# MicroBooNE: Experience Gained and Future Scenarios

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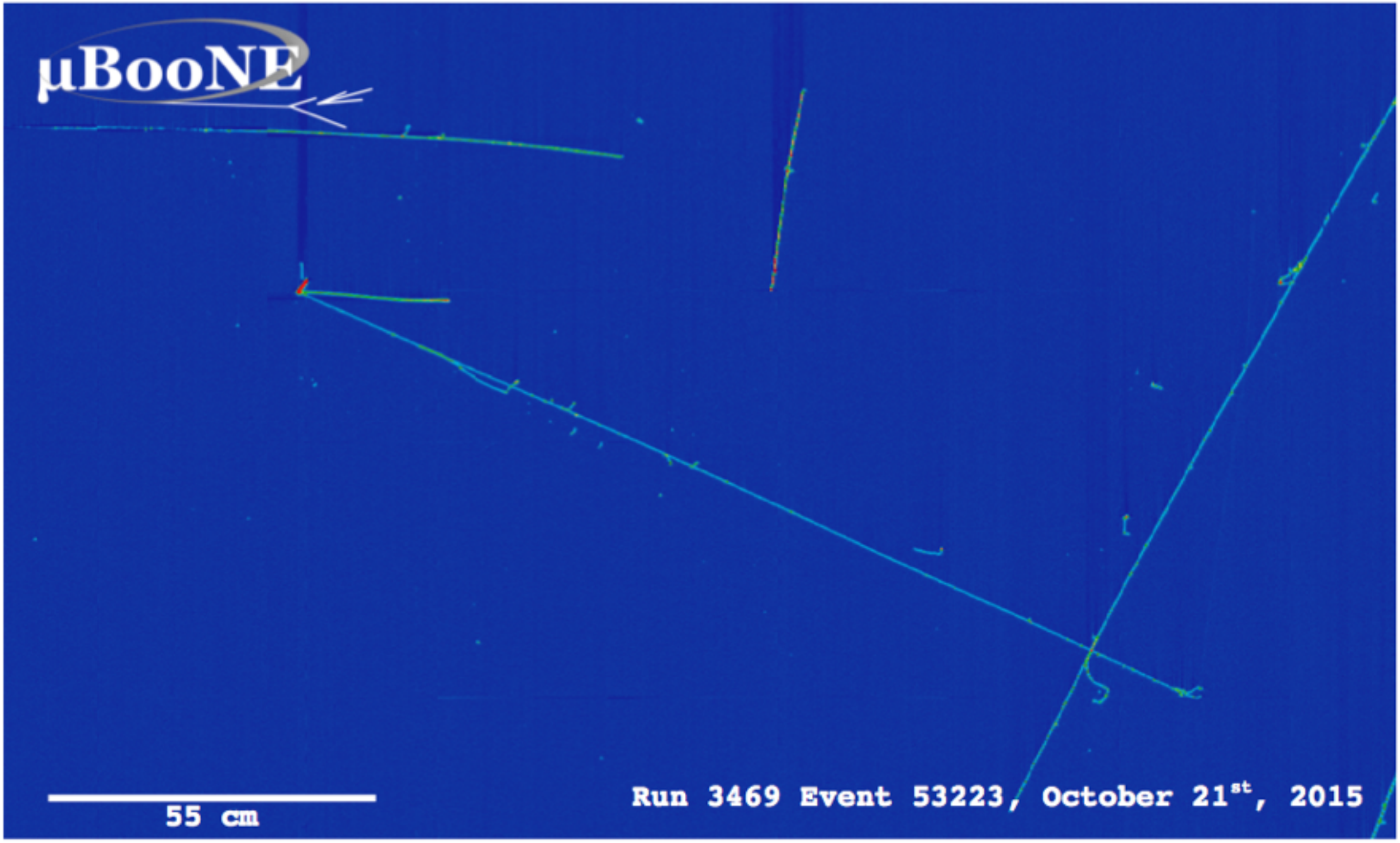
# Outline

- The MicroBooNE Experience, 2008-2016
  - Construction, installation, and commissioning tales
  - Lessons learned
  - Initial TPC data and discussion
  - Initial neutrino data and discussion
- Where MicroBooNE is going
  - Features of MicroBooNE's low-energy analysis
  - Scenarios for MicroBooNE's low-energy excess measurement: "What if…"

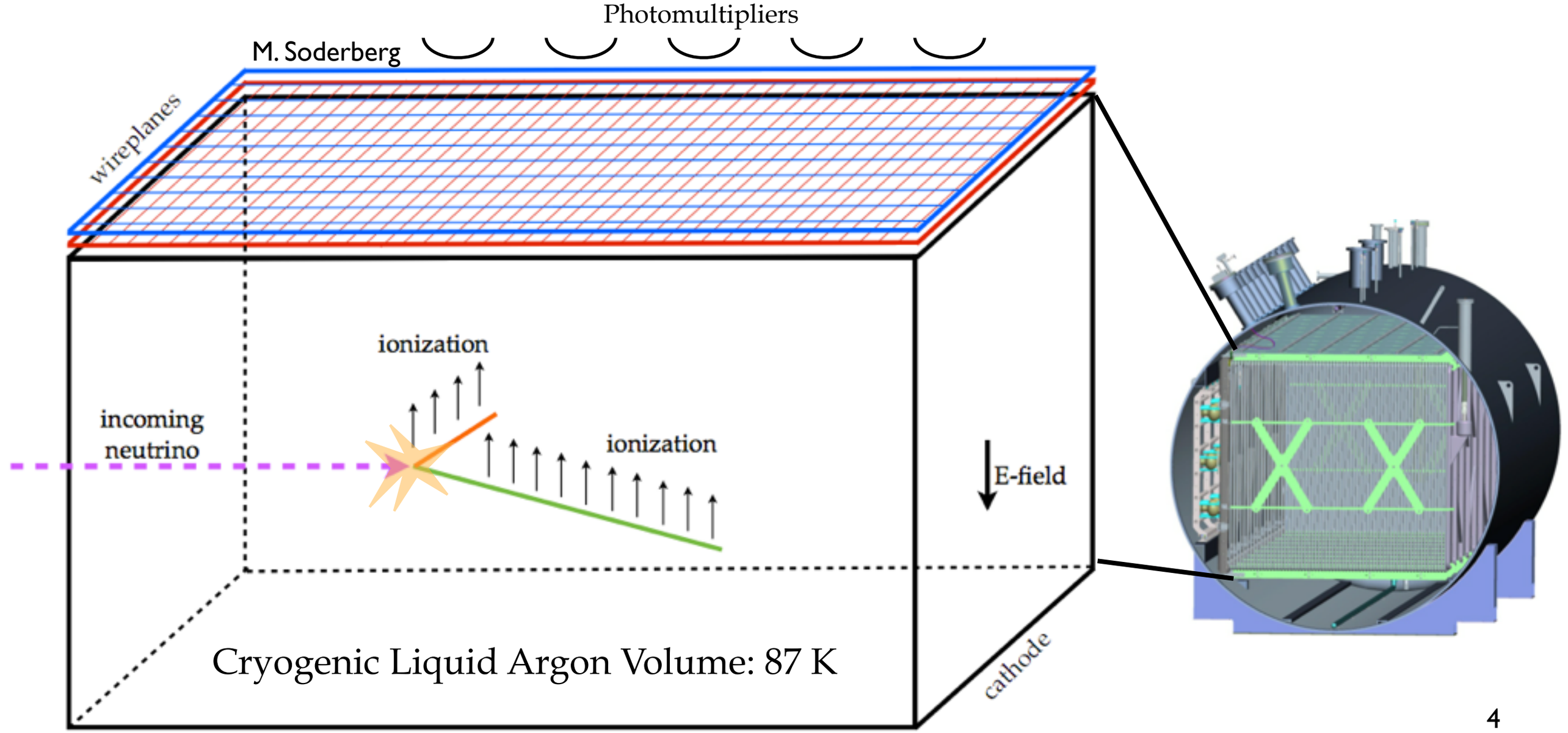
# MicroBooNE NOW:

- So here we are, with wonderful-looking neutrino event displays.
- How did we get here? What did we learn along the way?



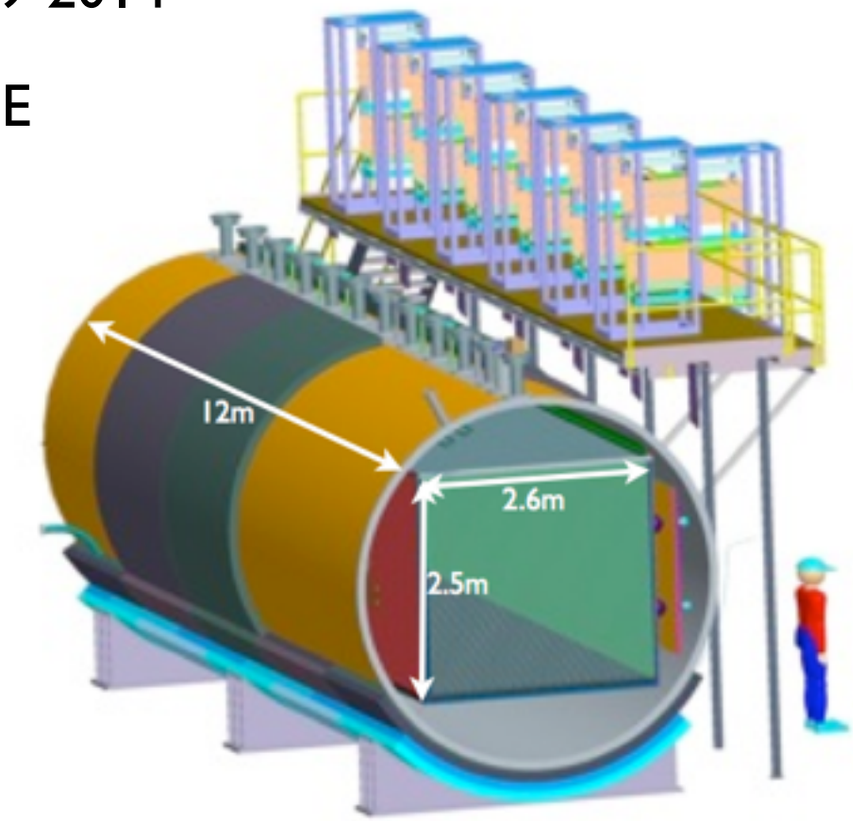
# Well, We Had to Build THIS Thing.

- Need a 170t cryostat full of ultra-pure LAr to produce ionization electrons
- Need reliable HV to drift produced electrons
- Need low-noise electronics on 8000+ taut wires to read out electron signal
- Need light detection system to properly find neutrinos in time and space.



# MicroBooNE: Genesis

- This goes quite a WAYS back! First uBooNE DocDB in 2008!
- Some perspective:
  - First miniBooNE result: 2007; 'low-energy excess' first osc-interpreted by mB in 2009!
  - 2009: ArgoNeuT takes first beam data…
  - Argon purity methods (MTS, LAPD, filters) publicized 2009-2014
  - Physics, R&D reality being established WHILE MicroBooNE is being designed and prepared for (sometimes BY uB…)
- LArTF ground-breaking: 2012

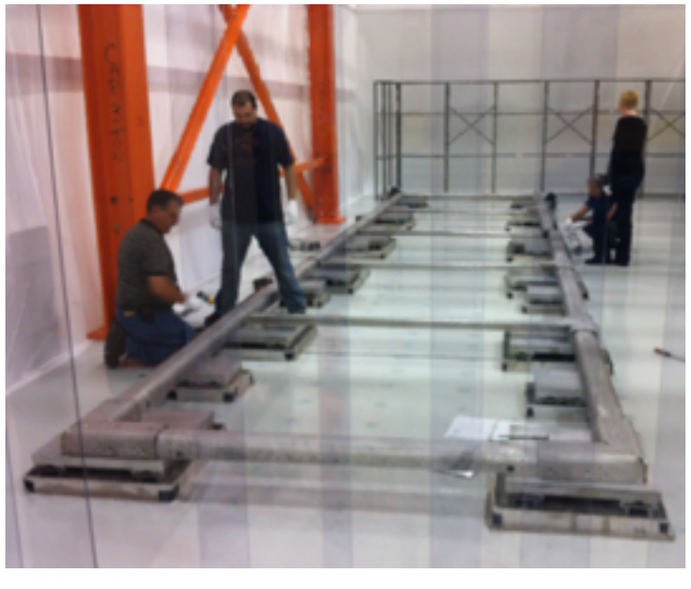



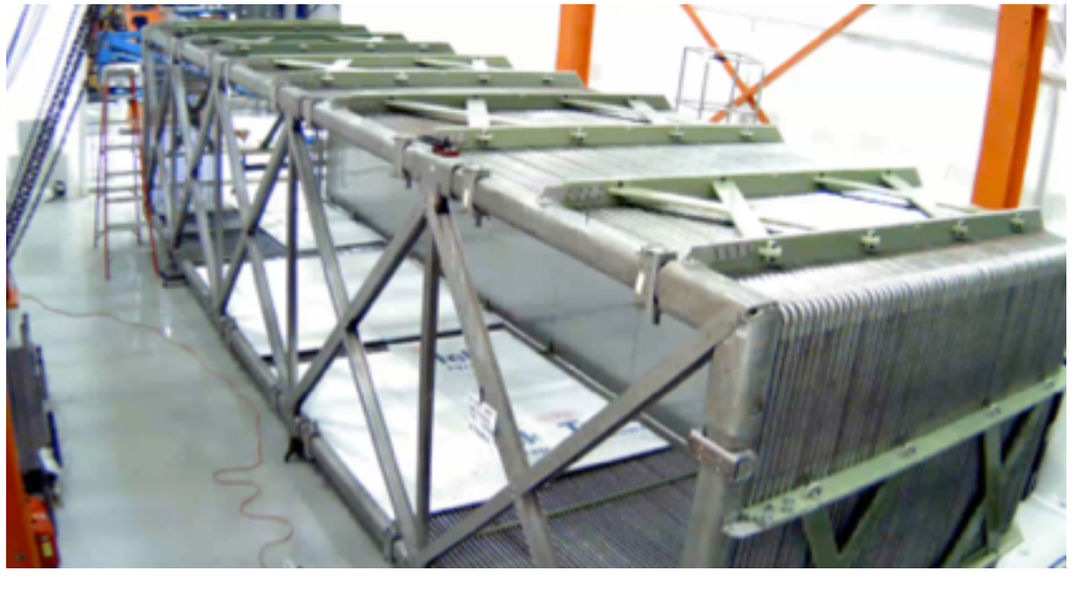

M. Soderberg, 2008 Seminar: looks kinda close to the real thing circa 2016…!

# MicroBooNE: 2012-2014

- 2012-2014: Constructing the TPC
- MicroBooNE was establishing LArTPC parameters all throughout this process
  - How do we installed/tensioned 8000+ wires?
  - How do we install/test cold electronics?
  - How do we ensure safe operation of a large TPC in the presence of HV?

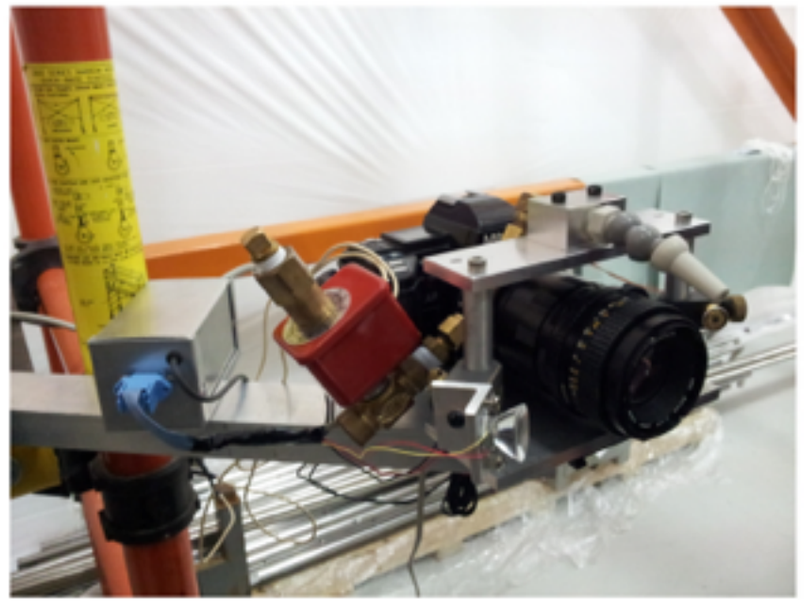
1 week → ~10 weeks → ~1+ year!

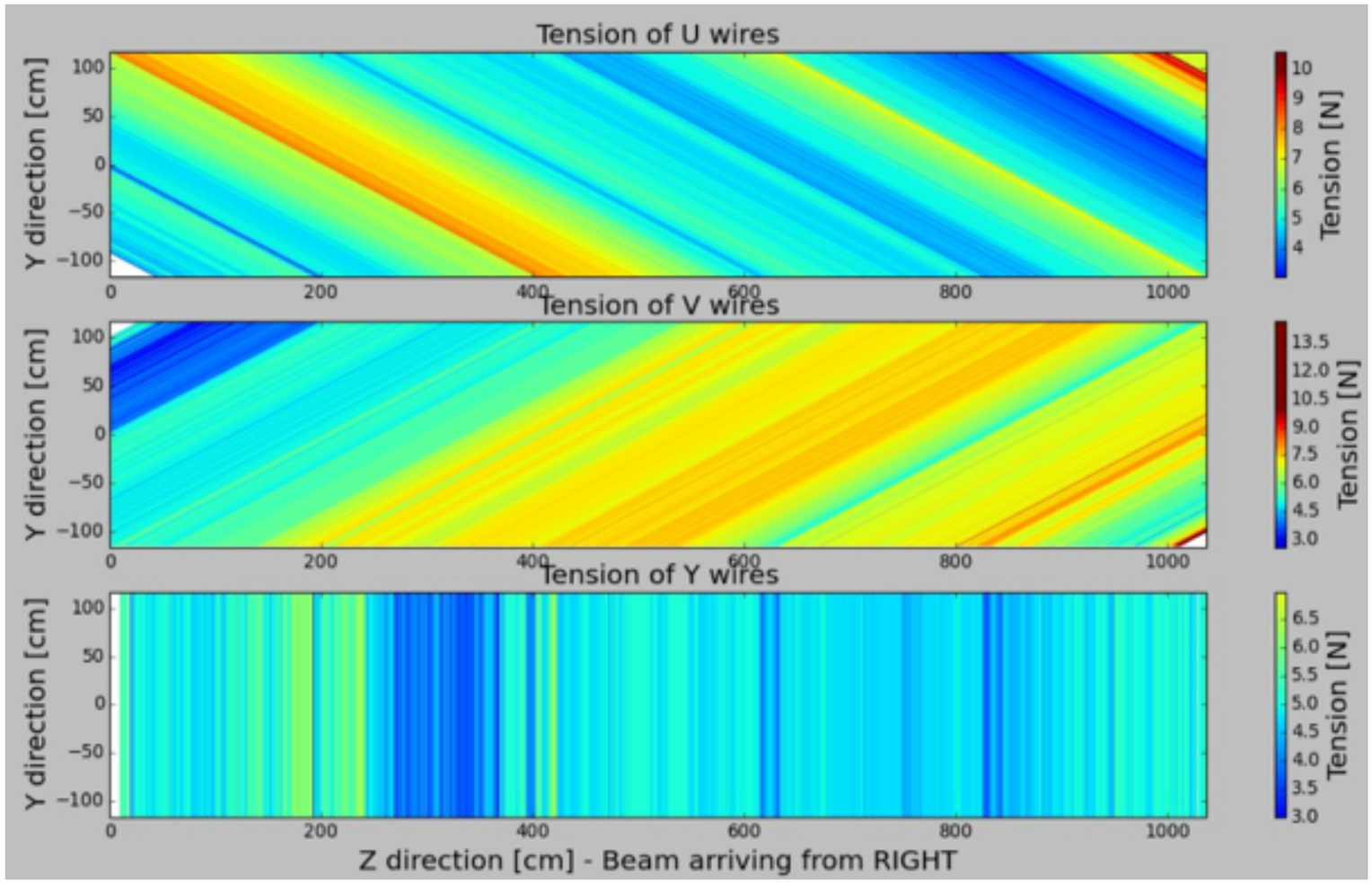


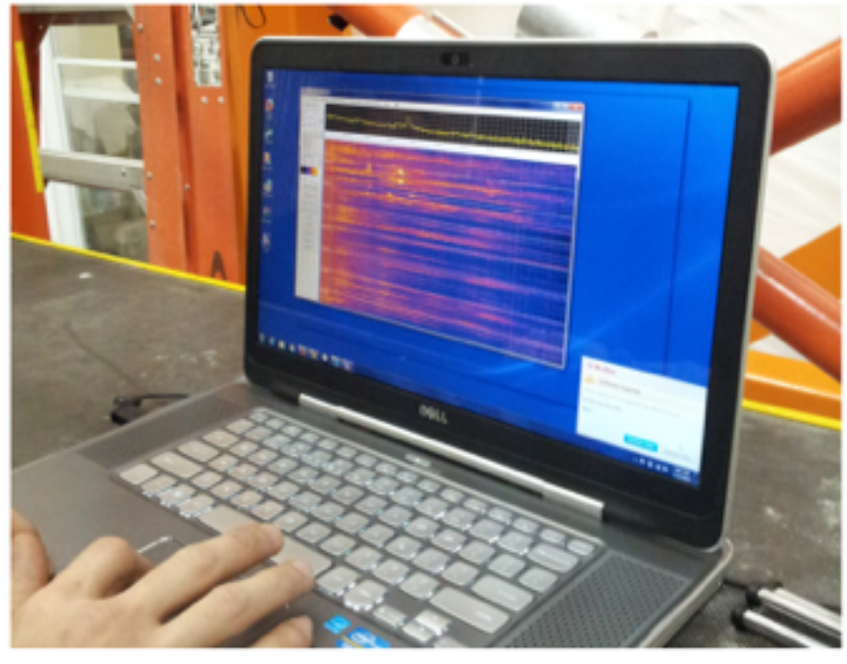


# MicroBooNE: 2012-2014

- Much hard data taken during this learning process:
  - It's a big effort to put 8000+ well-situated wires with 3mm spacing at 3 different orientations in your LArTPC
  - Verified every wire's tension prior to installation of TPC in cryostat!
  - Lesson: gather as much data on your TPC as possible during all steps of the process!

