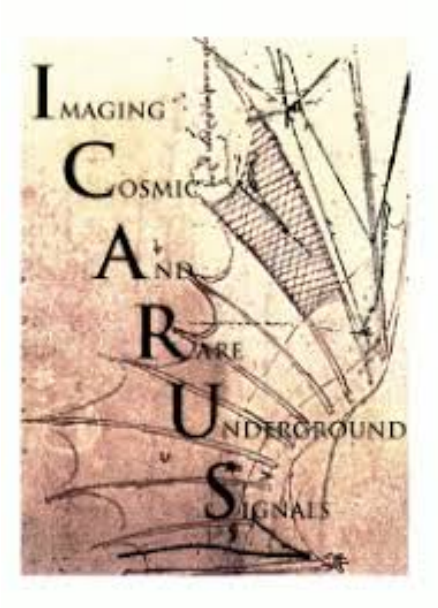


The Short Baseline Neutrino program at Fermilab

Diego Garcia Gamez for the SBN Collaboration

Outline

- Neutrino anomalies
- Detecting neutrinos with LArTPCs in the SBN programme
- Phase 1: MicroBooNE
- Phase 2: Full scale SBN (SBND + ICARUS)
- Conclusions

Short Baseline neutrino Anomalies

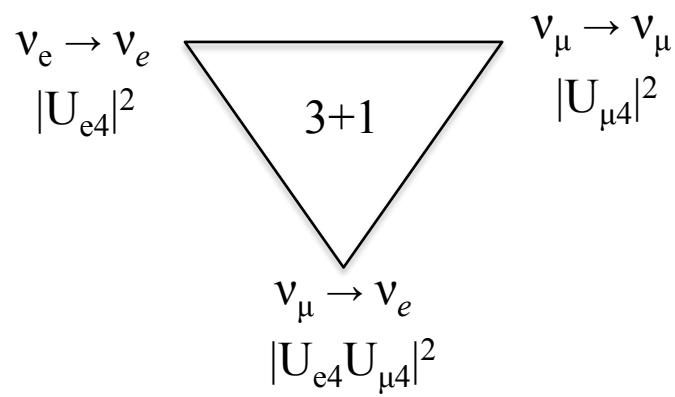
Experimental anomalies ranging in significance (2.8-4.5σ) have been reported over the past 20 years from a variety of experiments studying neutrinos at baselines less than 1 km.

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

Common interpretation is as evidence for one or more additional, mostly **"sterile" neutrino states** driving oscillations at $\Delta m^2_{new} \approx 1$ eV^2 and a relatively small $\sin^2(2\theta_{new})$.

Disappearance – Appearance Tension

Each of these anomalies can be **individually** explained by sterile neutrinos, but …

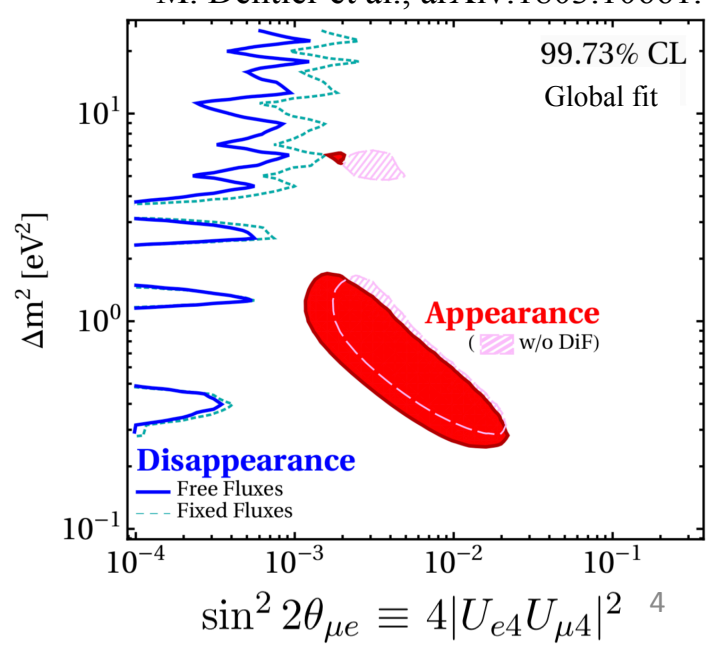


- Limits on $\nu_e \to \nu_e$ and $\nu_\mu \to \nu_\mu$ disappearance constrain the $\nu_\mu \to \nu_e$ appearance probability

