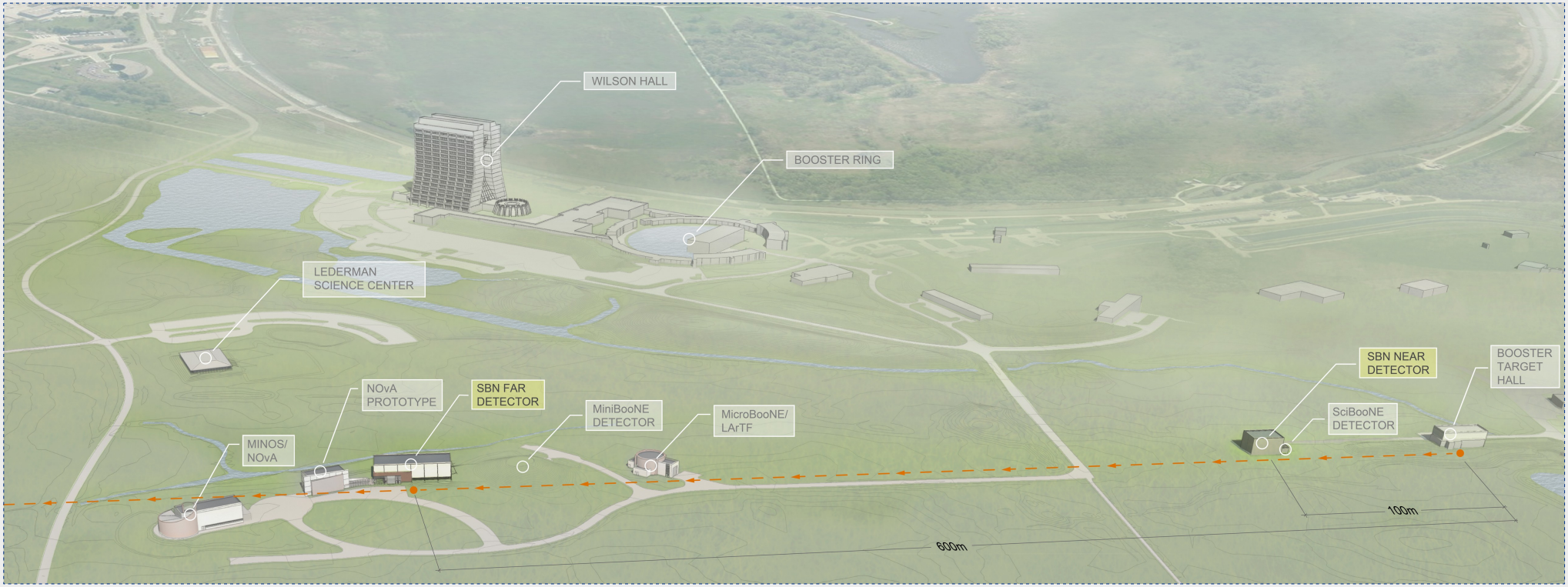


Short-Baseline Neutrino Program at FNAL and SBND

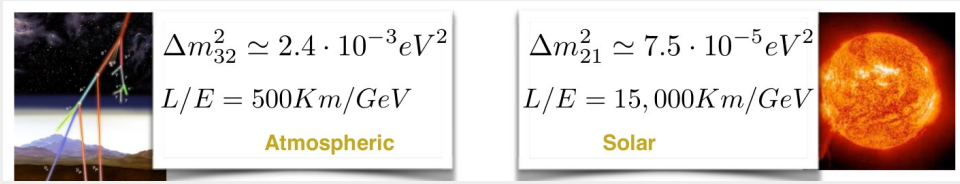
Serhan Tufanli
Yale University

XIIIth Heavy Quarks and Leptons
May 27th , 2016

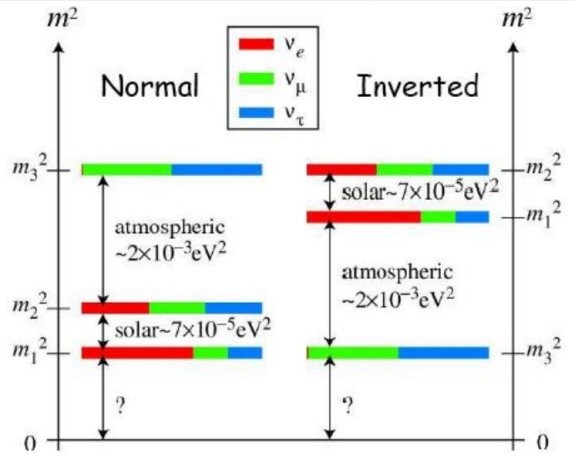
Neutrinos

- Well established three neutrino mixing and oscillations with the data from solar, atmospheric and accelerators
  - 2015 Nobel prize in physics
    - SuperKamiokande and SNO: “for the discovery of neutrino oscillations, which shows that neutrinos have mass”

$$P(\nu_\alpha \to \nu_\beta) = sin^2 2\theta_{ij} * sin^2\left(1.27\Delta m^2_{ij}\frac{L}{E}\right)$$

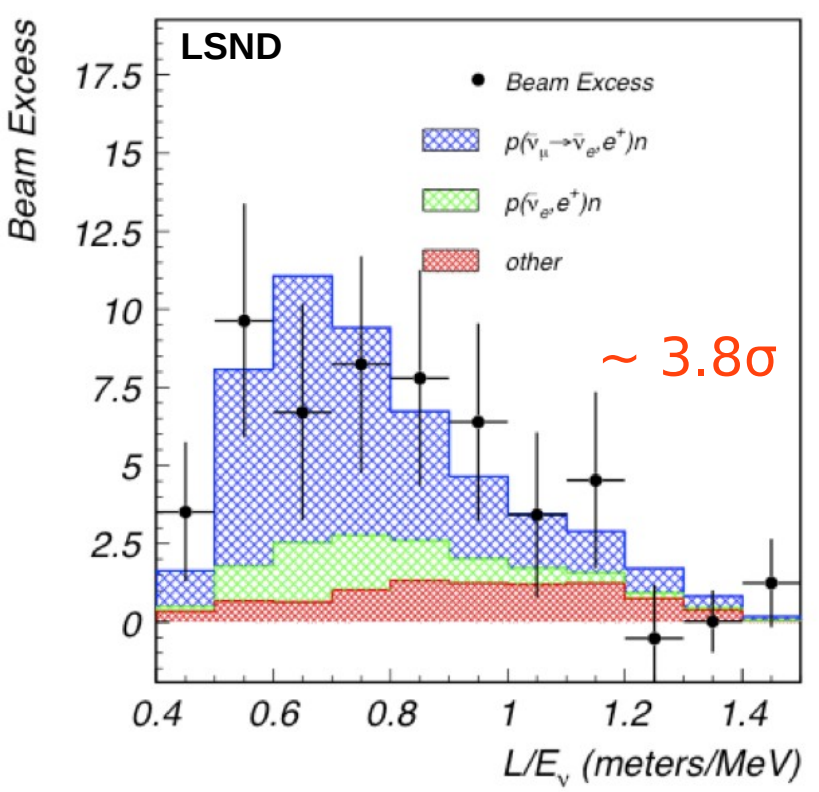


- What is next?
  - Neutrino mass hierarchy and absolute mass
  - CP violation in neutrino sector
  - Majorana or Dirac nature of neutrinos
  - **STERILE NEUTRINO/S**

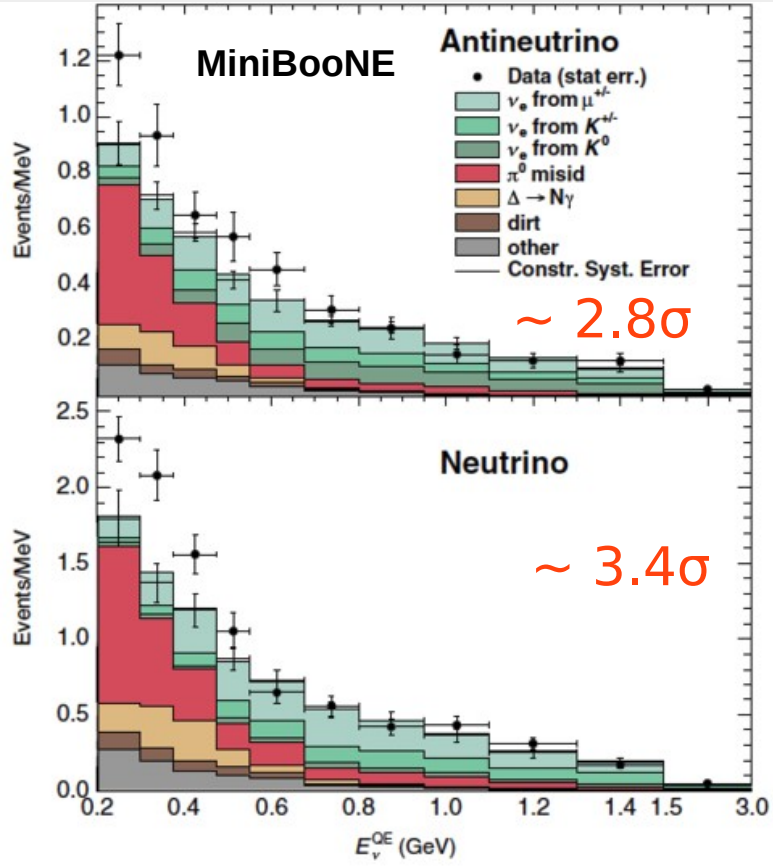


Neutrino anomalies

- Anomalies in a variety of experiments provide hints to the possible existence of sterile neutrino
  - Evidence for an electron-like excess from neutrinos from particle accelerators (the "LSND and Mini-BooNE anomalies")



