LArTPC Cold Electronics Response Calibration in MicroBooNE and protoDUNE

LArTPC Calibration Workshop

Brian Kirby, Brookhaven National Lab

Dec 10, 2018

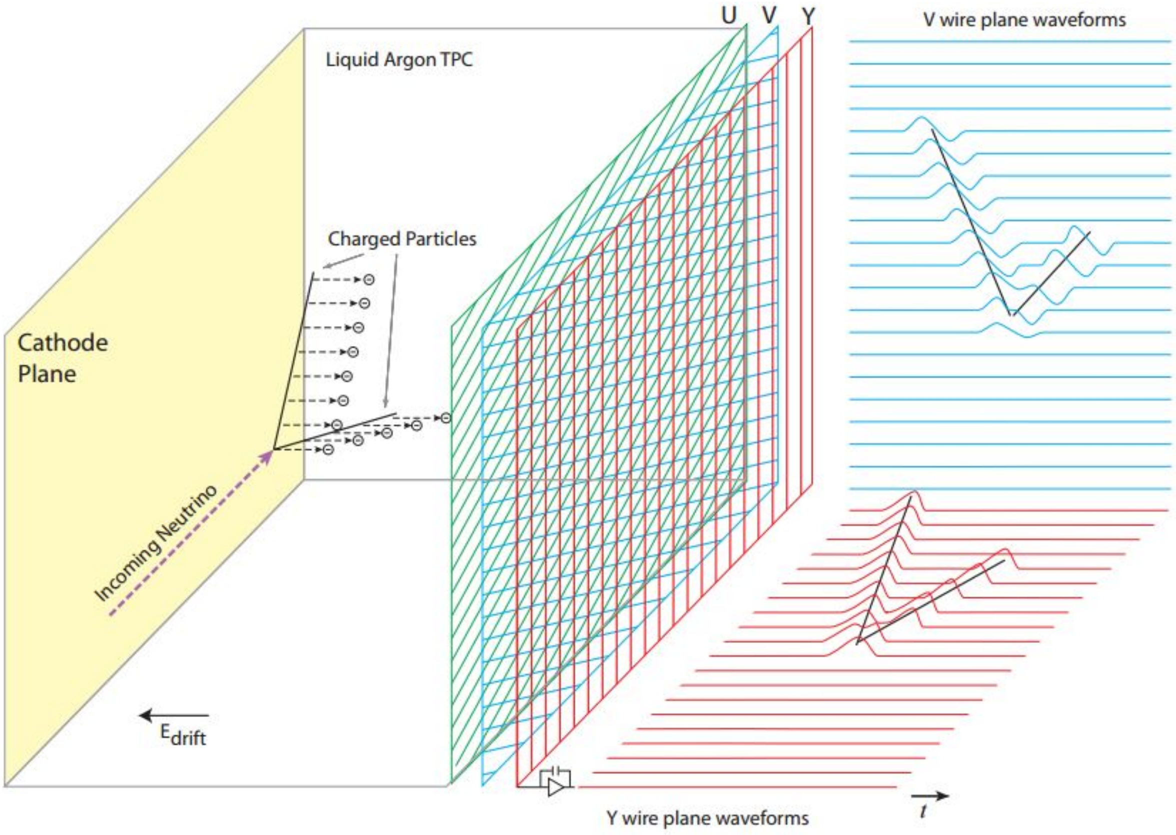
BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

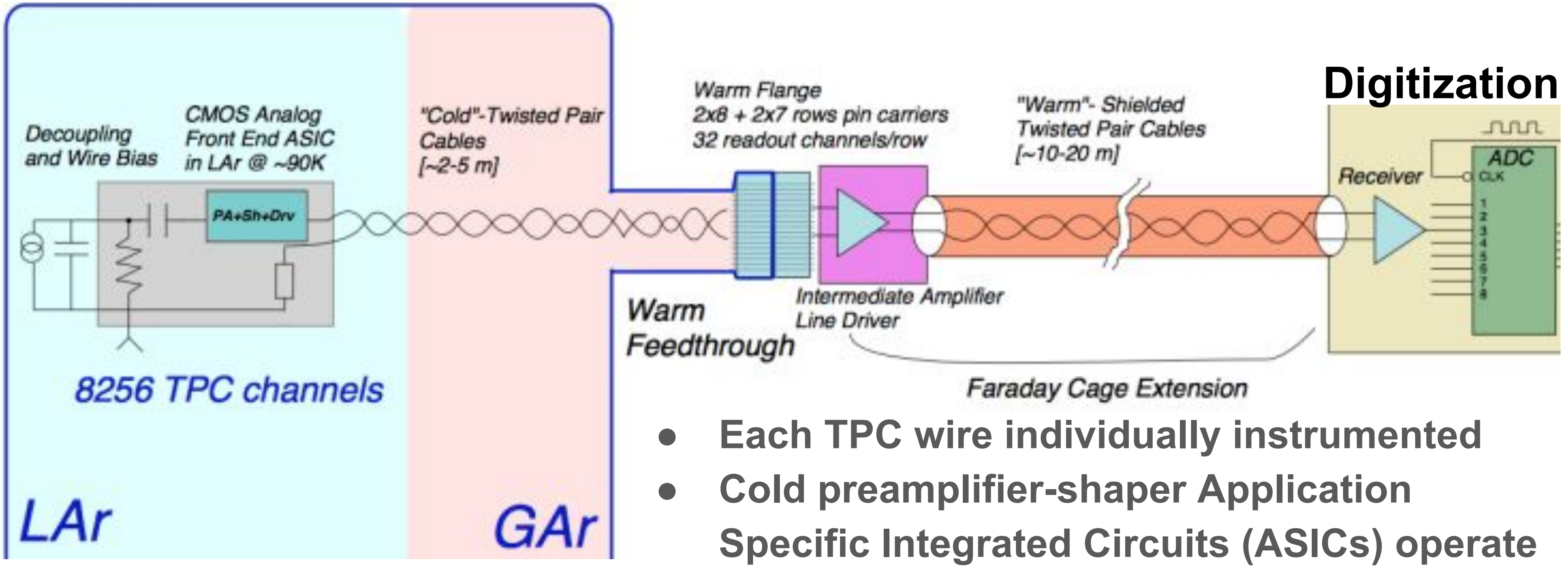
- What are LArTPC cold electronics and their response?
- How to calibrate cold electronics response with charge injection?
- MicroBooNE’s cold electronics calibration system + results
- protoDUNE cold electronics calibration system
- Cold electronics calibration and production testing
- Summary

LArTPC Wire Charge Signals and Cold Electronics



- Ionization charge induce signals on LArTPC wires
- Wire signals will be the convolution of the LArTPC field response AND **electronics response**
- Will focus on LArTPCs using **cold electronics:** MicroBooNE and protoDUNE

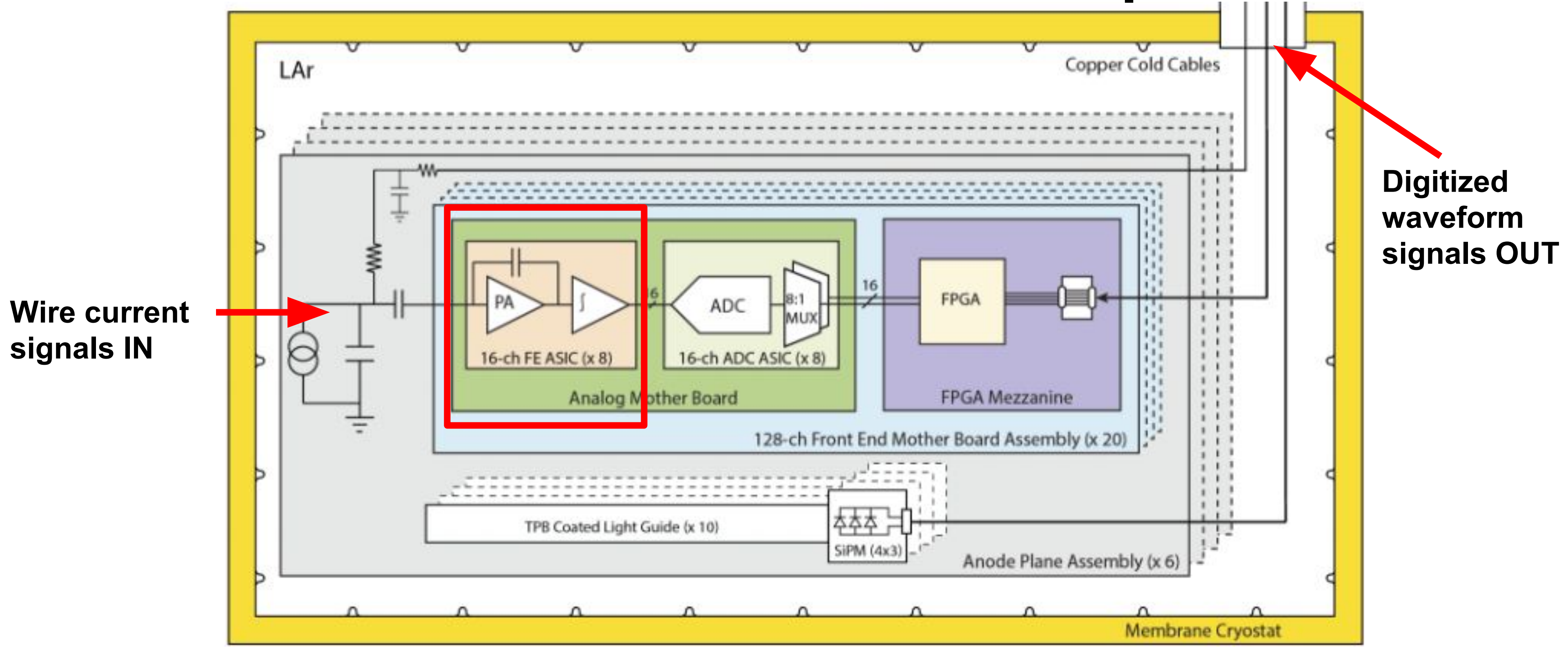
What are LArTPC Cold Electronics? MicroBooNE



