FIRST LOOK AT MICROBOONE

Ben Carls

Fermilab

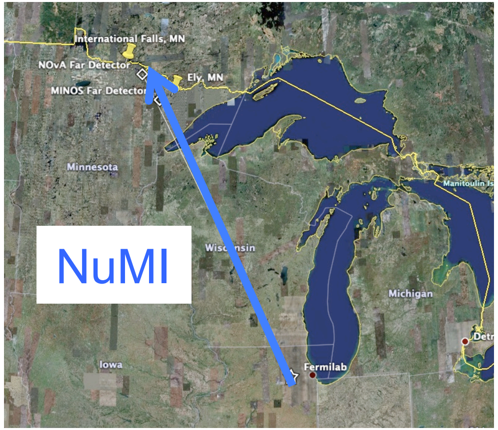
Short-baseline neutrinos

- Start with two neutrino oscillation

$$P(\alpha \to \beta) = \sin^2(2\theta)\sin^2\left(\frac{1.27 L \Delta m^2}{E}\right)$$

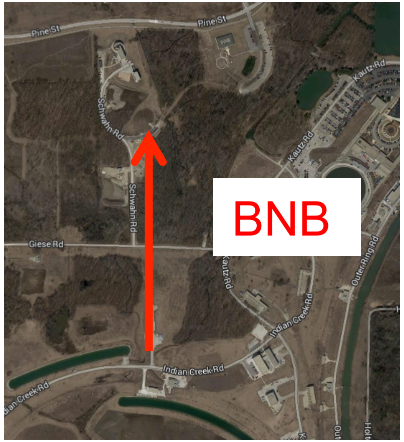
- L/E is the experimental parameter we set
  - —For long-baseline like NOvA, **E ~ 2 GeV**, **L ~ 810 km** for **L/E ~ 400 km/GeV**
  - —For short-baseline like MiniBooNE, **E ~ 0.8 GeV**, **L ~ 0.5 km** for **L/E ~ 0.6 km/GeV**
- Different baselines can bring out different physics, such as searches for sterile neutrinos

Long-baseline



vs.

Short-baseline



LSND Anomaly

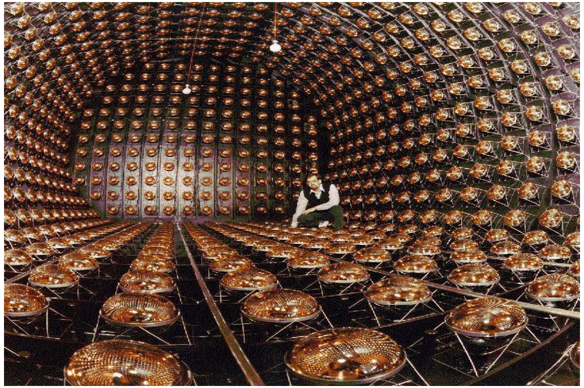
- The motivation for MicroBooNE begins with LSND
- LSND observed a $\bar{\nu}_e$ appearance signal in a $\bar{\nu}_\mu$ beam
- Excess of 87.9 ± 23.2, for 3.8σ

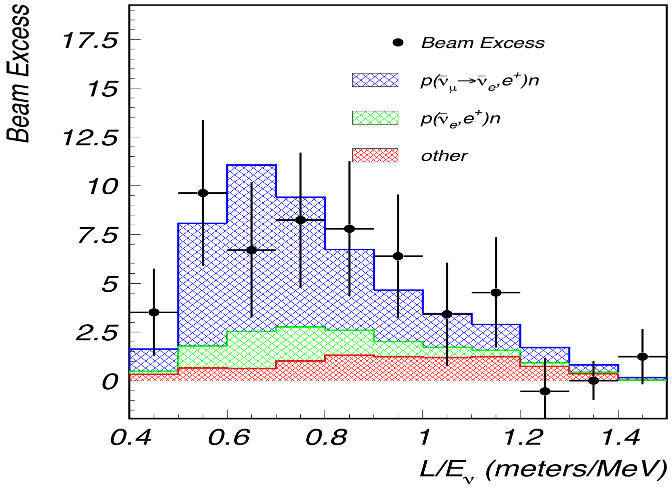
$$P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = \sin^2(2\theta)\sin^2\left(\frac{1.27L\Delta m^2}{E}\right) = 0.245 \pm 0.081\%$$

L/E – defined by experimental setup

θ – mixing angle

Δm^2 – oscillation frequency





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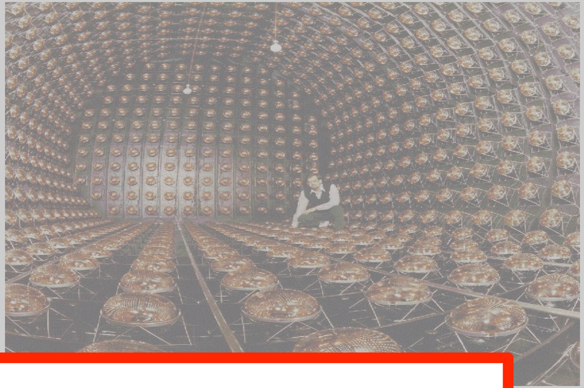

Stay tuned for Roxanne Guenette's talk about Fermilab's short-baseline program.

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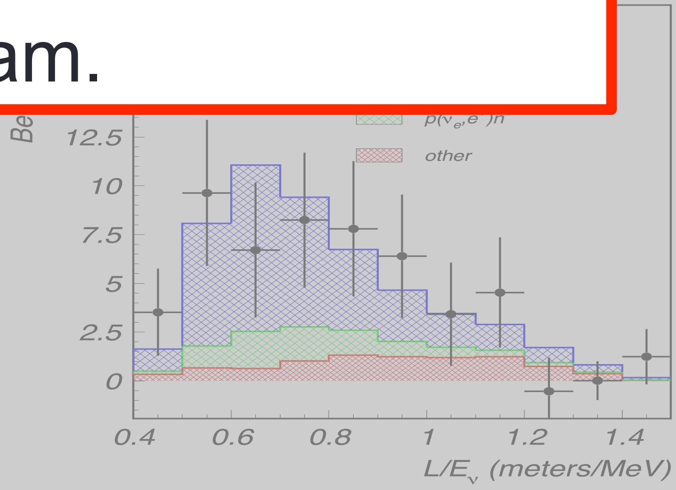
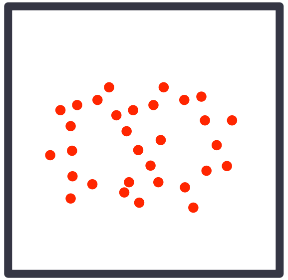
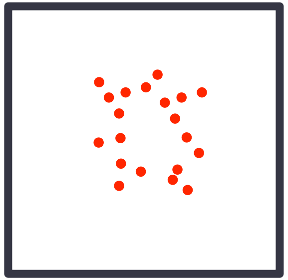


From LSND to MiniBooNE

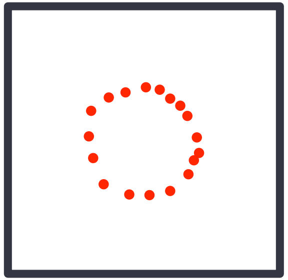
- MiniBooNE, a mineral oil based Cherenkov detector, was designed to observe or refute the LSND
- Looked for ν_e in a ν_μ beam off of the Fermilab Booster Neutrino Beam
- MiniBooNE, like all Cherenkov detectors, had trouble distinguishing π^0 to $\gamma\gamma$ (background, if a γ was missed) from a single electron (signal)



$\nu_\mu n \rightarrow \nu_\mu n \pi^0 (\pi^0 \rightarrow \gamma\gamma)$



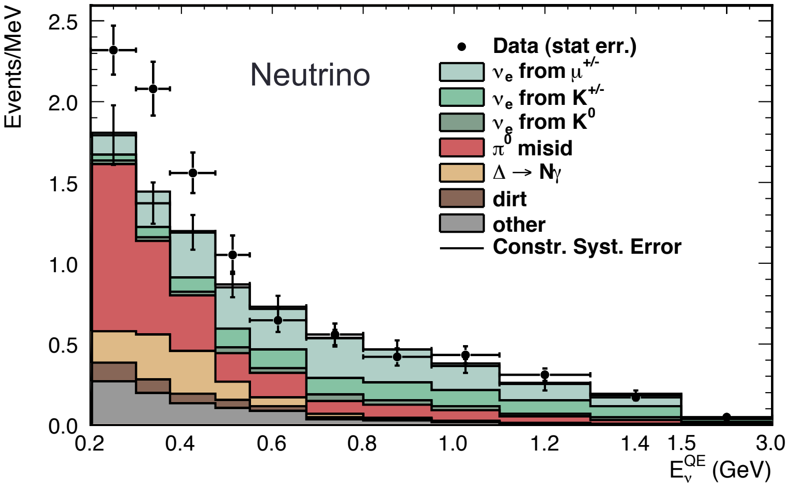
$\nu_e n \rightarrow e^- p$

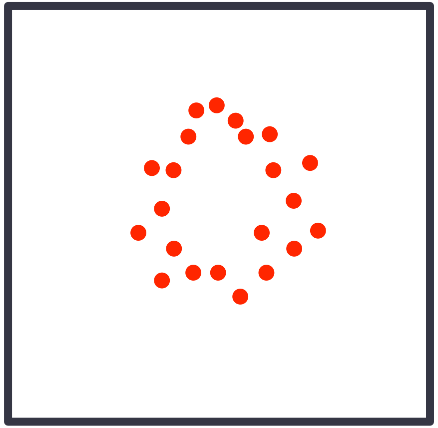


$\nu_\mu n \rightarrow \mu^- p$

MiniBooNE Excess

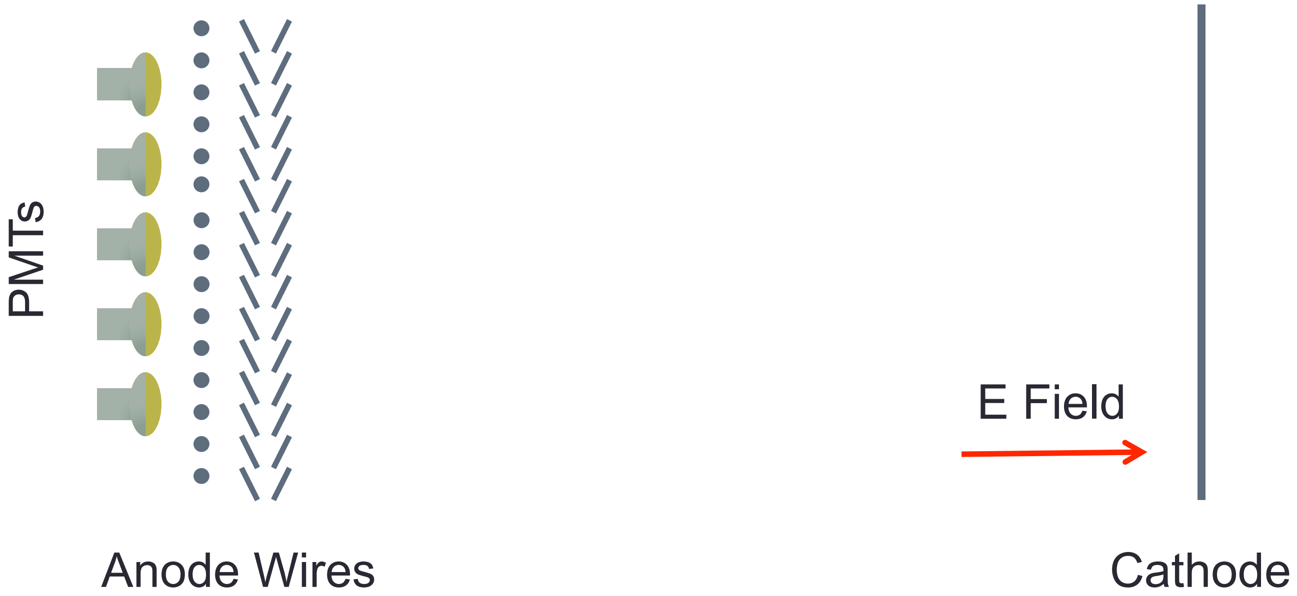
- MiniBooNE's oscillation analysis saw an excess in neutrino and antineutrino modes, 240.0 ± 62.9 events for 3.8σ
- Excesses appear in the region 0.2-0.475 GeV, where NC π^0 and processes producing a single photon dominate
- Problem is, a single photon looks just like an electron!





