Study of Trigger Pulses(Ch3)

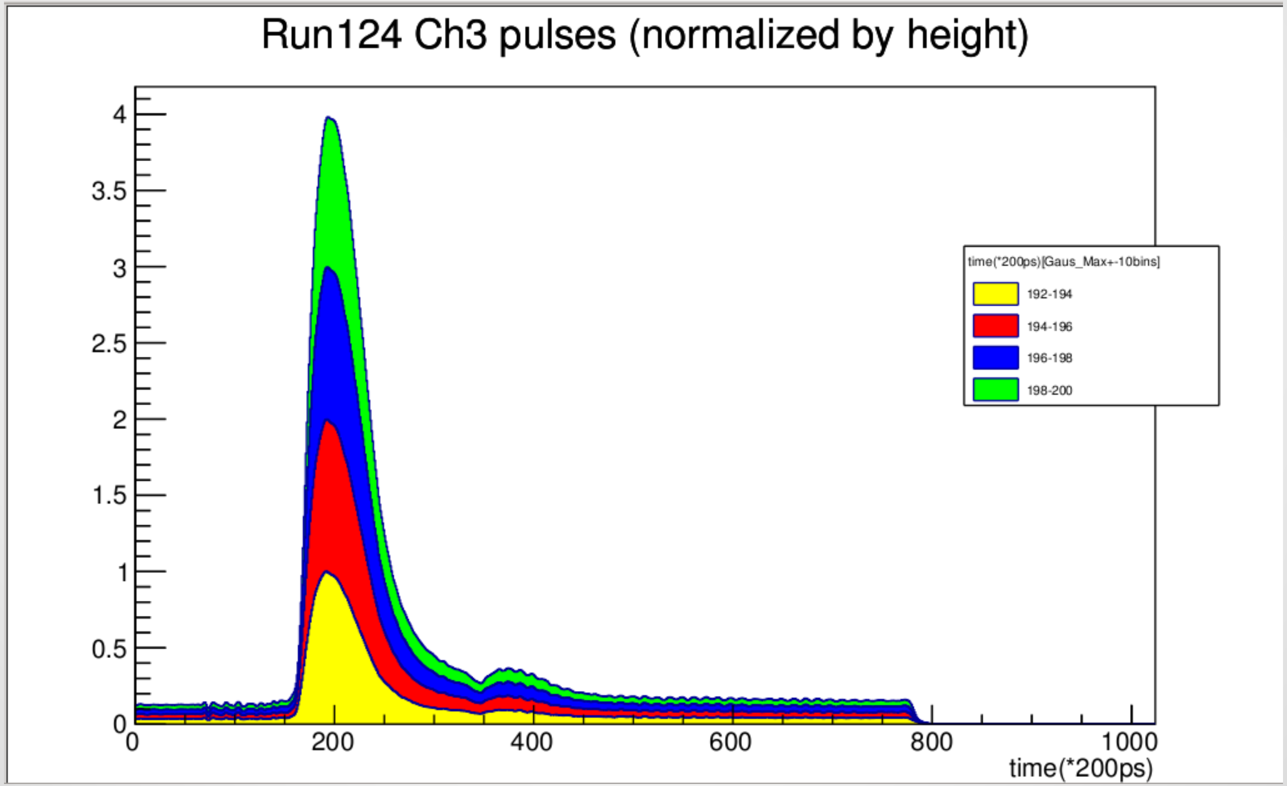
Run 124

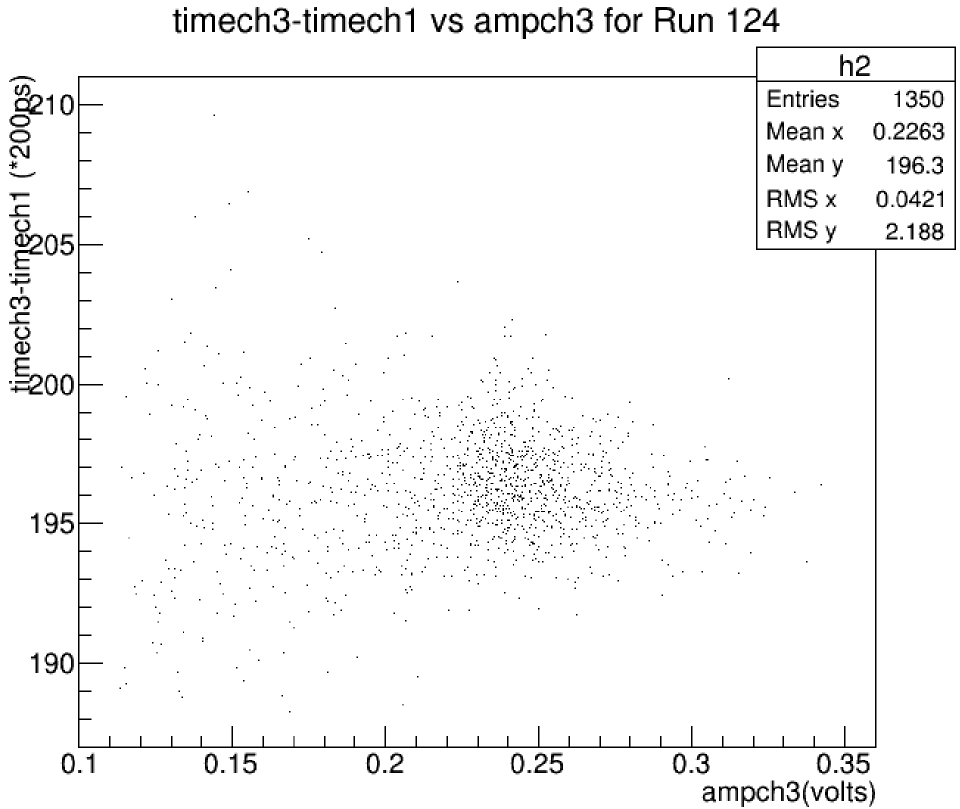
Run 124, ch3 trigger counter, ch1 Photek 10 dB 4.5 kV, ch2 Hama 10 db 3 kV, ch3 scint

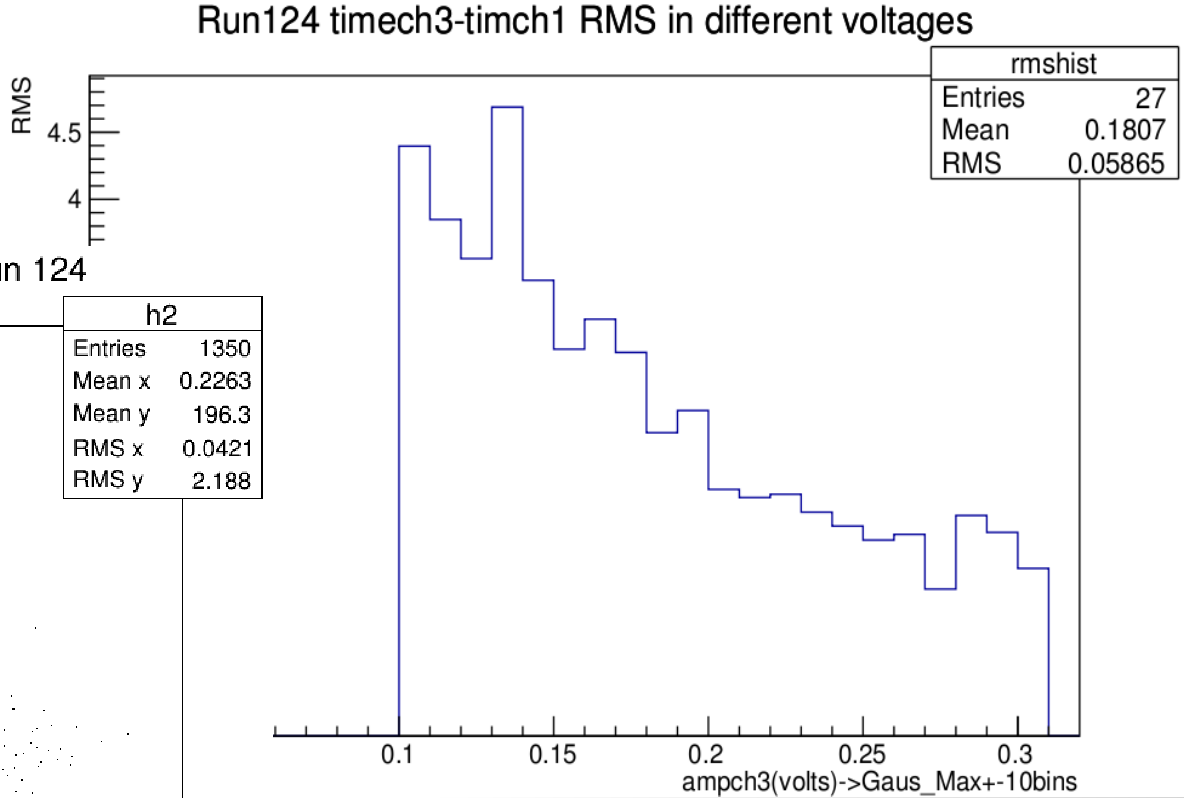
150 GeV

2180 events

Comparison of average pulses for different time intervals in ch3 for Run124




timech3-timech1 vs ampch3 for Run 124
h2
Entries 1350
Mean x 0.2263
Mean y 196.3
RMS x 0.0421
RMS y 2.188
timech3-timech1 (*200ps)
210
205
200
195
190
0.1
0.15
0.2
0.25
0.3
0.35
ampch3(volts)


Run124 timech3-timch1 RMS in different voltages
rmshist
Entries 27
Mean 0.1807
RMS 0.05865
RMS
4.5
4
0.1
0.15
0.2
0.25
0.3
ampch3(volts)->Gaus_Max+-10bins

Run 125

Run 125, ch3 trigger counter, ch1 Photek 20 dB 4.8 kV, ch2 Hama 6 db 2.95 kV, ch3 scint

150 GeV

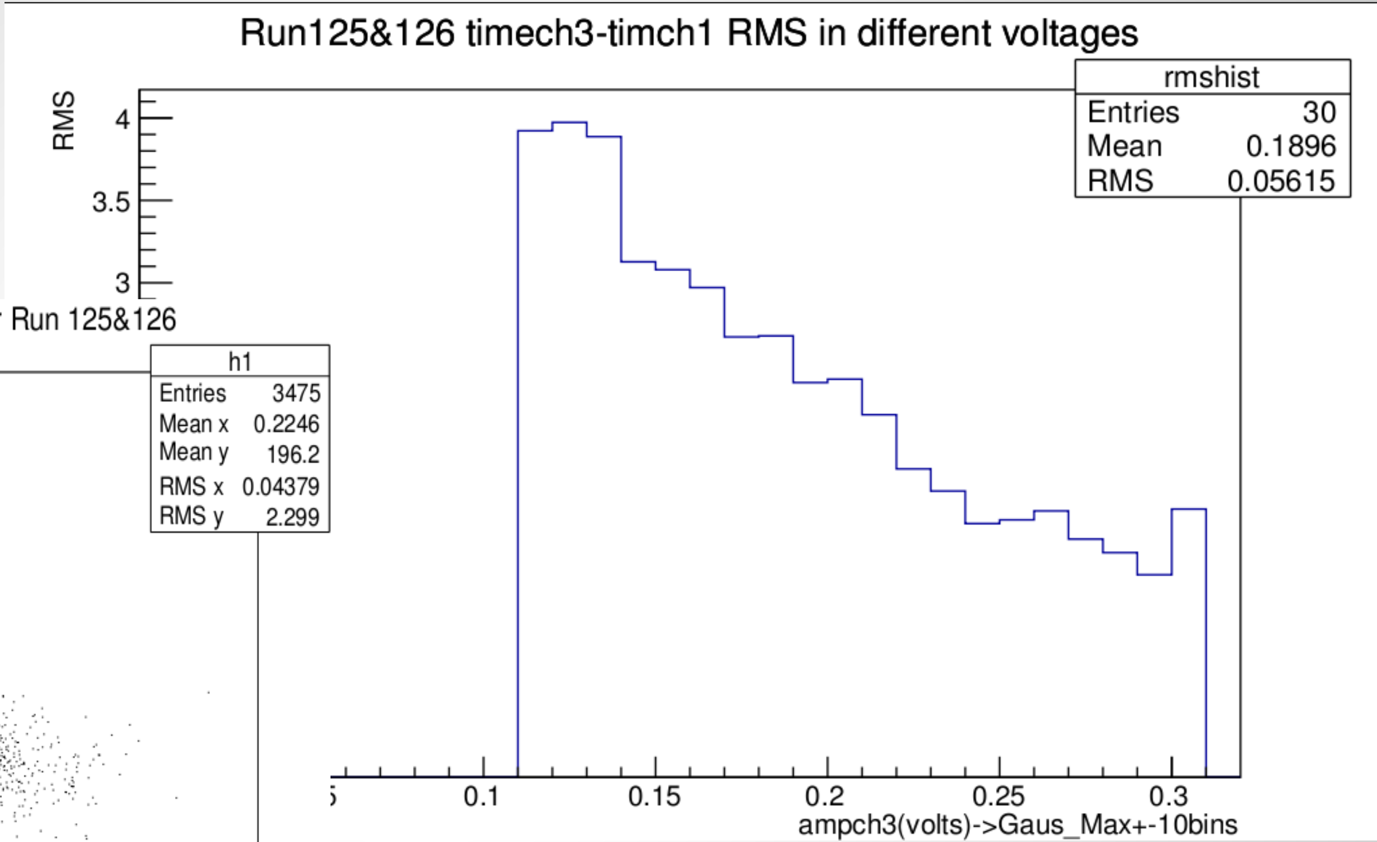
4936 events

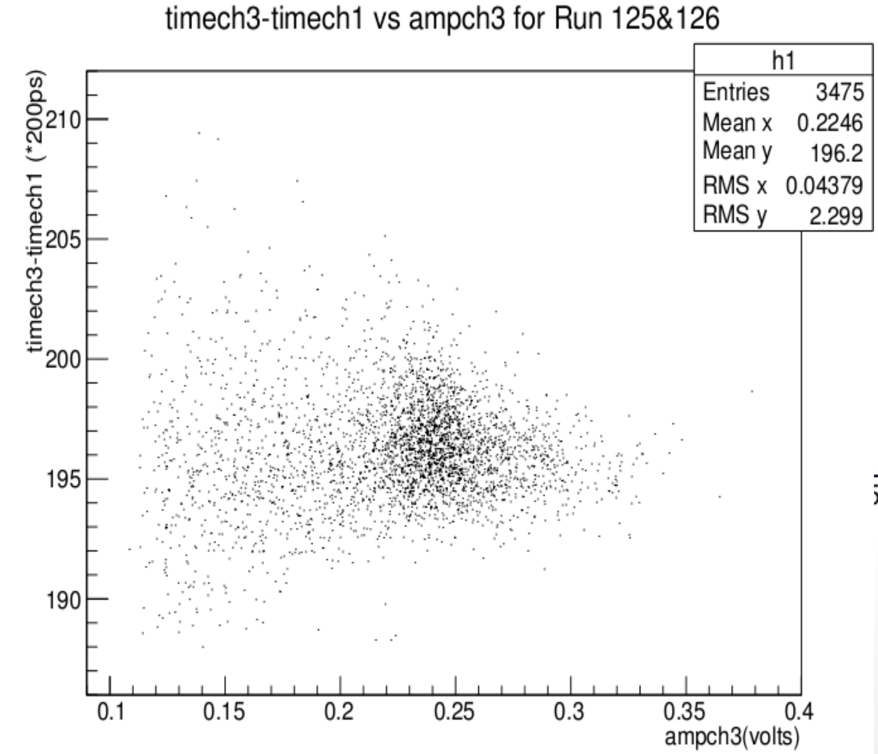
Run 126

Run 126, ch3 trigger counter, ch1 Photek 20 dB 4.9 kV, ch2 Hama 6 db 2.95 kV, ch3 scint

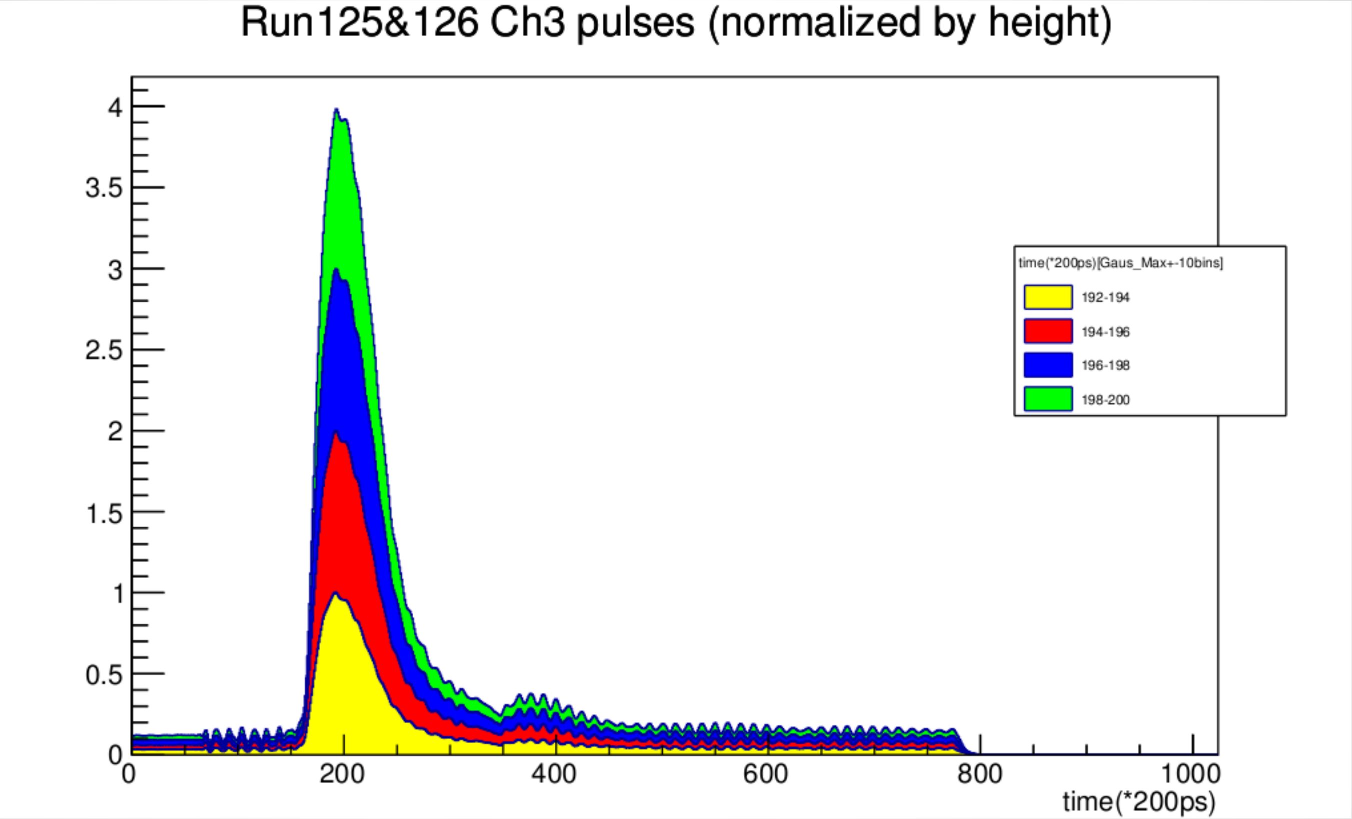
150 GeV

361 events


Run125&126 timech3-timch1 RMS in different voltages
rmshist
Entries 30
Mean 0.1896
RMS 0.05615
RMS
4
3.5
3
0.1
0.15
0.2
0.25
0.3
ampch3(volts)->Gaus_Max+-10bins


timech3-timech1 vs ampch3 for Run 125&126
h1
Entries 3475
Mean x 0.2246
Mean y 196.2
RMS x 0.04379
RMS y 2.299
timech3-timech1 (*200ps)
210
205
200
195
190
0.1
0.15
0.2
0.25
0.3
0.35
0.4
ampch3(volts)

Comparison of average pulses for different time intervals in ch3 for Run125&126



Study of time resolution for different fits and deposited energies

- In the following plots, since skewness dramatically depends on number of bins chosen, one should only consider the “sign” of the skewness to have an intuition about the deviation to either left or right.
- Honestly, I do not know whether kurtosis can help or not. I used it to find a probable trend in histograms.
- 40 bins are used in most of the histos and 70 for some of them in order to get a good intuition on shapes.
- The following fits are all linear from rising edge to some specific number of bins after rising edge which are mentioned on histos.

