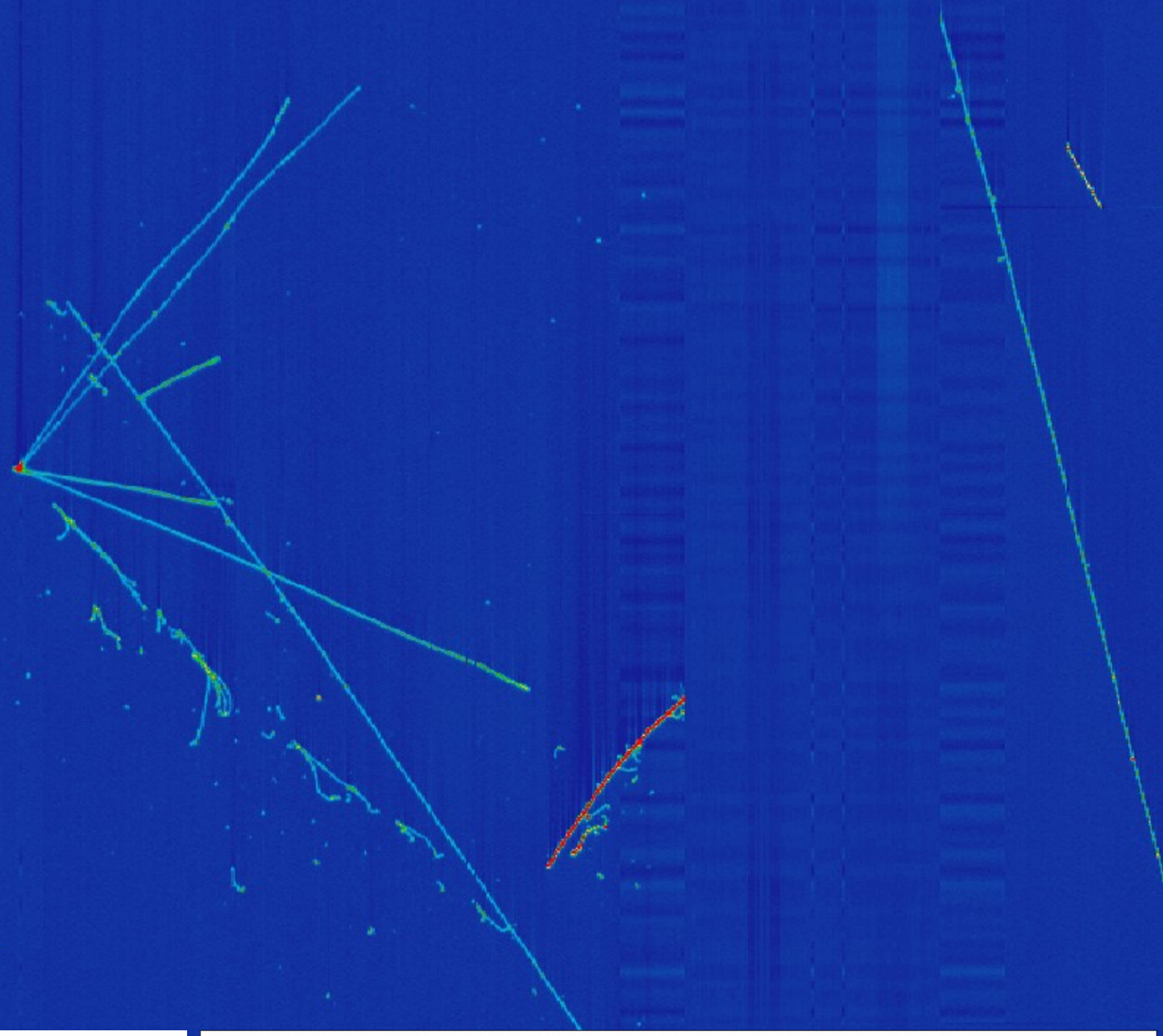
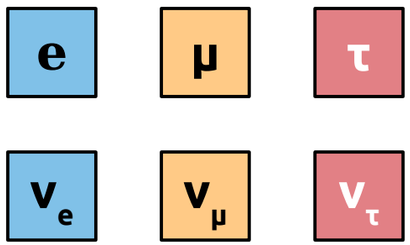
MicroBooNE in 10 Minutes: Neutrinos in HD

David Caratelli, Columbia Universty
Representing the MicroBooNE Collaboration

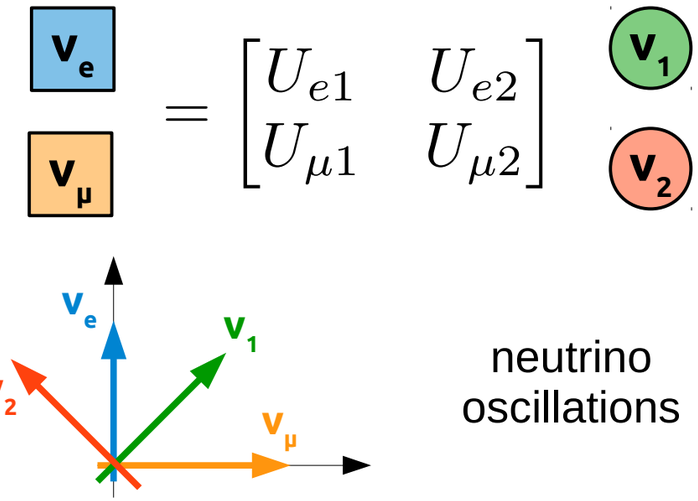
New Perspectives '16 @ Fermilab.



What are Neutrinos?



Neutral leptons. Very small mass.
Interact via weak force.

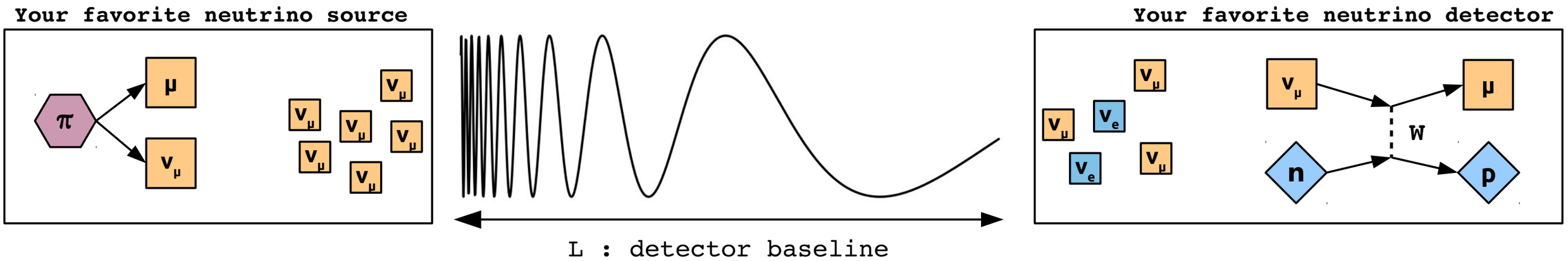


neutrino oscillations

Freq. Of oscillation.
Choose L, E appropriate for Δm^2.

$$P_{\mu \to e} \approx \sin^2(2\theta) \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

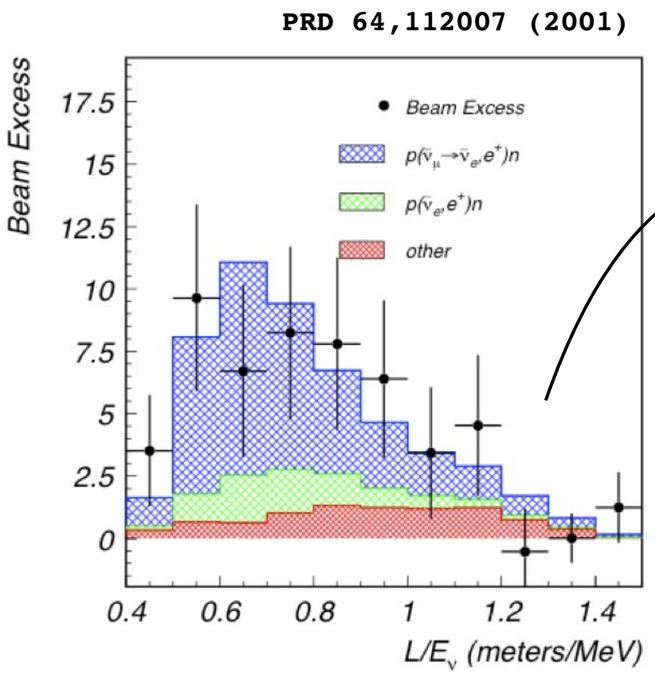
sets amplitude of oscillation.
large → "easy" to detect.



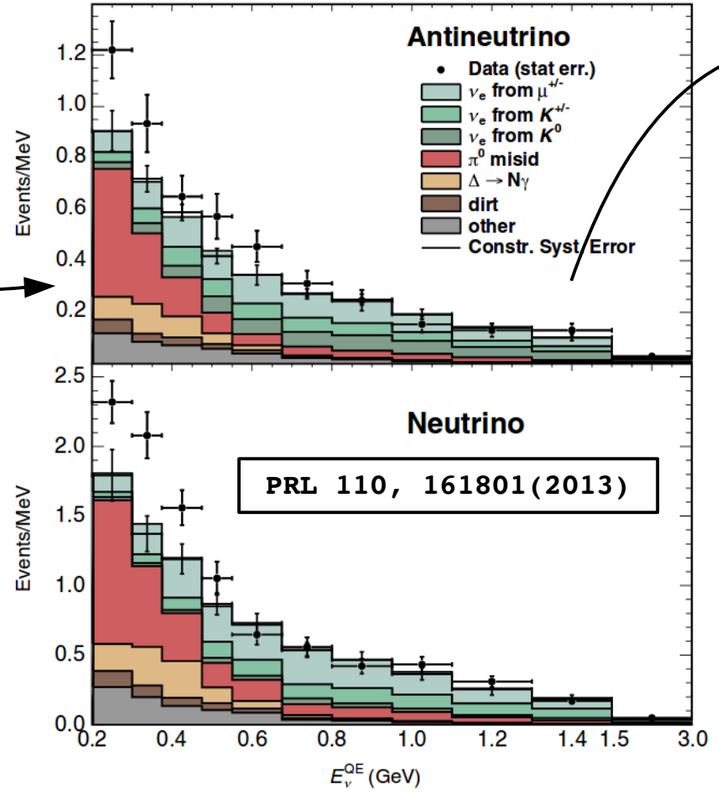
Why Build MicroBooNE?

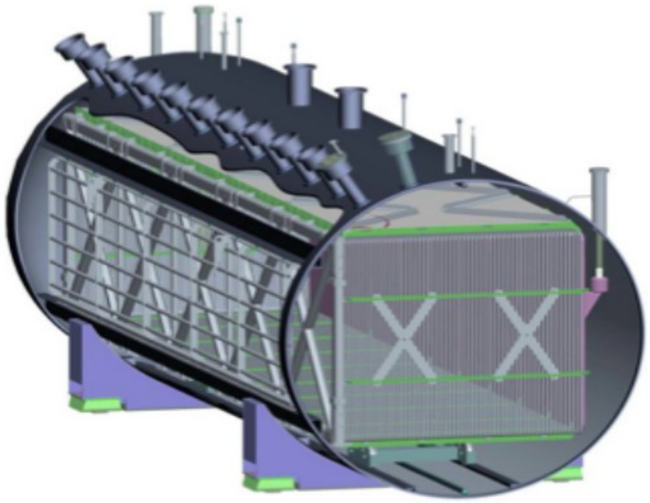
LSND : **Liquid scintillator** neutrino detector.
Studying $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations.
Notice excess of $\bar{\nu}_e$ events consistent with
~ 1 eV^2 mass-splitting.

(much larger than "standard" mass-splittings)



MiniBooNE : **Mineral Oil Cherenkov** detector.
Goal: address LSND anomaly.
Same L/E but different beam, Energy, Baseline.
Excess of events, but at low energies
→ "Low Energy Excess"



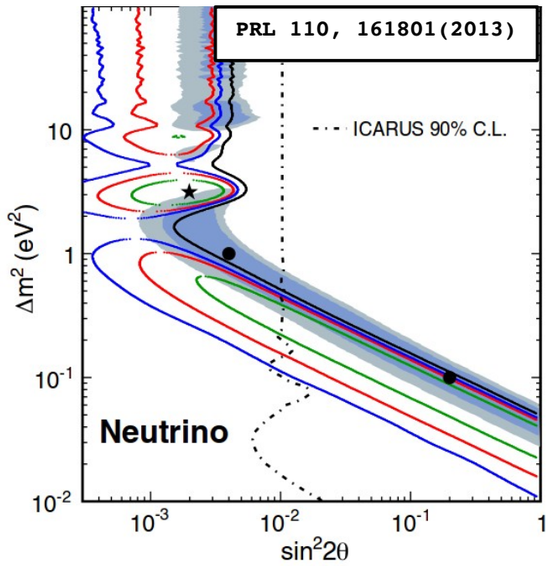


MicroBooNE's goal:
Address MiniBooNE's low energy excess.
Same beam, same baseline, different detector.

