Neutron / gamma separation using scintillation signal in LAr

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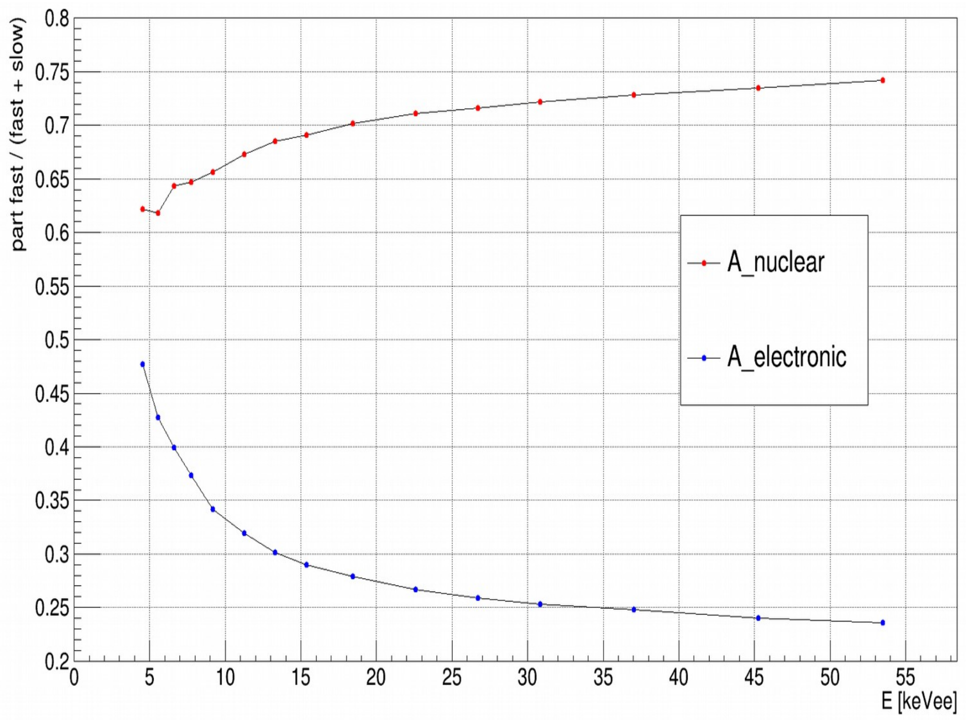
Physical PDF

$$PDF_{physical} = A \cdot PDF(\tau_{fast}) + (1 - A) \cdot PDF(\tau_{slow})$$

$$PDF(\tau) = 1/\tau \cdot \exp(-t/\tau)$$

Scintillation time dependence and pulse shape discrimination in liquid argon. PHYSICAL REVIEW C78, 035801 (2008)



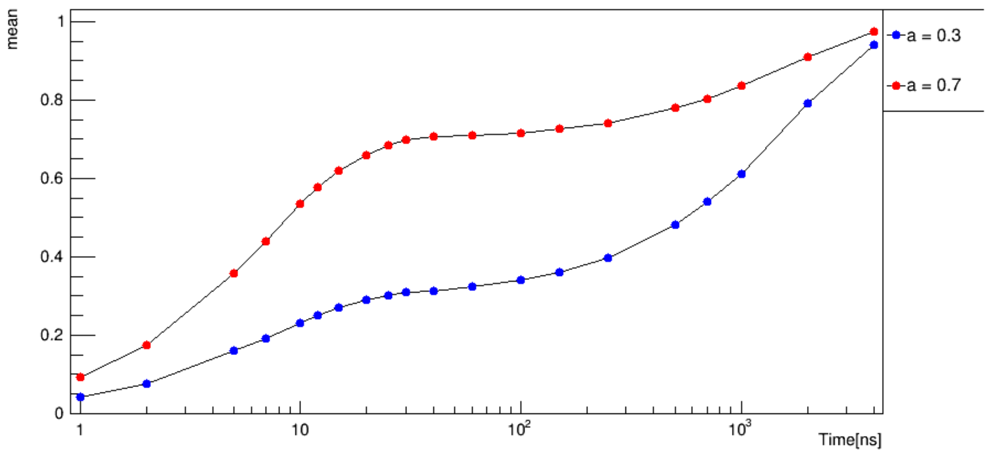
Effect of ionization density on the time dependence of luminescence from liquid argon and xenon. Phys. Rev. B 27, 5279 – Published 1 May 1983

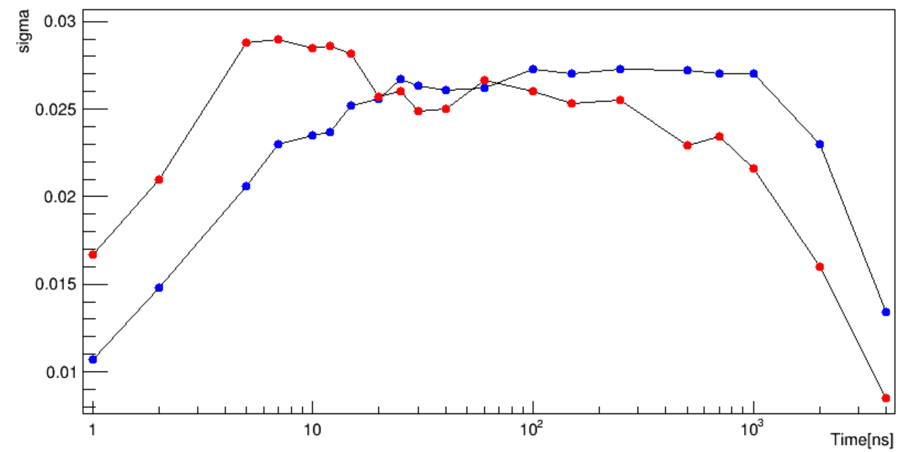
$$\tau_{fast} \approx 7 \pm 1[ns]$$

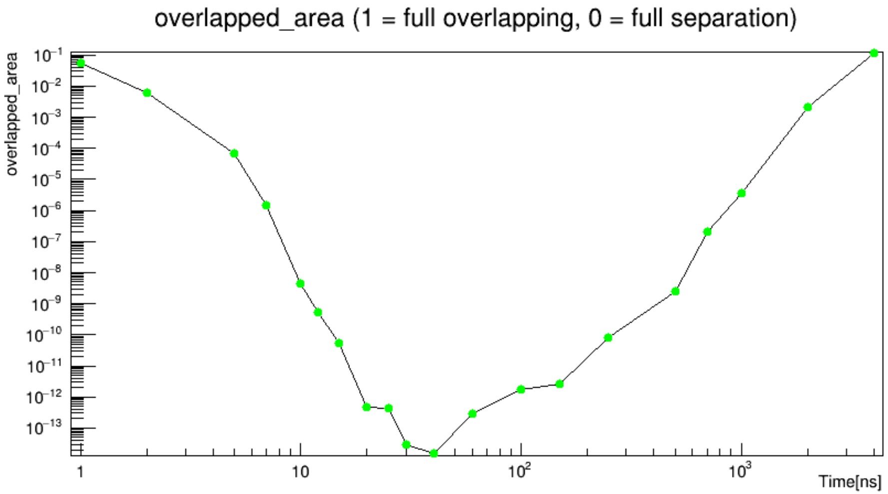
$$\tau_{slow} \approx 1600 \pm 100[ns]$$

Optimum in theory

Consider the case with delta-function response. N_pe = 300





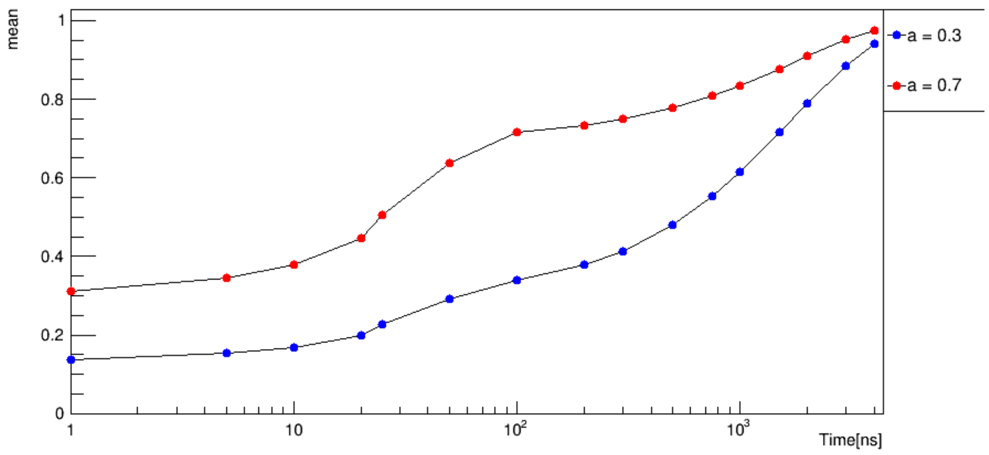


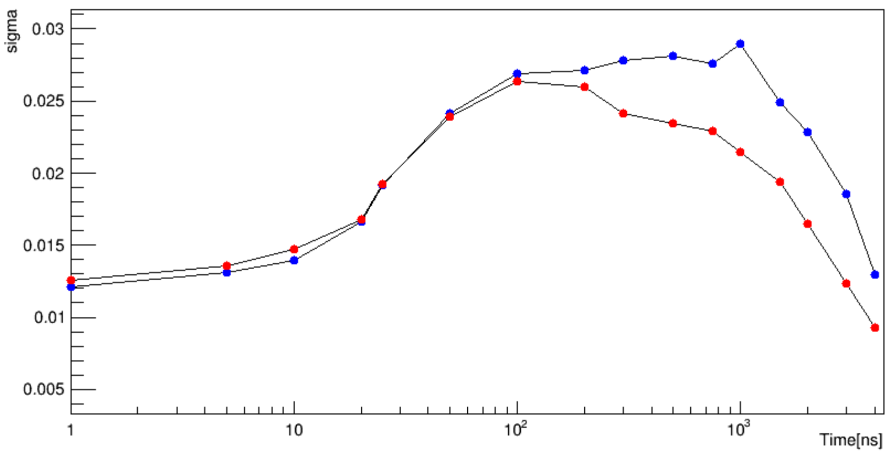
PDF = A * PDF_fast + (1 – A) * PDF_slow
A = intensity_fast / (intensity_fast + intensity_slow)
A = 0.2308 for e / gamma
A = 0.75 for neutrons

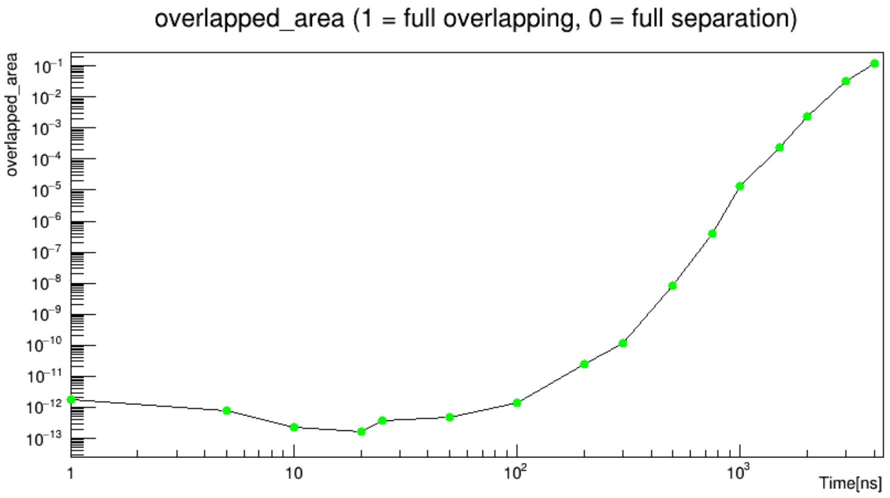
*this pictures for A=0.3 and A=0.7, because I chose wrong parameters.
But I think, that for right parameters the result will be very close to this.

Optimum in theory

Consider the case with gauss response (sigma = 33ns). N_pe = 300





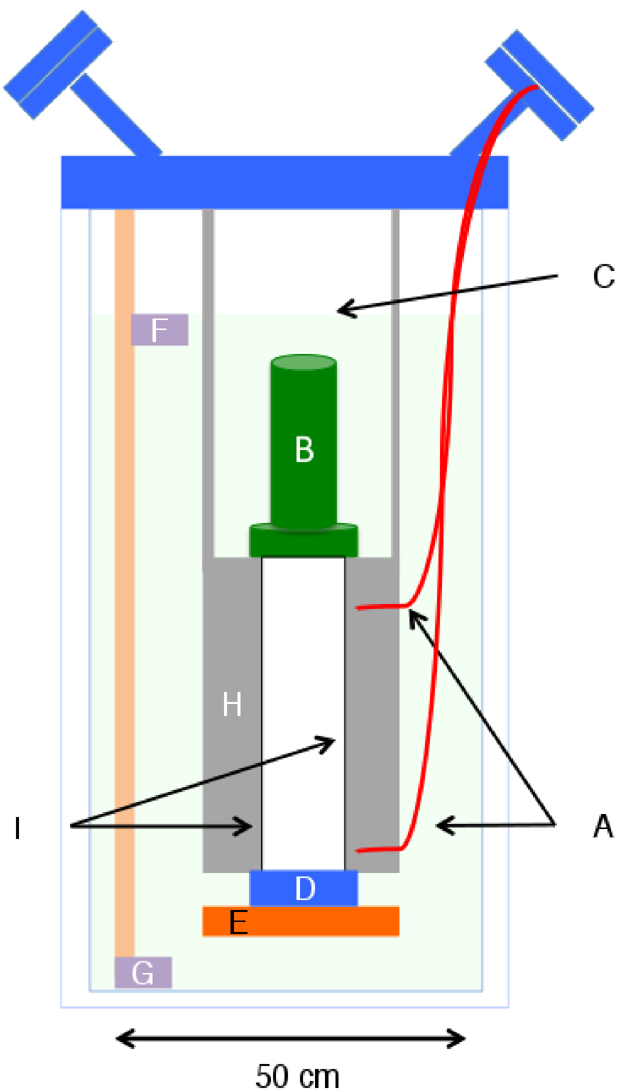


PDF = A * PDF_fast + (1 – A) * PDF_slow
A = intensity_fast / (intensity_fast + intensity_slow)
A = 0.2308 for e / gamma
A = 0.75 for neutrons

*this pictures for A=0.3 and A=0.7, because I chose wrong parameters.
But I think, that for right parameters the result will be very close to this.

Detector description

The GAP-TPCarXiv:1601.00819v2 [physics.ins-det] 6 Jan 2016

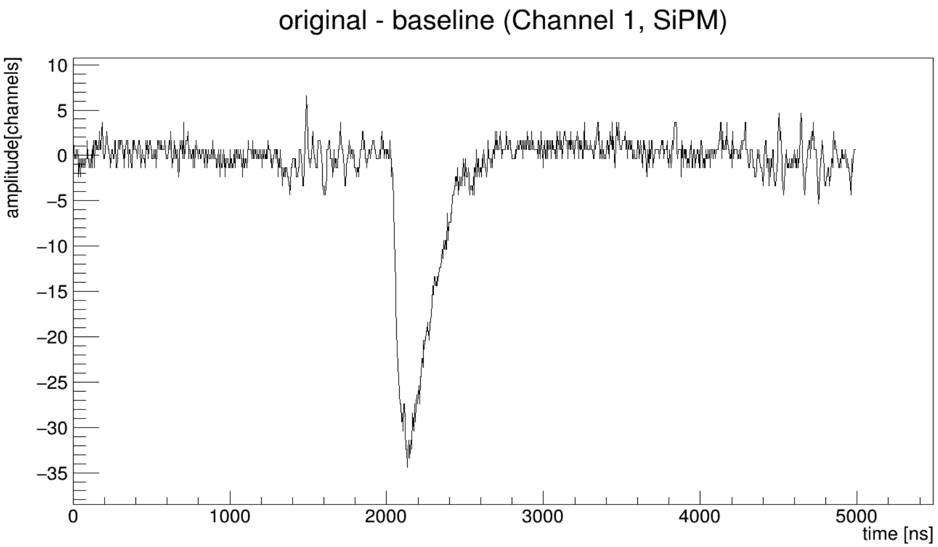


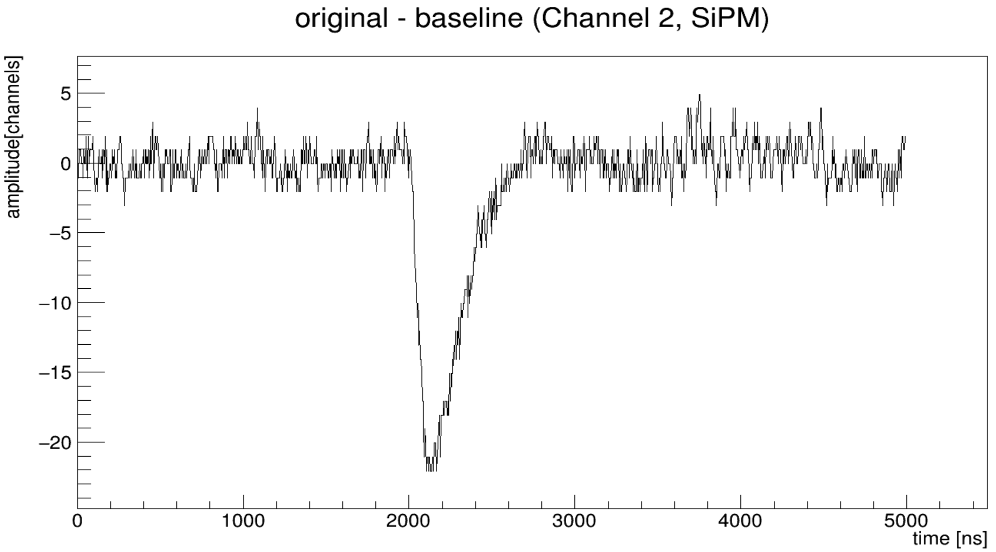
A. Optical fibers
B. PMT
C. LAr level
D. SiPM array
E. Readout board for SiPM array
F. PT1000 high level
G. PT1000 low level
H. PTFE cylinder
I. Spectralon foil+TPB

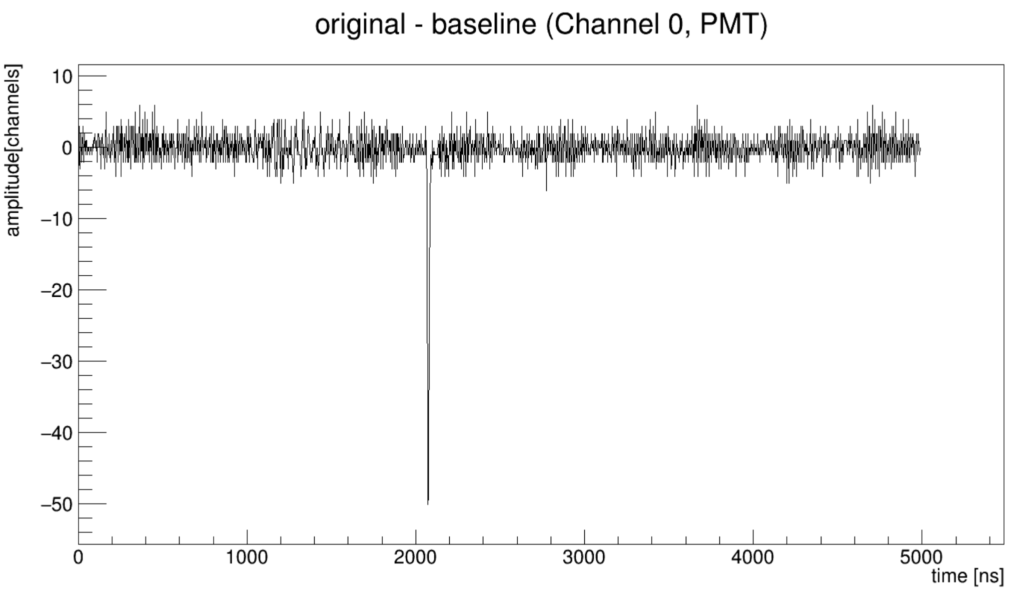
Hamamatsu 3 inch R11065 PMT and a 6x6 cm2 SensL-ArrayC-60035-64P SiPM array.

The LAr detector prototype has an active volume bounded by a PTFE cylinder of 100 mm height and 57 mm internal diameter. An enhanced specular reflector (Lumirror foils) was coated with the TPB wavelength shifter in use for Darkside-50 experiment and rested against the internal wall of the PTFE cylinder.

