Study on SiPM saturation

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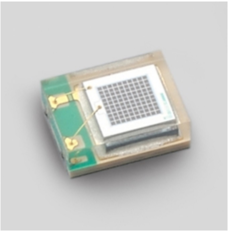
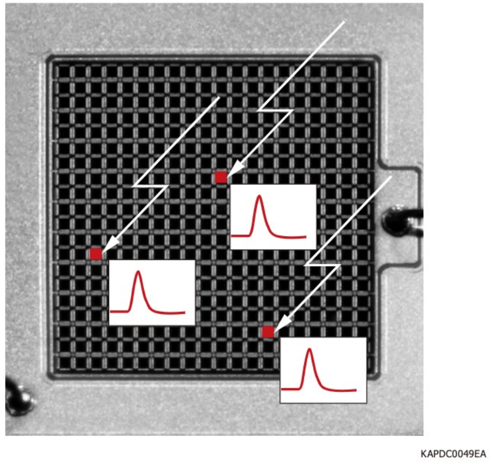
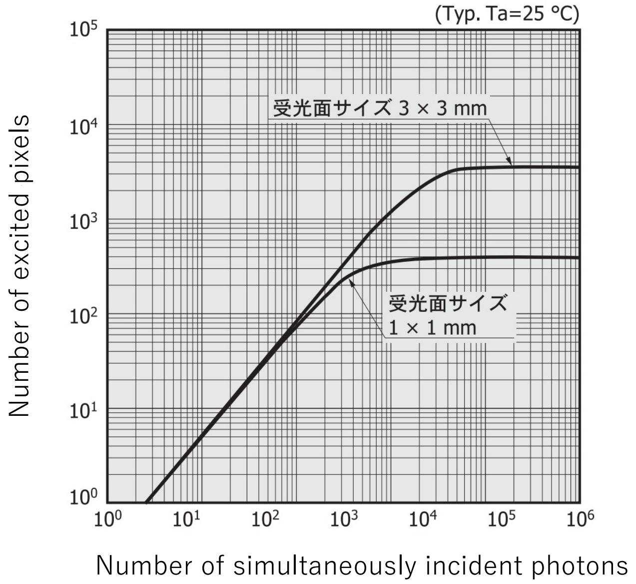
SiPM Saturation

- SiPM signal saturates for many photons due to limited number of pixels.
  - Pile-up hits in small and dense EM shower into ScECAL
  - Proper correction for SiPM saturation is crucial for ECAL
- This saturation curve is affected by
  - scintillation emission time constant (a few ns)
  - SiPM recovery time (a few ns)
- We propose a new method to <u>measure SiPM saturation curve with scintillation light excited by injecting UV light pulse</u>.

[Figure 1-2] Image of SiPM's photon counting





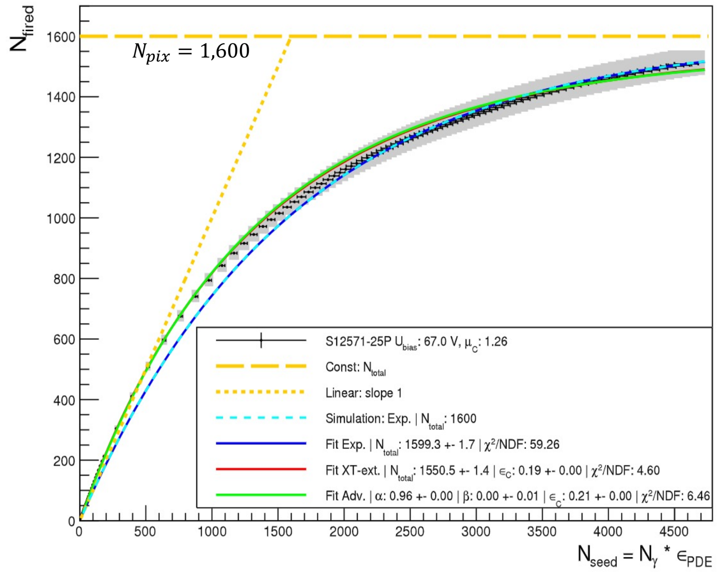


Hamamatsu Photonics K.K.
Opto-semiconductor Handbook

Experimental principle

N_{seed} : number of photoelectrons when assuming no saturation

$N_{detected}$: number of photons MPPC detected

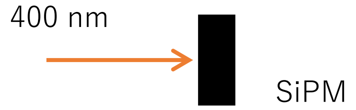


Q. Weitzel, et al. "Measurement of the response of Silicon Photomultipliers from single photon detection to saturation"

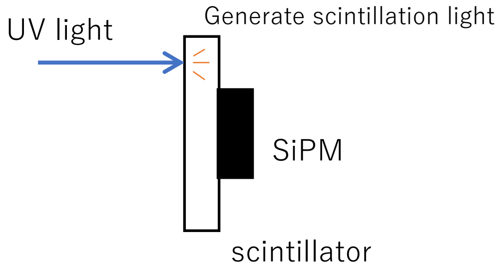
- Saturation is usually studied by injecting fast visible-light pulse (~400 nm) directly to SiPM.