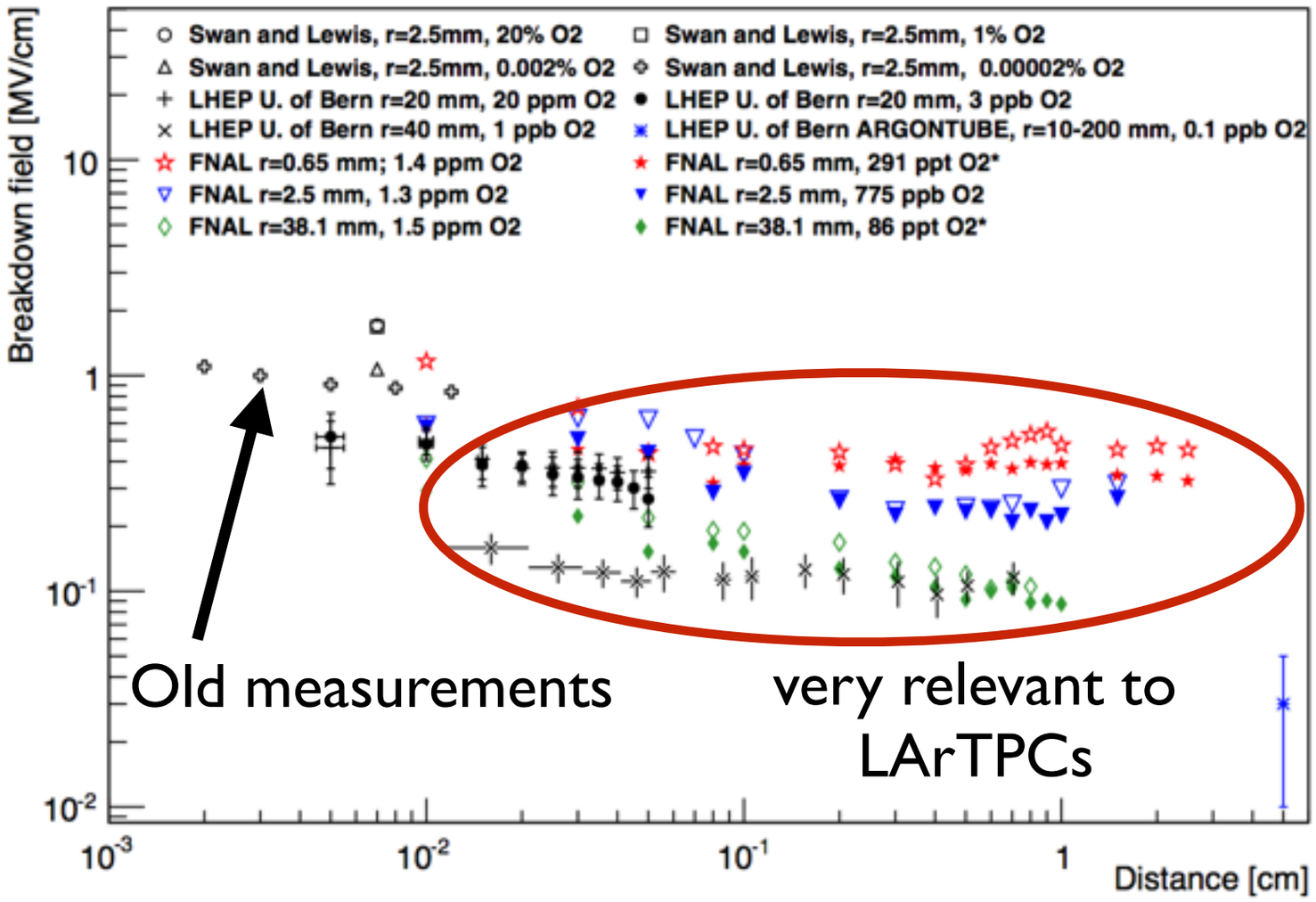


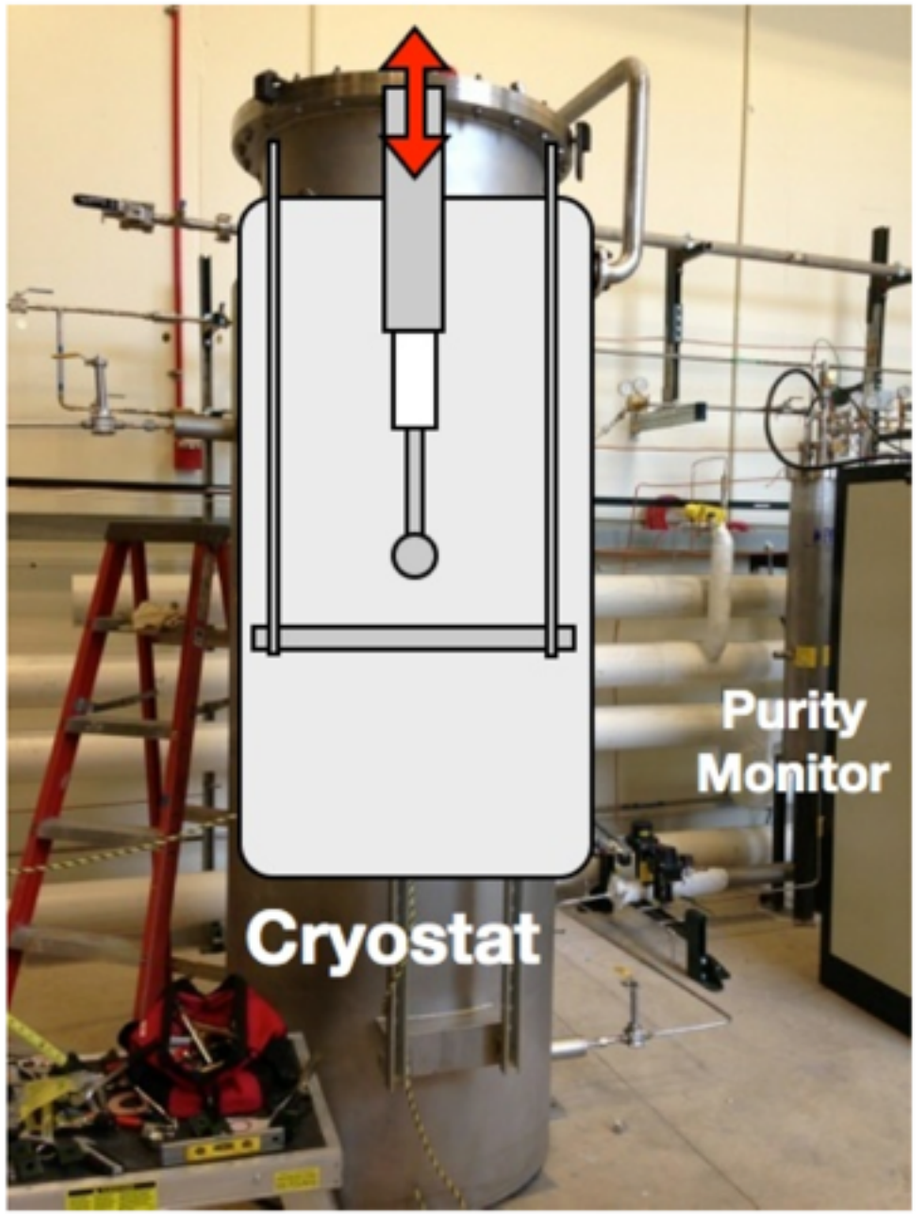


# MicroBooNE: 2012-2014

- Much hard data taken during this learning process:
  - HV Breakdown voltages are much lower than initial estimates indicated
  - Shown in uB test cryostat at LArTF: breakdown depends on geometry, purity!
  - Lesson: be conservative when planning/ designing for HV in your LArTPC!!!

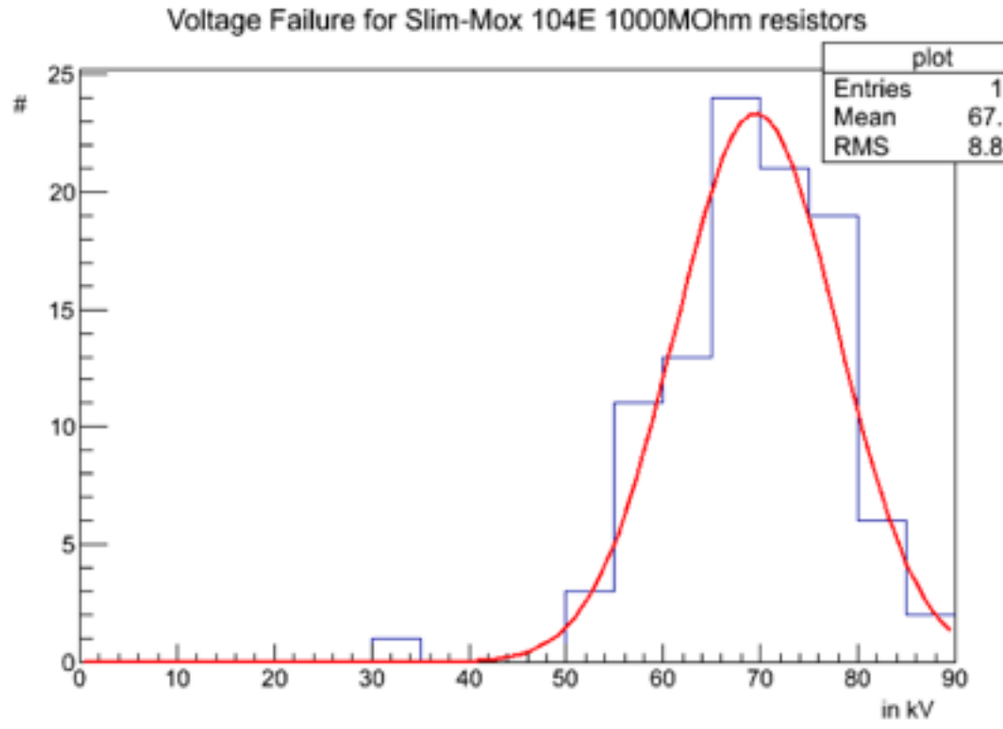


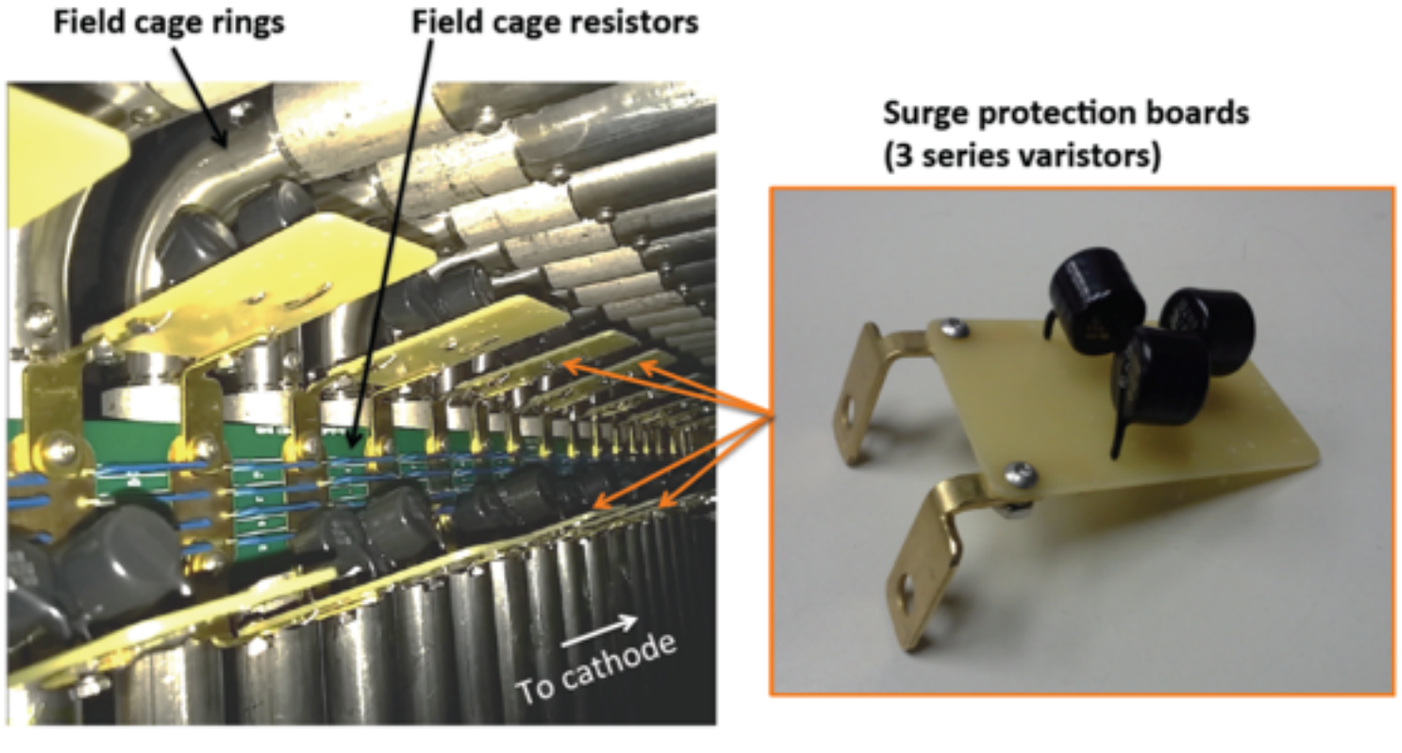



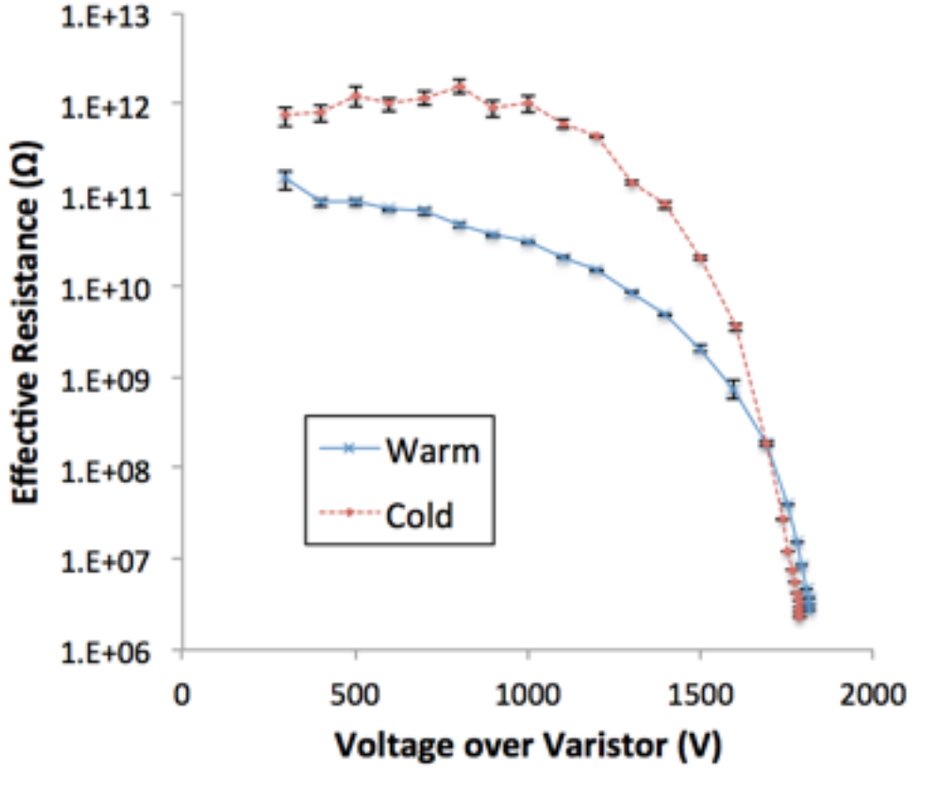
# MicroBooNE: 2012-2014

- Much hard data taken during this learning process:
  - Applied this last lesson to the field cage
  - **JINST 9 T11004 (2014):** Beefy resistors can endure breakdown-induced surges
  - **JISNT 9 P09002 (2014):** Varistors provide surge protection in event of HV breakdown

- Lesson: Consider the complicated electro-dynamics of your TPC: resistance, capacitance, etc etc!

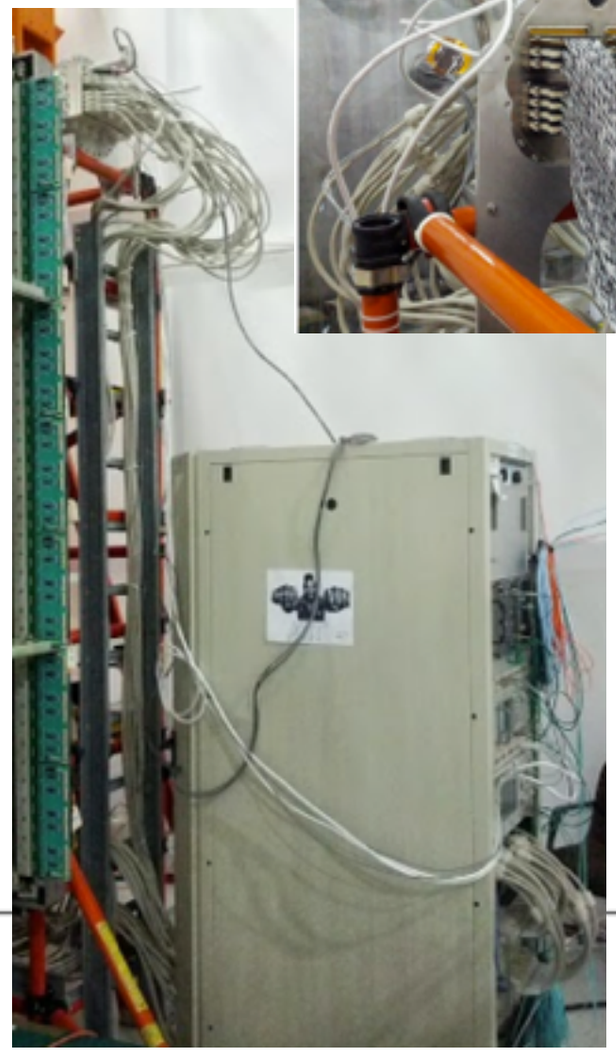


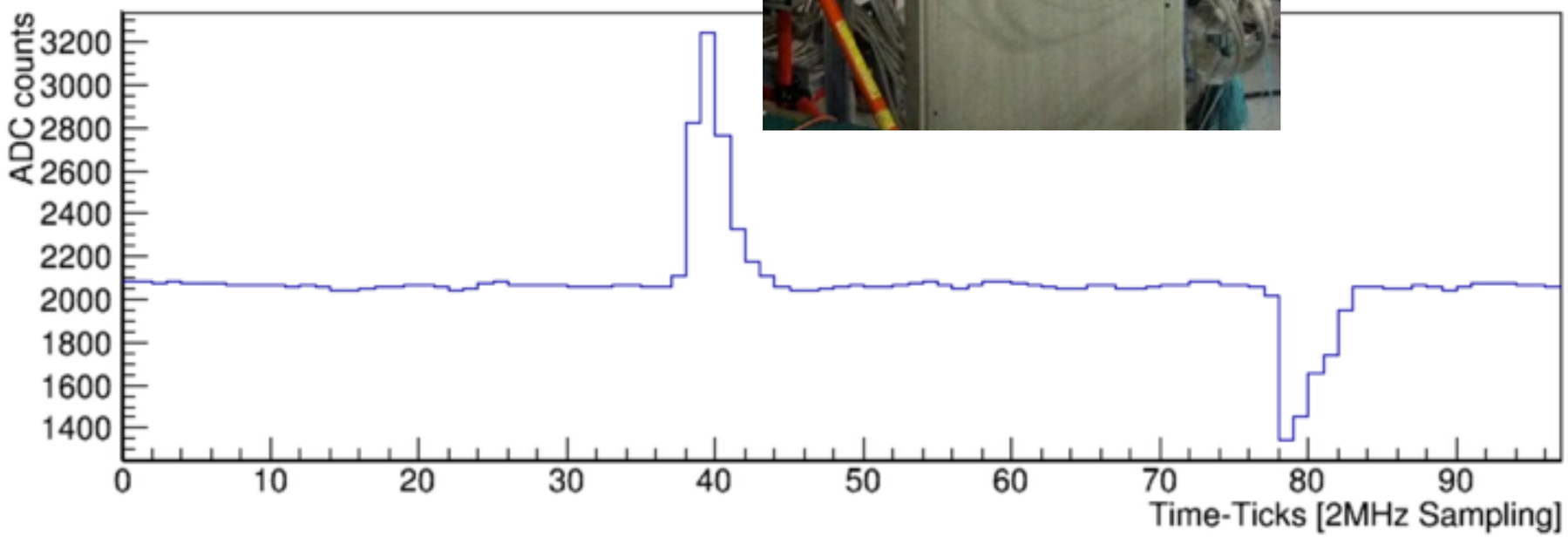



# MicroBooNE: 2012-2014

- Much data taken during learning process:
  - TONS of electronics testing to do:
  - Acceptance tests at Brookhaven on boards
  - At Fermilab, on each channel with a 'master feedthrough/DAQ' ('Mr. T test stand')
  - At Fermilab, on each channel in cryostat with its feedthrough and 'master DAQ'

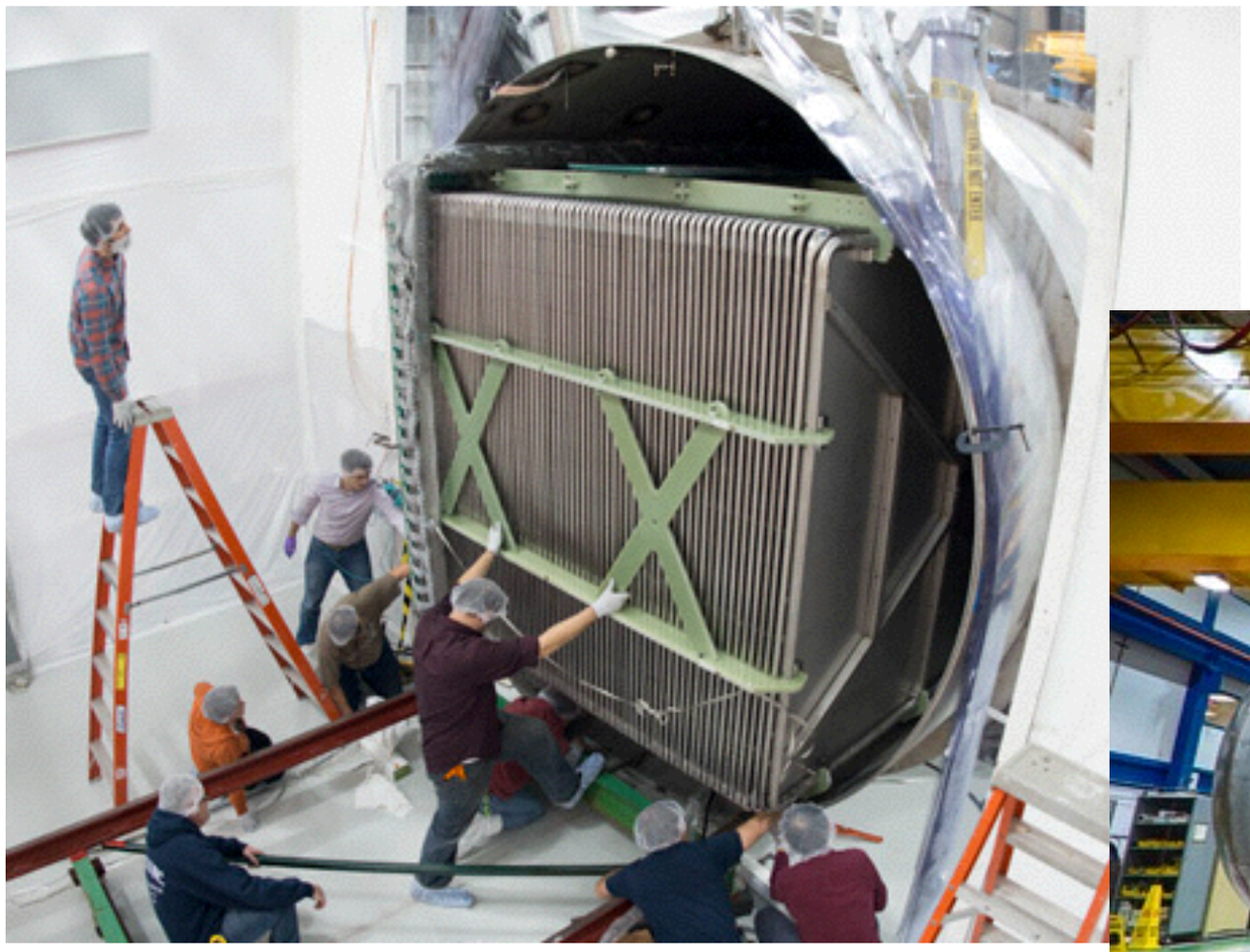


- Lesson: test electronics as much as possible ahead of time!
- Will reduce incidence of future problems that may be hard to resolve at a later time.
- Also excellent opportunity to exercise DAQ/ offline analysis chain!



