Cold LArTPC Electronics Response Calibration in MicroBooNE and protoDUNE

LArTPC Calibration Workshop

Brian Kirby, Brookhaven National Lab

Dec 10, 2018

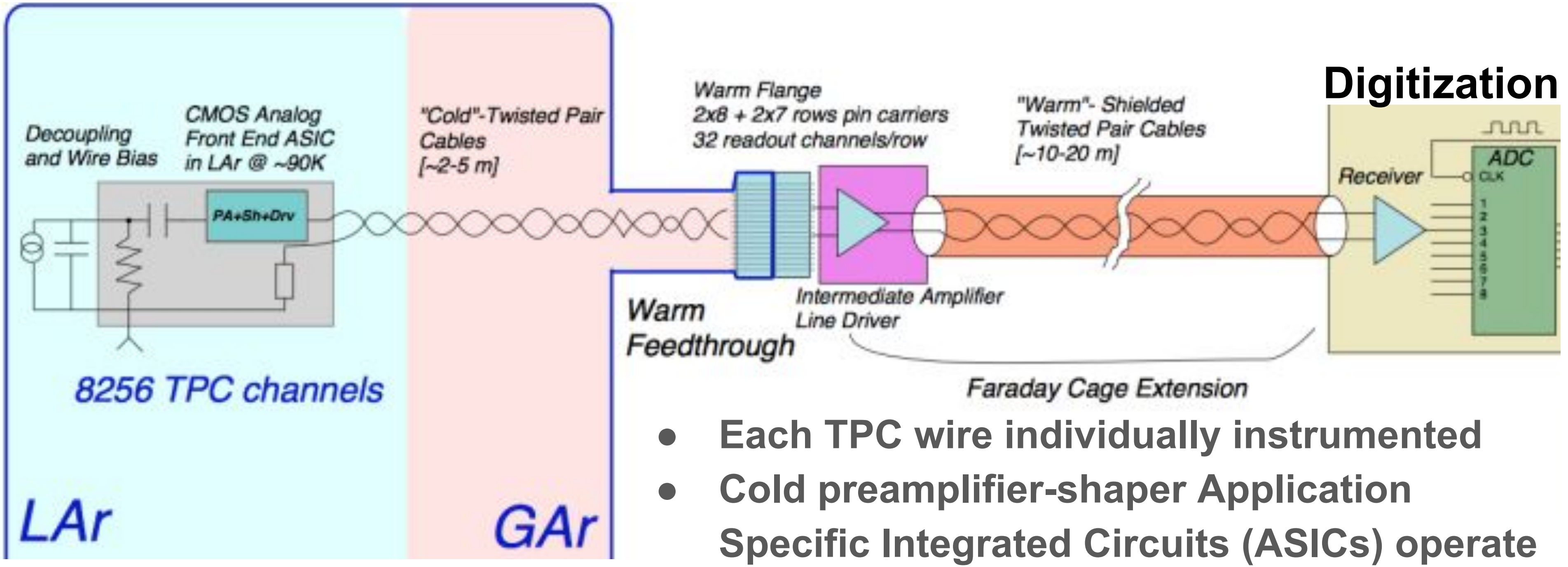
BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- What are 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

