Sterile Neutrino Searches with the ICARUS Detector

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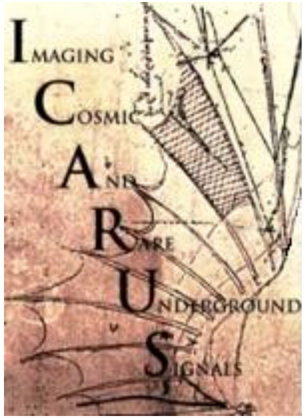
for the ICARUS Collaboration
NNN ‘18
November 2, 2018



The ICARUS Collaboration

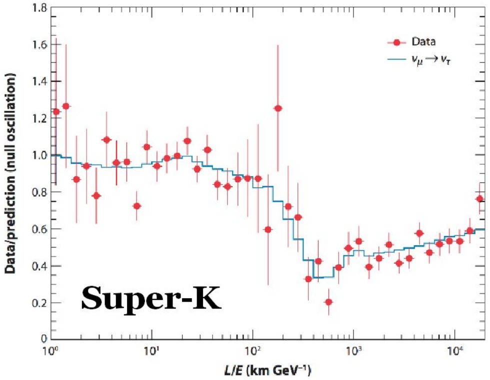
Catania (INFN and Univ.)
GSSI
LNGS
INFN Milano Bicocca
INFN Napoli
Padova (INFN and Univ.)
Pavia (INFN and Univ.)

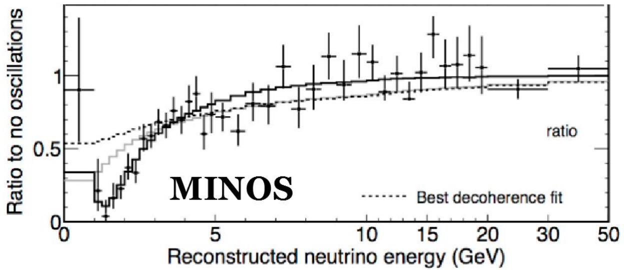
BNL
Colorado State
FNAL
Houston
Pittsburgh
Rochester
SLAC
Texas (Arlington)

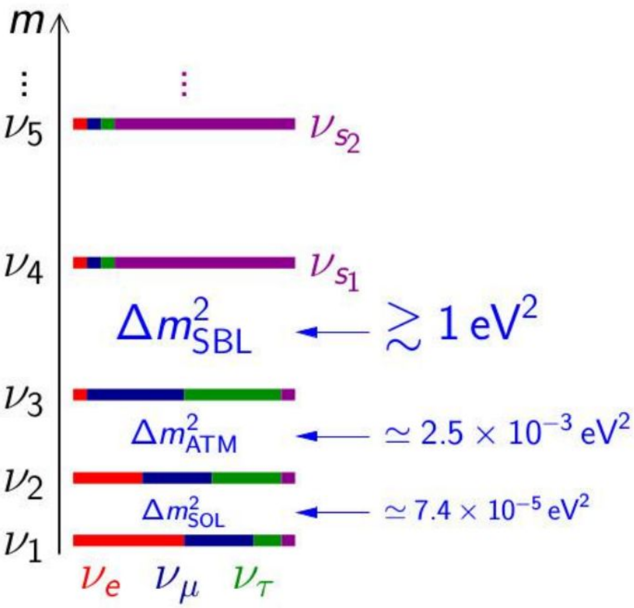
Spokesman: C. Rubbia (GSSI)

Three-Flavor Neutrino Oscillation

- Neutrino oscillation period related to Δm^2
  - Standard neutrino oscillation measured experiments with large L/E
  - Measurements made using very different detector technologies



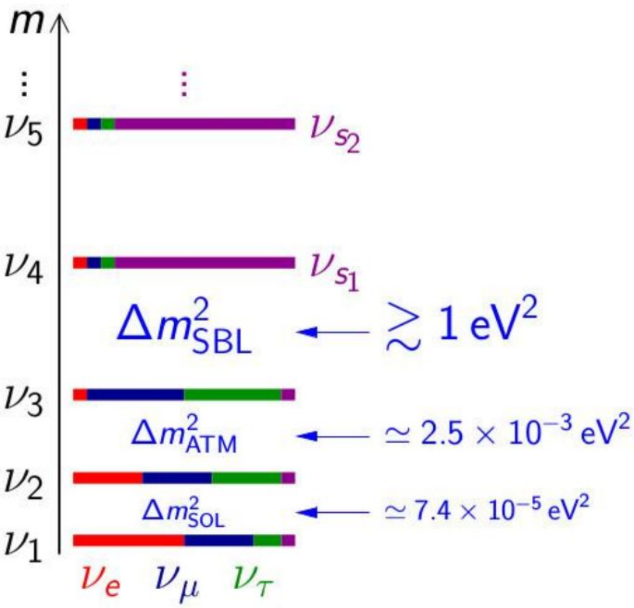




Two-flavor approximation: $$P_{\alpha\rightarrow\beta,\alpha\neq\beta} = \sin^2(2\theta)\sin^2\left(1.27\frac{\Delta m^2 L}{E}\frac{[\mathrm{eV}^2]\,[\mathrm{km}]}{[\mathrm{GeV}]}\right)$$

Sterile Neutrinos

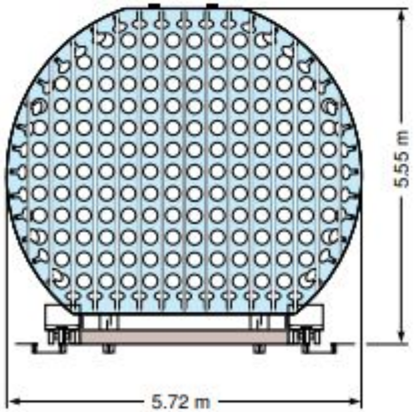
- Hypothetical neutrino that would only interact via gravity
- Could mix with ordinary neutrinos via mass term
  - Too quick to be normal neutrino oscillation
  - Must be more massive than ordinary neutrinos
- Possible candidate for warm dark matter
- Three types of anomalous results:
  - Disappearance of anti-ν_e events at nuclear reactors (measured/predicted ratio R = 0.938 ± 0.024)
  - Disappearance of ν_e from MCi sources used in calibration of solar neutrino experiments (SAGE/GALLEX, R = 0.84 ± 0.05)
  - Appearance of ν_e (anti-ν_e) in ν_μ (anti-ν_μ) beams at particle accelerators (LSND / MiniBooNE)

