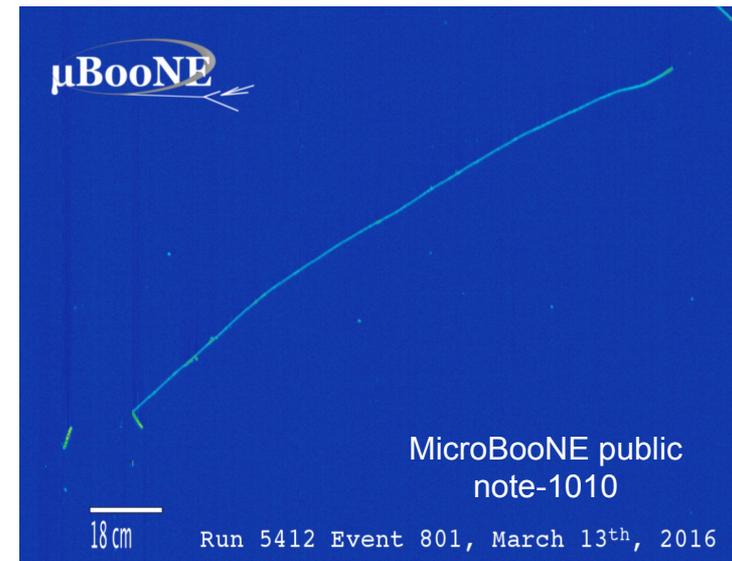
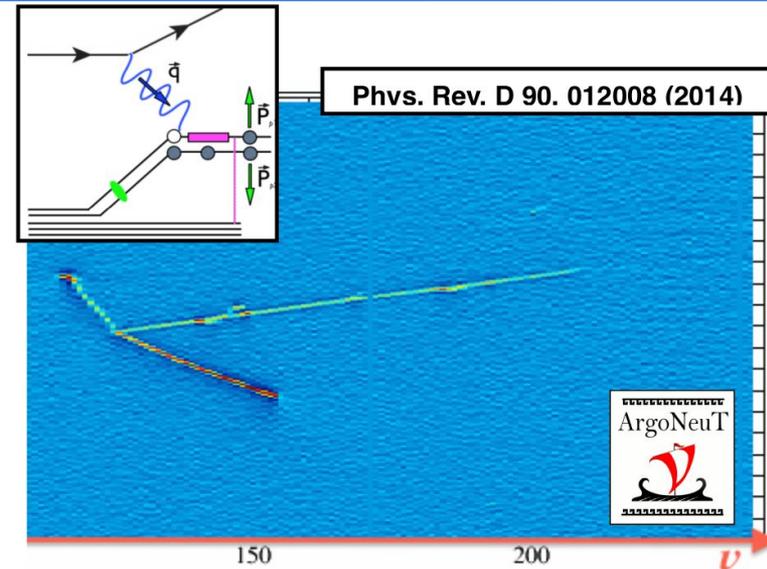
<http://arxiv.org/abs/1503.01520>

- SBN can extend the search for muon neutrino disappearance an order of magnitude beyond the combined analysis of SciBooNE and MiniBooNE
- Critical aspect to verify an oscillation hypothesis



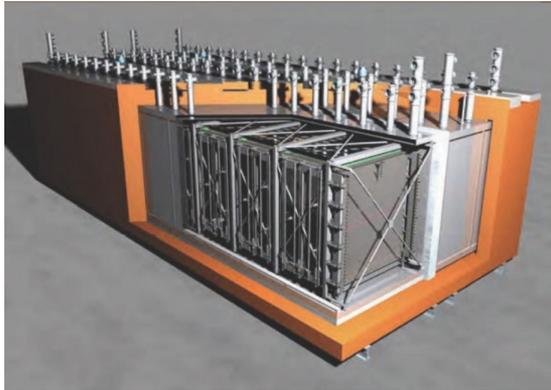
ν -Ar cross section studies

- ν oscillation experiments require precise understanding of ν -Ar interaction cross section for a correct interpretation of the experimental outcome
- The only existing published GeV ν -Ar data is ~6000 events from ArgoNeuT
- SBN will provide huge data sets of ν - Ar interactions from BNB and off-axis NuMI
 - Large samples in MicroBooNE are already under analysis
 - 140k ν_{μ} CC, 55k ν_{μ} NC BNB neutrinos
 - ~100k off-axis NuMI events
 - SBND will record 1.5 million ν_{μ} CC and ~12k ν_e CC interactions per year
 - ~100k NuMI off-axis events in T600 per year