What are LArTPC Cold Electronics? MicroBooNE

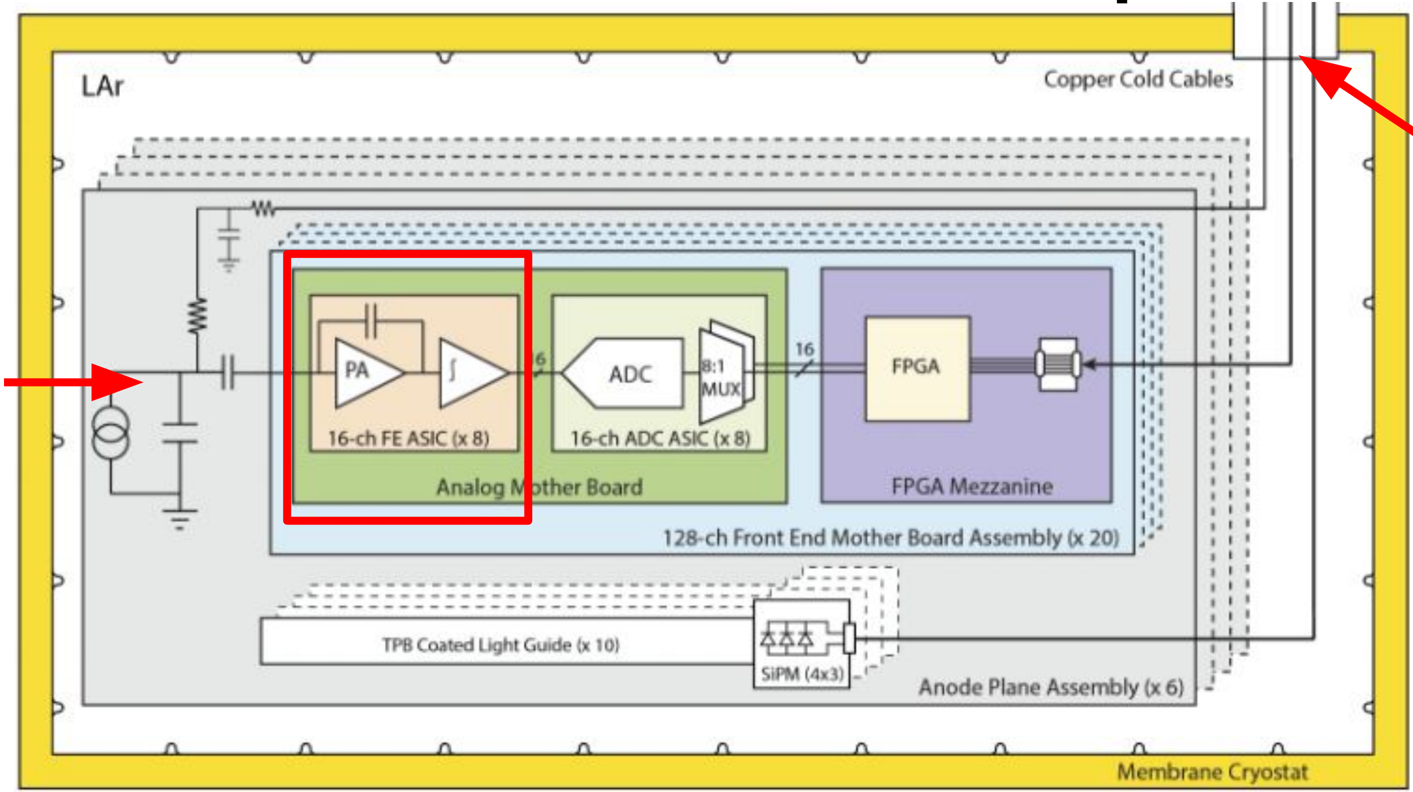


Cryostat
Wires + Cold Electronics

- 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

Wire current signals IN

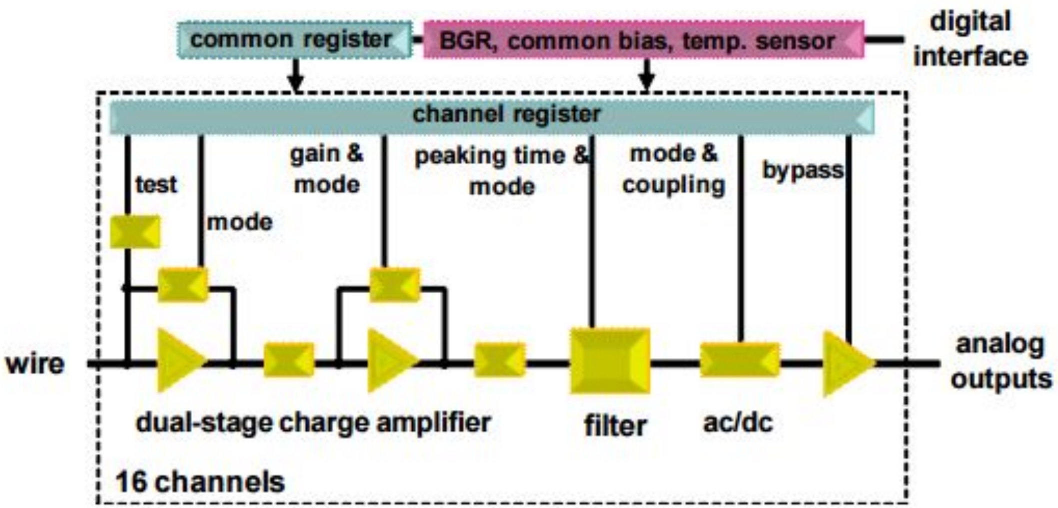


Digitized waveform signals OUT

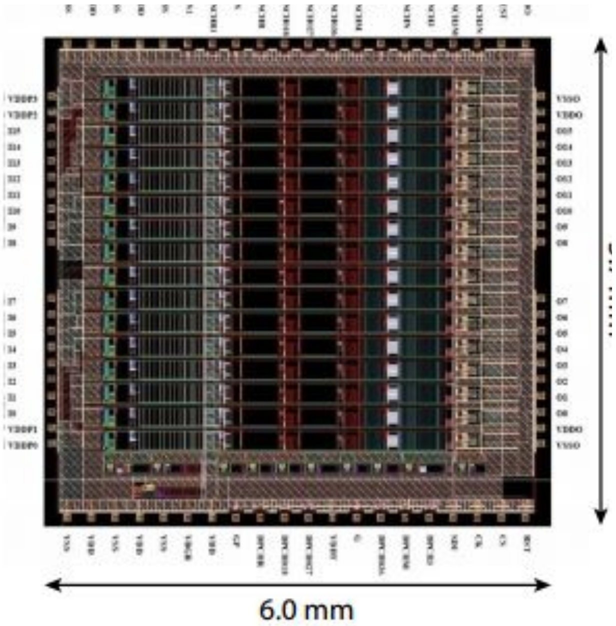
- Individual TPC wires instrumented like MicroBooNE
- Sampling and digitization provided by cold ADC (see Wenqiang's talk!)
- Cold Front End Mother Board (FEMB) co-ordinates readout via FPGA logic

What are LArTPC Cold Electronics? LArASIC

Individual Channel Preamp Block Diagram



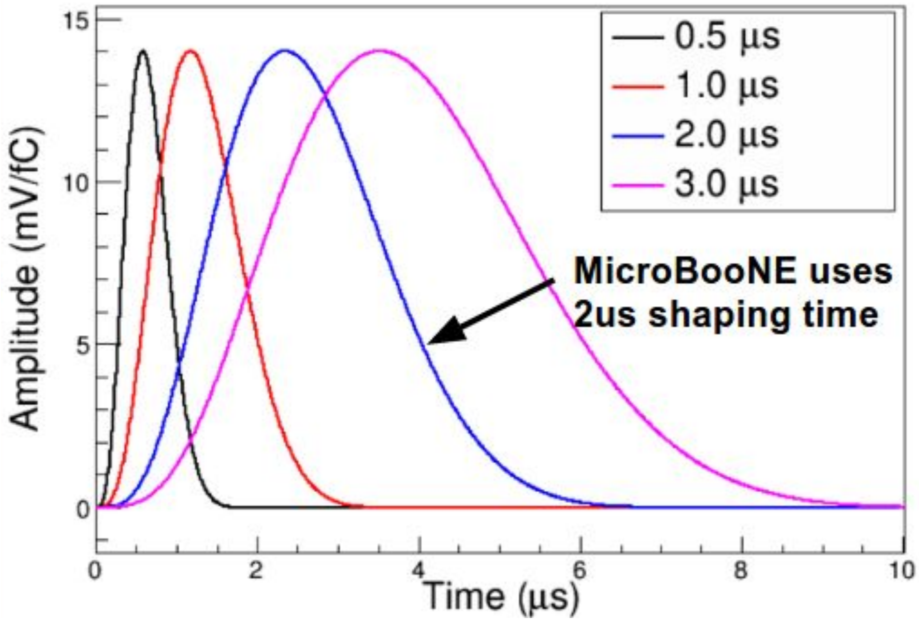
16-ch ASIC Schematic with Pins

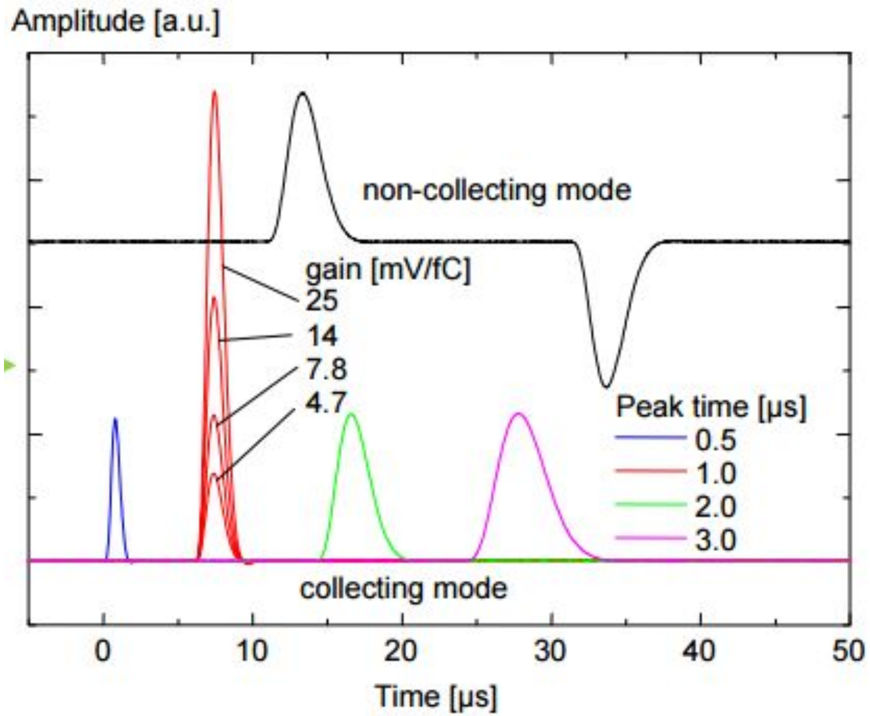


- CMOS pre-amp + shaping ASICs convert wire charge to analog voltage signals
- 16 ch, highly configurable, range of gain, shaping time etc settings available
- Various versions in use, see LArASIC datasheets here