# MicroBooNE: 2014

- 2014: Don't forget the cryostat…
  - Even after acceptance/installation, more testing should be done: electronics, PMTs, HV.



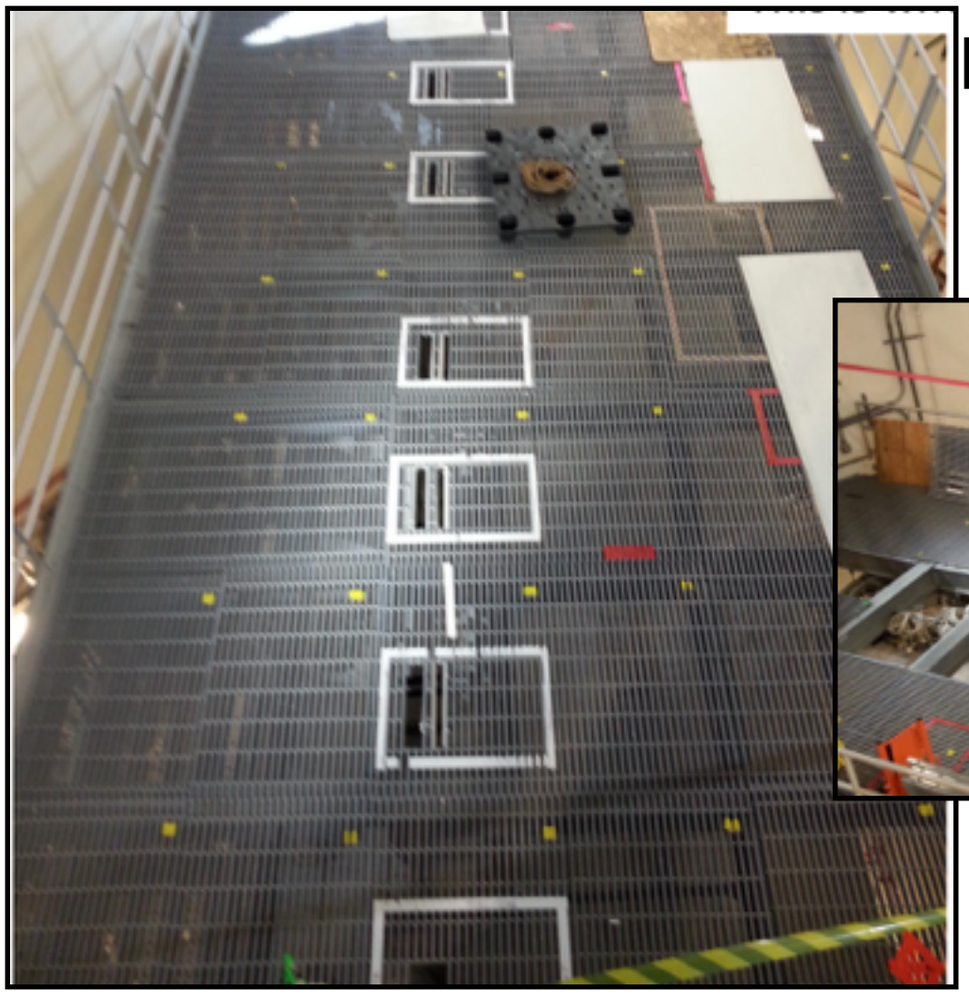

# MicroBooNE: June 2014

- When ALL that was finally done…
- We install!  And we live happy ever after, right?
- Wait, I'm only to 2014…


# MicroBooNE: Later in 2014…

- 2014 installation: cabling!
  - 6.2 km of data, power, network, etc. cables installed in <u>one month</u>
  - Thousands of connectors and cables, and all need to work correctly.

- Cryo installation and testing is similarly complex (and crucial!)



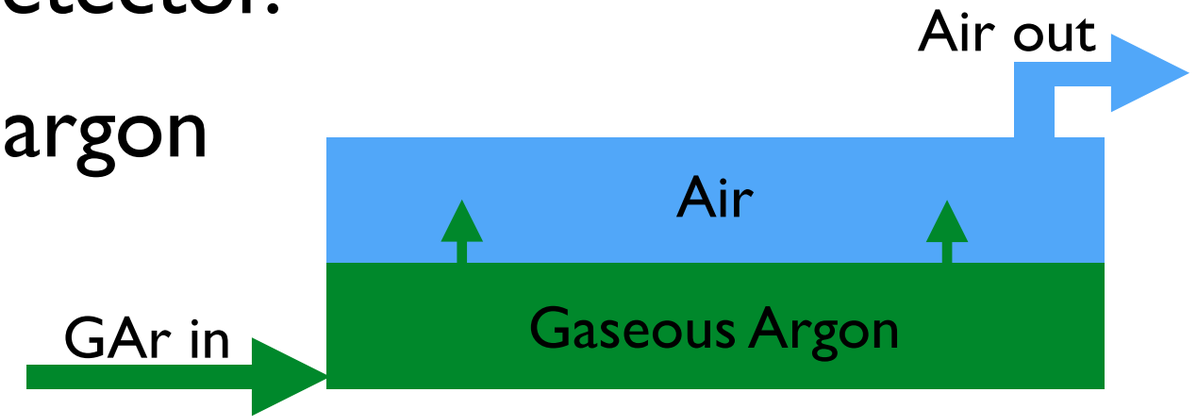
Before

During

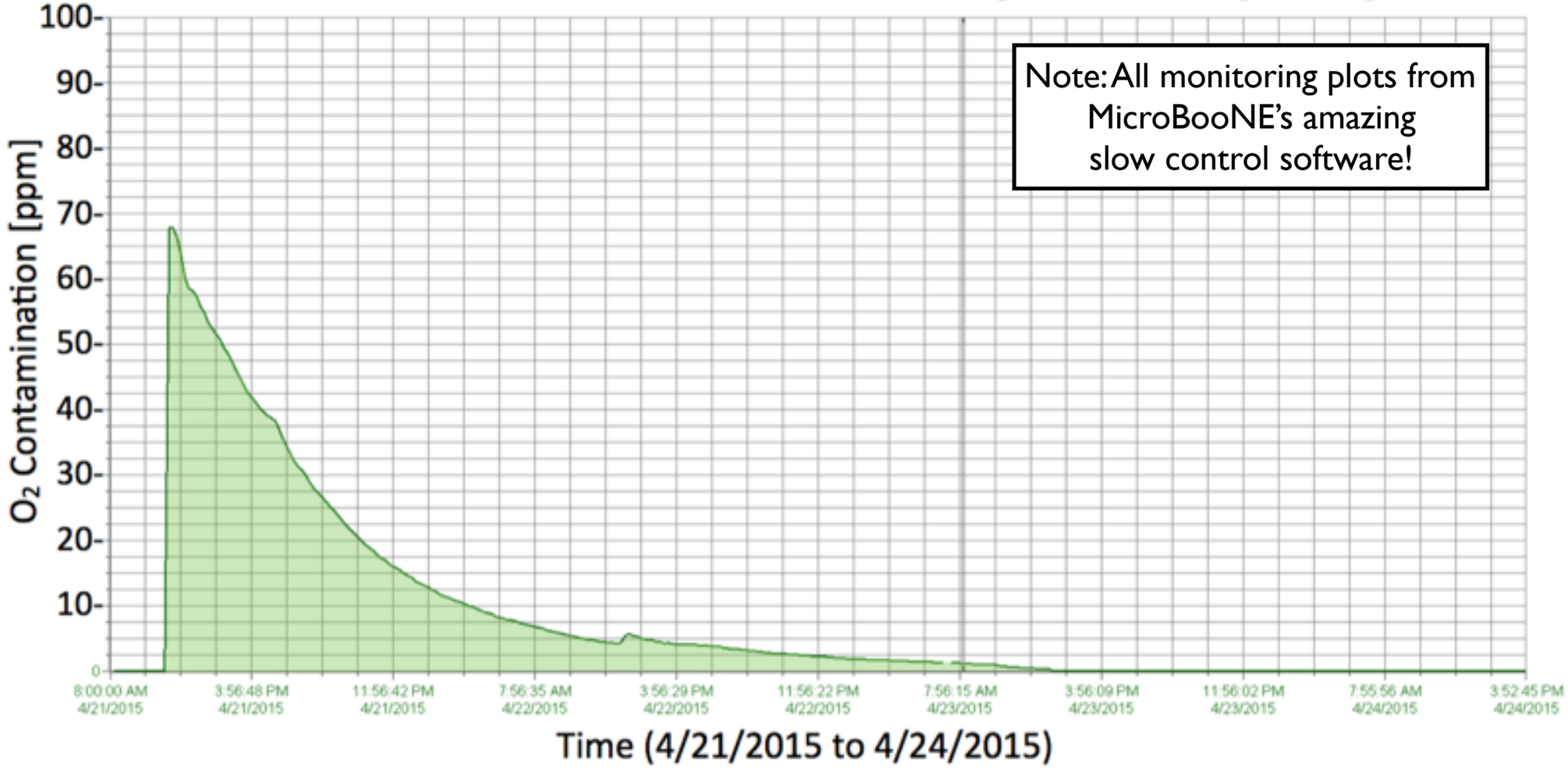
After

# MicroBooNE: 2015 Filling

- After installing/testing all electronics and laying all cryo pipe, it's time to prepare for filling our detector.
- Step 1: Purge tank with gaseous argon

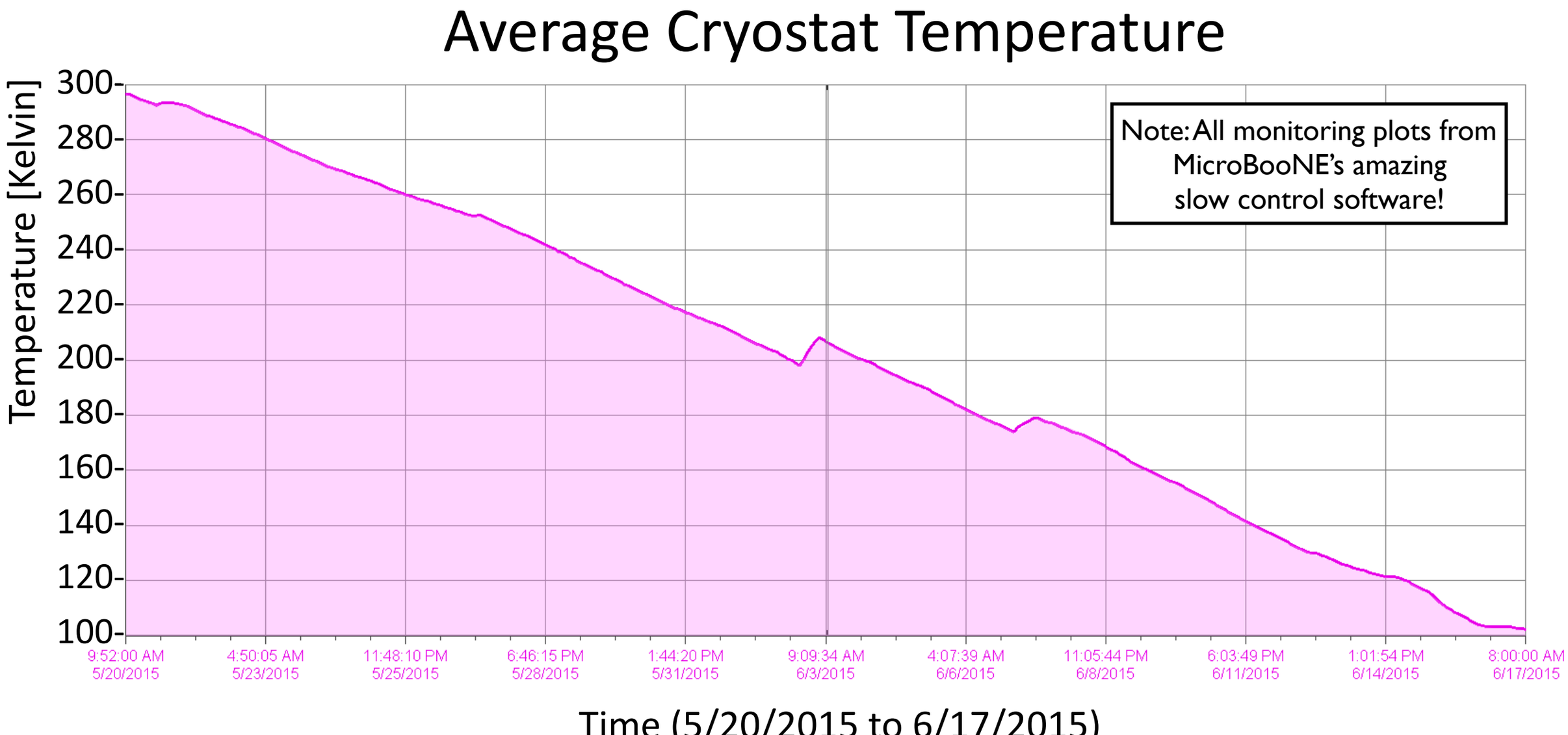



$O_2$ Contamination of Gaseous Argon During Purge



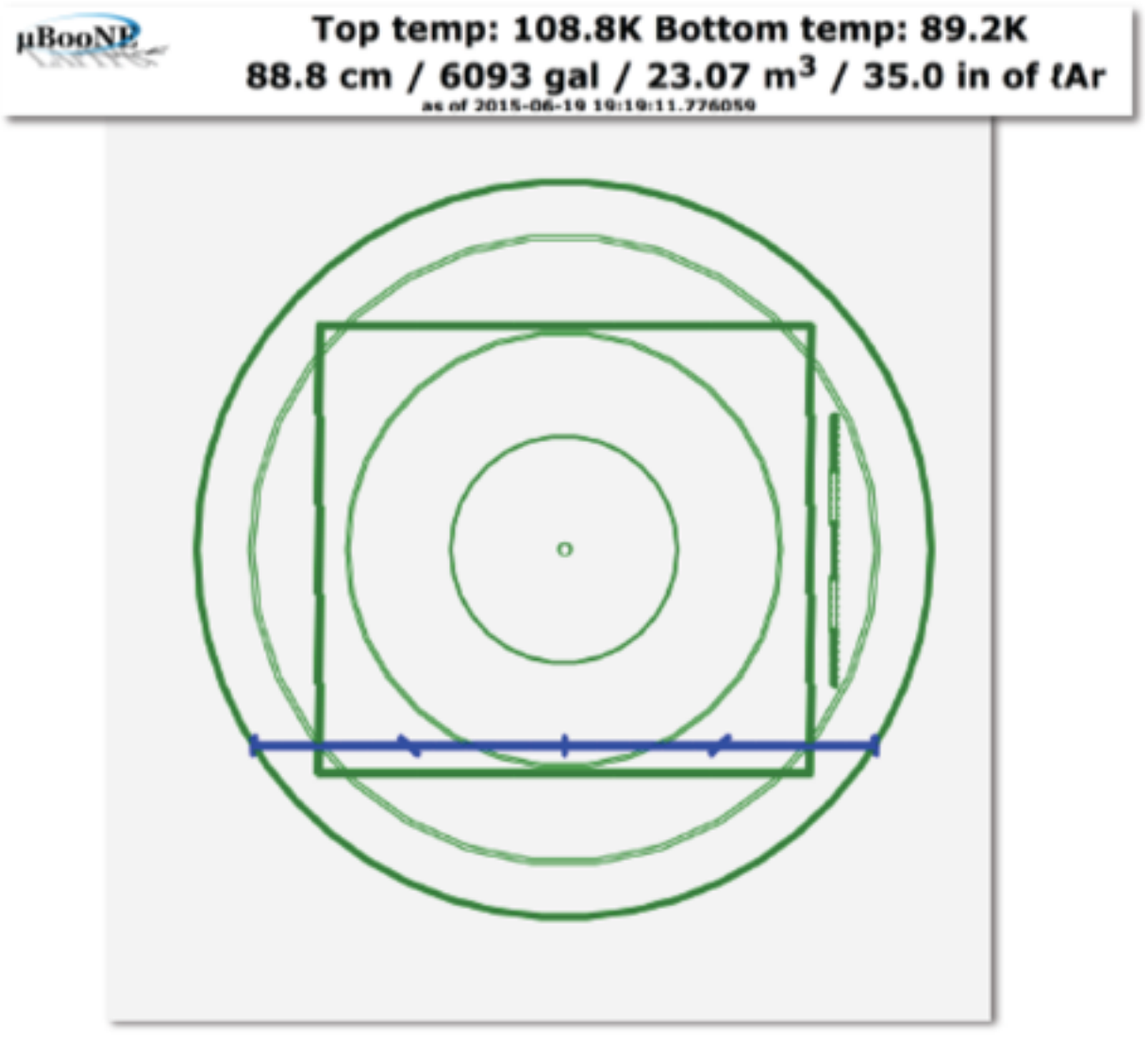
# MicroBooNE: 2015 Filling

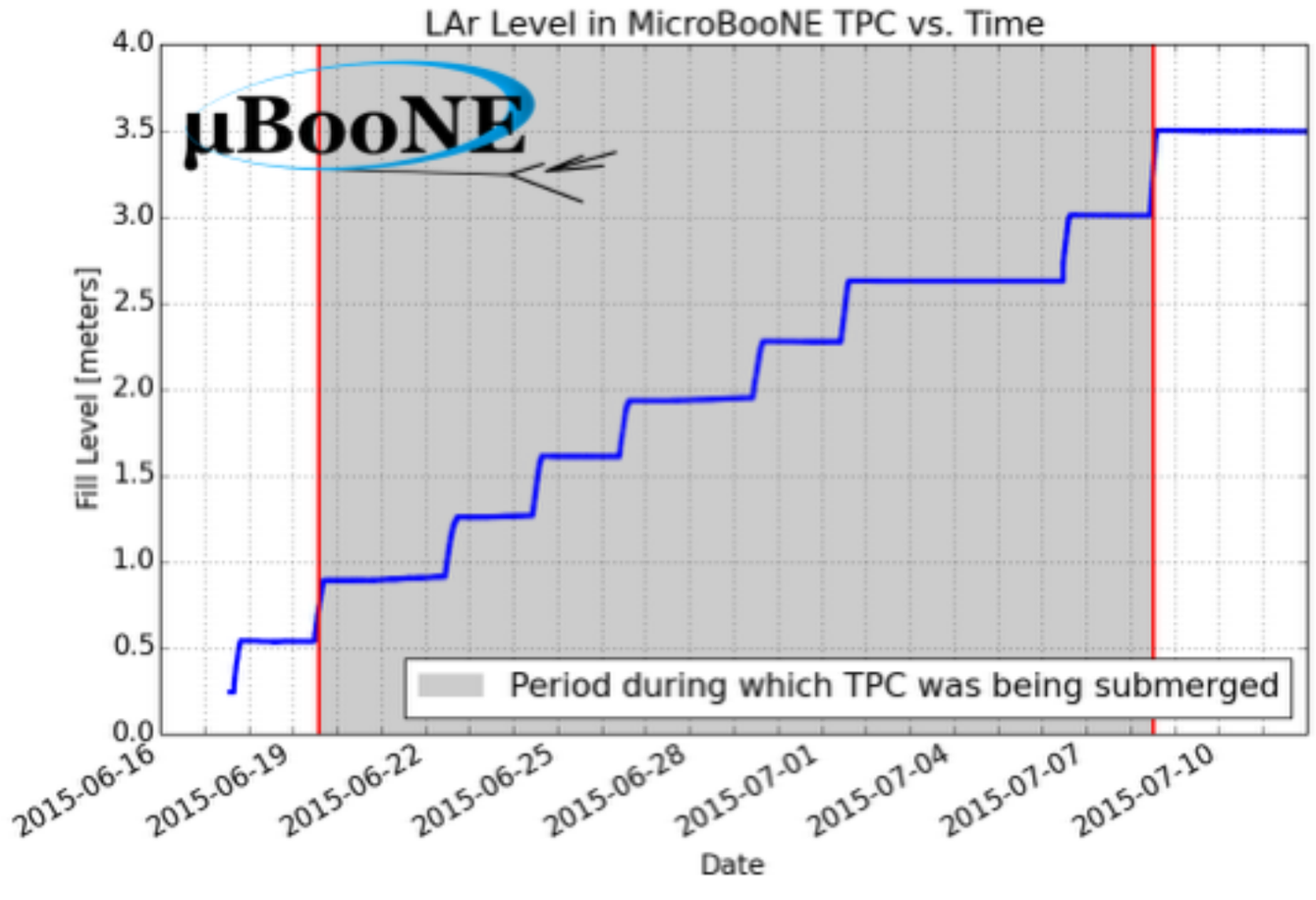
- Step 1: Purge tank with gaseous argon
- Step 2: Cool down the relatively pure gaseous argon



# MicroBooNE: 2015 Filling

- Step 1: Purge tank with gaseous argon
- Step 2: Cool down the relatively pure gaseous argon
- Step 3: Fill with Liquid Argon
  - Lesson: make sure your argon meets your delivery specs!

