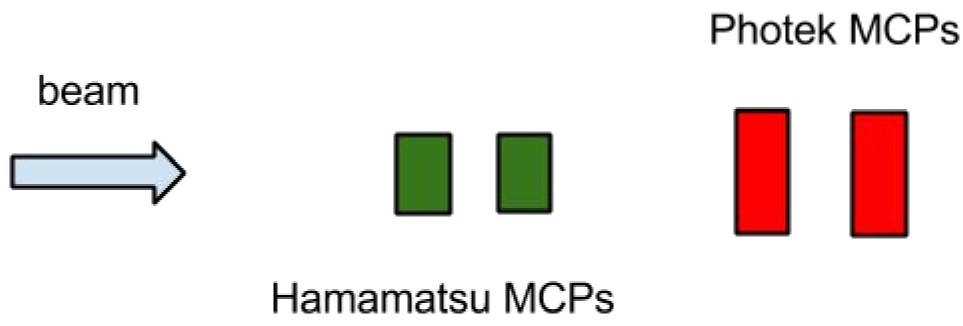
MCP TOF (No crystal)



(1) Beam -> | < Photek < Photek
TOF resolution about 20 ps

(2) Beam -> | < Ham < Ham
TOF resolution about 23 ps

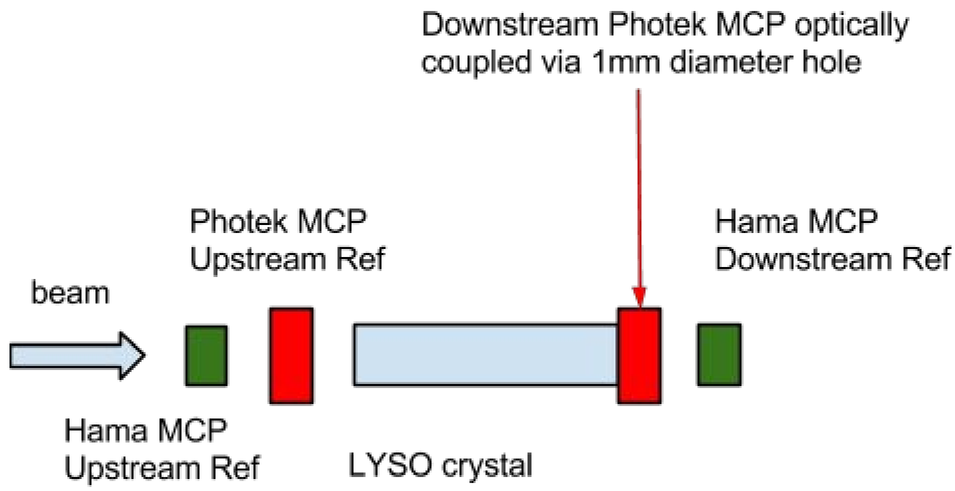
(3) Beam -> | <Ham < Ham < Photek < Photek
But Ham are turned off and not connected
TOF resolution on Photeks is about 22ps

(4) Beam -> | <Ham < Ham < Photek < Photek
Now Ham are turned on and connected. Photeks are connected to DRS via BNC cables instead of SMA cables (we used BNC-SMA adapters at the end)
TOF resolution on Photeks is about 31ps
TOF resolution on Hamamatsu is also 31ps

(5) Beam -> | Ham > < Ham Photek > < Photek
upstream photek and upstream hamamatsu are now facing away from the beam using SMA cables everywhere, but on one of the two photeks, and one of the two hamamatsu MCPs, we had to use 4 chained adapters in order to get the right cable connections.
TOF resolution on Photeks is about 26ps
TOF resolution on Hamamatsu is also 28ps

Beam Along Crystal

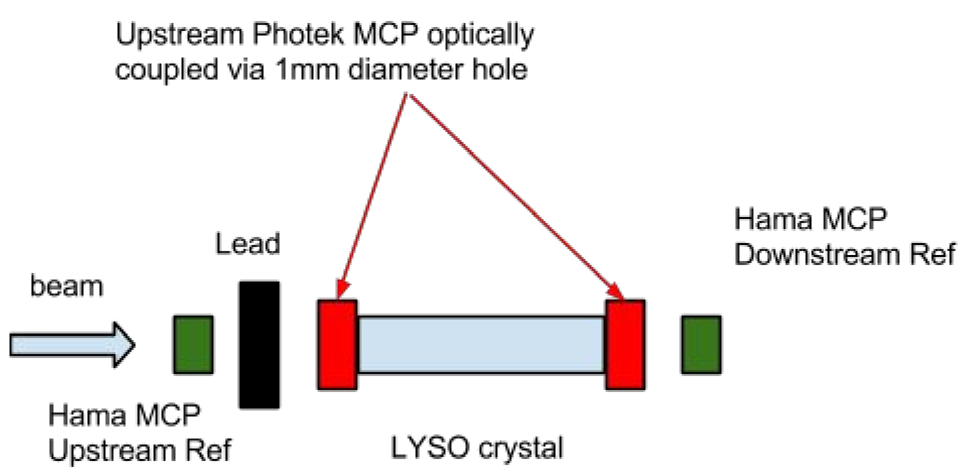
(1) beam -> | < hama | < photek | crystal < mounted photek | < hama |



only the downstream photek is optically coupled to the crystal
optical coupling to the photek had one edge with leakage (it was not taped well), so some pulses were of the multiple overlapping photon type

TOF resolution Photeks (120 GeV protons) : 40ps
TOF resolution Photeks (8 GeV electron) : 35ps (core) but has a long right side tail
TOF resolution Hamamatsu (120 GeV protons) : 45ps
TOF resolution Hamamatsu (8 GeV electron) : 44ps

(2) beam -> | < hama | photek > crystal < photek | < hama |



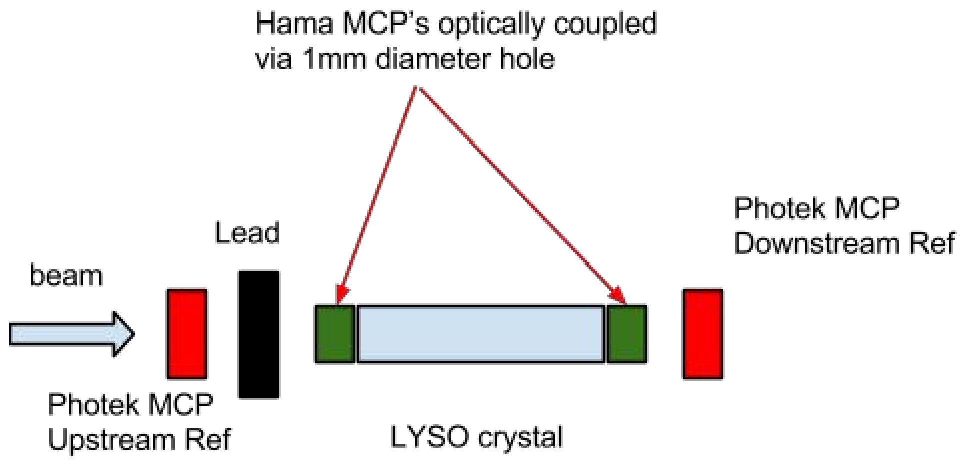
both photeks are optically coupled to crystal
no issues with leakage at the optical coupling to the crystal

DeltaT resolution (or maybe TOF) for photeks (8 GeV electron) : 34 ps
TOF resolution (Ham Reference to upstream photek, 8 GeV ele) : 30 ps (core) but has a little bit of non-gaussian tails
TOF resolution (Ham Reference to downstream photek, 8 GeV ele) : 35 ps (core) but has a little bit of non-gaussian tails

There is a correlation between DeltaT and TOF(ref to downstream). Slope is about -0.90 +- 0.02.
There is also a correlation between DeltaT and TOF(ref to upstream) but it is much smaller. Slope is about 0.09 +- 0.02

If we make corrections based on this slope we get time resolutions of:
TOF (ref to upstream) : 30ps
TOF (ref to downstream) : 31ps

(3) beam → | < Photek | Hamamatsu > LYSO < Hamamatsu | < Photek |



Si's Results

(1) 120 GeV protons

TOF (T0 Ref -> Upstream) : mean -4.984 +- 0.003ns , 52ps resolution
TOF (T0 Ref -> Downstream) : mean -4.512 +- 0.003ns , 45ps resolution
DeltaT(Upstream -> Downstream) : mean -0.477 +- 0.003ns, 48ps resolution

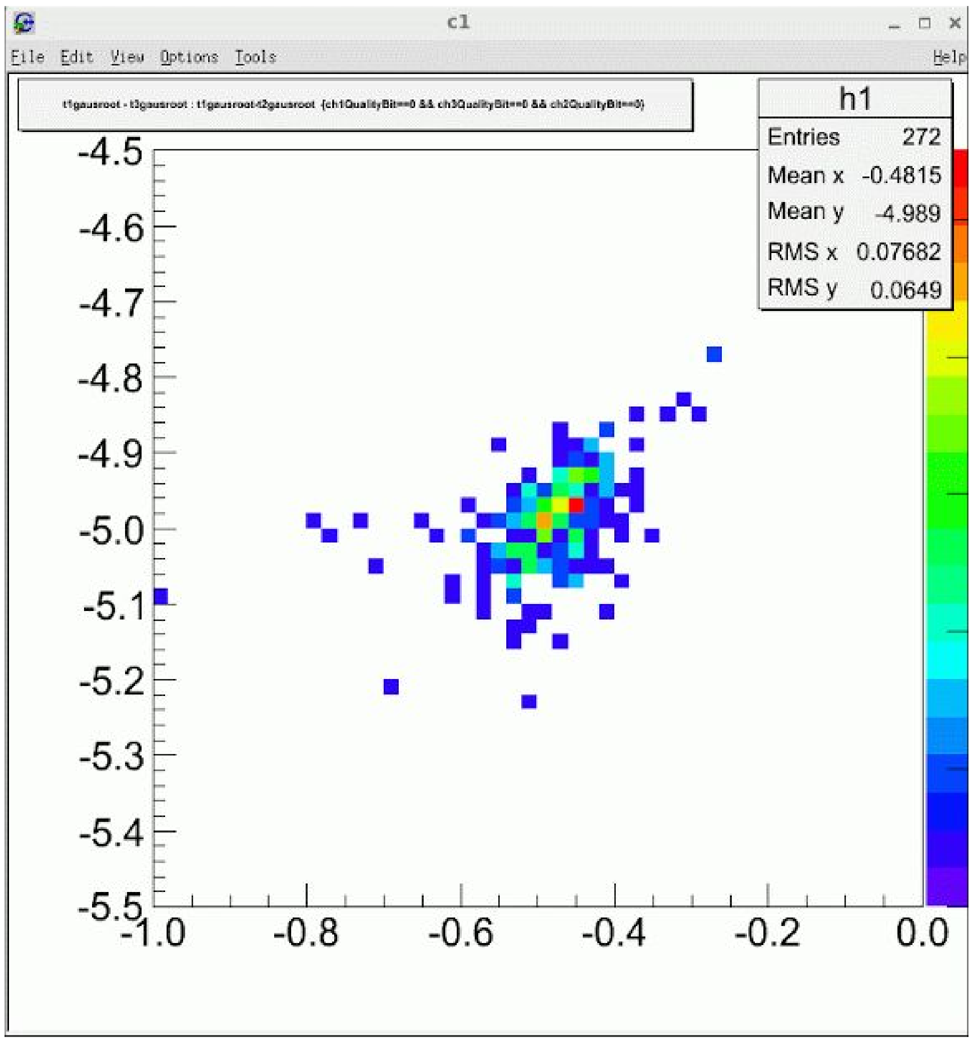
The difference between the TOF to upstream MCP and the TOF to downstream MCP is exactly equal to deltaT between upstream and downstream. This is evidence that the light collected has a single point source.