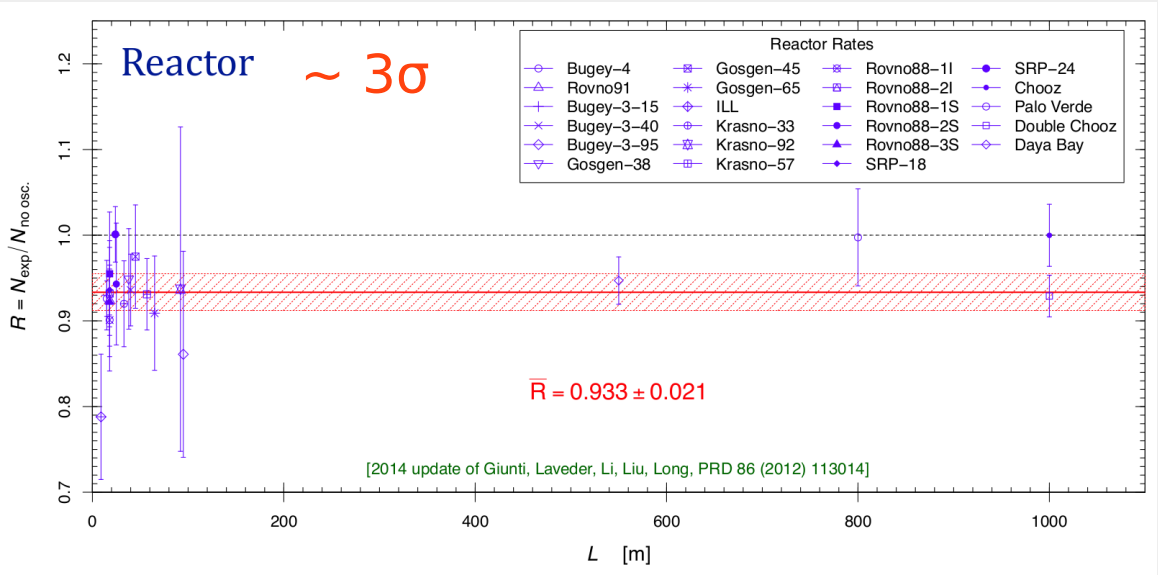
Phys. Rev. D 64, 112007

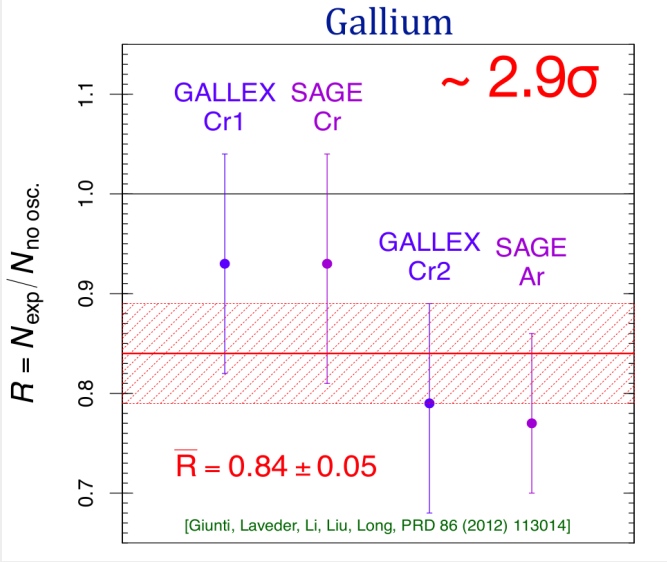


Phys. Rev. Lett. 110, 161801

Neutrino anomalies

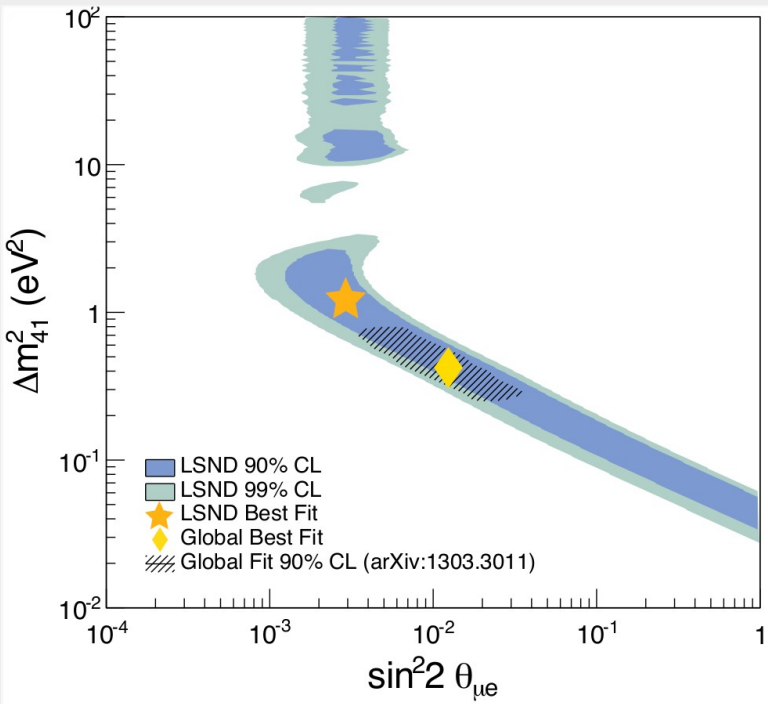
- ν_e disappearance signal in the low energy anti-neutrinos from nuclear reactors ("reactor anomaly") and from radioactive neutrino sources in the Gallium experiments ("Gallium anomaly")





Why a Short-Baseline Neutrino Program?

- Short-baseline anomalies can not be explained with three flavor neutrino oscillations
  - Interpreted as oscillations involving sterile neutrinos with $\Delta m^2 \sim 1 eV^2$ and an L/E ~ 1km/GeV
  - New experimental efforts are needed to eventually solve the puzzle



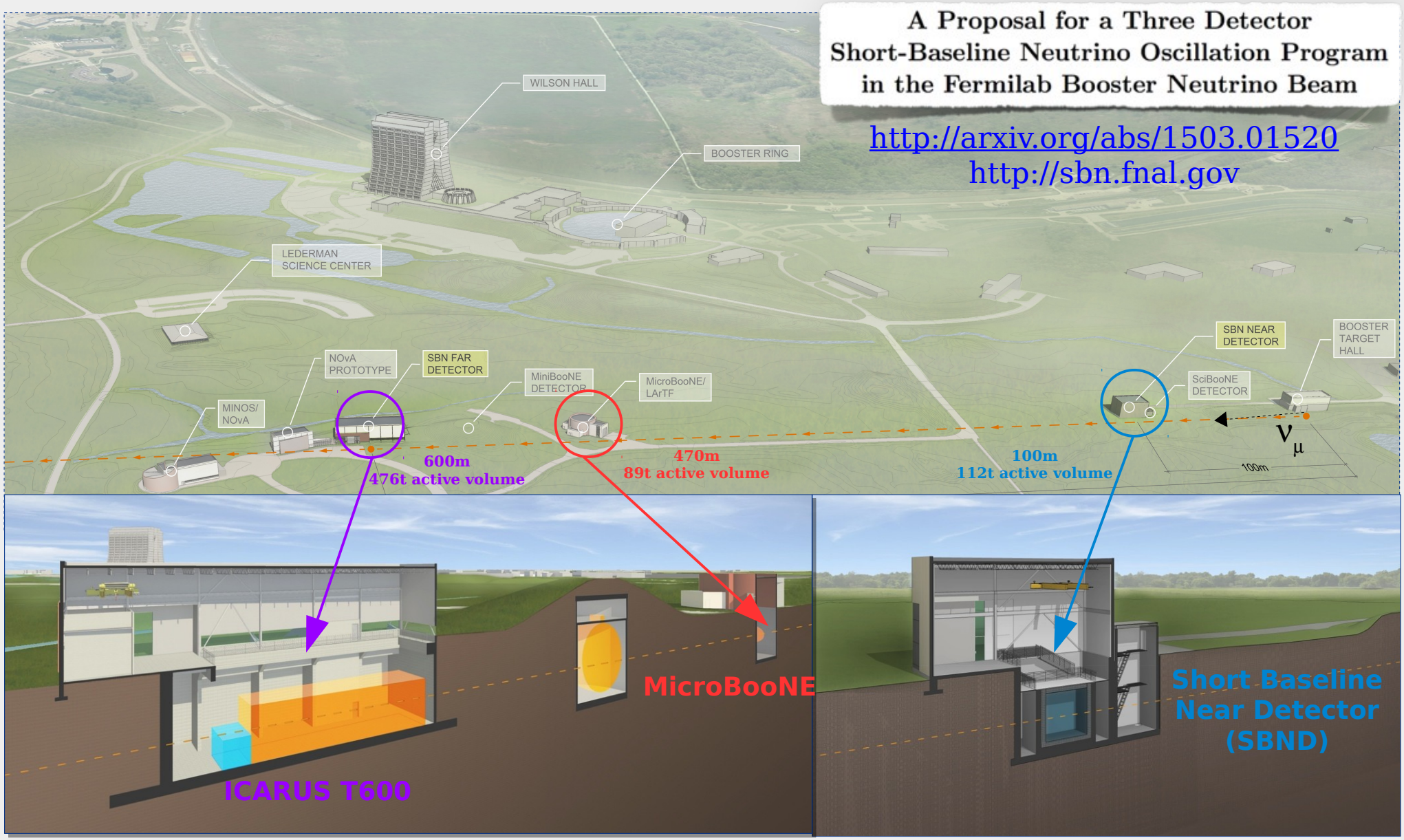
Experiment	Type	Channel	Significance
LSND	DAR	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	3.8σ
MiniBooNE	SBL accelerator	$\nu_\mu \to \nu_e$ CC	3.4σ
MiniBooNE	SBL accelerator	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	2.8σ
GALLEX/SAGE	Source - e capture	ν_e disappearance	2.8σ
Reactors	Beta-decay	$\bar{\nu}_e$ disappearance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

