Multidisciplinary Laboratory

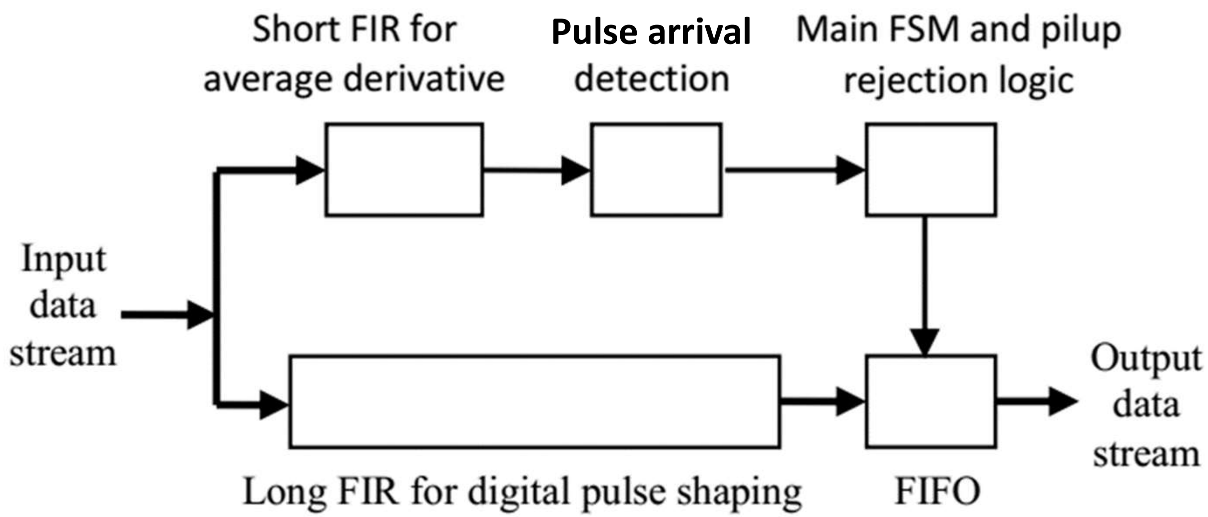
ECAL2 Data Analysis

Werner Florian

Overview

- DPP Strategy for high resolution amplitude measurements
- Ideal pulse model
  - Pulses classification criteria
  - Single pulse model
  - Pulse plus reflection model
  - Improved pulse model
- Noise analysis
  - Burst regime qualitative description
  - FFT
  - Autocorrelation

Digital Pulse Processing Strategy for High Resolution Amplitude Measurement

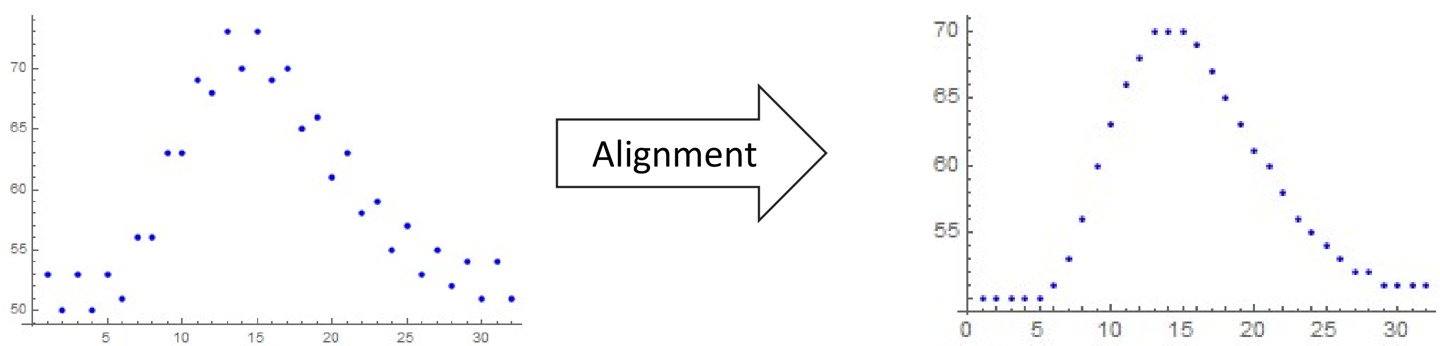


Data alignment

- Data is obtained by 2 ADCs interleaved
- Each ADC has a different offset

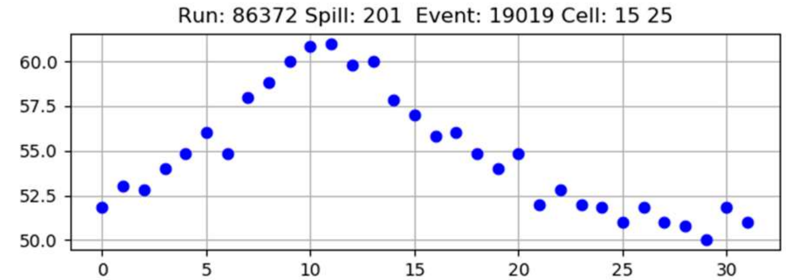
$$\overline{x_{odd}} - \overline{x_{even}} = d$$

d is subtracted form x_{even} and a new signal is created with its values aligned

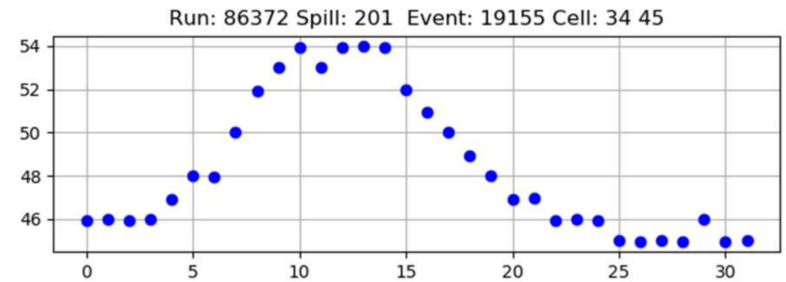


Some Typical Pulses

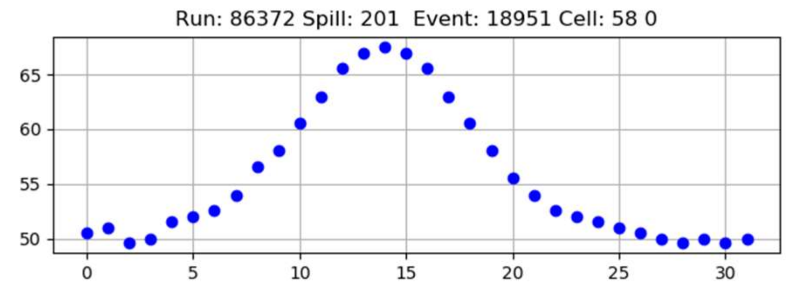
- Triangular



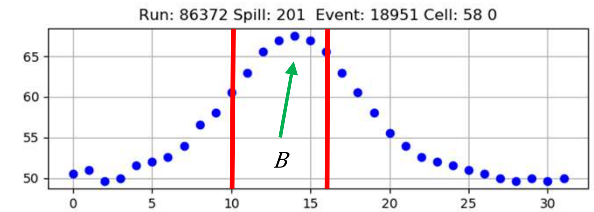
- Truncated



- Gaussian like



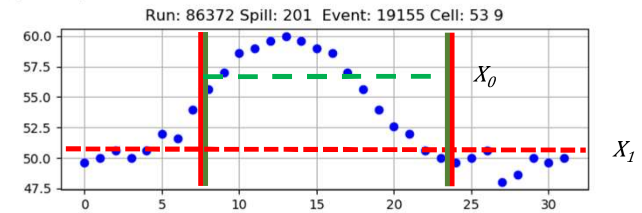
Pulses Selection Criteria



- Barycenter position:

Value must be between lower and higher limits

$$l_{inf} < B < lsup; \;\; where\ Baryceter\ B = \frac{\sum i_j\, A_j}{\sum\, A_i}$$



- Means difference:

This is used to reject negative pulses

$$\overline{X_0[8{:}24]} - \overline{X_1[0{:}8, 24{:}32]} > threshold$$

Fitting Model : CR-RC^N Shaper Single Pulse

- $$F(t, t_0, \tau, off, a, N) = \begin{cases} off & , t < t_0 \\ off + a \dfrac{e^N \left(\frac{(t-t_0)}{\tau}\right)^N e^{-\frac{(t-t_0)}{\tau}}}{N^N} & , t \geq t_0 \end{cases}$$

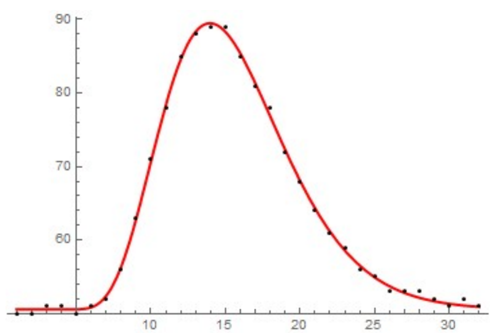
off := offset

t_0:= time of arrival

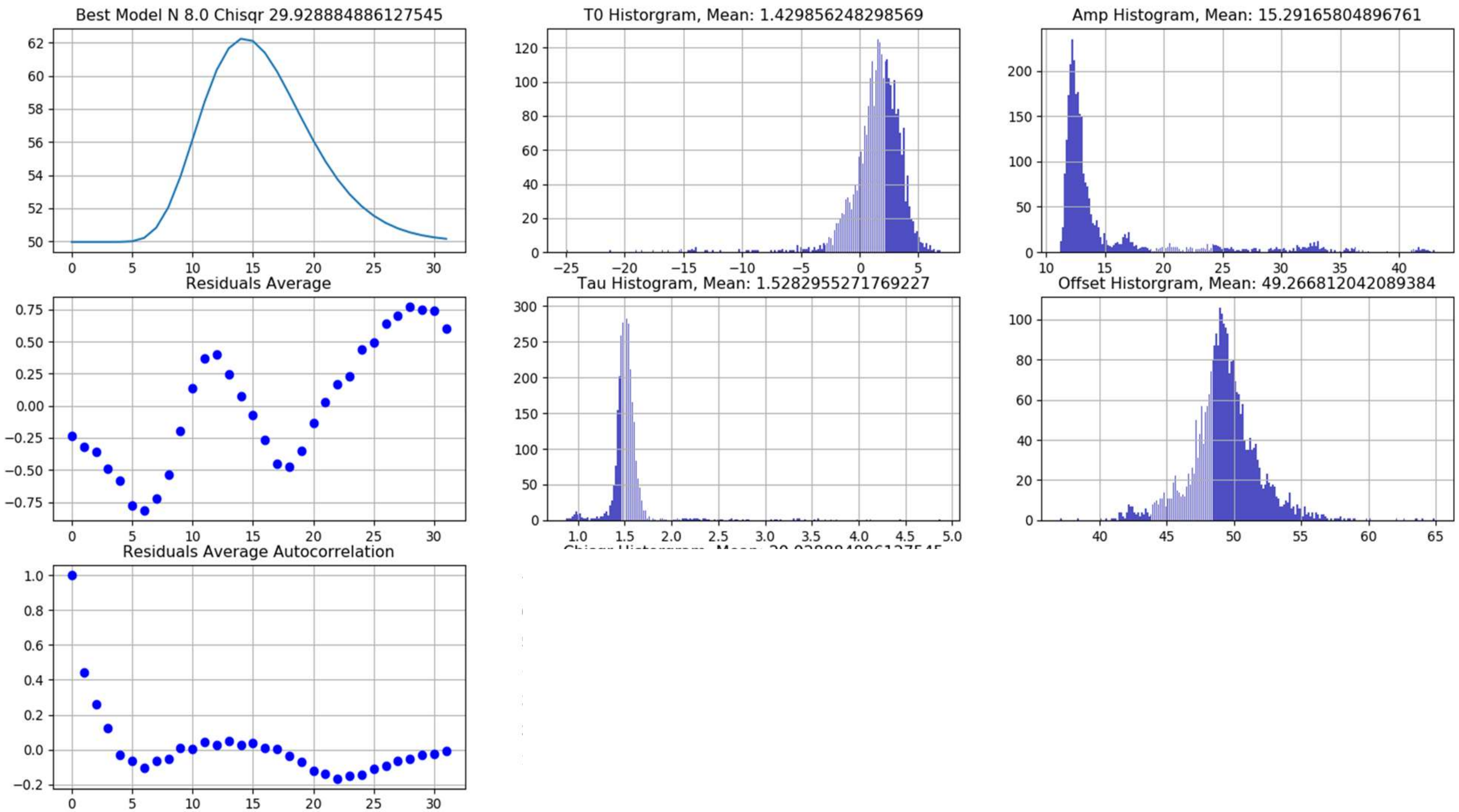
a:= amplitude

τ:= exponential time

N:= order



Fitting results



Fitting Model: Main Pulse Plus Reflection

$$F(t, t_0, \tau, off, a, N, k, t_d) =$$

$$\begin{cases} off & , t_0 > t \\ off + a\,\dfrac{e^N \left(\dfrac{(t-t_0)}{\tau}\right)^N e^{-\frac{(t-t_0)}{\tau}}}{N^N} & , t_0 + t_d > t \geq t_0 \\ off + a\,\dfrac{e^N \left(\dfrac{(t-t_0)}{\tau}\right)^N e^{-\frac{(t-t_0)}{\tau}}}{N^N} + k * a\,\dfrac{e^N \left(\dfrac{(t-(t_0+t_d))}{\tau}\right)^N e^{-\frac{(t-(t_0+t_d))}{\tau}}}{N^N} & , t \geq t_0 + t_d \end{cases}$$

