# ToF calibration of CNAO 03/2019 data

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# Introduction

- Uncalibrated ToF extraction:
  - STC time stamp
  - CLK phase jitter
  - TW time stamp
  - Problems: board79 + chip1 of board 78

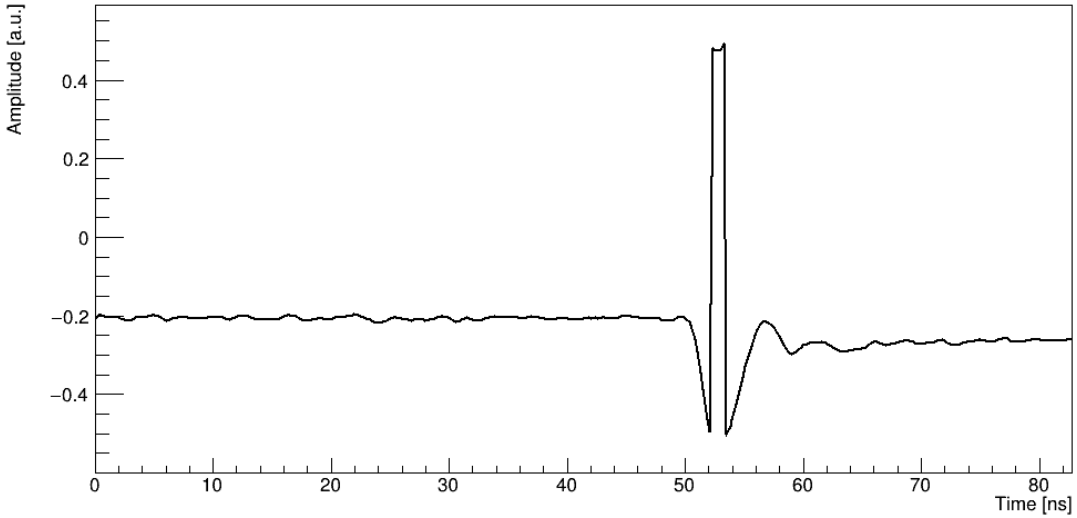
- ToF calibration:
  - Cabling offset
  - $ToF_0$ offset

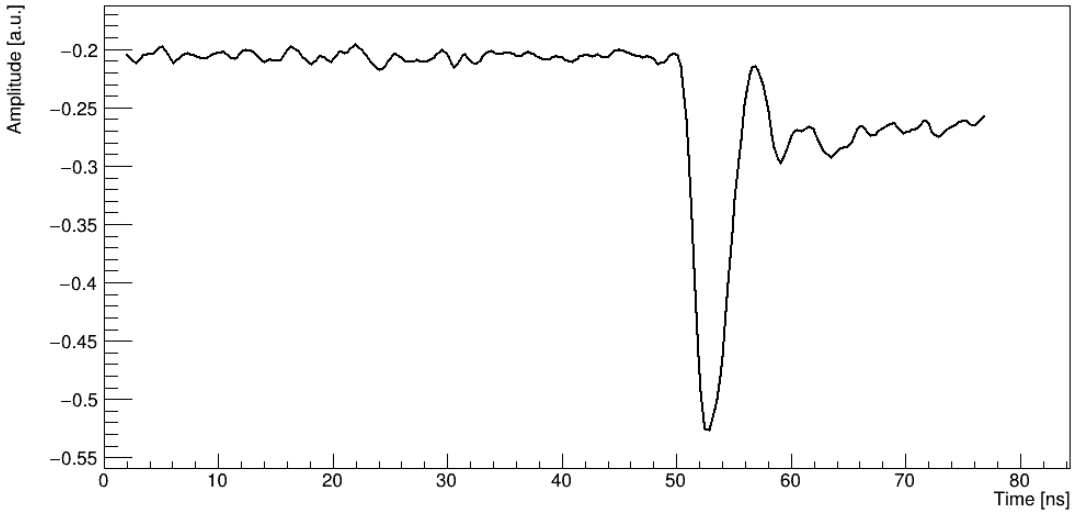
# STC analysis

- The channels had different amplitudes
- Some waveforms needed to be corrected for possible dynamic range overflows
- Time stamp not extracted for single channels

**Sum of the waveforms**

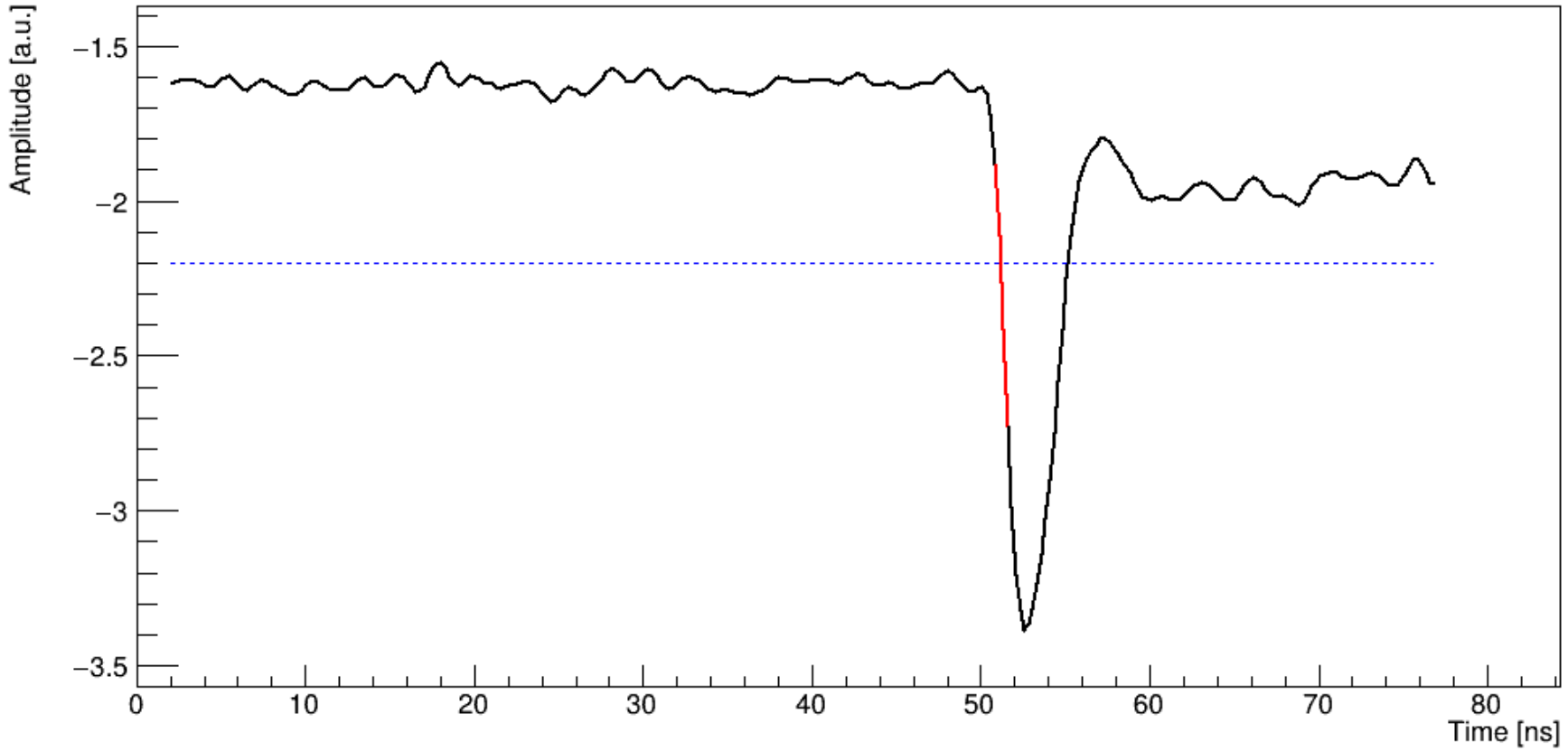
(thanks to Giacomo)



