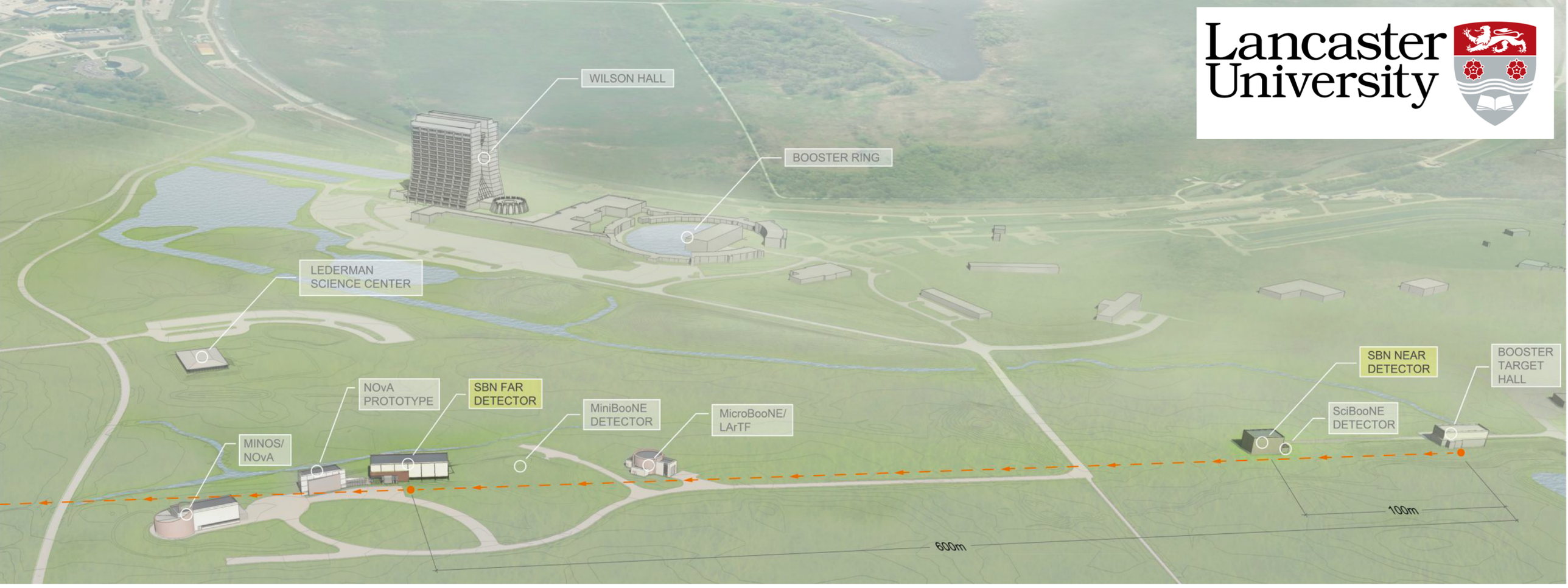


The Short Baseline Neutrino Programme At Fermilab

Jarek Nowak
Lancaster University

For the SBN collaborations

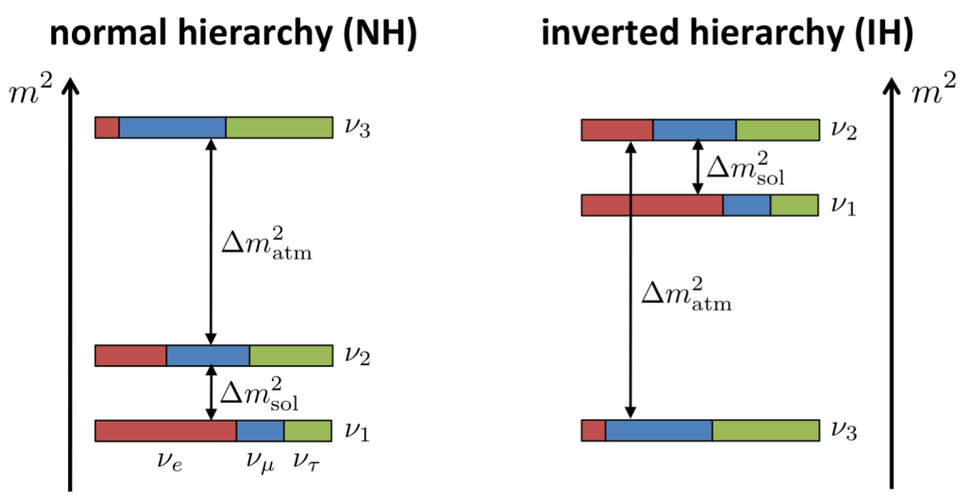
NuInt 18 - 12th International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region

OUTLINE

- Short-baseline anomalies
- The SBN programme at Fermilab
- LArTPC technology
- Phase I: MicroBooNE
- Phase II: SBN programme

KNOWN IN NEUTRINO OSCILLATIONS

- Our picture of neutrinos in the standard model is almost complete.



Current knowledge about mixing parameters (simplified)

$\theta_{12} \approx 33°$
$\theta_{23} \approx 45°$
$\theta_{13} \approx 9°$

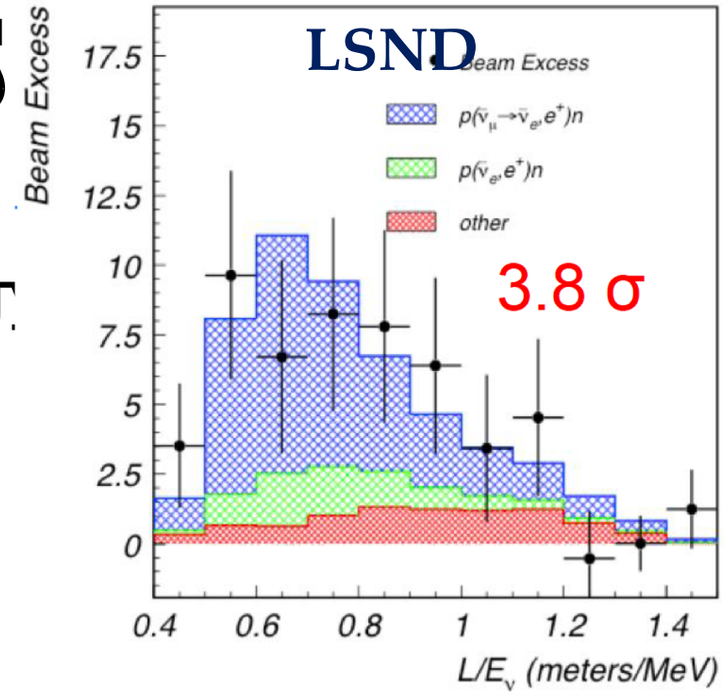
$\Delta m^2_{21} \approx 7.5 \times 10^{-5}\ \mathrm{eV}^2$
$|\Delta m^2_{32}| \approx 2.5 \times 10^{-3}\ \mathrm{eV}^2$

- The remaining measurements are very difficult (CP violations, confirmation of the three flavour paradigm, θ_{23} octan, etc.)
- "Large" mixing angle θ_{13} opens the way to measurements of δ_{CP}
- First hints that δ_{CP} is non-zero!.

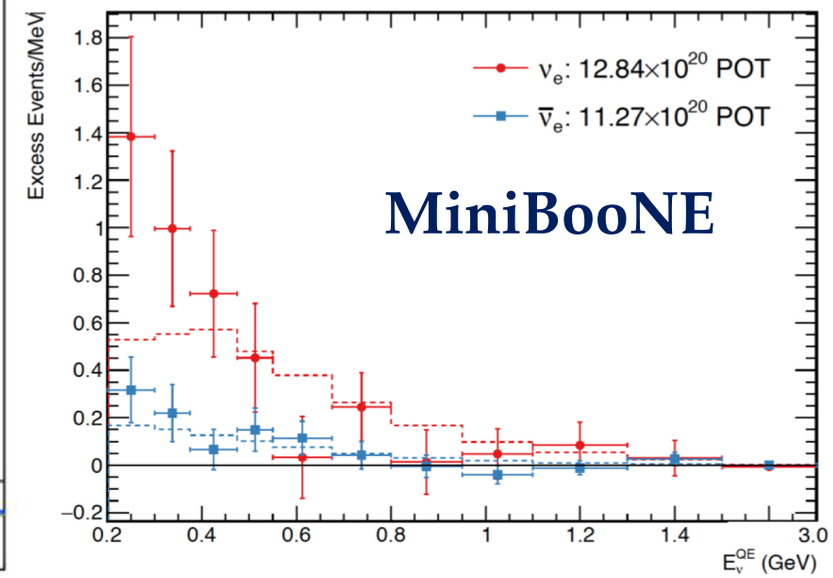
NEUTRINO ANOMALIES

- Evidence for an low energ electron-like excess from neutrinos from particle accelerators (the "**LSND and MiniBooNE anomalies**")

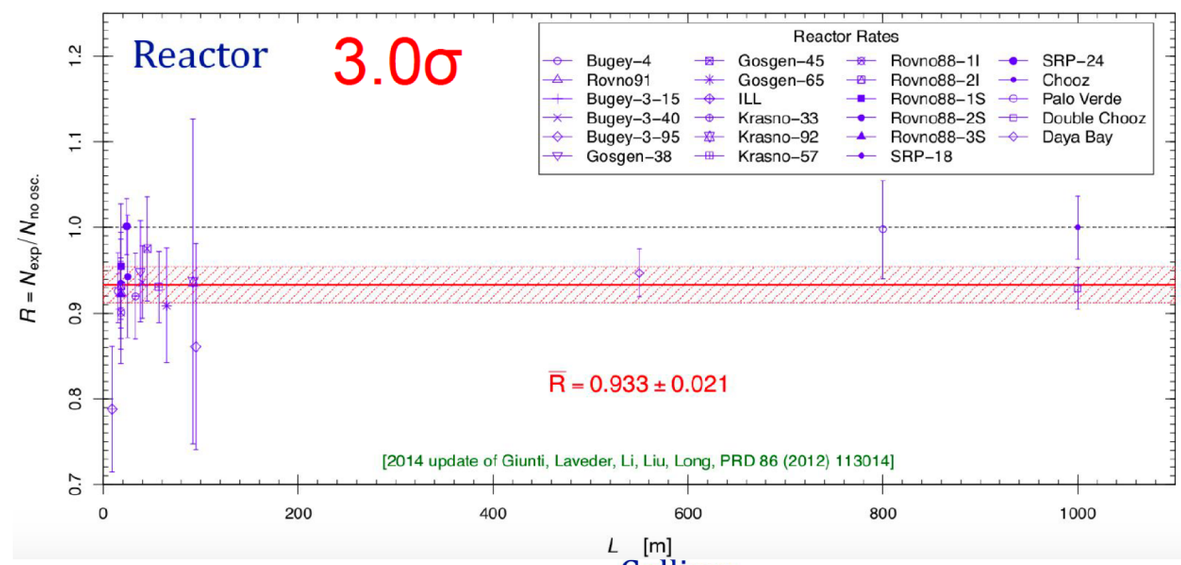
Phys.Rev.D64,11207

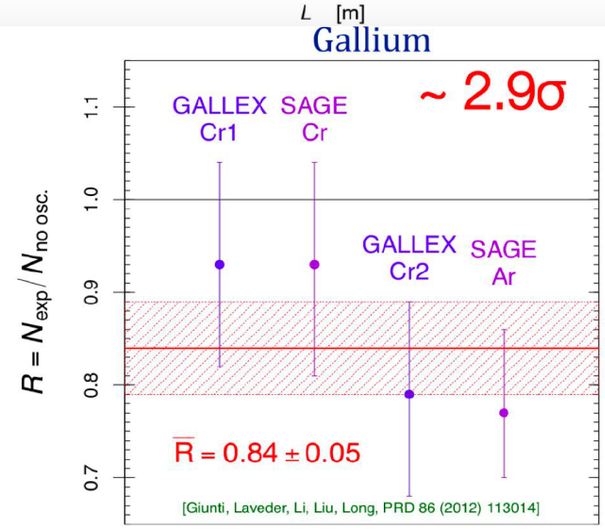


arXiv: 1805.12028



- 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**")



