Mu2E time calibration status, 2024-08-11

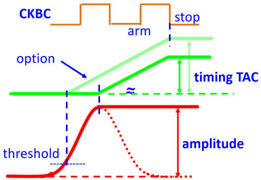
SPD Tracker group

August 20, 2024

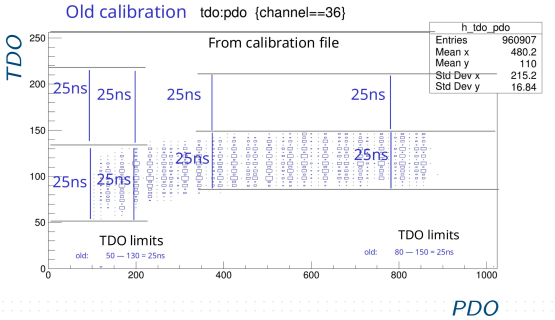
Current calibration: TDO

Time calculation: $t = BCID \cdot 25ns - \left(\frac{TDO - TDO_{min}}{TDO_{max} - TDO_{min}}\right) \cdot 25ns$, where:

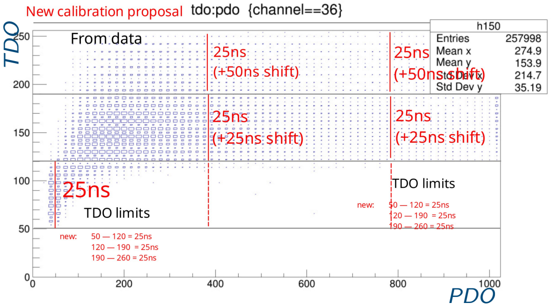
- BCID – 12-bit 25ns counter, common for all channels, does not require calibration
- TDO – 8-bit (?), correspond the time between threshold crossing and the first BCID clock after peak, need calibration
- Current TDO calibration: linear function with TDO_{min} as the moment of BCID change, and TDO_{max} as the 25ns to BCID clock



Current calibration



VB and VM proposal



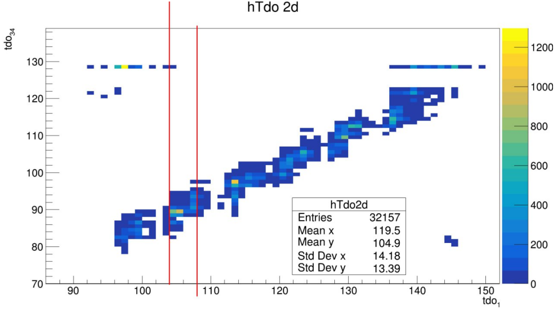
TDO time calibration method

We want to calibrate TDO to ns: $t = BCID \cdot 25ns - f_{cal}(TDO, PDO)$, where: f_{cal} – calibration function
There is a way to construct f_{cal} to have time not to the $BCID$ clock itself, but to the some constant time prior $BCID$ clock

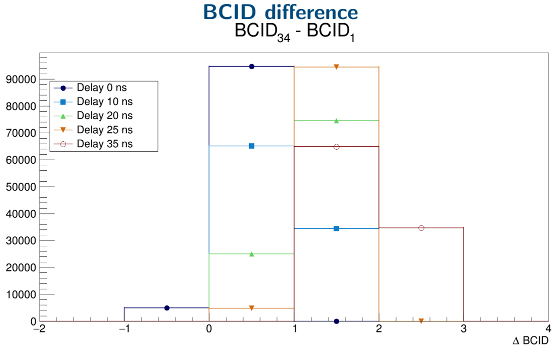
Method:

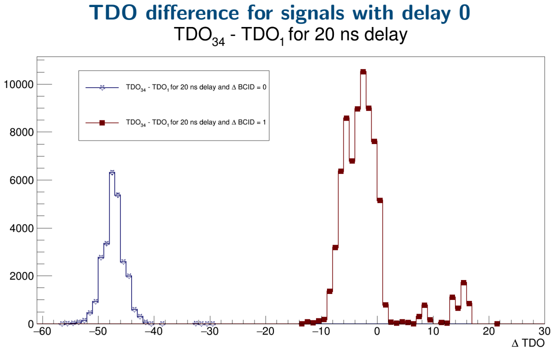
1. Select two channels (for example, channels 1 and 34)
2. Send "straw-like" signals (see slide 28) to both channels:
   - Synchronious signals to both channels with delay in range $[0, 75]$ ns
   - For channel 1: constant shape, constant charge
   - For channel 34: constant shape
3. Select events with constant time to BCID clock by applying cut to channel 1 TDO
   cut: $TDO_{ch1} = 105$
4. Check the channel 34 TDO for those events (see slide 6)
5. Check the calibrations for different $\Delta BCID$ (see slide 8)
6. Construct BCID-independent TDO calibration (see slide 34)

channel 1 TDO cut example



BCID and TDO diffrence

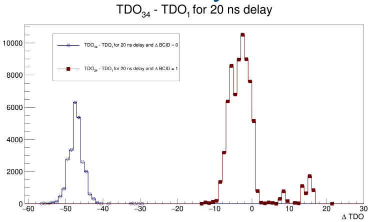




- Blue: $\Delta BCID = 0$
- Brown: $\Delta BCID = 1$

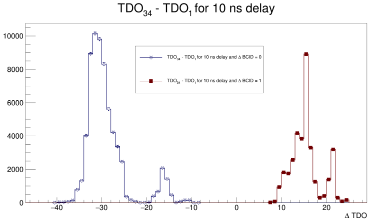
BCID and TDO diffrence

TDO difference for signals with delay 0



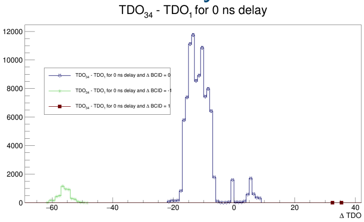
- Blue: $\Delta BCID = 0$
- Brown: $\Delta BCID = 1$

