ProtoDUNE Photon Detection Update May 2019

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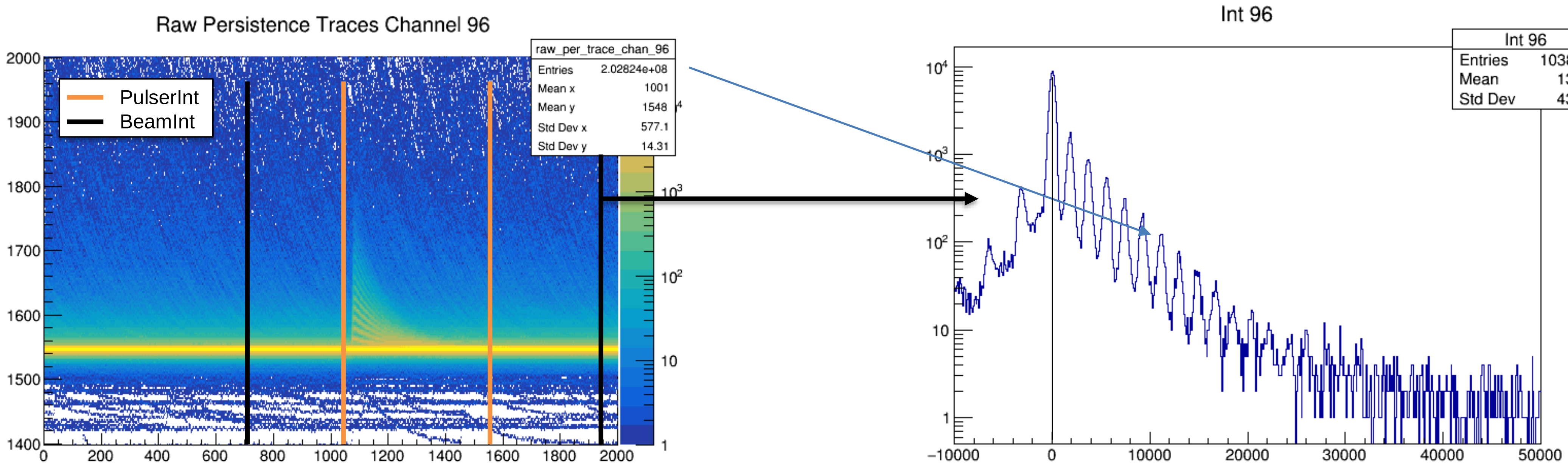
Outline - SensL Calibration

- Determine ADC/ Avalanche
  - Find ADC/Avalanche per SiPM voltage (gain)
  - Fit ADC/Avalanche vs SiPM voltage (gain)
  - Calculate ADC/Avalanche
- Determine ADC/ Photon
  - Find background rate per channel using a Random Trigger Run
  - Find average number of Photons per LED trigger window
  - Calculate ADC/Photon
- Determine PE/Photon
  - Combine ADC/Avalanche & ADC/Photon values

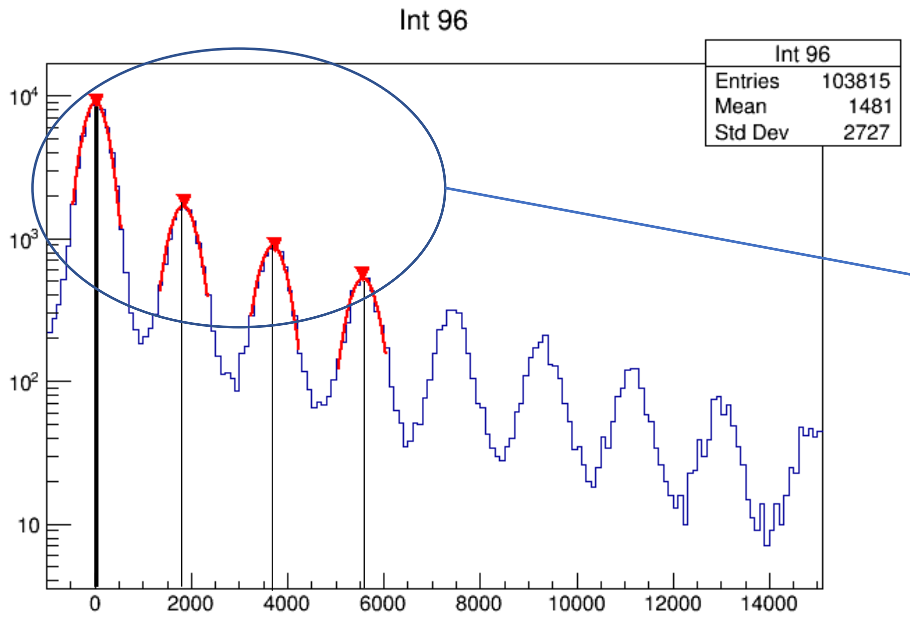
Determining SensL's ADC/Avalanche

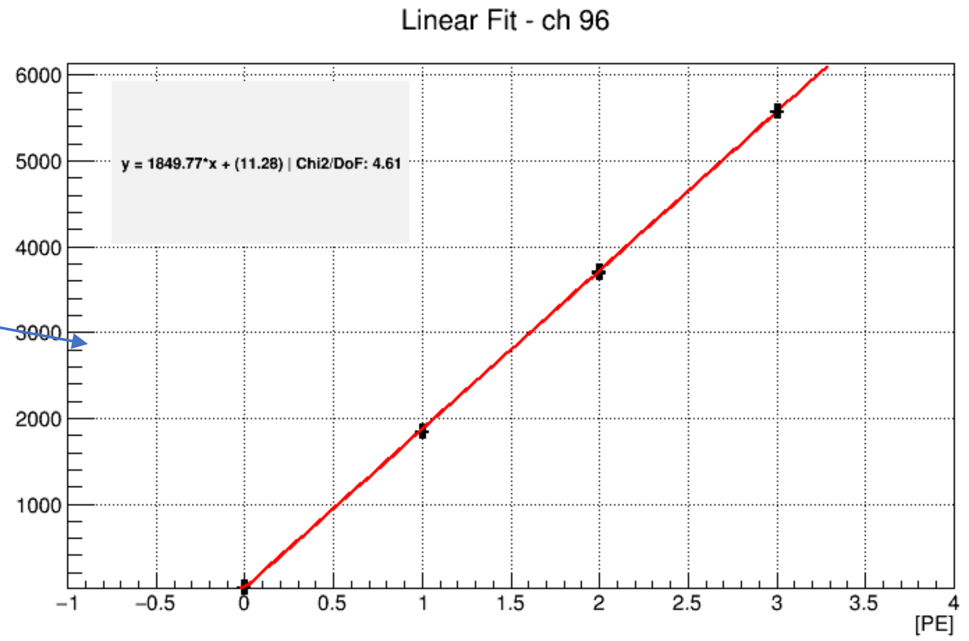
SensL Calibrations- ADC/Avalanche



- Processed Runs
  - Pedestal calculation (using 725 samples)
  - Integration, using fixed intervals
    - BeamInt - [700,1975] samples

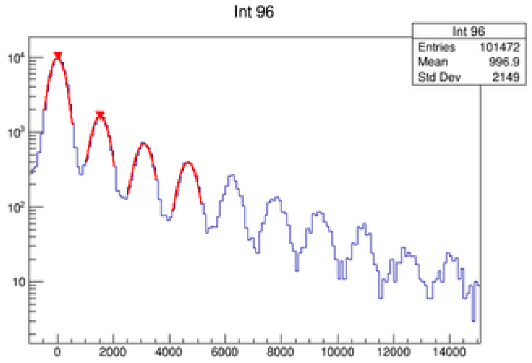
SensL Calibrations- ADC/Avalanche

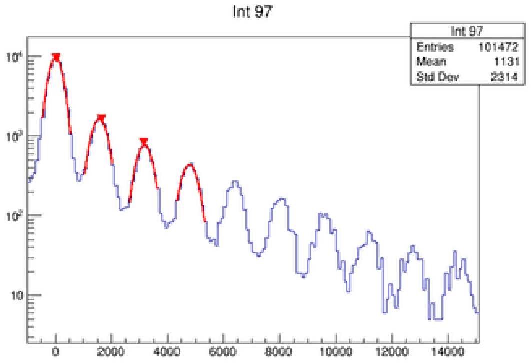


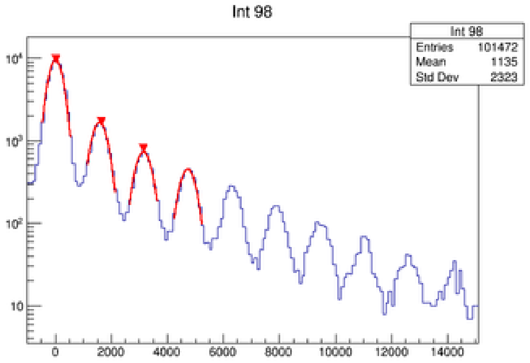


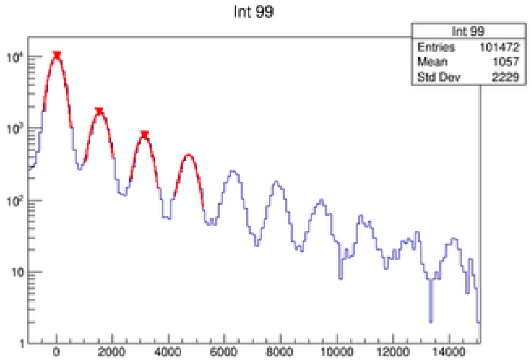
- Fit the first 4 Avalanche peaks with a gaussian, using TF1 fit.
  - Fit range - [Peak-500, Peak+500]
- Linear Fit, via TF1 fit, using
  - mean of each peak
  - sigma as error