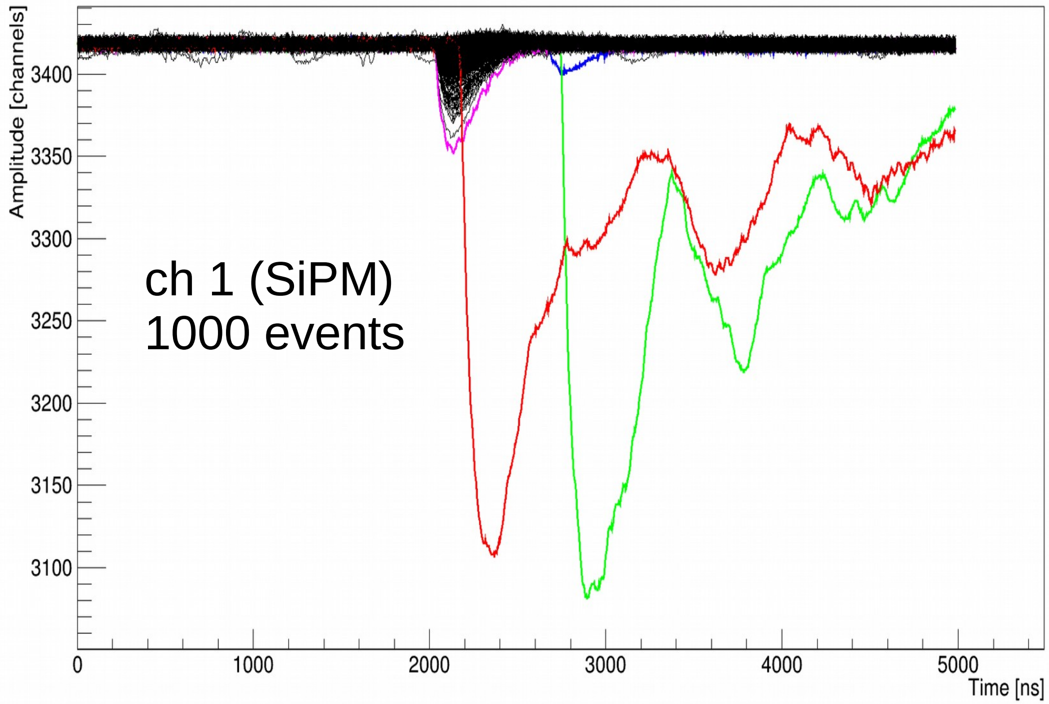
Laser run 6061. Typical signals

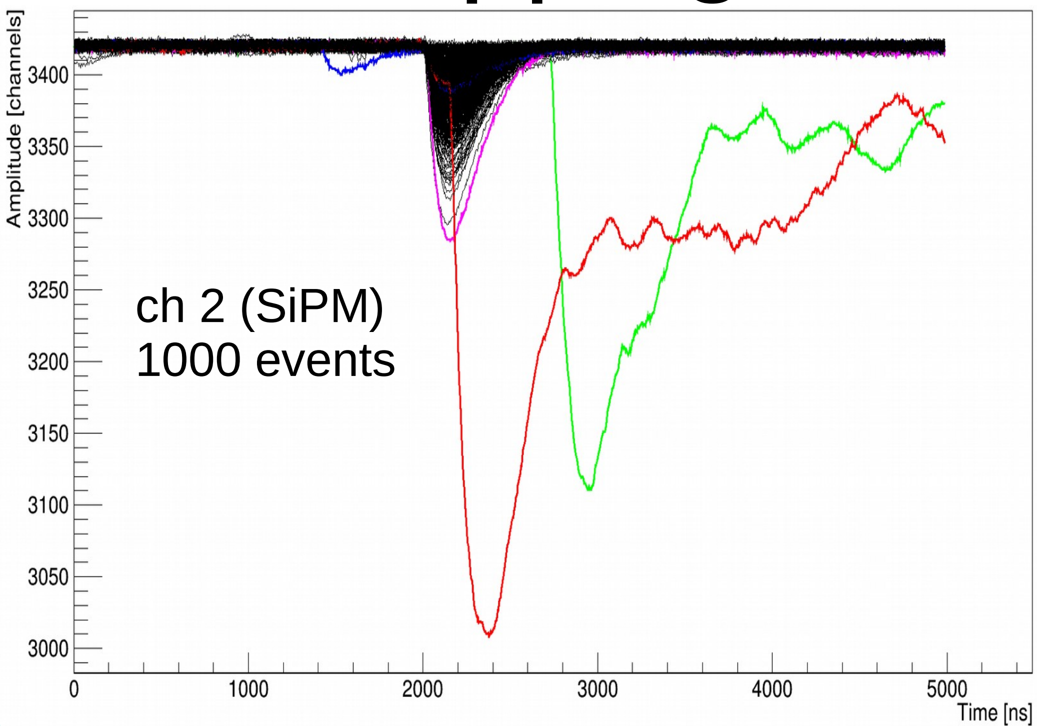


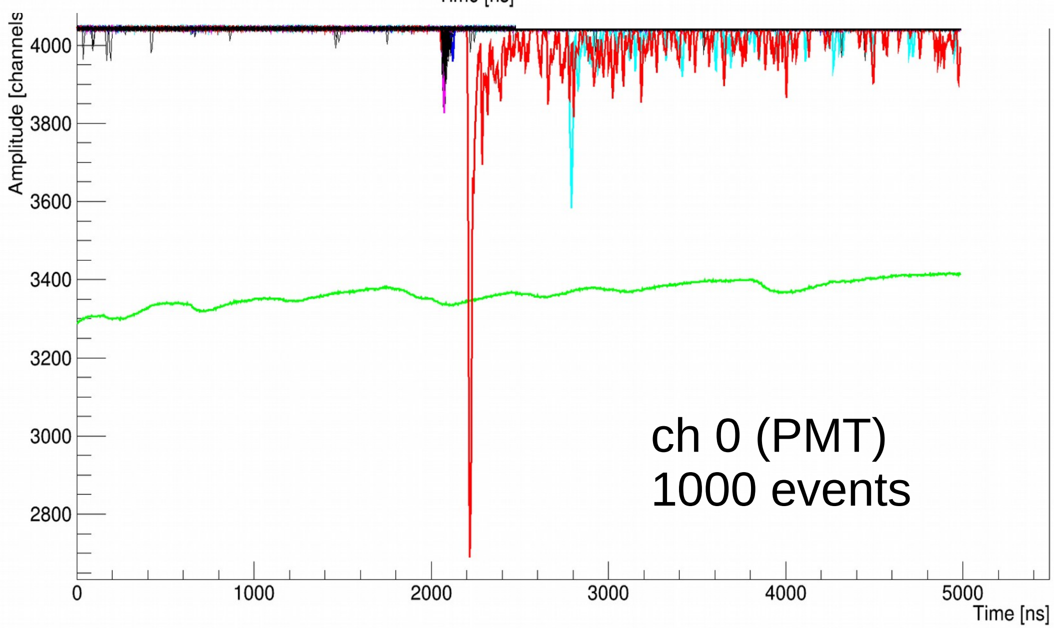




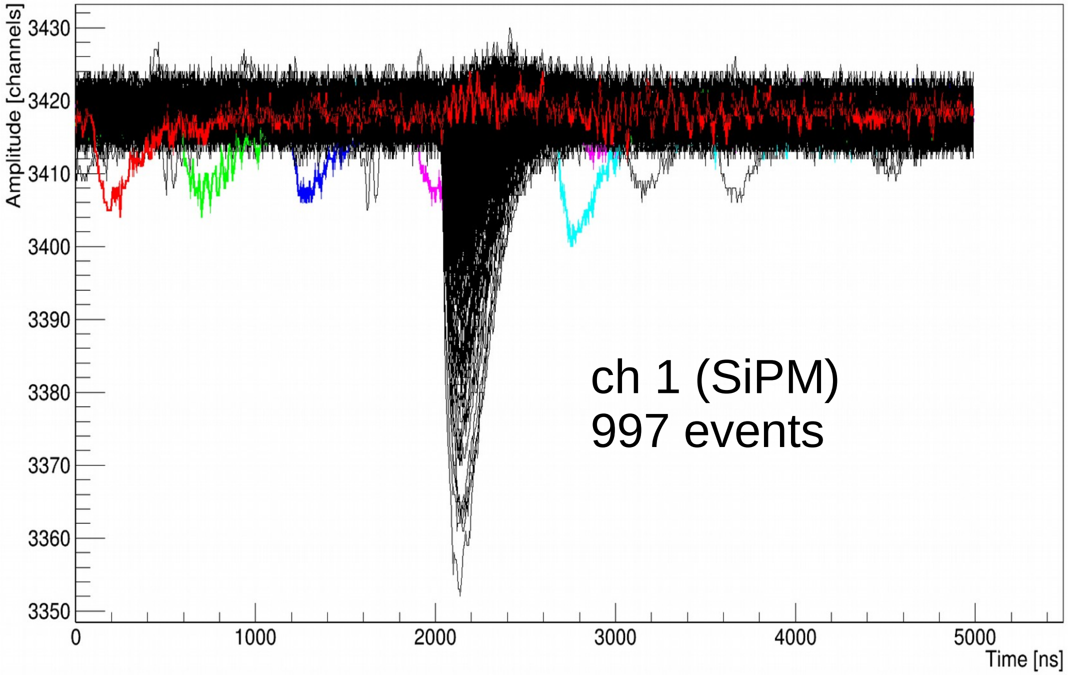
Laser run 6061. Overlapping

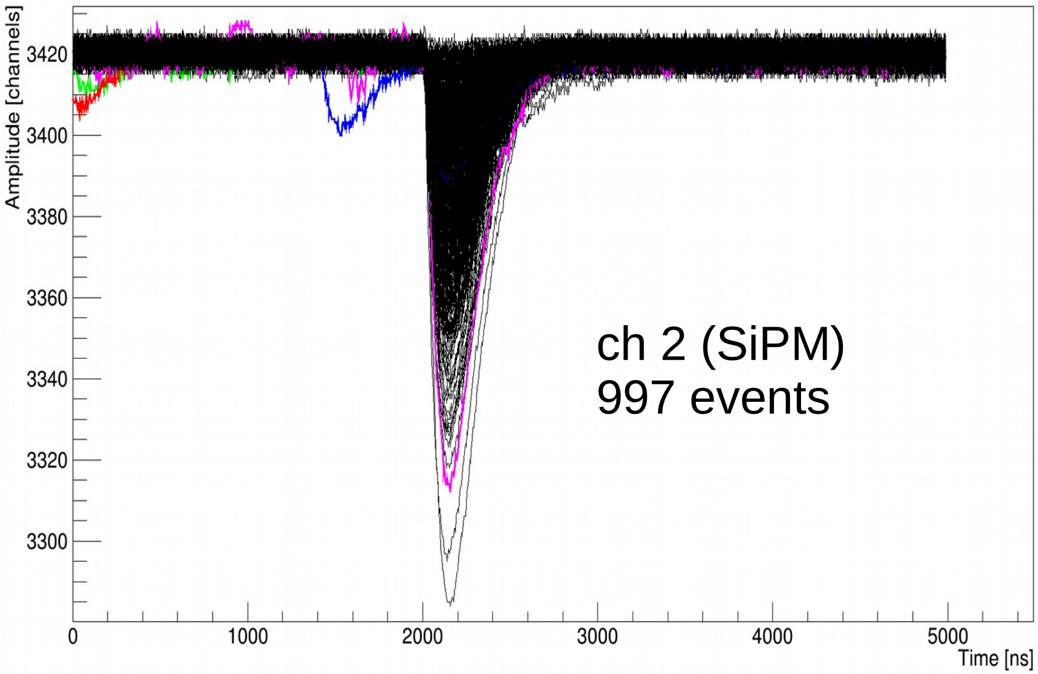






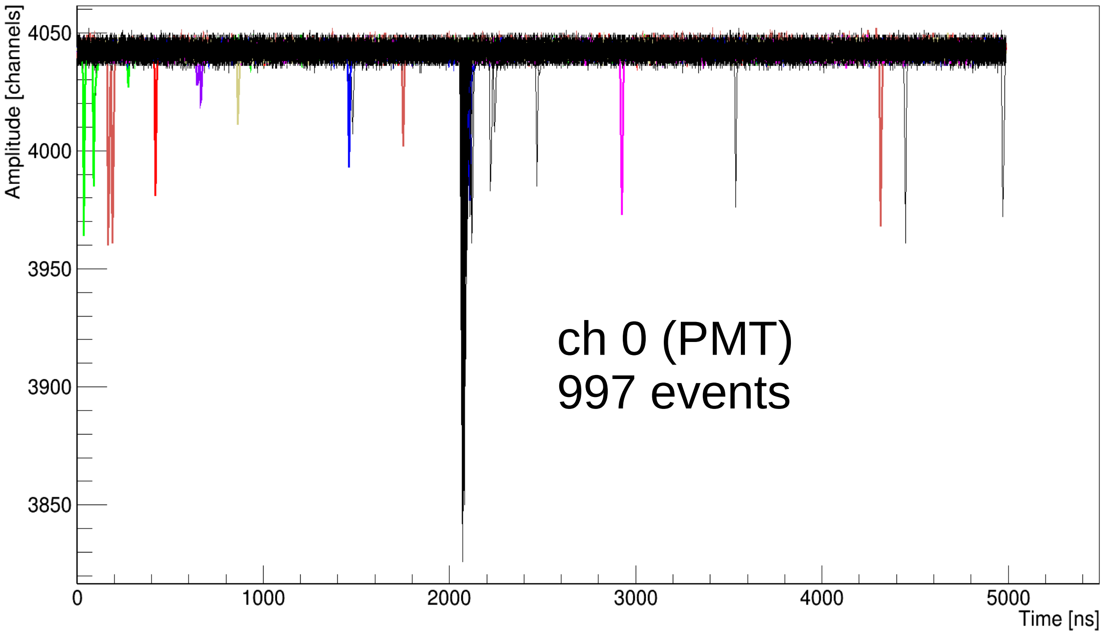
Laser run 6061. Overlapping + cut1



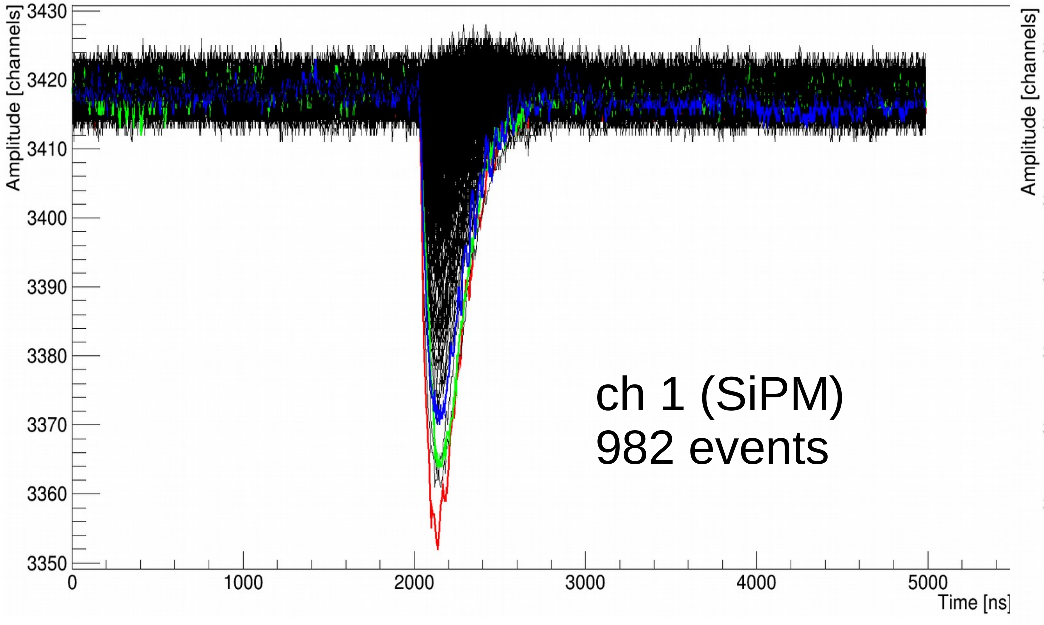


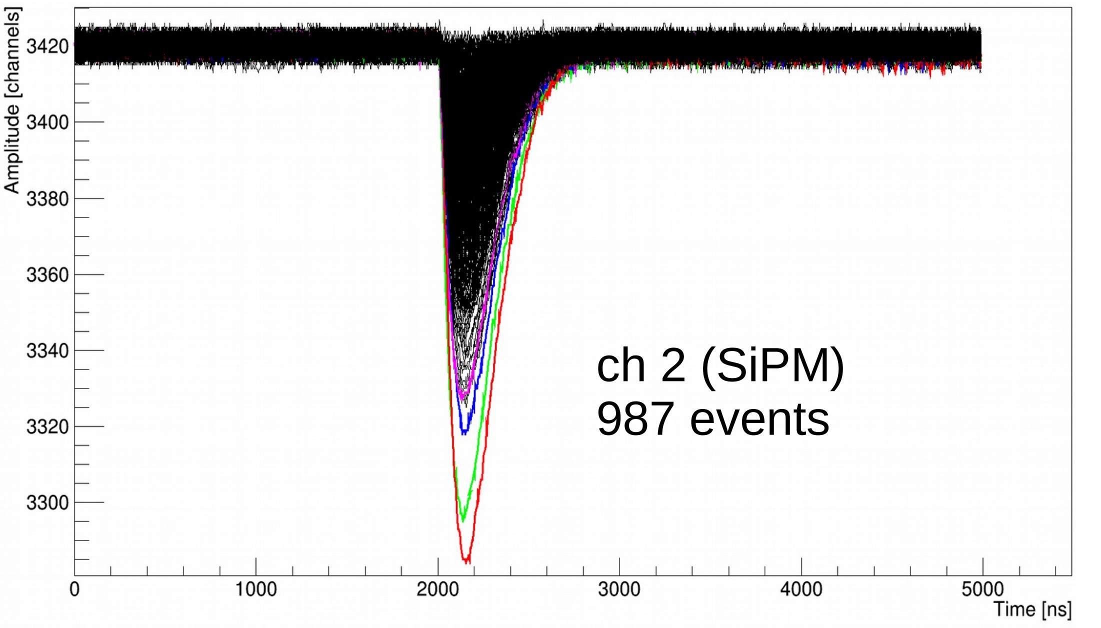
Cut1:

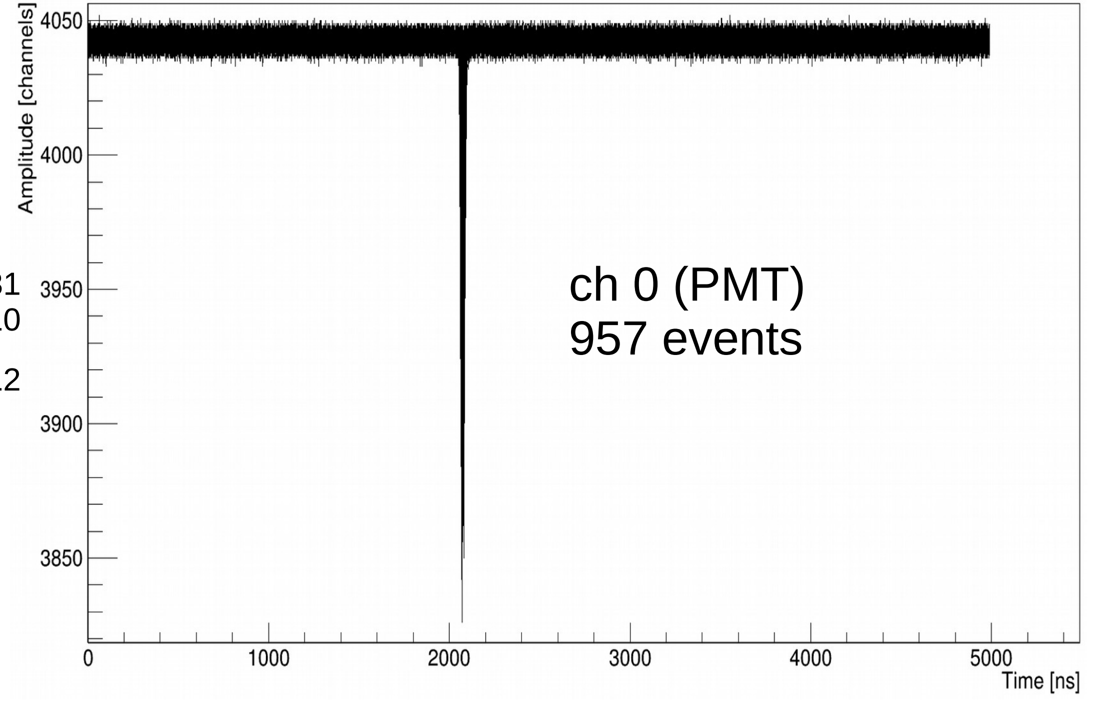
Ch0: min(y) > 3800
Ch1: min(y) > 3350
Ch2: min(y) > 3250



Laser run 6061. Overlapping + cut1 + cut2







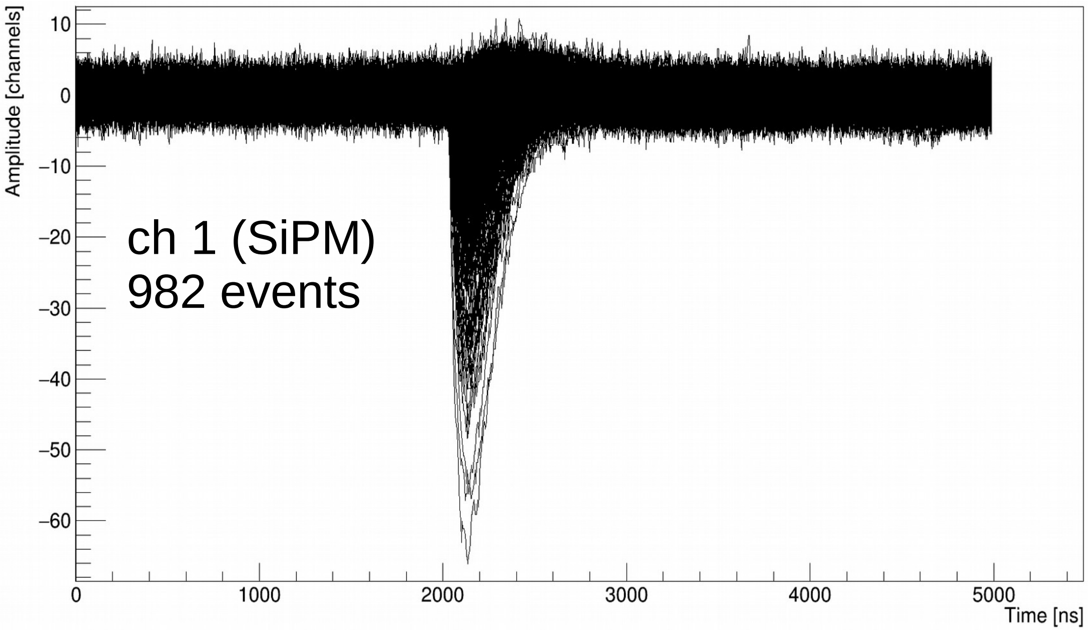
Cut2:

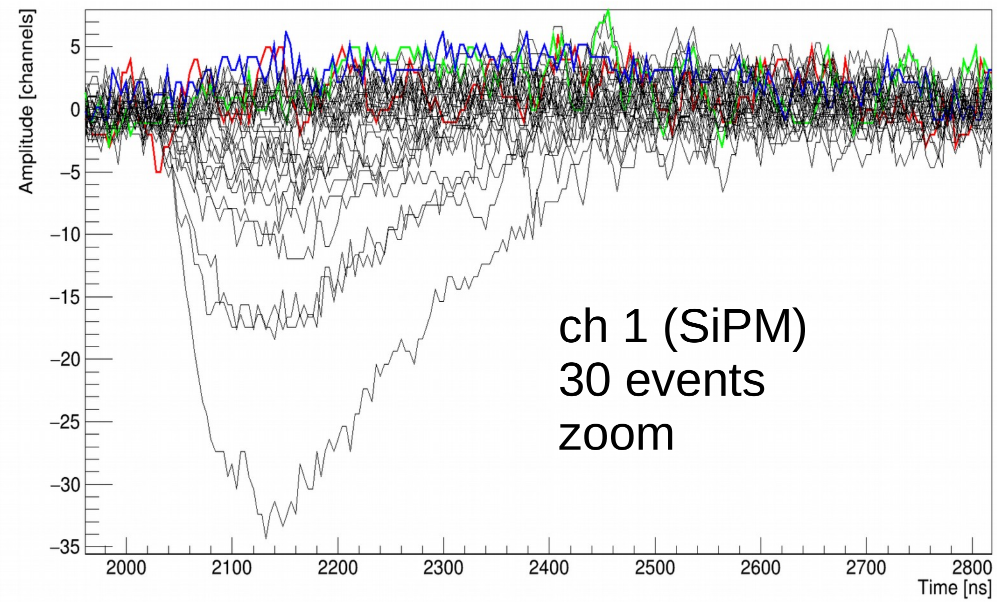
Ch0: min(y){0, 2045 ns} > 4031 && min(y){2100, 5000 ns} > 4031
Ch1: min(y){0, 2000 ns} > 3410 && min(y){2800, 5000 ns} > 3410

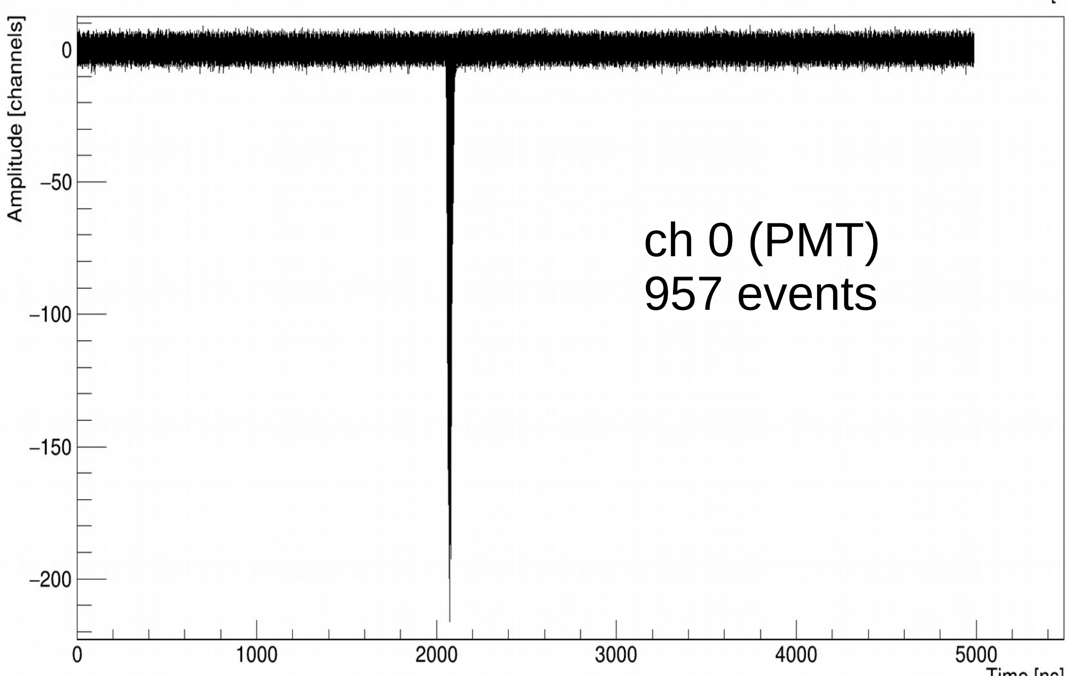
Ch2: min(y){0, 1900 ns} > 3412 && min(y){2800, 5000 ns} > 3412

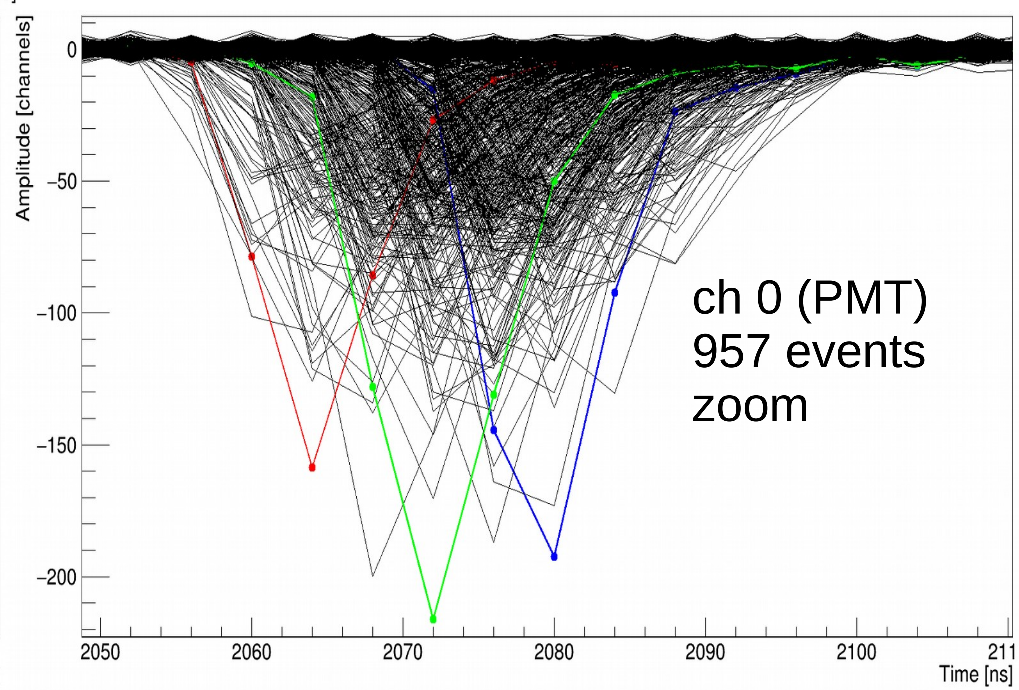
Laser run 6061.

Baseline subtraction(0,1600 ns). Cut1 + Cut2



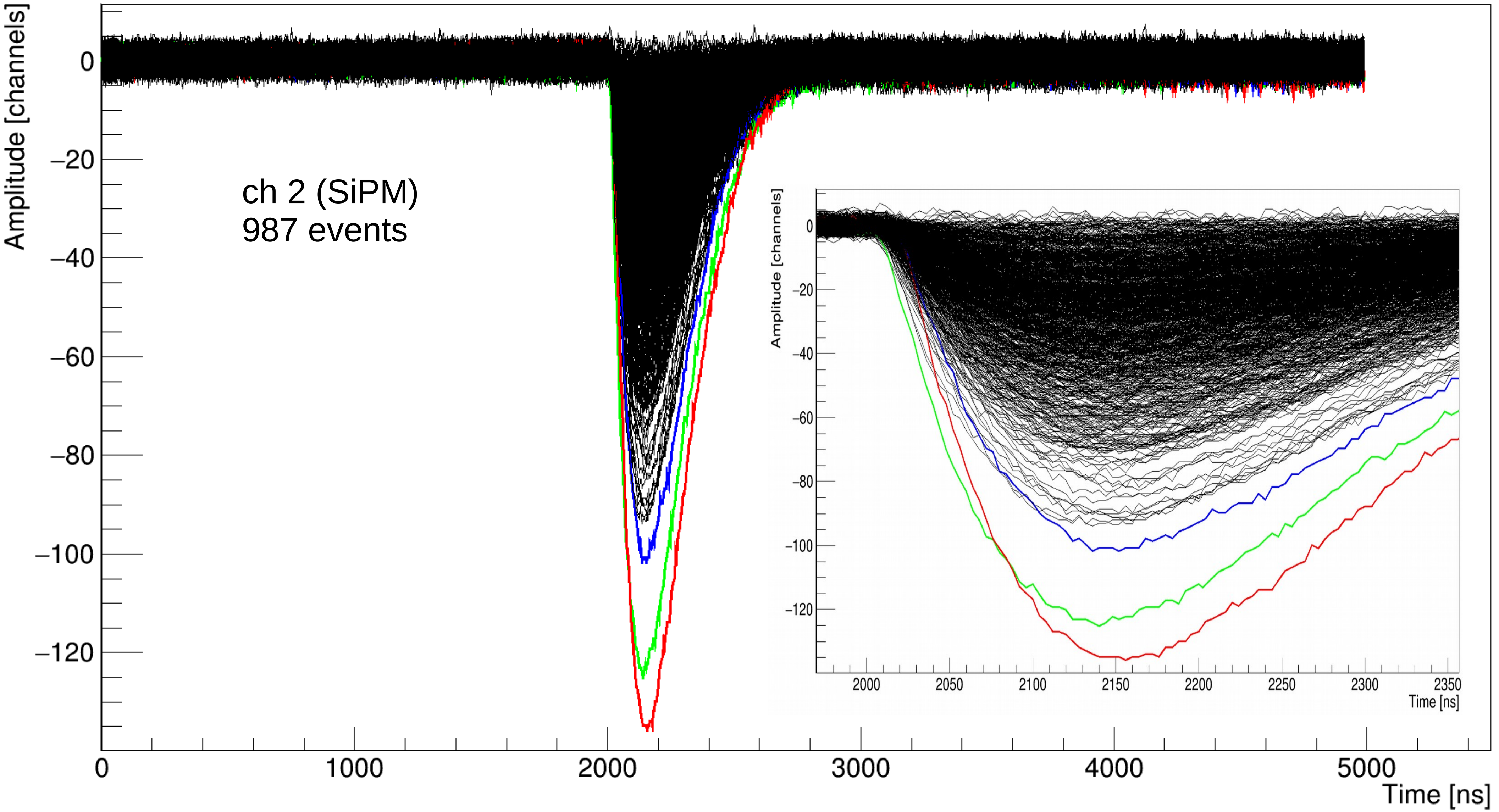




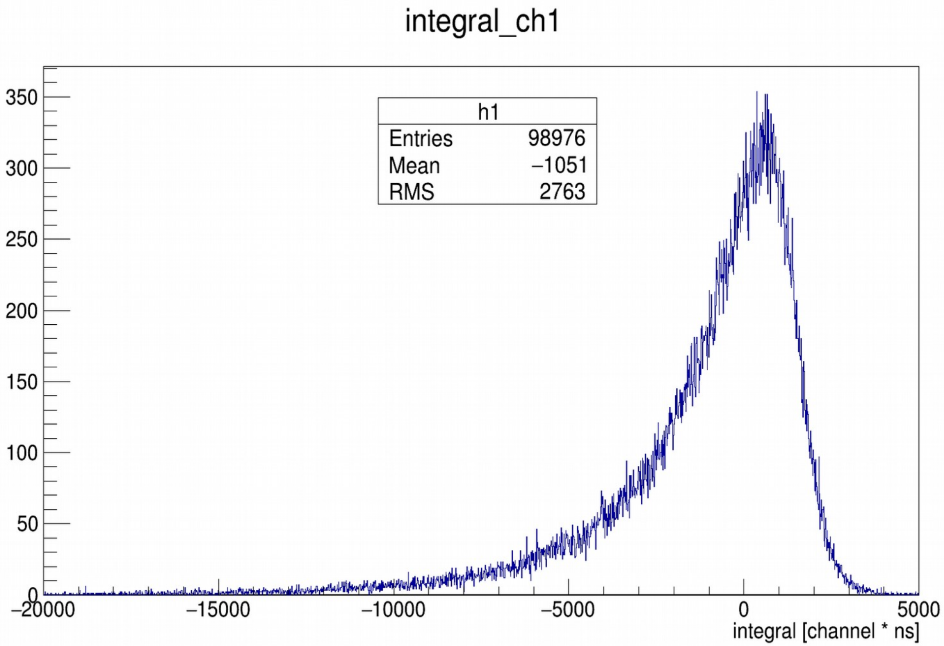


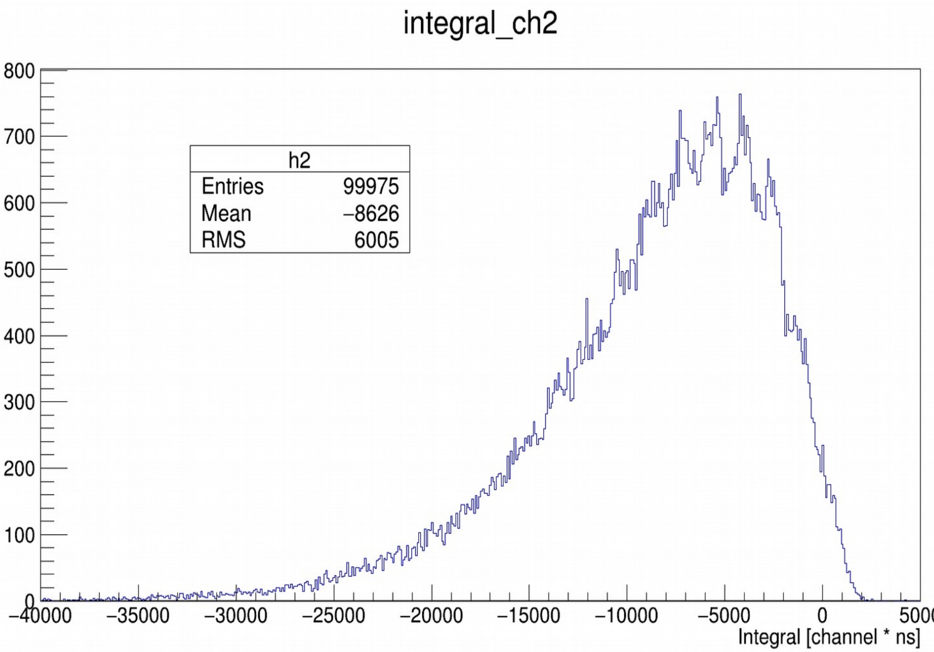
Laser run 6061.

