Gain, Stability, and TTS

for September measurement

October 19th, 2018

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Introduction

- These slides summarize the measurement in September.
  - the measurement for negative HV at the 28th of September.
- The differences from the measurement in July is-

-the LED current and time width

  - the current increased and the time width decreased, keeping the LED intensity which means the number of emitted photons from LED per unit time.
  - this change was made to avoid the LED instability which influences the TTS enlargement.

-the size of the lens placed btw the LED and the 3”PMT

  - it got smaller: Φ140.5 mm → Φ75.0 mm

Gain: Introduction

- The Fitting function is the product of Poisson distribution and Gaussian distribution:

p0	p1	p2	p3	p4
Q_0	σ_0	W	α	μ

p5	p6	p7	p8
σ_1	Q_1	Q_{sh}	Norm

$$arg = x - Q_0$$

$$S_{\mathrm{ped}} = \frac{1-W}{\sqrt{2\pi}\sigma_0} \exp\left(-\frac{1}{2}\left(\frac{arg}{\sigma_0}\right)^2 - \mu\right)$$

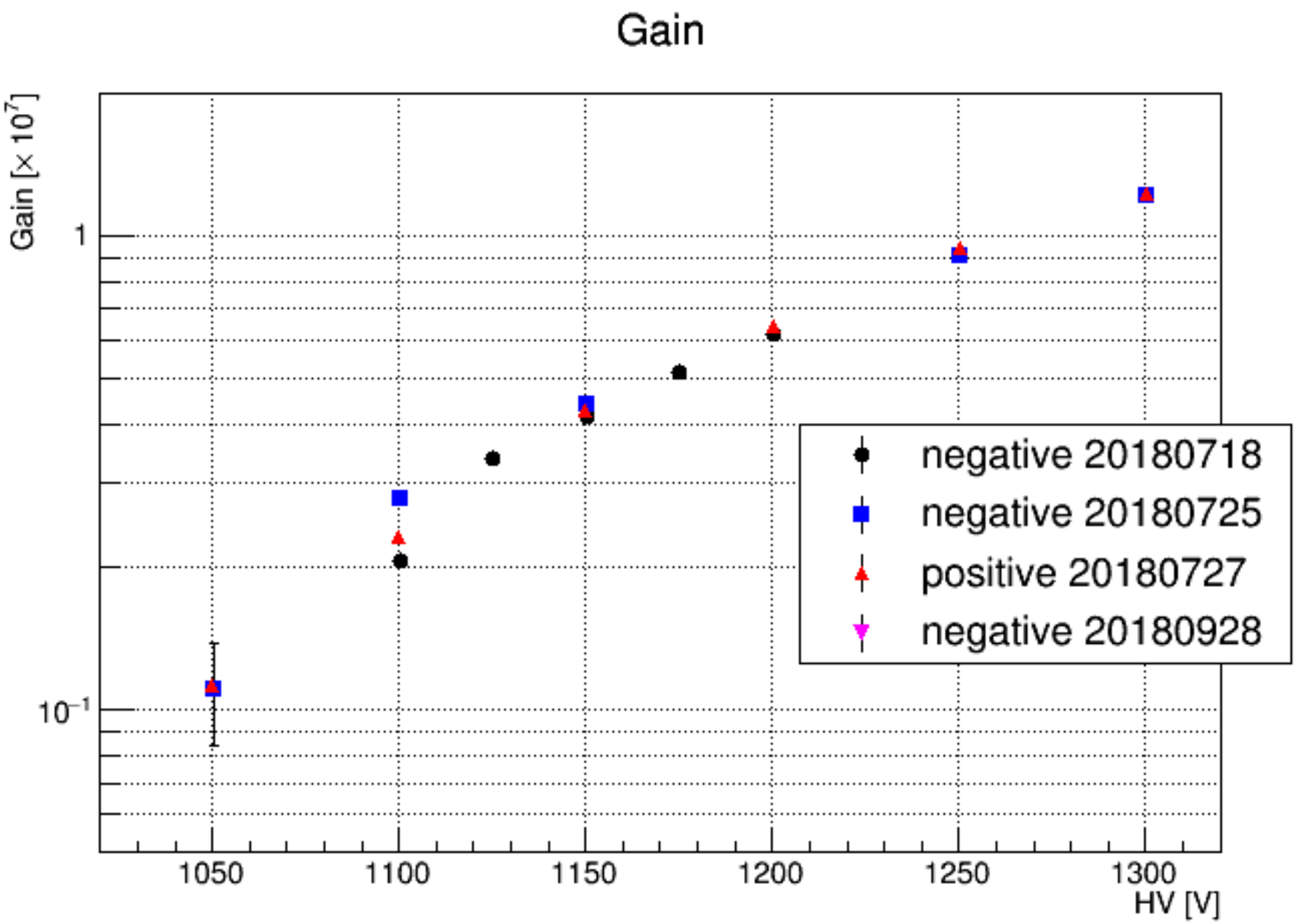
$$S_{\mathrm{noise}} = \alpha W \exp\left(-\alpha \cdot arg - \mu\right),\ 0\ (\text{if } arg < 0)$$

$$S_{\mathrm{sig1}} = \frac{\mu^k e^{-\mu}}{\sqrt{2\pi}\sigma_1} \exp\left(-\frac{1}{2}\left(\frac{arg - Q_1 - Q_{\mathrm{sh}}}{\sigma_1}\right)^2\right)$$

$$S_{\mathrm{sigN}} = \sum_{n=2}^{10} \frac{\mu^k e^{-\mu}}{n!} \cdot \frac{1}{\sqrt{2\pi n}\sigma_1} \exp\left(-\frac{1}{2n}\left(\frac{arg - nQ_1 - Q_{\mathrm{sh}}}{\sigma_1}\right)^2\right)$$

$$\sigma_1 \to \sqrt{\sum_{k=1}^{n} \sigma_1} = \sqrt{n}\sigma_1$$

Gain: plots



- Stat. error only.
- No special differences is seen.

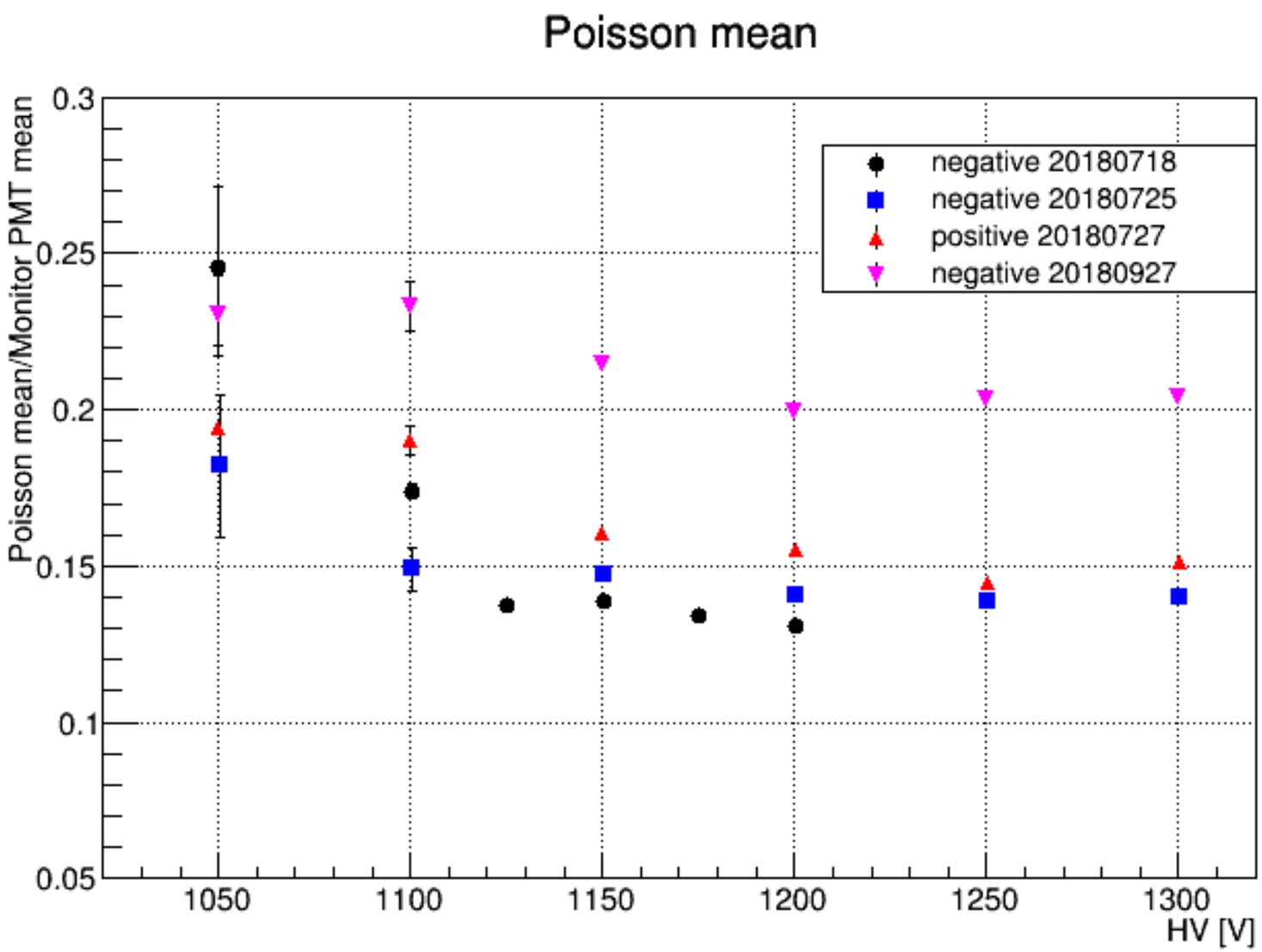
Stability: Introduction

- In this plots, the normalized Poisson mean is drawn which is normalized by Monitor PMT mean in order to exclude circumstance influences:

$$\text{Normalized Poisson mean} = \frac{\text{Poisson mean}}{\text{Monitor PMT mean}}$$

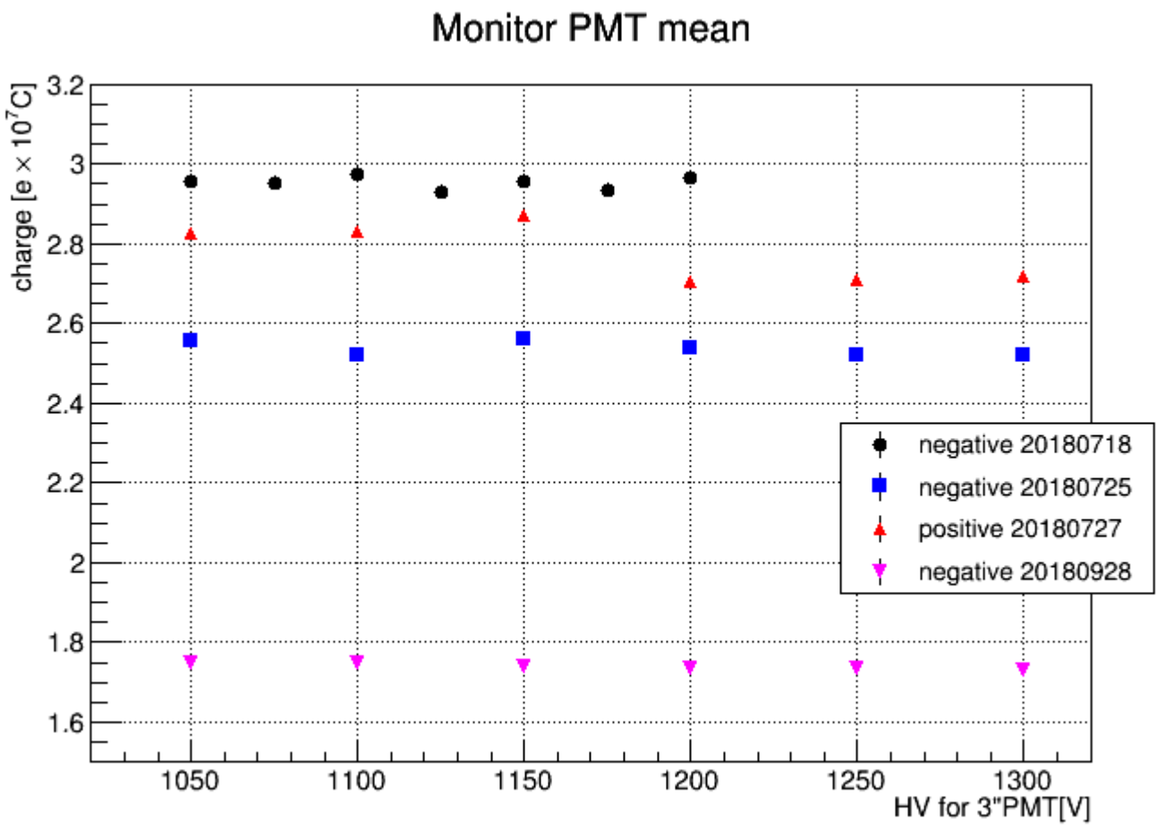
- Normalized Poisson mean is ideally considered to be stable against HV because Poisson mean doesn't depend on HV for 3" PMT.
- Poisson mean is obtained from a fitting to the corresponding charge histogram.
  Monitor PMT mean is equal to a mean of charge histogram not Poisson mean of that.

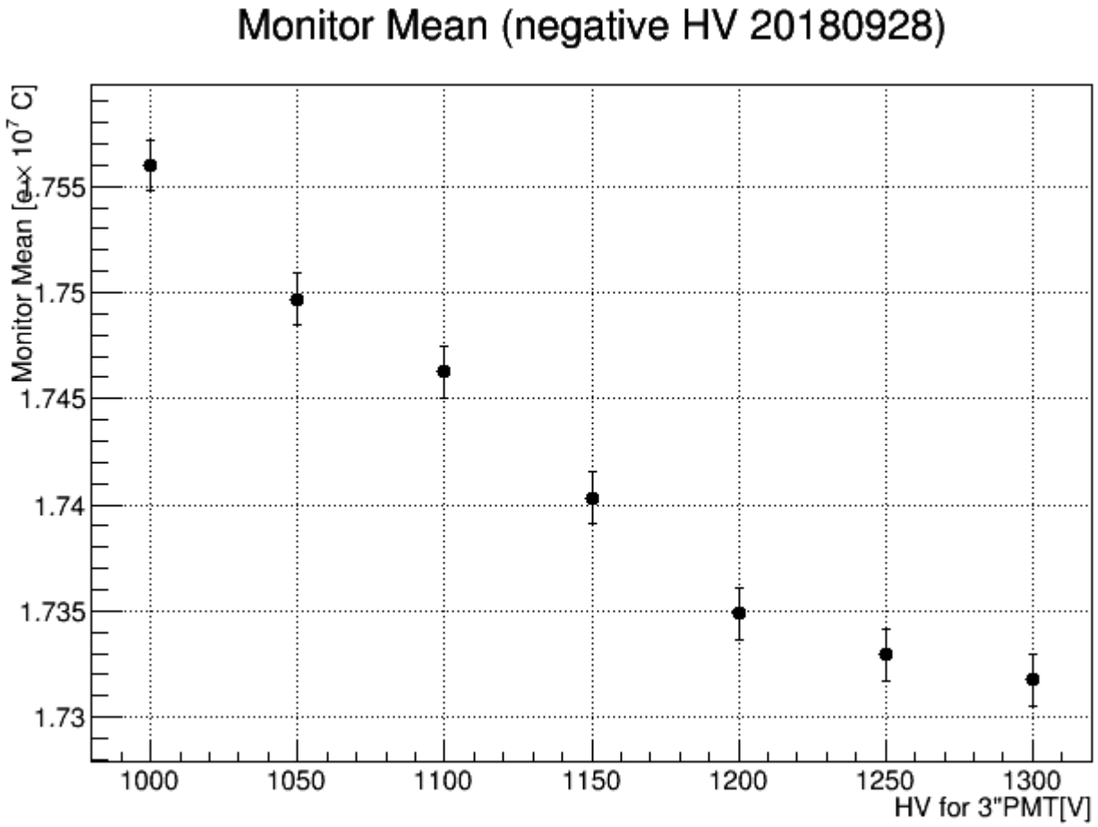
Stability: plots



- Stat. error only.
- The result in Sep. is seen above the ones in Jul.
  - the Monitor PMT mean got smaller. (→ the next page)

Stability: Monitor PMT mean





- The measurement was done in order from 1300 V to 1000 V.
  - LED intensity might increase over time.
- Monitor PMT mean got smaller than in July. Possibility is:
  - changed LED current and time width
  - LED fiber was broken not only 10 %. already broken in July (slightly different even among the measurement in Jul.).
  - Big gap btw Jul. and Sep. result from temperature or humidity.

