Laser Measurements of Large Dynamic Range SiPMs

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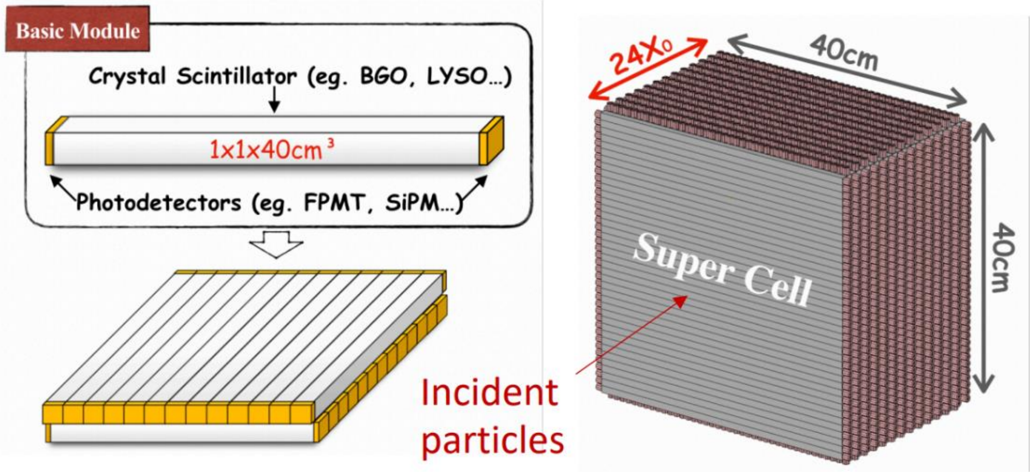
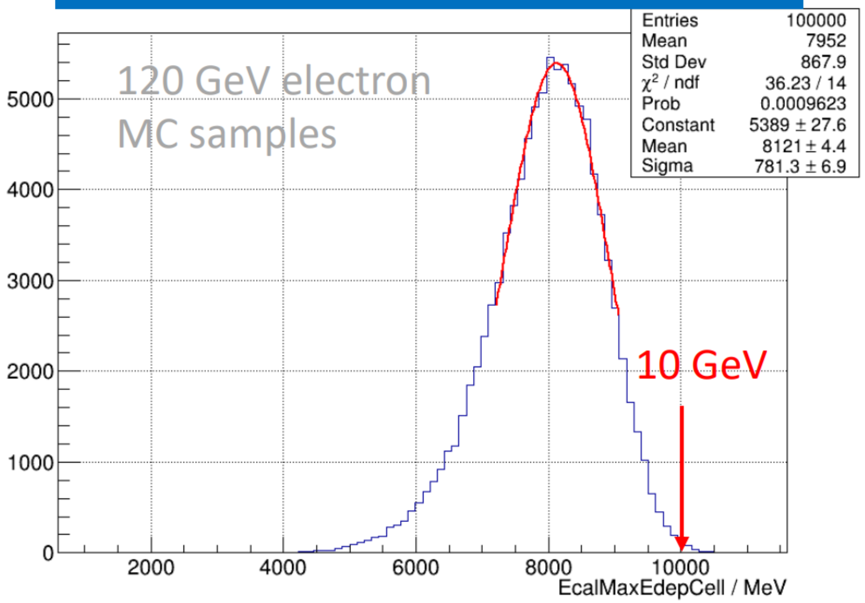
Motivation



Maximum energy deposition within a bar

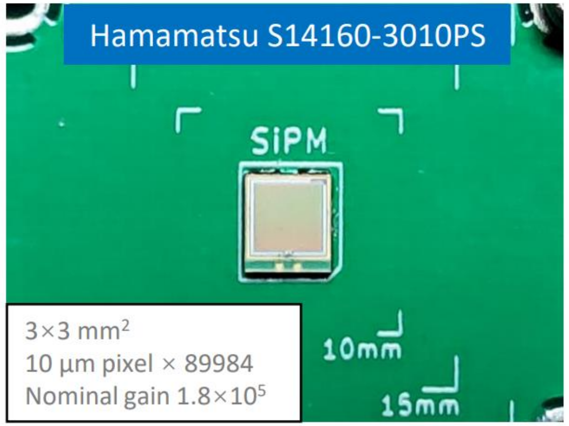


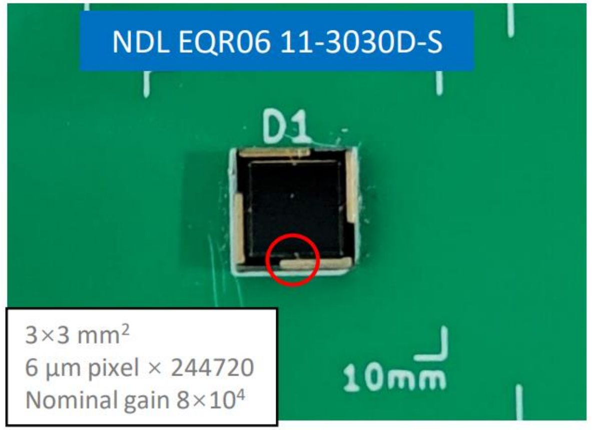
Baohua Qi (IHEP)

- BGO crystal bar ECAL: homogeneous, EM energy resolution < $3\%/\sqrt{E}$, SiPM dual-readout
- Physical requirement: energy range
  - Maximum energy deposition within a single bar: 10GeV → 50000 photons(1 side)
  - Low energy detection: source calibration ~500keV → 5 photons(1 side)
- To cover the range form 5 to 50000 photons, SiPMs with large dynamic range are needed.