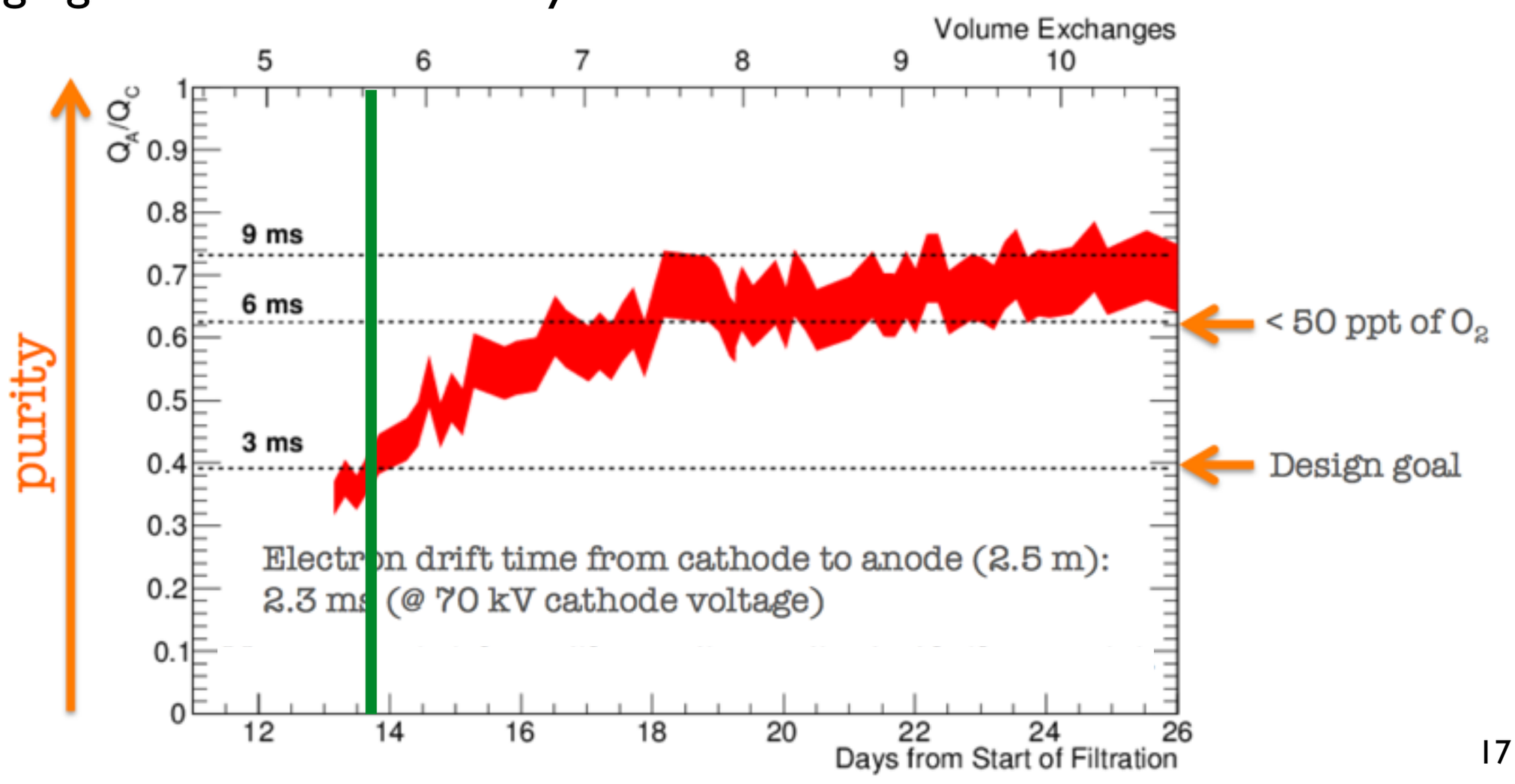



http://argo-microboone.fnal.gov/FillLevel/

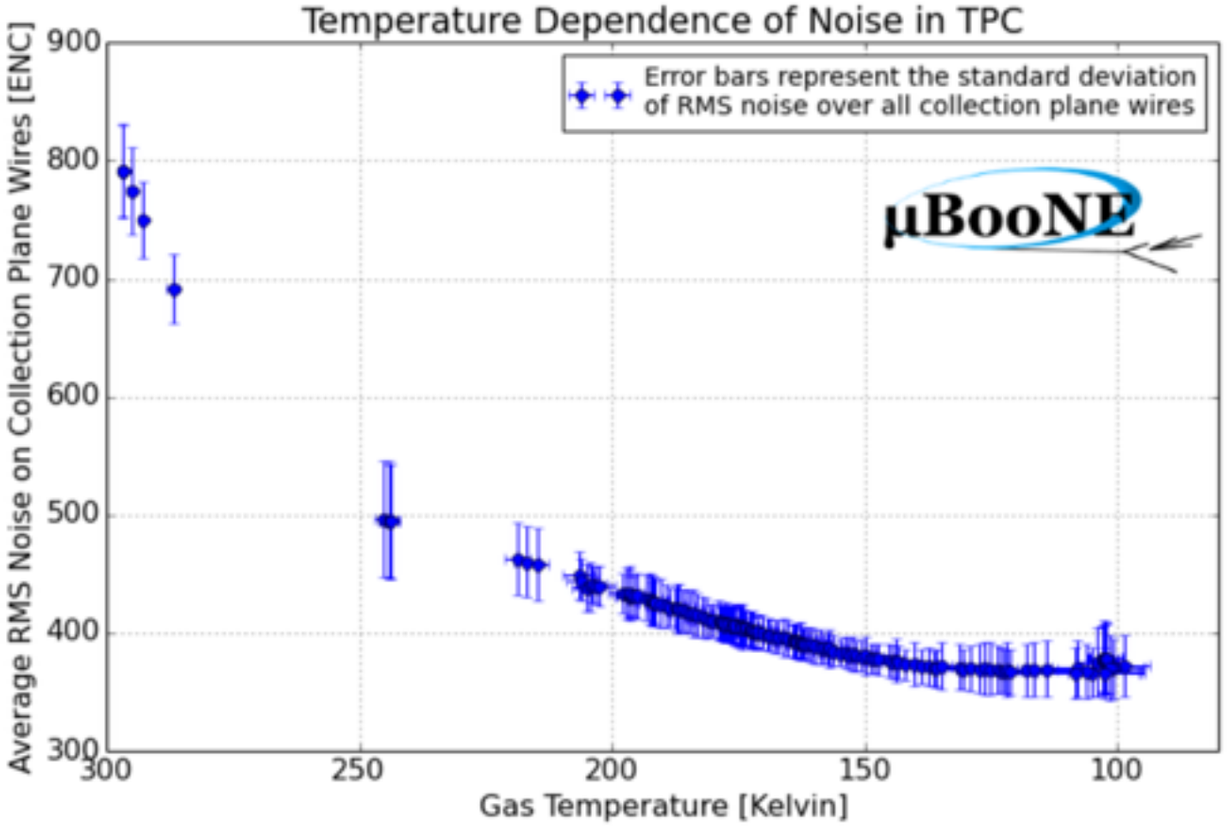
# MicroBooNE: 2015 Filling

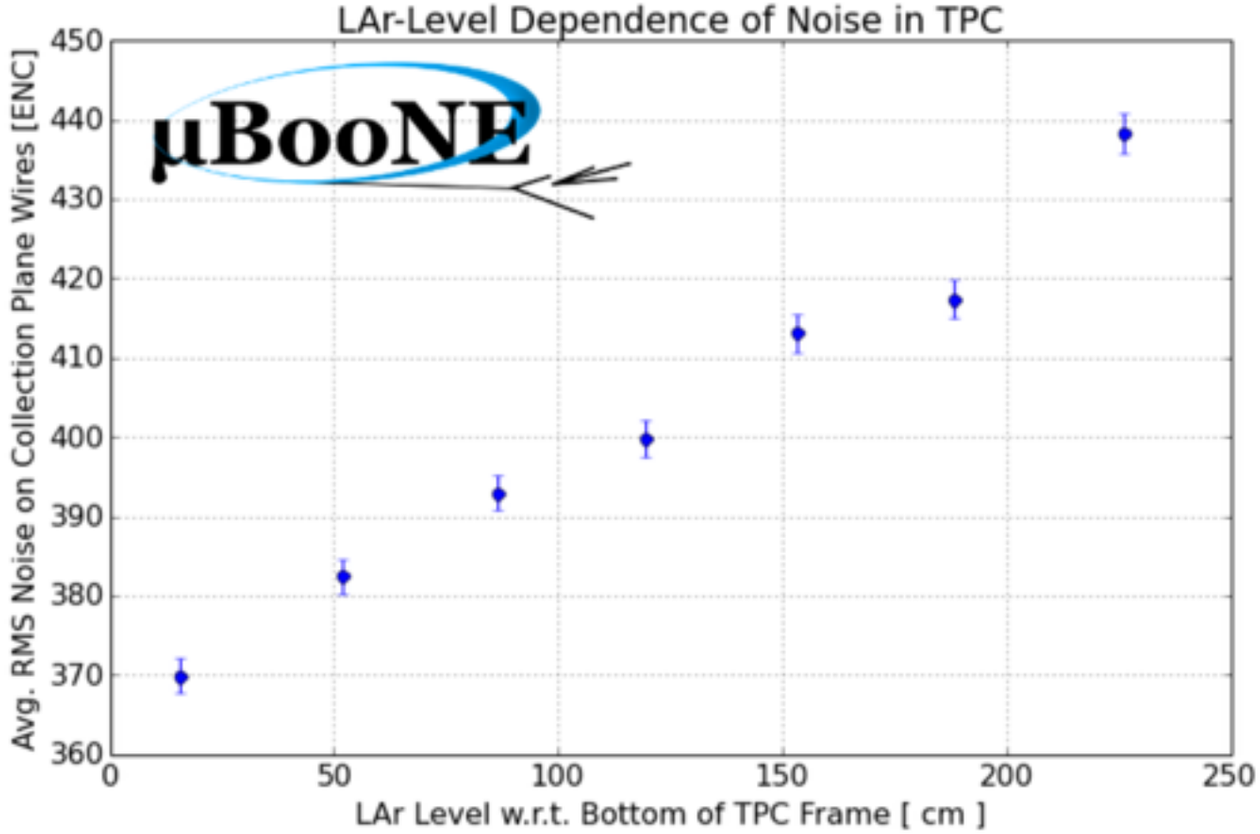
- Step 1: Purge tank with gaseous argon
- Step 2: Cool down the relatively pure gaseous argon
- Step 3: Fill with Liquid Argon
- Step 4: Filter while doing other commissioning, analysis
  - Met design goal within 6 volume cycles!



# MicroBooNE: 2015 Filling

- We even made sure the electronics were holding up well during this commissioning and filling period.
- Example: noise characterization
  - Lower temperatures = much lower electronics noise.
  - Lesson: It turn out cold electronics ARE a good idea! Much lower noise achieved!




**2008: WOW.** **2012** **2014** **2015: FILL**

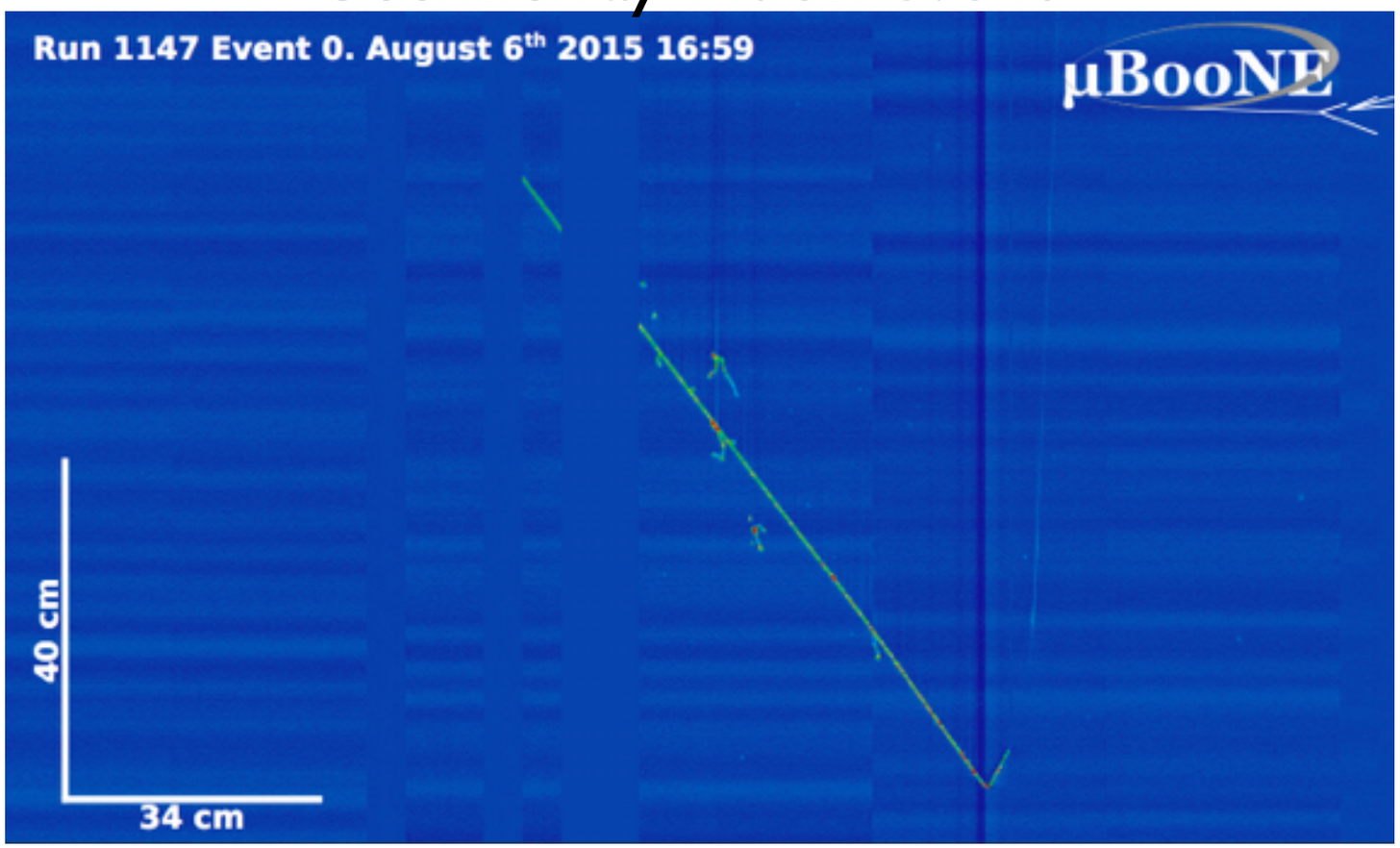
# Notes Before Turning to Data:

- We should note the R&D achievements met by MicroBooNE:
  - We have a full, stable, pure tank of liquid argon in MicroBooNE!
  - We have fully tested cold electronics on every channel in the TPC!
  - We have a LArTPC taking stable data in the presence of HV!
- We also should note the lessons learned (this is obviously NOT an exhaustive list…)
  - Lesson: test electronics as much as possible ahead of time!
  - Lesson: gather as much data on your TPC as possible during all steps of the process!
  - Lesson: Consider the complicated electro-dynamics of your TPC: resistance, capacitance, etc etc!
  - Lesson: make sure your argon meets your delivery specs!
  - Lesson: be conservative when planning/ designing for HV in your LArTPC!!!
  - Lesson: It turn out cold electronics ARE a good idea! Much lower noise achieved!
- R&D demonstrations, LAr/LArTPC property measurements, and these lessons learned will greatly accelerate timelines for designing, building, and operating future LArTPCs.

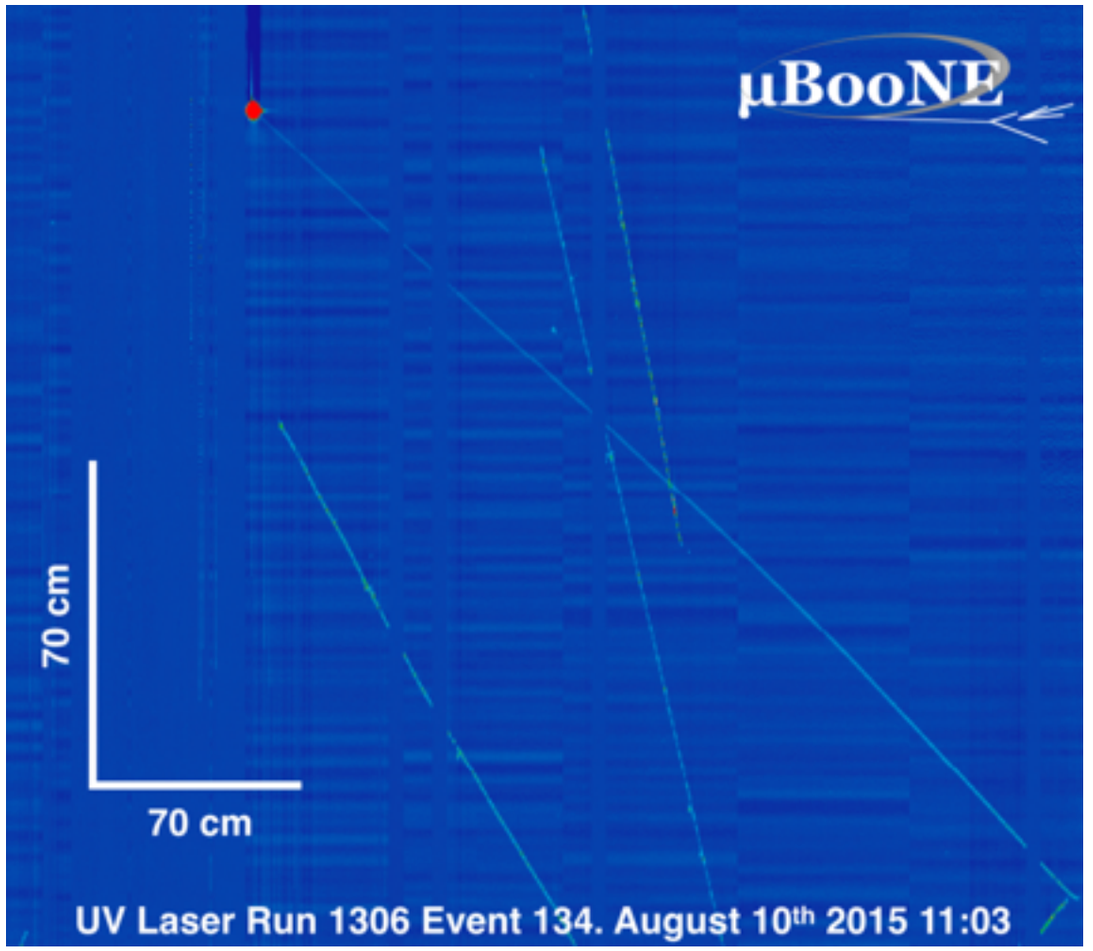
# MicroBooNE: 2015 DATA!

- After filling and HV ramp, start to look for tracks, and find them (from cosmics) in short order!
  - … Maybe a day or two of channel mapping pain, but worth the trouble!
  - … Maybe a little random noise in first data, but cleaned up with some focus.