TTS: Introduction

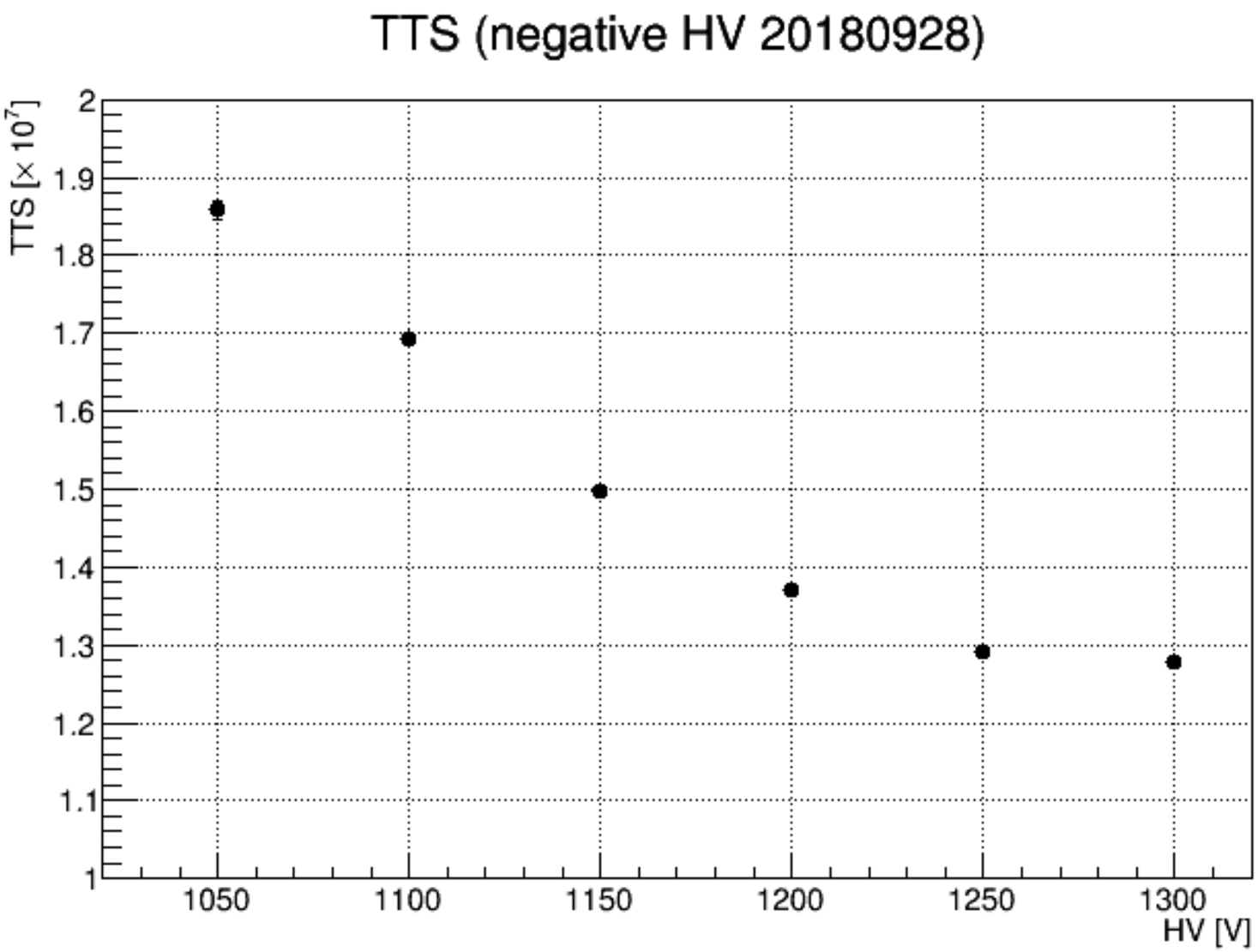
- The fitting function is

$$\frac{p_0}{2}\exp\left\{-p_1 \times \frac{(x-p_3)-p_2^2\cdot p_1}{2}\right\} \times\left[1+\mathrm{erf}\left(\frac{(x-p_3)-p_2^2\cdot p_1}{\sqrt{2}p_2}\right)\right]+p_4$$

$$\mathrm{erf}(x)=\frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt$$

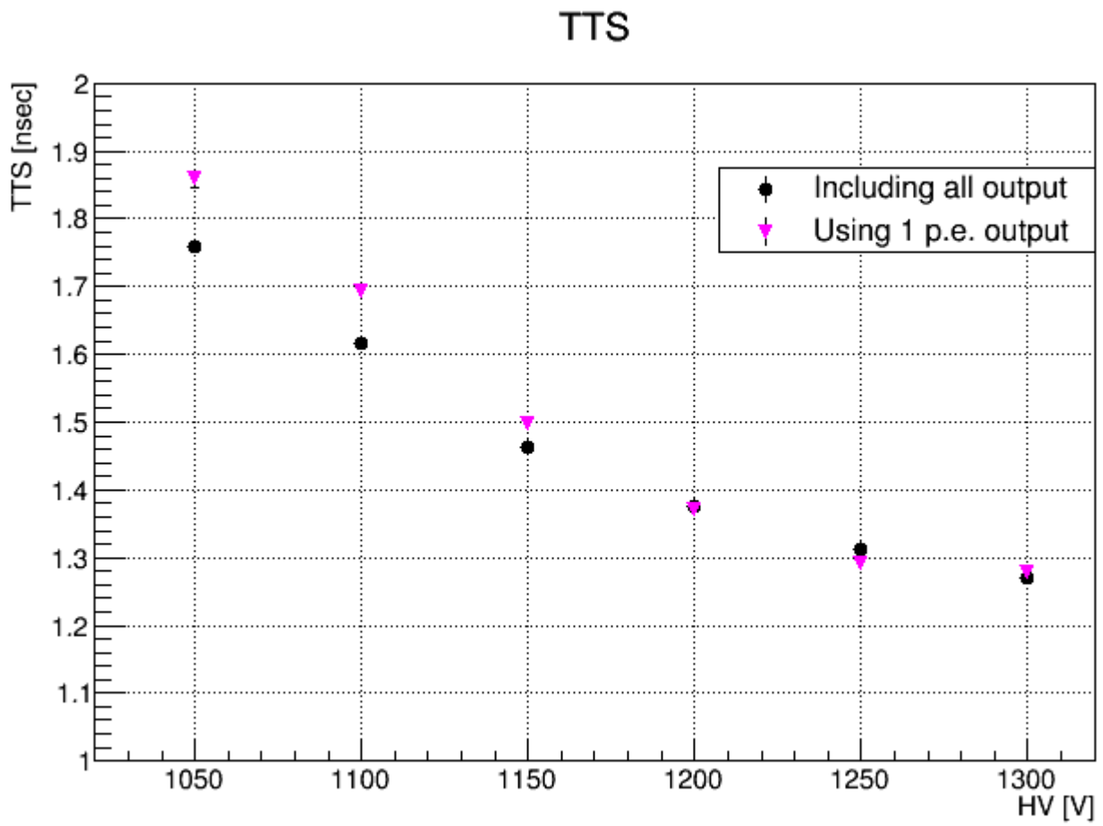
- The fitting to the time histogram is firstly done btw tmin and tmax.
  - tmin = GetBinCenter(maximum bin – 20)
  - tmax = GetBinCenter(maximum bin + 40)
- Then, p4 is set to zero and FWHM is looked for as TTS.
- When making a time histogram, 1 photoelectron events are used within +/- 1 sigma in a charge histogram.

TTS: plots 1 (only 1 photoelectron events)



- Stat. error only.
  - the parameter p2 is probably responsible for the width, so its error was brought as statistical errors of the TTS.

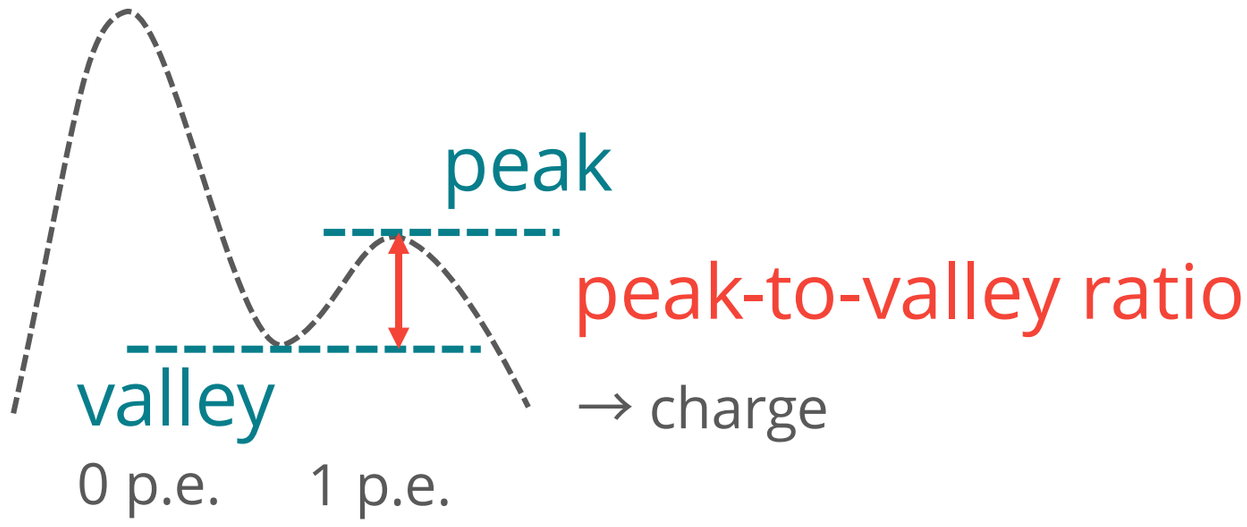
TTS: plots 2



Black: 0 to 100 [$e \times 10^7$C] events
Pink: 1 photoelectron events
within +/- 1 sigma in a charge histogram.

- Black locates below Pink in lower HV.
  - My opinion: this enlargement of 1 p.e. TTS could be caused by noise events which is not haven by Black and they exist within - 1 sigma from 1 p.e. (exist in under 0 C) .
  - to investigate: check the mean and width for each photoelectron event. Because there are 2 cases: width become smaller at high p.e. and-
    -mean doesn't change → total TTS gets smaller.
    -mean changes (shift) → total TTS gets bigger.

Peak to Valley Ratio: Introduction



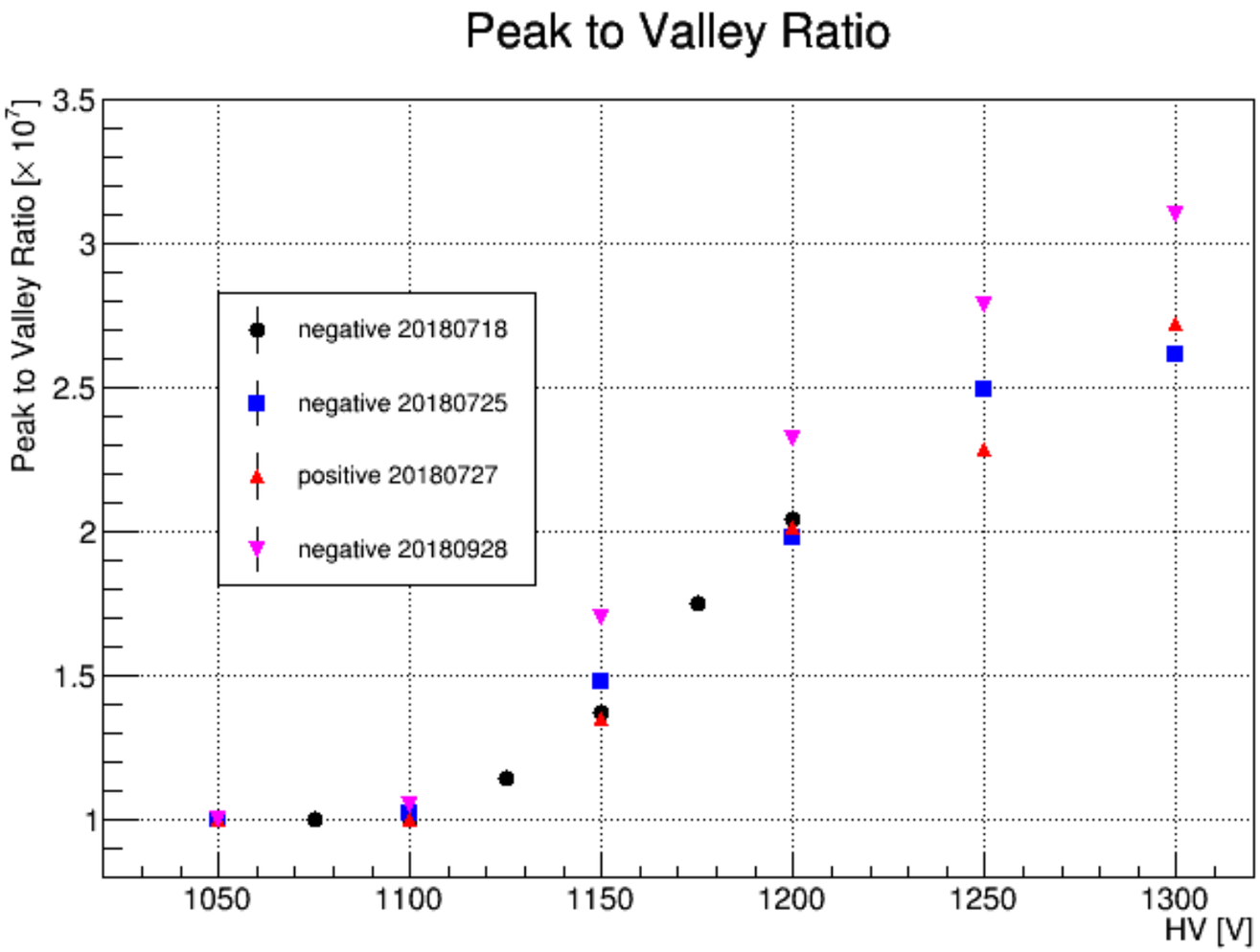
- the ratio is given by

$$\frac{\text{value at } Q_1}{\text{minimum value between } Q_0 \text{ and } Q_1}$$

using the values of fitted function (= qFunction)

- this value would be useful to find lower limit of operating voltage. this is decided by looking for the constant region where the ratio is unchangeable for voltage.

Peak to Valley Ratio: plots



No error applied.

- Why did the result in Sep. change, although the result of Gain is consistent with the ones in Jul.?
  - LED performance: which is the same reason as the Monitor PMT mean change
  - Lens which makes Uniform light different: in Sep. the smaller one is used

Summary

- Gain
  - the result is consistent with the previous result.
- Stability
  - stable in higher HV, but the upward trend is seen in lower HV.
- TTS
  - There is upward trend as it goes towards low HV.
    - This feature is reasonable, because in higher HV, photoelectrons produced at the photocathode directly get going to the anode.
    - To investigate the reason of the difference btw 1 p.e. and all output.
- Peak to Valley ratio
  - the behavior is similar with the result in July, but slightly different. need to investigate it.

Charge and Time histograms

Charge histogram
in Log y scale

Time histogram
for 1 photoelectron
Range: tmin to tmax

Time histogram
for 1 photoelectron
in Log y scale

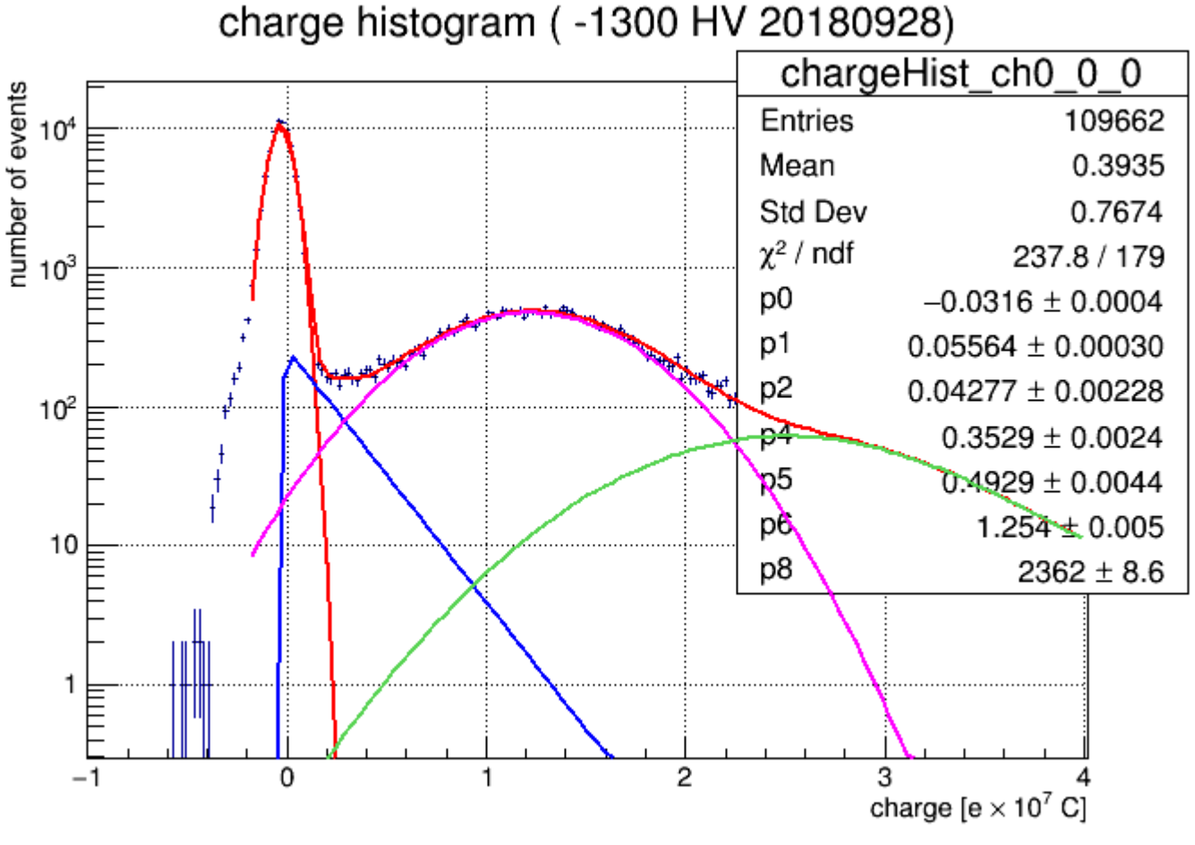
Time histogram
for 0 to 100 [$e \times 10^7$ C]
in Log y scale

