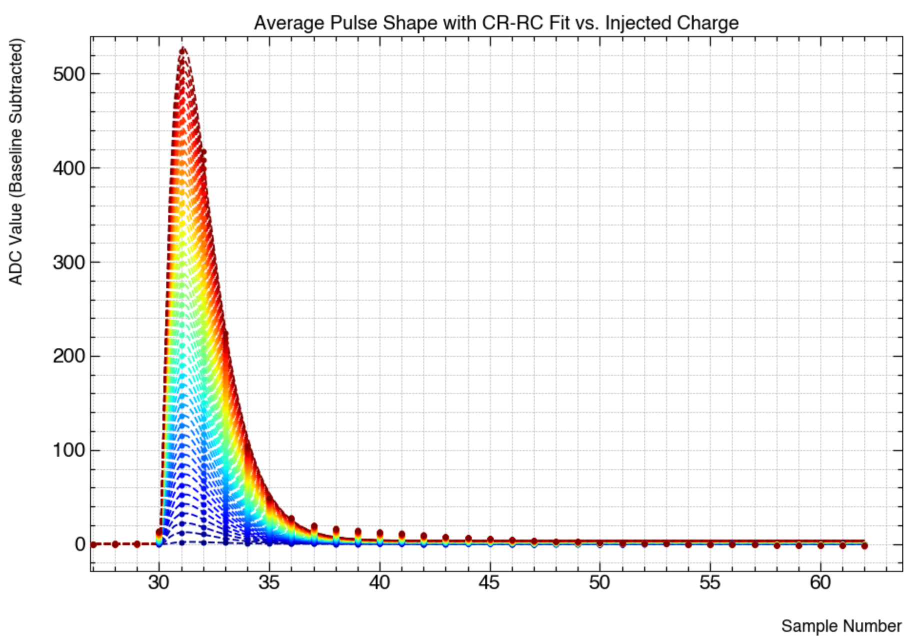
Frontend saturation correction

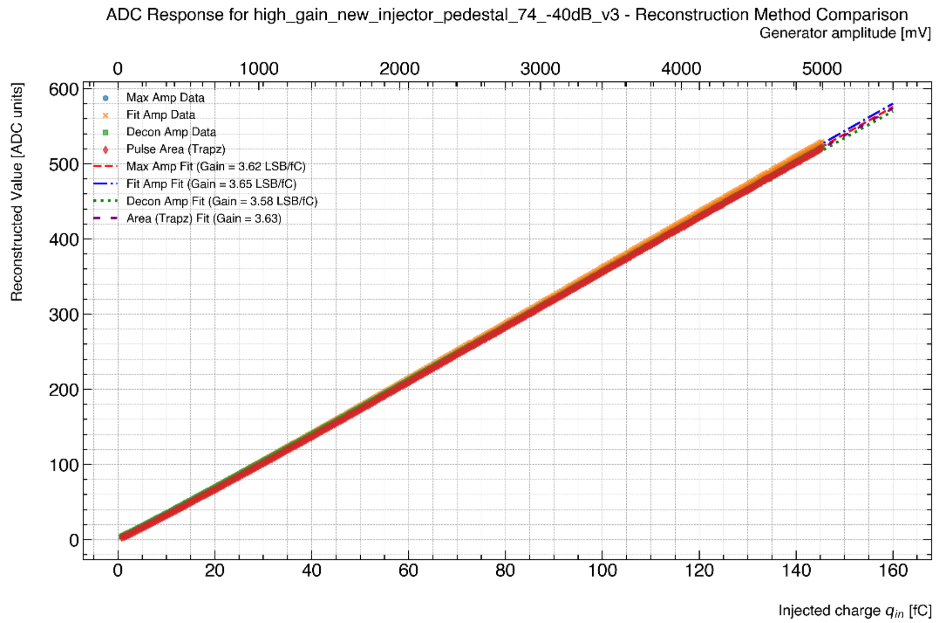
During FLAME measurements we decided to set pedestal value from 74 DAC to 60 DAC because of better linear response at the beginning of the range and for that pedestal value most of linearity measurements was done. But during TB we decided to set default 74 DAC for pedestal dac due to observed significant saturation at the end of range when pedestal dac was set to 60 DAC.

Examples of linearity measurements, three method was used for amplitude reconstruction:

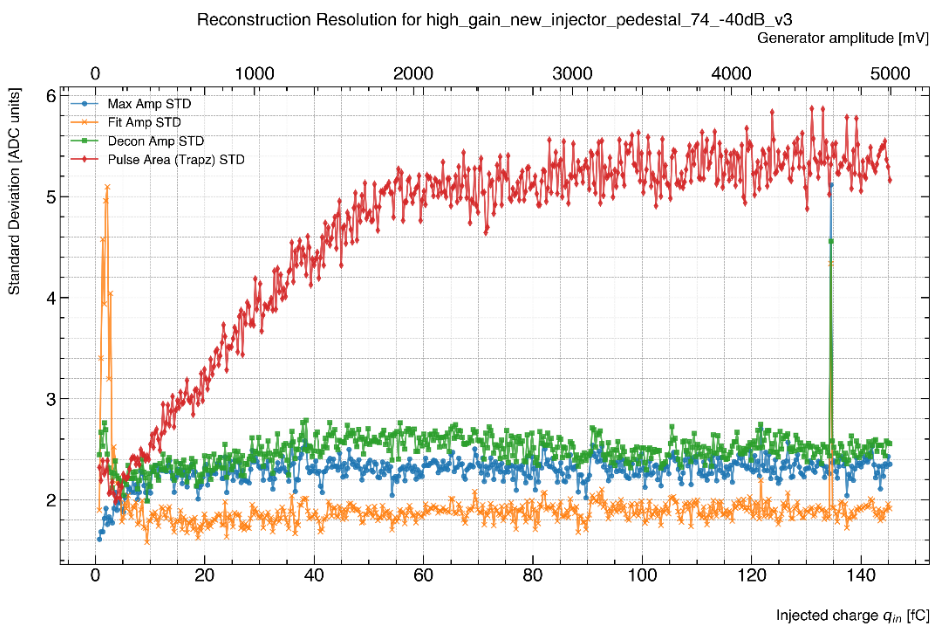
- Max amplitude (valid only when measurments was tuned to match peak value and phase of sampling)
- CR-RC fit
- deconvolution
- numerical integral trapez method

1.Pedestal DAC value 74 -Peak value and phase of sampling matched but end of the range was not tested

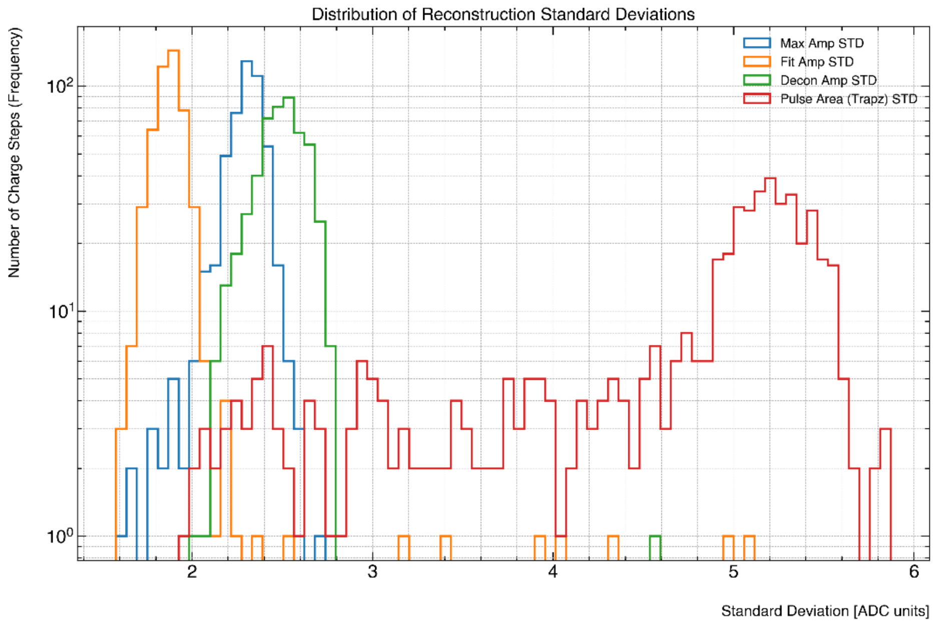




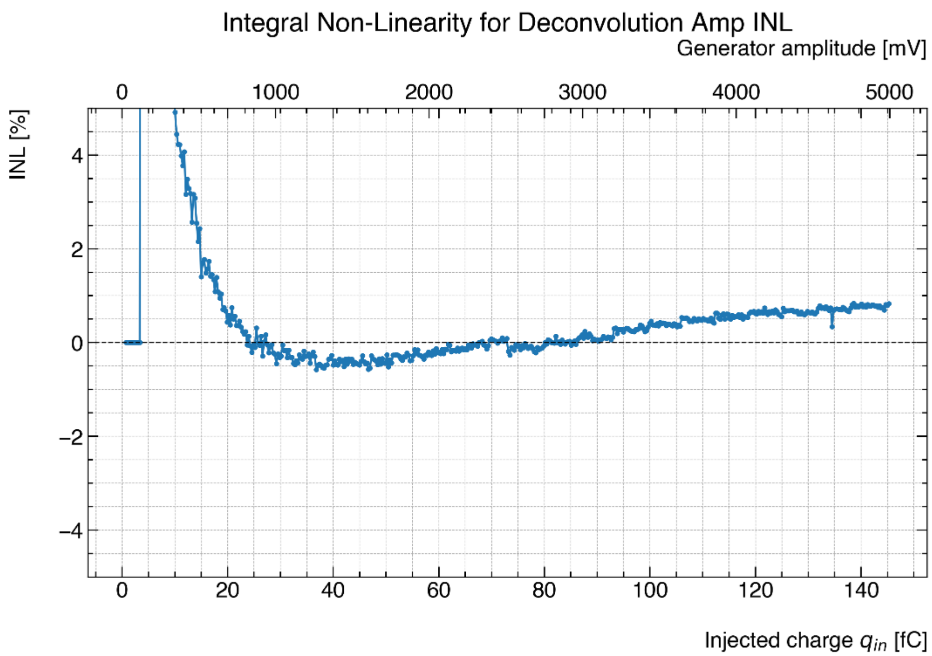
ADC Response for high_gain_new_injector_pedestal_74_-40dB_v3 - Reconstruction Method Comparison
Generator amplitude [mV]
Reconstructed Value [ADC units]
Injected charge q_{in} [fC]
Max Amp Data
Fit Amp Data
Decon Amp Data
Pulse Area (Trapz)
Max Amp Fit (Gain = 3.62 LSB/fC)
Fit Amp Fit (Gain = 3.65 LSB/fC)
Decon Amp Fit (Gain = 3.58 LSB/fC)
Area (Trapz) Fit (Gain = 3.63)



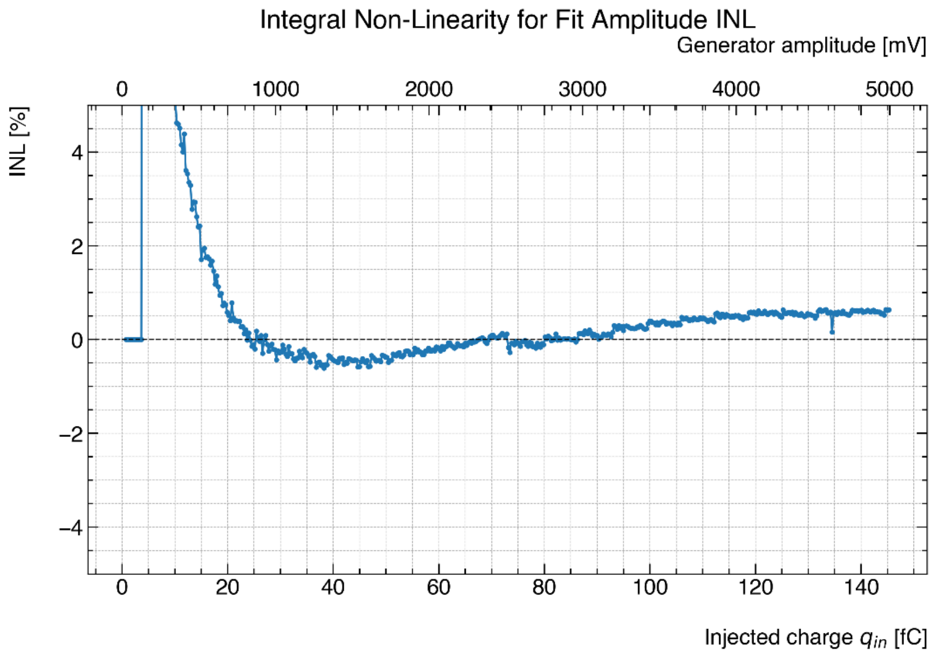
Reconstruction Resolution for high_gain_new_injector_pedestal_74_-40dB_v3
Generator amplitude [mV]
Standard Deviation [ADC units]
Injected charge q_{in} [fC]
Max Amp STD
Fit Amp STD
Decon Amp STD
Pulse Area (Trapz) STD

