Update 28/03/2025

FCC Naples

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Calibration with PLP Led and comparisons with the CAEN led

I performed calibrations with both methods:

- method A: peaks id, only applicable to amplitude. In this case we first perform a linear fit and then have to charge through the fit on the wf to derive the tau.

- method B: obtain the mean and standard deviation of the histogram of the amplitude or the integral and from this we derive the p1 of the linear fit which gives us the conversion factor to the number of photons

In the following slides I have summarised the results of all the work done for the calibrations for the 2 methods.

In the backup slides you will find details of how these calibrations were carried out

Summary SiPM 6x6 Calibration with PLP Led with method A (only amplitude)

SiPM	Gain	**Gain amplitude conversion**	Power	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]	$\tau(ns)$ $+error(ns)$	conversion factor $\tau(1-e^{-\frac{1500}{\tau}})$	Integral/amplitude	Conversion facto $p_1\tau(1-e^{-\frac{1500}{\tau}})$
6x6	28	25,12	15	3,7 ±0,2	3,36±0,02	154,19±0,48	154,18	147,73	518,045
6x6	28		6	0,45±0,1	3,33±0,02				513,42
6x6	18	7,94	15	-	-	156,42±0,49	156,41	146,90	195,51
6x6	18		6	0,20±0,06	1,25±0,01				

Summary SiPM 6x6 Calibration with CAEN Led with method A (only amplitude)

SiPM	Gain	**Gain amplitude conversion**	Power	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]	$\tau(ns)$ $+error(ns)$	conversion factor $\tau(1-e^{-\frac{600}{\tau}})$	Integral/amplitude	Conversion facto $p_1\tau(1-e^{-\frac{600}{\tau}})$
6x6	28	25,12	7	14,1±0,2	3,37±0,01	156,5±0,4	153,11		515,98
6x6	18	7,94	7	1,56±0,07	1,142±0,005	157,04+0,04	153,6		175,41

Summary SiPM 6x6 Calibration with PLP Led with method B integral

SiPM	Gain	**Gain amplitude conversion**	range	$p_0 + error$	$p_1 + error$ [mVns/n_{pe}]
6x6	28	25,12	0-600	-3,35*e^5±2,6*e^4	555,5±8
6x6	18	7,94	0-600	-7,1*e^4±2503	222±2

Summary SiPM 6x6 Calibration with CAEN Led with method B integral

SiPM	Gain	**Gain amplitude conversion**	range	$p_0 + error$	$p_1 + error$ [mVns/n_{pe}]
6x6	28	25,12	0-700	-2,3*e^5±2,7*e^4	614,7±4
6x6	18	7,94	0-700	-8,2*e^4±1714	226,3±1,95

Summary SiPM 6x6 Calibration with PLP Led with method B amplitude

SiPM	Gain	**Gain amplitude conversion**	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]	$\tau(ns) + error(ns)$ Range 5-1500	Constant factor factor charge $\tau(1-e^{-\frac{1500}{\tau}})$	Integral/amplitude	Conversion factor $p_1\tau(1-e^{-\frac{1500}{\tau}})$
6x6	28	25,12	-8±1	3,78±0,05	154,19±0,48	154,18	147,73	582,80±7,92
6x6	18	7,94	-1,0±0,1	1,39±0,01	156,42±0,49	156,41	146,90	217,41±1,71

Summary SiPM 6x6 Calibration with PLP Led with method B integral

SiPM	Gain	**Gain amplitude conversion**	range	$p_0 + error$	$p_1 + error$ [mVns/n_{pe}]
6x6	28	25,12	0-600	-3,35*e^5±2,6*e^4	555,5±8
6x6	18	7,94	0-600	-7,1*e^4±2503	222±2

Compare the two calibrations, with the same method B but one for amplitude and the other one with integral, and we can see that these values are close to each other

Summary SiPM 3x3 Calibration with PLP Led with method B integral

SiPM	Gain	**Gain amplitude conversion**	range	$p_0 + error$	$p_1 + error$ [mVns/n_{pe}]
3x3	28	25,12	0-400	-2,4*e^4±756	68,35±1
3x3	18	7,94	0-400	-4186±129,3	24,6±0,4
3x3	-		0-400	-179±48	5,3±0,2

Summary SiPM 3x3 Calibration with CAEN Led with method B integral

SiPM	Gain	**Gain amplitude conversion**	range	$p_0 + error$	$p_1 + error$ [mVns/n_{pe}]
3x3	28	25,12	0-400	-2,32*e^4±332	67,5±0,3
3x3	18	7,94	0-400	-4977±36,62	23,02±0,1
3x3	-		0-400	1837±84,14	6,8±0,2

Summary SiPM 3x3 Calibration with PLP Led with method B range fit 5-600 amplitude

SiPM	Gain	**Gain amplitude conversion**	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]	$\tau(ns) + error(ns)$	conversion factor charge $\tau(1 - e^{-\frac{600}{\tau}})$	Integral/amplitude	Integral=A* conversion factor
3x3	28	25,12	-1,8±0,2	1,38±0,02	56,21±0,00	56,21	50,52	73,70
3x3	18	7,94	-0,23±0,02	0,441±0,006	53,33±0,07	53,33	51,71	22,34
3x3	-	-	0,004±0,001	0,0423±0,0007	44,15±0,09	44,15	50,24	1,86

Summary SiPM 3x3 Calibration with PLP Led with method B integral

SiPM	Gain	**Gain amplitude conversion**	range	$p_0 + error$	$p_1 + error$ [mVns/n_{pe}]
3x3	28	25,12	0-400	-2,4*e^4±756	68,35±1
3x3	18	7,94	0-400	-4186±129,3	24,6±0,4
3x3	-		0-400	-179±48	5,3±0,2

Decisions

- From these results, we can see that the B model whether in amplitude or charge works, but we have to choose what to write in the paper.

- The advantage of using the B-method with integrals is that we directly have the calibration done on the charge and thus avoid having to create a model to fit our wf to derive the tau.

- The disadvantage is that with integrals, we cannot compare with method A, as the peak id is not possible in this case.

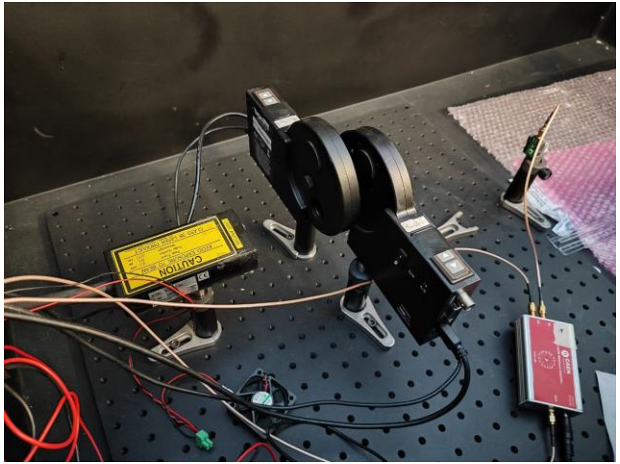
  -But we can use as a point in favour of method B the fact that in amplitudes method A and B agree.

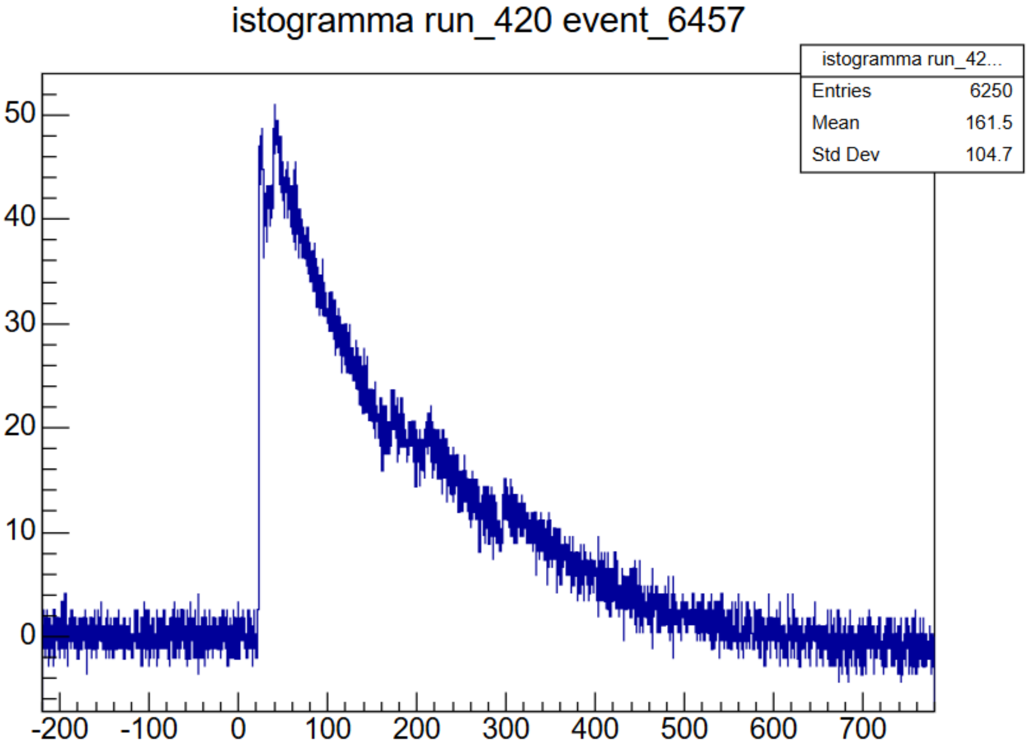
Backup Slides

SiPM 6x6 at Gain 28 Calibration with PLP Led

I tried to calibrate the 6x6 sipm with measurements taken with the PLP laser to see if they matched the calibrations made previously

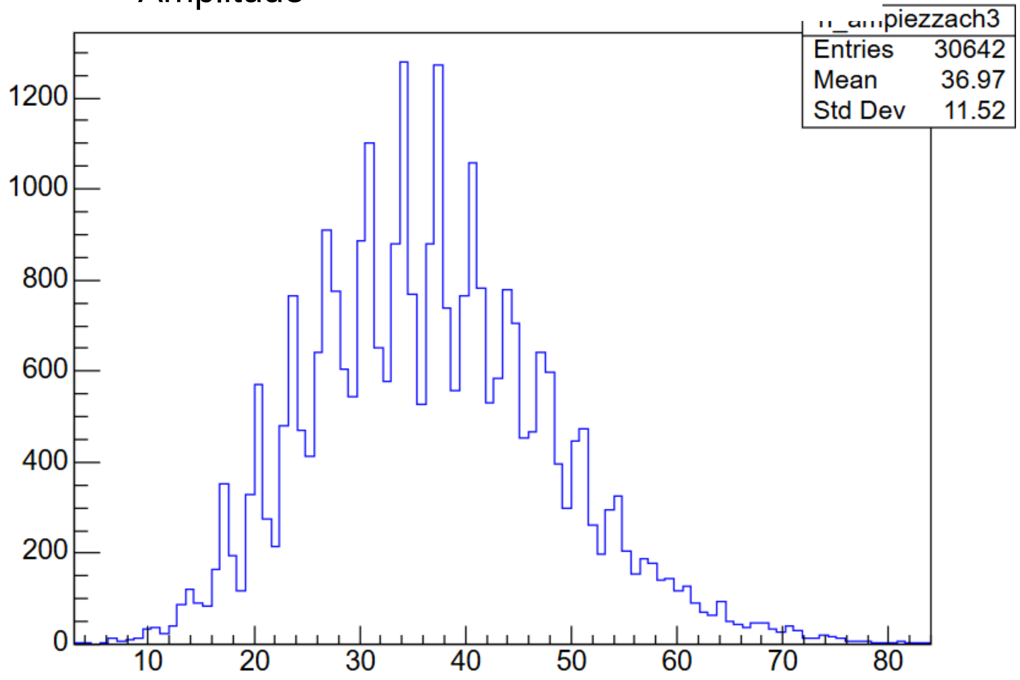
this waveform is the case where with the lens system I was able to put myself in a range of a few photons