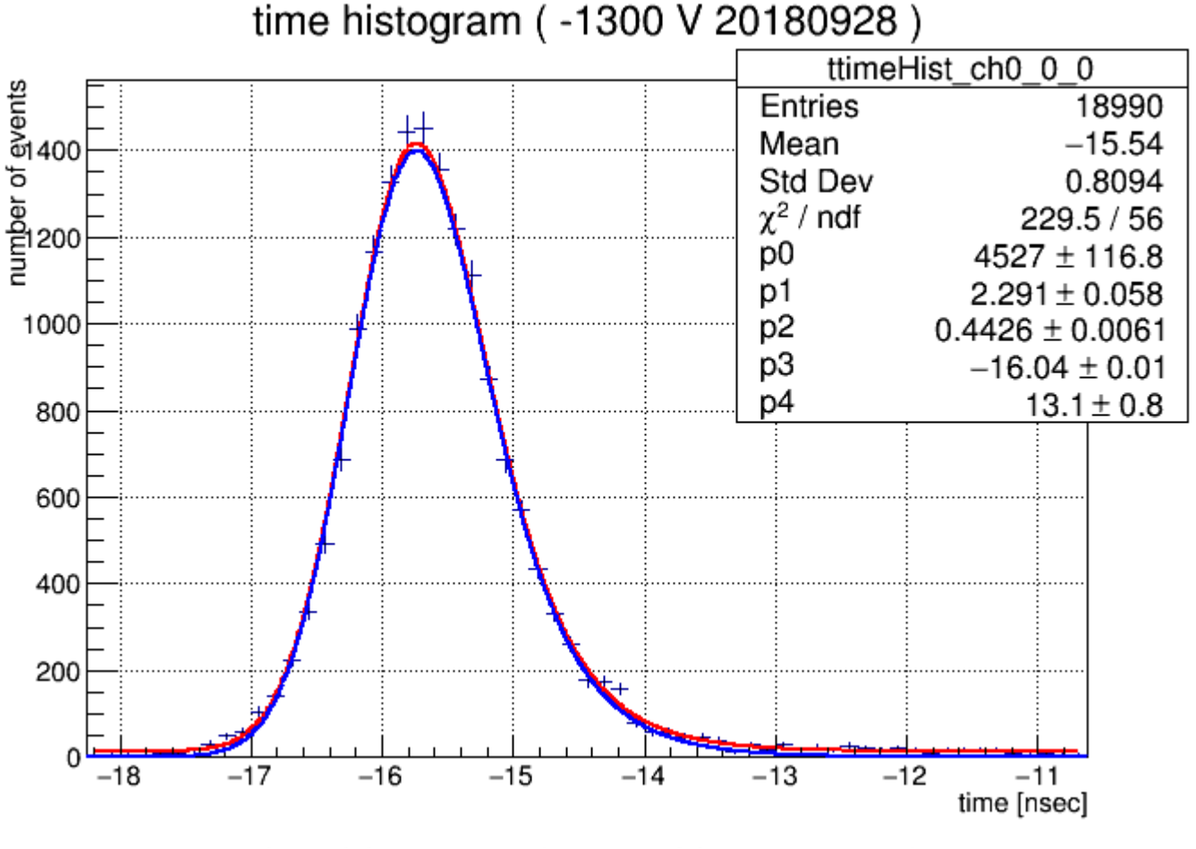
- In a time histogram:

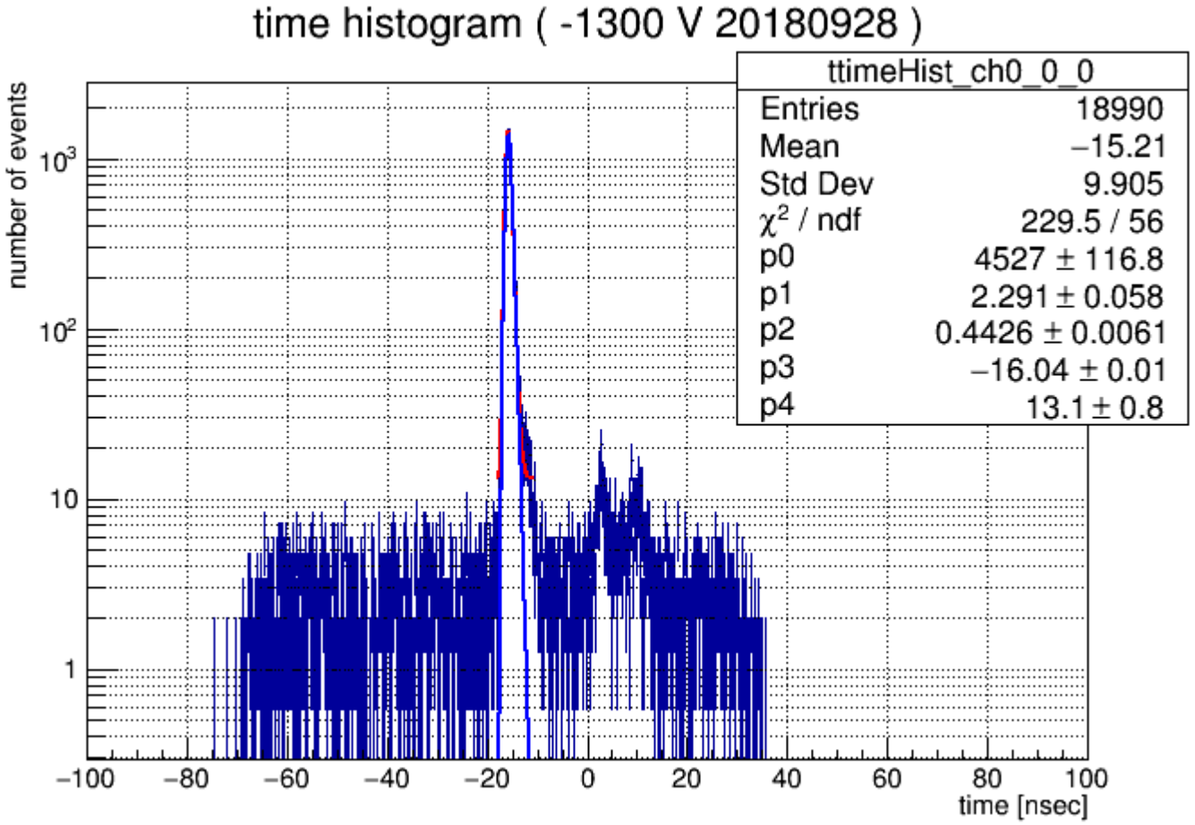
  The bump under the -40 ns is due to pedestal.

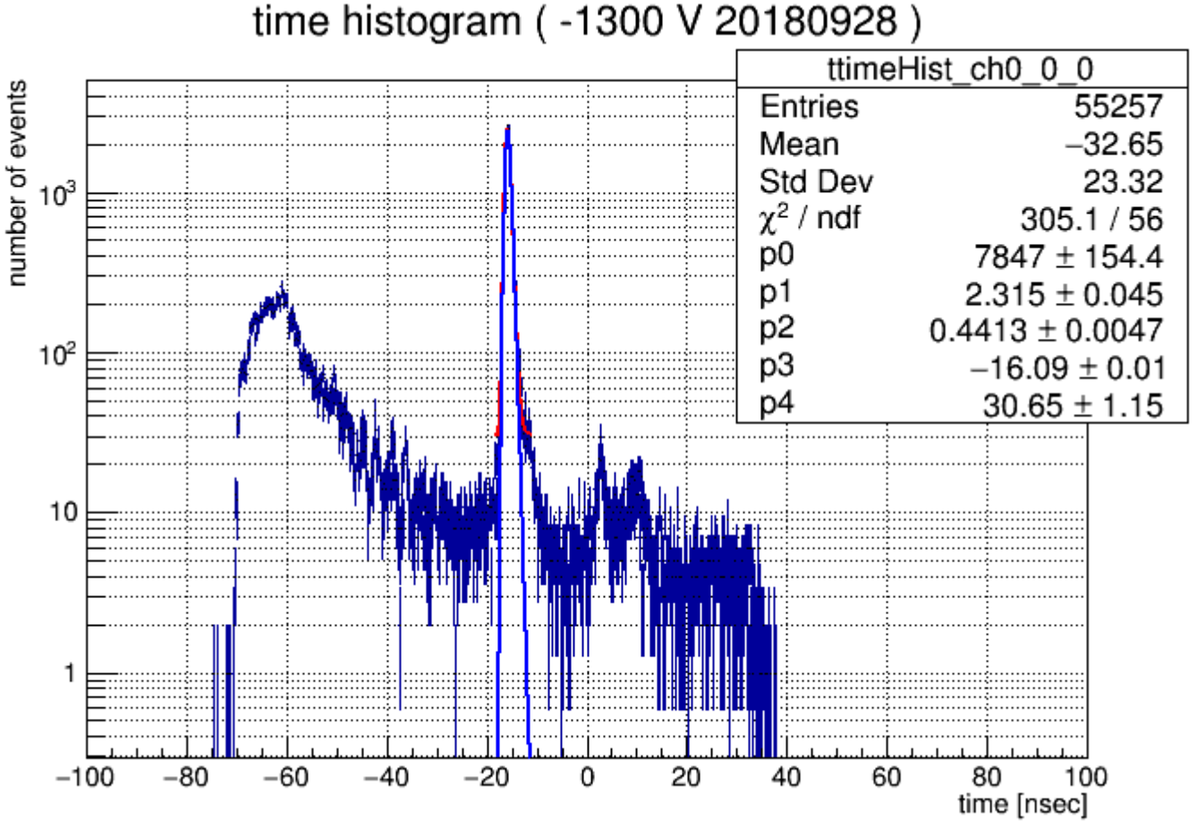
  The tiny bump around 10 ns in a time histogram is caused by …?

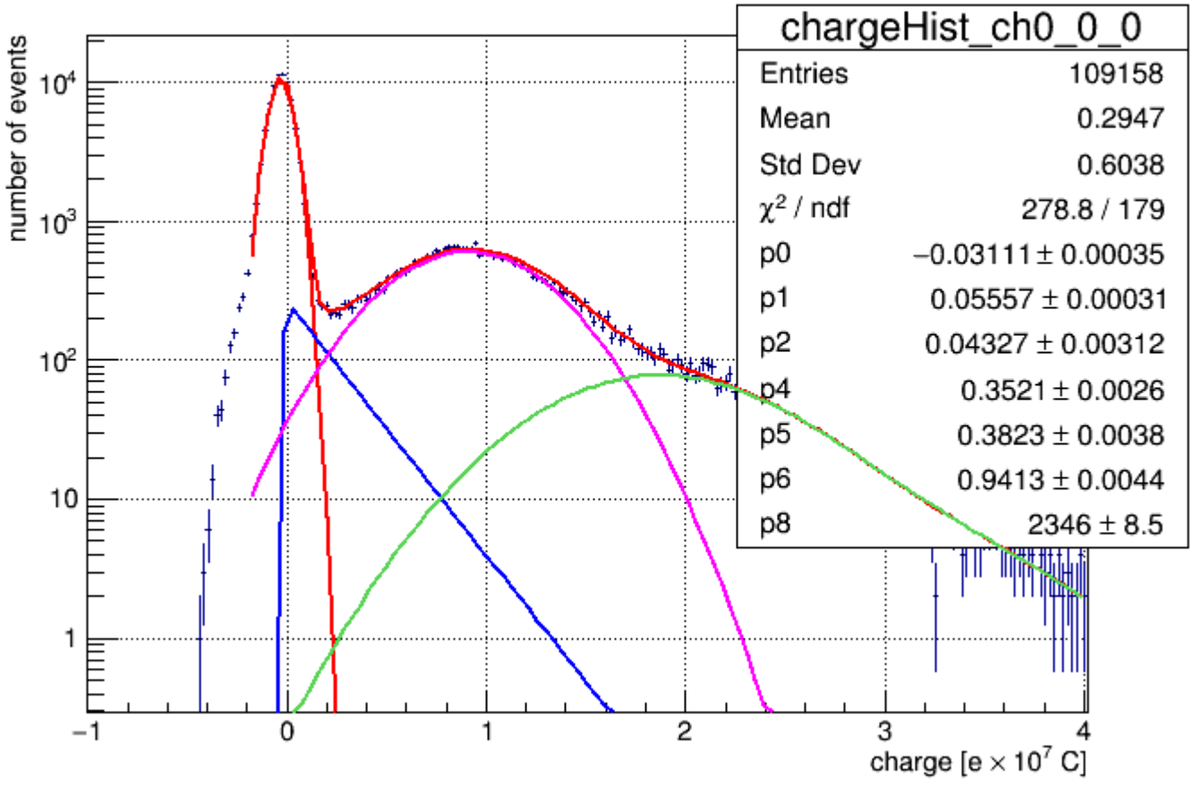
  → to investigate (after pulse?)

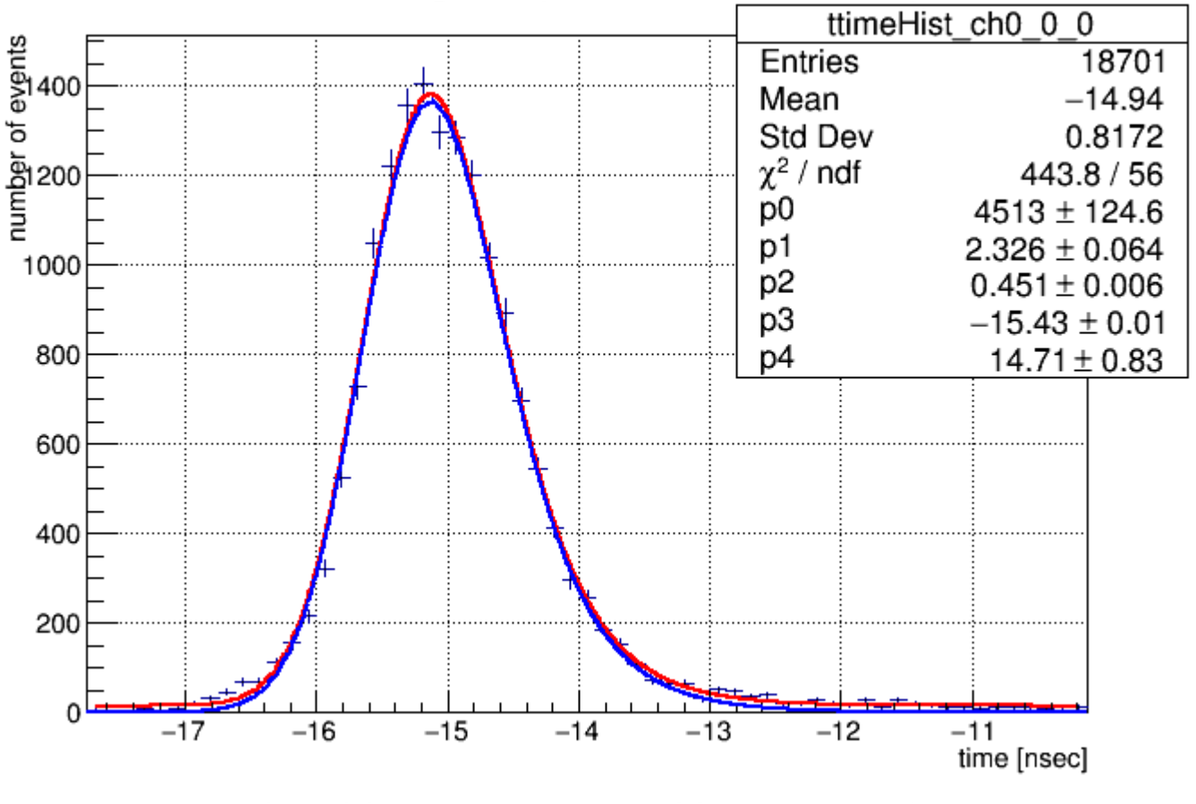

charge histogram (-1300 HV 20180928)
chargeHist_ch0_0_0
Entries 109662
Mean 0.3935
Std Dev 0.7674
χ² / ndf 237.8 / 179
p0 −0.0316 ± 0.0004
p1 0.05564 ± 0.00030
p2 0.04277 ± 0.00228
p4 0.3529 ± 0.0024
p5 0.4929 ± 0.0044
p6 1.254 ± 0.005
p8 2362 ± 8.6
number of events
charge [e × 10⁷ C]

