Time resolution of long scintillator

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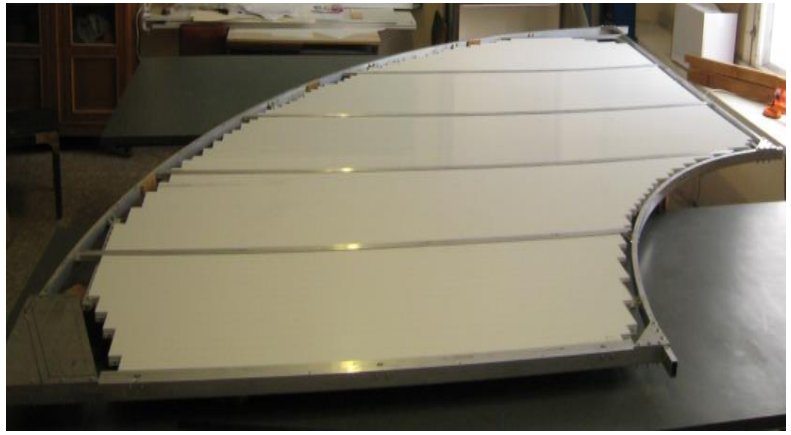
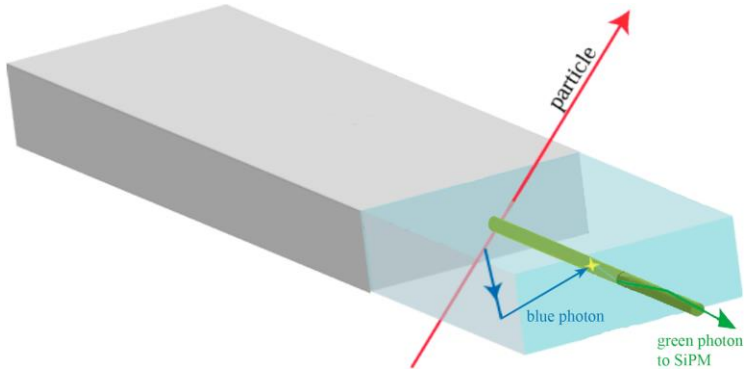
CEPC Day, 11/25/2022

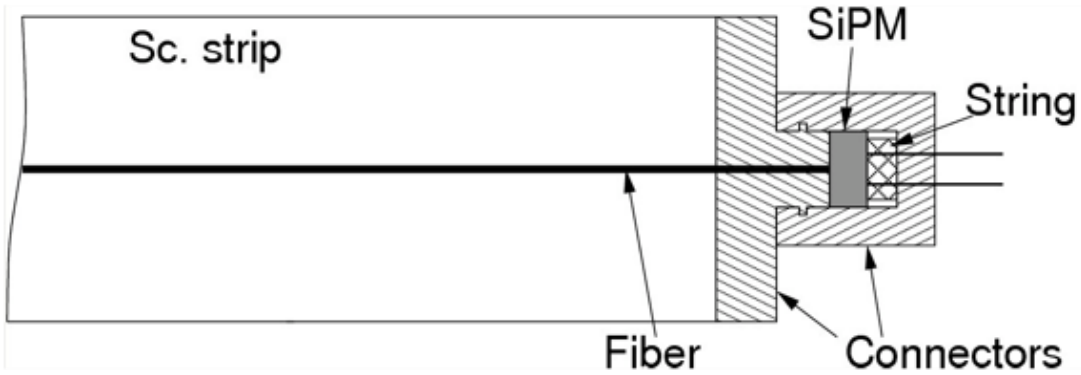
Two types of scintillator detector

1. Regular design as the Belle II KLM scintillator detector
2. A new TOF-like design for high time resolution

Regular design

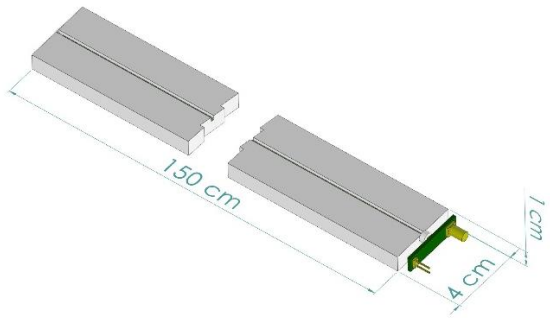




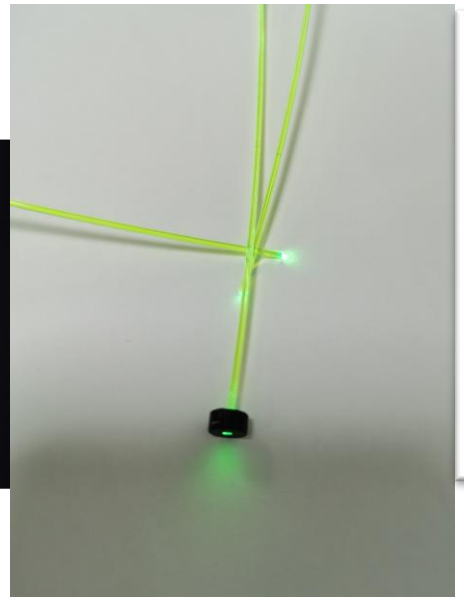


R&D for KLM-like detector based on scintillator

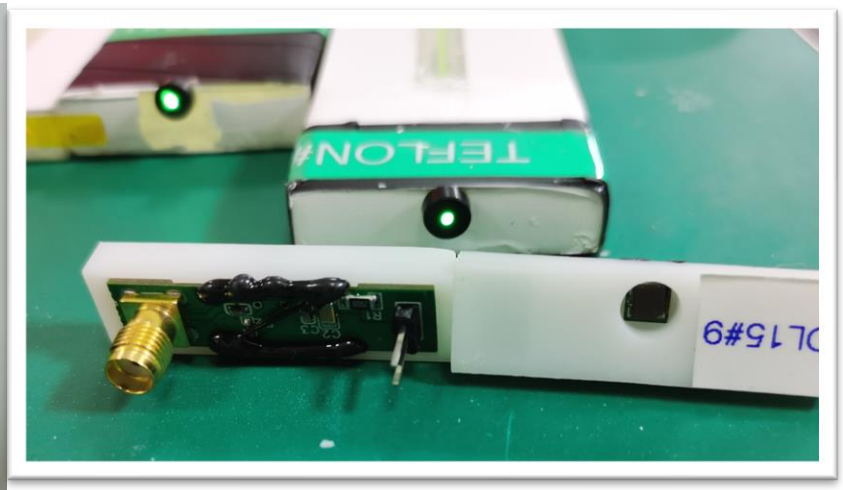
scintillator + WLS fiber + SiPM

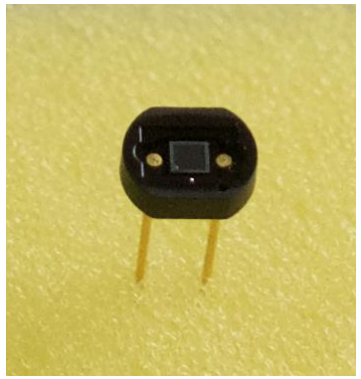


Reflective layer

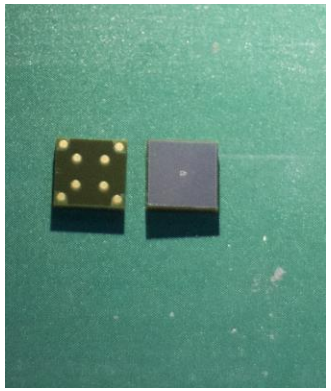


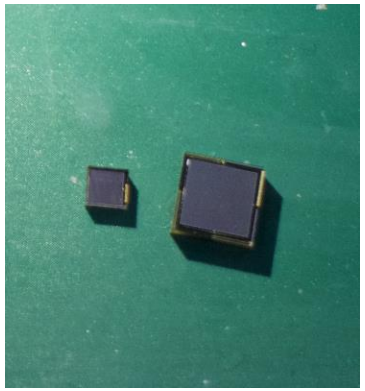
WLS fiber



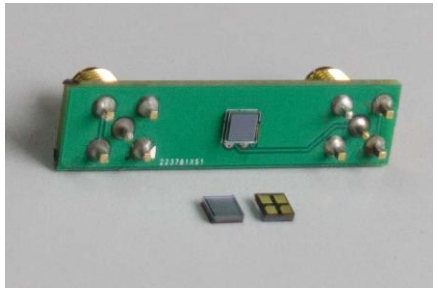


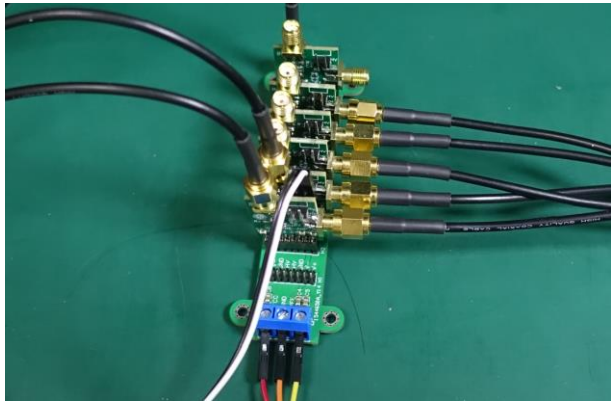
Hamamatsu S11360-1325/50/75cs





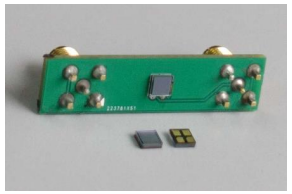
NDL SiPMs

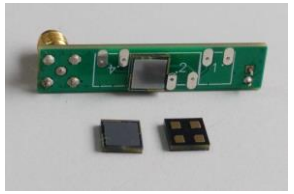




Preamplifier

Use the NDL SiPM





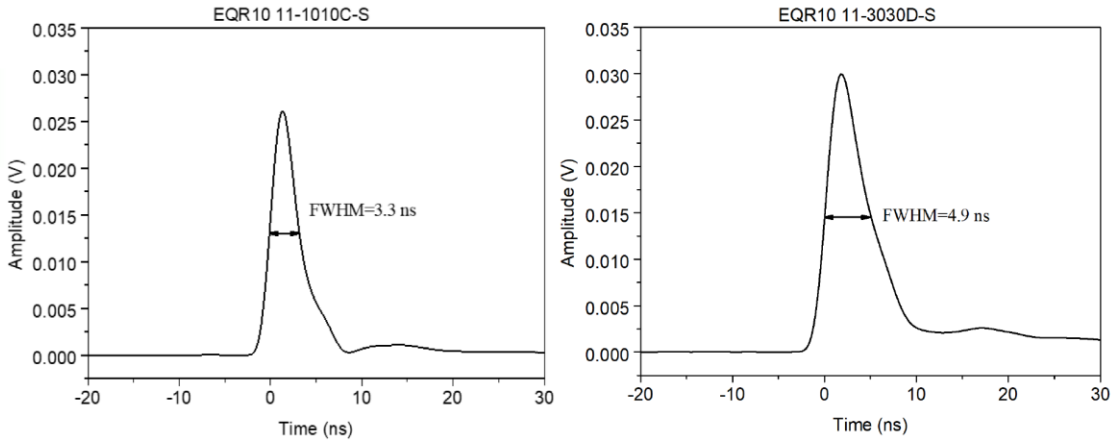
Specifications

Type	EQR10 11-1010C-S	EQR10 11-3030D-S
Effective Pitch	10 μm	
Element Number	1×1	1×1
Active Area	1.0×1.0 mm^2	3.0×3.0 mm^2
Micro-cell Number	10000	90000
Breakdown Voltage (V_B)	26.4 ± 0.4 V	28.5 ± 0.5 V
Temperature Coefficient for V_B	21 mV / ℃	19 mV / ℃
Recommended Operation Voltage	V_B + 6 V	V_B + 12 V
Peak PDE @420nm	32 %	36 %
Gain	2.0 × 10^5	1.7 × 10^5
Dark Count Rate (DCR)	500 kHz / mm^2	400 kHz / mm^2
Terminal Capacitance	7 pF	31 pF