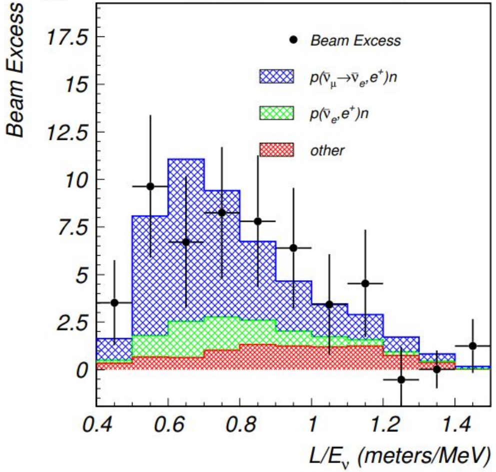


LSND Anomaly

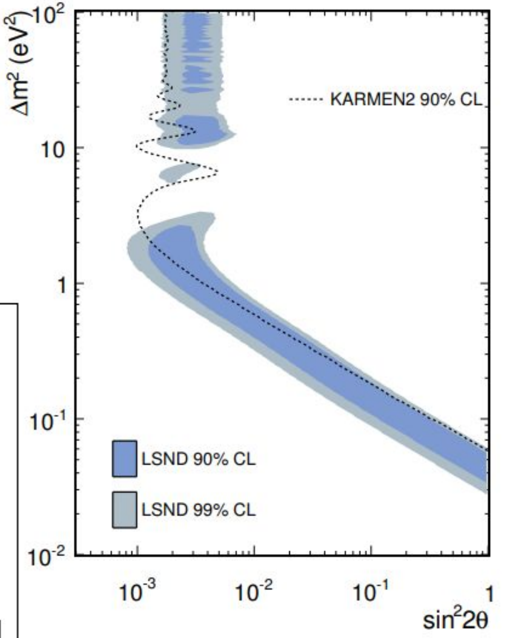
- Mineral oil and liquid scintillator detector
  - Located at Los Alamos National Laboratory
  - Measured Cherenkov and scintillator light
- Measured excess anti-ν_μ to anti-ν_e oscillation
  - Distance from target: ~ 30 m
  - Neutrino beam energy: 20 - 60 MeV
  - L/E ~ 1 m / MeV
  - Excess of 87.9 ± 22.4 ± 6.0 events

3.8σ effect; evidence for sterile neutrino oscillation?





LSND Collaboration Phys. Rev. D64 (2001) 112007

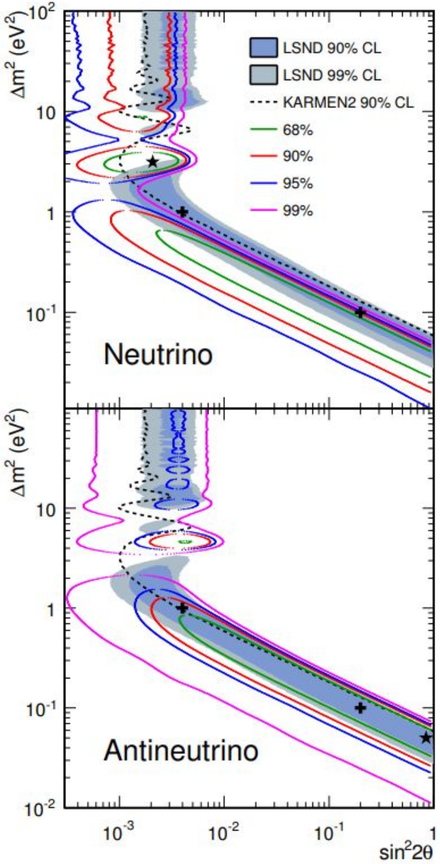


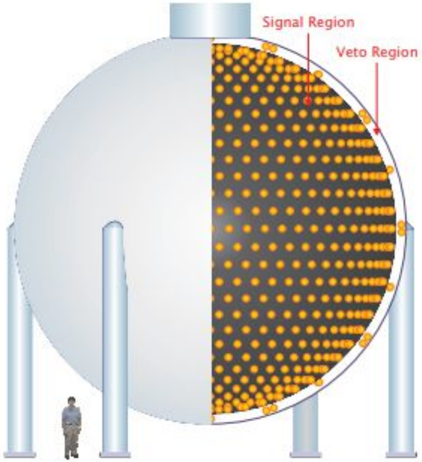
MiniBooNE Low Energy Excess

MiniBooNE Collaboration FERMILAB-PUB-18-219

- Similar technology to LSND
  - Mineral oil target measuring Cherenkov and scintillator light
  - Match L/E with different energy beam
- Located at Fermi National Accelerator Laboratory in Booster Neutrino Beam (BNB)
- Measured excess ν_e and anti-ν_e
  - Distance from target: ~0.5 km
  - Neutrino energy: 200 - 1250 MeV
  - Antineutrino excess: 78.4 ± 28.5 events
  - Neutrino excess: 162 ± 47.8 events

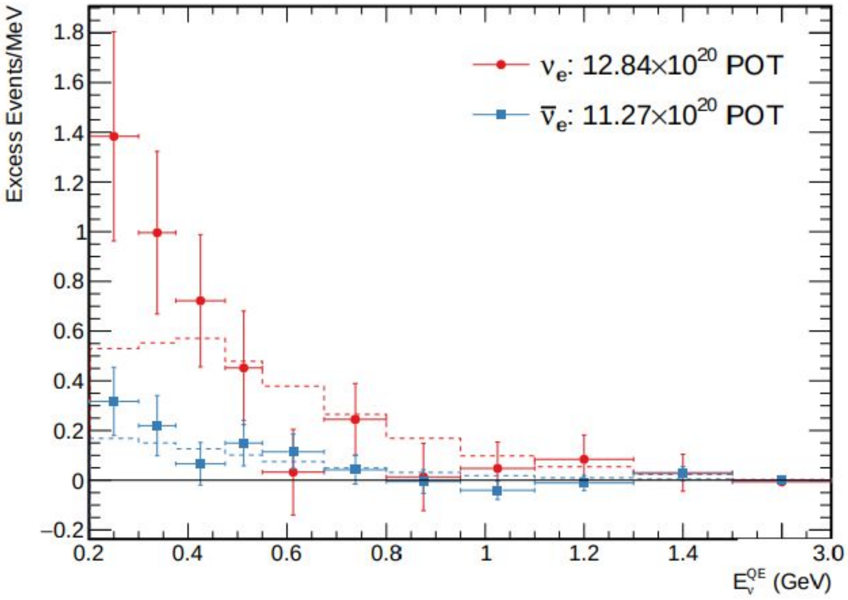
(2.8σ) 3.4σ effect; evidence for sterile neutrino oscillation using (anti)neutrinos?