$$\nu_e n \rightarrow e^- p$$

The operation of a LArTPC



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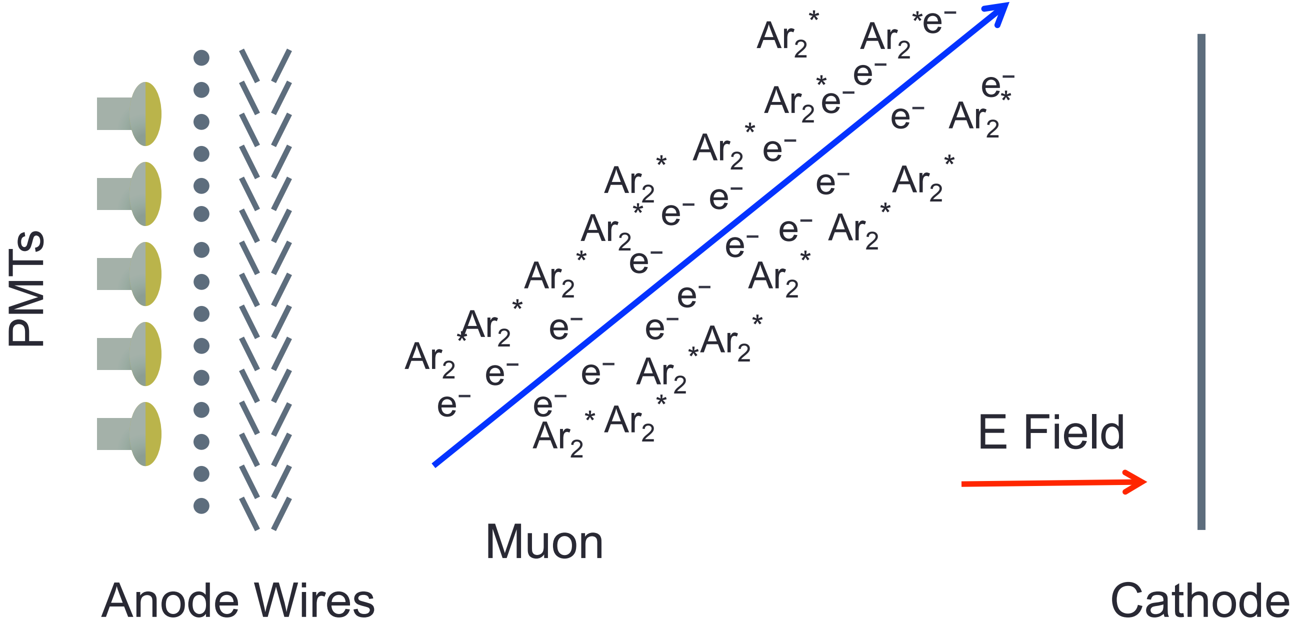

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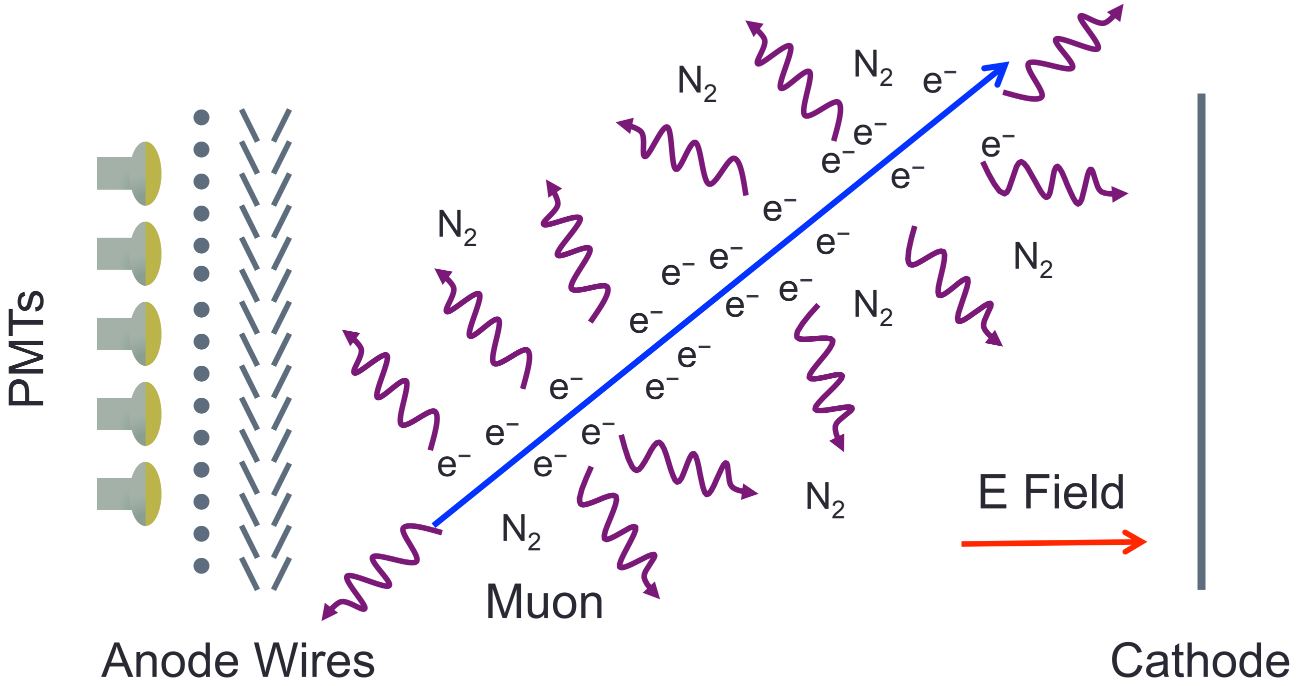

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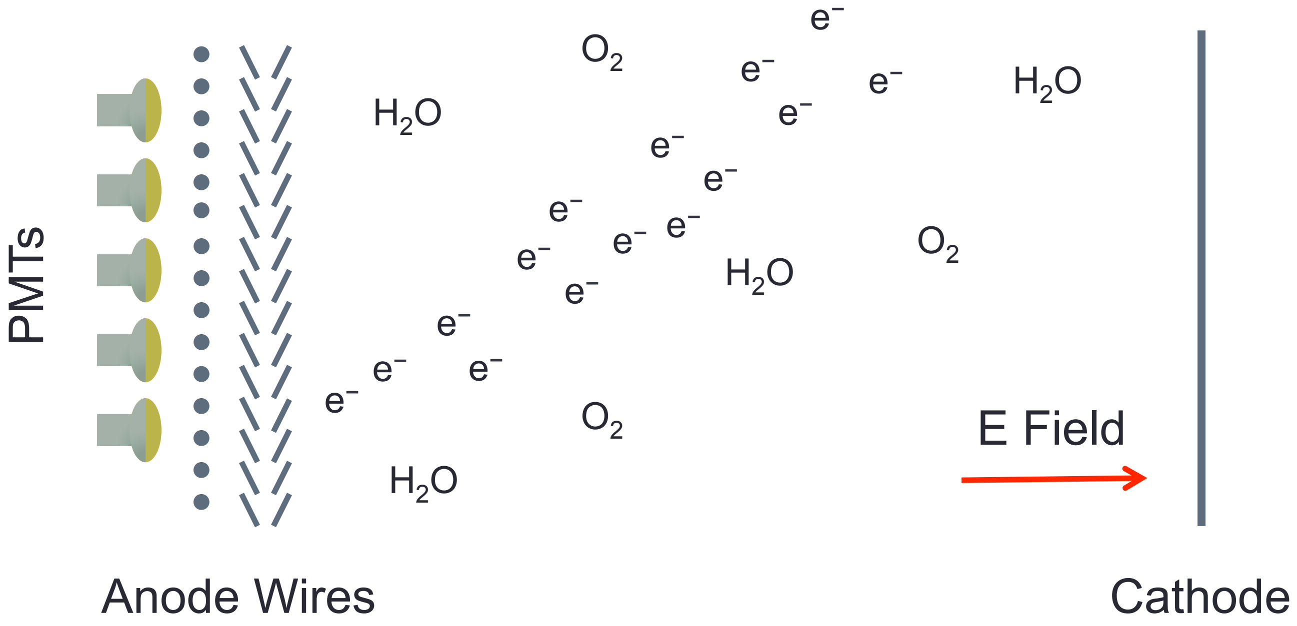

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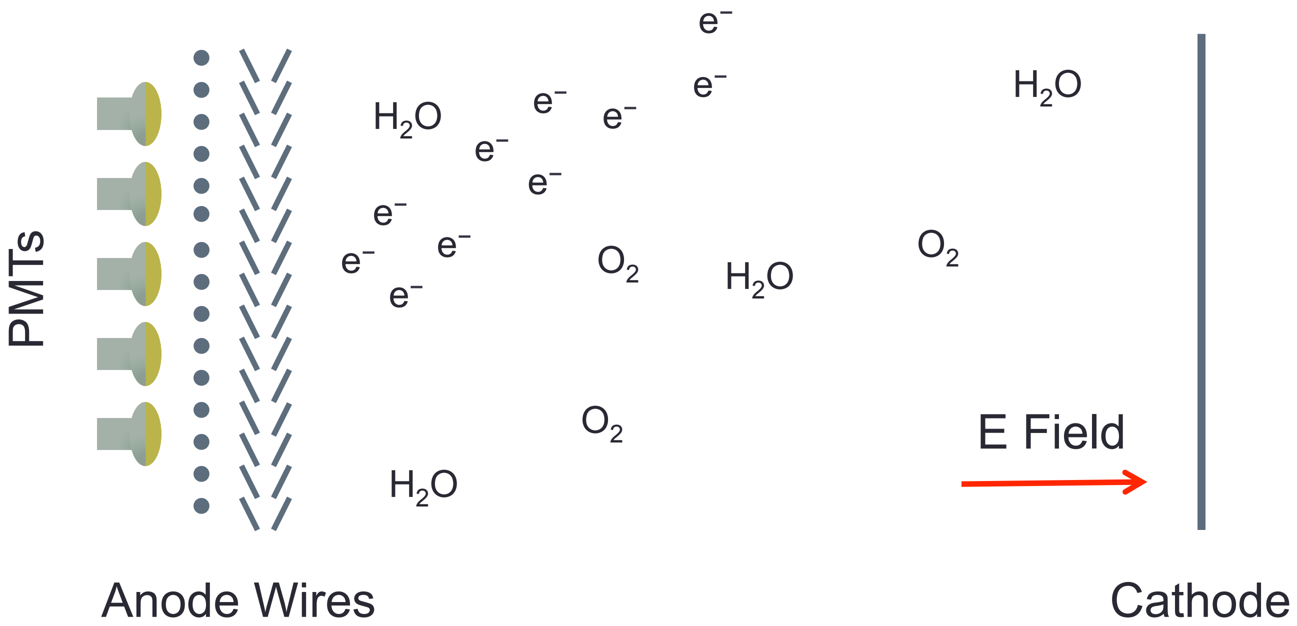

