Update : Time of Flight (ToF) with MURAVES data

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OUTLINE

- Time Expansion (Texp) Calibration : A short recap

- Time of Flight (ToF) with MURAVES data
  - ✔ Motivation
  - ✔ Measured vs Expected ToF
  - ✔ Raw TDC diff. In X and Y views
  - ✔ Use of Texp characterization results for ToF calculation (incl. Fiber Delay)

- Some issues with measured ToFs

- Use of “free-sky” calibration data to deal with ToF issues

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 layers consisting two planes, we have 16 boards in total
- The boards in BLU had to be refurbished and the Texp characterizations had to be re-done

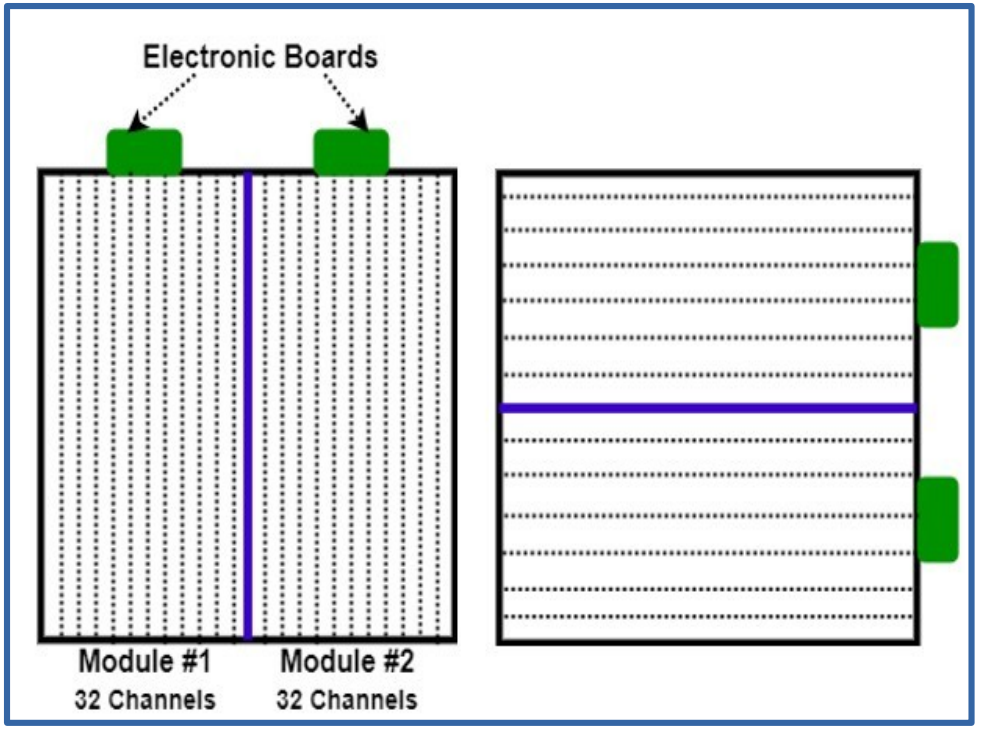


Figure : Schematics of one of the planes (both X and Y views) in MURAVES detector

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 introducted from 2 to 20 ns and the subsequent $t_{discharge}$ in terms of TDC units were read-out for each of boards
- $t_{discharge} = \boldsymbol{E} \,.\, t_{charge} + \boldsymbol{C}$

  Here ***E*** is the expansion factor and ***C*** is the intercept

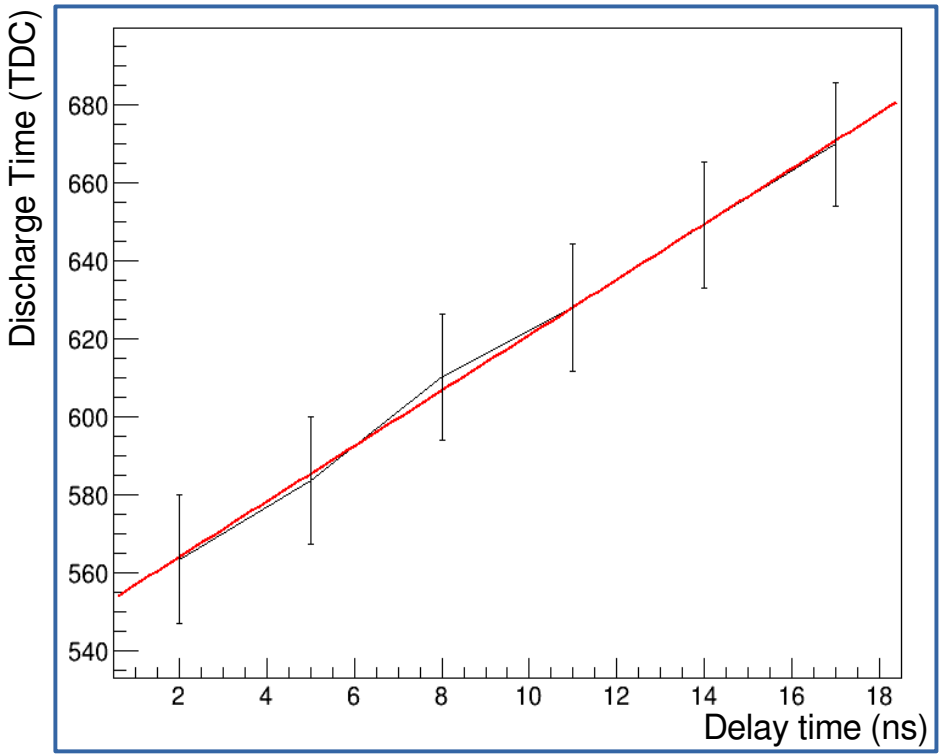


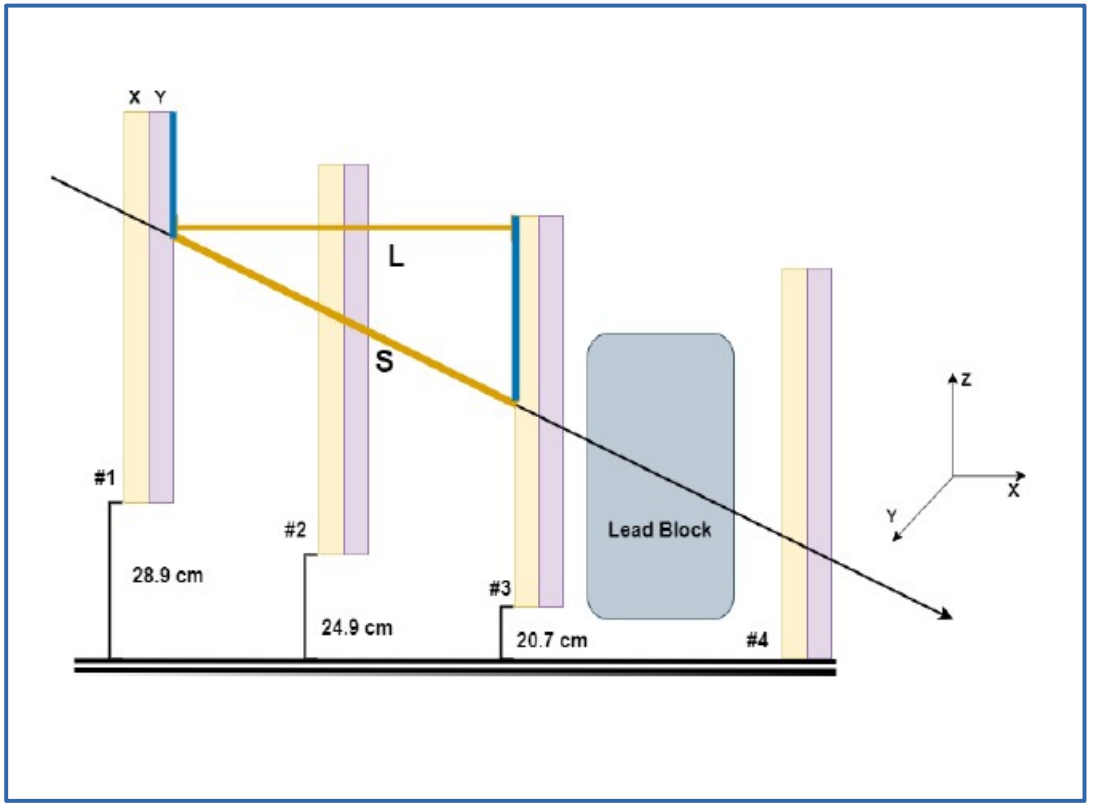
Figure : Correct Texp characterization of an electronic boards exhibiting linear behaviour

Texp Charaterization of the BLU boards results

Board #	E-factor (TDC/ns)	Intercept (TDC)
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

- For both NERO and ROSSO, the intercept results are not available; access only to the E-factors
- Moreover, no calibration results at all for Station 2 for ROSSO

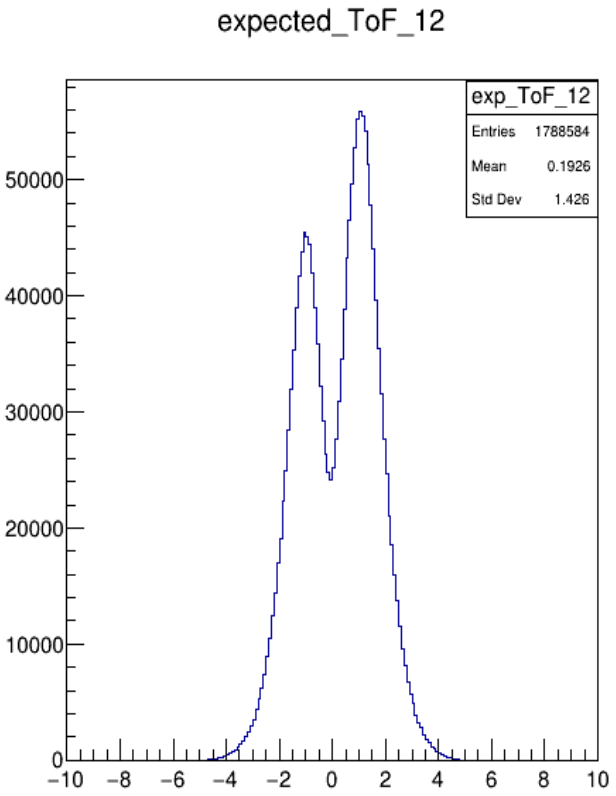
Expected Time of Flight (ToF_exp)

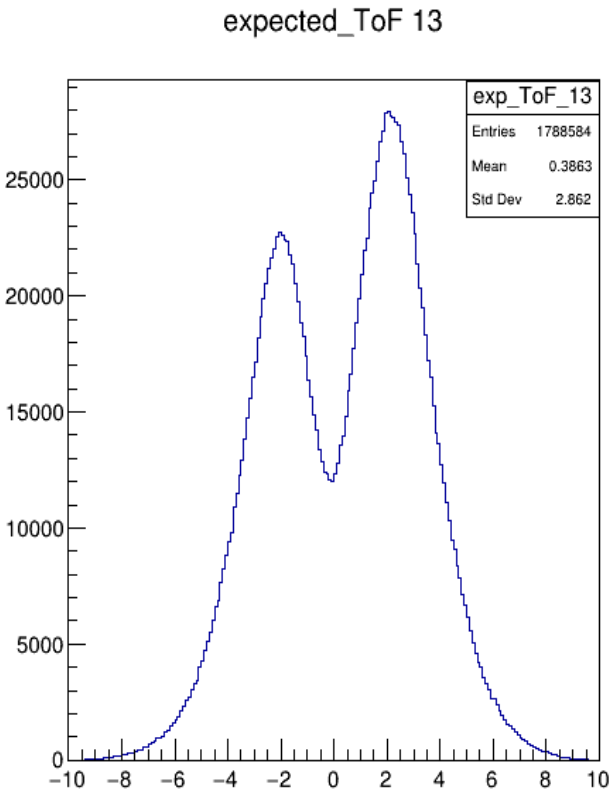


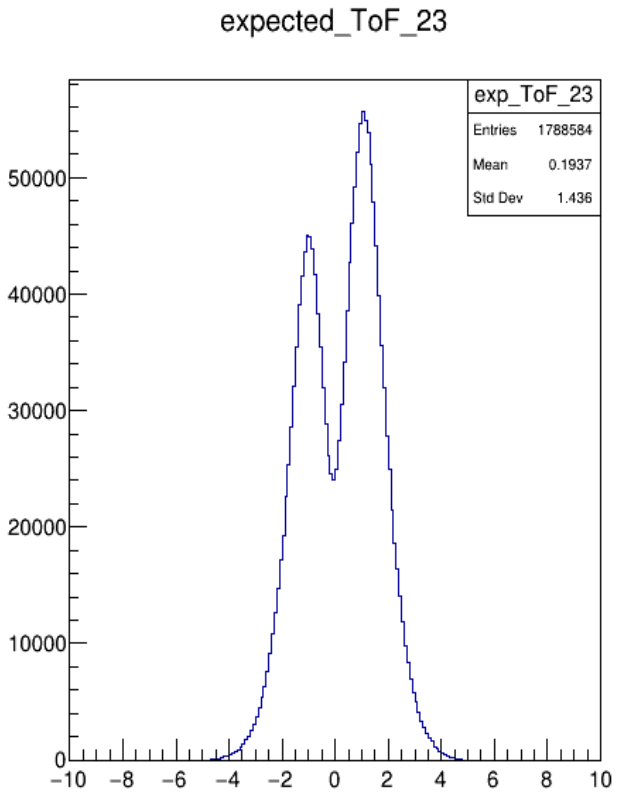
- Distance travelled by incoming muon between two chosen stations can be calculated based in the goemetry of the detector and the θ and φ information of the reconstructed track
- With speed of light (*c*), one can easily compute expected ToF using

