Update 19/02/2025

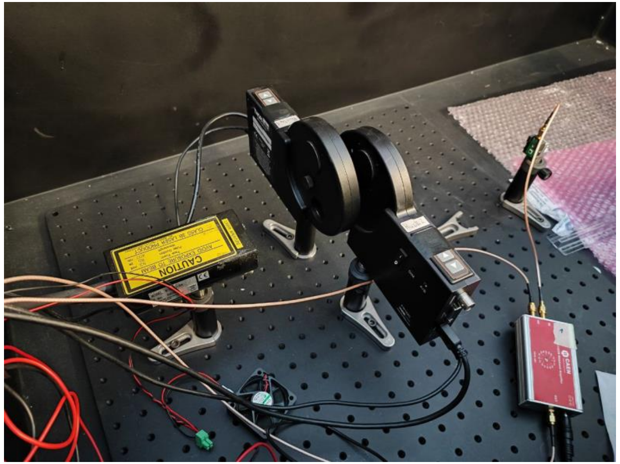
FCC Naples

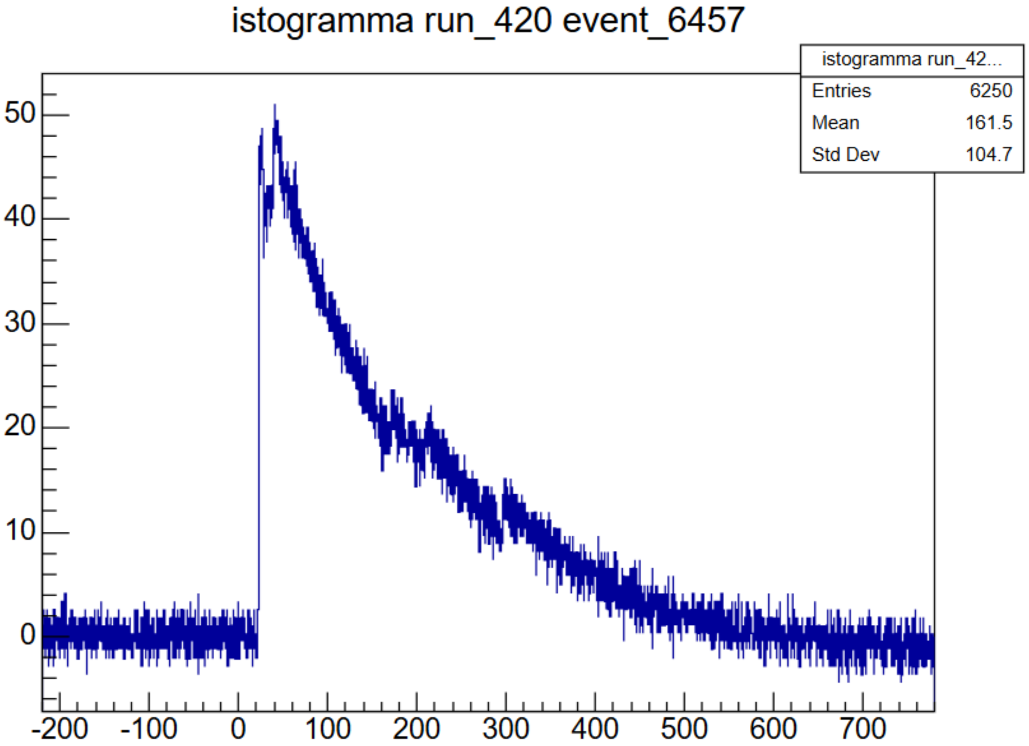
Work of:
Lucrezia Borriello (Istituto Nazionale di Fisica Nucleare Napoli)

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

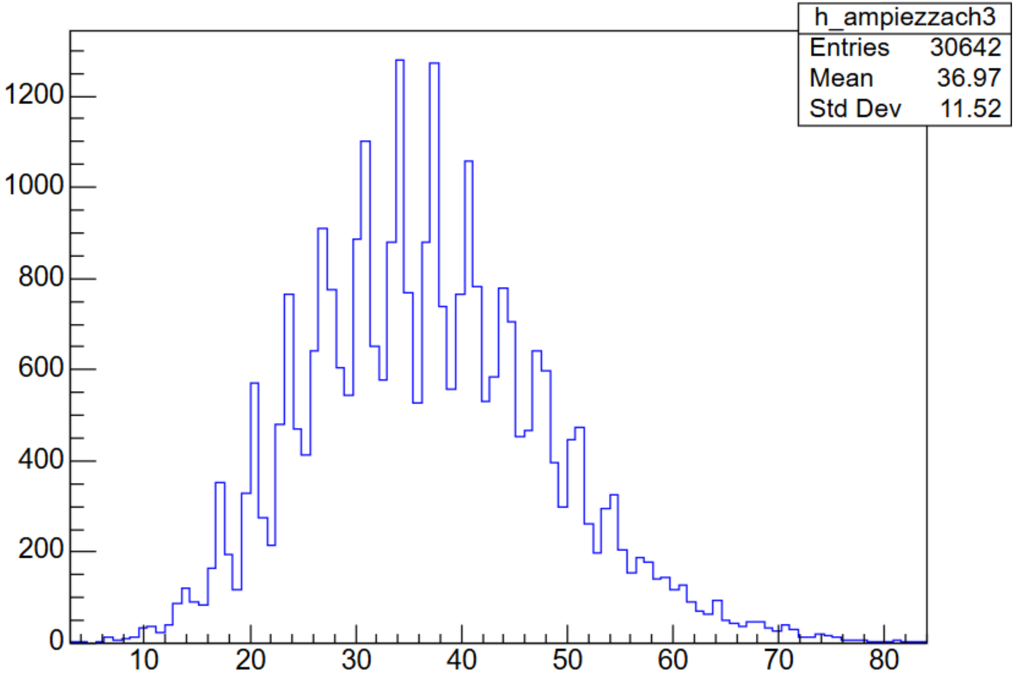
this waveform is the case where with the lens system I was able to put myself in a range of a few photons



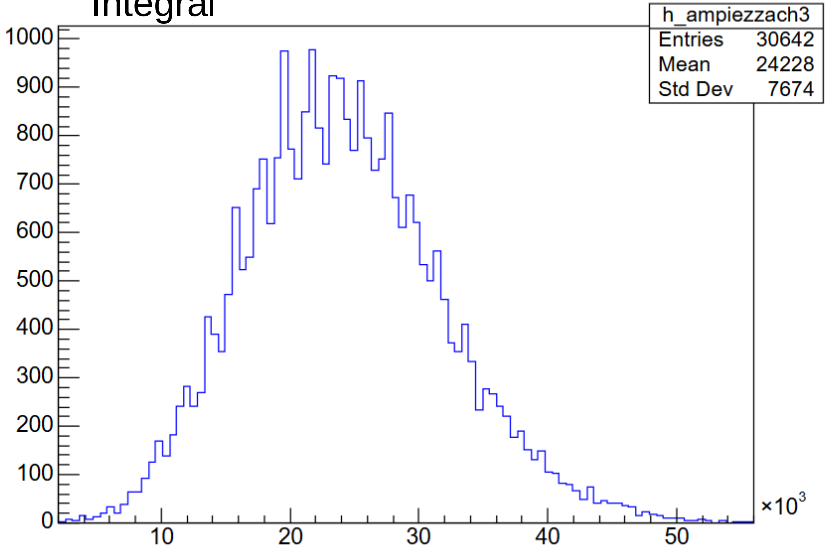


SiPM 6x6 at Gain 28 Calibration with PLP Led

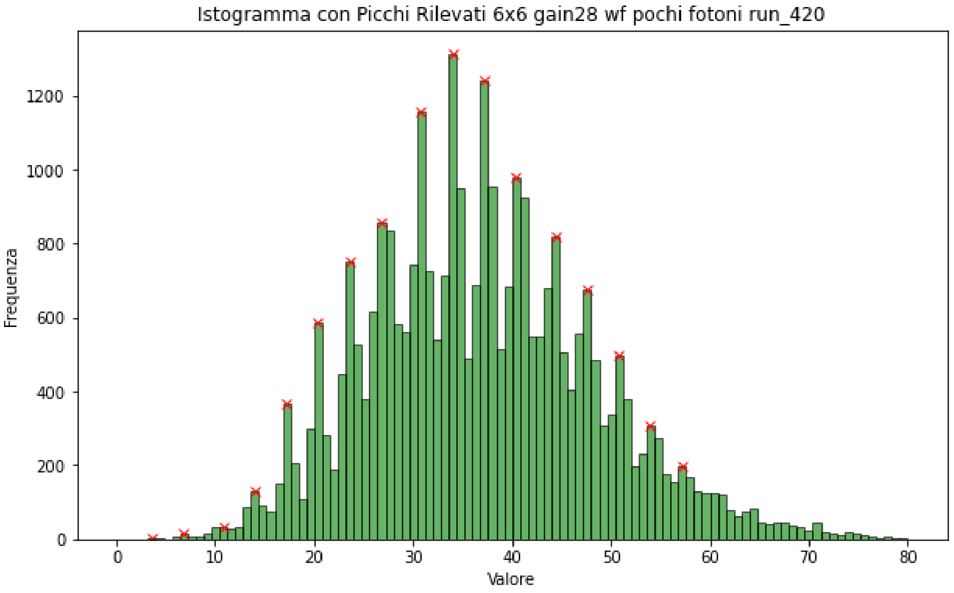
Amplitude

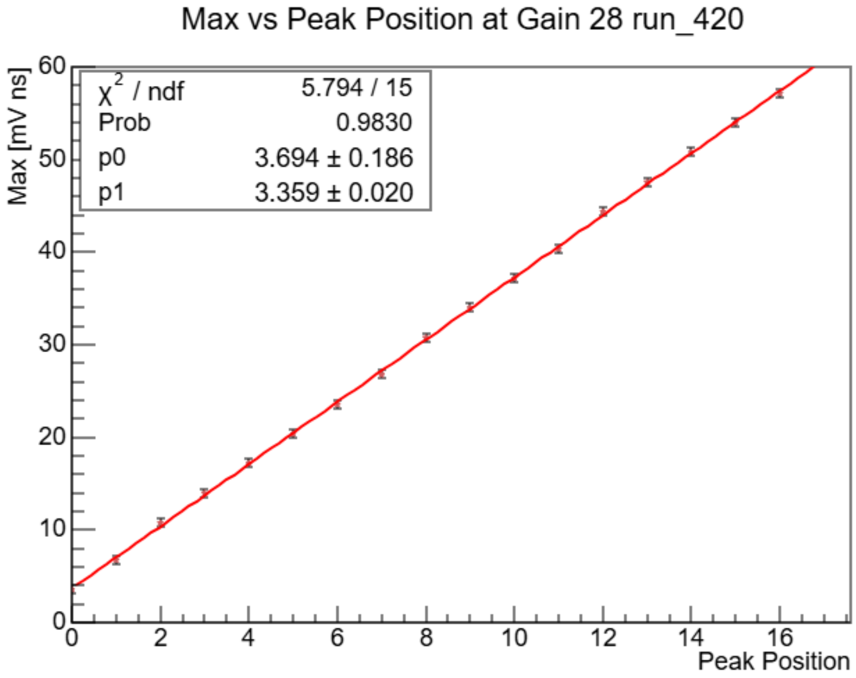


Integral

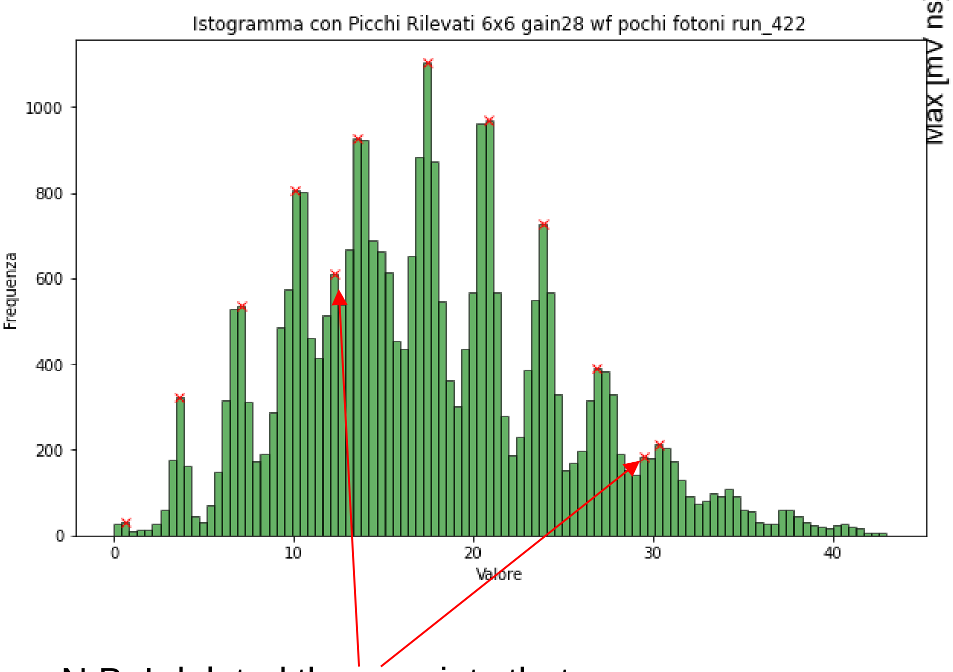


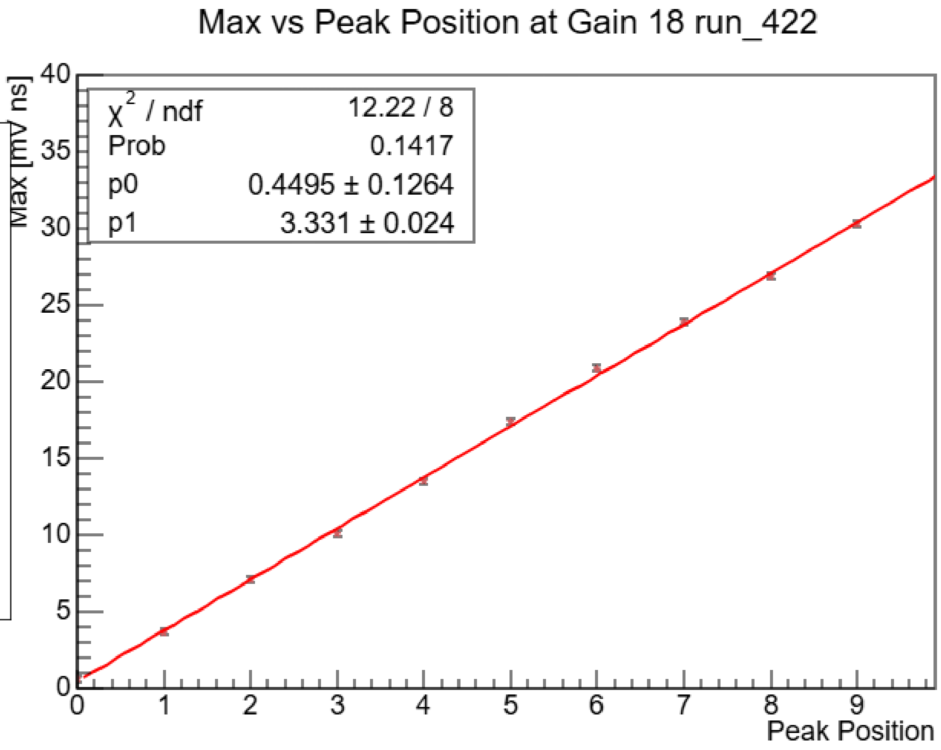
SiPM 6x6 at Gain 28 Calibration with PLP Led few photons and led power 15





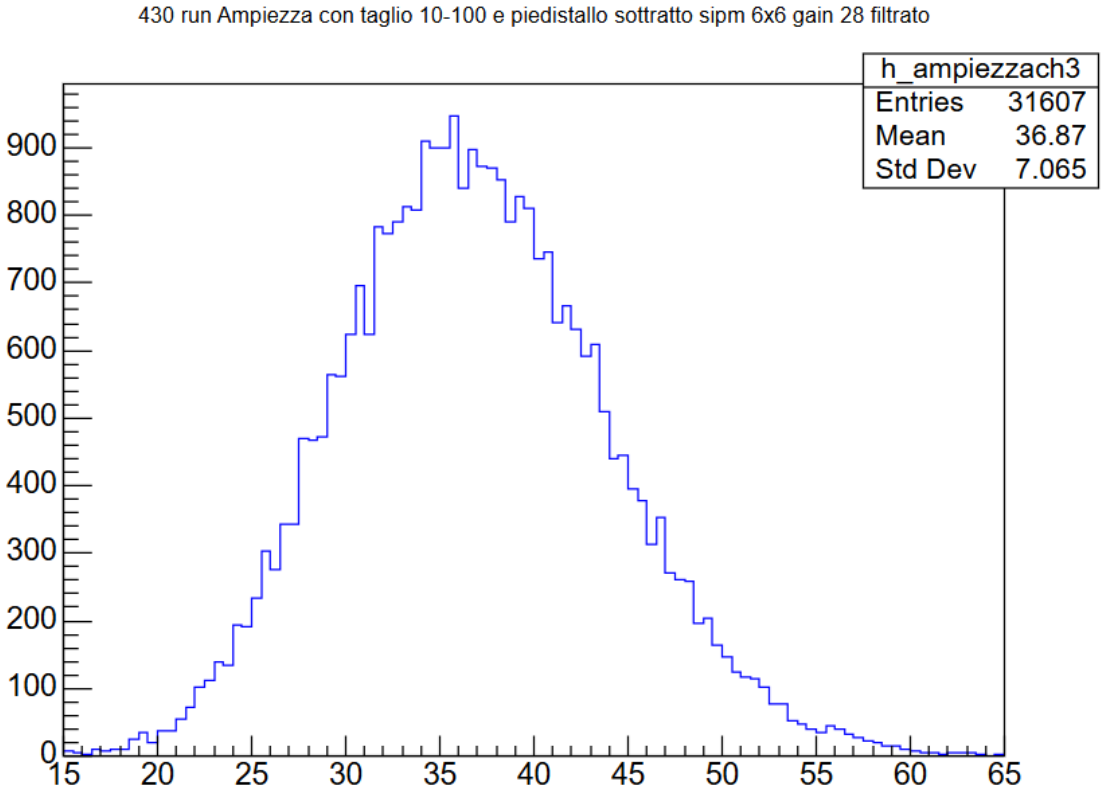
SiPM 6x6 at Gain 28 Calibration with PLP Led with few and led power 6





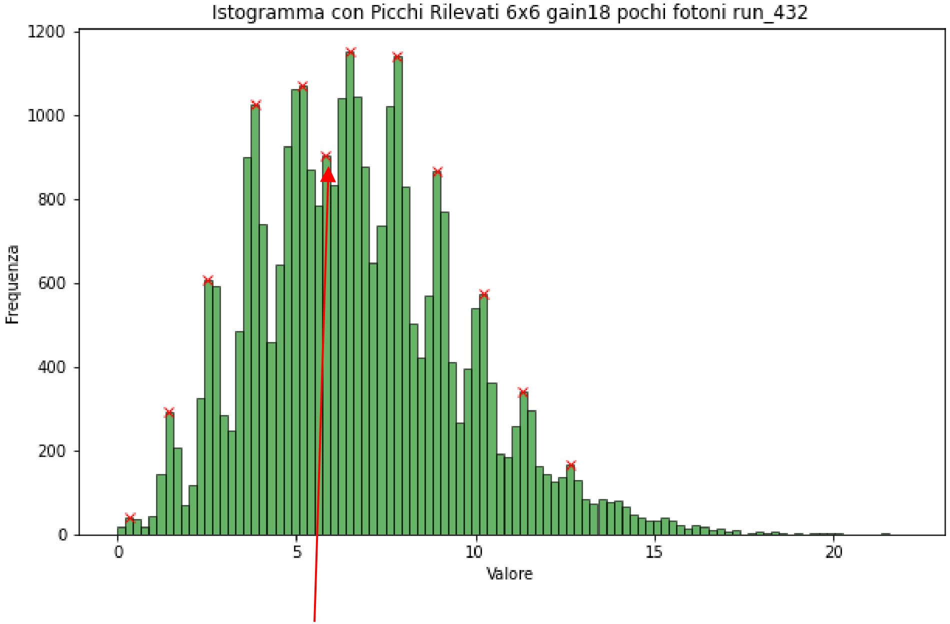
N.B. I deleted these points that were wrong

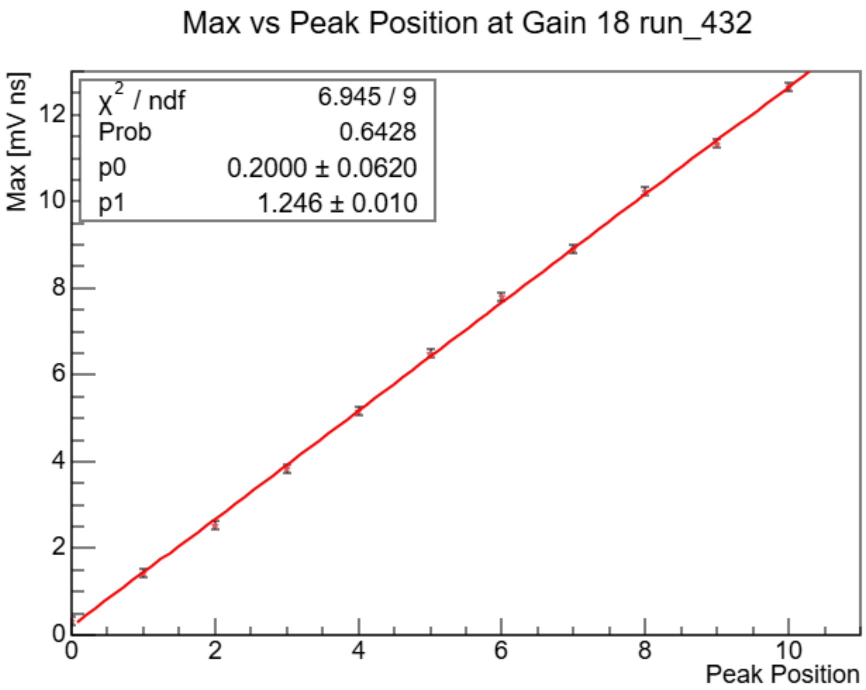
SiPM 6x6 at Gain 18 Calibration with PLP Led few photons and led power 15



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

ComparisonSiPM 6x6 at Gain 28 Calibration with PLP Led and led CAEN

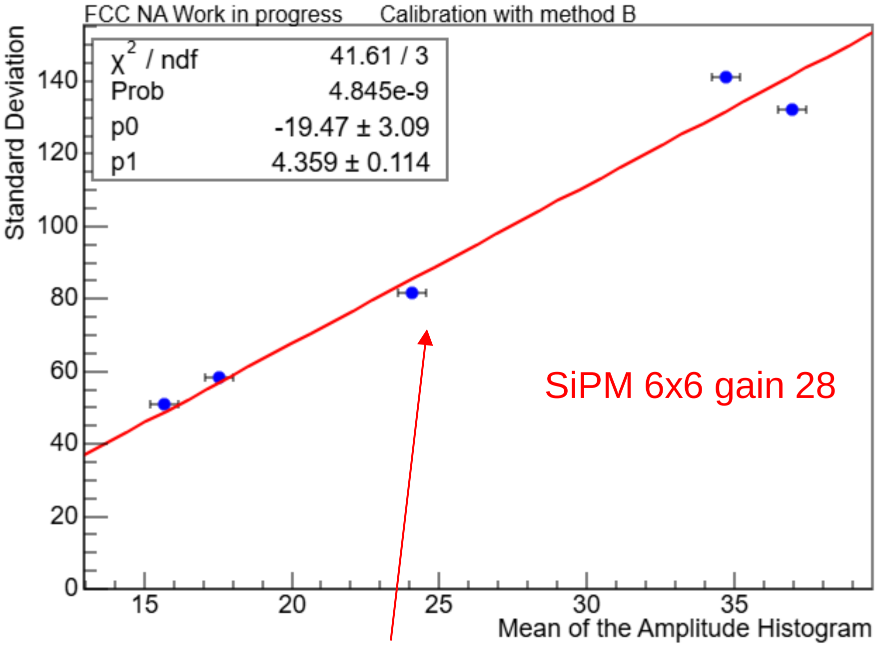
PLP LED Method A

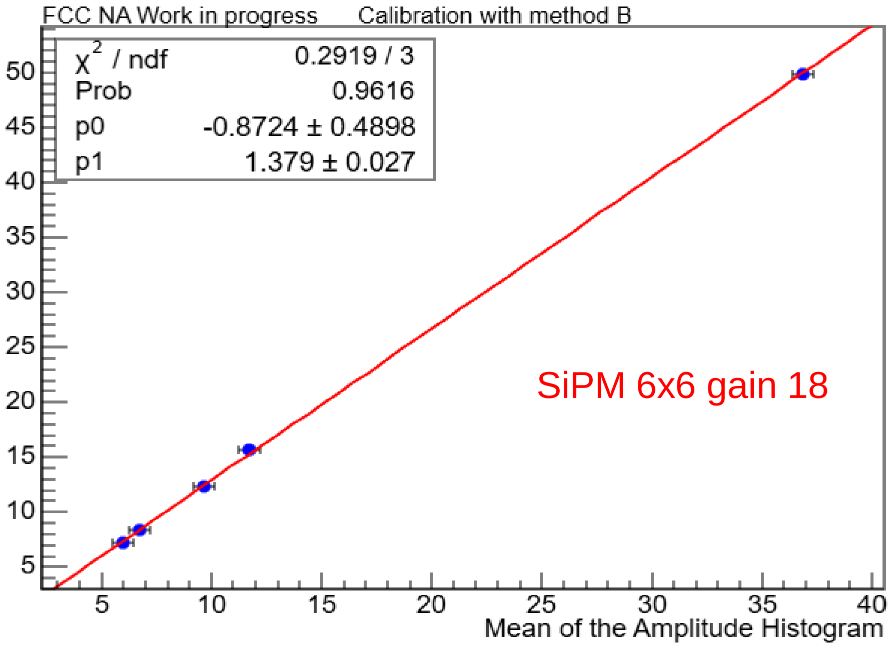
SiPM	Gain	Led power	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]
6x6	28	15	3,7 ±0,2	3,36±0,02
6x6	28	6	0,45±0,1	3,33±0,02
6x6	18	15	-	-
6x6	18	6	0,20±0,06	1,25±0,01