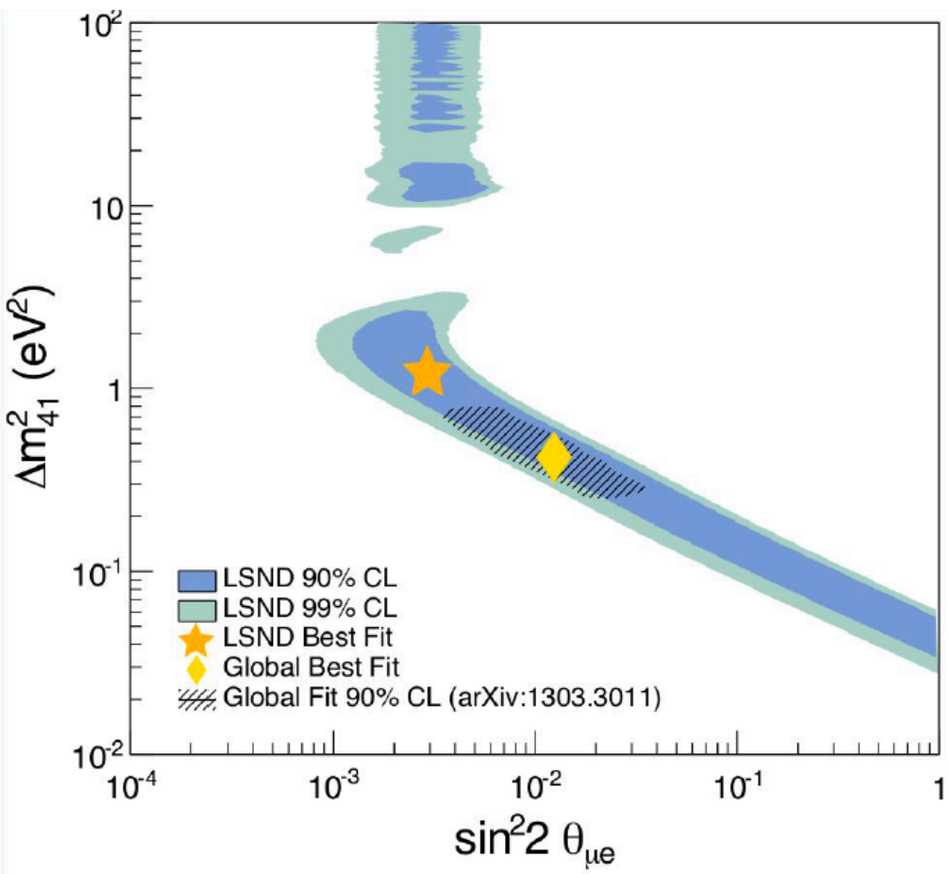


NEED FOR SHORT-BASELINE DEFINITE MEASUREMENT

- Interpreted as oscillations involving sterile neutrinos with

$$\Delta m^2 \sim 1 eV^2 \text{ for } L/E \sim 1 km/GeV$$

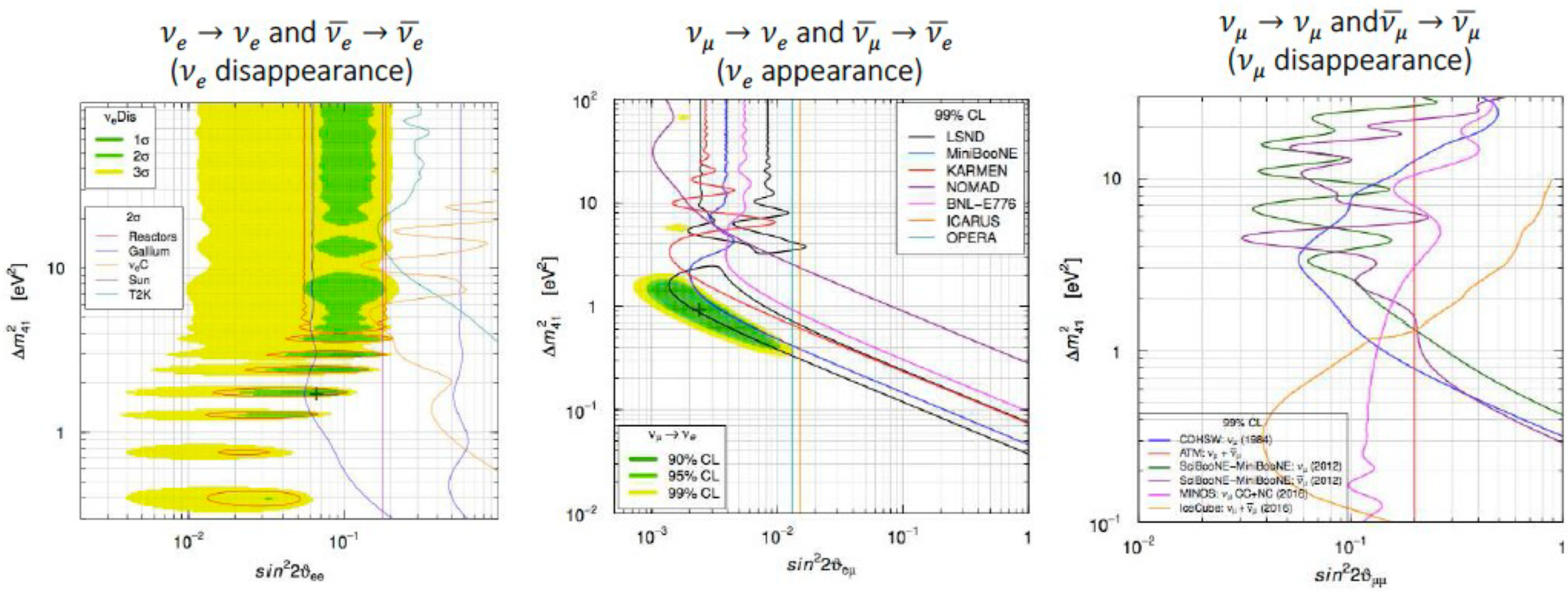
- New experimental efforts are needed to eventually solve the puzzle



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

GLOBAL FITS

S. Gariazzo, C. Giunti, M. Laveder, Y.F. Li, arXiv:1703.00860



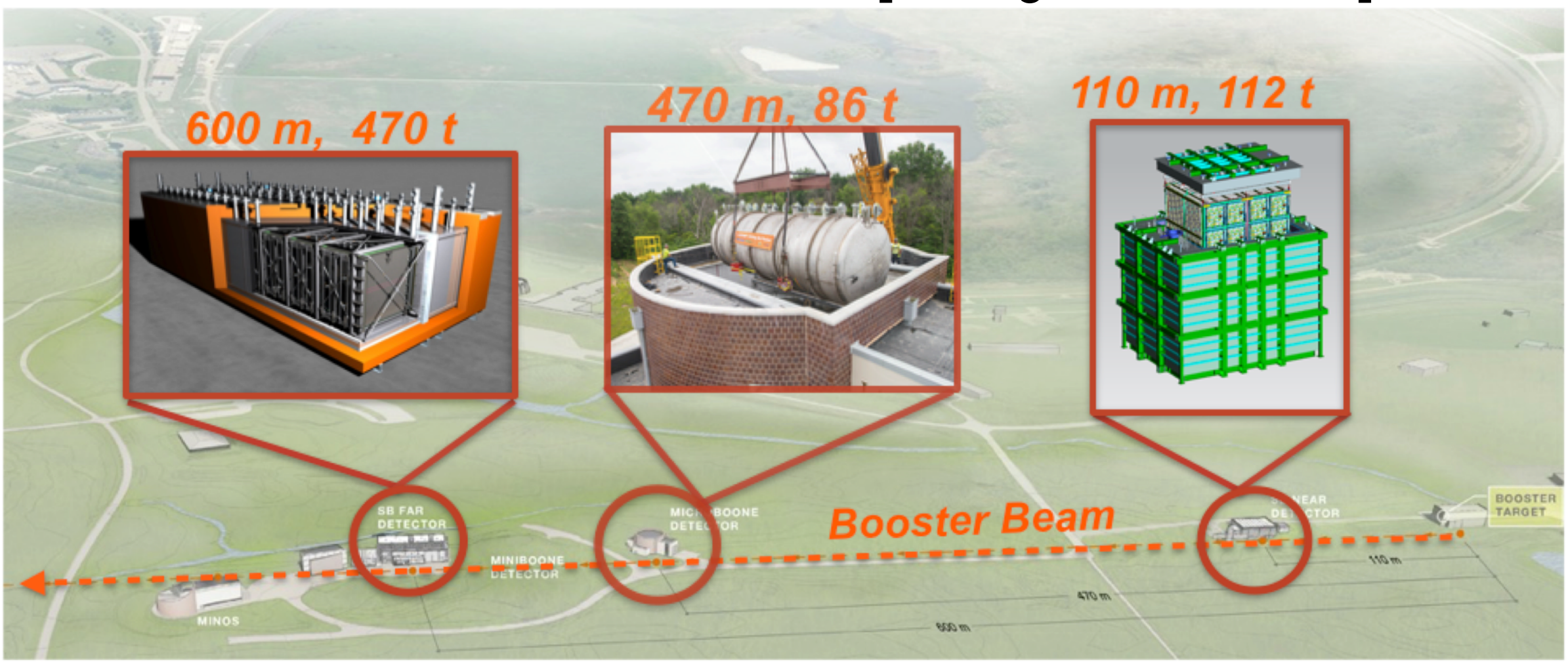
Current experiments are closing in on the allowed parameter space.

- Tension with experiments that observe no signal, e.g. recent measurements by NEOS, IceCube and MINOS+ leads to significant constraints on possible sterile neutrino parameters.

SHORT BASELINE NEUTRINO PROGRAMME AT FERMILAB

Program aimed at definitely solving the "sterile neutrino puzzle" by exploiting:

- the well characterized FNAL Booster ν beamline;
- three detectors based on the same liquid argon TPC technique.

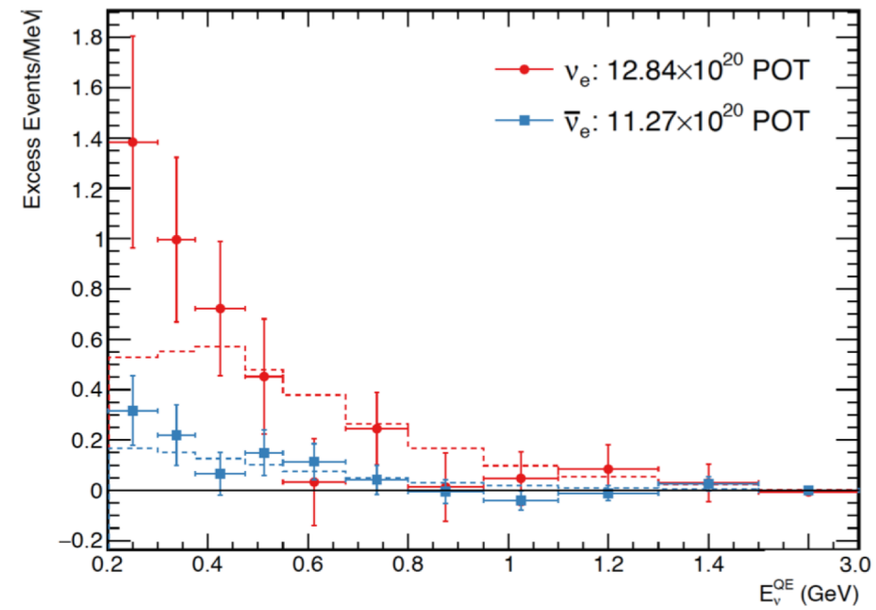


PRIMARY GOALS OF THE SBN PROGRAMME

Phase I: MicroBooNE

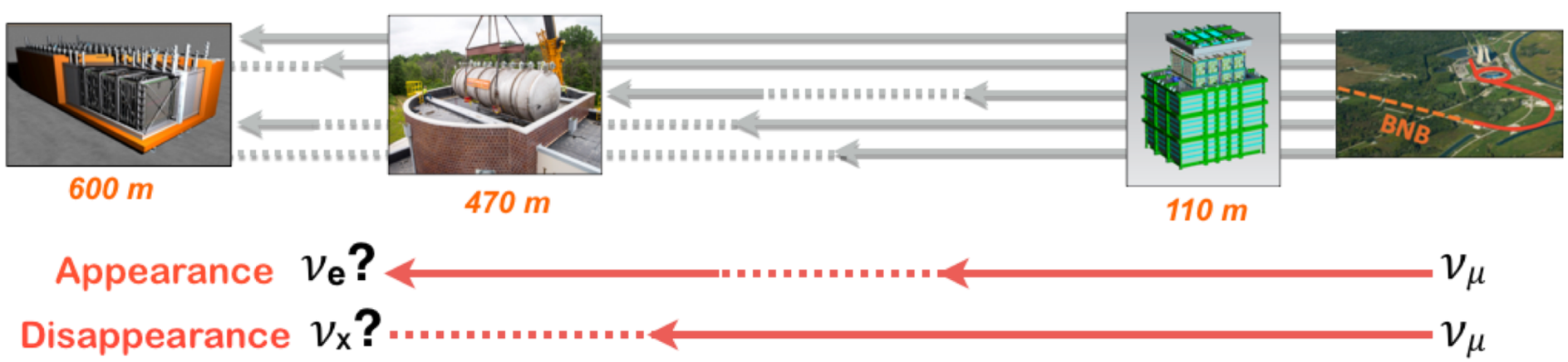
Understand the nature of the MiniBooNE "low energy" excess anomaly, using the same beam.

