# Status of the Short-Baseline Near Detector at Fermilab

Steve Dennis, for the SBND Collaboration
NuFact 2019
30/08/2019

# Outline

- Physics justification for building the SBN program.
  - Many great talks so far have covered LSND-MiniBooNE anomaly
    - Joshua Spitz 26th August
    - Adrien Hourlier 27th August
  - What the Short Baseline Neutrino program is.
  - And what physics it can achieve.
- Focus on the near detector SBND.
  - Detector design.
  - Cross-section physics at SBND.
  - Progress on SBND construction.
  - Timeline for physics running.
  - Outlook.

# A number of anomalies seem to indicate that there may be a new characteristic oscillation frequency mode (indicative of a new neutrino state).

J. Spitz
- Monday

| Experiment name | Type | Oscillation channel | Significance |
|---|---|---|---|
| LSND | Low energy accelerator | muon to electron (antineutrino) | 3.8σ |
| MiniBooNE | High(er) energy accelerator | muon to electron (antineutrino) | 2.8σ |
| MiniBooNE | High(er) energy accelerator | muon to electron (neutrino) | 4.5σ |
| Reactors | Beta decay | electron disappearance (antineutrino) | (varies) |
| GALLEX/SAGE | Source (electron capture) | electron disappearance (neutrino) | 2.8σ |

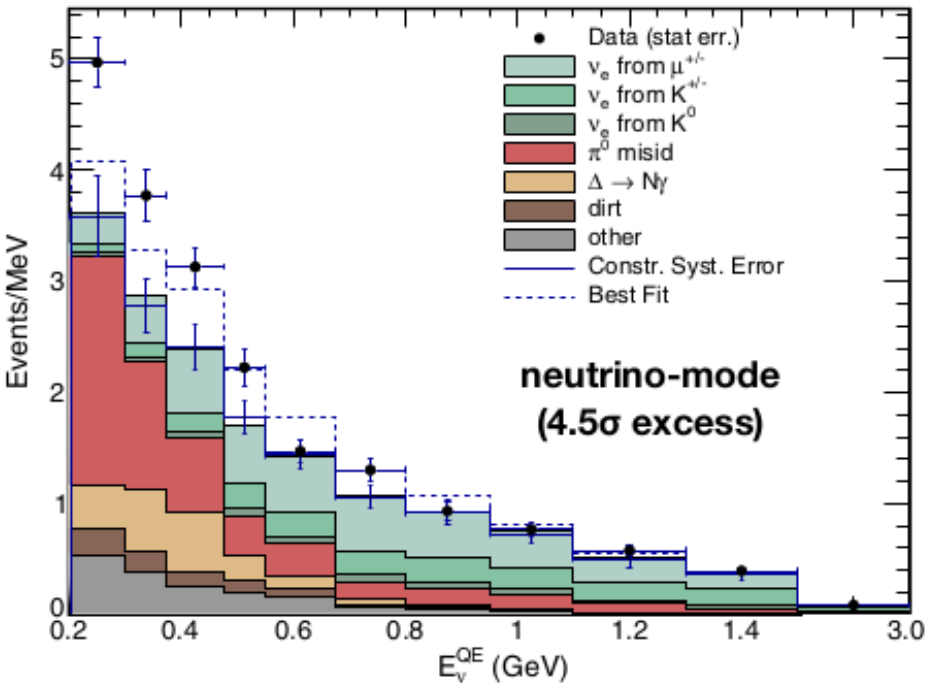
Now: 4.8σ (combined)

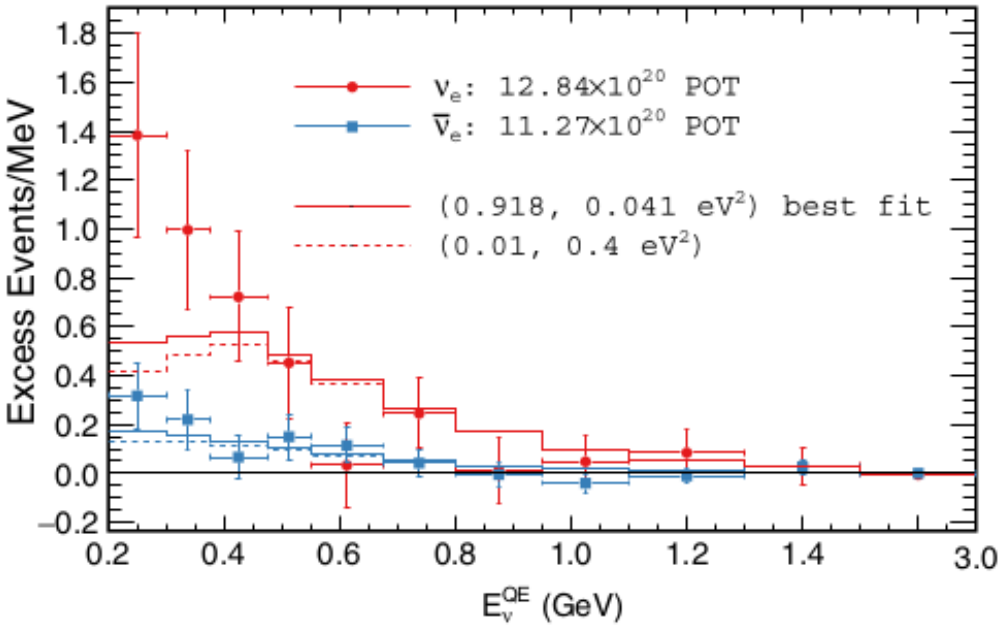
(there are also various null results in this "high-frequency oscillation" parameter space); MINOS(+), IceCube, KARMEN, CDHS, OPERA, …

J. Spitz - Monday

# The MiniBooNE anomalies

**MiniBooNE Collab., PRL 122 221801 (2018)**

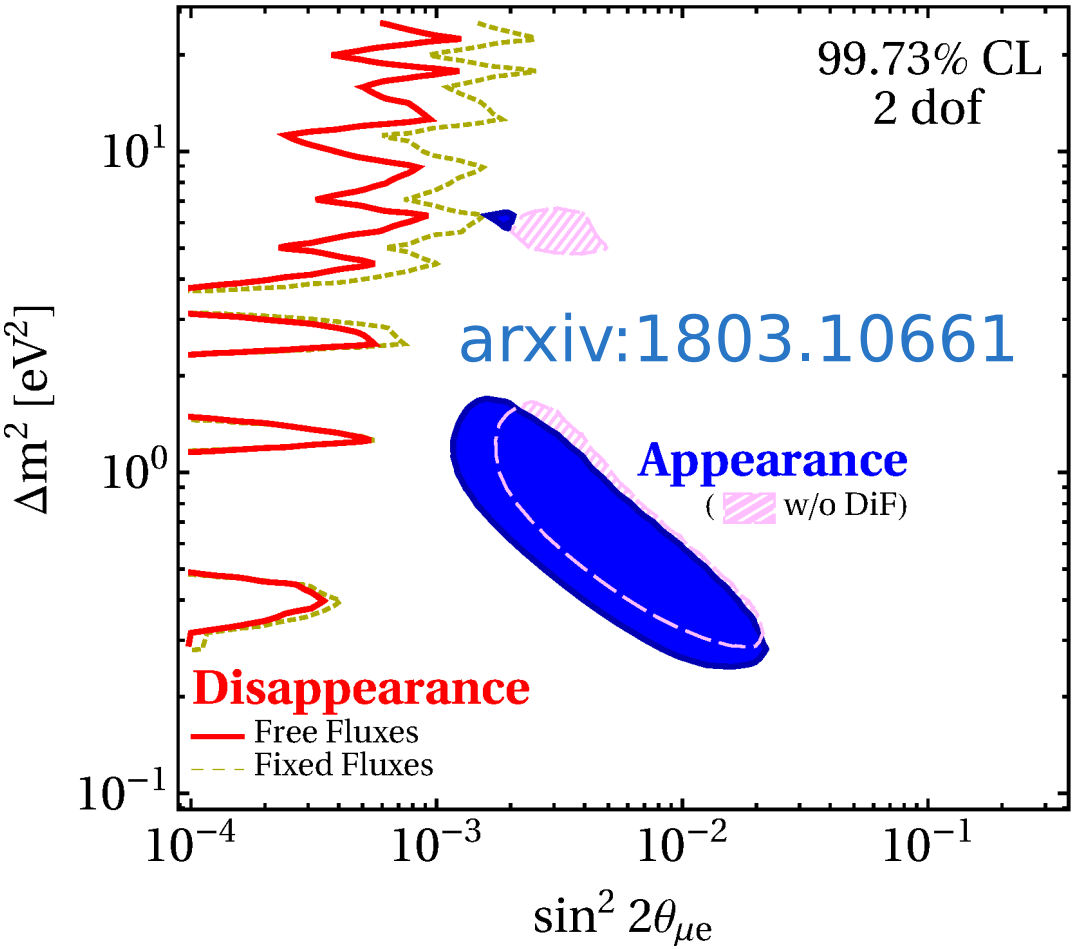



**Note: MiniBooNE does not have the ability to distinguish between electrons and single-gammas.**
**That is, it's not clear if the excess is electron-like or gamma-like.**

# Interpretation

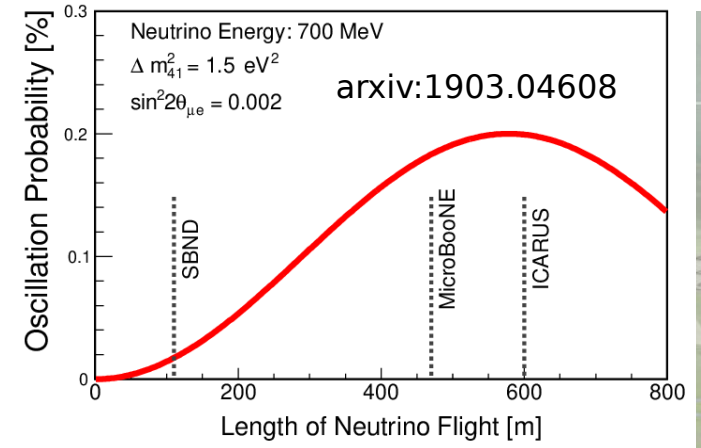
- High significance of excess.
  - MiniBooNE consistent between neutrinos and antineutrinos.
    - And over extended running periods
  - And with LSND.
- Assuming a two-neutrino oscillation fit, this is not consistent with the observed oscillations from the solar and atmospheric sectors.
  - Requires a fourth neutrino or some other unusual hypothesis.
  - Given LEP evidence for three active light neutrinos, the additional neutrino must be sterile.
- But simple 3+1 has been ruled out by lack of muon neutrino disappearance observed.
  - Eg MINOS+, IceCube – see Joshua Hignight in this session shortly



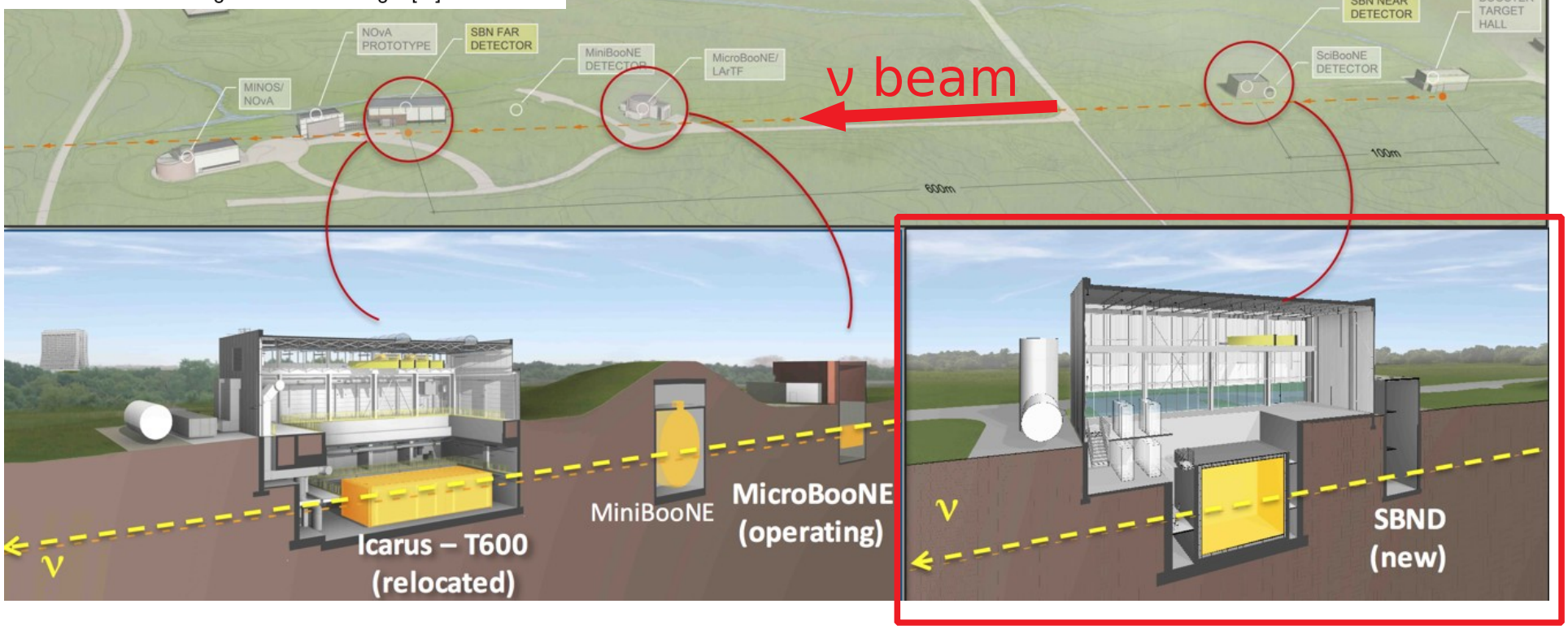
# A new experimental progam

- This excess must be confirmed or refuted.
  - Therefore we must design a robust experimental program that is capable of removing the any ambiguity.
- MiniBooNE saw a relatively small excess over a large background.
  - Mistakes could have been made.
  - Electron-photon confusion?
- Rather than relying on a single detector as MiniBooNE and LSND did, use the well-demonstrated power of the multi-detector experimental paradigm.
- Thus, the Short Baseline Neutrino program.
  - Three detectors at varying baselines.
  - Same beam, same nuclear target, same detector technology.
    - Powerful reduction in effects of systematic uncertainties.
  - All liquid argon TPCs, with their excellent resolution and PID.
  - Simultaneous measurement of multiple channels, including appearance and disappearance