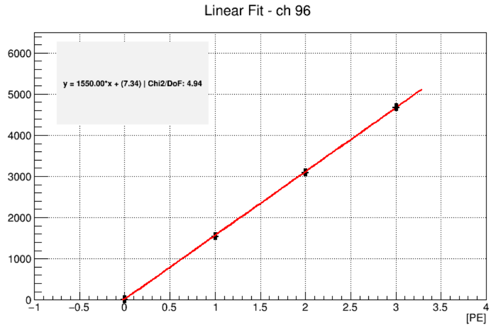
SensL's- ADC/Avalanche @ 26.0

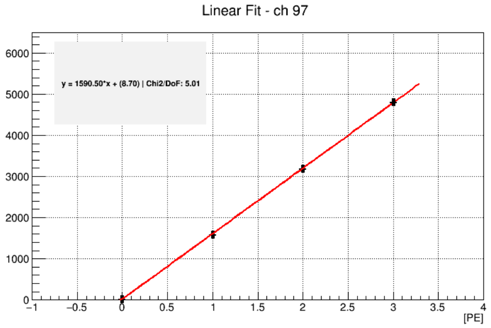


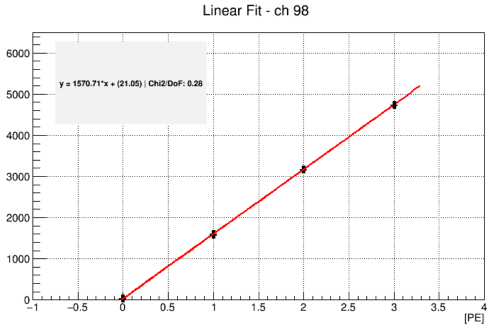


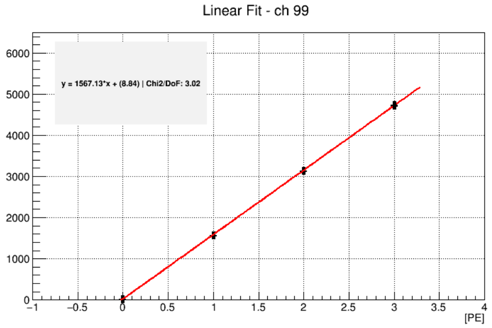




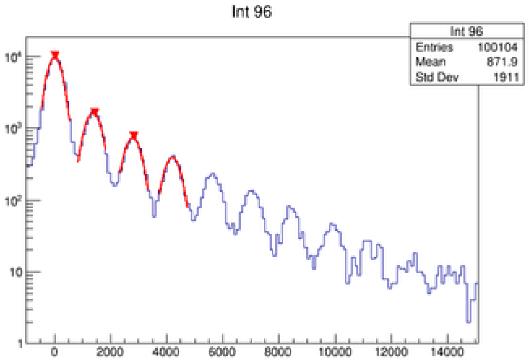


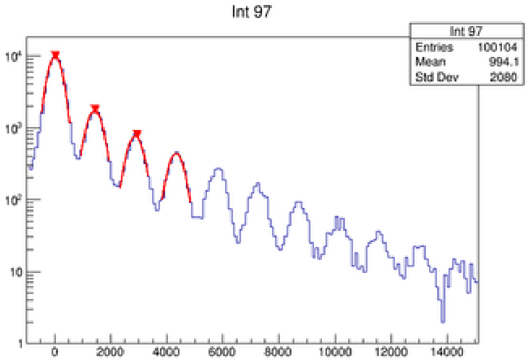


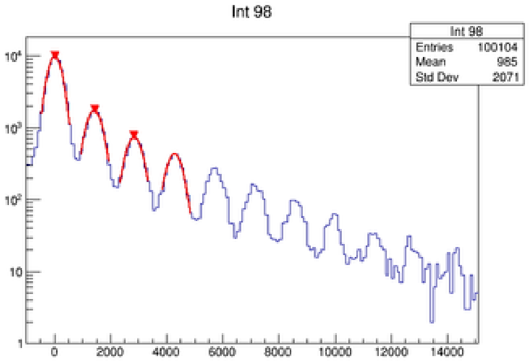


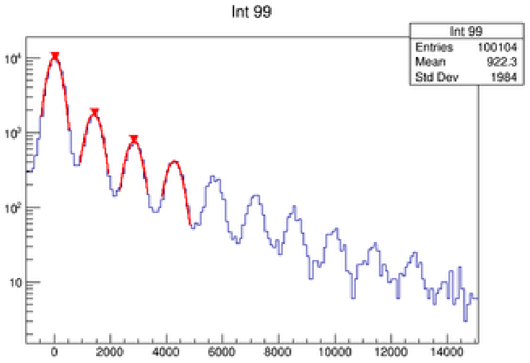


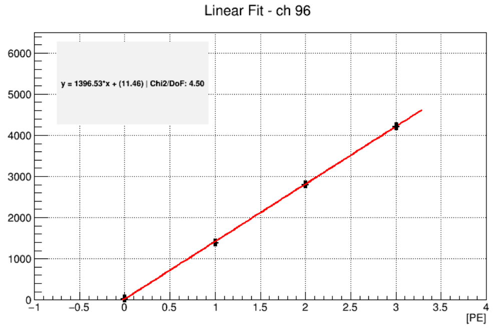
SensL's- ADC/Avalanche @ 25.5

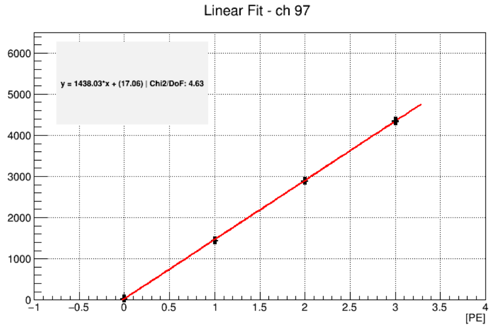


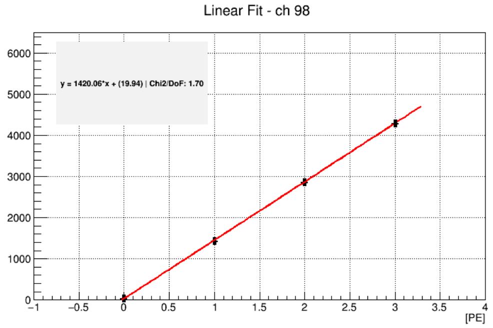


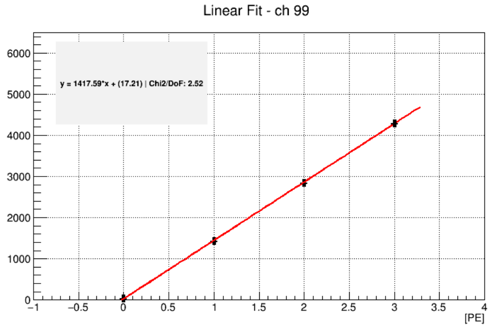






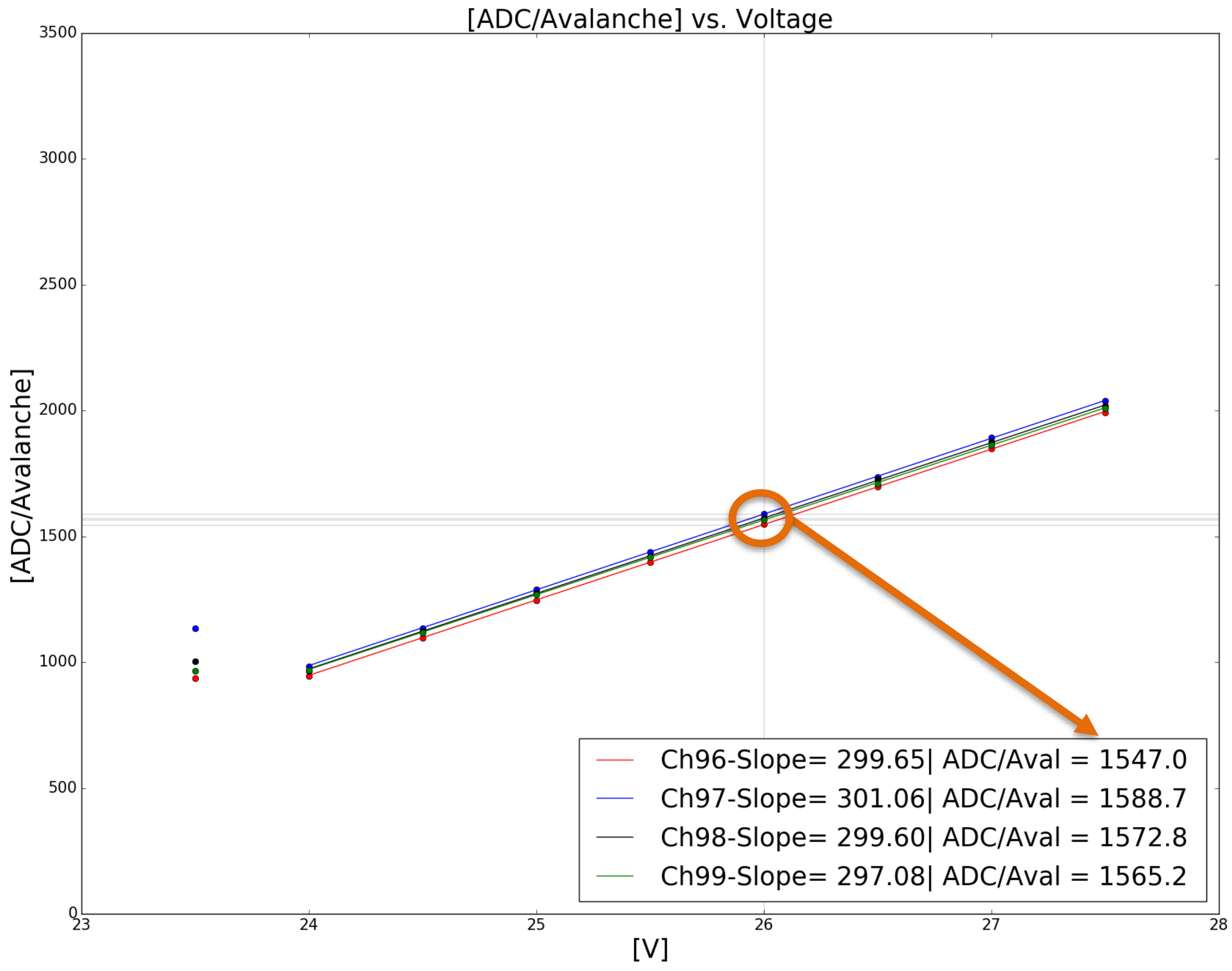






SensL's- ADC/Avalanche vs. Voltage

Consistent Slopes!