Use **Liquid Argon Time Projection Chamber** Technology to suppress backgrounds.

The MicroBooNE Experiment

Low Energy Excess



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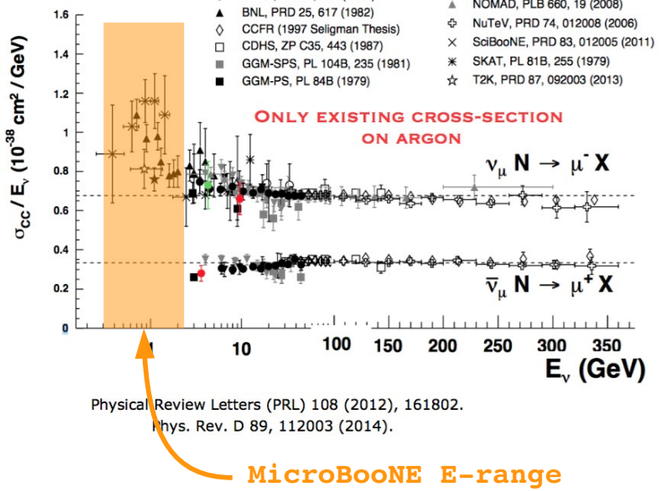
Cross-sections



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Detector R&D

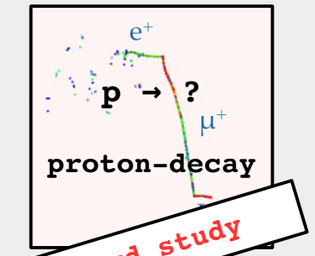
MicroBooNE is an international collaboration.

Located @ Fermilab.

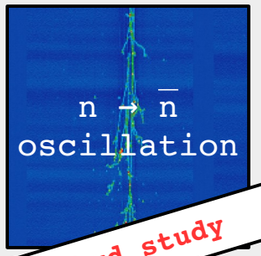
Largest LArTPC currently operational.

Part of Short Baseline Neutrino program.

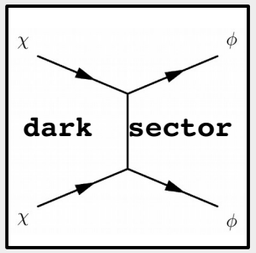
… and more!



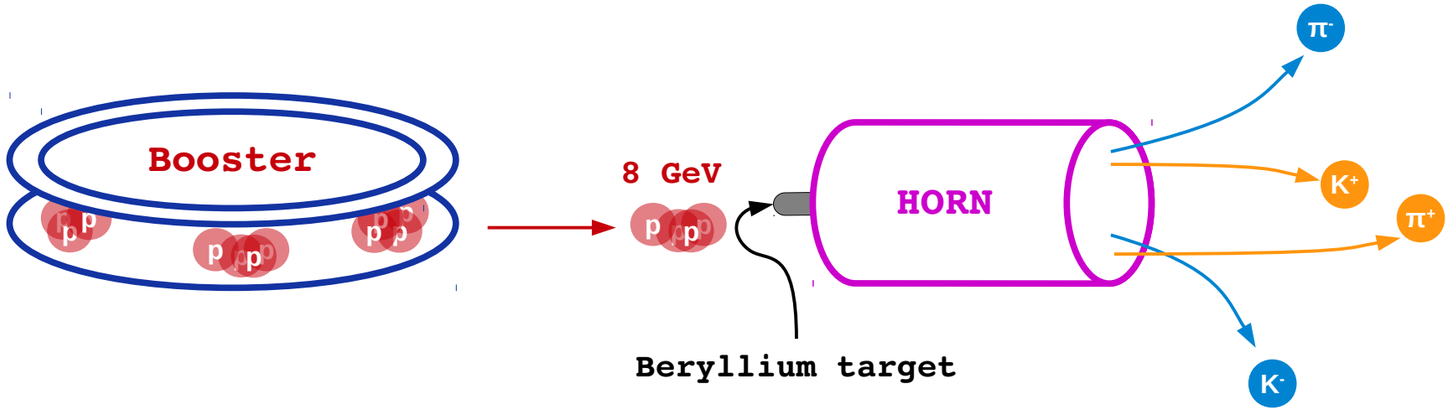
bkgd study

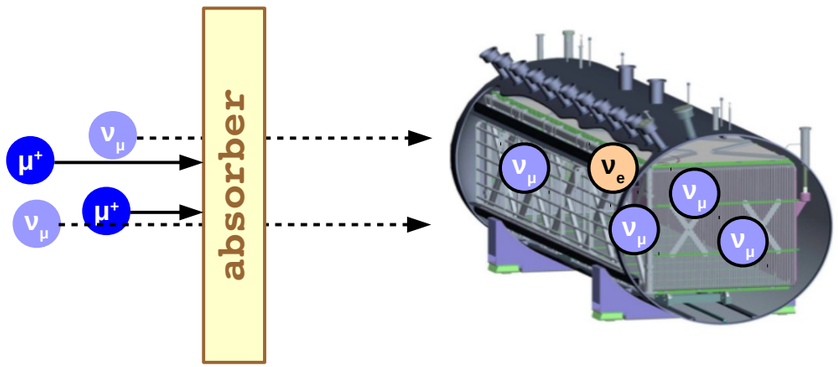


bkgd study

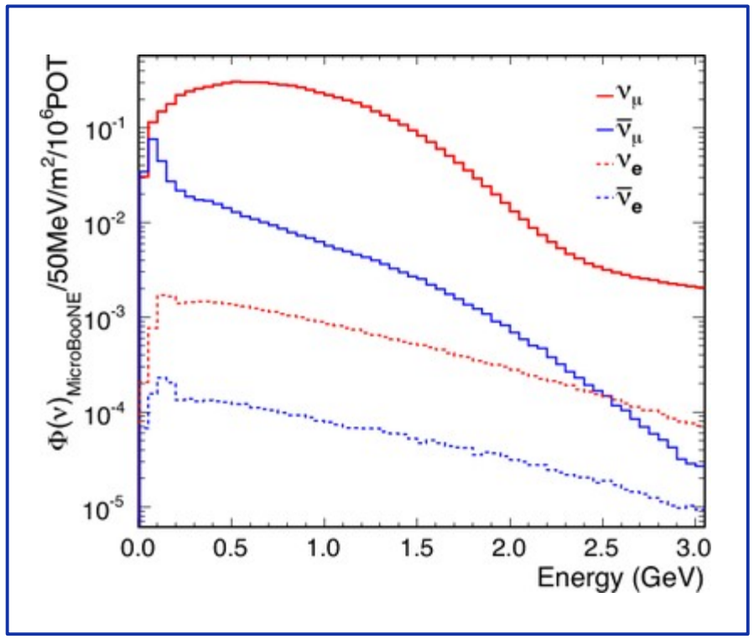


Where do the Neutrinos come from?





BNB Neutrino Flux [simulation]

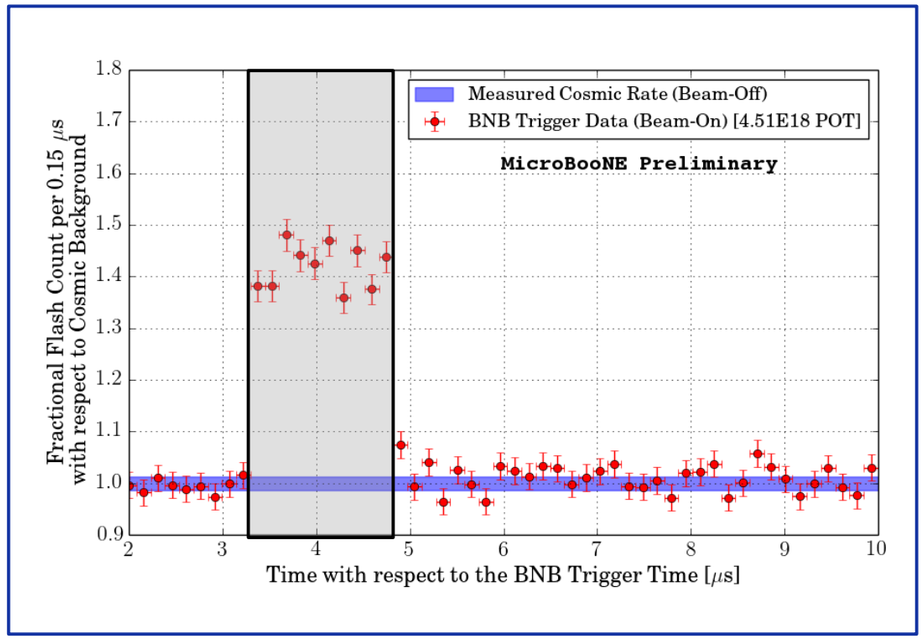


Booster Neutrino Beamline.

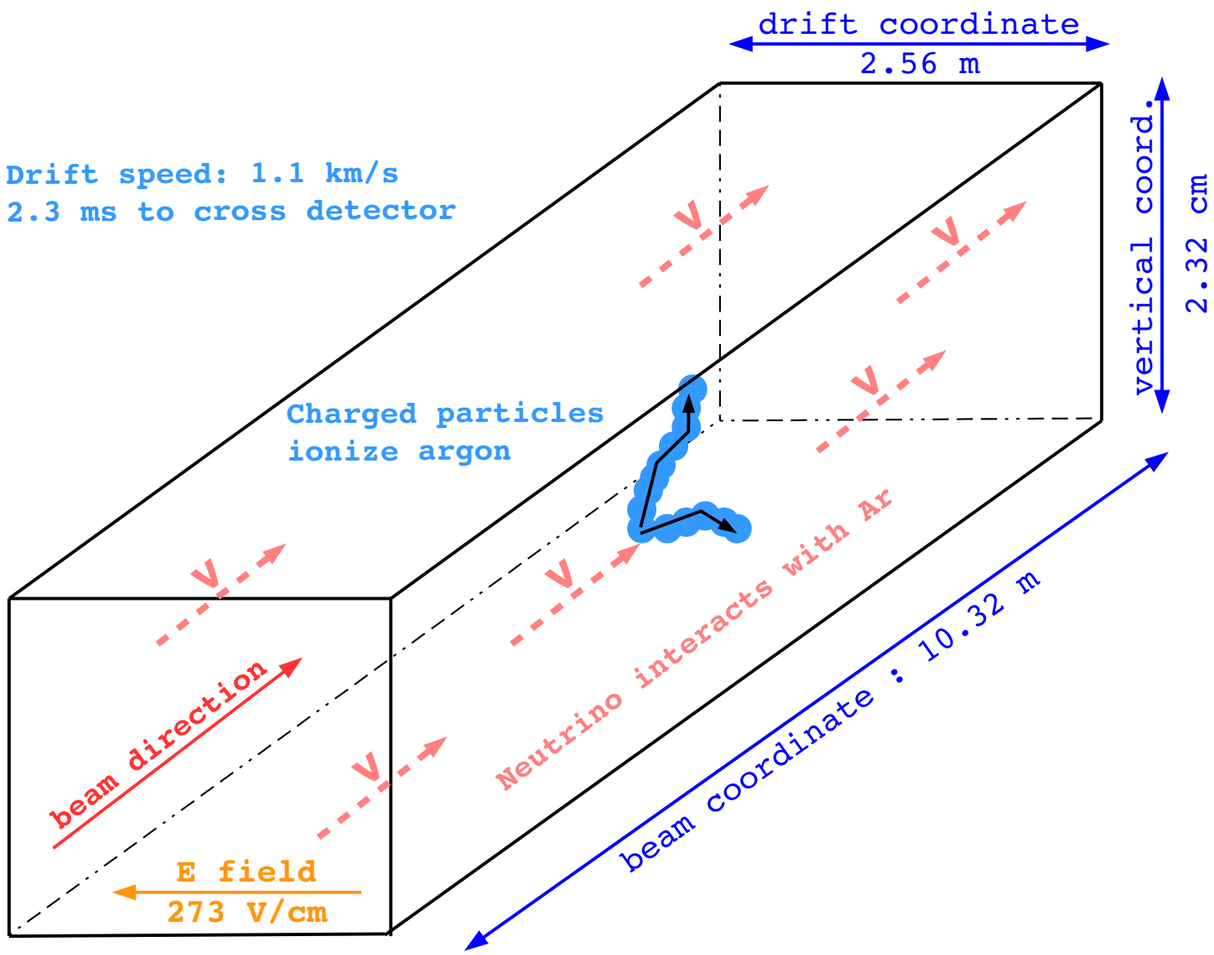
Running in neutrino mode.

