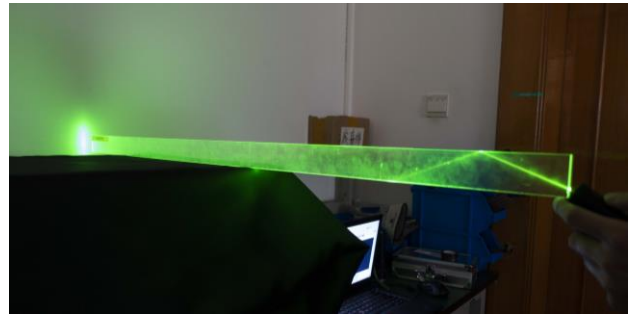
New achievement of time resolution of plastic scintillator

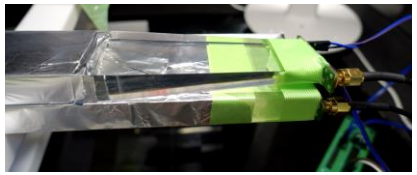
XiaoLong Wang

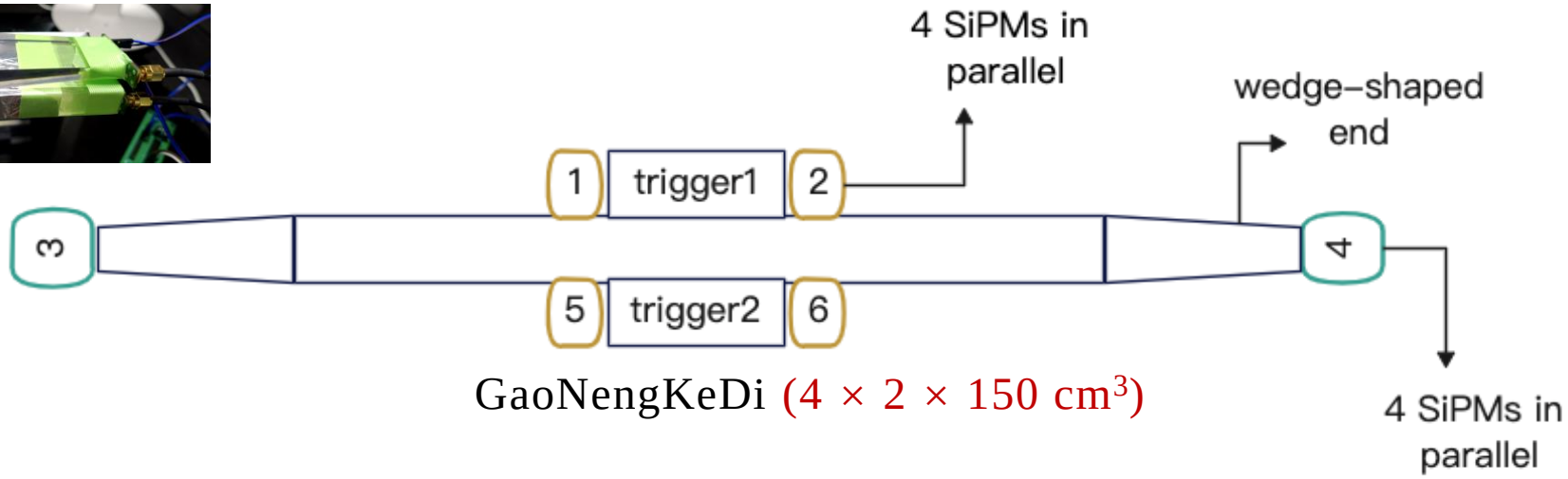
Fudan University

CEPC Day, 5/30/2023

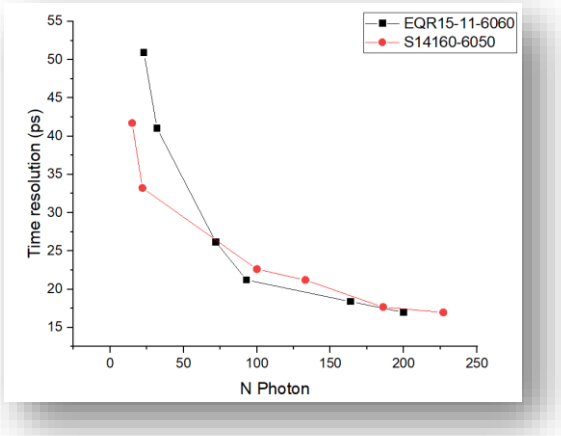
Last report: High time resolution







GaoNengKeDi ($4 \times 2 \times 150\ cm^3$)



σ_T of SiPM from testing

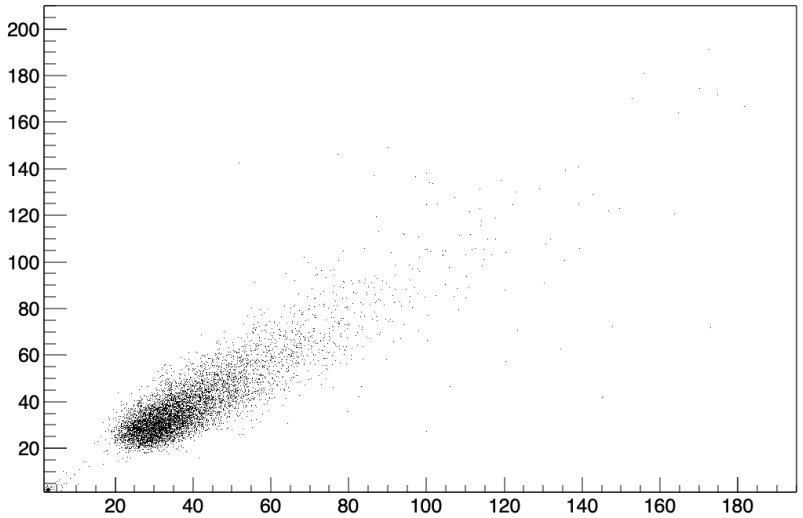
SiPM: Hamamatsu MPPC
NDL SiPM is under testing.

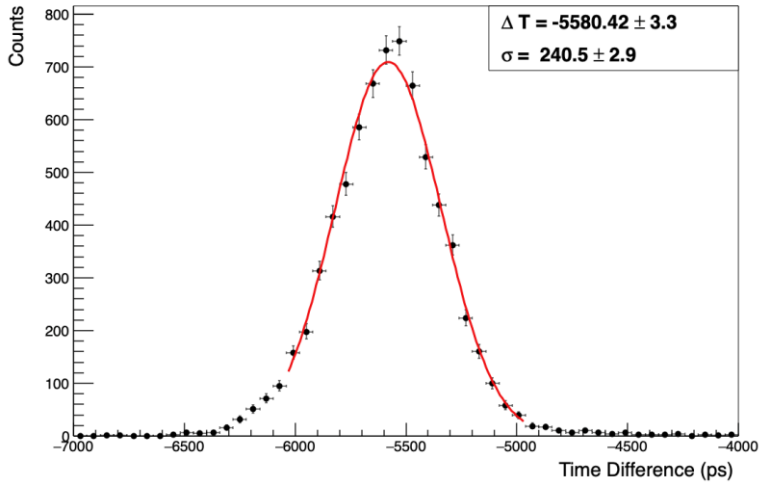
Working with GNKD to improve the scintillator.

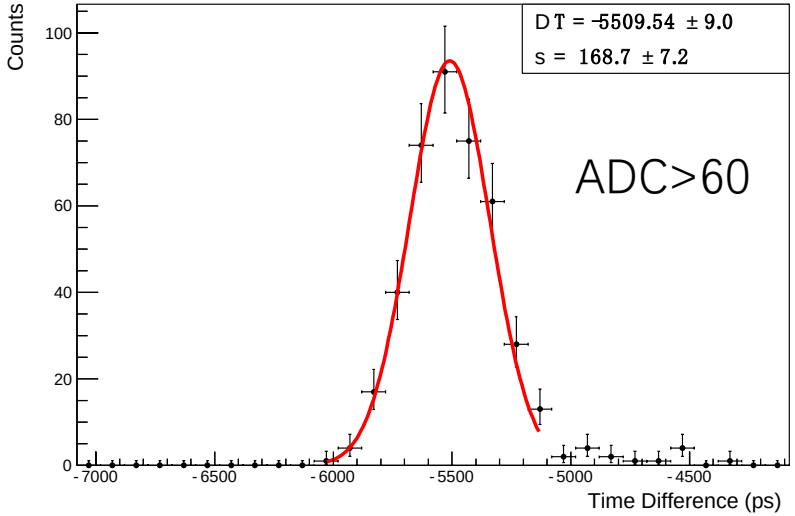
Result of long scintillator : GaoNengKeDi

ADC3:ADC4

$$\frac{T1+T2+T5+T6}{4}-\frac{T3+T4}{2}$$







$\sigma_{trg} = 73\ ps$

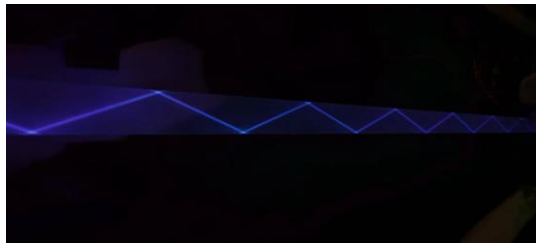
Time resolution of long strip using two end readout

$\sigma_{long} = 229\ ps$

$\sigma_{long} = 152\ ps$

Improve photon collection is effective

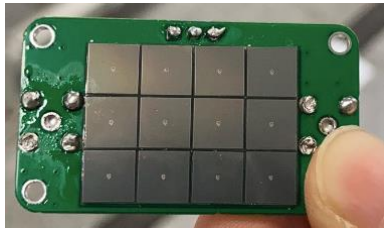
Testing on BC420 for comparison



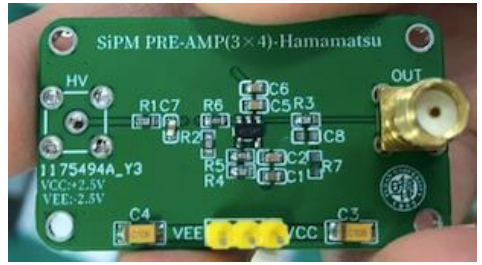
Saint-Gobain ($5 \times 4 \times 120\ cm^3$)

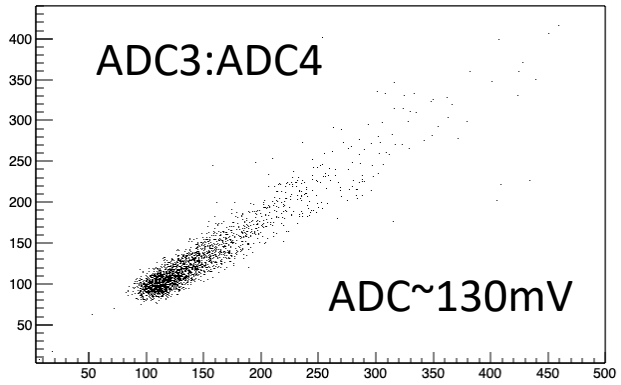
4 SiPMs in parallel

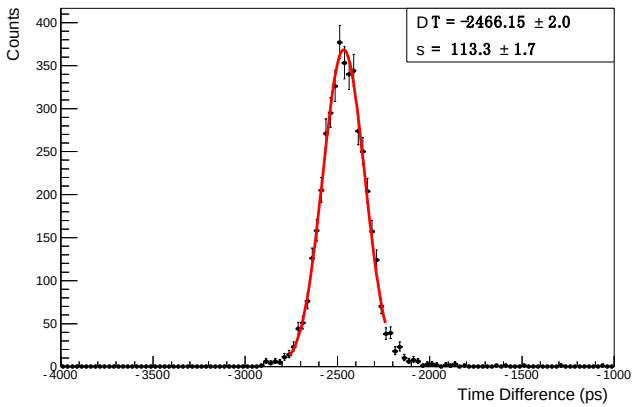
With Tin foil



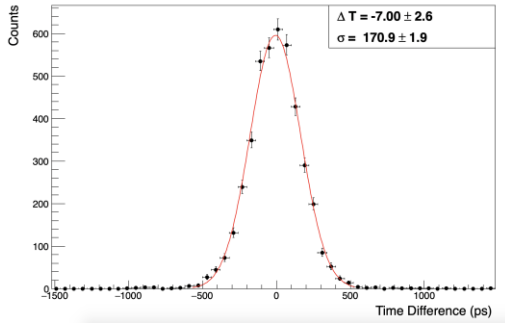
12 SiPMs in parallel

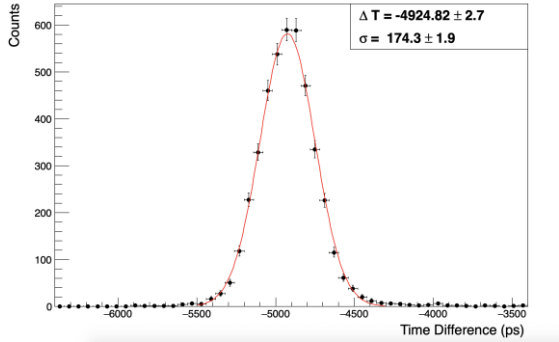






Time resolution from 3+4:
$\sigma_{long} = 87\ ps$





ΔT between 2+6 and 4 (left), or 1+5 and 3 (right)