Determination of ADC/Avalanche Constant @ Nominal Voltage

Determining SensL’s ADC/Photon

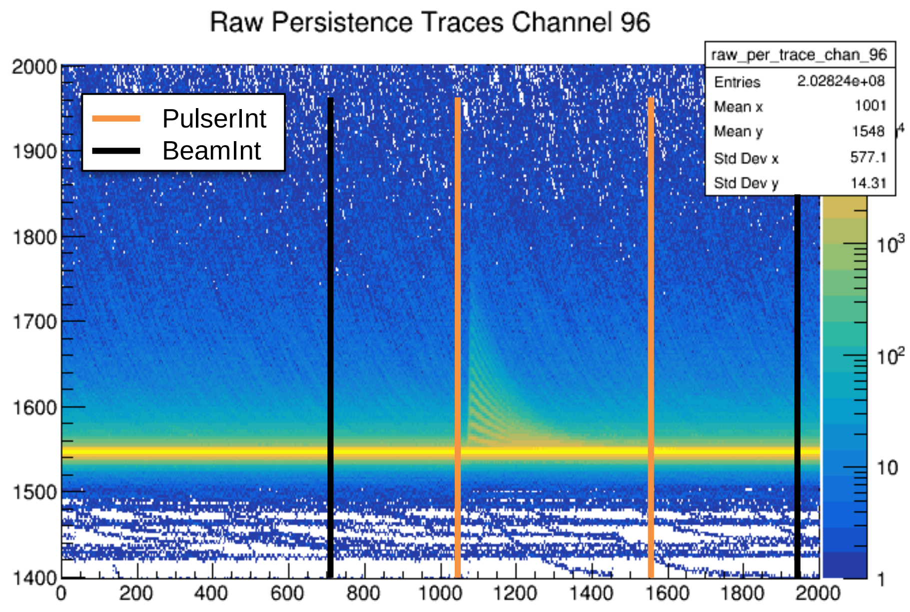
Poisson Statistics to Determine ADC/Photon

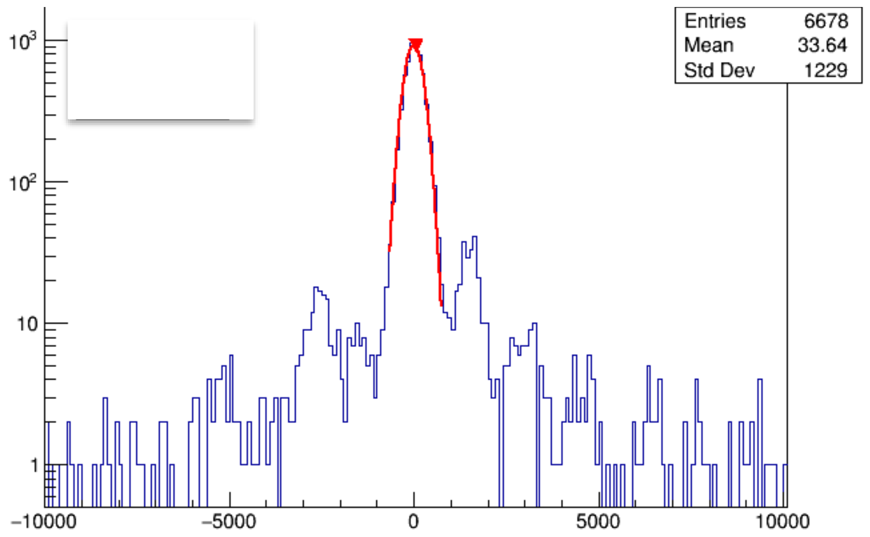
- Poisson statistics to determine the mean number of photons per window, λ, using the zero photon events.

$$\mathrm{P(x)} = \frac{\lambda^{x}\, e^{-\lambda}}{x!} \Rightarrow P(0) = \frac{\lambda^{0}\, e^{-\lambda}}{0!} = e^{-\lambda}$$

$$\mathrm{P(0)} = \frac{N(0)}{\sum_x N(x)} \Rightarrow \boxed{\boldsymbol{\lambda = -ln\left(\frac{N(0)}{\sum_x N(x)}\right)}}$$

  - Use Gaussian Fit to count how many zeros, N(0).





Correcting for Under/Over Counting Events - Using a Random Trigger

- Determine "Undercount Probability"

$$\text{fracUnder} = \frac{\sum(\textit{yellow box})}{\sum_x N(x)}$$

- Determine "Overcount Probability"

$$\text{fracOver} = \frac{\sum(\textit{green box})}{\sum_x N(x)} \times \textbf{fracUnder}^*$$

- Correct the fraction of Zero-Avalanche Events

$$\text{fracZero}_T = \frac{\sum(\textit{Gaussian})}{\sum_x N(x)} + \textbf{fracUnder} - \textbf{fracOver}$$

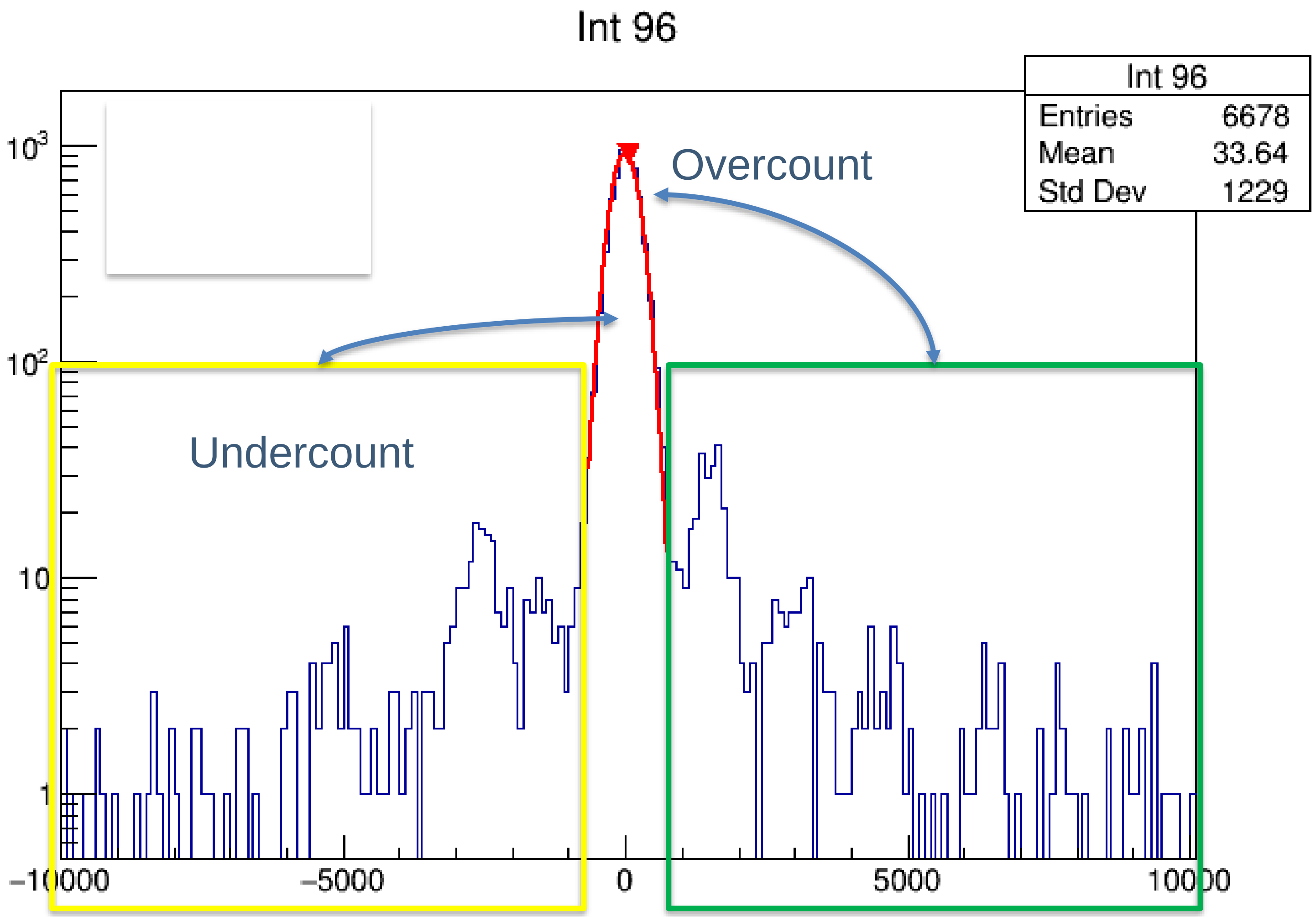
- Correct the Mean ADC value

$$< \text{ADC} >_T = \frac{\sum \textit{ADC}(\textit{green box})\,(1 + \textbf{fracOver})}{\sum_x N(x)}$$

- Corrected λ for random trigger is

$$\lambda_{RT} = -\ln(fracZero_T)$$

- For a Random Trigger, λ_{RT} is defined as
  - Average photons per random trigger window
  - Expected background probability
    - dark noise, cross talk, & after pulsing



* accounting for the same window (i.e. Pedestal & Beam window)

Correcting for Under/Over Counting Events - Using a LED Trigger

- Determine "Undercount Probability"

$$\text{fracUnder} = \frac{\sum(\boldsymbol{yellow\ box})}{\sum_x \boldsymbol{N(x)}}$$

- Determine "Overcount Probability"

$$\text{fracOver} = \frac{\sum(\boldsymbol{green\ box})}{\sum_x \boldsymbol{N(x)}} \times \ \mathbf{fracUnder}^*$$

- Correct the fraction of Zero-Avalanche Events

$$\text{fracZero}_\text{T} = \frac{\sum(\boldsymbol{Gaussian})}{\sum_x \boldsymbol{N(x)}} + \mathbf{fracUnder} \ - \mathbf{fracOver}$$

