From Time Expansion (Texp) to Time of Flight (ToF) with MURAVES Data

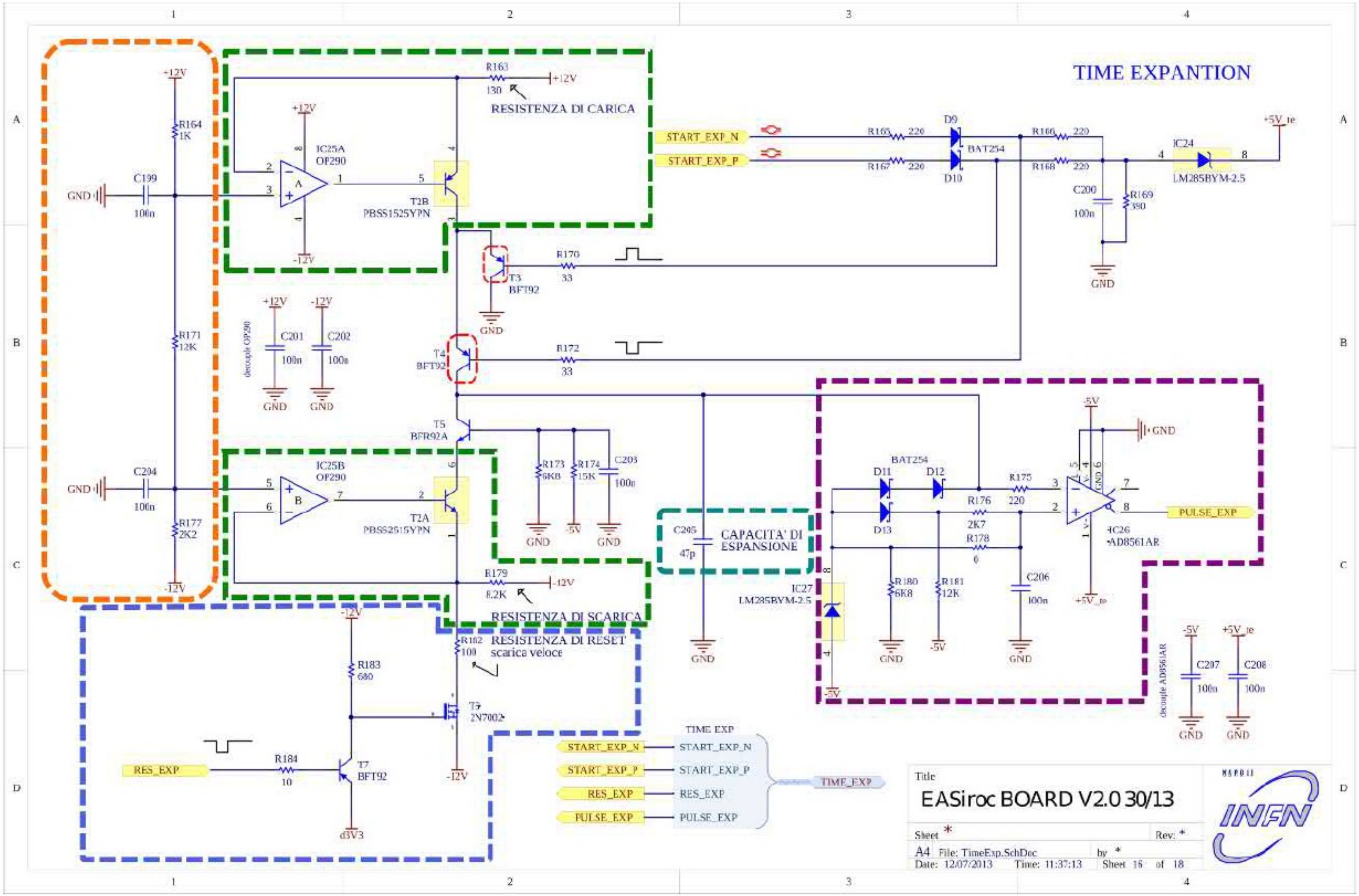
Sept. 23, 2021

Samip Basnet
Lectures in Muography (w/ Dr. L. Cimmino)

European Commission | Horizon 2020 European Union funding for Research & Innovation
fnrs LA LIBERTÉ DE CHERCHER FRIA
UCLouvain

OUTLINE

- Time Expansion (Texp) : A Short Recap
- Texp characterization of MURAVES boards
  - ✔ An example board in BLU telescope
  - ✔ Texp results
- Time of Flight (ToF) with MURAVES data
  - ✔ Motivation
  - ✔ Expected ToF vs measured ToFs
  - ✔ Raw TDC diff. X and Y views
  - ✔ Use of Texp characterization results for ToF calculation (incl. Fiber Delay)
- Issues with measured ToFs
- Use of ‘free-sky’ data to deal with ToF issues



TIME EXPANTION
RESISTENZA DI CARICA
RESISTENZA DI SCARICA
RESISTENZA DI RESET
scarica veloce
CAPACITA' DI ESPANSIONE
START_EXP_N
START_EXP_P
RES_EXP
PULSE_EXP
TIME_EXP
Title
EASiroc BOARD V2.0 30/13
File: TimeExp.SchDoc
Date: 12/07/2013
Time: 11:37:13
Sheet 16 of 18
INFN

Texp Charaterization of the MURAVES boards

- Each plane consisits of two electronics boards (i.e., ‘slave’ boards) for two modules, handling 32 channels each
- With each layer consisting two planes, we have 16 boards in total for calibration
- Due to incorrect capacitance being used, the boards had to be refurbished and their Texp characterization had to be performed again

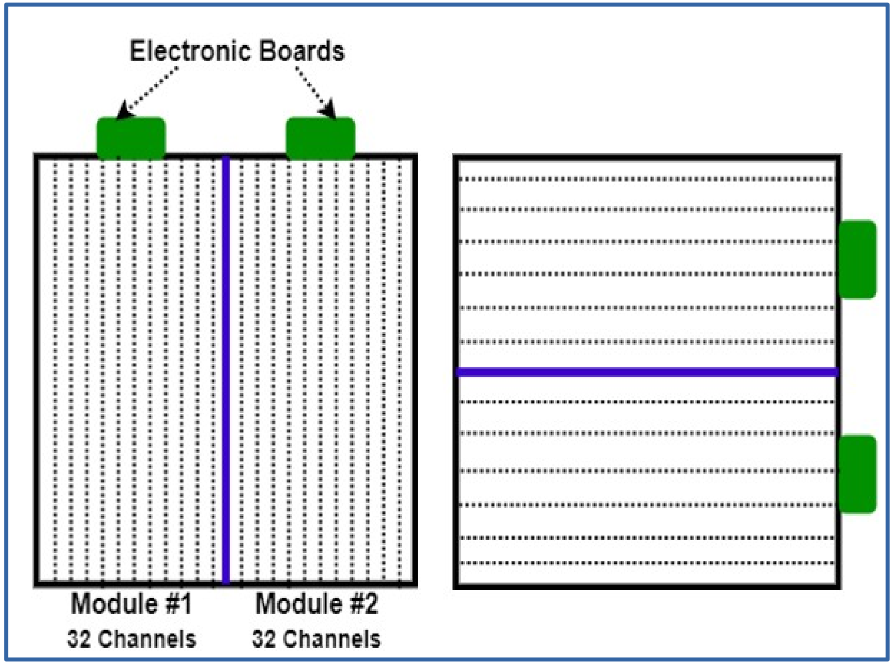


Figure : Schematics of one of the planes in MURAVES detector

Texp Charaterization of the MURAVES boards

- Each plane consisits of two electronics boards (i.e., ‘slave’ boards) for two modules, handling 32 channels each
- With each layer consisting two planes, we have 16 boards in total for calibration
- Due to incorrect capacitance being used, the boards had to be refurbished and their Texp characterization had to be performed again

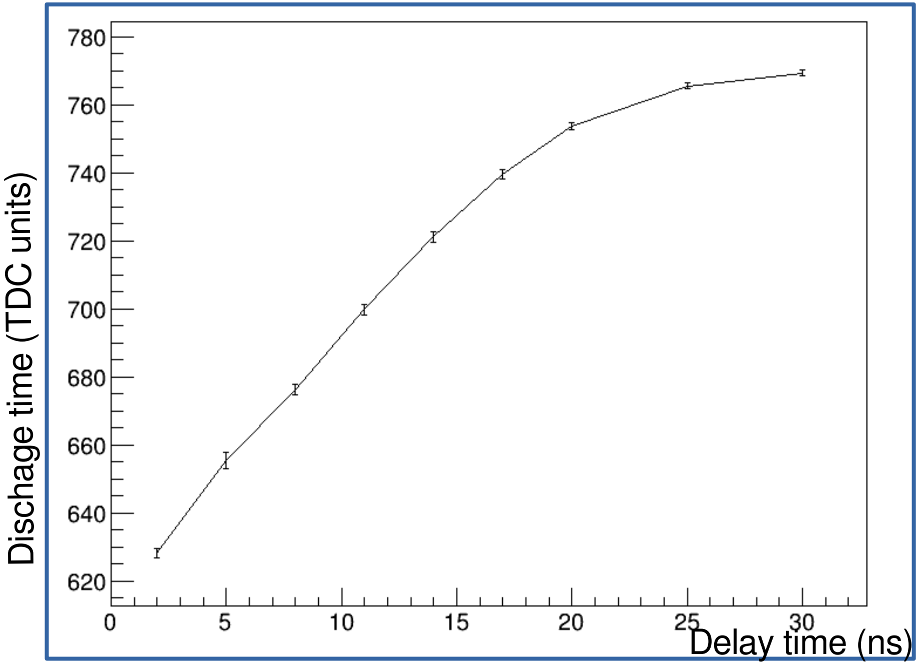


Figure : Non-linear behaviour shown by the board

Texp Charaterization of the MURAVES boards

- A reference board with known time expansion characteristics and a master board to provide a global stop trigger were used for this calibration
- Delays (which is correlated with the t_{charge}) were introduced from 2 to 20 ns and the subsequent t_{charge} (in terms of TDC counts) were read-out for each board
- $t_{dicharge} = \mathbf{E}.\ t_{charge} + \mathbf{C}$ (1)

  Here, ***E*** is the expansion factor (E-factor) and ***C*** is the intercept

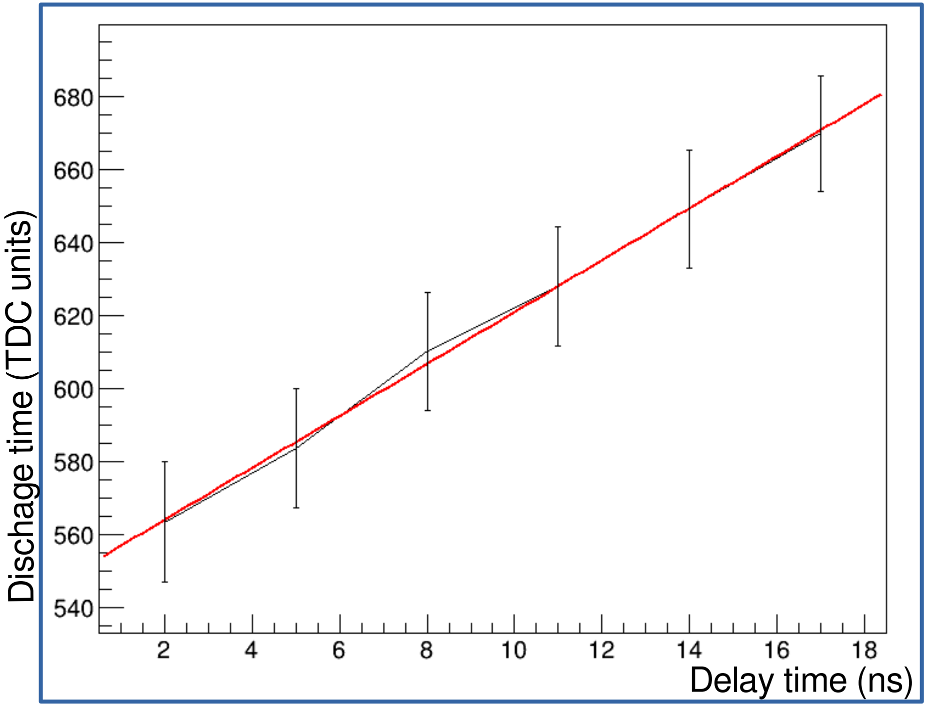
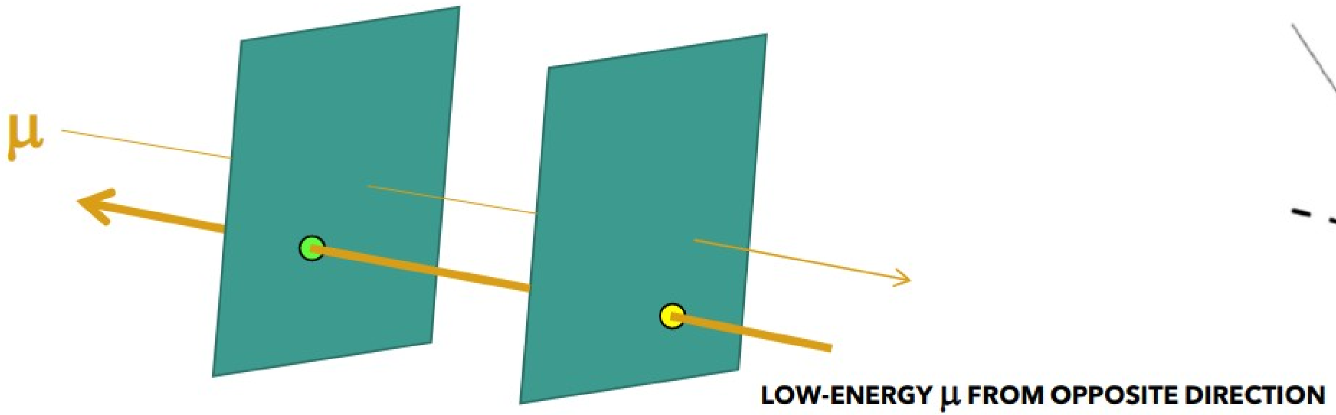


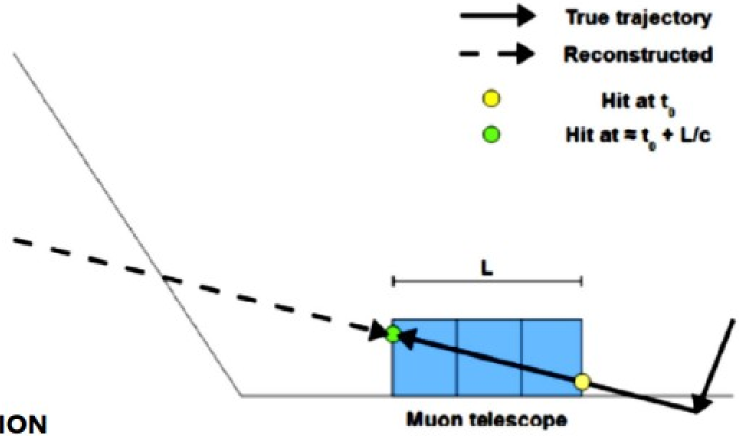
Figure : Correct Texp characterization of an electronic boards exhibiting linear behaviour

