3"PMT Test: Uniform light @IPMU

TYPE: R14374 (Hamamatsu Photonics K.K.)

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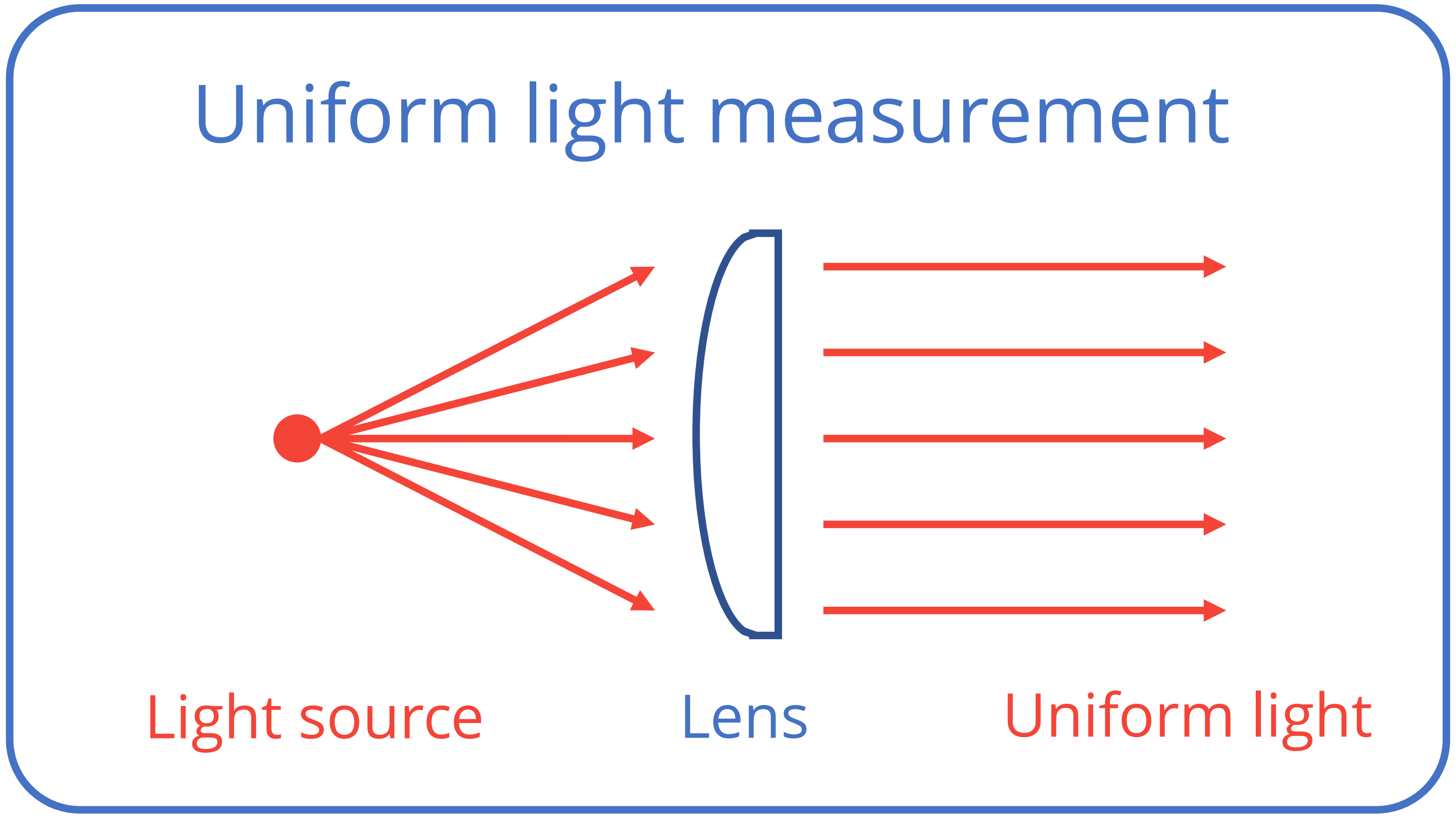
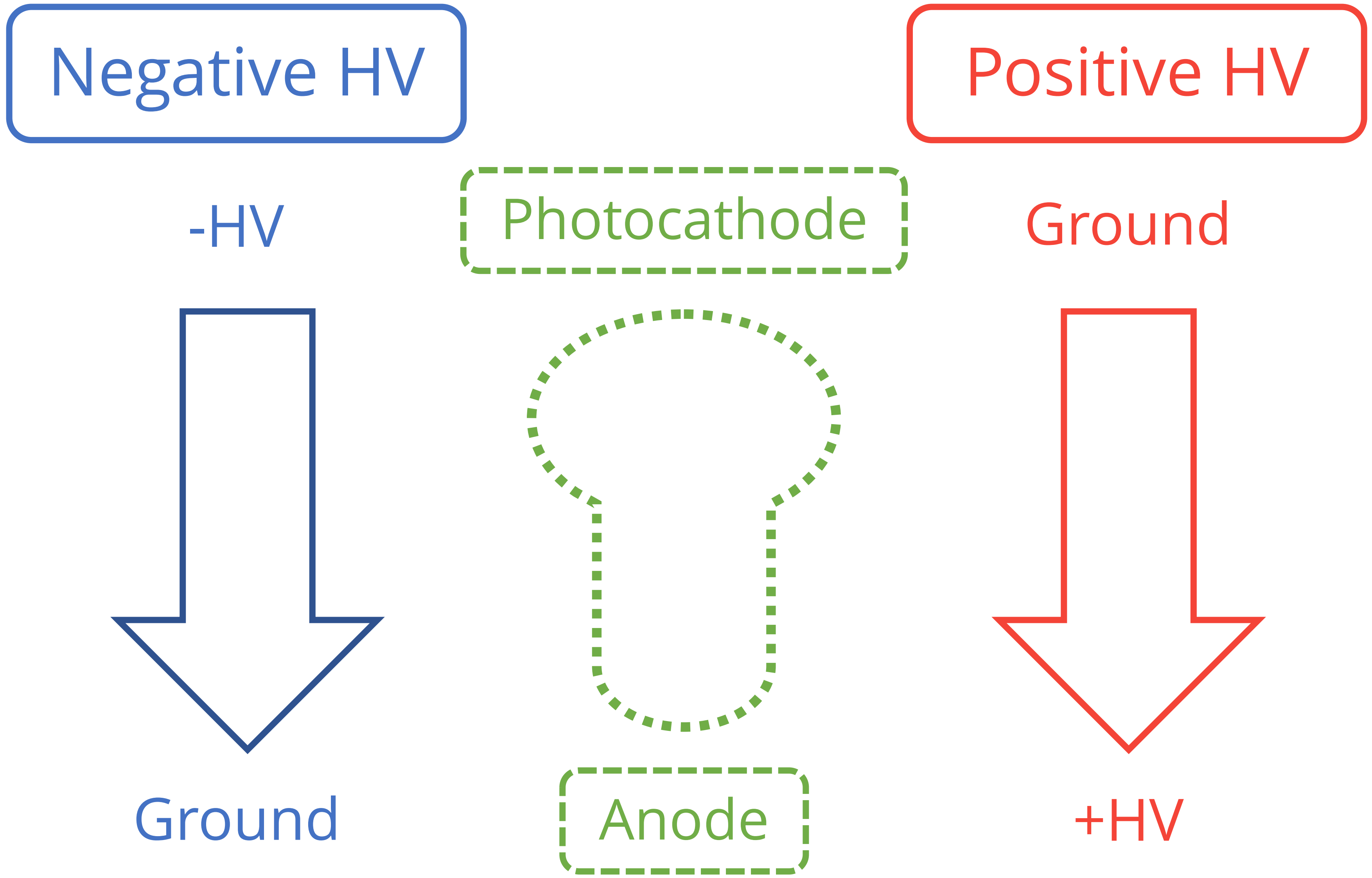
- Introduction



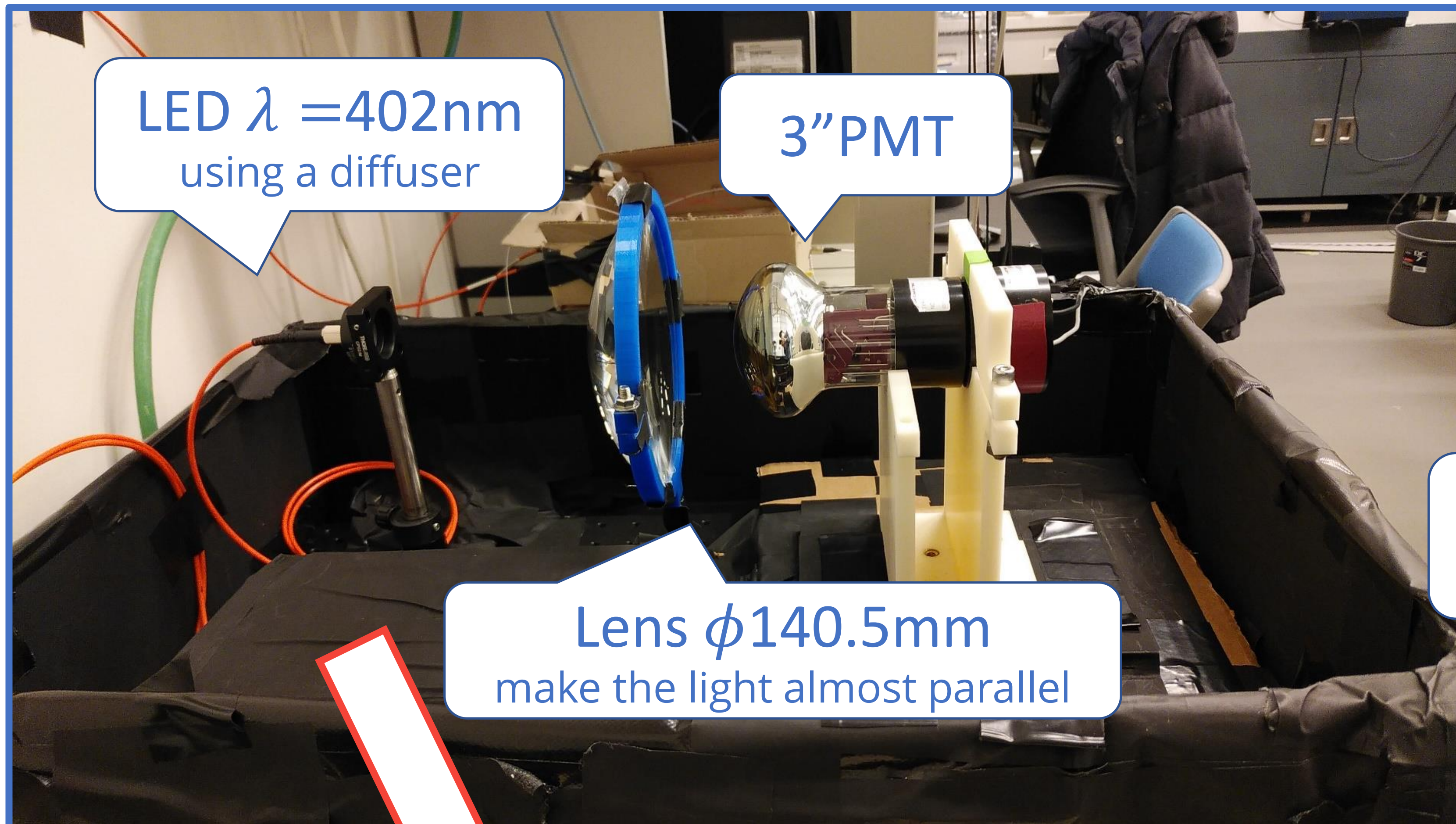
- Gain
- Peak-to-valley ratio
- TTS
- Summary