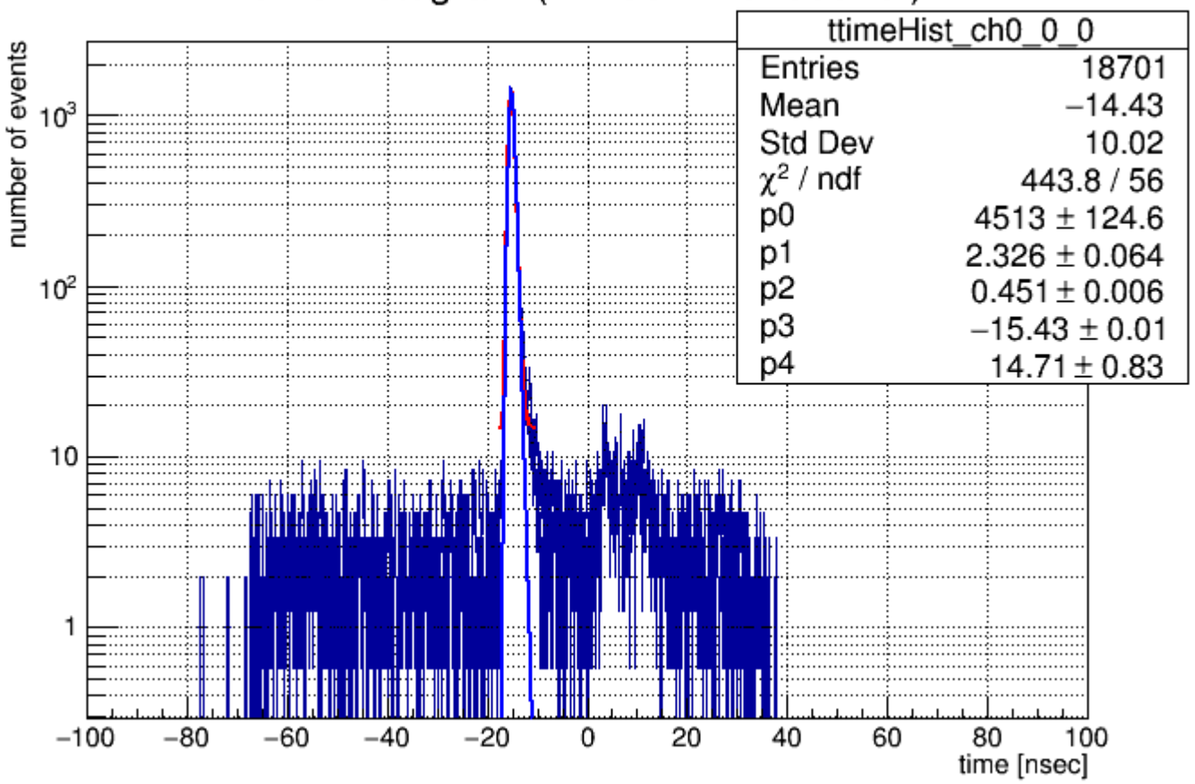

time histogram (-1300 V 20180928)
ttimeHist_ch0_0_0
Entries 18990
Mean −15.54
Std Dev 0.8094
χ² / ndf 229.5 / 56
p0 4527 ± 116.8
p1 2.291 ± 0.058
p2 0.4426 ± 0.0061
p3 −16.04 ± 0.01
p4 13.1 ± 0.8
number of events
time [nsec]

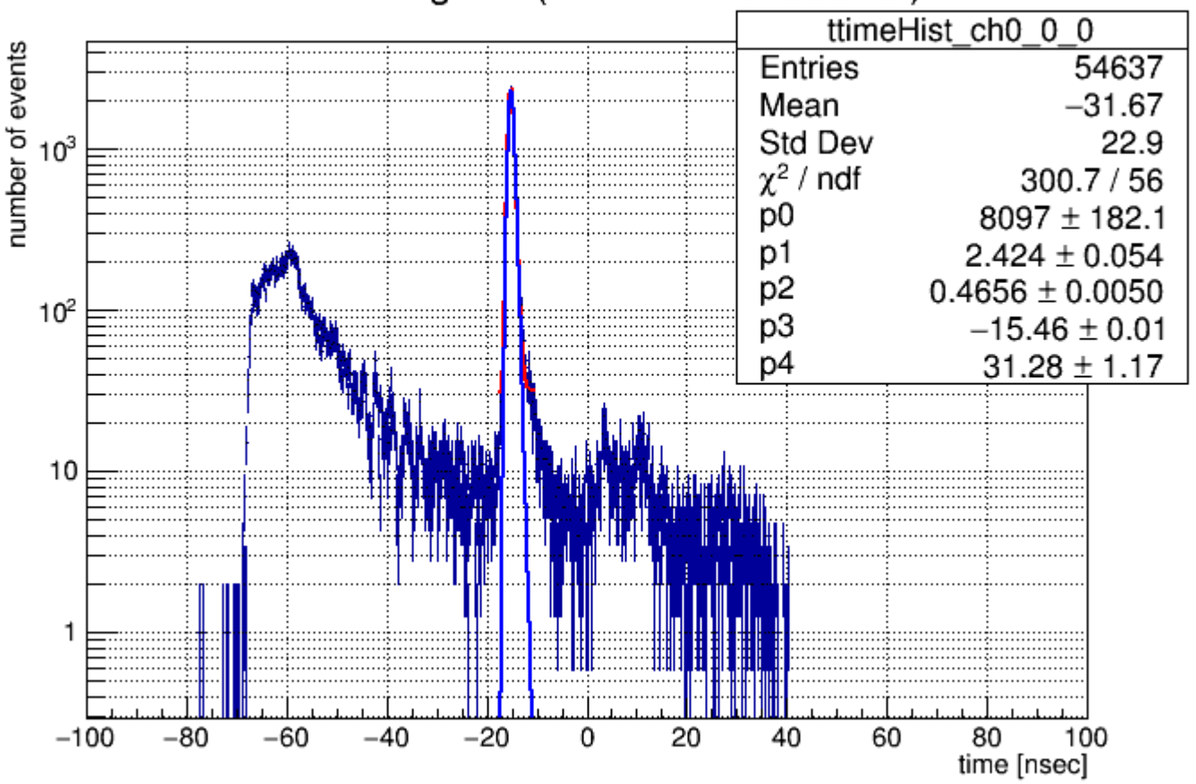

time histogram (-1300 V 20180928)
ttimeHist_ch0_0_0
Entries 18990
Mean −15.21
Std Dev 9.905
χ² / ndf 229.5 / 56
p0 4527 ± 116.8
p1 2.291 ± 0.058
p2 0.4426 ± 0.0061
p3 −16.04 ± 0.01
p4 13.1 ± 0.8
number of events
time [nsec]

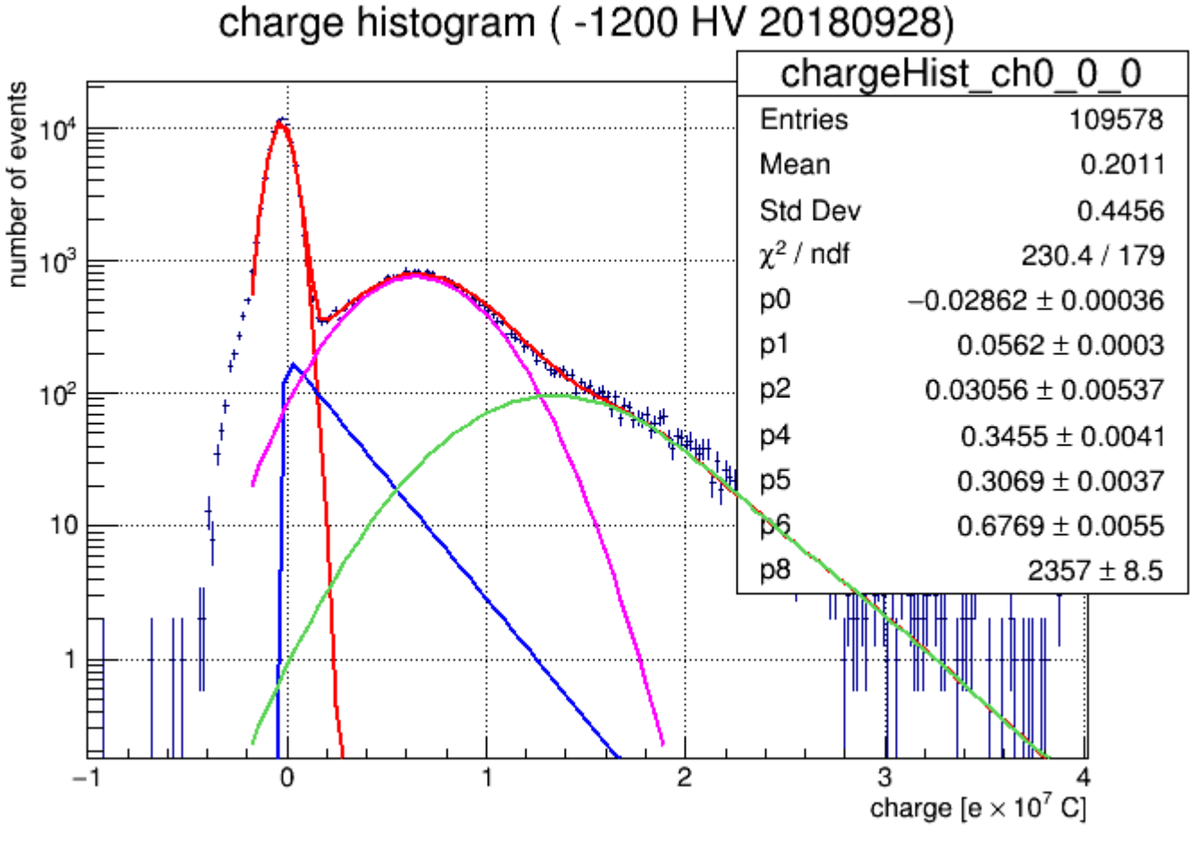

time histogram (-1300 V 20180928)
ttimeHist_ch0_0_0
Entries 55257
Mean −32.65
Std Dev 23.32
χ² / ndf 305.1 / 56
p0 7847 ± 154.4
p1 2.315 ± 0.045
p2 0.4413 ± 0.0047
p3 −16.09 ± 0.01
p4 30.65 ± 1.15
number of events
time [nsec]

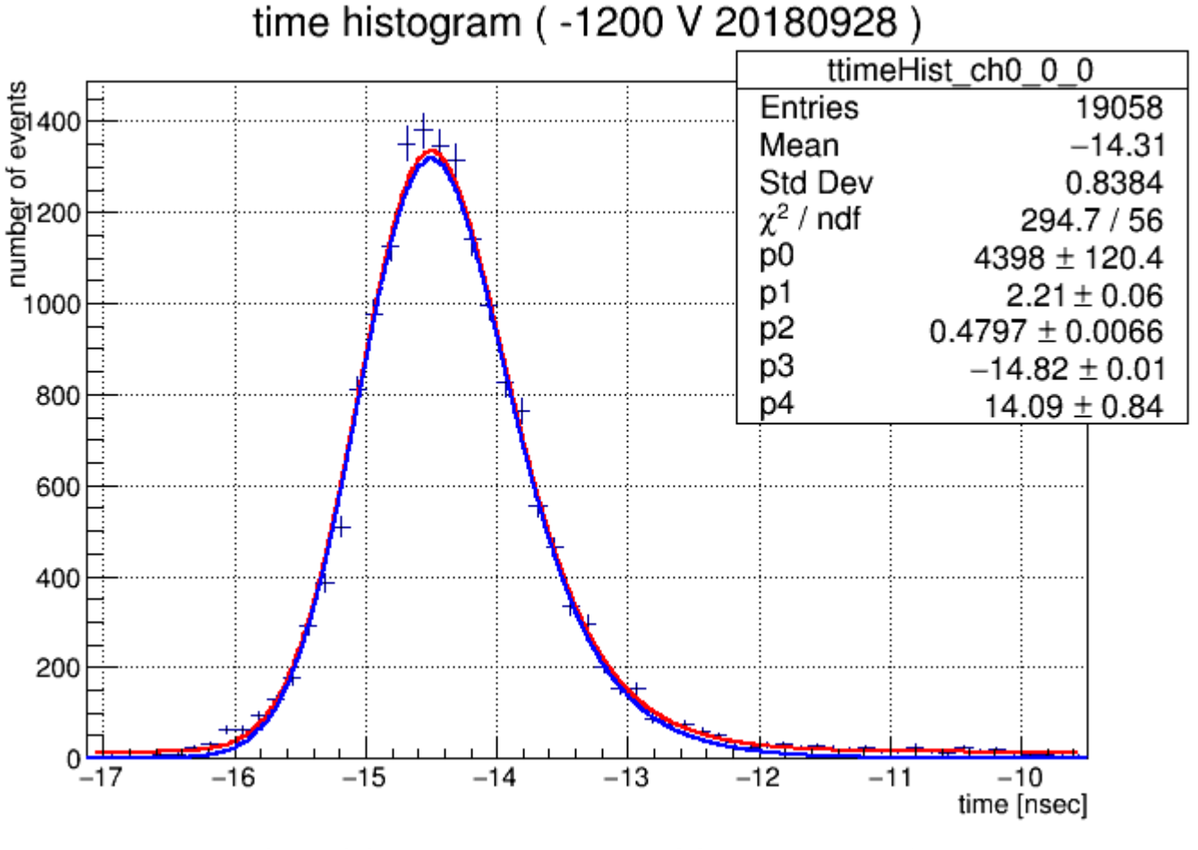

charge histogram (-1250 HV 20180928)
chargeHist_ch0_0_0
Entries 109158
Mean 0.2947
Std Dev 0.6038
χ² / ndf 278.8 / 179
p0 −0.03111 ± 0.00035
p1 0.05557 ± 0.00031
p2 0.04327 ± 0.00312
p4 0.3521 ± 0.0026
p5 0.3823 ± 0.0038
p6 0.9413 ± 0.0044
p8 2346 ± 8.5
number of events
charge [e × 10⁷ C]

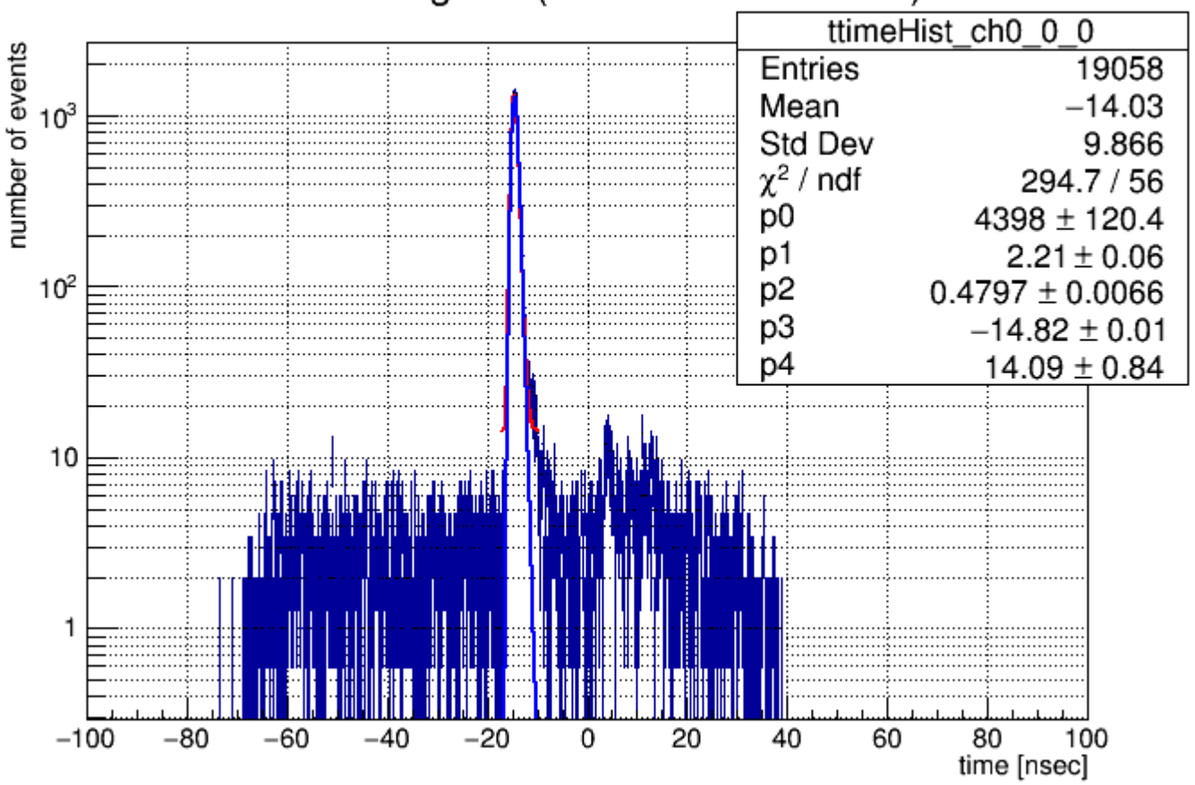

time histogram (-1250 V 20180928)
ttimeHist_ch0_0_0
Entries 18701
Mean −14.94
Std Dev 0.8172
χ² / ndf 443.8 / 56
p0 4513 ± 124.6
p1 2.326 ± 0.064
p2 0.451 ± 0.006
p3 −15.43 ± 0.01
p4 14.71 ± 0.83
number of events
time [nsec]