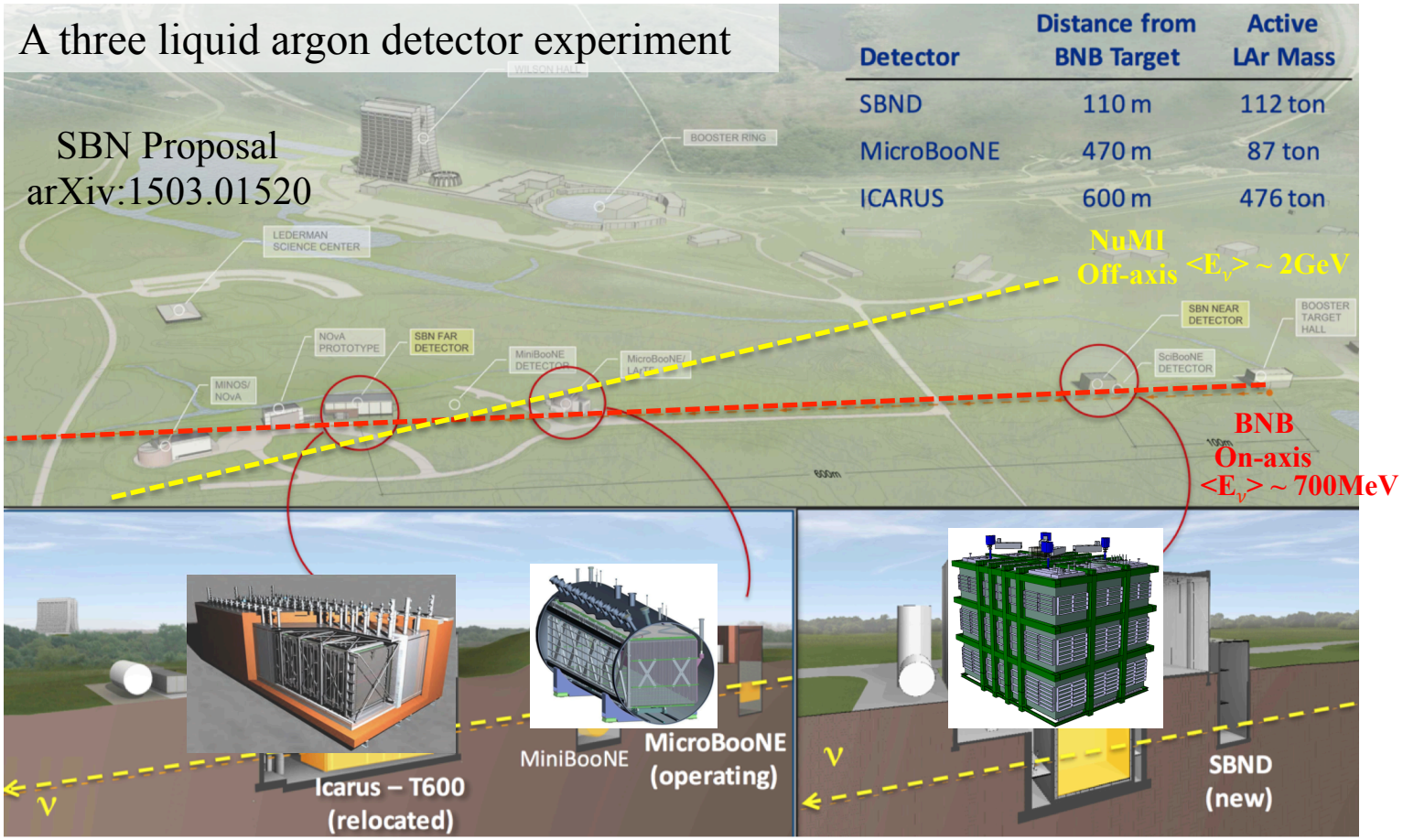
- Constraints on disappearance have become exceedingly strong, due to recent data

- **Crucial to have appearance AND disappearance data in the SAME experiment → SBN**

M. Dentler et al., arXiv:1803.10661.



Short Baseline Neutrino (SBN) program

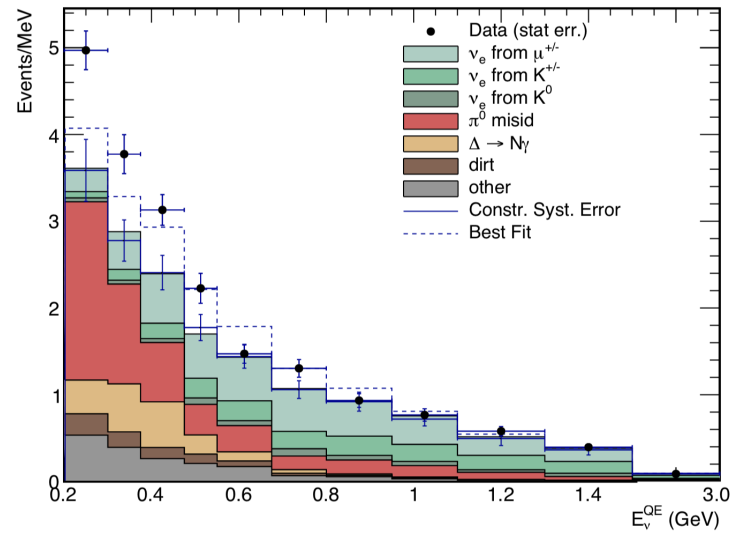


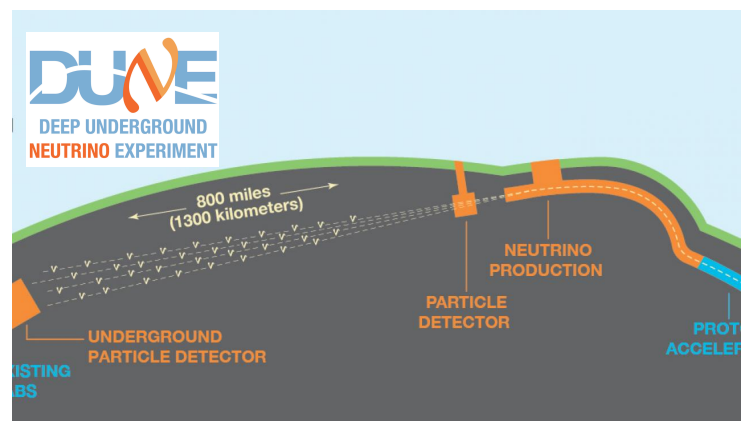
- The SBN Program is composed of three LArTPC detectors with the goal of definitively addressing the hints of eV-scale sterile neutrinos
- The low energy Booster Neutrino Beam (BNB) allows us to search for neutrino oscillations over a baseline of 600 m