- Here, the measurement can be done by injecting UV light to the scintillator-SiPM system
    - **Excite scintillator by UV light**
    - **Scintillation light intensity is controlled by the UV light intensity**
    - **Effect of scintillation emission time constant is included.**
    - **Measured saturation curve can be used directly for the saturation correction.**

Conventional method

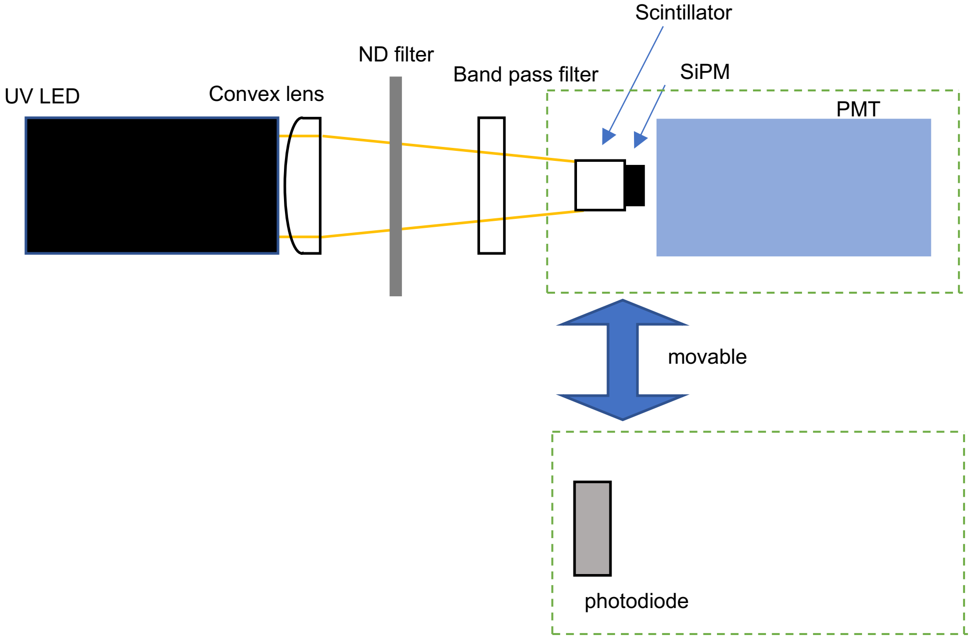


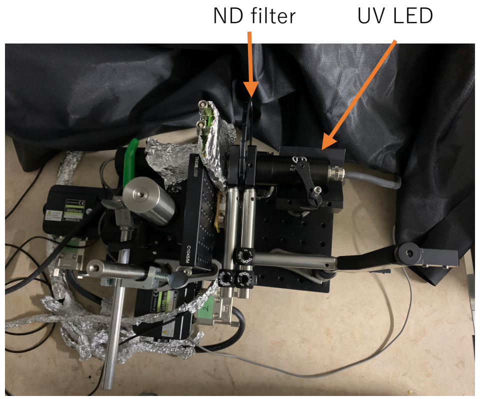
New method

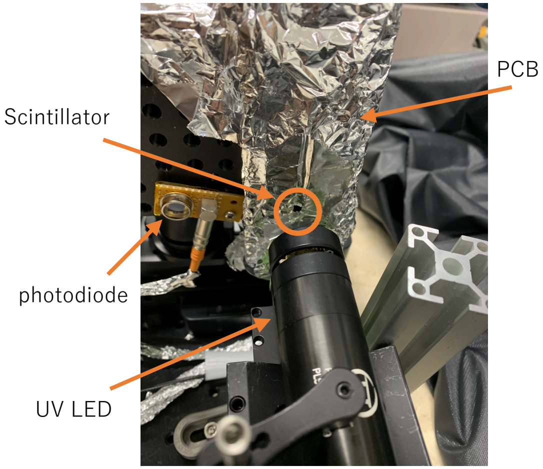


Saturation measurement -set up-

- UV light pulse irradiate scintillator and photodiode by using moving stage
  - Photodiode monitors the intensity of UV light
    - The intensity is controlled using ND filter
  - SiPM detects scintillation light to observe saturation
  - PMT also detects scintillation light
    - PMT has much wider range
    - To check the relation between the intensity of the UV light and the scintillation light
- SiPM : Hamamatsu MPPC S12571-025P
- Scintillator : EJ-200
- Light source : PicoQuant PLS series
  - Measured also with visible light pulse for comparison