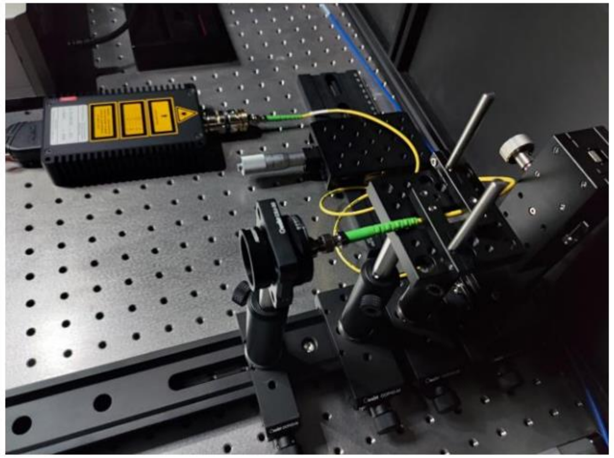
SiPM Types and Calibration

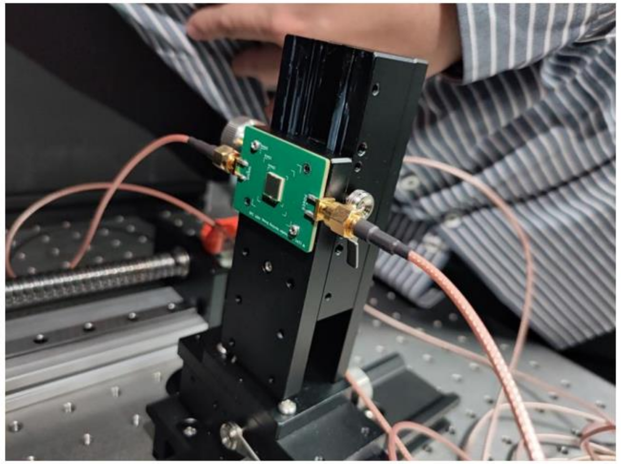
- Some large dynamic range SiPMs

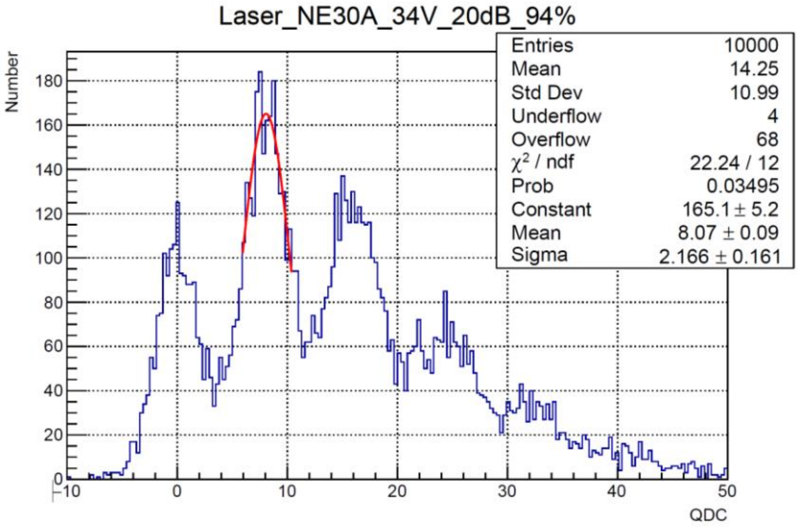




- Single photon QDC calibration using laser

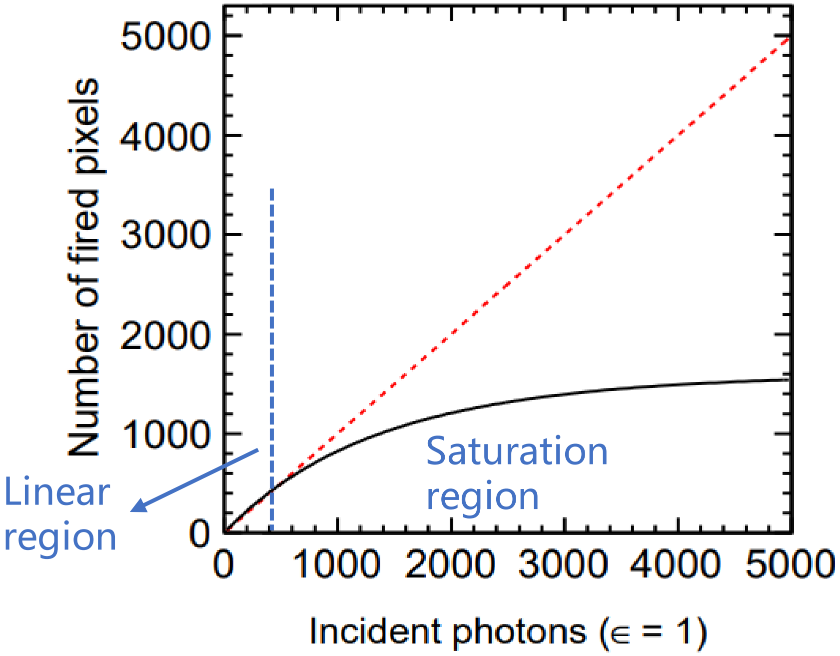






SiPM Response with Incident Light Intensity

[1] 1510.01102.pdf (arxiv.org)



- In linear region, the number of fired pixels increases linearly with the intensity of incident light.
- In saturation region, because the pixel number is limited and multiple photons may hit on the same pixel, the response of SiPM is no longer linear.
- Need a detector whose linear response region could cover the whole dynamic range of SiPM.

Setup of a Dynamic Range Test Experiment

USTC, Yazhou Niu

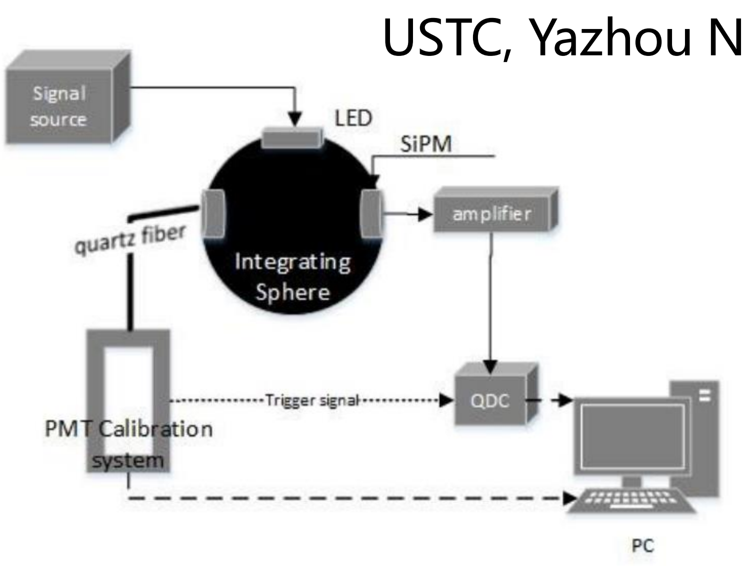
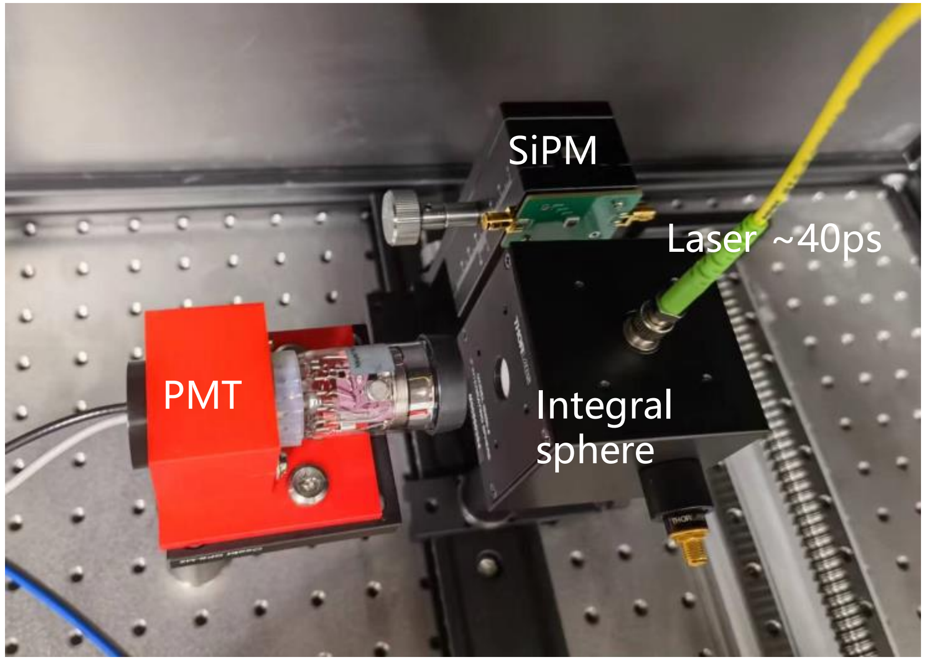


