Summary of Joint DUNE/SBN "Lessons Learned" Meeting

- Meeting Overview
- Summaries and Highlights

Josh Klein, Penn

Overview

Representatives from MicroBooNE, DUNE 35t, and DUNE
Two sessions:

- Detector Operations
- "Detector Physics" Measurements

But topics really were:

- Cryogenics
- High Voltage
- Electronics Noise and Performance
- Photon system
- Monitoring tools
- Detector Performance/Calibrations
- Measurements

Overview

09:00 - 12:45 Detector Operations

09:00 **Welcome** *10'*
Aims of the meeting.

09:10 **Cryogenics: Experience from MicroBooNE and the DUNE 35-t prototype** *20'*
Speaker: Mike Zuckerbrot (Fermilab)
Material: Slides

09:30 **Measurements in the 35-t Prototype** *20'*
Speaker: Dr. Thomas Junk (Fermilab)
Material: Slides

09:50 **Electronics and Noise: Experience from MicroBooNE and SBND/ProtoDUNE status** *30'*
Speaker: Dr. Hucheng Chen (Brookhaven National Lab)
Material: Slides

10:20 **HV system: Experience from MicroBooNE** *25'*
Speaker: Dr. Corey Adams (Yale Unversity)
Material: Slides

10:45 **Experience from the LArIAT Photon System** *15'*
Speaker: Dr. Andrzej Szelc (University of Manchester)
Material: Slides

11:00 **HV System: Tests in the 35-t Prototype** *25'*
Speaker: Dr. Sarah Lockwitz (Fermilab)
Material: Slides

11:25 **Lessons Learned: Diagnostics and Monitoring Tools** *50'*
Speakers: Dr. Jonathan Asaadi (University of Texas Arlington), Jennifer Raaf (Fermilab), Dr. Xiao Luo (Yale University)
Material: Slides

13:30 - 18:15 Detector Physics Measurements

13:30 **Lifetime, Space Charge, Diffusion and Recombination measurements in MicroBooNE** *30'*
Speaker: Prof. Sowjanya Gollapinni (University of Tennessee, Knoxville)
Material: Slides

14:00 **Michel electrons in MicroBooNE** *30'*
Speaker: David Caratelli (Columbia University)
Material: Slides

14:30 **Deep Learning Techniques in MicroBooNE** *30'*
Speaker: Mr. Kazuhiro Terao (Nevis Laboratories, Columbia University)
Material: Slides

15:00 **MuCS measurements and CRT measurements** *25'*
Speaker: Elena Gramellini (Yale University)
Material: Slides

15:40 **Inputs to LArIAT physics results and lessons for broader LArTPC program** *30'*
Speaker: Dr. Andrea Falcone (UTA)
Material: Slides

16:10 **Electronics and Noise - the experience from LArIAT** *20'*
Speakers: Prof. Carl Bromberg (Michigan State University), Dean Shooltz (MSU)
Material: Slides

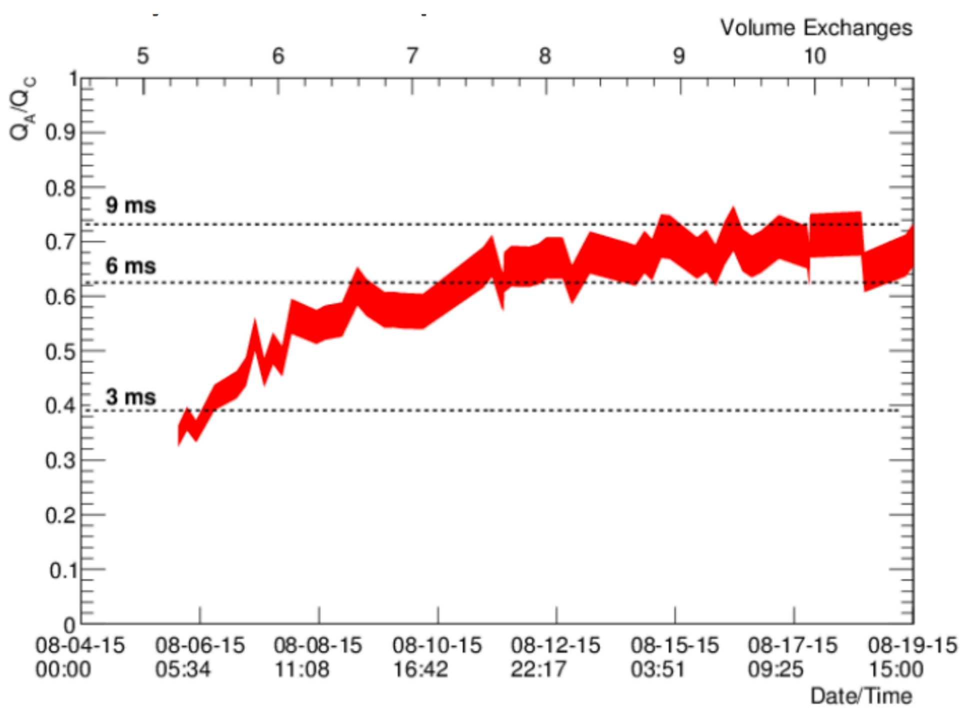
16:30 **Closing Discussion** *35'*

Representatives from MicroBooNE, LArIAT, DUNE 35 t, DUNE

Cryogenics

MicroBooNE cryogenics overall very successful:

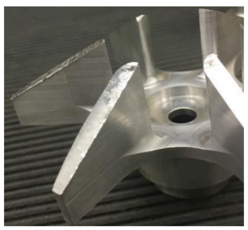
- Demonstrated "piston purge" technique
- Achieved remarkable purity levels (electron lifetimes > 9 ms) quickly



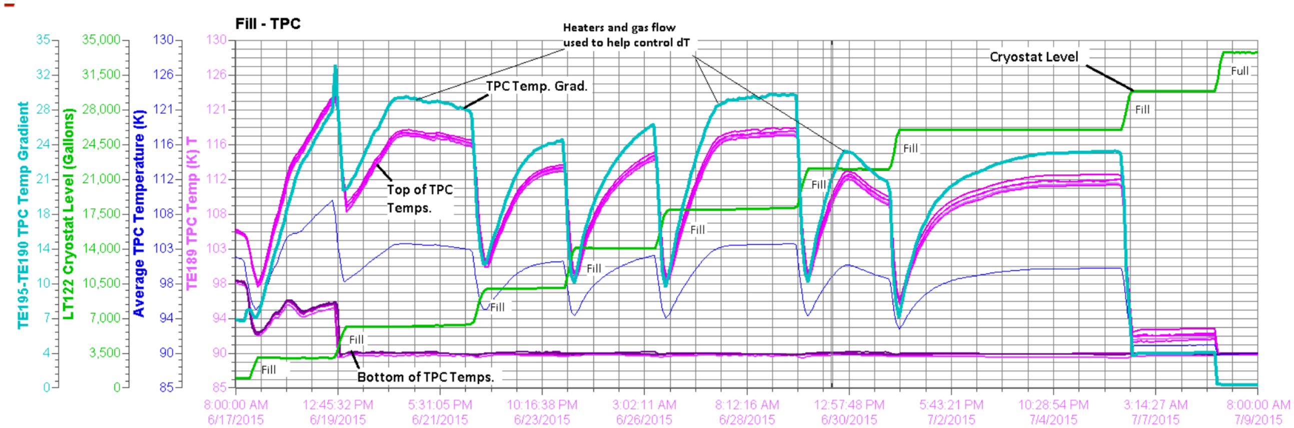
Cryogenics

MicroBooNE cryogenics overall very successful:

- Biggest hiccup may have been dealing with LAr vendors to get desired initial purity delivered on time
- One failed pump (Barber Nichols)



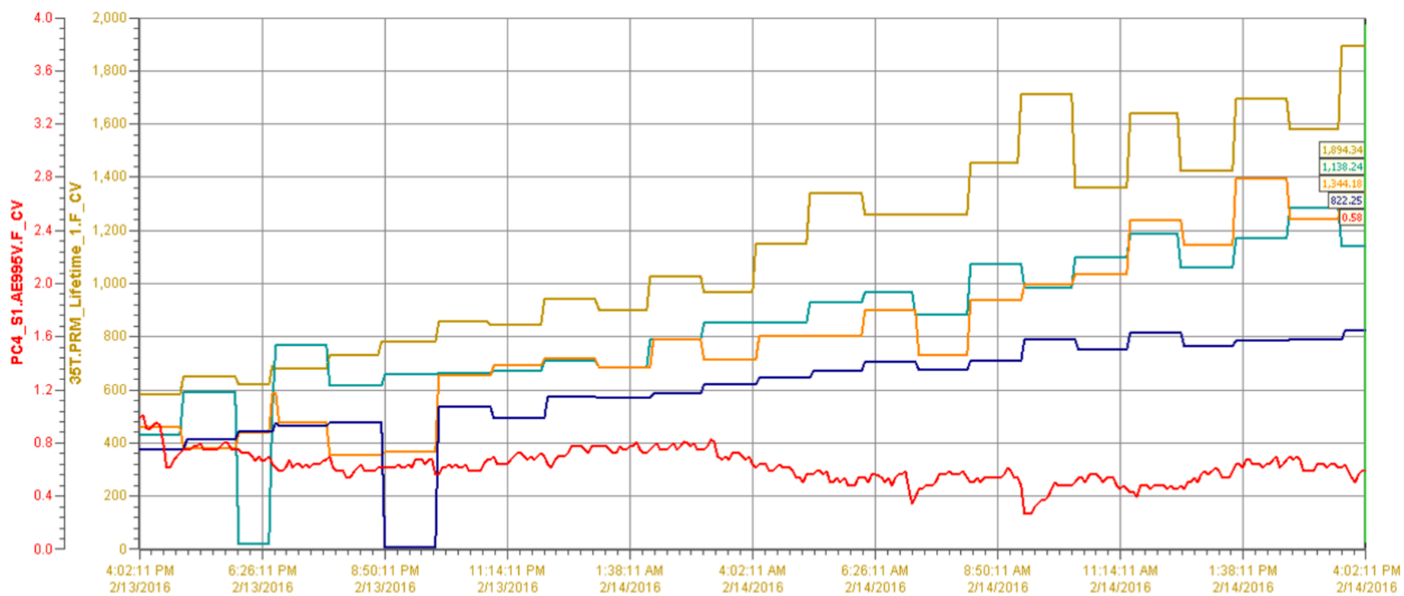
- Also had some temperature stratification during fill---solved with heaters for convection



Cryogenics

35 t cryogenics not as smooth:

- Best achieved purity gave lifetime of ~4.5 ms
- A lot of purity stratification seen during initial "Phase 2" run