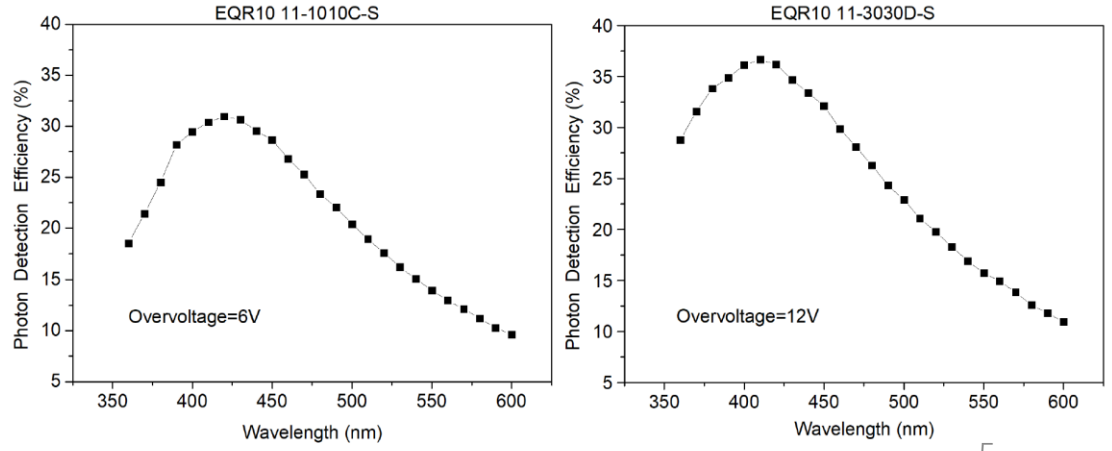
Above parameters are measured at their recommended operation voltage and 20 ℃.

The EQR10 11-1010C-S can operate at 77 K.

Characteristics



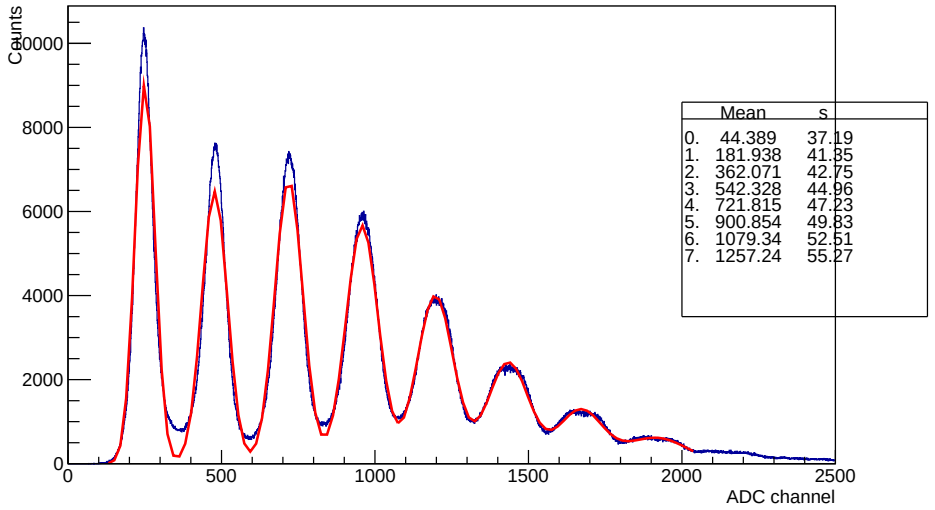
The single photoelectron pulse (amplified by a 40dB fast amplifier).

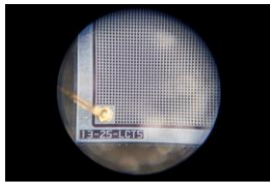


The PDE versus overvoltage and wavelength, deducted crosstalk and afterpulse and measured at 20 ℃ .