# STC time stamp

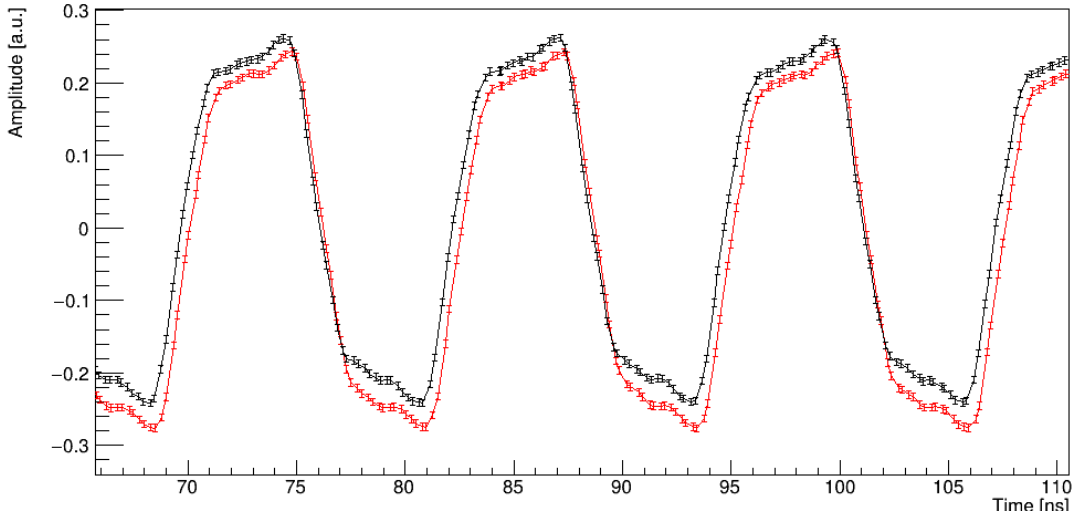
- CFD method (threshold fraction = 0.3) applied to extract event timestamp → $t_{STC}$

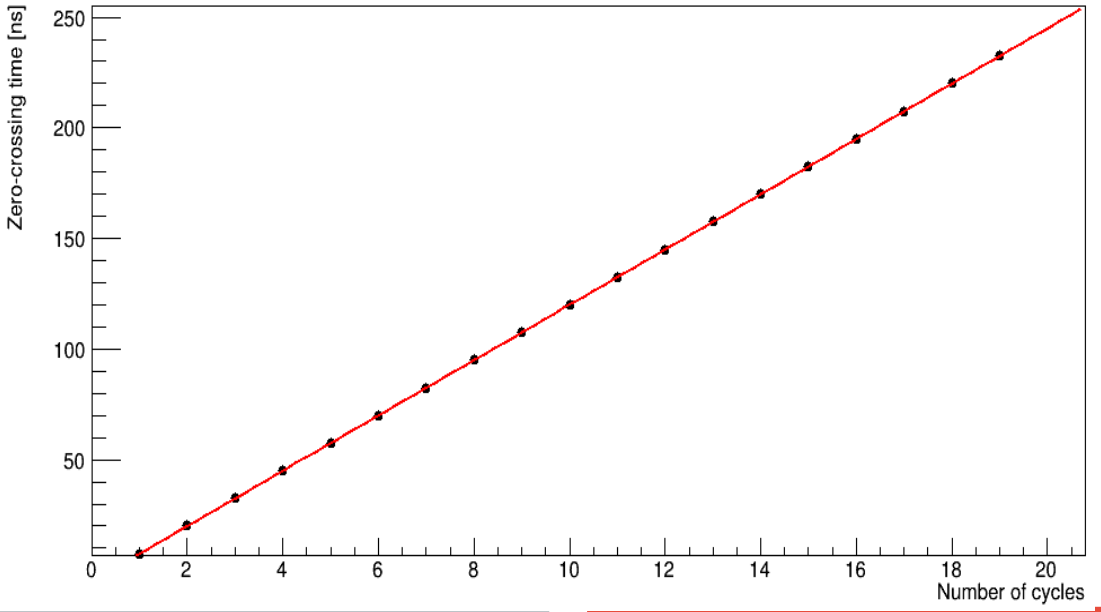


# Clock phase jitter

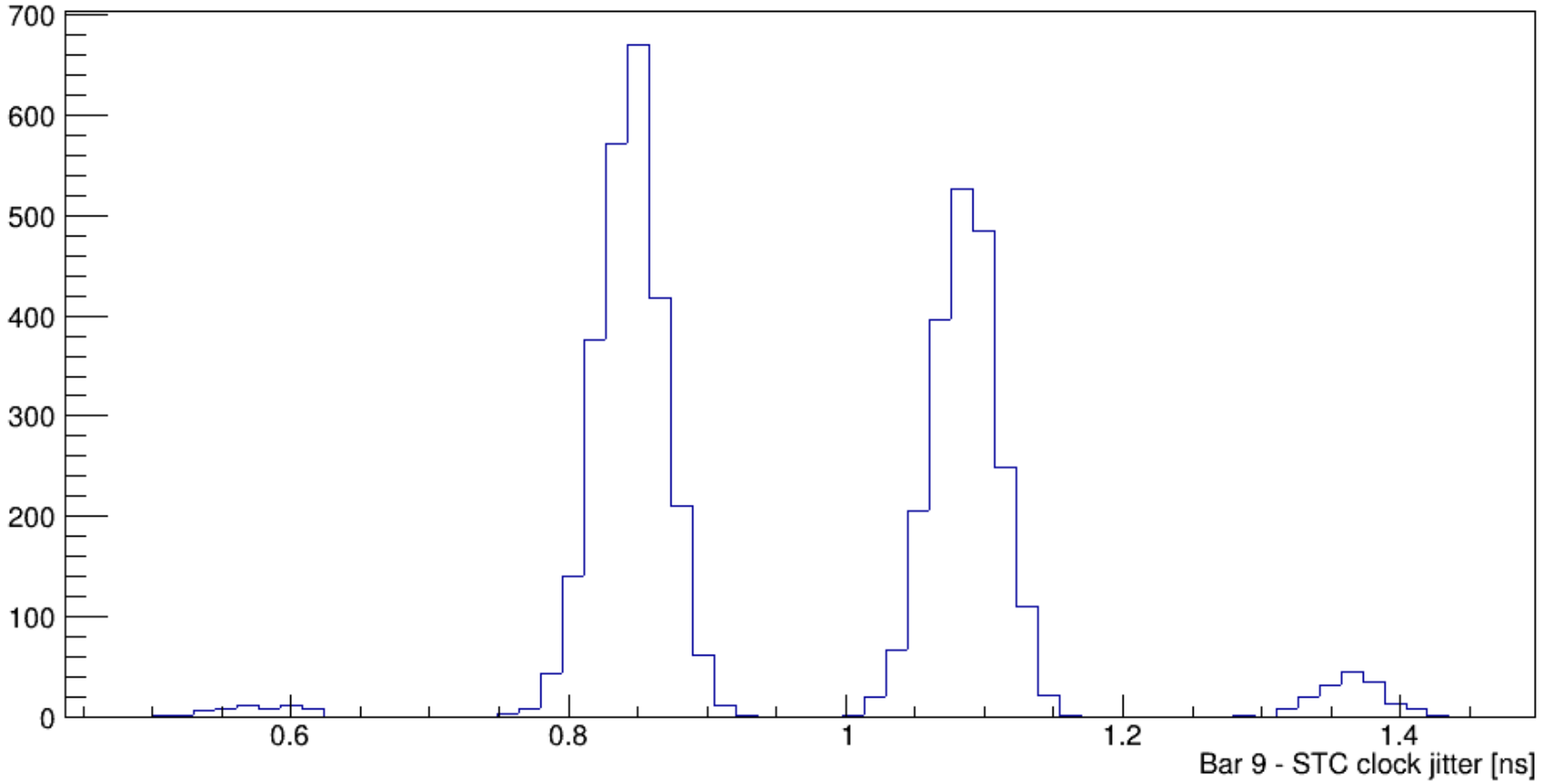
- Variable phase difference between the clocks
- Find the phase of all the clocks involved
  - ➔ Find all the zero-crossing time stamps of the clock  with a linear interpolation
  - ➔ Linear fit of $t_{0\text{-cross}}$ vs Number of clock cycles elapsed
    - Slope = clk period = 12.5 ns
    - **Intercept = clk phase**