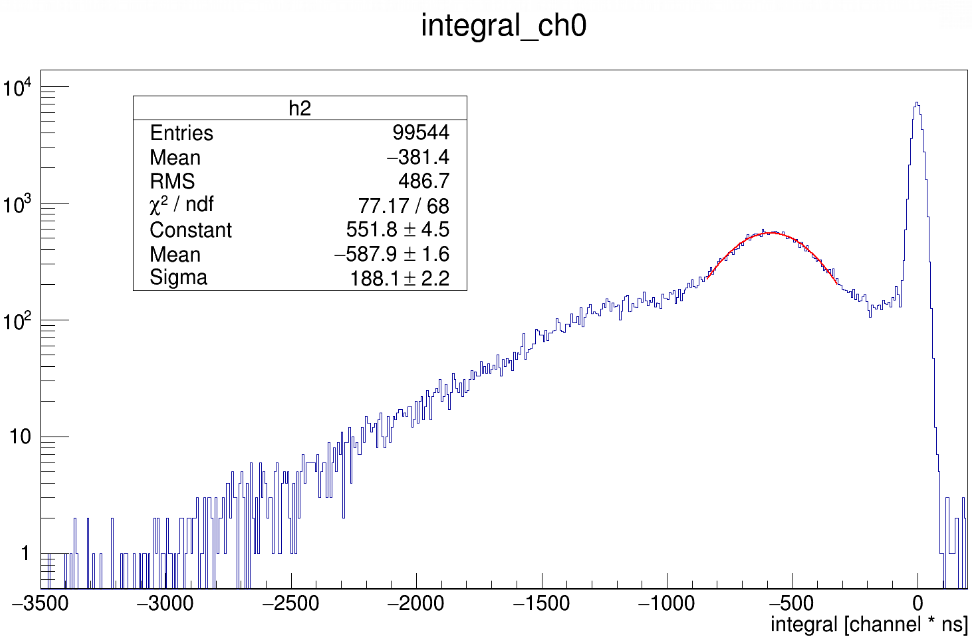
Baseline subtraction(0,1600 ns). Cut1 + Cut2



Laser run 6061. Integration spectra







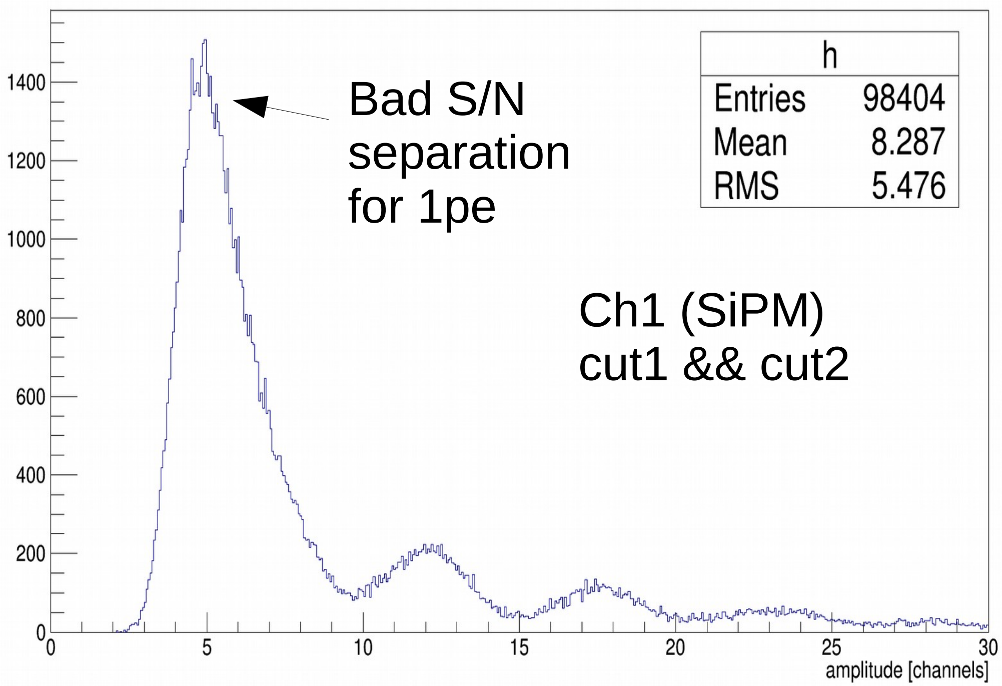
For ch0:
Integral from 2050 to 2100 ns

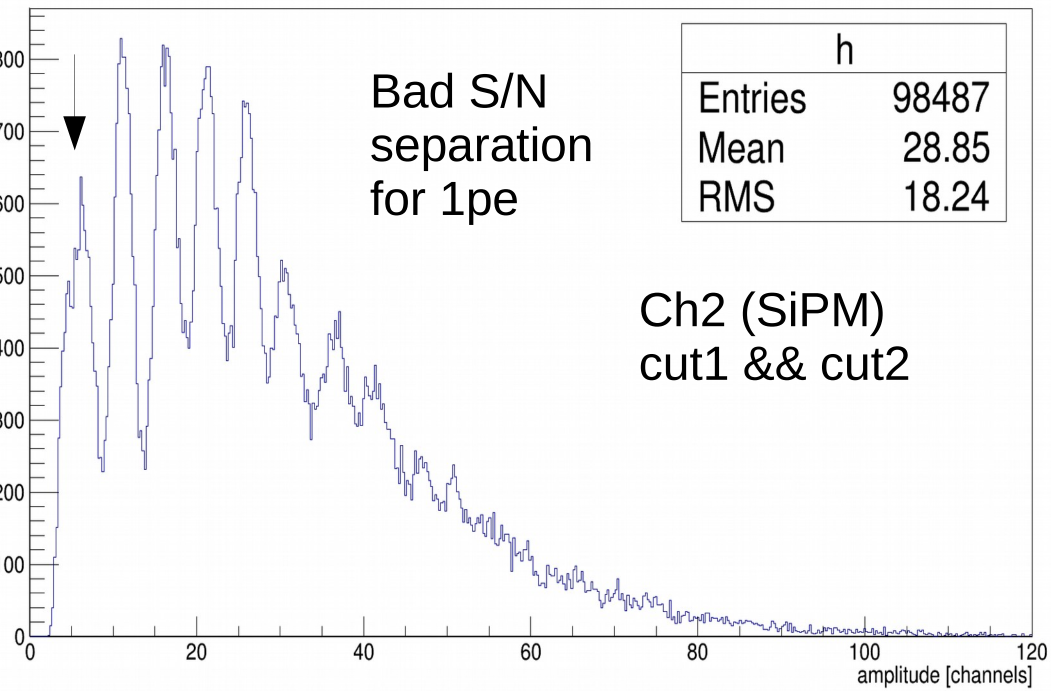
For ch1 and ch2:
Integral from 1950 to 2650 ns

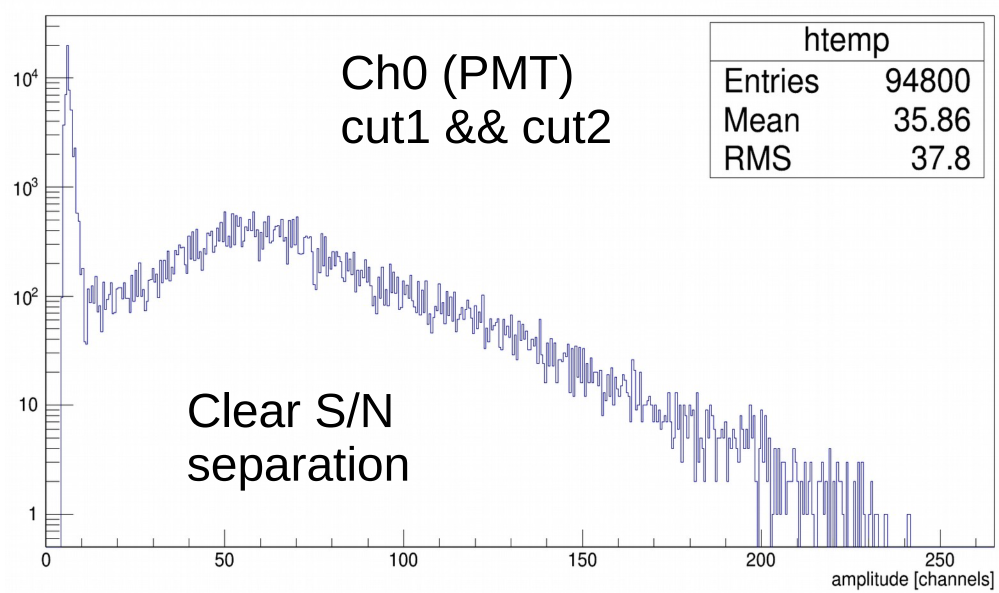
I have not found any peaks for ch1 (for any binning)
Avr spe integral for ch2 is -1484 [channel * ns]

Laser run 6061. Amplitude spectra

|max(y - y_baseline)|



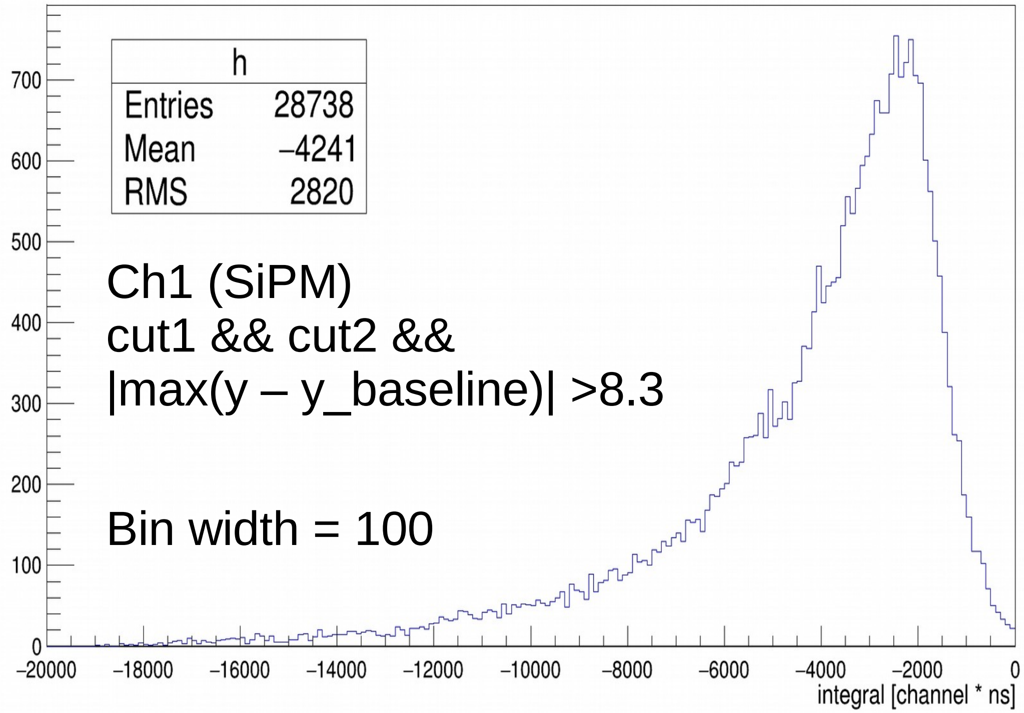


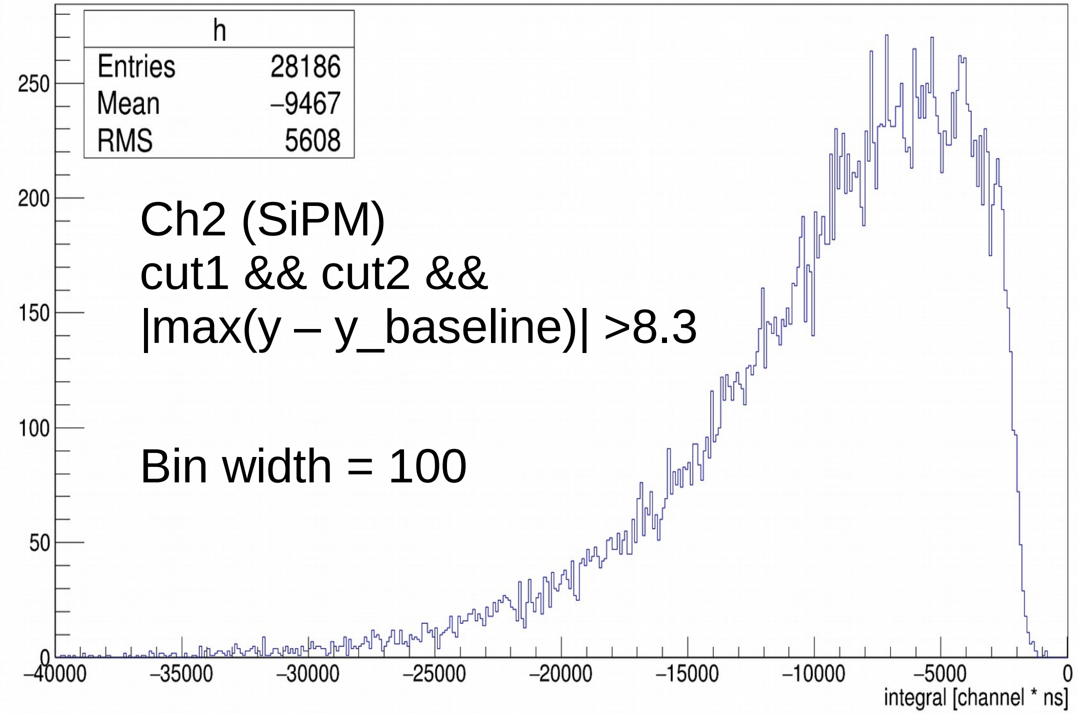


Let's introduce new cut for all channels to cut all noise events

cutAbsAmp:
|max(y - y_baseline)| > 15

Broadening

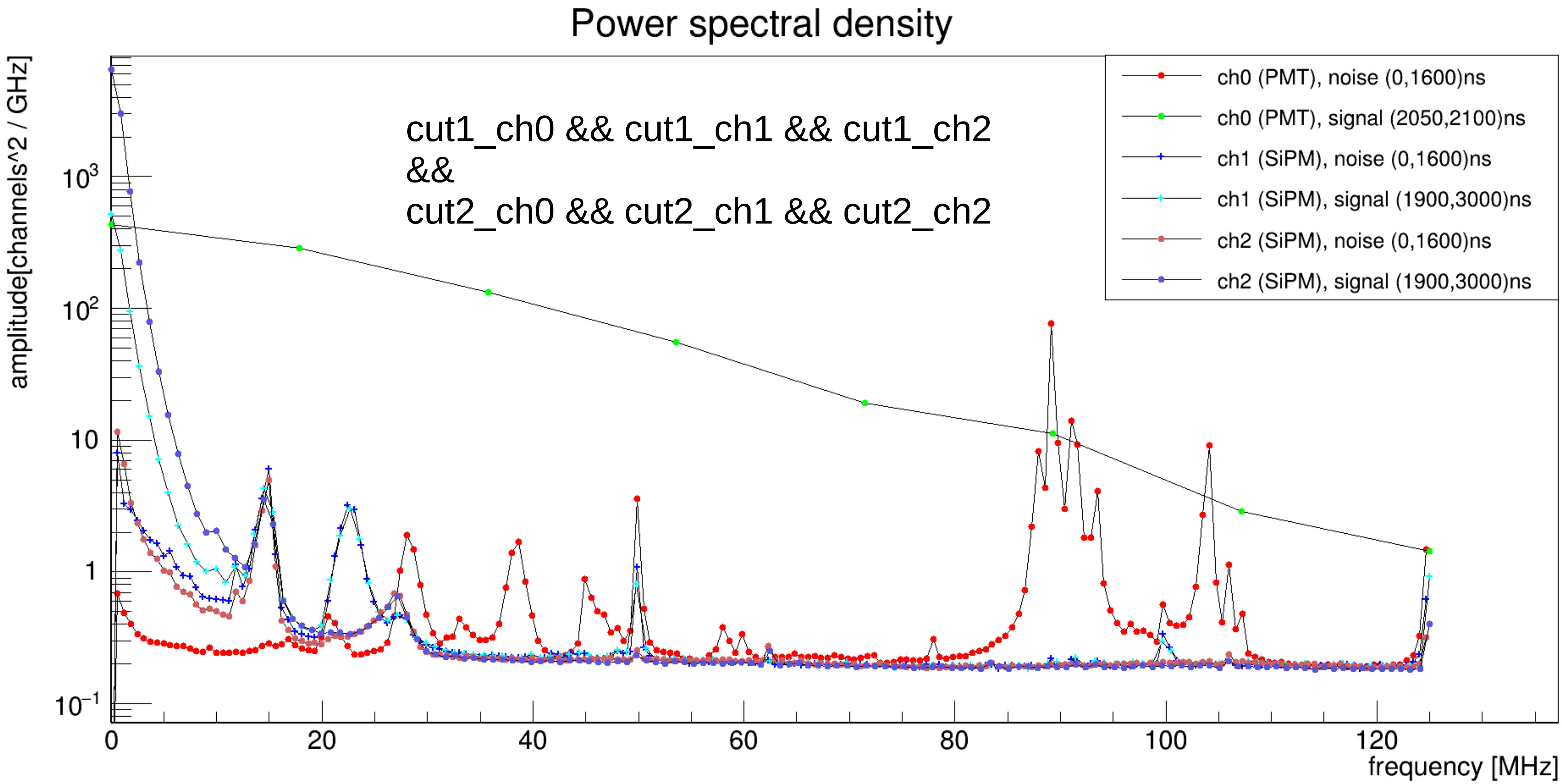




The same integration window, bin width, statistics and cut conditions and events only with signals

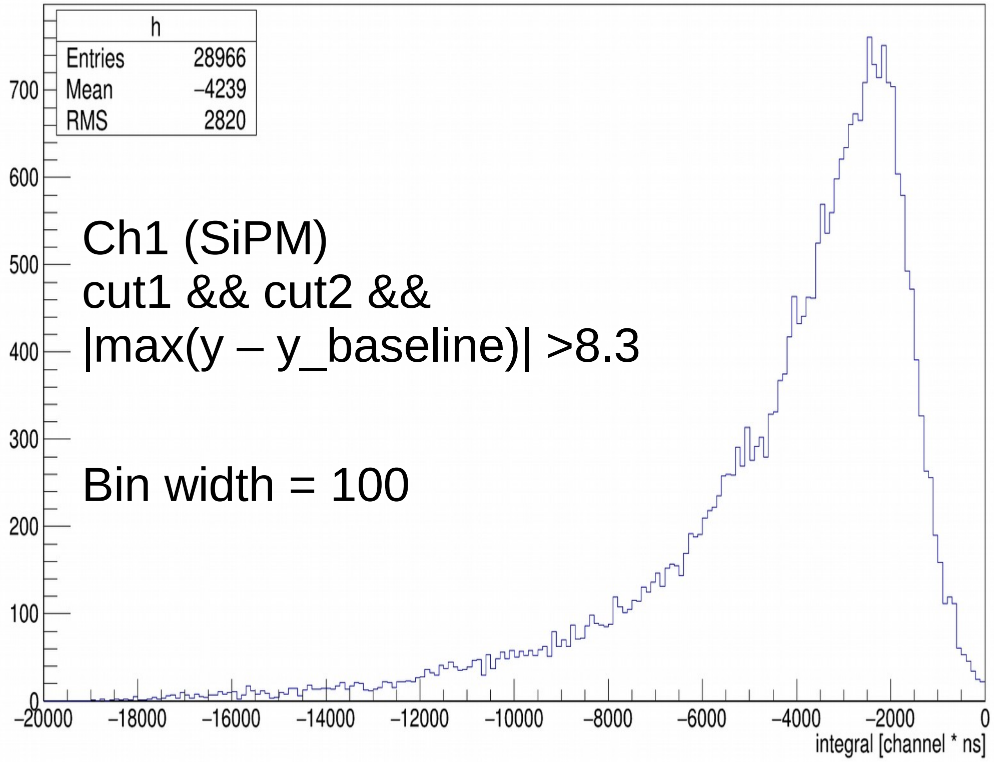
Peaks: 4120, 5620, 7128
dI ~ 1500 +- 50

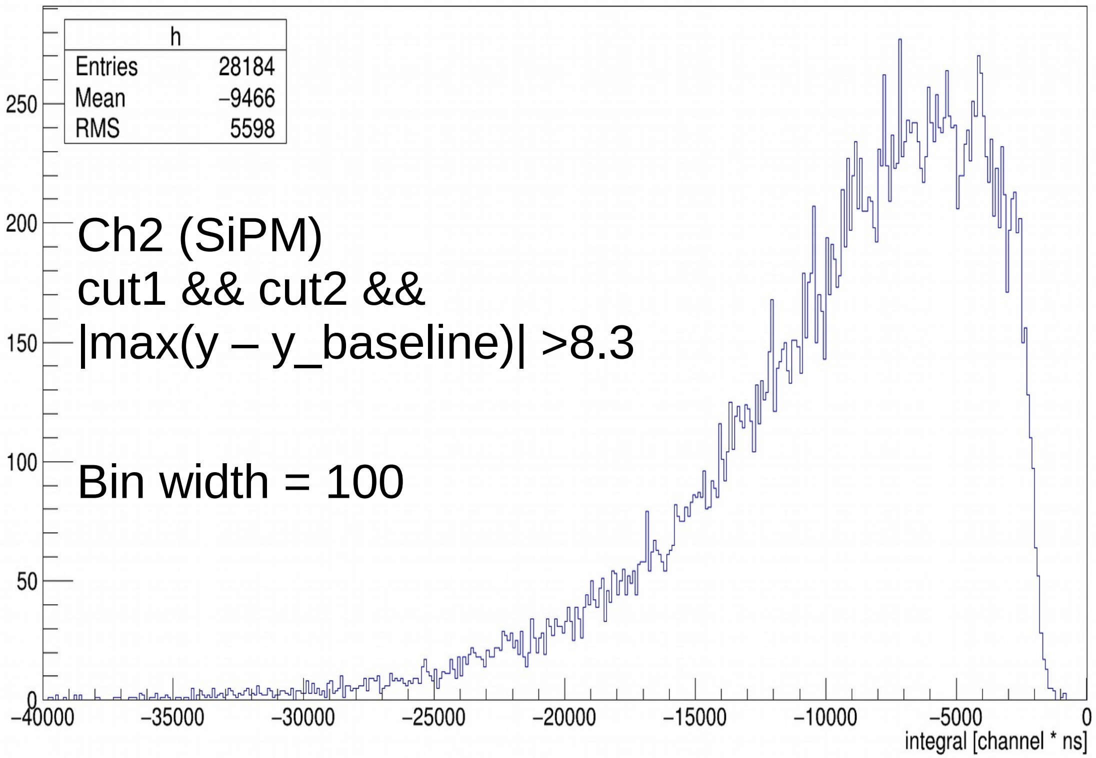
Laser run 6061. Fourier transform



Baseline was subtracted before ft. 5000 averaged events.
PMT signal is short → amplitude spectrum of signal is wide (ft of delta-func is constant)
PMT signal is short and sampling rate is low →bad frequency resolution

