Study on SiPM saturation using UV light

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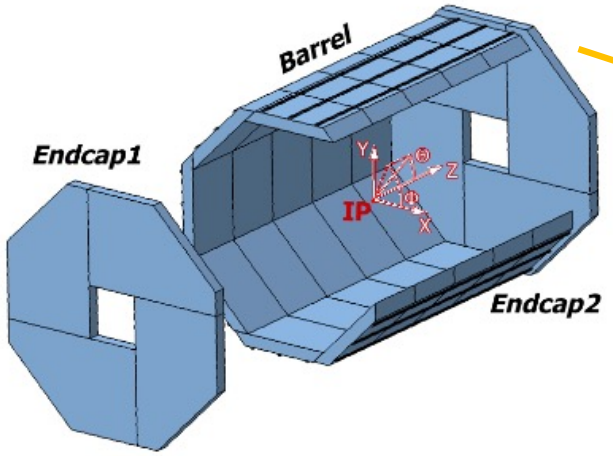
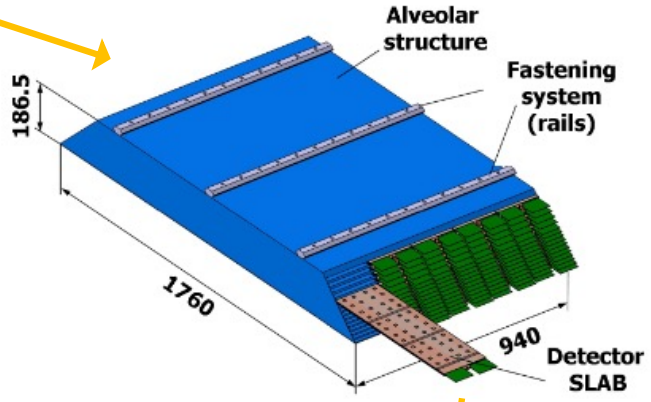
Scintillator ECAL

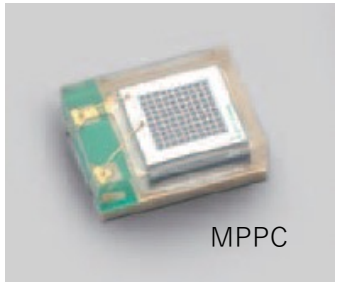
- Technology option of ILD ECAL
- Sampling calorimeter
  - Detection layer : scintillator
  - Absorption layer : tungsten

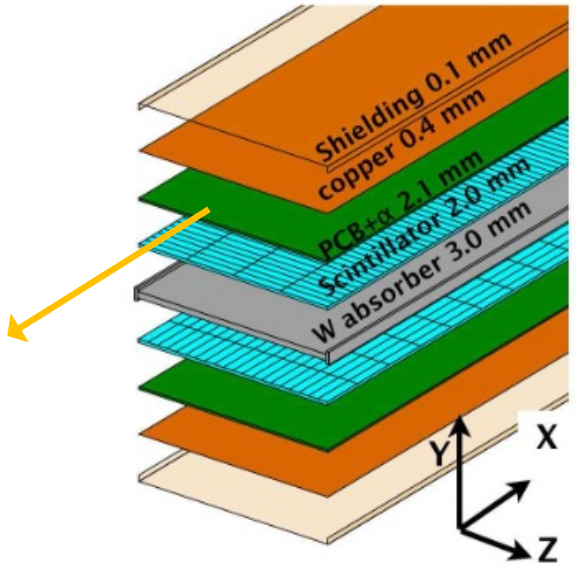
- Detection layer
  - 45×5×2 $\mathbf{mm^3}$ scintillator strip
    - Virtual segmentation : 5mm × 5mm with strips in x-y configuration
  - SiPM readout
    - MPPC by Hamamatsu photonics
    - Excellent photon-counting capability





