ProtoDUNE analysis: Pulser study of new sticky code interpolation II

ProtoDUNE sim/reco

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BNL

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Pulser signals

Cold electronics provide the option to inject pulses

- At regular intervals, injected voltage is raised and then lowered
  - Controlled with 6-bit DAC ➔ 64 levels
  - Fairly linear with step size V_S = 18.75 mV
- Capacitively coupled to preamp input
  - C = 183 fF
- Voltage change corresponds to fast charge collection
  - Step size is Q_S = (183 fF) × (18.75 mV) = 3.43 fC = 21.4 ke
  - This is about 1 MIP
    - Prefer something smaller?

Signal may be generated in either of two places

- Internal: signal generated in the preamp ASIC
  - Input voltage has significant offset that varies from ASIC to ASIC
  - Variations are a large fraction of the step size
- External: signal generated on the FEMB
  - Little or no offset: for DAC setting S, Q = S × Q_S

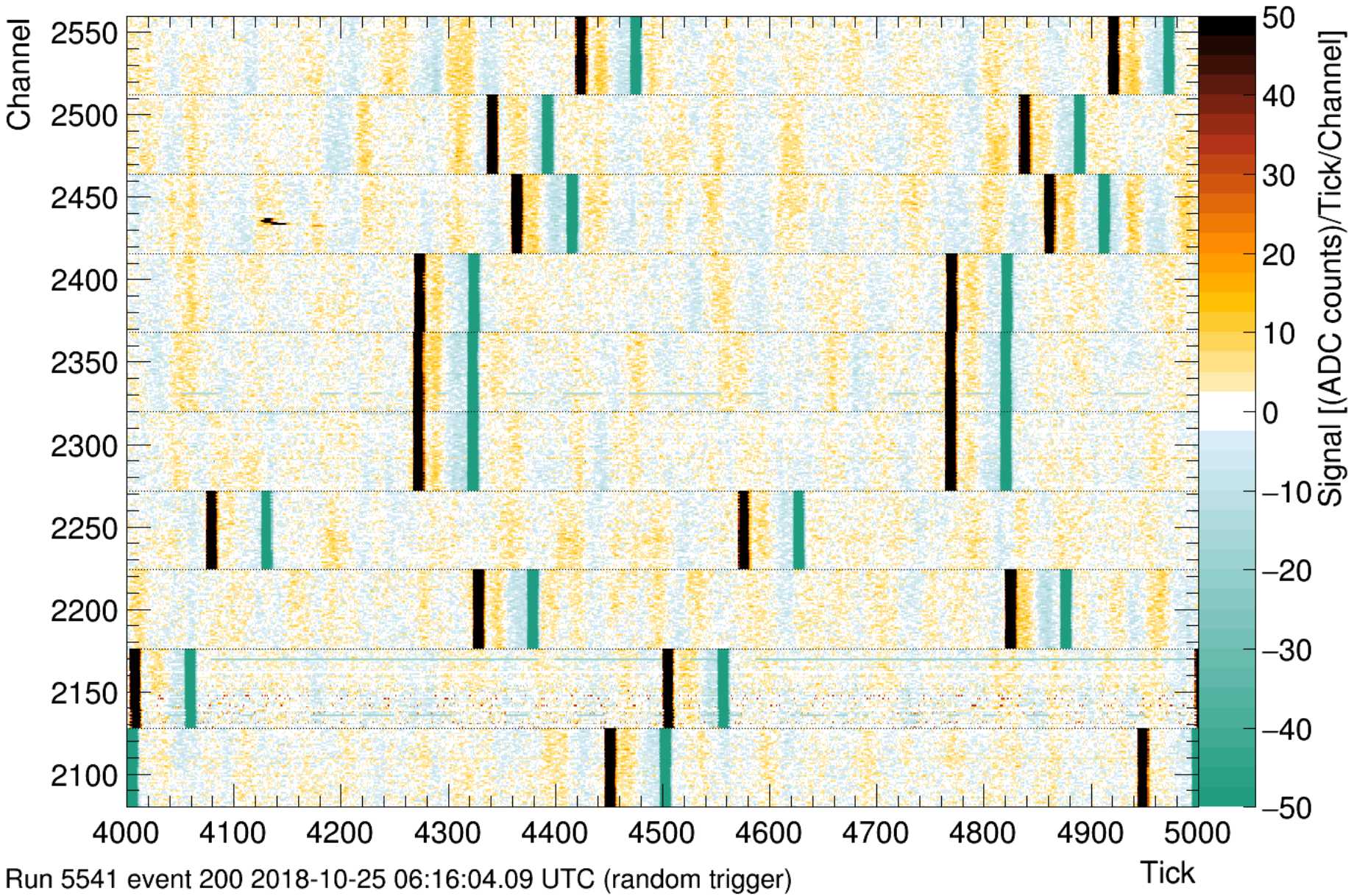
ProtoDUNE data

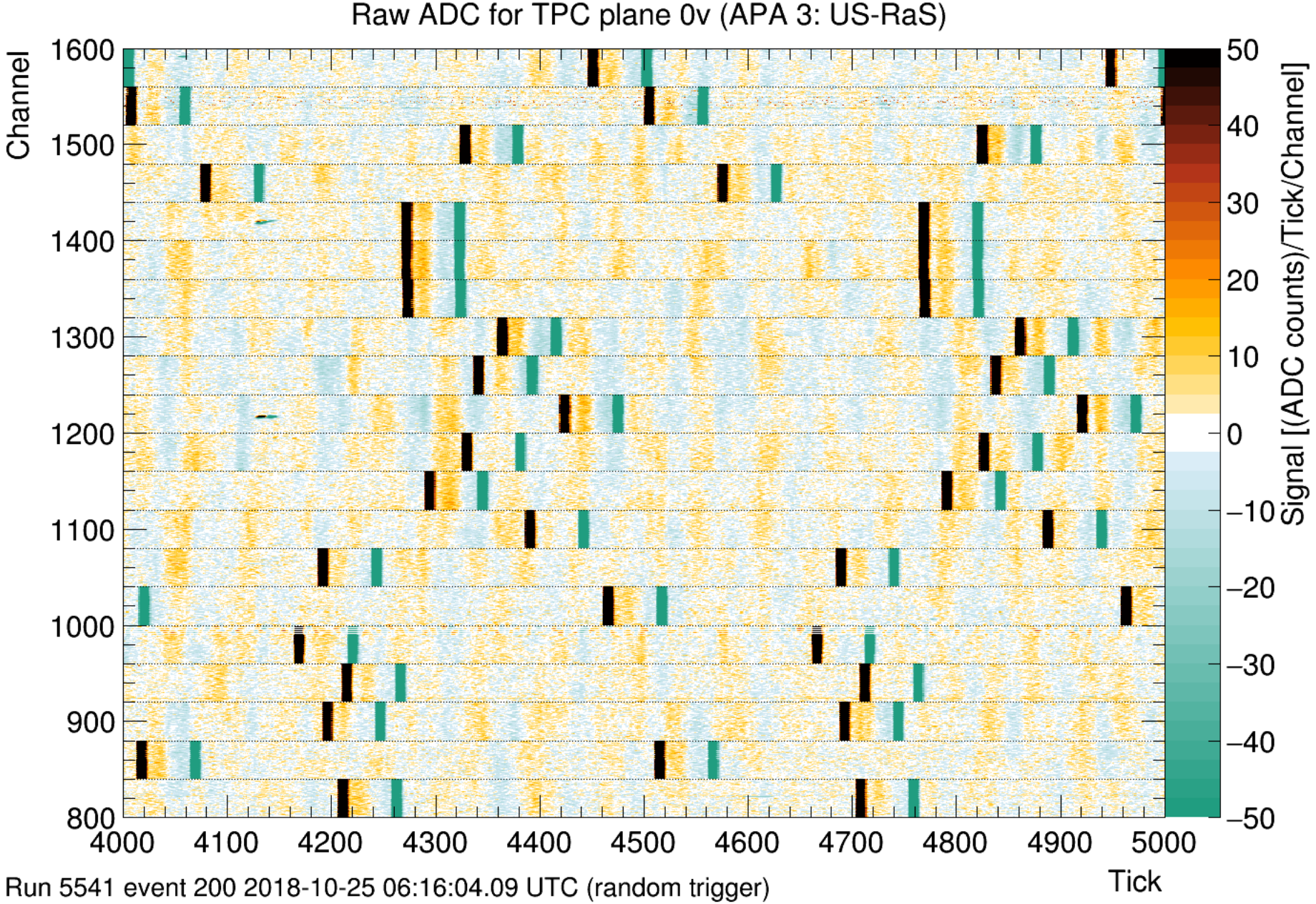
Some pulser amplitude scans have been taken with protoDUNE

- Amplitude scan means the voltage DAC is varied
  - New run started for each DAC setting (0,1 , 2, …)
- All taken with internal pulser
- Aug 9-21
  - Detector filling
- Sep 21
  - Before baseline shift to fix “ledge effect”
- Oct 25
  - Cathode HV off, anode and grid on
  - After baseline shift (Oct 11)

I have requested more data ASAP

- Amplitude scan with all HV off and all HV on
  - Both internal and external pulser (4 scans total)
- Later multiple scans with varying timing offset


Raw ADC for TPC plane 0z (APA 3: US-RaS)
Channel
2550
2500
2450
2400
2350
2300
2250
2200
2150
2100
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
Tick
50
40
30
20
10
0
−10
−20
−30
−40
−50
Signal [(ADC counts)/Tick/Channel]
Run 5541 event 200 2018-10-25 06:16:04.09 UTC (random trigger)


Raw ADC for TPC plane 0v (APA 3: US-RaS)
Channel
1600
1500
1400
1300
1200
1100
1000
900
800
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
Tick
50
40
30
20
10
0
−10
−20
−30
−40
−50
Signal [(ADC counts)/Tick/Channel]
Run 5541 event 200 2018-10-25 06:16:04.09 UTC (random trigger)

Pulser studies

The pulser data can be used for many important studies

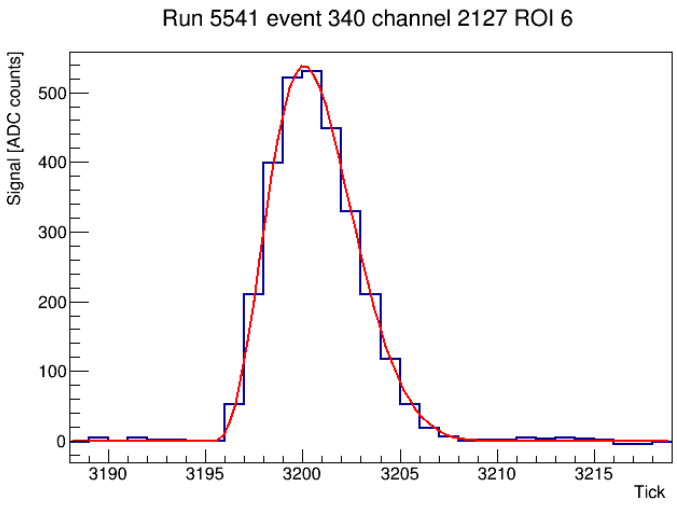
- Resolution
  - For a given amplitude setting, measure how the height and area of the processed signal vary
    - RMS, tails, etc.
    - Area measurement directly applicable to collection signals from tracks
  - At different stages and with different processing options
    - Pedestal evaluation, sticky code mitigation, tail correction, deconvolution
- Gain calibration
  - Processed signal height or area vs pulser amplitude provides gains
  - Also find the range of (roughly) linear response for each channel
    - ADC and preamp may restrict this range
- Gain nonlinearities
  - Expect signal to be the same for each tick along the pulse
  - Use tickmod = tick%497 to get a finer mapping of gain vs input charge
- Sticky codes
  - Use tickmods to search for sticky codes as was done for pedestal

Today

Tools

There are some tools useful for studying pulser data

- AdcRoiViewer
  - Waveform for each ROI (pulser signal and more)
    - Includes option to fit with CE waveform
  - Summary histograms of ROI properties
    - Area, fitted height, shaping time, …
  - Summary params (e.g. RMS) vs. channel
  - Under continuing development
    - Many changes over last week



- AdcTickModViewer
  - Histograms of ADC counts filled separately for each tickmod
  - Use mean for gain studies
  - Look at tails and sticky codes

Rough calibration

Rough height calibration

- ProtoDUNE data taken with gain 14 mV/fC
  - Pulse height for rapid charge injection
- Nominal shaping time is 2 μs—actual 4.35 ticks with variation
- ADC response is 3.0 ADC/mV with variation
  - Combining these, the rapid pulse gain is 42 ADC/fC = 6.7 ADC/ke
  - I.e. pulse height calibration is 150 e/ADC

Area calibration

- Detector signals do not have rapid charge injection
  - See example waveforms on following pages
- Best estimate of FE input charge is presumably the area in an ROI
- Rapid pulse area = 1.269 × Height × (Shaping time)
  - From CE response function checked with pulser data
- Nominal FE-ADC calibration is 27.2 e/(ADC-tick)
  - Channel variations from ADC response, preamp gain and shaping

Sticky code mitigation

Search for stick codes described previously

- I looked at waveforms for all channels
- Record (in fcl) codes that look sticky
  - Only in pedestal region

Mitigation is applied to those codes

- For release v07_12_00 and earlier, this was linear interpolation
  - Between nearest good samples below and above
- New in v07_13_00 (now improved), constant-curvature interpolation
  - I.e. quadratic function of tick
  - Still required to pass through two nearest samples
  - Choose curvature to come close to the second closest good sample below and above the mitigated sample
    - Could use 3rd order polynomial and cross both but too many wiggles
    - Last release, choose equally close to the 2nd nearest samples (call this ccv1)
      - » But sample in a signal can push the other side away from the baseline
    - Now weight the 2nd samples to favor one close to the 1st sample on its side

Evaluating resolution

Resolution is a key performance metric

- Response can be calibrated out
  - But calibration residuals may contribute to resolution
- Use (calibrated) resolution to see if we are making things better

How to evaluate resolution?

