中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

上海交通大学
SHANGHAI JIAO TONG UNIVERSITY

李政道研究所
Tsung-Dao Lee Institute

大动态范围SiPM的响应刻度

赵芷钰 (TDLI/SJTU)

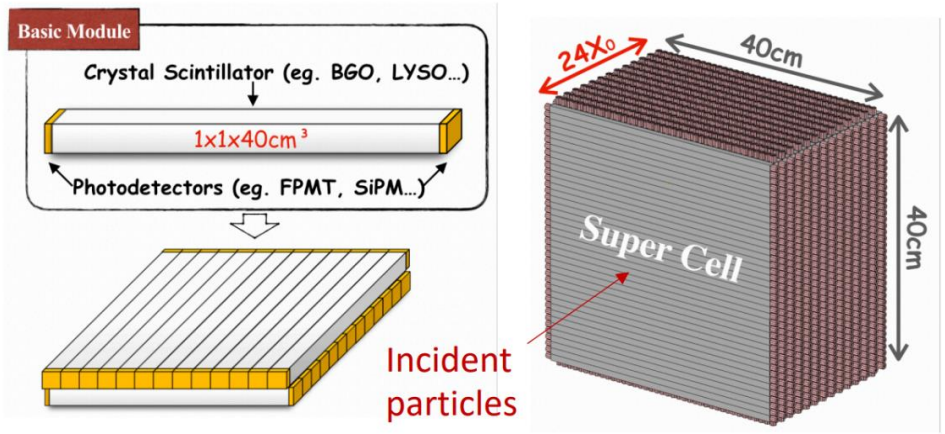
CEPC Calorimeter Working Group

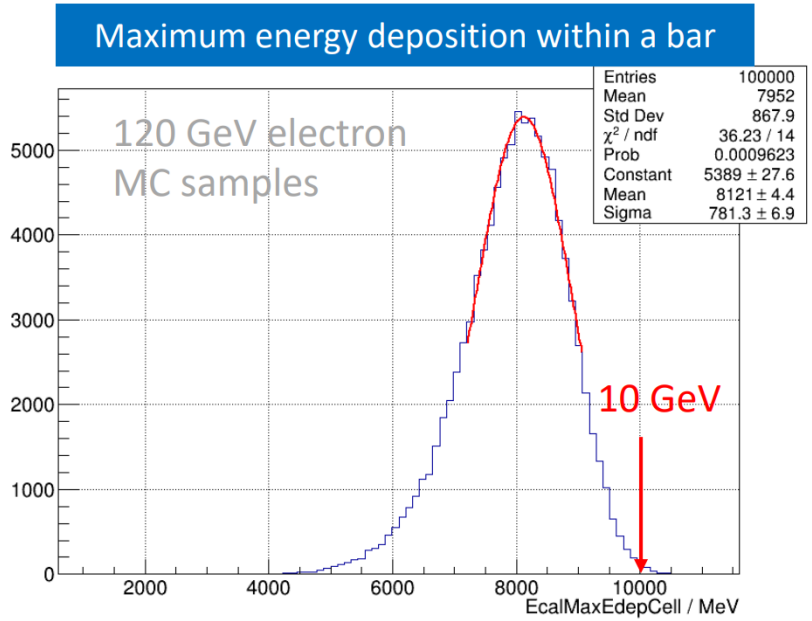
第二十一届全国核电子学与核探测技术学术年会

2023.8.10

Motivation

未来高能对撞机上的高粒度晶体电磁量能器研发进展-NED2023





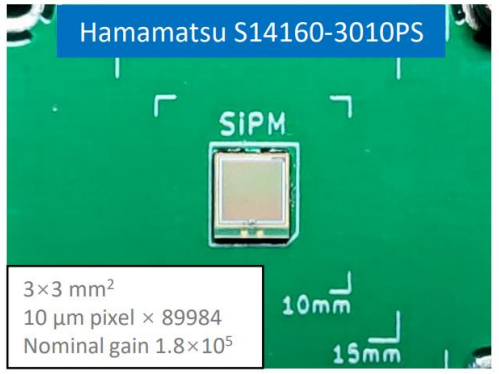
- Highly granular crystal electromagnetic calorimeter for CEPC:
  - EM energy resolution: ~3%/$\sqrt{E}$ $\oplus$ ~1%
  - Fine segmentation: PFA capability for jets (3~4% resolution)
- Dynamic range requirement:
  - Maximum energy deposition (from Bhabha electrons): ~10GeV → ~50000 pe(1 side)
- To cover the range up to 50000 photons, SiPMs with large dynamic range are needed and also need to calibrate the relationship between input and output.

