ProtoDUNE TPC calibration with pulser data

ProtoDUNE simulation and reconstruction

David Adams

BNL

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Introduction

I have performed a gain calibration for the protoDUNE TPC

- Evaluated gain for each TPC channel
  - Q = gain × (ADC – pedestal)
- Area normalization
  - Sum of charge in a peak gives the collected charge
  - Gain units are ke/(ADC count)/tick
- Based on December external pulser data
  - Assume pulser step charge is Q_{step} = 3.448 fC
    - Obtained from linear fit of pulser circuit response with nominal values for resistors and injection capacitor
- Calibration is in dunetpc
  - Retrieve values with tools.areaGain_calib20190205
    - Tool interface is FloatArrayTool
    - Values are stored in fcl files
  - Apply calibration in dataprep with tools.adcSampleCalibration
    - Tool interface is AdcChannelTool
    - Replace tools.adcSampleFiller in current default reco

Pulser data

Results here based on external (FEMB) pulser data

- I use data taken with preamp gain 14 mV/fC and shaping 2 µs
- December data
  - Runs taken with 15 amplitude settings
    - A = 1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 15, 18, 21, 25, 30
    - Q = A ×(3.45 fC) = A × (21.5 ke) ≈ A MIP
- Standard preamp setting (14 mV/fC, 2 us)
- January data to fill in gaps and repeat some settings
  - Jan 29: A = 3, 9, 10, 11, 13, 14, 16, 17. Camera LEDs on.
  - Jan 30: A = 3, 10. Camera LEDs off.
- February data A = 1, 2, …, 15

Other data

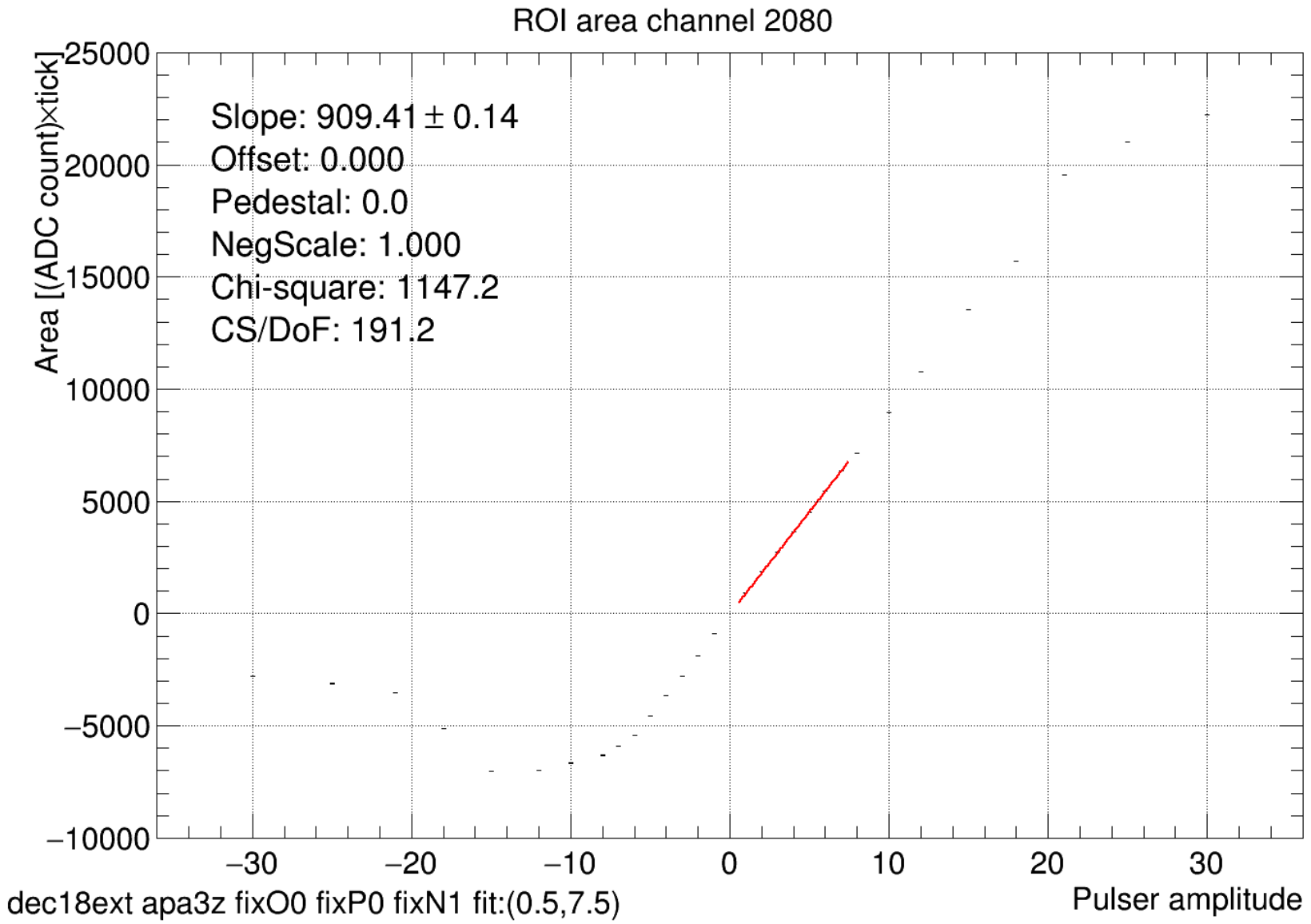
- There is also data taken with internal (ASIC) pulser
- Has large (~ 1 MIP) unexplained (?) voltage offsets which vary from channel to channel (maybe ASIC to ASIC)
- May still be useful for calibration as offset appears to be the same for all pulser settings (one extra nuisance parameter)
- This data is not used here