This plot should be considered before seeing fits:

Comparing integral of Shahslik pulse for different 150 Gev runs

Run124:

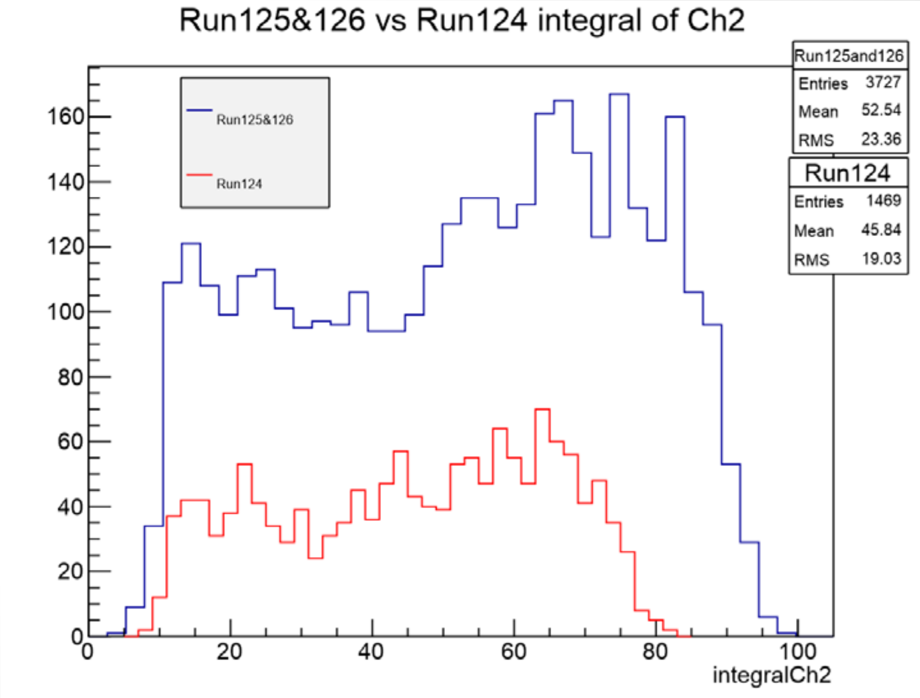
ch1 Photek 10 dB 4.5 kV, ch2 Hama 10 db 3 kV

Run125:

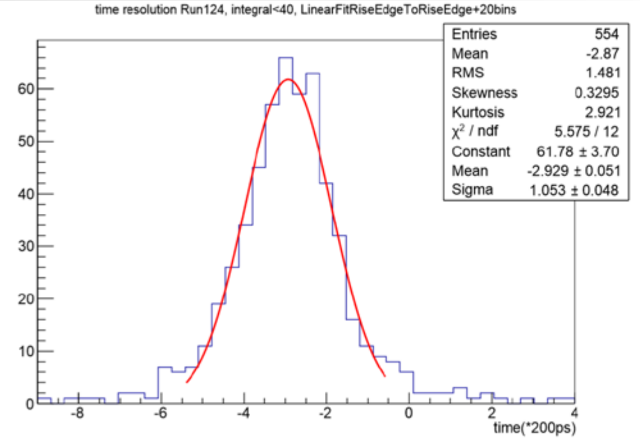
ch1 Photek 20 dB 4.8 kV, ch2 Hama 6 db 2.95 kV

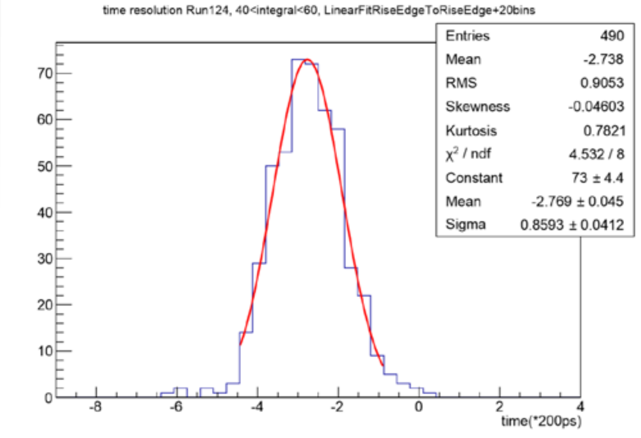
Run126:

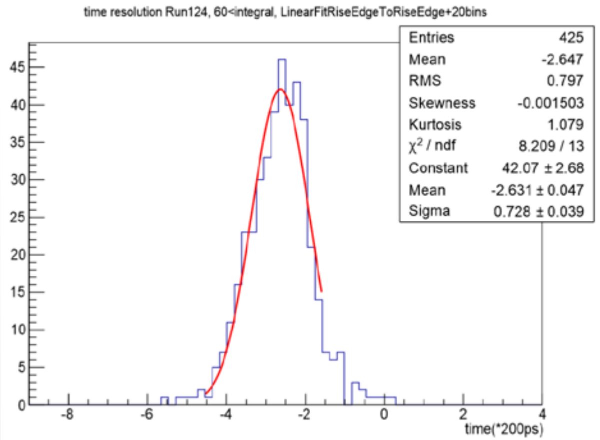
ch1 Photek 20 dB 4.9 kV, ch2 Hama 6 db 2.95 kV