Scintillator strip

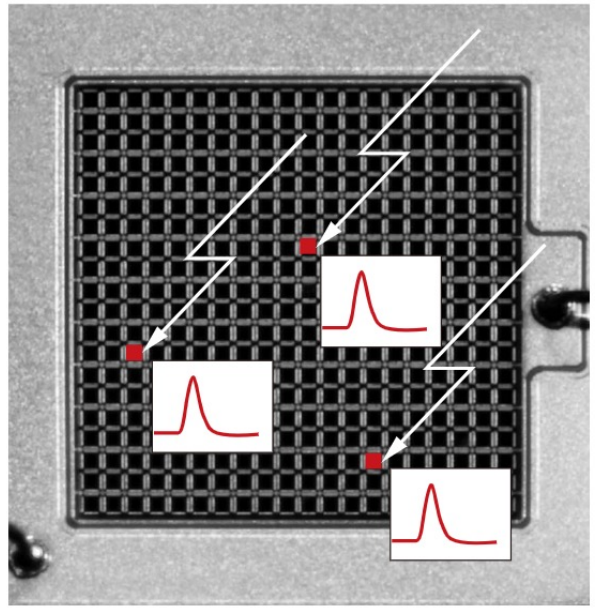


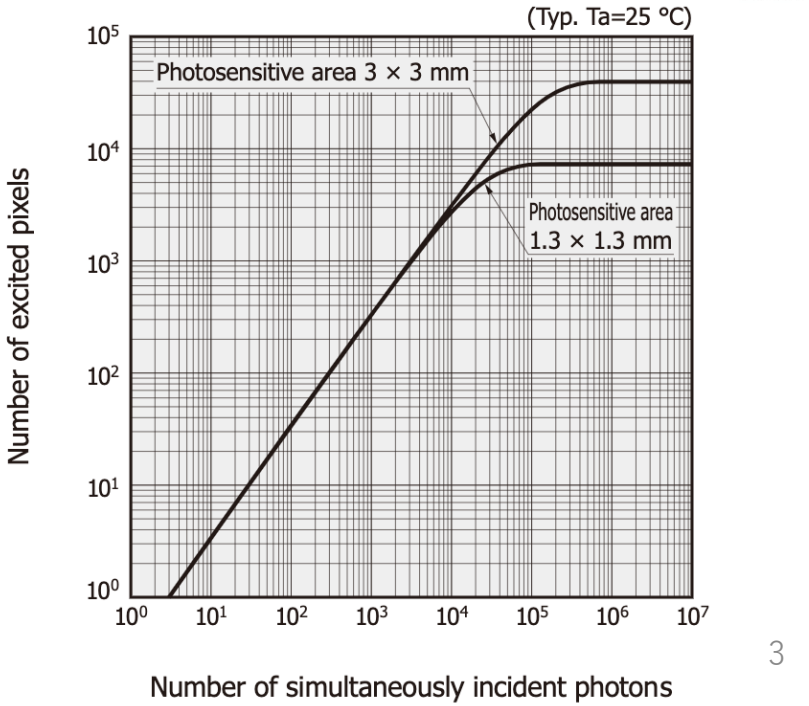


SiPM Saturation

- SiPM signal saturates for many photons due to limited number of pixels.
  - Proper correction for SiPM saturation is crucial
- The saturation of SiPM can be an issue for scintillator detector with SiPM readout
- This saturation curve is affected by
  - scintillation emission time constant (a few ns)
  - SiPM recovery time (a few ns)
- We <u>developed a new method to measure SiPM saturation</u>.

Image of SiPM's photon counting





Hamamatsu Photonics K.K.
Opto-semiconductor Handbook

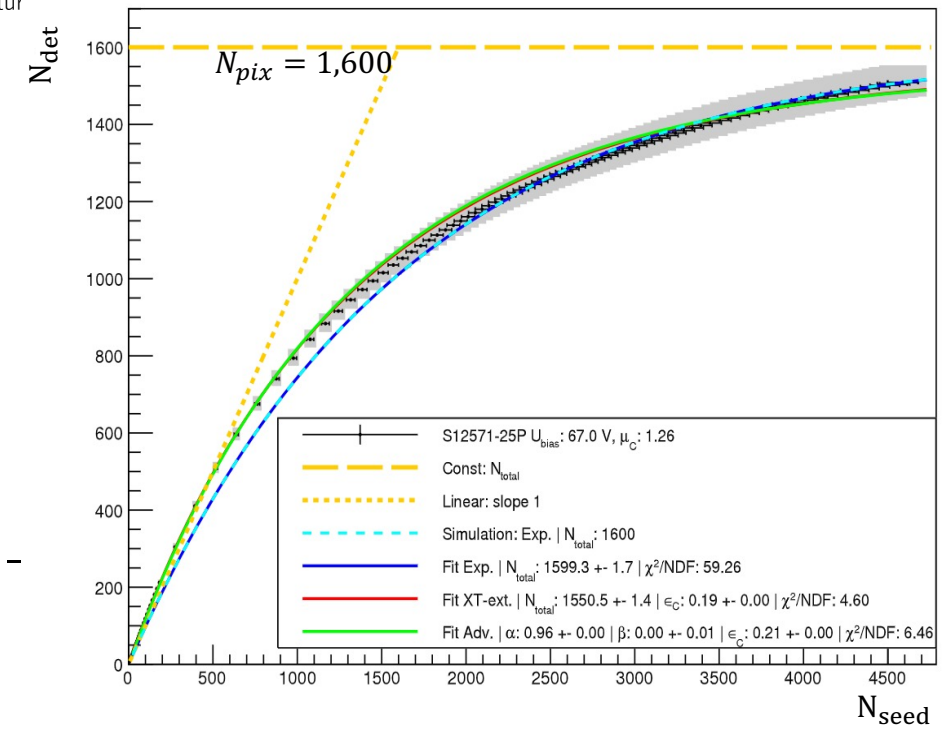
Experimental principle

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

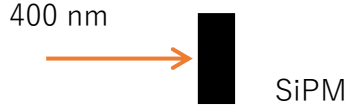
- Saturation curve : $\mathbf{N_{seed}}$ vs $\mathbf{N_{det}}$
  - $\mathbf{N_{seed}}$: number of photoelectrons when assuming no saturation
  - $\mathbf{N_{det}}$: number of photons MPPC detected

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

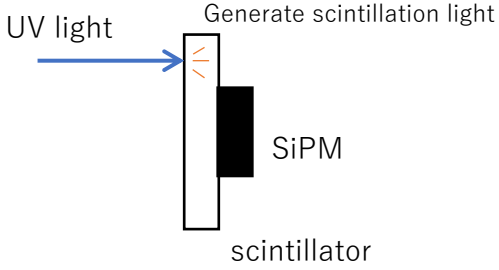
- New method by injecting UV light to the scintillator-SiPM system
  - **Excite scintillation light by injecting fast UV light pulse**
  - **Scintillation light intensity is controlled by the UV light intensity to measure the SiPM saturation**
  - **Advantages**
    - **Effect of scintillation emission time constant is included in measured SiPM saturation**
    - **Saturation effect can be directly measured with the actual detector setup**