LED CAEN

SiPM	Gain	Method	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]
6x6	28	A	0,4±0,1	3,46±0,02
6x6	28	B	15±1	3,49±0,006
6x6	18	A	1,31±0,06	1,161±0,005
6x6	18	B	3,0±0,4	1,156±0,003
6x6	24	A	0,20±0,05	2,27±0,01
6x6	24	B	17,5±0,7	2,169±0,003

SiPM 6x6 Calibration with PLP Led few photons with method B



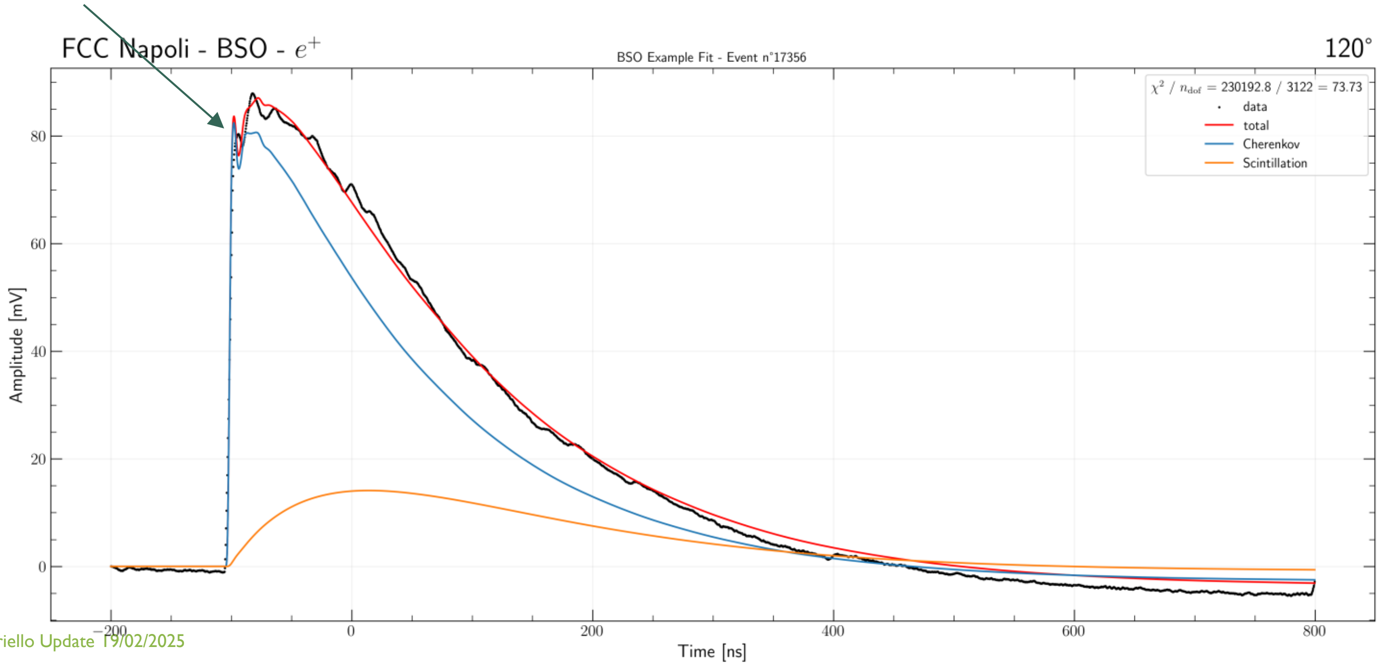


I am working on trying to understand why this trend

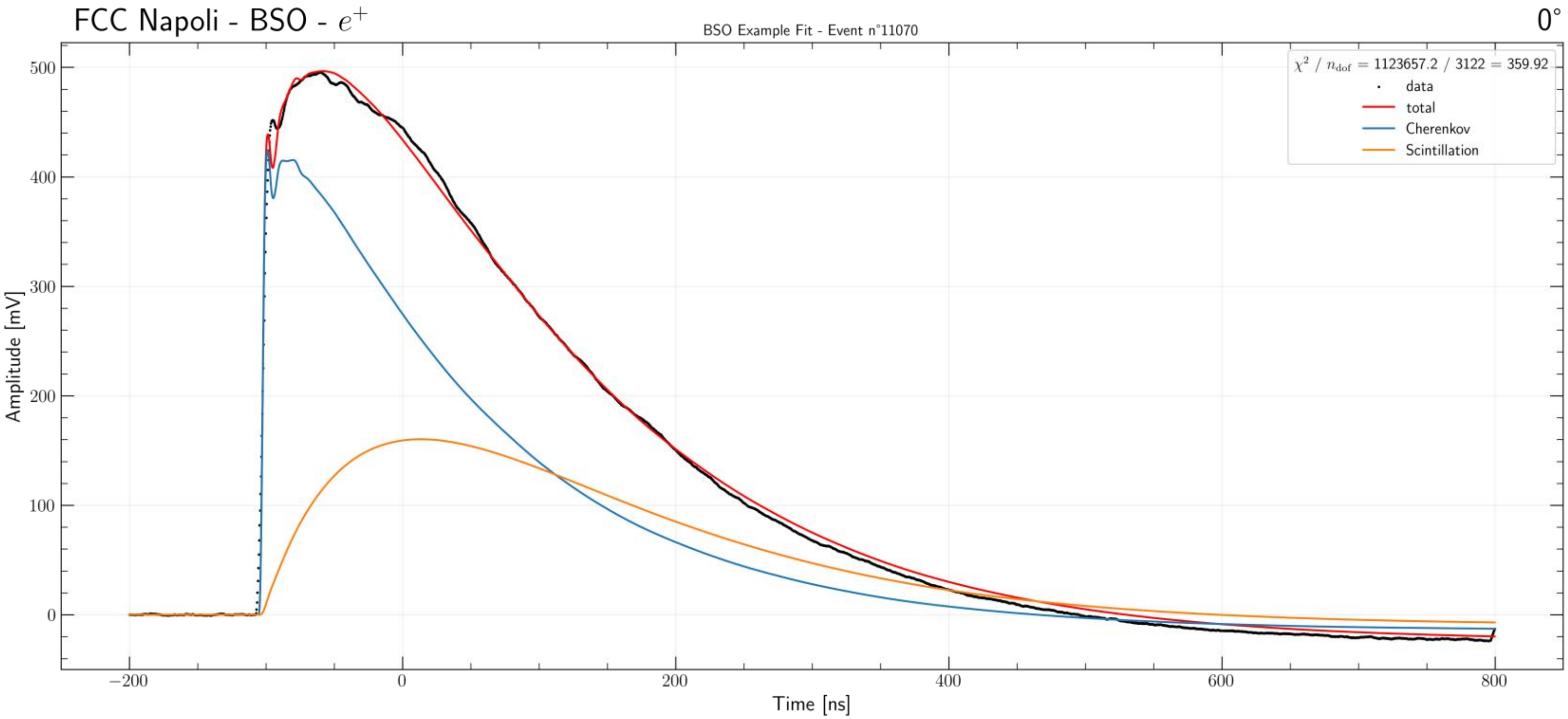
Using Template for fit the single waveforms of BSO

-We used as template the shape obtained with the PLP laser with many photons + the characteristic exponentials for cherenkov and scintillation, see Giovanni's presentation for more details on the template

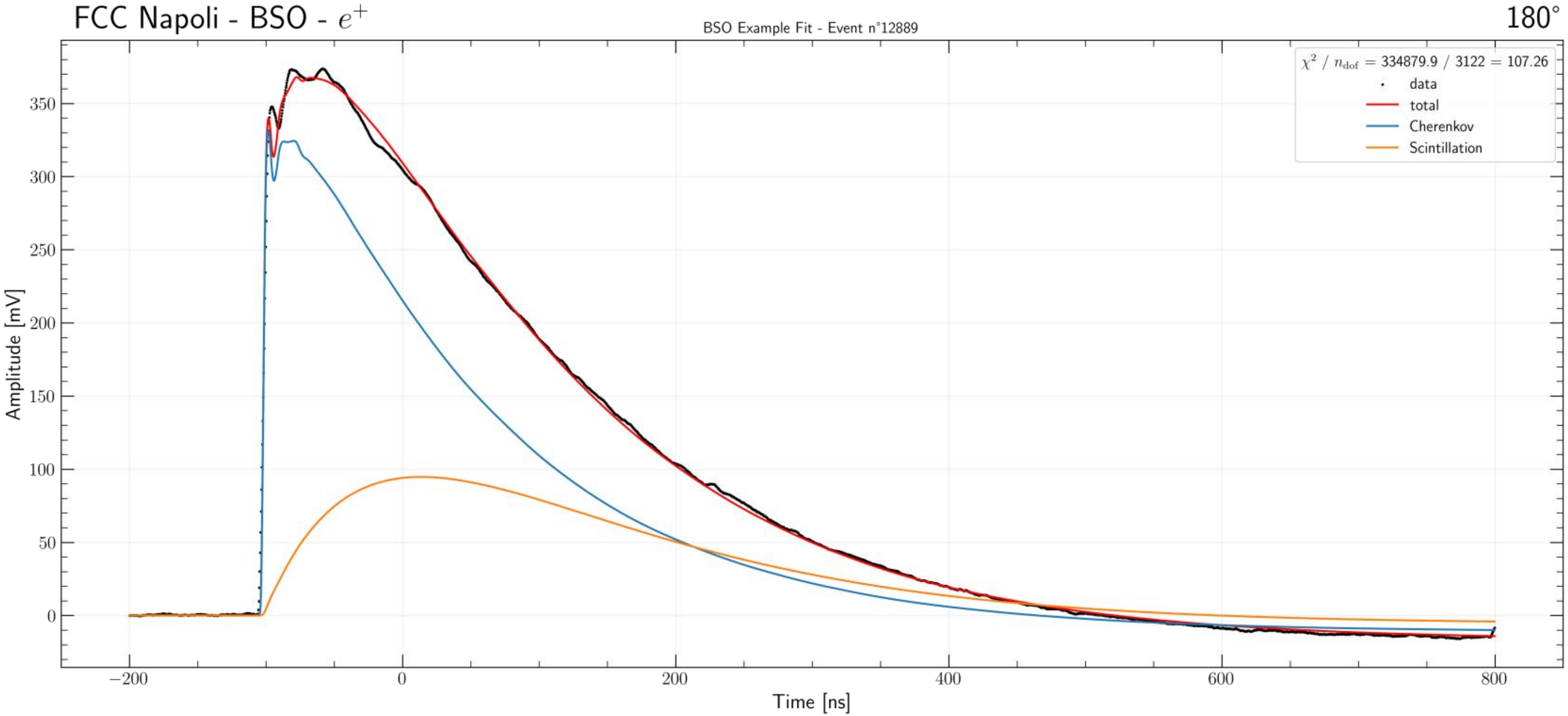
-as can be seen, the peak of the data seems to have shifted with respect to our template



Using Template for fit the waveforms of BSO



Using Template for fit the waveforms of BSO

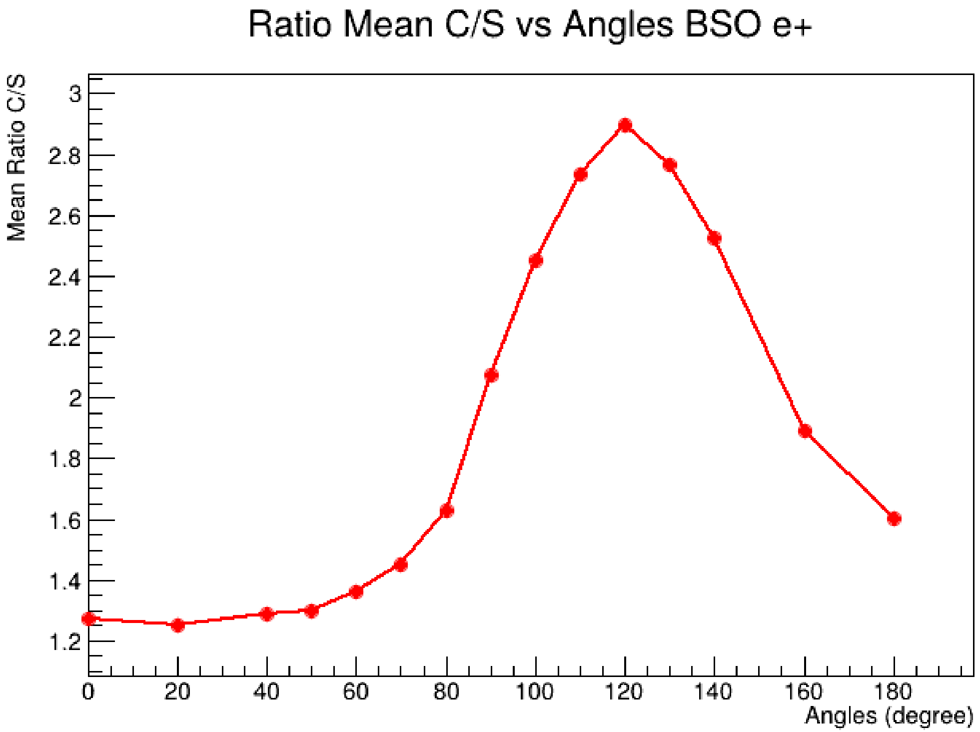


Study of the Ratio of C/S on Angle Scan for Ch2

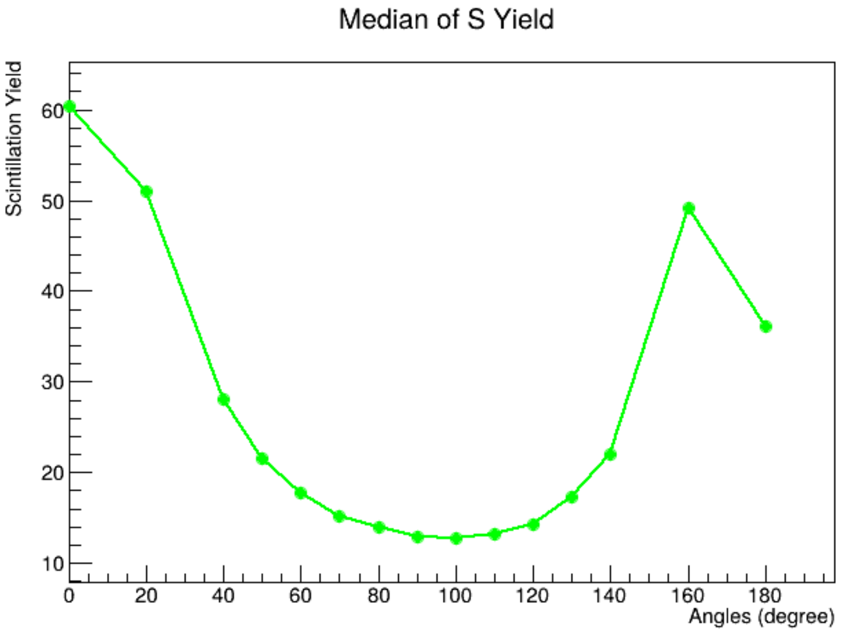
I perform the fit with the template for all the run of BSO with e+, and the result is the expetted shape

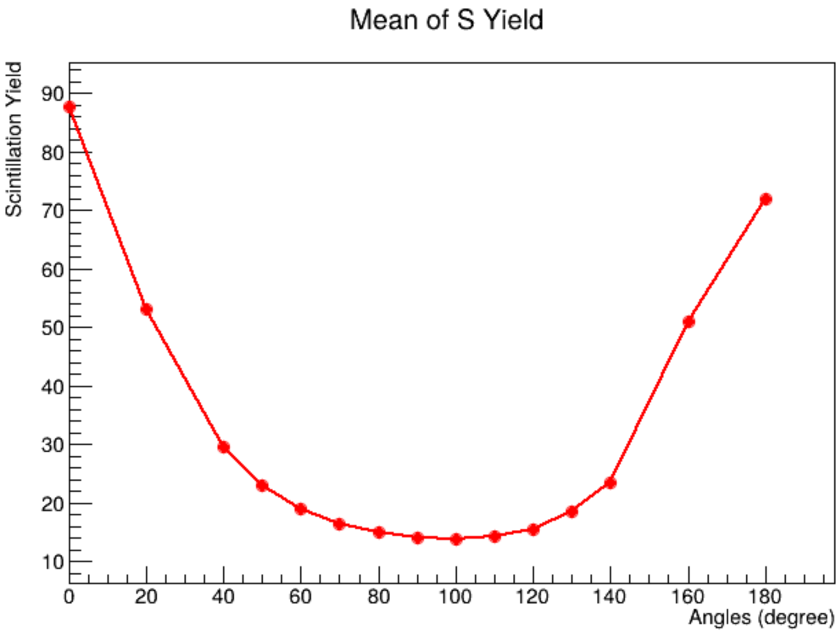
With a peak at 120° , cherenkov emission angle

Giovanni is working on the BGO with e+



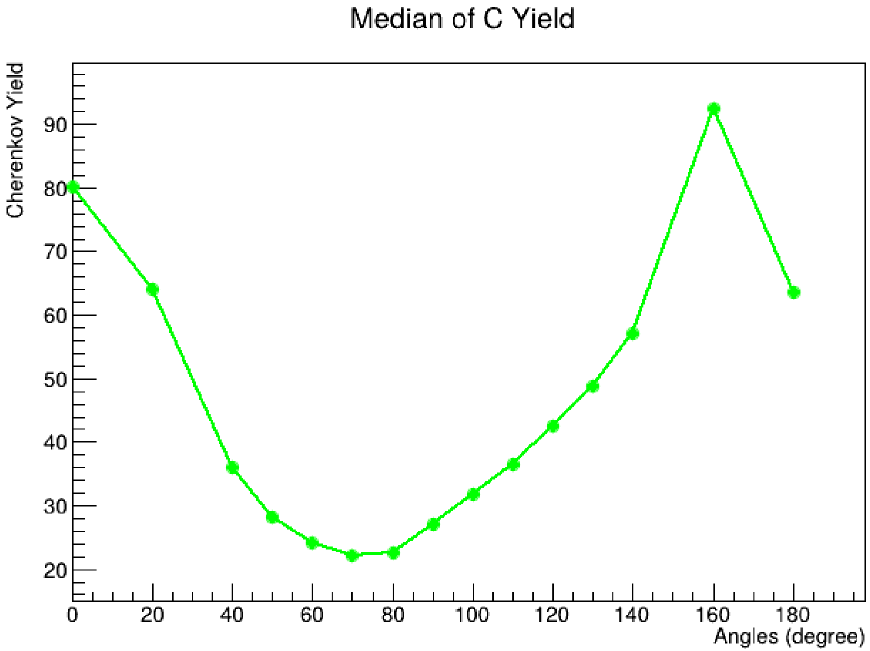
Study of the Scintillation Yield on Angle Scan for Ch2

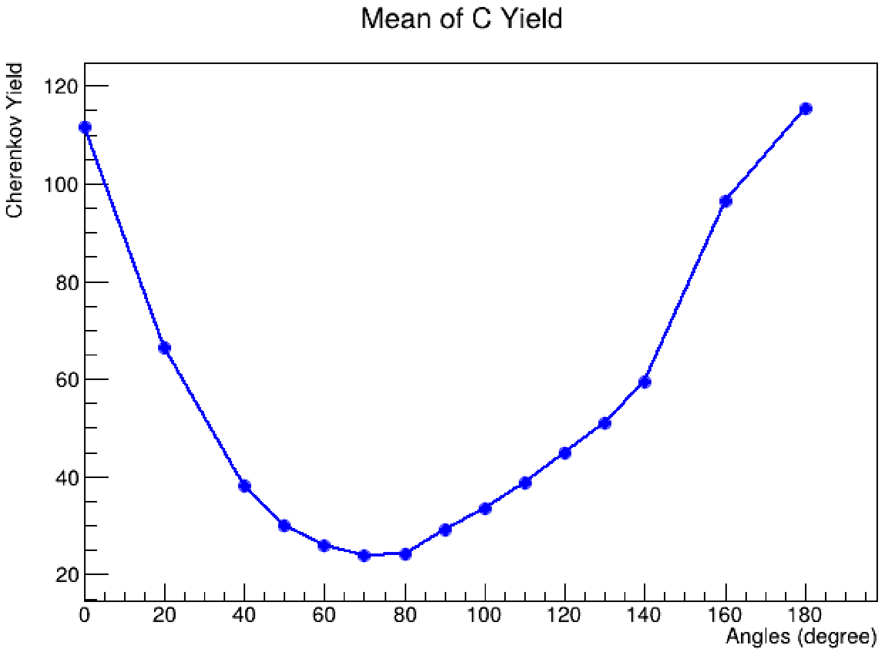




I perform the median (on the left) anche the mean (on the right), the expected U-shape is observed, except in the case of the median, where a reduction in the number of photons is observed at 180°.

Study of the Cherenkov Yield on Angle Scan for Ch2



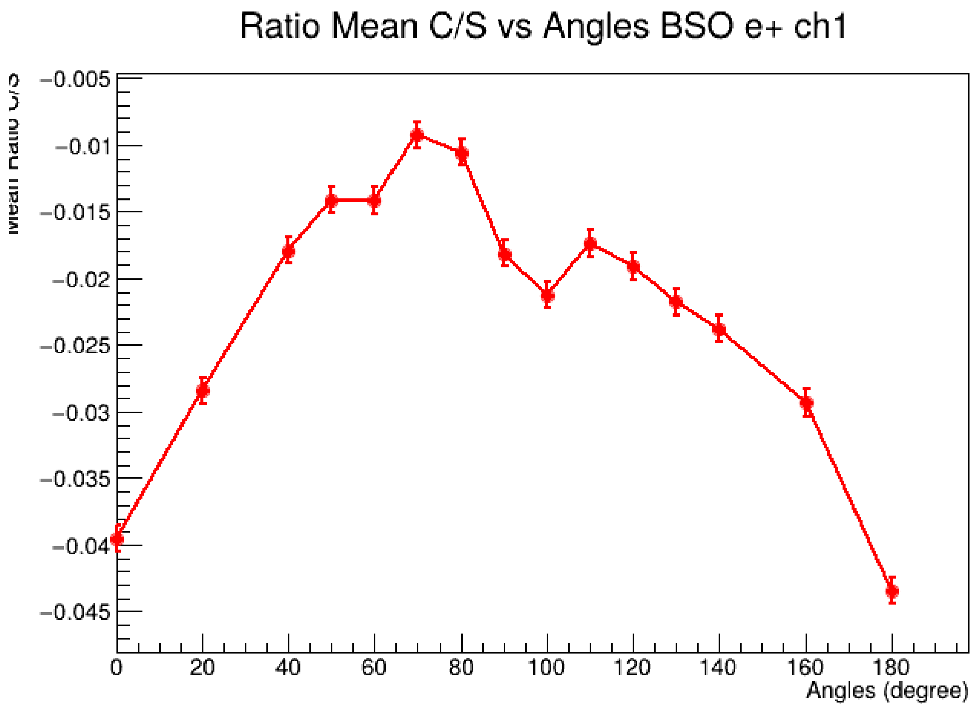


I perform the median (on the left) anche the mean (on the right), the expected U-shape is observed, except in the case of the median, where a reduction in the number of photons is observed at 180°.

