Timing Studies with a Crystal ECAL Readout Unit

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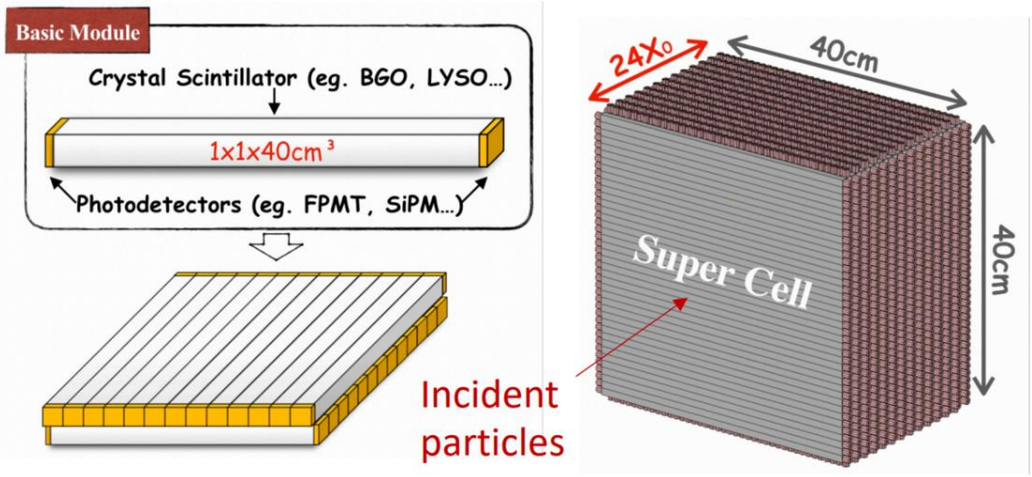
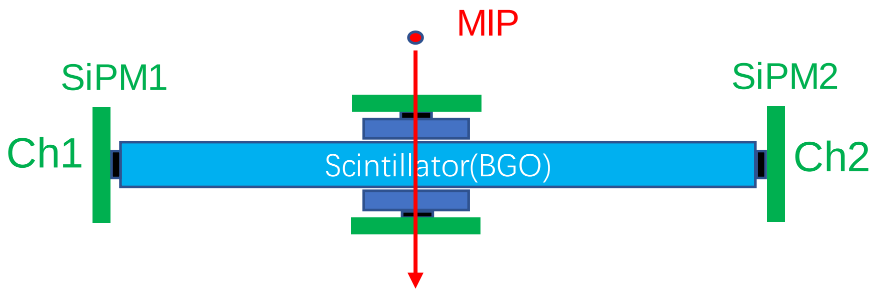
Motivation

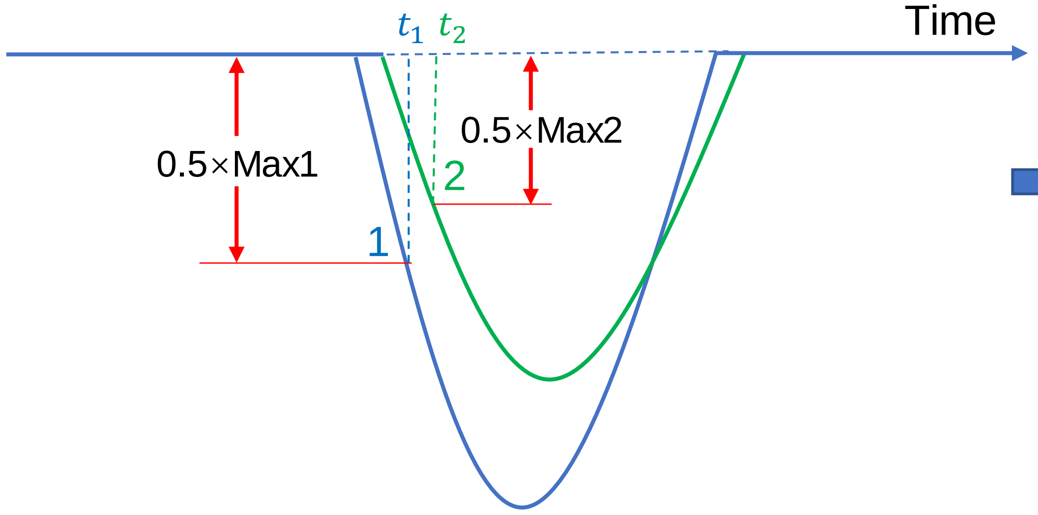


- 4D Detector — x, y, z, t
- Usage of time information:
  - Determine the incidence position by timing at two sides
  - Figure out the development process of a shower, benefit to reconstruction
  - Reject the background which are generated beyond the time window of some adjacent crystals
- Related factors: scintillation, photon transport, response of SiPM, electronics, timing method