off := offset

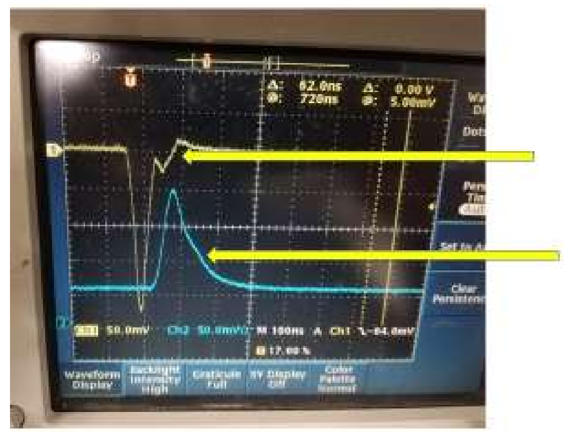
t_0:= time of arrival

a:= amplitude

τ:= exponential time

k:= reflection attenuation factor

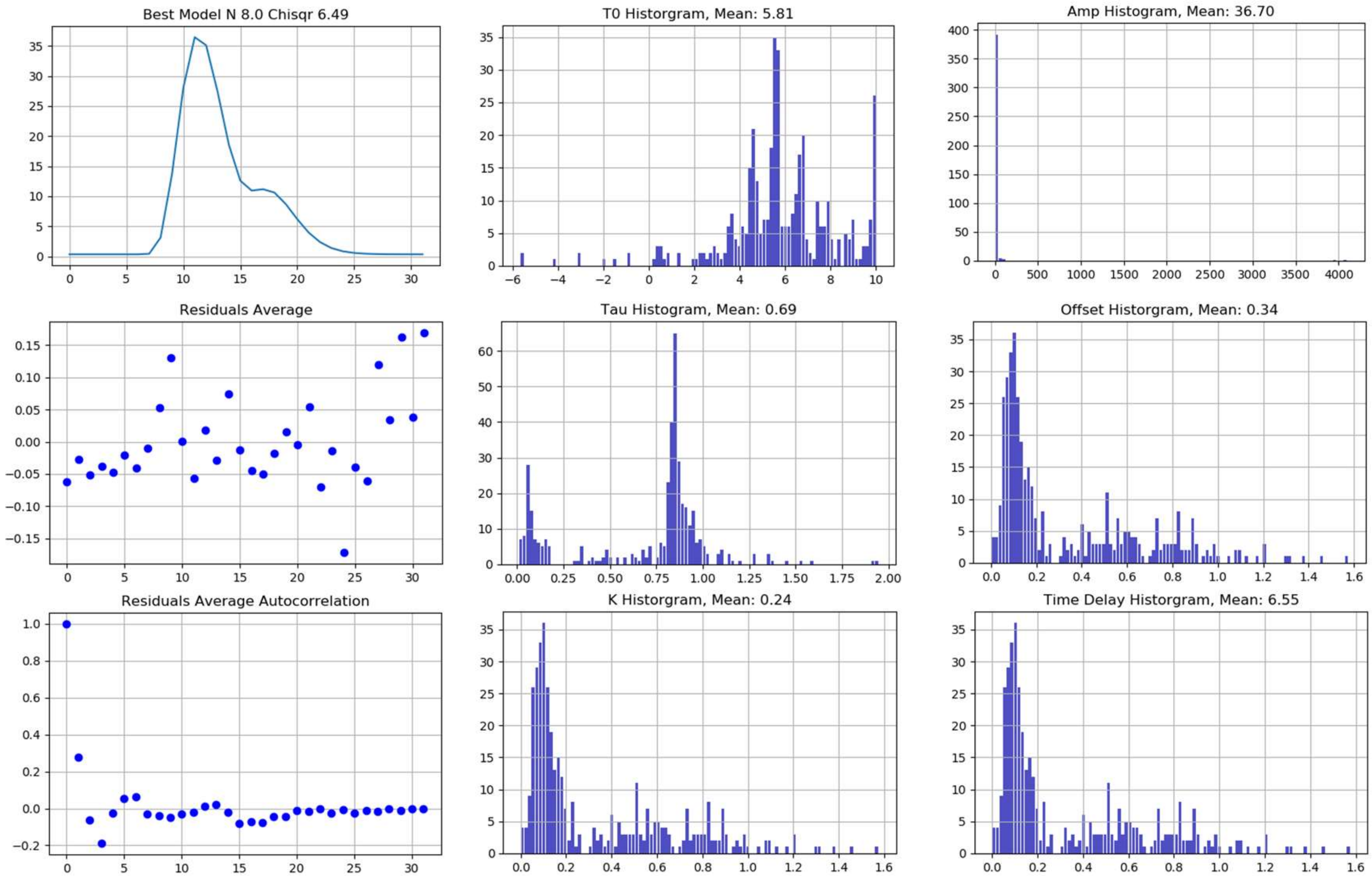
t_d:= time delay



Reflection of PMT pulse

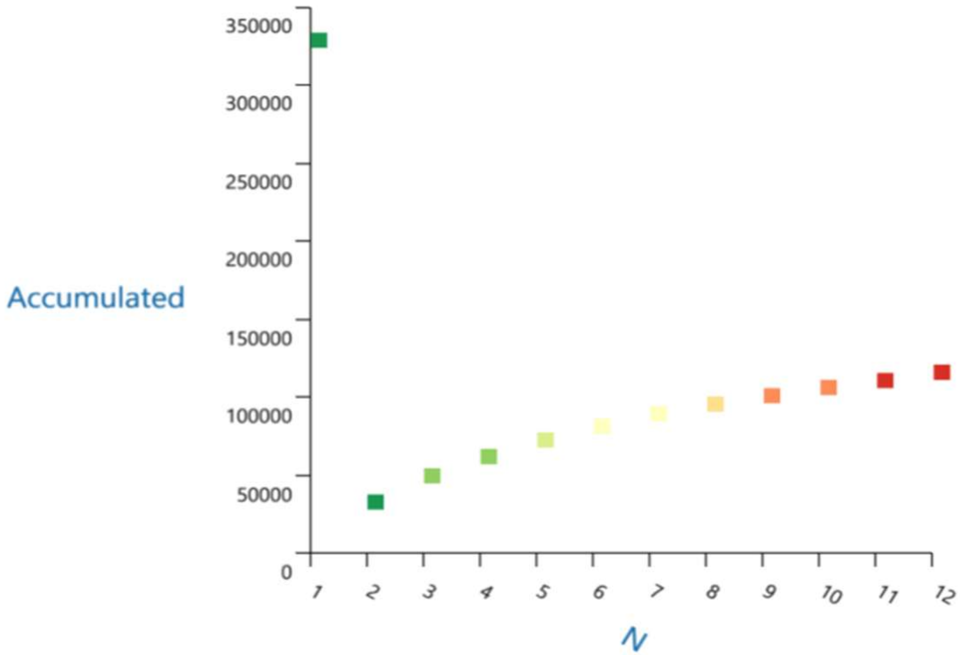
Matching reflection on Shaper output

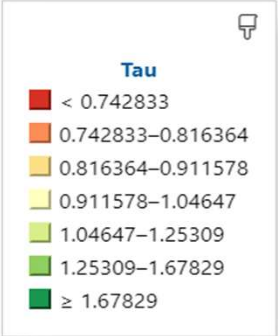
Fitting results



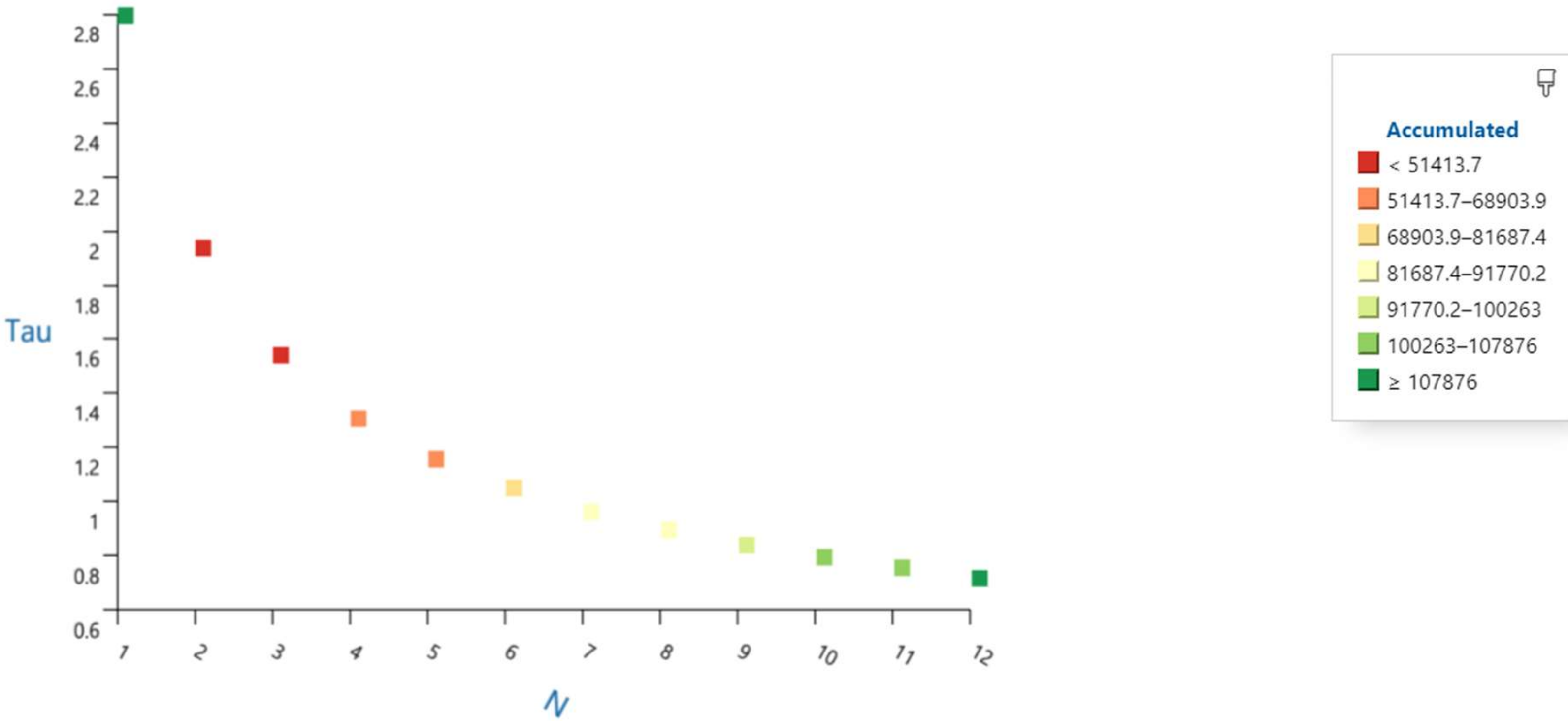
N value analysis

- Fit with fixed N: {1,..,12} vs Accumulated x^2 of all fits

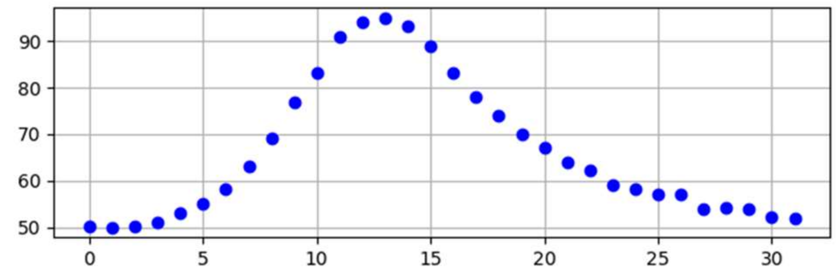




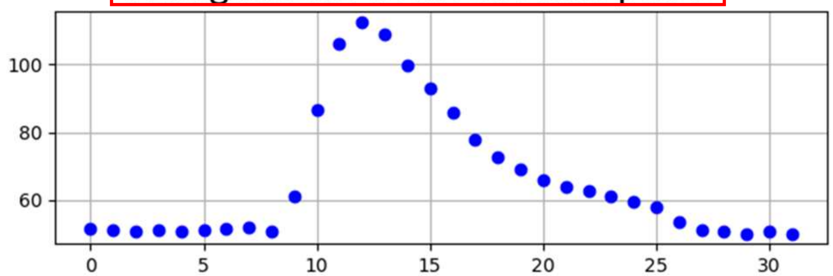
Tau vs N


Tau
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
1 2 3 4 5 6 7 8 9 10 11 12
N
Accumulated
< 51413.7
51413.7–68903.9
68903.9–81687.4
81687.4–91770.2
91770.2–100263
100263–107876
≥ 107876