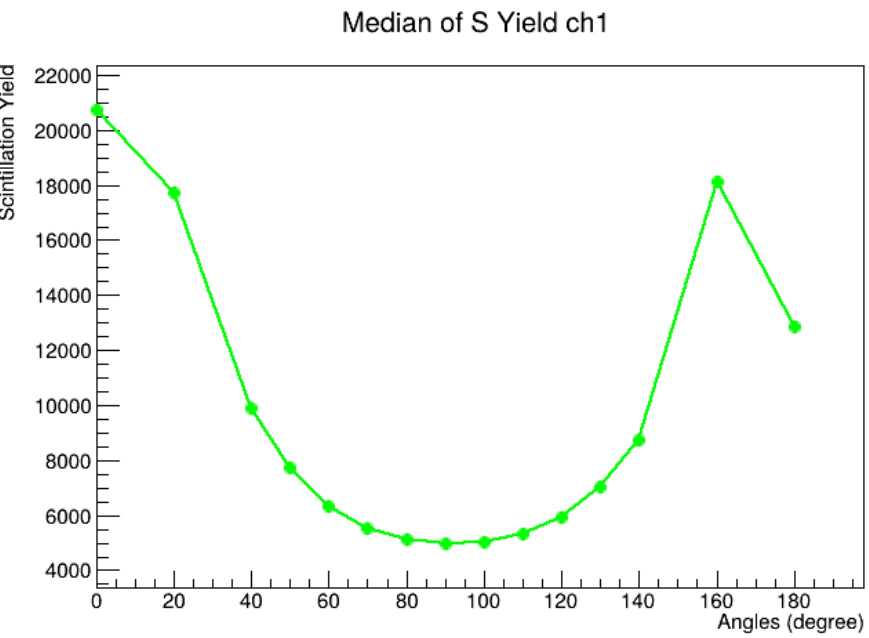
Study of the Ratio of C/S on Angle Scan for Ch1

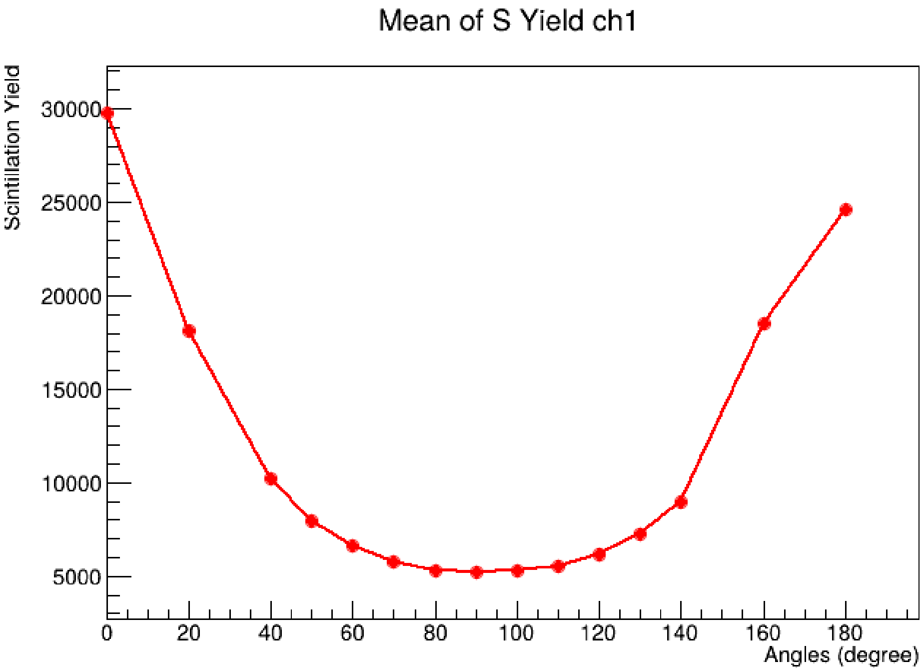
I perform the fit with the template for all the run of BSO with e+ for ch1

With a peak at 70° , and a smaller peak at ~120° cherenkov emission angle



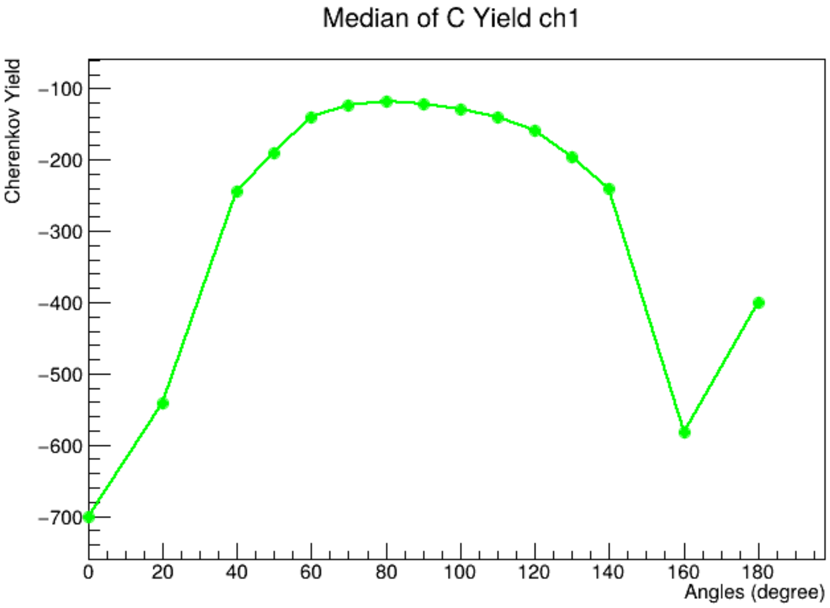
Study of the Scintillation Yield on Angle Scan for Ch1

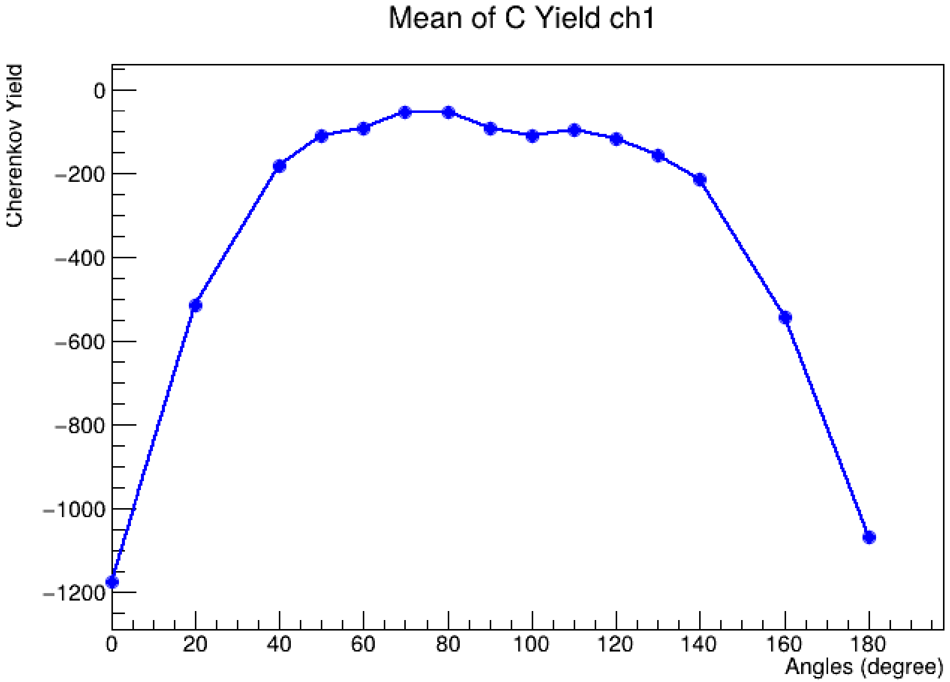




I perform the median (on the left) anche the mean (on the right), the expected U-shape is observed, except in the case of the median, where a reduction in the number of photons is observed at 180°.

Study of the Cherenkov Yield on Angle Scan for Ch2

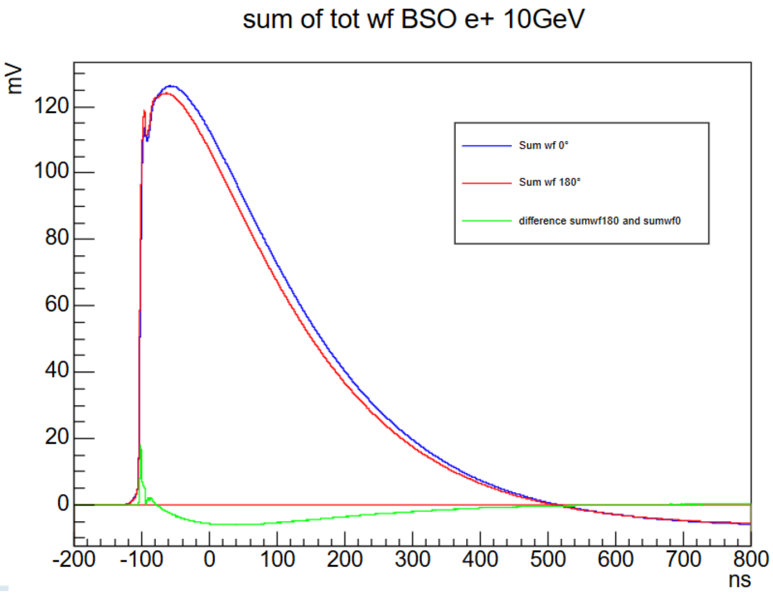




I perform the median (on the left) anche the mean (on the right), an unexpected inverted U-shape is observed

Backup Slides

Signal extraction Strategy of November-Dicember 2024 with our CAEN led driver



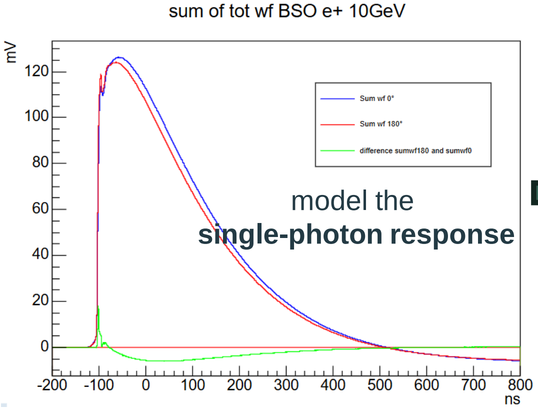
In figure: sum of all waveforms at 0° and 180°:
→ proxy of what the "average" response looks like

→ We want to model the shape as function of the **single photon shape** and characteristic scintillation time, with C photons considered prompt.

→ Once that is done **we fit the waveform and extract C and S components**

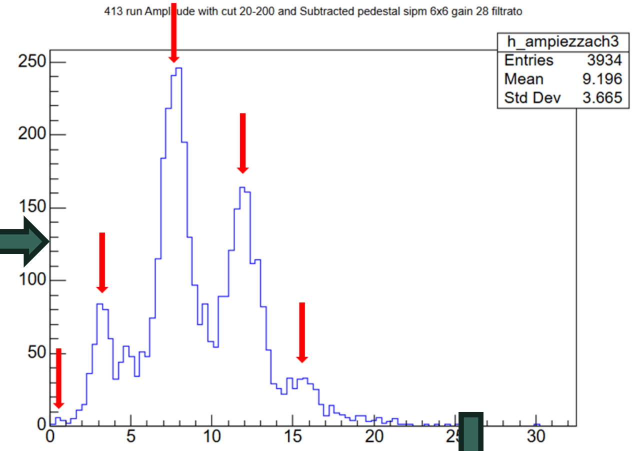
→ We need to model the **single-photon response**!

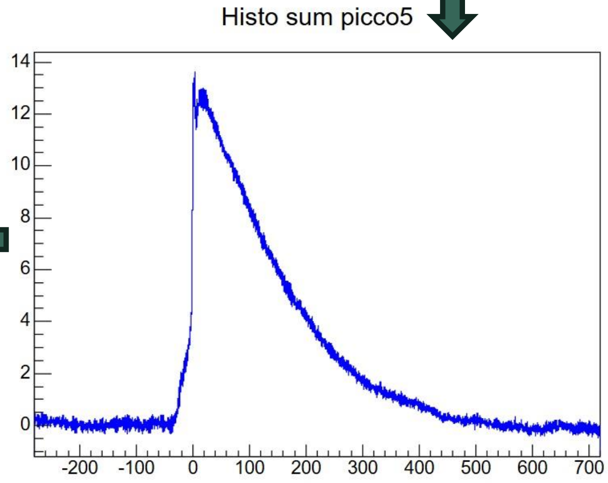
Signal extraction Strategy

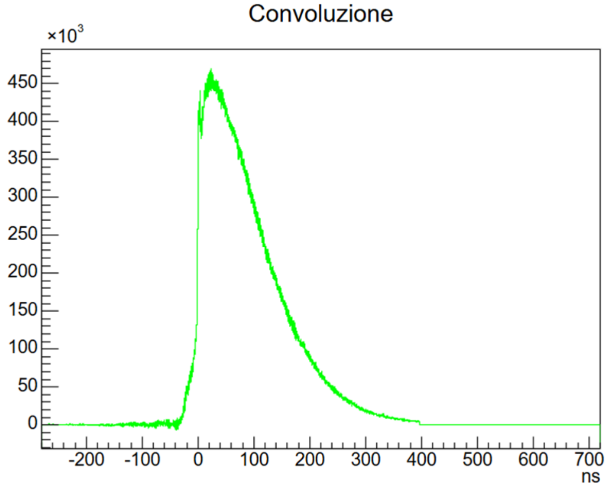


model the **single-photon response**

“Dark” measurement:
I have studied the amplitudes of the wf,there is the presence of 5 distinct peaks.
Then what I did was to study the wf corresponding to these 5 peaks and I made the average wf for each peak



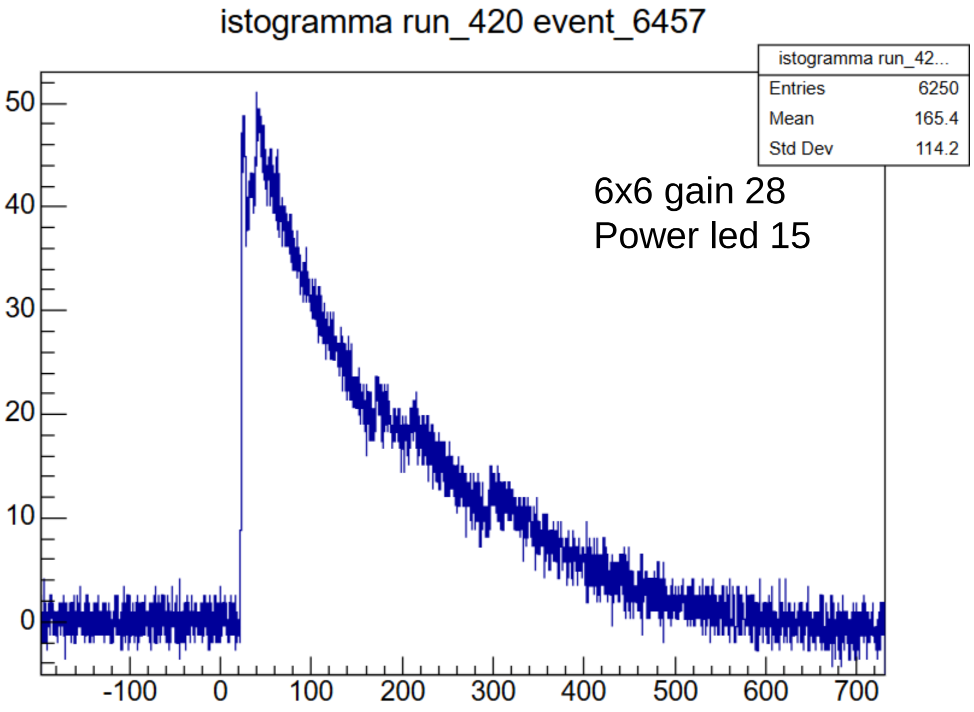




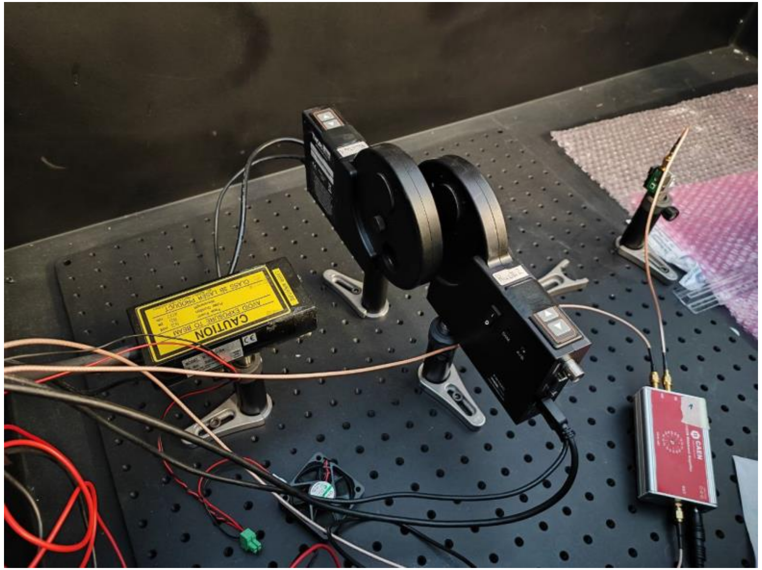
I used for the convolution the shape of the average wf for peak 5 of the dark measurements + an exponential that represent time of fall of BSO

Now: Measurements with Picoseconds light pulser Guarino's LAB

- I made measurements with the PLP laser for the SiPM 6x6 at the gain configurations used at the test beam



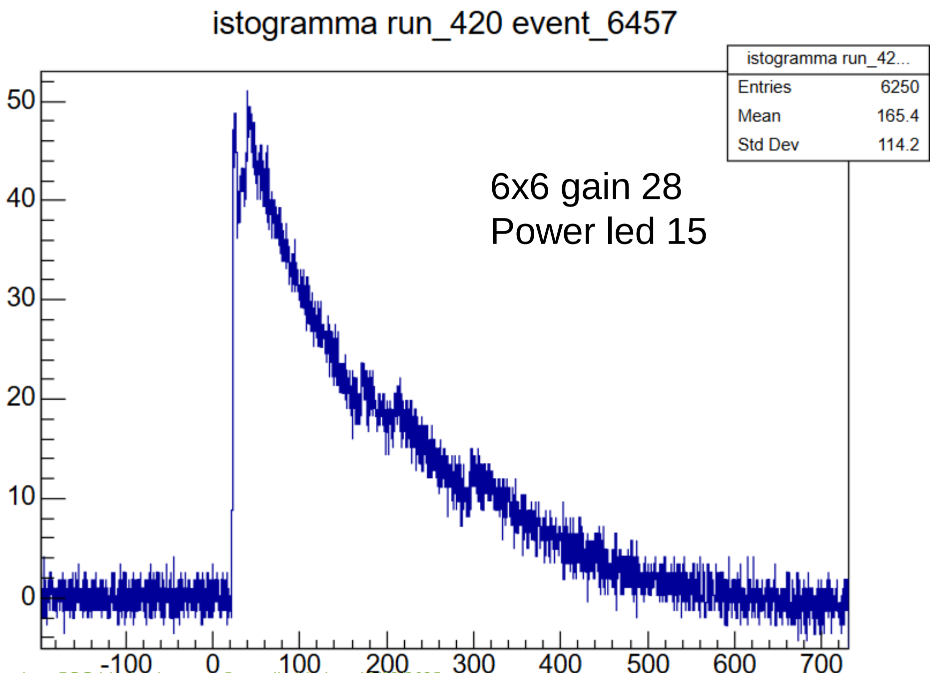
6x6 gain 28
Power led 15

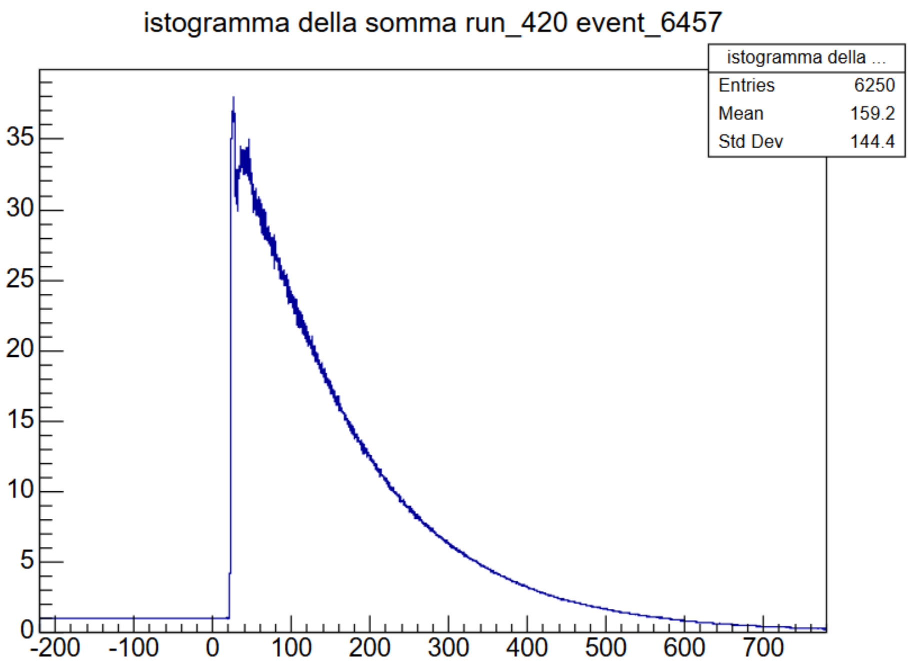


Measurements with Picoseconds light pulser

- I made measurements with the PLP laser for the SiPM 6x6 at the gain configurations used at the test beam
- Here we are in a range of ~9 photons

SiPM	Gain	Gain amplitude conversion	Method	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]
6x6	28	25,12	A	0,4±0,1	3,46±0,02
6x6	28		B	15±1	3,49±0,006