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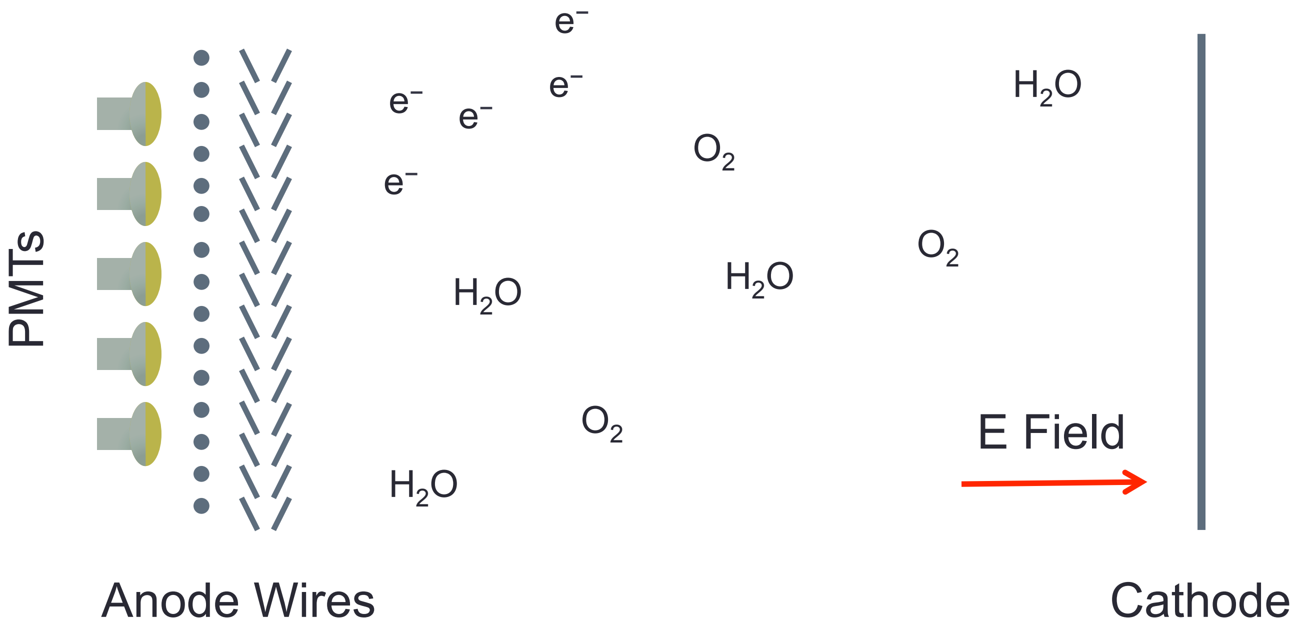
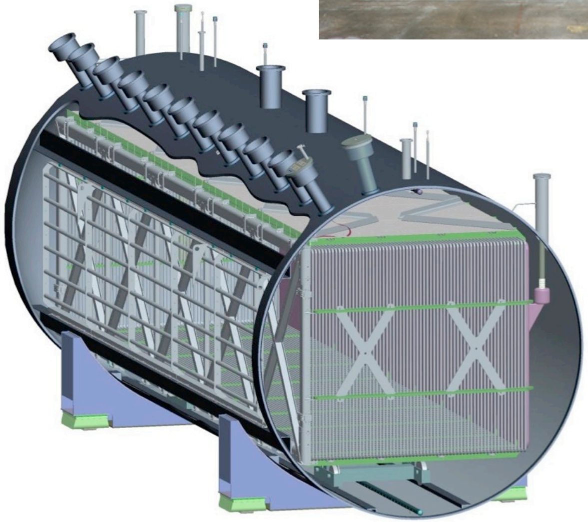


We need a few things to make it work

- First, we need high-voltage for drifting electrons
- Second, we need clean liquid argon
  - —Need a low-level of electronegative molecules like oxygen and water that eat up the drift electrons
  - —Need low-level of nitrogen since it quenches the scintillation process and absorbs the scintillation light

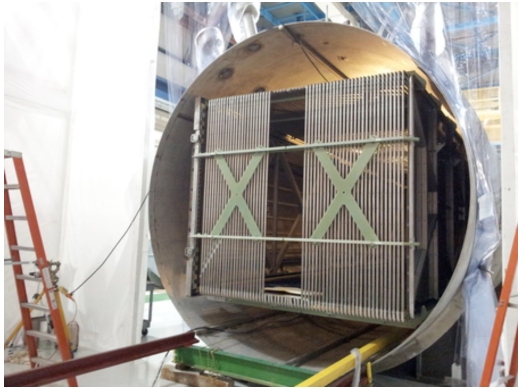
MicroBooNE Detector

- 60 ton fiducial volume (of 170 tons total) liquid Argon TPC
- TPC consists of 3 planes of wires; vertical Y, ±60° from Y for U and V
- Array of 32 PMTs sit behind TPC wires
- Purification and cryogenic system capable of achieving < 100 ppt O_2 and < 2 ppm N_2

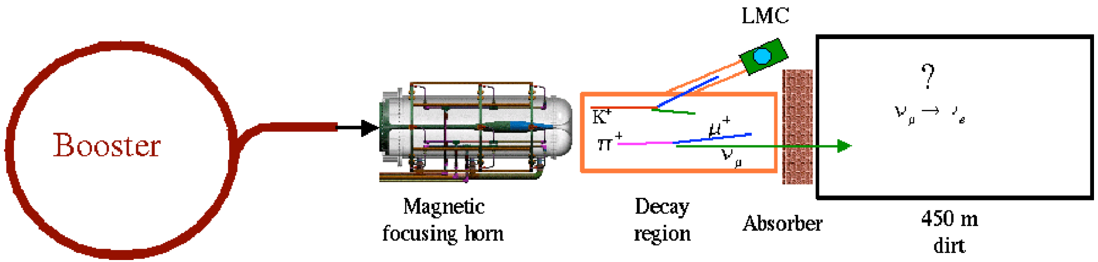


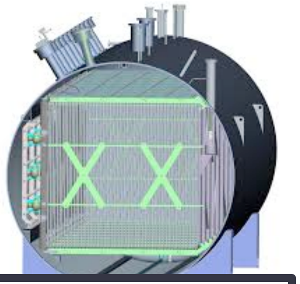
MicroBooNE Detector

- MicroBooNE has several R&D goals
  - —Cold front-end electronics which reside inside the vessel
  - —2.56 m drift distance across the TPC, longest done in a beam experiment
  - —Gas purge of cryostat instead of vessel evacuation

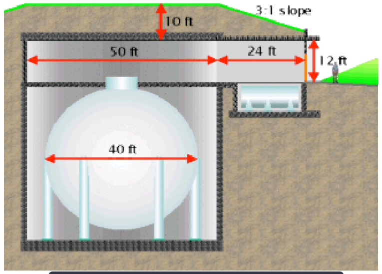


We get most of our neutrinos from the Booster Neutrino Beam at Fermilab





MicroBooNE

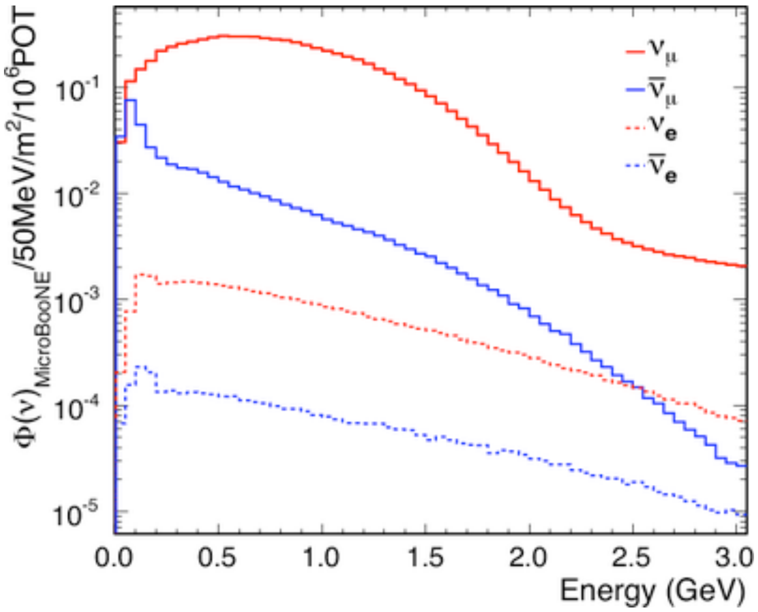


MiniBooNE

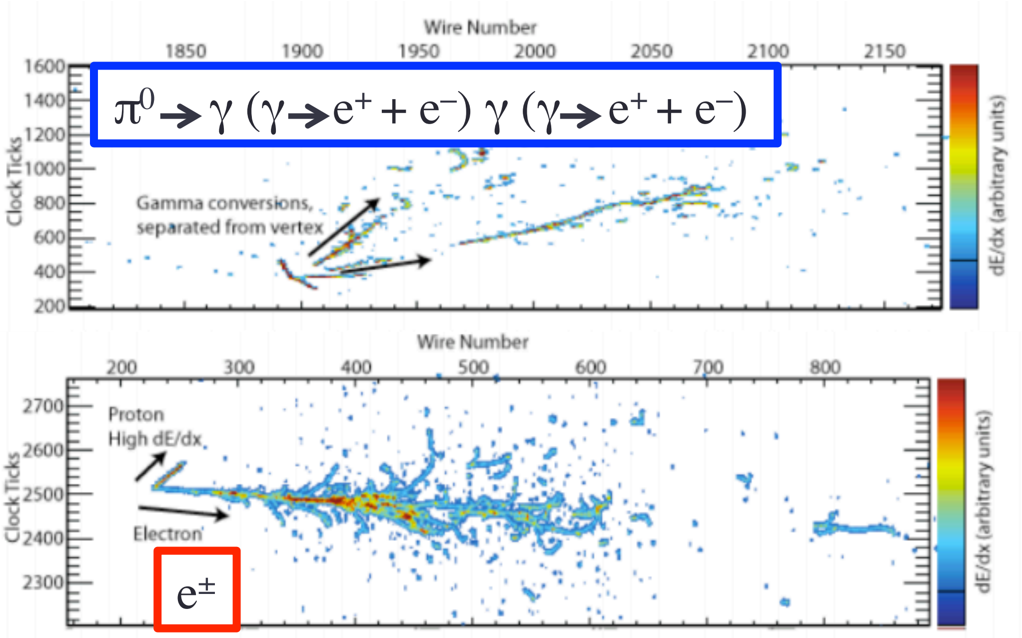
Not to scale!

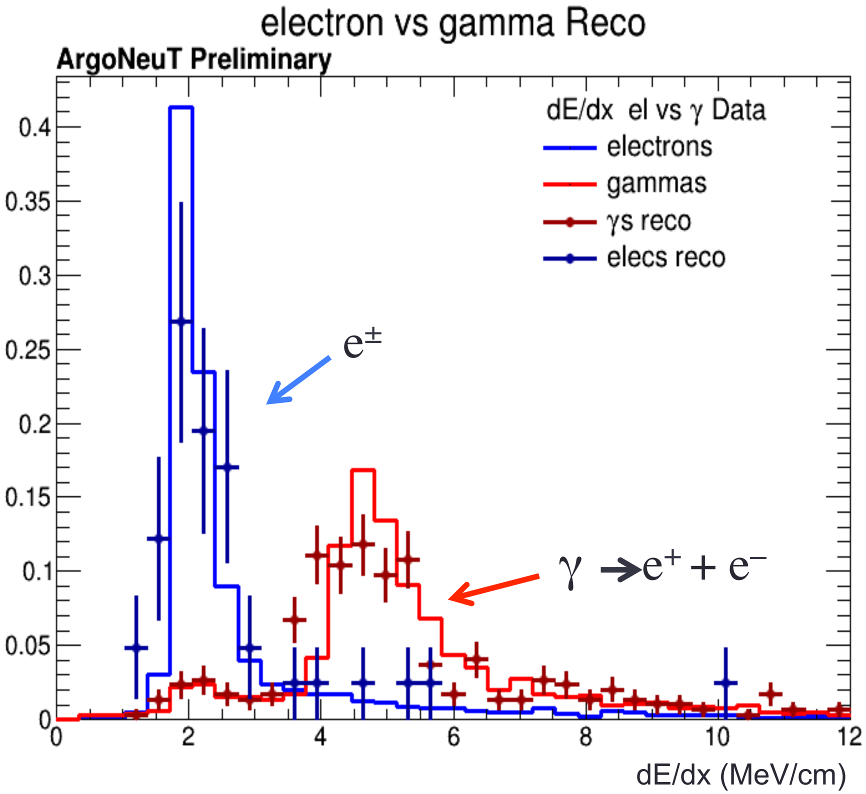
We get most of our neutrinos from the Booster Neutrino Beam at Fermilab