What are Cold Electronics? LArASIC Response

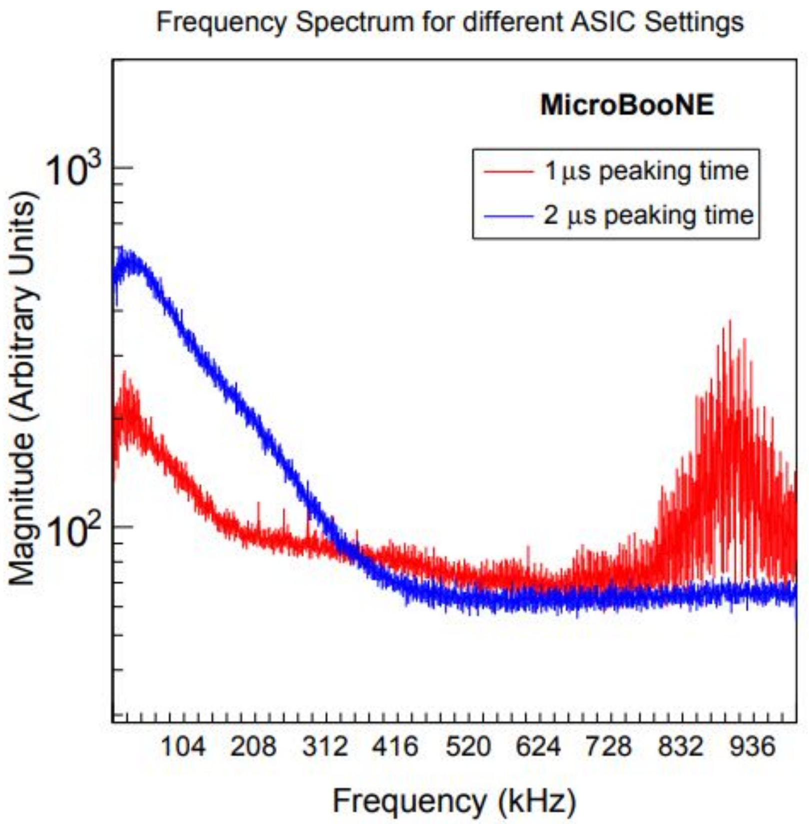
Simulated Cold Electronics Response





- Cold ASIC response well matched to electron drift speed of ~1.5mm/us
- <1000e- Equivalent Noise Charge (ENC) at 77K,MIP signals >15000e-
  - eg. MicroBooNE is using 14mV/fC gain and 2us shaping time setting

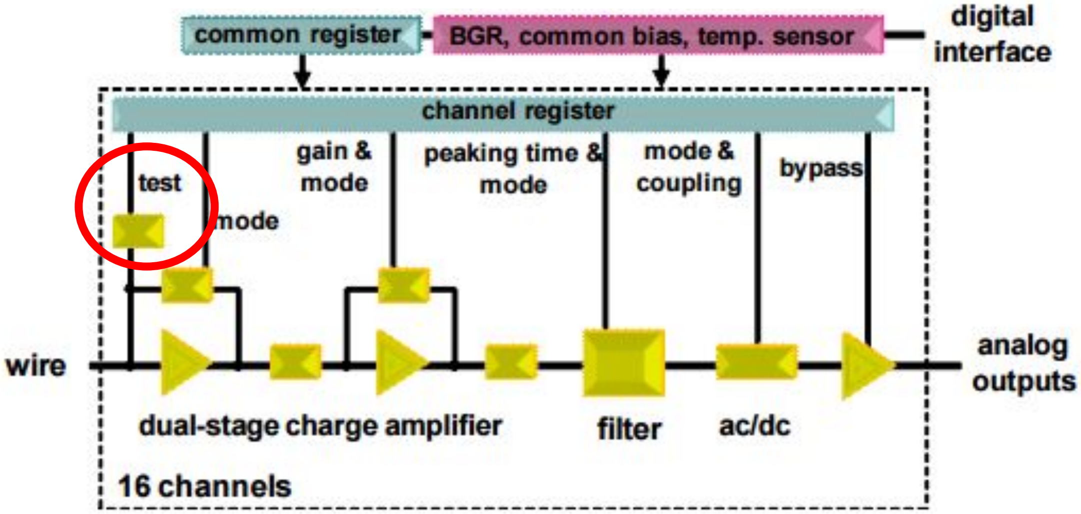
Nyquist Criterion and Electronics Response

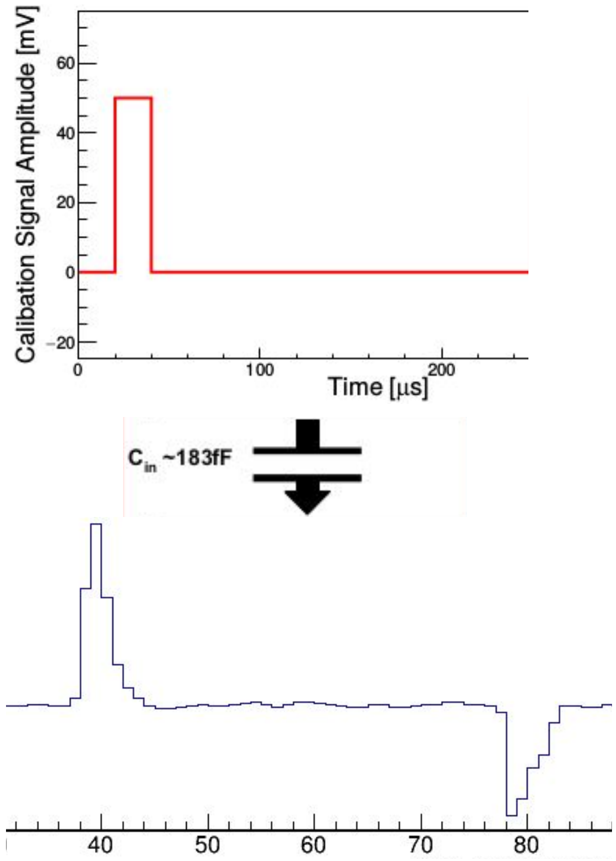


- Frequency content of cold electronics response at 1us and 2us shaping time settings largely below 1MHz
- Compatible with 2MHz sampling + digitization (1MHz Nyquist frequency)
- Note: 0.5us shaping time setting not compatible with 2MHz sampling!
  - Expect aliasing

Measuring Electronic Response with Charge Injection

Individual Channel Preamp Block Diagram





- **Directly measure full electronics response using in-situ calibration system that injects charge into amplifier input via a dedicated channel-specific coupling capacitor**

Parameterizing LArTPC Cold Electronics Response

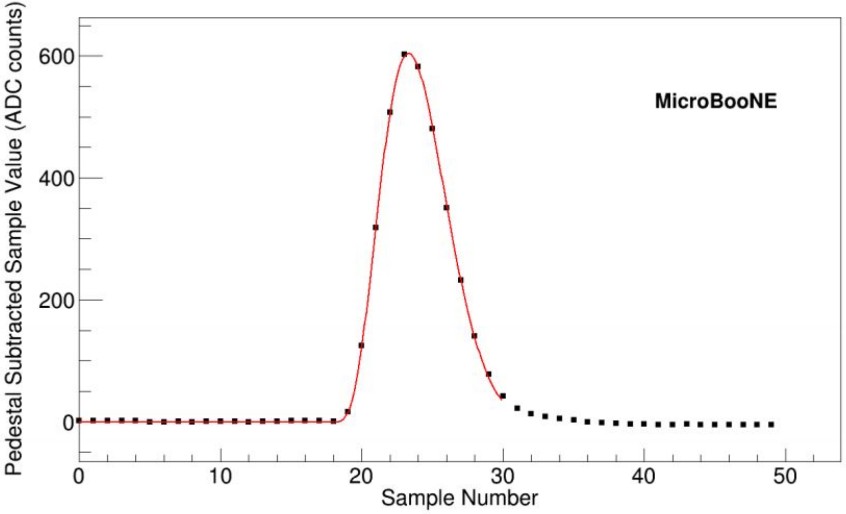
LArASIC Cold Electronics Time-Domain Response Function

$$R(t, A_0, t_p) = A_1 E_1 - A_2 E_2(\cos\lambda_1 + \cos\lambda_1 \cos\lambda_2 + \sin\lambda_1 \sin\lambda_2)$$
$$+ A_3 E_3(\cos\lambda_3 + \cos\lambda_3 \cos\lambda_4 + \sin\lambda_3 \sin\lambda_4)$$
$$+ A_4 E_2(\sin\lambda_1 - \cos\lambda_2 \sin\lambda_1 + \cos\lambda_1 \sin\lambda_2)$$
$$- A_5 E_3(\sin\lambda_3 - \cos\lambda_4 \sin\lambda_3 + \cos\lambda_3 \sin\lambda_4)$$

