Update of the scintillator based Muon detector

Xiaolong Wang (for the Fudan team)

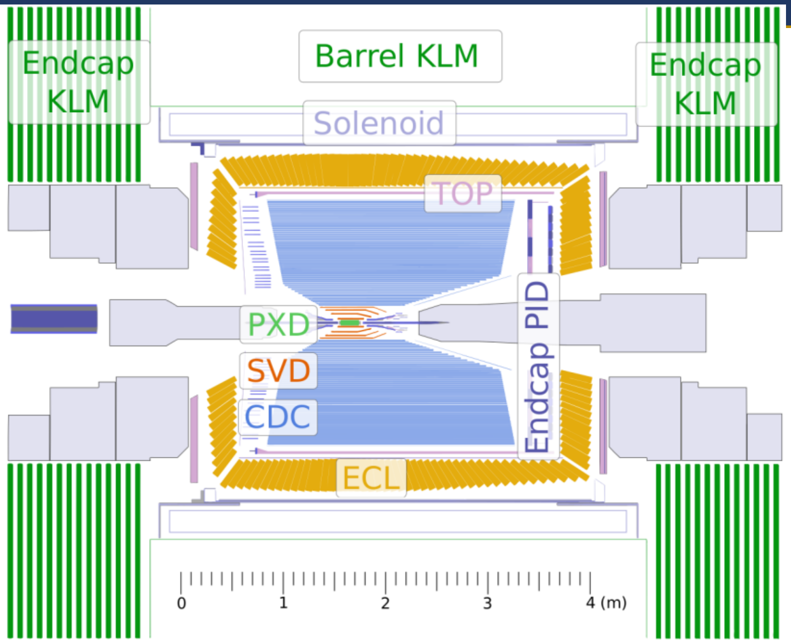
Fudan University

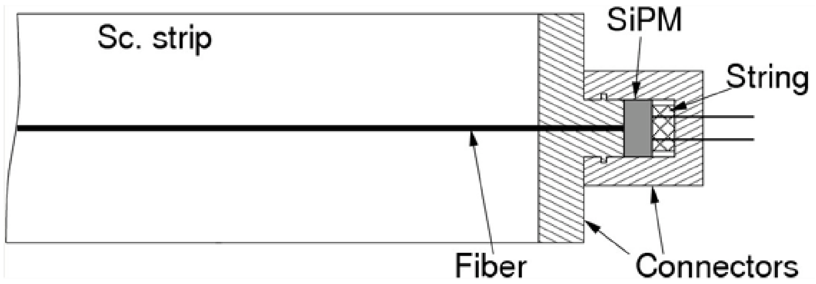
CEPC Day, August 29, 2022

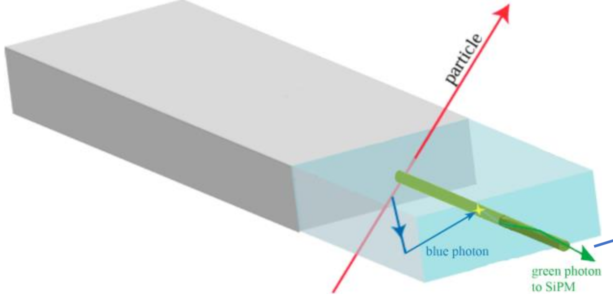
Outline

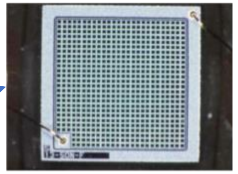
Structure of Belle II KLM design

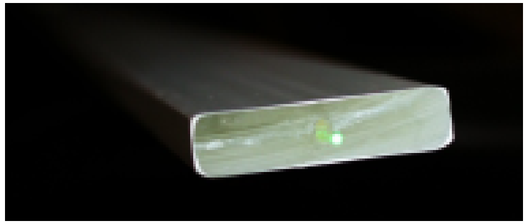
- A simple structure: scintillator+WLS fibre+SiPM.
- Good performance at Belle II KLM.
- Easy for large size production and maintenance.