TDO difference for signals with delay 10



- Blue: $\Delta BCID = 0$
- Brown: $\Delta BCID = 1$

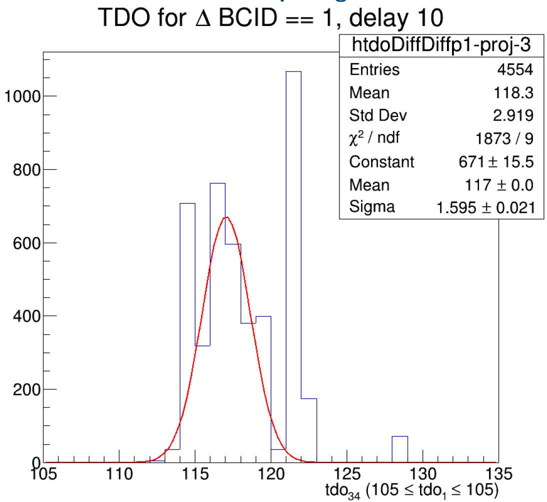
TDO difference for signals with delay 20



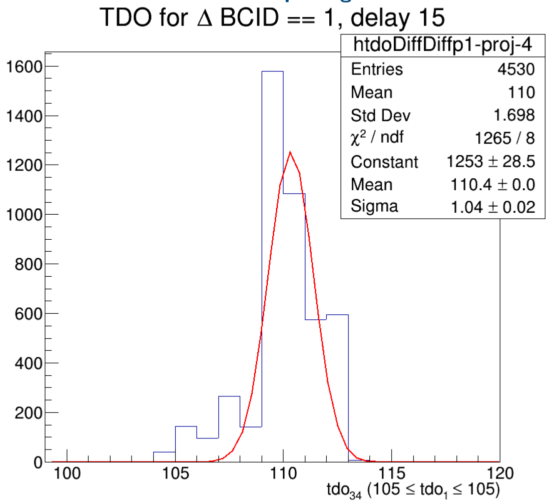
- Blue: $\Delta BCID = 0$
- Brown: $\Delta BCID = 1$
- Green: $\Delta BCID = -1$

TDO fit examples, channel 34 signal charge 210fC

TDO fit example – good ?



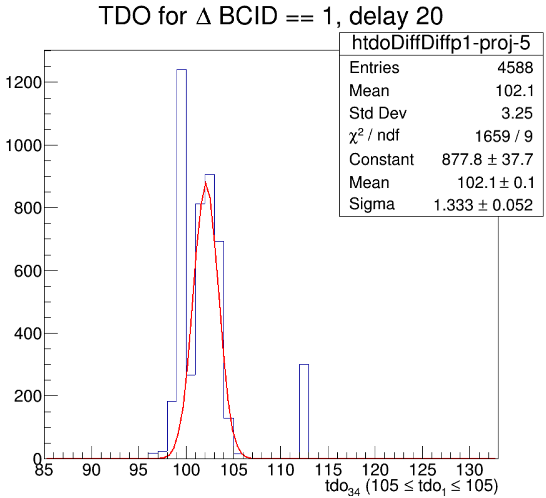
TDO fit example – good ?



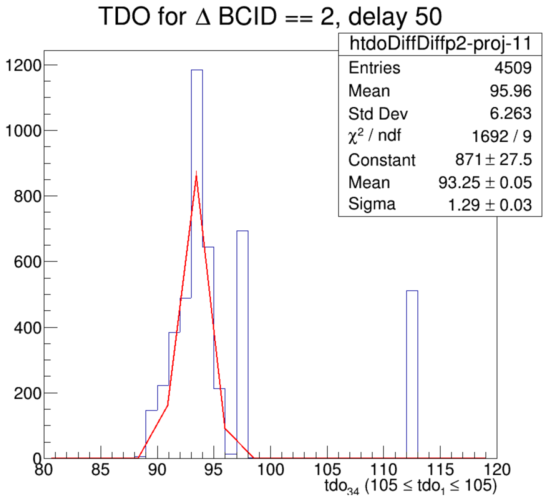
Seems, ADC has less then 8 bit, 5 bit?

TDO fit examples, channel 34 signal charge 210fC

TDO fit example – not-so-good



TDO fit example – not-so-good

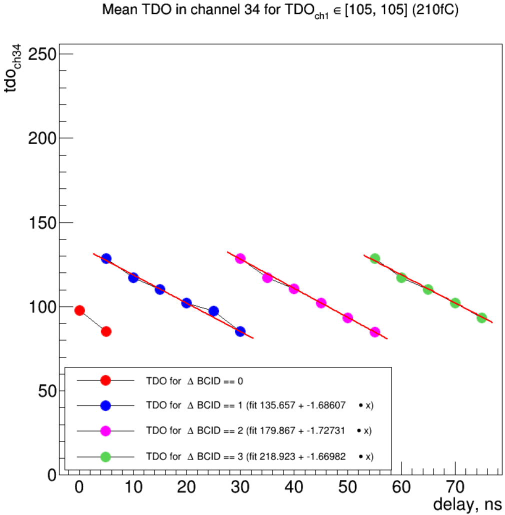


Seems, ADC has less then 8 bit. 5 bit?

Calibration results, channel 34 signal charge 210fC

- We know, that each line (for each $\Delta BCID$) shifted to the 1 $BCID$, which correspond to the TDO window size
- That mean, we can estimate TDO window as the difference between p0 (free parameter) between fit results (see right)
- Also, TDO dependence of the delay shoulde be independent of $\Delta BCID$, since the signal shape stays the same
- So, we need to reconstruct that dependence for the events with the $\Delta BCID = 0$

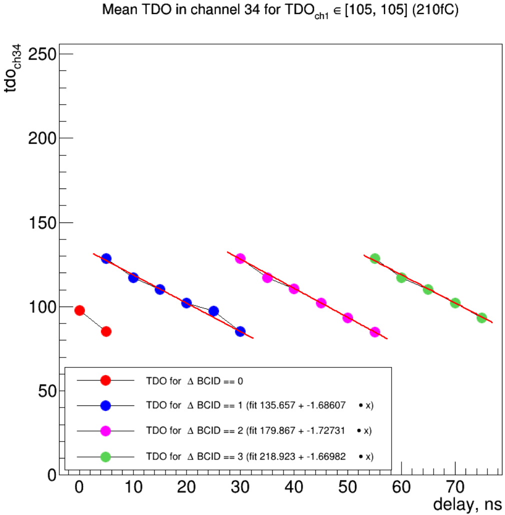
Results for different $\Delta BCID$ fitted with pol1



Calibration results, channel 34 signal charge 210fC

- So, we need to reconstruct that dependence for the events with the $\Delta BCID = 0$
- That can be done by:
  - Or shifting all points left to $25 \cdot \Delta BCID$ ns
  - Or shifting all points down to $TDO_{window} \cdot \Delta BCID$
- The global fit can be estimated as mean $pol1$ between all fitted dependences ?