Method

Calibration procedure

- Mean response evaluated for channel and pulser setting (A)
  - Discussed in previous meetings
    - Mean area evaluated with truncated RMS
    - Height and shaping time fitted with CE response for each pulse are also studied but calibration here is based on area
  - Typically 50 events each with 12 pulses
  - Each charge sign treated separately
  - Uncertainty on mean area is RMS/sqrt(N)
- Response is evaluated from mean area vs (signed) pulser setting
  - Example shown of following page
  - Results here based on a one-parameter fit (slope) for $+1 \leq A \leq +7$
  - December data is used for the fit (first protoDUNE external pulser data)
  - Channel gain is then obtained from Q_{step}/slope

Example response fit

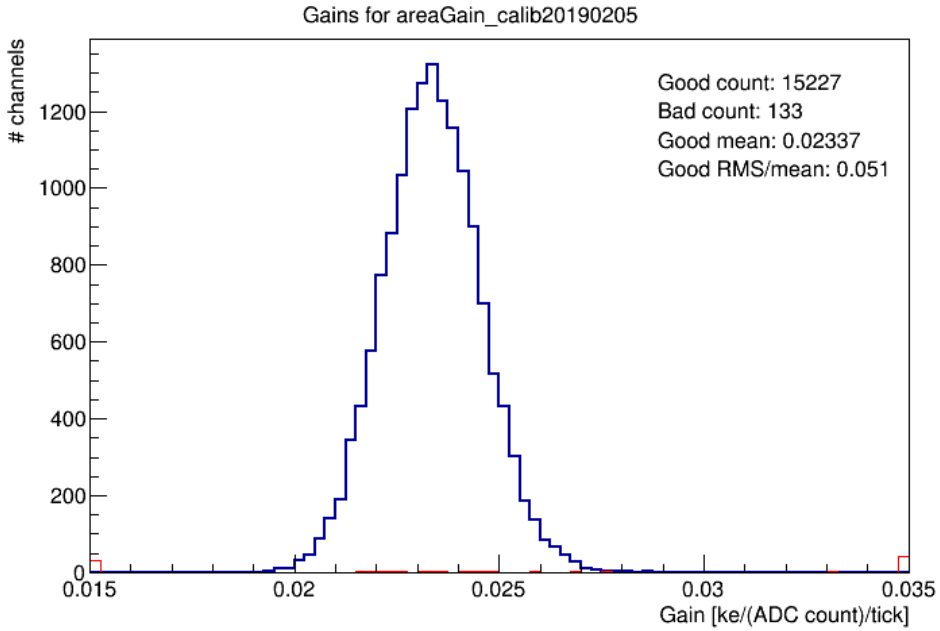


Calibration results: gains

Plot shows distribution of gains

- Mean value is

  0.0234 ke/(ADC count)/tick
- RMS is 5.1%
- Red are channels previously flagged as bad
  - I.e. using ChannelStatusService
  - Only these are outside plot range