Texp Charaterization of the BLU boards results

Boards #	E-factor	Intercept
0	7.21	558.1
1	6.87	532.5
2	6.73	494.7
3	7.11	549.9
4	7.26	620.2
5	6.99	565.3
6	7.35	651.3
7	7.33	594.3
8	7.99	620.5
9	7.30	578.8
10	6.95	564.1
11	7.37	655.0
12	7.18	571.6
13	7.30	584.5
14	7.05	566.5
15	7.45	659.1

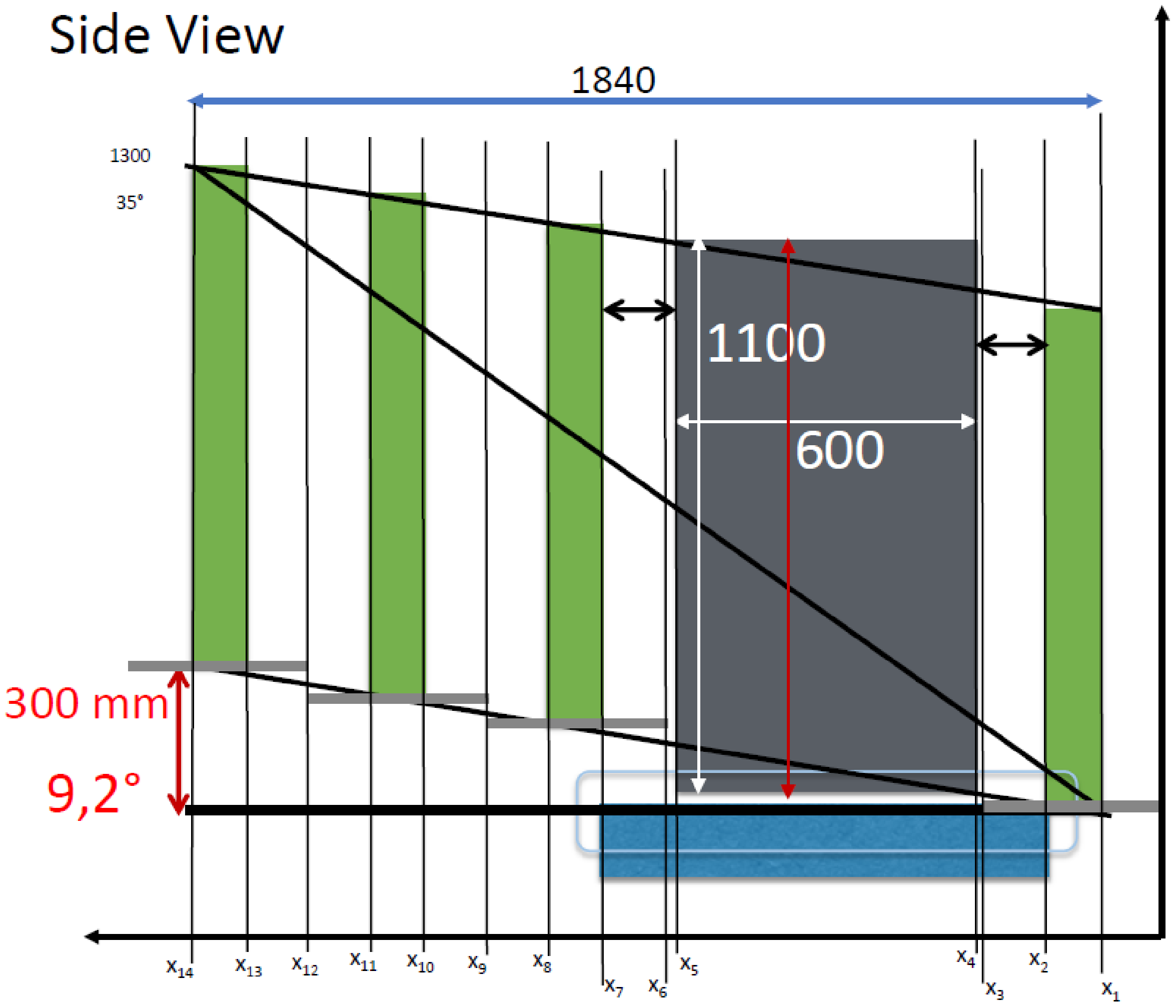
Time of Flight (ToF) in absorption-based muography





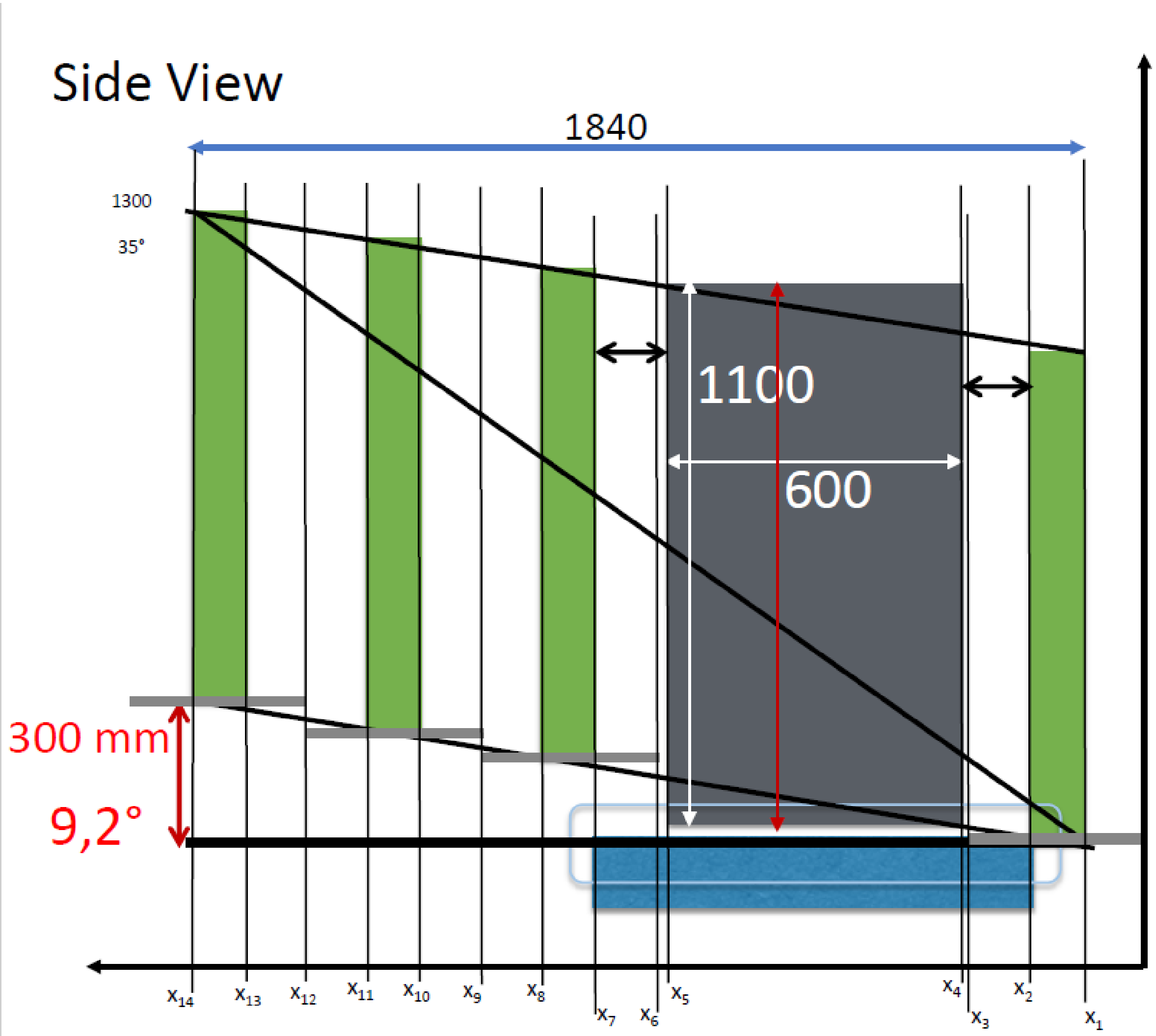
- In high energy physics, ToF is typically used as a means to separate particles by mass
- For MURAVES, the detector is oriented quasi-horizontally so soft muons scattering off the ground behind the detector can enter from its rear
- These backward muons may even overwhelm the muons that carry information about the target and thus have to be rejected
- ToF of the detected muons between front and rear layer of the telescope can be used to reject these backward muon background

MURAVES Geometry



x_1	125	0
x_2	235	+110
x_3	360	+125
x_4	385	+25
x_5	985	+600
x_6	1010	+25
x_7	1135	+125
x_8	1245	+110
x_9	1370	+125
x_{10}	1495	+125
x_{11}	1605	+110
x_{12}	1730	+125
x_{13}	1855	+125
x_{14}	1965	+110

Expected Time of Flight (ToF_exp)

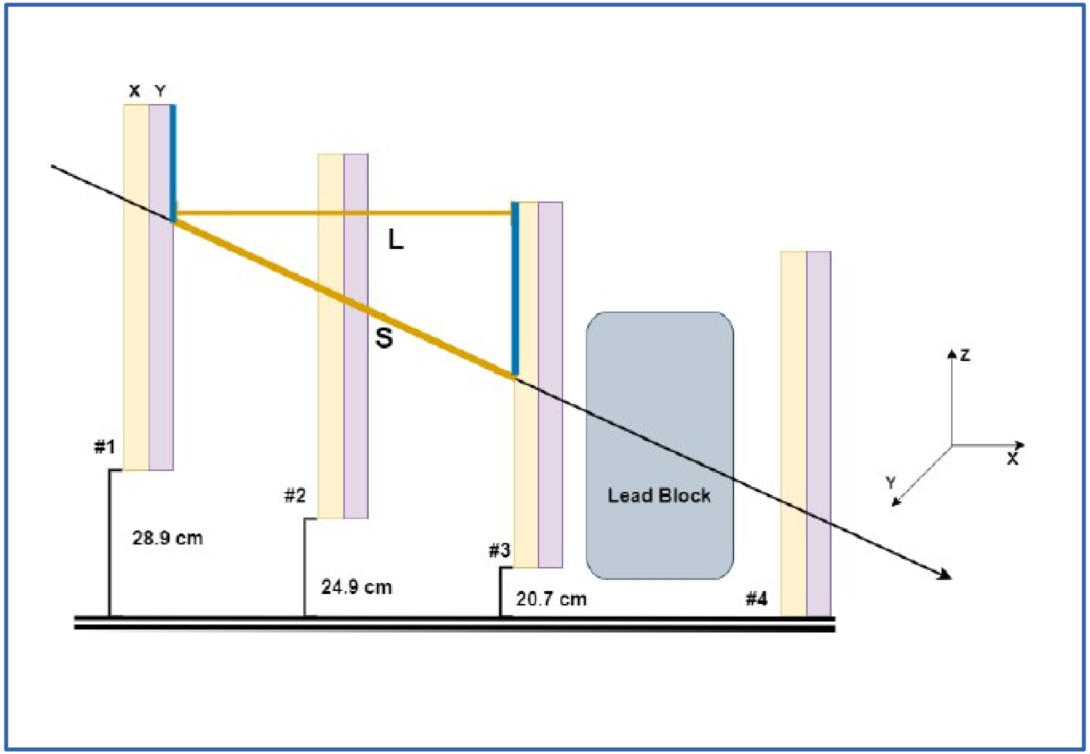


- Distance travelled by incoming muon between two chosen stations can be calculated based in the goemetry of the detector and the θ and φ information of the reconstructed track

- With speed of light (*c*), one can easily compute expected ToF using

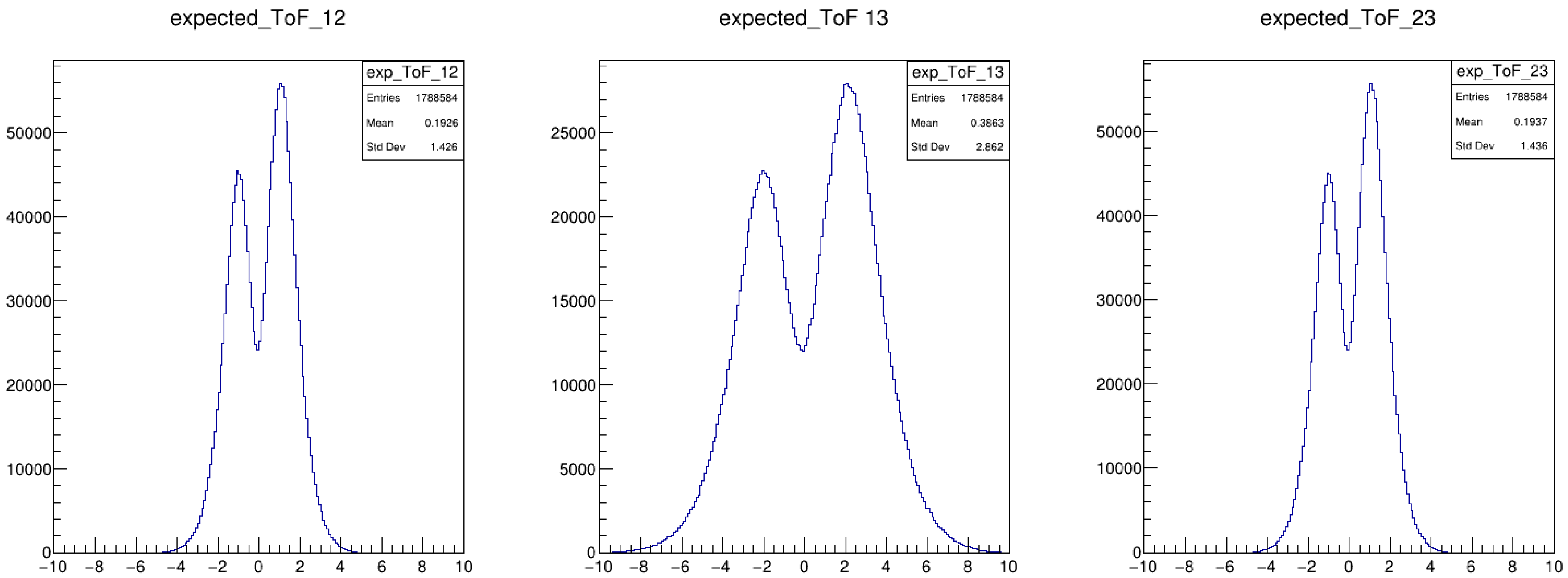
  ToF_{exp}= (total distance travelled)/c

Expected Time of Flight (ToF_exp)