Definition of Time Resolution

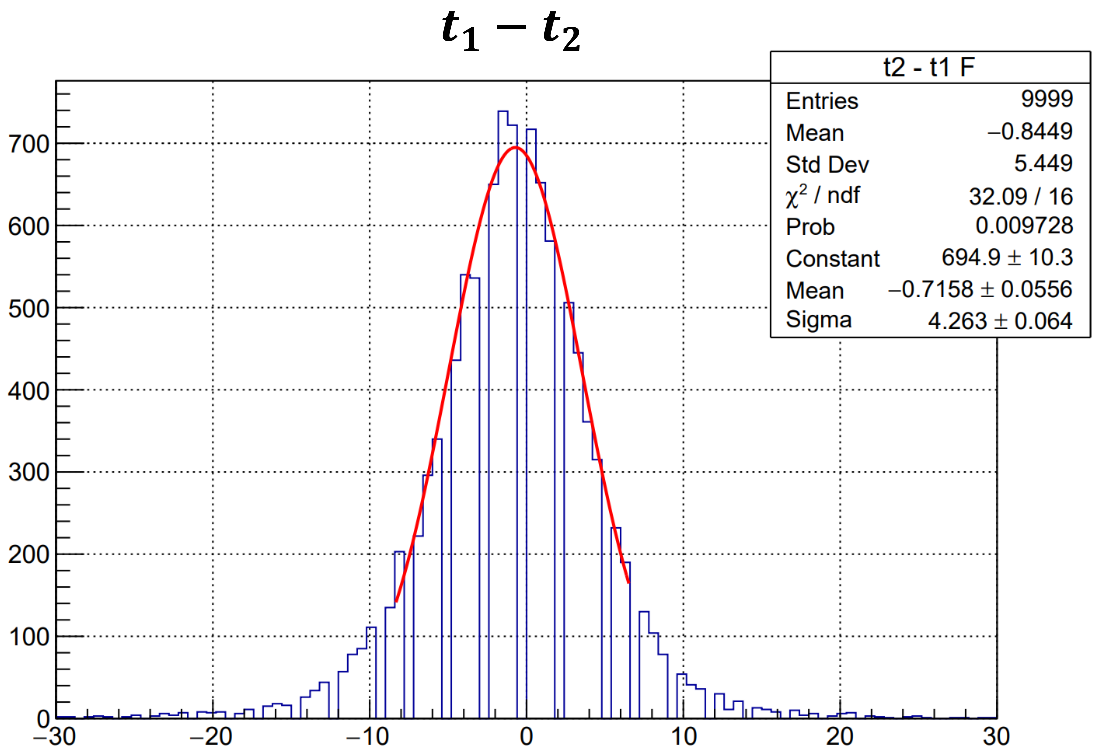


constant fraction timing



$$\Delta T = t_1 - t_2$$

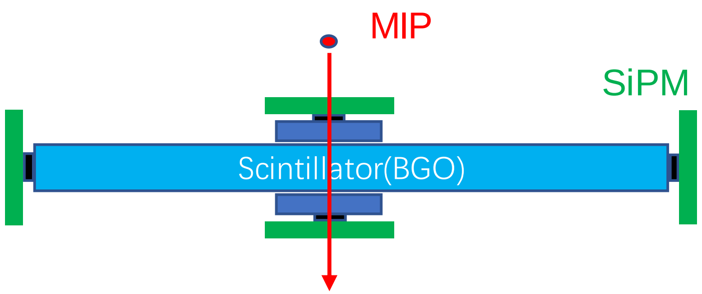
$$T_{res} = \delta_{\Delta T}$$



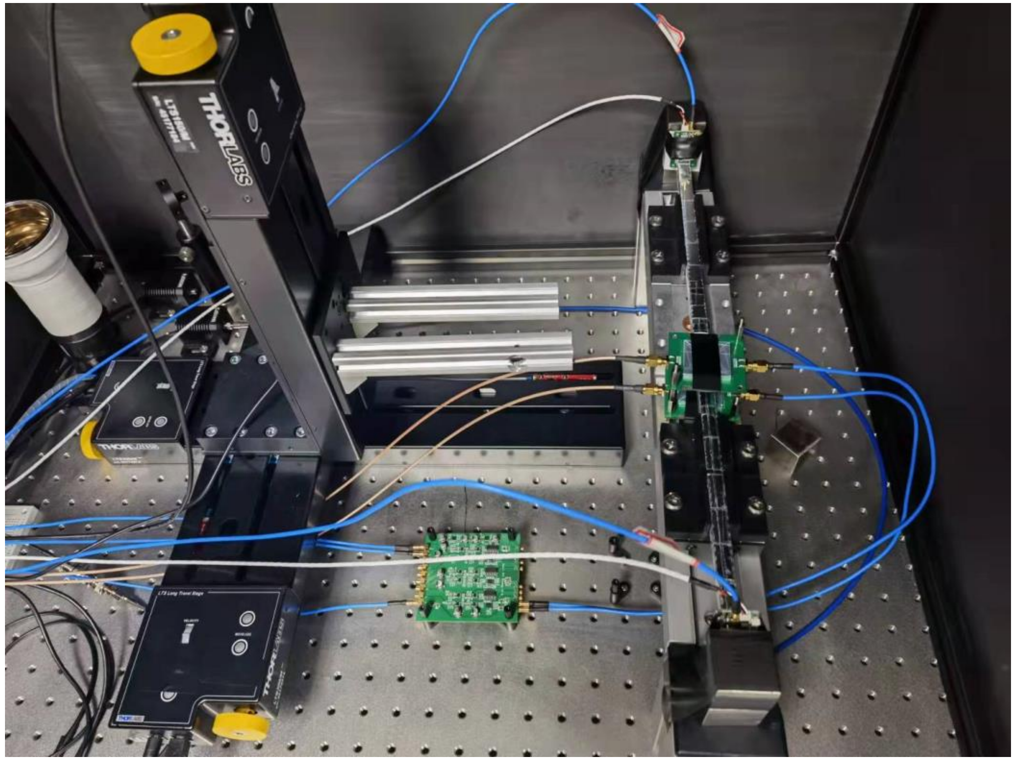
$$T_{res} = \sqrt{T_{res1}^2 + T_{res2}^2} = 4.263\ ns$$

one channel $T_{res1} = T_{res2} = \frac{T_{res}}{\sqrt{2}} = 3.014\ ns$

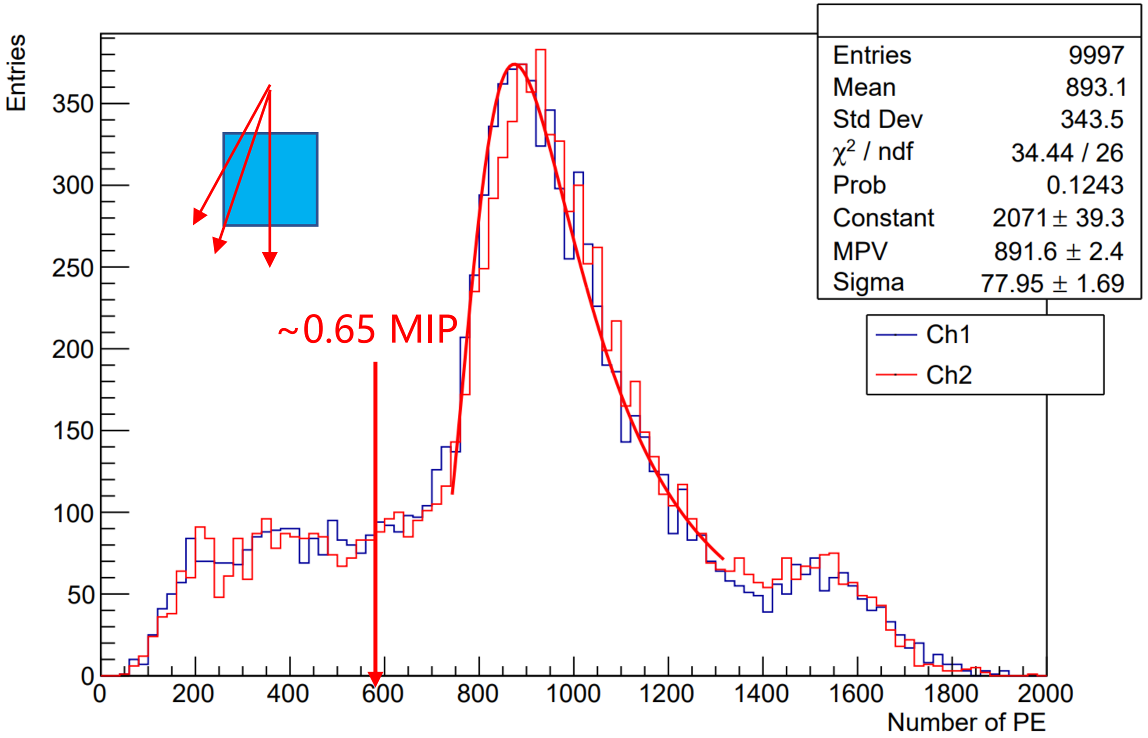
Setup

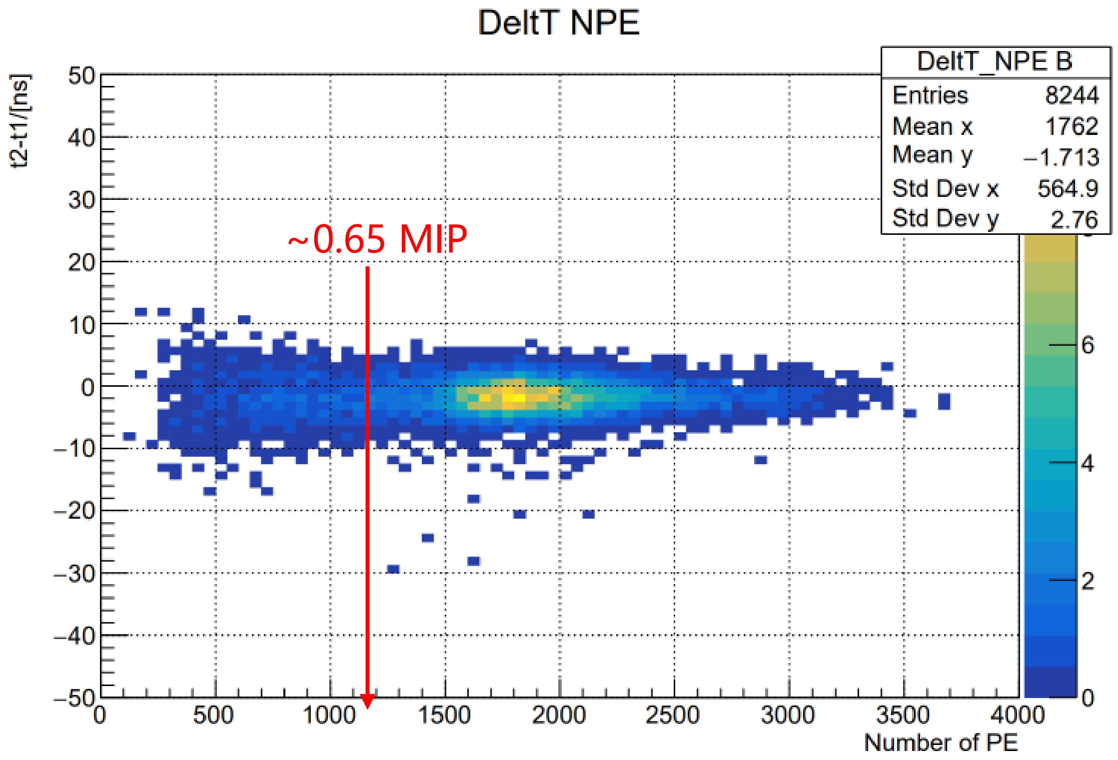


- $40 \times 1 \times 1\ cm^3$ BGO covered by ESR
- $4 \times 4\ cm^2$ plastic scintillator (coincidence)
- SiPM: C13360-3050SA, $3 \times 3\ mm^2$ sensor size
- Cosmic ray samples
- 0.8ns sample rate