SBN experimental setup

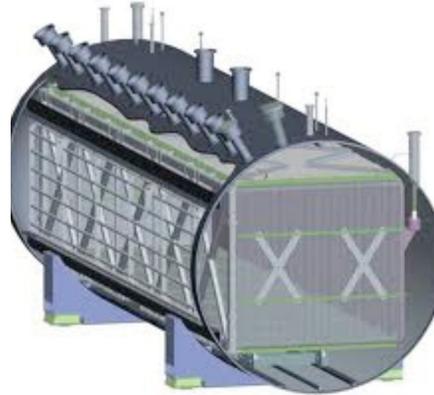
ICARUS



- LArTPC
- 600 m from ν production
- 476 ton active volume
- 4x1.5 m drift length
- 75kV high voltage
- 0.95 ms drift time at 500V/cm
- 3 wire planes: horizontal, ∓ 30 deg, 3mm wire pitch, 53246 wires
- Warm analog and digital electronics
- 360 8" PMTs

INSTALLATION

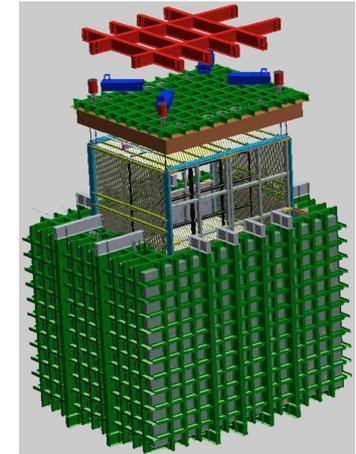
MicroBooNE



- LArTPC
- 470 m from ν production
- 85 ton active volume
- 2.56 m drift length
- 128 kV high voltage
- 1.6 ms drift time at 500V/cm
- 3 wire planes: 0, ∓ 60 deg, 3mm wire pitch, 8256 wires
- Cold analog/warm digital electronics
- 32 8" PMTs

RUNNING

SBND



- LArTPC
- 110 m from ν production
- 112 ton active volume
- 2x2.0 m drift length
- 100 kV high voltage
- 1.28 ms drift time at 500V/cm
- 3 wire planes: 0, ∓ 60 deg, 3mm wire pitch, 11264 wires
- Cold analog and digital electronics
- 120 8" PMTs & scin. bars

UNDER CONSTRUCTION

Short Baseline Near Detector – SBND



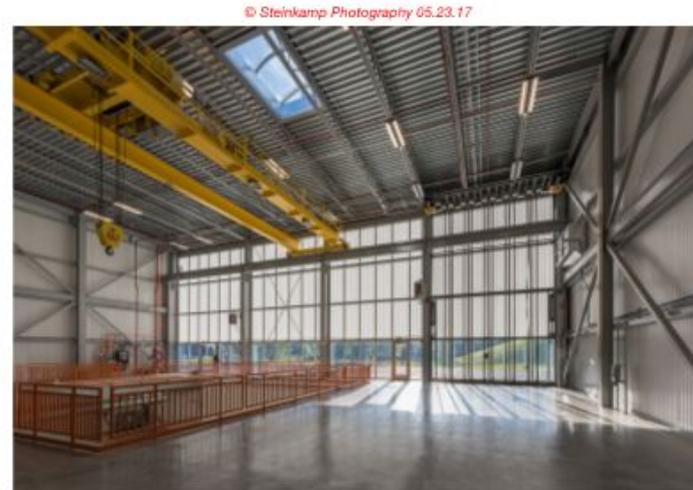
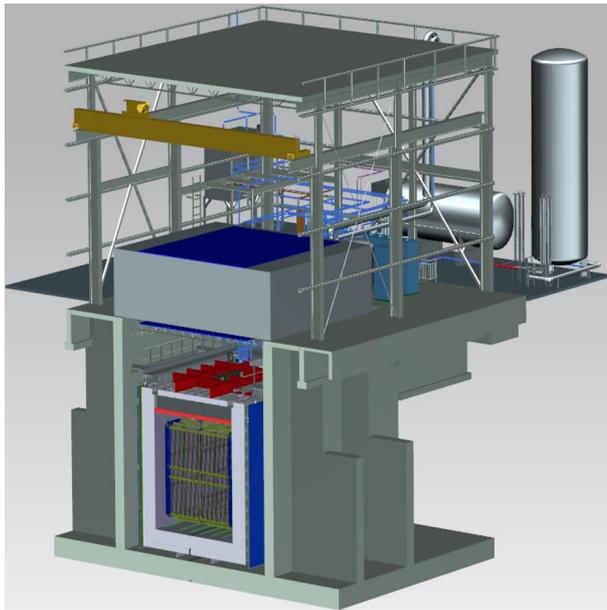
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8850-22_DSC6481.MP