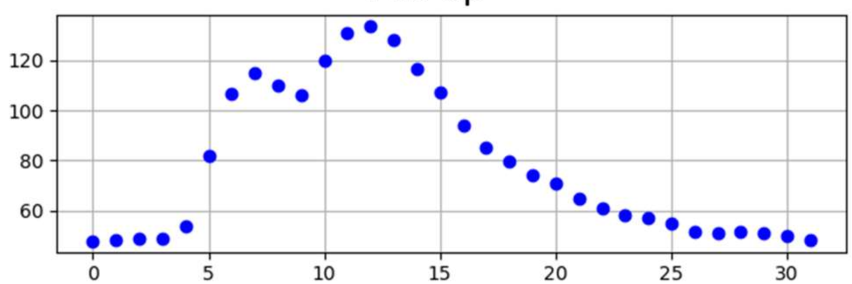
Gaussian-like



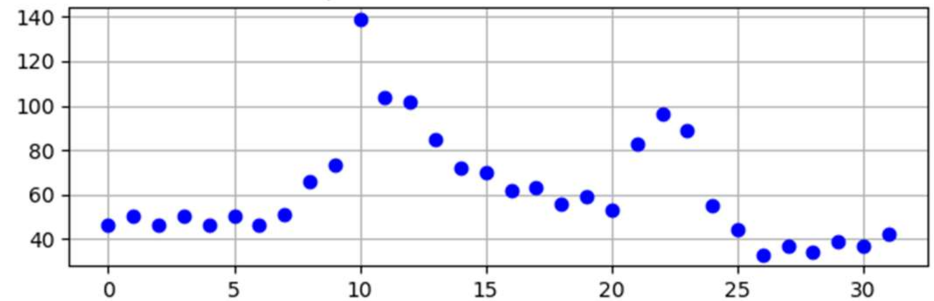
Semigaussian with reflected pulse



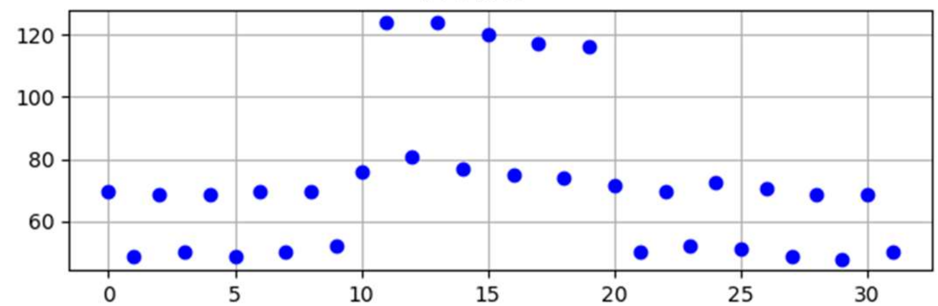
Pile up

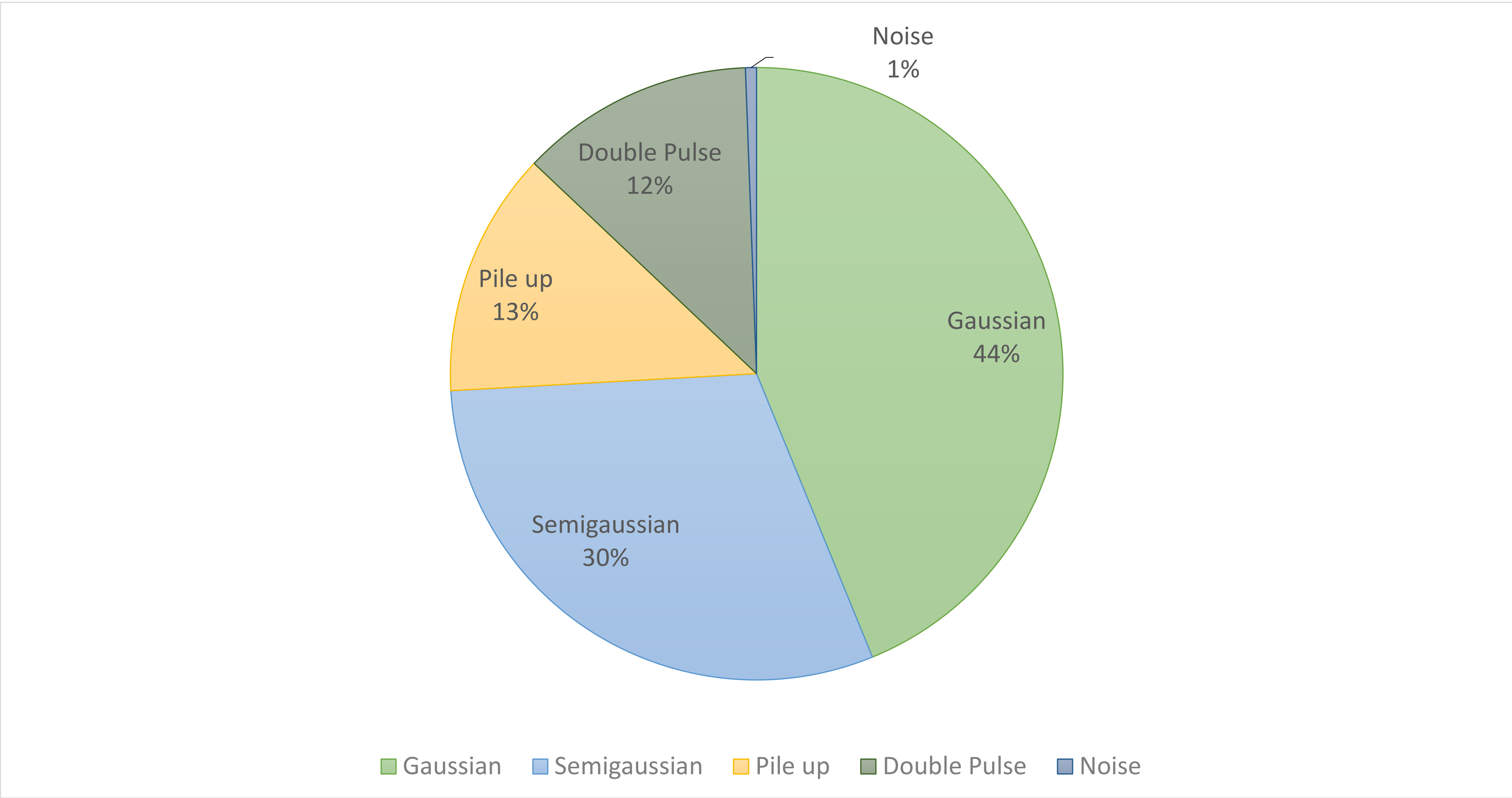


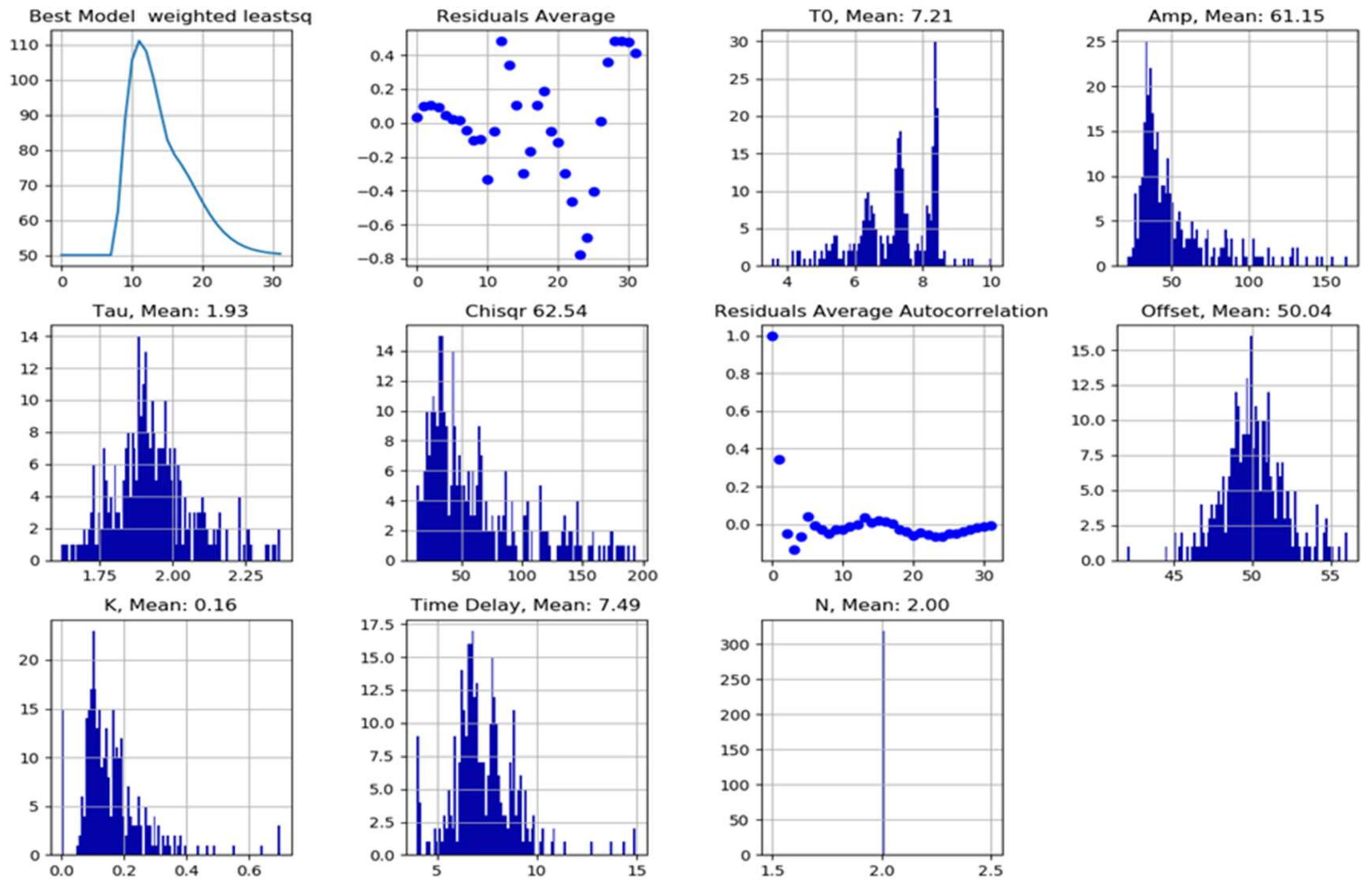
Double pulse



Noise




Noise
1%
Double Pulse
12%
Pile up
13%
Gaussian
44%
Semigaussian
30%
Gaussian Semigaussian Pile up Double Pulse Noise


Best Model weighted leastsq
Residuals Average
T0, Mean: 7.21
Amp, Mean: 61.15
Tau, Mean: 1.93
Chisqr 62.54
Residuals Average Autocorrelation
Offset, Mean: 50.04
K, Mean: 0.16
Time Delay, Mean: 7.49
N, Mean: 2.00

Issues

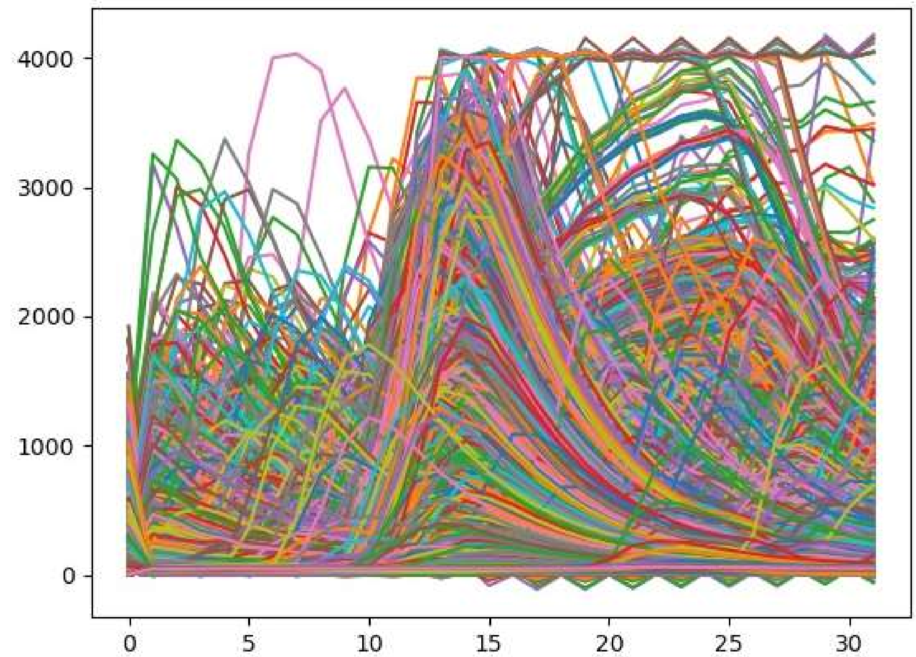
- Not ideal data (muon runs)
- Poor fit on pulse rising time

Proposals

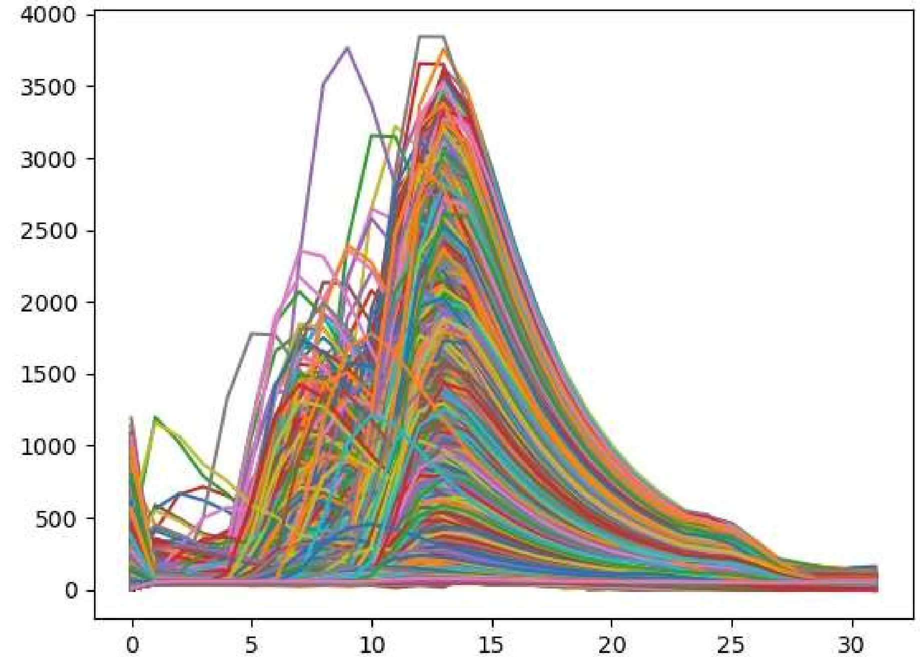
- New model
- New hadronic data

Overlay Plots

Plot of 1 million traces and no filters



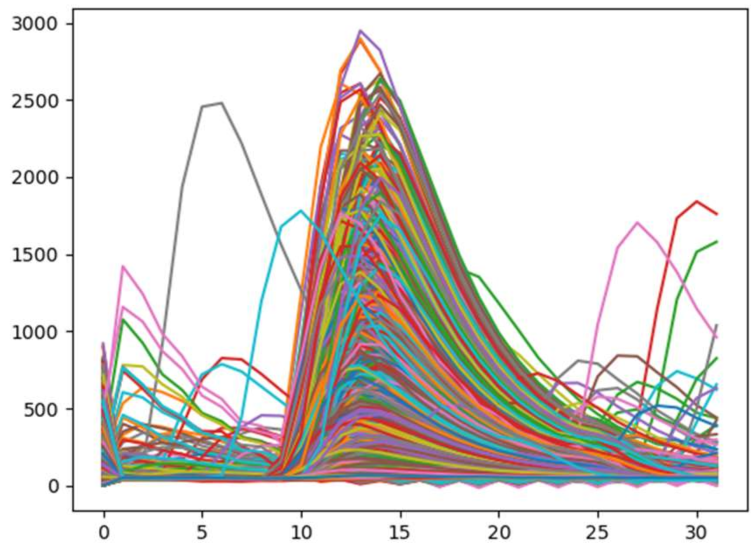
Plot of 224507 trace, filtered by barycenter



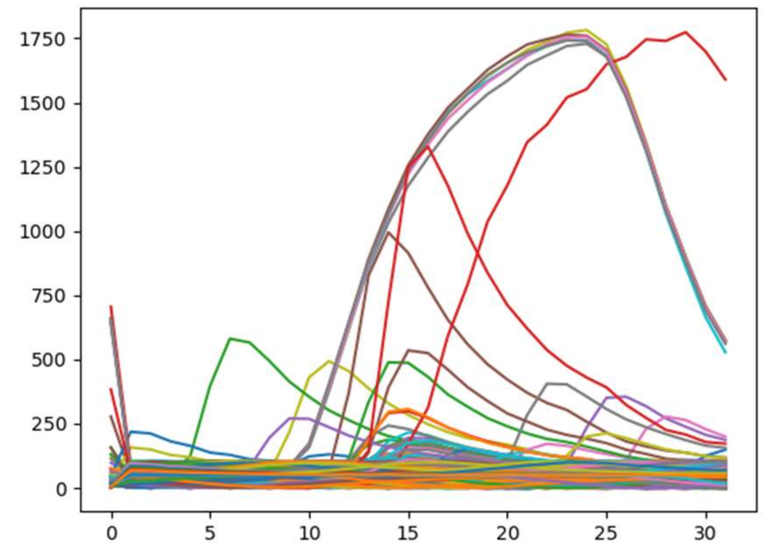
Both plots on ADC counts vs sample

Overlay plots from previously categorized channels

Plot of a single channel categorized as Semi Gaussian (31,24)



Plot of a single channel categorized as Gaussian (52,8)



Both plots on ADC counts vs sample

New model

$$
\mathrm{F}(\mathrm{t}, t_0, d_t, \tau, off, k\,) = \begin{cases} off, & if\ t < t_0 \\ off + a\,\mathrm{e}^{\frac{-2t+t_0}{\tau}} \dfrac{\left(-2\tau^2 \mathrm{e}^{t_0/\tau} + \mathrm{e}^{t/\tau}\left(t^2 + {t_0}^2 + 2t\tau + 2\tau^2 - 2t(t_0+\tau)\right)\right)}{norm(\tau)}, & if\ d_t + t_0 > t \geq t_0 \\ off + \dfrac{a}{norm(\tau)} \left(\begin{array}{l} \mathrm{e}^{\frac{-2t+t_0}{\tau}}\left(-2\tau^2 \mathrm{e}^{t_0/\tau} + \mathrm{e}^{t/\tau}\left(t^2 + {t_0}^2 + 2t\tau + 2\tau^2 - 2t(t_0+\tau)\right)\right) + \\ e^{\frac{-2t+(t_0+d_t)}{\tau}}\left(-2\tau^2 \mathrm{e}^{(t_0+d_t)/\tau} + \mathrm{e}^{t/\tau}\left(t^2 + (t_0+d_t)^2 + 2t\tau + 2\tau^2 - 2t(t_0+\tau+d_t)\right)\right) \end{array} \right), & if\ t \geq d_t + t_0 \end{cases}
$$

New model hints:

- Consideration of non ideal charge sensitive amplifier:

$$S_i = \begin{cases} 0, & i \le t_0 \\ A, & i > t_0 \end{cases} \longrightarrow S_i = \begin{cases} 0, & i \le t_0 \\ A\left(1 - e^{-(i-t_0)/\tau}\right), & i > t_0 \end{cases}$$