arXiv: 1805.12028



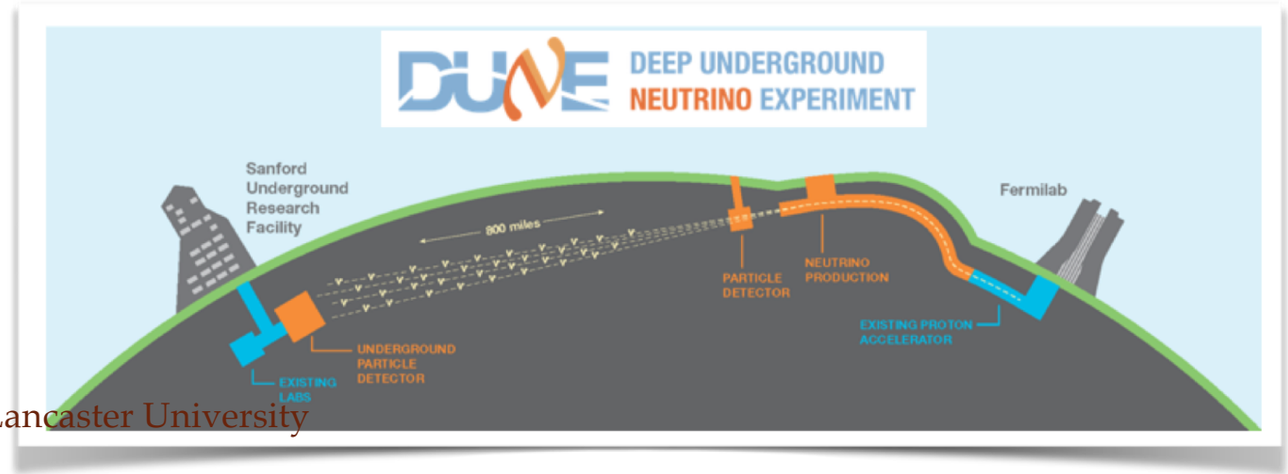
Phase II: SBND + ICARUS

Search for short baseline oscillations both in appearance and disappearance channels.

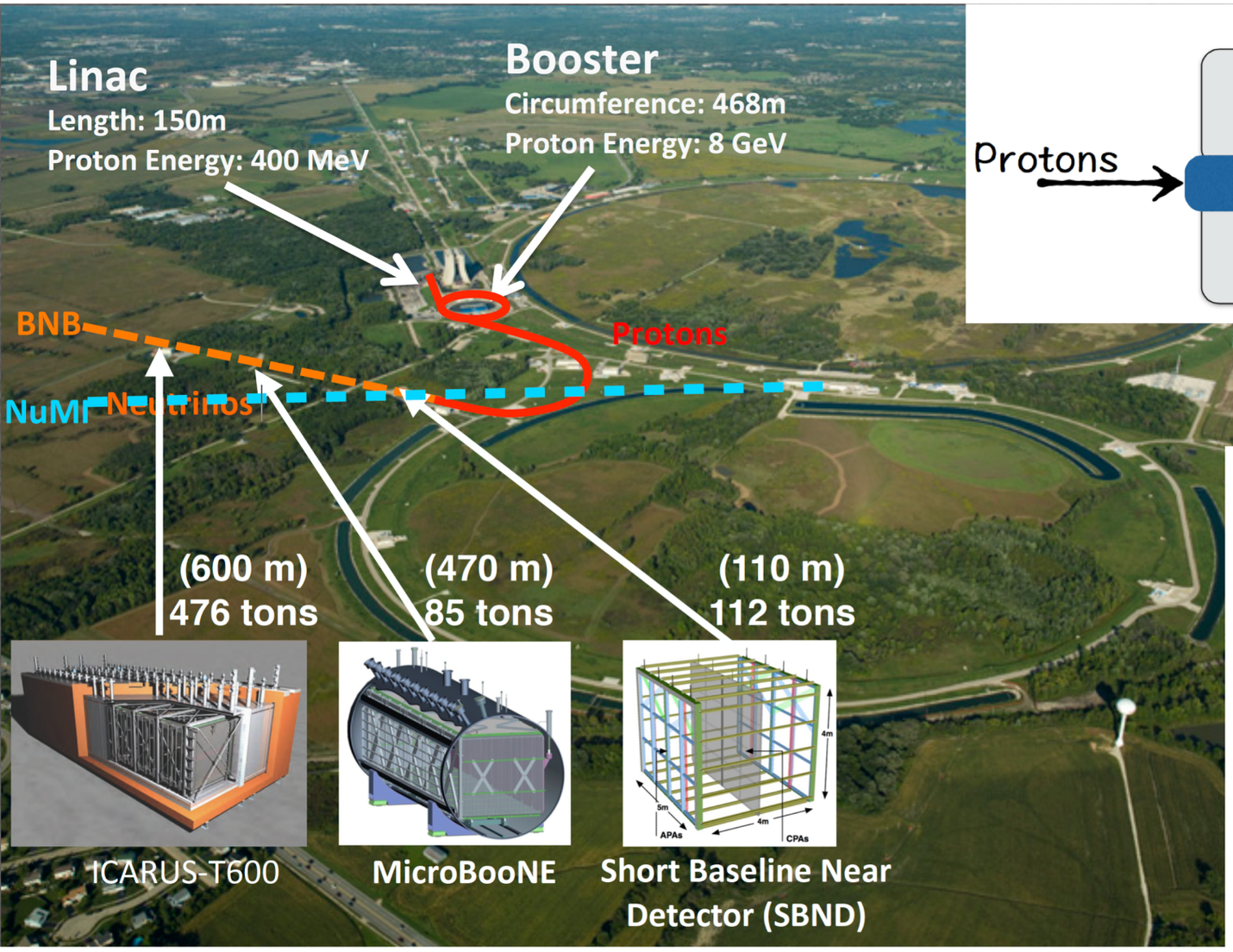


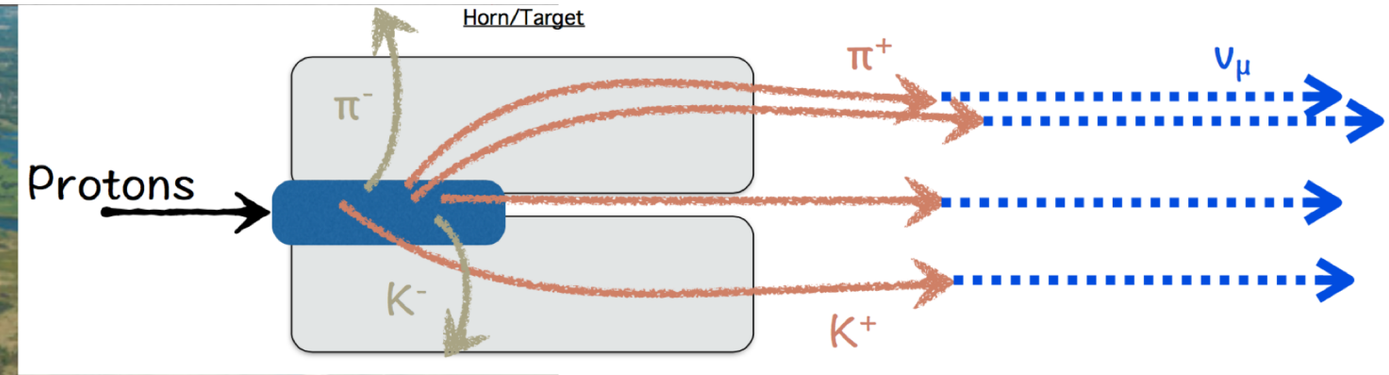
Lay the ground for future long-baseline program

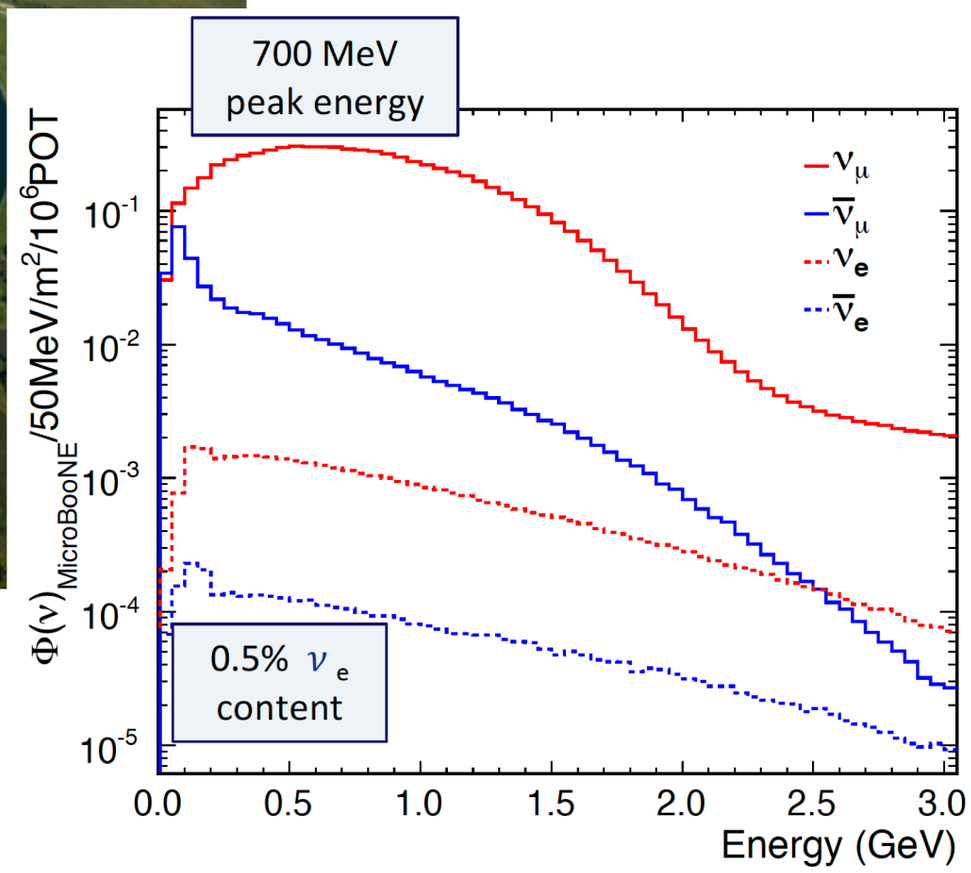
- Further develop LAr-TPC detector technology
- Measure ν-Ar cross sections at energies relevant to DUNE