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

Worldwide program proposing/building experiments

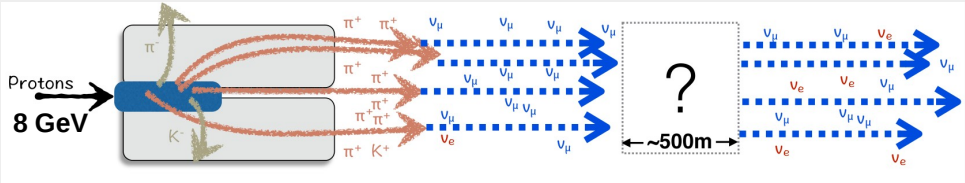
Radioactive neutrino sources	$\nu_e/\bar{\nu}_e$ dis.	$100s$ of keV, $10s$ of cm
Nuclear reactor antineutrinos	$\bar{\nu}_e$ dis.	< 10 MeV, < 20 m
Stopped π beams	$\bar{\nu}_\mu \to \bar{\nu}_e$	~ 30 MeV, 30 m
Stopped K beams	$\nu_\mu \to \nu_e$	235.5 MeV, 160 m
Decay in flight π/K beams	$\nu_\mu \to \nu_e$, $\bar{\nu}_\mu \to \bar{\nu}_e$ $\nu_\mu/\bar{\nu}_\mu$ 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, $< 1.3 \times 10^4$ km
Cosmology	indirect N_s, m_ν	

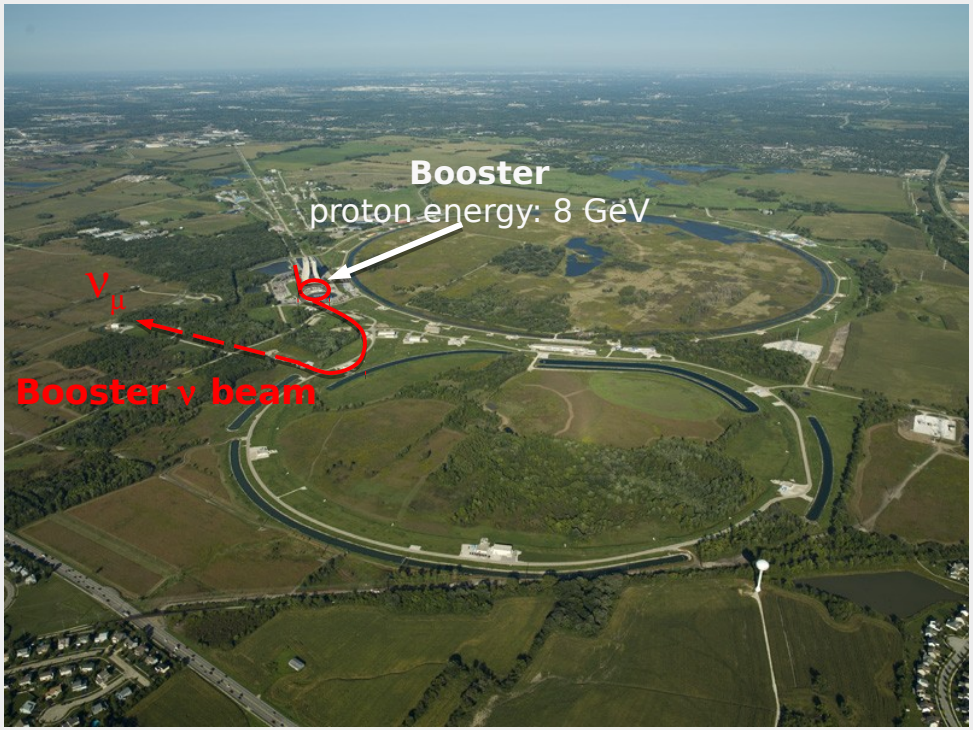
SBN program at Fermilab

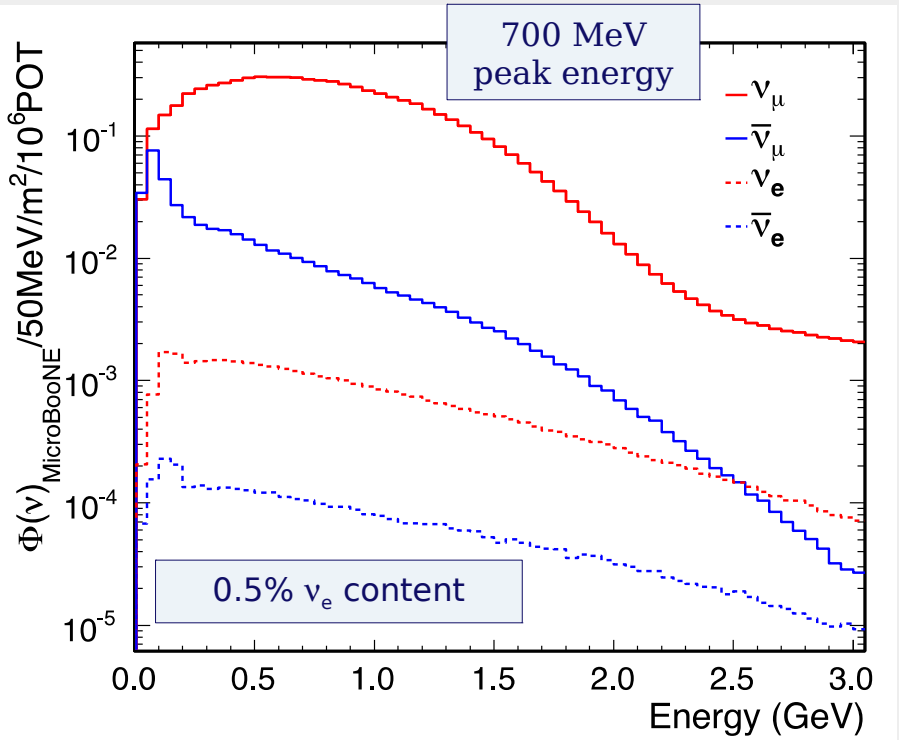


The Booster Neutrino Beam

- Fermilab's low-energy Booster Neutrino Beam (BNB)
  - 700 MeV peak energy
  - Small electron neutrino contamination: <0.5%
  - BNB is stably running for decade (well characterized)