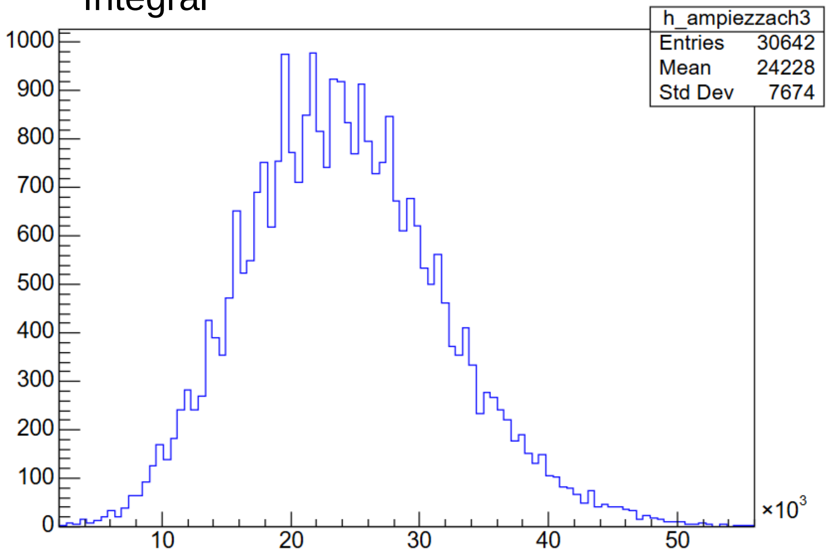


SiPM 6x6 at Gain 28 Calibration with PLP Led

Amplitude

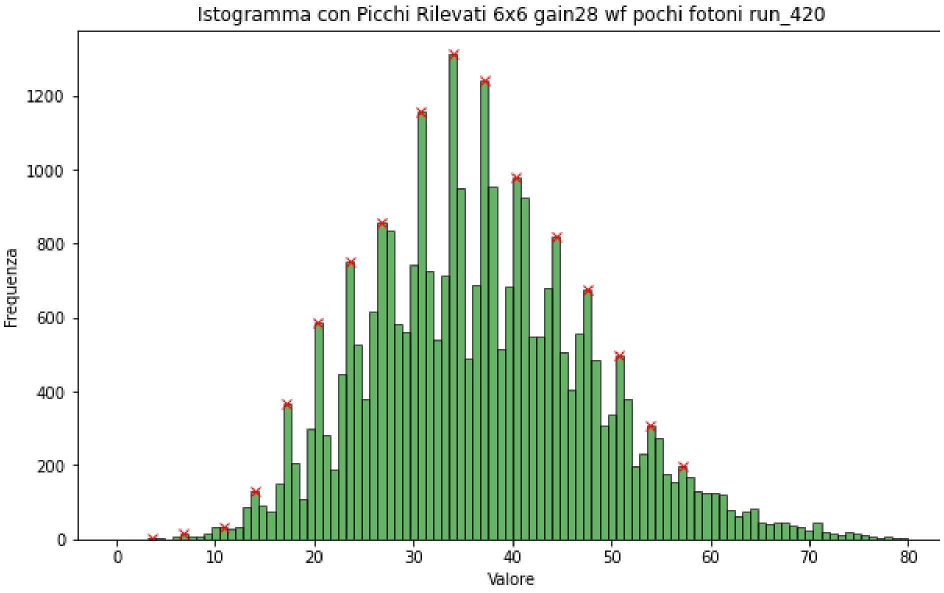


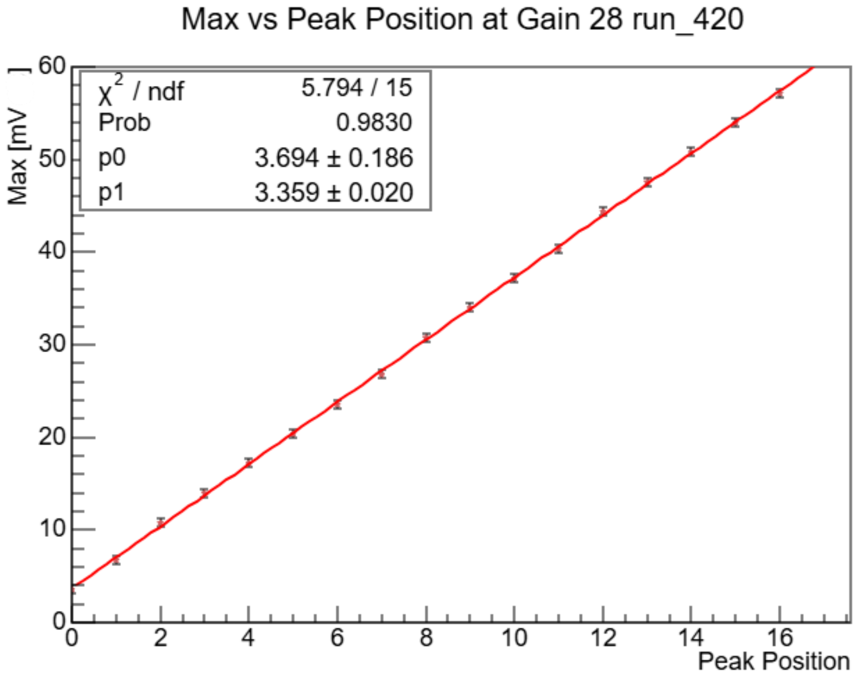
Integral



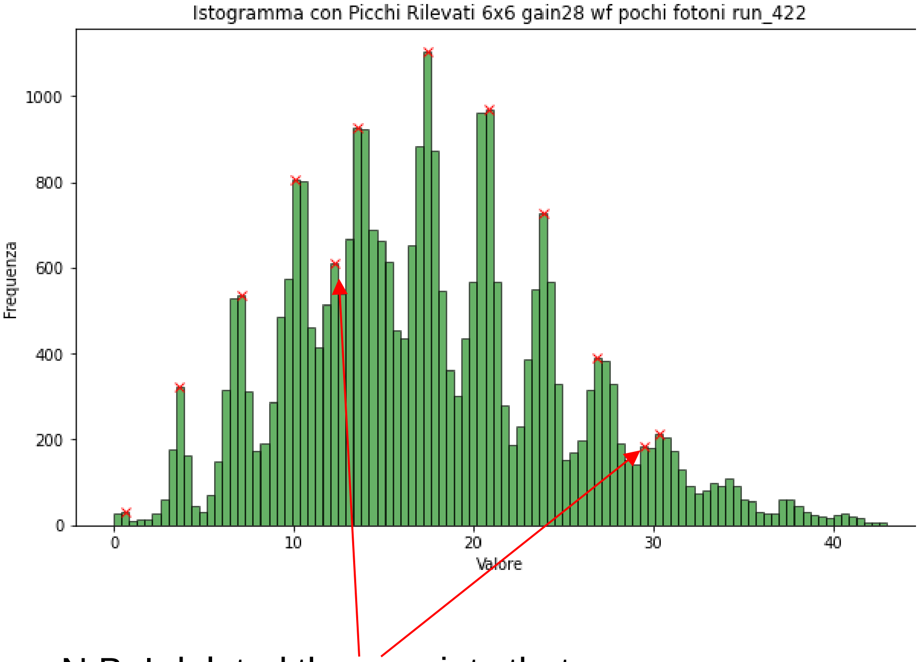
From this we understand that we can only derive a calibration from amplitudes and not from integrals, since with integrals we do not have a definition of peaks

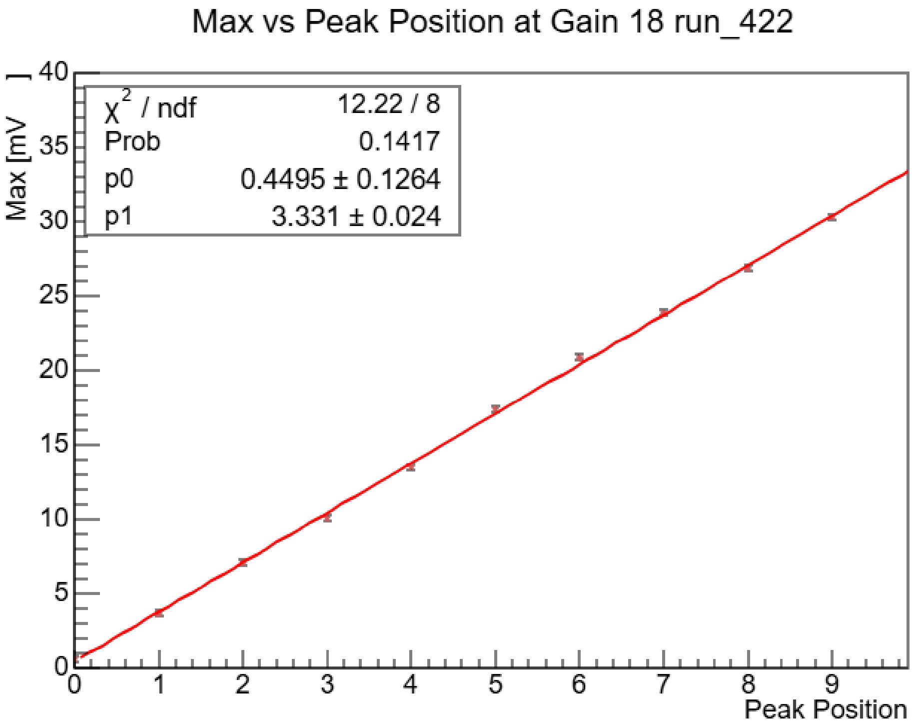
SiPM 6x6 at Gain 28 Calibration with PLP Led few photons and led power 15 Method A: pick id





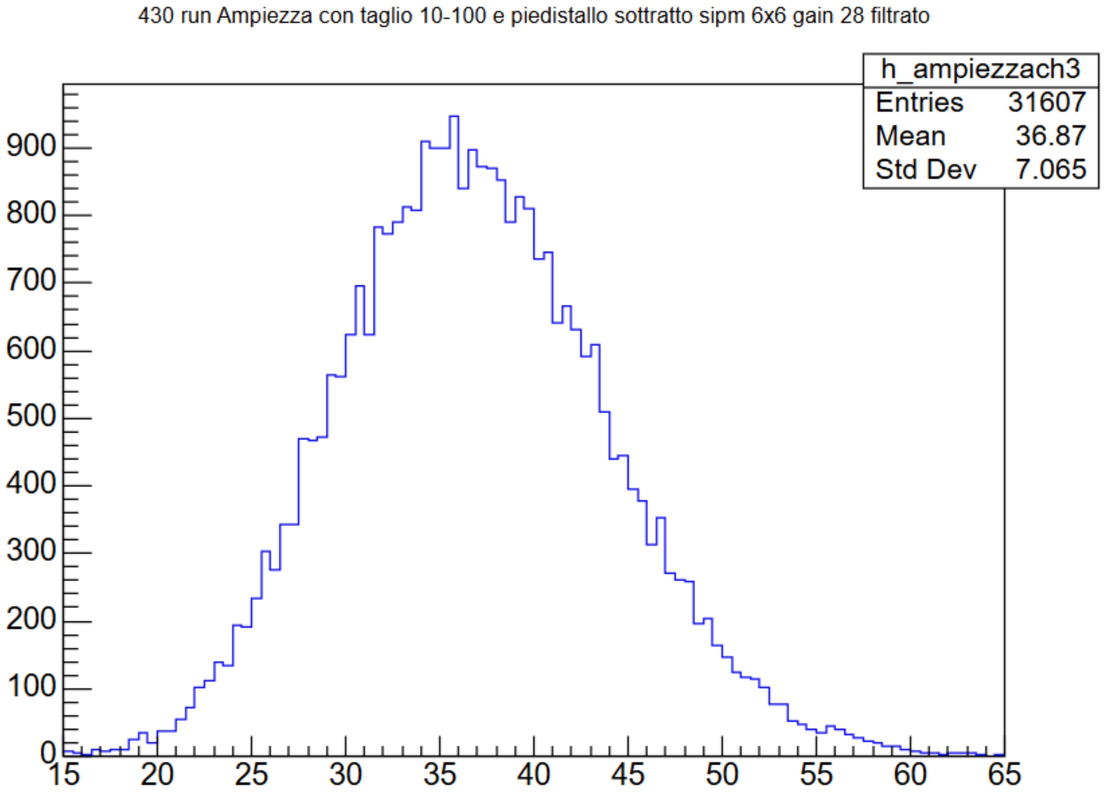
SiPM 6x6 at Gain 28 Calibration with PLP Led with few and led power 6





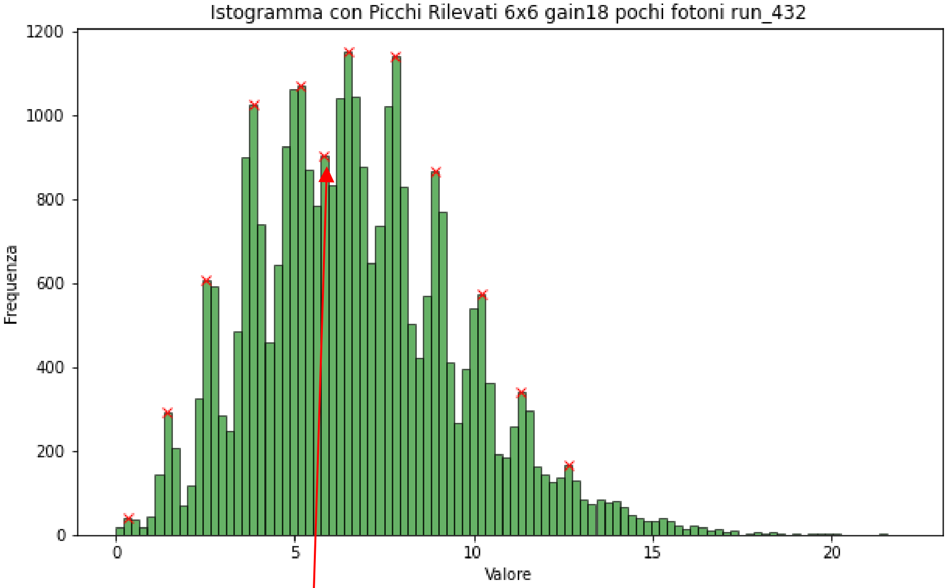
N.B. I deleted these points that were wrong