Impact of PE Number

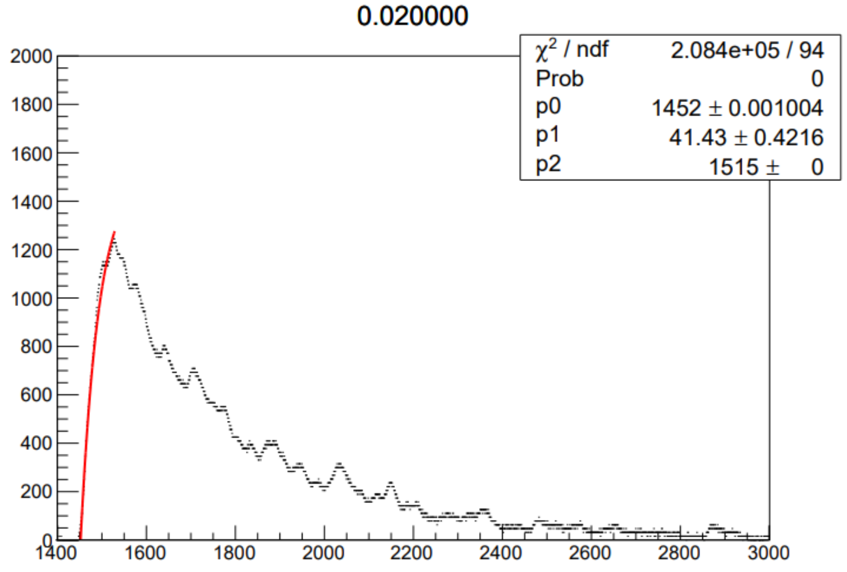


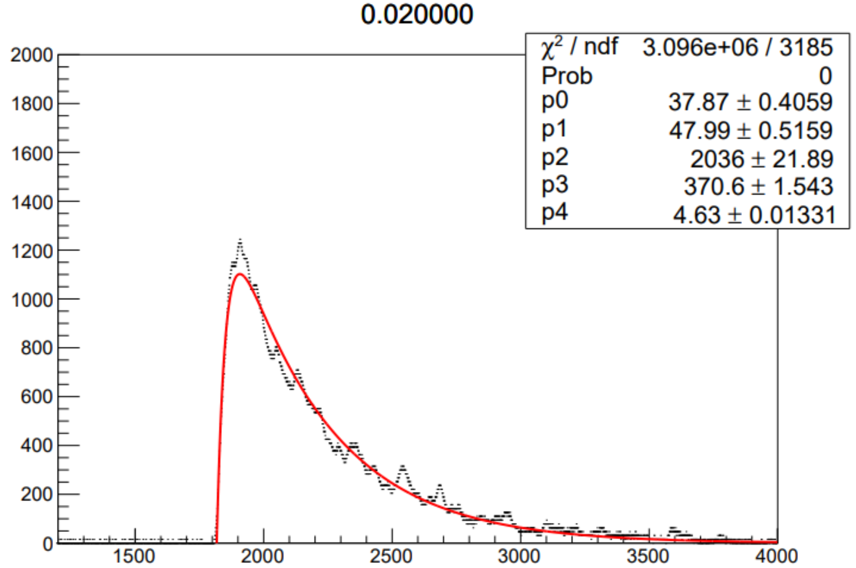


- The time resolution gets better as the PE number increases. Because in one event, the more PE number the waveform contains, the steeper the leading edge.
- In order to exclude the influence of energy change on time resolution. Set a cut of about 0.65 MIP.