**Realign clocks**



# Clock phase jitter example: Bar 9-STC

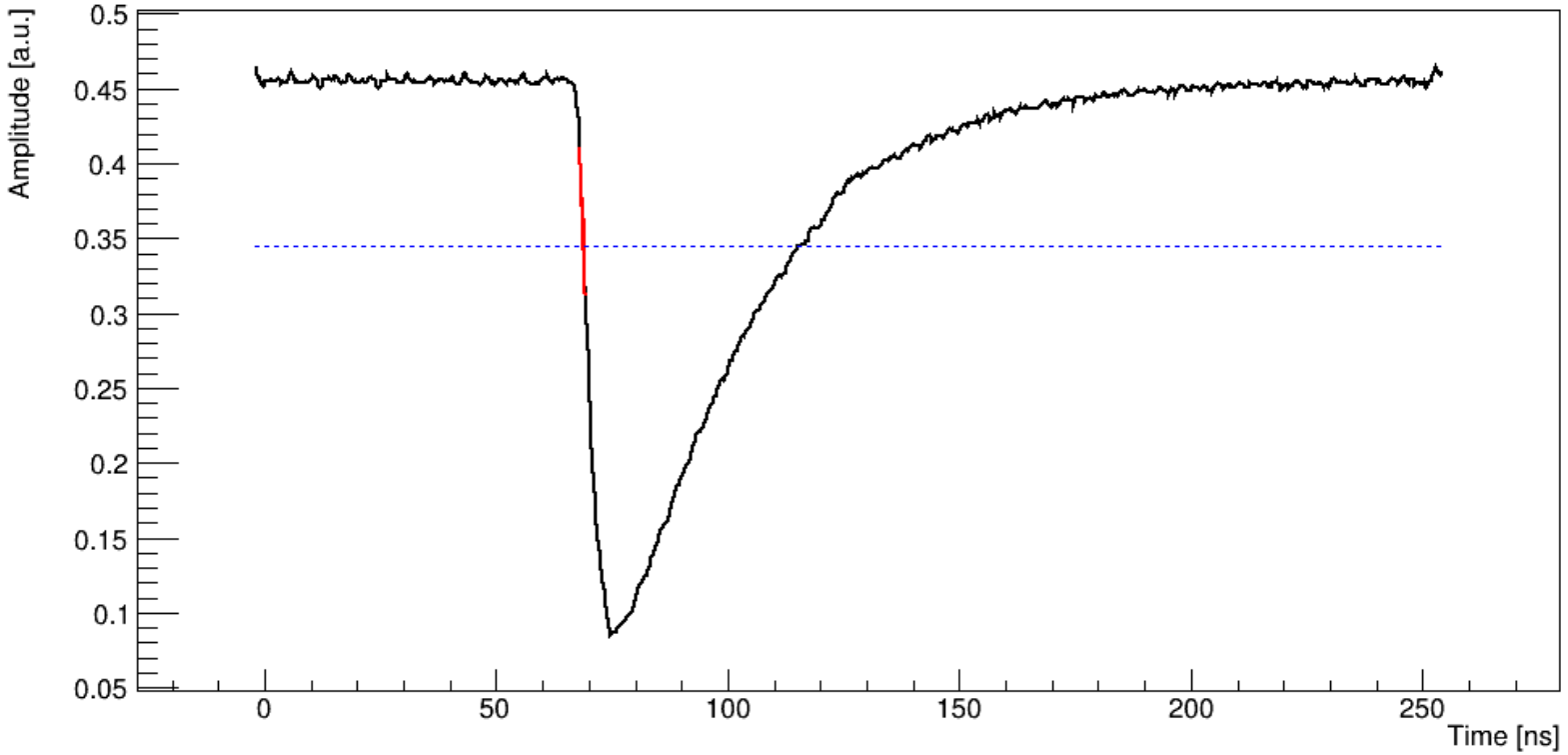



**Phase jitter → Gaussian spread (~25-30 ps)**

**Trigger cell jitter → N gaussians (time bin ~ 250 ps)**

# TW time stamp

TW channel time stamp evaluated with CFD method (th = 0.3)