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

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

Example Calibration Pulse Approximating Cold Electronics Impulse Response

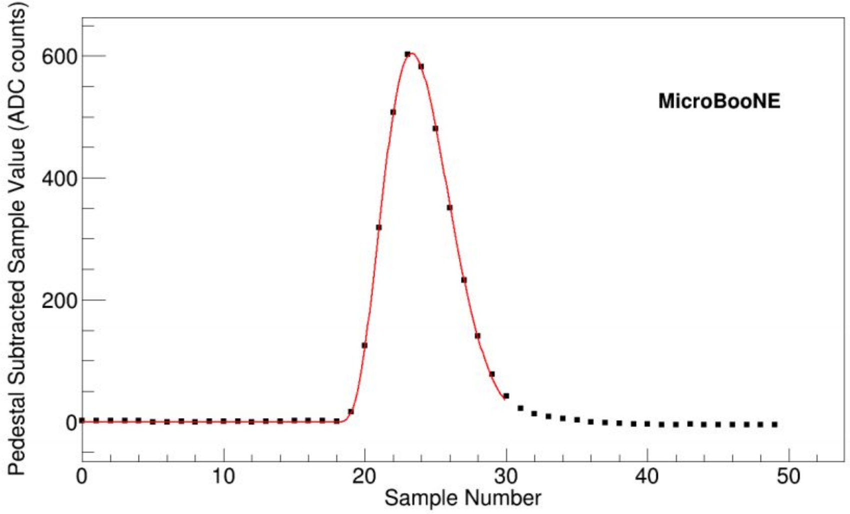


- Can fit full response to injected charge with known response function
- Alternatively for gain measurements can use simpler measures like pulse height/integral to calibrate response etc
- Question: **what is the goal of electronics response calibration?**

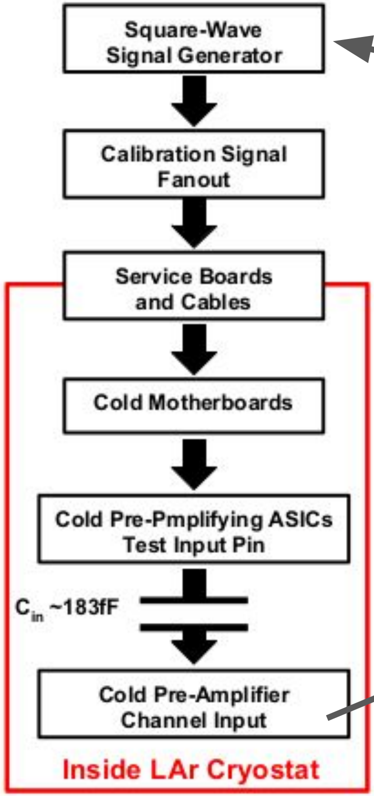
What's the Goal of Electronics Response Calibration?

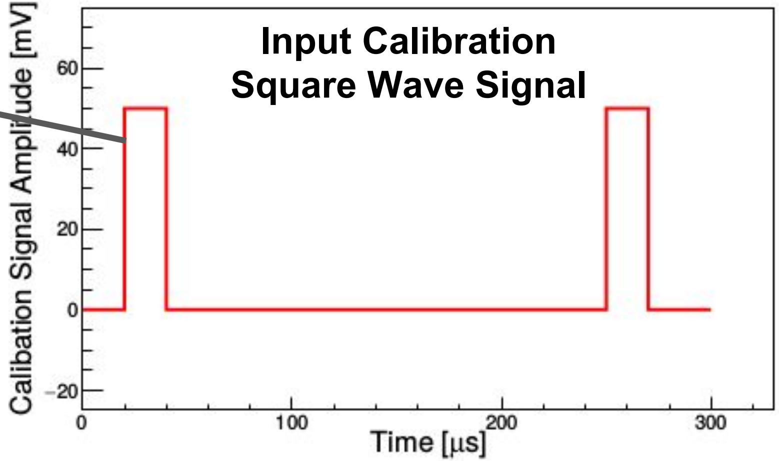
- Can parameterize electronics response using different measures:
  - **Pulse height** : sufficient for defining "hit" thresholds
  - **Pulse integral** : suitable to do calorimetry
  - **Preamp gain + shaping time parameters** : use with deconvolution-based signal processing
  - **Full response shape** : 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

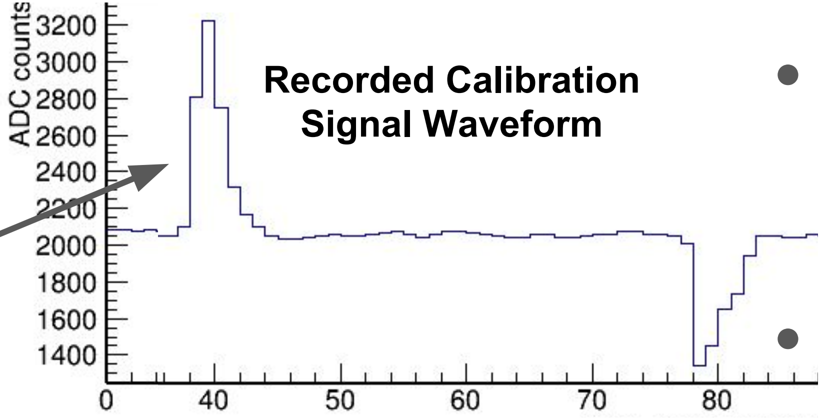
Example Calibration Pulse Approximating Cold Electronics Impulse Response

