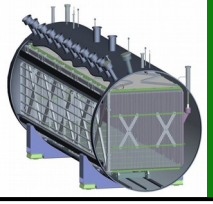


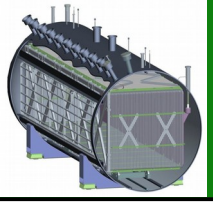
TPC Noise at MicroBooNE and ProtoDUNE-SP

Michael Mooney

Colorado State University

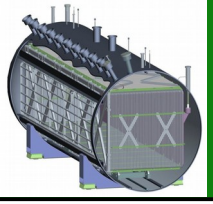
Workshop on Calibration and Reconstruction for LArTPC Detectors

December 10th, 2018



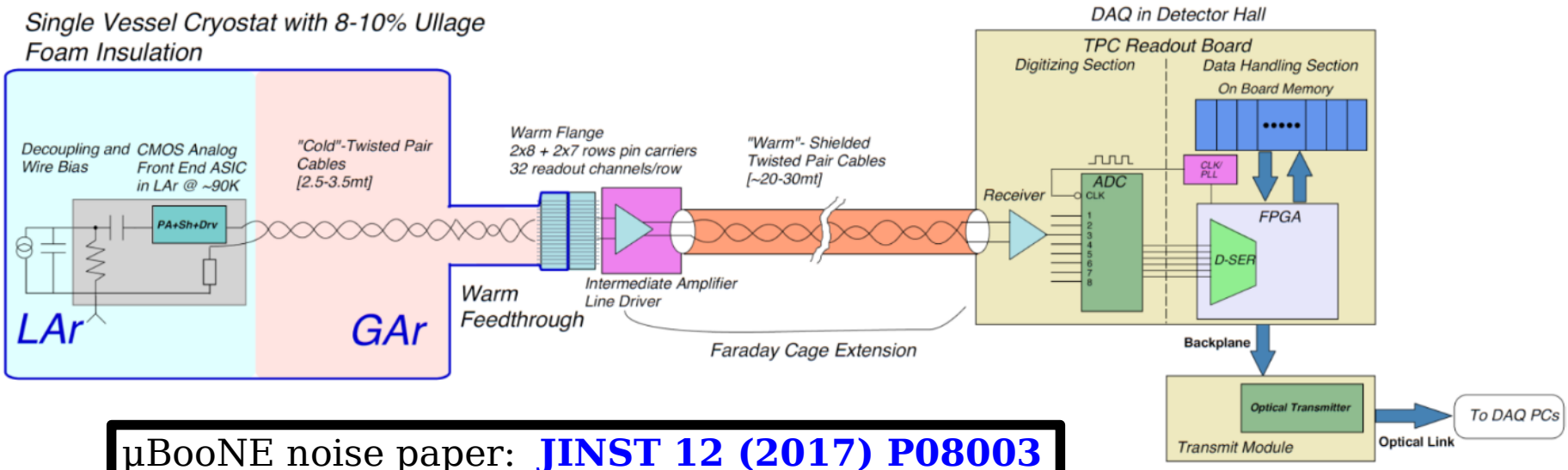
Introduction

- TPC noise levels must be low enough to enable high enough S/N to accomplish physics goals
  - Impacts finding of signals and charge (energy) resolution
  - Relevant for DAQ/triggering (e.g. supernova/solar ν)
- Three large LArTPC detectors previously, or currently, operating: **ICARUS, MicroBooNE, ProtoDUNE-SP**
  - Also ArgoNeuT/LArIAT, 35-ton, 3x1x1, small test setups
- Focus of this talk: MicroBooNE and ProtoDUNE-SP
  - Front-end electronics very similar to SBND/DUNE design
  - Noise @ ICARUS not discussed in depth here, but:
    - New electronics paper: **JINST 13 (2018) P12007**