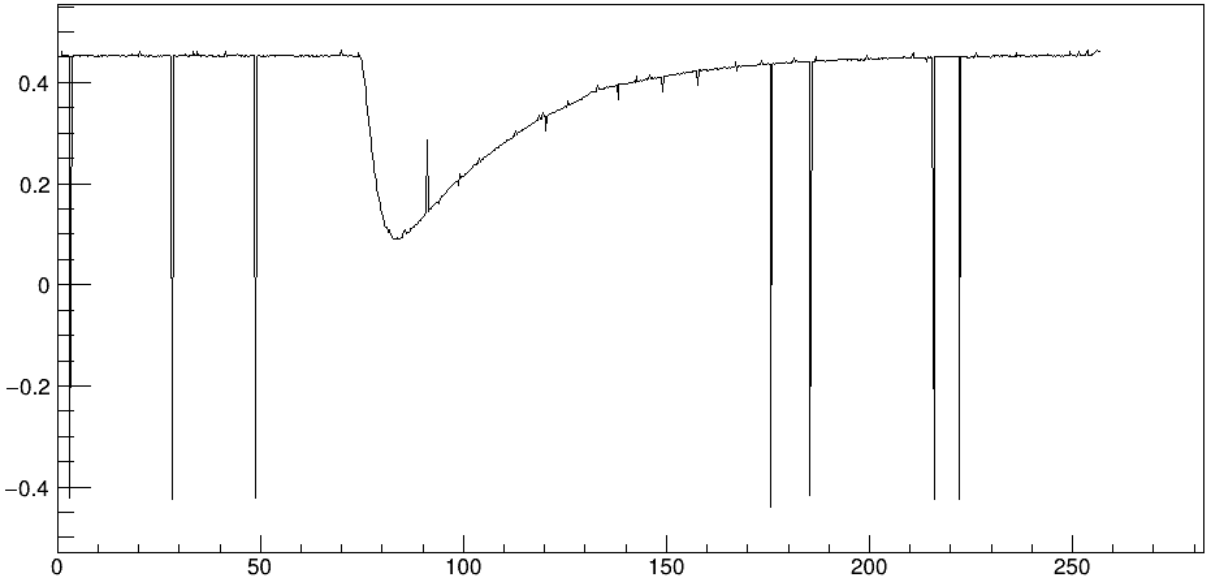

$$T_{\text{Bar}} = \frac{T_{\text{left}} + T_{\text{right}}}{2}$$

# TW time stamp: corrections

Problems:

- ➔ Board 79
- ➔ Chip 1 of board 78: ADC-DRS synch

**Random spikes in the signals**




**Corrected with a 7-point median filter**

**WFs retrieved**

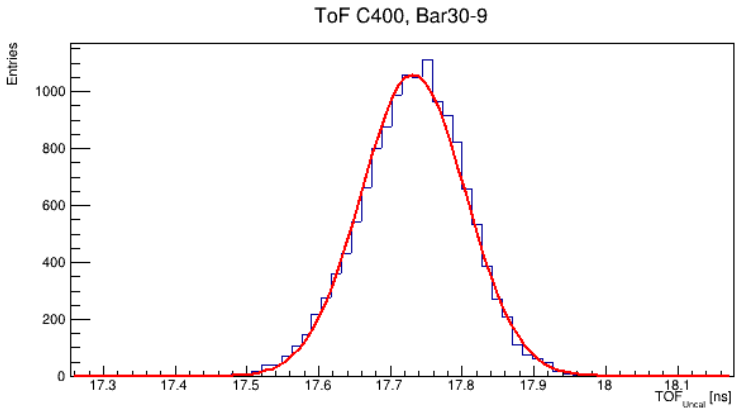
**Board 78 → Fixed**

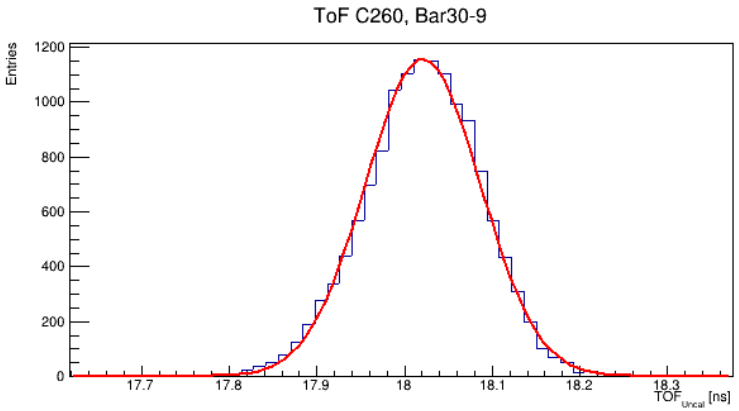
**Board 79 → ToF values**

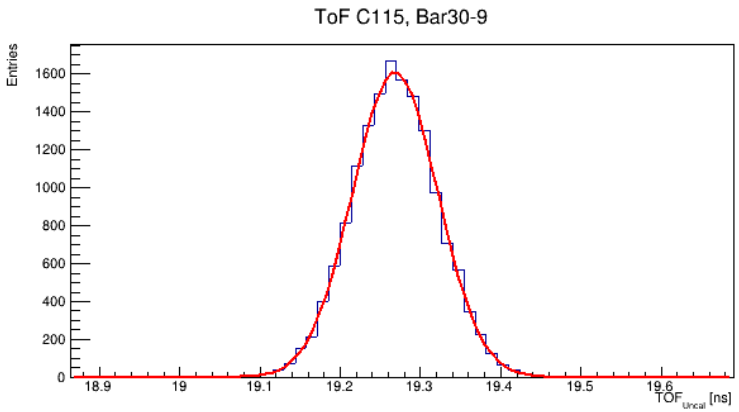
# Uncalibrated ToF

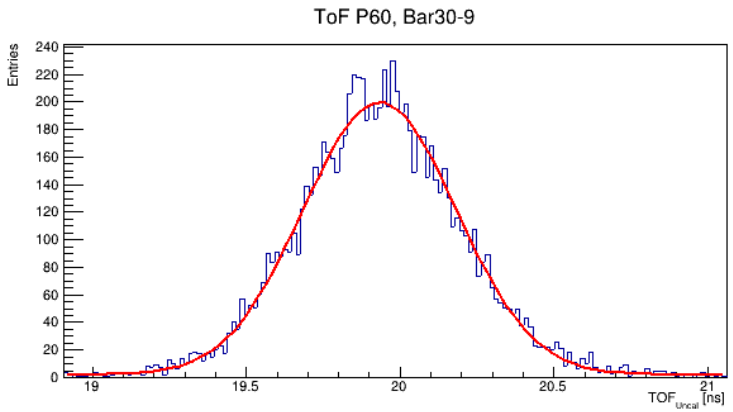
The uncalibrated ToF of each event was evaluated as

$$ToF_{Uncal} = \frac{T_{\mathrm{Bar},Front} + T_{\mathrm{Bar},Rear}}{2} - T_{STC} - \Delta_{CLK}$$