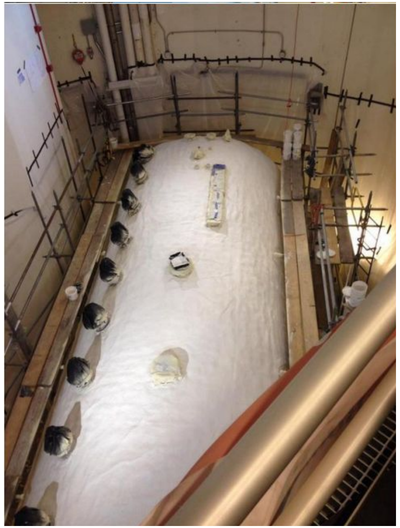


MicroBooNE In-Situ Cold Electronics Calibration System



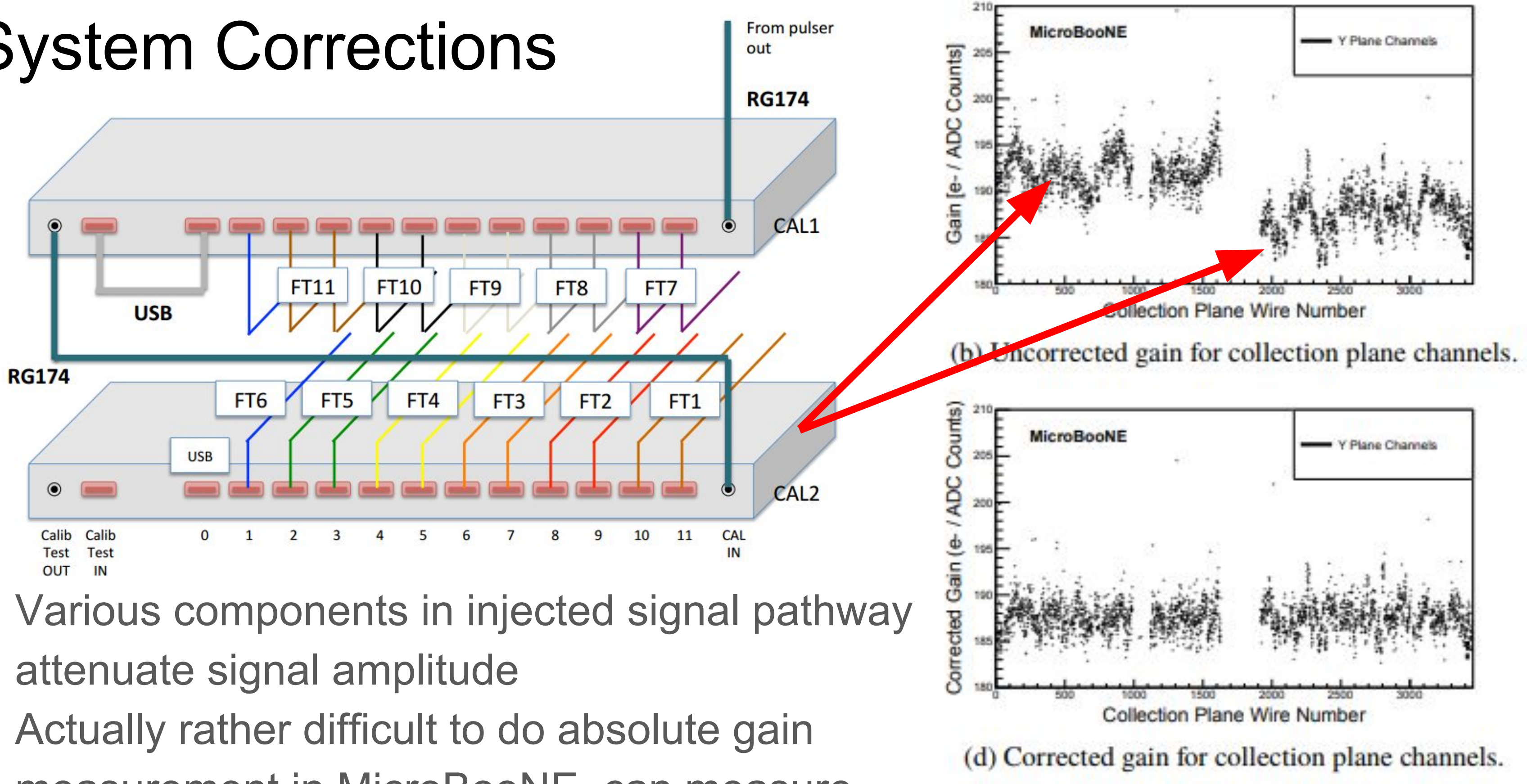






- External calibration signal routed into cryostat, coupled into cold electronic ASIC channel inputs via
- Vary input signal amplitude to measure response

MicroBooNE In-Situ Cold Electronics Calibration System Corrections

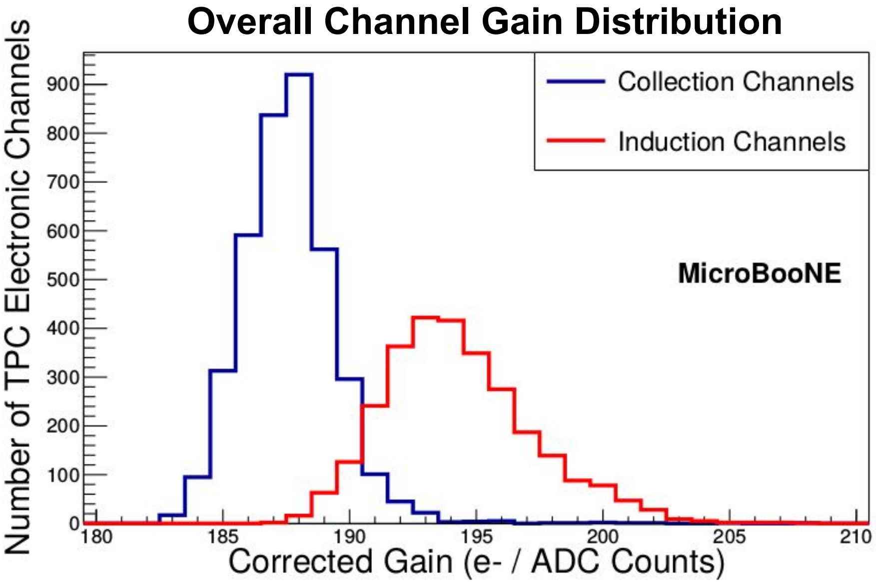


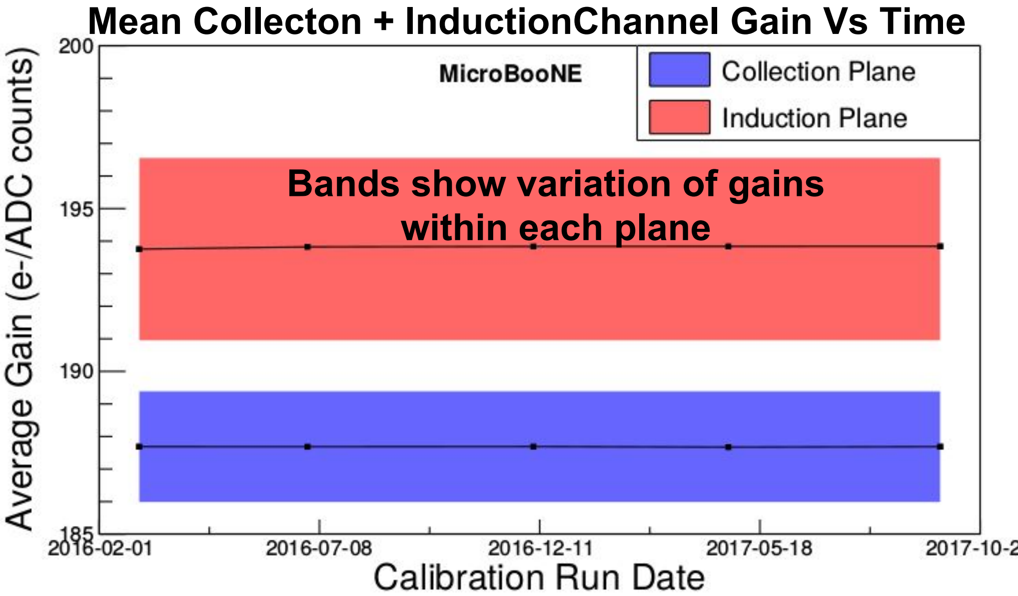
(b) Uncorrected gain for collection plane channels.

(d) Corrected gain for collection plane channels.