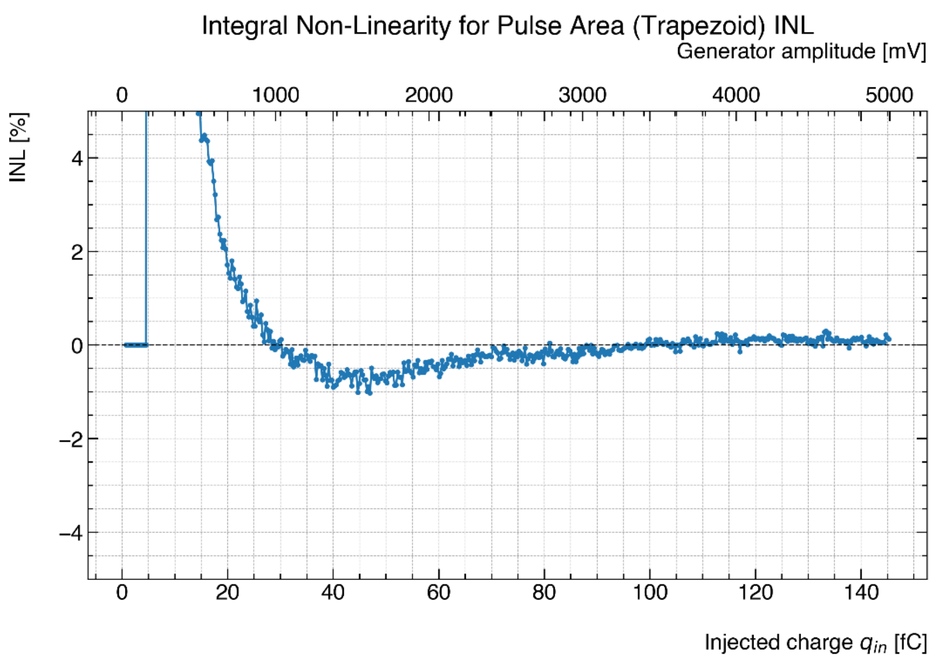


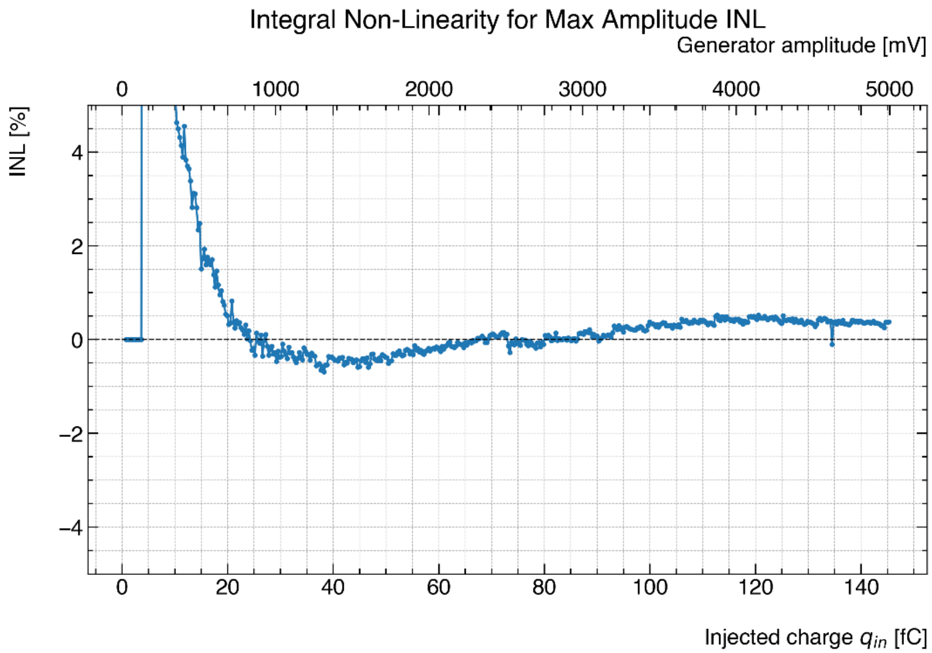
Distribution of Reconstruction Standard Deviations
Max Amp STD
Fit Amp STD
Decon Amp STD
Pulse Area (Trapz) STD
Number of Charge Steps (Frequency)
Standard Deviation [ADC units]

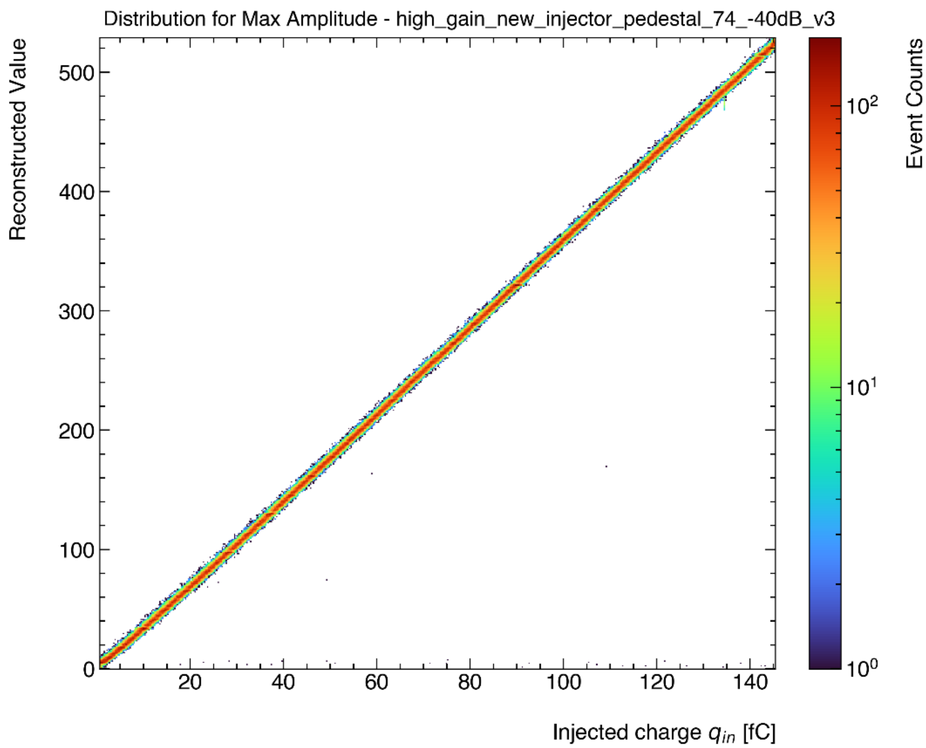


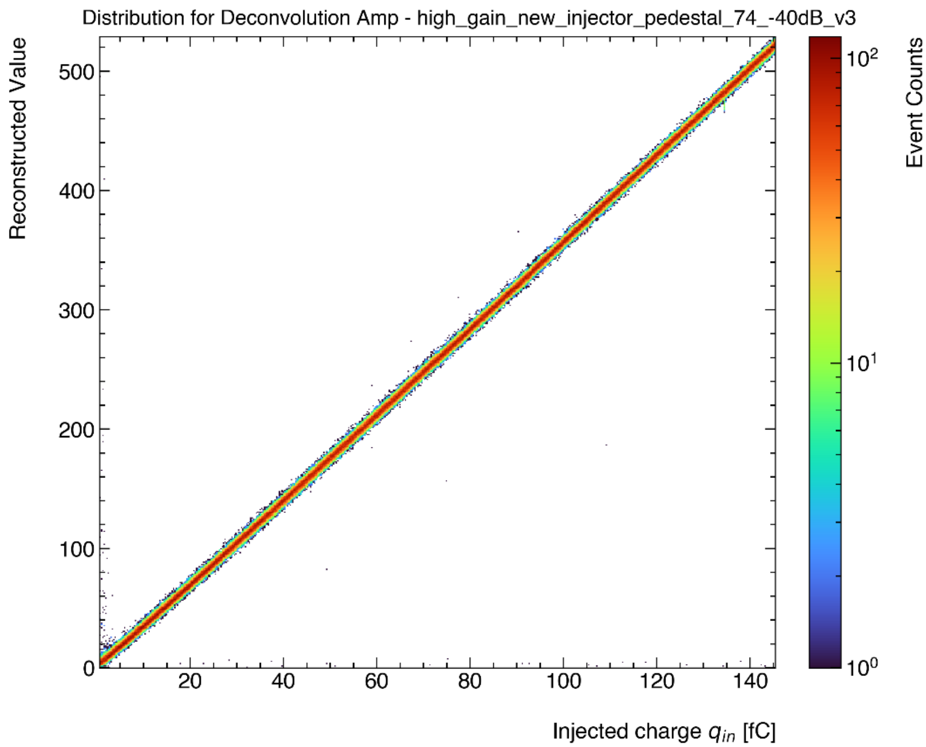
Integral Non-Linearity for Deconvolution Amp INL
Generator amplitude [mV]
INL [%]
Injected charge q_{in} [fC]


Integral Non-Linearity for Fit Amplitude INL
Generator amplitude [mV]
0
1000
2000
3000
4000
5000
INL [%]
4
2
0
−2
−4
0
20
40
60
80
100
120
140
Injected charge q_{in} [fC]

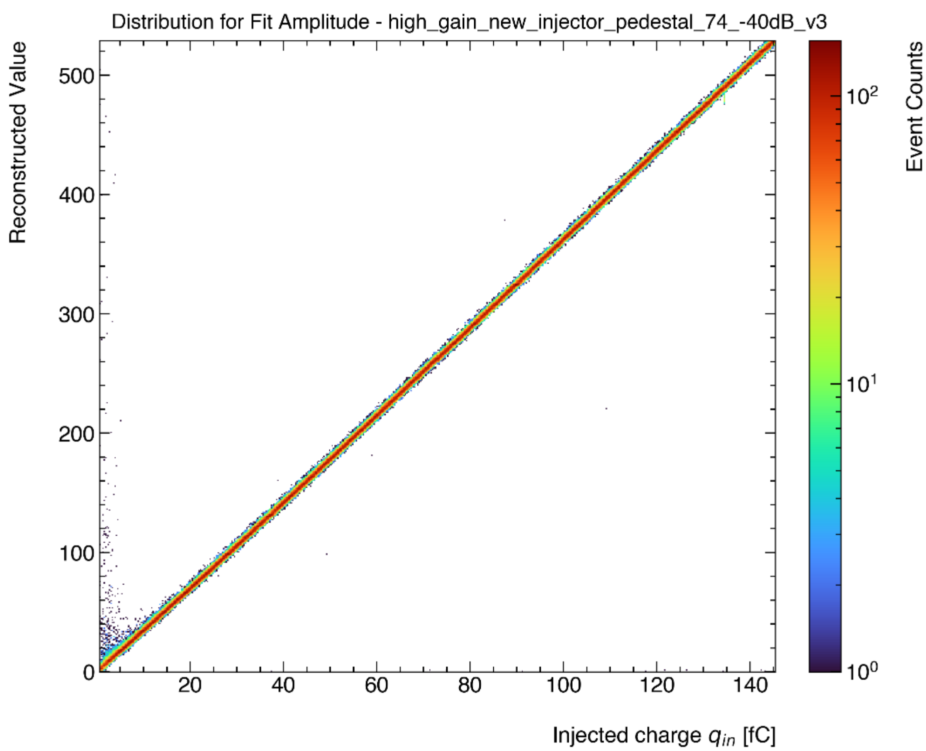

Integral Non-Linearity for Pulse Area (Trapezoid) INL
Generator amplitude [mV]
0
1000
2000
3000
4000
5000
INL [%]
4
2
0
−2
−4
0
20
40
60
80
100
120
140
Injected charge q_{in} [fC]


Integral Non-Linearity for Max Amplitude INL
Generator amplitude [mV]
0
1000
2000
3000
4000
5000
INL [%]
4
2
0
−2
−4
0
20
40
60
80
100
120
140
Injected charge q_{in} [fC]

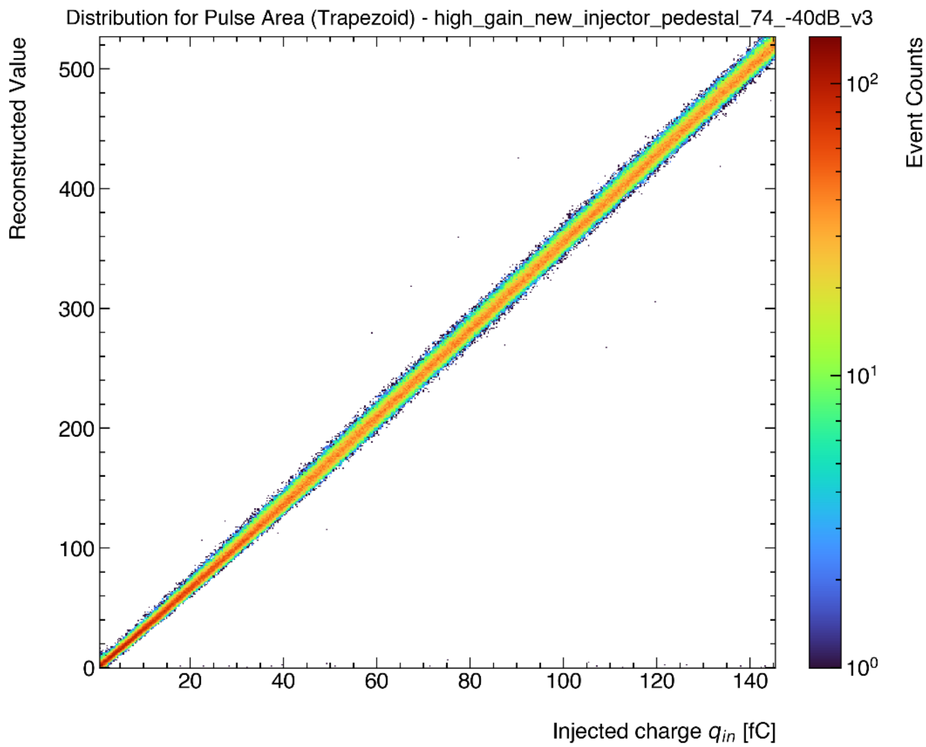

Distribution for Max Amplitude - high_gain_new_injector_pedestal_74_-40dB_v3
Reconstructed Value
500
400
300
200
100
0
20
40
60
80
100
120
140
Injected charge q_{in} [fC]
Event Counts
10^2
10^1
10^0



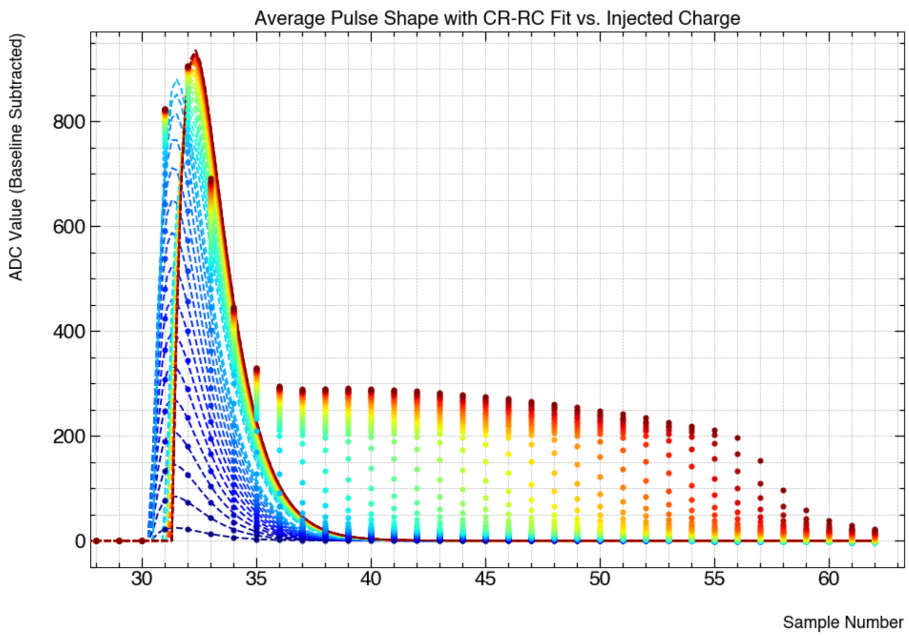
Distribution for Deconvolution Amp - high_gain_new_injector_pedestal_74_-40dB_v3
Reconstructed Value
Injected charge q_{in} [fC]
Event Counts