TPC Noise at MicroBooNE

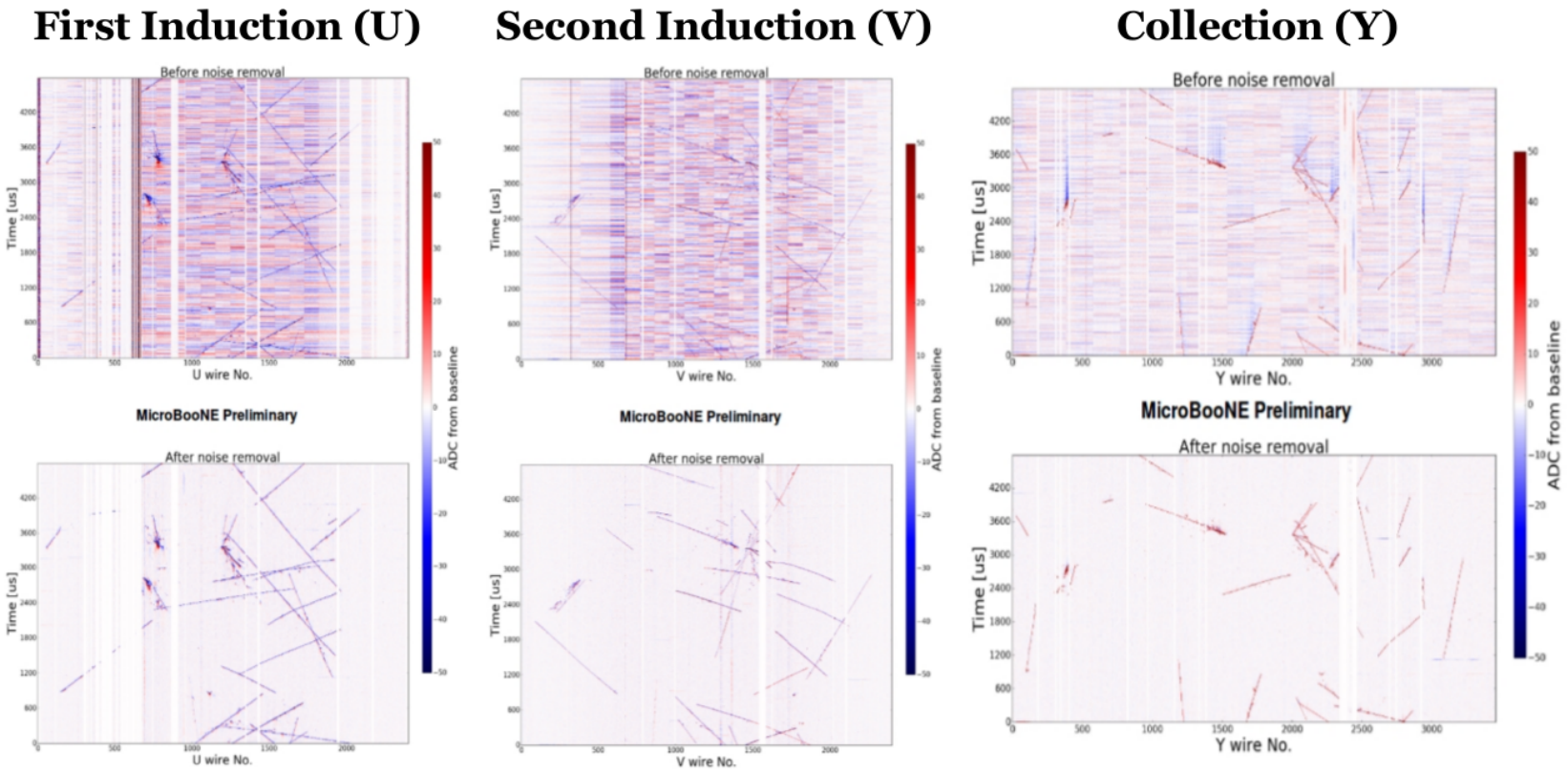
MicroBooNE FE Electronics



µBooNE noise paper: **JINST 12 (2017) P08003**

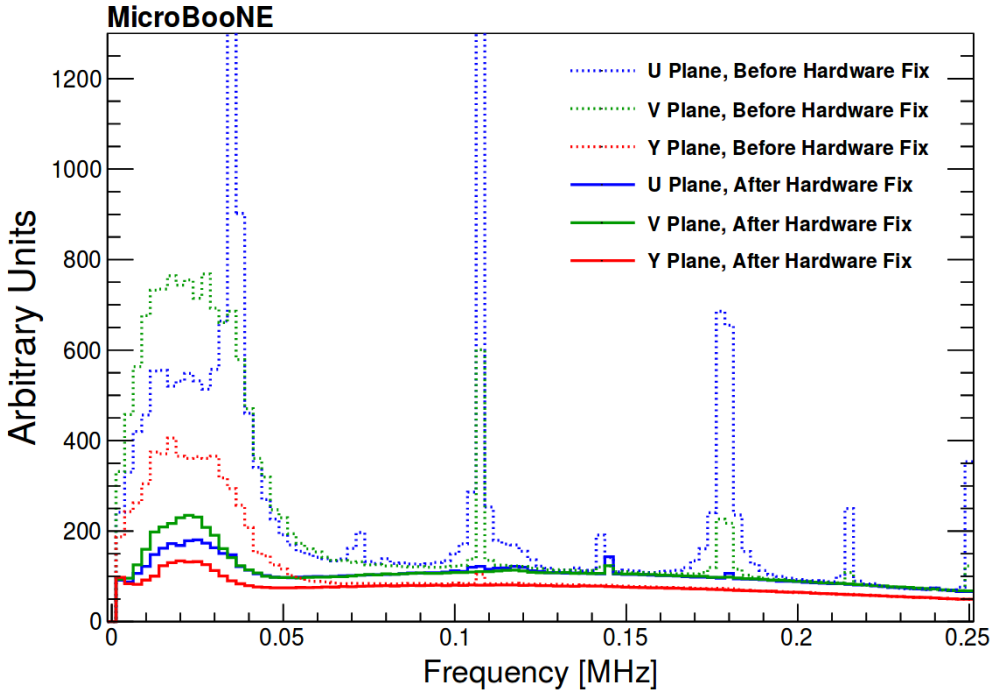
- Front-end (FE) electronics in LAr: BNL LArASIC-v4
  - Lower noise levels in cold; also less input capacitance
  - See Brian Kirby's talk for more information
- ADCs formed outside of LAr: ADC receiver boards attached to FEMs (Nevis Labs) in warm elec. crate

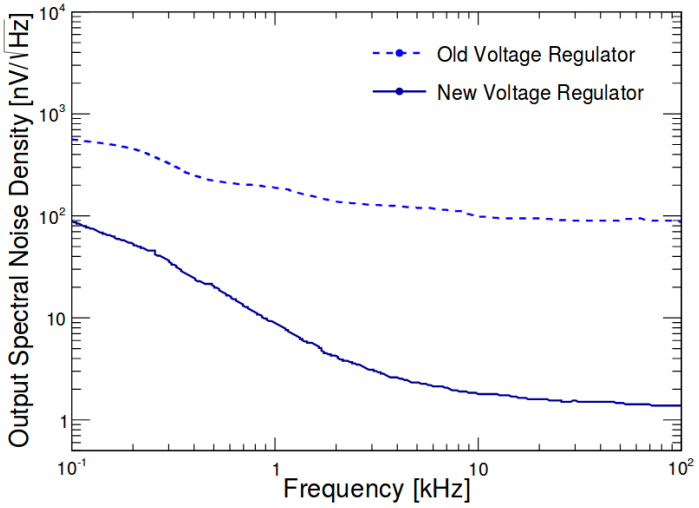
Turning On The Detector

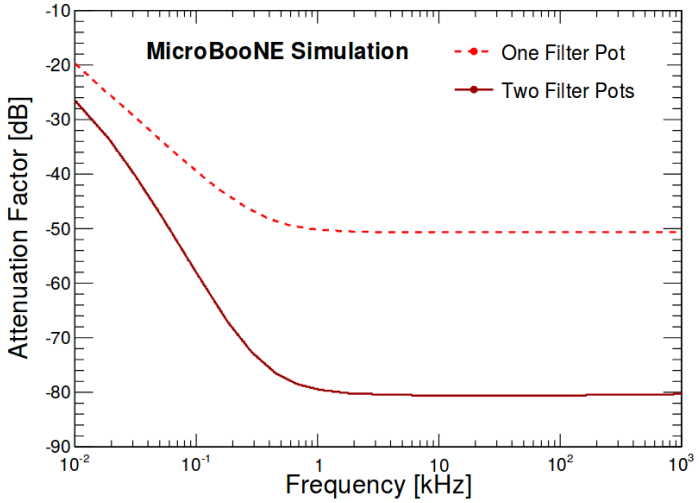


- During commissioning, saw signs of “extrinsic” noise
  - Particularly bad on U/V (induction) planes
- Largely coherent across common electronics channels, so easily removed in software

Extrinsic Noise Sources



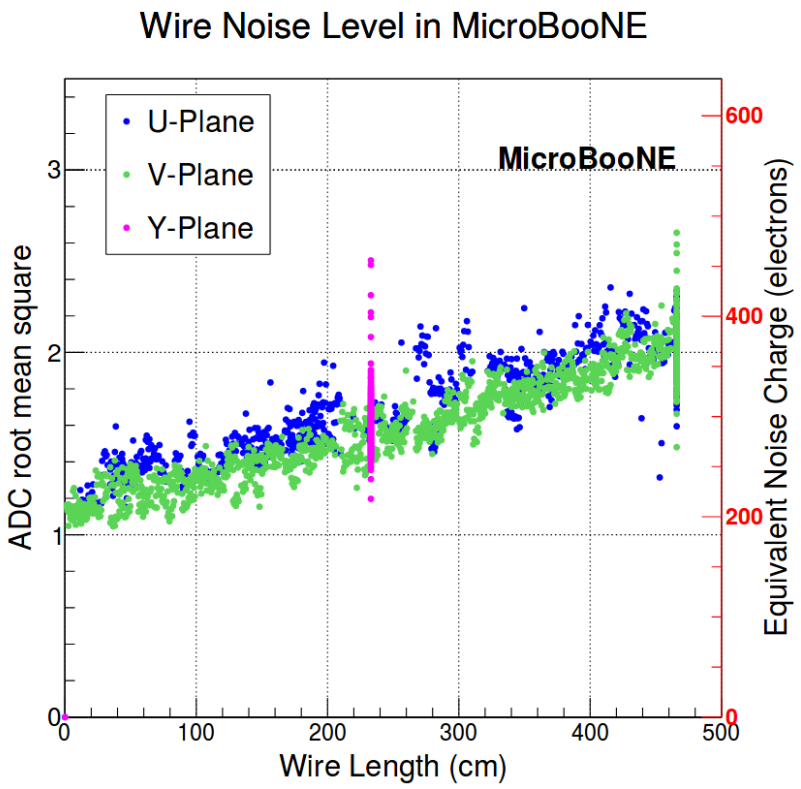




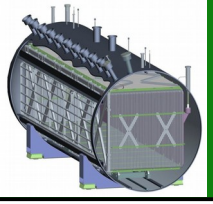
- Primary noise sources/fixes:
  - **Voltage regulator on ASIC LV power** – change regulator on service boards (warm side of FT)
  - **Cathode HV ripple** – add second filter pot