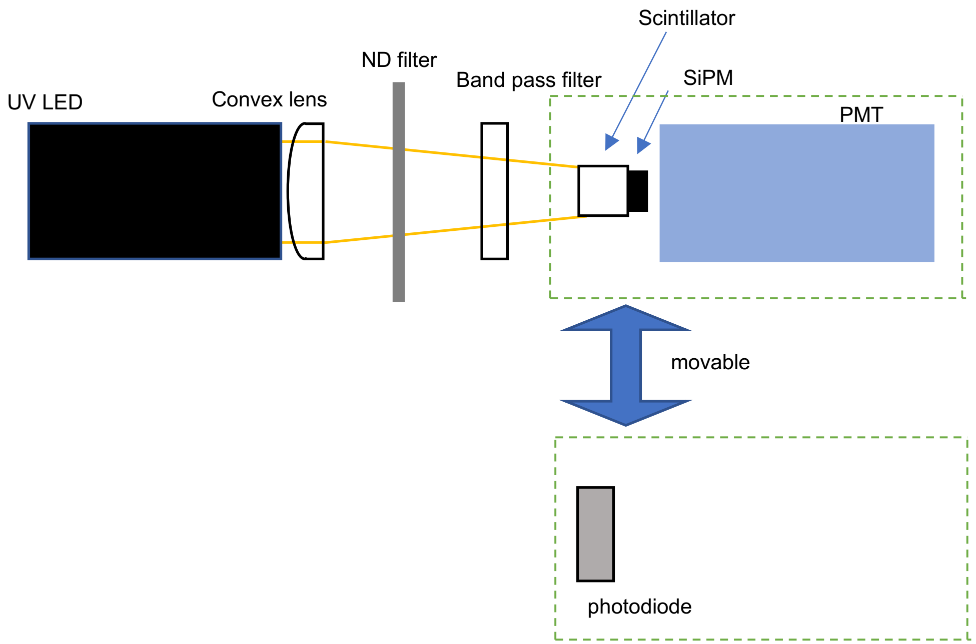
S12571-025P	
Effective area	1×1 mm^2
Pixel pitch	25 μm
Number of pixels	1,600

EJ-200	
Attenuation length	380 cm
Maximum wavelength emission	425 nm
rise time	0.9 ns
decay time	2.1 ns

	PLS 255	PLS 500
Wavelength [nm]	255 (±10)	485 (±10)
Pulse width (FWHM) [ps]	~400	~800

Saturation measurement -DAQ-

- Signal readout
  - SiPM signal is mainly measured in current at source meter.
    - To avoid the saturation of electronics
    - Also measured at digitizer at low UV intensity
      - To calibrate SiPM current and photoelectrons (p.e.)
  - Photodiode is measured in current at source meter
  - PMT is measured in photoelectrons at waveform digitizer

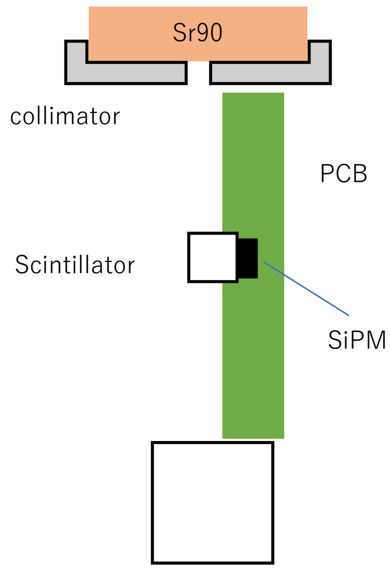


Detector	Signal Readout
SiPM	current
	photoelectron
Photodiode	current
PMT	Photoelectron

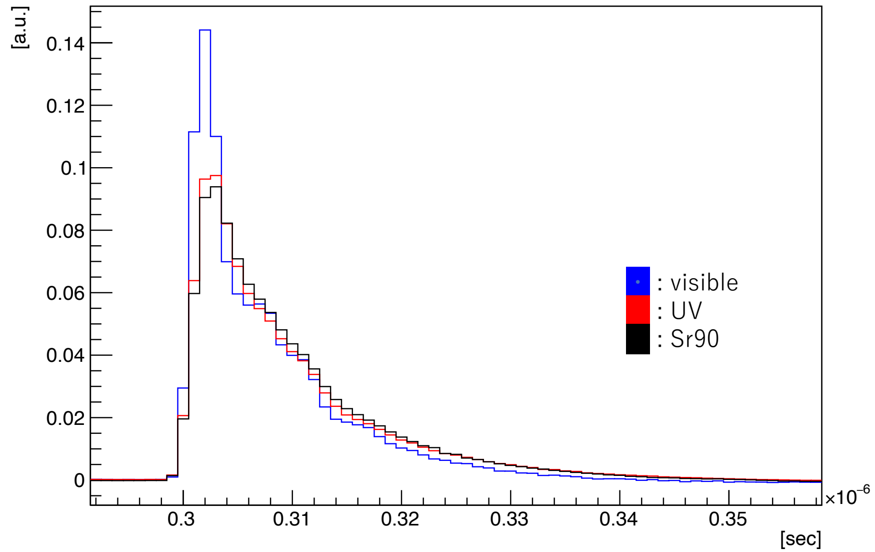
Excitation of scintillator

- Compared waveforms of SiPM signals of UV light, visible light, Sr90
  - Visible light : sharp peak
  - UV light, Sr90 : gentle peak