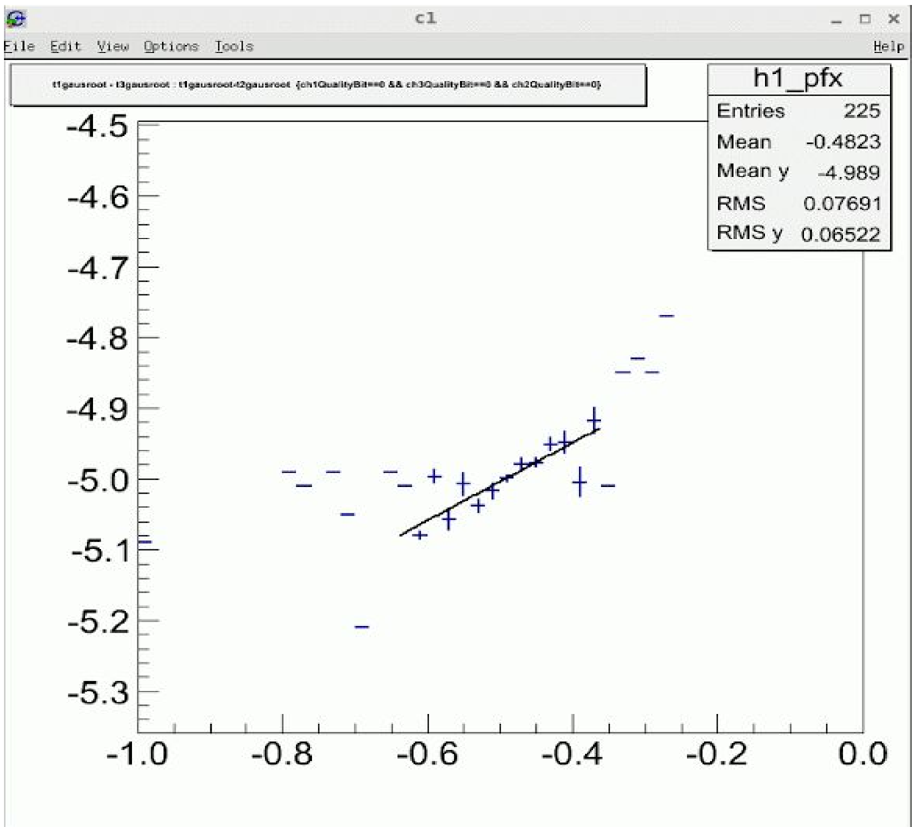
TOF (Upstream -> DownstreamRef) : mean -8.123 +- 0.002ns , 58ps resolution
TOF (Downstream -> DownstreamRef) : mean -7.640 +- 0.001ns , 45ps resolution

TOF (UpstreamRef -> DownstreamRef) :
Observe two peaks.
(A) with mean 3.140+- 0.001ns , 36ps resolution
(B) with mean 3.380 +- 0.004ns, 60ps resolution
events in (B) have large amplitude in downstream Ham MCP and large amplitude in downstream reference (all of them are saturated here). They appear to be events where the proton interacts in the crystal (ie. there was some EM-type shower)

Why is there this time difference of 240ps?

Observe a correlation between TOF(T0Ref->Upstream) vs DeltaT(t_upstream - t_downstream):




c1
File Edit View Options Tools Help
t1gausroot - t3gausroot : t1gausroot-t2gausroot {ch1QualityBit==0 && ch3QualityBit==0 && ch2QualityBit==0}
h1_pfx
Entries 225
Mean -0.4823
Mean y -4.989
RMS 0.07691
RMS y 0.06522
-4.5
-4.6
-4.7
-4.8
-4.9
-5.0
-5.1
-5.2
-5.3
-1.0
-0.8
-0.6
-0.4
-0.2
0.0

We get slopes of:

TOF(T0Ref->Upstream) vs DeltaT(upstream-downstream) : +0.55 +- 0.04
TOF(T0Ref->Downstream) vs DeltaT(upstream-downstream) : -0.36 +- 0.04

TOF(Upstream->DownstreamRef) vs DeltaT(upstream-downstream) : 0.78 +- 0.01
TOF(Downstream->DownstreamRef) vs DeltaT(upstream-downstream) : -0.23 +- 0.03

If we correct by this slope, we get:

TOF resolution (T0 Ref -> Upstream): 45ps (improves from 52ps without correction)
TOF resolution (T0 Ref -> Upstream): 43ps (improves from 45ps, but makes the distribution less gaussian, ie. it has more left side tails)

TOF resolution (Upstream -> DownstreamRef): 45 ps (improves from 60ps without correction)
TOF resolution (Downstream->DownstreamRef): 45ps (no significant improvement here)

Amplitudes:
Upstream MCP has smaller signal amplitude than downstream MCP.
Consistent with the hypothesis that the proton interacts later in the crystal

(2) 8 GeV electrons

Amplitudes:
Upstream MCP has larger signal amplitude than downstream MCP.
Consistent with hypothesis that electron loses most of its energy early in the crystal.

TOF (T0 Ref -> Upstream) : mean -5.136 +- 0.002ns , 49ps resolution
TOF (T0 Ref -> Downstream) : mean -4.600 +- 0.002ns , 40s core resolution (little bit of non-gaussian tails)
DeltaT(Upstream -> Downstream) : mean -0.543 +- 0.002ns, 30ps core resolution (has non-gaussian tails) - and there are lots and lots of very far tails. needs pulse cleaning and better algorithm!

TOF (Upstream -> DownstreamRef) : mean -8.261 +- 0.002ns, 60ps resolution
TOF (Downstream -> DownstreamRef) : mean -7.708 +- 0.002ns , 46ps resolution

TOF (UpstreamRef -> DownstreamRef) : mean -3.110 +- 0.001ns, 33ps resolution
Here I see a single peak, not the double peak structure as in the proton beam case. There is some dependence of TOF on DownstreamRef amplitude at very low amplitude (below 50mV), but its effect on resolution is not too big. resolution goes from 30ps to 35ps, from the region above 50 mV to region below 50mV.

Correlations between TOF and DeltaT
Slopes are:
TOF(T0Ref->Upstream) vs DeltaT(upstream-downstream) : +0.62 +- 0.04
TOF(T0Ref->Downstream) vs DeltaT(upstream-downstream) : -0.36 +- 0.04

TOF(Upstream->DownstreamRef) vs DeltaT(upstream-downstream) : 0.61 +- 0.07
TOF(Downstream->DownstreamRef) vs DeltaT(upstream-downstream) : -0.37 +- 0.07

If we correct by this slope, we get:

TOF resolution (T0 Ref -> Upstream): 51ps (improves from 60ps without correction)
TOF resolution (T0 Ref -> Upstream): 43ps (no improvement here, but makes the distribution more gaussian)

TOF resolution (Upstream -> DownstreamRef): 45 ps (improves from 60ps without correction, and is much more gaussian after correction)
TOF resolution (Downstream->DownstreamRef): 49ps (no mprovement here)

Cristian’s Results

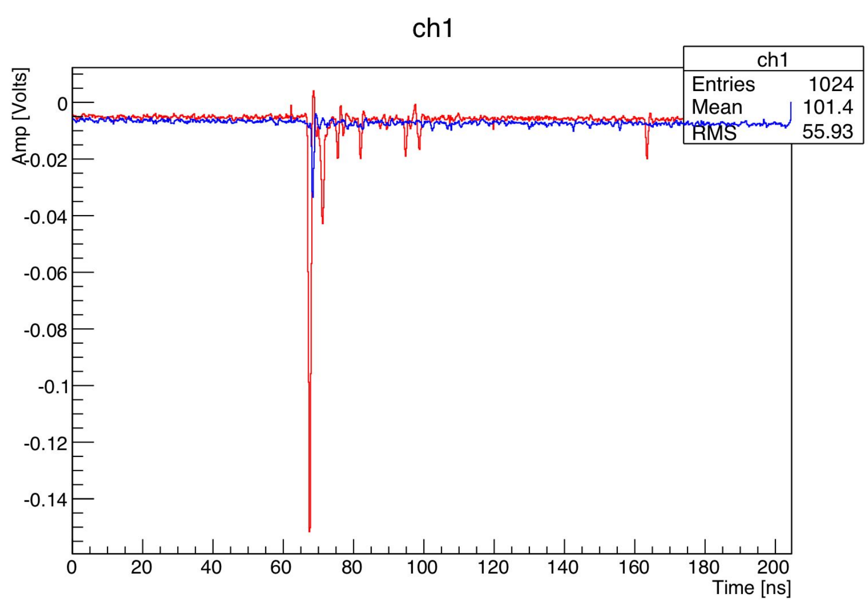
CH1:HamUp(t1)
CH2:HamDown(t2)
CH4:PhotekDown(t4)

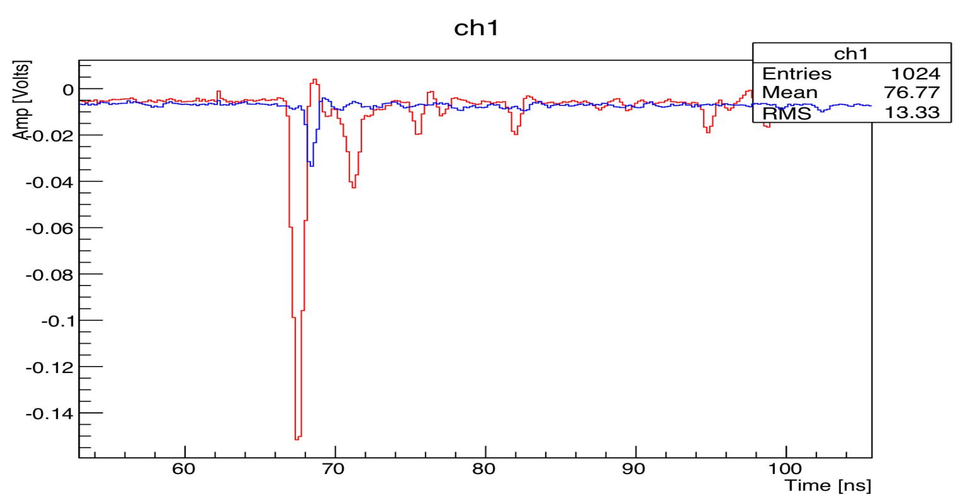
I selected only events with pass the quality requirements and that t2>t1

From these events I created two categories:

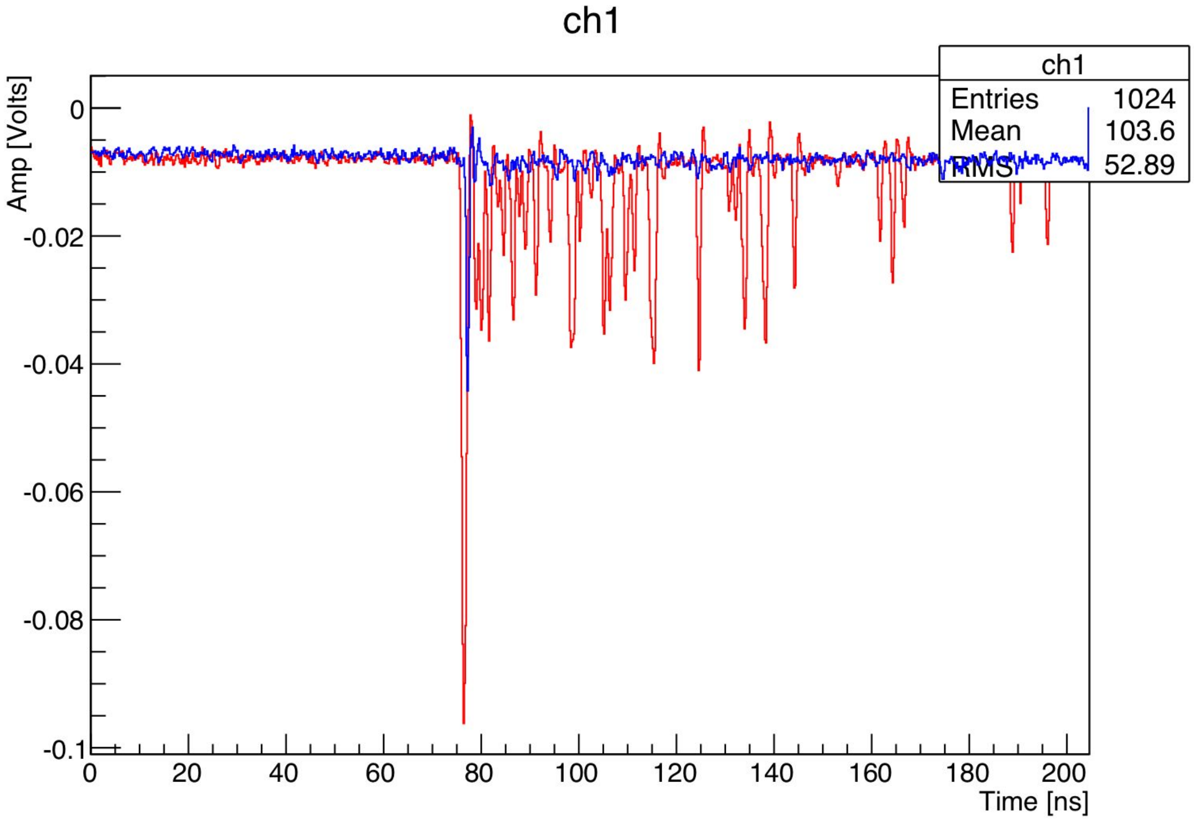
Cat1: ch1Amp > ch2Amp

Pulse Examples: Normal scale then zoomed in

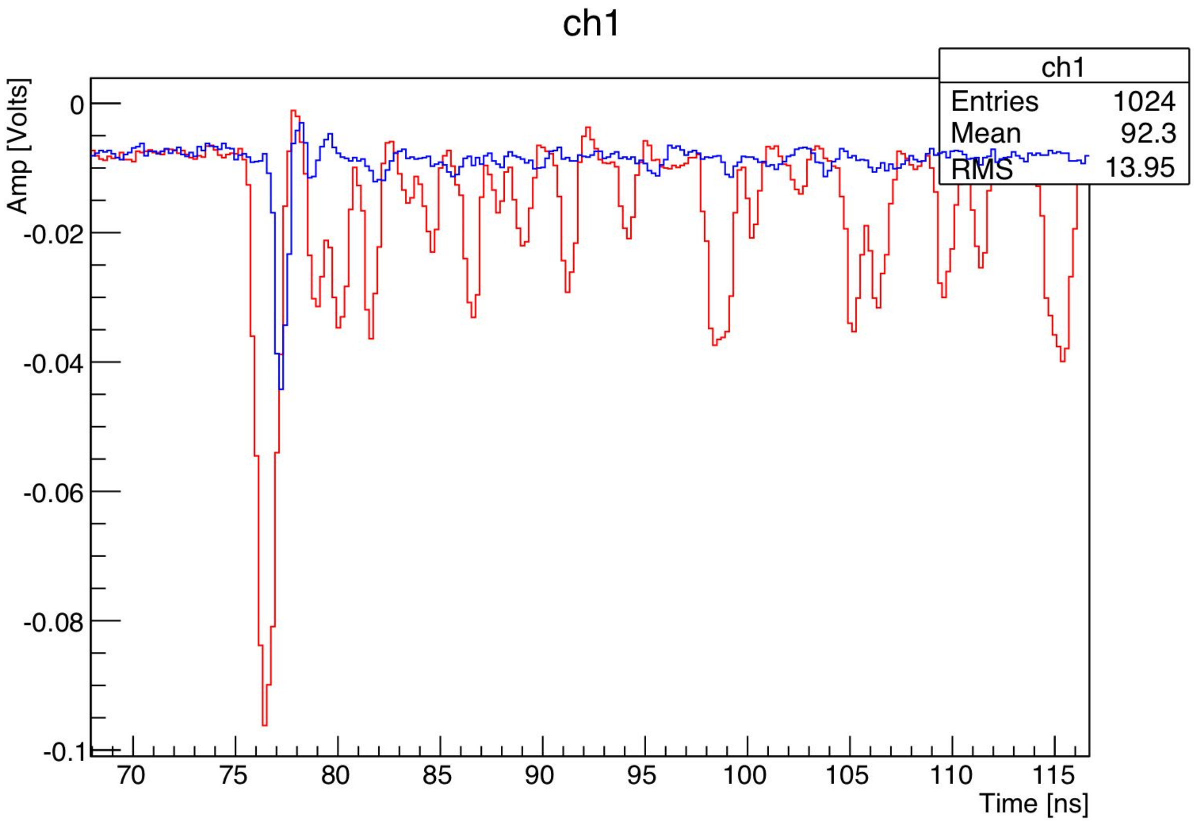




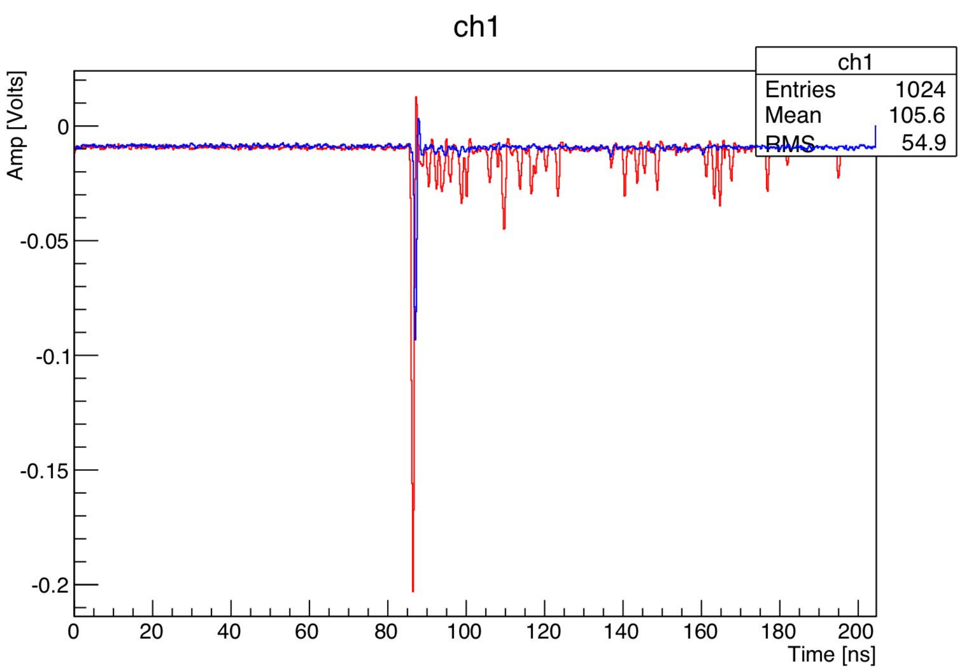
New Pulse

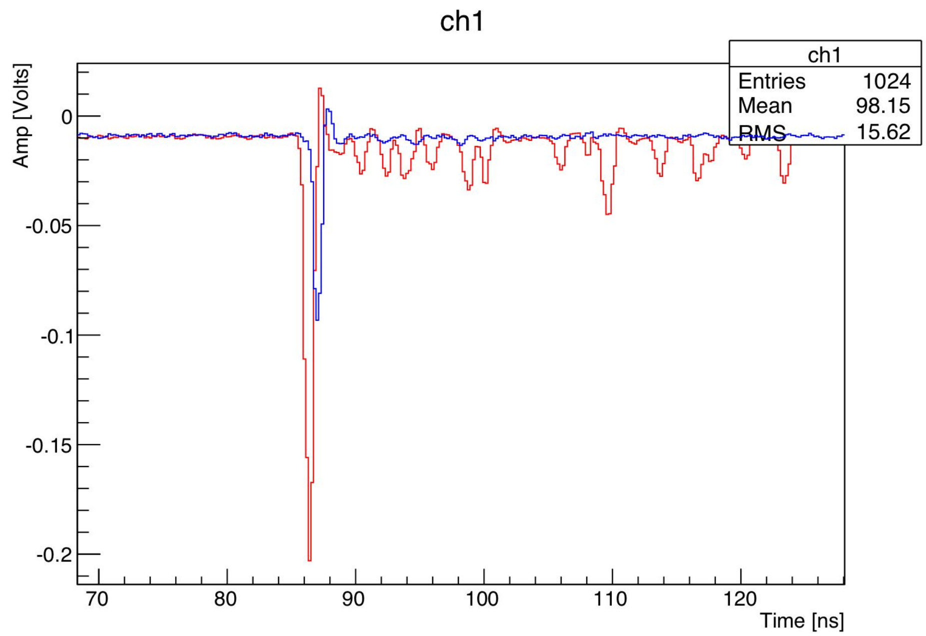


ch1
ch1
Entries 1024
Mean 103.6
RMS 52.89
Amp [Volts]
0
-0.02
-0.04
-0.06
-0.08
-0.1
0
20
40
60
80
100
120
140
160
180
200
Time [ns]

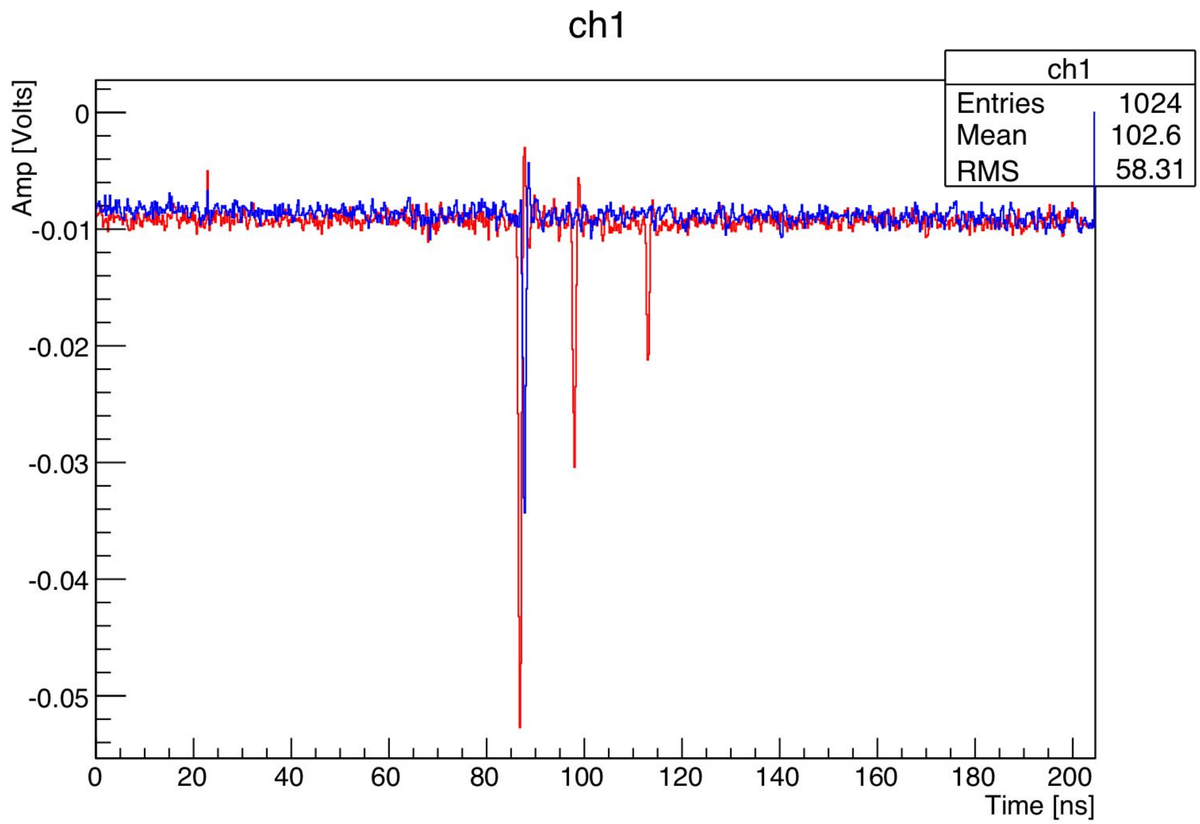

ch1
ch1
Entries 1024
Mean 92.3
RMS 13.95
Amp [Volts]
0
-0.02
-0.04
-0.06
-0.08
-0.1
70
75
80
85
90
95
100
105
110
115
Time [ns]

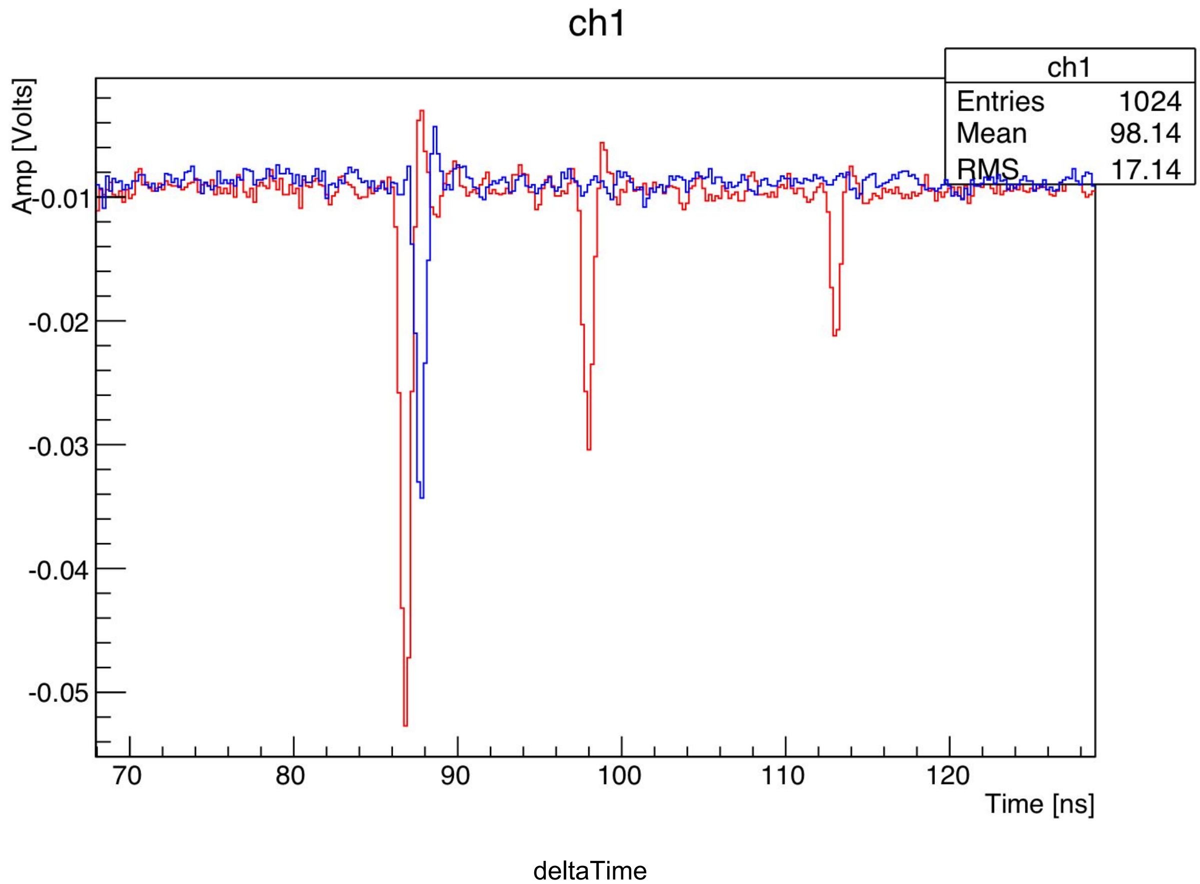
New Pulse


ch1
ch1
Entries 1024
Mean 105.6
RMS 54.9
Amp [Volts]
0
-0.05
-0.1
-0.15
-0.2
0
20
40
60
80
100
120
140
160
180
200
Time [ns]