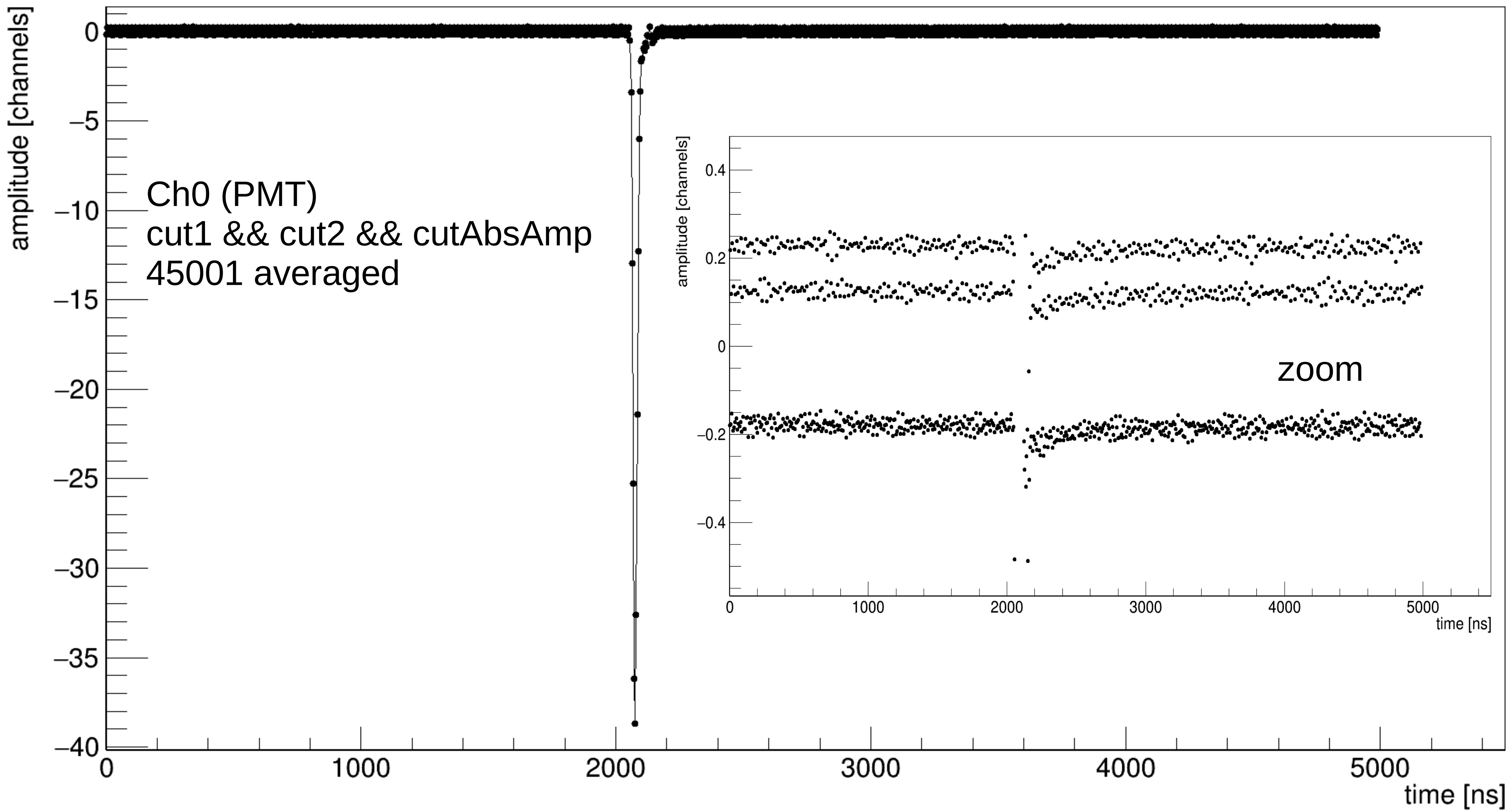
Integral spectra after 10 MHz cut





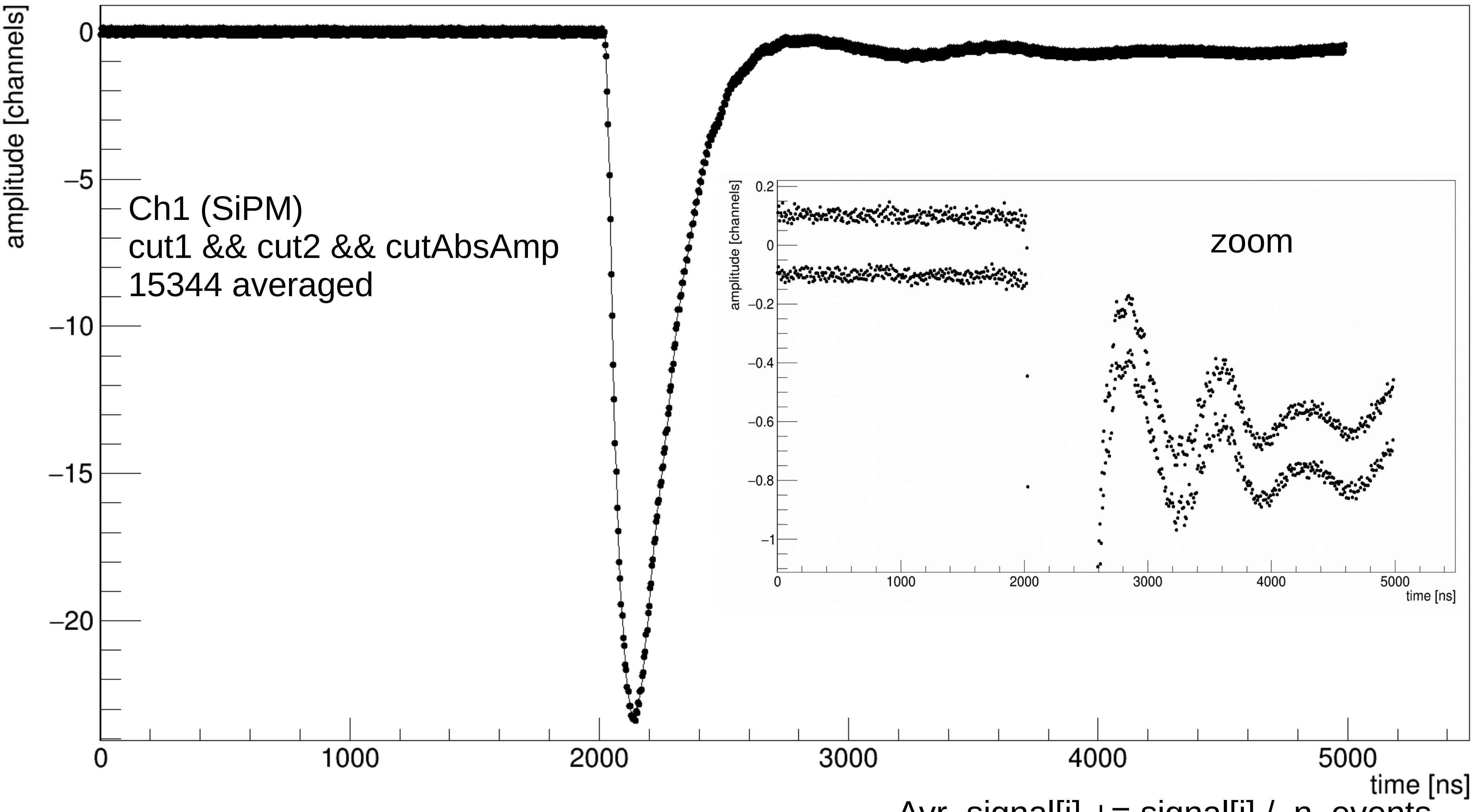
Peaks: 4077, 5628, 7073
dI ~ 1500 +- 50

Laser run 6061. Simple averaging



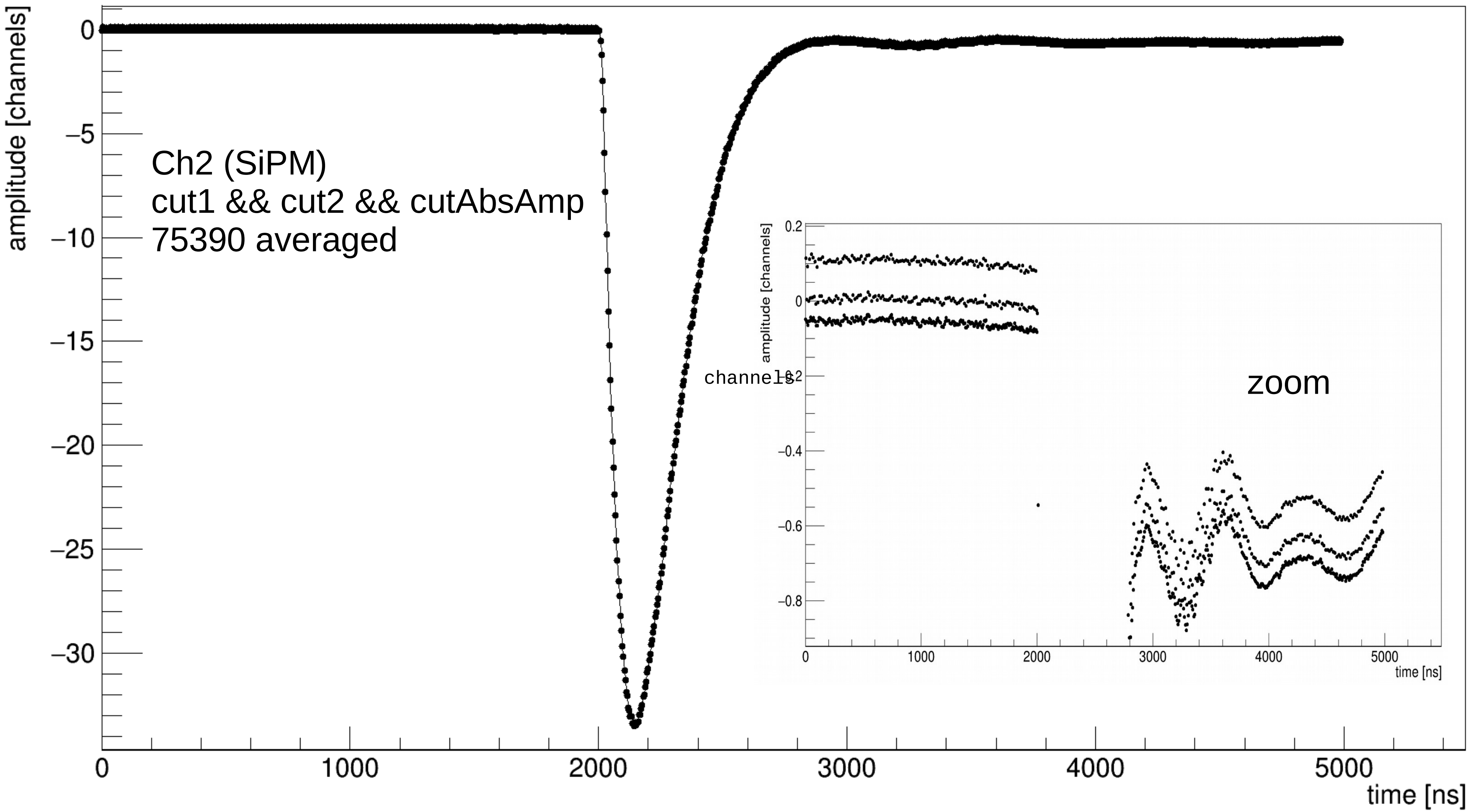
Avr_signal[i] += signal[i] / n_events

Laser run 6061. Simple averaging



Avr_signal[i] += signal[i] / n_events

Laser run 6061. Simple averaging

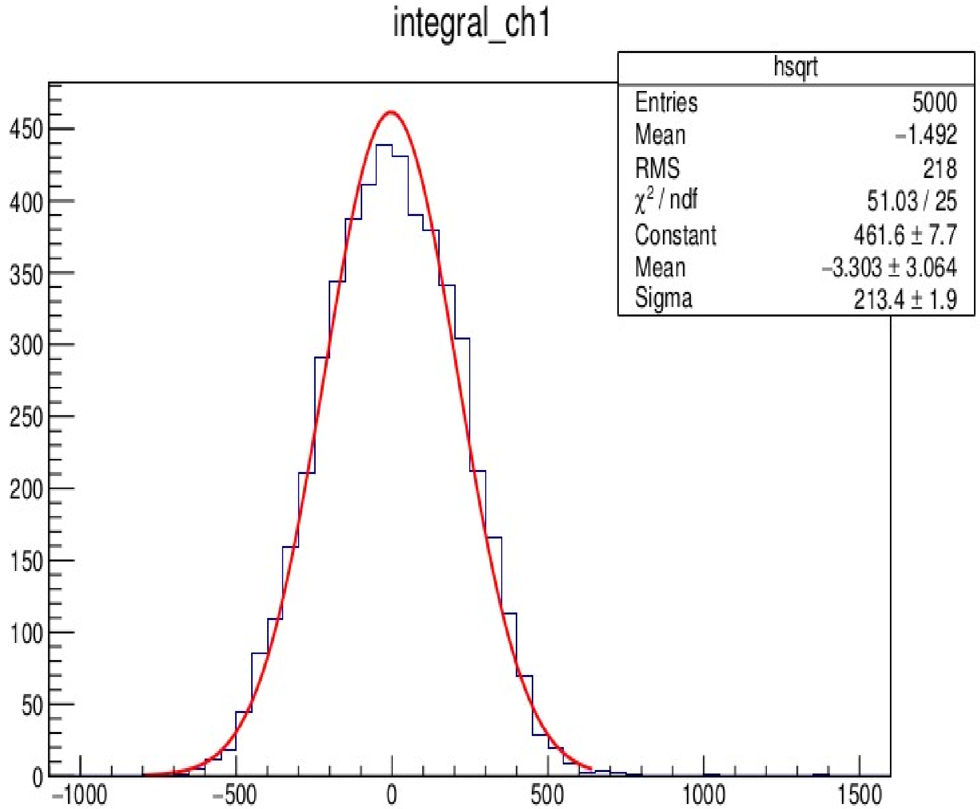


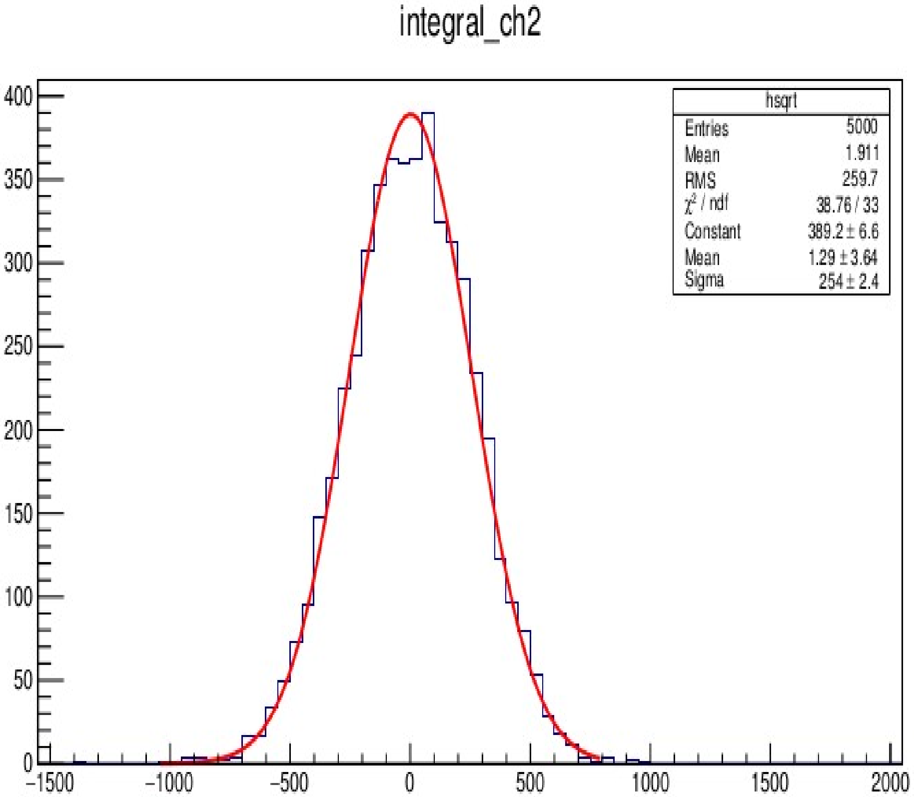
Avr_signal[i] += signal[i] / n_events

Laser run 6061. Integration spectra

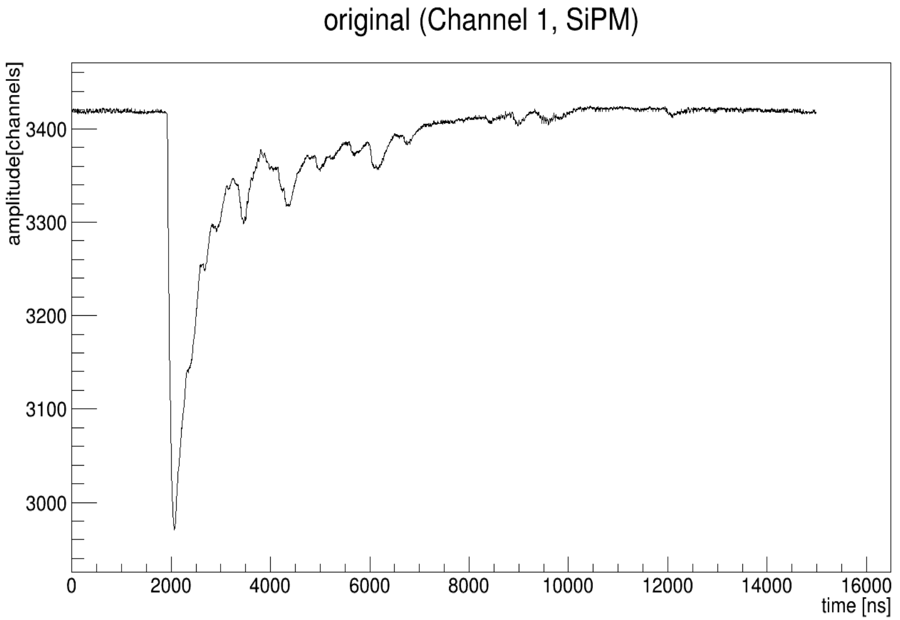
- Integral = sum(y[i] – baseline[i]) * sampling_rate

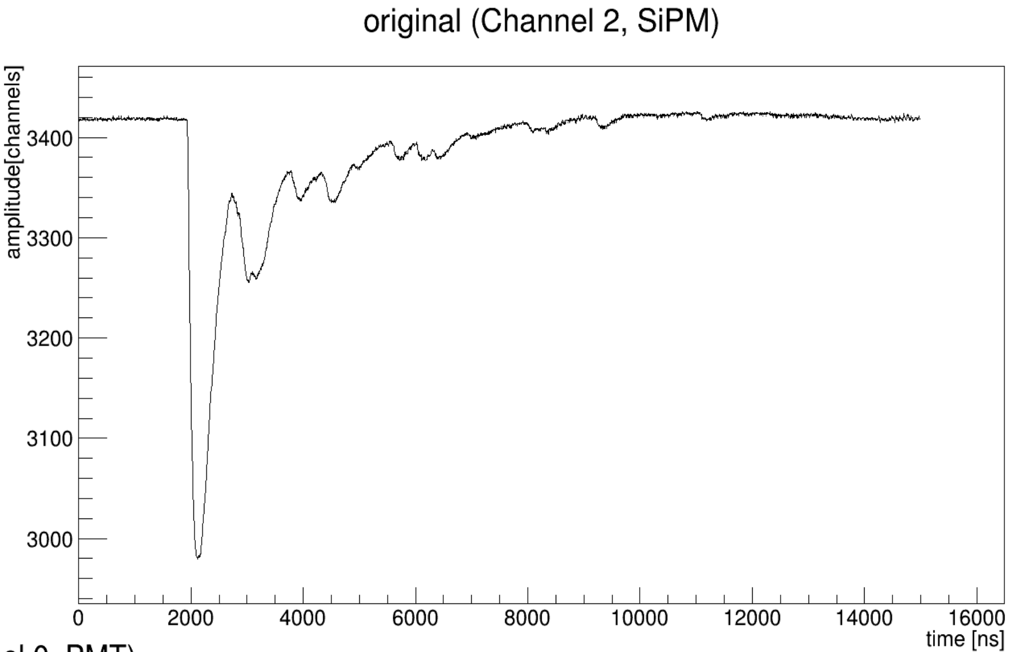
  baseline = avr(y) from 0 to 1600 ns
- Let's calculate integral from 0 to 1600 ns just to check

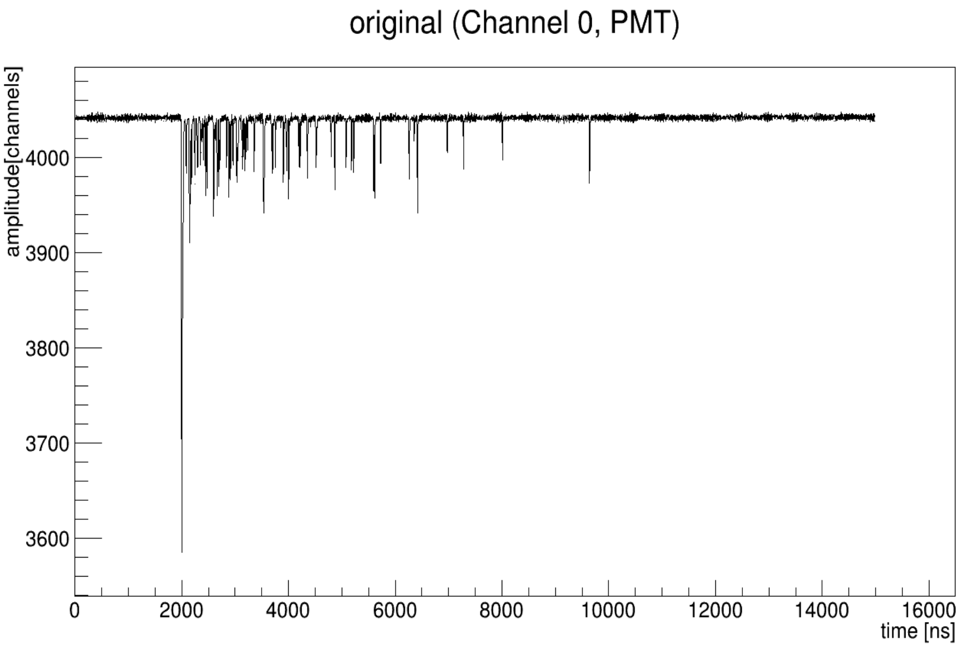




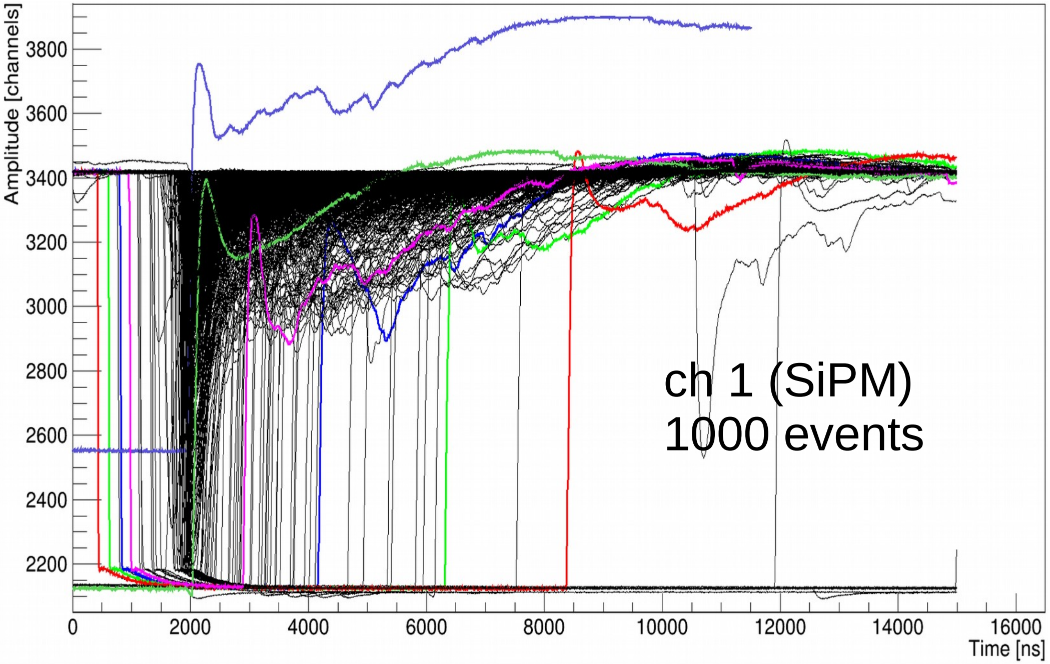
Am run 6064. Typical signals

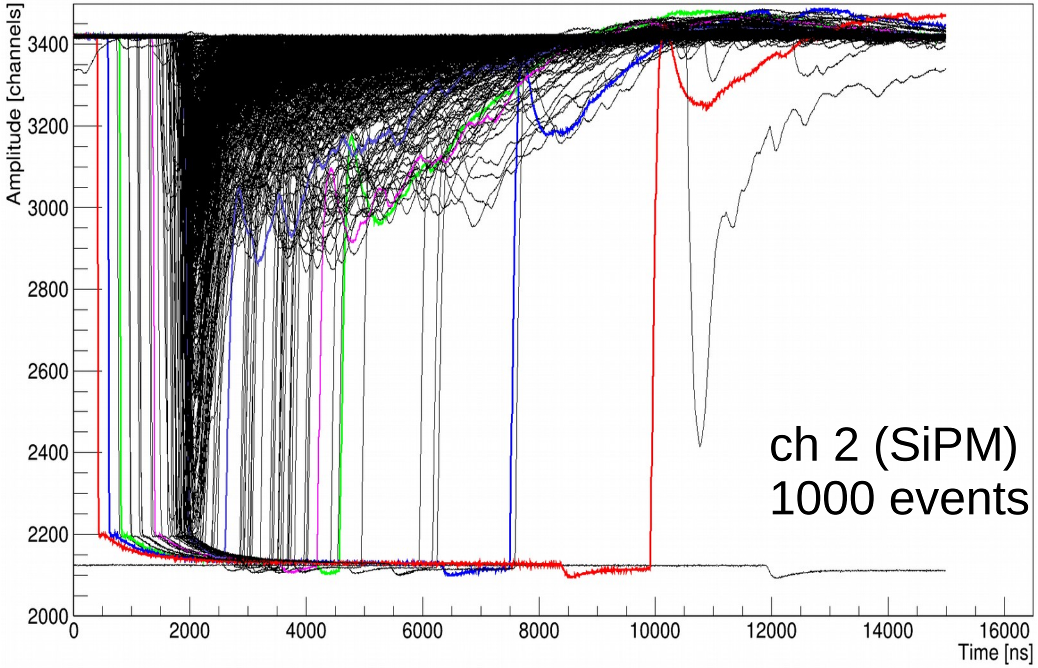


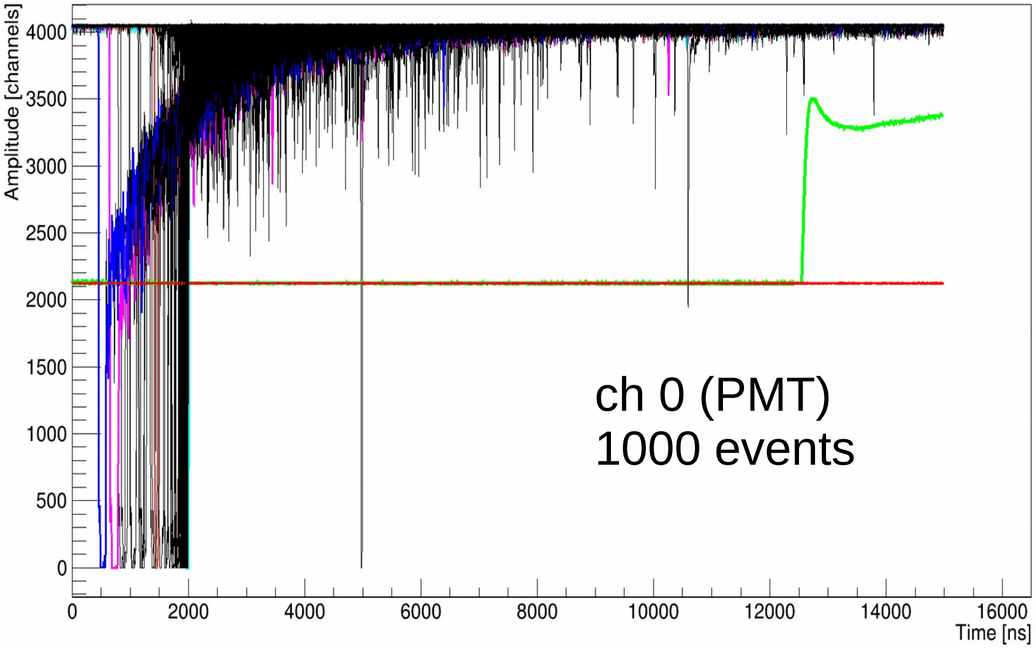




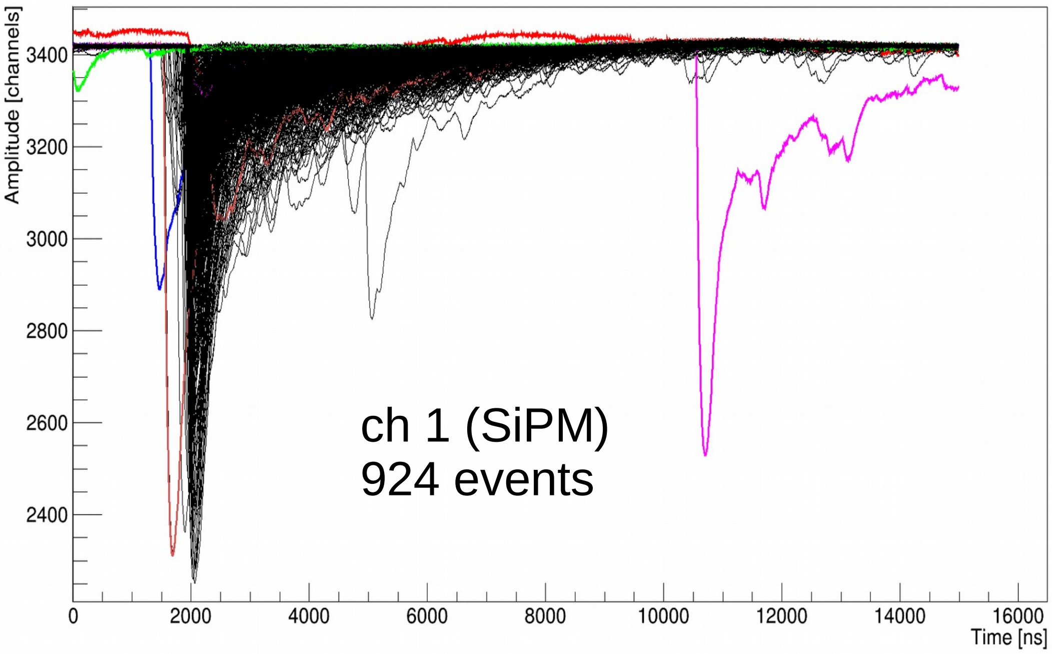
Am run 6064. Overlapping

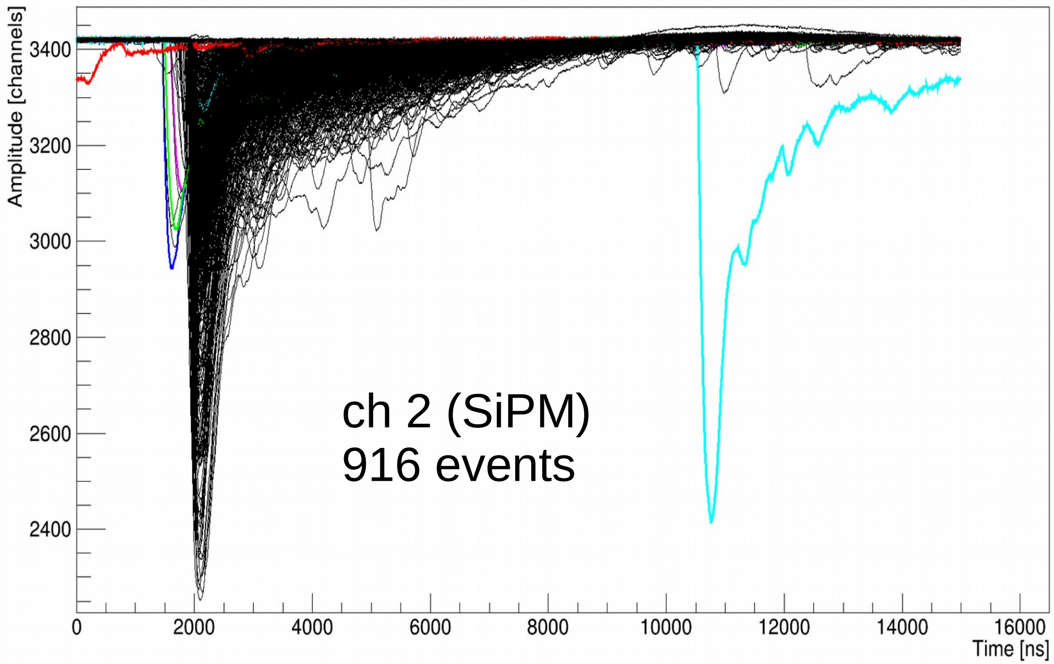


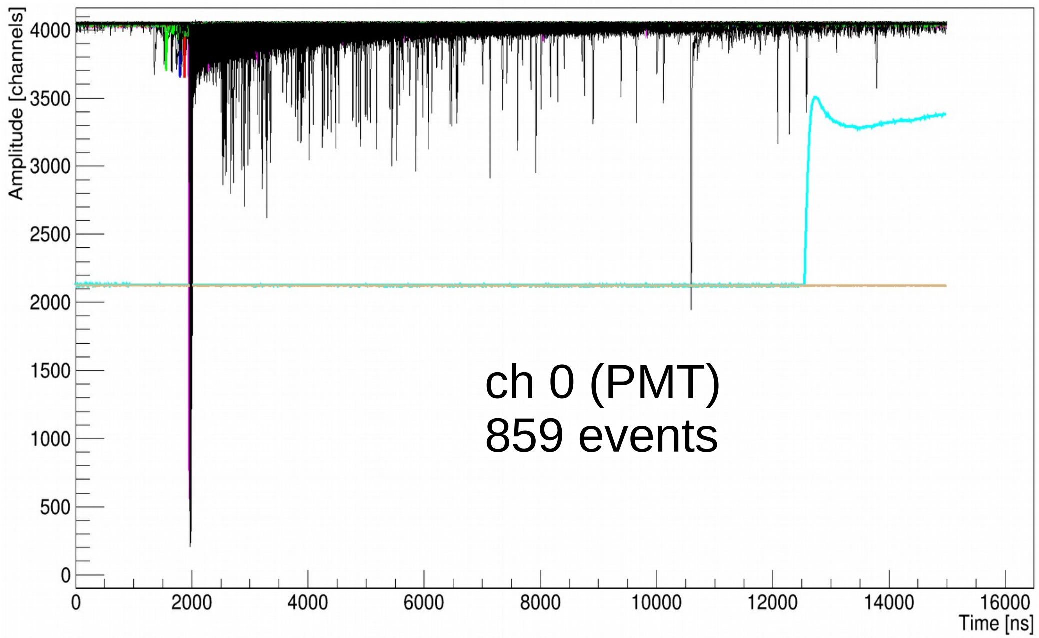




Am run 6064. Overlapping + cut1



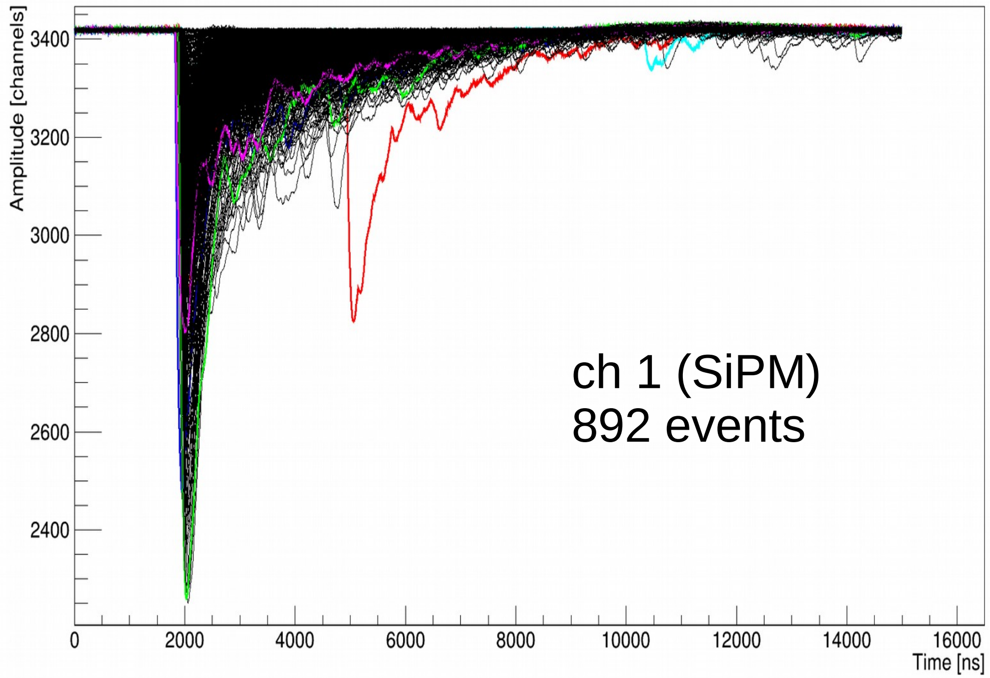


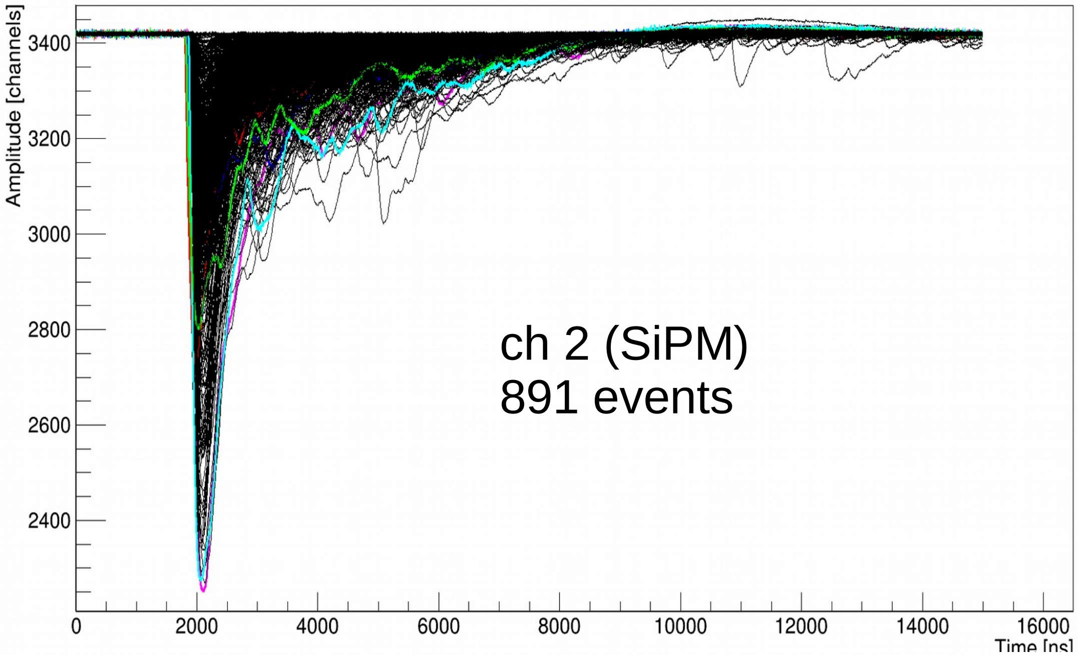


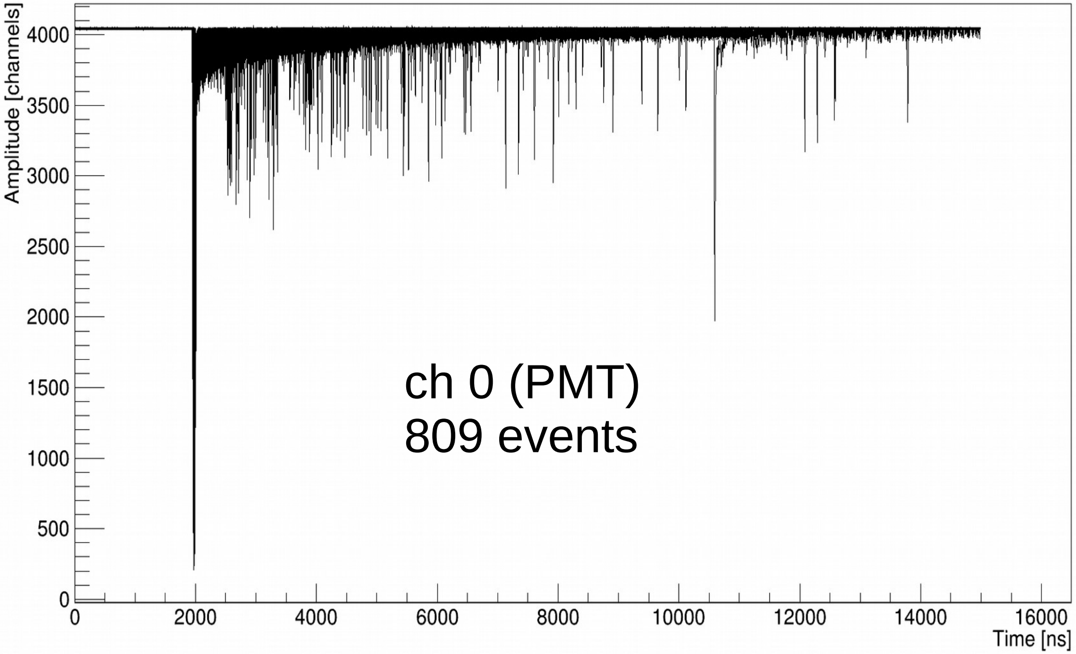
Cut1:

- Ch0: min(y) > 200
- Ch1: min(y) > 2250
- Ch2: min(y) > 2250

Am run 6064. Overlapping + cut1 + cut2







Cut2:

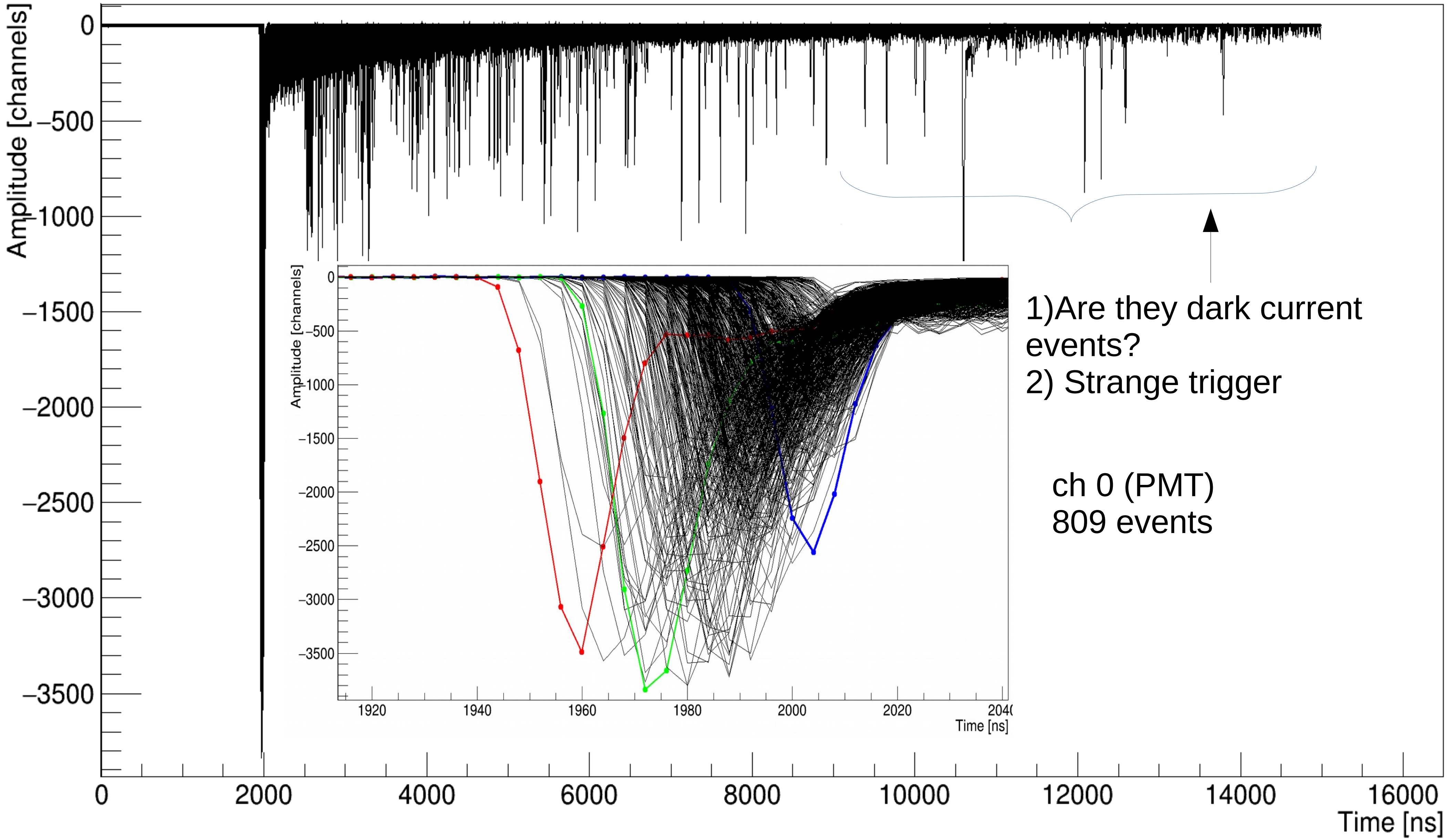
Ch0: min(y){0, 1920 ns} > 4030 && min(y){0, 1920 ns} < 4050

Ch1: min(y){0, 1800 ns} > 3410 && min(y){0, 1800 ns} < 3430 && min(y){8000, 15000 ns} < 3300

Ch2: min(y){0, 1800 ns} > 3412 && min(y){0, 1800 ns} < 3430 && min(y){8000, 15000 ns} < 3300

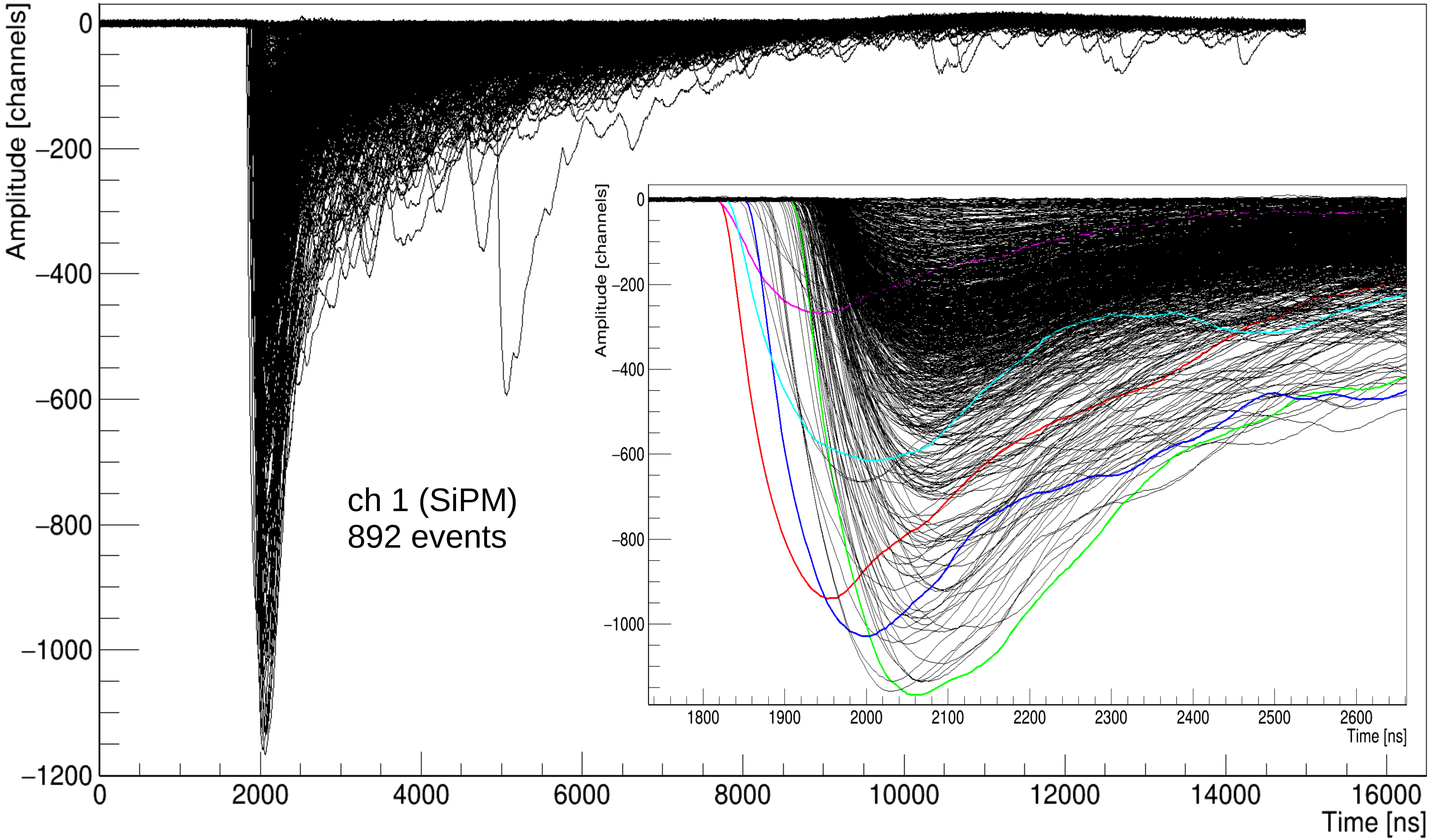
Am run 6064. Ch0

Baseline subtraction(0,1600 ns). Cut1 + Cut2



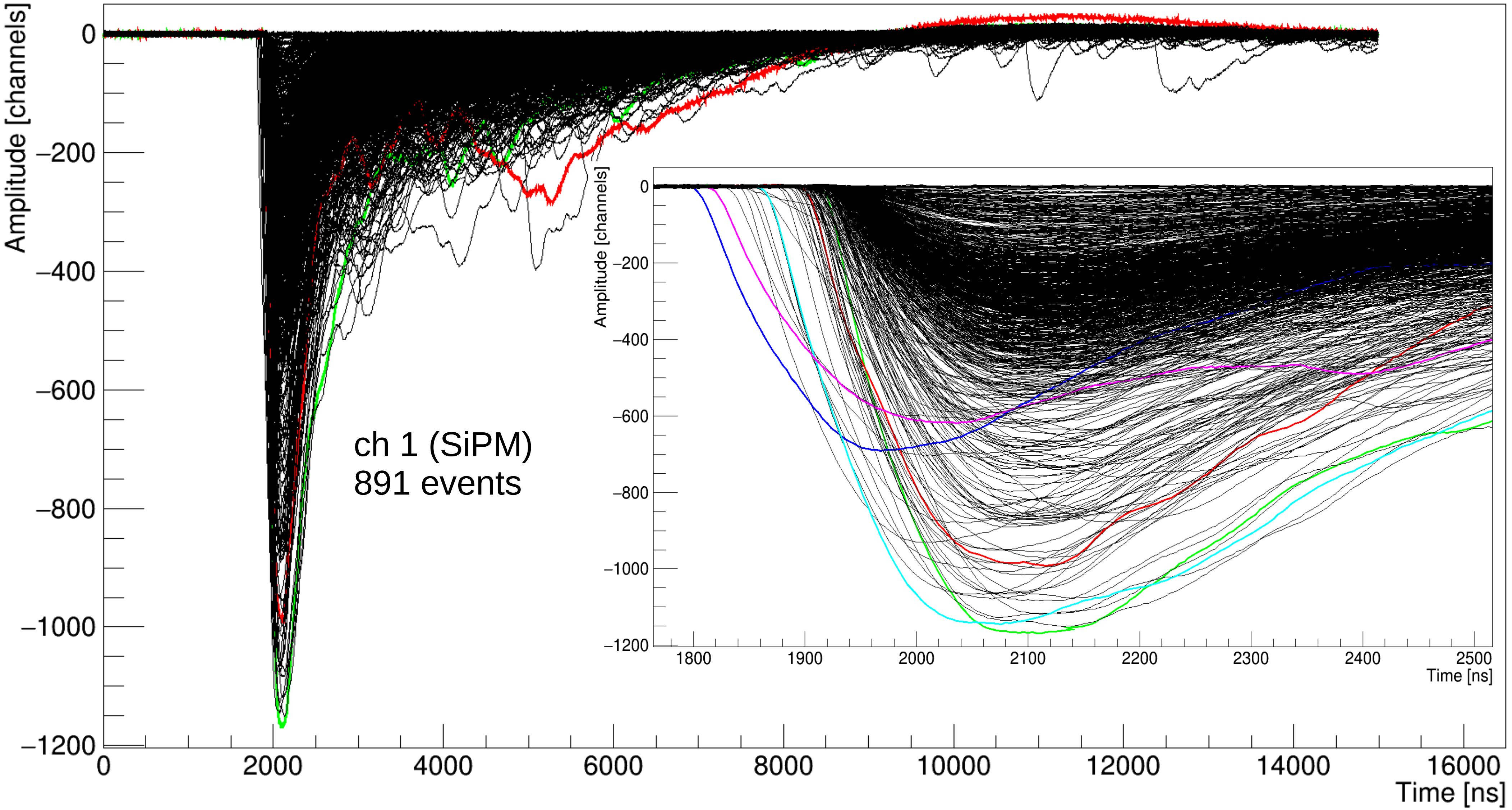
Am run 6064. Ch1

Baseline subtraction(0,1600 ns). Cut1 + Cut2

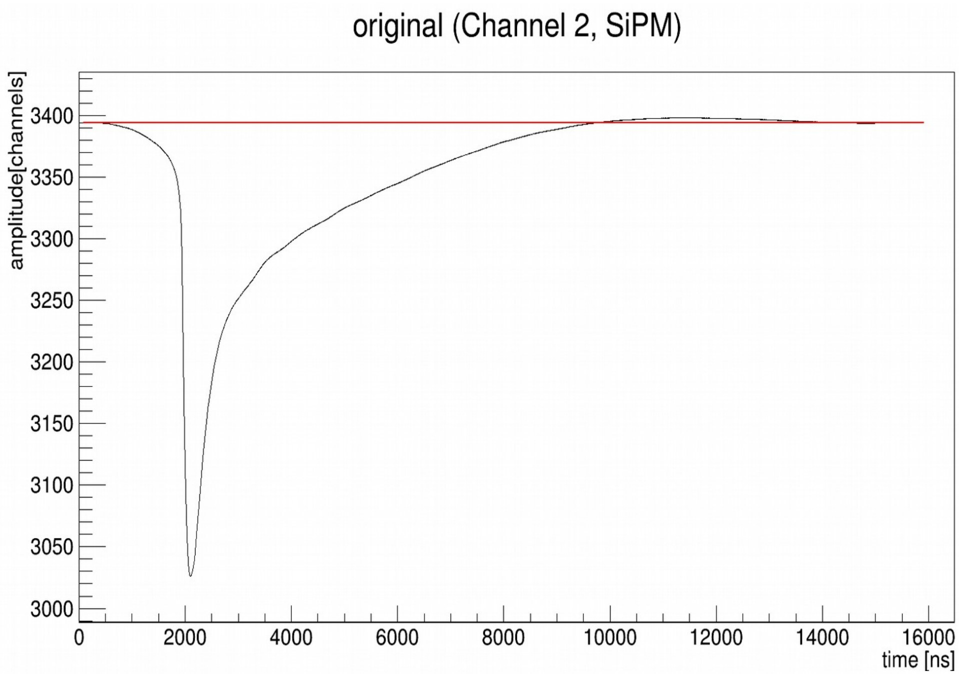


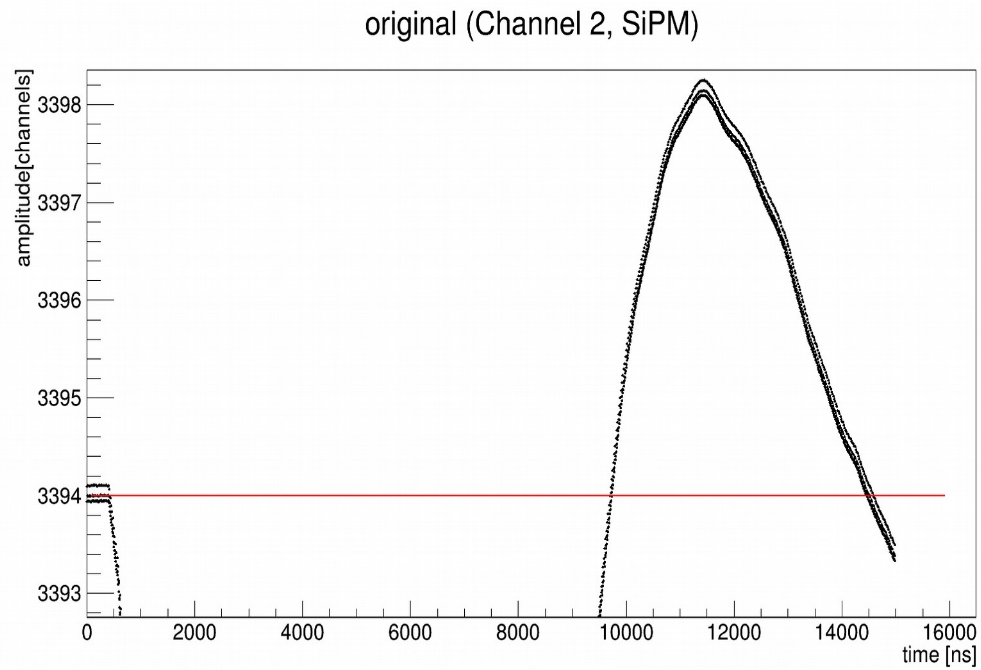
Am run 6064. Ch2

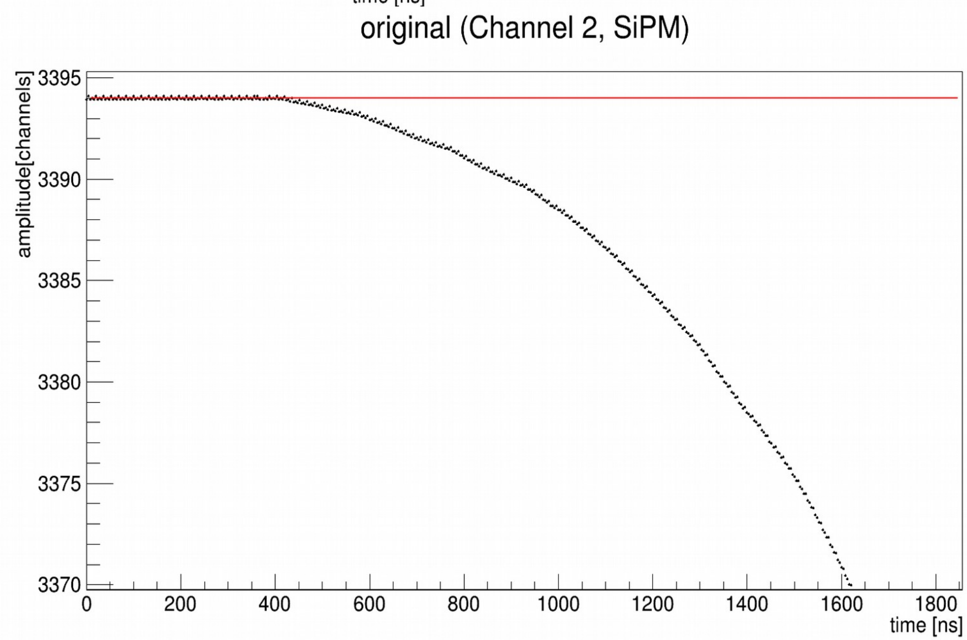
Baseline subtraction(0,1600 ns). Cut1 + Cut2



Am run 6064. Averaged signals

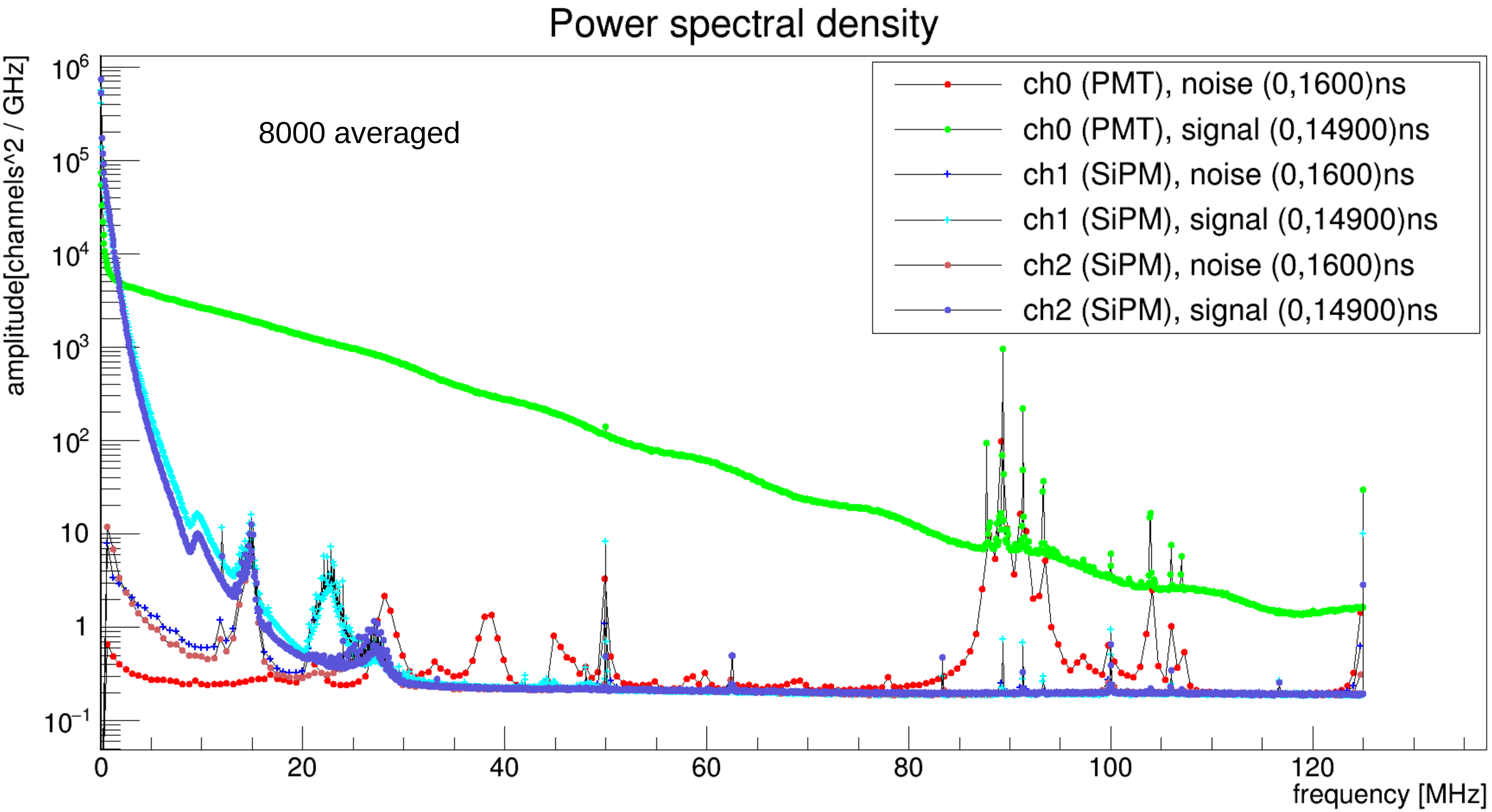






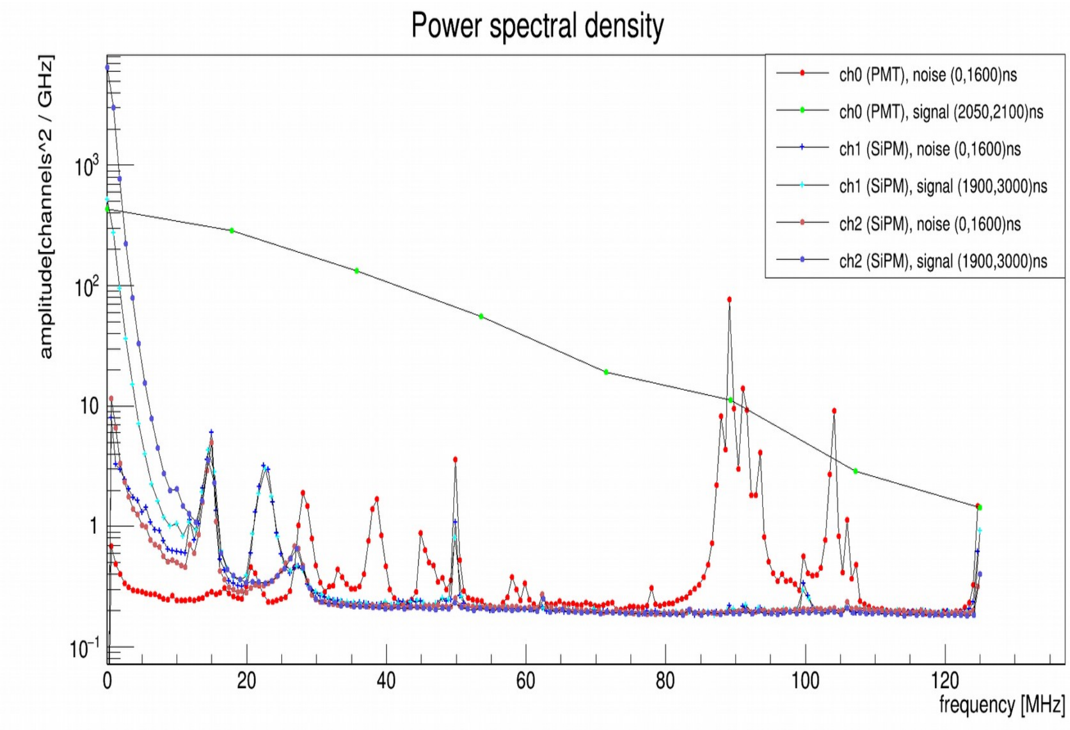
Old slide:
No cuts

Am run 6064. Fourier transform

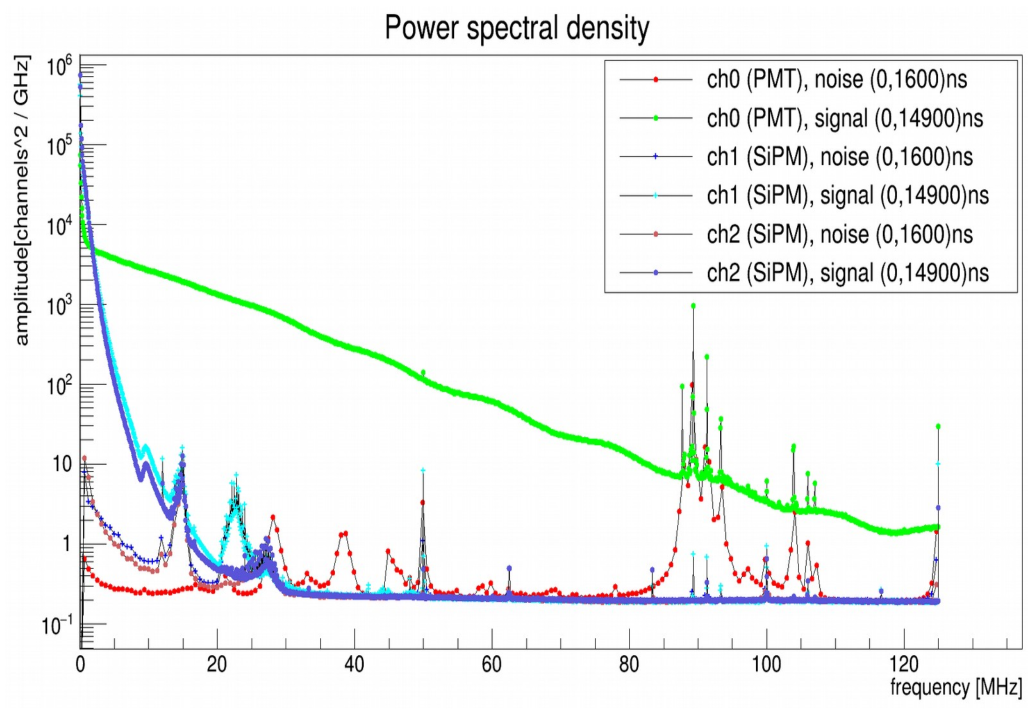


Fourier transform

Spe run 6061. 5000 averaged



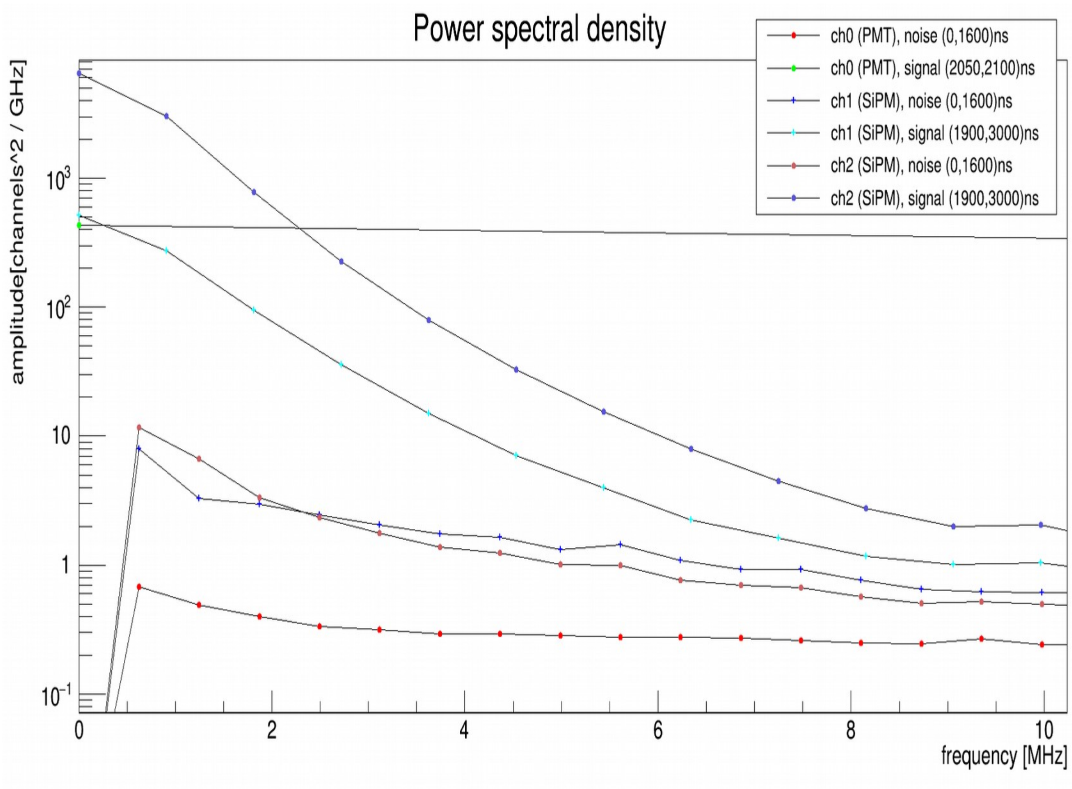
Am run 6064. 8000 averaged



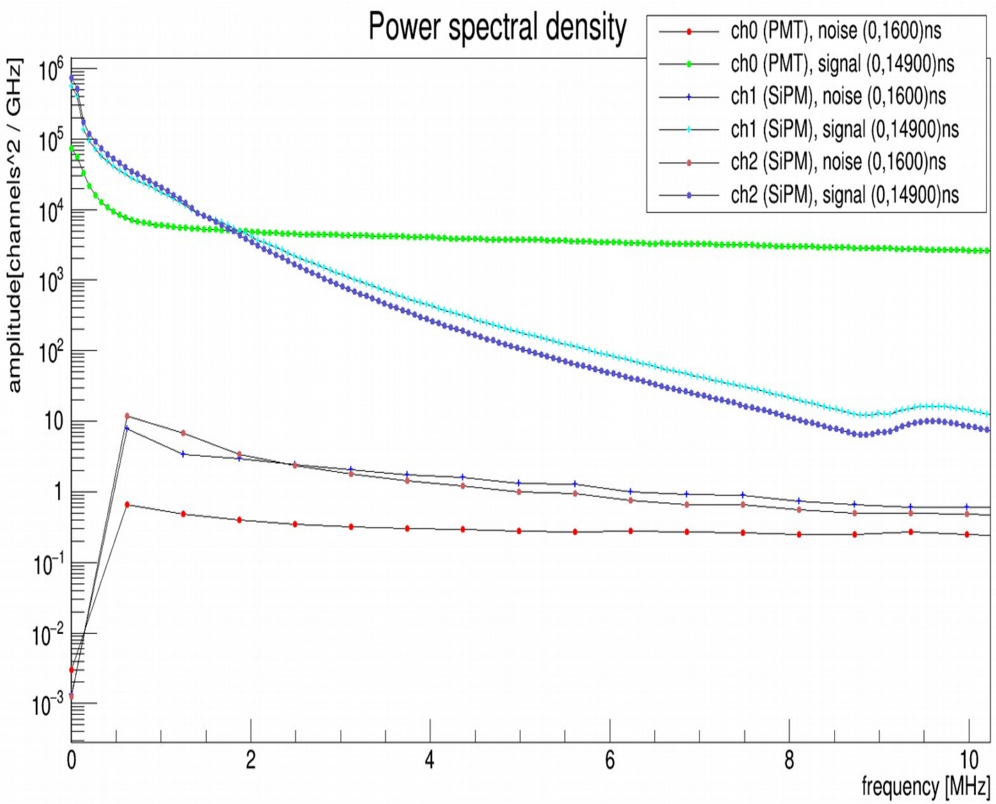
The same noise spectra of for Spe and Am runs.
Signal spectra for Spe and Am runs are different because of another signal amplitude and (probably) longer window range. With longer range we can see lower frequencies.