Conventional method



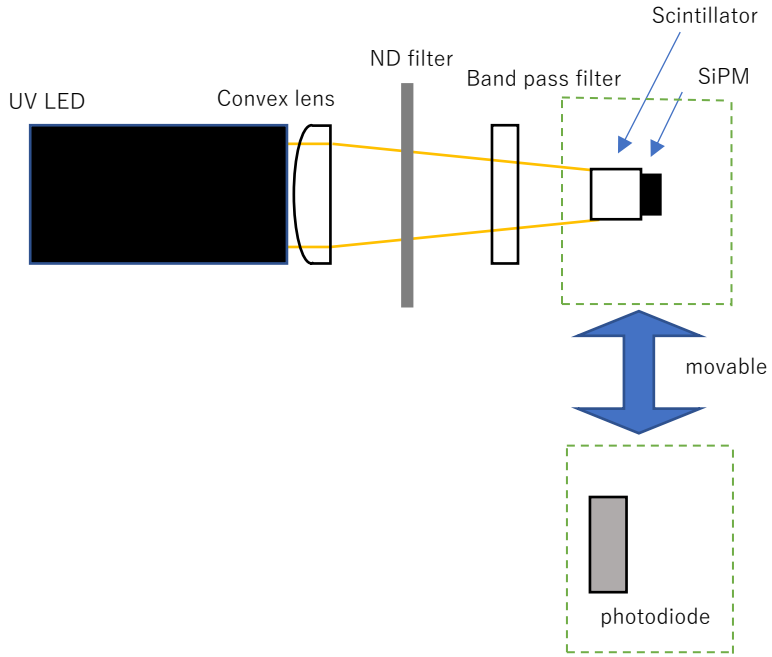
New method



Saturation measurement -setup-

- Scintillator-SiPM and photodiode are irradiated by the same UV light pulse using moving stage
  - The intensity is controlled using ND filter
  - SiPM detects scintillation light to observe saturation
  - Photodiode monitors the intensity of UV light

- SiPM : Hamamatsu MPPC S12571-025P
- Scintillator : EJ-200 ($2\times2\times2\ \mathrm{mm}^3$)
- Light source : PicoQuant PLS series
  - Measured also with visible light pulse for comparison



SiPM (S12571-025P)

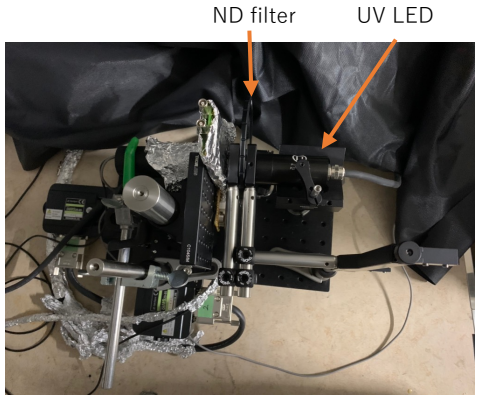
Effective area	$1\times1\ \mathrm{mm}^2$
Pixel pitch	25 μm
Number of pixels	1,600

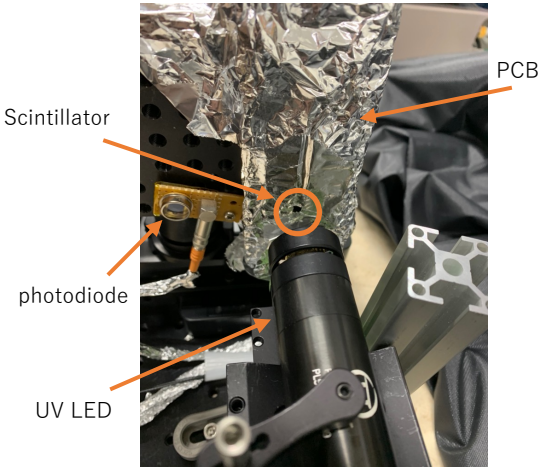
Sintillator (EJ-200)

Attenuation length	380 cm
Maximum wavelength emission	425 nm
rise time	0.9 ns
decay time	2.1 ns
size	$2\times2\times2\ \mathrm{mm}^3$

Light source

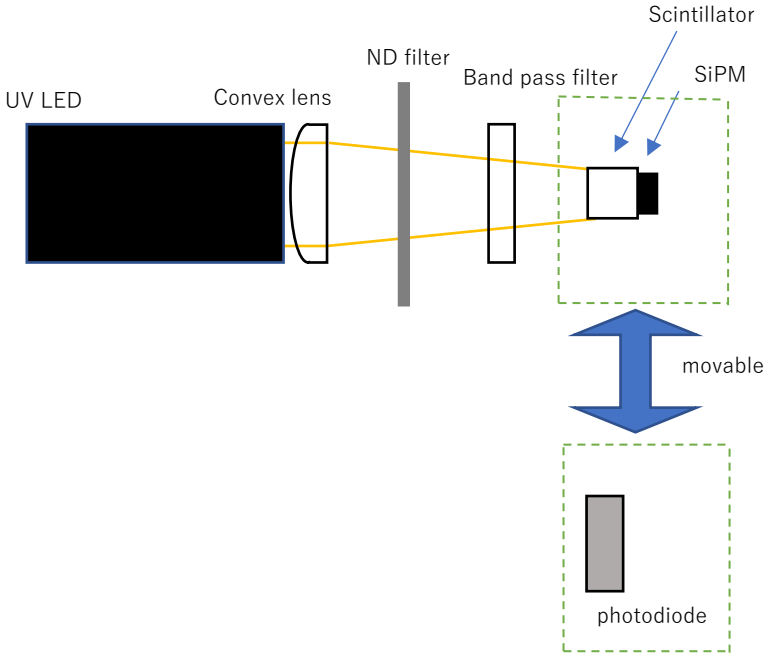
	PLS 255	PLS 500
Wavelength [nm]	255 (±10)	485 (±10)
Pulse width (FWHM) [ps]	~400	~800