Collected > 3E20 POT
Out of 6.6E20 since October

MicroBooNE: events in time with beam



The MicroBooNE Detector



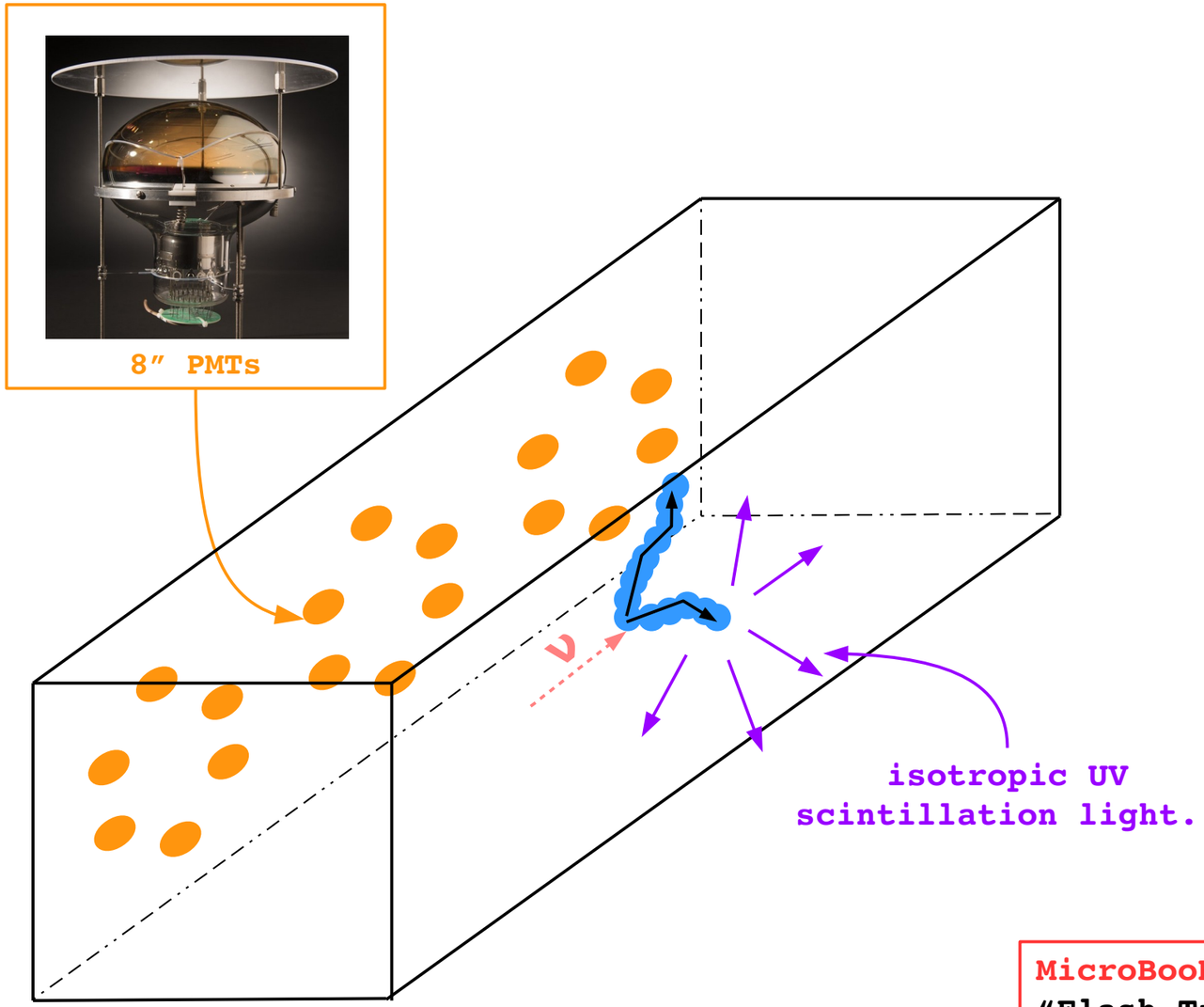
170 (90 active)Ton Liquid Argon Time Projection Chamber.

ν interact with Ar nucleus → charged particles.

Ar is ionized → trail of e^- which follow particle trajectories.

Uniform 273 V/cm drift-field moves charge towards anode.

The MicroBooNE Detector



Detector equipped with 32 8” PMTs.

While ionization electrons slowly drift…
… cosmic rays are constantly coming through the detector [5 kHz rate].

Scintillation light reaches PMTs instantaneously.

PMT system can provide timing of interactions
→ separate cosmic muons from neutrino-induced tracks.

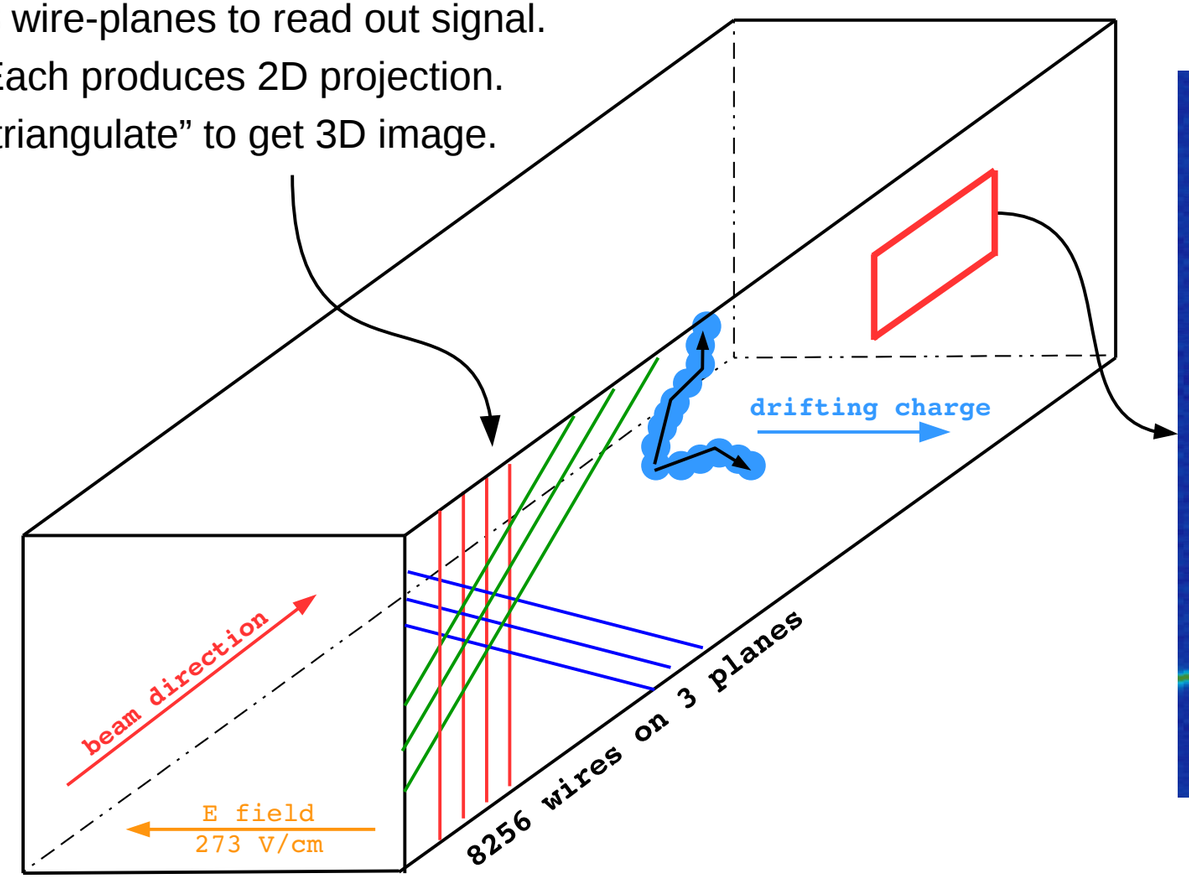
Requires matching PMT and TPC information.

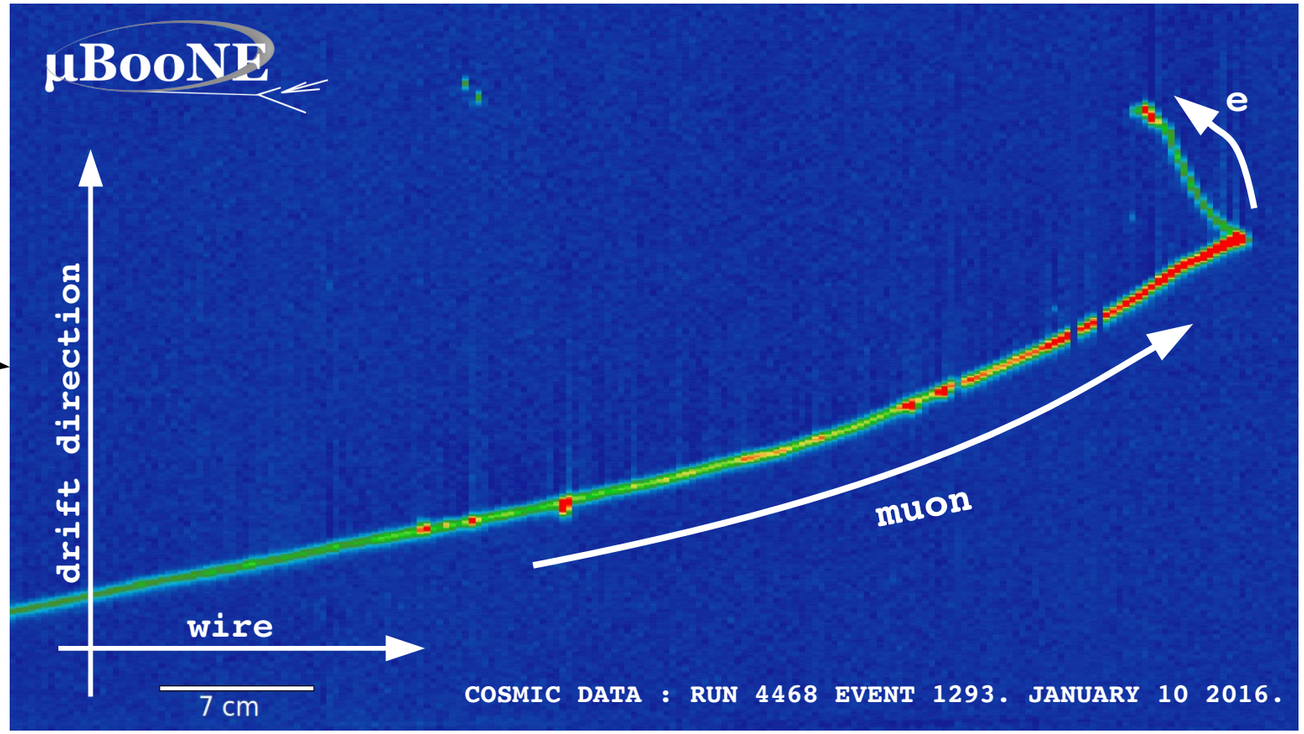
+ PMT signals used to generate Trigger.

MicroBooNE Talk @ Session 3:
“Flash Track Matching Development in MicroBooNE” – Rui An

The MicroBooNE Detector

3 wire-planes to read out signal.
Each produces 2D projection.
“triangulate” to get 3D image.



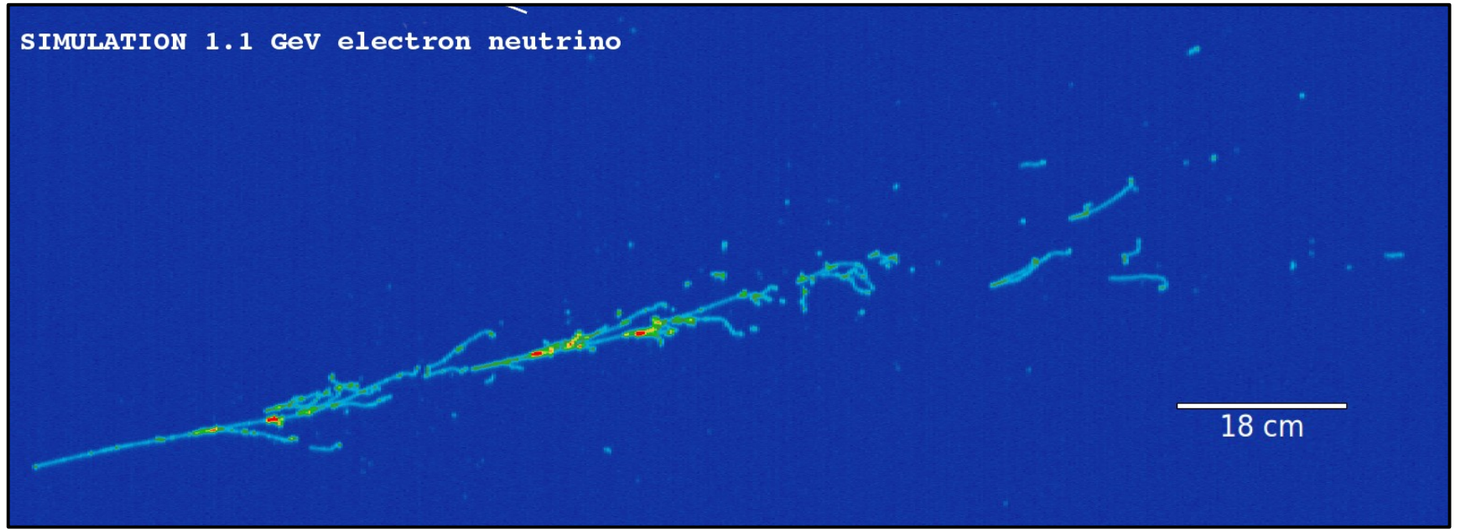


Addressing the Low Energy Excess

MiniBooNE's most significant backgrounds to ν_e appearance are from photons.