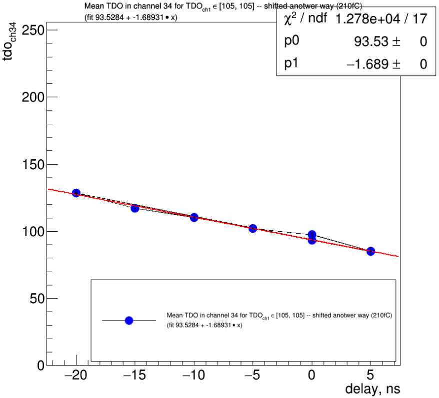
Results for different $\Delta BCID$ fitted with pol1



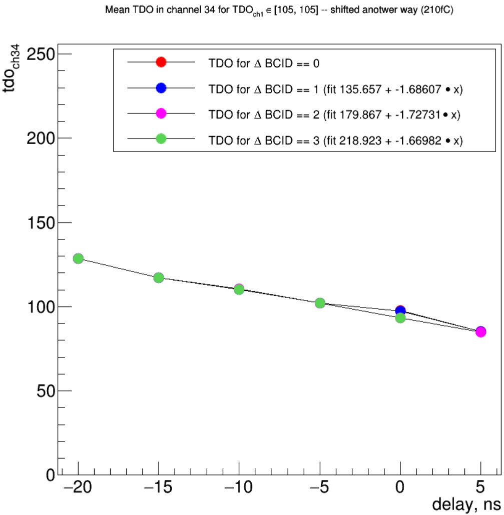
Calibration results, channel 34 signal charge 210fC

- The method "shifting all points left to $25 \cdot \Delta BCID$ ns" was used
- The global fit can be done $pol1$ from all points

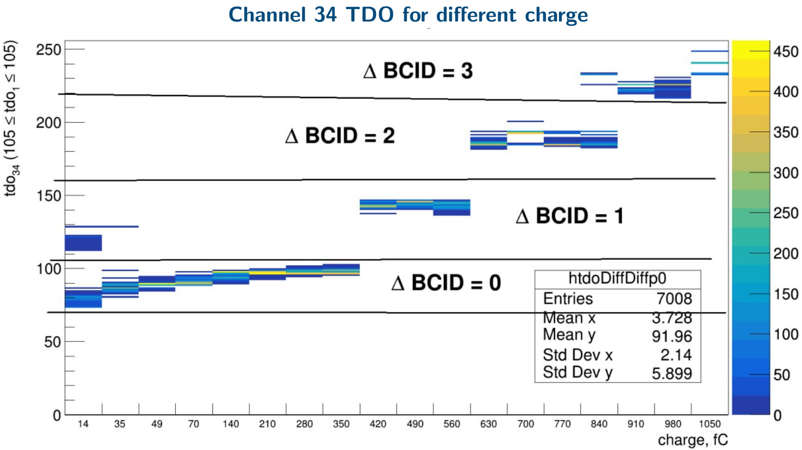
Fit result



Results after shift left (for events with $\Delta BCID = 0$)



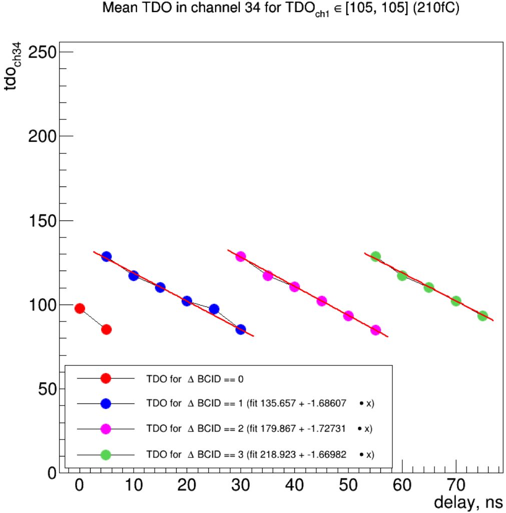
Charge dependence



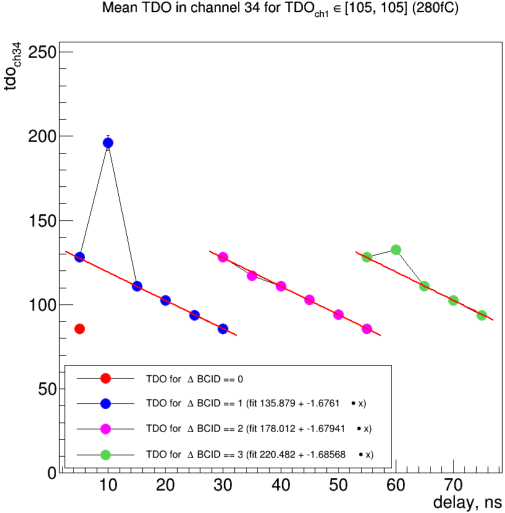
- There is a dependence for the signals with charge lower 200fC (time walk)
- No significant dependence for "high" signals (above 350 fC)