Residuals

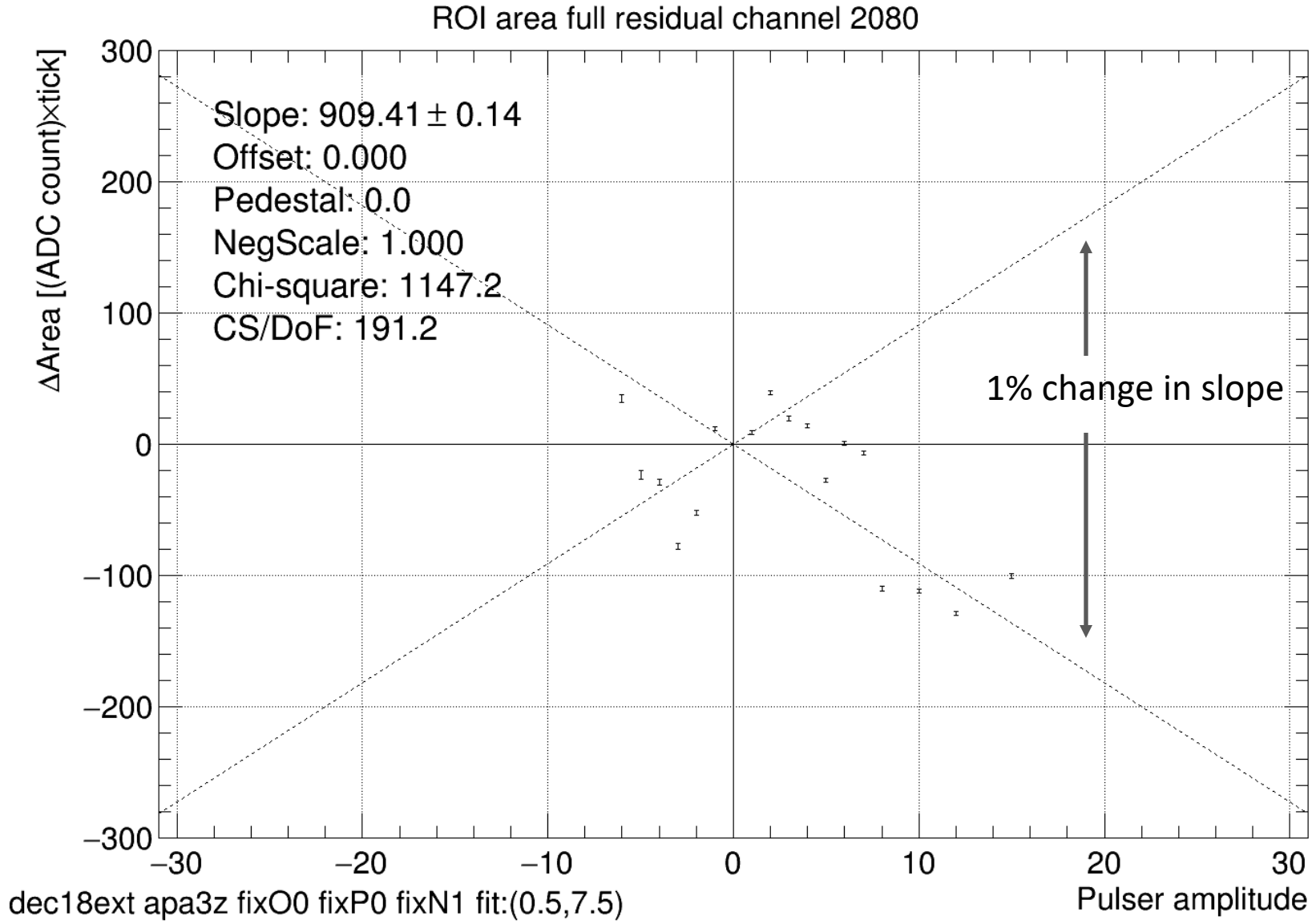
Look at residuals to judge fit quality

- Raw residual = (measured area) – slope × A
- This is plotted vs. A for each channel
  - Example plots follow showing fitted data and same adding other data
  - All 15360 plots may be found at
    - http://internal.dunescience.org/people/dladams/protodune/calibrations/calib20190205/areaResidualPlots
    - Follow up link to find height residuals, shaping time distributions and calib fcl

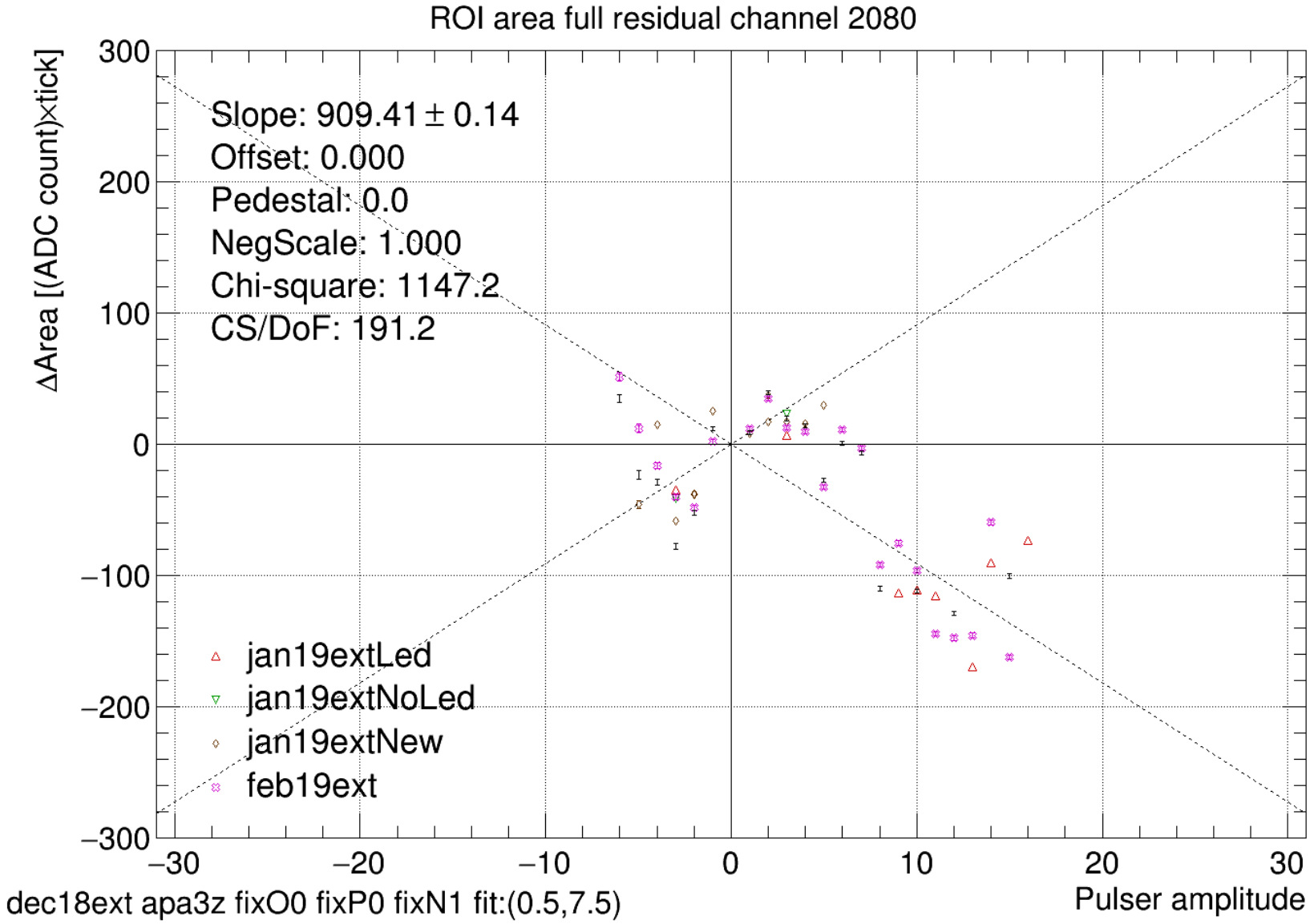
Residual summary plots also follow

- Fit residual = (calibrated area) – $A \times Q_{step}$
- Distribution plotted for all channels separately for each gain setting
  - Systematic shifts seen

