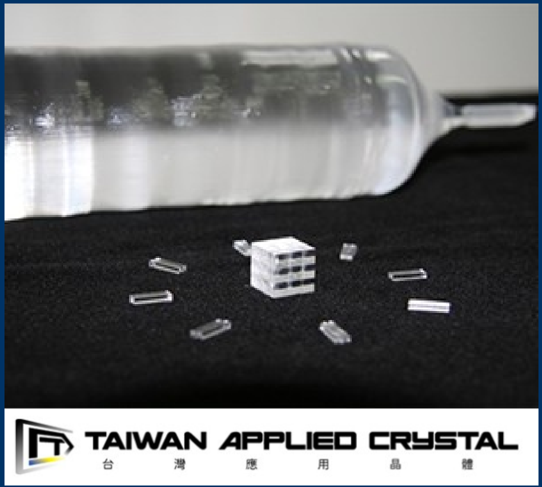
LYSO calibration and measurement

Jing-Ge Shiu (NTU)

- Introduction
- Light yield measurement
- Time jitter measurement
- Summary



Introduction

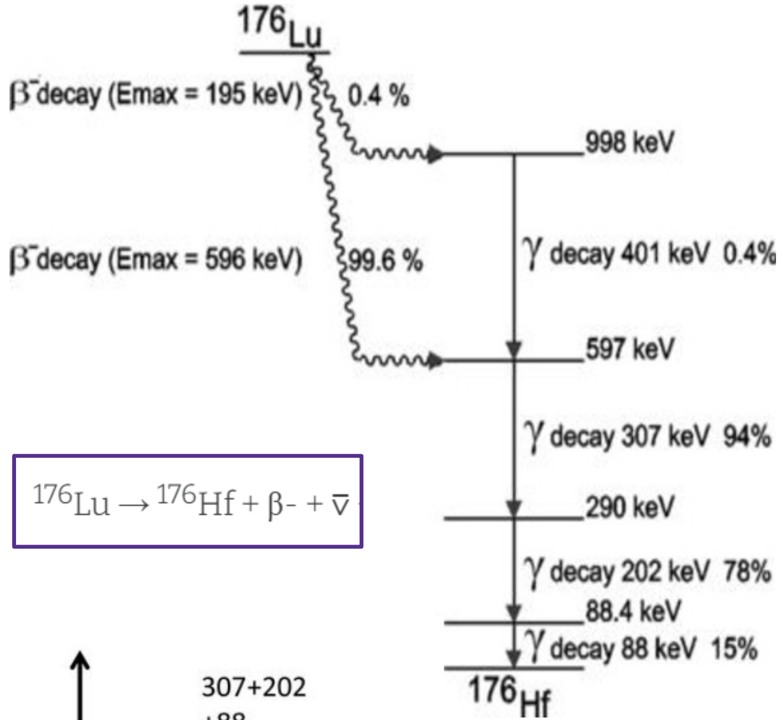
- LYSO: Lutetium-Yttrium oxyorthosilicate, $Lu_{2(1-x)}Y_{2x}SiO_5$:Ce:[M]

  Its properties strongly depend on the composition and manufacture process.

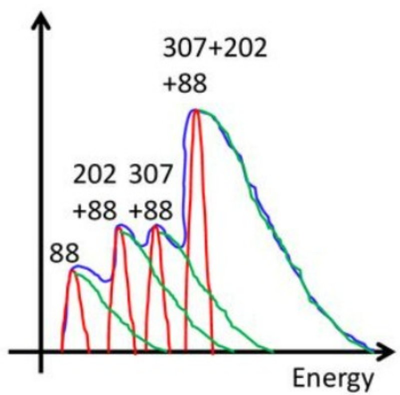
density	~7.1 g/cm^3	
refractive index	~1.8	
decay times	~40 ns	
small response time jitter	O(2) ps	
light yield	~28 photons/keV	(4xBGO; 75% of NaI(Tl))
peak wavelength emission	420 nm	
radiation length (511keV)	1.2 cm	
energy resolution	~10 %	
$R_{Moliere}$	2.07 cm	
hygroscopic	No	
radiation hardness	1x10$^{6\sim8}$ rad	**[Shalom EO and SA Materials]**
price	~ $100 /cm^3	

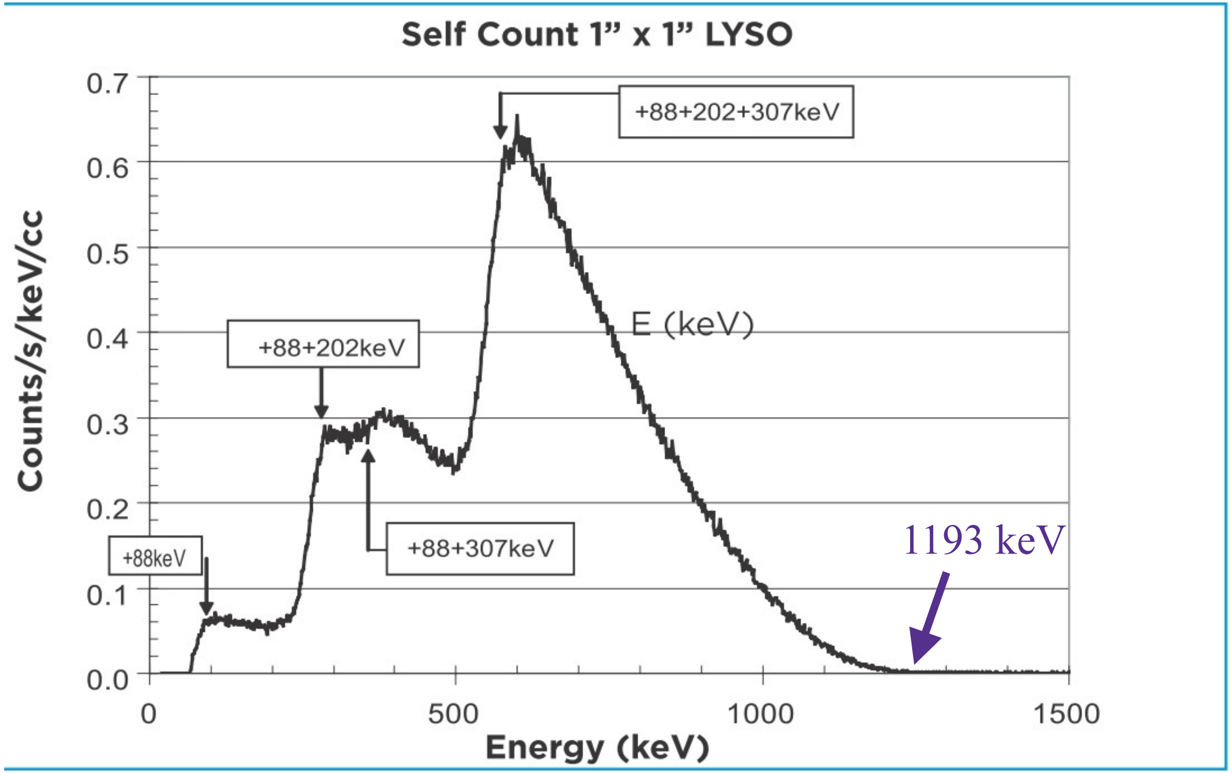
- intrinsic radiation activity due to ^{176}Lu (about 2.6% in natural Lutetium).
- non-linear γ absorption (self-detection)

LYSO intrinsic radiation



$^{176}\mathrm{Lu} \rightarrow {}^{176}\mathrm{Hf} + \beta^{-} + \bar{\nu}$





The spectrum shape is size and shape dependent, due to the γ self-detection.

[H. Alva-Sánchez et al.]

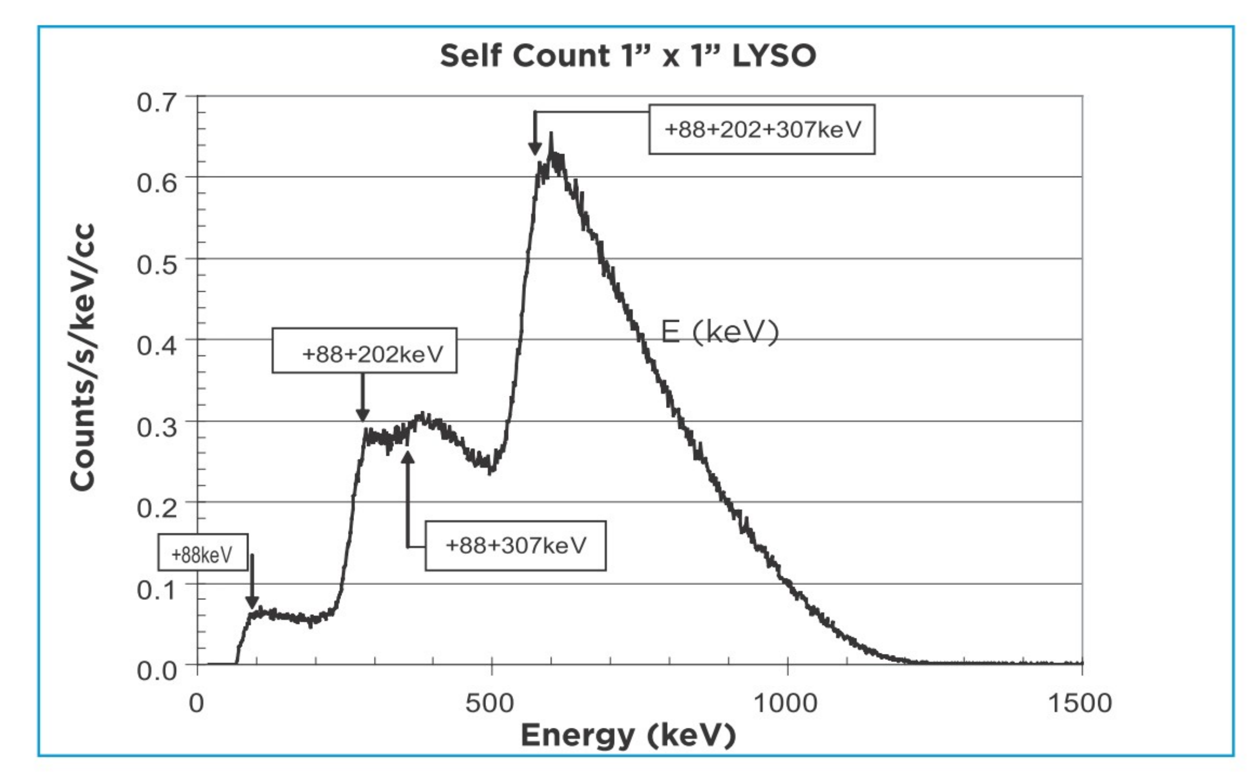
- LYSO high light yield (temperature coefficient -0.2%/ºC), short decay time, small time jitter, high stopping power, and good radiation hardness
  → suitable for small volume detector: PET, XCT, HEP, …