Electrons and photons are indistinguishable in a Cherenkov detector.

Calorimetry + topology information from LArTPC → e / γ separation.

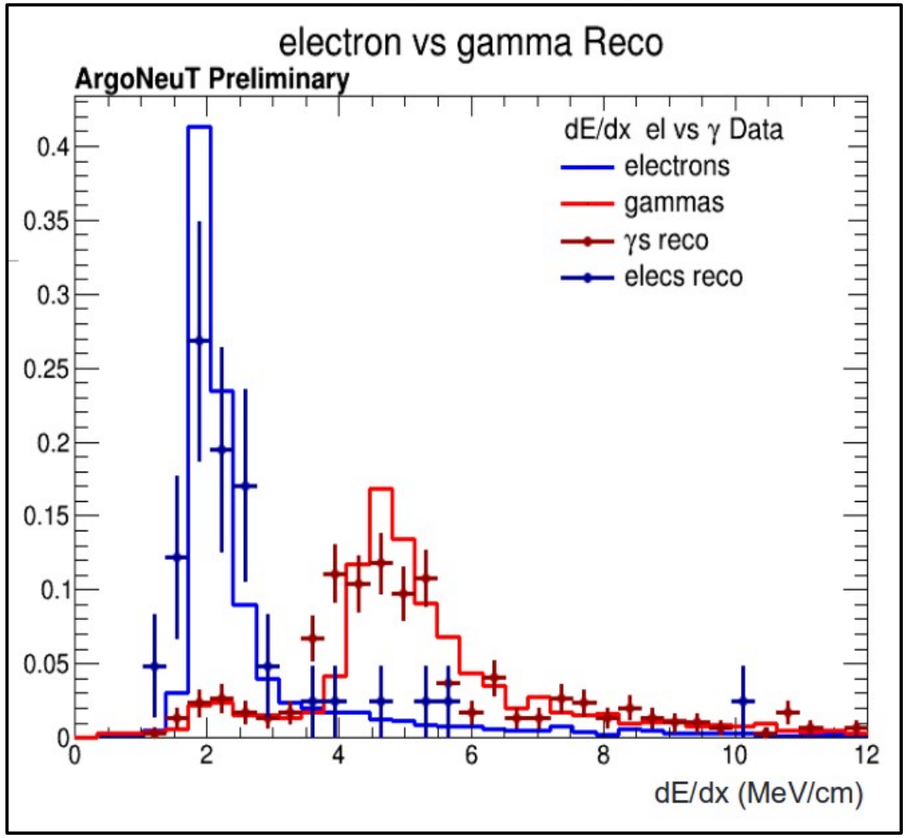


Photons pair-convert to e^+/e^- pair. Can leverage:

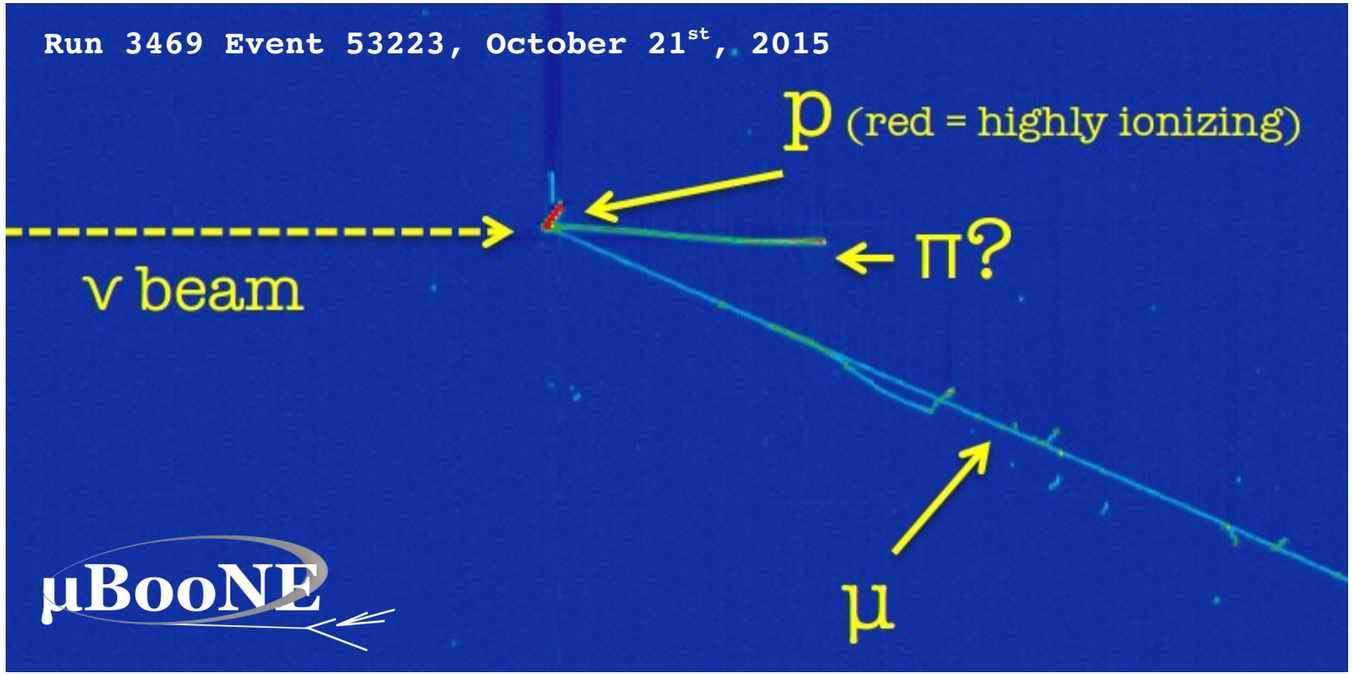
1) Displacement from neutrino vertex of EM shower.

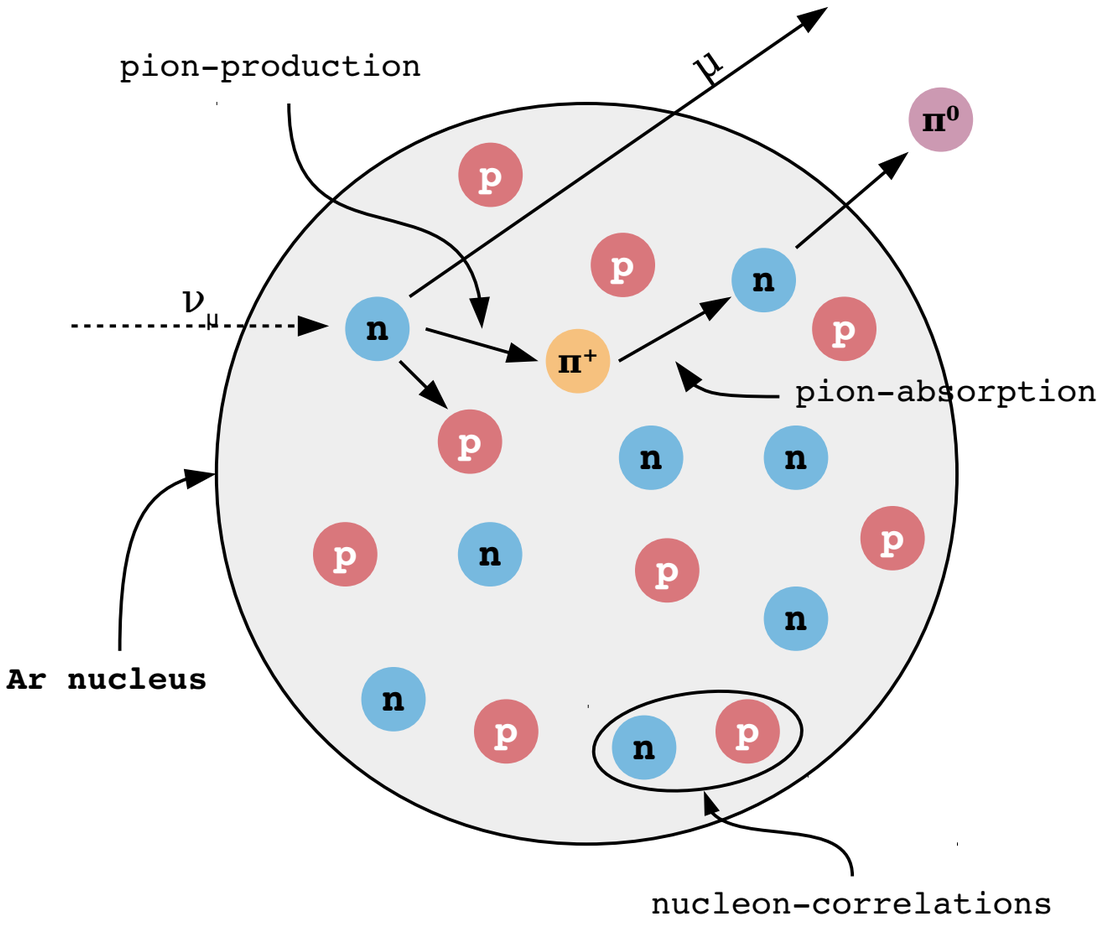
2) Twice as much energy deposited in first few cm of EM shower.

e / γ separation in ArgoNeuT detector.



Cross-Section Program





MicroBooNE Talk @ Session 3:
"Measuring Nucleon Structure from Neutrino Interactions in MicroBooNE" – Katherine Woodruff

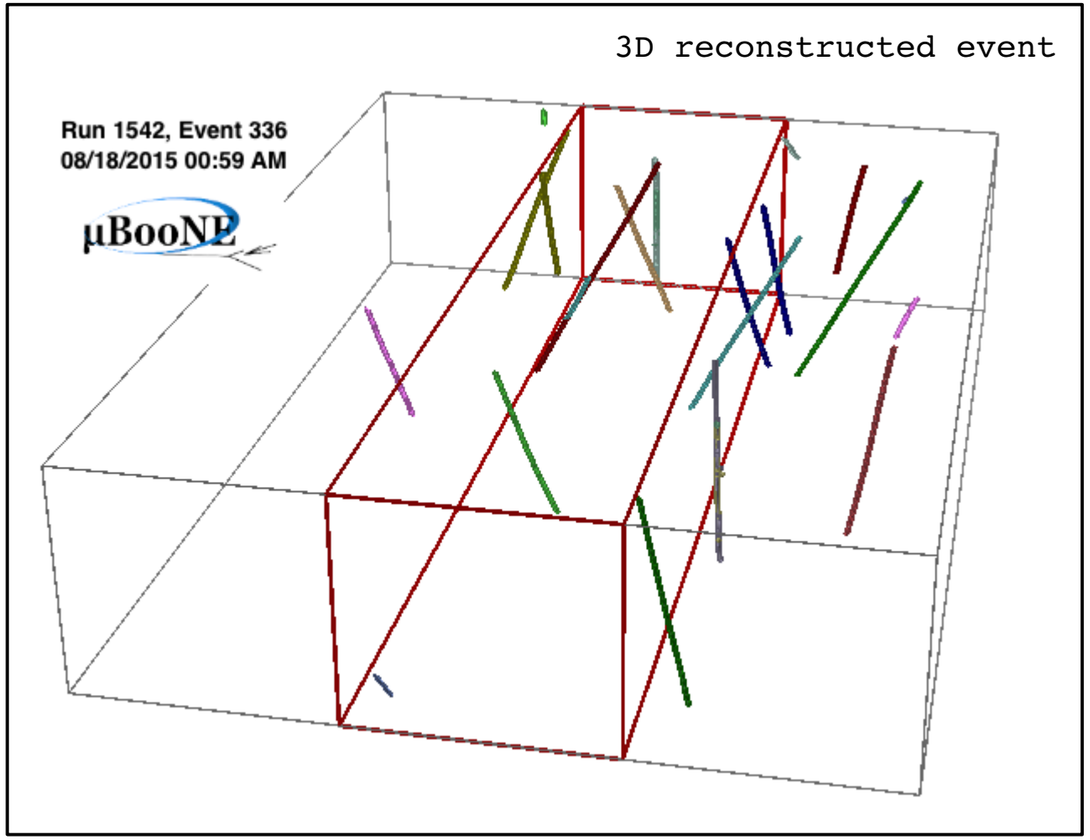
Reconstruction

MicroBooNE's high-quality neutrino-images provide lots of information.