Cryostat
Wires + Cold Electronics

- Each TPC wire individually instrumented
- Cold preamplifier-shaper Application Specific Integrated Circuits (ASICs) operate inside the cryostat at LAr temperature
- Cold electronics simplify cryostat design and optimize LArTPC performance

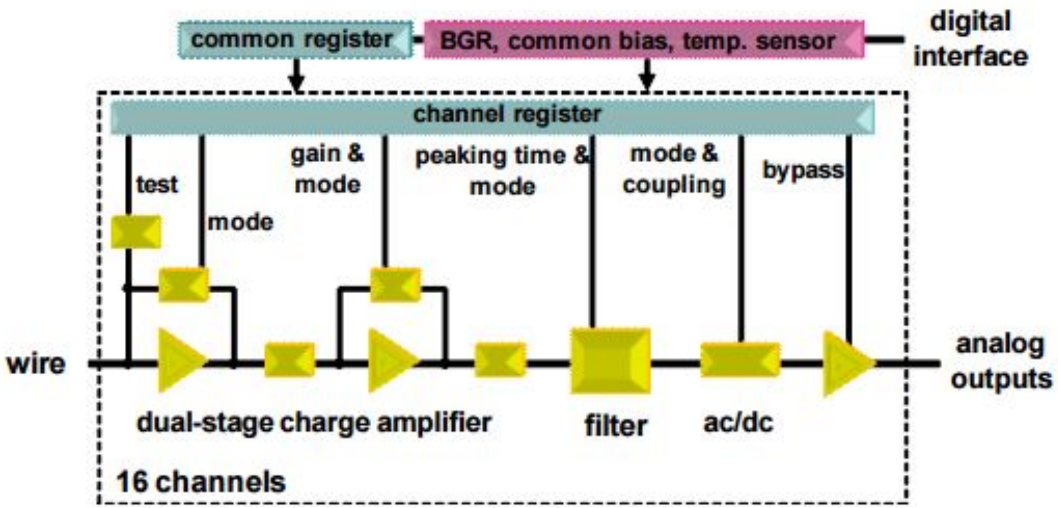
What are LArTPC Cold Electronics? protoDUNE



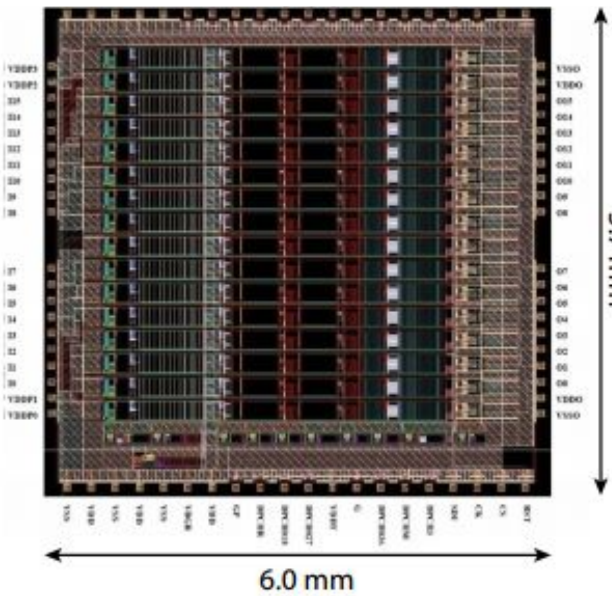
- Individual TPC wires instrumented like MicroBooNE
- Sampling and digitization provided by cold ADC (see Wenqiang's talk!)
- Cold Front End Mother Board (FEMB) co-ordinates readout via FPGA logic

What are LArTPC Cold Electronics? LArASIC

Individual Channel Preamp Block Diagram

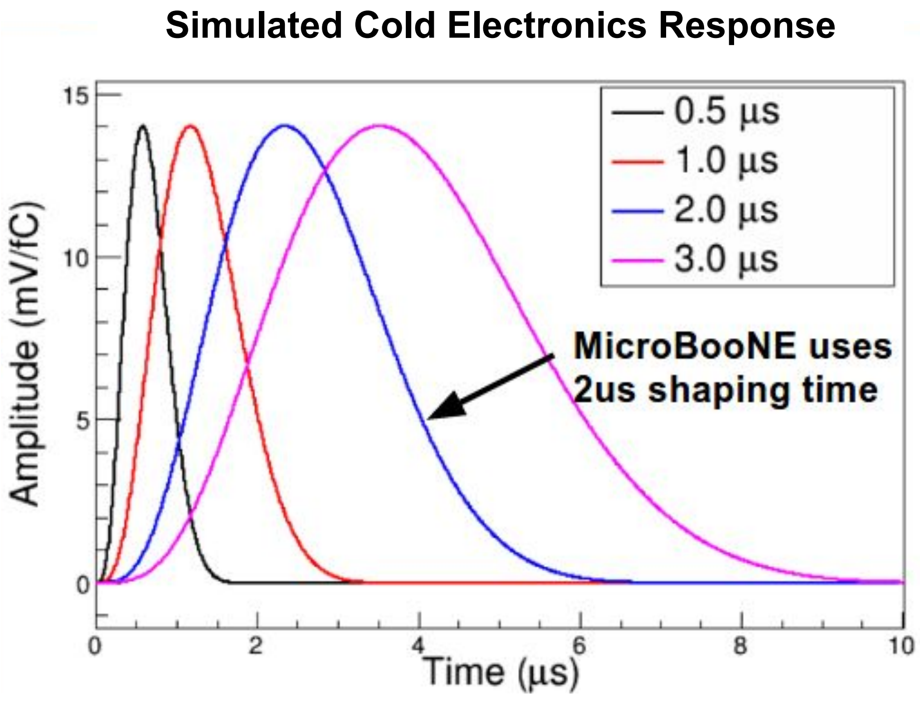


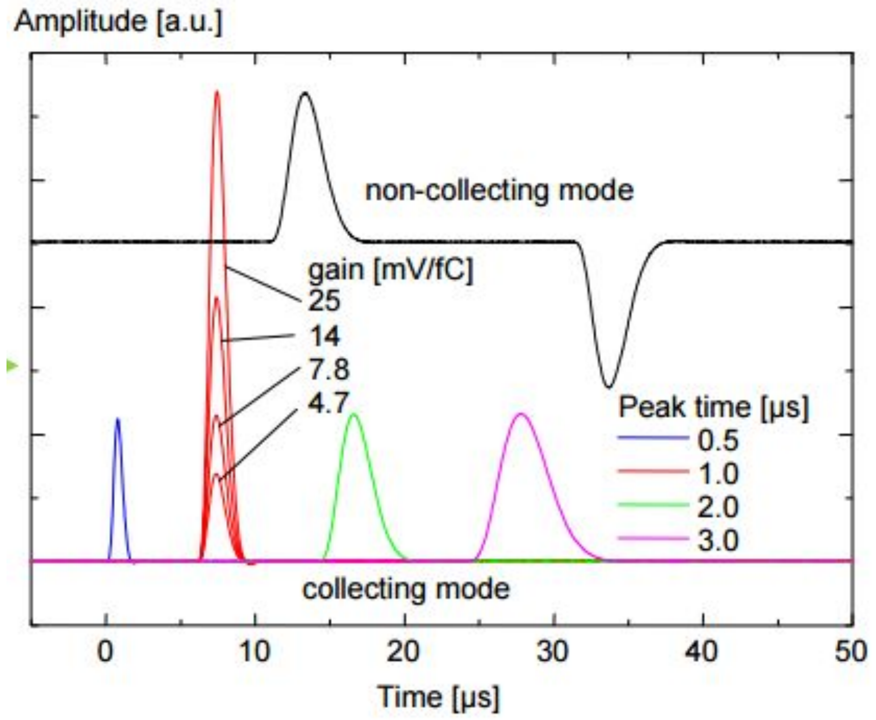
16-ch ASIC Schematic with Pins



- CMOS pre-amp + shaping ASICs convert wire charge to analog voltage signals
- 16 ch, highly configurable, range of gain, shaping time etc settings available
- Various versions in use, see LArASIC datasheets here

