Status of R&D for muon detector based on scintillator

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Content

Structure of current KLM design

- Scintillator shape is flexible, easy to get good spatial resolution:
  - σ = Width/$\sqrt{12}$
- Wave length shift (WLS) fiber inside scintillator to collect photons and guide them to SiPM.
- Use SiPM at one or both ends, small size, low cost and can work at high magnetic field.

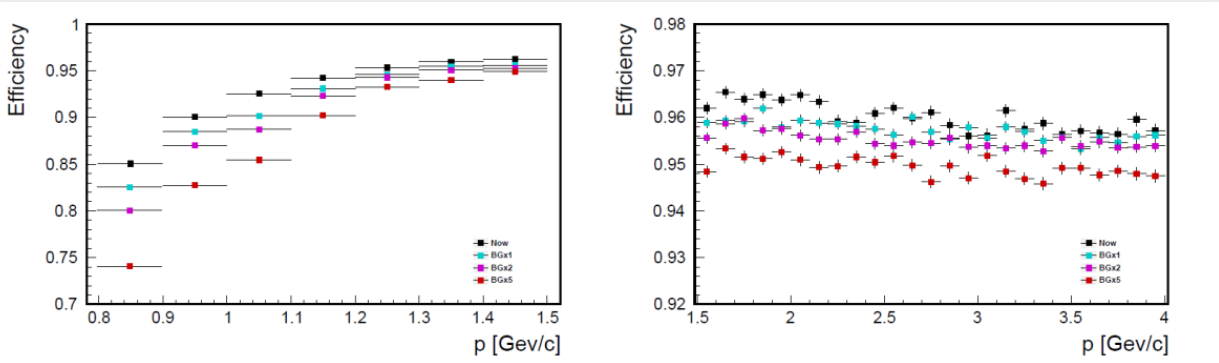
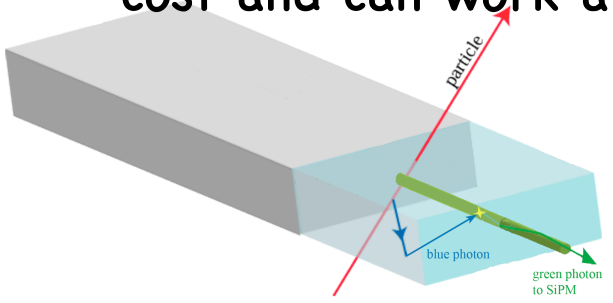
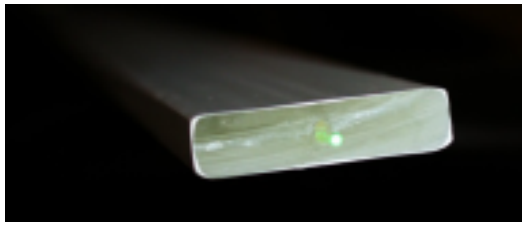
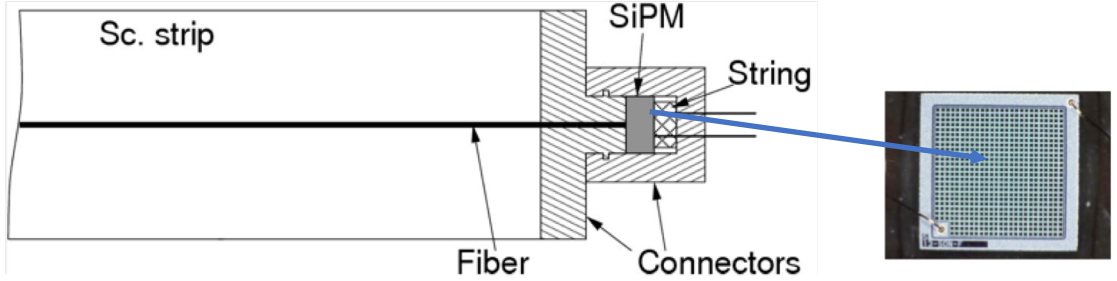


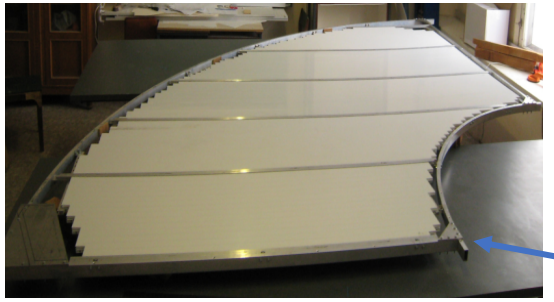
Figure 4: *Muon identification efficiency after the requirement muonID > 0.9 in the three considered scenarios for tracks with $0.8 < p < 1.5$ GeV/c (on the left) and for tracks with $1.5 < p < 4.9$ GeV/c (on the right).*

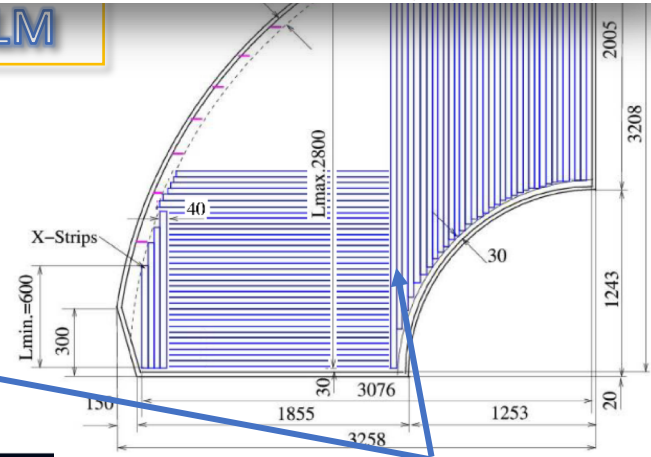


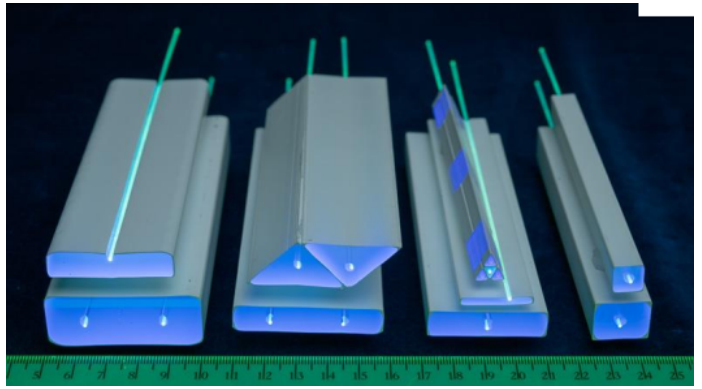




Belle II KLM



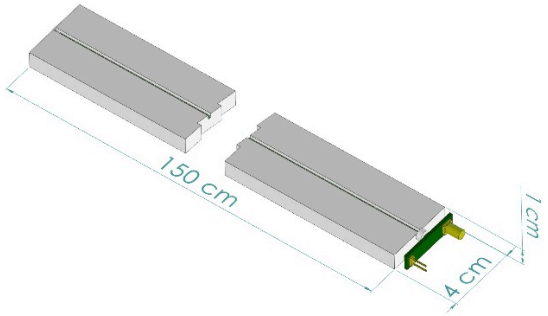




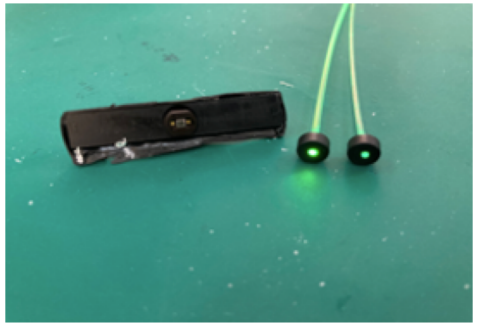
Superlayer for good 2-D resolution

Set up of scintillation detector

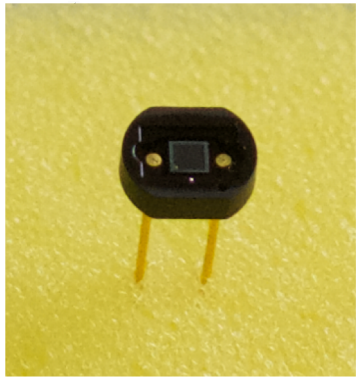
scintillator + WLS fiber + SiPM

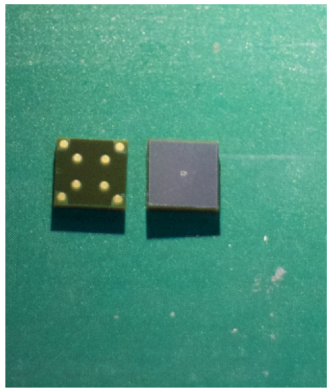


Reflective layer

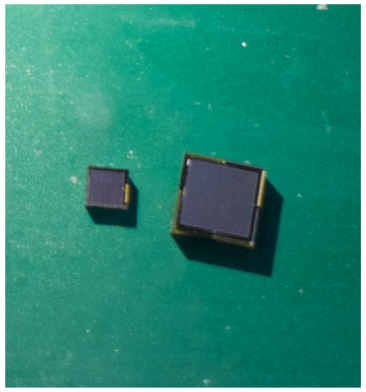


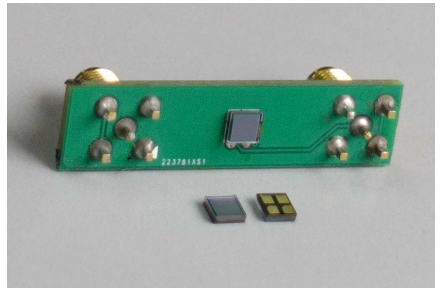
WLS fiber



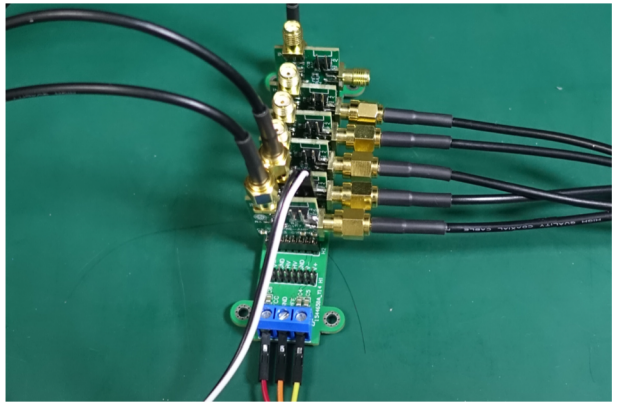


Hamamatsu S11360-1325/50/75cs



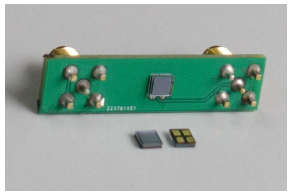


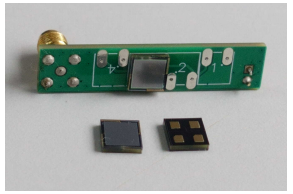
NDL SiPMs



Preamplifier

Using new NDL SiPM





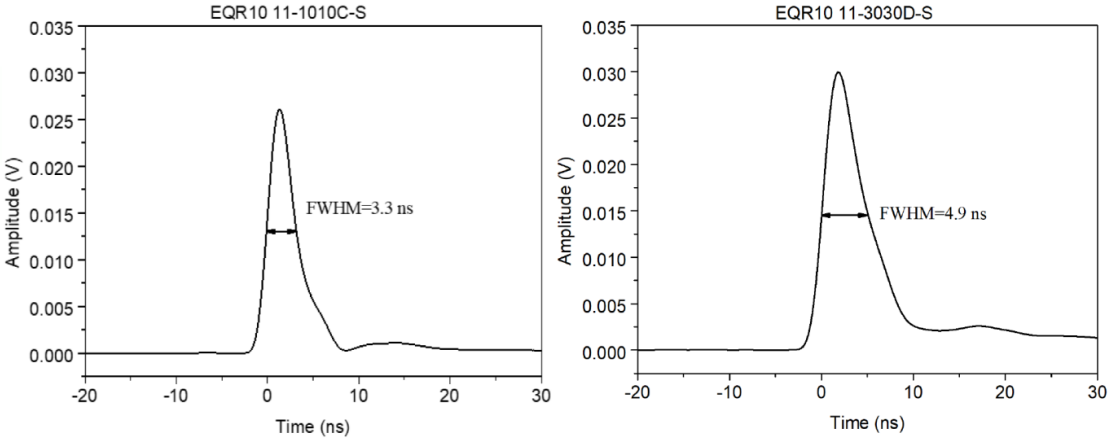
Specifications

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

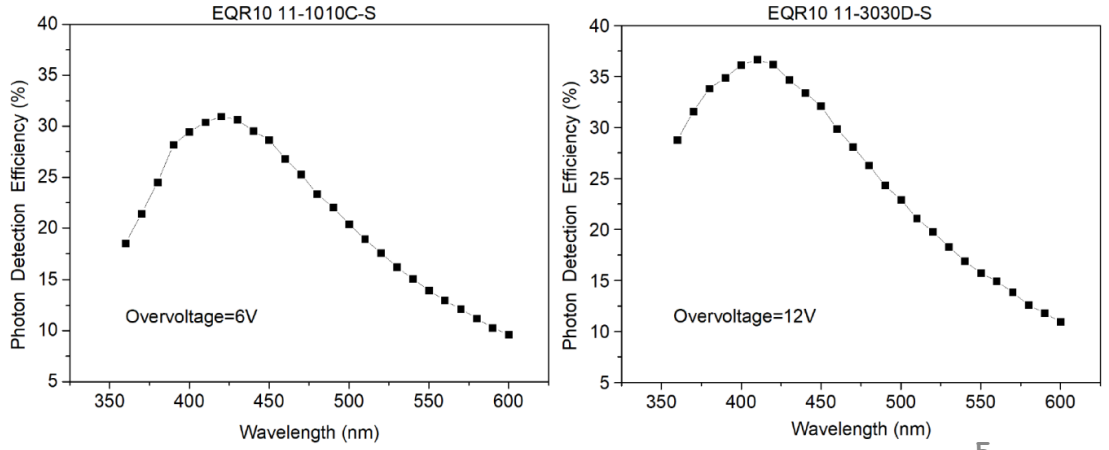
Above parameters are measured at their recommended operation voltage and 20 ℃.

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

Characteristics



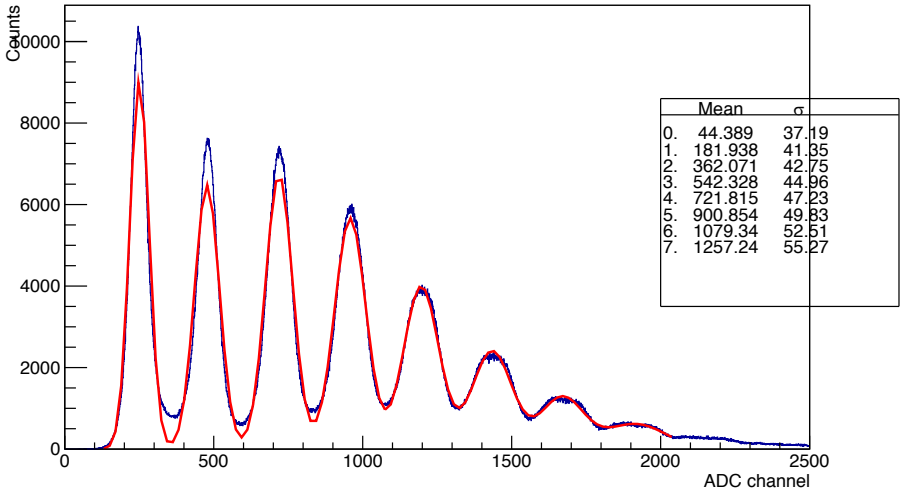
The single photoelectron pulse (amplified by a 40dB fast amplifier).