- The report is based on the studies done by
  Chin-Chia Kuo [MS]
  Yun-Chen Shen
  Chen-Yu Tao [MS]
  for
  - The light yield
  - Timing resolution
    (the supplier's major concerns)
  - These studies are more to establish working test benches than to make precision measurements.

- The LYSO samples are supplied by Taiwan Applied Crystal.

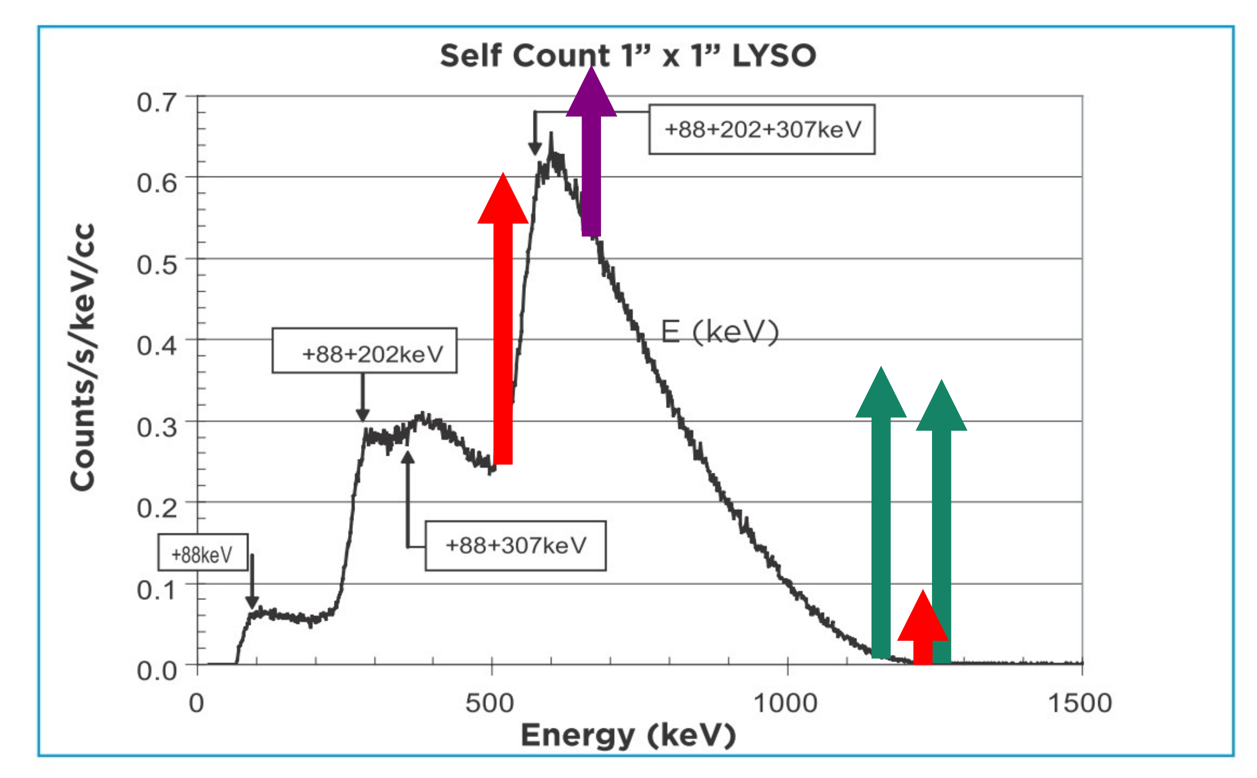
Light yield measurement

- Methodology to measure the light yield of a scintillator
  - Self-calibration (w/o external source)



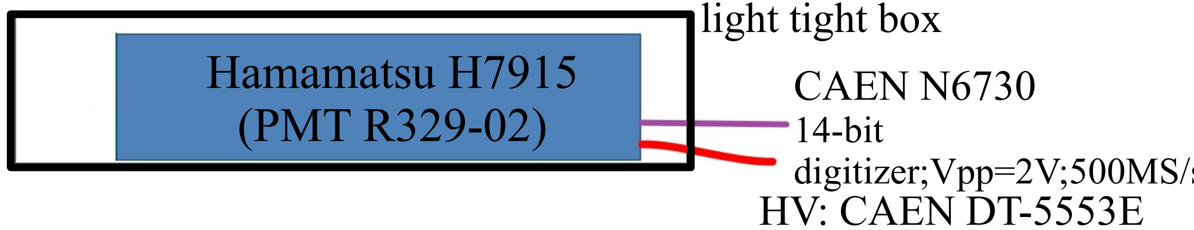
Light yield measurement

- Methodology to measure the light yield of a scintillator
  - Self-calibration (w/o external source)
  - With external source (Na-22, Cs-137, Co-60)
    - Calibration with a standard scintillator, e.g. NaI(Tl), or a golden sample.
    - Calibration with single photon signal (✓)



Light yield measurement

- Apparatus
  - Detector and DAQ



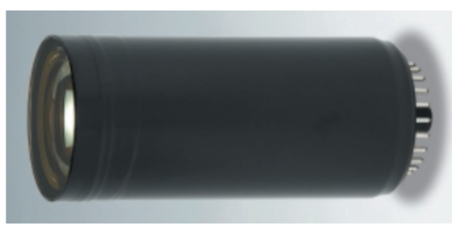


Figure 1: Typical spectral response

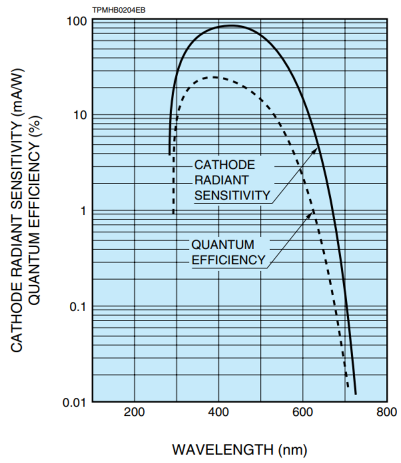
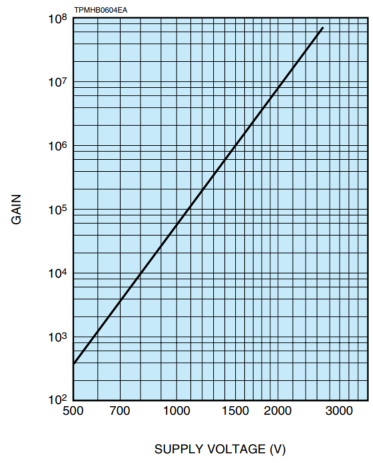
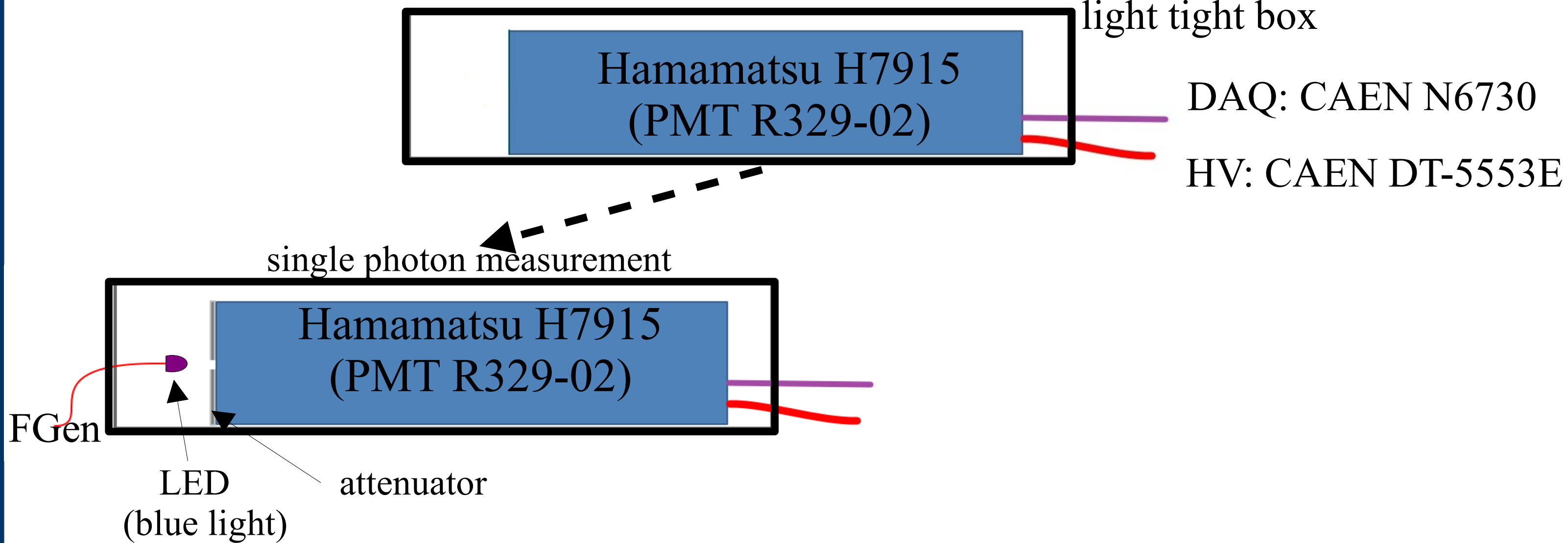