→ Using UV light, photons are injecting SiPM for a long time compared to visible light



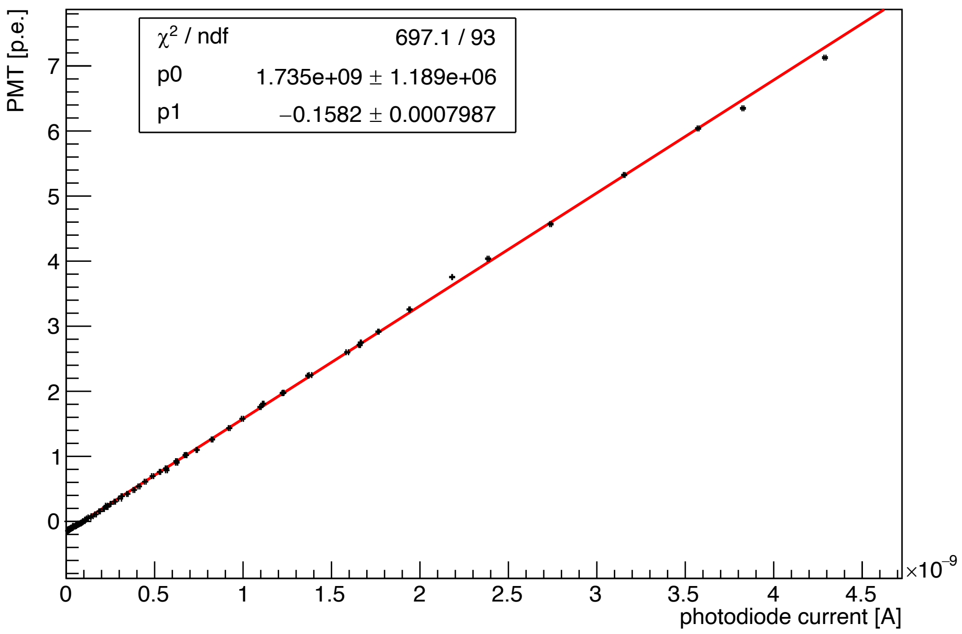
Trigger counter (5×5×5 mm^3 scintillator + SiPM)



Relation between UV and scintillation light

- PMT is placed behind the SiPM to calibrate the relation between the intensity of UV light and generated scintillation light

- Linear relation is observed in wide range
  - The number of incident scintillation photons can be estimated from the intensity of UV light