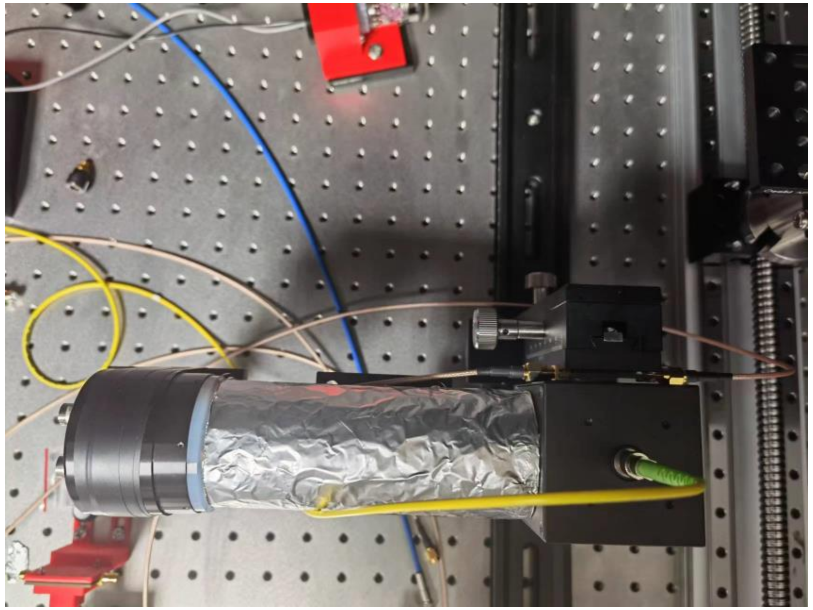
图 3.9 基于 LED 的光刻度系统示意图

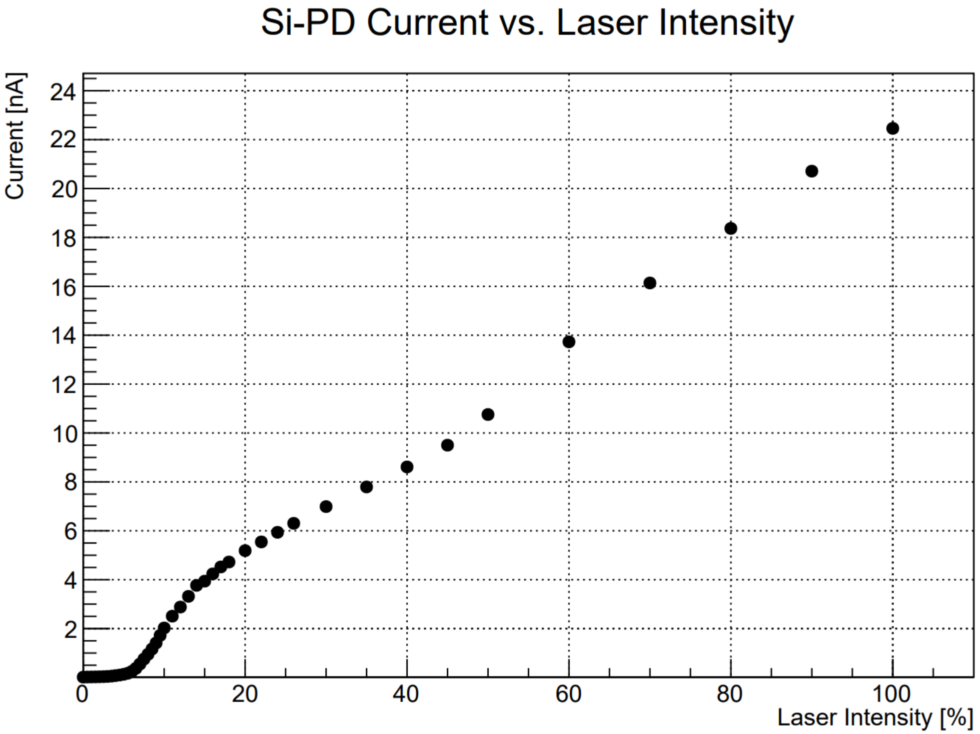


- PMT's dynamic range is not related to pixels number. We can change the dynamic range or linear region of PMT by adjusting the bias voltage.

Linear region selection at different bias voltage → PMT gain calibration → PMT QDC calibration → Response of SiPM with PMT readout

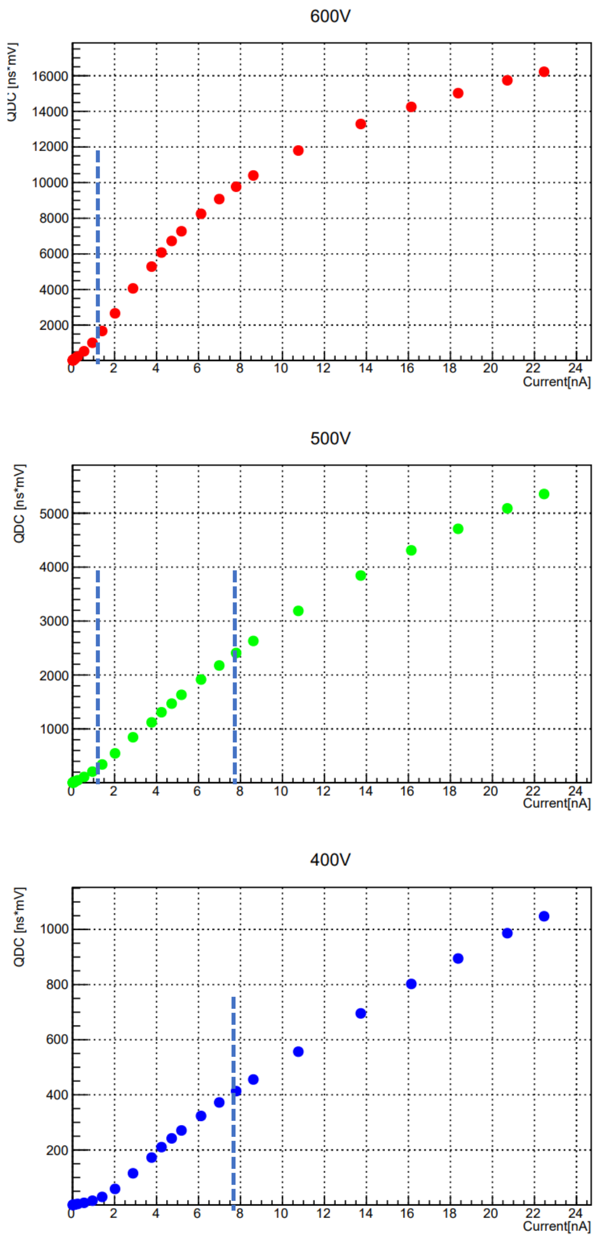
A Preliminary Laser Calibration Using Si-PD