Cosmic ray muon event




UV laser event

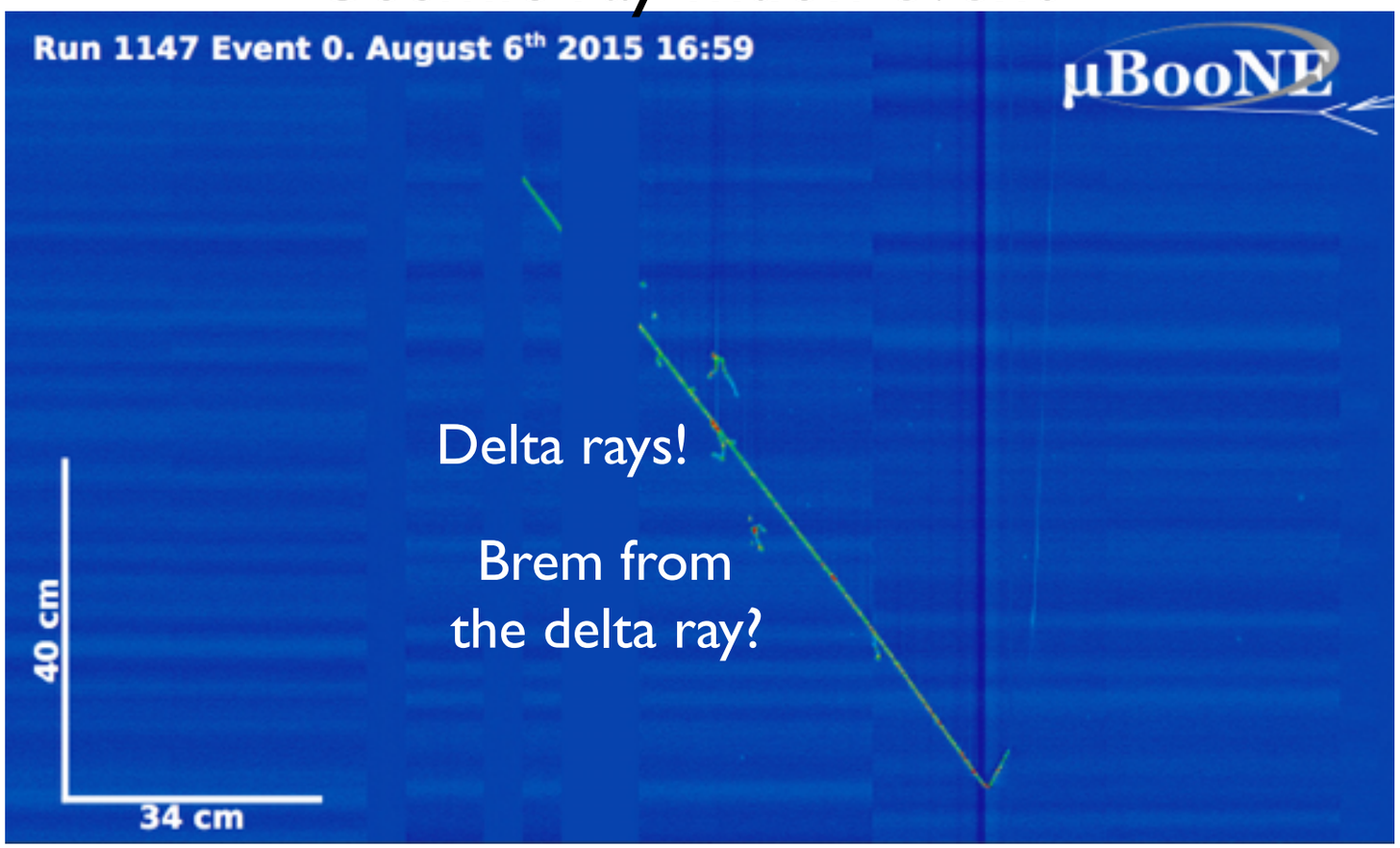



2008: WOW. — 2012 — 2014 — 2015: DATA!

# MicroBooNE: 2015 DATA!

- After filling and HV ramp, start to look for tracks, and find them (from cosmics) in short order!
  - Analyzers are hard at work pulling reconstruction, detector physics results out of this first (and ongoing) set of cosmic MicroBooNE triggers
  - Drift loss, re-combination, diffusion, etc. etc!

Cosmic ray muon event

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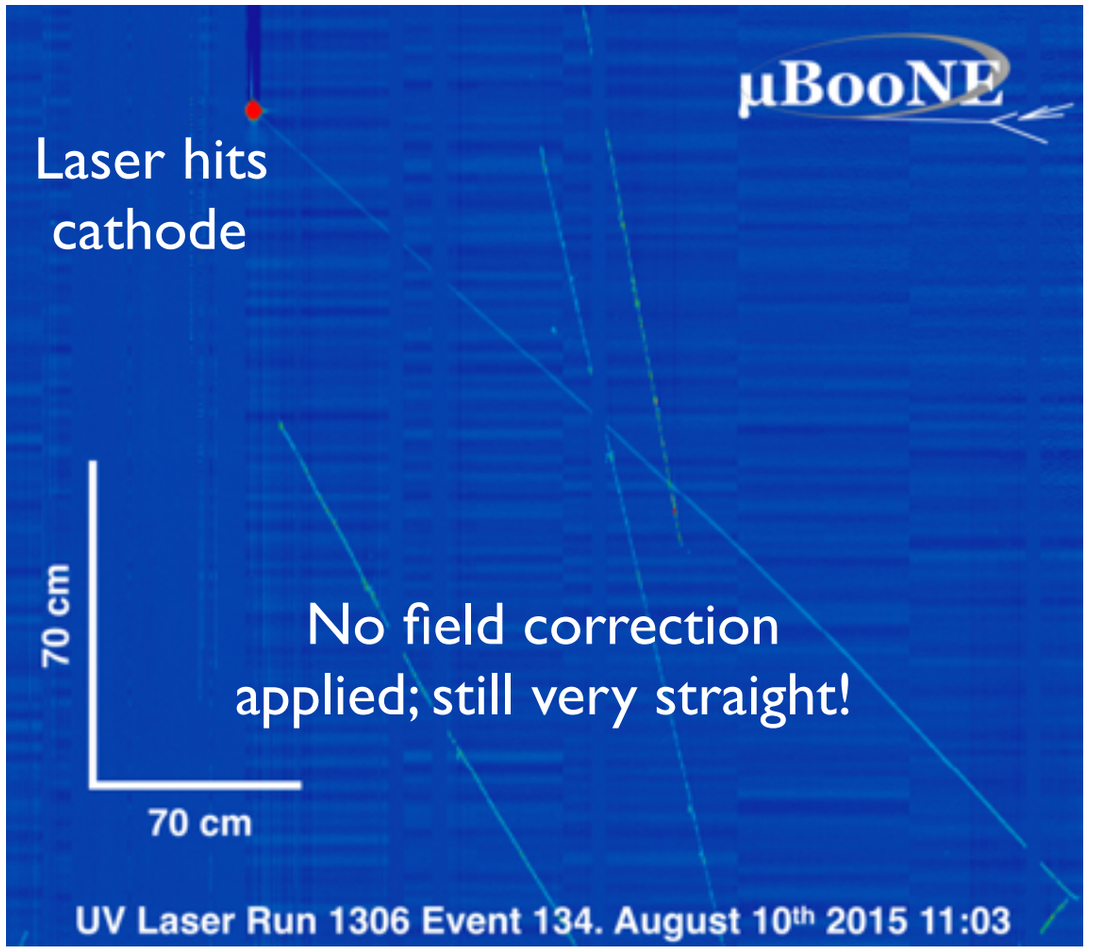
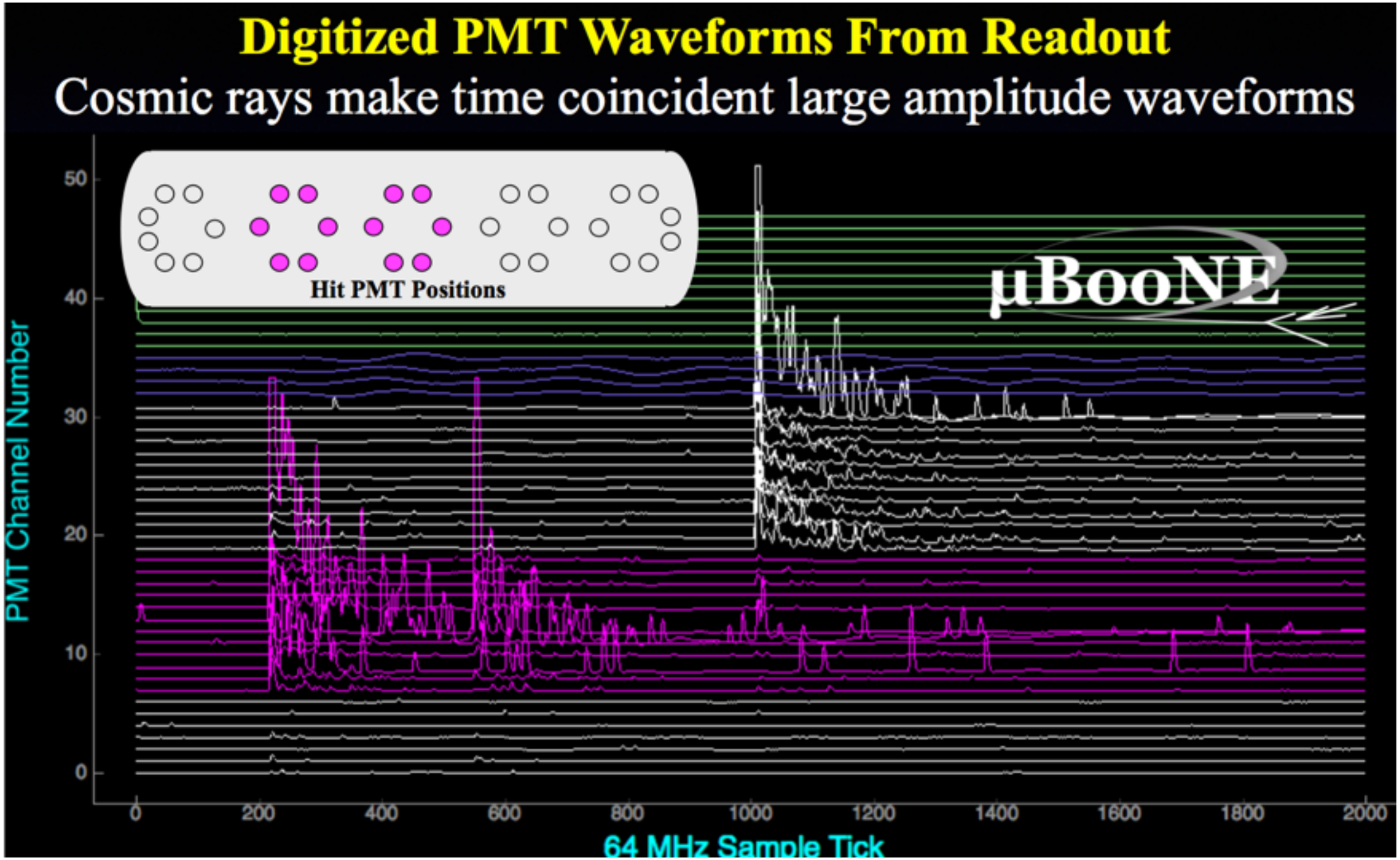



2008: WOW. — 2012 — 2014 — 2015: DATA!

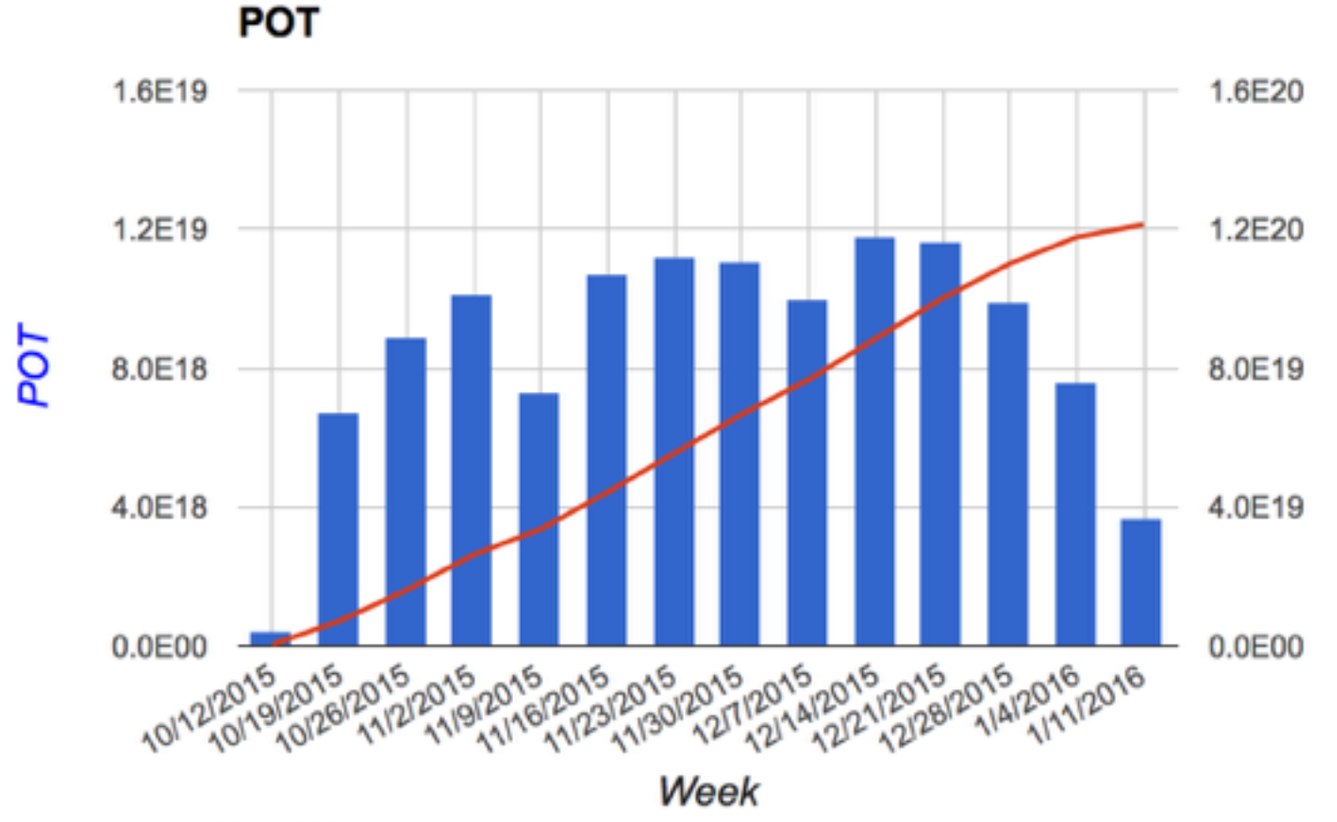
# MicroBooNE: 2015 DATA!

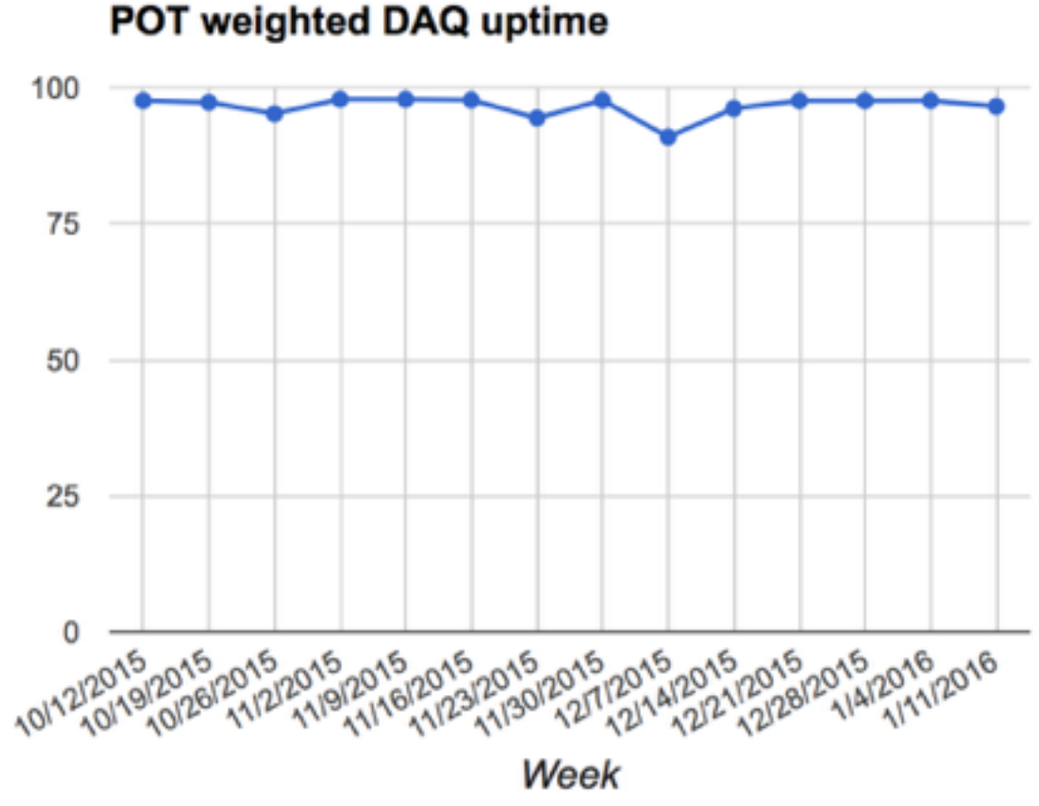
- Also having success utilizing PMT system to look at cosmics



# MicroBooNE: 2015 BEAM!

- We started getting BNB beam in 15 October 2015
- We have had excellent DAQ uptime for beam-on periods
- We are getting spills on tape from NuMI, as well.



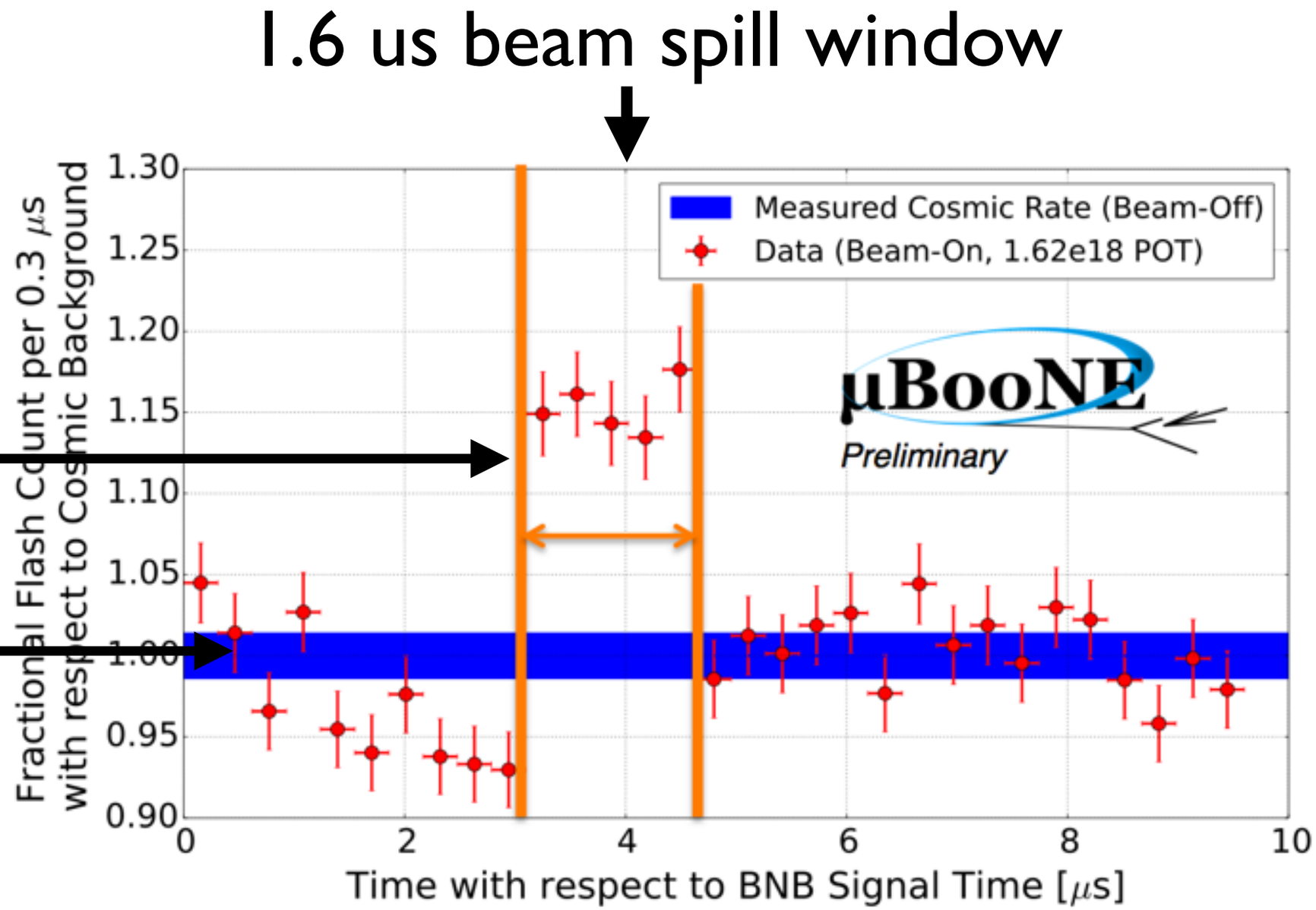

2008: WOW. 2012 2014 2015: BEAM!

# MicroBooNE: 2015 NEUTRINOS!

- First we saw them with PMTs…

cosmics plus… neutrinos!

cosmics




2008: WOW. 2012 2014 2015: BEAM!