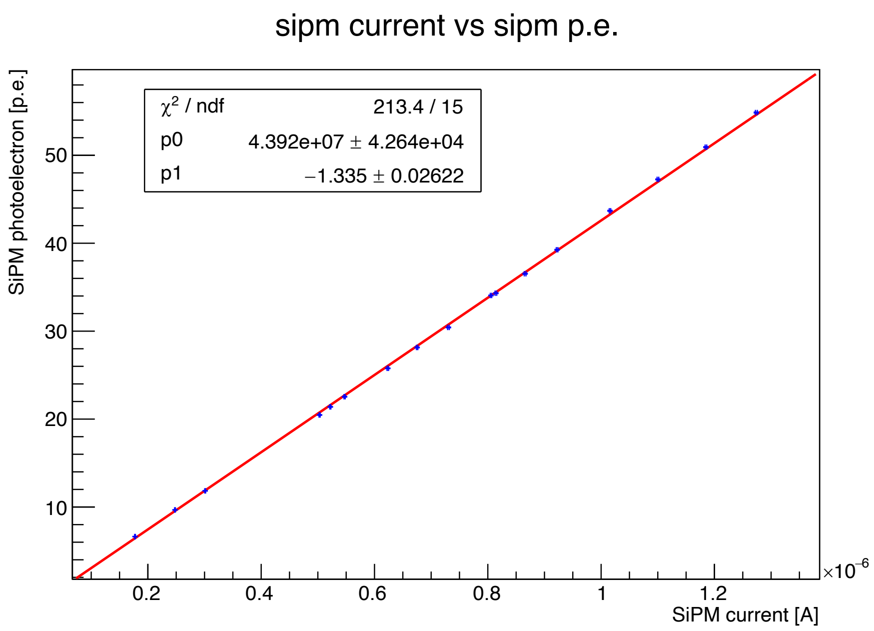
Analysis $N_{detected}$

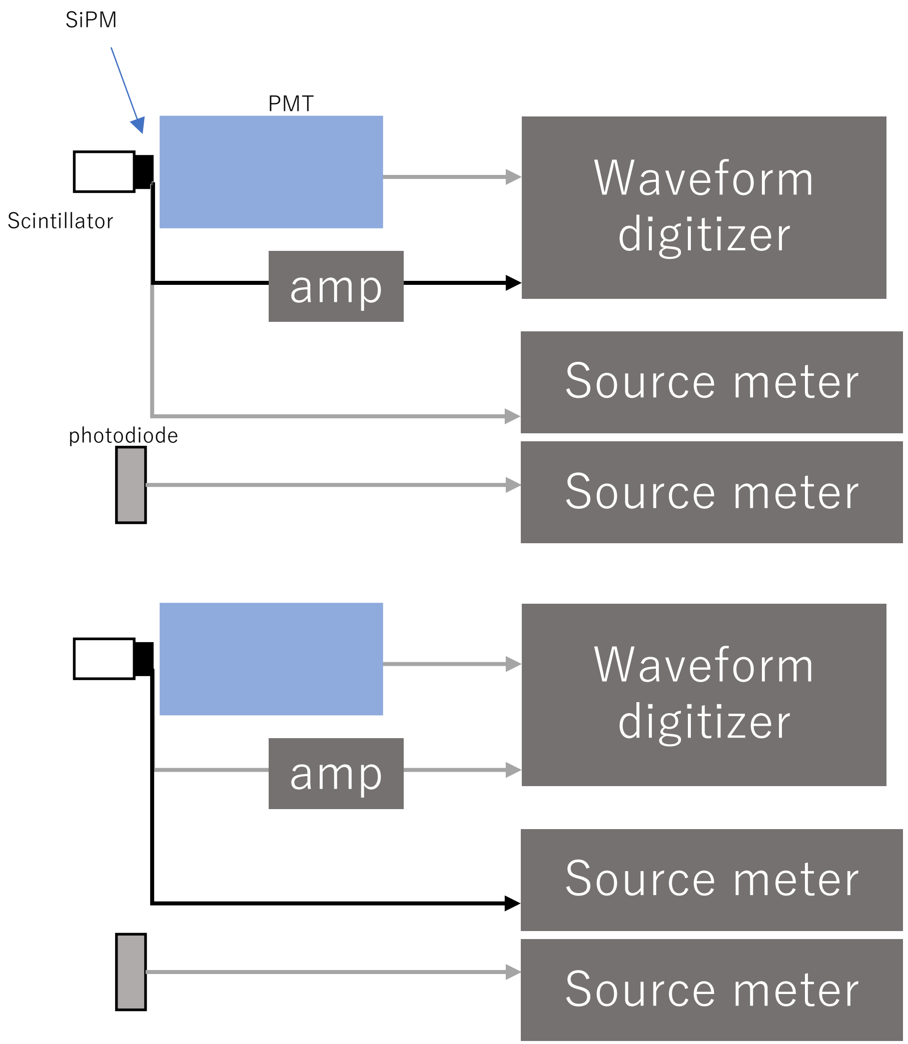
N_{seed} : number of photoelectrons when assuming no saturation

$N_{detected}$: number of photons MPPC detected

- SiPM signal is measured by two ways
  - Current at source meter
  - Photoelectron at digitizer

- $N_{detected}$ calibration
  - Convert SiPM current [mA] into photoelectrons [p.e.] using relation at low LED intensity.