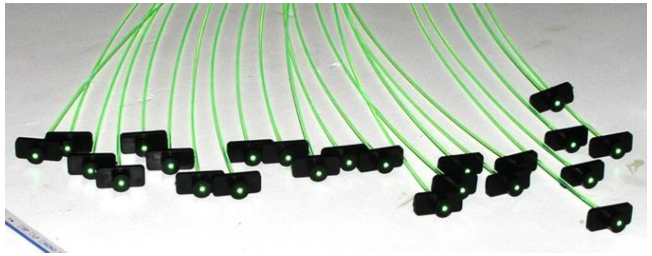




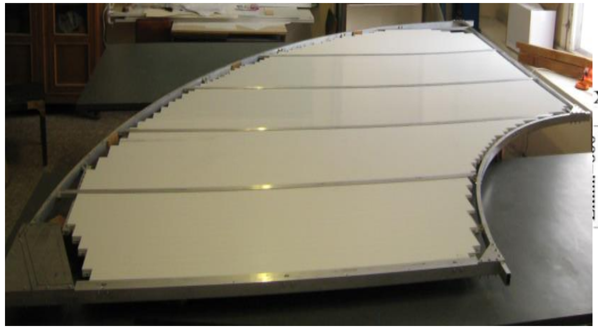


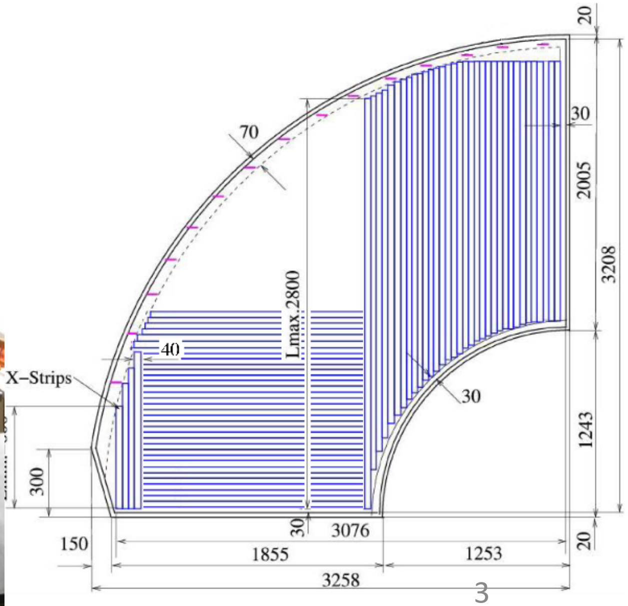




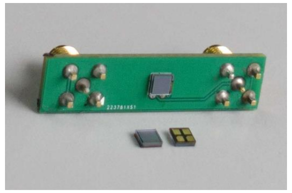


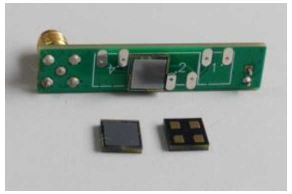
Superlayer for 2D hit position.





New choice: NDL SiPM





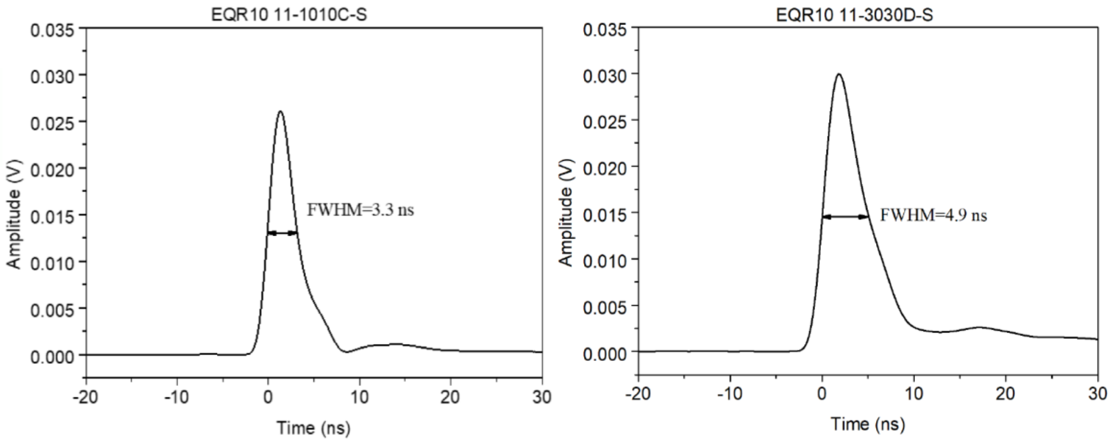
Specifications

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 / °C	19 mV / °C
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