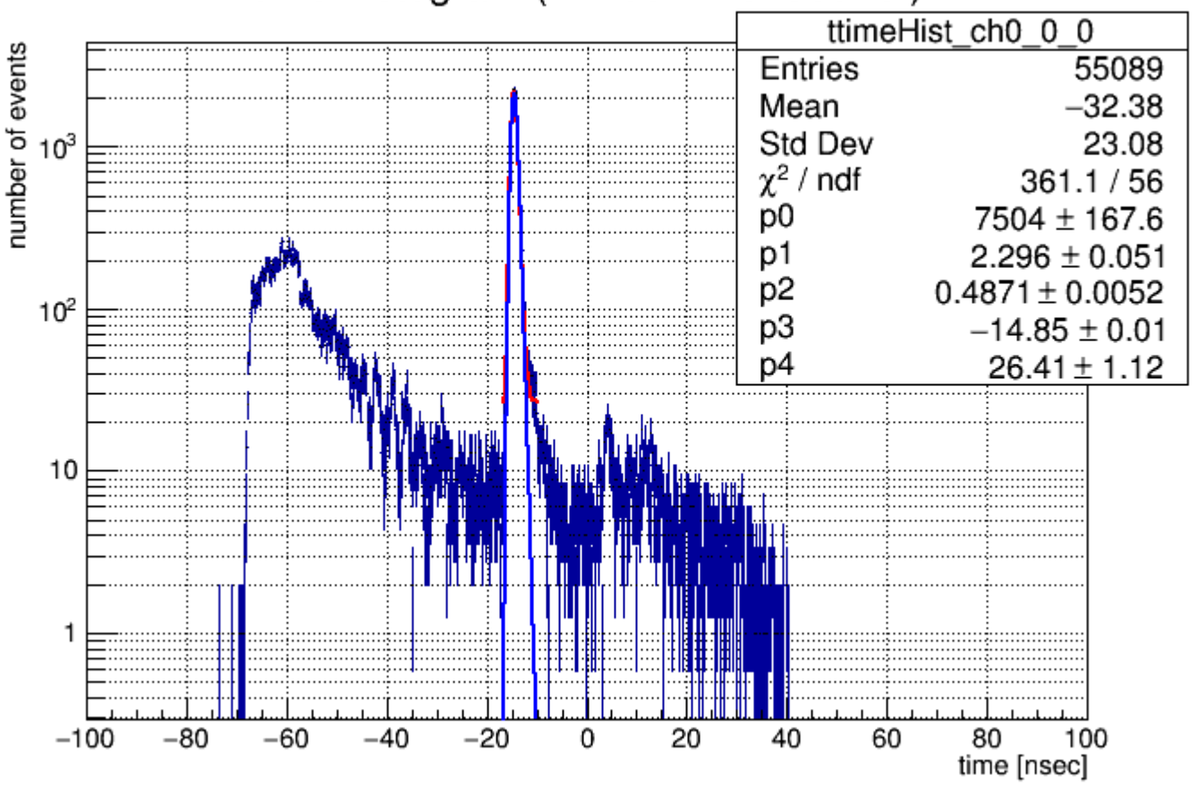

time histogram (-1250 V 20180928)
ttimeHist_ch0_0_0
Entries 18701
Mean −14.43
Std Dev 10.02
χ² / ndf 443.8 / 56
p0 4513 ± 124.6
p1 2.326 ± 0.064
p2 0.451 ± 0.006
p3 −15.43 ± 0.01
p4 14.71 ± 0.83
number of events
time [nsec]

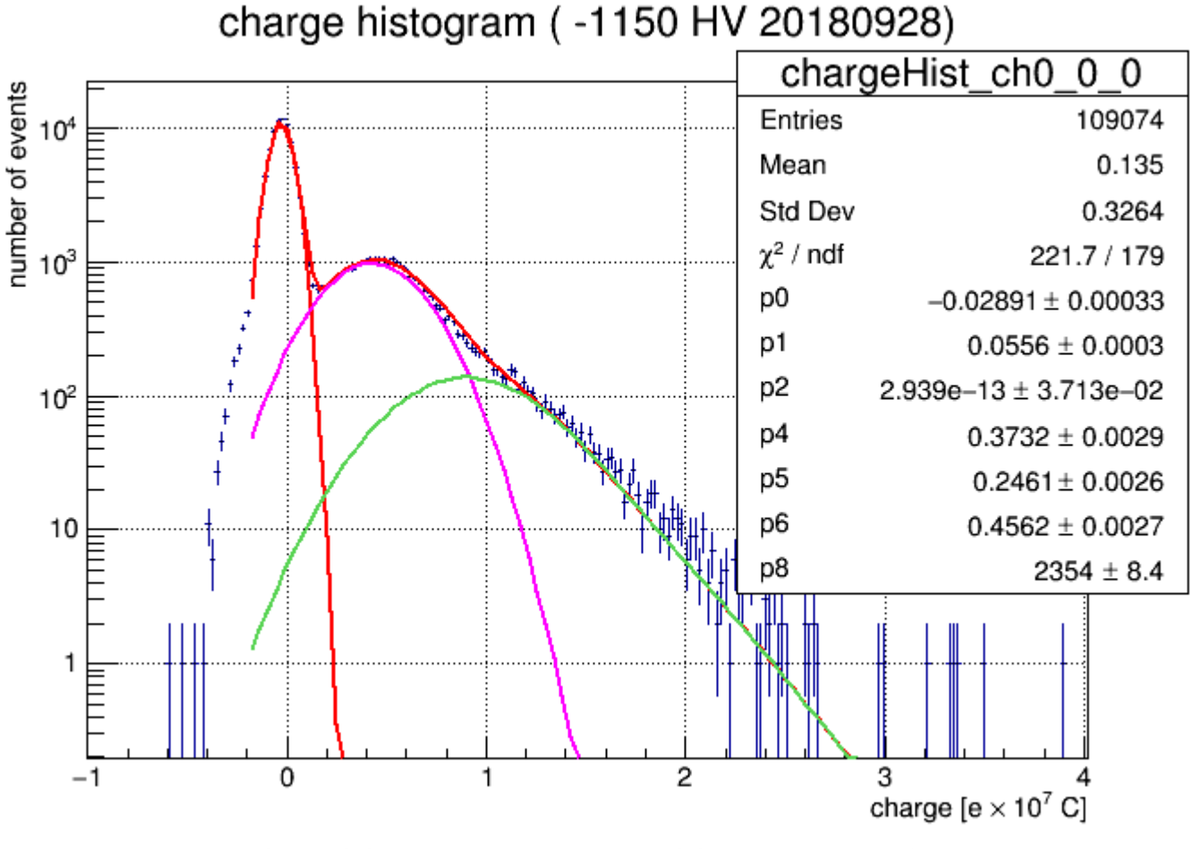

time histogram (-1250 V 20180928)
ttimeHist_ch0_0_0
Entries 54637
Mean −31.67
Std Dev 22.9
χ² / ndf 300.7 / 56
p0 8097 ± 182.1
p1 2.424 ± 0.054
p2 0.4656 ± 0.0050
p3 −15.46 ± 0.01
p4 31.28 ± 1.17
number of events
time [nsec]

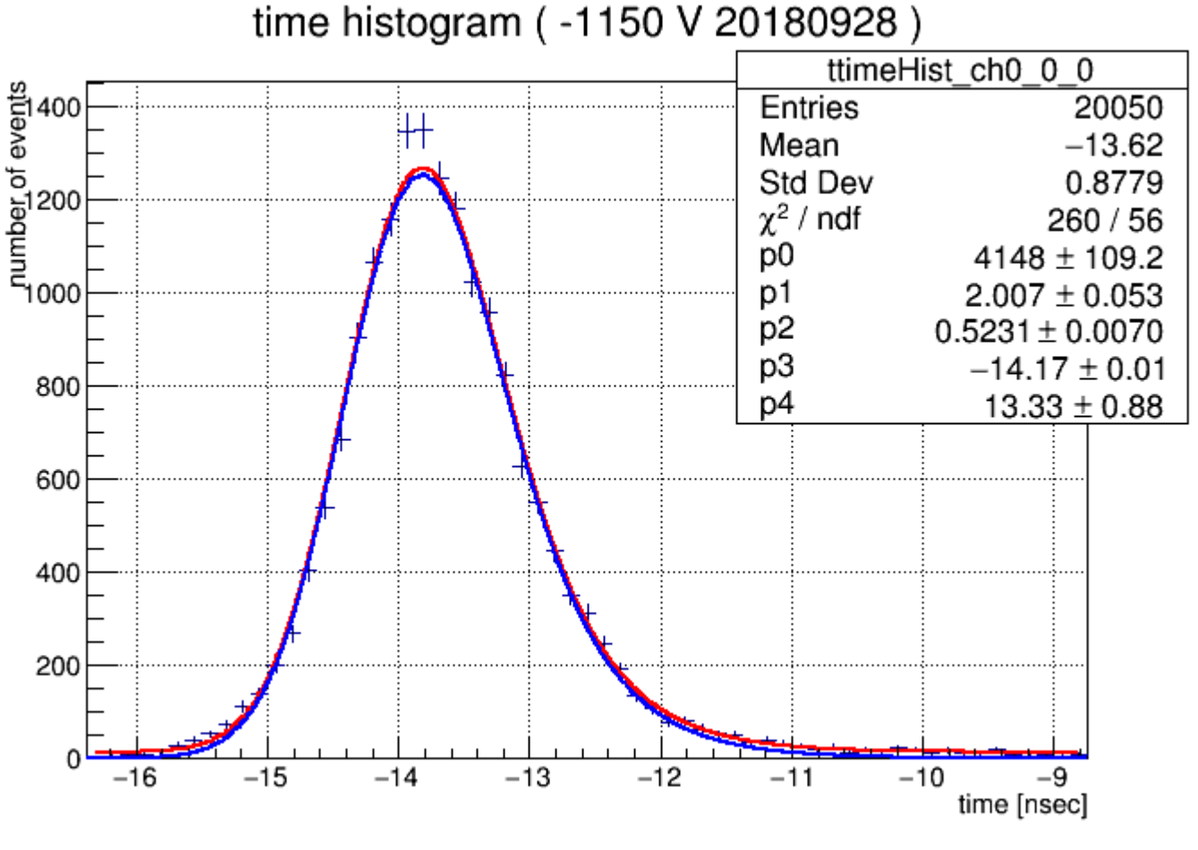

charge histogram (-1200 HV 20180928)
chargeHist_ch0_0_0
Entries 109578
Mean 0.2011
Std Dev 0.4456
χ² / ndf 230.4 / 179
p0 −0.02862 ± 0.00036
p1 0.0562 ± 0.0003
p2 0.03056 ± 0.00537
p4 0.3455 ± 0.0041
p5 0.3069 ± 0.0037
p6 0.6769 ± 0.0055
p8 2357 ± 8.5
number of events
charge [e × 10⁷ C]

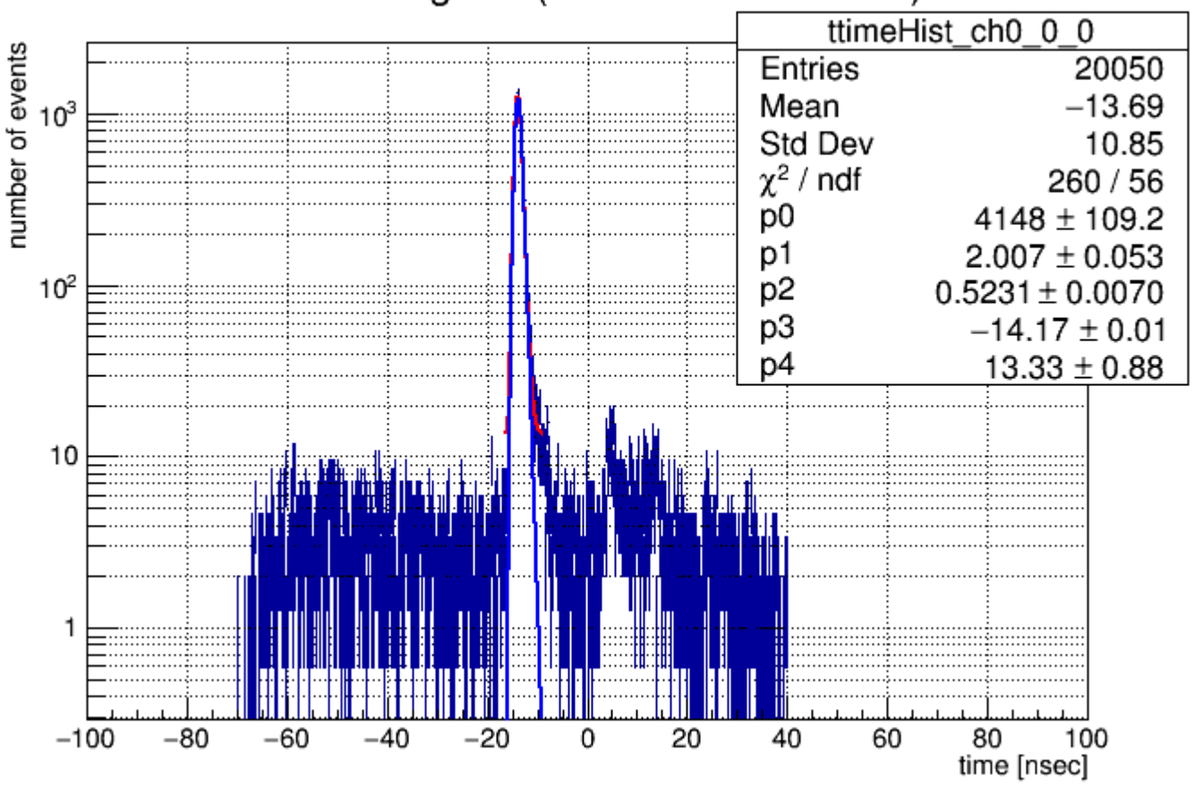

time histogram (-1200 V 20180928)
ttimeHist_ch0_0_0
Entries 19058
Mean −14.31
Std Dev 0.8384
χ² / ndf 294.7 / 56
p0 4398 ± 120.4
p1 2.21 ± 0.06
p2 0.4797 ± 0.0066
p3 −14.82 ± 0.01
p4 14.09 ± 0.84
number of events
time [nsec]

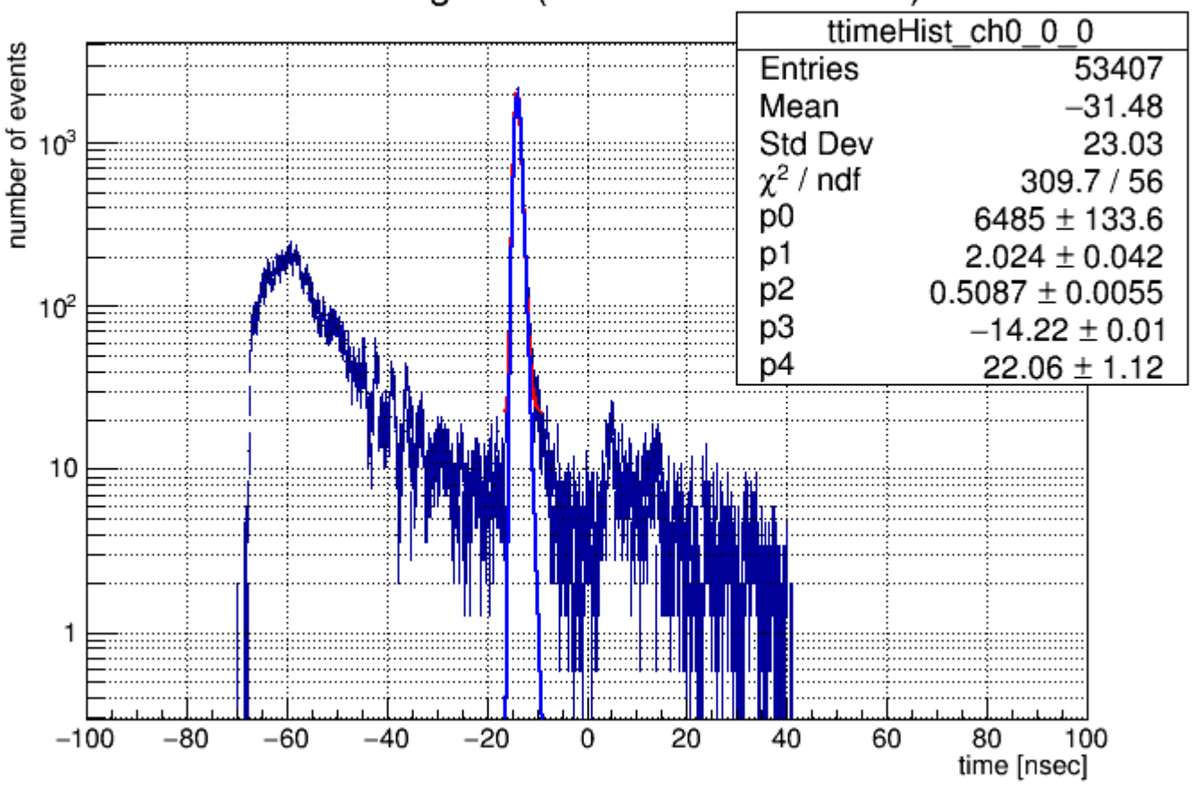

time histogram (-1200 V 20180928)
ttimeHist_ch0_0_0
Entries 19058
Mean −14.03
Std Dev 9.866
χ² / ndf 294.7 / 56
p0 4398 ± 120.4
p1 2.21 ± 0.06
p2 0.4797 ± 0.0066
p3 −14.82 ± 0.01
p4 14.09 ± 0.84
number of events
time [nsec]