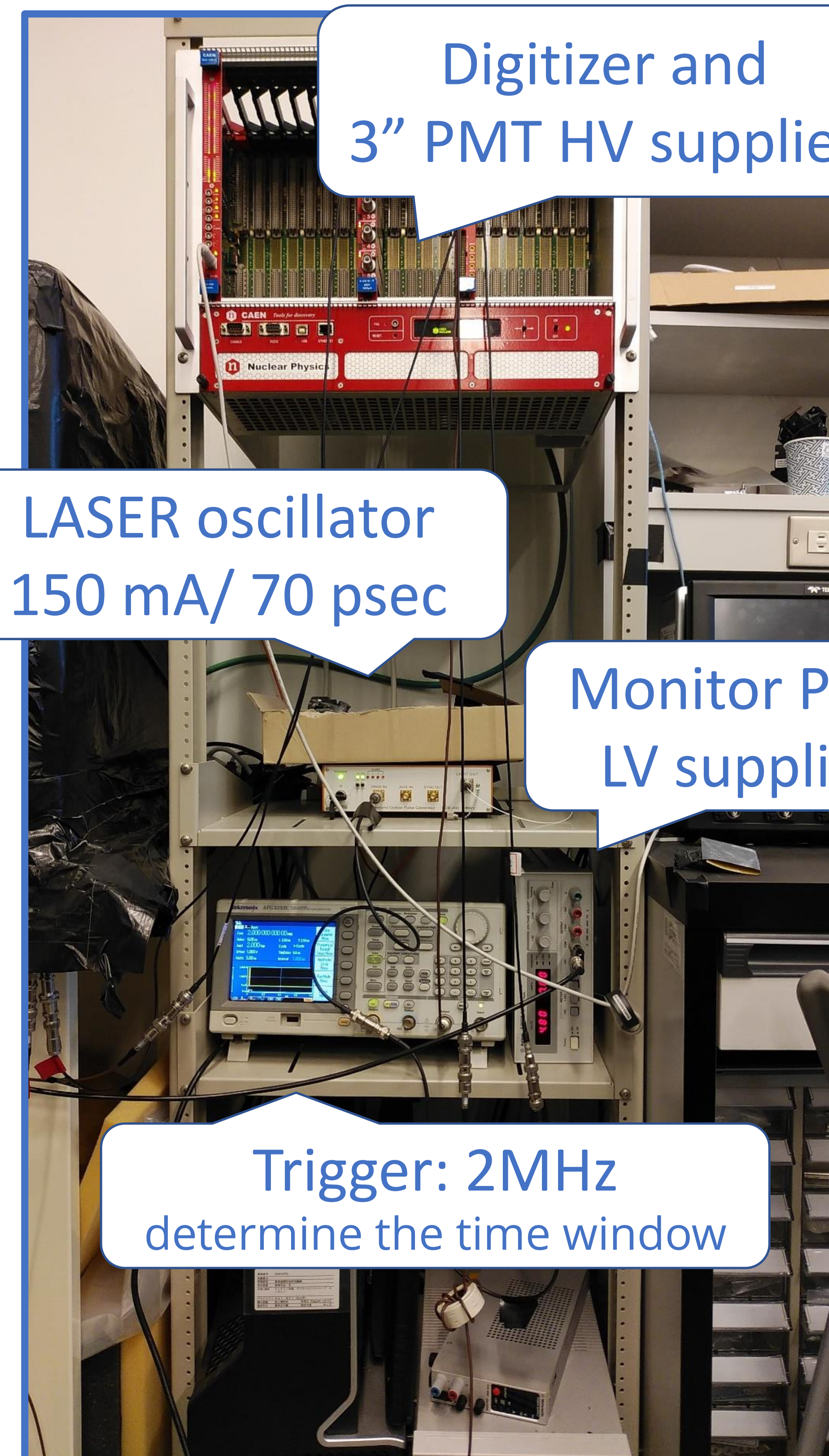
3"PMT: R14374



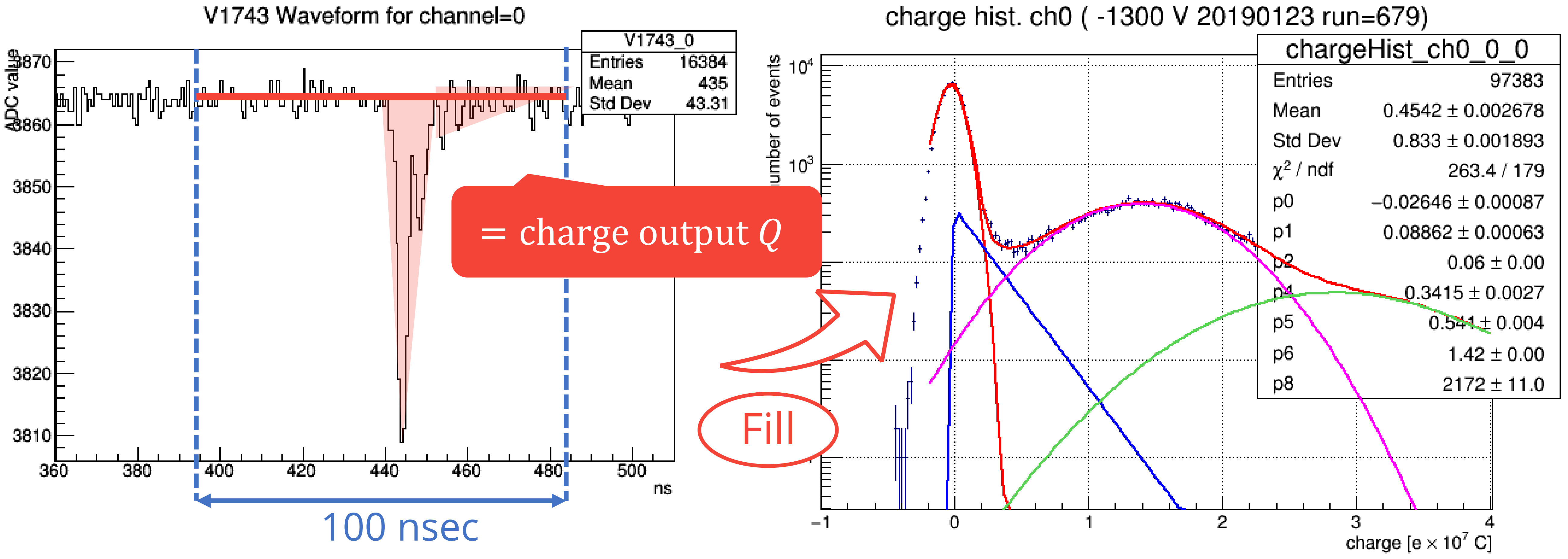
- R14374: produced by Hamamatsu Photonics K.K.
  - Dynode type: Circular and Linear-focused type
- Test on two serial numbers: BC0035 and BC0038

Setting @IPMU





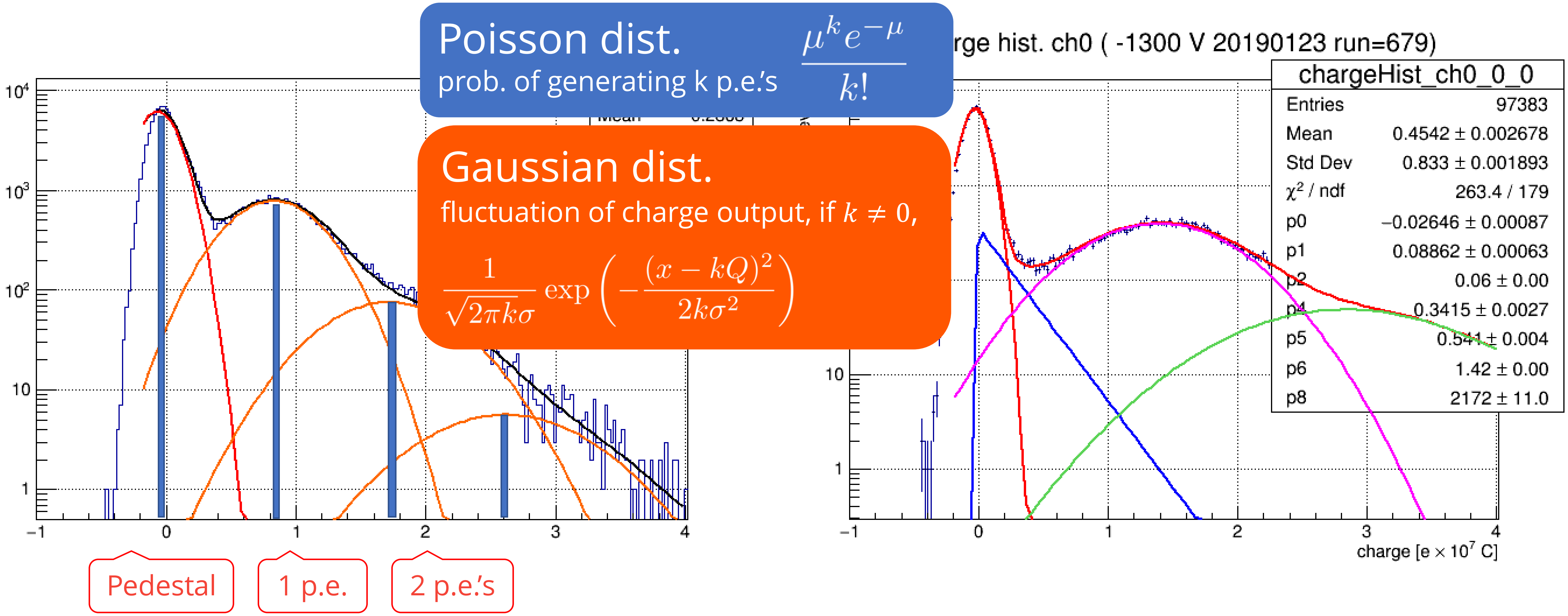
Charge histogram



- event by event..