  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

Expected Time of Flight (ToF_exp)



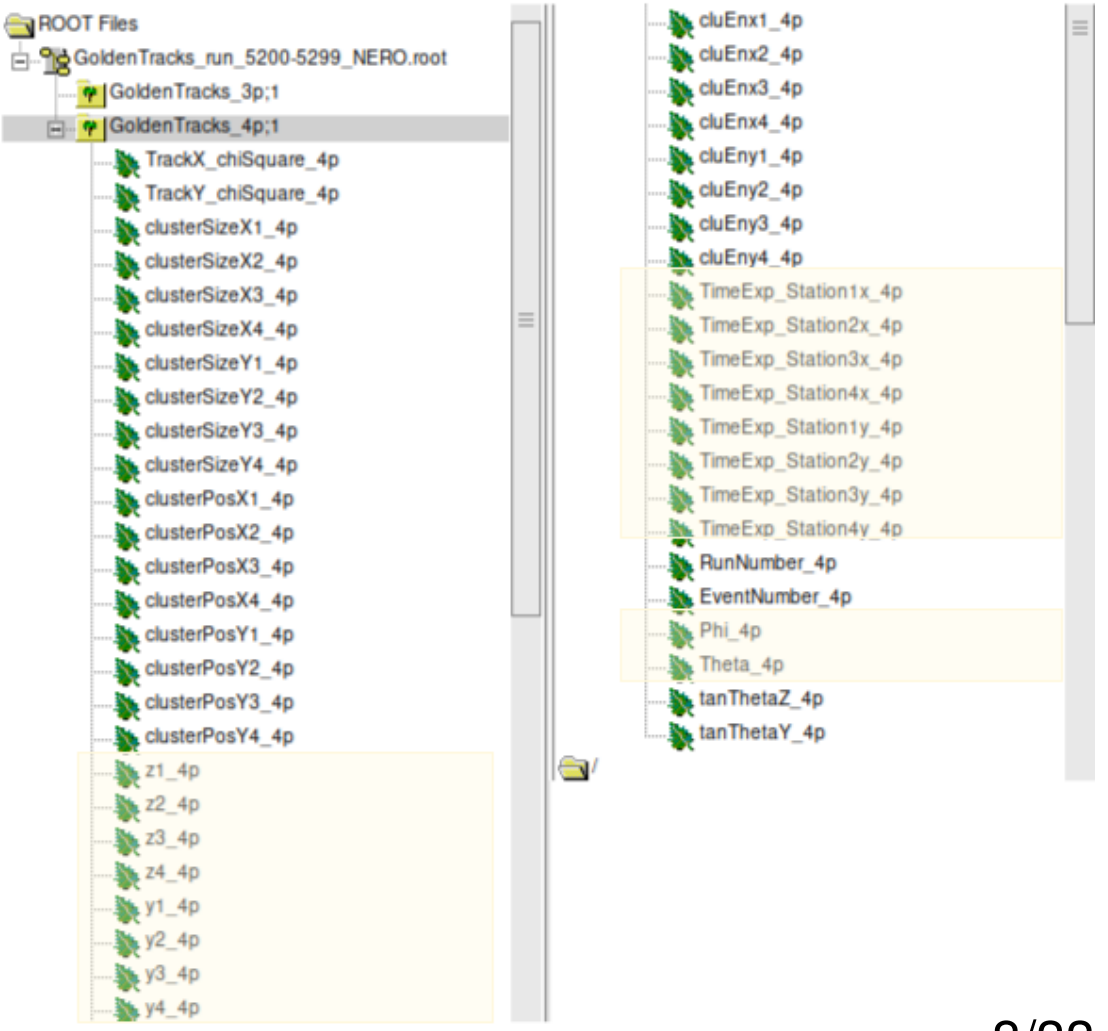




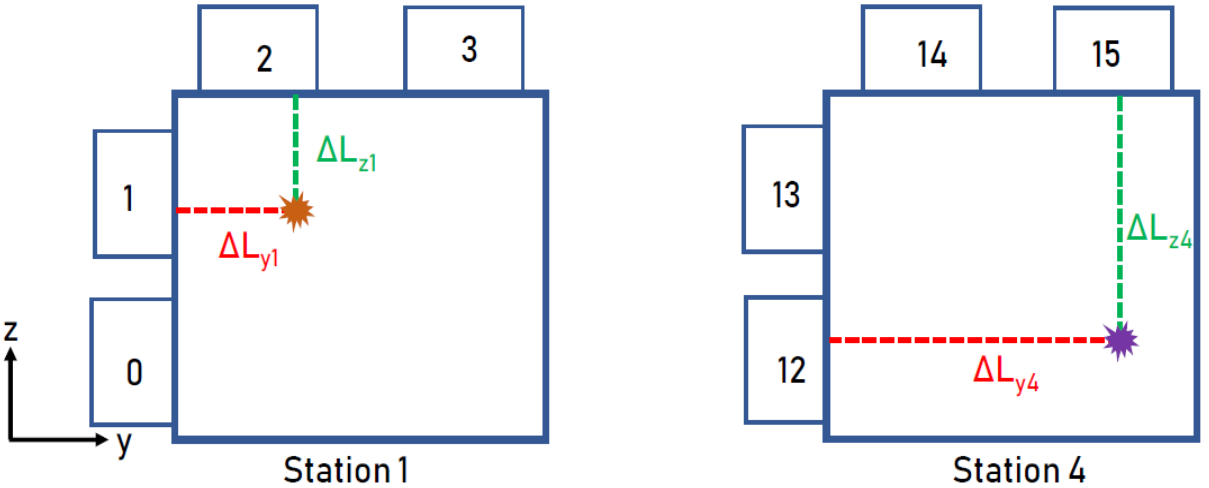
Example of expected ToF using hit-position information and including fibre delay for NERO

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)

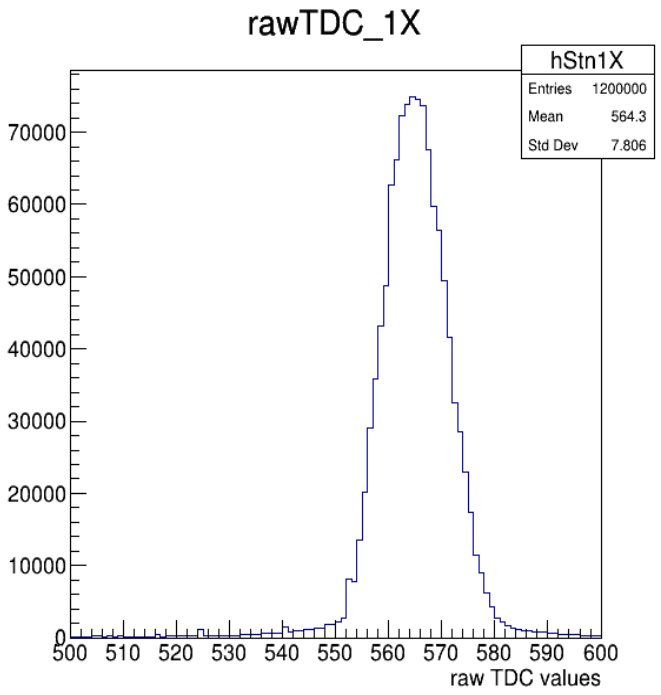


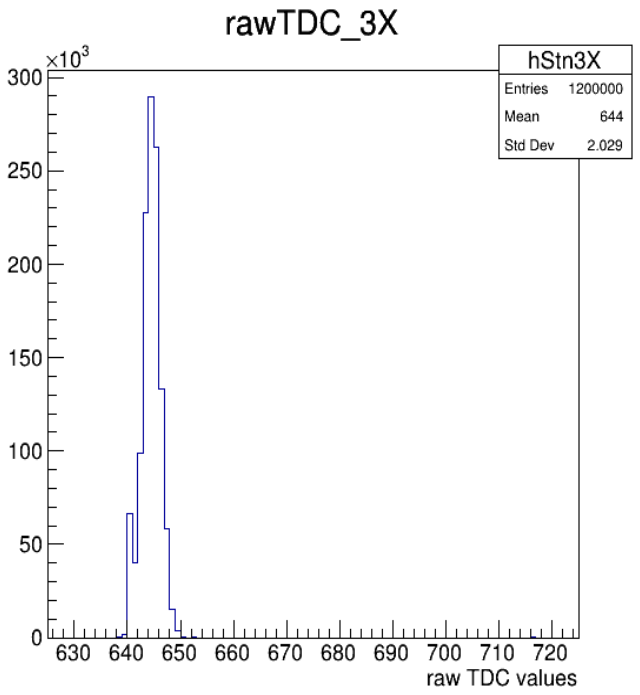
For XX view : $$ToF_X = \left(\frac{(T_{1X} - T_1^0)}{E_1} + \frac{\Delta L_{y1}}{\vartheta_{fiber}}\right) - \left(\frac{(T_{4X} - T_4^0)}{E_4} + \frac{\Delta L_{y4}}{\vartheta_{fiber}}\right)$$

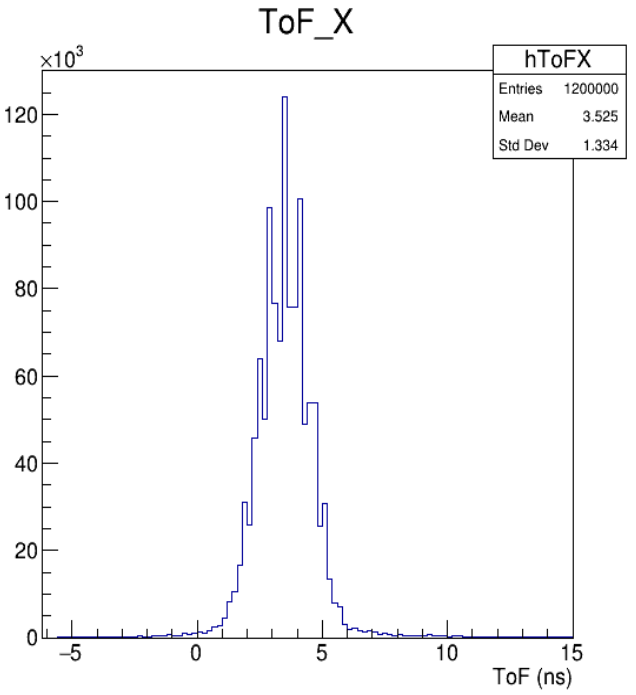
For YY view : $$ToF_Y = \left(\frac{(T_{1Y} - T_1^0)}{E_1} + \frac{\Delta L_{z1}}{\vartheta_{fiber}}\right) - \left(\frac{(T_{4Y} - T_4^0)}{E_4} + \frac{\Delta L_{z4}}{\vartheta_{fiber}}\right)$$

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

Measured Time of Flight (ToF_mes)