Final Noise Levels

Waveform Type	U Plane ENC	V Plane ENC	Y Plane ENC
Before Hardware Fix	1570	1340	640
After Hardware Fix	480	490	350
Subsequent Offline Filter	400	380	300

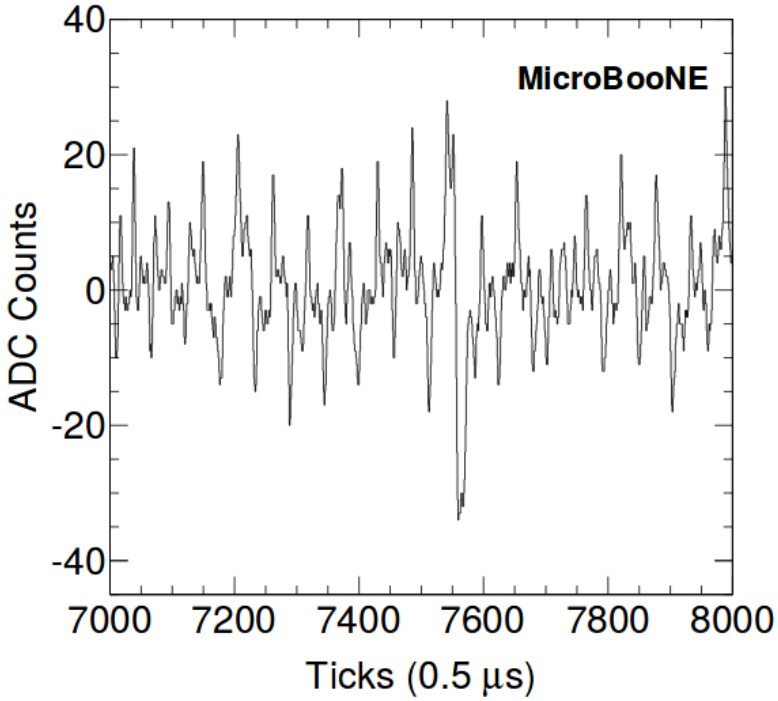


- After hardware fixes, noise levels much improved
- Still small amount of residual external noise; filtered out in software
  - Subtract median ADC value across channels on FEMB for each time tick
  - Does it bias extraction of charge from ionization signals? See later slide

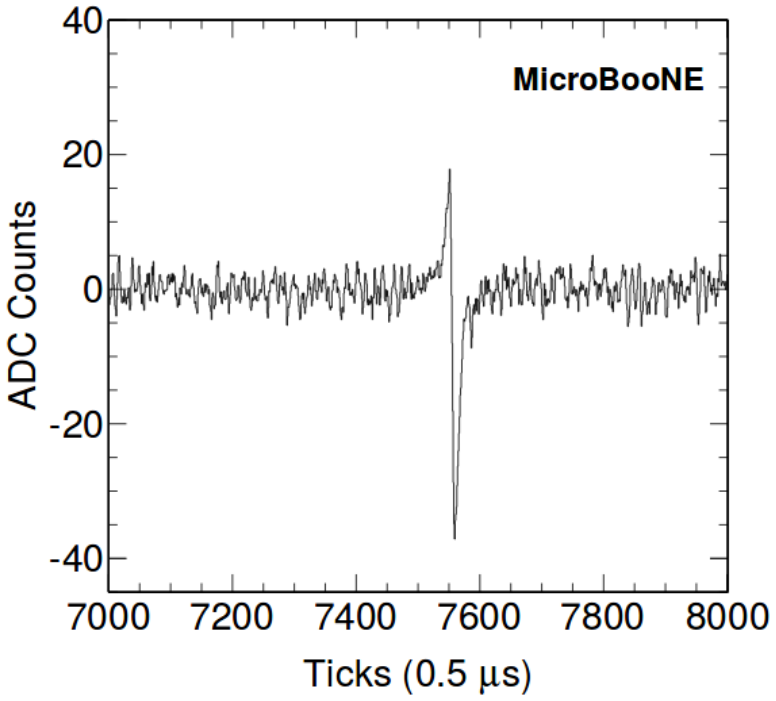


Example Waveforms

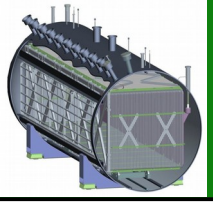
U Plane – No Filtering



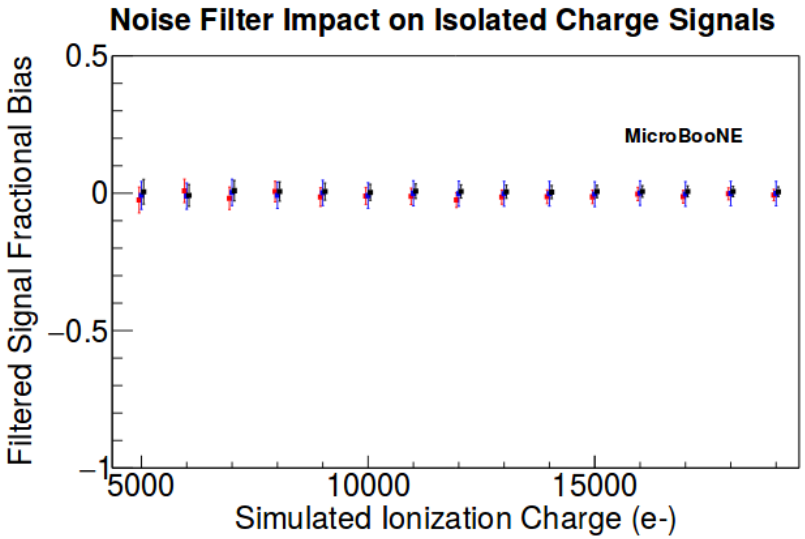
U Plane – With Filtering

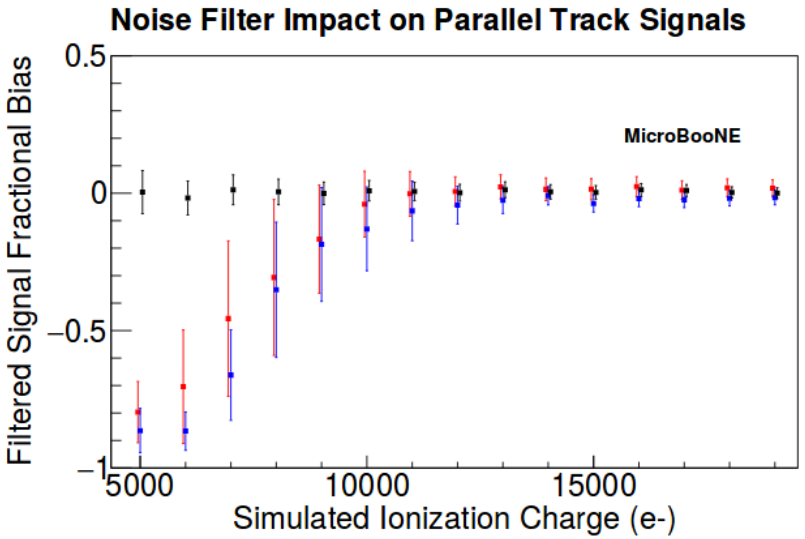


- On U/V planes, difference before and after noise filtering (or hardware fix) is stark!
- Addressing problems in hardware was important accomplishment of µBooNE, looking ahead to DUNE