SBN physics goals

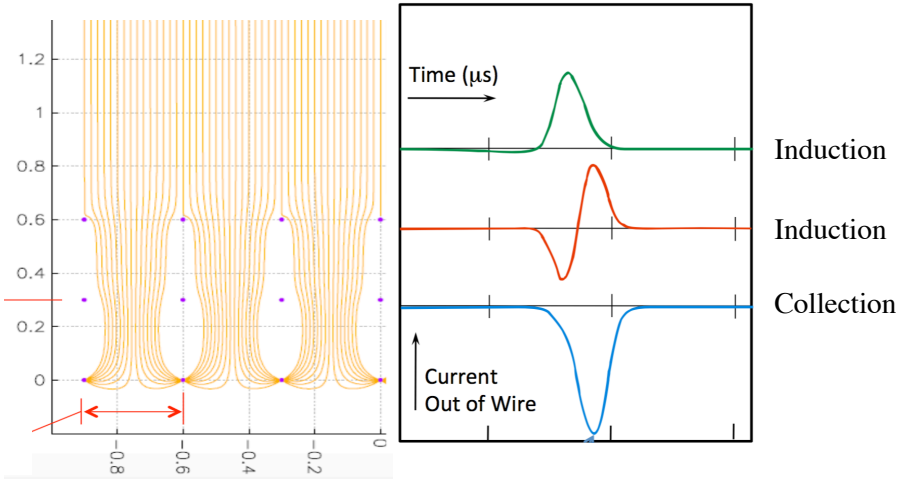
- Resolve the *low-energy excess* anomaly
  - ✓ Understand the nature of the MiniBooNE excess: is it electron-like or photon-like?
- Search for ν_e appearance and ν_μ disappearance in the same experiment
  - ✓ Multiple detectors at different baselines and with same target and same beam are key for reducing systematic uncertainties
- Lay groundwork for future long-baseline program
  - ✓ Further develop Liquid Argon TPC detector technology
  - ✓ Measure ν-Ar cross sections with unprecedented resolution at energies relevant to DUNE