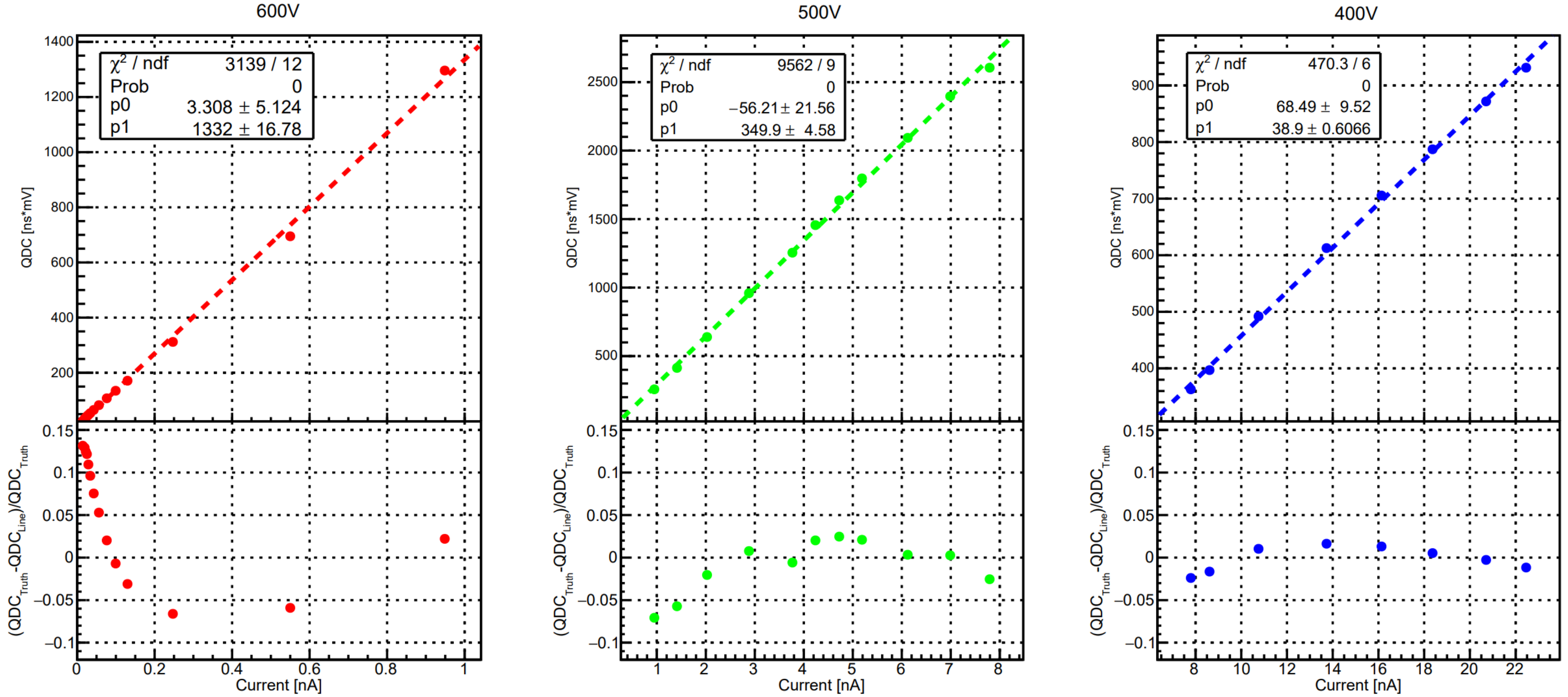




- Change intensity of laser from minimum to maximum. The Si-PD receives the light transmitted through the integrating sphere.
- This measurement was done at a frequency of 1MHz for the laser. While the frequency was 1kHz in PMT and SiPM test.

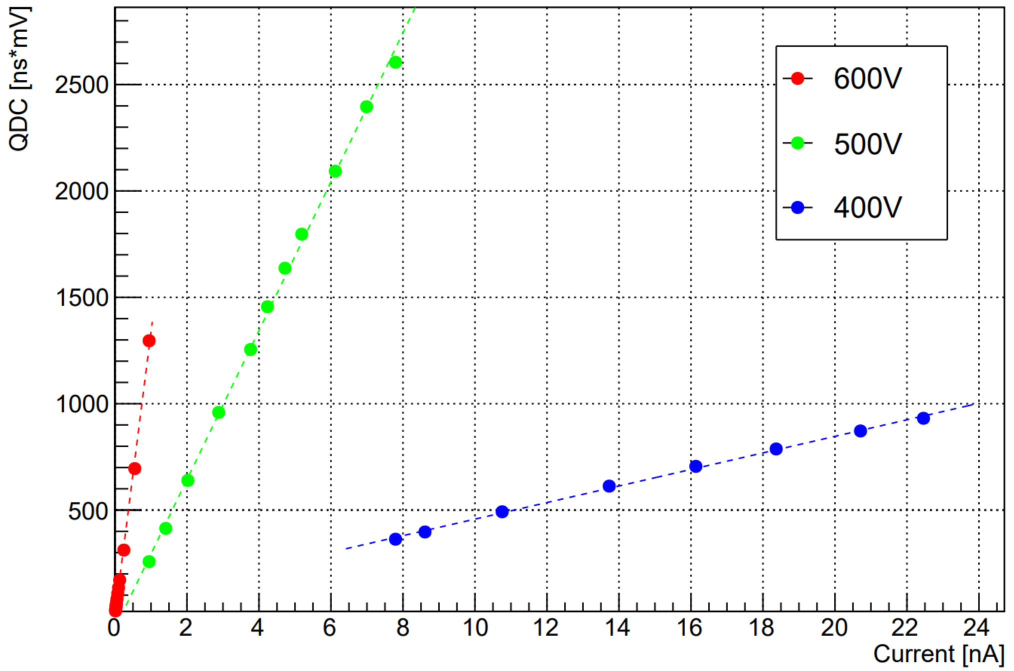
PMT(R7725) Response at Different Voltages