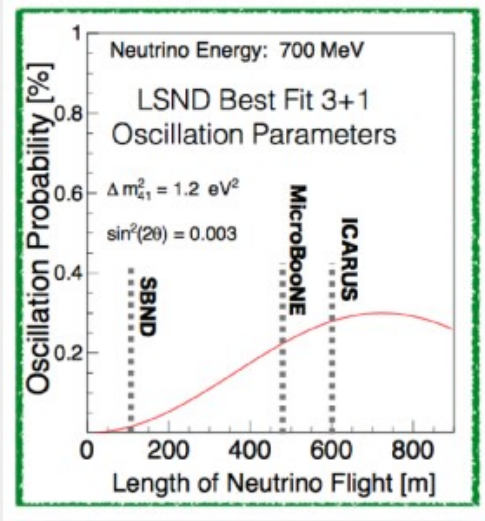


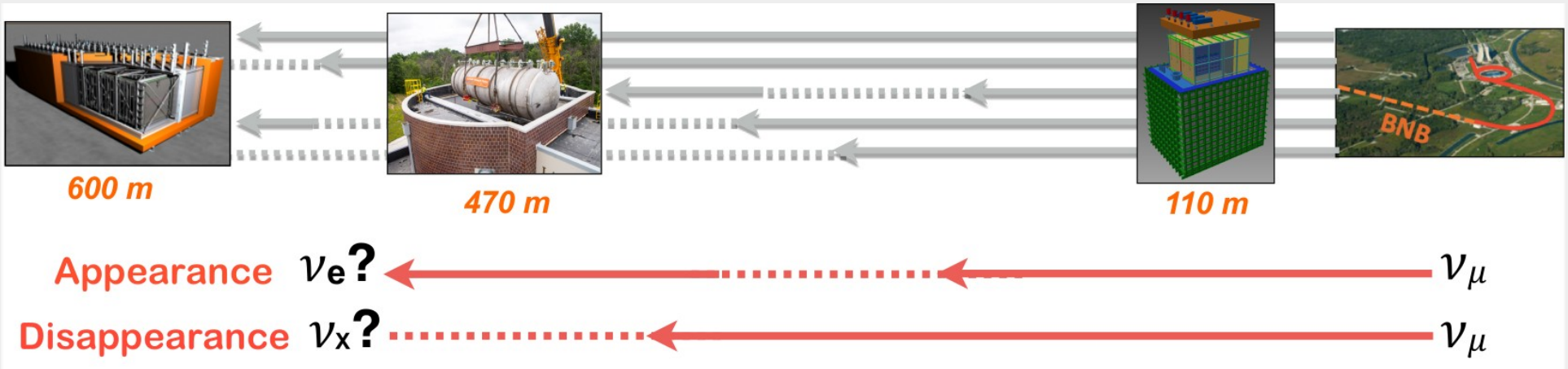




Physics goals

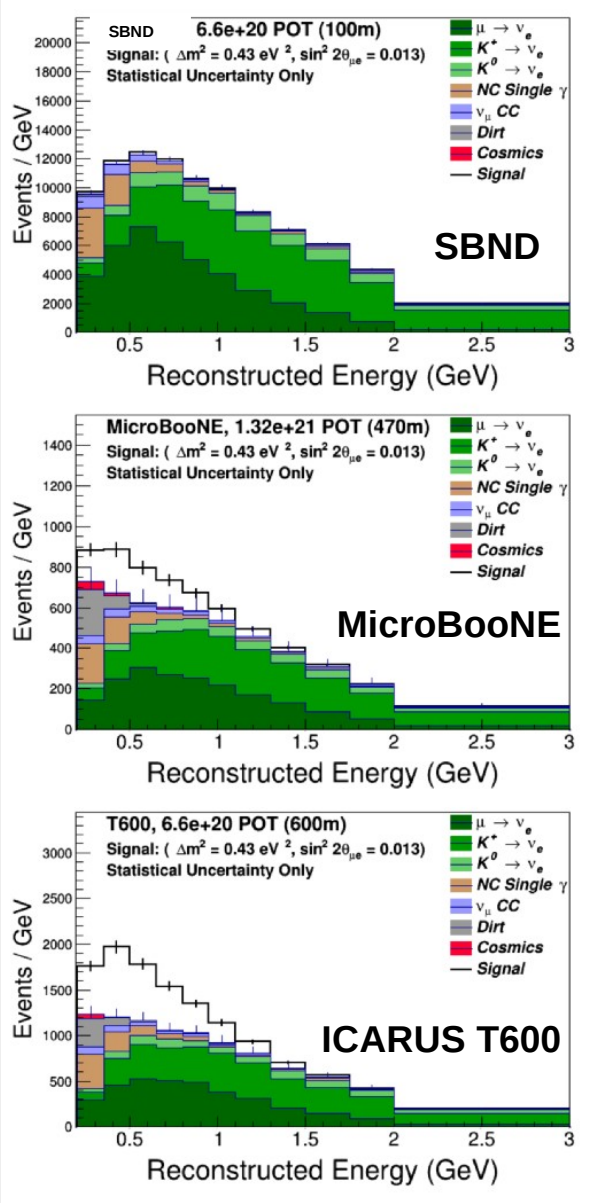
- Oscillation studies, sterile neutrinos
  - $\nu_\mu \rightarrow \nu_e$ appearance
  - ν_μ disappearance
- ν-Ar cross section
- R&D for future large LArTPCs





Having multiple detectors allows simultaneous searches for oscillations in appearance and disappearance channels, a very important constraint for interpreting the experimental observations.

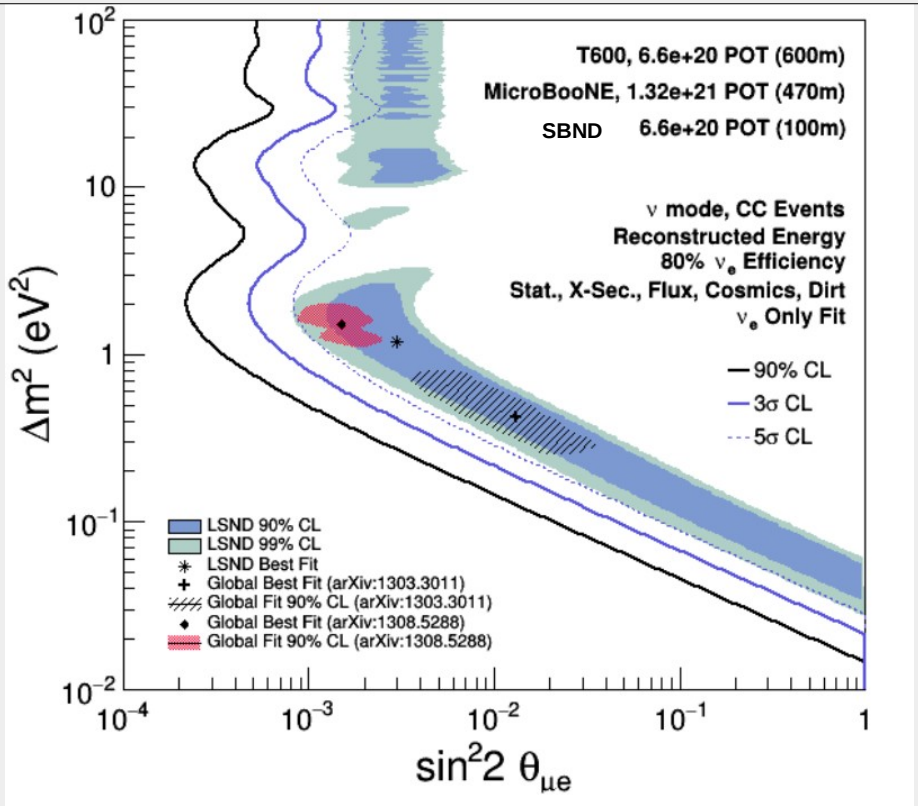
$\nu_\mu \rightarrow \nu_e$ appearance



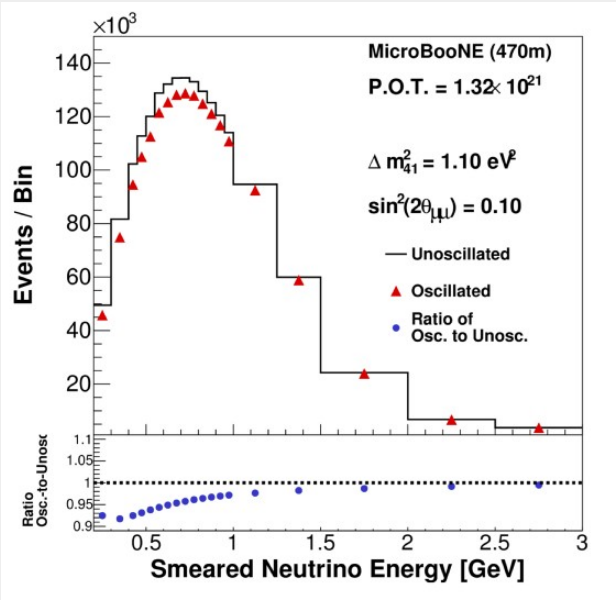
http://arxiv.org/abs/1503.01520

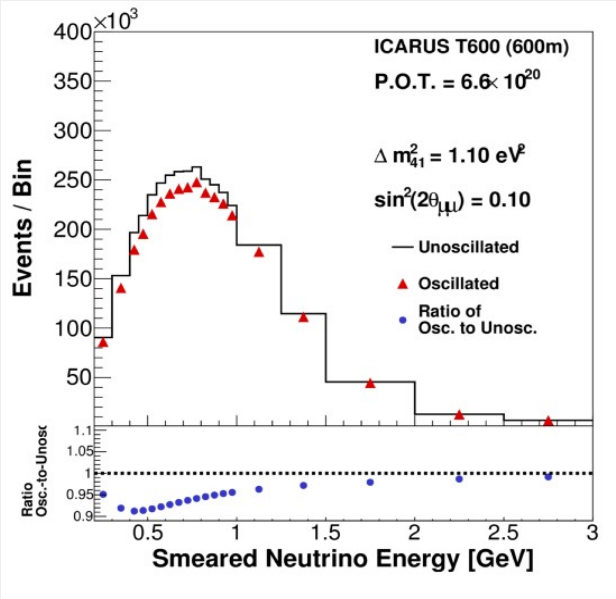
- A large mass far detector and a near detector of the same technology reduces both statistical and systematic uncertainties
- SBN will cover the LSND 99% C.L. allowed region with ≥ 5σ significance

$\nu_\mu \rightarrow \nu_e$ Appearance sensitivity (~3 years of run)