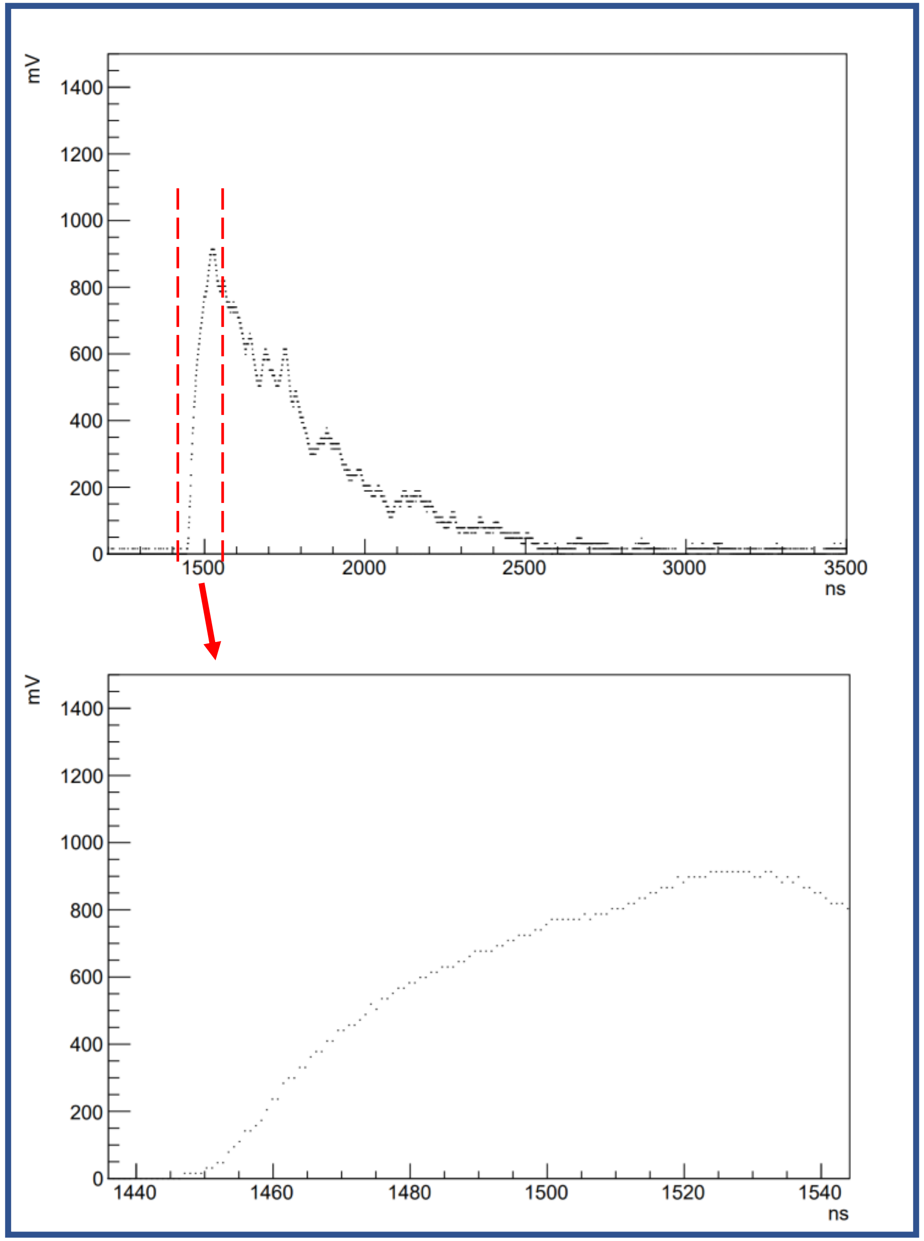
Methods for Timing

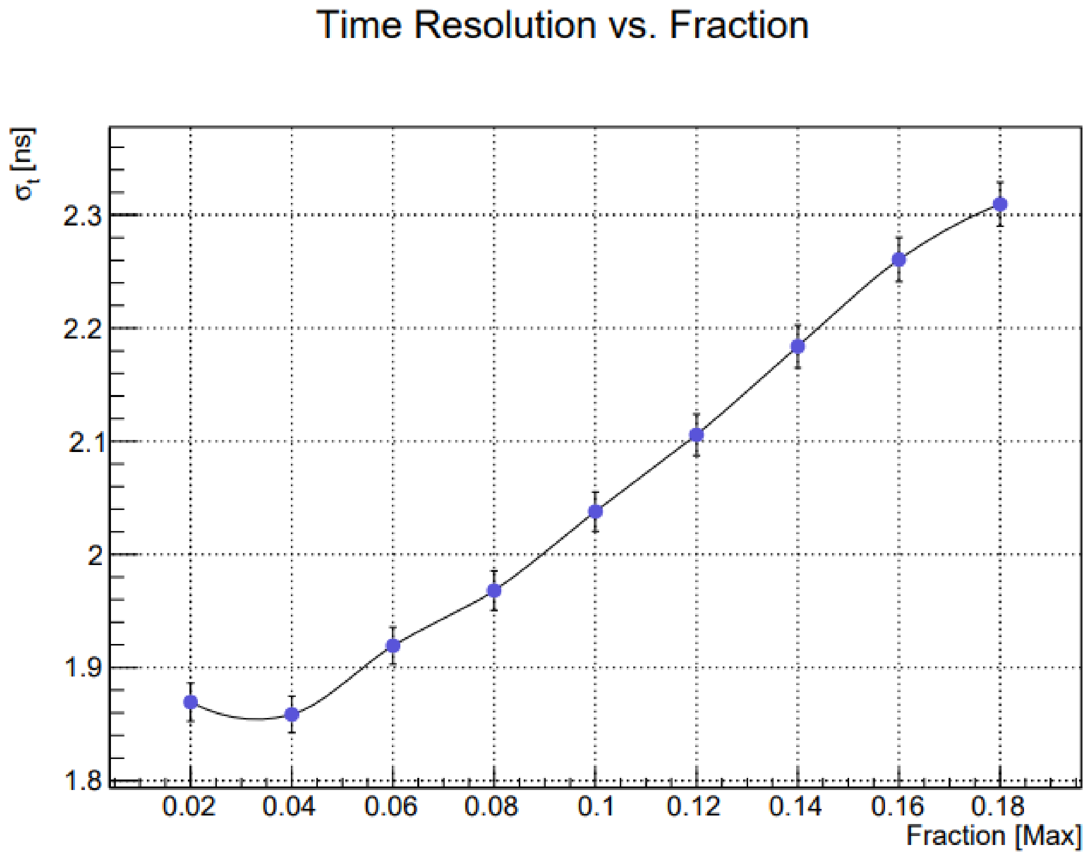
- No fitting
- Leading edge fitting
  - Function: $\left(1 - e^{-\frac{x-[0]}{[1]}}\right) \cdot [2]$
  - Fit range: leading edge
- Waveform fitting
  - Function: $\left(1 - e^{-\frac{x}{[0]}+[1]}\right) \cdot [2] \cdot e^{-\frac{x}{[3]}+[4]}$
  - Fit range: first fit the whole waveform, then fit the leading edge with parameters [2], [3] and [4] fixed





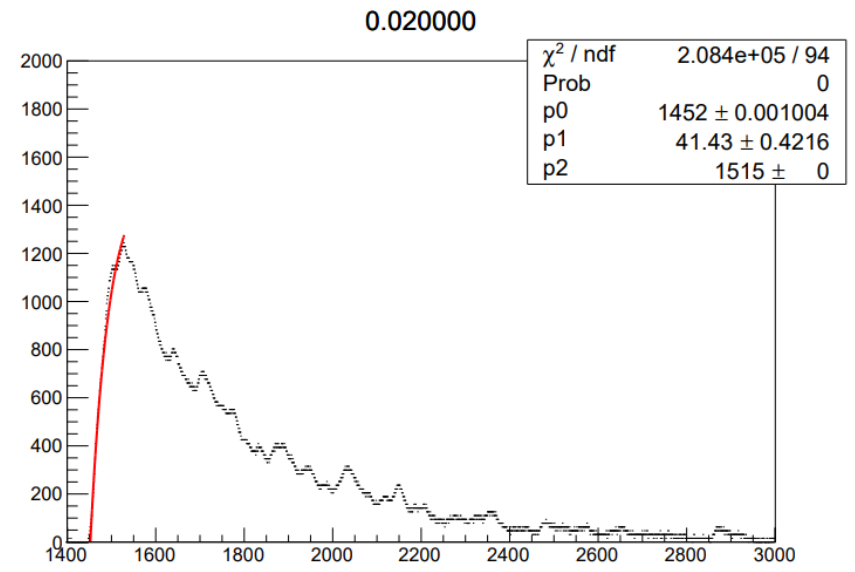
No Fitting

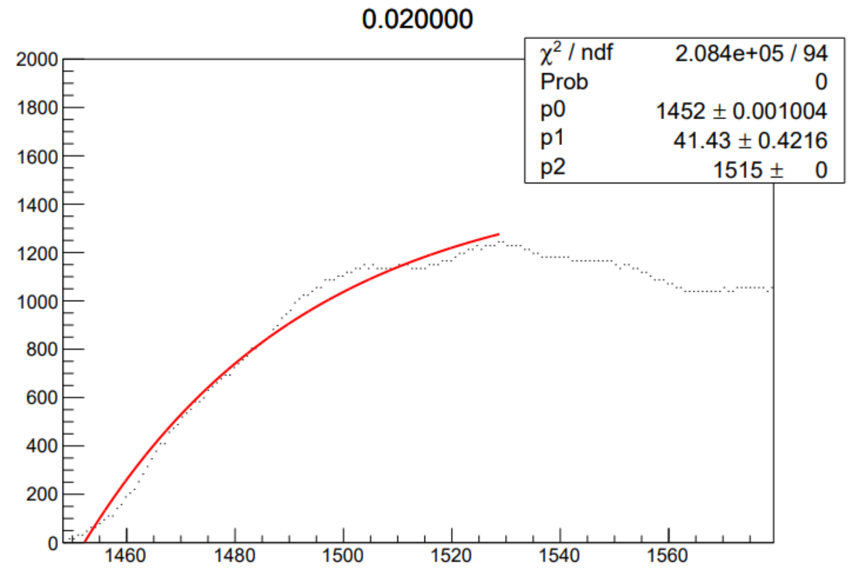


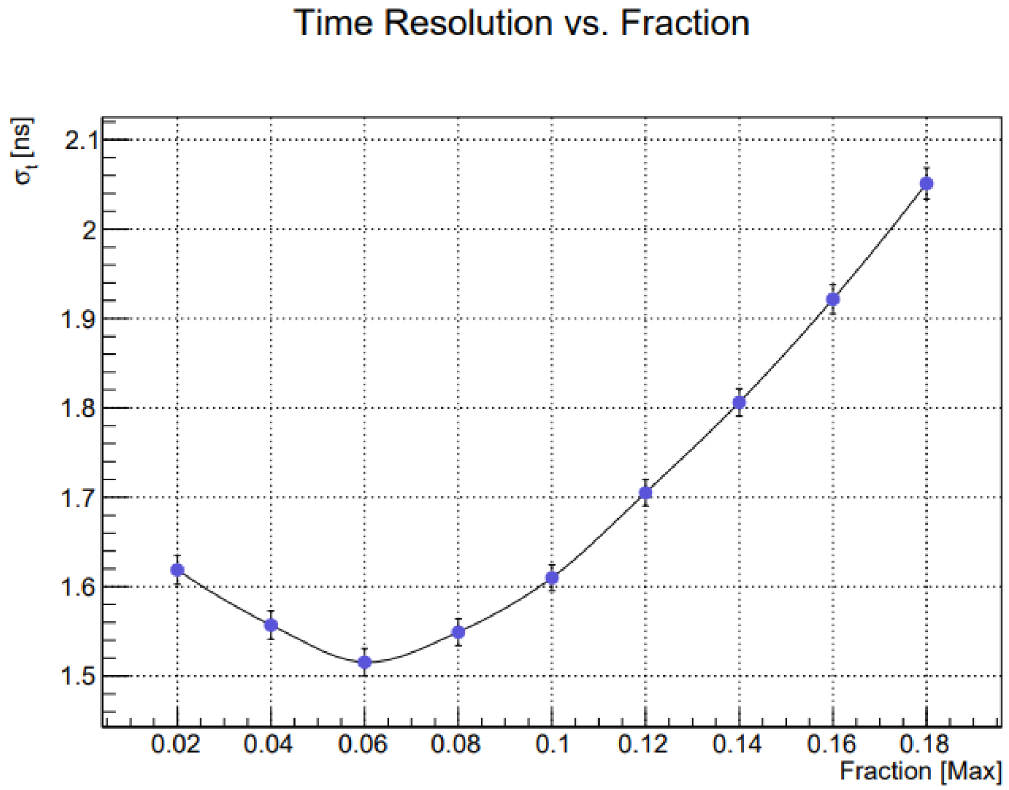


- Linear interpolation
- The time resolution changes with constant fraction
- $\delta_{\Delta T} = \frac{1.859}{\sqrt{2}} ns = 1.314ns$