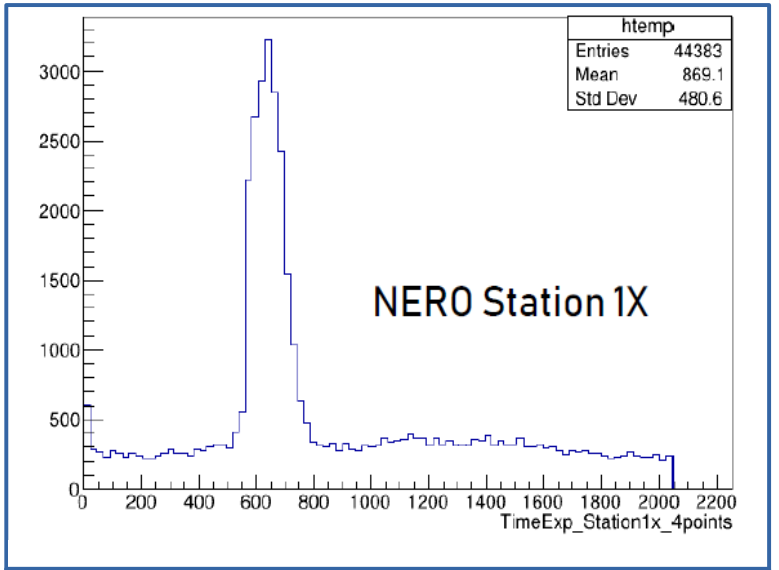


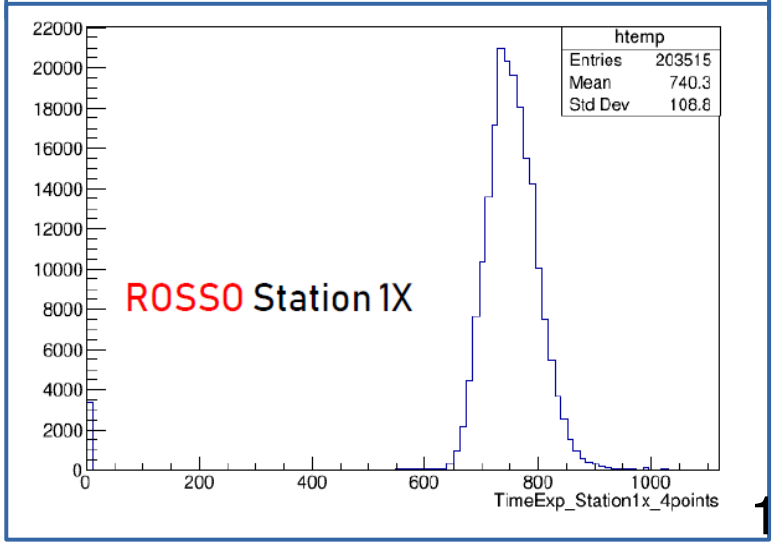


Example of meaured ToF using TDC information and Texp calibration results

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)





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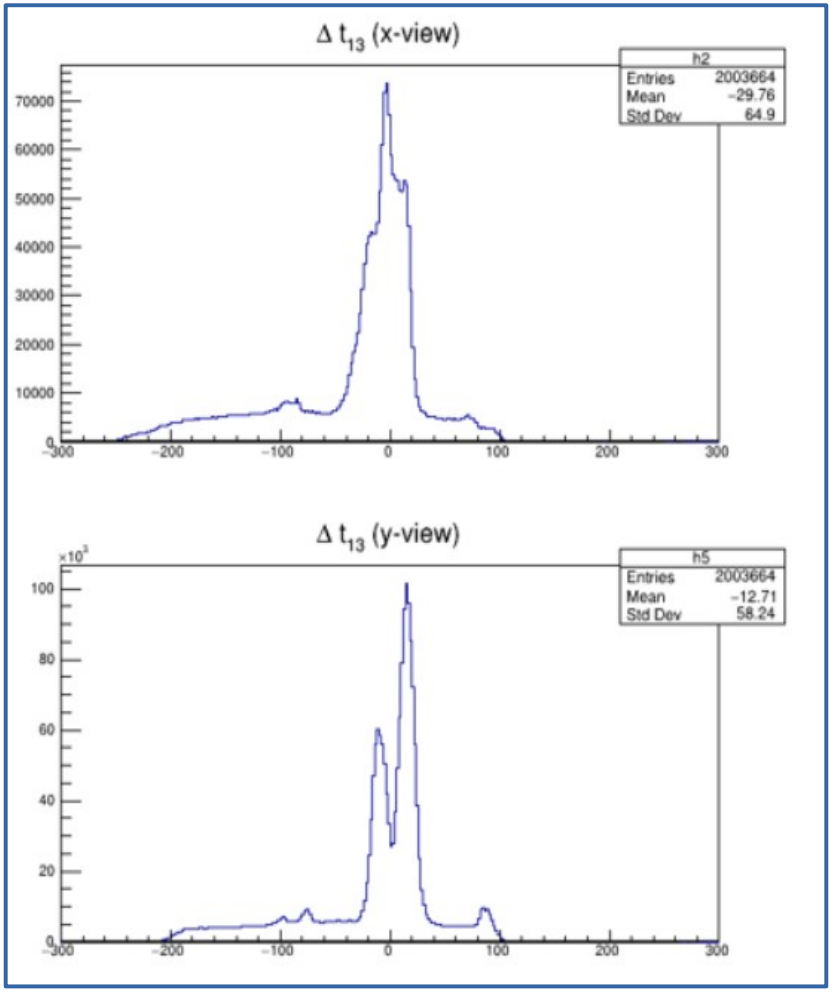
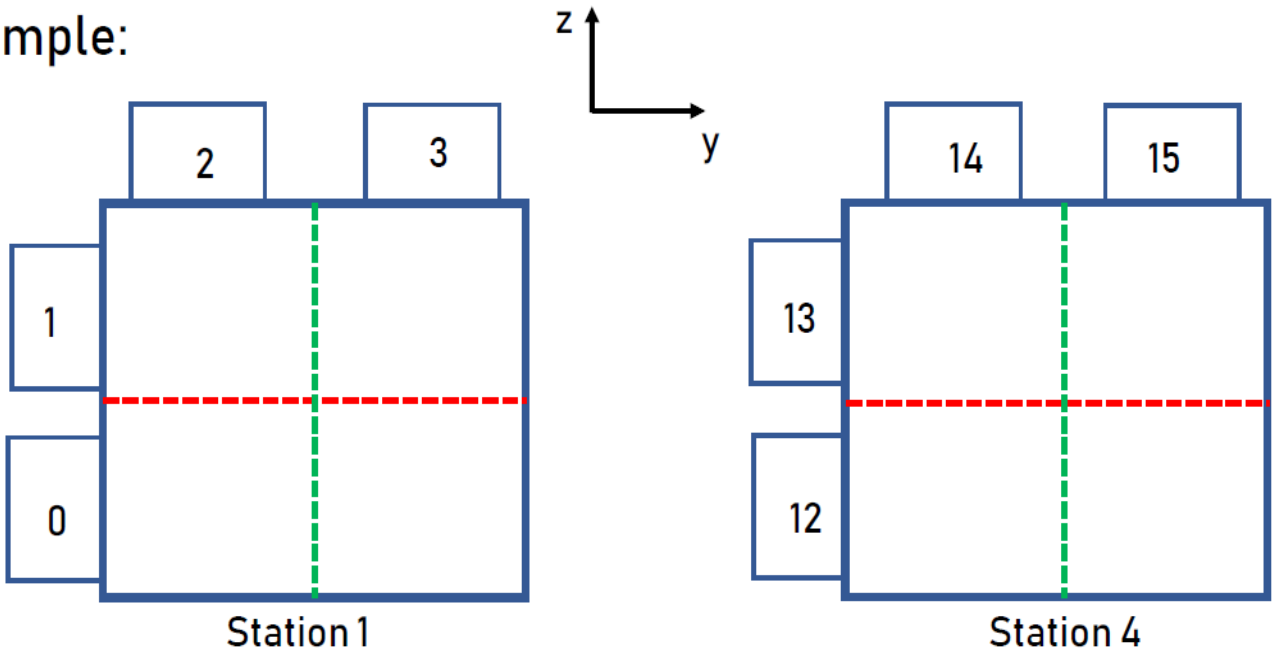


Measured ToFs between Stn#1 and Stn#3 for NERO in X and Y views

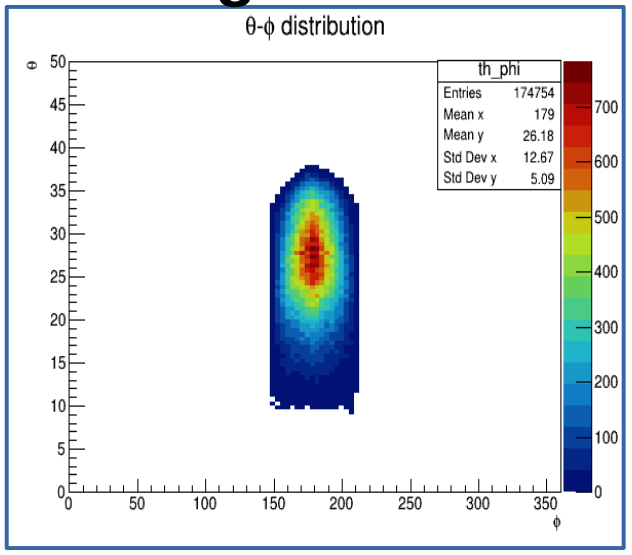
Dividing the detector planes in various regions (BLU lab data)

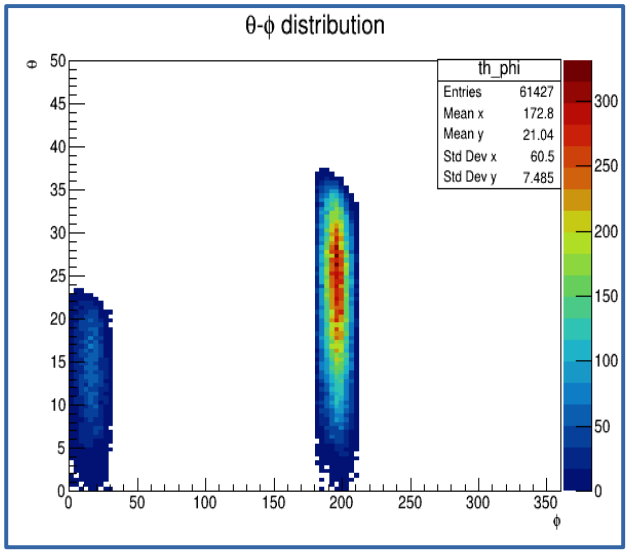
Example:

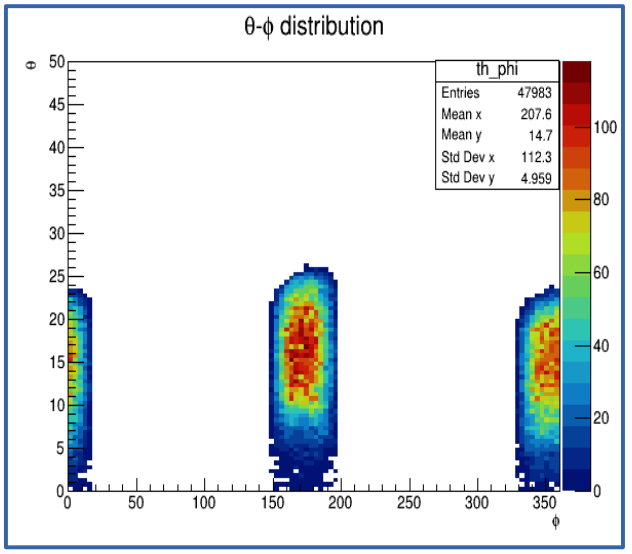


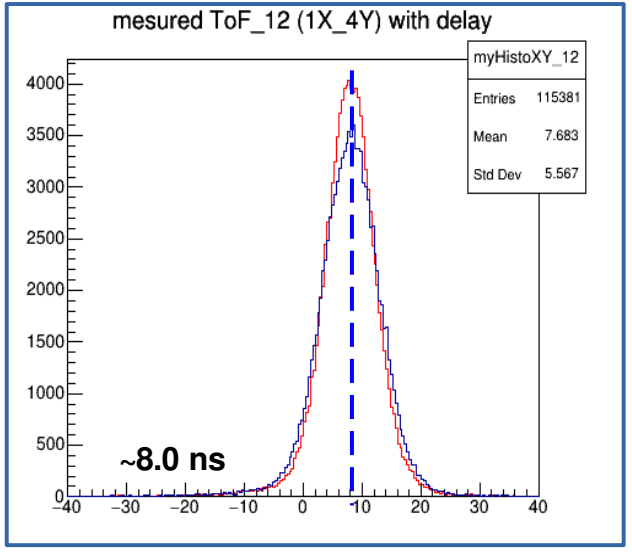
XX – boards	YY – boards	XY – boards	YX – boards
✓ 0-12	✓ 2-14	✓ 0-14	✓ 2-12
✓ 0-13	✓ 2-15	✓ 0-15	✓ 2-13
✓ 1-12	✓ 3-14	✓ 1-14	✓ 3-12
✓ 1-13	✓ 3-15	✓ 1-15	✓ 3-13

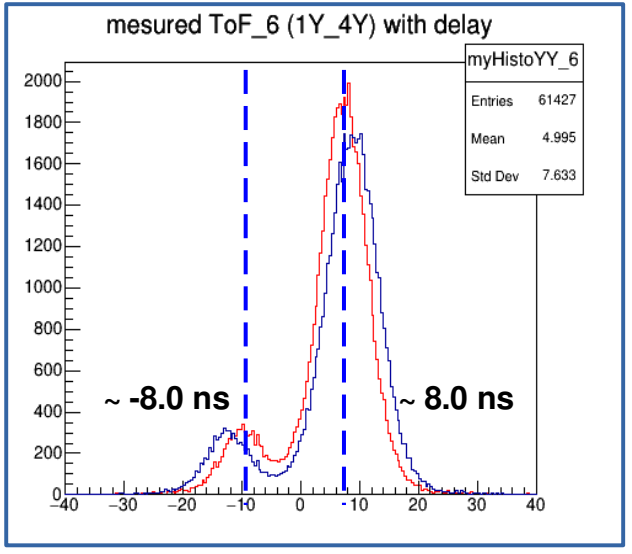
Dividing the detector planes in various regions