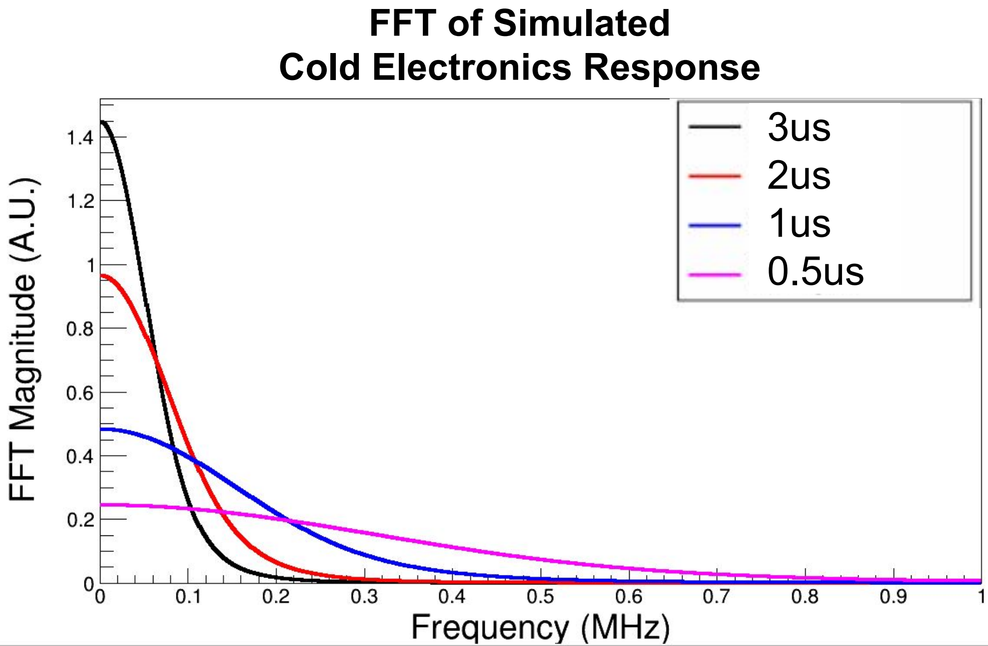
What are Cold Electronics? LArASIC Response





- Cold ASIC response well matched to electron drift speed of ~1.5mm/us
- <1000e- Equivalent Noise Charge (ENC) at 77K,MIP signals >15000e-

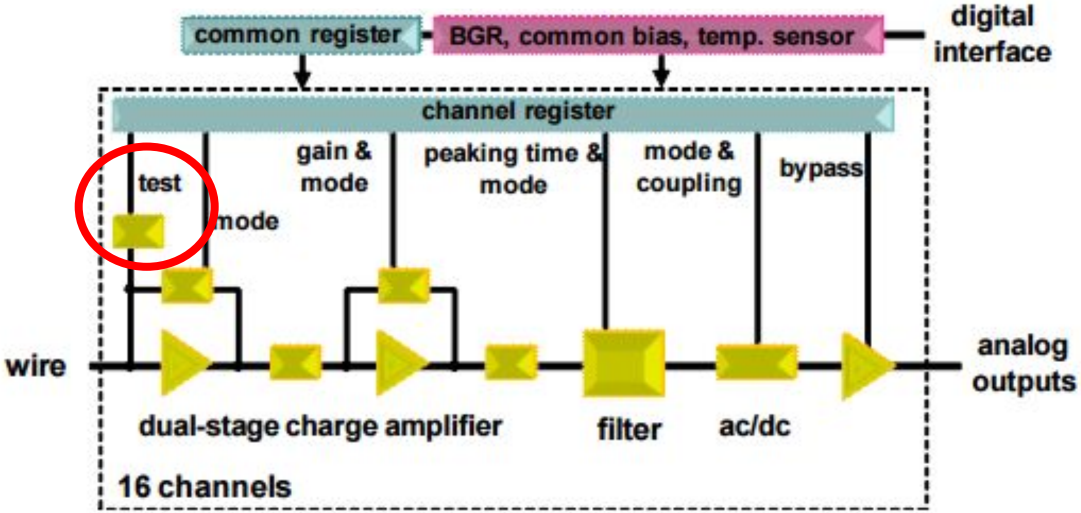
Nyquist Criterion and Electronics Response



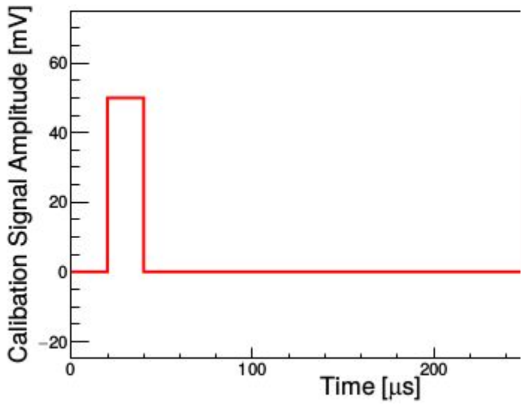
- Frequency content of cold electronics response at 1us, 2us, 3us shaping time settings largely below 1MHz
- Compatible with 2MHz sampling + digitization rate used in MicroBooNE and protoDUNE
  - 1MHz Nyquist frequency
- Note: 0.5us shaping time setting not compatible with 2MHz sampling!
  - Expect aliasing if this setting is used

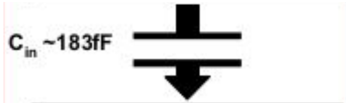
Measuring Electronic Response with Charge Injection

Individual Channel Preamp Block Diagram

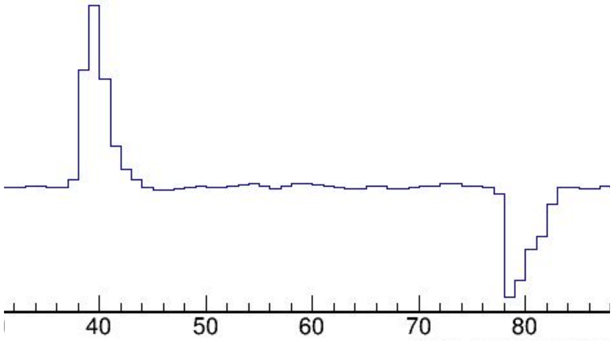


Input Sqaure Wave Signal





Measured Response



- Can directly measure electronics response using in-situ calibration system
- Injects charge into amplifier input via a dedicated channel-specific coupling capacitor

Parameterizing LArTPC Cold Electronics Response

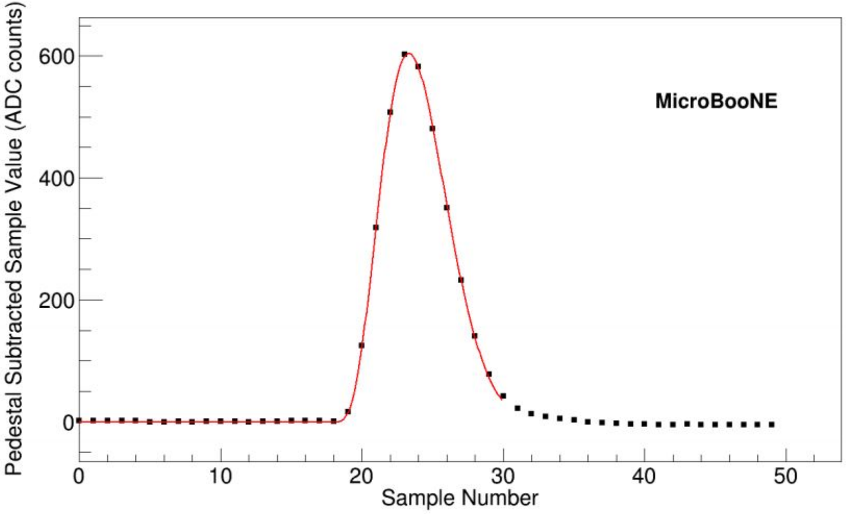
LArASIC Cold Electronics Time-Domain Response Function

$$R(t, A_0, t_p) = A_1E_1 - A_2E_2(\cos\lambda_1 + \cos\lambda_1\cos\lambda_2 + \sin\lambda_1\sin\lambda_2)$$
$$+ A_3E_3(\cos\lambda_3 + \cos\lambda_3\cos\lambda_4 + \sin\lambda_3\sin\lambda_4)$$
$$+ A_4E_2(\sin\lambda_1 - \cos\lambda_2\sin\lambda_1 + \cos\lambda_1\sin\lambda_2)$$
$$- A_5E_3(\sin\lambda_3 - \cos\lambda_4\sin\lambda_3 + \cos\lambda_3\sin\lambda_4)$$

$$A_1 = 4.31054A_0, \quad A_2 = 2.6202A_0,$$
$$A_3 = 0.464924A_0, \quad A_4 = 0.762456A_0, \quad A_5 = 0.327684A_0,$$
$$E_1 = e^{\frac{-2.94809t}{t_p}}, \quad E_2 = e^{\frac{-2.82833t}{t_p}}, \quad E_3 = e^{\frac{-2.40318t}{t_p}},$$
$$\lambda_1 = 1.19361\frac{t}{t_p}, \quad \lambda_2 = 2.38722\frac{t}{t_p},$$
$$\lambda_3 = 2.5928\frac{t}{t_p}, \quad \lambda_4 = 5.18561\frac{t}{t_p},$$