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 signal is measured in current at source meter



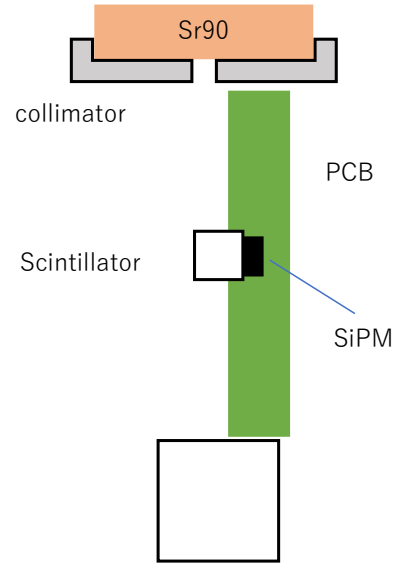
Detector	Signal Readout
SiPM	current
	photoelectron
Photodiode	current

Excitation of scintillator

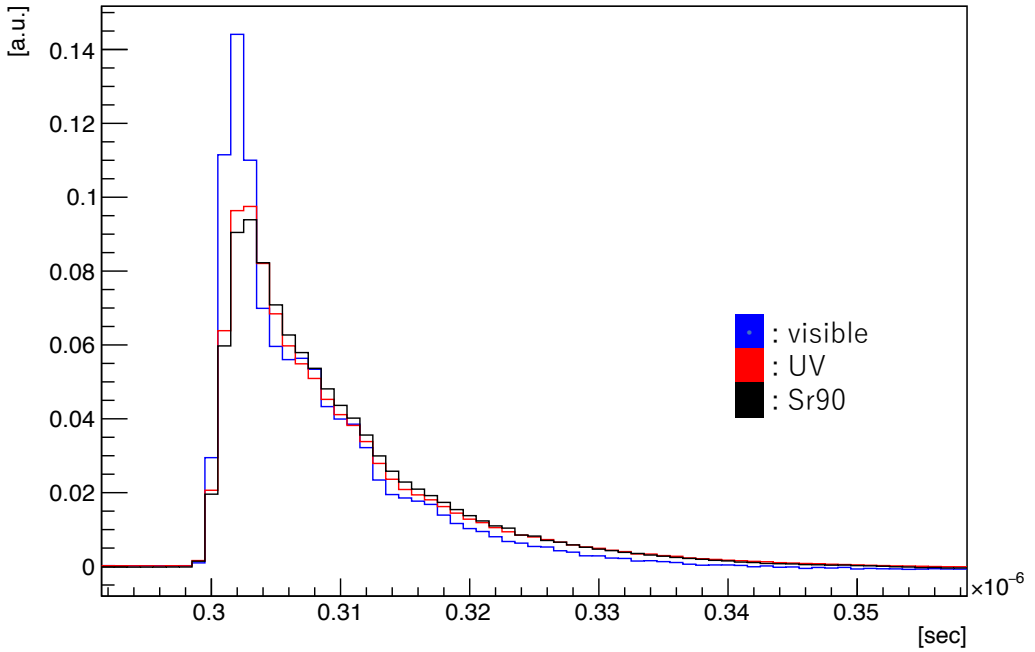
- Compared waveforms of SiPM signals of UV light, visible light, Sr90

- Waveforms of UV light and Sr90 are almost the same
- Smeared waveform compared to visible light

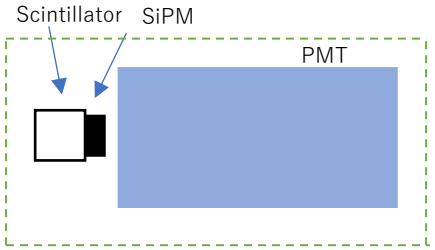
  →suggesting that scintillation light is excited by UV light