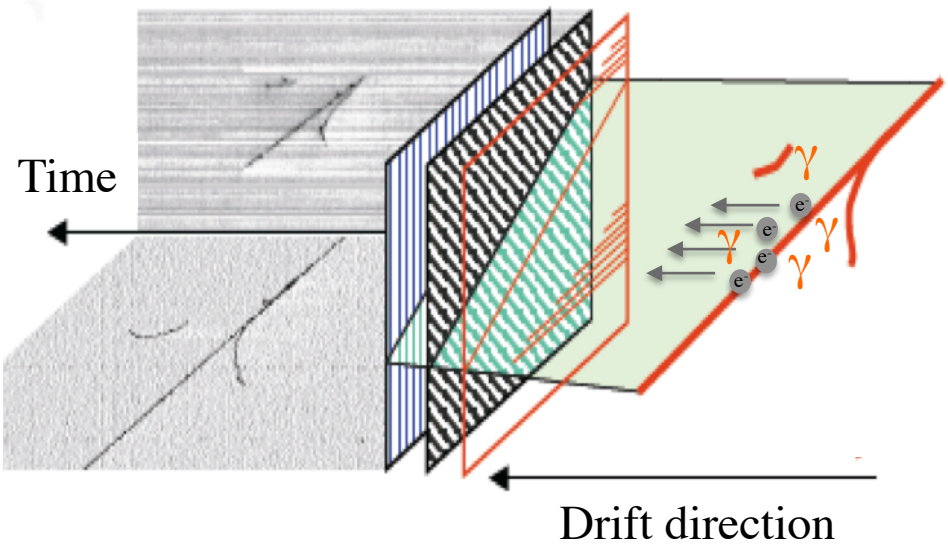
arXiv:1805.12028

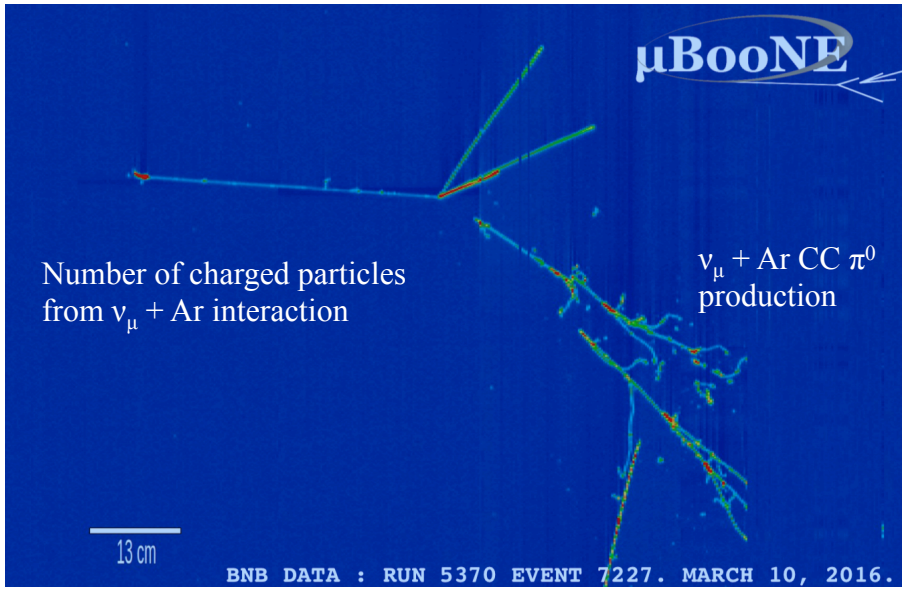




LArTPC Technology



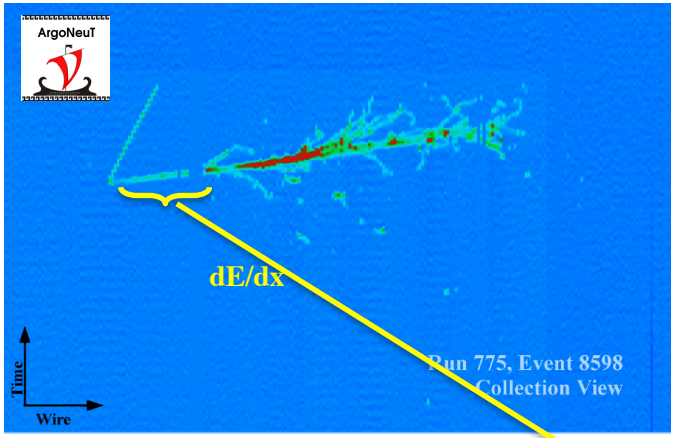


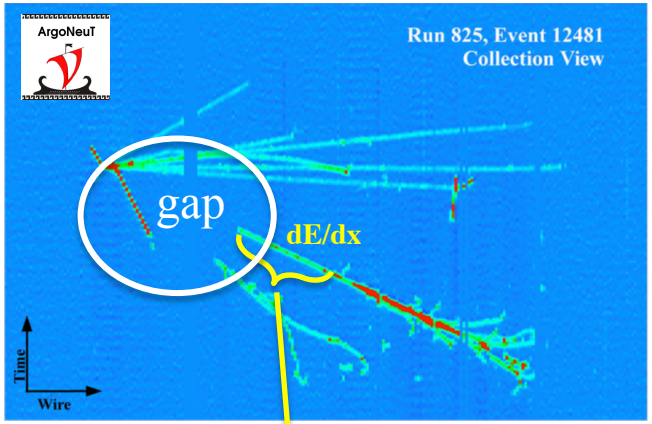


- Passing charged particles ionize argon
- Electric field drifts electrons meters to wire chamber planes
- Induction/Collection planes (3-5 mm wire pitch) image charge, record dE/dx
- Scintillation light in LAr
- 3D reconstruction of the events

LArTPCs and Electron Neutrinos

LArTPC offers incredible fine tracking along with electron/photon separation: topology (**gap** between shower and vertex) and **dE/dx**

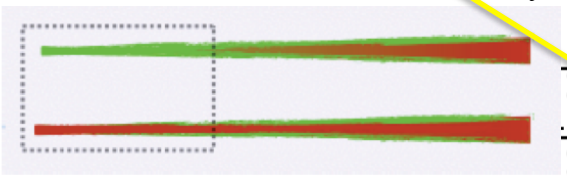




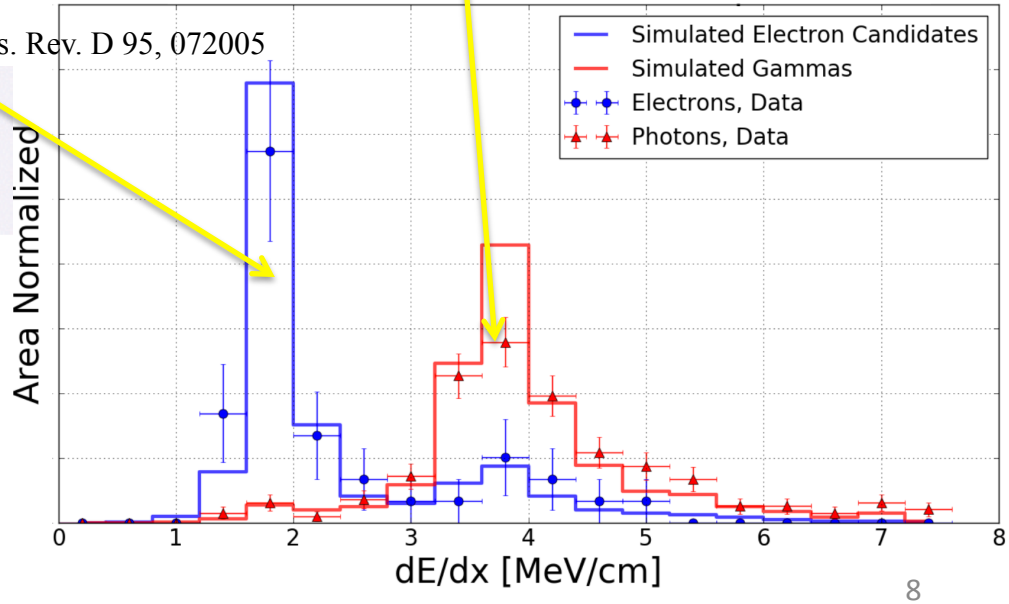
4 cm x 1 cm

Electron

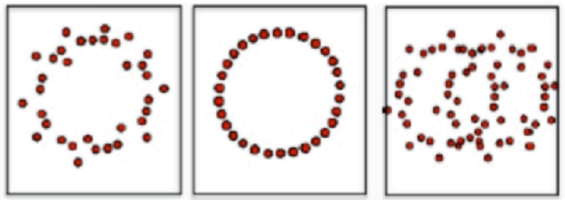
$\gamma \rightarrow e^{+} + e^{-}$



Phys. Rev. D 95, 072005



Cherenkov detectors like MiniBooNE

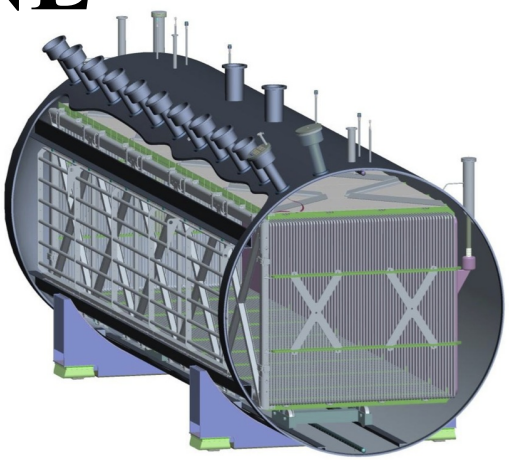


Electron, photon | Muon | $\pi^0 \rightarrow \gamma\gamma$

Phase 1: MicroBooNE

Began data taking in Oct 2015

- Designed to search for an excess of low energy ν-like events observed by MiniBooNE
- Pioneering the tools and analyses that will enable success of future LArTPC programs



87 ton LArTPC at 470 m from the neutrino source

MicroBooNE Analysis:

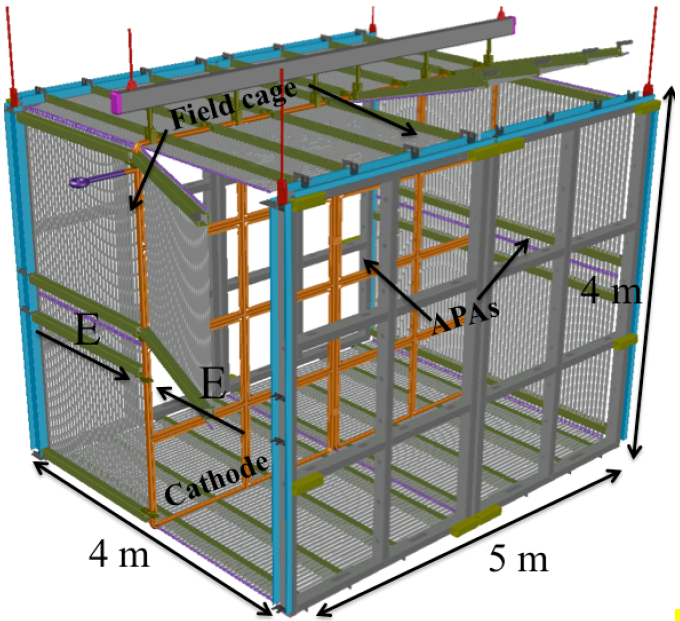
- Working at understanding the detector effects (noise, diffusion, recombination, space charge effect...) → essential to understand physics
- Great progress on automated event reconstruction in LAr using **data**
- First physics results: ν_μ CC inclusive differential cross section and CCπ^0 total cross section, and many more are underway
- First fully automated ν_e and single photon selections → towards the low-energy search

All the details in

The MicroBooNE Detector	*david caratelli*
COEX, SEOUL	17:00 - 17:15
Latest Results from MicroBooNE	*Dr Pip Hamilton*
COEX, SEOUL	17:15 - 17:30

Phase 2: SBND + ICARUS

- SBND is a modular LArTPC with a central cathode plane assembly (CPA) and two drift regions (2m)
- Both anode plane assemblies (APAs) are instrumented with 3 wire planes
- 7 Cosmic Ray Tagger planes
- High Light Yield Light Detection System behind wire planes: PMTs + Light Guide Bars + Arapucas



112 ton LArTPC at 110 m from the neutrino source

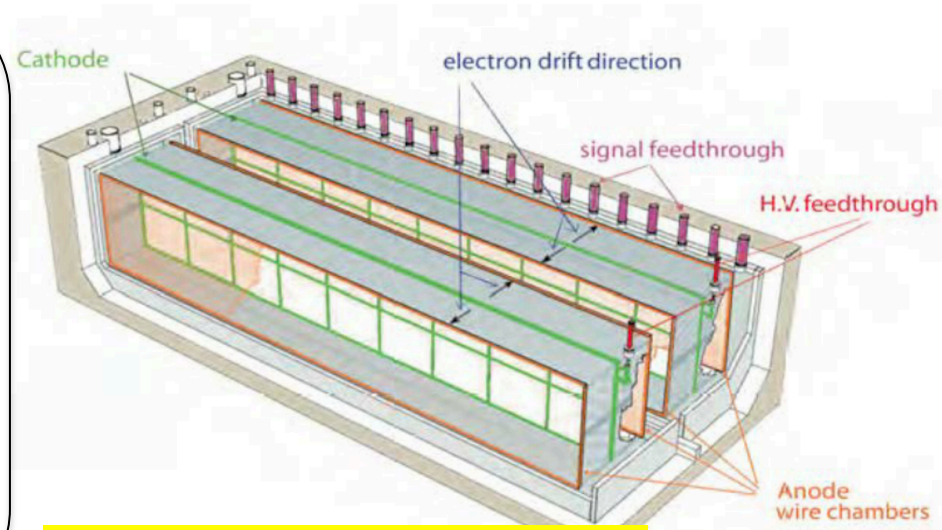
Physics program:

Physics Programme for the SBND (Short-Baseline Near Detector)	*Dr Joel Mousseau*
COEX, SEOUL	16:45 - 17:00

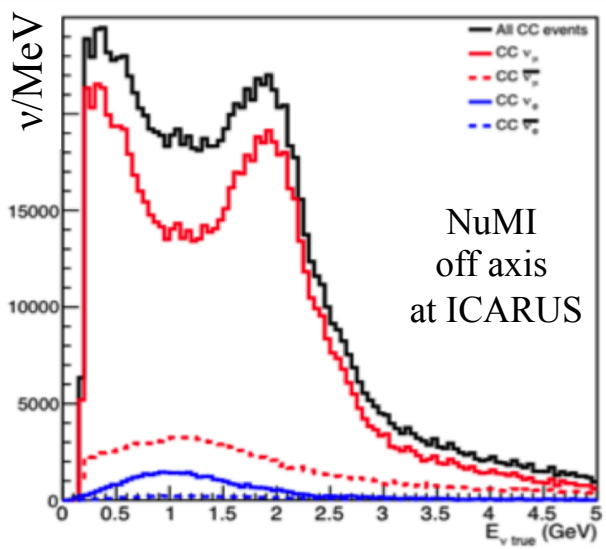
- Measure the unoscillated fluxes
- Study neutrino-nucleus interactions on argon with unprecedented precision and detail
- Detection of supernova ν, dark matter searches (Sub-GeV) …

Phase 2: SBND + ICARUS

- ICARUS T600 is the world's largest liquid-argon neutrino detector
- Refurbishment at CERN after successful operation at Gran Sasso:
  - Updated PMTs and electronics
  - Cathode plane smoothing
  - Recirculation/purification
- Arrived at Fermilab last summer



476 ton LArTPC at 600 m from the neutrino source



ICARUS: 10^5 NuMI off-axis events/year
many at the DUNE 1st osc. max

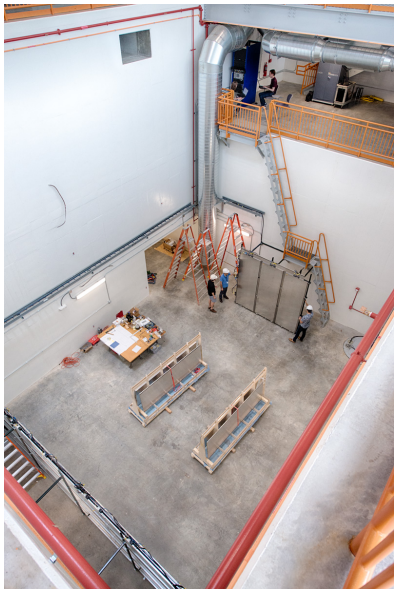
Physics Program:

- Given its large mass and far location ICARUS-T600 will provide high sensitivity to oscillated neutrinos allowing for a precision search
- ~100k NuMI off-axis events in T600 per year

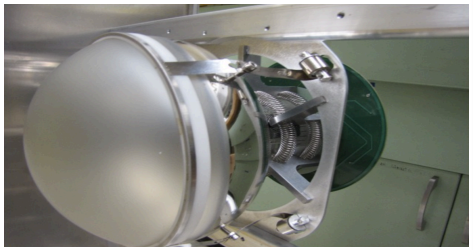
Phase 2: SBND + ICARUS

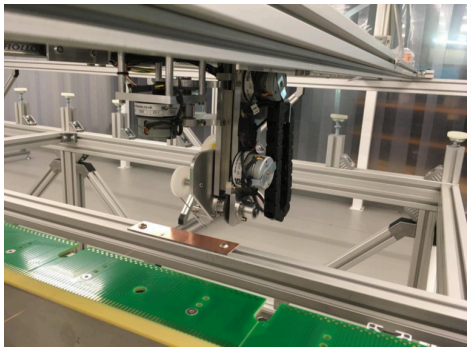
SBND:

- Detector design finalized
- Installation is going to happen in 2019



SBND Detector Hall: Test installation of CRT panels



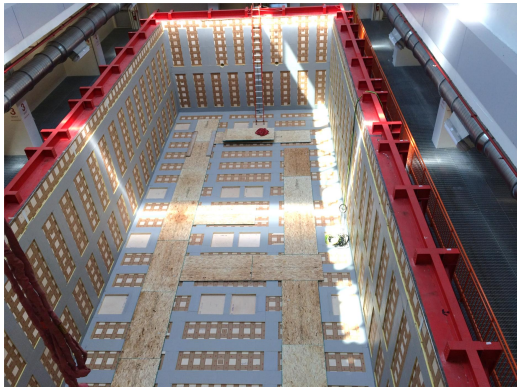


TPC and other components under construction

- Planned data taking **2020**

ICARUS:

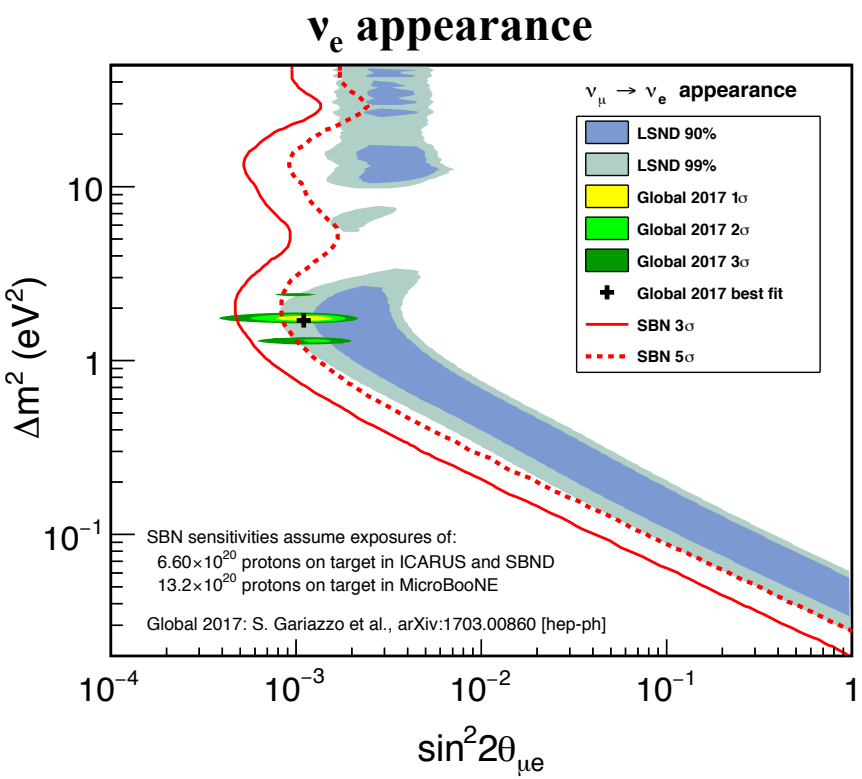
- Currently in the installation phase
- Cosmic Ray Taggers are being installed and tested