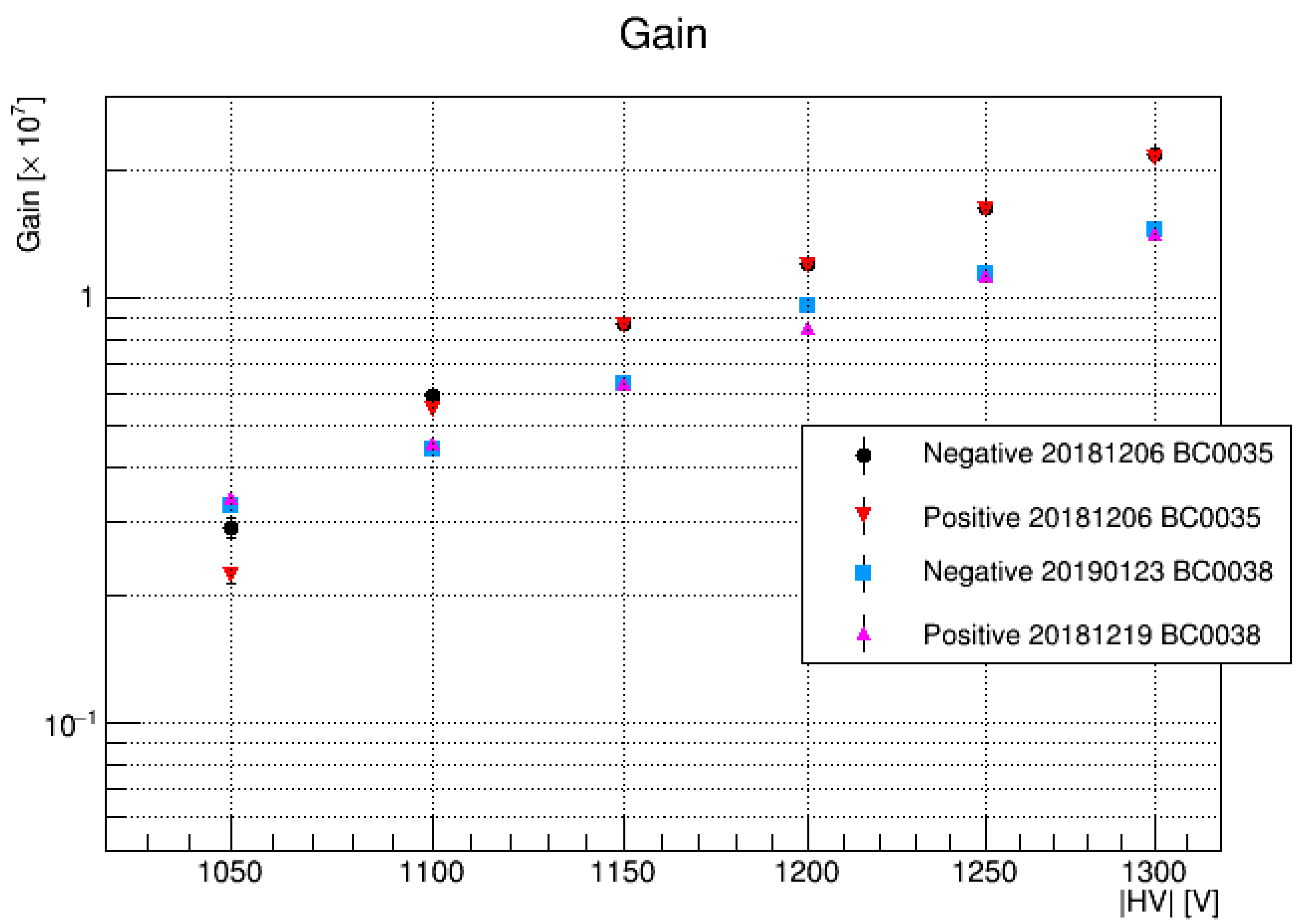
1. baseline of integral: the mean of noise
2. integrate in 100 nsec region
3. convert integral value to charge, then fill it

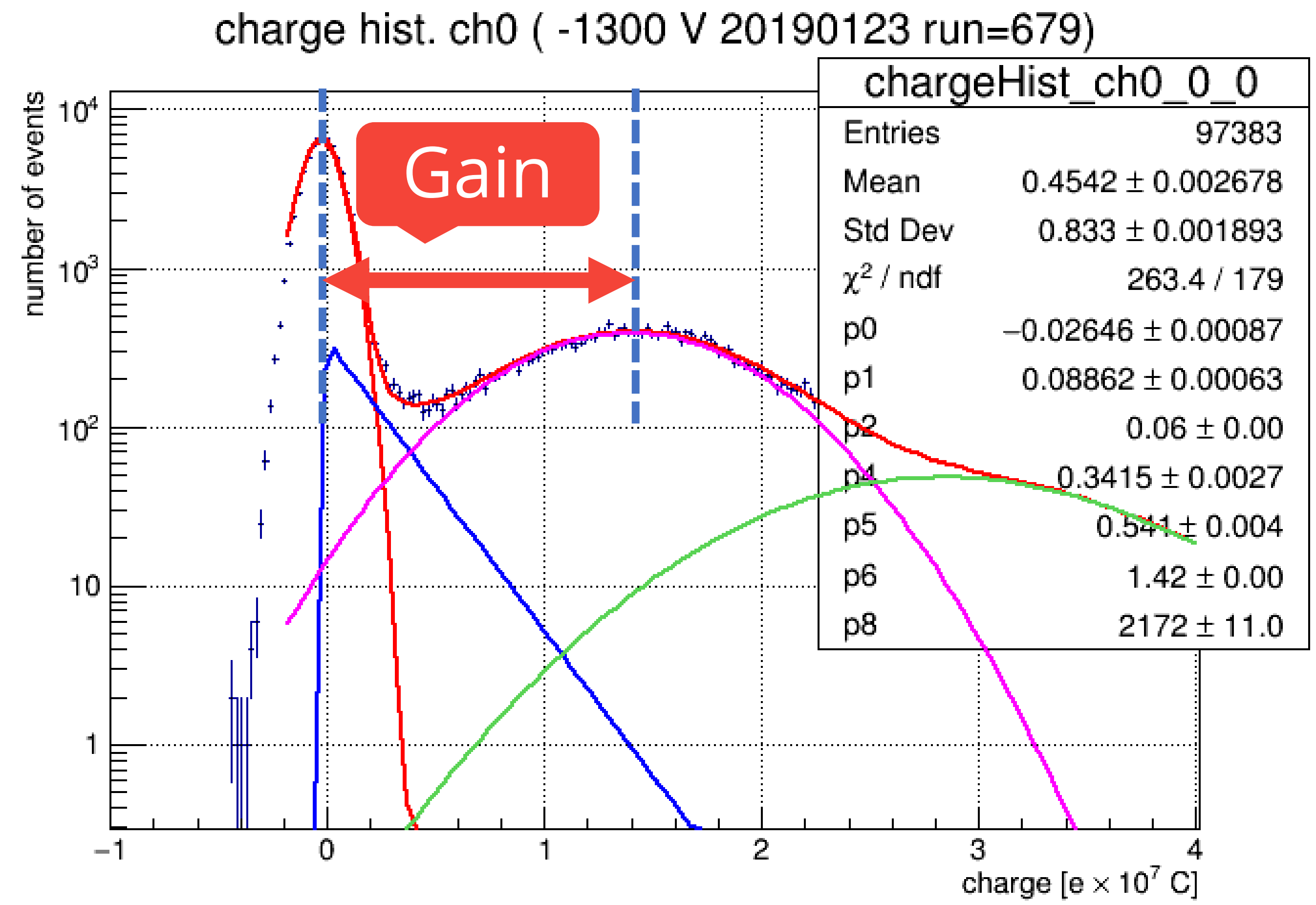
Charge histogram: distribution



- charge distribution = Poisson dist. ∗ Gaussian dist.
  - Poisson dist. : prob. of generating k (≥ 0) photoelectrons on photocathode
  - Gaussian dist. : fluctuation of charge output at each event
  - 0 p.e. distribution (so-called "pedestal") has different σ from k ($\neq 0$) p.e.'s distribution. (σ is Gaussian's σ.)