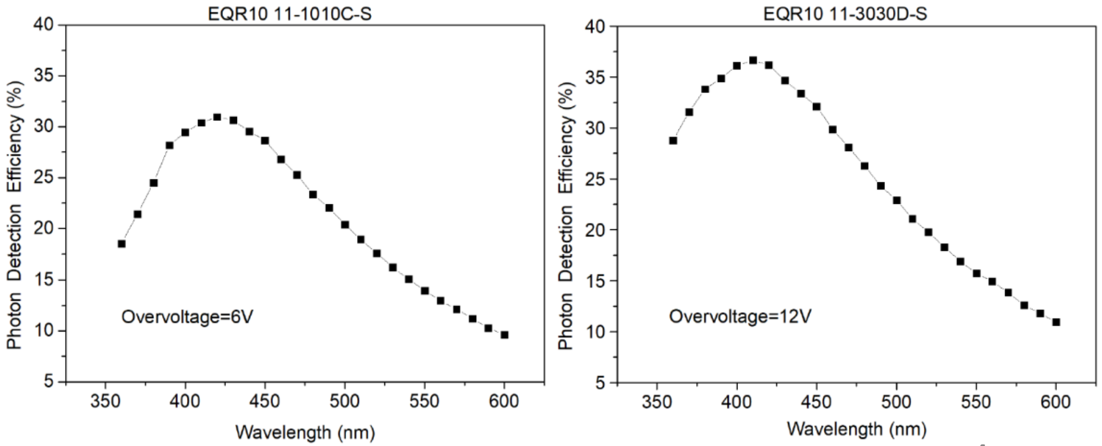
Above parameters are measured at their recommended operation voltage and 20 °C.

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

Characteristics

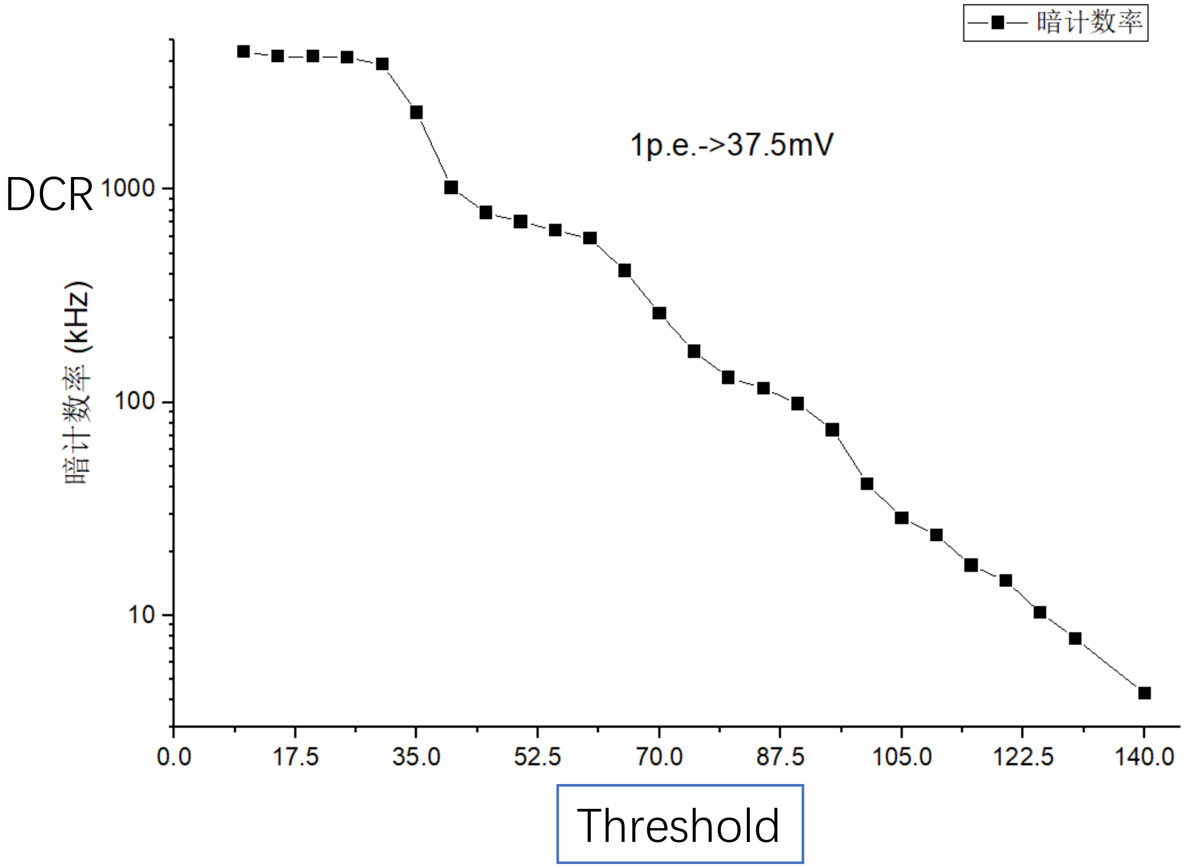


The single photoelectron pulse (amplified by a 40dB fast amplifier).



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

Dark Count Rate vs. # of p.e.