To fully take advantage of this information requires sophisticated reconstruction techniques.

MicroBooNE is developing tools to automatically extract physics from LArTPC detectors.

Addressing challenges such as a long drift-window and large cosmic-ray flux will benefit LArTPC community.



New technology → new challenges → new ideas.

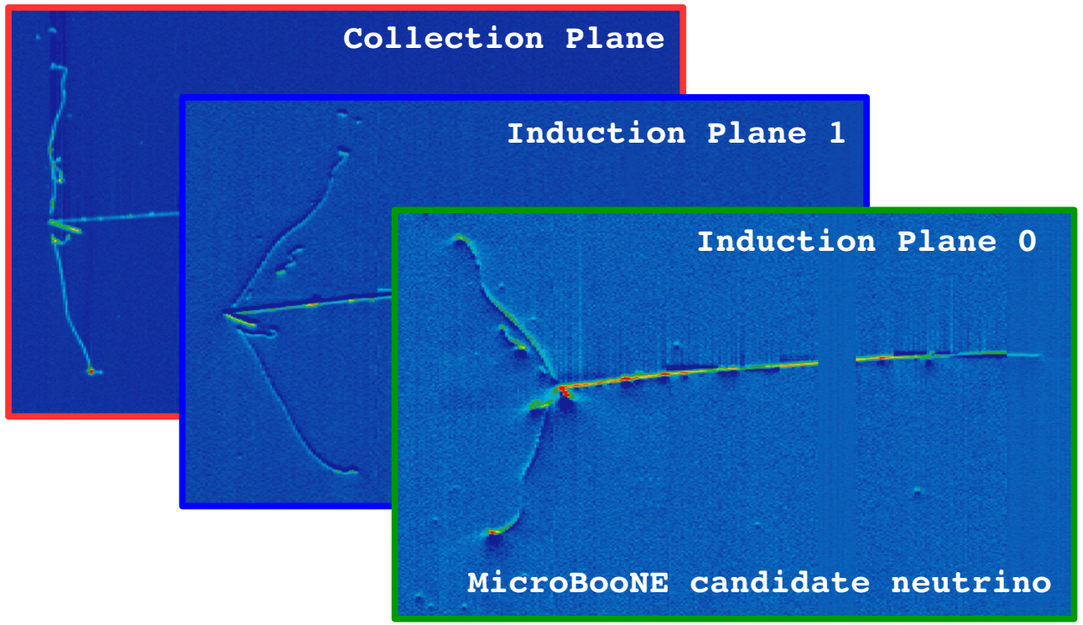
Lots of exciting work inspired by other fields.

Place for young collaborators to make impact.

MicroBooNE Talks @ Session 8:
"Deep Learning MicroBooNE" – Victor Genty.

"Reconstruction in MicroBooNE Using OpenCV Image Processing" - Ariana Hackenburg.

What we've been up to … and the road ahead!

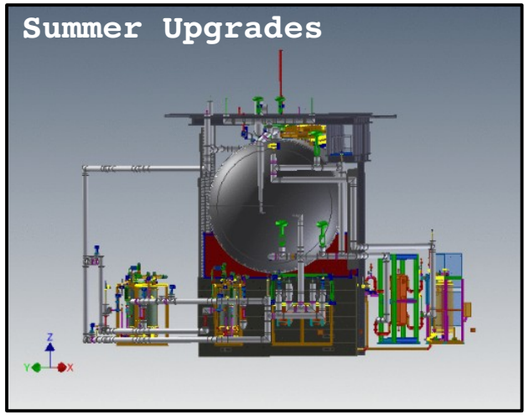


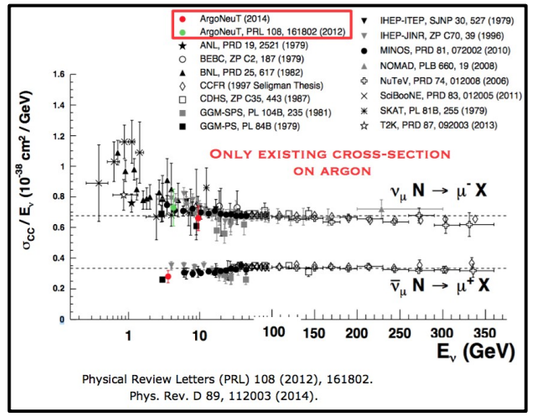
Lots of detector R&D to get to where we are.

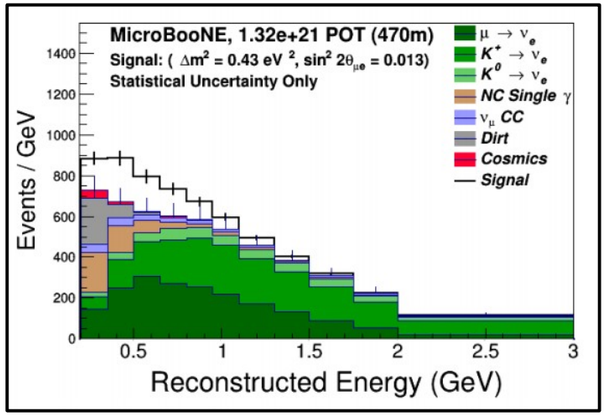
TPC construction, electronics, Ar filling + purification, drift HV, etc…

Started taking Beam data in October 2015.

First neutrinos just a few weeks later!







May 2016

MicroBooNE Collaboration

University of Bern, Switzerland: M. Auger, A. Ereditato, D. Goeldi, I. Kreslo, D. Lorca, M. Lüthi, C. Rudolf von Rohr, J. Sinclair, M. Weber
Brookhaven: M. Bishai, H. Chen, J. Joshi, B. Kirby, Y. Li, M. Mooney, X. Qian, B. Viren, C. Zhang
University of Cambridge: J. Jan de Vries, J. Marshall, L. Escudero Sanchez, M. Thomson, J. Weston
University of Chicago: W.M. Foreman, J. Ho, D.W. Schmitz, J. Zennamo
University of Cincinnati: R. Grosso, R.A. Johnson, J. St. John
Columbia University: L. Camilleri, D. Caratelli, J. Crespo, V. Genty, D. Kaleko, W. Seligman, M. Shaevitz, K. Terao
Fermilab: R. Acciarri, L. Bagby, B. Baller, B. Carls, F. Cavanna, R. Castillo Fernandez, H. Greenlee, C. James, H. Jostlein, W. Ketchum, M. Kirby, T. Kobilarcik, S. Lockwitz, B. Lundberg, A. Marchionni, C. Moore, O. Palamara, Z. Pavlovic, S. Pordes, J.L. Raaf, A. Schukraft, E. Snider, P. Spentzouris, T. Strauss, M. Toups, T. Yang, G.P. Zeller*
Illinois Institute of Technology: R. An, B. Littlejohn, D. Martinez
Kansas State University: T. Bolton, S. Gollapinni, G. Horton-Smith, V. Meddage, A. Rafique
Lancaster University: A. Blake, D. Devitt, A. Lister, J. Nowak
Los Alamos: G. Garvey, W.C. Louis, G.B. Mills, R. Van de Water
University of Manchester: D. Cianci, A. Furmanski, J. Hewes, C. Hill, G. Karagiorgi, R. Murrells, D. Porzio, S. Söldner-Rembold, A.M. Szelc
MIT: J.M. Conrad, O. Hen, J. Moon, M.H. Moulai, T. Wongjirad
University of Michigan, Ann Arbor: C. Barnes, R. Fitzpatrick, J. Mousseau, J. Spitz
New Mexico State University: T. Miceli, V. Papavassiliou, S.F. Pate, K. Woodruff
Oregon State University: H. Schellman, S. Wolbers
Otterbein University: N. Tagg
University of Oxford: G. Barr, M. Bass, A. Laube, R. Soleti, M. Del Tutto, R. Guenette
University of Pittsburgh: S. Dytman, N. Graf, L. Jiang, D. Naples, V. Paolone, A. Wickremasinghe
Pacific Northwest National Laboratory: E. Church
Princeton University: K. McDonald
Saint Mary's University of Minnesota: P. Nienaber
SLAC: M. Convery, B. Eberly, L. Rochester, Y-T. Tsai, T. Usher
Syracuse University: J. Esquivel, P. Hamilton, G. Pulliam, M. Soderberg
University of Texas at Arlington: J. Asaadi
Tubitak Space Technologies Research Institute, Turkey: F. Bay, B. Kocaman, M. Kopru
Virginia Tech: C.M. Jen, C. Mariani
Yale University: C. Adams, B.T. Fleming*, E. Gramellini, A. Hackenburg, X. Luo, B. Russell, S. Tuflani

143 collaborators
28 institutions (6 non-U.S.)
36 postdocs
37 graduate students

*spokespeople

Backup : why argon?

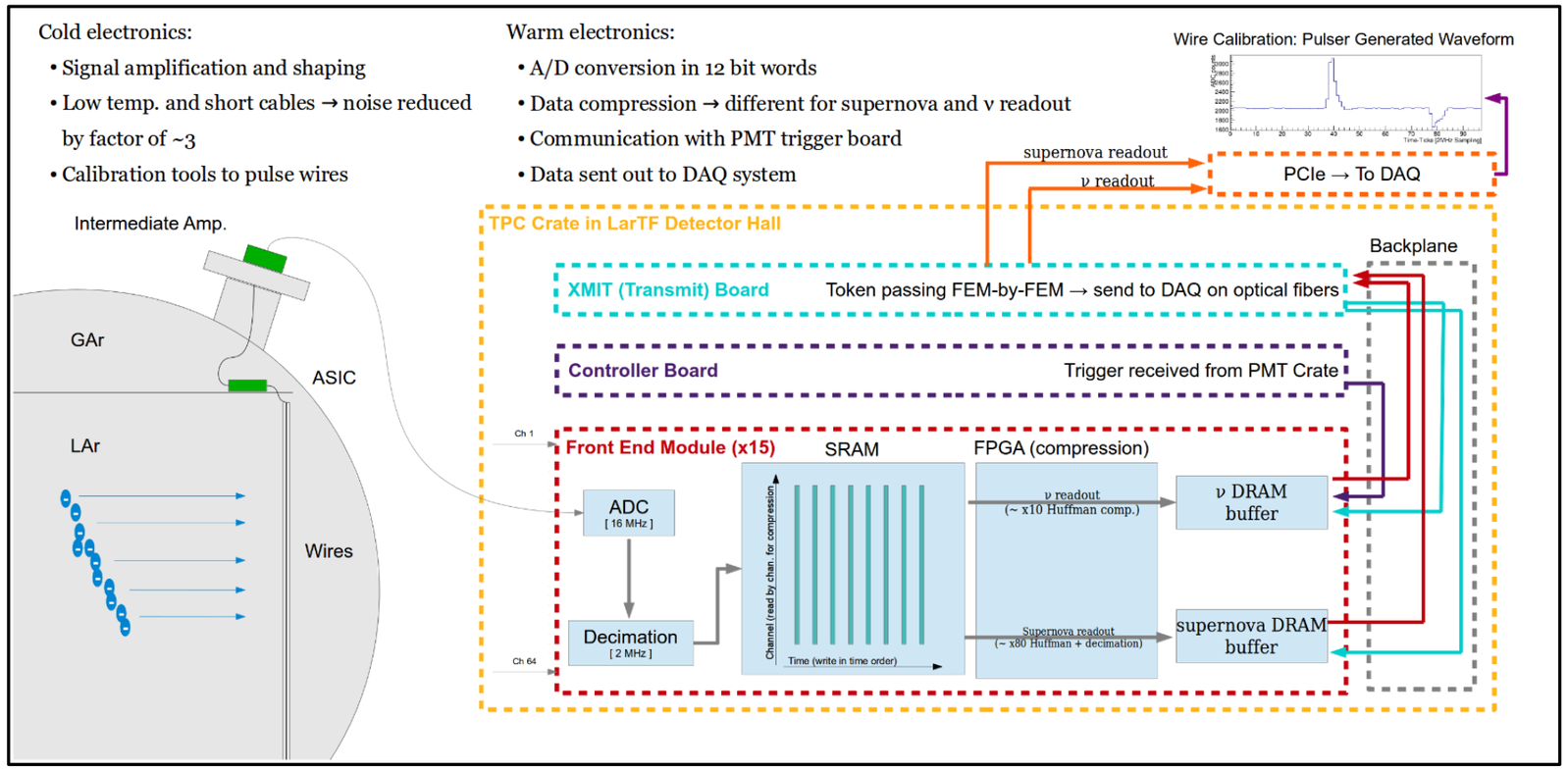
	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120	165	373
Density [g/cm³]	0.125	1.2	1.4	2.4	3	1
Radiation Length [cm]	755.2	24	14	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3	3.8	1.9
Scintillation [γ/MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [nm]	80	78	128	150	175	
Approx. Cost [$/kg]	52	330	5	330	1200	