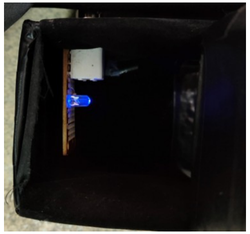
Figure 2: Typical gain characteristics



Light yield measurement

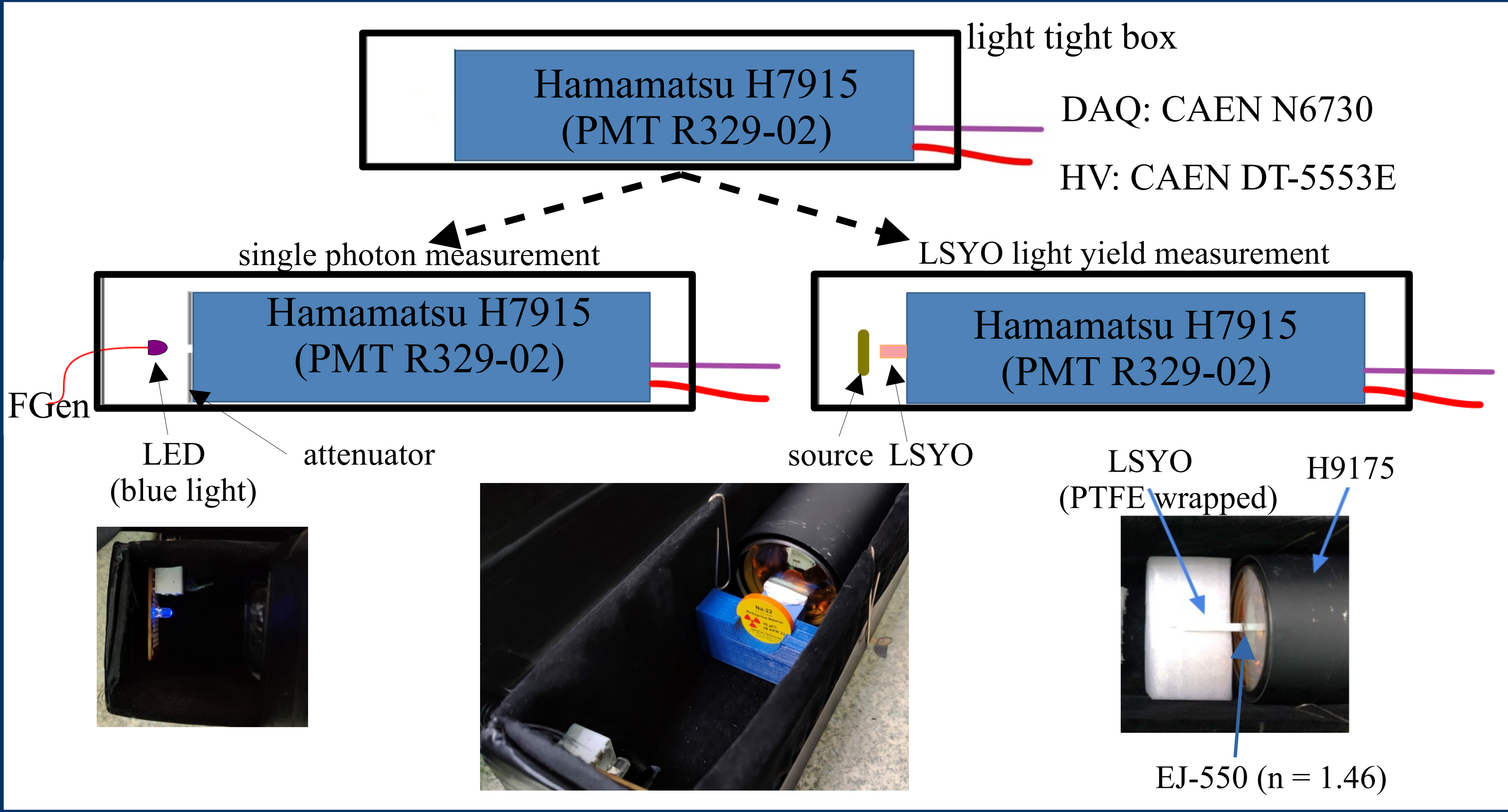
- Apparatus
  - Detector and DAQ





Light yield measurement

- Apparatus
  - Detector and DAQ



Light yield measurement

- Method: calibration with single photon signal
  due to the sensitivity and dynamic range, the measurements are done at two HV levels.
  - measure the single photoelectron signal (ADU = ADC count) at HV_h, ADC_{single}
  - measure the gain difference between HV_h and HV_ℓ, G_{HV}
  - measure the LYSO photoelectron signal, with Na-22 source, at HV_ℓ, ADC_{LYSO}
  - estimate the PMT QE from its datasheet, QE = (20±X)%
  - assuming the emission light collection efficiency ~100%

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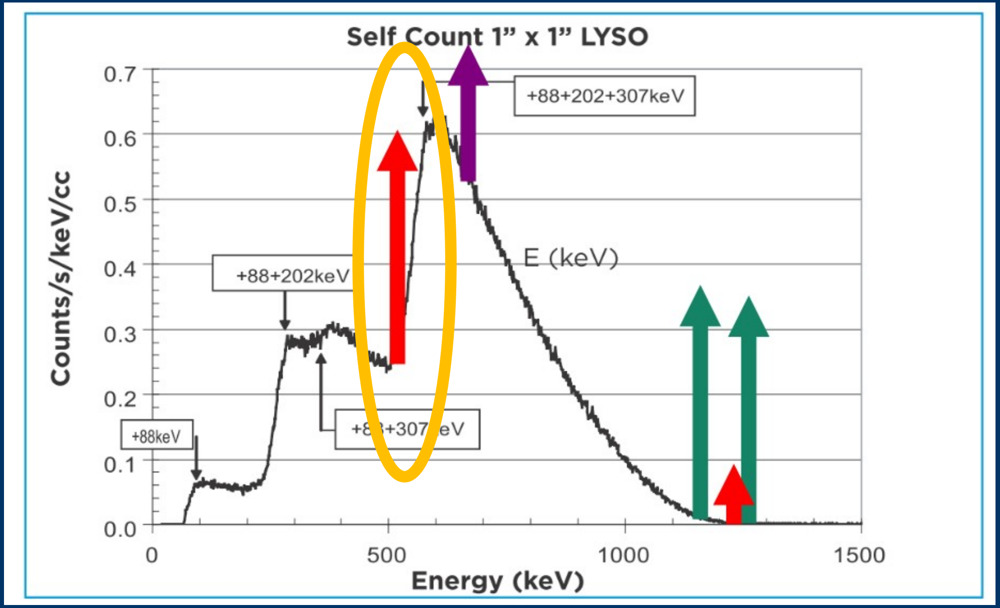
  - assuming the emission light collection efficiency ~100%

The light output of LYSO:

$$LO_{LYSO}(photon/keV) = \frac{ADC_{LYSO}}{ADC_{single}} * \frac{G_{HV}}{QE * 511}$$