- Raw RMS provides simple measure but may be dominated by tails
  - E.g. overlap with or confusion from cosmic or radiological signals
- Gaussian fit often provides nice measure of core resolution
  - Typically unaffected by tails (good and bad)
  - Poor estimate for split peaks often seen with with sticky codes
    - Fit often settle on one (sometimes the wrong) peak
    - Utility GausStepFitter helps find the peak with expected resolution
- Have added truncated RMS “fitter”
  - Evaluate RMS over a region centered on peak
  - Iterate until region covers ±N×RMS around peak. Here N = 4.
  - Utility GausRmsFitter

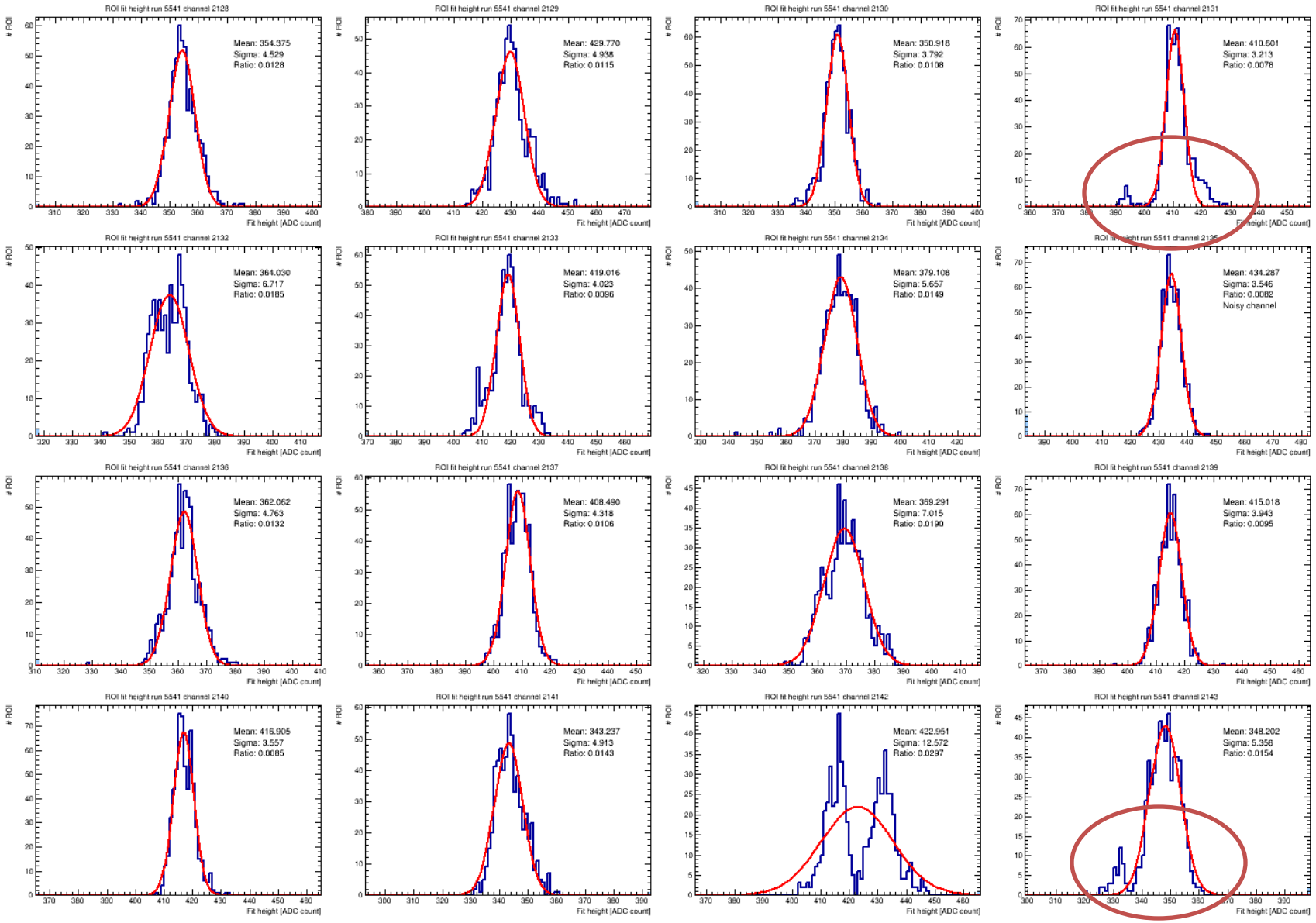
Analysis

Use AdcRoiViewer to study resolution

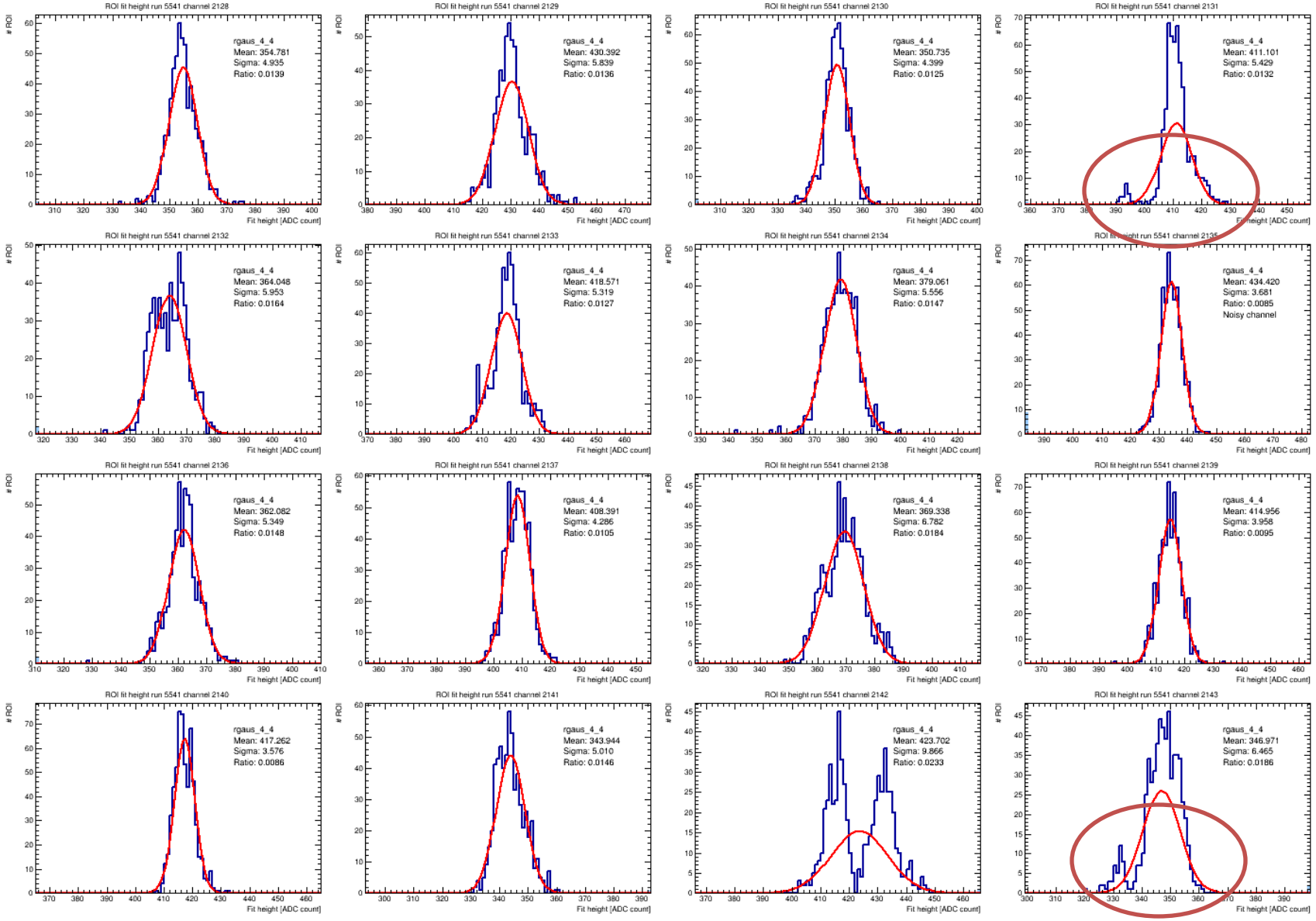
- Without and with ADC mitigation
- Results shown with and without (new) mitigation
- For old (Gaus fit) and new (truncated RMS) estimates of resolution