Tracked with temperature stratification

Cryogenics

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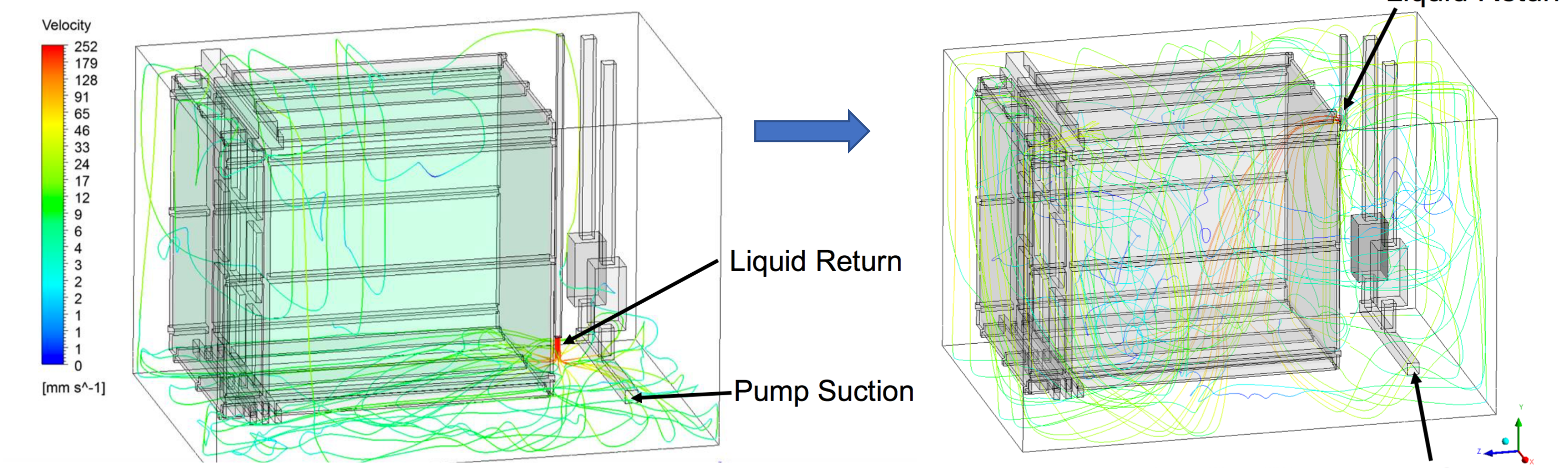
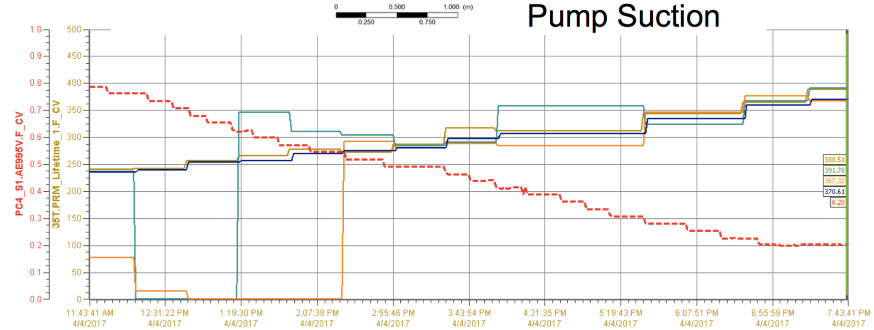




Cryogenics

35 t cryogenics not as smooth:

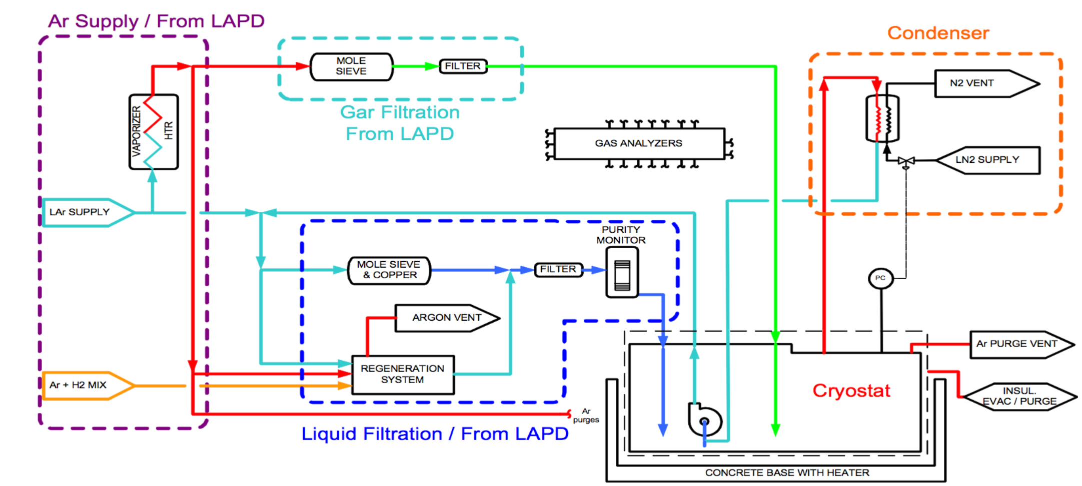
- Failure of tubing on compressor spoiled entire 35 tonne argon volume in 30 min

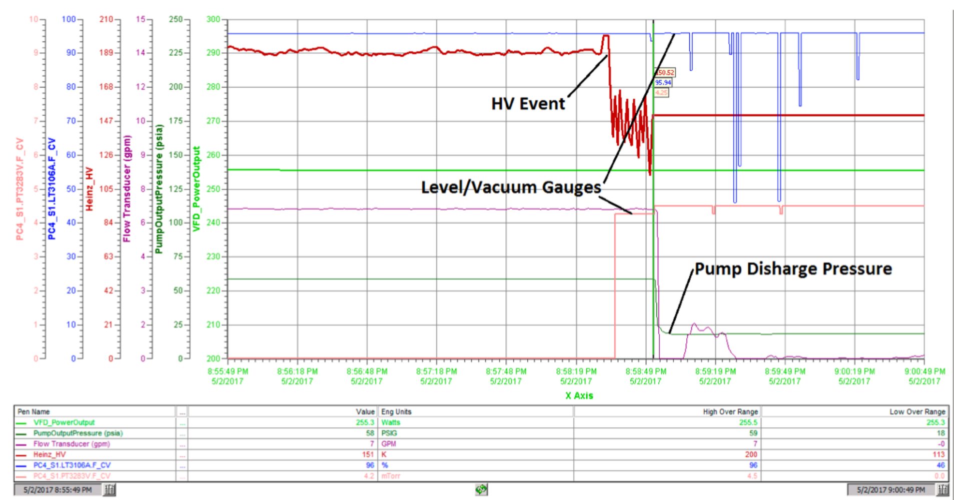
Lesson learned: Don't do this.

Cryogenics

35 t cryogenics not as smooth:

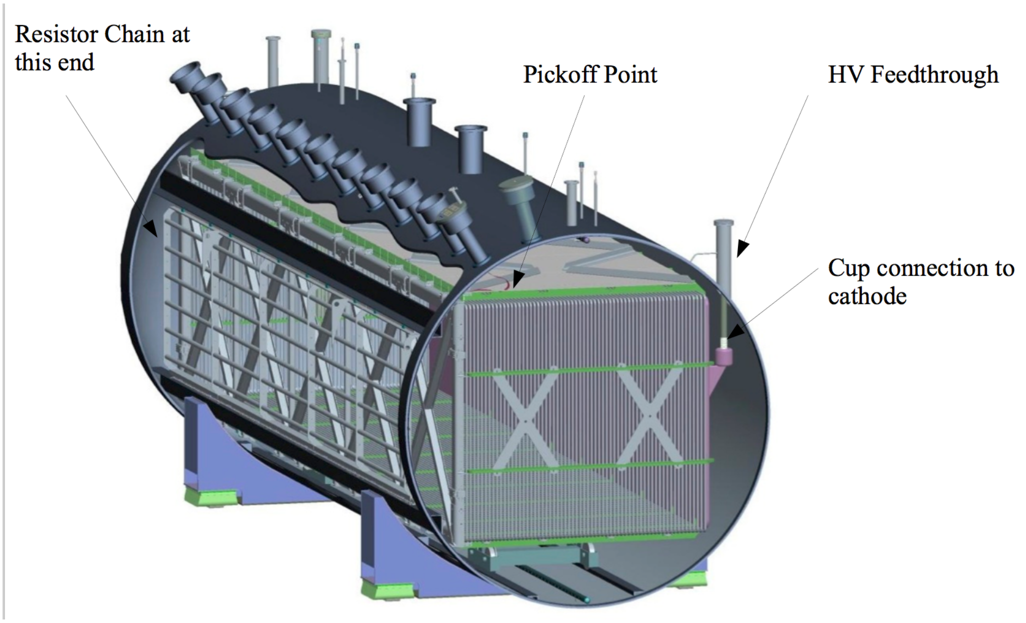
- Submersible pumps are problematic and frustrating

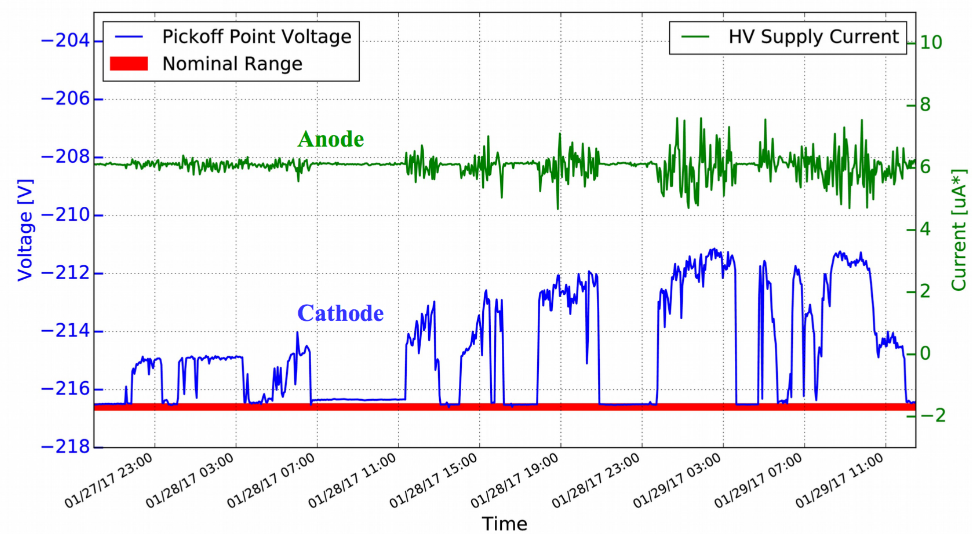




High Voltage

MicroBooNE had "bursts" of noise associated with cathode HV transients:





High Voltage

Tour de force investigation (about 1 month of downtime):

- Exploited MicroBooNE HV pickoffs and ability to connect test supplies
- All the while running both TPC and PMTs and doing offline analysis
- Ultimately tracked problem down to supply connection to cathode
- And discovered…