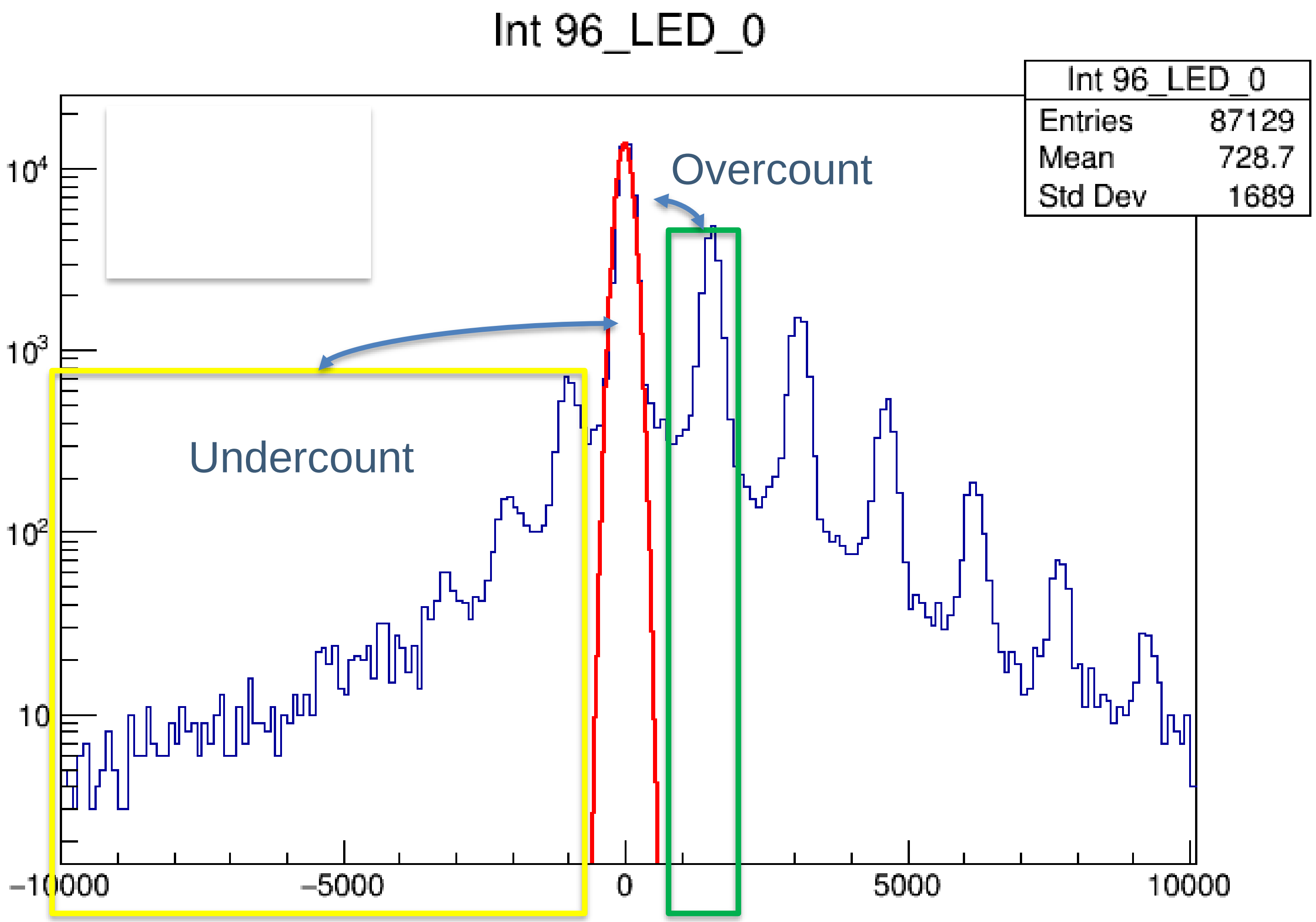
- Correct the Mean ADC value

$$< \text{ADC} >_\text{T} = \frac{\sum \boldsymbol{ADC}(\boldsymbol{green\ box})\ (\mathbf{1} + \mathbf{fracOver})}{\sum_x \boldsymbol{N(x)}}$$

- Corrected λ for LED trigger, accounting for background is

$$\boldsymbol{\lambda_{LED}} \ = -\boldsymbol{ln}[\boldsymbol{fracZero_T} \times (\mathbf{1} + \boldsymbol{\lambda_{RT}})]$$

- For a LED Trigger, $\boldsymbol{\lambda_{LED}}$ is defined as
  - Average number of Photons per LED trigger window
    - Accounting for background



* accounting for the same window (i.e. Pedestal & Beam window)

Poisson Statistics to Determine ADC/Photon

- Poisson statistics to determine the mean number of photons per window, λ, using the zero photon events.

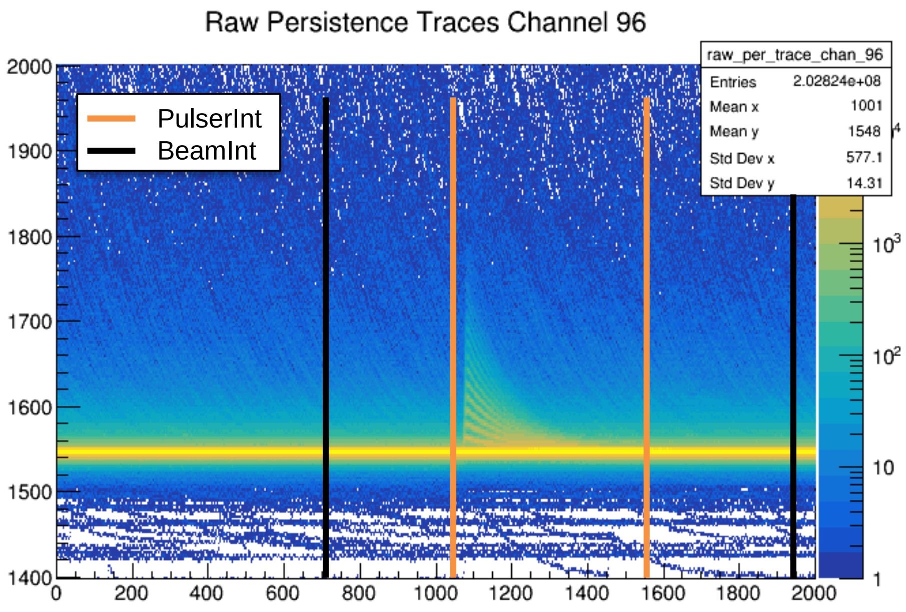
$$P(x) = \frac{\lambda^x e^{-\lambda}}{x!} \Rightarrow P(0) = \frac{\lambda^0 e^{-\lambda}}{0!} = e^{-\lambda}$$

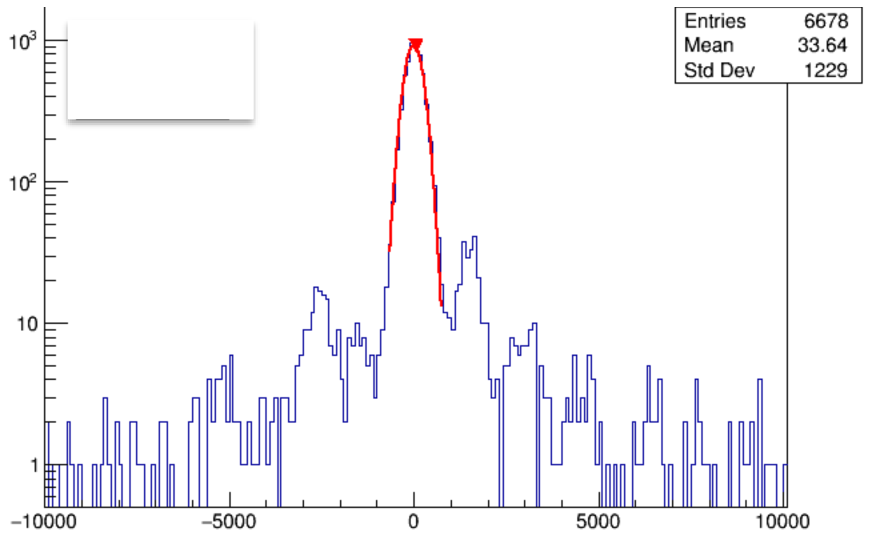
$$P(0) = \frac{N(0)}{\sum_x N(x)} \Rightarrow \boldsymbol{\lambda = -ln\left(\frac{N(0)}{\sum_x N(x)}\right)}$$

  - Use Gaussian Fit to count how many zeros, N(0).

- Determining ADC/Photon

$$\frac{ADC}{\gamma} = \frac{< ADC >_{Hist}}{\lambda}$$





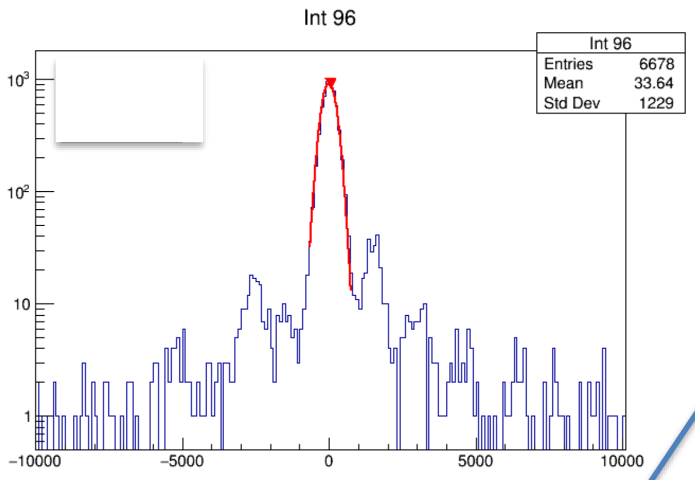
Determining SensL's PE/Photon

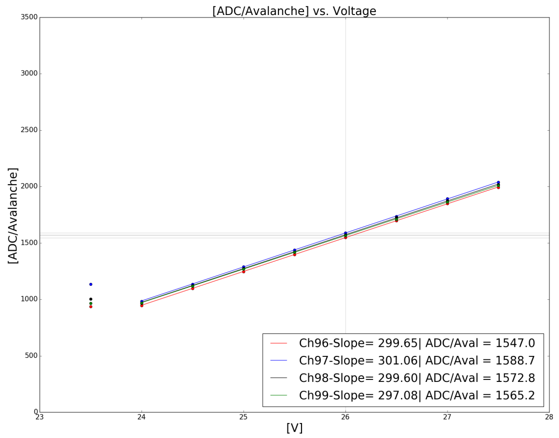
Calculating PE/Photon

- We now have ADC/Avalanche
  - Slides (4-8)
- We know have ADC/Photon
  - Slides (10-13)
- PE/Photon Calculation

$$\frac{\text{PE}}{\gamma} = \frac{\text{ADC}}{\gamma} \Big/ \frac{\text{ADC}}{\text{Avalanche}}$$