Resolution fit spectra: old vs. new

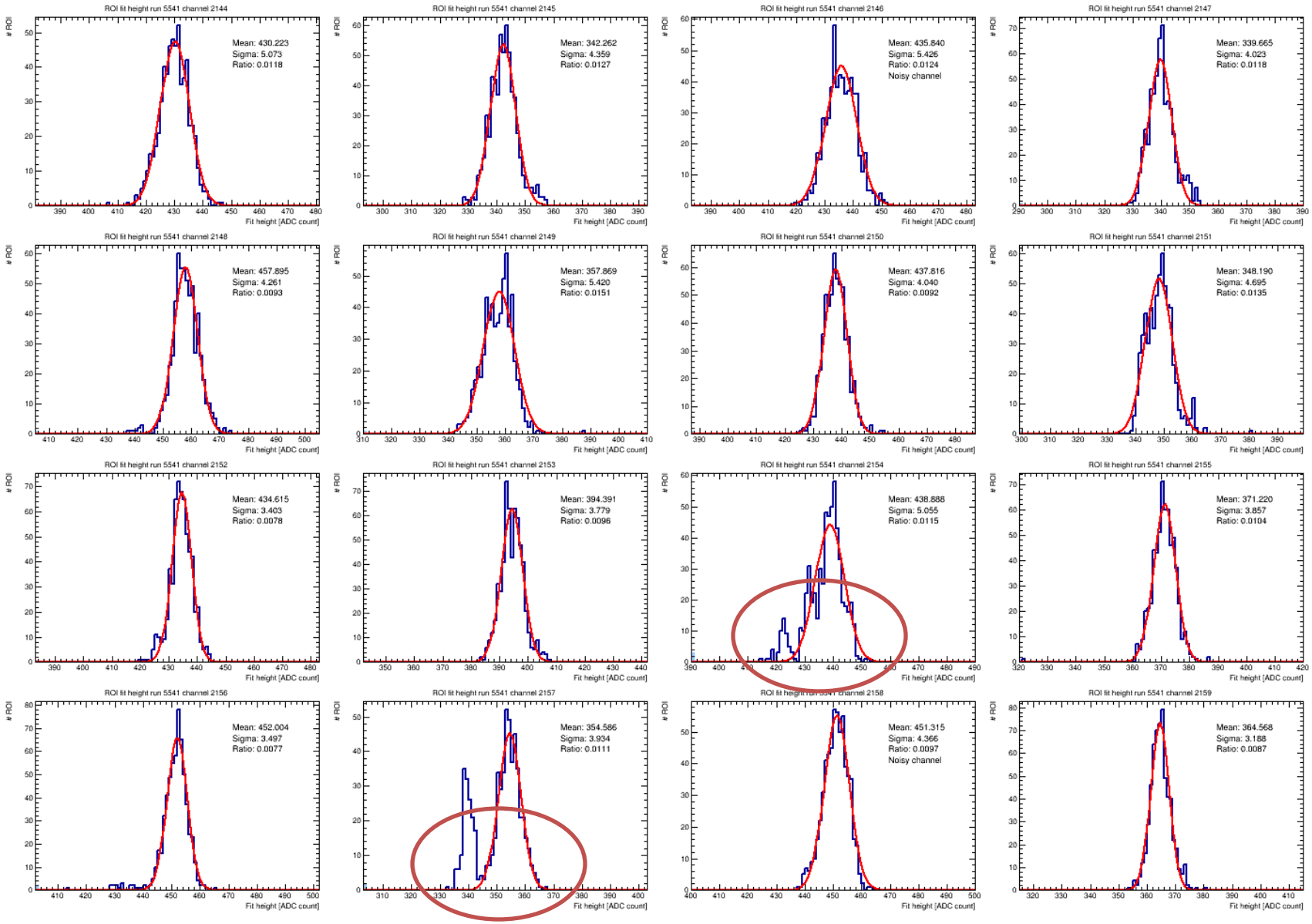
Old fit


ROI fit height run 5541 channel 2128
Mean: 354.375
Sigma: 4.529
Ratio: 0.0128
ROI fit height run 5541 channel 2129
Mean: 429.770
Sigma: 4.938
Ratio: 0.0115
ROI fit height run 5541 channel 2130
Mean: 350.918
Sigma: 3.792
Ratio: 0.0108
ROI fit height run 5541 channel 2131
Mean: 410.601
Sigma: 3.213
Ratio: 0.0078
ROI fit height run 5541 channel 2132
Mean: 364.030
Sigma: 6.717
Ratio: 0.0185
ROI fit height run 5541 channel 2133
Mean: 419.016
Sigma: 4.023
Ratio: 0.0096
ROI fit height run 5541 channel 2134
Mean: 379.108
Sigma: 5.657
Ratio: 0.0149
ROI fit height run 5541 channel 2135
Mean: 434.287
Sigma: 3.546
Ratio: 0.0082
Noisy channel
ROI fit height run 5541 channel 2136
Mean: 362.062
Sigma: 4.763
Ratio: 0.0132
ROI fit height run 5541 channel 2137
Mean: 408.490
Sigma: 4.318
Ratio: 0.0106
ROI fit height run 5541 channel 2138
Mean: 369.291
Sigma: 7.015
Ratio: 0.0190
ROI fit height run 5541 channel 2139
Mean: 415.018
Sigma: 3.943
Ratio: 0.0095
ROI fit height run 5541 channel 2140
Mean: 416.905
Sigma: 3.557
Ratio: 0.0085
ROI fit height run 5541 channel 2141
Mean: 343.237
Sigma: 4.913
Ratio: 0.0143
ROI fit height run 5541 channel 2142
Mean: 422.951
Sigma: 12.572
Ratio: 0.0297
ROI fit height run 5541 channel 2143
Mean: 348.202
Sigma: 5.358
Ratio: 0.0154
ROI
Fit height [ADC count]

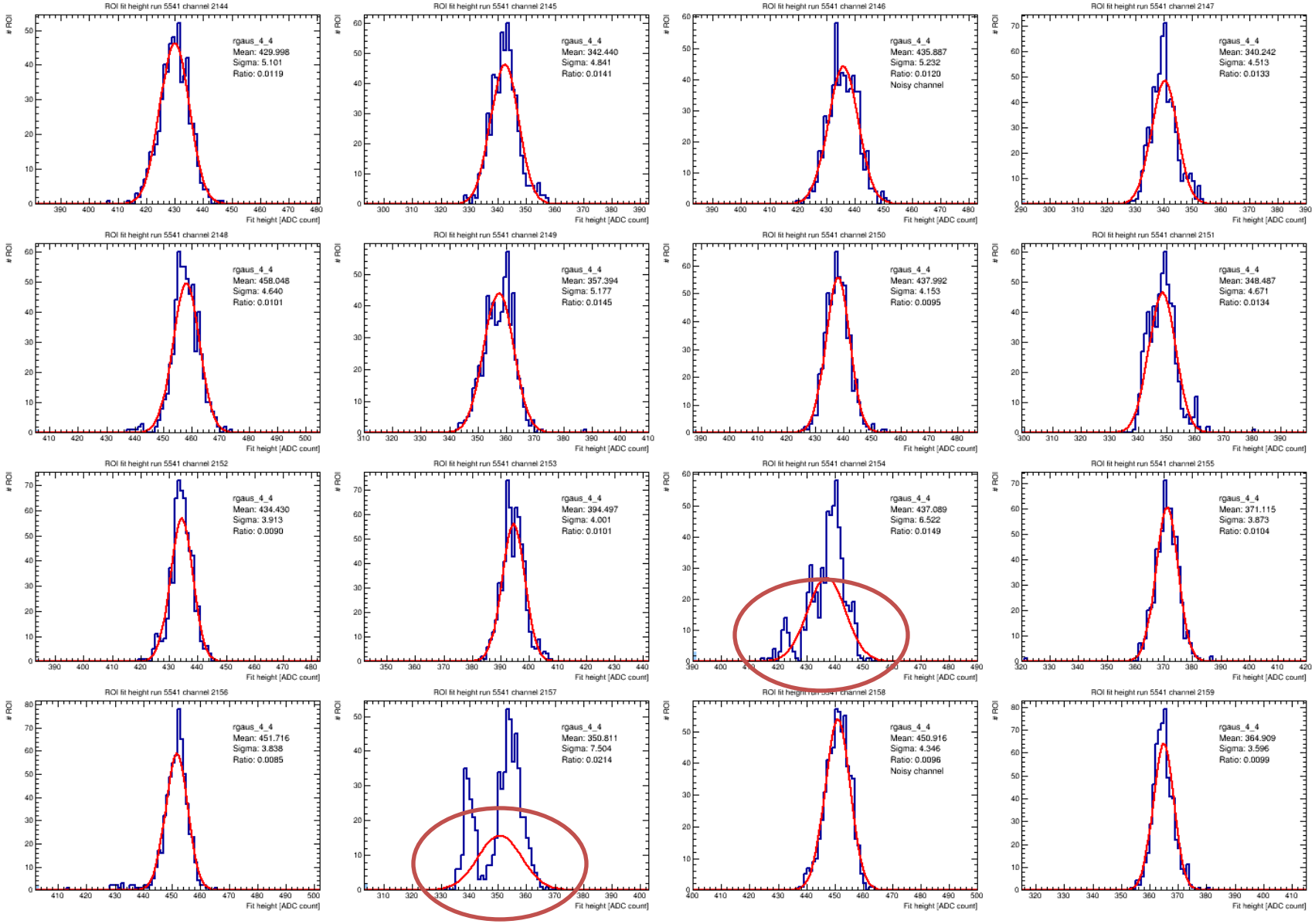
New “fit”


ROI fit height run 5541 channel 2128
rgaus_4_4
Mean: 354.781
Sigma: 4.935
Ratio: 0.0139
ROI fit height run 5541 channel 2129
rgaus_4_4
Mean: 430.392
Sigma: 5.839
Ratio: 0.0136
ROI fit height run 5541 channel 2130
rgaus_4_4
Mean: 350.735
Sigma: 4.399
Ratio: 0.0125
ROI fit height run 5541 channel 2131
rgaus_4_4
Mean: 411.101
Sigma: 5.429
Ratio: 0.0132
ROI fit height run 5541 channel 2132
rgaus_4_4
Mean: 364.048
Sigma: 5.953
Ratio: 0.0164
ROI fit height run 5541 channel 2133
rgaus_4_4
Mean: 418.571
Sigma: 5.319
Ratio: 0.0127
ROI fit height run 5541 channel 2134
rgaus_4_4
Mean: 379.061
Sigma: 5.556
Ratio: 0.0147
ROI fit height run 5541 channel 2135
rgaus_4_4
Mean: 434.420
Sigma: 3.681
Ratio: 0.0085
Noisy channel
ROI fit height run 5541 channel 2136
rgaus_4_4
Mean: 362.082
Sigma: 5.349
Ratio: 0.0148
ROI fit height run 5541 channel 2137
rgaus_4_4
Mean: 408.391
Sigma: 4.286
Ratio: 0.0105
ROI fit height run 5541 channel 2138
rgaus_4_4
Mean: 369.338
Sigma: 6.782
Ratio: 0.0184
ROI fit height run 5541 channel 2139
rgaus_4_4
Mean: 414.956
Sigma: 3.958
Ratio: 0.0095
ROI fit height run 5541 channel 2140
rgaus_4_4
Mean: 417.262
Sigma: 3.576
Ratio: 0.0086
ROI fit height run 5541 channel 2141
rgaus_4_4
Mean: 343.944
Sigma: 5.010
Ratio: 0.0146
ROI fit height run 5541 channel 2142
rgaus_4_4
Mean: 423.702
Sigma: 9.866
Ratio: 0.0233
ROI fit height run 5541 channel 2143
rgaus_4_4
Mean: 346.971
Sigma: 6.465
Ratio: 0.0186
ROI
Fit height [ADC count]

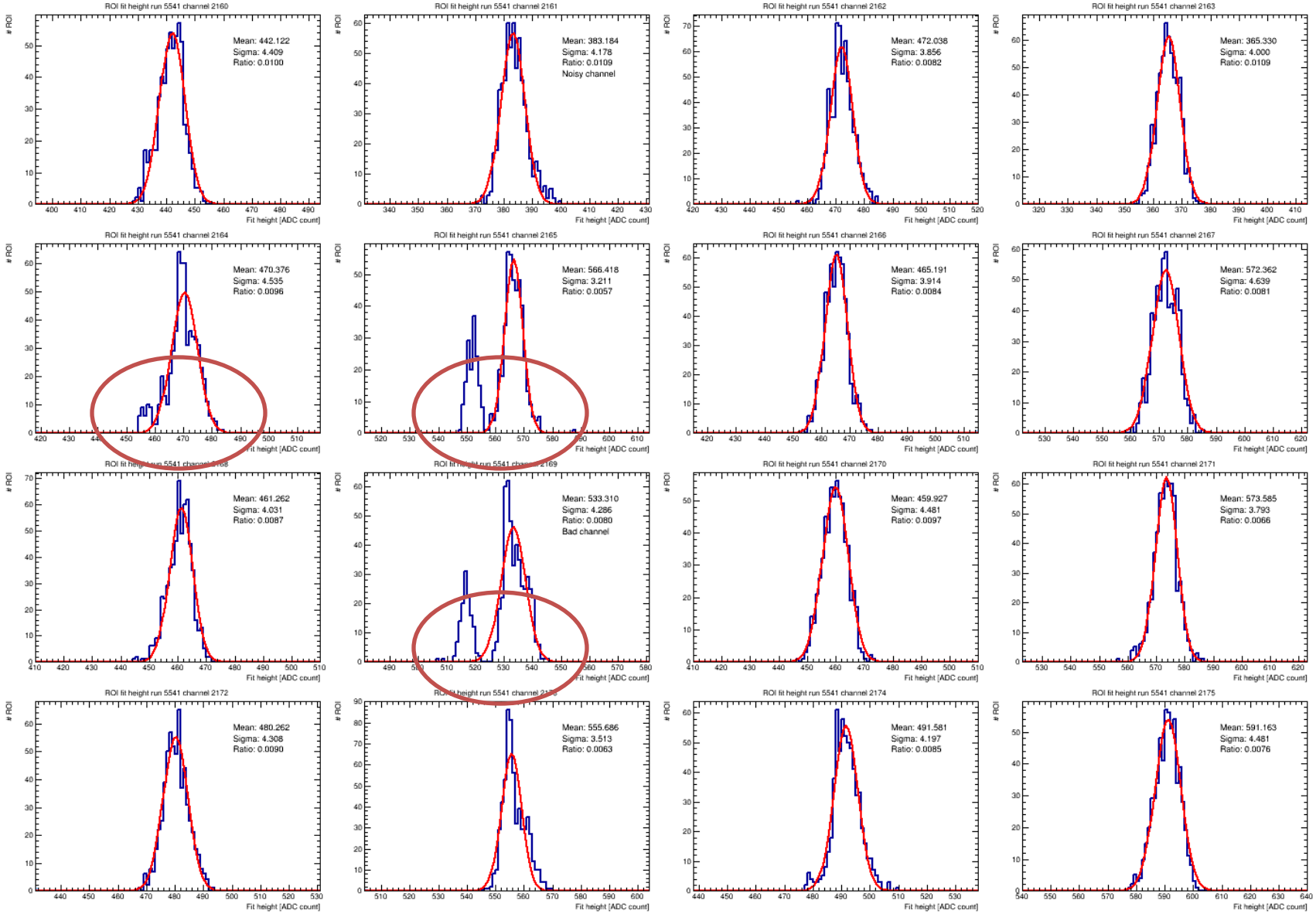
Old fit


ROI fit height run 5541 channel 2144
Mean: 430.223
Sigma: 5.073
Ratio: 0.0118
ROI fit height run 5541 channel 2145
Mean: 342.262
Sigma: 4.359
Ratio: 0.0127
ROI fit height run 5541 channel 2146
Mean: 435.840
Sigma: 5.426
Ratio: 0.0124
Noisy channel
ROI fit height run 5541 channel 2147
Mean: 339.665
Sigma: 4.023
Ratio: 0.0118
ROI fit height run 5541 channel 2148
Mean: 457.895
Sigma: 4.261
Ratio: 0.0093
ROI fit height run 5541 channel 2149
Mean: 357.869
Sigma: 5.420
Ratio: 0.0151
ROI fit height run 5541 channel 2150
Mean: 437.816
Sigma: 4.040
Ratio: 0.0092
ROI fit height run 5541 channel 2151
Mean: 348.190
Sigma: 4.695
Ratio: 0.0135
ROI fit height run 5541 channel 2152
Mean: 434.615
Sigma: 3.403
Ratio: 0.0078
ROI fit height run 5541 channel 2153
Mean: 394.391
Sigma: 3.779
Ratio: 0.0096
ROI fit height run 5541 channel 2154
Mean: 438.888
Sigma: 5.055
Ratio: 0.0115
ROI fit height run 5541 channel 2155
Mean: 371.220
Sigma: 3.857
Ratio: 0.0104
ROI fit height run 5541 channel 2156
Mean: 452.004
Sigma: 3.497
Ratio: 0.0077
ROI fit height run 5541 channel 2157
Mean: 354.586
Sigma: 3.934
Ratio: 0.0111
ROI fit height run 5541 channel 2158
Mean: 451.315
Sigma: 4.366
Ratio: 0.0097
Noisy channel
ROI fit height run 5541 channel 2159
Mean: 364.568
Sigma: 3.188
Ratio: 0.0087
ROI
Fit height [ADC count]