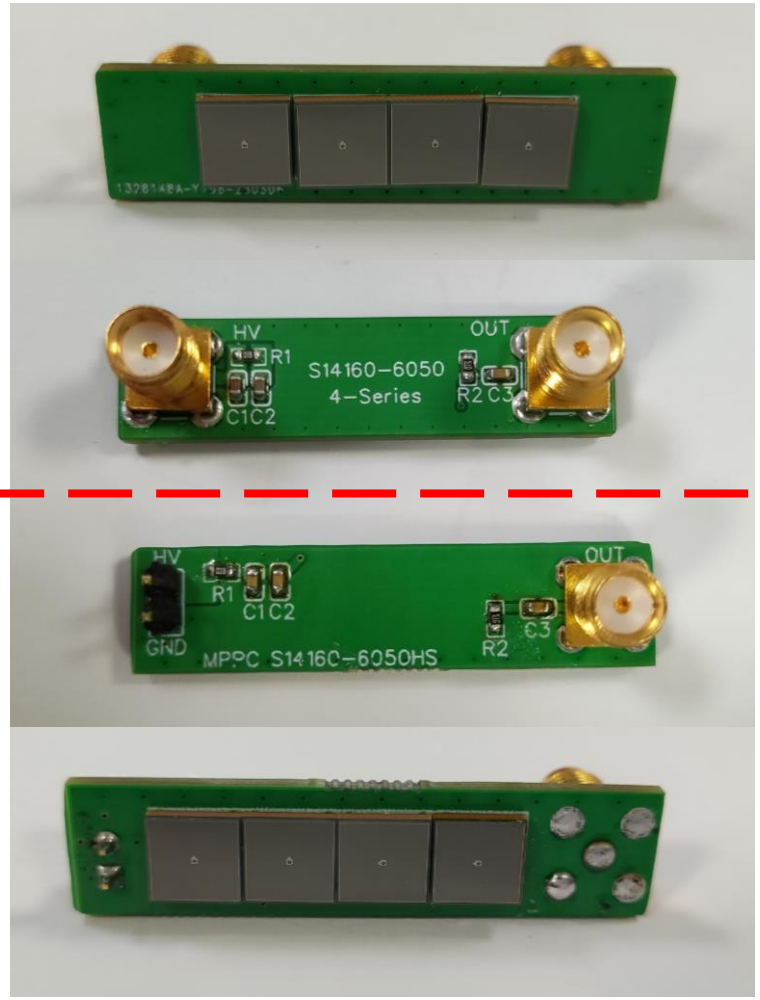
Spatial resolution according to ΔT between 3 and 4 should be $\sim 0.17 \times \frac{30}{n}\ cm$, which is 3.4cm

Improvements

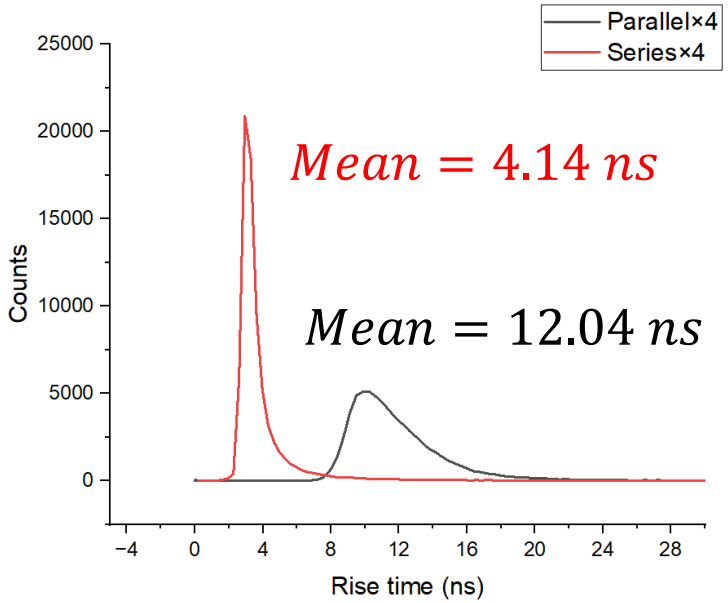
- FE readout: SiPM array, from parallel to series. Improve the rise time.
- New scintillator: attenuation length is much larger. Improve the light collection.

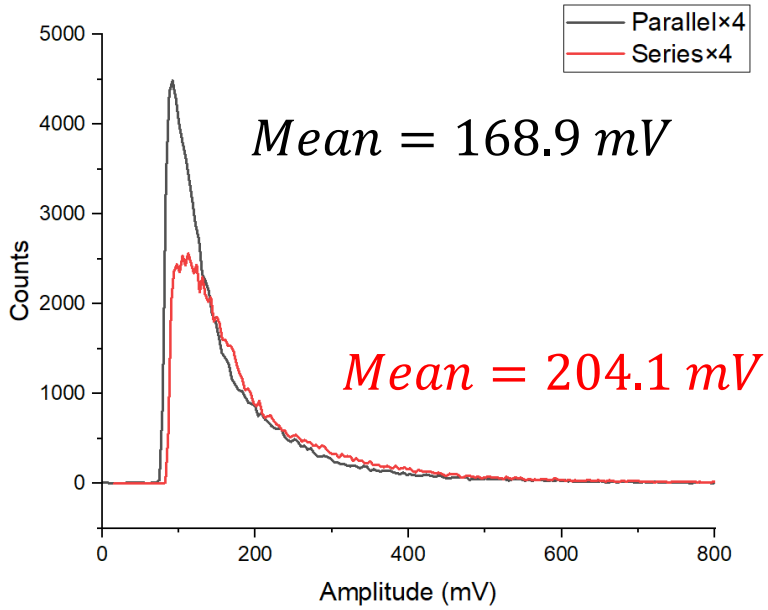
Array of SiPMs: Series vs. parallel

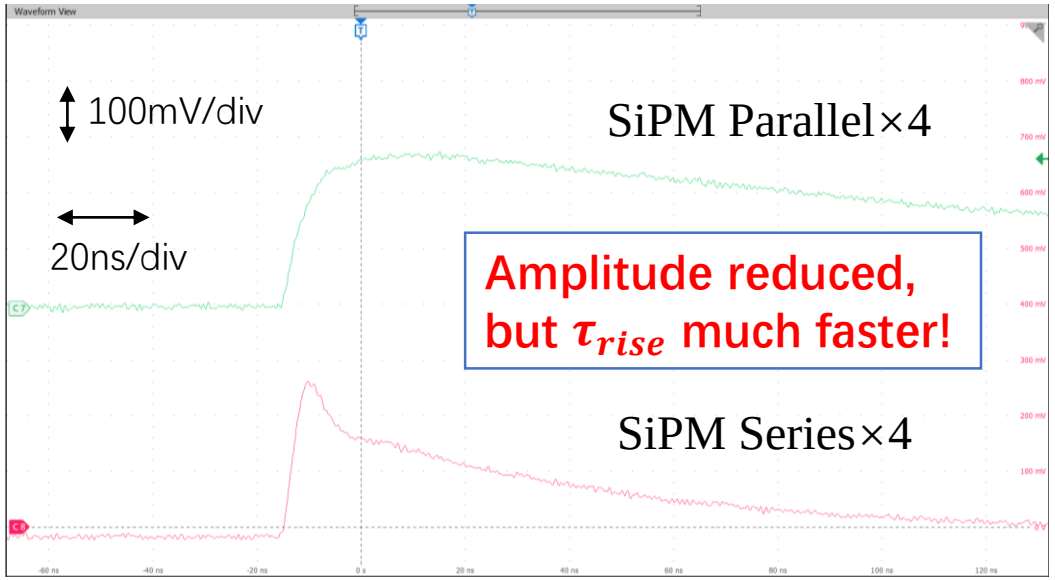
HV for series: 168V

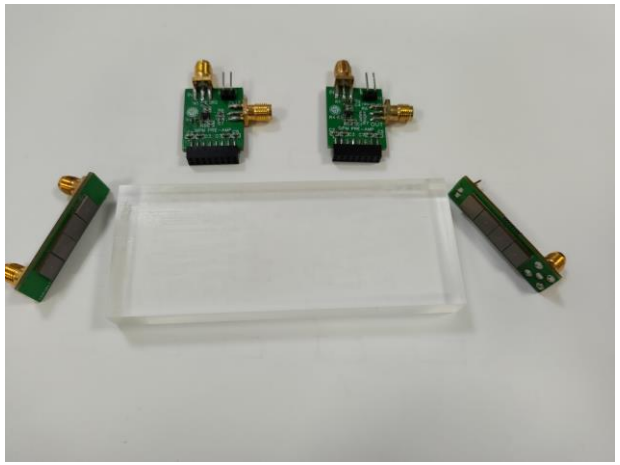


HV for parellel:+42V

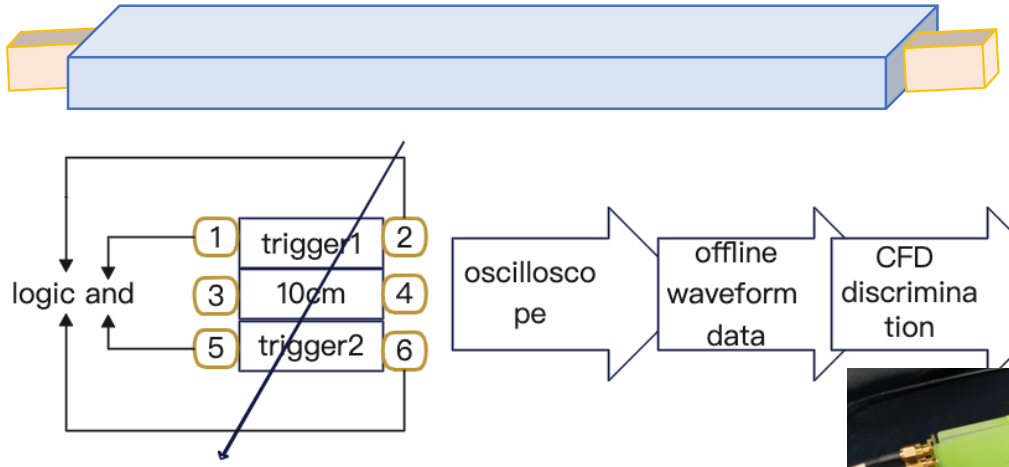


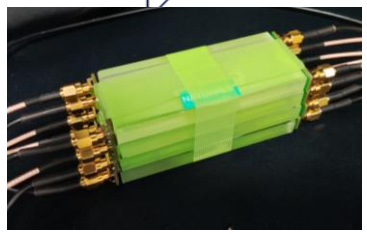


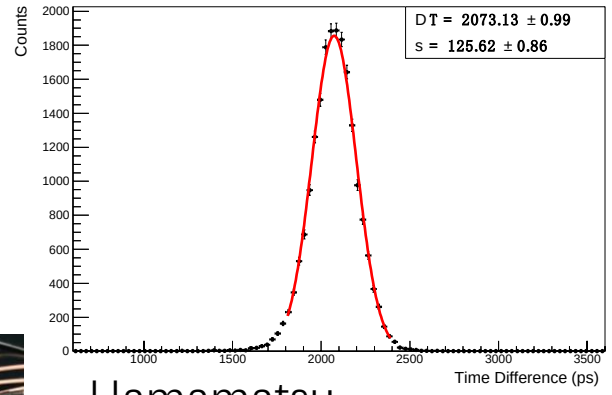




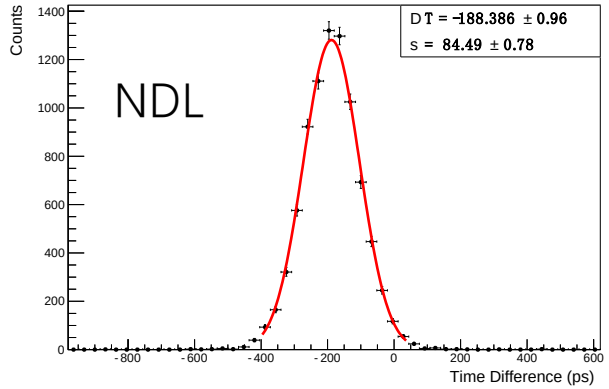
Time resolution of short strip







Hamamatsu



- 10cm triggers
- Readout from two ends
- 4 SiPMs （MPPC） in parallel / series

$$\Delta T = (T_1 + T_2 + T_5 + T_6)/4 - (T_3 + T_4)/2$$

$$\sigma^2(\Delta T) = (\sigma_1^2 + \sigma_2^2 + \sigma_5^2 + \sigma_6^2)/16 + (\sigma_3^2 + \sigma_1^2)/4$$

- Reduce the hitting position variation of the cosmic ray and the uncertainty of start time of the system.