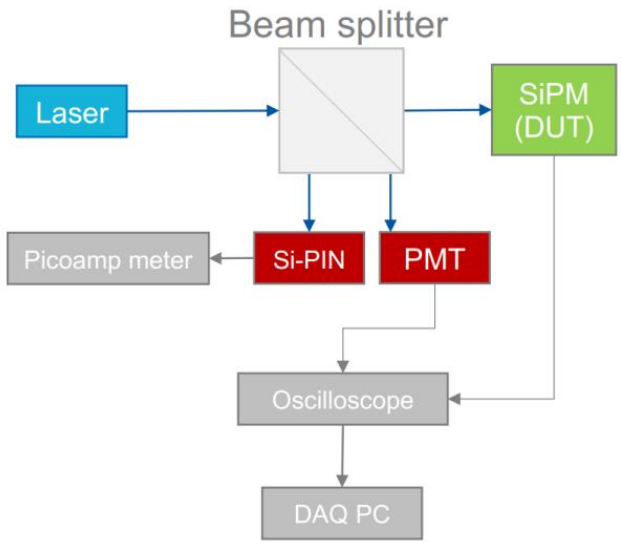
Outline

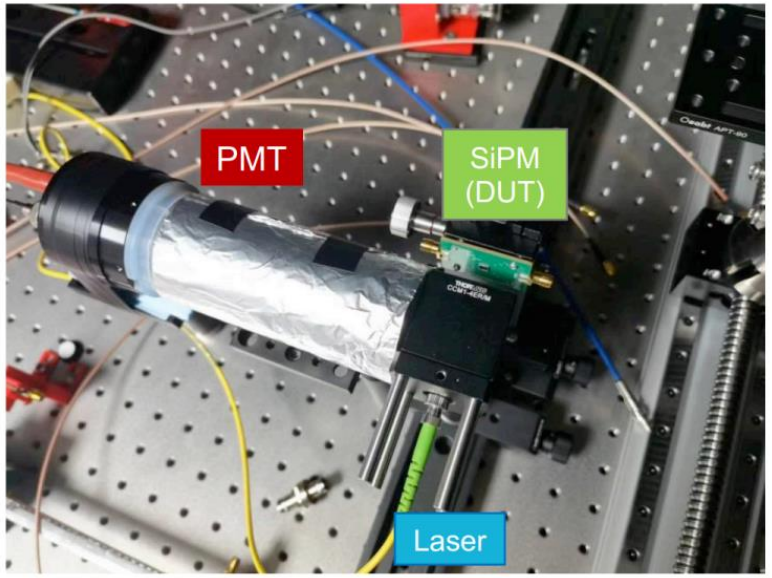
- Measurement
  - Setup
  - PMT linear region selection, gain calibration, and PE number calibration by Si-PIN
  - Response curve of SiPMs
- Simulation
  - A model for simulating the number of photons output by SiPM at different incident light intensities, including SiPM pixel density, PDE, crosstalk and recovery effect
- Summary

Setup

- The linearity region of the PMT can be adjusted by changing its bias voltage so that it could remain linear throughout the whole response interval of SiPM
  - Pico-second laser: ~40ps pulse width, 405nm wavelength
  - Beam splitter: divide the light between SiPM and PMT
  - SiPM
    - HAMAMATSU S14160-3010PS, $10\mu m$ pixel, $3 \times 3mm^2$, 89984 pixels
    - NDL EQR06 11-3030D-S, $6\mu m$ pixel, $3 \times 3mm^2$, 244720 pixels
  - PMT(HAMAMATSU R7725), Si-PIN(Thorlab): scaler