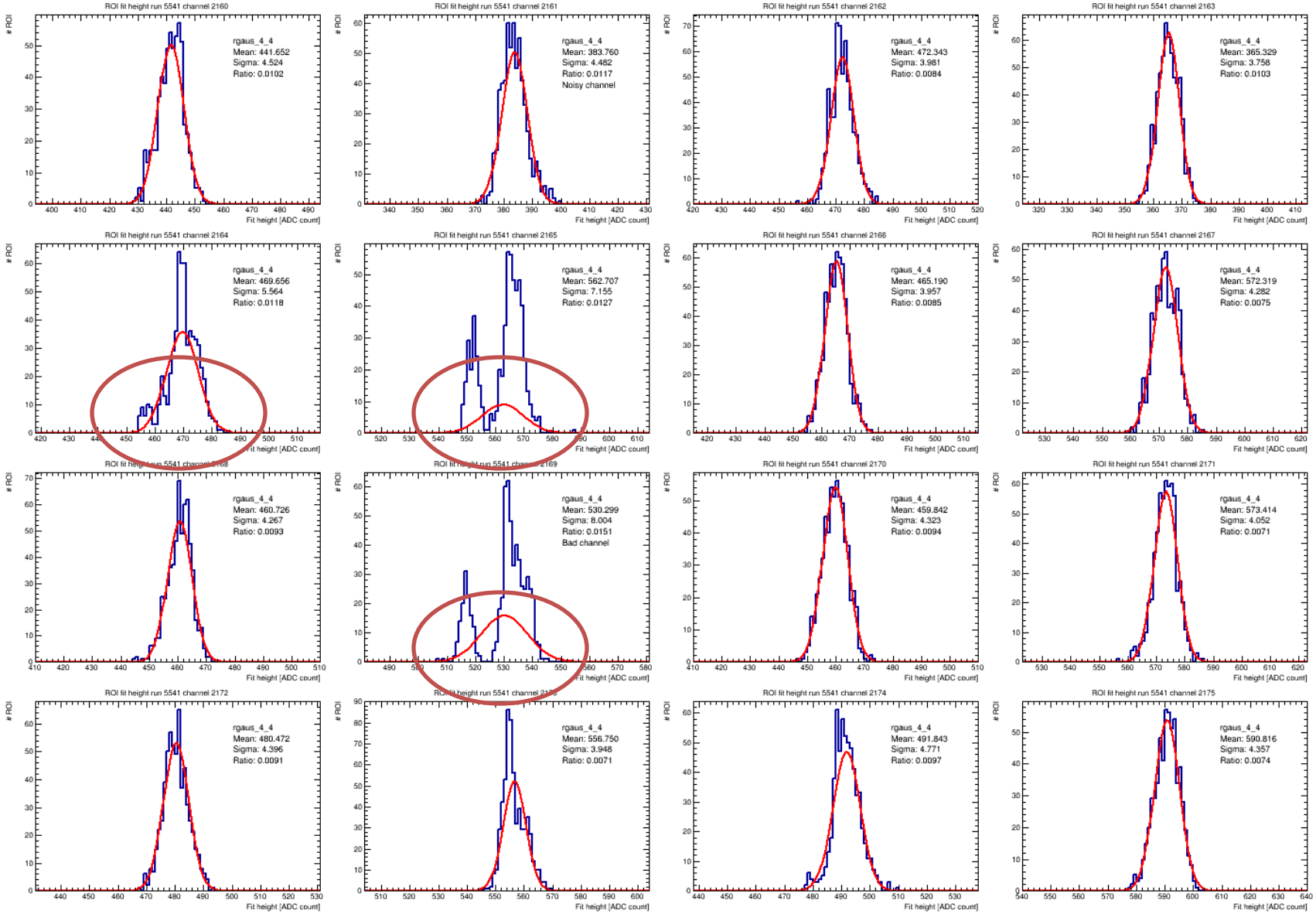
New “fit”


ROI fit height run 5541 channel 2144
rgaus_4_4
Mean: 429.998
Sigma: 5.101
Ratio: 0.0119
ROI fit height run 5541 channel 2145
rgaus_4_4
Mean: 342.440
Sigma: 4.841
Ratio: 0.0141
ROI fit height run 5541 channel 2146
rgaus_4_4
Mean: 435.887
Sigma: 5.232
Ratio: 0.0120
Noisy channel
ROI fit height run 5541 channel 2147
rgaus_4_4
Mean: 340.242
Sigma: 4.513
Ratio: 0.0133
ROI fit height run 5541 channel 2148
rgaus_4_4
Mean: 458.048
Sigma: 4.640
Ratio: 0.0101
ROI fit height run 5541 channel 2149
rgaus_4_4
Mean: 357.394
Sigma: 5.177
Ratio: 0.0145
ROI fit height run 5541 channel 2150
rgaus_4_4
Mean: 437.992
Sigma: 4.153
Ratio: 0.0095
ROI fit height run 5541 channel 2151
rgaus_4_4
Mean: 348.487
Sigma: 4.671
Ratio: 0.0134
ROI fit height run 5541 channel 2152
rgaus_4_4
Mean: 434.430
Sigma: 3.913
Ratio: 0.0090
ROI fit height run 5541 channel 2153
rgaus_4_4
Mean: 394.497
Sigma: 4.001
Ratio: 0.0101
ROI fit height run 5541 channel 2154
rgaus_4_4
Mean: 437.089
Sigma: 6.522
Ratio: 0.0149
ROI fit height run 5541 channel 2155
rgaus_4_4
Mean: 371.115
Sigma: 3.873
Ratio: 0.0104
ROI fit height run 5541 channel 2156
rgaus_4_4
Mean: 451.716
Sigma: 3.838
Ratio: 0.0085
ROI fit height run 5541 channel 2157
rgaus_4_4
Mean: 350.811
Sigma: 7.504
Ratio: 0.0214
ROI fit height run 5541 channel 2158
rgaus_4_4
Mean: 450.916
Sigma: 4.346
Ratio: 0.0096
Noisy channel
ROI fit height run 5541 channel 2159
rgaus_4_4
Mean: 364.909
Sigma: 3.596
Ratio: 0.0099
ROI
Fit height [ADC count]

Old fit

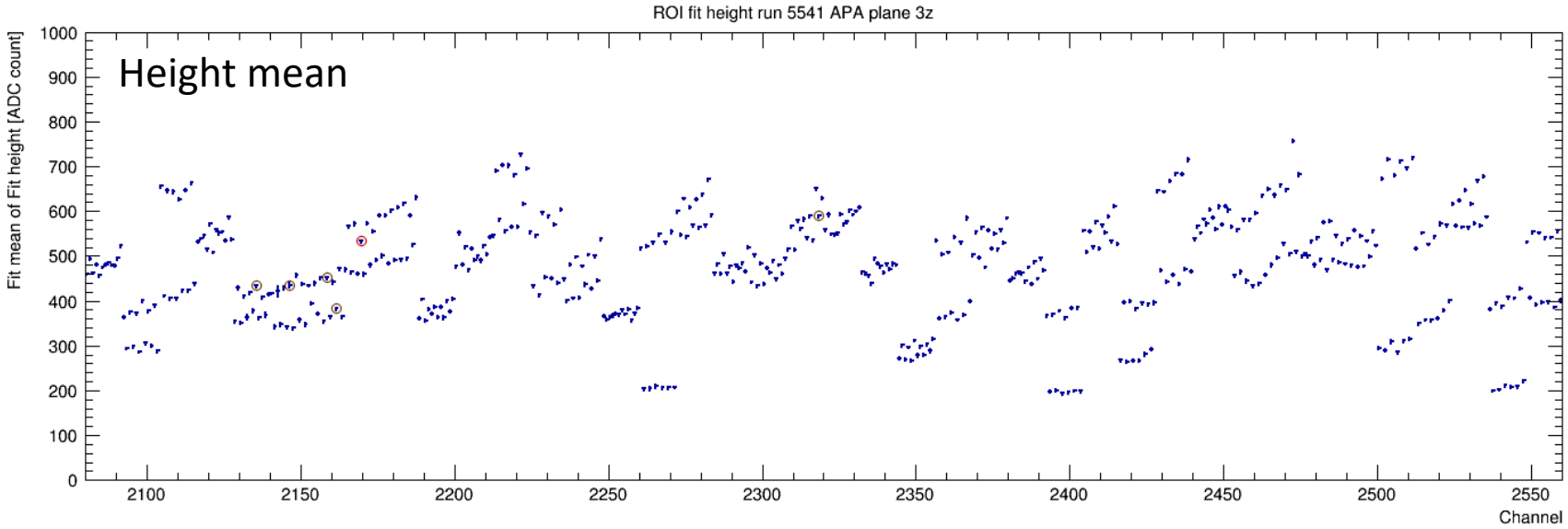

ROI fit height run 5541 channel 2160
Mean: 442.122
Sigma: 4.409
Ratio: 0.0100
ROI fit height run 5541 channel 2161
Mean: 383.184
Sigma: 4.178
Ratio: 0.0109
Noisy channel
ROI fit height run 5541 channel 2162
Mean: 472.038
Sigma: 3.856
Ratio: 0.0082
ROI fit height run 5541 channel 2163
Mean: 365.330
Sigma: 4.000
Ratio: 0.0109
ROI fit height run 5541 channel 2164
Mean: 470.376
Sigma: 4.535
Ratio: 0.0096
ROI fit height run 5541 channel 2165
Mean: 566.418
Sigma: 3.211
Ratio: 0.0057
ROI fit height run 5541 channel 2166
Mean: 465.191
Sigma: 3.914
Ratio: 0.0084
ROI fit height run 5541 channel 2167
Mean: 572.362
Sigma: 4.639
Ratio: 0.0081
ROI fit height run 5541 channel 2168
Mean: 461.262
Sigma: 4.031
Ratio: 0.0087
ROI fit height run 5541 channel 2169
Mean: 533.310
Sigma: 4.286
Ratio: 0.0080
Bad channel
ROI fit height run 5541 channel 2170
Mean: 459.927
Sigma: 4.481
Ratio: 0.0097
ROI fit height run 5541 channel 2171
Mean: 573.585
Sigma: 3.793
Ratio: 0.0066
ROI fit height run 5541 channel 2172
Mean: 480.262
Sigma: 4.308
Ratio: 0.0090
Mean: 555.686
Sigma: 3.513
Ratio: 0.0063
ROI fit height run 5541 channel 2174
Mean: 491.581
Sigma: 4.197
Ratio: 0.0085
ROI fit height run 5541 channel 2175
Mean: 591.163
Sigma: 4.481
Ratio: 0.0076
ROI
Fit height [ADC count]

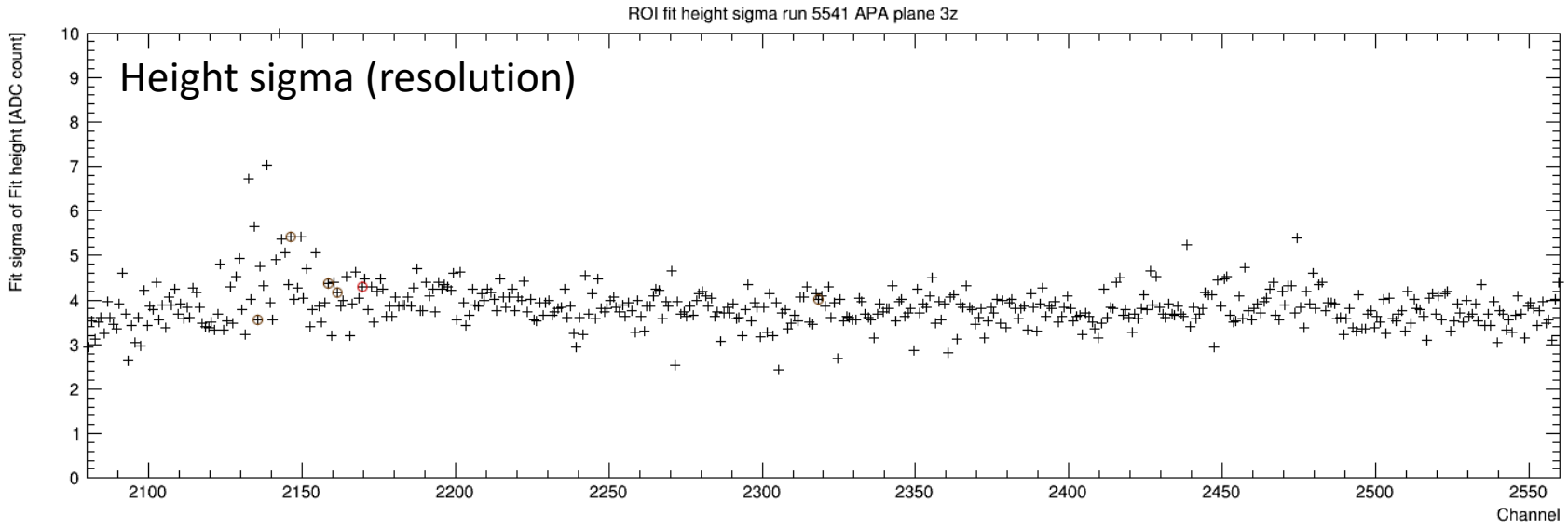
New “fit”