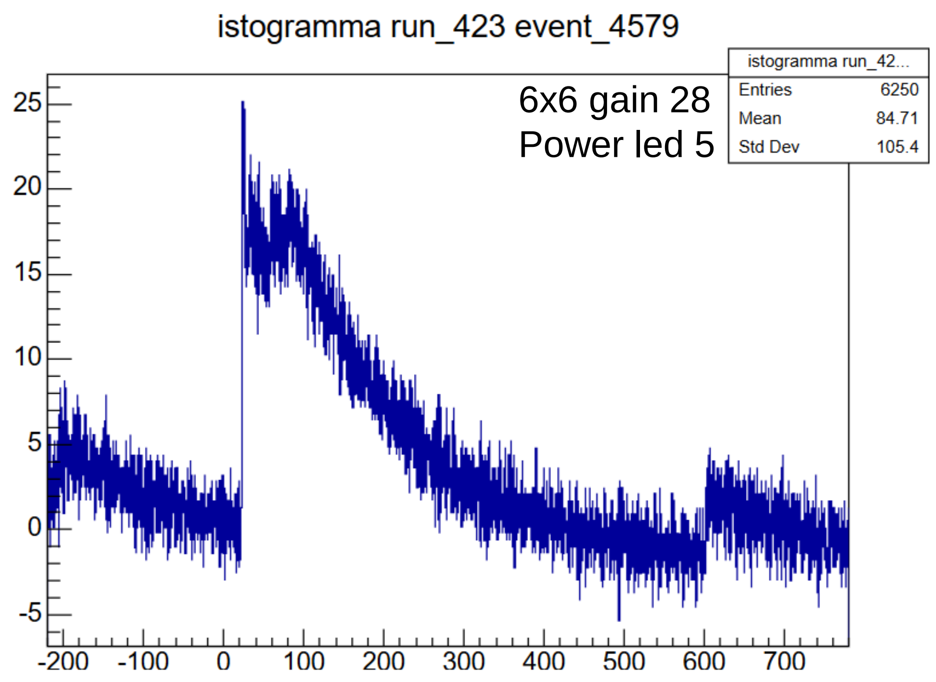


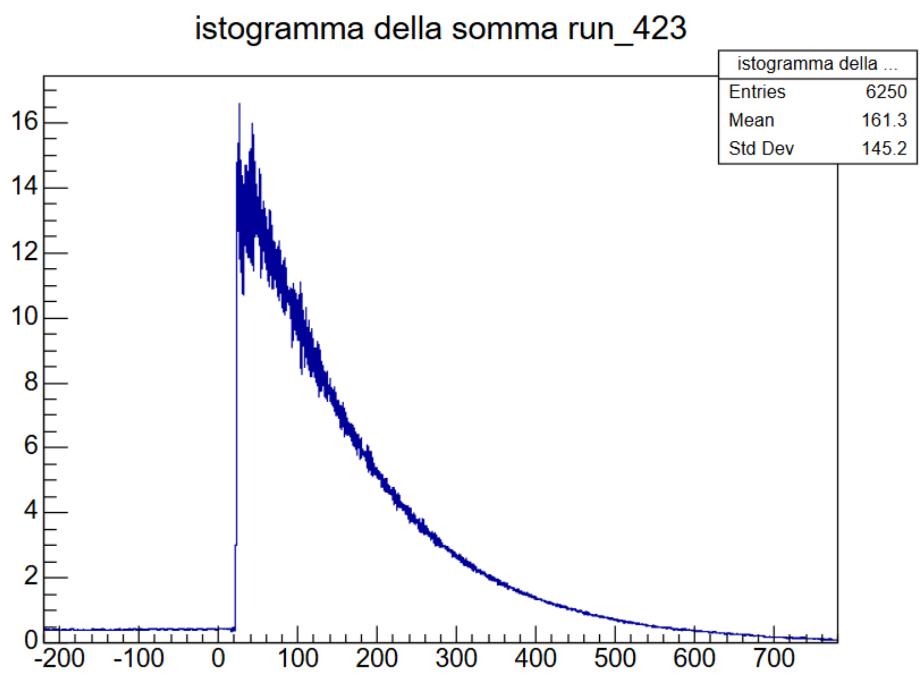


Measurements with Picoseconds light pulser

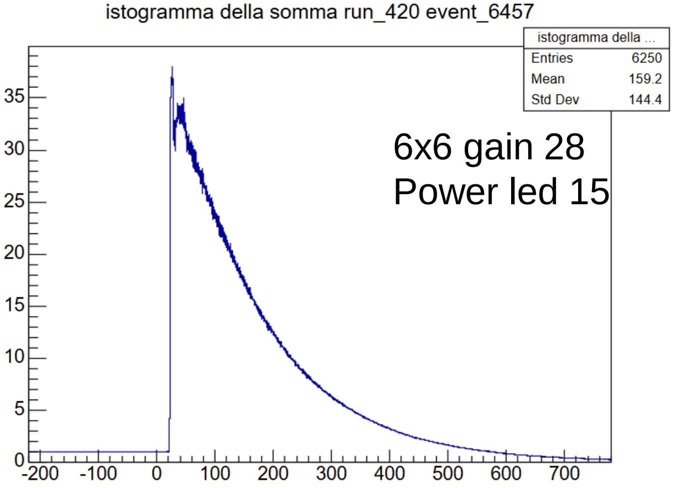
- I made measurements with this laser for the SiPM 6x6 at the gain configurations used at the test beam
- Here we are in a range of ~4 photons

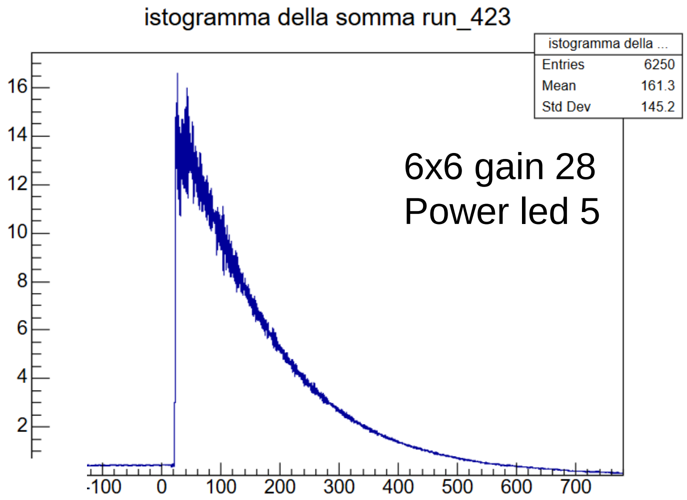
SiPM	Gain	Gain amplitude conversion	Method	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]
6x6	28	25,12	A	0,4±0,1	3,46±0,02
6x6	28		B	15±1	3,49±0,006

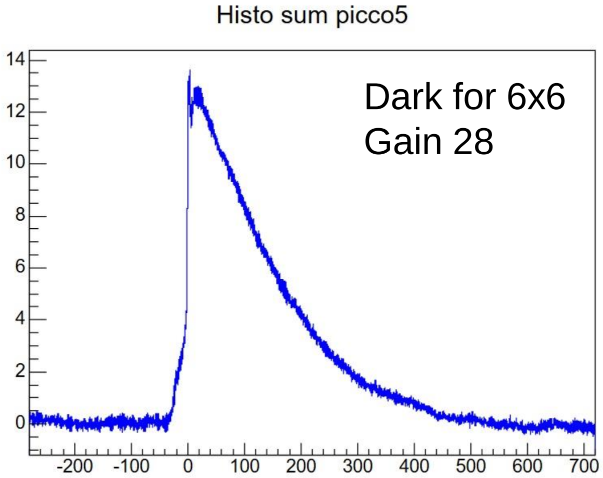




Preliminary Measurement Comparison



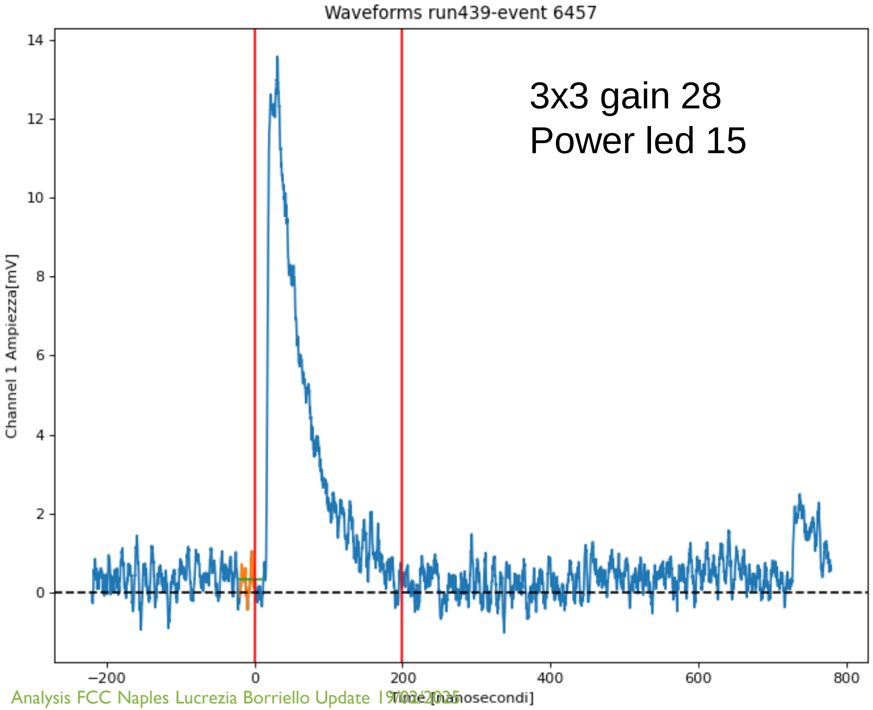


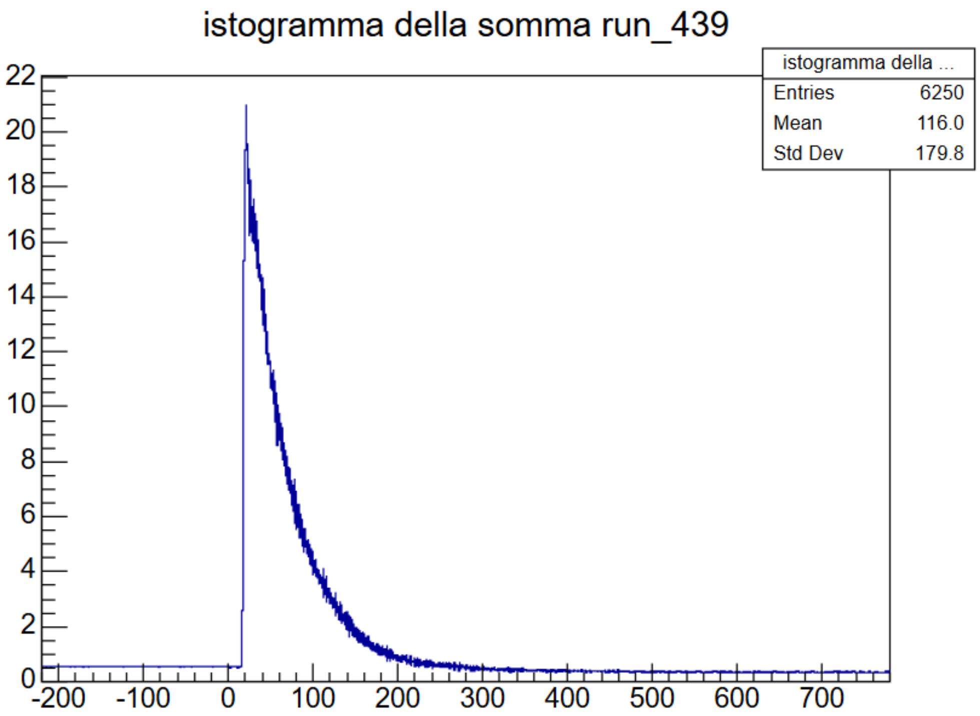


Measurements with Picoseconds light pulser

- I made measurements with the PLP laser for the SiPM 3x3 at the gain configurations used at the test beam
- Here we are in a range of ~20 photons

SiPM	Gain	Gain amplitude conversion	Method	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]
3x3	28	25,12	B	-1,4±0,4	1,236±0,002

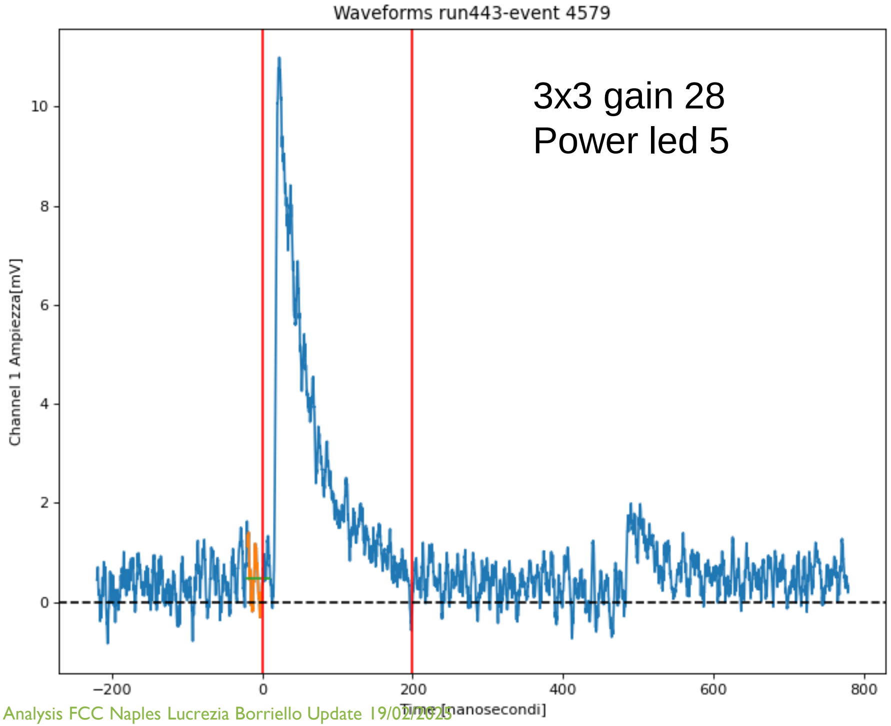


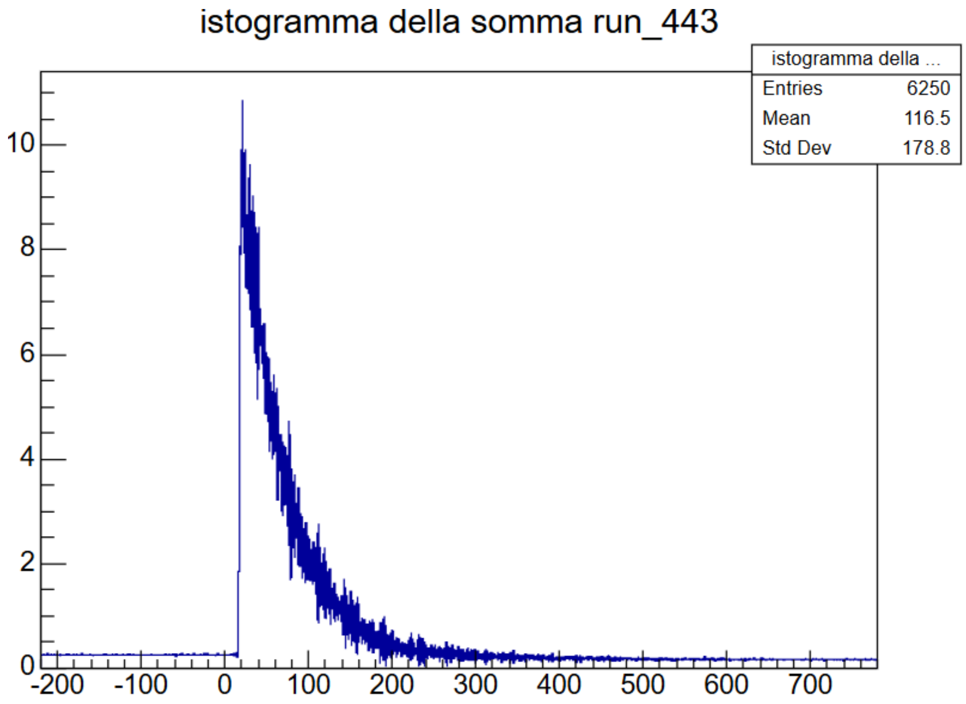


Measurements with Picoseconds light pulser

- I made measurements with the PLP laser for the SiPM 3x3 at the gain configurations used at the test beam
- Here we are in a range of ~10 photons

SiPM	Gain	Gain amplitude conversion	Method	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]
3x3	28	25,12	B	-1,4±0,4	1,236±0,002

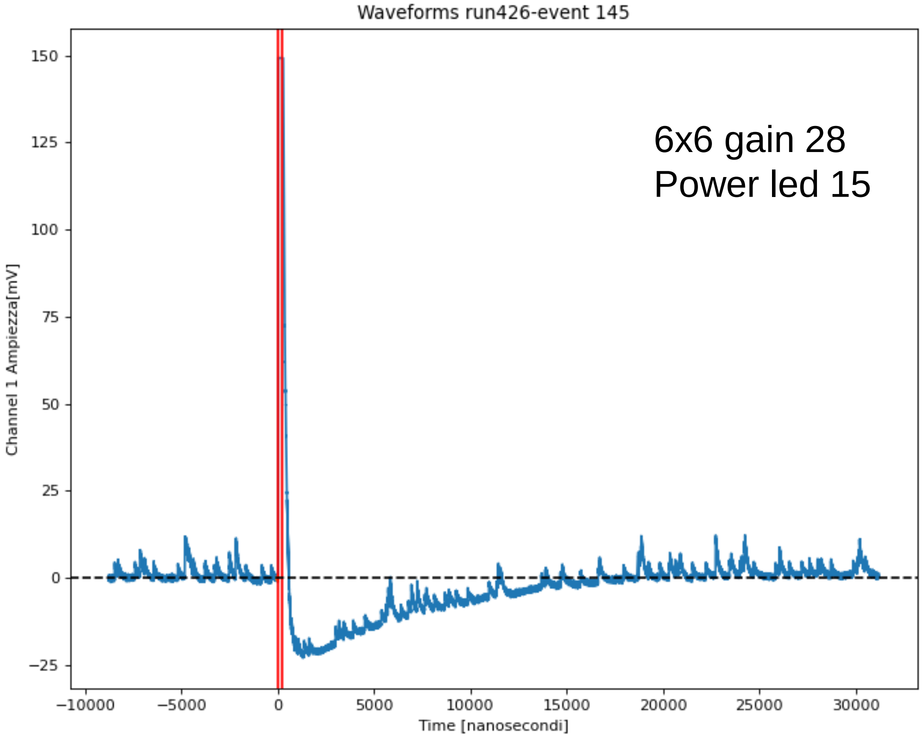




Undershoot Measurements with Picoseconds light pulser

- I made measurements of the undershoot of the sipm with the PLP laser for the SiPM 6x6 and 3x3 at the gain configurations used at the test beam

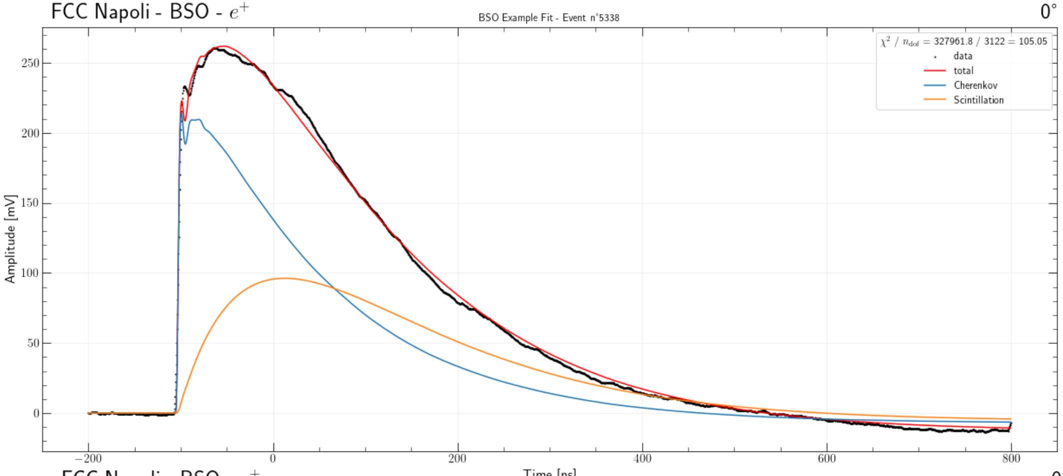
- Undershoot in a SiPM occurs in the electrical signal produced by the device. After the main signal peak, the signal may show a descent below the baseline level before gradually stabilising again.



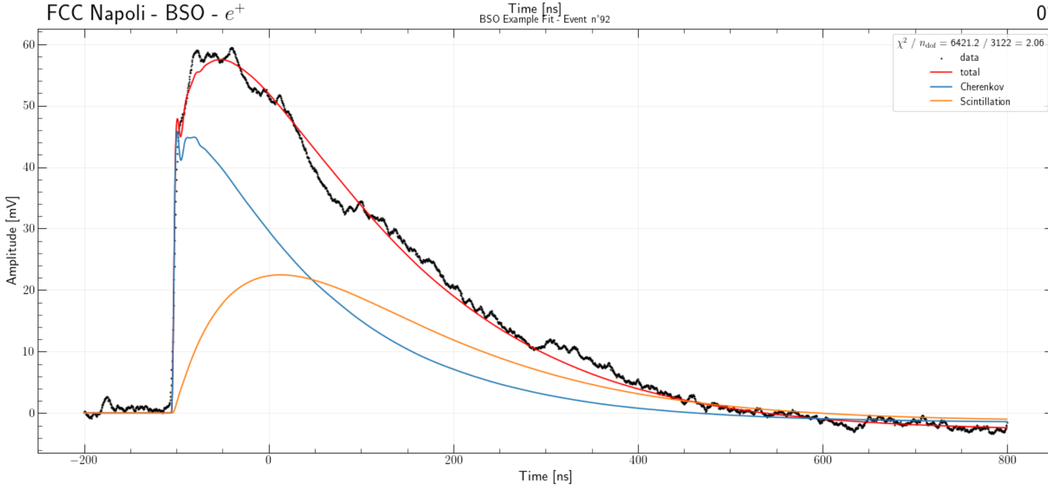
Summary of PLP Measurements

20/01/2025	sipm 6x6	preamp 2			
misure led PLP	run	gain	configurazione le	power	t
	417	28	nn	15	
misura undershoot	419	28	2x5	15	r
	420	28	4x5	15	
	421	28	4x5	10	
	422	28	4x5	6	
	423	28	4x5	5	
	sipm 6x6	gain			
ho ripreso una misu	436	28	4x5	13	
21/01/2025	sipm 6x6	preamp 2			
misure led PLP	run	gain	configurazione le	power	t
molti fotoni	424	28	3x5	15	
ancora più fotoni	425	28	3x3	15	
misura undershoot	426	28	3x3	15	
molti fotoni	427	18	3x3	15	
ancora più fotoni	428	18	2x3	15	
ritorno a pochi fotor	429	18	4x5	15	
	430	18	4x4	15	
	431	18	4x5	10	
	432	18	4x5	6	
	433	18	4x5	5	
	434	18	4x5	13	
misura undershoot	435	18	6x2	15	

	sipm 3x3	preamp 1			
misure led PLP	run	gain	configurazione le	power	trigger led PLP
~30 fotoni	439	28	3x4	15	
	440	28	3x4	13	
	441	28	3x4	10	
	442	28	3x4	6	
	443	28	3x4	5	
~100 fotoni	444	28	1x2	15	
undershoot	445	28	1x2	15	
~70 fotoni	446	18	1x2	15	
~30 fotoni	447	18	2x4	15	
	448	18	3x4	15	
	449	18	3x4	13	
	450	18	3x4	10	
	451	18	3x4	6	
	452	18	3x4	5	
undershoot	453	18	1x2	15	
	sipm 3x3	preamp passivo			
misure led PLP	run	gain	configurazione le	power	trigger led PLP
in teoria massimi fo	454	-	1x2	15	
	455	-	1x2	13	
	456	-	1x2	10	
	457		1x2	6	
	458		1x2	5	

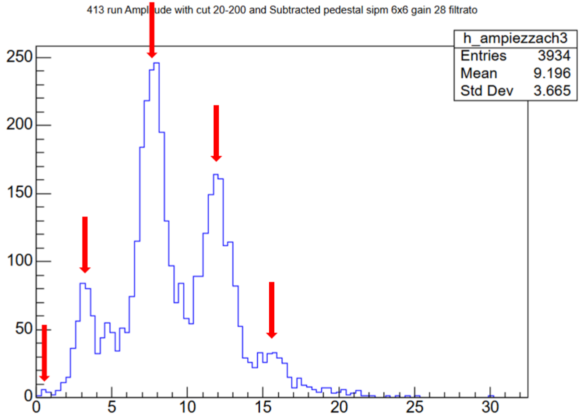


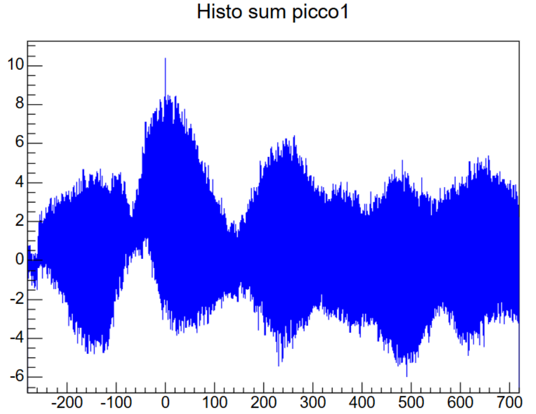
FCC Napoli - BSO - e^+
BSO Example Fit - Event n°5338
0°
χ^2 / n_{dof} = 327961.8 / 3122 = 105.05
data
total
Cherenkov
Scintillation
Amplitude [mV]
Time [ns]