Charge dependence

Results for channel 34 signal with charge 210fC

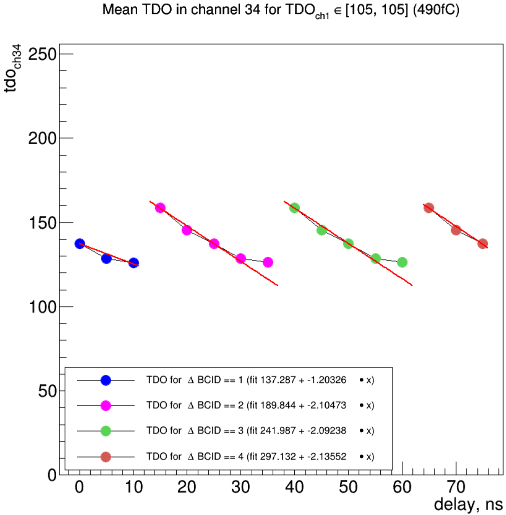


Results for channel 34 signal with charge 280fC

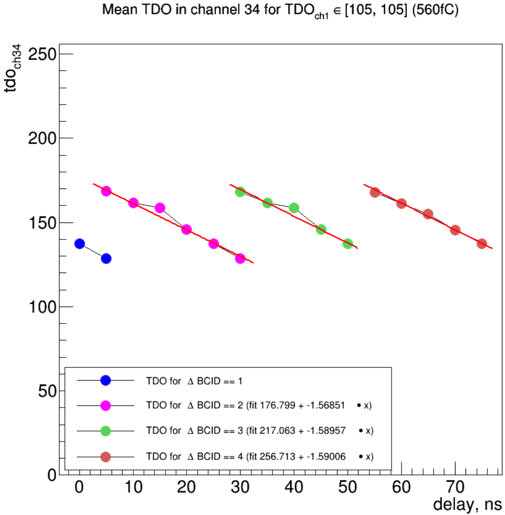


Charge dependence

Results for channel 34 signal with charge 490fC

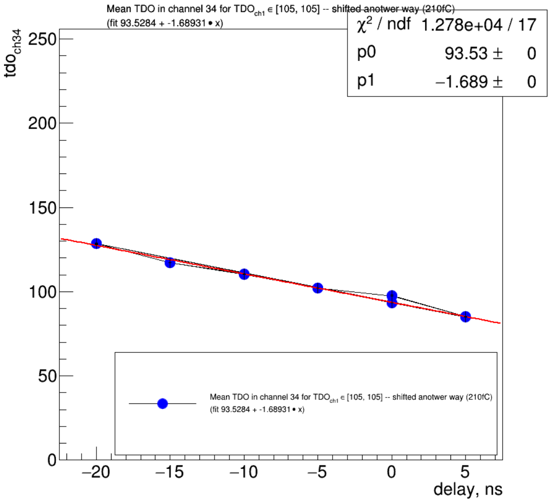


Results for channel 34 signal with charge 560fC

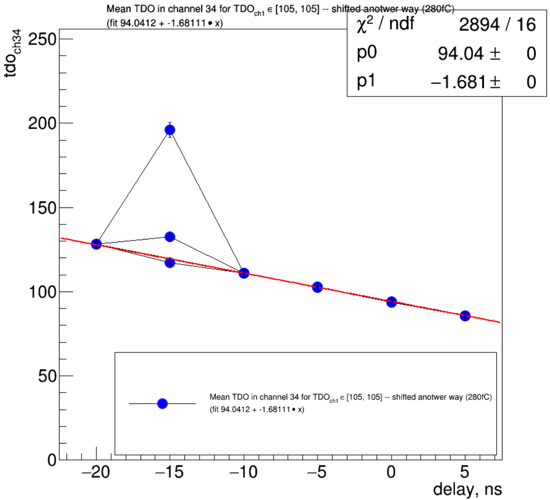


Charge dependence

Results for channel 34 signal with charge 210fC

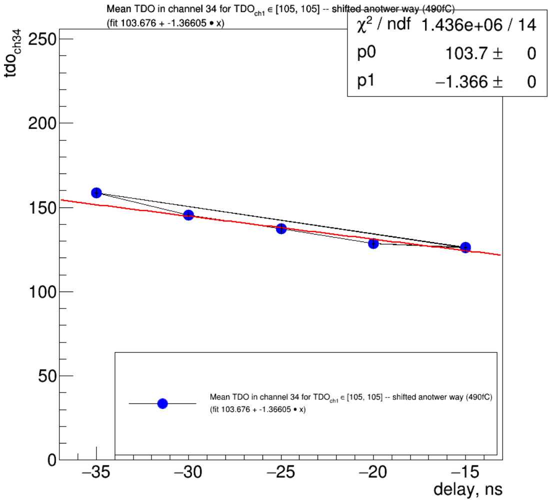


Results for channel 34 signal with charge 280fC

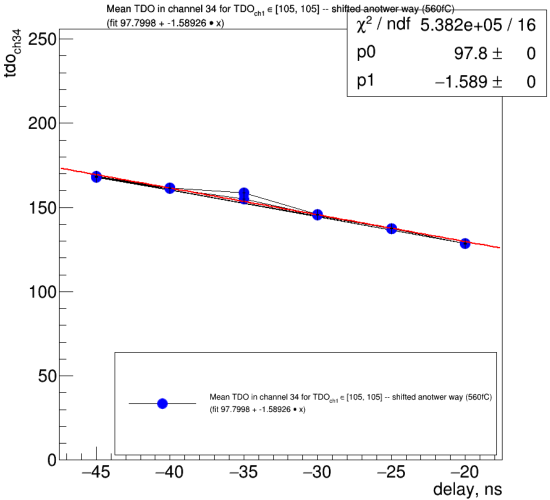


Charge dependence

Results for channel 34 signal with charge 490fC

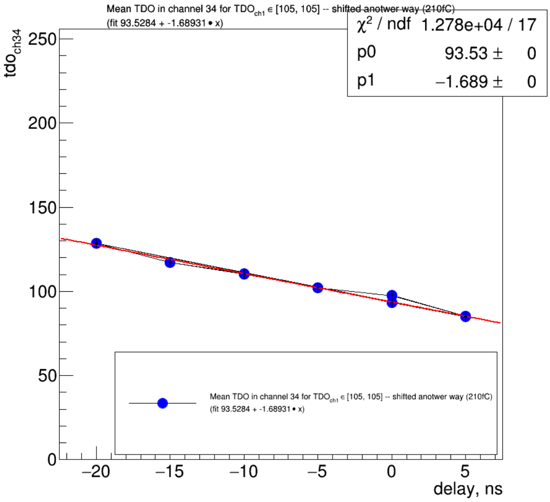


Results for channel 34 signal with charge 560fC

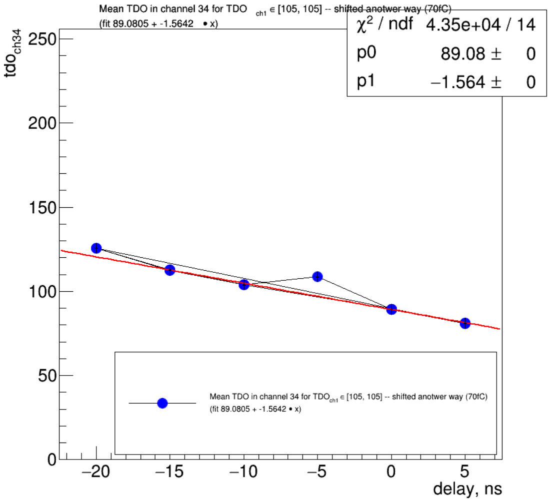


Charge dependence – small charges

Results for channel 34 signal with charge 210fC



Results for channel 34 signal with charge 70fC



Charge dependence – table

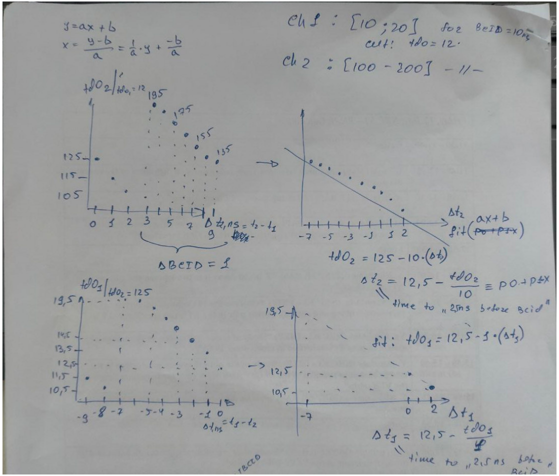
pol1 fit results for different charges

Charge	p0	p1
70 fC	89.08	−1.56
210 fC	93.53	−1.69
280 fC	94.04	−1.68
490 fC	~~103.7~~	~~−1.37~~
560 fC	97.8	−1.59

Update 11.08.2024

Calculations

Yes, we need calibration for both channels:



Let fit with pol1: $t(TDO) = p0 + p1 \cdot TDO$

$p1 = -\frac{T_{BCID}}{TDO^{max} - TDO^{min}}$, where T_{BCID} is the clock period

$$p0_{chX} = TDO^{min}_{ch1} \cdot p1_{ch1} - TDO^{min}_{chX} \cdot p1_{chX} - TDO^{cut}_{ch1} \cdot p1_{ch1}$$

So,

$$\Delta T = (BCID_{ch2} - BCID_{ch1}) \cdot T_{BCID} - \left[TDO^{min}_{ch1} \cdot p1_{ch1} - TDO^{min}_{ch2} \cdot p1_{ch2} + p1_{ch2} \cdot TDO_{ch2} - p1_{ch1} \cdot TDO_{ch1} - TDO^{cut}_{ch1} \cdot p1_{ch1} + TDO^{cut}_{ch1} \cdot p1_{ch1}\right]$$