Fourier transform

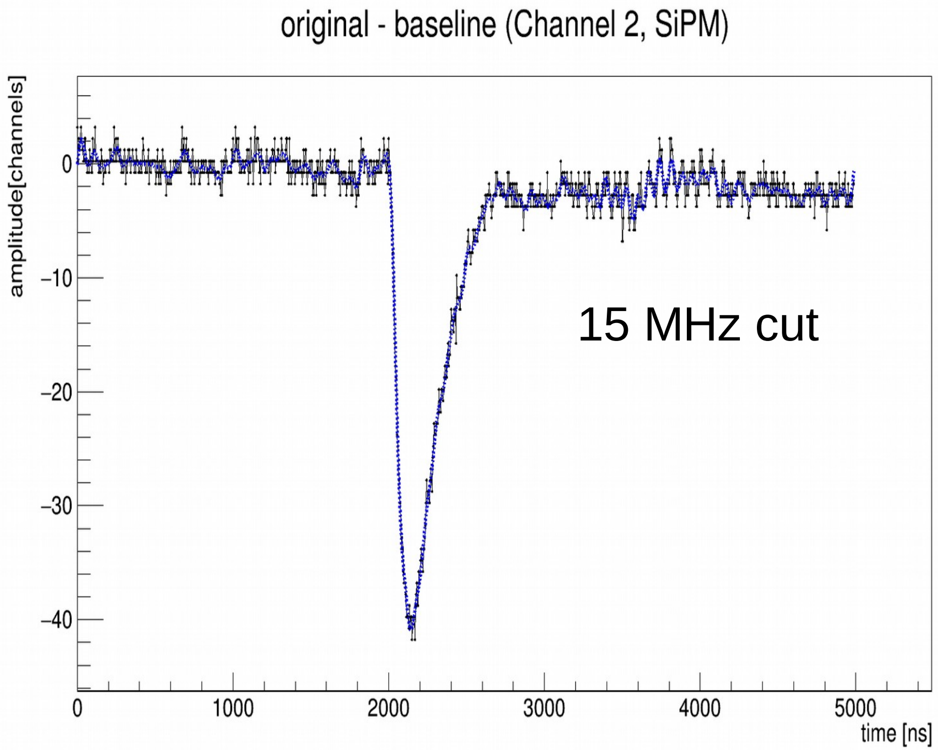
Spe run 6061. 5000 averaged

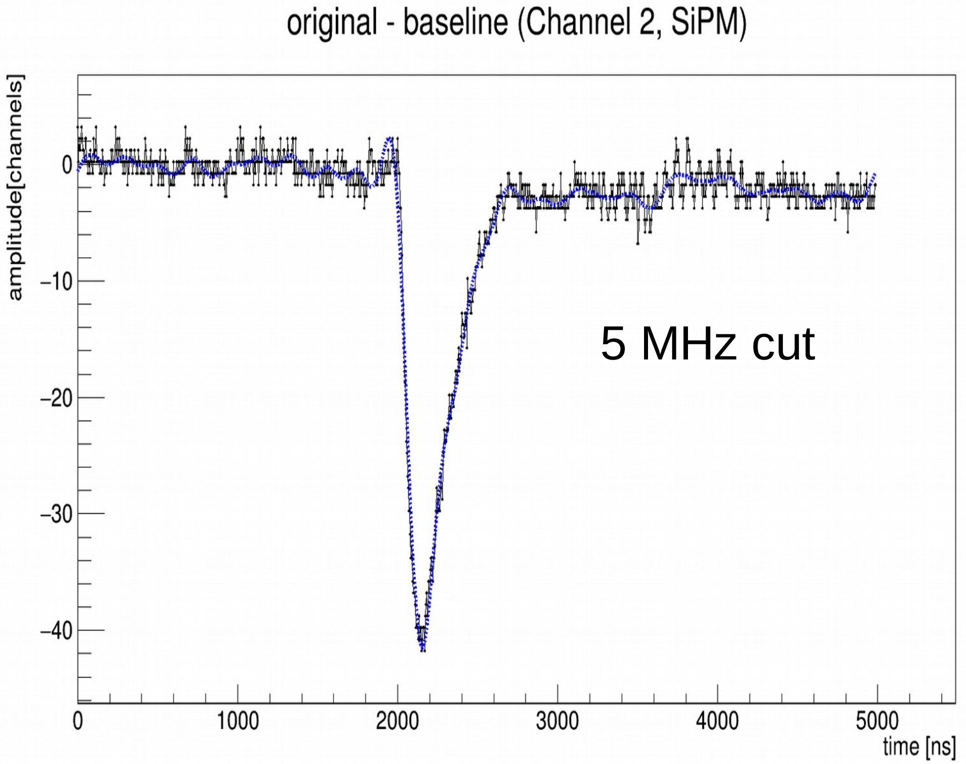


Am run 6064. 8000 averaged

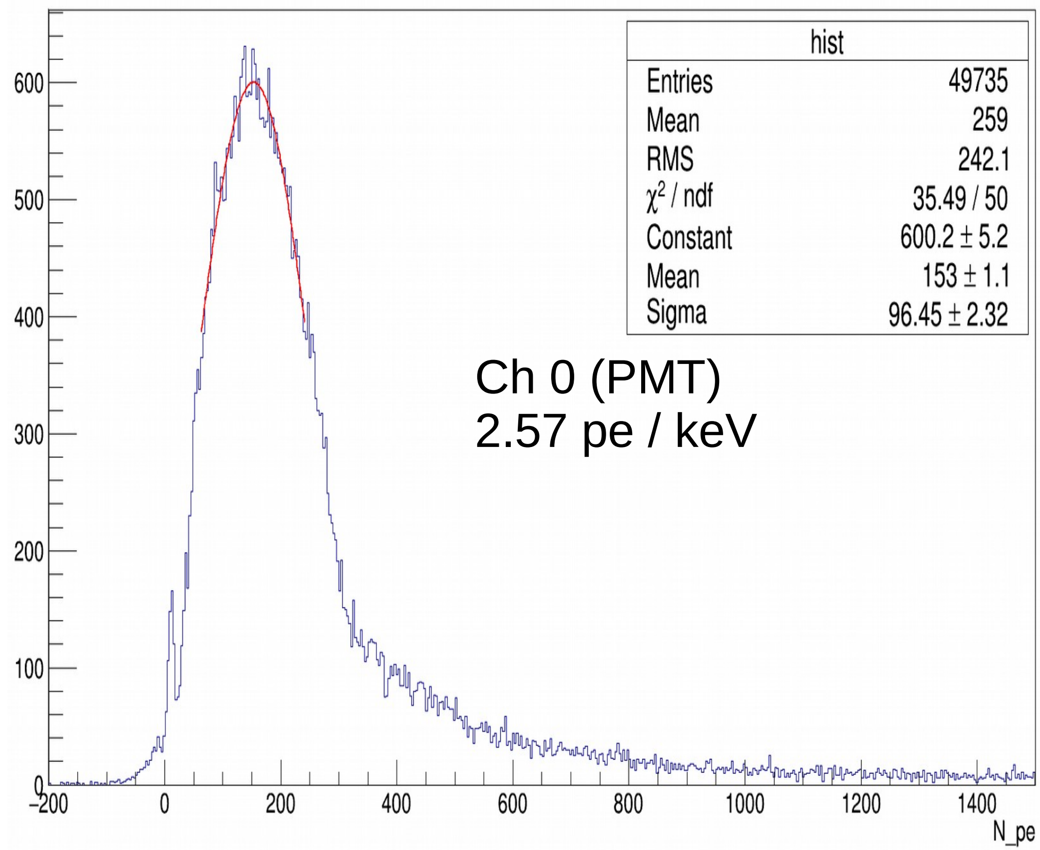


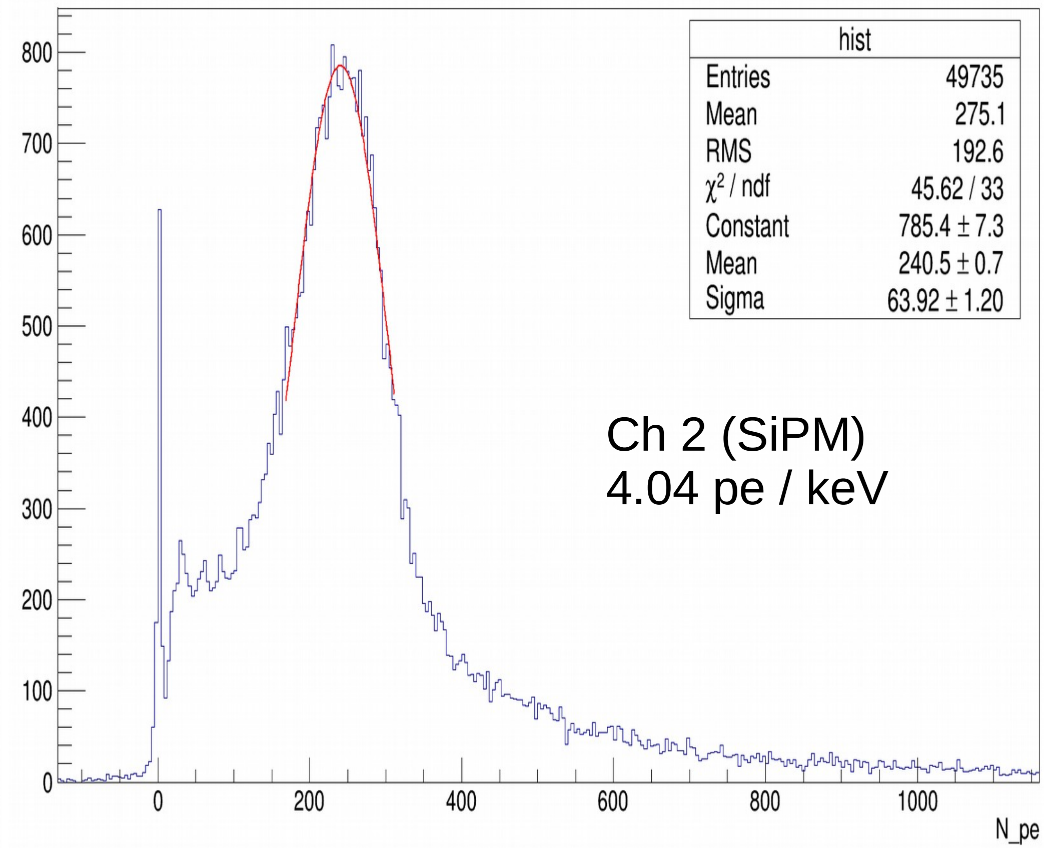
Inverse Fourier transform





Energy calibration

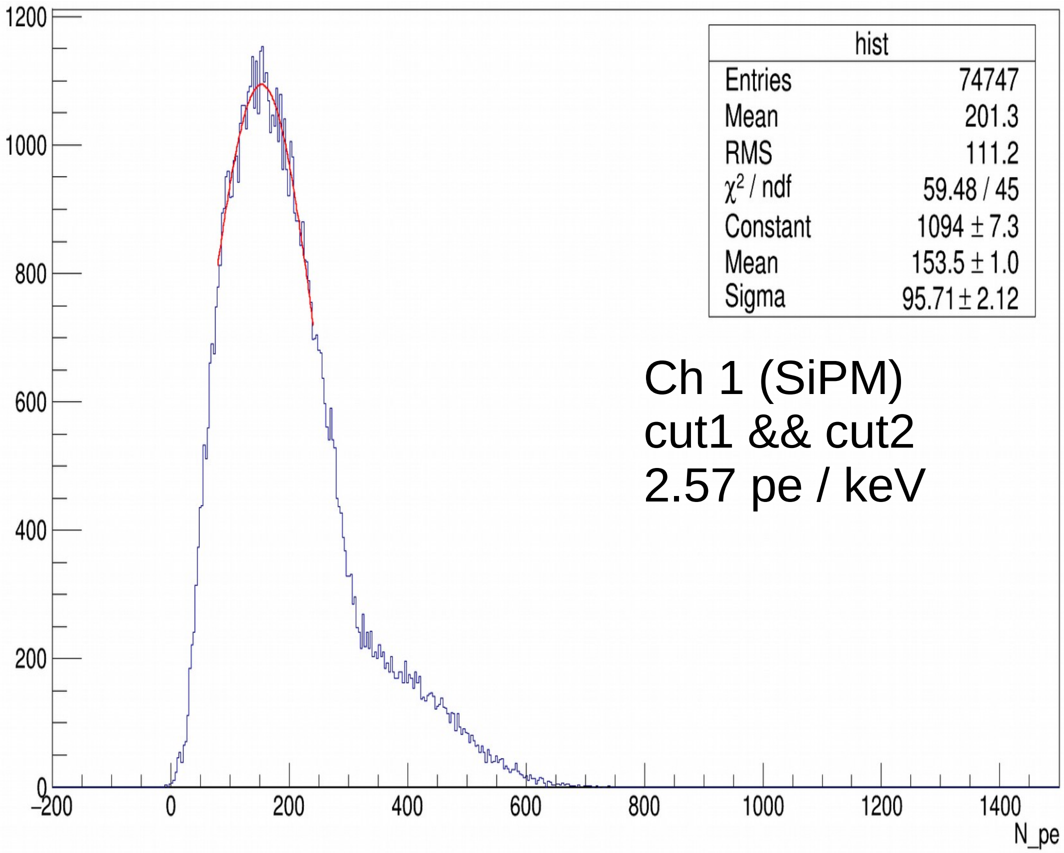


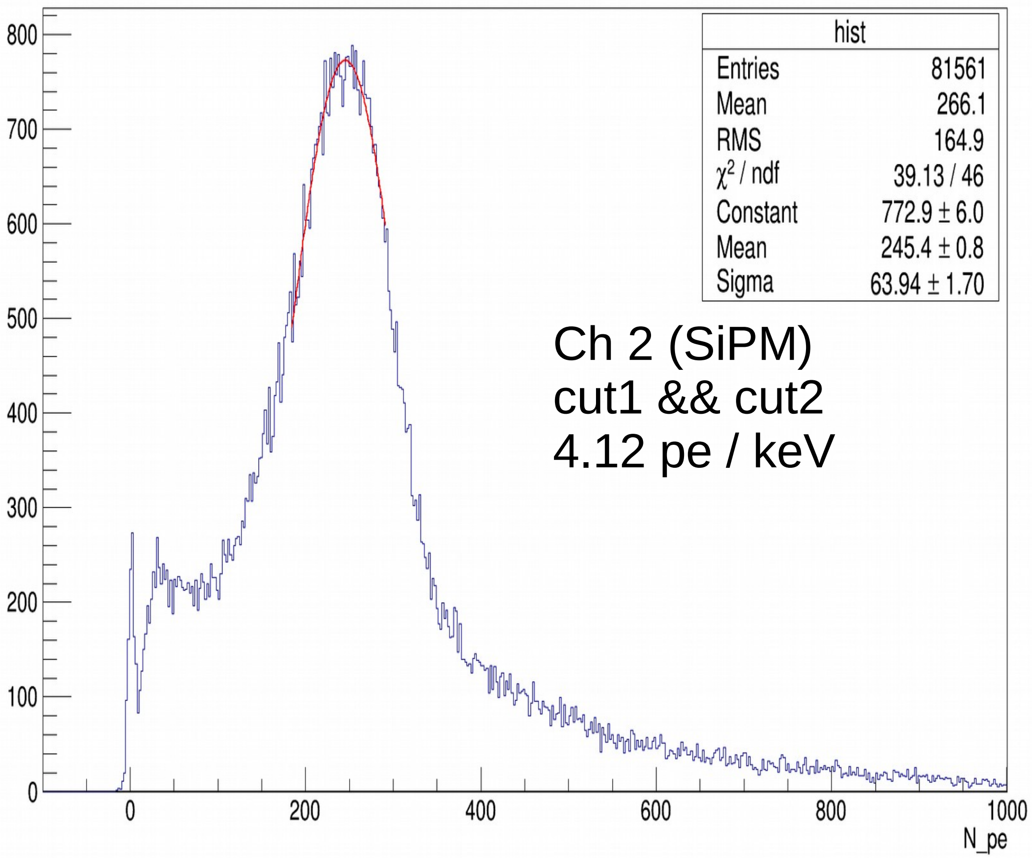


Ch 1 (SiPM)
Do not know spe integral

Integration window:
from 0 to 7900 ns for
all channels

Energy calibration





Integration window:
from 0 to 7900 ns for
all channels

Signal reconstruction

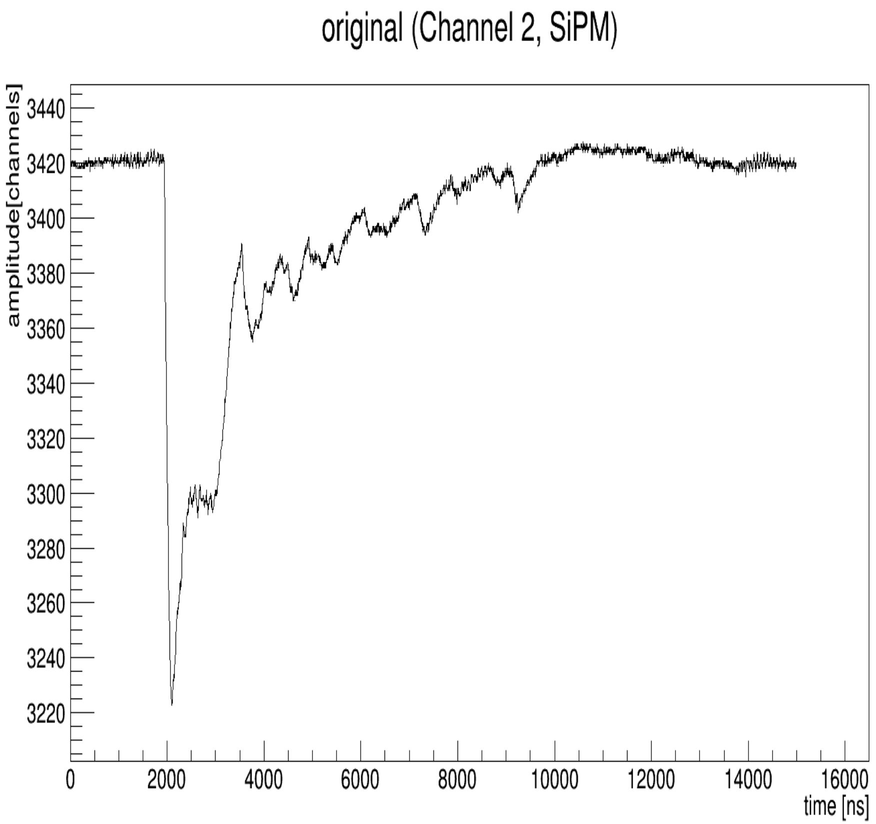
We want to find the arrival time for individual photons. This information will help to improve neutron / gamma separation. There are several methods.

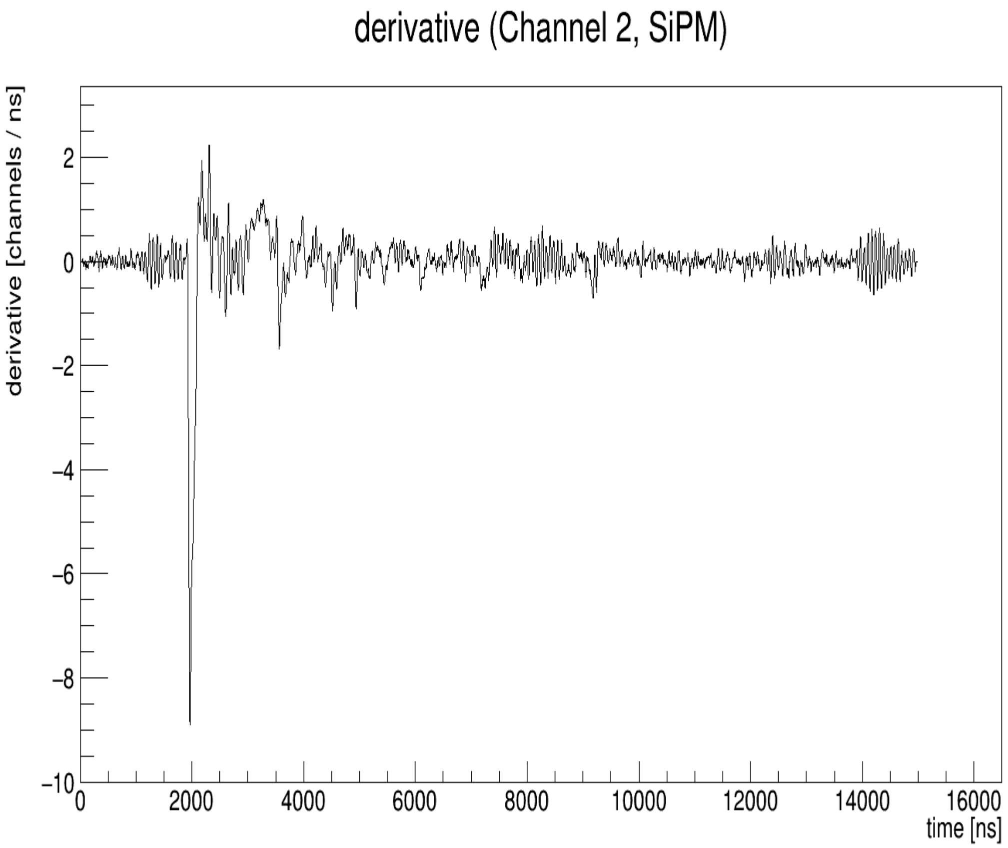
- Find derivative and identify peaks
- Approximation by sum of individual responses
- Deconvolution

Find derivative and identify peaks

"+" The simplest method

"-" Works incorrect for close signals
Overlapping of negative part of the 1st signal with positive part of the 2nd (for derivative)





Approximation by sum of individual responses

“+”

There are a lot of parameters, which we can change to get the best results for arrival time.
Can separate close peaks.

“-”

High CPU consumption (especially if there are a lot of signals).
It is difficult to find initial parameters for approximation.
A lot of manual work.
Each case is individual and require proper initialization for initial parameters.

Deconvolution

“+”
A variety of methods. Can reconstructs signal close to delta function (narrow peaks).

“-”
High CPU consumption (but independent from number of signals).
There are artifacts of deconvolution.
We should understand how it works in presence of noise.
Some algorithm only for positive data.

Deconvolution algorithms

- Strictly speaking, deconvolution is to solve overdetermined linear system. This topic requires a separate presentation

Some realized algorithms

- Root CERN TUnfold
- Gold deconvolution (Root CERN TSpectrum::Deconvolution)
- Richardson–Lucy deconvolution (Root CERN TSpectrum::DeconvolutionRL)

Root CERN TSpectrum::Deconvolution

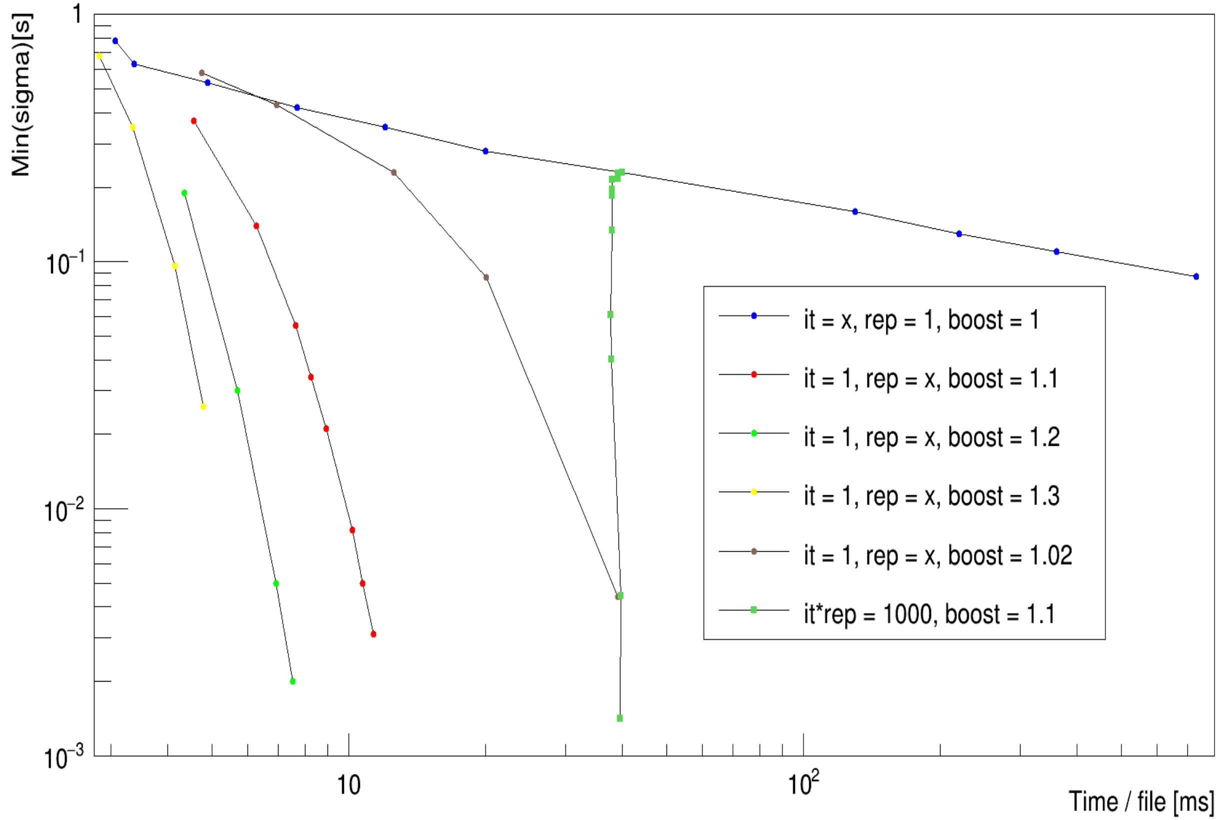
3 parameters: N_iter, N_rep, boost

Works only with positive data!