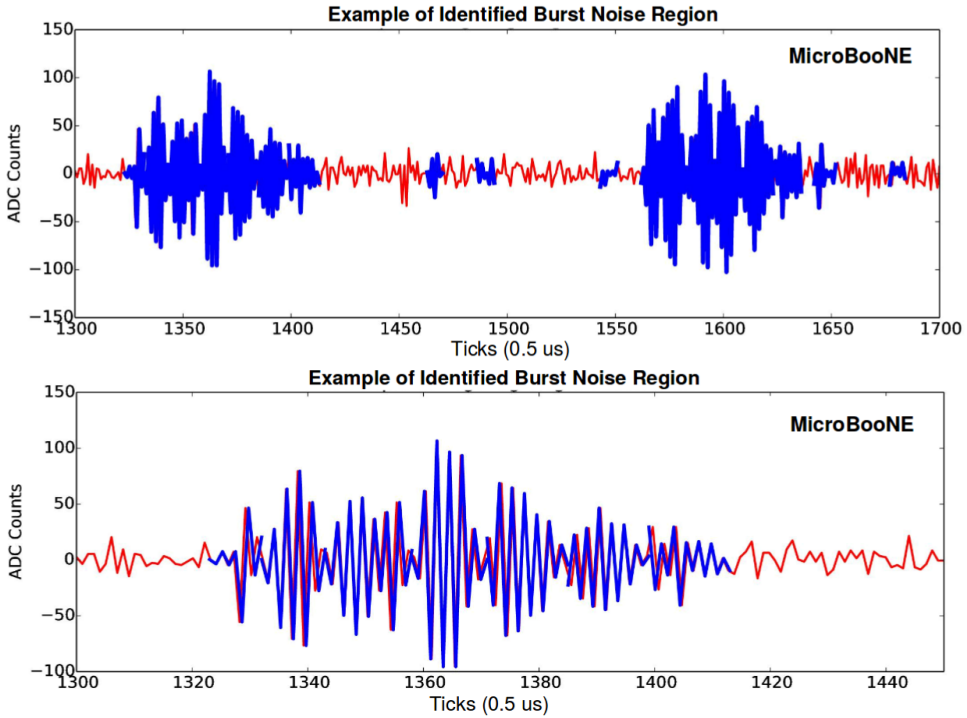
Impact on Signal Charge





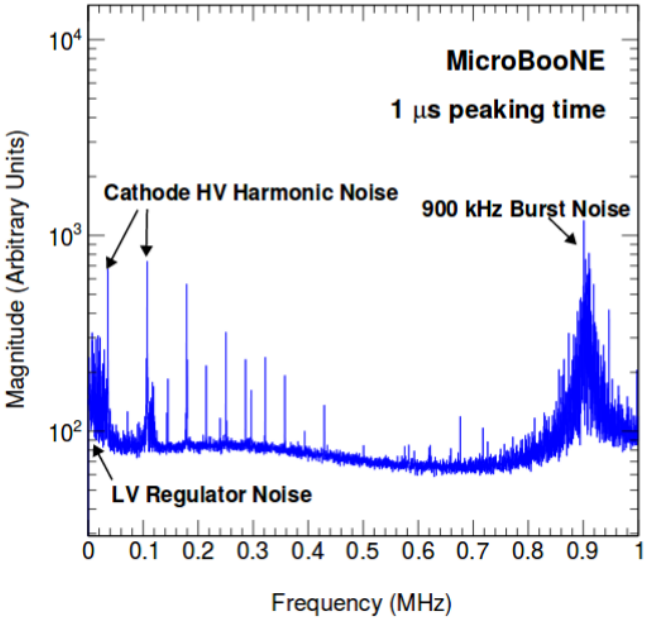
- Software noise filtering technique uses “signal protection” to avoid deleting signals from tracks nearly parallel to anode plane
  - But signal must be “large”: > 5 times ENC
- Isolated signals (e.g. ^{39}Ar) and MIPs (> 16,000 e^-) are safe, but electron lifetime very high at MicroBooNE
  - Problems near cathode if lifetime lower at DUNE?

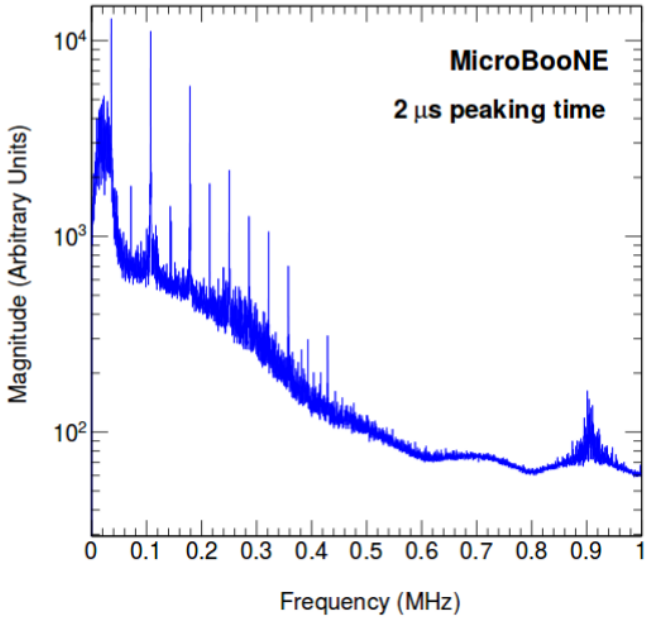
High-Frequency Noise



- Another noise issue: high-frequency pick-up noise
  - Comes in bursts, with frequency content around 900 kHz
  - Low-pass filter in deconvolution **completely removes**
  - Worst at downstream end of detector, and on U/V planes
  - Endearingly (?) called “zig-zag noise” by MicroBooNErs

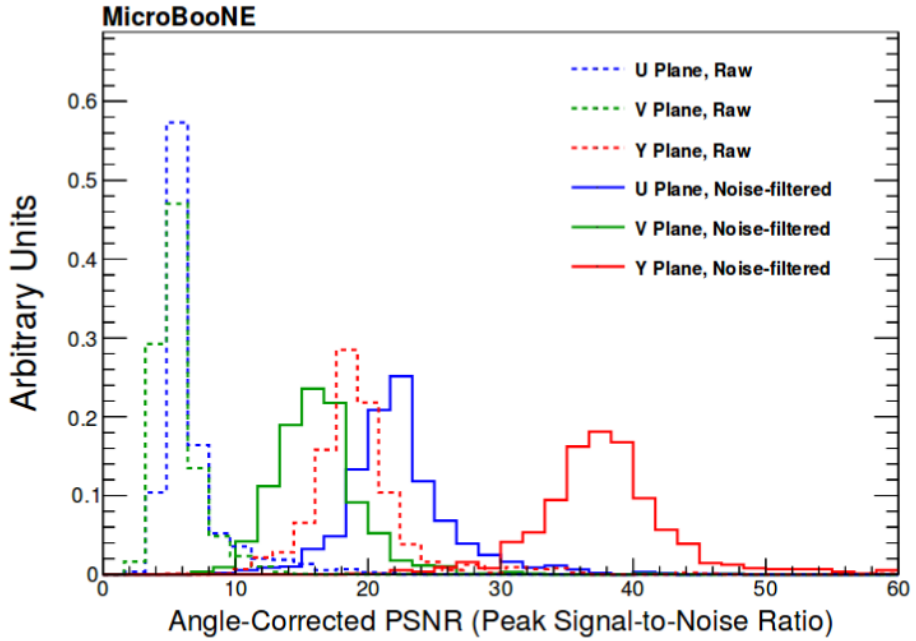
Cause of the Zig-Zags





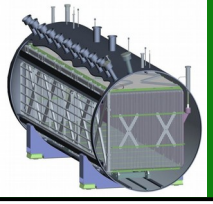
- Increasing shaping time of FE ASICs leads to suppression of noise → noise upstream of ASICs
  - Evidence of noise pick-up on wires
- Largely mitigated by modifying grounding at laser-PMT hardware interlock chassis
  - **Good grounding/shielding extremely important!**