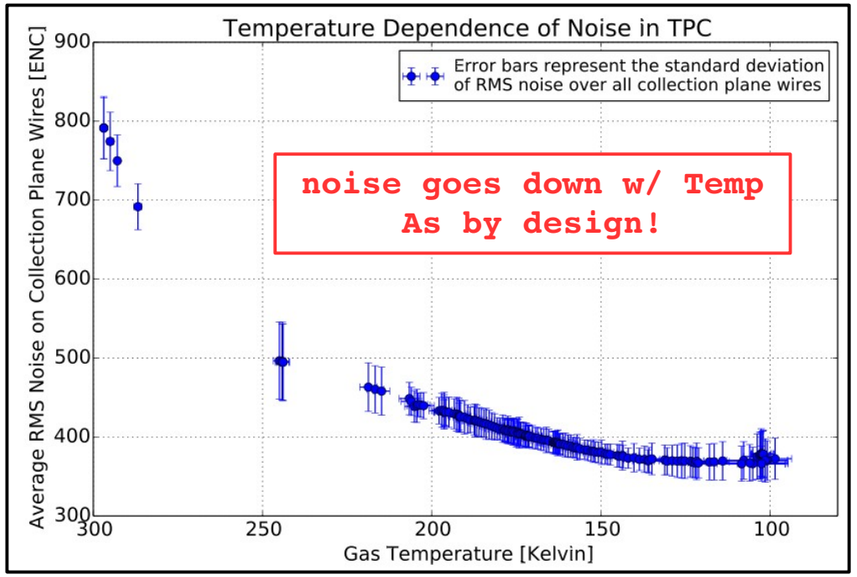
Table by Mitch Soderberg

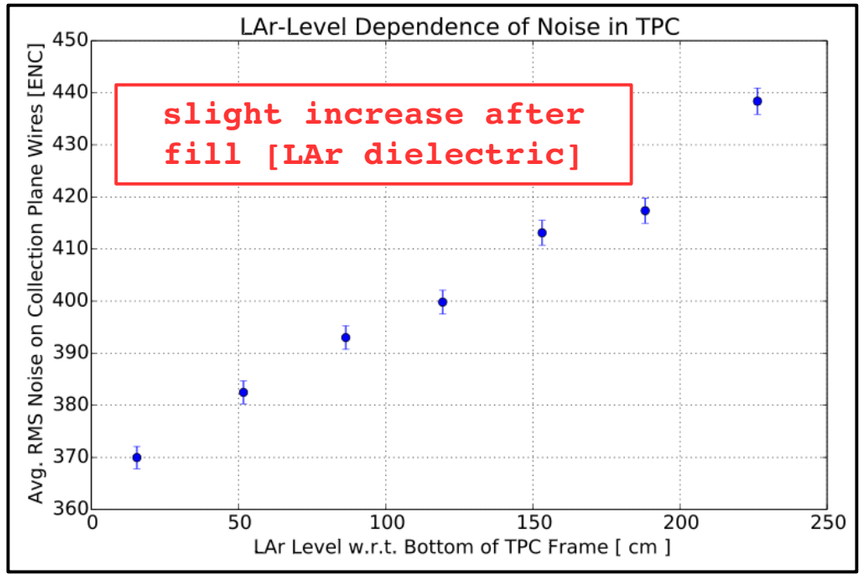
Backup : MicroBooNE electronics

MicroBooNE operates with cold electronics to enhance Signal-to-Noise.

Analog-to-Digital conversion, signal compression, and data-handling in warm.







Backup : data rates

TPC sends us lots of information:

1 event → 4.8 ms of data.

16 bit / data-word x **2 MHz sampling-rate** x **4.8 ms readout** x **8,256 channels** x **5 Hz BNB rate** → **800 MB / second.**

Huffman compression (lossless) to reduce data-rate.

Why read out for such a long time?

Electron ions drift “slowly” in argon. At 270 V/cm field e^- speed is 1.1 km/sec. Drift entire width of TPC [2.56 m] in ~2.3 ms.

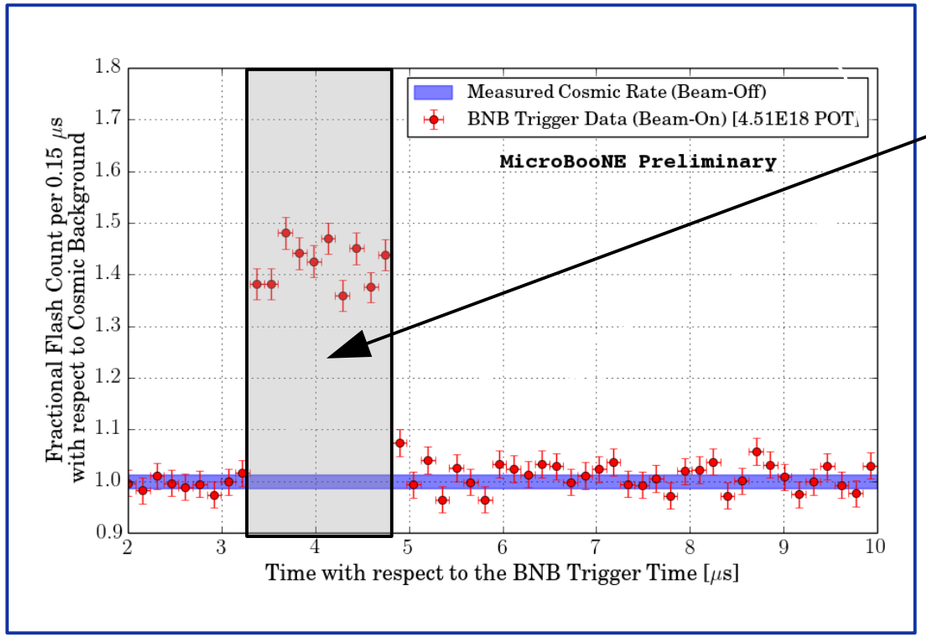
Backup : trigger

MicroBooNE triggers on **BNB** & **NuMI** signals from Accelerator division.

Most Beam spills are empty. No interaction occurs in the detector.

Apply PMT-based trigger to only select events with activity in coincidence with the beam-spill.

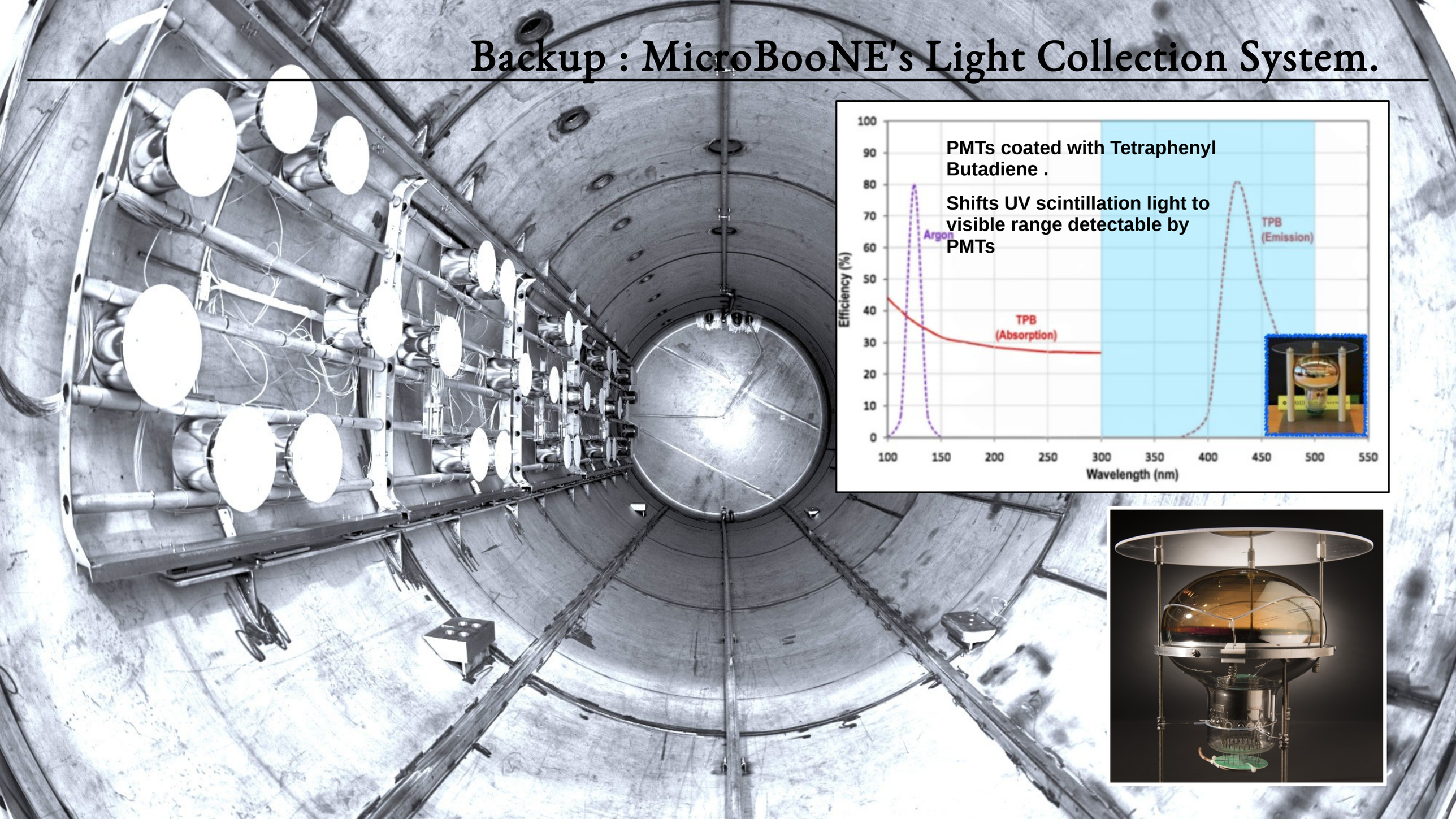
MicroBooNE: events in time with beam



If **flash of light** in coincidence with beam → trigger the readout.

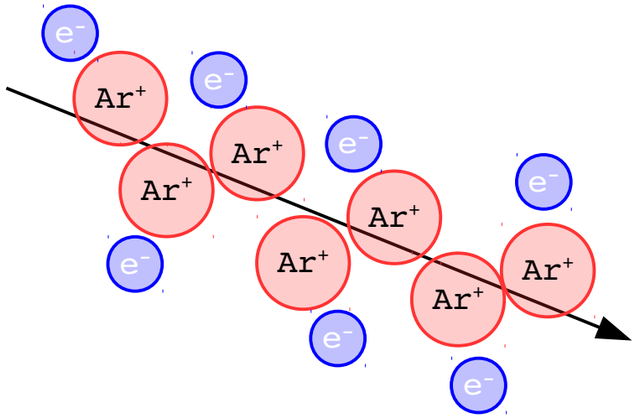
PMT trigger ensures manageable data-rates!

Backup : MicroBooNE's Light Collection System.