ROI fit height run 5541 channel 2160
rgaus_4_4
Mean: 441.652
Sigma: 4.524
Ratio: 0.0102
ROI fit height run 5541 channel 2161
rgaus_4_4
Mean: 383.760
Sigma: 4.482
Ratio: 0.0117
Noisy channel
ROI fit height run 5541 channel 2162
rgaus_4_4
Mean: 472.343
Sigma: 3.981
Ratio: 0.0084
ROI fit height run 5541 channel 2163
rgaus_4_4
Mean: 365.329
Sigma: 3.758
Ratio: 0.0103
ROI fit height run 5541 channel 2164
rgaus_4_4
Mean: 469.656
Sigma: 5.564
Ratio: 0.0118
ROI fit height run 5541 channel 2165
rgaus_4_4
Mean: 562.707
Sigma: 7.155
Ratio: 0.0127
ROI fit height run 5541 channel 2166
rgaus_4_4
Mean: 465.190
Sigma: 3.957
Ratio: 0.0085
ROI fit height run 5541 channel 2167
rgaus_4_4
Mean: 572.319
Sigma: 4.282
Ratio: 0.0075
ROI fit height run 5541 channel 2168
rgaus_4_4
Mean: 460.726
Sigma: 4.267
Ratio: 0.0093
ROI fit height run 5541 channel 2169
rgaus_4_4
Mean: 530.299
Sigma: 8.004
Ratio: 0.0151
Bad channel
ROI fit height run 5541 channel 2170
rgaus_4_4
Mean: 459.842
Sigma: 4.323
Ratio: 0.0094
ROI fit height run 5541 channel 2171
rgaus_4_4
Mean: 573.414
Sigma: 4.052
Ratio: 0.0071
ROI fit height run 5541 channel 2172
rgaus_4_4
Mean: 480.472
Sigma: 4.396
Ratio: 0.0091
rgaus_4_4
Mean: 556.750
Sigma: 3.948
Ratio: 0.0071
ROI fit height run 5541 channel 2174
rgaus_4_4
Mean: 491.843
Sigma: 4.771
Ratio: 0.0097
ROI fit height run 5541 channel 2175
rgaus_4_4
Mean: 590.816
Sigma: 4.357
Ratio: 0.0074
ROI
Fit height [ADC count]

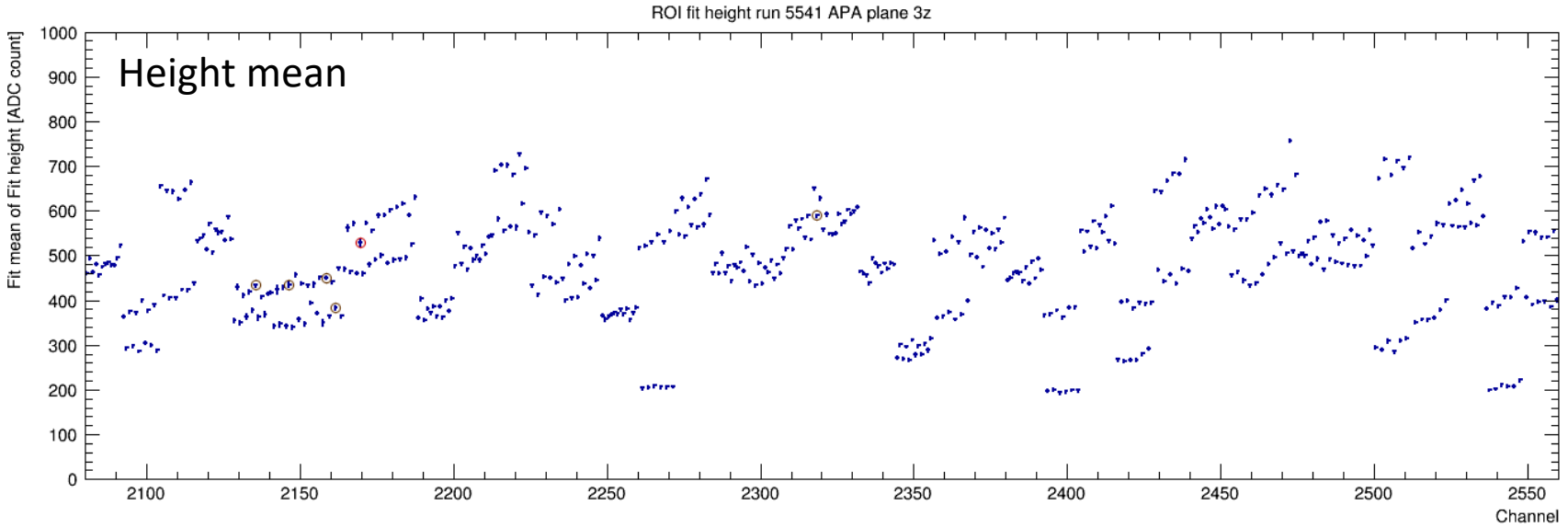
APA3z resolutions: old vs. new

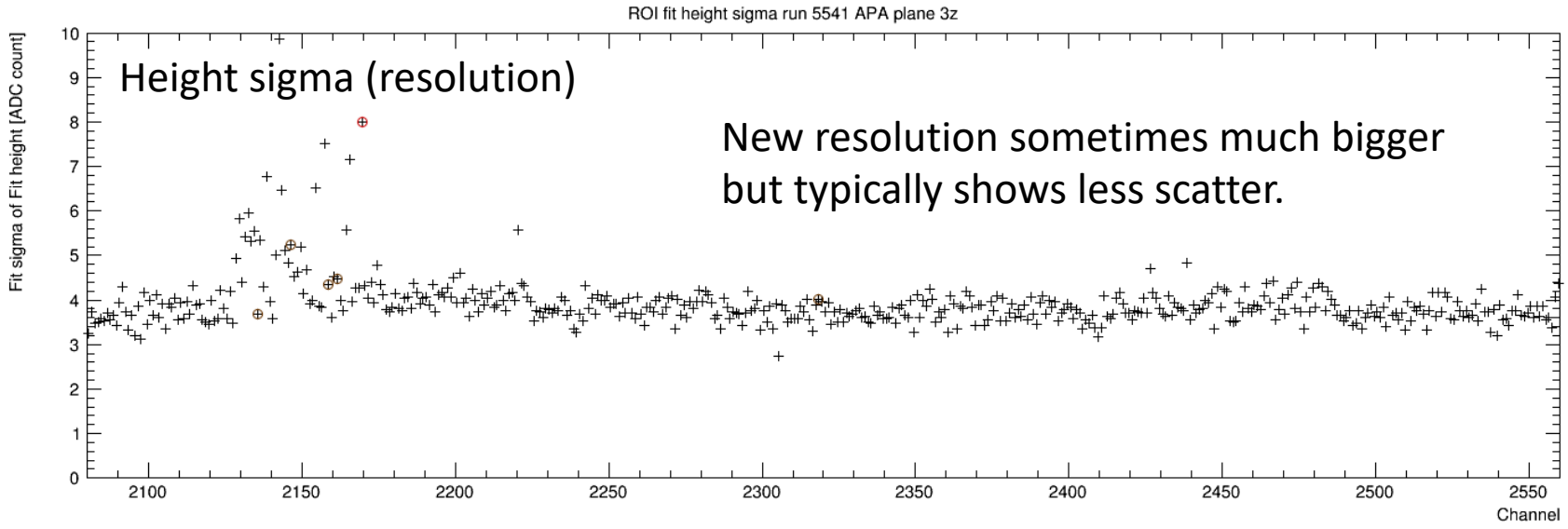
Fit height with new mitigation, old fit



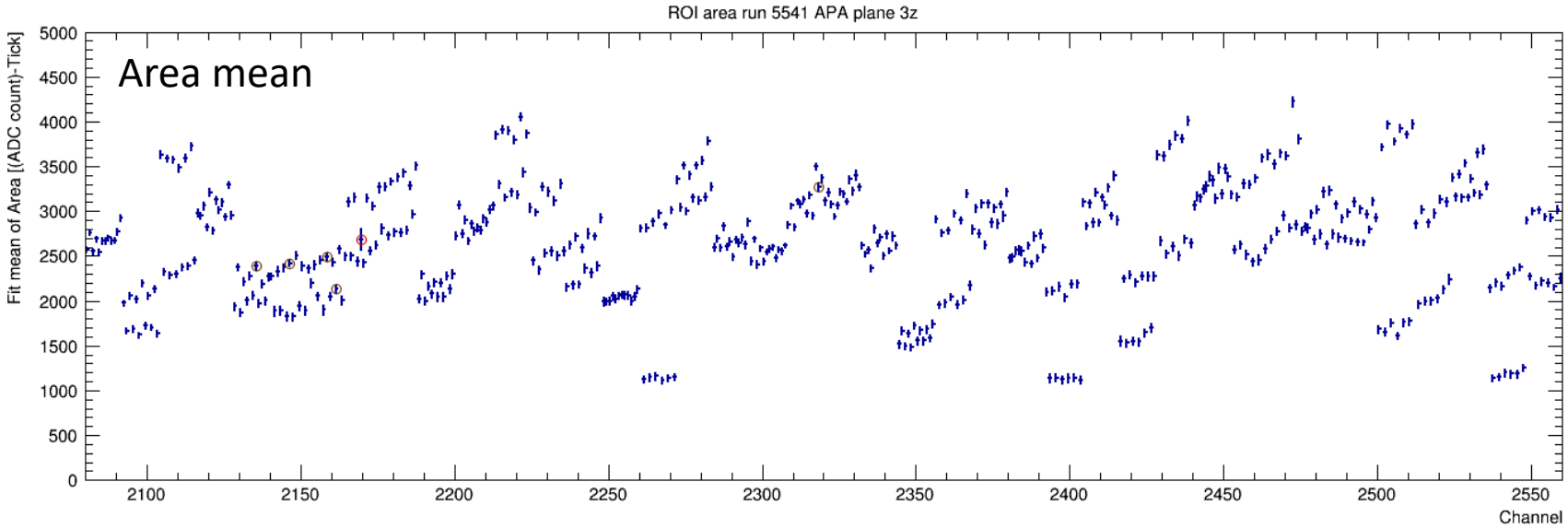


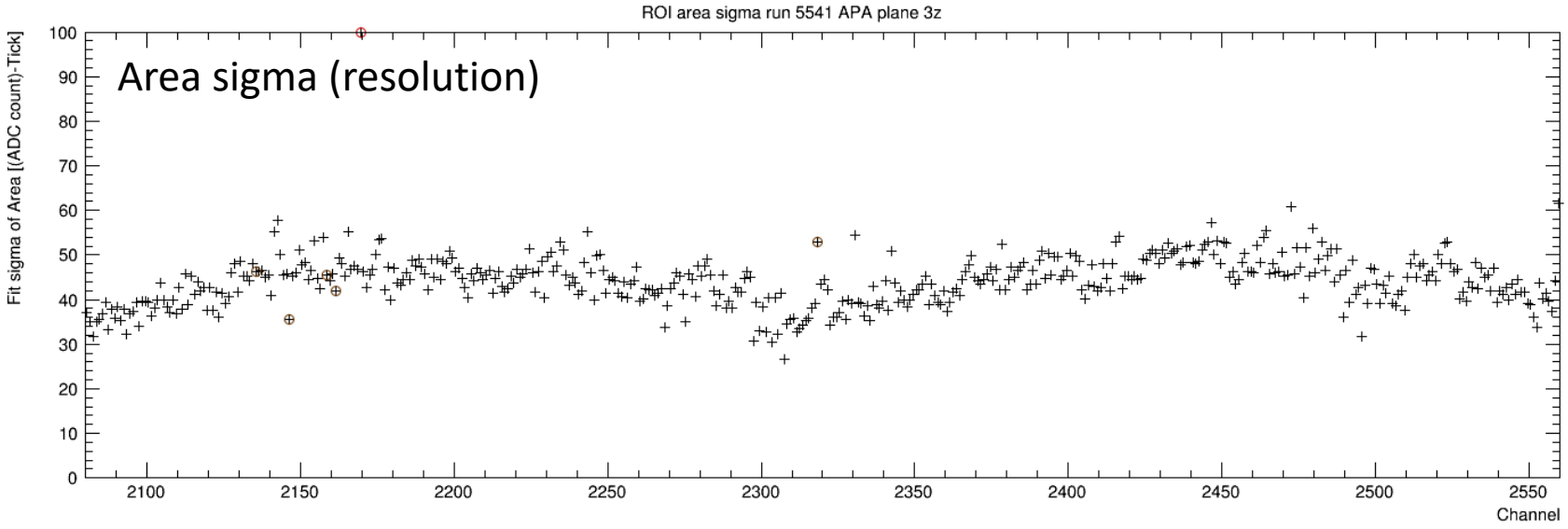
Fit height with new mitigation, new “fit”