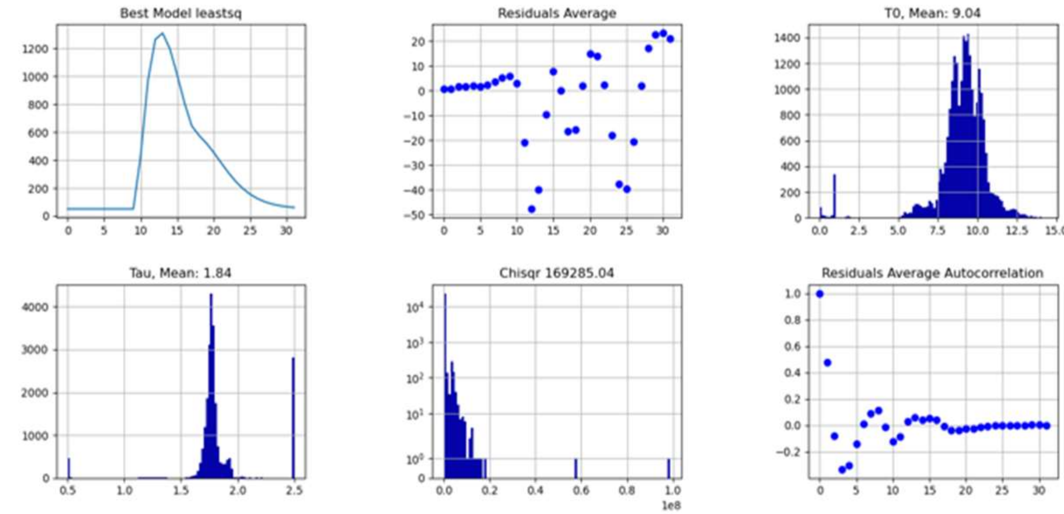
- New time constant

$$\tau_d = \tau_i = \tau\,; \quad \tau_r = \frac{\tau}{2}$$

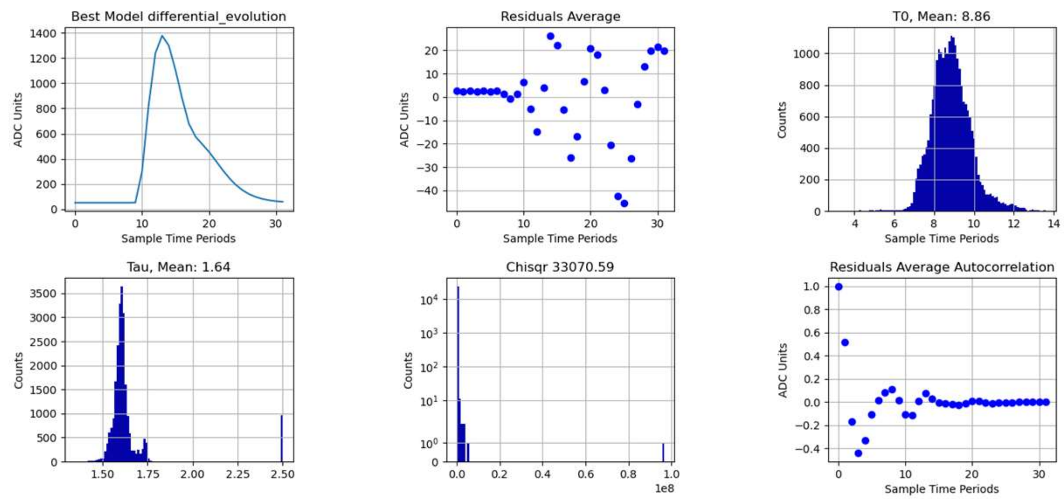
- Required normalization

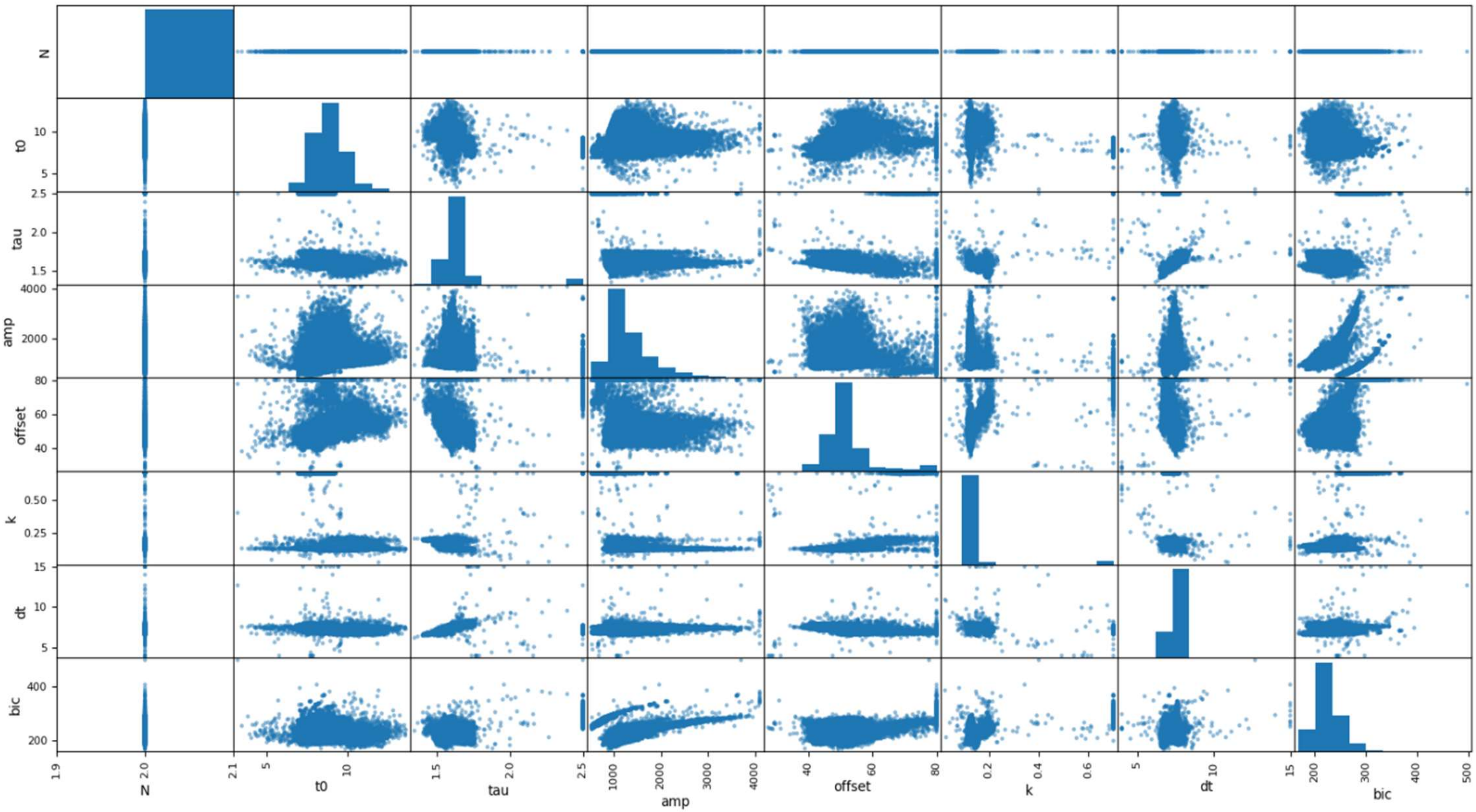
$$norm(\tau) = e^{-\frac{4\left(\tau+\tau*\mathrm{ProductLog}\left[\frac{1}{e}\right]\right)}{\tau}}\left(-2\tau^2 + e^{\frac{2\left(\tau+\tau*\mathrm{ProductLog}\left[\frac{1}{e}\right]\right)}{\tau}}\left(2\tau^2 - 4\tau\left(\tau + \tau * \mathrm{ProductLog}\left[\frac{1}{e}\right]\right) + 4\left(\tau + \tau * \mathrm{ProductLog}\left[\frac{1}{e}\right]\right)^2\right)\right)$$

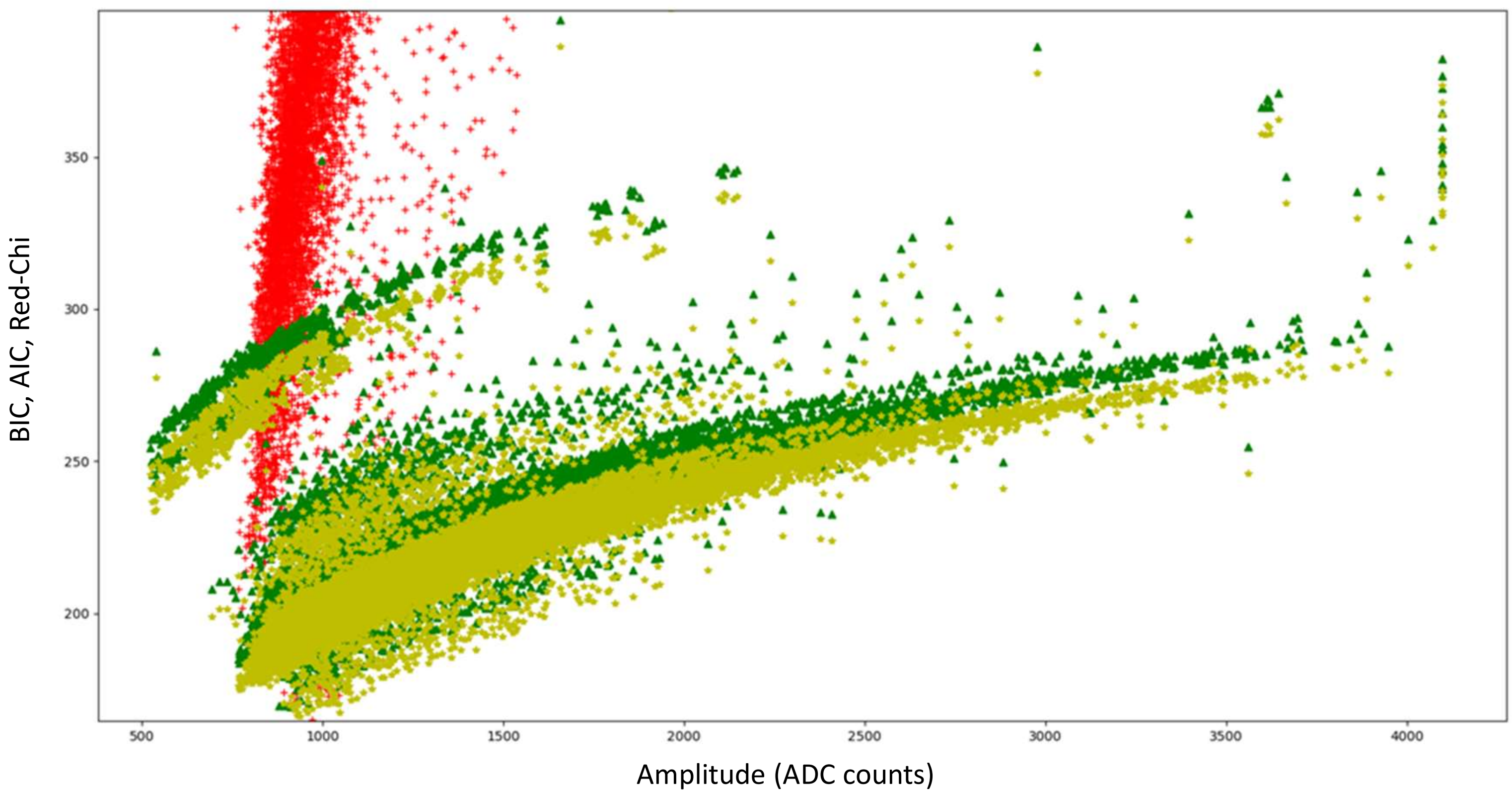
Old model



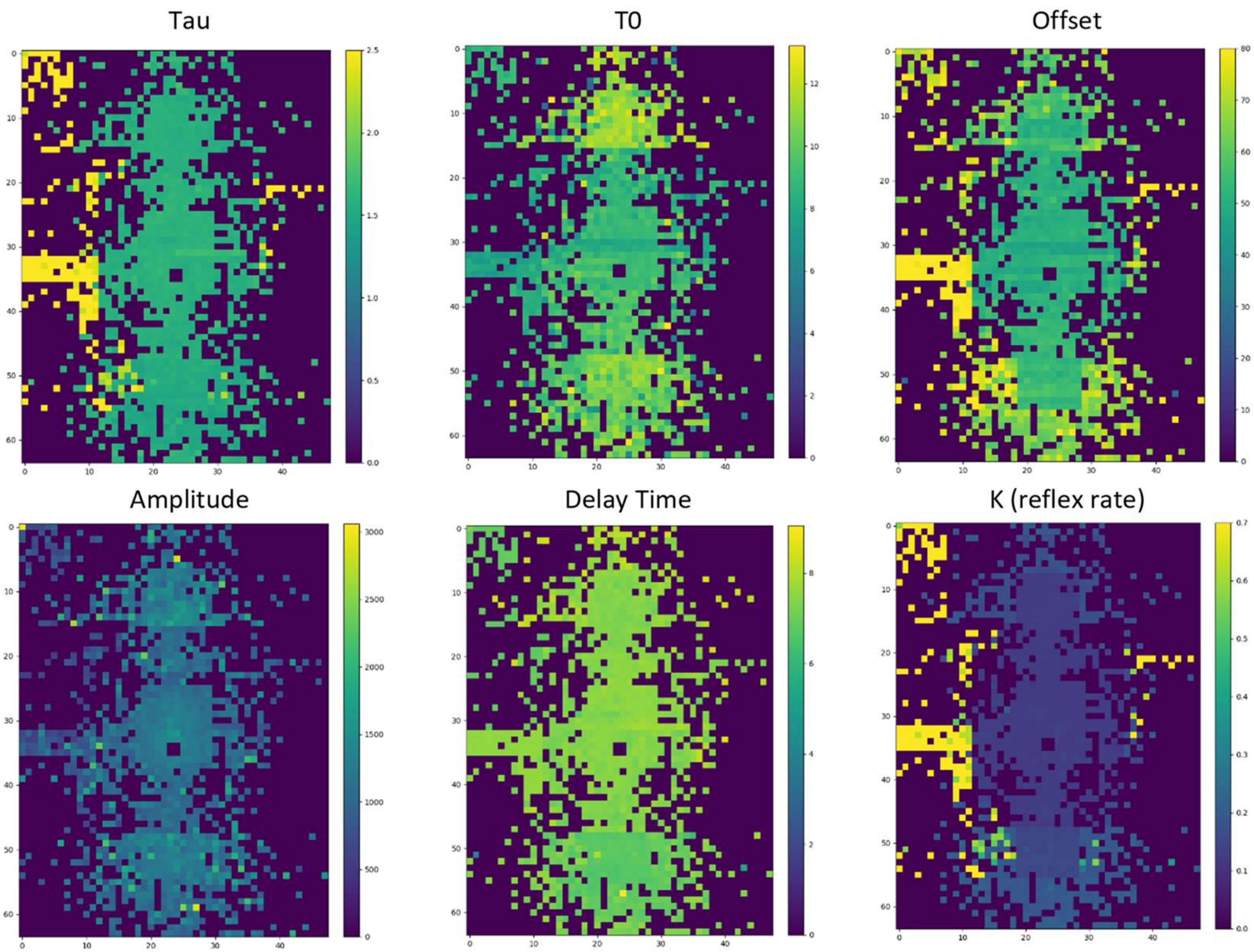
New Model




N
t0
tau
amp
offset
k
dt
bic

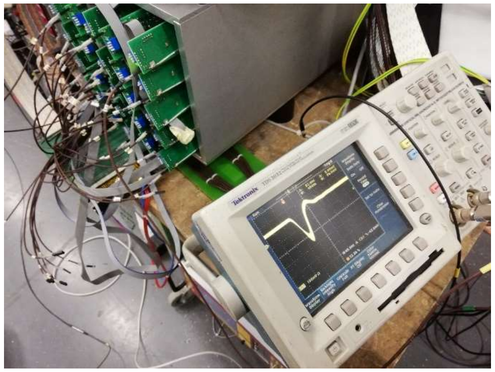


On red the reduced chi-square, green the Bayesian information criterion, yellow Akaike information criterion.