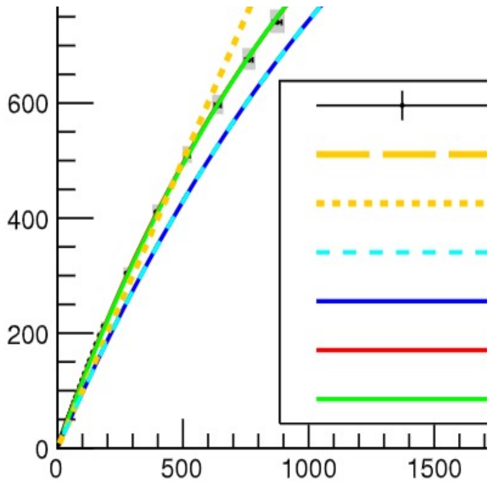


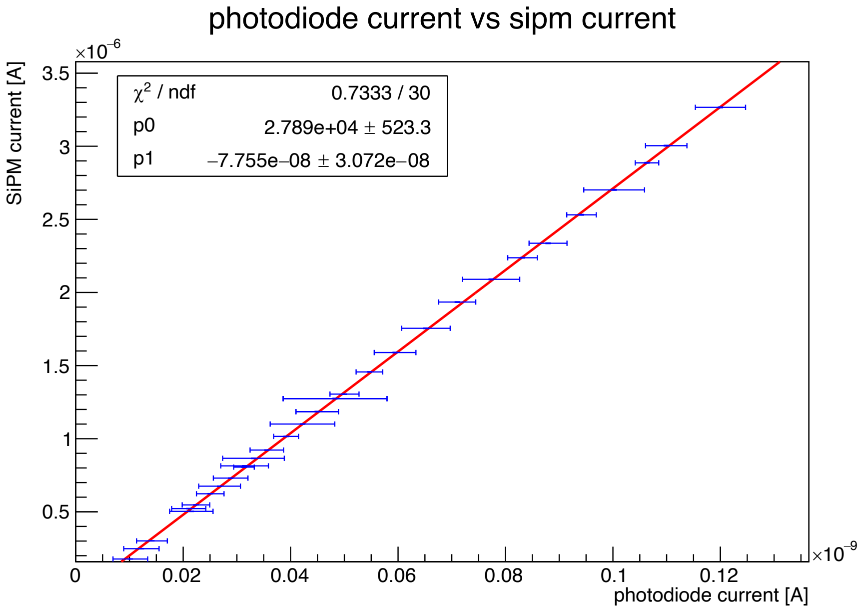
Analysis N_{seed}

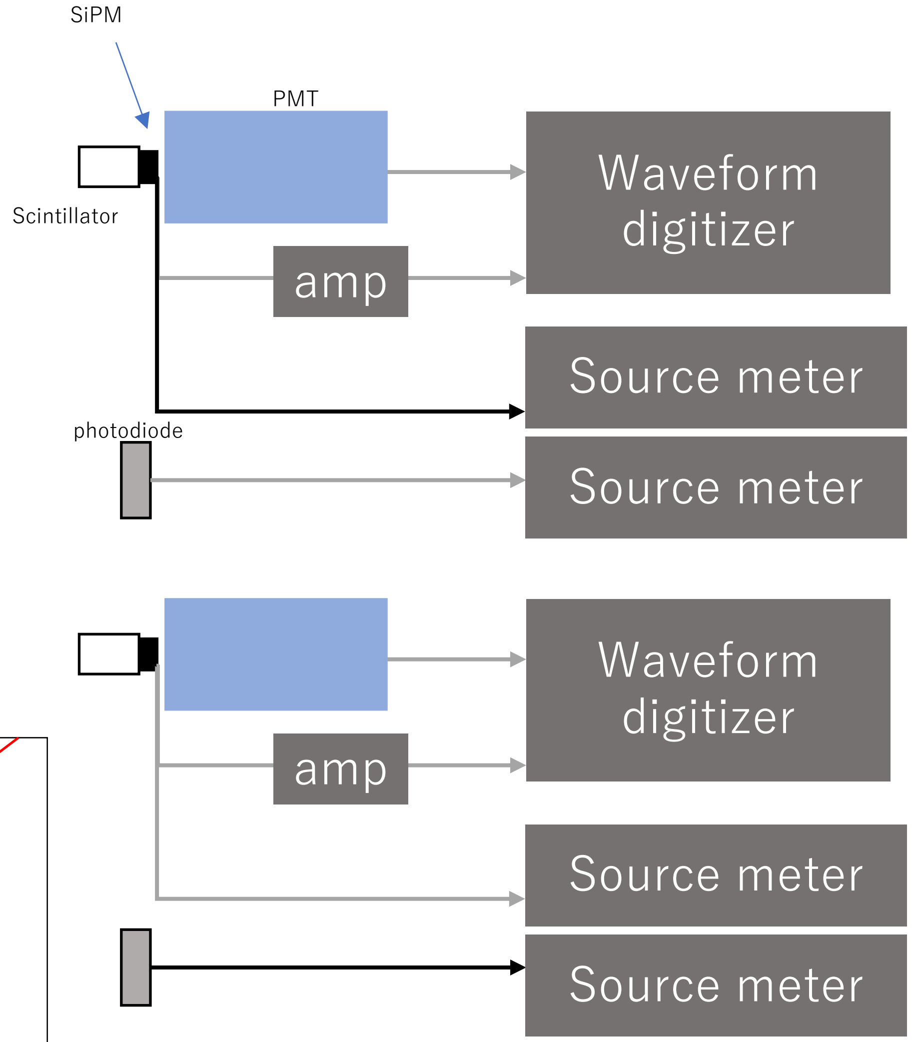
N_{seed} : number of photoelectrons when assuming no saturation

$N_{detected}$: number of photons MPPC detected

- Source meter measures SiPM and photodiode current
- Photodiode monitors the intensity of UV
  - To estimate N_{seed}
- N_{seed} calibration
  - Relation between photodiode current and SiPM output at low LED intensity.