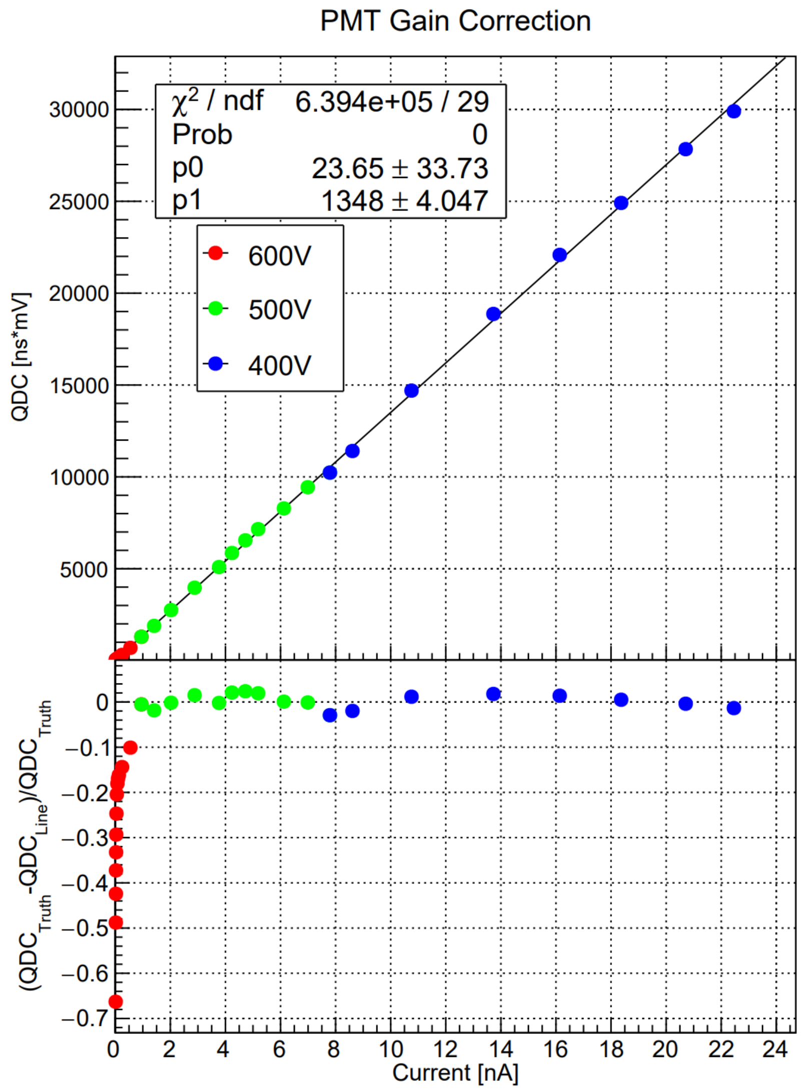




- First, change the bias voltage of PMT. At every voltage, measure the PMT response with the intensity of incident light.
- Then select the linear region of PMT response for every voltage. Different voltages have different linear regions.

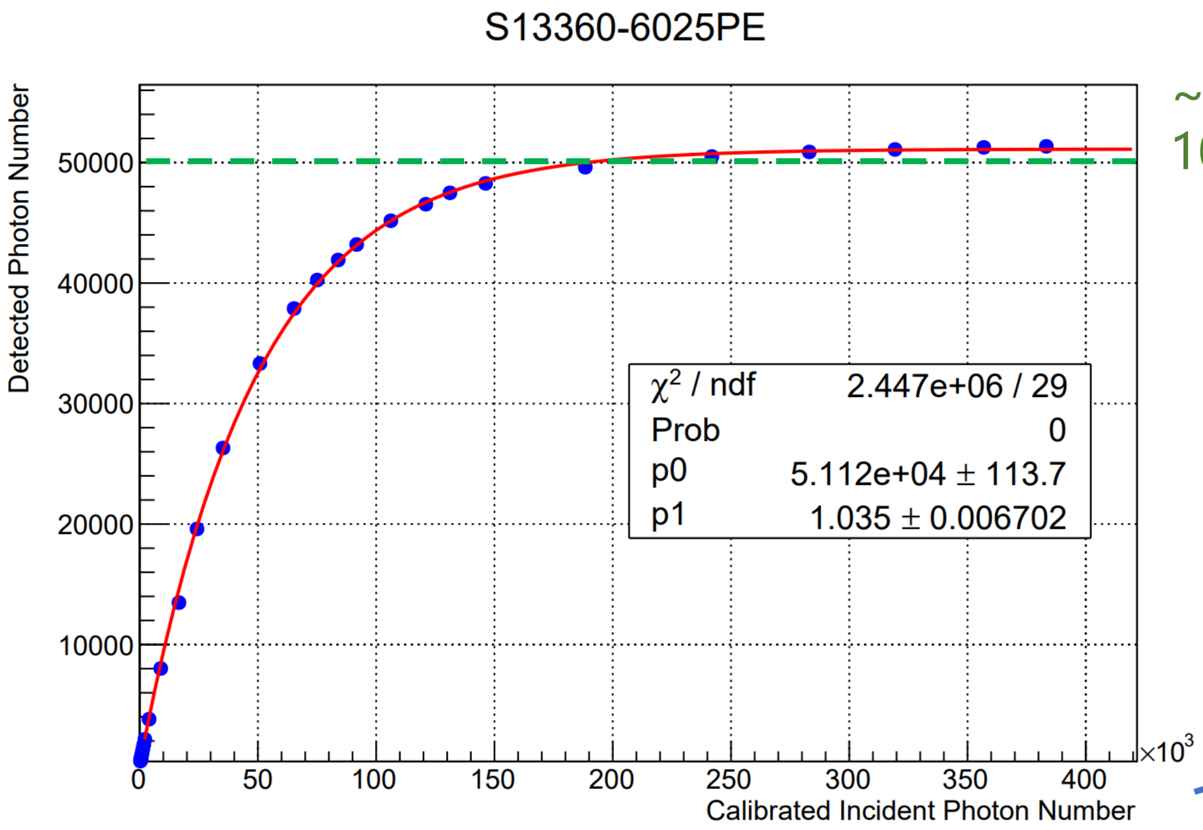
PMT Gain Calibration





- The slopes represent gain at different voltages. Make the slope of 500V and 400V lines the same as the 600V line. And different lines are connected end to end.