Single p.e.：37.5mV

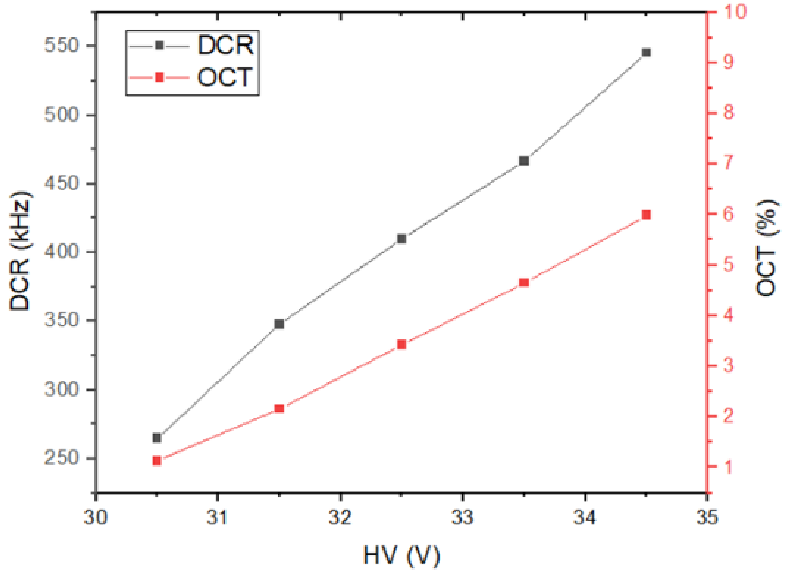
Threshold>6p.e. DCR<10 Hz
Threshold>7p.e. DCR<1 Hz

The DCR is high, comparing to MPPC.
But it's possible to reduce it.