1) N_iter >1, N_rep = 1, boost = 1
Works correct, but slowly

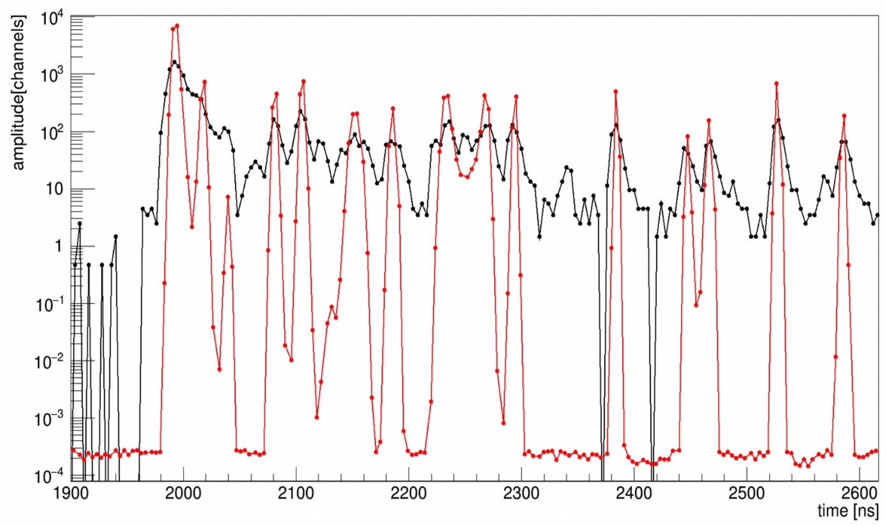
2) N_iter >1, N_rep > 1, boost >1
Distorts small signals, but can be very fast

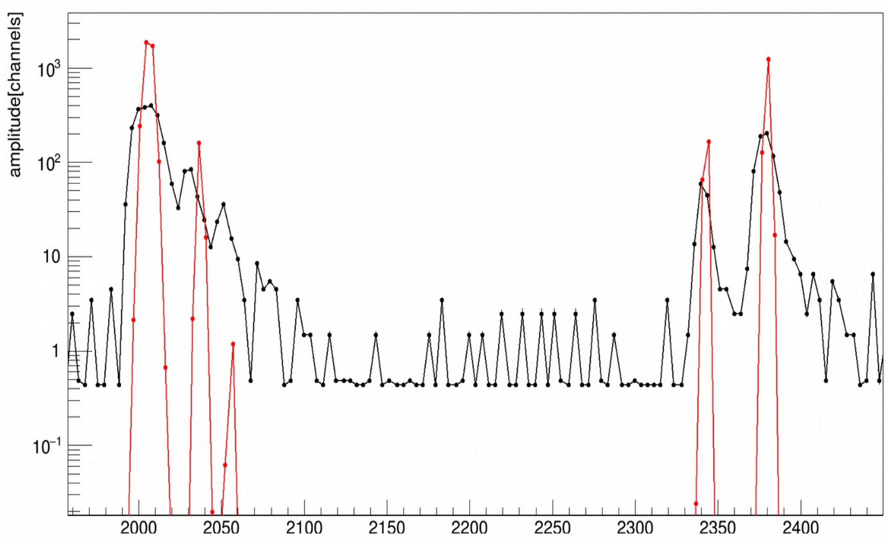
Simulation (in order to measure width correct)

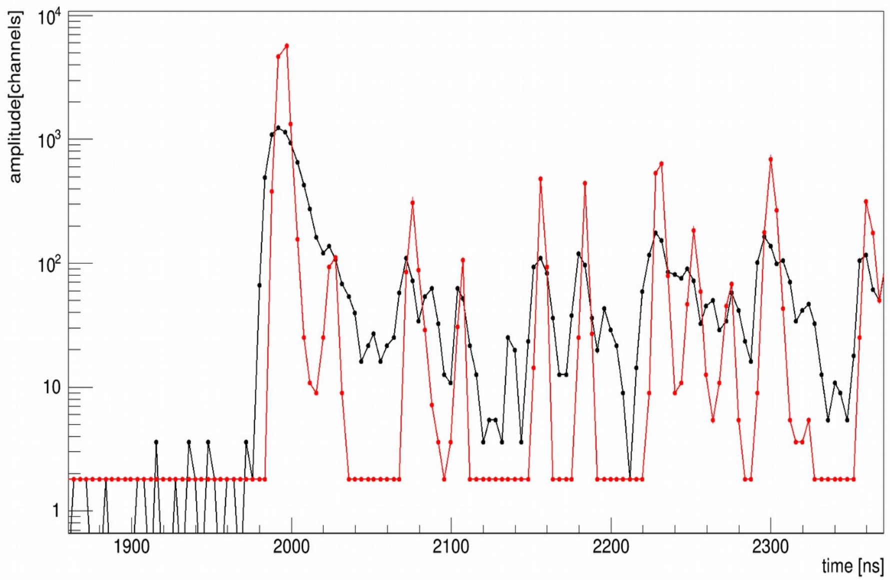


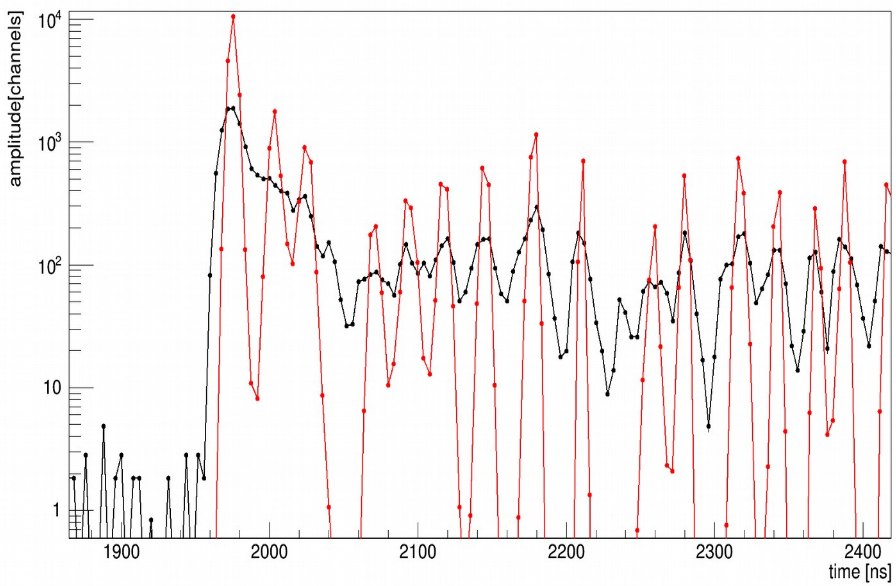
Tspectrum::Deconvolution ch0 results

N_iter = 100, N_rep = 1, boost = 1



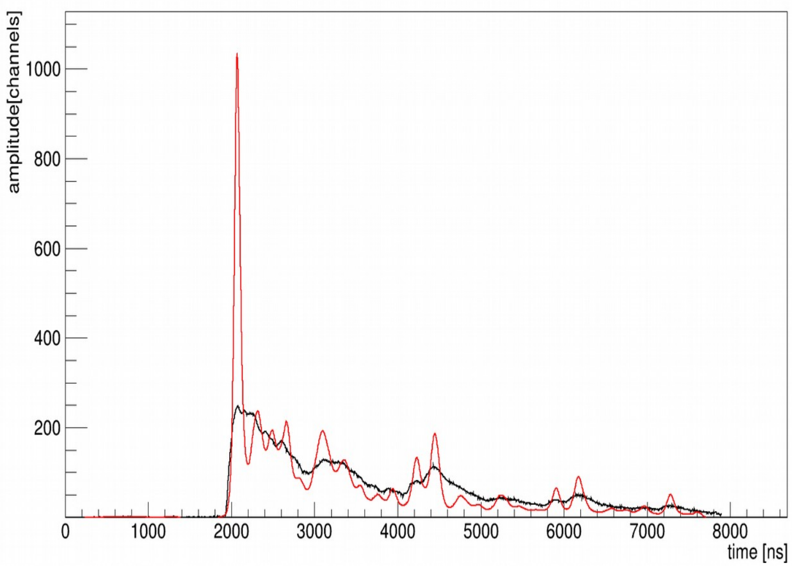


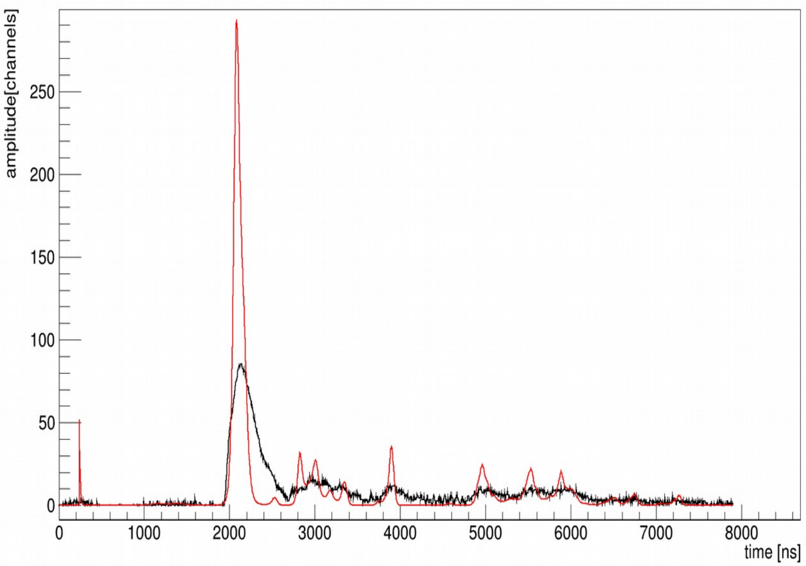


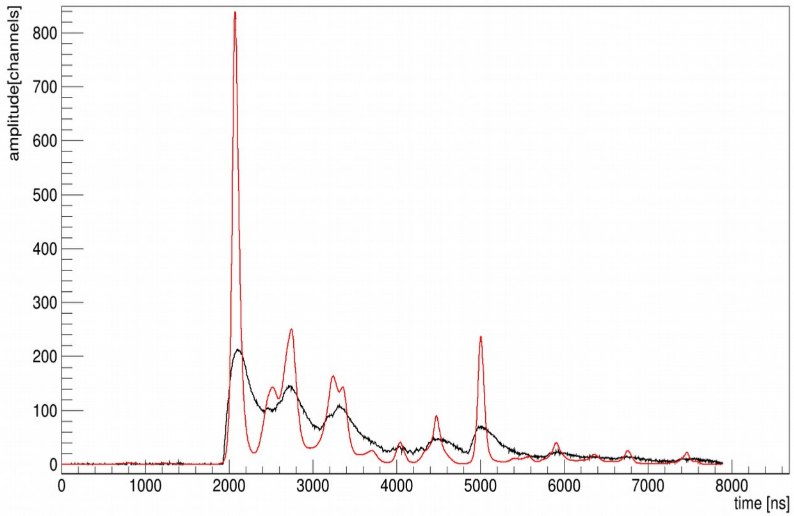


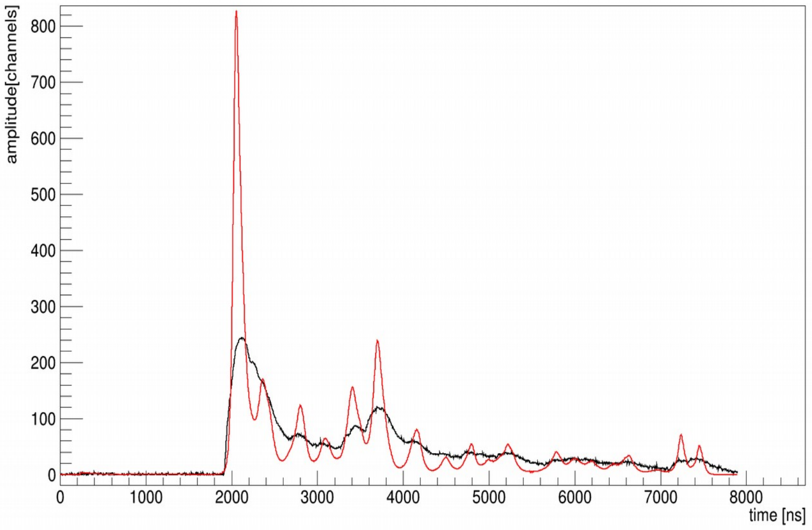
Tspectrum::Deconvolution ch2 results

N_iter = 100, N_rep = 1, boost = 1





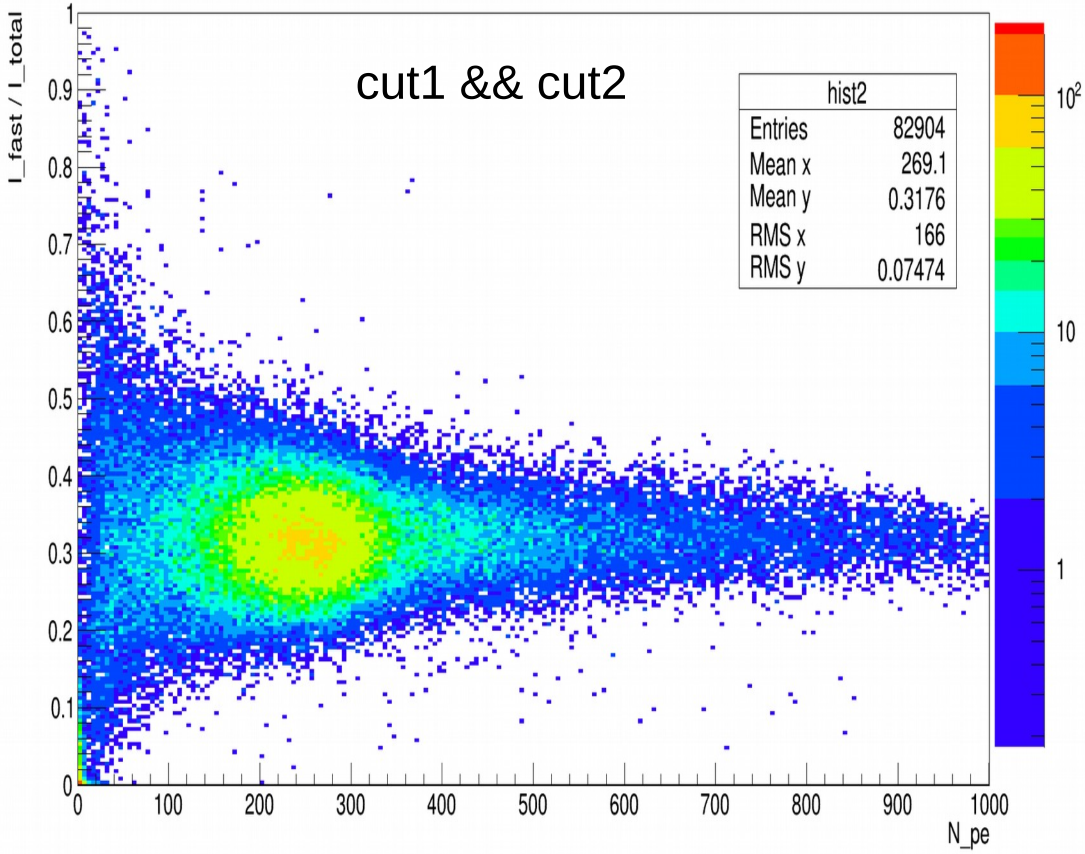


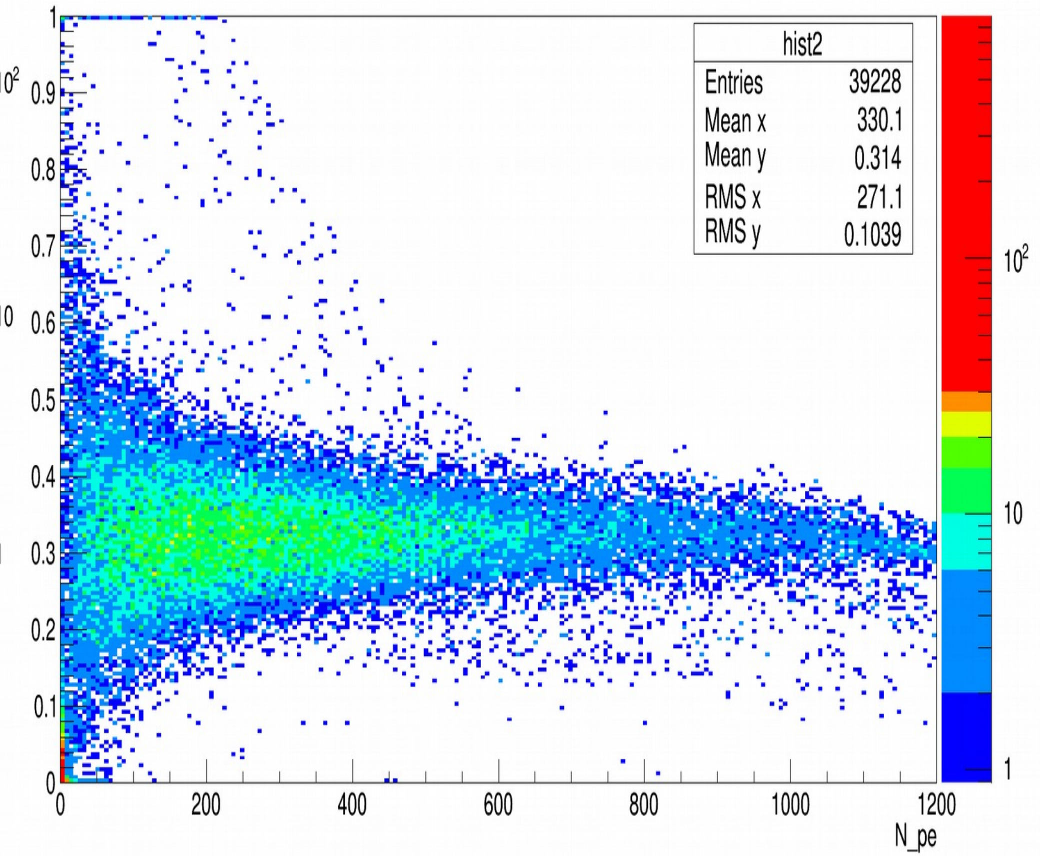


Ratio vs N_pe (ch 2, SiPM)

Run 6064 Am

Run 6053 bg



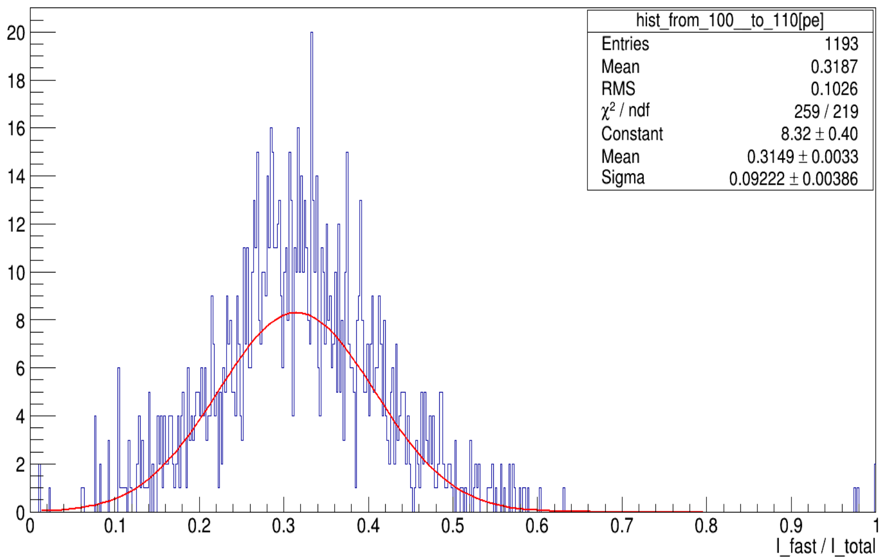


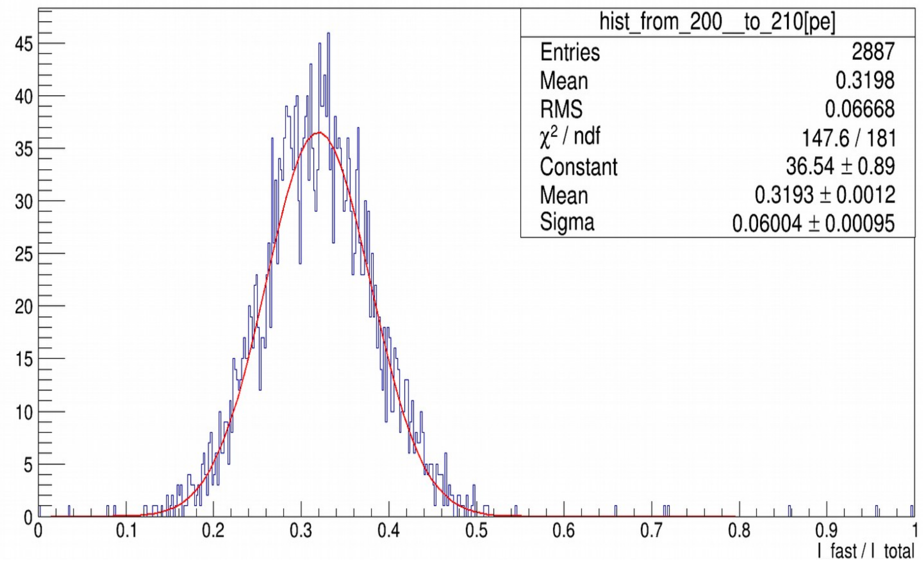
$$ratio = \frac{\int fast}{\int total} = \frac{\int_{1900[ns]}^{2200[ns]} S_{unfold}(t)dt}{\int_{1900[ns]}^{7900[ns]} S_{unfold}(t)dt}$$

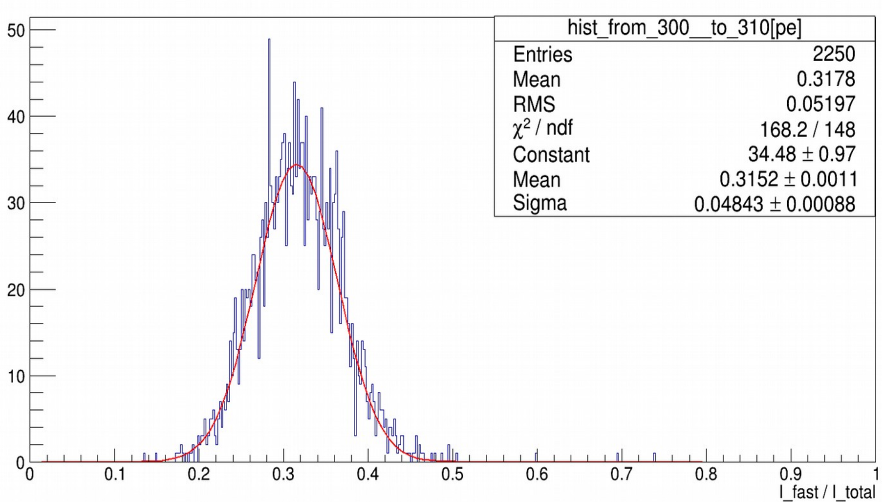
Ratio vs N_pe (ch 2, SiPM): slices

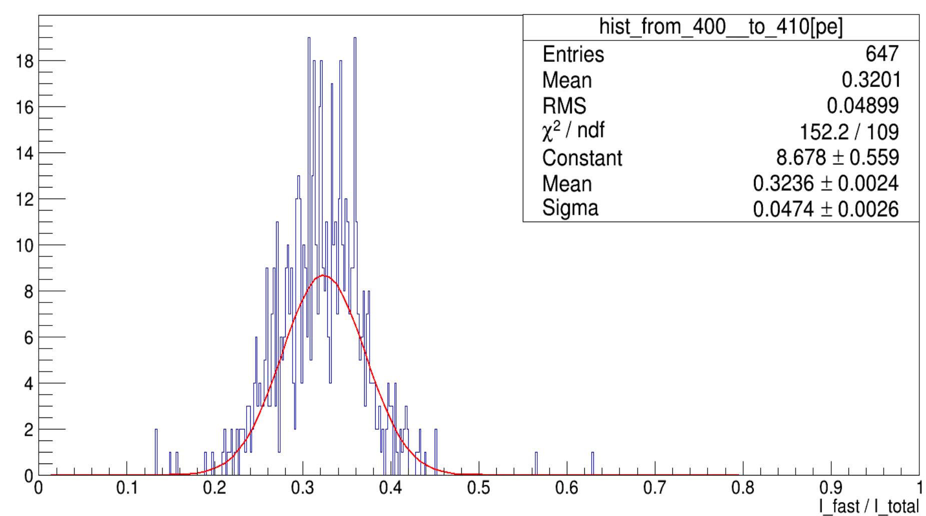
Let's project 2D histogram to N_pe axis with 10 pe step and make gauss fit (binned fit)

Run 6064 Am



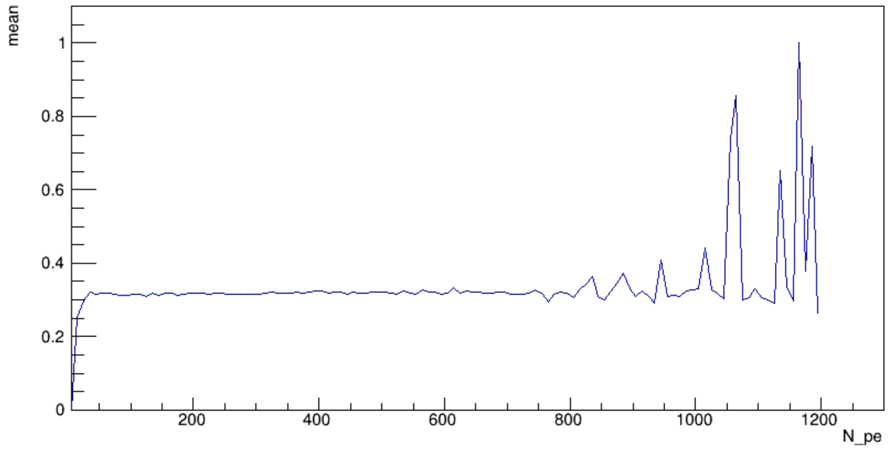


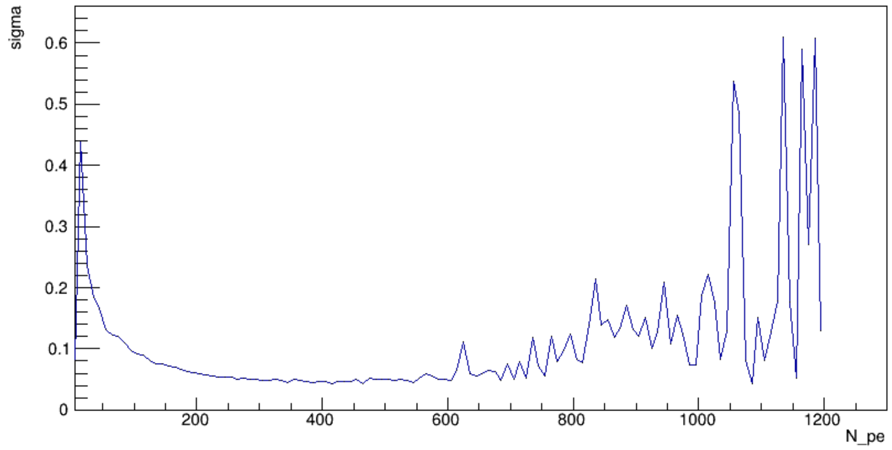


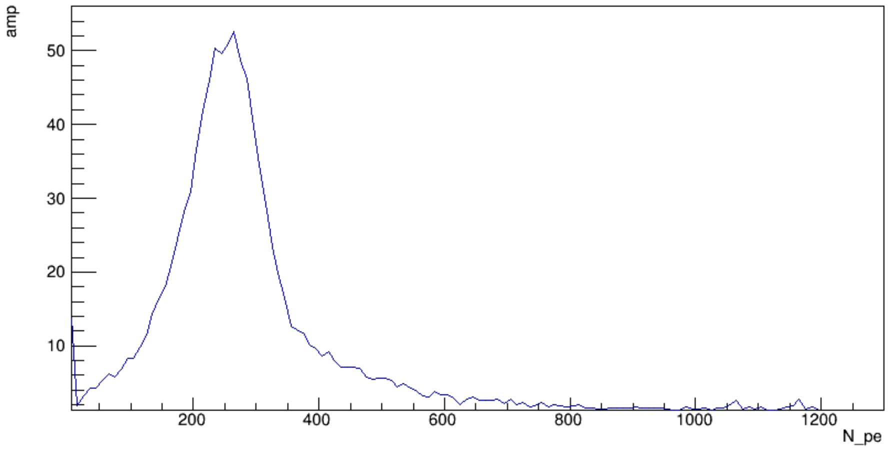


Ratio vs N_pe (ch 2, SiPM): slices

Run 6064 Am

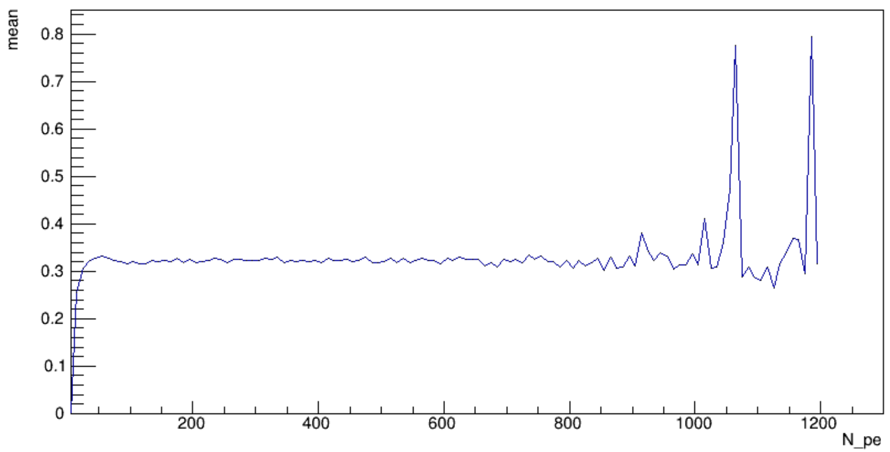


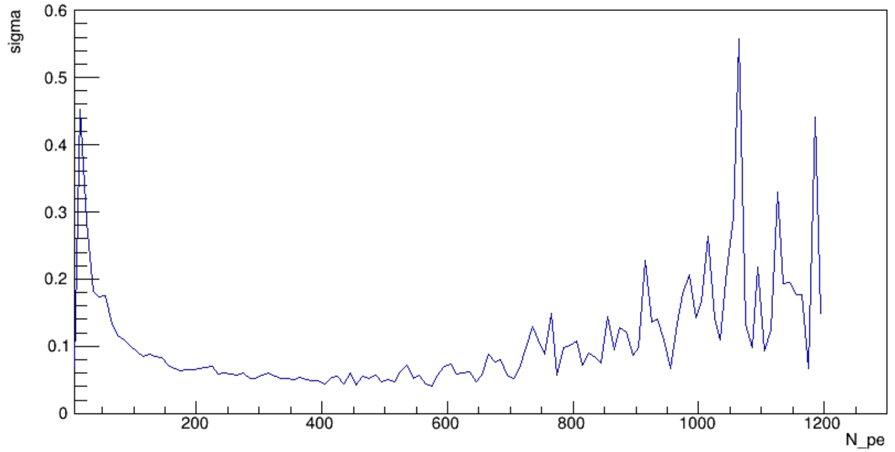


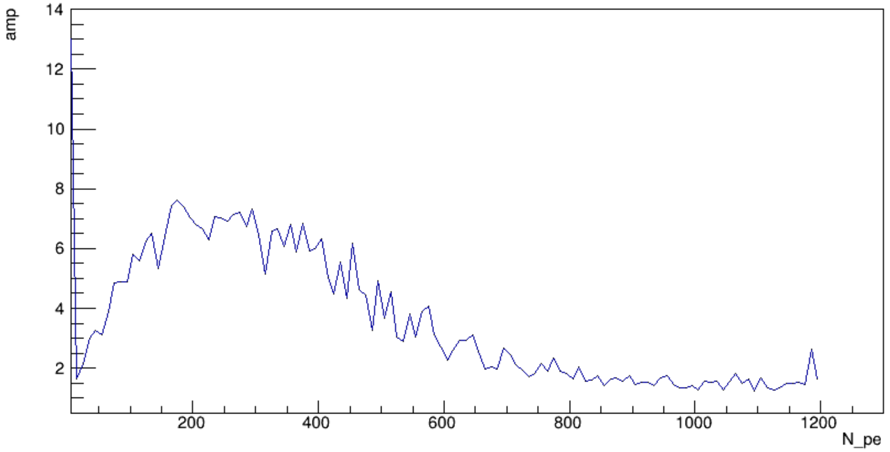


Ratio vs N_pe (ch 2, SiPM): slices

Run 6053 bg



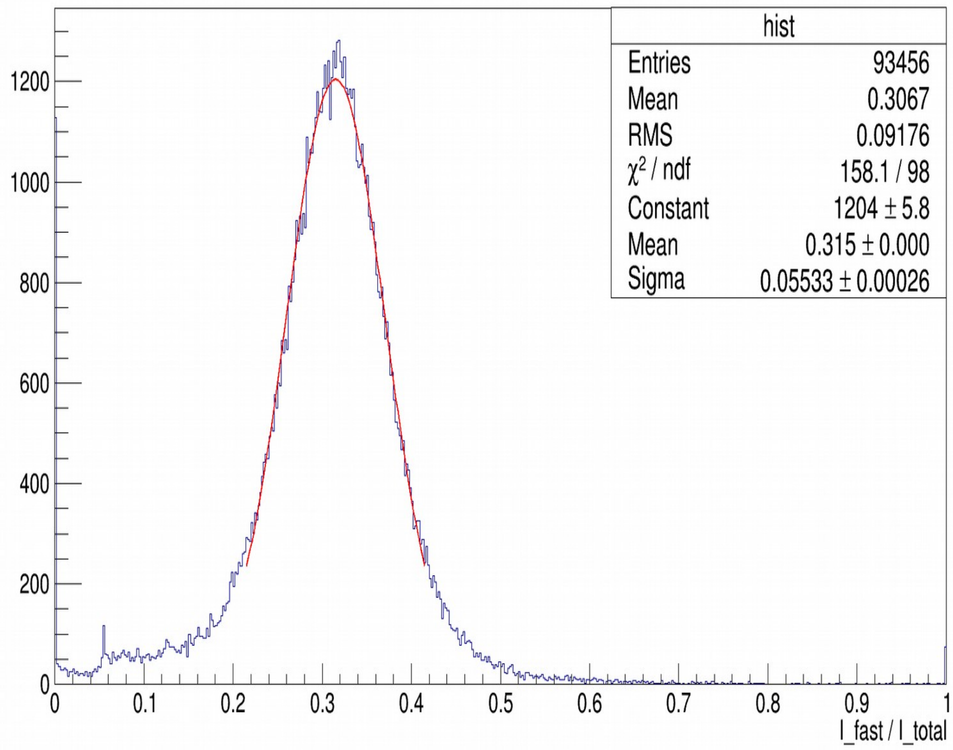




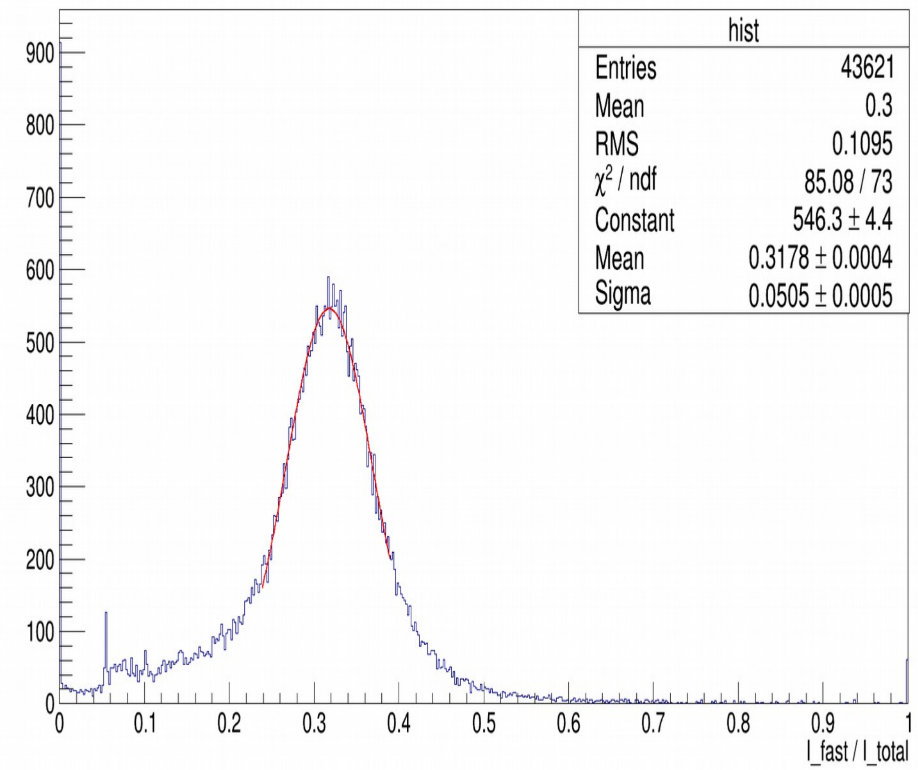
Ratio vs N_pe (ch 2, SiPM)