ν_μ disappearance

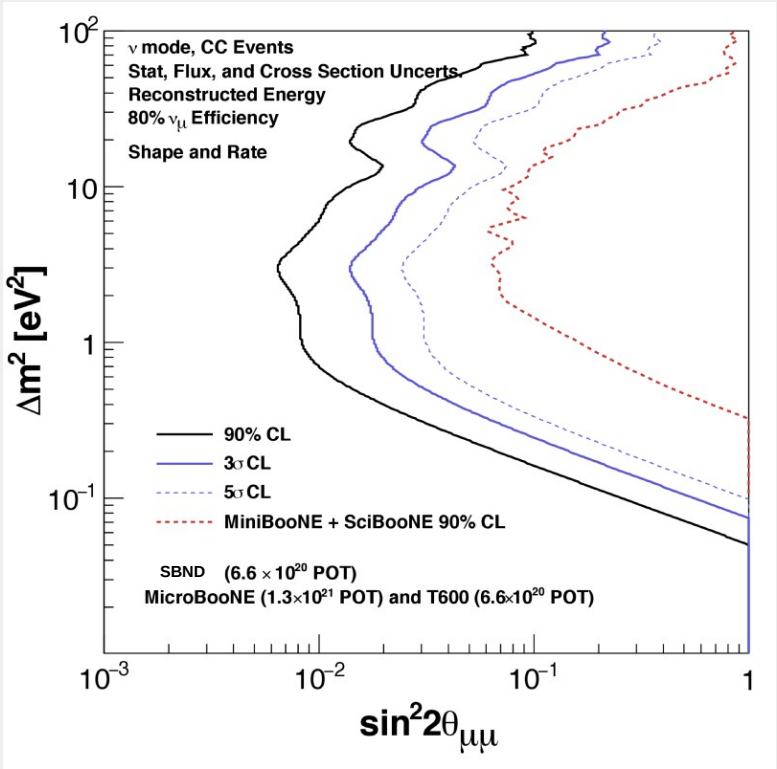




http://arxiv.org/abs/1503.01520

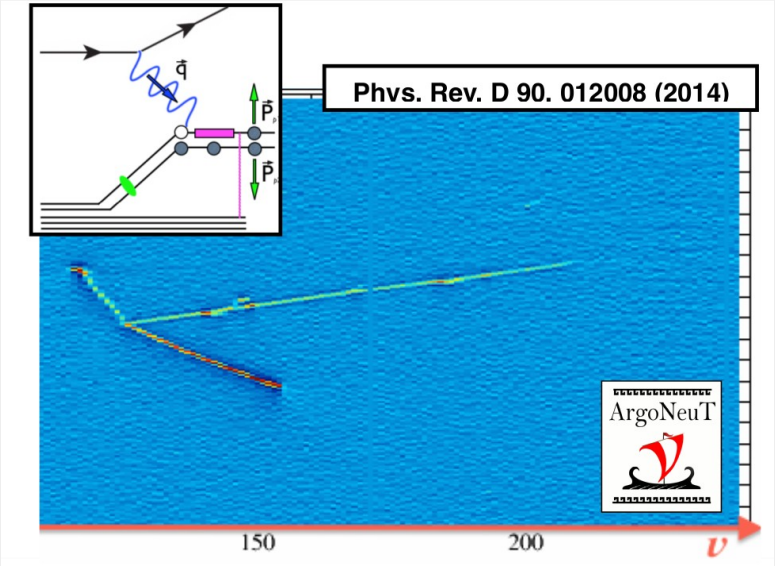
- SBN can extend the search for muon neutrino disappearance on order of magnitude beyond the combined analysis of SciBooNE and MiniBooNE

$\nu_\mu \rightarrow \nu_x$ disappearance sensitivity

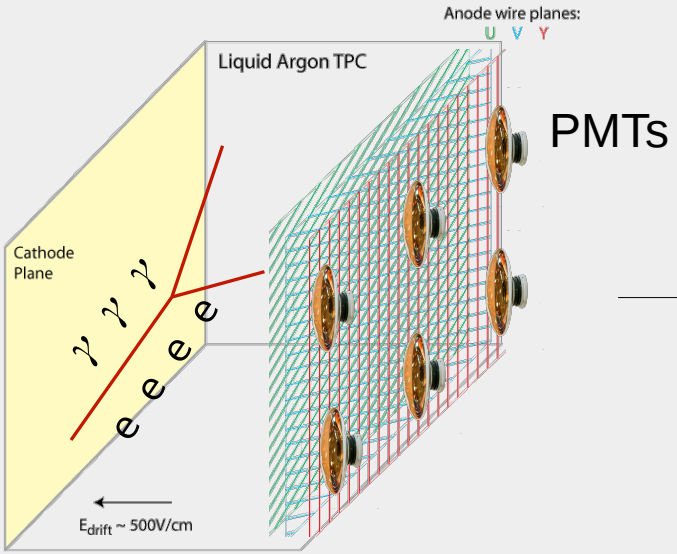


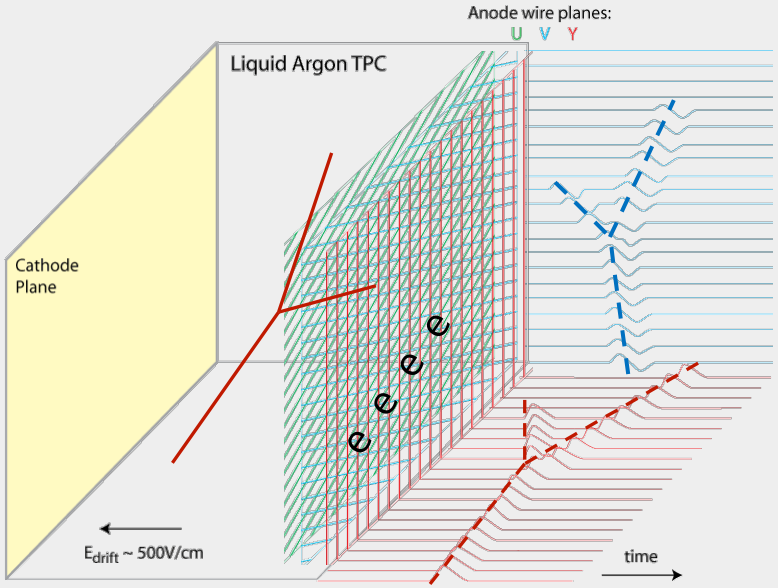
ν-Ar cross section studies

- ν oscillation experiments require precise understanding of ν–Ar interaction cross section for a correct interpretation of the experimental outcome
- The only existing GeV ν–Ar data are ~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 coming
  - 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



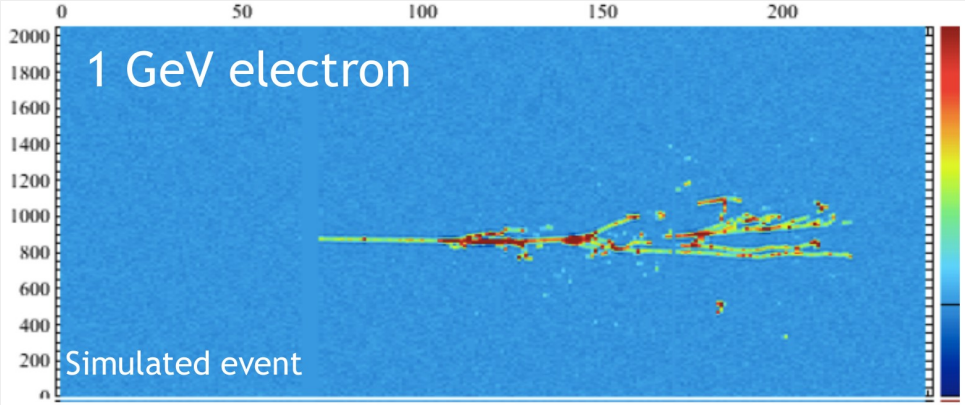
Liquid Argon Time Projection Chambers

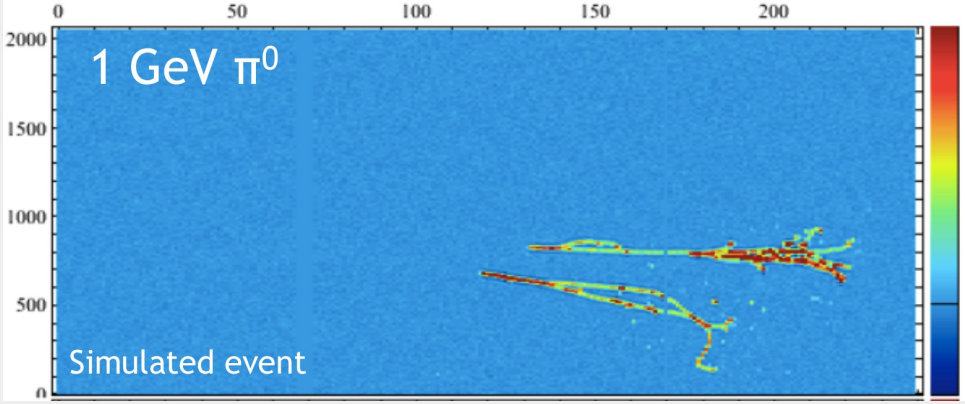




- Charged particles ionize argon and creates scintillation light
- Scintillation light is detected by PMTs
- Electric field drifts electrons to wire chamber planes where they read-out

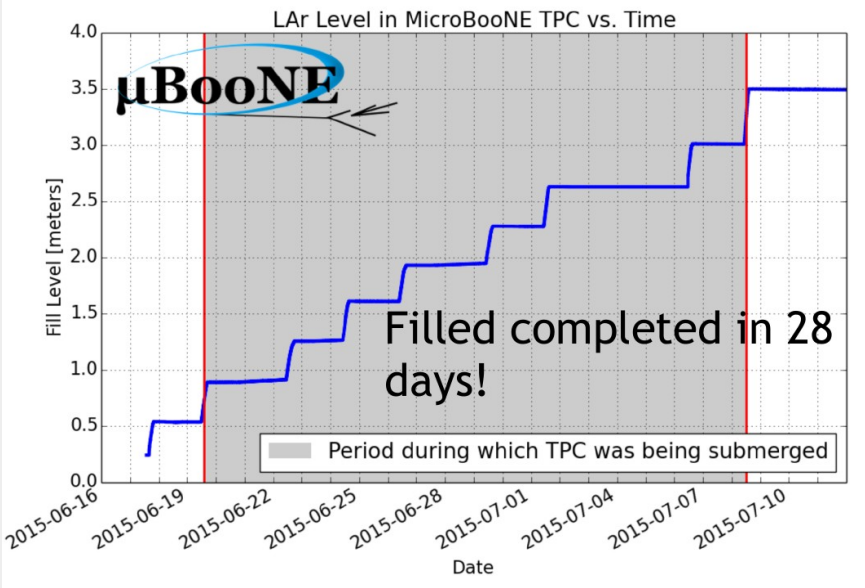
- 2D, 3D reconstruction of charge particle tracks
- Total charge is proportional to the deposited energy → calorimetry
- dE/dx along the track → Particle identification