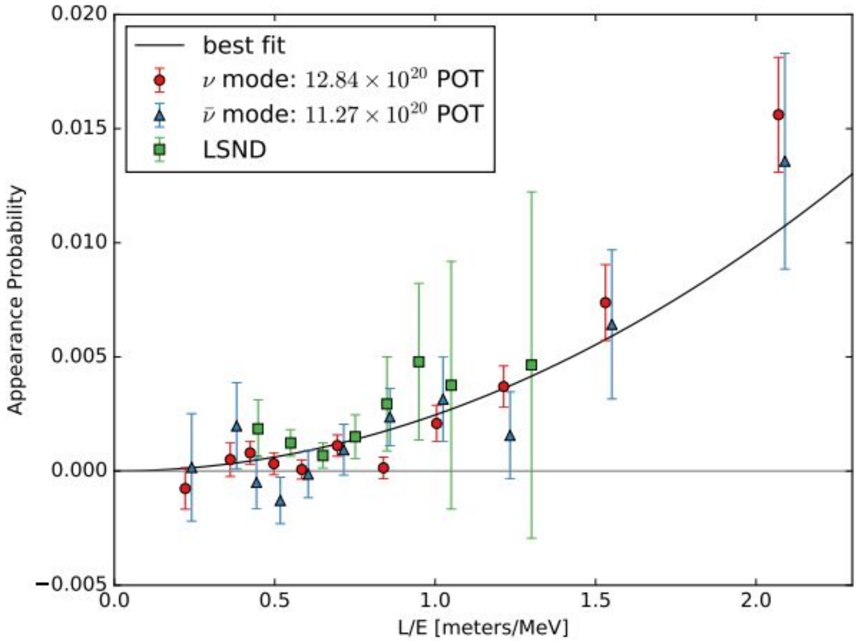




Updated MiniBooNE Result

MiniBooNE Collaboration arXiv:1805.12028

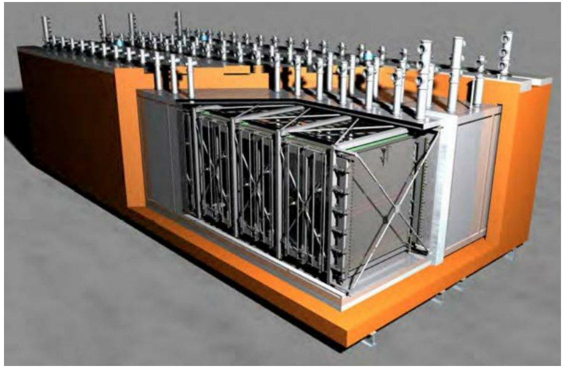


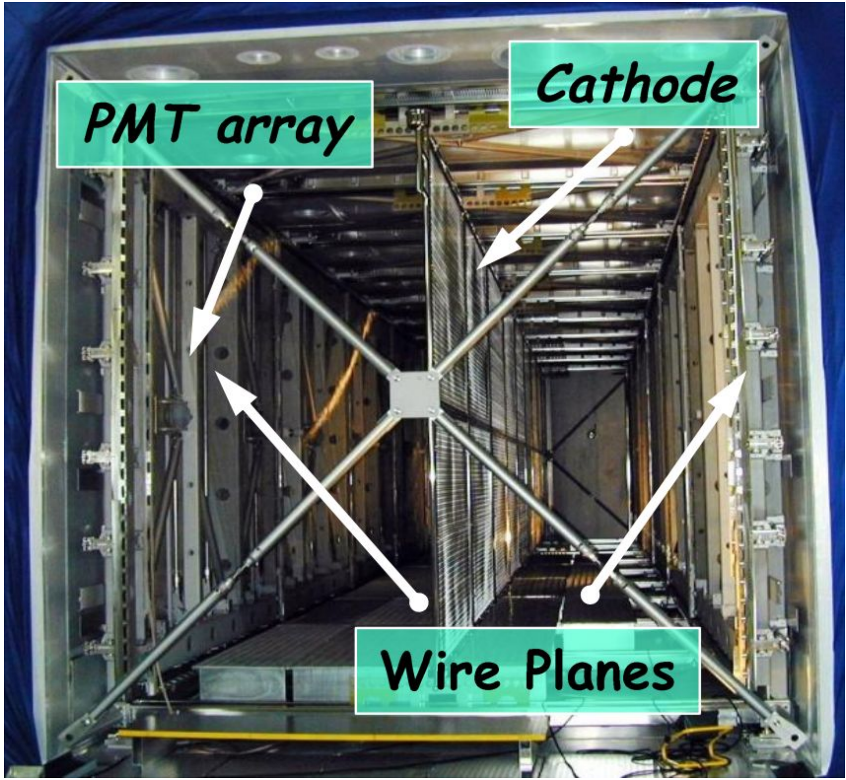


New results show excess with a total significance of 4.8σ and agrees with LSND result

ICARUS T600 Detector

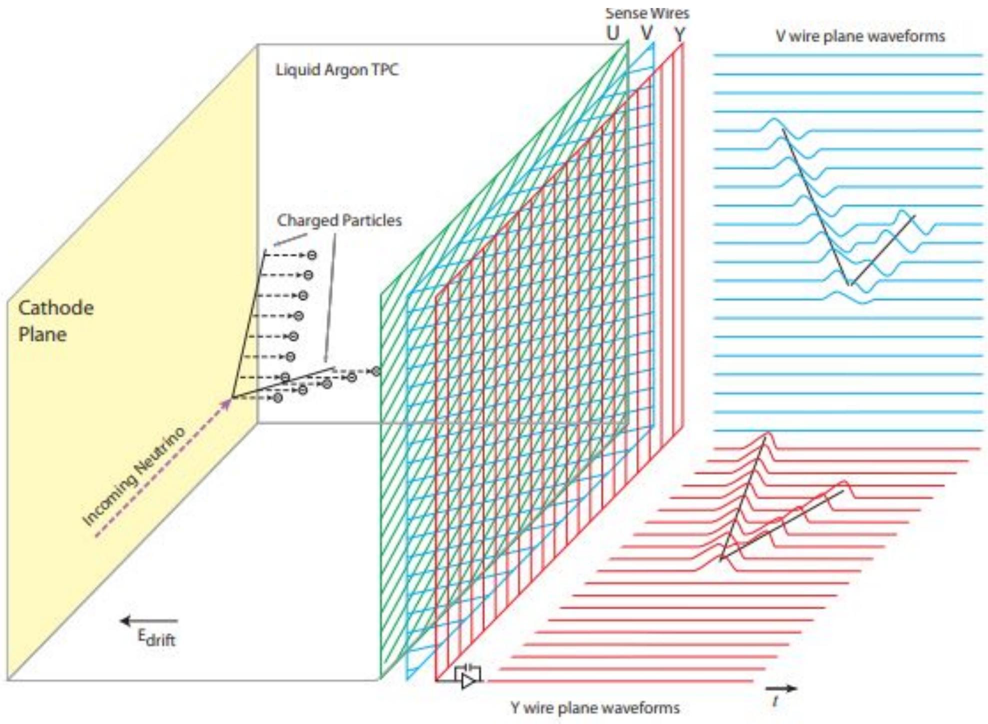
- Two identical LArTPC modules
  - 476 tonnes total fiducial mass
  - Two drift modules per module sharing central cathode
  - 1.5 m drift length
  - ~ 500 V/cm drift field (~1.6 mm/μs drift velocity)
- Three wire planes with 3 mm pitch (0°, ±60° wrt horizontal)
  - Two induction and one collection (last plane)
  - ~54,000 total wires
  - 400 ns sampling time
- VUV scintillation light read out by PMTs coated in wavelength shifter