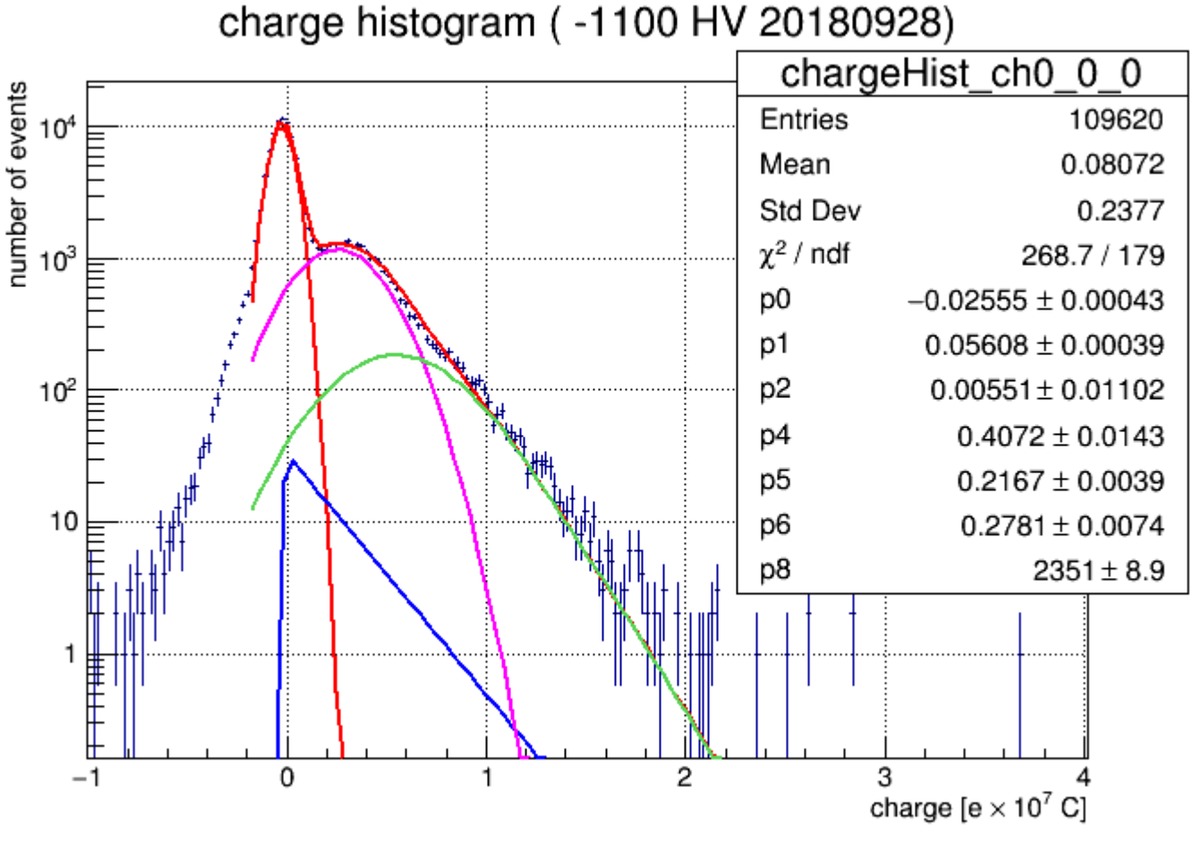

time histogram (-1200 V 20180928)
ttimeHist_ch0_0_0
Entries 55089
Mean −32.38
Std Dev 23.08
χ² / ndf 361.1 / 56
p0 7504 ± 167.6
p1 2.296 ± 0.051
p2 0.4871 ± 0.0052
p3 −14.85 ± 0.01
p4 26.41 ± 1.12
number of events
time [nsec]

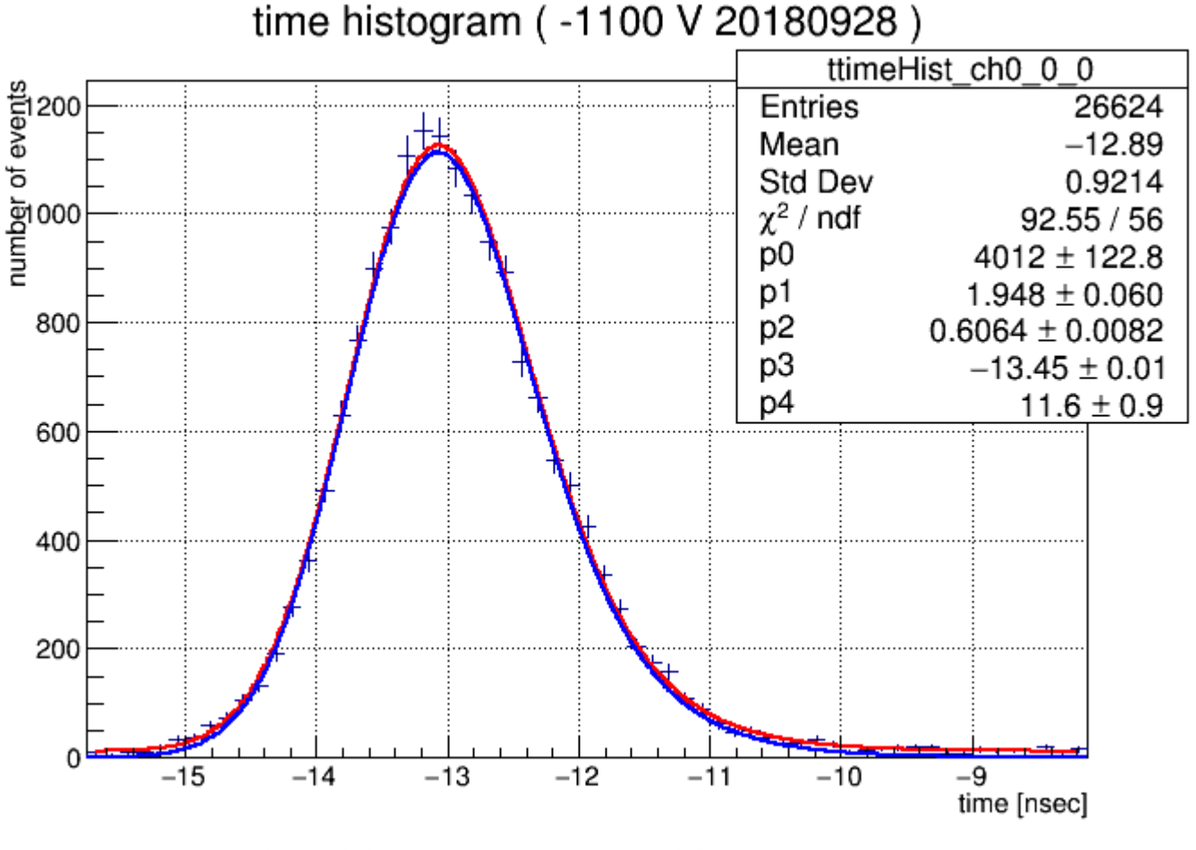

charge histogram (-1150 HV 20180928)
chargeHist_ch0_0_0
Entries 109074
Mean 0.135
Std Dev 0.3264
χ² / ndf 221.7 / 179
p0 −0.02891 ± 0.00033
p1 0.0556 ± 0.0003
p2 2.939e−13 ± 3.713e−02
p4 0.3732 ± 0.0029
p5 0.2461 ± 0.0026
p6 0.4562 ± 0.0027
p8 2354 ± 8.4
number of events
charge [e × 10⁷ C]

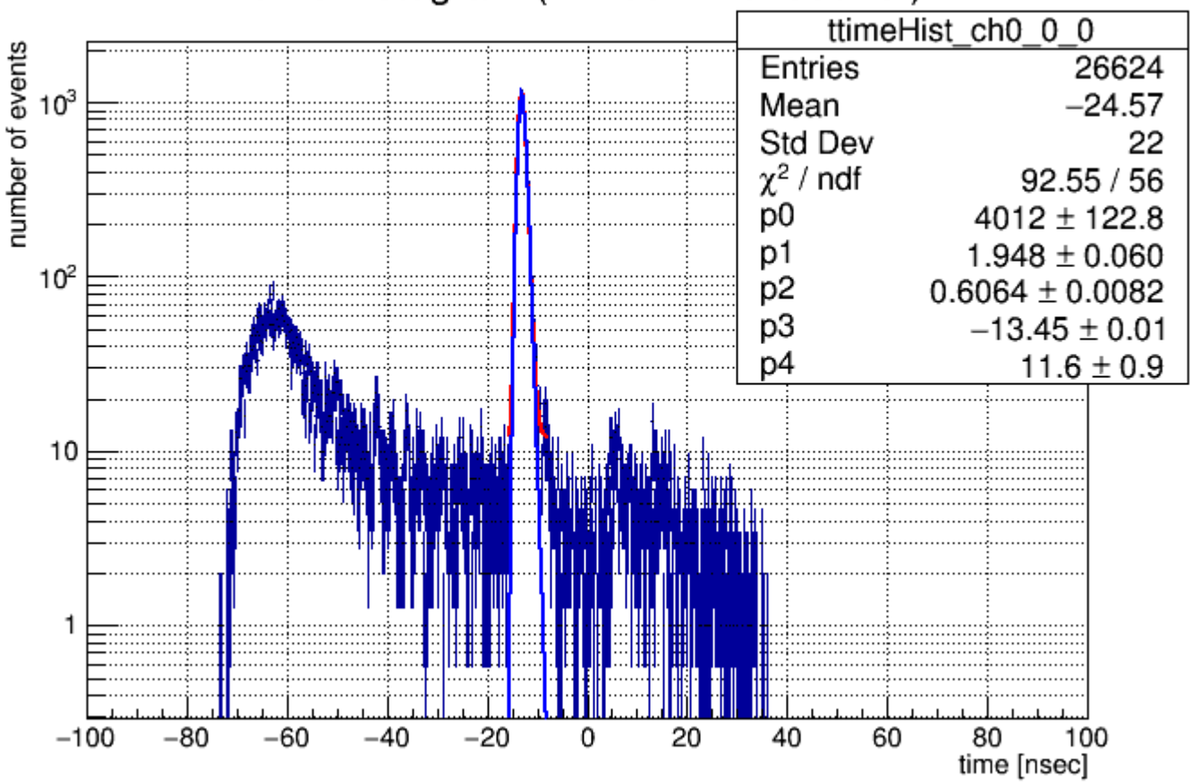

time histogram (-1150 V 20180928)
ttimeHist_ch0_0_0
Entries 20050
Mean −13.62
Std Dev 0.8779
χ² / ndf 260 / 56
p0 4148 ± 109.2
p1 2.007 ± 0.053
p2 0.5231 ± 0.0070
p3 −14.17 ± 0.01
p4 13.33 ± 0.88
number of events
time [nsec]

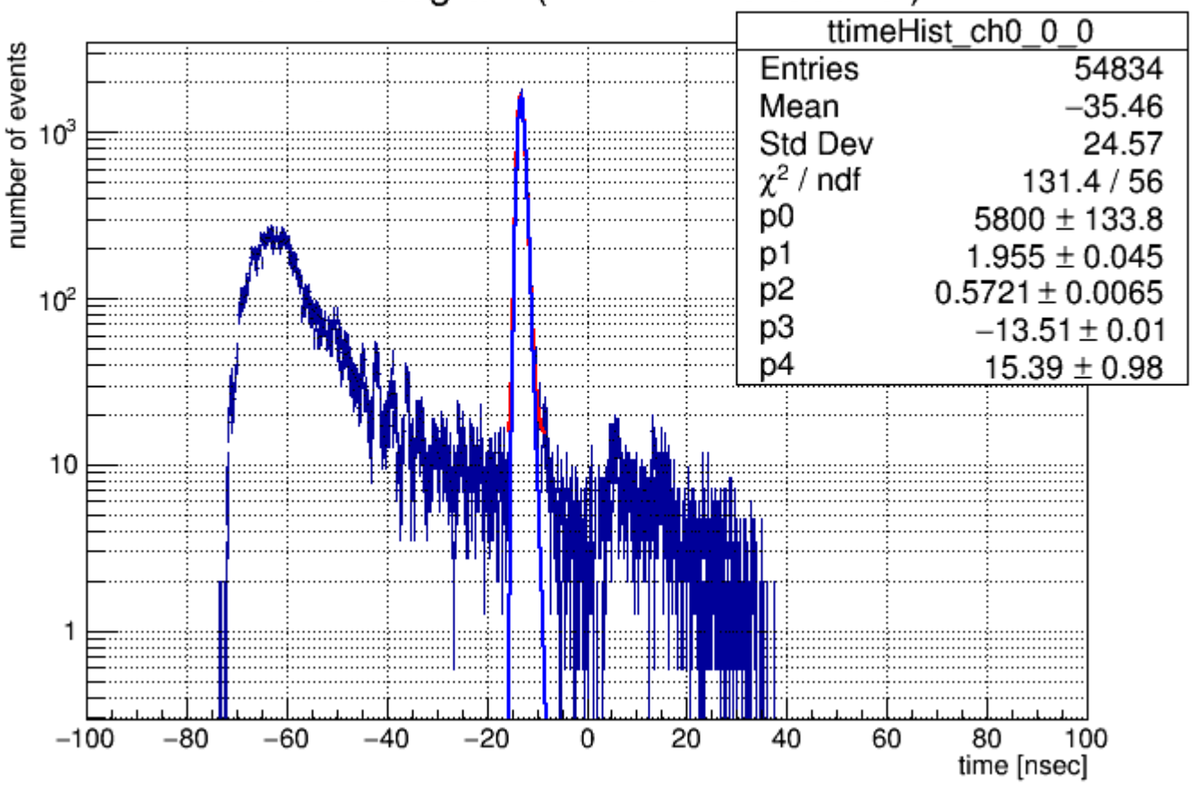

time histogram (-1150 V 20180928)
ttimeHist_ch0_0_0
Entries 20050
Mean −13.69
Std Dev 10.85
χ² / ndf 260 / 56
p0 4148 ± 109.2
p1 2.007 ± 0.053
p2 0.5231 ± 0.0070
p3 −14.17 ± 0.01
p4 13.33 ± 0.88
number of events
time [nsec]

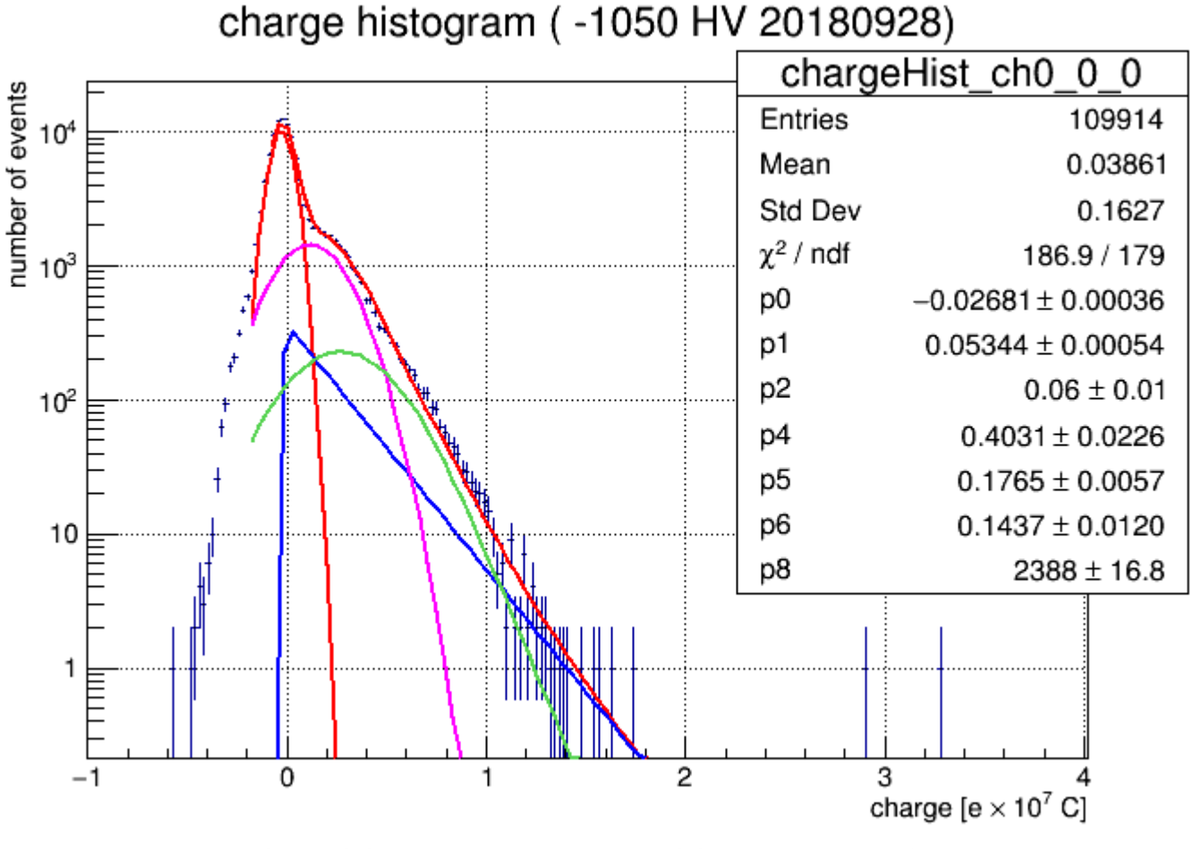

time histogram (-1150 V 20180928)
ttimeHist_ch0_0_0
Entries 53407
Mean −31.48
Std Dev 23.03
χ² / ndf 309.7 / 56
p0 6485 ± 133.6
p1 2.024 ± 0.042
p2 0.5087 ± 0.0055
p3 −14.22 ± 0.01
p4 22.06 ± 1.12
number of events
time [nsec]