Tightening bellows to move feedthrough fixed the problem

High Voltage

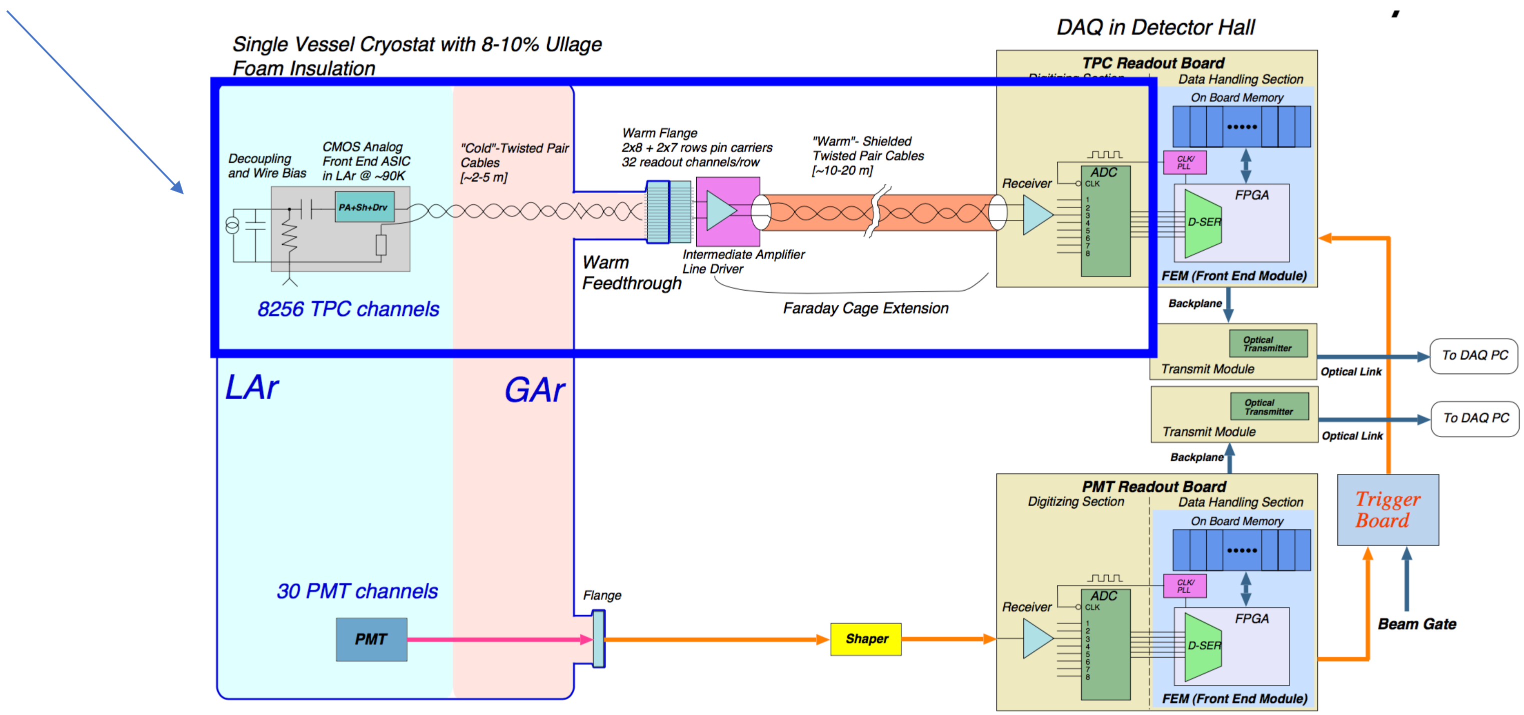
Lessons learned:

- Accessible/configurable pickoff points to test HV
- [Also need good QA/QC during installation]
- Taking both TPC and PMT data while doing tests is critical
- Feedthrough is a single-point failure and difficult to access---making this serviceable, or redundant would be a big win

No explicit discussion (in slides) of why MicroBooNE HV not at original design---not sure if this was just because lifetime is good enough not to need it or there were other issues.

Electronics Noise

MicroBooNE first LAr TPC to use cold front-end ASICs.



ADCs are outside and "in the warm."

Electronics Noise

Three “excess” (above intrinsic 500 e) noise sources found:

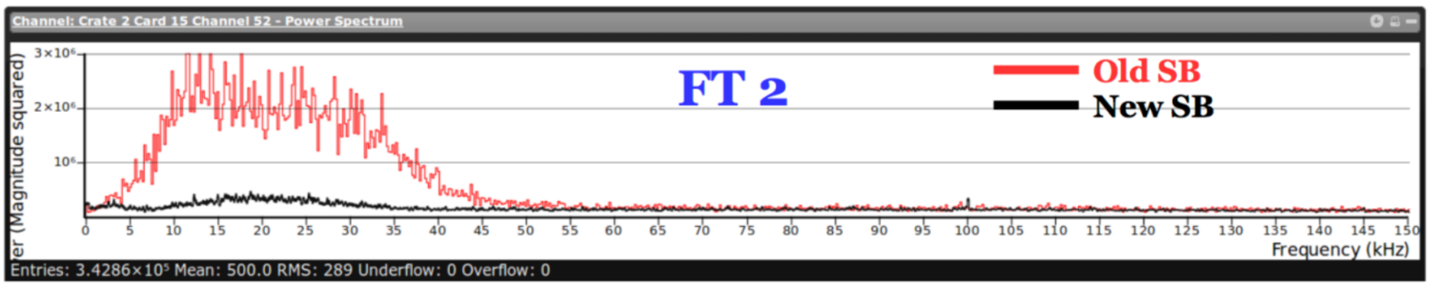
1. Low frequency coherent noise from (warm) voltage regulators
2. Ripple from cathode HV power supply capacitively coupled from cathode to anode
3. Burst or “zig-zag” noise

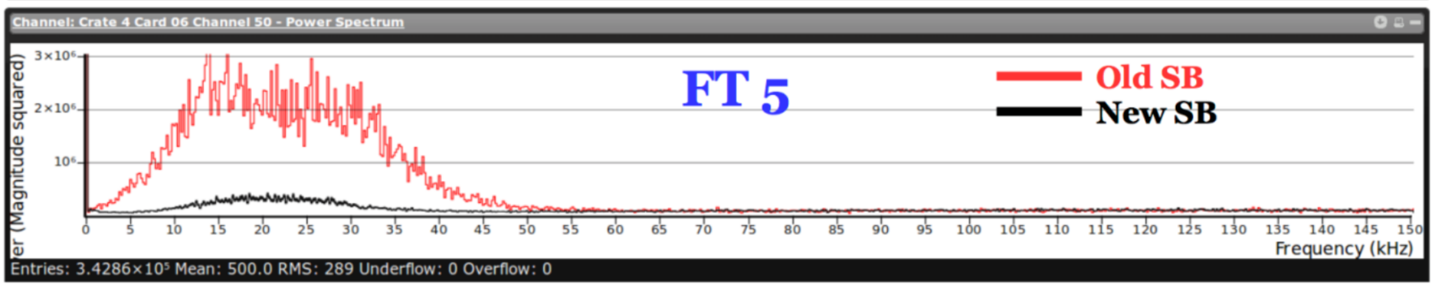
Electronics Noise

Three “excess” (above intrinsic 500 e) noise sources found:

1. Low frequency coherent noise from (warm) voltage regulators

10-30 kHz regulator noise spanned several channels and initially was mitigated with offline subtraction. As of last Summer, new service boards with better regulators replaced originals:

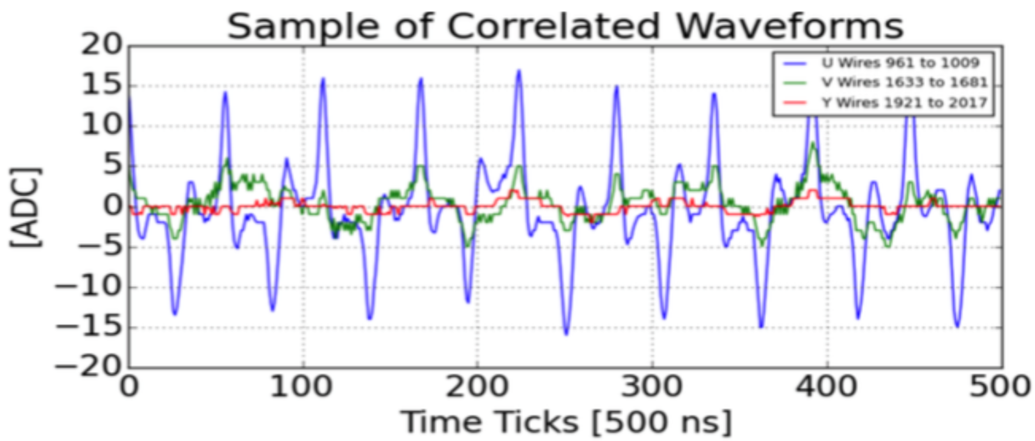




Electronics Noise

Three "excess" (above intrinsic 500 e) noise sources found

2. Ripple from cathode HV power supply capacitively coupled from cathode to anode



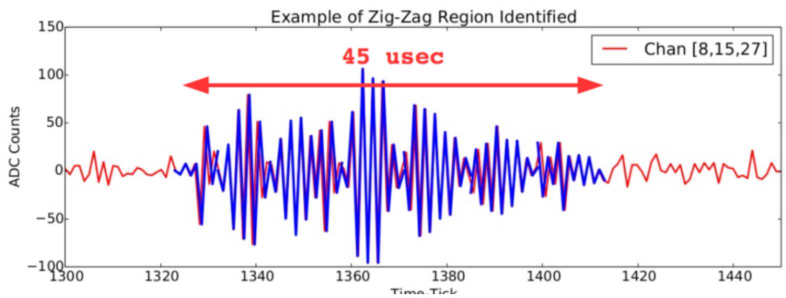
Worst wire plane (u) is the one closest to cathode.

Initially mitigated by frequency-domain filtering of such sharp harmonics.
Noise eventually suppressed with additional filtering on HV system added in 2016.

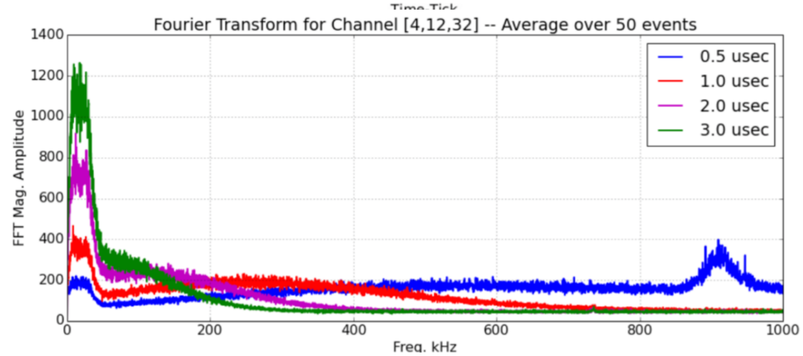
Electronics Noise

Three “excess” (above intrinsic 500 e) noise sources found:

3. Burst or “zig-zag” noise



Time domain



Frequency domain

Source is unknown but for MicroBooNE high enough in frequency to be filtered by nominal 2μs shaping time.