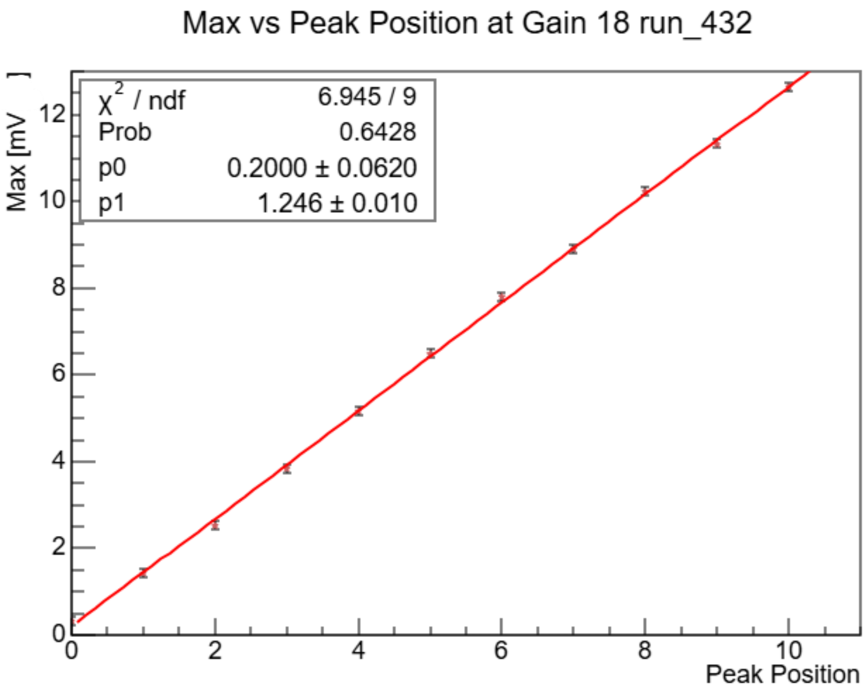
SiPM 6x6 at Gain 18 Calibration with PLP Led few photons and led power 15



In this case we are not able to find picks, even with stringent cuts

SiPM 6x6 at Gain 18 Calibration with PLP Led few photons and led power 6

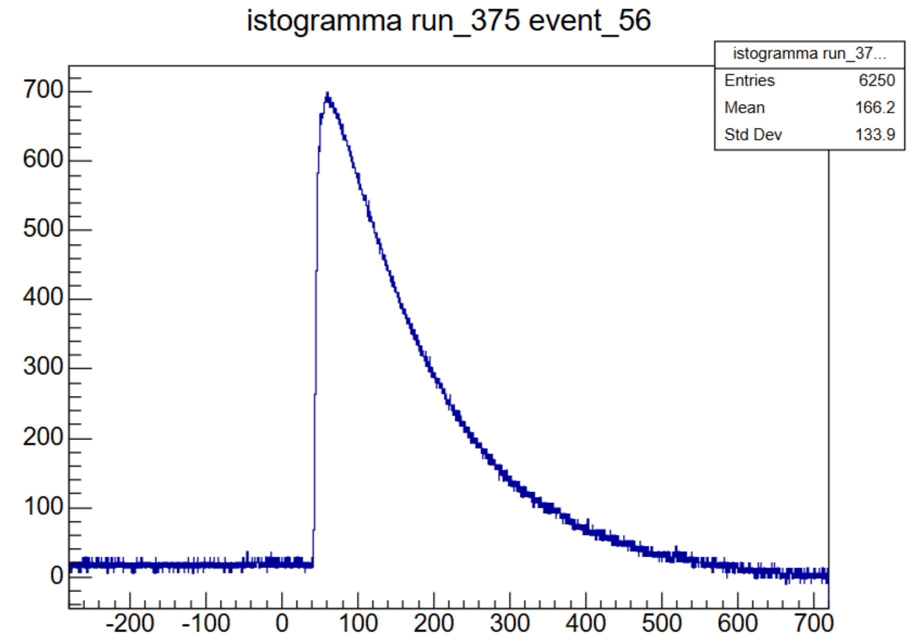


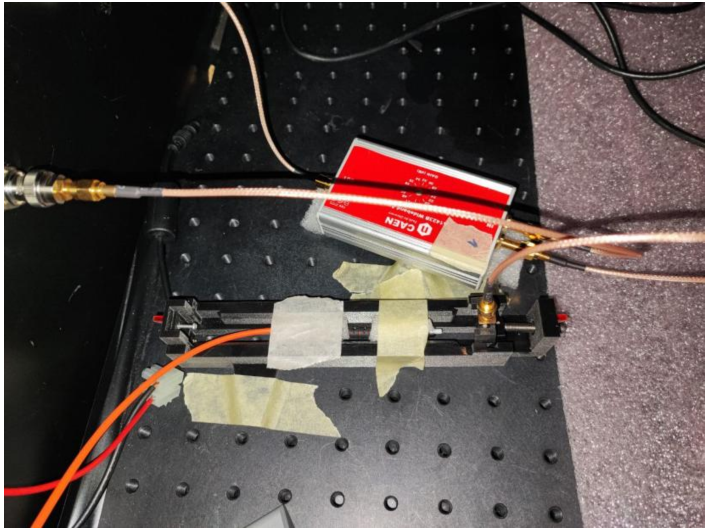


N.B. I deleted this point which was wrong

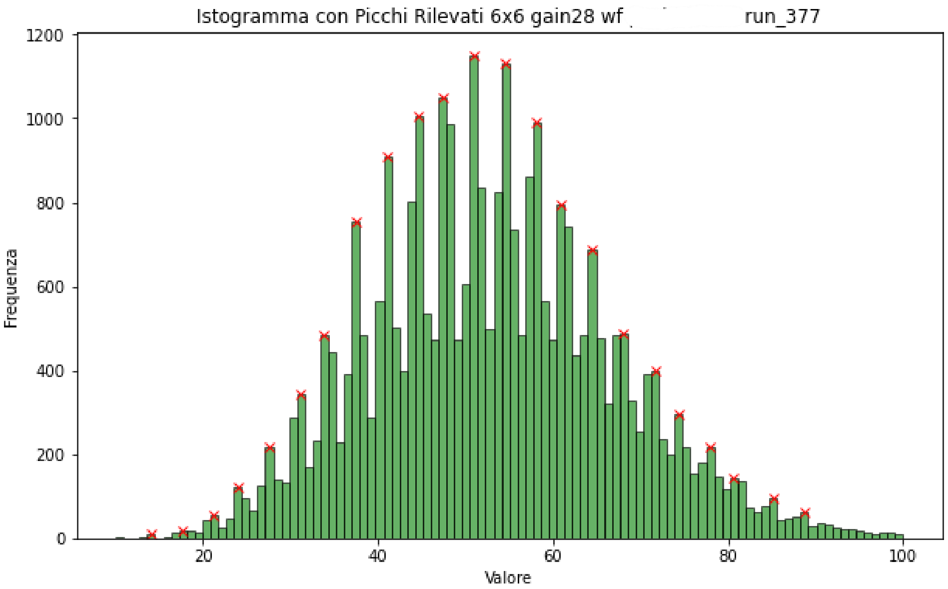
SiPM 6x6 at Gain 28 Calibration with CAEN Led

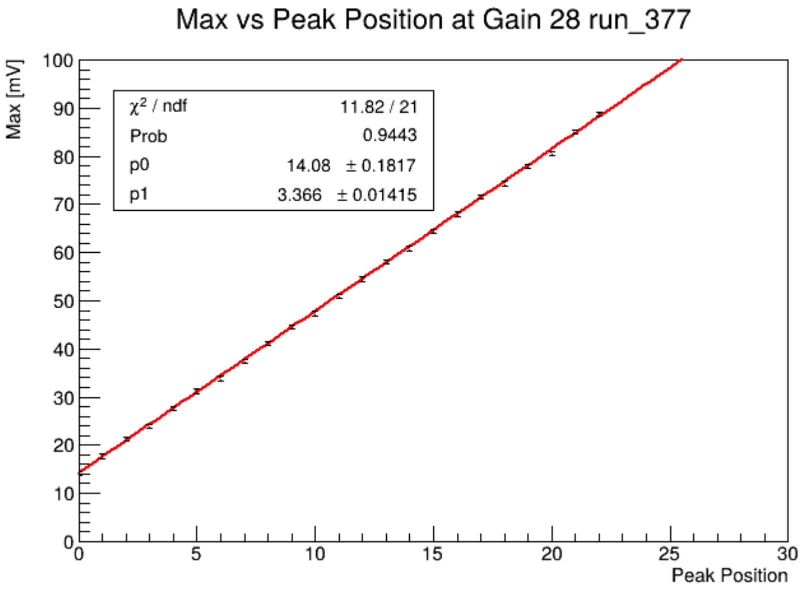
The LED emits light in pulses longer in time than a single photon, generating packets of photons distributed over time. This can lead to a convolution of the SiPM output, making it more difficult to isolate the single-photon response. If the LED intensity is high, saturation and photon pile-up effects can occur.



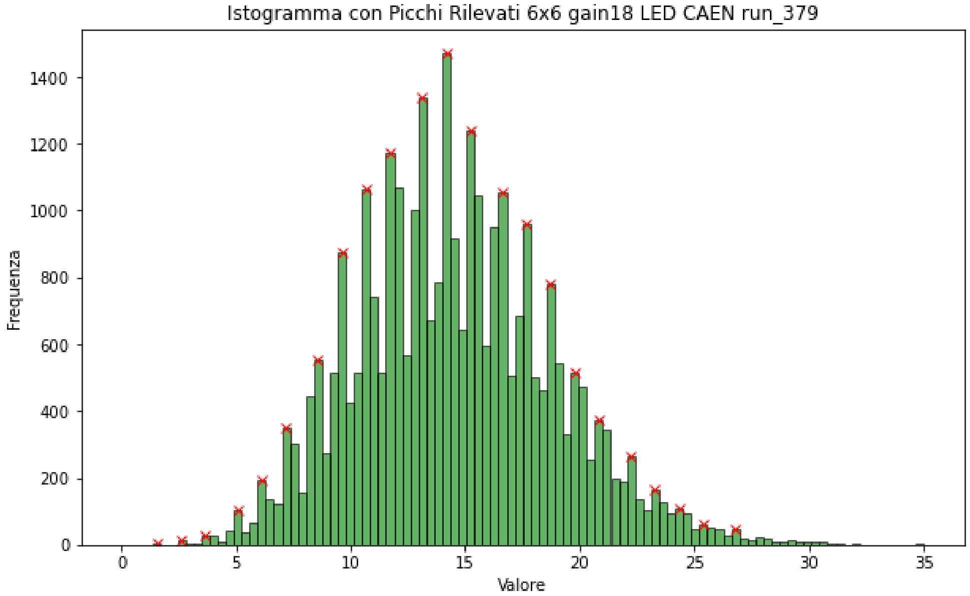


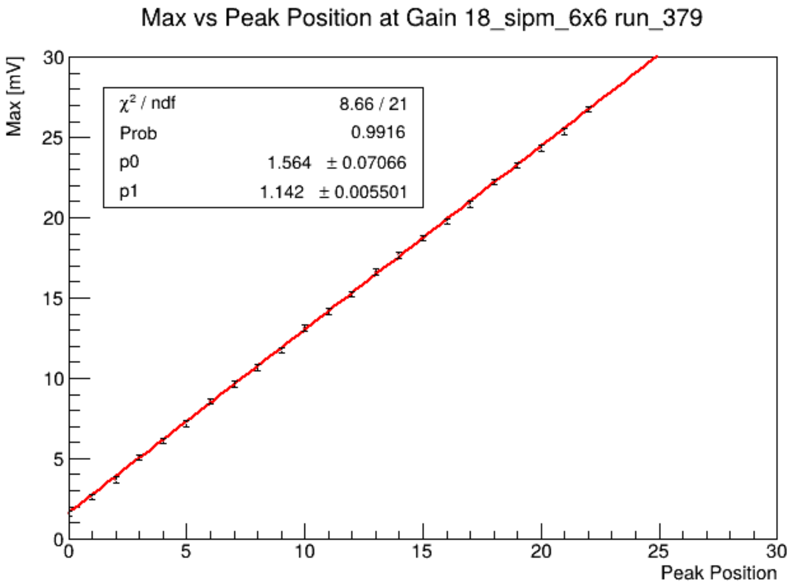
SiPM 6x6 at Gain 28 Calibration with CAEN Led few photons and led power 7





SiPM 6x6 at Gain 18 Calibration with CAEN Led few photons and led power 7





From Amplitude to Charge

From the fit of the amplitude we get: $A = p_0 + p_1 n_{pe}$

To have the conversion in charge, we fit the downslope front of our waveform.