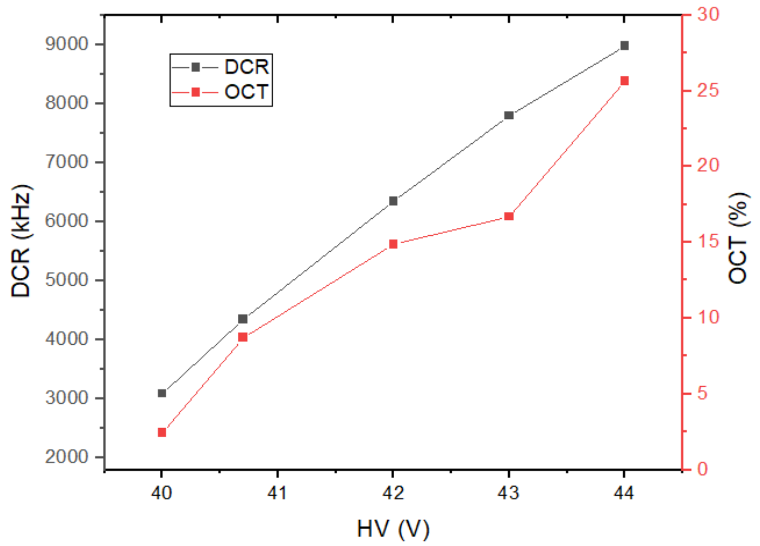
NDL-EQR15 At operating voltage

Dark Count Rate and optical crosstalk

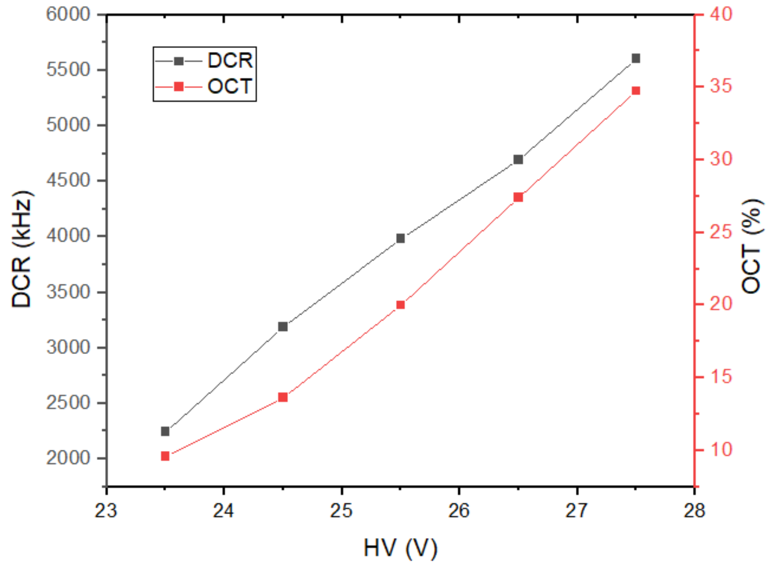
EQR10 11-1010C-S



EQR10 11-3030



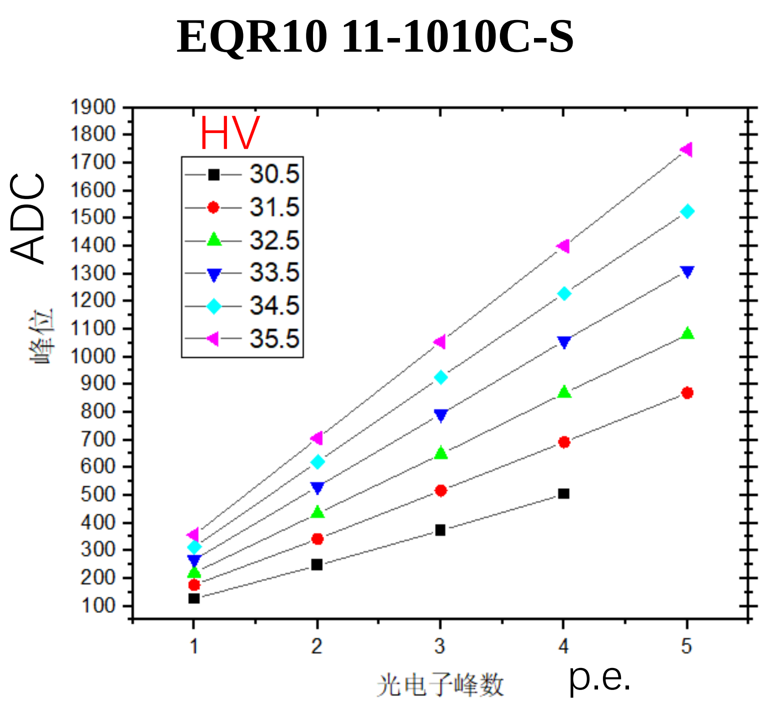
EQR15 11-3030D-S

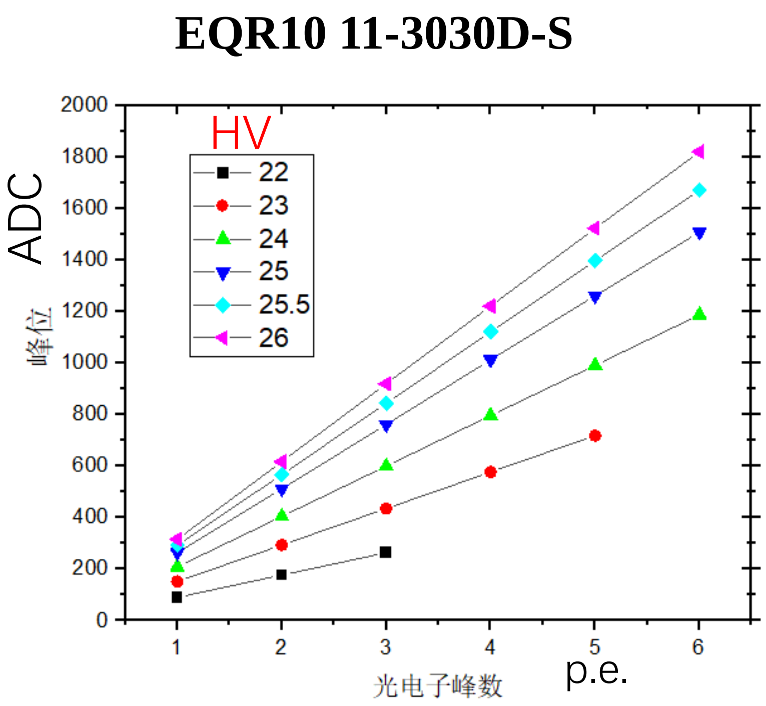


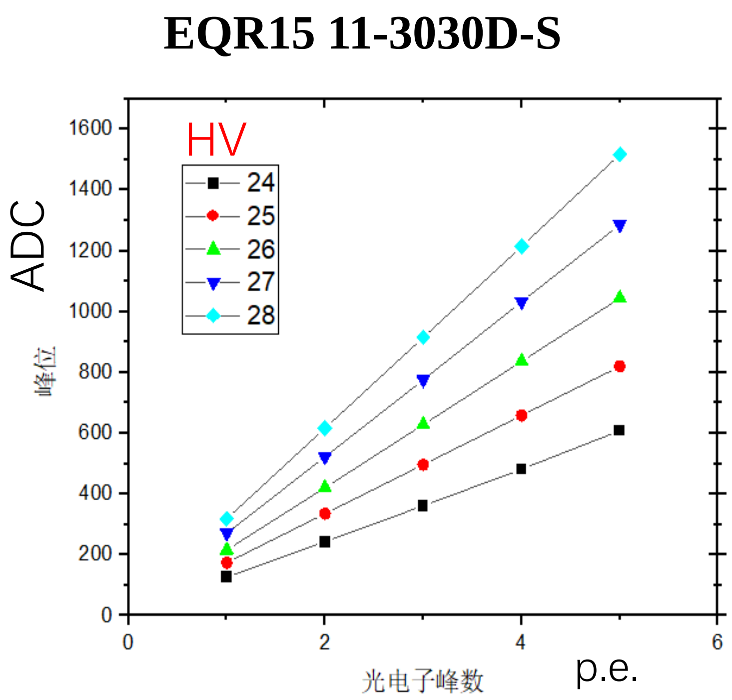
$3mm \times 3mm$

- The larger pixel, the lower DCR;
- The larger sensitive area, the higher DCR and OCT.
- They increase with higher HV.