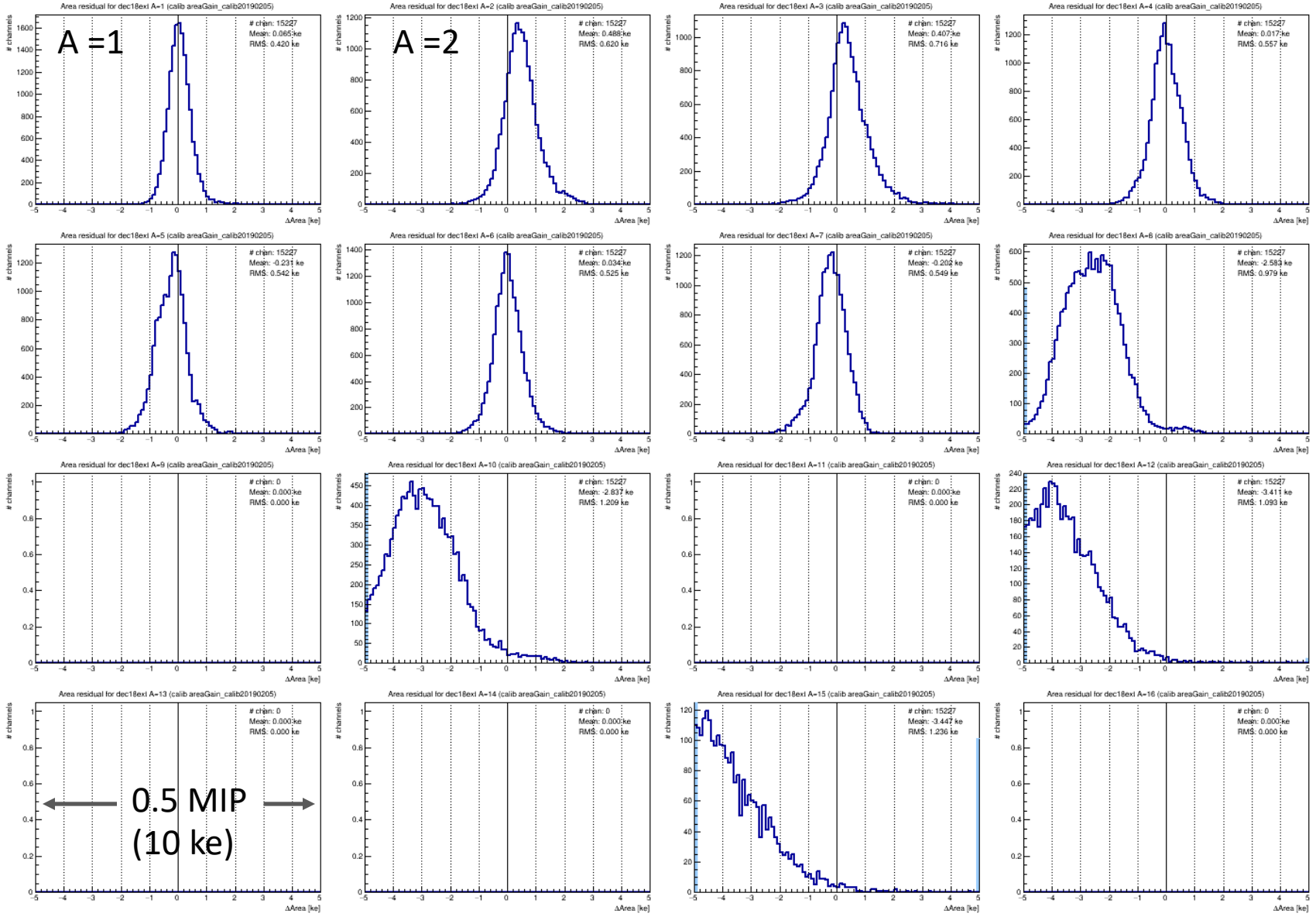
Example residual plot



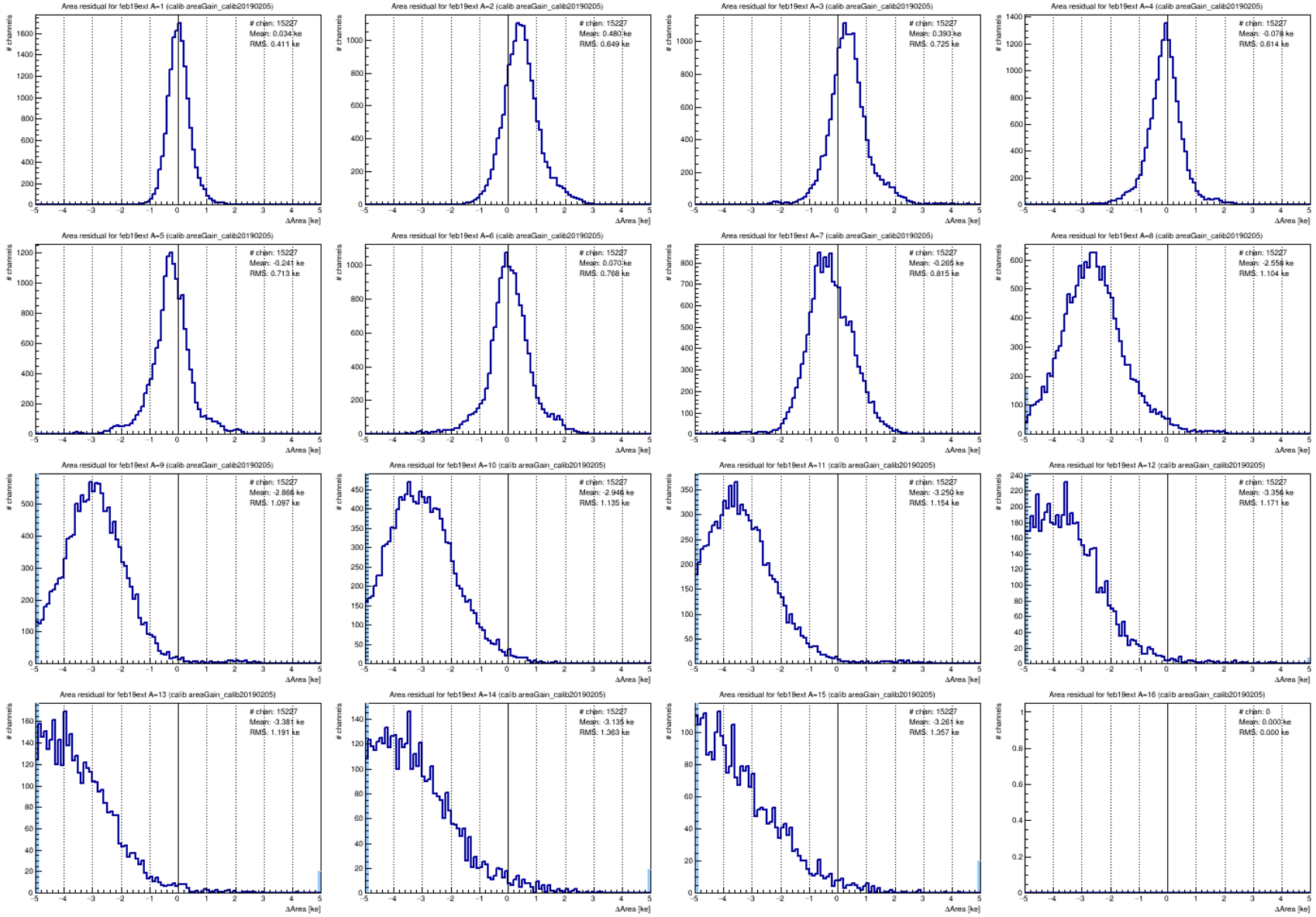