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

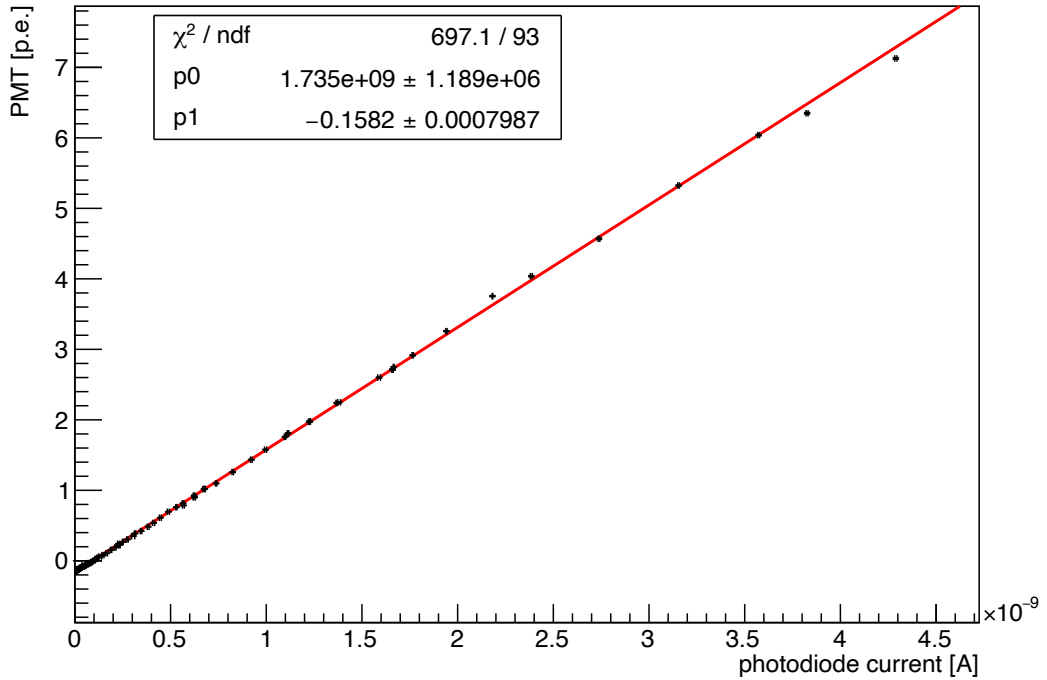


Relation between UV and scintillation light



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

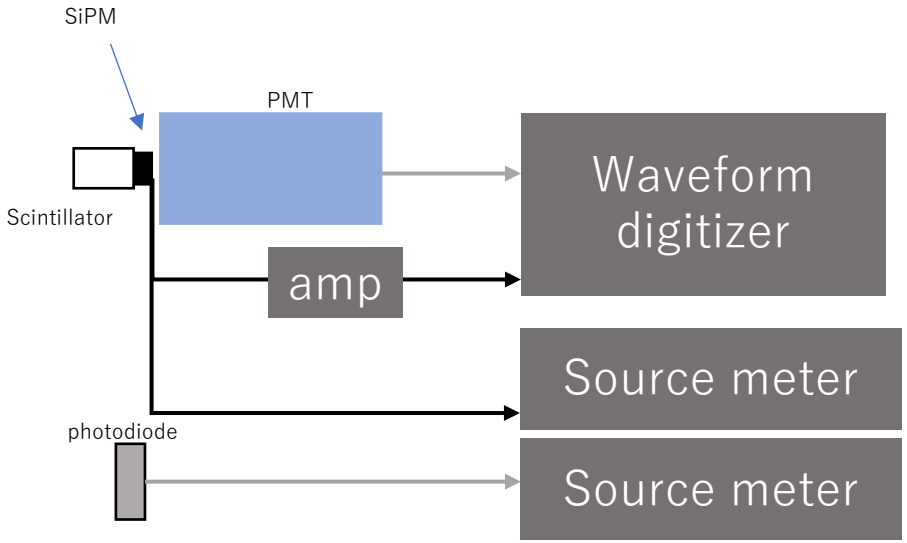
- <u>Linear relation is observed in wide range</u>
  - It is observed for the first time as far as we know
  - The number of incident scintillation photons can be estimated from the intensity of UV light



Analysis $N_{detected}$

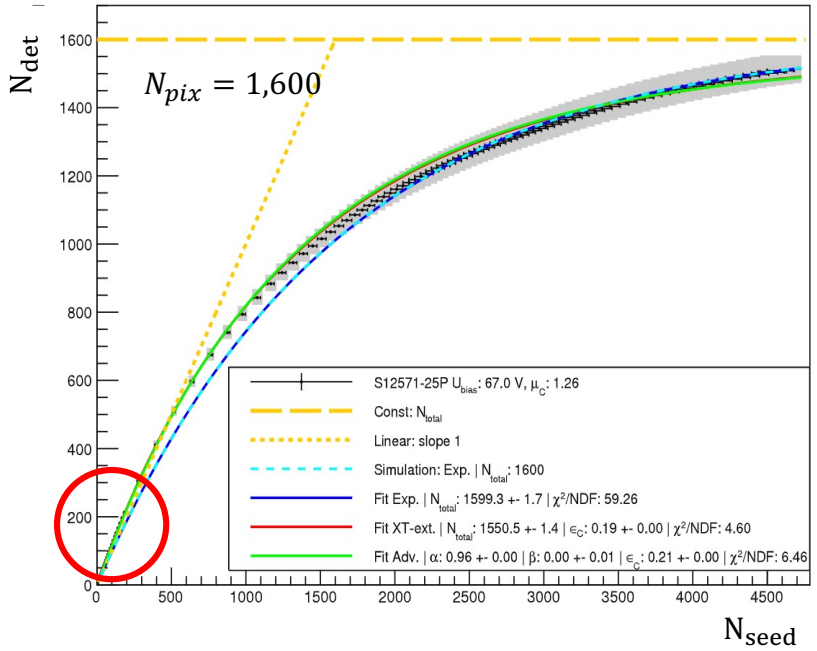
N_{seed} : number of photoelectrons when assuming no saturation