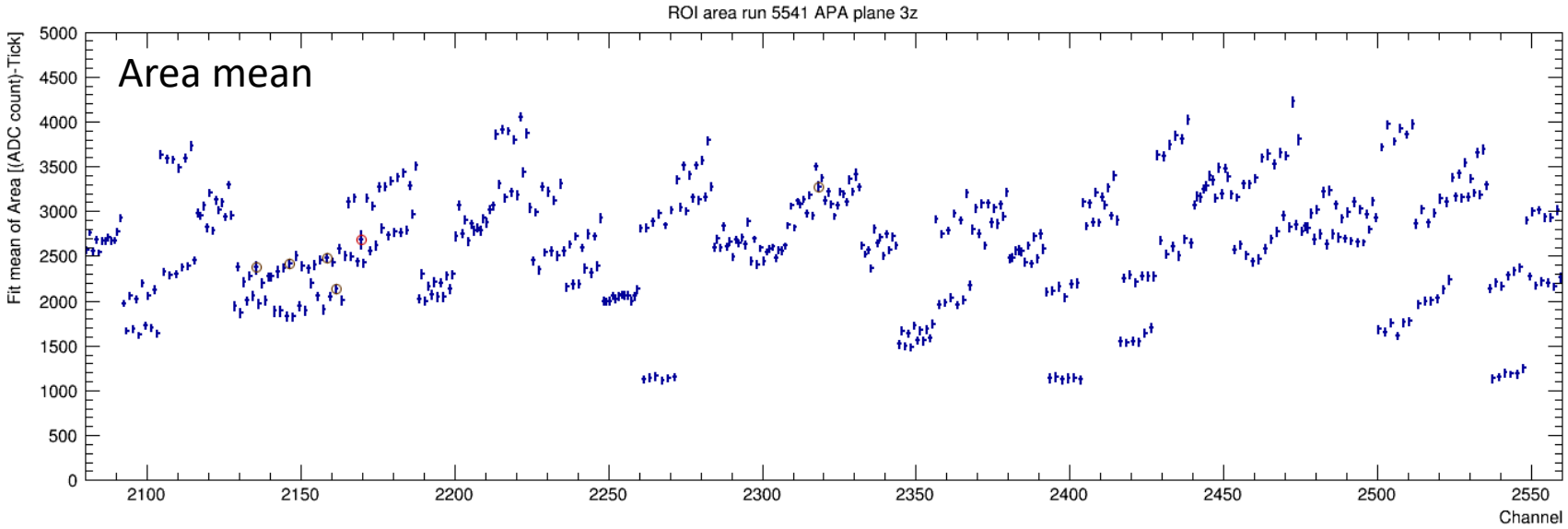


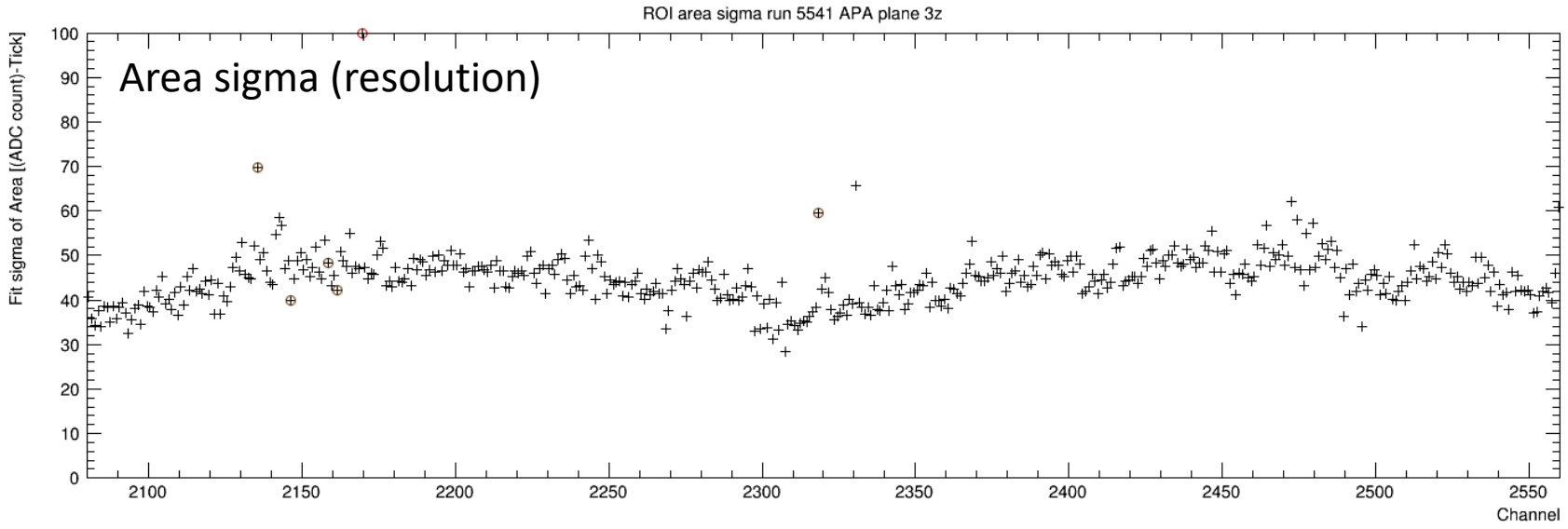
Signal area with new mitigation, old fit





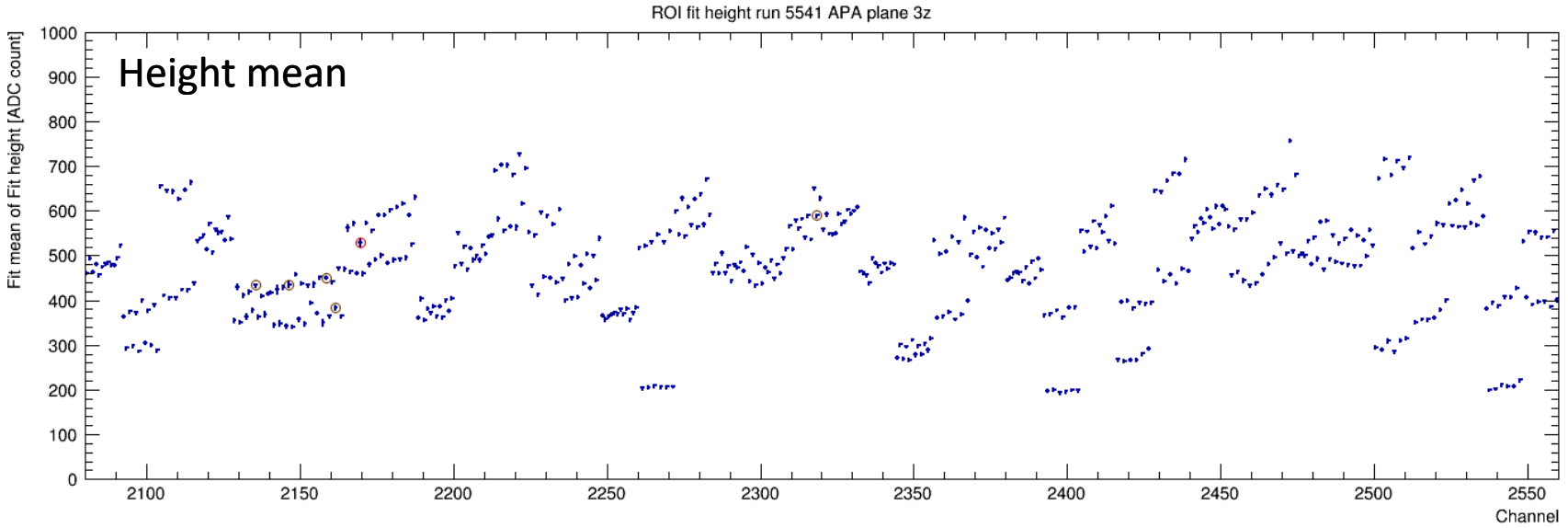
Signal area with new mitigation, new “fit”

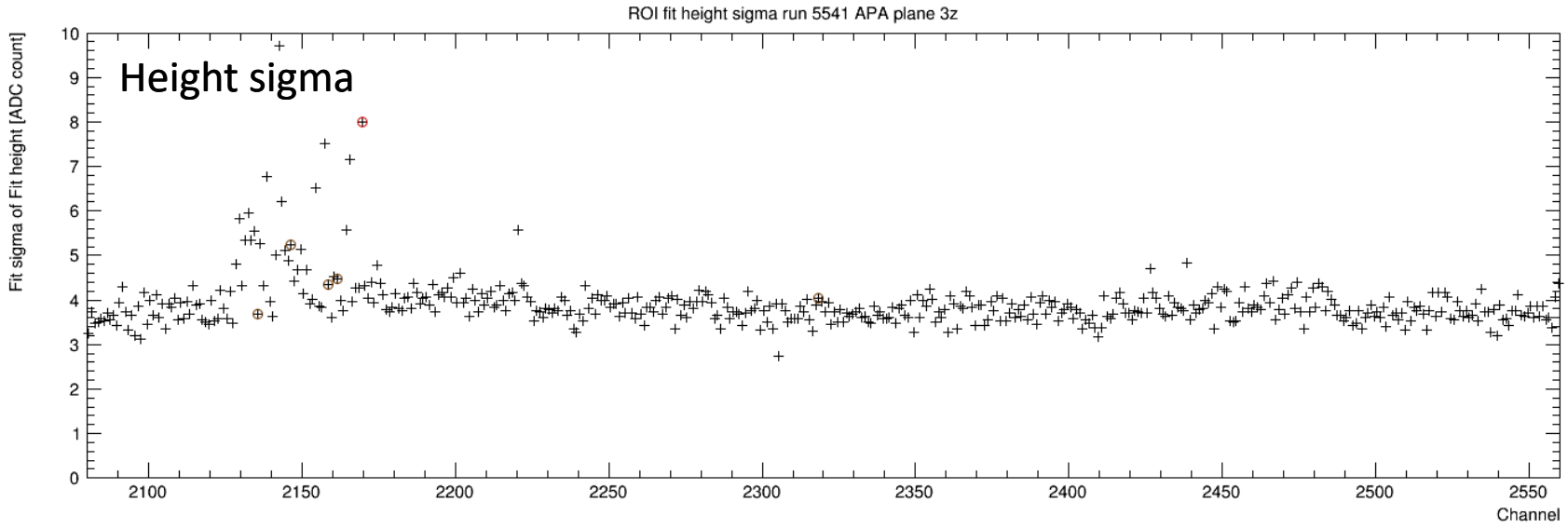




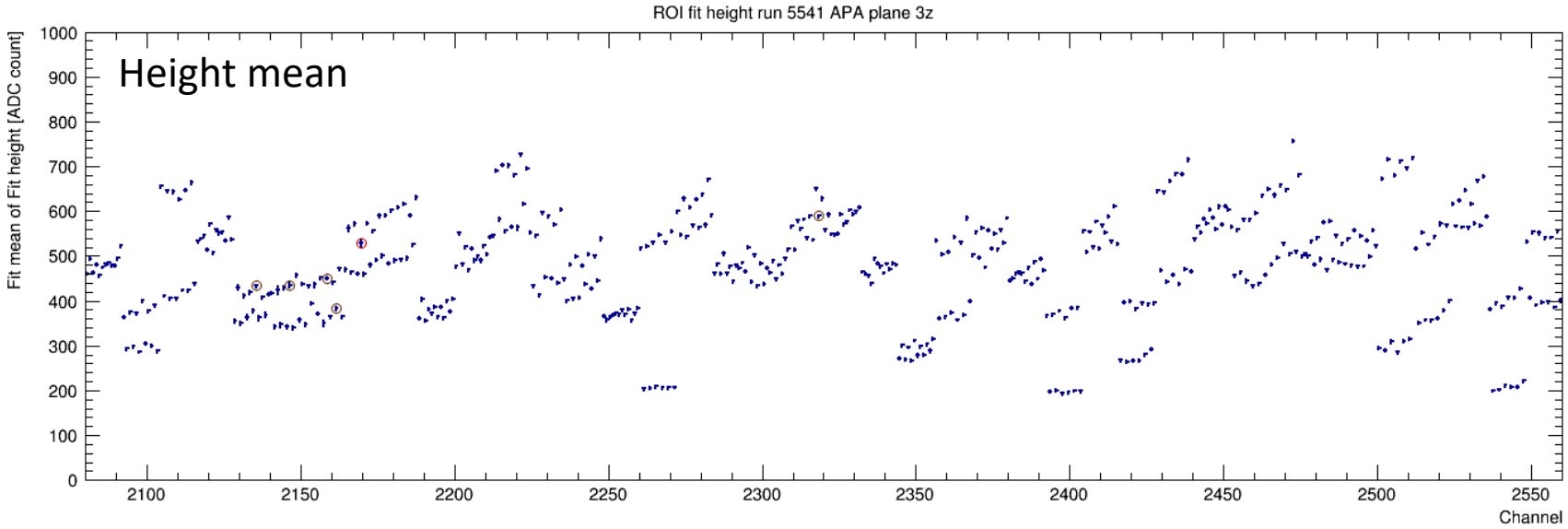
APA3z resolutions varying mitigation
New “fit” (showed last week with old fit)