- Distance travelled by incoming muon between two chosen stations can be calculated based in the goemetry of the detector and the θ and φ information of the reconstructed track
- With speed of light (*c*), one can easily compute expected ToF using

  ToF_{exp}= (total distance travelled)/c
- There is delay between the hit time and the time taken for the signals to reach the electronic boards
- This delay time can be also be calculated if the hit positions are known



Example of expected ToF using hit-position information and including fibre delay for NERO

Measured Time of Flight (ToF_mes)

- Raw TDC information as well as positions of the hits are easily accessible in the ntuples

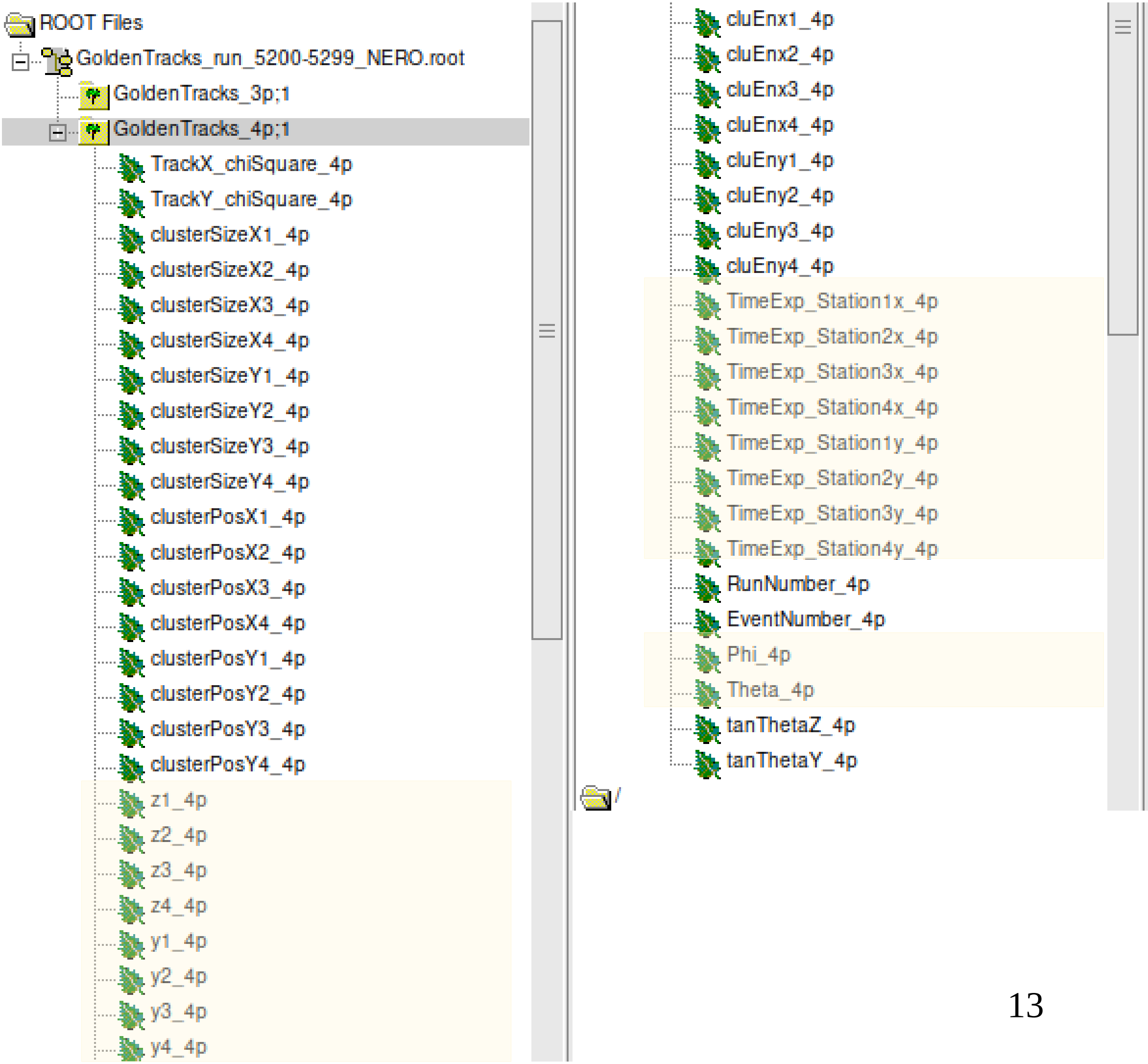
- First, the raw TDC is converted into ‘actual’ time in ns

- However, in order to do so, it is necessary to determine the relevant boards that were involved in the data-taking

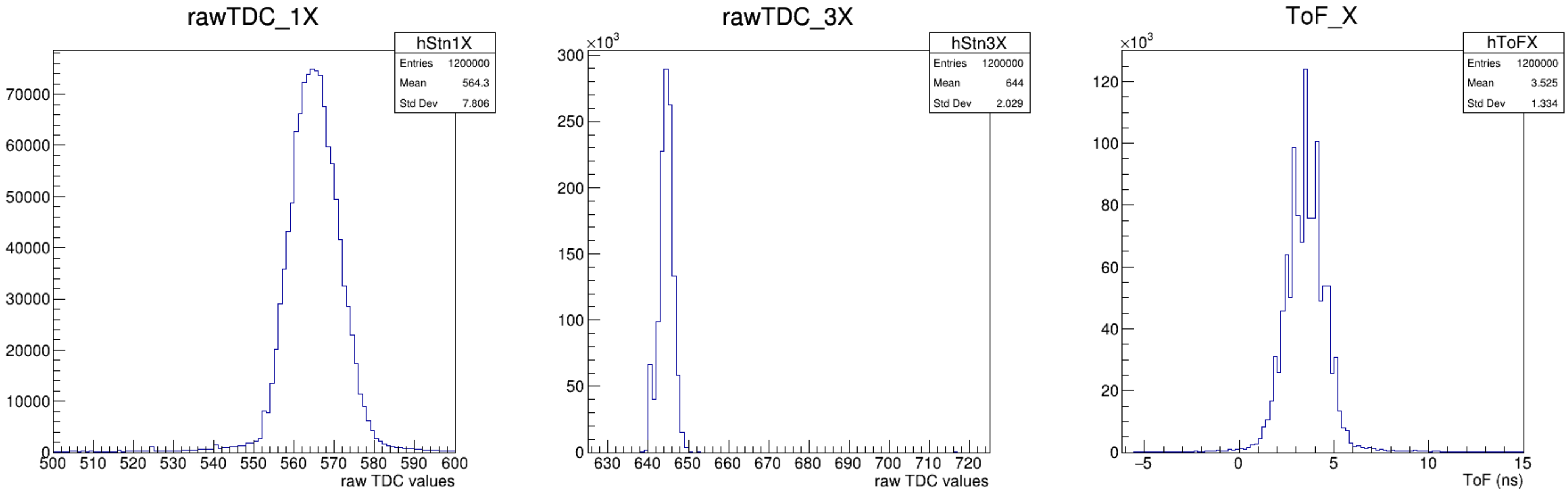
- Once the relevant boards are known, the time expansion calibration results has to be applied for TDC-ns converison

- Delay correction

- The difference between the converted time after correcting for fiber delays across two different stations gives an estimate on ToF (i.e, measured ToF).

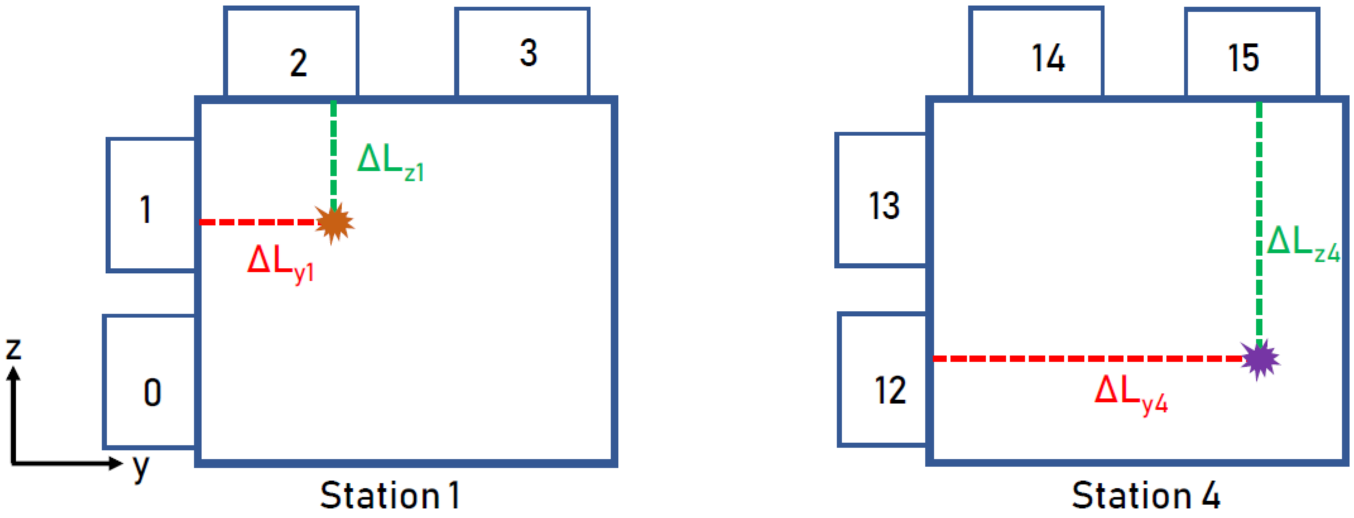


Measured Time of Flight (ToF_mes)



Example of meaured ToF using TDC information and Texp calibration results

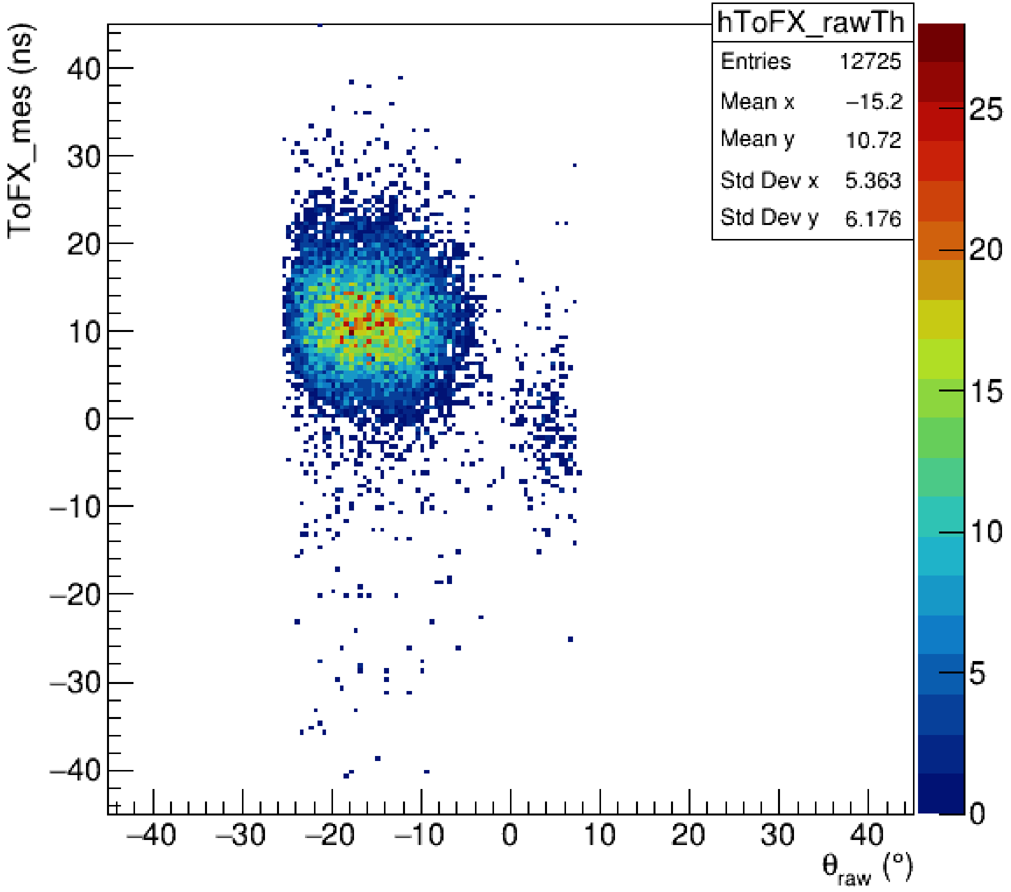
Measured Time of Flight (ToF_mes)

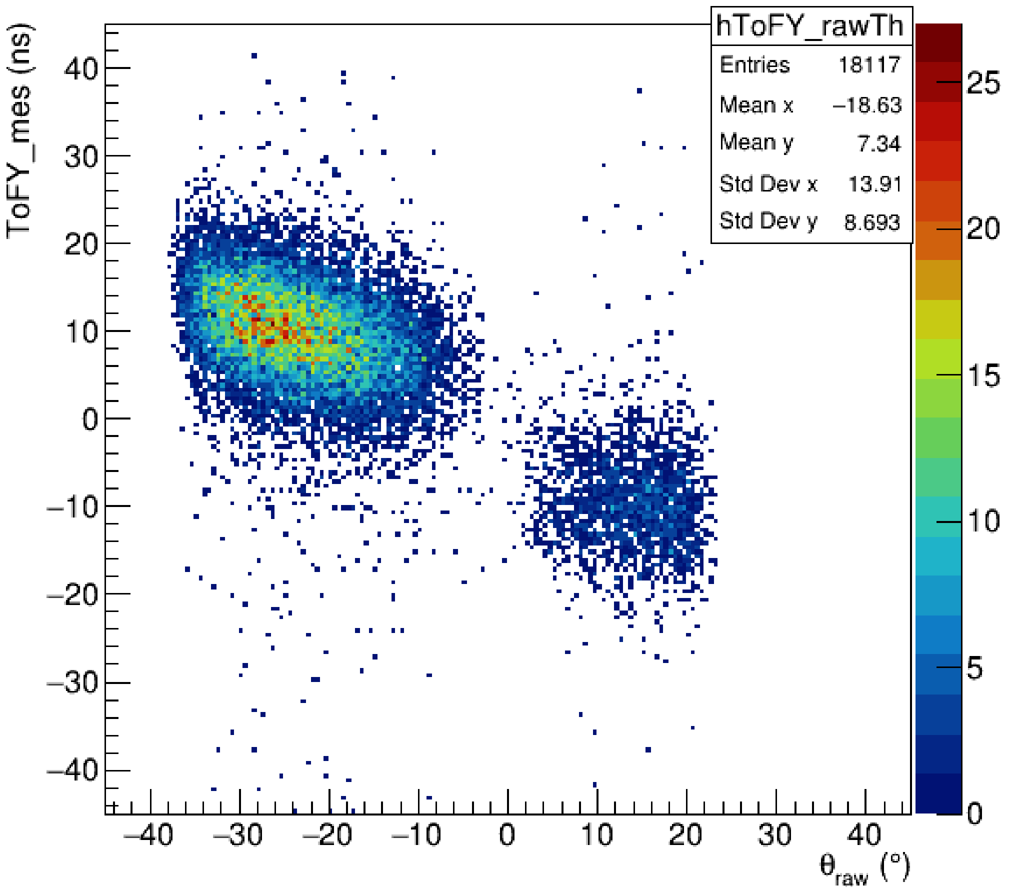


For XX view :
$$ToF_X = \left(\frac{(T_{1X} - T_1^0)}{E_1} + \frac{\Delta L_{y1}}{\vartheta_{fiber}}\right) - \left(\frac{(T_{4X} - T_4^0)}{E_4} + \frac{\Delta L_{y4}}{\vartheta_{fiber}}\right)$$

For YY view :
$$ToF_Y = \left(\frac{(T_{1Y} - T_1^0)}{E_1} + \frac{\Delta L_{z1}}{\vartheta_{fiber}}\right) - \left(\frac{(T_{4Y} - T_4^0)}{E_4} + \frac{\Delta L_{z4}}{\vartheta_{fiber}}\right)$$

- Adjust the equations above accordingly for XY and YX views ToF (w/ delay) calculation.