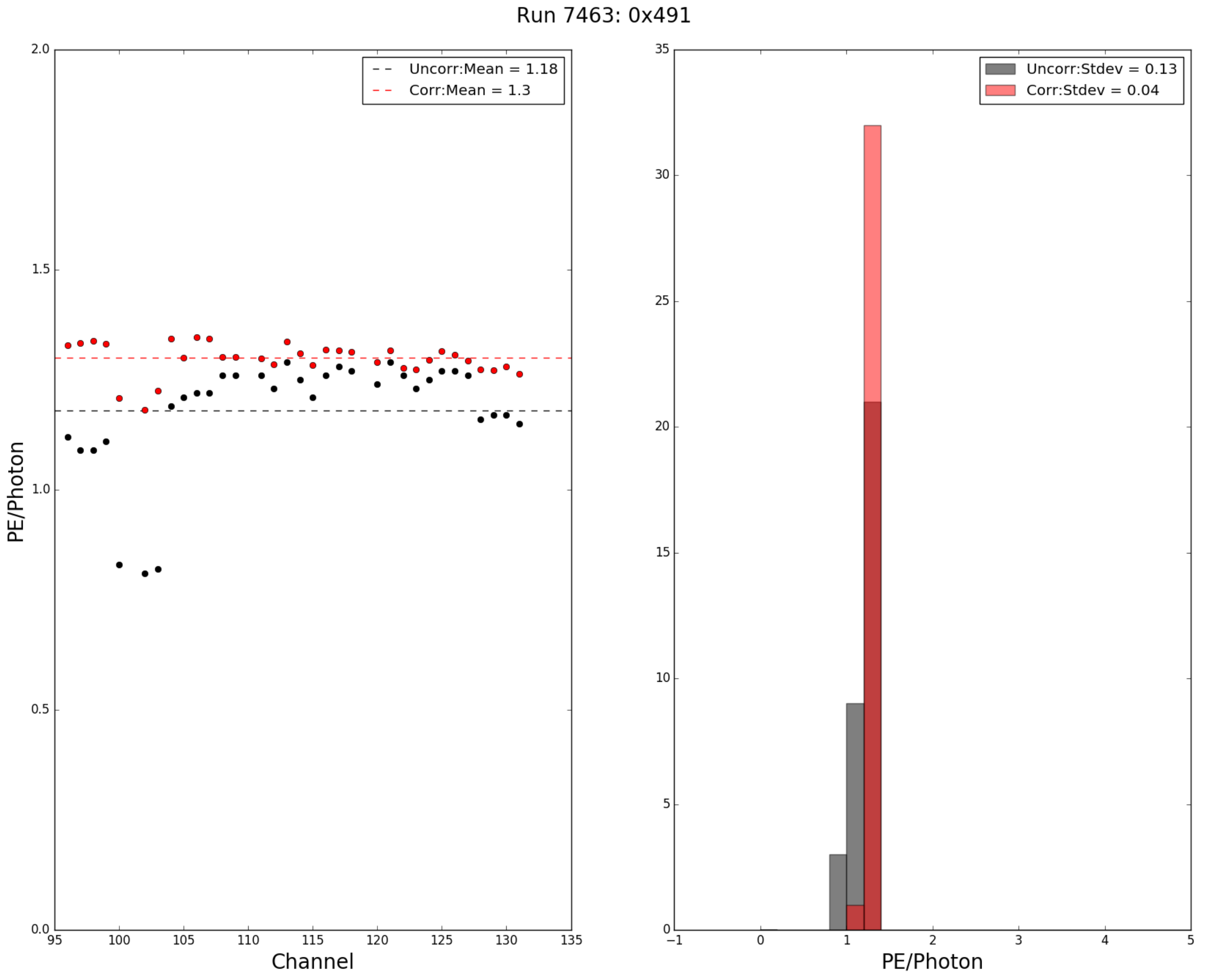
- Time to run through Photon Detector Channels…





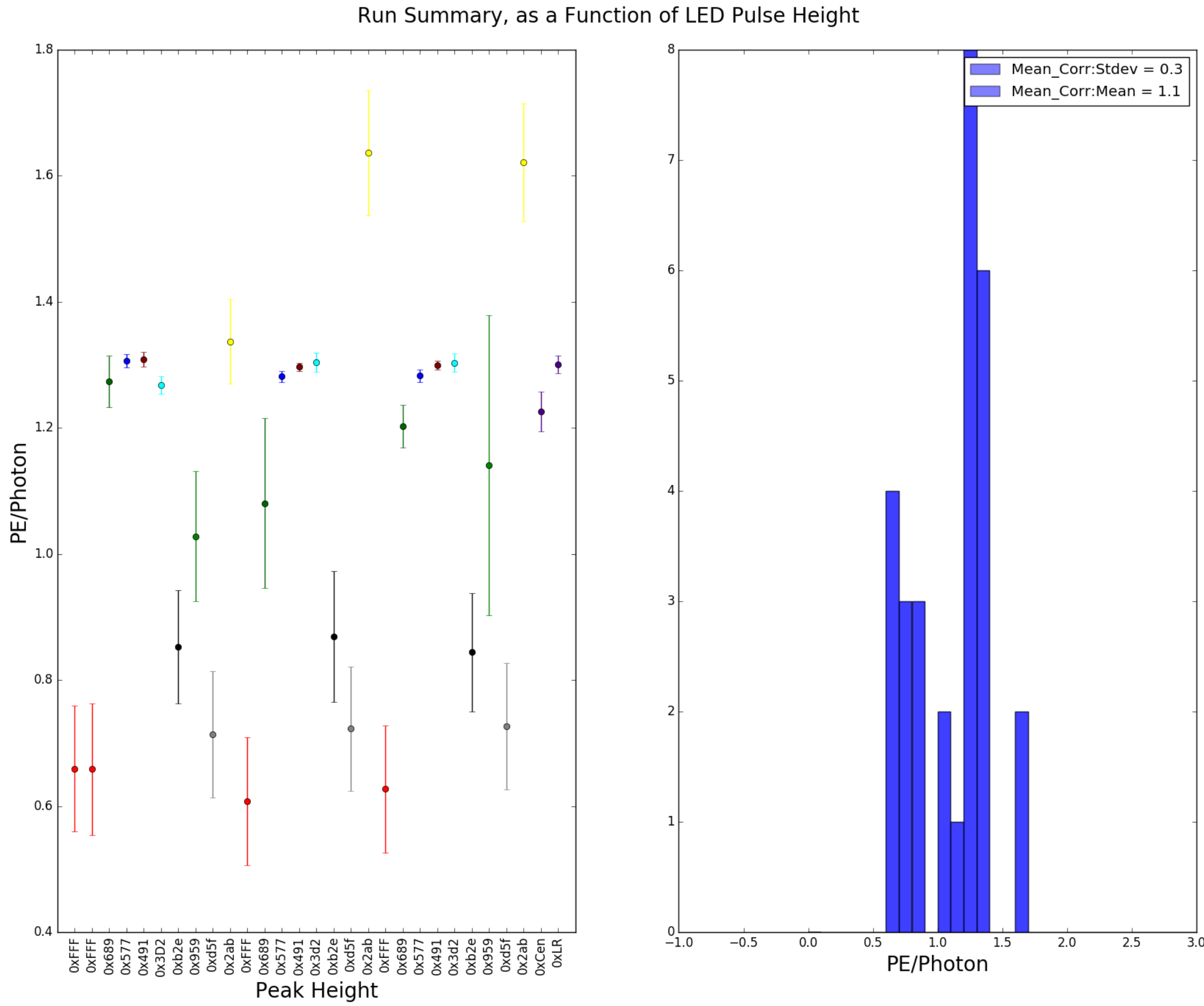
APA3 SensL PE/Photon- Example

- Example Run 7463
  - Stability Run
  - Pulse Peak Height = ‘0x491’
  - All viable LEDs on
- Uncorrected: Black
- Correction: Red