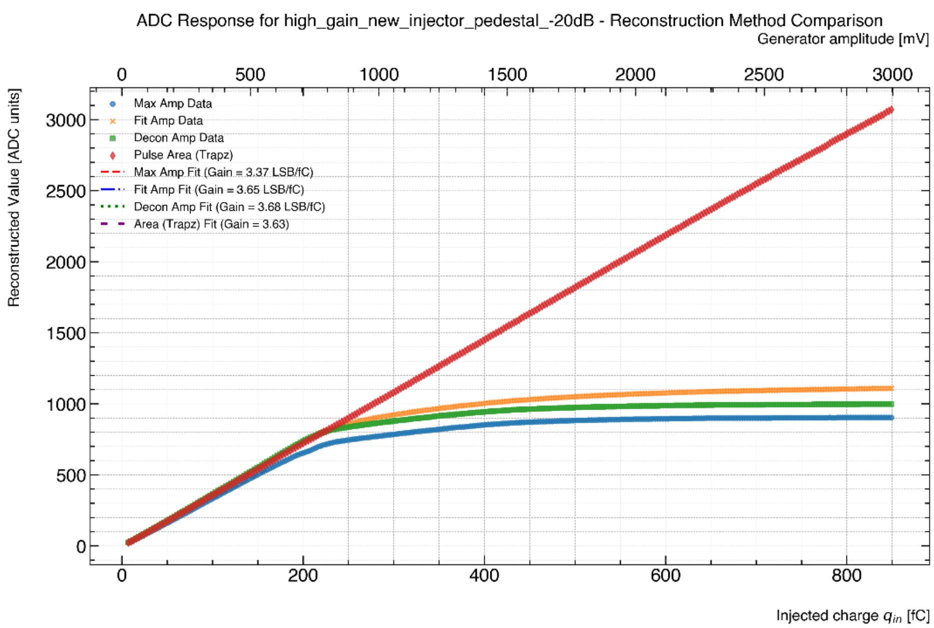


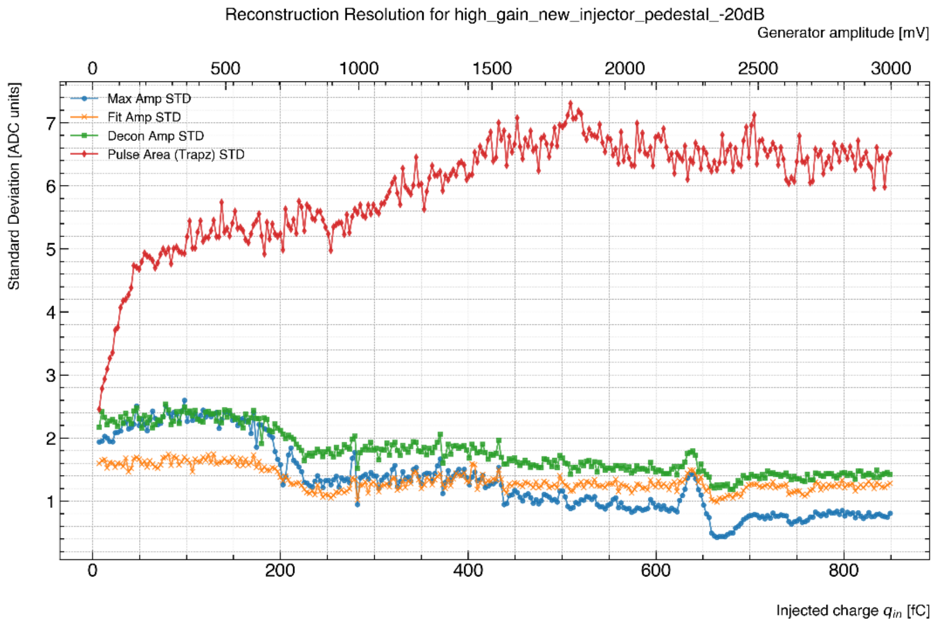
Distribution for Fit Amplitude - high_gain_new_injector_pedestal_74_-40dB_v3
Reconstructed Value
Injected charge q_{in} [fC]
Event Counts



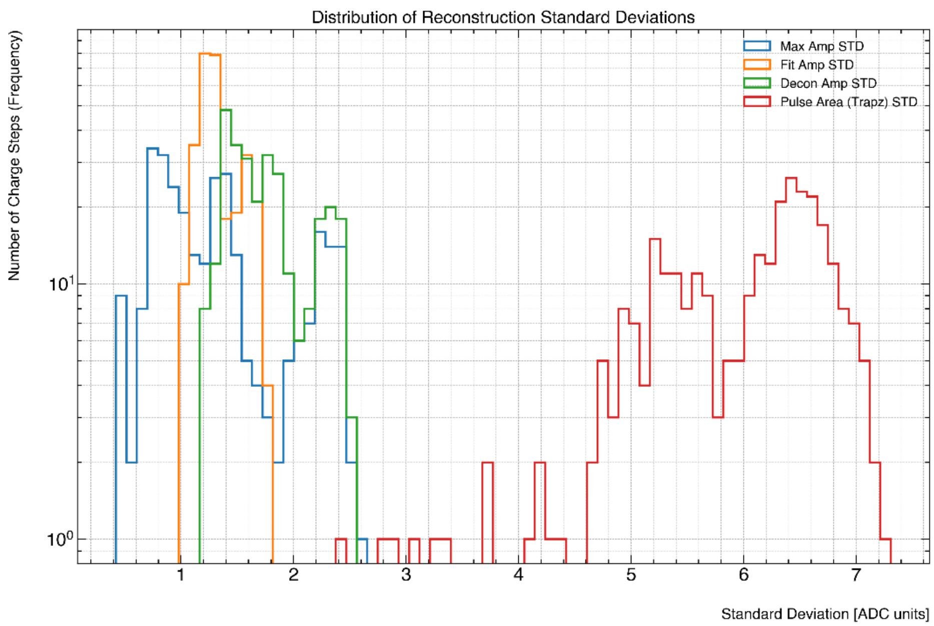
2. Pedestal DAC value 75 -Peak value not in phase of sampling but ful range was tested. 33 samples of tail TB2022 setting


Average Pulse Shape with CR-RC Fit vs. Injected Charge
ADC Value (Baseline Subtracted)
0
200
400
600
800
30
35
40
45
50
55
60
Sample Number

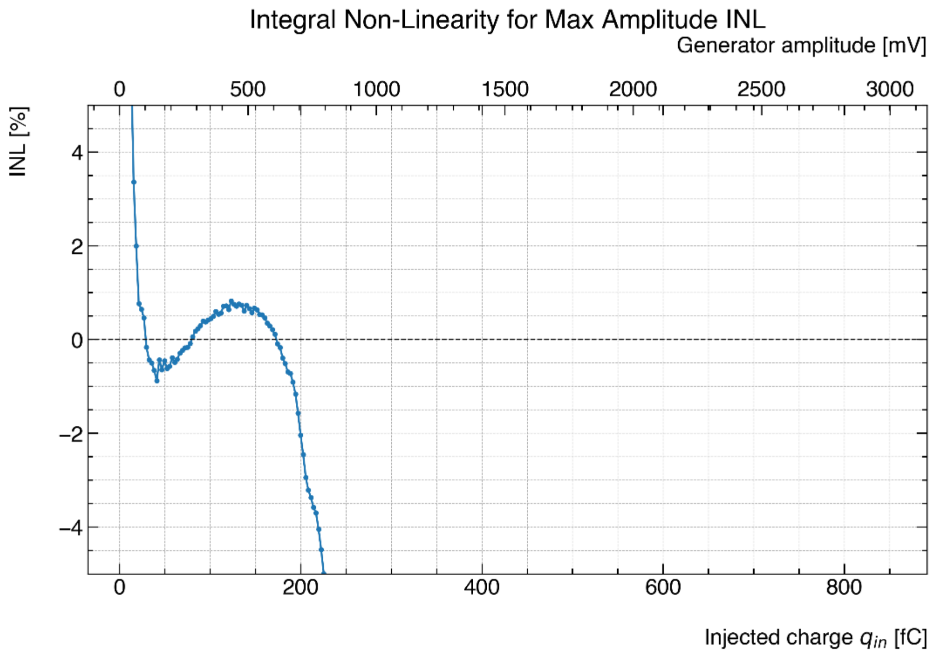

ADC Response for high_gain_new_injector_pedestal_-20dB - Reconstruction Method Comparison
Generator amplitude [mV]
0
500
1000
1500
2000
2500
3000
Max Amp Data
Fit Amp Data
Decon Amp Data
Pulse Area (Trapz)
Max Amp Fit (Gain = 3.37 LSB/fC)
Fit Amp Fit (Gain = 3.65 LSB/fC)
Decon Amp Fit (Gain = 3.68 LSB/fC)
Area (Trapz) Fit (Gain = 3.63)
Reconstructed Value [ADC units]
0
500
1000
1500
2000
2500
3000
0
200
400
600
800
Injected charge q_{in} [fC]

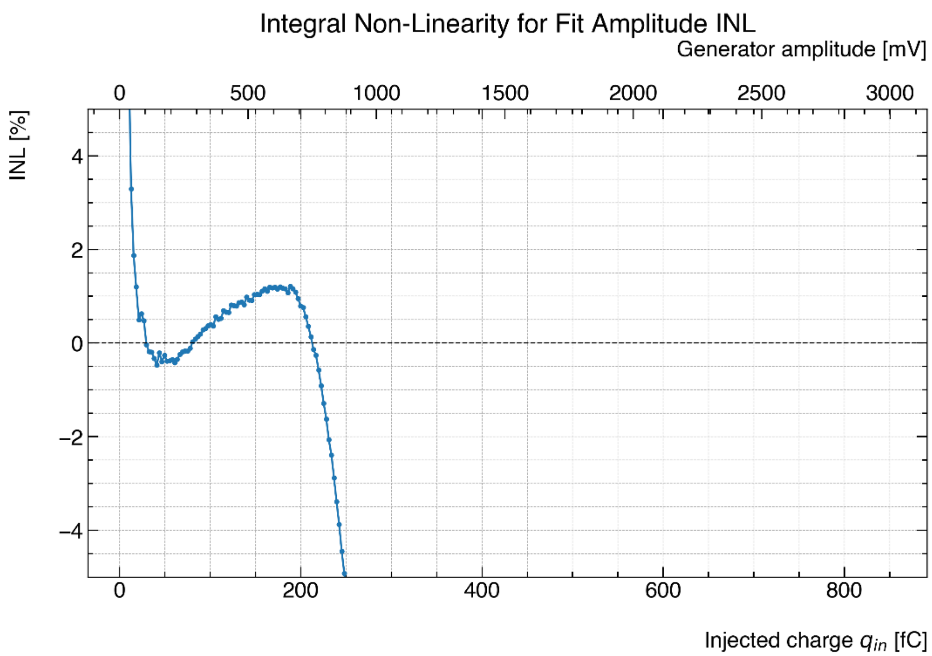


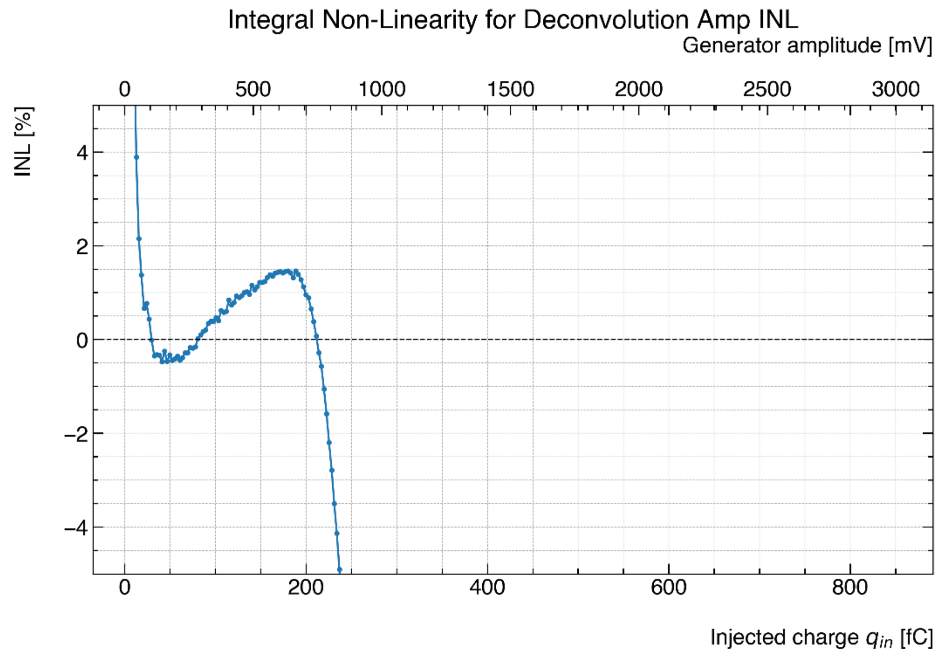
Reconstruction Resolution for high_gain_new_injector_pedestal_-20dB
Generator amplitude [mV]
Max Amp STD
Fit Amp STD
Decon Amp STD
Pulse Area (Trapz) STD
Standard Deviation [ADC units]
Injected charge q_{in} [fC]