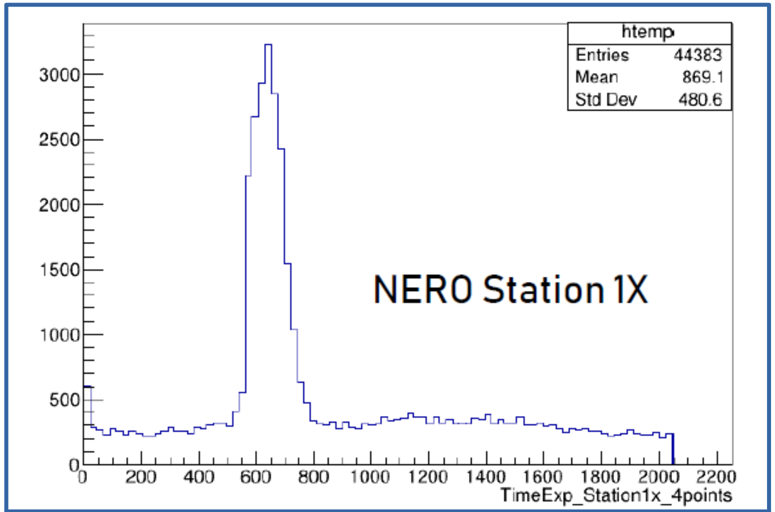


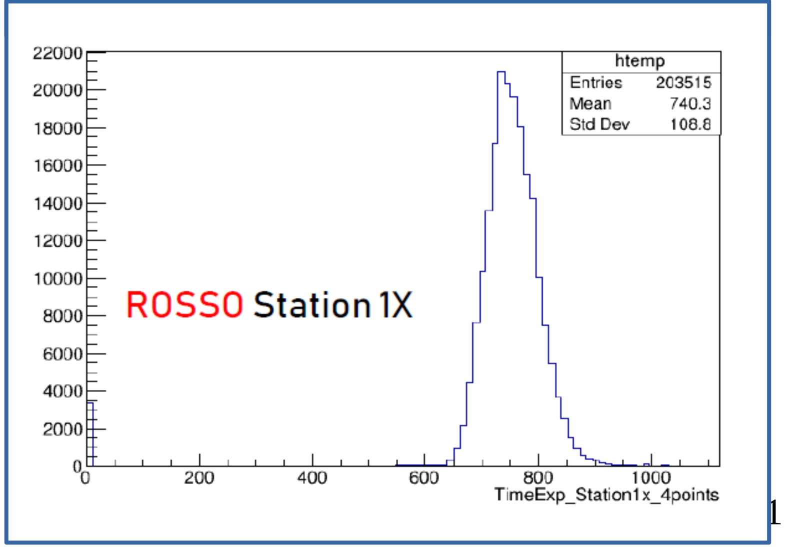


Representative ToF_mes vs θ_{raw} distributions in both X and Y views

Concerns and Issues after the first look

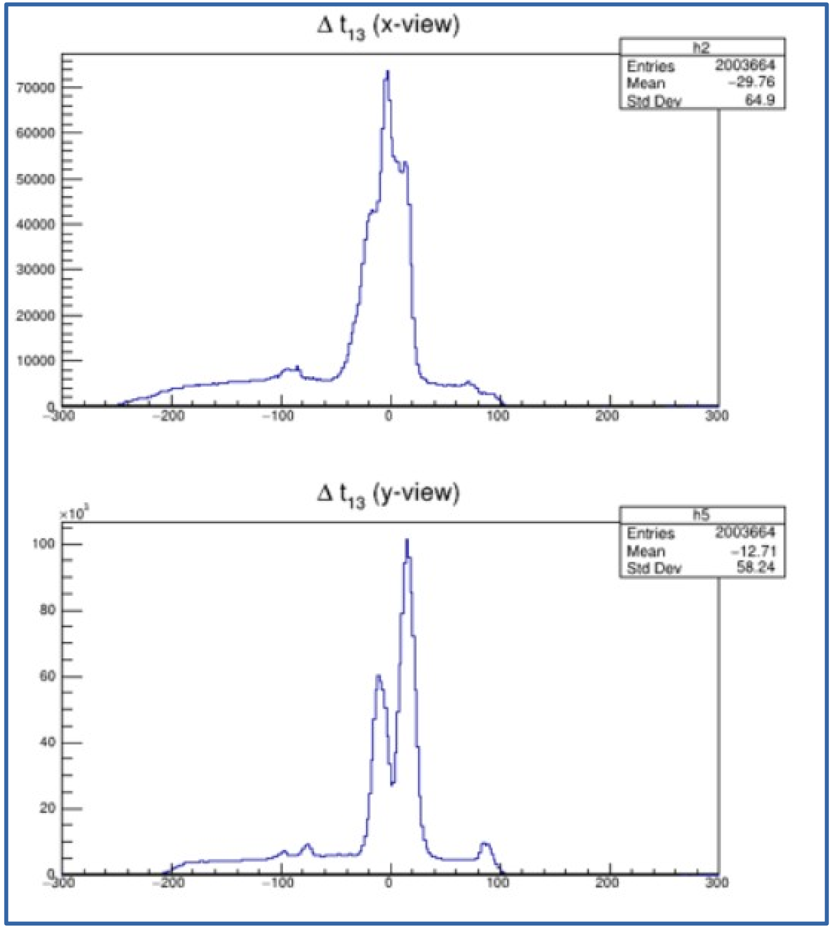
- Presence of pedestal in the measured ToF distributions (in NERO)
- Unusual peak positions in the mesured ToF distributions
- Wide range of ToFs (~-200 to 200 ns)
- Disagreement between measured ToFs from X and Y views
- Discrepancy between measured ToFs and expected ToFs (Note that average of ToF_exp distribution gives ‘correct’ time)





Concerns and Issues after the first look

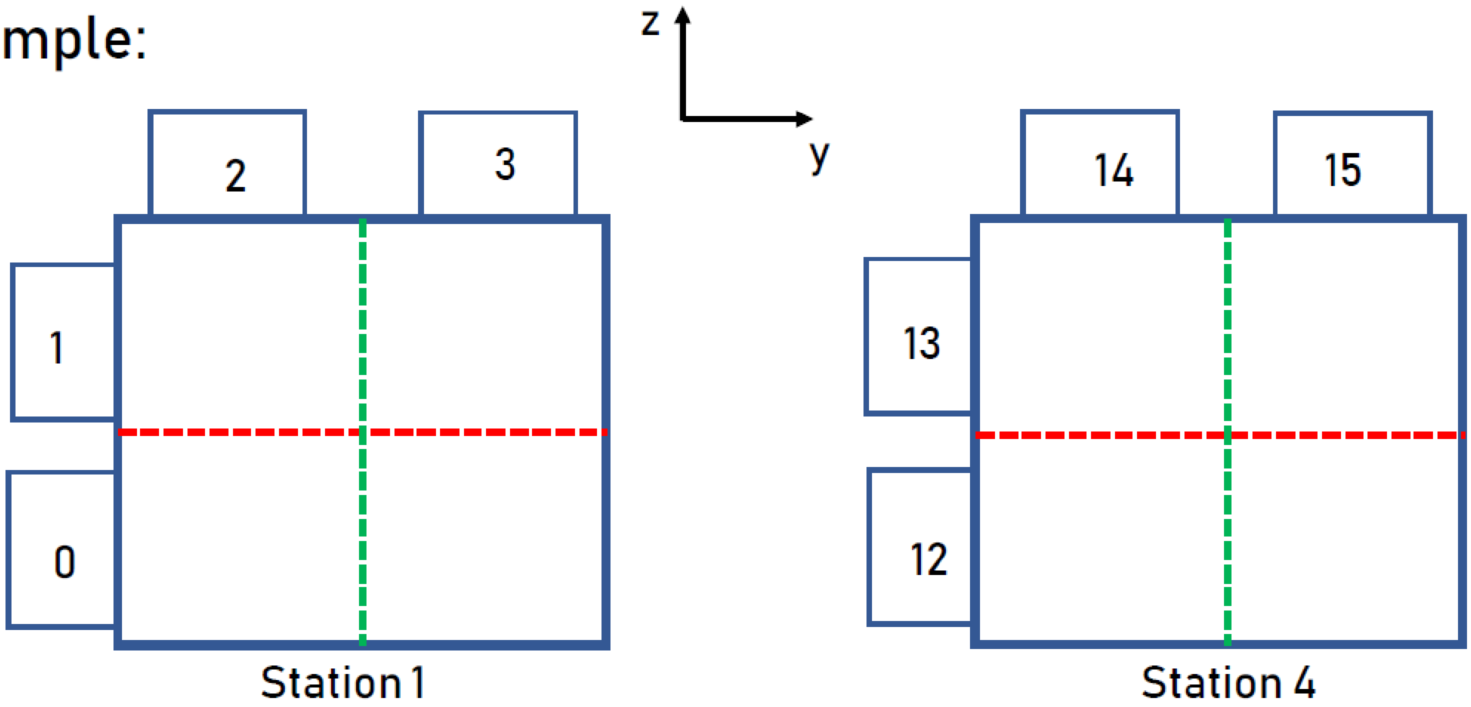
- Presence of pedestal in the measured ToF distributions (in NERO)
- Unusual peak positions in the mesured ToF distributions
- Wide range of ToFs (~-200 to 200 ns)
- Disagreement between measured ToFs from X and Y views
- Discrepancy between measured ToFs and expected ToFs (Note that average of ToF_exp distribution gives 'correct' time)



Measured ToFs between Stns #1 and #3 for NERO in X and Y views

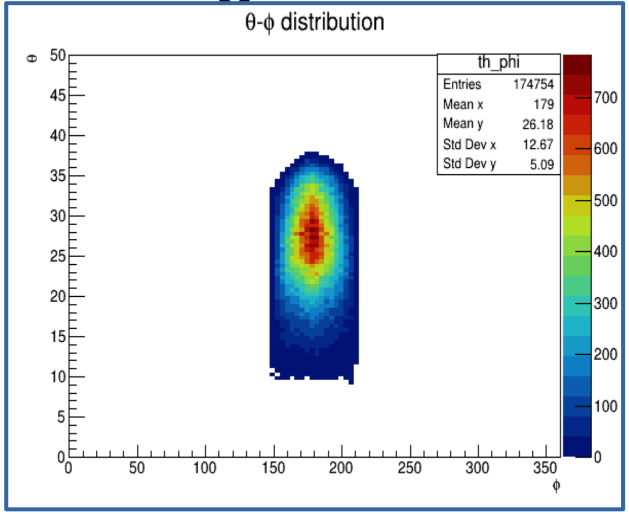
Dividing the detector planes in various regions

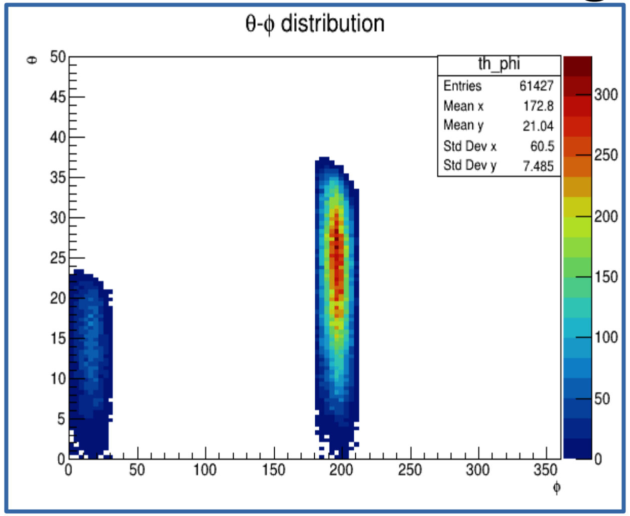
Example:

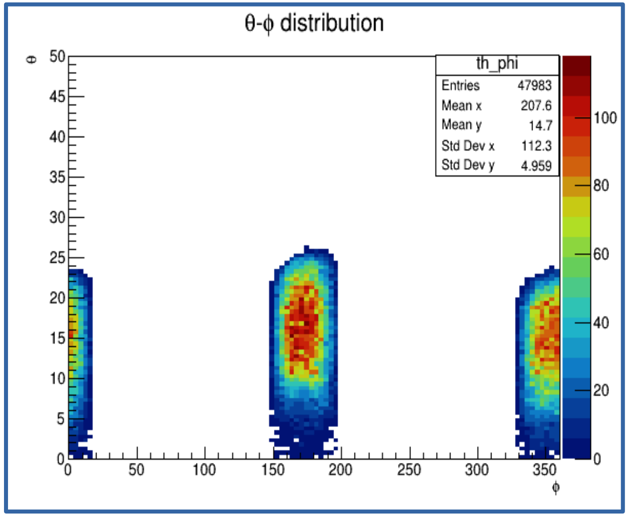


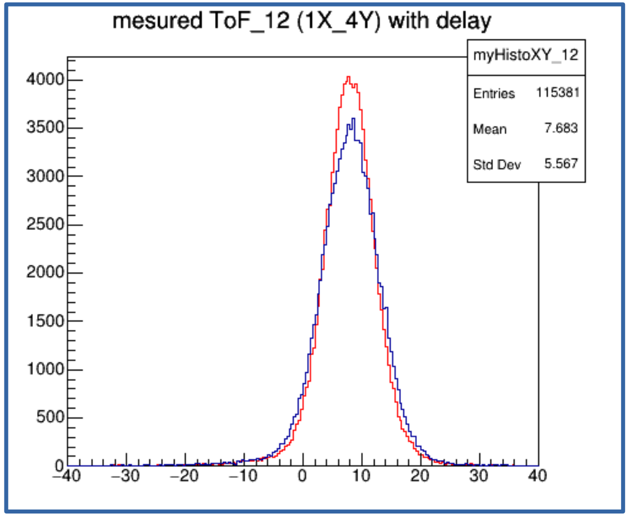
XX – boards	YY – boards	XY – boards	YX – boards
✓ 0-12	✓ 2-14	✓ 0-14	✓ 2-12
✓ 0-13	✓ 2-15	✓ 0-15	✓ 2-13
✓ 1-12	✓ 3-14	✓ 1-14	✓ 3-12
✓ 1-13	✓ 3-15	✓ 1-15	✓ 3-13