Comparison between NDL SiPM and Hamamatsu MPPC

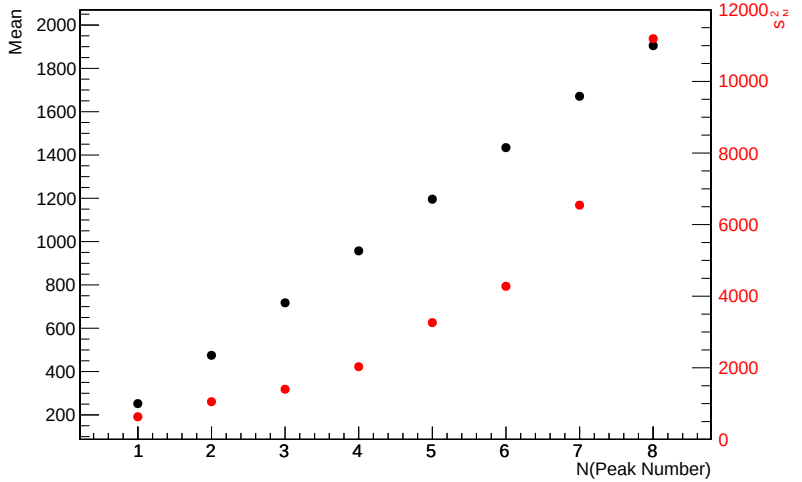
QDC distribution using DT5725

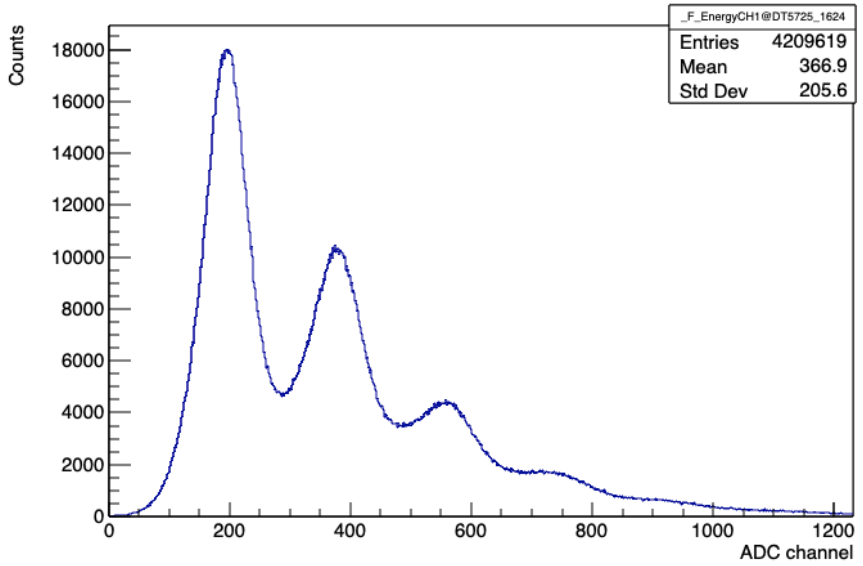


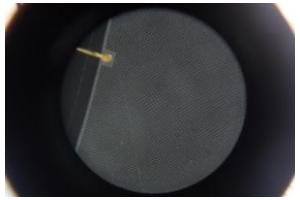


MPPC
1.3*1.3 mm^2

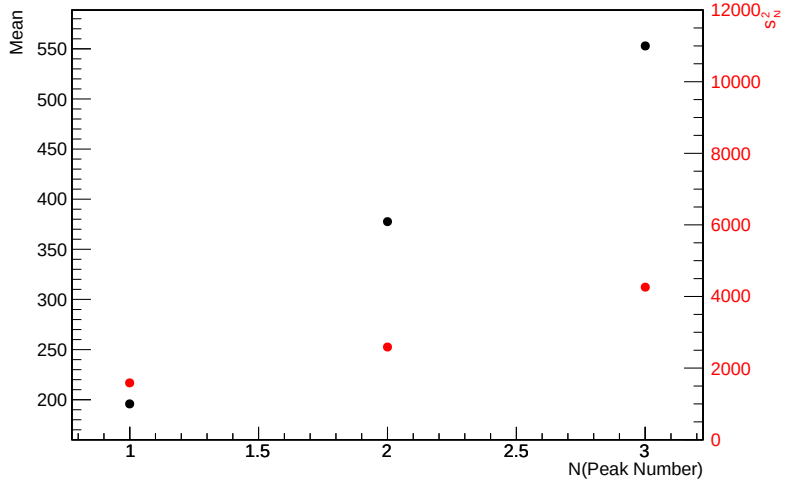
- Mean of each peak
- σ^2 of each peak



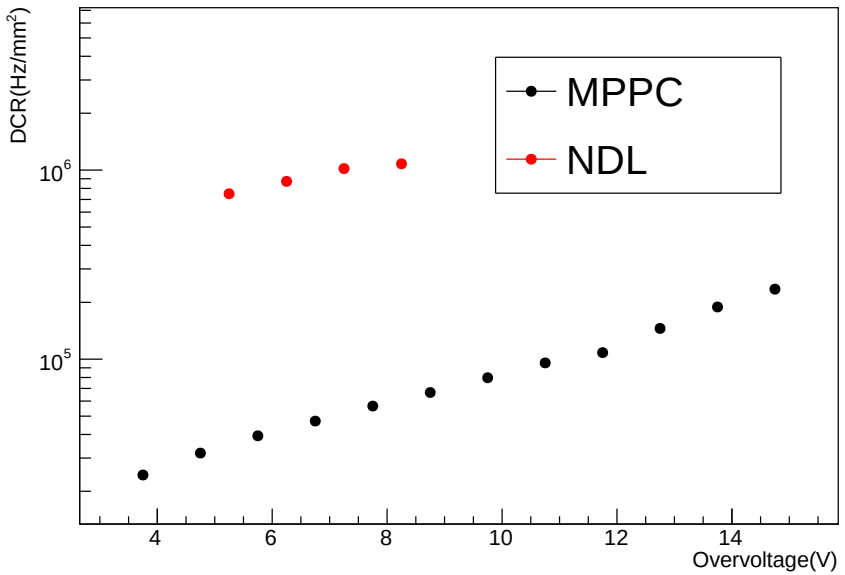


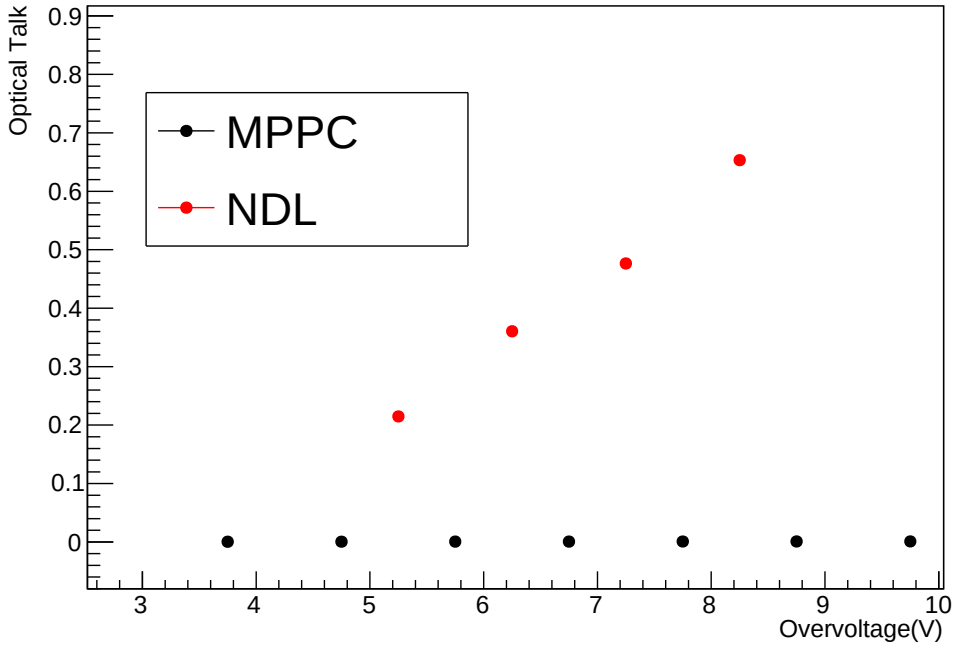


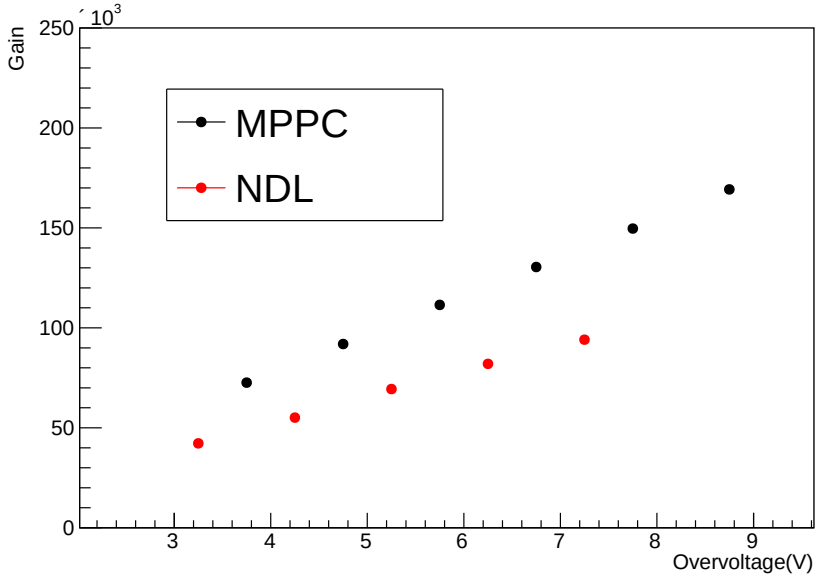
NDL
3*3 mm^2



NDL SiPM vs Hamamatsu MPPC





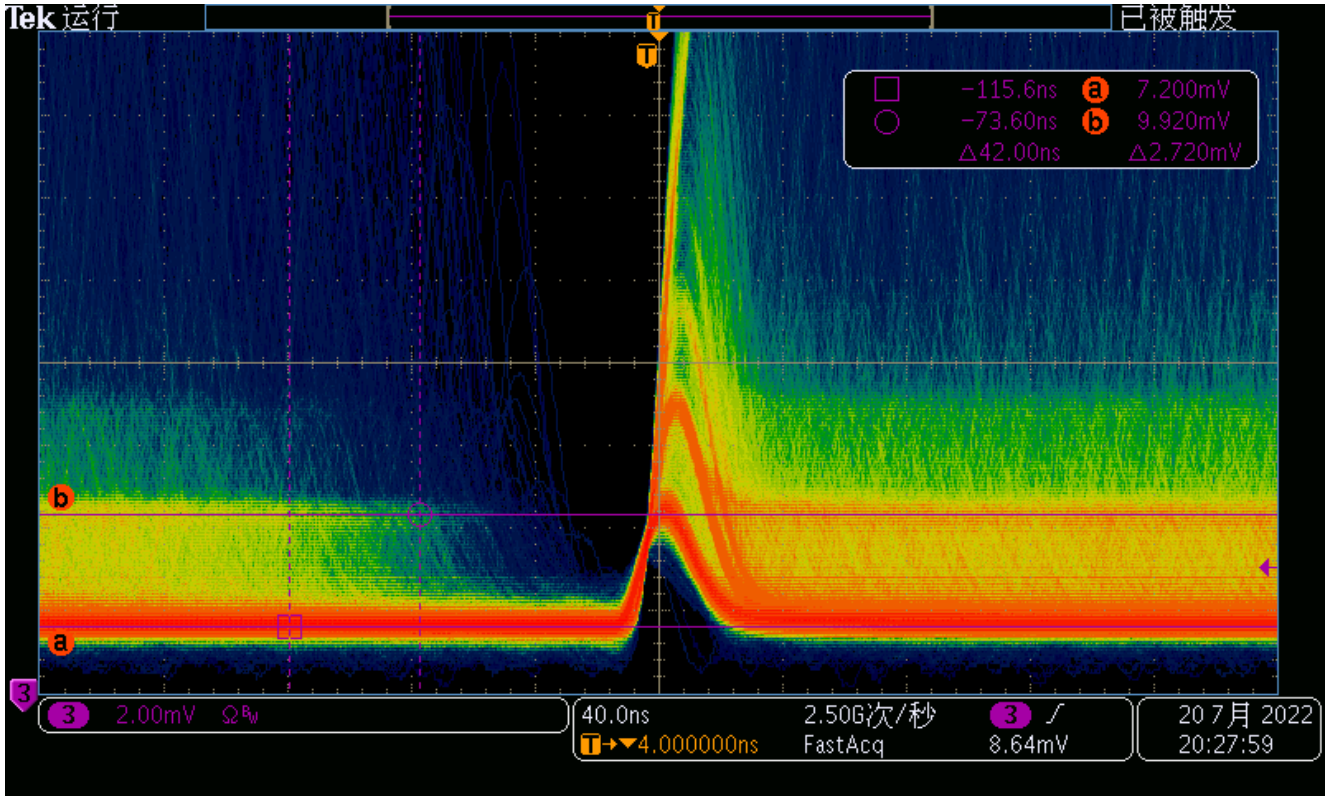


NDL SiPM:

- ✓ Higher dark count rate
- ✓ Higher optical cross talk
- ✓ Lower Gain…
- ✓ Much more cheaper
- ✓ On developing……