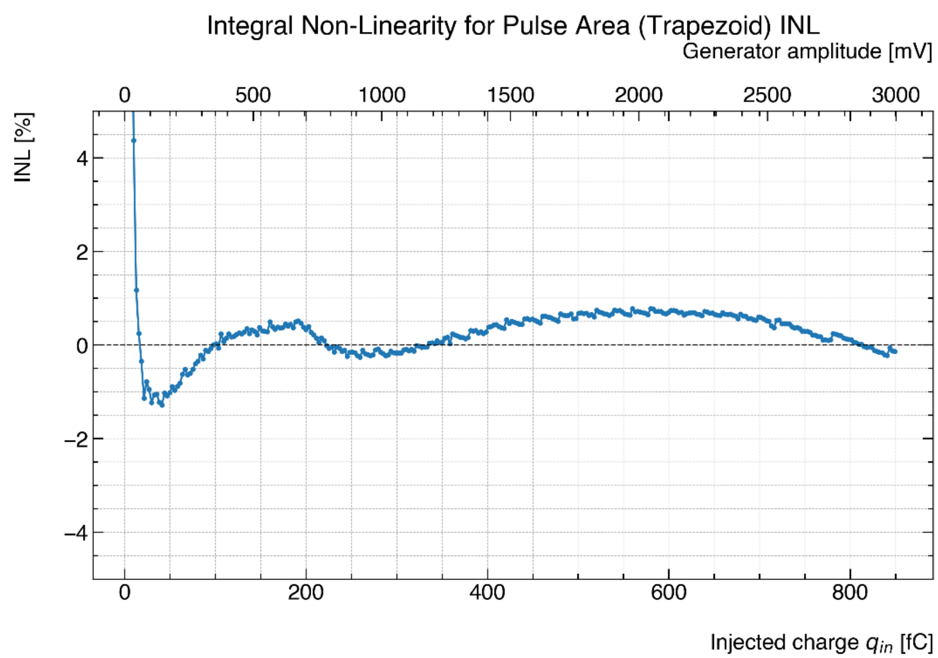


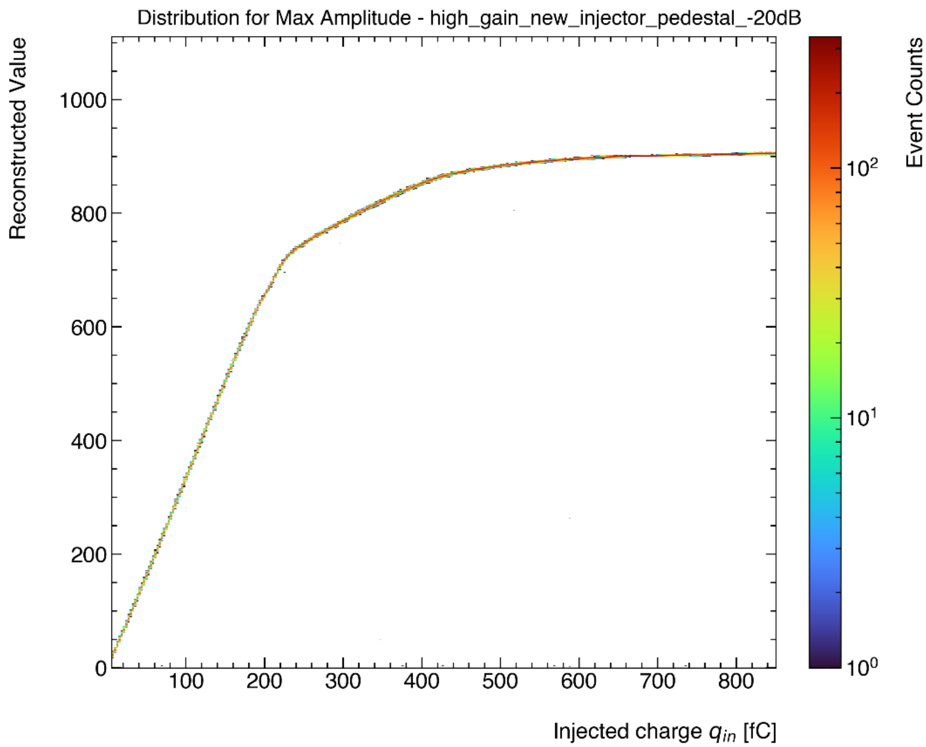
Distribution of Reconstruction Standard Deviations
Max Amp STD
Fit Amp STD
Decon Amp STD
Pulse Area (Trapz) STD
Number of Charge Steps (Frequency)
Standard Deviation [ADC units]


Integral Non-Linearity for Max Amplitude INL
Generator amplitude [mV]
0
500
1000
1500
2000
2500
3000
INL [%]
4
2
0
−2
−4
0
200
400
600
800
Injected charge q_{in} [fC]

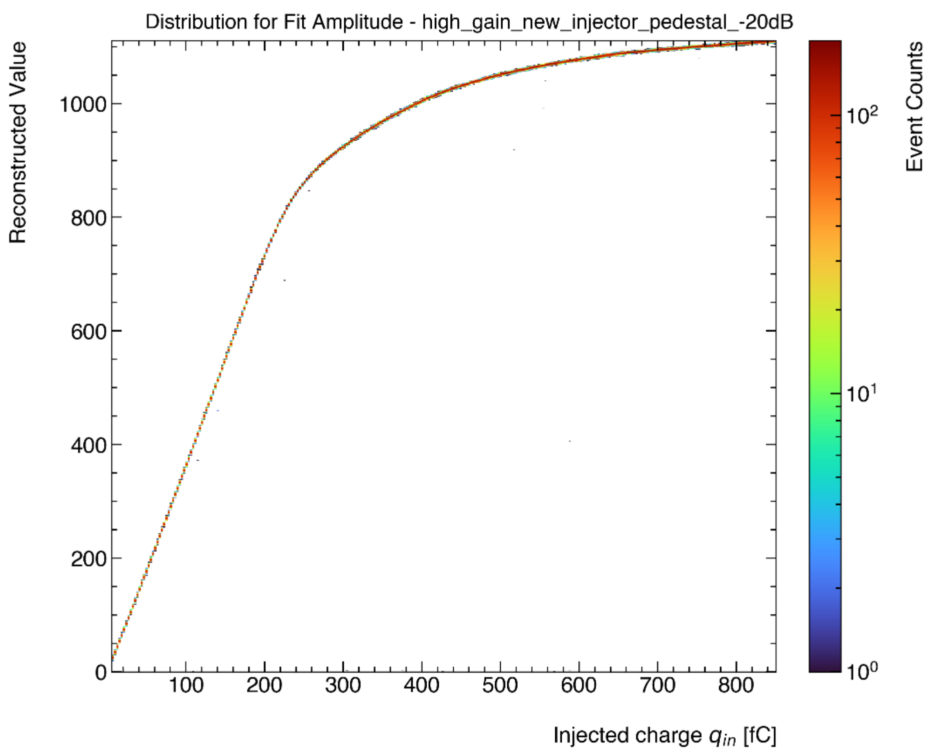

Integral Non-Linearity for Fit Amplitude INL
Generator amplitude [mV]
0
500
1000
1500
2000
2500
3000
INL [%]
4
2
0
−2
−4
0
200
400
600
800
Injected charge q_{in} [fC]


Integral Non-Linearity for Deconvolution Amp INL
Generator amplitude [mV]
0
500
1000
1500
2000
2500
3000
INL [%]
4
2
0
−2
−4
0
200
400
600
800
Injected charge q_{in} [fC]

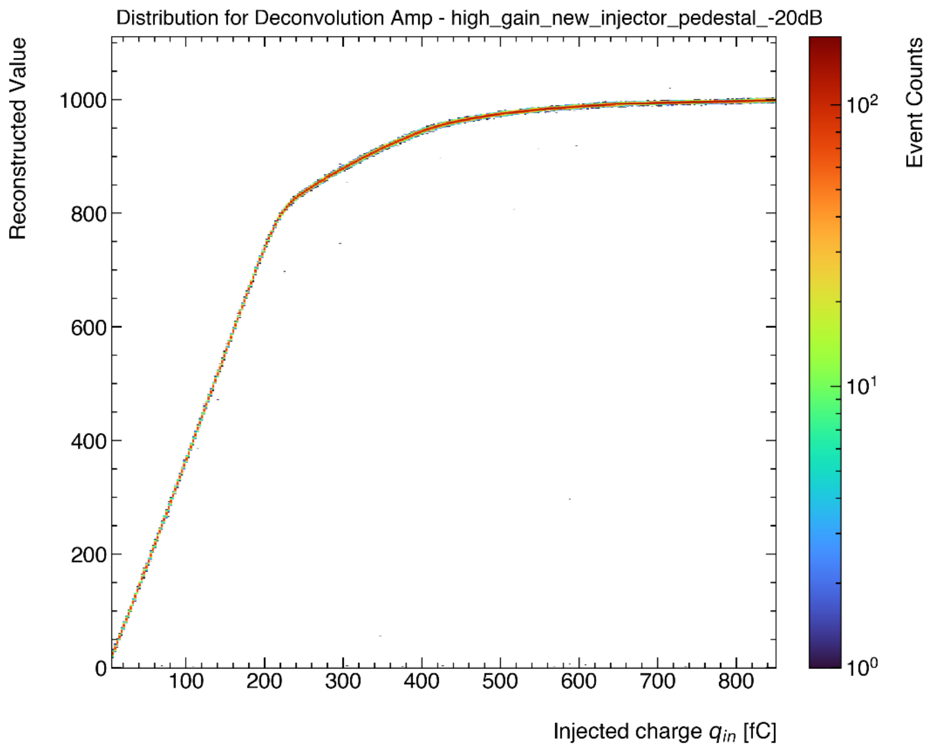

Integral Non-Linearity for Pulse Area (Trapezoid) INL
Generator amplitude [mV]
0
500
1000
1500
2000
2500
3000
INL [%]
4
2
0
−2
−4
0
200
400
600
800
Injected charge q_{in} [fC]

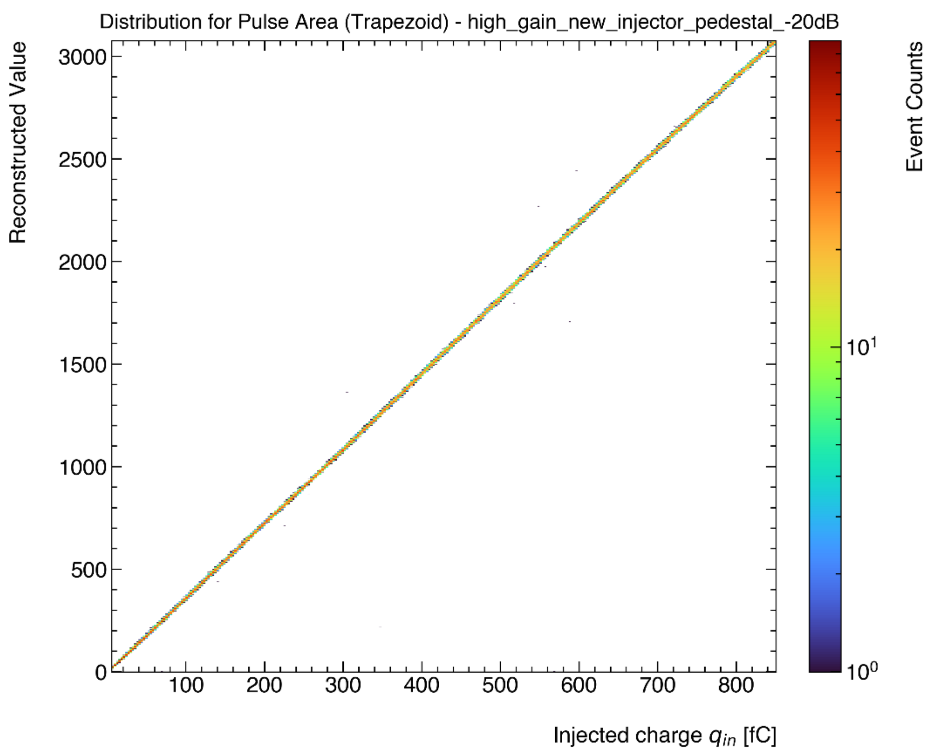


Distribution for Max Amplitude - high_gain_new_injector_pedestal_-20dB
Reconstructed Value
Injected charge q_{in} [fC]
Event Counts

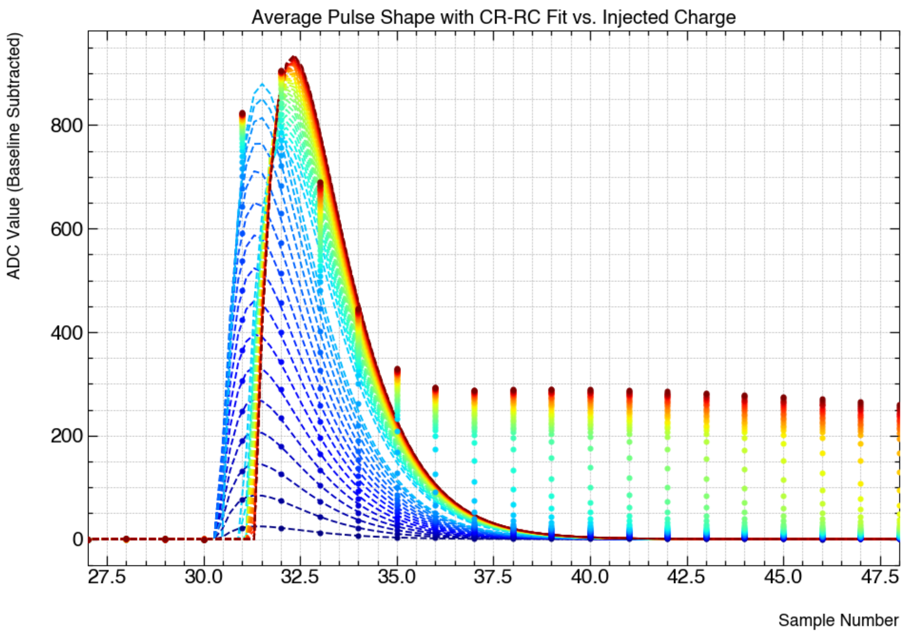


Distribution for Fit Amplitude - high_gain_new_injector_pedestal_-20dB
Reconstructed Value
Injected charge q_{in} [fC]
Event Counts

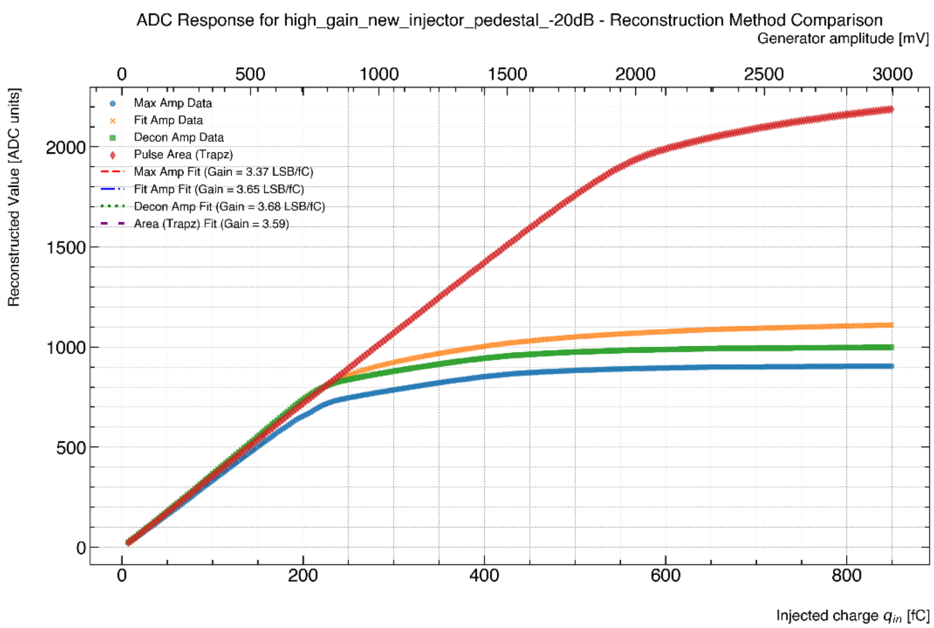




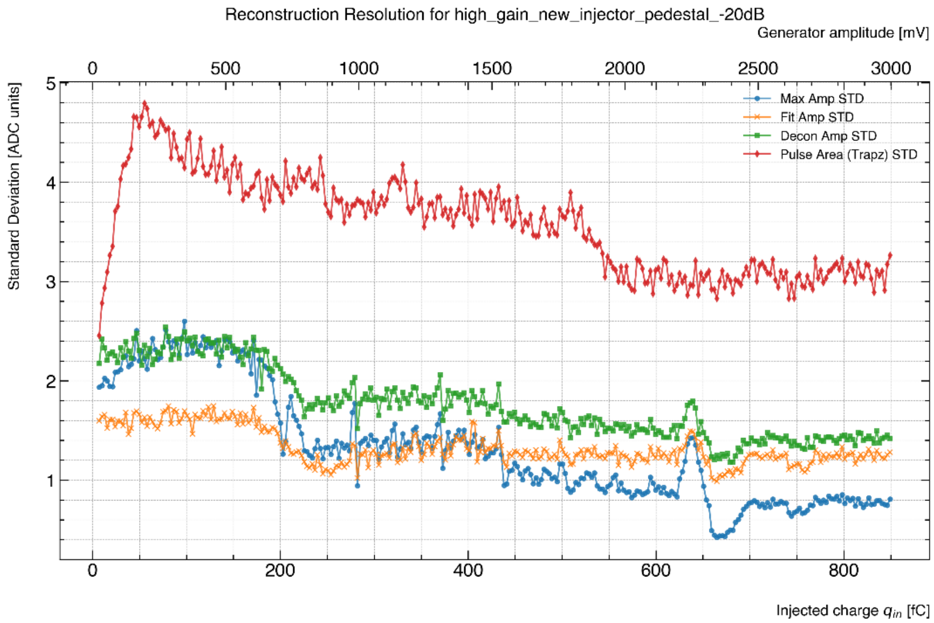
3. Pedestal DAC value 75 -Peak value not in phase of sampling but ful range was tested. 19 samples of tail TB2025 setting