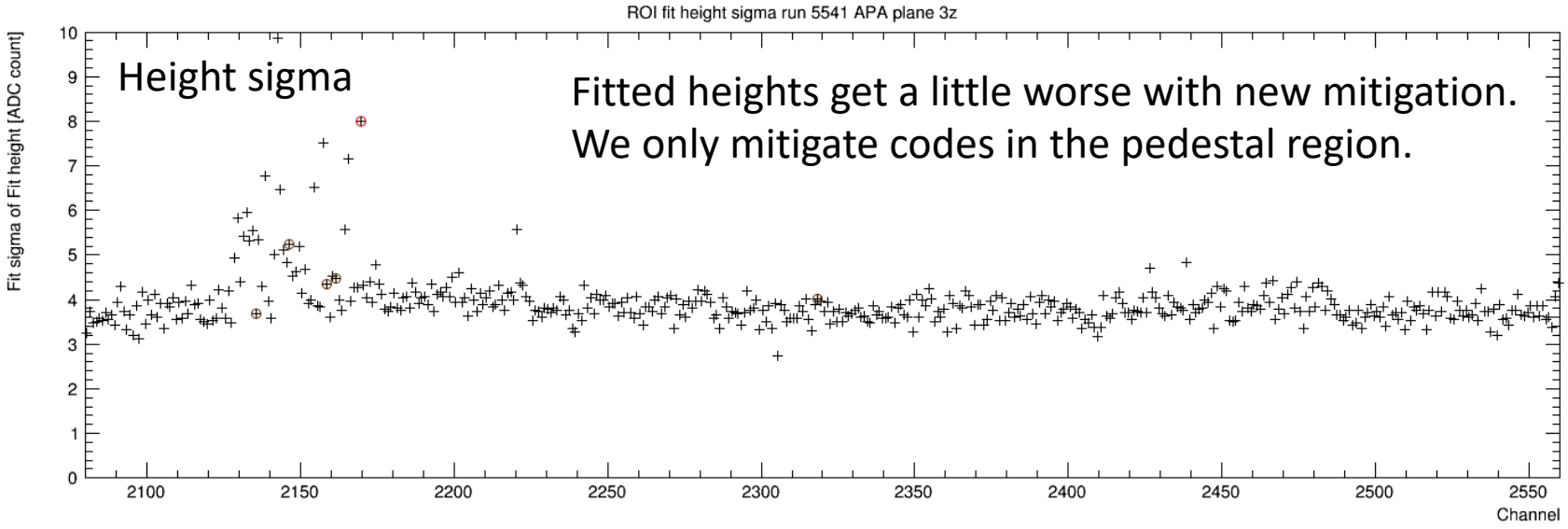
Fit height unmitigated, new fit



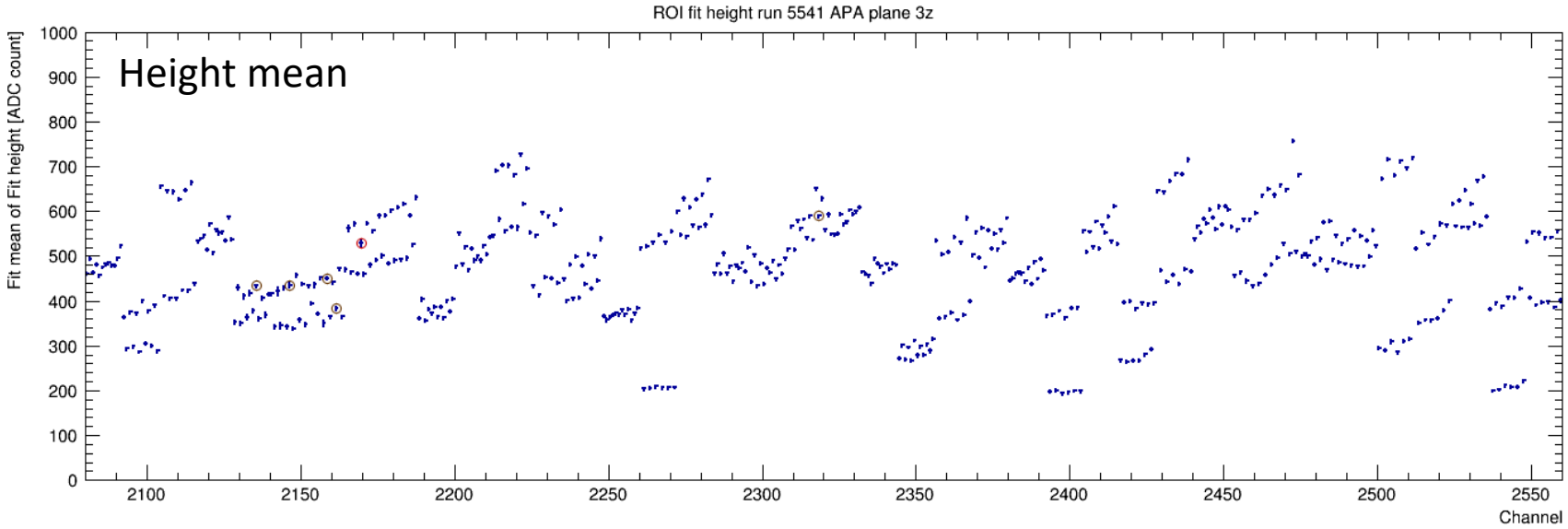


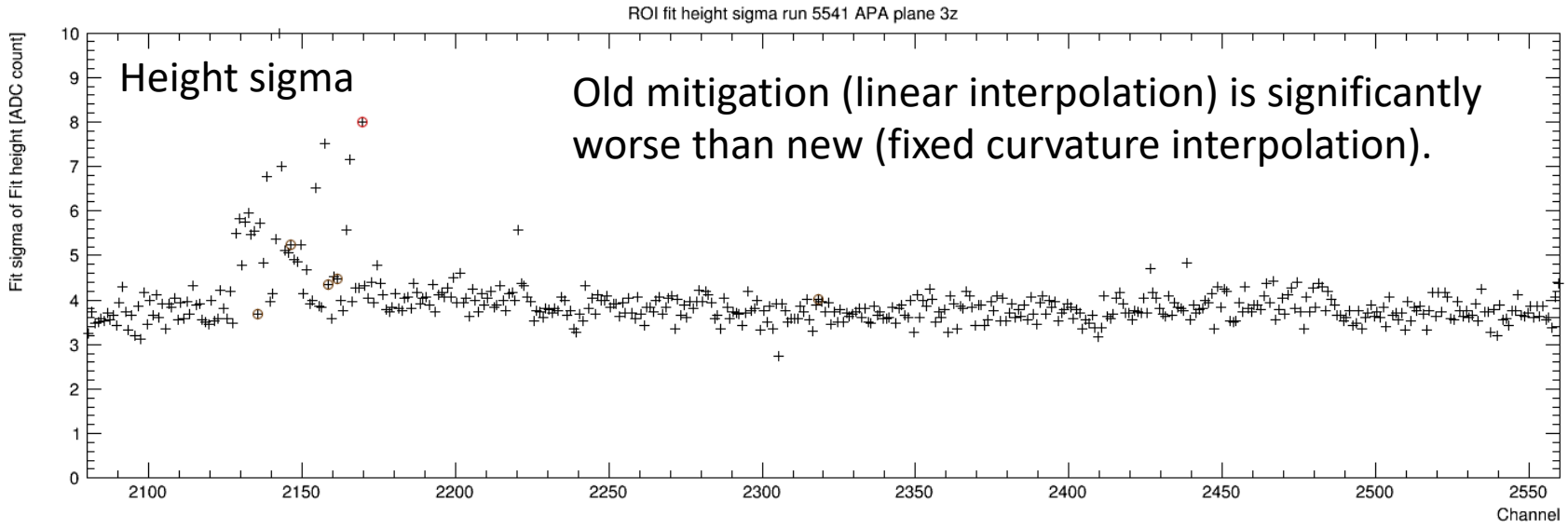
Fit height with new mitigation, new fit



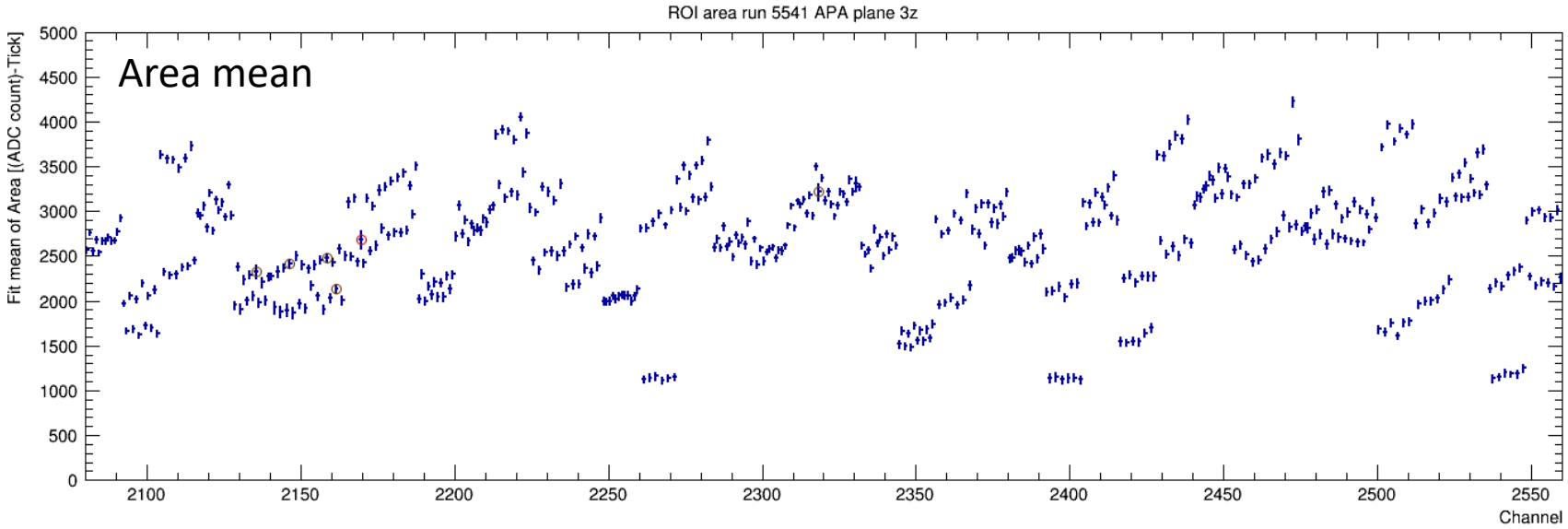


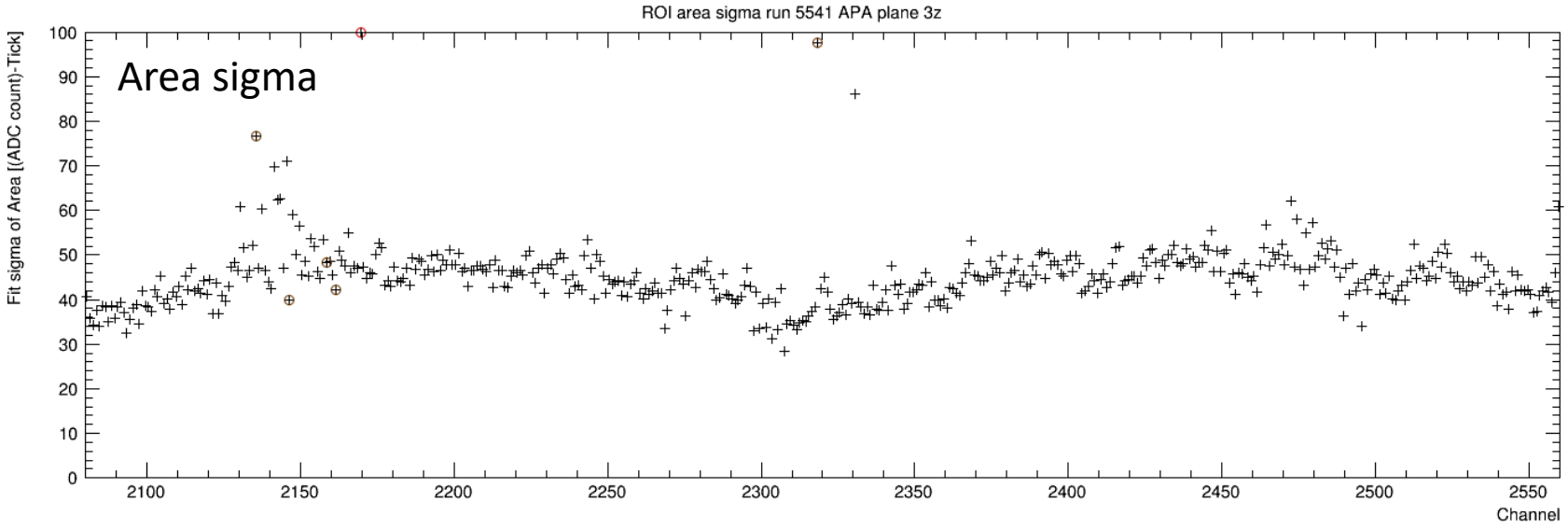
Fit height with old mitigation, new fit



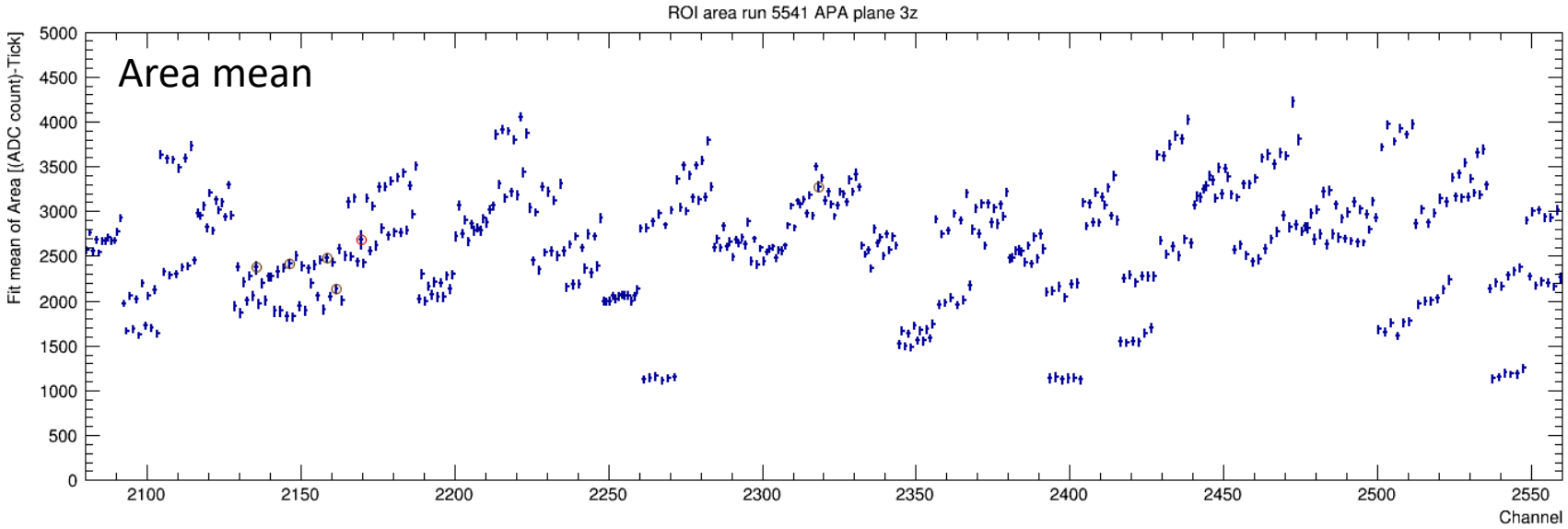


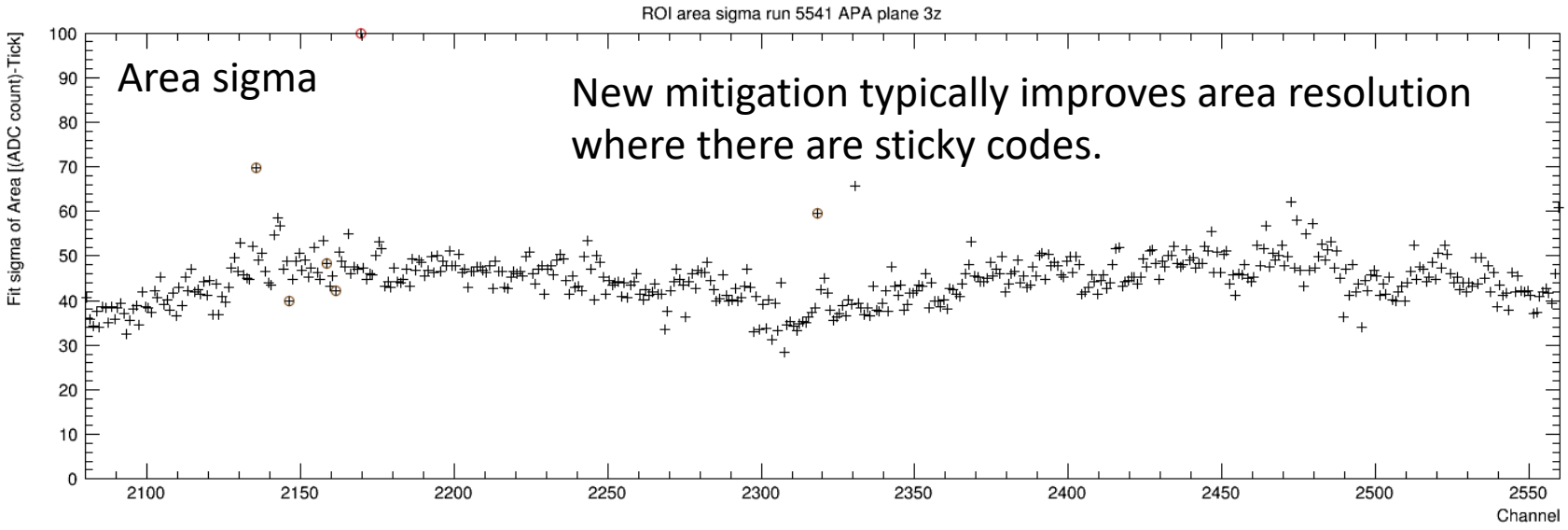
Signal area unmitigated, new fit



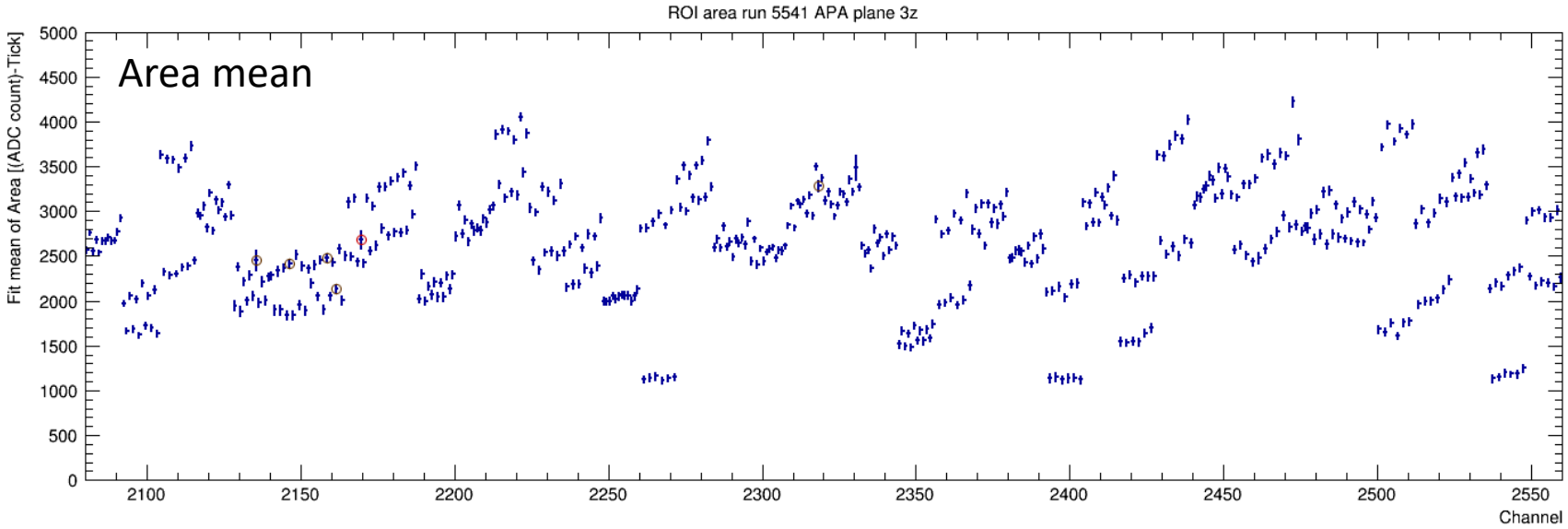


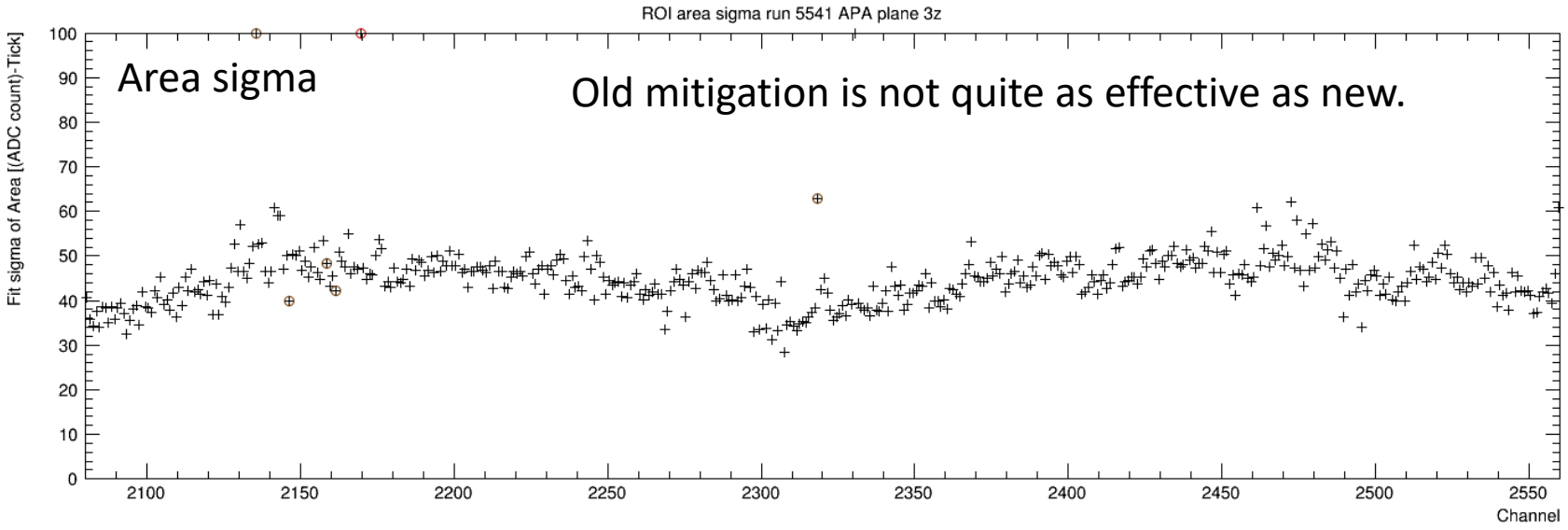
Signal area with new mitigation, new fit





Signal area with old mitigation, new fit





Comments

Resolution with truncated RMS

- Looks better than Gaussian fit for bimodal distributions
  - Those are common with sticky codes
- Avoids problem/feature of fit settling on one peak
- Also avoids tail contribution of raw RMS
- Header in dunetpc/dune/DuneCommon/GausRmsFitter.h

Sticky code mitigation

- Sam conclusion as with old fitter: new mitigation algorithm is an improvement

Future

Future pulser resolution studies

- Check effect of mitigation on other APA planes
- Look at other dataprep steps
  - Timing mitigation
  - Tail correction
  - Deconvolution
- Try out other ideas for dataprep
  - Nice to have a quantitative measure of performance in signal region

Search for sticky codes in signal regions

- Use pulser tickmods to get better coverage
- Like also to have data with pulser timing offsets to improve coverage

Truncated RMS resolution

- Switch to this for pedestal evaluation?
- Report also the tail: fraction of fitted distribution outside N×RMS
- Replace fitted height with value that gives area of fitted data