Example residual plot adding other data



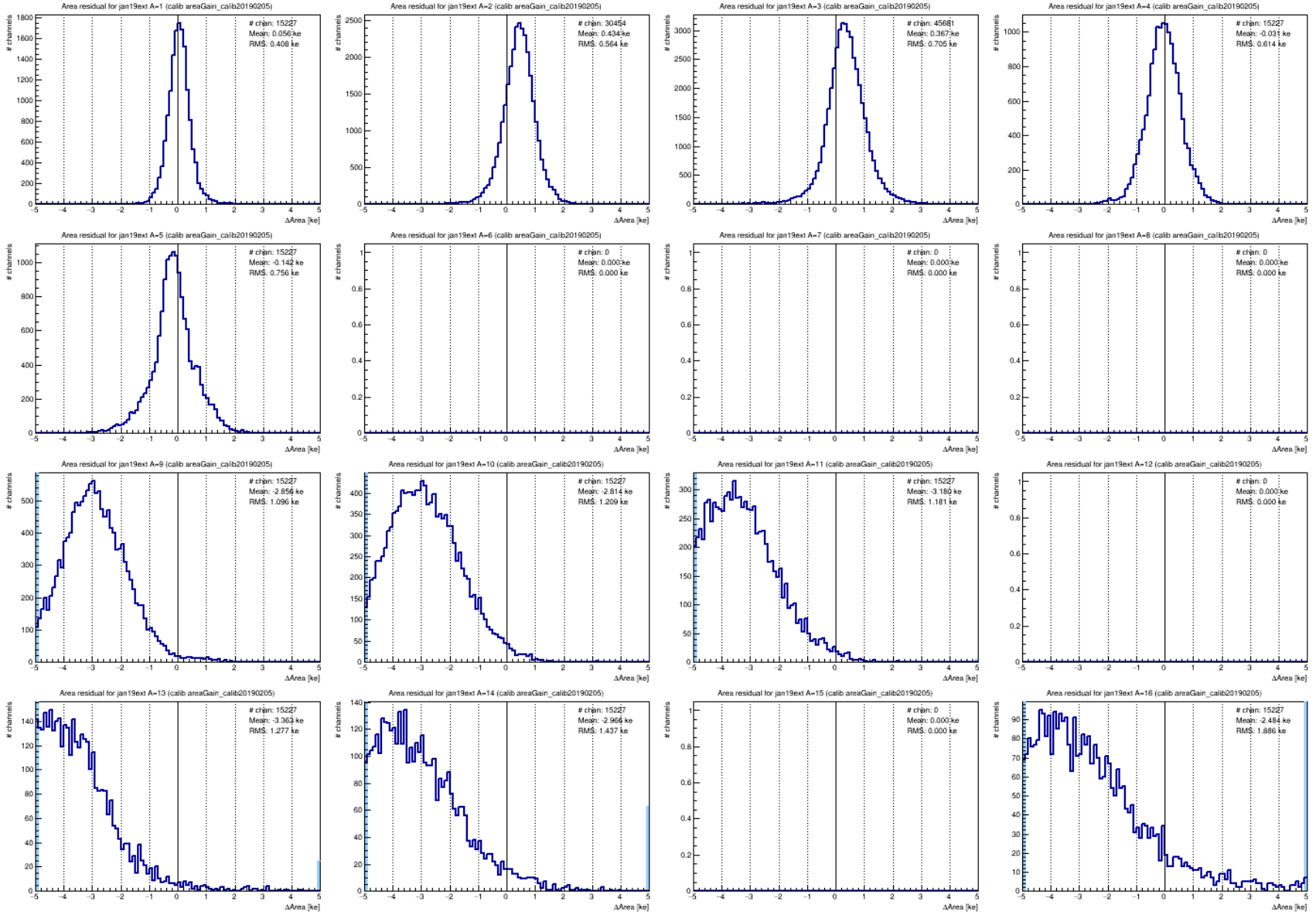
Residual summaries for fitted data