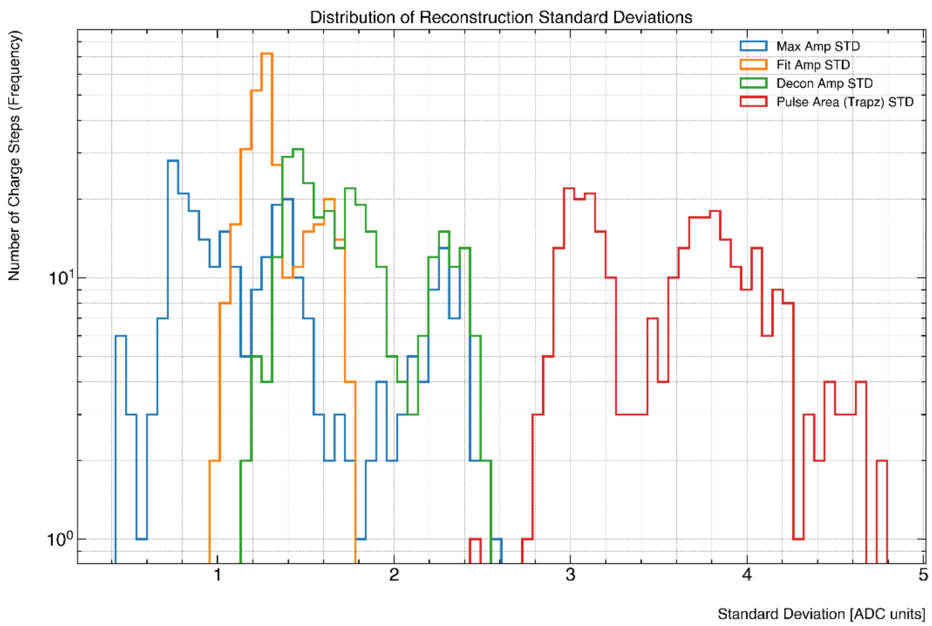


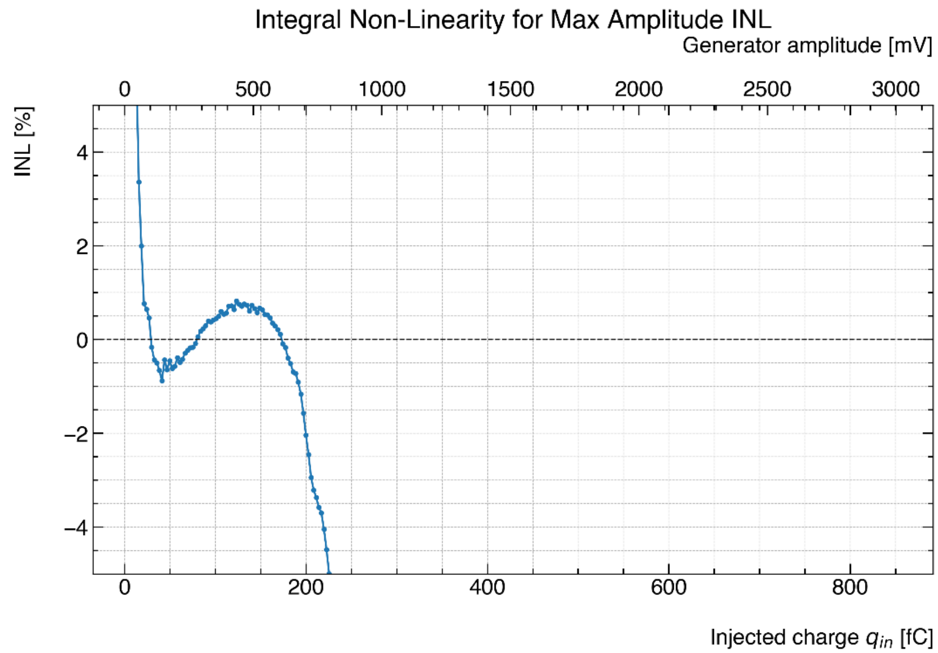
Average Pulse Shape with CR-RC Fit vs. Injected Charge
ADC Value (Baseline Subtracted)
Sample Number

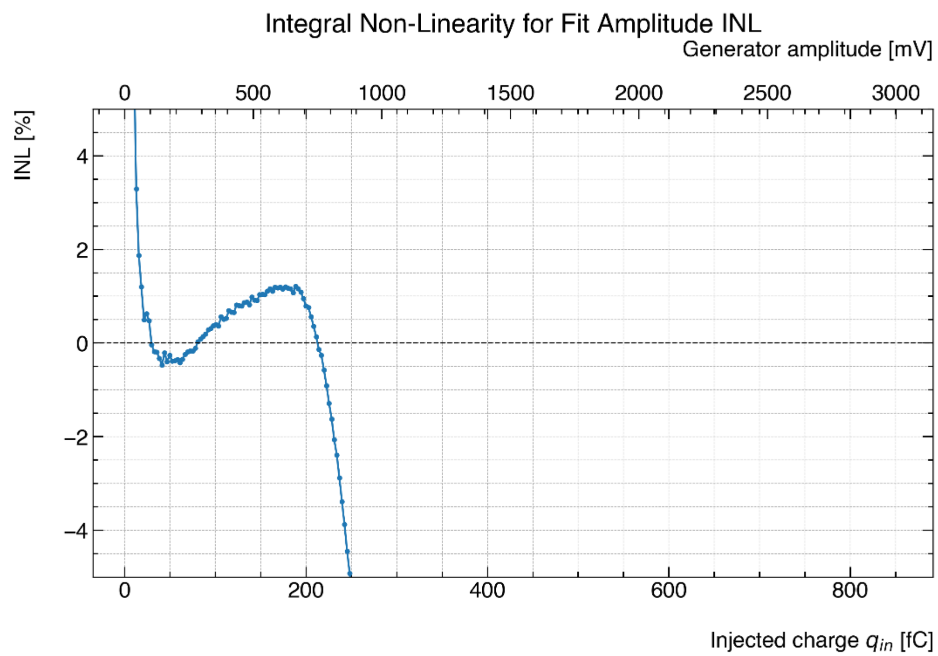


ADC Response for high_gain_new_injector_pedestal_-20dB - Reconstruction Method Comparison
Generator amplitude [mV]
Reconstructed Value [ADC units]
Injected charge q_{in} [fC]
Max Amp Data
Fit Amp Data
Decon Amp Data
Pulse Area (Trapz)
Max Amp Fit (Gain = 3.37 LSB/fC)
Fit Amp Fit (Gain = 3.65 LSB/fC)
Decon Amp Fit (Gain = 3.68 LSB/fC)
Area (Trapz) Fit (Gain = 3.59)

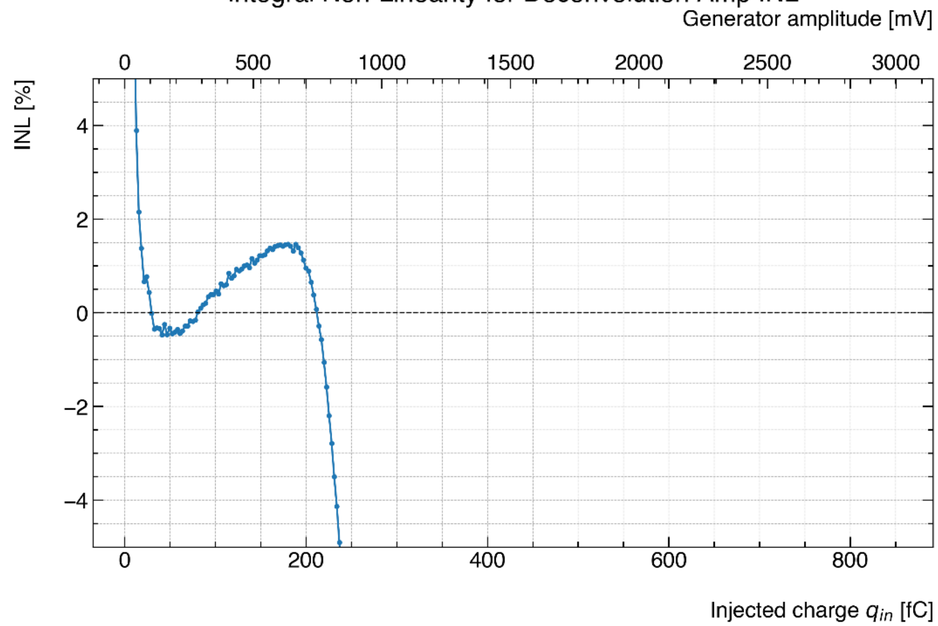

Reconstruction Resolution for high_gain_new_injector_pedestal_-20dB
Generator amplitude [mV]
0
500
1000
1500
2000
2500
3000
Standard Deviation [ADC units]
5
4
3
2
1
Max Amp STD
Fit Amp STD
Decon Amp STD
Pulse Area (Trapz) STD
0
200
400
600
800
Injected charge q_{in} [fC]


Distribution of Reconstruction Standard Deviations
Number of Charge Steps (Frequency)
10^1
10^0
Max Amp STD
Fit Amp STD
Decon Amp STD
Pulse Area (Trapz) STD
1
2
3
4
5
Standard Deviation [ADC units]

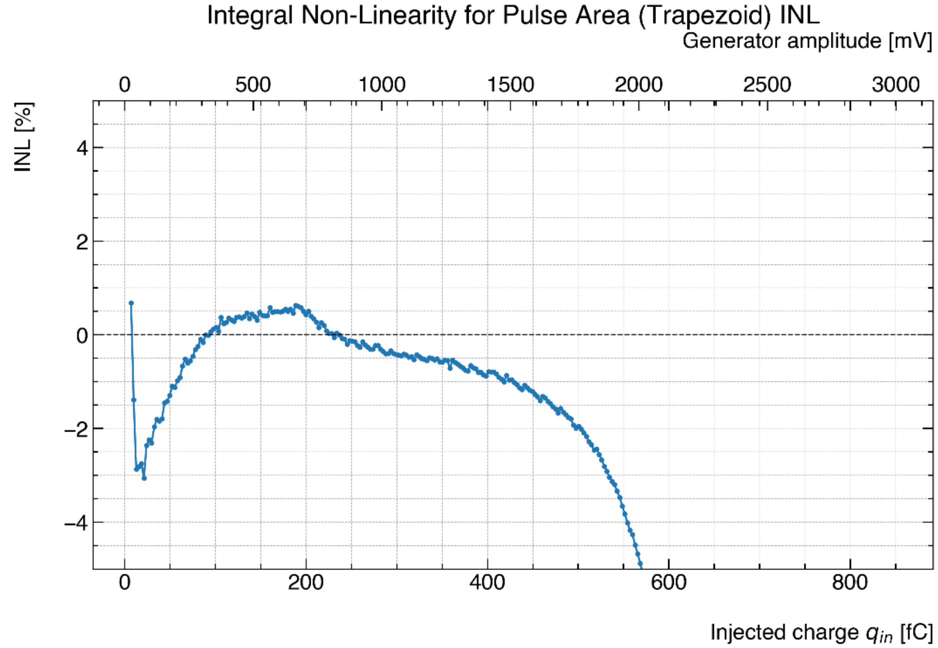

Integral Non-Linearity for Max Amplitude INL
Generator amplitude [mV]
0
500
1000
1500
2000
2500
3000
INL [%]
4
2
0
−2
−4
0
200
400
600
800
Injected charge q_{in} [fC]

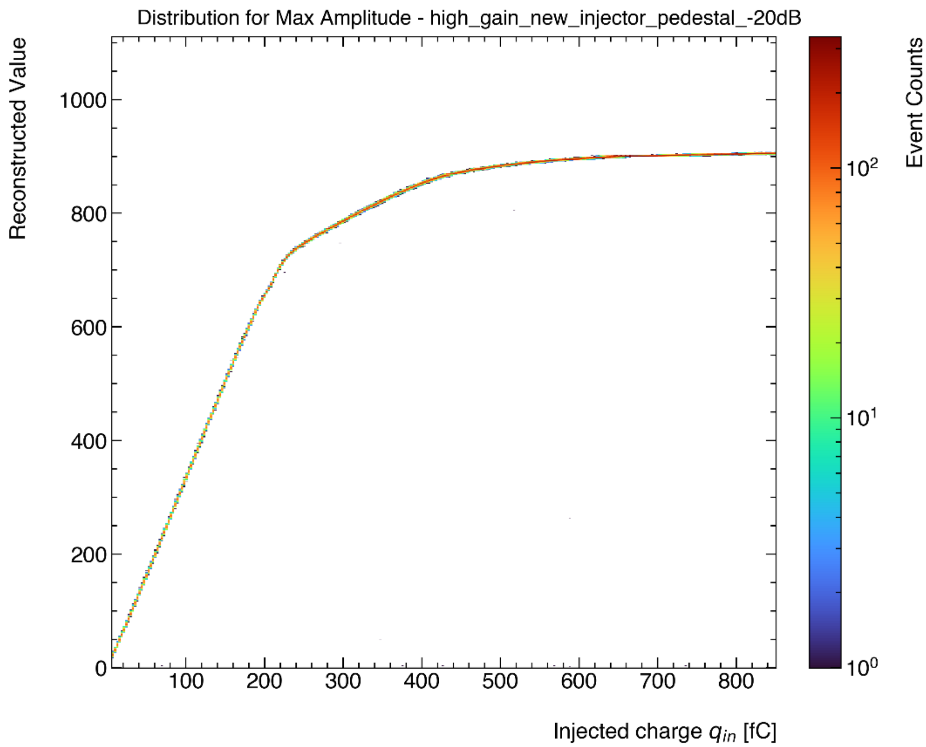

Integral Non-Linearity for Fit Amplitude INL
Generator amplitude [mV]
0
500
1000
1500
2000
2500
3000
INL [%]
4
2
0
−2
−4
0
200
400
600
800
Injected charge q_{in} [fC]