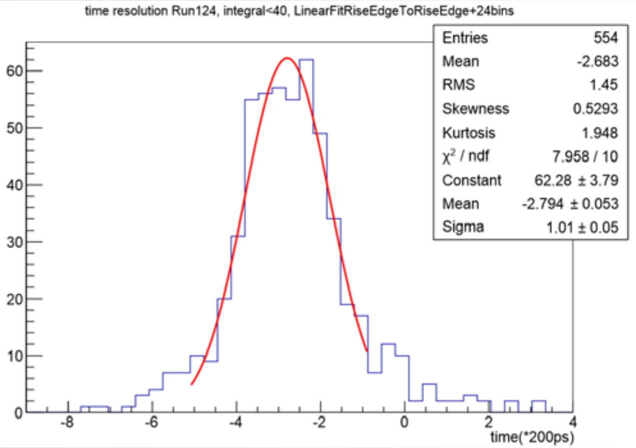
Run 124 Linear Fit+20

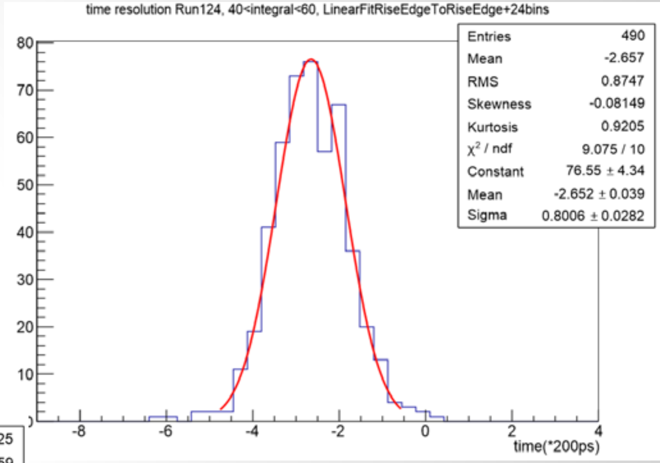


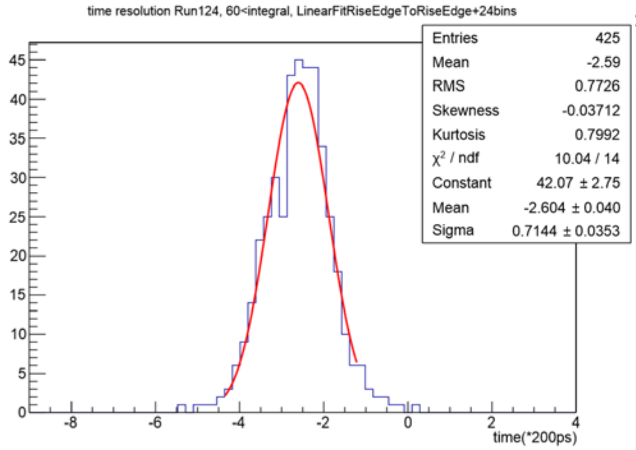




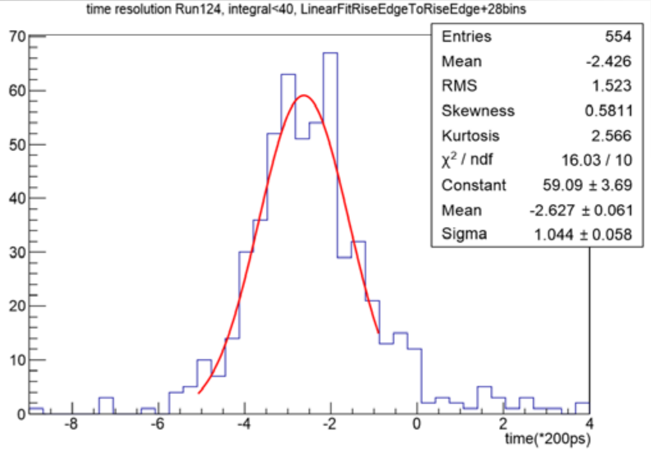
Run 124 Linear Fit+24

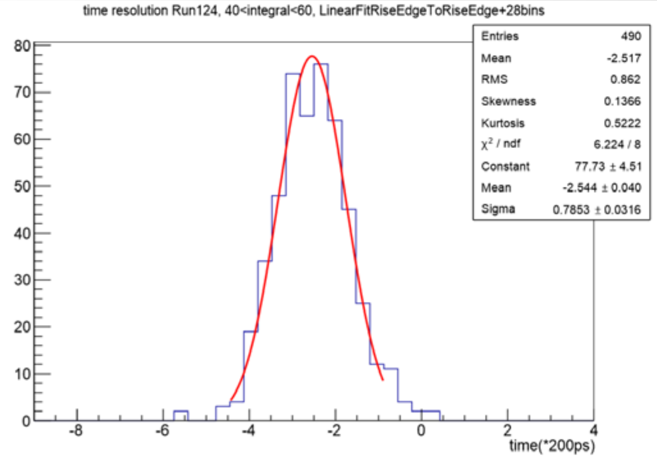


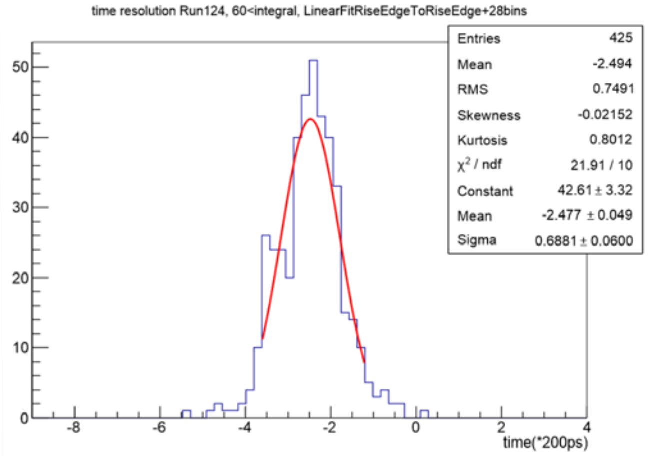




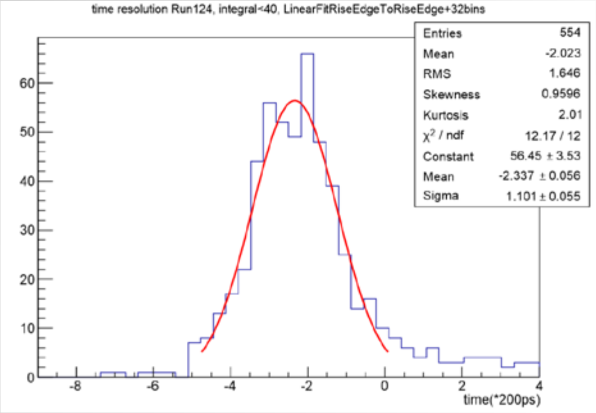
Run 124 Linear Fit+28

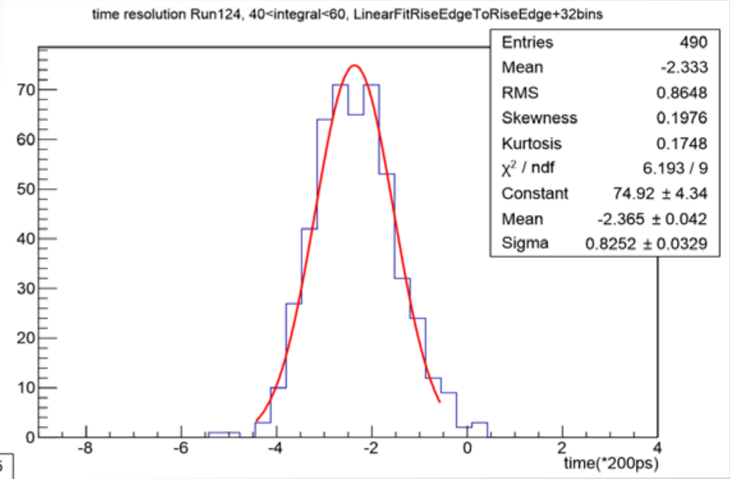


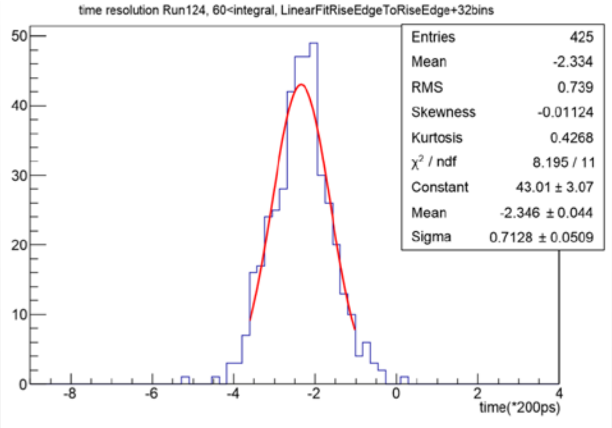




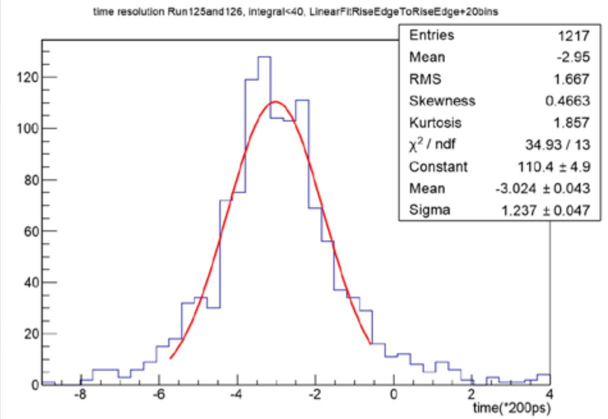
Run 124 Linear Fit+32

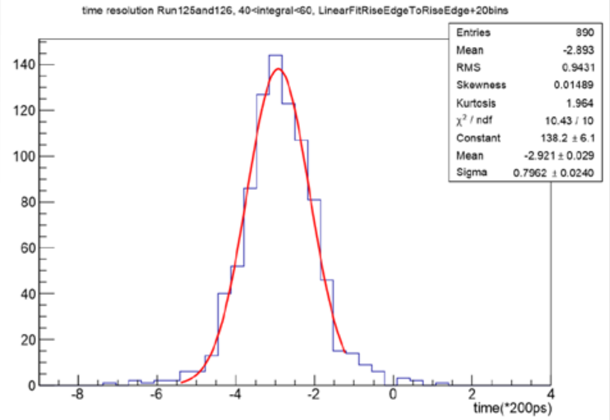


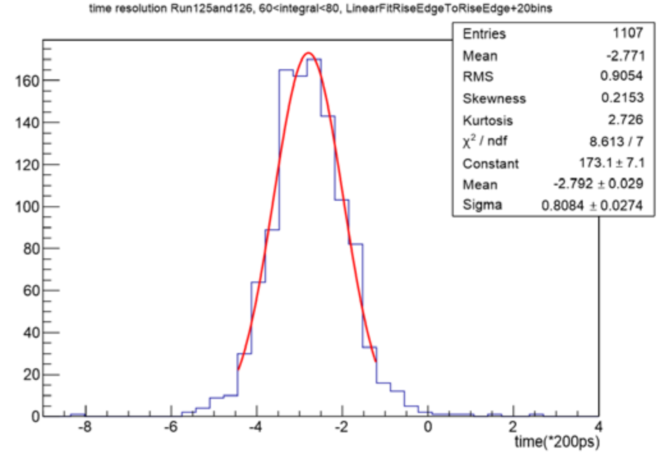


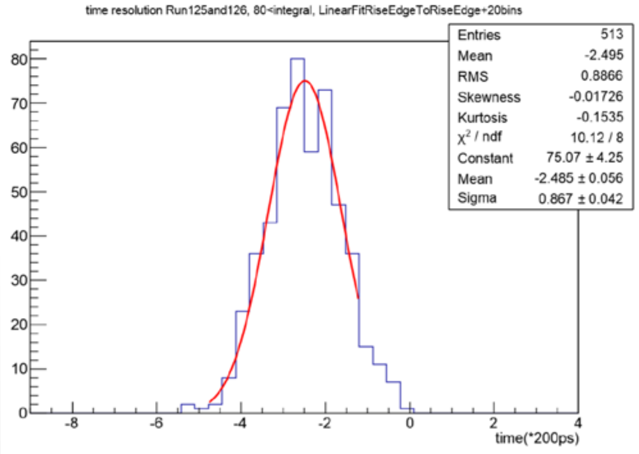


Run 125&126 Linear Fit+20

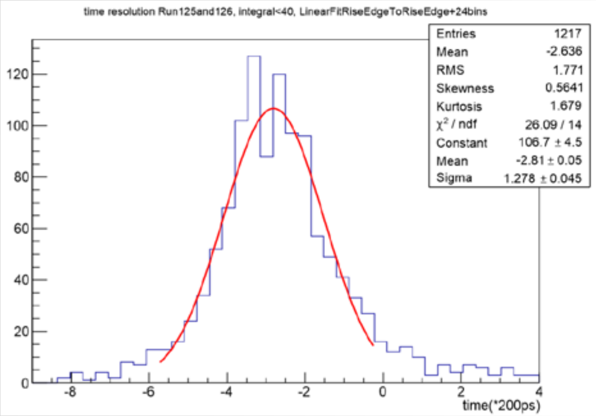


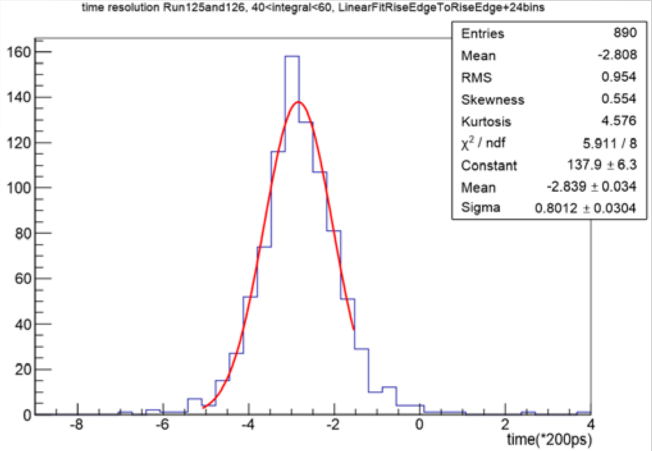


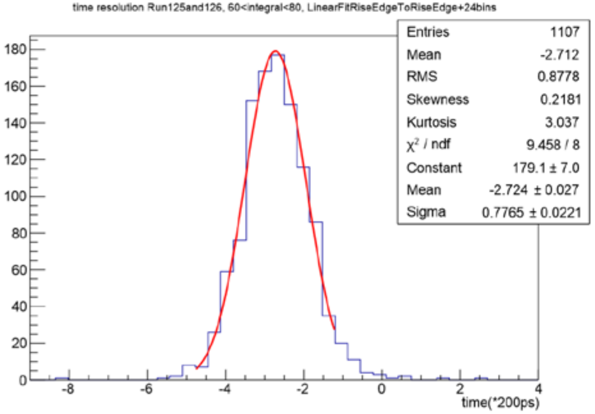


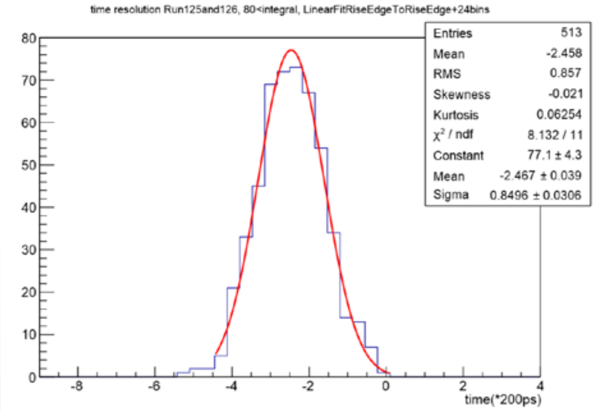


Run 125&126 Linear Fit+24

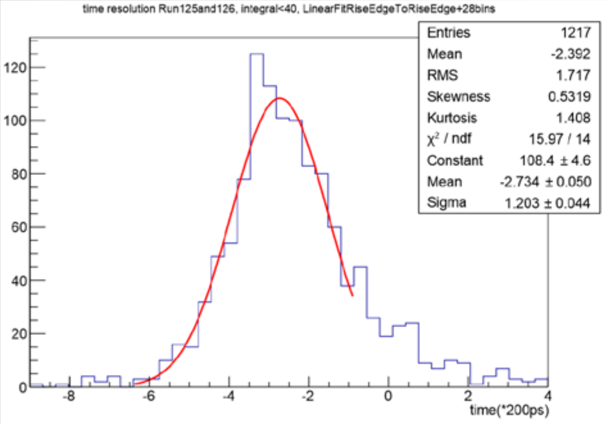


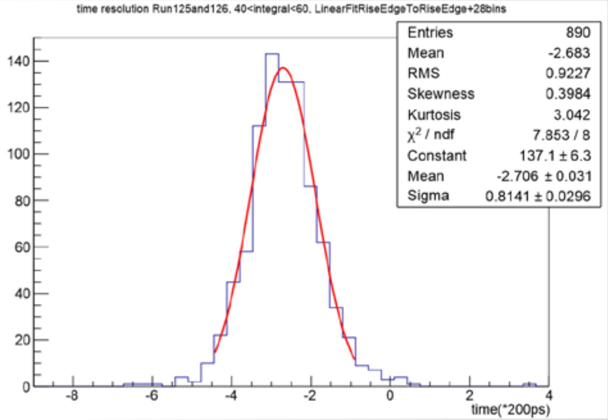


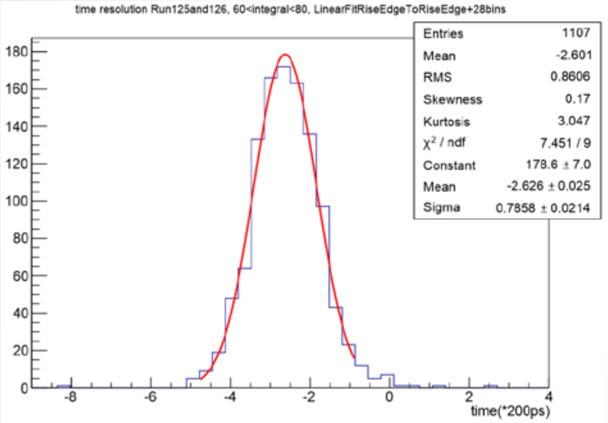


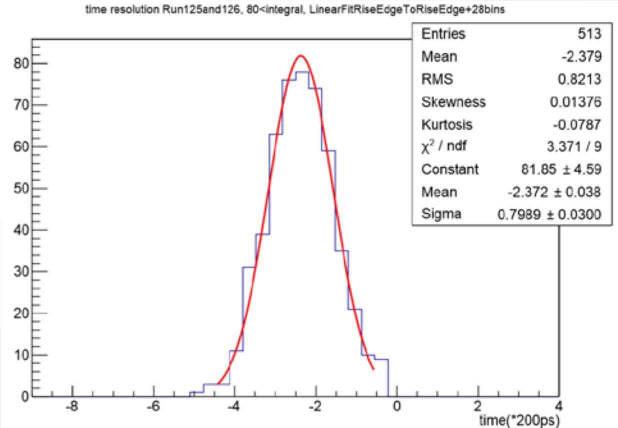


Run 125&126 Linear Fit+28

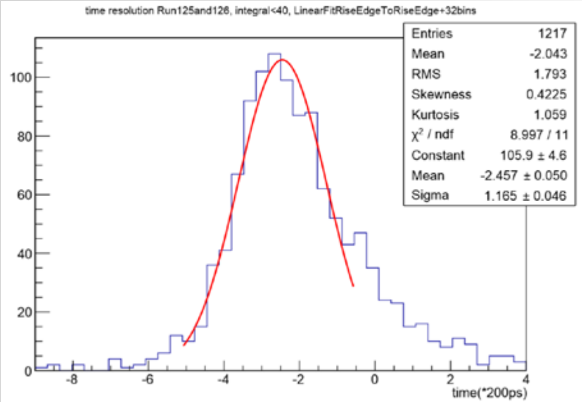


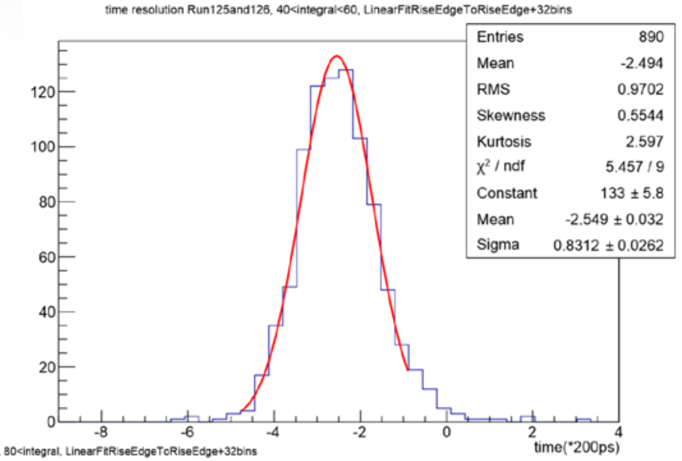


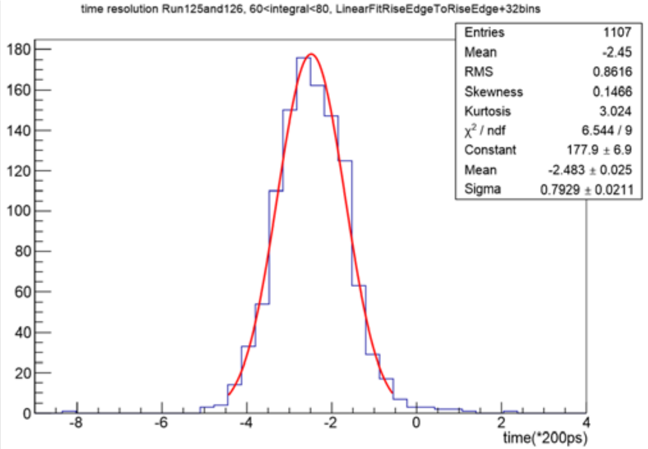


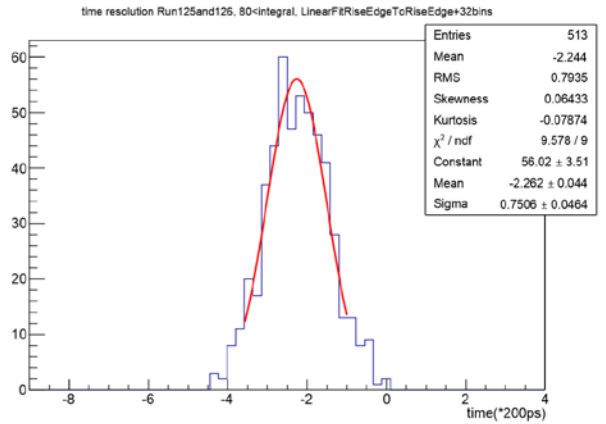


Run 125&126 Linear Fit+32

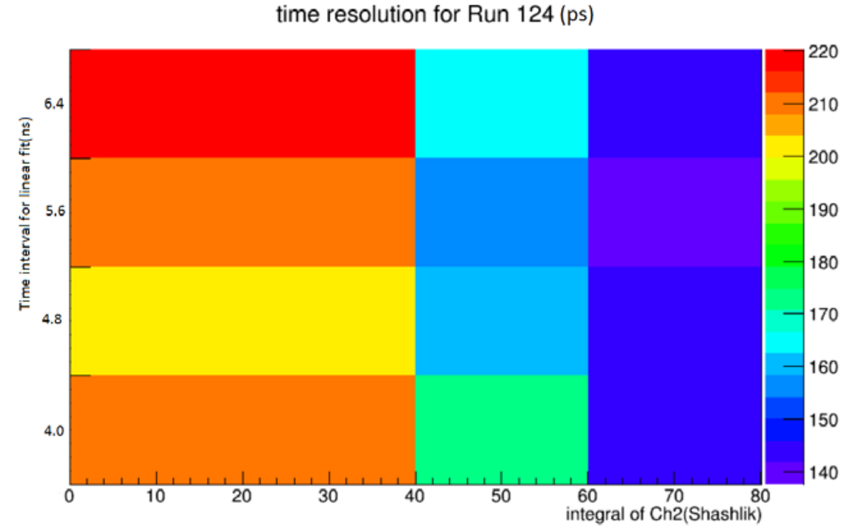


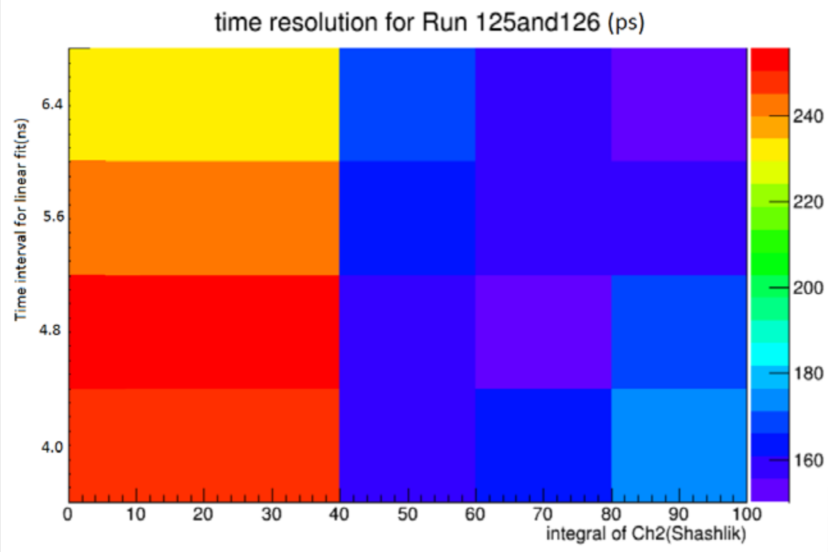






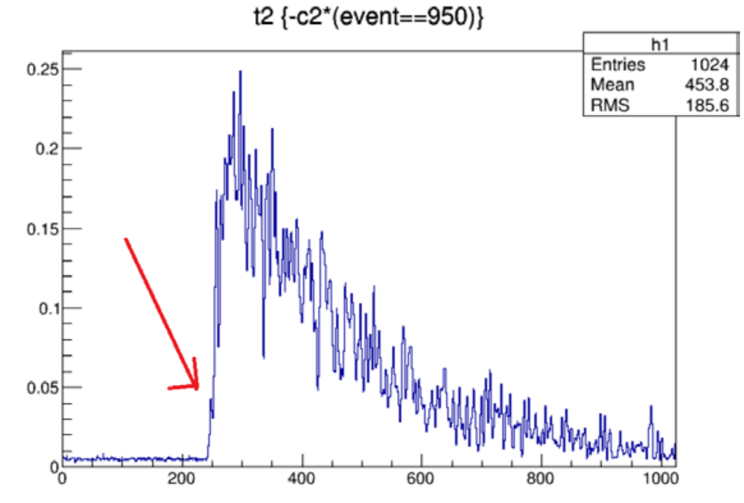
In summary:

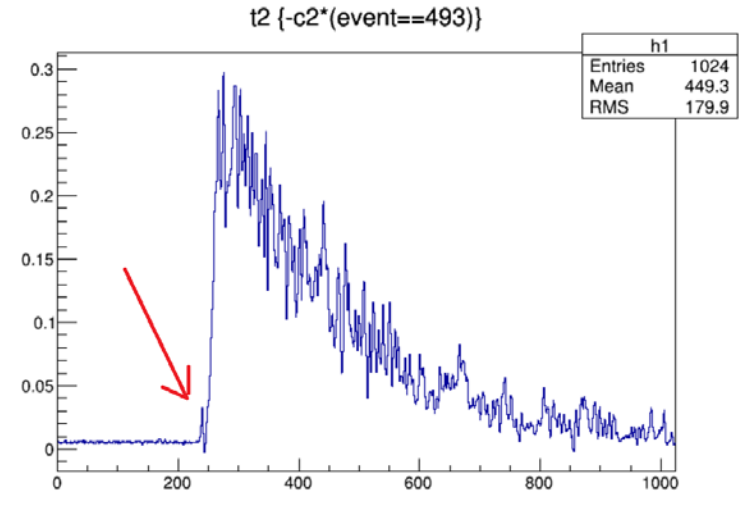




After this plots, I changed a little bit the definition of RiseEdge. The change is just 1 bin because of the difference between “i”th bin and “i”, in the function: “GetBinContent(i)”

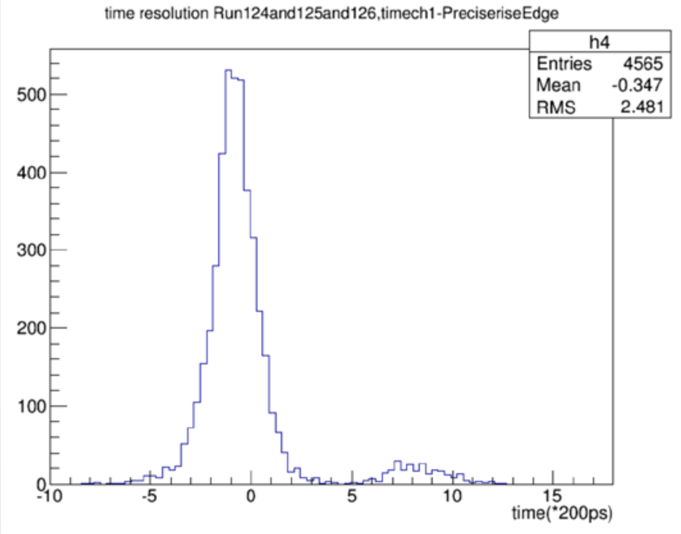
Study of wiggles in shashlik pulses

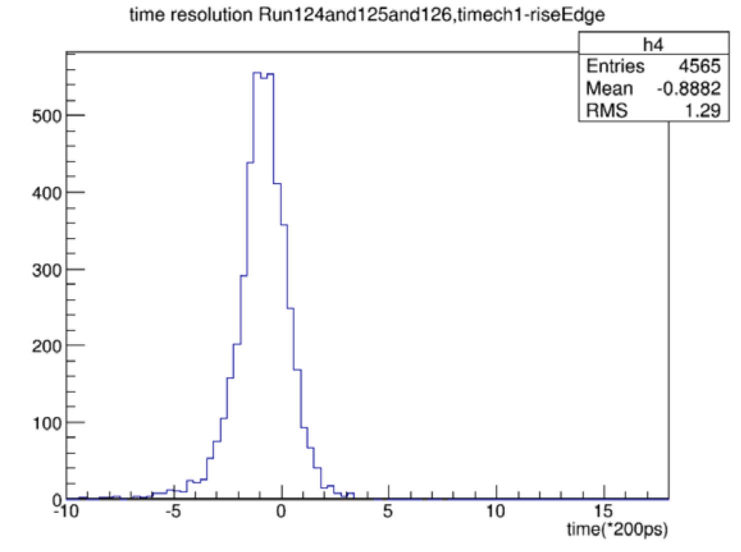




They start from about 10-13 bins before average rising edge and they can be seen until the peak of the main pulse by eye, but they may happen also after the peak(I do not know yet). The left histogram shows time resolution with an algorithm that precise such that it can find the little bumps. The right one passes and ignores the bump.

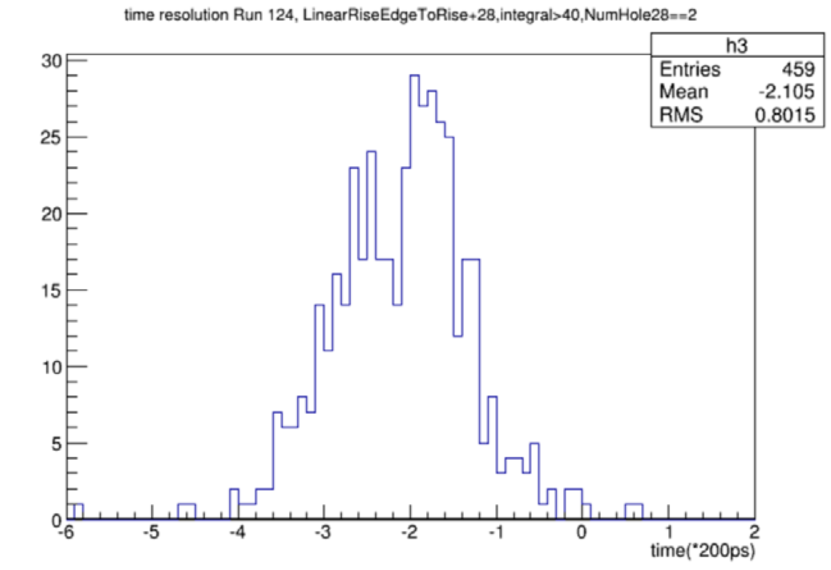
In spite of the discreteness which can be seen on the left histogram, the wiggles can happen at any time in the aforementioned interval. Discreteness is due to the algorithm that one uses for defining the rising edge point.

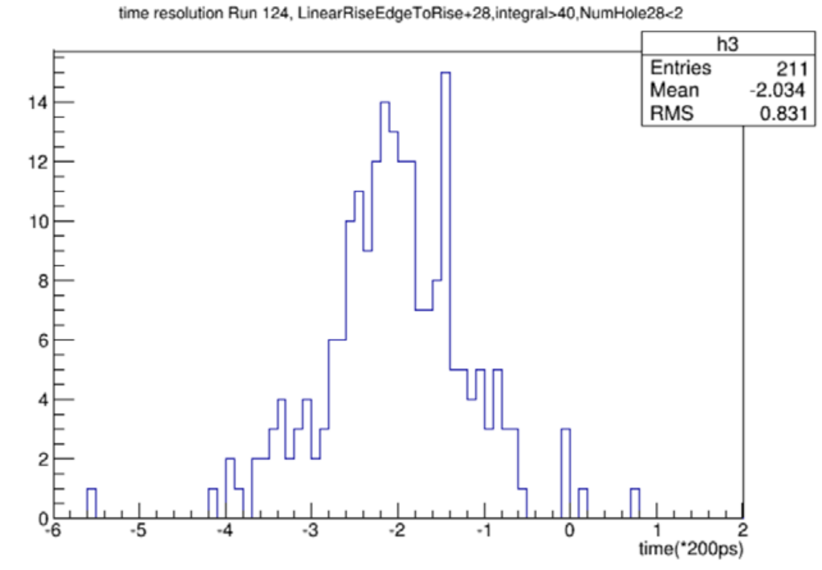




The Important point is that these wiggles do affect the time resolution. In current resolution -about 125 ps- which is less than one bin even small wiggles can cause bad fits, hence bad time resolution.

To see an example, these histos compare time resolution for events with 2 wiggles in first 28 bins after rising edge, and for events with less than two wiggles.