- Various components in injected signal pathway attenuate signal amplitude
- Actually rather difficult to do absolute gain measurement in MicroBooNE, can measure relative gain

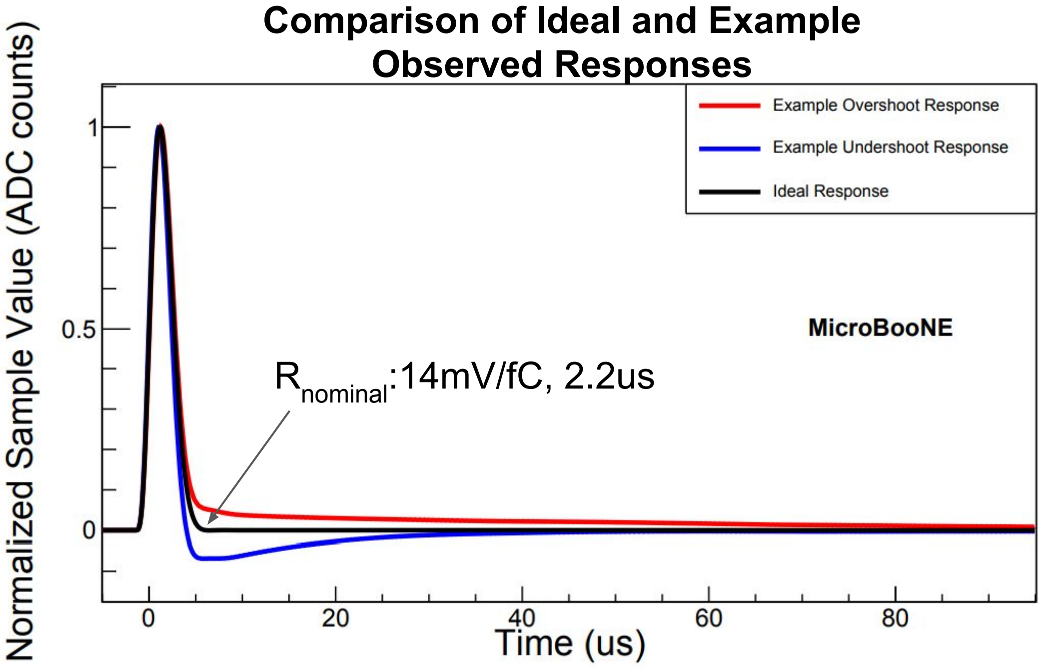
Cold Electronics Response Stability in MicroBooNE





- 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%**

Mitigating MicroBooNE's Non-Ideal Elec. Response



- 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 ($M_i(t_0)$); Channel "i" Elec. Response (R_i); Induced Current ($I(t)$)

Frequency Domain

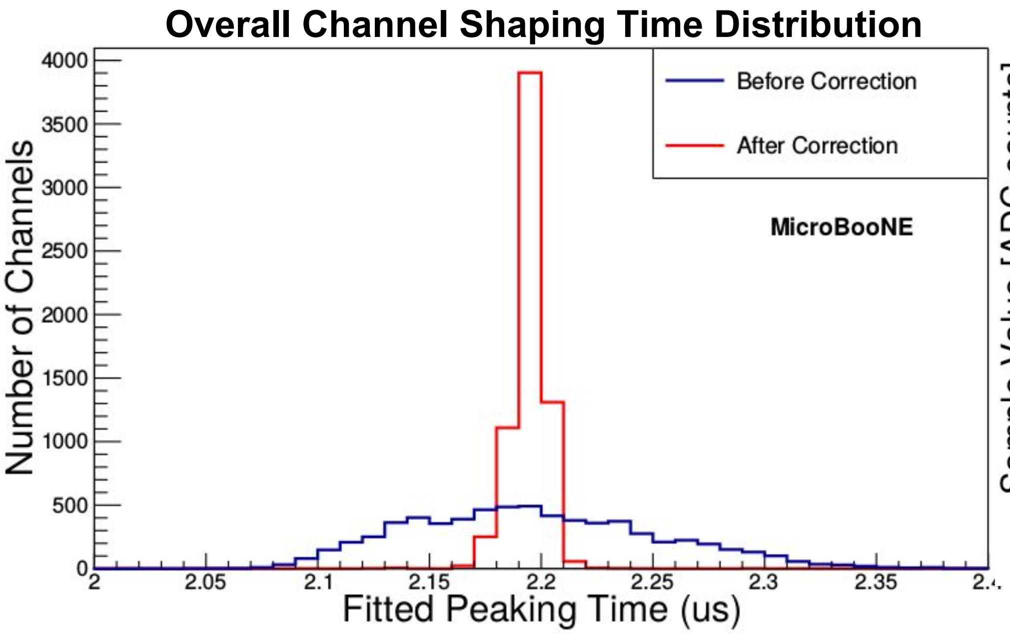
$$M_i(\omega) = R_i(\omega) \cdot I(\omega).$$

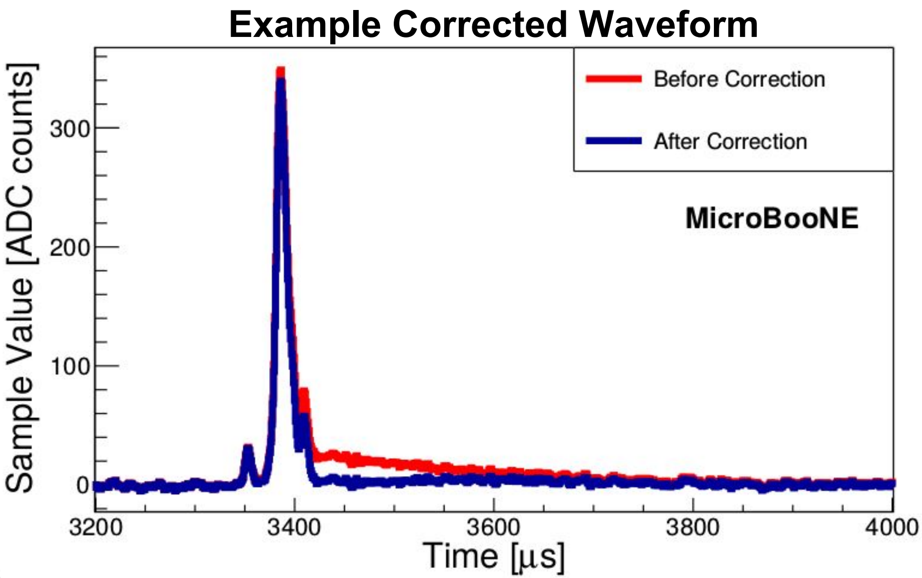
Electronics Response Correction

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

Channel "i" measured response FFT ($R_i(\omega)$)