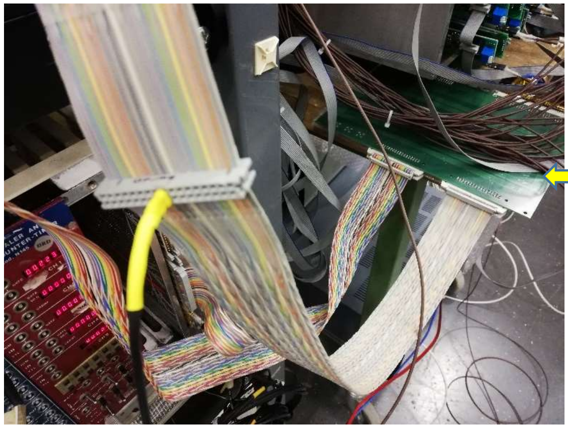

Tau
T0
Offset
Amplitude
Delay Time
K (reflex rate)

Thanks for your attention

Experimental Setup at CERN

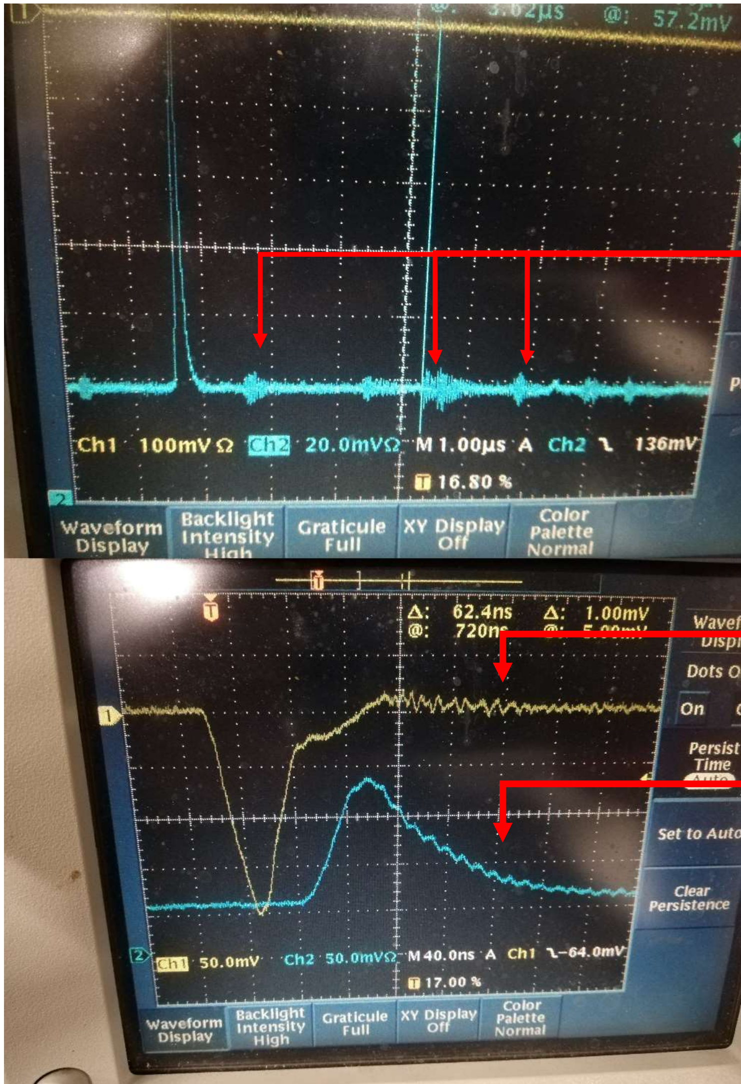


Oscilloscope connected to PMT output of ECAL2.



Oscilloscope connected to shaper output

Shaper board

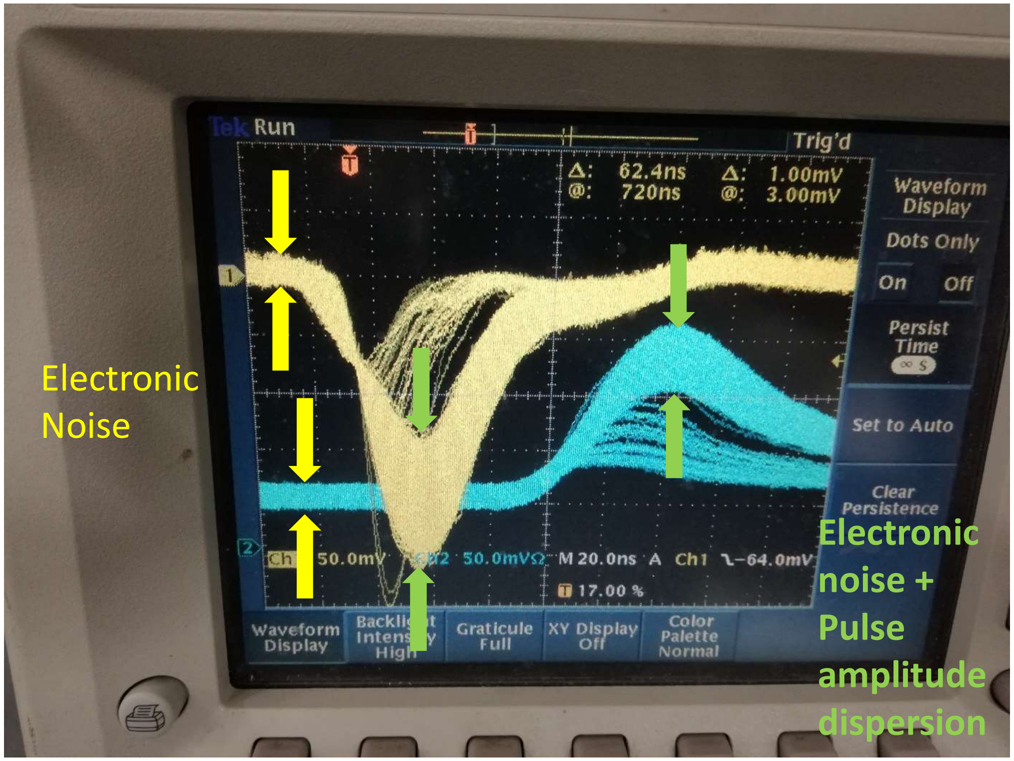


Bursts of noise zoomed out

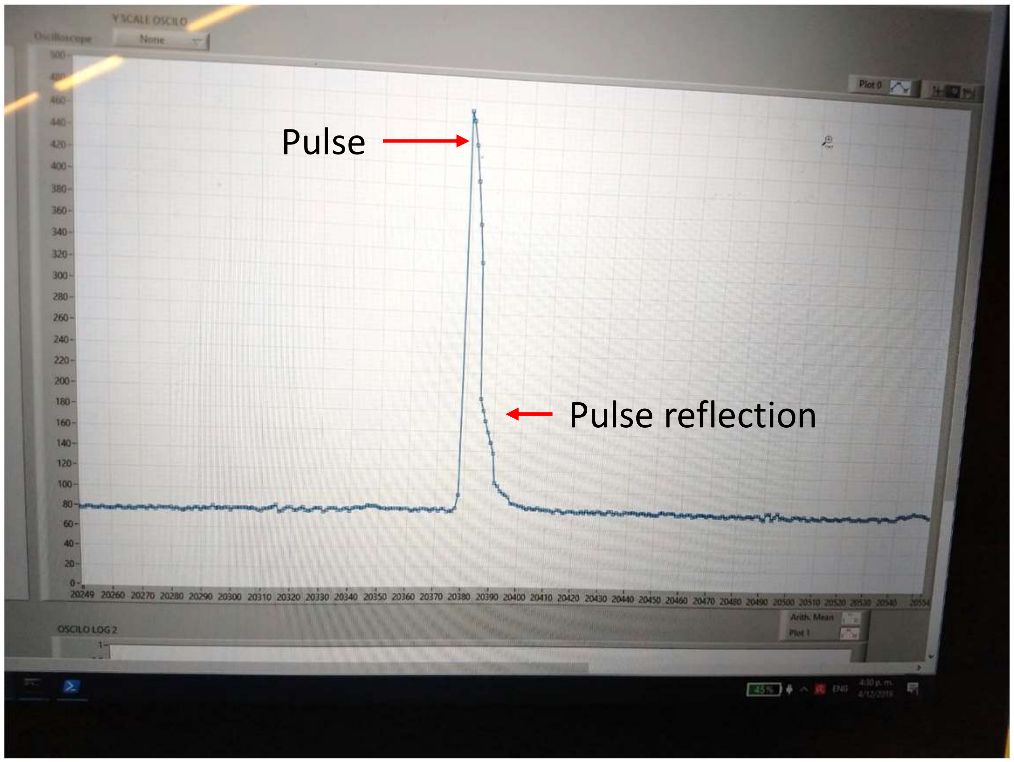
Burst of noise before shaper

Burst of noise after shaper

Analog Persistence



SoC-FPGA Oscilloscope

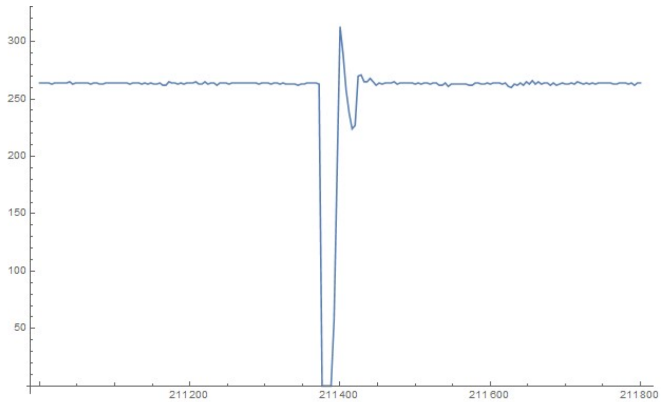


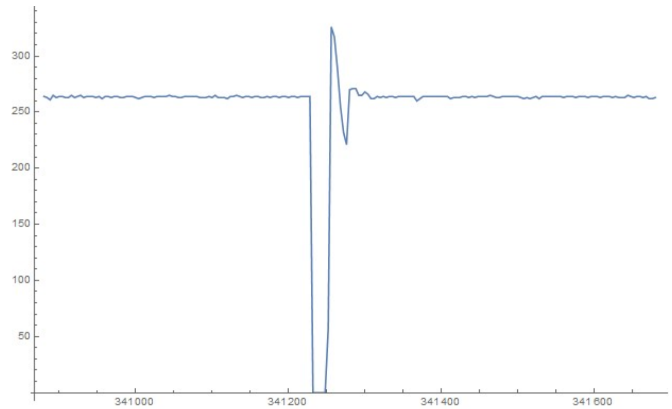
LabView GUI Plot of acquired data from CIAA+ADC500.

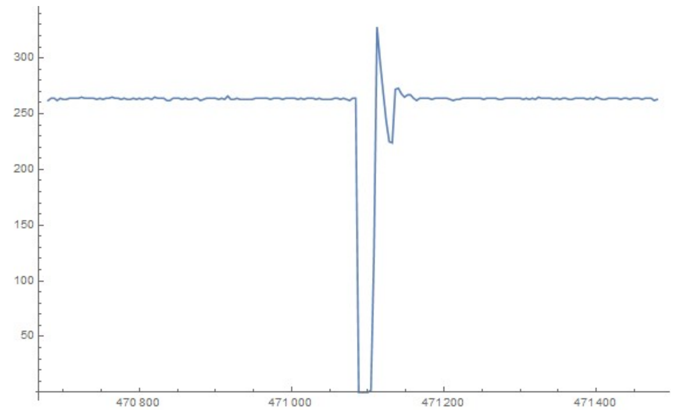
Data is plotted in real time on a PC via Ethernet.

Pulses before Shaper

Signals sampled at 250MSPS



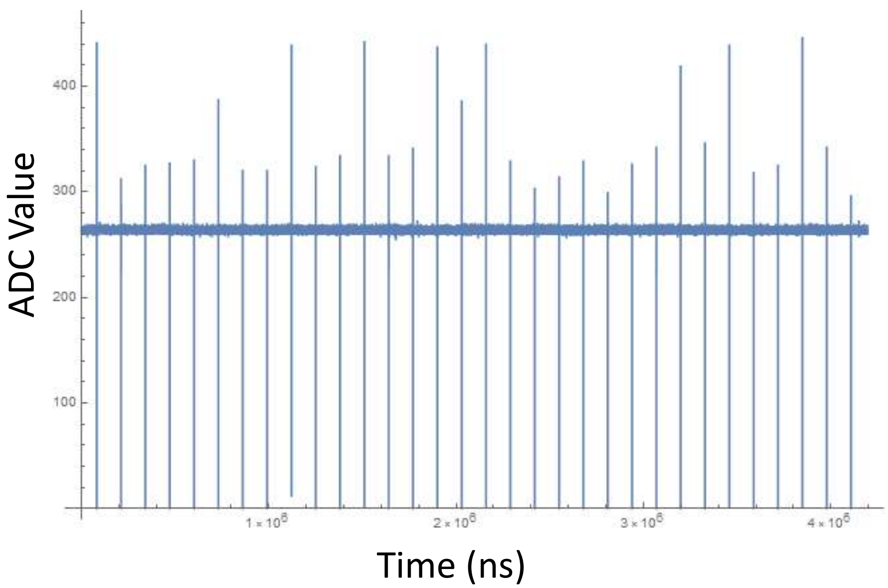


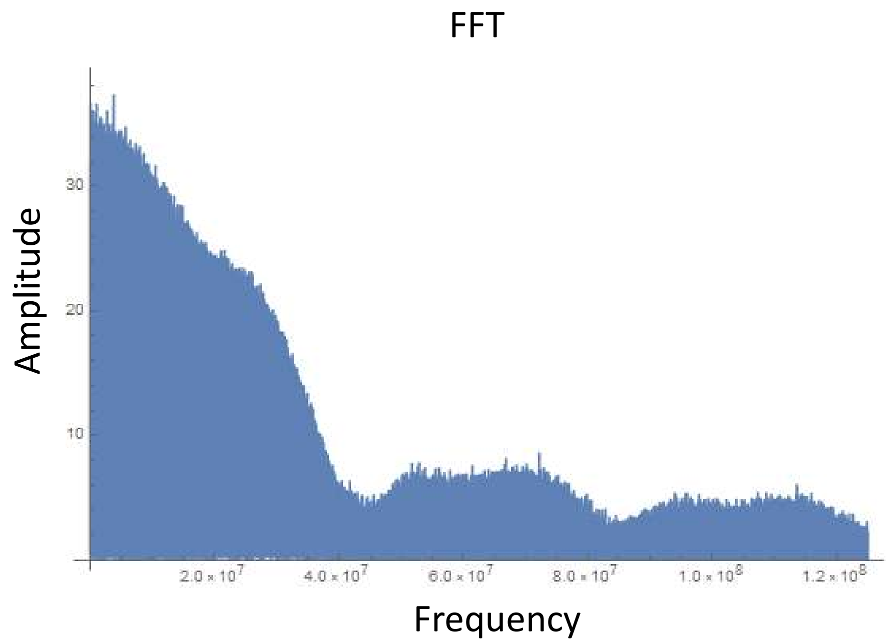


Time (ns)