THE BOOSTER NEUTRINO BEAM

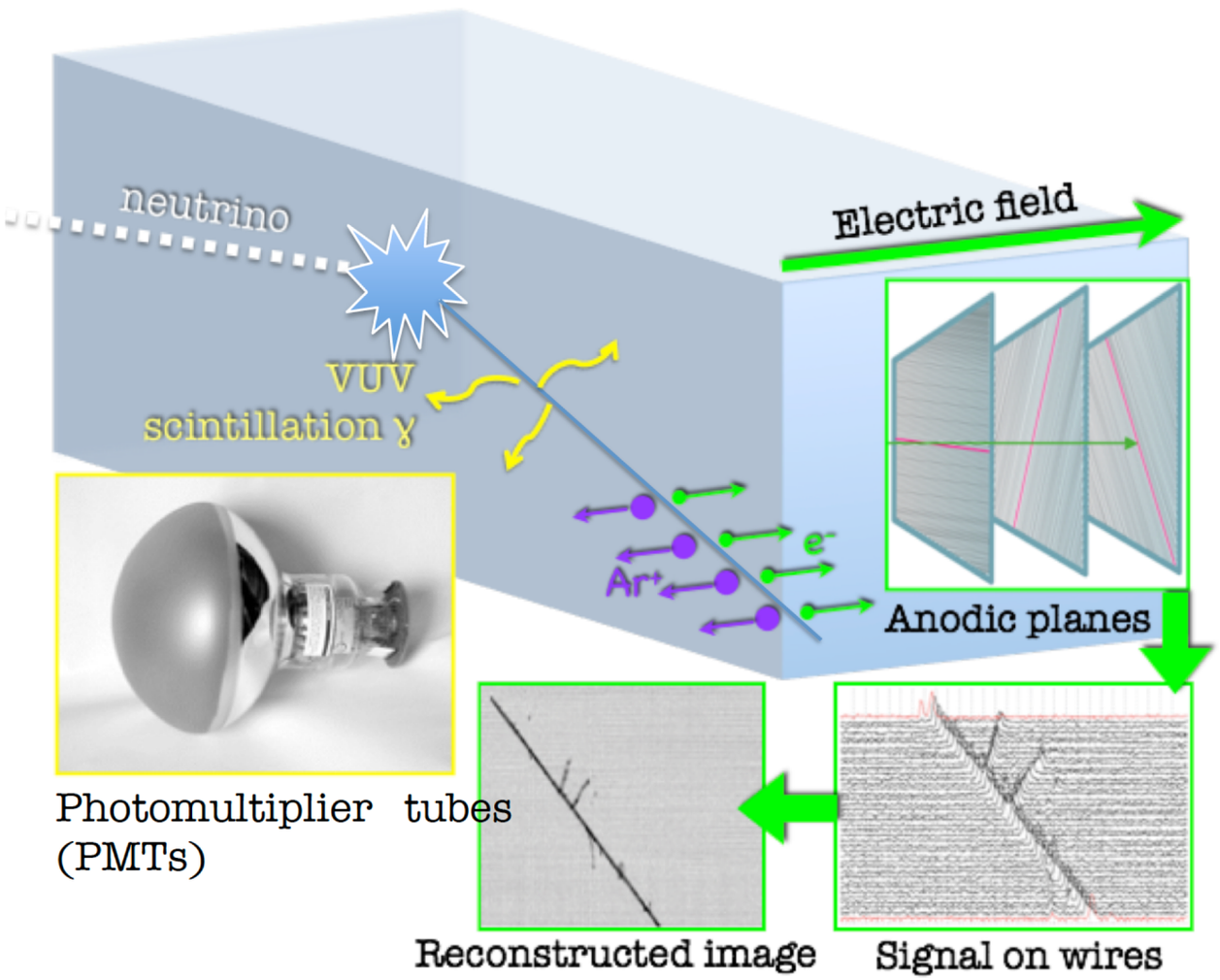






LIQUID ARGON TPC DETECTION TECHNIQUE

- Massive yet homogeneous target, excellent tracking & calorimetric capabilities.



λ = 128 nm scintillation light:

- 40000 γ/MeV wo electric field.
- Response time ~ 6 ns ÷ 1.8 μs.

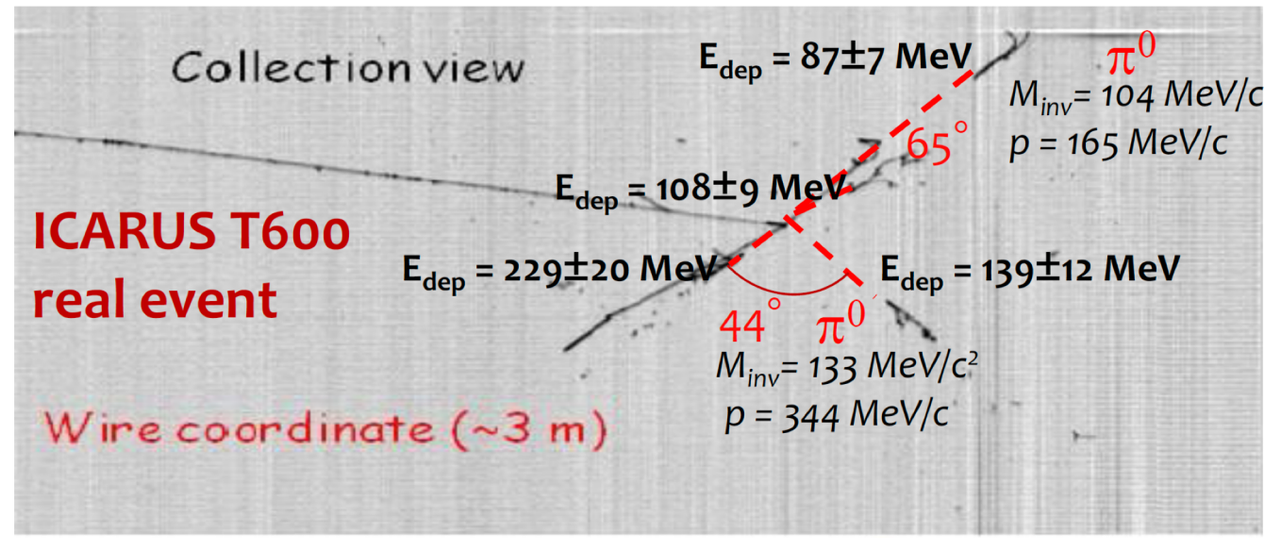
Ionisation electrons:

- 42000 e-/MeV.
- Drifted (E) toward planes of wires on which they induce a signal.
- Response time = drift time (~ ms).

3D image reconstruction by combining coordinates on different wire planes at the same drift time.

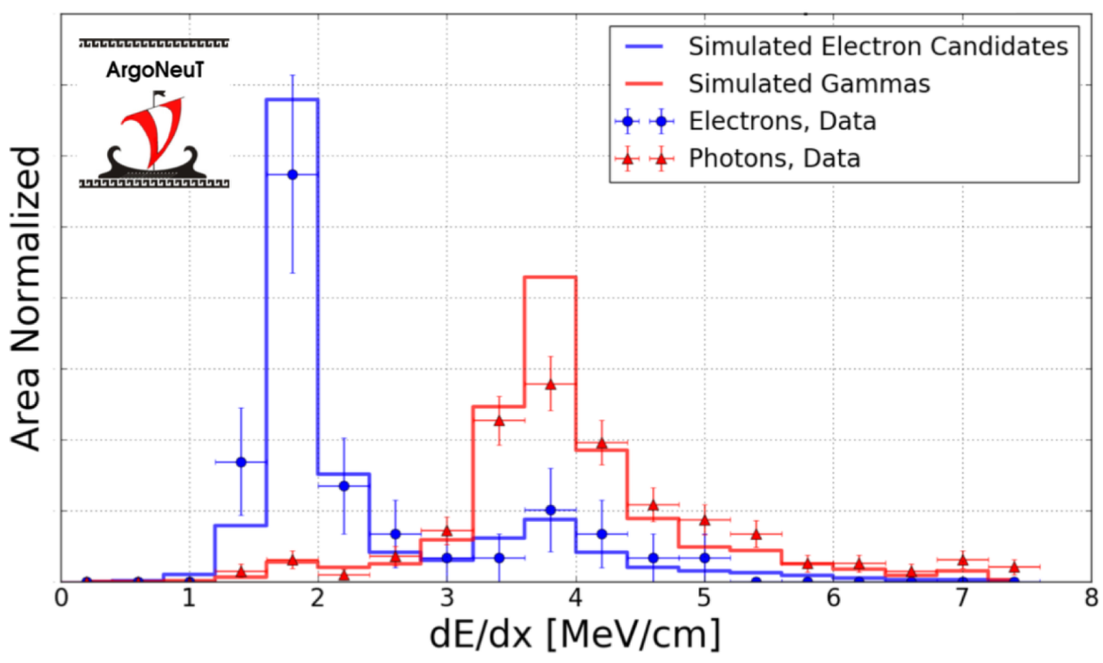
ELECTRON NEUTRINOS IN LAr-TPC

- Fine tracking & calorimetry
- essential for e/γ separation
- and π^0 reconstruction



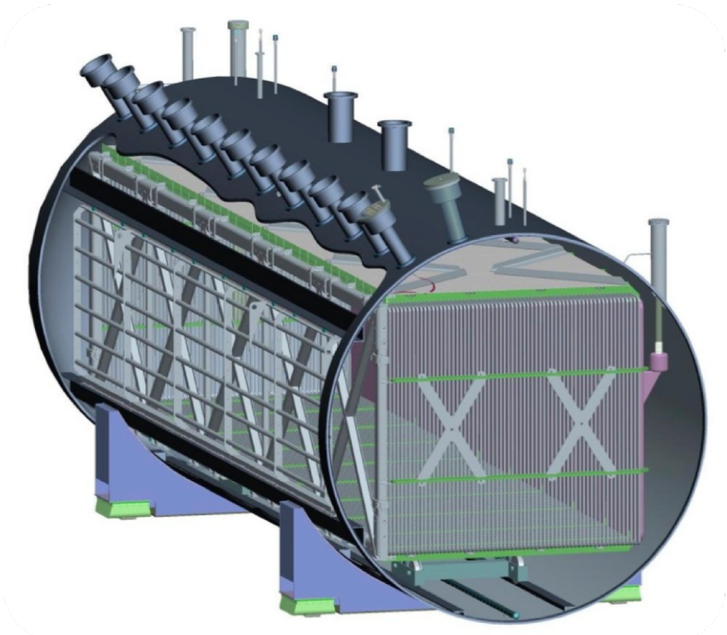
CNGS beam direction

Phys.Rev.D95,072005



- Gap between vertex and shower.
- Ionization in the first segment of showers (1 mip or 2 mips).
- π^0 invariant mass

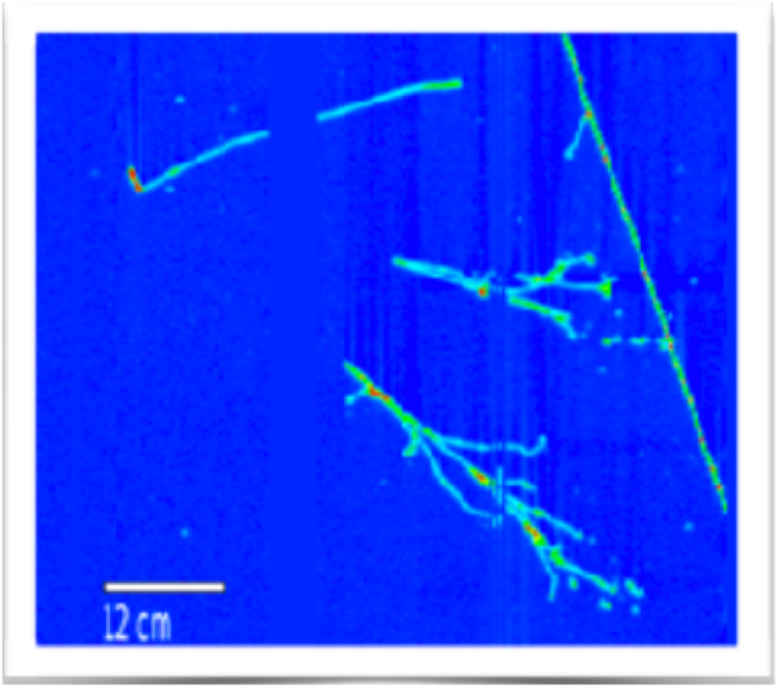
PHASE I - MICROBOONE



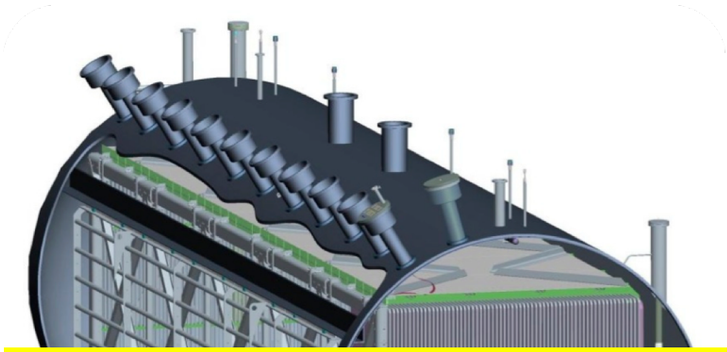
- 170 t of LAr, 87 t active mass.
- 470 m from the source.
- 1 TPC with 2.5 m drift.
- 3 wire planes with 3 mm pitch.
- 32 8" PMTs on acrylic support coated with TPB.
- Cosmic Ray Tagger (CRT) for identifying cosmic μ.