Electronics Performance

Table 1. Summary of the non-functioning channels for Run 3455 Event 6. A total of ~862 channels are considered non-functioning. MB stands for front-end motherboard.

# non-functioning channels	Reason
~20	ASIC saturation
96	6 ASICS on one MB not connected to wires
304	19 ASICs due to start-up problem
126	channels sorrounding U-Y shorted wires with 10 noisy channels
287	channels sorrounding U-V shorted wires with 28 noisy channels
36	noisy channels not located near the shorted wires

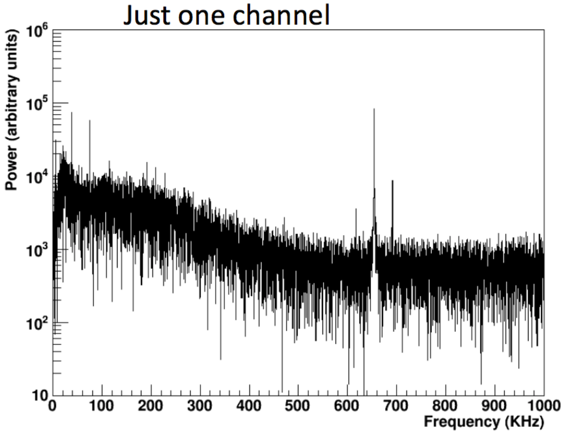
About 10% of total but since only need 2 wires/hit, overall impact just 3%.

Electronics Noise

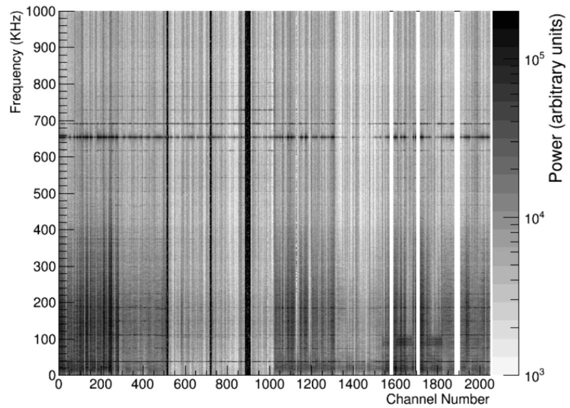
DUNE 35 t first LAr TPC to use cold front-end ASICs *and ADCs.*

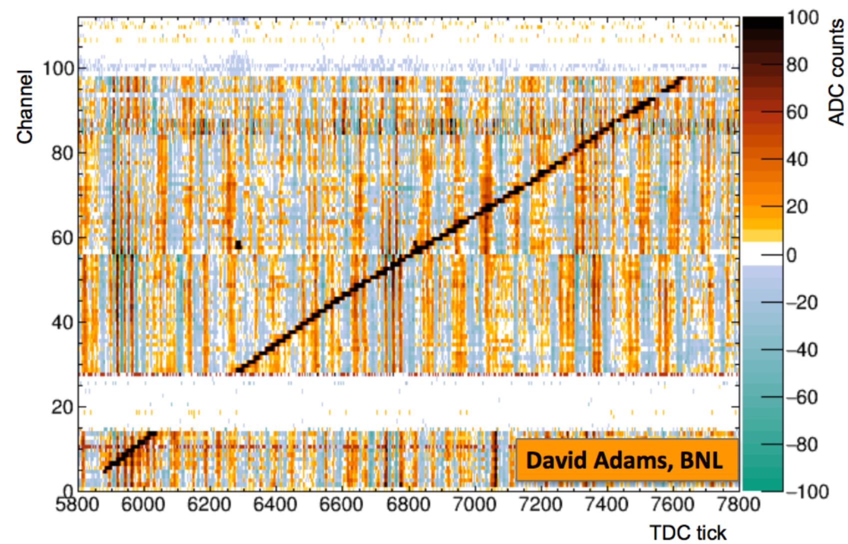
- Saw similar noise as MicroBooNE (e.g. regulators)

Just one channel



All channels



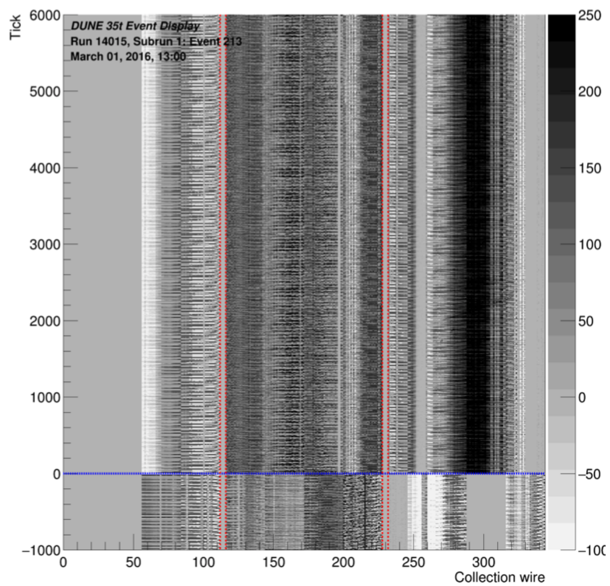


Electronics Noise

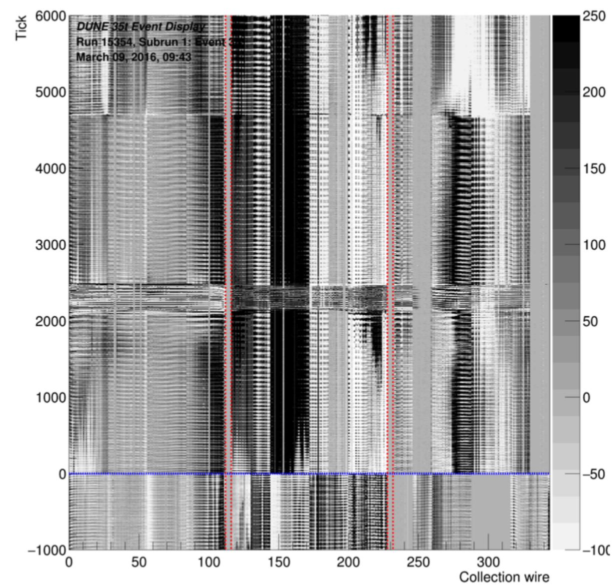
DUNE 35 t first LAr TPC to use cold front-end ASICs *and ADCs.*

- But also a "high noise state" that made detector unusable and could persist for hours.

Oscillatory noise



Transients

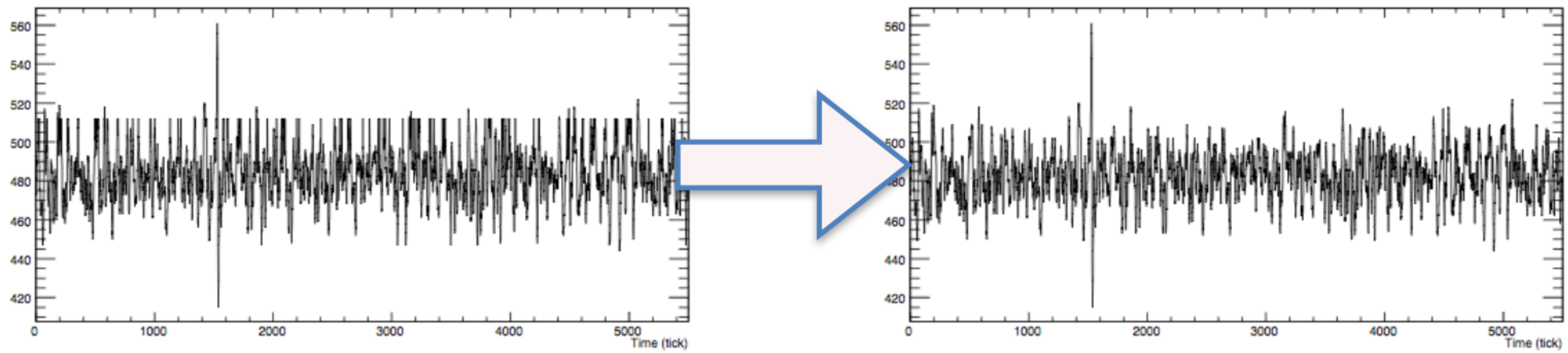


Cause of this unknown. [But some (Johnson, Rivera, Van Berg) have argued this is a more extreme version of MicroBooNE "zig-zag" noise, exacerbated by cold ADCs and wire length or configuration, and that the system is intrinsically unstable. Others have argued it was caused by an imperfect Faraday cage and grounding. ProtoDUNE and/or SBND may resolve the question].

Electronics Performance

DUNE 35 t first LAr TPC to use cold front-end ASICs *and ADCs*.

- ADCs also had "stuck code" problem that added complexity for analysis.



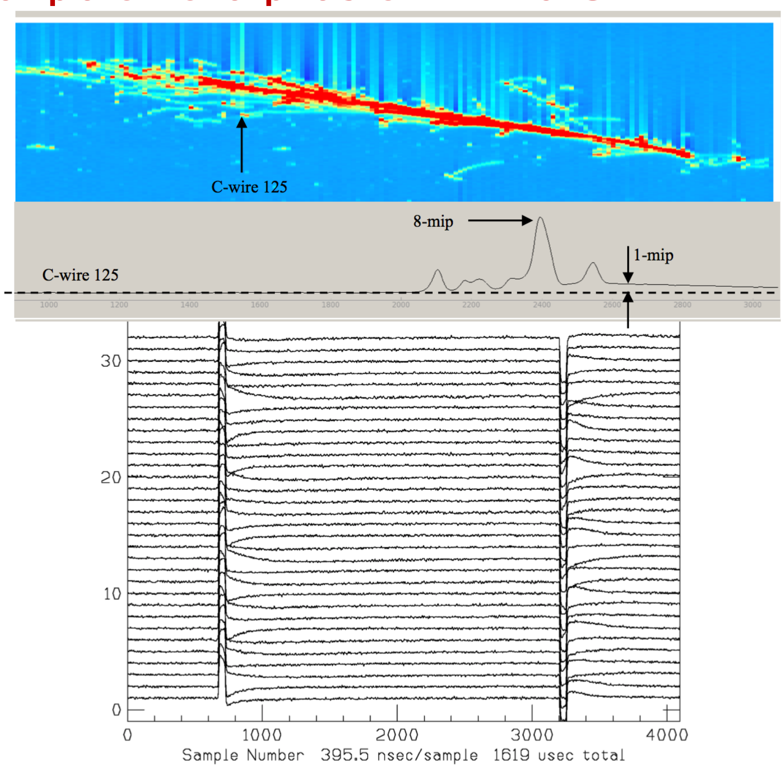
Mitigated with software interpolation.