We fit with $e^{-\frac{x}{\tau}}$, and we get factor τ.

Taking as a function:

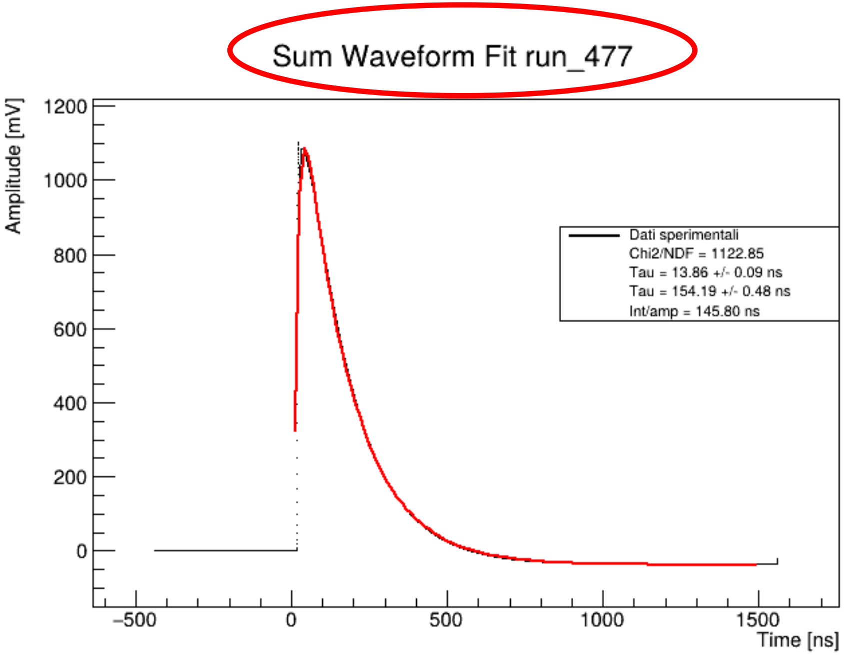
$$f(x) = A\, e^{-\frac{x}{\tau}}$$

And going to do the integral

$$I = \int_0^{3\tau} f(x)dx = \underbrace{A\tau(1 - e^{-3})}_{\alpha}$$

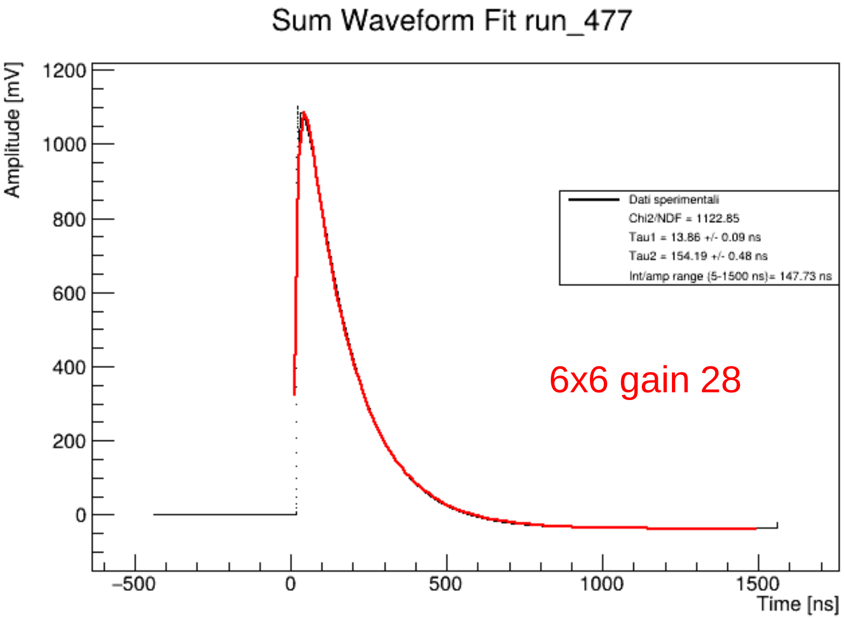
We get the factor that we need to switch from amplitude to charge

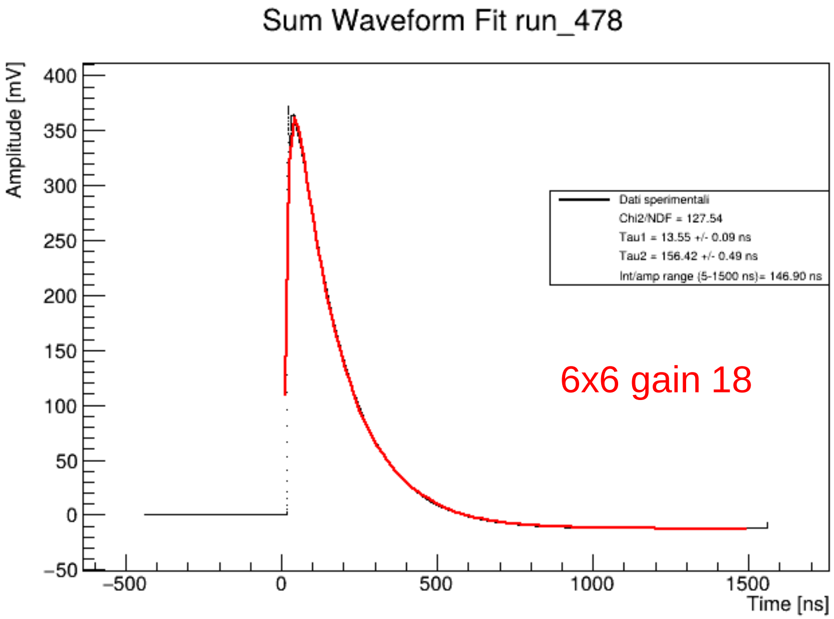
In this case I use the Sum of the waveform



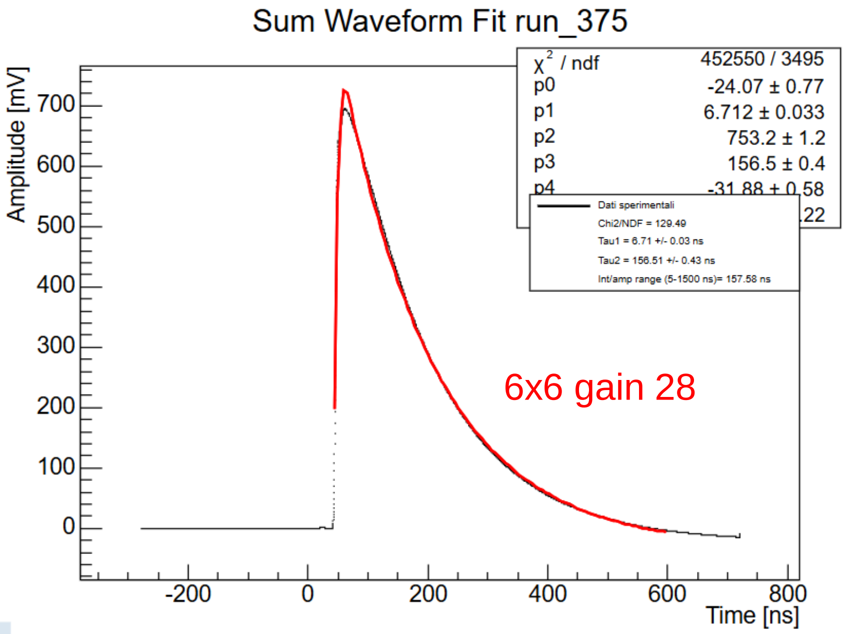
So our conversion in photon number is $A = p_0 + \alpha p_1 n_{pe}$

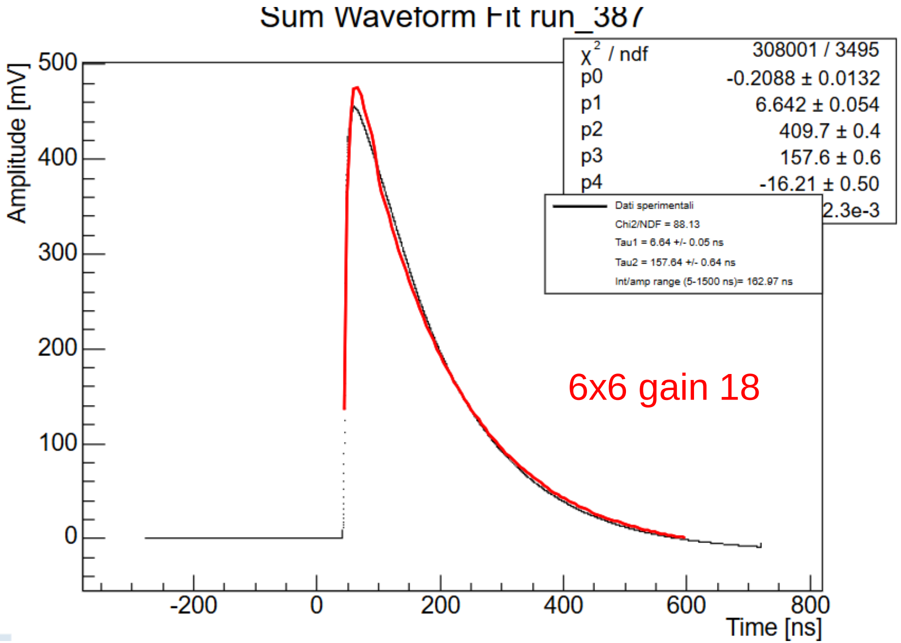
SiPM 6x6 Calibration with PLP Led few photons fit of sumwaveforms





SiPM 6x6 Calibration with CAEN Led few photons fit of sumwaveforms





Summary SiPM 6x6 Calibration with PLP Led with method A (only amplitude)

SiPM	Gain	**Gain amplitude conversion**	Power	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]	$\tau(ns)$ +$error(ns)$	conversion factor $\tau(1 - e^{-\frac{1500}{\tau}})$	Integral/amplitude	Conversion facto $p_1\tau(1 - e^{-\frac{1500}{\tau}})$
6x6	28	25,12	15	3,7 ±0,2	3,36±0,02	154,19±0,48	154,18	147,73	518,045
6x6	28		6	0,45±0,1	3,33±0,02				513,42
6x6	18	7,94	15	-	-	156,42±0,49	156,41	146,90	195,51
6x6	18		6	0,20±0,06	1,25±0,01				

Summary SiPM 6x6 Calibration with CAEN Led with method A (only amplitude)

SiPM	Gain	**Gain amplitude conversion**	Power	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]	$\tau(ns)$ +$error(ns)$	conversion factor $\tau(1 - e^{-\frac{600}{\tau}})$	Integral/amplitude	Conversion facto $p_1\tau(1 - e^{-\frac{600}{\tau}})$
6x6	28	25,12	7	14,1±0,2	3,37±0,01	156,5±0,4	153,11		515,98
6x6	18	7,94	7	1,56±0,07	1,142±0,005	157,04+0,04	153,6		175,41

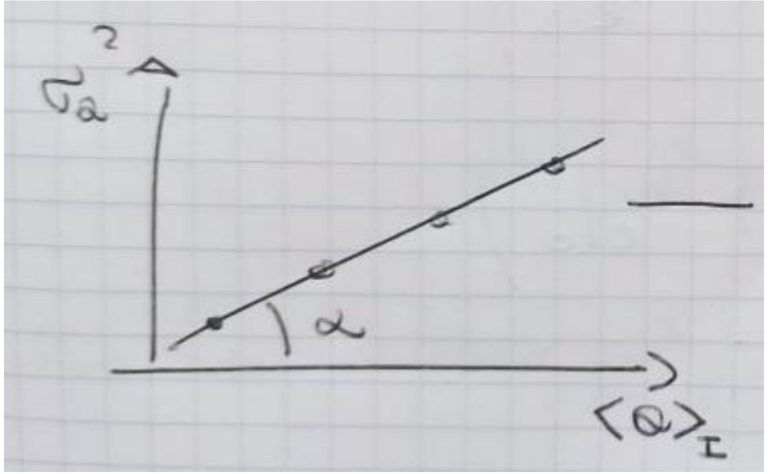
Calibrations SiPM 6x6 Gain 28 with other method