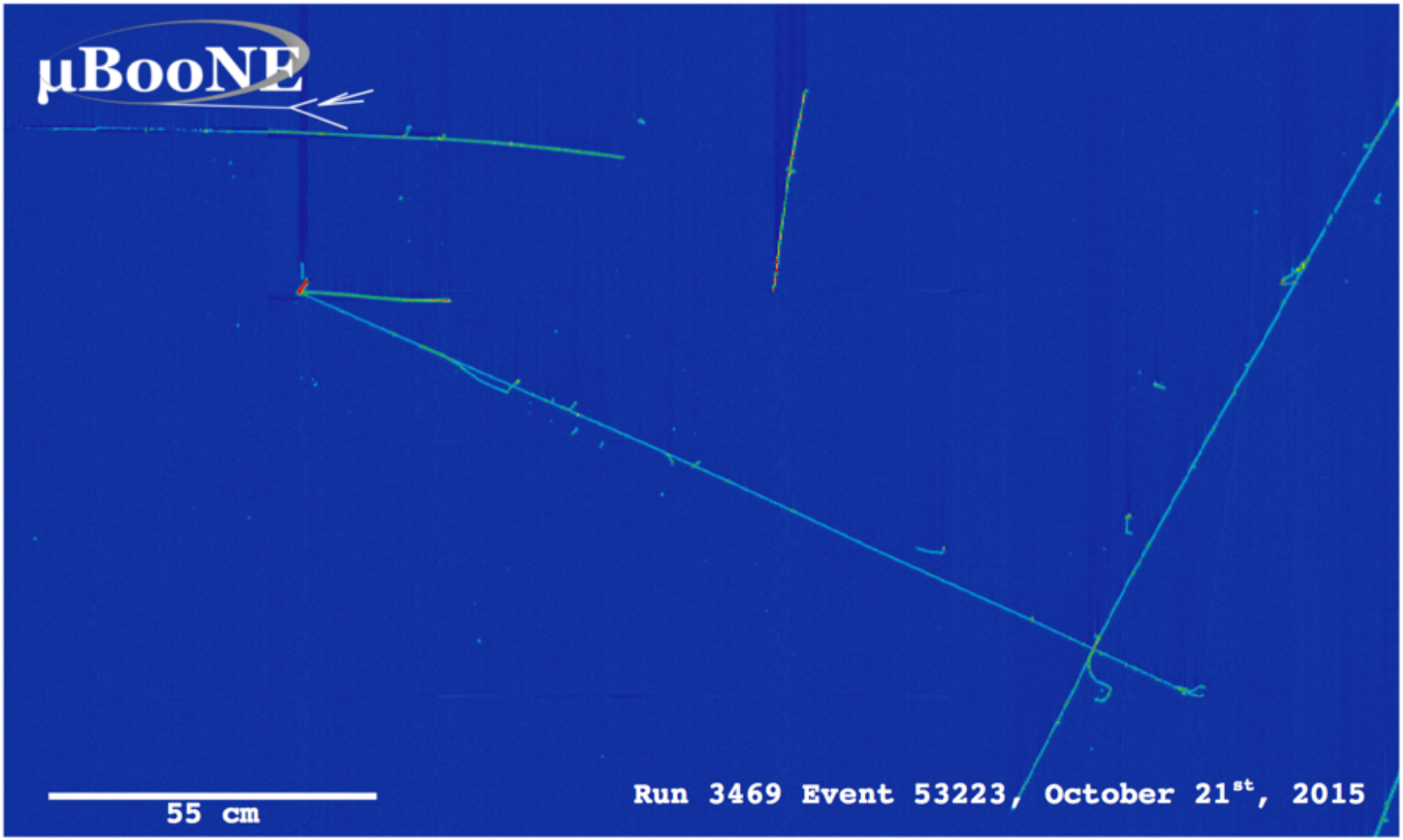
# MicroBooNE: 2015 NEUTRINOS!

- …then we saw them with the TPC.
- TPC neutrino ID possible with a cuts on a few key quantities
- For example, the analysis using *automated* 3D-reconstruction:
  - Two or more reconstructed tracks with start points within 5cm of each other
  - All tracks must be fully-contained
  - Longest track must satisfy $\cos(\theta) > 0.8$
  - >5sigma CL observation of neutrinos with the TPC!
- Have a similar *automated* algorithm for 2D reconstruction

| Number of events | Optical + 3D-based | Optical + 2D-based |
|---|---|---|
| Non-beam background (expected from off-beam measurements) | $4.6 \pm 2.6$ | $385 \pm 24$ |
| Total observed (during beam) | 18 | 463 |

# MicroBooNE: 2015 NEUTRINOS!

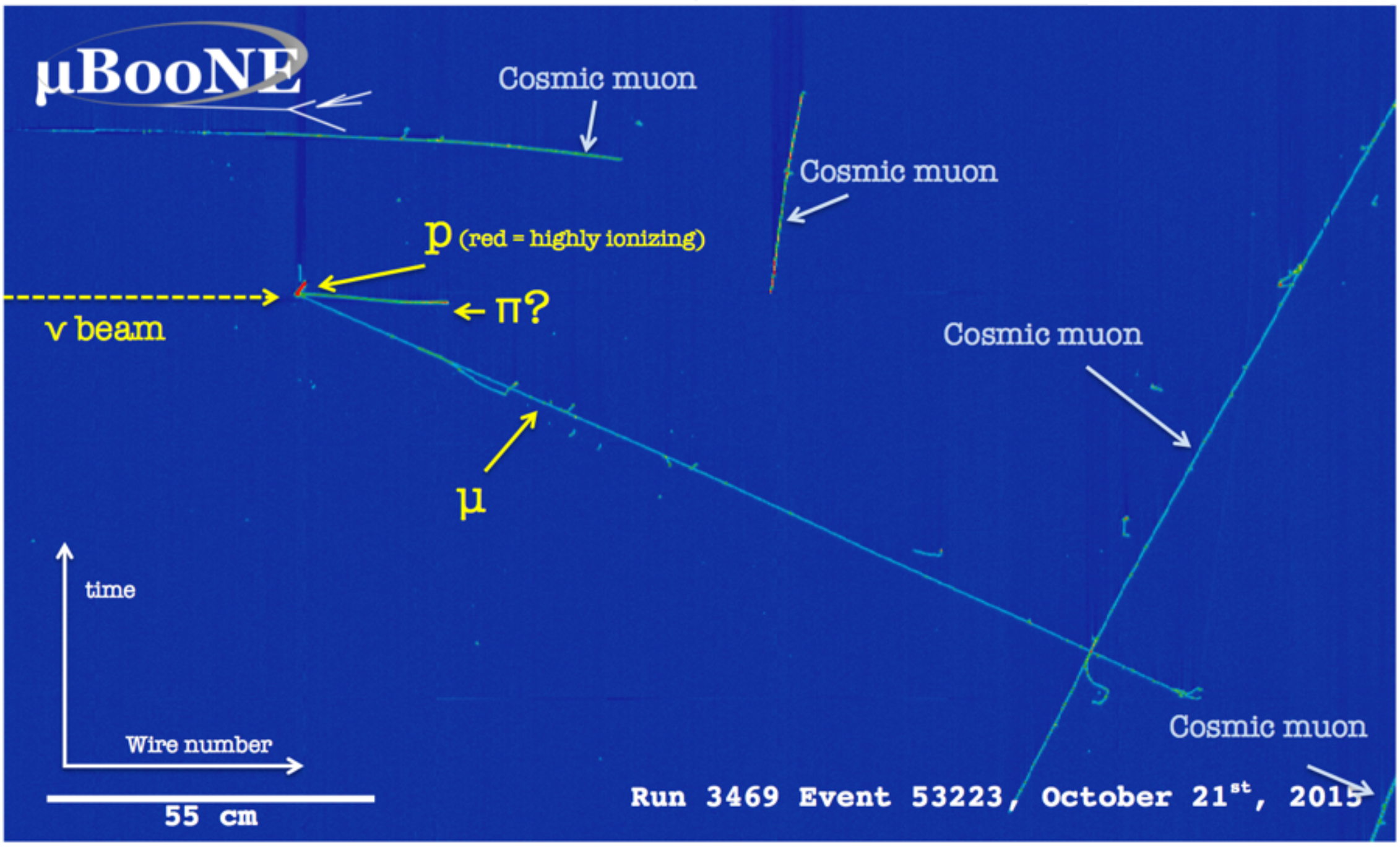
- …then we identified them in the TPC!




2008: WOW. 2012 2014 2015: BEAM!

# MicroBooNE: 2015 NEUTRINOS!

- Breaking one event display down:



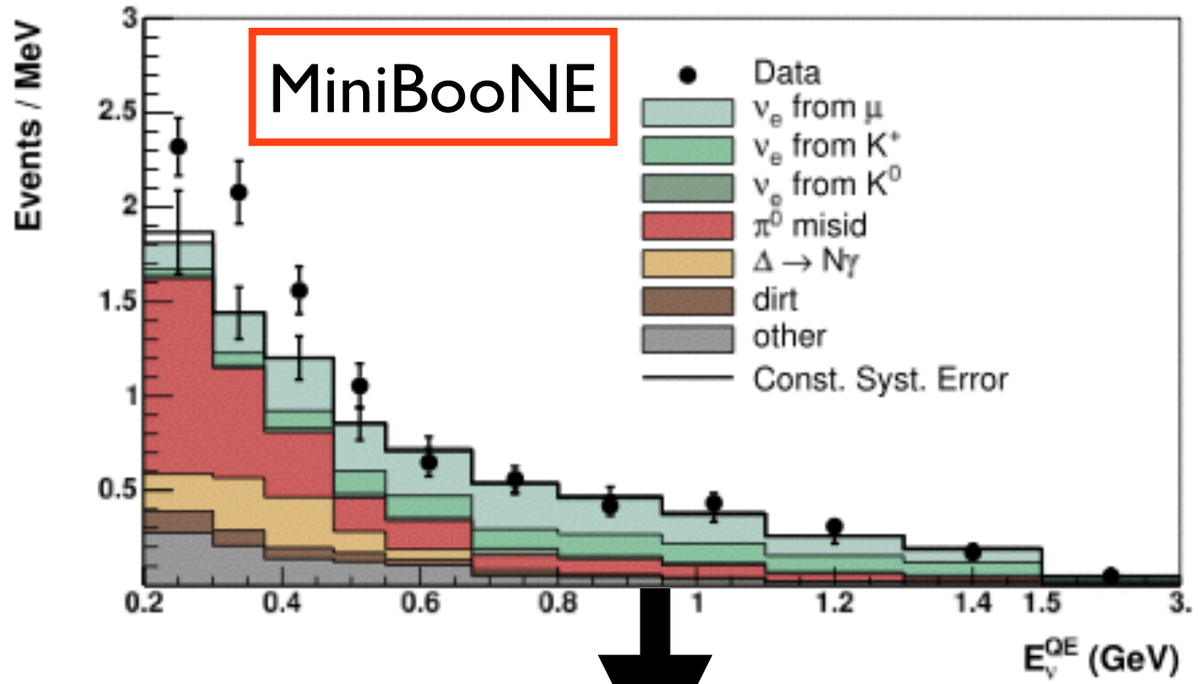
# MircoBooNE: 2015 NEUTRINOS!

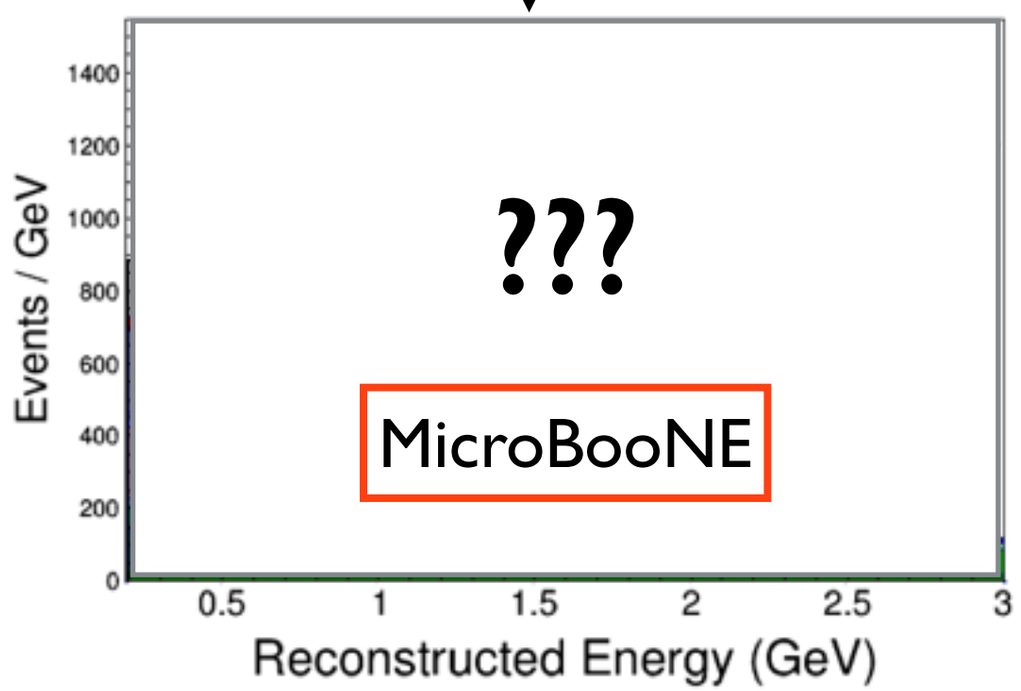
- Then we celebrate MircoBooNE's accomplishment!
- …and get back to work.

# Post-MicroBooNE Scenarios

# Sterile ν Mystery at Fermilab

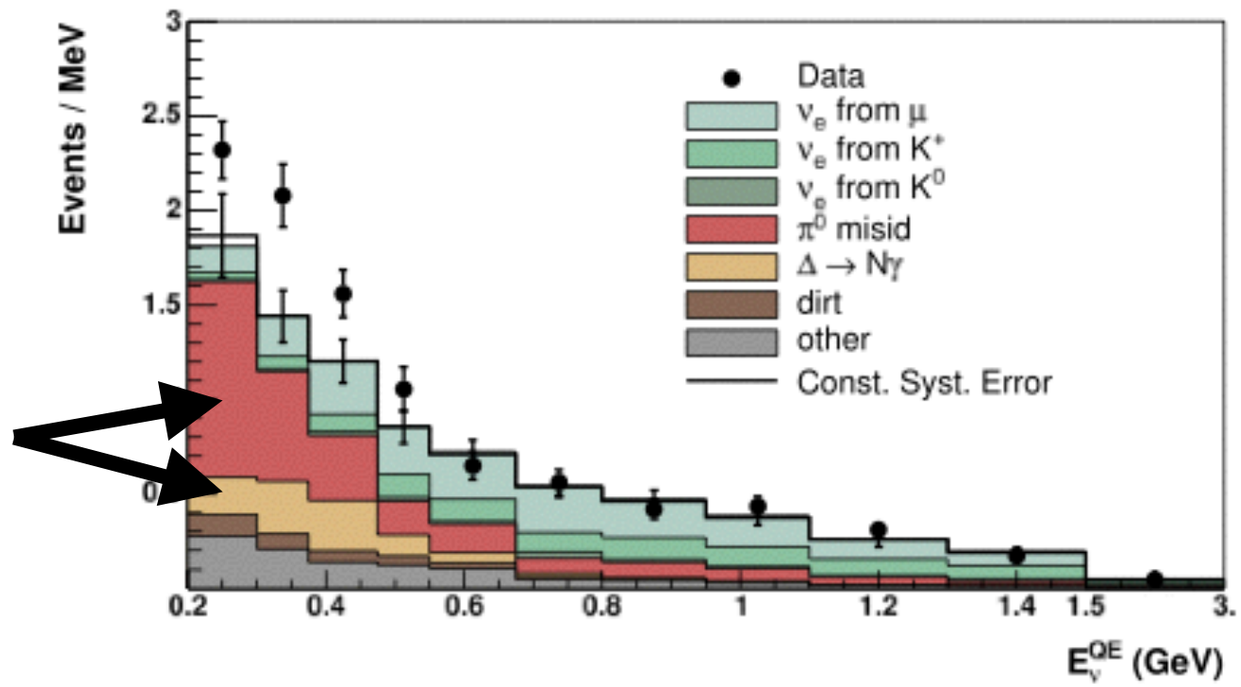
- It's now 3 years in the future, and MicroBooNE has released their full-dataset low-energy excess result.
  - Will definitively test MiniBooNE excess by measuring the same neutrinos with a more sensitive detection technique.
- What might it show?
  - Electron-like excess
  - Photon-like excess
  - No excess?
  - Excess in both channels?
  - Something else?
- Let's investigate these scenarios in more detail



# Electron-Like Excess: Differences

- How will the electron-like result look different than MiniBooNE?
  - Gamma-related backgrounds should be way smaller in this stack.



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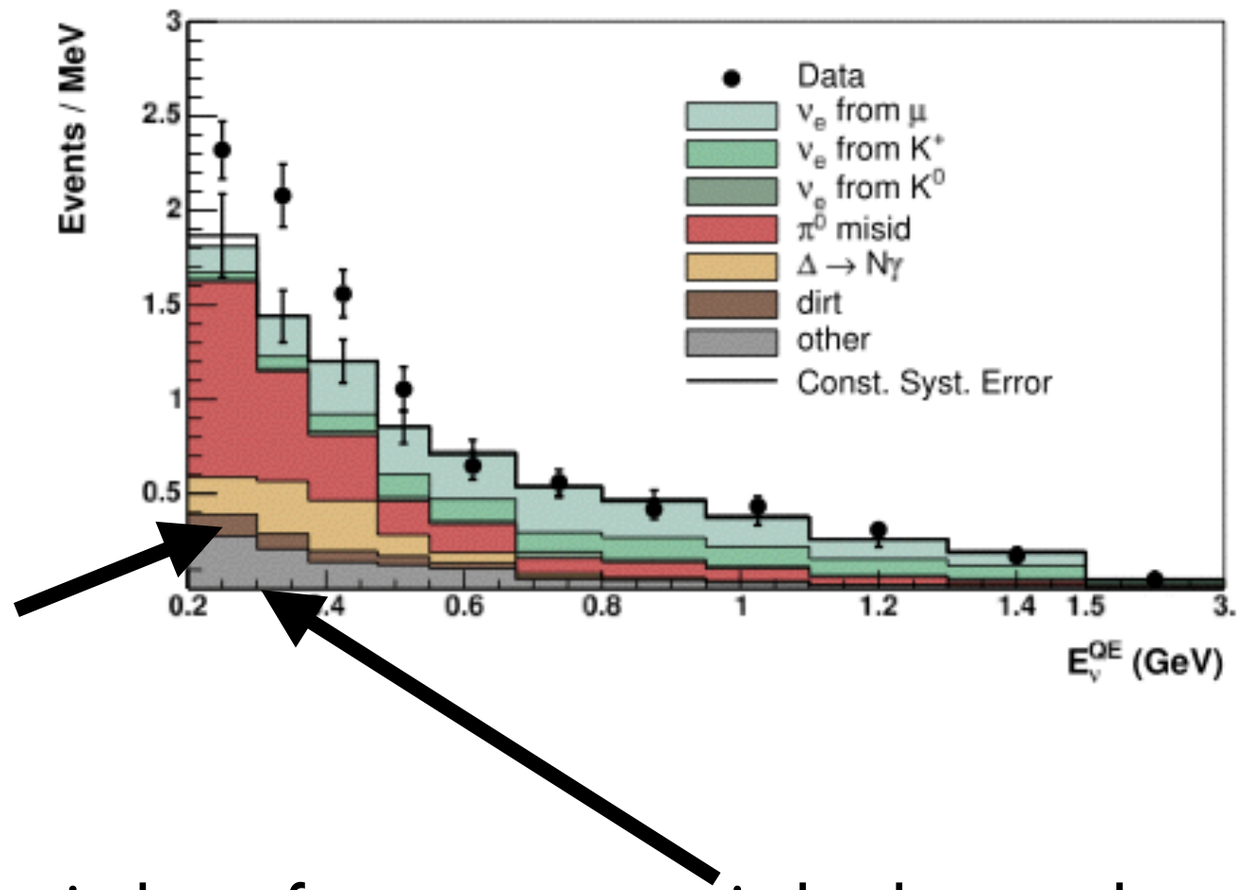


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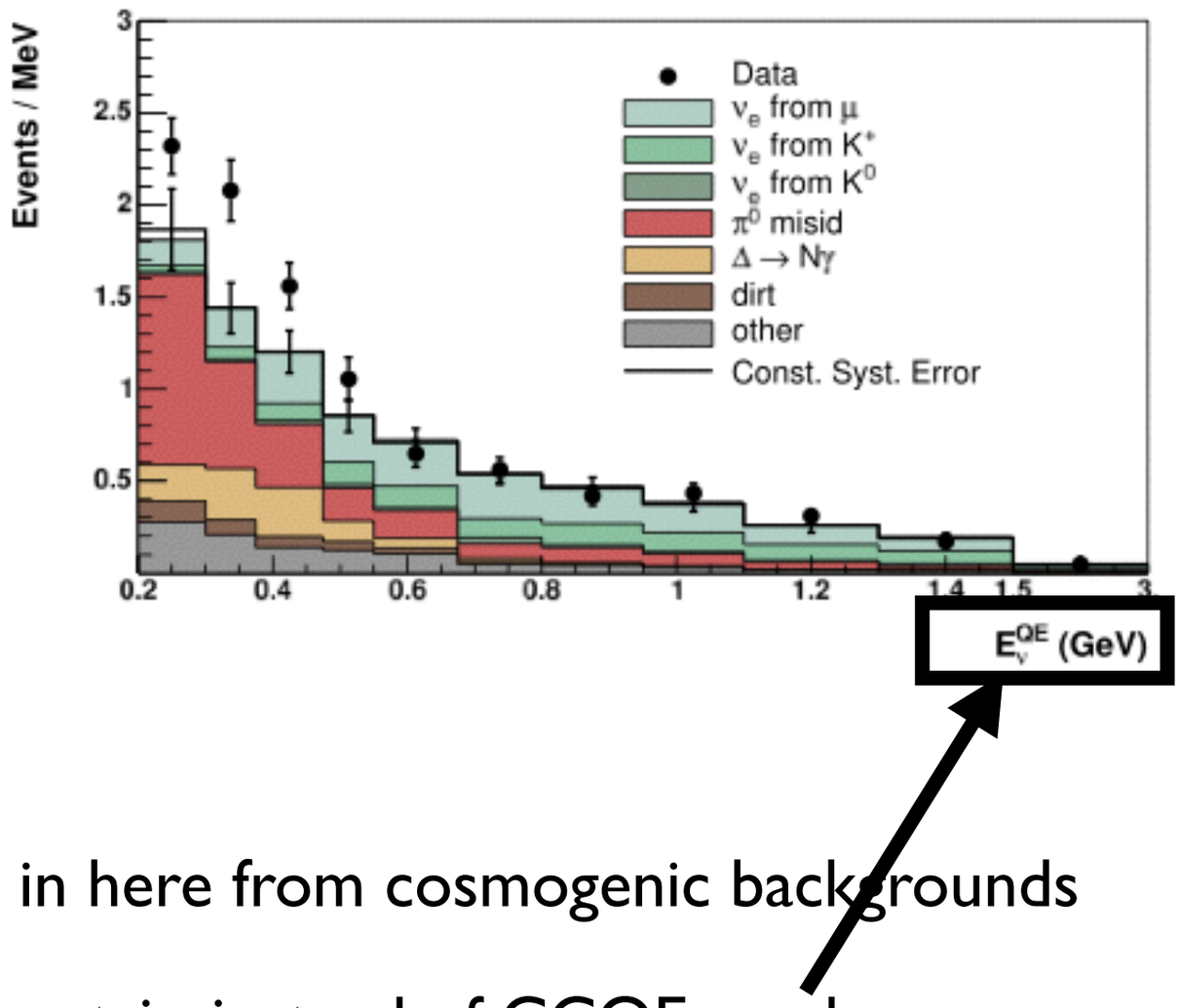
  - You might see a totally different x-axis metric: instead of CCQE, maybe lepton+vertex energy, or maybe something else!