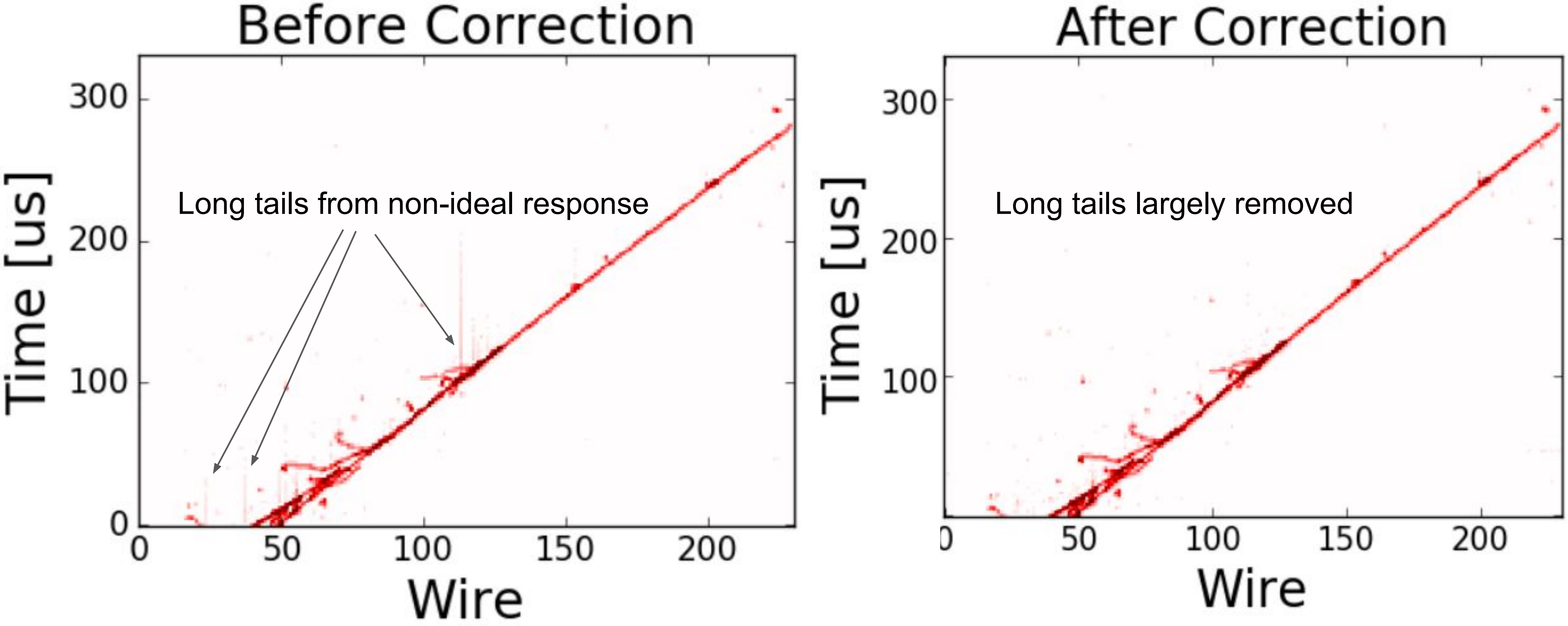
Validated Cold Electronics Response Correction





- Cold electronics response correction largely removes original ~3.5% shape parameter variation
- Effectively removes artificial “tail” after initial charge deposit

Cold Electronics Response Correction in Data

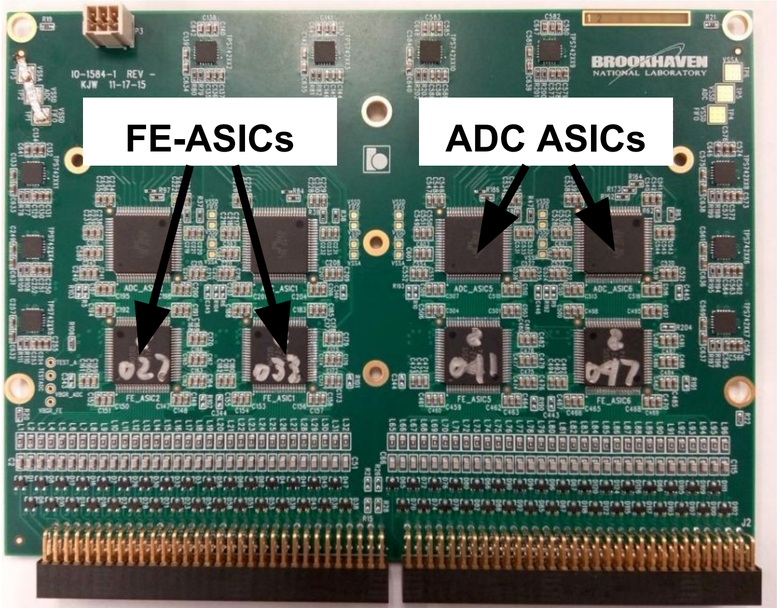


- Cold electronics response correction qualitatively improves event display
- Expect some improvement to reconstruction

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

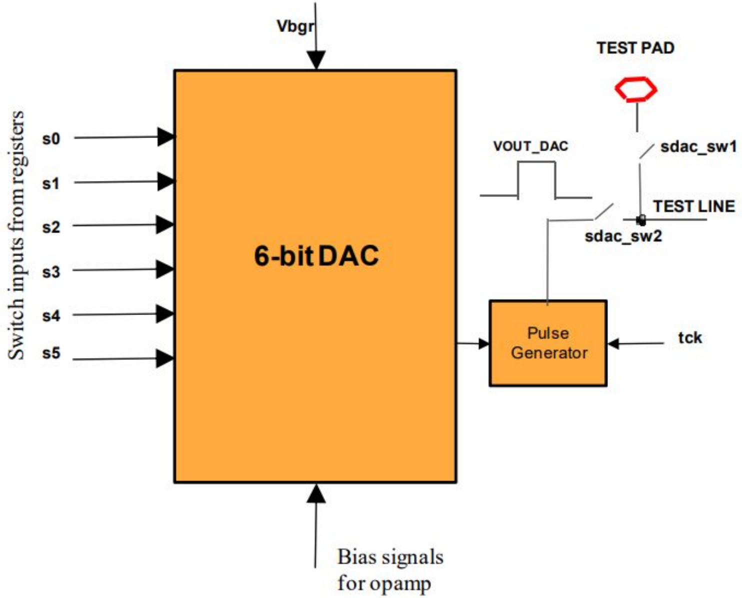


SBND/protoDUNE FEMB

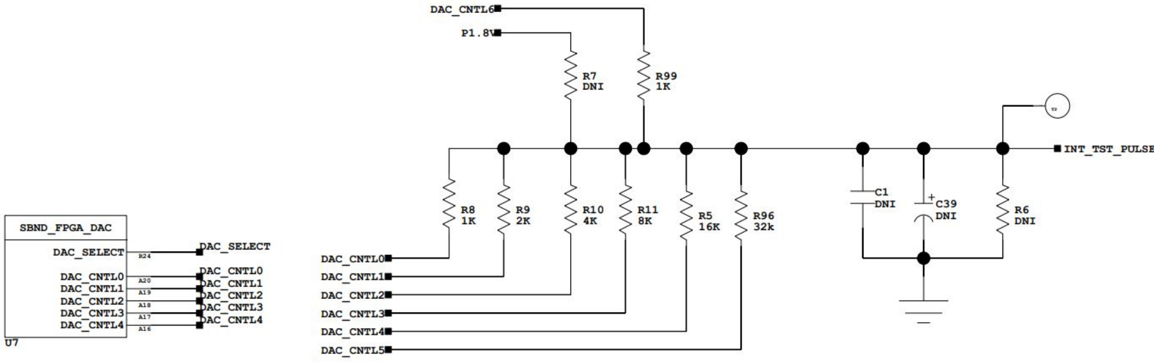
ProtoDUNE Electronic Response Calibration System

- protoDUNE cold electronics calibration injected signal calibration sources
  - 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