Efficiency measurement

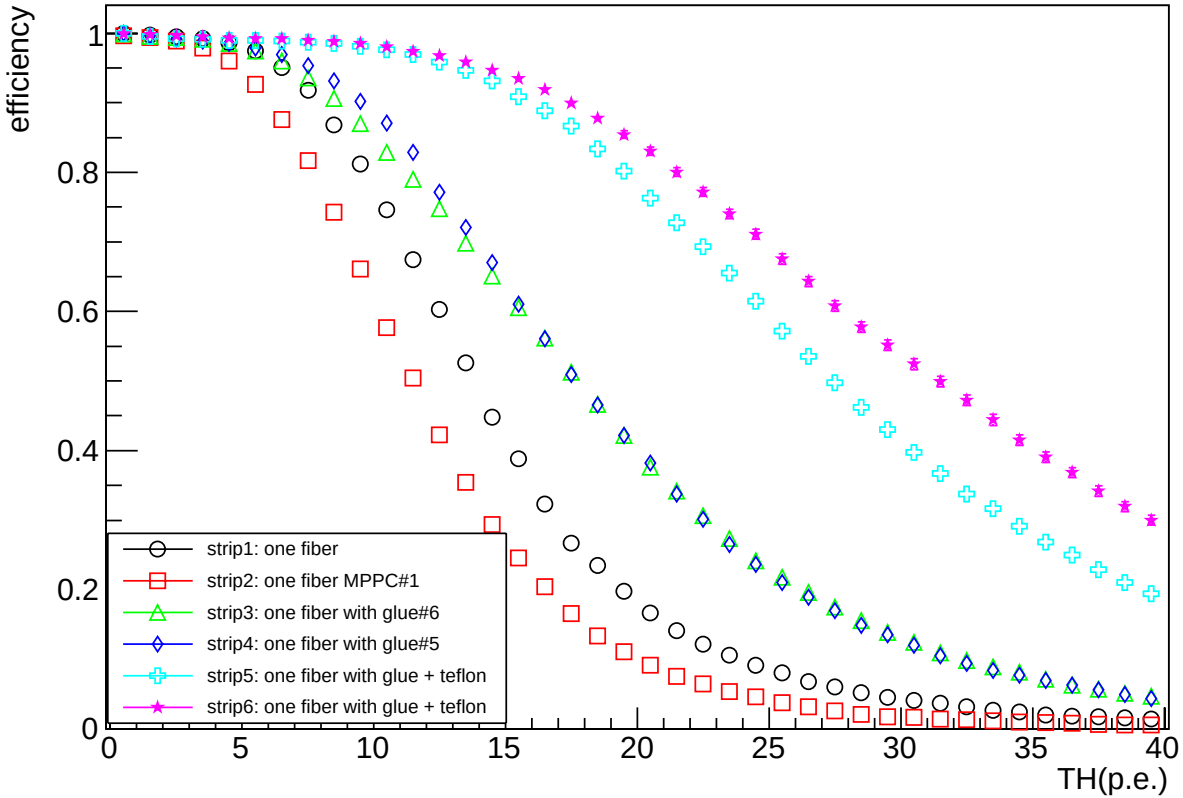
1.5m scintillation detector



1 p.e. : 2.7mV

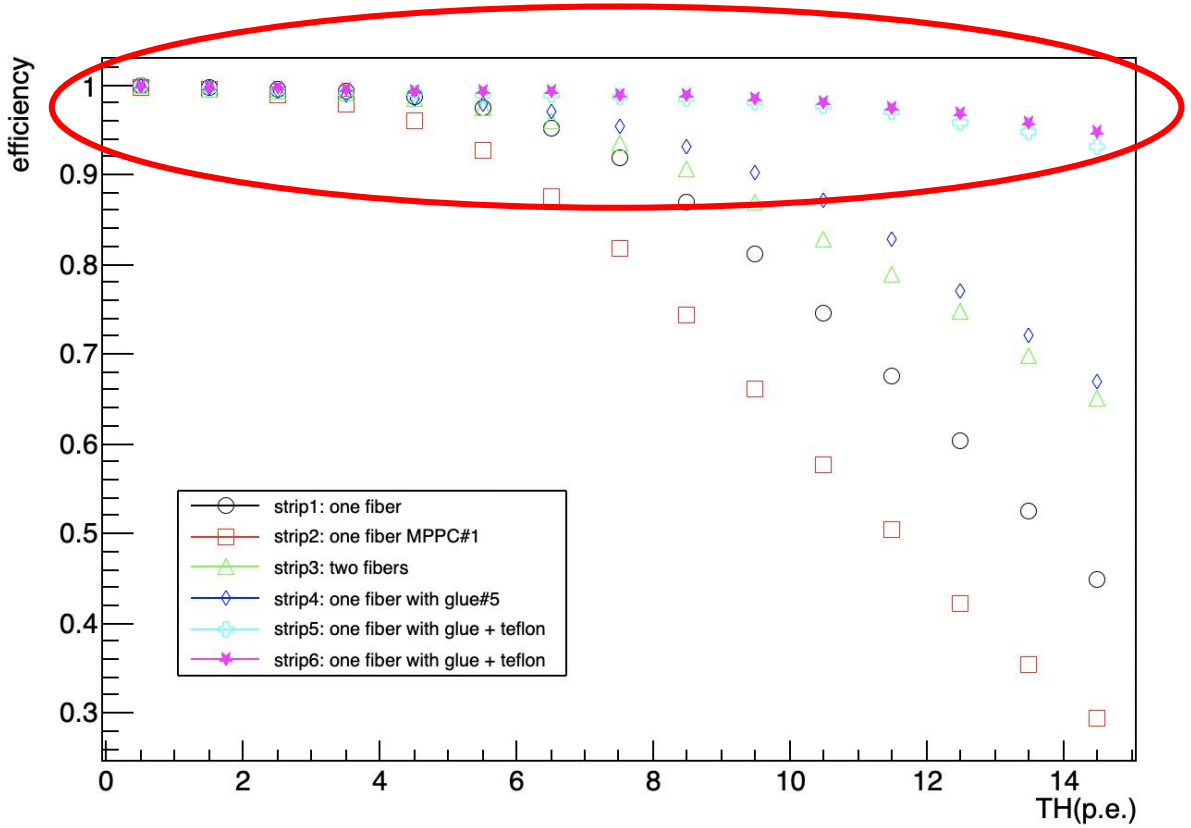
Efficiency measurement

Mostly with NDL
$3mm \times 3mm$ SiPM



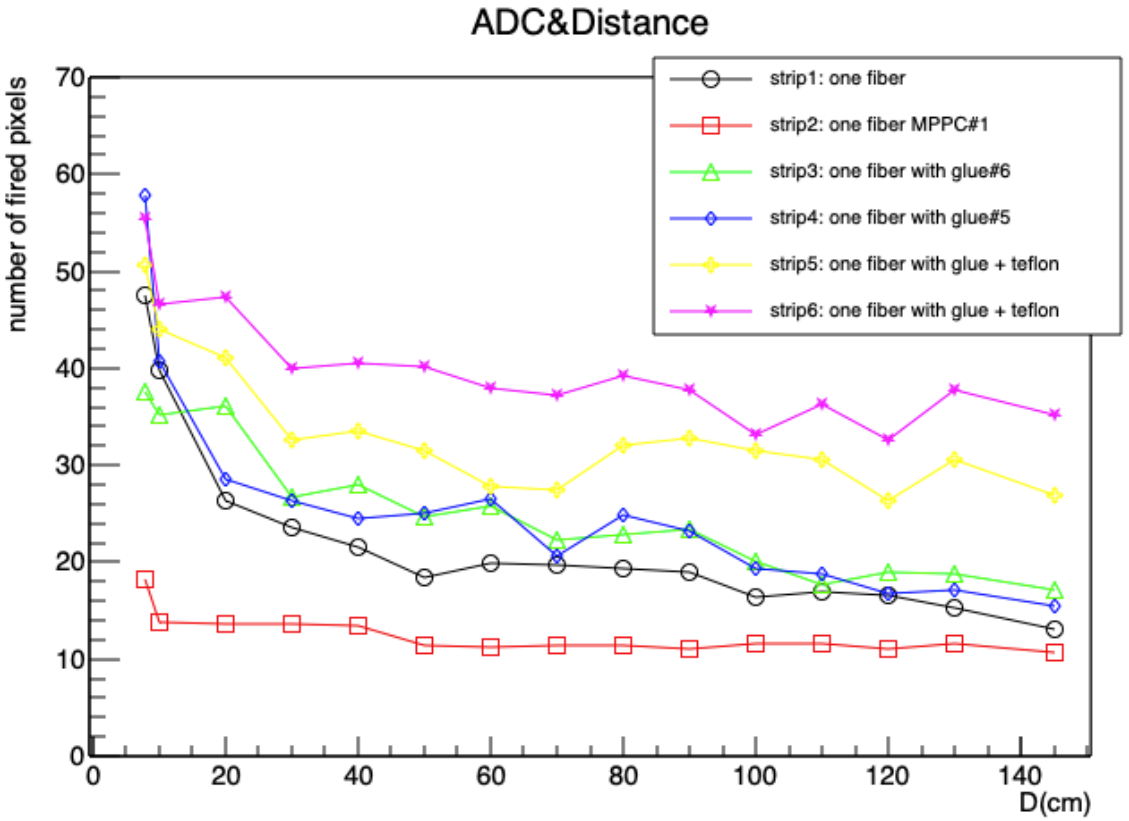
Efficiency with the trigger at the far end (145cm)

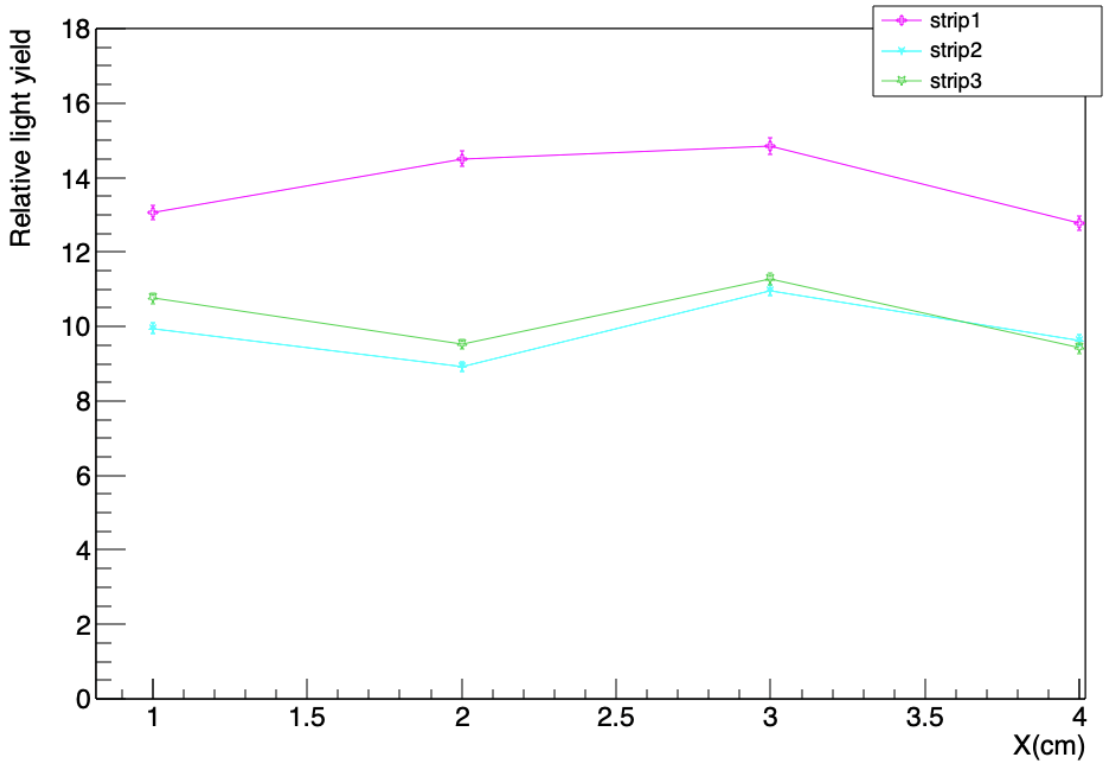
Optical glue and Teflon covering



$\epsilon > 98\%$ at the threshold of 10 p.e.

Light collection from different position





- Wavelength-shifting fiber keeps good photon collection at long distance
- the relative light yield on the transverse position of the hit

TOF-like design

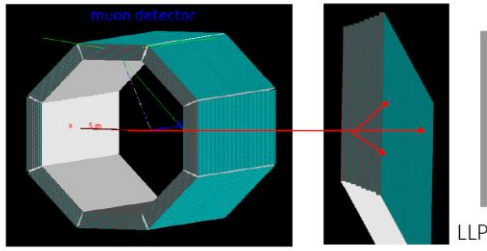
1.5 m long bar

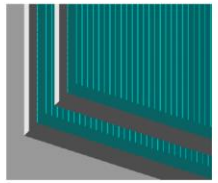
Need to use more SiPMs pieces!!!

- To increase the performance of a muon detector;
- To build a new separate detector for LLP search.

How about implementing timing?

- Two options of scintillator detector:
  - A. Cheap scintillator+WLS fibre+small SiPM, low cost for large size
  - B. Excellent scintillator+large SiPMs, reasonable cost with good timing
- We can combine them for LLP, to extend the study area of CEPC
  - One sector far away from IP,
  - Measure the tracks with good spatial resolution,
  - Measure the TOF of tracks (and charge?) for velocity (and dEdx?).
  - The distance between layers can be tuned.