Helmut Root Fermilab 1st Edit

- Near detector at SBN with main goals
 - Detailed characterization of beam before oscillation
 - Reduction of the dominant systematics
 - Cross section studies with **1.5 million ν_μ CC** and **12k ν_e CC** interactions per year
 - Detector R&D for DUNE far detector
- Detector design has been finalized. Components are under construction
- Detector building is ready at Fermilab



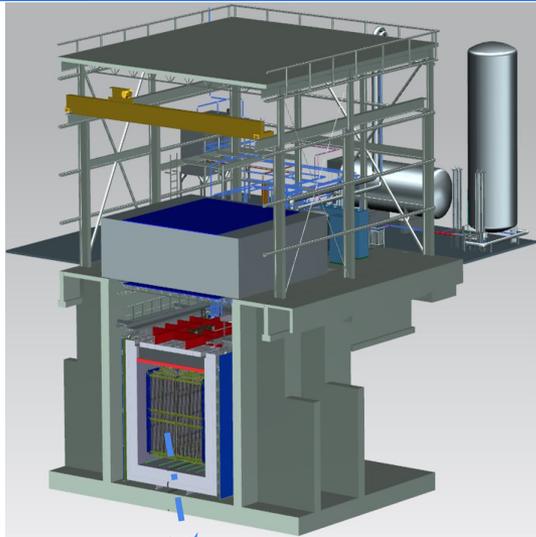
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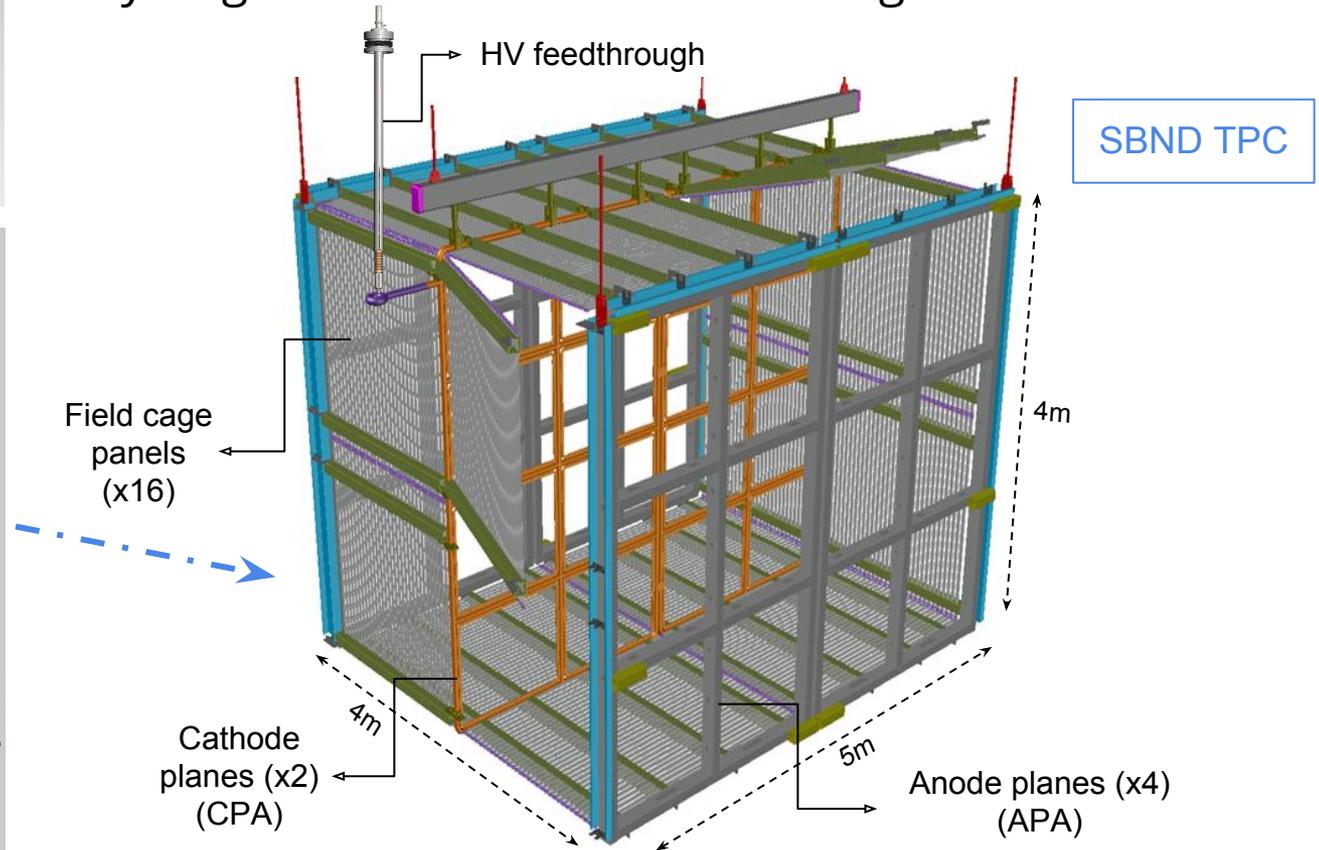
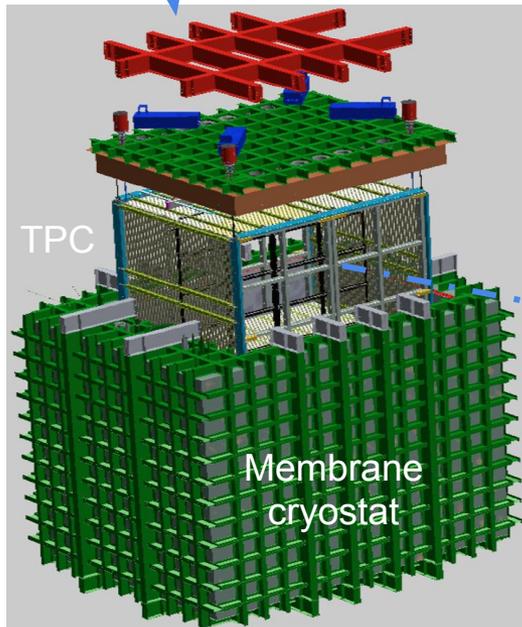
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Helmut Root Fermilab 1st Edit