[Dune is no longer pursuing this particular cold ADC technology.]

Electronics Noise

LArIAT also used cold Front-end ASICs (but warm ADCs)

- Very good noise levels (270 e), lower than MicroBooNE in part because of shorter wires
- Allowed discovery of pole-zero problem in ASIC



Problem tracked down and mitigated in new version of ASIC

“Detector Physics”

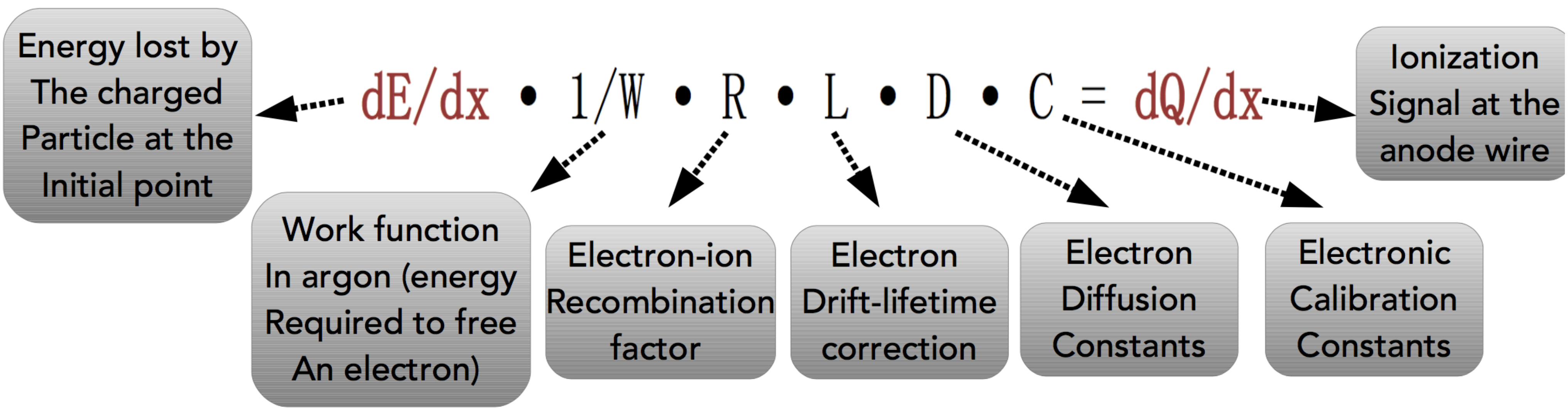
- MicroBooNE Calibrations (lifetime, space charge, diffusion, recombination)
- MicroBooNE Michel electrons
- MicroBooNE muons and cosmic tracker
- DUNE 35 t analysis techniques
- LArIAT physics

MicroBooNE Calibrations

Focus on four linked measurements:

- Space charge
- Electron lifetime
- Electron-ion recombination
- Electron diffusion

Example: calorimetry

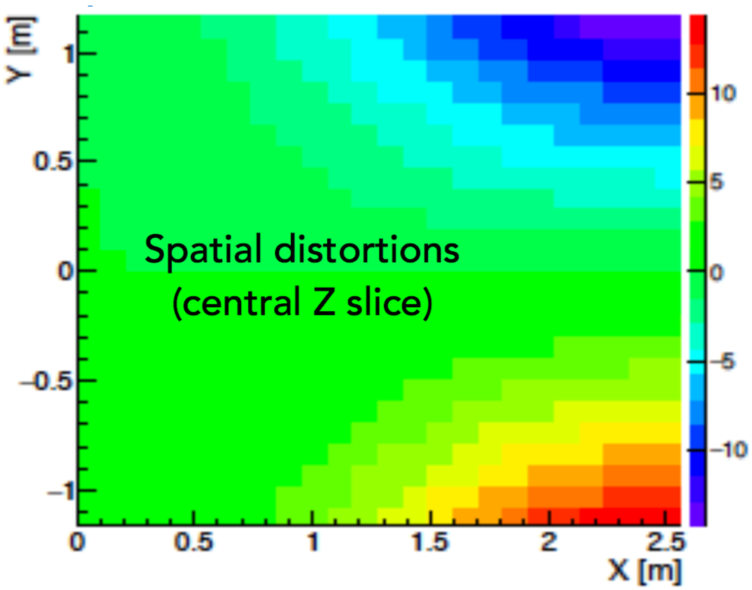


MicroBooNE Calibrations

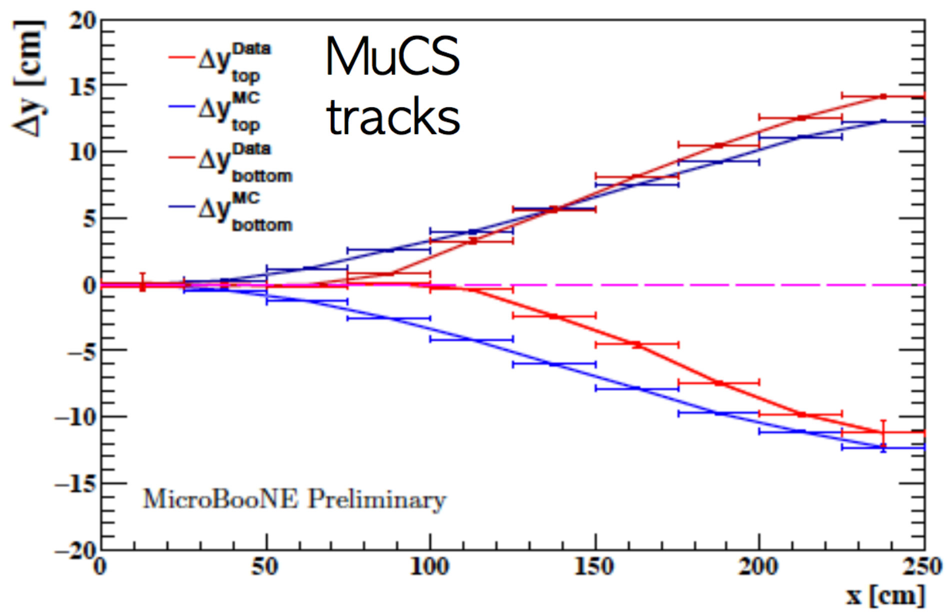
Focus on four linked measurements:

- Space charge---in a surface detector cosmics build up charge distorting field locally

Calculation of spatial distortions due to local field



Measurement of distortions compared to MC using ``small" muon counters.



Analysis using laser data not yet complete.

MicroBooNE Calibrations

Focus on four linked measurements:

- Space charge---in a surface detector cosmics build up charge distorting field locally

“Importance of Laser System, Cosmic Ray Tagger system, cannot be [over]stated.”

[N.B. DUNE FD currently has no planned laser or tagger.
(But space charge at least should not be an issue)]

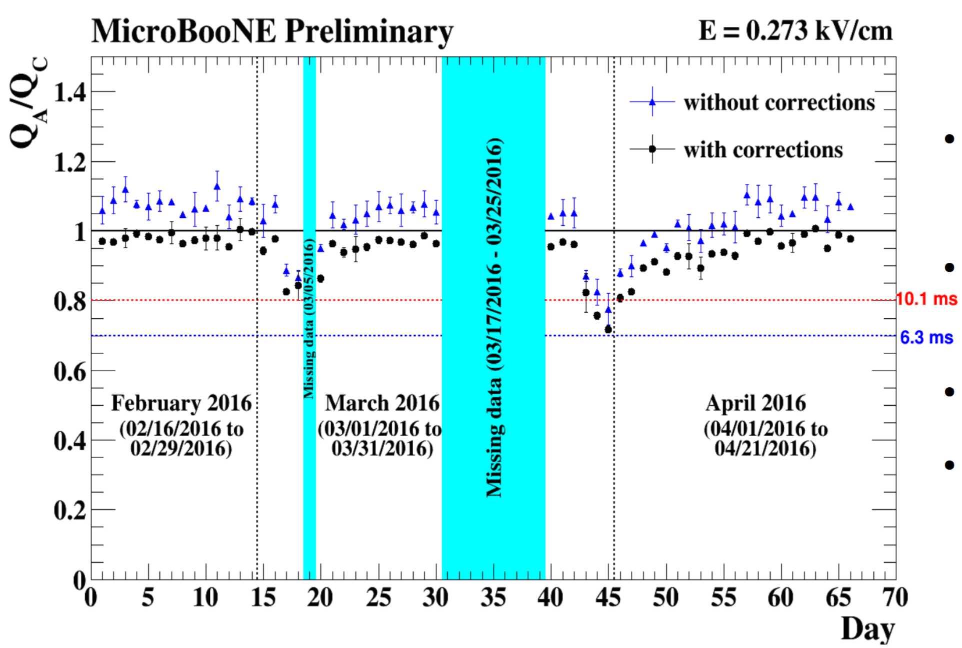
[N.B. ProtoDUNE-SP will not have a laser.]

MicroBooNE Calibrations

Focus on four linked measurements:

- Electron lifetime

Measured using cosmics that cross both anode and cathode



- "Unphysical" ratio >1 caused by space charge distortions---these measurements covary
-
-
-

Systematic name	Uncertainty (%)
Space charge correction	5.0
Recombination model	1.0
Diffusion	2.0
Total	5.5

(% of final space-charge correction Q_A/Q_C value)

Q_A/Q_C=0.88+/-0.04

Important to have "t0-tagged" samples

MicroBooNE Calibrations

Focus on four linked measurements:

- Recombination

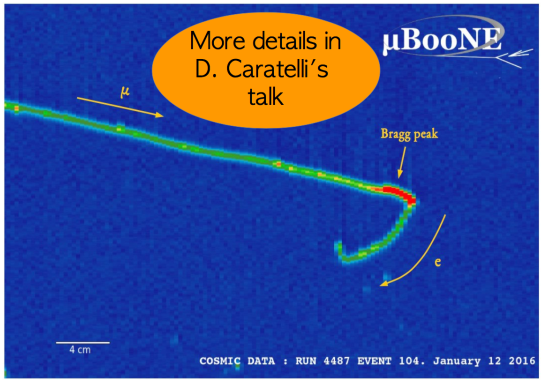
  - Birk's Model and Modified Box Model

$$R_{Birk's} = \frac{A_B}{1 + \frac{k_B}{\rho} \cdot \frac{dE}{dx} \cdot \frac{1}{\mathcal{E}}}$$

$$R_{ModBox} = \frac{\ln(\alpha + \frac{\beta_P}{\rho \mathcal{E}} \cdot \frac{dE}{dx})}{\frac{\beta_p}{\rho \mathcal{E}} \cdot \frac{dE}{dx}}$$

There are strong opinions about whether recombination parameters are universal and measurable entirely ex situ.

Stopping muons used



Identification of stopping muons improving---good to have samples "centrally available."