Leading Edge Fitting

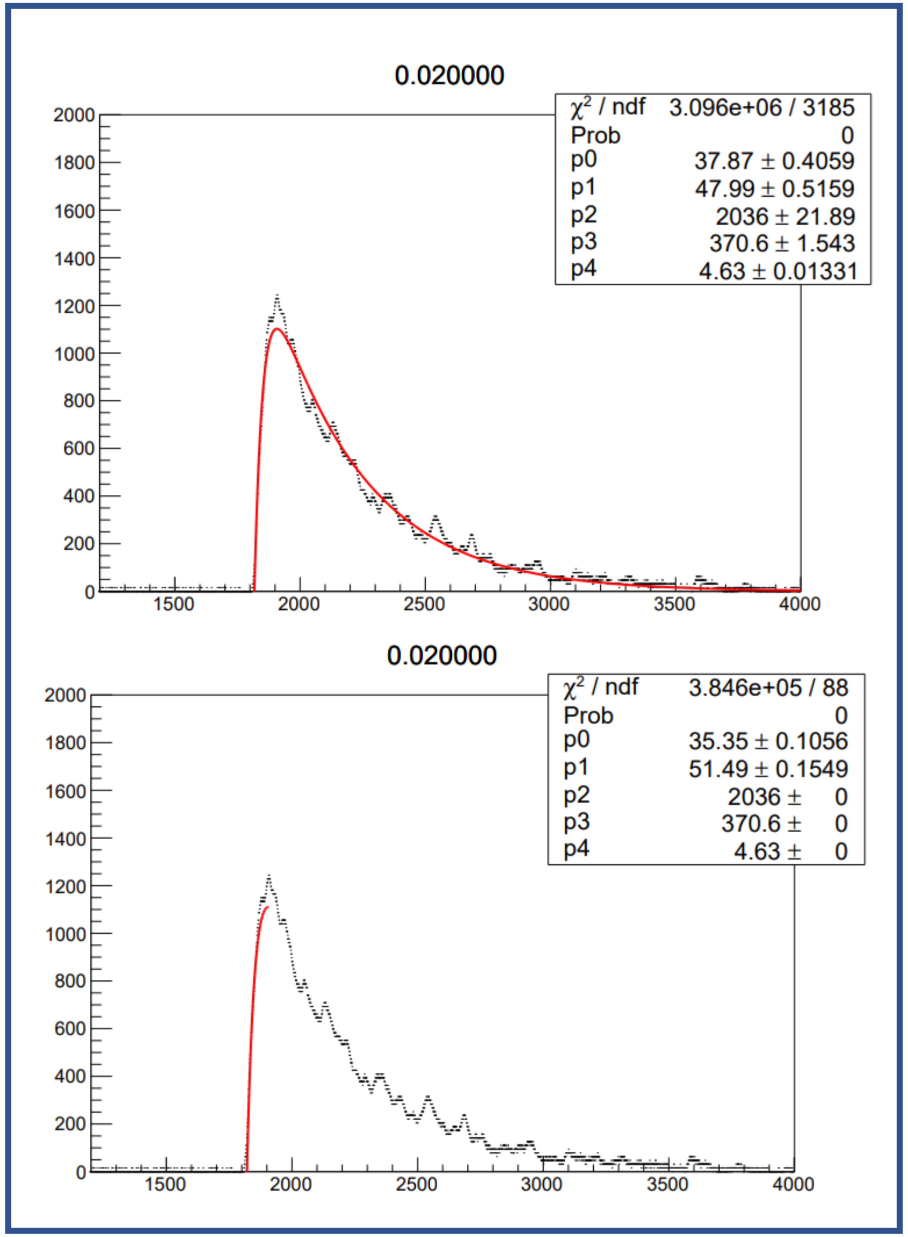


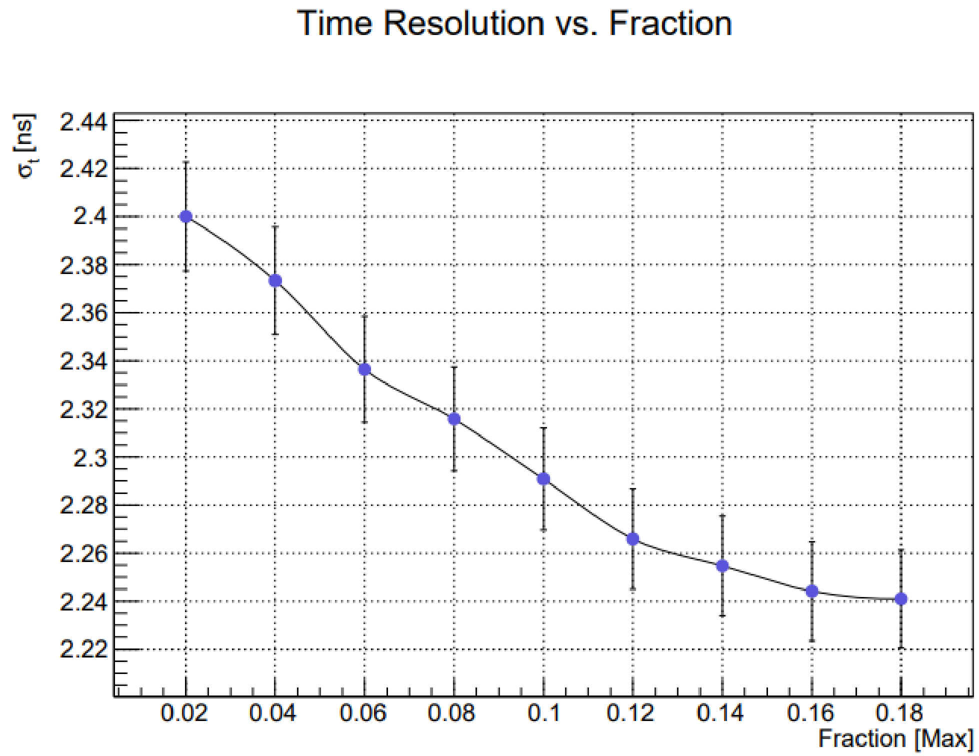




- Fit function: $\left(1 - e^{-\frac{x-[0]}{[1]}}\right) \cdot [2]$
- Double fit, constrain the range of parameters
- $\delta_{\Delta T} = \frac{1.515}{\sqrt{2}} ns = 1.071 ns$