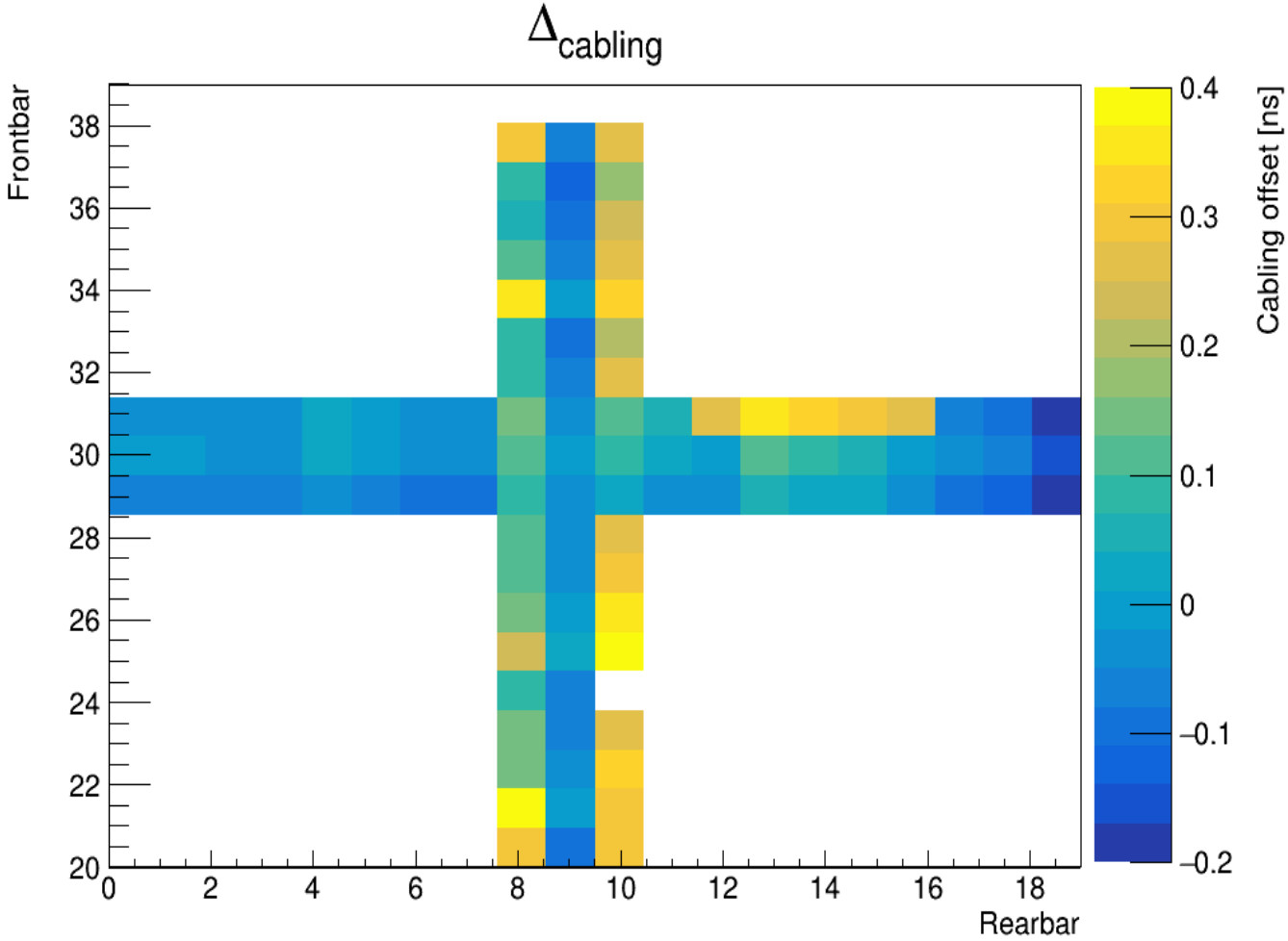




| Beam | $\sigma_{ToF}$ [ps] |
|---|---|
| C400 | 72.8 ± 0.5 |
| C260 | 65.4 ± 0.5 |
| C115 | 53.1 ± 0.3 |
| P60 | 250 ± 2 |

# ToF calibration: cabling correction

ToF values needed to be corrected for cabling delay

- Gaussian fit of all the uncalibrated ToF histograms (>100 events) poisition-by-position for each beam
- Calculated cabling delay from the central point (bars 30-9) separately for each beam energy
- Weighted mean position-by-position of the cabling delay