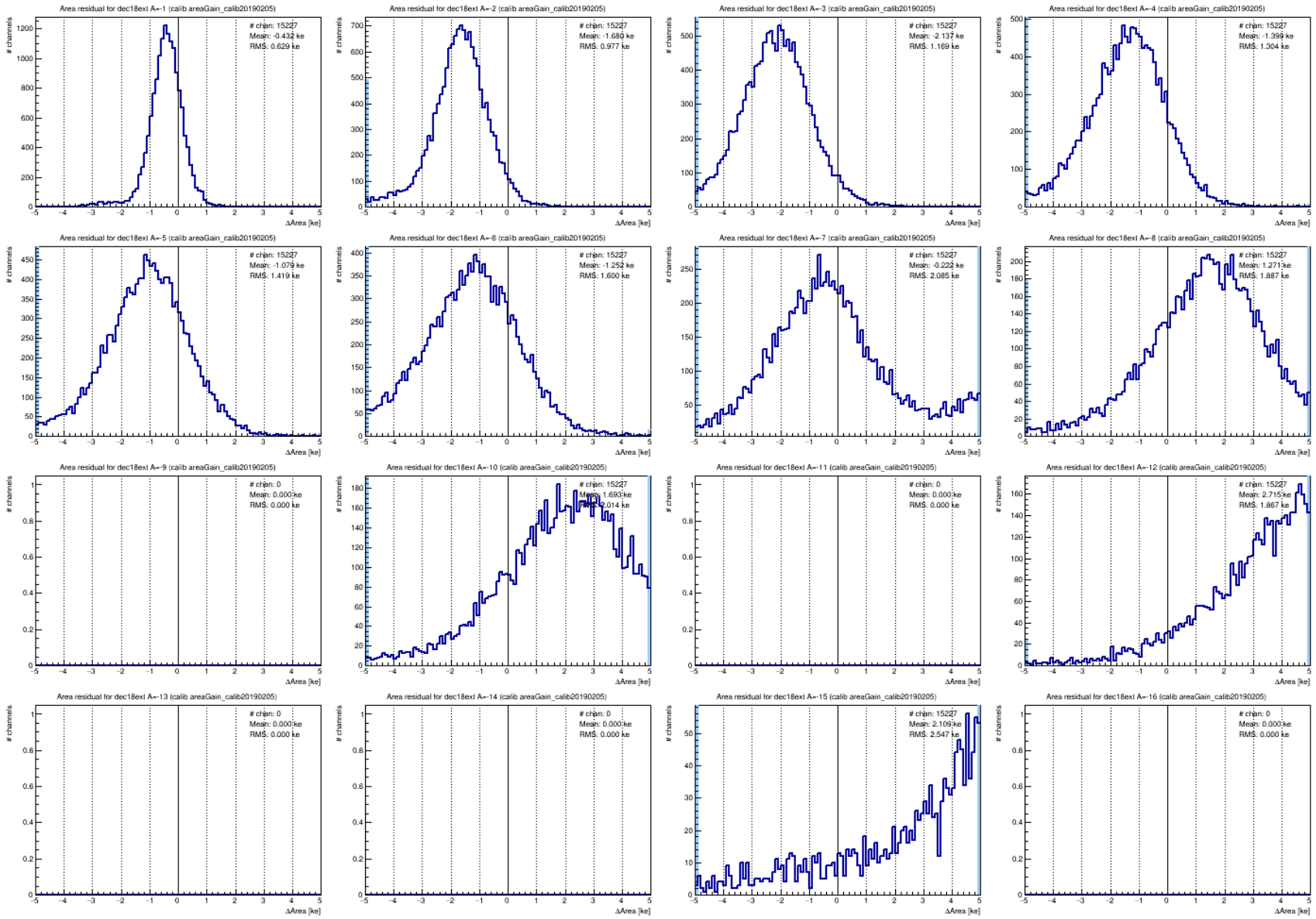
Residual summaries for February data



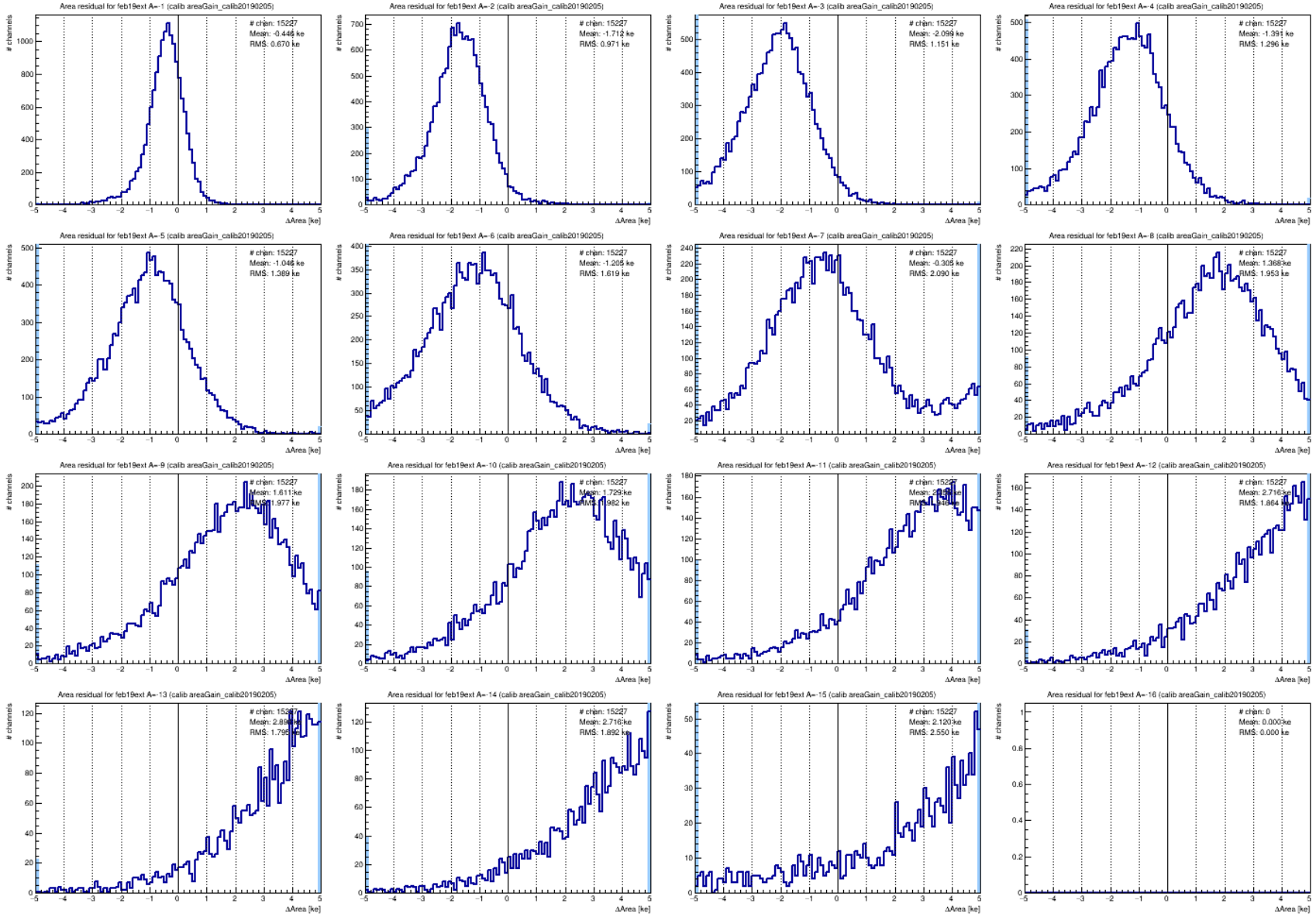