Response of S13360-6025PE

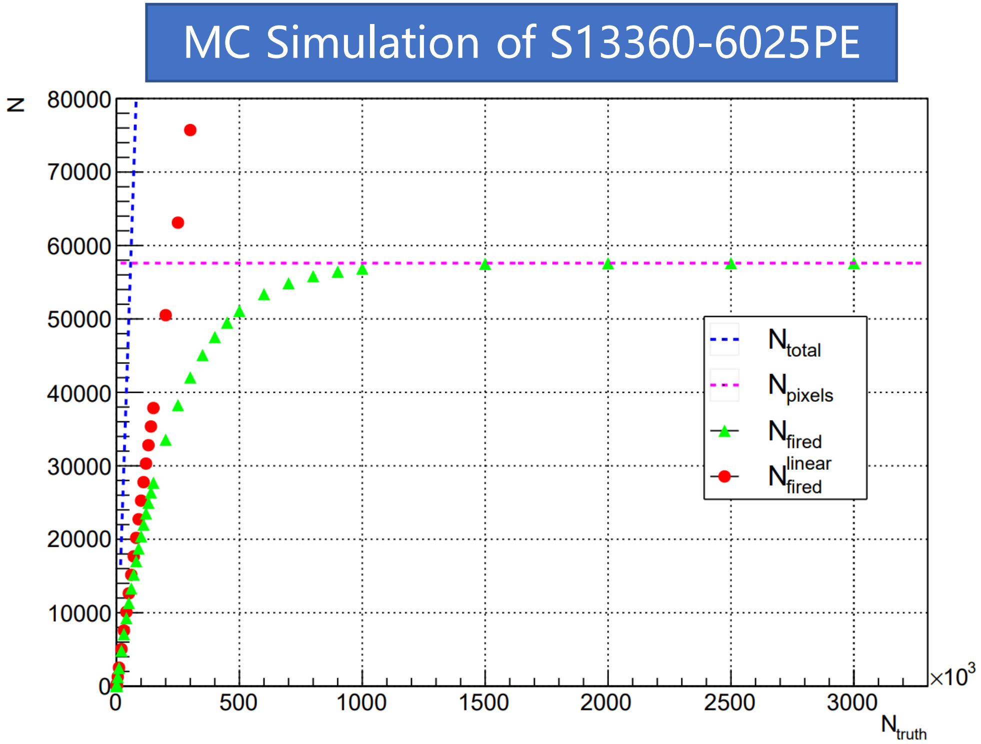


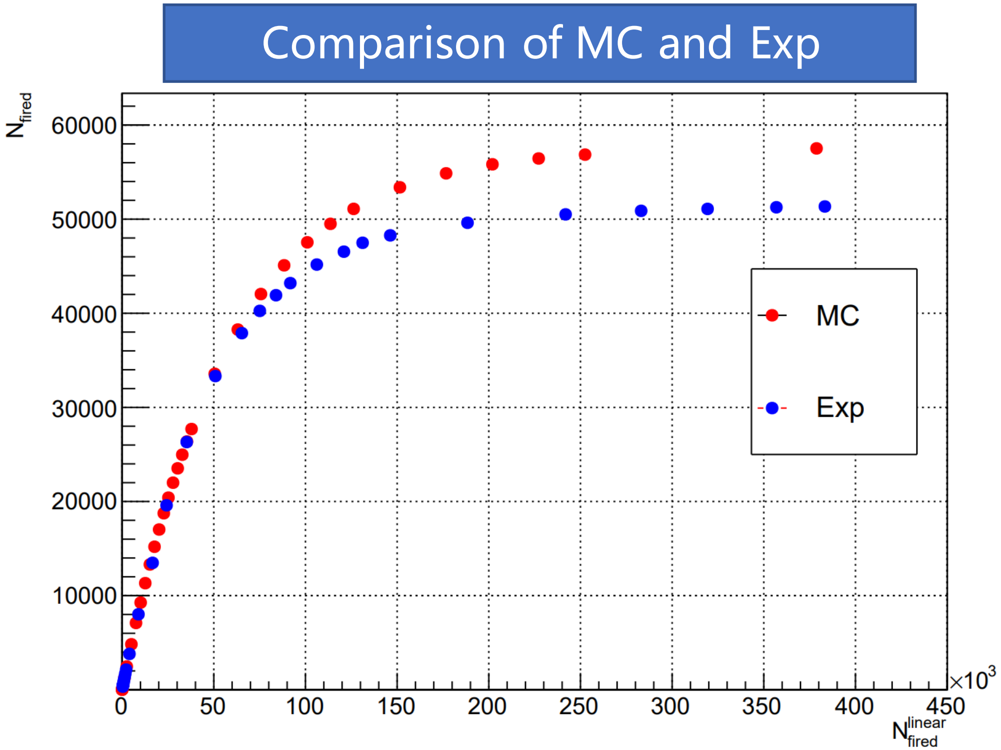
~50000 photons for 10GeV deposition energy

Fired pixels number without considering saturation

- S13360-6025PE, $6 \times 6mm^2$ sensor size, 57600 pixels
- Fitting function: $p_0 * \left(1 - e^{\frac{-p_1 * x}{p_0}}\right)$
- p_0 < 57600： Fluctuation of temperature, stability of laser intensity over time, current tolerance of SiPM electronics