$$\Delta T = (BCID_{ch2} - BCID_{ch1}) \cdot T_{BCID} - \left(p1_{ch2} \cdot (TDO_{ch2} - TDO^{min}_{ch2}) - p1_{ch1} \cdot (TDO_{ch1} - TDO^{min}_{ch1})\right)$$

But since $p0_{ch1} = TDO^{cut}_{ch1} \cdot p1_{ch1}$, and $p1_{ch1}$ should be constant, we can set $p0^{NEW}_{chX} = p0_{chX} - p0_{ch1}$ and $p0_{ch1} = 0$
And then, we can select TDO^{cut}_{ch1} for each channel separately.

Calculations

Let fit with pol1: $t(TDO) = p0 + p1 \cdot TDO$

$$p1 = -\frac{T_{BCID}}{TDO^{max} - TDO^{min}}$$

, where T_{BCID} is the clock period

$$p0_{chX} = TDO^{min}_{ch1} \cdot p1_{ch1} - TDO^{min}_{chX} \cdot p1_{chX} - TDO^{cut}_{ch1} \cdot p1_{ch1}$$

So, $\Delta T = (BCID_{ch2} - BCID_{ch1}) \cdot T_{BCID} - \Big(TDO^{min}_{ch1} \cdot p1_{ch1} - TDO^{min}_{ch2} \cdot p1_{ch2} \quad - TDO^{cut}_{ch1} \cdot p1_{ch1} + TDO^{cut}_{ch1} \cdot p1_{ch1}$

$+ p1_{ch2} \cdot TDO_{ch2} - p1_{ch1} \cdot TDO_{ch1})$

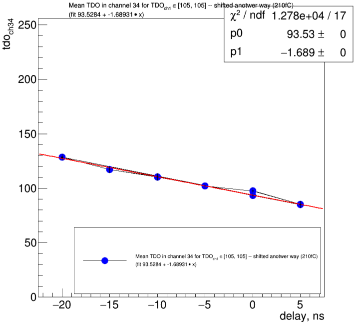
$$\Delta T = (BCID_{ch2} - BCID_{ch1}) \cdot T_{BCID} - (p1_{ch2} \cdot (TDO_{ch2} - TDO^{min}_{ch2}) - p1_{ch1} \cdot (TDO_{ch1} - TDO^{min}_{ch1}))$$

But since $p0_{ch1} = TDO^{cut}_{ch1} \cdot p1_{ch1}$, and $p1_{ch1}$ should be constant, we can set $p0^{NEW}_{chX} = p0_{chX} - p0_{ch1}$ and $p0_{ch1} = 0$
And then, we can select TDO^{cut}_{ch1} for each channel separately.

I do not see dependency of $TDO_{ch2} - TDO_{ch1}$

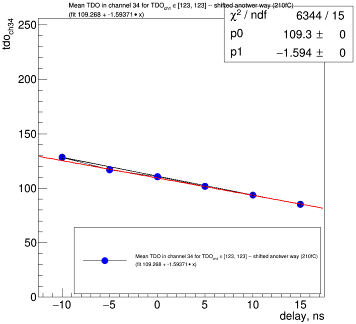
Calibration for different ch1 TDO cut

channel 1 TDO cut: 105



$TDO = 93.5 - 1.69 \cdot \Delta t$

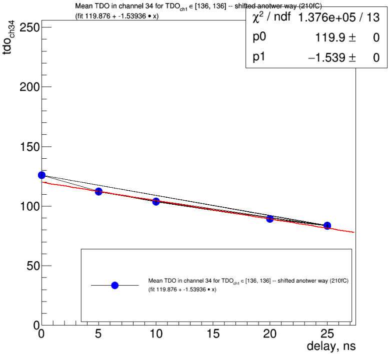
channel 1 TDO cut: 123



$TDO = 109.3 - 1.59 \cdot \Delta t$

Slope differs...