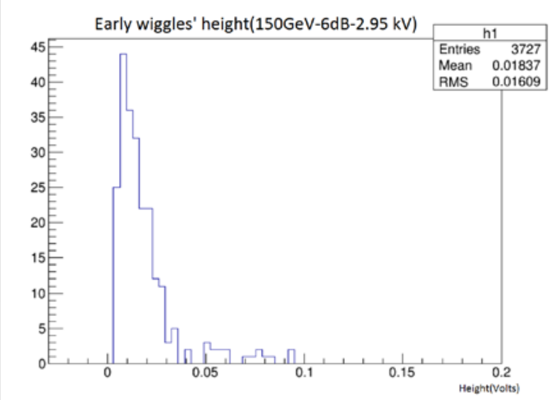


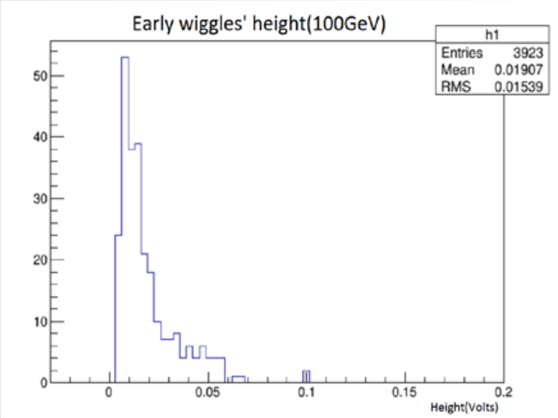


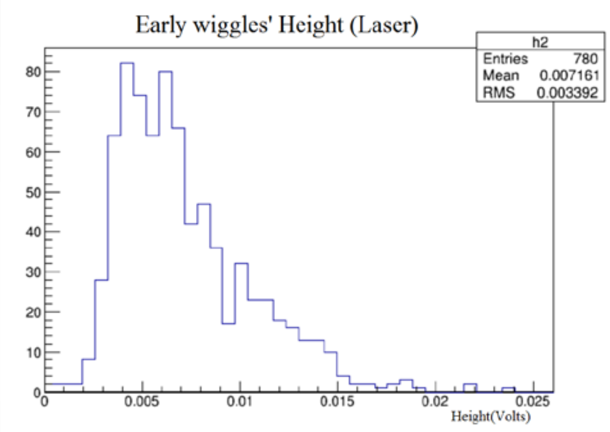
"Early" wiggles' height	October 2014 150 GeV 30db attenuator (31.6 times decrease in voltage)	July 2015 150 GeV 10db attenuator (3.16 times decrease in voltage)	July 2015 150 GeV 6db attenuator (2 times decrease in voltage)	July 2015 100 GeV 6db attenuator (2 times decrease in voltage)	July 2015 50 GeV 6db attenuator (2 times decrease in voltage)
Absolute wiggles' average height:	Height=**0.0077** RMS=0.0031	Height=**0.0183** RMS=0.0149	Height=**0.0184** RMS=0.0161	Height=**0.0191** RMS=0.0154	Height=**0.0185** RMS=0.0162
Raw amplitude of the wiggles	Raw Height=0.2433	Raw Height=0.0578	Raw Height=0.0368	Raw Height=0.0382	Raw Height=0.0370
Wiggles' height Relative to amplitude:	Ratio=0.0503 RMS=0.0263	Ratio=0.0693 RMS=0.0565	Ratio=0.0567 RMS=0.0556	Ratio=0.0562 RMS=0.0572	Ratio=0.0528 RMS=0.0457
Number of events with early wiggles	16 out of 1555=>1.0%	101 out of 1469 =>6.9%	235 out of 3727 =>6.3 %	266 out of 3915 => 6.8%	297 out of 3965 =>7.5%

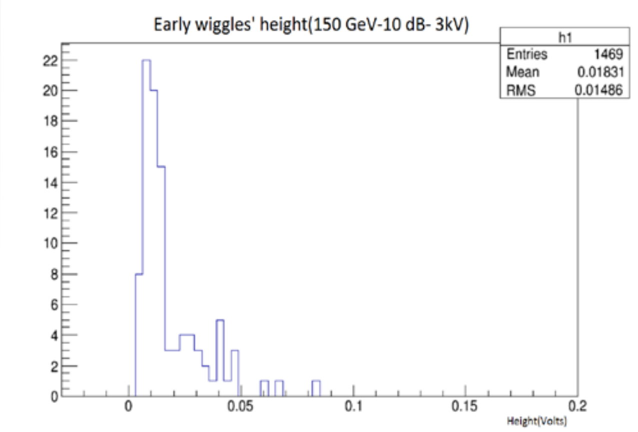
“Early” wiggles’ height	32GeV Ch3	32GeV Ch4	Laser Run#41		
Absolute wiggles’ average height:	Height=**0.0046** RMS=0.0030	Height=**0.0162**	Height=**0.0072**		
Raw amplitude of the wiggles	Raw Height=				
Wiggles’ height Relative to amplitude:			Ratio=0.0211		
Number of events with early wiggles	61 out of 1696=>3.5%	42 out of 2171 =>1.9%	776 out of 1000 =>77.6%		

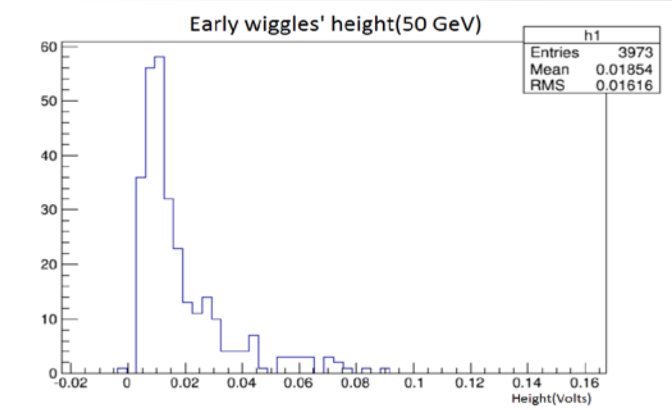
Distribution of “early” wiggles’ height



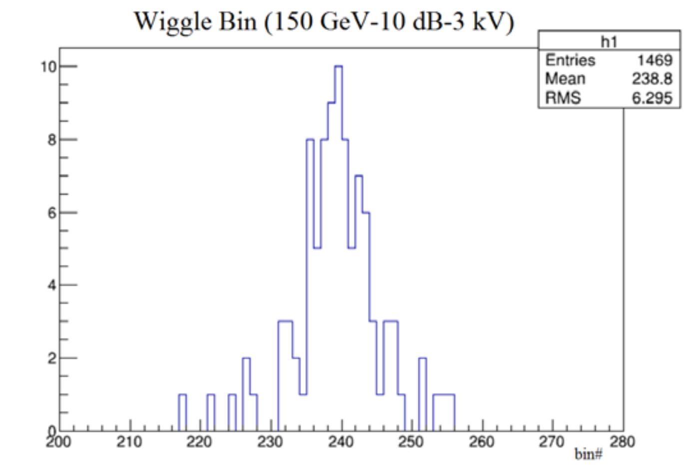






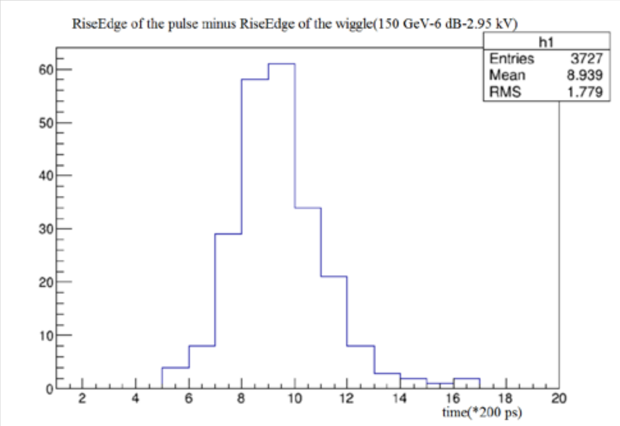


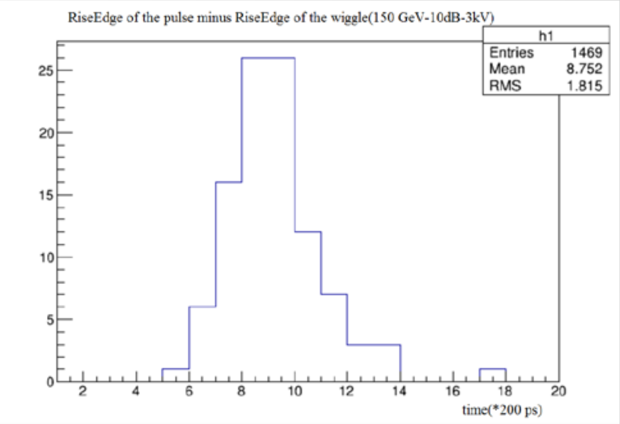
It seems that all have the same distributions. The October test has few statistics so drawing that plot may not convey any useful information.

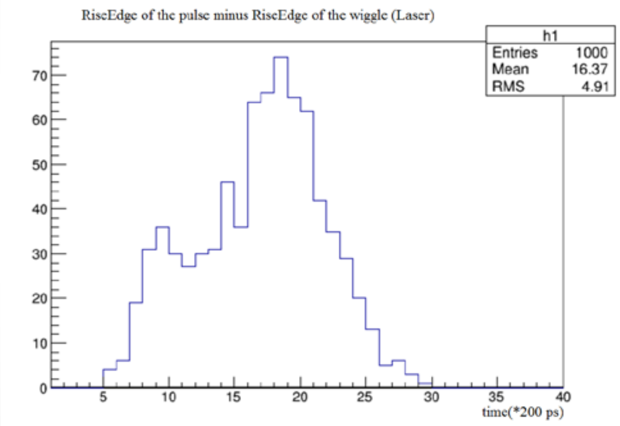

Wiggle Bin (150 GeV-10 dB-3 kV)
h1
Entries 1469
Mean 238.8
RMS 6.295
0
2
4
6
8
10
200
210
220
230
240
250
260
270
280
bin#

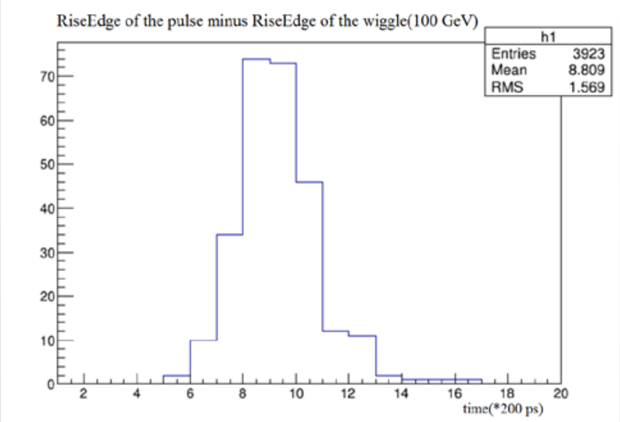
Although the RMS is roughly the same as the mean for height of early wiggles, if the mean value of two distributions with large statistics are the same, one can conclude that they behave in the same way. The reason is they obey the same non-Gaussian distribution. Their distributions are drawn in one of the pages close to this page.

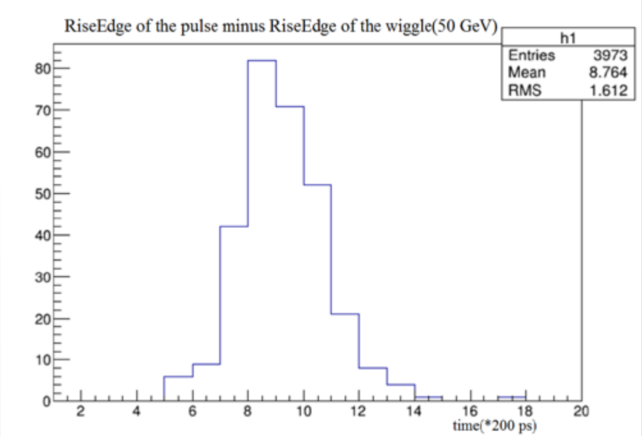
To find out how far from the rising edge the early wiggles are, two parameters are defined in this page and the plots are drawn in the next page.


RiseEdge of the pulse minus RiseEdge of the wiggle(150 GeV-6 dB-2.95 kV)
h1
Entries 3727
Mean 8.939
RMS 1.779
time(*200 ps)


RiseEdge of the pulse minus RiseEdge of the wiggle(150 GeV-10dB-3kV)
h1
Entries 1469
Mean 8.752
RMS 1.815
time(*200 ps)


RiseEdge of the pulse minus RiseEdge of the wiggle (Laser)
h1
Entries 1000
Mean 16.37
RMS 4.91
time(*200 ps)


RiseEdge of the pulse minus RiseEdge of the wiggle(100 GeV)
h1
Entries 3923
Mean 8.809
RMS 1.569
time(*200 ps)


RiseEdge of the pulse minus RiseEdge of the wiggle(50 GeV)
h1
Entries 3973
Mean 8.764
RMS 1.612
time(*200 ps)

Some points on
Hamamatsu MCP-PMT

The schematic is in Figure 10-2 which I got from PMT-handbook.

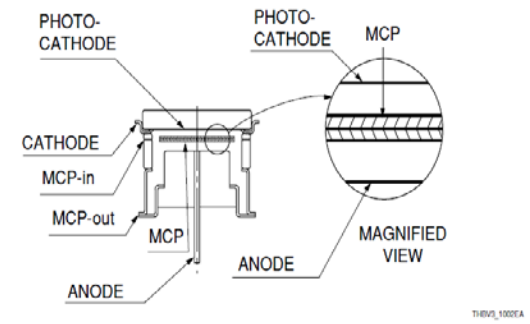


Figure 10-2: Cross section of a typical MCP-PMT

The MCP (NOT photocathode) is blind to visible light.
(Table 3 from "MCP Assembly" pdf file from Hamamatsu)

Table 3: Detection Efficiency of MCP

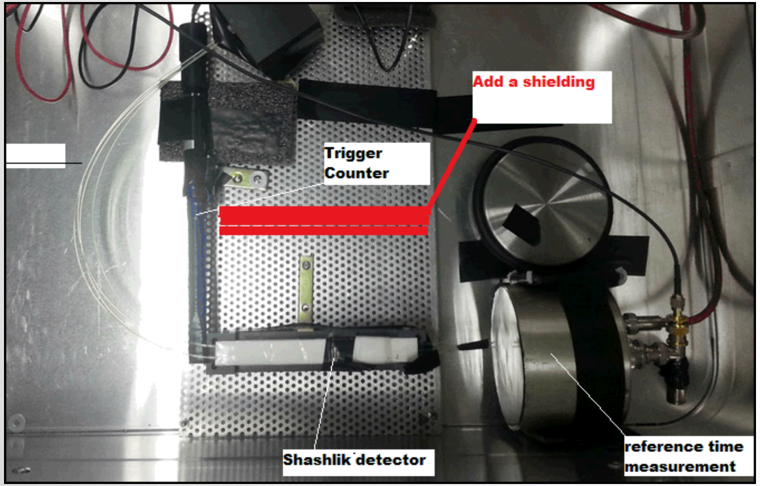
Types of Radiation	Energy or Wavelength	Detection Efficiency (%)
Electron	0.2 keV to 2 keV	50 to 85
	2 keV to 50 keV	10 to 60
	0.5 keV to 2 keV	5 to 58
Ion (H^+, He^+, Ar^+)	2 keV to 50 keV	60 to 85
	50 keV to 200 keV	4 to 60
UV	300 Å to 1100 Å	5 to 15
	1100 Å to 1500 Å	1 to 5
Soft X-ray	2 Å to 50 Å	5 to 15
Hard X-ray	0.12 Å to 0.2 Å	to 1
High energy particle (ρ, π)	1 GeV to 10 GeV	to 95
Neutron	2.5 MeV to 14 MeV	0.14 to 0.64

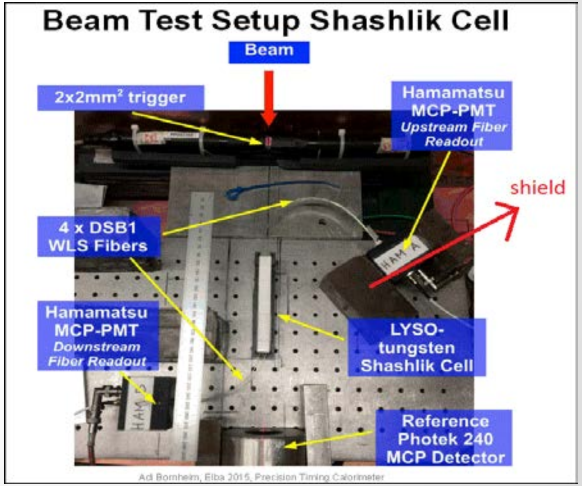
Some points on Hamamatsu MCP-PMT

The photocathode though, in Hamamatsu R3809U-50 which is used in our experiments, can detect from 160 nm to 850 nm

http://www.hamamatsu.com/us/en/R3809U-50.html

Can the wiggles, random wiggles and not large fluctuations in the decay part, be because of shielding problem? Electrons can produce X-ray via Bremsstrahlung radiation as they hit the metals.





This conclusion is WRONG! Please look at the data in previous pages!

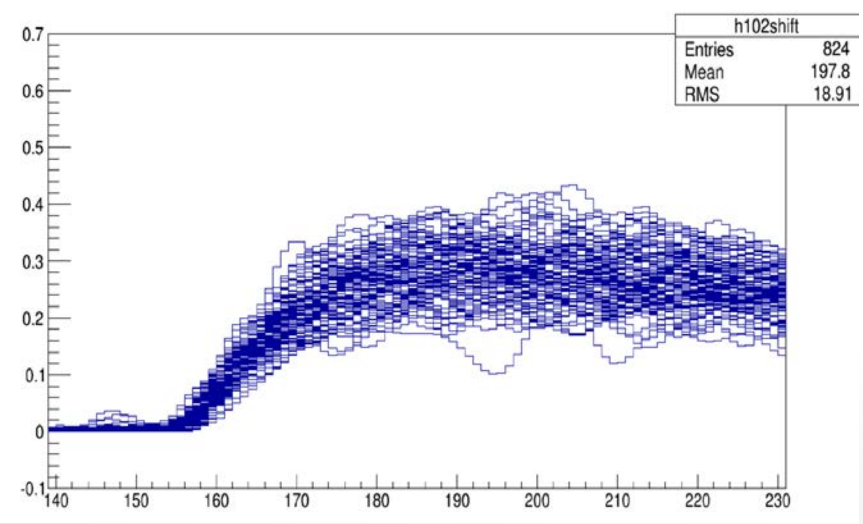
Comparing experiments

	2014fiber	2014LYSO
Early wiggles	Yes	Not at all! In none of four different energies!

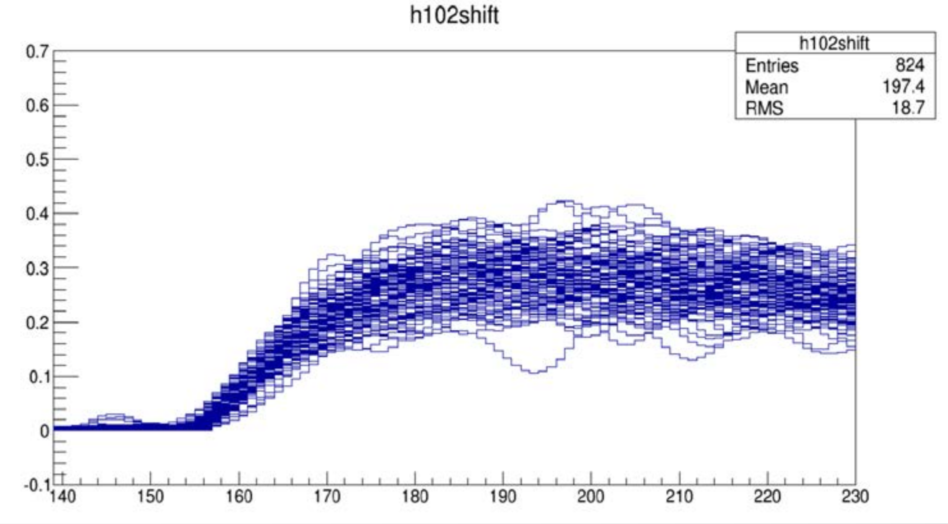
Fourier transform

The following plots show 100 shashlik pulses of which some frequencies are eliminated and then shifted by reference time. Also they are shifted downward so that all of them start at zero voltage.The plots are in a window around rising edge. Look at the wiggles before rising edge!
I am almost sure that frequency 128, for example, means somehow waves with wavelength (1024/128)=8 bins period.