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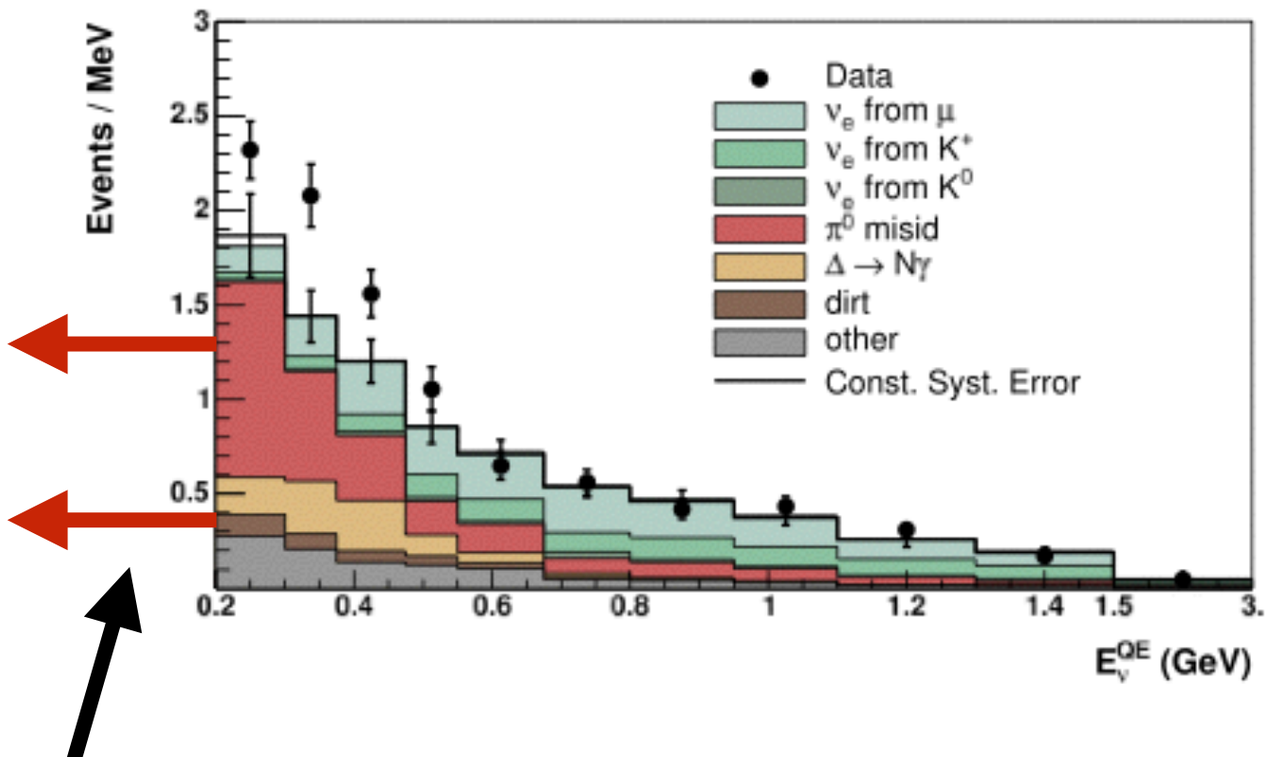
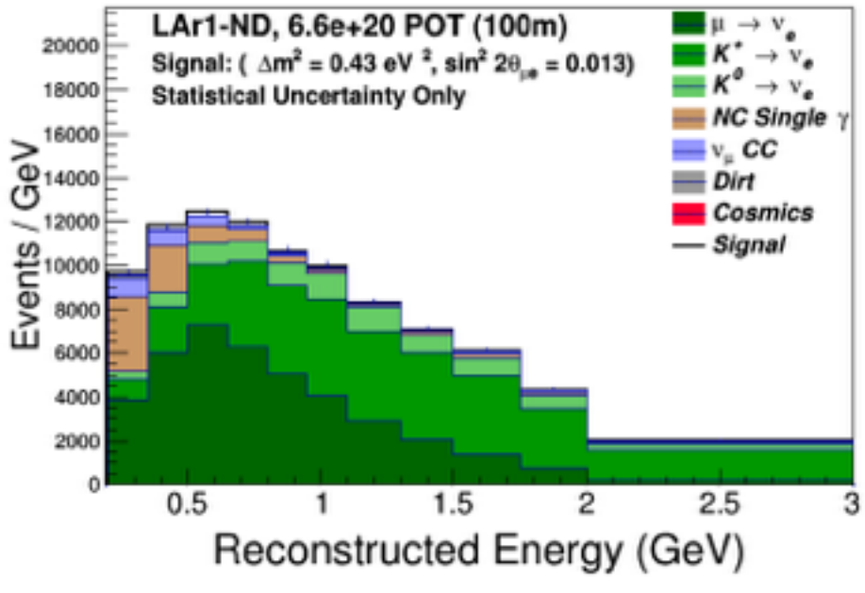
  - There will likely be a new (small) color in here from cosmogenic backgrounds
  - You might see a totally different x-axis metric: instead of CCQE, maybe lepton+vertex energy, or maybe something else!
  - You might also see a different range on this plot: no Cerenkov thresholds and excellent 3D position information could enable a lowered threshold.

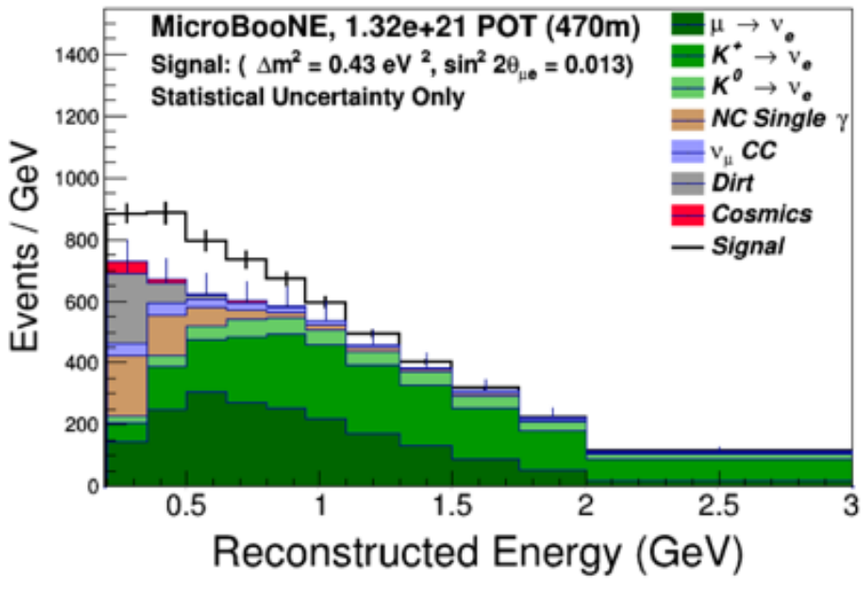


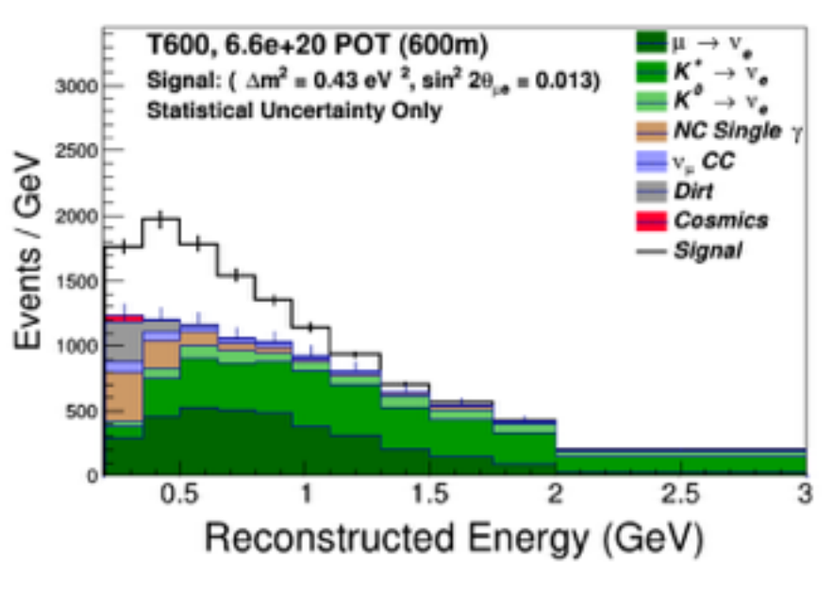

- So more than just an improvement in e/γ separation.

# Electron-Like Excess: Scenarios

- If we see an electron-like excess, this would be amazing!
  - SBND would collect statistics quickly at its shorter baseline, giving very convincing confirmation of the nue appearance interpretation.
  - Full SBN would then provide the precision measurement of this oscillation.
  - Must be diligent in our proper estimation of TPC-external beam backgrounds and cosmic backgrounds.

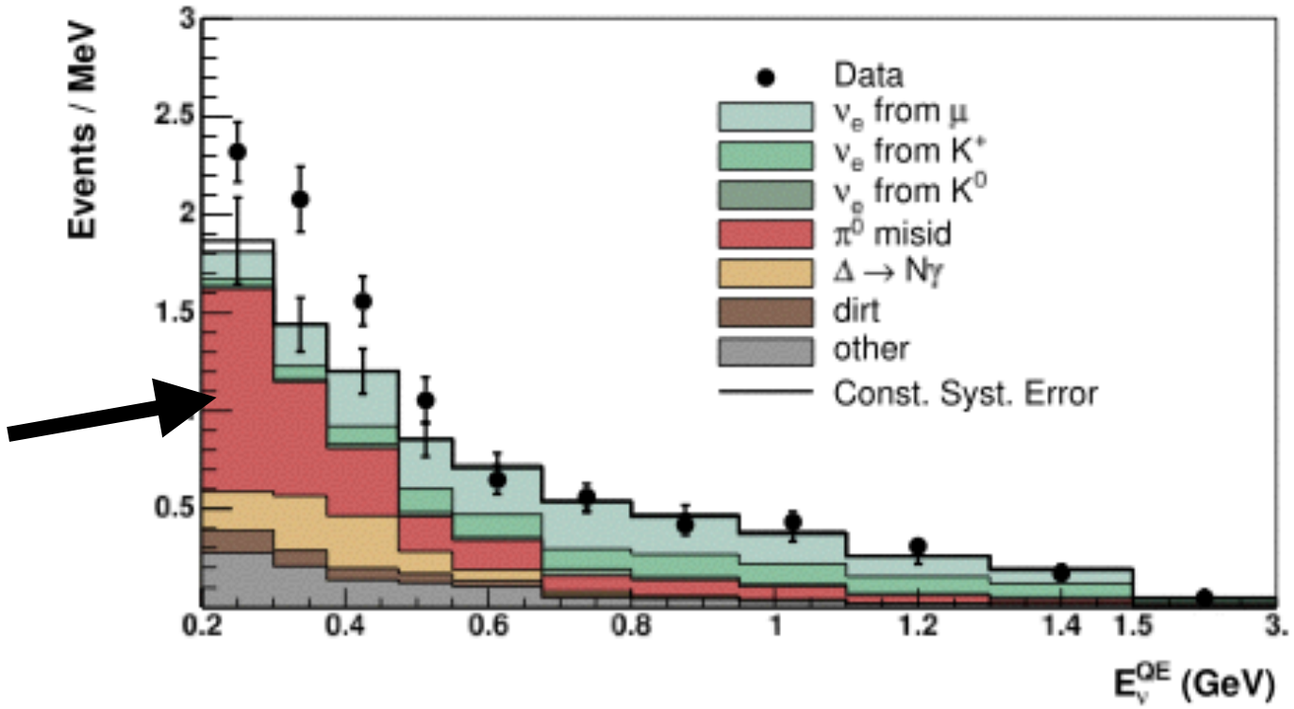


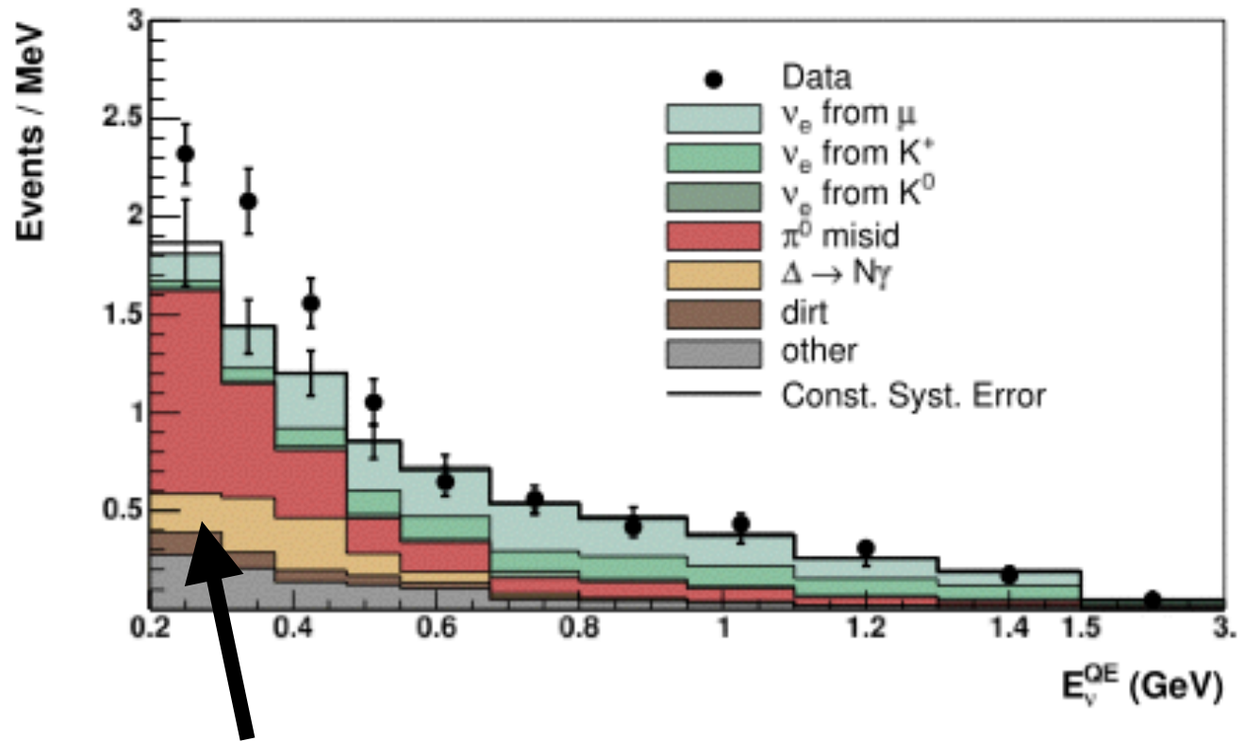
# Photon-Like Excess: Scenarios

- A big question in this case: where is the excess?
  - If excess picks up at lowest energies, this could point an issue with $\pi^0$s:
    - enhanced neutrino NC $\pi^0$ production?
    - improper estimation of 'BITE' single-gammas-from-$\pi^0$ ?



# Photon-Like Excess: Scenarios

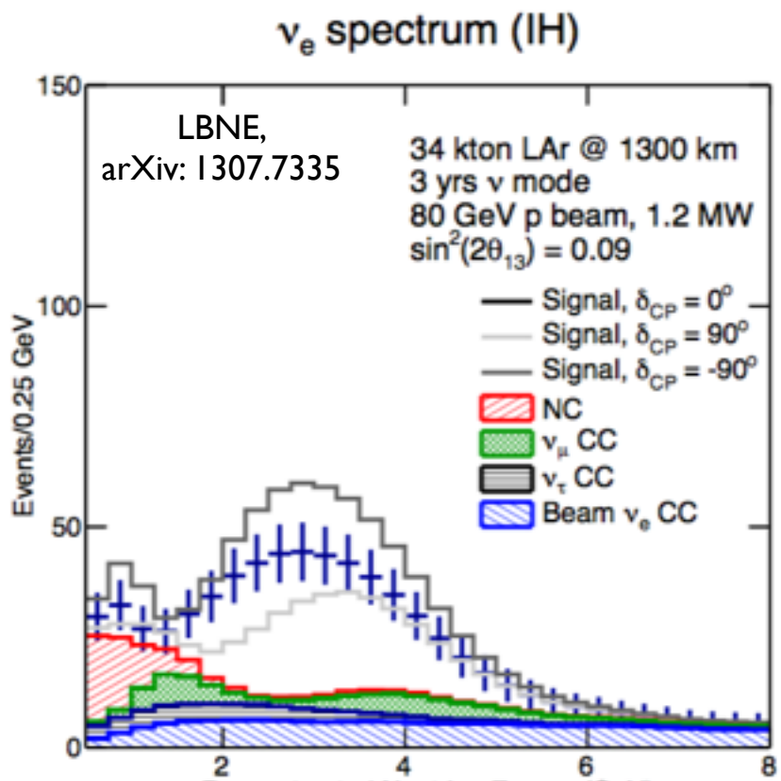
- A big question in this case: where is the excess?
  - If excess picks up at lowest energies, this could point an issue with $\pi^0$s:
    - Issues with neutrino NC $\pi^0$ mis-identification estimates?
    - Improper estimation of external single-gammas-from-$\pi^0$ ?

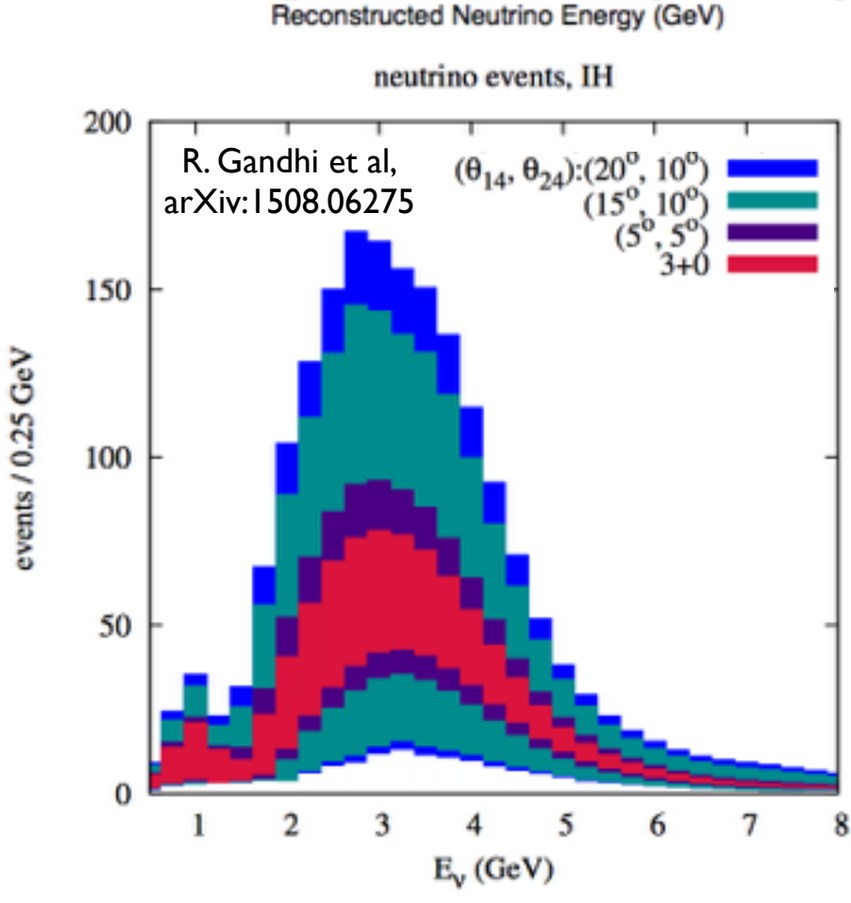



  - Excess at low-energy, but not TOO low: additional single-gamma processes…
  - Massive uptick at very low energies could come from cosmic mis-estimation.
- In all these scenarios, subsequent SBND measurement is <u>crucial</u>
  - If it's 'BITE'- or cosmic-related, SBND's signature will look totally different.
  - If it's a neutrino cross-section thing, SBND, ICARUS will provide very valuable high-statistics measurements for…