Two Parameters: Gain (A0), Shaping Time (tp)

Example Calibration Pulse Approximating Cold Electronics Impulse Response

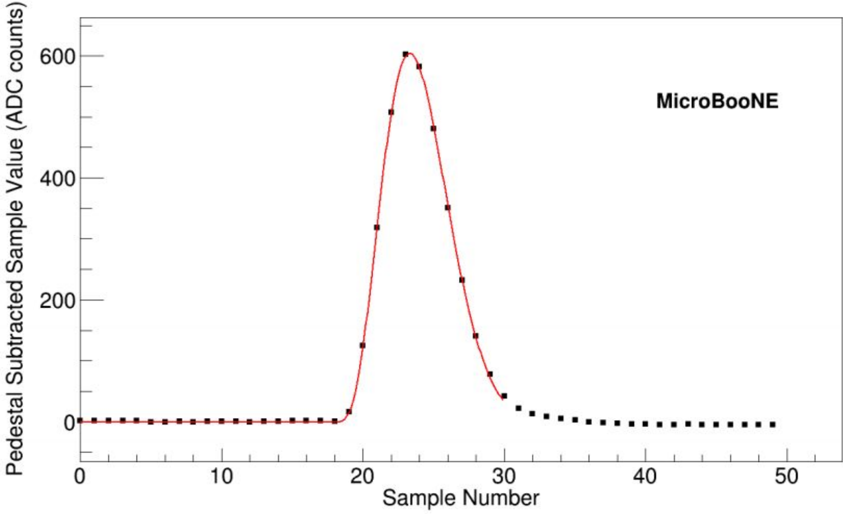


- Can fit known response function to impulse response from injected charge
  - Extract gain and shaping time factor, do linearity measurement for gain etc
- Question: **what is the goal of electronics response calibration?**

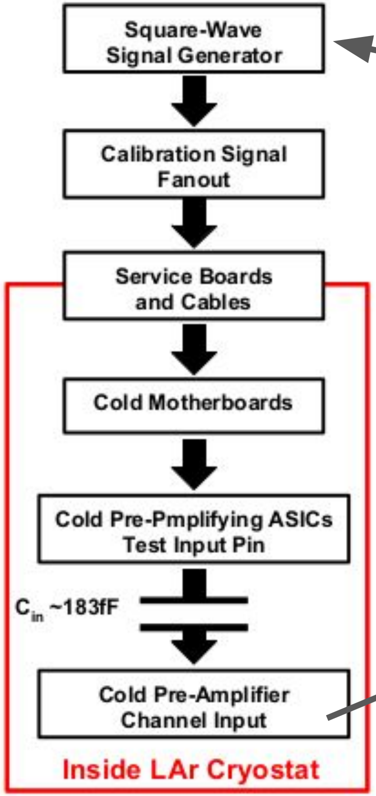
What's the Goal of Electronics Response Calibration?

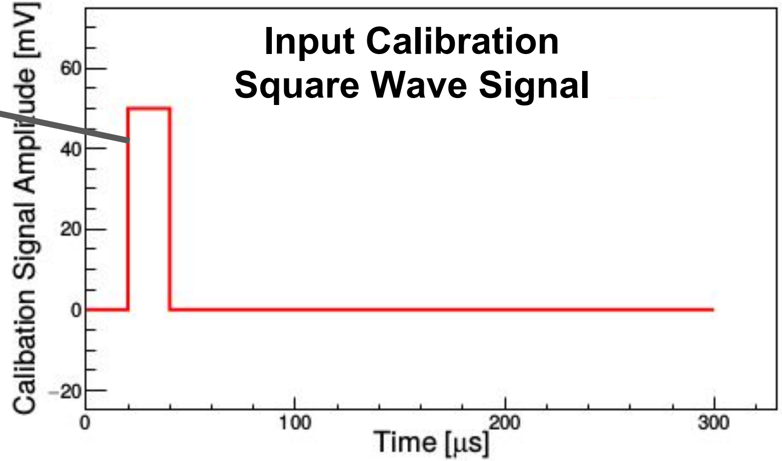
- Can parameterize electronics response using different measures for different purposes:
  - **Pulse height** : sufficient for defining "hit" thresholds
  - **Pulse integral** : suitable for calorimetry
  - **Preamp gain + shaping time parameters** : used with deconvolution-based signal processing
  - **Full response shape** : account for non-ideal pulse shape, improve deconvolution
- **Constrained by implementation of calibration system, ADCs**
  - Will compare MicroBooNE vs protoDUNE cases
  - ADC non-linearity (Wenqiang will discuss)

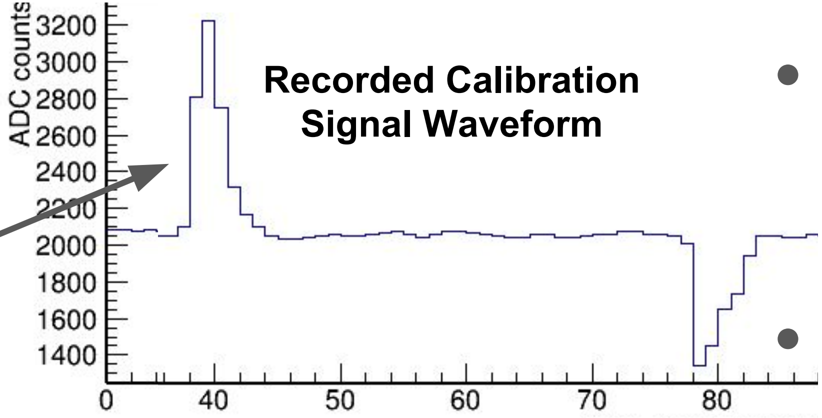
Example Calibration Pulse Approximating Cold Electronics Impulse Response