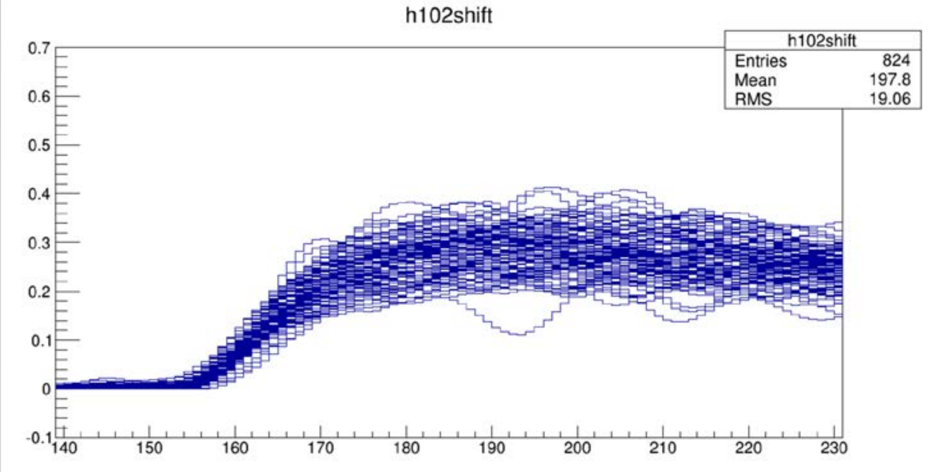
only frequencies less than 100 remained



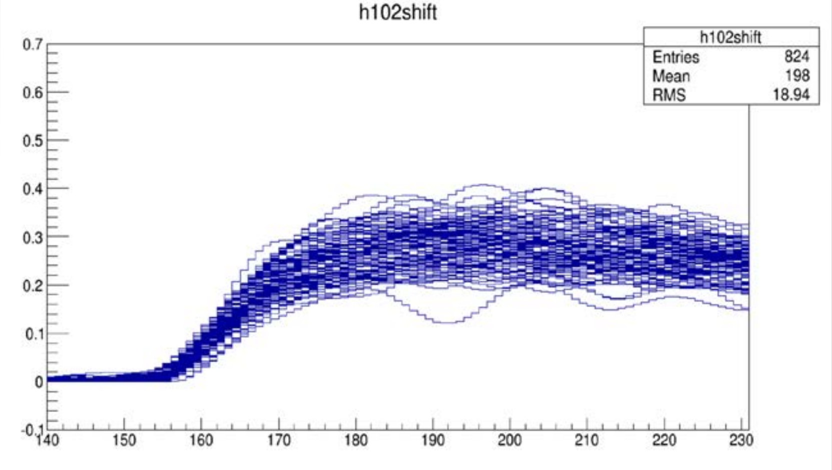
only frequencies less than 80 remained



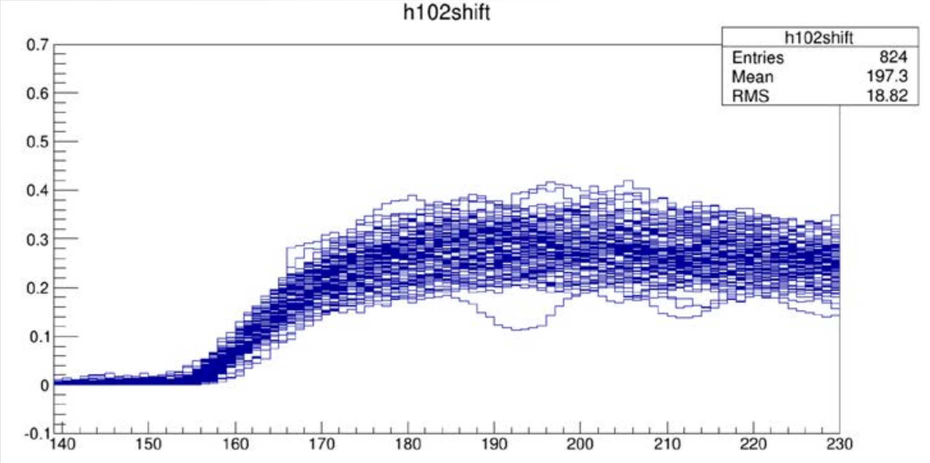
only frequencies less than 70 remained



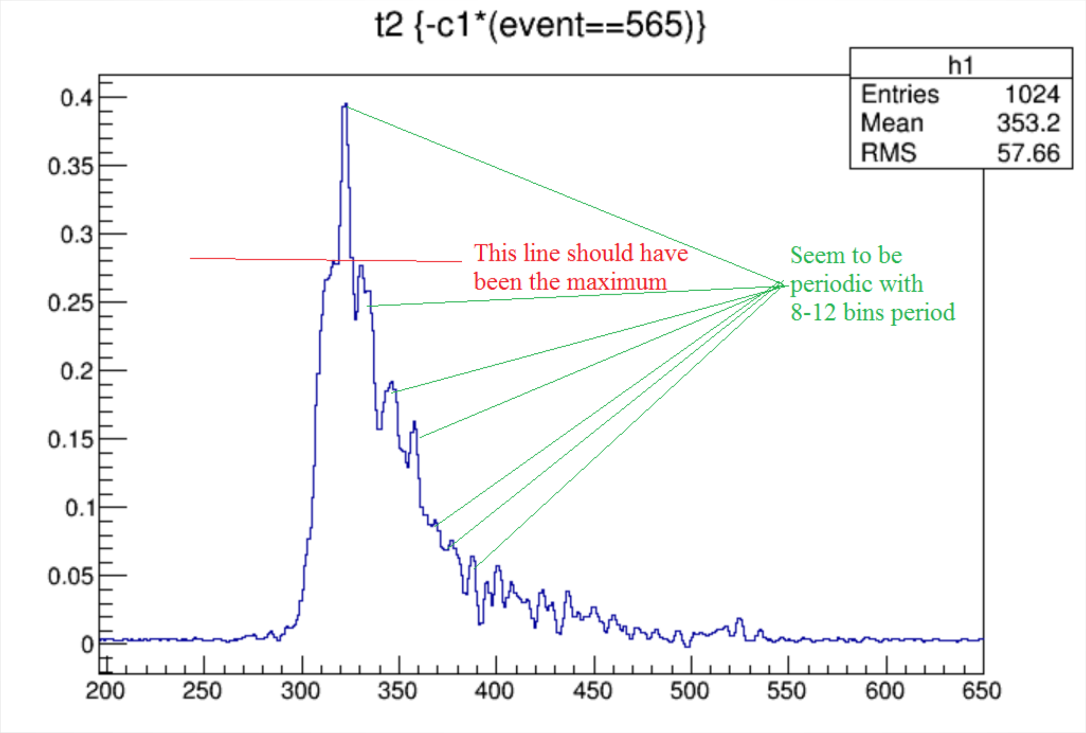
only frequencies less than 60 remained



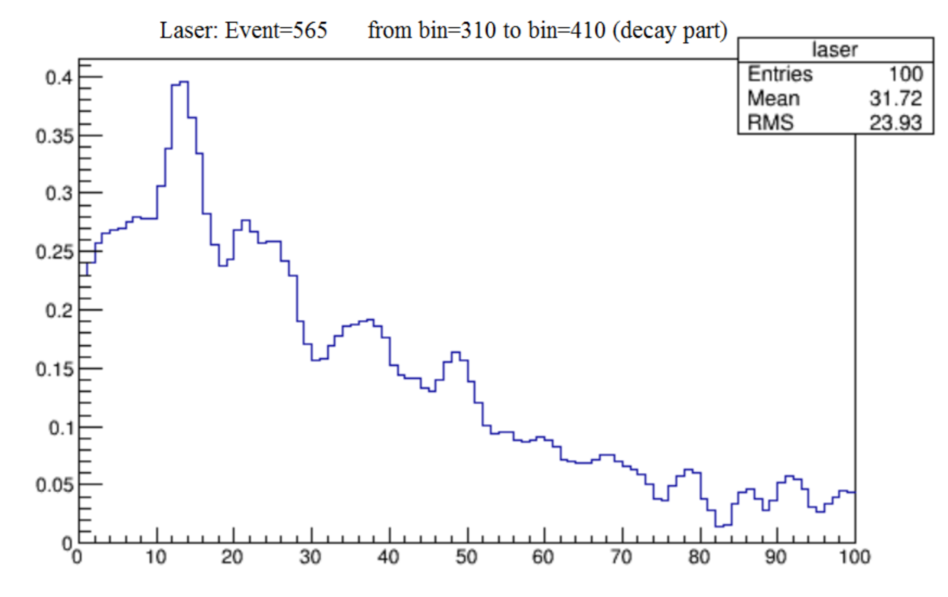
only frequencies less than 70 and more than 200 remained

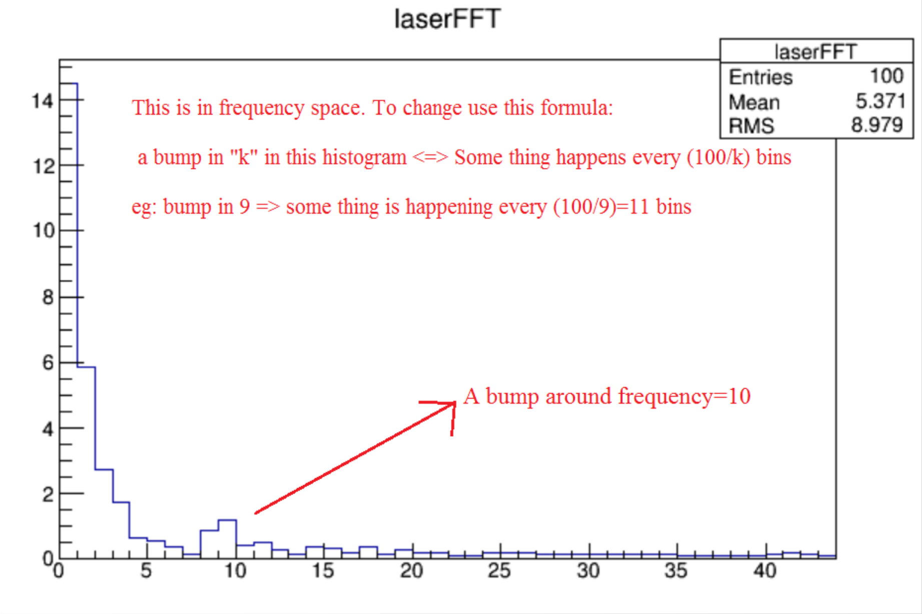


Laser pulses are way smoother. It seems that they are affected by some oscillating voltage which the amplitude of that is proportional to the amplitude of the readout voltage. I do not have many evidences for that, if we assume that, many problems can be solved.



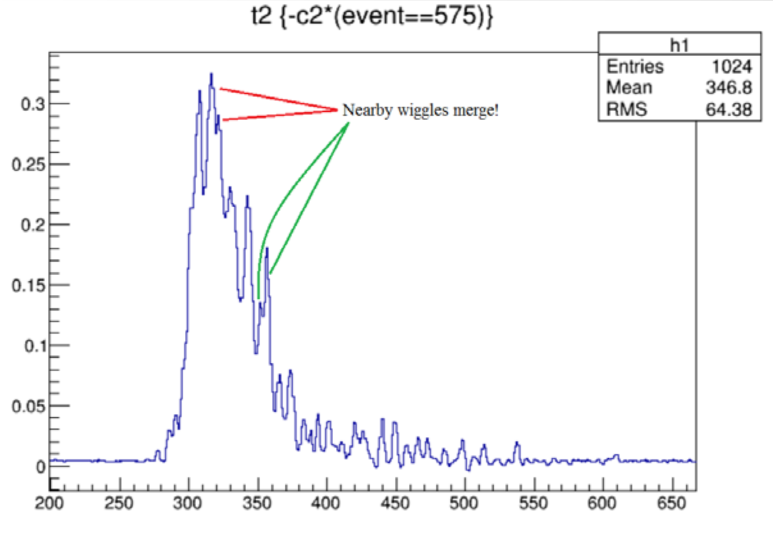
The left plot is the decay part of a sample event for laser experiment(with MCP) and the right plot is the fourier transform of it. The complete plot of the pulse can be found in previous pages.



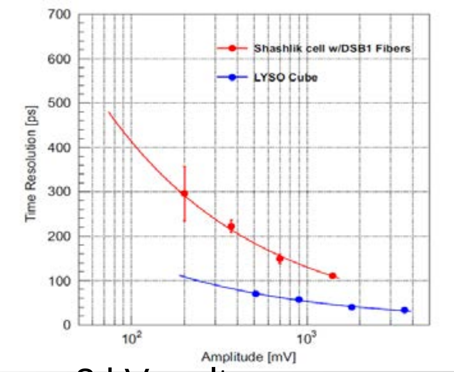


One should be careful about periodicity of the wiggles by just looking at fourier transform. Since the width of a single wiggle is large enough compared to the wavelength associated to its period, even if the wiggles are not periodic they may seem in this way. To clarify, look at this laser pulse example which is measured by MCP after being scintillated in DSB1 fibers:

Since overlapped wiggles can be inferred as a single one, this apparent periodicity -- which can be deduced with FFT plot -- might be just a result of wiggles' large width.



Comparing different experiments

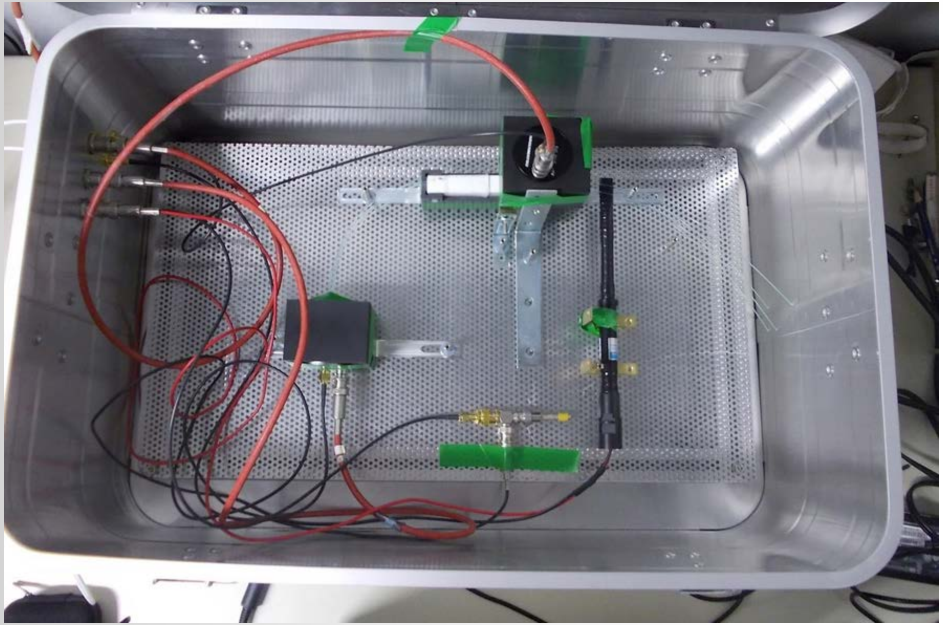


I got a resolution of about 103 ps for the run in October 2014 in contrast to the one which is done in July 2014 that was about 123 ps. The 103 seems to be rational , for this result is gotten using just one MCP as a timestamp of particle entering shashlik cell. If there were two, it would decrease by a factor of second root of 2 which becomes around 103/sqrt(2)= 72.8 which scales well with respect to the figure in Caltech paper.

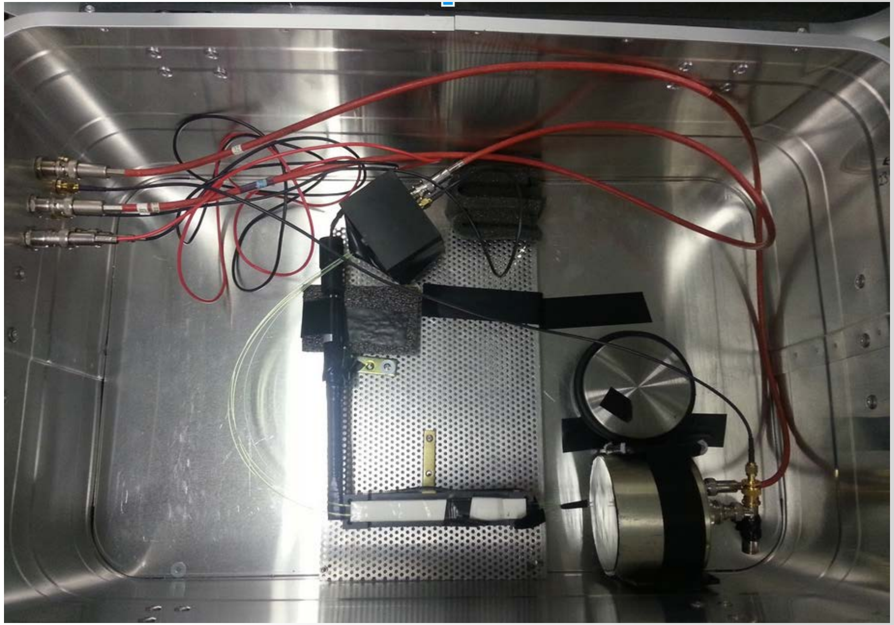
Both experiments are done at CERN with the same 150 GeV energy. Almost the same 3 kV voltage applied as gain. Assuming the same frequency of beam - which results in the same saturation behaviour - the only rational differences are shown in the table below(Figure in the next slide):

Comparing Setup for 2014 October 150 GeV and 2015 July 150 GeV		
	2014 October 150 GeV	2015 July 150 GeV
photons are transferred:	end of shashlik	front of shashlik
rough fiber length:	1 * shashlik length	2 * shashlik length
curvature of the fiber	almost same	almost same

2014 October setup



2015 July setup

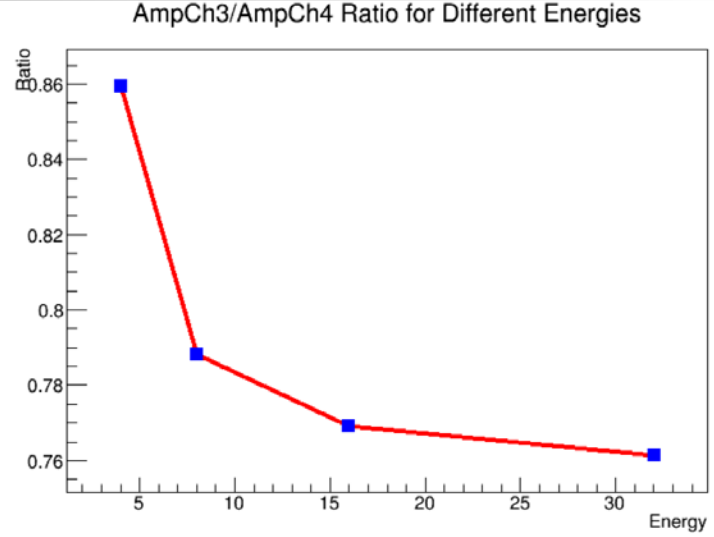


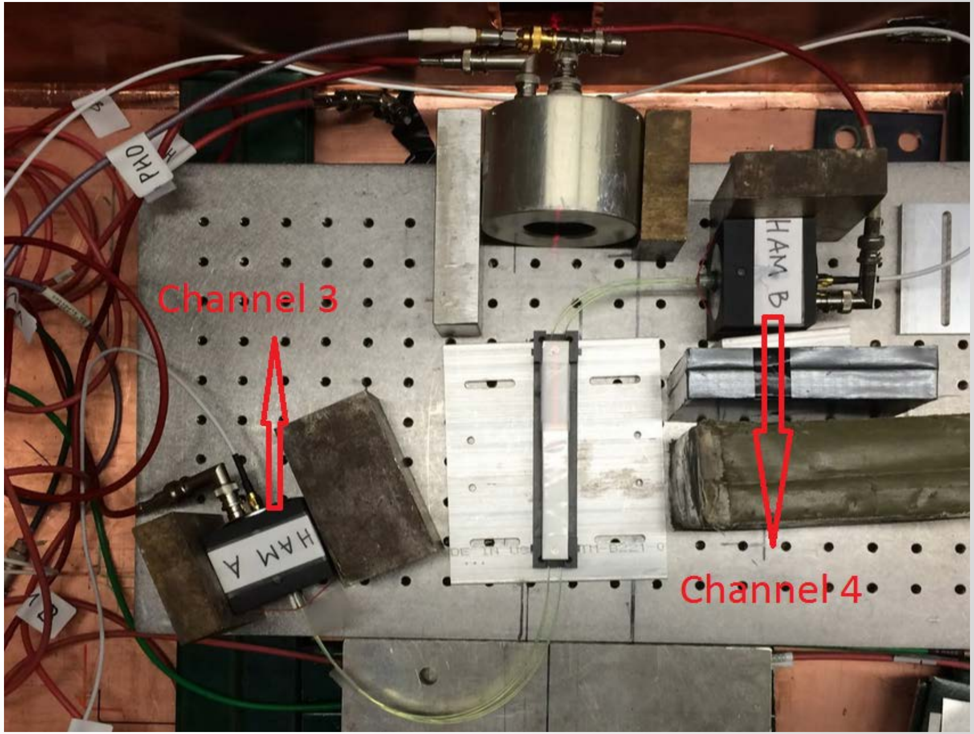
Getting data from the end or front does not differ since the process of scintillation emits photons in spherically symmetric directions.
The efficiency of the fibers - the number of photons that the fiber successfully transfers, over all photon which enter the fiber- is 8 percent.
(Reference: http://www.google.com/patents/US6078052)

Therefore, the only remaining difference is the curvature of the two fibers. This might not be important at first glance but if we look at the amplitude difference between the two completely similar hamamatsu on previous tests which both were connected to the same shashlik cell on the next page:

“Only those photons that happen to be re-emitted at a sufficiently acute angle with respect to the axis of the fiber will undergo total internal reflection so as to be transmitted the length of the fiber to the PMT or other photosensor at the fiber's end. The rest of the re-emitted photons pass through the walls of the fiber and never reach the photosensor at the end of the fiber.”