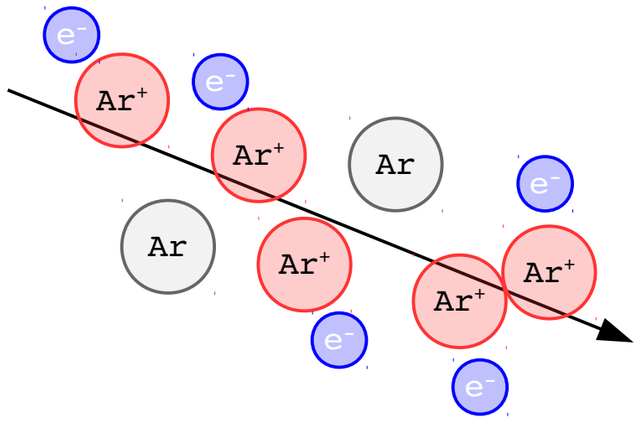
Backup : what happens to ionization electrons in a TPC?

$$dQ = dE \times \frac{W_{ion}}{e^-}$$



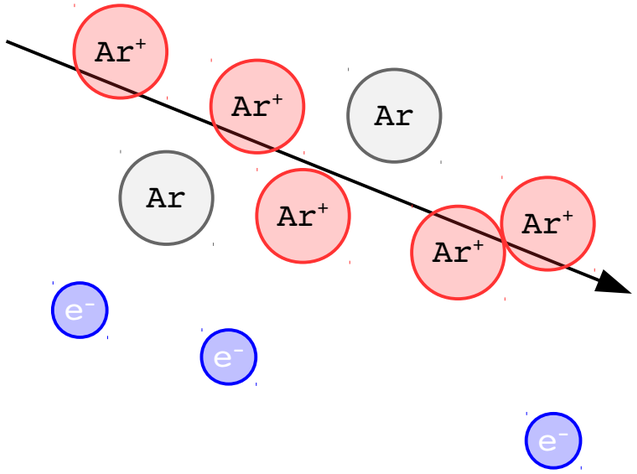
Argon is ionized
W_{ion} = 23.6 eV

$$dE/dx = \frac{e^{\beta\, W_{ion}\, dQ/dx} - \alpha}{dE/dx\, \beta}$$



Ion Recombination
JINST Vol.8 P08005

$$Q = Q_0 e^{-t/\tau}$$



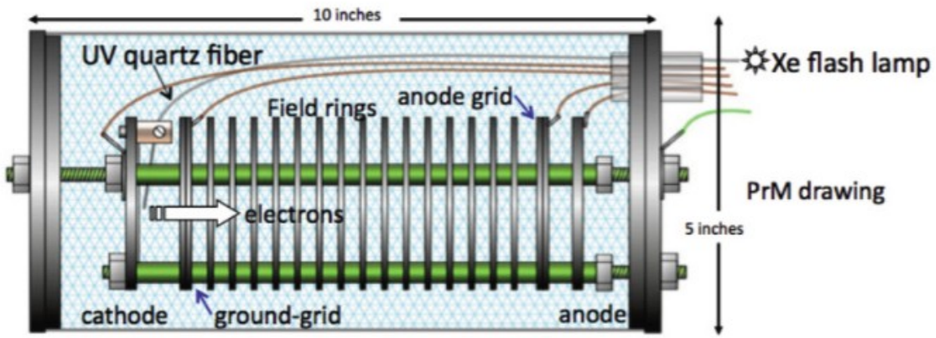
Impurities absorb drifting electrons

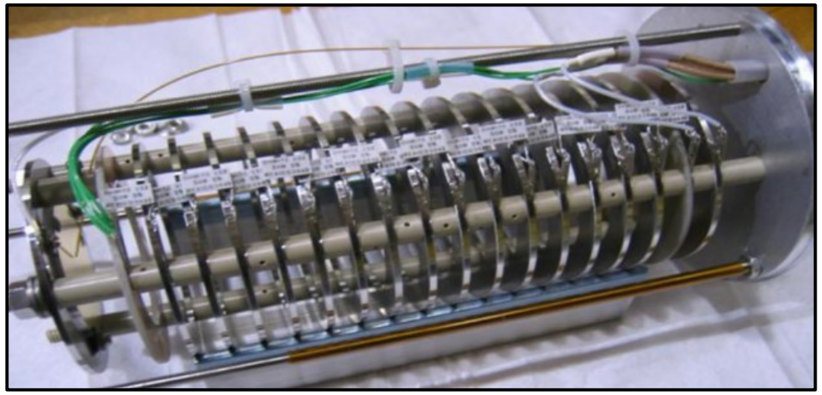
Backup : argon purity

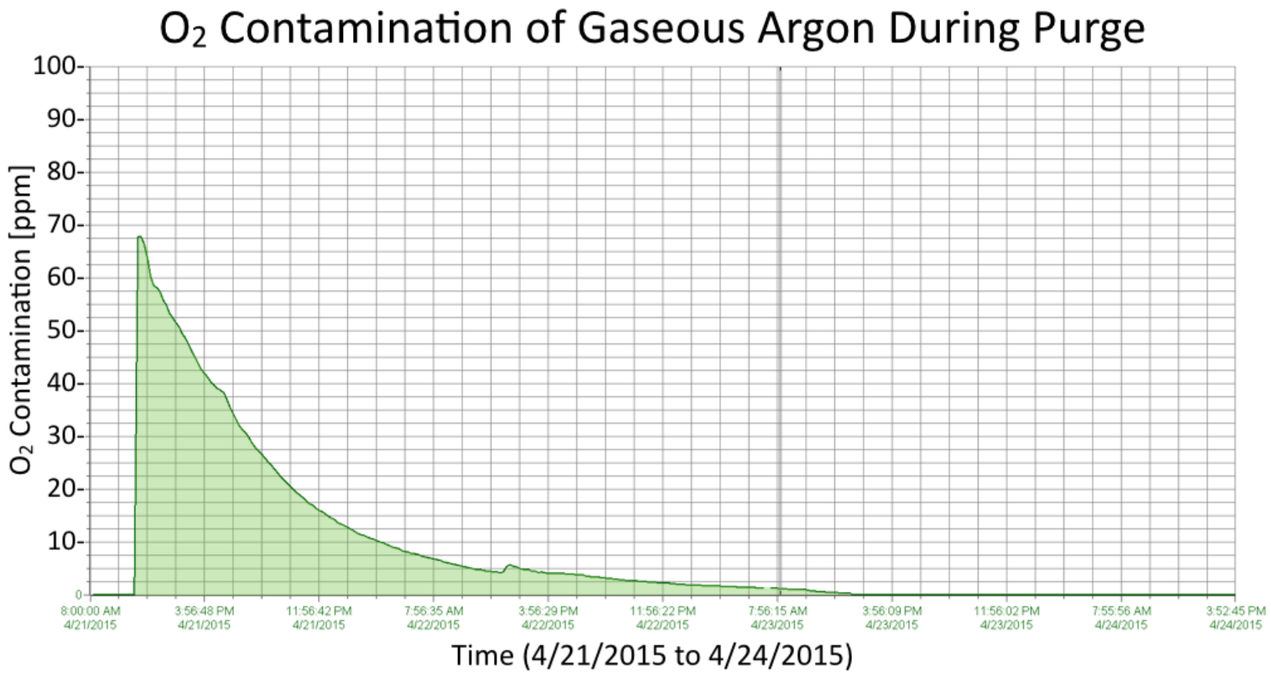
Argon in TPC needs to be pure:

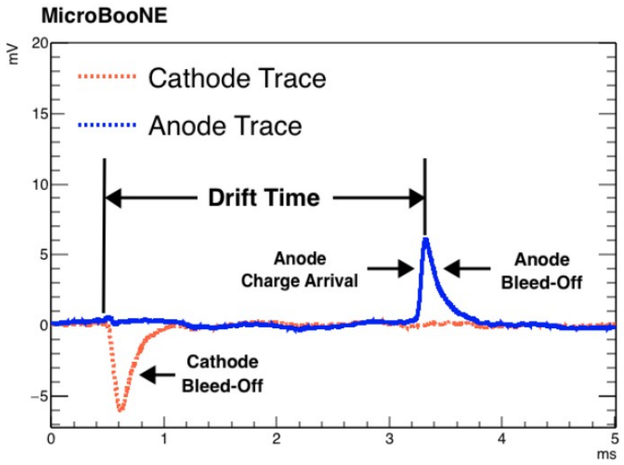
Impurities [H_2O and O_2] absorb drifting electrons and attenuate our signal. N_2 absorbs scintillation light.

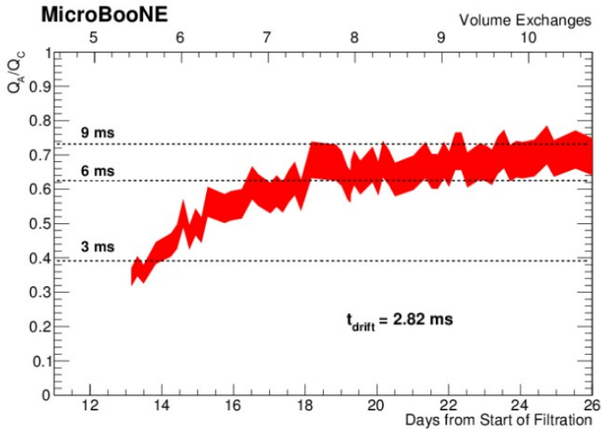
Argon filling occurred after gaseous purge.











Backup : the laser system

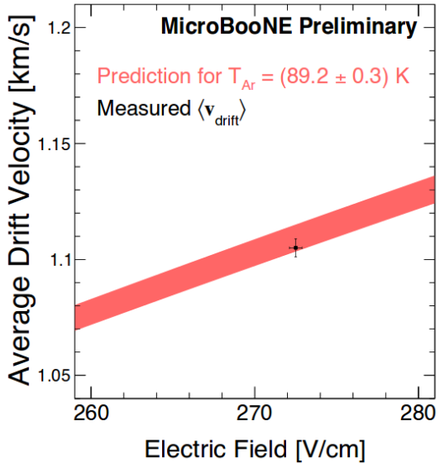
MicroBooNE has a laser!

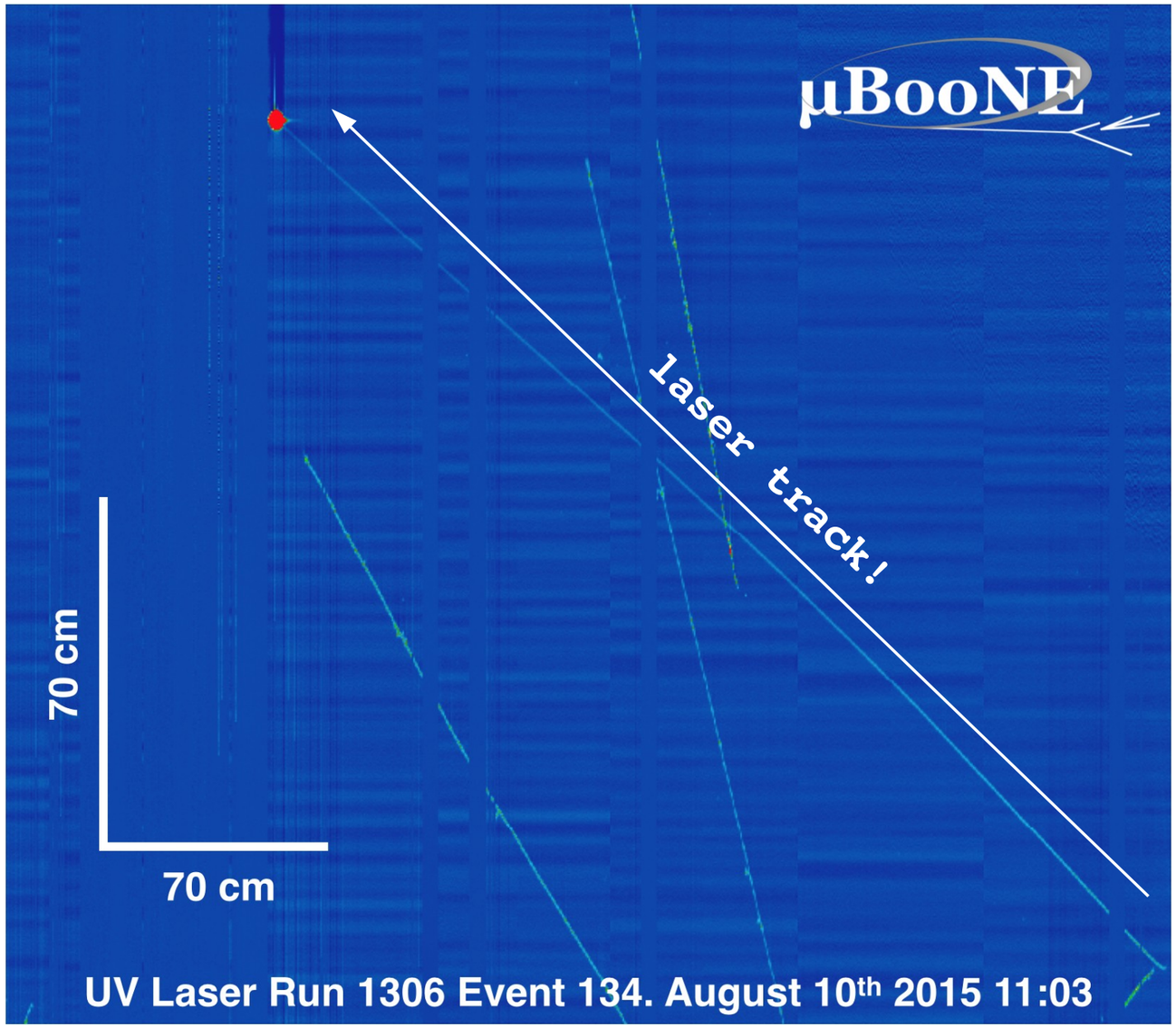
Creates a narrow, straight column of ionization charge.

Studying the detector's response to the laser signal can help study space-charge effects*

*non-uniformities in E-field which may distort image seen on wires.