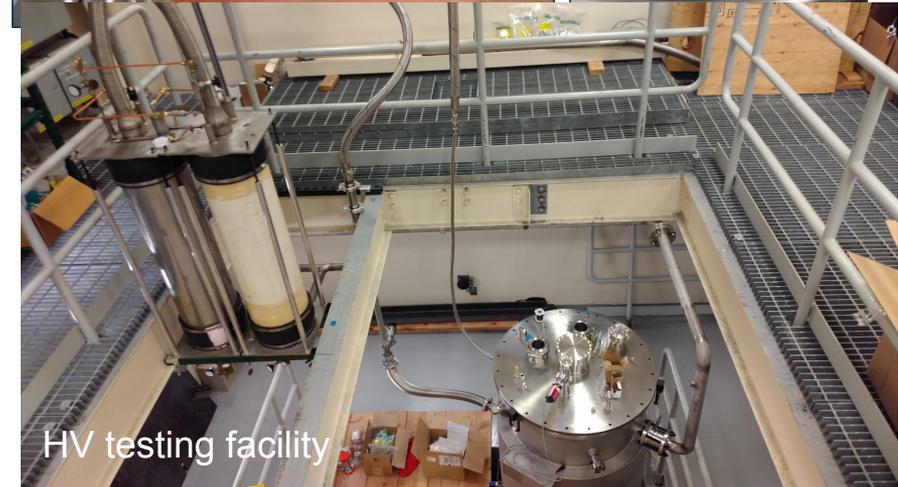
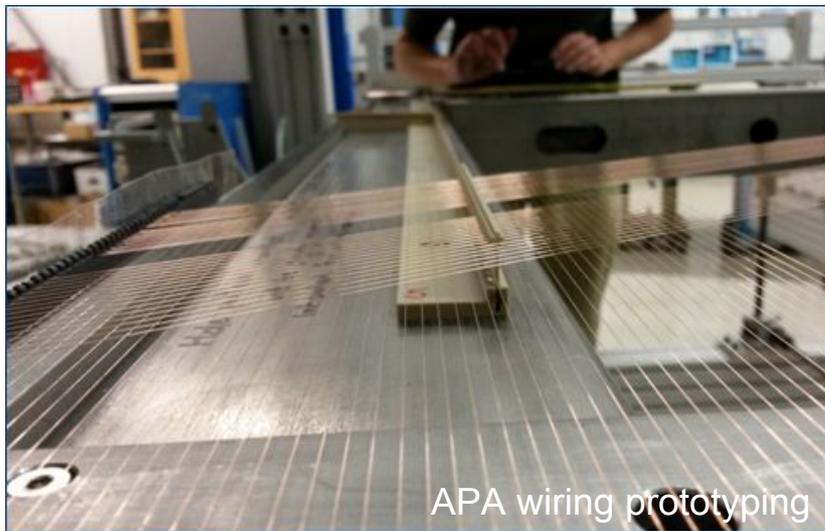
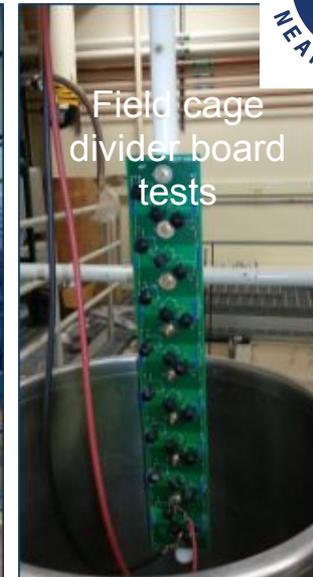
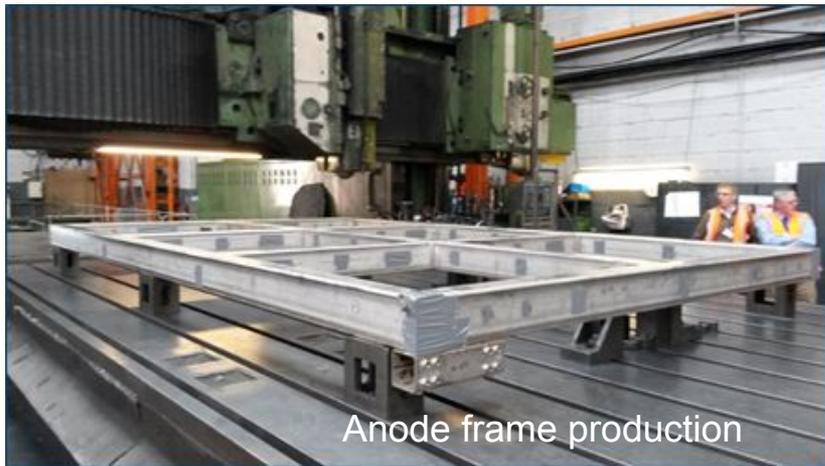
SBND detector