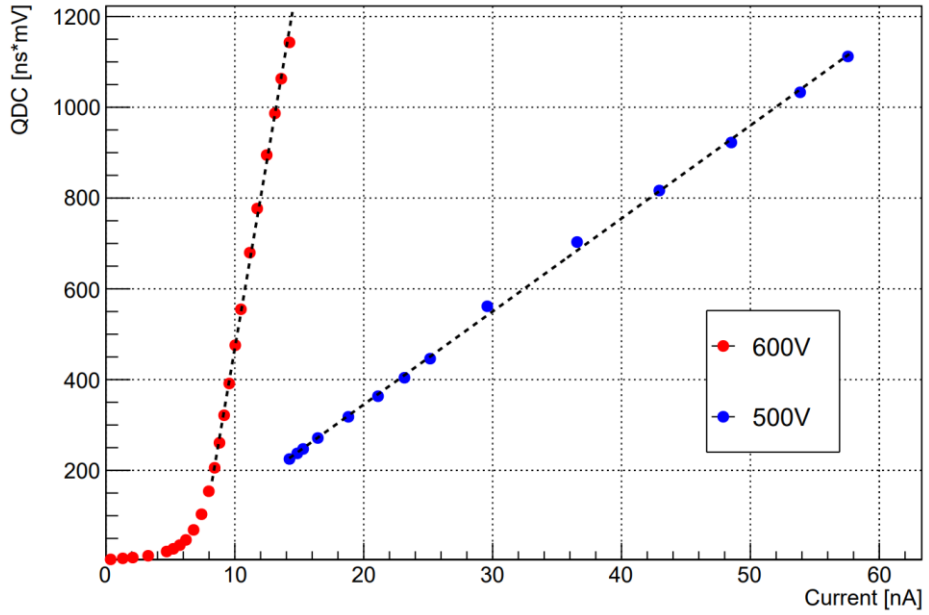
PMT Calibration

① Linear region selection: determine the linear response region for PMT at 600/500V bias voltage

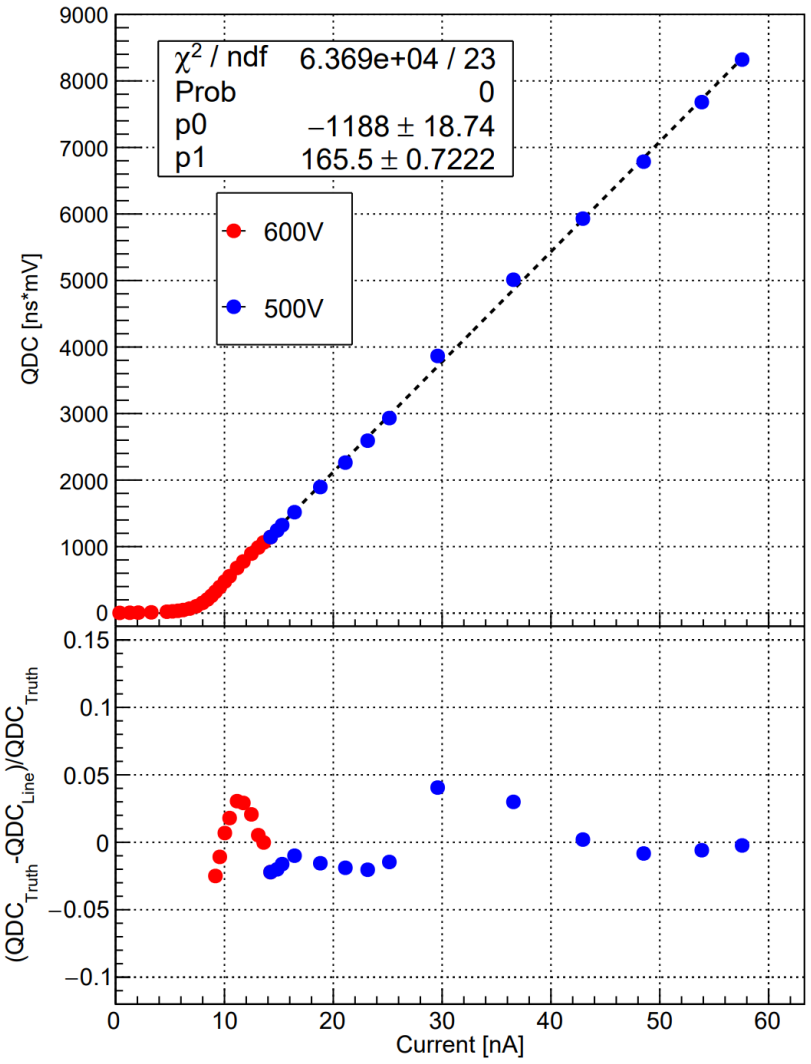
② Gain calibration: connect two linear regions and make their gains in equal

③ PE number calibration: QDC → NPE, SiPM calibrates PMT in weak light intensity region