Signal-to-Noise Ratio



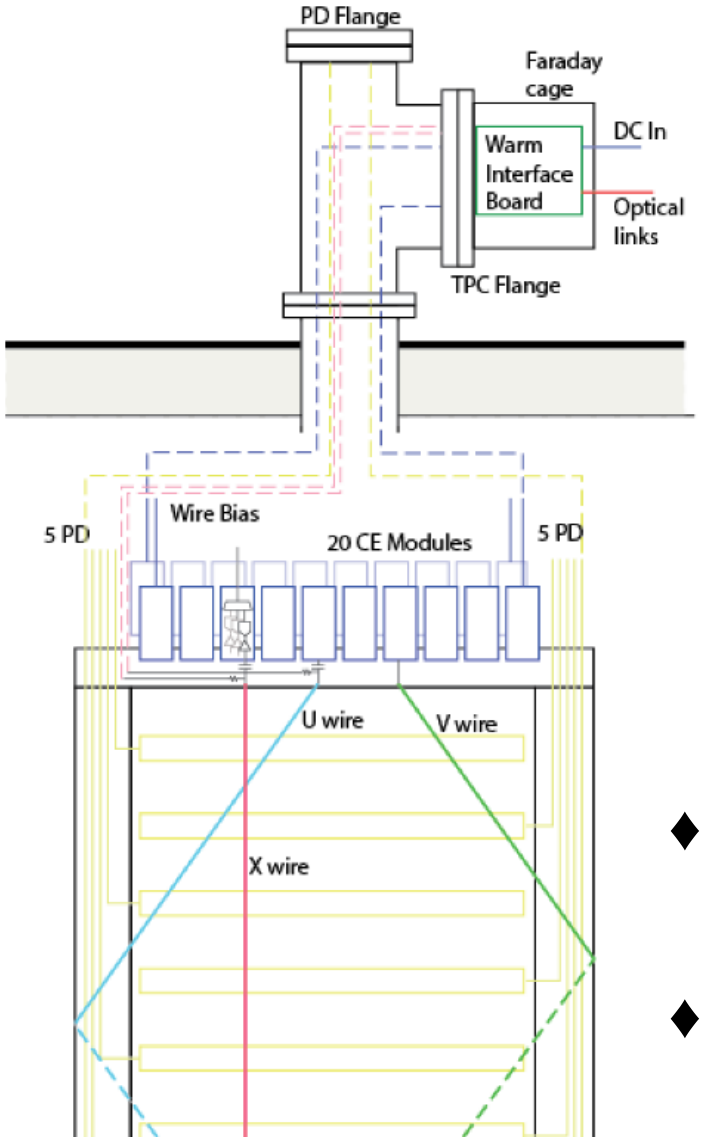
Waveform Type	U Plane PSNR	V Plane PSNR	Y Plane PSNR
Raw Data	6.6	5.7	19.5
After Noise Filtering	22.3	16.2	37.9

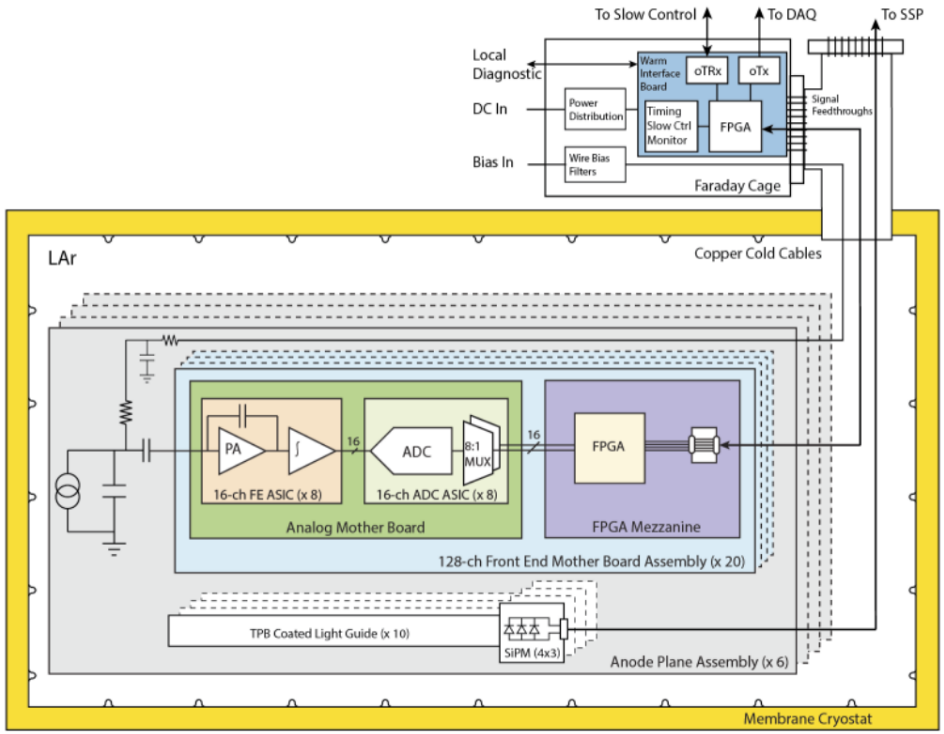
- Peak Signal-to-Noise Ratio (PSNR) very high after software noise filtering: **> 15** for **U/V**, **> 35** for **Y**
  - Includes angular correction to account for track-wire angle
  - Study uses cosmic tracks in data