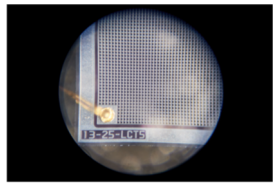


The PDE versus overvoltage and wavelength, deducted crosstalk and afterpulse and measured at 20 ℃ .

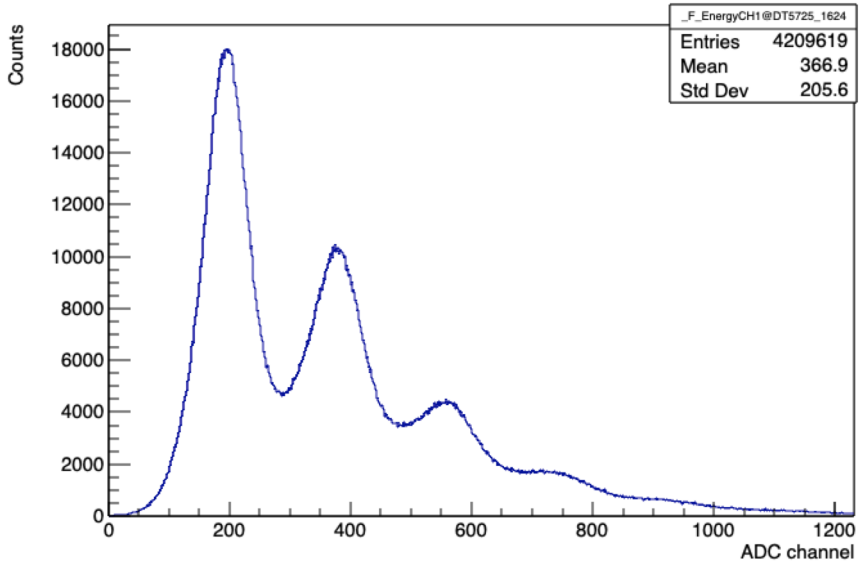
Test of NDL & MPPC SiPM using laser

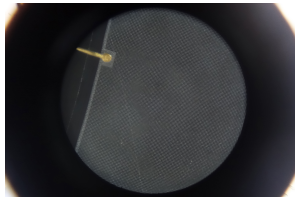
QDC distribution using DT5725





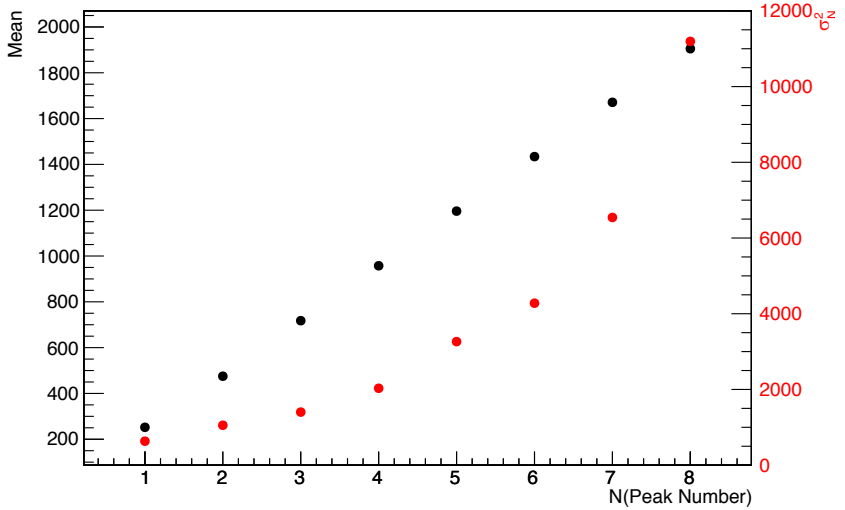
MPPC
1.3*1.3 mm^2

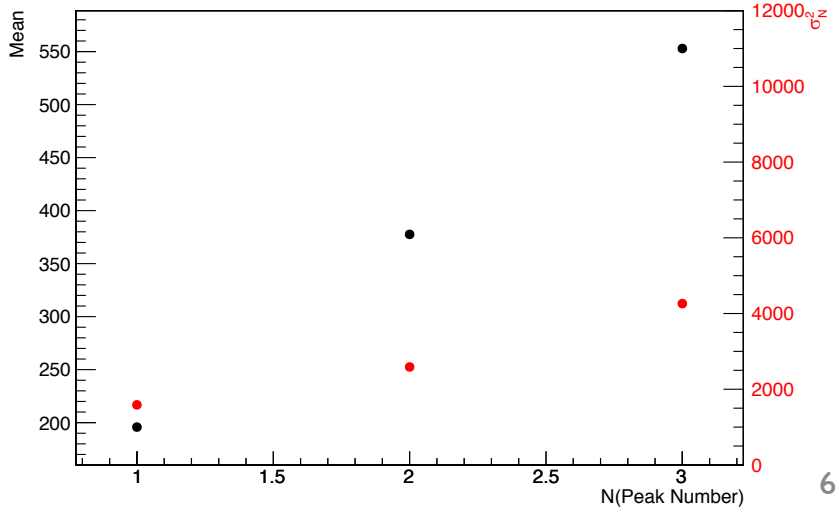




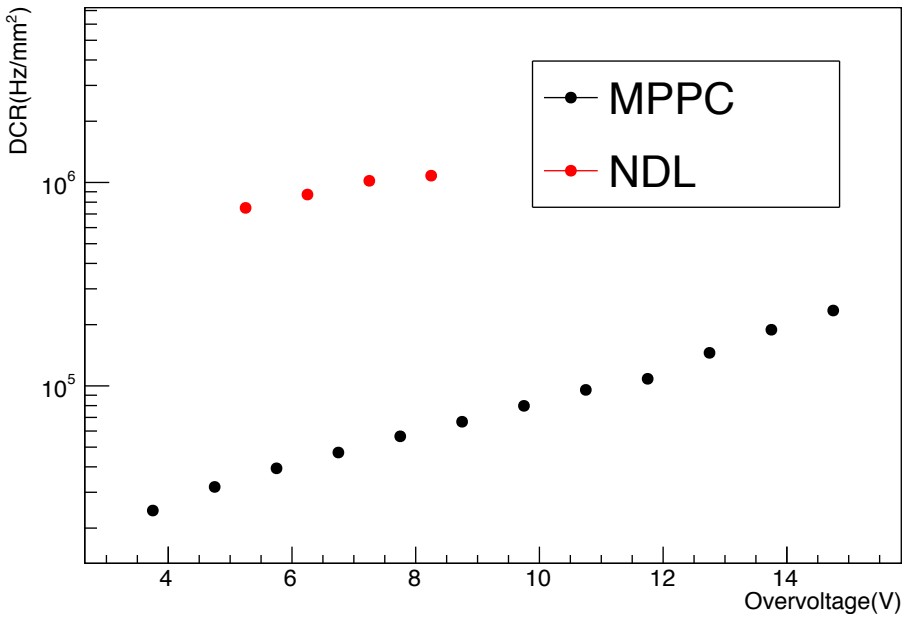
NDL
3*3 mm^2

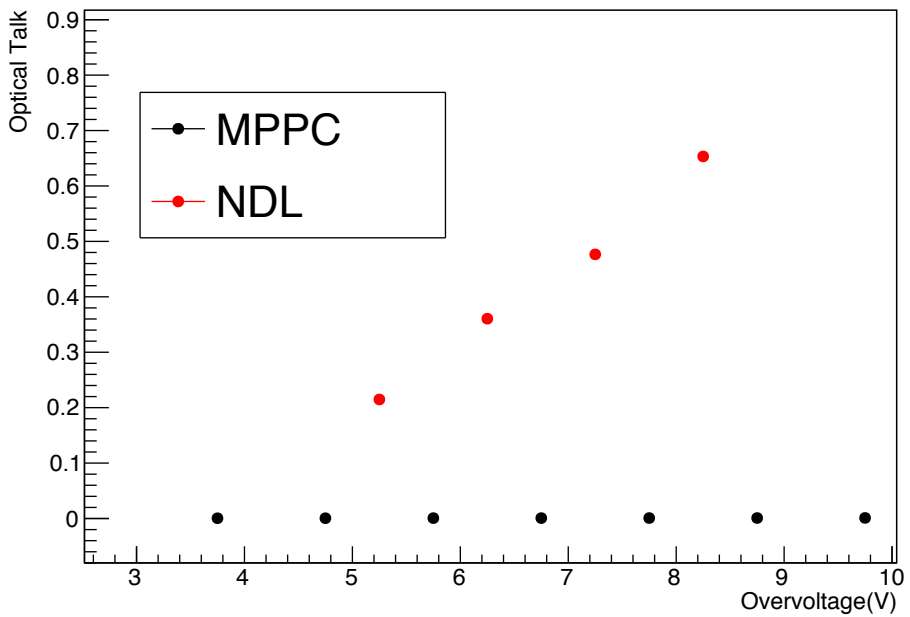
- Mean of each peak
- σ^2 of each peak

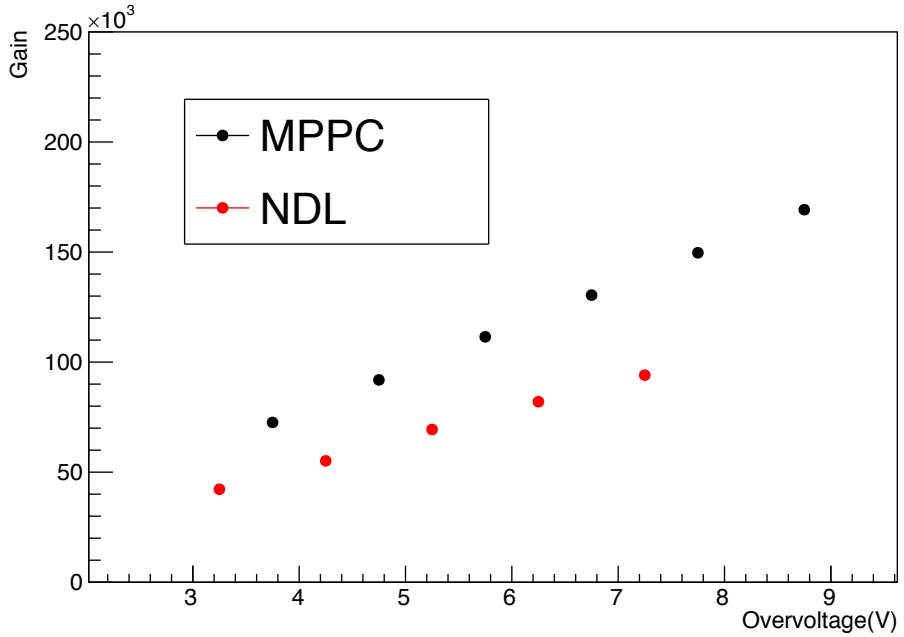




Test of NDL & MPPC SiPM





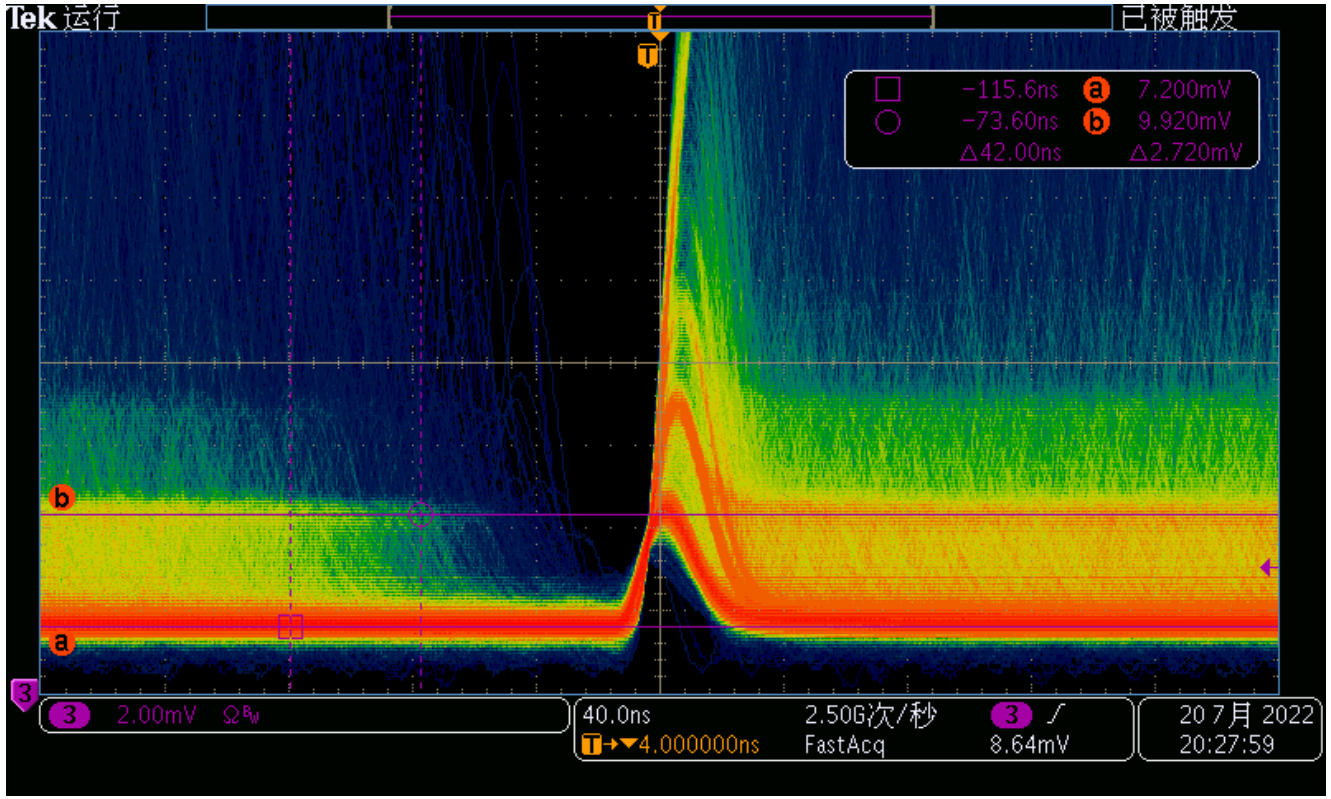


NDL:
higher dark count rate
Higher optical cross talk
Lower Gain
Much more cheaper
On developing……