LLP decay

MATHUSLA

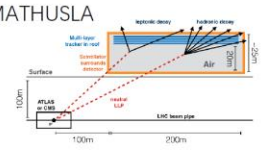


Fig. 1: Simplified detector layout showing the position of the 200 m × 200 m × 20 m LLP decay volume used for physics studies. The tracking planes in the roof detect charged particles, allowing for the reconstruction of displaced vertices in the air-filled decay volume. The scintillator surrounding the volume provides vetoing capability against charged particles entering the detector.

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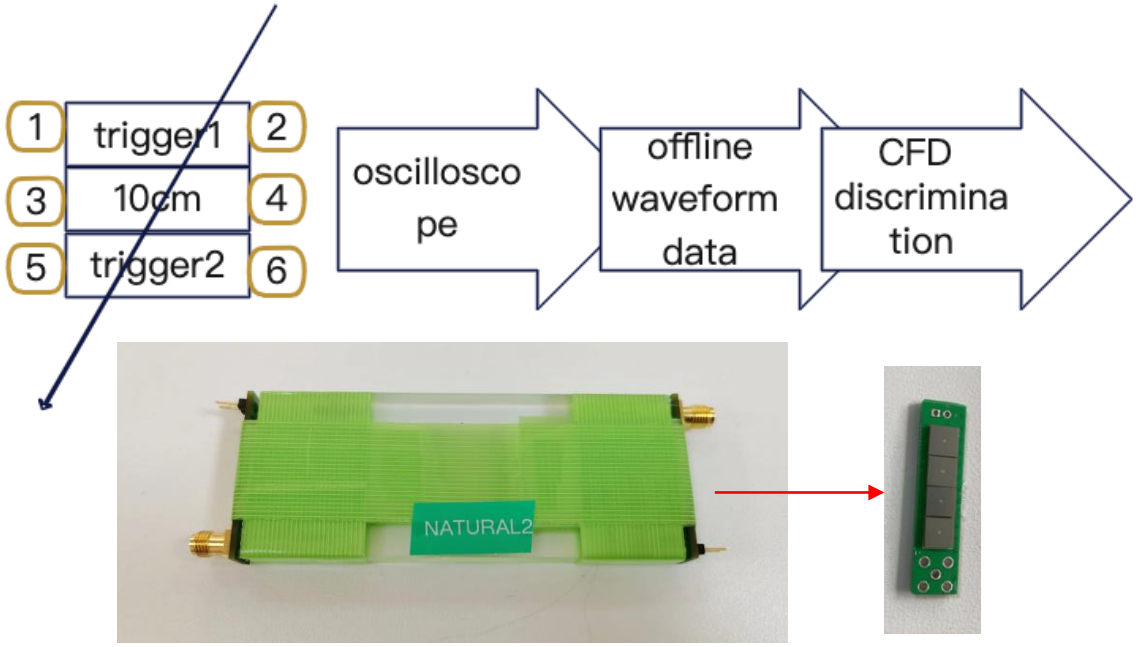
My talk at CEPC day on 1/29/2022

Time resolution of trigger



- 10cm strips for trigger
- 4 SiPMs in parallel
- Readout from both ends

Time difference and the resolution:

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

$$\sigma^2(\Delta T) = \frac{\sigma_1^2 + \sigma_2^2 + \sigma_5^2 + \sigma_6^2}{16} + \frac{\sigma_3^2 + \sigma_4^2}{4}$$

$$\sigma = \sigma_1 = \sigma_2 = \sigma_3 = \sigma_4 = \sigma_5 = \sigma_6$$

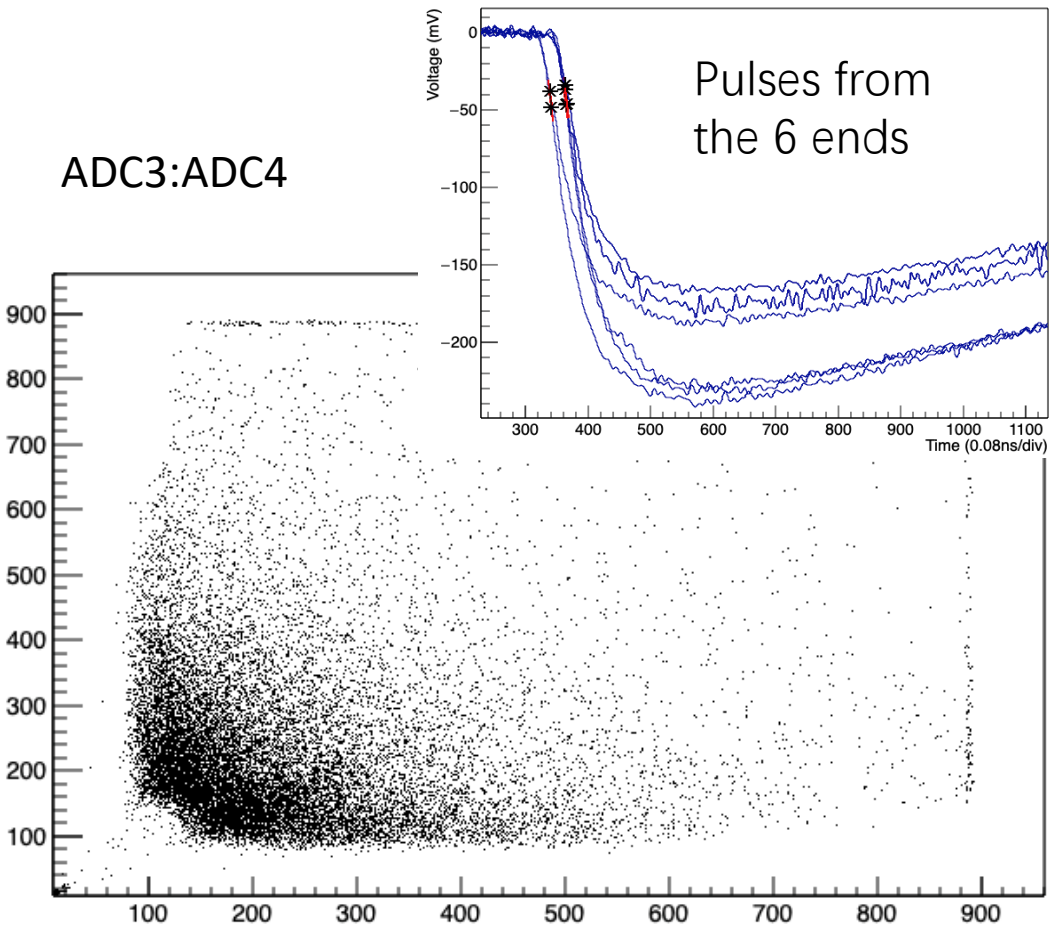
$$\sigma(\Delta T) = \frac{\sqrt{3}\sigma}{2}$$

- Average time from the two ends of a strip, like TOF detector.
- Reduce the uncertainty due to the hitting position by cosmic ray.

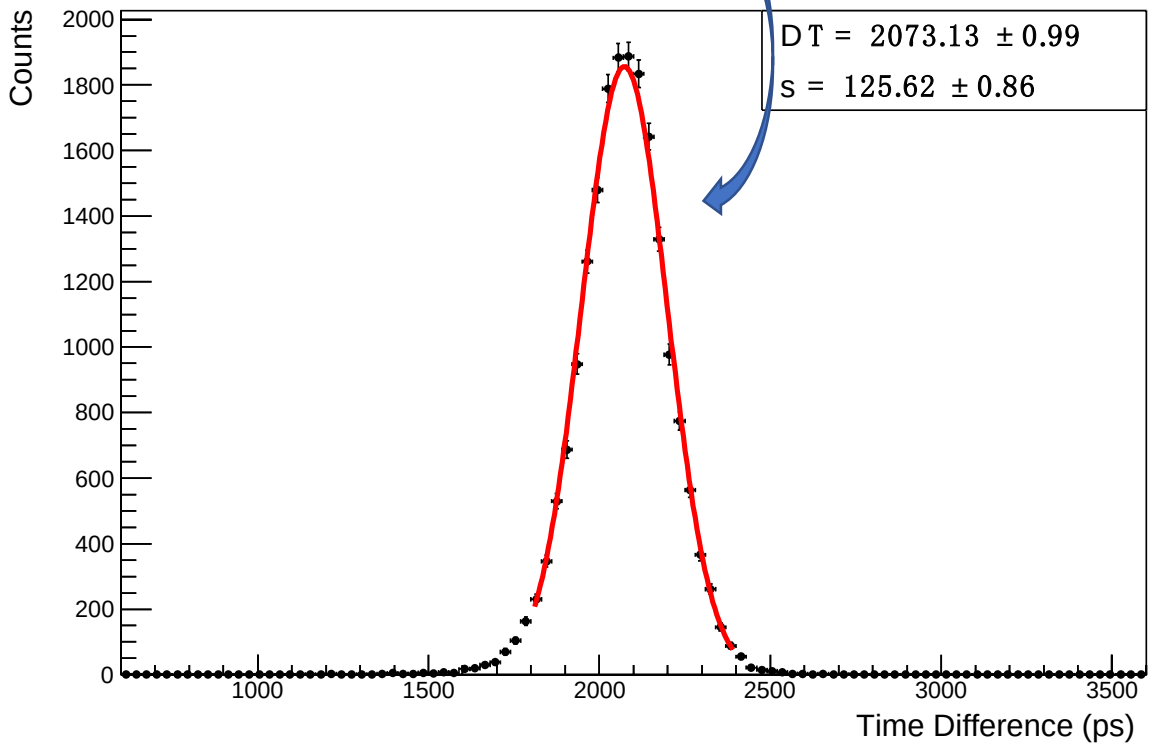
- Time resolution of a short strip using two end readout: $\sigma_{short} = \sigma/\sqrt{2}$
- Trigger system using two strips: $\sigma_{trg} = \sigma/2$.