- Driven by 8 GeV protons hitting a beryllium target for a mean neutrino energy of 0.8 GeV
- Will provide MicroBooNE with the same L/E (oscillation parameter experiments set) to that of MiniBooNE
- Well known beam, already run for a decade, allows focus to be placed on understanding detector



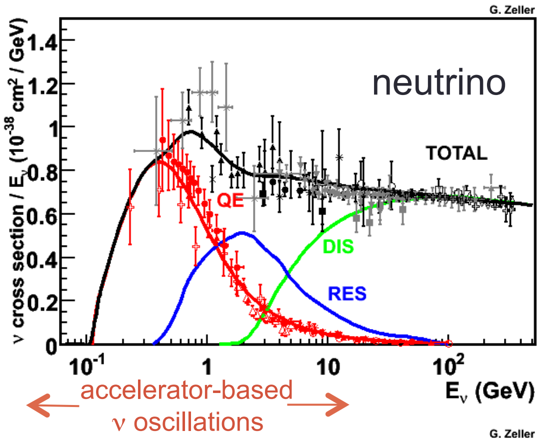
MicroBooNE

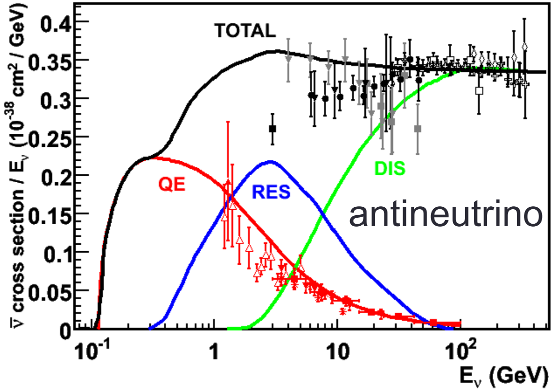




LArTPCs are excellent for distinguishing electrons from photons using dE/dx and event topologies

Neutrino Cross Sections

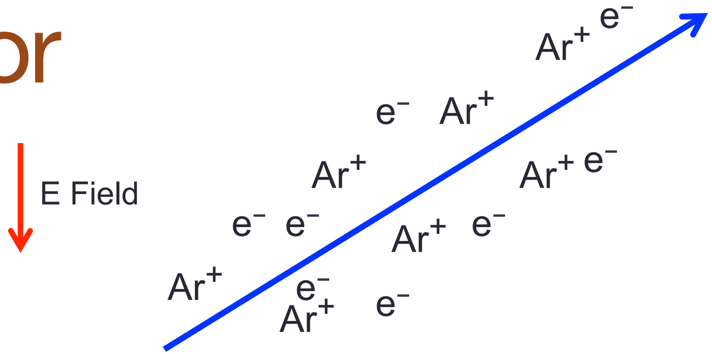




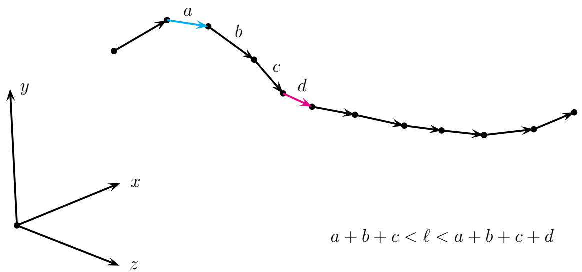
- Recently received a lot of attention, crucial for ν oscillations
- ν cross sections are historically not well known in the energy range we care about
- In the 1 GeV range, driven by results from MiniBooNE, MicroBooNE will probe the exact same energy region
  - —LArTPC provide great resolution for position and momentum in neutrino detectors
  - —Possible to reconstruct complicated topologies
  - —High statistics mean measurements likely systematically limited

First things first though, we need to understand our detector

- First cross section and oscillation analyses will take some time
- In getting ready, we can do physics along the way
  - —Recombination
  - —Diffusion
  - —Lifetime measurements
  - —Field distortions



Muon track affected by recombination



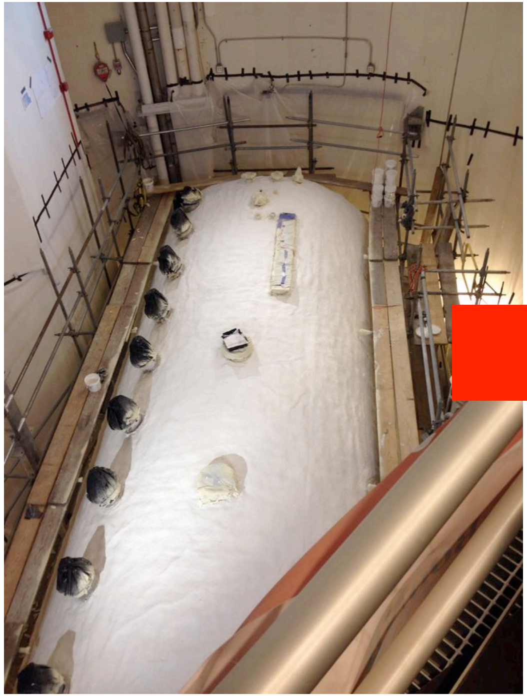
Multiple Coulomb Scattering

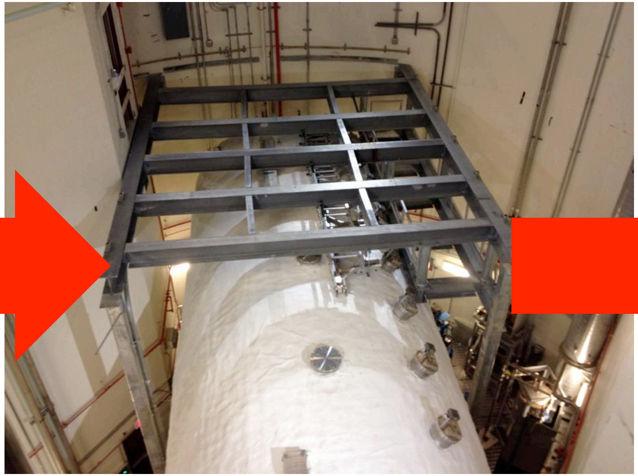
Preparing the Detector for Data

On June 23, 2014, we moved the cryostat across site

Everything in the cryostat went: electronics, TPC (including wires), and PMTs (not full of argon yet though)

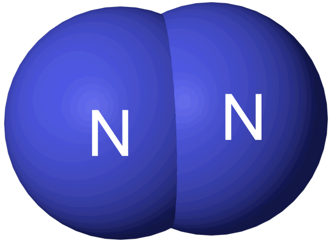
Insulated, racks moved in, and everything cabled up

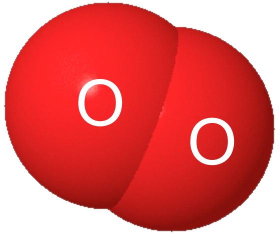


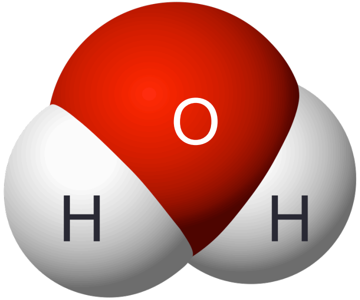


We need to get clean argon

- We have two primary requirements for operation
  - —Need < 2 ppm nitrogen
  - —Need < 100 ppt oxygen equivalent contamination (water and oxygen)
- Few steps to get there
  1. Start with “piston” purge with Ar gas
  2. Recirculate gas
  3. Fill with liquid
  4. Filter the liquid

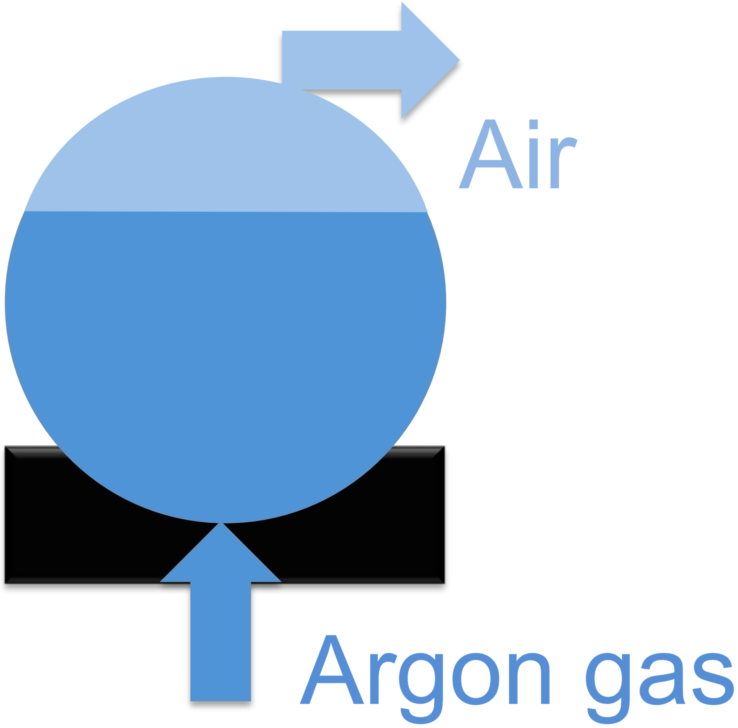






We start with the gaseous argon purge

- We fill with Ar gas through sparger holes in the bottom of the cryostat
- Since Ar is heavier than ambient air, acts like a piston and pushes air out
- See no need to evacuate the cryostat

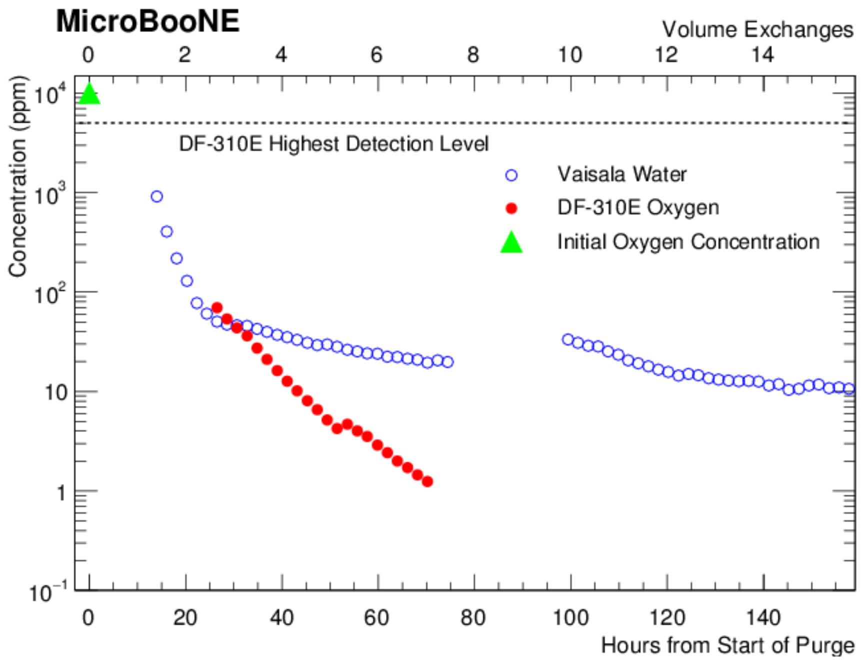


MicroBooNE employs gas analyzers to monitor purity

- Capability to measure at several points in the system
- Two oxygen sensors for high and low sensitivities, lower limit of 75 ppt
- Water sensor with lower limit of 2 ppb, also a Vaisala dew point sensor for higher concentrations
- Nitrogen analyzer 0-10 ppm

We monitored the purge with the gas analyzers

- We started the purge on April 20
- We followed the oxygen and water concentrations as the purge progressed