Reference: http://www.google.com/patents/US6078052



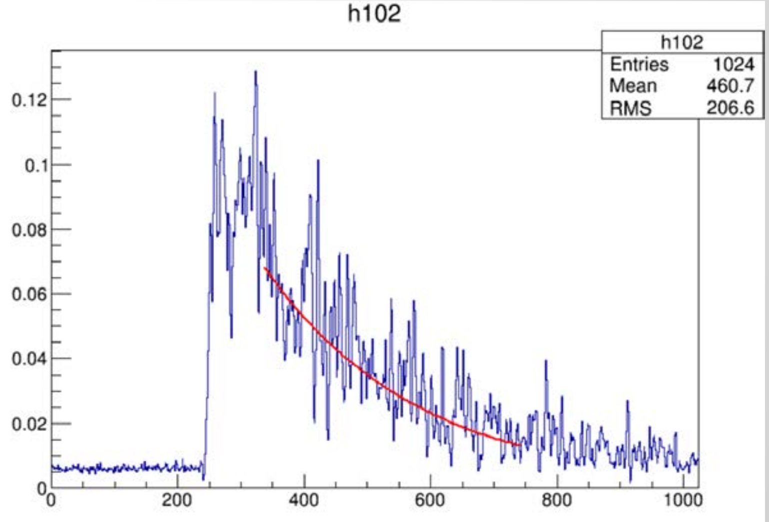


As I searched in:
http://www.inp.demokritos.gr/~km3net/Aristeia/Waveshifter/albrecht_Ruchti.pdf
which is the citation of DSB1 fibers in the Caltech paper, it seems that most of fiber is plastic and plastics have refractive index of 1.50 for green light:
http://refractiveindex.info/?shelf=3d&book=plastics&page=pmma
therefore, 41 degree is the critical angle for total reflection which is a large angle. So, reason for this huge loss of amplitude *can* be the curvature in the fibers.

NOTE 1:I'm not sure about the refractive index of the fiber!
NOTE 2: In the logbook for July 2014 run -- of which result is published in the Caltech Paper -- from Aug 17 every label "Ham A" and "Ham B" are changed to "Ham 1" and "Ham 2". I assume that Ham 1 is Ham A and Ham2 is Ham B(for the result in the previous page about which one is ch3 and ch4.)

Study of fluctuations in shashlik pulse

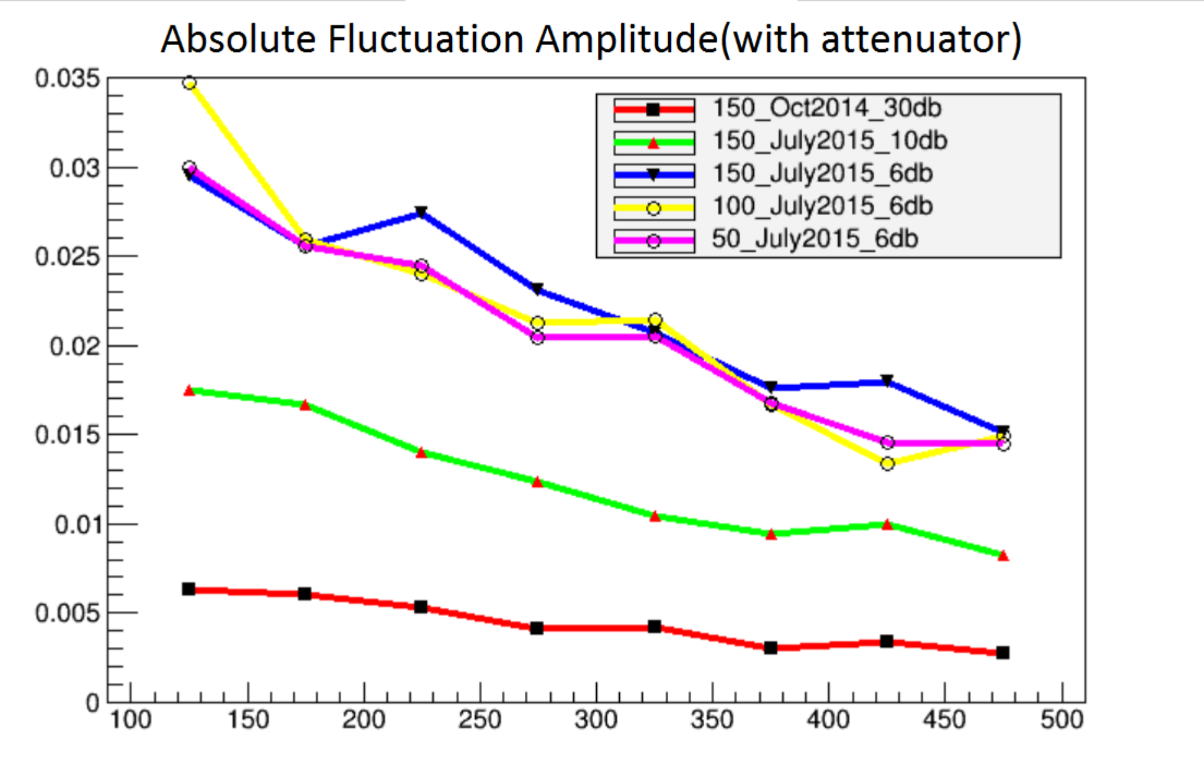
Do the fluctuations in the decay part of shashlik pulses behave the same way for different energies? In order to find this, I fitted an exponential function with 3 free parameter, [2]+exp(-(x-[0])/[1]), from RiseEdge+100 to RiseEdge+500 bins. Because in October-pulse the RiseEdge is usually around 350, RiseEdge+500 is a good place to finish the fit and since after the pulse increases to maximum value, it does not behave as an exponential decay, RiseEdge+100 is proper time to start the fit. I divided this interval to 8 equal intervals and calculated the absolute distance to the fit and NOT the RMS value; since RMS does not have a linear behaviour and therefore comparing it with maximum value is not reasonable. The numbers in the following tables are the average over 6 samples.



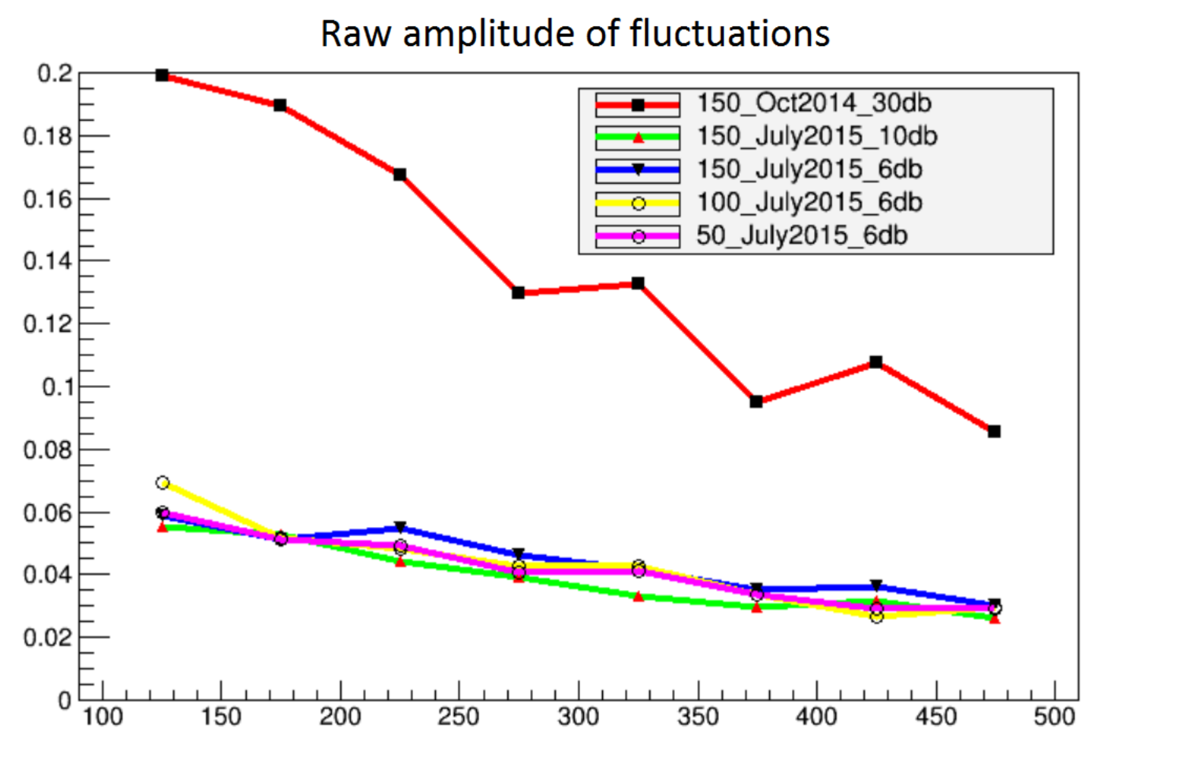
Absolute value of fluctuations(voltage)

	October 2014 150 GeV 30db attenuator (31.6 times decrease in voltage)	July 2015 150 GeV 10db attenuator (3.16 times decrease in voltage)	July 2015 150 GeV 6db attenuator (2 times decrease in voltage	July 2015 100 GeV 6db attenuator (2 times decrease in voltage)	July 2015 50 GeV 6db attenuator (2 times decrease in voltage)
Rise+100,Rise+150	0.0063	0.0175	0.0295	0.0347	0.0300
Rise+150,Rise+200	0.0060	0.0167	0.0256	0.0259	0.0256
Rise+200,Rise+250	0.0053	0.0140	0.0274	0.0240	0.0245
Rise+250,Rise+300	0.0041	0.0124	0.0231	0.0213	0.0204
Rise+300,Rise+350	0.0042	0.0104	0.0207	0.0214	0.0205
Rise+350,Rise+400	0.0030	0.0094	0.0176	0.0167	0.0168
Rise+400,Rise+450	0.0034	0.0100	0.0180	0.0134	0.0146
Rise+450,Rise+500	0.0027	0.0082	0.0151	0.0149	0.0145

Absolute value of Fluctuations



Raw Amplitude of Fluctuations



Ratio of Fluctuations with respect to pulses' height

	October 2014 150 GeV 30db attenuator (31.6 times decrease in voltage)	July 2015 150 GeV 10db attenuator (3.16 times decrease in voltage)	July 2015 150 GeV 6db attenuator (2 times decrease in voltage	July 2015 100 GeV 6db attenuator (2 times decrease in voltage)	July 2015 50 GeV 6db attenuator (2 times decrease in voltage)
Rise+100,Rise+150	0.1307	0.2582	0.2962	0.3156	0.3076
Rise+150,Rise+200	0.1181	0.2876	0.2518	0.2327	0.2595
Rise+200,Rise+250	0.0953	0.2401	0.2486	0.2215	0.2636
Rise+250,Rise+300	0.0816	0.1838	0.2224	0.1836	0.1994
Rise+300,Rise+350	0.0777	0.1735	0.1976	0.1964	0.1920
Rise+350,Rise+400	0.0590	0.1492	0.1549	0.1452	0.1686
Rise+400,Rise+450	0.0692	0.1697	0.1646	0.1163	0.1537
Rise+450,Rise+500	0.0523	0.1278	0.1462	0.1403	0.1568

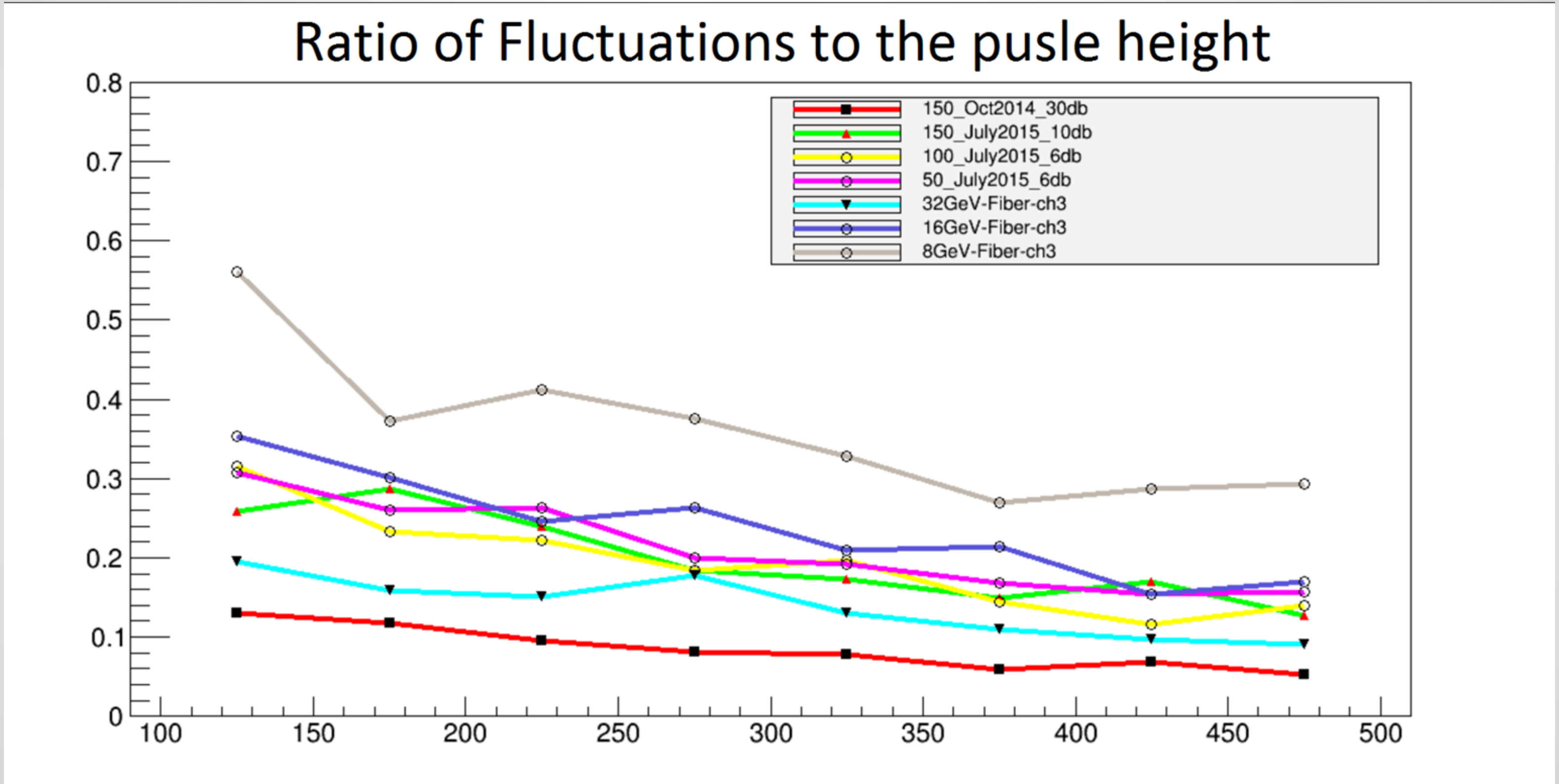
Ratio of Fluctuations with respect to pulses' height(continue)

	July 2014 32GeV 10db		July 2014 16GeV 6db		July 2014 8GeV 6db		July 2014 4GeV 6db	
	ch3	ch4	ch3	ch4	ch3	ch4	ch3	ch4
100,150	0.1955	0.2623	0.3527	0.3873	0.5602	0.7575		
150,200	0.1585	0.1985	0.3011	0.3397	0.3725	0.4713		
200,250	0.1515	0.1841	0.2458	0.3364	0.4122	0.4560		
250,300	0.1784	0.1771	0.2630	0.2780	0.3751	0.5586		
300,350	0.1307	0.1418	0.2100	0.2408	0.3282	0.4017		
350,400	0.1095	0.1386	0.2138	0.2142	0.2689	0.3516		
400,450	0.0975	0.1175	0.1542	0.1672	0.2874	0.3375		
450,500	0.0914	0.1012	0.1692	0.1588	0.2932	0.2879		

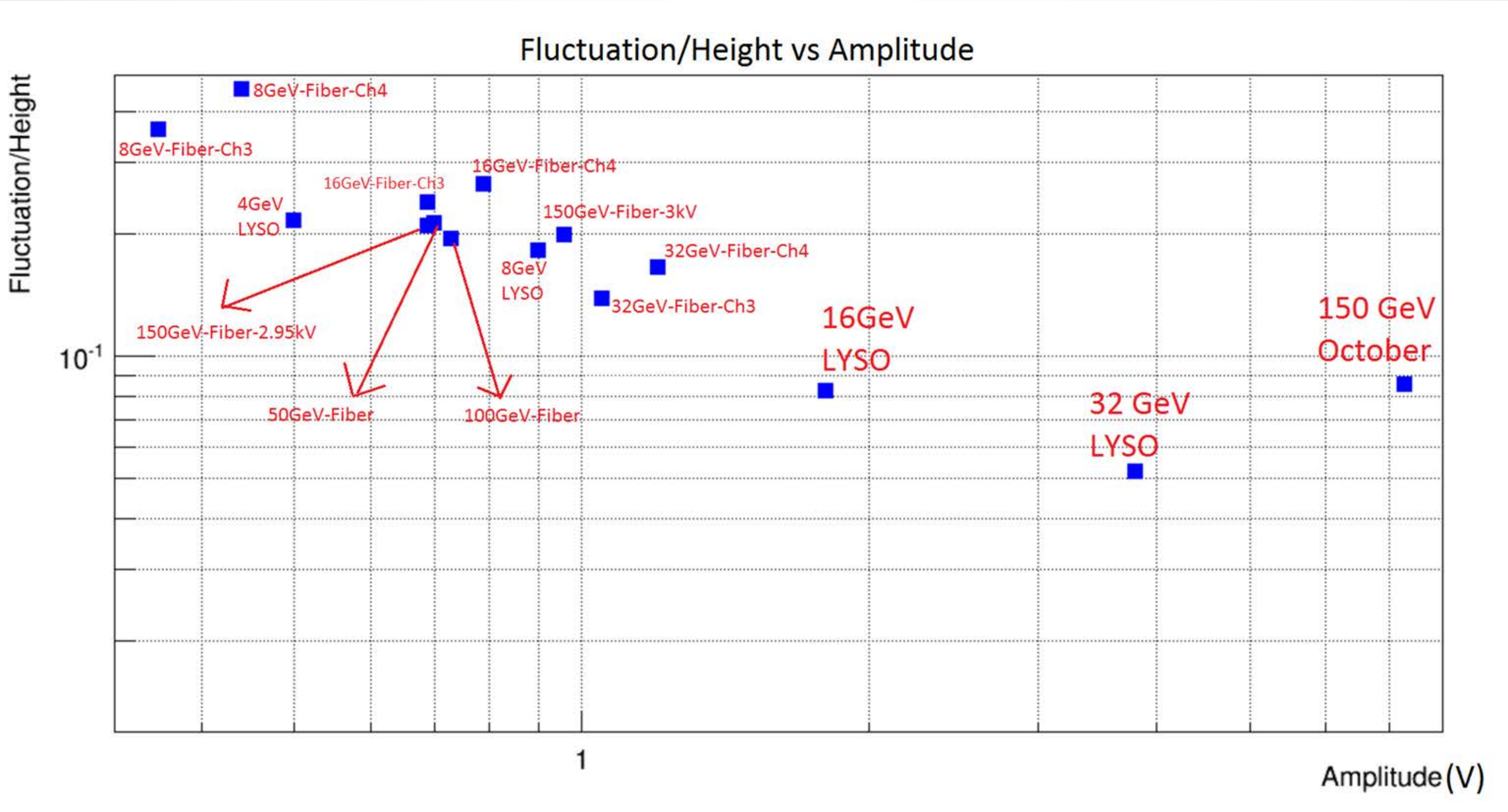
Ratio of Fluctuations with respect to pulses' height(continue)

	32 GeV LYSO 26 db	16 GeV LYSO	8 GeV LYSO	4 GeV LYSO
Rise+100,Rise+150	0.0770	0.119	0.2190	0.2975
Rise+150,Rise+200	0.0758	0.1156	0.2768	0.2671
Rise+200,Rise+250	0.0619	0.0802	0.1978	0.2748
Rise+250,Rise+300	0.0425	0.0891	0.1660	0.2599
Rise+300,Rise+350	0.0465	0.0694	0.1684	0.1630
Rise+350,Rise+400	0.0447	0.0656	0.1800	0.1857
Rise+400,Rise+450	0.0331	0.0627	0.1625	0.1702
Rise+450,Rise+500	0.0321	0.0515	0.0886	0.1096