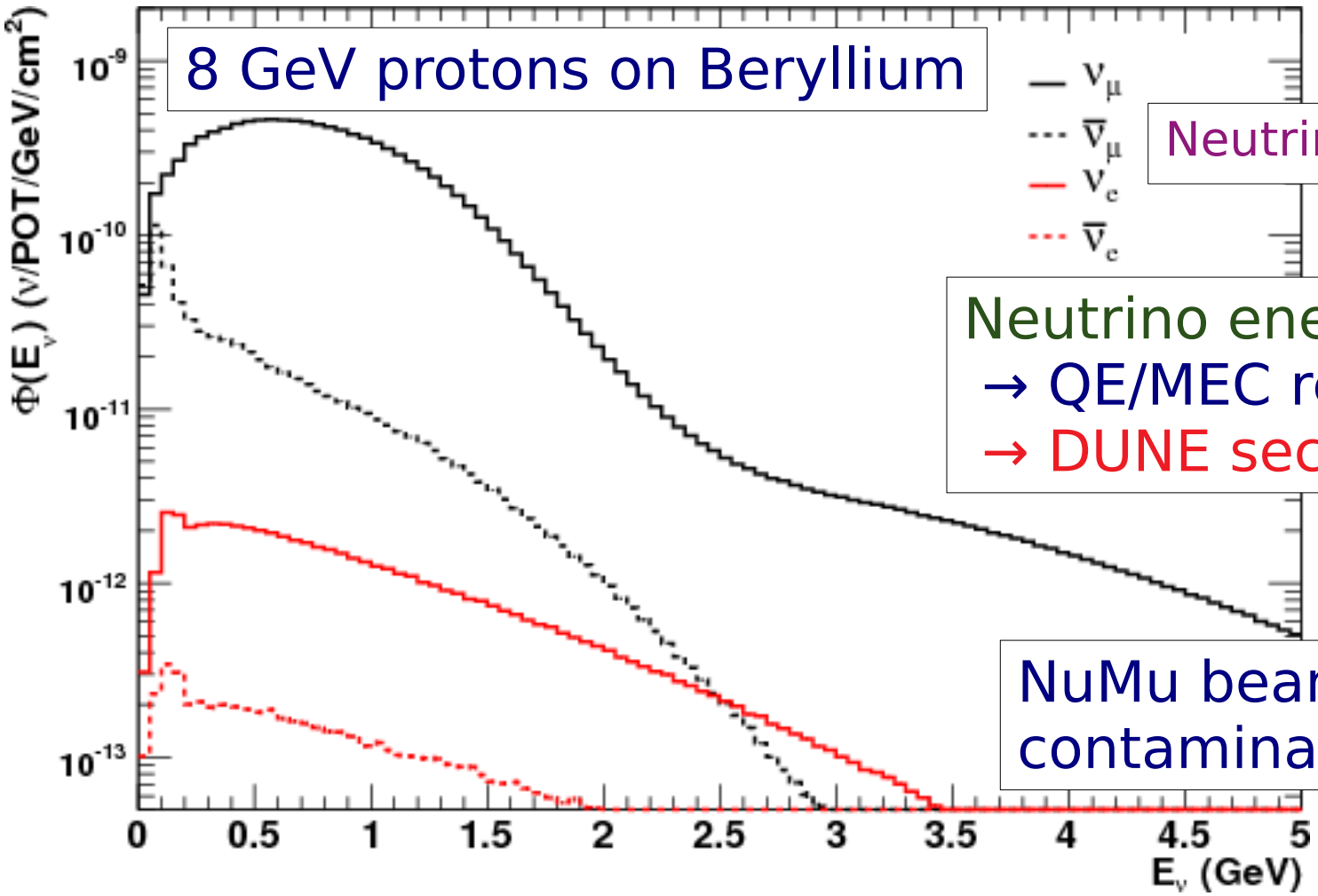
# The Short Baseline Neutrino Program




| Detector | Distance from BNB Target | Active LAr Mass |
|---|---|---|
| SBND | 110 m | 112 ton |
| MicroBooNE | 470 m | 87 ton |
| ICARUS | 600 m | 476 ton |



# Booster Neutrino Beam



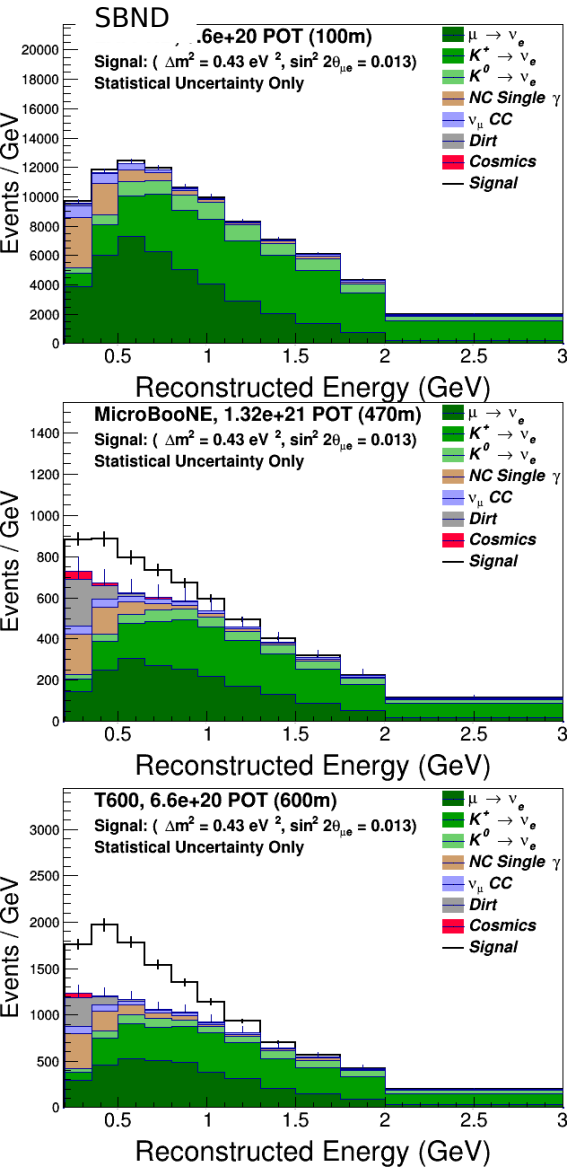

Neutrinos from pion decay

Neutrino energy ~0.8 GeV
→ QE/MEC region
→ DUNE second maximum

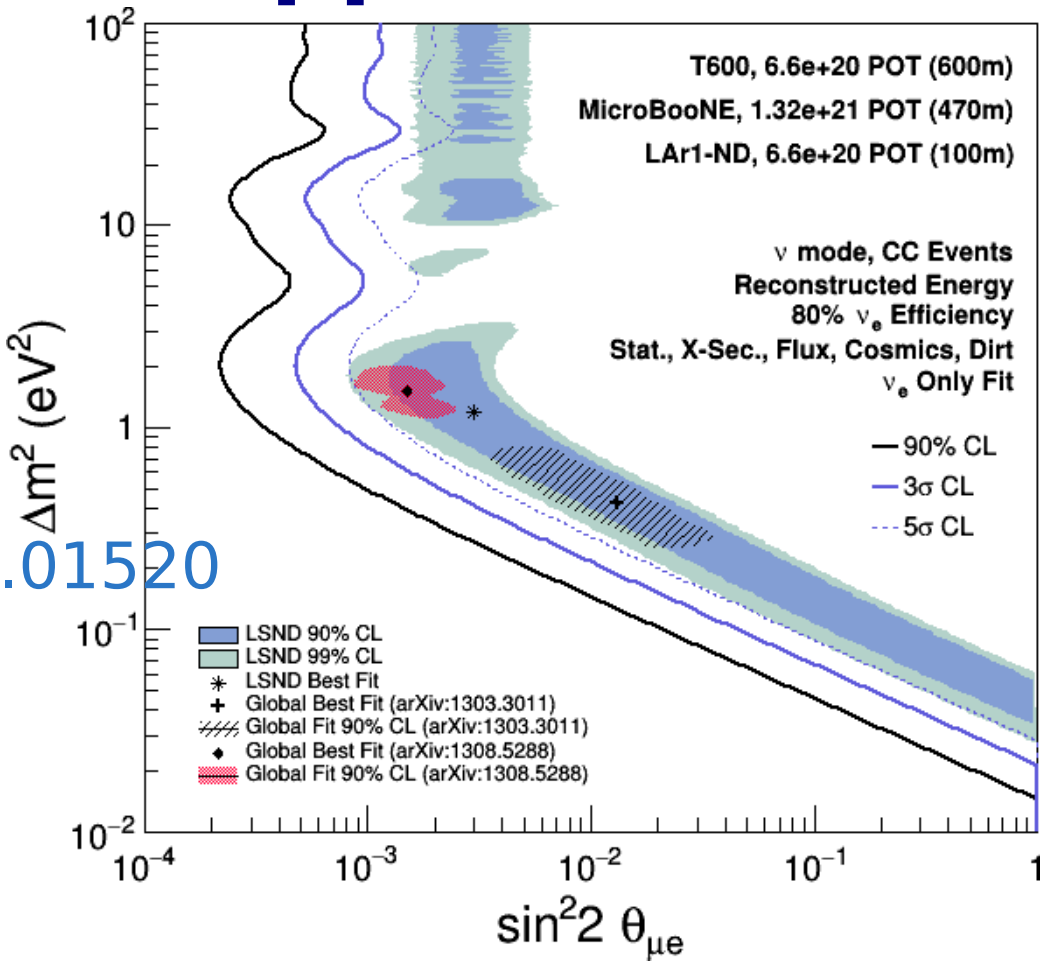
NuMu beam with small NuE contamination (~0.5%)

9% NuMu flux uncertainty at energy peak

# SBN Physics – NuE Appearance

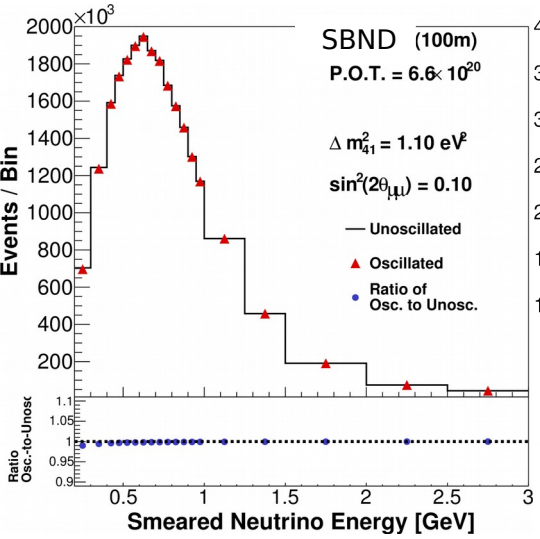


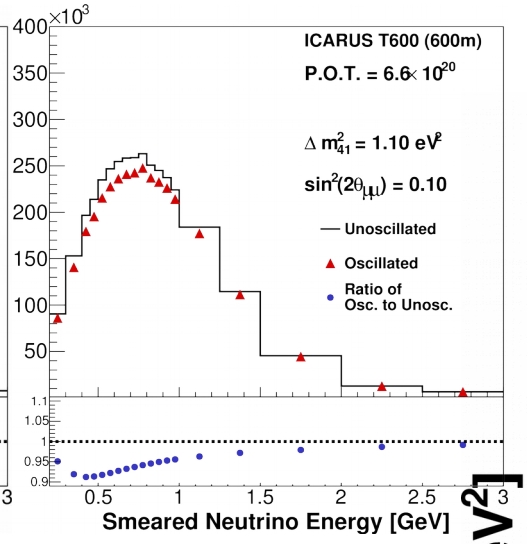

arXiv:1503.01520

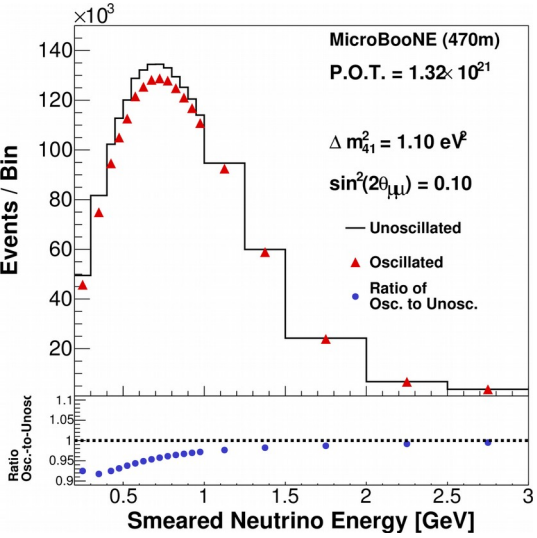



Powerful ability to rule out LSND signal!