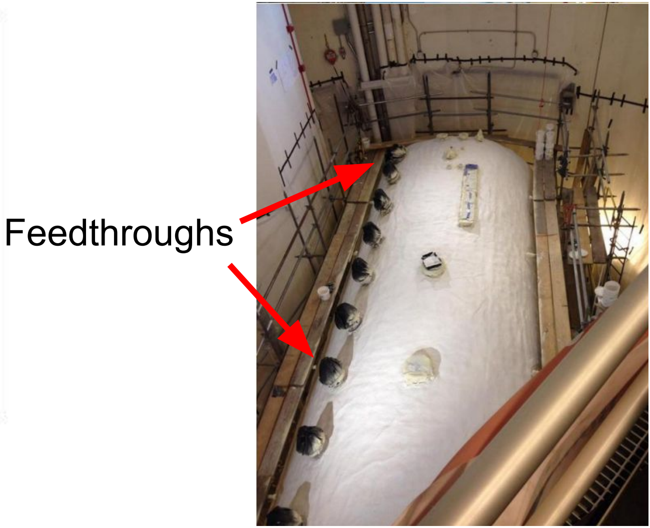


MicroBooNE In-Situ Cold Electronics Calibration System



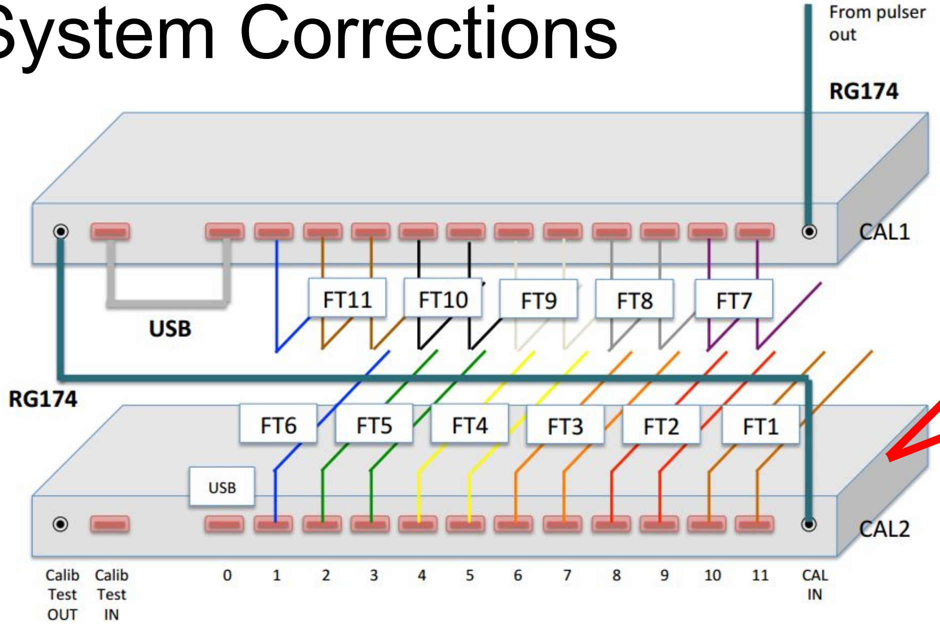


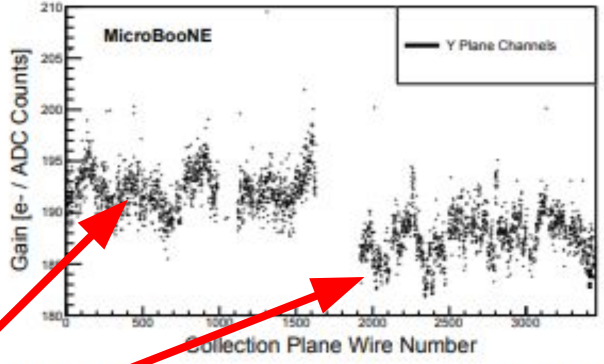




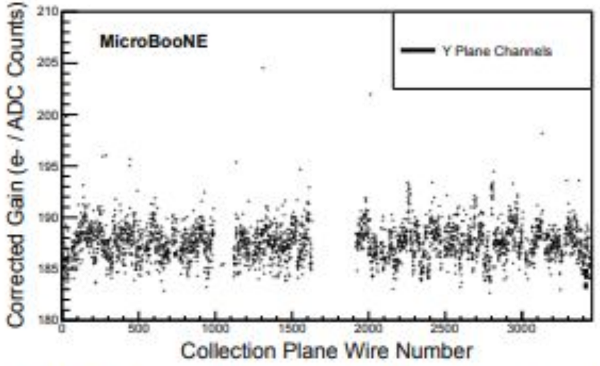
- External calibration signal routed into cryostat, coupled into cold electronic ASIC channel inputs via
- Vary input signal amplitude to measure response

MicroBooNE In-Situ Cold Electronics Calibration System Corrections





(b) Uncorrected gain for collection plane channels.

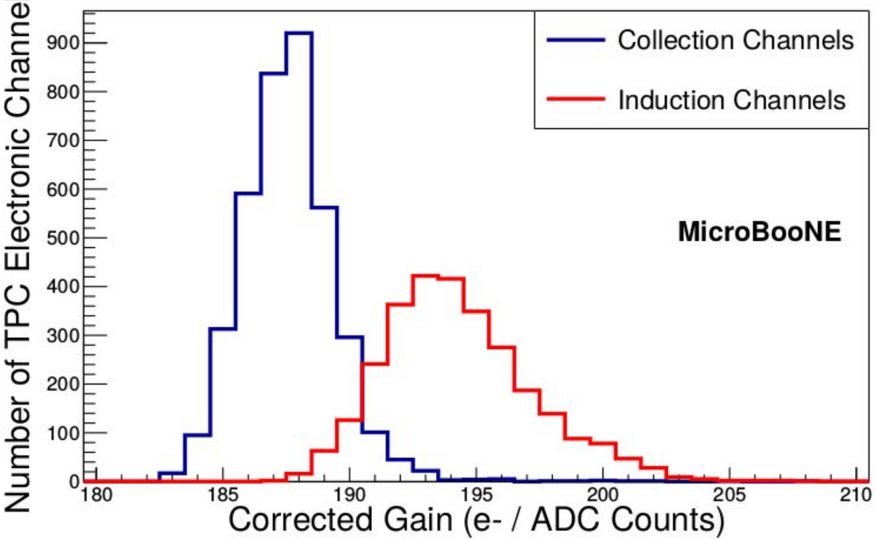


(d) Corrected gain for collection plane channels.

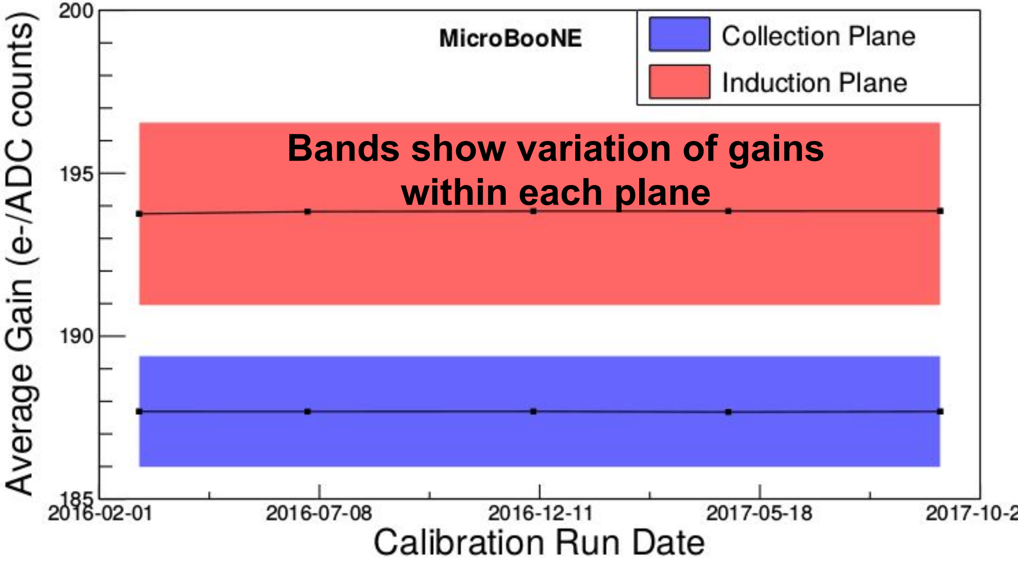
- Various components in injected signal pathway attenuate signal amplitude
- Actually difficult to do **absolute** gain measurement in MicroBooNE
    - Can measure **relative** gain up to overall scale factor

Evaluating Electronics Response Stability

Overall Channel Gain Distribution

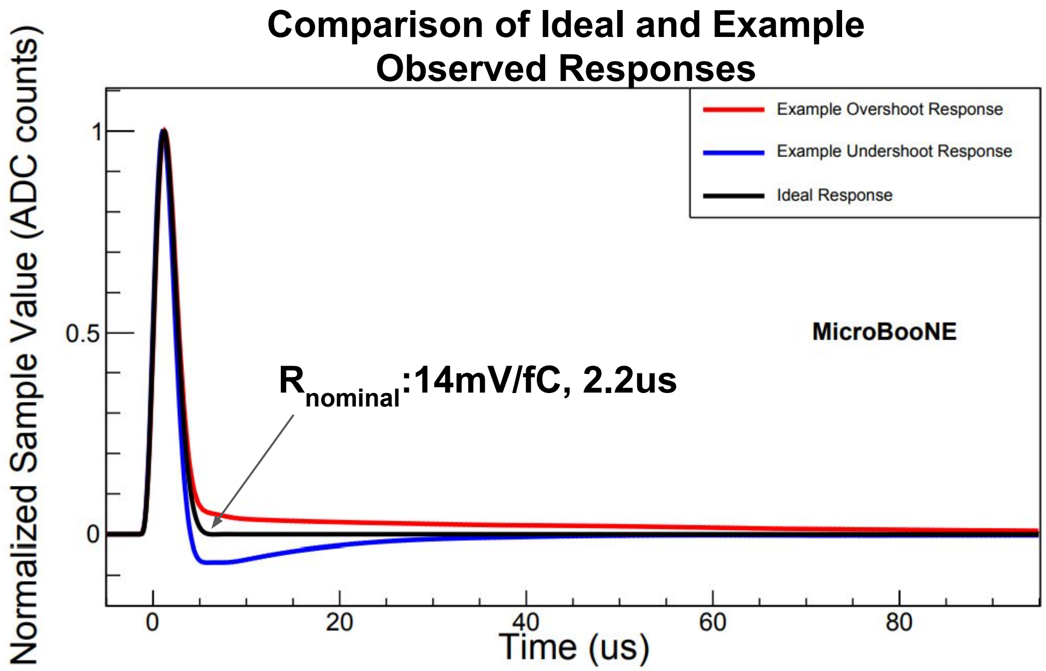


Mean Collecton + InductionChannel Gain Vs Time



- TPC channel electronic gains measured in-situ using nominal response function
  - Corrections applied to account for implementation of calibration system
  - Mean induction gain is 194.3 ± 2.8 [e − /ADC], Mean collection gain is 187.6 ± 1.7 [e − /ADC]
- **Cold electronics gain stable over two year period,variation ~0.2%**

Correcting Non-Ideal Elec. Response with Full Shape



- Identify non-ideal long tail components in cold electronic response
- Define a correction using measured response