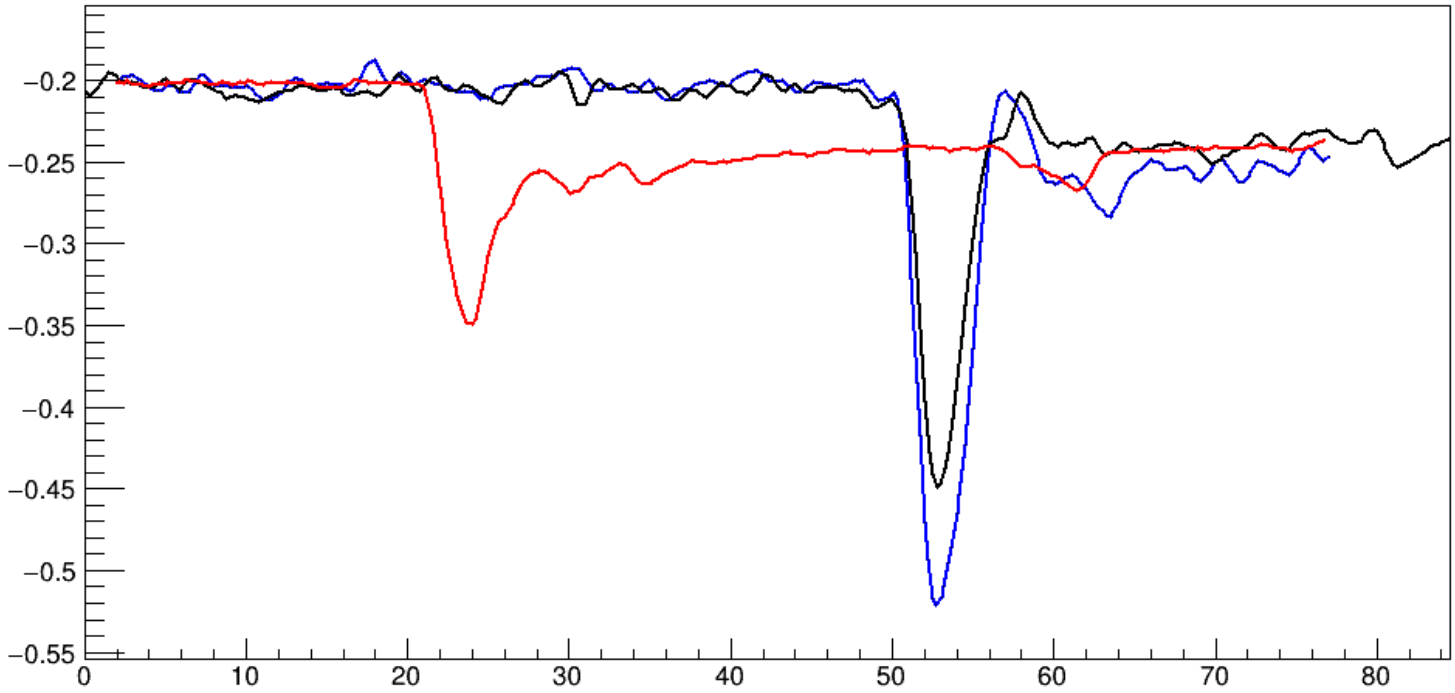


# ToF calibration: $ToF_0$ offset correction

$$ToF_{Uncal} = ToF_0 + \frac{d}{\beta c}$$

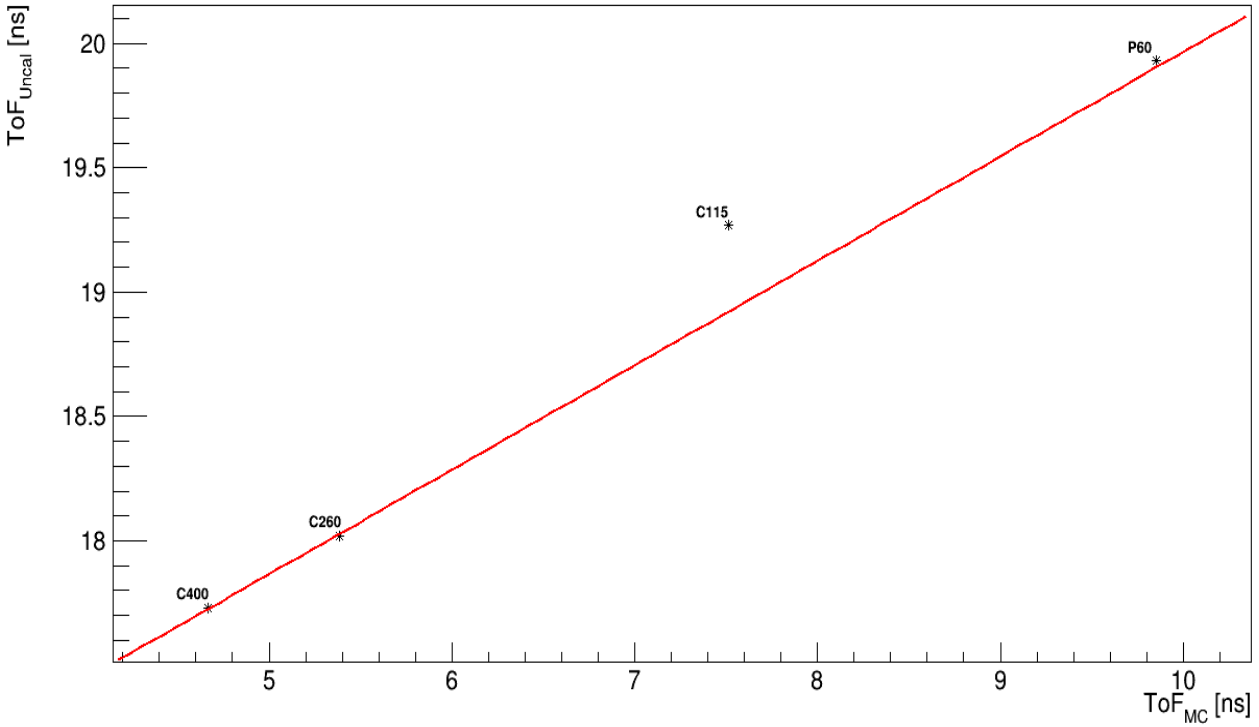
Offset correction needed

- Compare $ToF_{Uncal}$ values with MC simulations' results
- Couldn't use STC data for C115: waveforms had different shape (pole-zero cancellation not performed?)



# ToF calibration: $ToF_0$ offset correction

Fitted uncalibrated ToF values of the central point vs $ToF_{MC}$ with $ToF_0$ and d as free parameters

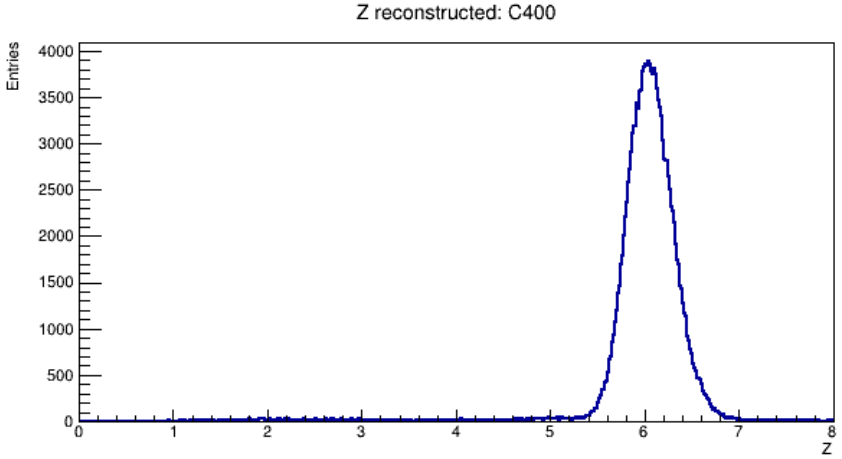


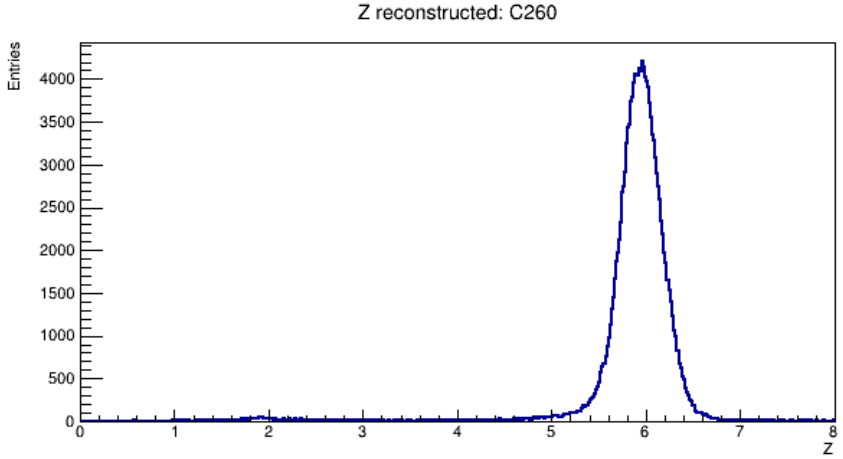

$$ToF_0 = 15.766 \pm 0.004\ ns$$
$$d = 42.00 \pm 0.07\ cm$$

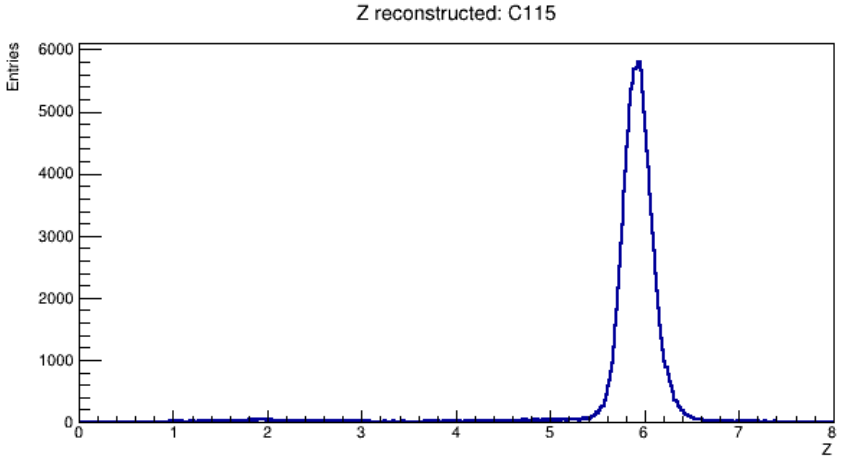
$$ToF_{Cal} = ToF_{Uncal} - ToF_0 - \Delta_{cabling}$$