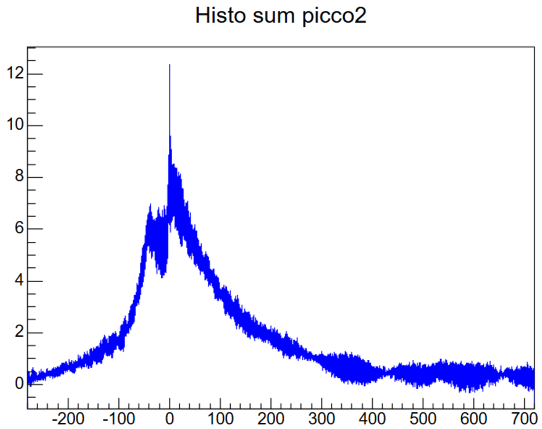


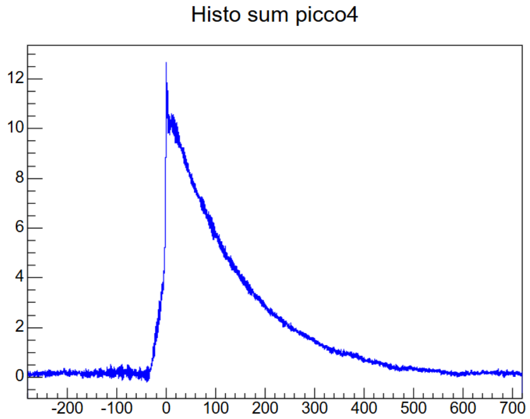
FCC Napoli - BSO - e^+
BSO Example Fit - Event n°92
0
χ^2 / n_{dof} = 6421.2 / 3122 = 2.06
data
total
Cherenkov
Scintillation
Amplitude [mV]
Time [ns]

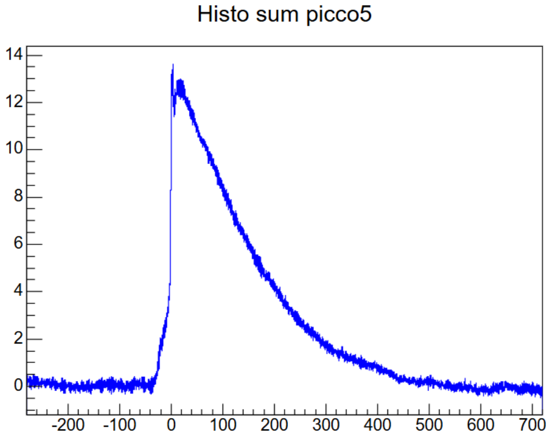
dark measurements for single-photon resolution studies sipm 6x6 gain 28

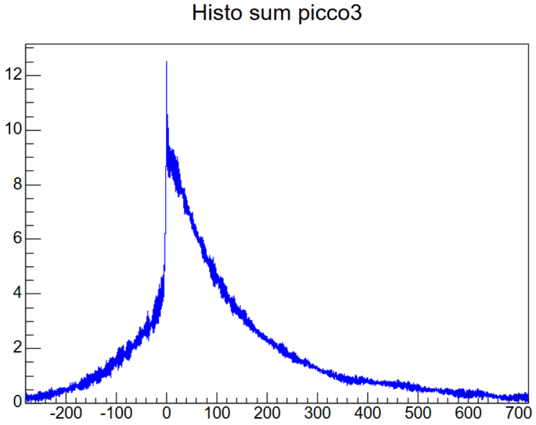








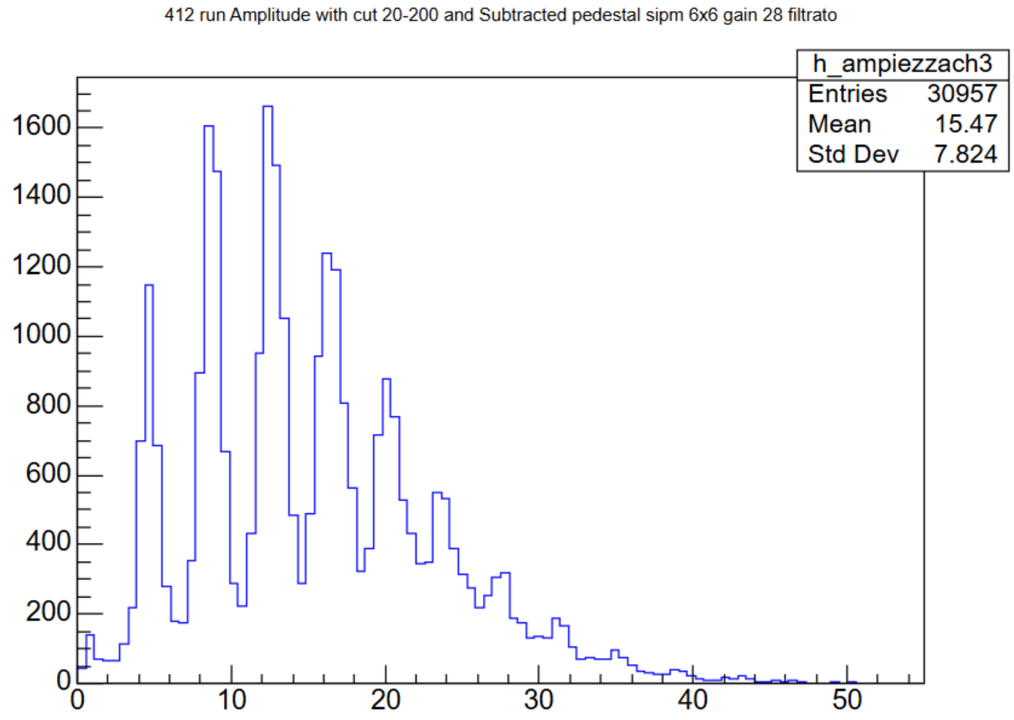




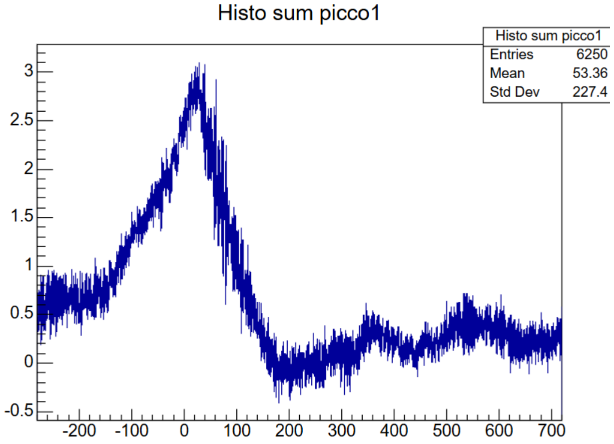
Measurements with frequency led 6

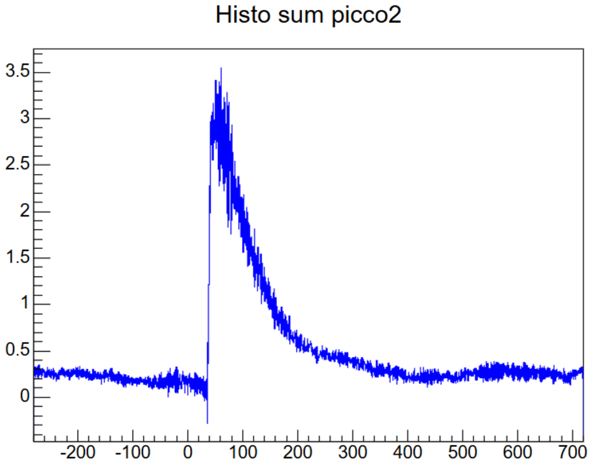
I have studied the amplitudes of the wf, what is observed is the presence of 10 distinct peaks.

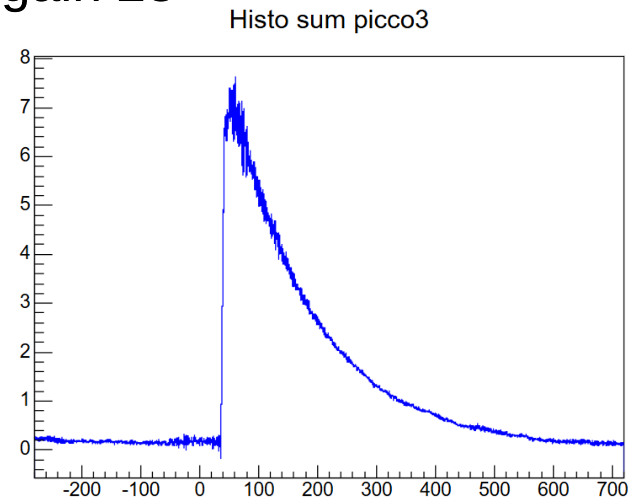
Then what I did was to study the wf corresponding to these 10 peaks and I made the average wf for each peak



Measurements with frequency led 6 for SiPM 6x6 gain 28

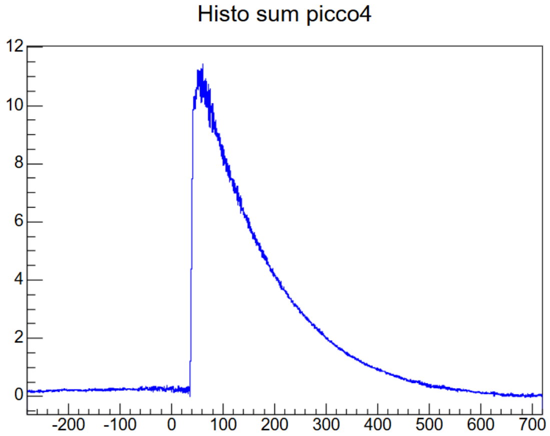


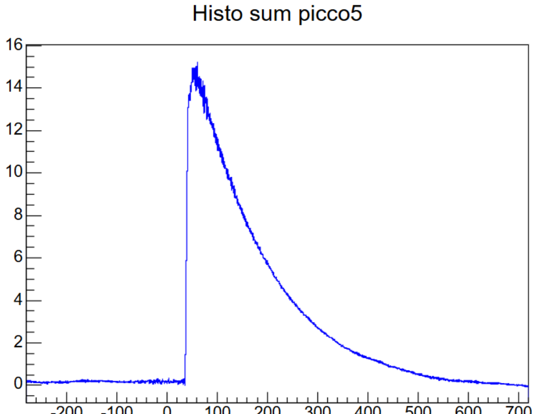




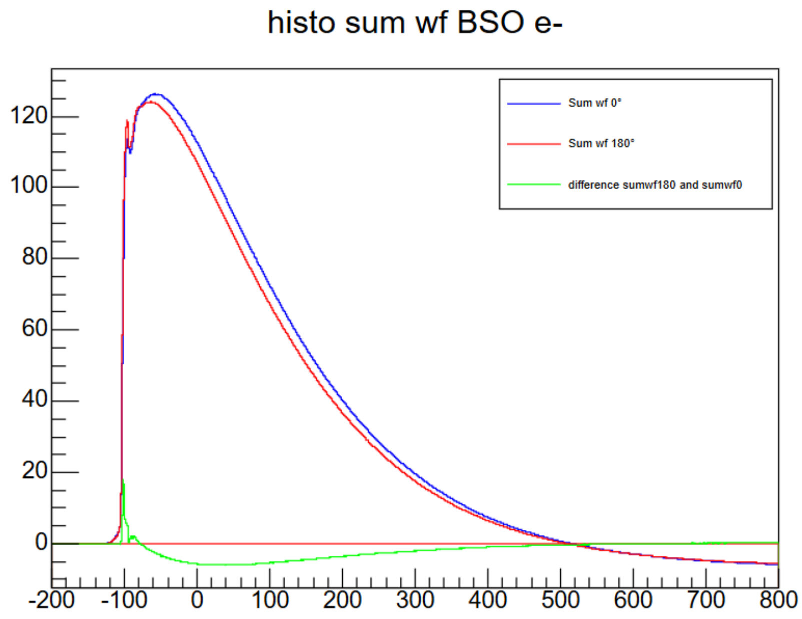
In this case we see that there is no presence, as in the case of the dark, of the initial peak.

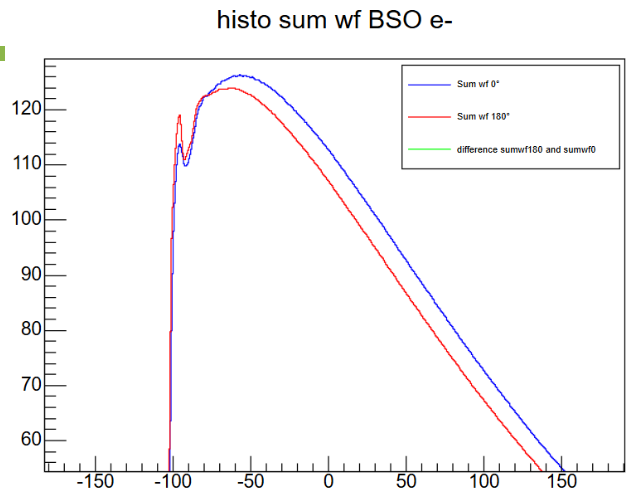
This may be due to the led

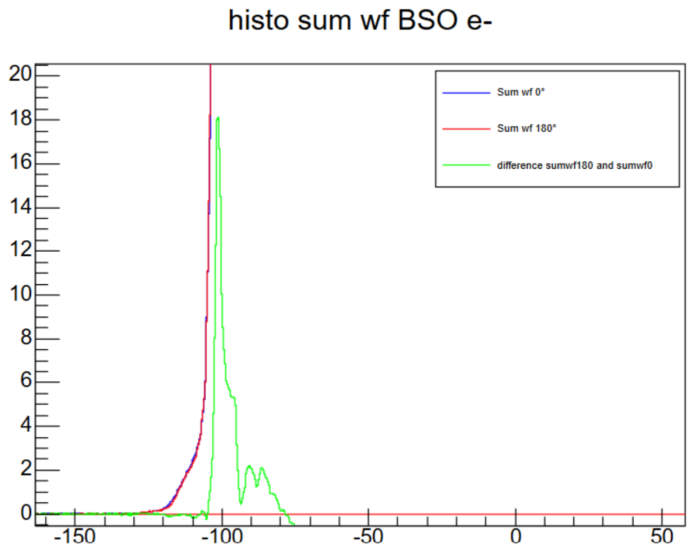




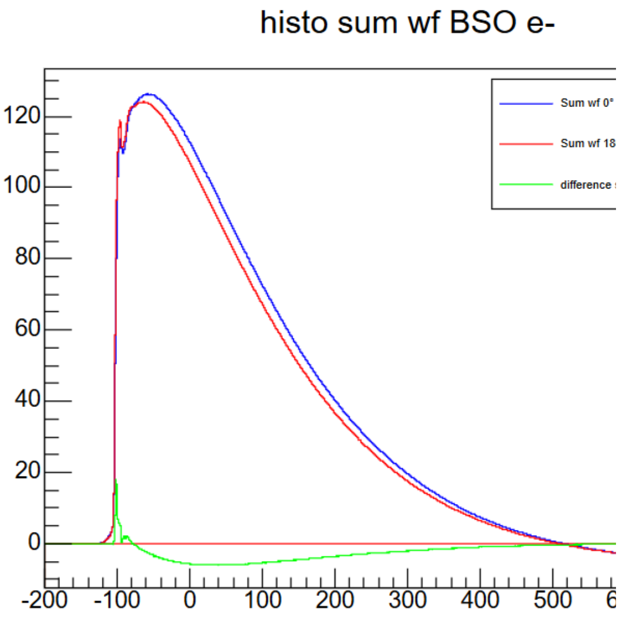
Waveform study for the BSO with e+10GeV

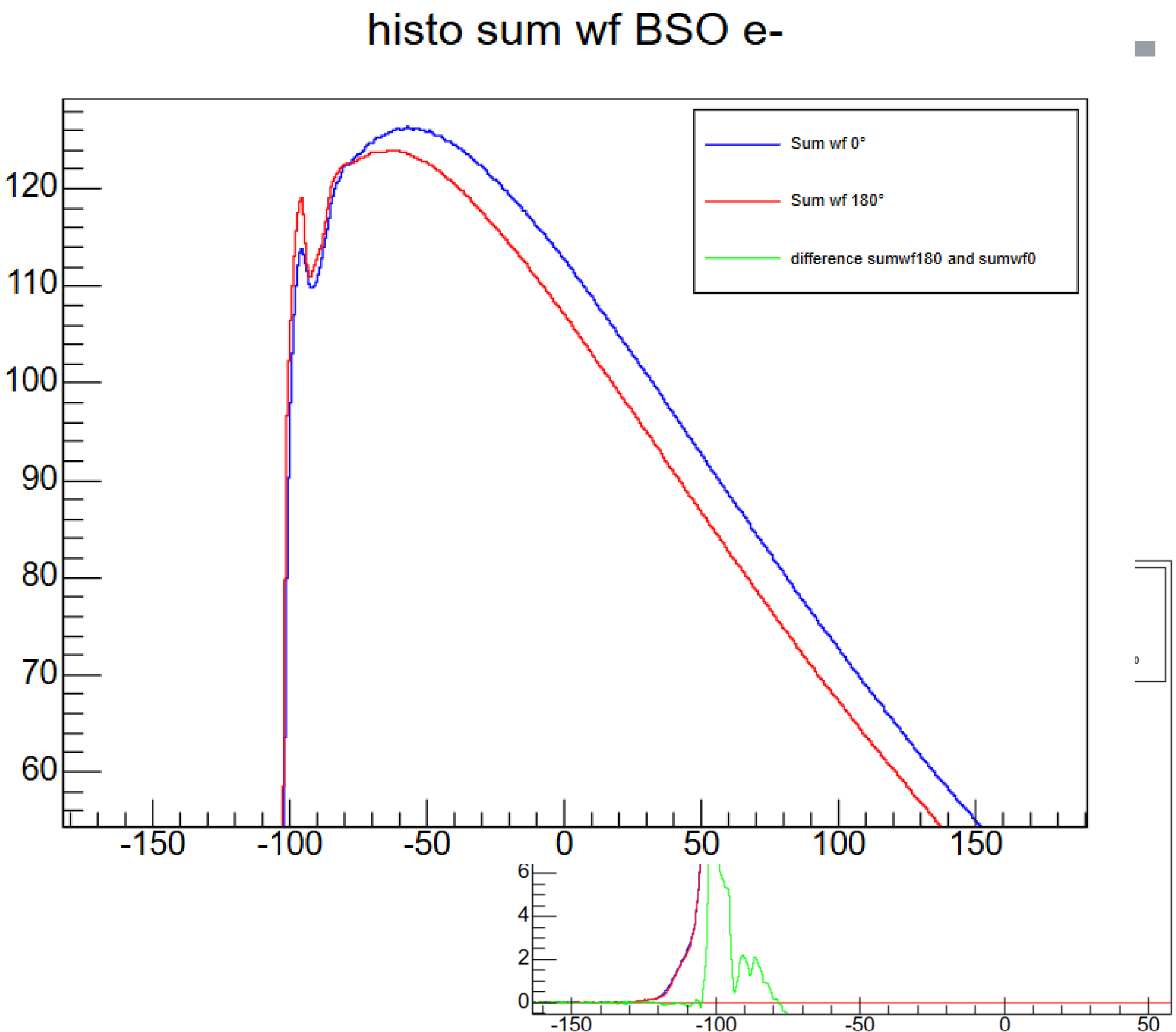




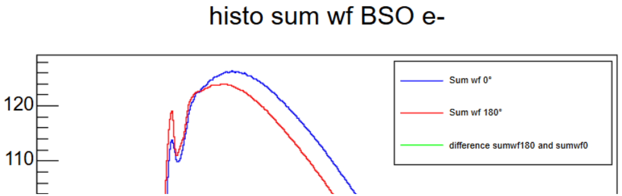


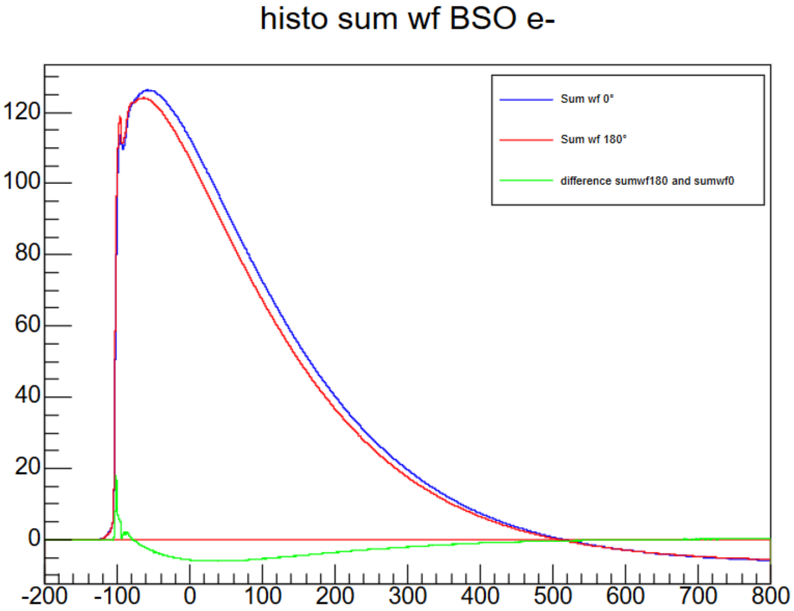
Waveform study for the B

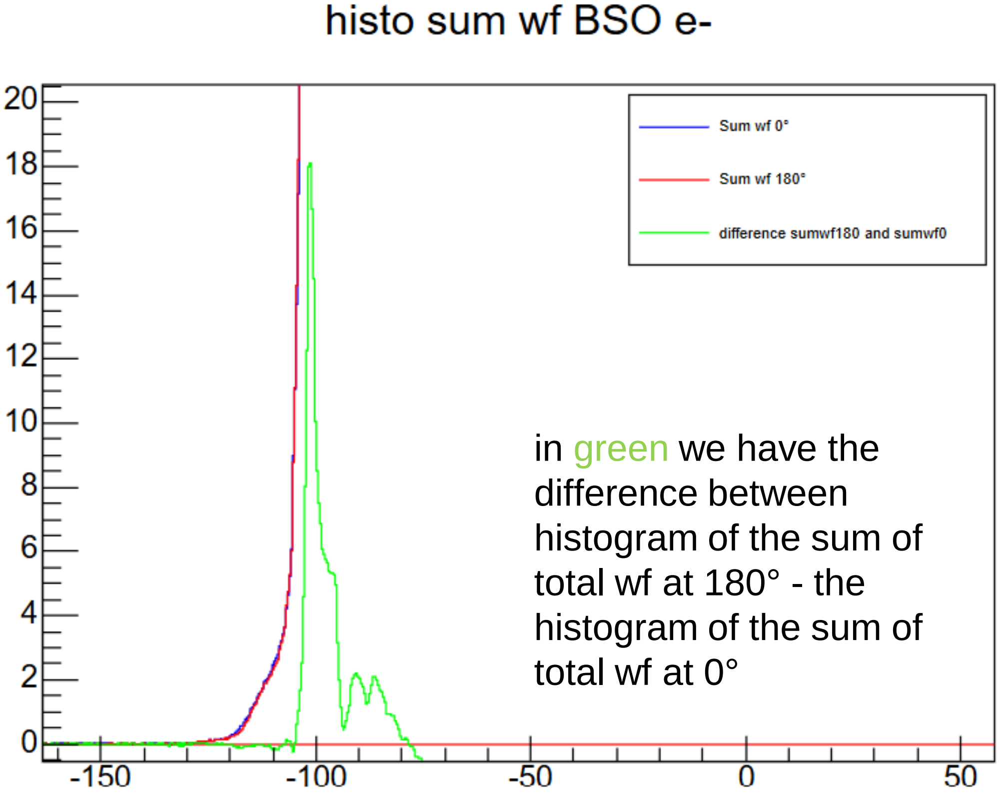




Waveform study for the BSO with e+10GeV

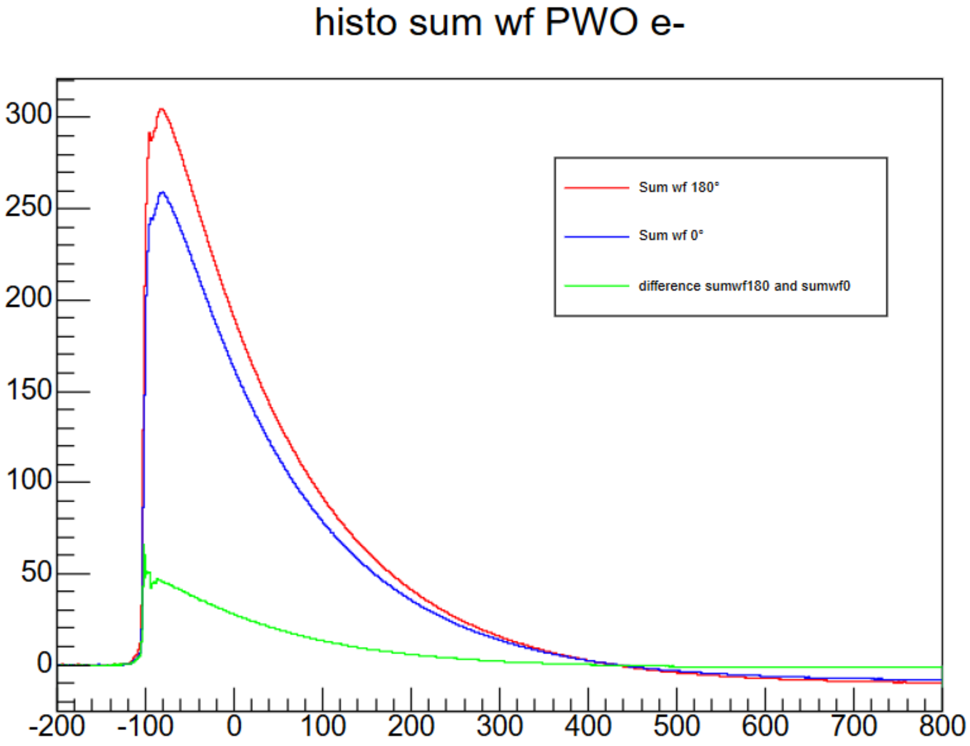


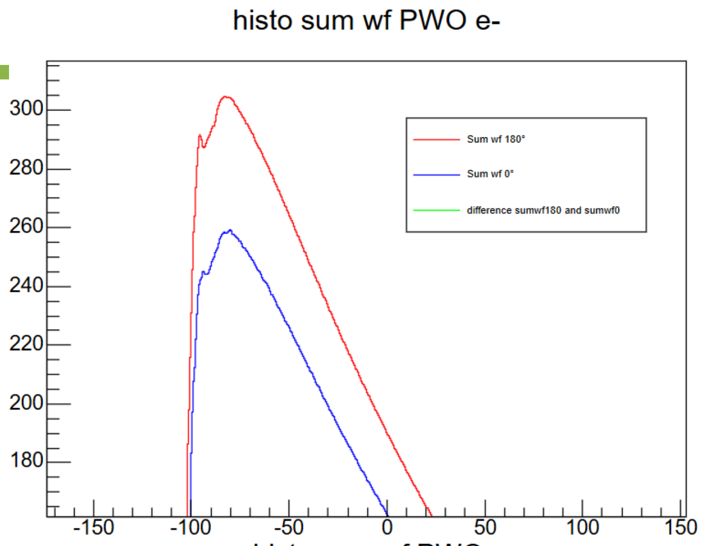


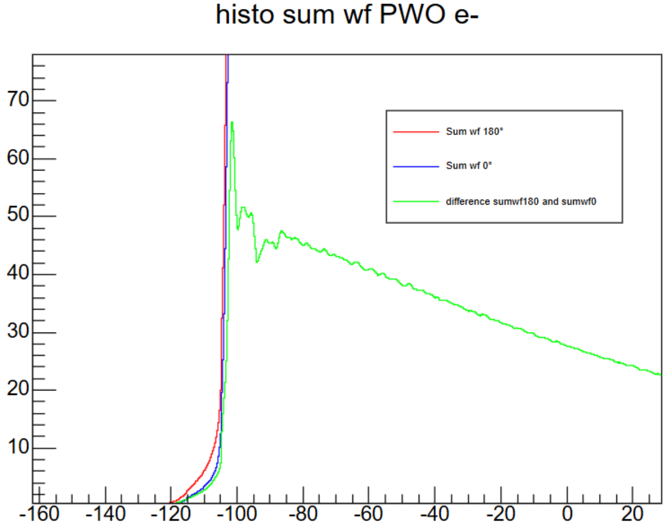


in green we have the difference between histogram of the sum of total wf at 180° - the histogram of the sum of total wf at 0°