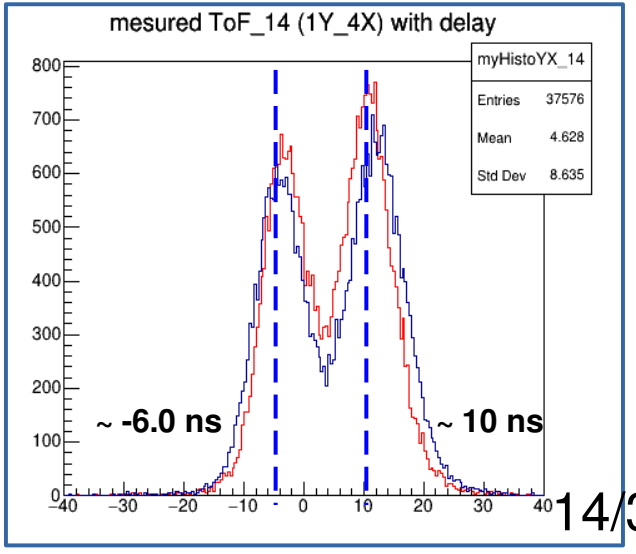












Dividing the detector planes in various regions

Single Peak Feature
- 8 ToF distributions in total

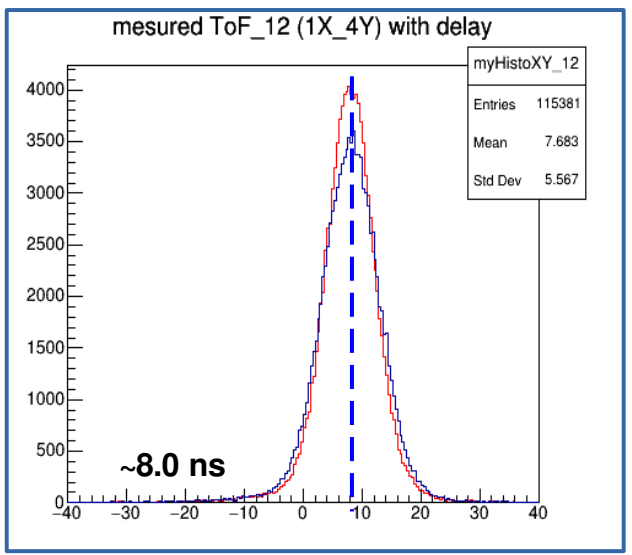
- 4 with XX boards combination
- 2 with XY boards combination
- 2 with YX boards combination

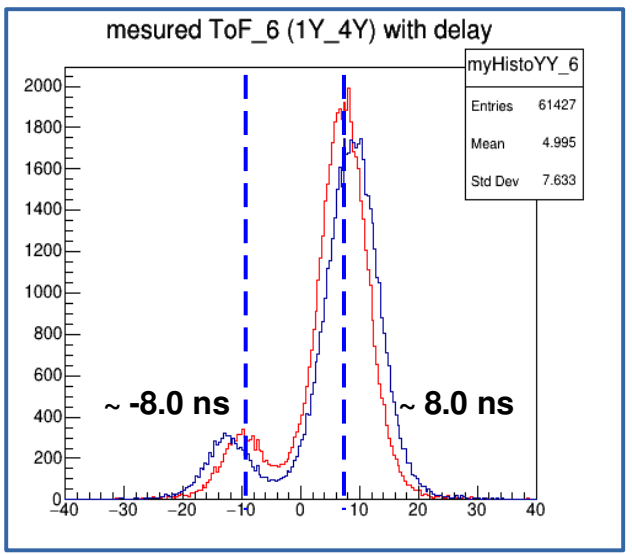
Single Peak with "Shoulder "Feature
- 4 ToF distributions in total

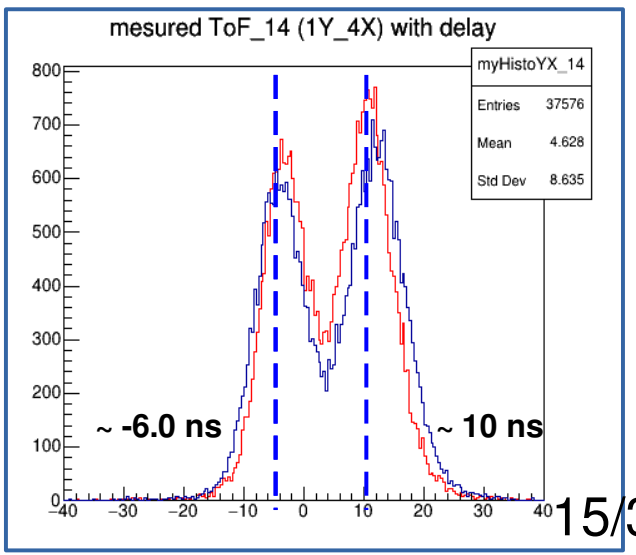
- All 4 with YY boards combination

Double Peaks Feature
- 4 ToF distributions in total

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







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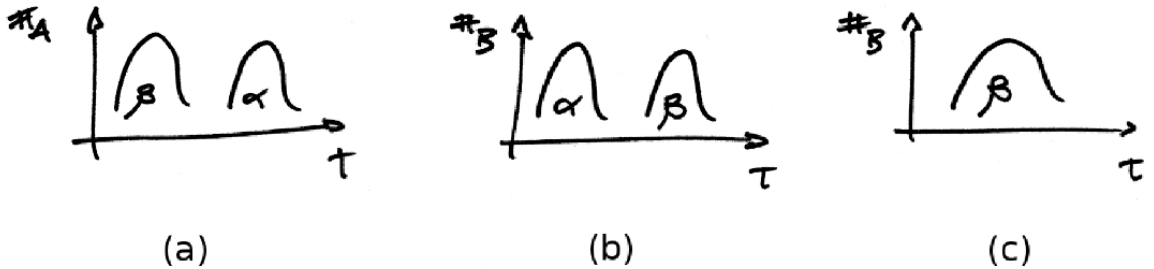
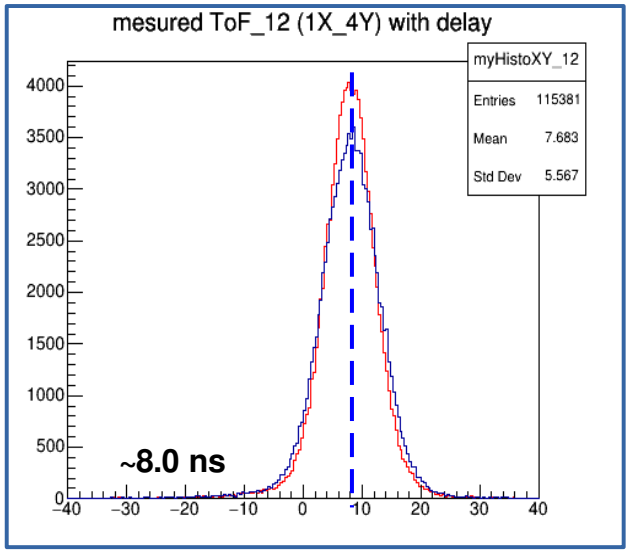
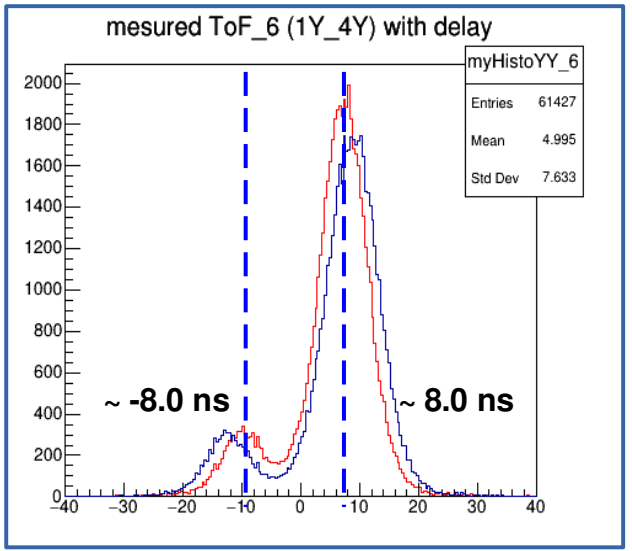
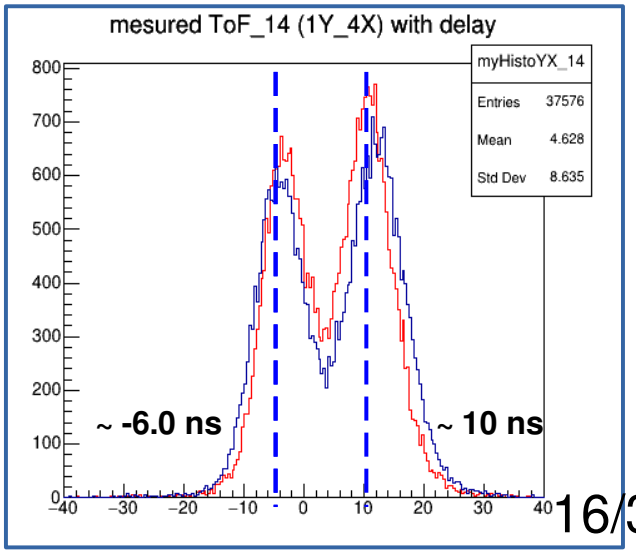


- Similar behavior in the shapes of measured ToFs is expected, as confirmed by Gigi's thesis
- Horizontal vs transverse (steep) tracks not quantified; the thesis qualitatively describes these

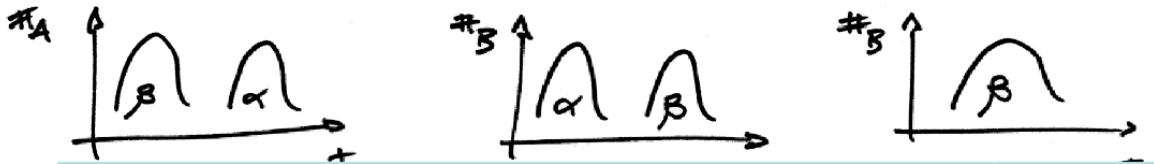
Figure 4.6.: Expected distributions for the plane A (a) and for the plane B for horizontal (b) and transverse (c) tracks. .







Dividing the detector planes in various regions



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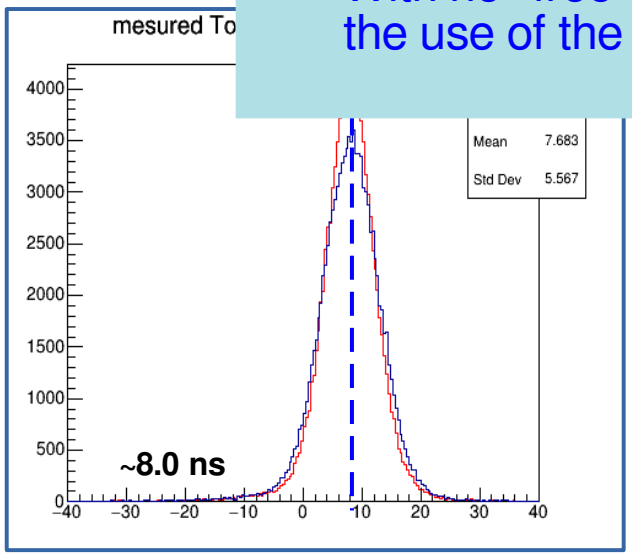
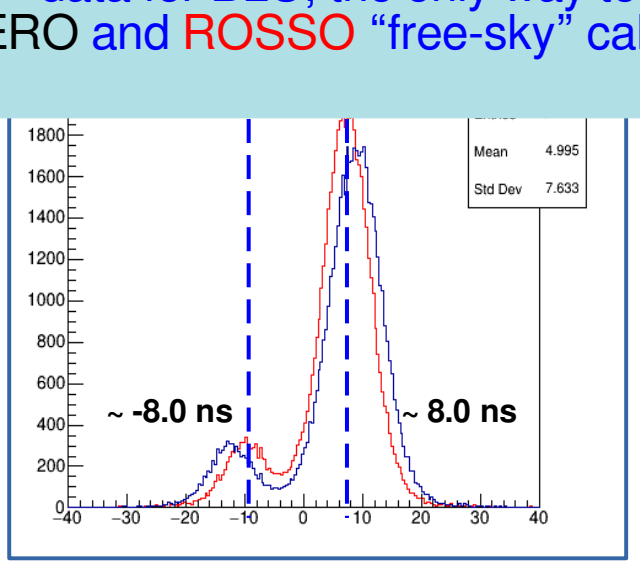
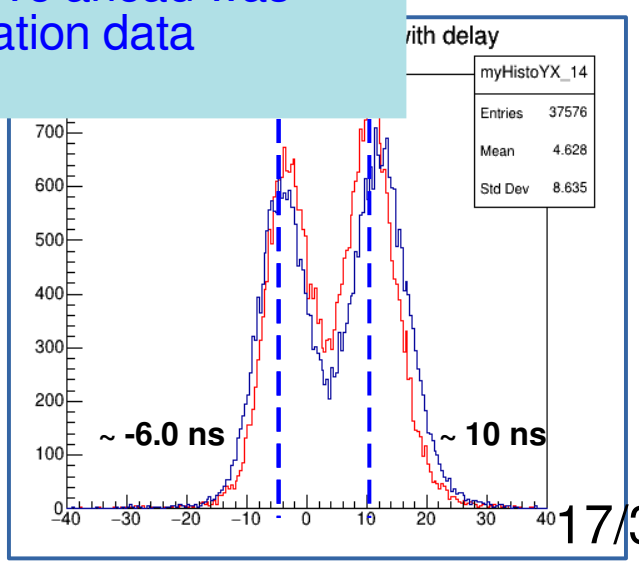
- Promising results from BLU data when using the intercept values!!
- But unfortunately, we lack those intercept values from the Texp calibrations for NERO and ROSSO boards.
- With no "free-sky" data for BLU, the only way to move ahead was the use of the NERO and ROSSO "free-sky" calibration data