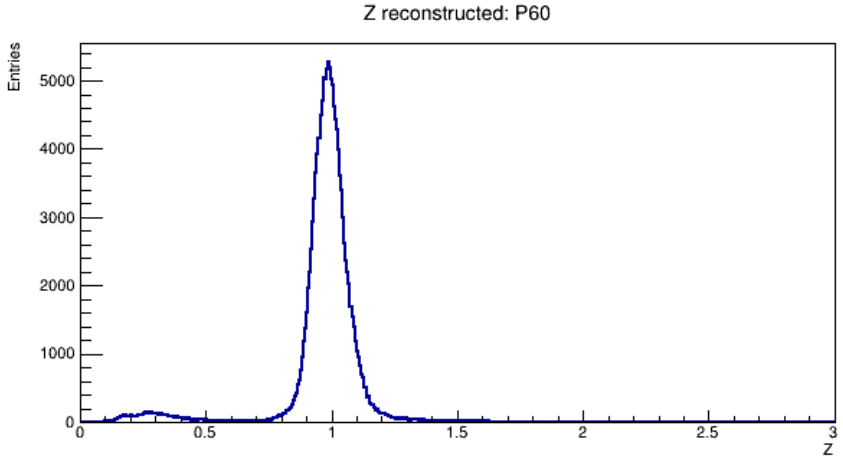
# Z reconstruction

With ToF and energy (thanks to Bologna team) calibration, it’s possible to reconstruct the Z of the incident particles



# Z reconstruction: results

- The resolutions obtained for carbon are mainly given by
  - ➔ Energy resolution
  - ➔ Charge equalization: only performed for bars 9 and 30

- ToF resolution effects are important for protons, but the peak is still well resolved

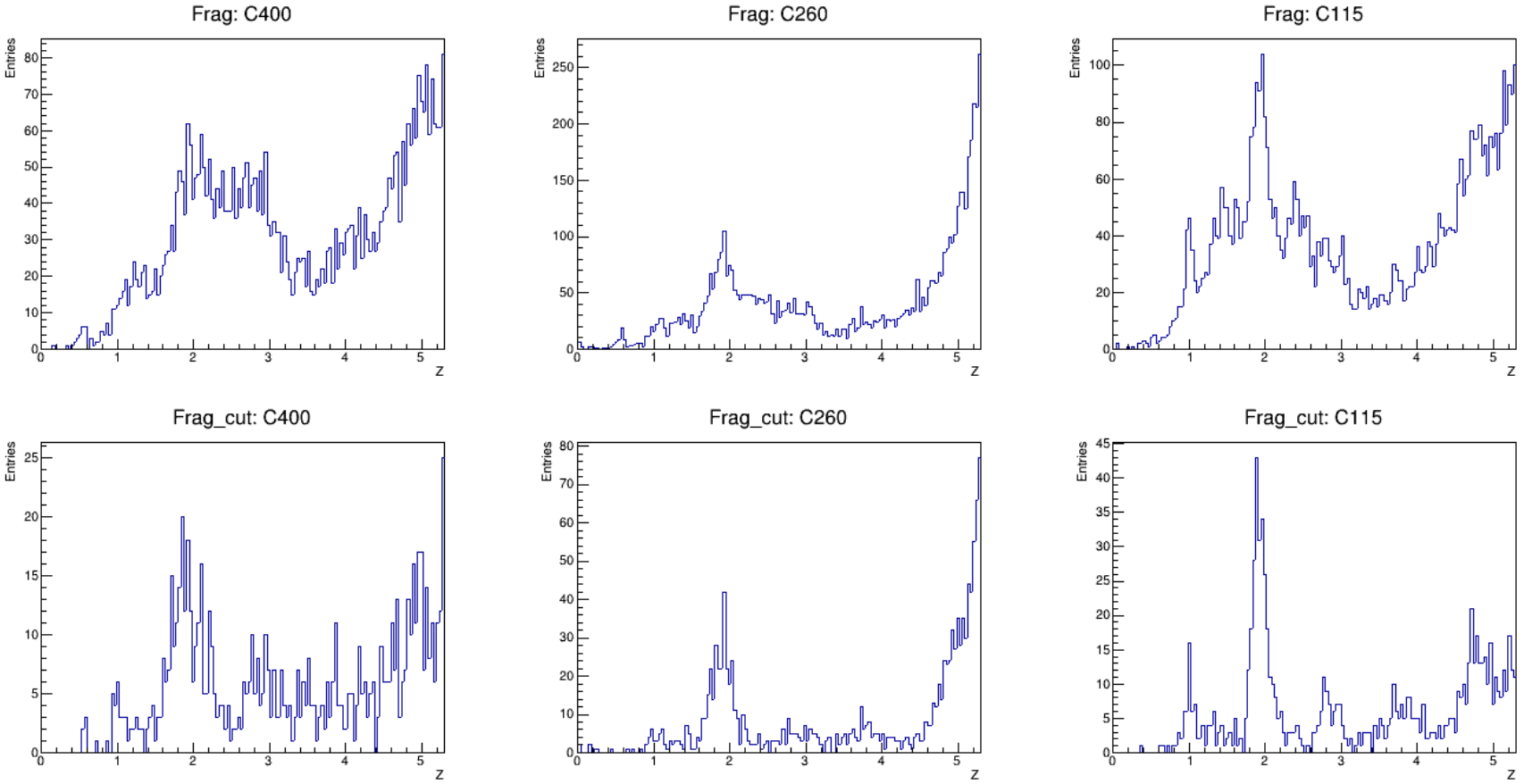
- For carbon, $\mu_z$ slightly changes with beam energy → currently under investigation

| Beam | $\mu_z \pm \sigma_z$ | $\sigma_z/\mu_z$ [%] |
|---|---|---|
| C400 | 6.06 ± 0.24 | 3.9 ± 0.2 |
| C260 | 5.95 ± 0.21 | 3.5 ± 0.2 |
| C115 | 5.93 ± 0.15 | 2.6 ± 0.1 |
| P60 | 0.99 ± 0.06 | 6.2 ± 0.3 |

# Z reconstruction: fragments

It was also possible to identify some fragments (probably coming from interactions in air or in the STC)
The energy cut suggested by the Bologna team was also applied to eliminate some of the possible ghosts

$$\frac{\left|dE_{Front} - dE_{Rear}\right|}{dE_{mean}} \leq 10\%$$



# Future work

- Application of the trigger cell correction to ToF data
- Better understanding of the values of Z obtained for different carbon beams
- Further study of the possible energy and ToF cuts used to eliminate ghosts (choice criterion?)

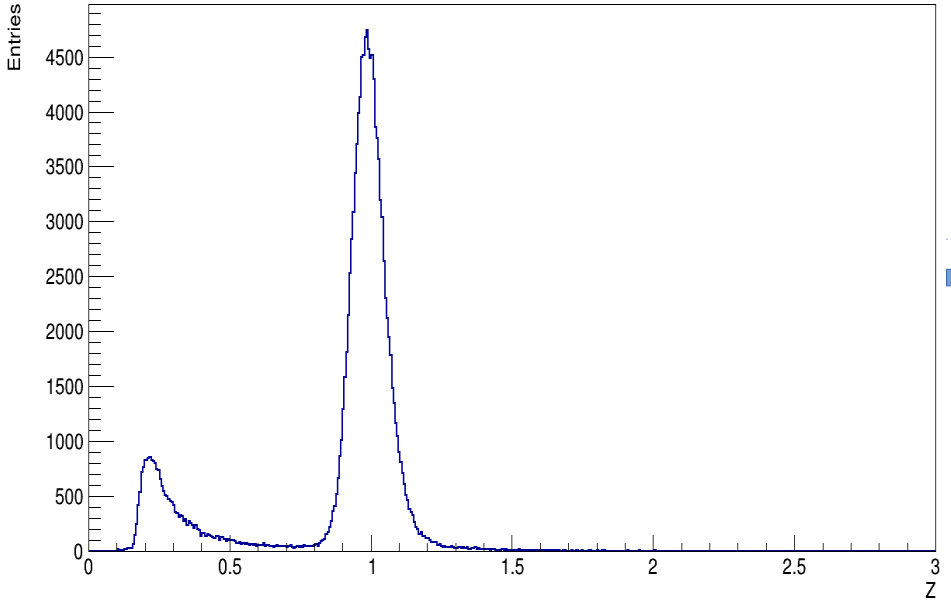
- **Analysis of GSI WaveDREAM data with new stand-alone software**