Gain

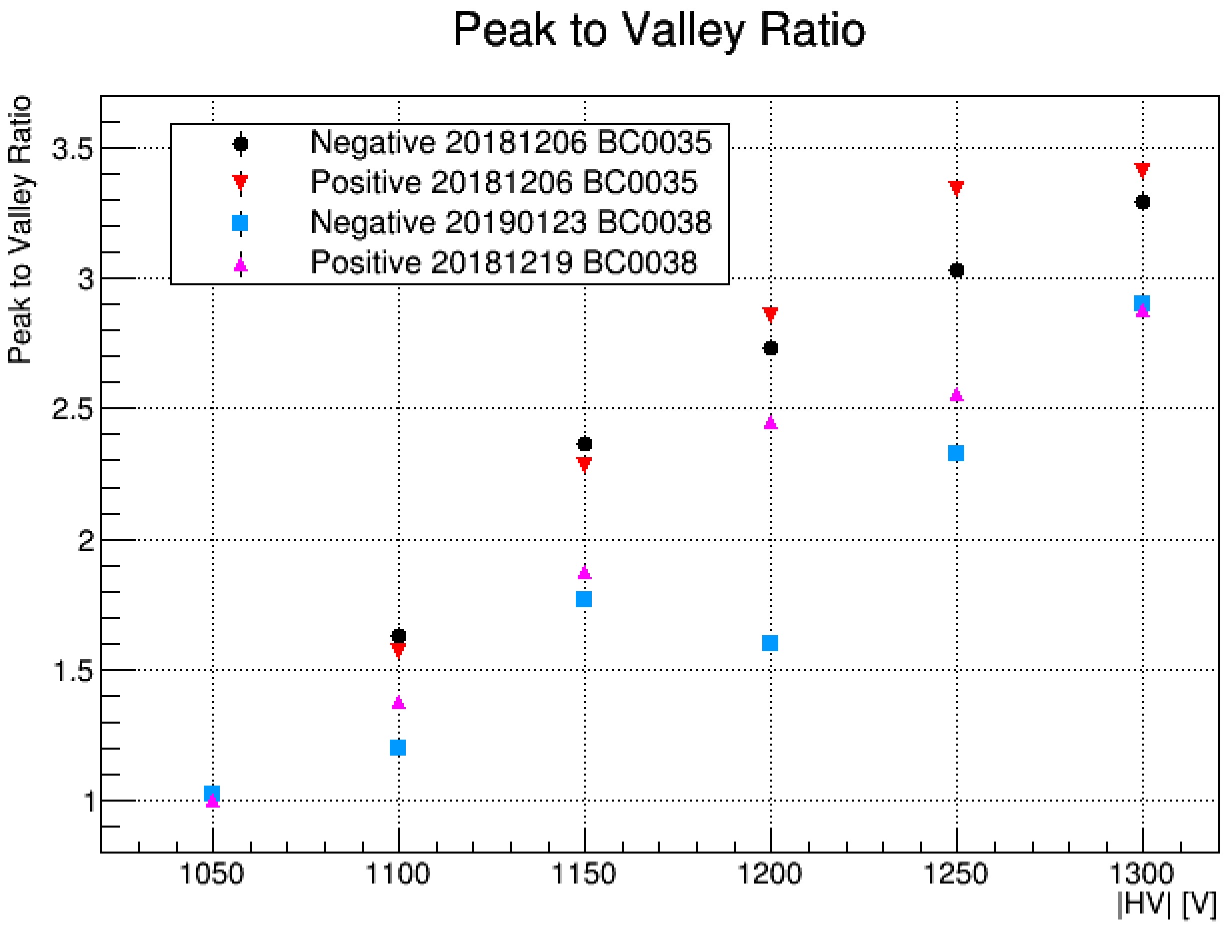


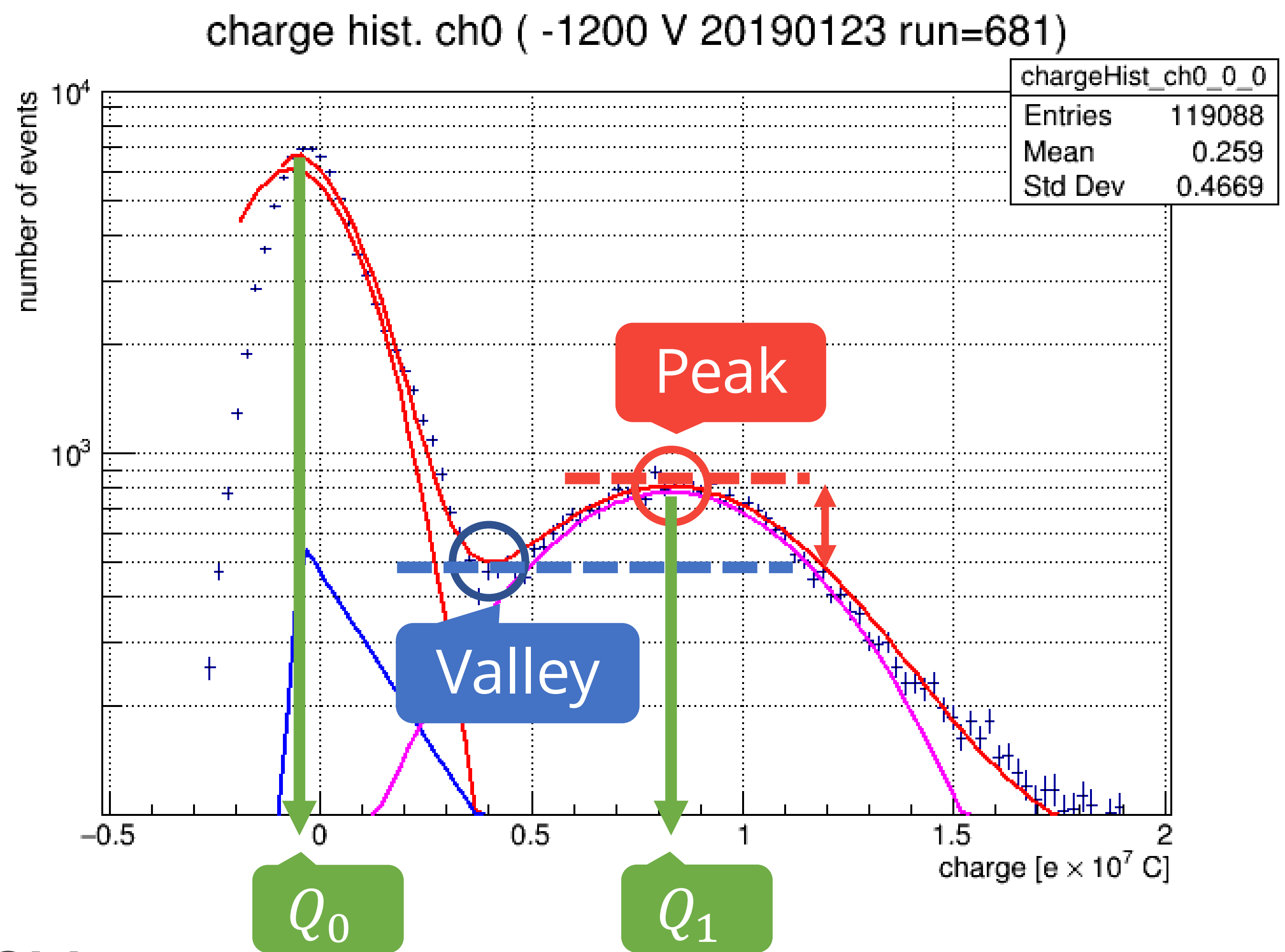


log-log scale

- Gain
  - # of electrons at the anode when 1 p.e. is generated on the photocathode
- $= 1.0 \times 10^7$ @1172 V (BC0035)
  - We couldn’t find significant difference btw Negative and Positive HV.
  - Gain(BC0035) / Gain(BC0038) ~ 1.4 @ 1250 V

Peak-to-Valley ratio





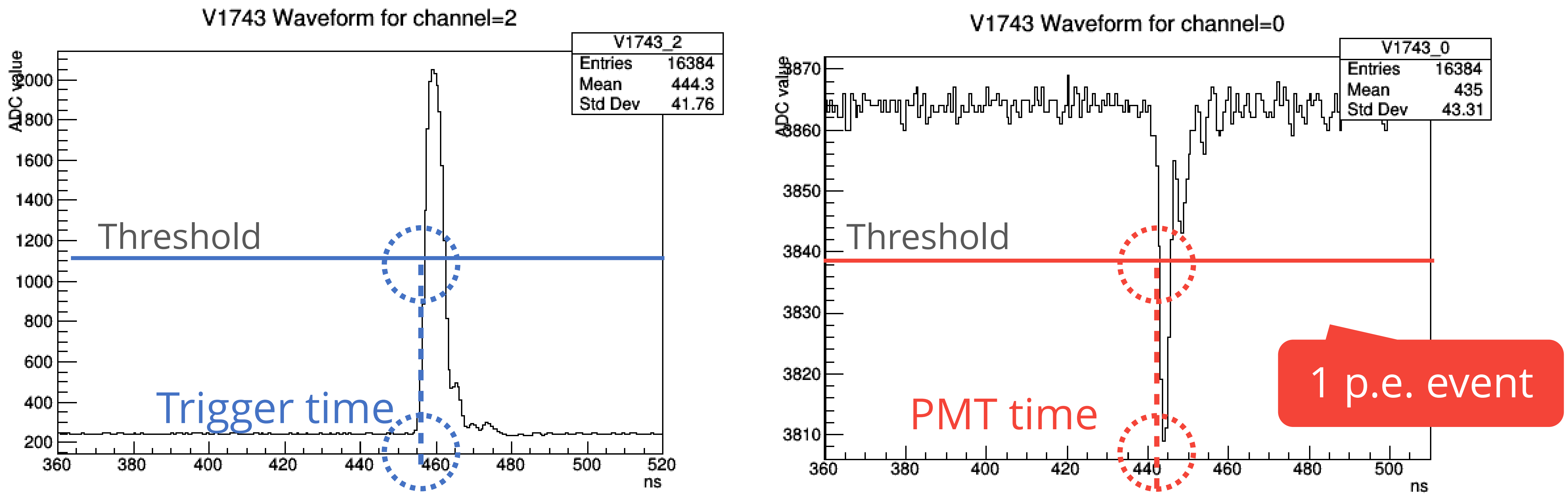
- Peak-to-Valley ratio is given by

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

  - using the value of the fitting function
  - Q_0 and Q_1 is the mean of pedestal and 1 p.e. distribution, respectively
- The HV in actual operation could be set above 1250 V.