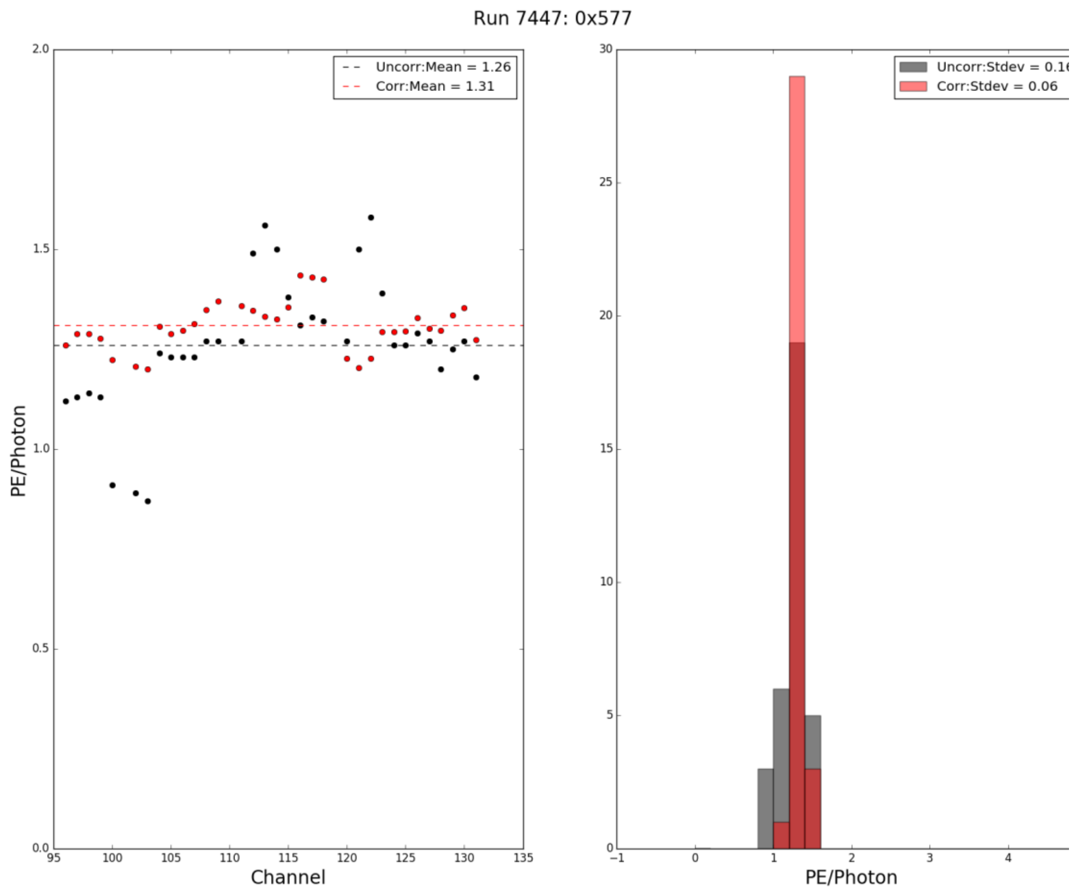


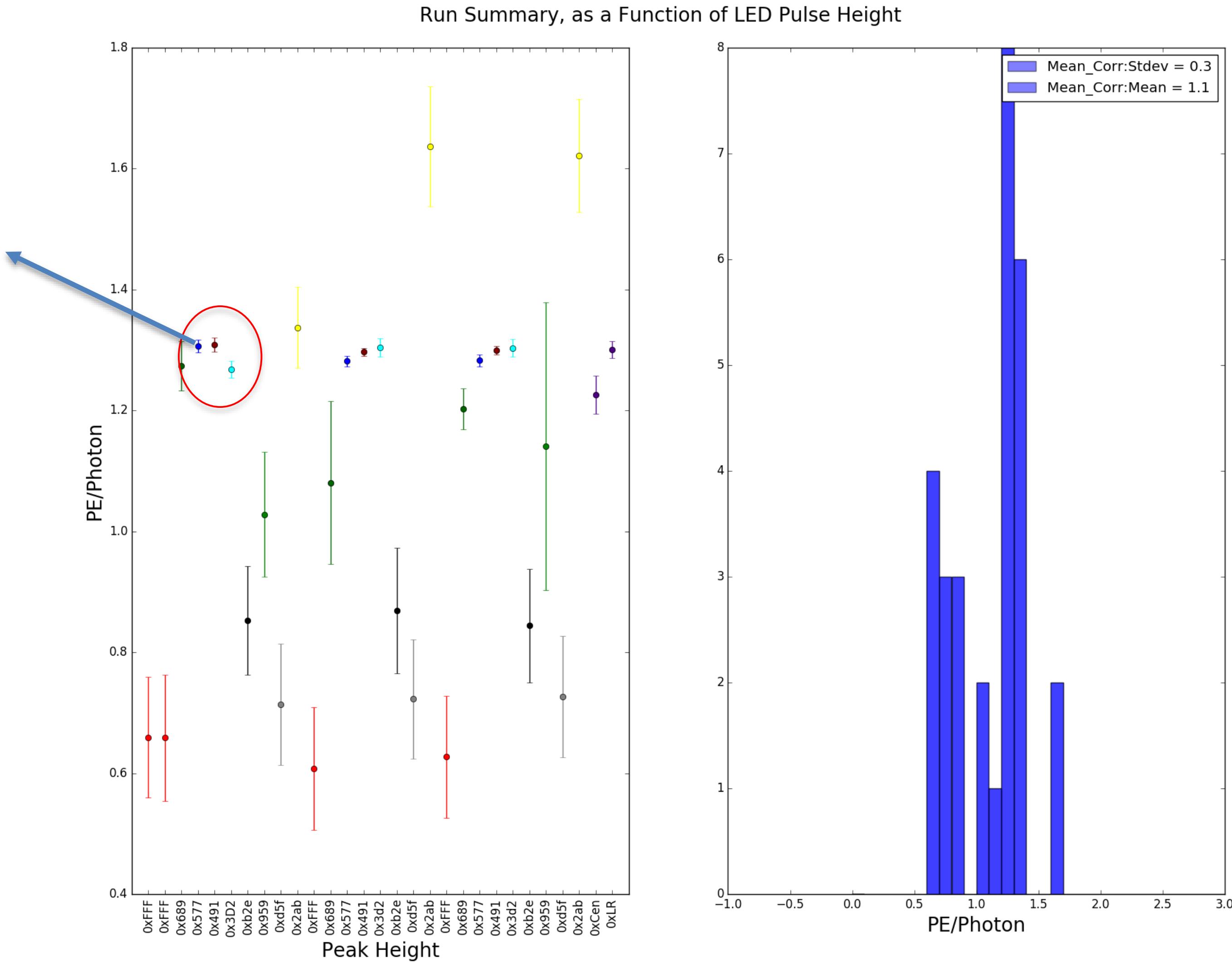
APA3 SensL PE/Photon- as a Function of LED Pulse Height

- Multiple Pulse Height Runs
  - Taken from “Stability Runs”
  - All viable LEDs on
- Color coordinated by Pulse Peak Height
- Shows which pulse heights give the best stability using this method