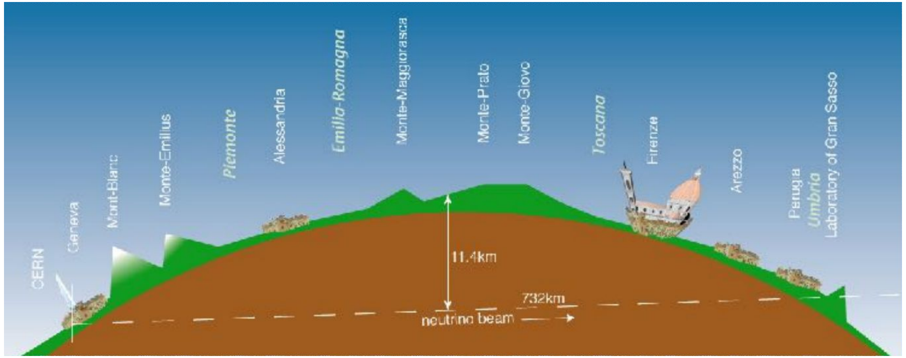
The Liquid Argon Time Projection Chamber

- LArTPCs ideal detectors for neutrino physics and other rare phenomena (e.g. nucleon decay)
  - Excellent 3D imaging capability
  - Scintillation light provides fast signals for timing / triggering
  - Uniform, full-sampling calorimetry
  - Argon acts both as massive target and detection medium
  - Relatively cheap → can be scaled to huge masses

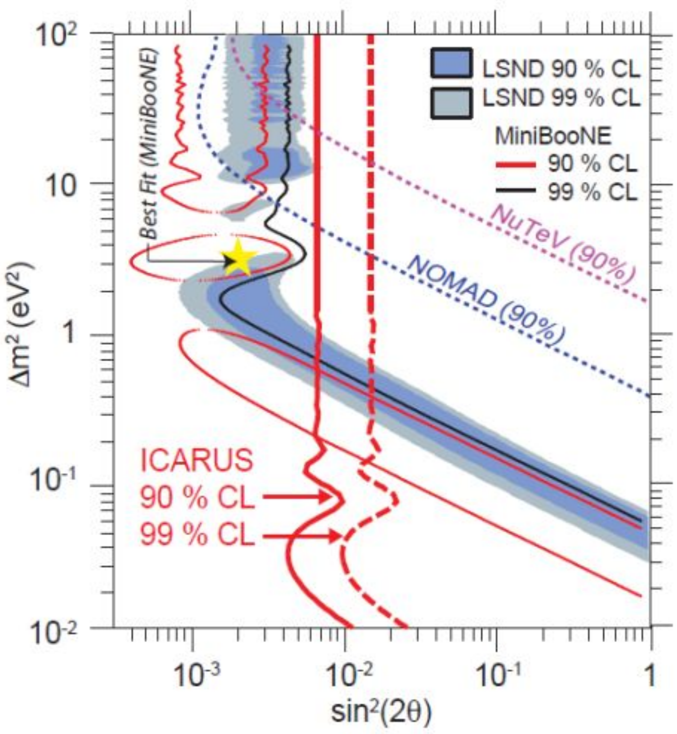


ICARUS at Gran Sasso

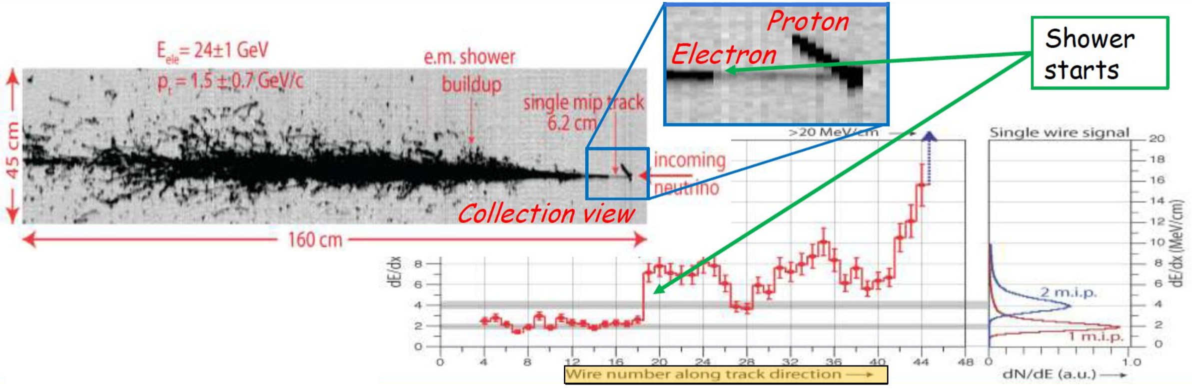
- Took data from 2010 - 2013
- Underground detector (1400 m deep)
- Exposed to CNGS beam from CERN (8.6×10^{19} POT) and atmospheric neutrinos
  - 730 km from CERN to Gran Sasso
- Very successful run! (livetime > 93%)
  - Proved maturity of LArTPC technology for physics experiments with large masses / long exposure time