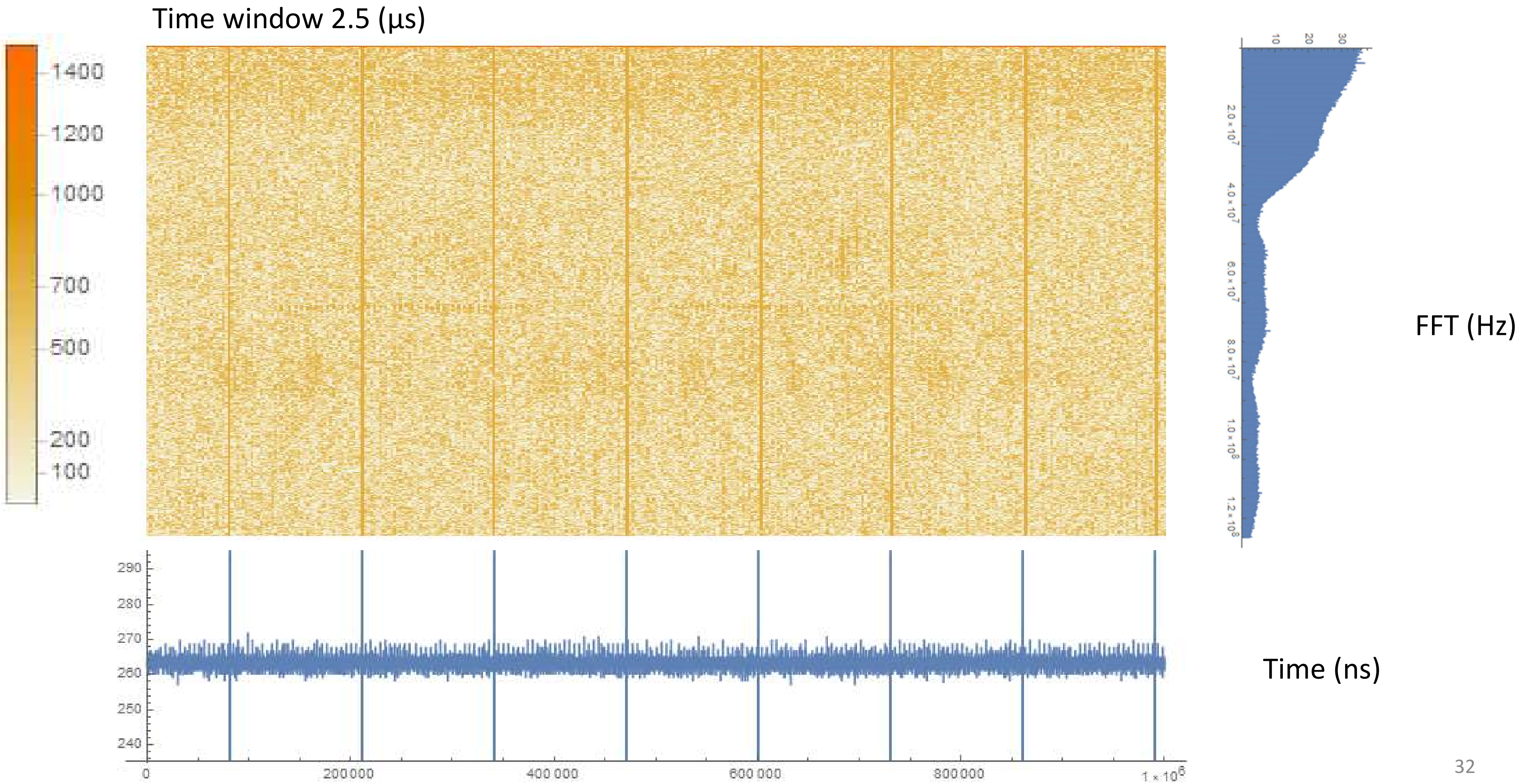
Spectrum of Signal Before Shaper

Decimation factor: 2, Effective sampling frequency: 250 Mhz



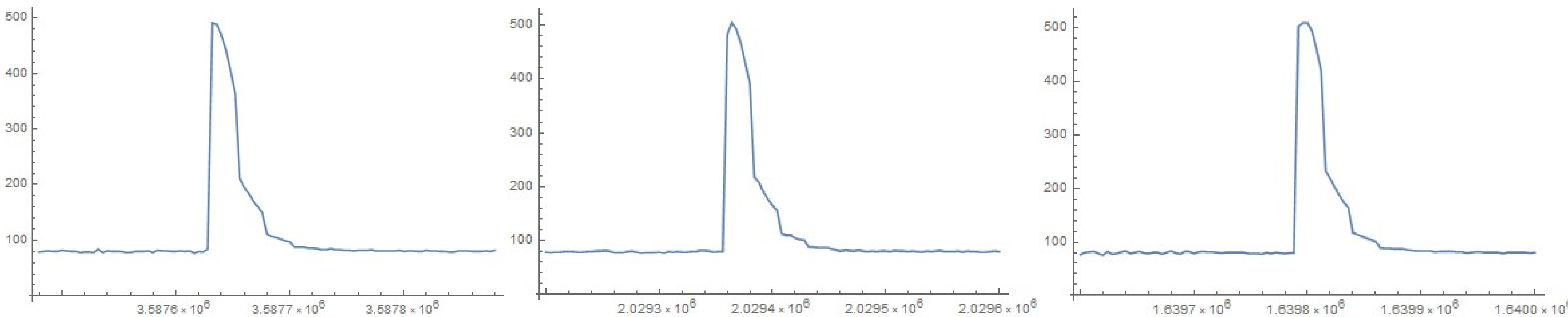


Spectrogram of a Slice of the Signal before Shaper



Pulses After Shaper

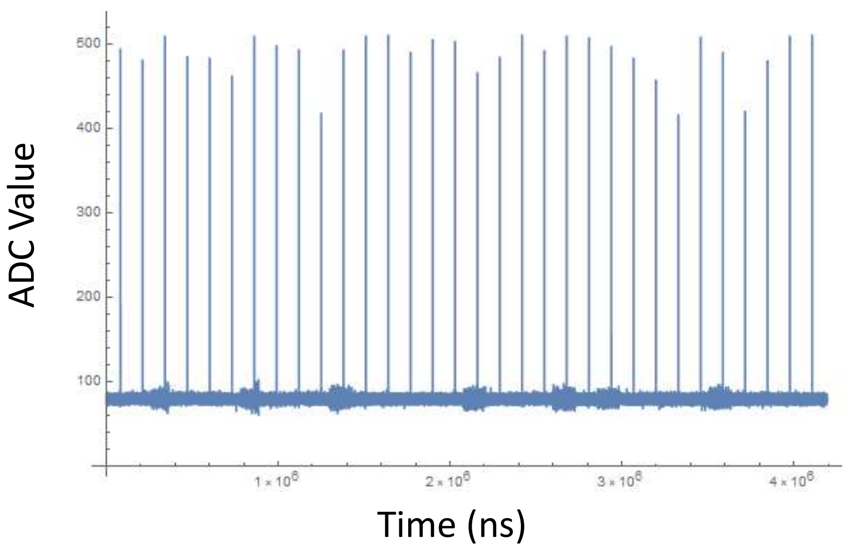
Signals sampled at 250MSPS

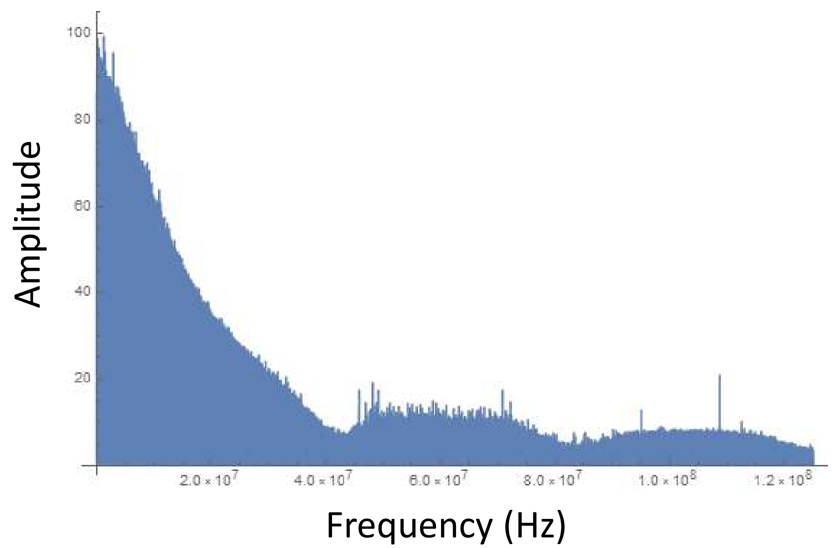


Time (ns)

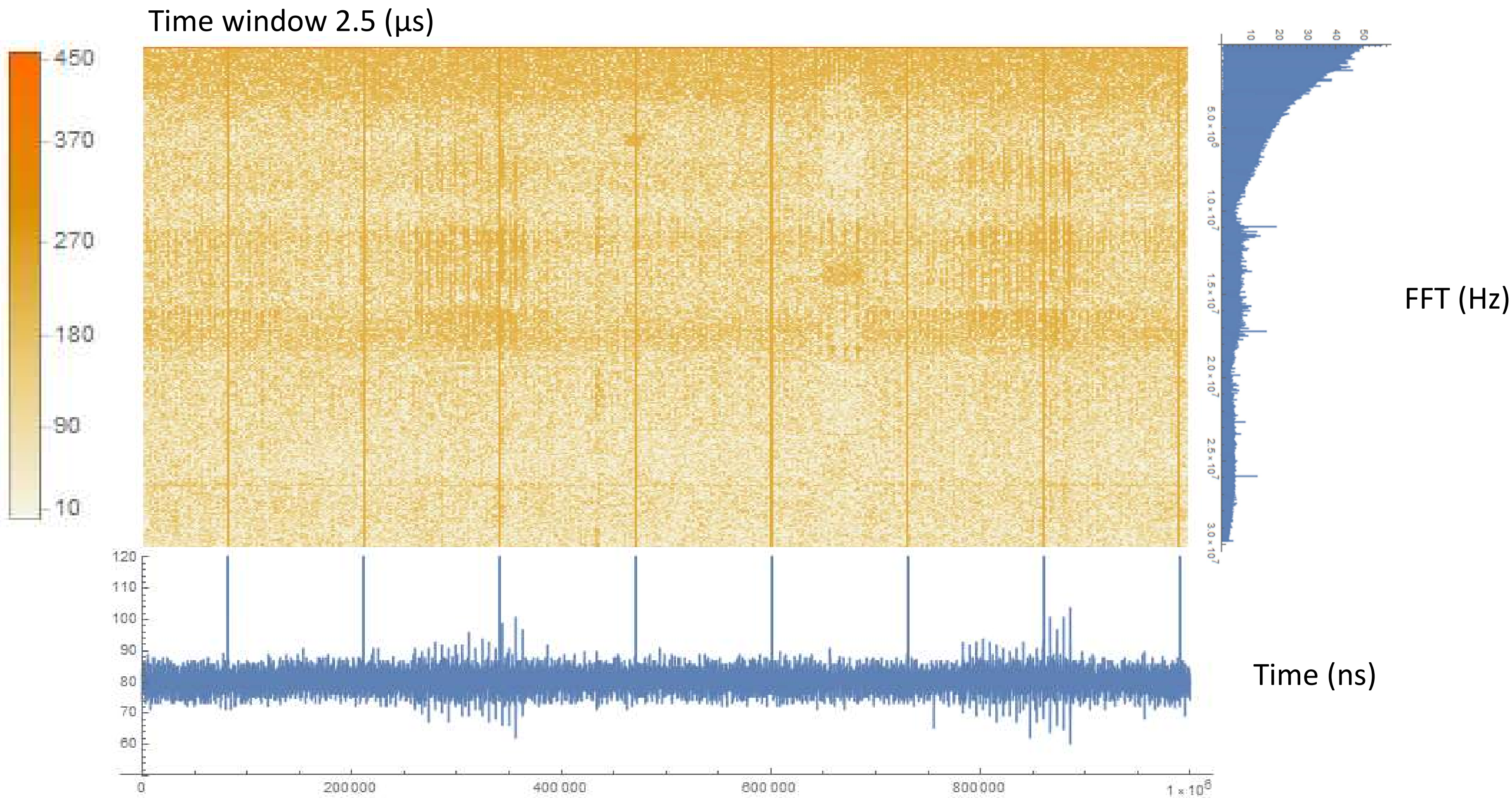
Spectrum of Signals after Shaper

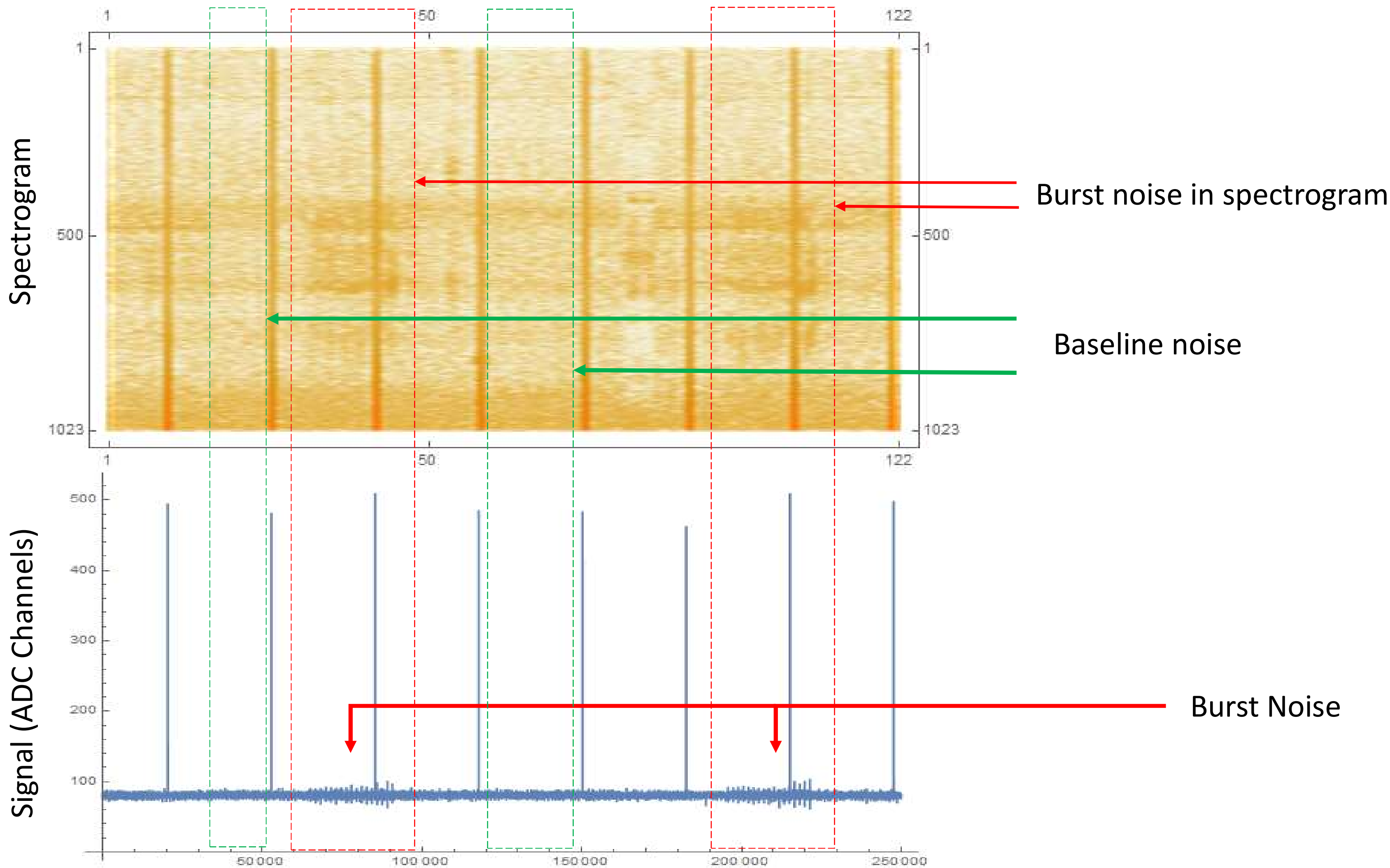
Decimation factor: 2, Effective sampling frequency: 250 Mhz