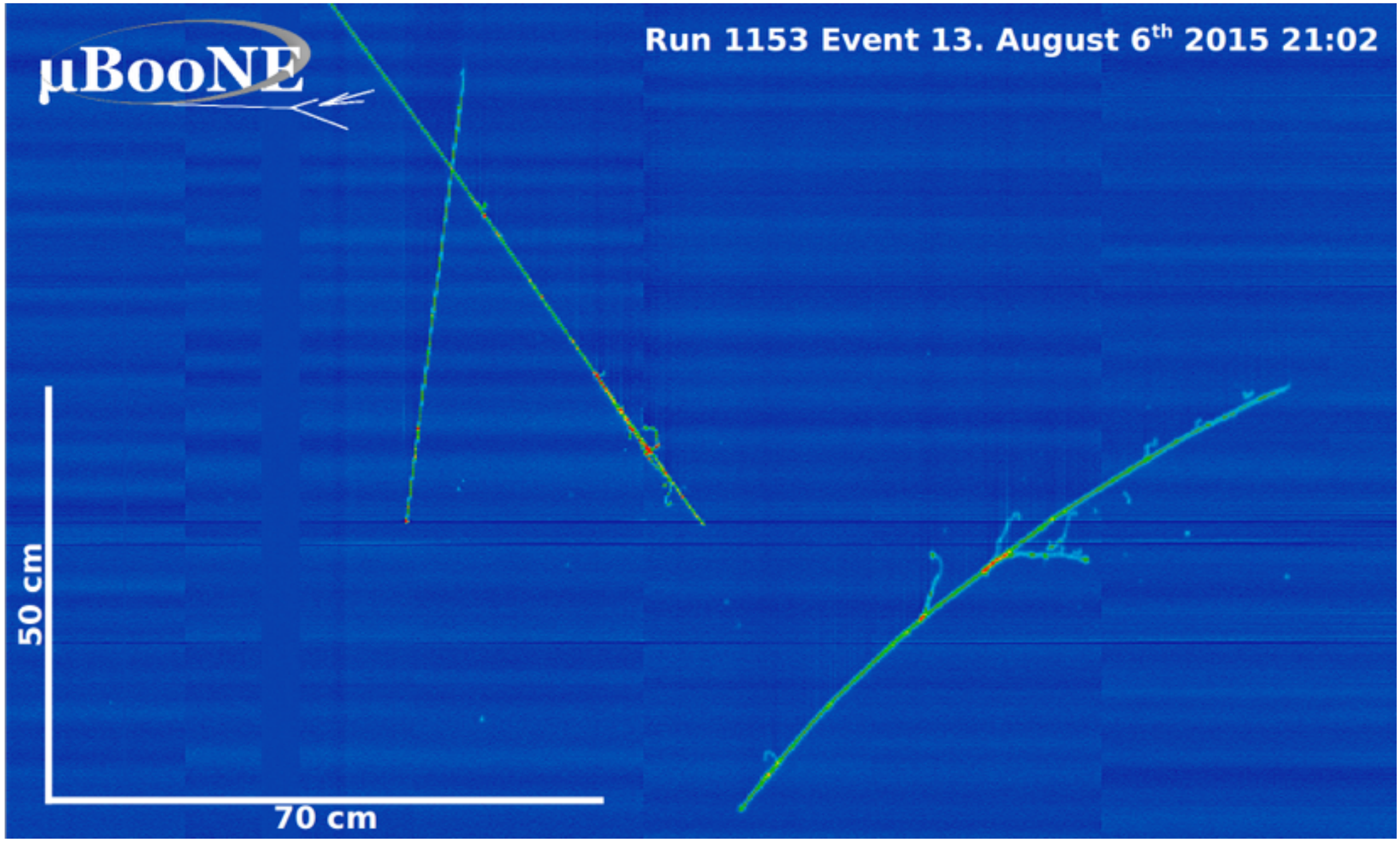
# DUNE Impacts

- Crucial for DUNE that MicroBooNE (and the rest of SBN) tell us what is causing the excess.
- If electrons:
  - We must correct our predictions for the existence of a new short-baseline oscillation!
- If photons:
  - We must properly re-configure our background estimates; particularly valuable for properly understanding the 2nd oscillation maximum
- If both electron and photon excess, ditto, for same reasons as above.
- If no excess in MicroBooNE:
  - Still extremely important to address sterile phase space in full to properly interpret DUNE results — i.e. DUNE would still need SBN



# Thanks for your attention!

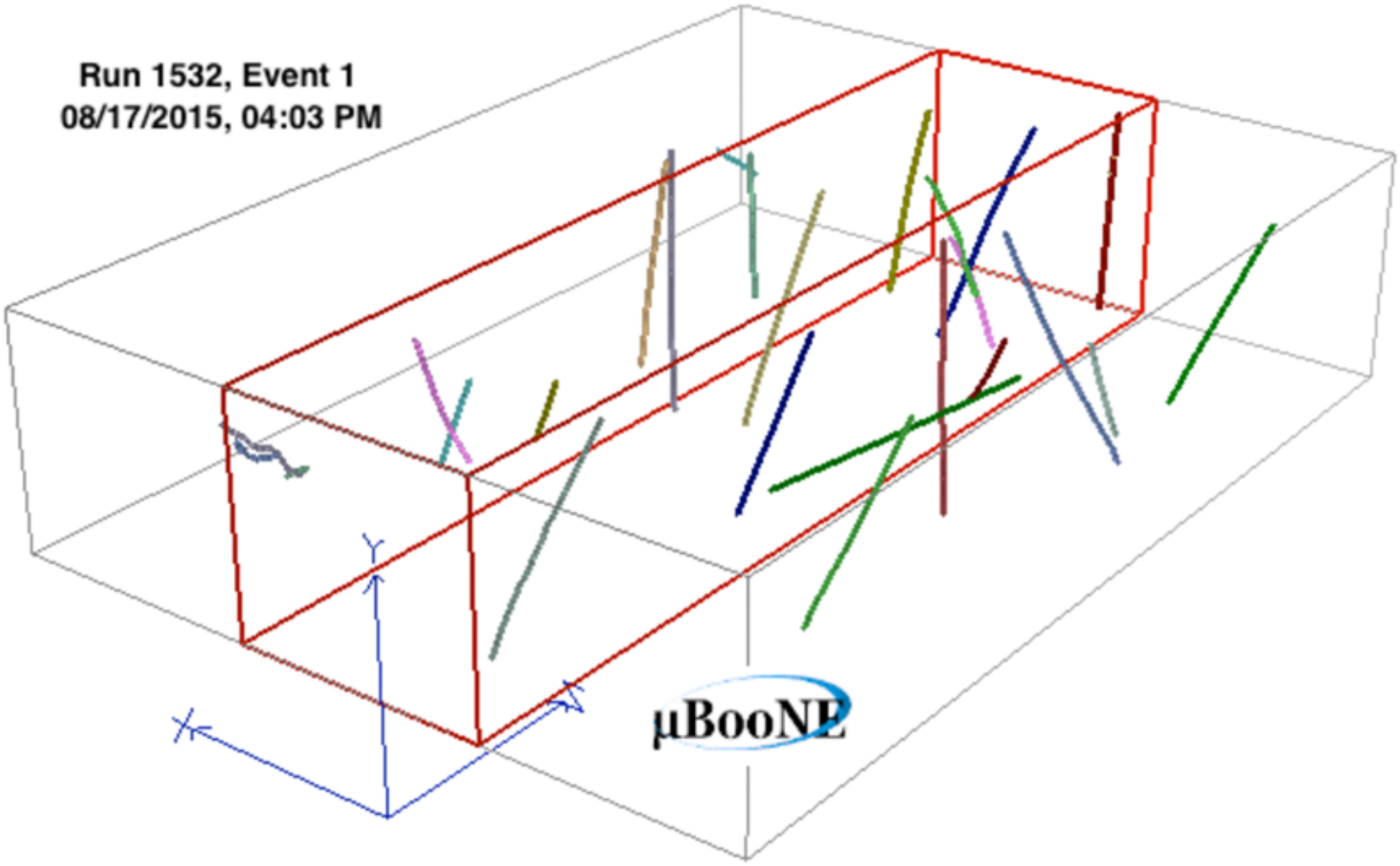



# Questions/Comments?

# BACKUP

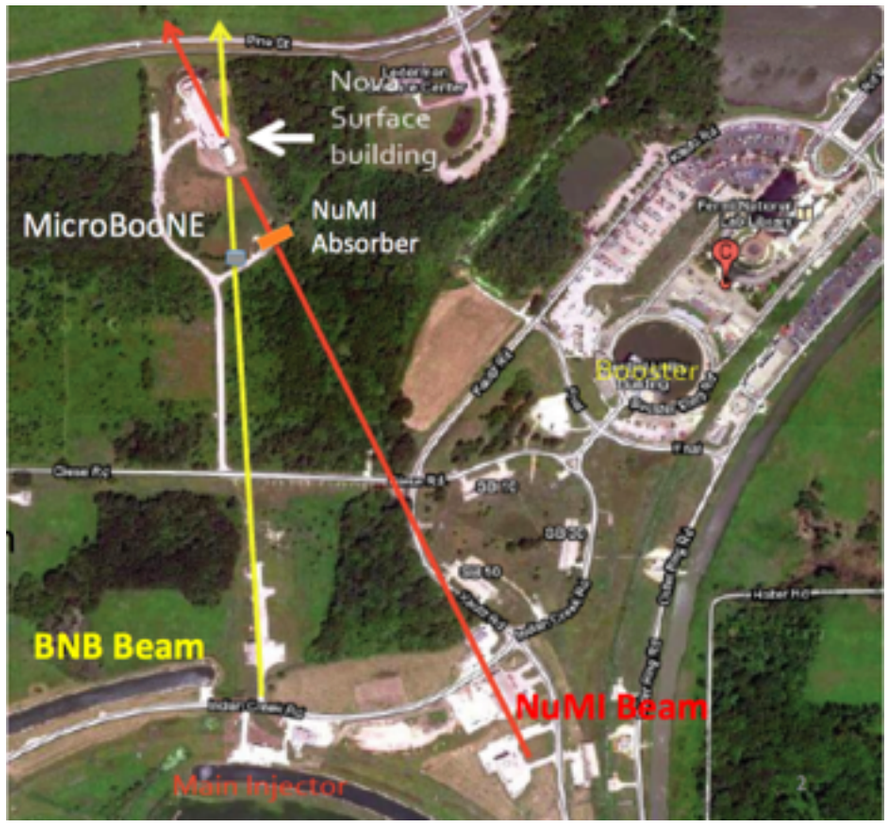
# MicroBooNE: 2015 DATA!

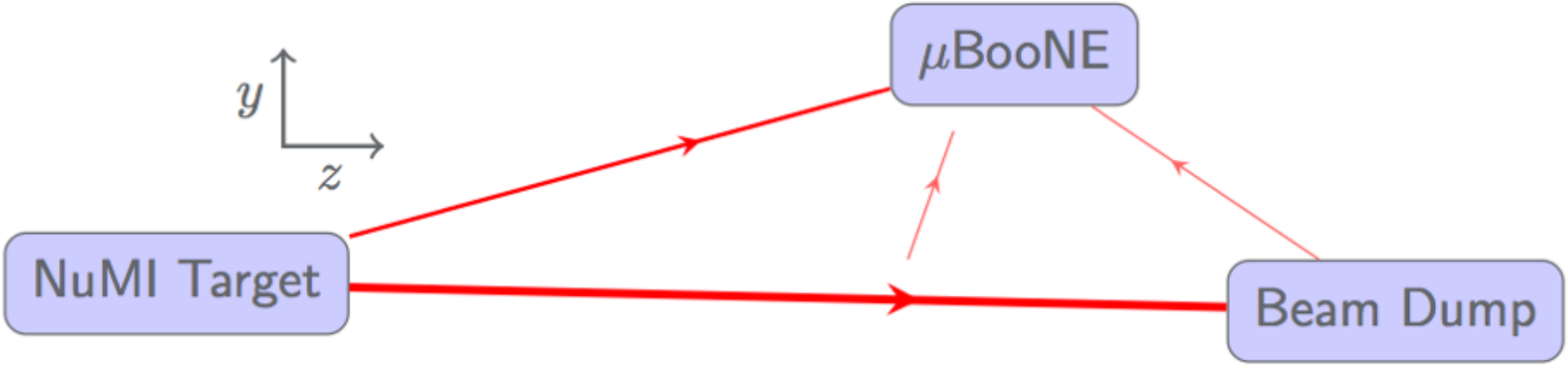
- An example: automated track reconstruction on cosmic muons



# MicroBooNE Cross-Checks

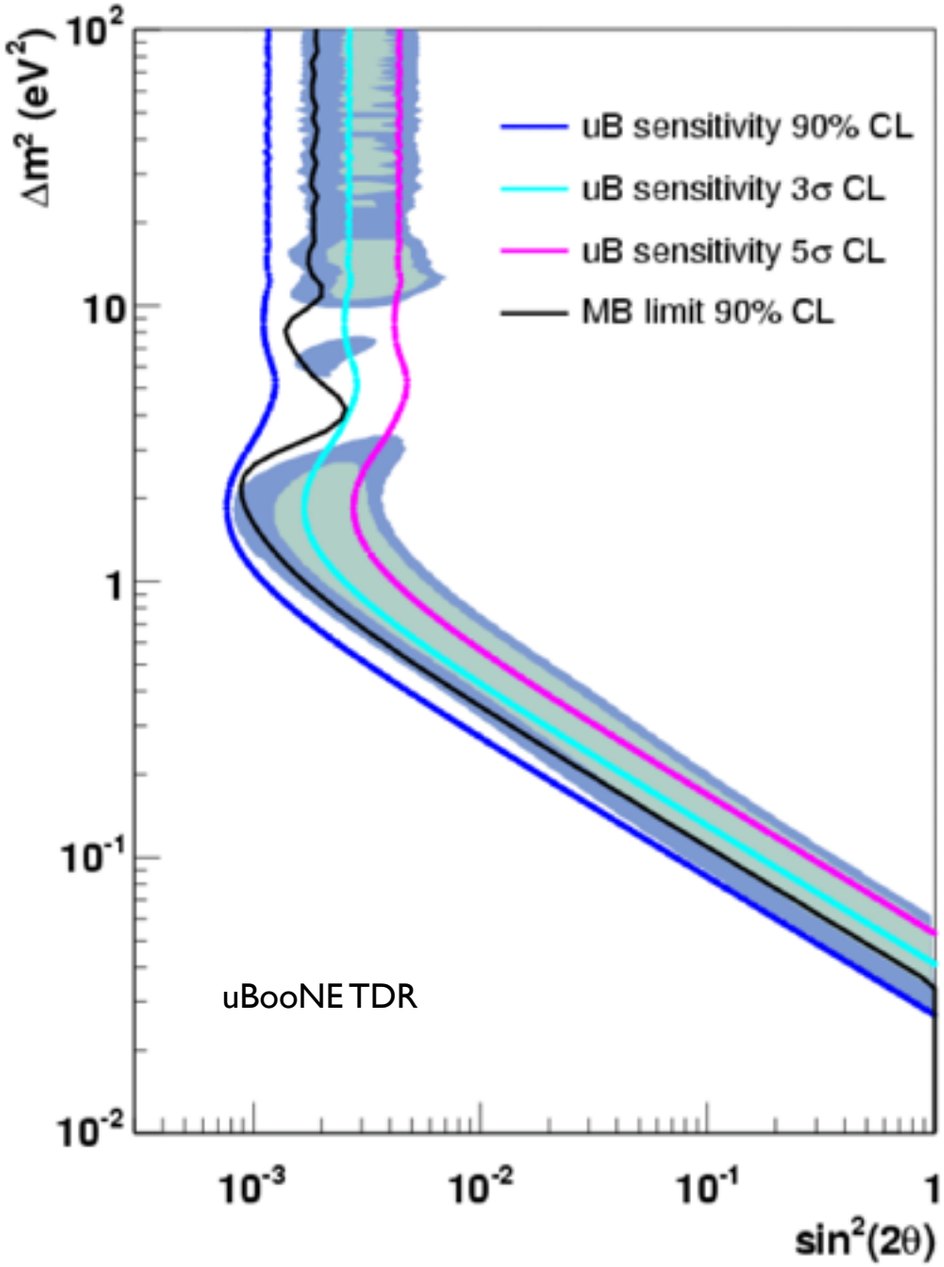
- We have other abilities to cross-check any BNB-related low-energy-excess-like signals that we see
  - If we see a photon-like or electron-like excess: do we also see hints of the same excess from NuMI?
    - Similar NuMI hints in ICARUS would be even better
  - If electron-like excess: do we see other oscillatory hints in other channels, i.e. numu disappearance from BNB, or nue disappearance from NuMI?
    - Also better-measured in full SBN case…

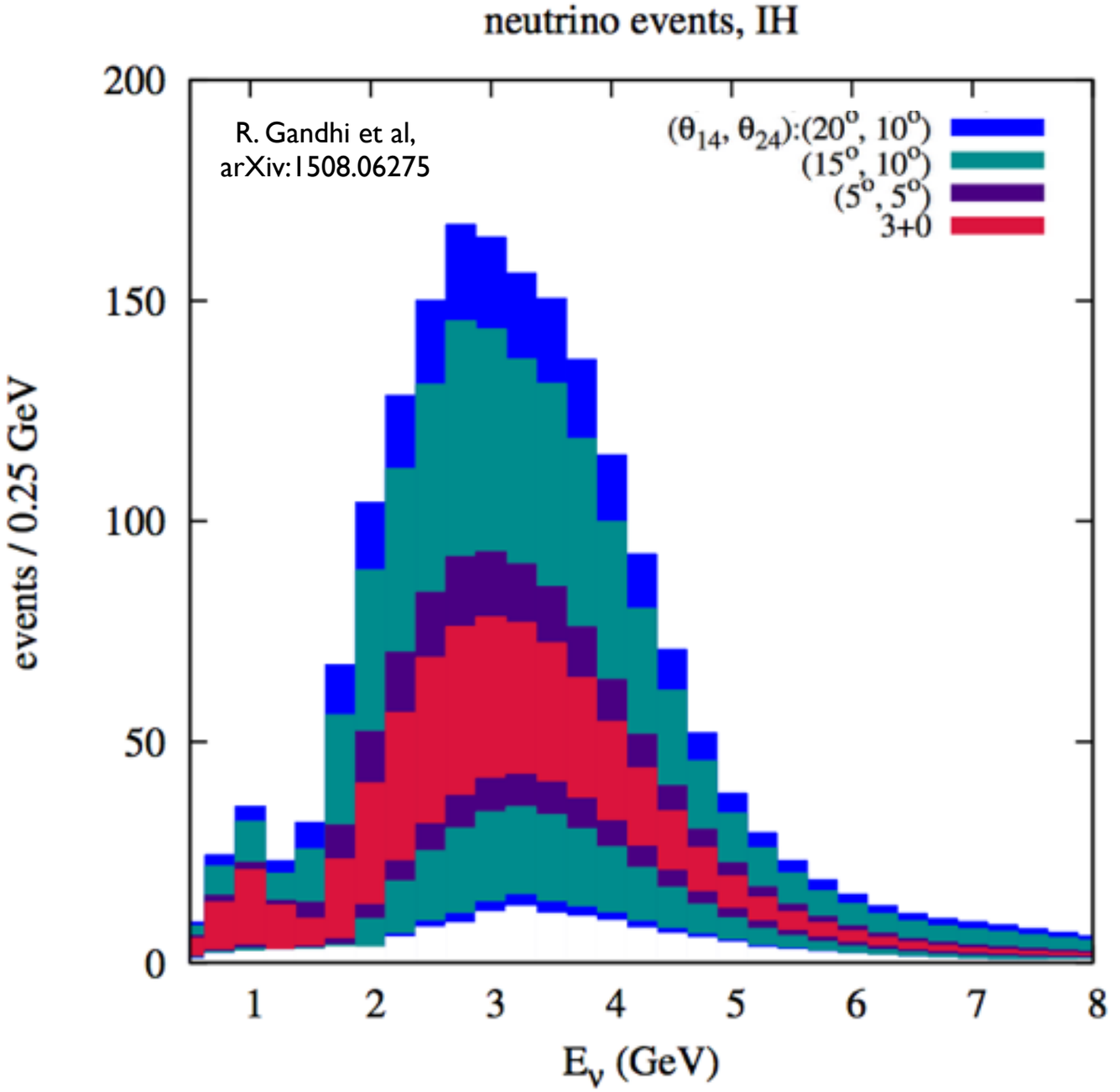


# DUNE Impacts

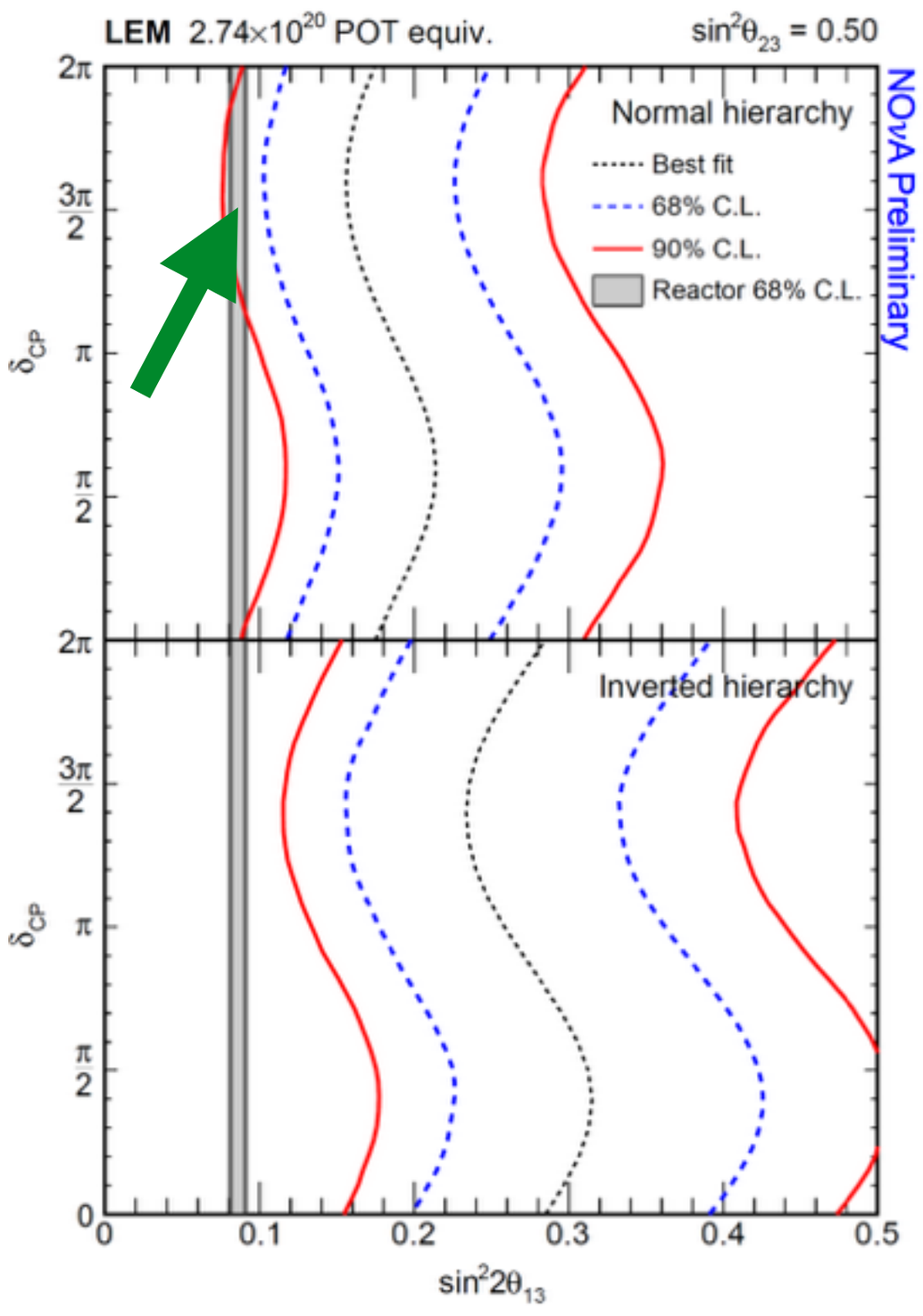
- What if we only had MicroBooNE sterile search?



# Early Hints: NOvA

## Selection 1




## Selection 2