Efficiency measurement

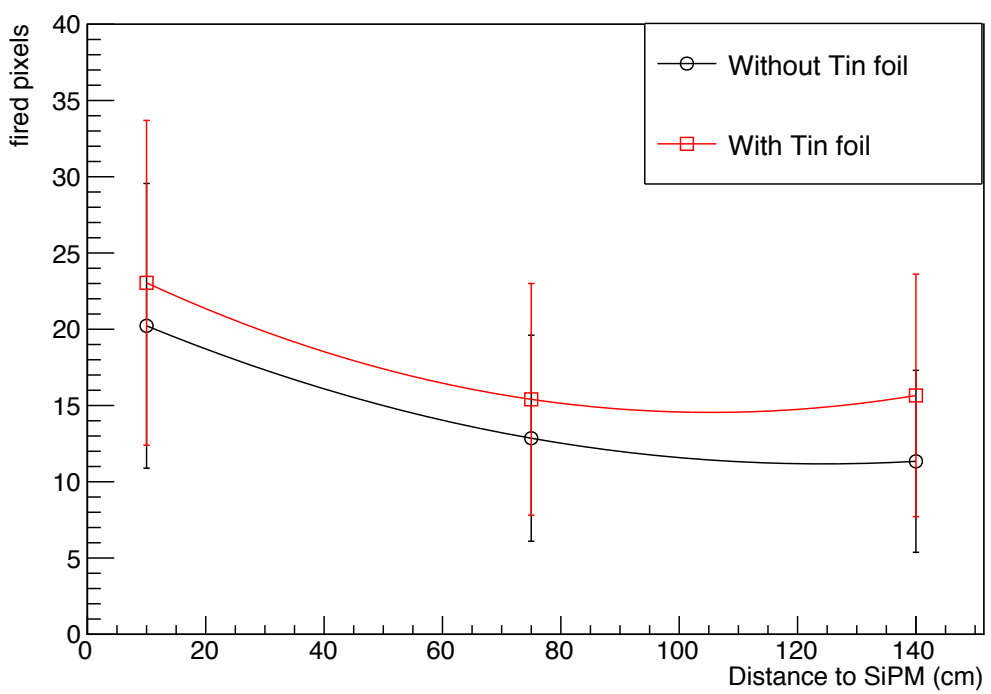
Dark box

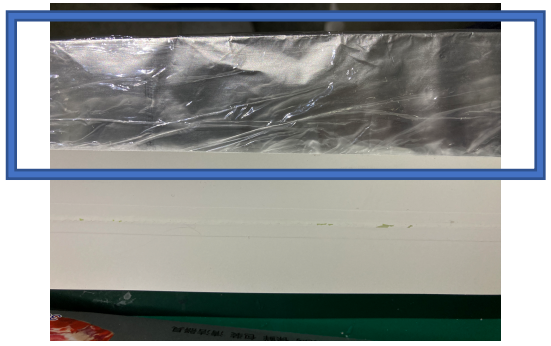
1.5m scintillation detector



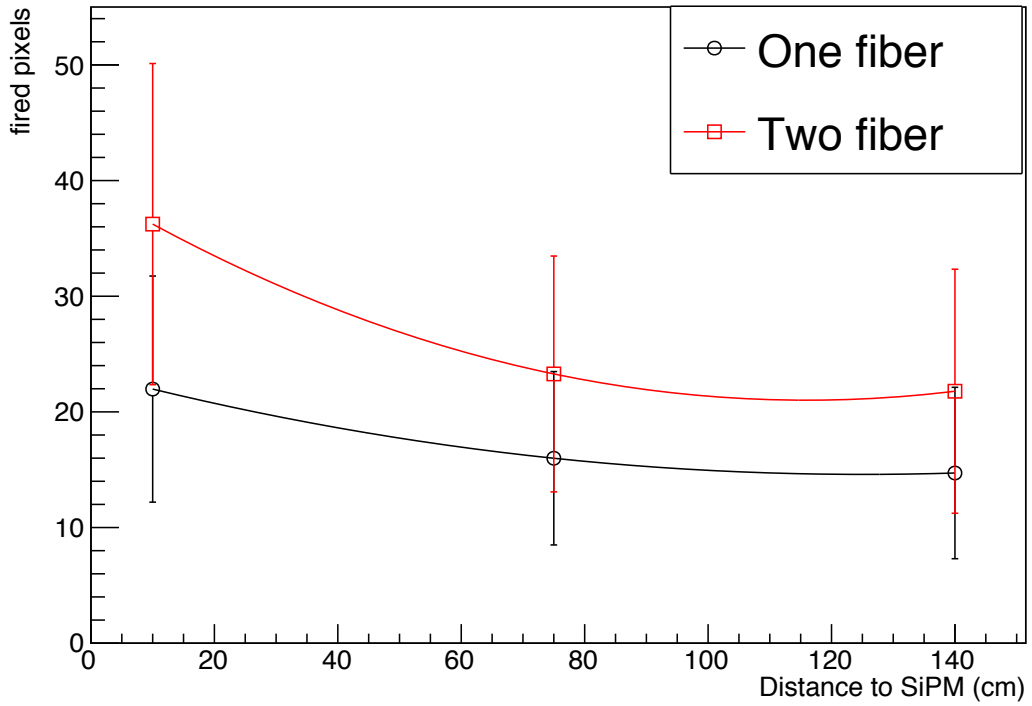
1 p.e. : 2.7mV

Light collection of scintillation detector



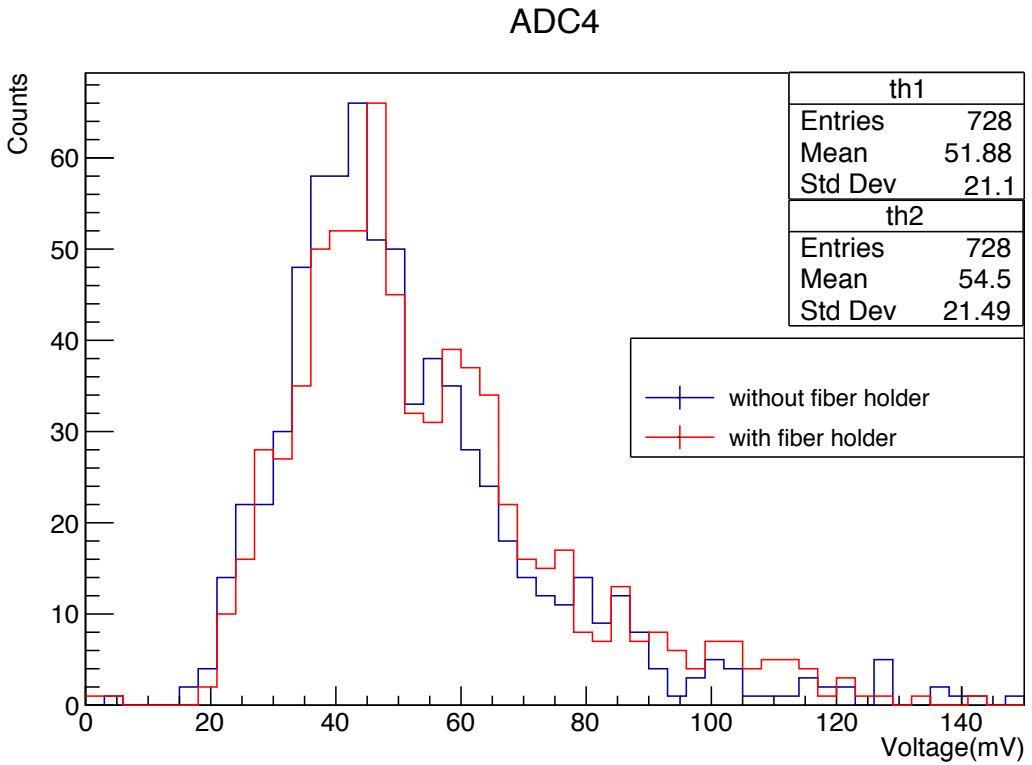


Light collection improved by Tin foil

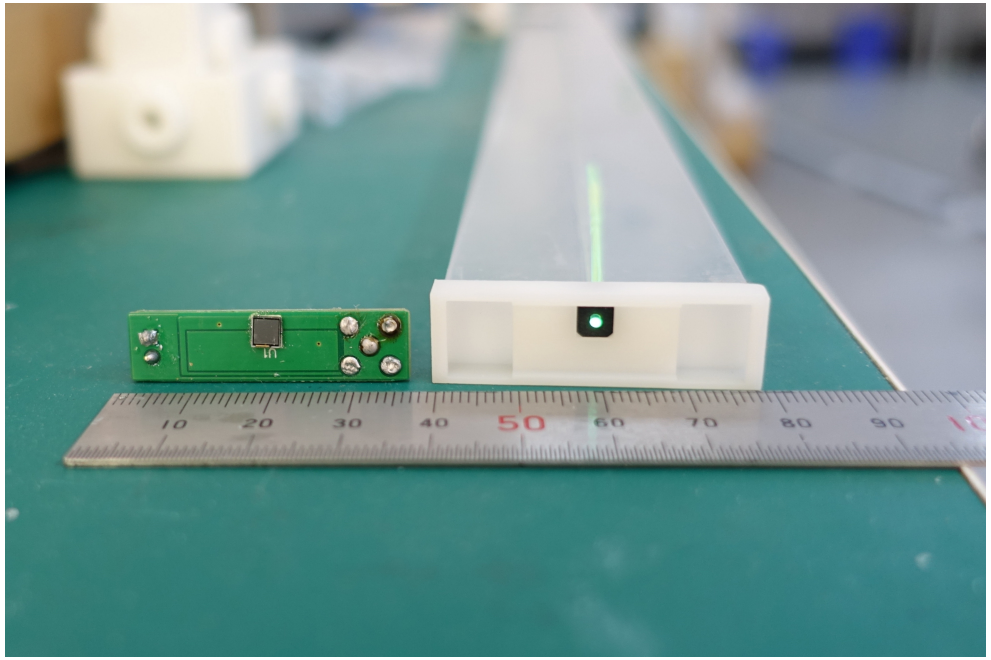


Adding fiber to improve light collection

Light collection of scintillation detector

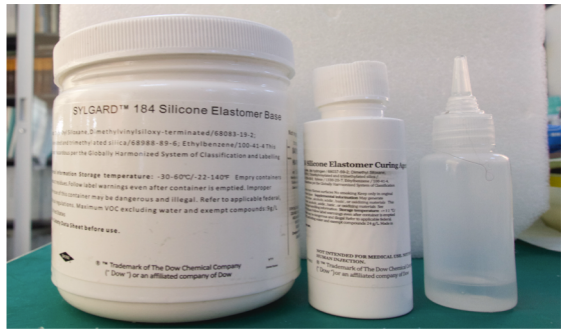


Fiber holder used to securing and aligning SiPM to fiber

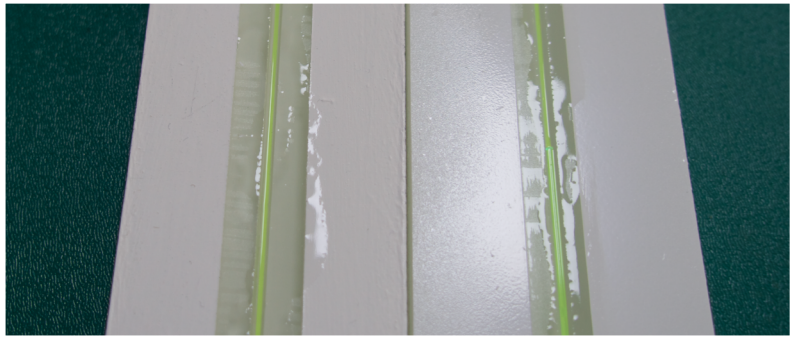


Easy & stable connection

Coupling of scintillator and fiber

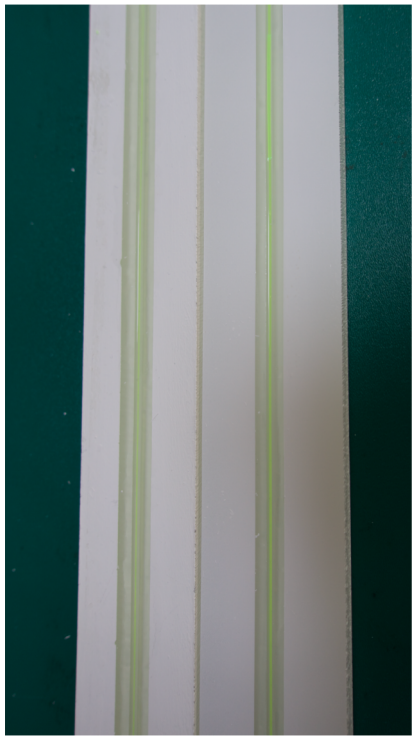


Optical glue : dowcorning 184
(Corrosion-free and light-transparent)



48h room temperature curing

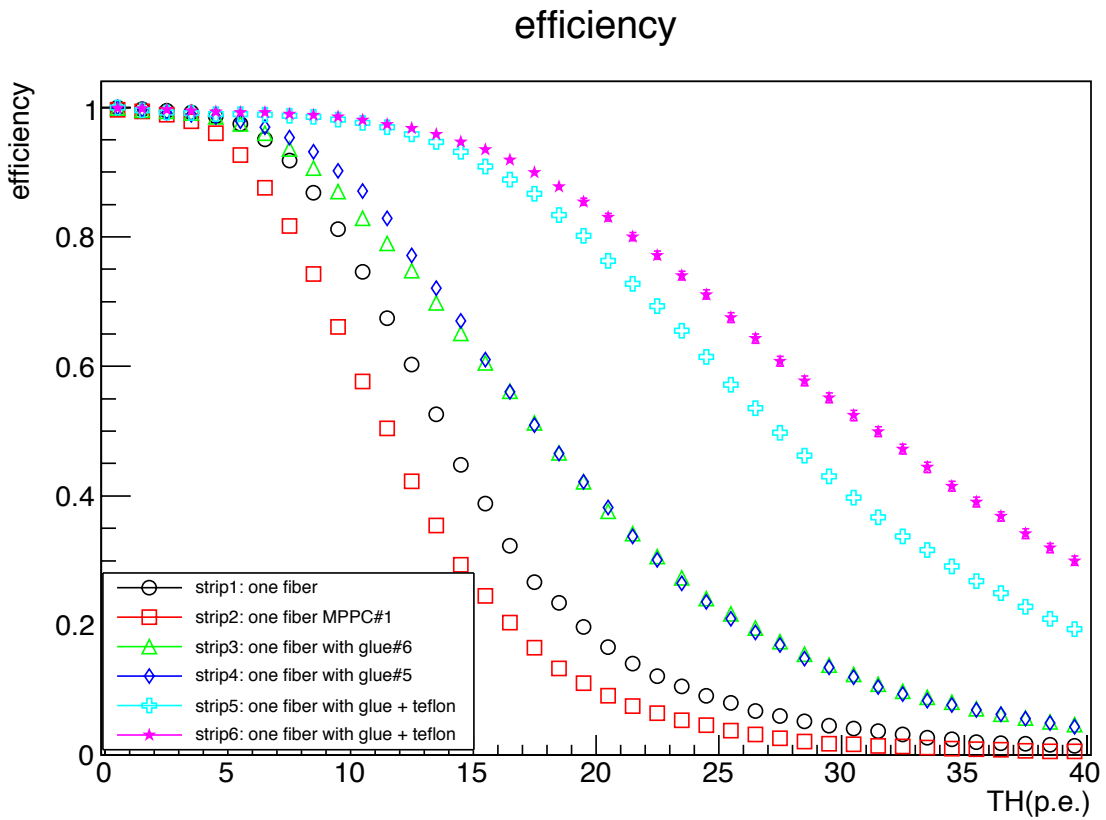
improve the optical coupling efficiency



Covered with Teflon coating

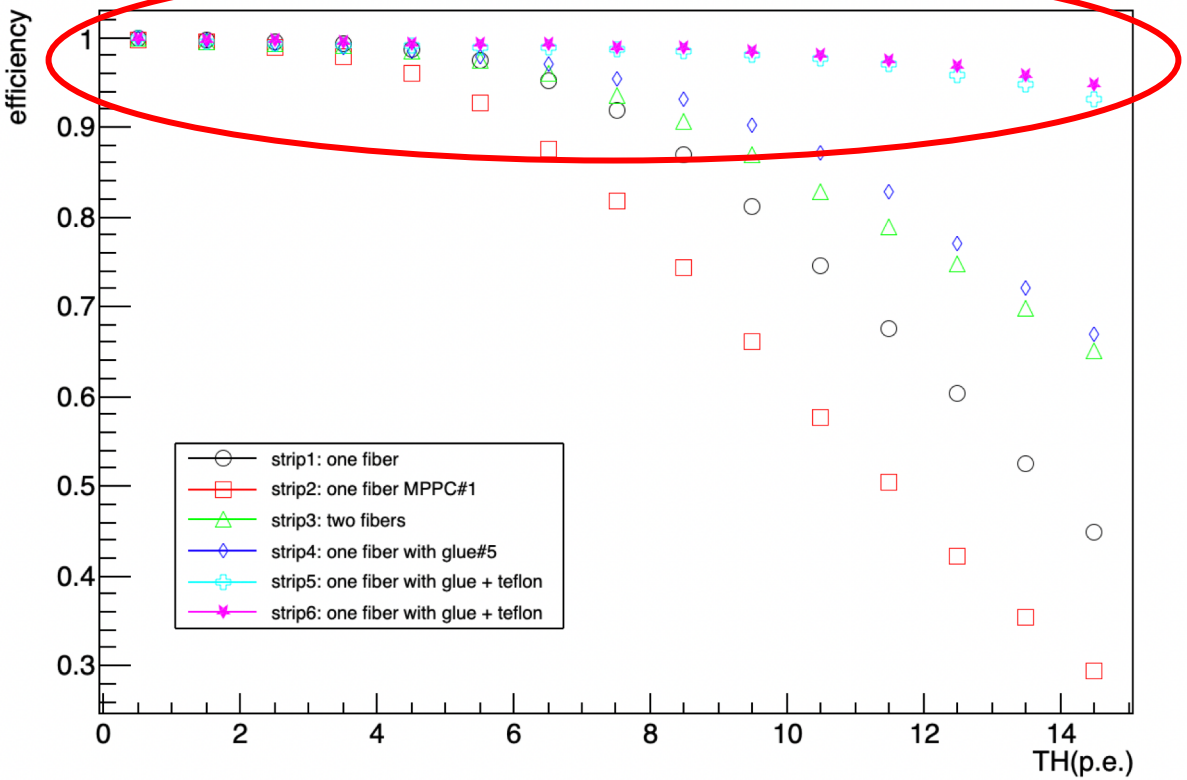
Completely wraps the scintillator to reduce light leakage