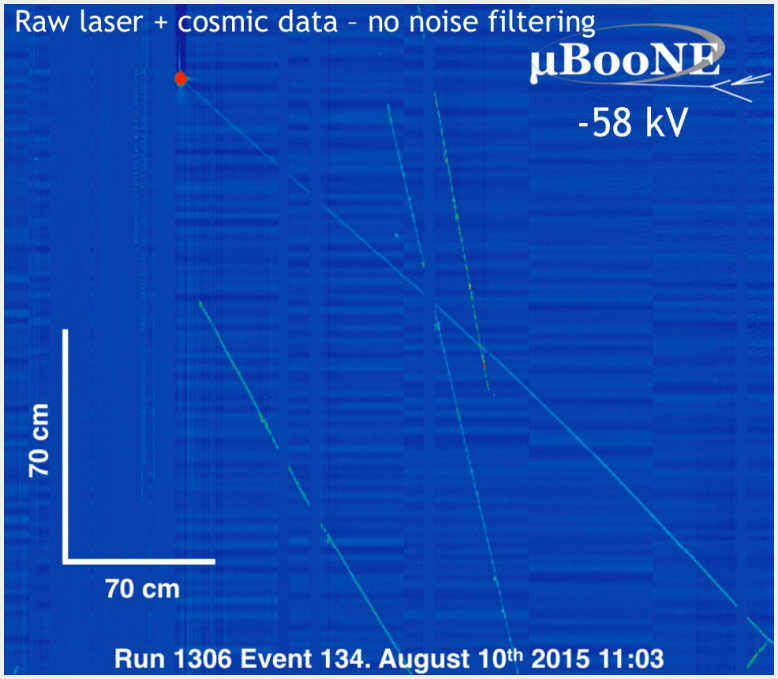


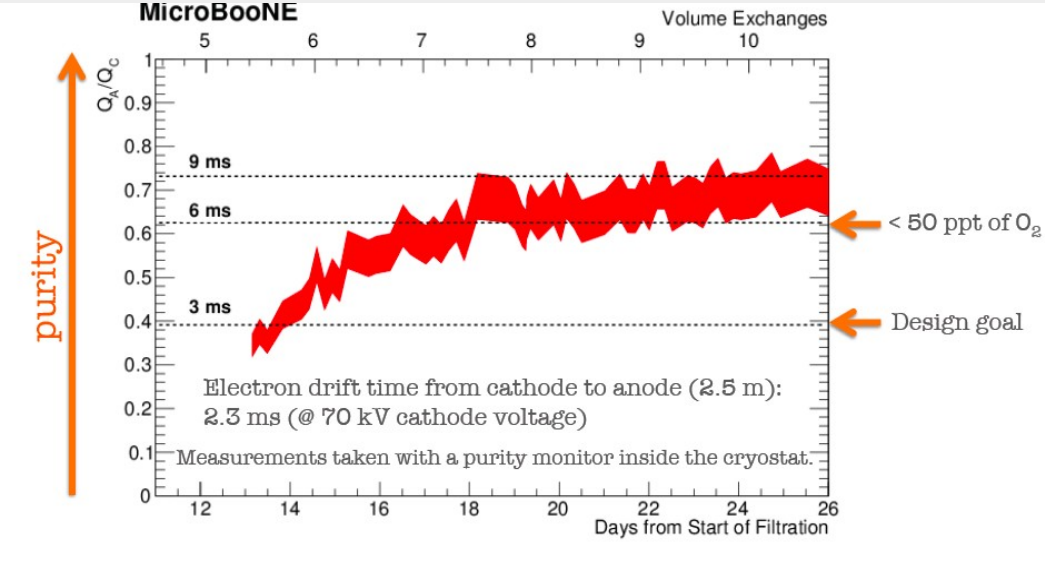


Experiments: MicroBooNE

- Address the MiniBooNE low energy access
- R&D for future LArTPCs
- 89t active LAr TPC
- Detector components installed, cabled up, and granted final safety clearance on Dec 2014
- After completion of commissioning, cryostat filled with LAr, HV ramped up and detector collected first events from cosmics and laser.

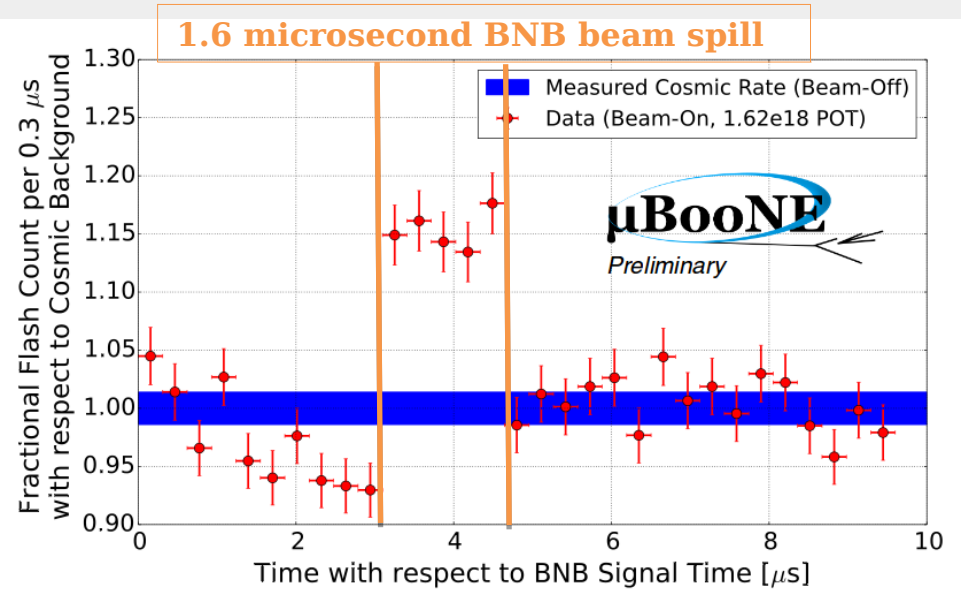


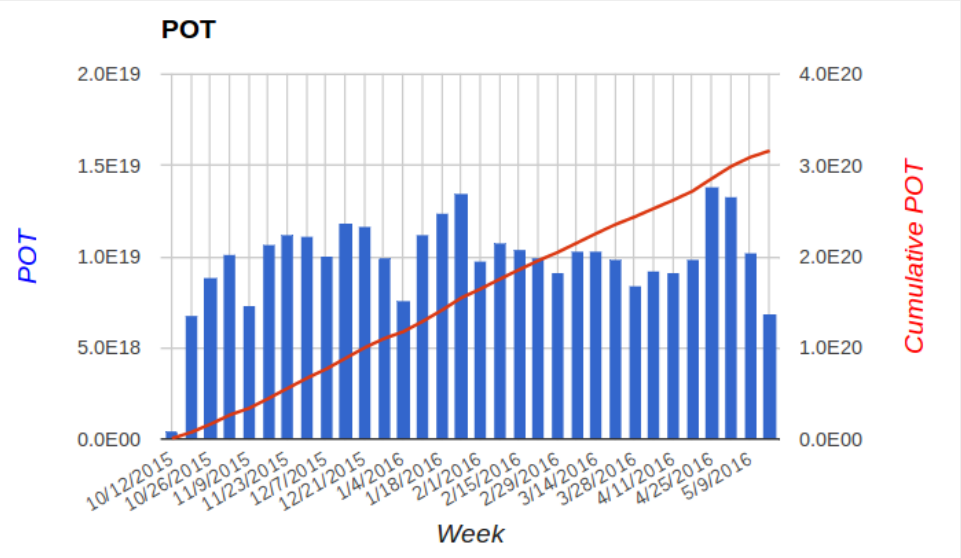


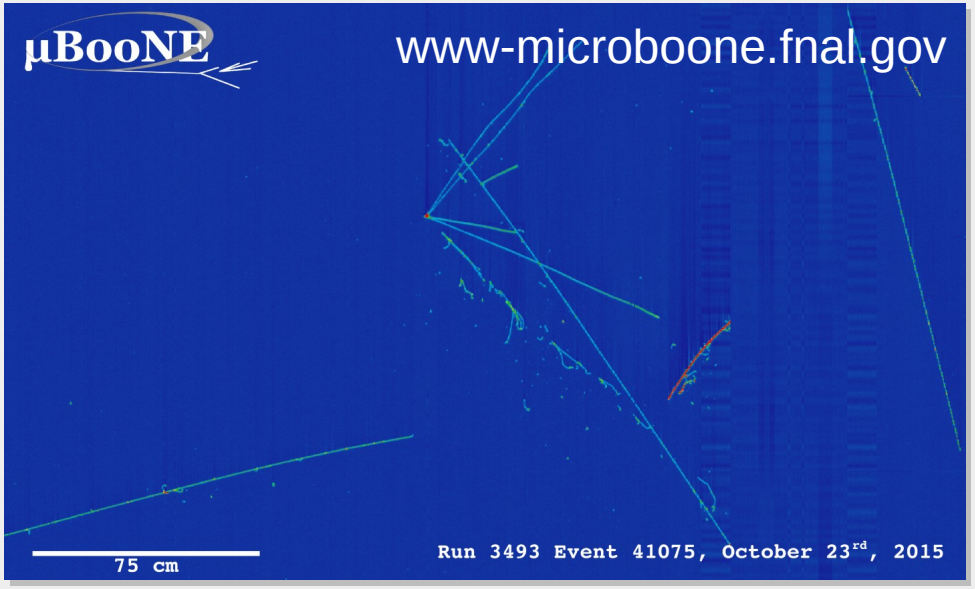


Experiments: MicroBooNE

- First neutrinos on October 15th
- MicroBooNE has accumulated 3.2 x 10^{20} POT in 6 months
- Experiment is running well
- Preparing first ν-Ar cross section measurements
- First results in this year