Time resolution of short strip

ADC3:ADC4



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

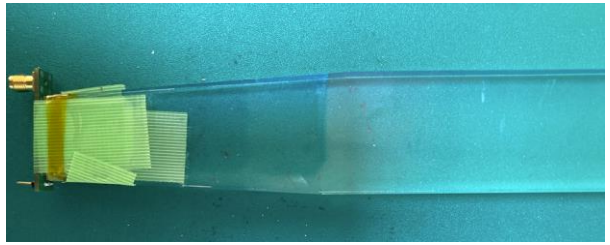


$\sigma_{short} = 103\ ps$

$\sigma_{trg} = 73\ ps$

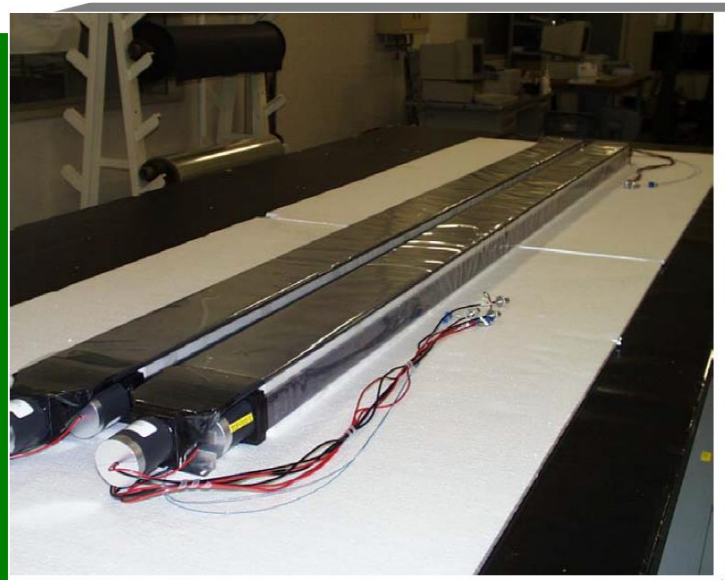
CRT on long GNKD scintillator bar

GNKD: 高能科迪

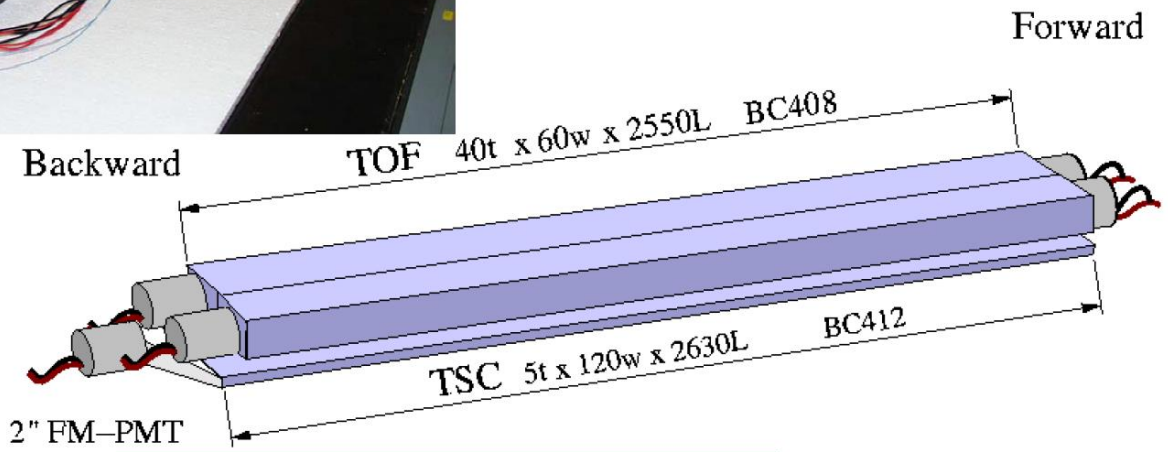


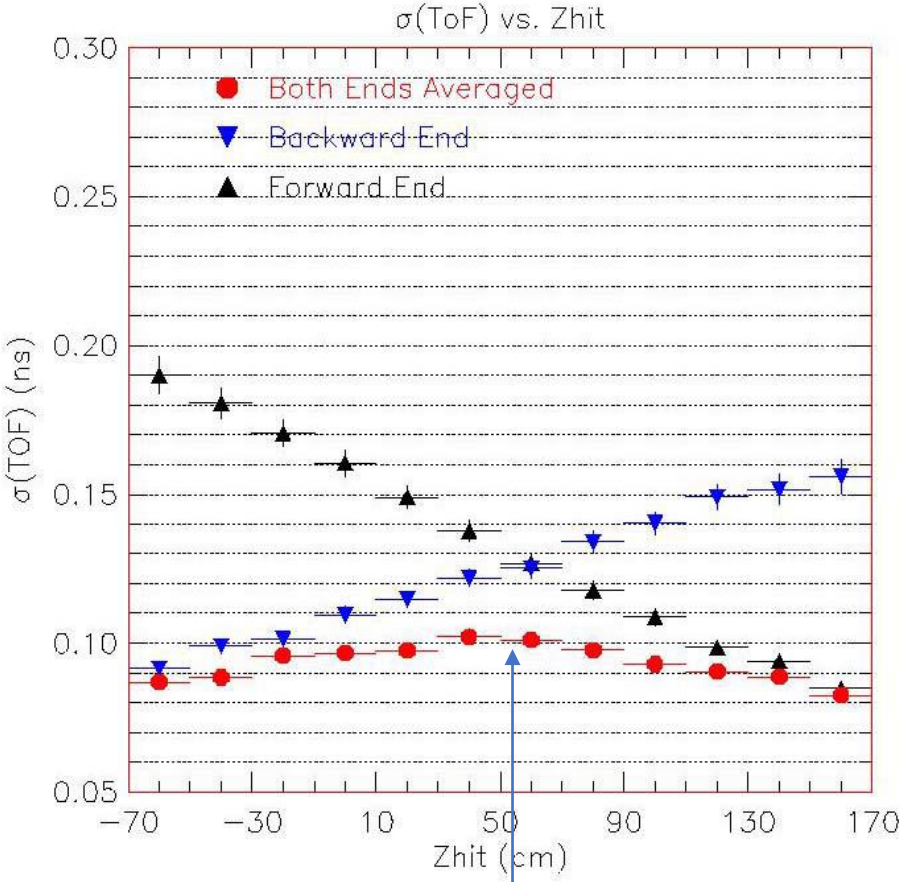
- Trigger at middle of the long scintillator bar, where is the lower limit of the time resolution.

Reference from Belle TOF



- High B-field Operation
- Hamamatsu R6680 Fine Mesh PMTs
  - 24 stages
  - 2000 mesh/in.
  - G>3x10^6 in 1.5T field
- TSC radius = 118 cm
- TOF radius = 120 cm

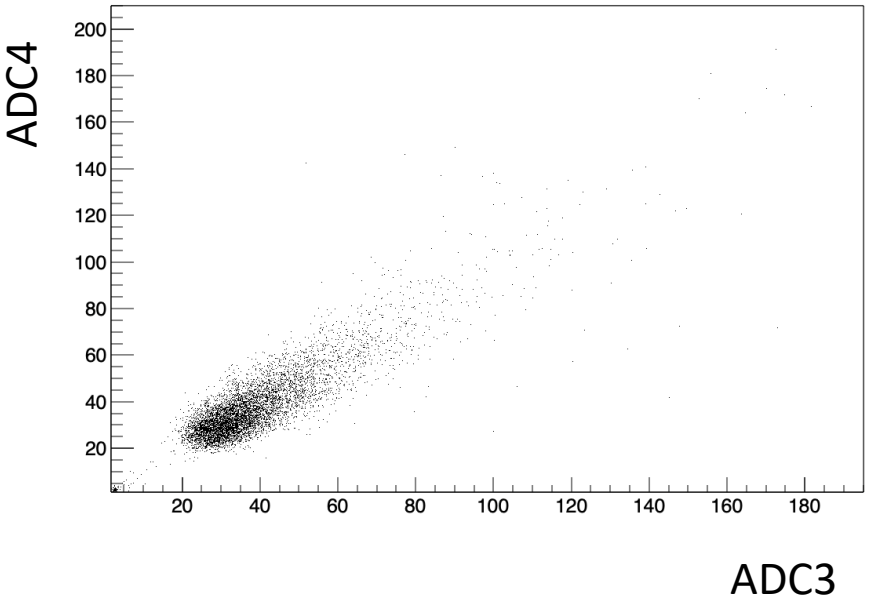


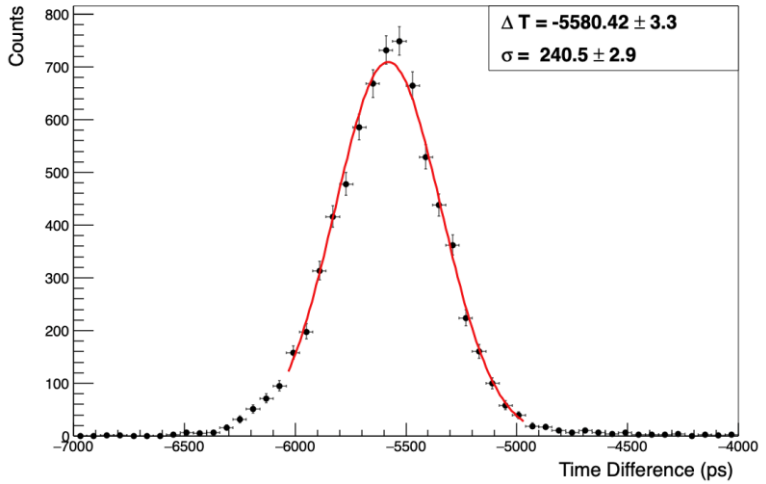


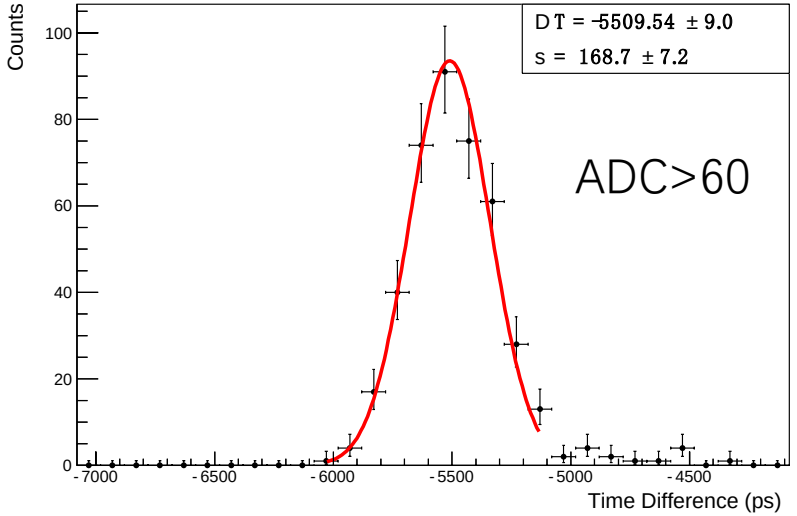
Worst at middle

Result from testing on GNKD scintillator

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







- Signal is small, thickness is 1.5 cm.
- The attenuation length of GNKD looks not long enough.