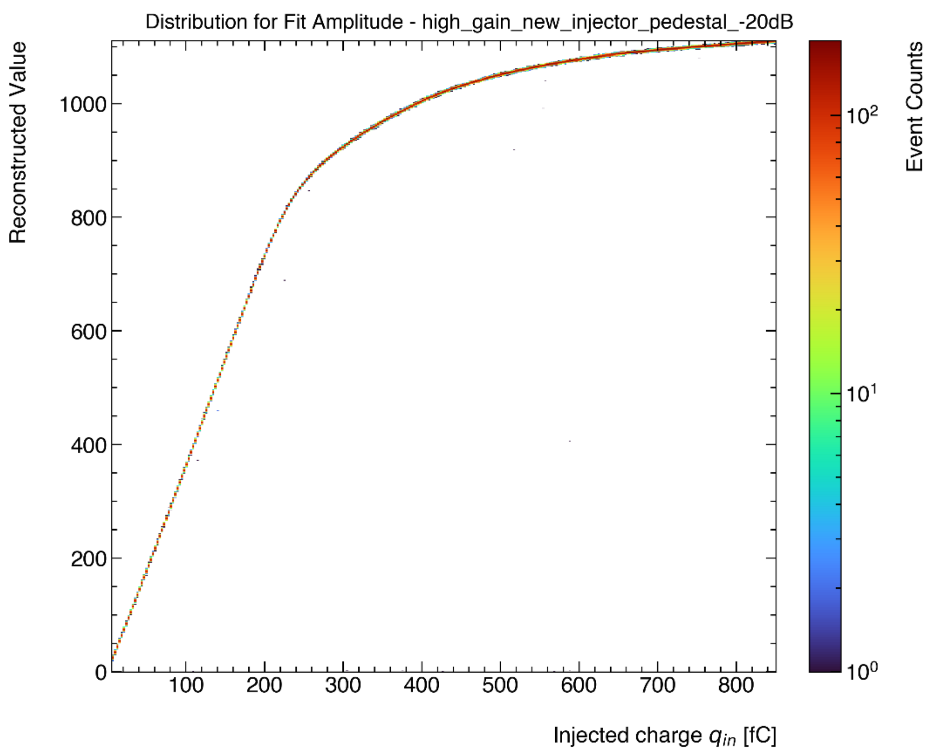
Integral Non-Linearity for Deconvolution Amp INL

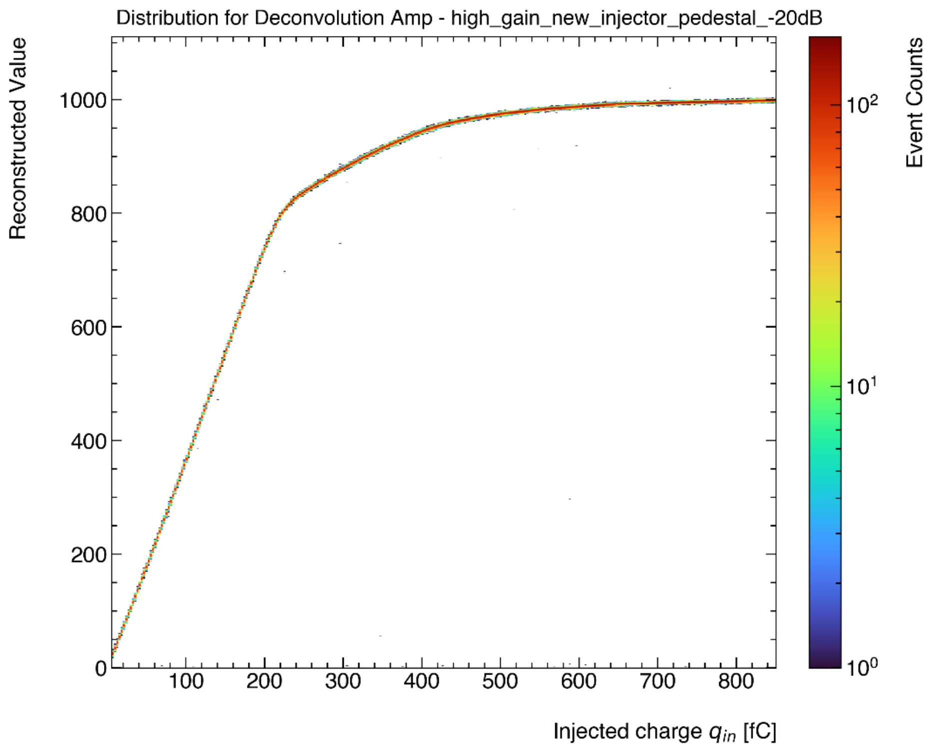


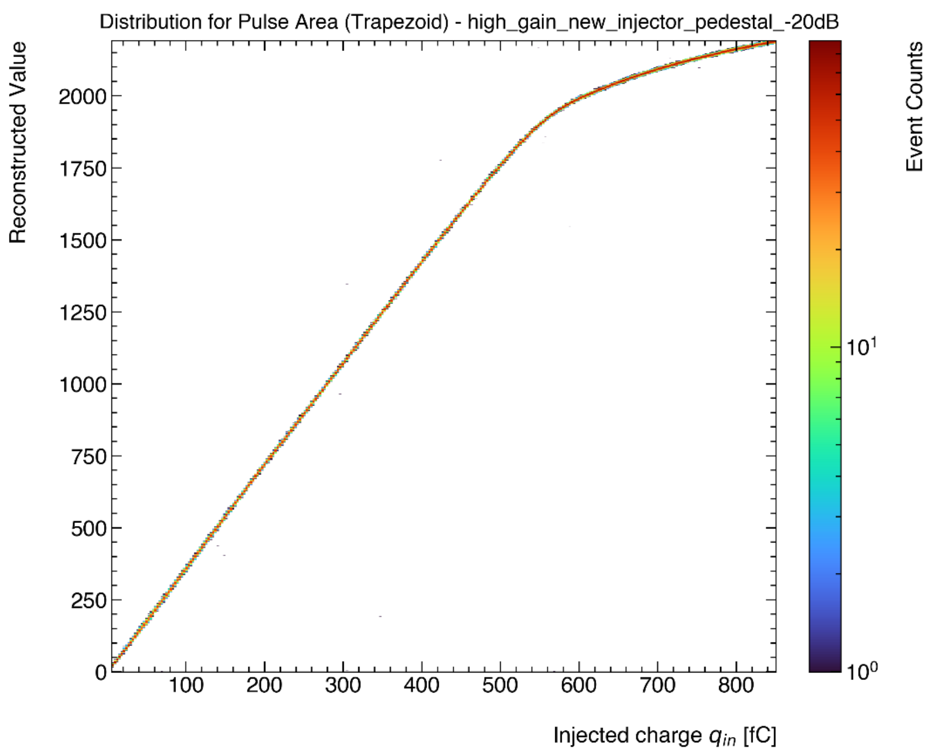
Integral Non-Linearity for Pulse Area (Trapezoid) INL




Distribution for Max Amplitude - high_gain_new_injector_pedestal_-20dB
Reconstructed Value
Injected charge q_{in} [fC]
Event Counts
0
200
400
600
800
1000
100
200
300
400
500
600
700
800
10^0
10^1
10^2


Distribution for Fit Amplitude - high_gain_new_injector_pedestal_-20dB
Reconstructed Value
Injected charge q_{in} [fC]
Event Counts
0
200
400
600
800
1000
100
200
300
400
500
600
700
800
10^0
10^1
10^2


Distribution for Deconvolution Amp - high_gain_new_injector_pedestal_-20dB
Reconstructed Value
Injected charge q_{in} [fC]
Event Counts
0
200
400
600
800
1000
100
200
300
400
500
600
700
800
10^0
10^1
10^2


Distribution for Pulse Area (Trapezoid) - high_gain_new_injector_pedestal_-20dB
Reconstructed Value
Injected charge q_{in} [fC]
Event Counts
0
250
500
750
1000
1250
1500
1750
2000
100
200
300
400
500
600
700
800
10^0
10^1

4. Finding function which describe well frontend response in function of charge

I assume that we can divide response in to three regions initial linear response, saturation knee described by polynomial and saturated but linear part.

- First linear function was fitted in region 100 - 300 fC
- Crucially, the polynomial for the transition region is not fitted to the data in the conventional sense. Instead, its parameters are **analytically solved** to create a "bridge" that smoothly connects the two previously determined linear sections. This is accomplished by imposing a set of strict mathematical boundary conditions.

  For a polynomial of order N, N+1 conditions are required to uniquely determine its N+1 coefficients. The script generalizes this by constructing a system of linear equations based on a hierarchy of constraints. Using a 5th-order polynomial ($ax^5 + ... + f$) as an example, which has six unknown coefficients, the following six boundary conditions are enforced:

  1. **Value at x_1 (300 fC):** The polynomial's value must equal the first line's value at the connection point.
  2. **Slope at x_1:** The polynomial's first derivative (slope) must equal the slope m_1 of the first line.
  3. **Curvature at x_1:** The polynomial's second derivative (curvature) is set to zero to match the zero curvature of the straight line, ensuring an exceptionally smooth transition.
  4. **Value at x_2 (750 fC):** The polynomial's value must equal the second line's value at the second connection point.
  5. **Slope at x_2:** The polynomial's slope must equal the slope m_2 of the second line.
  6. **Curvature at x_2:** The polynomial's second derivative is also set to zero to smoothly merge into the final linear section.

  The Linear Algebra Solution

  Each boundary condition described before forms a linear equation. This creates a system of N+1 equations for N+1 unknowns, which is expressed in the standard matrix form: **M * p = v**.

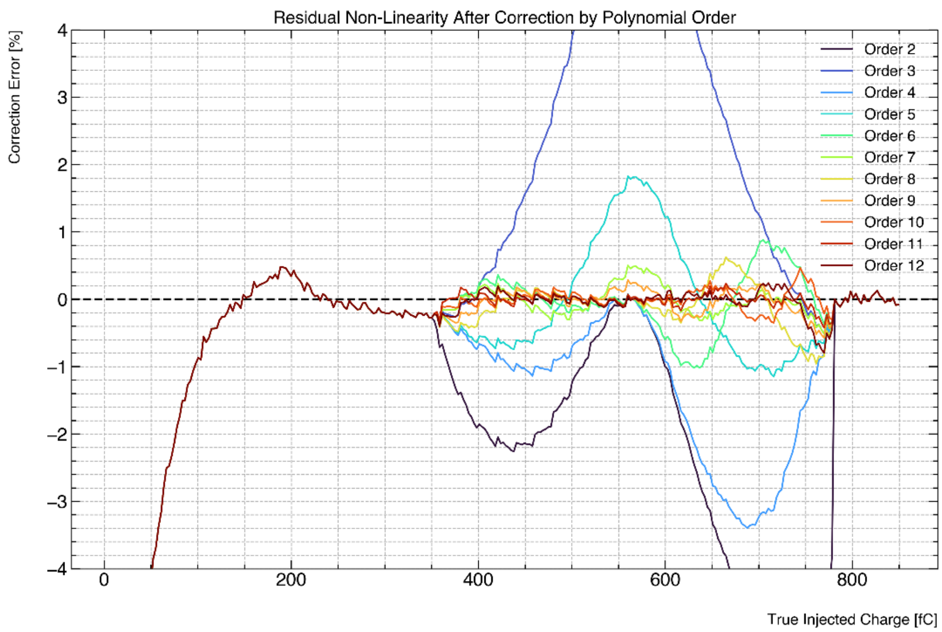
  - M is the coefficient matrix derived from the polynomial and its derivatives evaluated at the boundary points x_1 and x_2.
  - p is the vector of unknown polynomial coefficients that the script needs to find.
  - v is the vector of known target values, determined from the linear fits in Stage 1 (e.g., y_1, m_1, 0, y_2, m_2, 0).
  -
- The script used to find polynomial which describe transition region utilizes a deterministic linear algebra solver (np.linalg.solve) to find the unique vector p that

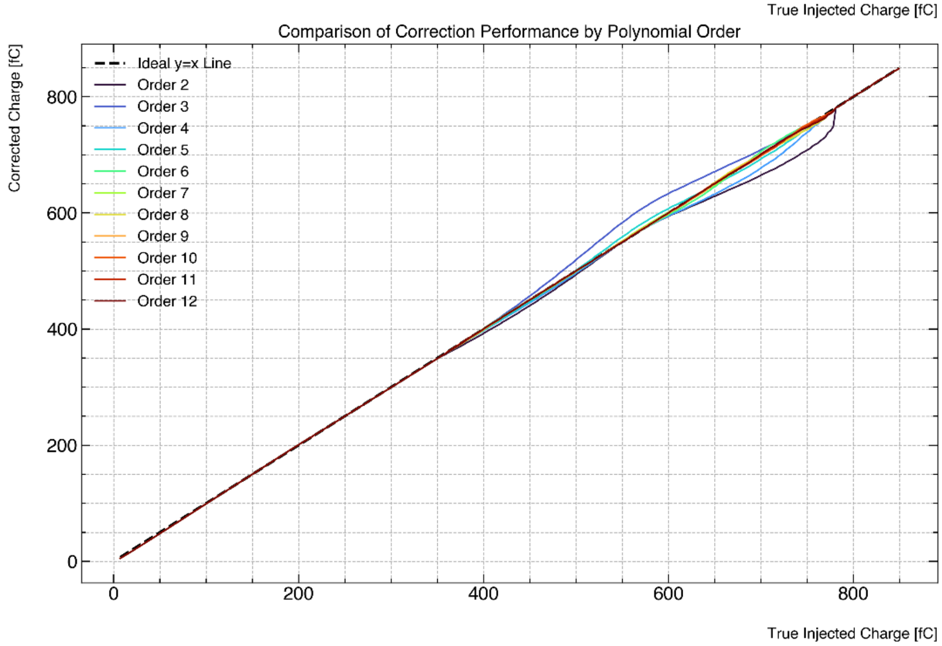
satisfies all imposed conditions. The resulting polynomial coefficients are therefore not the result of an iterative optimization against the middle data points but a direct analytical solution that guarantees a smooth, continuous function across the entire range.