# SBN Physics – NuMu Disappearance

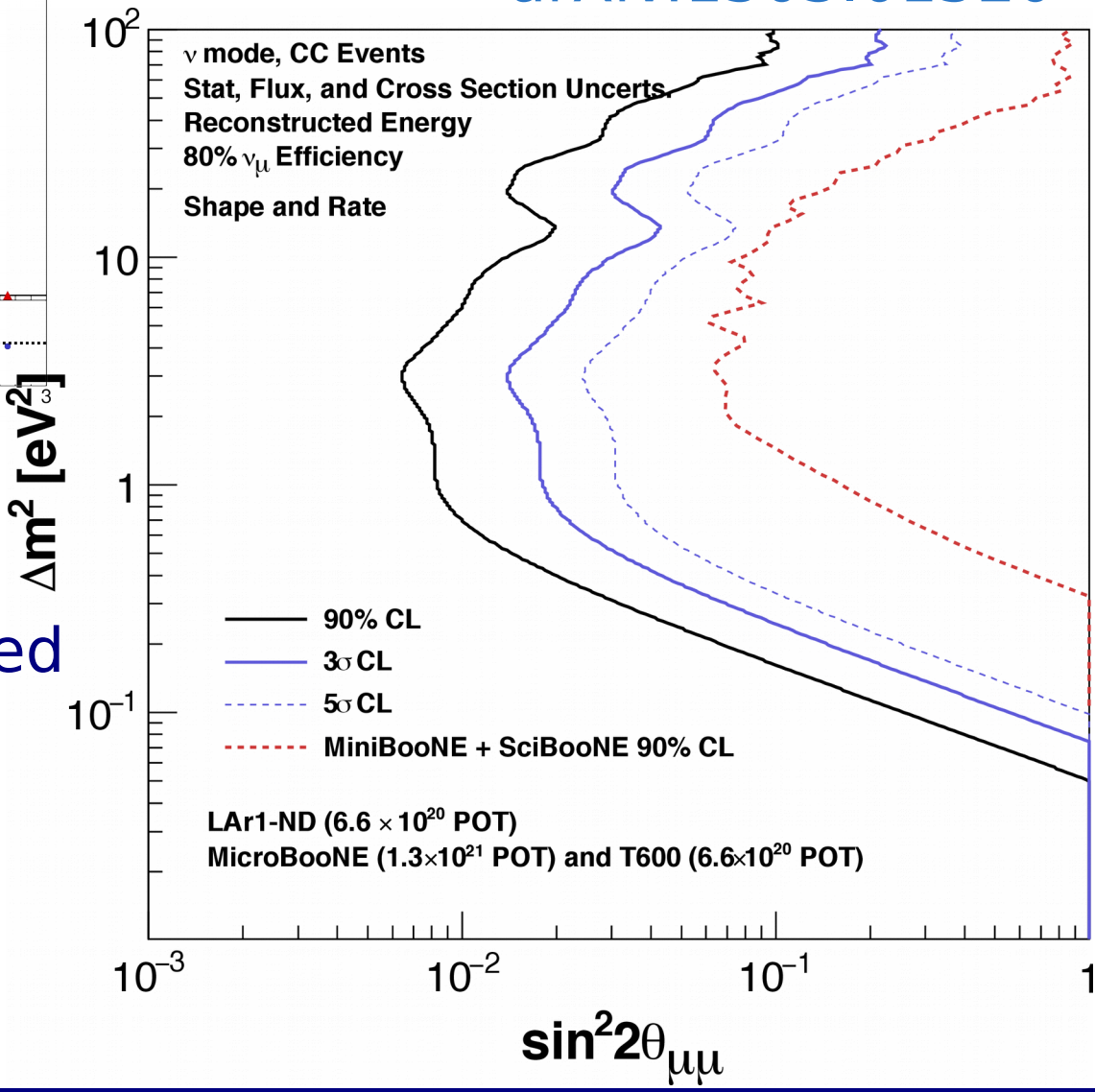



Unprecedented sensitivity around 1eV²!

arXiv:1503.01520



# Steriles are not the only new physics we can look for!

Electronvolt scale sterile neutrino decay?

Large extra dimensions?

Resonant NuE appearance?

Lorentz Violation?

Steriles and altered dispersion relations?

Heavy sterile neutrinos?

Charged current non-standard interactions?

Dark neutrino sectors?

Heavy neutrinos and transition magnetic moment?

Neutrino tridents?

Millicharged particles?

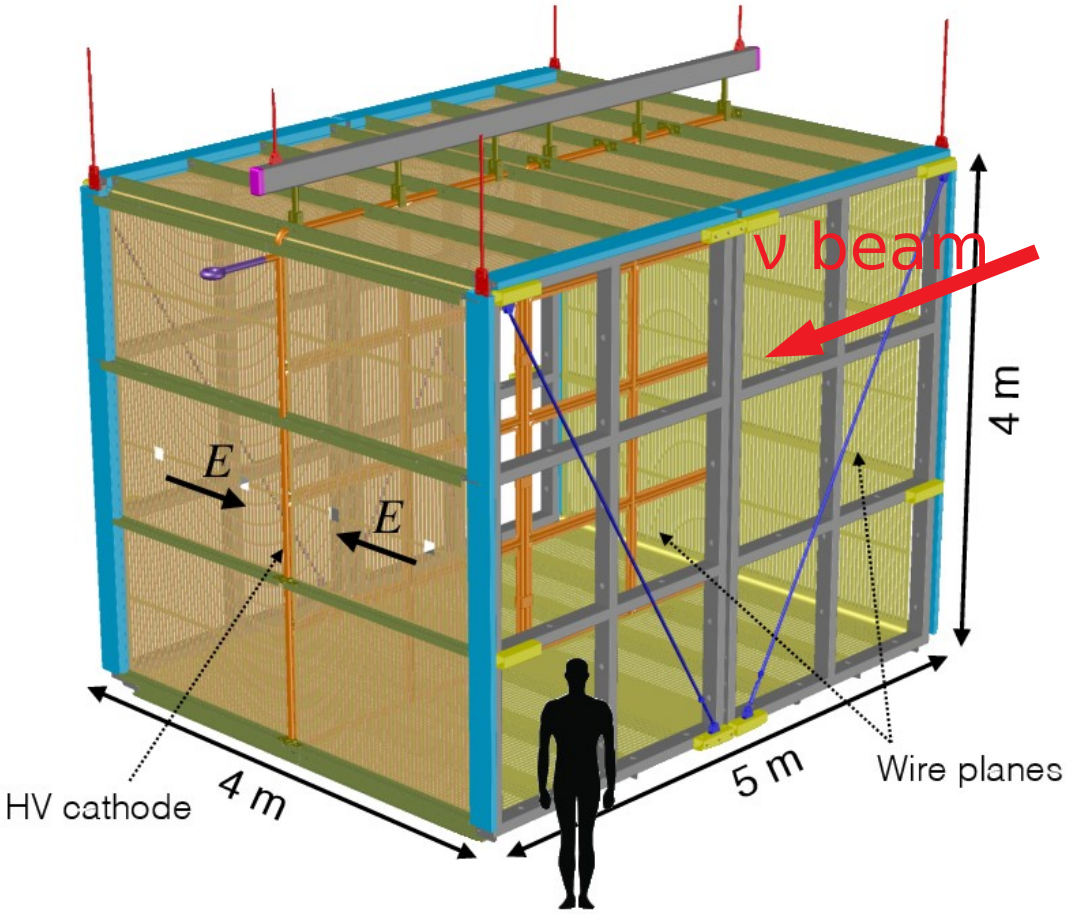
Light dark matter?

Neutrinophilic, lepton-number charged scalars?

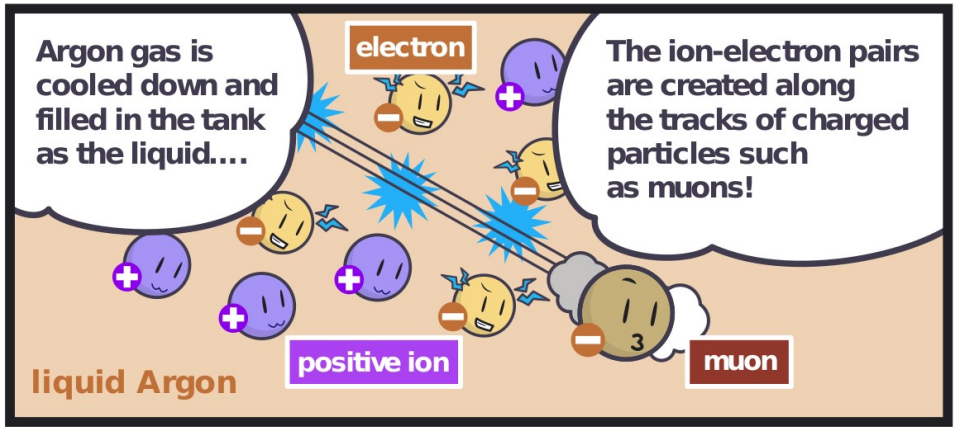
arxiv:1903.04608

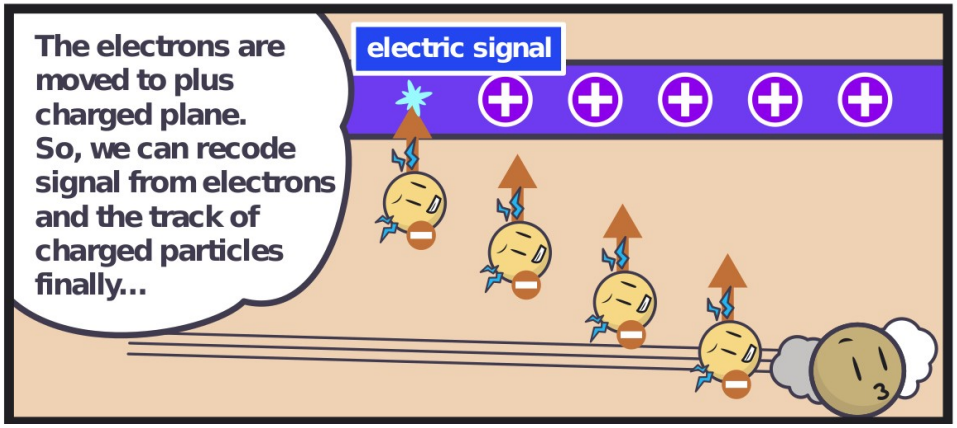
# Short Baseline Near Detector

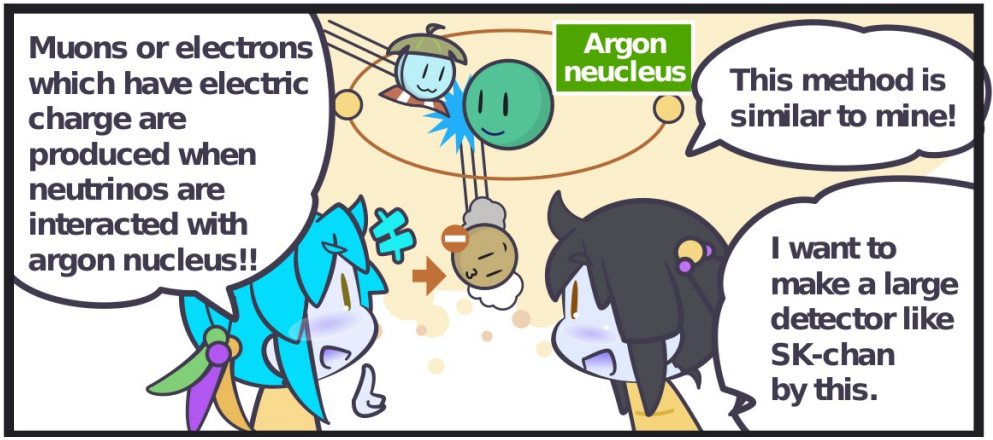
- The largest, and closest detector.
- 112t LArTPC placed at 110m from the beam pipe.
- Capable of excellent precision cross-section measurements.
  - On argon
  - Which of course can feed into DUNE.
- Under construction.
  - All TPC components have arrived at Fermilab!
  - Expect to start taking physics data in early 2021.