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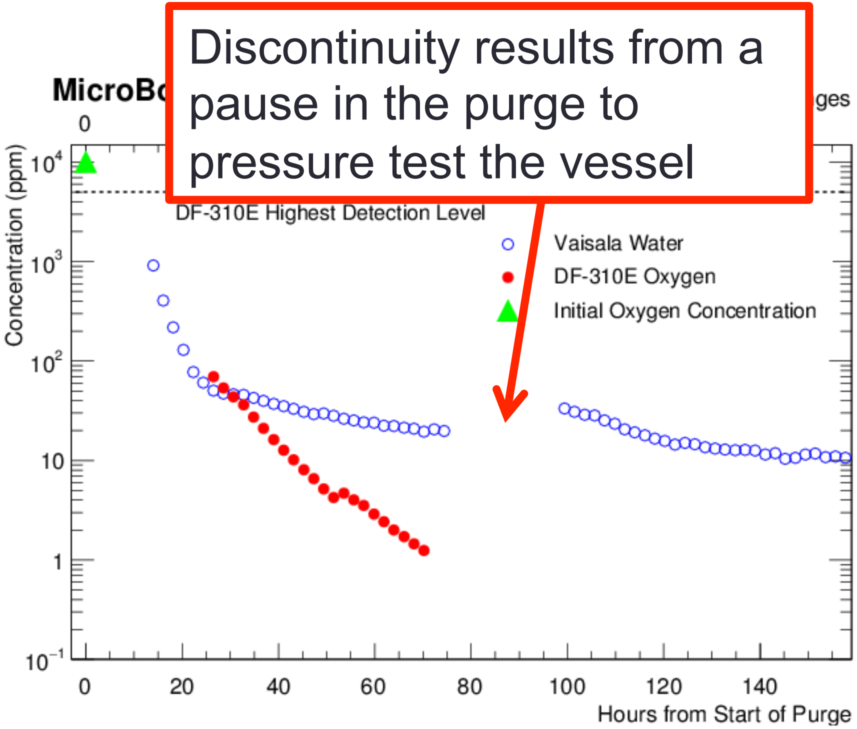
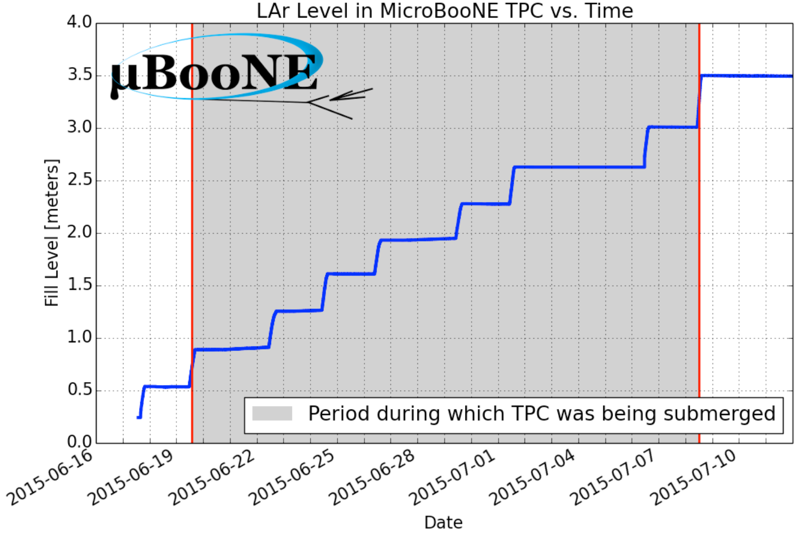
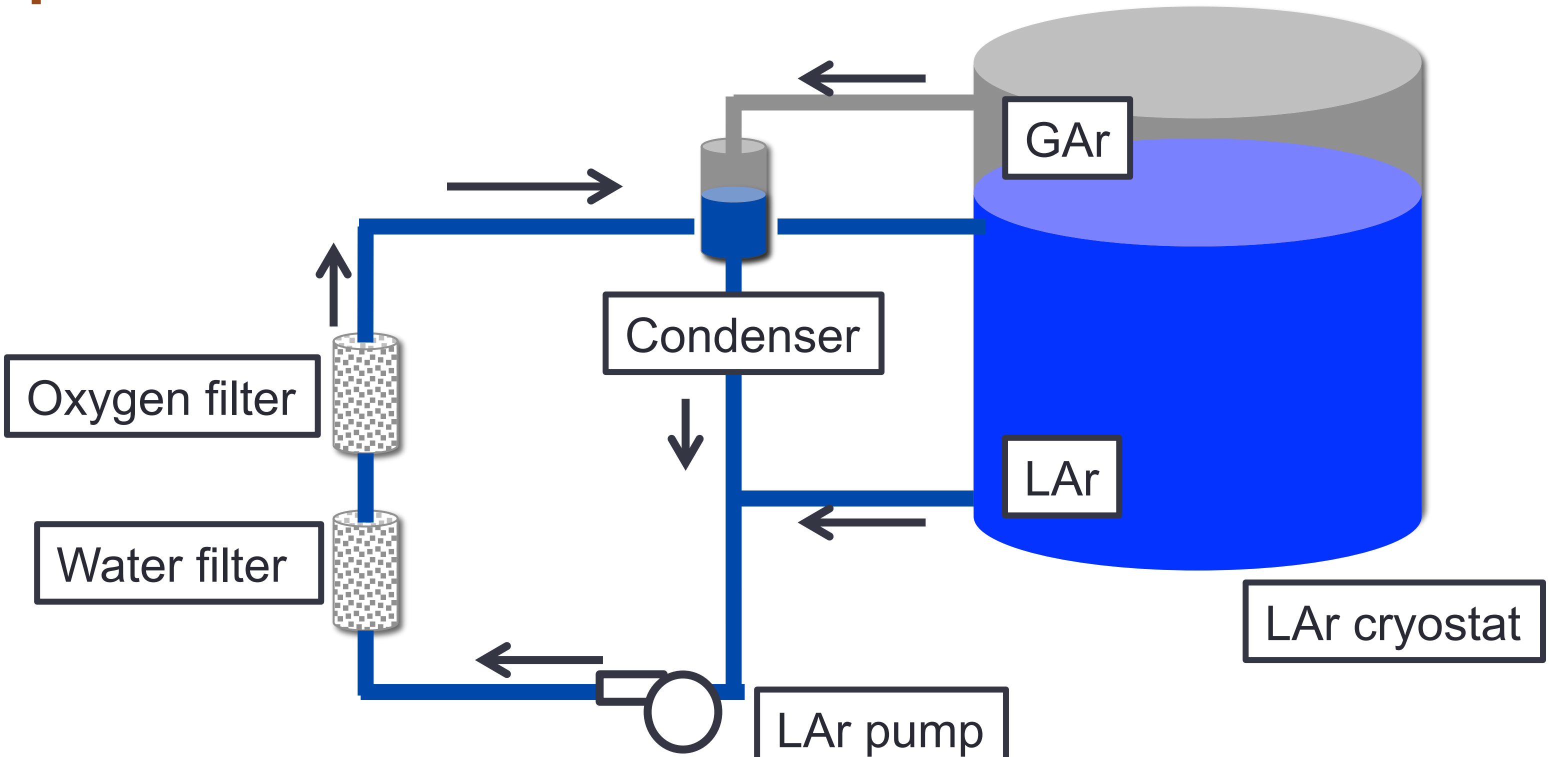


Now it's time to fill

- Took 9 trucks of liquid argon, roughly a month, went quickly
- Needed to get argon low in nitrogen since, can't filter it
- Every trailer was checked before we accepted it
  - —We ended up accepting all of them
  - —Vendor exceeded our specs, nitrogen way less than 2 ppm, around 0.5 ppm

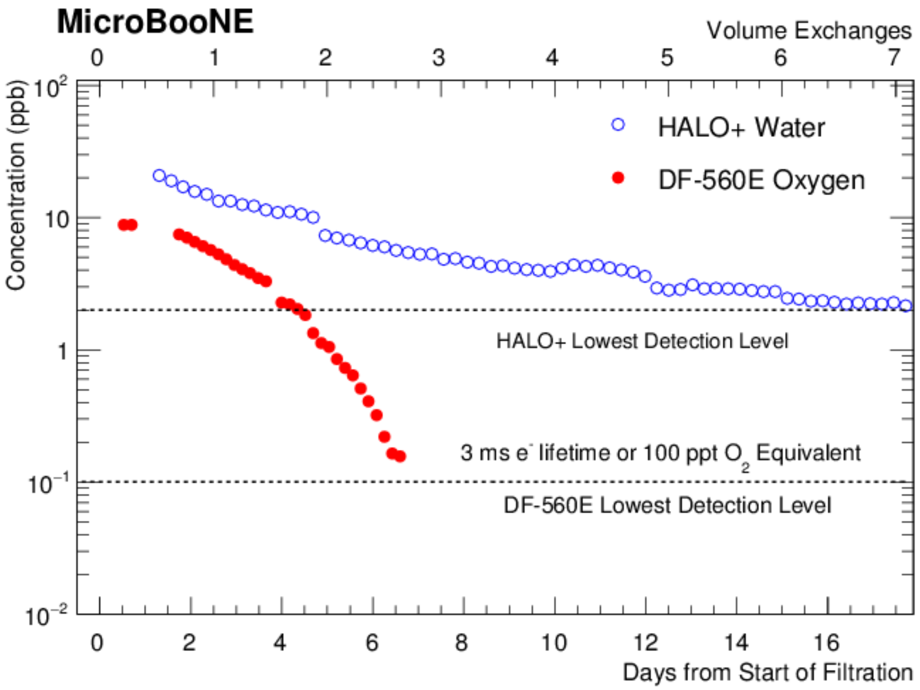


Operation of Purification



The cleanup of the liquid

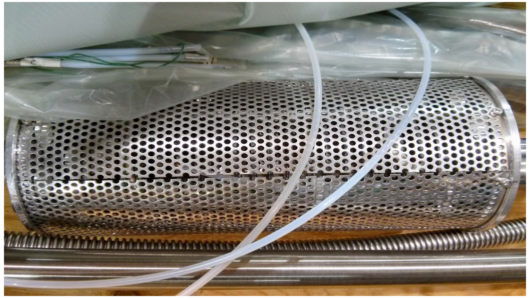
- We started filtering on July 24
- Here the high-sensitivity analyzers are shown
- Plot goes to the lower detection limits of both
  - —2 ppb for the HALO+ water analyzer
  - —100 ppt for the DF-560E oxygen analyzer

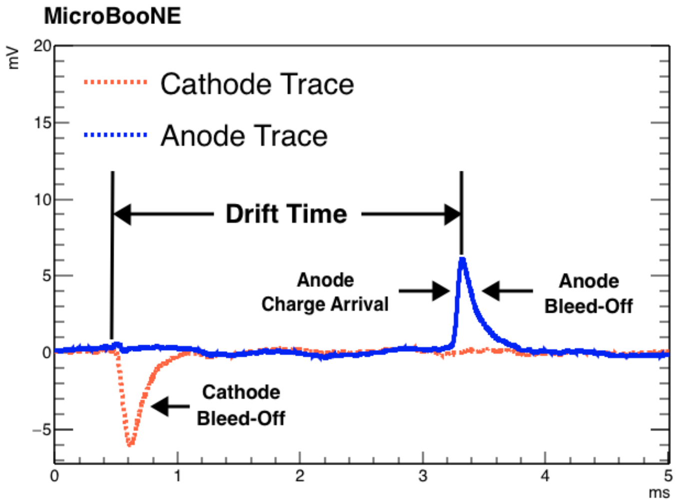


To measure higher purities, we need purity monitors

- Use purity monitors, consisting of a field cage, photocathode and anode
- A quartz fiber optic cable carries UV light from a flash lamp to a gold photocathode
- Measure electron signal loss from cathode to anode to find lifetime:

$$Q_{anode} = Q_{cathode} \times \exp(-t_{drift} / \tau)$$





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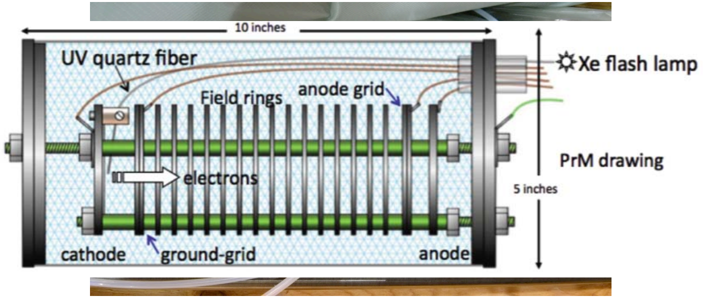
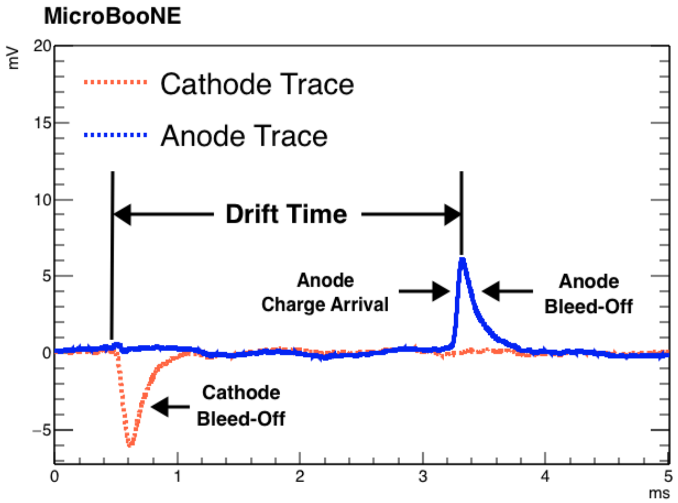
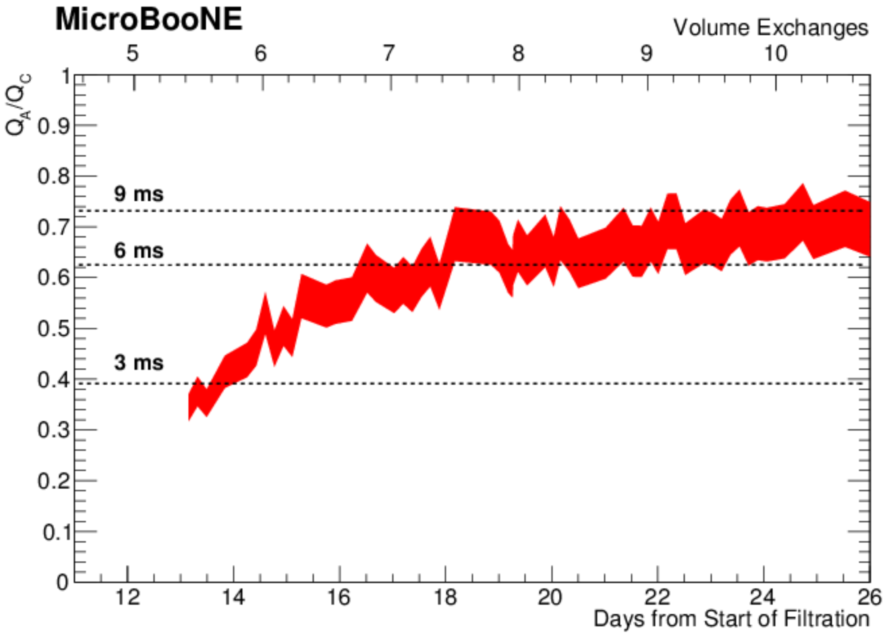




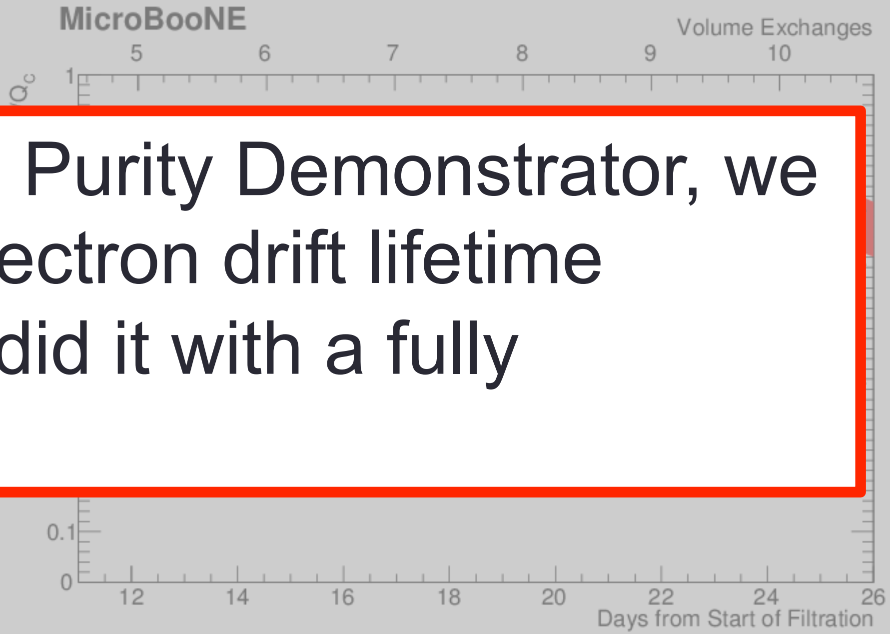
Looking at Q_A/Q_C

- We opt to look at the ratio of Q_A to Q_C
  - —Closer to what's measured
  - —Easier to spot trends such as hitting a sensitivity limit
- We see lifetimes greater than 6 ms
- Our spec was only 3 ms!



Looking at Q_A/Q_C

- We opt to look at the ratio
- drift lifetimes of 3, 6, and 9 ms
- We see lifetimes greater than 6 ms



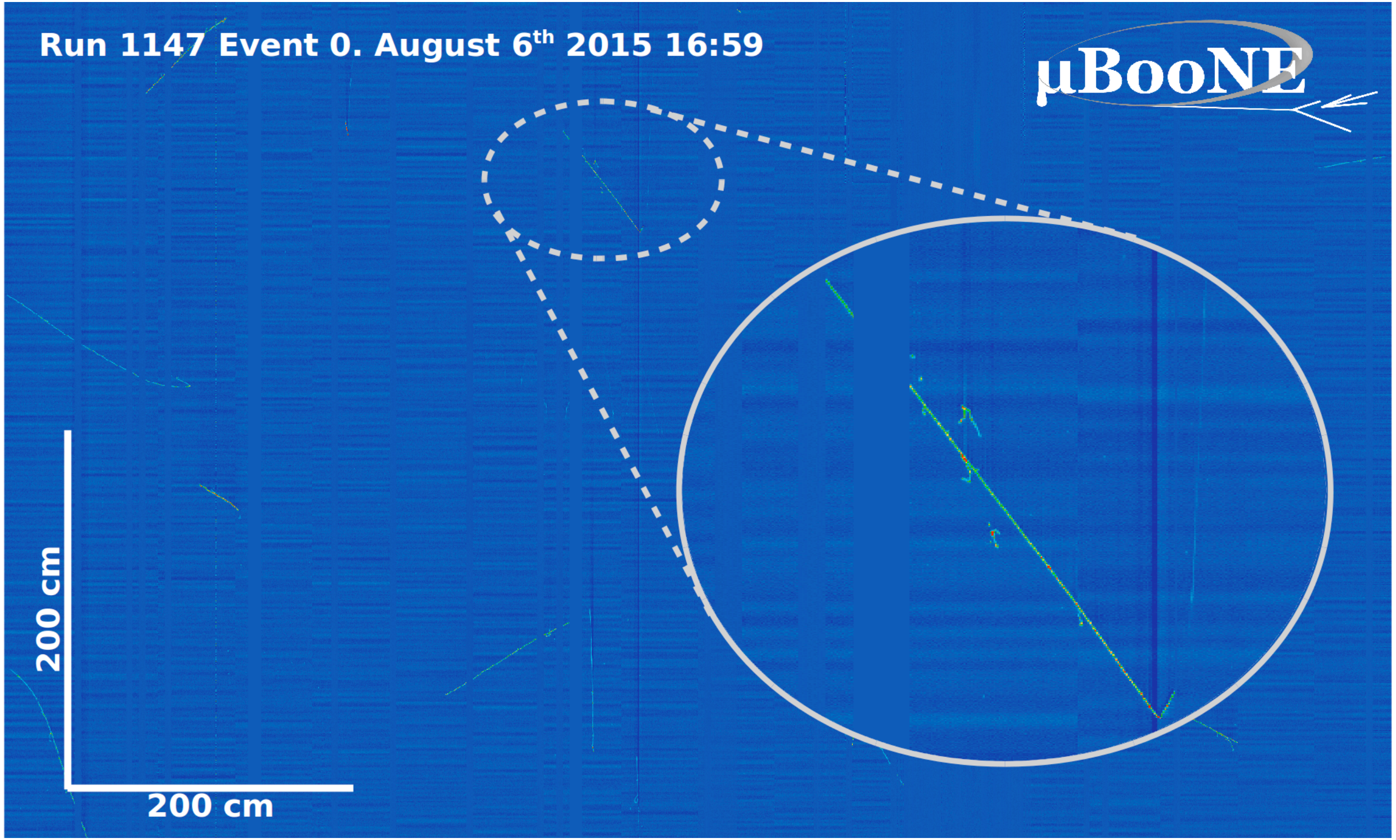
As with the Liquid Argon Purity Demonstrator, we surpassed our design electron drift lifetime without evacuation. We did it with a fully instrumented detector!

Flipping the switch on the drift HV

Now that we have clean argon, time to ramp the HV and see cosmics

- We ramped our HV on August 6
- Since we're on the surface, we see lots of cosmics
- It works!

Our first cosmic rays!



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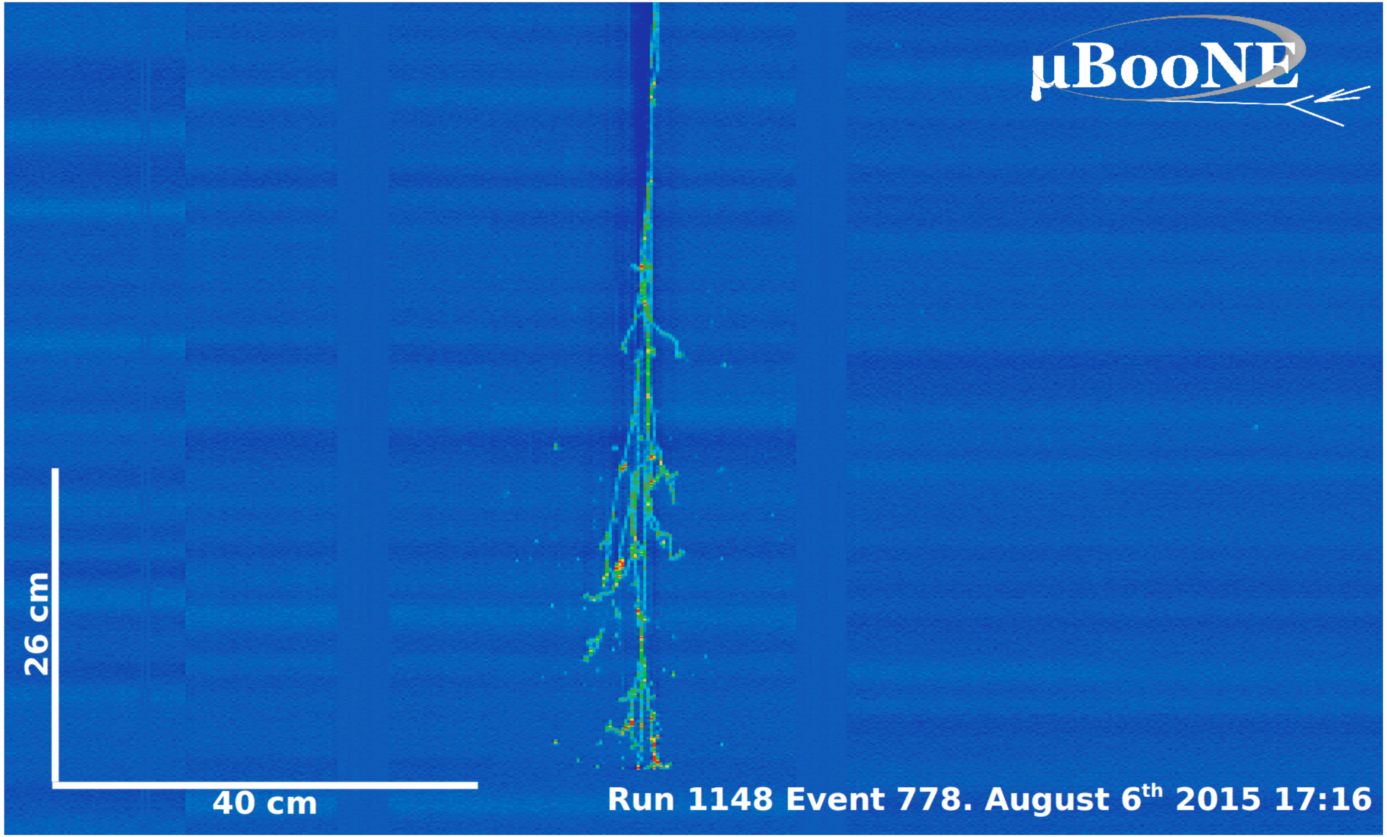