Efficiency measurement



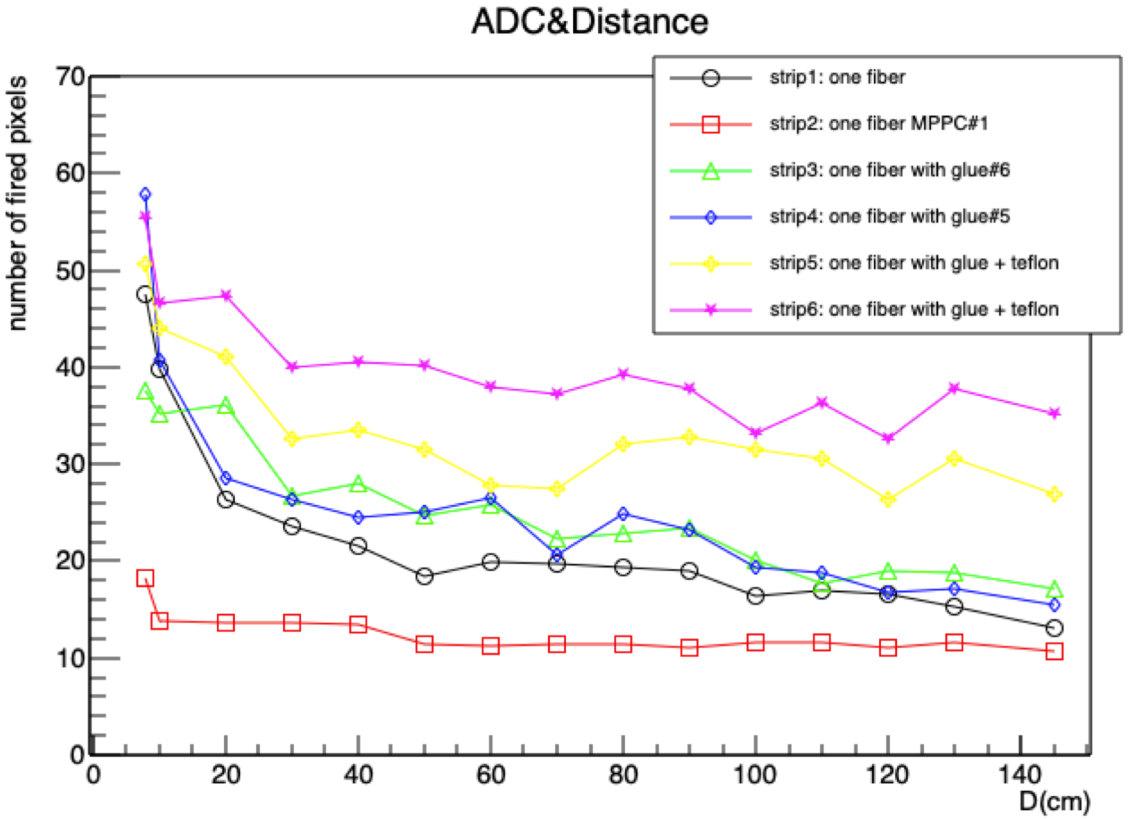
Efficiency at far end (145cm)

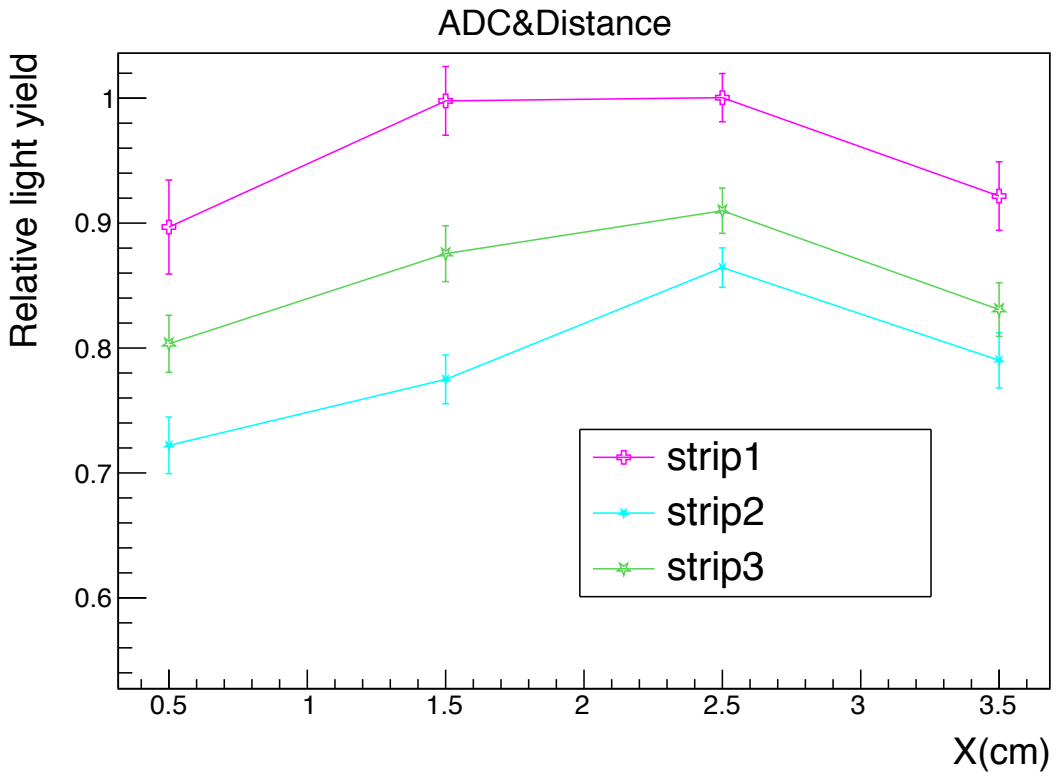
Optical glue and Teflon covering



At threshold of 10 p.e. Keep upon 98%

Efficiency measurement

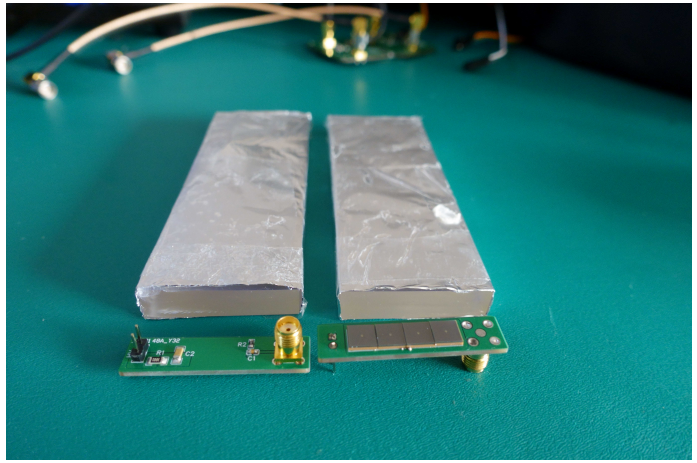


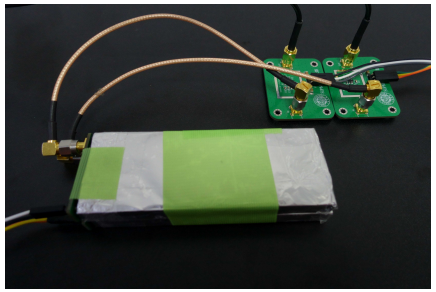


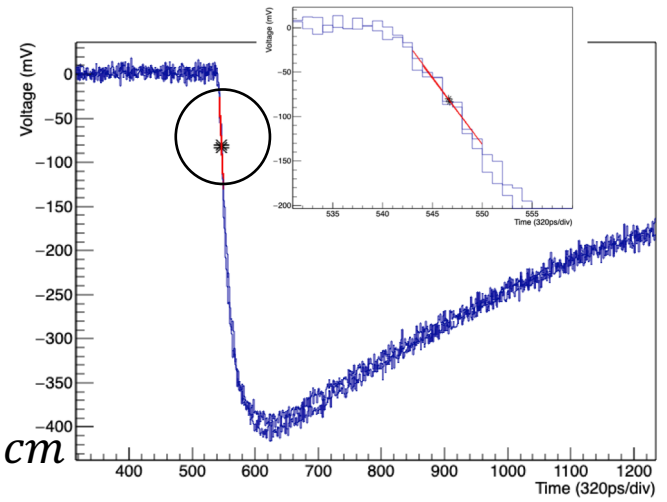
- Wavelength-shifting fiber keeps good photon collection at long distance
- the relative light yield on the transverse position of the hit