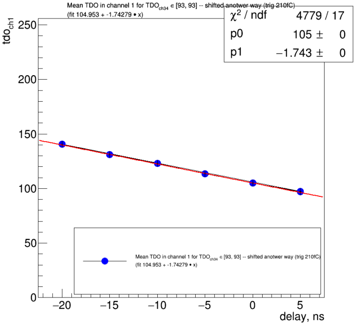
channel 1 TDO cut: 136



$TDO = 119.9 - 1.54 \cdot \Delta t$

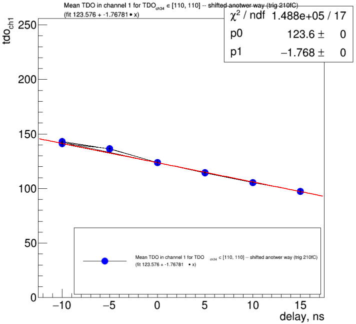
Channel 1 calibration

channel 34 TDO cut: 93
(TDO_{ch1} should be 105)



$$TDO = 105.0 - 1.74 \cdot \Delta t$$

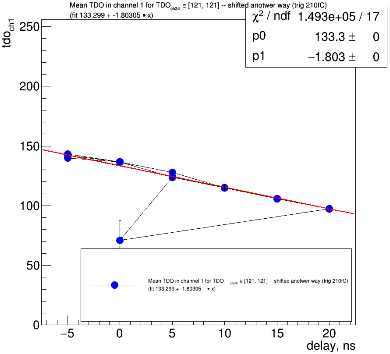
channel 34 TDO cut: 110
(TDO_{ch1} should be 123)



$$TDO = 123.6 - 1.77 \cdot \Delta t$$

Slope differs...

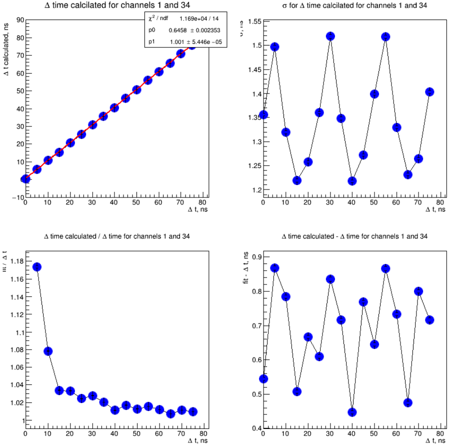
channel 34 TDO cut: 121
(TDO_{ch1} should be 136)



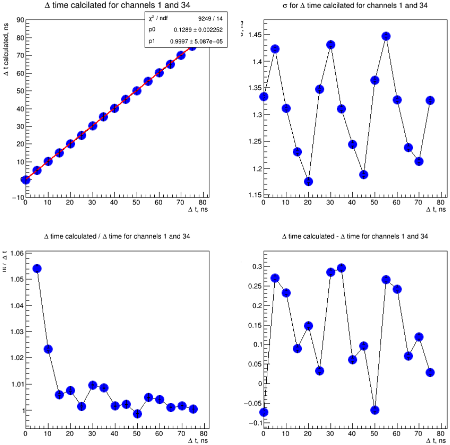
$$TDO = 133.3 - 1.80 \cdot \Delta t$$

Time difference for both channels

Calibration for 210fC signals and channel 1 cut 105 applied to 210fC signals



Calibration for 210fC signals and channel 1 cut 105 applied to 280fC signals

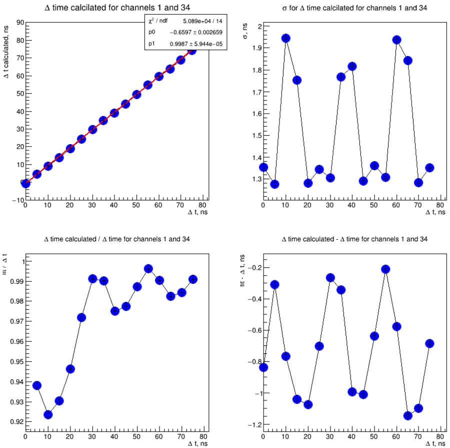


$\sigma \sim 1.5ns$

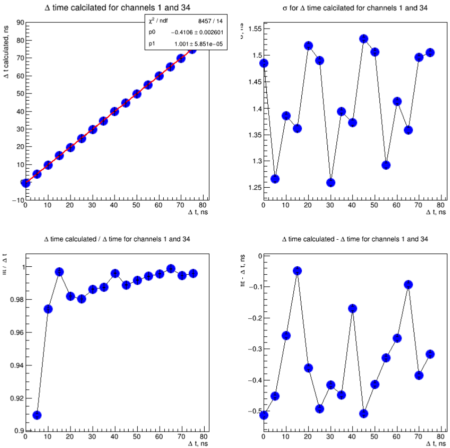
$\Delta t_{calculated} - \Delta t_{real}$ up to $0.9ns$!

Time difference for both channels

Calibration for 210fC signals and channel 1 cut 105 applied to 490fC signals



Calibration for 210fC signals and channel 1 cut 105 applied to 560fC signals

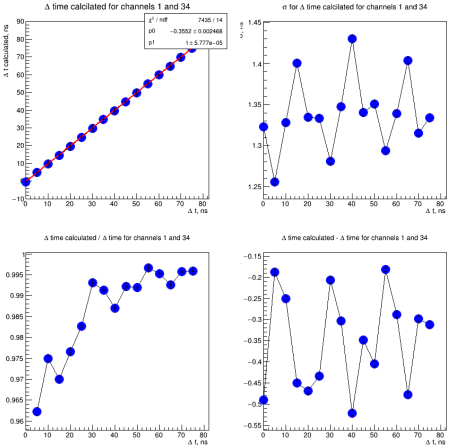


$\sigma \sim 1.5ns$

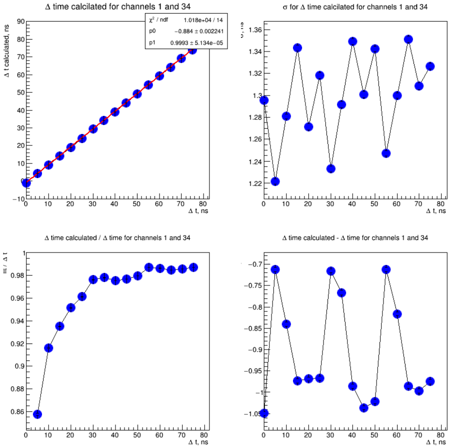
$\Delta t_{calculated} - \Delta t_{real}$ up to $1.1ns$!