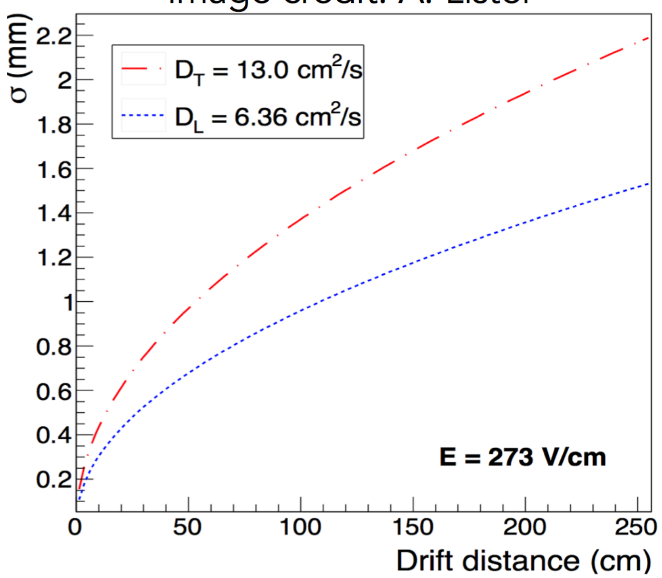
MicroBooNE Calibrations

Focus on four linked measurements:

- Diffusion

Longitudinal and transverse---difficult to measure due to dependence on other things.

Image credit: A. Lister



All of these covary with measurement:

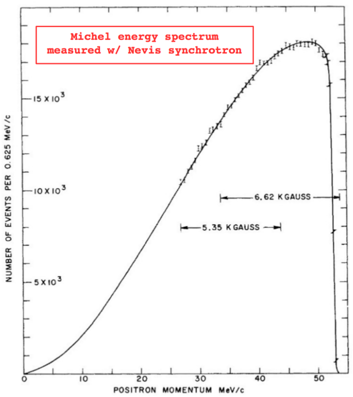
- Noise
- Channel threshold
- Electronics transfer function
- Space charge and recombination
- Track angle and wire field response

This will matter more for protoDUNE/DUNE.

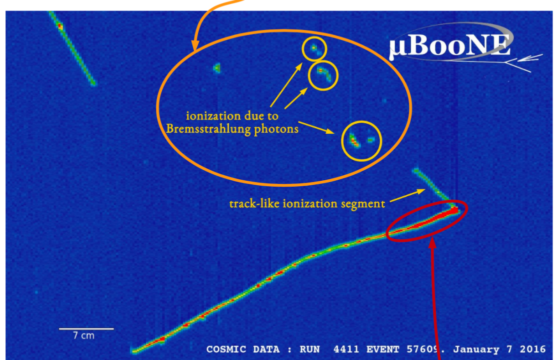
MicroBooNE Michels

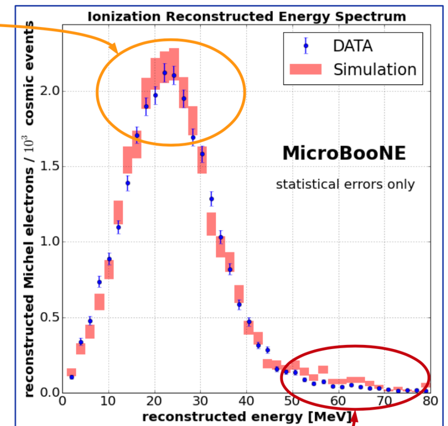
Michel spectrum spans critical energy---both significant ionization and brem losses.

PRL, 14, 449 (1965)

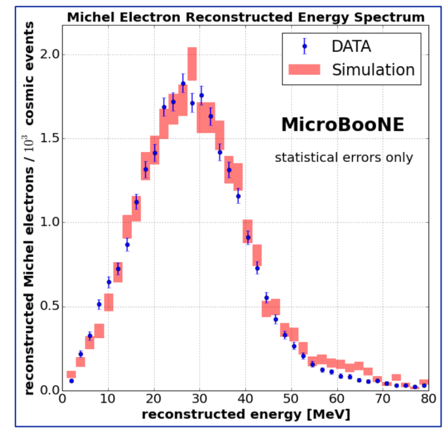


Exclusion of radiative photons causes shift in spectrum.





photon tagging cut:
80 cm & 25 degrees



Where is the remaining charge?
- inefficiency in clustering.
- charge under hit-threshold.

Muon Bragg peak can contaminate clustered Michel energy

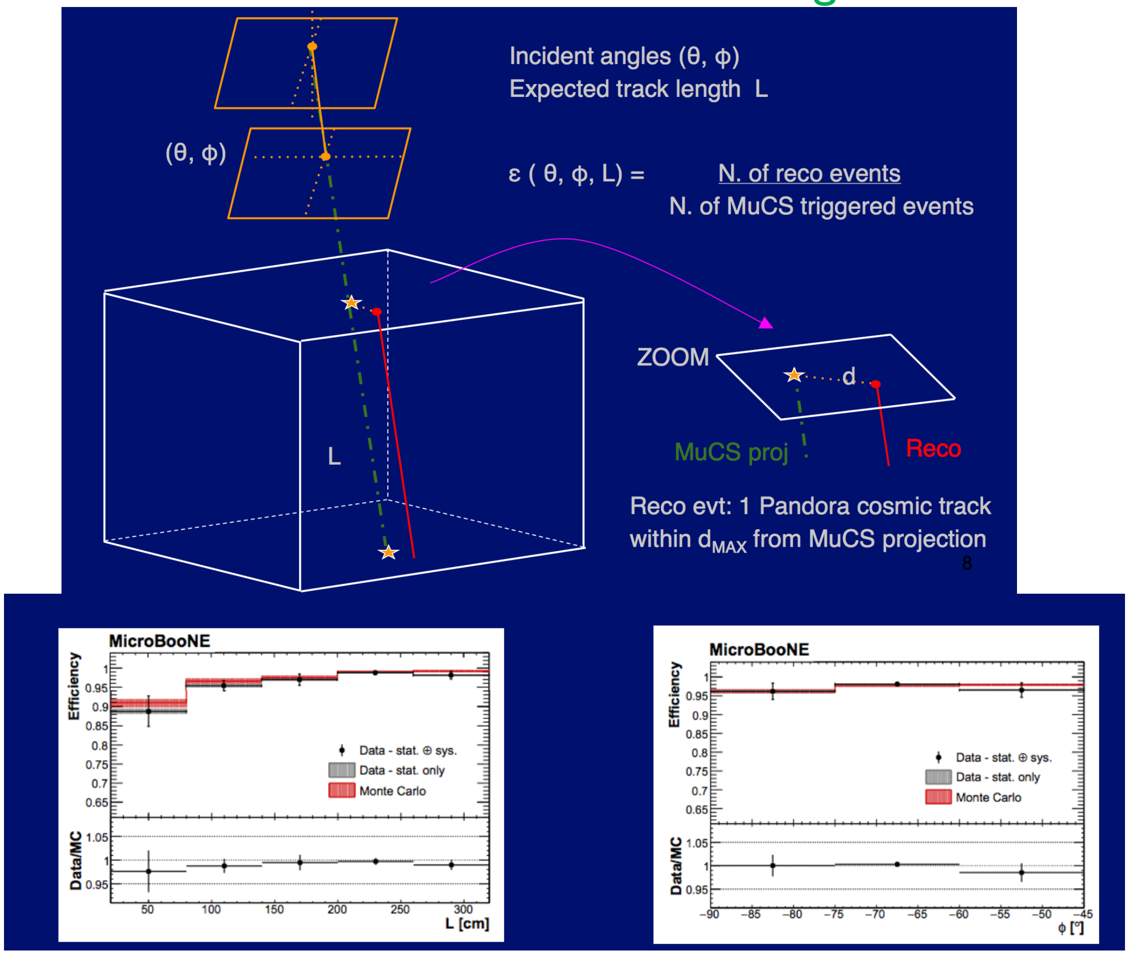
16

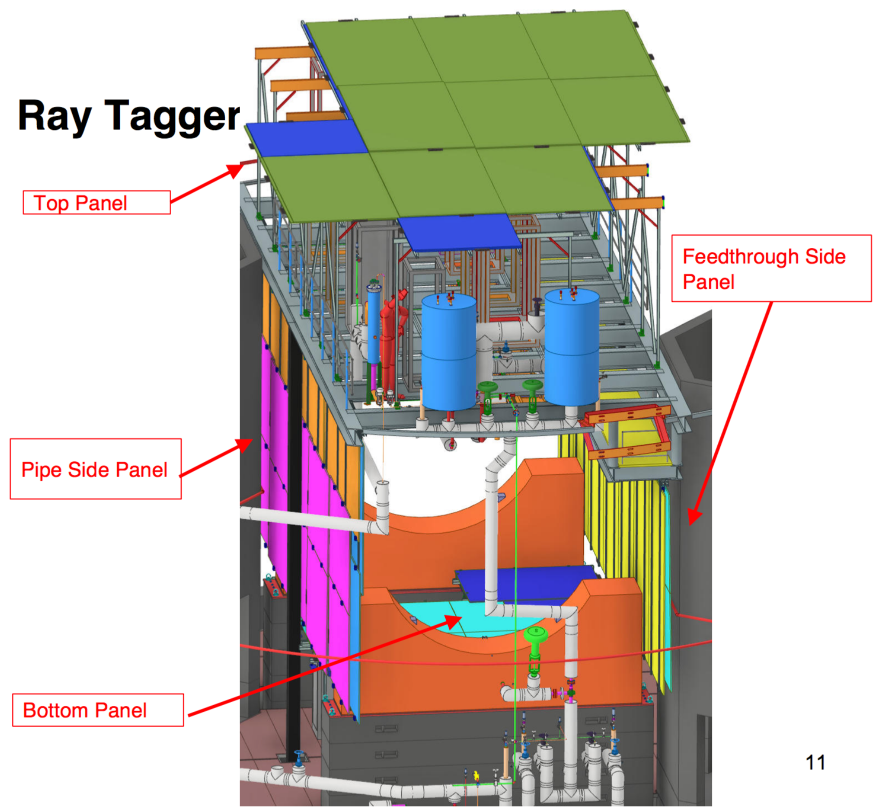
$[\langle E_d\rangle - \langle E_{MC}\rangle / \langle E_{MC}\rangle \sim 6\%]$

Energy Definition	Energy Bias	Energy Resolution
Ionization only	-40%	> 30%
+ tagged photons	-25%	20%