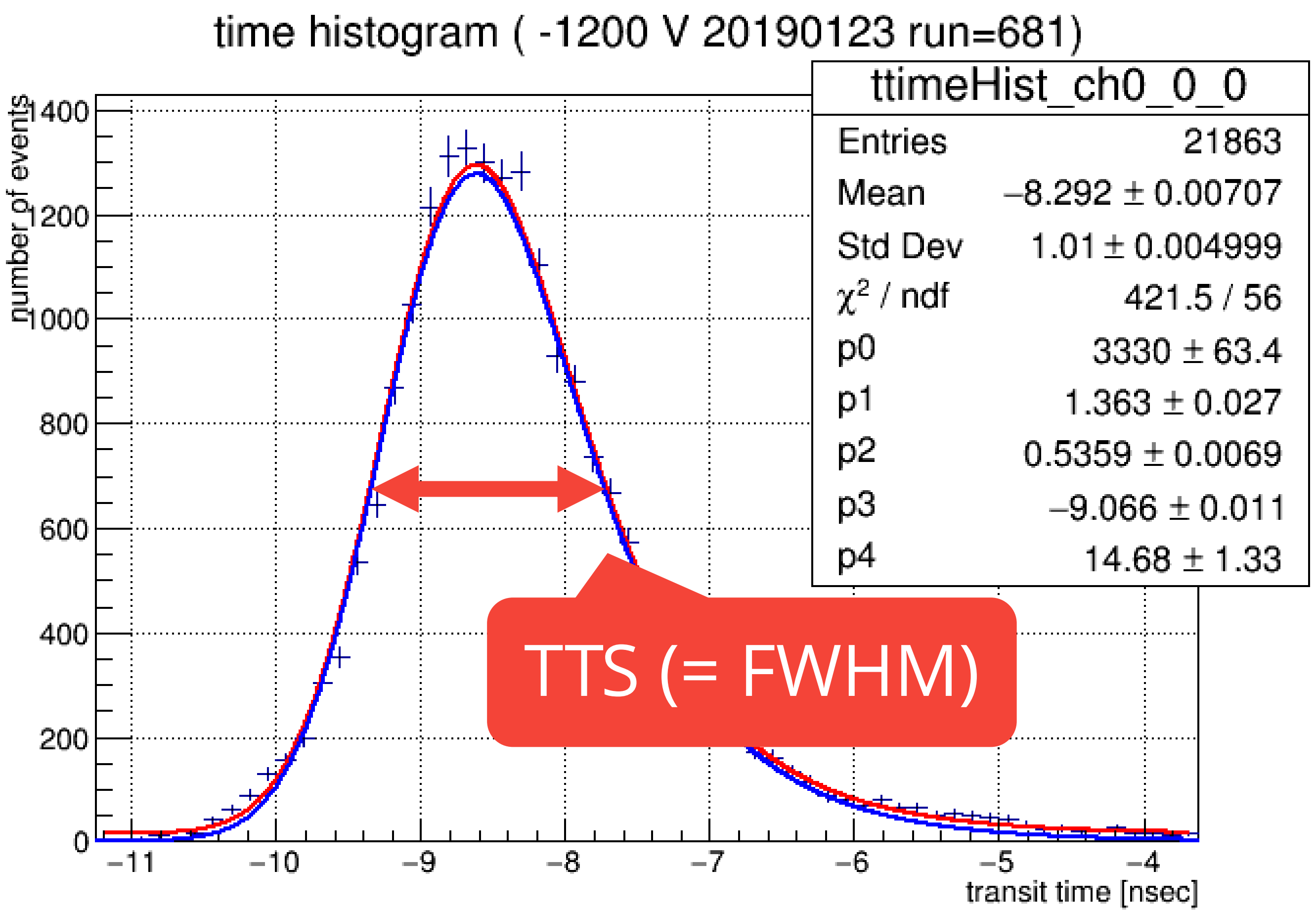
TTS: Transit Time Spread

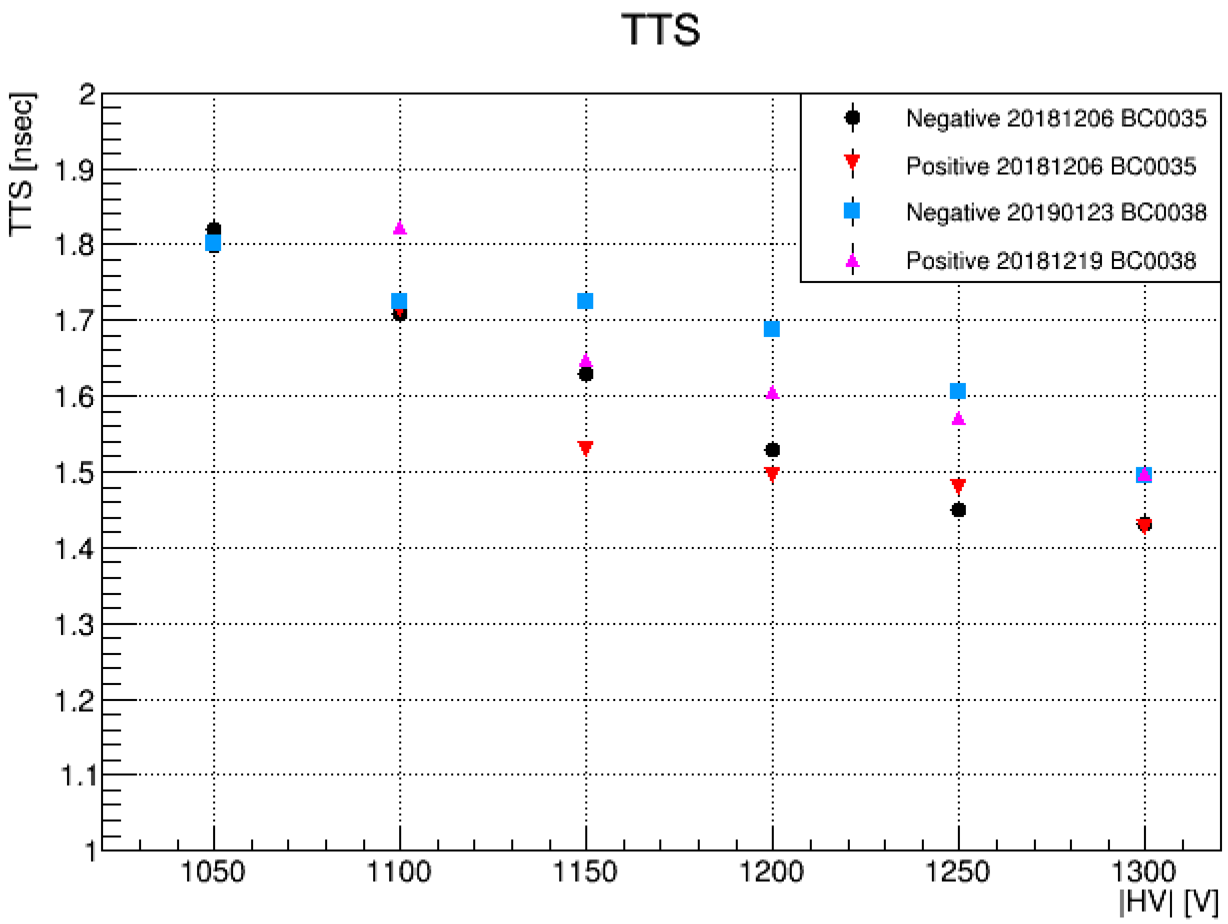
- Transit Time: TT
  - Flight time of electrons from photocathode to anode
- TTS: Calculate as FWHM of TT histogram



- Threshold = 1/2 x (noise average + peak max/min)
  - like Constant Fraction Discriminator
- TT = PMT time – Trigger time, for 1 p.e. events
  - use the events where one photoelectron is generated on the photocathode.