TPC Noise at ProtoDUNE-SP

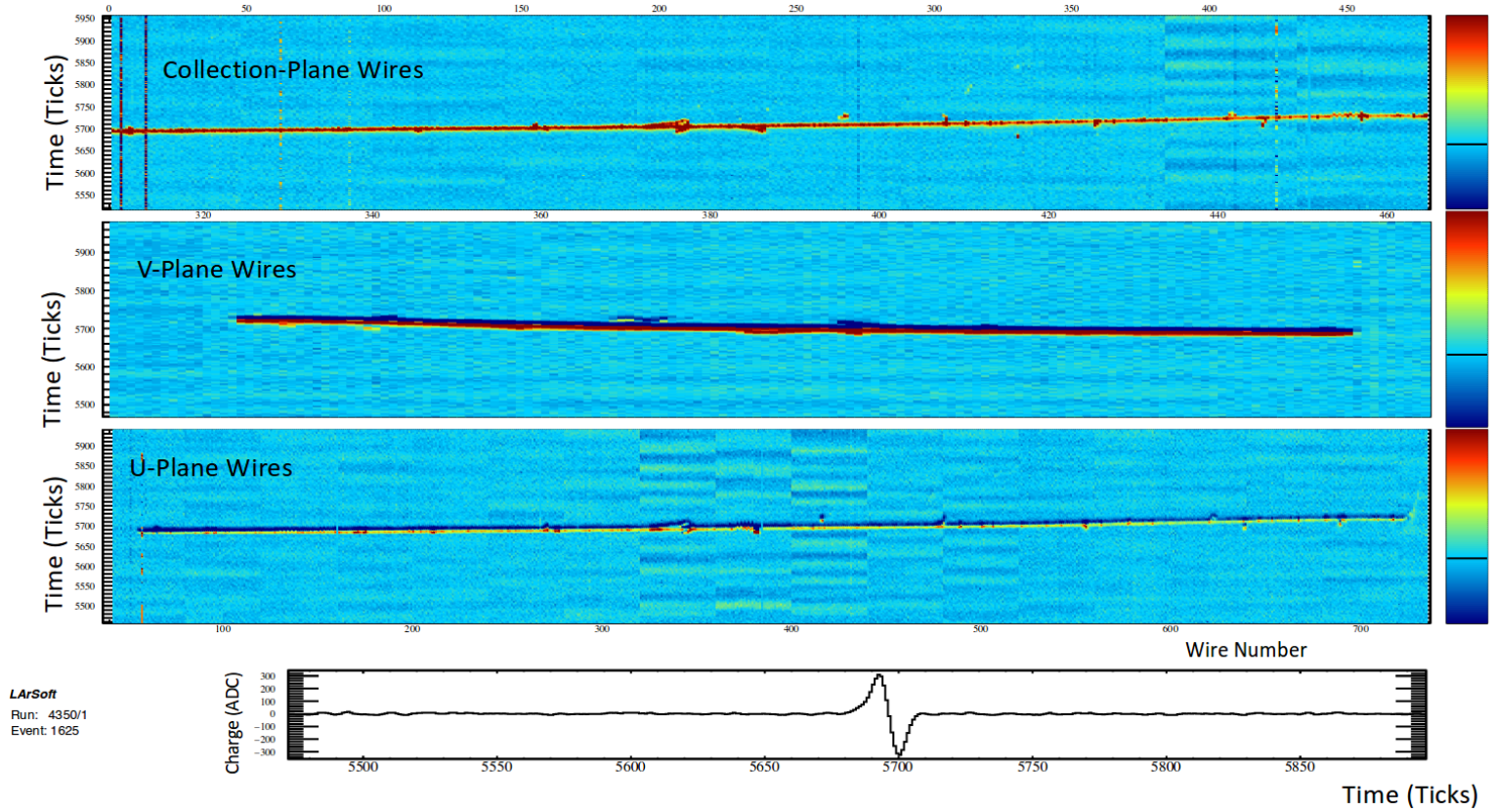
ProtoDUNE-SP FE Electronics





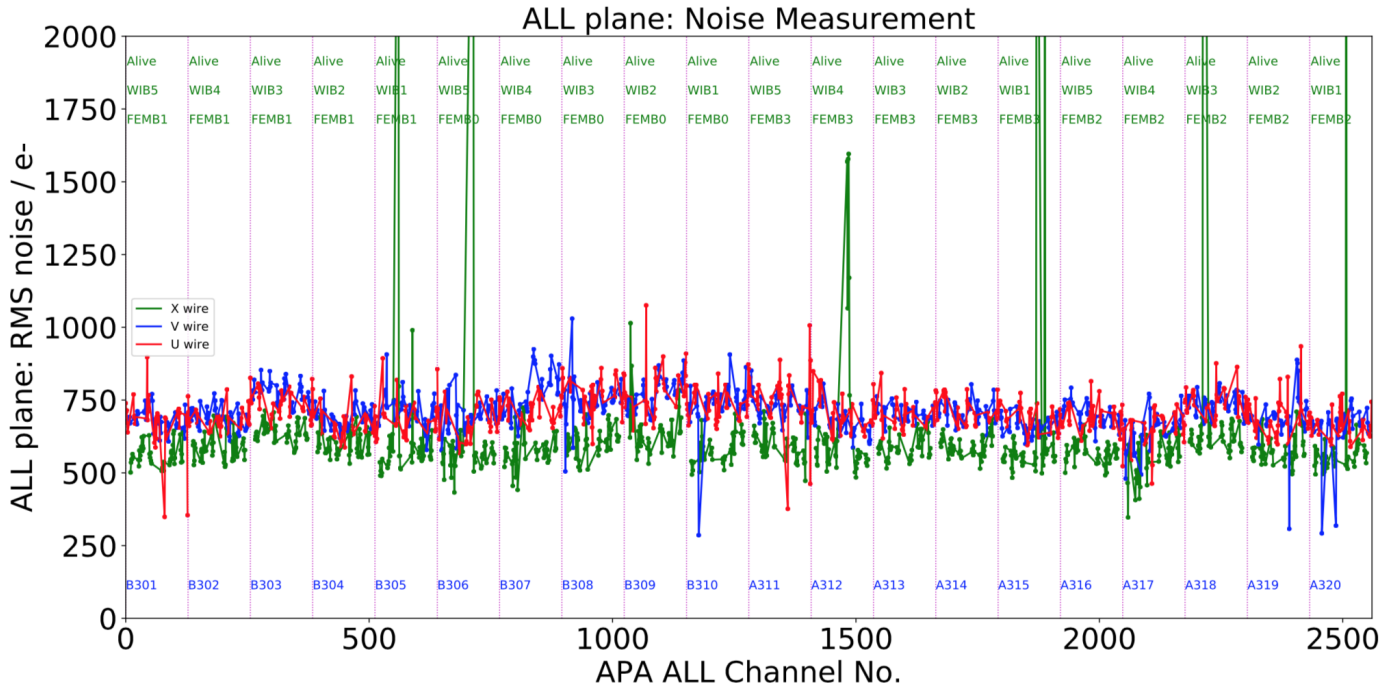
- Similar FE ASIC to MicroBooNE
  - BNL LArASIC-v7 (v4 → v7)
- ProtoDUNE-SP also has **ADCs in LAr** (ADC ASIC on FEMB)

Data Event Display



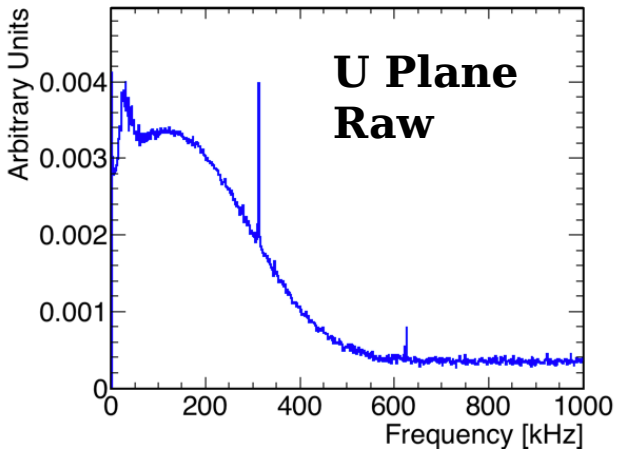
- Without any software noise filtering, event display looks very clean!
- Some very mild coherent noise, but manageable