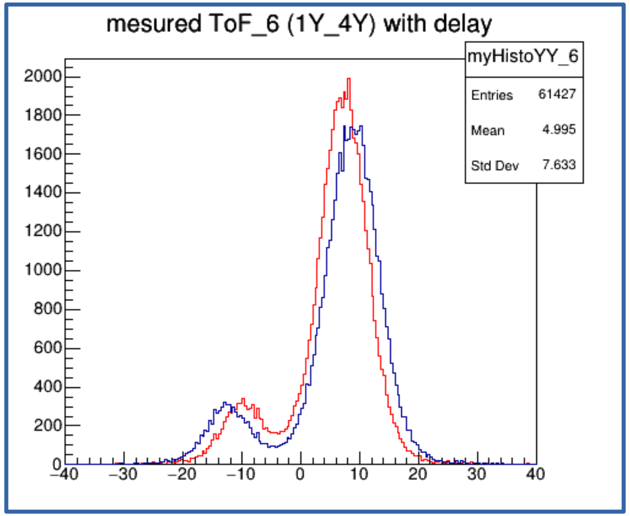
Dividing the detector planes in various regions

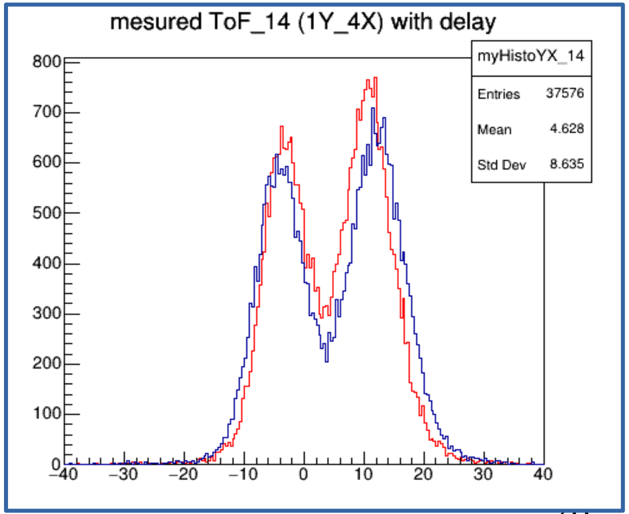












Dividing the detector planes in various regions

Single Peak Feature
- 8 ToF distributions in total

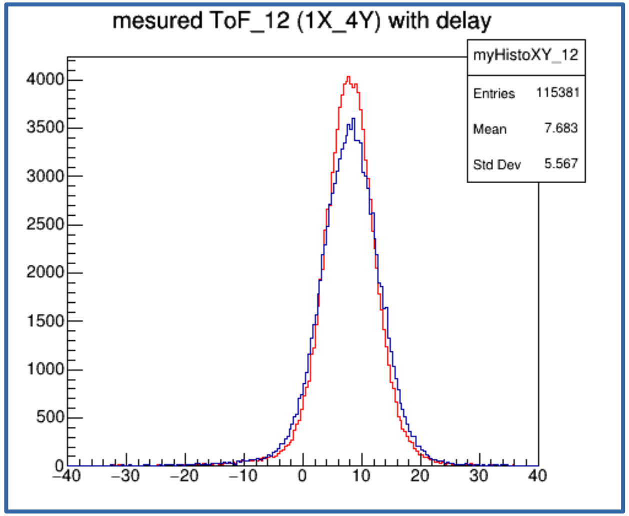
- 4 with XX boards combination
- 2 with XY boards combination
- 2 with YX boards combination

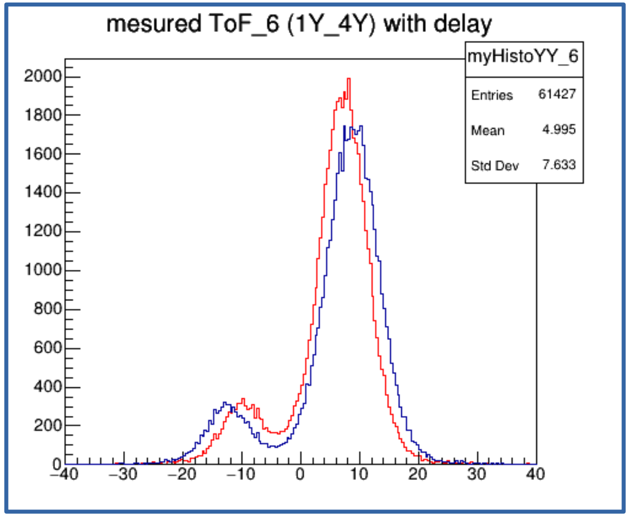
Single Peak with “Shoulder ”Feature
- 4 ToF distributions in total

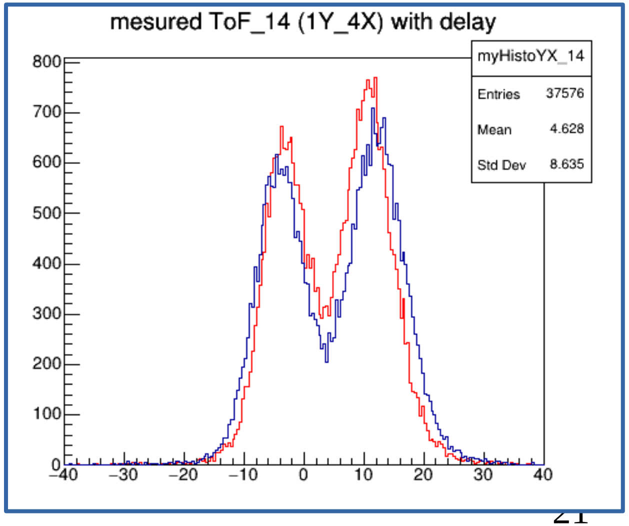
- All 4 with YY boards combination

Double Peaks Feature
- 4 ToF distributions in total

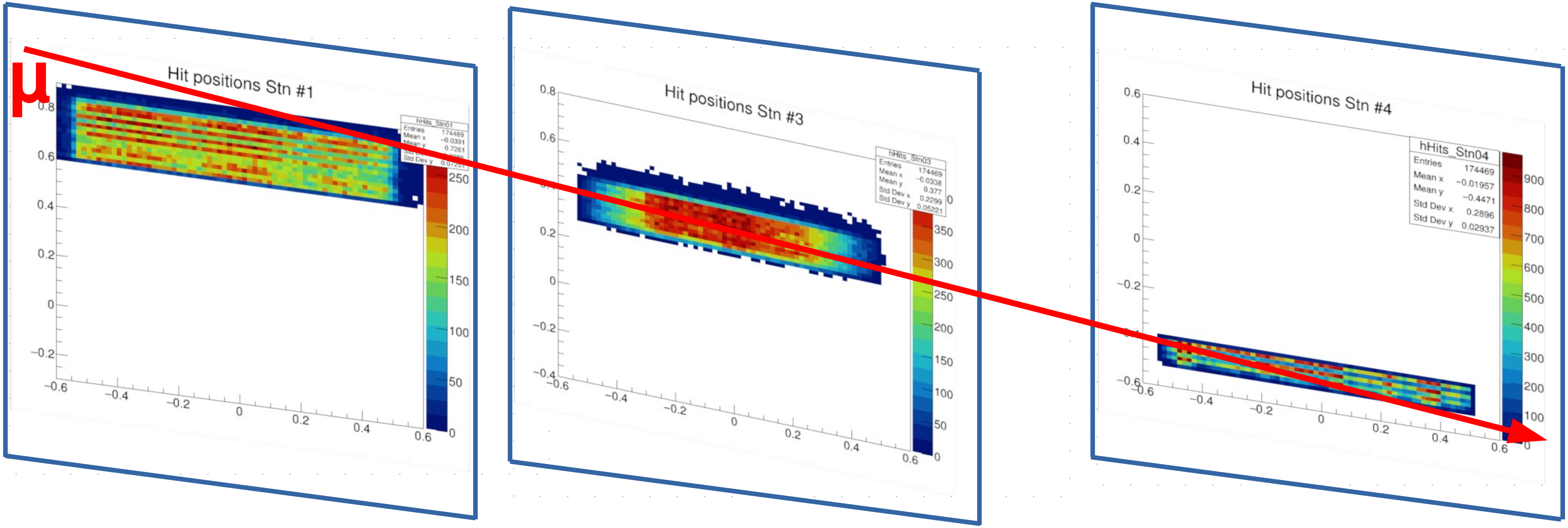
- 2 with X Y boards combination
- 2 with YX boards combination





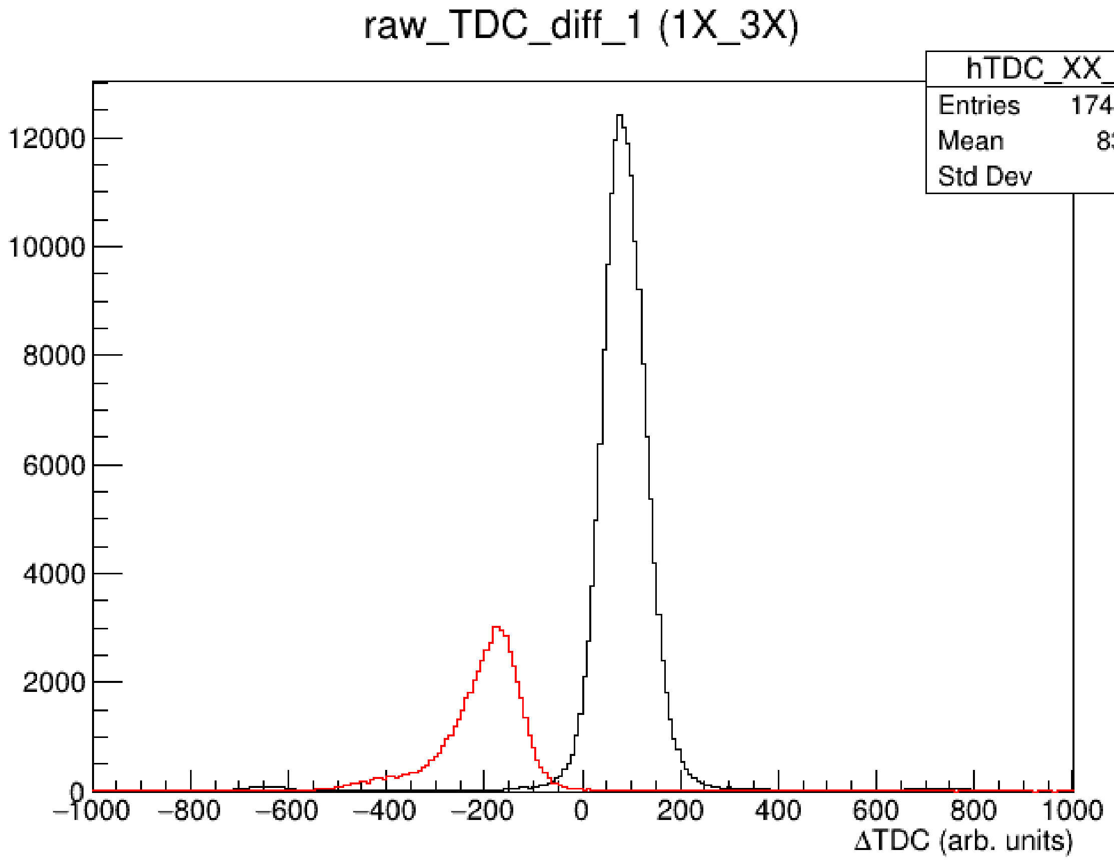


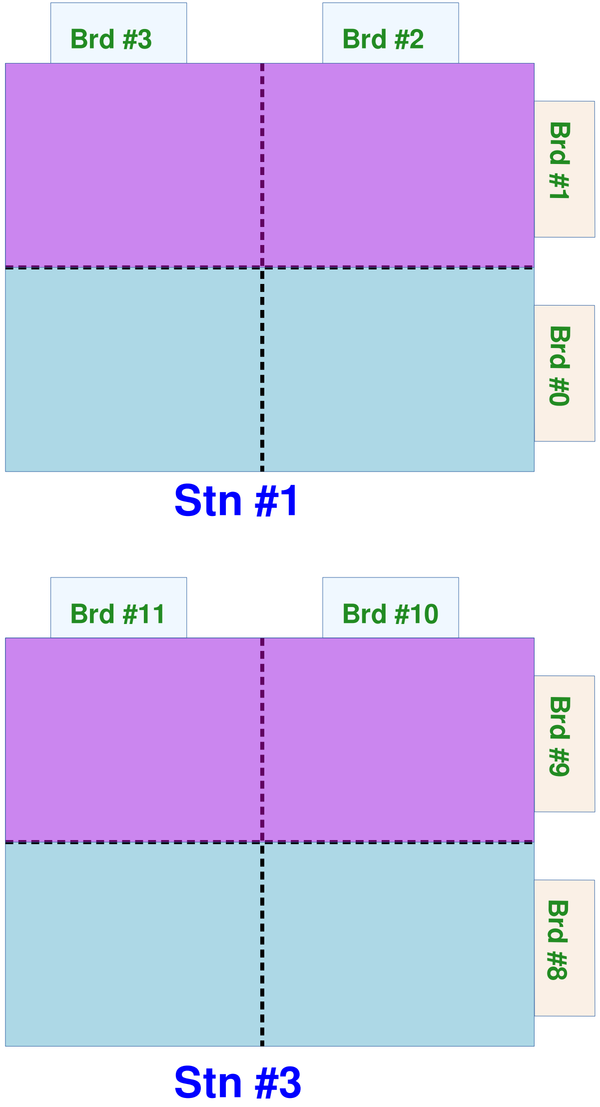
Use of ‘free-sky’ data to deal with ToF issues