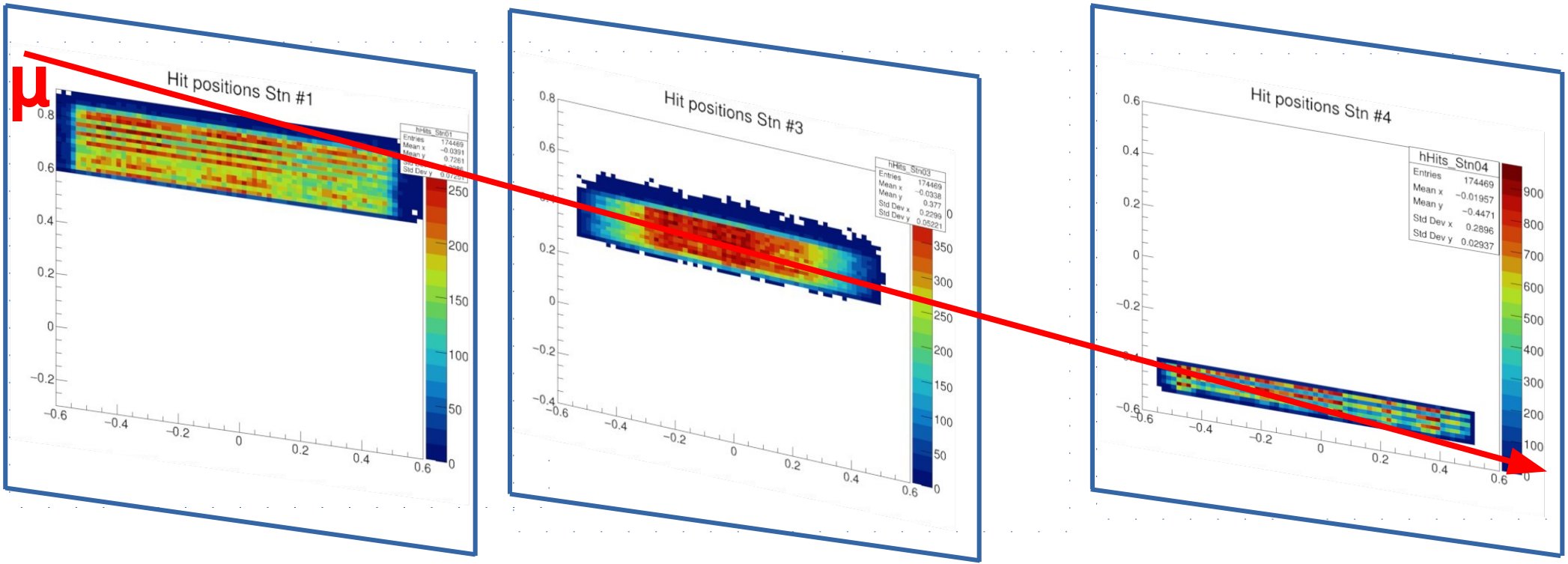
Figure 4.6.:





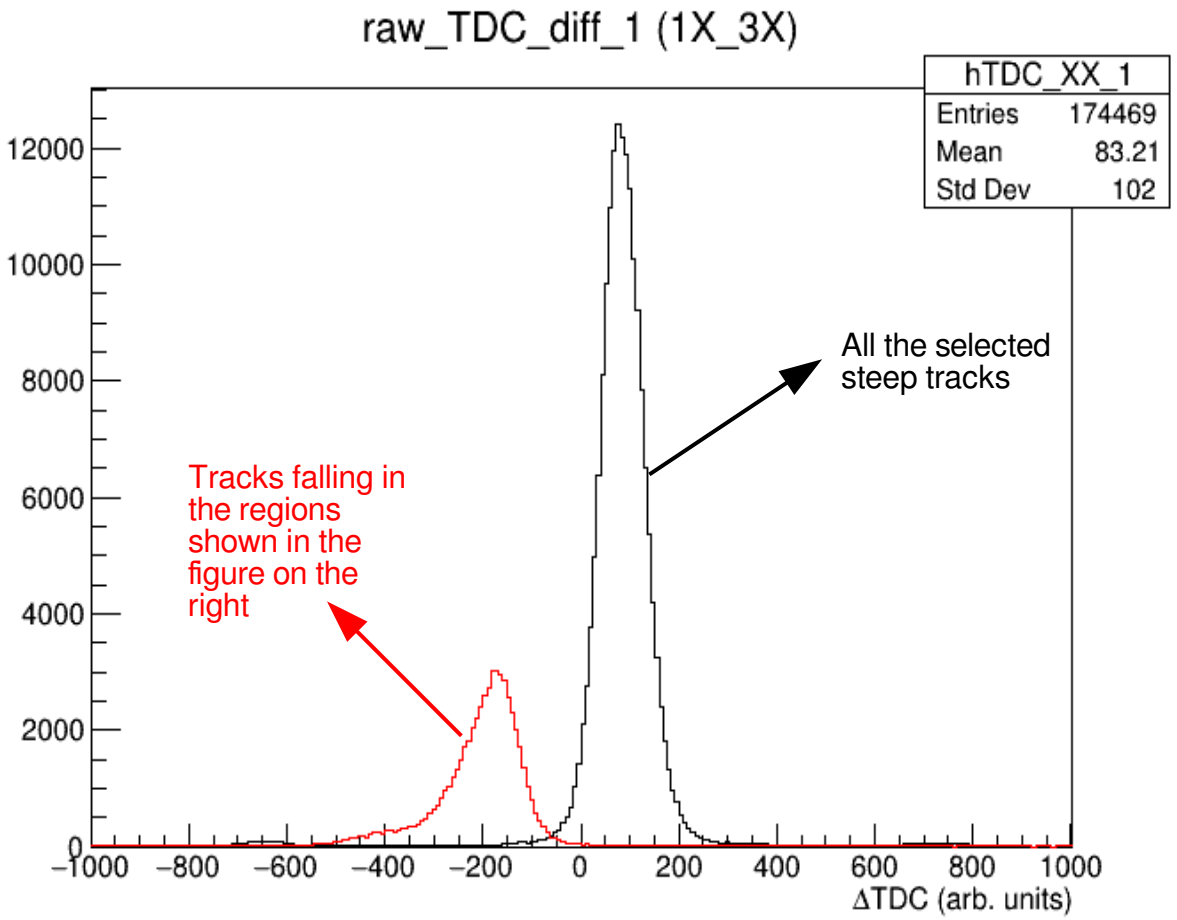


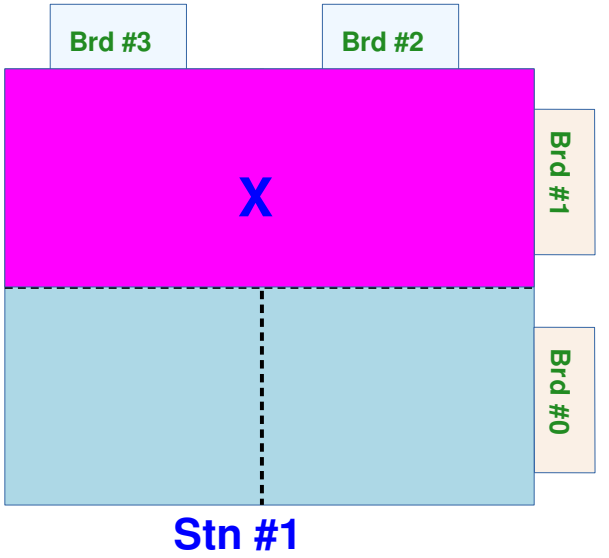
Use of ‘free-sky’ calibration data, aiming to deal with the ToF issues

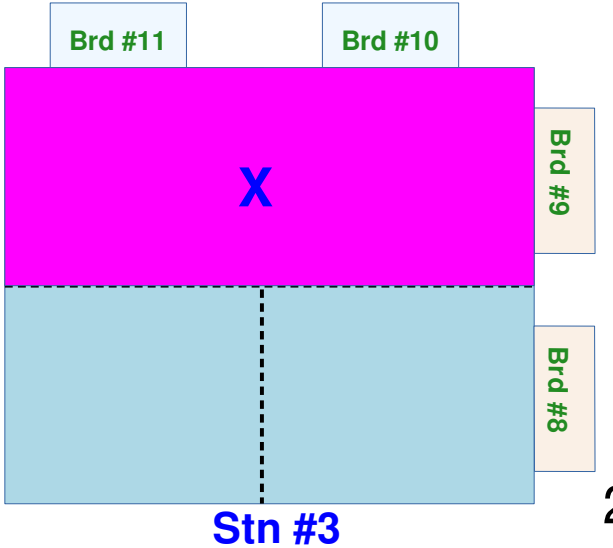


Steep Track Selection

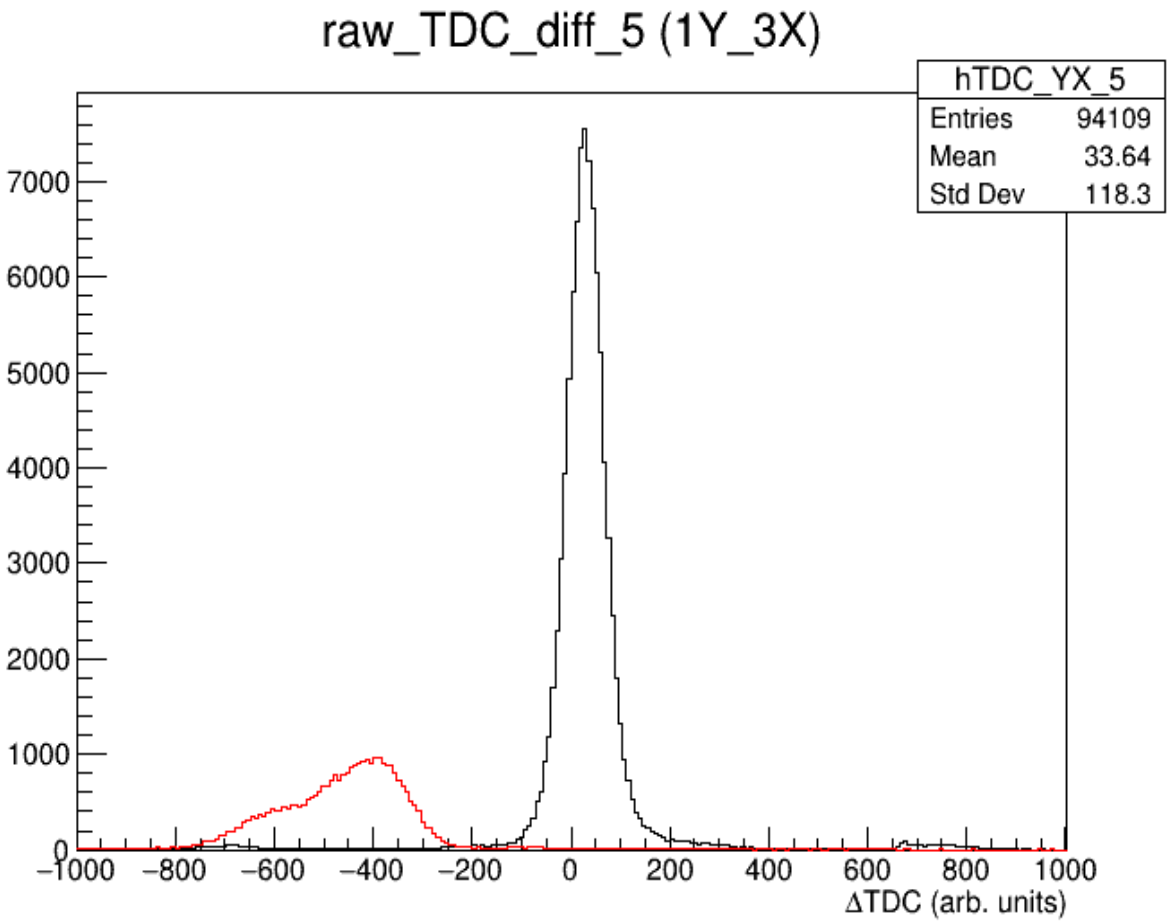
Raw TDC Difference (Stns #1 and 3)