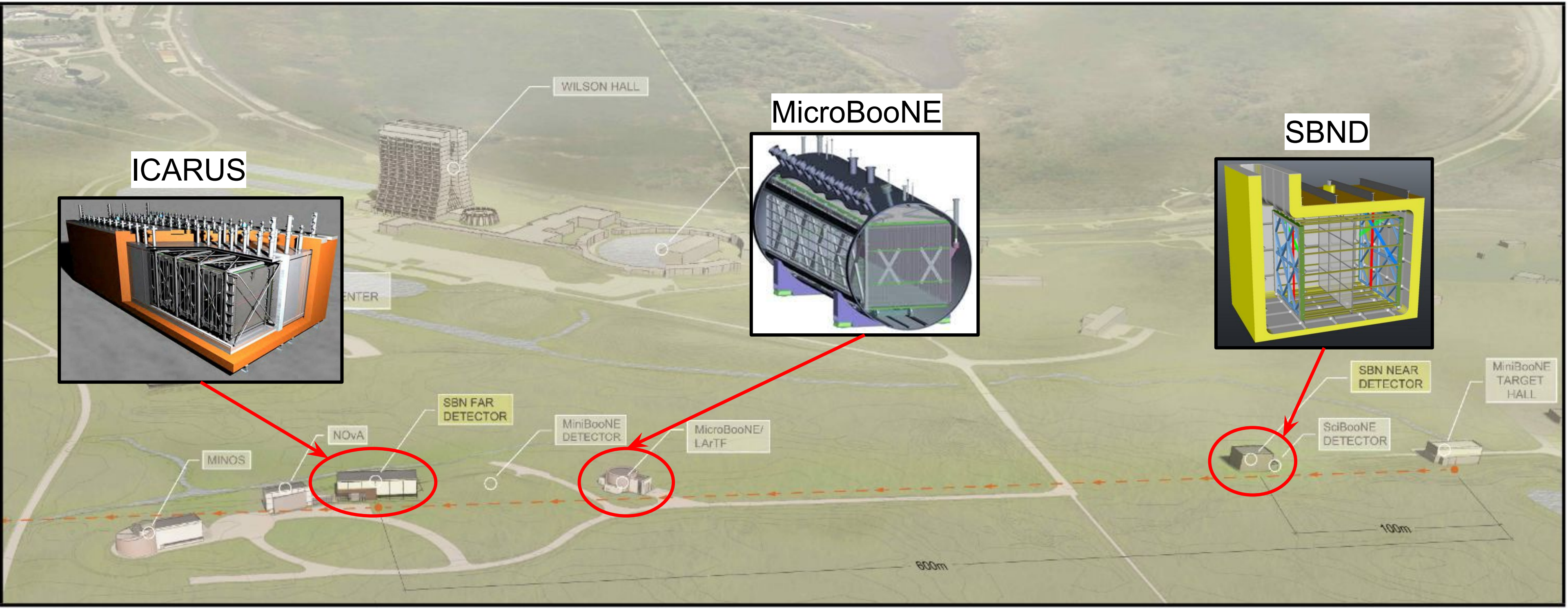
Sterile Neutrino Search with ICARUS



- Searched for ν_e appearance in CNGS beam
- L/E = ~ 36.5 m/MeV
- 7 ν_e events observed with expected background of 8.5 ± 1.1 events
  - Sets upper limits on oscillation parameters



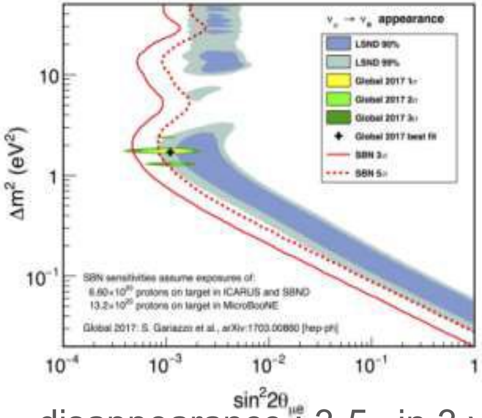
Short-Baseline Neutrino Program

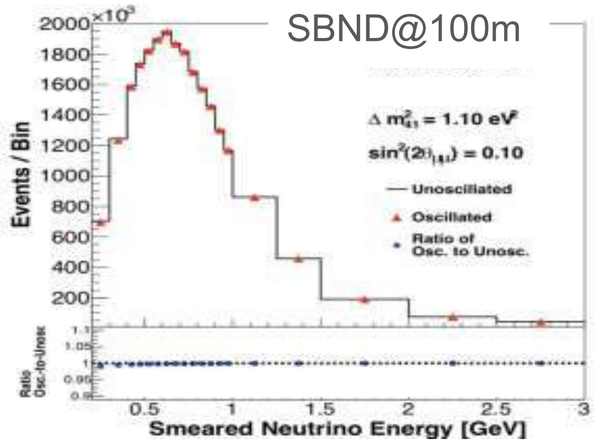


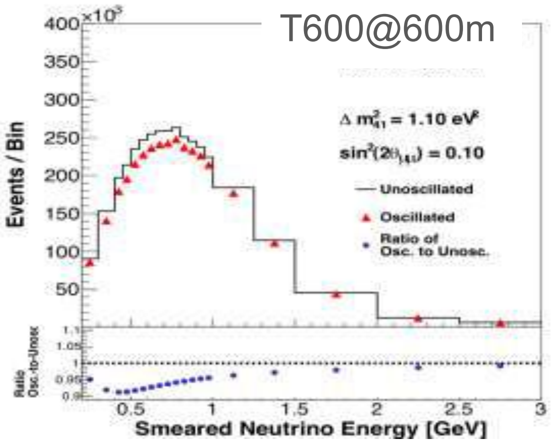
SBN Sensitivity

- SBN will use 3 very similar LArTPCs at different distances from target
  - Similarity reduces systematics
  - SBND (near detector) will provide “initial” flux composition and spectrum
- Oscillation will be studied both in ν_e appearance and ν_μ disappearance channels (ICARUS / MicroBooNE)