Linear region selection



Gain Calibration

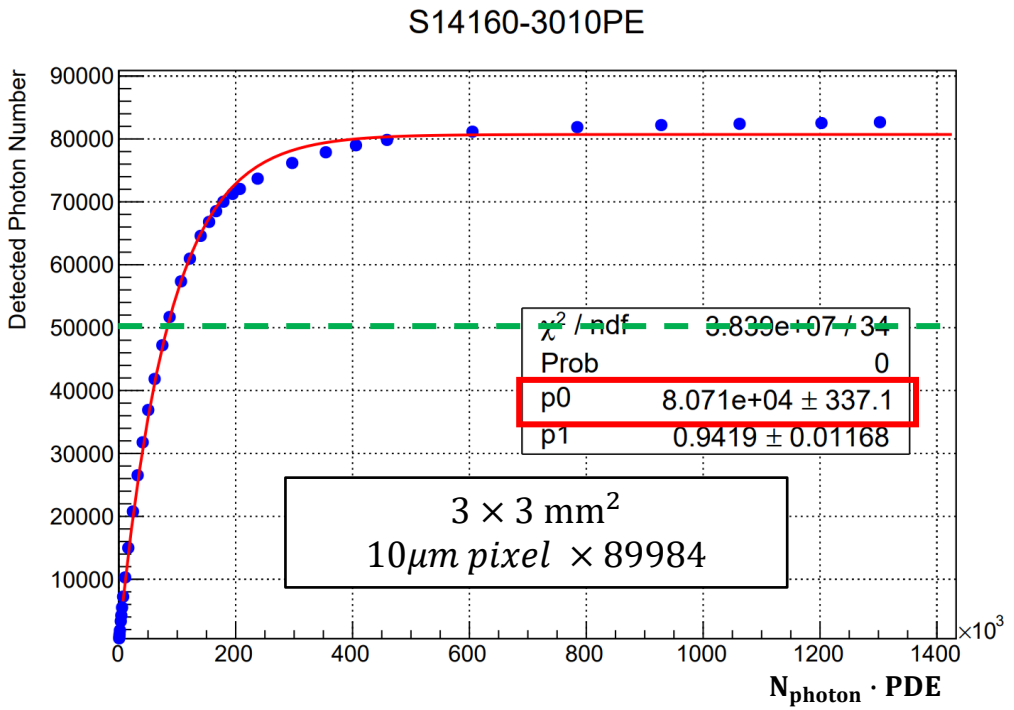


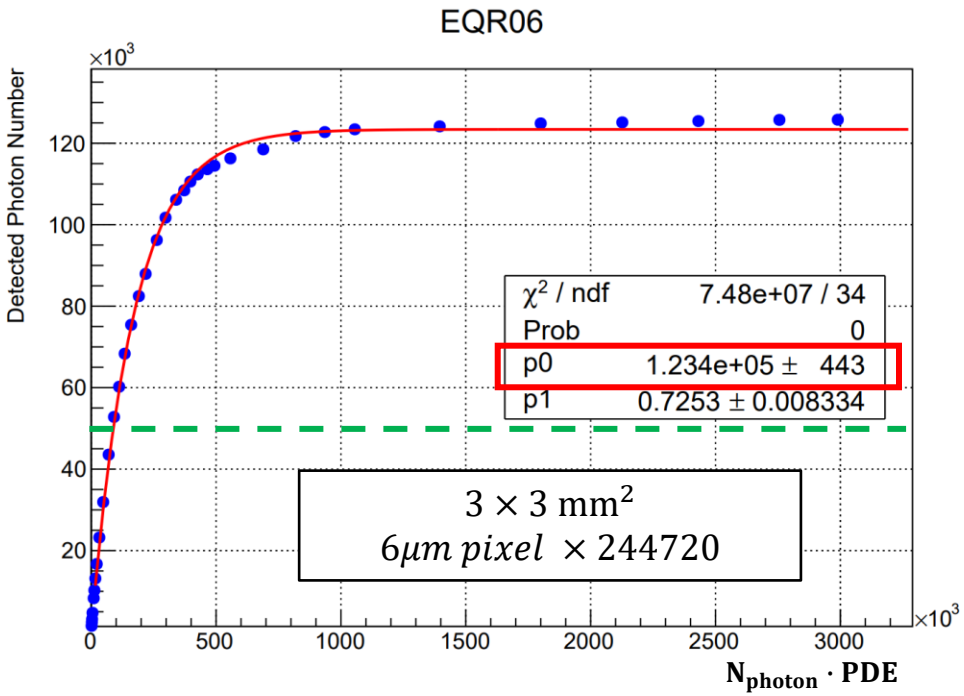
Response of S14160-3010PS and EQR06

- SiPM
  - HAMAMATSU S14160-3010PS, $10\mu m$ pixel, $3 \times 3mm^2$, 89984 pixels
  - NDL EQR06 11-3030D-S, $6\mu m$ pixel, $3 \times 3mm^2$, 244720 pixels
- Picosecond laser as source, no recovery effect
- Saturation value of 3010PS is close to its pixels number. But the result of EQR06 are quite different.
  - Limit by laser power? Spot non-uniformity?