Time resolution: Scintillator + SMD SiPM

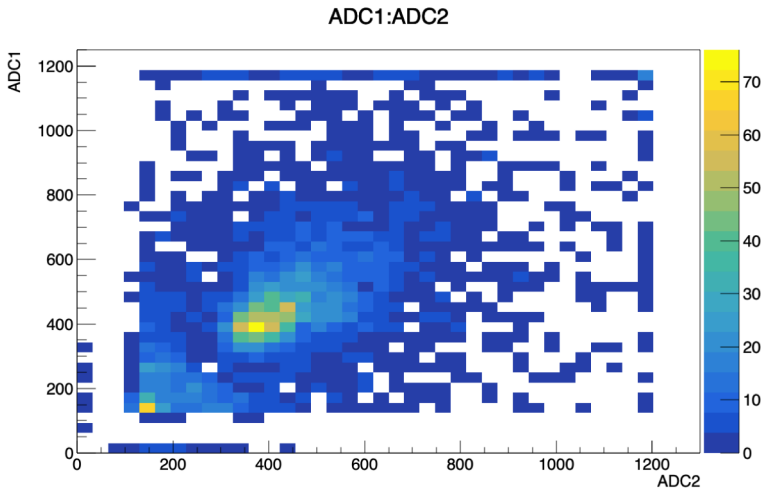
4 SiPMs in parallel

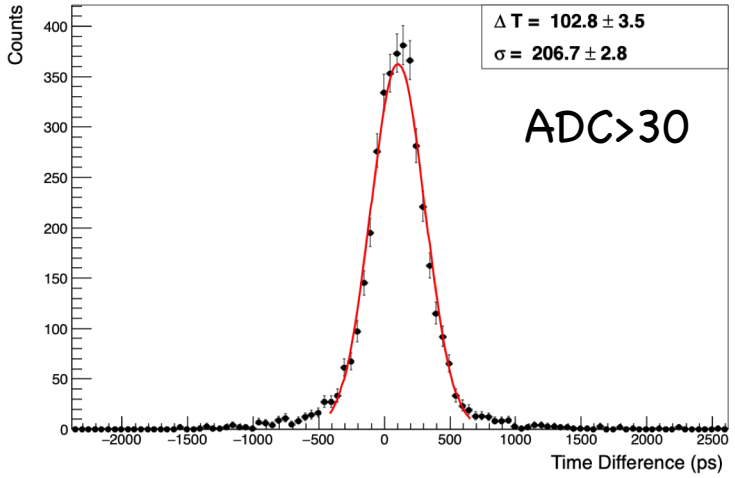


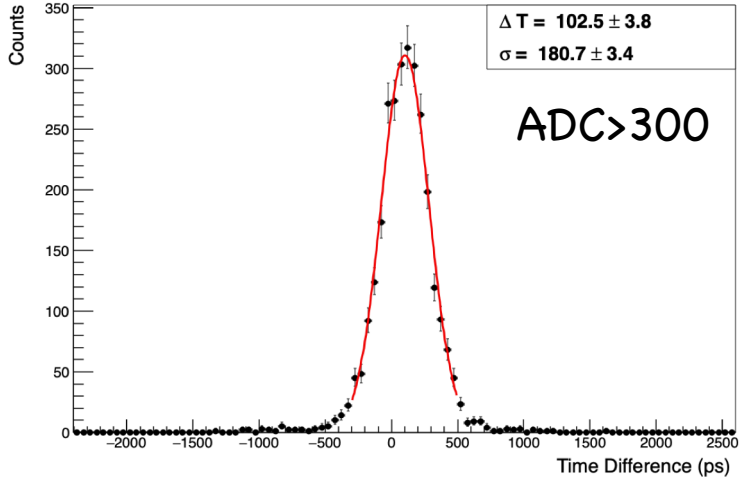




Two new strips: 4 cm × 1 cm × 10 cm
From Gaonengkedi company



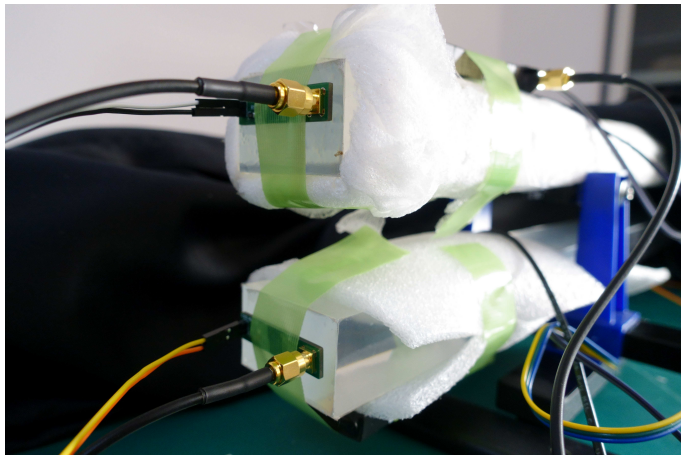


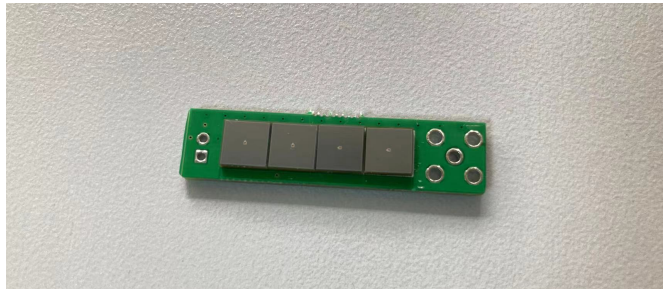


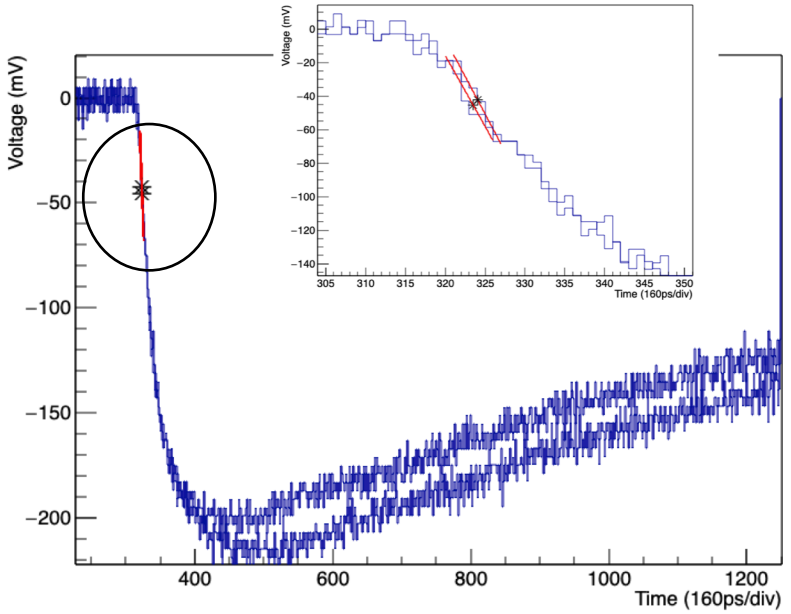
Time resolution: (146.2±2.0) ps

(127.8±3.0) ps

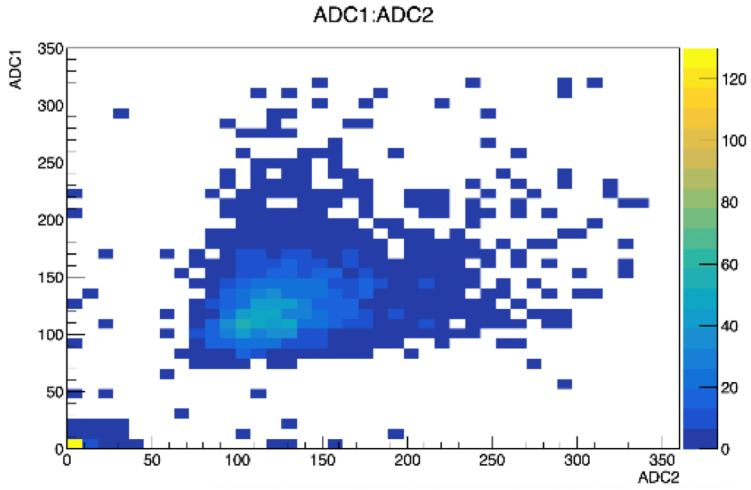
Santi-Gobain scintillators and SiPMs

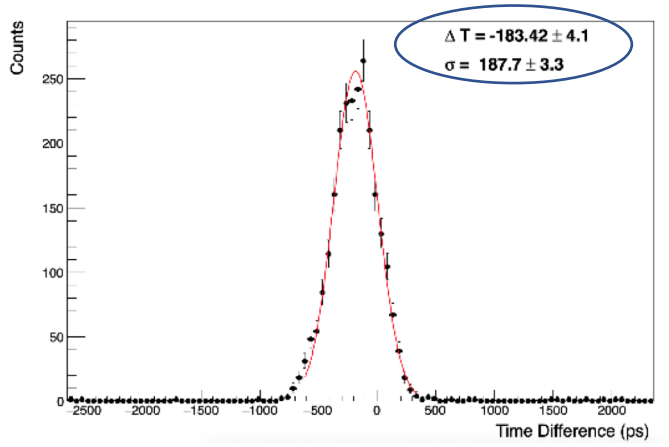






A combination of 4 pieces of $6mm \times 6mm$ SiPMs as the photon sensor.





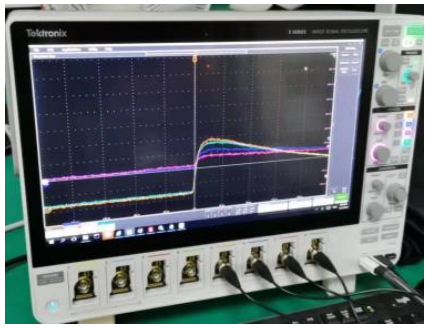
Almost a same performance as MCP-PMT for timing!!!

ADC>30

Time resolution of scintillator + SiPM

ch1、ch4

Ch2、ch3



Time resolution:

T2,T3: 132.0 ± 3.3ps

T1,T2: 127.2 ± 2.7ps

T3,T4: 119.5 ± 2.0ps

T1,T3: 199.2 ± 4.5ps

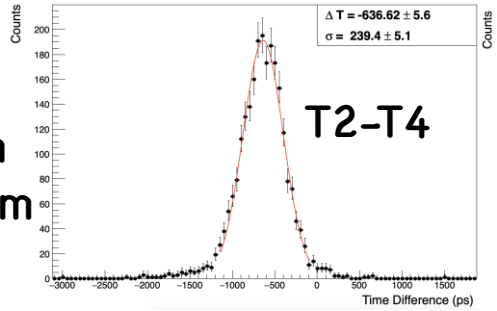
T2,T4: 169.3 ± 3.6ps

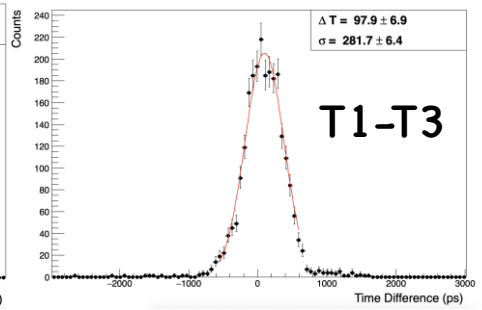
T1,T4: 222.1 ± 4.4ps

top to bottom ：1， 2， 3， 4

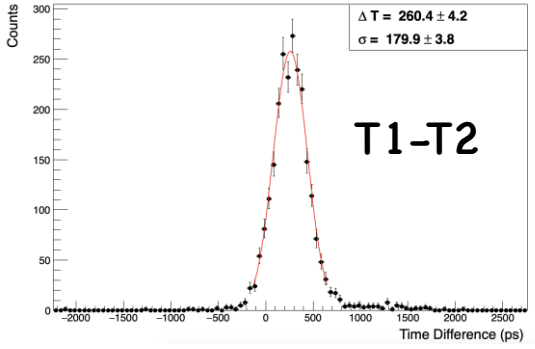
T2 and T3 with distance of ~4 cm

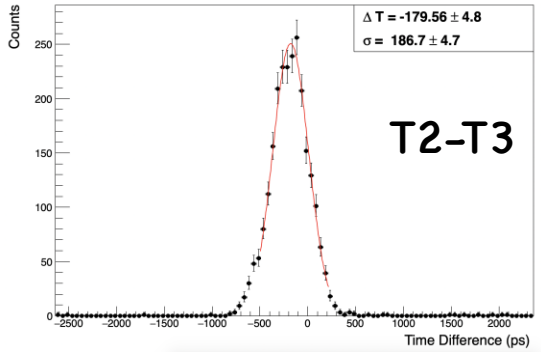
T1 and T4 with distance of ~10 cm

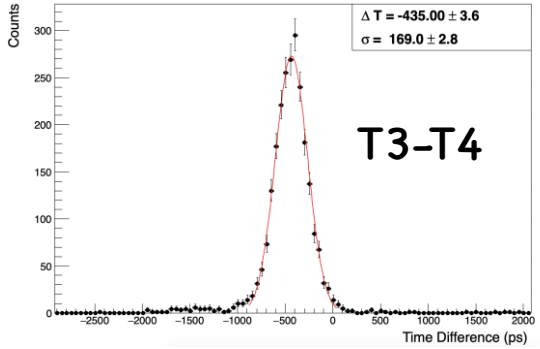


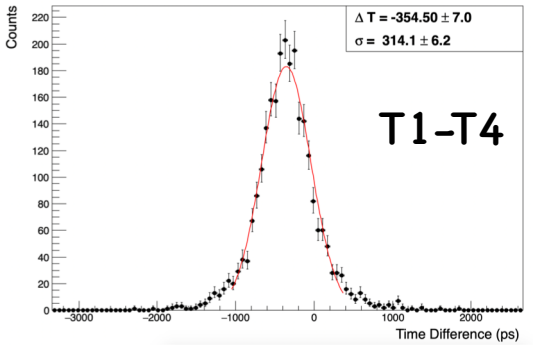


- Caused by photon propagation&& cosmic ray angle effect

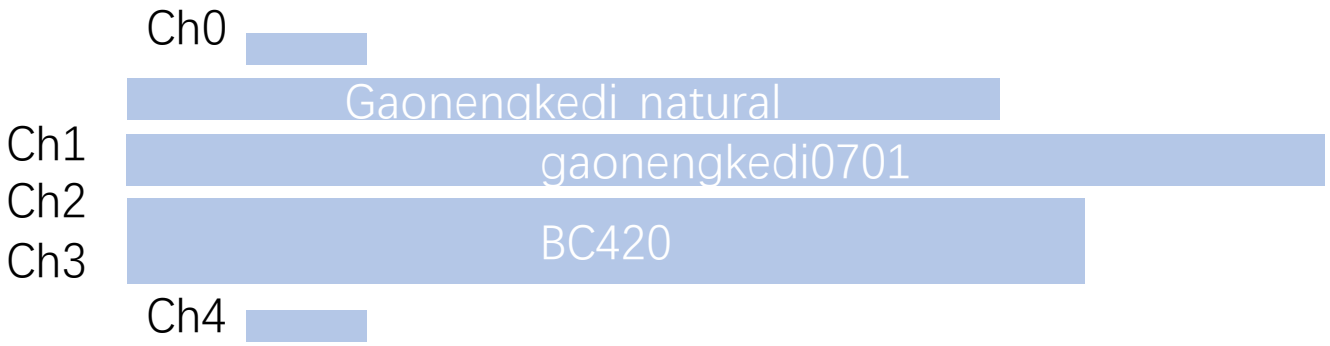


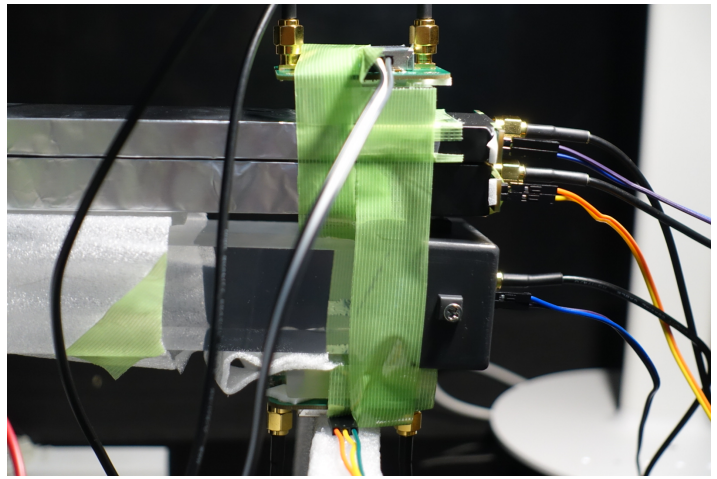






Time resolution of scintillator + SiPM



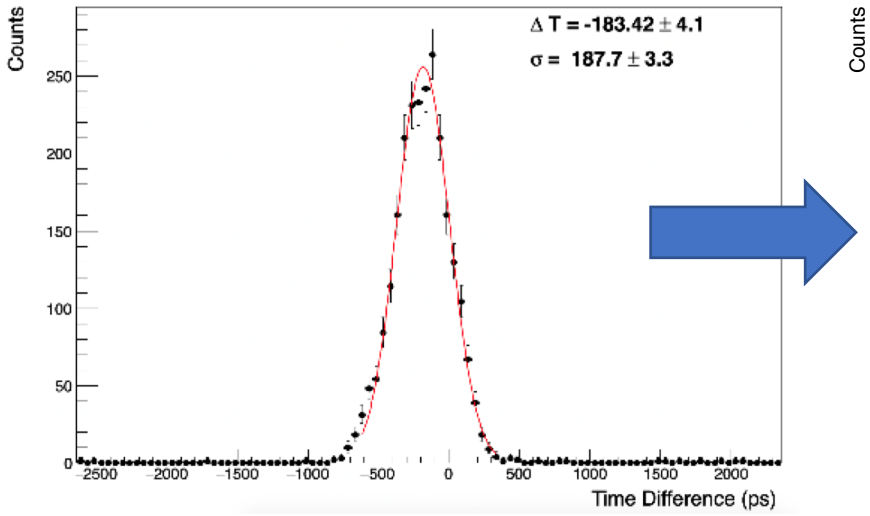


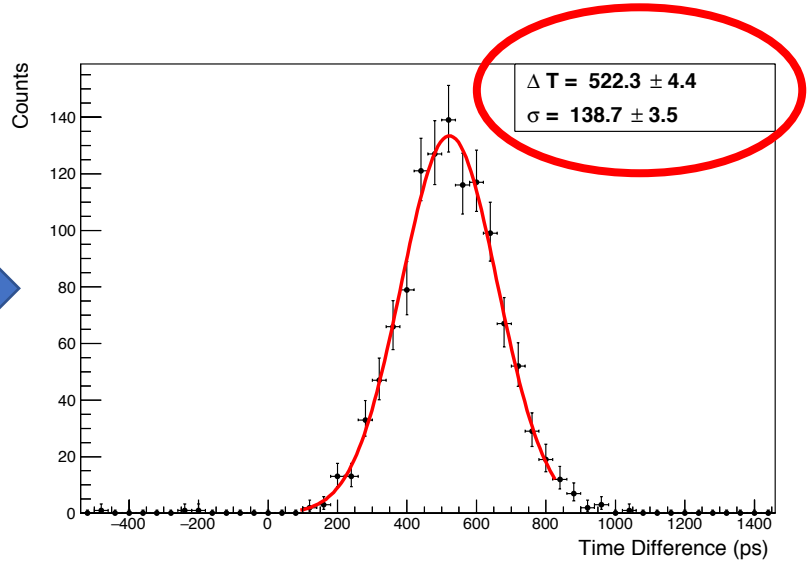
threshold：ADC0&&ADC4>50

trigger: 4 cm strips

Time resolution getting better with shorter trigger strips for better position resolution of CR

T23

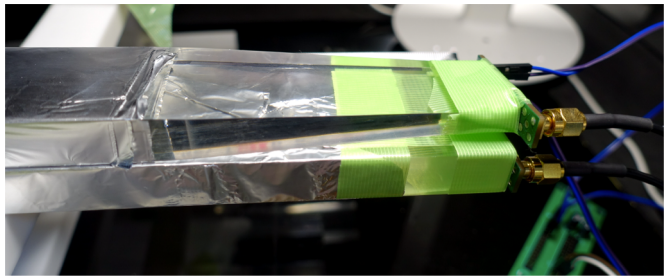




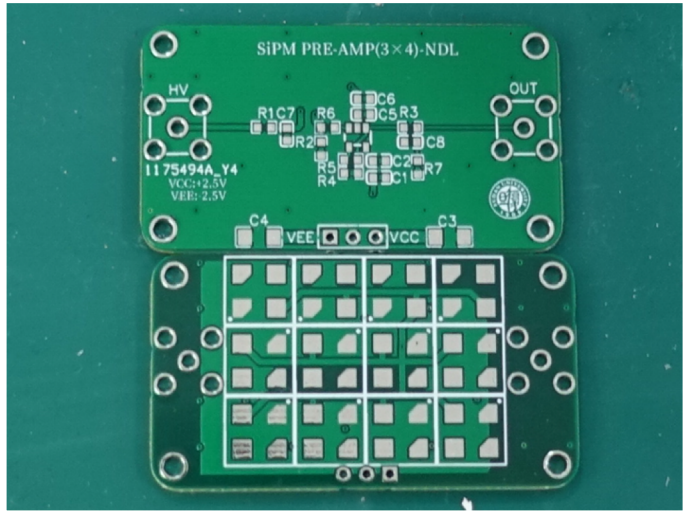
Design and test for good timing at far position