Time difference for both channels

Calibration for 210fC signals and channel 1 cut 123 applied to 210fC signals



Calibration for 210fC signals and channel 1 cut 123 applied to 280fC signals

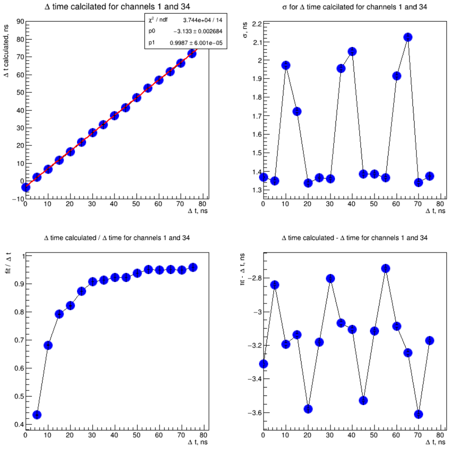


$\sigma \sim 1.3ns$

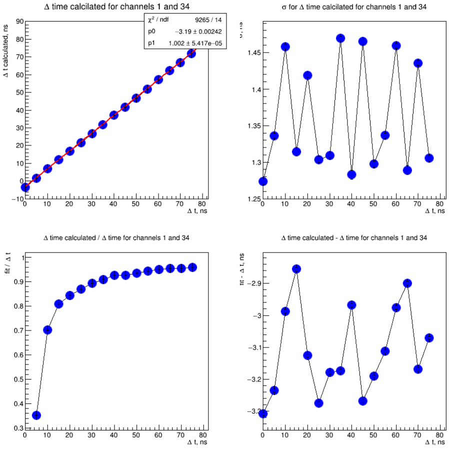
$\Delta t_{calculated} - \Delta t_{real}$ up to $1.0ns$

Time difference for both channels

Calibration for 210fC signals and channel 1 cut 123 applied to 490fC signals



Calibration for 210fC signals and channel 1 cut 123 applied to 560fC signals



$\sigma \sim 1.5ns$

Variation of $\Delta t_{calculated} - \Delta t_{real}$ is about $0.5ns$, but the value shifted to $\sim 3ns$

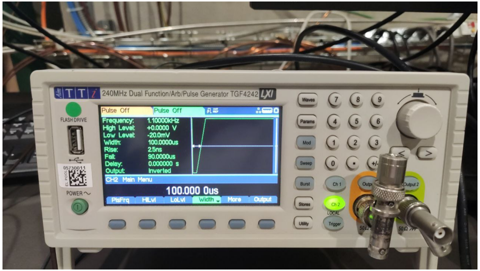
Time difference for both channels

I do not understand, why the fit with different cuts so differs...
May be, time-of-charge dependence ("time walk") even between 200fC and 500fC signals.
Is it possible to check / measure with the generated signals?

Backup slides

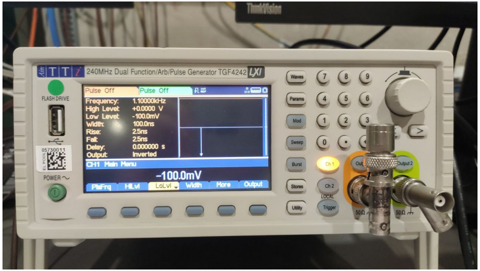
Test signal examples

Straw-like



- High level: 0
- Low level: variable
- Width: 100 μs
- Rise edge: 2.5 *ns*
- Fall edge: 900 μs
- Output: inverted

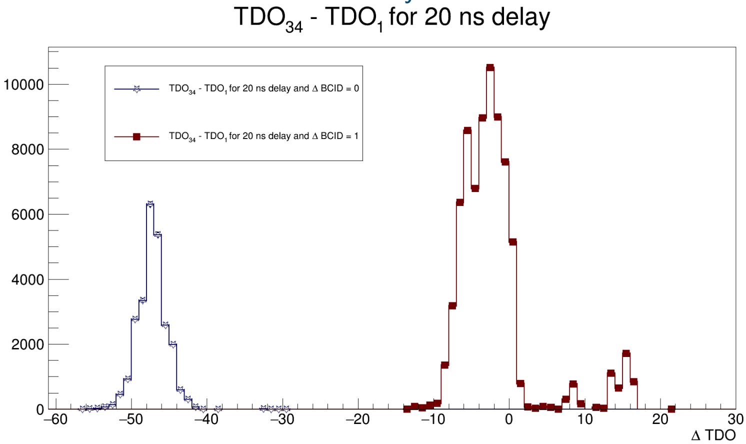
NIM-like



- High level: 0
- Low level: variable (-100 mV / -700 mV)
- Width: 100 *ns*
- Rise edge: 2.5 *ns*
- Fall edge: 2.5 *ns*
- Output: inverted