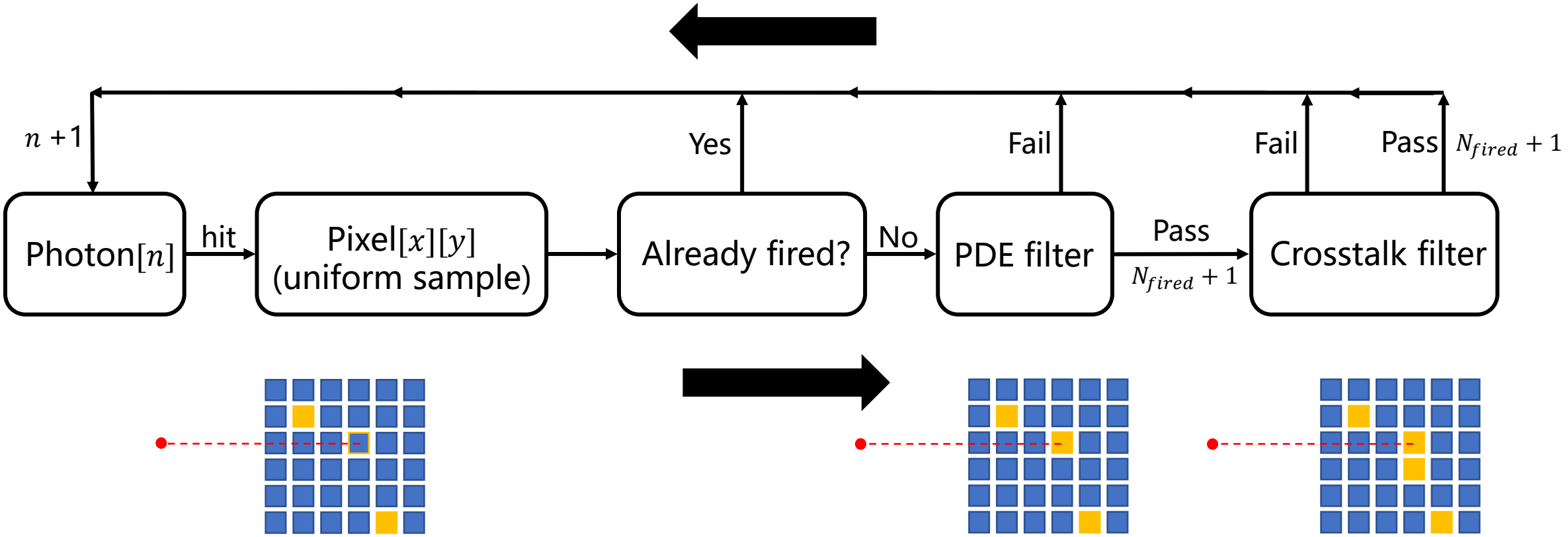
$$p_0 * \left(1 - e^{\frac{-p_1 * x}{p_0}}\right)$$