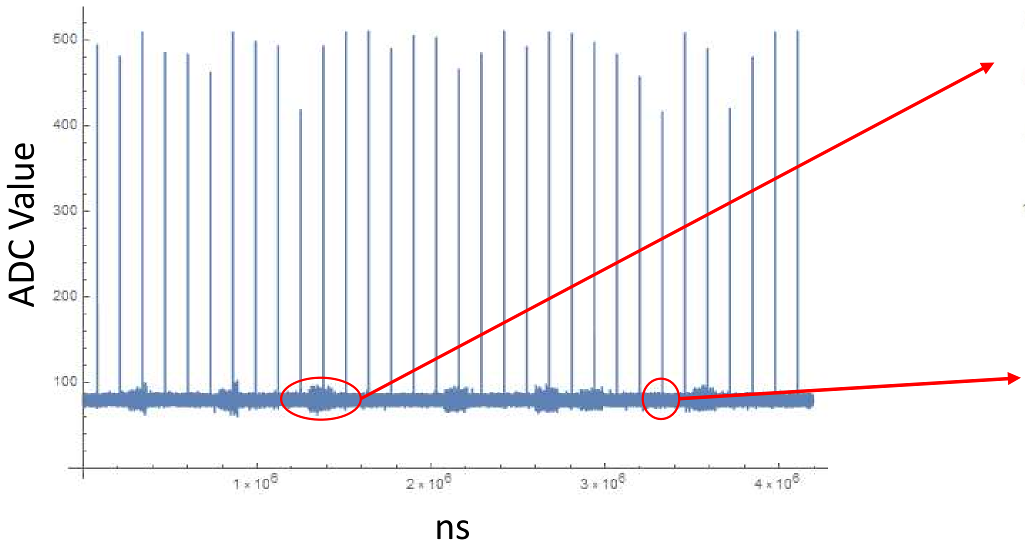
Spectrogram of a Slice of the Signal after the Shaper

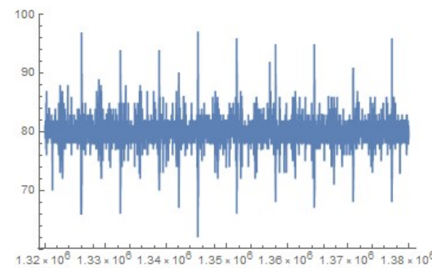



Spectrogram
Signal (ADC Channels)
Burst noise in spectrogram
Baseline noise
Burst Noise
1
50
122
500
1023
100
200
300
400
500
50 000
100 000
150 000
200 000
250 000

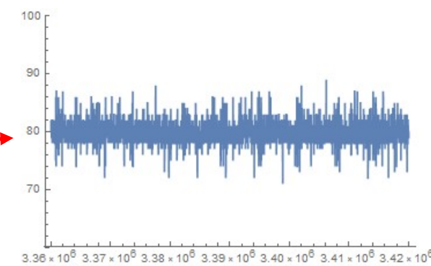
Noise Analysis after Shaper

Decimation factor: 2, Effective sampling frequency: 250 MSPS
Two noise regimes identified





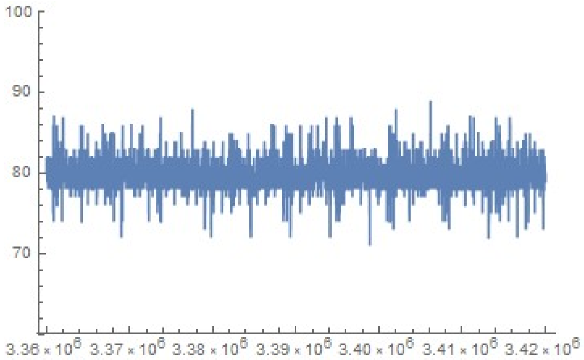
Burst noise 15KS
RMS = 80.0459
STD = 1.81031
Peak to peak = 35



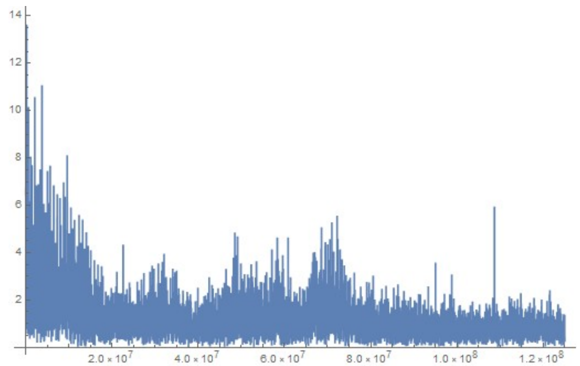
Noise 15KS
RMS = 79.9201
STD = 1.45537
Peak to peak = 18

Burst and Baseline noise Comparison

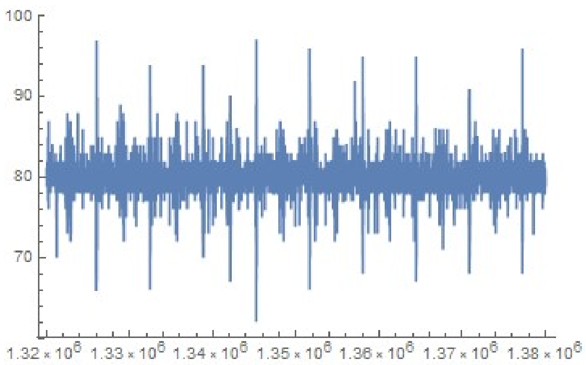
Baseline noise



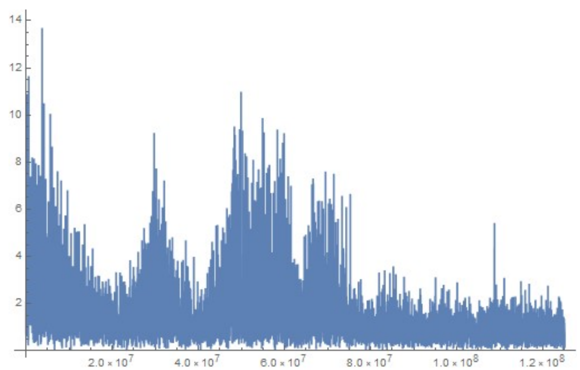
Baseline noise FFT



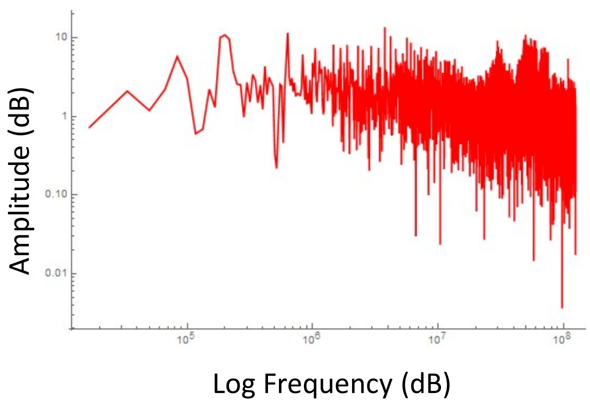
Burst noise



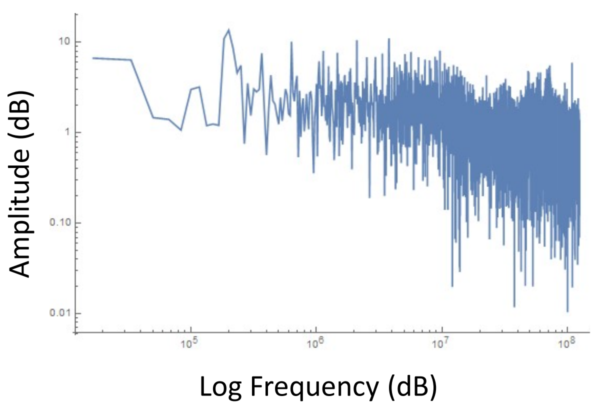
Burst noise FFT



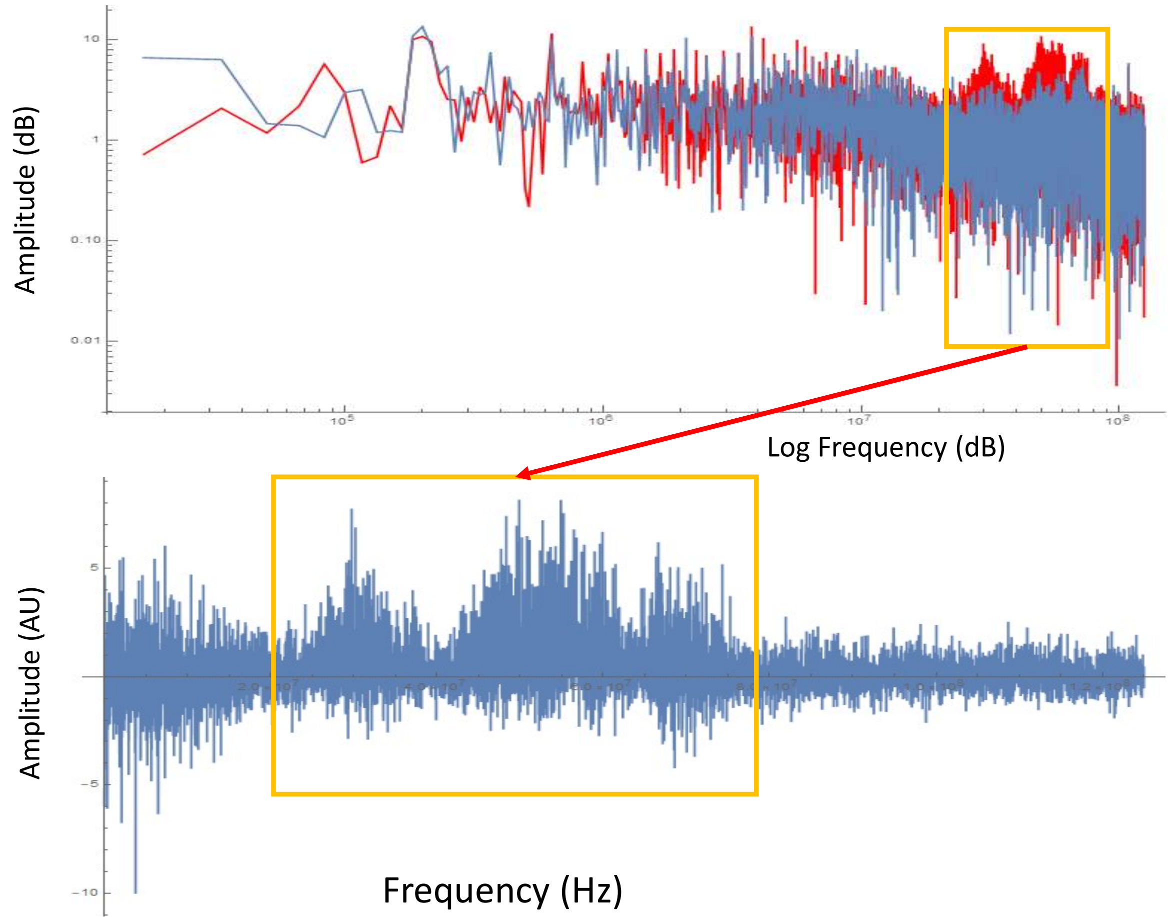
FFT Burst noise



FFT Baseline noise

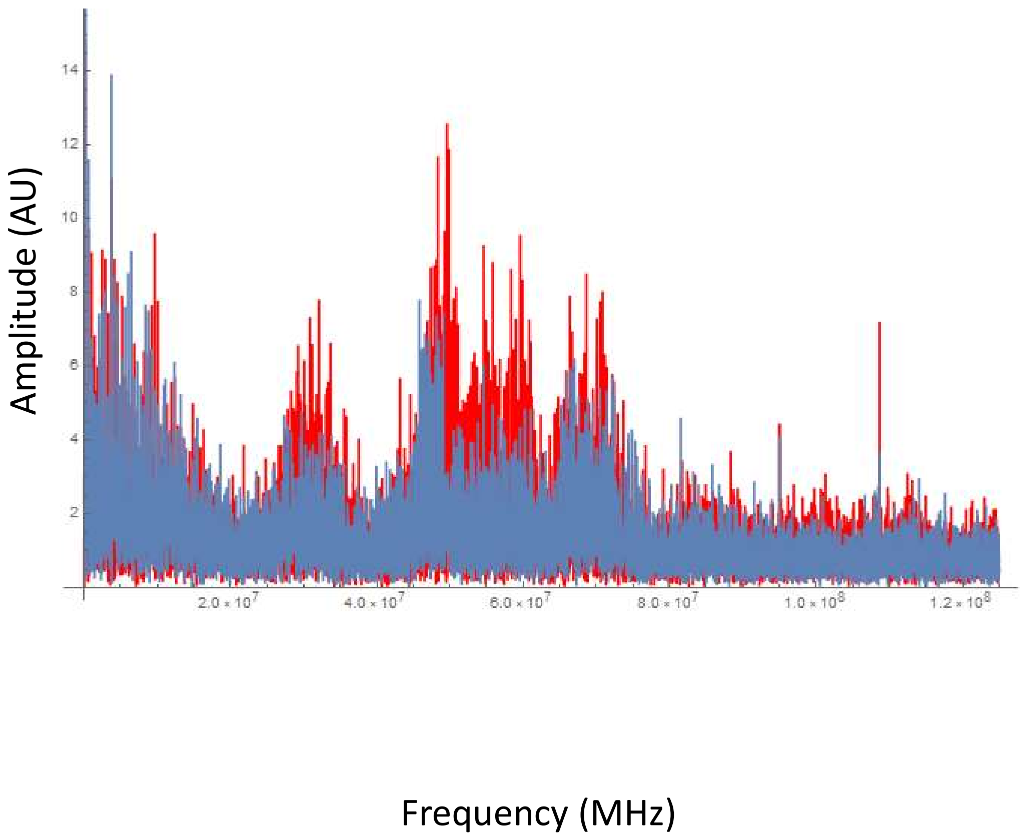


FFT Burst Noise and Baseline Compared

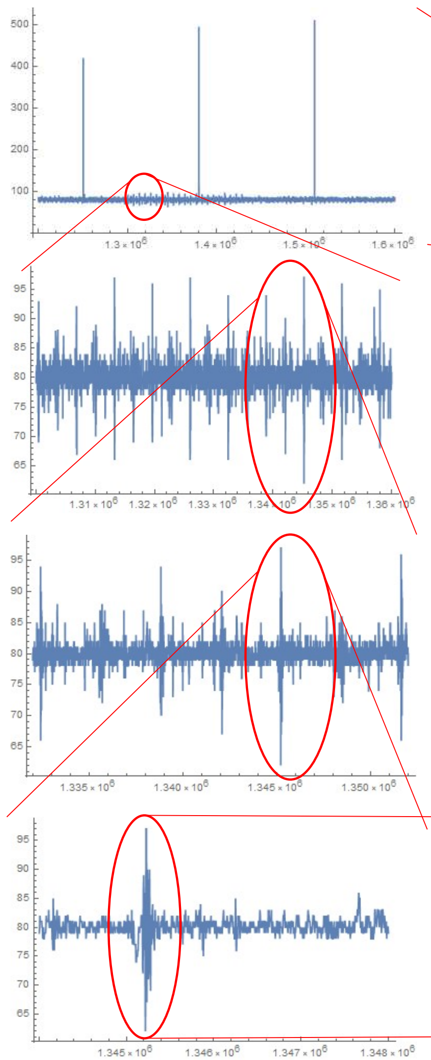


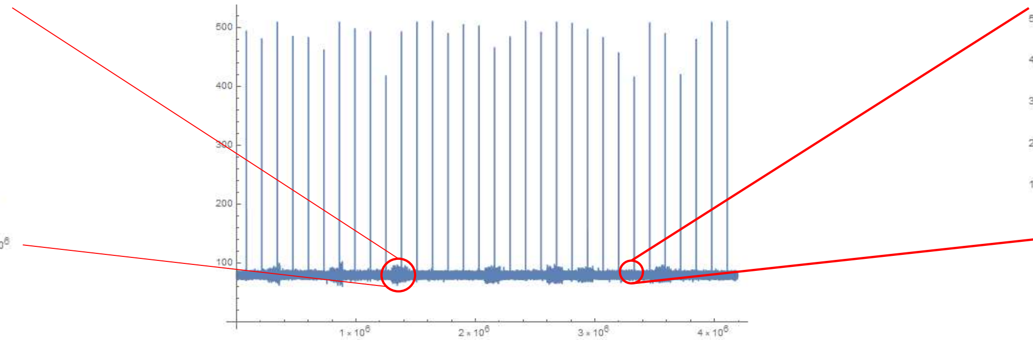
Burst Noise Comparison In Two Different Traces In Frequency Domain