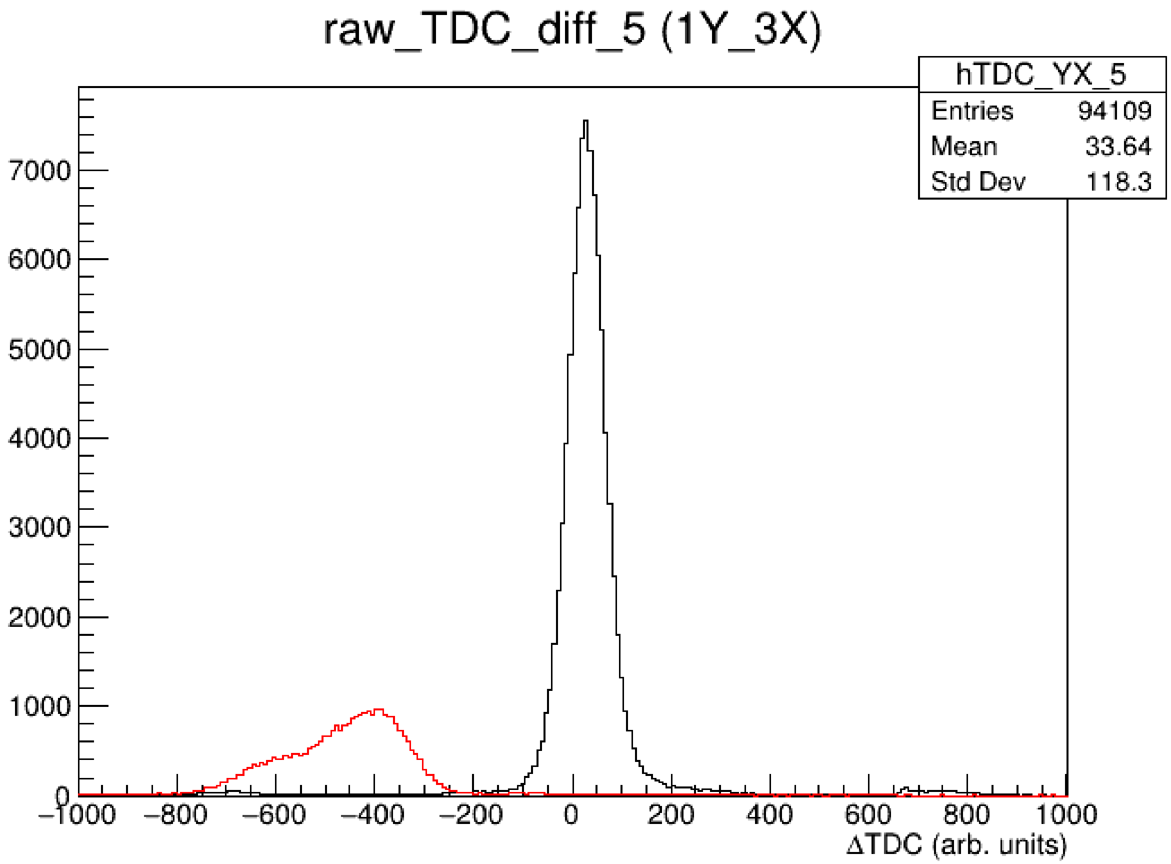
[Steep Track Selection]()

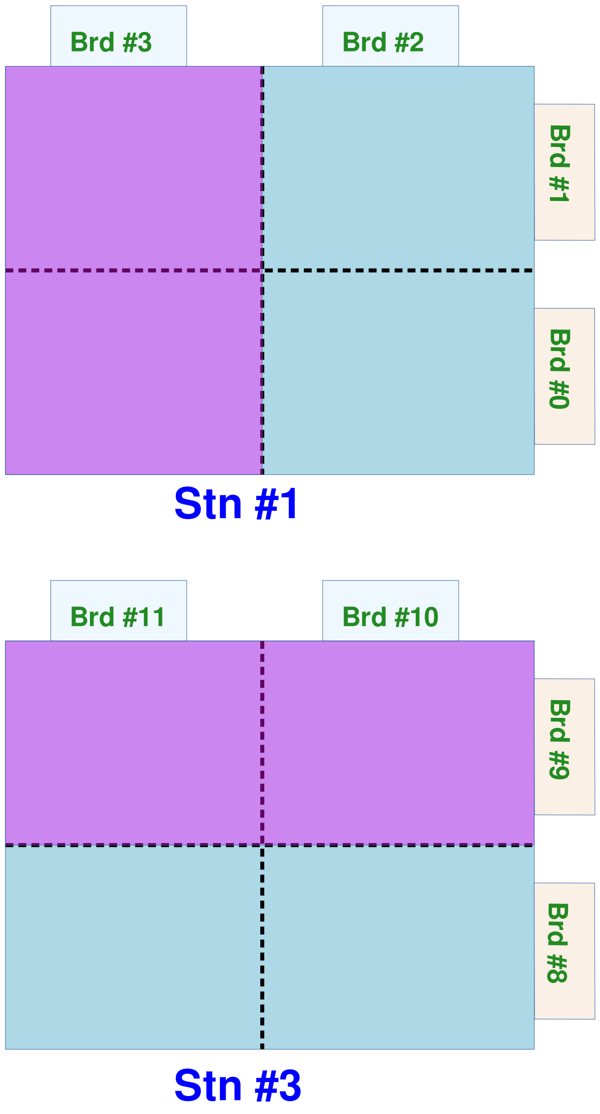
Raw TDC Difference (Stns #1 and 3)



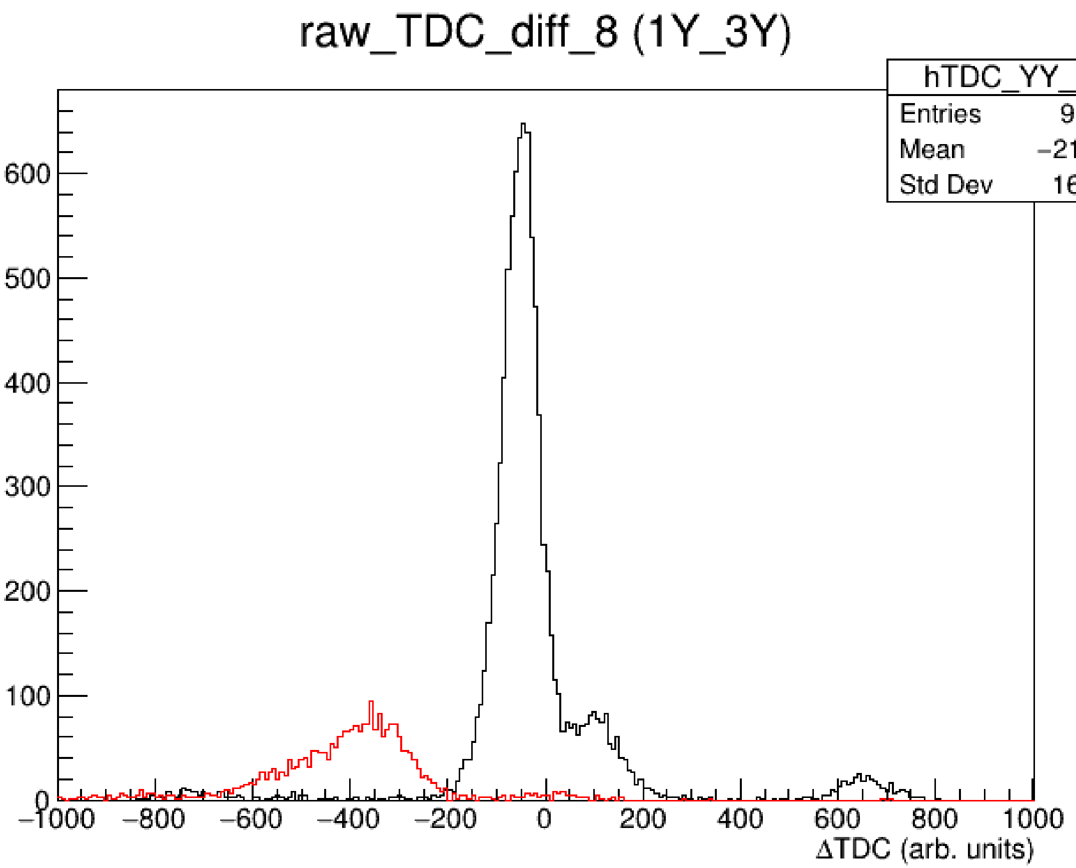


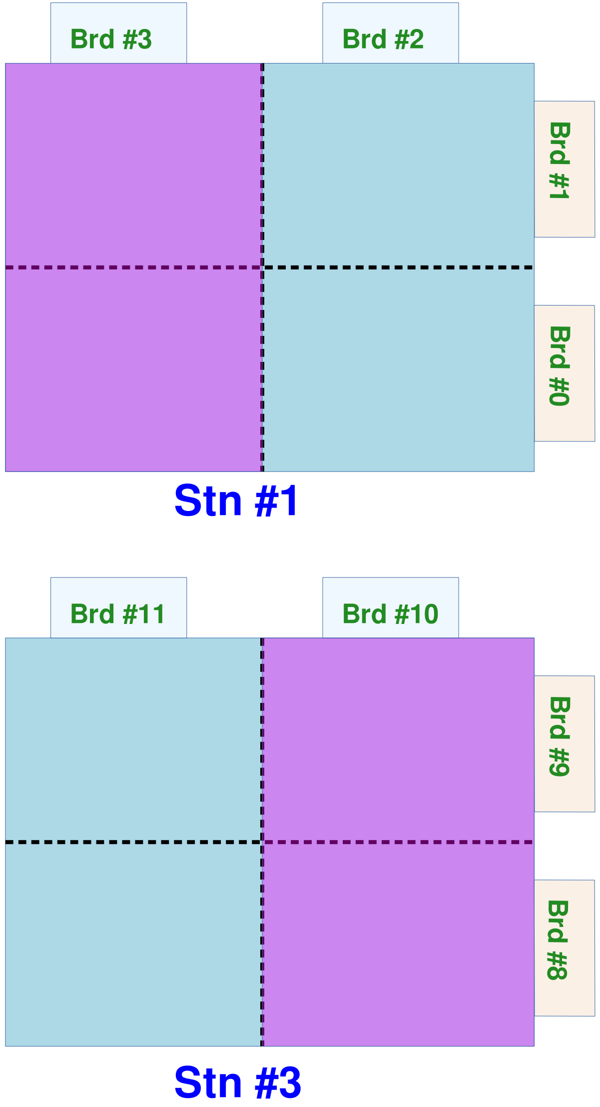
Raw TDC Difference (Stns #1 and 3)



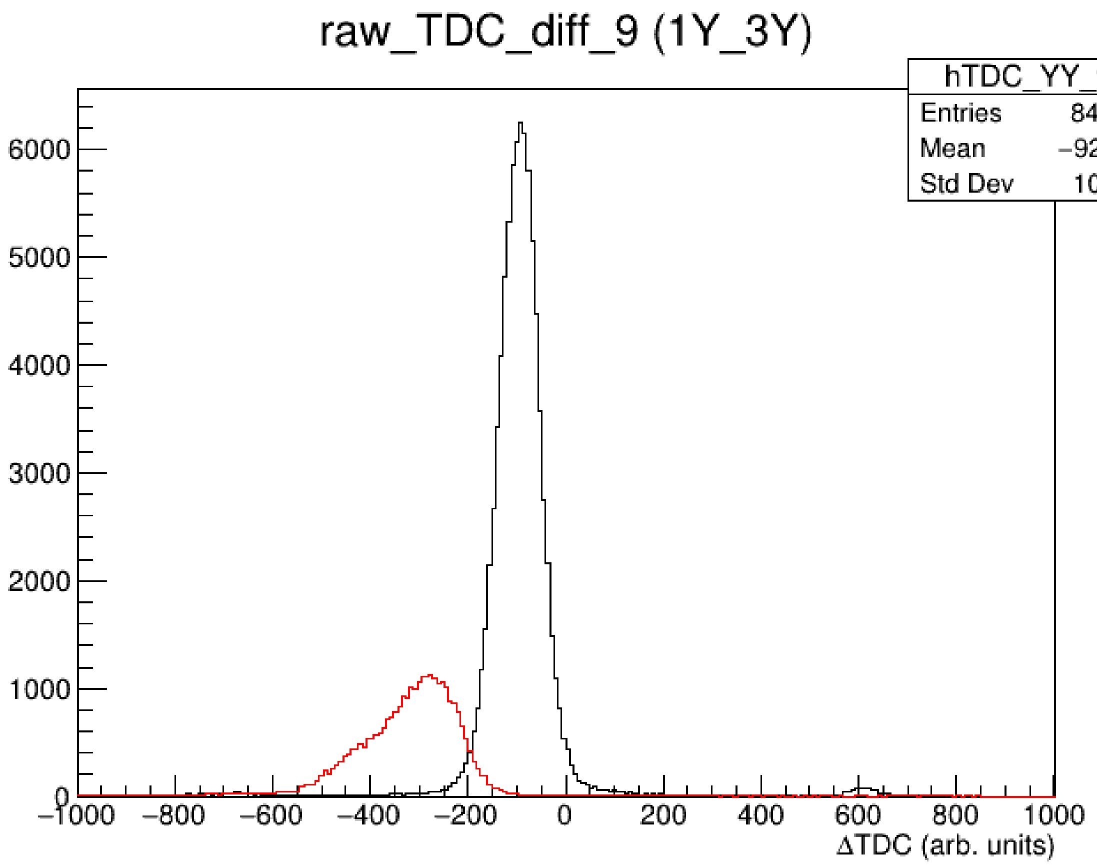


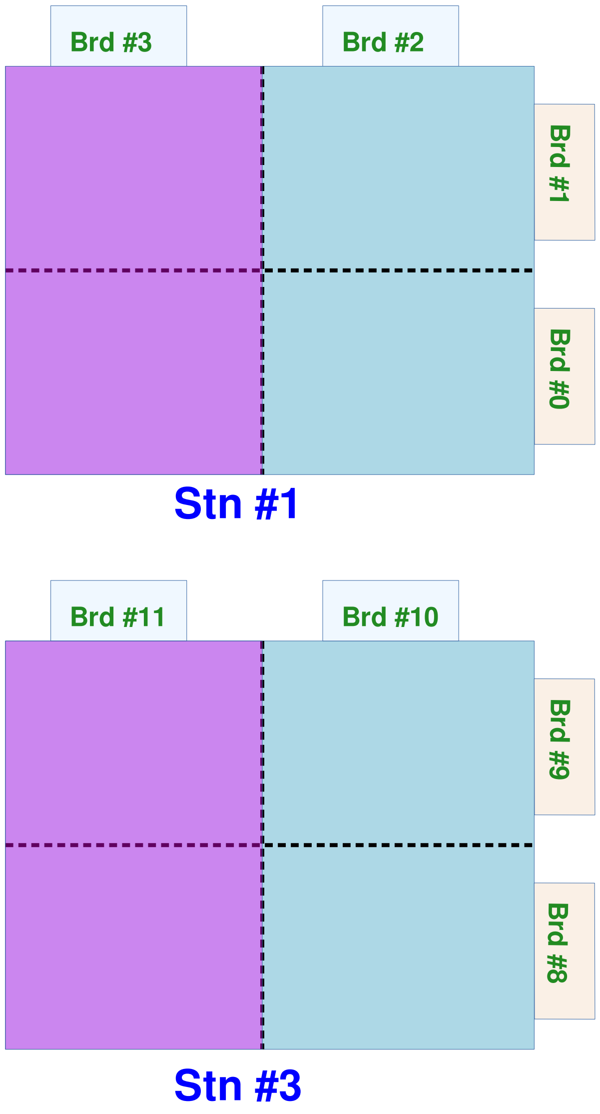
Raw TDC Difference (Stns #1 and 3)