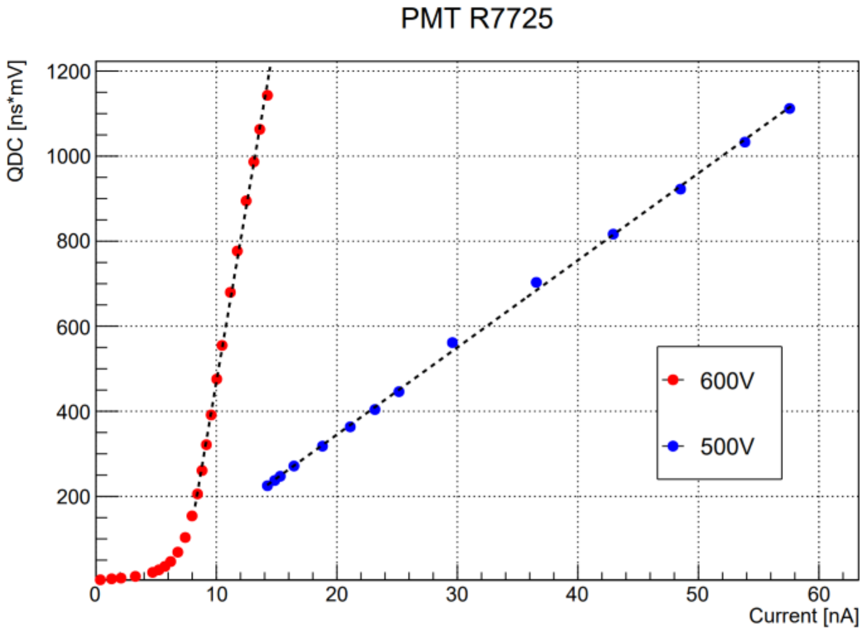
Simulation of SiPM Response

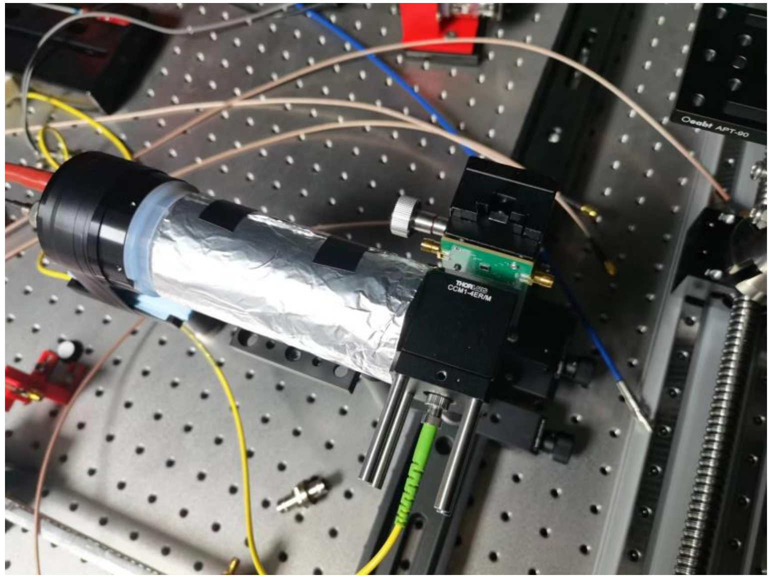


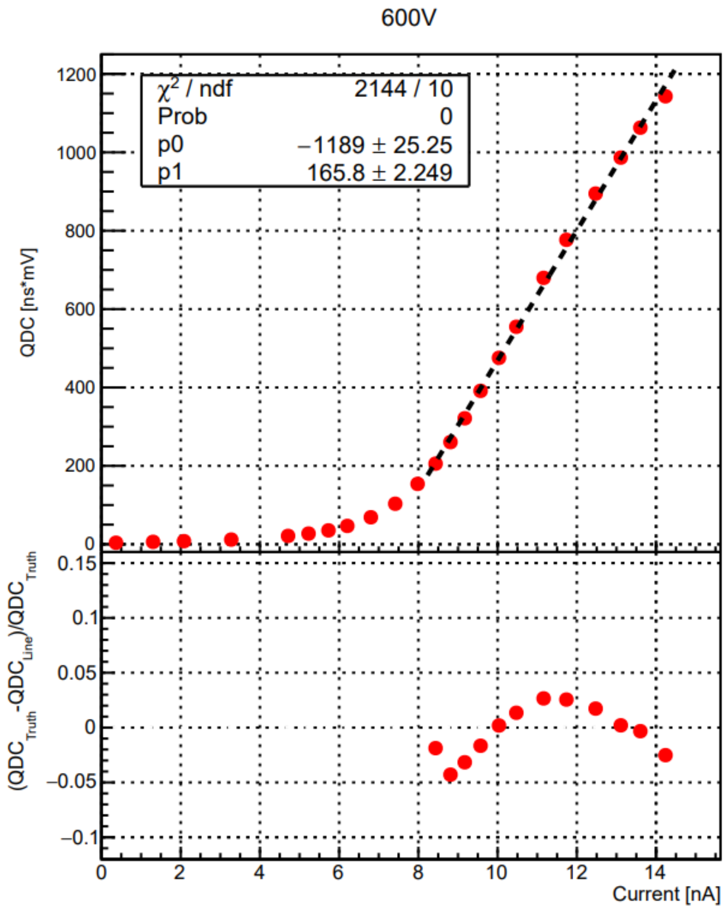


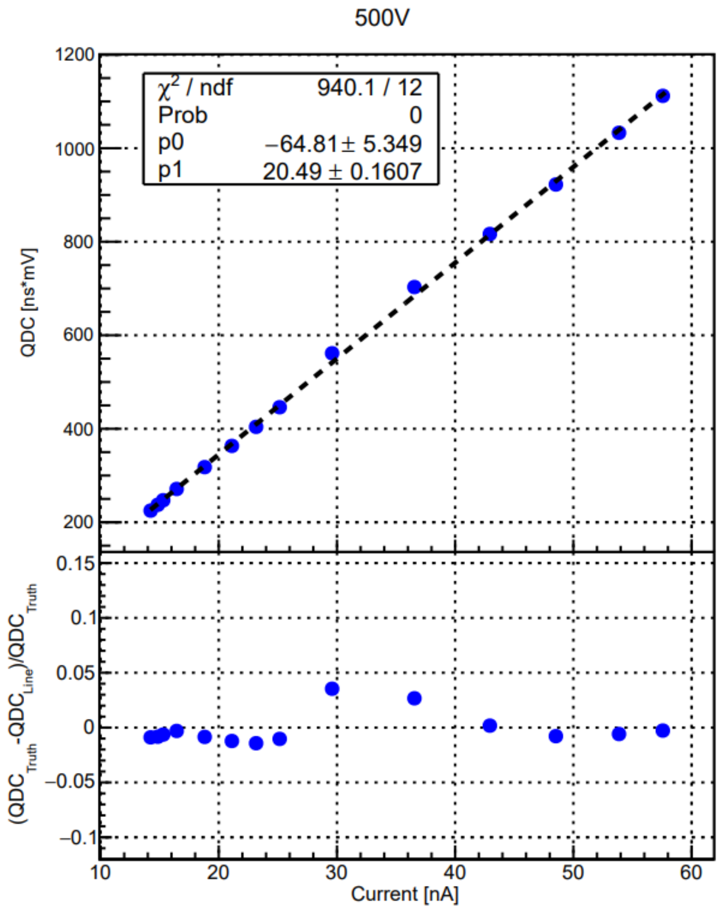
- MC simulation: scale factor, PDE, crosstalk
- N_{total}: incident photon number
- N_{pixel}: pixel number
- N_{fired}: The number of pixels in which avalanche discharge occurred(consider saturation)
- N_{fired}^{linear}: The number of pixels in which avalanche discharge occurred(saturation is not considered)