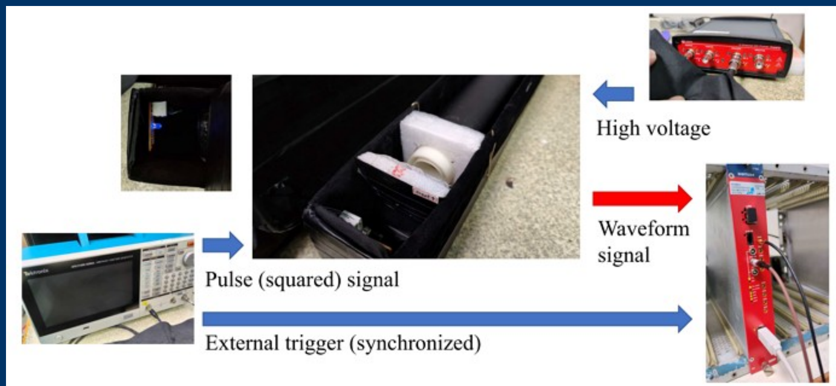
HV_h = 2500V; HV_ℓ = 1500V

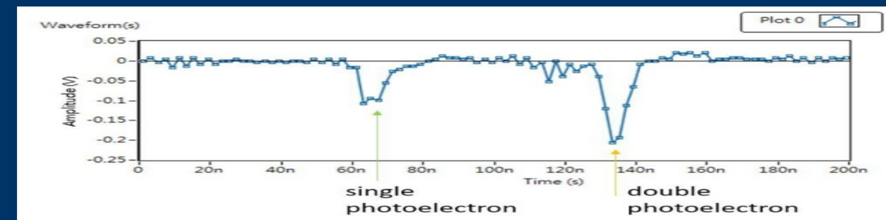
$G_{HV} = Gain(HV_h)/Gain(HV_\ell)$



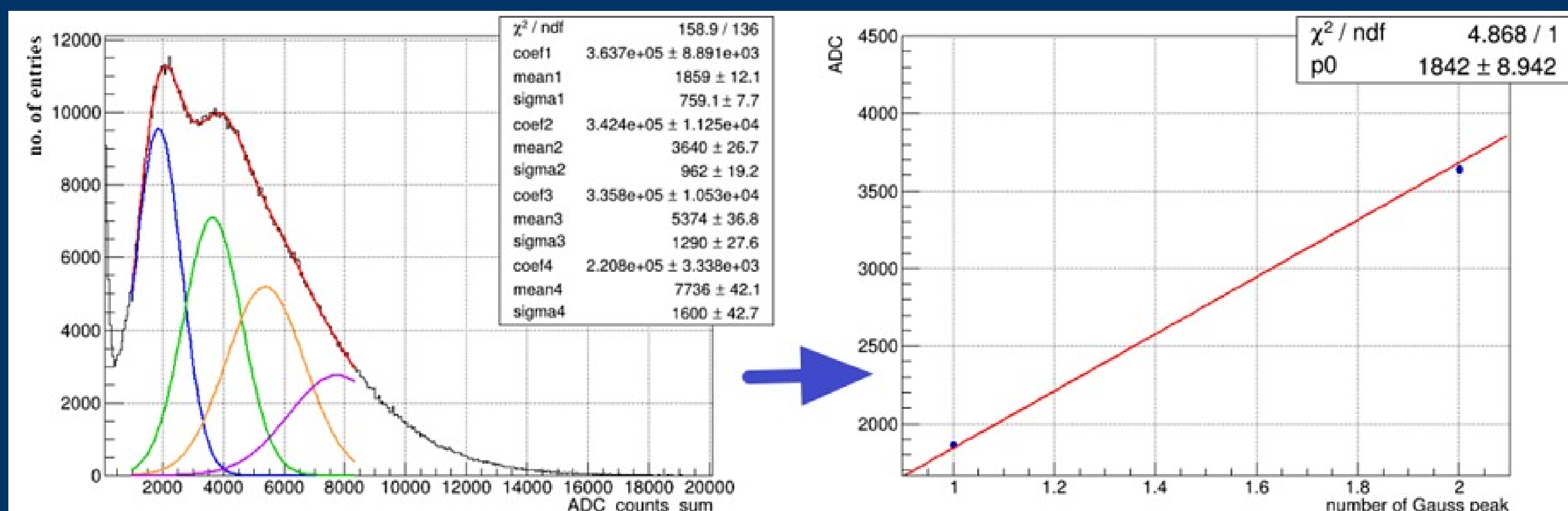
Light yield measurement

- ADC_{single} at HV_h (2500V):
  first tuning the FGen to get the single photoelectron signal from LED source.



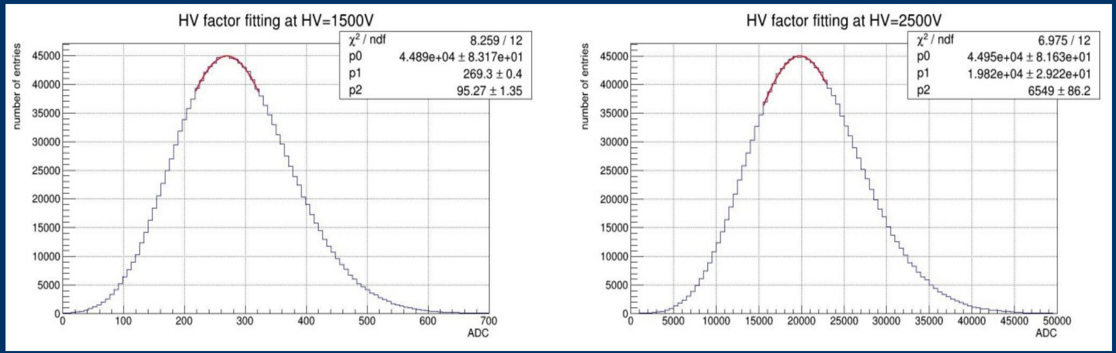


$$ADC_{single} = 1839 \pm 40$$



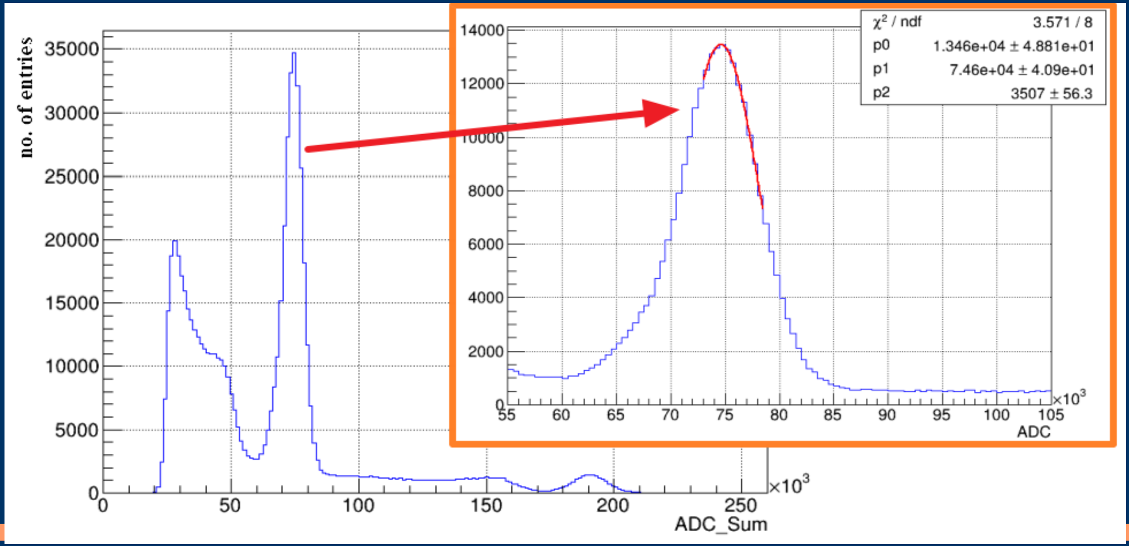
Light yield measurement

- G_{HV} = Gain(HV_h)/Gain(HV_ℓ) determination (~ 10 photoelectron)
  - set a moderate LED signal
  - fit the spectrum peaks at HV_h and HV_ℓ by Gaussian



G_{HV} = 73±1

- ADC_{LYSO} at HV_ℓ (1500V)
  - LYSO sample 3.0 mm x 20.0 mm x 3.0 mm (Ca), illuminated with Na-22
  - wrapped with 4 layers of PTFE pipe sealant tape (acceptable and easiest to apply)



ADC_{LYSO} = 74500±2119

Light yield measurement

ADC_{LYSO}
$= 74500 \pm 2119$

ADC_{single}
$= 1839 \pm 40$

$$LO_{LYSO}(photon/keV) = \frac{ADC_{LYSO}}{ADC_{single}} * \frac{G_{HV}}{QE * 511}$$

$G_{HV} = 73 \pm 1$

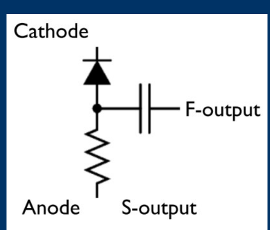
$QE = 0.2 \pm X$

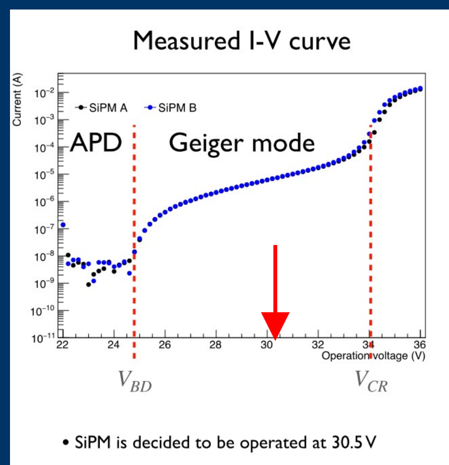
$LO_{LYSO} = 29 \pm 1 \pm x$ photon/keV

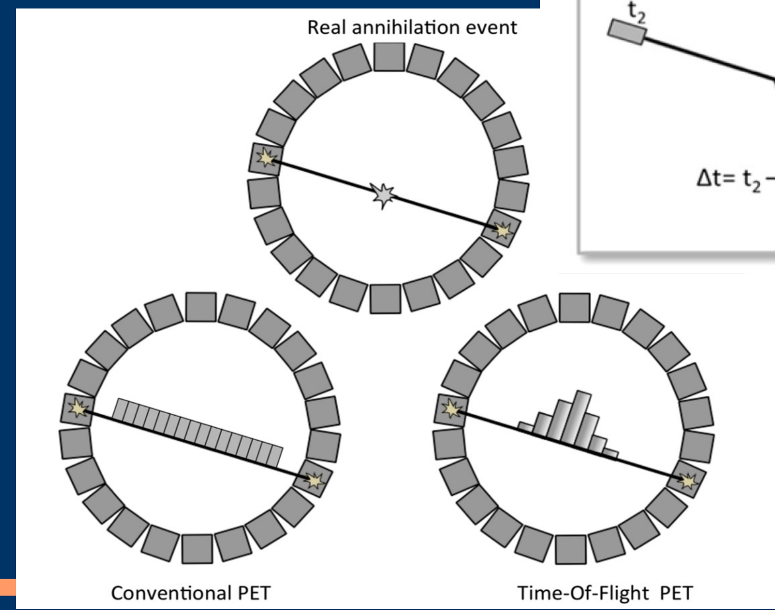
* LYSO sample with other dimentionals and doppings are also tested preliminarily.