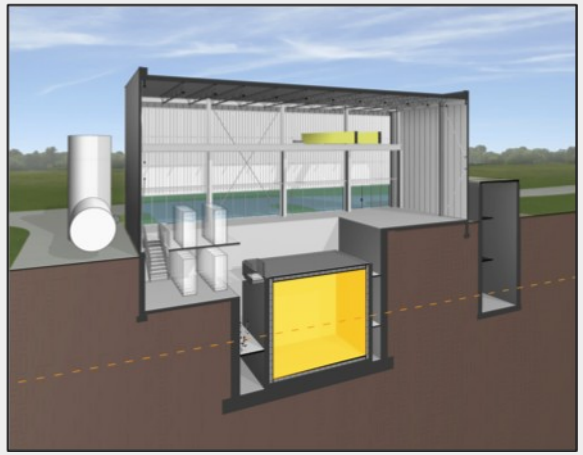


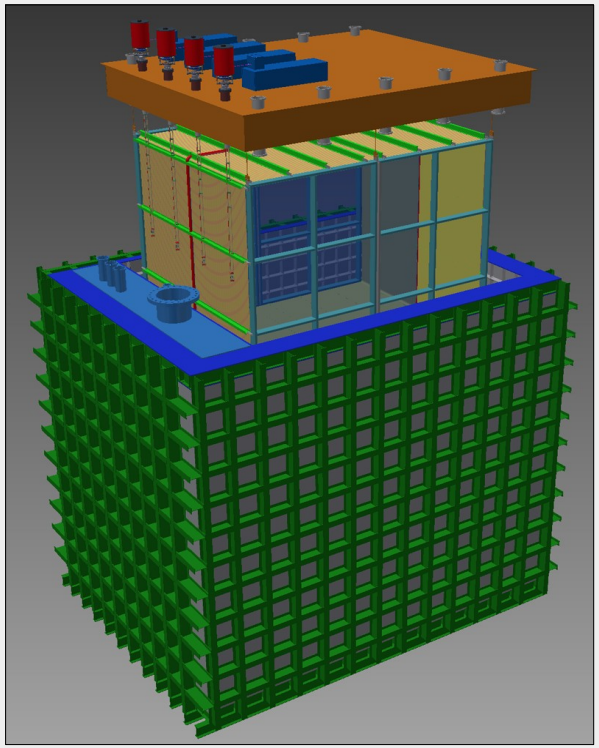
Experiments: ICARUS T600

- Far detector of the SBN program
  - Operated at LNGS from 2010-2013
  - Currently at CERN for refurbishing
    - Flatten cathodes
    - Replace internal TPC cabling
    - New HV decoupling boards
    - New 8” PMTs
    - Upgrade TPC readout electronics
    - Rebuild cryogenic system
  - Building construction at FNAL will be finalized end of this year
  - Installation at Fermilab in 2017
  - Data taking in 2018

Experiments: SBND

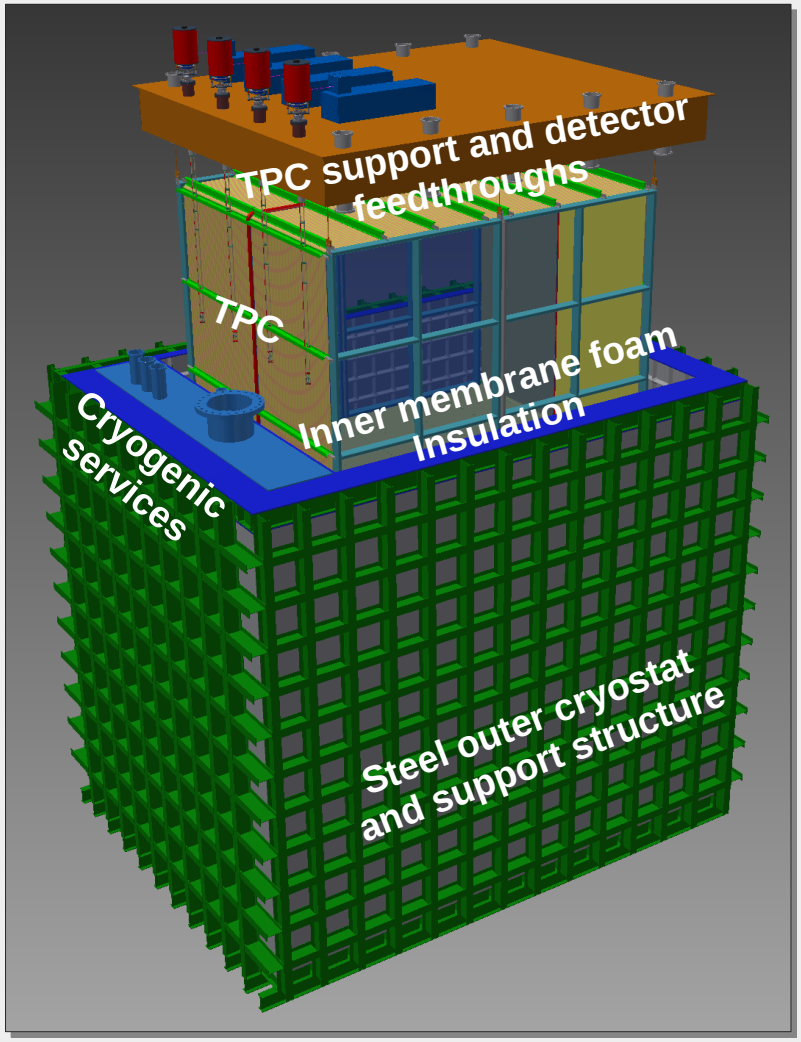
- Short Baseline Near Detector
  - 163 collaborators from 18 US and 12 international institutions
  - Provide a detailed characterization of the beam before oscillation
  - Cancellation of dominant systematics
  - Cross section studies with **1.5 million ν_μ CC and 12k ν_e CC interactions per year**





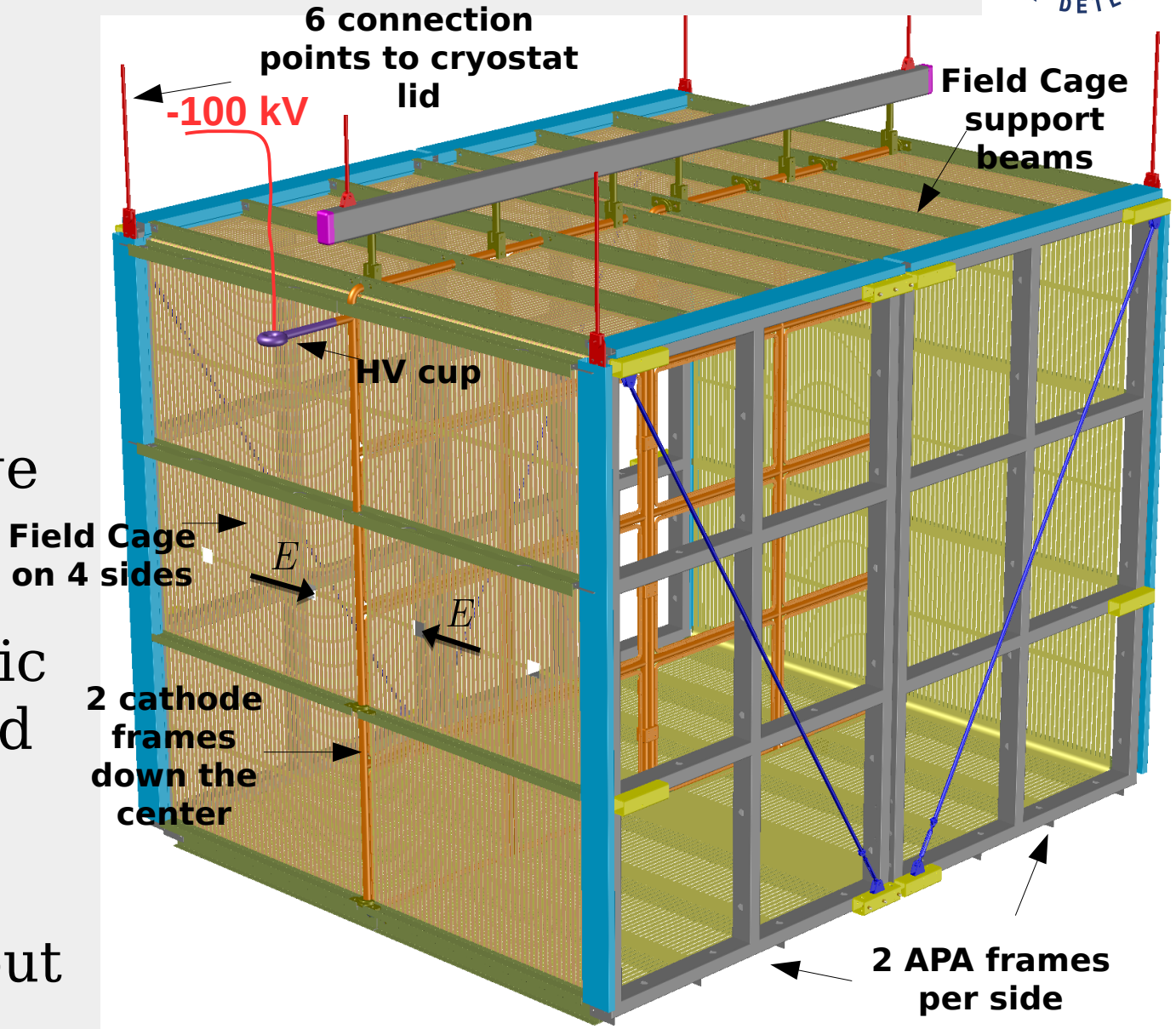
SBND detector

- Completely new detector incorporating experience from ICARUS, MicroBooNE
- 112t Active volume LArTPC
  - Membrane cryostat
  - TPC dimensions: 5m long x 4m tall x 4 m wide
  - 2m drift length
  - UV laser based calibration system
  - Light collection system for the scintillating light
  - External cosmic ray tagging system