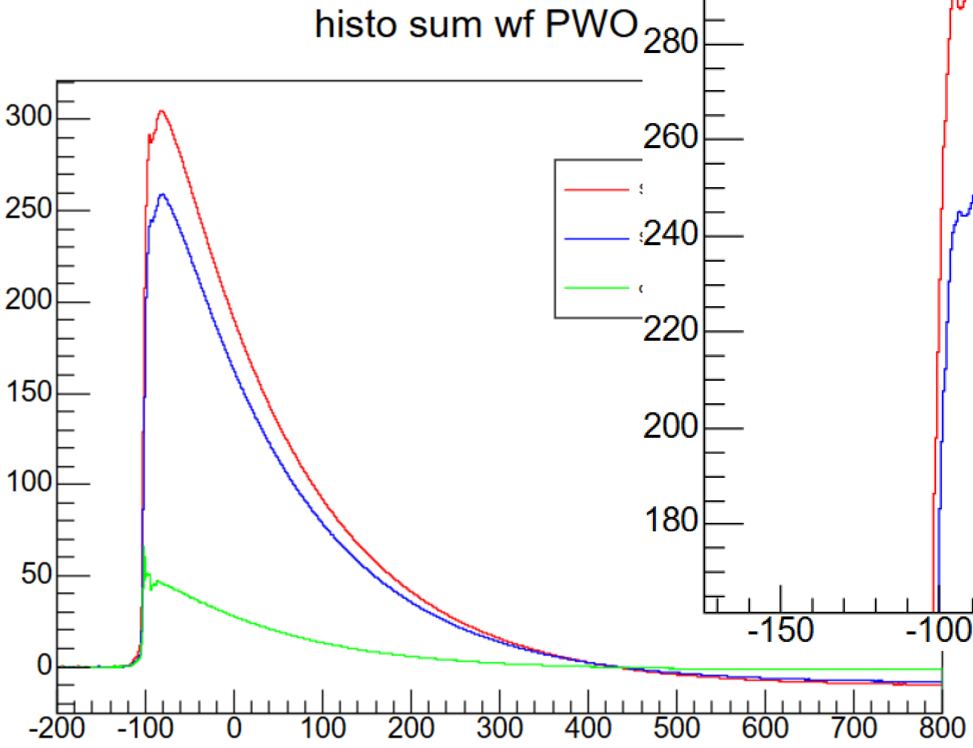
Waveform study for the PWO with e+10GeV

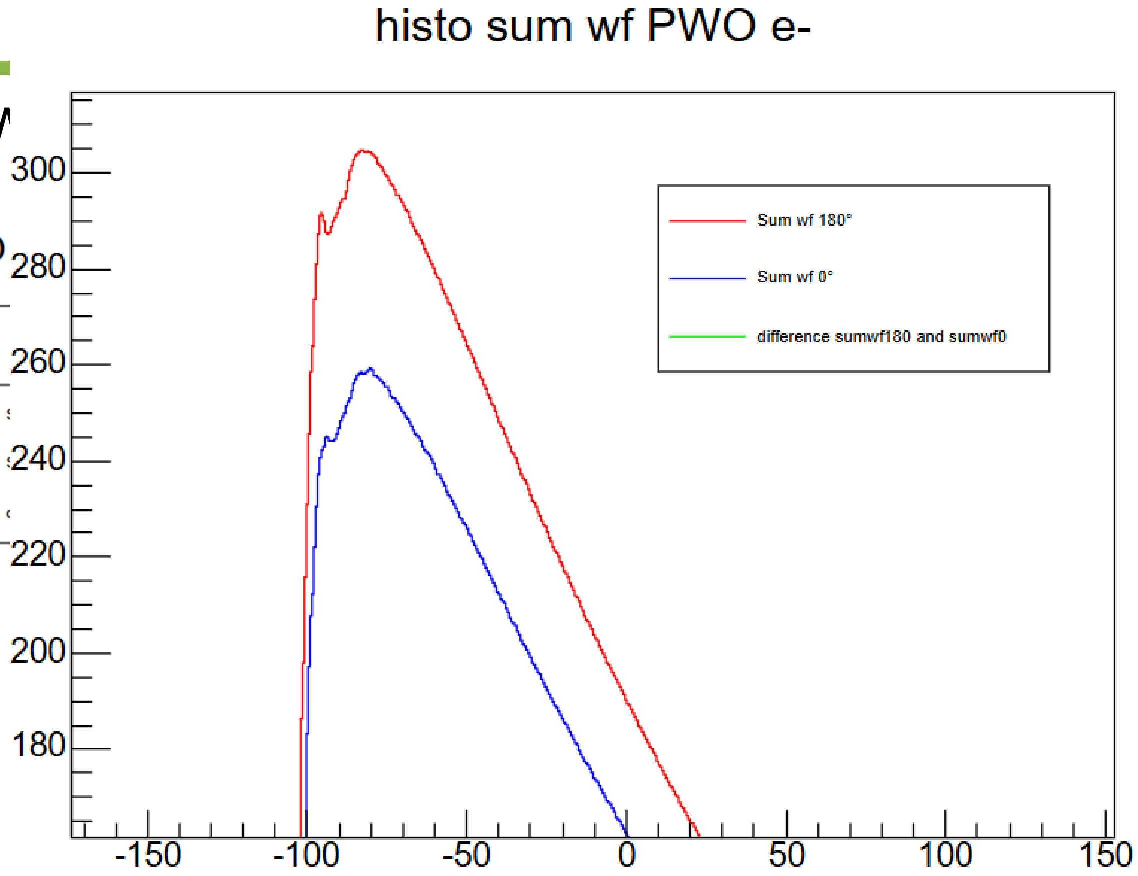


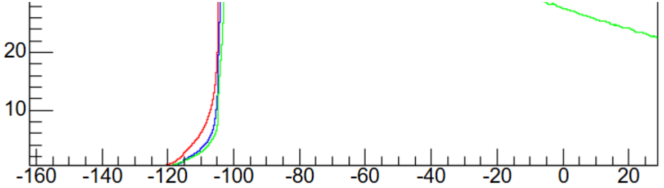


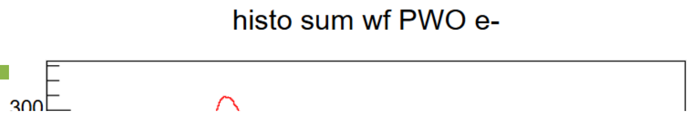


Waveform study for the PW

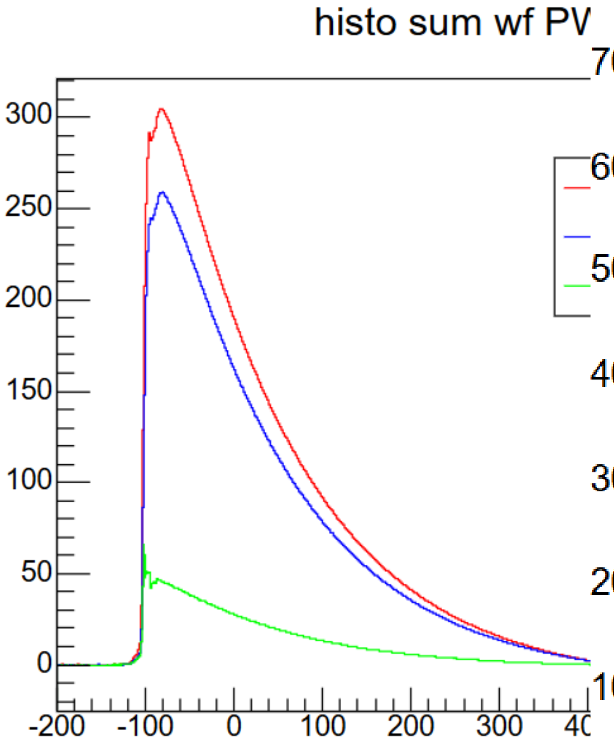


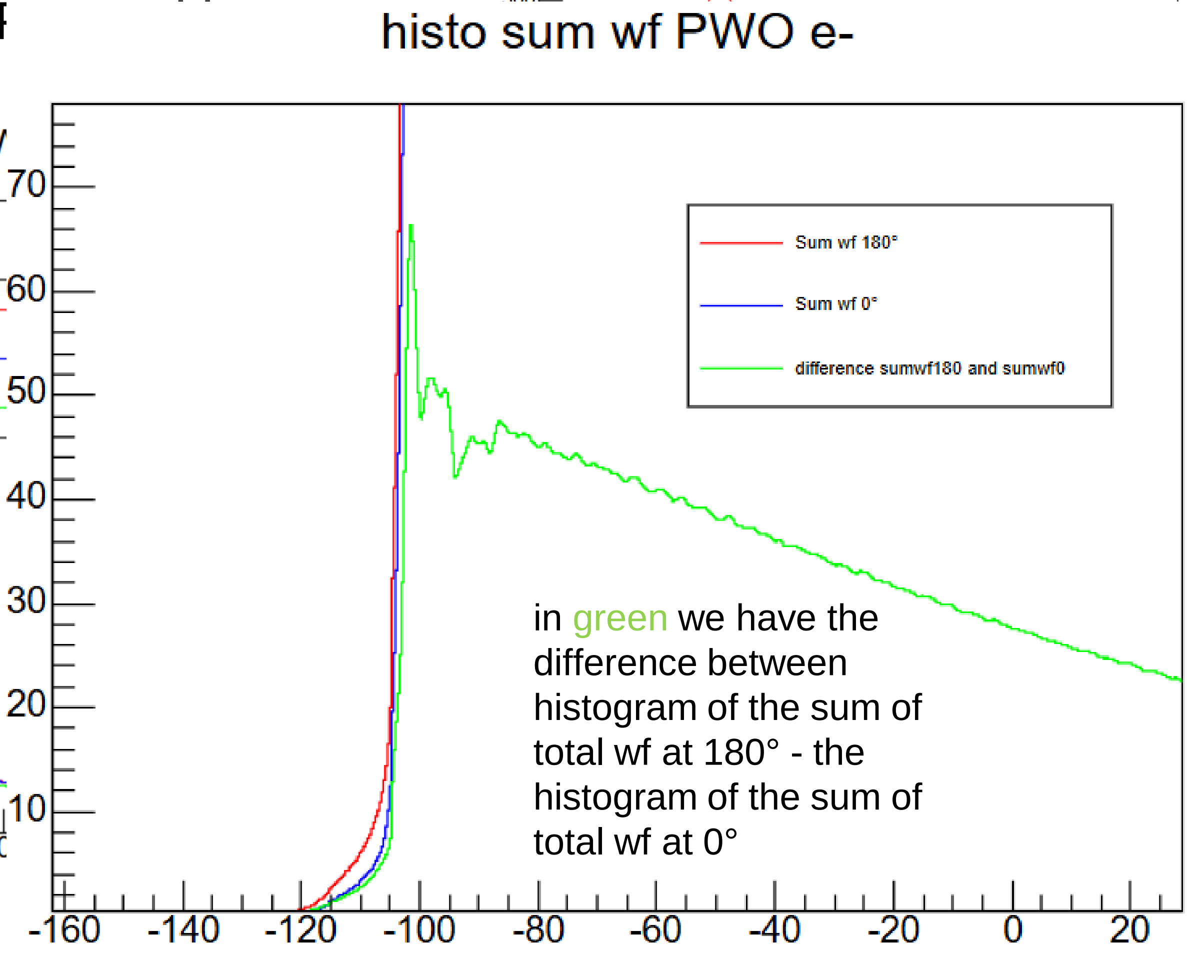






Waveform study for the F





in green we have the difference between histogram of the sum of total wf at 180° - the histogram of the sum of total wf at 0°

Evidence of single-photon resolution studies

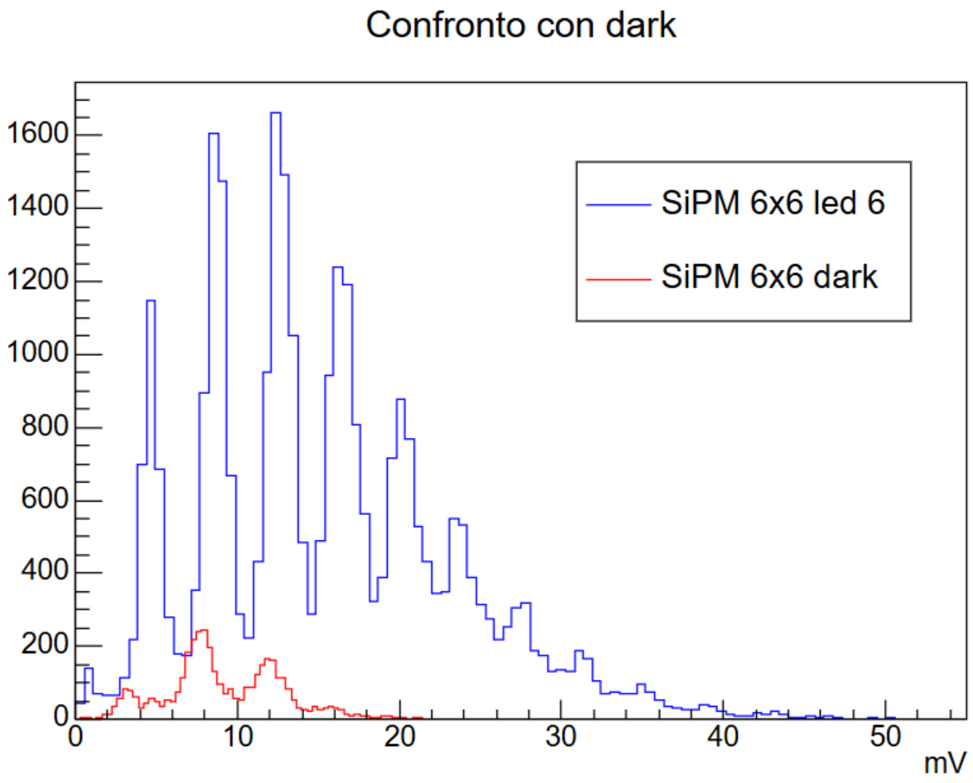
- I made dark measurements of the SiPM specifically, study the shape of the single photon.

Why these studies?

- because we could use the single photon shape as a template to fit individual wf

- Specifically, it could help to fit the first peak of the wf

Amplitude comparison with led and dark



Summary SiPM 6x6 Calibration

SiPM	Gain	**Gain amplitude conversion**	Method	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]	$\tau(ns)$	conversion factor charge $\tau(1-0{,}0497)$
6x6	28	25,12	A	0,4±0,1	3,46±0,02	132,26	125,7
6x6	28		B	15±1	3,49±0,006		
6x6	18	7,94	A	1,31±0,06	1,161±0,005	120,72	114,7
6x6	18		B	3,0±0,4	1,156±0,003		
6x6	24	15,85	A	0,20±0,05	2,27±0,01	149,72	142,3
6x6	24		B	17,5±0,7	2,169±0,003		

Summary SiPM 3x3 Calibration

SiPM	Gain	**Gain amplitude conversion**	Method	$p_0 + error$	$p_1 + error$ [mV/n_{pe}]	$\tau + error(ns)$	conversion factor charge $\tau(1 - 0{,}0497)$
3x3	28	25,12	B	-1,4±0,4	1,236±0,002	46,9±0,2	44,61
3x3	24	15,85	B	-0,9±0,2	0,785±0,002	45,2±0,2	42,93
3x3	18	7,94	B	-0,3±0,1	0,401±0,002	46,3±0,6	44,02
3x3	Passive Preamp	-	B	0,064±0,005	0,0425±0,0009	18,3±0,3	17,41

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 ⟹ $$V_{BD}(T°) = V_{BD}(25°) - 0{,}034\frac{V}{°C}\ \delta T$$

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

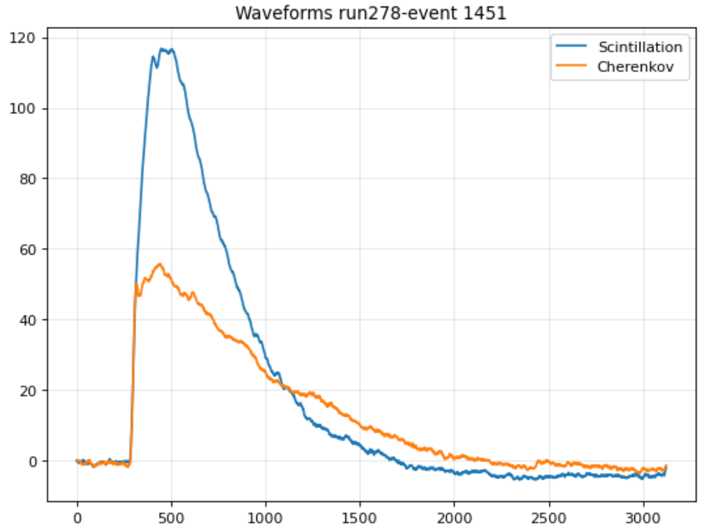
$$G(23°C) = \alpha V_{OV}(23°C)$$

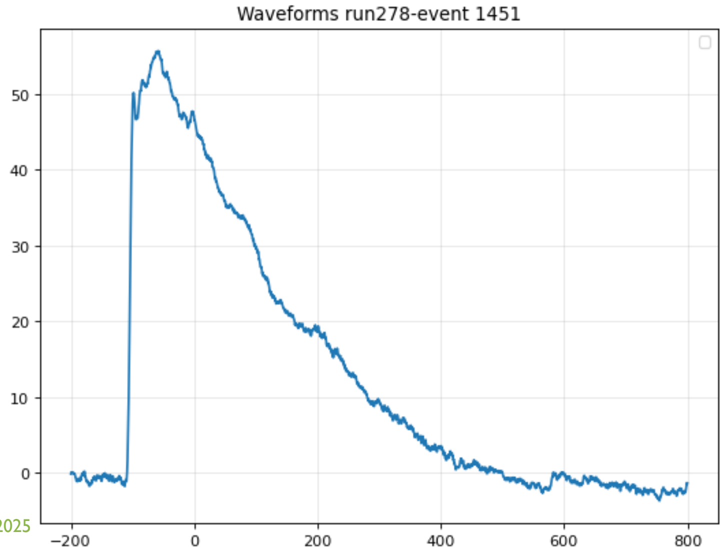
We then have the 26°C gain and we want to know how much is the gain at 23°C:

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

Analysis of the 264-278 BSO angular scan with e+ 10GeV

- Ch1 CAEN amp 18
- CH2 CAEN amp 18 e Filtro UG11
- CH3 LYSO
- CH4 MPC
- CH5 Plastico 1x1x1 cm3
- CH6 Trigger signal (from MIB plastic)



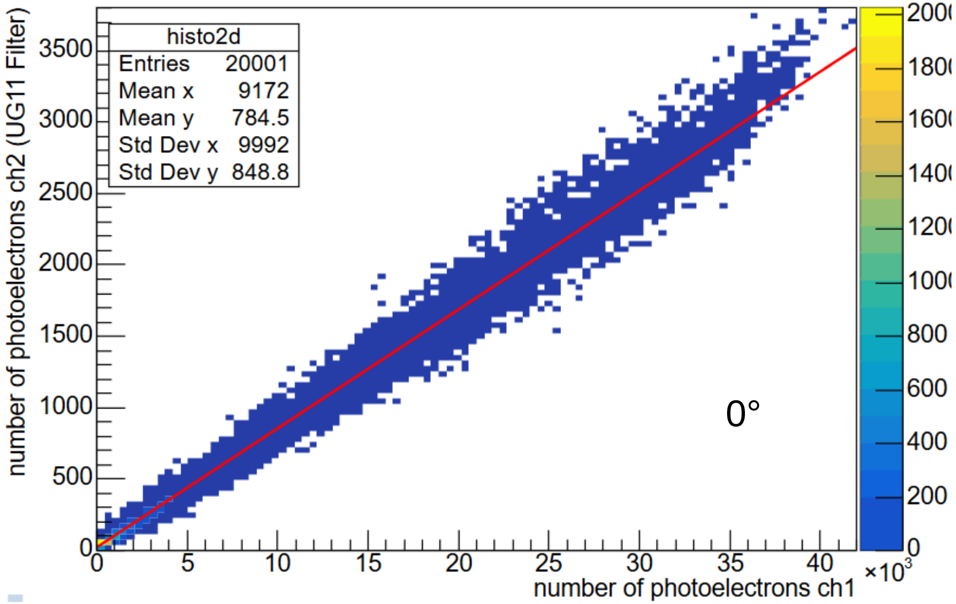


2D Histogram and fit for BSO e+10GeV

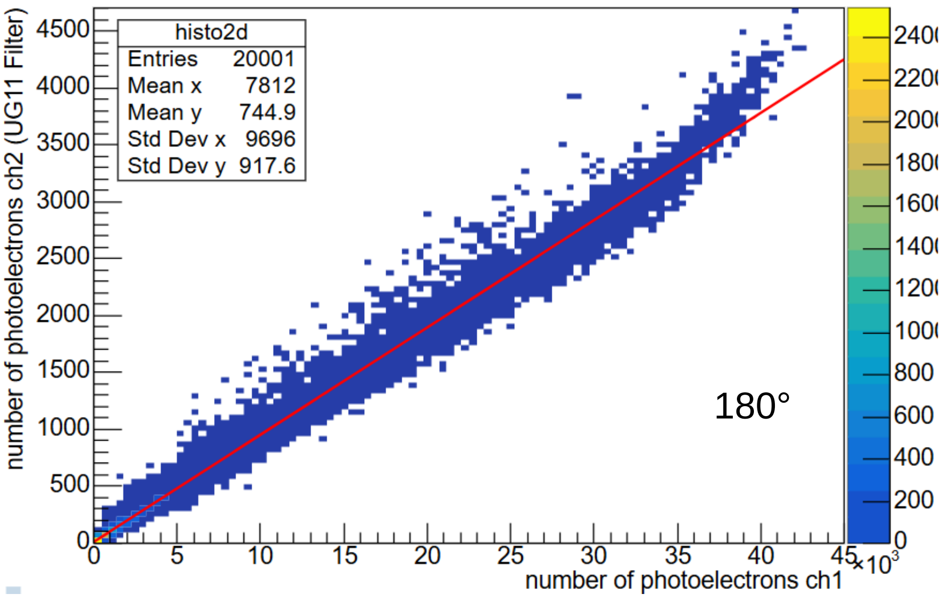
```
# Calcolo l'integrale delle waveforms
integral_ch1 = np.sum(np.abs(wf_channel1))
integral_ch2 = np.sum(np.abs(wf_channel2))

a=integral_ch1/(44.02*0.401)
b=integral_ch2/(114.7*1.16)
```