# BACKUP SLIDES

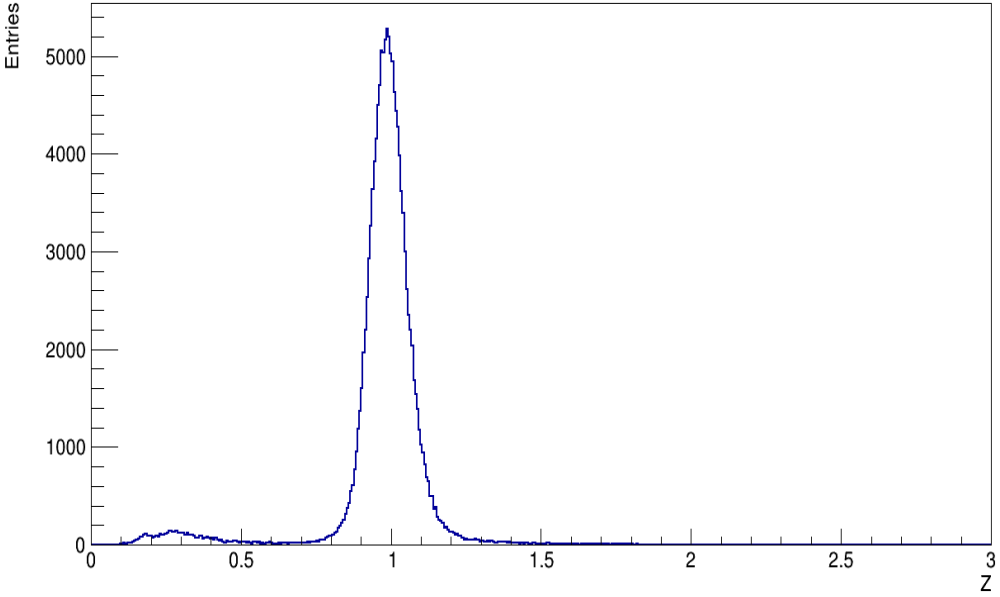
# Proton STC time stamp correction

STC proton signals were often dominated by noise so the CFD method had to be applied backwards, i.e. finding the min of the waveform and returning back to the threshold

“Forward” CFD



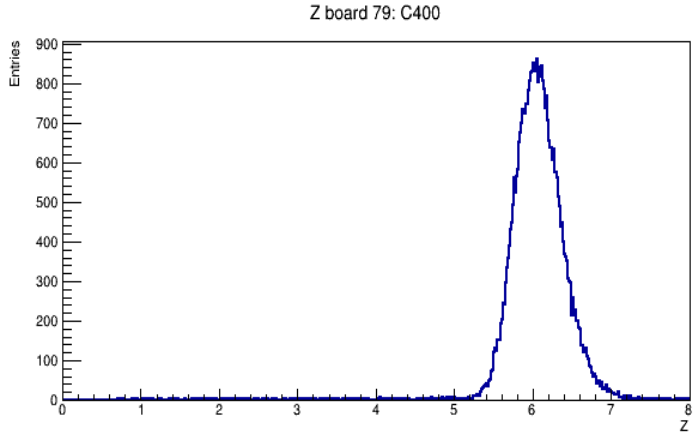

“Backward” CFD

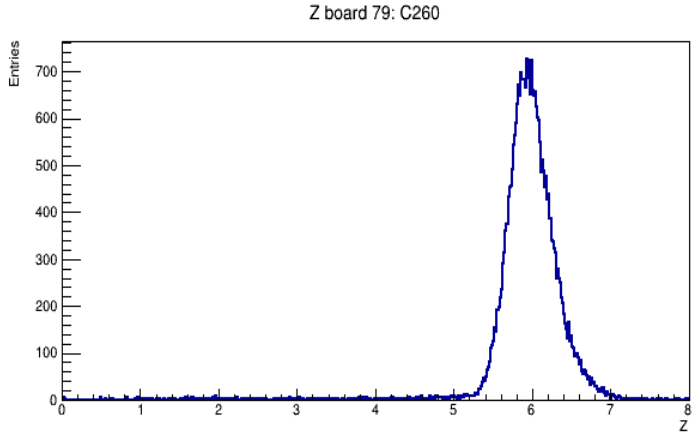


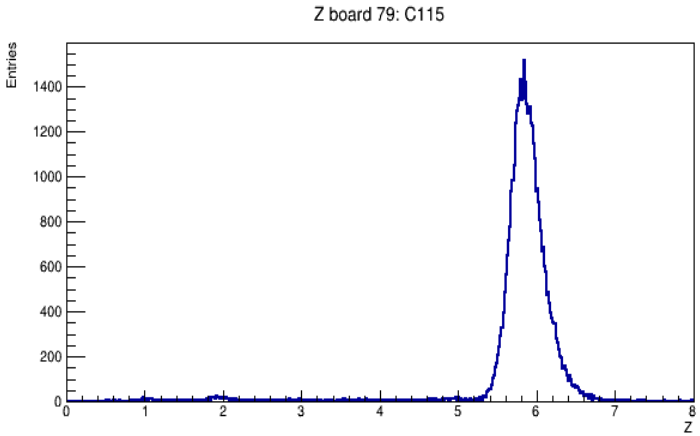

Recovered a good number of clean events

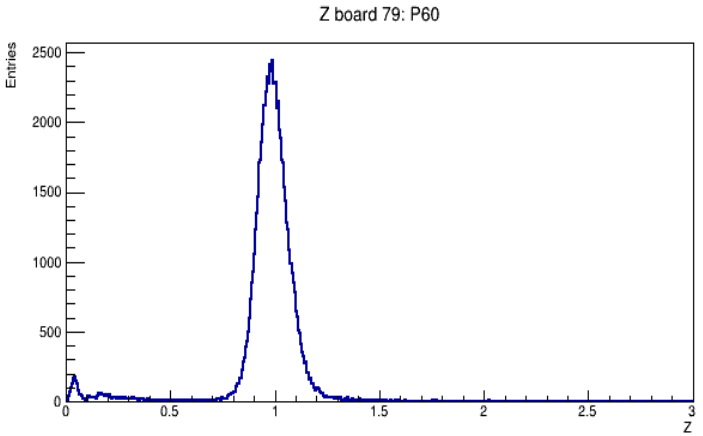
# Z reconstruction: Board 79

An attempt to reconstruct Z for board 79 data was also made, using only the deposited energy on the front layer




| Beam | $\mu_Z \pm \sigma_Z$ |
|---|---|
| C400 | 6.1 ± 0.3 |
| C260 | 6.0 ± 0.3 |
| C115 | 5.9 ± 0.2 |
| P60 | 0.99 ± 0.07 |