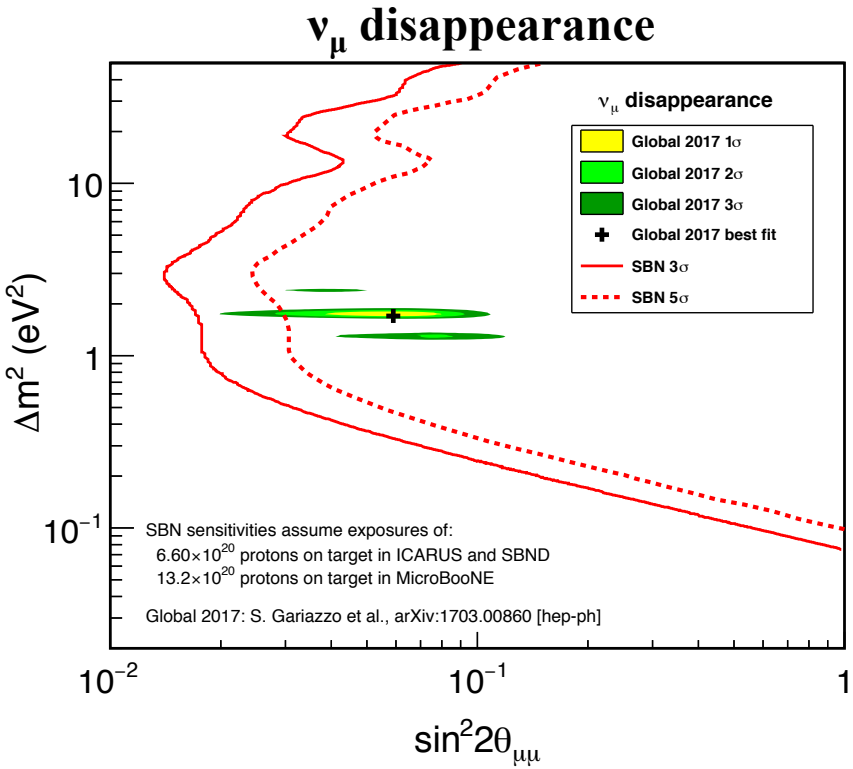


- Warm vessel completed
- Cold shield recently installed

- Planned data taking **2019**

Physics reach of the SBN Program





- Definite test (> 5σ) of the currently allowed oscillation parameter regions
- In addition to ν_e appearance, SBN also has sensitivity to ν_μ disappearance
  - ✓ Needed to confirm an oscillation interpretation of any observed appearance signal
  - ✓ Providing a more robust result on sterile-neutrino-induced oscillations

Summary

- The Short Baseline Programme at Fermilab will use three LArTPC detectors to resolve the question of the existence of sterile neutrinos.
- MicroBooNE is already running and successfully producing physics results.
- ICARUS and SBND will come online in the next two years enabling the full scale oscillation analysis.

Stay tuned!

Back-Up

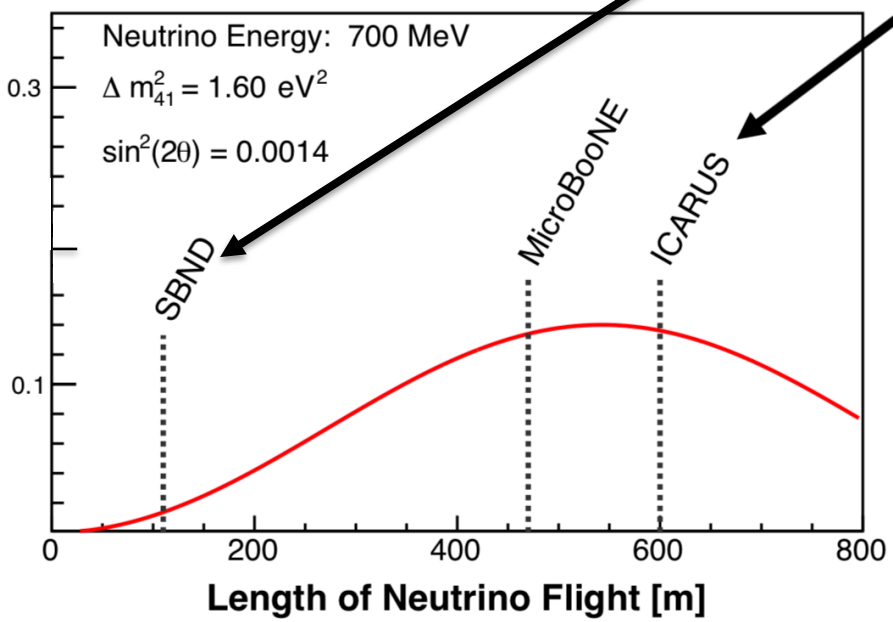
The search for sterile neutrinos in SBN

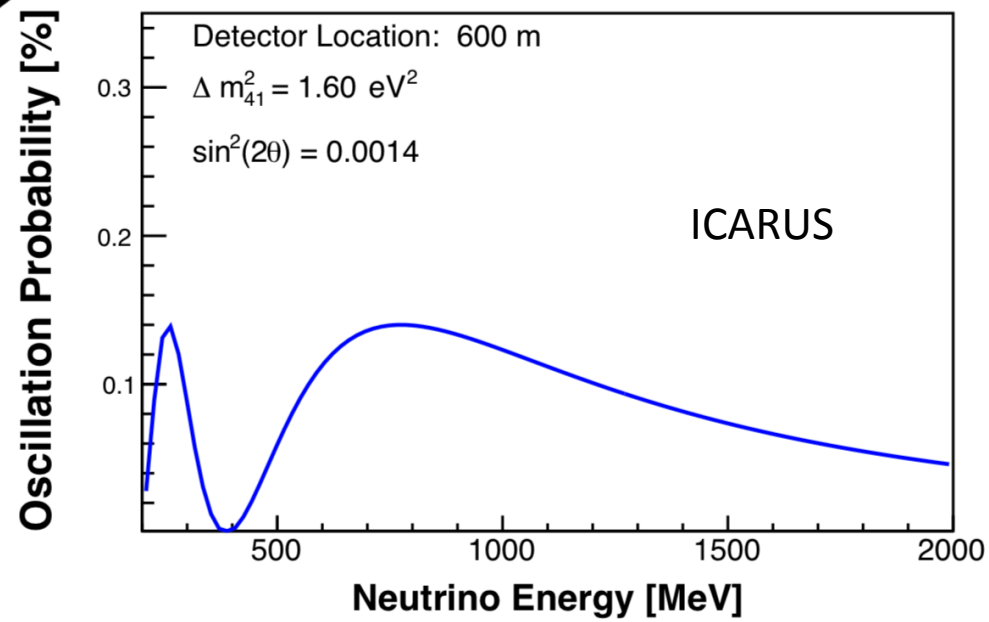
(3+1 neutrino model)

$$P^{3+1}_{\nu_\mu \to \nu_e} = \sin^2 2\theta_{\mu e} \sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$