To improve time resolution at far end
Improve photon collection

- thicker scintillator (need light guide)
- more SiPMs (2 * 4、3 *4 array)
- Readout from both two ends

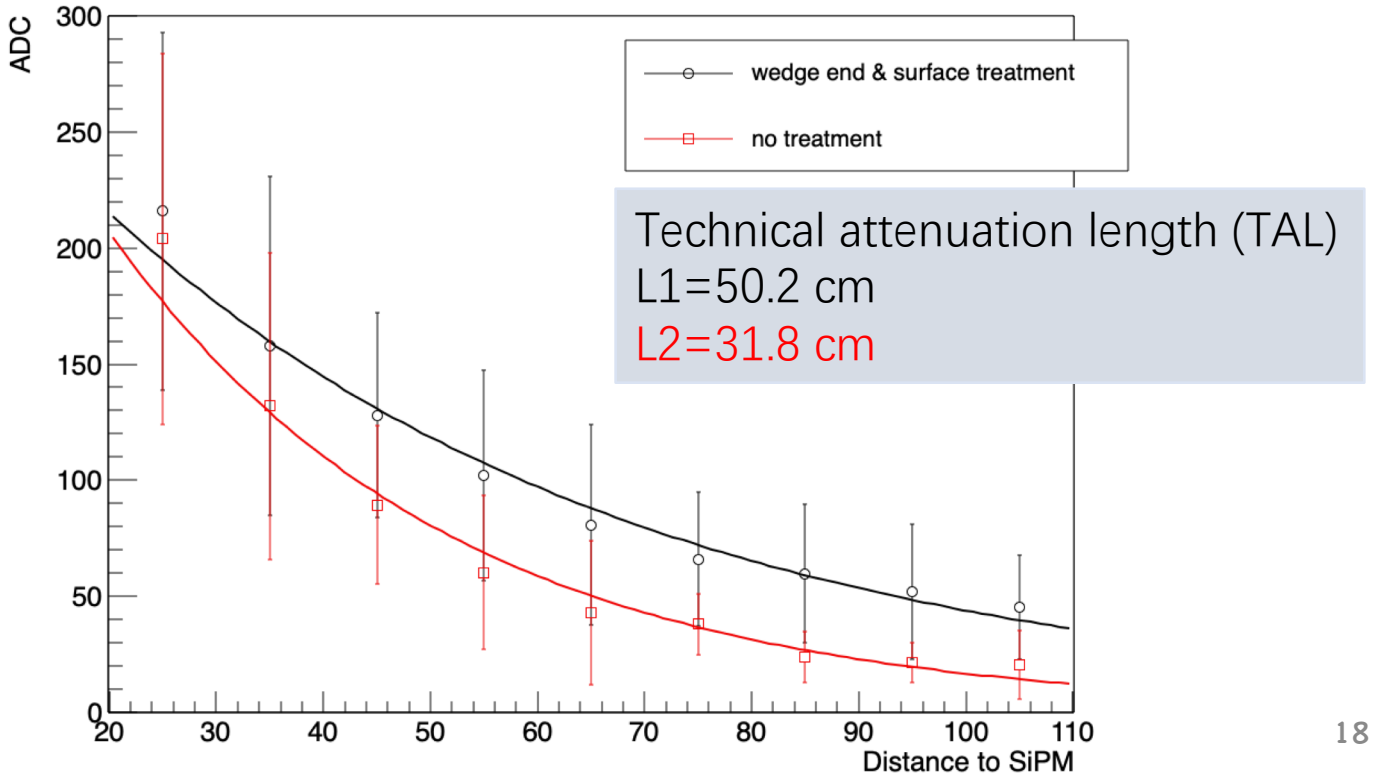


3.2*4*150 cm

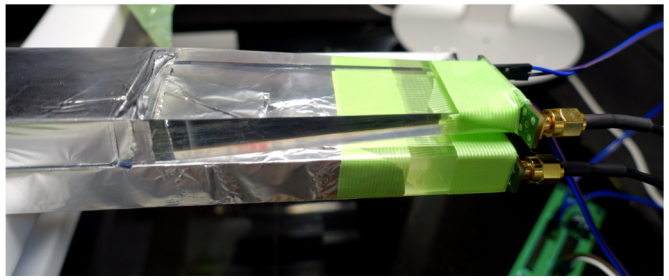


PCB for SiPM-preamplifier

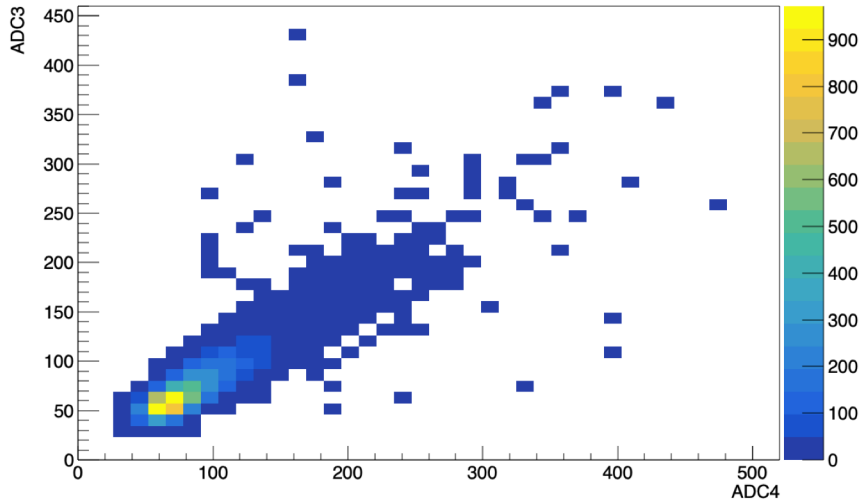
To be tested……



Design and test for good timing at far position

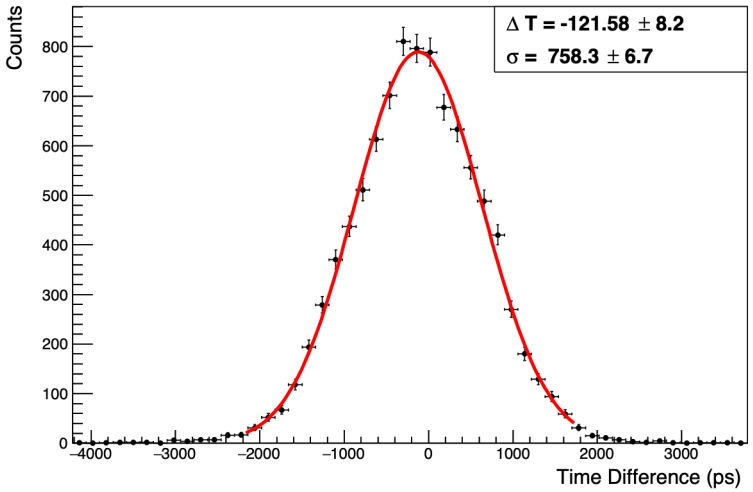


Readout at both ends
10cm trigger at middle

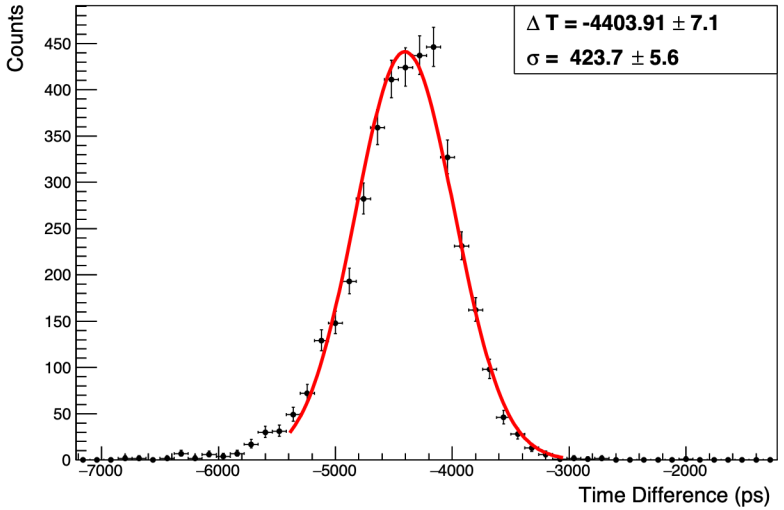


Limited light collection

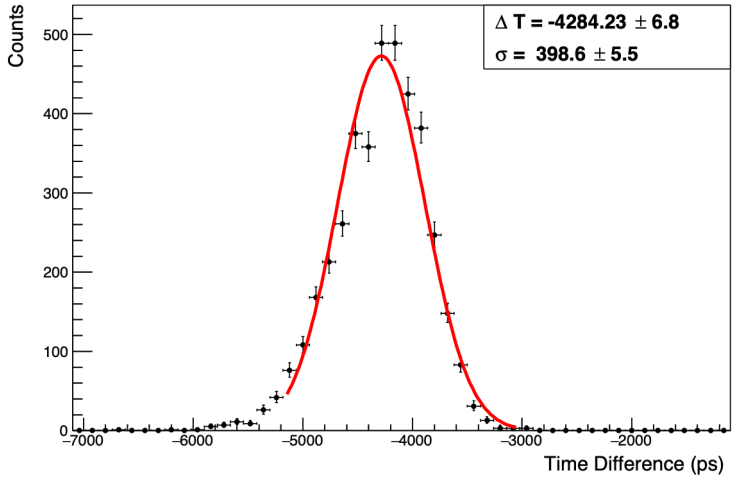
Time resolution
at 75cm : 363ps



ΔT of two ends



ΔT of one end and trigger



ΔT of average(two ends) and trigger

Summary

- Good performance of the current design for efficiency.
- Time resolution of about 100 ps has been obtained at near end.
- Time resolution of about 360 ps has been obtained at 75cm.

- Try better light collection to improve time resolution.

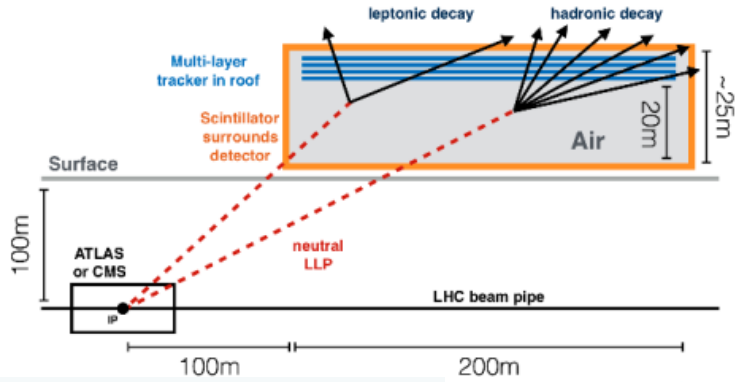
Thank you!

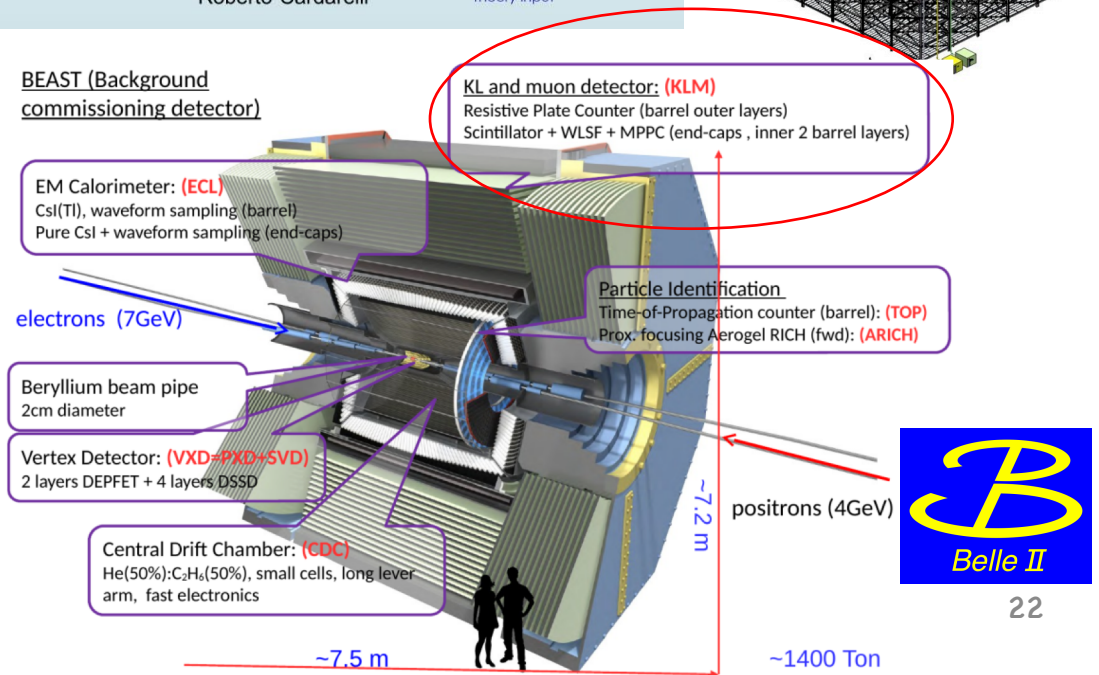
Back up

For reference

Scinti + SiPM

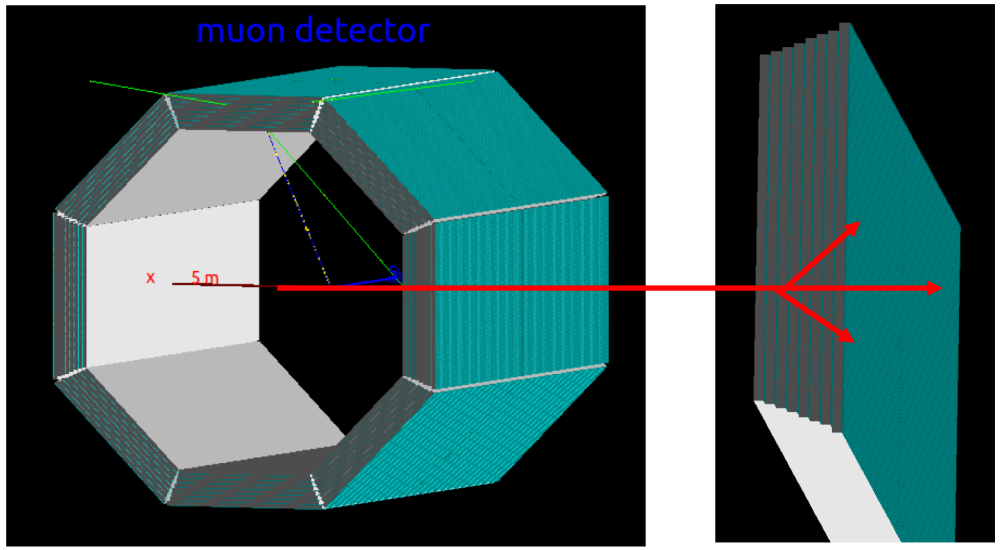
- MUTHUSLA experiment
  - Large size detector based on scintillator to search for long-live particle
  - Institutions: SLAC, Fermilab…
- Belle II experiment: L = 10^{36} $cm^{-2}s^{-1}$
  - Belle II started physics running on 11/3/2019
  - Endcap and inner 2 barrel layers: RPC → Scintillator
  - Good performance achieved
  - Belle II is considering the upgrade: all the barrel RPC → scintillator; new readout system
  - Institutions: Fudan U., U of Hawaii, Virginia Tech, …
- Helpful for R&D, testing, production, price…
- SiPM is becoming popular



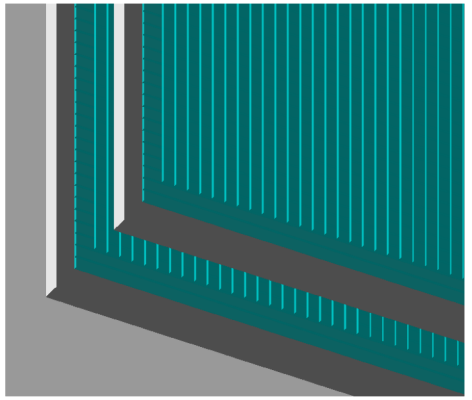


How about implementing timing?