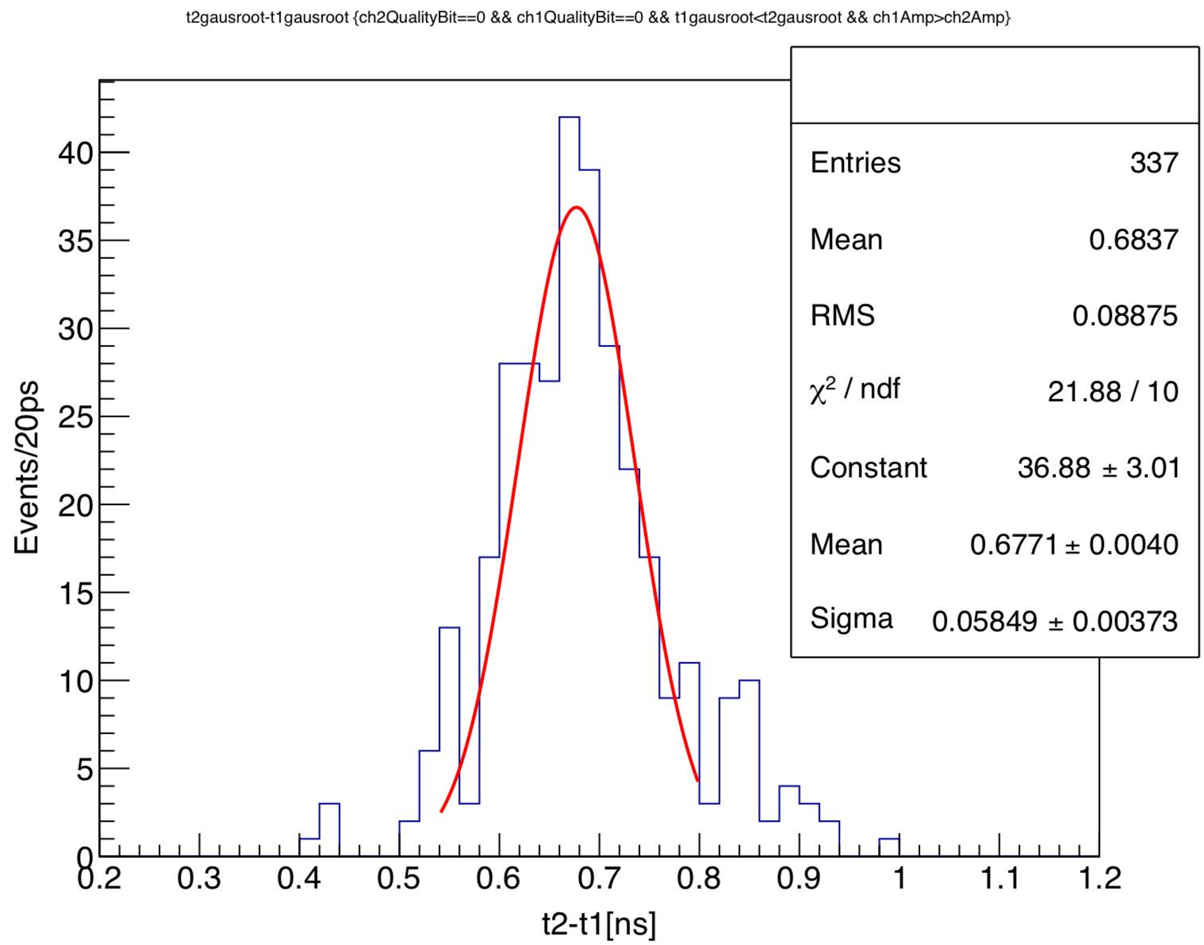

ch1
ch1
Entries 1024
Mean 98.15
RMS 15.62
Amp [Volts]
0
-0.05
-0.1
-0.15
-0.2
70
80
90
100
110
120
Time [ns]

New Pulse

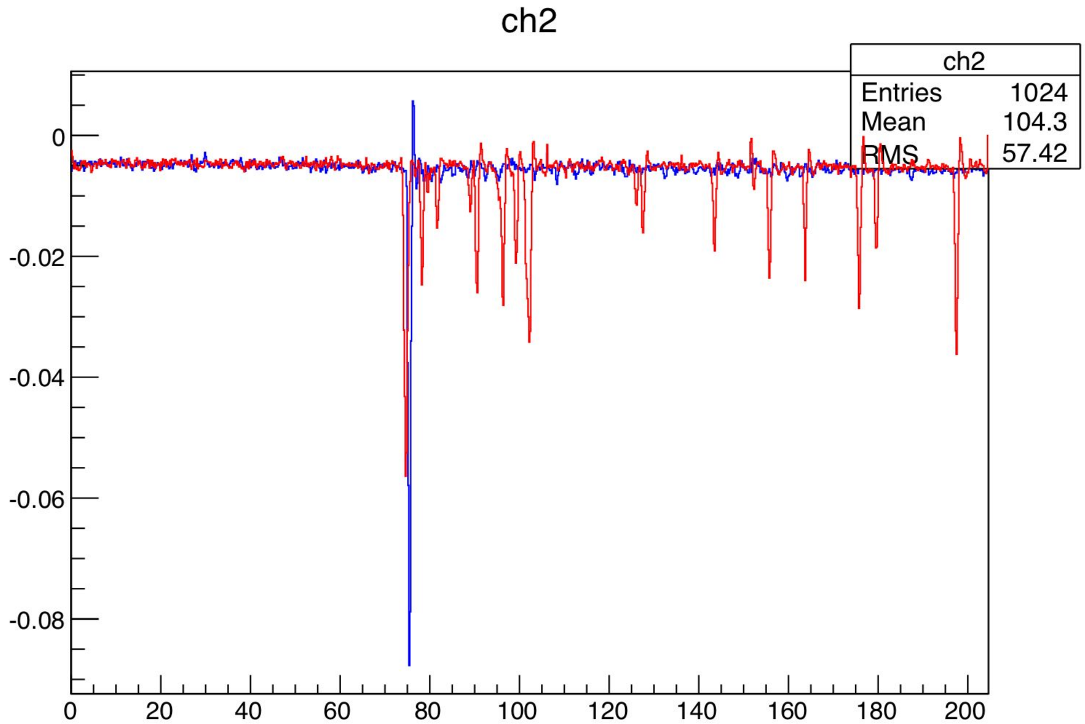

ch1
ch1
Entries 1024
Mean 102.6
RMS 58.31
Amp [Volts]
0
-0.01
-0.02
-0.03
-0.04
-0.05
0
20
40
60
80
100
120
140
160
180
200
Time [ns]

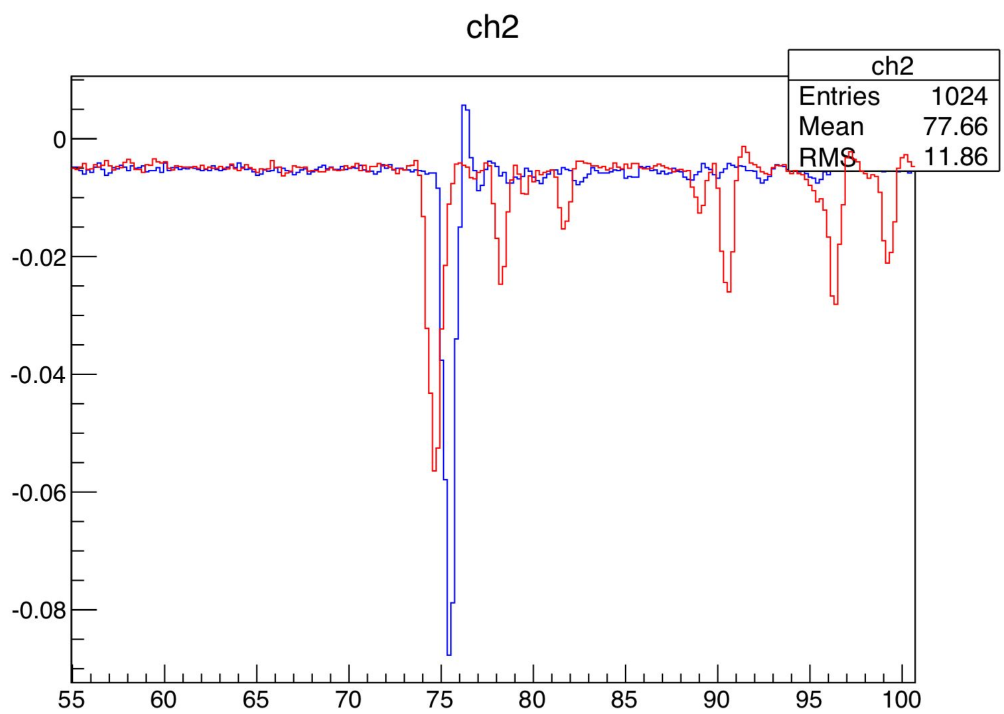


ch1
ch1
Entries 1024
Mean 98.14
RMS 17.14
Amp [Volts]
-0.01
-0.02
-0.03
-0.04
-0.05
70
80
90
100
110
120
Time [ns]
deltaTime