Time resolution of short strip using two end readout $\sigma_{short} = \sigma/\sqrt{2}$

Parallel: $\sigma_{short} = 103\ ps$

Series: $\sigma_{short} = 69\ ps$

Time resolution of two triggers $\sigma_{trg} = \sigma/2$

Parallel : $\sigma_{trg} = 73ps$

Series: $\sigma_{trg} = 49ps$

For NDL in Series : $\sigma_{short} = 85.6\ ps$

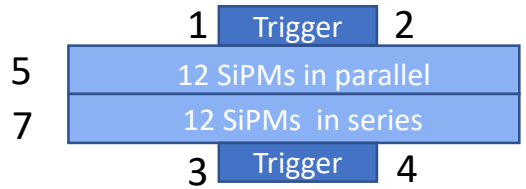
$\sigma_{trg} = 60.5ps$

Time resolution of long strip: GNKD(3cm)

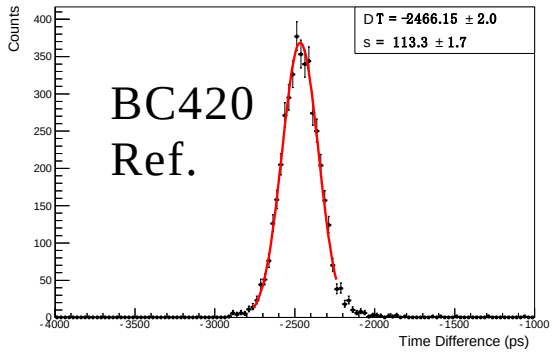
Old scint. samples

GNKD: $4 \times 3 \times 150\ cm^3$

Without polish and light guide



$\sigma_{trg} = 73ps$

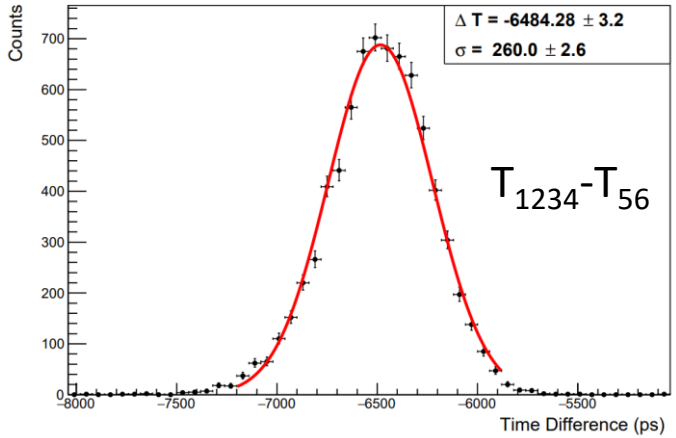


$\sigma_{long} = 87\ ps$

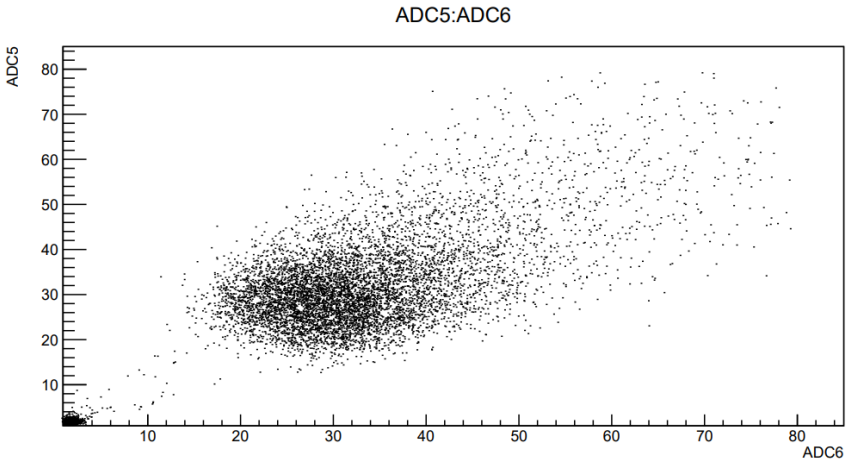
GNKD

- Longer strip
- Shorter attenuation length

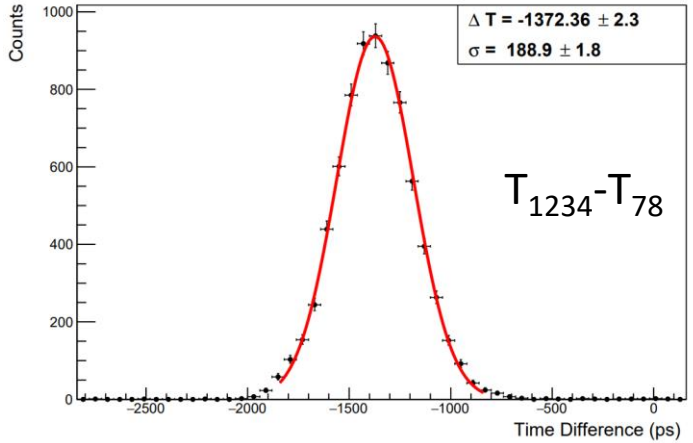
Working with GNKD to improve the scintillator.