Another method is to base on the hypothesis that the n_{pe} follows a Poissonian statistic so we have that:

$$Q = \alpha n_{pe} \qquad < Q >= \alpha < n_{pe} >= \alpha\mu$$

$$\sigma_Q = \alpha\sigma_{pe} = \alpha\sqrt{\mu} = \sqrt{\alpha}\sqrt{< Q >}$$

$$\frac{\sigma_Q^2}{< Q >} = \alpha$$

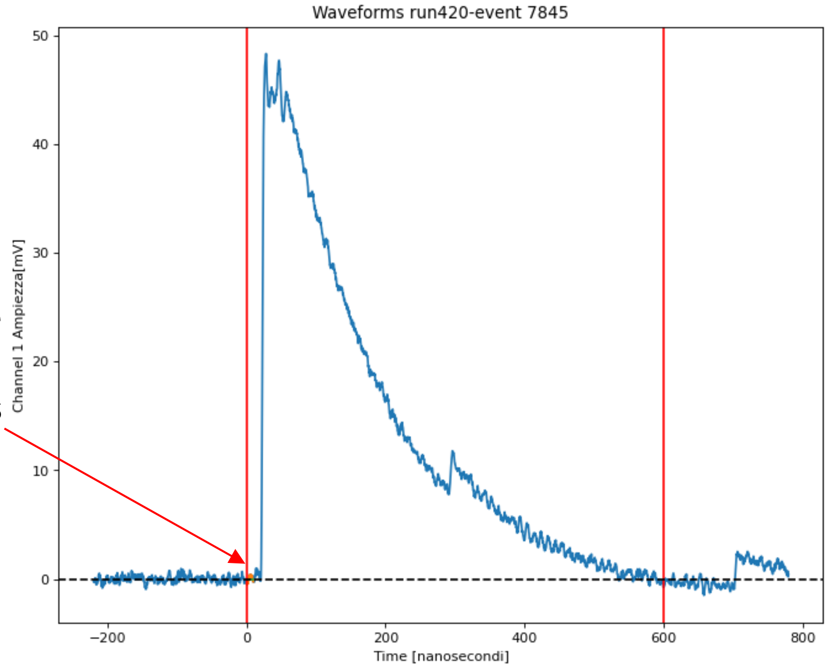


In this case we measure at different power of the led

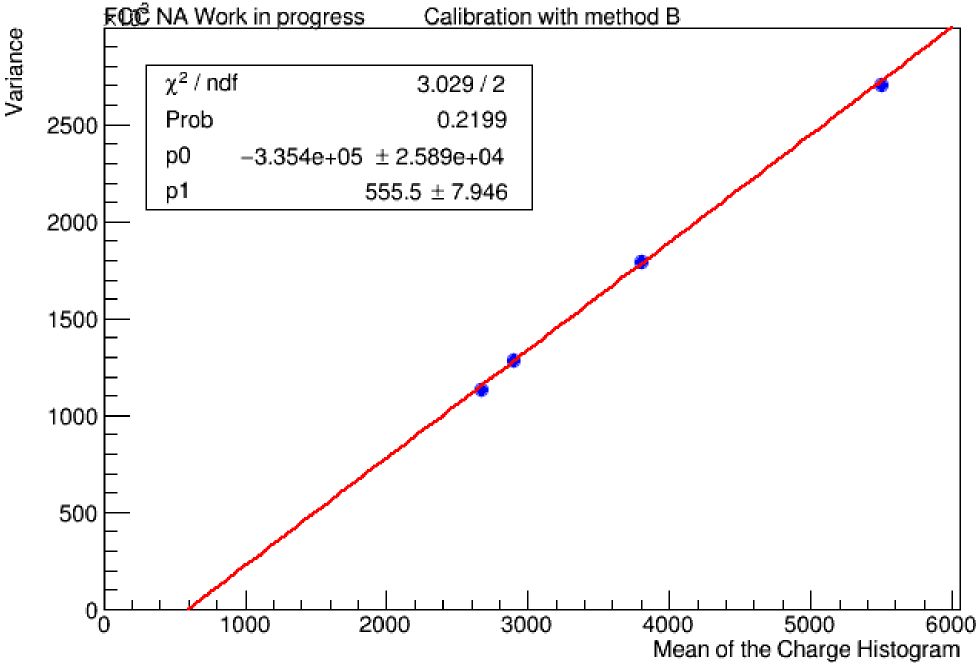
SiPM 6x6 gain 28 Calibration with PLP Led few photons with method B integral

I have studied the best range to perform the integral and then apply our method, here are the 2 ranges used for the 6x6 from 0-600. The range was chosen to take as much of the wf information as possible

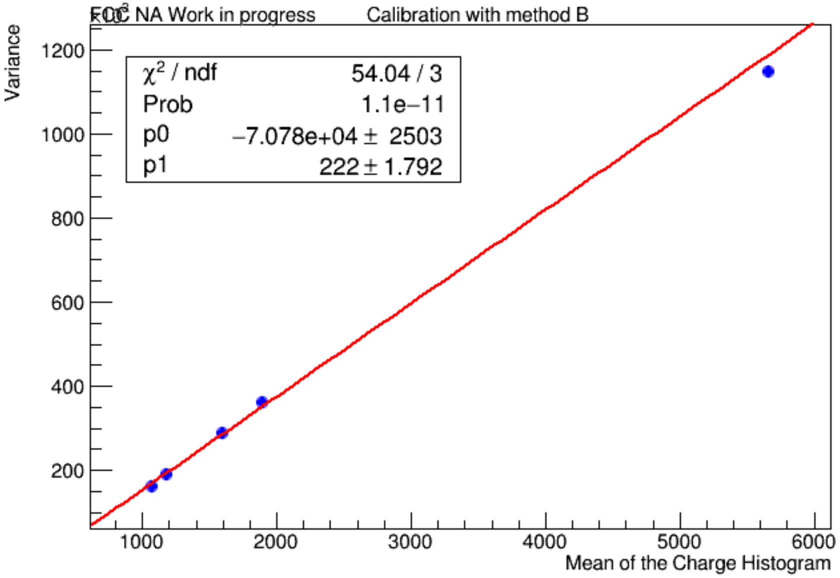
subtraction of the baseline as the average of points 0 to 10

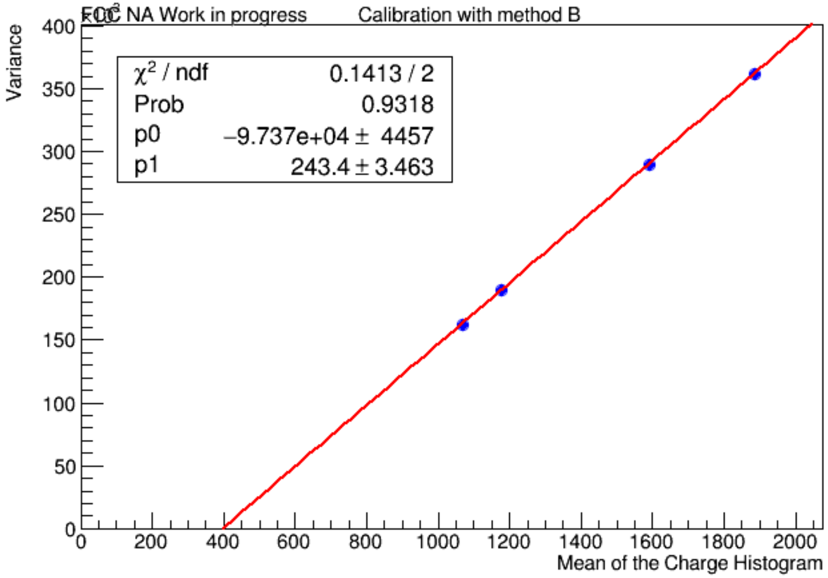


SiPM 6x6 gain28 Calibration with PLP Led few photons with method B integral range 0-600



SiPM 6x6 gain18 Calibration with PLP Led few photons with method B integral range 0-600

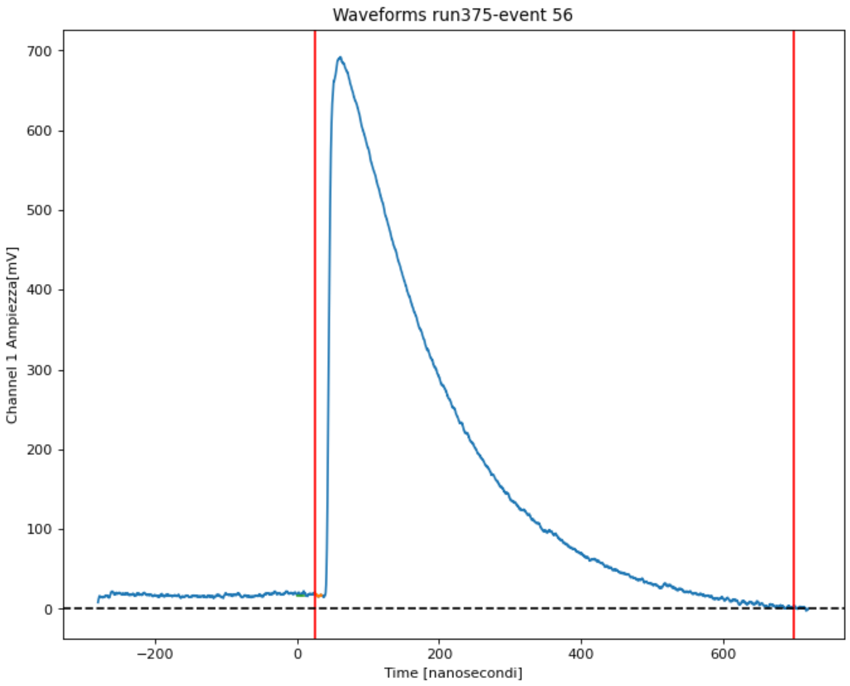




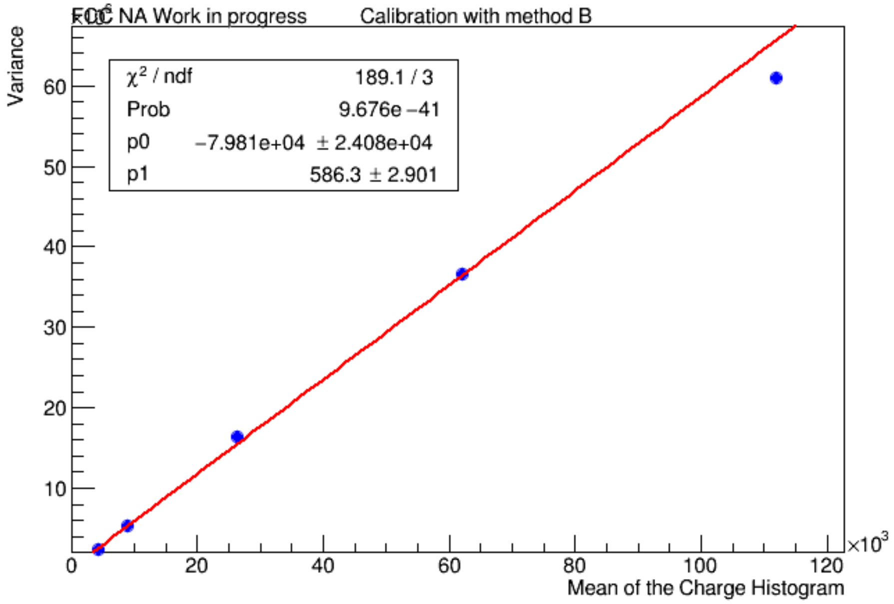
SiPM 6x6 gain 28 Calibration with CAEN Led few photons with method B integral