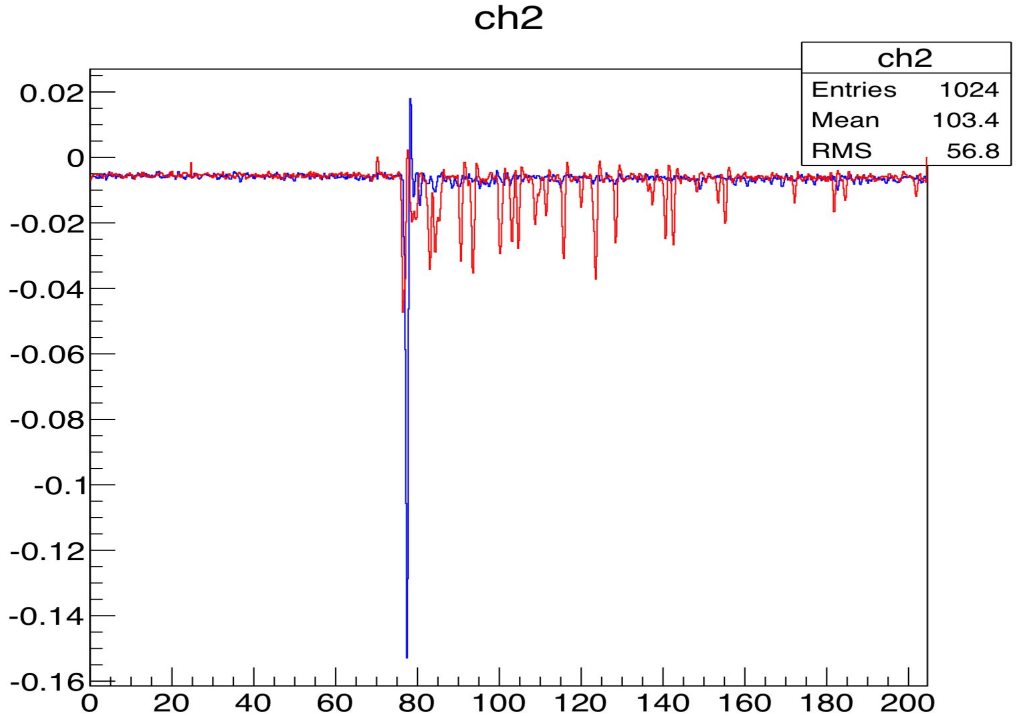


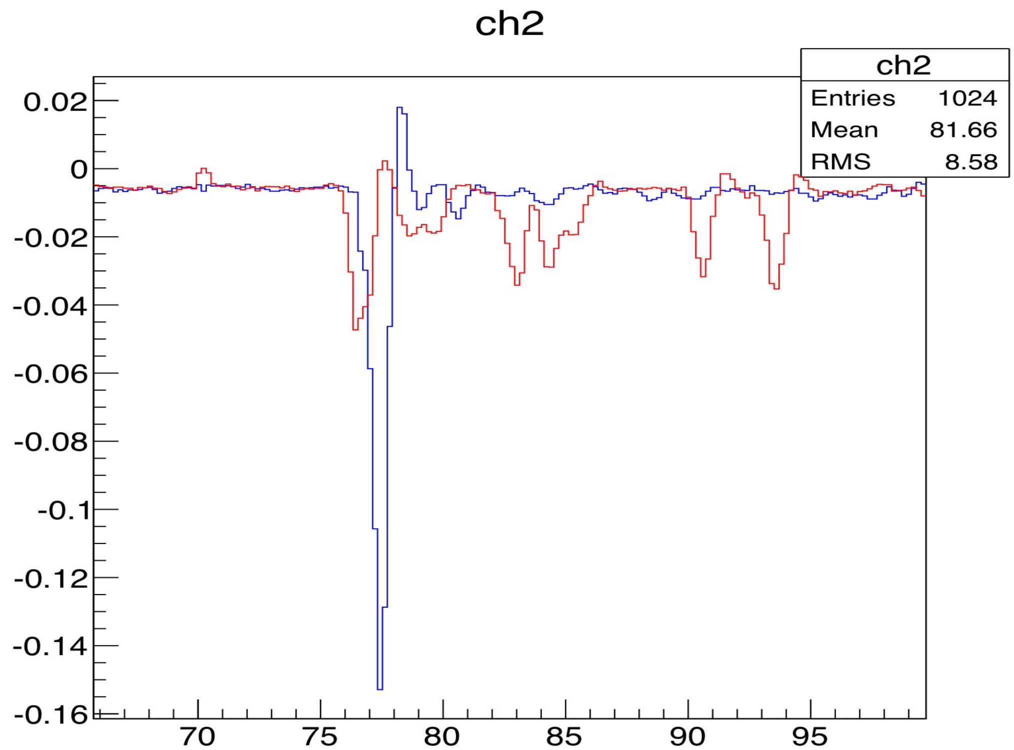
Cat2: ch2Amp > ch1Amp


ch2
ch2
Entries 1024
Mean 104.3
RMS 57.42
0
-0.02
-0.04
-0.06
-0.08
0 20 40 60 80 100 120 140 160 180 200

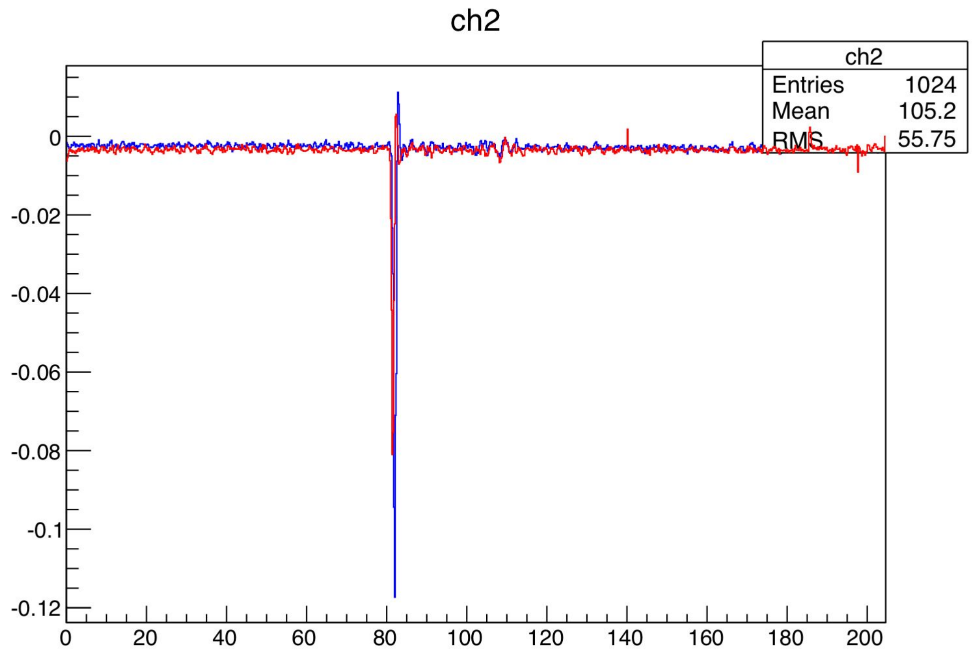

ch2
ch2
Entries 1024
Mean 77.66
RMS 11.86
0
-0.02
-0.04
-0.06
-0.08
55 60 65 70 75 80 85 90 95 100

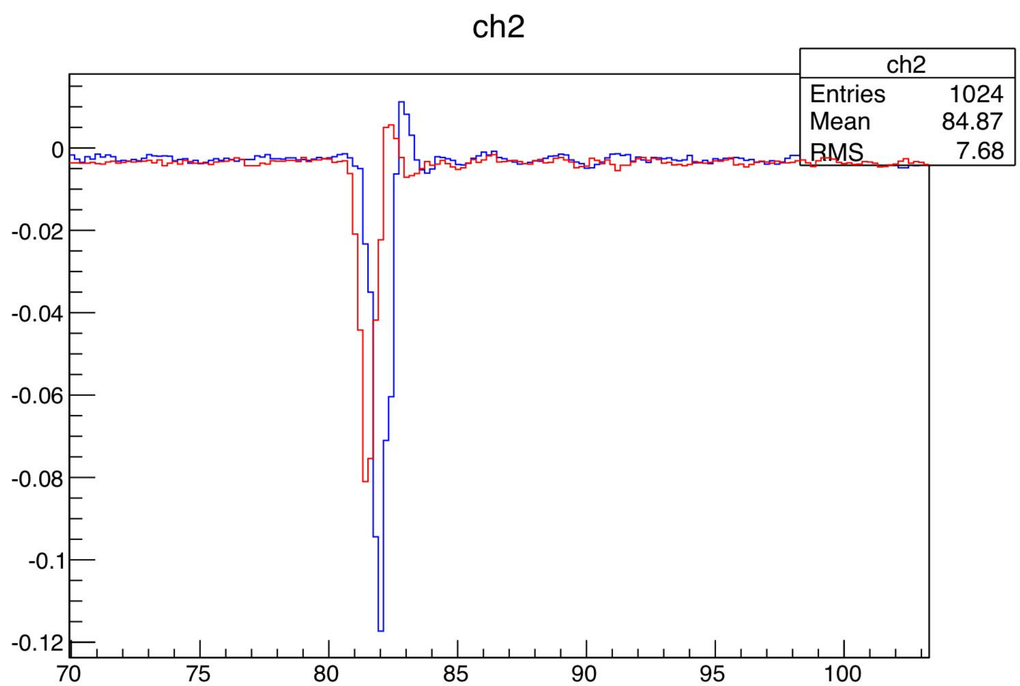
New Pulse


ch2
ch2
Entries 1024
Mean 103.4
RMS 56.8
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
0
20
40
60
80
100
120
140
160
180
200

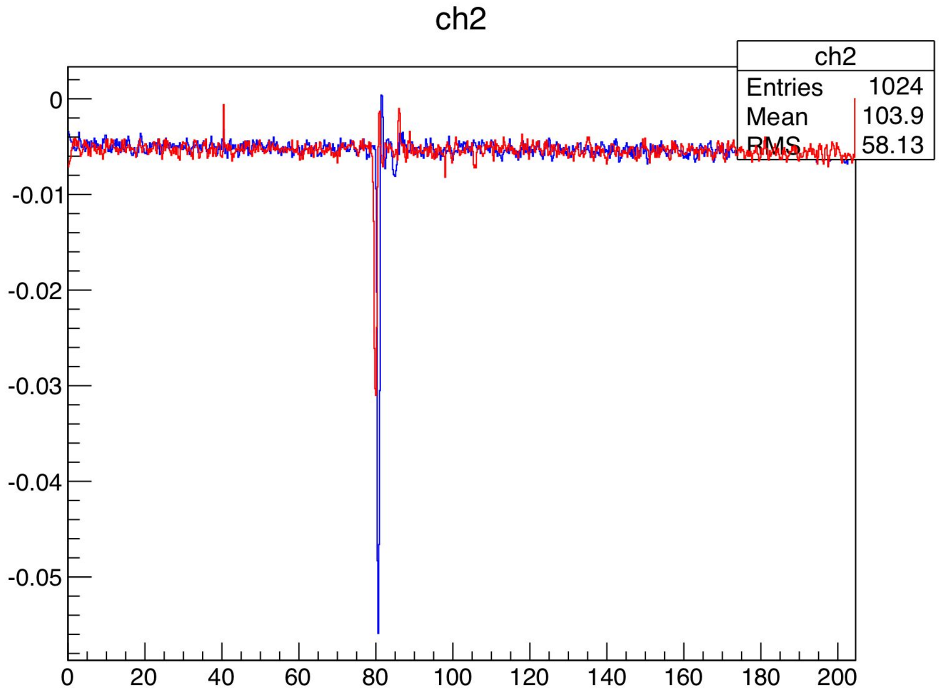

ch2
ch2
Entries 1024
Mean 81.66
RMS 8.58
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
70
75
80
85
90
95

New Pulse

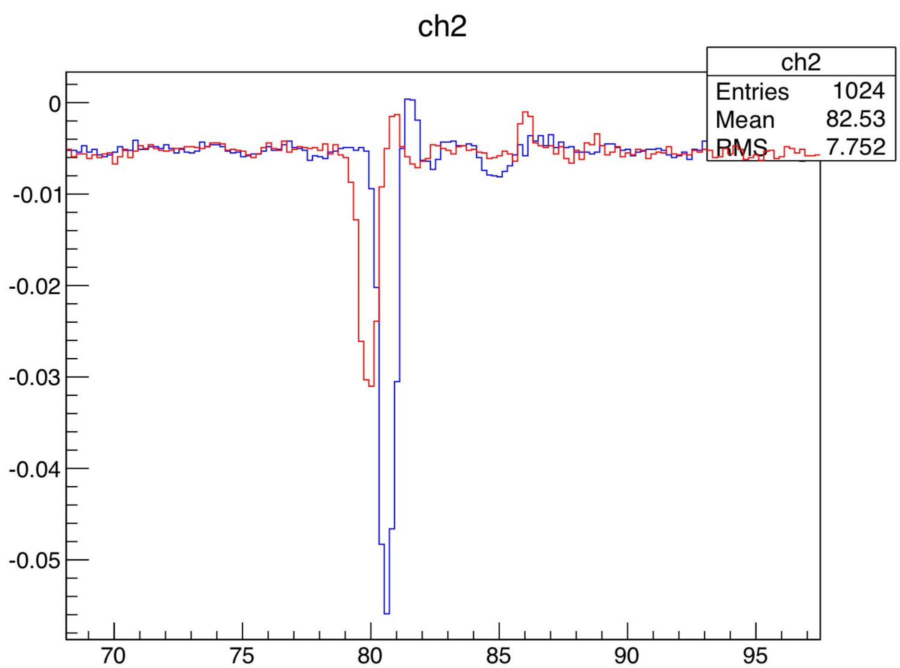

ch2
ch2
Entries 1024
Mean 105.2
RMS 55.75
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
0 20 40 60 80 100 120 140 160 180 200


ch2
ch2
Entries 1024
Mean 84.87
RMS 7.68
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
70 75 80 85 90 95 100