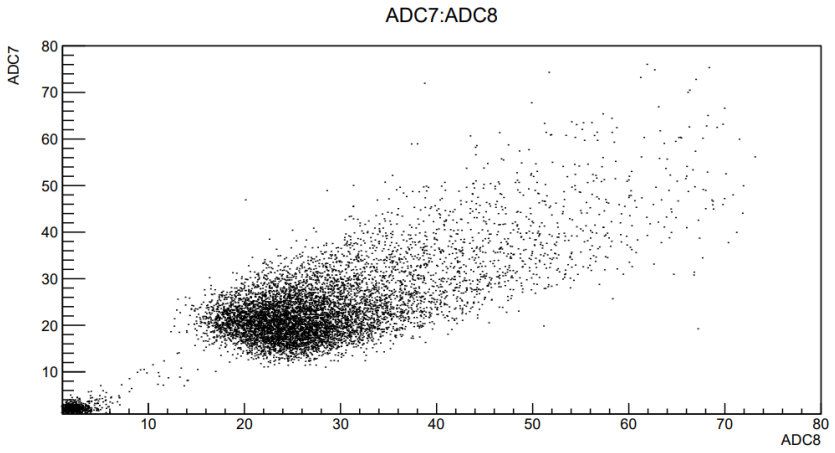
σ_{long}: 249 ps



SiPM*12 in parallel

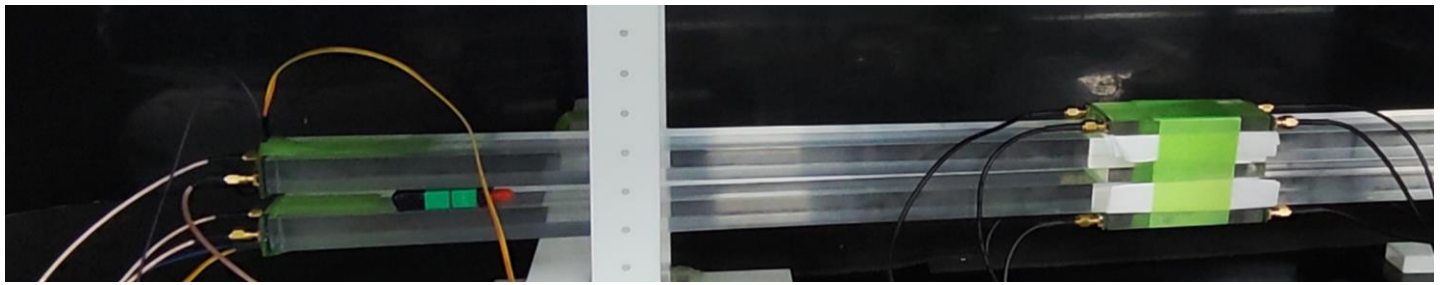


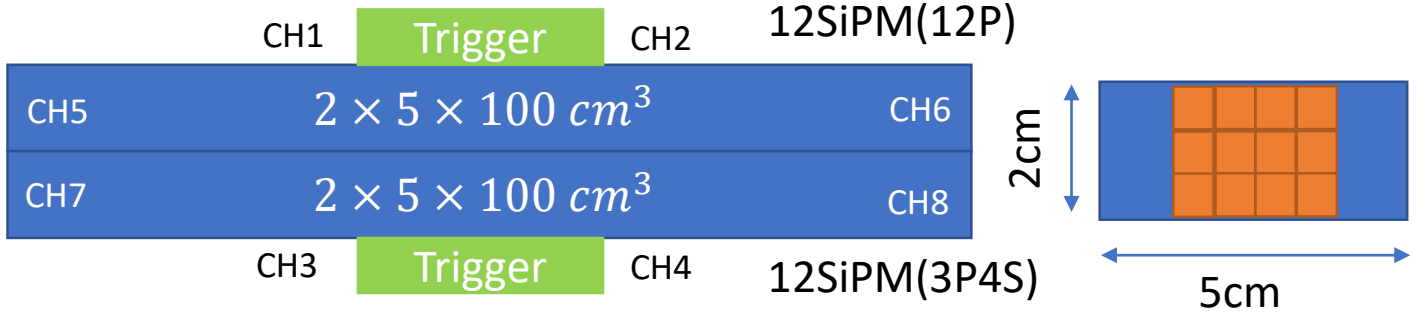
σ_{long}: 174ps

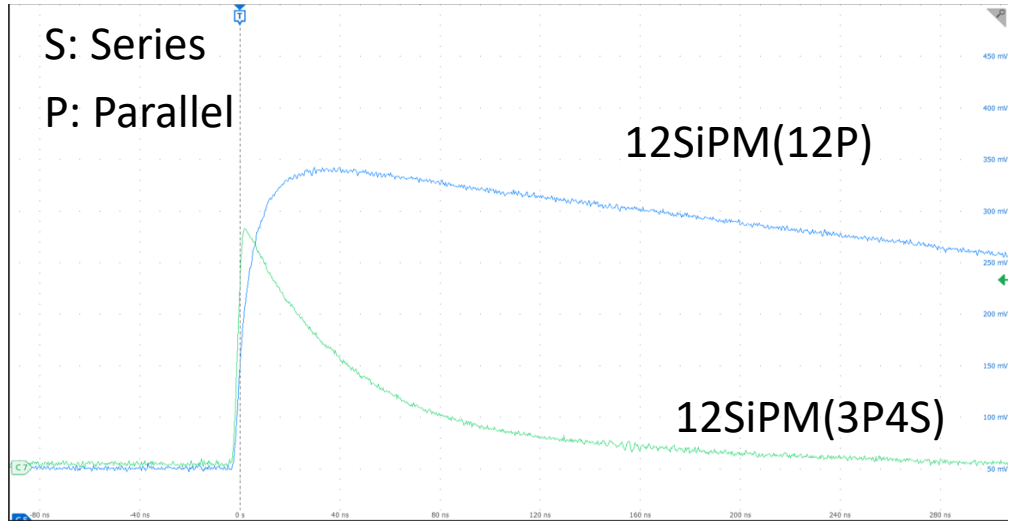


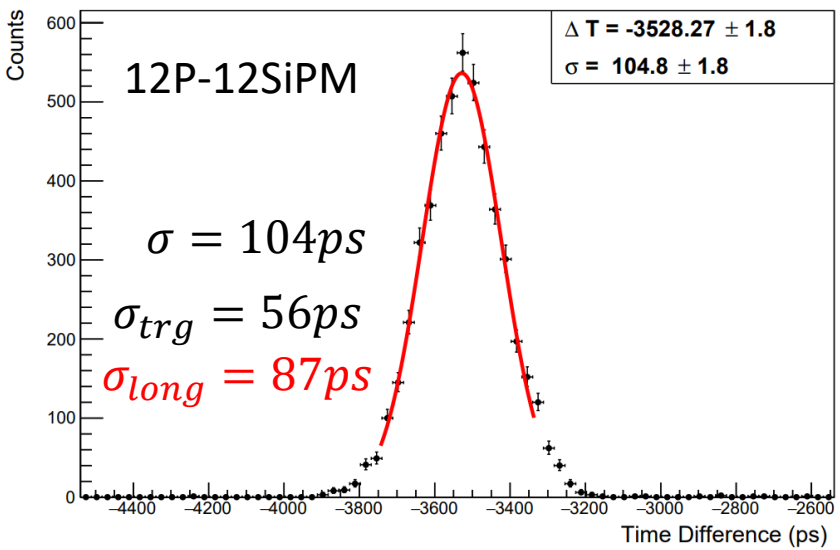
SiPM*12 in series

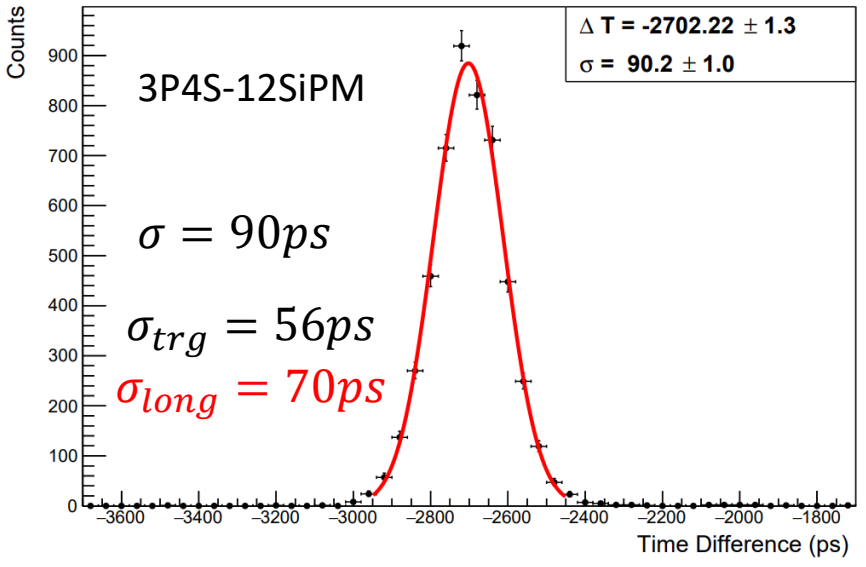
Time resolution of long strip: GNKD_new(2cm)

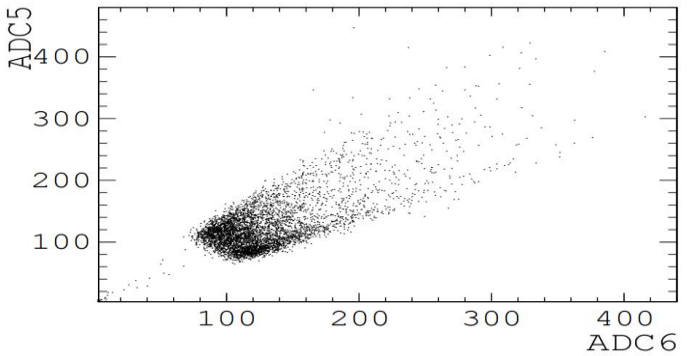


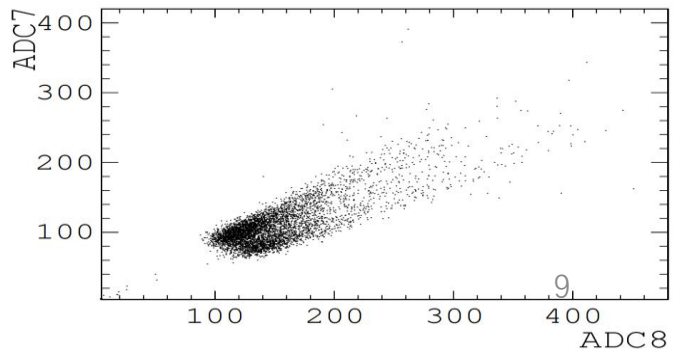




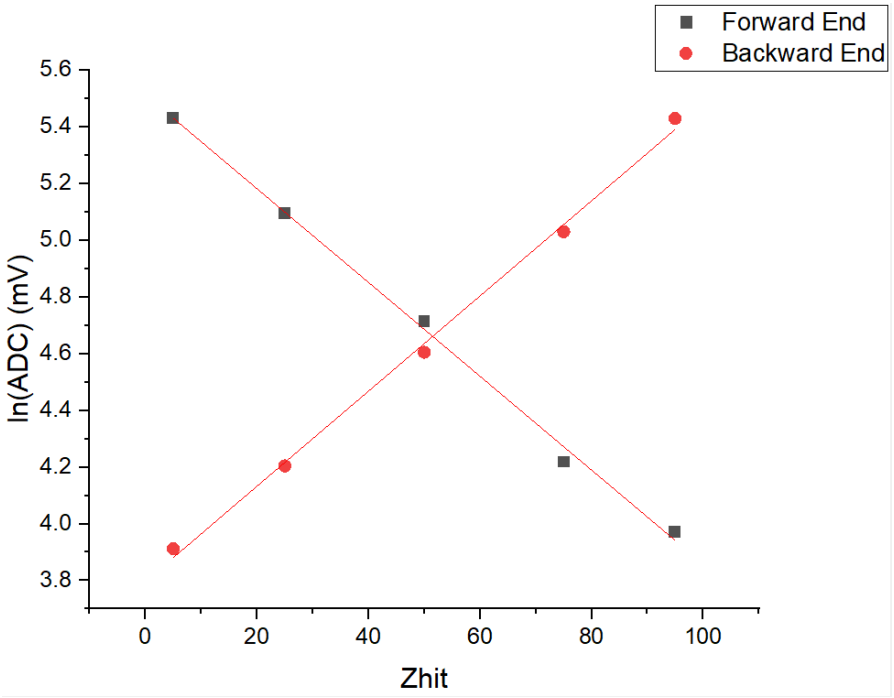




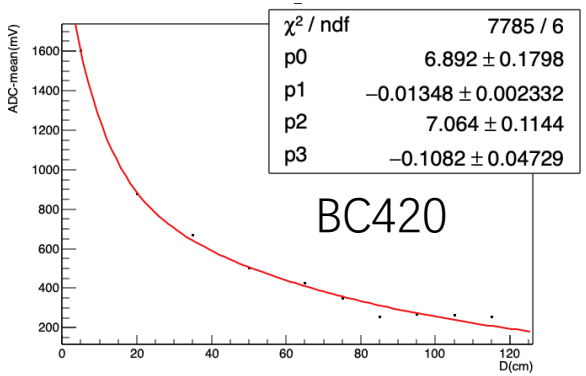




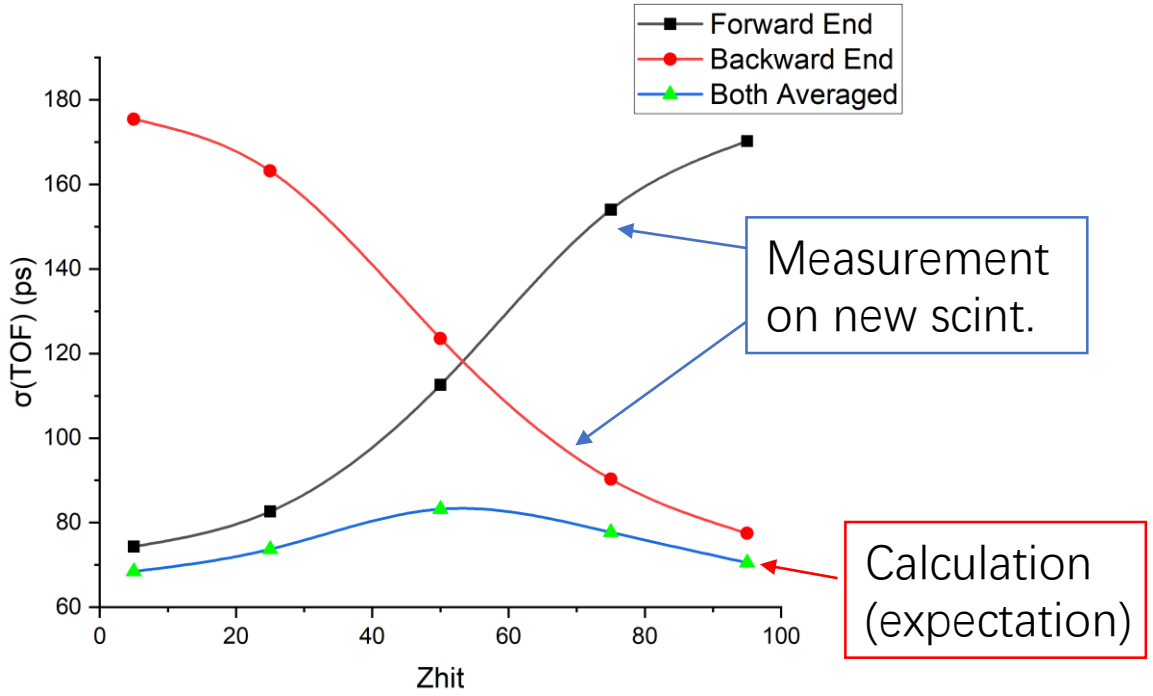
Estimation on the global σ_T



Effective attenuation length: $\mathbf{L \approx 60cm}$!!!