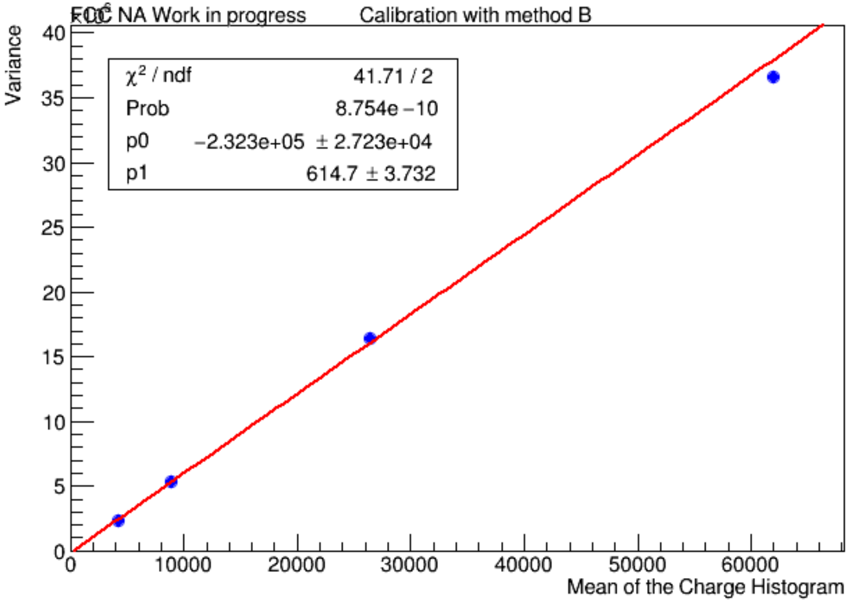
I have studied the best range to perform the integral and then apply our method, here are the 2 ranges used for the 6x6 from 0-700. The range was chosen to take as much of the wf information as possible

subtraction of the baseline as the average of points 25 to 35

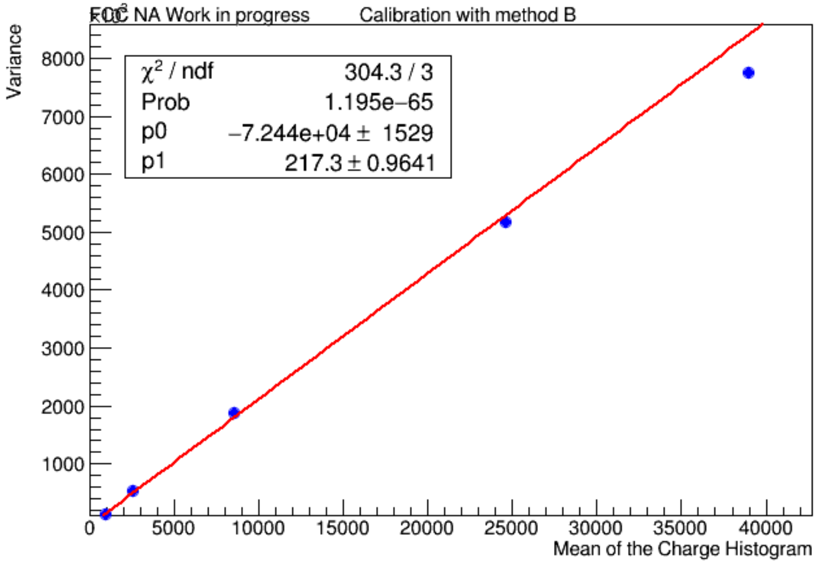


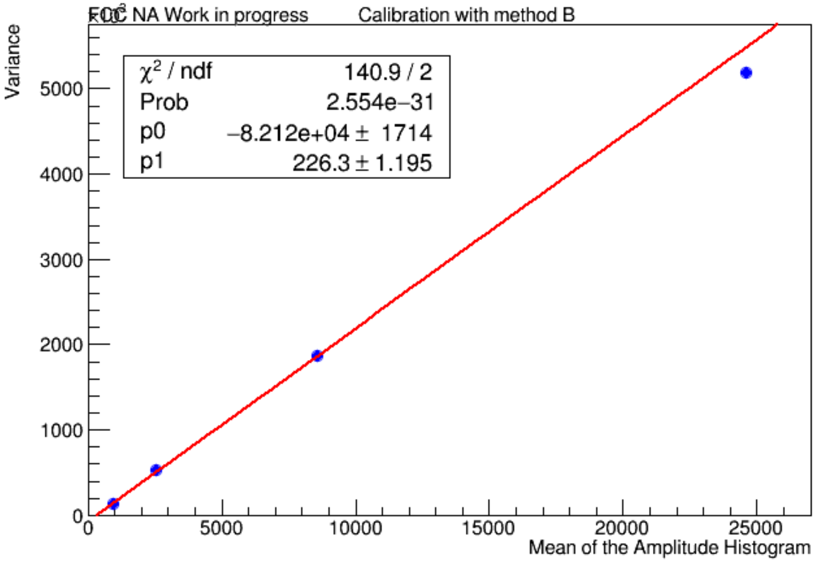
SiPM 6x6 gain28 Calibration with CAEN Led few photons with method B integral





SiPM 6x6 gain18 Calibration with CAEN Led few photons with method B integral





Summary SiPM 3x3 Calibration with PLP Led with method B integral

SiPM	Gain	**Gain amplitude conversion**	range	$p_0 + error$	$p_1 + error$ [mVns/n_{pe}]
3x3	28	25,12	0-400	-2,4*e^4±756	68,35±1
3x3	18	7,94	0-400	-4186±129,3	24,6±0,4
3x3	-		0-400	-179±48	5,3±0,2

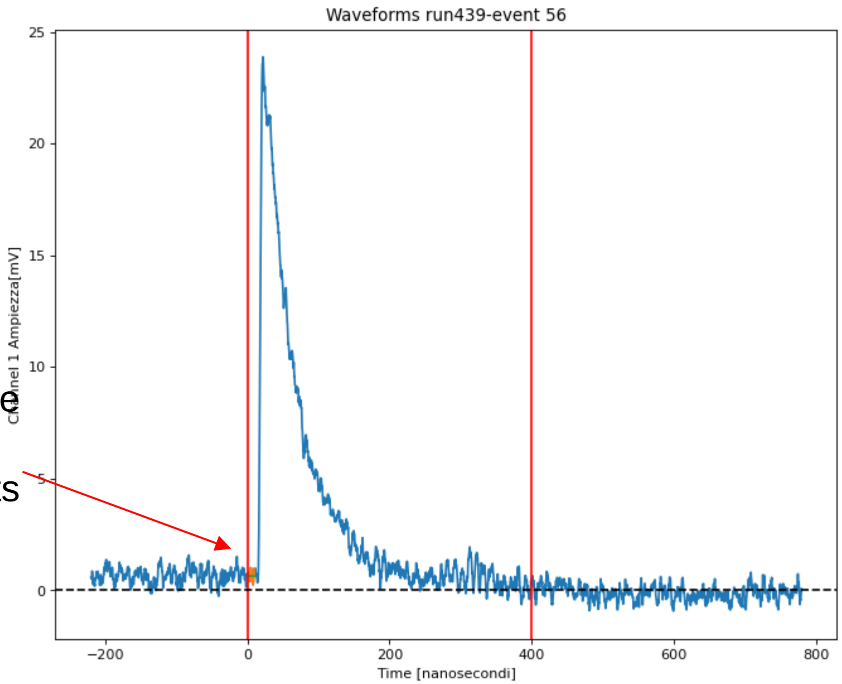
Summary SiPM 3x3 Calibration with CAEN Led with method B integral

SiPM	Gain	**Gain amplitude conversion**	range	$p_0 + error$	$p_1 + error$ [mVns/n_{pe}]
3x3	28	25,12	0-400	-2,32*e^4±332	67,5±0,3
3x3	18	7,94	0-400	-4977±36,62	23,02±0,1
3x3	-		0-400	1837±84,14	6,8±0,2

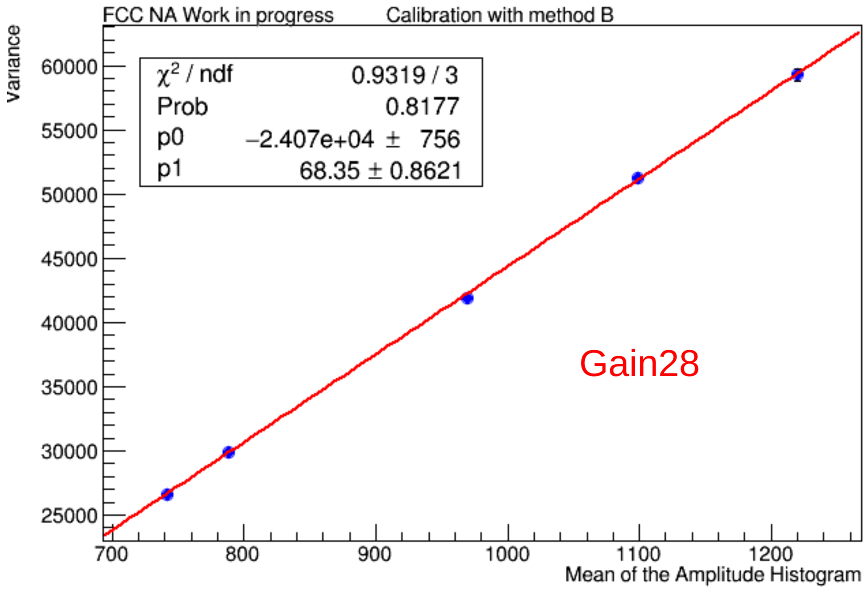
SiPM 3x3 gain 28 Calibration with PLP Led few photons with method B integral

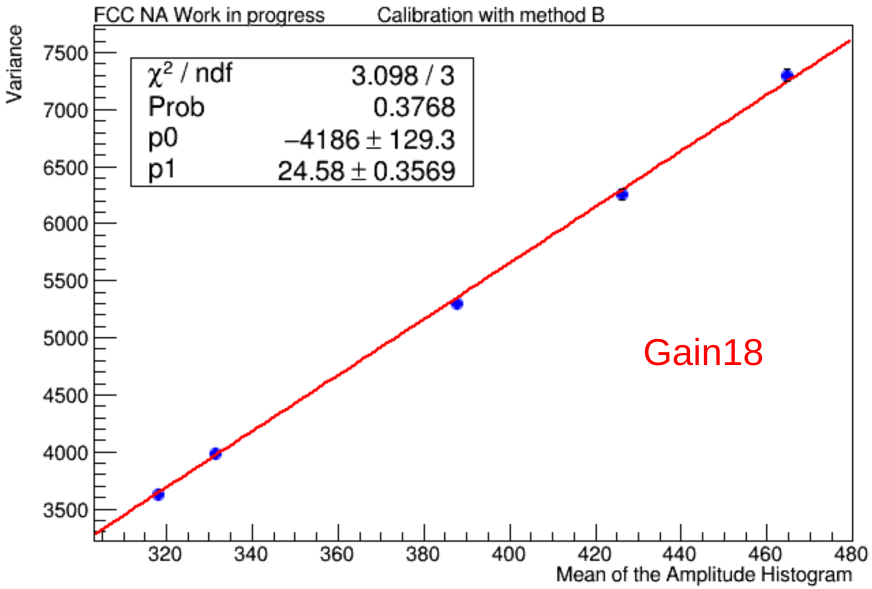
I have studied the best range to perform the integral and then apply our method, here are the 2 ranges used for the 3x3 from 0-400. The range was chosen to take as much of the wf information as possible

subtraction of the baseline as the average of points 0 to 10

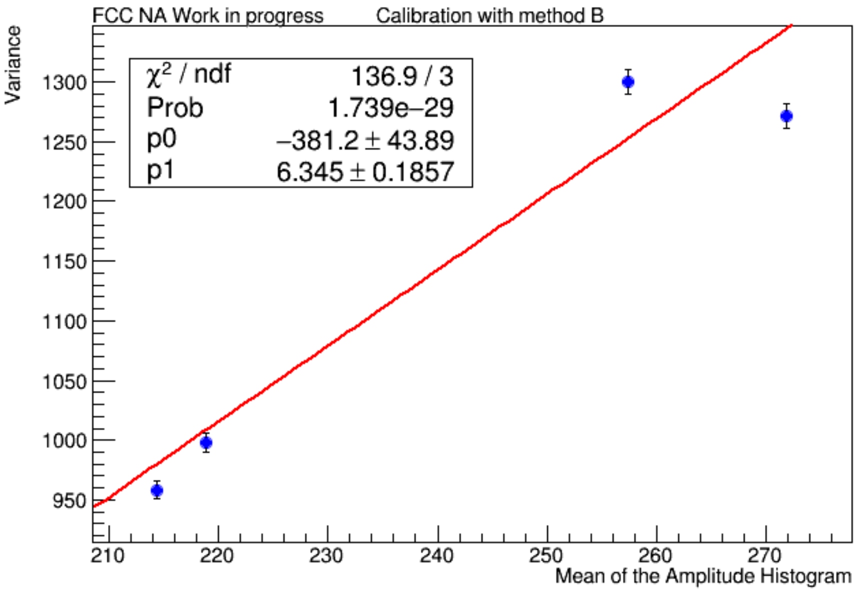


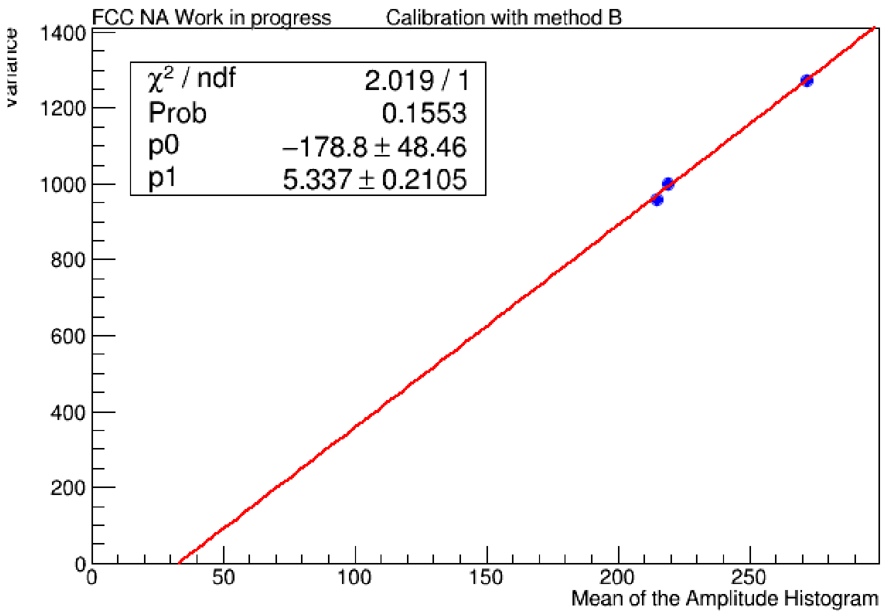
SiPM 3x3 gain28-18 Calibration with PLP Led few photons with method B integral range 0-400