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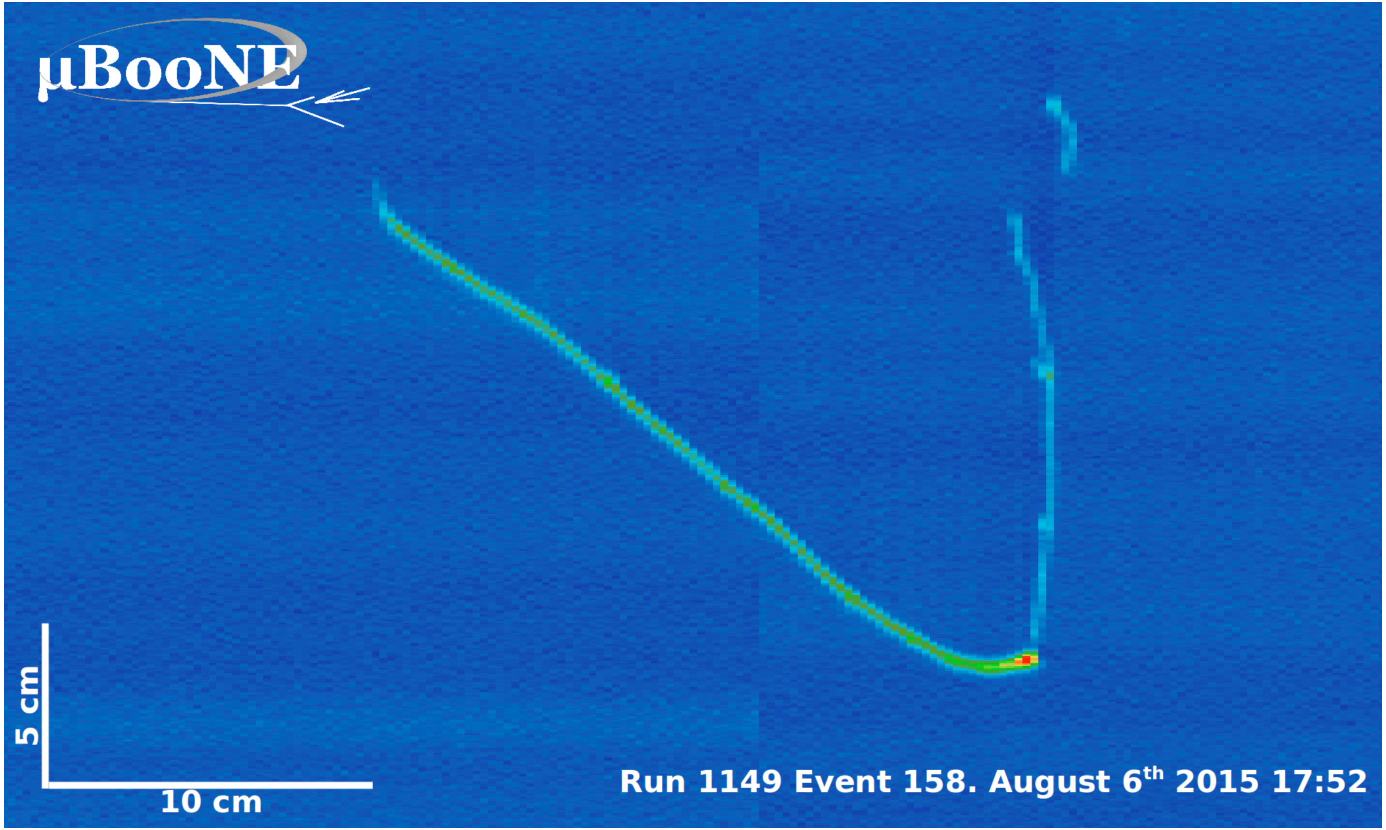
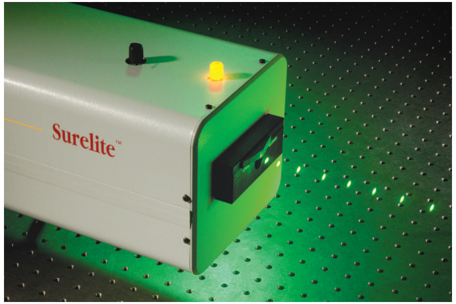
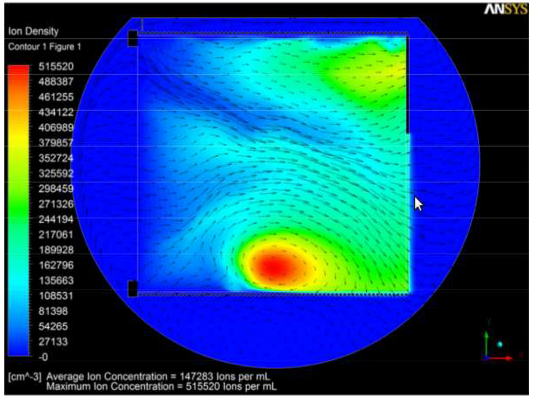
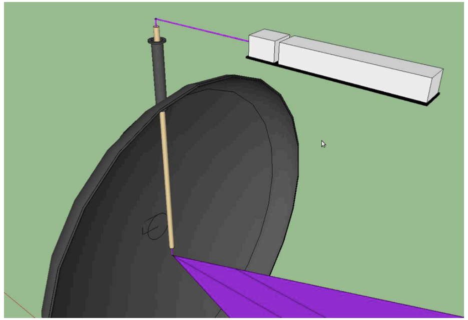


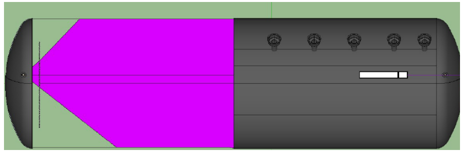
Our laser calibration system

- The two UV lasers produce tracks we know are straight
- We can calibrate for space charge and other field distortions
- Allows measurements of the electron drift lifetime

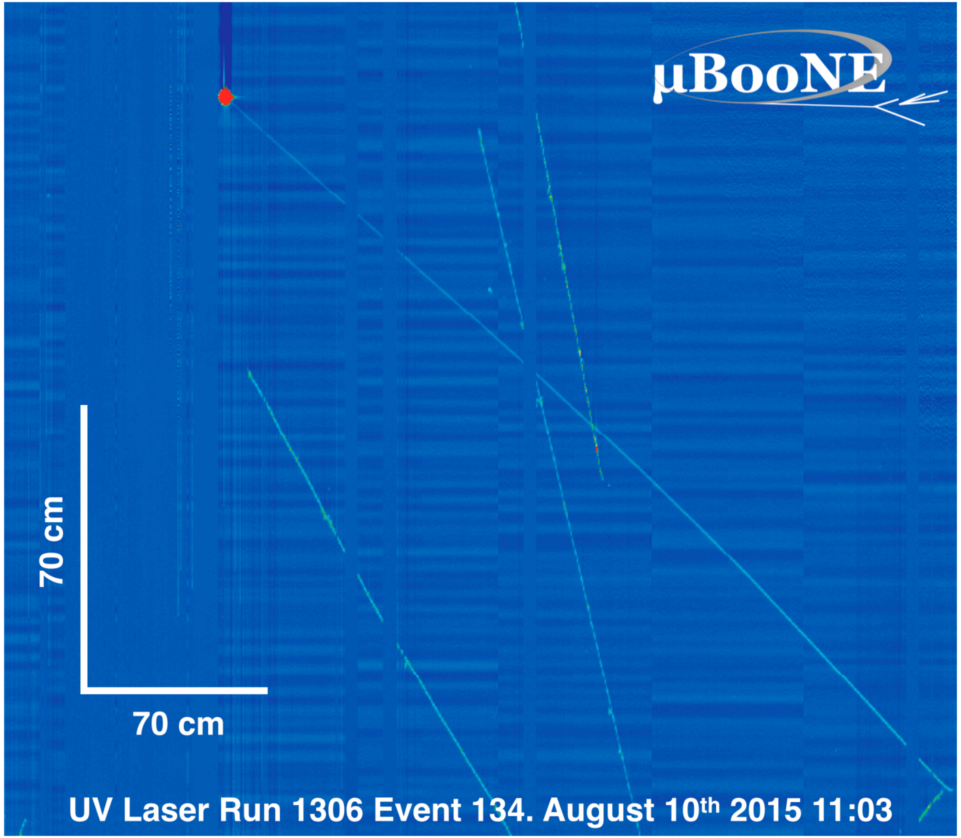






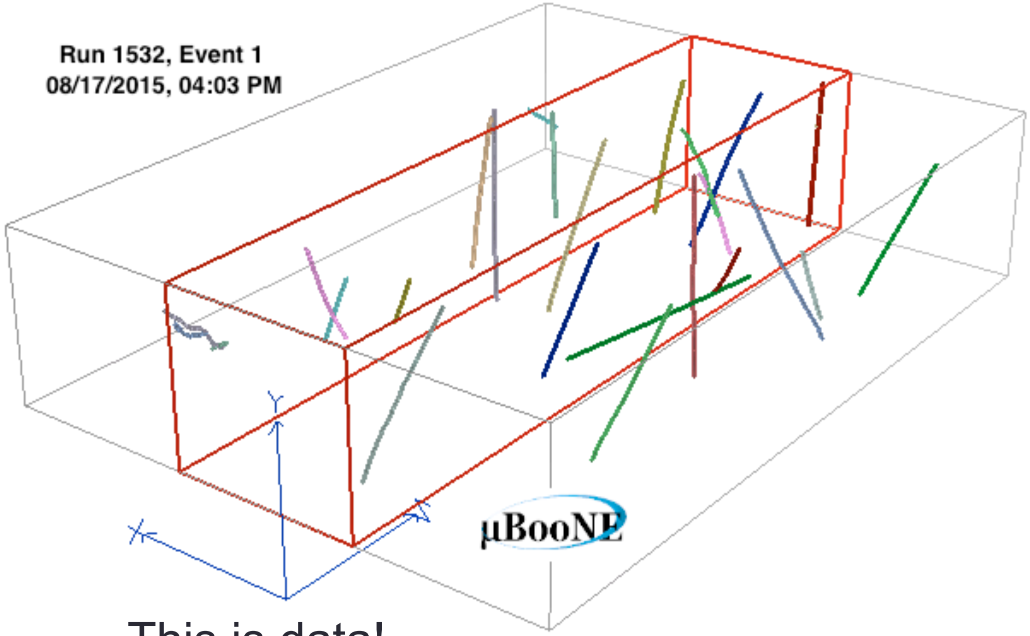


Our first laser track!