- If there were only scintillation the slope would always be equal depending on the angle

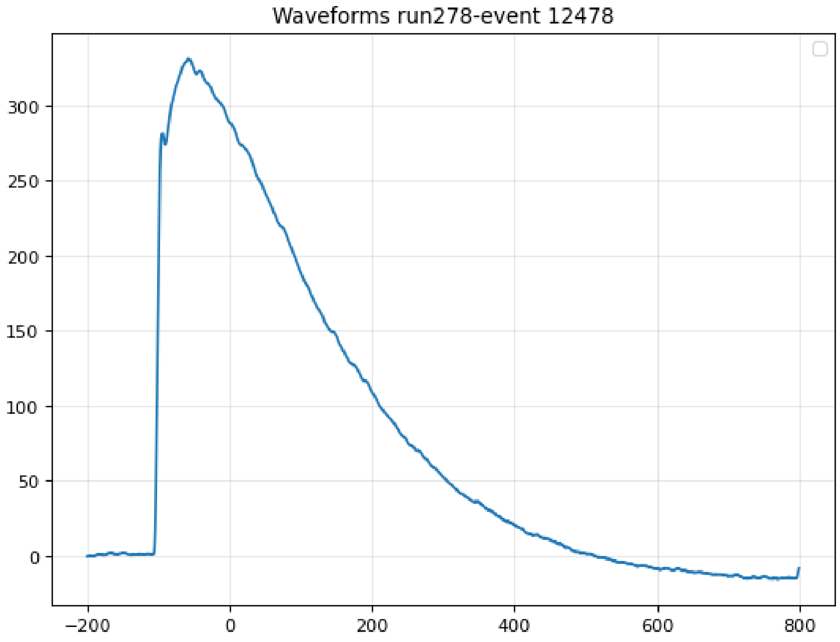
number of photoelectrons ch2 vs number of photoelectrons ch1 run278

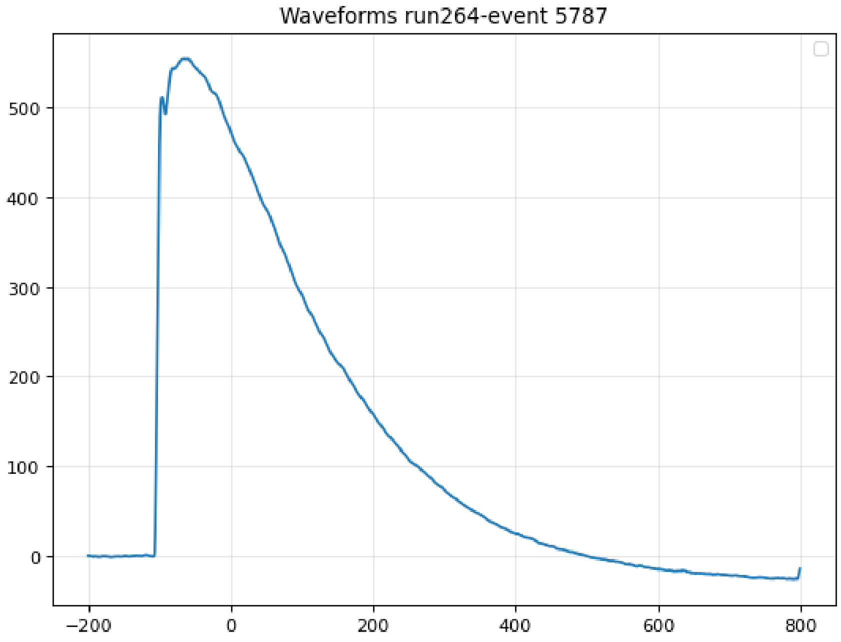


number of photoelectrons ch2 vs number of photoelectrons ch1 run264

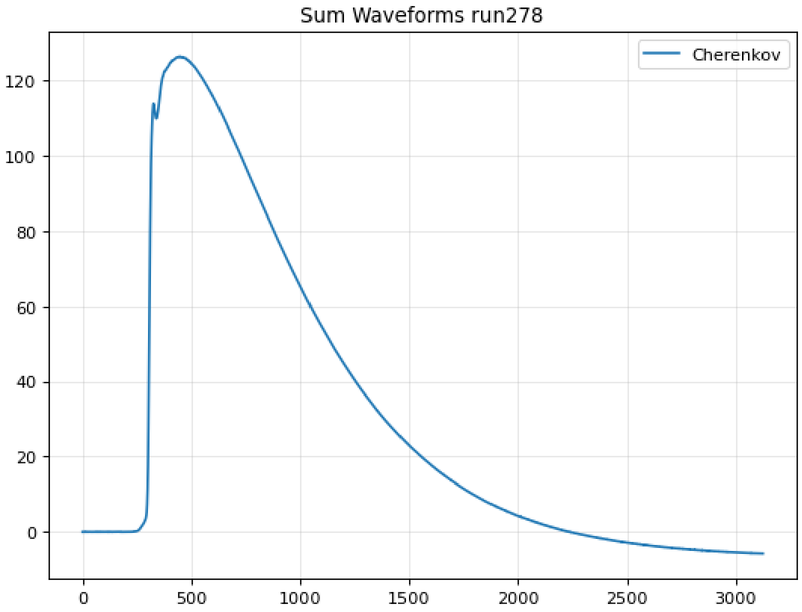


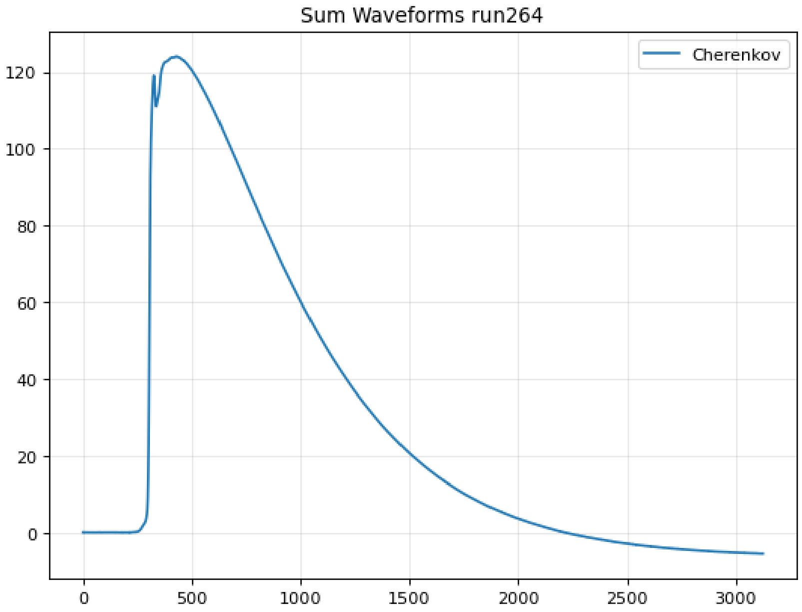
Wf for BSO e+10GeV





Wf for BSO e+10GeV





Calibration procedure

We want to calibrate the Silicon Photomultiplier (SiPM) that we used at the test beam: 2 SiPM of different sizes and using a variable-gain preamplifier that allows us to have various gains.

Procedure:

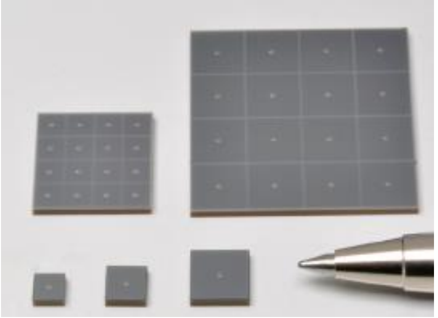
- Reproduce the SiPM - Preamplifier - Oscilloscope chain in the Naples lab
- Use a led drive that to generate light for our sipm in a controlled way
- Acquire our signal with the oscilloscope
- Calibrate the SiPM response to derive the number of incoming photons.

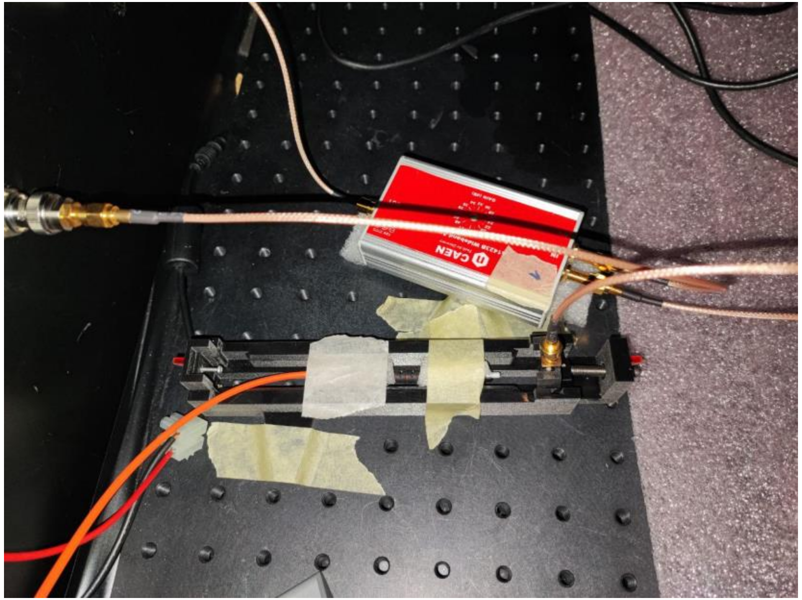
Two different methods have been used (to be described in the next slides):

A) Waveform integral measurement from the amplitude (Peak id)
B) Photoelectrons counting (PE Count)

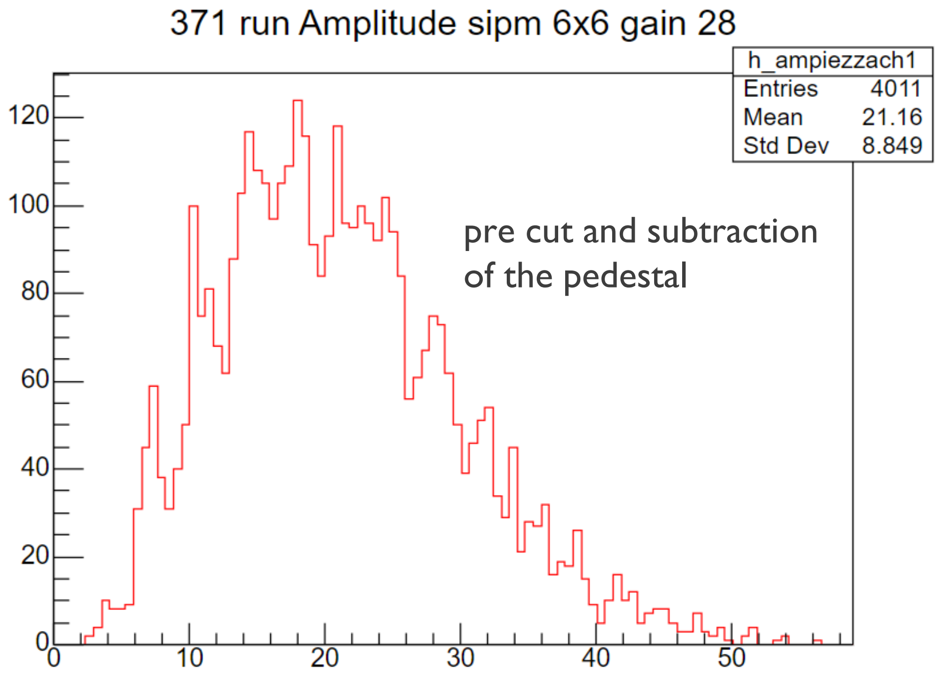
Setup:

- 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

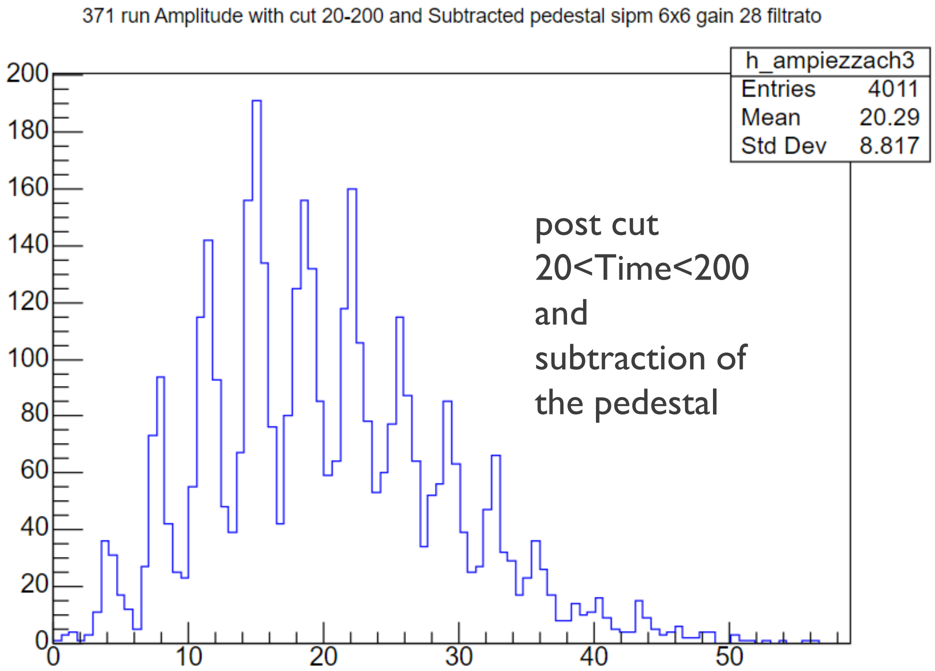




SiPM 6x6 at Gain 28 Calibration

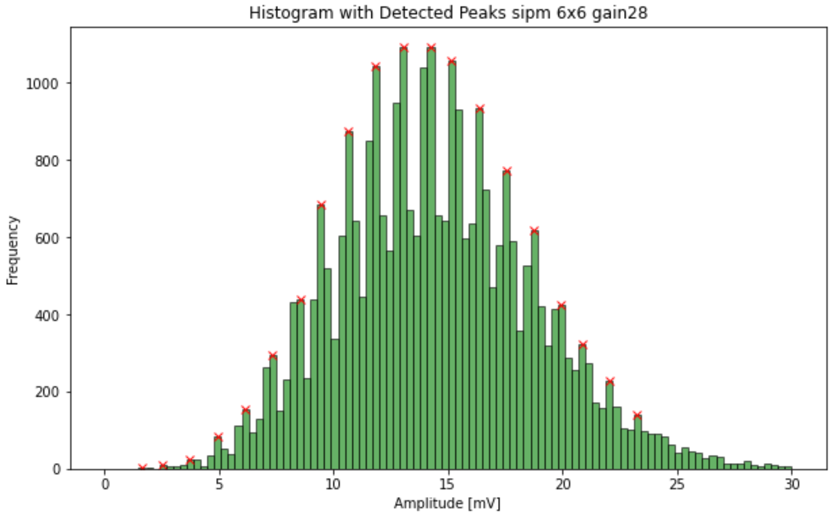


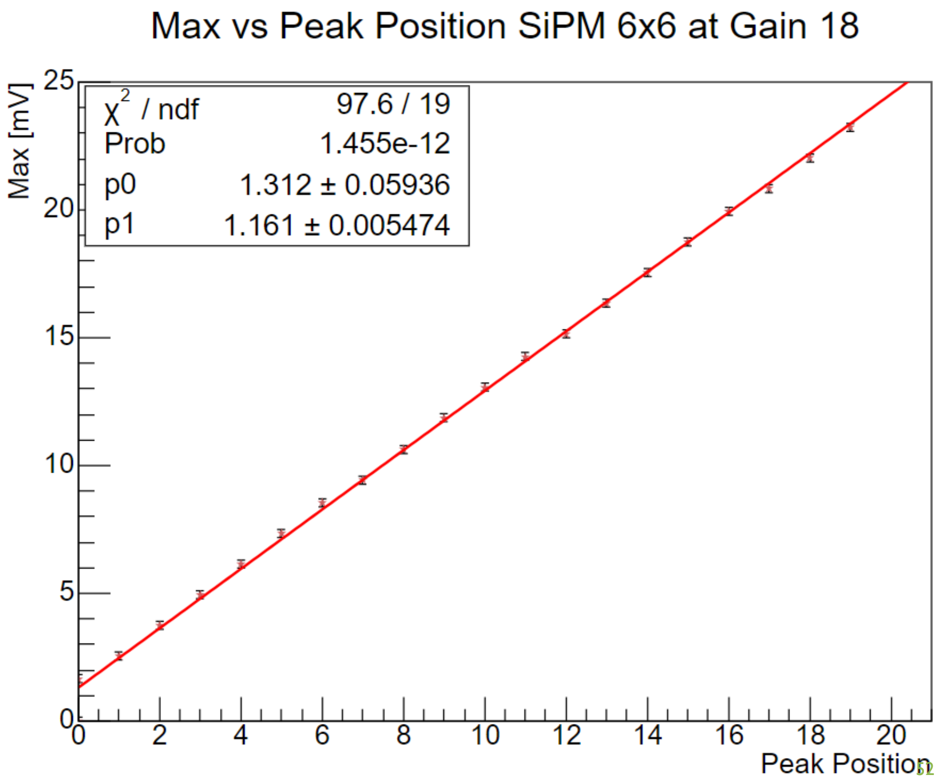
pre cut and subtraction of the pedestal



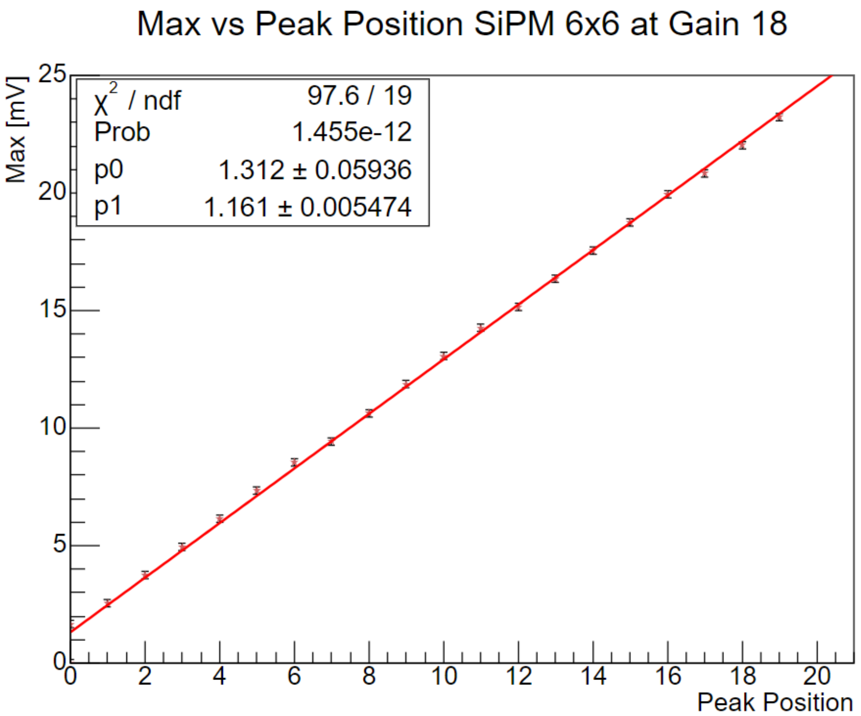
post cut 20<Time<200 and subtraction of the pedestal

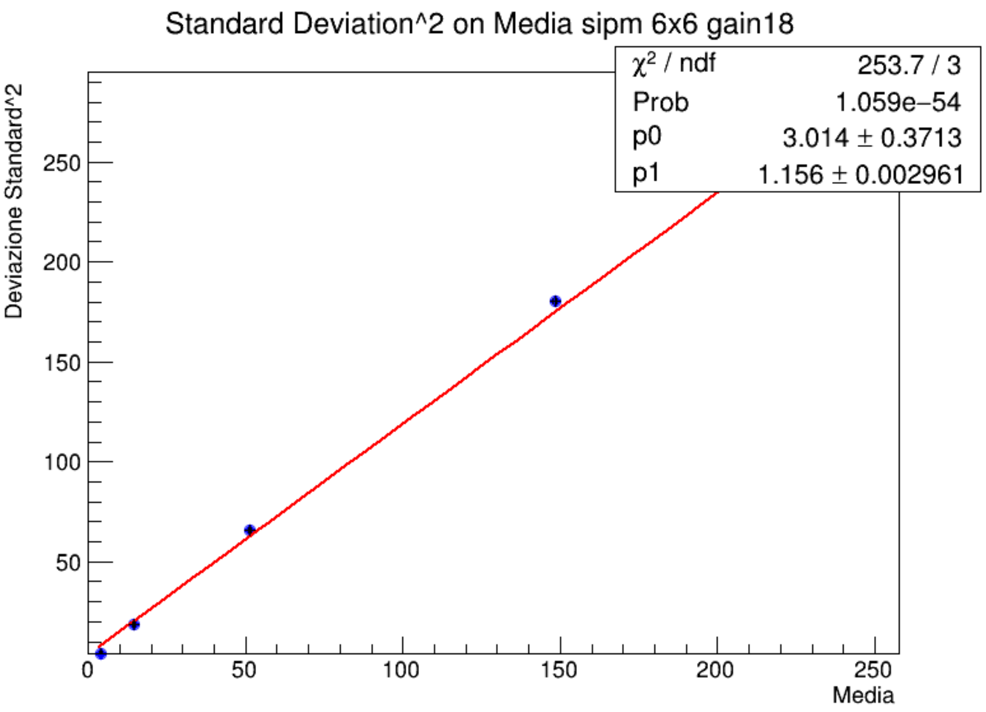
SiPM 6x6 at Gain 18 Calibration



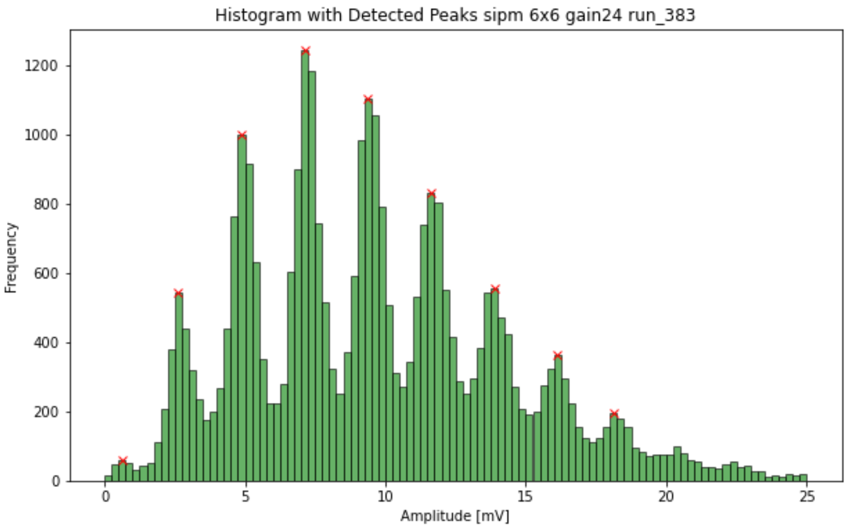


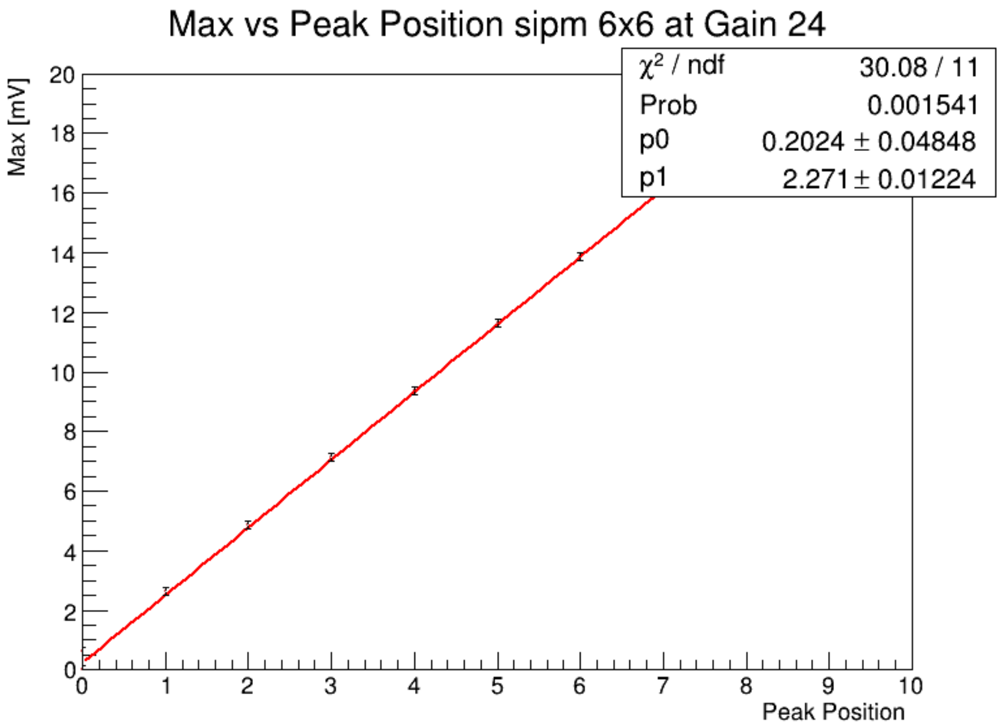
Calibrations SiPM 6x6 Gain 18 with other method and Comparison 2 methods