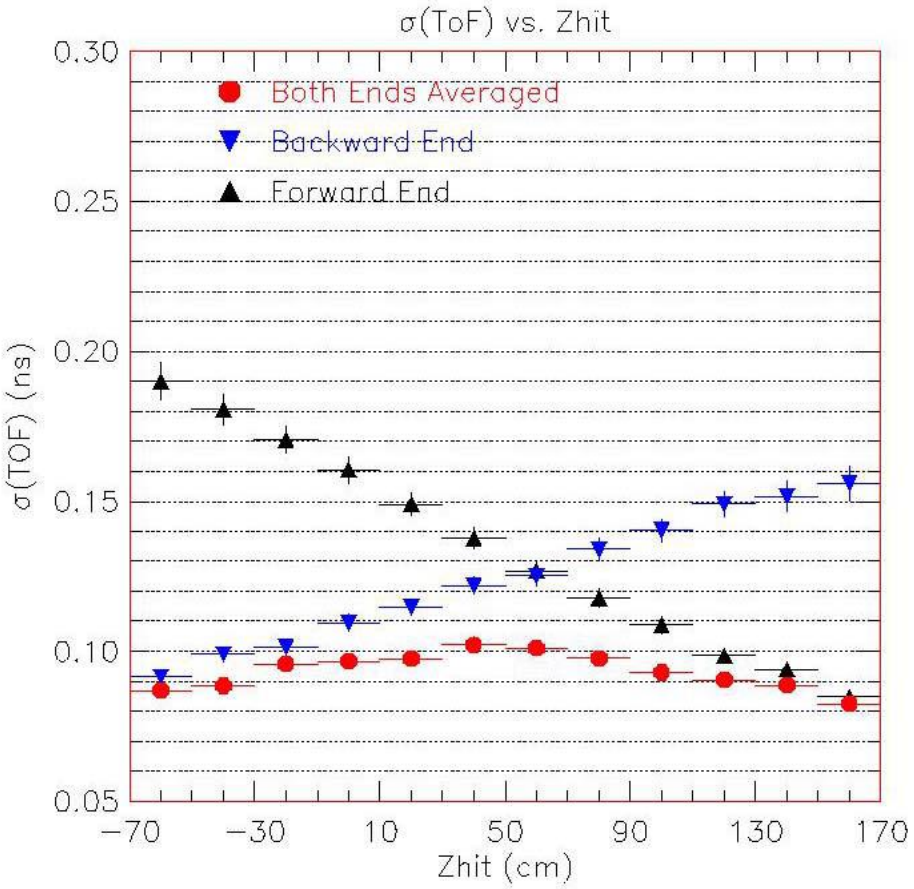
$L \approx 74cm$



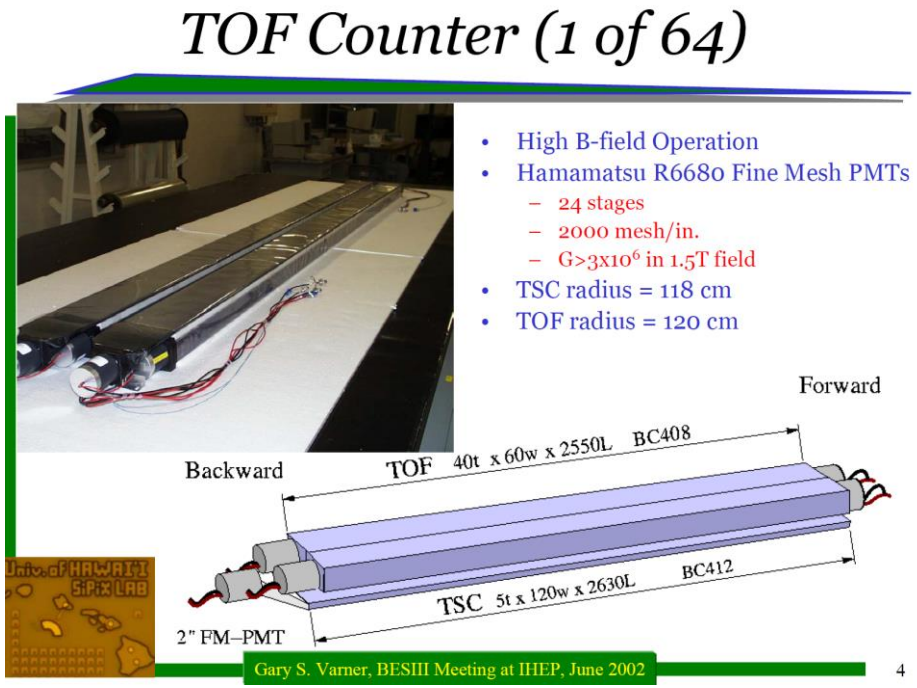
$$T_{AVG} = \frac{T_F\sigma_F^{-2} + T_B\sigma_B^{-2}}{\sigma_F^{-2} + \sigma_B^{-2}}$$

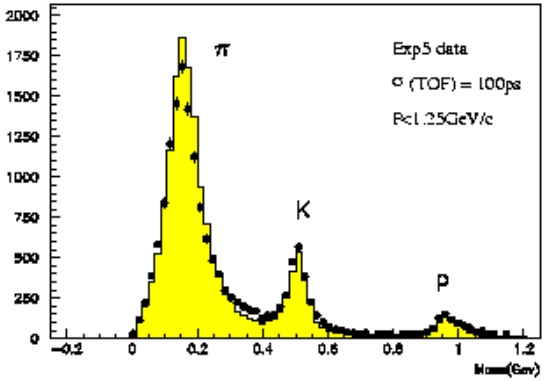
Non-center position suffers trouble from the uncertainty of hit position in trigger system.

Belle TOF for comparison



Gary Varner's talk, 20 years ago.

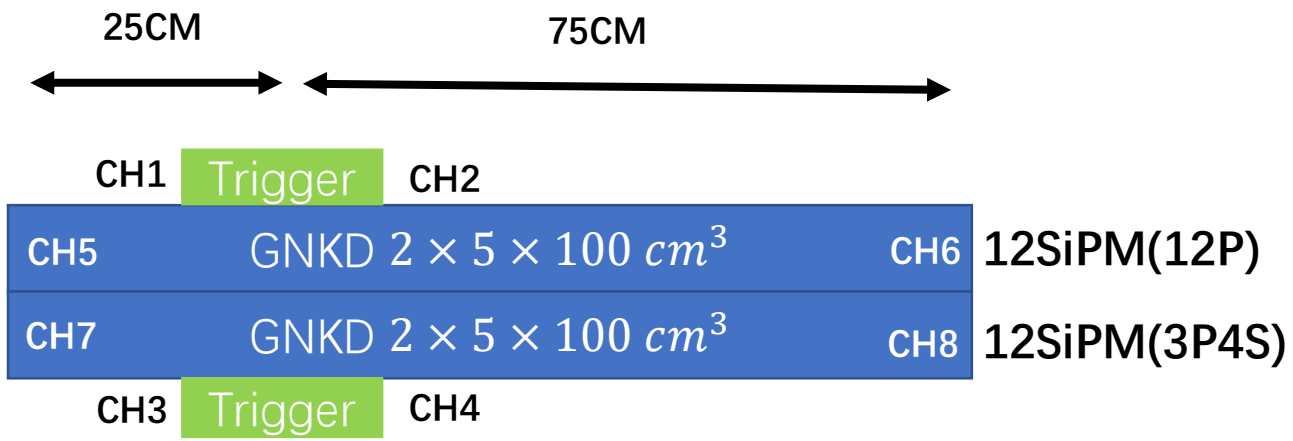




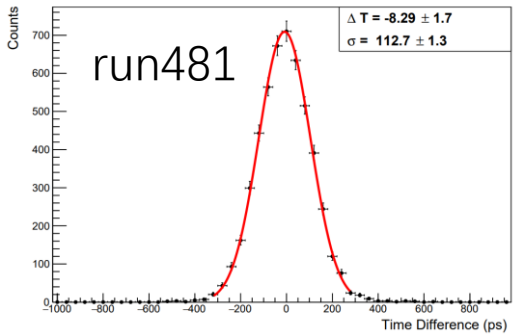
TOF scintillator (BC408)	
Base	Polyvinyl toluene
Density	1.032
Refractive index	1.58
Rise Time	0.9 ns
Decay Time	2.1 ns
Pulse Width	~2.5 ns
Atten. Length	~ 300 cm
λ Max. Emission	425 nm

FM PMT (R6680)	
Photocathode Dia.	39mm (effective)
Transit Time Spread	320 ps (rms)
Q.E.	~21%
e^- collection	0.6
Rise Time	3.5 ns
Fall Time	4.5 ns
Pulse Width	6 ns (FWHM)