MicroBooNE Cosmic Tracker

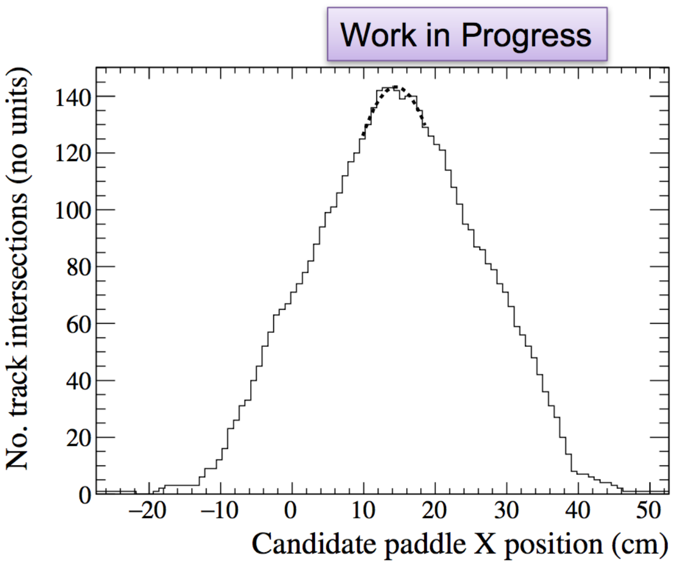
CRT allows measurement test of straight-track reconstruction





DUNE 35 t Analysis Techniques

Despite noise problems and reduced running time, lots of analyses possible

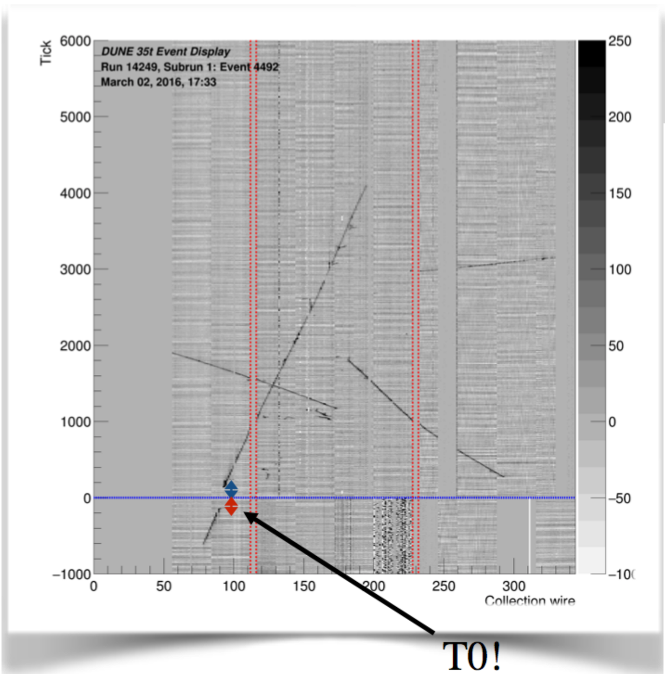


Distribution of expected counter position, used to figure out the alignment of the external cosmic trigger counters relative to the wires.

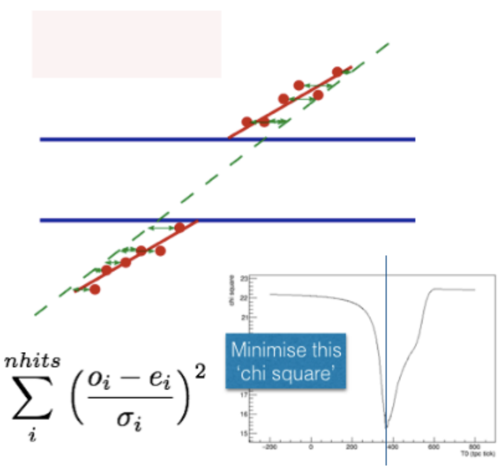
[Lesson learned: SURVEY your counters.]

DUNE 35 t Analysis Techniques

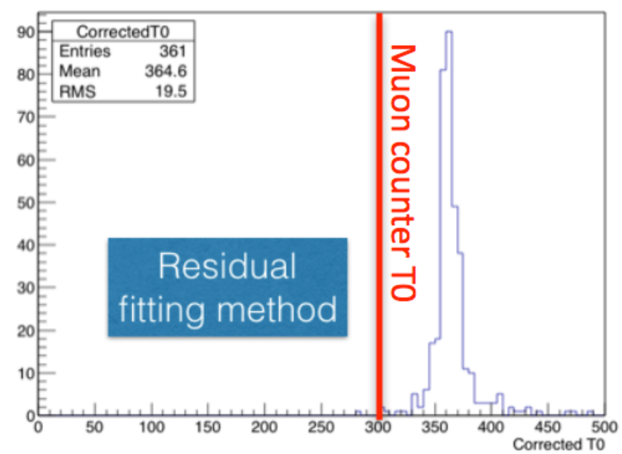
Despite noise problems and reduced running time, lots of analyses possible



First "APA crossing" events in LAr TPC---used to show 32 μs offset in timing between cosmic trigger counters and TPC.

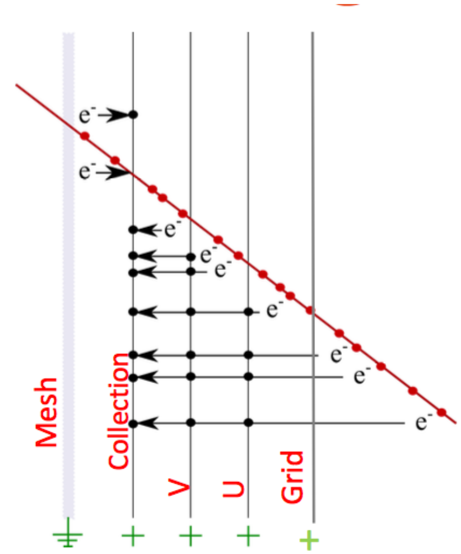


$$\sum_{i}^{nhits}\left(\frac{o_i - e_i}{\sigma_i}\right)^2$$

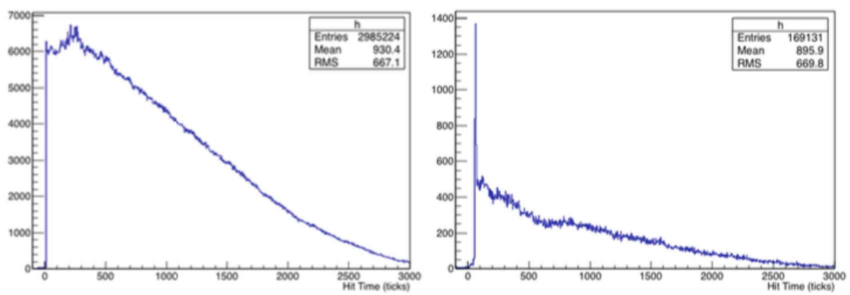


DUNE 35 t Analysis Techniques

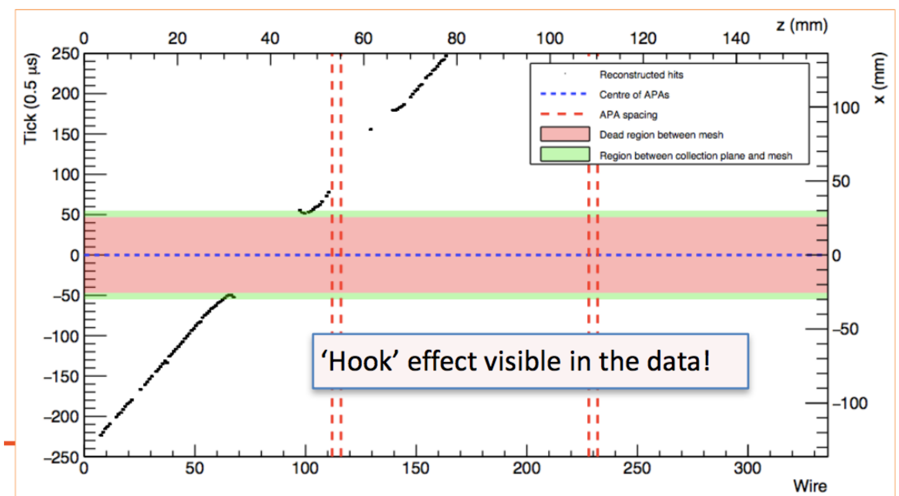
- ”Backdoor” E field sends electrons in opposite direction
- Creates “hooked” tracks near endpoint because times are positive
- Not yet part of simulation



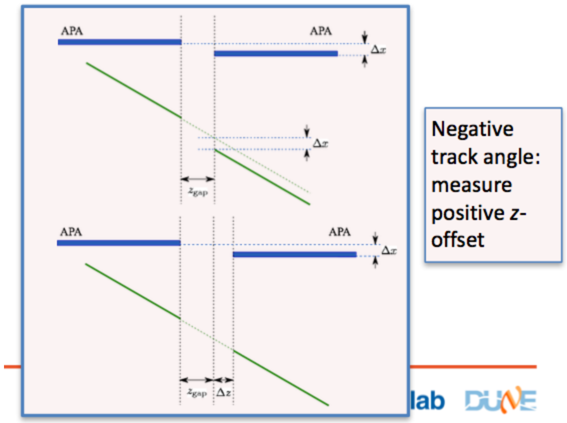
Work in Progress

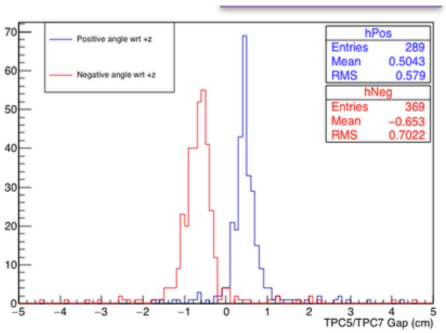


Hit time distributions for simulation (left) and data (right)