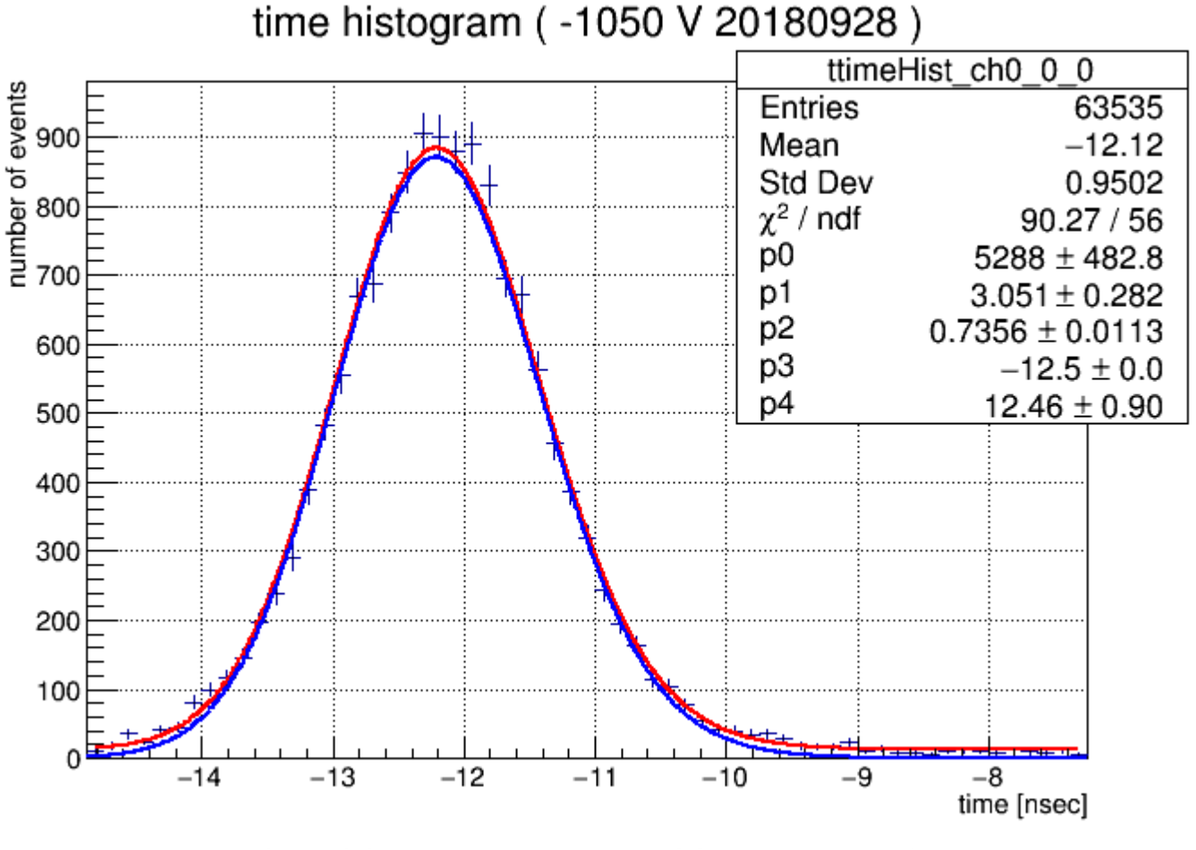

charge histogram (-1100 HV 20180928)
chargeHist_ch0_0_0
Entries 109620
Mean 0.08072
Std Dev 0.2377
χ² / ndf 268.7 / 179
p0 −0.02555 ± 0.00043
p1 0.05608 ± 0.00039
p2 0.00551 ± 0.01102
p4 0.4072 ± 0.0143
p5 0.2167 ± 0.0039
p6 0.2781 ± 0.0074
p8 2351 ± 8.9
number of events
charge [e × 10⁷ C]

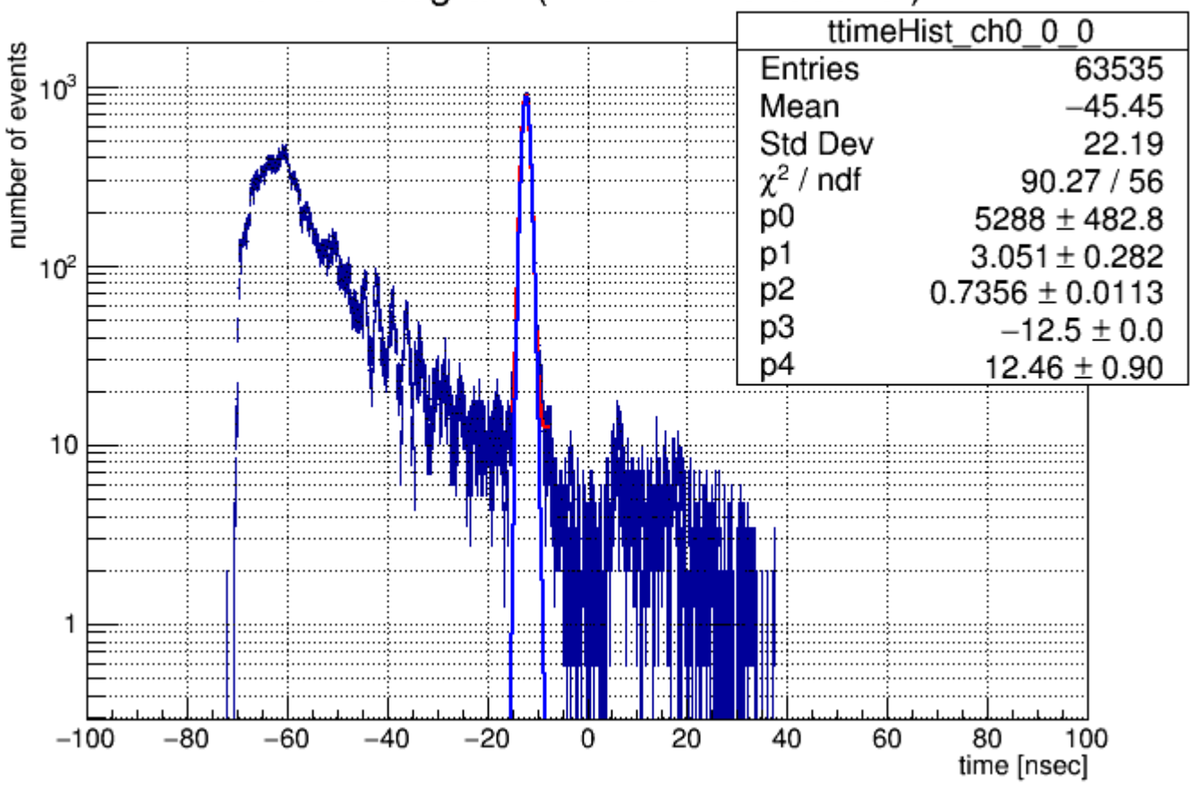

time histogram (-1100 V 20180928)
ttimeHist_ch0_0_0
Entries 26624
Mean −12.89
Std Dev 0.9214
χ² / ndf 92.55 / 56
p0 4012 ± 122.8
p1 1.948 ± 0.060
p2 0.6064 ± 0.0082
p3 −13.45 ± 0.01
p4 11.6 ± 0.9
number of events
time [nsec]

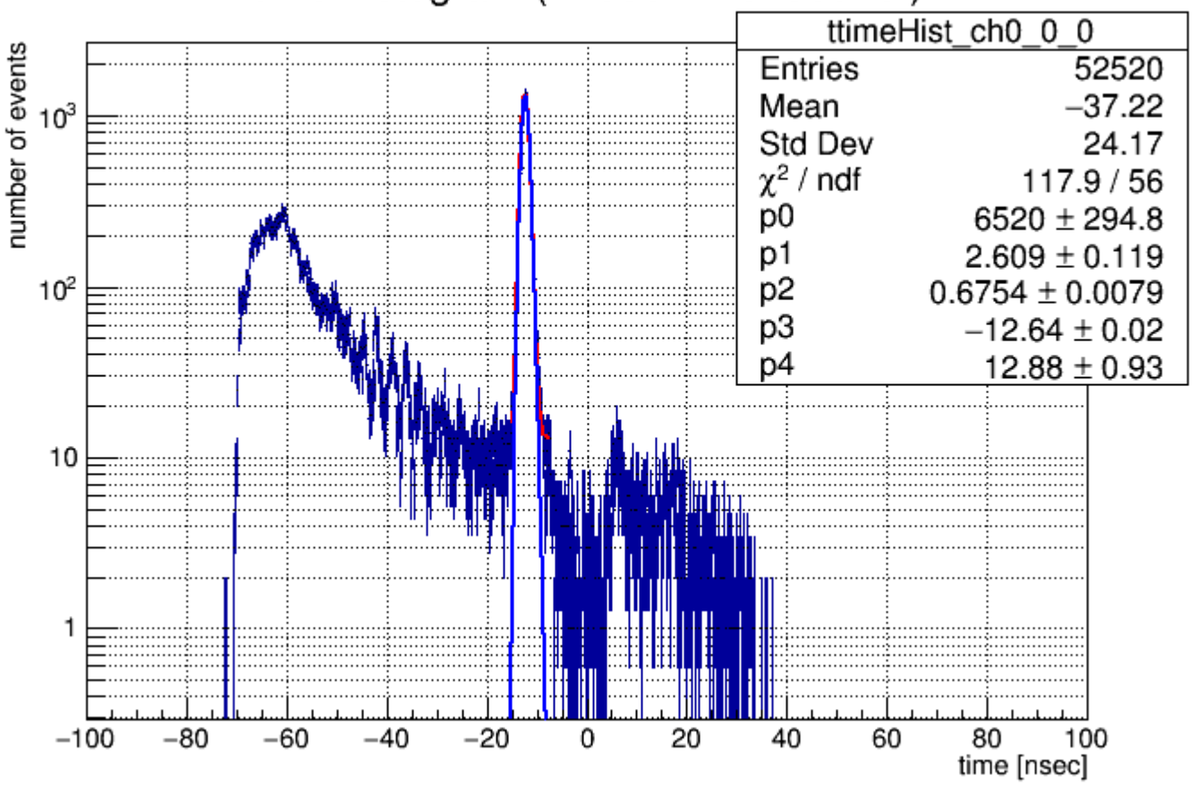

time histogram (-1100 V 20180928)
ttimeHist_ch0_0_0
Entries 26624
Mean −24.57
Std Dev 22
χ² / ndf 92.55 / 56
p0 4012 ± 122.8
p1 1.948 ± 0.060
p2 0.6064 ± 0.0082
p3 −13.45 ± 0.01
p4 11.6 ± 0.9
number of events
time [nsec]


time histogram (-1100 V 20180928)
ttimeHist_ch0_0_0
Entries 54834
Mean −35.46
Std Dev 24.57
χ² / ndf 131.4 / 56
p0 5800 ± 133.8
p1 1.955 ± 0.045
p2 0.5721 ± 0.0065
p3 −13.51 ± 0.01
p4 15.39 ± 0.98
number of events
time [nsec]

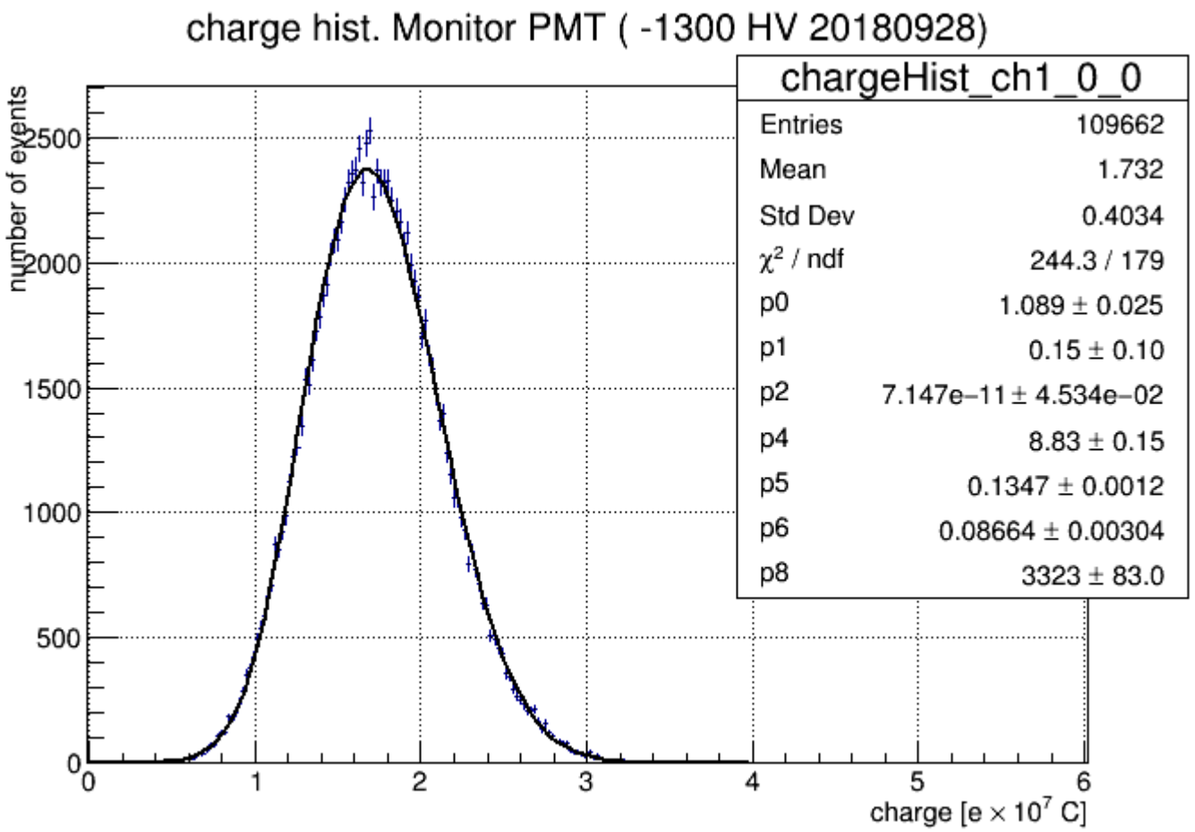

charge histogram (-1050 HV 20180928)
chargeHist_ch0_0_0
Entries 109914
Mean 0.03861
Std Dev 0.1627
χ² / ndf 186.9 / 179
p0 −0.02681 ± 0.00036
p1 0.05344 ± 0.00054
p2 0.06 ± 0.01
p4 0.4031 ± 0.0226
p5 0.1765 ± 0.0057
p6 0.1437 ± 0.0120
p8 2388 ± 16.8
number of events
charge [e × 10⁷ C]