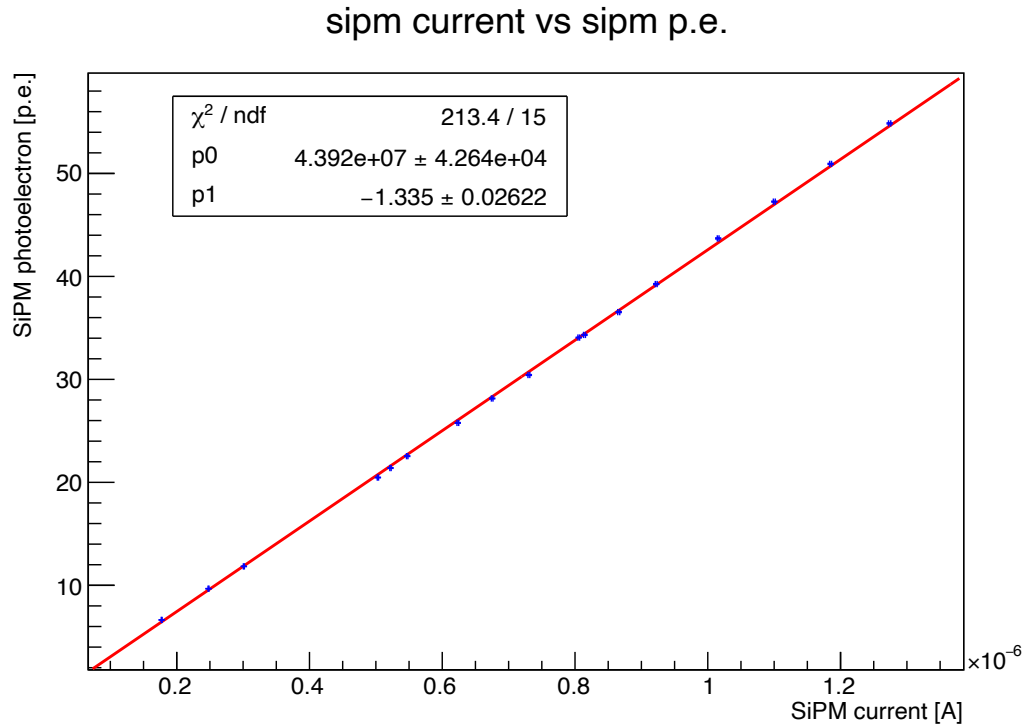
$N_{detected}$: number of photons MPPC detected