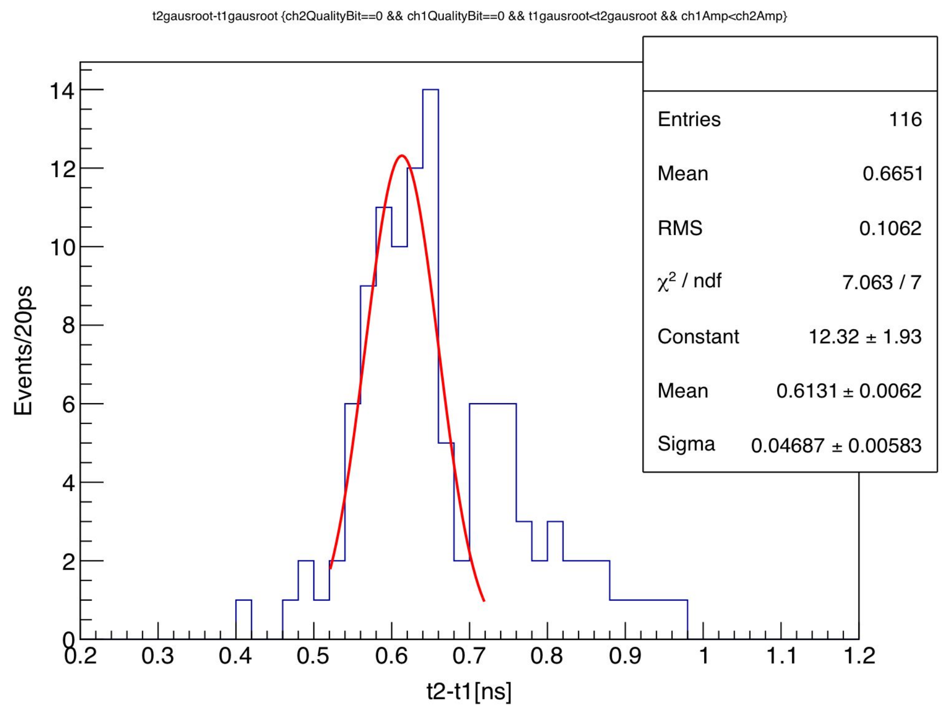
New Pulse



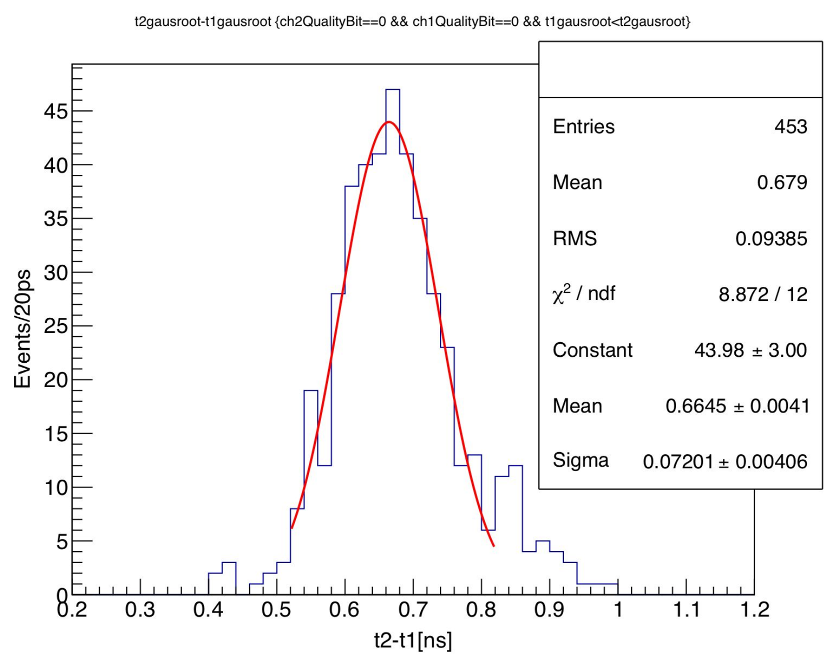
ch2
ch2
Entries 1024
Mean 103.9
RMS 58.13
0
-0.01
-0.02
-0.03
-0.04
-0.05
0
20
40
60
80
100
120
140
160
180
200



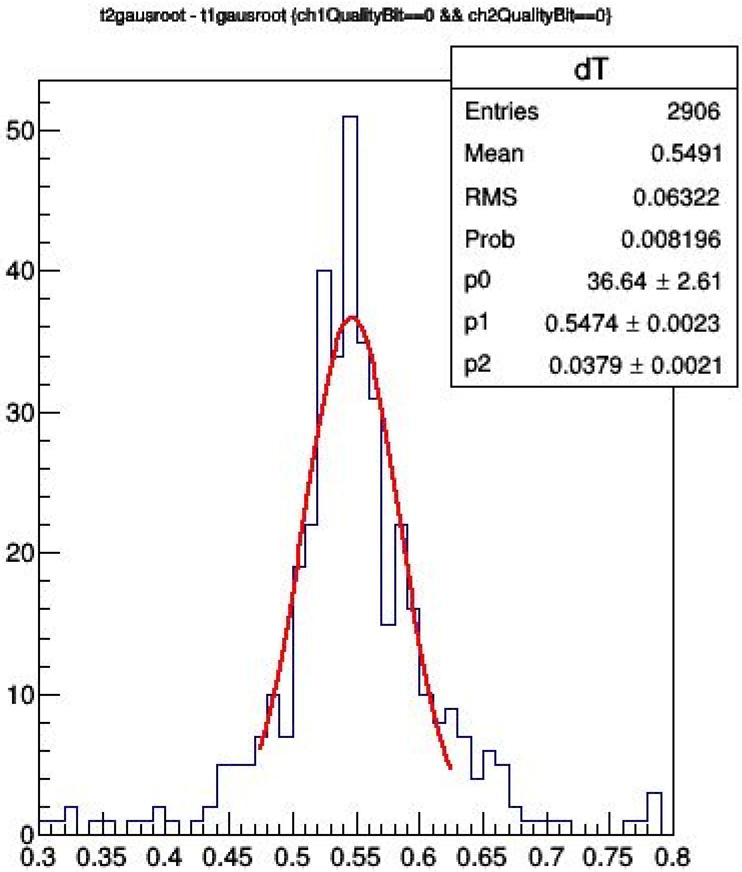
ch2
ch2
Entries 1024
Mean 82.53
RMS 7.752
0
-0.01
-0.02
-0.03
-0.04
-0.05
70
75
80
85
90
95



Cat1 and Cat2 combined:



SAME CONFIGURATION 8GeV Electons



Mean changed! I believe the cables are the same length for Ham MCPs in both cases.

$C = 3\times10^8\ m/s = 300\times10^8\ cm/s = 30\ cm/ns$

$C = 30\ cm/ns$

assuming particles travel at "c"

a 20 cm long crystal corresponds to $\frac{2}{3}$ ns

$\Rightarrow$ 20 cm $\rightarrow$ 666 ps

Close to what we measure with protons

For 8 GeV electrons we obtain 547 ps = ΔT

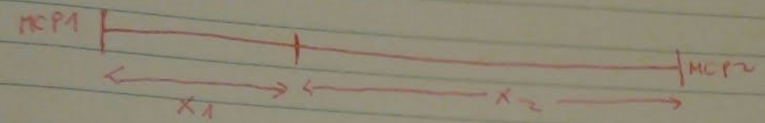
if we assume speed is "c"

$\Rightarrow \Delta d = C \cdot \Delta T = 30\ \frac{cm}{ns} \cdot 0.547\ ns$

$\Delta d = 16.41\ cm$. case (a)

If we assume index of refraction $n_{LYSO} \approx 1.82$

$\Rightarrow \Delta d = \frac{C}{n_{LYSO}} \cdot \Delta T \approx 9\ cm$ case (b) case (a) $\Delta d = 16.41$ cm



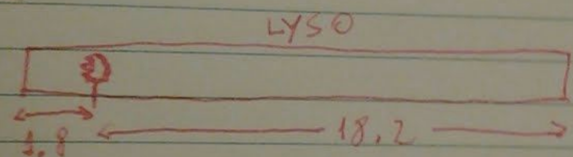
$x_2 - x_1 = 16.41$ cm

$x_2 + x_1 = 20.0$ cm

$2x_2 = 36.41$

$x_2 = 18.205$

$\Rightarrow$



$\Rightarrow x_1 \approx 1.55 X_0$

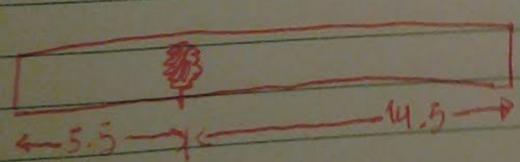
Case 2

$\Rightarrow$ $x_2 - x_1 = 9$ cm

$x_2 + x_1 = 20$cm

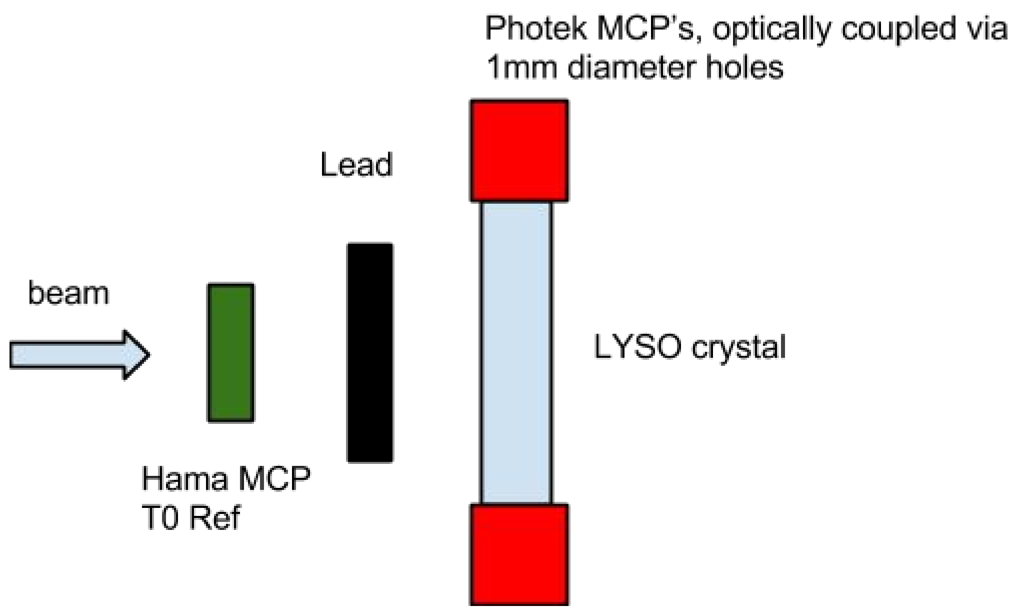
$2x_2 = 29$cm

$x_2 = 14.5,\ x_1 = 5.5$ (cm)



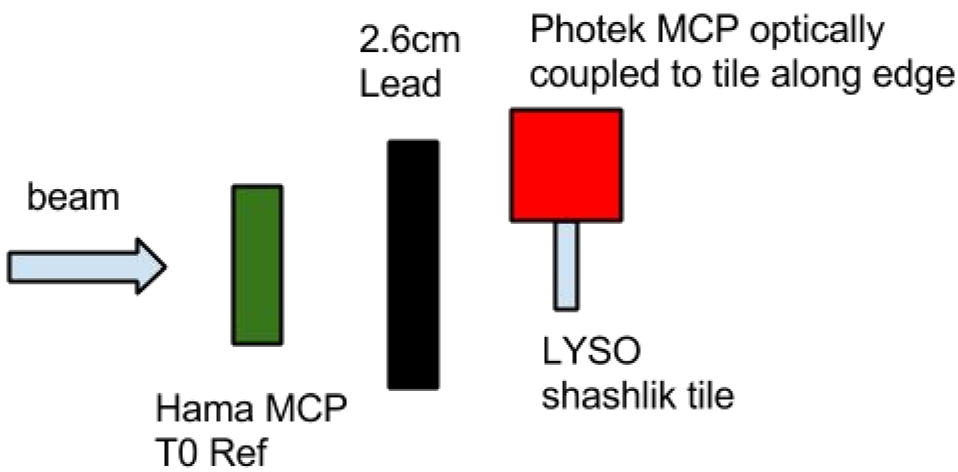
$\Rightarrow x_1 \simeq 4.74 X_0$

Crystal Position Scan



Shashlik Tile

Experimental set up is as follows:



We measure the time of flight (TOF) between the T0 ref detector, and the signal detected in the photek MCP. We trigger on the signal of the T0 ref detector.