- 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 search, 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

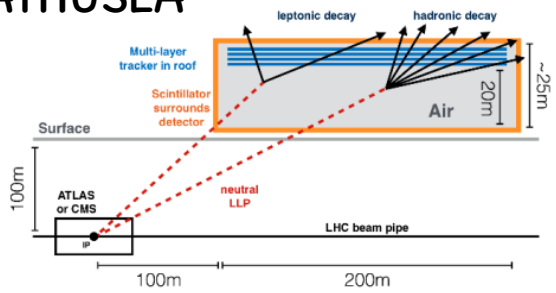
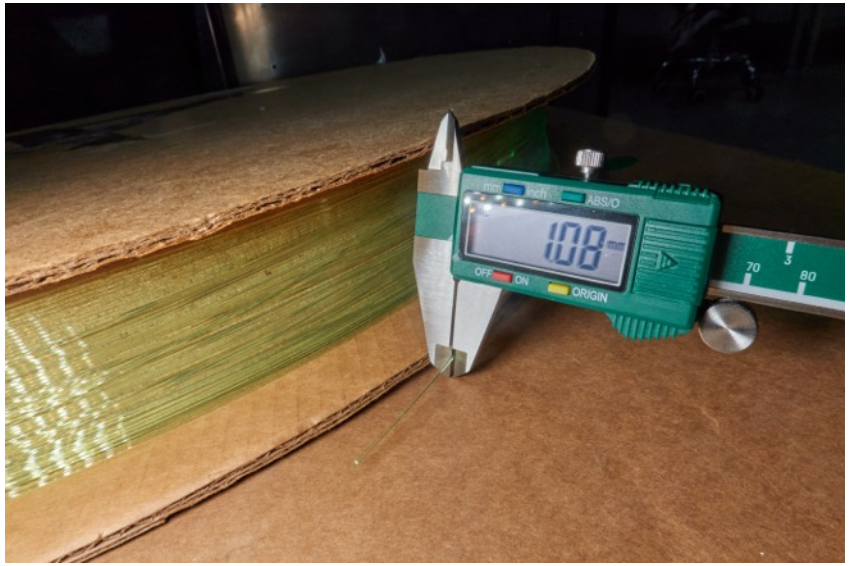


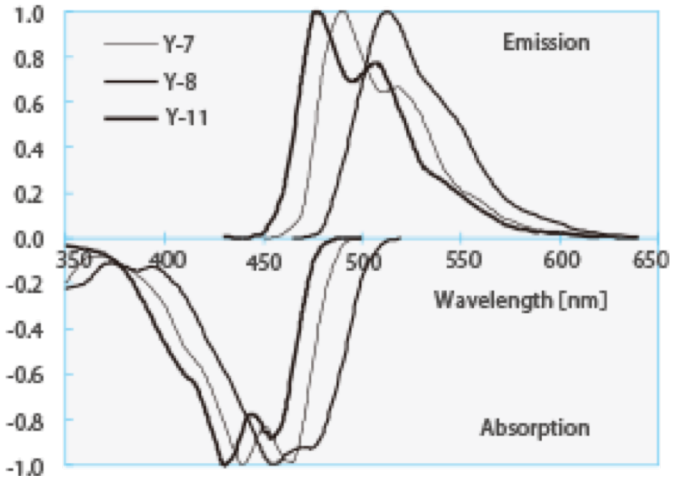
Fig. 1: Simplified detector layout showing the position of the 200 m × 200 m × 20 m LLP decay volume used for physics studies. The tracking planes in the roof detect charged particles, allowing for the reconstruction of displaced vertices in the air-filled decay volume. The scintillator surrounding the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

Two kinds of WLS fiber

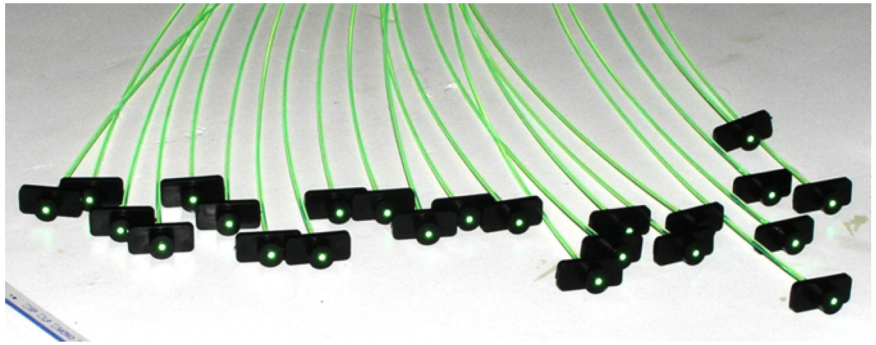
- Wavelength-shifting fibers



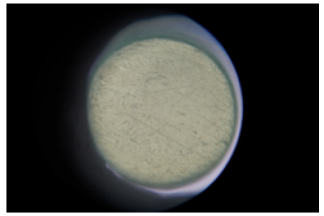
Saint-Gobain WLS Fiber
1.0mm Dia.



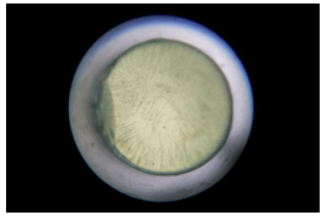
Blue to Green Shifter (Kuraray)



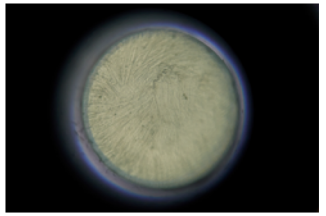
KURARAY WLS Fiber
Y-11(200)MSJ
1.2mm Dia.



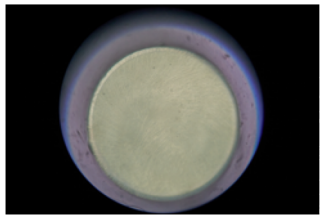
- File



- 1000 grit sandpaper



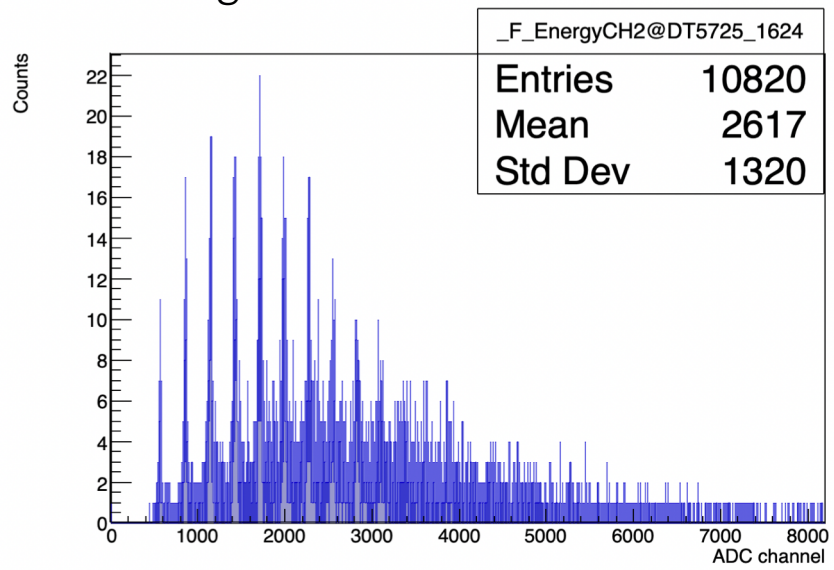
- 1500 grit sandpaper



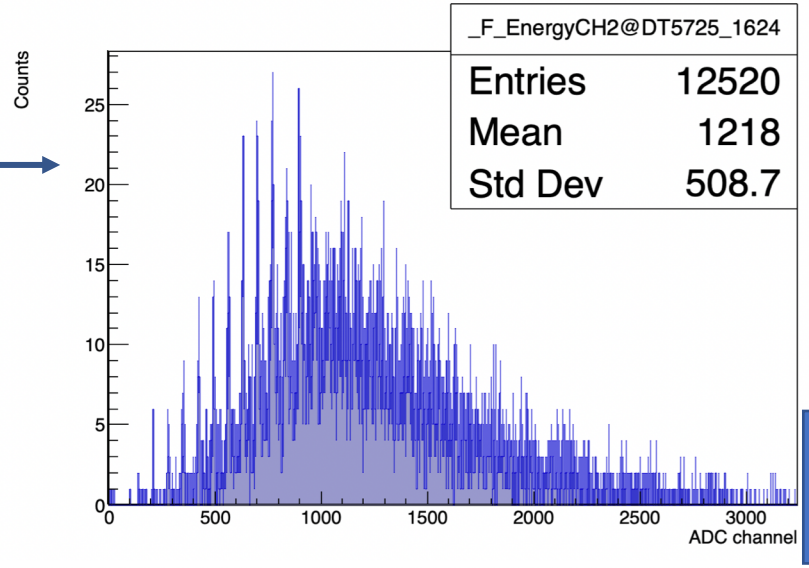
- 2000 grit sandpaper

Comparison of two WLS fibers

Choosing better fiber



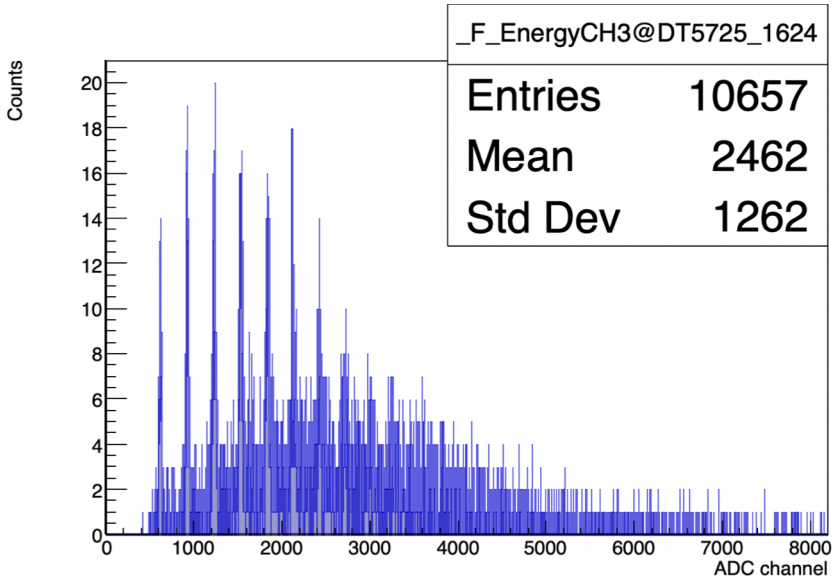
SD#1



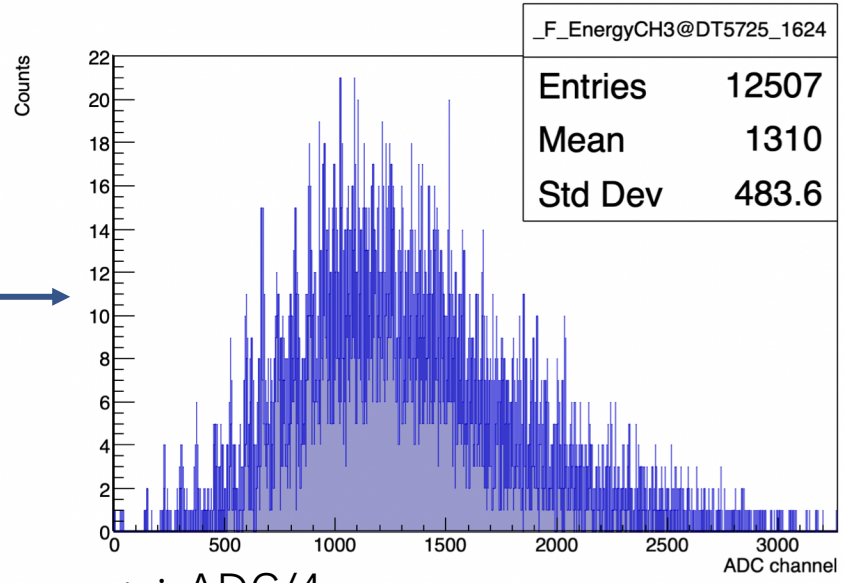
Better light yield

Left：saint_gobain
Right：kuraray

scintillator：150cm



SD#2



*：ADC/4

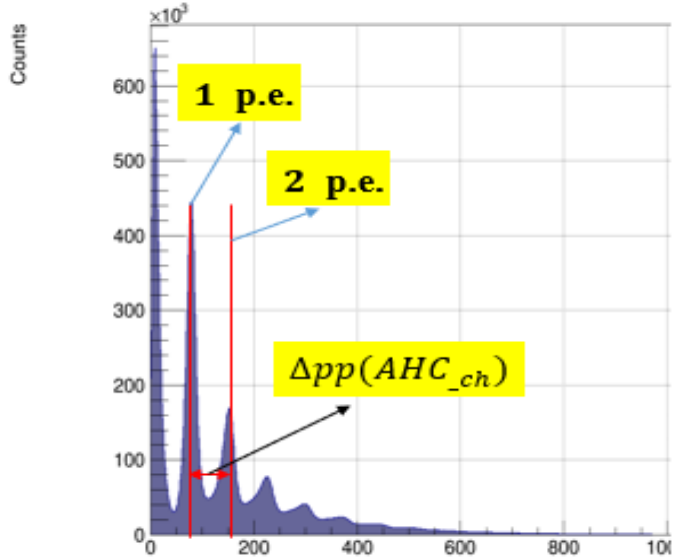
NDL性能测试——增益测量

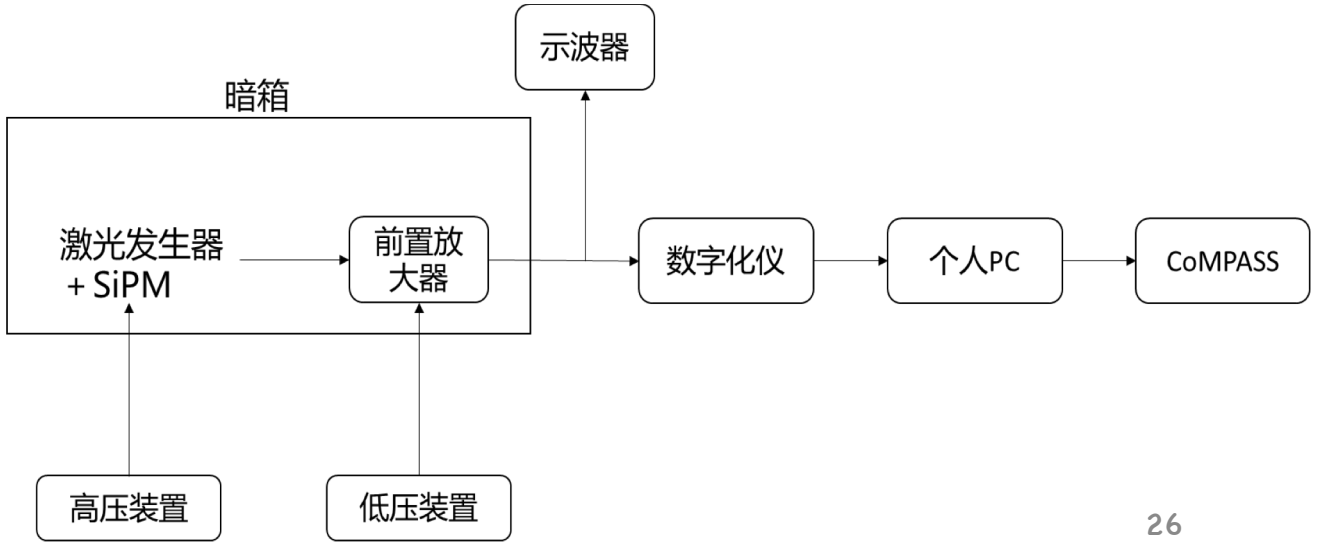
$$Gain = \frac{Q}{e} = \frac{(V_{op} - V_{br})C_{pixel}}{e}$$