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

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



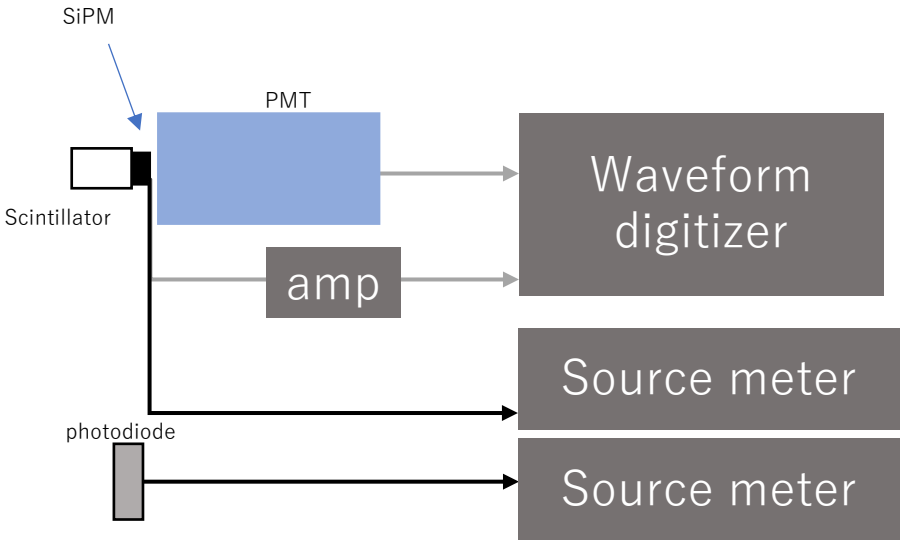


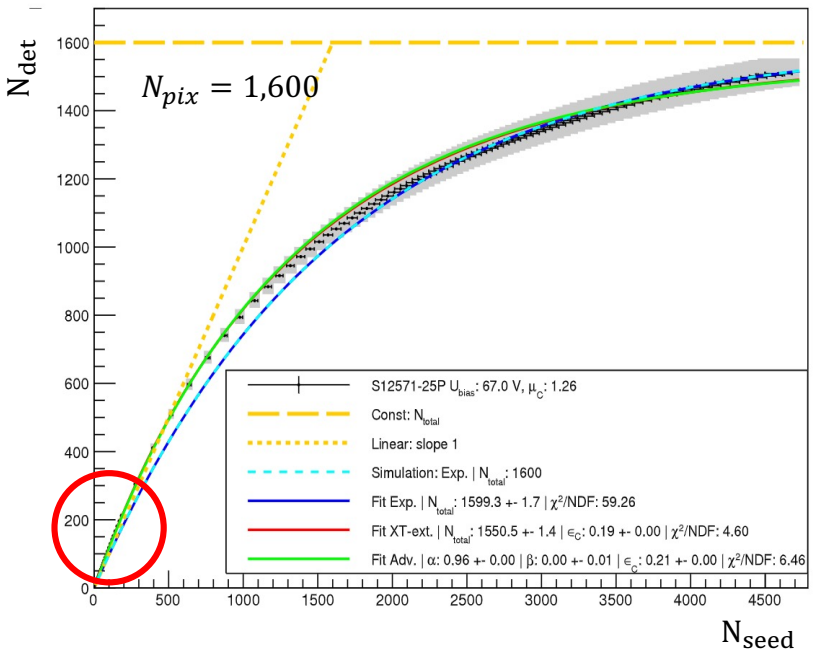
Analysis $\mathbf{N_{seed}}$

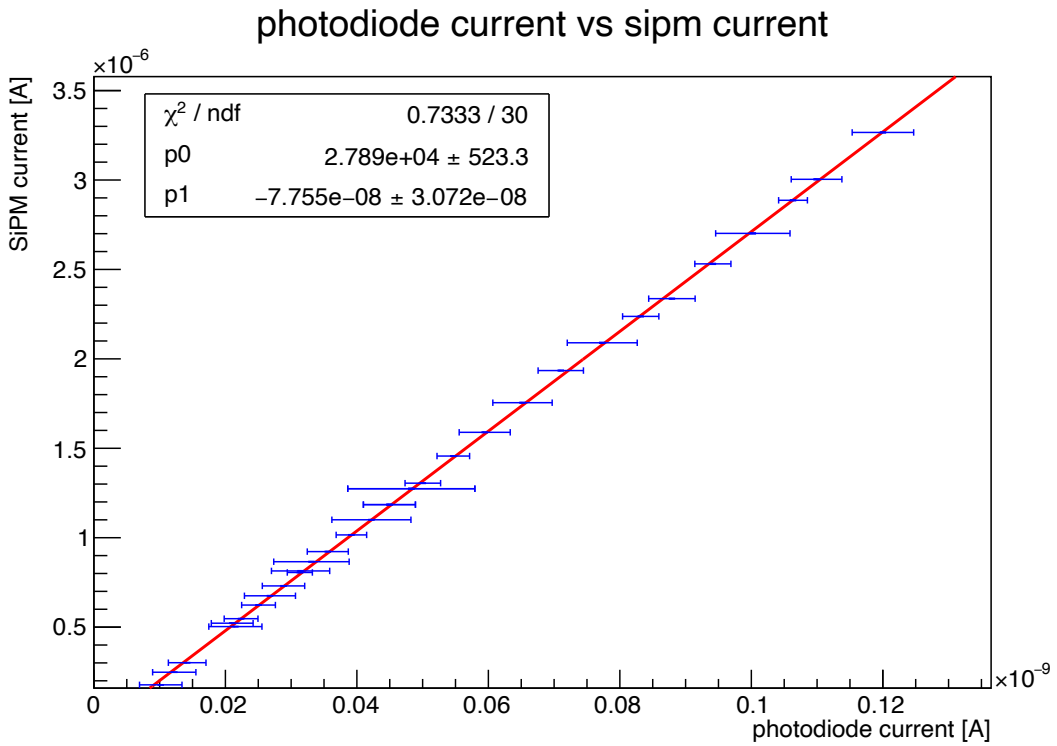
$\mathbf{N_{seed}}$: number of photoelectrons when assuming no saturation

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

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



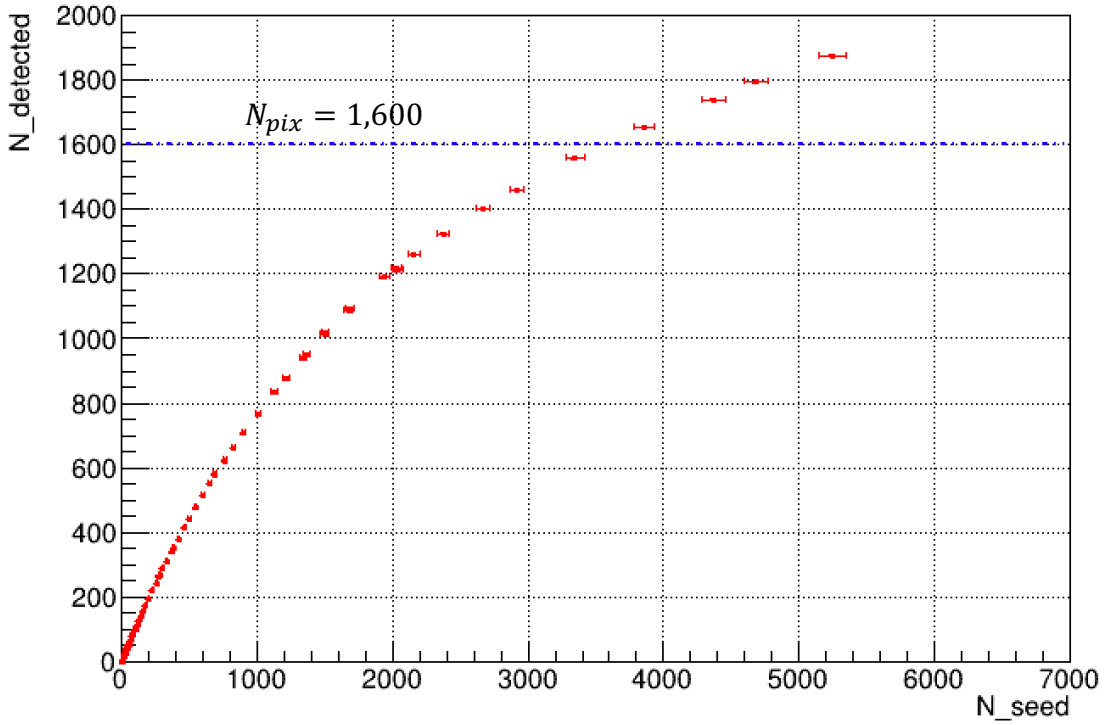




Saturation curve

- Saturation curve is obtained after the $\mathbf{N_{detected}}$ and $\mathbf{N_{seed}}$ calibration