# Liquid Argon TPCs






Exploration of Particle Physics and Cosmology with Neutrinos, Higgstan and KEK

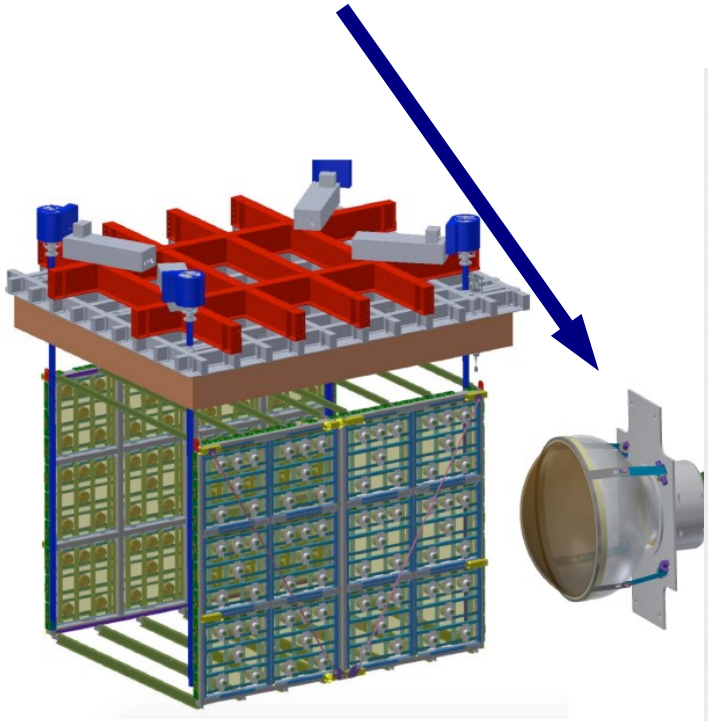
# Photon Detection System

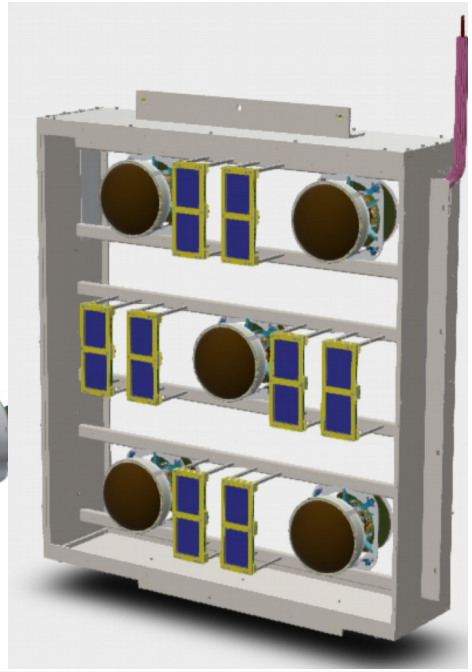
Photon detection is critical to LArTPC operation

→ SBND has a powerful compound photon detection system

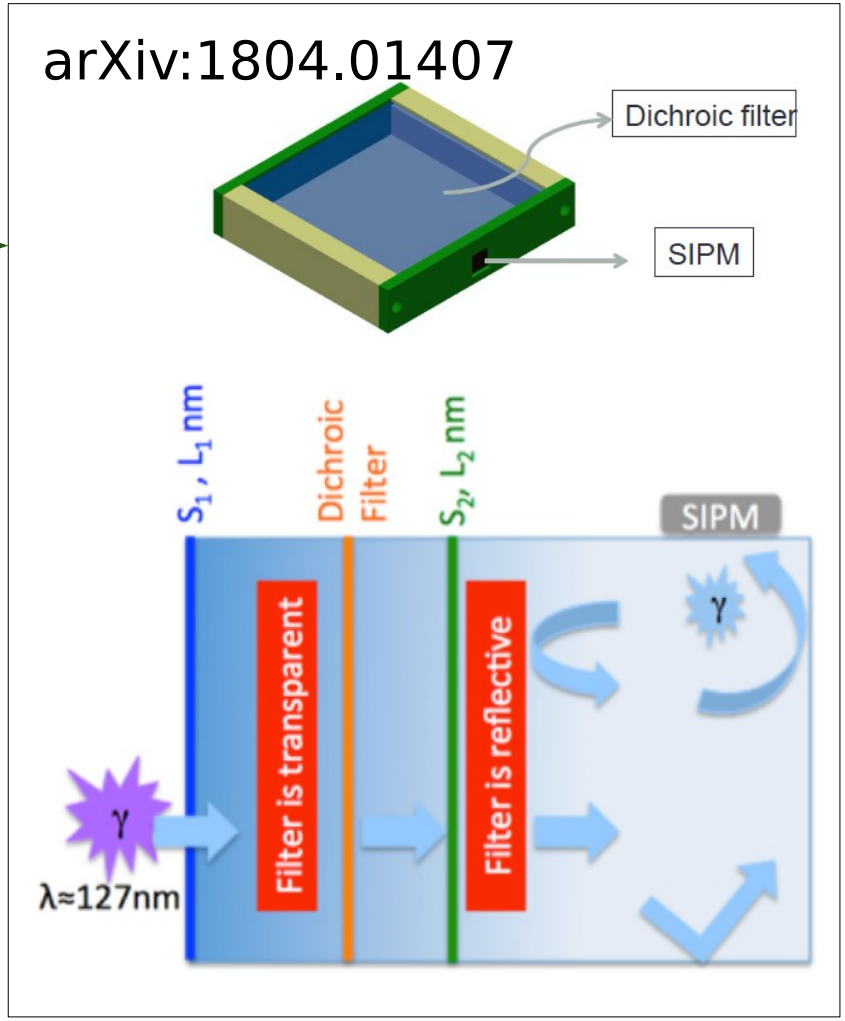
144 PMTs

X-ARAPUCA

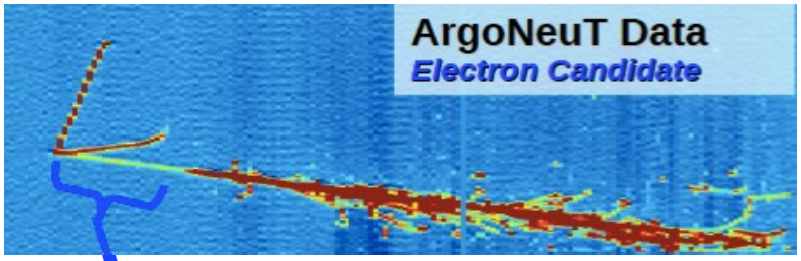


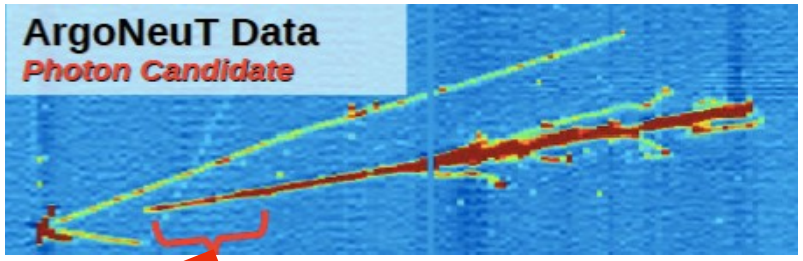


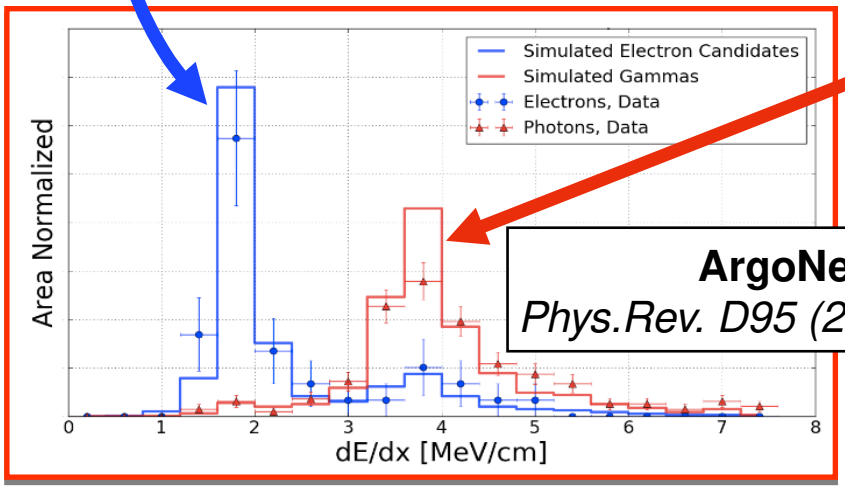
arXiv:1804.01407



# Electron-Photon Separation

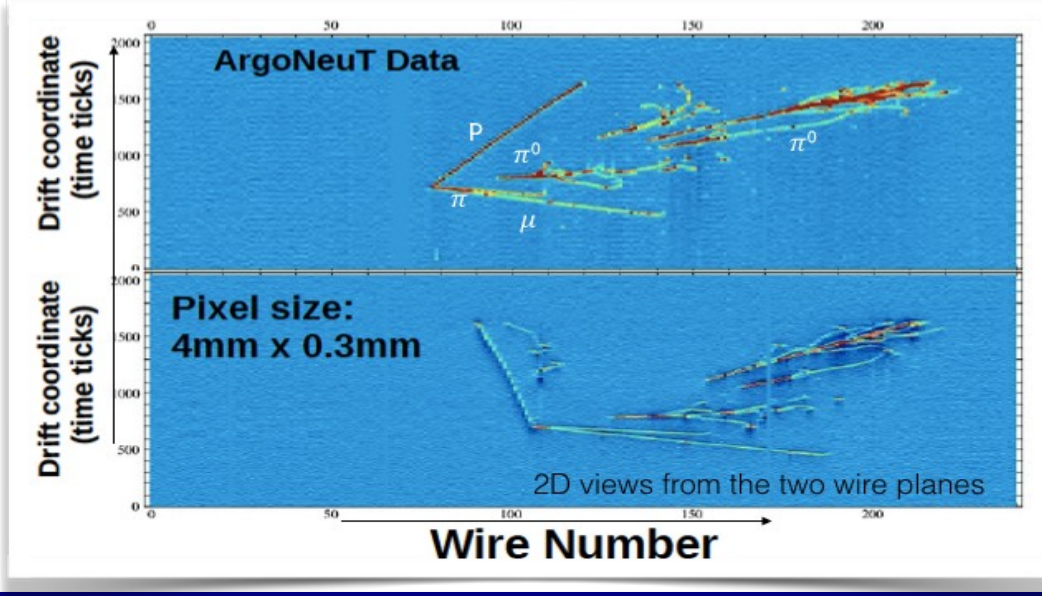



**ArgoNeuT**
*Phys.Rev. D95 (2017) 072005*

Analysing topology and dE/dx




e-$\gamma$ discrimination capability of LAr is crucial to understand the signal/background nature of the $\nu_e$-like events observed by MiniBooNE