$$Gain = \frac{\Delta pp(AHC_{\mathrm{ch}}) \times ADC_{c.r.}}{e}$$

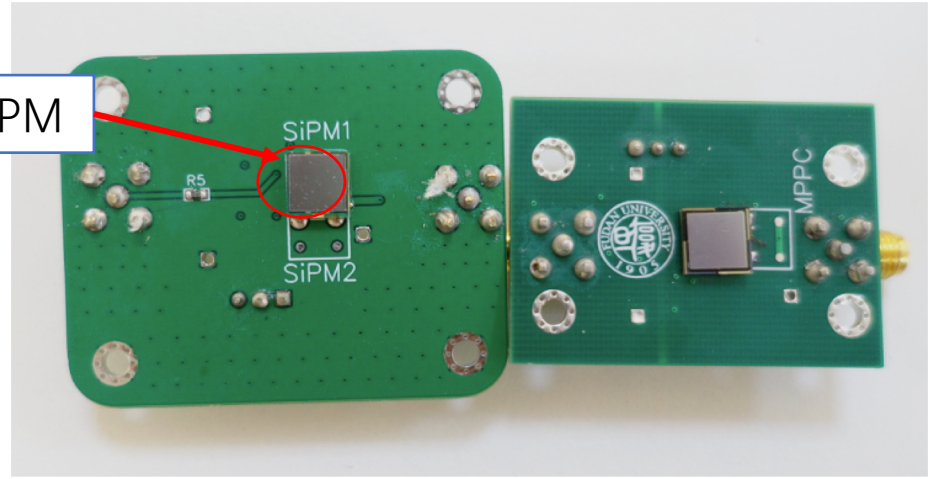
$$\Delta pp(AHC_{ch}) = V_{op}\frac{C_{pixel}}{ADC_{c.r.}} - V_{br}\frac{C_{pixel}}{ADC_{c.r.}}$$

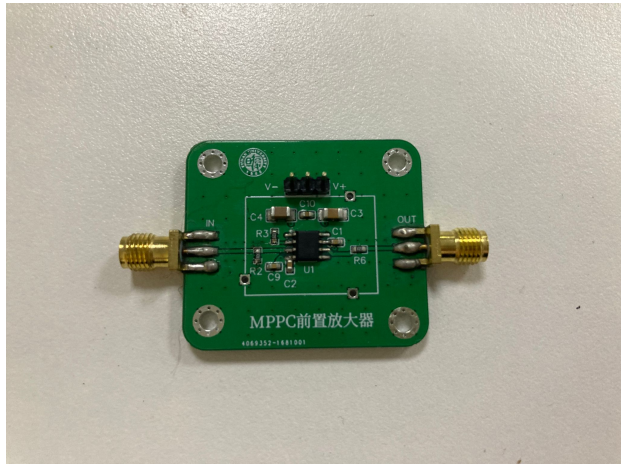
$\Delta pp(\mathrm{AHC_{ch}})$为输出电荷积分频谱中峰与峰之间的道数差；**e**为电子电量；$ADC_{\mathrm{c.r.}}$为**ADC**转换系数；**n p.e. (photon equivalent)**为由**n**个光子所引发的脉冲





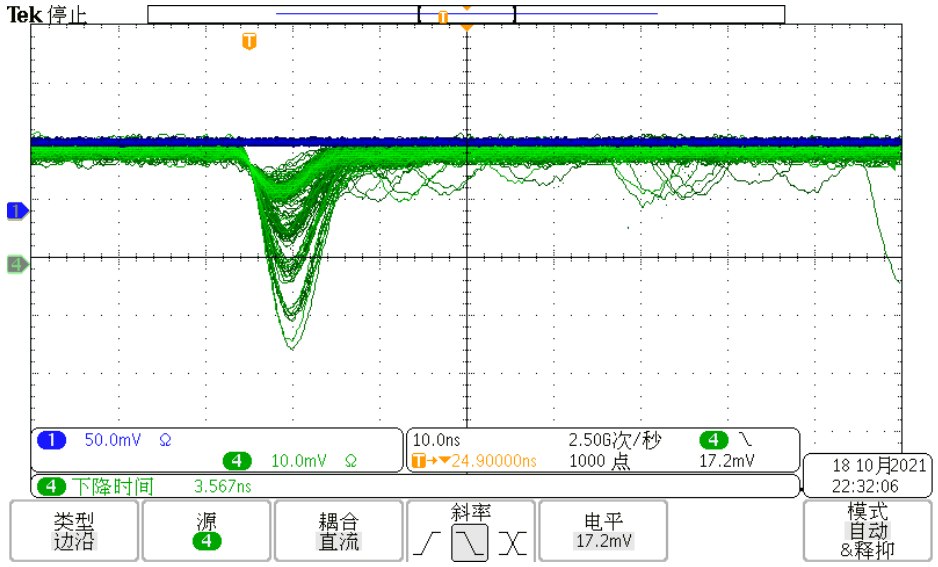
New design on the FE and NDL SiPM



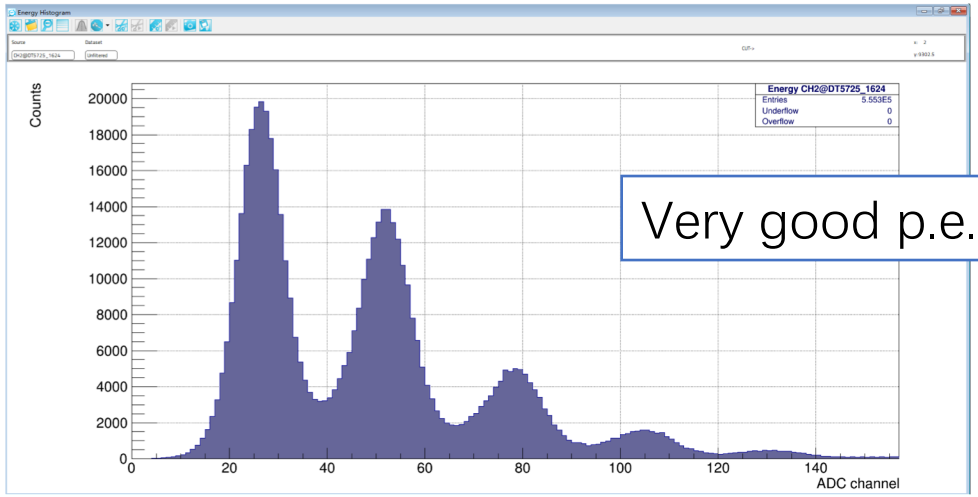


Register with high frequency amplifier

*Suitable for MPPC



Rising time: ~3.5 ns!

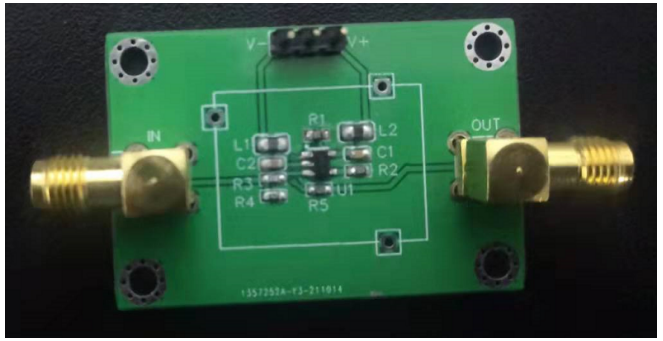


Very good p.e. peaks!

The preams are tuned at FDU for different kinds of SiPMs.

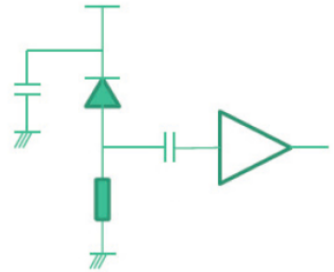
Design of fast preamplifier

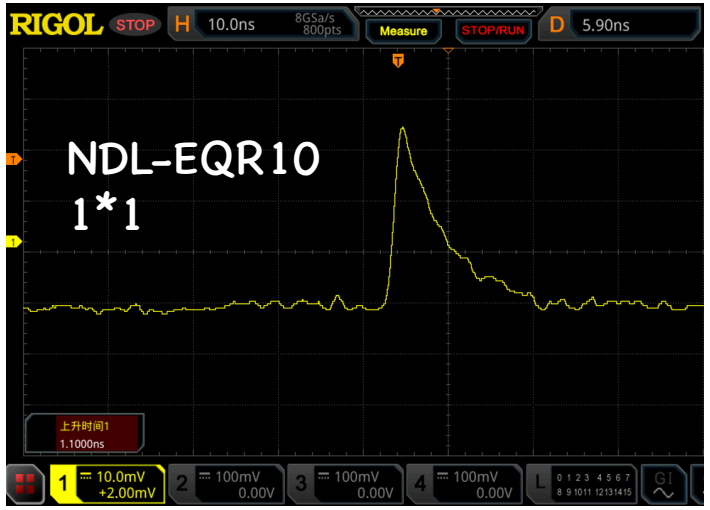
Resistor sampling and negative feedback amplifier circuit



Register with high frequency amplifier

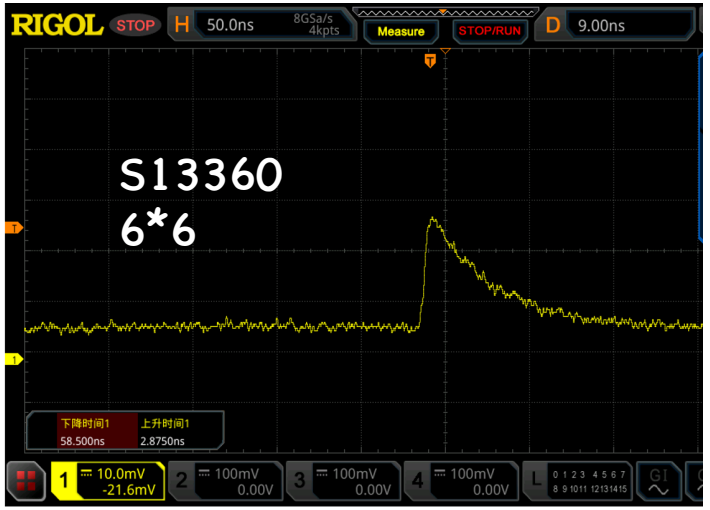
*Suitable for MPPC





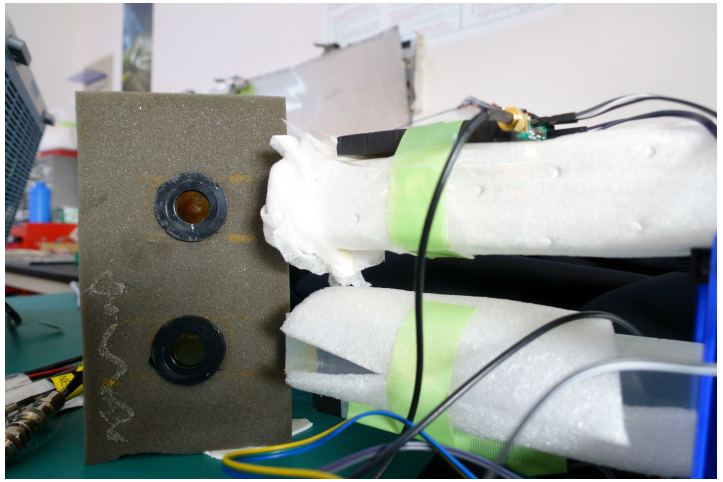
Rise time : 1-2ns
HWHM : 3-4ns

Rise time : 2-4ns
HWHM : 6-8ns



Rise time : 5-10ns
HWHM : 40-60ns

Testing with two long Santi-Gobain scintillators

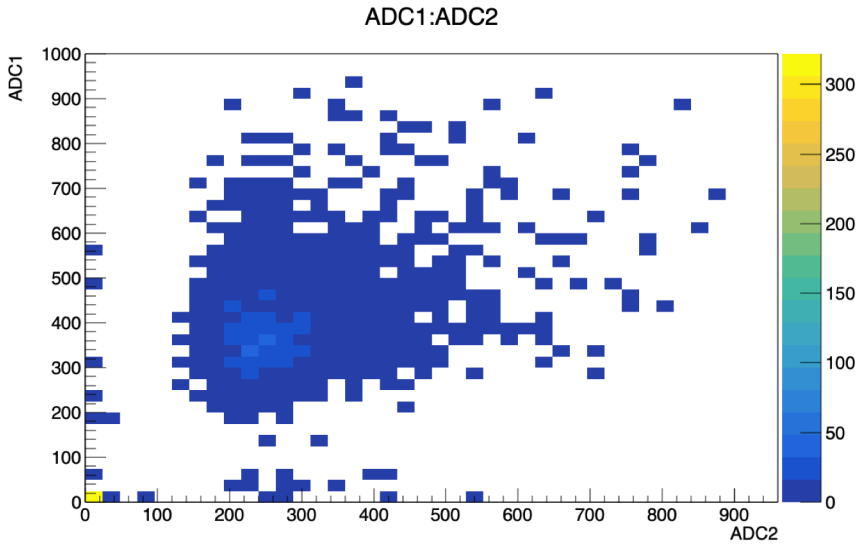


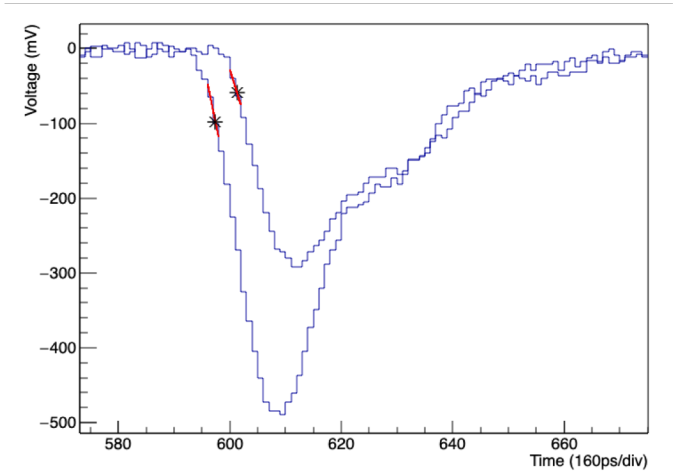
Two MCP-PMT

Trigger strips at near end:
$4cm \times 1cm \times 10cm$

Two long strips from IHEP with excellent time resolution:

$3cm \times 5cm \times 1m$





Time resolution: $< 130ps$