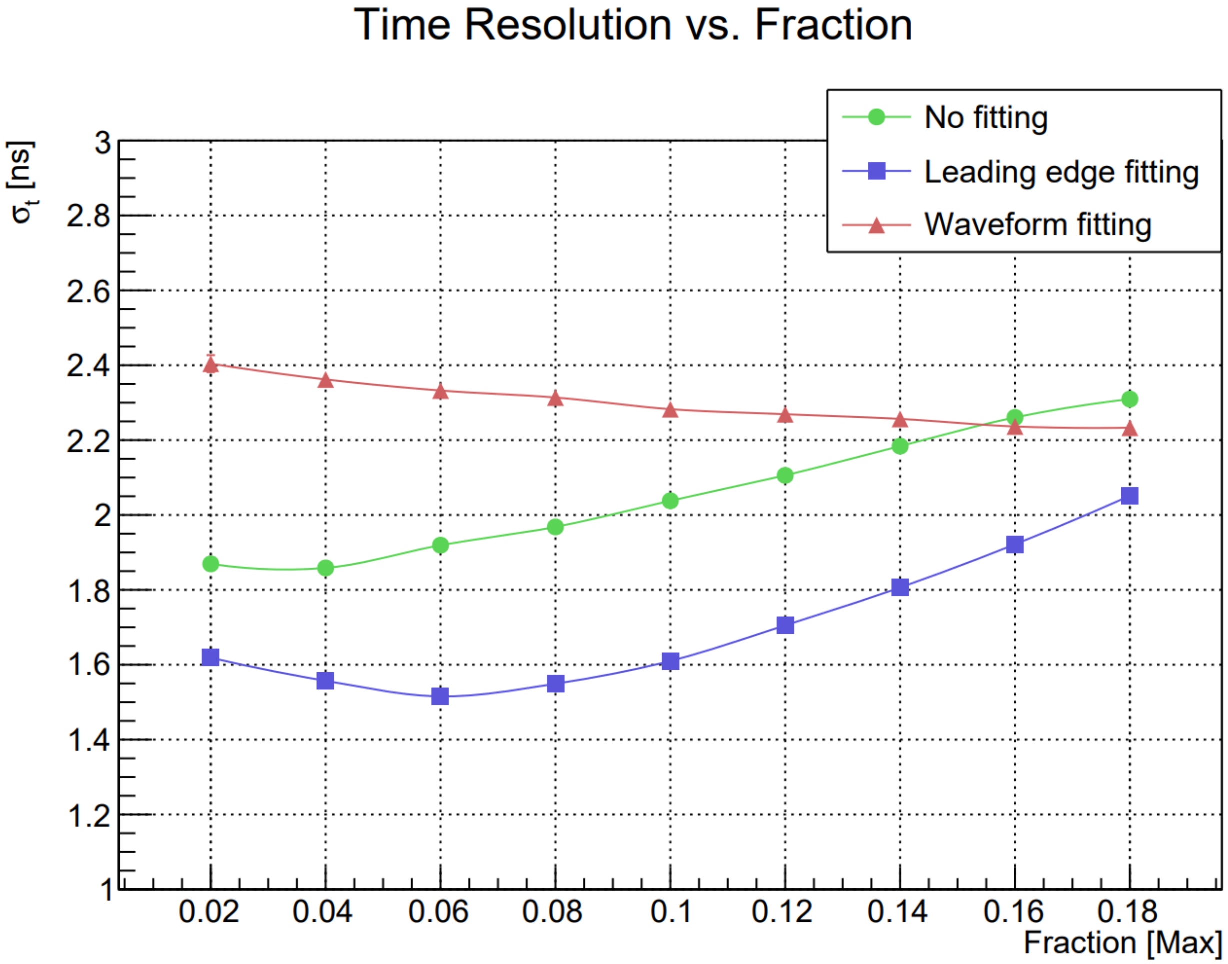
Waveform fitting





- Fit function: $\left(1 - e^{-\frac{x}{[0]}+[1]}\right) \cdot [2] \cdot e^{-\frac{x}{[3]}+[4]}$
- First fit the whole waveform, then fit the leading edge with parameters [2] ,[3] and [4] fixed
- $\delta_{\Delta T} = \frac{2.237}{\sqrt{2}} ns = 1.582 ns$

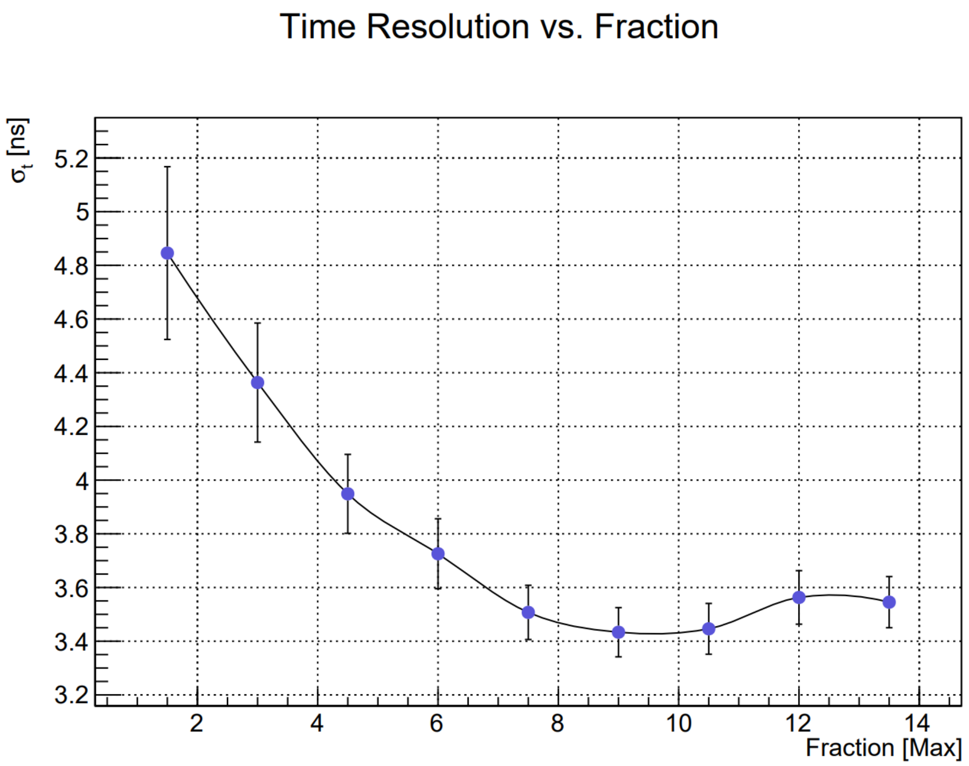
Comparison of the Three Results

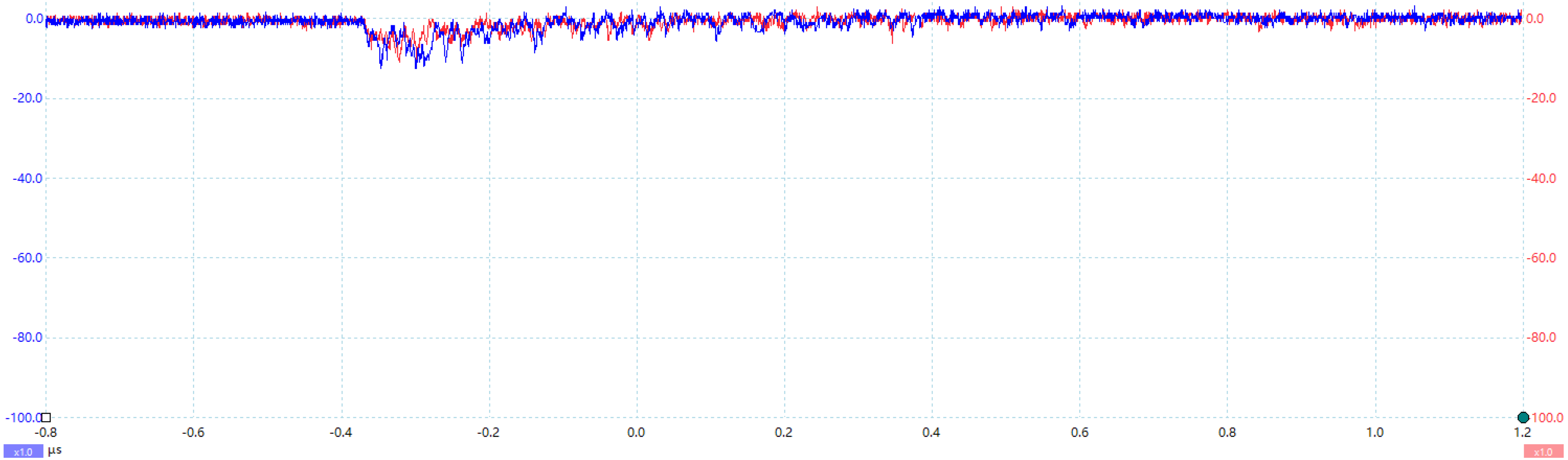


- The best result we can get is about $\frac{1.515}{\sqrt{2}}ns = 1.071ns$(~17.8cm), by leading-edge-fitting. We must constrain the parameters strictly when using this method, or the failure rate of fitting will be higher.
- In waveform-fitting, the fitting result is relatively stable. However, due to the large number of parameters fit range, the time cost is much higher. It is also difficult to get a similar result as the other two methods.

NDL EQR06

- SiPM: NDL EQR06, $6\ \mu m$ pixel, $3 \times 3\ mm^2$ sensor size
- Timing method:
  - First set a threshold, then integrate the 2 channels until they are above the threshold. The end point of integral is the time we want.