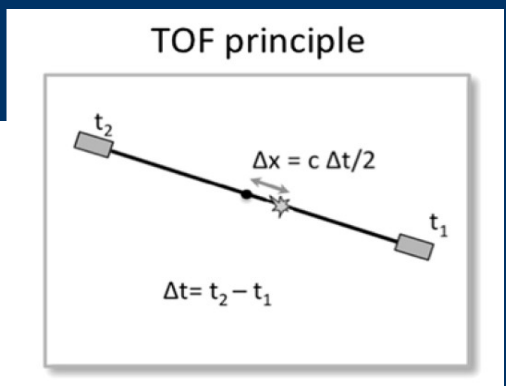
Time jitter measurement

- In timing applications, one critical issue is the variation of the “response time” while one signal is received by the detector → coincidence time resolution (CTR).
- CTR dertermination could depend on how one defines “signal ON”.
- In general, CTR refers to the FWHM of the arrival time distribution. (For a Gaussian distribution, this is about 2.355 σ).
- For TOP-PET, required CTR from O(3) → O(2) → O(1) ps.
  - O(2) corresponding to a few cm position uncertainty
  - the advantage of lower CTR is to reduce the nois
- SiPM MicroFC-60035 (ONSEMI) for photon detector
  - operating at 30.5V



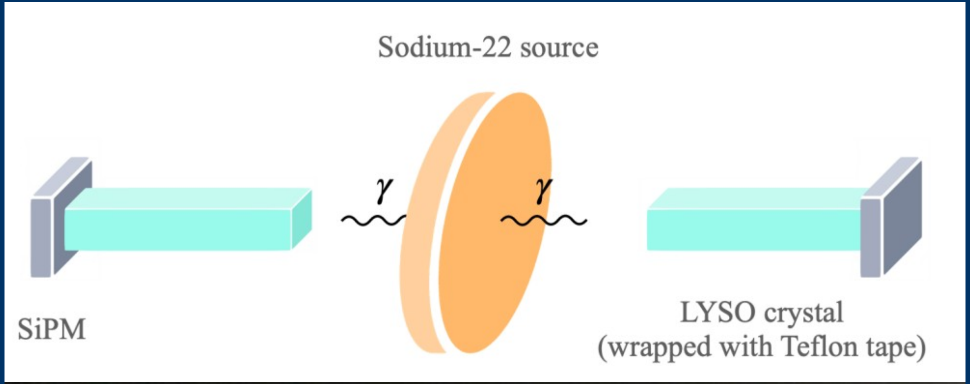


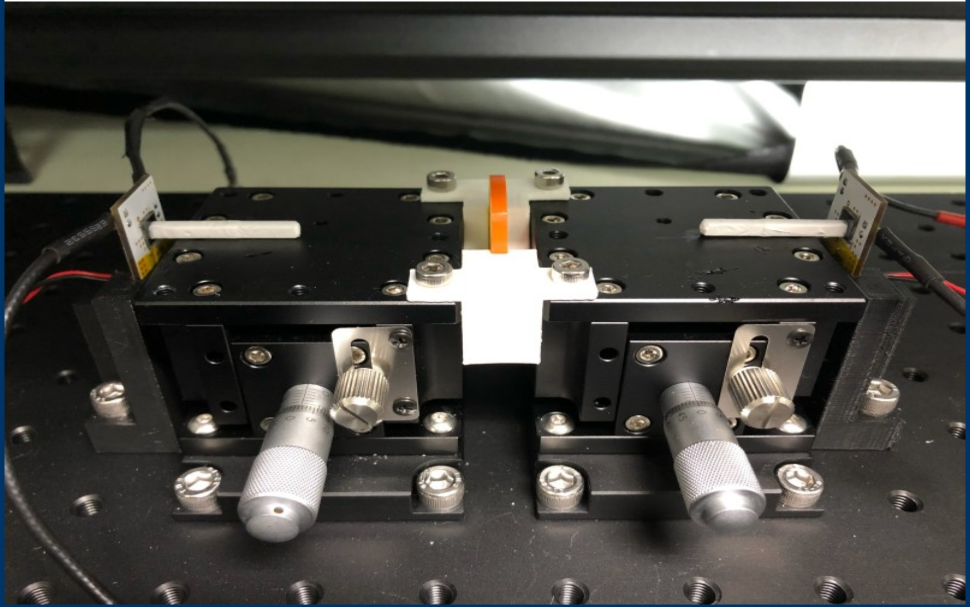




Time jitter measurement

- Thanks to Chih-Hsun for help to set up the test bench.
  - Na-22 radiates back to back photons to two LYSO samples at same time
  - each LYSO is attached to one SiPM
  - Tek DPO7354C (40GS/s) to measure the time difference bwteen two SiPM outputs. (50ps tick for 2-channle reading).





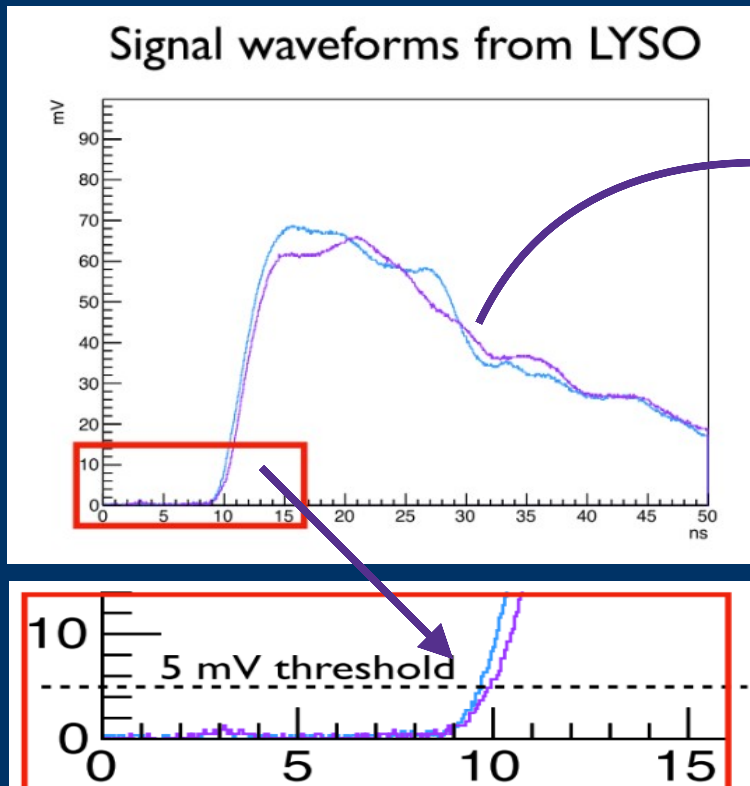
The response time jitter of LYSO, σ_{LYSO}, could be gotten from:

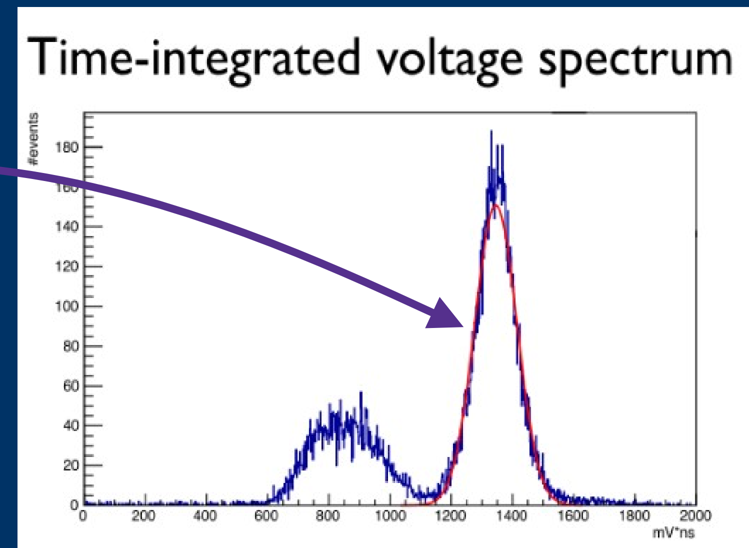
$$\sigma^2_{total} = 2*\sigma^2_{LYSO} + \sigma^2_{DAQ}$$

$$\sigma^2_{DAQ} = 2*\sigma^2_{SiPM} + \sigma^2_{noise}$$

Time jitter measurement

- Test procedure
  - rough coincident two SiPM signals recorded.
  - first 50 data points used to determined the pedestal
  - the integrated signal area is checked to exclude random background.
  - proper “threshold” choosed to measure the time difference between 2 SiPM signals.