Electronics Response in Waveform Data

$$M_i(t_0) = \int_{-\infty}^{\infty} R_i(t - t_0) \cdot I(t) \cdot dt$$

Digitized Waveform — Channel "i" Elec. Response — Induced Current

Frequency Domain

$$M_i(\omega) = R_i(\omega) \cdot I(\omega).$$

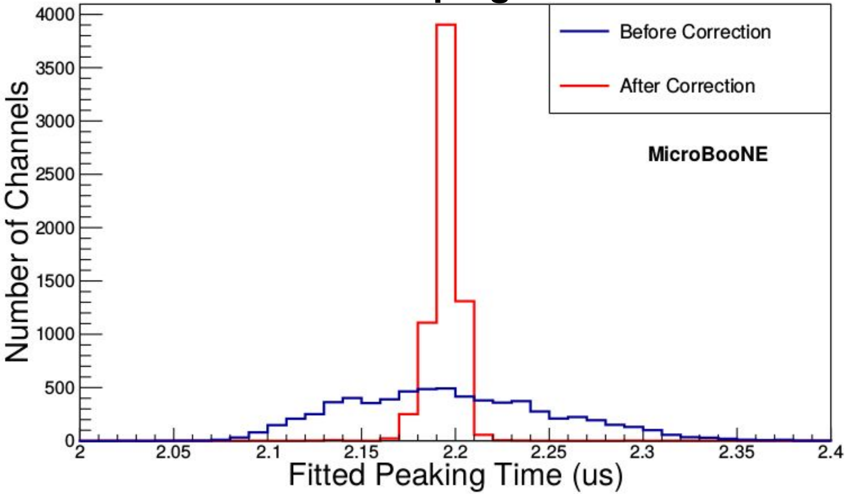
Electronics Response Correction

$$M_i^{Corr}(\omega) = M_i(\omega) \cdot \frac{R_{nominal}(\omega)}{R_i(\omega)}$$

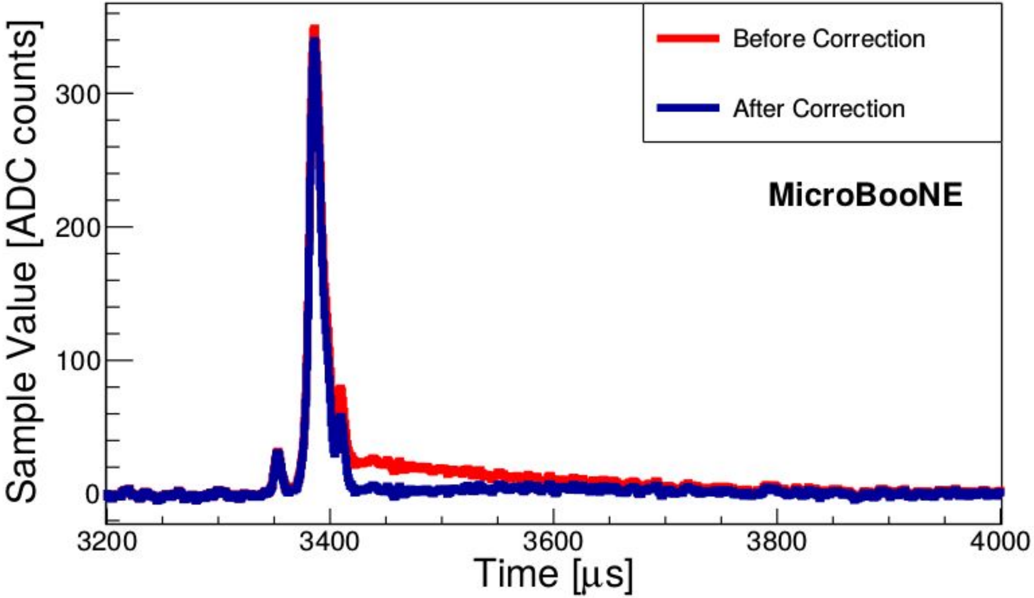
Channel "i" measured response FFT

Validated Cold Electronics Response Correction

Overall Channel Shaping Time Distribution

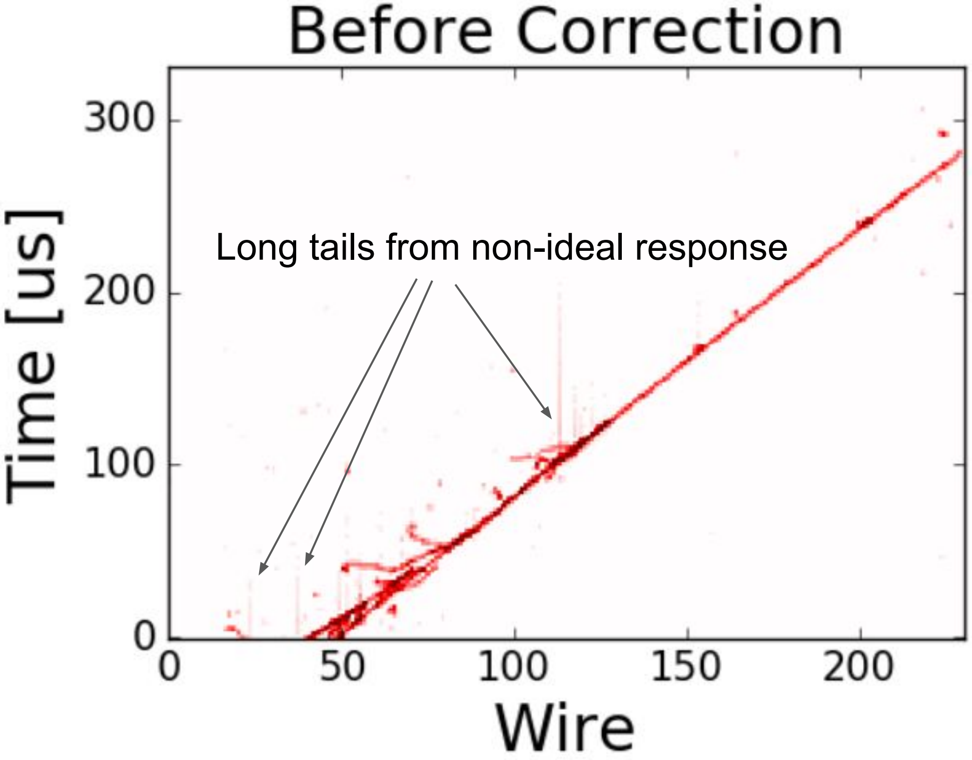


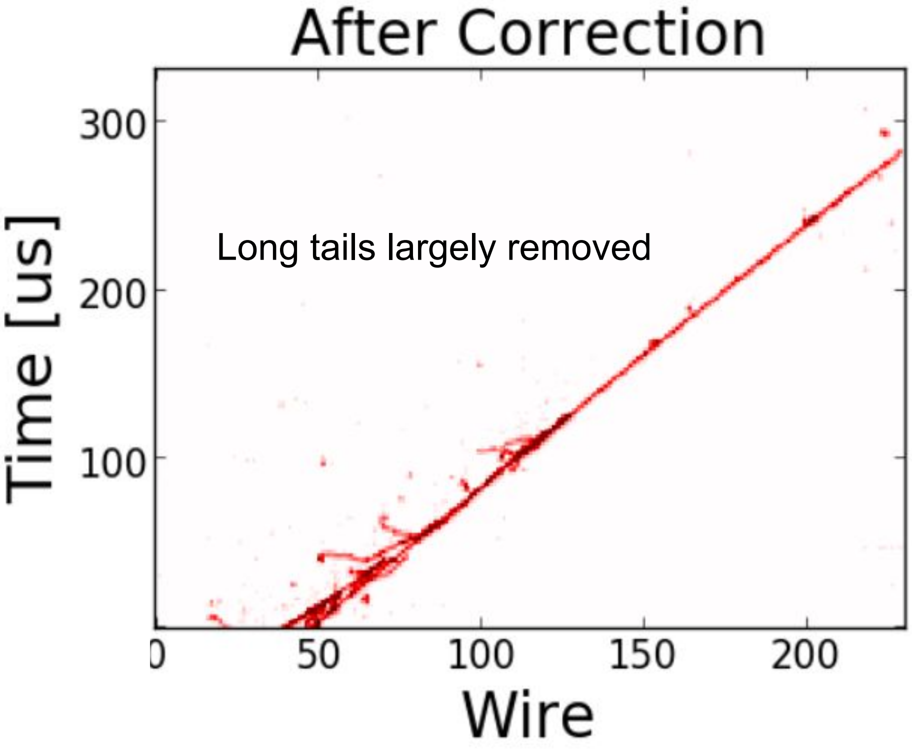
Example Corrected Waveform



- Cold electronics response correction largely removes original ~3.5% shape variation
- Effectively removes artificial “tail” after initial charge deposit
  - Otherwise tail could be mis-id’d as an extended charge distribution