Gain with different HV



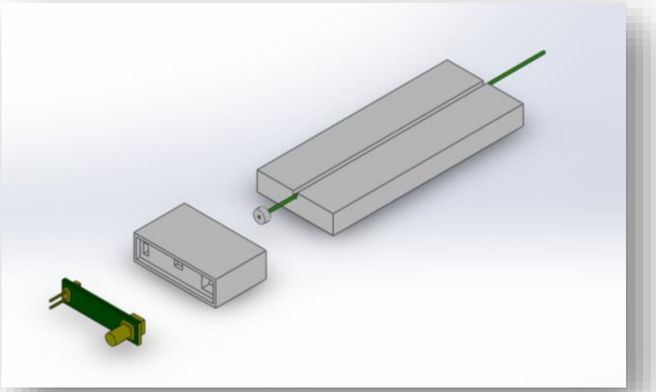




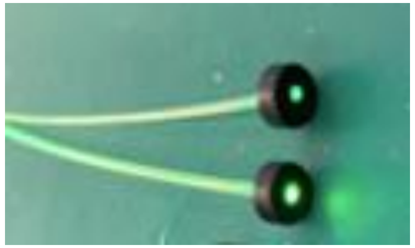
- Independent, equally spaced peaks.
- The higher the HV, the larger the gain.