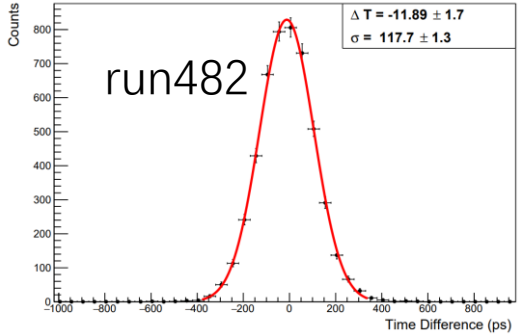
Time resolution at a new position

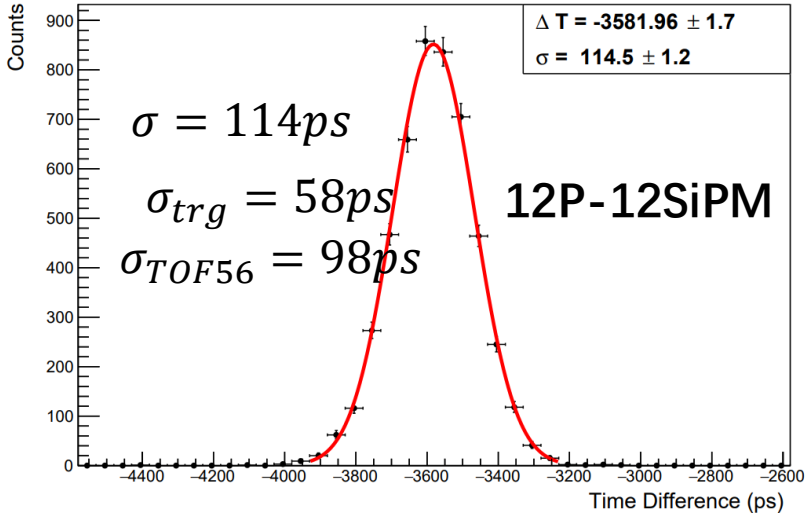


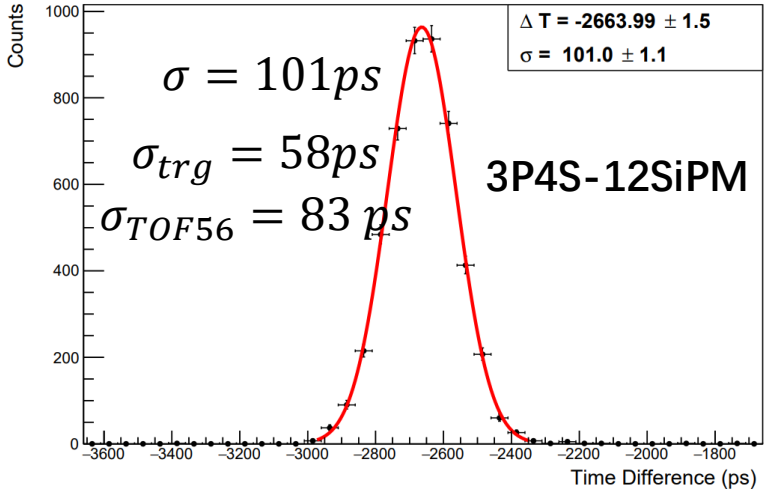
$\sigma_{trg} = 56ps$

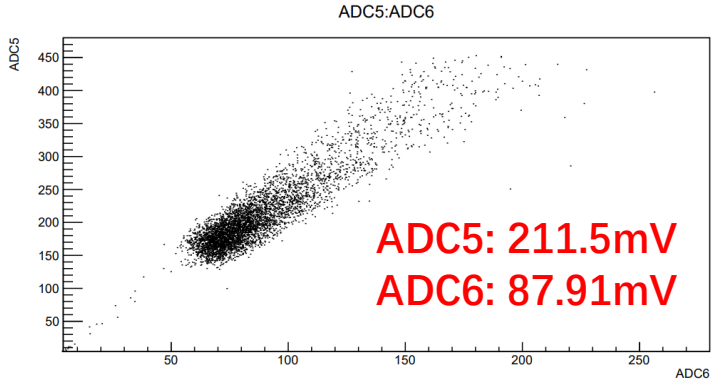


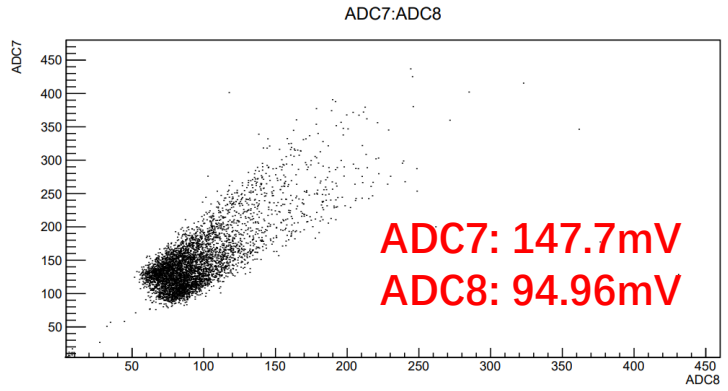
$\sigma_{trg} = 58ps$





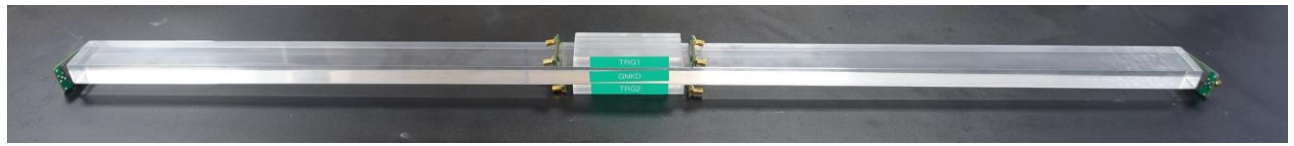


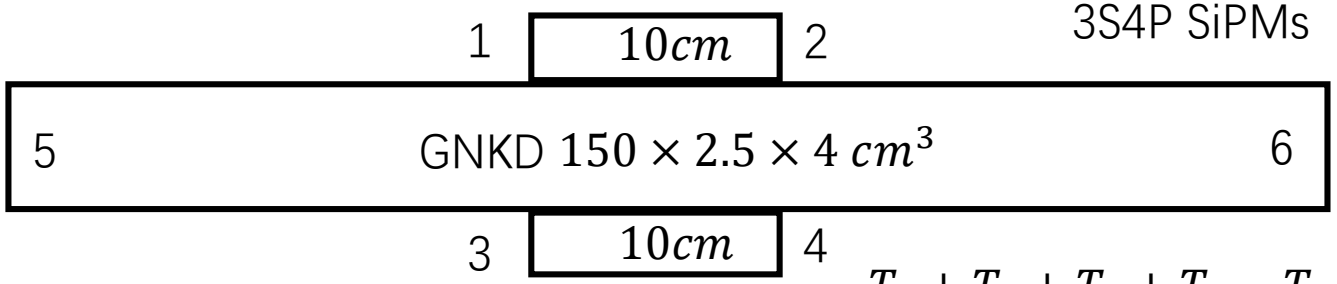




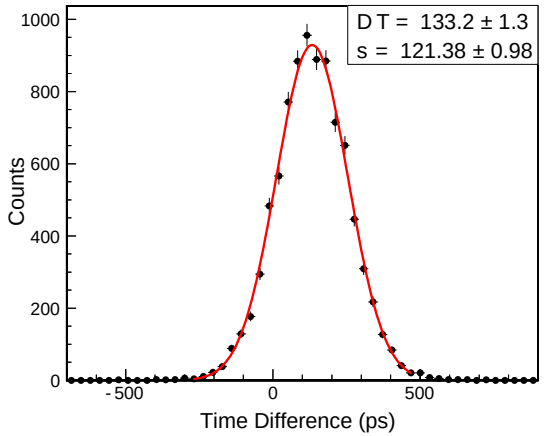
Newest testing with trigger at 85cm, $\sigma_T = 72\ ps$.
Good agreement with calculation!

Time resolution of a (new) 1.5 m scint.



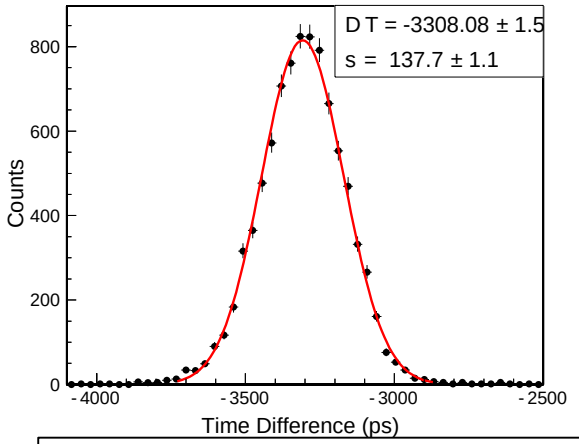


$$\frac{T_1+T_2}{2}-\frac{T_3+T_4}{2}$$



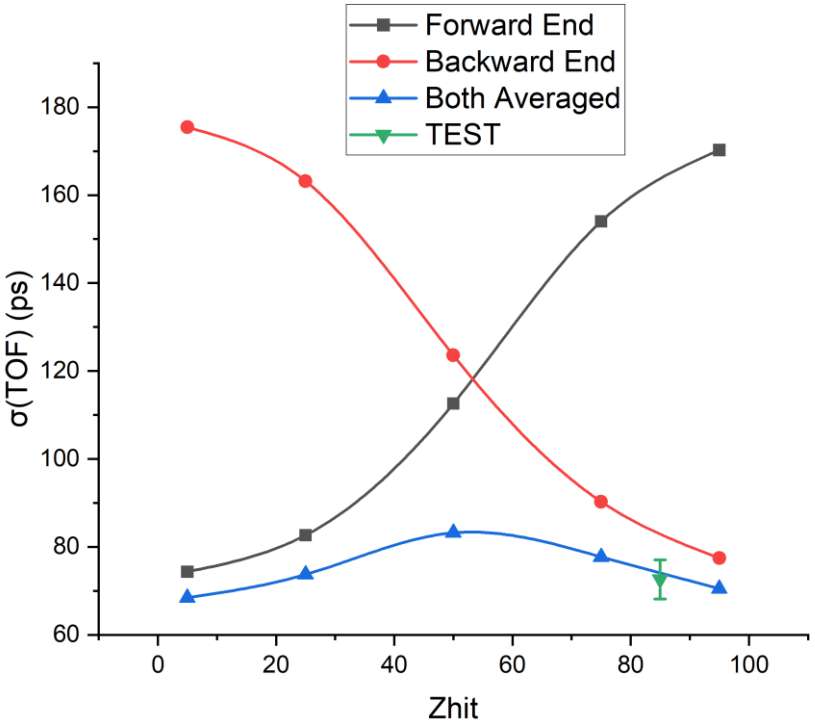
$$\sigma_{trg} = 60.7\ ps$$

$$\frac{T_1+T_2+T_3+T_4}{4}-\frac{T_5+T_6}{2}$$



$$\sigma_{TOF} = 123.6\ ps\ @75cm$$

ADC$_5$ mean: 51.8mV
ADC$_6$ mean: 47.6mV

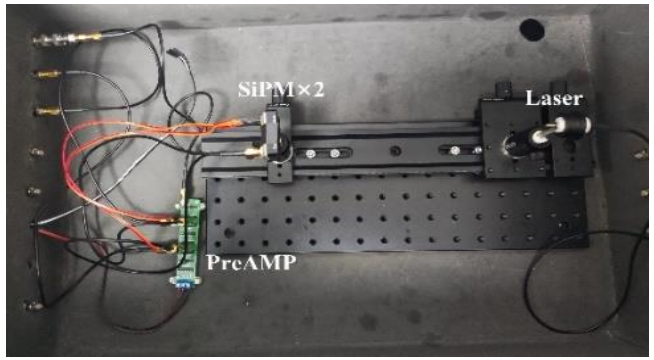


Reference: GNKD $100 \times 2 \times 4\ cm^3$
σ_{end} =163ps @75cm
$\sigma_{TOF} = \sigma_{end}/\sqrt{2}$=115ps @75cm

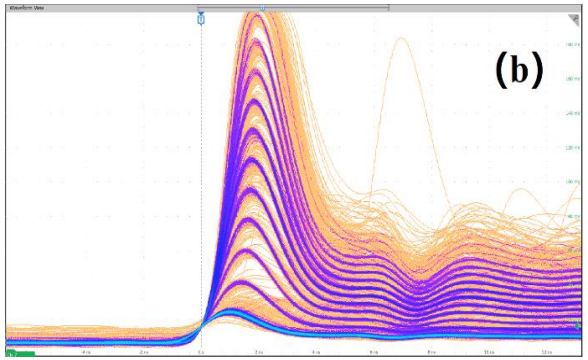
ADC mean: 66.7mV

Compared with 2cm thick GNKD,
2.5cm thick cause less photon collection and worse time resolution

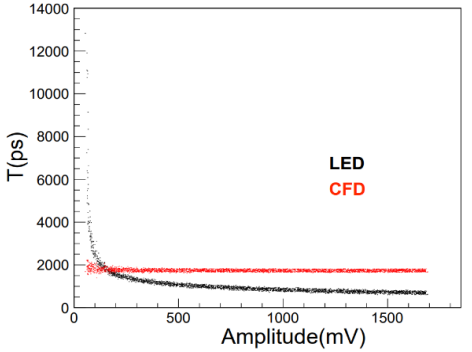
Additional: time resolution of SiPM+Pream

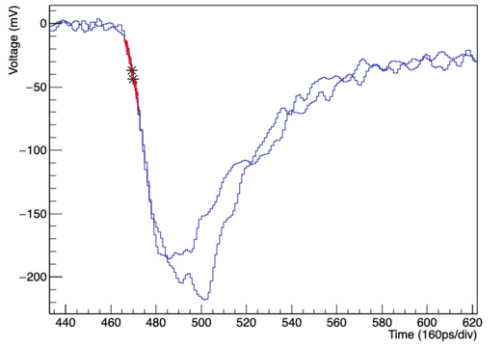


Setup of SiPM+Pream

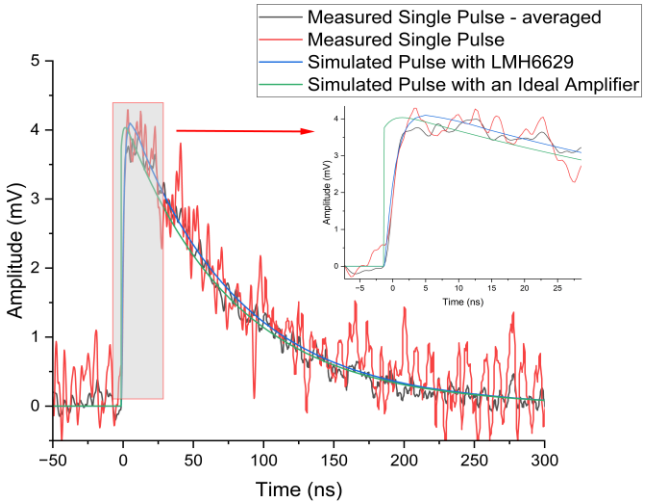


Signals in oscilloscope

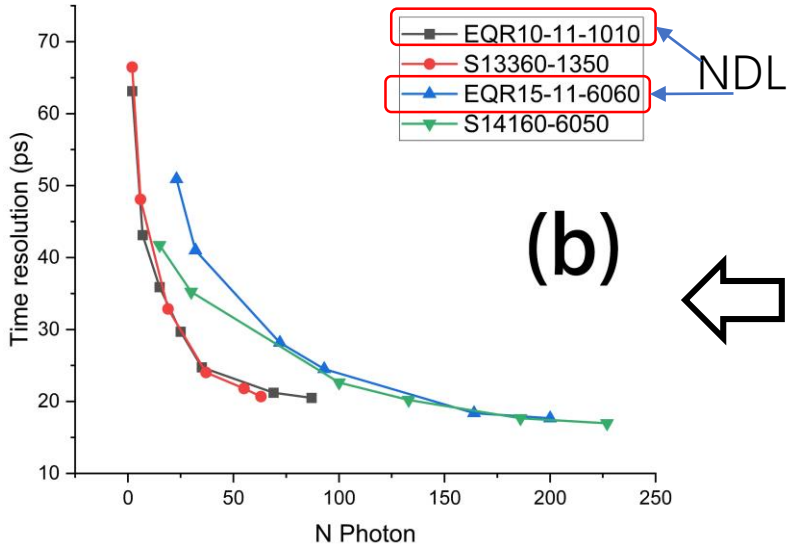




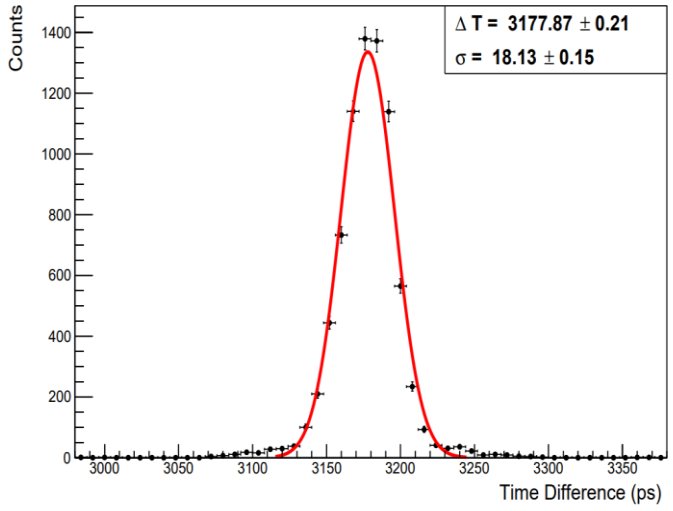
Time measurement via CFD



Signal of single photon



Time resolution versus $N_{p.e.}$



Time resolution @ $N_{p.e.} = 100$

- Small size SiPM : $N_{p.e.} > 20$, $\sigma_T \approx 30\ ps$
- Large size SiPM : $N_{p.e.} > 50$, $\sigma_T \approx 30\ ps$ (different at noise level, DCR, etc)

Summary

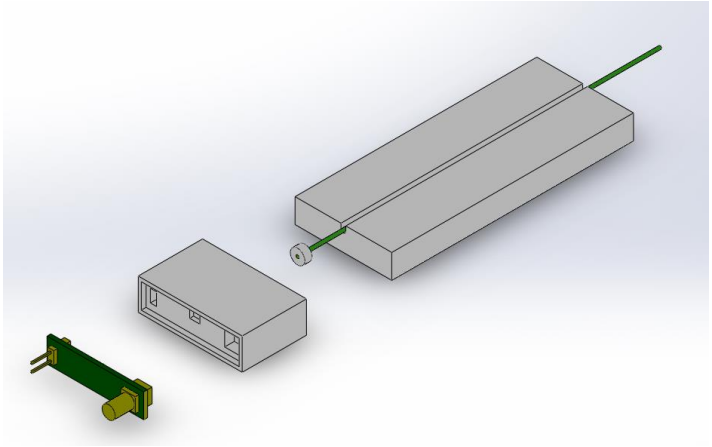
- The readout is upgraded with new array of SiPMs: series+parallel, hybrid.
- New scintillator from GNKD shows very good improvement in attenuation length.
- We have achieve time resolution better than $80\ ps$ from 1 meter new scintillator.
- New $1.5m$ long scintillator shows a time resolution of $124\ ps$ at the middle.