Cold Electronics Response Correction in Data



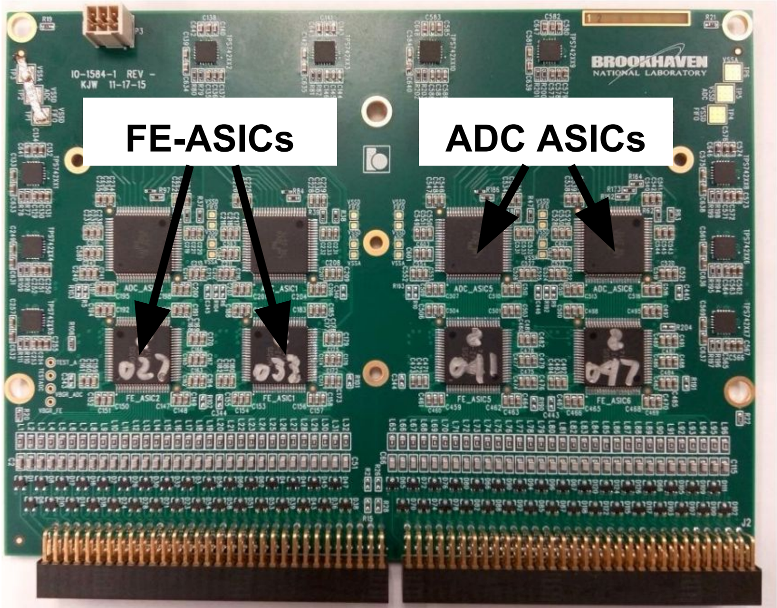


- Cold electronics response correction qualitatively improves event display
- Expect some improvement to reconstruction

protoDUNE Cold Electronic FEMBs

- **Front-End Motherboards (FEMBs)** integrate analog, digital electronics
- **Analog board:** 8 pairs of shaping-amplifier ASICs and digitizing ADC ASICs
- **FPGA board**: Programs and coordinates ASIC operation and readout, multiplexes and streams data to backend through GB transceivers

Analog and ADC Board

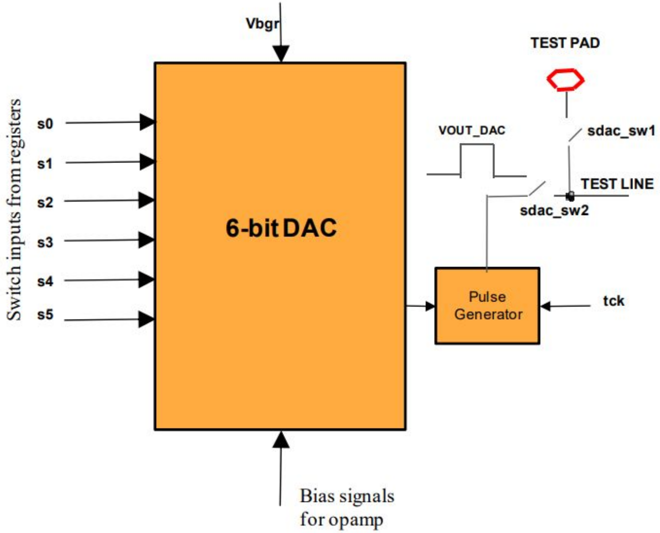


protoDUNE FEMB

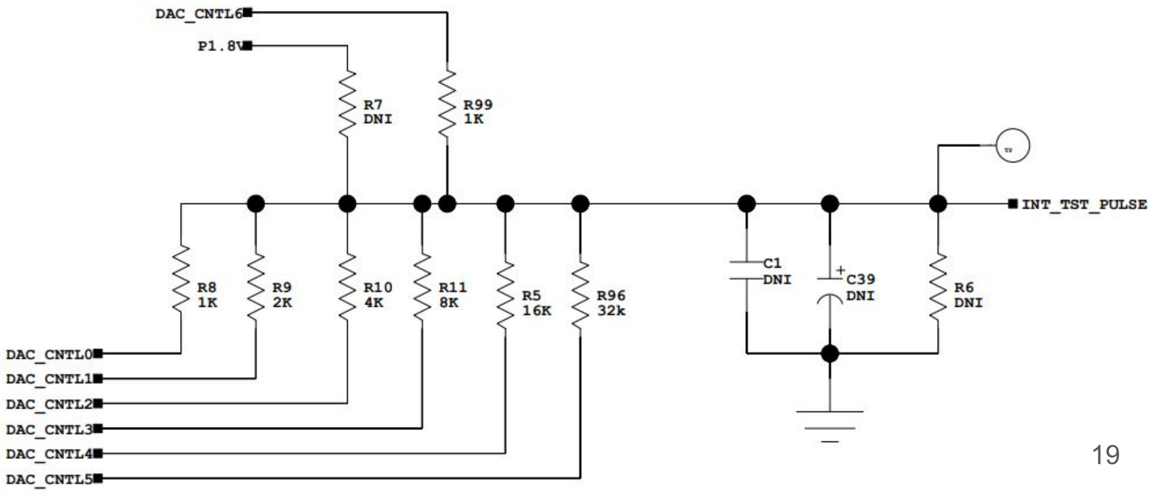
ProtoDUNE Electronic Response Calibration System

- protoDUNE cold electronics has two injected signal calibration sources implemented directly on front-end readout boards
  - On-board DAC and pulse generator in LArASIC7, “internal DAC”
  - DAC derived from FEMB FPGA pins + resistor divider network, “external DAC”
- Attenuation in injected signal path is negligible, can measure absolute gain
- Digital logic allows test signal injection at specific phase wrt sampling clock

LArASIC On-Board DAC and Pulse Generator

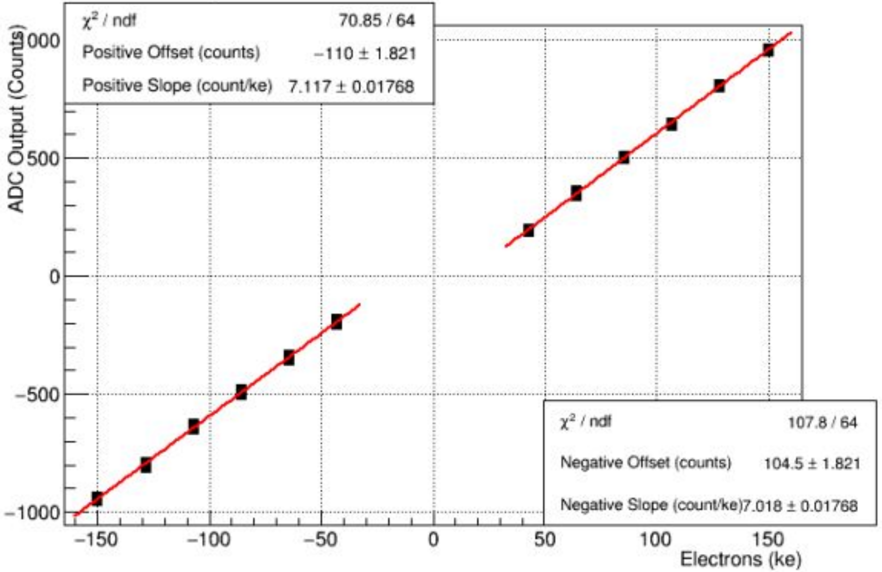


External DAC FPGA Pins and Resistor Divider



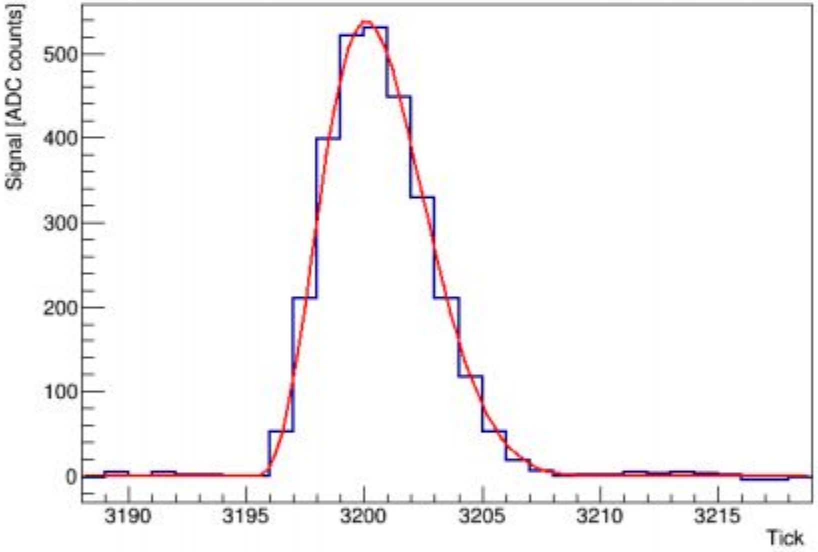
Initial protoDUNE Response Calibration Results

Example Linearity Fit Using Internal DAC Fitting Both Positive and Negative Response