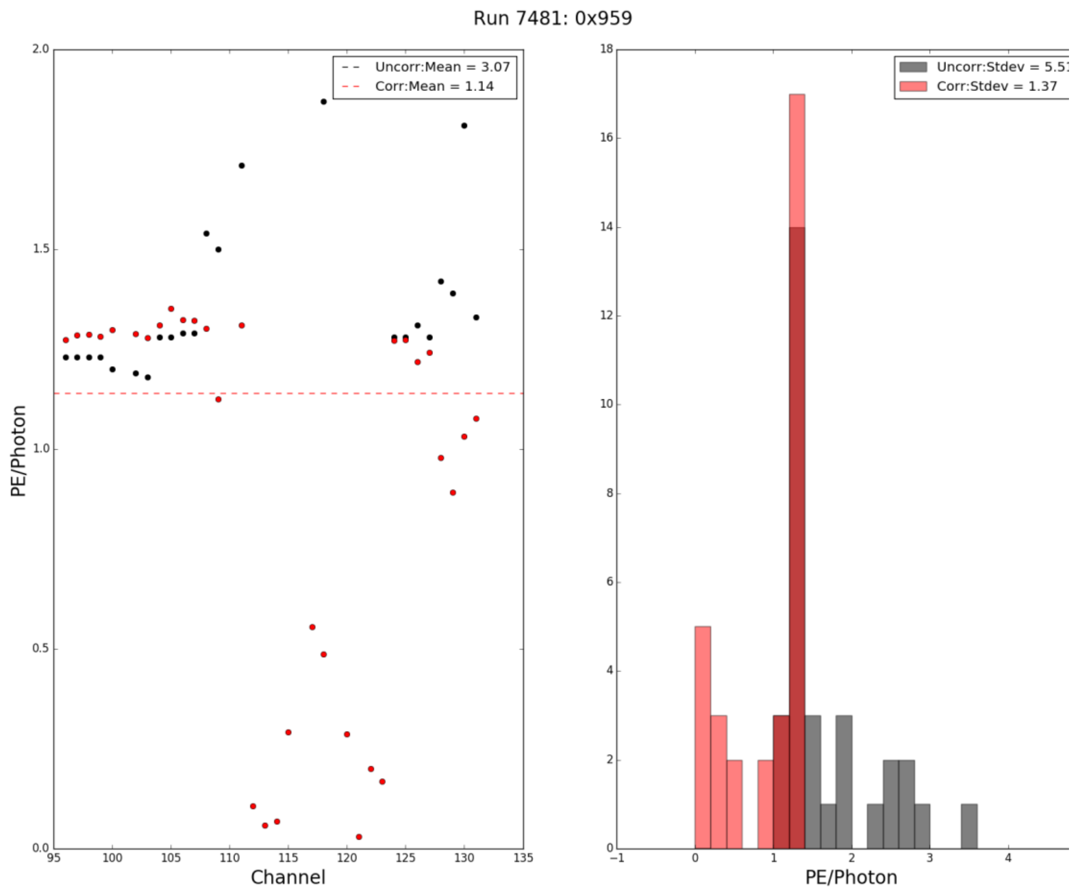


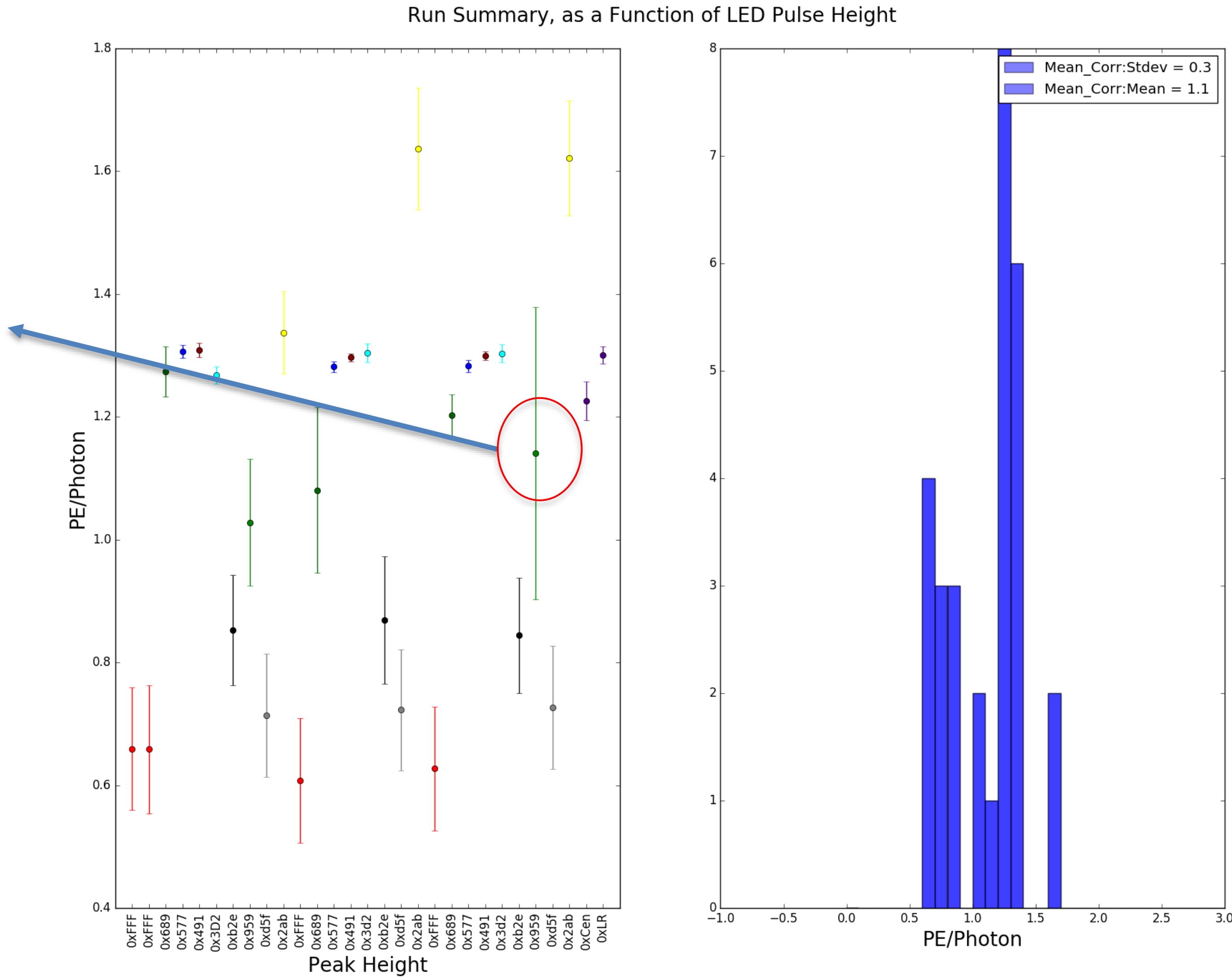
APA3 SensL PE/Photon- as a Function of LED Pulse Height



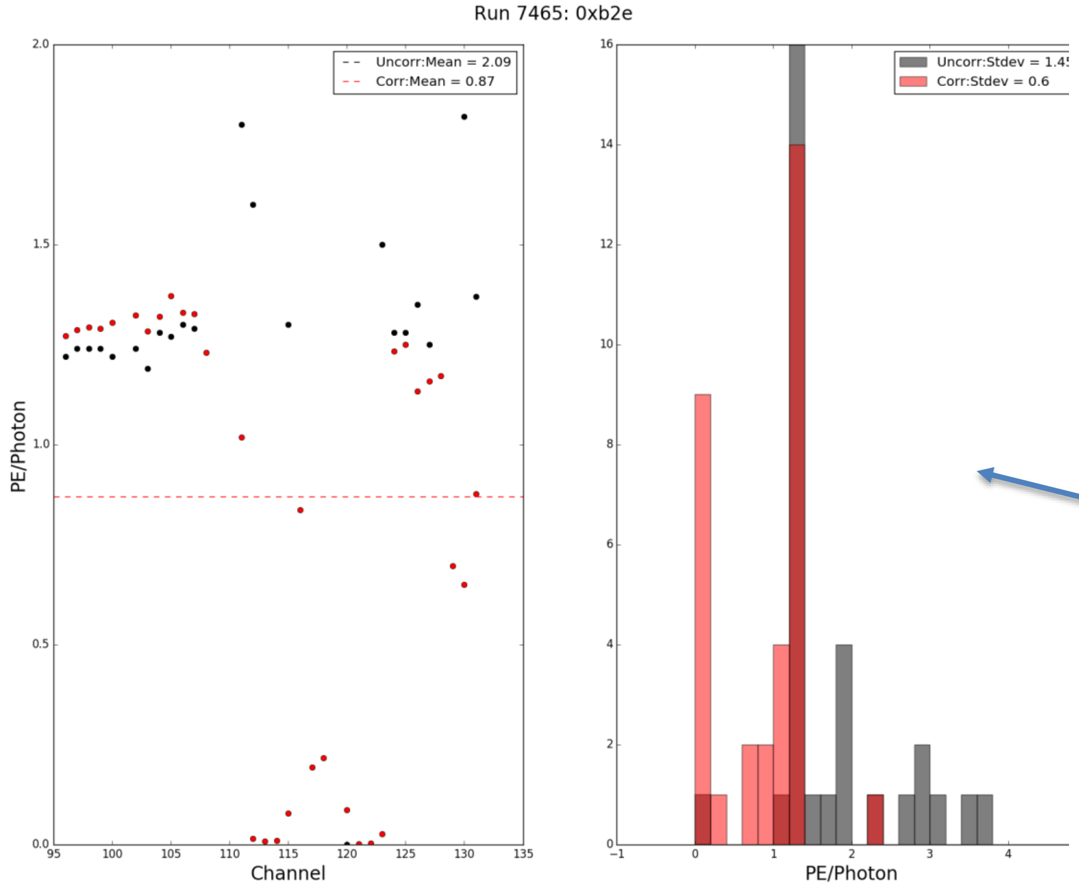


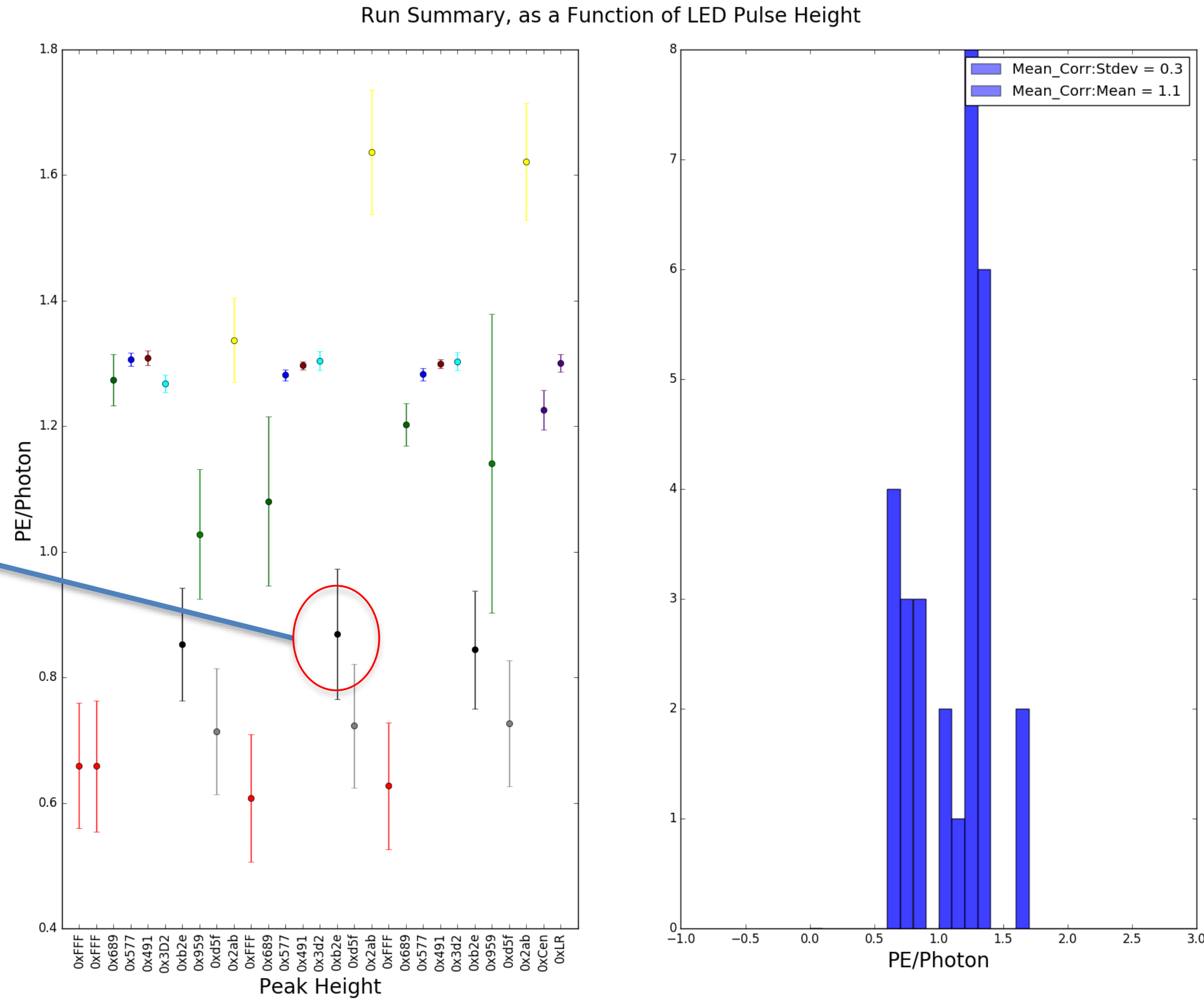
APA3 SensL PE/Photon- as a Function of LED Pulse Height