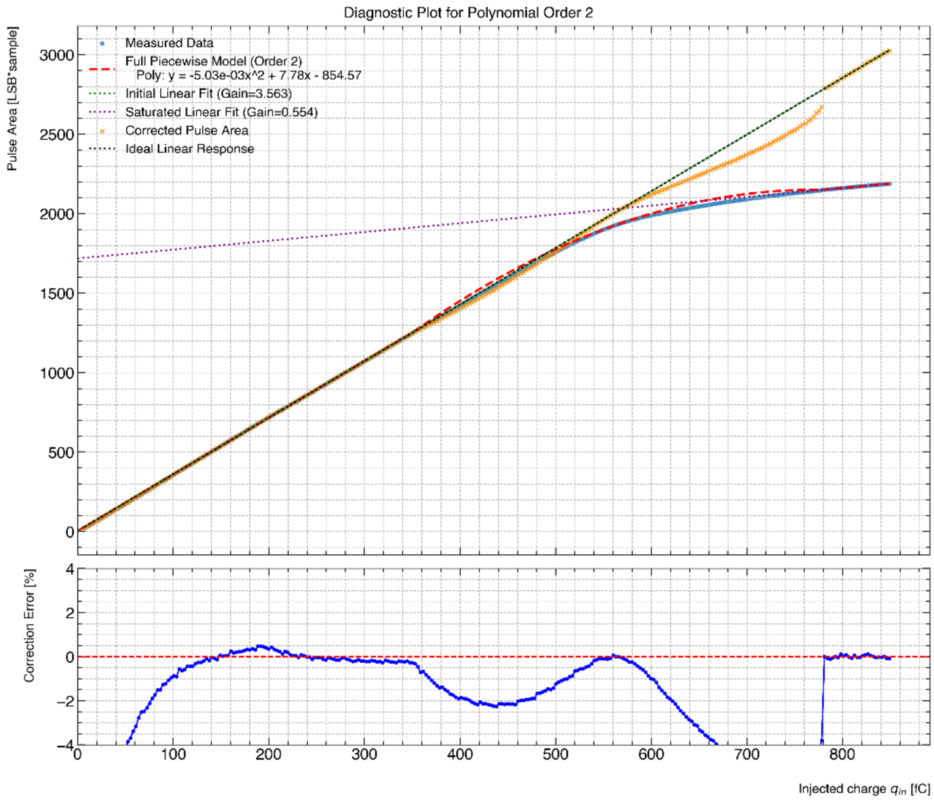
- Second linear function fitted in region 750 fC to the end

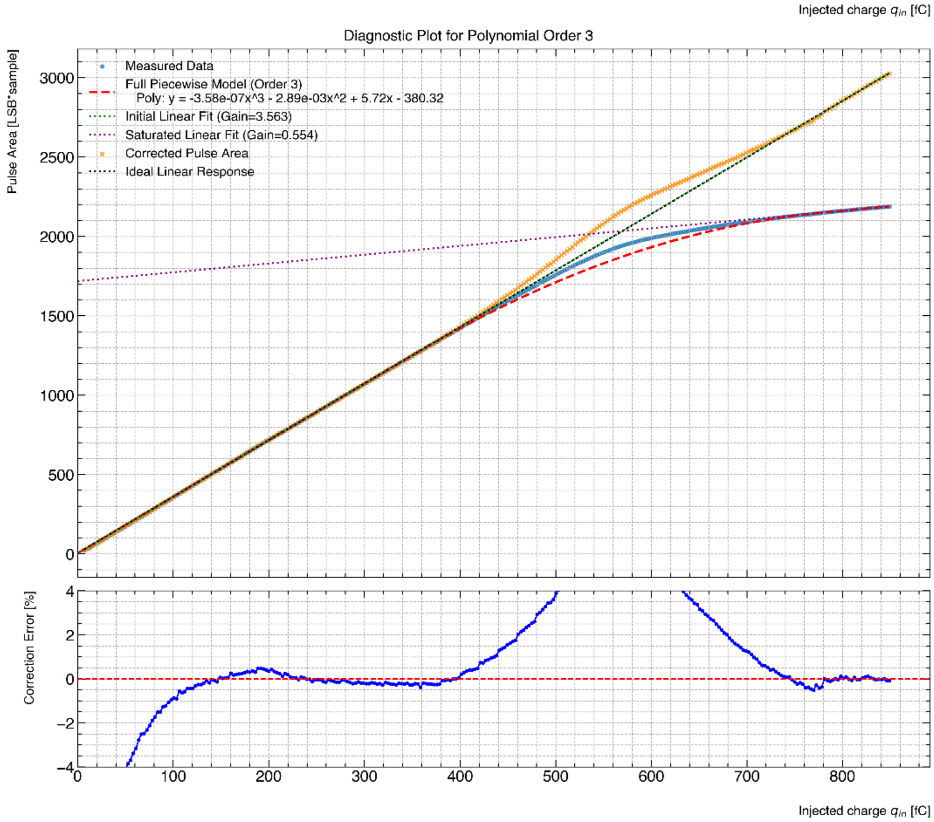
Results of finding appropriate model

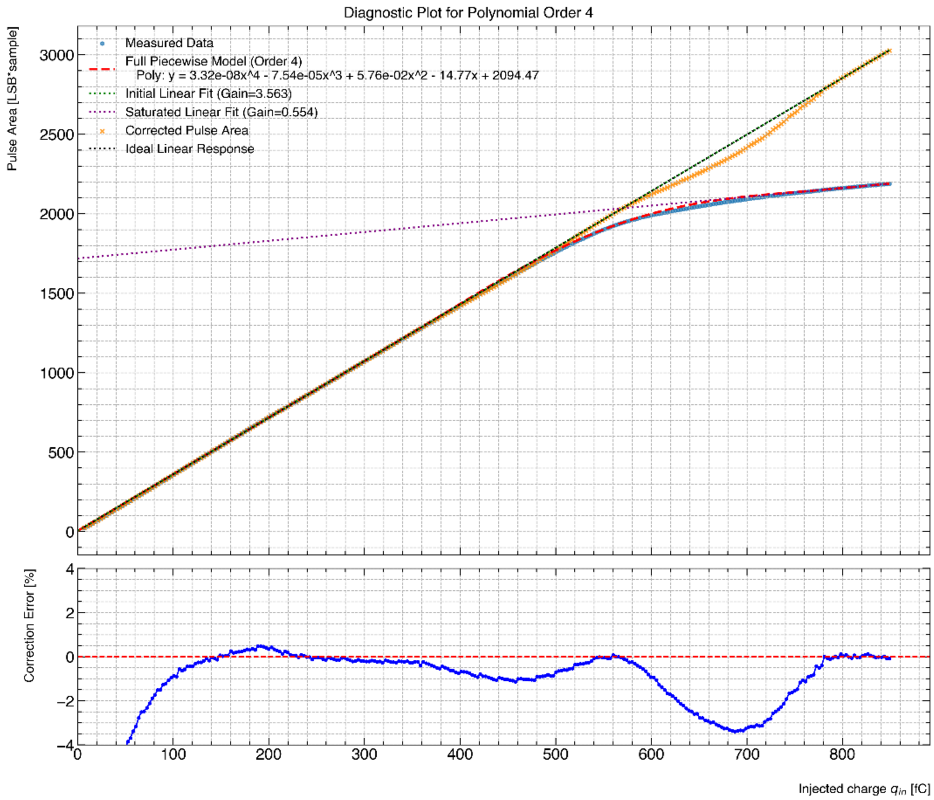
Polynomial order 7 seems to be enough for accurate describe and correct saturation region.

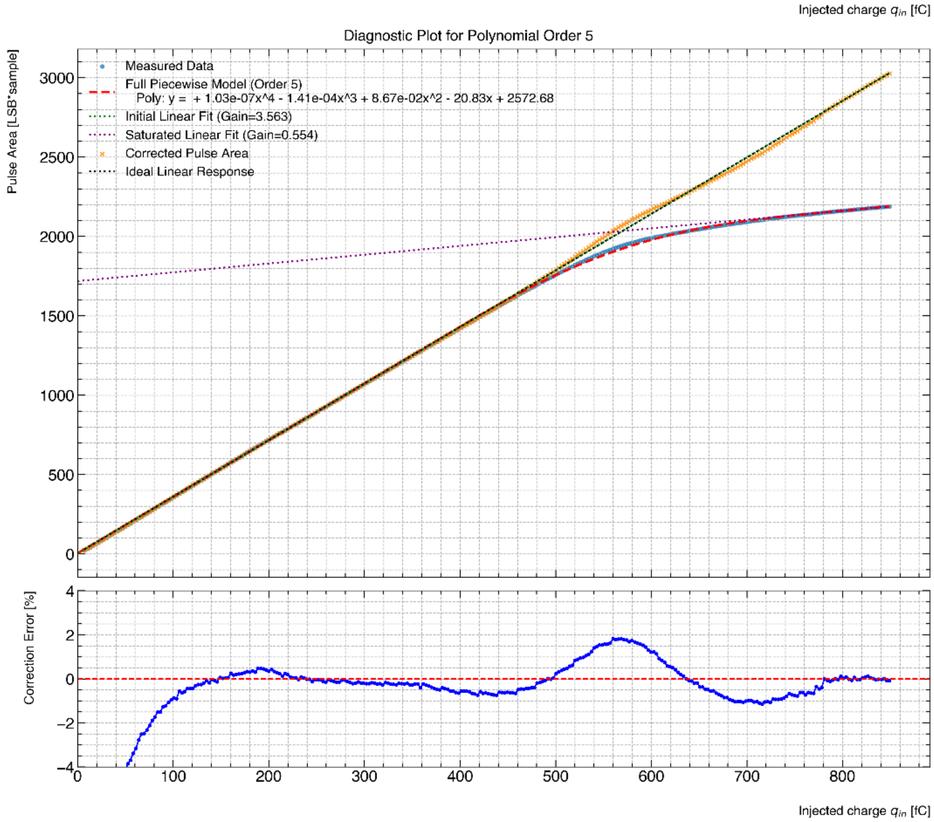


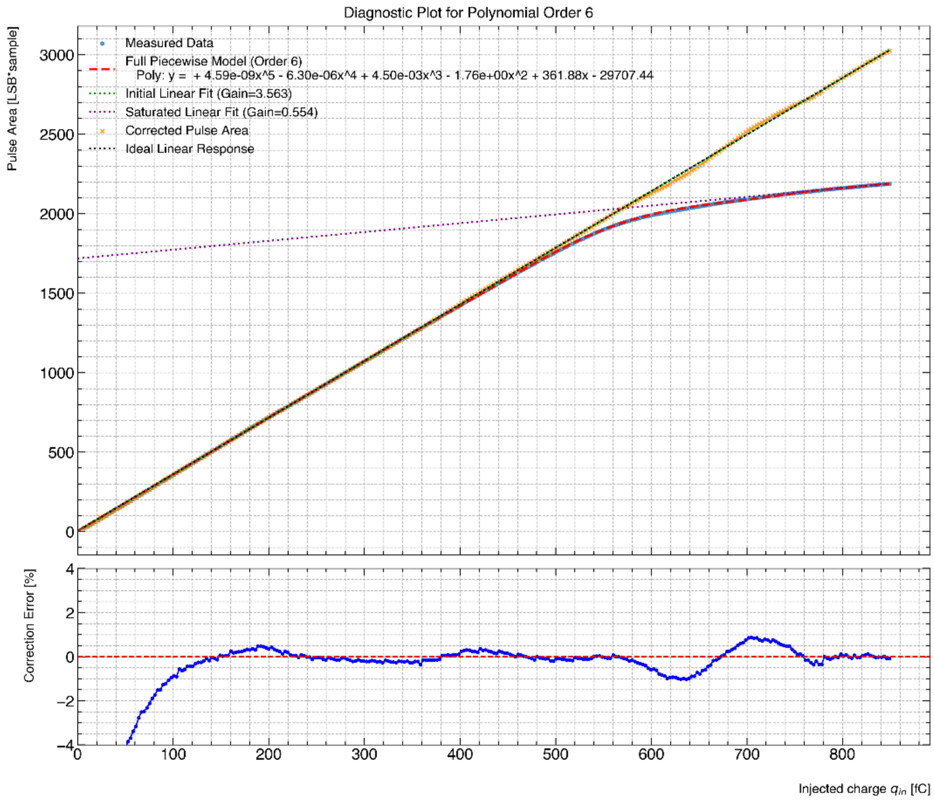


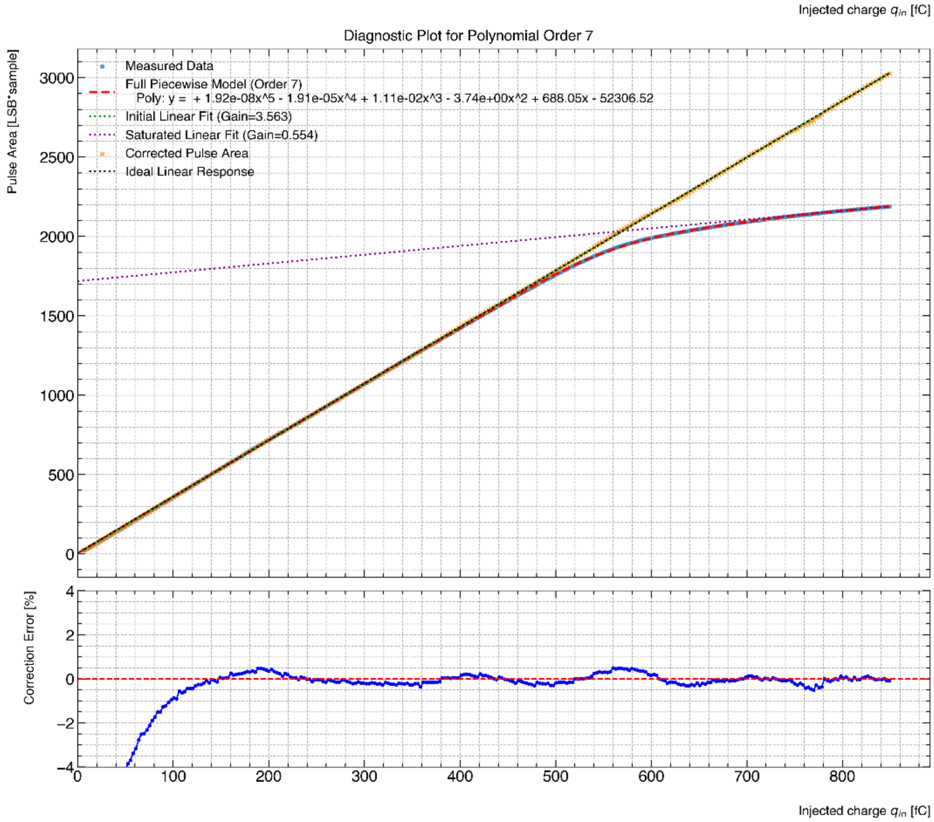

Diagnostic Plot for Polynomial Order 2
Measured Data
Full Piecewise Model (Order 2)
Poly: y = -5.03e-03x^2 + 7.78x - 854.57
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]