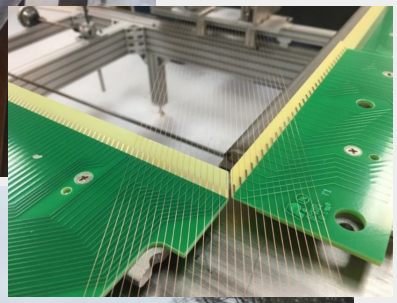
SBND TPC

- 4 Anode plane frames (APA)
- Central cathode with 2m drift regions
- -100kV high voltage
- 3 wire planes
- Roll formed metallic profiles for the field cage
- 112 8” PMTs for scintillation read-out



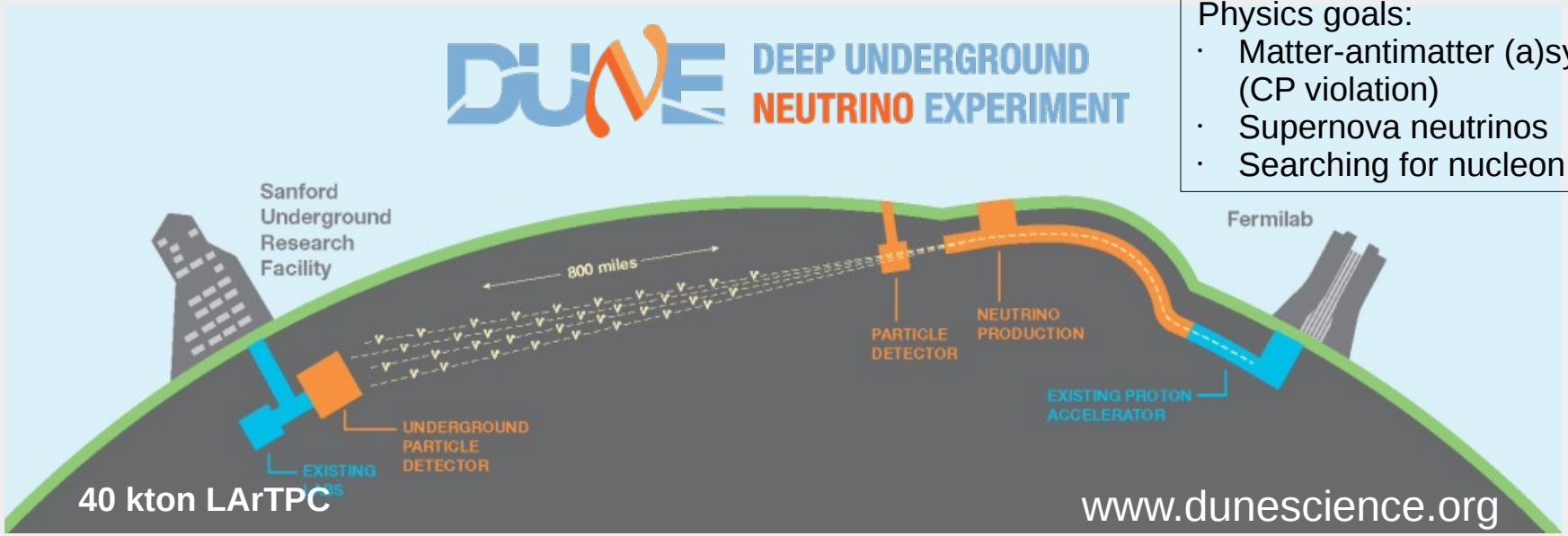
Current status of SBND

- Detector:
  - TPC in final design stages
    - Production of anode plane frames are started
    - Cathode and HV review in the beginning of June
    - Wire winding will start at the end of summer
  - PMTs ordered
  - CRT completed final design
  - Cryostat design nearly completed
  - Installation in 2017-2018



- Building in preparation
  - November 2016 beneficial occupancy

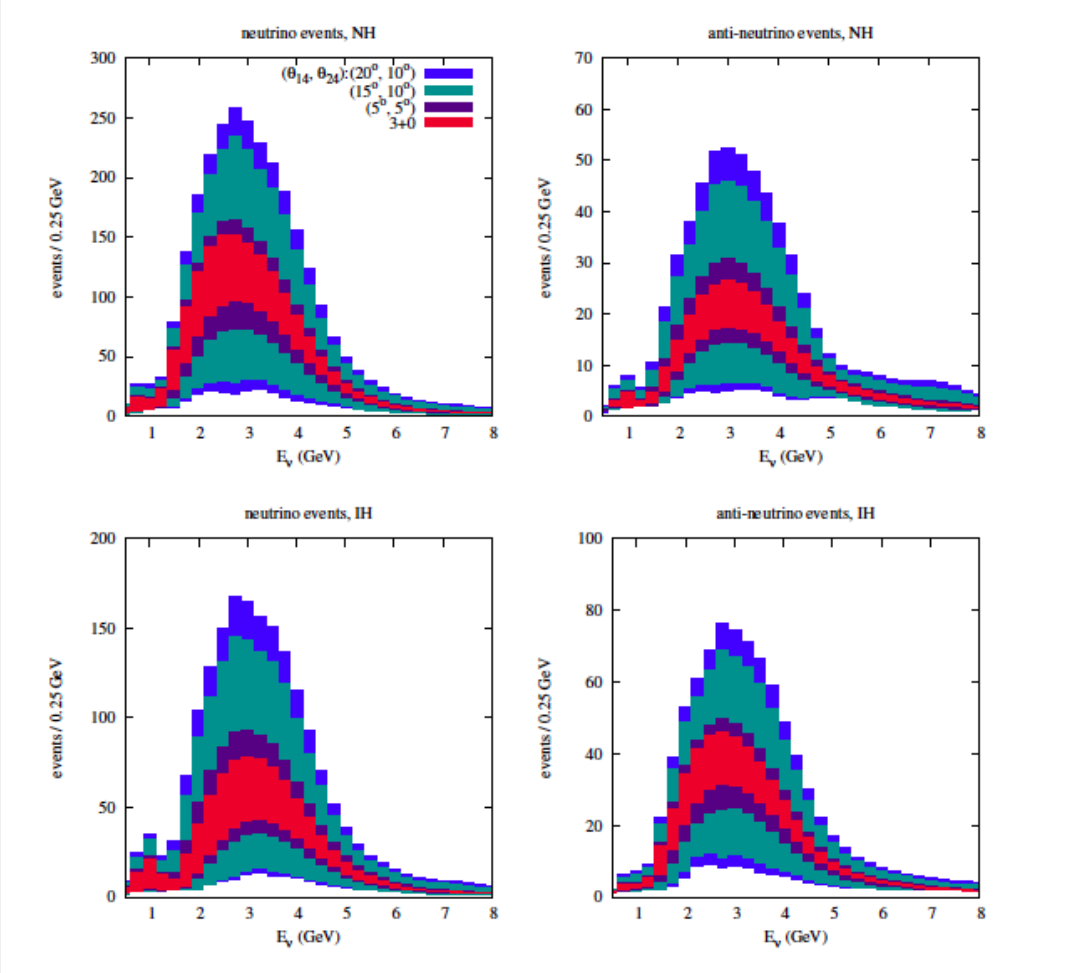
Ties to the Long-Baseline Program



Physics goals:
- Matter-antimatter (a)symmetry? (CP violation)
- Supernova neutrinos
- Searching for nucleon decay

- Development of LarTPC technology toward the DUNE long-baseline program
- Measurement of GeV scale ν-Ar cross section
- Developing reconstruction and analysis tools for LArTPCs

Impact of sterile neutrino on long-baseline measurements



R. Gandhi, B. Kayser, M. Masud, S. Prakash, arXiv:1508.06275

- $\nu_\mu \rightarrow \nu_e$ oscillations in 3+0 vs 3+1 with varying values of mixing angles
  - Results on CP can not be correctly interpreted without definitive conclusions drawn from SBL on sterile states of mass ~1eV

Conclusions

- Three international collaborations have come together to form the SBN program.
  - MicroBooNE has running and collected 3.3 x 10^{20} POT in 6 months
  - Refurbishing of ICARUS is progressing well for delivery to Fermilab in early 2017
  - SBND design is in final stage and starting constructions
  - Civil construction of experiment buildings expected to be finalize at the end of 2016
- Looking forward to three detector operation and physics
- SBN will give a definitive answer to LSND/MiniBooNE anomaly

μBooNE + ICARUS + SBND = SBN Program

2015 2017-18 2018-19 Sterile ν Search