$\sigma_{\text{long}} = 229$ ps

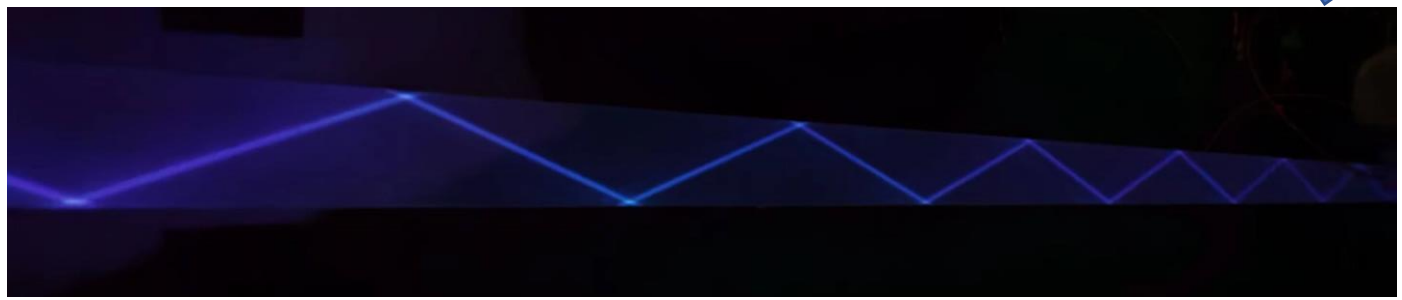
$\sigma_{\text{long}} = 152$ ps

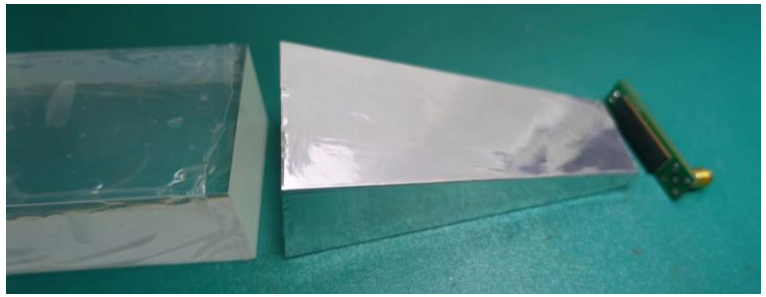
Need to improve the light yield!

CRT on long BC420 scintillator bar

SAINT-GOBAIN: BC420

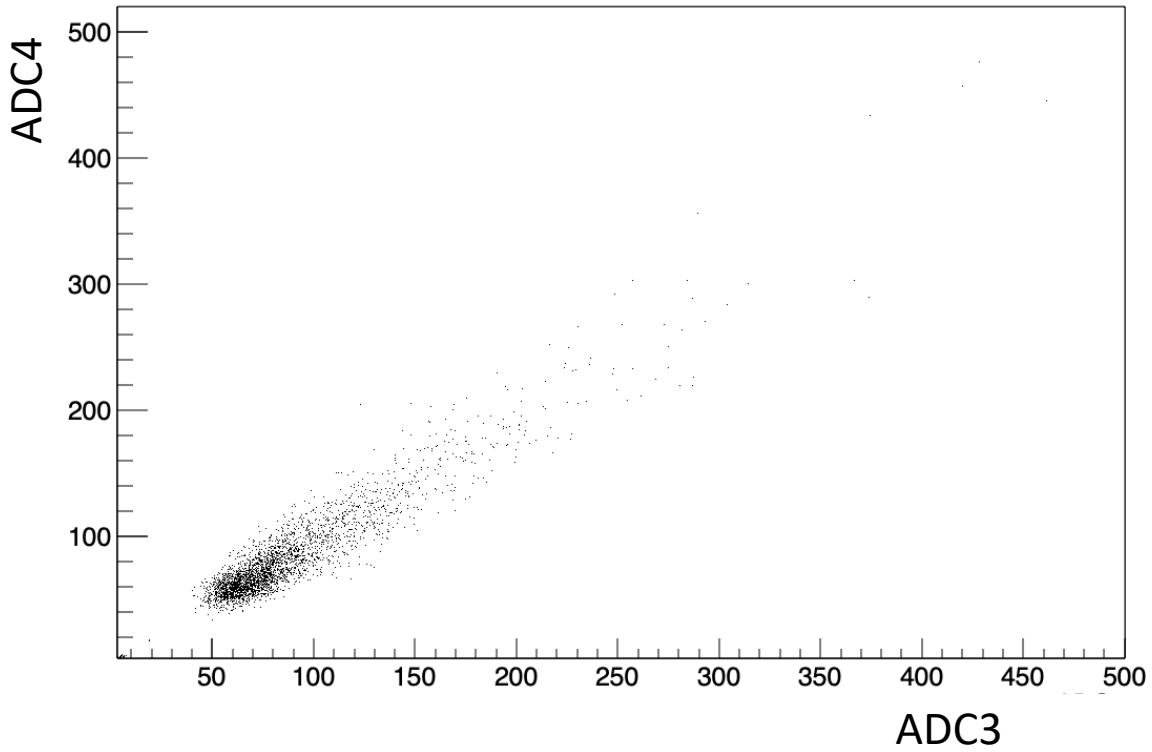
Long attenuation length

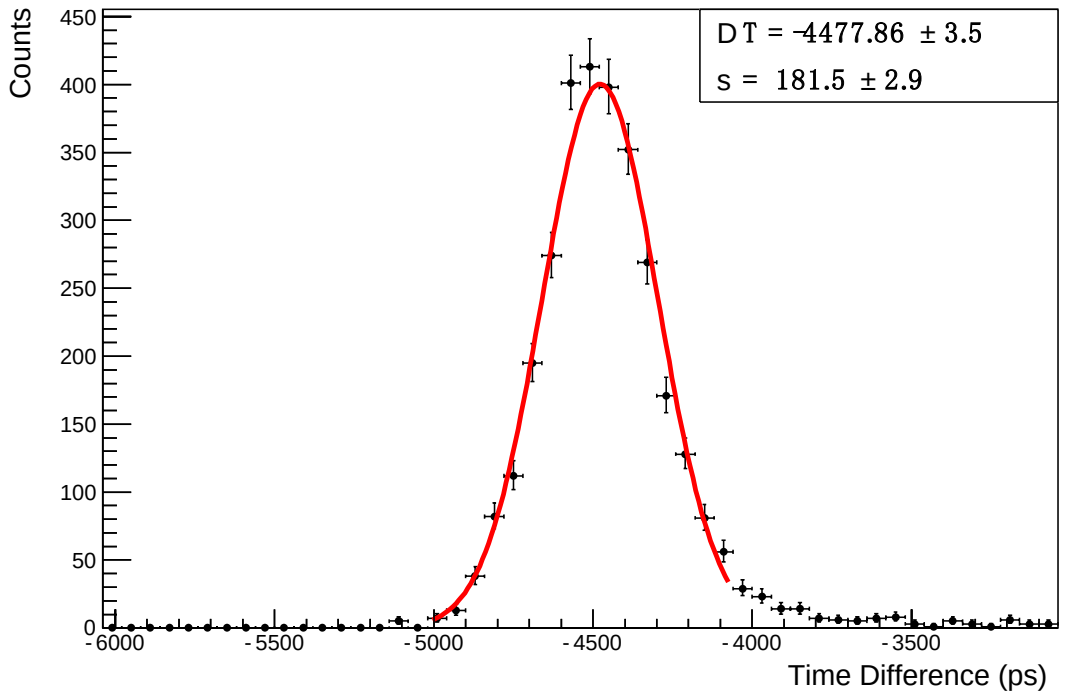




Result of BC420 long bar

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

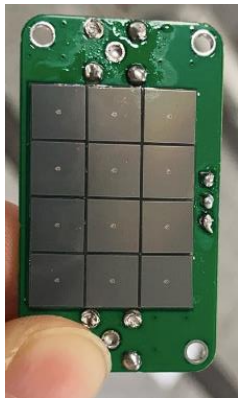


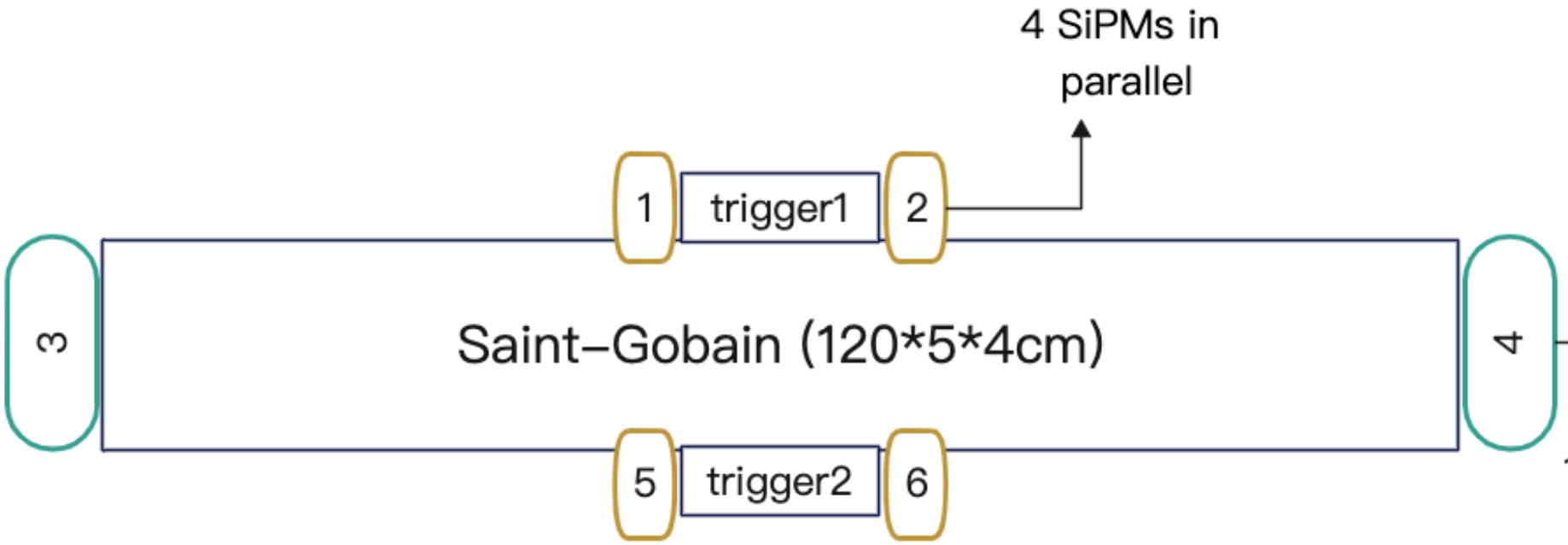


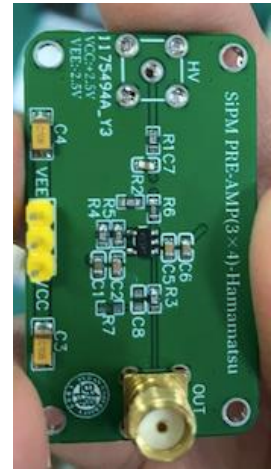
Time resolution of long strip using readouts at two terminals.