SiPM 3x3 passive Calibration with PLP Led few photons with method B integral

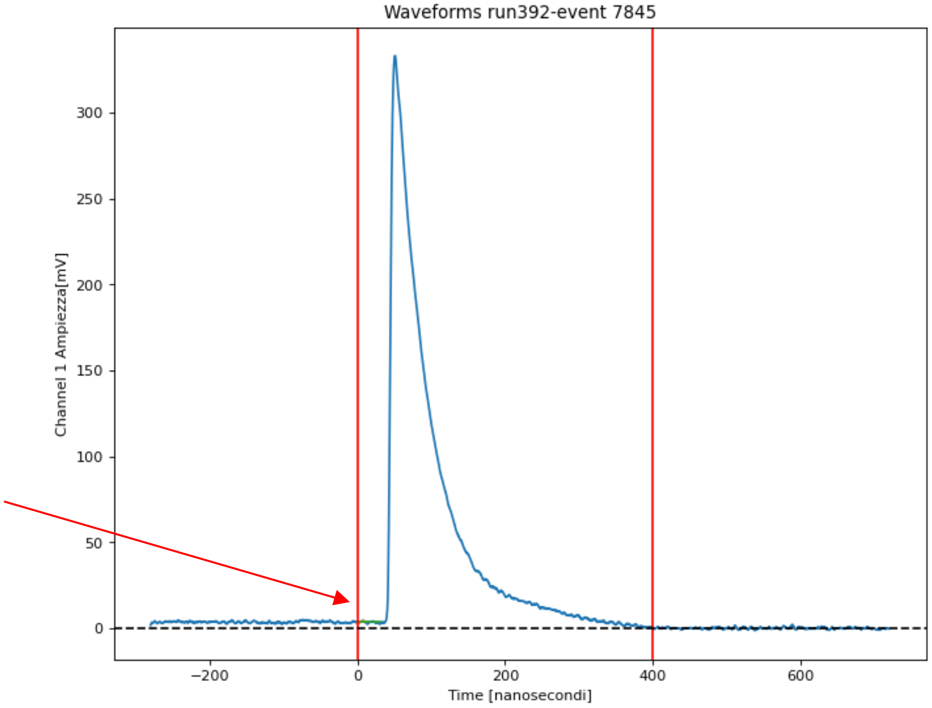




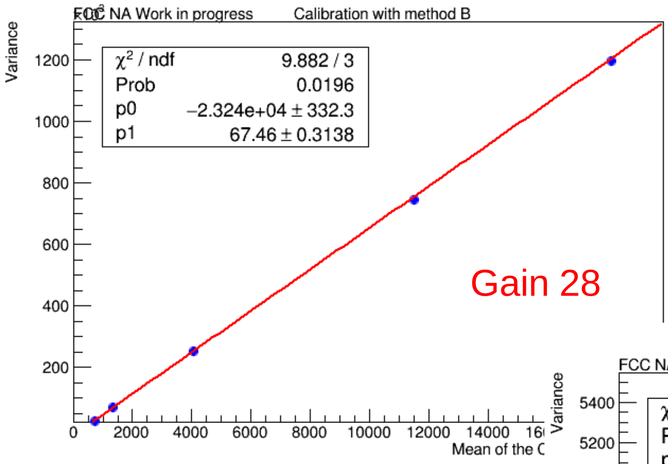
SiPM 3x3 gain 28 Calibration with CAEN Led few photons with method B integral

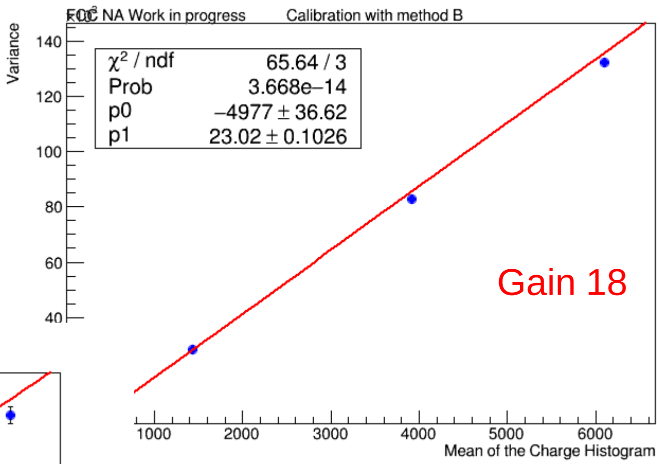
I have studied the best range to perform the integral and then apply our method range used for the 3x3 from 0-400. The range was chosen to take as much of the wf information as possible

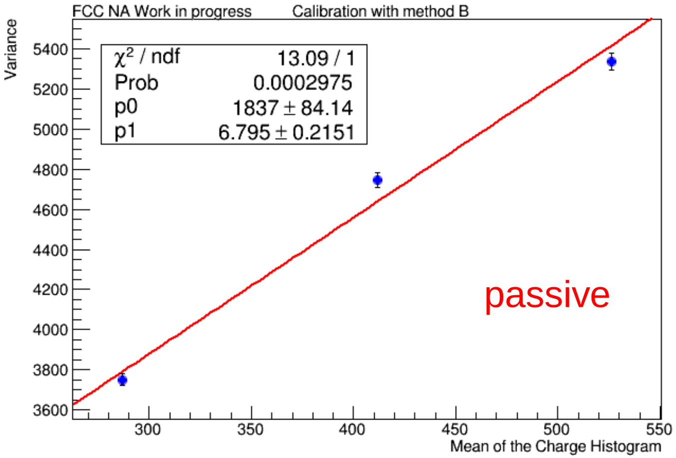
subtraction of the baseline as the average of points 0 to 10



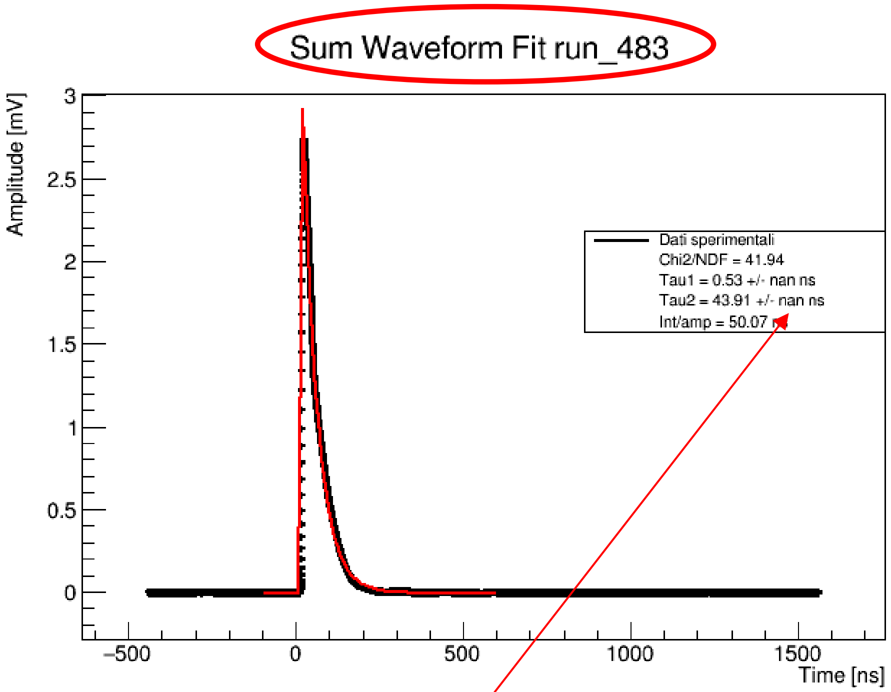
SiPM 3x3 all gain Calibration with CAEN Led few photons with method B integral range 0-400







SiPM 3x3 Calibration with PLP Led few photons fit of sumwaveforms



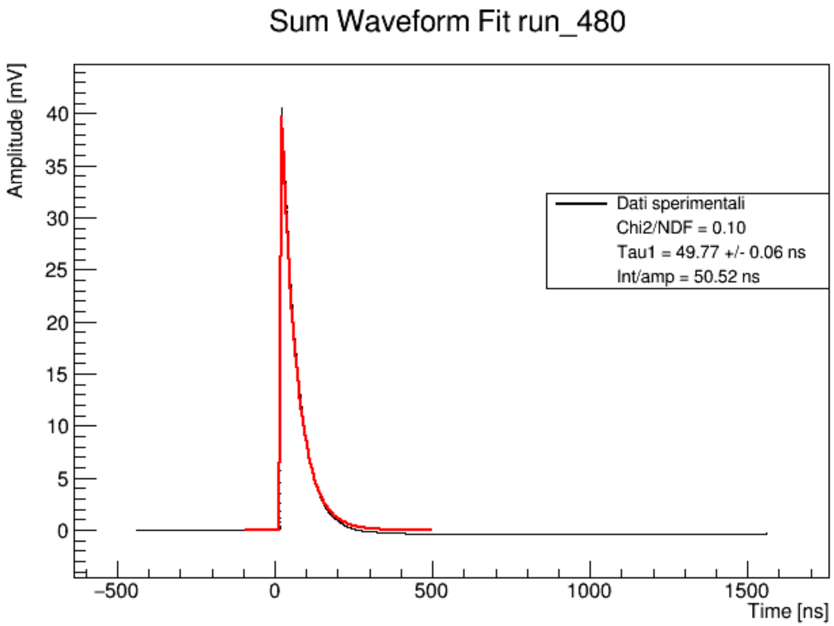
As you can see we have no error with this fit

-Range Fit -100-600

-The fit is obtained by using a sigmoid+exponential+decreasing exponential (which simulates the behaviour of the RC) as a trait function on the Sum of all wf

```
(([0]/(1+TMath::Exp(-(x-[1])/[2]))+[3])*(x<=[1]) + ([6]*TMath::Exp(-(x-[1])/[4])+[3]-TMath::Exp(-(x-[1])/[5]))*(x>[1]))
```

SiPM 3x3 Calibration with PLP Led few photons fit of sumwaveforms

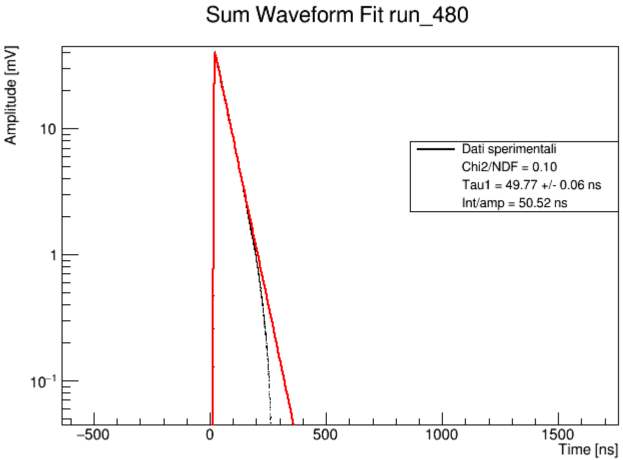


I performed an other fit, at the suggestion of Massimo Della Pietra, with a convolution of an exponential distribution, typical of the arrival times of Poissonian events, convolved with Gaussian resolution.