BCID and TDO diffrence

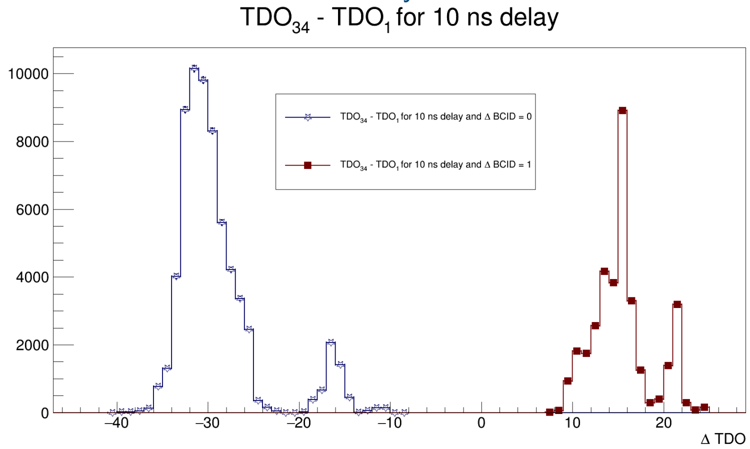
TDO difference for signals with delay 0



- Blue: $\Delta BCID = 0$
- Brown: $\Delta BCID = 1$

BCID and TDO diffrence

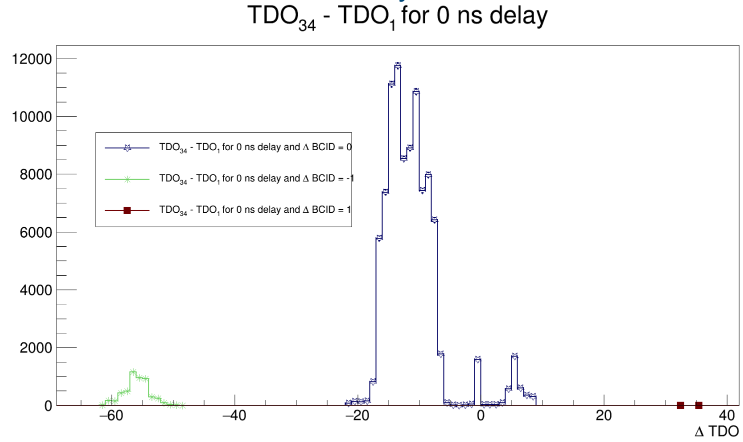
TDO difference for signals with delay 10



- Blue: $\Delta BCID = 0$
- Brown: $\Delta BCID = 1$

BCID and TDO diffrence

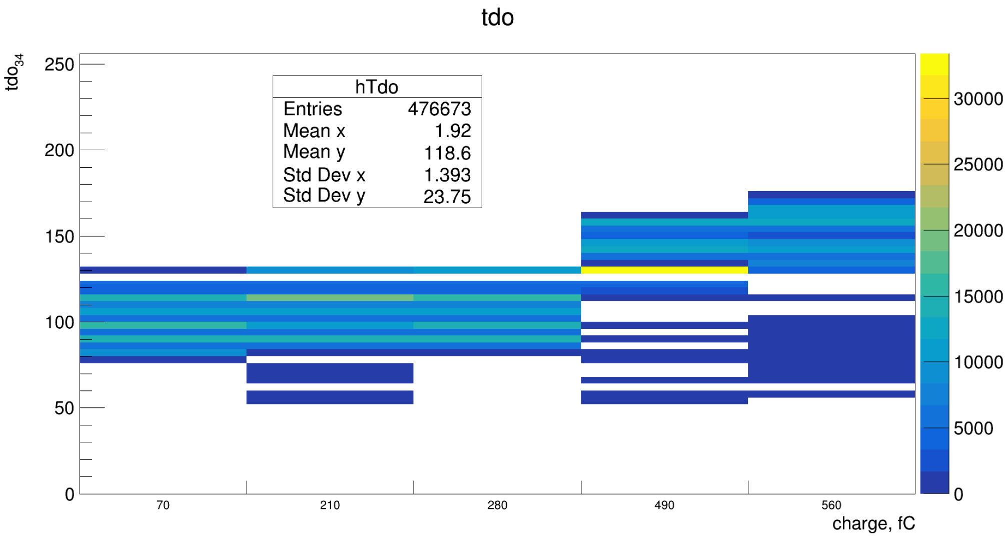
TDO difference for signals with delay 20



- Blue: $\Delta BCID = 0$
- Brown: $\Delta BCID = 1$
- Green: $\Delta BCID = -1$

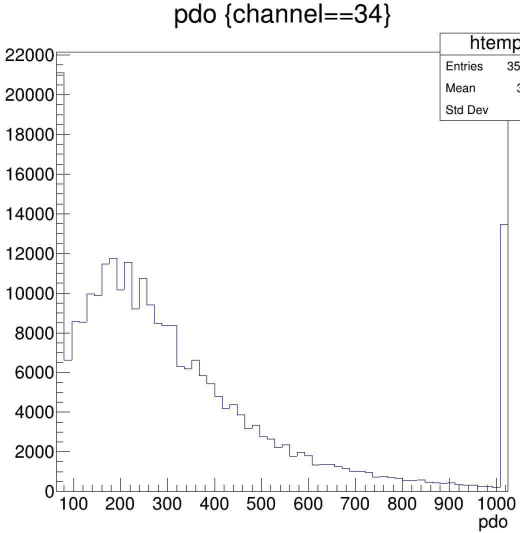
TDO per charge

Channel 34 TDO for different signal charges

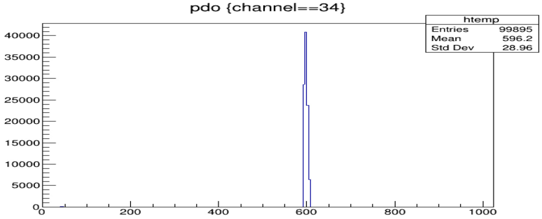


PDO for 3mV/fC, 25ns

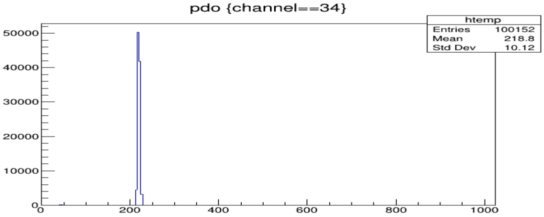
μ PDO for 3mV/fC, 25ns



PDO for straw-like signal, 210fC, 3mV/fC, 25ns



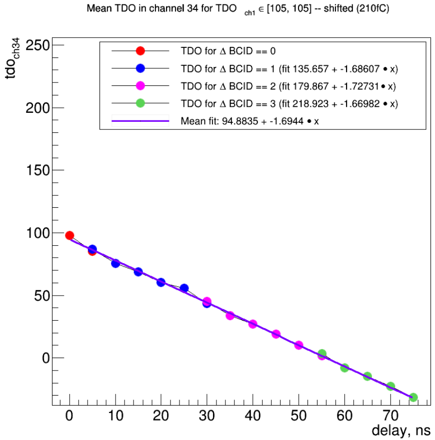
PDO for straw-like signal, 70fC, 3mV/fC, 25ns



Calibration results, channel 34 signal charge 210fC

NOT ACTUAL. See page 9

Results after shift down (for events with $\Delta BCID = 0$)



- The method "shifting all points down to $TDO_{window} \cdot \Delta BCID$" was used
- The global fit can estimated as mean $pol1$ between all fitted dependences