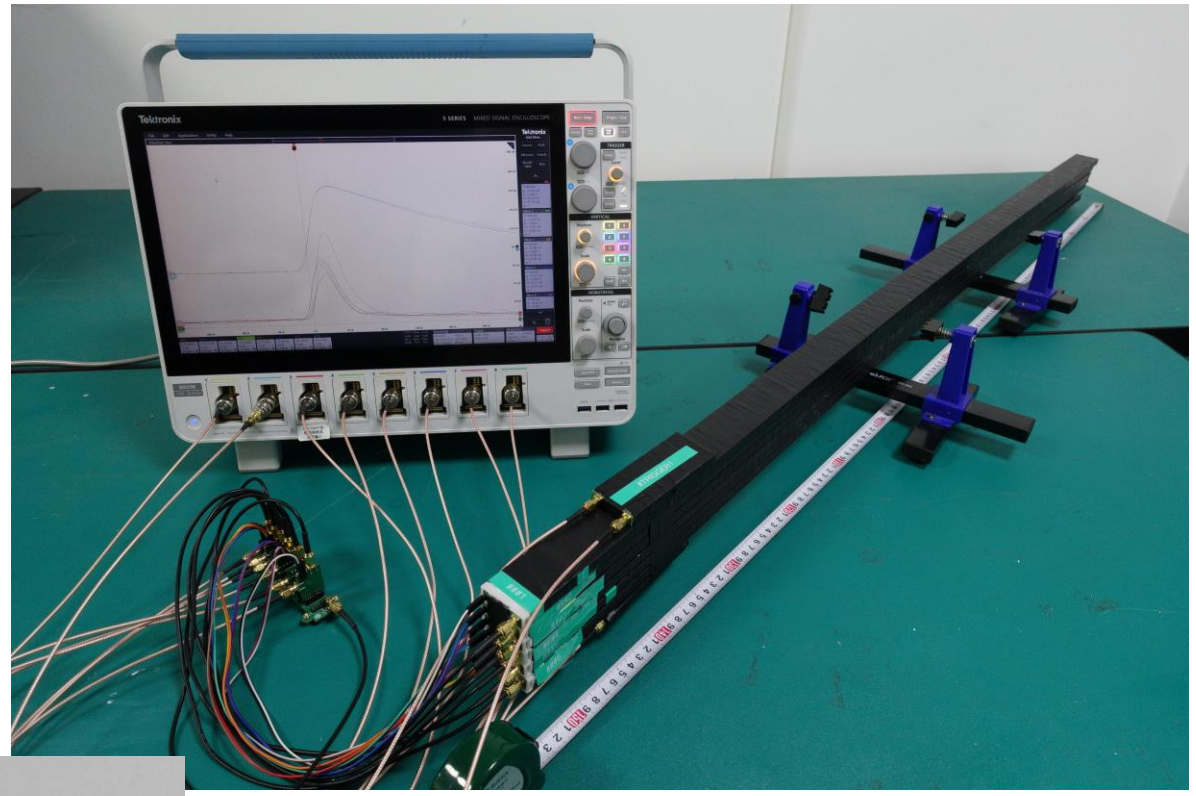
Thank you!

- Backup

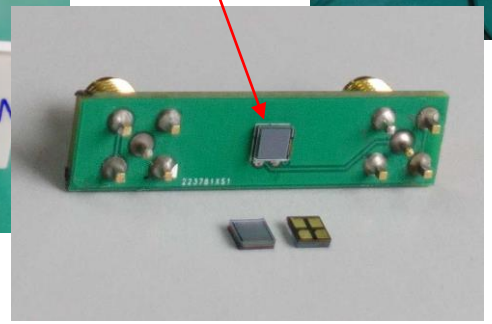
Status of R&D: Regular design

- GNKD scintillator + Kuraray WLS fibre + NDL SiPM($3mm \times 3mm$)