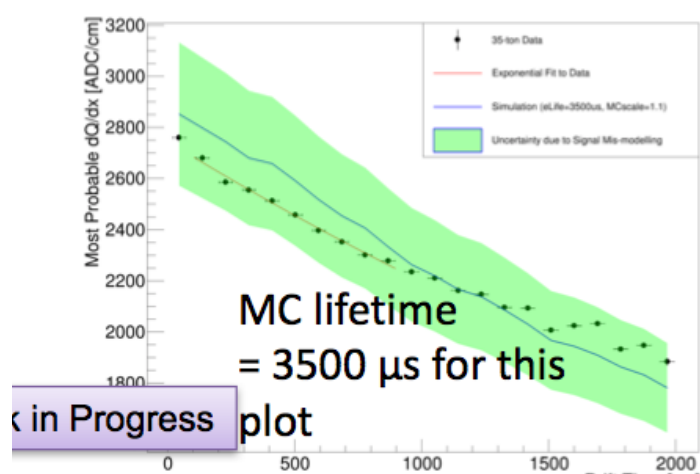


DUNE 35 t Analysis Techniques

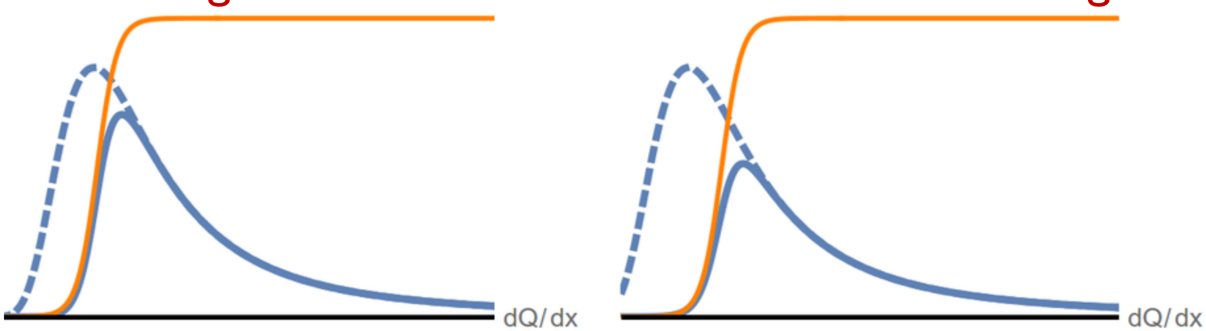




Gap between different wire planes can be measured with enough tracks



Hit-finding threshold biases lifetime to look too long

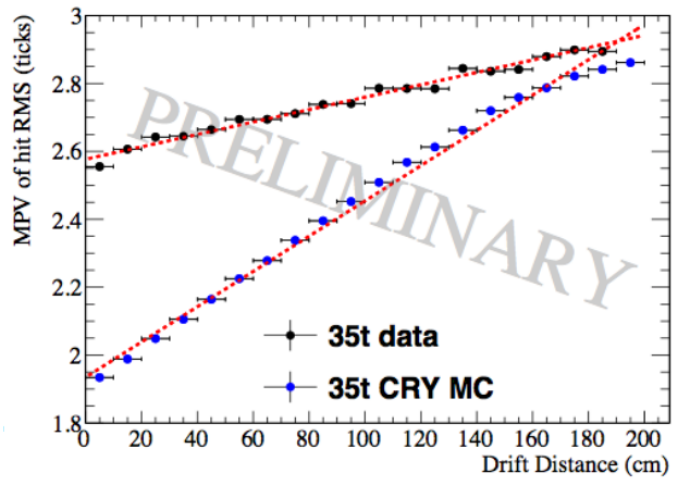


Measured Lifetime = 3683^{+169}_{-160} (stat.) ± 789 (syst.) μs

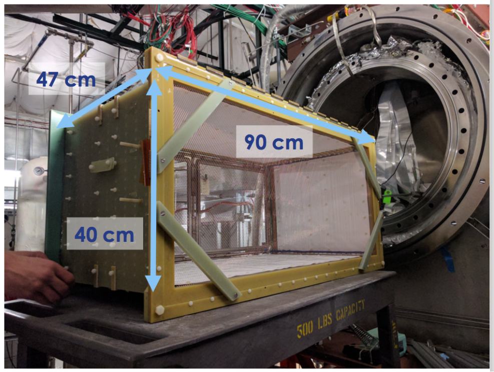
DUNE 35 t Analysis Techniques

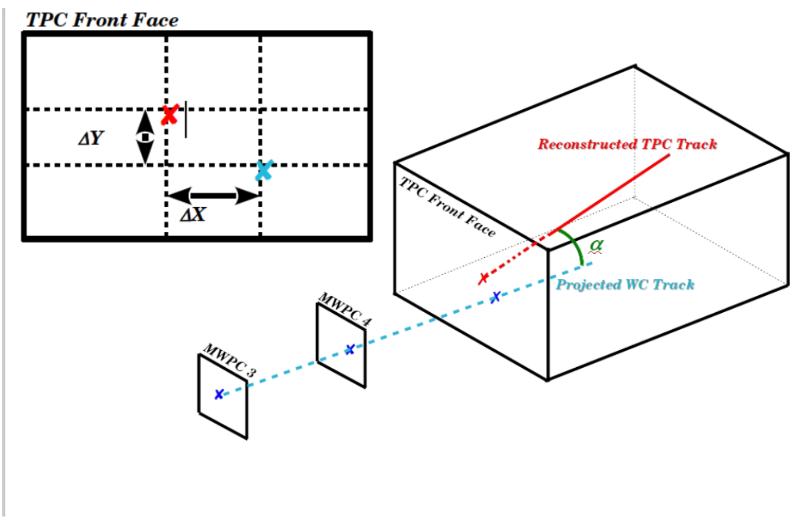
K. Warburton
M. Stancari

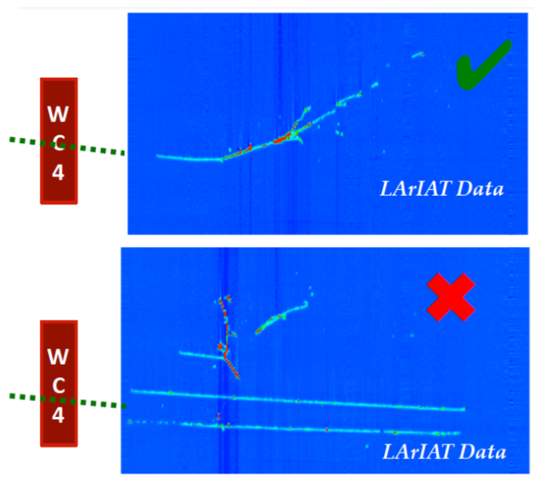
- Longitudinal diffusion can be used to measure distance independent from t

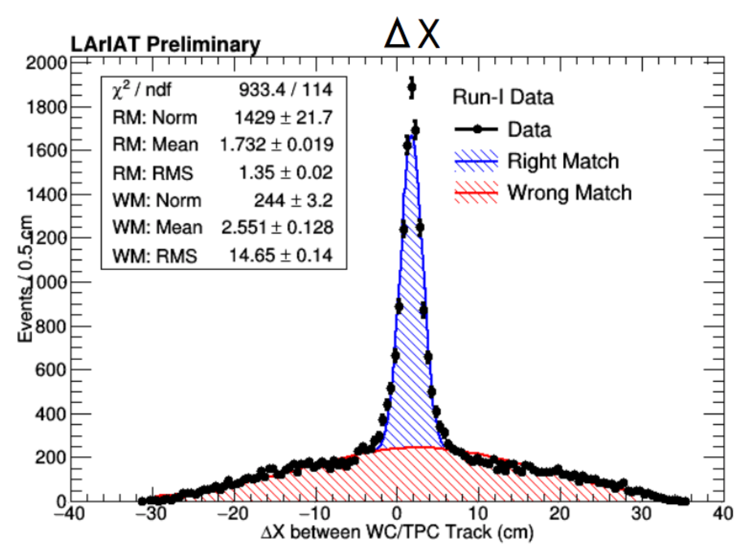


LArIAT and Test Beam Detectors



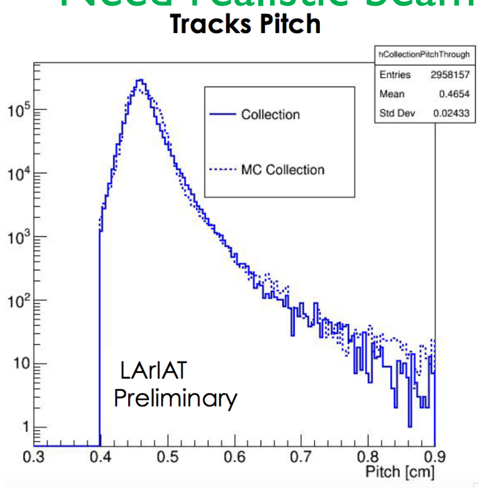


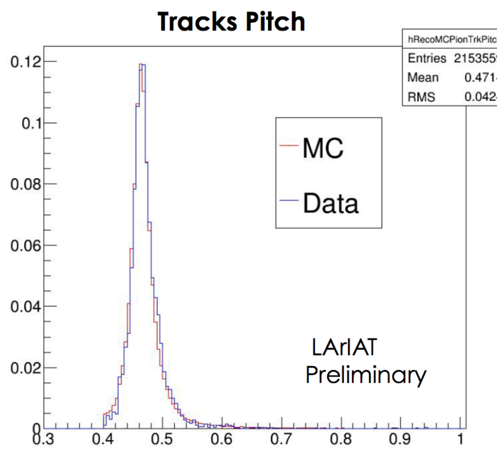




LArIAT and Test Beam Detectors

- Need realistic beam simulation to get track pitch reconstruction correct



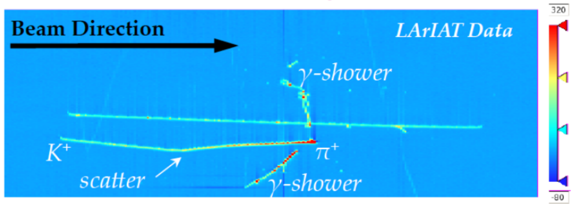


- Need to reduce beam halo! [N.B. ProtoDUNE has a large halo]
- Position and momentum determination as close as possible to TPC
- As little material as possible [ProtoDUNE has a low-mass beam plug]

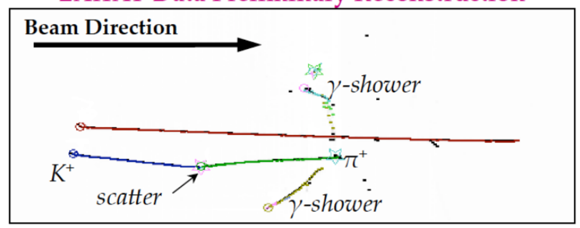
LArIAT and Test Beam Detectors

- Particle ID must use more than just "residual range" curves---topology matters!

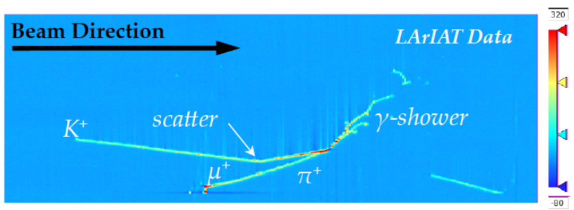
LArIAT Data Preliminary K^+ Candidate



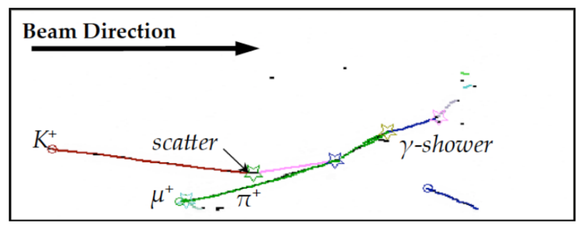
LArIAT Data Preliminary Reconstruction



LArIAT Data Preliminary K^+ Candidate



LArIAT Data Preliminary Reconstruction



- Particle ID must be tested on real data. [DUNE ND may not be LArTPC]

Not Included Here

- Monitoring tools
- 35 t HV test
- LArIAT Photon System
- Deep Learning Techniques

Conclusions

- Suite of FNAL LArTPCs is teaching us many things that will be important for DUNE
- State-of-the-art is still somewhat immature, but hope for milestones very soon
- Critical to see *precision science* from these detectors soon
- protoDUNE will be a critical technical step (e.g. noise environment?)
- SBND will be critical scientific step
- There is not that much time.