- Stable operation since October 2015.
- Understanding the detector effects (noise, diffusion, recombination, space charge…)

  →essential to understand physics
- Great progress on automated event reconstruction
- ν_μ CC inclusive differential cross section and CC π^0 total cross section
- **Many new and exciting results at NuInt18**



PHASE I - MICROBOONE



- 170 t of LAr, 87 t active mass.
- 470 m from the source.
- 1 TPC with 2.5 m drift.
- 3 wire planes with 3 mm pitch

See talks by:

Anne Schukraft: **Detector, modelling and performance**

Marco Del Tutto: **Charged-current inclusive cross section measurement**

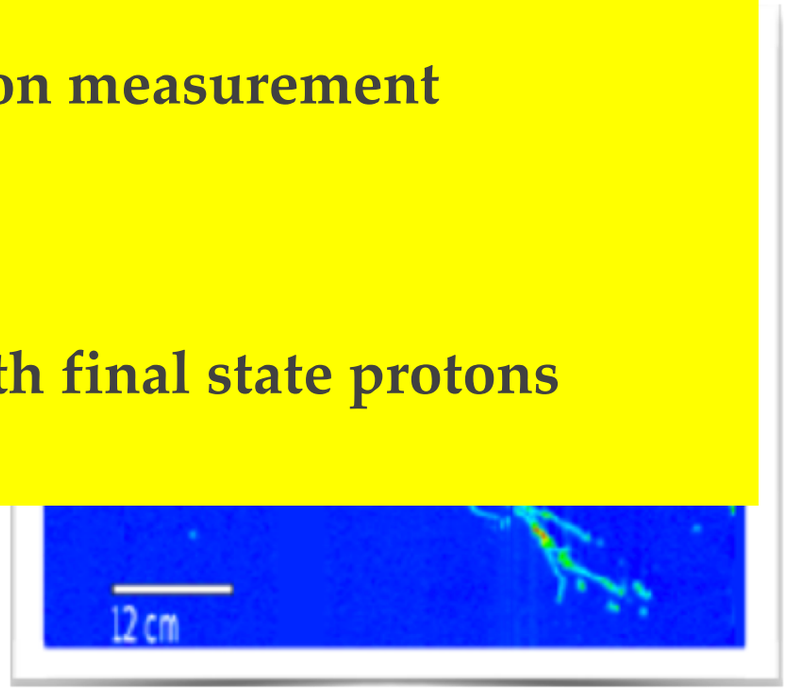
Joel Musseau: **Charged-current neutral pion cross section measurement**

Colton Hill: **Electron neutrino inclusive cross section**

Raquel Castillo Fernandez: **Charged-current analyses with final state protons**

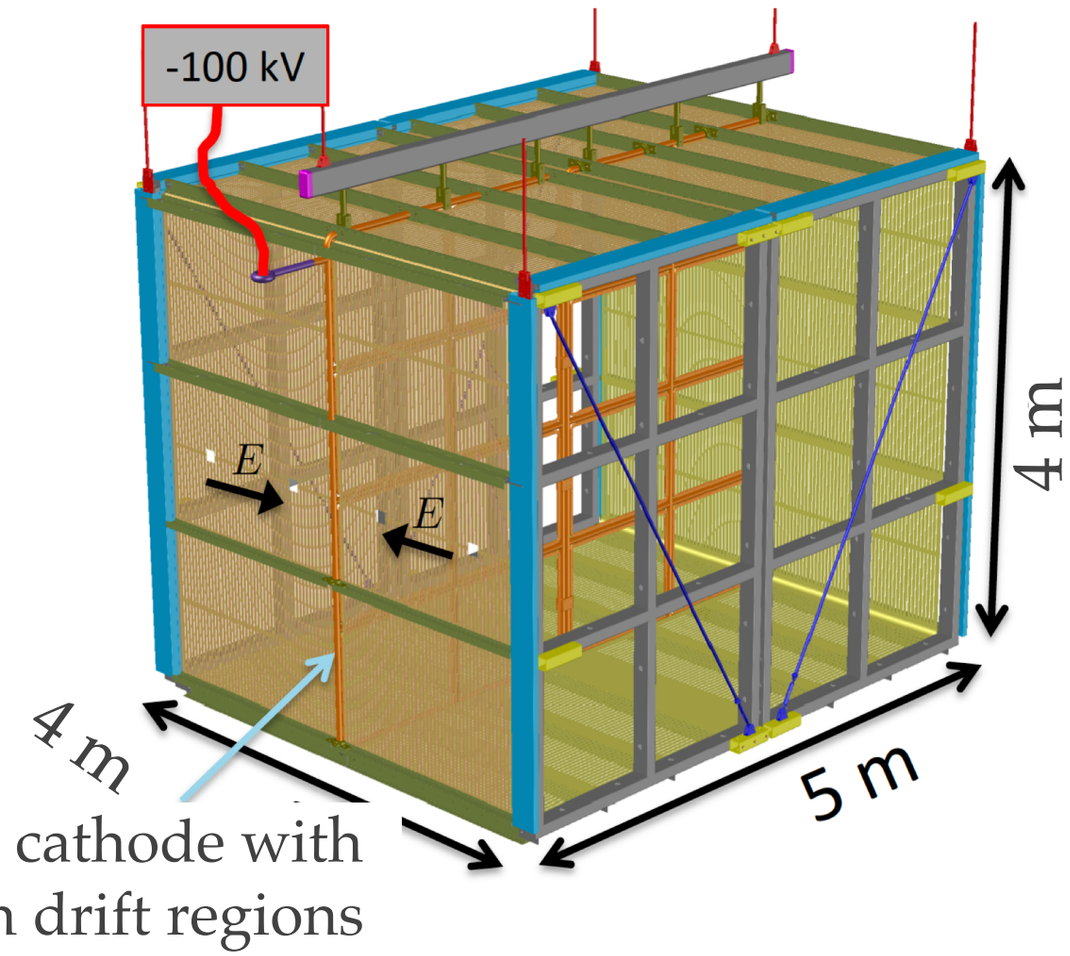
ν_μ CC inclusive differential cross section and CC π^0 total cross section

- **Many new and exciting results at NuInt18**

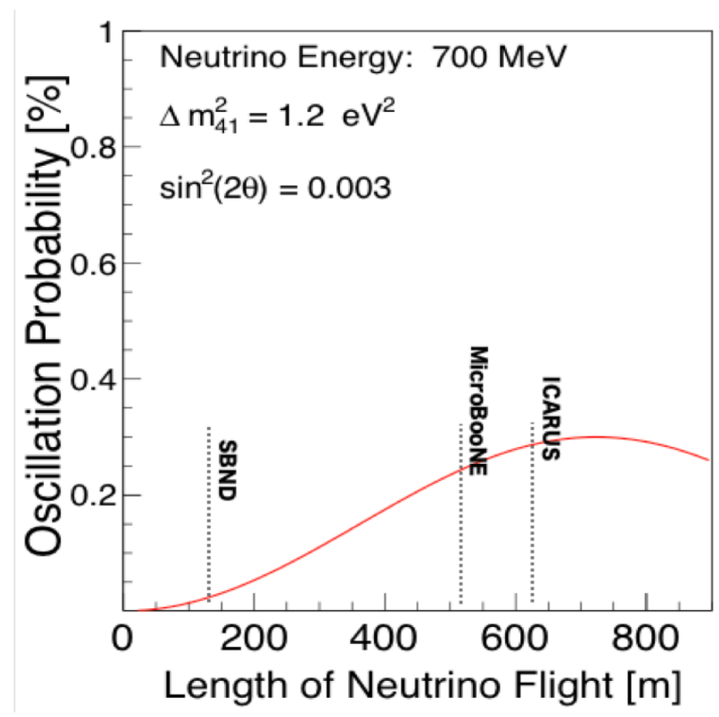


PHASE II SBND + ICARUS

- 260 t of LAr, 112 t active mass.
- 110 m from the source
- 2 TPCs with 2 m drift and 3 wire planes.
- Hybrid photodetection system
  - 8'' PMTs coated with TPB
  - TPB coated light guided foils
  - ARAPUCA
- 4π CRT coverage.



It will characterize the neutrino beam before the onset of oscillations, addressing one of the dominant systematic uncertainties.

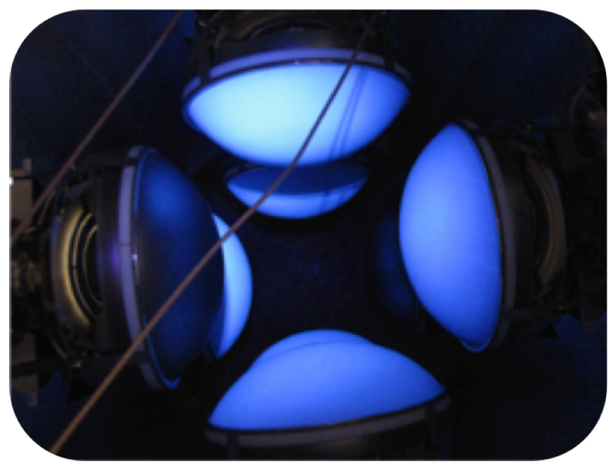


More about SBND on Friday in a talk by Andrzej Szelc

PHASE II SBND + ICARUS

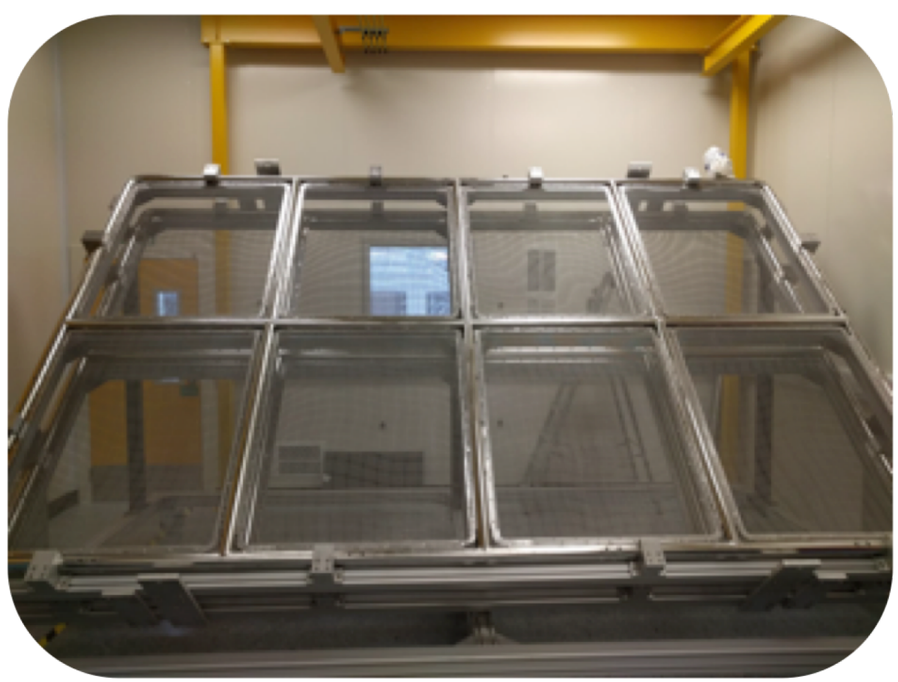
Expected data taking 2020

CRT panels (Switzerland) installed for preliminary beam data

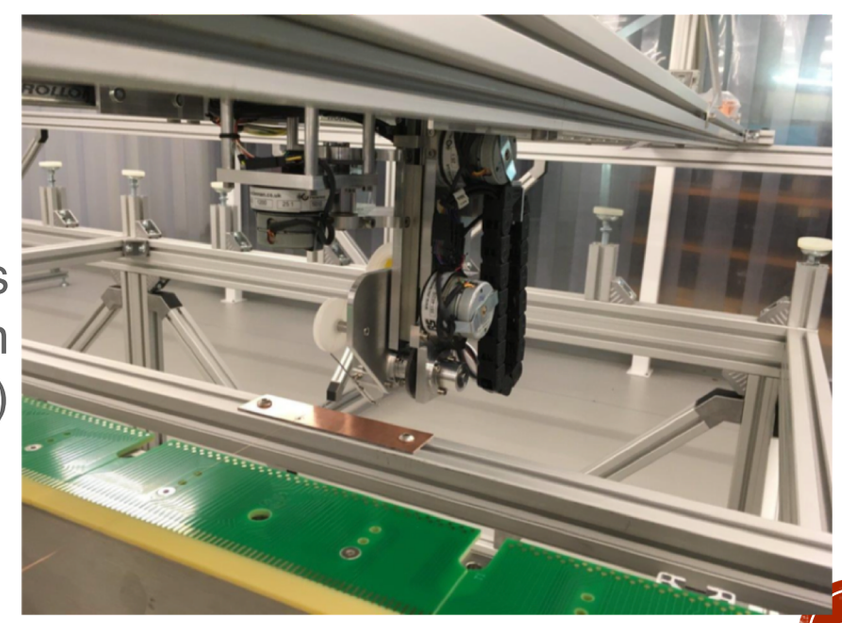


PMT testing

Cathode arrived at FNAL!