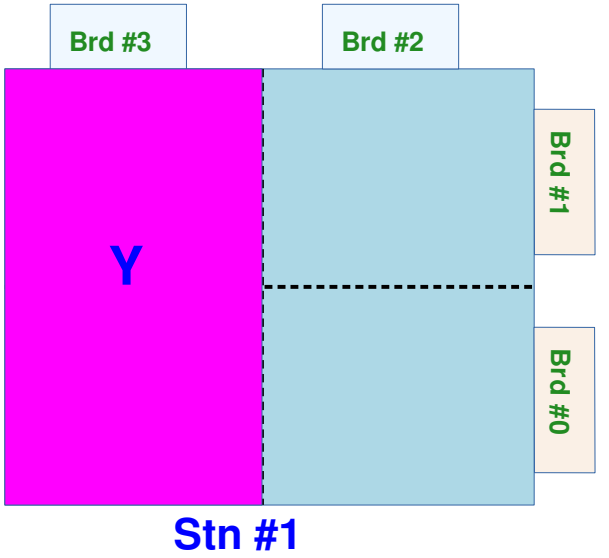


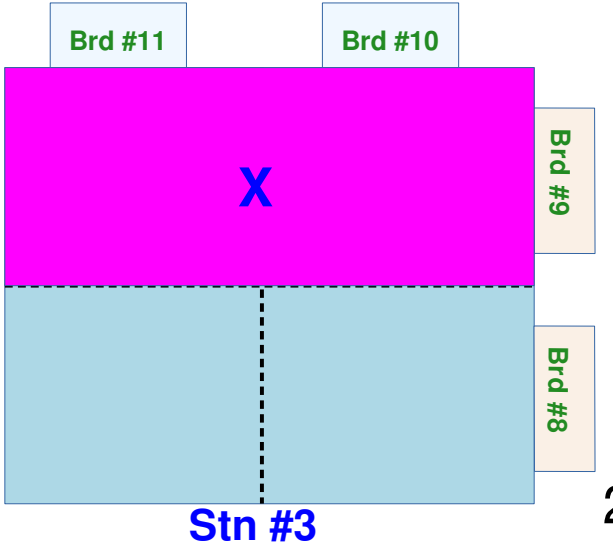




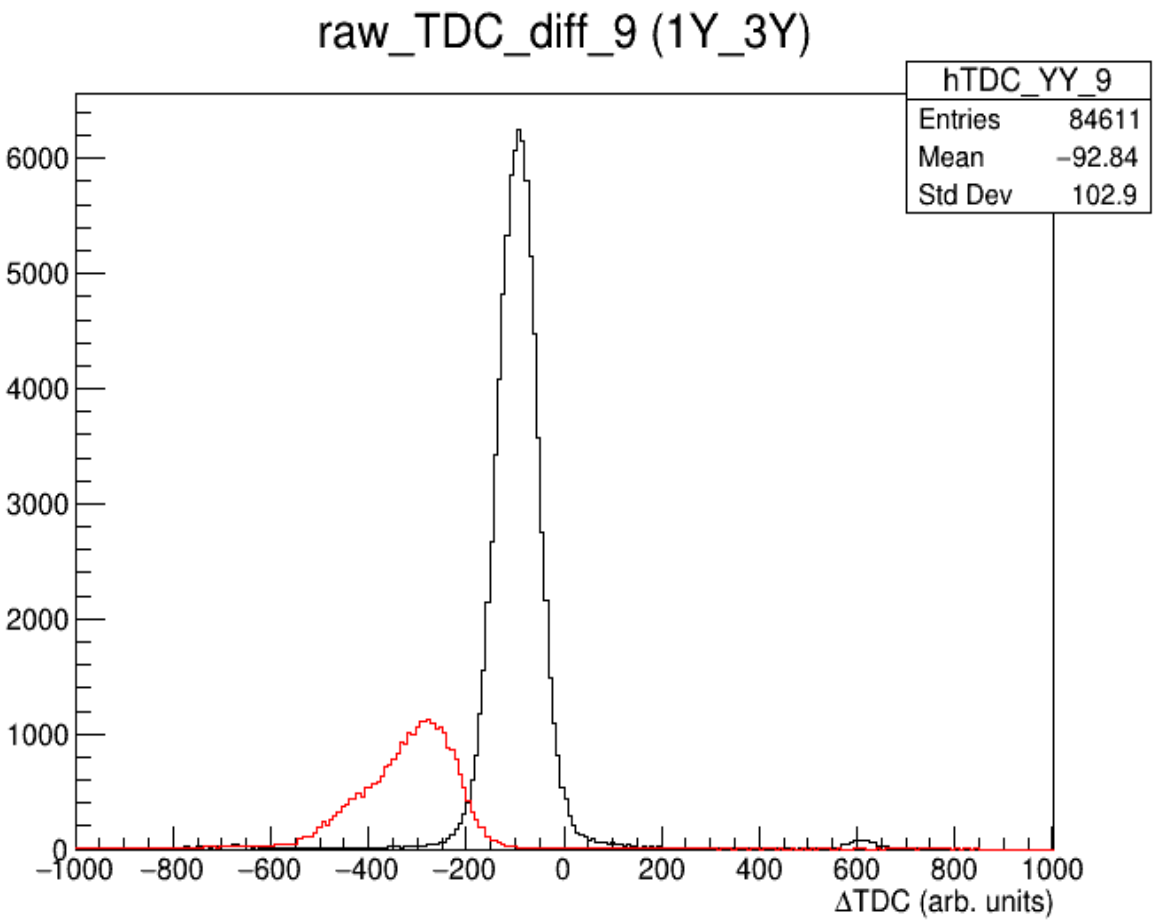
Raw TDC Difference (Stns #1 and 3)

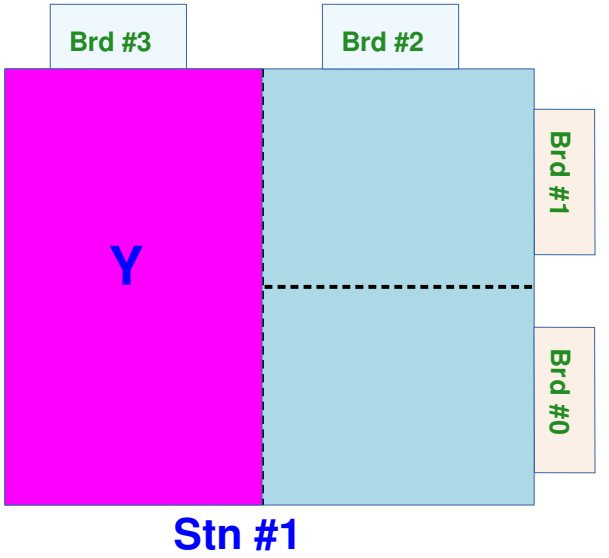


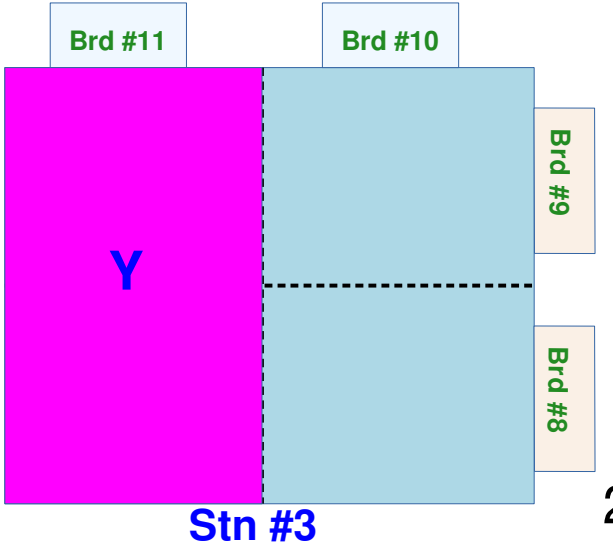




Raw TDC Difference (Stns #1 and 3)

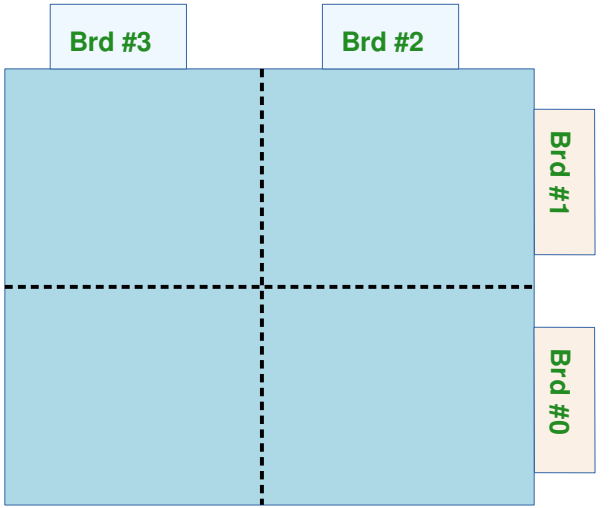




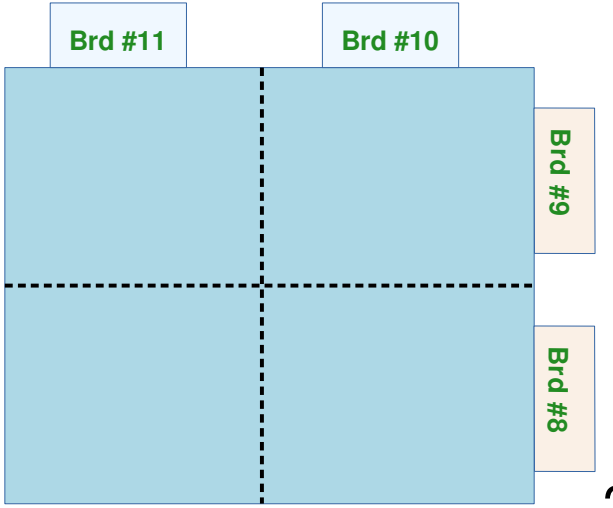


Raw TDC Difference (Stns #1 and 3)

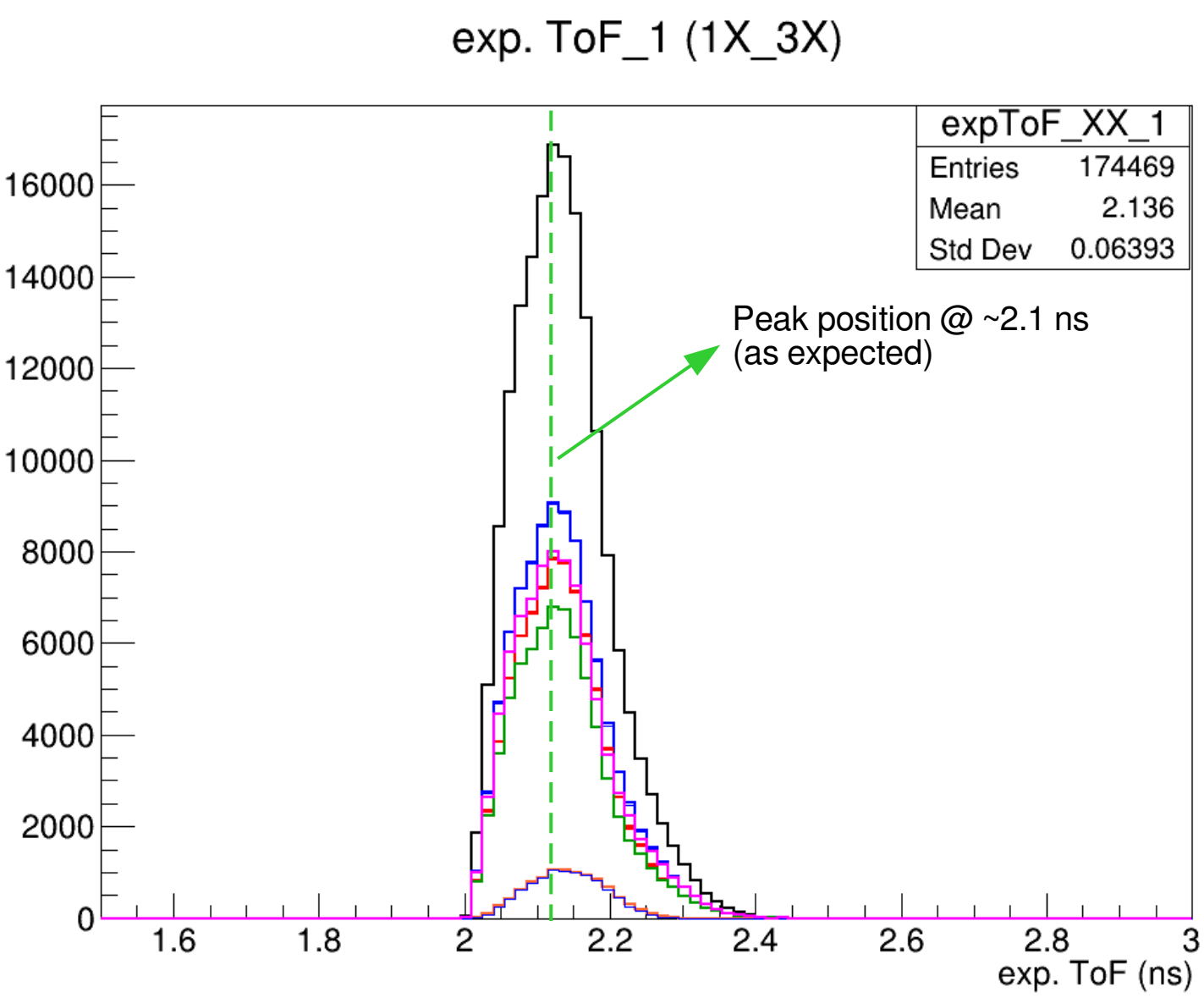
Regions	Boards Involved	Raw TDC Difference	
		ROSSO	NERO
1	#1 & #9	-197.1	83.2
2	#1 & #10	-130.8	18.3
3	#1 & #11	-64.0	-42.1
4	#2 & #9	-106.0	192.1
5	#3 & #9	-453.2	33.6
6	#2 & #10	-49.2	126.6
7	#2 & #11	-20.6	72.1
8	#3 & #10	-402.4	-21.7
9	#3 & #11	-320.0	-92.8