Residual summaries for January data



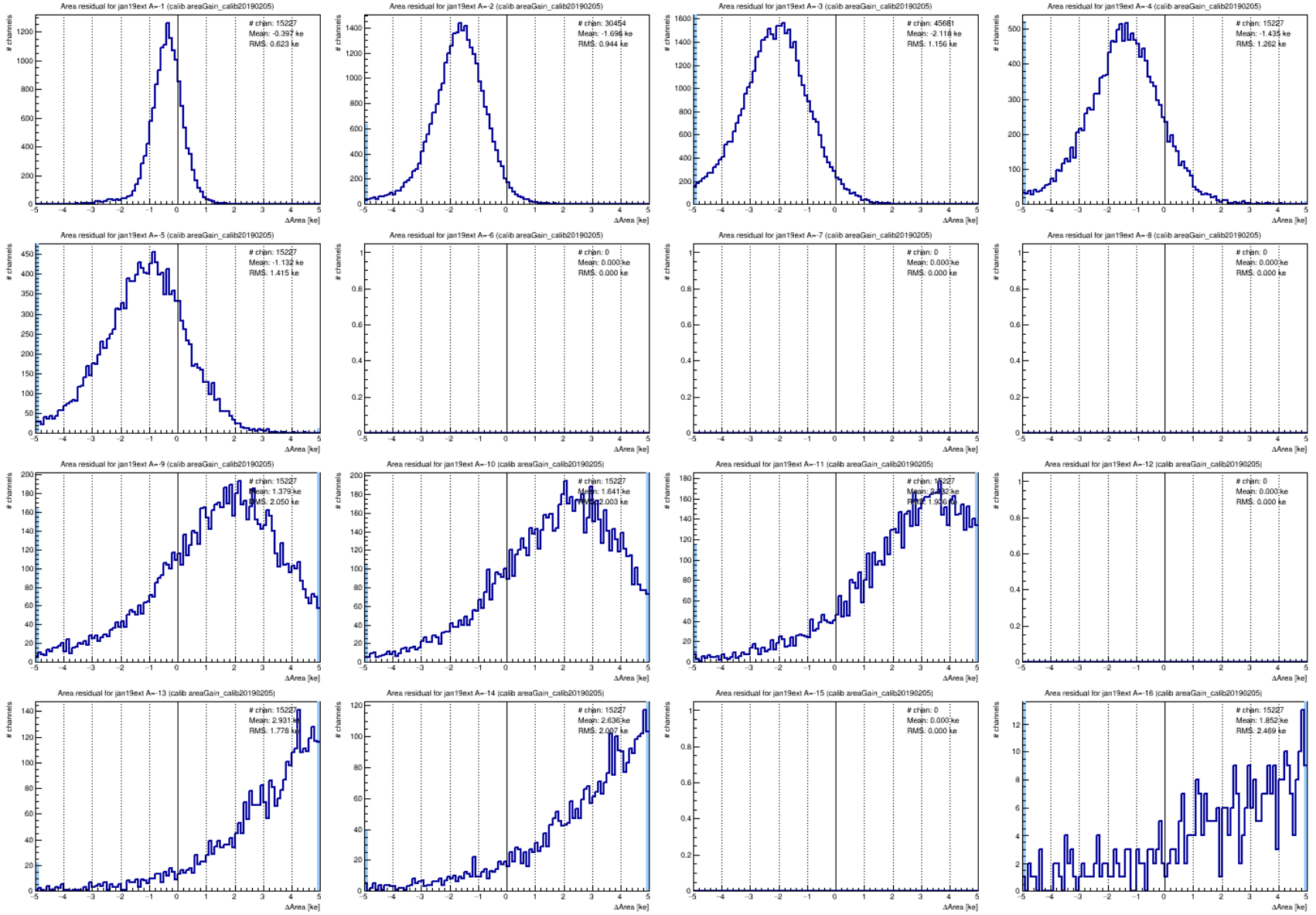
Neg pulse residual summaries for fitted data