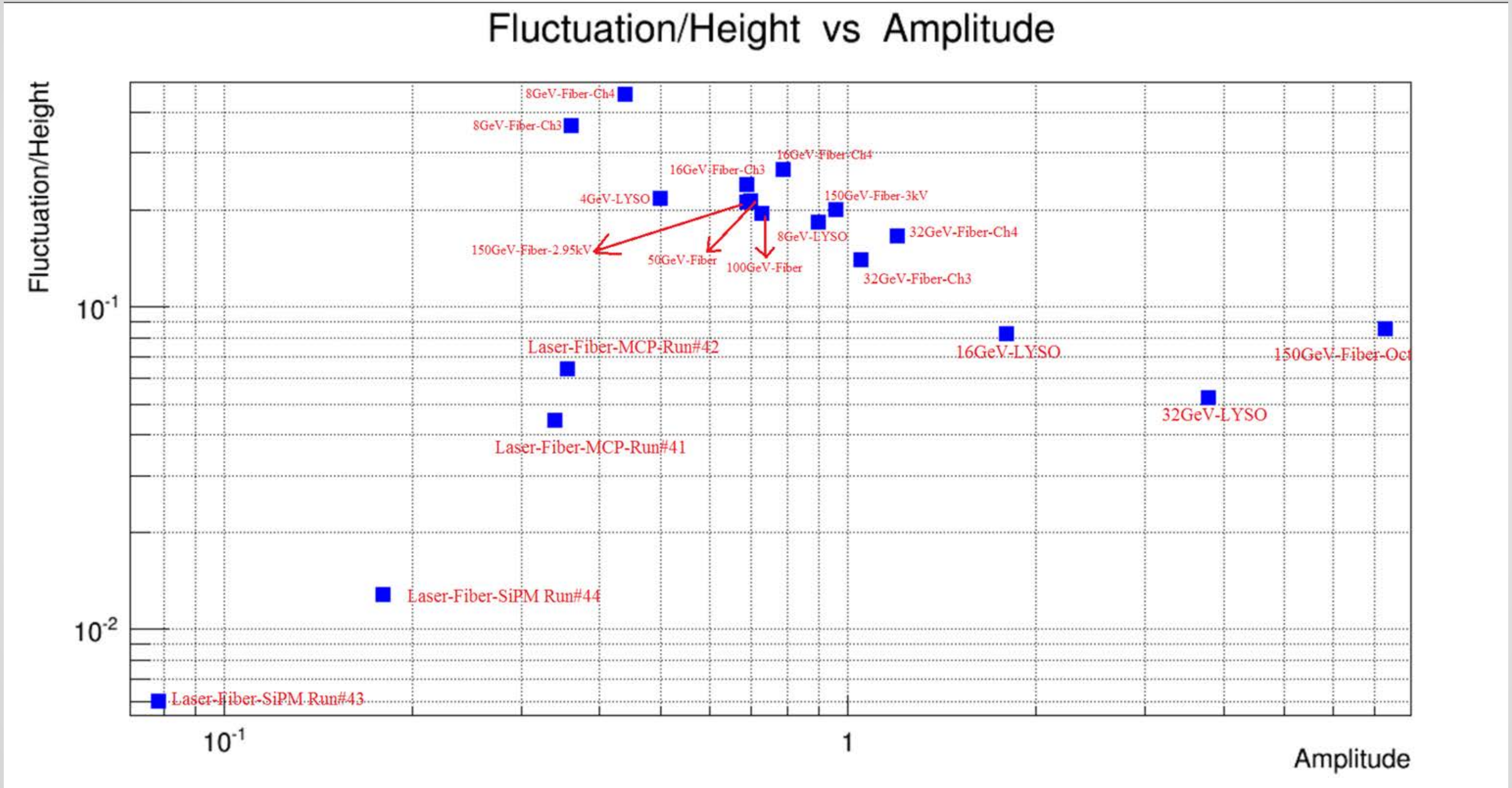
Ratio of Fluctuations to the Height

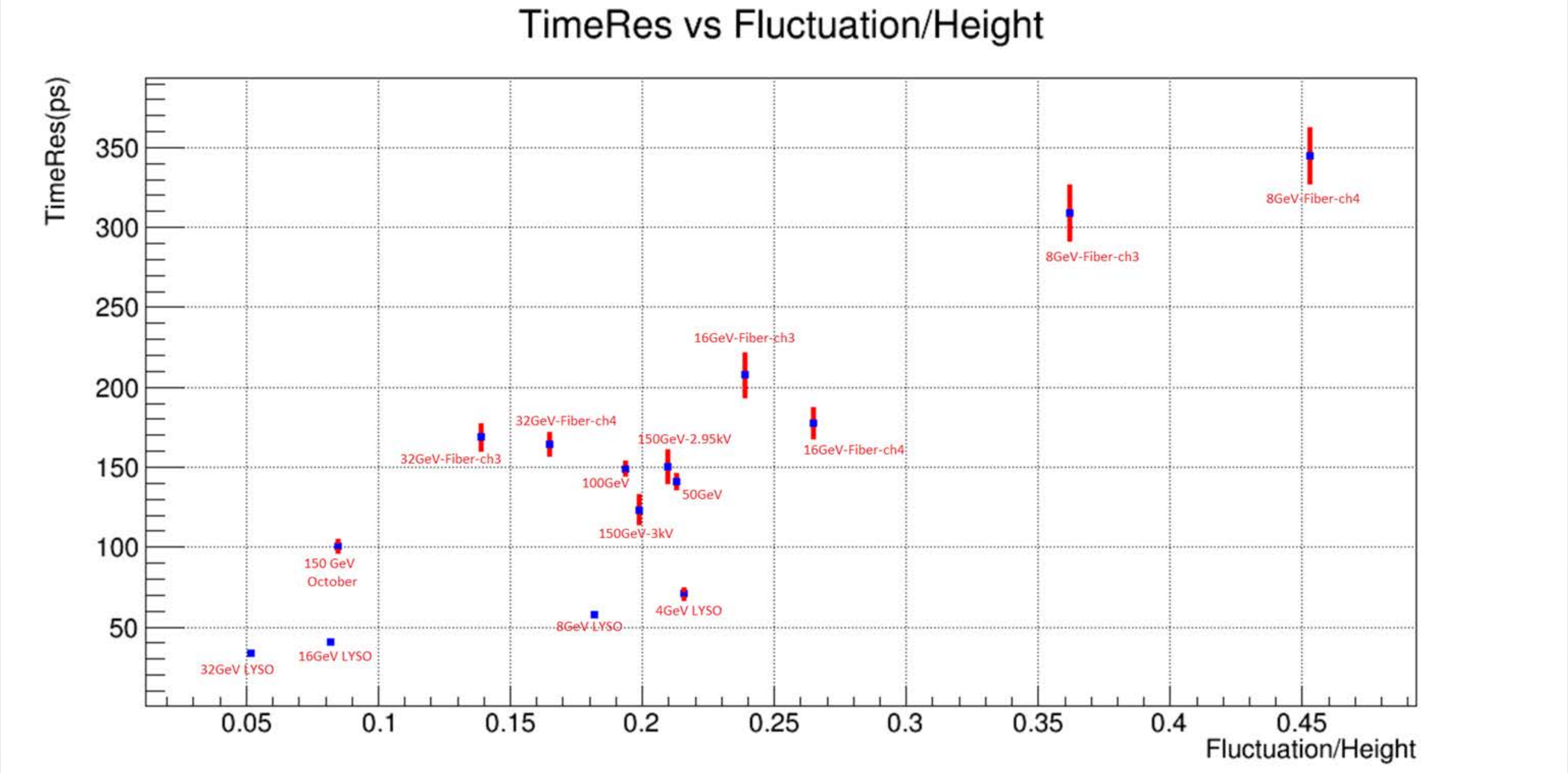


This would be the result if one chooses the average of each column in “Ratio of Fluctuations with respect to pulses’ height” table and plot it versus amplitude of that Run:

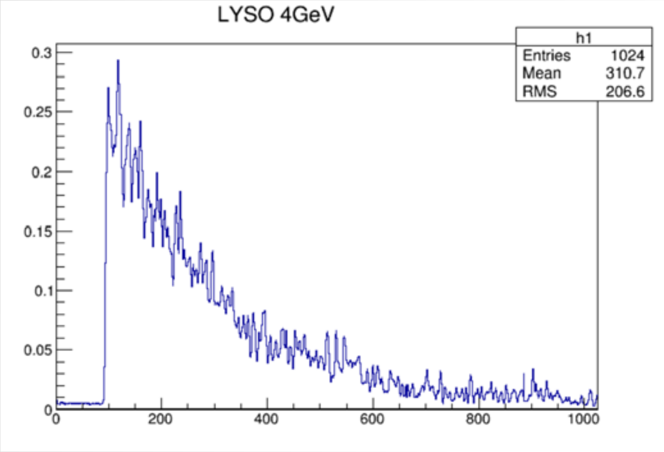


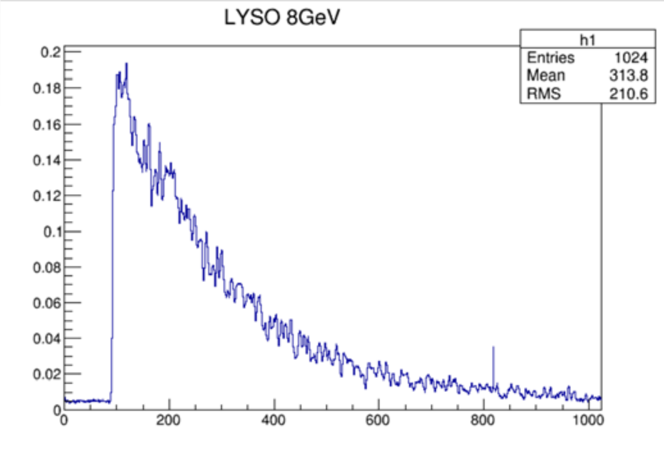
Adding Laser data

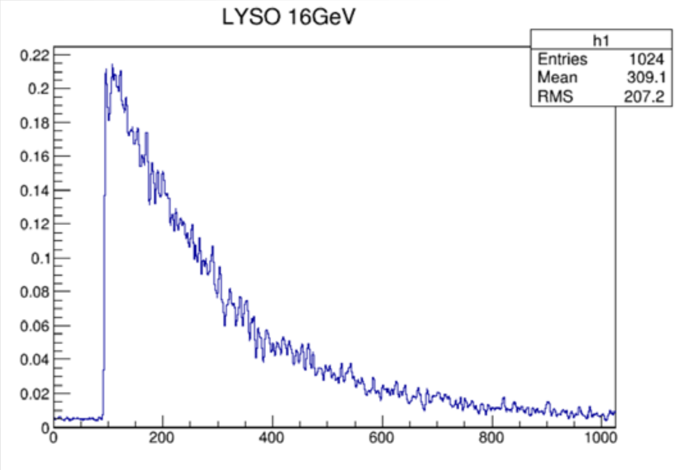


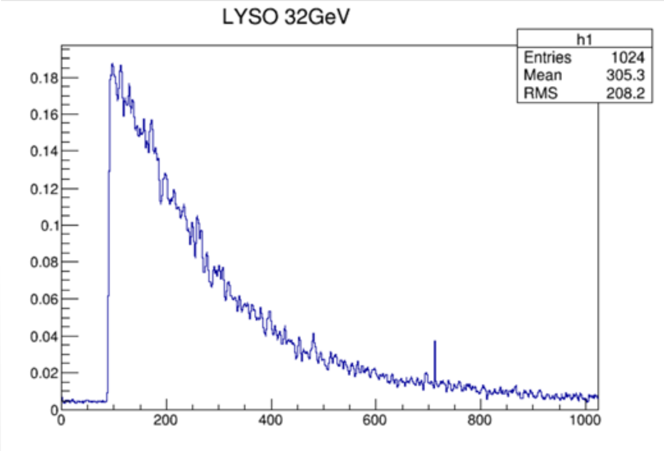

TimeRes vs Fluctuation/Height
TimeRes(ps)
350
300
250
200
150
100
50
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
Fluctuation/Height
8GeV-Fiber-ch4
8GeV-Fiber-ch3
16GeV-Fiber-ch3
32GeV-Fiber-ch4
150GeV-2.95kV
16GeV-Fiber-ch4
32GeV-Fiber-ch3
100GeV
50GeV
150GeV-3kV
150 GeV
October
4GeV LYSO
8GeV LYSO
32GeV LYSO
16GeV LYSO