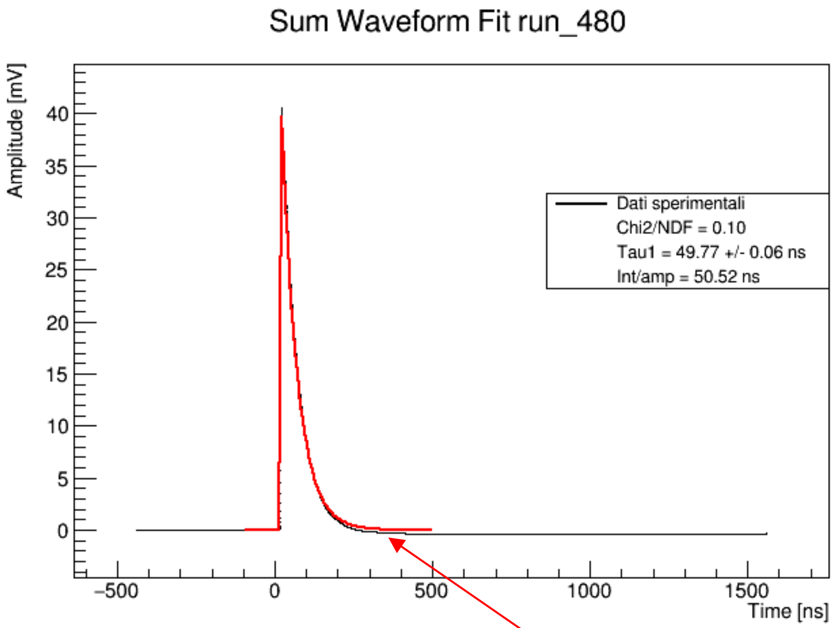
has the advantage of:

1) Having a ‘more solid’ foundation and more physically interpretable parameters;
2) Having no discontinuities;
3) If you add the baseline constant, you can fit it over the entire range, because it is defined over the entire R

```
Matrice di correlazione:
[1.0, 0.23384509728564867, 0.18892218930105353, -0.6831272817474916]
[0.23384509728564867, 1.0, 0.09462551736899166, -0.15309203297754487]
[0.18892218930105353, 0.09462551736899166, 1.0, -0.0018372277997145557]
[-0.6831272817474916, -0.15309203297754487, -0.0018372277997145557, 1.0]
```



SiPM 3x3 Calibration with PLP Led few photons fit of sumwaveforms



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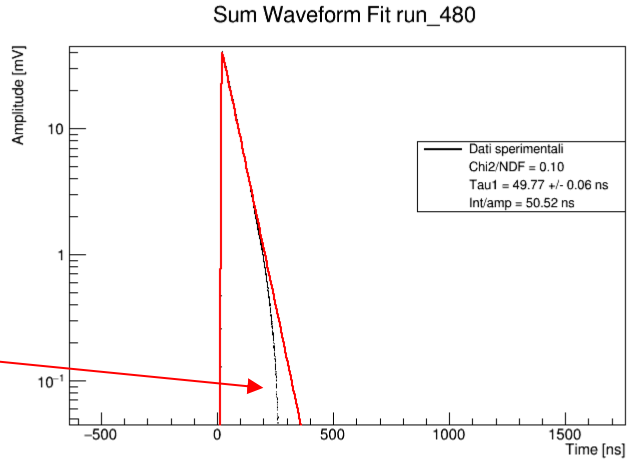


But I’m working on the RC part

Summary SiPM 6x6 Calibration with PLP Led with method B amplitude

SiPM	Gain	**Gain amplitude conversion**	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]	$\tau(ns) + error(ns)$ Range 5-1500	Constant factor factor charge $\tau(1-e^{-\frac{1500}{\tau}})$	Integral/amplitude	Conversion factor $p_1\tau(1-e^{-\frac{1500}{\tau}})$
6x6	28	25,12	-8±1	3,78±0,05	154,19±0,48	154,18	147,73	582,80±7,92
6x6	18	7,94	-1,0±0,1	1,39±0,01	156,42±0,49	156,41	146,90	217,41±1,71

Error for Conversion factor:

General formula with partial derivatives

$$\sigma_C = \sqrt{\left(\frac{\partial C}{\partial p_1}\sigma_{p_1}\right)^2 + \left(\frac{\partial C}{\partial \tau}\sigma_\tau\right)^2}$$

$$\frac{\partial C}{\partial p_1} = \tau(1 - e^{-1500/\tau})$$

$$\frac{\partial C}{\partial \tau} = p_1\left(1 - e^{-1500/\tau}\right) + p_1\tau\left(\frac{1500}{\tau^2}e^{-1500/\tau}\right)$$

Final formula

$$\sigma_C = \sqrt{\left[\tau(1 - e^{-1500/\tau})\sigma_{p_1}\right]^2 + \left[p_1(1 - e^{-1500/\tau}) + p_1\tau\frac{1500}{\tau^2}e^{-1500/\tau}\right]^2\sigma_\tau^2}$$

Gain conversion factor at various temperatures

$$V_{OV}(26°C) = V_{OP}(25°C) - V_{BD}$$

$$V_{BD}(T°) = V_{BD}(25°) + 0{,}034\frac{V}{°C}\ \delta T$$ ➡ This is in case of temperature increase from 25°C, or in case of temperature decrease ➡ $V_{BD}(T°) = V_{BD}(25°) - 0{,}034\frac{V}{°C}\ \delta T$

$$G(26°C) = \alpha V_{OV}(26°C) = calculated \rightarrow \alpha = \frac{G(26°C)}{V_{OV}(26°C)}$$

$$G(23°C) = \alpha V_{OV}(23°C)$$

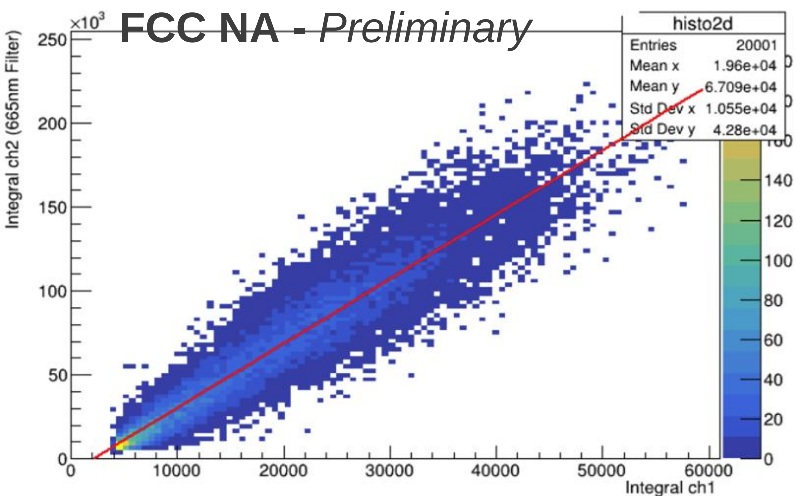
We then have the 26°C gain and we want to know how much is the gain at 23°C:

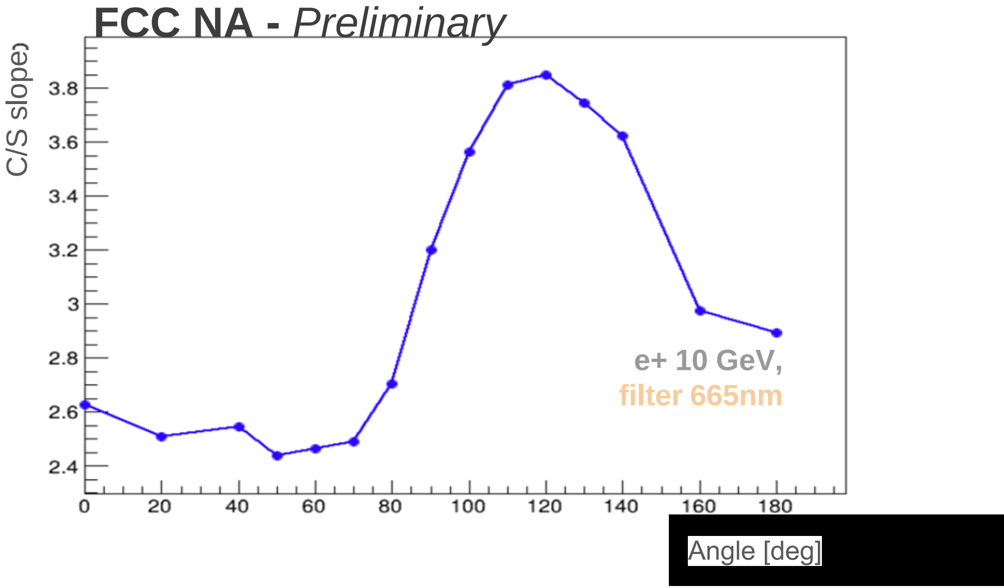
SiPM	$V_{OP}(V)$ tabulated 25°C	$V_{BD}(V)$ tabulated 25°C	V_{OV}(26°)	G(26°C)	α	V_{OV}(23°)	V_{BD}(23°)	G(23°C)
6x6	40,7	38	2,67	3,461	1,30	2,77	37,93	3,59
3x3	44	39	4,97	1,236	0,25	5,07	38,93	1,26

Study of C/S Variation in angular scan with PWO

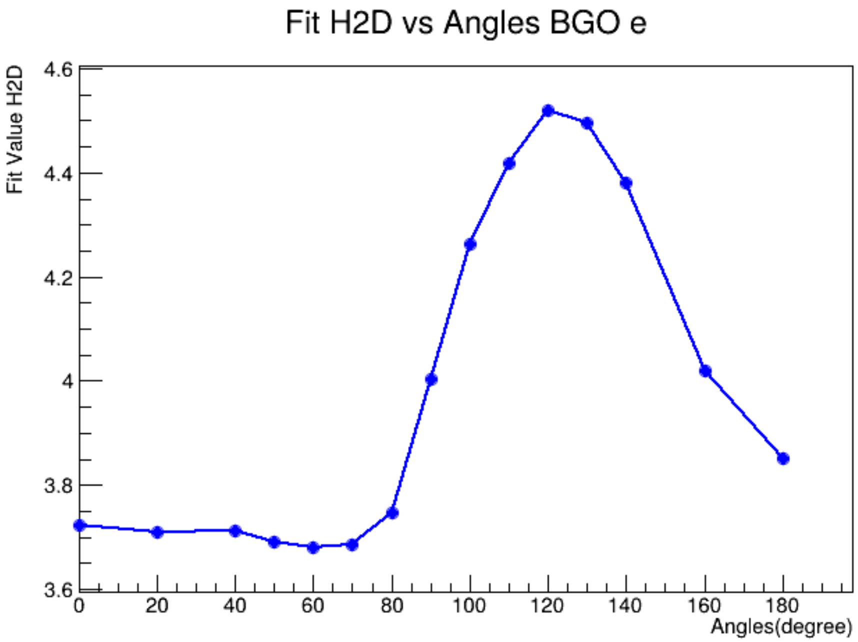
- We studied the 2D histogram of the integrals of channel with the filter dominated by contribution cherenkov on the integral of channel without filter dominated by scintillation.

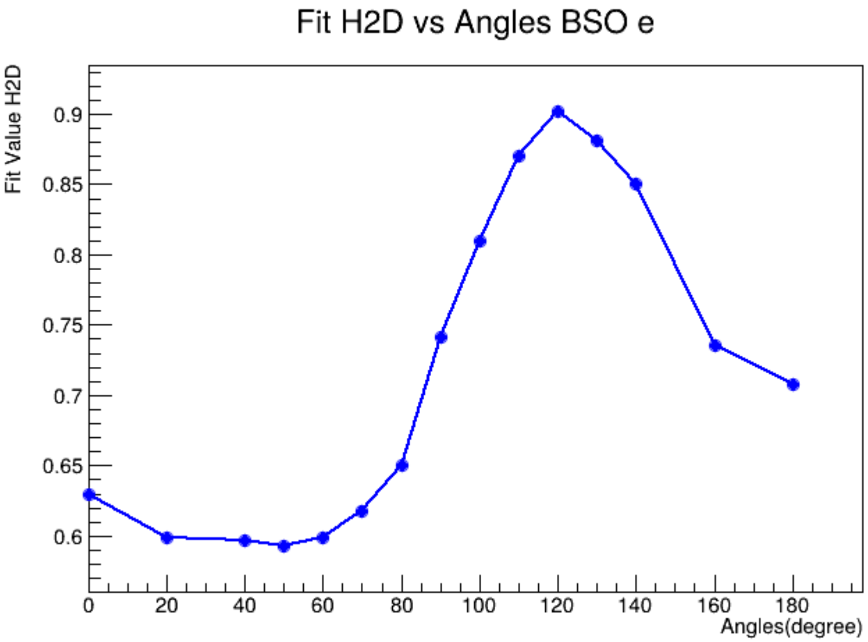
- Then we performed a linear fit, since if there were only scintillation the slope would always be equal depending on the angle. I have done this for all the runs of the angular scan





Study of C/S Variation in angular scan with BGO and BSO





Setup:

- SiPM Hamamtsu S14160-6050HS:
  - -photosensitive area 6x6 mm^2
  - -number of pixels= 14331
- SiPM Hamamatsu S14160-3010PS:
  - - photosensitive area 3x3 mm^2
  - - number of pixels= 89984
- Preamplifier CAEN serie A1423B:
  - -Gain range from +18dB to +54dB
- CAEN Led Driver SP5601
- CAEN NIM HV Power supply module N1419ET
  - - 4 Ch Reversible 500 V/200 µA
- Tektronix Oscilloscope MSO66B:
  - - 1,5 GHz Bandwidth
  - - 6 Analog channels