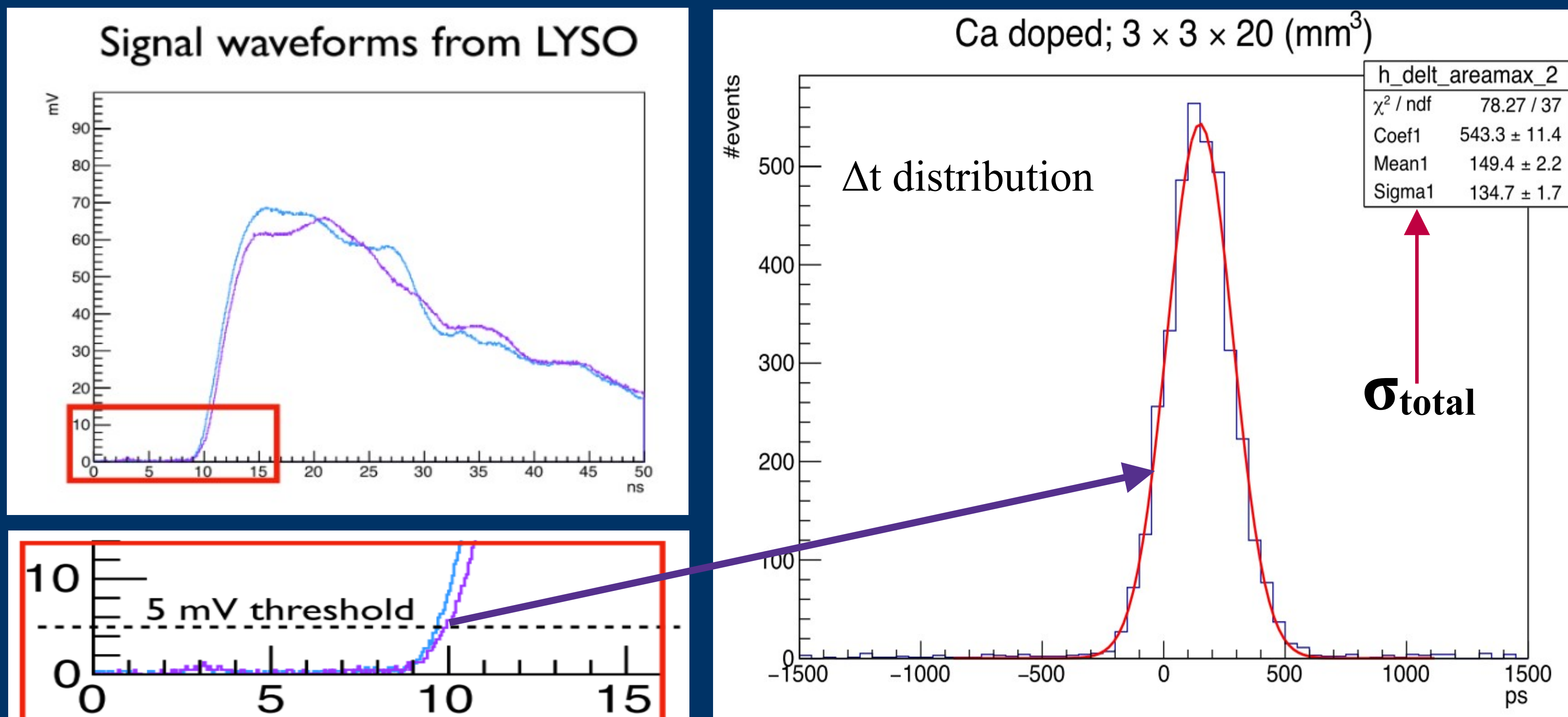




Lower threshold gives better CTR mesurement. 5 mV thresho is found high enough to reject random noise.

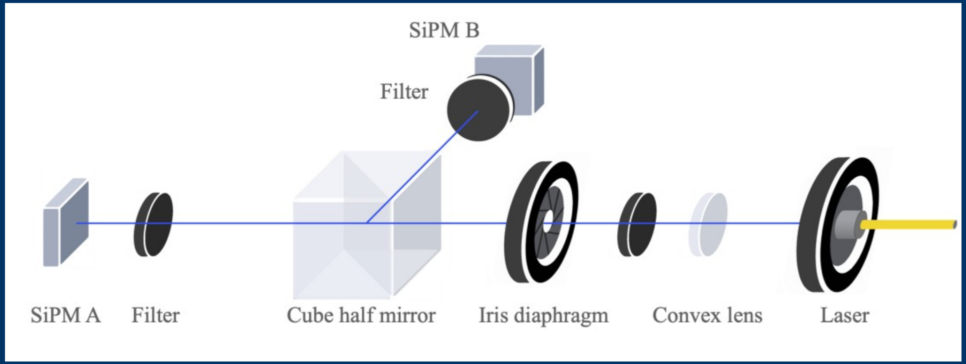
Time jitter measurement

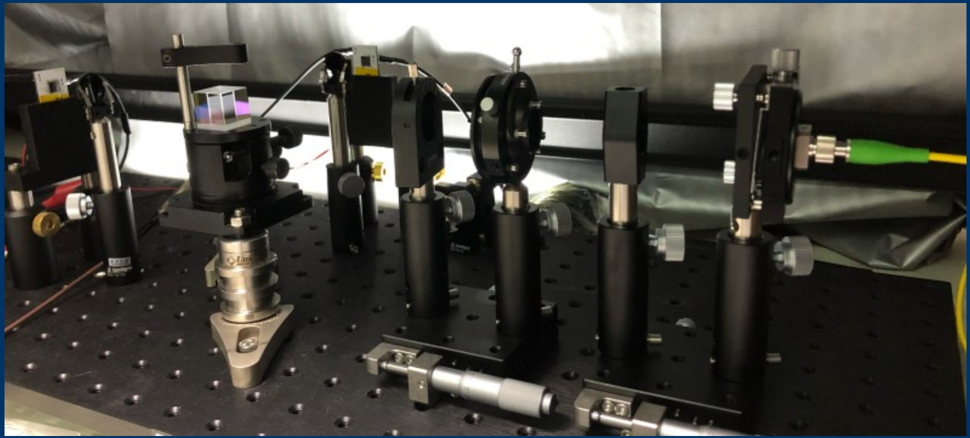
- Test procedure
  - rough coincident two SiPM signals recorded.
  - first 50 data points used to determined the pedestal
  - the integrated signal area is checked to exclude random background.
  - proper "threshold" choosed to measure the time difference between 2 SiPM signals.