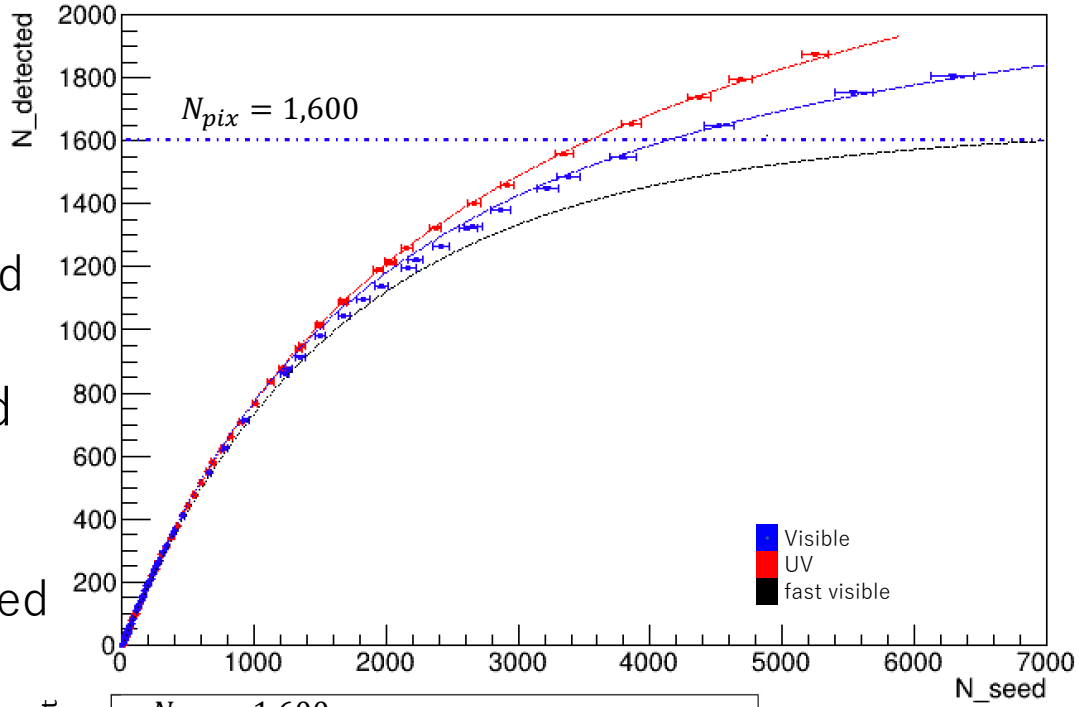
- Over saturation and a large recovery of SiPM saturation is observed
  - Due to the scintillation emission time constant

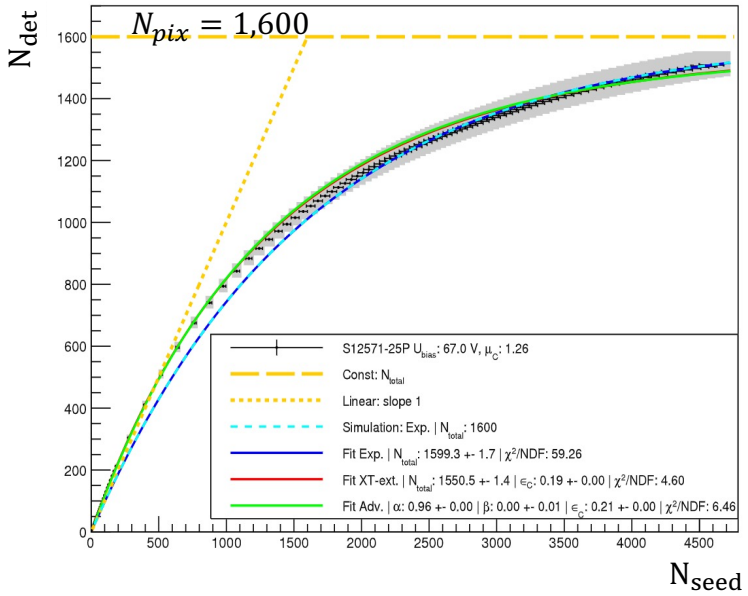


Saturation model

- Developed new saturation model
  - Including the effects such as crosstalk, after-pulse, and recovery time of a pixel
- The saturation model is compared with the measured curve
  - Model curve well describes measured curve.
  - N.B. scintillation emission time constant had to be tuned
- Longer pulse for the visible light in this study (~2 ns) is compared to the conventional saturation measurement (~100 ps)

  →smaller saturation
- Our saturation model nicely describes the measured curve for visible light and the conventional curve too.





SiPM	catalog	Measured
Recovery time [ns]	A few	7.4 ± 0.1
Crosstalk probability [%]	20	34 ± 2
After pulse probability [%]	-	4.0 ± 0.4

Scintillator	catalog	Fit
Rise time [ns]	0.9	1.3
Decay time [ns]	2.1	2.6

Summary

- We developed a new method to measure SiPM saturation with scintillation light excited by UV light pulse.
- Linear relation between the scintillation light and the intensity of injected UV light is observed.
- Large saturation recovery is observed in the measured saturation curve.
- Developed new saturation model including the effect of crosstalk, after-pulse, pixel recovery, and scintillation emission time constant.
  →Confirmed the new model well describes the measured saturation curve.