Stn #1



Stn #3

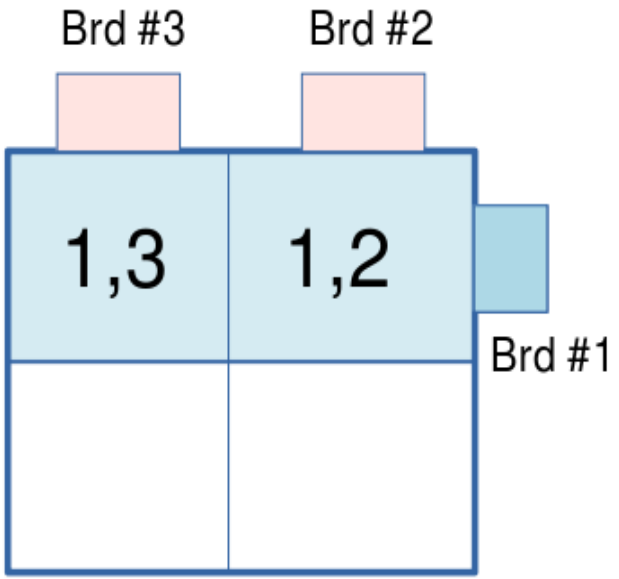


- All the expected ToF distributions between stns #1 and #3 is ~2.1 ns (horizontal distance between stns #1 and #3 is ~0.53m, corresponding to ~1.8 ns)
- The idea is to use exp. ToF as a proxy for measured ToF, on an event-by-event basis to gain information about missing intercept values

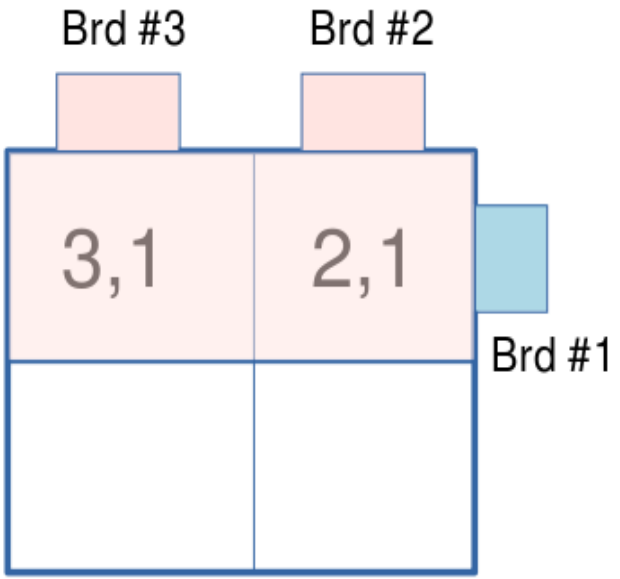
Note that exp. ToF distributions only has “single” peak feature

The Overlap Region

The events in a certain region can be analyzed with X-board Texp calibrations results **OR** with Y-board results