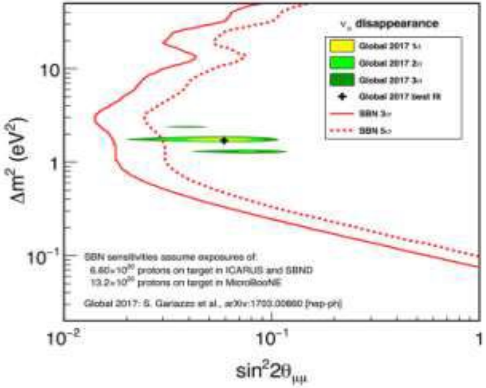
ν_e appearance: 5σ in 3 years





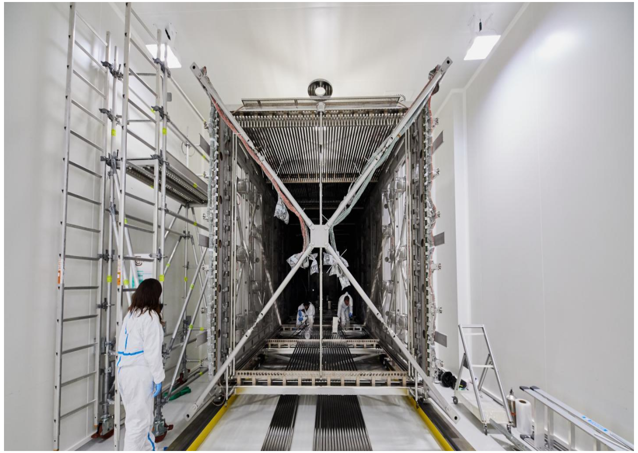


ν_μ disappearance : 3-5σ in 3 years



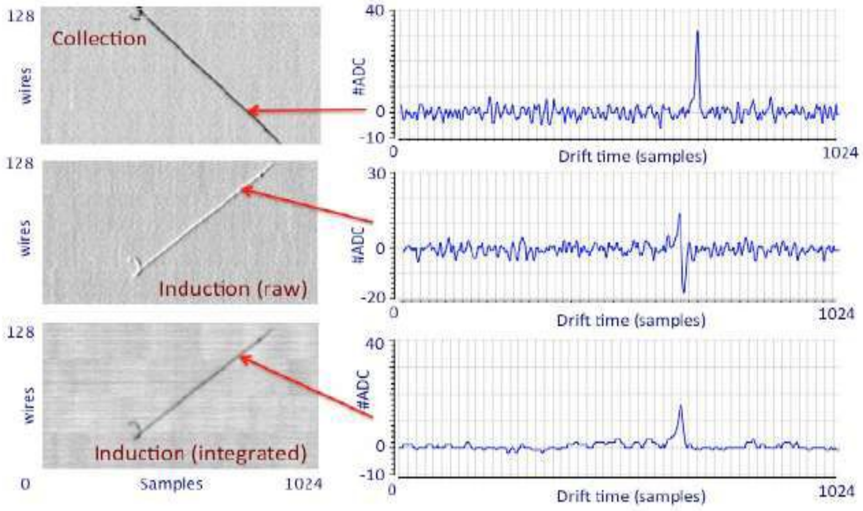
Upgrades at CERN

- Experimental conditions at FNAL (shallow depth, higher beam rate) required intensive overhaul starting in 2015 in the CERN Neutrino Platform framework
- Goal: Introduce technology developments while maintaining already achieved performance
  - New cold vessels with purely passive insulation coupled with standard N_2 cooling
  - Improved cathode planarity by factor ~10
  - Renovated LAr cryogenics / purification equipment
  - New, faster, higher-performance read-out electronics
  - Upgrade PMT system: higher granularity and ~ns resolution



Upgrade of the Read-out Electronics

- Redesign of analogue front-end improves reconstruction
  - Faster shaping time (~0.6 μs for all wire planes matches electron transit time between planes)
  - Drastic reduction of undershoot around signals
  - Integrating induction signal provides calorimetric information (deconvolution gives even more improvement)
  - Synchronous sampling of whole detector improves resolution of MCS muon momentum measurement

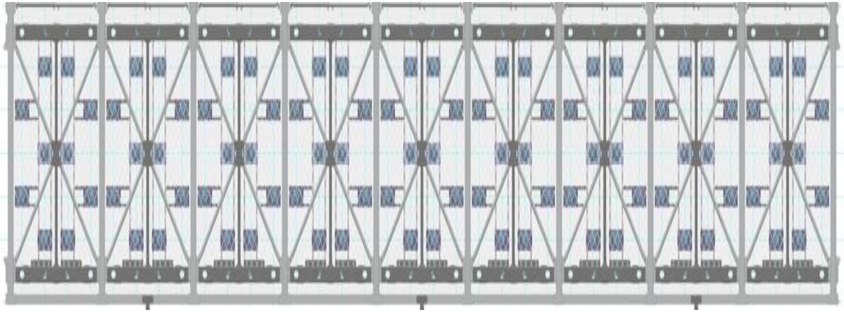


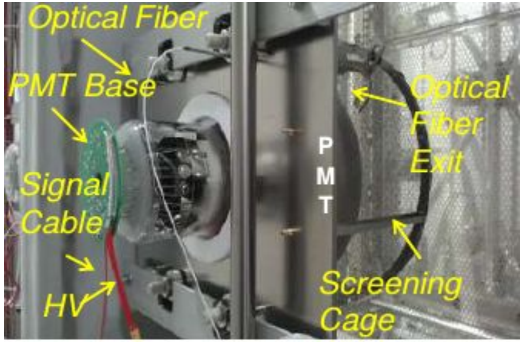
- Noise ~ 2ADC (1200 e^-) for all planes
- Unipolar collection signal with S/N ~15
- Bipolar induction signal
  - Offline integration provides S/N ~10