- Completely new detector incorporated experience from ICARUS and MicroBooNE
- LArTPC with 112 ton active volume
- Synergies with DUNE for future large LArTPCs



SBND detector construction/prototyping/testing



- More details in the talk by [Diego.G. Gamez](#), *"The Short Baseline Neutrino Detector at Fermilab"*, later in this session

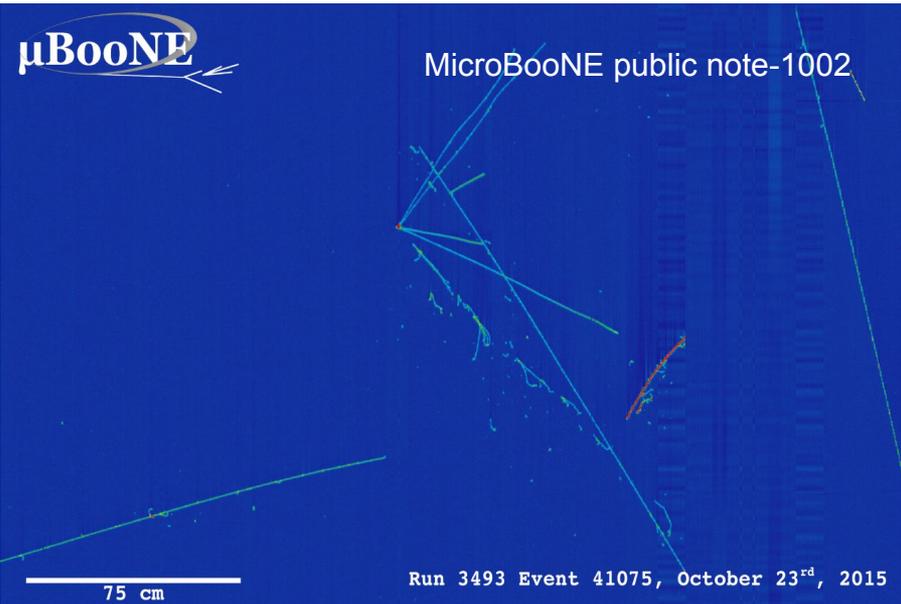
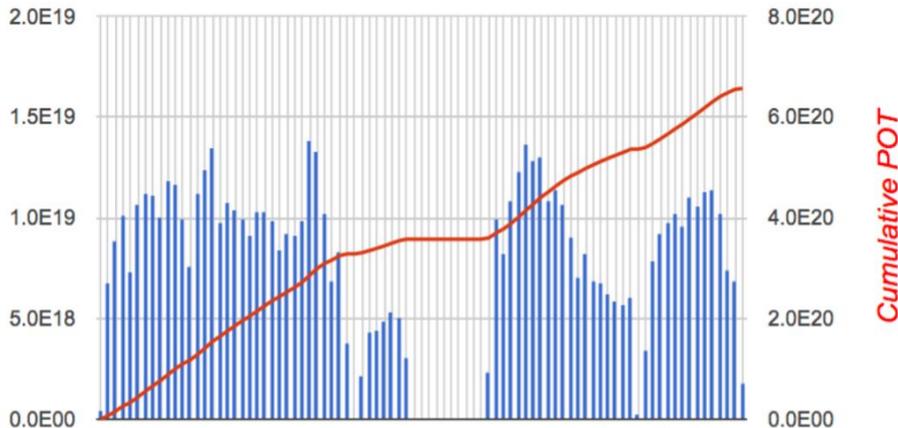
The MicroBooNE experiment