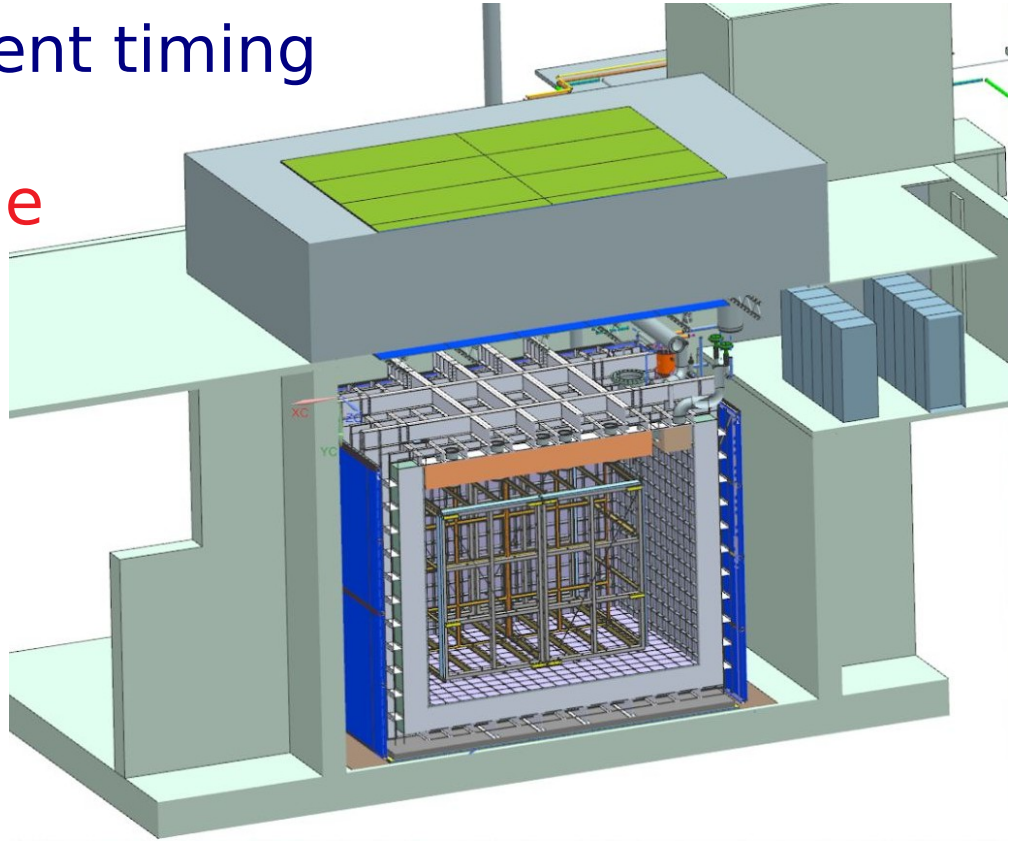
# Cosmic Ray Reduction

- LArTPCs are slow (~ms timing)
  - With SBN on the surface, cosmics are a major concern.

arXiv:1612.04614

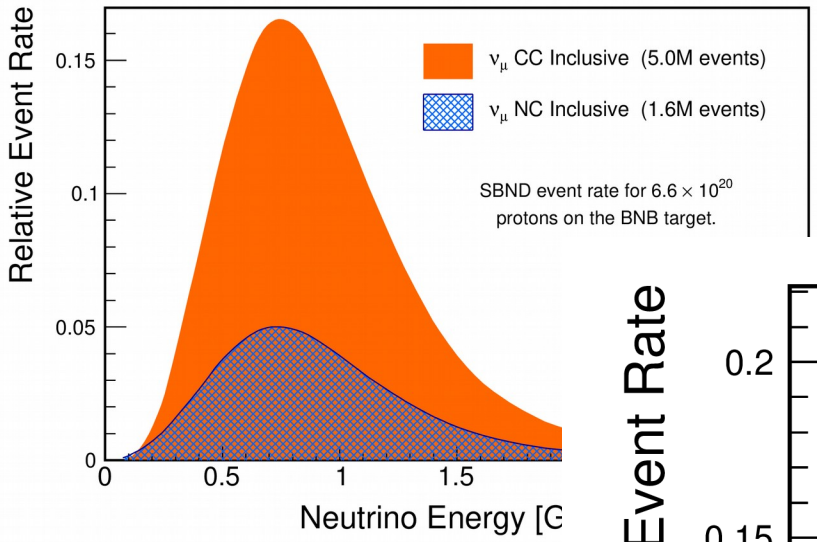
Add powerful Cosmic Ray Tagger using scintillator bars for excellent timing

Seven planes, >95% coverage



3m concrete overburden
→ Removes 99% of photon and hadron from cosmic showers

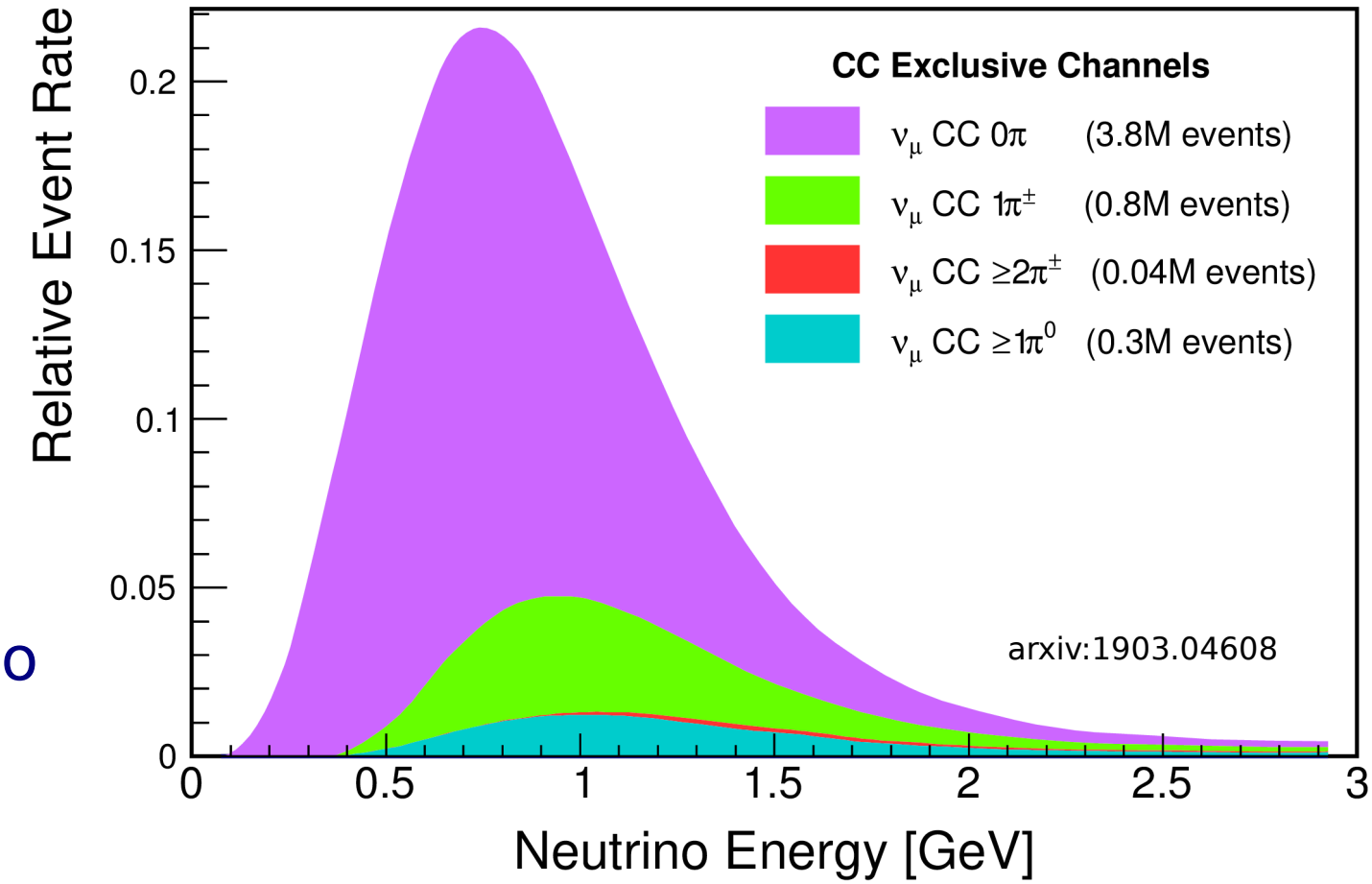
# SBND Physics – NuMu Event Rates



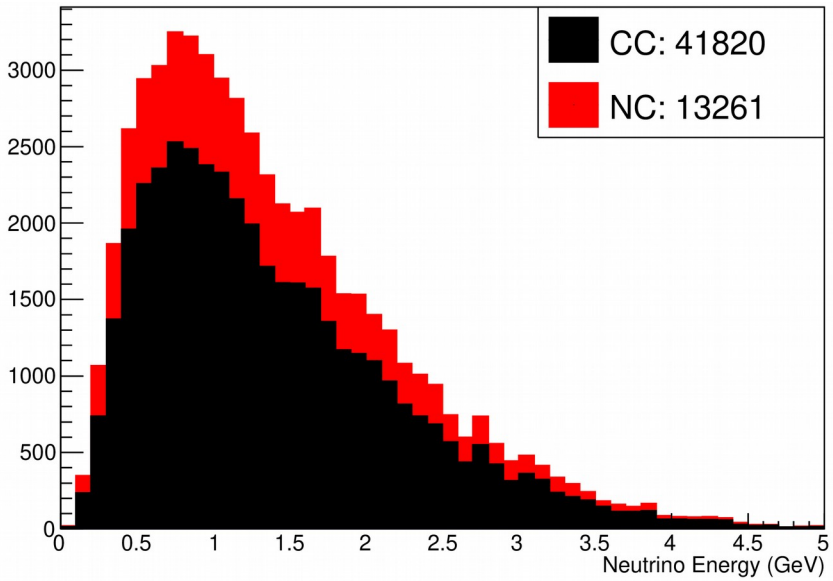

Five million ~1GeV NuMu CC events in three years running!

→ Unmatched cross-section precision.

LArTPC tracking efficiency allows breaking down cross-section measurements into many exclusive topologies.

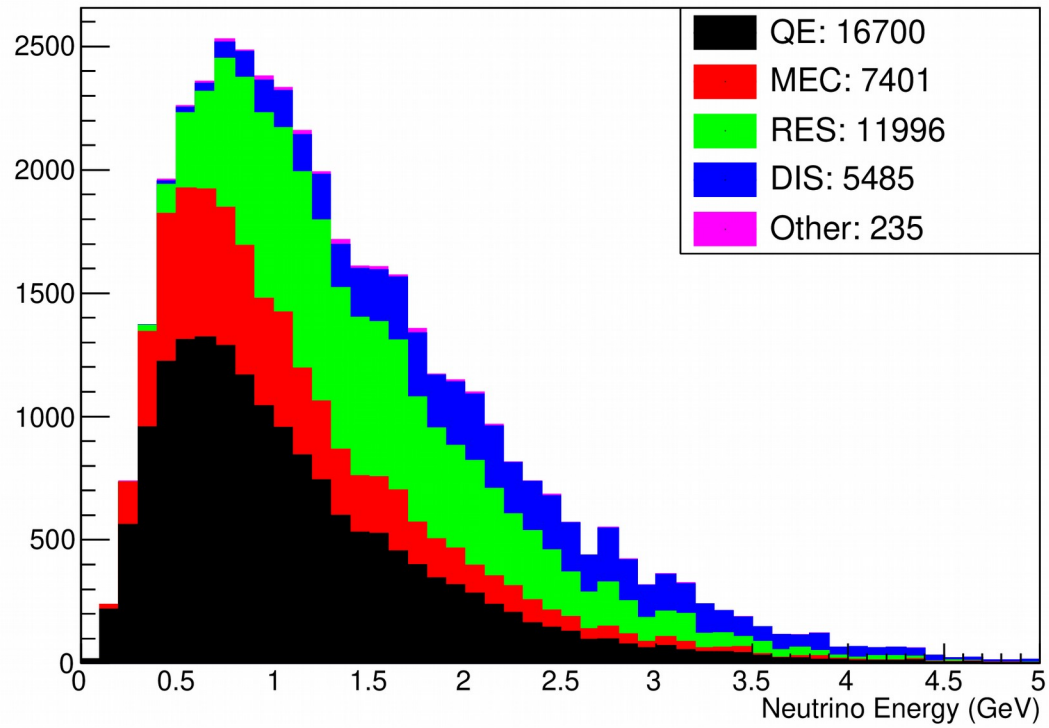


# SBND Physics – NuE Event Rates




~40k NuE CC events in three years running!

→ Significant statistics to analyse

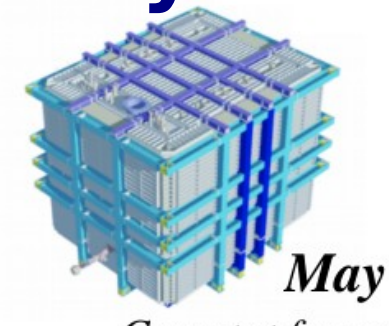



Also ~400 NuE electron elastic scatters

# SBND Progress

- Rapid progress being made on construction.
- Cryostat support structure fabricated at CERN – en route to FNAL.
- TPC assembly, DAQ and cold electronics work being performed at D-Zero Assembly Building at FNAL.
- Cryogenics are being installed at the SBN-ND building at FNAL.
  - This is the final location where SBND will run.