R. Diurba, Minn

Example Calibration Signal Fitted Using protoDUNE DataPrep Tools

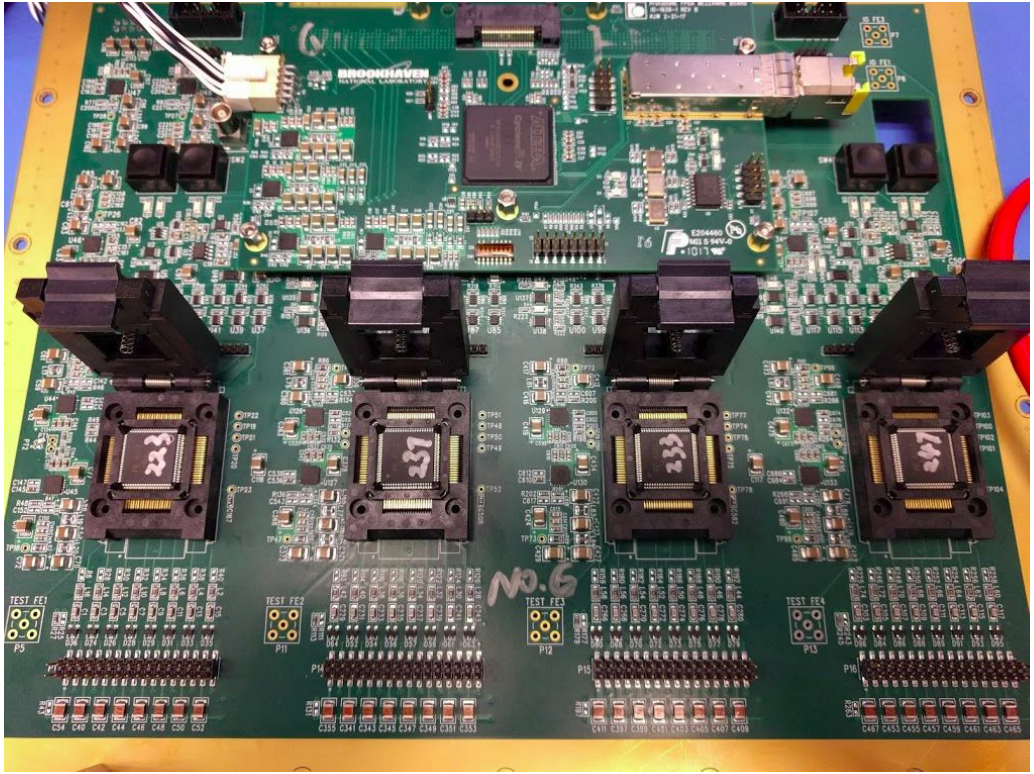


D. Adams, BNL

- Ongoing effort to evaluate protoDUNE electronics response in-situ using onboard injected charge calibration sources

Cold Electronics Calibration: Test Signal Capacitor and Production Testing

protoDUNE LArASIC Production Test Board



- For protoDUNE-syle electronics, main uncertainty in injected signal magnitude is due to value of test input capacitor
- Can measure the value of this capacitor in production testing to optimize electronics response calibration
- Implications for design of production test stand and procedures

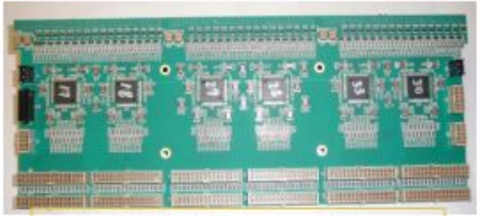
Summary

- LArASIC cold electronics well-suited to LArTPC wire-charge signals, shaping time compatible with ionization charge nominal drift speed and 2MHz sampling
- Electronics response parameterization needs to be appropriate for signal-processing reconstruction methods
    - Correctly accounting for non-ideal response could benefit image-processing inspired measurements
- Implementation of calibration system and ADCs constrains electronic response measurement
    - There has been incremental improvement between successive LArTPC experiments

Backup

The MicroBooNE Detector: Frontend Electronics

Cold electronics



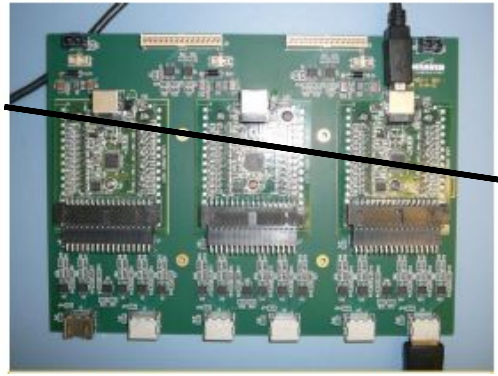
Horiz Cold Motherboard

Vertical Cold Motherboard

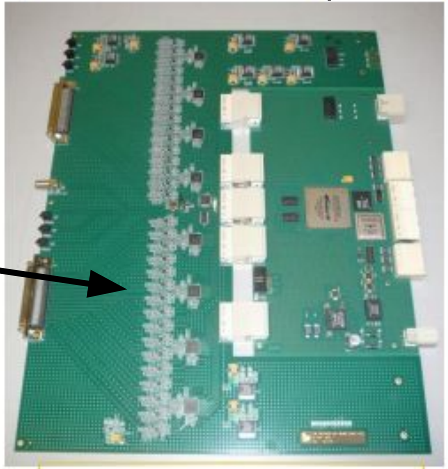
Intermediate Amplifier

Service Board

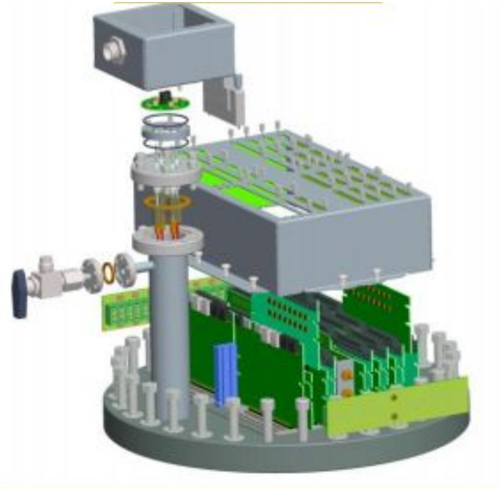
12-bit ADCs
Sampling at 2MHz



ASIC Configuration Board



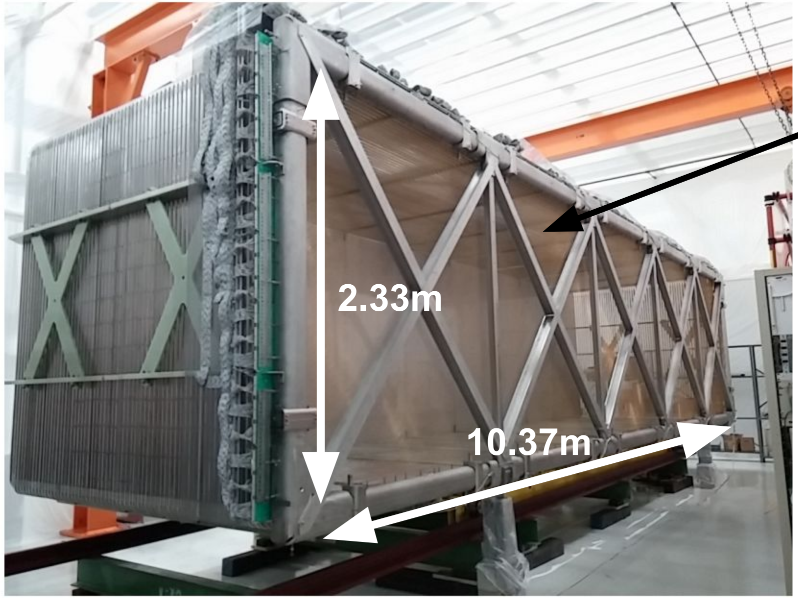
ADC Receiver Board



Signal Feed-Through

Reminder: The MicroBooNE Detector: Cryostat, TPC

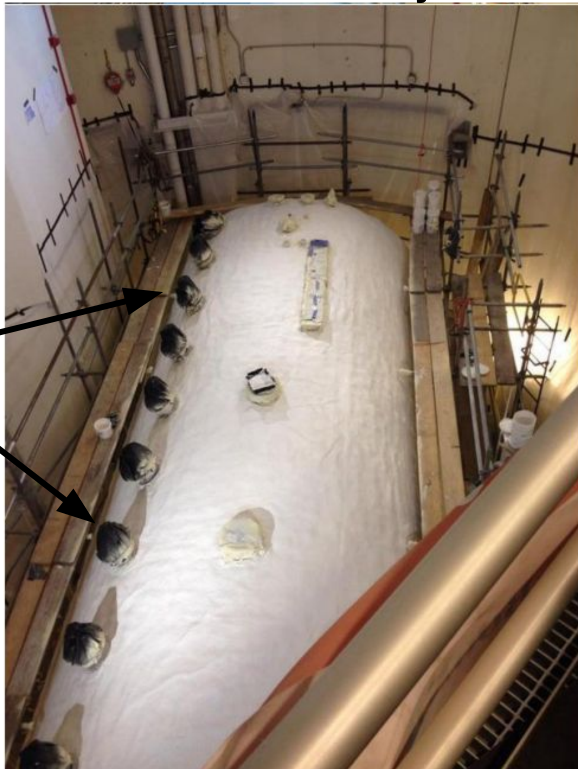
MicroBooNE LArTPC with Wire Planes + Cold Electronics Installed



Wire planes

Feedthroughs

MicroBooNE Foam Insulated Cryostat



- 2.56m drift length, ~1.6ms maximum drift time
- Cold electronics mounted on TPC top and sides
- Feedthroughs for power, signal and service cabling