- p_0 : effective pixels number
- $p_1 \cdot x$: $N_{photon} \cdot PDE$





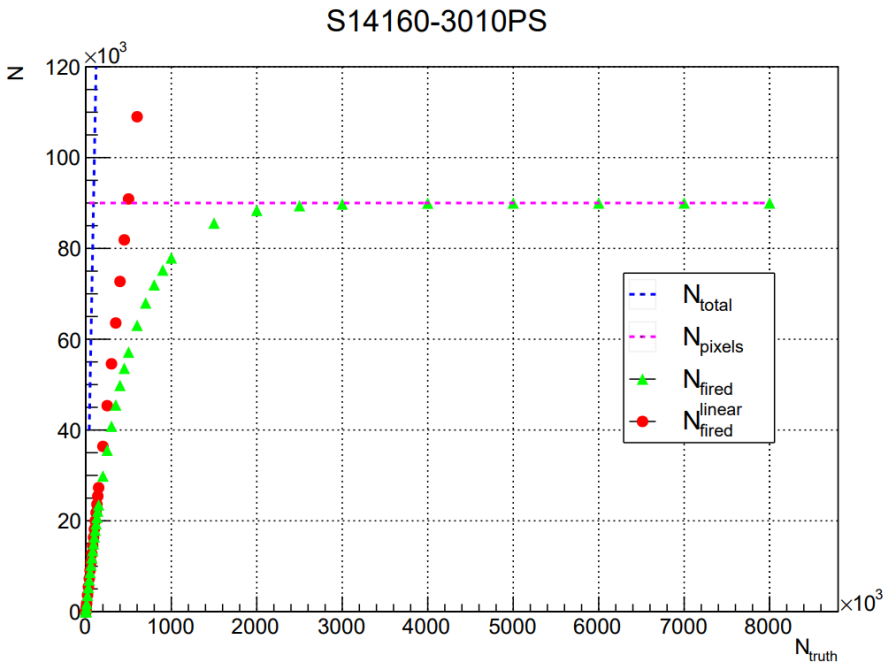
Simulation Workflow

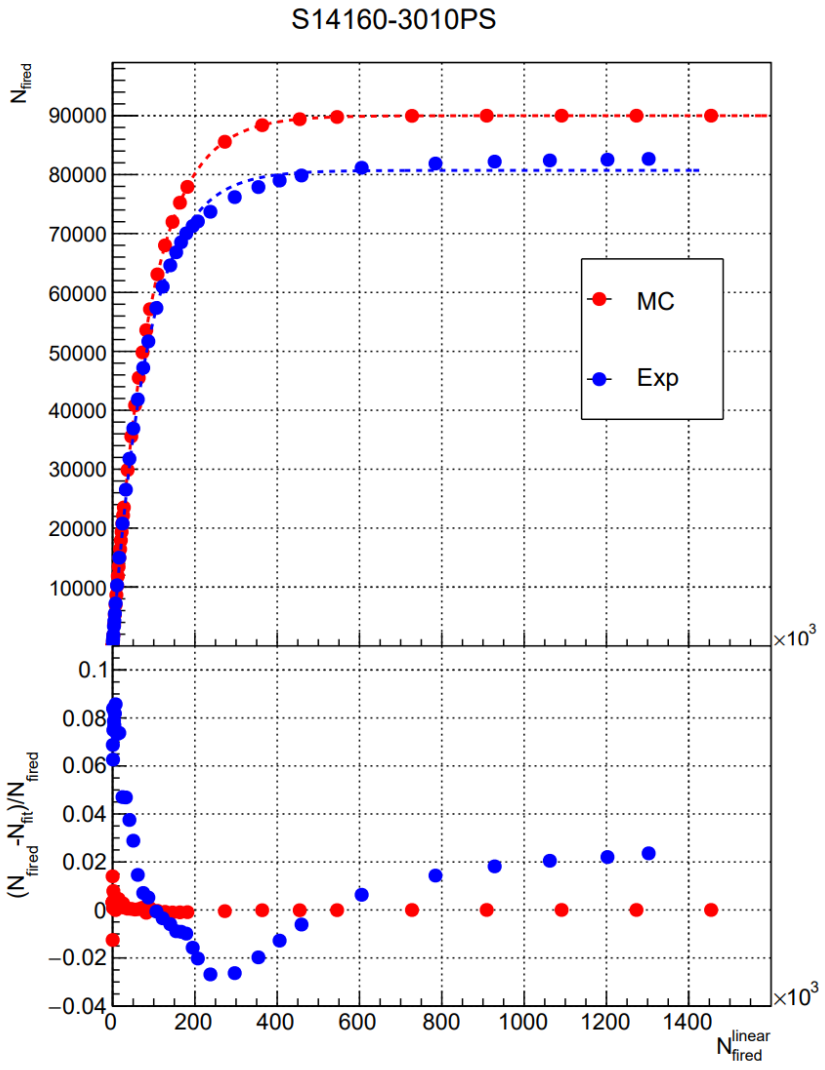


- PDE filter: the random number is smaller than PDE
- Crosstalk filter: random number smaller than crosstalk probability && at least one adjacent pixel is not in fired

MC of S14160-3010PS – w/o Recovery

- SiPM: S14160-3010PS, $3 \times 3mm^2$ sensor size, 89984 pixels, PDE=18%, Crosstalk=1%
- N_{total}: incident photon number
- N_{pixel}: pixel number
- N_{fired}: number of fired pixels (w/ saturation)
- N_{fired}^{linear}: number of fired pixels (w/o saturation)