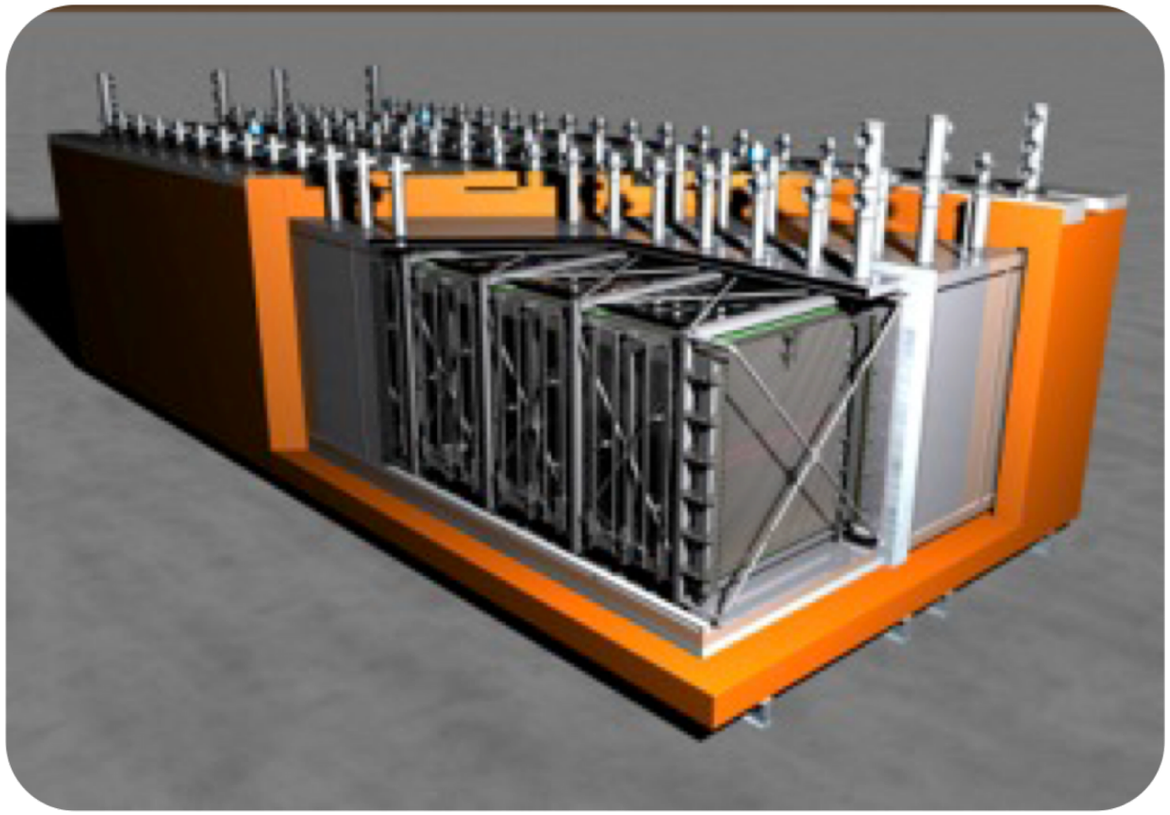


Anode Plane Assemblies under construction (US & UK)



PHASE II SBND + ICARUS

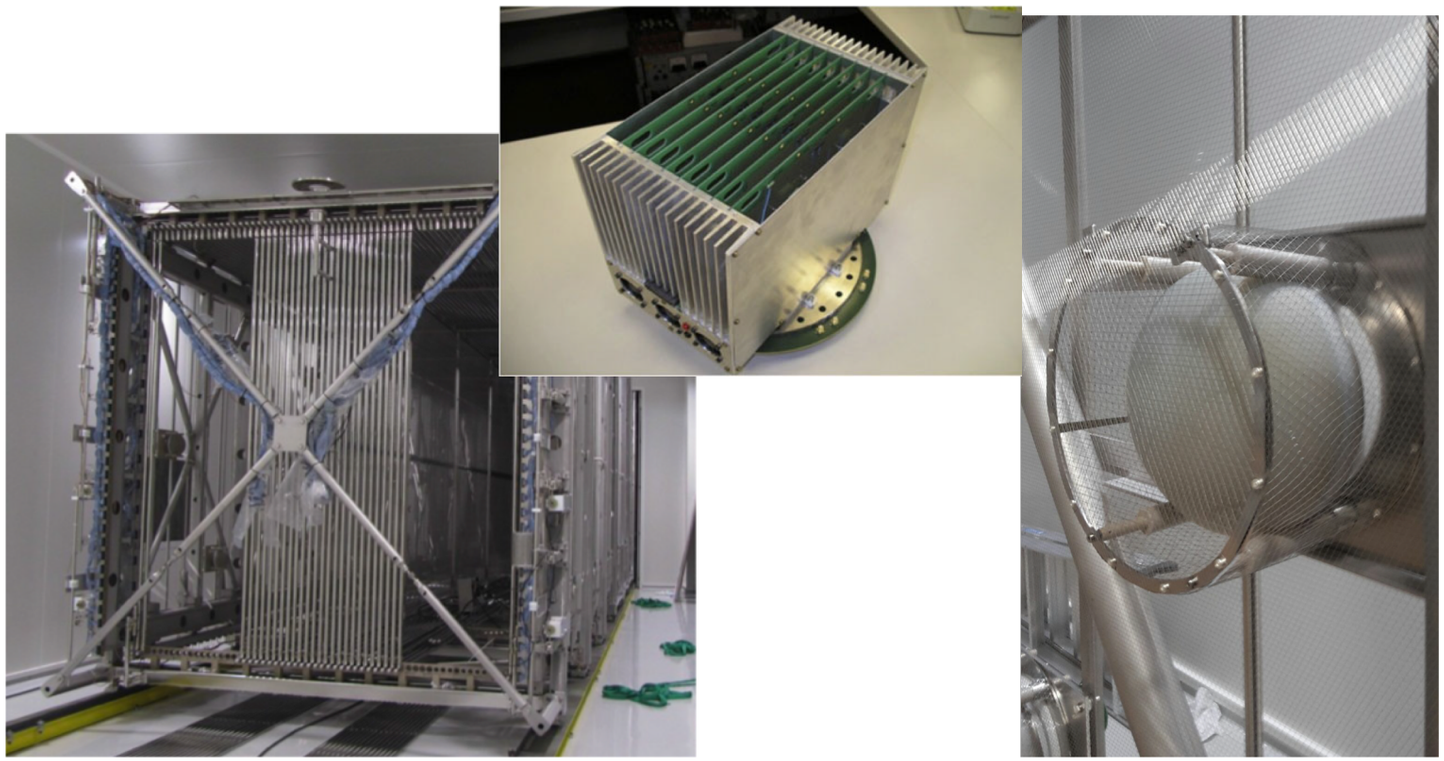
- 760 t of LAr, 476 t active mass.
- 600 m from the source.
- 4 TPCs with 1.5 m drift and 3 wire planes.
- 360 8" PMTs coated with TPB.
- Almost full CRT coverage.



Given its large mass and far location ICARUS-T600 will provide high sensitivity to oscillated neutrinos

→ precision search.