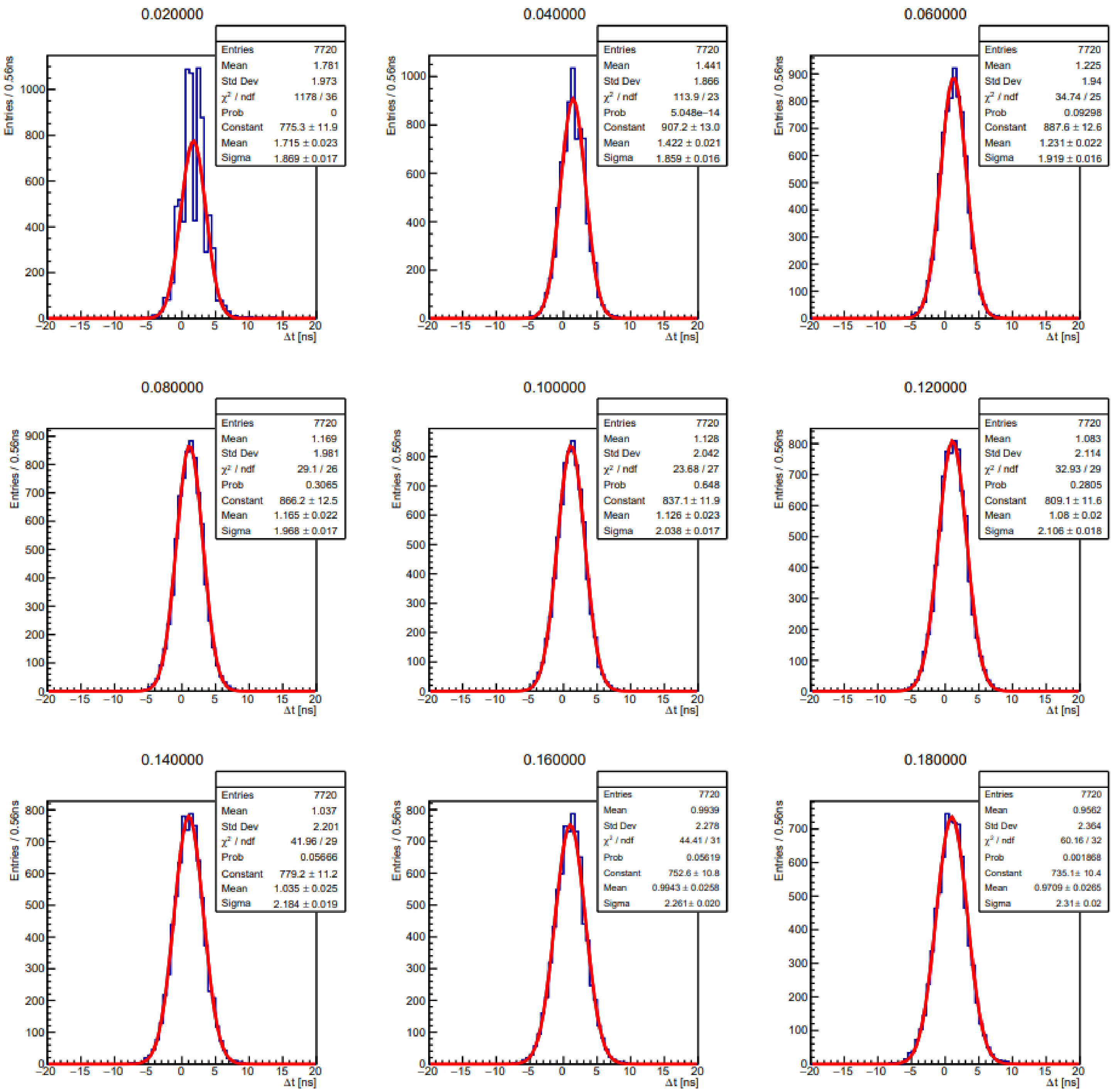


Summary & Prospects

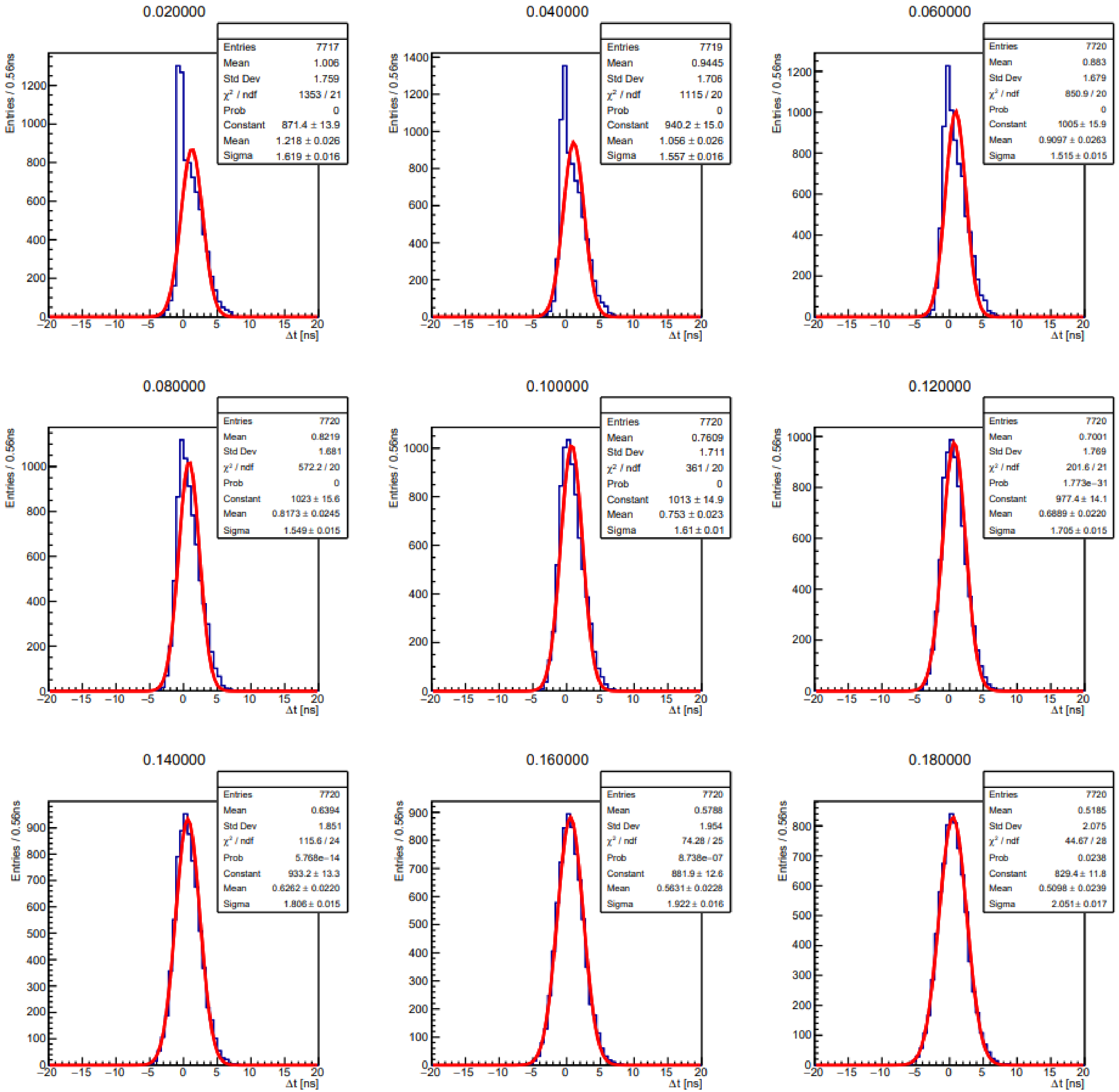
- Summary:
  - Develop some timing methods to calculate time resolution of BGO crystal bar. The best result is about $\frac{1.515}{\sqrt{2}}ns = 1.071ns$.
- Prospects:
  - Change to an oscilloscope with higher sample rate.
  - Use SiPM with better time performance.
  - Change energy and position of the incident particle to examine how precise we can locate the hit position.