$\sigma_{long} = 165$ ps

CRT testing with larger SiPM array

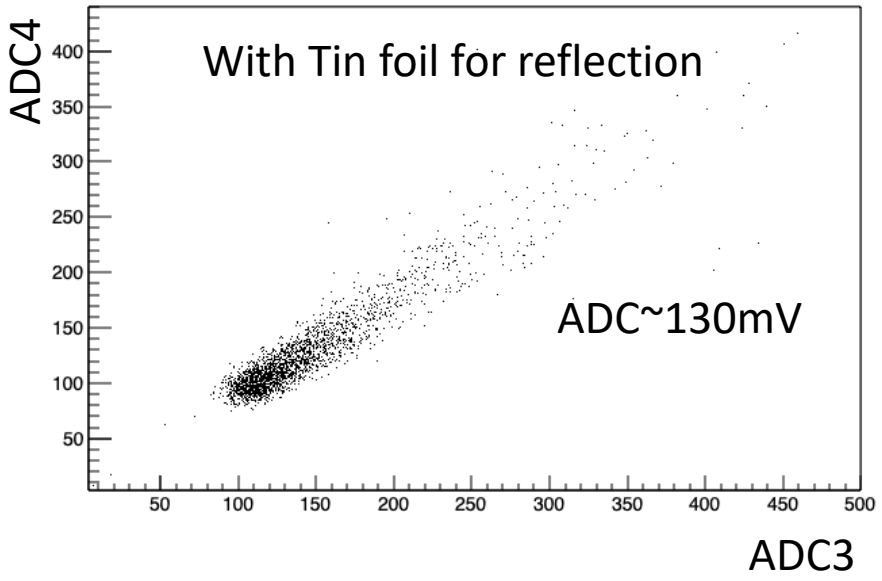




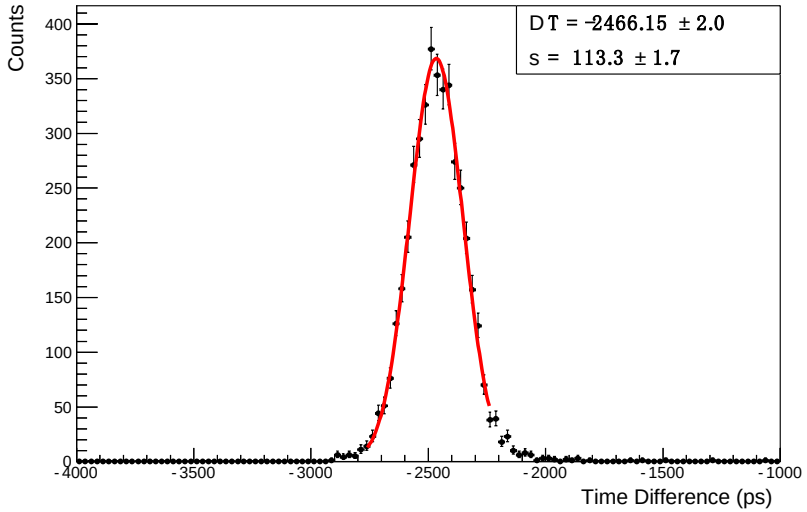


- Use 3×4 SiPMs to increase the photosensor area.
- Each SiPM has $6mm \times 6mm$.

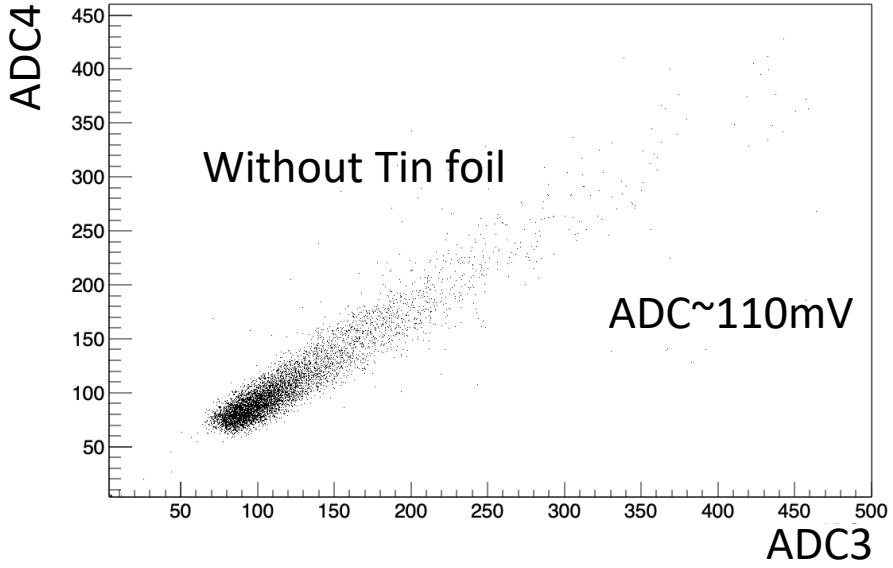
Time resolution from BC420 scintillator bar

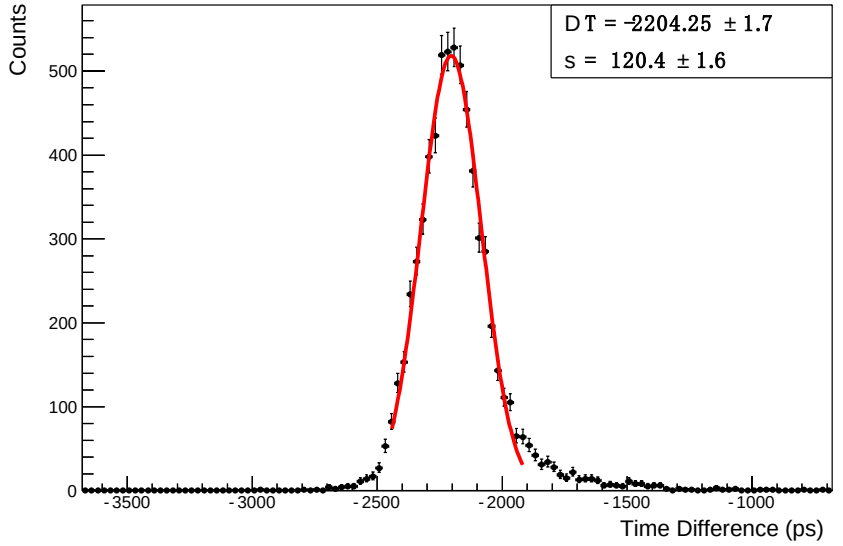


$$\Delta T = \frac{T_1 + T_2 + T_5 + T_6}{4} - \frac{T_3 + T_4}{2}$$



$\sigma_{long} = 87$ ps





$\sigma_{long} = 96$ ps

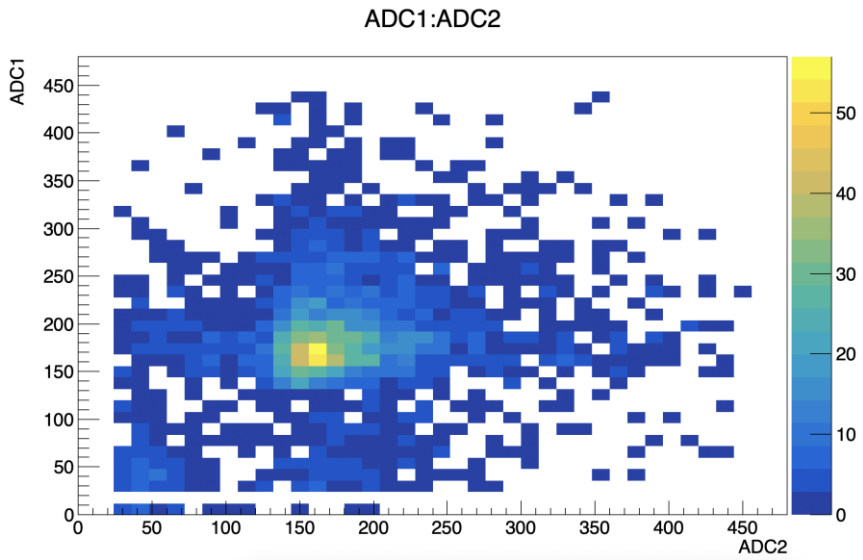
Summary

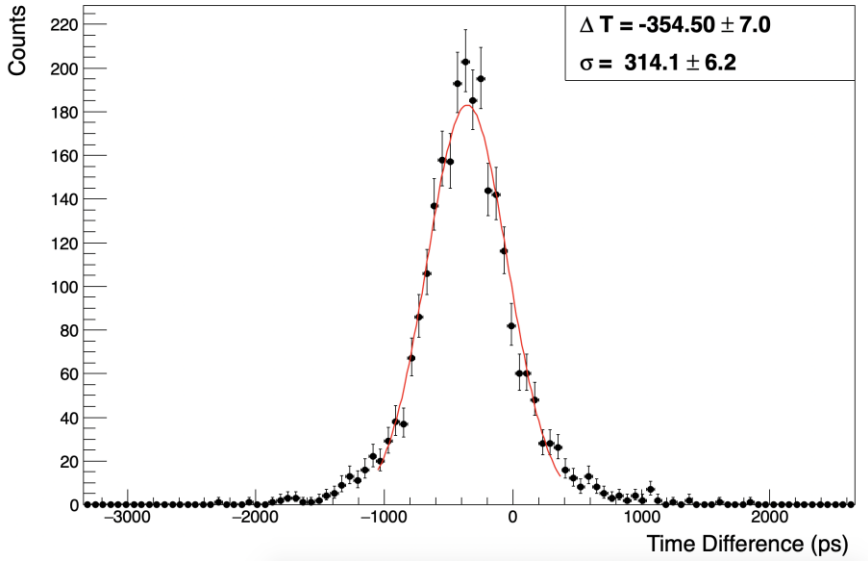
- The regular design shows good light collection and high efficiency, even the NDL cross talk is high.
- TOF-like design shows a time resolution of about 200 ps from a 1.5 m long scintillator bar.
- The limitation is mainly due to the light yield and the attenuation in the long bar.
- Using arrays of 3×4 SiPMs with $6mm \times 6mm$ active area, a time resolution of 87 ps is achieved from a 1.2 m BC420 bar.
- Further testing is ongoing.

Thank you!

Back up

Time resolution: 5*3/natural+6629PZx25





T1-T4

Ch1: short strip
Ch2: long strip
Ch3: long strip
Ch4: short strip