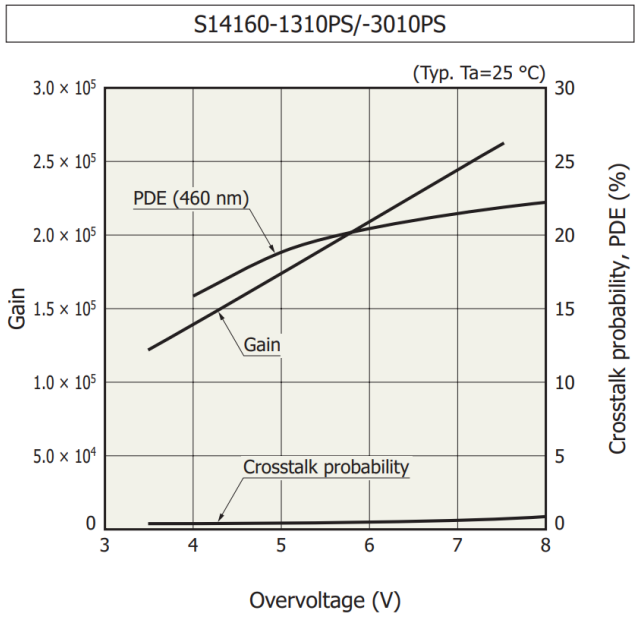
Microcell Electronical Model

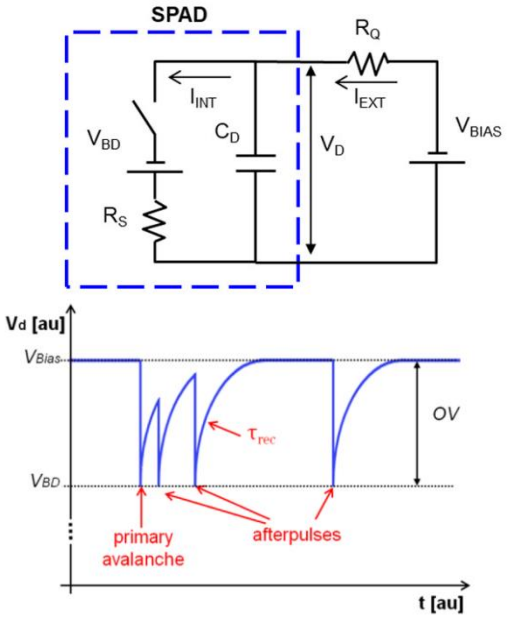
- PDE and gain will decrease if the pixel is not recovered completely.
- SiPM pixel response function:

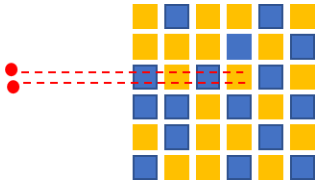
$$A(t) = (1 - e^{-\frac{t}{\tau_1}}) \cdot e^{-\frac{t}{\tau_2}}$$

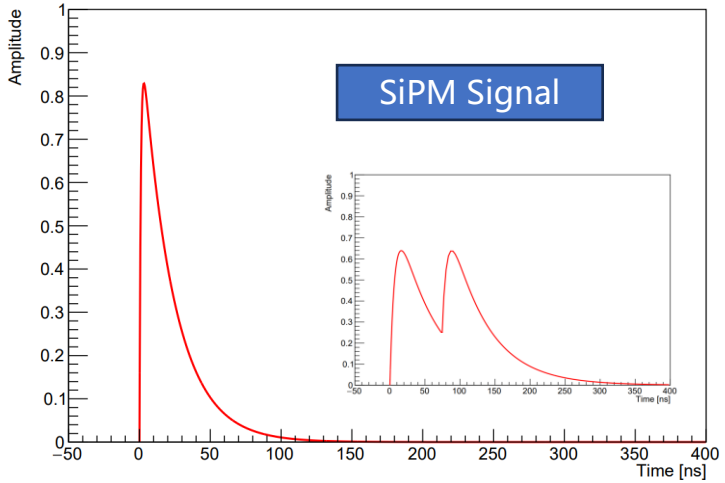
  - τ_1: discharge time constant of junction capacitance (C_D), ~1ns for S14160-3010PS
  - τ_2: recharge time constant of junction capacitance (C_D), ~22ns for S14160-3010PS
- PDE function:

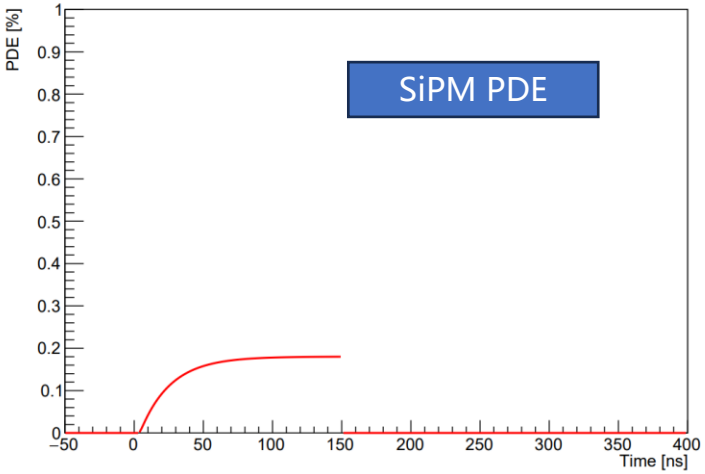
$$PDE = \begin{cases} 0, \ t_0 \sim t_{max} \\ PDE_0 \cdot \dfrac{A_{max} - A(t)}{A_{max} - A_{end}}, \ t_{max} \sim t_{end} \end{cases}$$