Backup

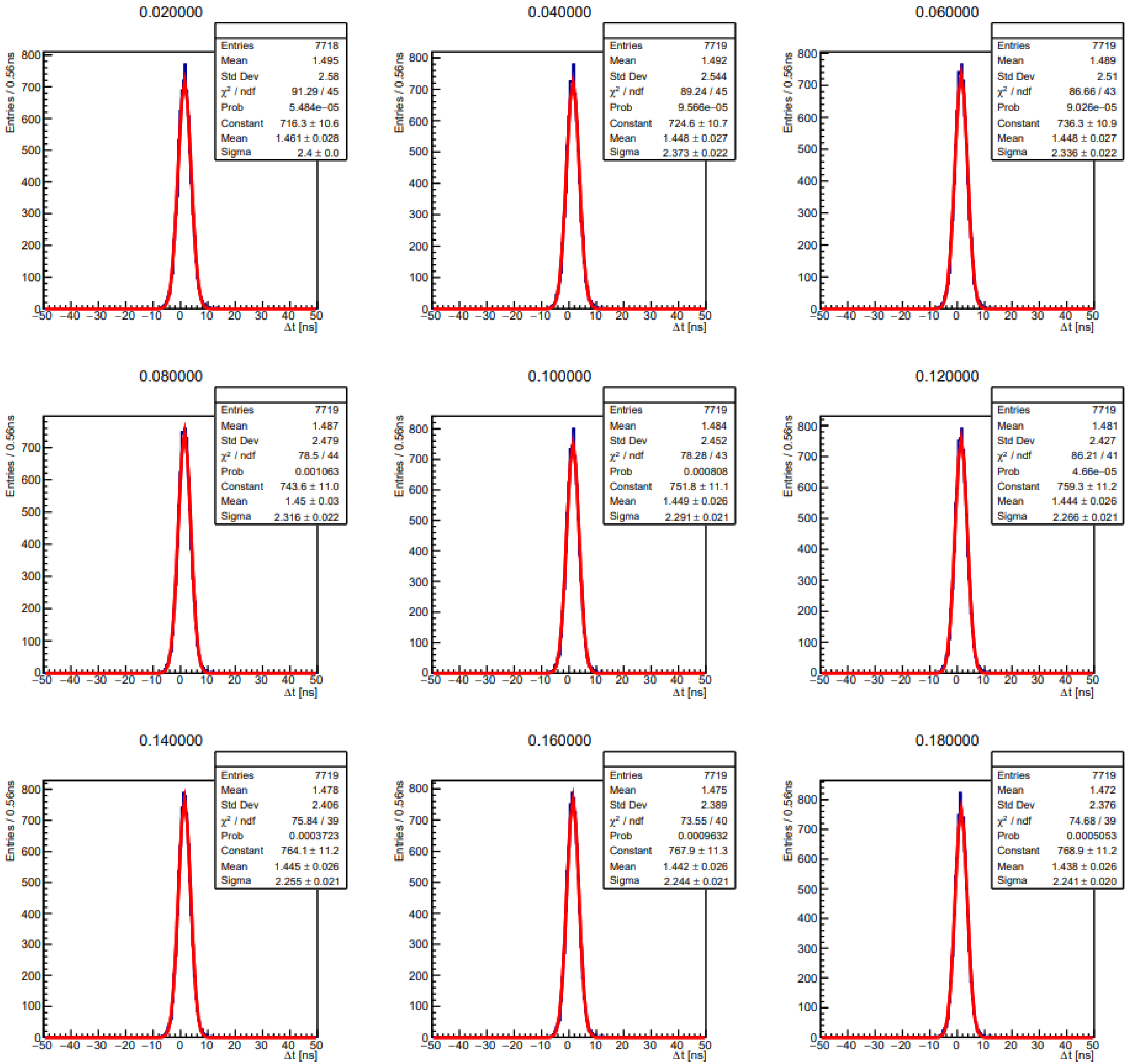
No fitting
2% ~ 18%

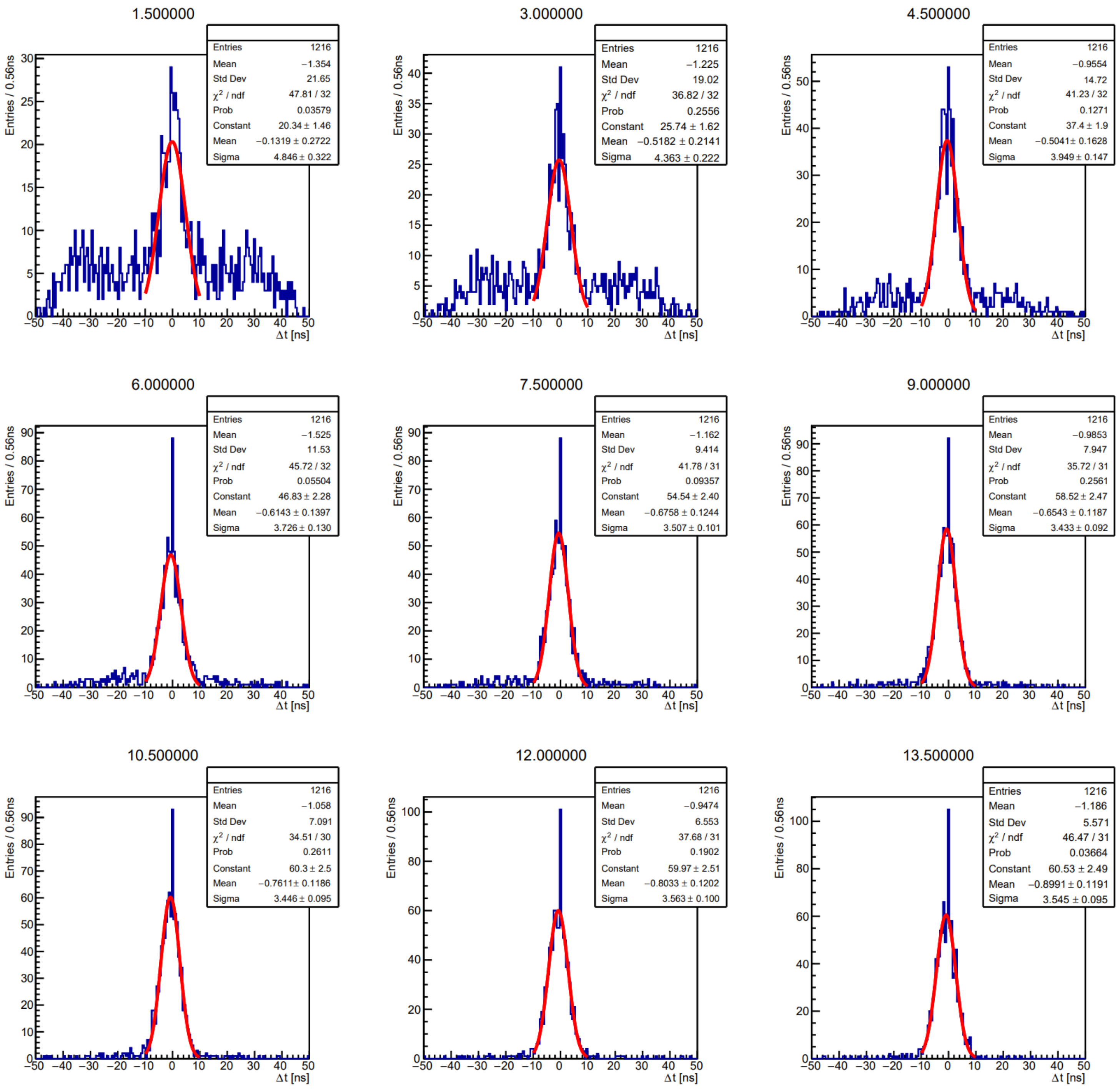


Leading edge fitting
2% ~ 18%



Waveform fitting
2% ~ 18%




1.500000
Entries 1216
Mean −1.354
Std Dev 21.65
χ2 / ndf 47.81 / 32
Prob 0.03579
Constant 20.34 ± 1.46
Mean −0.1319 ± 0.2722
Sigma 4.846 ± 0.322
3.000000
Entries 1216
Mean −1.225
Std Dev 19.02
χ2 / ndf 36.82 / 32
Prob 0.2556
Constant 25.74 ± 1.62
Mean −0.5182 ± 0.2141
Sigma 4.363 ± 0.222
4.500000
Entries 1216
Mean −0.9554
Std Dev 14.72
χ2 / ndf 41.23 / 32
Prob 0.1271
Constant 37.4 ± 1.9
Mean −0.5041 ± 0.1628
Sigma 3.949 ± 0.147
6.000000
Entries 1216
Mean −1.525
Std Dev 11.53
χ2 / ndf 45.72 / 32
Prob 0.05504
Constant 46.83 ± 2.28
Mean −0.6143 ± 0.1397
Sigma 3.726 ± 0.130
7.500000
Entries 1216
Mean −1.162
Std Dev 9.414
χ2 / ndf 41.78 / 31
Prob 0.09357
Constant 54.54 ± 2.40
Mean −0.6758 ± 0.1244
Sigma 3.507 ± 0.101
9.000000
Entries 1216
Mean −0.9853
Std Dev 7.947
χ2 / ndf 35.72 / 31
Prob 0.2561
Constant 58.52 ± 2.47
Mean −0.6543 ± 0.1187
Sigma 3.433 ± 0.092
10.500000
Entries 1216
Mean −1.058
Std Dev 7.091
χ2 / ndf 34.51 / 30
Prob 0.2611
Constant 60.3 ± 2.5
Mean −0.7611 ± 0.1186
Sigma 3.446 ± 0.095
12.000000
Entries 1216
Mean −0.9474
Std Dev 6.553
χ2 / ndf 37.68 / 31
Prob 0.1902
Constant 59.97 ± 2.51
Mean −0.8033 ± 0.1202
Sigma 3.563 ± 0.100
13.500000
Entries 1216
Mean −1.186
Std Dev 5.571
χ2 / ndf 46.47 / 31
Prob 0.03664
Constant 60.53 ± 2.49
Mean −0.8991 ± 0.1191
Sigma 3.545 ± 0.095
Entries / 0.56ns
Δt [ns]

NDL EQR06