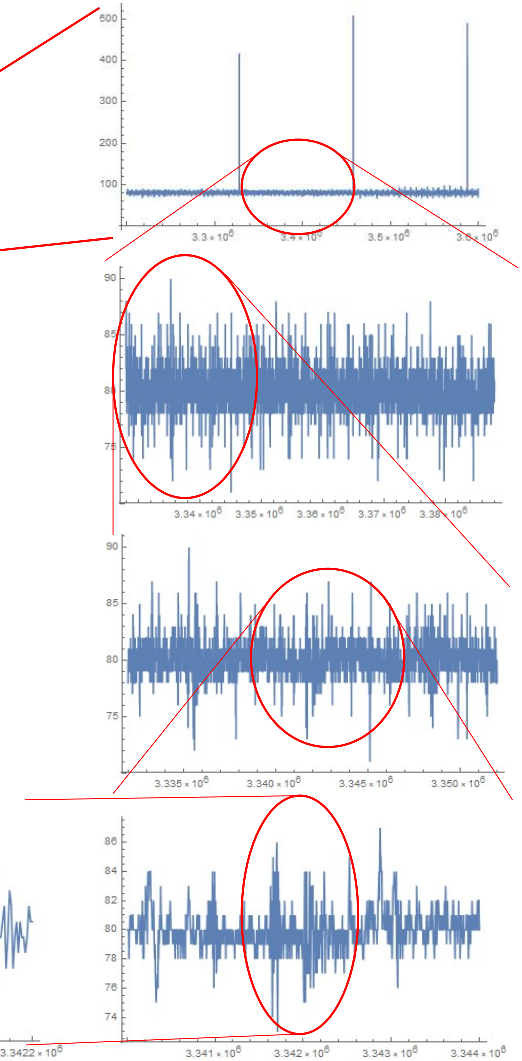
Both are 15KS in length and 250MSPS effective



	RMS	STD	Peak-to-peak
Red	80.407	1.699	32
Blue	79.395	1.742	30



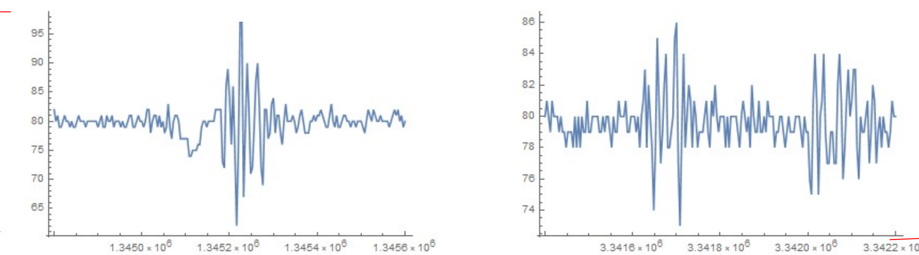




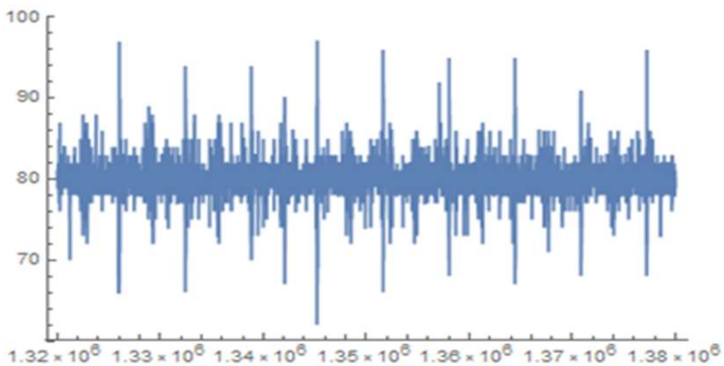
Qualitative Analysis of Both Noise Regimes

Burst noise

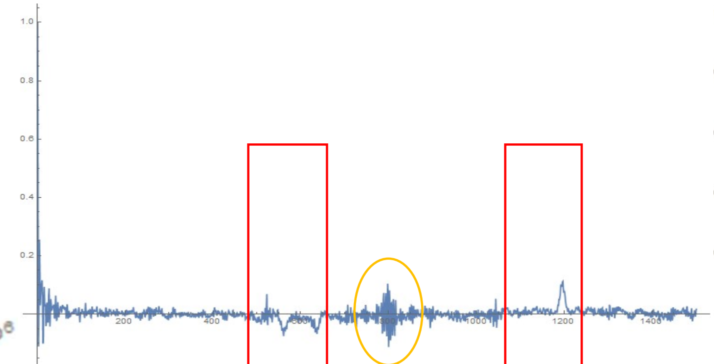
Noise



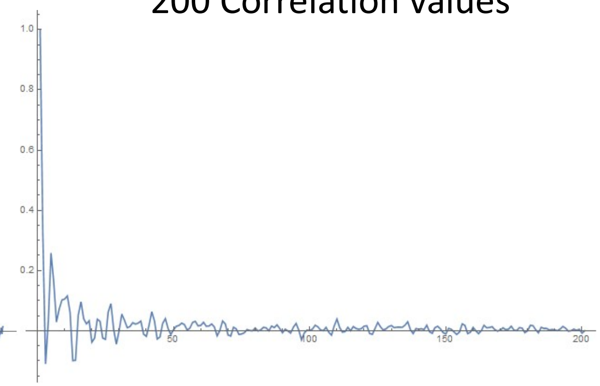
Comparison of Autocorrelation of Both Noise Regimes



1500 Correlation values

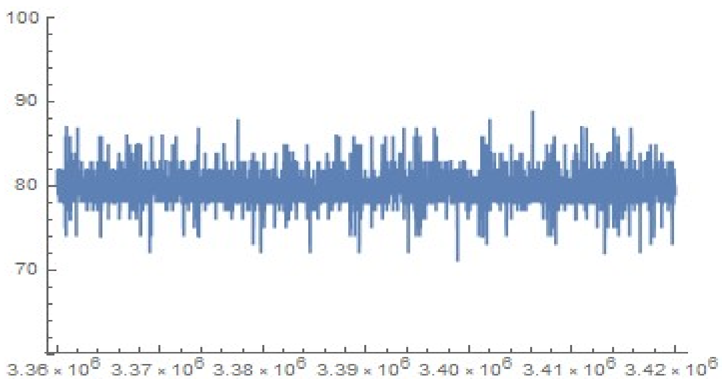


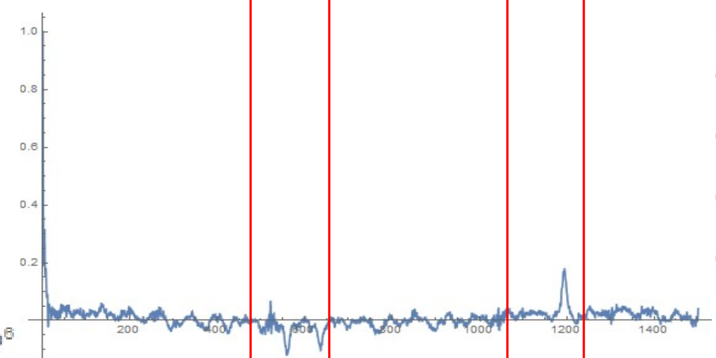
200 Correlation values

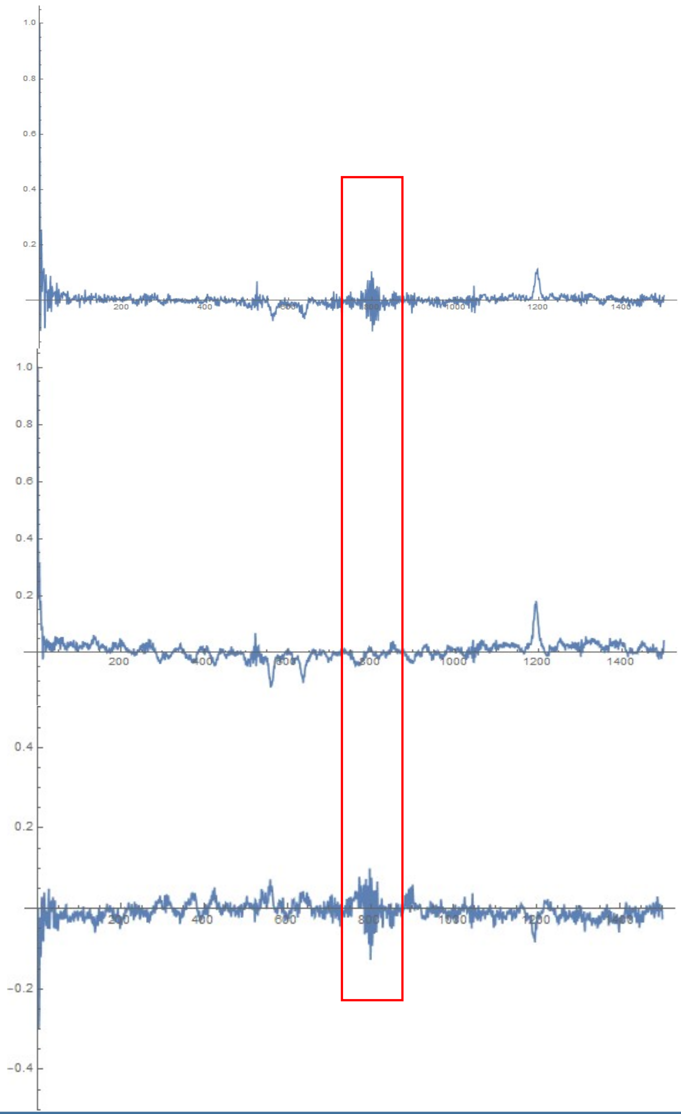


The red rectangles emphasize similarities between the bursts of noise and the baseline. This similarities indicate that the noise itself presents a complex pattern.

In the yellow circle the more distinctive pattern is highlighted.







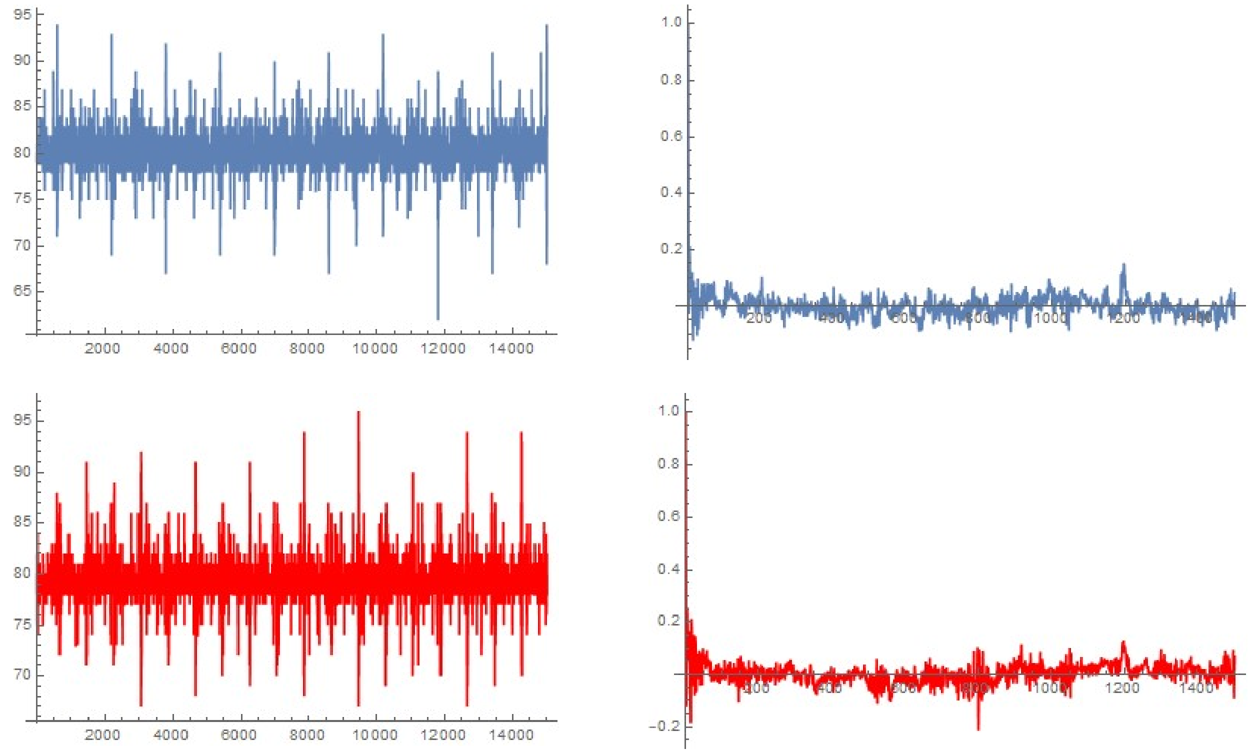
The autocorrelation of the burst noise.

The autocorrelation of the baseline.

The difference of the autocorrelations.

Burst Noise Comparison In Two Different Traces

Both are 15KS in length and 250MSPS effective



Conclusions

- Satisfactory ideal pulse model identified

- Observed complex noise structures. It may need further analysis.

- Data analysis procedure has been defined:
  - Model parameters extraction
  - Noise autocorrelation function

  Next Steps:
  Design of a reconfigurable digital pulse processor for amplitude measurement ECAL2
  FIR optimization
  Pile-up rejection strategy implementation