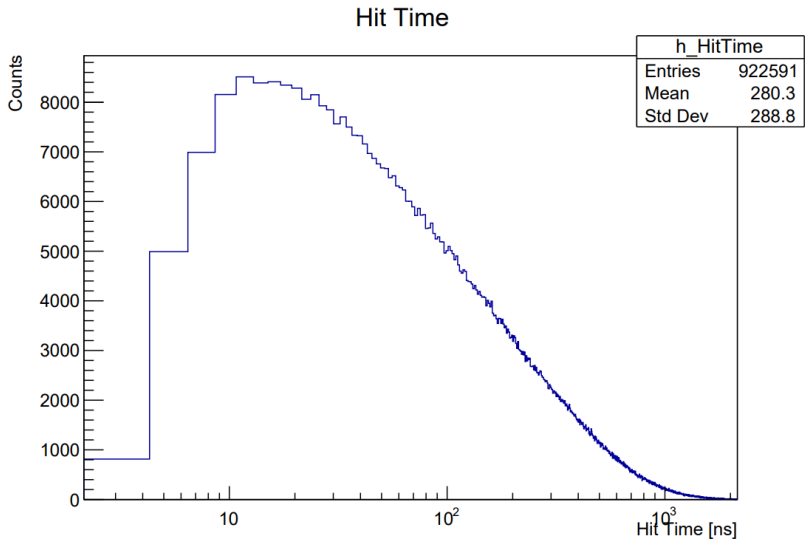


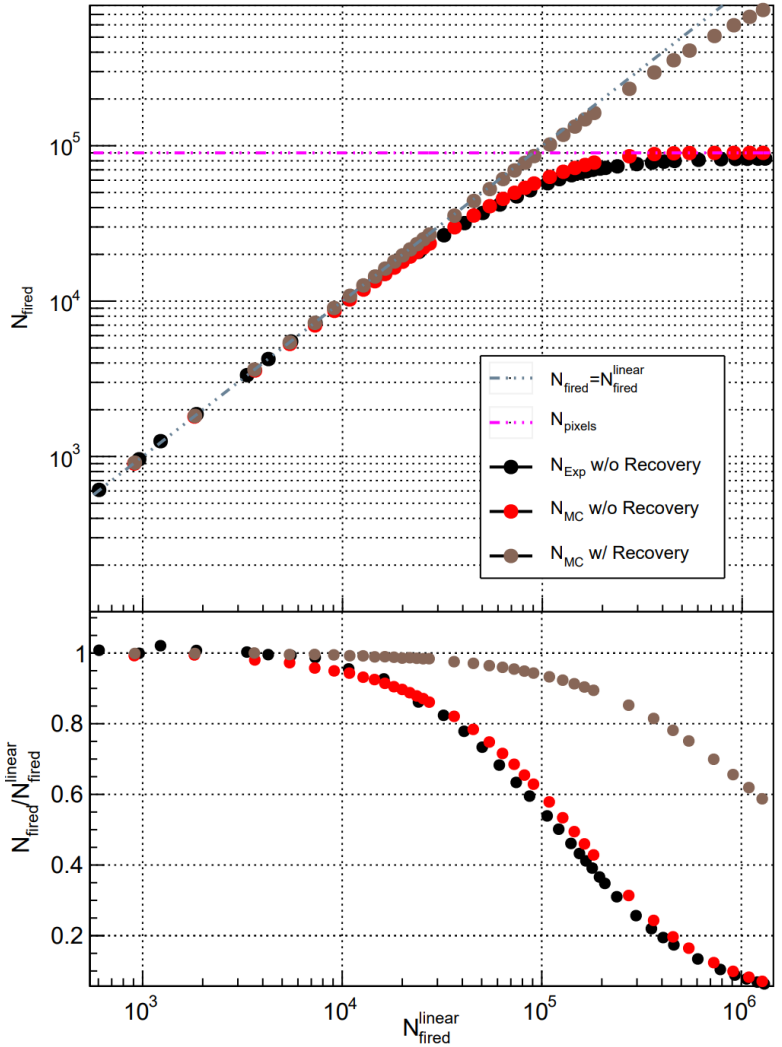


[1] https://doi.org/10.1016/j.nima.2014.04.045 [2] https://doi.org/10.1016/j.nima.2018.11.119

MC of S14160-3010PS – w/ Recovery

- MC with recovery effect:
  - Incident time of photon comes from Geant4 optical simulation
  - S14160-3010PS, $3 \times 3mm^2$ sensor size, 89984 pixels, PDE=18%, Crosstalk=1%
- If the incident photons have a wide time distribution, SiPM is less likely to saturate.





Summary

- Develop a method to measure the dynamic range of SiPM with large pixel number.
- Build a MC model for simulating the number of photons output by SiPM at different incident light intensities, including SiPM pixel density, PDE, crosstalk and recovery effect.
- Some factors that may deviate the results of the experiment from expectations:
  - Laser power
  - Spot non-uniformity

Measurement with Laser Diode

- Driver circuit: <5ns pulse width, kHz trigger rate(by AWG), 0~30V power supply
- Laser diode: 450nm peak wavelength, 1.6W
- SiPM: EQR06 11-3030D-S, 244720 pixels / EQR15 11-3030D-S, 40000 pixels
- The width of light pulse is lagger than SiPM recovery time