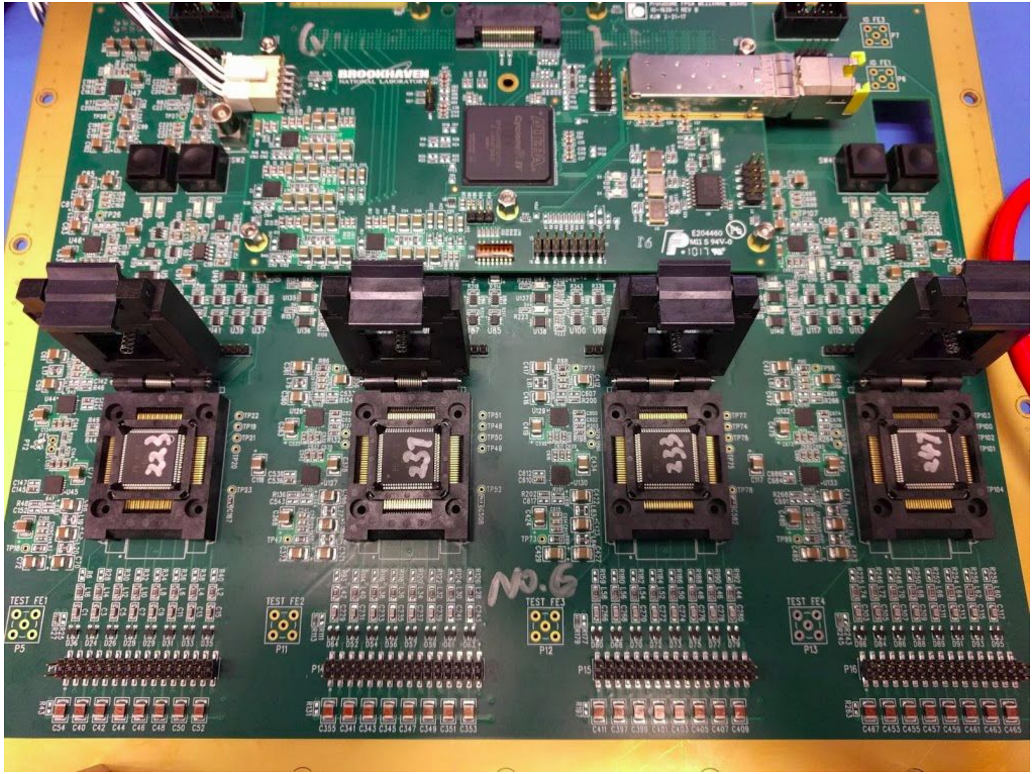
LArASIC On-Board DAC and Pulse Generator



External DAC FPGA Pins and Resistor Divider



Cold Electronics Calibration: Test Signal Capacitor and Production Testing



- Main uncertainty in injected signal magnitude is due to value of test input capacitor
- Need to measure this in production testing for optimal calibration

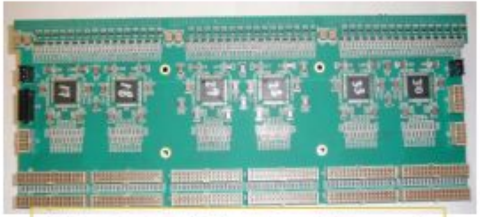
Summary

- 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

Backup

The MicroBooNE Detector: Frontend Electronics

Cold electronics



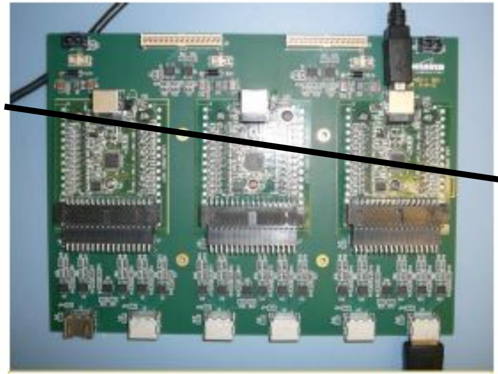
Horiz Cold Motherboard

Vertical Cold Motherboard

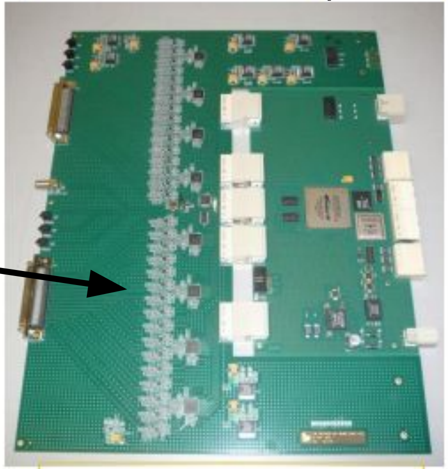
Intermediate Amplifier

Service Board

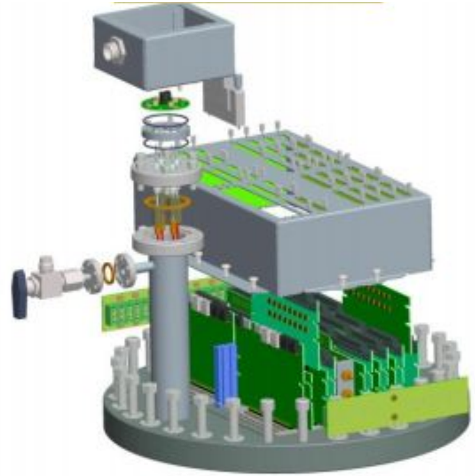
12-bit ADCs
Sampling at 2MHz



ASIC Configuration Board



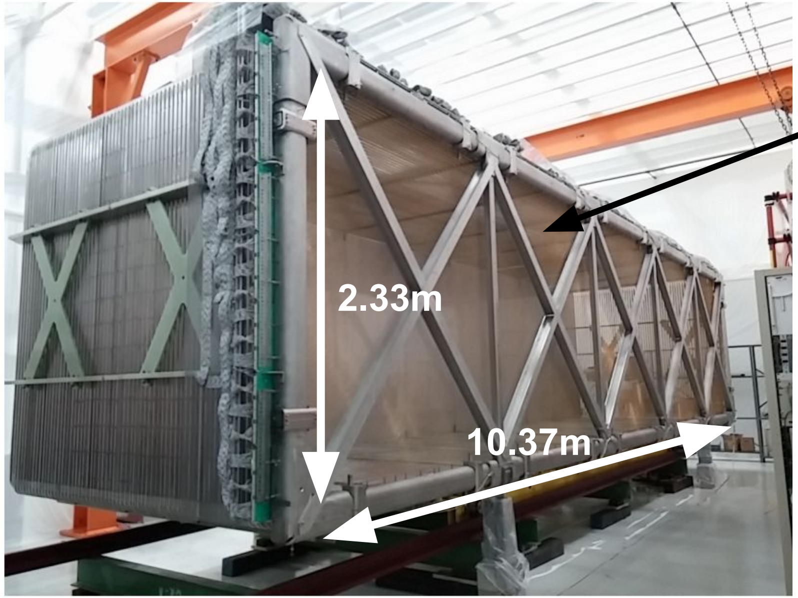
ADC Receiver Board



Signal Feed-Through

Reminder: The MicroBooNE Detector: Cryostat, TPC

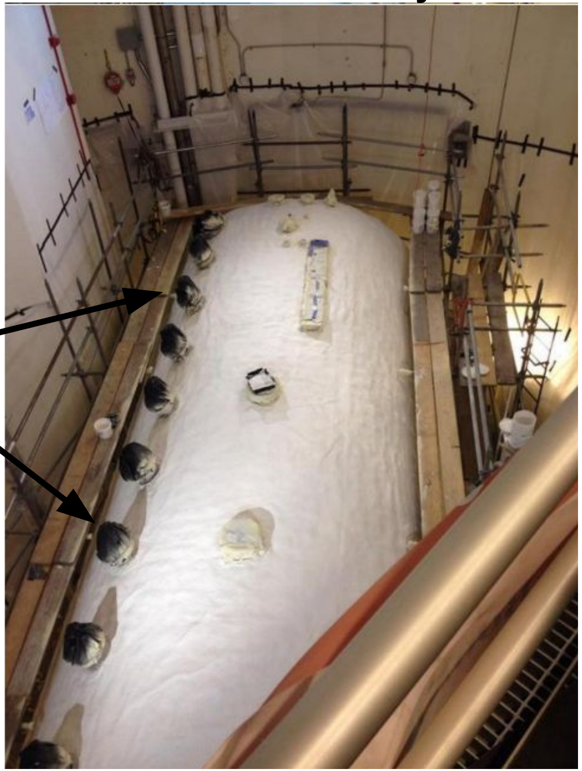
MicroBooNE LArTPC with Wire Planes + Cold Electronics Installed



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