- Installation completed in 2015
- Collection date since October 2015 at BNB line at Fermilab with main goals to
 - Address the MiniBooNE low energy access
 - Neutrino -- Argon cross section measurements
 - R&D for future LArTPCs
- ~97% uptime during stable operations and so far collected $>6.1 \times 10^{20}$ POT

Fermilab Today

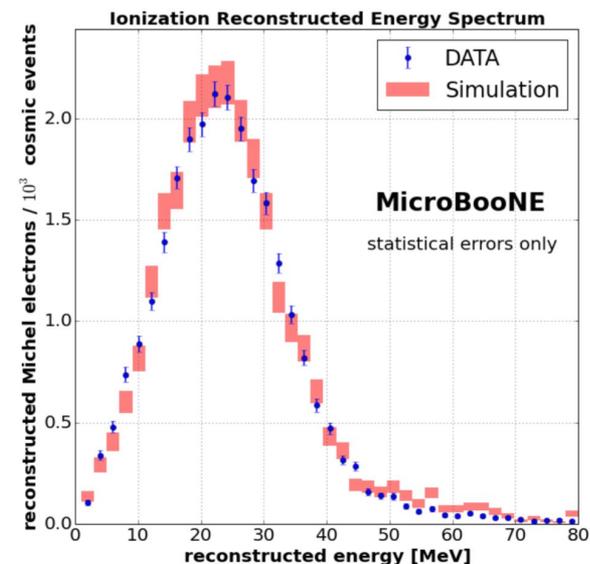
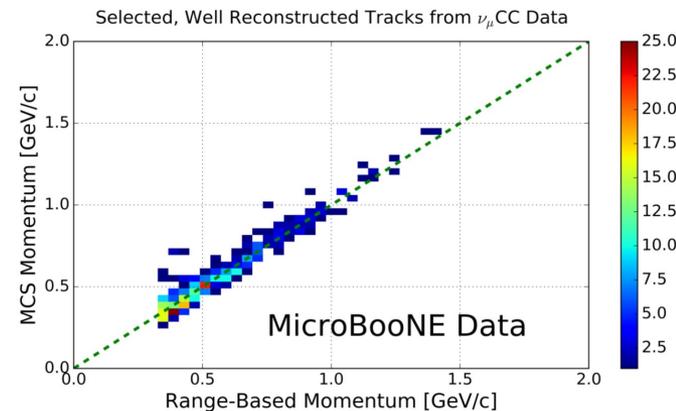
MicroBooNE installs time projection chamber inside vessel, prepares for move