Paper accepted by JINST! arXiv: 1805.03931

Upgrade of the Light Collection System

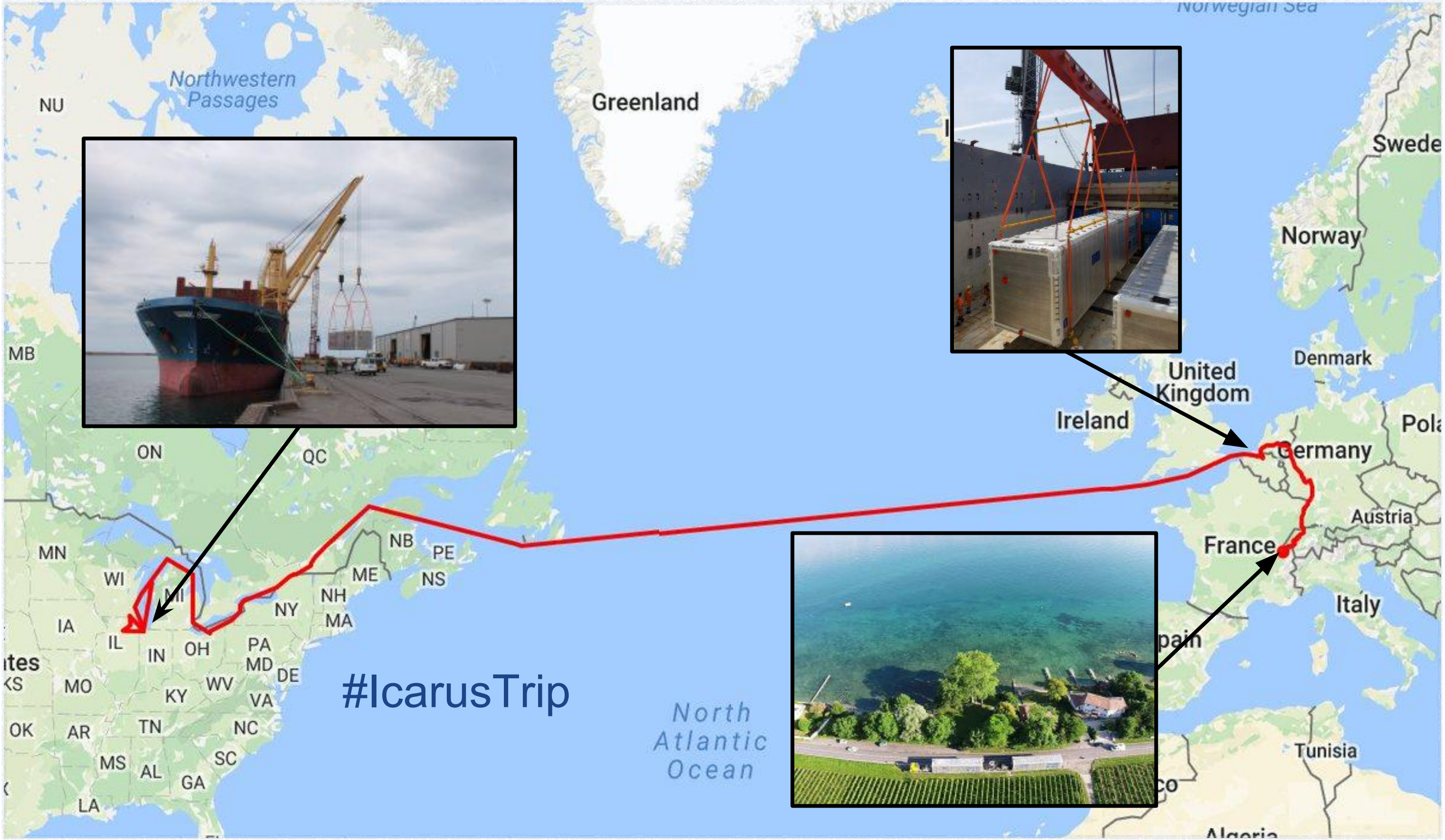
- Requirements of light collection system:
  - Identify t_0 (time of occurrence) for any ionizing event in the TPC
  - Determine rough event topology for selection purposes
  - Generate trigger signal for read-out from:
    - Pattern / majority of fired PMT signals
    - Signal from external CRT
    - Beam spill bunched structure
- System contains 360 PMTs (90 per TPC) providing:
  - High coverage (5% cathode area)
  - Sensitivity down to ~100 MeV (roughly lowest expected energy from neutrino events)
  - High time resolution (~ns)
  - Possible identification of cosmics by PMT space / time pattern





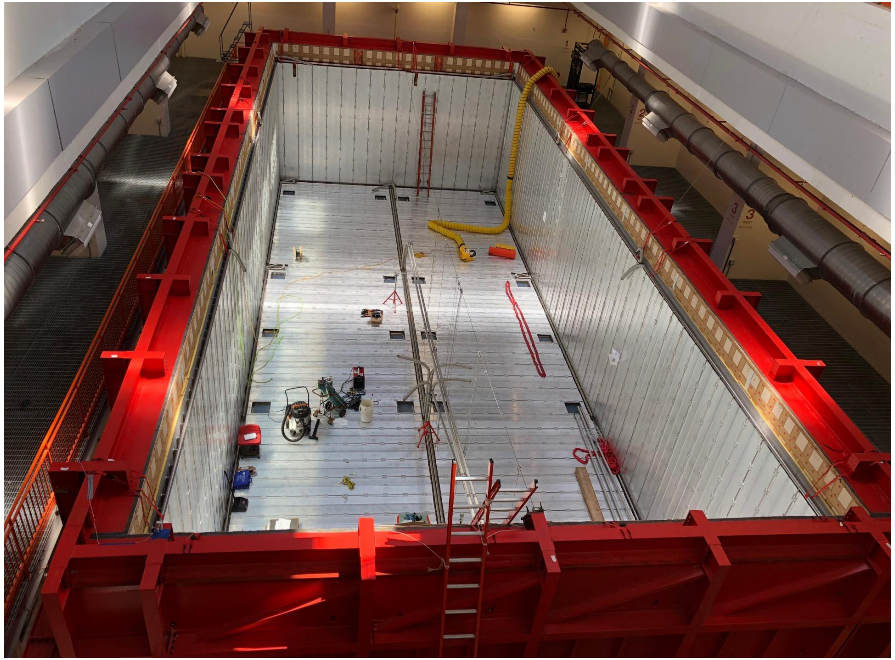
Paper published by JINST!
ICARUS Collaboration, JINST 13 (2018) no.10, P10030

Move to Fermilab

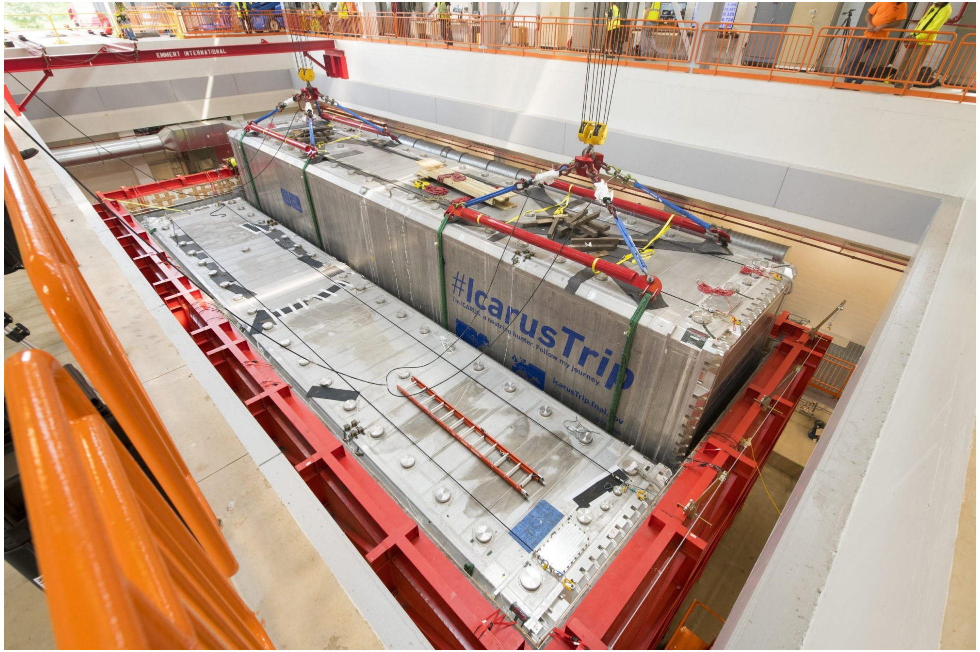


ICARUS at Fermilab

Warm vessel and cold shields (June 2018)