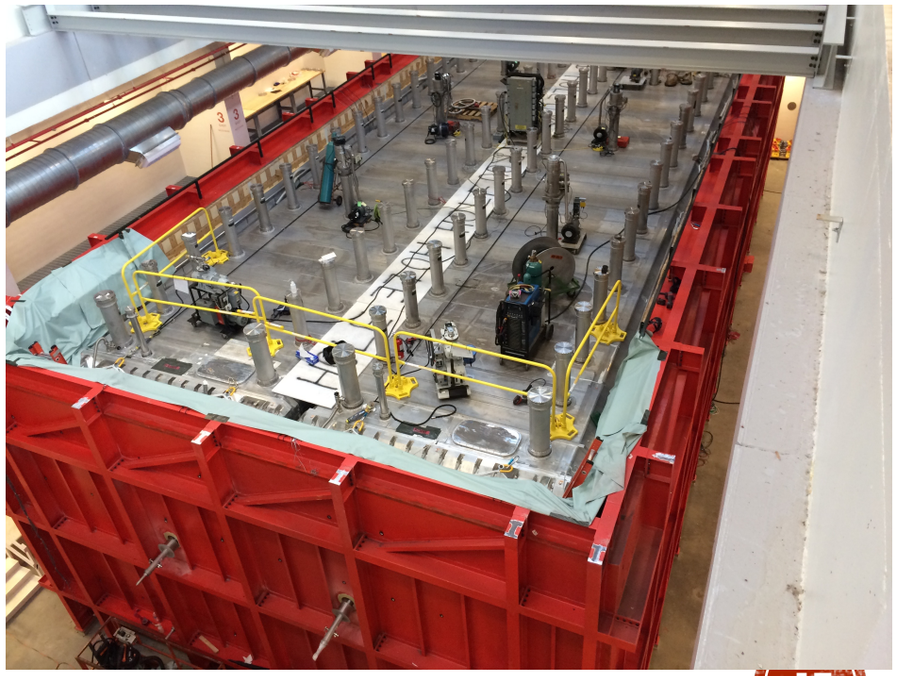
PHASE II SBND + ICARUS



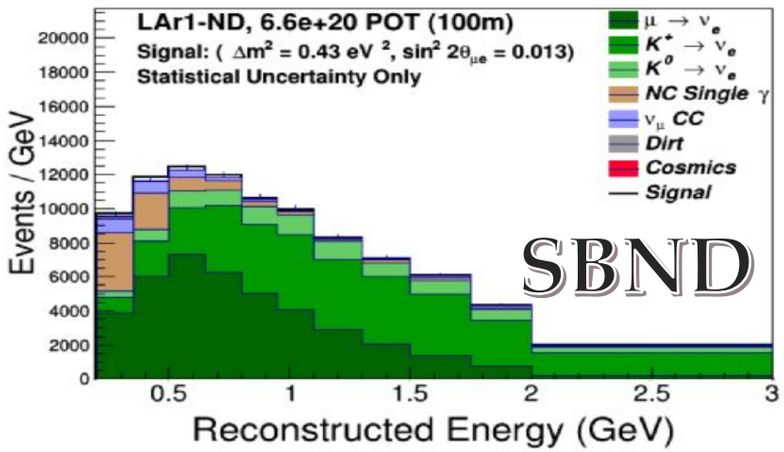
Overhauling at CERN 2015-2017

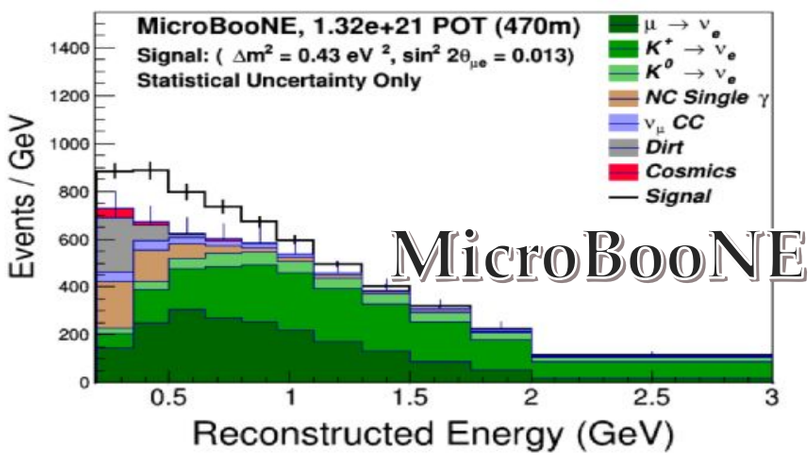
Expected data taking 2019

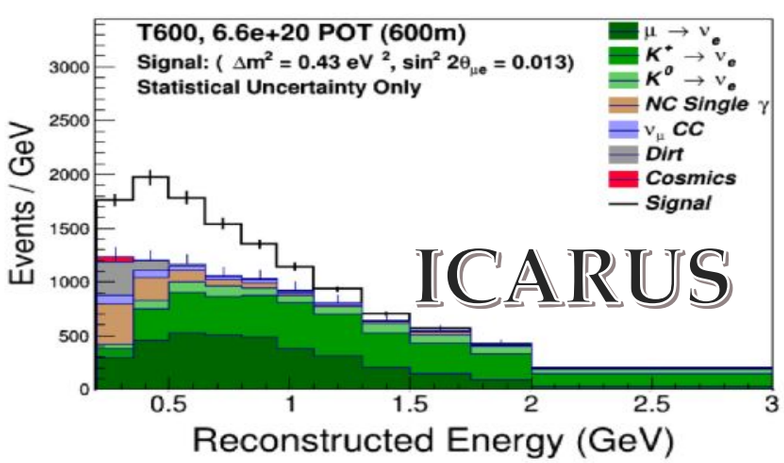
Far Detector building@FNAL



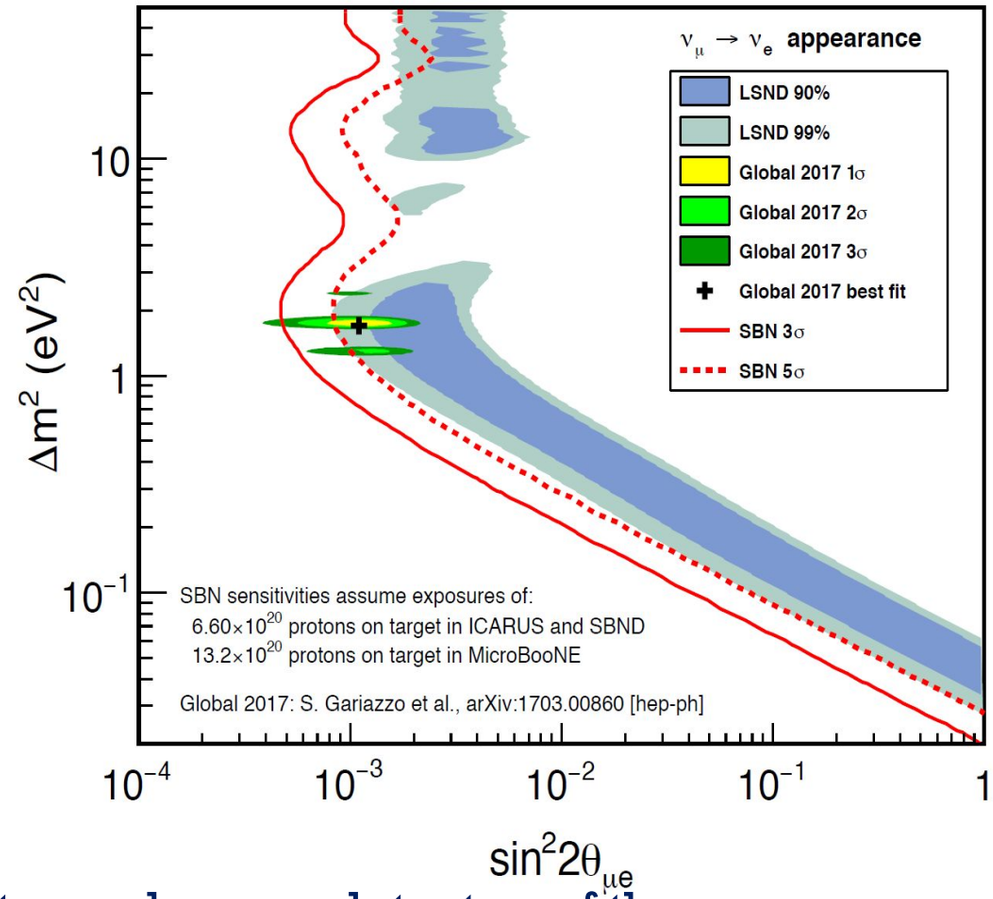
SEARCH FOR STERILE NEUTRINOS: $\nu_\mu \rightarrow \nu_e$ APPEARANCE





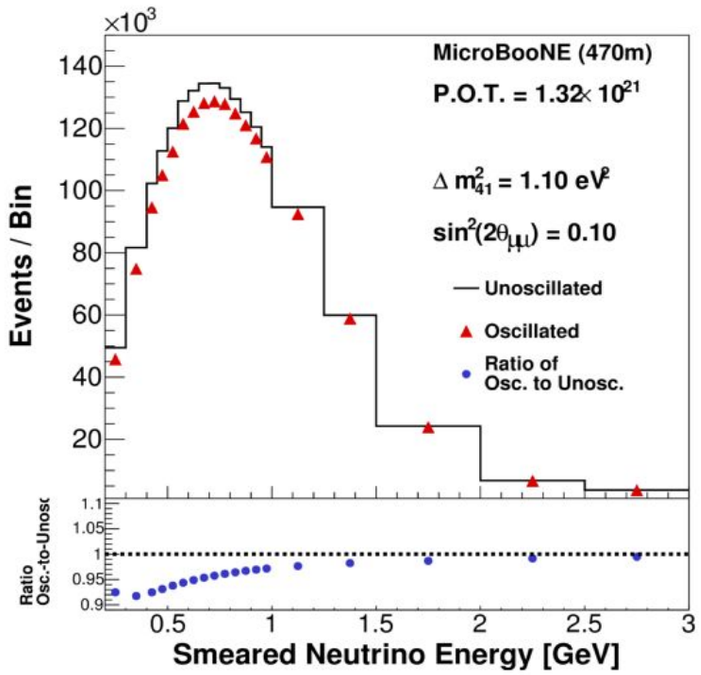


http://arxiv.org/abs/1503.01520

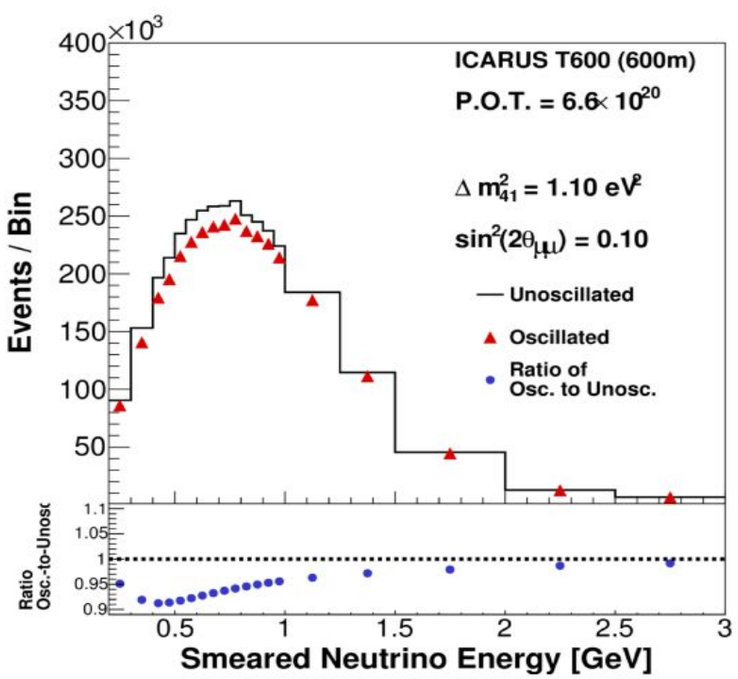


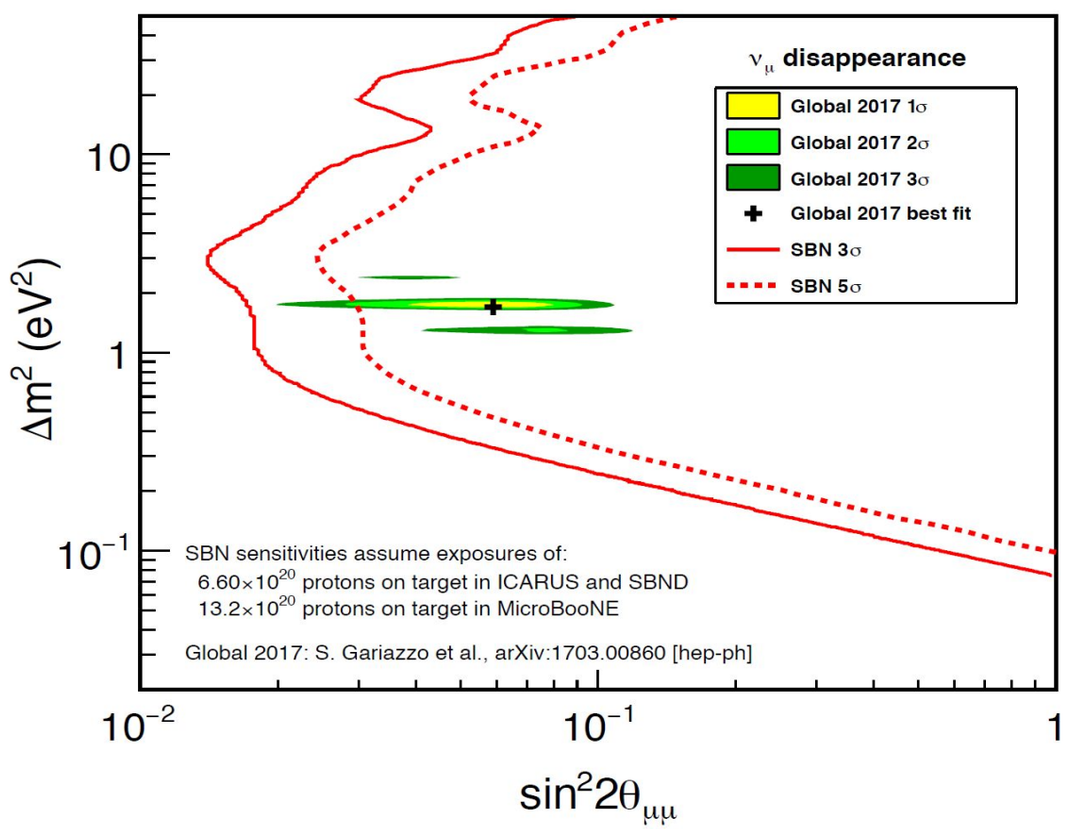
- A large mass far detector and a near detector of the same technology reduces both statistical and systematic uncertainties
- SBN detectors enable 5σ coverage of the 99% C.L. allowed region of the LSND signal and global best fit values
- The analysis leveraged MiniBooNE expertise in simulating BNB neutrino fluxes.
- Major background source related to cosmic rays:
  - spurious triggers; several uncorrelated cosmic rays in LAr active volume during drift window recording
  - All detectors have CRTs and light detection systems to reject the background

SEARCH FOR STERILE NEUTRINOS: ν_μ DISAPPEARANCE



- SBN can extend the search for muon neutrino disappearance an order of magnitude beyond the combined analysis of SciBooNE and MiniBooNE in 3 years of data-taking.
- Critical aspect to verify an oscillation hypothesis