# Cryostat Support Pre-assembly at CERN



***May 28th***

*Cryostat frame pre-assembly ongoing*

***July 10th***

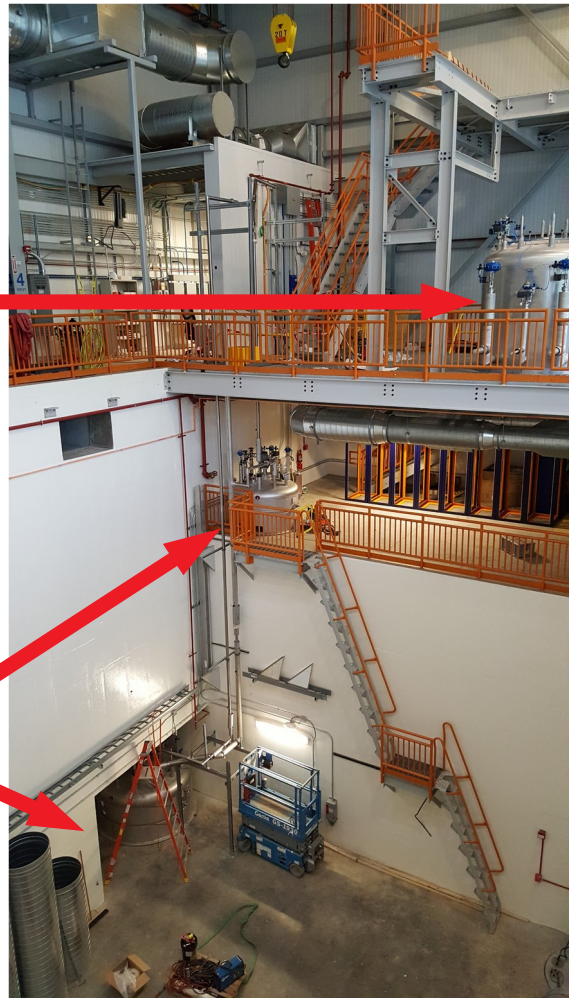
*Frame pre-assembly and painting near completion*

from R.Acciari

***July 15h***

*Painting and trial assembly completed. Getting ready for shipping*

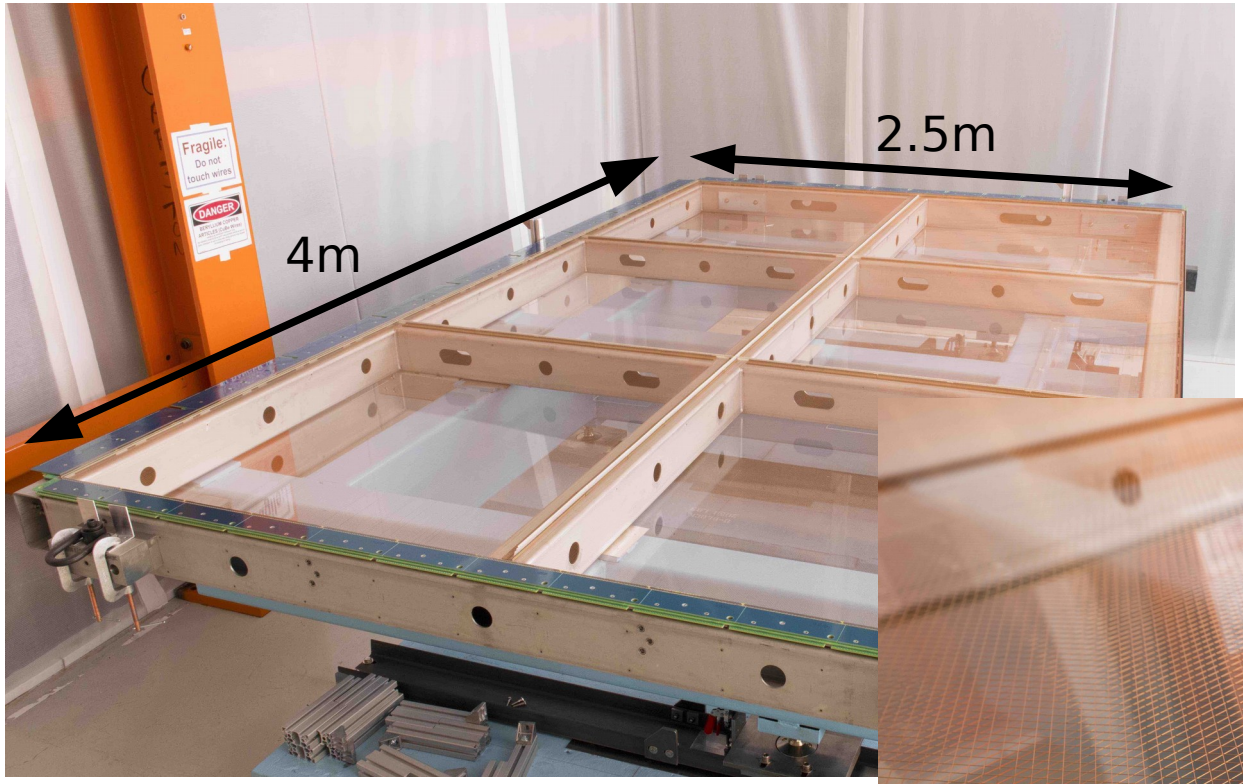
# SBN ND Building - Cryogenics



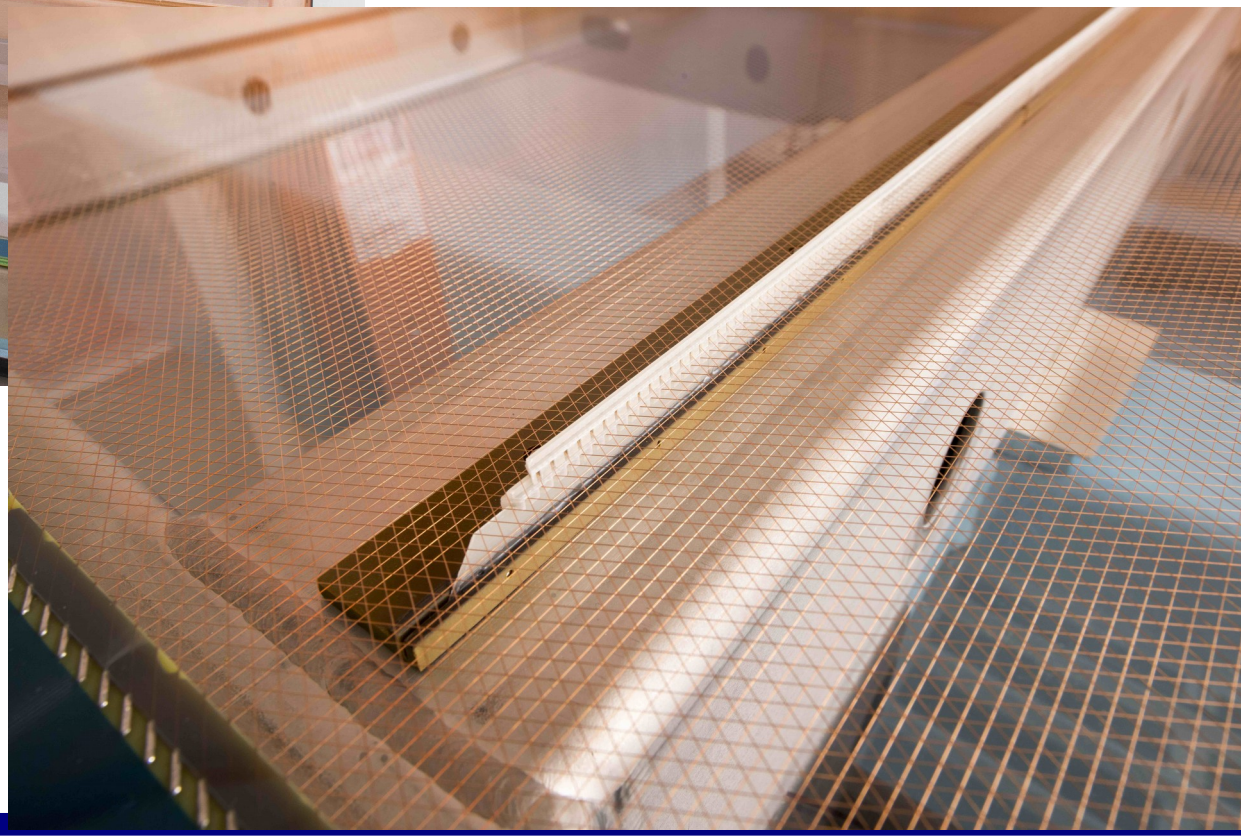
3 ND valve boxes

ND Argon filter, at FD building

# TPC Assembly – D-Zero Building



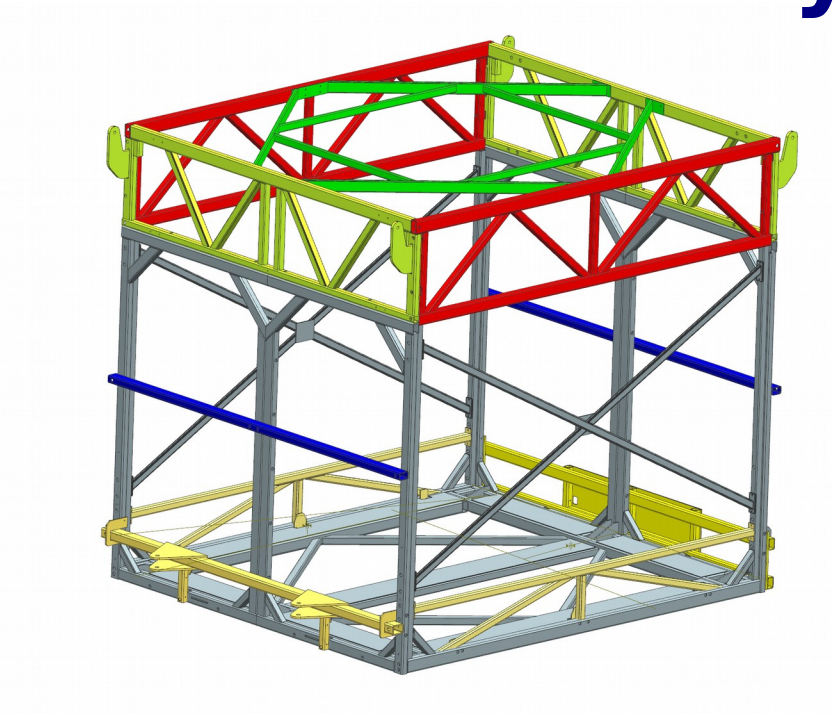

Anode Plane Assembly: 2800 Copper-Beryllium wires in 3 planes.