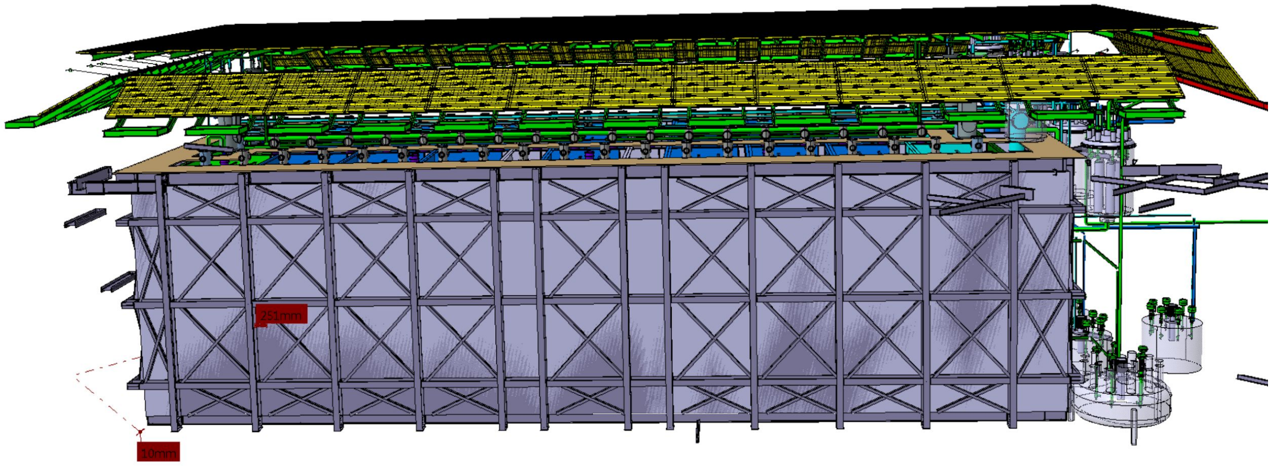
Installing second cold vessel (August 14, 2018)



ICARUS at Fermilab

- Installation Timeline
  - ✓ 2017 - Warm vessel floor / walls assembled in pit, bottom CRT modules installed
  - ✓ May 2018 - Cold shield assembly (bottom / sides) completed
  - ✓ June 2018 - Detector supports installed, main vessel door sealed, helium leak tests finished
  - ✓ August 2018 - Both modules placed in pit
  - ✓ September 2018 - Chimney installation and readout cable recovery completed
  - ✓ Install top-side of cold shield and top of warm vessel
  - ○ Activities on top (cryogenics, purification, vacuum system, feedthrough flanges, read-out / decoupling boards…)
  - ○ Early 2019 - Vacuum pumping until TPCs are ready to cool

Commissioning ICARUS at Fermilab



- Commissioning phases:
    1. CRYOGENICS: vacuum (1 month), cooling (15 days), filling (15 days), purification (1 month), stabilization (1 month)
    2. TPC / PMT (2 months): HV system, PMT supply, calibrations, DAQ / trigger
    3. ~4π Cosmic Ray Tagger (CRT) in parallel with other two phases

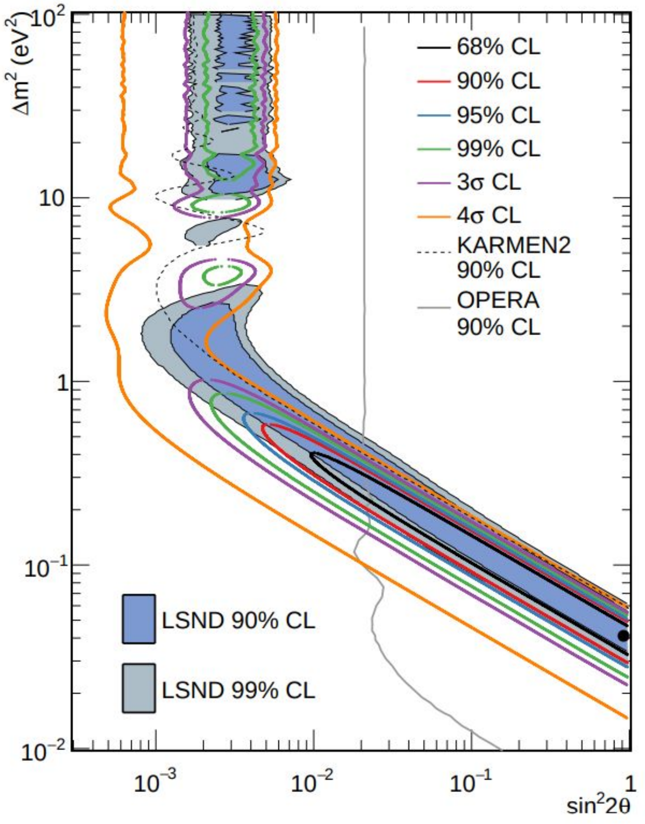
Conclusions

- ICARUS-T600 successful three-year run at LNGS proved that LArTPC technology is fully mature and ready for next generation (DUNE)
- ICARUS searched for possible LSND-like anomaly through ν_e appearance in the CNGS beam.
  - No excess found, identified a small allowed parameter region where the sterile neutrinos have not been excluded
- The SBN program at FNAL will be able to clarify the sterile neutrino puzzle, by looking at both appearance and disappearance channels with three LArTPCs (ICARUS acting as far detector)
- ICARUS-T600 was extensively refurbished at CERN (2015-2017) and is now being installed at the Far Detector Hall on the BNB beamline
- The strong cooperative effort by INFN, CERN, FNAL, and other US groups will allow commissioning to start and data taking in 2019.

Thank you!

Backup Slides

Update MiniBooNE Result - Contours



Neutrino mode only

Combined neutrino and antineutrino modes