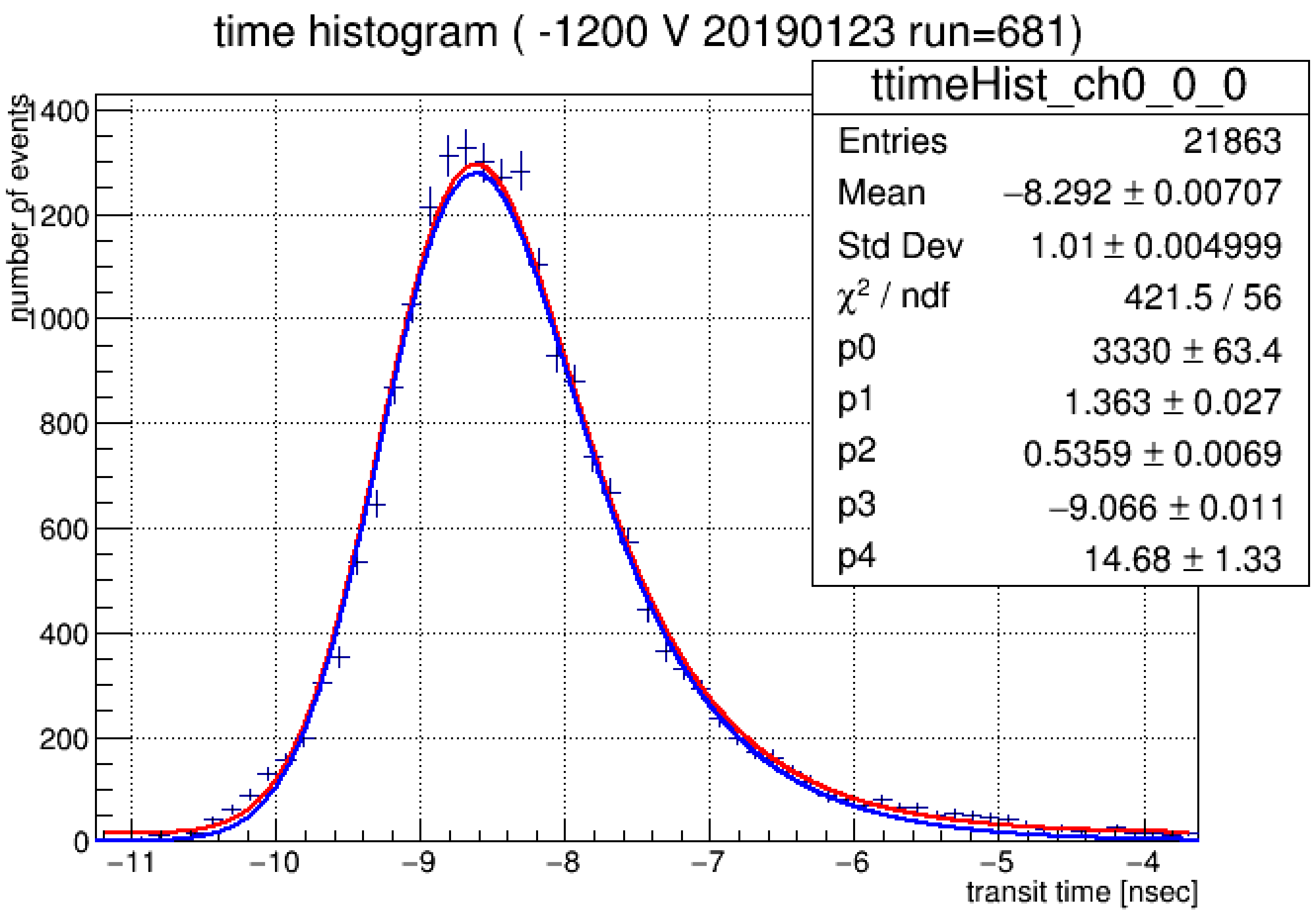
TTS

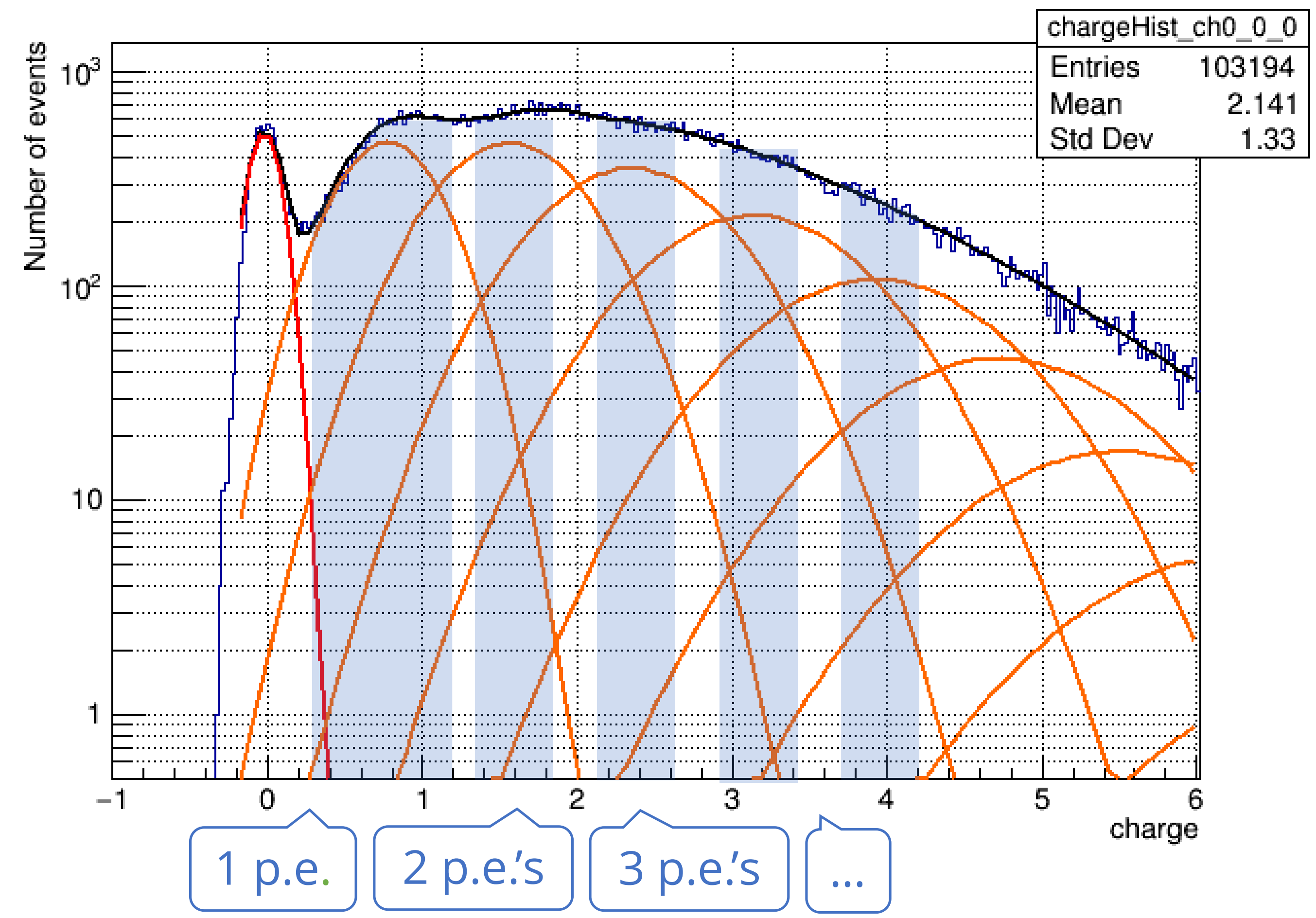




- TT distribution: Exponentially modified Gaussian distribution
  - FWHM is directly gained by looking for the position with half the value of the peak, not by using some mathematical formula.
- TTS < 1.65 nsec above 1250 V
  - BC0035 has better TTS than BC0038