Control systematics

Increase statistics of signal

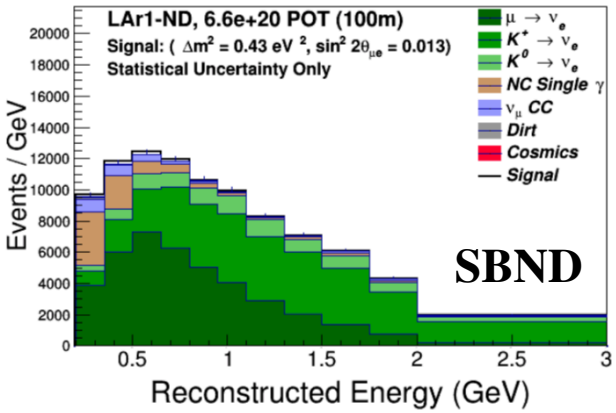


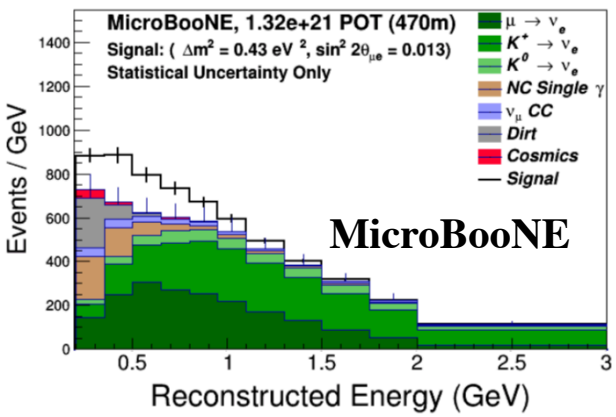


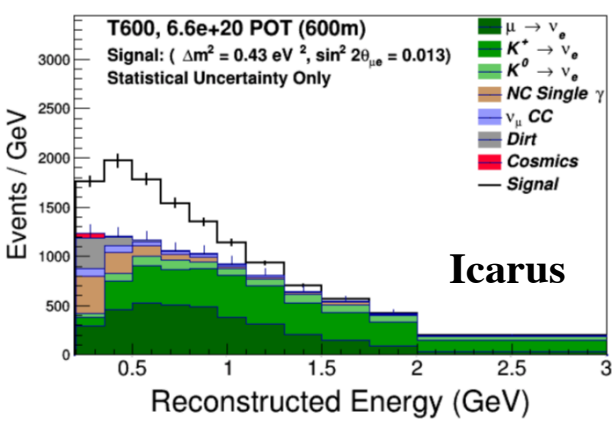
Three-detectors combined:

- SBND provides flux and cross section constraints
- MicroBooNE and ICARUS-T600 provide signal events

Multiple Detectors in SBN

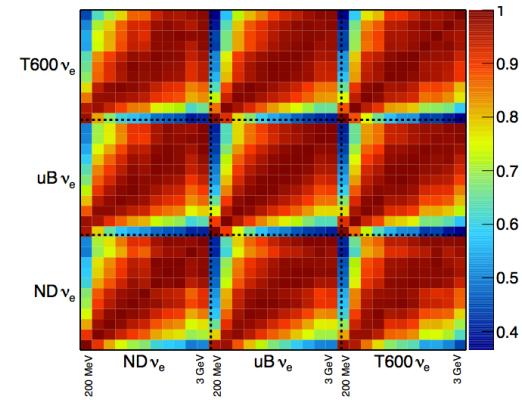




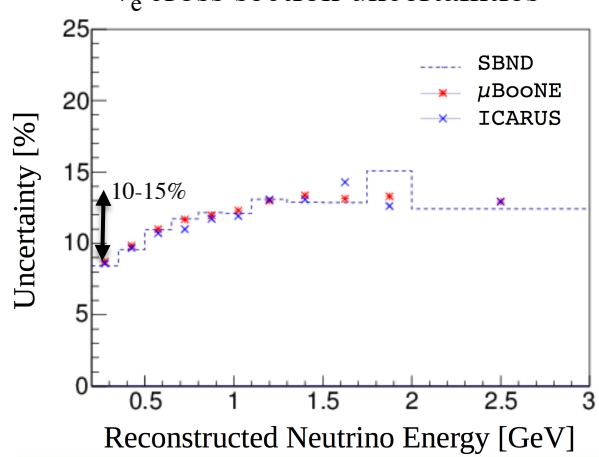
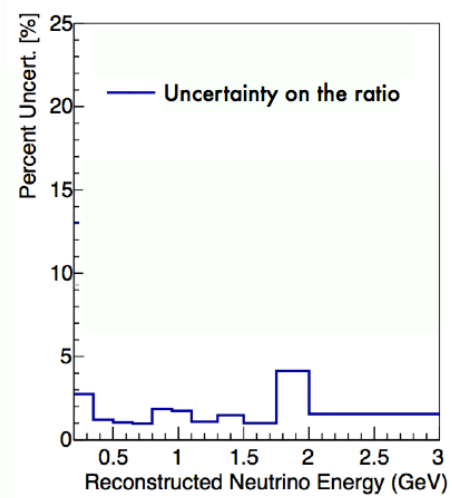


- Correlations between detectors (same beam and detection technique) allow for cancelations in systematic uncertainties

ν_e cross section correlation matrix



$$N_{ND}^{data}(\nu_\mu) = \Phi_{ND}(\nu_\mu) \otimes \varepsilon_{ND}(\nu_\mu) \otimes \sigma_{ND}(\nu_\mu)$$

$$N_{FD}^{expected}(\nu_\mu) = N_{ND}^{data}(\nu_\mu) \otimes \frac{\Phi_{FD}(\nu_\mu)}{\Phi_{ND}(\nu_\mu)} \otimes P(\nu_\mu \to \nu_\mu) \otimes \frac{\varepsilon_{FD}(\nu_\mu)}{\varepsilon_{ND}(\nu_\mu)} \otimes \frac{\sigma_{FD}(\nu_\mu)}{\sigma_{ND}(\nu_\mu)}$$

ν_e cross section uncertainties