TOF Resolution Study

(1) TOF resolution with 2.6cm lead (8GeV electron):
about 70ps
(But with large dependence of resolution on amplitude of photek MCP. resolution goes from about 105ps below 50mV to 60ps above 350mV)

(2) TOF resolution with 2x2.6cm lead (8GeV electron):
about 79ps

- (also see a similar dependence of resolution on amplitude). the average amplitude is smaller for this run than the previous run with less lead.
- also looked at the events with larger amplitude on the channel with the 10db attenuator, and do not see much improvement in resolution beyond 350mV on the unattenuated channel

(3) TOF resolution with 1cm lead (8GeV electron):

75ps

(4) TOF resolution with 1cm lead (120GeV proton):
45ps

- dependence of resolution on amplitude is not very clear, it seems to fluctuate with no clear pattern

(5) TOF resolution with 1cm lead (120GeV proton) and 1mm hole optical coupling:
48 ps

- there's dependence on signal amplitude. resolution goes from 55ps for pulses below 50mV to 45ps for pulses above 300mV, and to 40ps for pulses above 200mV on the channel with the 10db attenuator

TOF mean dependence on beam position relative to center of the tile:

center: 9.434 +- 0.002ns

5mm away from MCP: 9.429 +- 0.002 ns

- (but I'm not sure if this is a good measurement because the table seems to have moved by 2mm during the run by itself, and also because the tile was broken towards the end that the beam was moved towards)

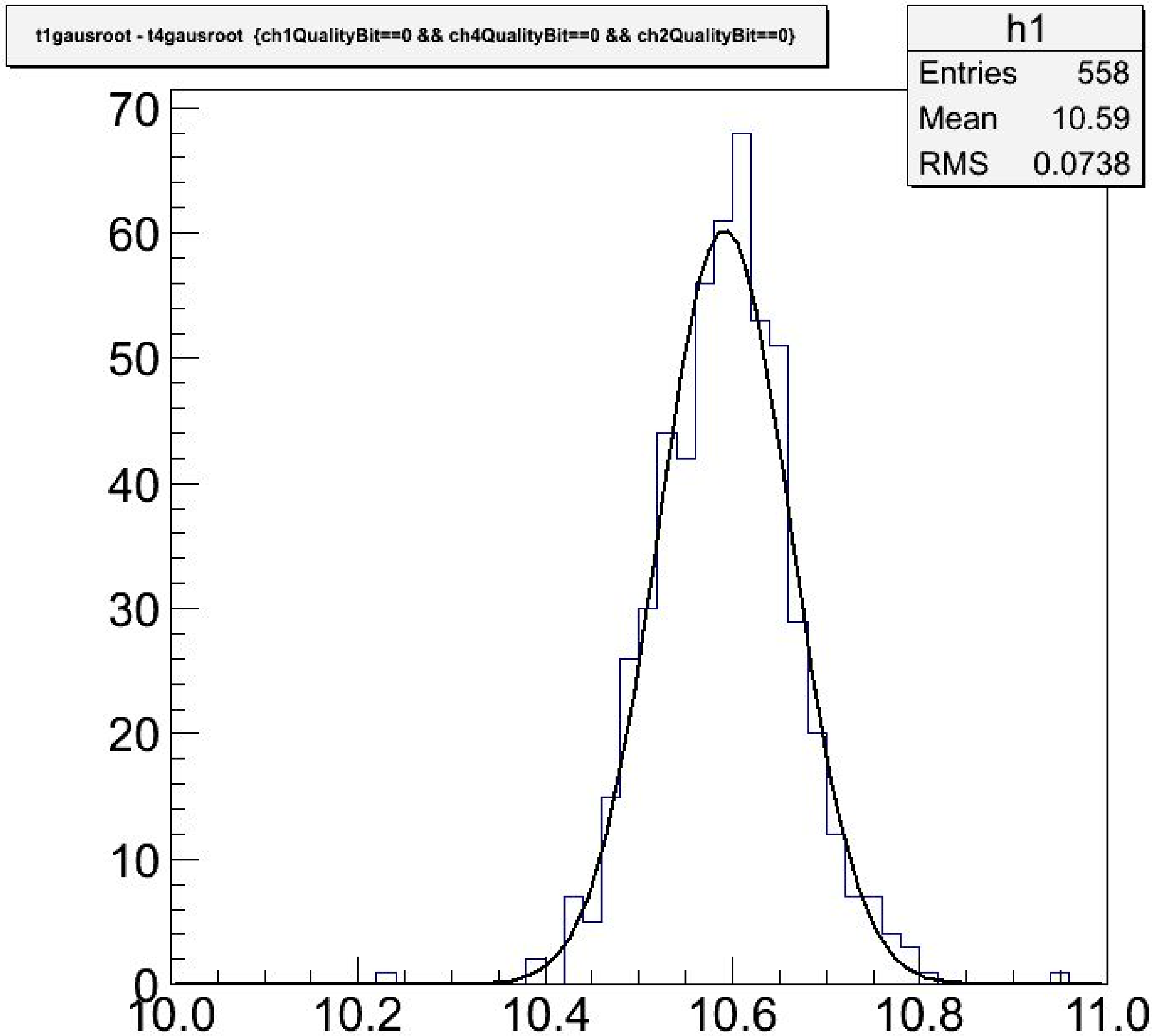
5mm towards MCP: 9.417 +- 0.002ns

- if we believe this measurement, then there's a difference of 17ps, which corresponds to 5mm travelling at the speed of light in vacuum…
- but again, we're not sure if this observation is impacted by the fact that the tile was broken - possibly causing reflections, etc.

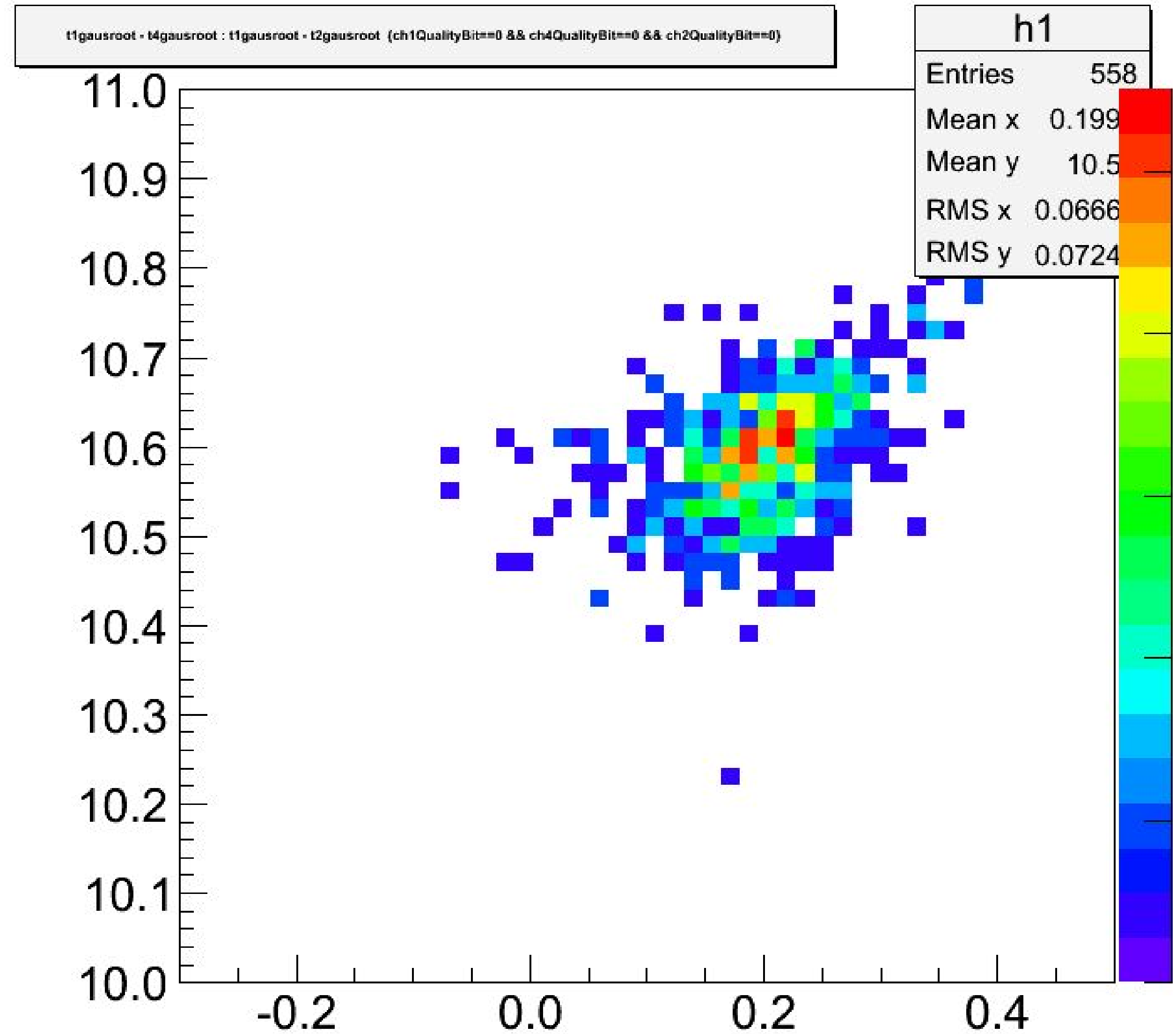
Exercise: Attempt Dual Readout TOF correction

Run 118+120
8GeV electron beam (beamspot has width of about 2-3cm)
10cm LYSO crystal
NO Lead
beam center located at center of crystal
measure TOF between Hamamatsu MCP reference, and CH1 side MCP

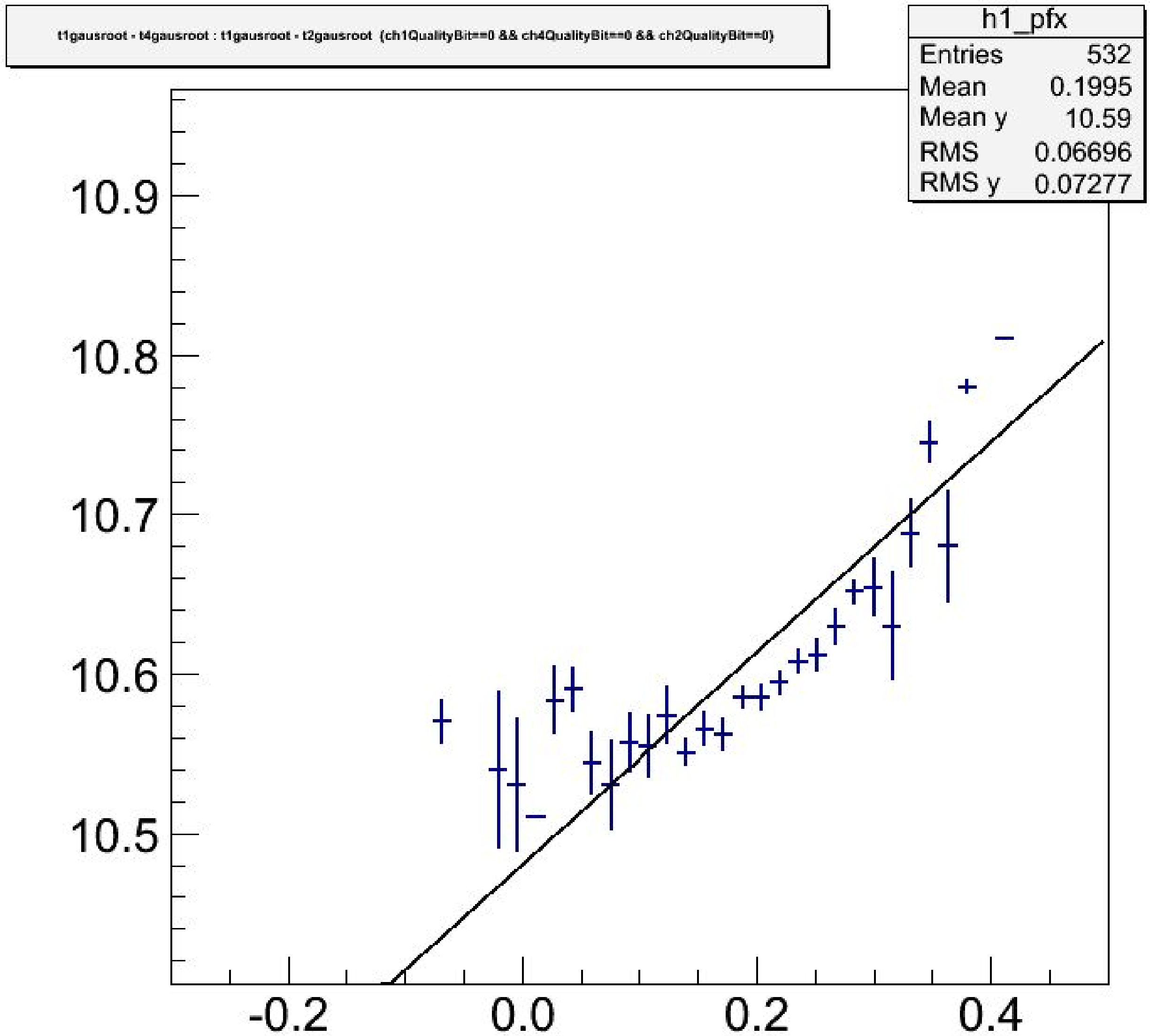
Measure TOF
tree->Draw("t1gausroot - t4gausroot >>h1(50,10,11)","ch1QualityBit==0 && ch4QualityBit==0 && ch2QualityBit==0");
Get resolution of about 71ps



Look at correlation between TOF and dual readout deltaT:
tree->Draw("t1gausroot - t4gausroot : t1gausroot - t2gausroot >>h1(50,-0.3,0.5,50,10,11)","ch1QualityBit==0 && ch4QualityBit==0 && ch2QualityBit==0","colz");



Do profile plot, and fit it with a line.