Pulse samples 2014-LYSO

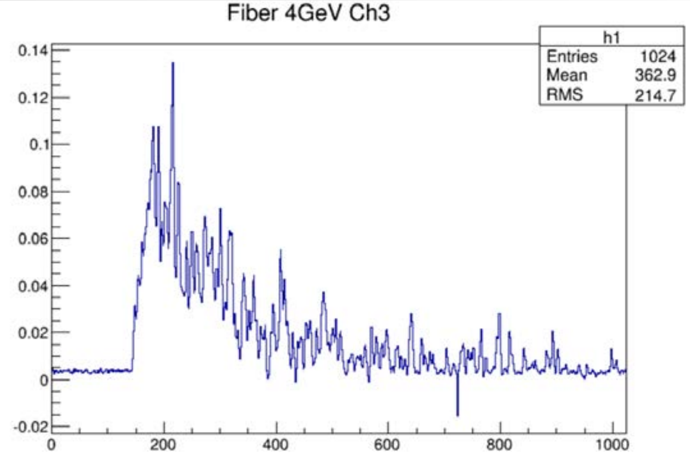


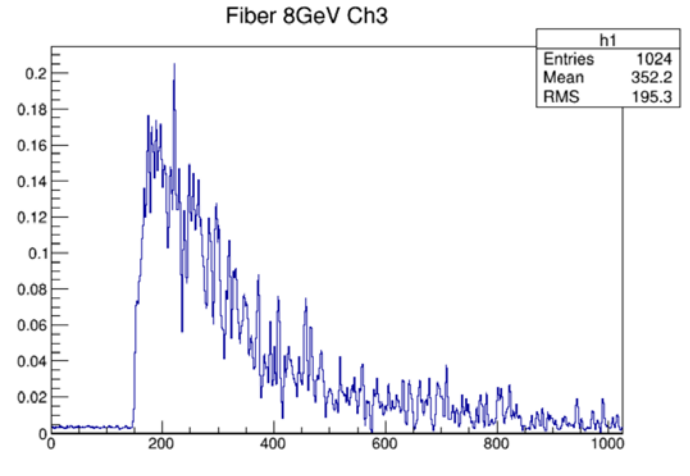


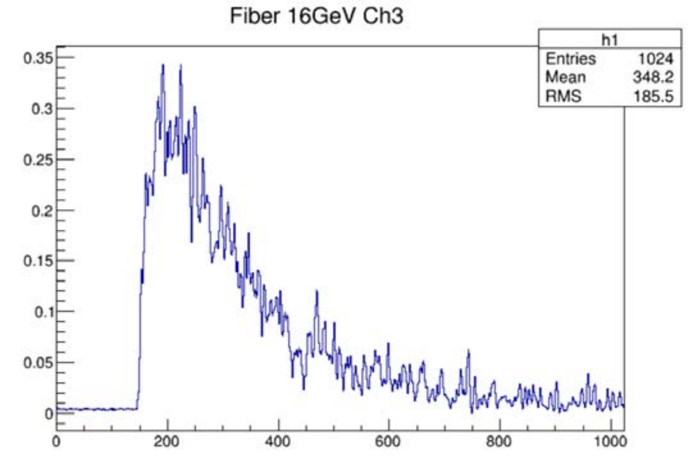


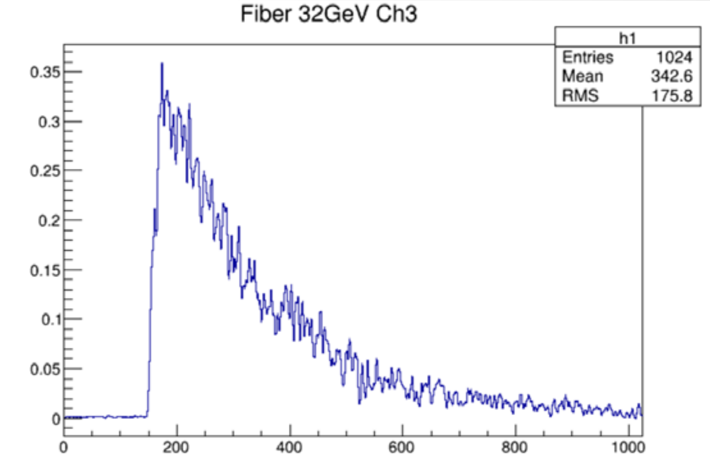


Pulse samples 2014-Fiber-Ch4

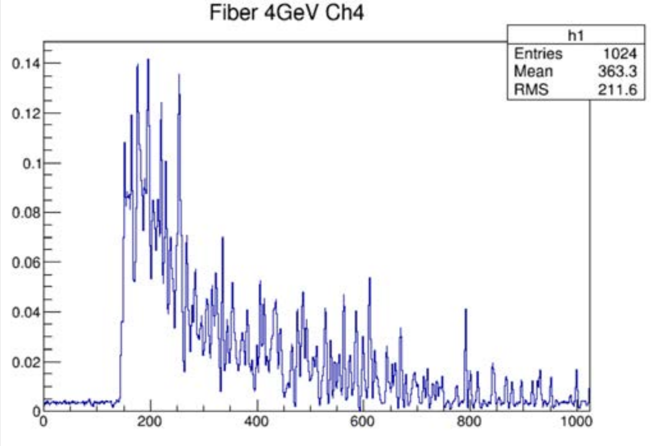


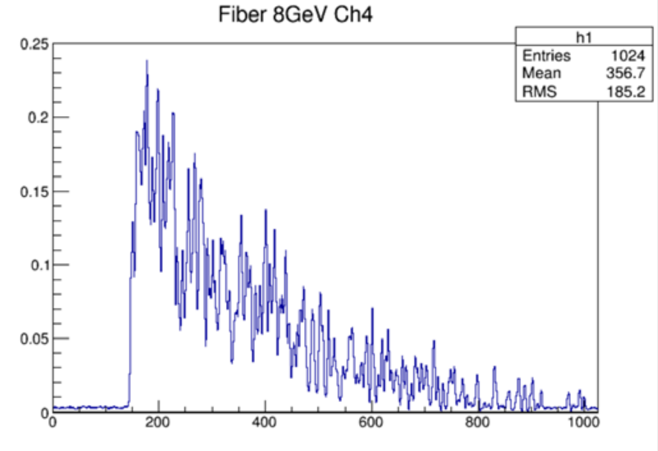


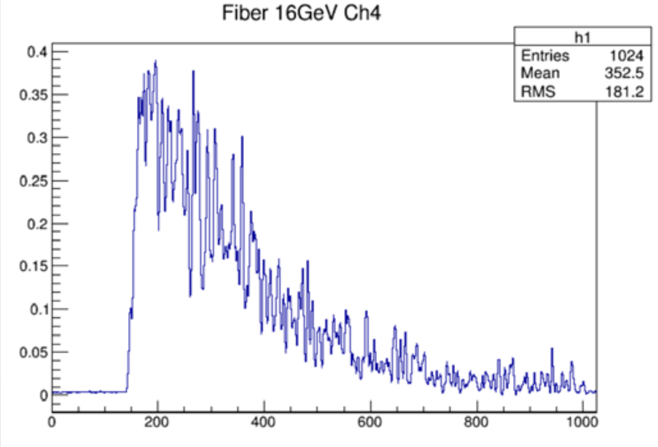


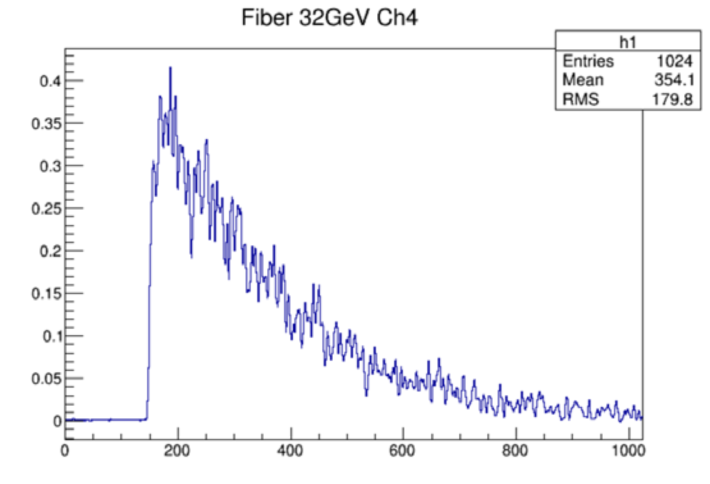


Pulse samples 2014-Fiber-Ch4

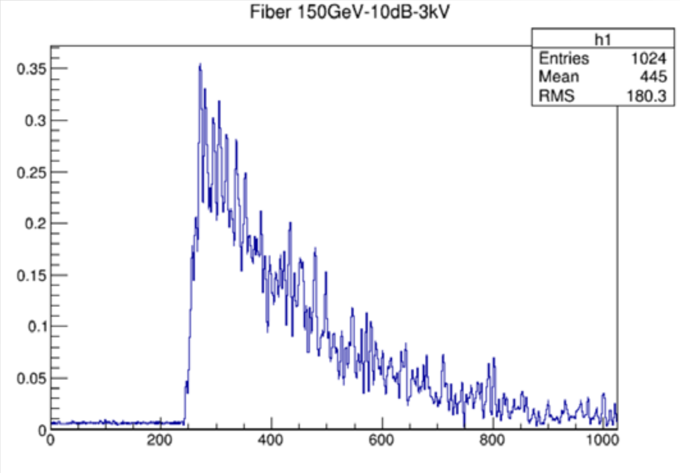


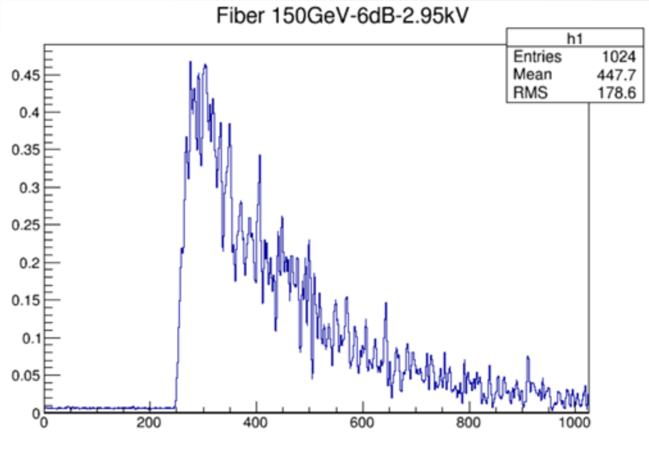


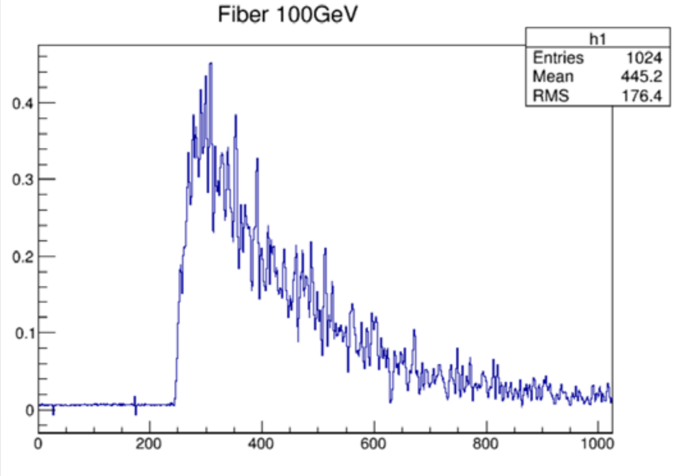


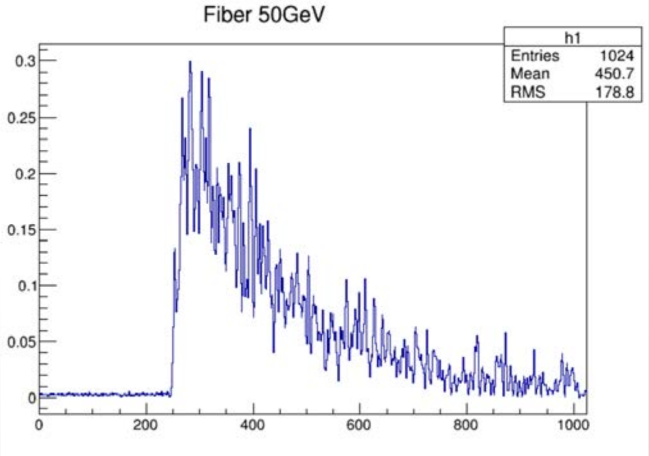


Pulse samples July 2015

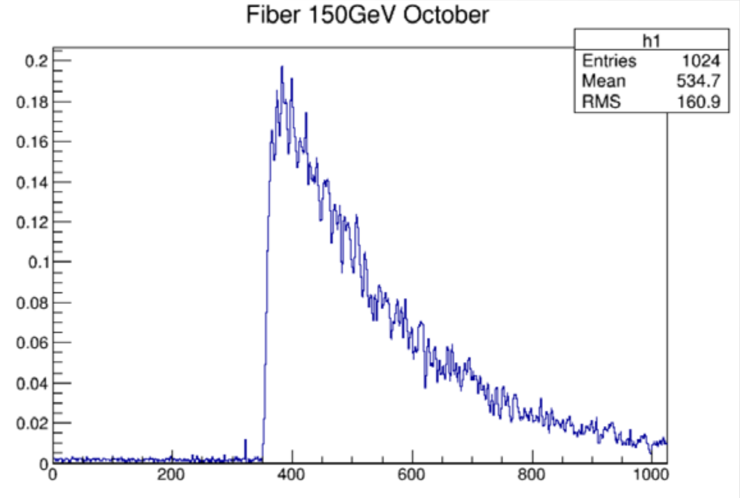




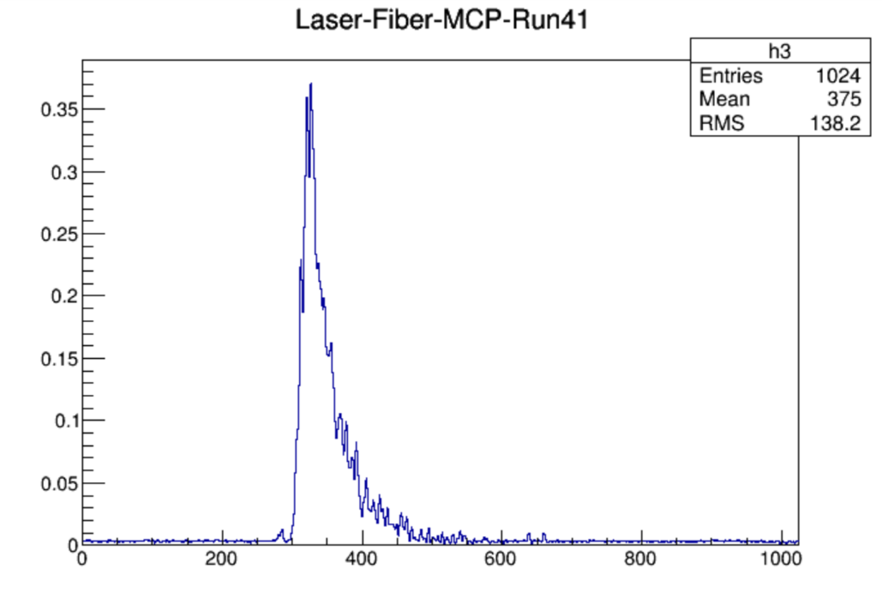


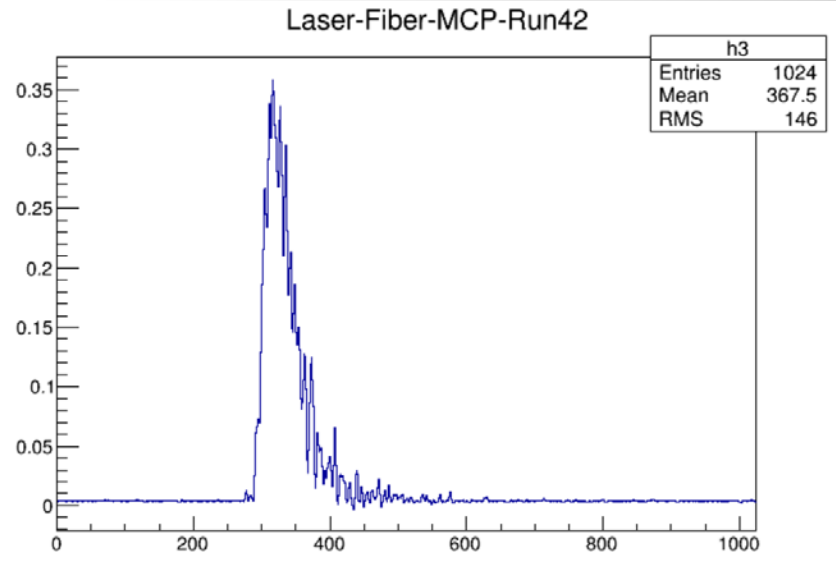


Pulse samples October-150

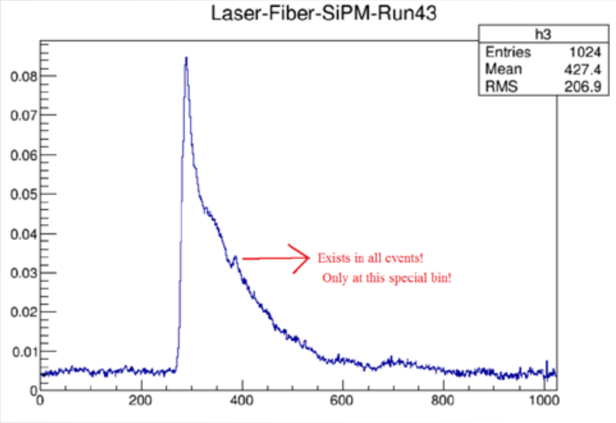


Pulse samples Laser-Fiber-MCP



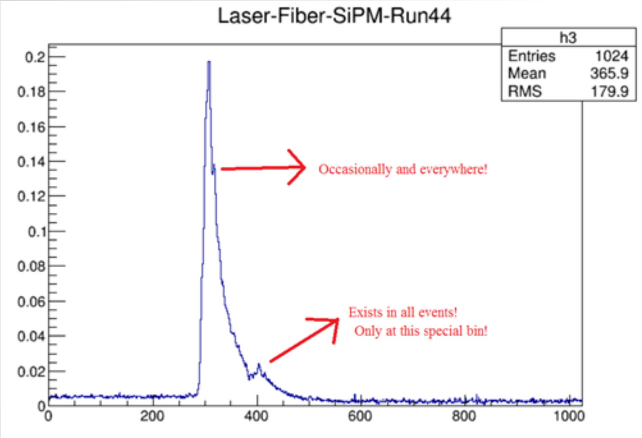


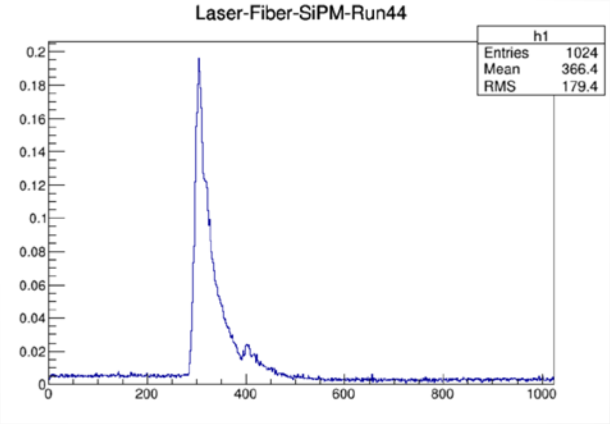
Pulse samples Laser-Fiber-SiPM



7: cell 7, large SiPM, CH4, run43, 3rd laser connector, 69.1 V, 75 mv

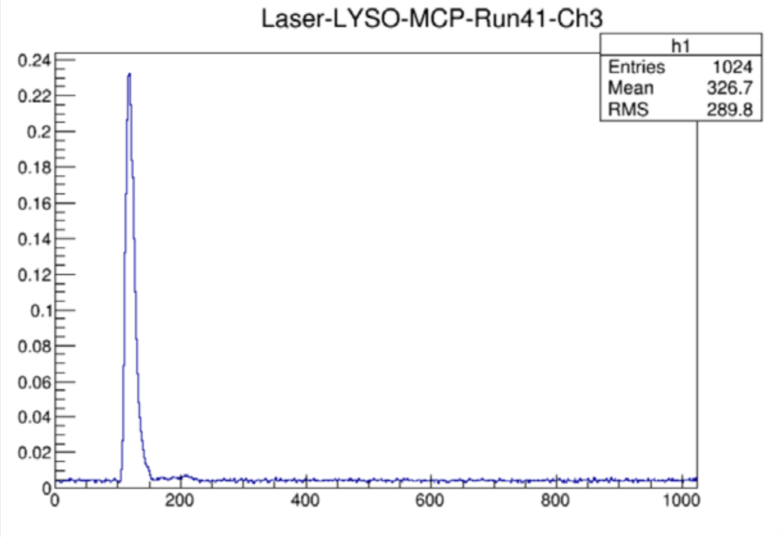
8 : cell8, small SiPM, CH3, run44, used 1st laser connector, 200 mv, 4 fibers

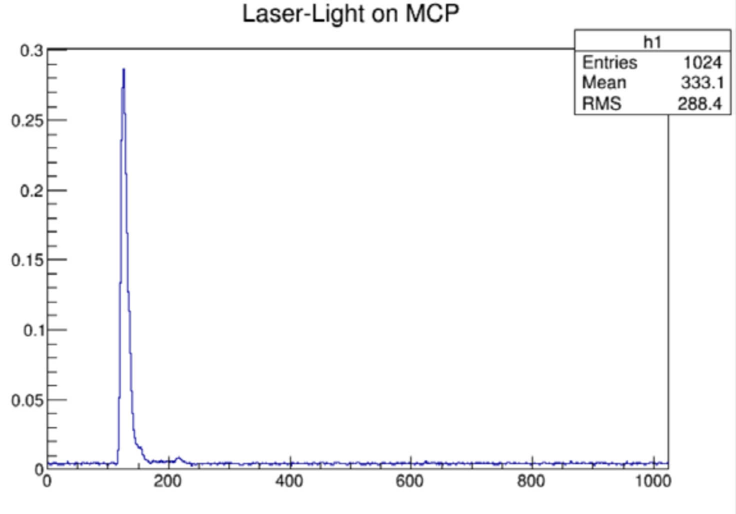




Note: In Run43 the wiggles cannot be detected by eyes.

Pulse samples Laser-MCP(with/without LYSO)





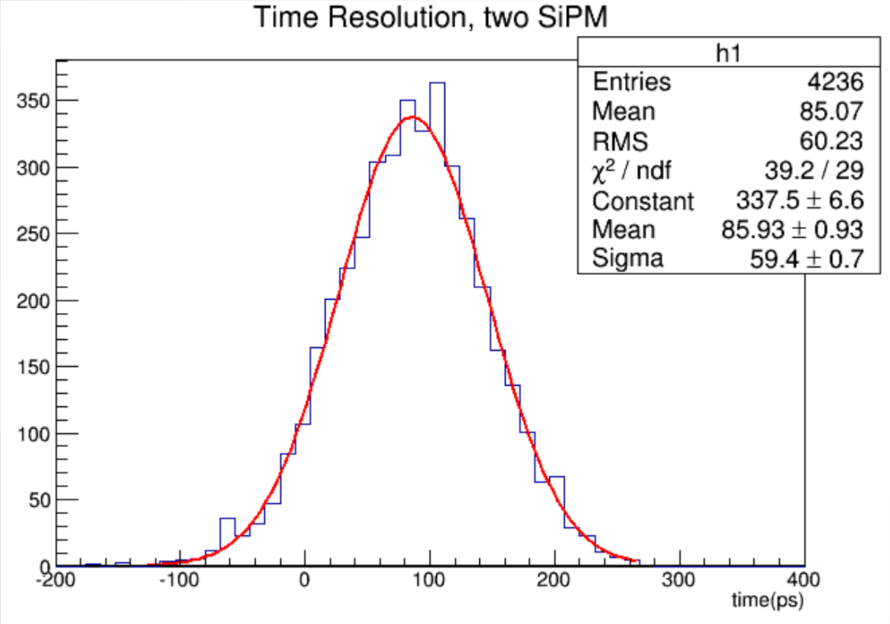
Note: All events are similar to each other.

Observations:

The fluctuations can be divided in two different kinds, only by looking at the pulses and comparing them. First, the fluctuations that come from statistics. They

Run with 2 SiPM and 1 MCP

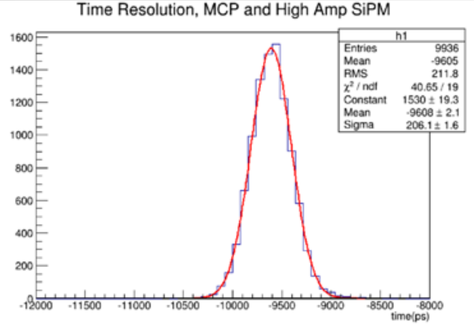
Time resolution for two SiPM:



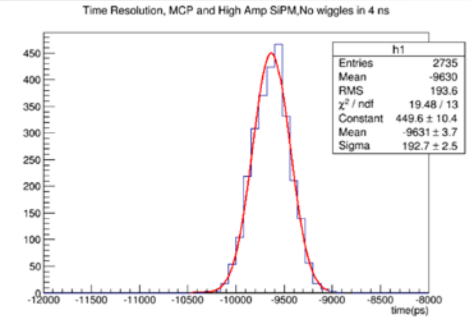
59.4 ± 0.7 ps

I put a cut for the intergral of low-amplitude SiPM. Without cut, it does not change a lot. It will be around 61 ps.

Time Resolution for MCP and High-amplitude SiPM

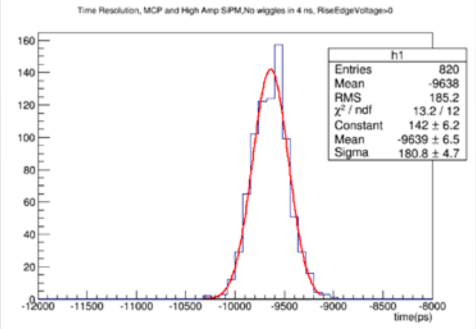


206.1 ± 1.6 ps



192.7 ± 2.5 ps

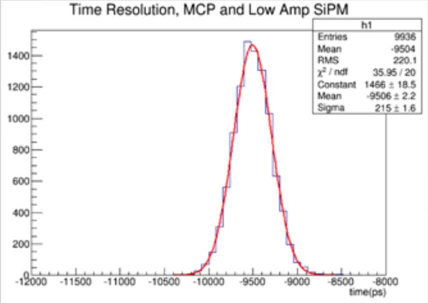
For events which do not have any wiggles from rising edge to 4 ns after it.



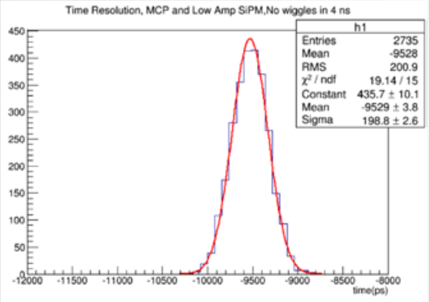
180.8 ± 4.7 ps

For events which do not have any wiggles from rising edge to 4 ns after it and their rising edge voltage is positive.

Time Resolution for MCP and Low-amplitude SiPM

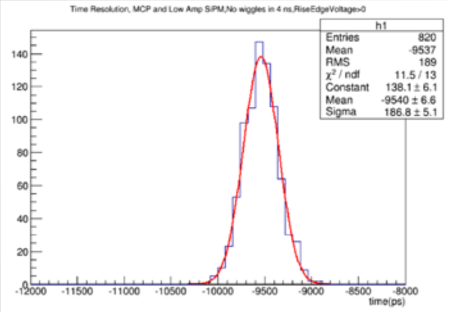


215 ±1.6 ps



198.8 ±2.6 ps

For events which do not have any wiggles from rising edge to 4 ns after it.



186.8 ±5.1 ps

For events which do not have any wiggles from rising edge to 4 ns after it and their rising edge voltage is positive.

Run with 2 SiPM and 2 MCP

(Run 262)

Two devices	Time Resolution
MCP1 and MCP2	284.4 ± 18.3
SiPM1 and SiPM2	45.4 ± 0.3
MCP1 and SiPM1	220 ± 8.0
MCP1 and SiPM2	232.2 ± 9.9
MCP2 and SiPM1	203.1 ± 9.5
MCP2 and SiPM2	206.4 ± 8.6

Run with 2 SiPM and 2 MCP

(Run 274)

Two devices	Time Resolution
MCP1 and MCP2	362.3 ± 17.6
SiPM1 and SiPM2	79.9 ± 0.8
MCP1 and SiPM1	340.9 ± 12.0
MCP1 and SiPM2	338.7 ± 12.5
MCP2 and SiPM1	242.8 ± 5.8
MCP2 and SiPM2	242.4 ± 5.2