Neg pulse residual summaries for February data



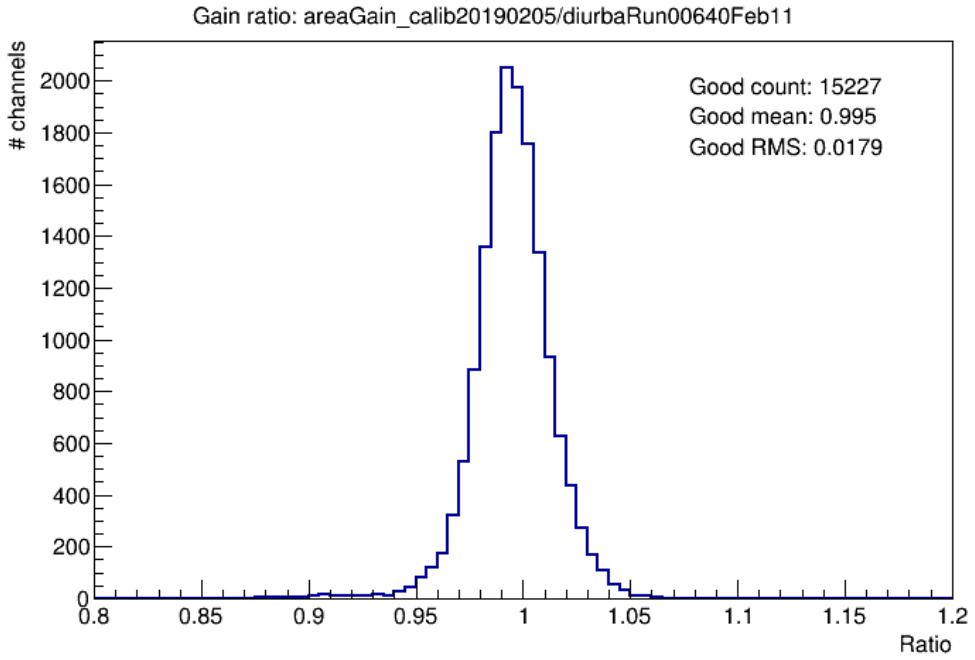
Neg pulse residual summaries for January data



Comparison with other calibrations

Richie Diurba has also been working on calibration

- Same dataset (I think) but he fits +2 ≤ A ≤ +7
- He gave me his gains and the ratio of his and mine are shown in figure
  - Histogram has the ratio of my gain to his for each good channel
- Mean is close to one (good!)
- RMS of 1.8% is a bit more than I would like to see



Comments/conclusions

Charge calibration is now available

- Tools in dunetpc to access gains and apply them in dataprep
- We should enable this in default reconstruction
- Need adjustment of downstream tools to cope with new charge scale
  - ke/tick instead of ADC counts
- Reduces channel-channel RMS scale variation from 5% to ∼1% (?)

Some systematic non-linearities are observed

- A = 2, 3 residuals 400 e high and A = 5, 7 200 e low
- Residuals low and broad for A ≥ 8
- Negative pulse residuals
  - Scale (shaping time) is different for negative pulses
- Likely the non-linearity has significant contribution from both the pulser and the ADC

Future work

Look at internal (ASIC) pulser data

- Is it consistent with external?
- We have some such data taken during the run
- But why does internal pulser have large voltage offsets?
  - Can we assume these are independent of gain setting?
  - And common to all 6 channel on an ASIC?

Study/remove pulser non-linearity

- Response change at A = 2, 4, 8, 16, 32 is qualitatively explained by the pulser's voltage divider
- Include some or all of the 6 resistance values in the pulser circuit as nuisance parameters in the gain fit
  - Common to all channels in each FEMB
- What can we gain by measuring the values or pulser response
  - Or using resistors with better than 1% tolerance?
- Data at different preamp gains can help to distinguish ADC and pulser