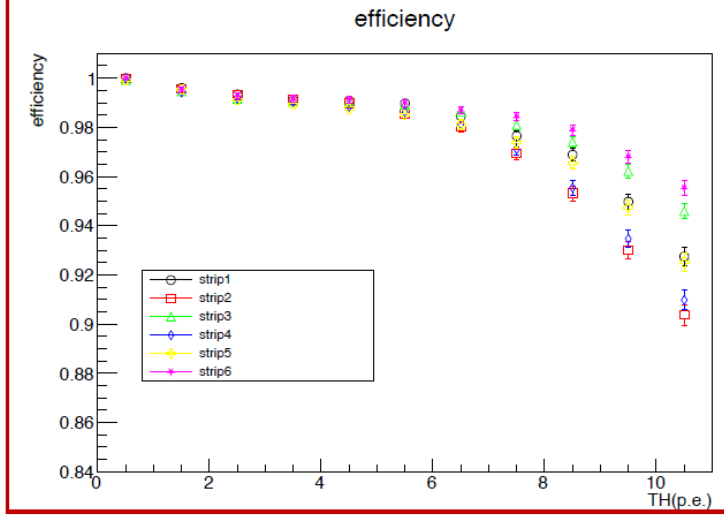


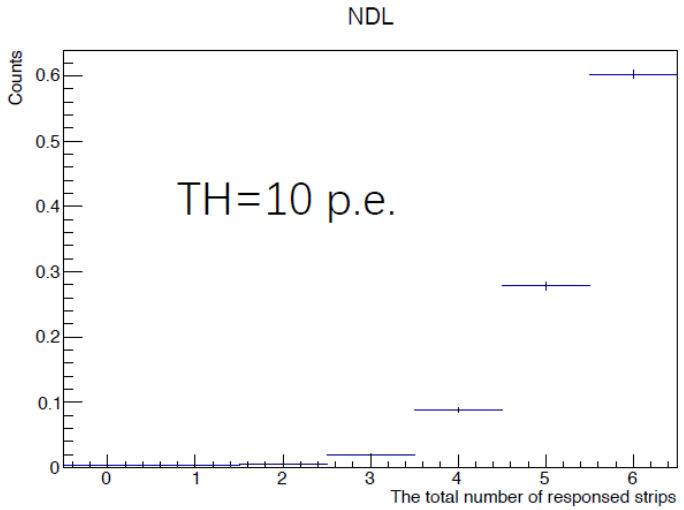


$3mm \times 3mm$
NDL SiPM



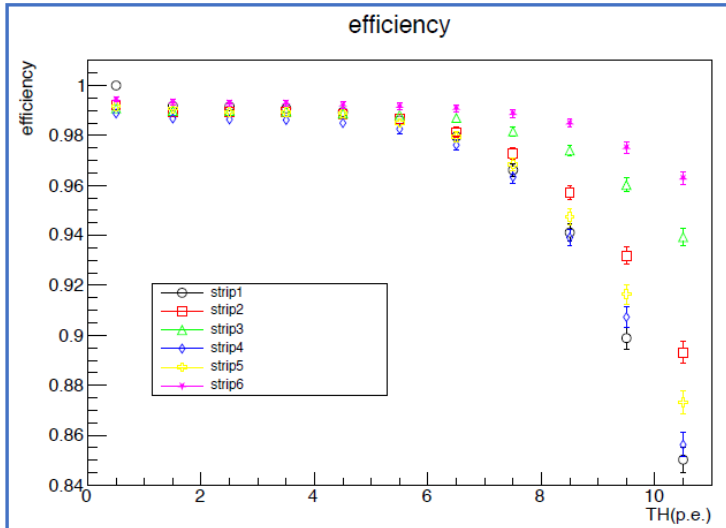
efficiency



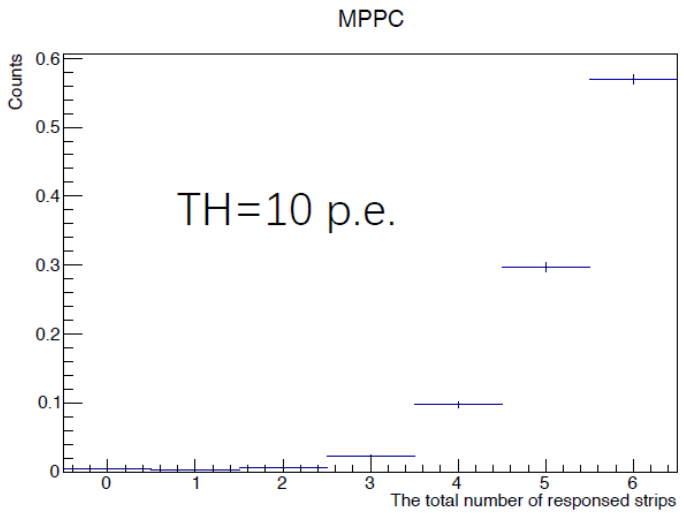


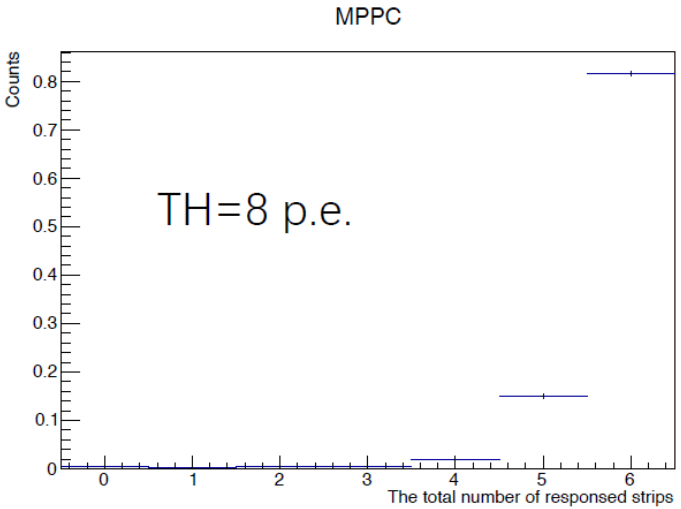
NDL

MPPC



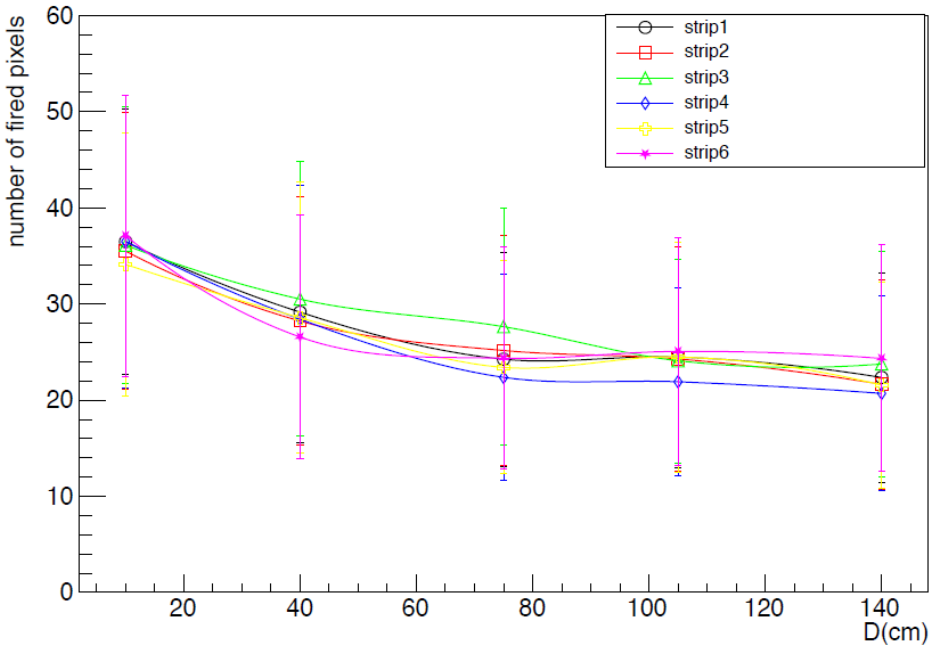
140cm处



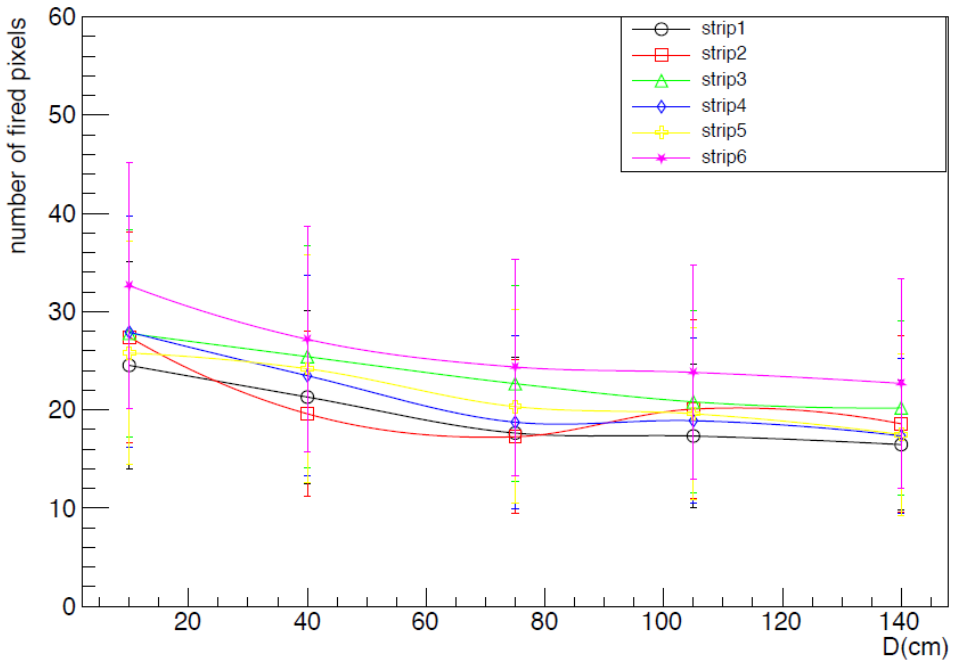


ADC distribution

Cross talk of about 21%

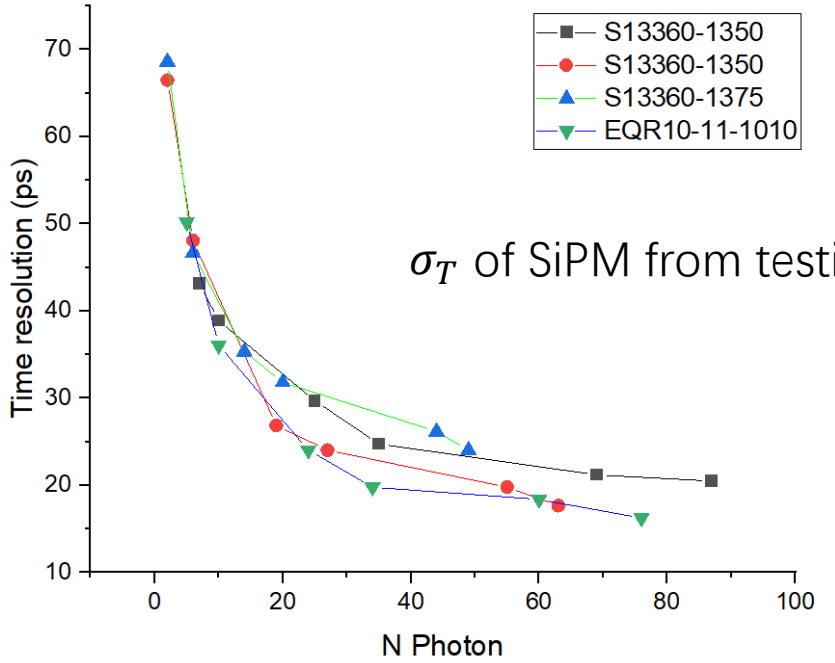


NDL

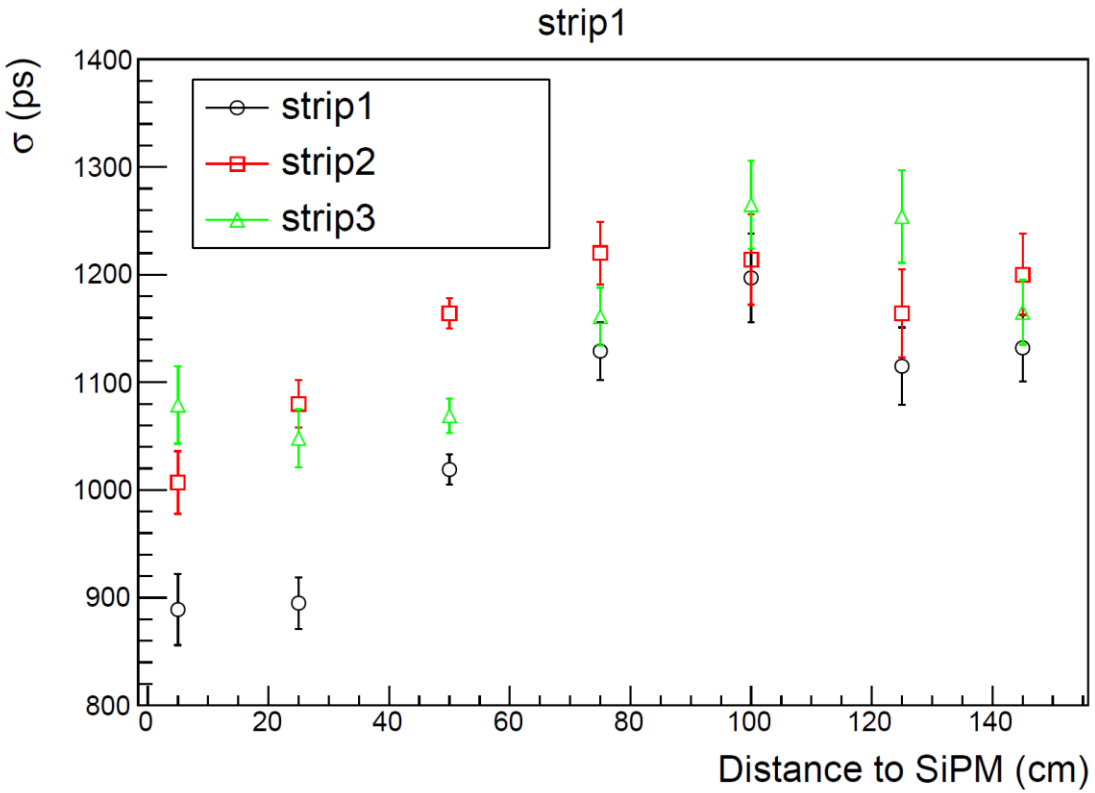


MPPC

Time resolution

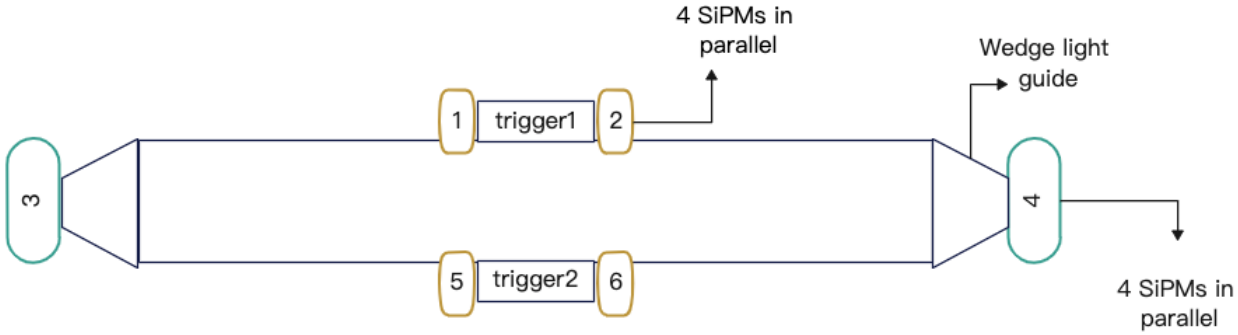


σ_T of SiPM from testing

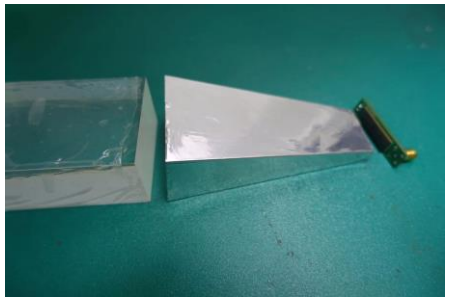


$3mm \times 3mm$ allows more fibre to increase the efficiency and the time resolution.

Time resolution of long strip： S-G + 4SiPMs

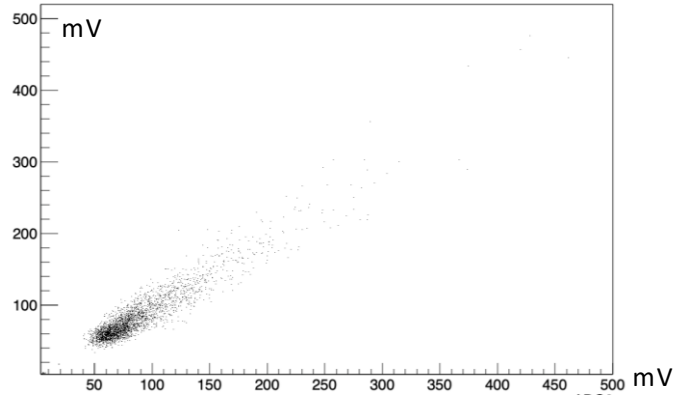


Saint-Gobain ($5 \times 3 \times 120\ cm^3$)



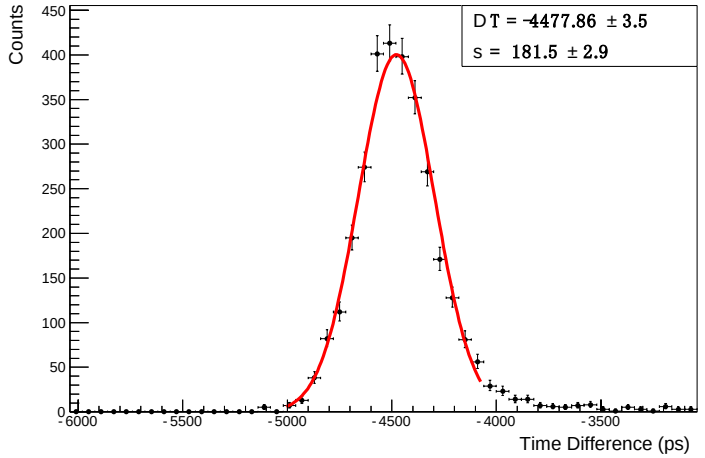
BC420
Attenuation length： 1.1m

For beeter light collection
- Wedge light guide
- 4 SiPMs in parallel



ADC3:ADC4

$\Delta T=(T1+T2+T5+T6)/4-(T3+T4)/2$



Time resolution of long strip using two end readout

σ_{long}=165 ps

- Trigger at middle
- signals generated from the middle of the bar would give out the worst time resolution.