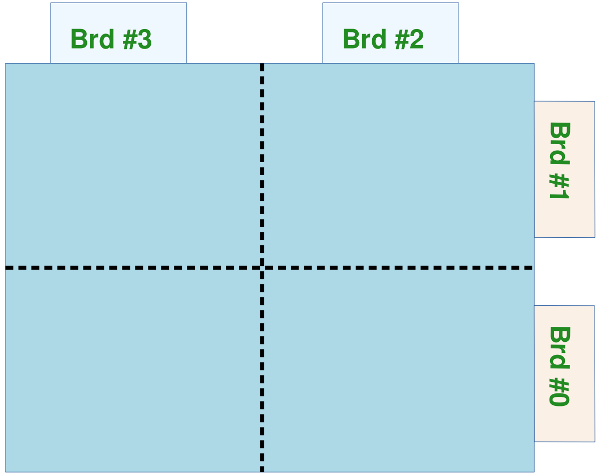
Raw TDC Difference (Stns #1 and 3)



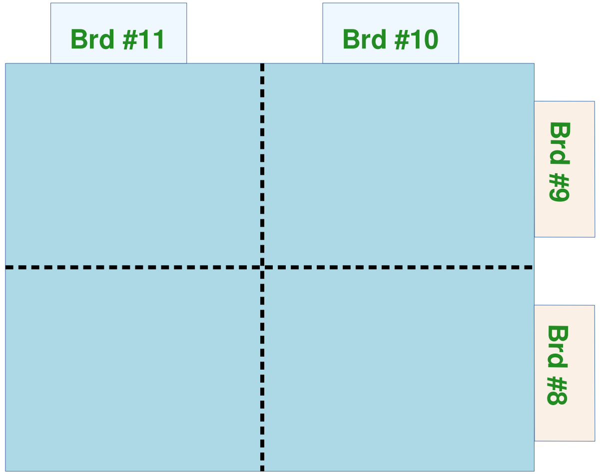


Raw TDC Difference (Stns #1 and 3)

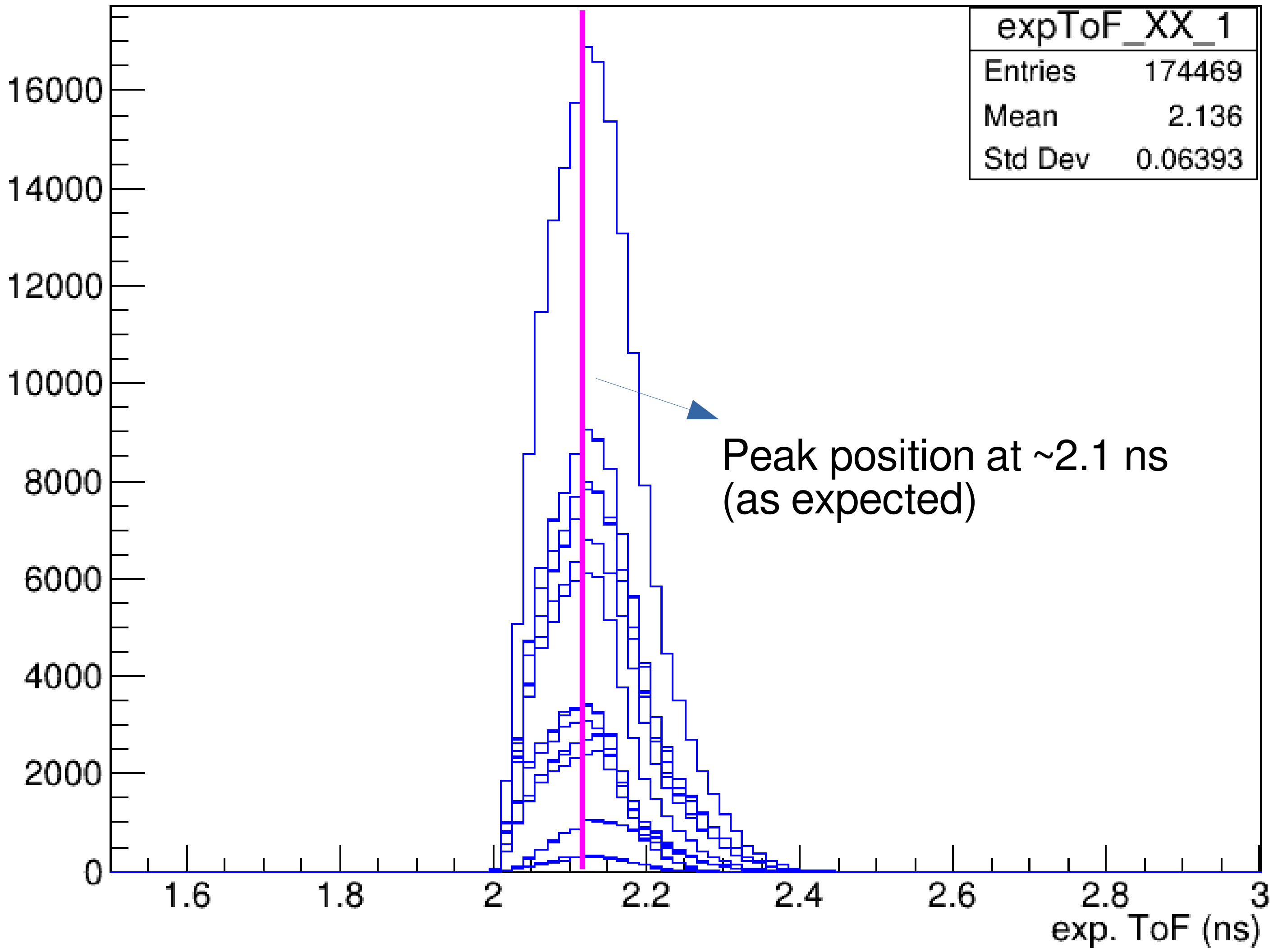
Regions	Boards Involved	Raw TDC Difference	
		ROSSO	NERO
1	#1 & #9	-197.1	83.2
2	#1 & #10	-130.8	18.3
3	#1 & #11	-64.0	-42.1
4	#2 & #9	-106.0	192.1
5	#3 & #9	**-453.2**	33.6
6	#2 & #10	-49.2	126.6
7	#2 & #11	-20.6	72.1
8	#3 & #10	**-402.4**	-21.7
9	#3 & #11	**-320.0**	-92.8



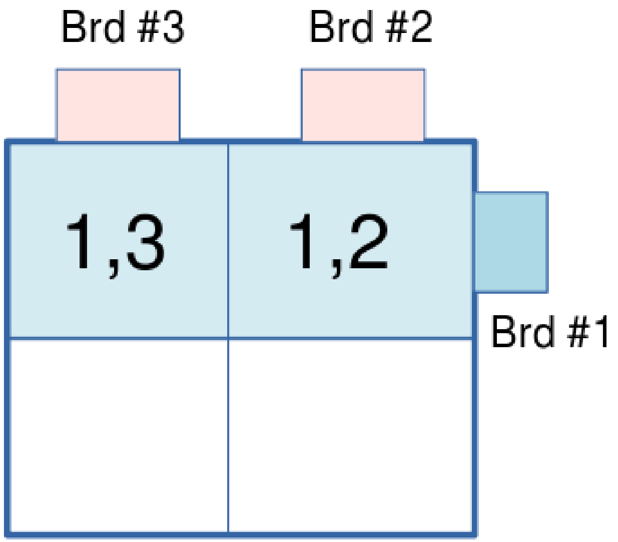
Stn #1



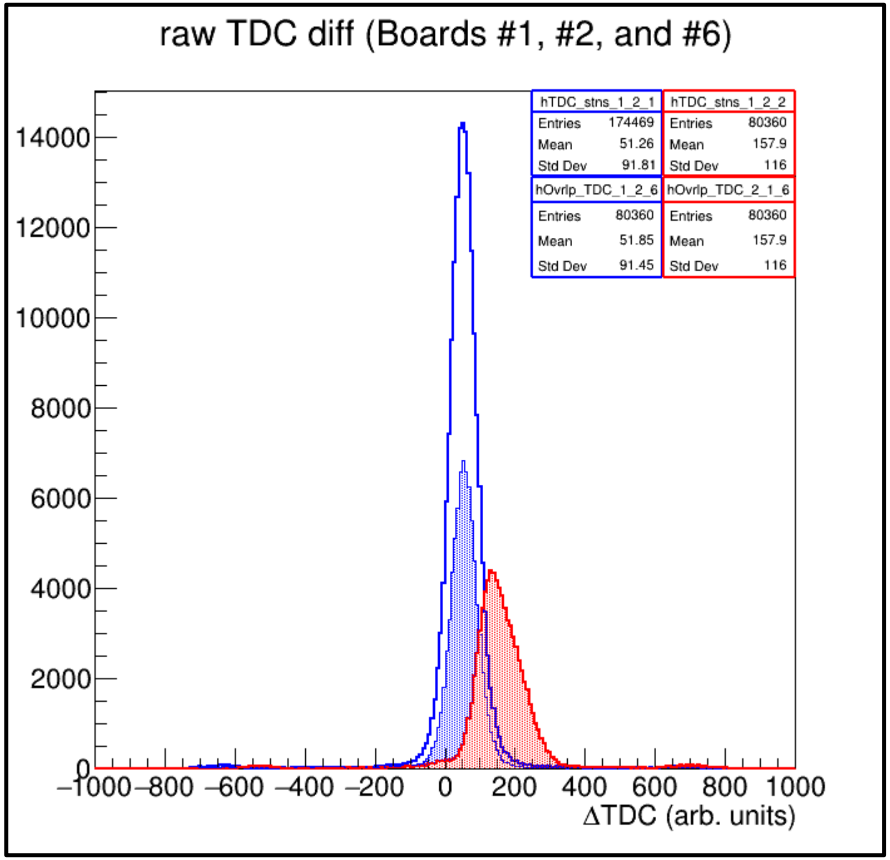
Stn #3

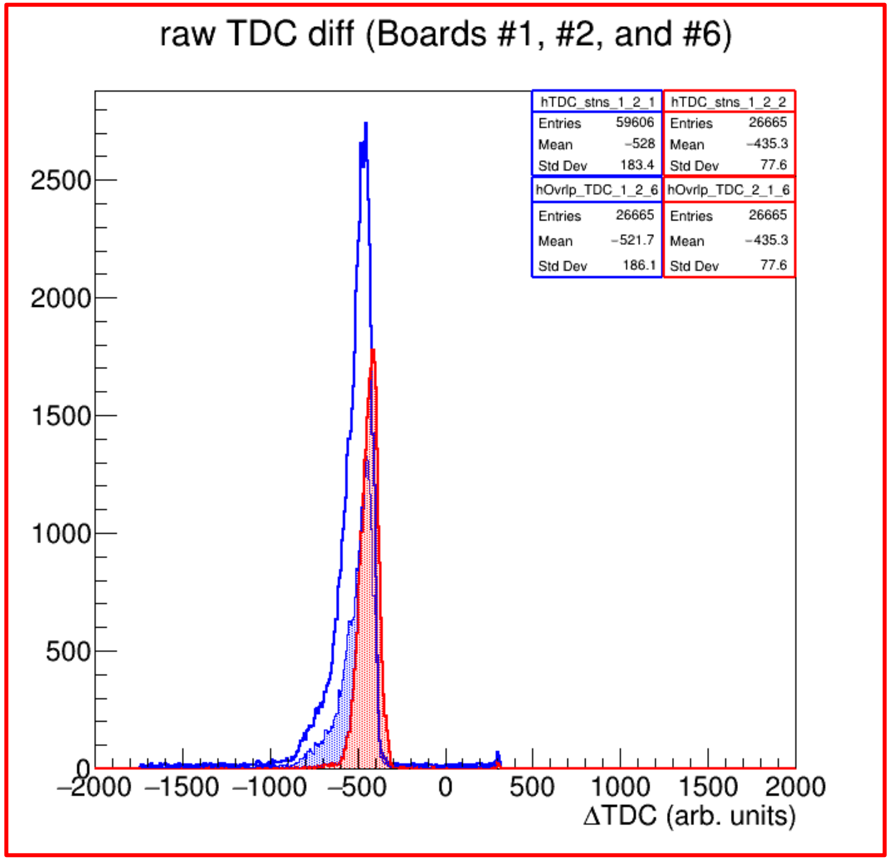

expToF_XX_1
Entries 174469
Mean 2.136
Std Dev 0.06393
16000
14000
12000
10000
8000
6000
4000
2000
0
1.6
1.8
2
2.2
2.4
2.6
2.8
3
exp. ToF (ns)
Peak position at ~2.1 ns
(as expected)