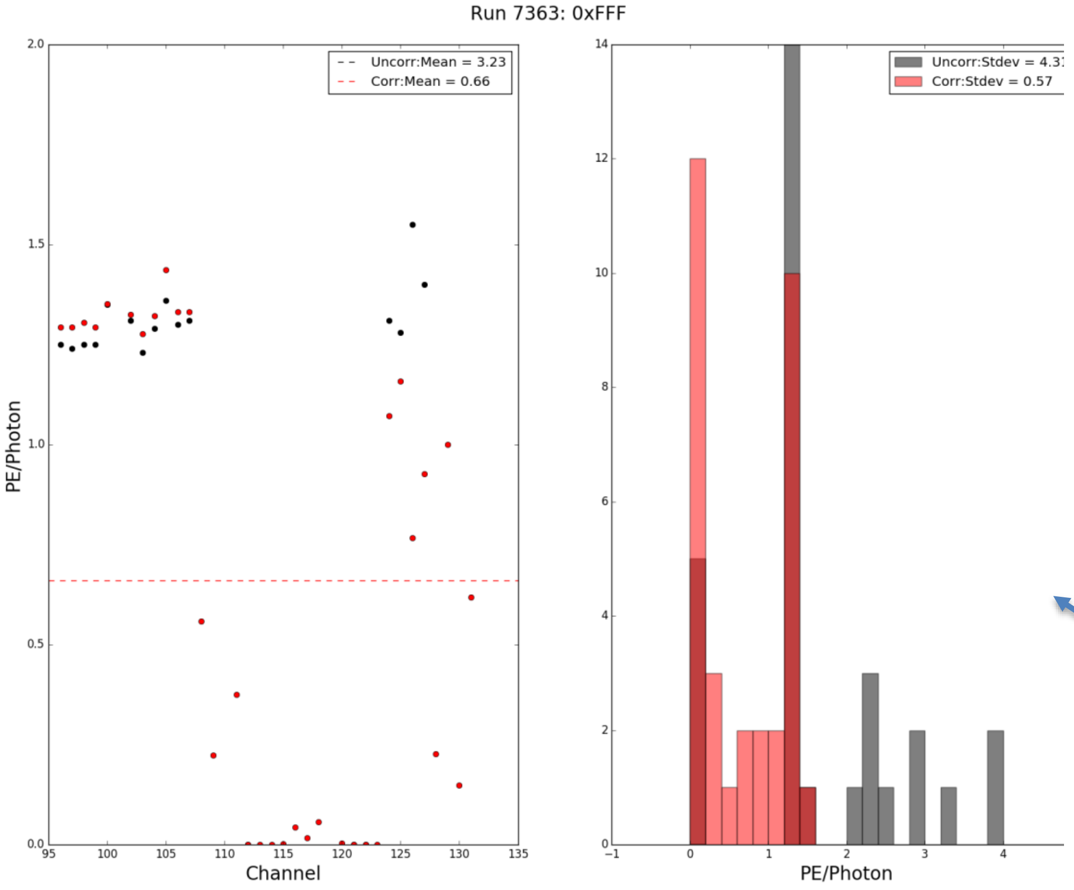


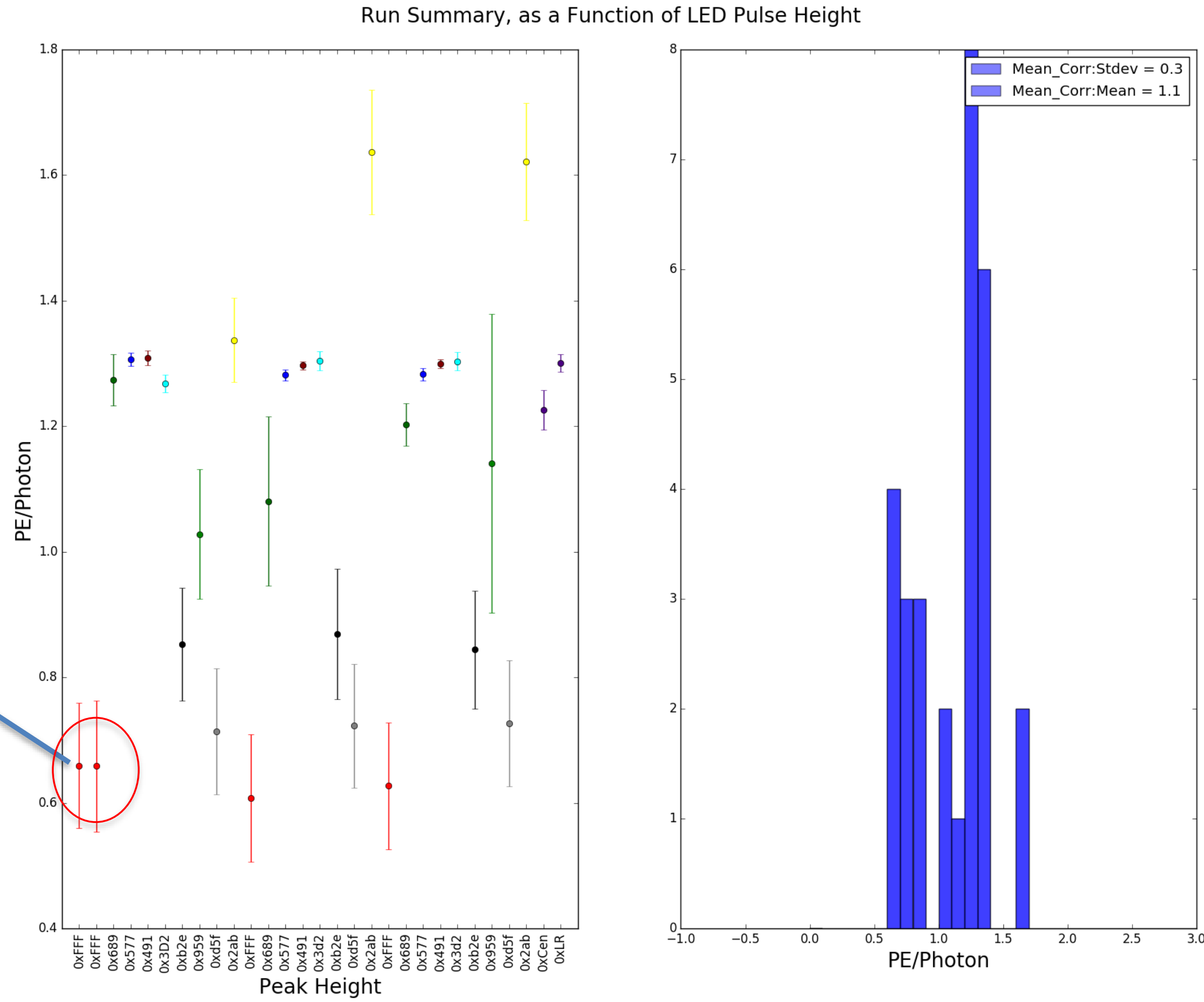
APA3 SensL PE/Photon- as a Function of LED Pulse Height





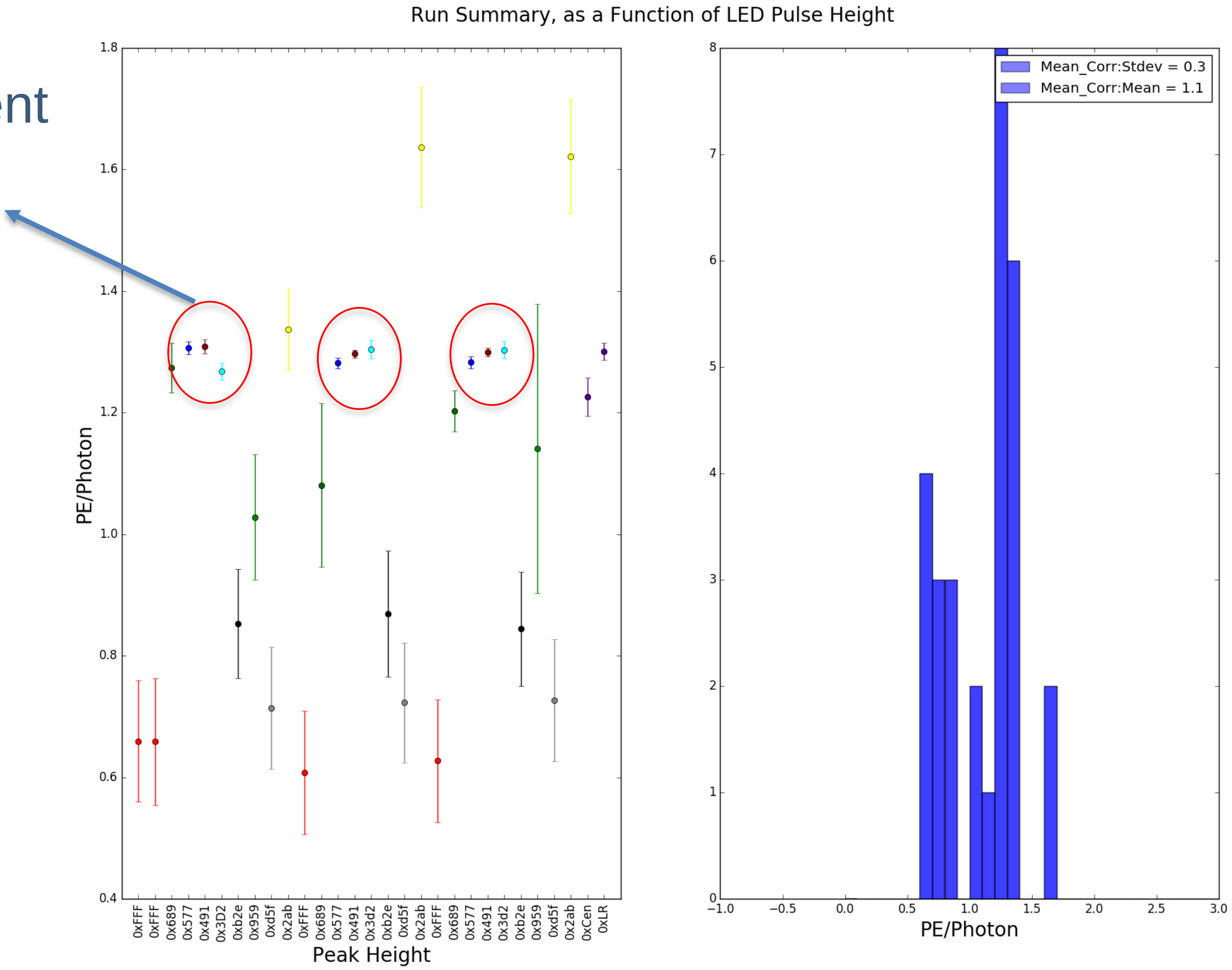
APA3 SensL PE/Photon- as a Function of LED Pulse Height





APA3 SensL PE/Photon- as a Function of LED Pulse Height

- Best Peak heights for consistent calibration measurements
  - ‘0x577’
  - ‘0x491’
  - ‘0x3D2’
- Take a look closer on the next slide…



APA3 SensL PE/Photon- as a Function of LED Pulse Height

- Best Peak heights for consistent calibration measurements
  - ‘0x577’
  - ‘0x491’
  - ‘0x3D2’
- Prelim $< PE/\gamma >_{Ch}$ = 1.29
- Going Forward
  - Calculate for Indiv. Channel.
  - Apply to Beam Data