SBND uses four of these APAs in two coupled pairs

# TPC Assembly

# Assembly Transport Frame

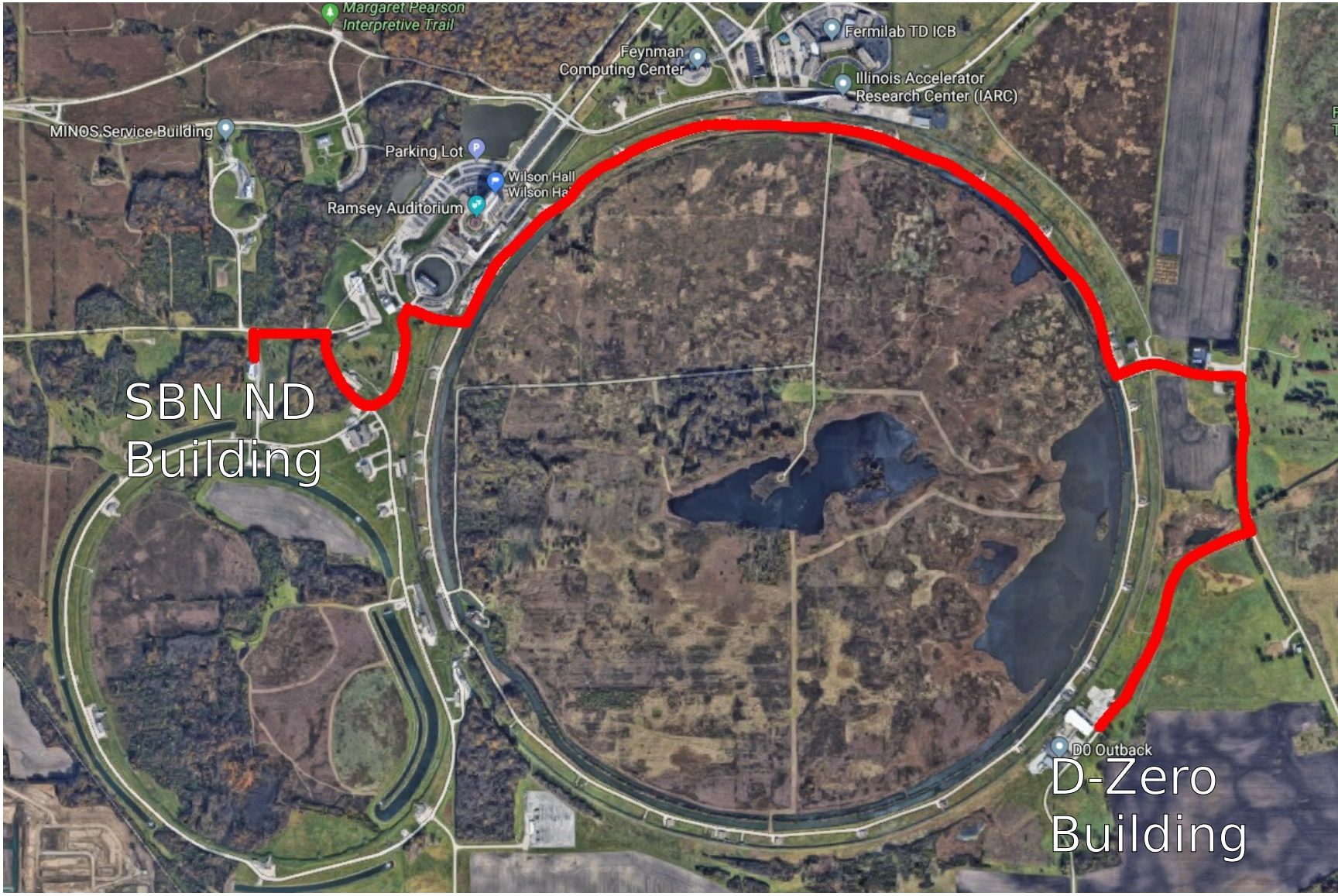


Frame for assembling TPC and transporting to SBN ND building:

→ nearing completion!

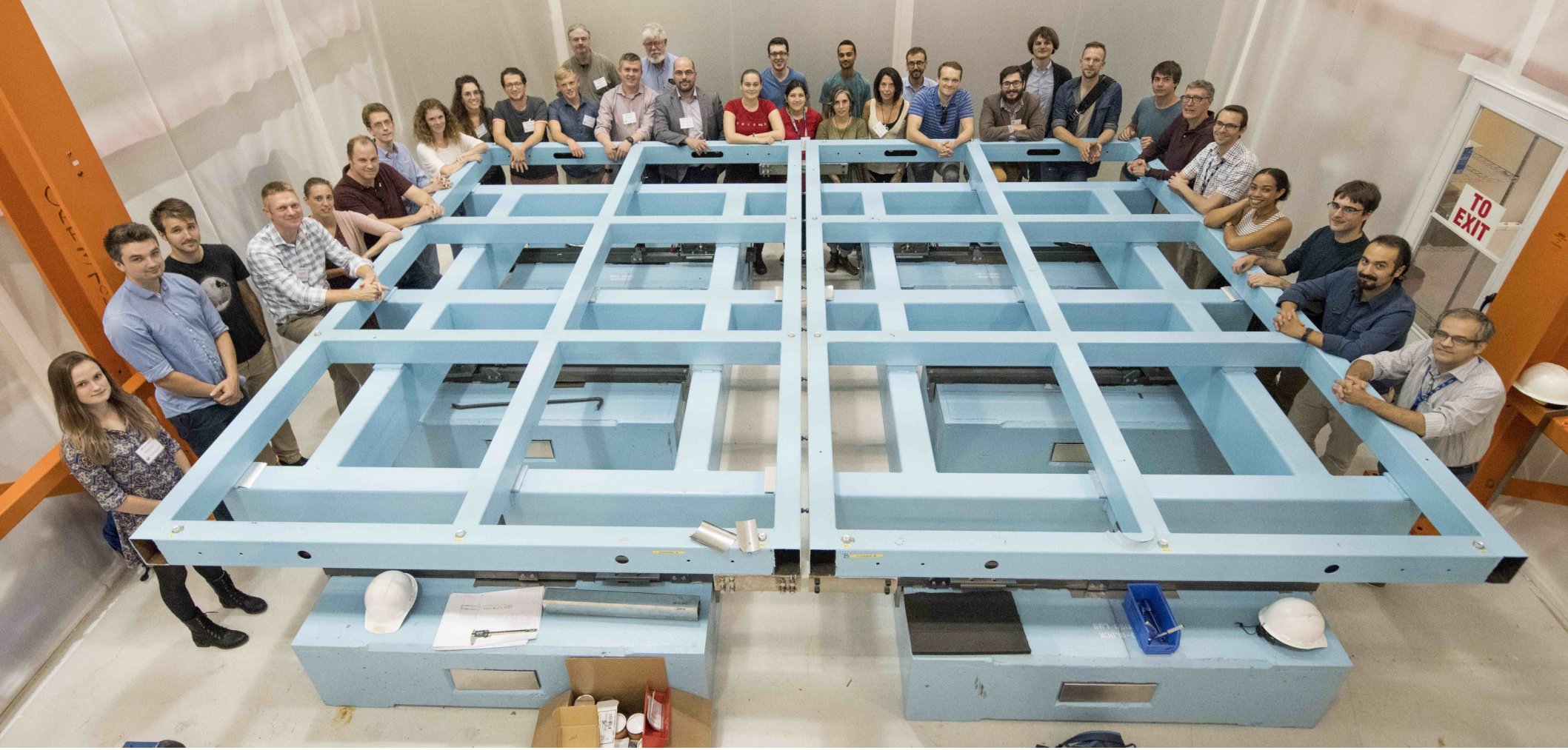
# TPC Transport Expected Route

Expected to transport TPC to ND building in early 2020



# Outlook

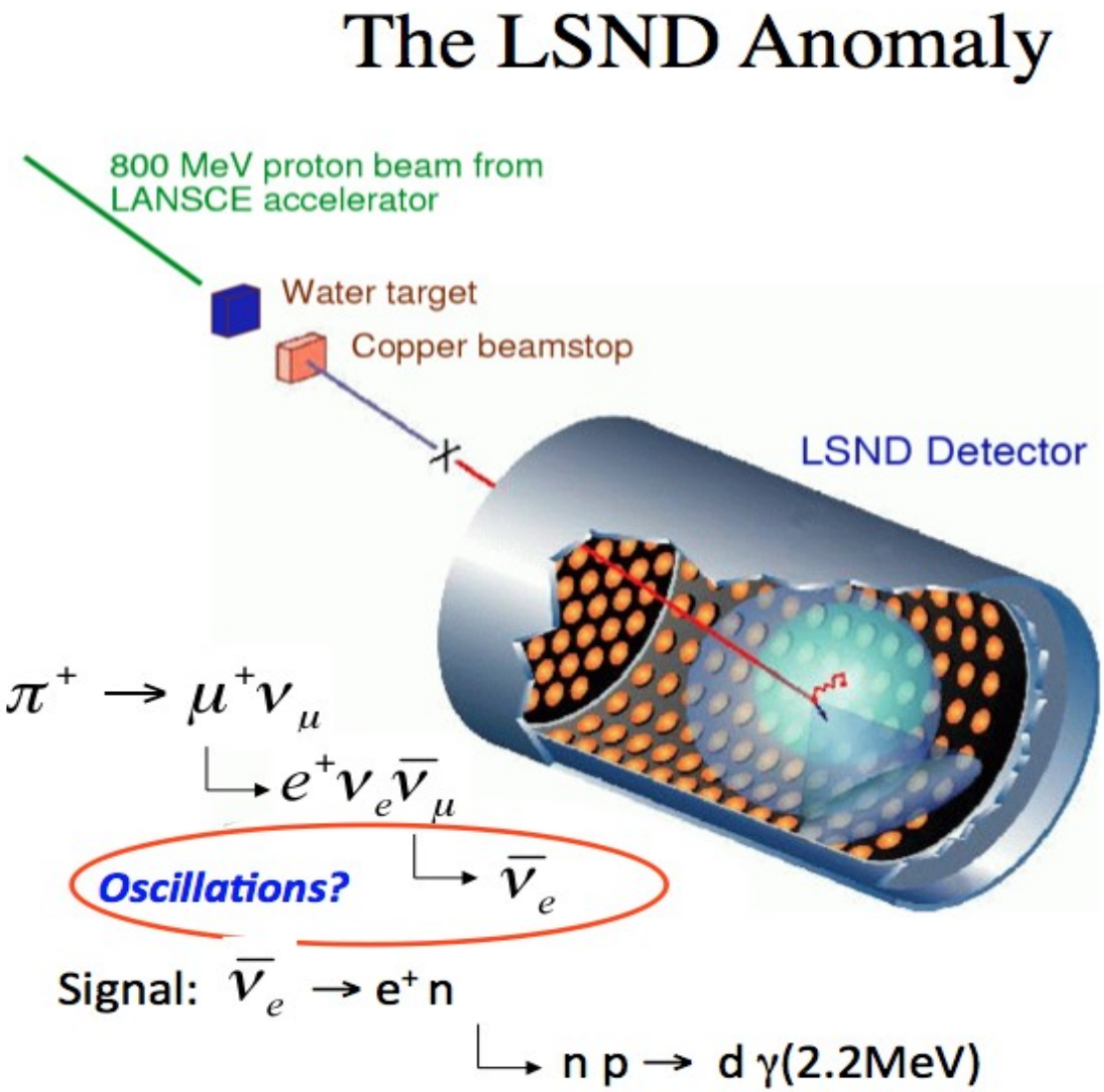
- SBND is a new Liquid Argon TPC being built for the SBN program at FNAL.
  - Powerful capability to investigate potential light steriles and other new physics.
  - Unprecedented precision cross-section measurements on Argon.
- Rapid progress being made.
  - Most components now at FNAL.
    - Cryostat to be assembled in October 2019.
    - TPC to be completed and moved to final building early 2020.
    - Commissioning and filling in 2020.
    - Collect 3 years of neutrino beam data from early 2021.
- An exciting time to be on SBND!