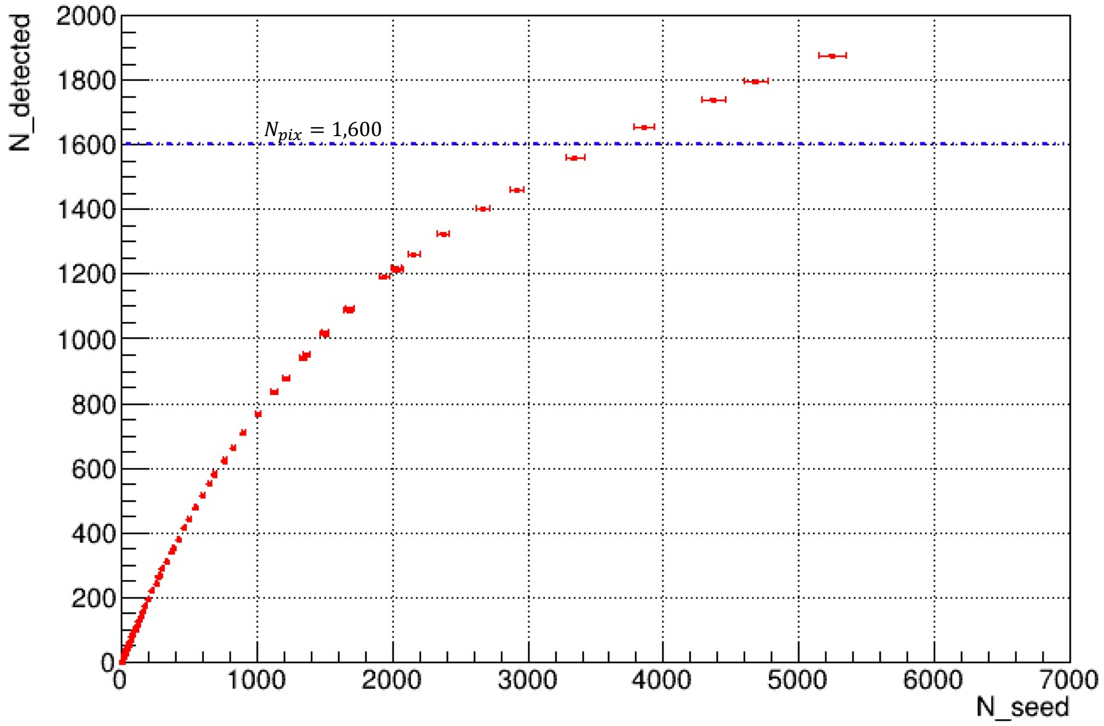






Saturation curve

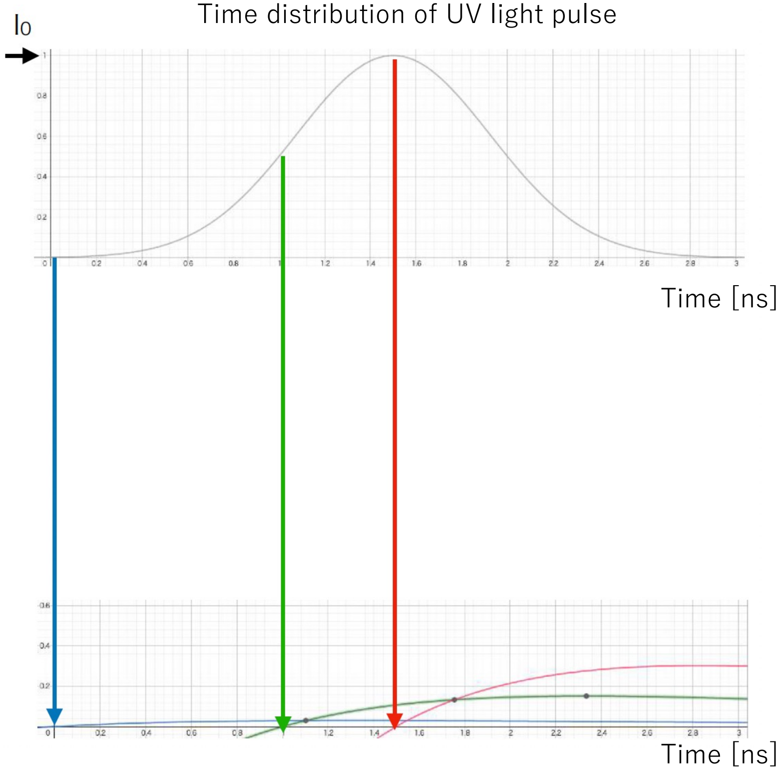
- Saturation curve is obtained after the $\mathrm{N_{detected}}$ and $\mathrm{N_{seed}}$ calibration
- Over saturation and a large recovery of SiPM is observed
  - Saturation is relieved for UV curve



Saturation model

- Developed new saturation model by calculation
  - Prepare time distribution of incident photon
    - For UV, convolution of UV light pulse and scintillation emission
  - Divide time by the step width and for each time i, calculate incident photons $N_{int}(i)$, detected photons $N_{det}(i)$ and $N_{seed}(i)$
  - Sum up $N_{det}(i)$ and $N_{seed}(i)$ for all time
  - Increase the intensity of light pulse and repeat the calculation