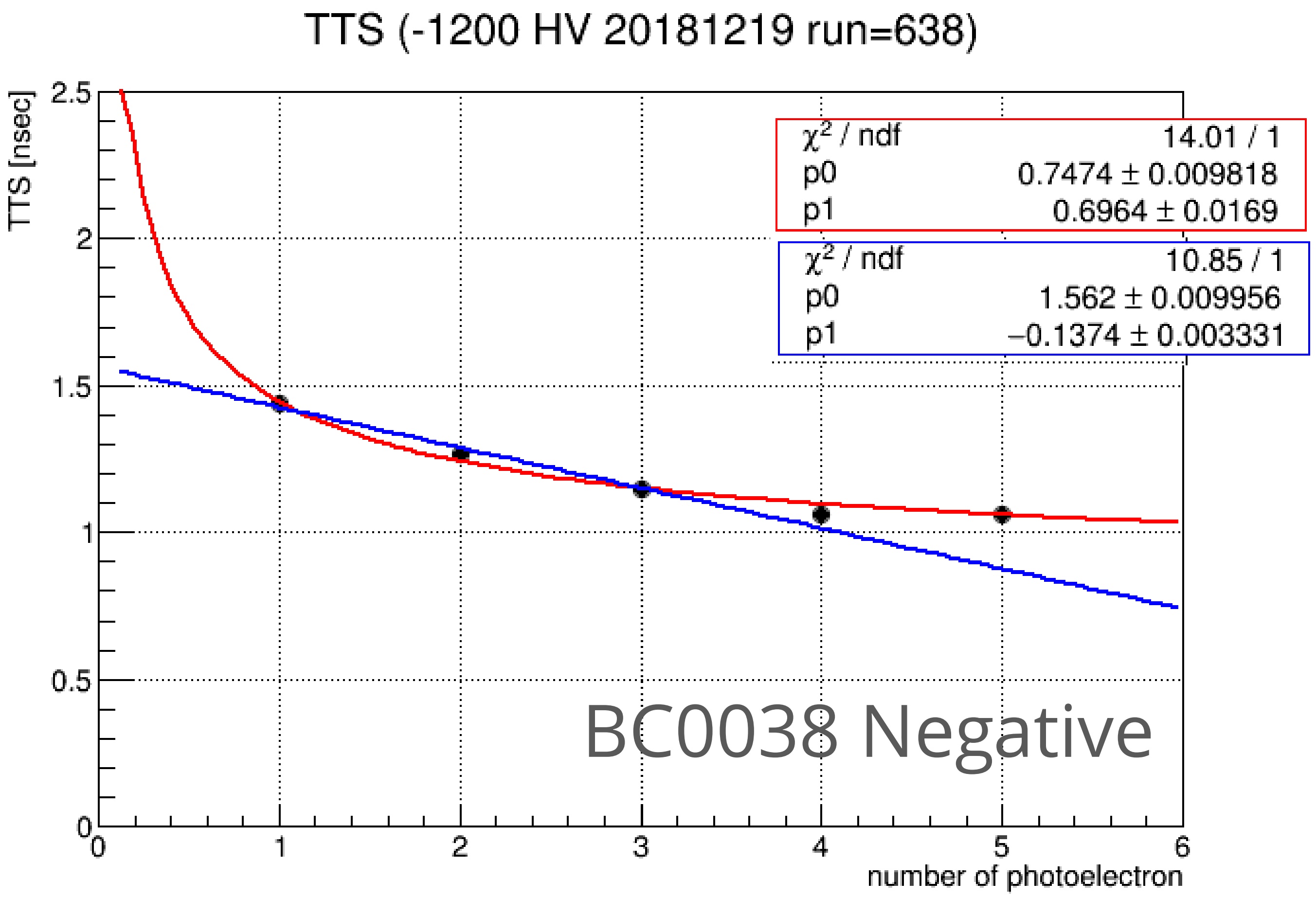
TTS: number of p.e.'s

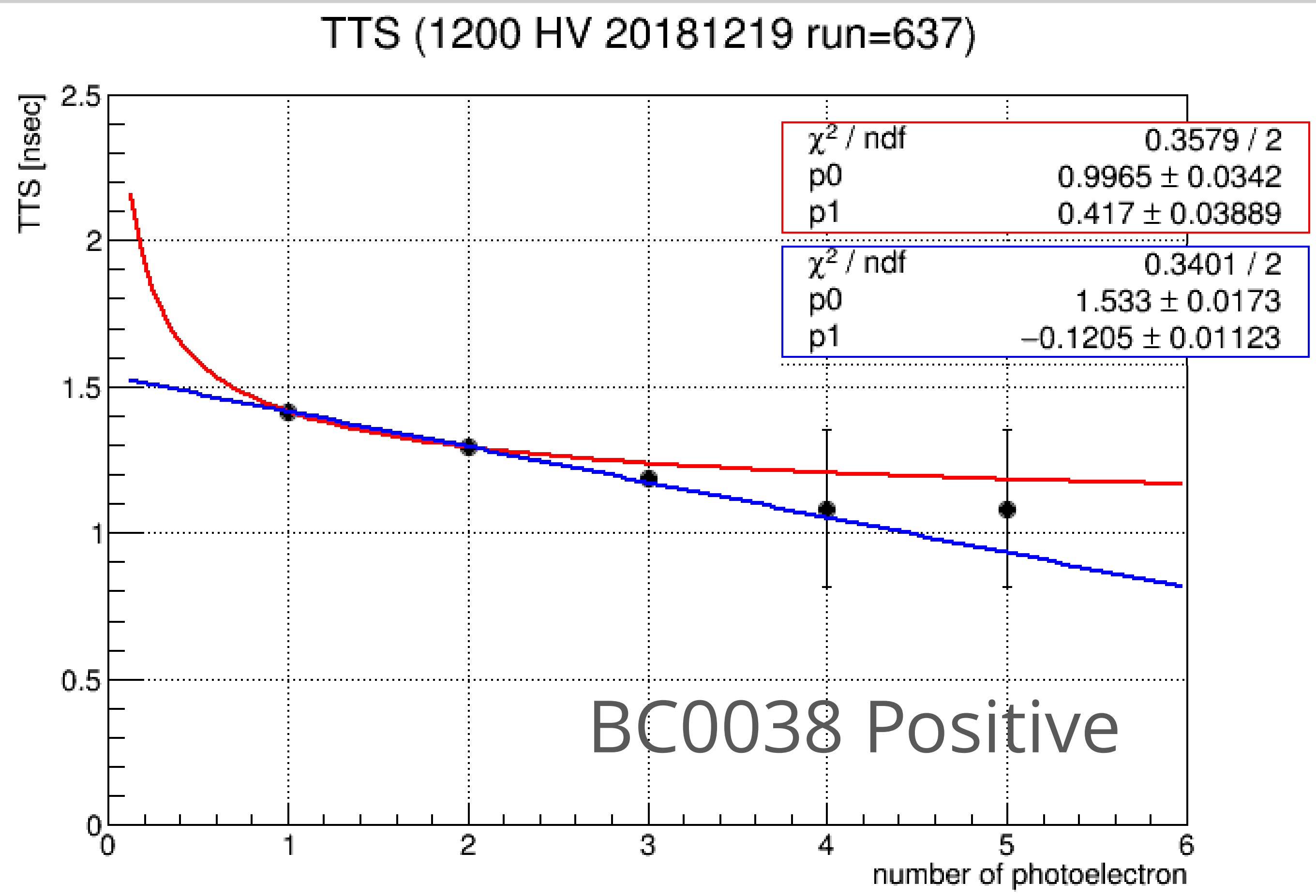


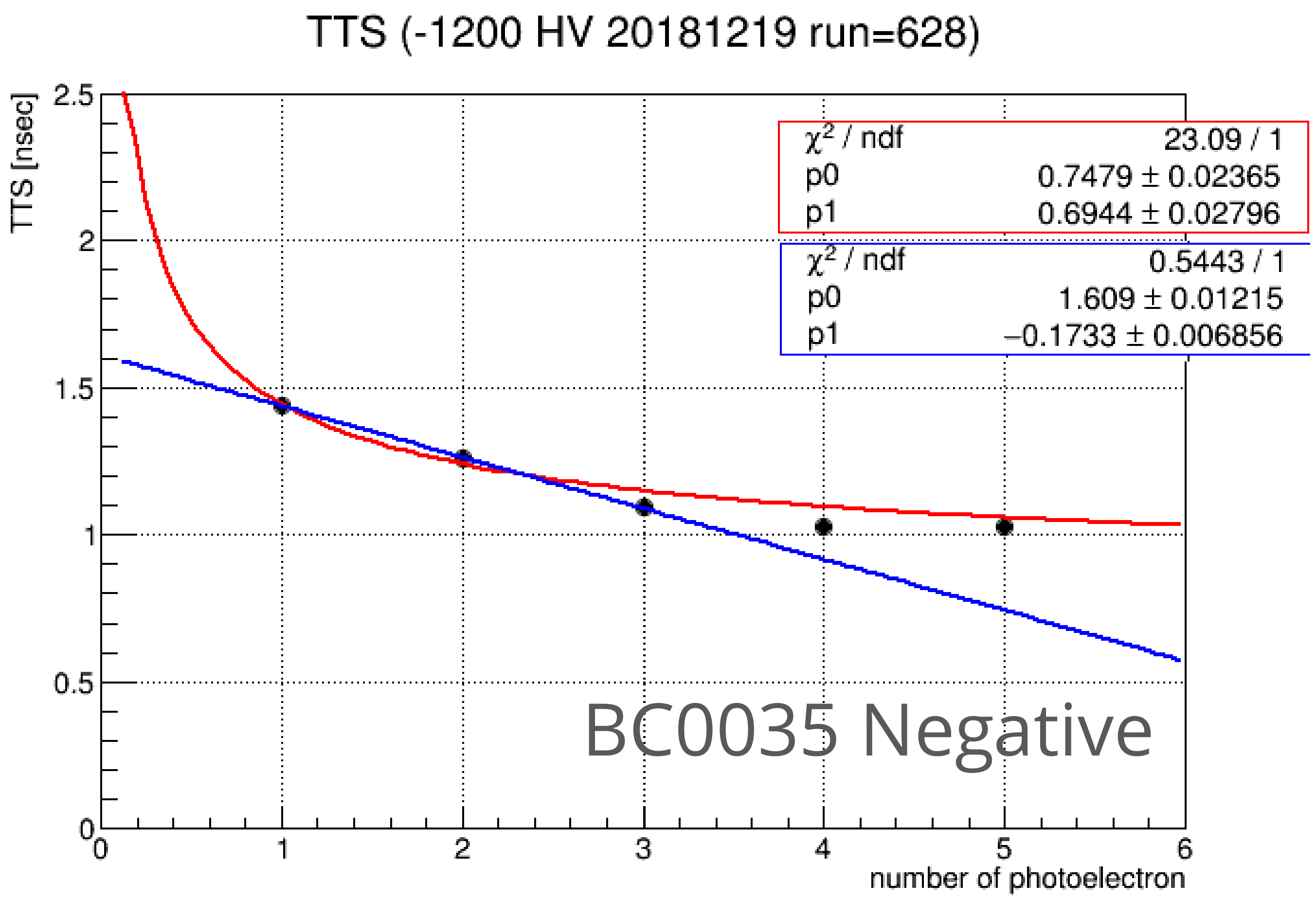


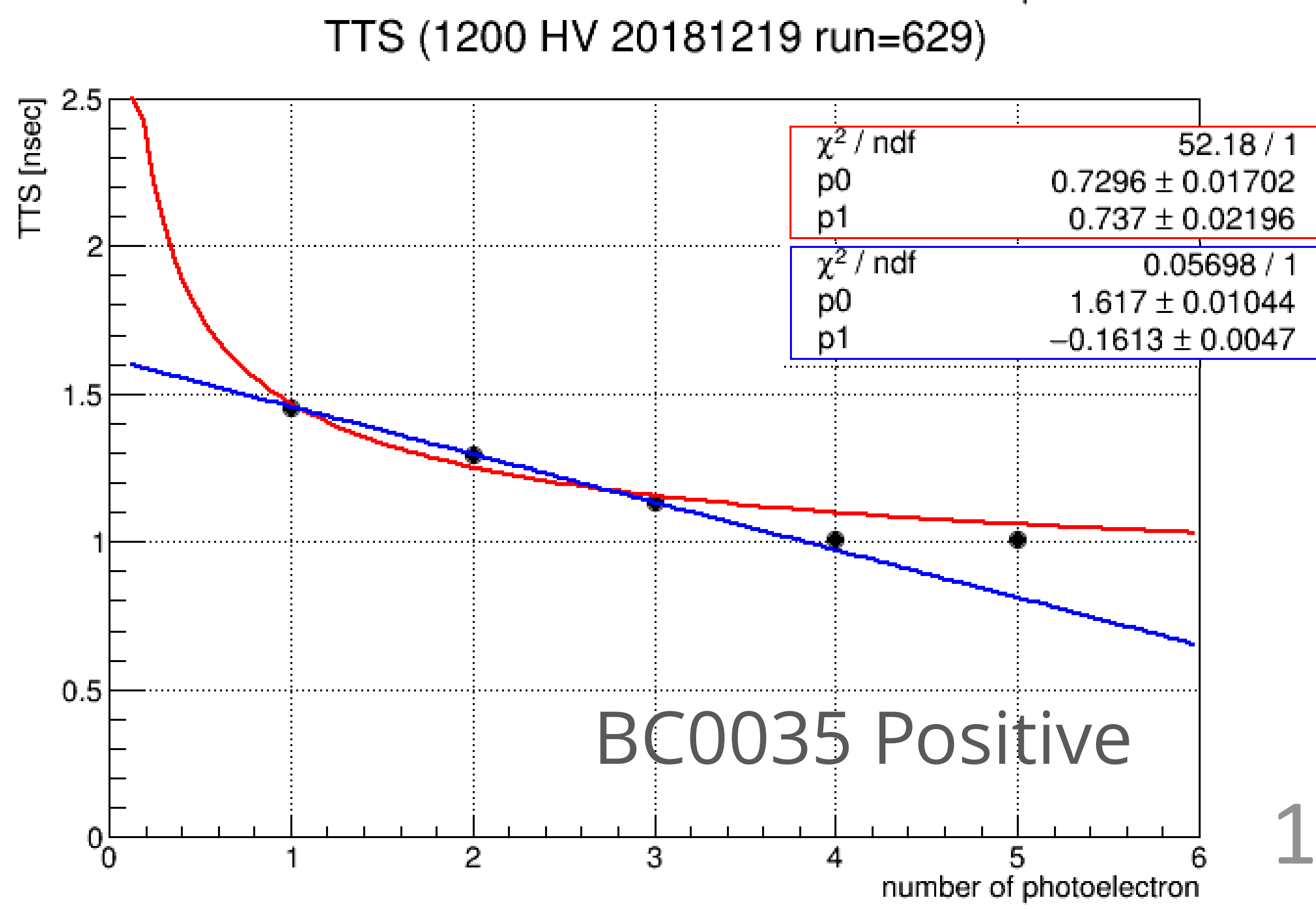
- When creating a TT histogram of n>1 p.e., the corresponding events are extracted to satisfy $nQ_1 \pm 0.5\sigma_1$ (blue area),
  - where Q_1 and σ_1 are mean and sigma of 1 pe peak.
  - $Q_1 \pm \sigma_1$ for 1 p.e. events extraction.
- The overlap effect of n p.e. peaks is not considered
  - this might cause worse fit result
  - but we can see the curve of 1/√x

TTS: # of p.e.'s: p[0]+p[1]/√x, p[0]+p[1]*x









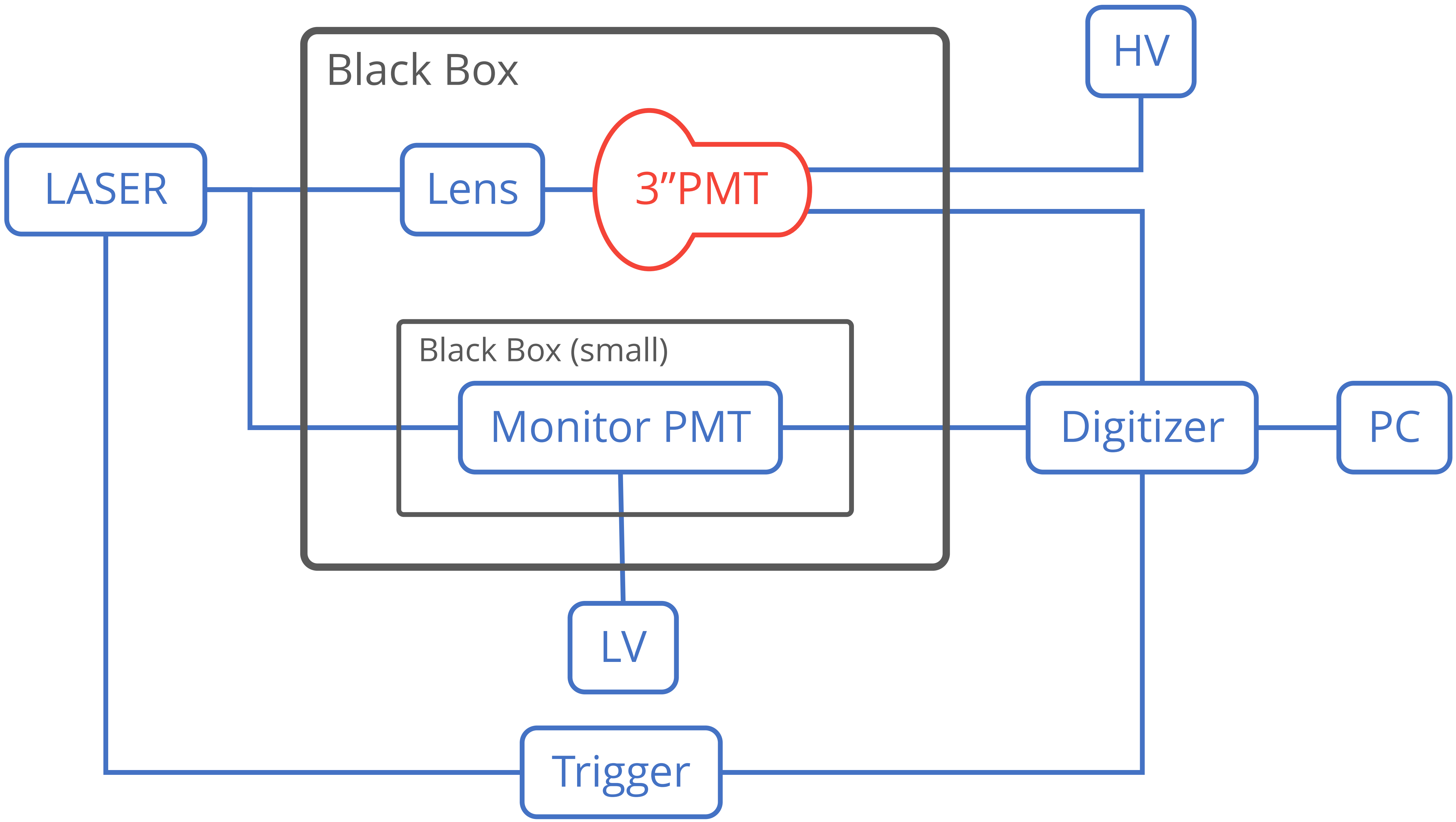
Summary

- Uniform light source test of R14374 @IPMU
  - 3"PMT from Hamamatsu Photonics K.K.
  - Test on two serial number: BC0035 and BC0038