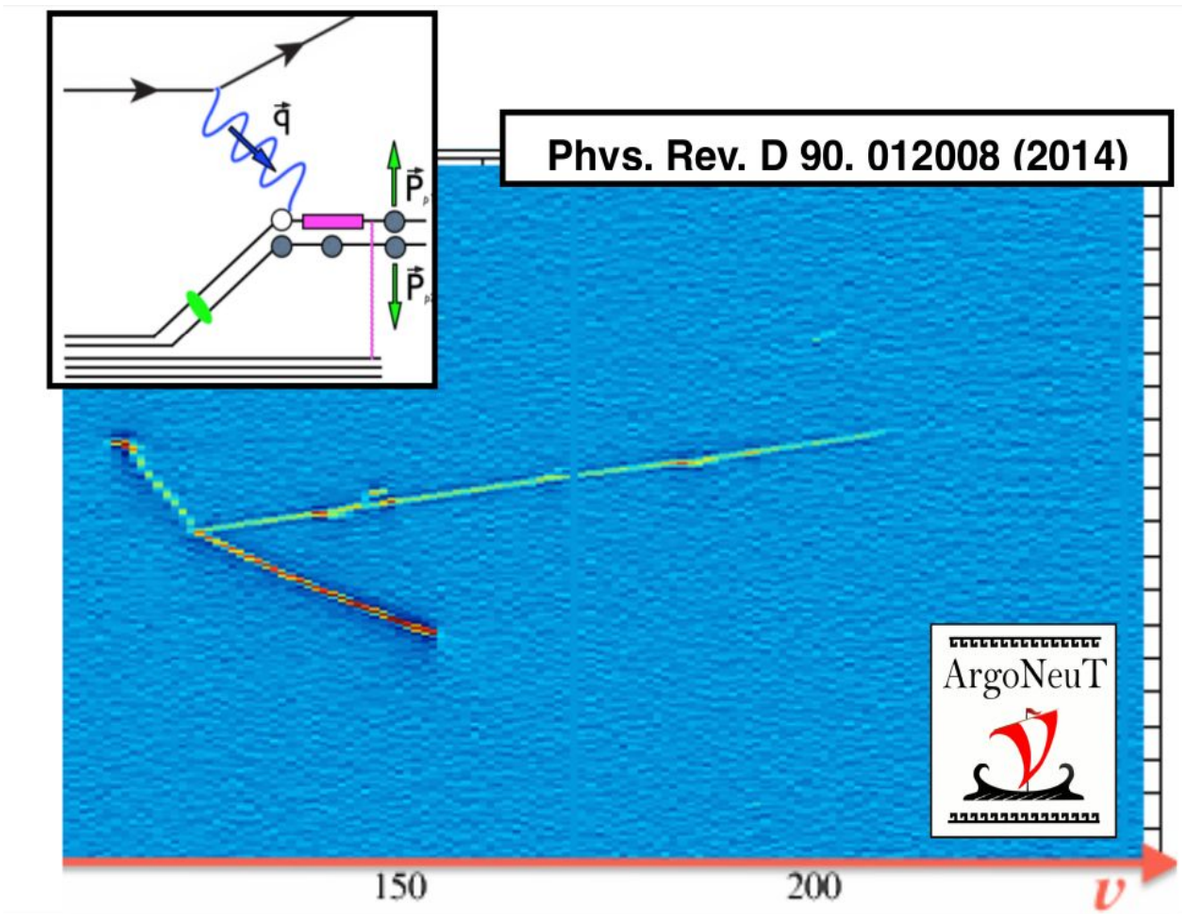


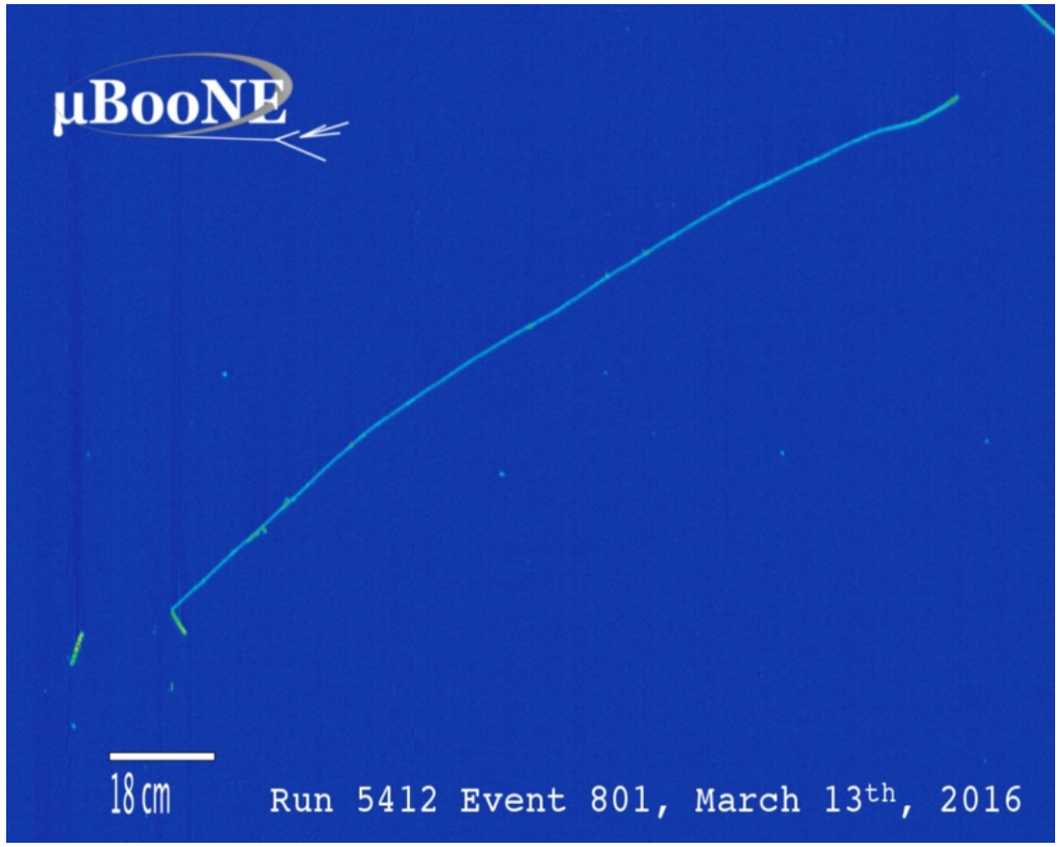


http://arxiv.org/abs/1503.01520

ν-Ar CROSS SECTION STUDIES

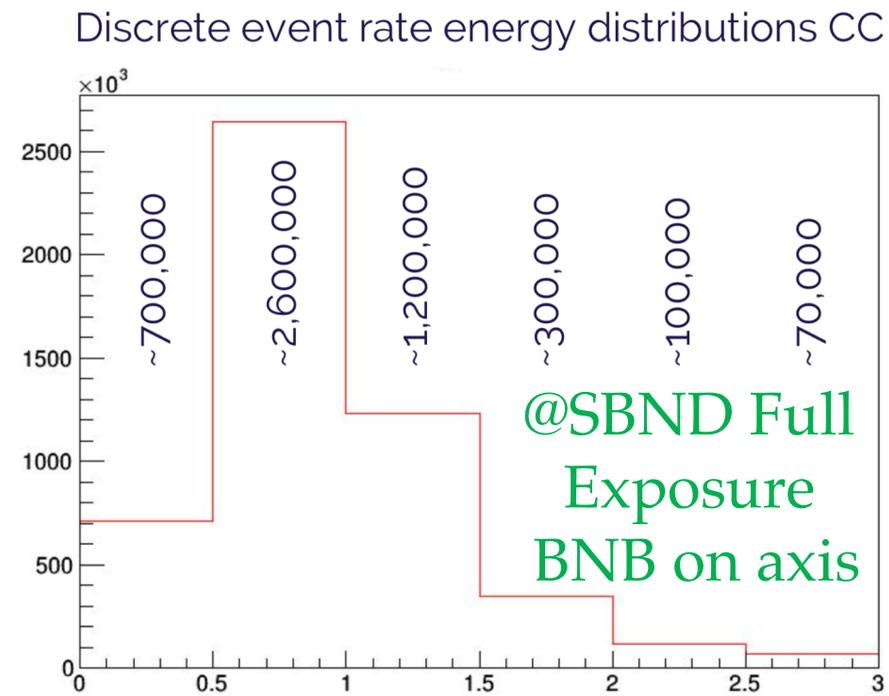
- Oscillation experiments require precise understanding of ν-Ar interaction cross section for a correct interpretation of the experimental outcome
- The only existing published GeV ν-Ar data is ~6000 events from ArgoNeuT

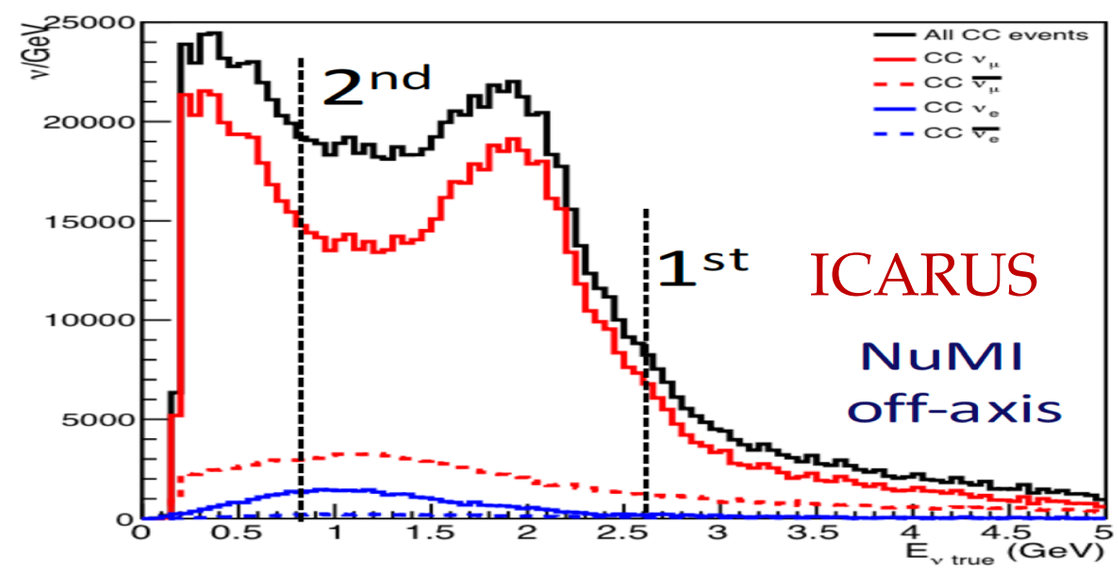


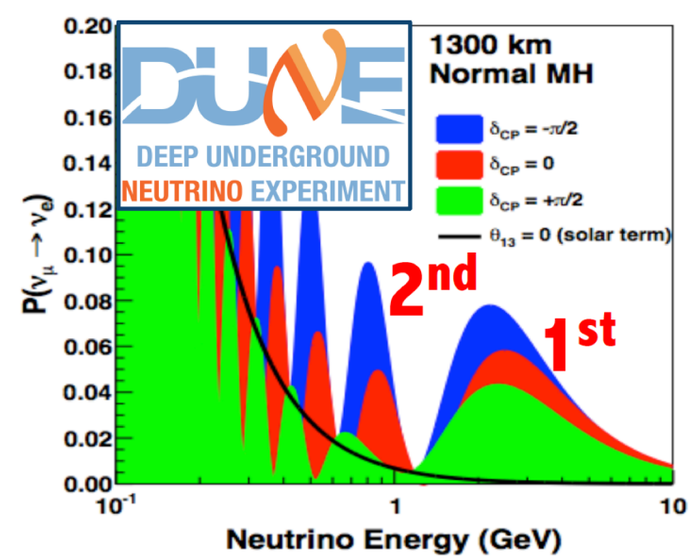


ν-Ar CROSS SECTION STUDIES

- 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







STATUS OF ANALYSES

- The SBN collaborations are in preparation for upcoming data
  - Common analysis framework based on LArSoft.
  - Consistent simulation of the flux and neutrino interactions.

- Established SBN-wide working groups that will focus on reconstructions, MC generators and simulations, oscillation analyses.

- One of the next goals is to update the sensitivities studies with new simulations and information from MicroBooNE about detector systematics

CONCLUSIONS

- SBN program consists of three LArTPCs that will sit in the Fermilab BNB beam and will
  - study the baseline dependence of the appearance and disappearance channels 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 close to ~10^{21} pot from BNB, doing the groundwork for LArTPCs and working on its first physics results.
  - SBND is making excellent technical progress on the construction of the detector and will start taking data in 2020.
  - ICARUS detector is already at Fermilab and will start taking data in 2019.