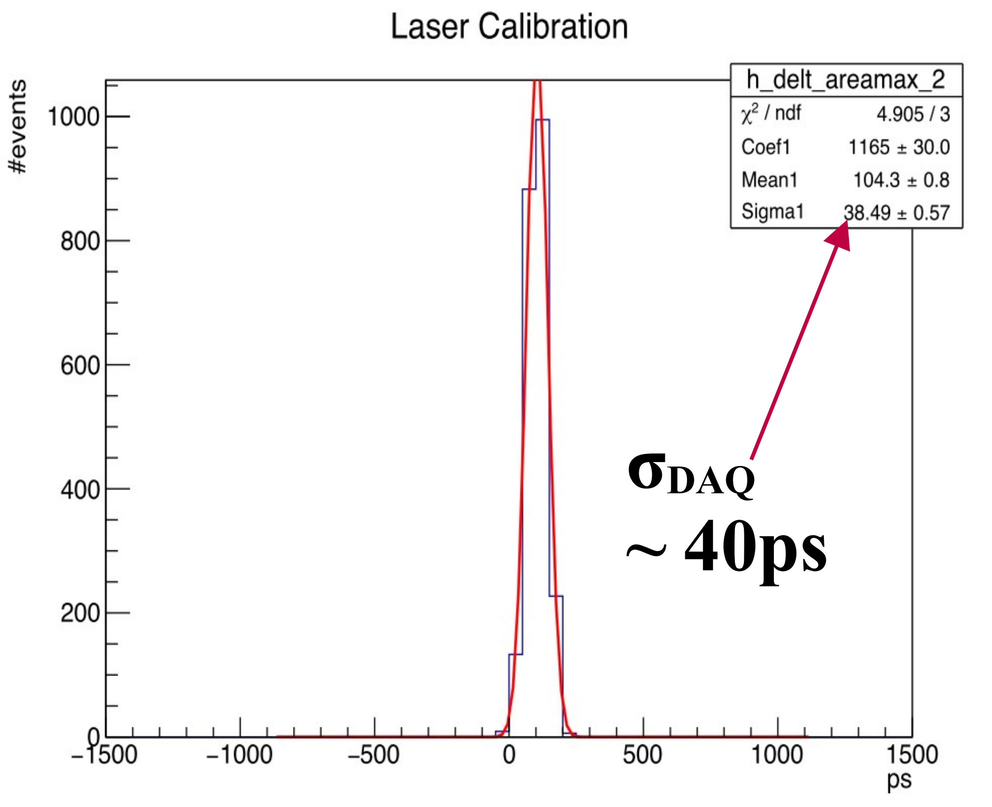


Time jitter measurement

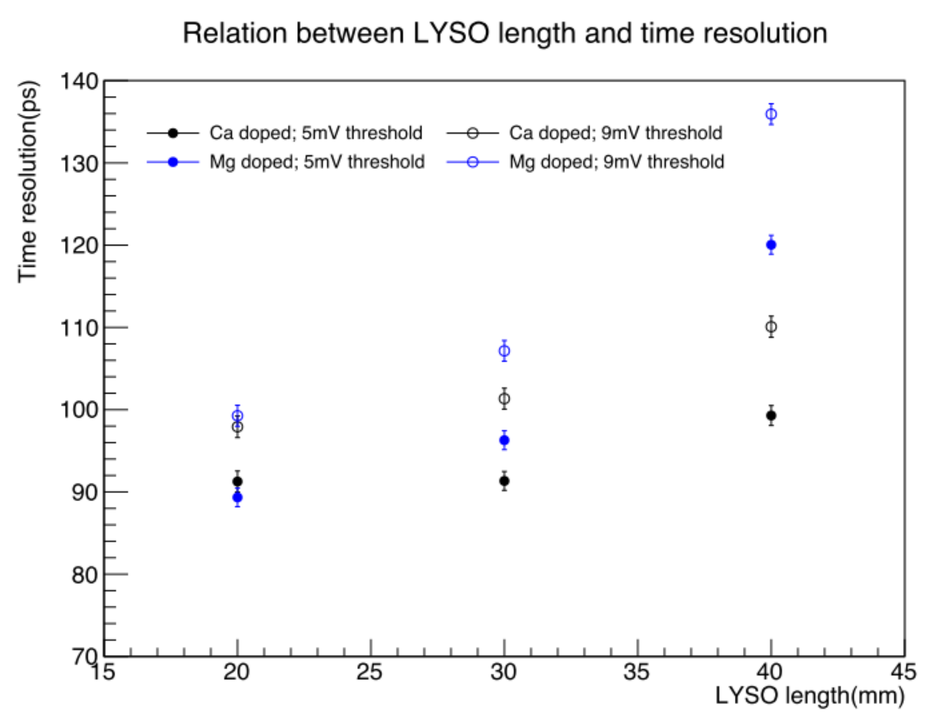
- Determination of σ_{DAQ}
  - 407.6nm laser beams split into two beams to shoot on two SiPM
  - the intensity is tuned closed to the LYSO signal from 511keV photon
  - follow a similar procedure to measure the time difference between 2 SiPM signals.

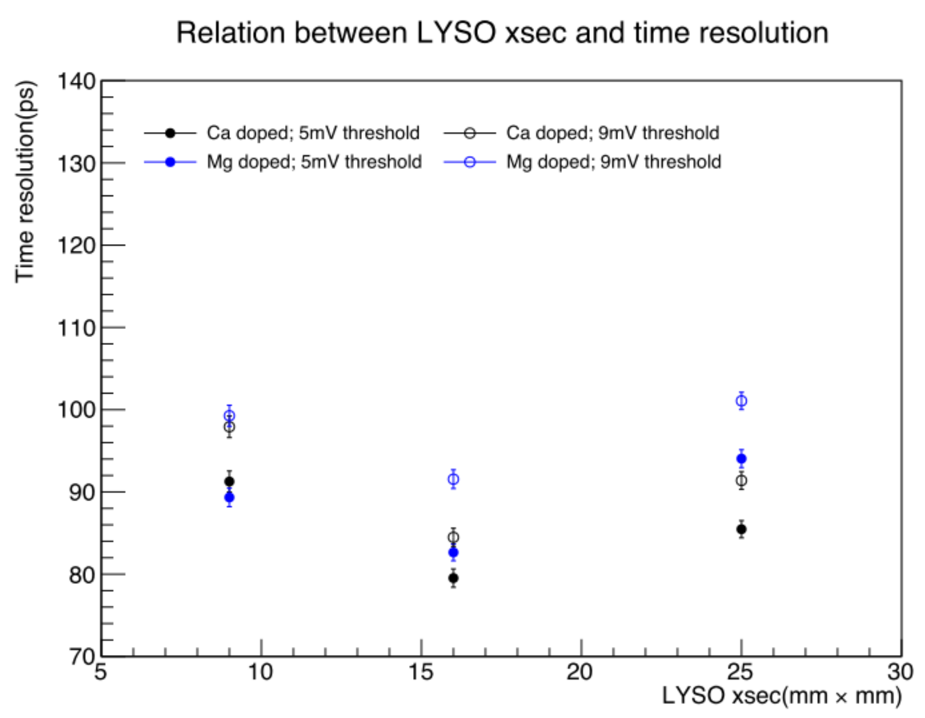






Time jitter measurement (σ_{LYSO})





3 mm x 3 mm x L mm samples
L = 20, 30, 40

α mm x α mm x 20 mm samples
α = 3, 4, 5

σ_{LYSO} ~ 90 ps (200 ps FWHM)

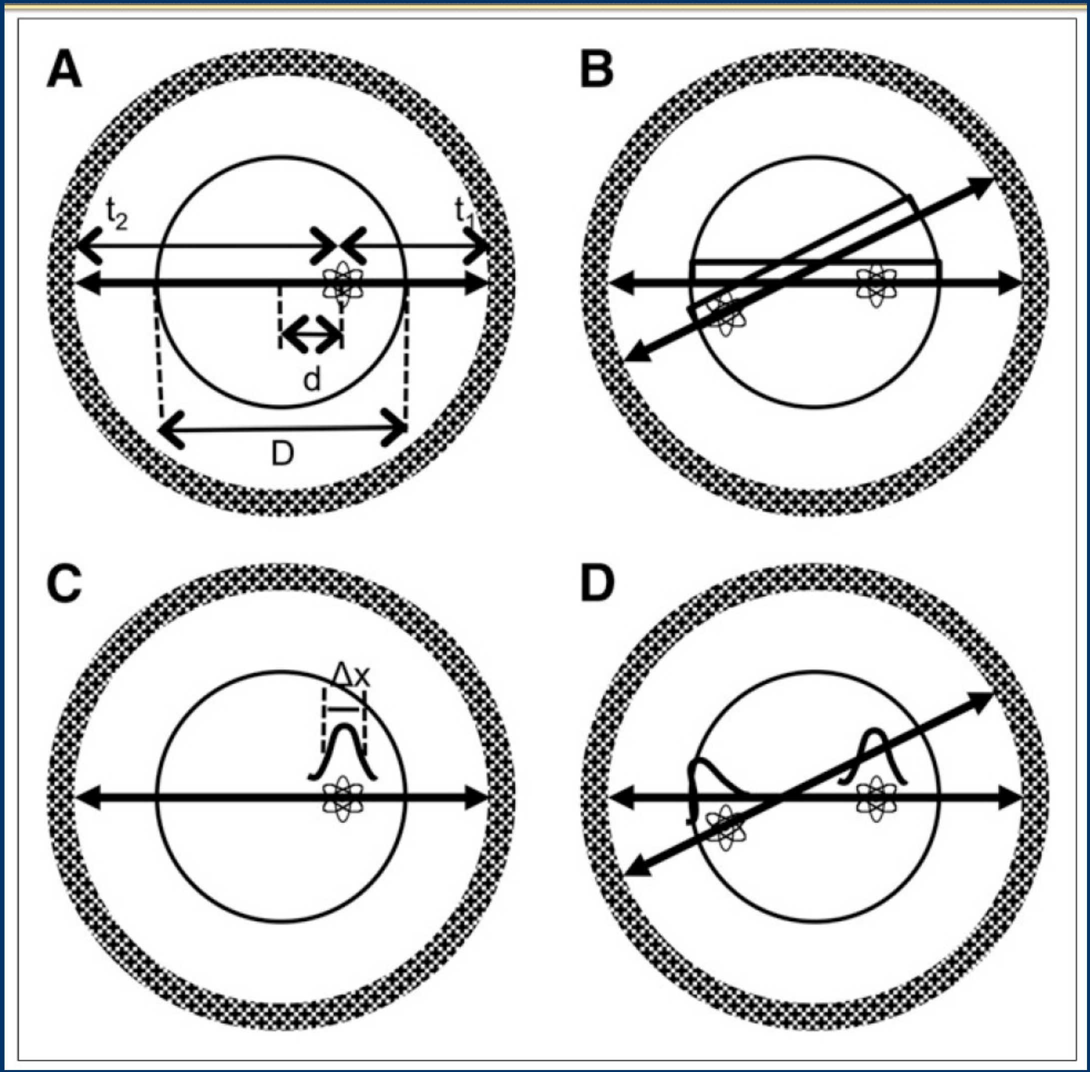
Summary

- We have establised test benches to measure scintillator light yield and responsible time resolution.
  - The light yield measurement uses PMT as photon detector. The system could use standard sample or single photon signal for photon number calibration.
  - The responsible time resolution uses SiPM as photon detector. The σ_{DAQ} could be down to 40 ps level.

- Measurement results of the LYSO sample from TACrystal
  - The light yield is 29 photon/keV (@511keV, for 3mm x 20mm x3mm size)
  - The response time resolution is around 90 ps.

- The studies could be the baseline experience to build other scintillation object test system, and precision could be further improved.