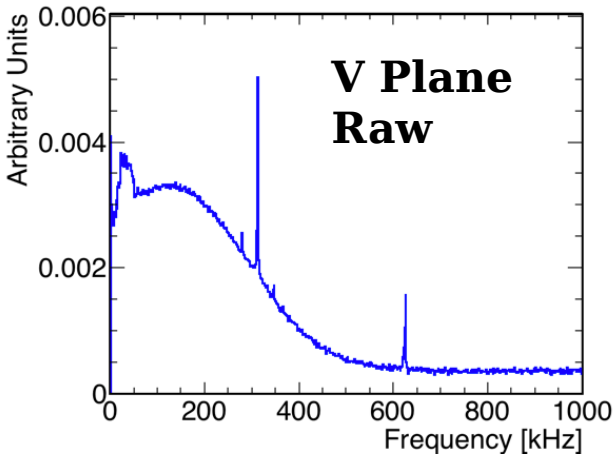
Noise Levels in LAr

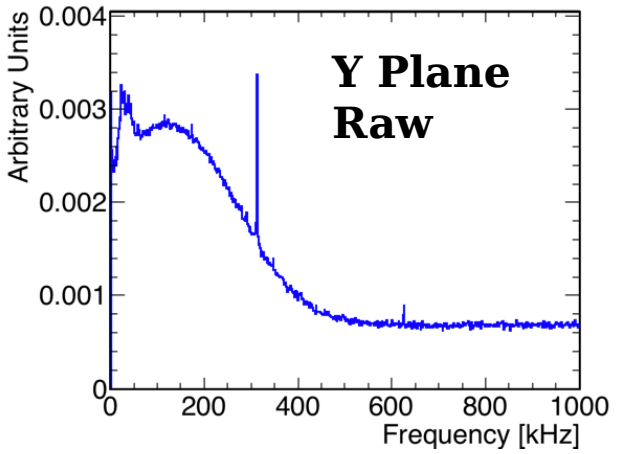


- Without any software noise filtering, noise levels roughly 600 (700) e^- ENC for Y (U/V) plane
  - Shown above: APA 3 (similar for other APAs)
- Expectations: 500 (600) e^- ENC for Y (U/V) plane
  - First measurements very close to expectations

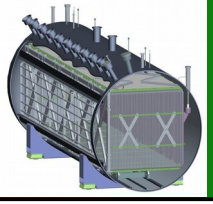
Raw Noise Spectra



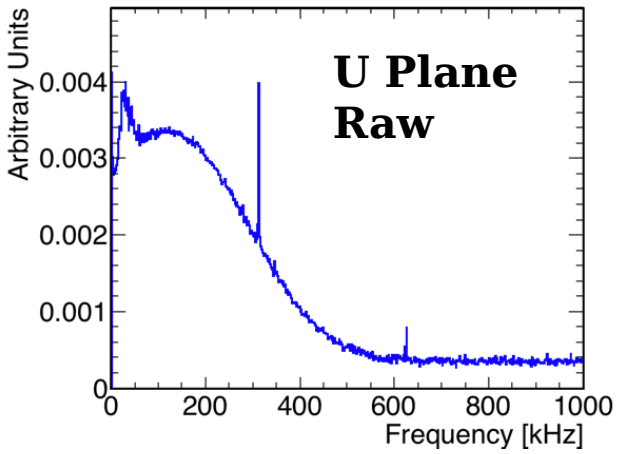


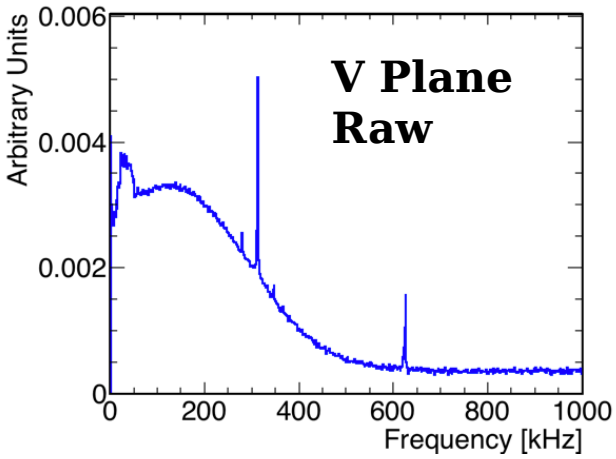


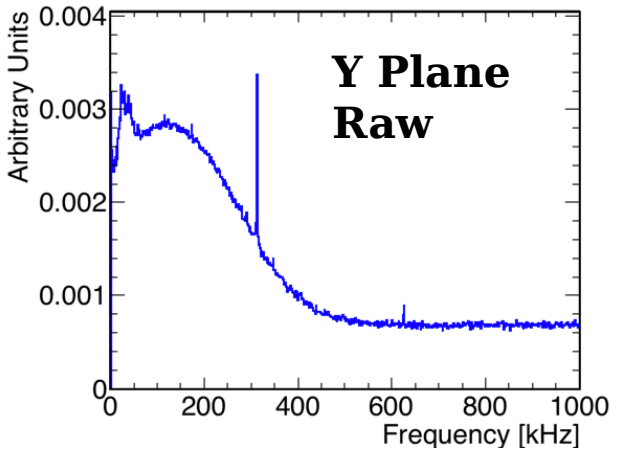
- Noise spectra largely free of extrinsic noise
  - Small low-frequency bump, similar to MicroBooNE LV regulator issue (lower magnitude than at MicroBooNE)
  - Small spikes at higher frequencies are still being investigated
  - Differences between planes in white noise contribution at higher frequencies also still being understood
- Though little extrinsic noise, try software noise filter