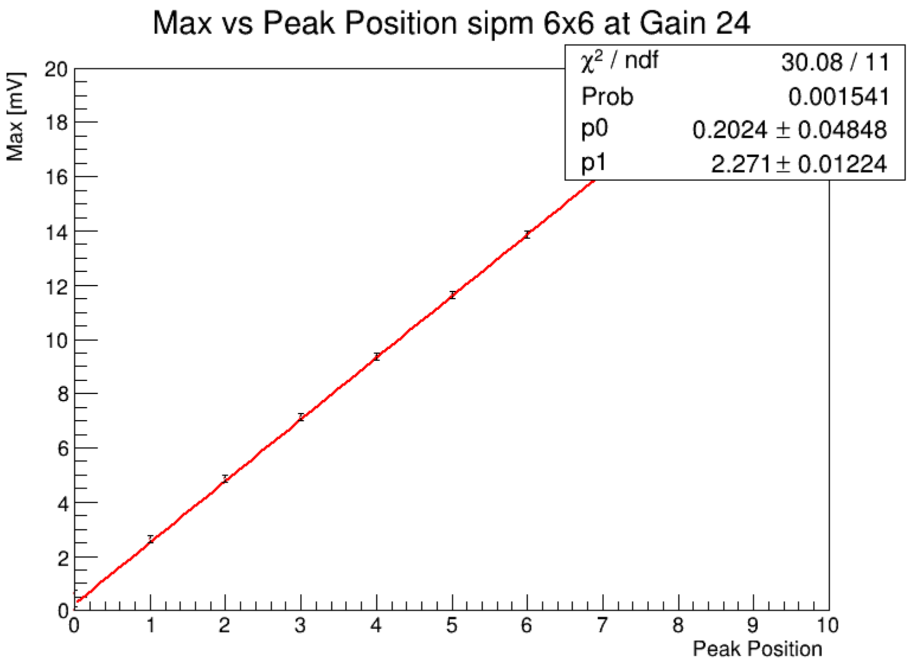


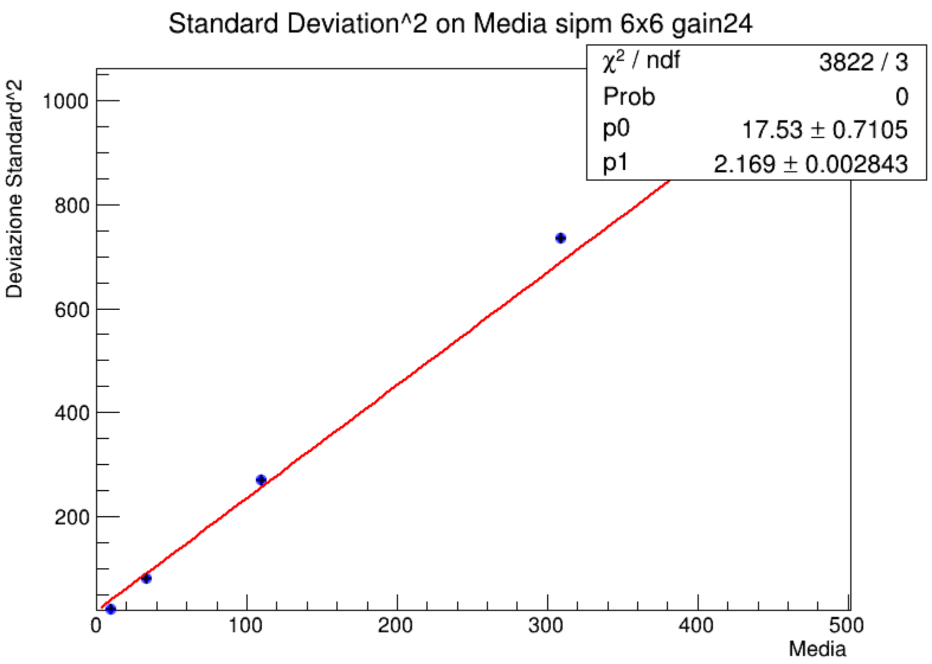
SiPM 6x6 at Gain 24 Calibration





Calibrations SiPM 6x6 Gain 24 with other method and Comparison 2 methods



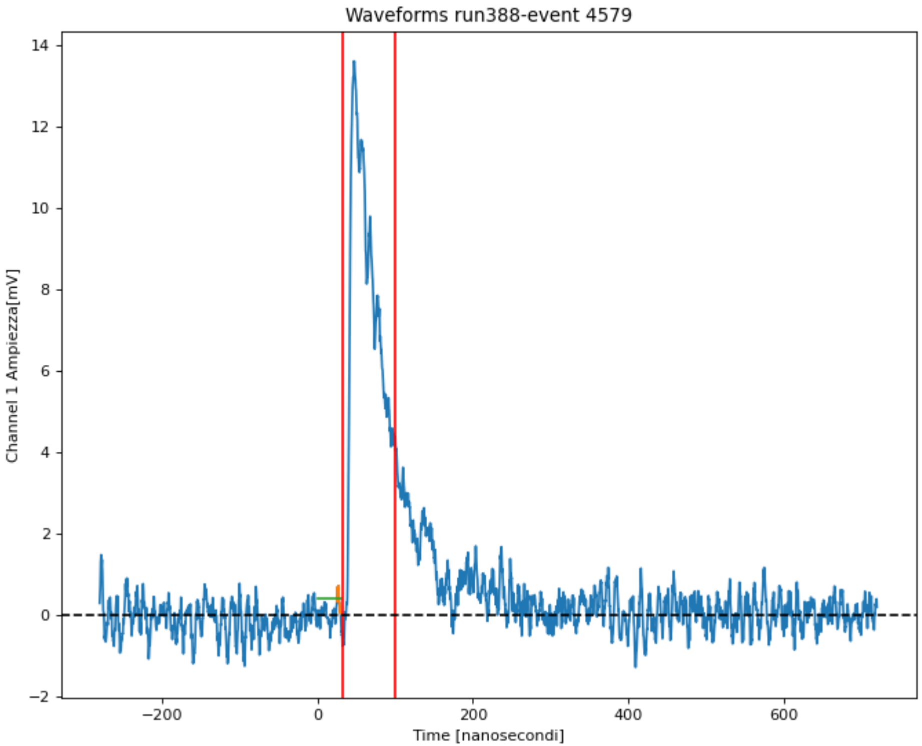


Calibrazioni sipm 3x3 Gain 28

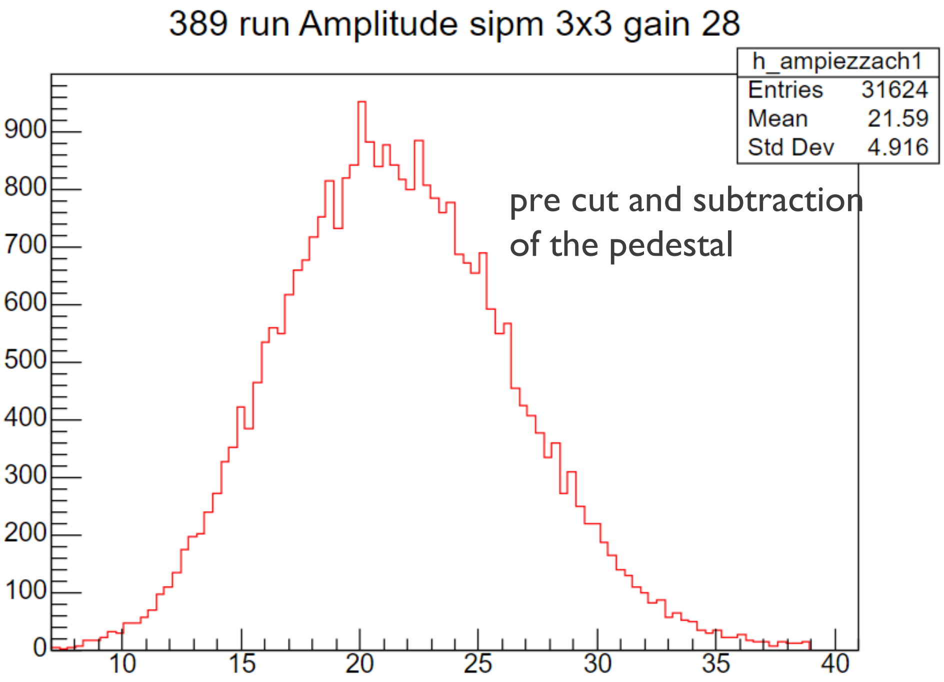
- Power suply 44V
- CAEN Preamplifier at gain 28

- In red= cut on waveform at 33<Time<100

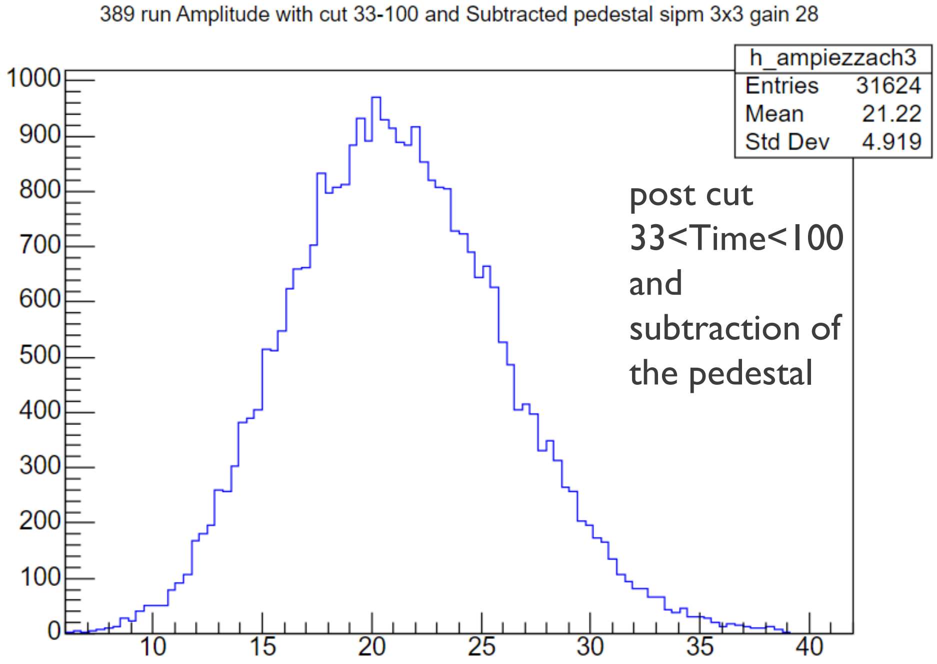
- In orange= pedestal to subtract



Calibrazioni sipm 3x3 Gain 28

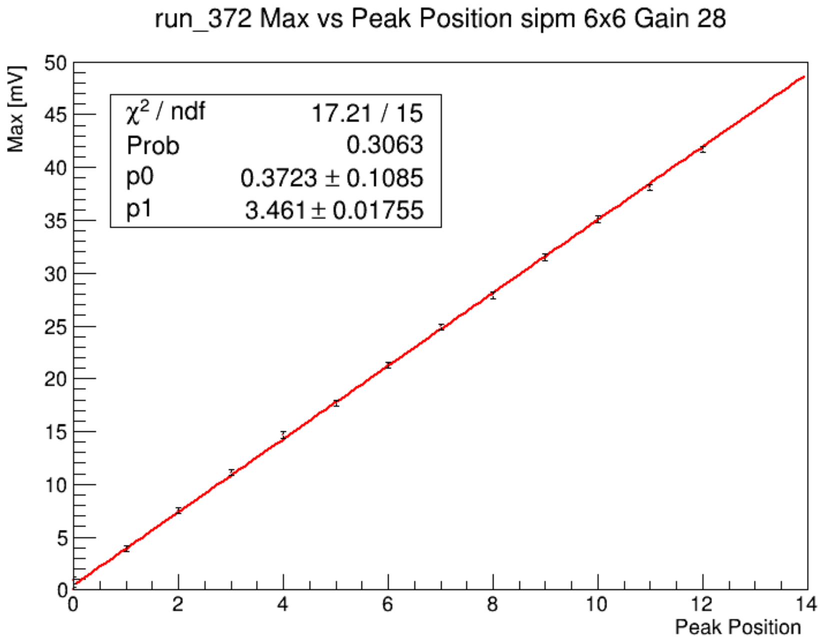


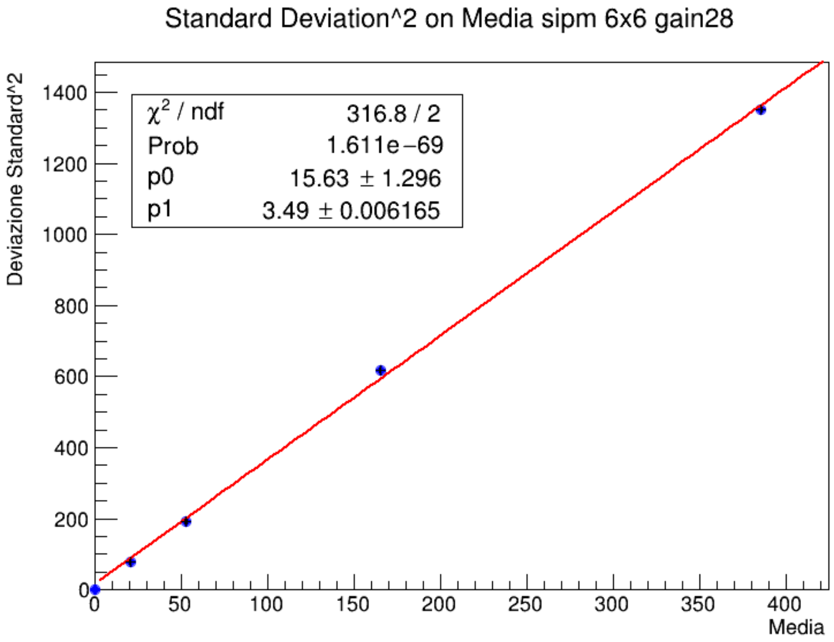
pre cut and subtraction of the pedestal



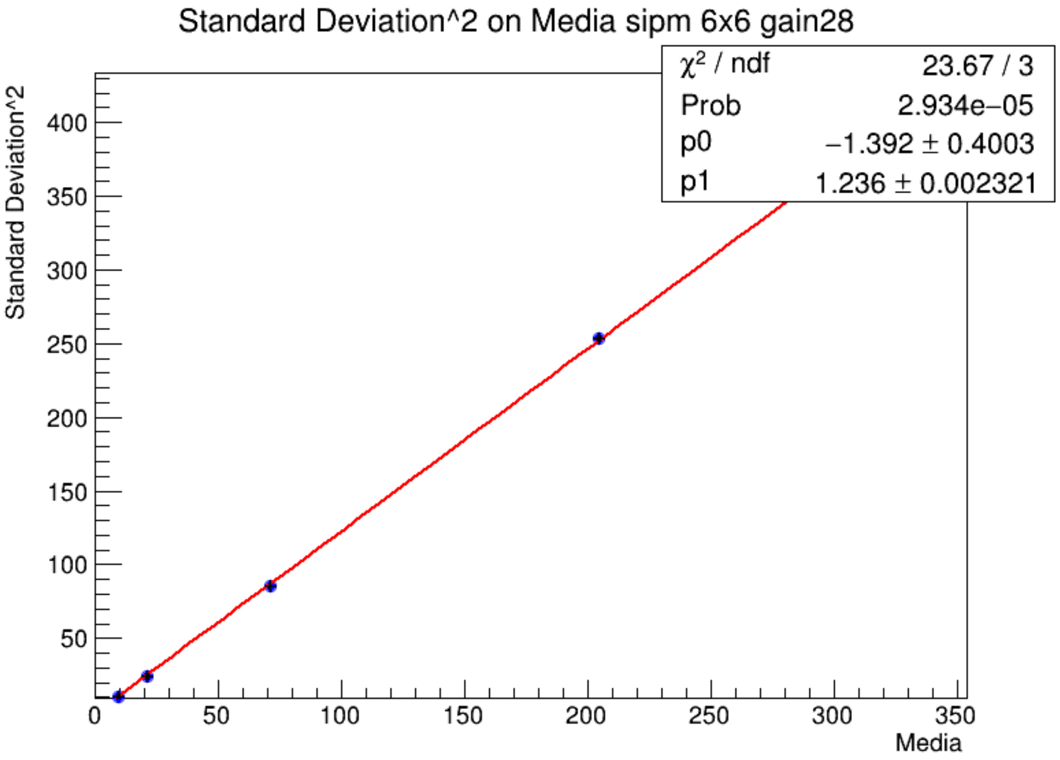
post cut 33<Time<100 and subtraction of the pedestal

Comparison 2 methods

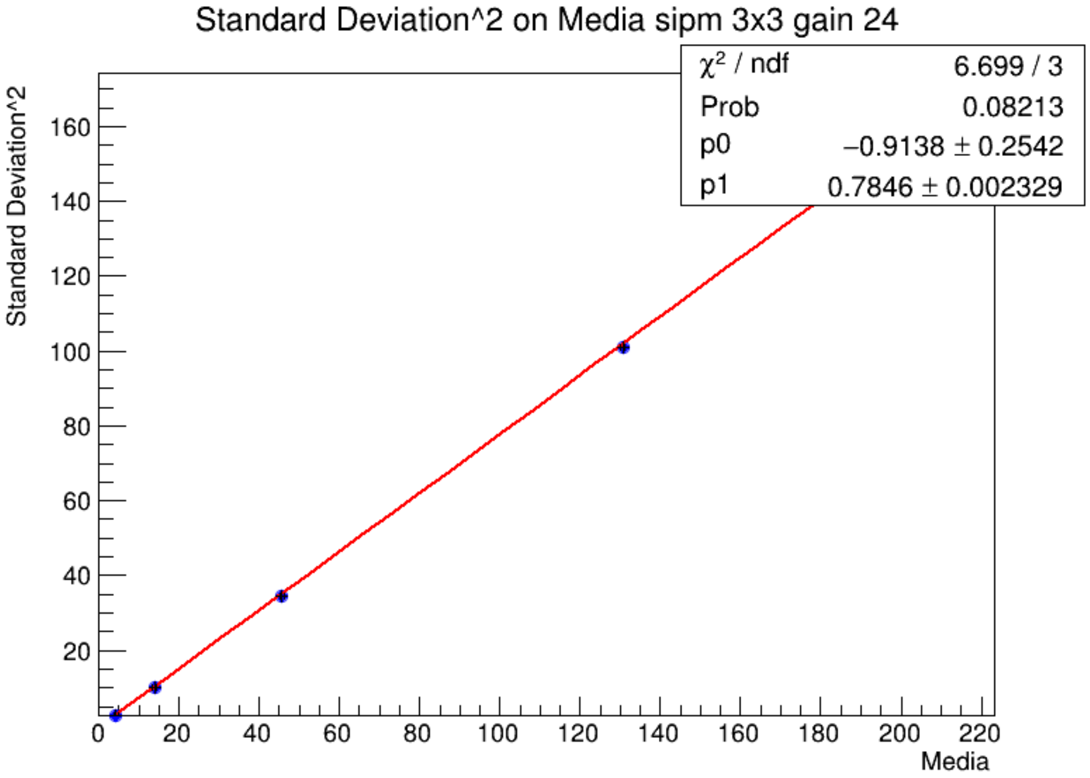




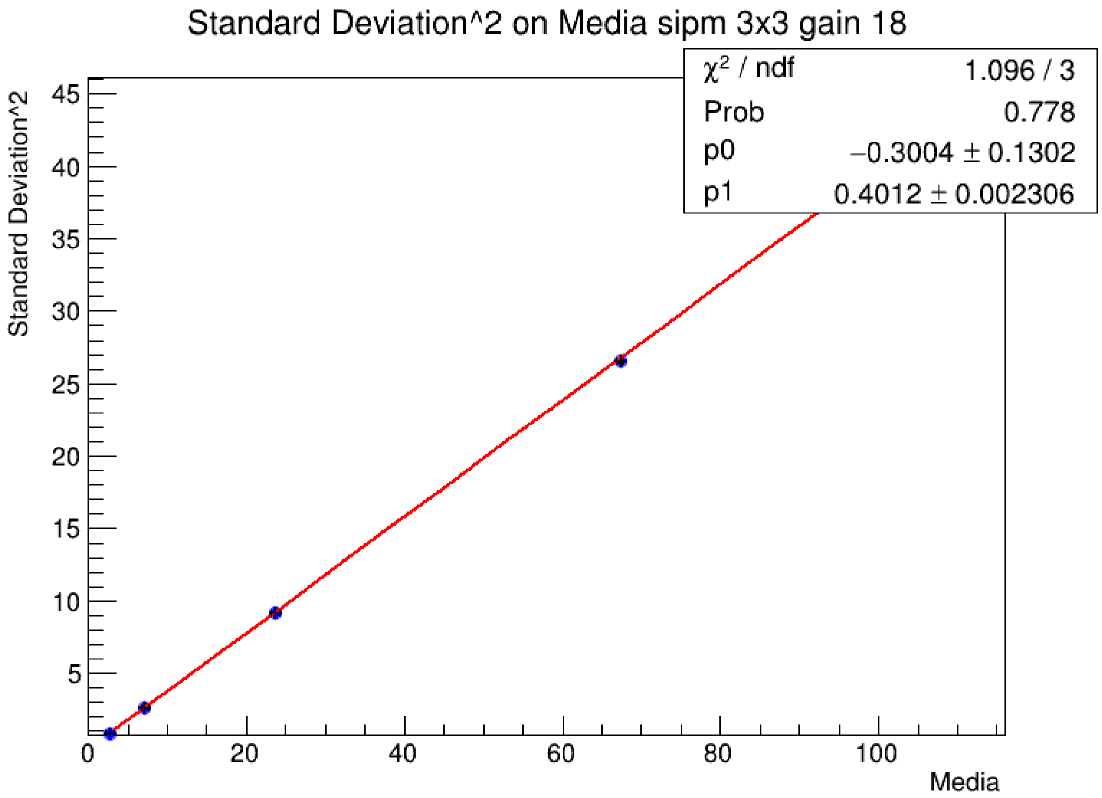
Calibrations SiPM 3x3 Gain 28 with other method



Calibrations SiPM 3x3 Gain 24 with other method



Calibrations SiPM 3x3 Gain 18 with other method



Calibrations SiPM 3x3 with passive preamp with other method