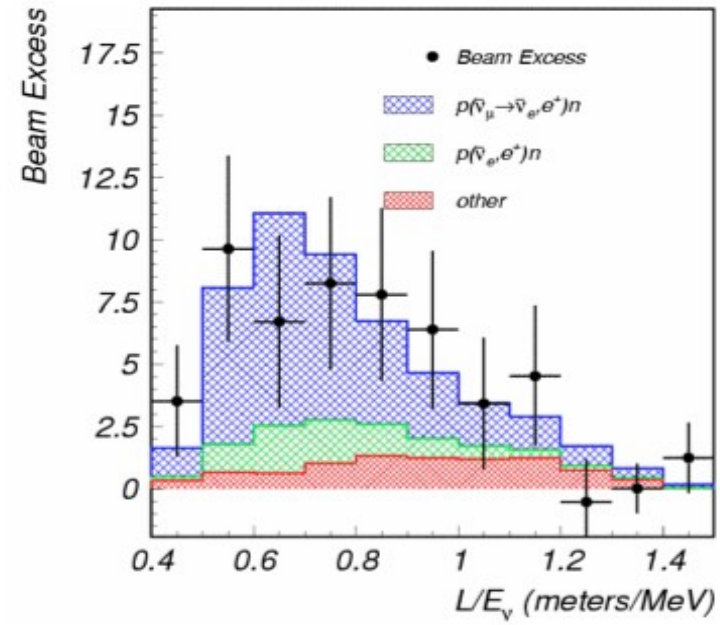



# Thanks for listening!

# Bonus Slides

# LSND Excess



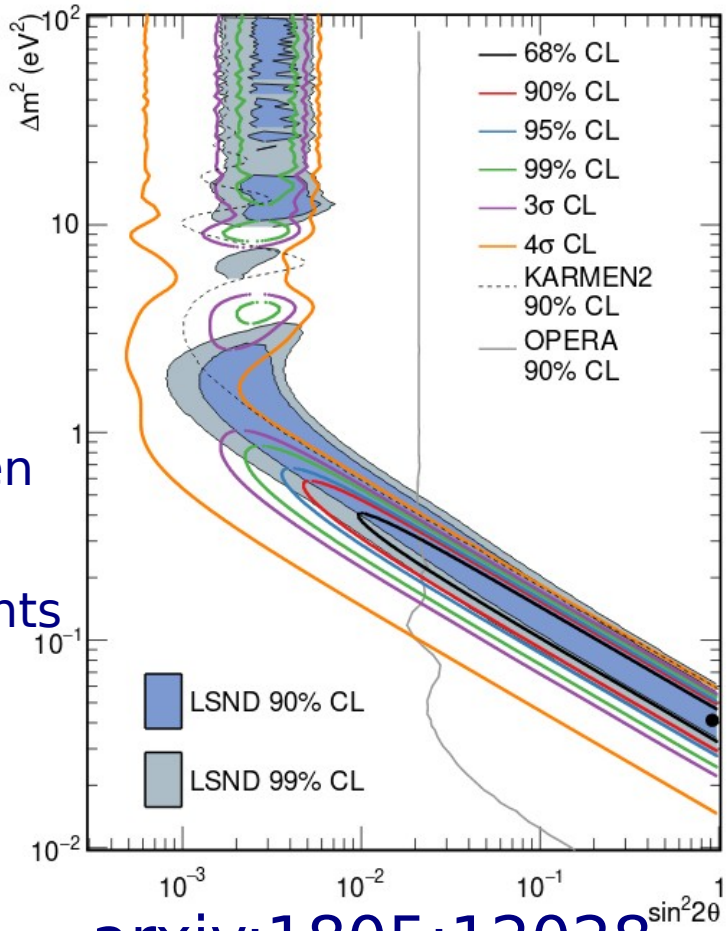




3.8 sigma excess

arXiv:nucl-ex/9605002

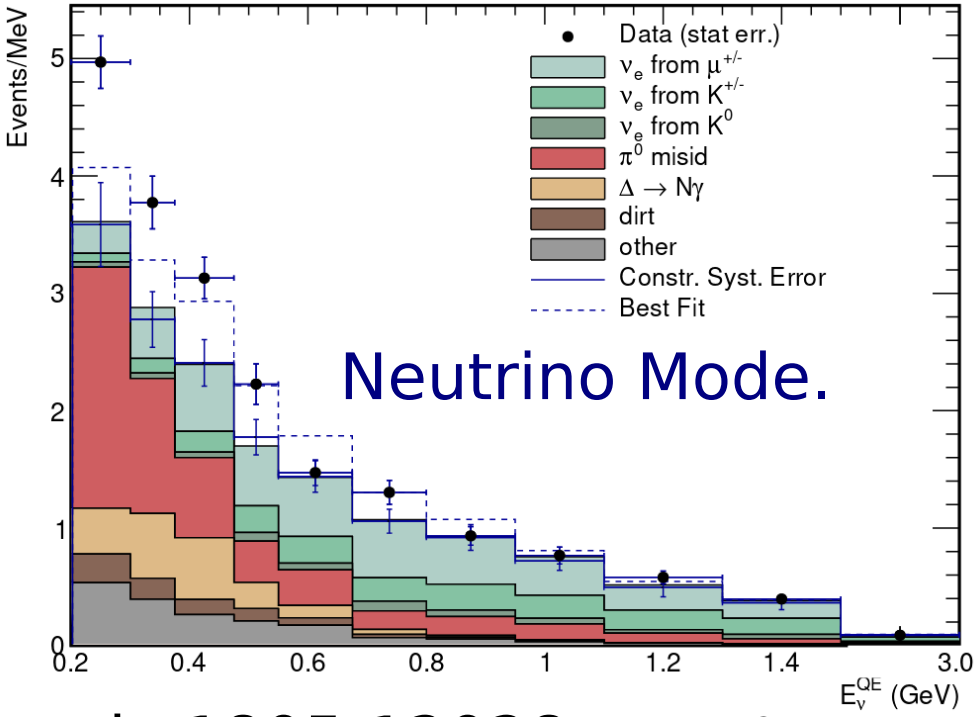
# LSND and MiniBooNE

- 20 years ago, the Liquid Scintillator Neutrino Detector at LANL saw an unexpected signal. arXiv:nucl-ex/9605002
  - Excess of electron antineutrinos in a muon antineutrino beam, 3.8σ
  - Evidence for a sterile neutrino?
- Development of the MiniBooNE experiment to test this hypothesis.
  - MiniBooNE collected 12.84E20 POT in neutrino and 11.27E20 POT in antineutrino mode between 2002 and 2017.
  - Also observed excess of electron-like CCQE events
    - 4.5σ excess in neutrino mode.
    - 4.7σ excess in antineutrino mode.
    - 6.0σ when combined with LSND.

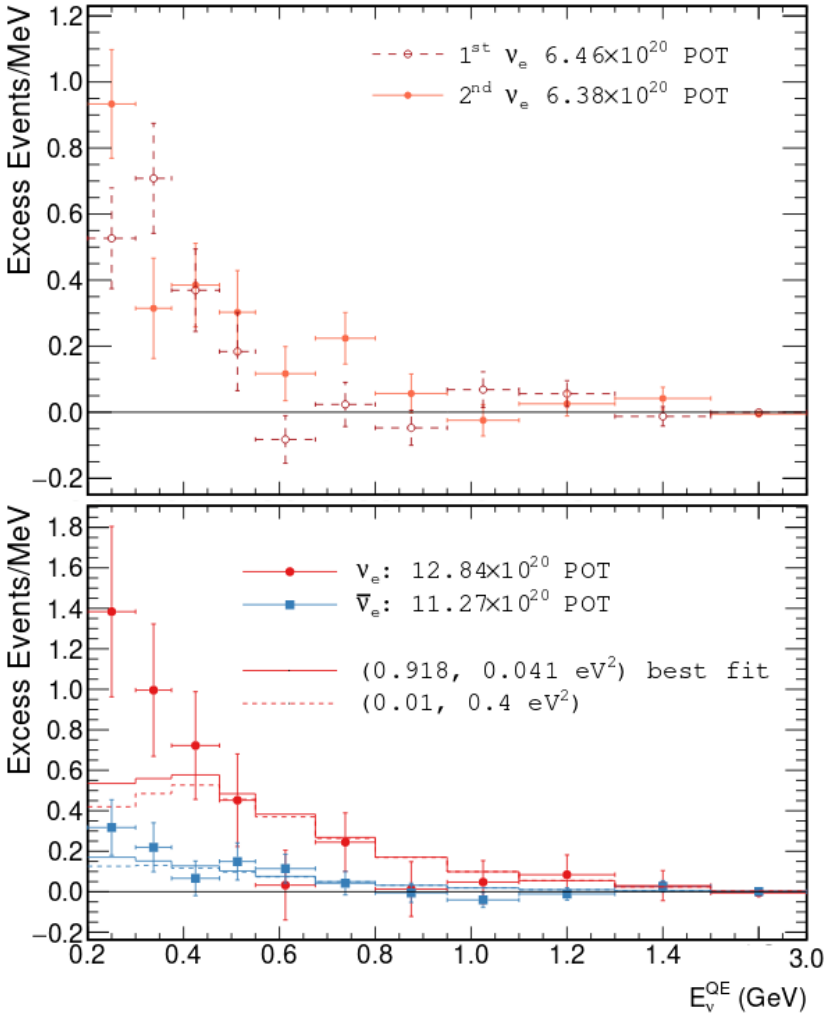



arxiv:1805:12028

# MiniBooNE Excess



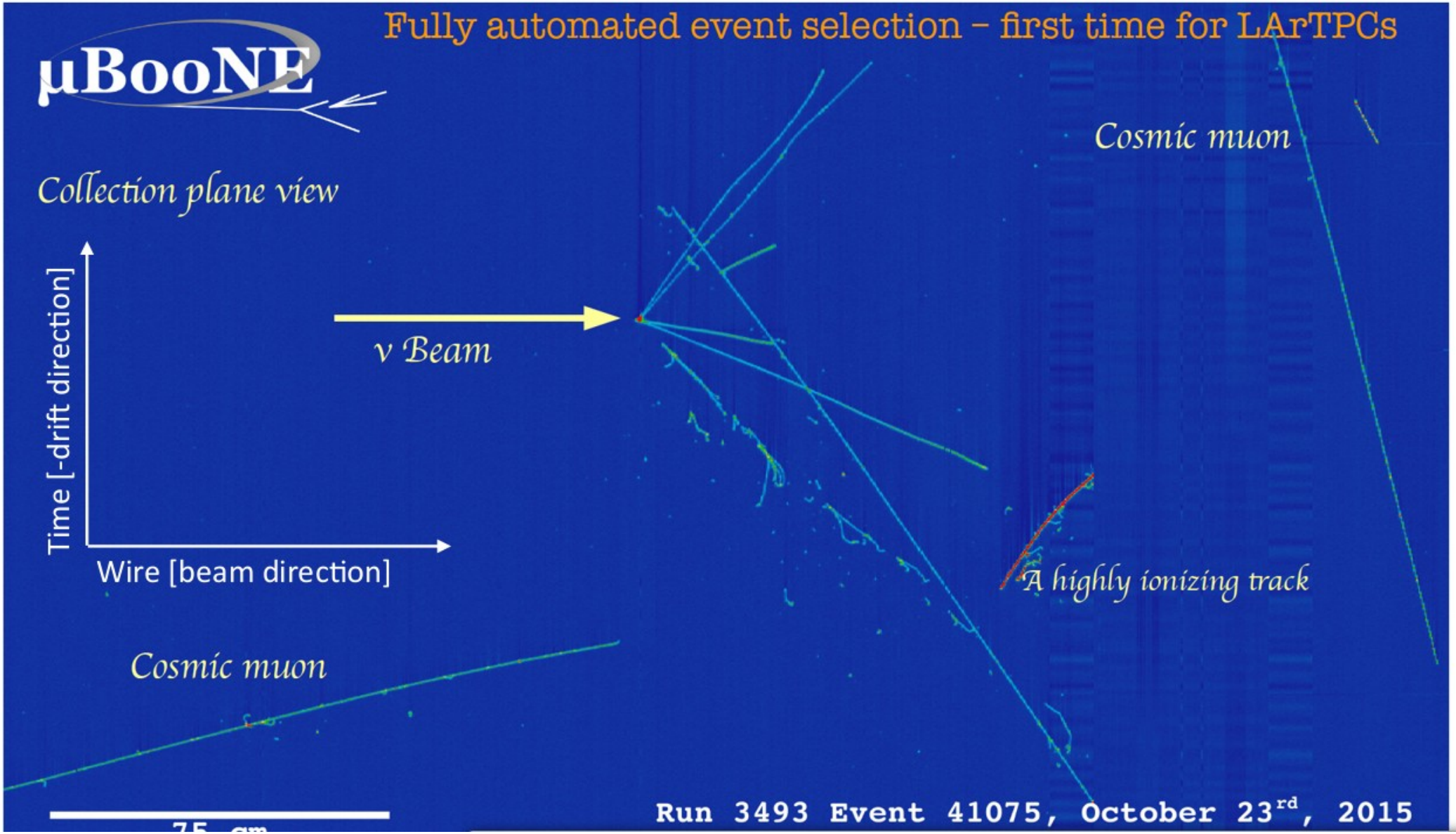

arxiv:1805:12028




MiniBooNE does not have good electron-photon separation

# Liquid Argon TPCs

- First proposed by Carlo Rubbia in 1977.
  - A “digital bubble chamber”.
- Excellent capabilities for tracking, PID and calorimetry.
- Very high resolution.
- Capable of being run at very high sensitive masses.
- The “dream” detector for neutrino experiments
  - Which require large masses and accurate ability to differentiate many different processes.


Fully automated event selection – first time for LArTPCs
μBooNE
Collection plane view
Time [-drift direction]
Wire [beam direction]
ν Beam
Cosmic muon
A highly ionizing track
Cosmic muon
Run 3493 Event 41075, October 23rd, 2015

# What is going on?

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- 3+1 doesn't work.
  - A number of global-fit papers consider the removal of an experiment or class of experiments when performing a 3+1 or 3+0 fit. In general, it is *still* hard to perform a reasonable fit in these cases.
- It is fairly clear that any new physics explanation likely requires 'multiple layers' to explain all the results.
  - One sterile neutrino and a new interaction or decay? Two/three sterile neutrinos?
- There may be new physics here. But, the possibility of underestimated/unknown systematics ("bad data") remains. Global fits suffer badly from this very real possibility. We shouldn't forget: Neutrino experiments are hard.
- Unfortunately, we have entered the realm of 'sigmas doesn't matter', recalling that the MiniBooNE+LSND combo (w/o considering others) is now 6.1σ.
  - **A wiggle in L/E, observation in multiple channels with *coherence* among the results (and cosmology), or some other smoking gun, needs to be seen for discovery!**
- What to do? Keep pushing with better detectors and better neutrino sources. **We must figure this out!**
  - Even in the absence of an actual light sterile neutrino or other new physics, short-baseline experiments remain highly compelling.