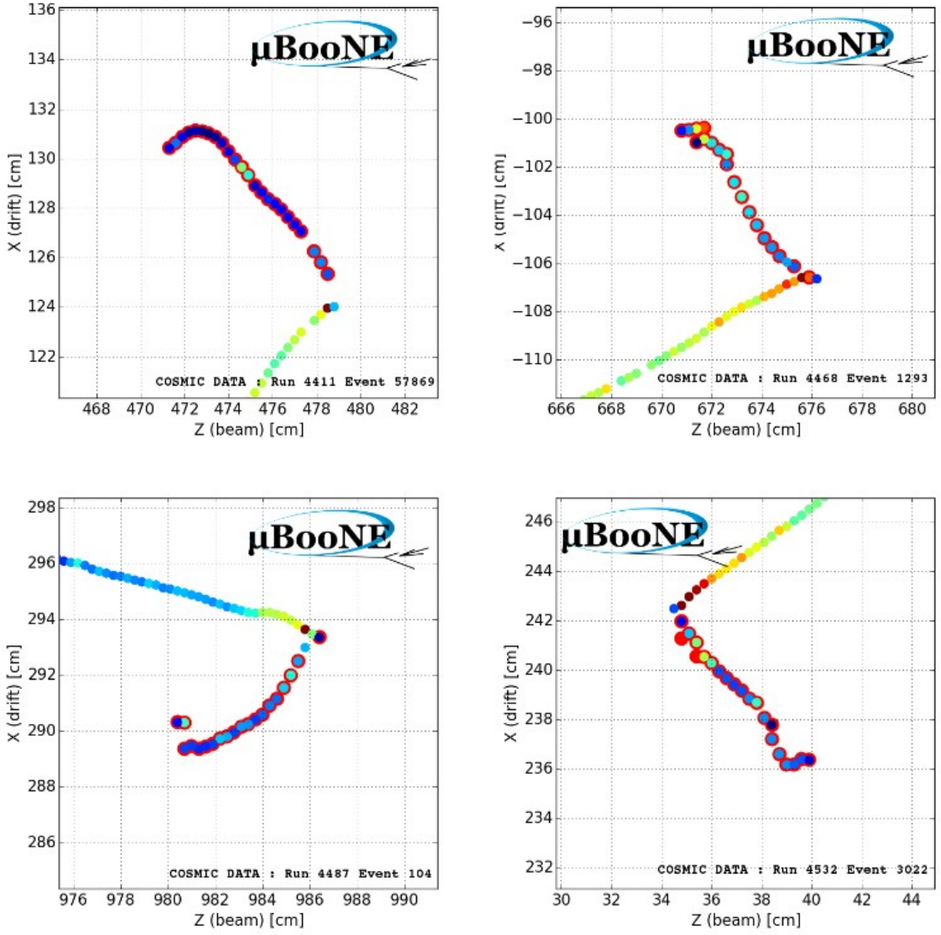
Also, use laser to measure drift velocity!

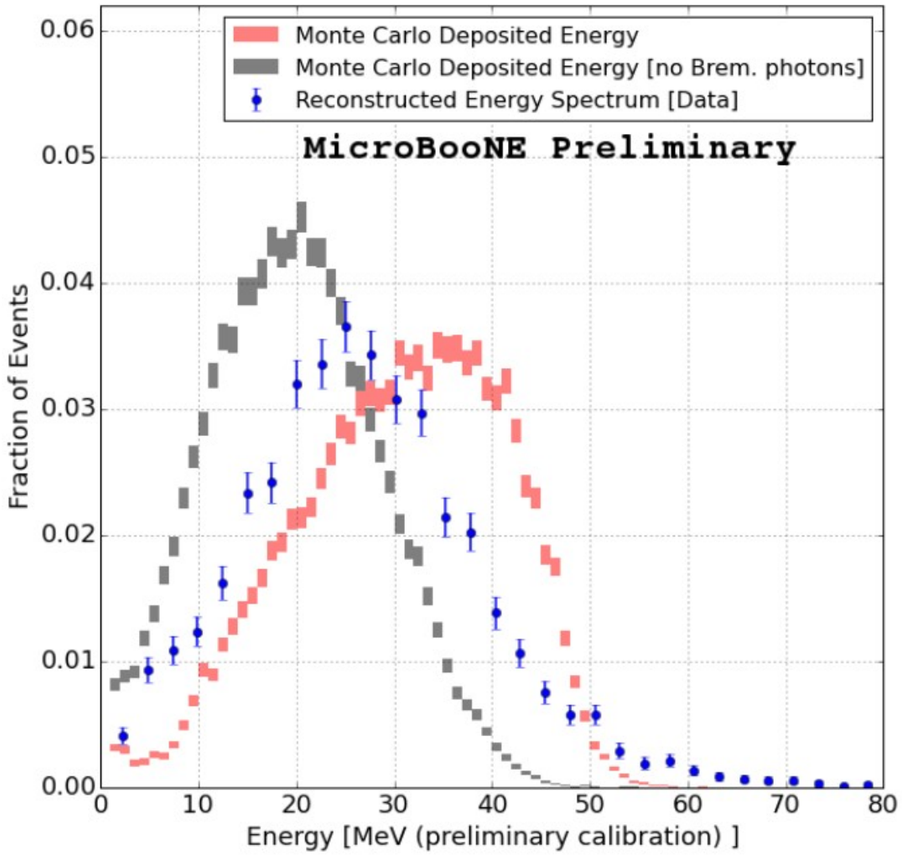




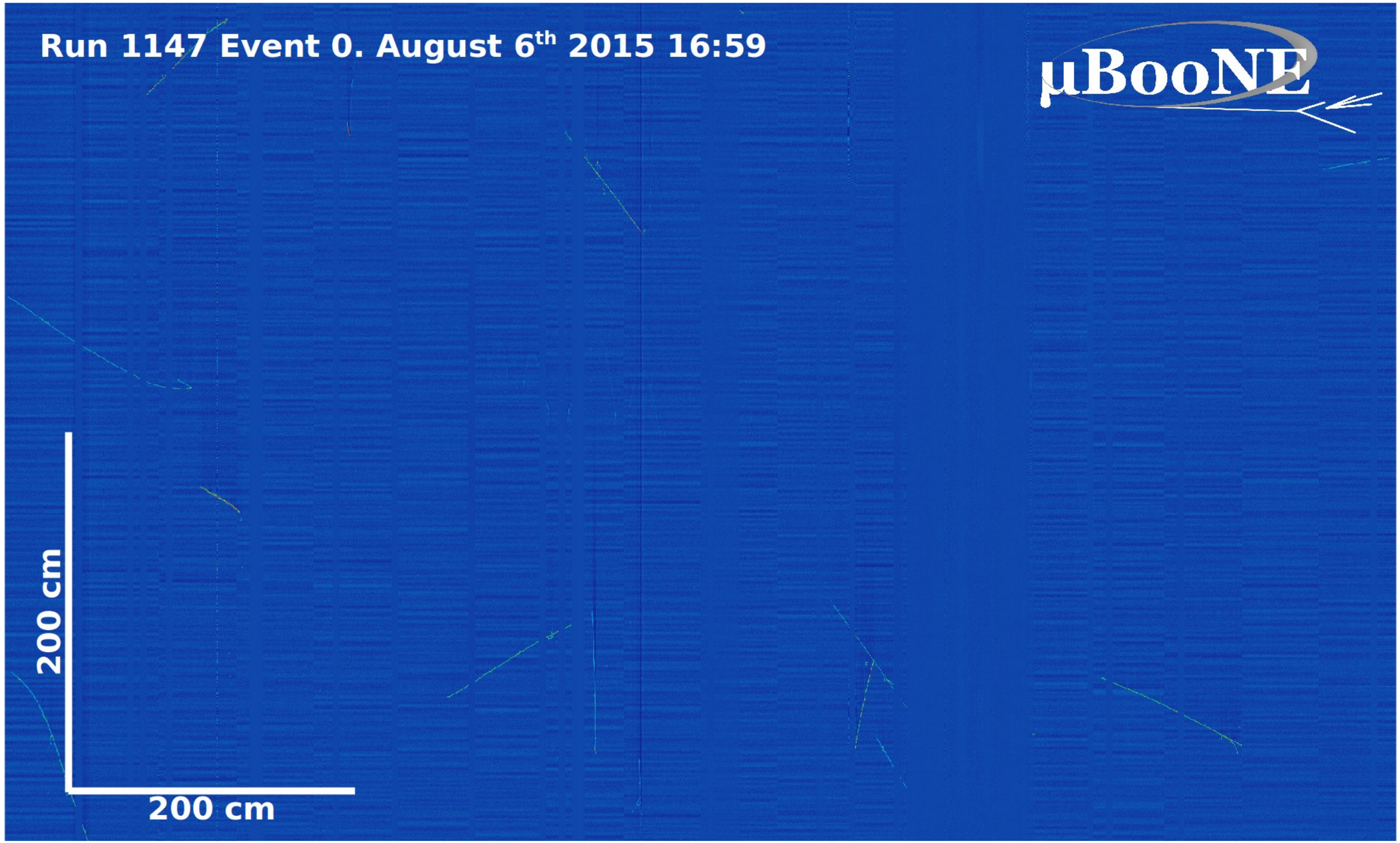
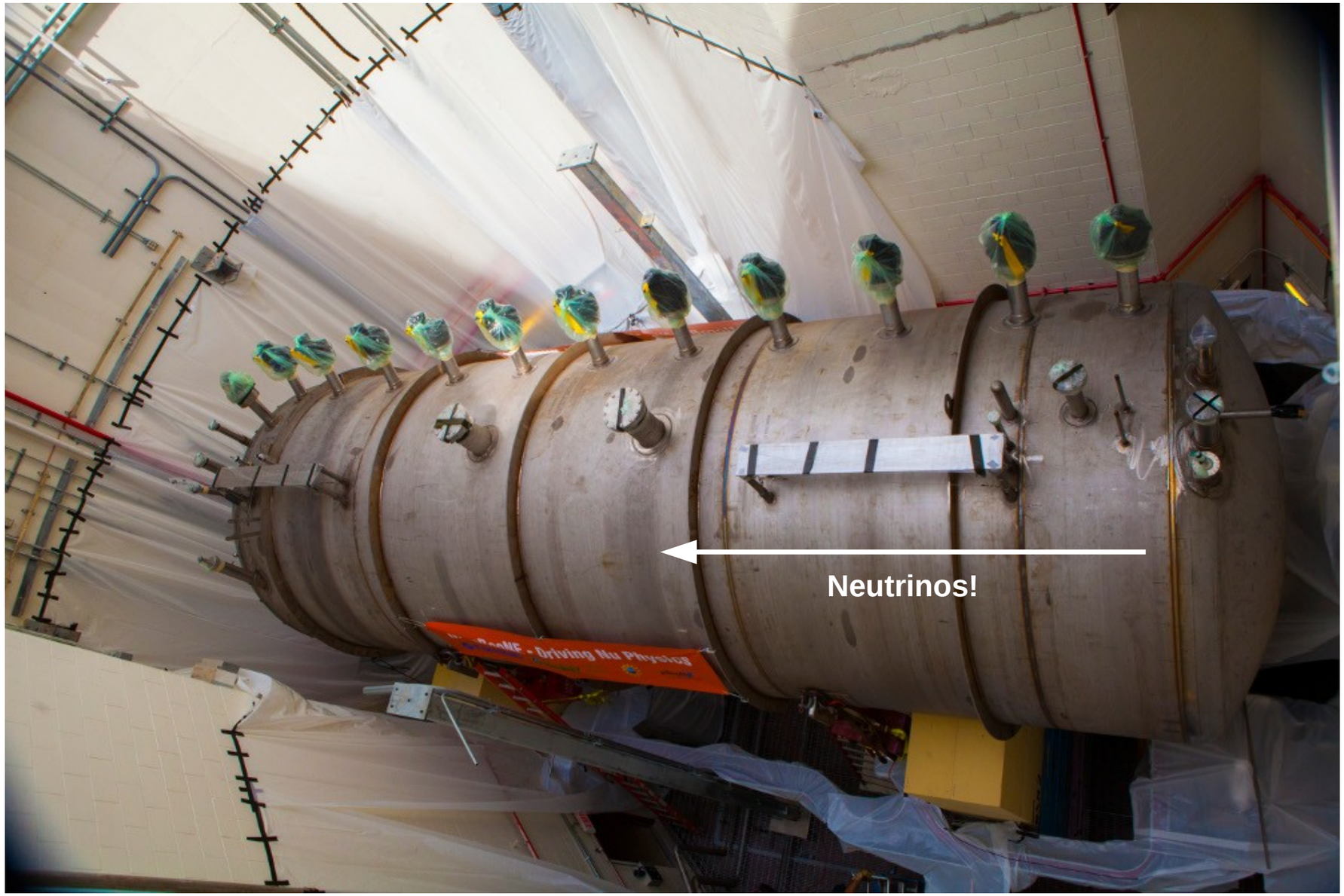
Backup : Michel Electrons

Michel electrons [decay product of stopping muons] are a great source for studying detector response to low [0-50 MeV] electrons





Backup : Full event display! Event 0!



Backup : MicroBooNE @ LArTF!