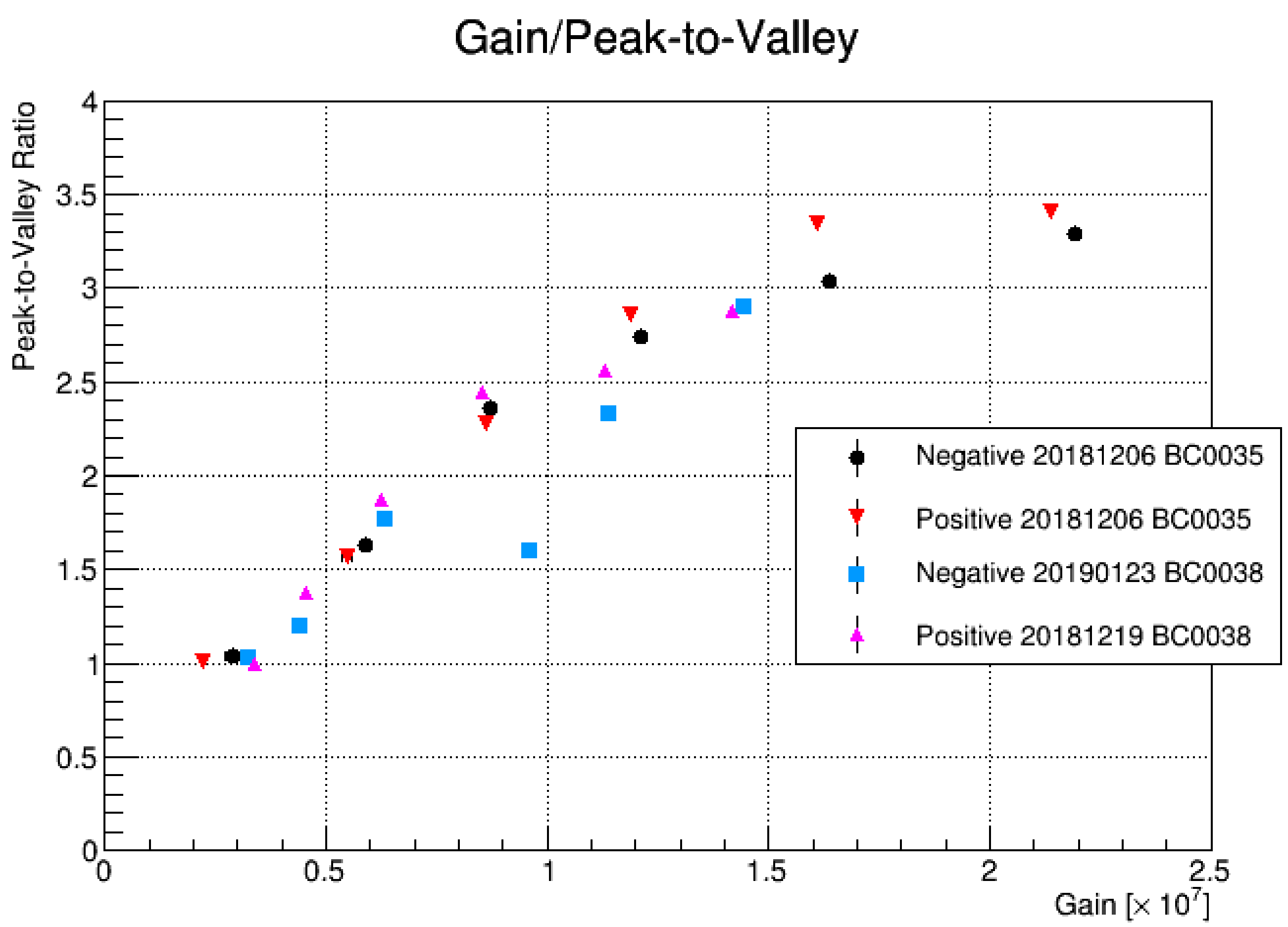
- Gain = 1.0×10^7 @1172 V (BC0035)
  - No significant difference btw Negative and Positive HV
- Peak-to-Valley ratio > 3.0 above 1250 V (BC0035)
  - above 1250 V is enough to separate noise and signal in this meas.
  - No significant difference btw Negative and Positive HV
- TTS < 1.65 nsec above 1250 V
- Dependence of TTS on photoelectron number n
  - the trend of $1/\sqrt{n}$ could be seen

Back up

Schematic of the set up

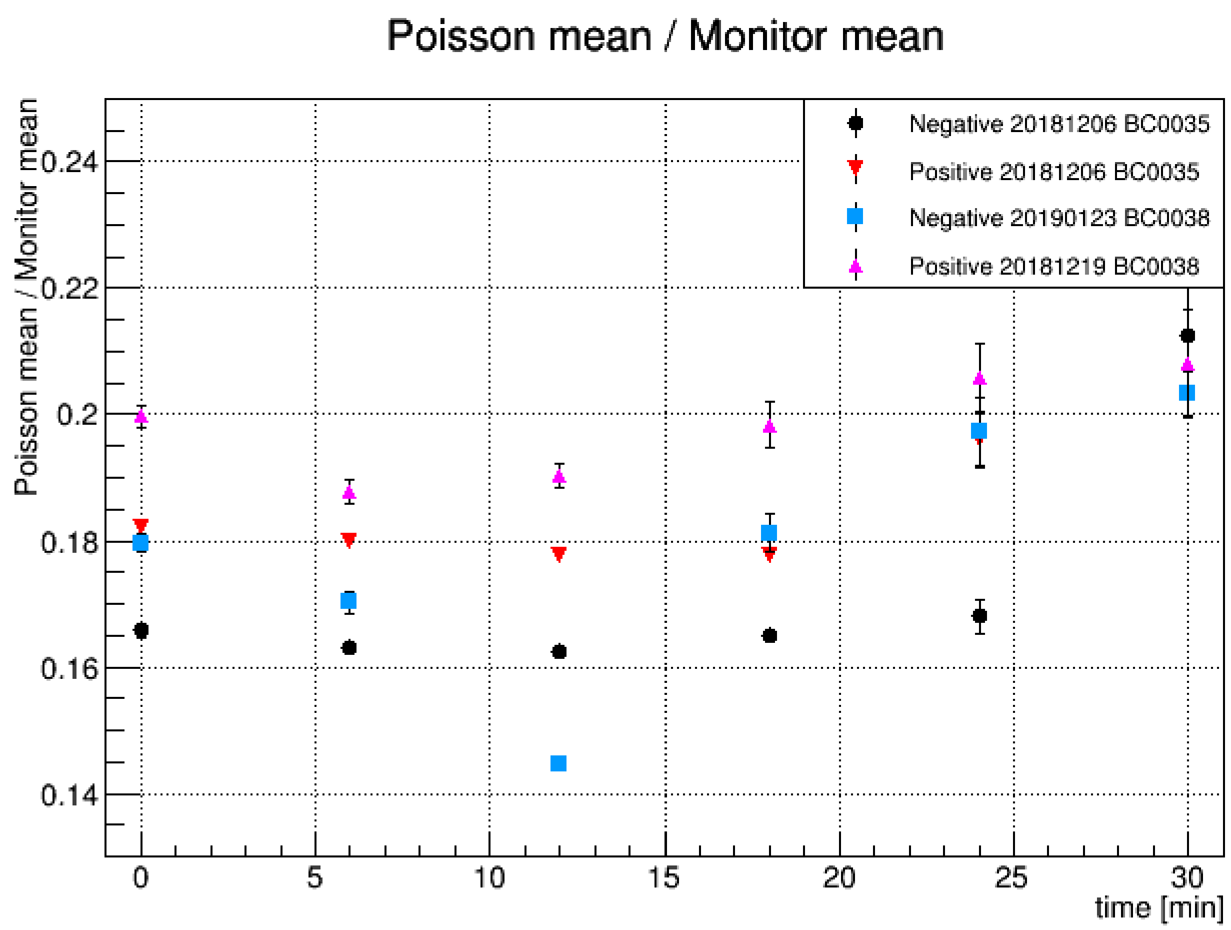


Gain vs. Peak-to-Valley Ratio



- There is no difference btw Negative and Positive HV

Poisson mean



- Poisson mean should be stable
  - Poisson mean: the fitted parameter
  - Monitor mean: the mean of histogram
  - x-axis(time) is roughly estimated
  - the measurements were done in turn from 1300 V to 1000 V

Fitting function: Charge histogram

- Number of photoelectron: Poisson distribution
- Output fluctuation: Gaussian distribution

$$arg = x - Q_0$$

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

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

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

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

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

p0	p1	p2	p3	p4
Q_0	σ_0	W	α	μ

p5	p6	p7	p8
σ_1	Q_1	Q_{sh}	Norm

Fitting function: Transit Time histogram

- Convolution of Gaussian and exponential:

$$h(x) = \frac{N}{2} \exp\left(-\lambda \cdot (x-\mu) + \frac{1}{2}\lambda^2\sigma^2\right) \times \left[1 + \mathrm{erf}\left(\frac{(x-\mu) - \lambda\sigma^2}{\sqrt{2}\sigma}\right)\right] + C$$

p0	p1	p2	p3	p4
Norm	λ	σ	μ	C

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

- Gaussian distribution : $f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$,
  Exponential : $g(x) = \exp(-\lambda x)$
- Then, $h(x) = f(x) * g(x) = \int_{-\infty}^{+\infty} dx' f(x') g(x - x')$
  - called Exponentially modified Gaussian distribution