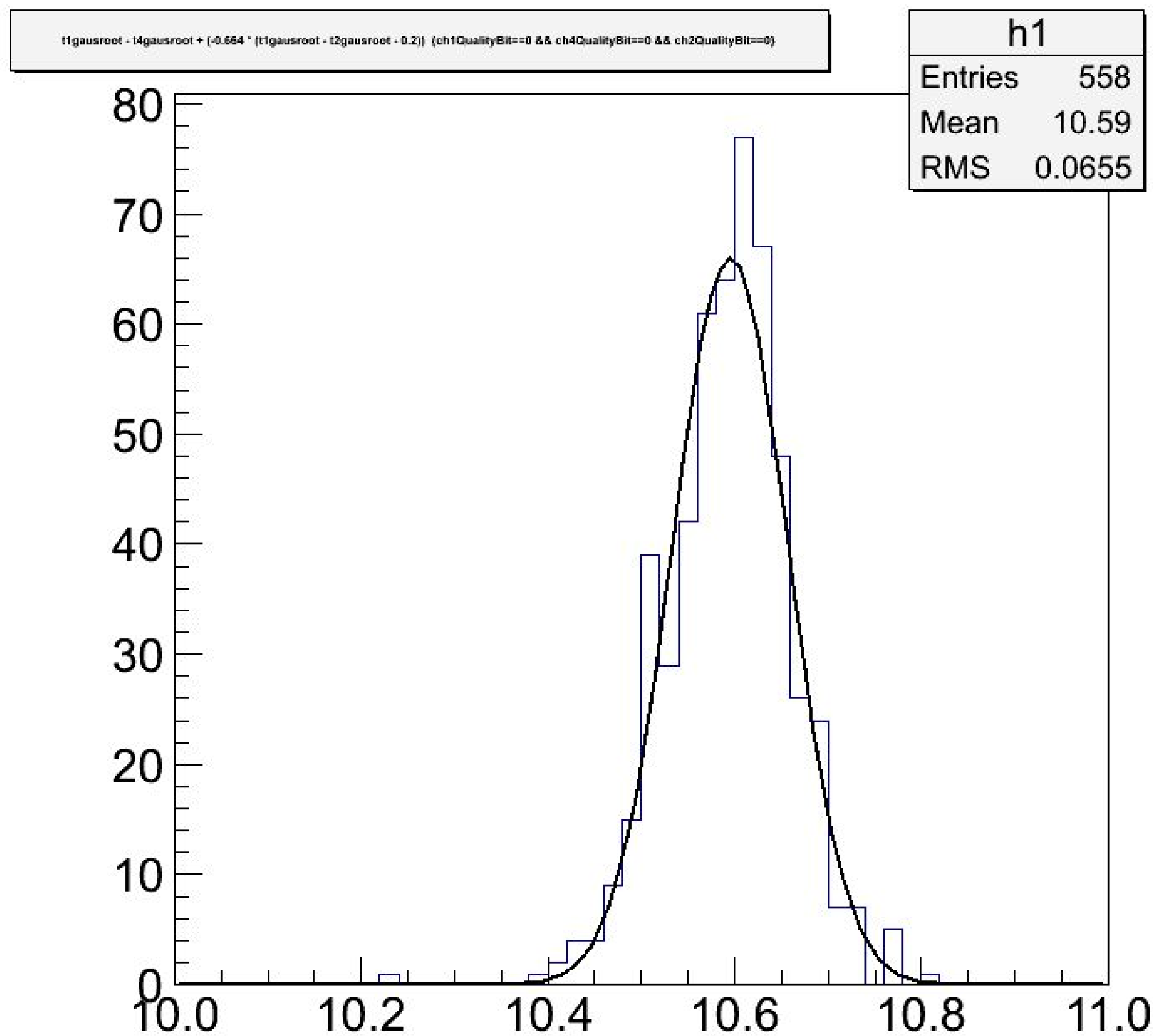


Verify that correction makes the slope flat:

tree->Draw("t1gausroot - t4gausroot + (-0.664 * (t1gausroot - t2gausroot - 0.2)) : t1gausroot - t2gausroot >>h1(50,-0.3,0.5,50,10,11)","ch1QualityBit==0 && ch4QualityBit==0 && ch2QualityBit==0","colz")

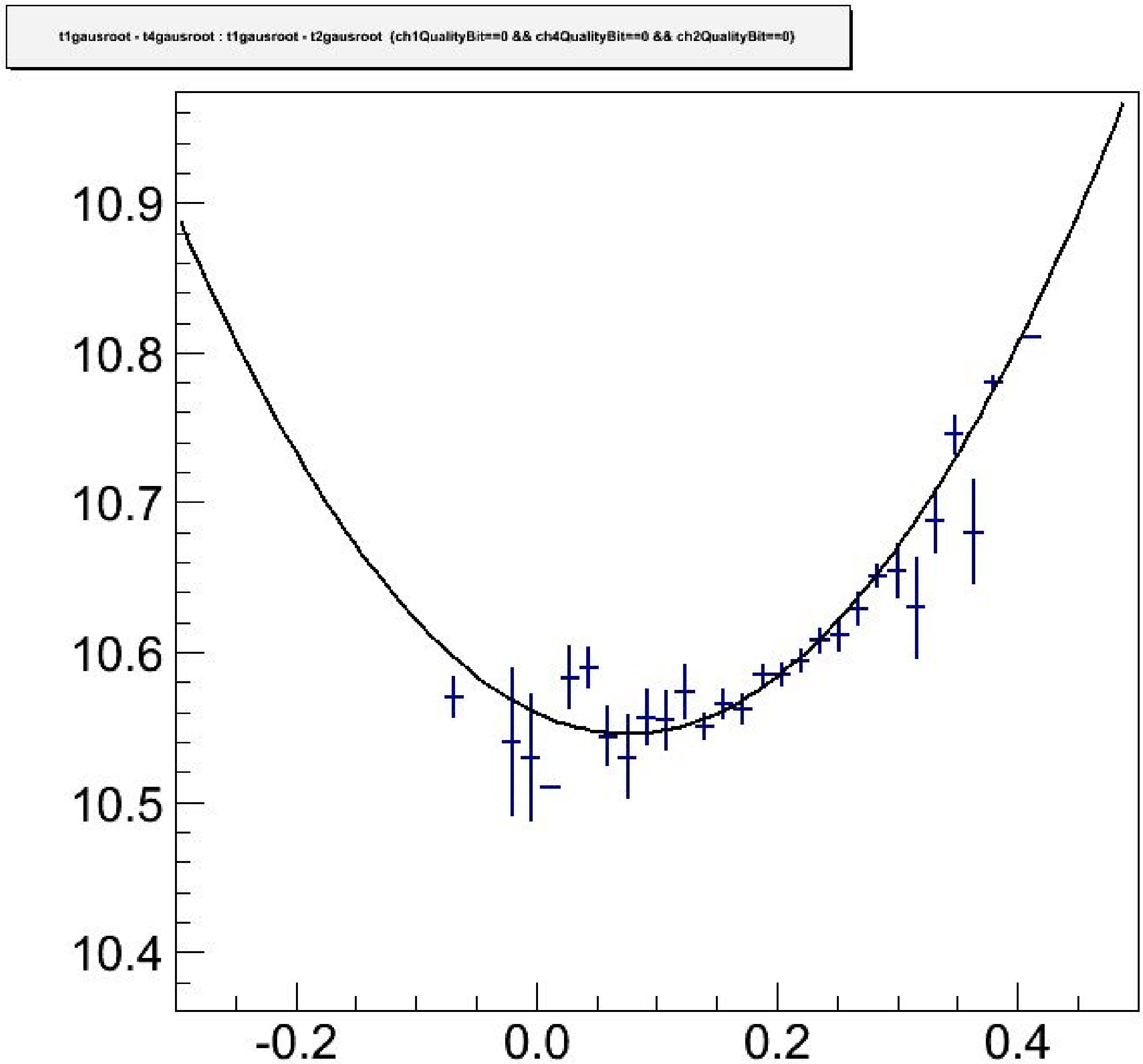
Then do TOF with correction:

tree->Draw("t1gausroot - t4gausroot + (-0.664 * (t1gausroot - t2gausroot - 0.2)) >>h1(50,10,11)","ch1QualityBit==0 && ch4QualityBit==0 && ch2QualityBit==0","");



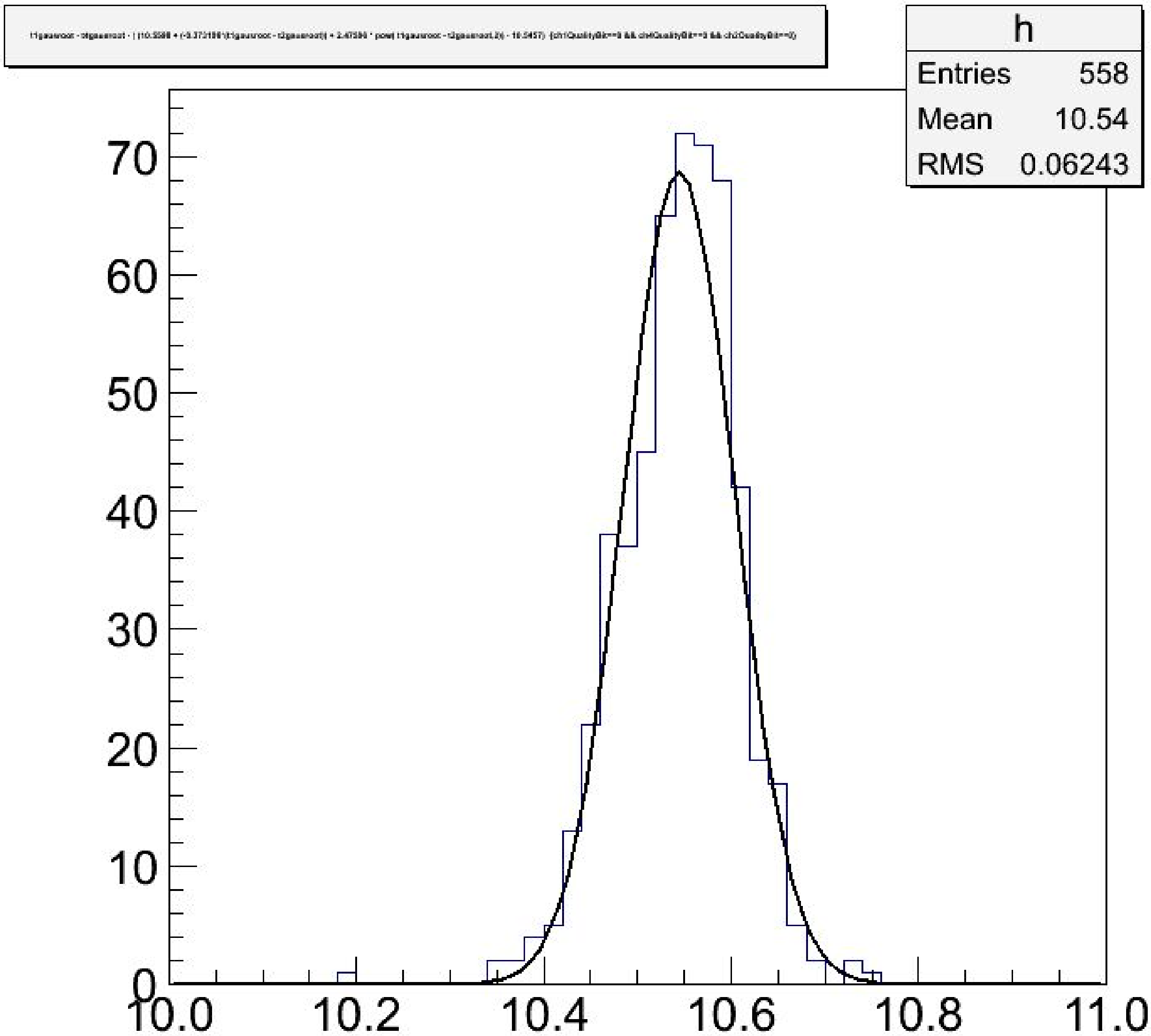
Now I get 62 ps resolution

Instead of linear fit, try parabola fit. Seems to give a much better fit.



Now do correction
tree->Draw("t1gausroot - t4gausroot - ((10.5598 + (-0.373196*(t1gausroot - t2gausroot)) + 2.47506 * pow(t1gausroot - t2gausroot,2)) - 10.5457) : t1gausroot - t2gausroot >>h1(50,-0.3,0.5,50,10,11)","ch1QualityBit==0 && ch4QualityBit==0 && ch2QualityBit==0","colz");

Plot TOF with pol2 correction:
tree->Draw("t1gausroot - t4gausroot - ((10.5598 + (-0.373196*(t1gausroot - t2gausroot)) + 2.47506 * pow(t1gausroot - t2gausroot,2)) - 10.5457) >> h(50,10,11)","ch1QualityBit==0 && ch4QualityBit==0 && ch2QualityBit==0","");



Now I get 59ps resolution

Subtracting in quadrature 59 from 71, we get about 39ps. We infer that the spread in time due to transit time jitter from the unknown interaction position (known to within a 1.6cm x 1.6cm square region) is about 39ps. this corresponds to about 1.2cm if propagating at the speed of light, and about 2.2cm if propagating at speed of light inside LYSO (with index of refraction of about 1.8).