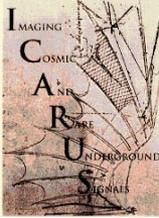
Ongoing efforts and publications



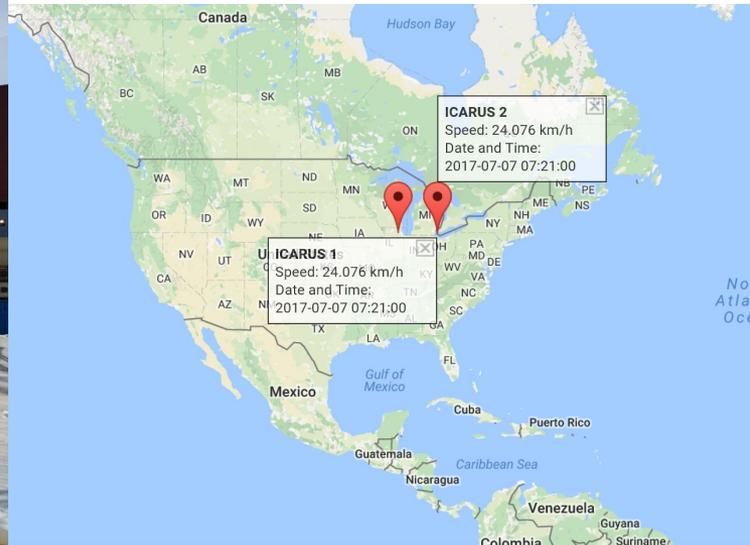
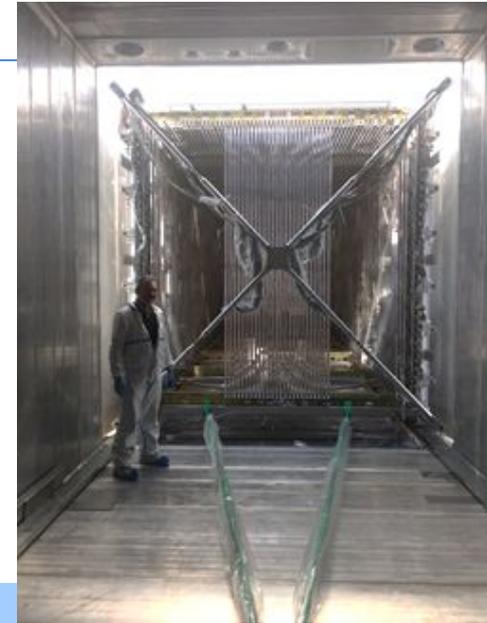
- MicroBooNE is doing groundwork for LArTPC calibration, simulation, reconstruction and analysis for future detectors.
 - **Publications:**
 - Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber; **arXiv:1611.05531**
 - Design and Construction of the MicroBooNE Detector; **arXiv:1612.05824**
 - Determination of muon momentum in the MicroBooNE LArTPC using an improved model of multiple Coulomb scattering; **arXiv:1703.06187**
 - Michel Electron Reconstruction Using Cosmic-Ray Data from the MicroBooNE LArTPC; **arXiv:1704.02927**
 - Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC; **arXiv:1705.07341**
 - **Public notes:**
 - <http://www-microboone.fnal.gov/publications/publicnotes/>
- More details in the talk by **Martin Auger**, "*Latest results from MicroBooNE*", neutrino parallel session on Thursday



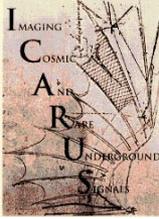
The ICARUS experiment



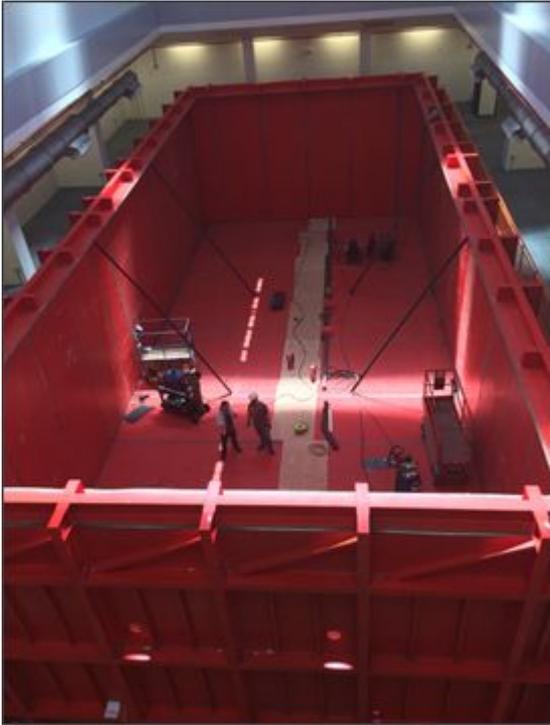
- Far detector in the SBN program
- It was operational in LNGS from 2010-2013
- Then refurbished at CERN
- Currently two TPC are on their way to Fermilab
 - Follow from <http://icarustrip.fnal.gov>



Status of the ICARUS experiment



- Detector hall installation has been finalized
- Warm vessel installation has started at Fermilab
- In early September, cold vessel is going to be installed into the warm vessel.
- Commissioning in the second half of 2018



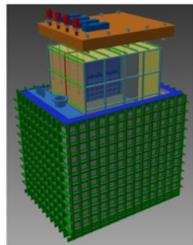
- More details in the talk by **Filippo Varanini**, *"The ICARUS Experiment"*, later in this session