Let's project 2D histogram to I_fast / I_total axis and make gauss fit (binned fit)

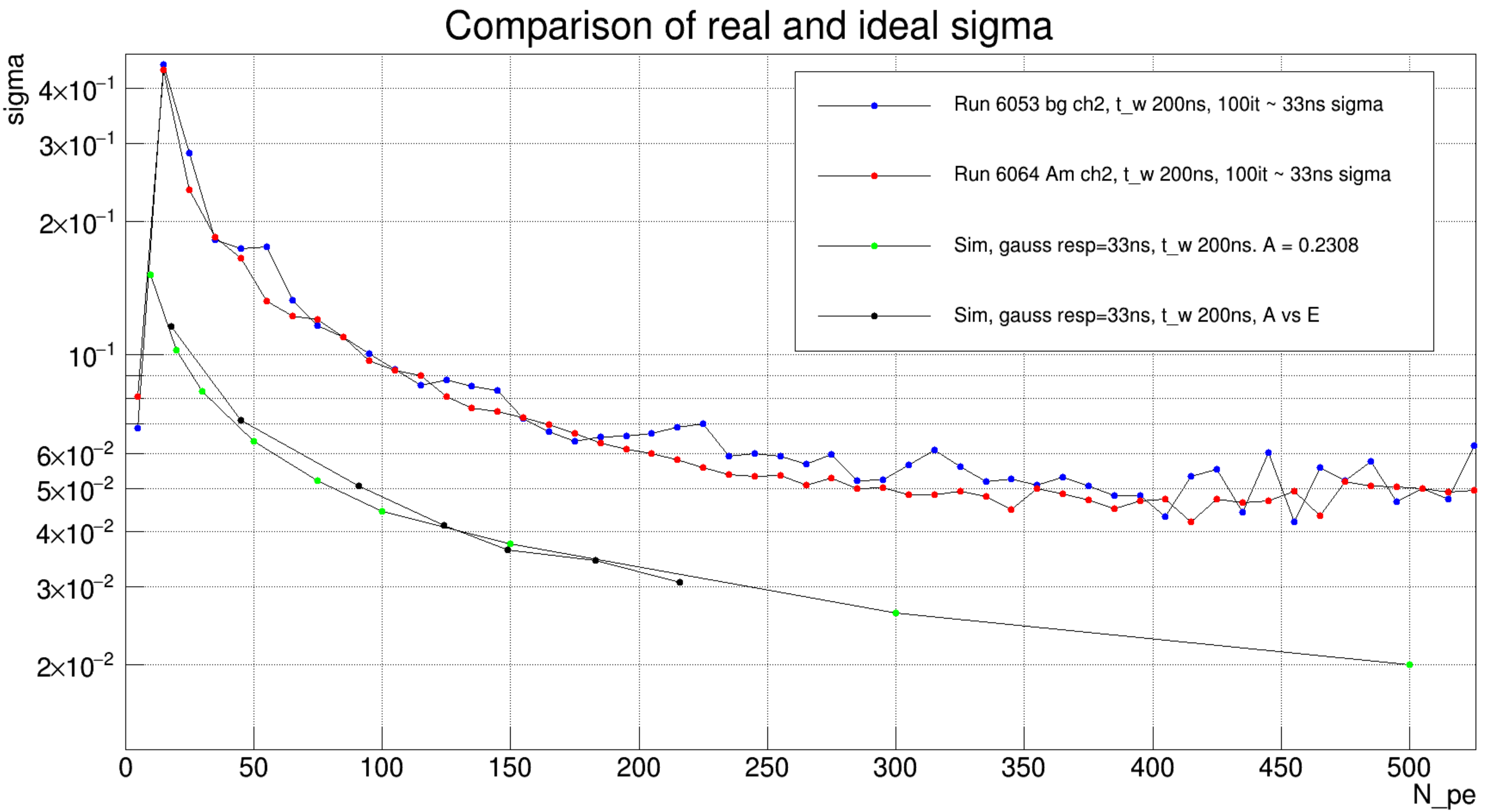
Run 6064 Am



Run 6053 bg



Sigmas comparison



What are reasons of broadening?

- Another PDF in simulation.
  May be because of wavelength shifter.
- SiPM(or PMT) dark noise
- Low frequency noise.
  Integration window is 200ns and noise concentrated from 0 to 5 MHz (i.e. period more than 200 ns). So, it is very probable to have non zero integral of noise.
- We do not know full information about response.
  Length of signal in laser run is 5 us.
  It is not enough, because baseline does not return to origin value.
  Also, we know only estimation of true response, because of experimental errors.
- Consequence of deconvolution algorithm applied to noise data.
  In simulation without noise Gold deconvolution algorithm do not change position and total integral, may be the reason of broadening (I should check). Also we should understand what will be in presence of noise.

Further steps

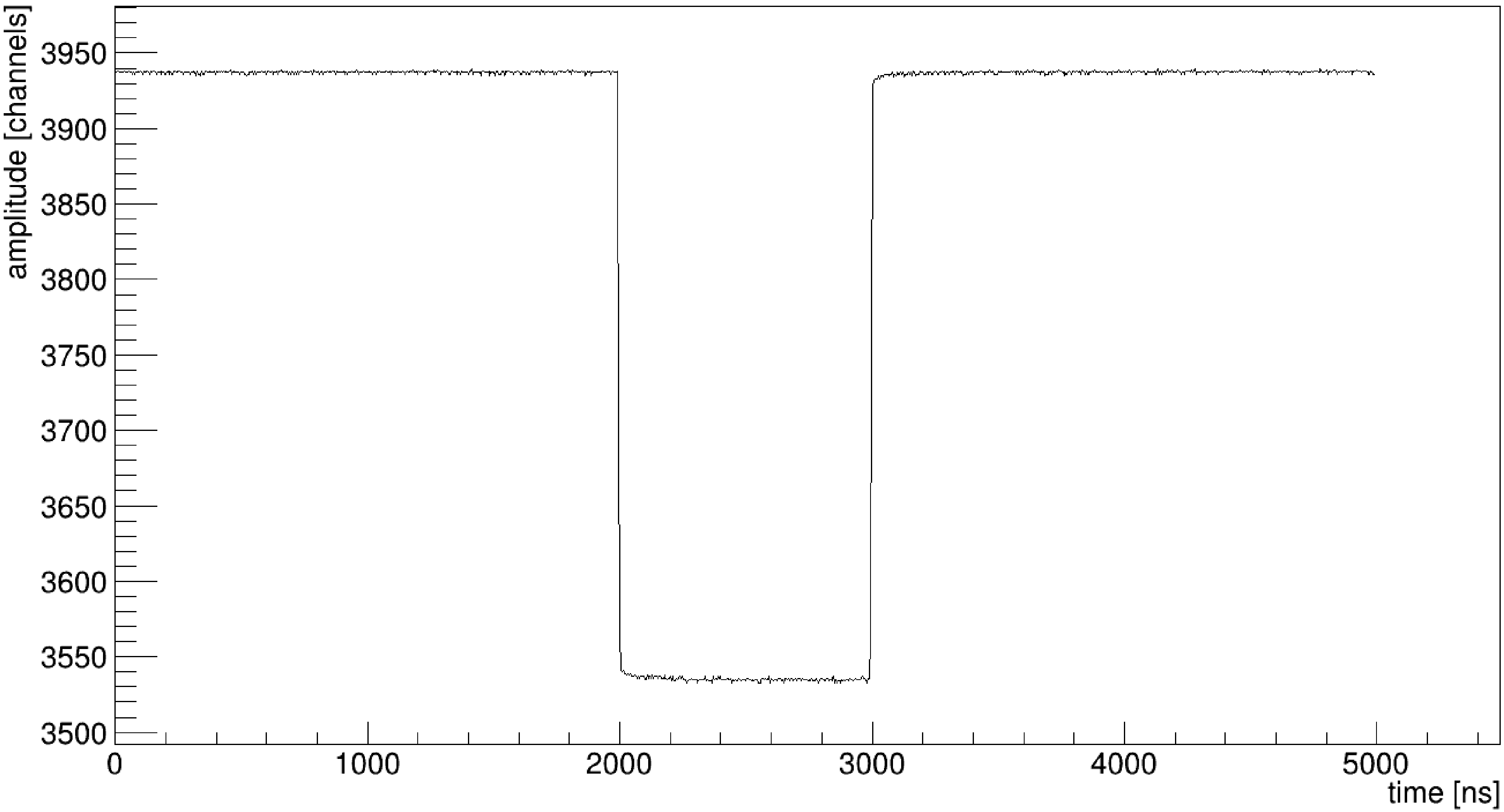
- Write laser run with longer period (~20 us)
- Understand the reason of non-smooth averaged signal
- Simulate signals for real response, add some noise and make deconvolution
- Find fast algorithm which will work with positive and negative data correctly
- Find optimum of separation algorithm for real data (need neutron run)

You can find source code here
https://github.com/Vlad-ole/s1_fast_slow_separation_darkside

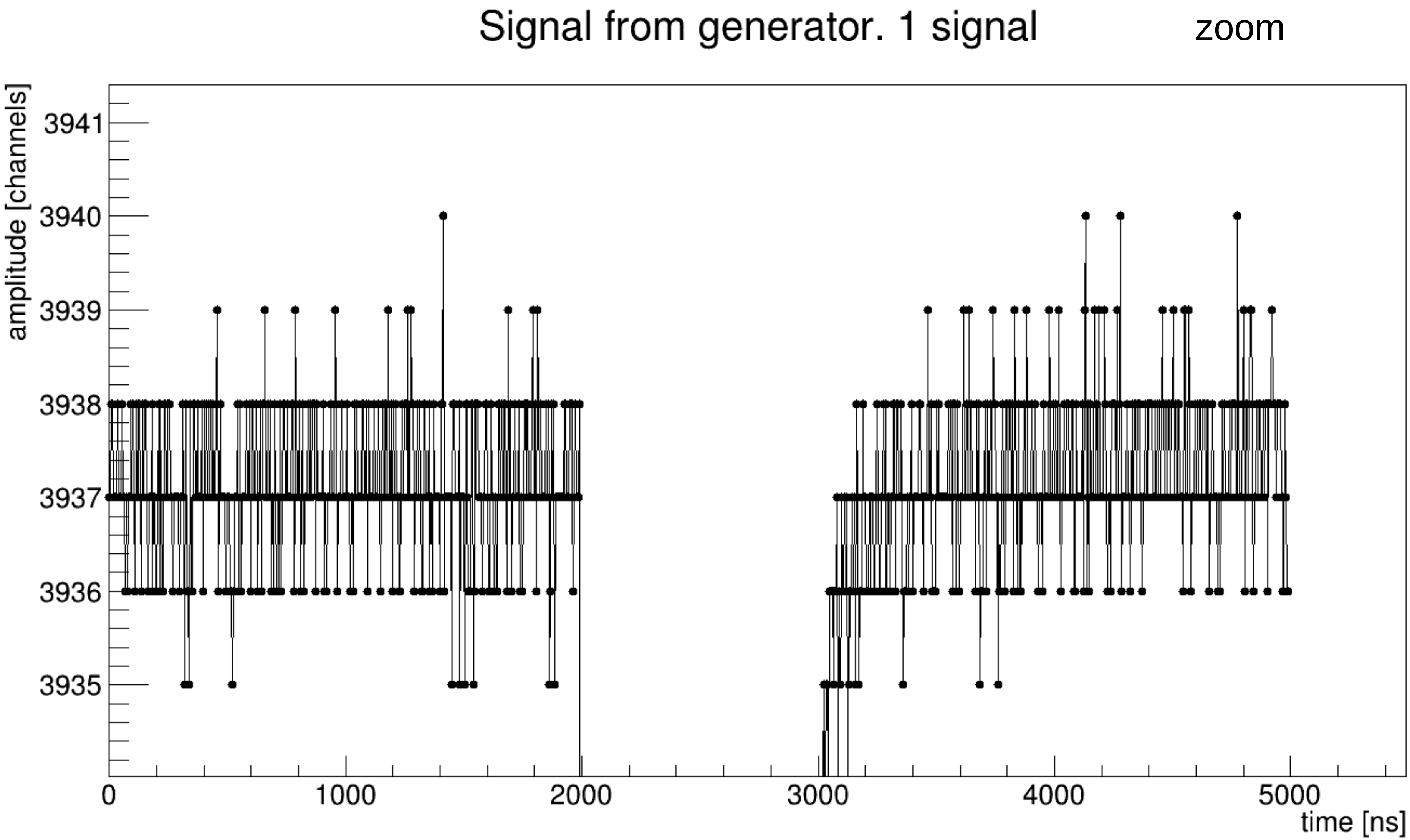
Thank you for your attention!

Generator run 6157

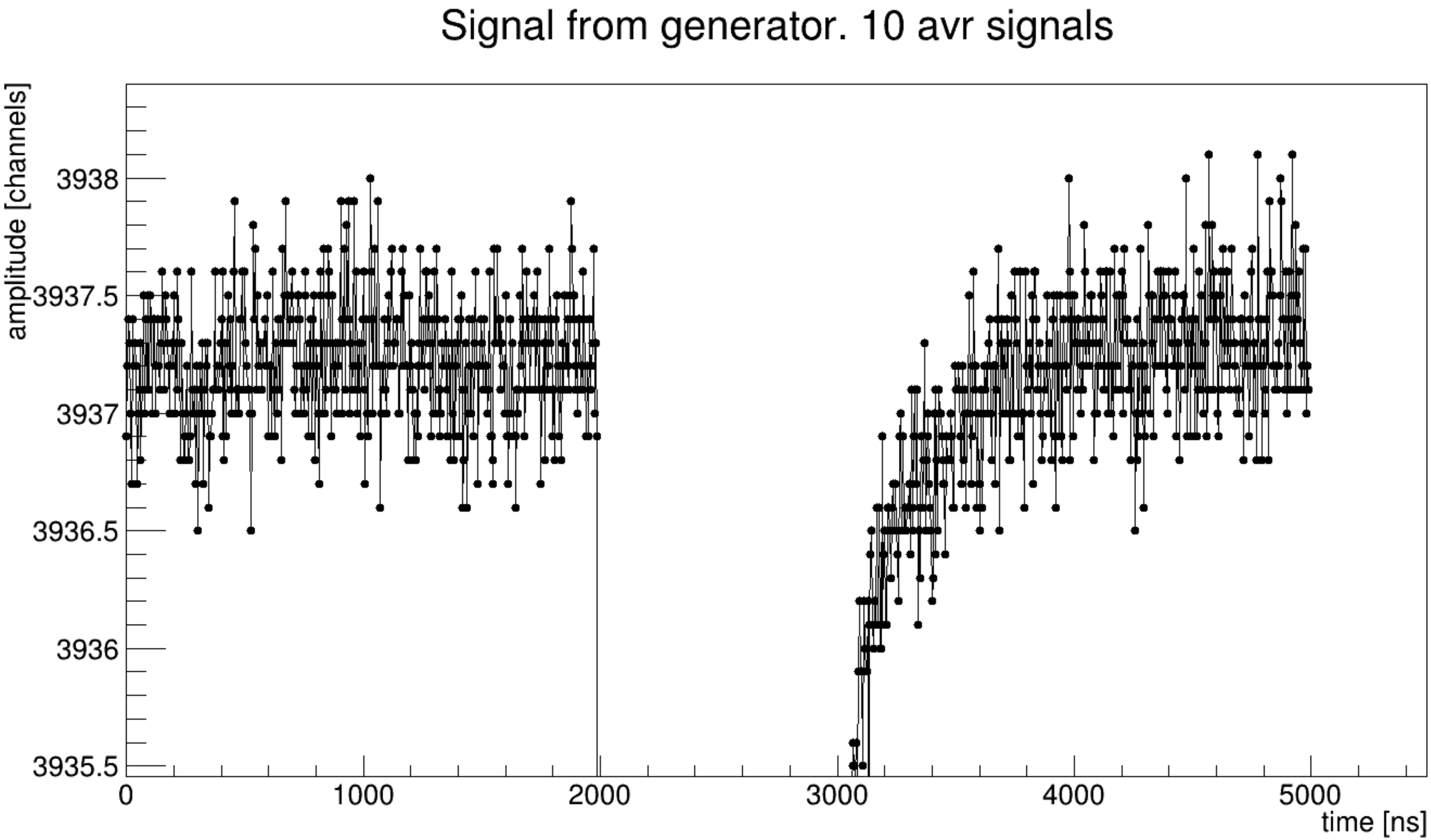
Signal from generator. 1 signal



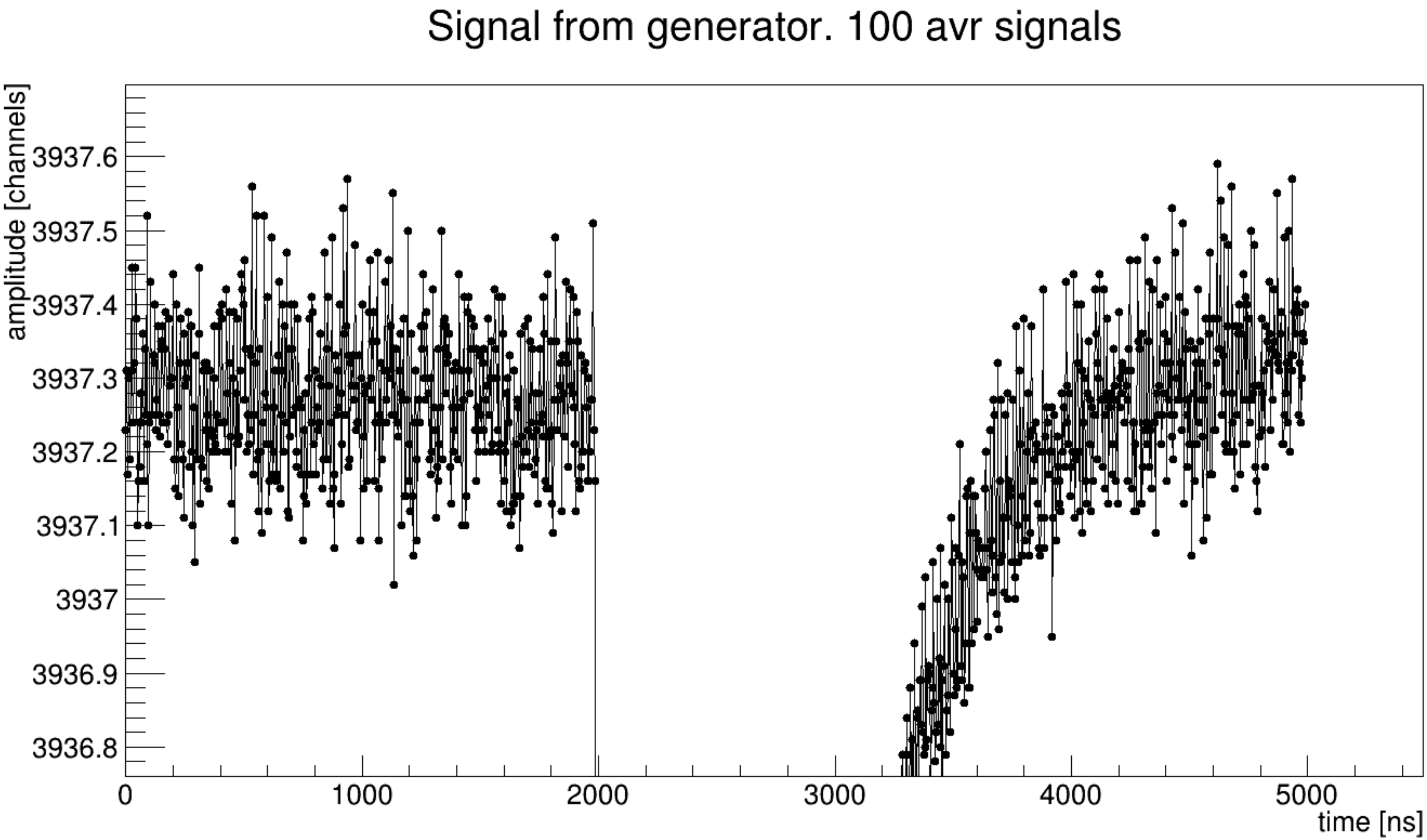
Generator run 6157



Generator run 6157

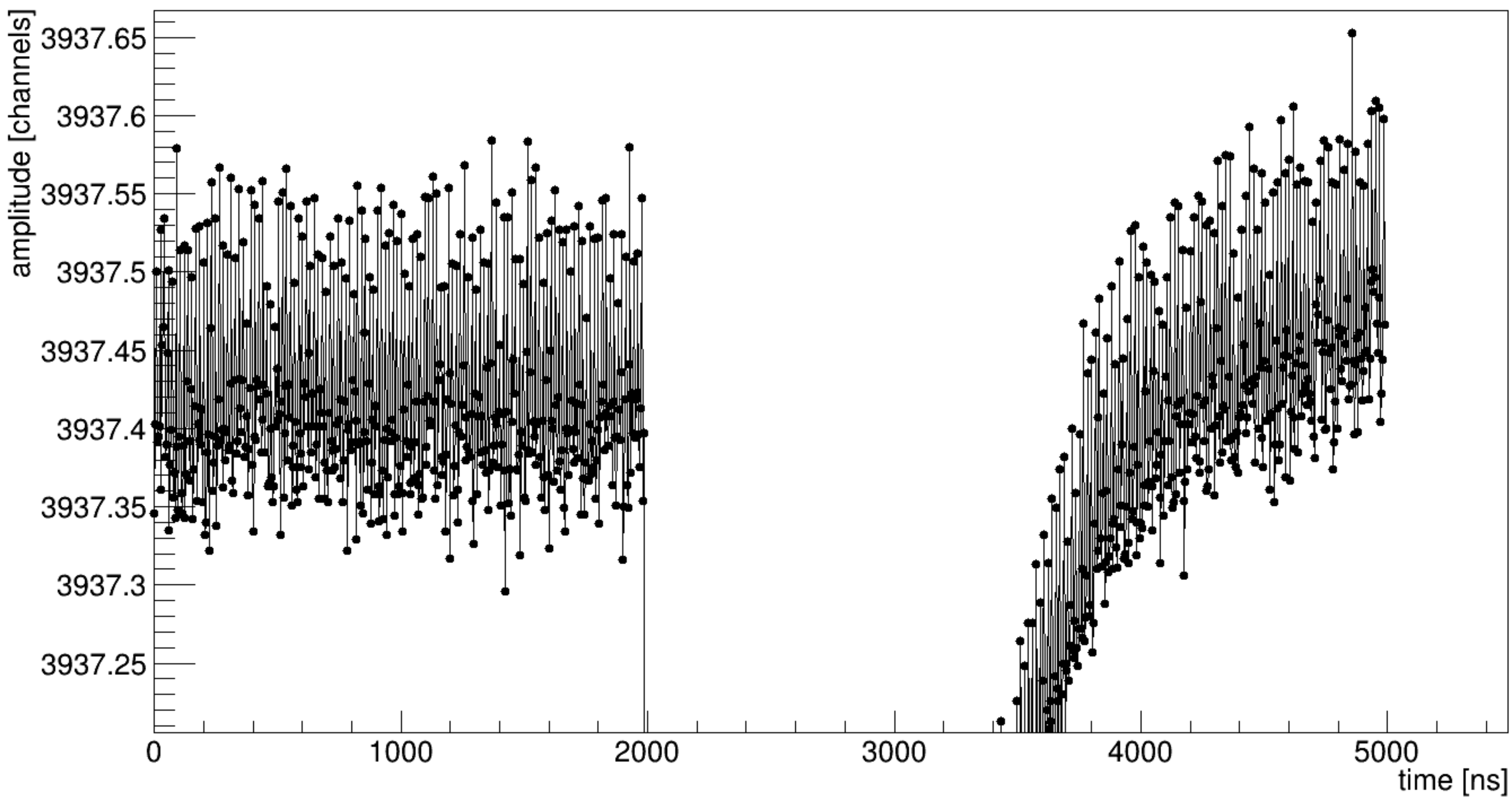


Generator run 6157

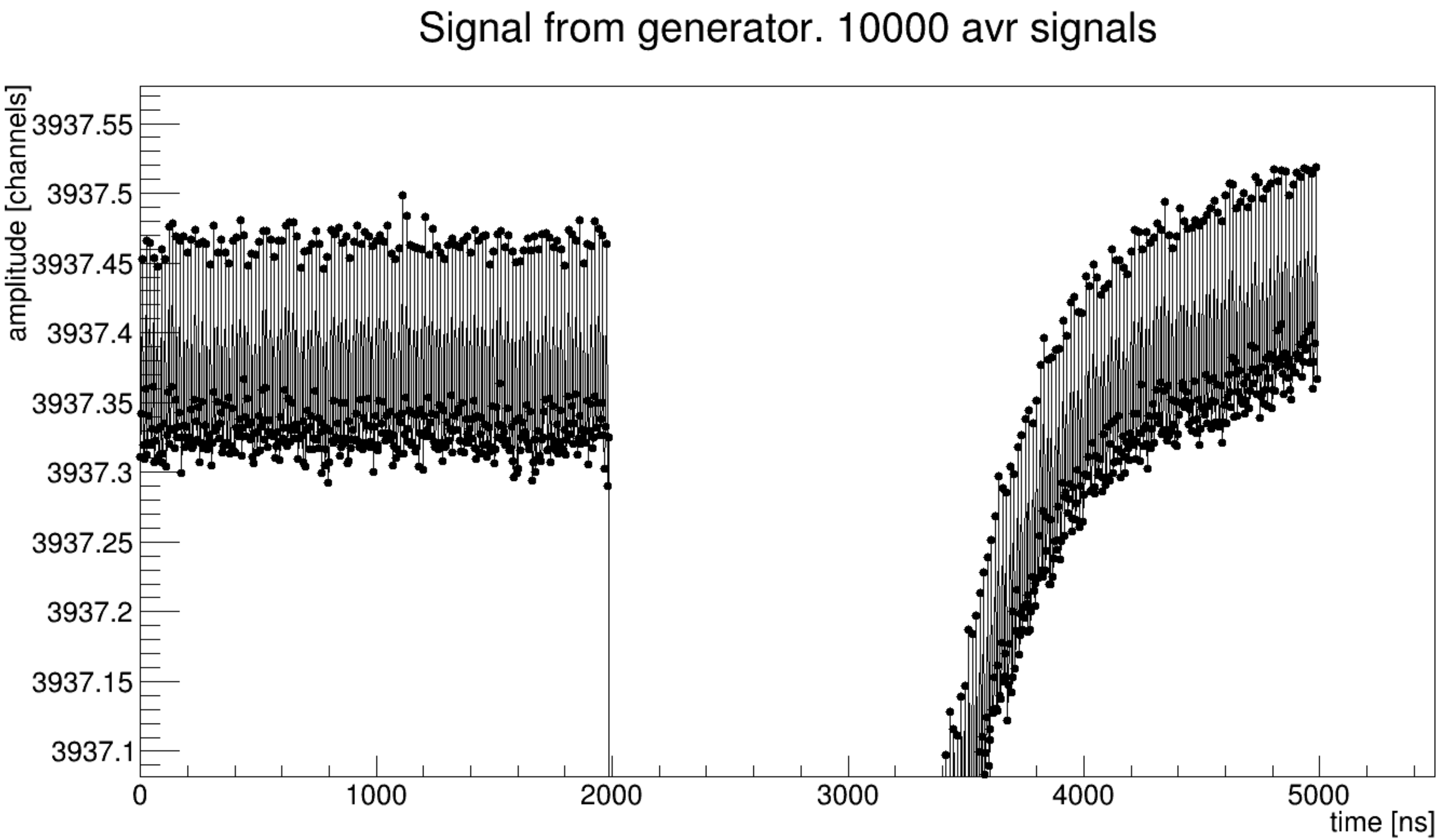


Generator run 6157

Signal from generator. 1000 avr signals



Generator run 6157



Generator run 6157