Set up of detector strip

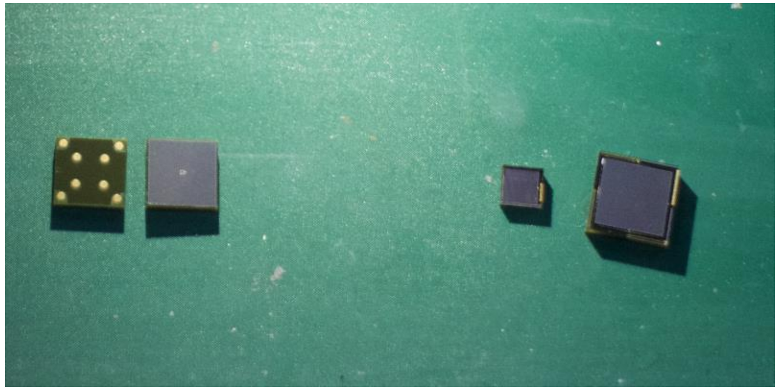
The structure



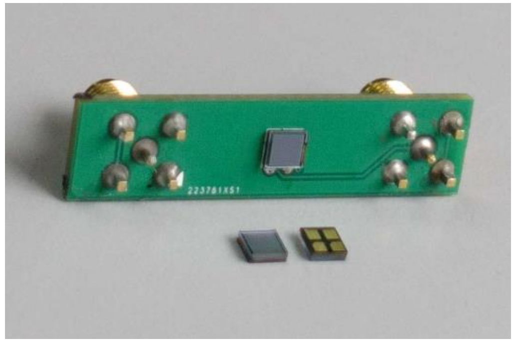
Reflective layer



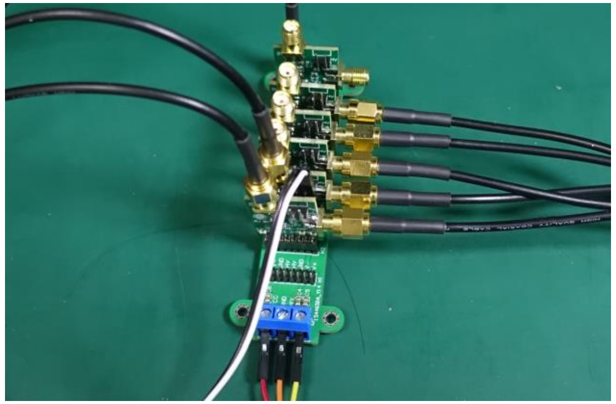
WLS fiber



NDL SiPMs

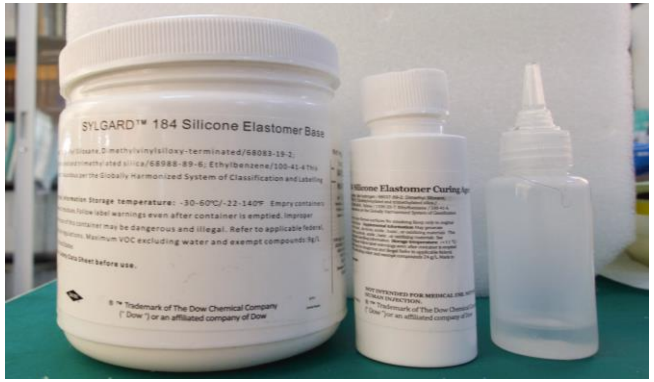


Readout

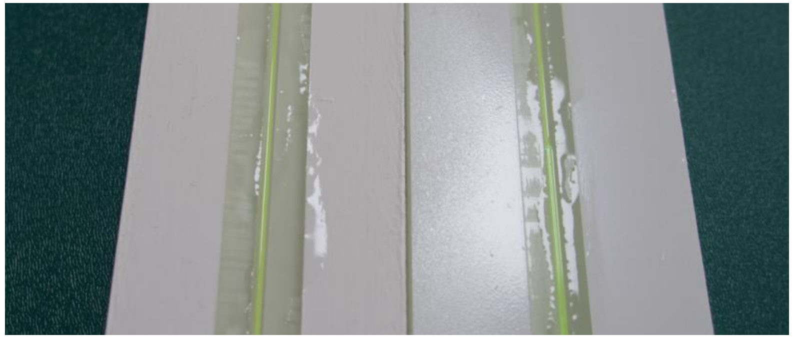


Pream array for multiple channels

Optical coupling and reflecting layer

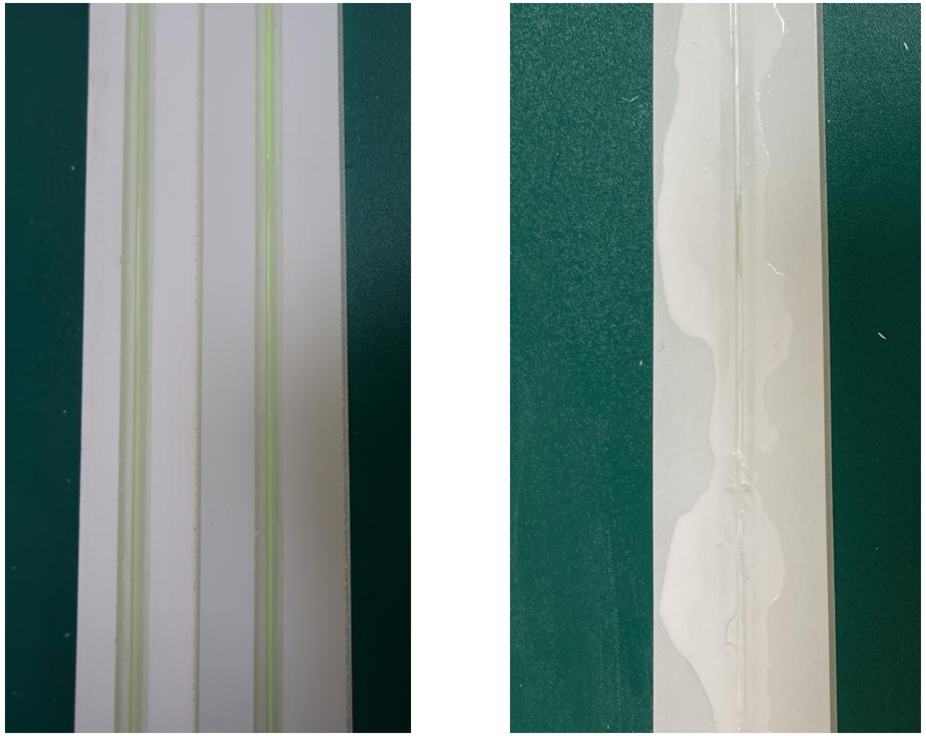


Optical glue： dowcorning 184
(Corrosion-free and light-transparent)



48h room temperature curing

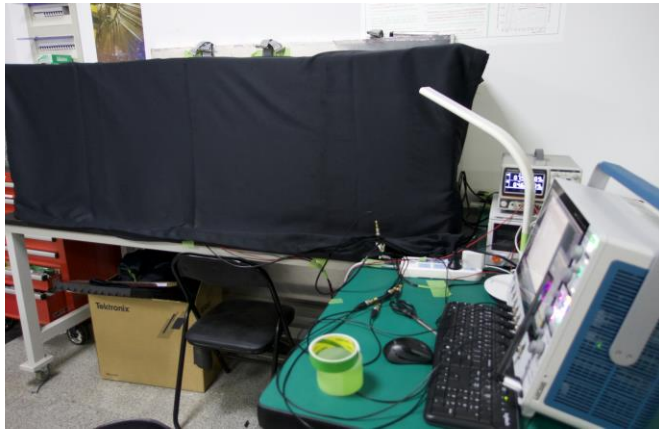
Improve the optical coupling for light collection