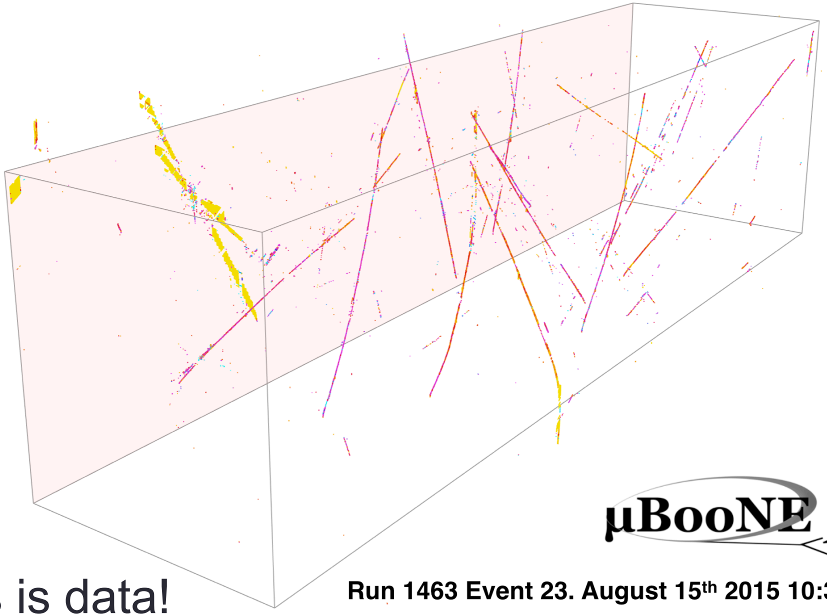
We use fully automated event reconstruction

- This event display comes from LArSoft, showing 3D tracks
- Display shows the full drift window of 4.8 ms
  - We take a window before and after beam
  - Red wireframe represents the physical detector
- Different colors are different tracks



This is data!

Wire-cell reconstruction



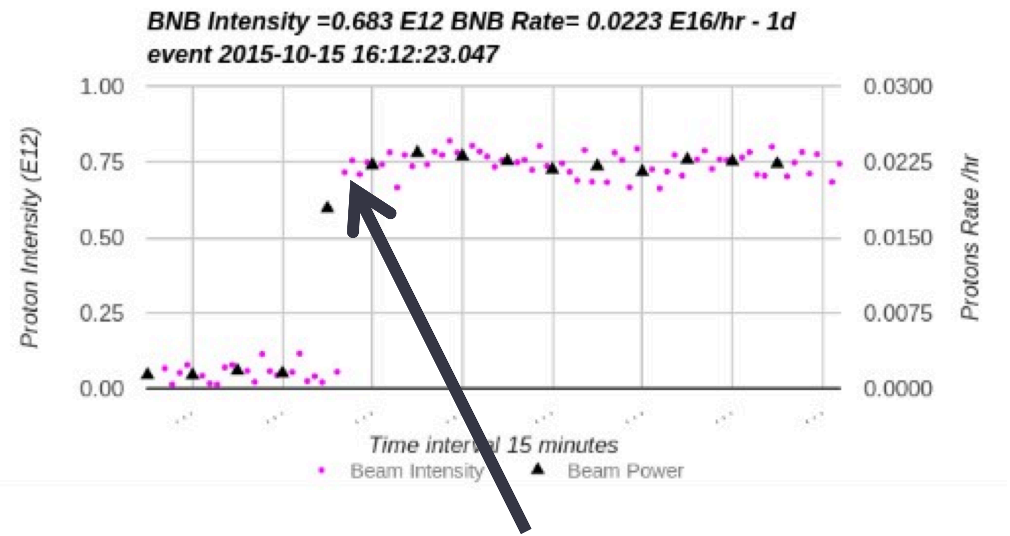
This is data!

Run 1463 Event 23. August 15th 2015 10:37

- Another approach for our reconstruction employs tomography techniques
- Very similar to an MRI
- This helps tremendously with ambiguities

More details on the poster from Xin Qian, check it out

First Booster Neutrino Beam On October 15

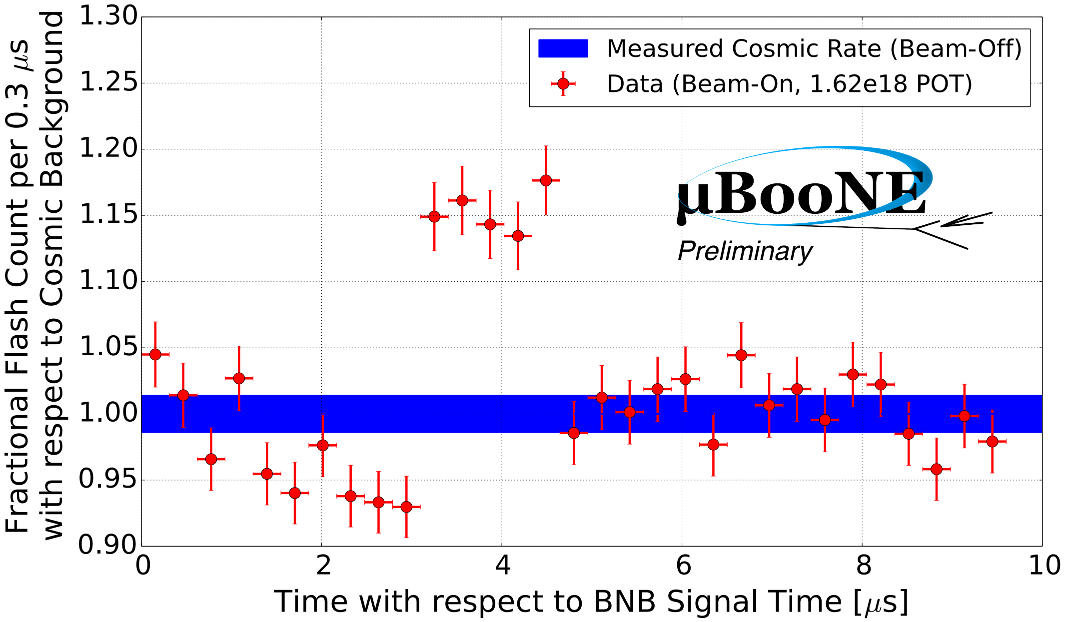


4:02 PM

That was two weeks ago! Where are the neutrinos?

Here they are!

- Expect more light during beam window due to neutrinos
- Increased scintillation light from neutrinos coincides with the beam
- We compare the PMT flash rate to that of cosmics only and see an excess



Our automated reconstruction sees them!

MicroBooNE Preliminary
1.86E18 POT, BNB

First ν identification

Number of events	Automated event selection Optical + 3D-based	Automated event selection Optical + 2D-based
Non-beam background (expected)	4.6 ± 2.6	385 ± 24
Total observed	18	463

- One of the goals of MicroBooNE was to demonstrate fully automated reconstruction
- This involved no hand scanning!
- Event displays of these events will be available Monday in a mini-press release!

In Summary

- Construction of MicroBooNE was completed
- Operations have begun
  - —Our detector has been filled with liquid argon and filtration started
  - —We surpassed our required electron drift lifetime for operating
- We are seeing our first tracks
  - —Cosmic rays abound, useful for physics studies
  - —Laser tracks are being used for calibrations
  - —First neutrinos are on disk, stay tuned for the mini-press release on Monday!

We get most of our neutrinos from the Booster Neutrino Beam at Fermilab

- Driven by 8 GeV protons hitting a beryllium target for a mean neutrino energy of 0.8 GeV
- Will provide MicroBooNE with the same L/E (oscillation parameter experiments set) to that of MiniBooNE
- Well known beam, already run for a decade, allows focus to be placed on understanding detector

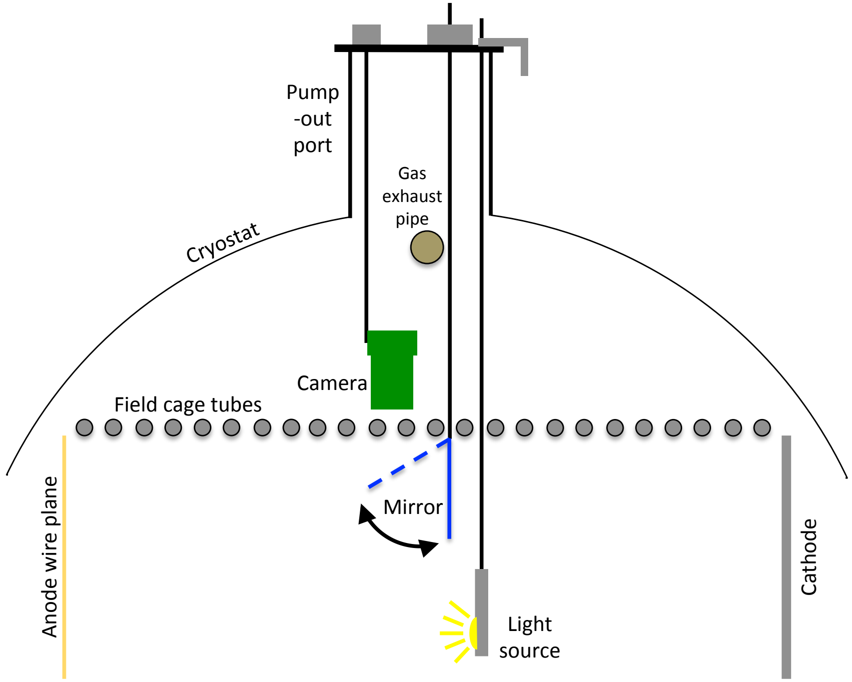
6.6e20 POT (~3 years)

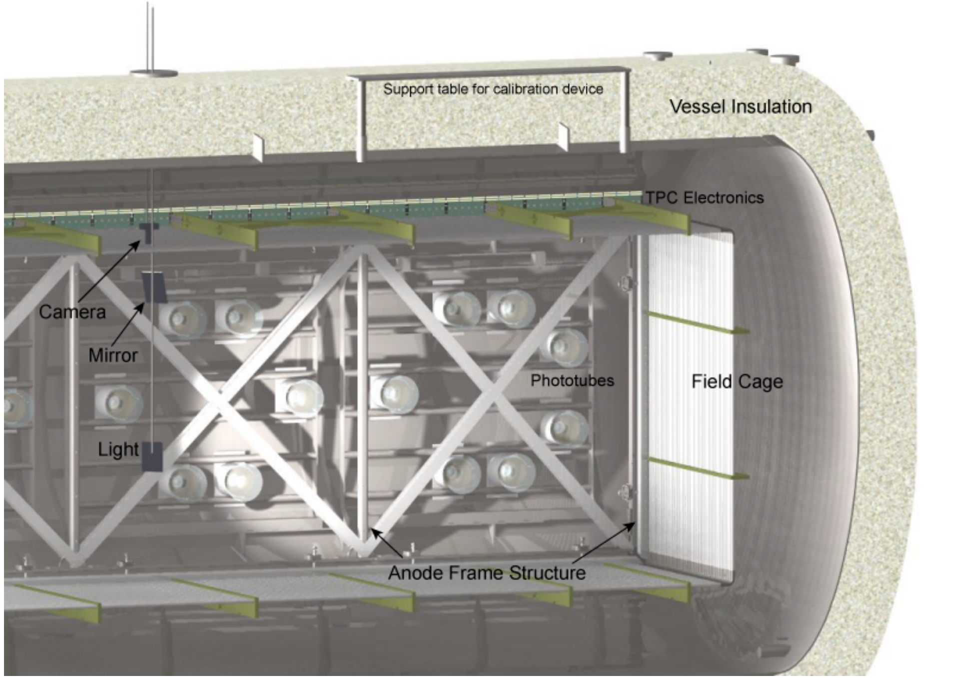
	numu	numubar	nue	nuebar
CC Total	173302	1407	1469	36
CC - QE	95296	773	729	17
CC – RES	75657	604	702	18
CC – DIS	1607	1.3	29	0.5
CC - COH	740	29	8.5	0.7
NC Total	64661	1002	502	17
NC - QE	35951	633	254	7.0
NC - RES	27665	358	236	9.4
NC - DIS	519	1.3	8.8	0.2
NC - COH	525	10	3.2	0.6

POT – protons on target
CC – charged current
NC – neutral current
COH - coherent

QE – quasielastic
DIS – deep inelastic scattering
RES – resonant

How did we know it survived its trip? We looked!





How did we know it survived its trip? We looked!