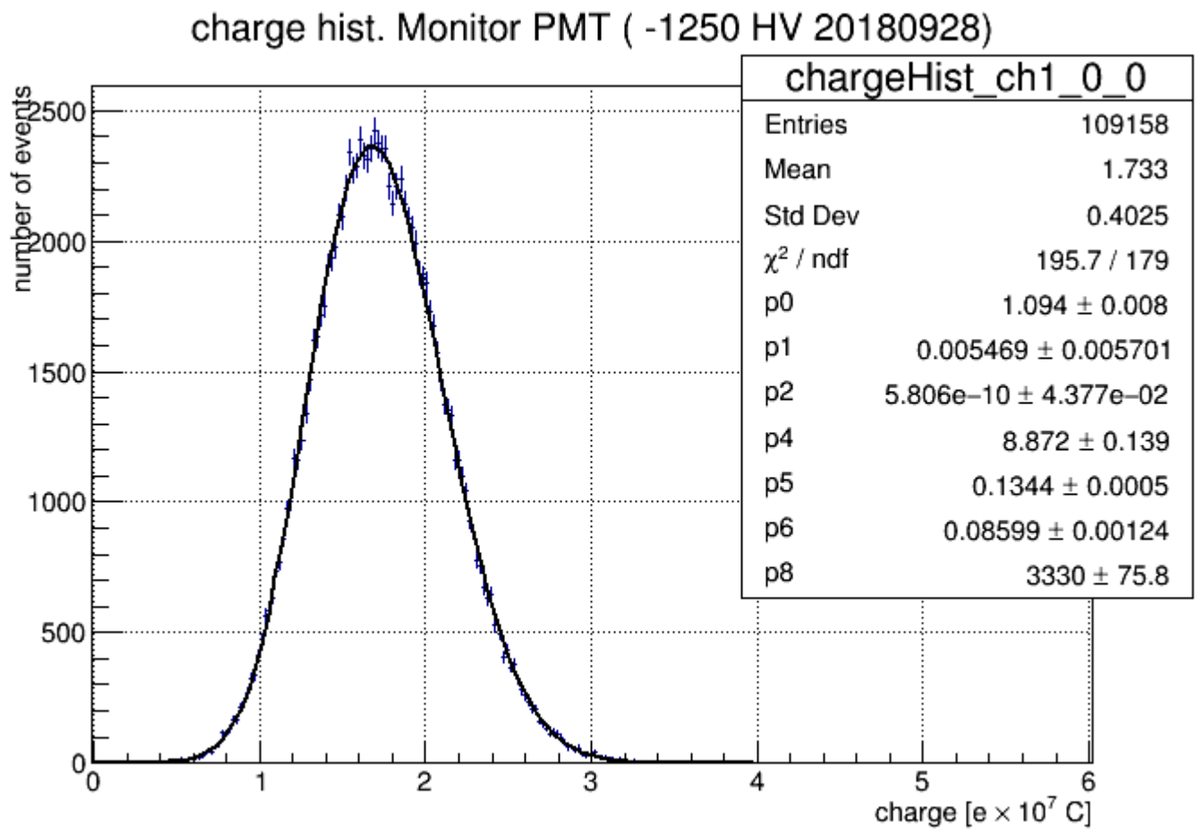

time histogram (-1050 V 20180928)
ttimeHist_ch0_0_0
Entries 63535
Mean −12.12
Std Dev 0.9502
χ² / ndf 90.27 / 56
p0 5288 ± 482.8
p1 3.051 ± 0.282
p2 0.7356 ± 0.0113
p3 −12.5 ± 0.0
p4 12.46 ± 0.90
number of events
time [nsec]


time histogram (-1050 V 20180928)
ttimeHist_ch0_0_0
Entries 63535
Mean −45.45
Std Dev 22.19
χ² / ndf 90.27 / 56
p0 5288 ± 482.8
p1 3.051 ± 0.282
p2 0.7356 ± 0.0113
p3 −12.5 ± 0.0
p4 12.46 ± 0.90
number of events
time [nsec]

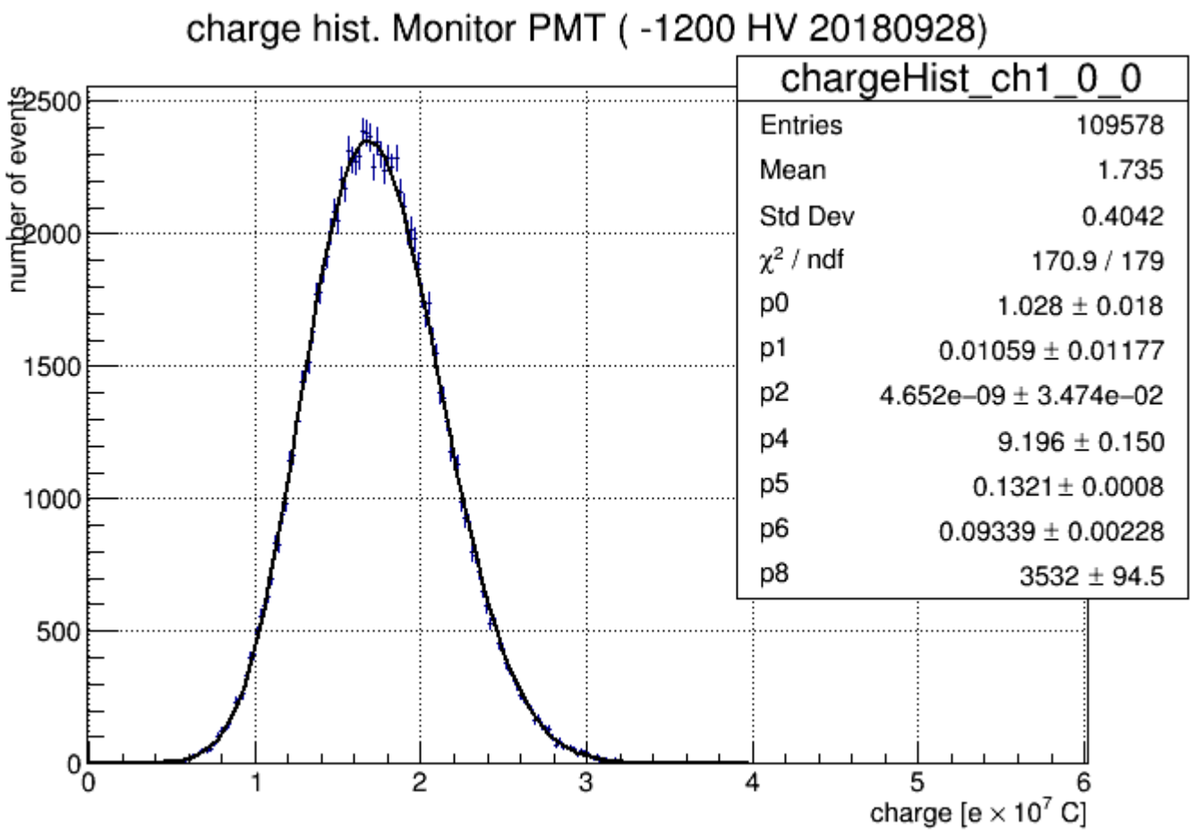

time histogram (-1050 V 20180928)
ttimeHist_ch0_0_0
Entries 52520
Mean −37.22
Std Dev 24.17
χ² / ndf 117.9 / 56
p0 6520 ± 294.8
p1 2.609 ± 0.119
p2 0.6754 ± 0.0079
p3 −12.64 ± 0.02
p4 12.88 ± 0.93
number of events
time [nsec]

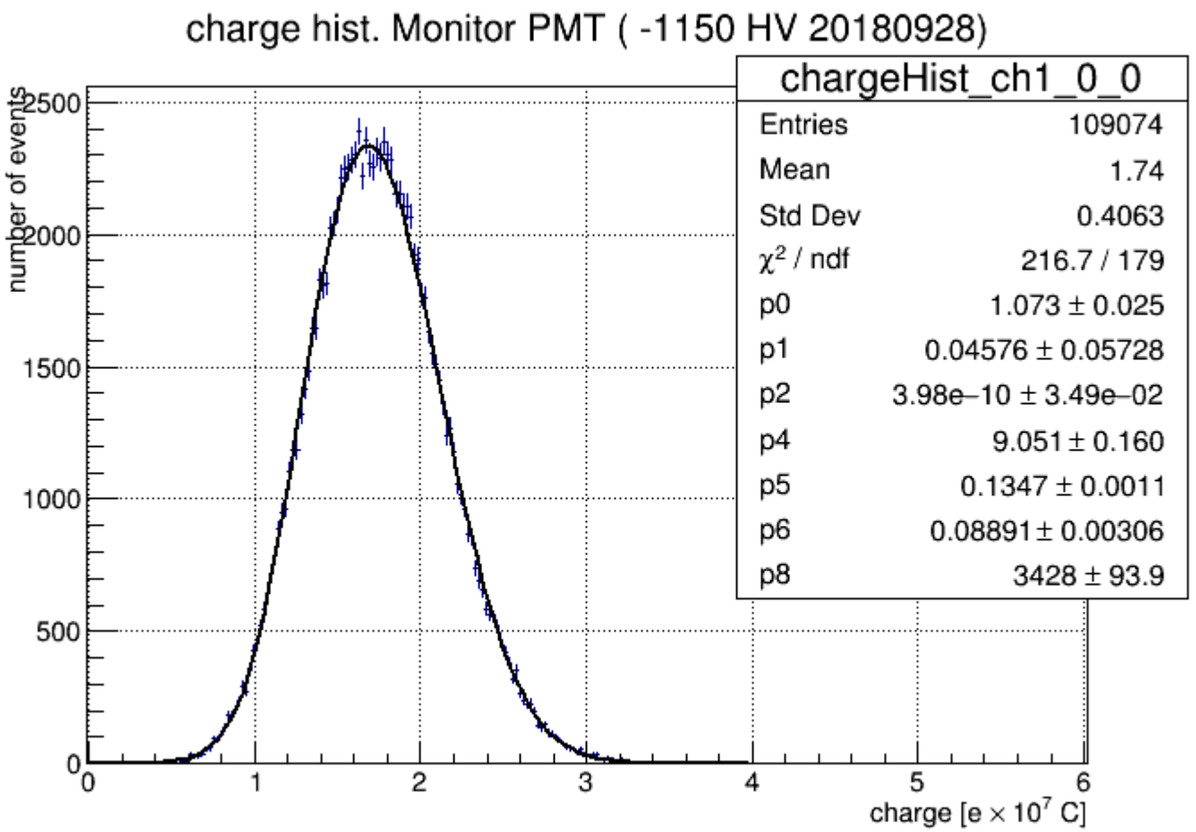
Monitor PMT histogram

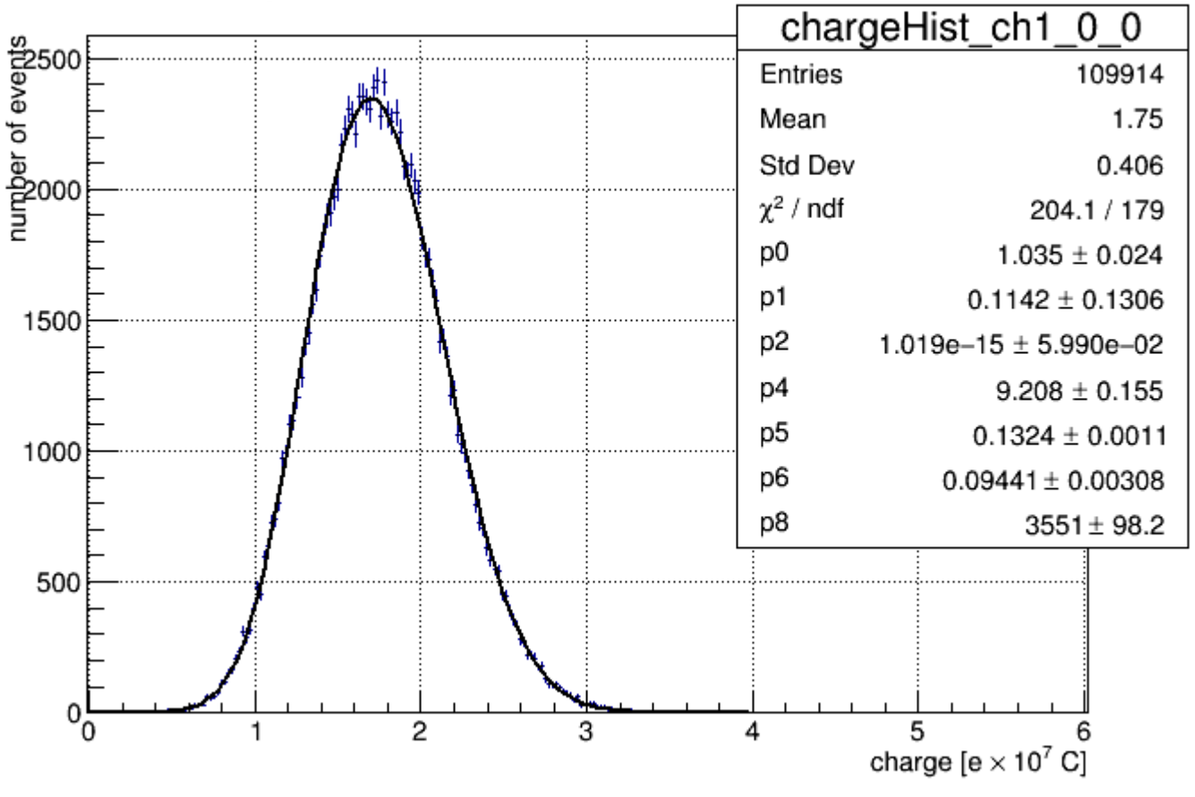


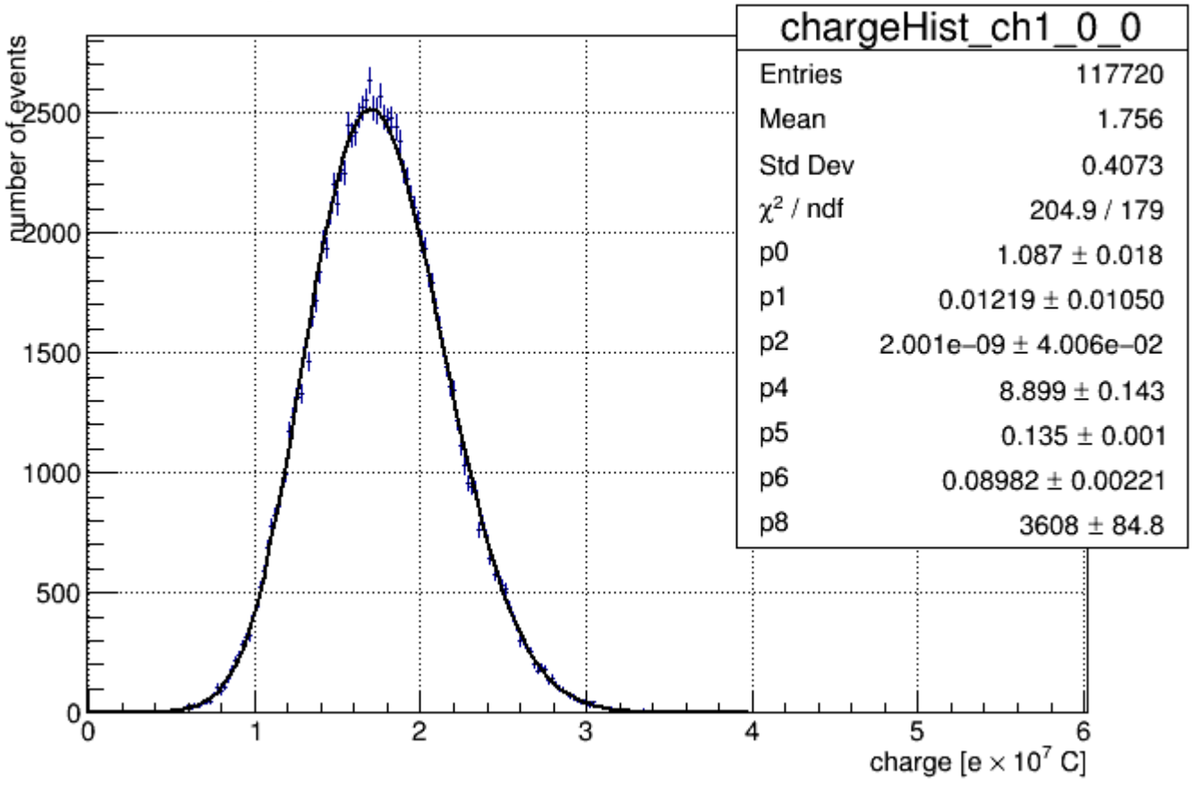


- “Monitor PMT mean” is equal to the mean of the histogram.
- Fitting function is the same as 3” PMT charge histograms, but fit result has less meanings because each parameter doesn’t reflect its own physical meaning.
  - for example, p6 is a mean value of charge, but it’s obviously small.
  - though fits goes well thanks to lots of parameters.


charge hist. Monitor PMT (-1200 HV 20180928)
chargeHist_ch1_0_0
Entries 109578
Mean 1.735
Std Dev 0.4042
χ² / ndf 170.9 / 179
p0 1.028 ± 0.018
p1 0.01059 ± 0.01177
p2 4.652e−09 ± 3.474e−02
p4 9.196 ± 0.150
p5 0.1321 ± 0.0008
p6 0.09339 ± 0.00228
p8 3532 ± 94.5
number of events
charge [e × 10⁷ C]


charge hist. Monitor PMT (-1150 HV 20180928)
chargeHist_ch1_0_0
Entries 109074
Mean 1.74
Std Dev 0.4063
χ² / ndf 216.7 / 179
p0 1.073 ± 0.025
p1 0.04576 ± 0.05728
p2 3.98e−10 ± 3.49e−02
p4 9.051 ± 0.160
p5 0.1347 ± 0.0011
p6 0.08891 ± 0.00306
p8 3428 ± 93.9
number of events
charge [e × 10⁷ C]


charge hist. Monitor PMT (-1050 HV 20180928)
chargeHist_ch1_0_0
Entries 109914
Mean 1.75
Std Dev 0.406
χ² / ndf 204.1 / 179
p0 1.035 ± 0.024
p1 0.1142 ± 0.1306
p2 1.019e−15 ± 5.990e−02
p4 9.208 ± 0.155
p5 0.1324 ± 0.0011
p6 0.09441 ± 0.00308
p8 3551 ± 98.2
number of events
charge [e × 10⁷ C]


charge hist. Monitor PMT (-1000 HV 20180928)
chargeHist_ch1_0_0
Entries 117720
Mean 1.756
Std Dev 0.4073
χ² / ndf 204.9 / 179
p0 1.087 ± 0.018
p1 0.01219 ± 0.01050
p2 2.001e−09 ± 4.006e−02
p4 8.899 ± 0.143
p5 0.135 ± 0.001
p6 0.08982 ± 0.00221
p8 3608 ± 84.8
number of events
charge [e × 10⁷ C]