Using Spectroscope to Replace Integrating Sphere

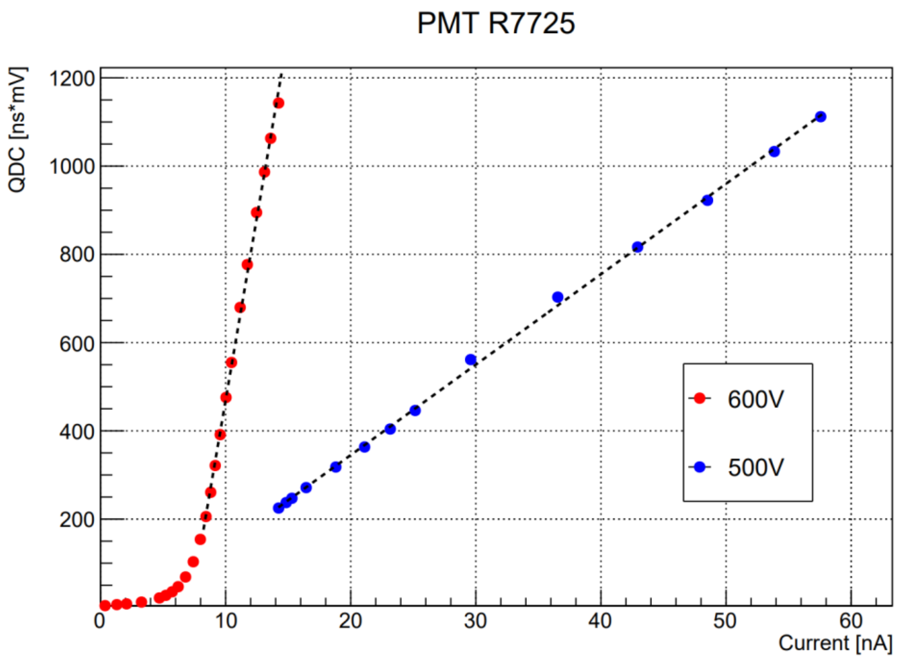


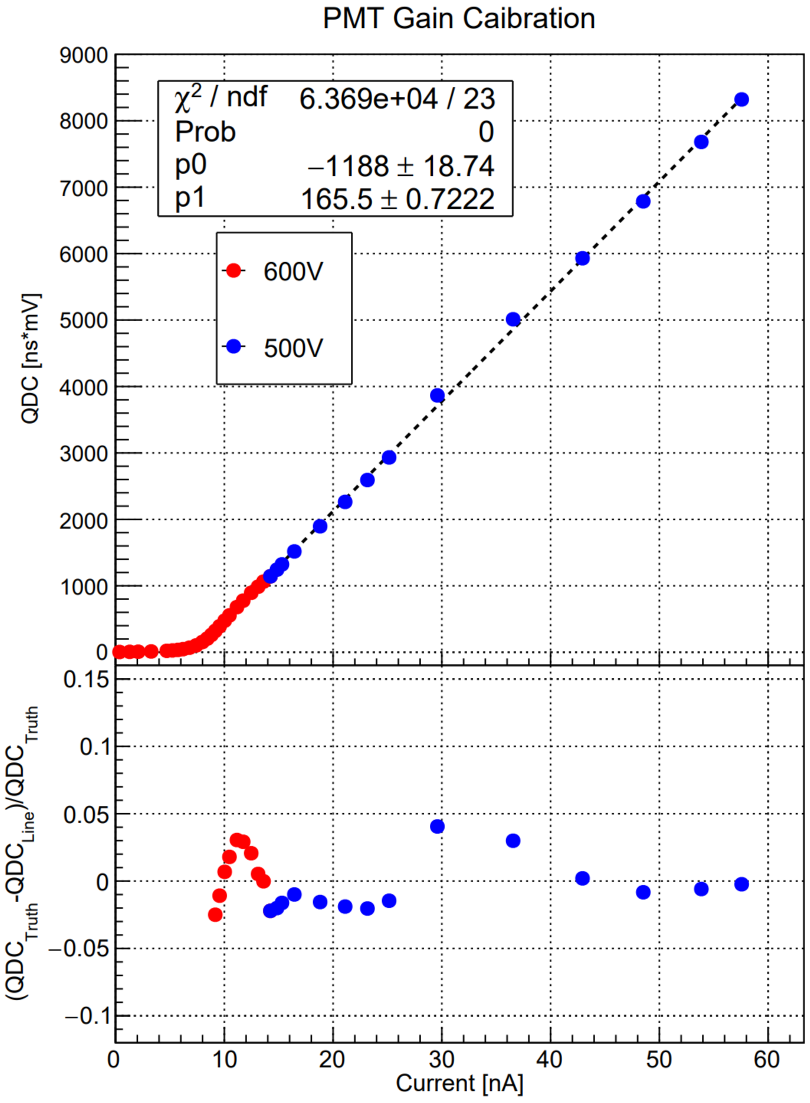






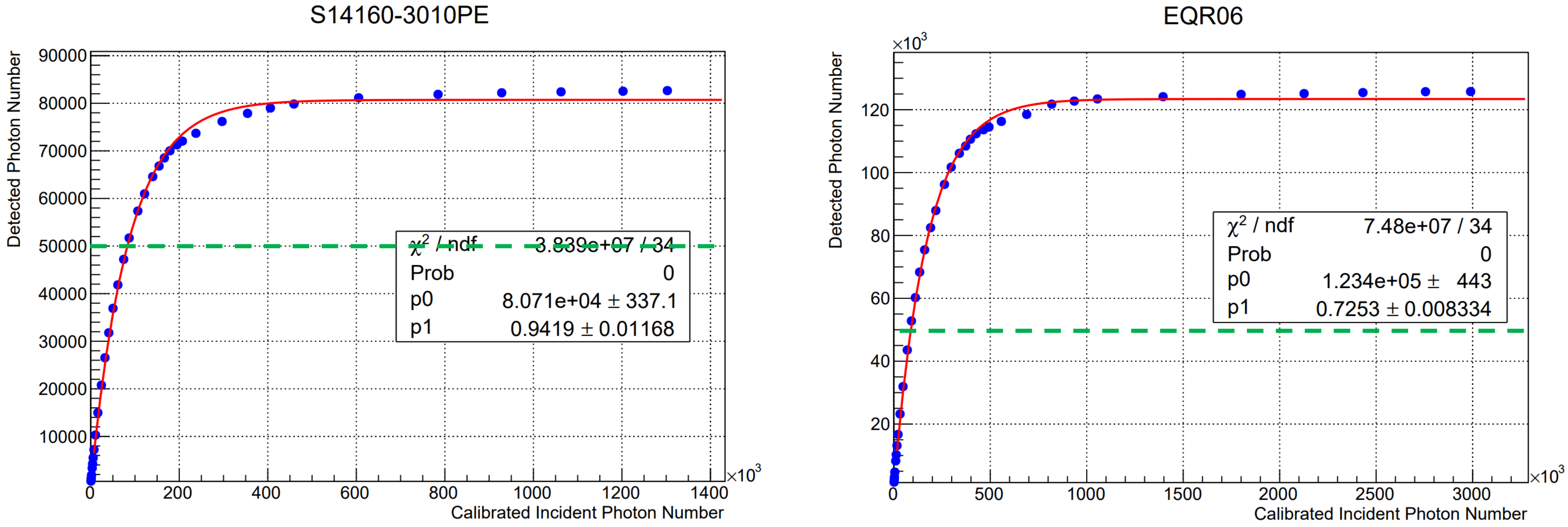
PMT Gain Correction





- The slopes represent gain at different voltages. Make the slope of 500V line the same as the 600V line. And different lines are connected end to end.

Response of S14160-3010PS and EQR06



- S14160-3010PE, $3 \times 3mm^2$ sensor size, 89984 pixels
- EQR06, $3 \times 3mm^2$ sensor size, 244720 pixels
- Fitting function: $p_0 * \left(1 - e^{\frac{-p_1 * x}{p_0}}\right)$

Summary & Next

- Summary:
  - Develop a method to measure the dynamic range of SiPM with large pixel number
  - Some factors that may deviate the results of the experiment from expectations:
    - Current tolerance of SiPM electronics
    - Temperature
    - Stability of devices over time
    - Laser intensity limit
    - Change bias voltage of PMT
- Next
  - Multi-dynodes-readout PMT, not to change bias voltage
  - SiPM electronics optimization
  - Use LED to simulate the signal generated in crystal