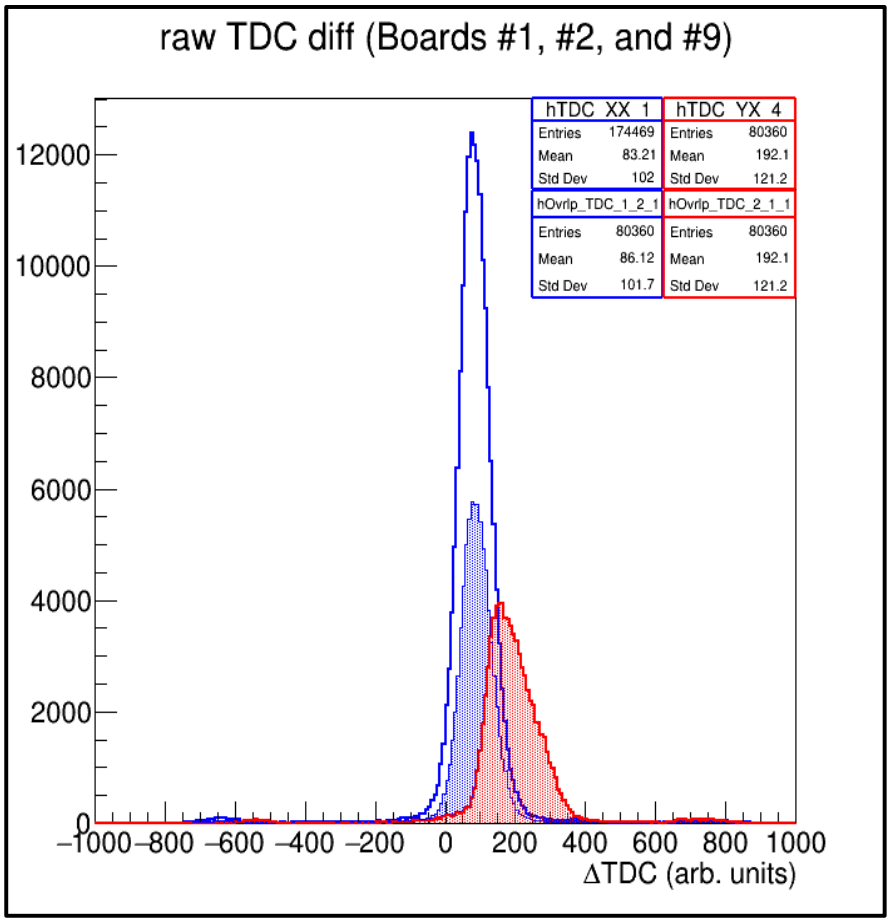


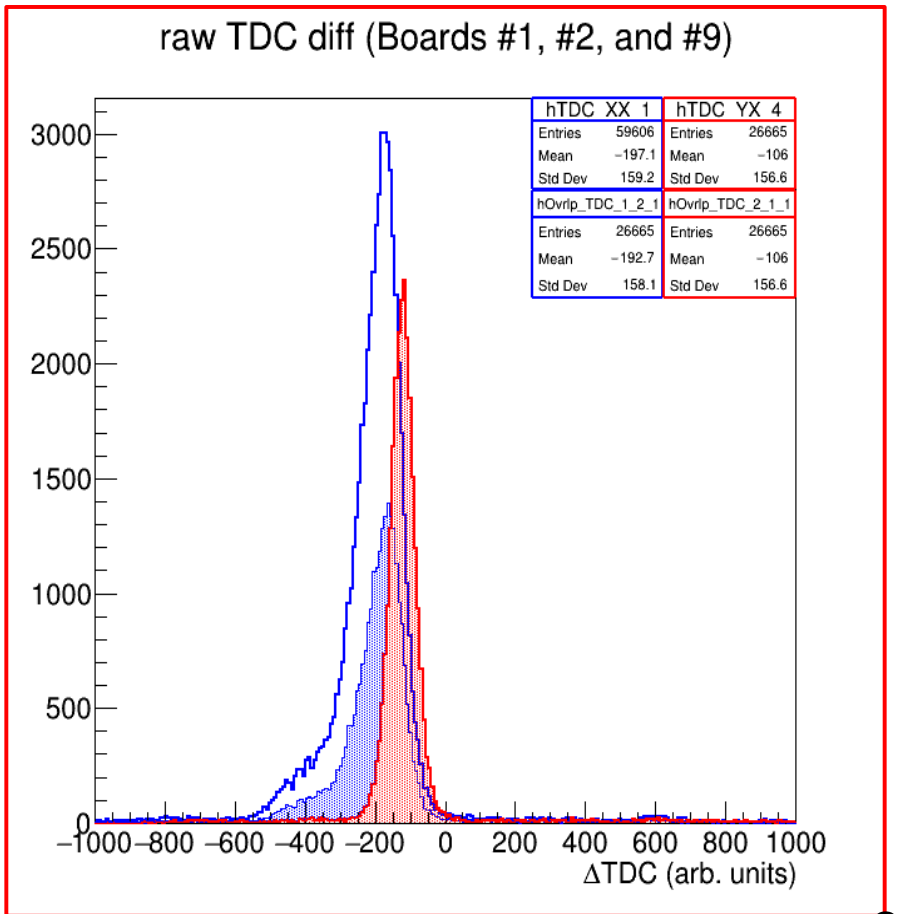
With X-board results



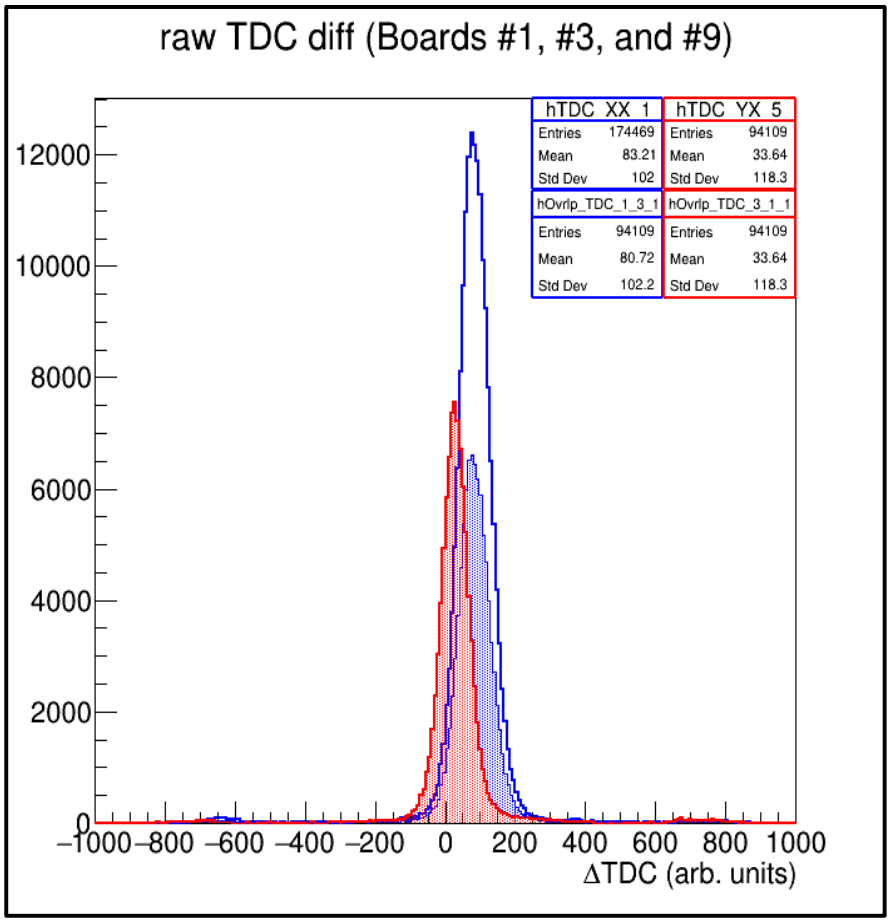
With Y-board results

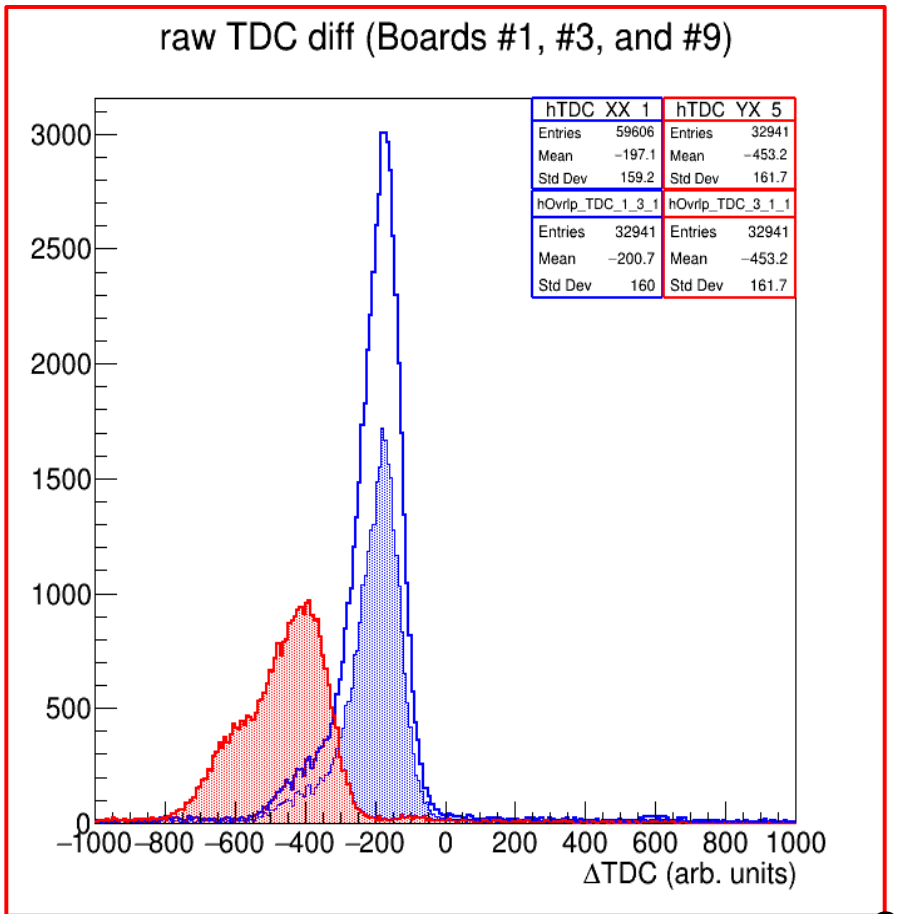
Boards 1, 2, and 9





Boards 1, 3, and 9

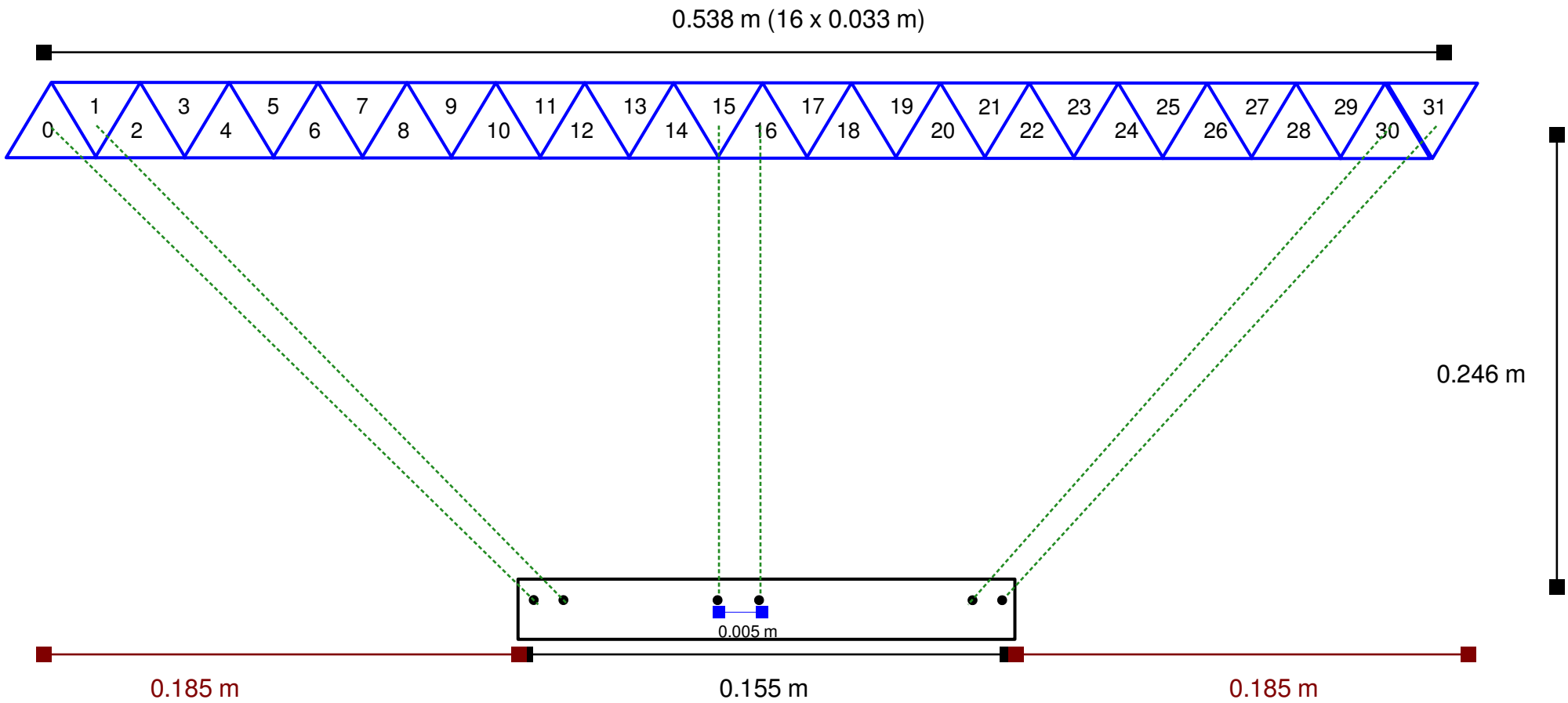




	Boards Combination	NERO						
		TDC diff. (counts)			Delay term (ns)			
		Blank Blue	Shaded Blue	Shaded Red	Blank Blue	Shaded Blue	Shaded Red	
Stns 1 v 3	1-2 (9 fixed)	83.2	86.1	192.1	7.1	5.1	-21.0	ΔTDC = -5.4 counts Δ delay = 3.6 ns
	1-3 (9 fixed)	83.2	80.7	33.6	7.1	8.7	3.1	
Stns 2 v 3	5-6 (9 fixed)	32.7	53.5	48.1	-2.4	-2.9	14.2	ΔTDC = -1.1 counts Δ delay = 0.8 ns
	5-7 (9 fixed)	32.7	52.4	138.2	-2.4	-2.1	-14.6	
Stns 3 v 1	9-10 (1 fixed)	83.2	84.7	18.4	7.1	5.8	5.5	ΔTDC = -2.8 counts Δ delay = 2.3 ns
	9-11 (1 fixed)	83.2	81.9	-42.1	7.1	8.1	14.3	
Stns 2 v 1	5-6 (1 fixed)	52.8	53.5	39.9	7.4	7.0	0.9	ΔTDC = -0.6 counts Δ delay = 0.6 ns
	5-7 (1 fixed)	52.8	52.9	-54.5	7.4	7.6	19.2	

	Boards Combination	ROSSO						
		TDC diff. (counts)			Delay term (ns)			
		Blank Blue	Shaded Blue	Shaded Red	Blank Blue	Shaded Blue	Shaded Red	
Stns 1 v 3	1-2 (9 fixed)	-197.1	-192.7	-106.0	16.5	14.4	0.4	ΔTDC = **-8.0** counts Δ delay = 3.5 ns
	1-3 (9 fixed)	-197.1	-200.7	-453.2	16.5	18.1	56.0	
Stns 2 v 3	5-6 (9 fixed)	313.2	-521.6	-272.2	n/a	n/a	n/a	ΔTDC = **-11.5** counts Δ delay = n/a
	5-7 (9 fixed)	313.2	-533.1	596.7	n/a	n/a	n/a	
Stns 3 v 1	9-10 (1 fixed)	-197.1	-193.4	-130.8	16.5	14.9	5.3	ΔTDC = **-6.7** counts Δ delay = 2.8 ns
	9-11 (1 fixed)	-197.1	-200.1	-64.0	16.5	17.7	2.5	
Stns 2 v 1	5-6 (1 fixed)	-528.0	-521.6	-461.1	n/a	n/a	n/a	ΔTDC = **-11.5** counts Δ delay = n/a
	5-7 (1 fixed)	-528.0	-533.1	-493.5	n/a	n/a	n/a	

Additional correction to fiber delays



Not drawn to scale

	Boards Combination	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 **(8.6)**	5.1 **(6.7)**	-21.0 **(-20.3)**	
Stns 1 v 3	**1-3 (9 fixed)**	83.2	80.7	33.6	7.1 **(8.6)**	8.7 **(10.1)**	3.1 **(4.5)**	ΔTDC = **-5.4** counts Δ delay = 3.6 ns **(3.4 ns)**
	5-6 (9 fixed)	32.7	53.5	48.1	-2.4 **(1.1)**	-2.9 **(-2.7)**	14.2 **(16.1)**	
Stns 2 v 3	**5-7 (9 fixed)**	32.7	52.4	138.2	-2.4 **(1.1)**	-2.1 **(-1.8)**	-14.6 **(-13.8)**	ΔTDC = **-1.1** counts Δ delay = 0.8 ns **(0.9 ns)**
	9-10 (1 fixed)	83.2	84.7	18.4	7.1 **(8.6)**	5.8 **(6.1)**	5.5 **(6.3)**	
Stns 3 v 1	**9-11 (1 fixed)**	83.2	81.9	-42.1	7.1 **(8.6)**	8.1 **(8.8)**	14.3 **(16.0)**	ΔTDC = **-2.8** counts Δ delay = 2.3 ns **(2.7 ns)**
	5-6 (1 fixed)	52.8	53.5	39.9	7.4 **(8.7)**	7.0 **(8.3)**	0.9 **(1.6)**	
Stns 2 v 1	**5-7 (1 fixed)**	52.8	52.9	-54.5	7.4 **(8.7)**	7.6 **(8.8)**	19.2 **(21.4)**	ΔTDC = **-0.6** counts Δ delay = 0.6 ns **(0.5 ns)**

Note: New results after taking into account additional fiber delays are shown in the parenthesis.

	Boards Combination	ROSSO						
		TDC diff. (counts)			Delay term (ns)			
		Blank Blue	Shaded Blue	Shaded Red	Blank Blue	Shaded Blue	Shaded Red	
Stns 1 v 3	1-2 (9 fixed)	-197.1	-192.7	-106.0	16.5 (18.2)	14.4 (15.6)	0.4 (1.7)	ΔTDC = -8.0 counts Δ delay = 3.5 ns (3.8 ns)
	1-3 (9 fixed)	-197.1	-200.7	-453.2	16.5 (18.2)	18.1 (19.4)	56.0 (57.8)	
Stns 2 v 3	5-6 (9 fixed)	313.2	-521.6	-272.2	n/a	n/a	n/a	ΔTDC = -11.5 counts Δ delay = n/a
	5-7 (9 fixed)	313.2	-533.1	596.7	n/a	n/a	n/a	
Stns 3 v 1	9-10 (1 fixed)	-197.1	-193.4	-130.8	16.5 (18.2)	14.9 (15.4)	5.3 (6.7)	ΔTDC = -6.7 counts Δ delay = 2.8 ns (3.9 ns)
	9-11 (1 fixed)	-197.1	-200.1	-64.0	16.5 (18.2)	17.7 (19.3)	2.5 (3.3)	
	5-6 (1 fixed)	-528.0	-521.6	-461.1	n/a	n/a	n/a	
Stns 2 v 1	5-7 (1 fixed)	-528.0	-533.1	-493.5	n/a	n/a	n/a	ΔTDC = -11.5 counts Δ delay = n/a

SUMMARY

- Time Expansion (Texp) Calibration for BLU vs ROSSO and NERO

- Time of Flight (ToF) with MURAVES data
  - ✔ Most issues we were experiencing before with ROSSO and NERO data are not present in BLU data from the lab
  - ✔ Promising results showing the behaviors that are described in Gigi's thesis
  - ✔ Cannot perform similar analysis for ROSSO and NERO due to lack of proper calibration results

- In this talk, we sketched out a possible plan to make use of "free-sky" calibration data to deal with ToF issues, using ROSSO and NERO data (with more work on-going!!)

- Future work : need to verify our approach with BLU "free-sky" data since all the Texp variables are known for BLU and then, work towards extracting missing Texp calibration parameters ROSSO and NERO for so that complete ToF calibration can be performed