Thank you!!

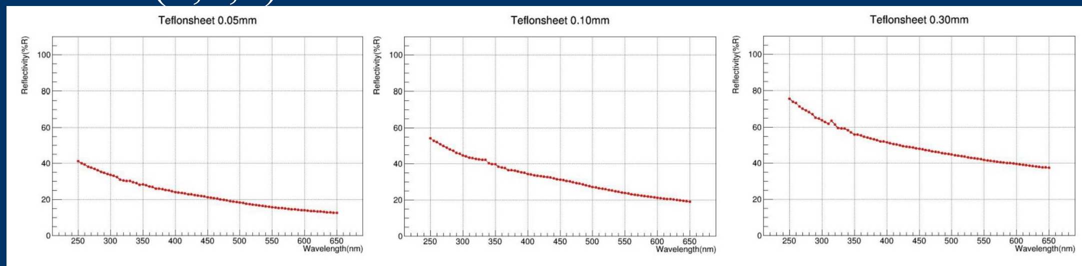

A
B
C
D
t2
t1
d
D
Δx

Properties	NaI(Tl)	BGO	CeF_3	BaF_2	CsI(Tl)	$PbWO_4$
Density (g cm^{-3})	3.67	7.13	6.16	4.89	4.53	8.28
Radiation						
Length (cm)	2.59	1.12	1.68	2.05	1.85	0.89
Moliere radius (cm)	4.5	2.4	2.6	3.4	3.8	2.2
$\mathrm{d}E/\mathrm{d}x$(MeV cm^{-1} per mip)	4.8	9.2	7.9	6.6	5.6	13.0
Decay time (ns)						
short	230	300	$\sim$5	0.6	$>$1000	5
long	150[ms]		30	620		15
Peak emission (nm)						
short	415	480	310	220	550	440
long			340	310		530
Refractive index						
at peak emission	1.85	2.20	1.68	1.56	1.80	2.16
Light yield						
(versus NaI(Tl))	1.00	0.15	0.10	0.05(fast)	0.40	0.01
				0.20(slow)		
Light yield γ/MeV	4×10^4	8×10^3	2×10^3	10^4	5×10^4	1.5×10^2

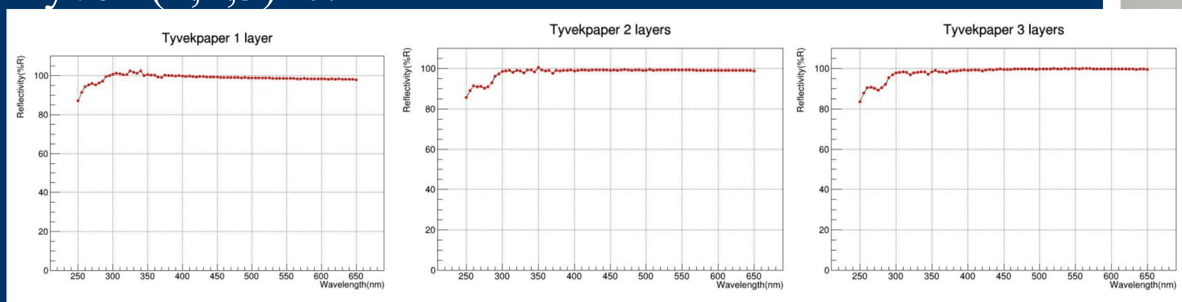
Wrapping material study

MgO(cru), pure Telfon sheet, Tyvek paper, PTFE sealant tape
Reflectivity measured by Lambda 650 spectrometer

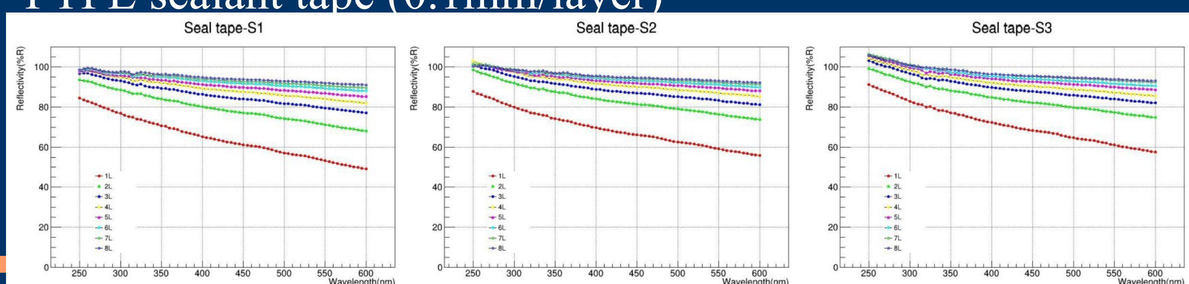
Telfon (1,2,3)x0.05mm

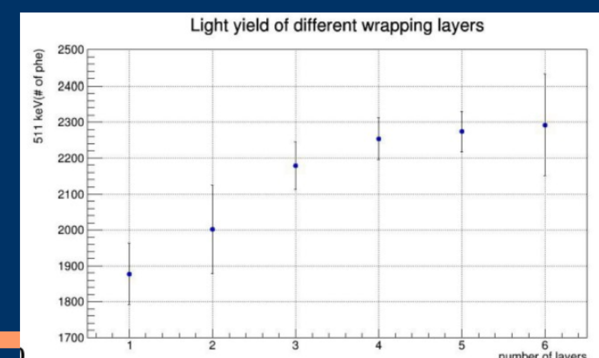


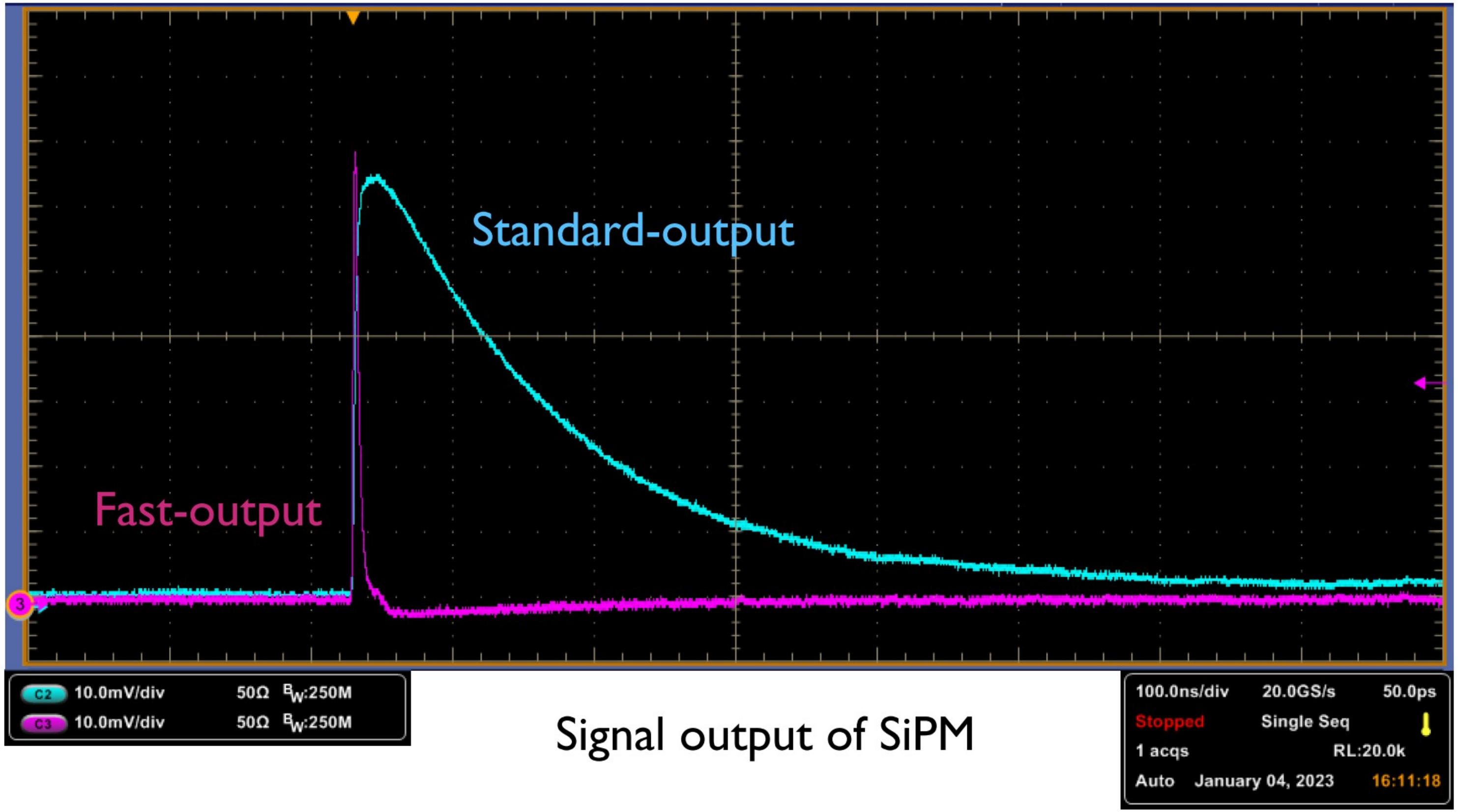
Tyvek (1,2,3)x0.1mm



PTFE sealant tape (0.1mm/layer)







Signal output of SiPM

- Fast-output with a small width is used for time resolution measurement