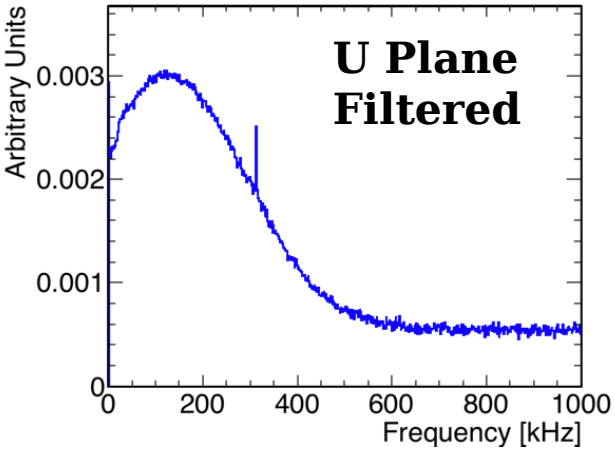


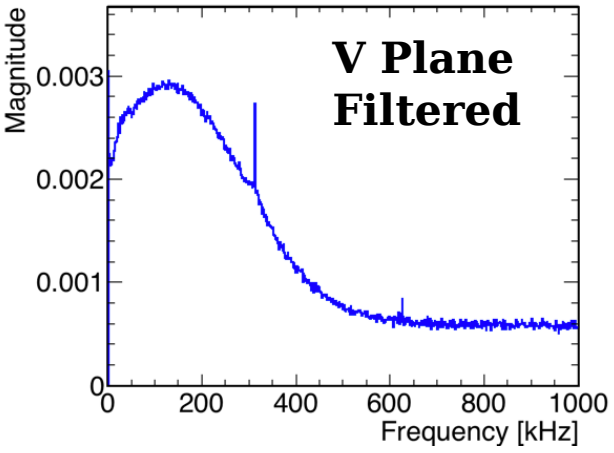
Noise Filtering Results

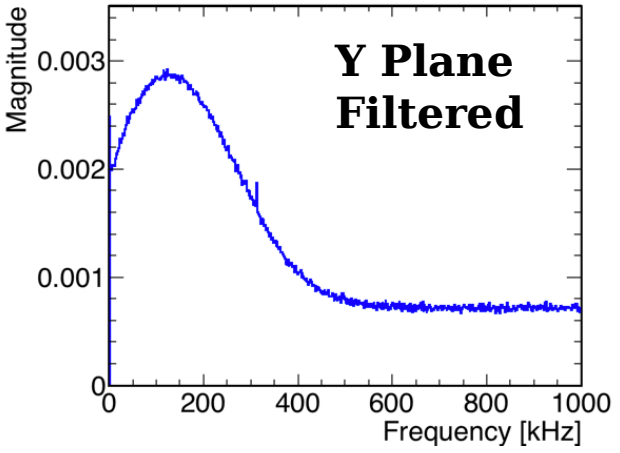






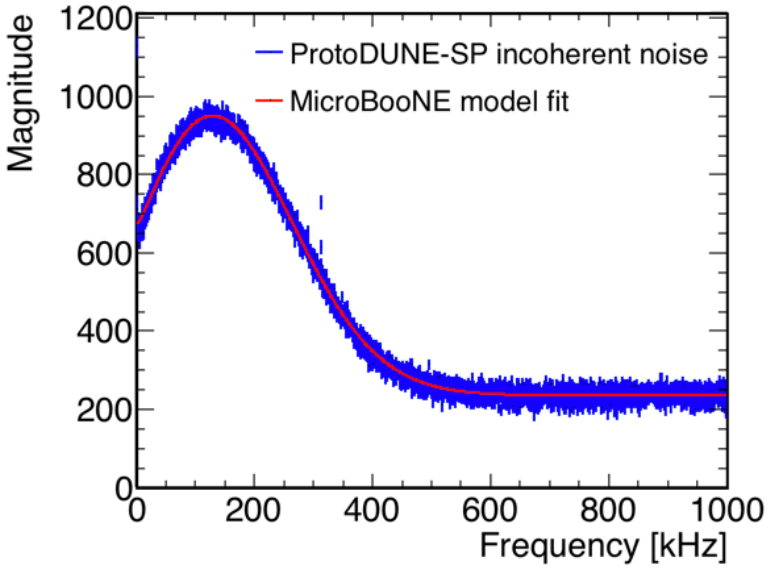




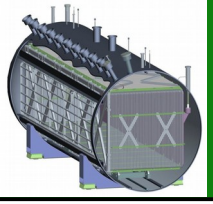


- Most of extrinsic noise easily filtered out in software

Modeling Noise



- After software noise filtering, noise spectrum in ProtoDUNE-SP data and MicroBooNE data very similar
- Plan: use data-driven spectrum and simulated pick-up noise to study impact on DUNE CP violation measurement
- More information on LArTPC noise modeling/simulation:
  - μBooNE noise paper: **JINST 12 (2017) P08003**
  - μBooNE signal proc. paper #1: **JINST 13 (2018) P07006**

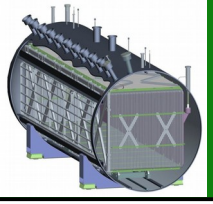


Summary

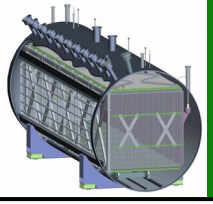
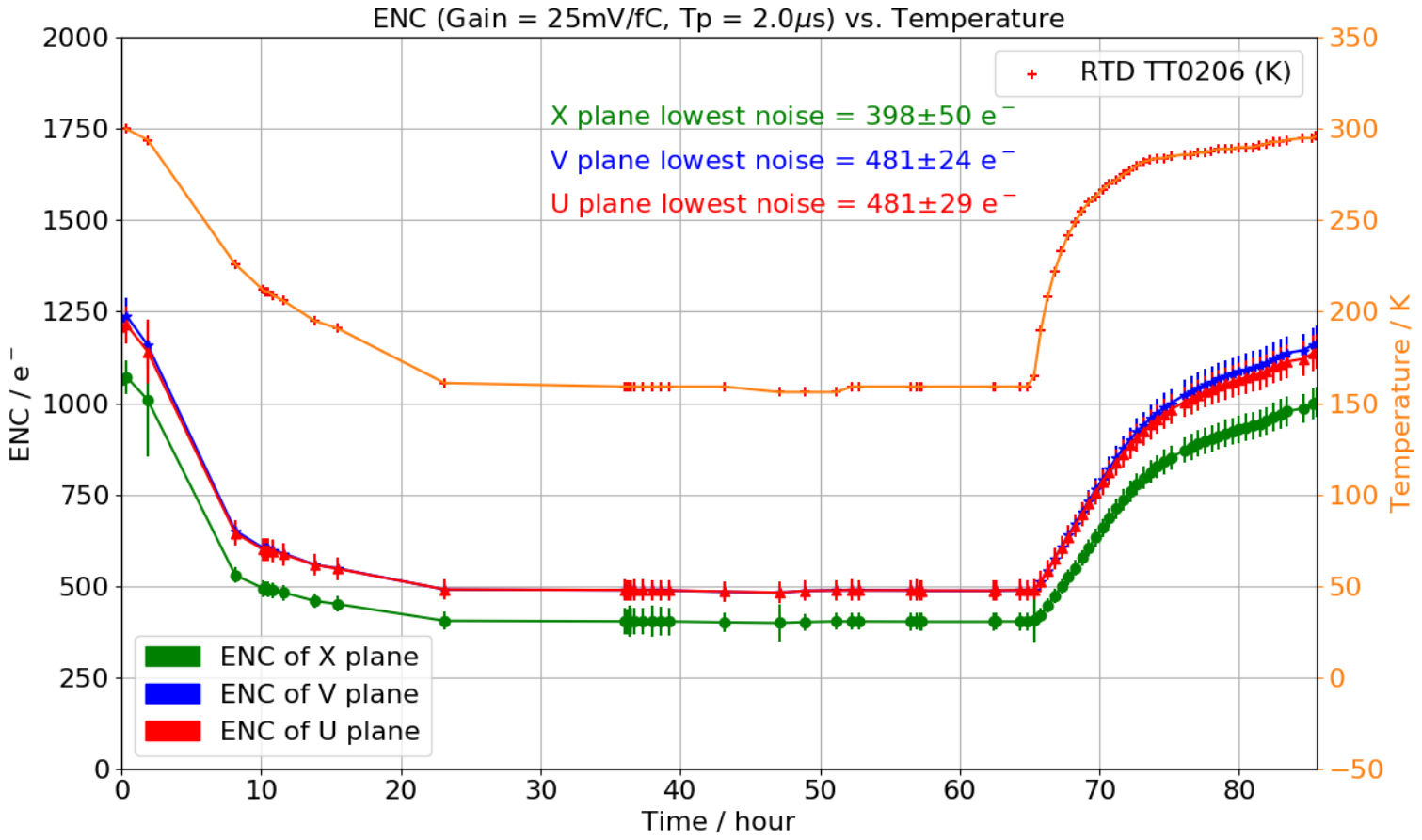
- MicroBooNE and ProtoDUNE-SP paving the way for understanding TPC noise at SBN/DUNE
  - Also ICARUS (not reported in these slides), which uses different front-end electronics (not in LAr)
- MicroBooNE observed a number of noise issues, addressed in hardware and software
  - Informed grounding, FE electronics designs for SBN/DUNE
- ProtoDUNE-SP observes very little extrinsic noise
  - Stay tuned for more results on electronics performance

Summary of Expected Intrinsic Noise Levels at Different LArTPC Detectors

Experiment	Noise (ENC)	FE in LAr?
MicroBooNE	300-400 e^-	yes
SBND	400-500 e^-	yes
ICARUS	1200-1500 e^-	no
DUNE	500-600 e^-	yes



BACKUP SLIDES



Noise in PD-SP Cold Box