Overlap Region
NERO vs ROSSO

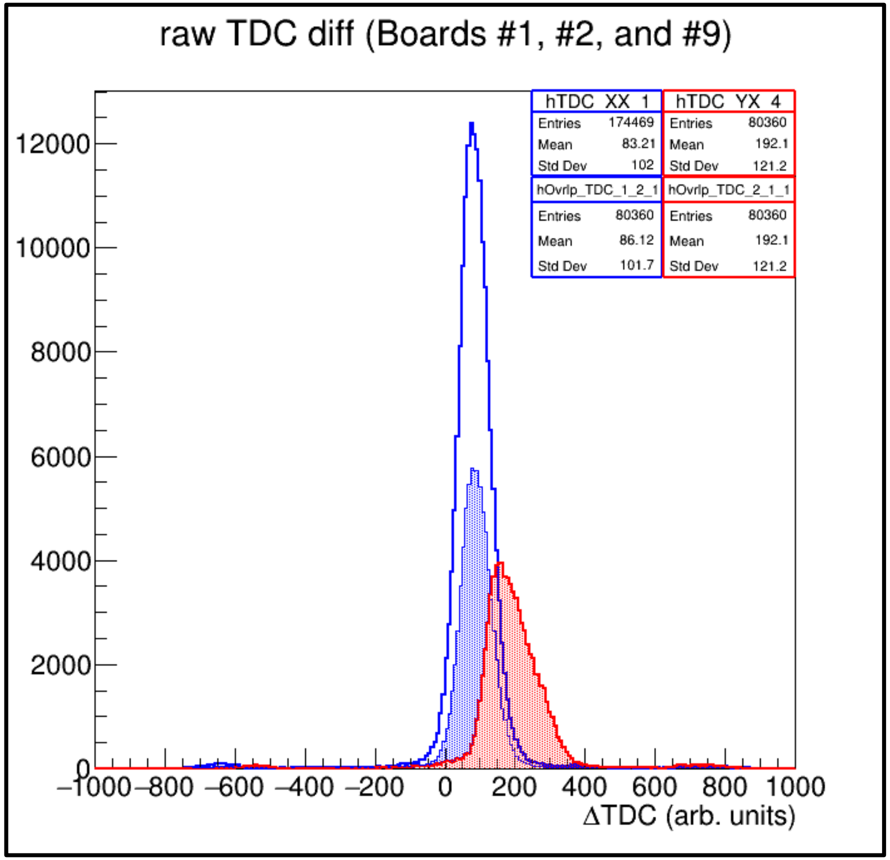


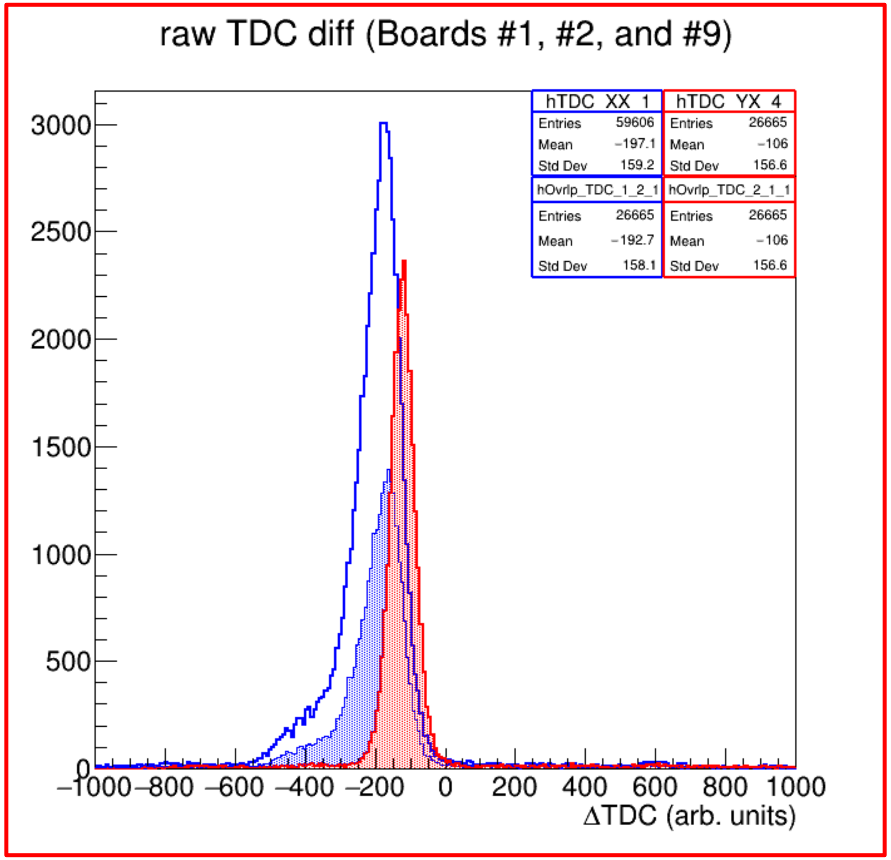
Boards 1, 2, and 6



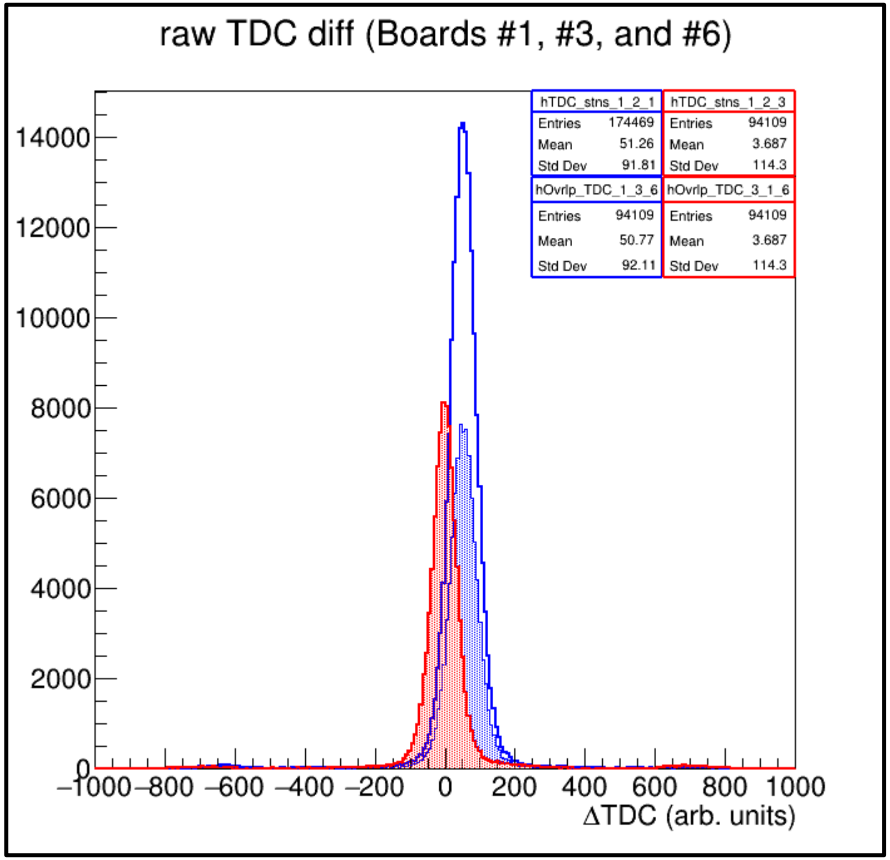


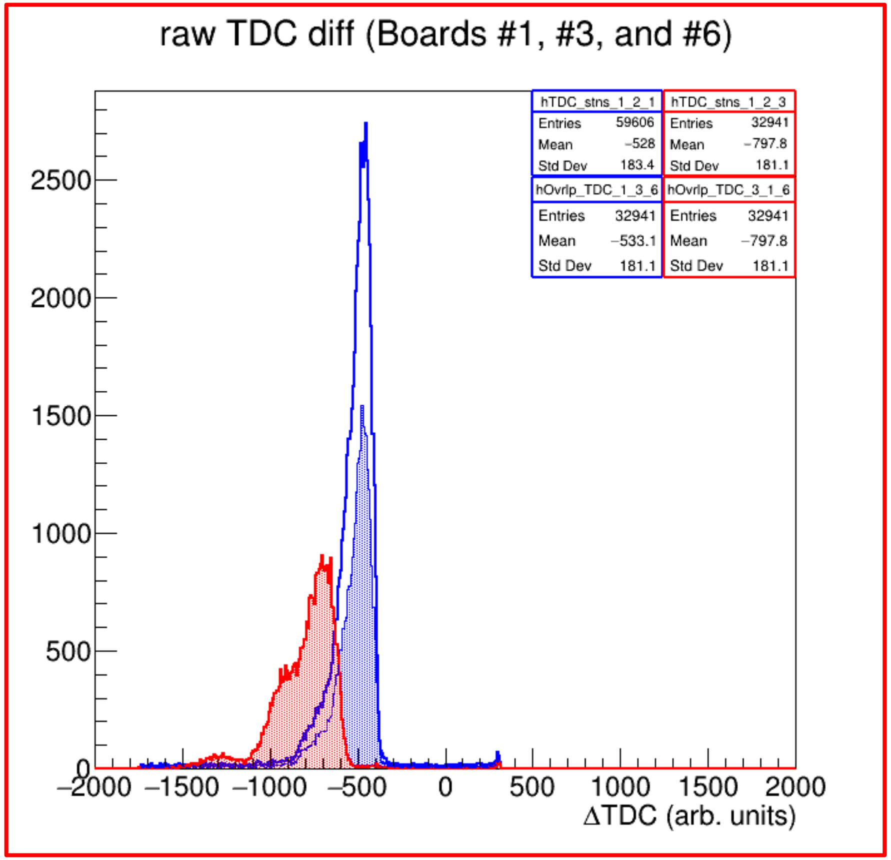
Boards 1, 2, and 9



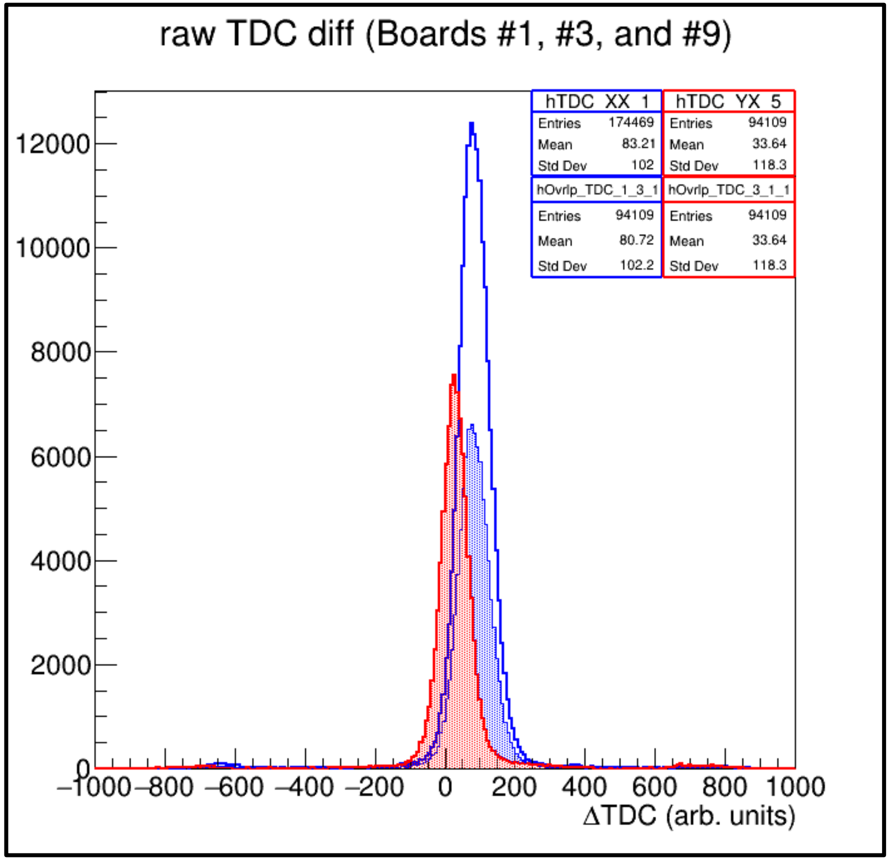


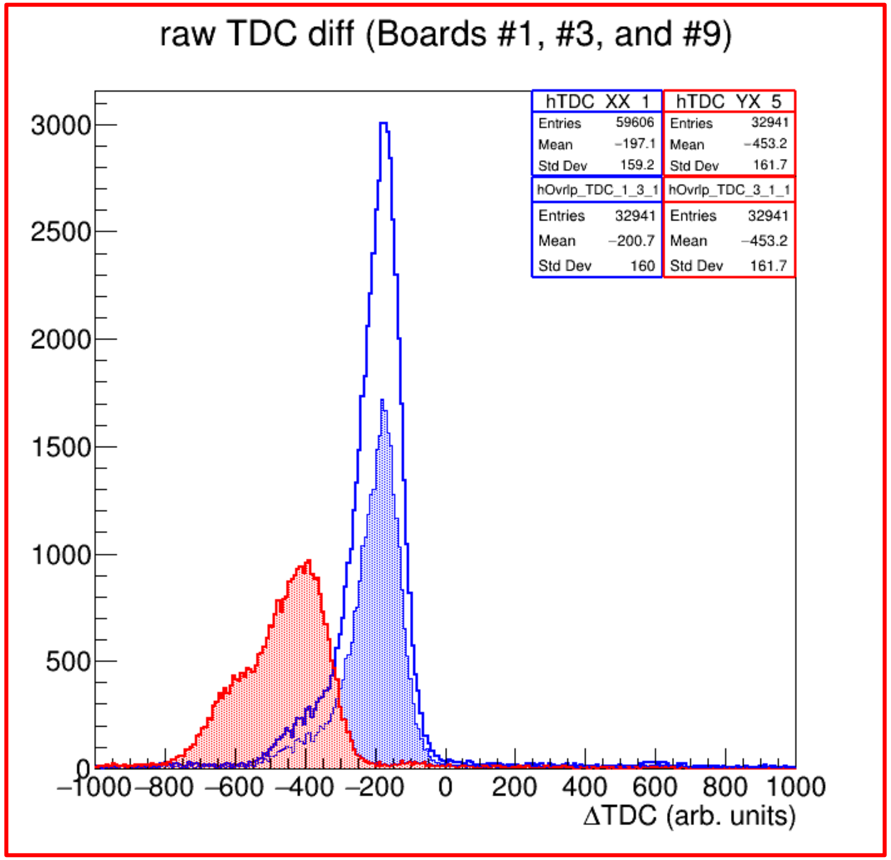
Boards 1, 3, and 6





Boards 1, 3, and 9





Boards Combo	NERO					
	TDC diff. (counts)			Delay term (ns)		
	Blank Blue	Shaded Blue	Shaded Red	Blank Blue	Shaded Blue	Shaded Red
1-2 (9 fixed)	83.2	86.1	192.1	7.1	5.1	-21.0
1-3 (9 fixed)	83.2	80.7	33.6	7.1	8.7	3.1
5-6 (9 fixed)	32.7	53.5	48.1	-2.4	-2.9	14.2
5-7 (9 fixed)	32.7	52.4	138.2	-2.4	-2.1	-14.6
9-10 (1 fixed)	83.2	84.7	18.4	7.1	5.8	5.5
9-11 (1 fixed)	83.2	81.9	-42.1	7.1	8.1	14.3
5-6 (1 fixed)	52.8	53.5	39.9	7.4	7.0	0.9
5-7 (1 fixed)	52.8	52.9	-54.5	7.4	7.6	19.2

ΔTDC = **-5.4** counts
Δ delay term = 3.6 ns

ΔTDC = **-1.1** counts
Δ delay term = 0.8 ns

ΔTDC = **-2.8** counts
Δ delay term = 2.3 ns

ΔTDC = **-0.6** counts
Δ delay term = 0.6 ns

Boards Combo	ROSSO					
	TDC diff. (counts)			Delay term (ns)		
	Blank Blue	Shaded Blue	Shaded Red	Blank Blue	Shaded Blue	Shaded Red
1-2 (9 fixed)	-197.1	-192.7	-106.0	16.5	14.4	0.4
1-3 (9 fixed)	-197.1	-200.7	-453.2	16.5	18.1	56.0
5-6 (9 fixed)	313.2	-521.6	-272.2	n/a	n/a	n/a
5-7 (9 fixed)	313.2	-533.1	596.7	n/a	n/a	n/a
9-10 (1 fixed)	-197.1	-193.4	-130.8	16.5	14.9	5.3
9-11 (1 fixed)	-197.1	-200.1	-64.0	16.5	17.7	2.5
5-6 (1 fixed)	-528.0	-521.6	-461.1	n/a	n/a	n/a
5-7 (1 fixed)	-528.0	-533.1	-493.5	n/a	n/a	n/a

ΔTDC = **-8.0** counts
Δ delay term = 3.5 ns

ΔTDC = **-11.5** counts
Δ delay term = n/a

ΔTDC = **-6.7** counts
Δ delay term = 2.8 ns

ΔTDC = **-11.5** counts
Δ delay term= n/a