Conclusions

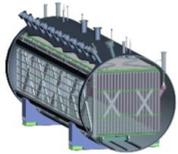
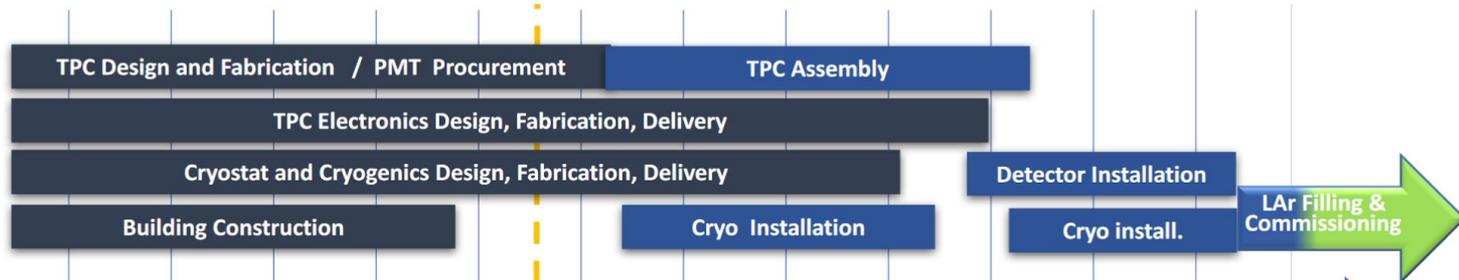
- SBN program consists of three LArTPCs that will sit in the Fermilab BNB beam and will
 - study the baseline dependence of the low energy event excess and cover the full LSND allowed parameter space with 5σ
 - make a high precision measurement on ν -Ar cross sections
 - develop LArTPC technology for future large neutrino experiments like DUNE
- A lot of progress has been achieved in the program
 - MicroBooNE is running well, has already collected $>6.1 \times 10^{20}$ pot from BNB, doing the groundwork for LArTPCs and working on it's first physics results.
 - SBND is making excellent technical progress on prototyping and construction of the detector pieces.
 - ICARUS detector is on its way to Fermilab and will arrive in July.
- Stay tuned for three detector run and physics results

Back-up

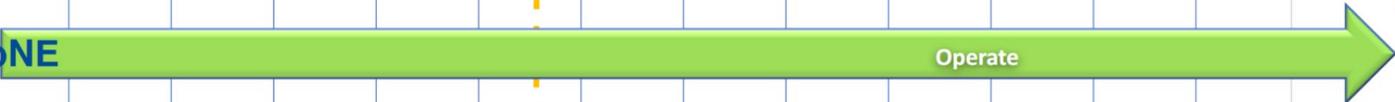
SBN schedule



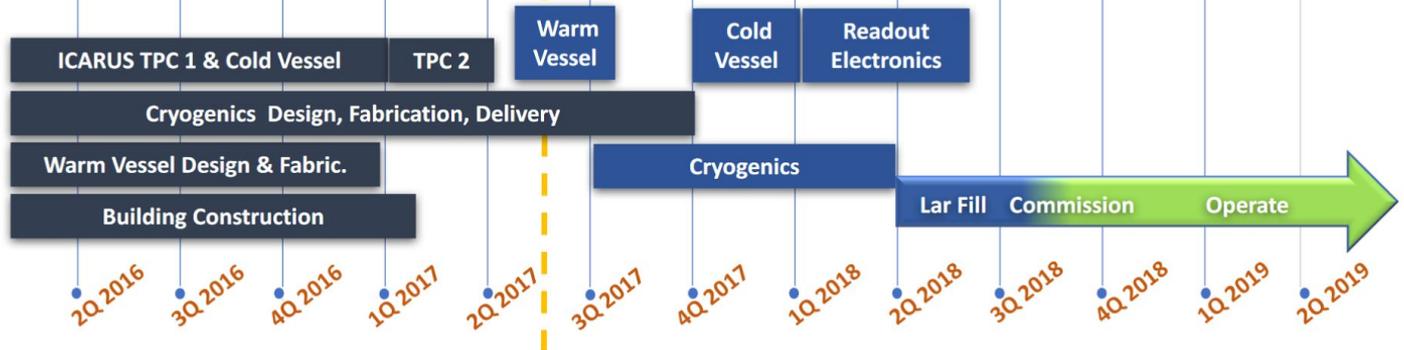
SBND



MicroBooNE



ICARUS



Anne Schukraft (FNAL)
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