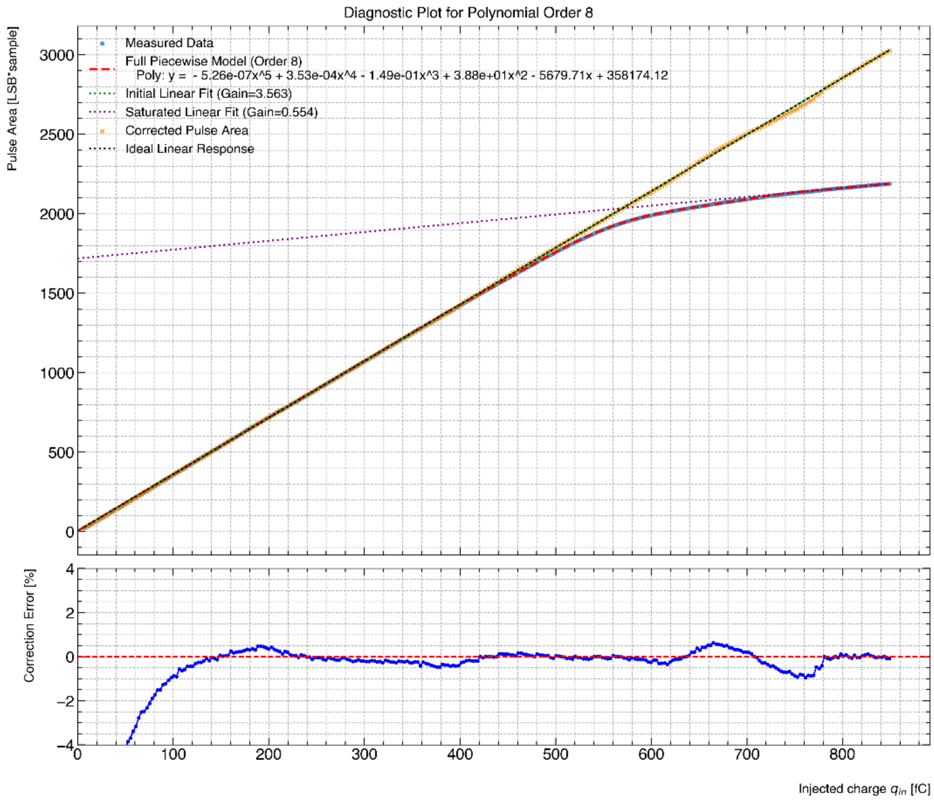

Diagnostic Plot for Polynomial Order 3
Measured Data
Full Piecewise Model (Order 3)
Poly: y = -3.58e-07x^3 - 2.89e-03x^2 + 5.72x - 380.32
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]


Diagnostic Plot for Polynomial Order 4
Measured Data
Full Piecewise Model (Order 4)
Poly: y = 3.32e-08x^4 - 7.54e-05x^3 + 5.76e-02x^2 - 14.77x + 2094.47
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]

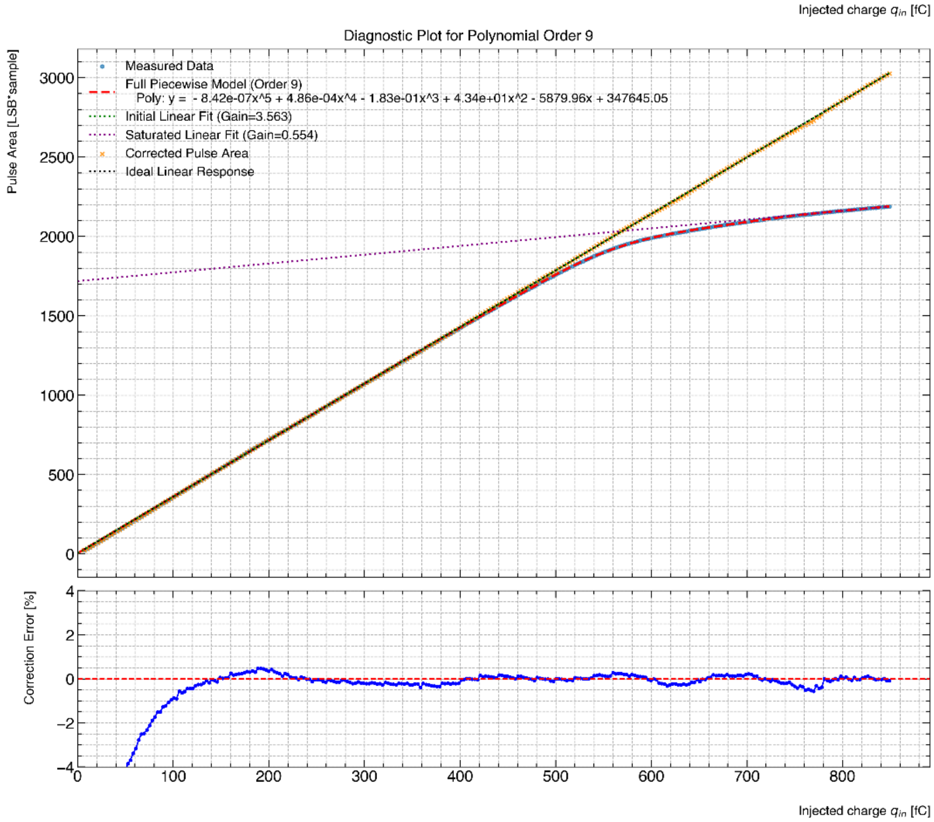

Diagnostic Plot for Polynomial Order 5
Measured Data
Full Piecewise Model (Order 5)
Poly: y = + 1.03e-07x^4 - 1.41e-04x^3 + 8.67e-02x^2 - 20.83x + 2572.68
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]


Diagnostic Plot for Polynomial Order 6
Measured Data
Full Piecewise Model (Order 6)
Poly: y = + 4.59e-09x^5 - 6.30e-06x^4 + 4.50e-03x^3 - 1.76e+00x^2 + 361.88x - 29707.44
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]

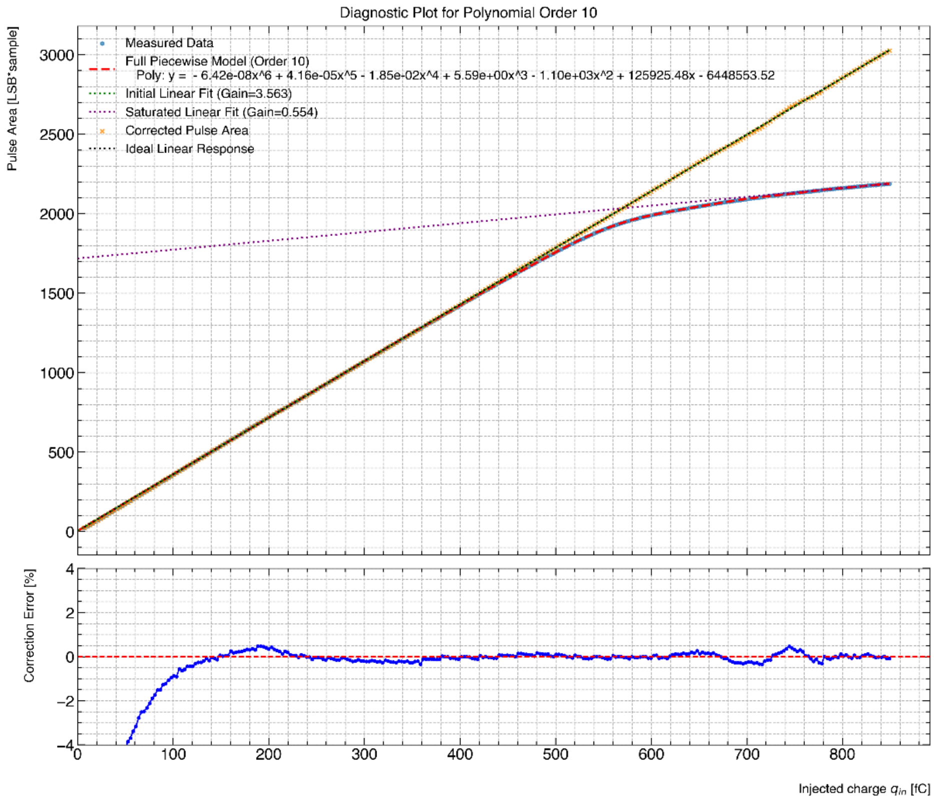

Diagnostic Plot for Polynomial Order 7
Measured Data
Full Piecewise Model (Order 7)
Poly: y = + 1.92e-08x^5 - 1.91e-05x^4 + 1.11e-02x^3 - 3.74e+00x^2 + 688.05x - 52306.52
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]

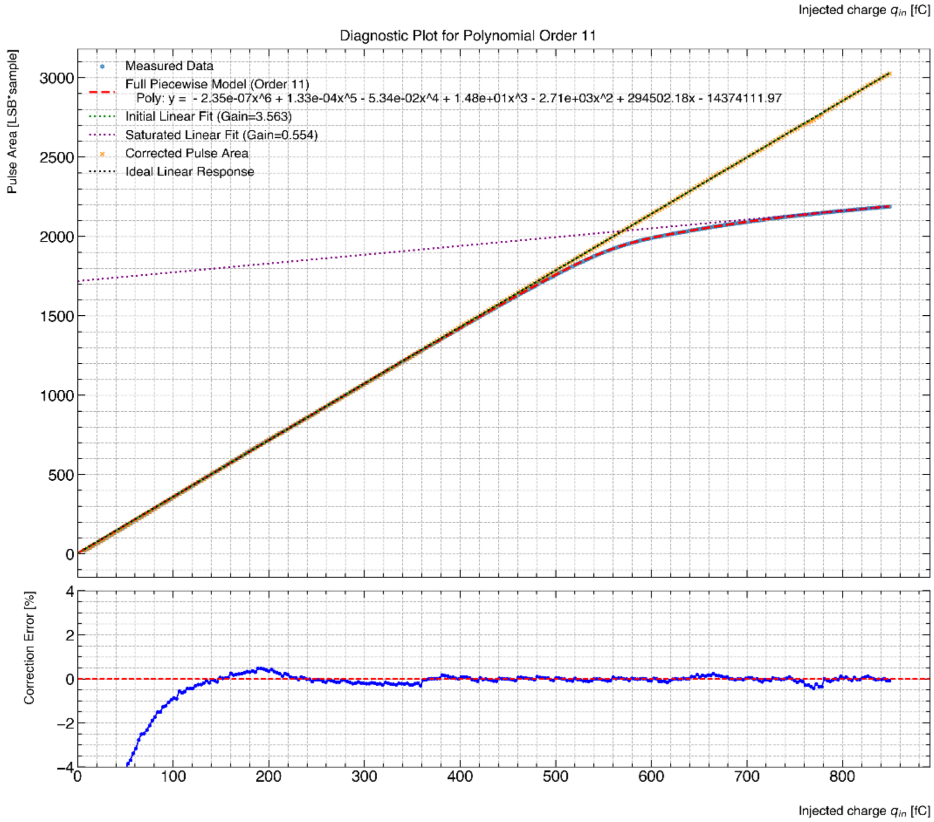


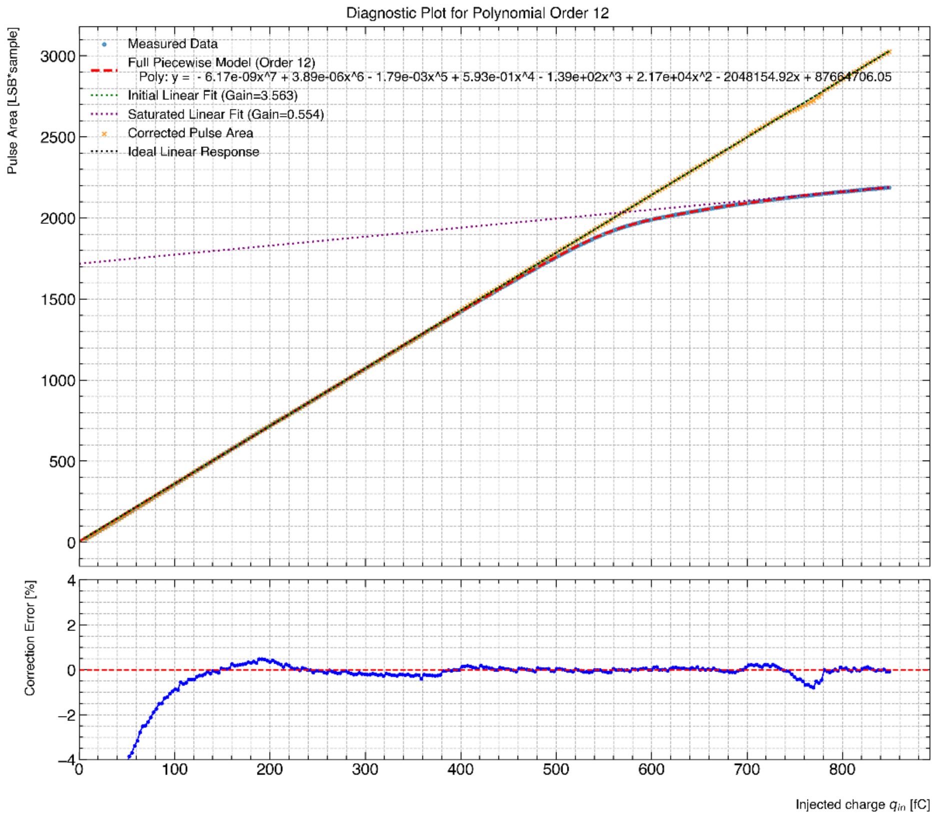
Diagnostic Plot for Polynomial Order 8
Measured Data
Full Piecewise Model (Order 8)
Poly: y = - 5.26e-07x^5 + 3.53e-04x^4 - 1.49e-01x^3 + 3.88e+01x^2 - 5679.71x + 358174.12
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]



Diagnostic Plot for Polynomial Order 9
Measured Data
Full Piecewise Model (Order 9)
Poly: y = - 8.42e-07x^5 + 4.86e-04x^4 - 1.83e-01x^3 + 4.34e+01x^2 - 5879.96x + 347645.05
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]


Diagnostic Plot for Polynomial Order 10
Measured Data
Full Piecewise Model (Order 10)
Poly: y = - 6.42e-08x^6 + 4.16e-05x^5 - 1.85e-02x^4 + 5.59e+00x^3 - 1.10e+03x^2 + 125925.48x - 6448553.52
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]


Diagnostic Plot for Polynomial Order 11
Measured Data
Full Piecewise Model (Order 11)
Poly: y = - 2.35e-07x^6 + 1.33e-04x^5 - 5.34e-02x^4 + 1.48e+01x^3 - 2.71e+03x^2 + 294502.18x - 14374111.97
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
Correction Error [%]
Injected charge q_{in} [fC]



Diagnostic Plot for Polynomial Order 12
Measured Data
Full Piecewise Model (Order 12)
Poly: y = - 6.17e-09x^7 + 3.89e-06x^6 - 1.79e-03x^5 + 5.93e-01x^4 - 1.39e+02x^3 + 2.17e+04x^2 - 2048154.92x + 87664706.05
Initial Linear Fit (Gain=3.563)
Saturated Linear Fit (Gain=0.554)
Corrected Pulse Area
Ideal Linear Response
Pulse Area [LSB*sample]
3000
2500
2000
1500
1000
500
0
Correction Error [%]
4
2
0
−2
−4
0
100
200
300
400
500
600
700
800
Injected charge q_{in} [fC]