Time distribution of UV light pulse



Time distribution of generated scintillation light

- For each time i,
  - $N_{seed}(i) = \frac{N_{int}(i)}{N_{pix}} * \sum_j^i \left(N_j * PDE(i-j)\right)$
  - $N_{CT}(i) = N_{seed}(i) * (P_{CT} + P_{CT}^2 + \cdots)$
  - $N_{det}(i) = N_{seed}(i) + \frac{N_{CT}(i)}{N_{pix}} * \sum_j^i \left(N_j * PDE(i-j)\right)$
  - $N_{AP}(\mathrm{i}) = \sum_j^i \left(N_j * AP(i-j)\right)$
  - $N_{seed}(i) = N_{seed}(i) - N_{AP}(i)$

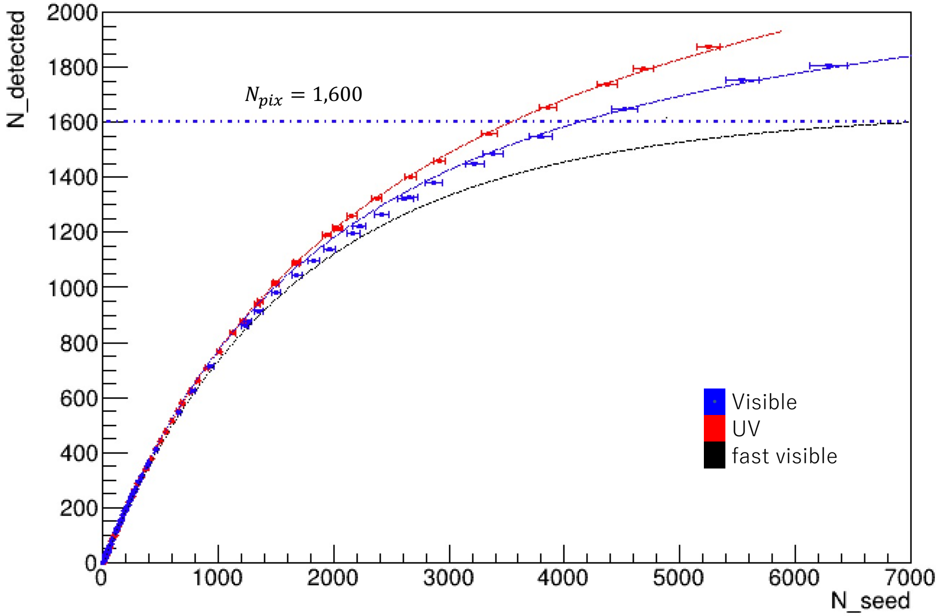
N_j : number of pixels the last photon enters at time j
$PDE(i-j)$: decrease of PDE caused by recovery time
N_{CT}: increased number of photon due to crosstalk
N_{AP}: decreased number of N_{seed} due to after-pulse
$AP(i-j)$: time distribution of after-pulse

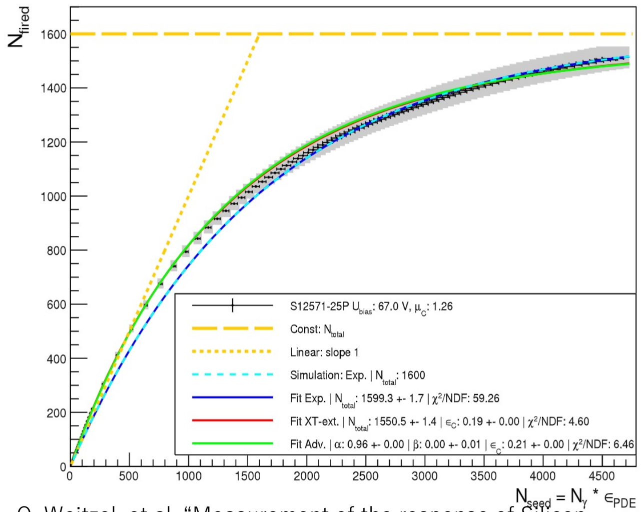
Comparison of measured and model curve

- Measured curve and model curve is compared.
  - Model curve well describes measured curve.

- Visible light had longer pulse (~2ns) than the conventional saturation measurement (~100ps)
  - Calculated conventional saturation curve (black curve)
    - consistent with the conventional curve

- Curve with UV light observed over saturation and large pixel recovery comparing to conventional measurement
  - Due to scintillation emission time constant





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Summary and prospect

- We propose a new method to measure SiPM saturation with scintillation light
  - Scintillation light is excited by injecting UV light pulse
- Found a linear relation between the scintillation light and the intensity of UV light
- Measured saturation curve
  - A large recovery of the SiPM saturation is observed
- Developed new saturation model including the effect of crosstalk, after-pulse, and pixel recovery
  - Confirmed the new model well describes the measured saturation curve.

Back ups