Covered with Teflon coating

Completely wraps the scintillator to reduce light leakage

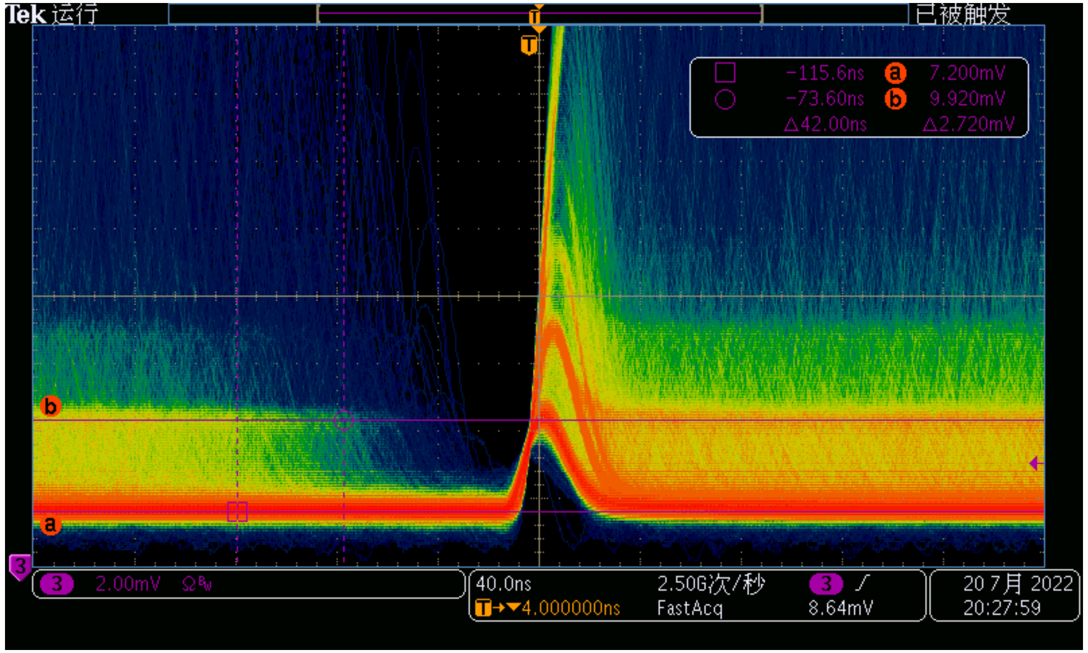
Setup and CR testing



~2m long dark box

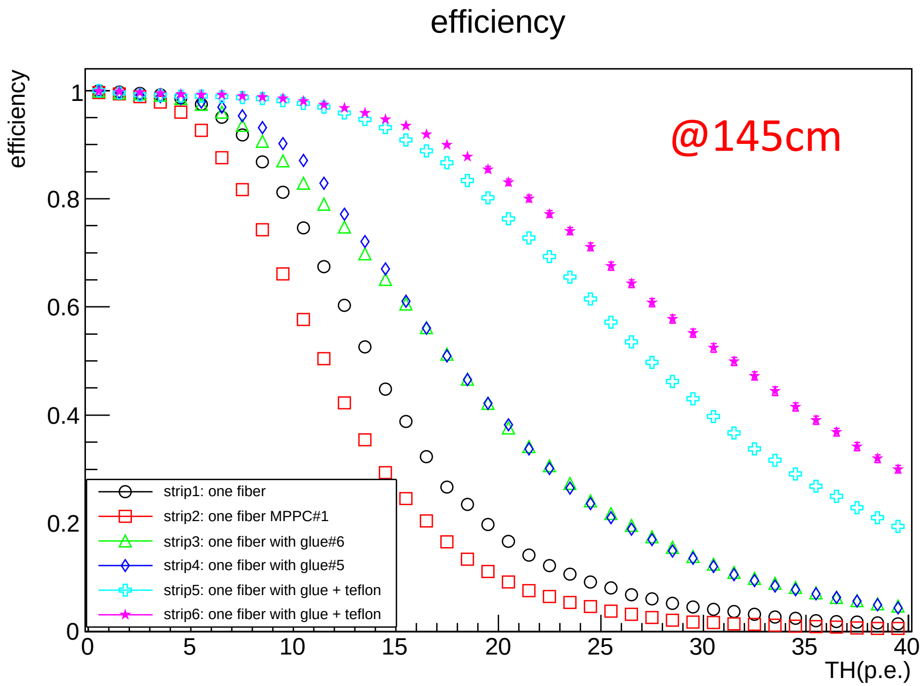
1.5m scintillator channels

Pulse from $3mm \times 3mm$ NDI SiPMs

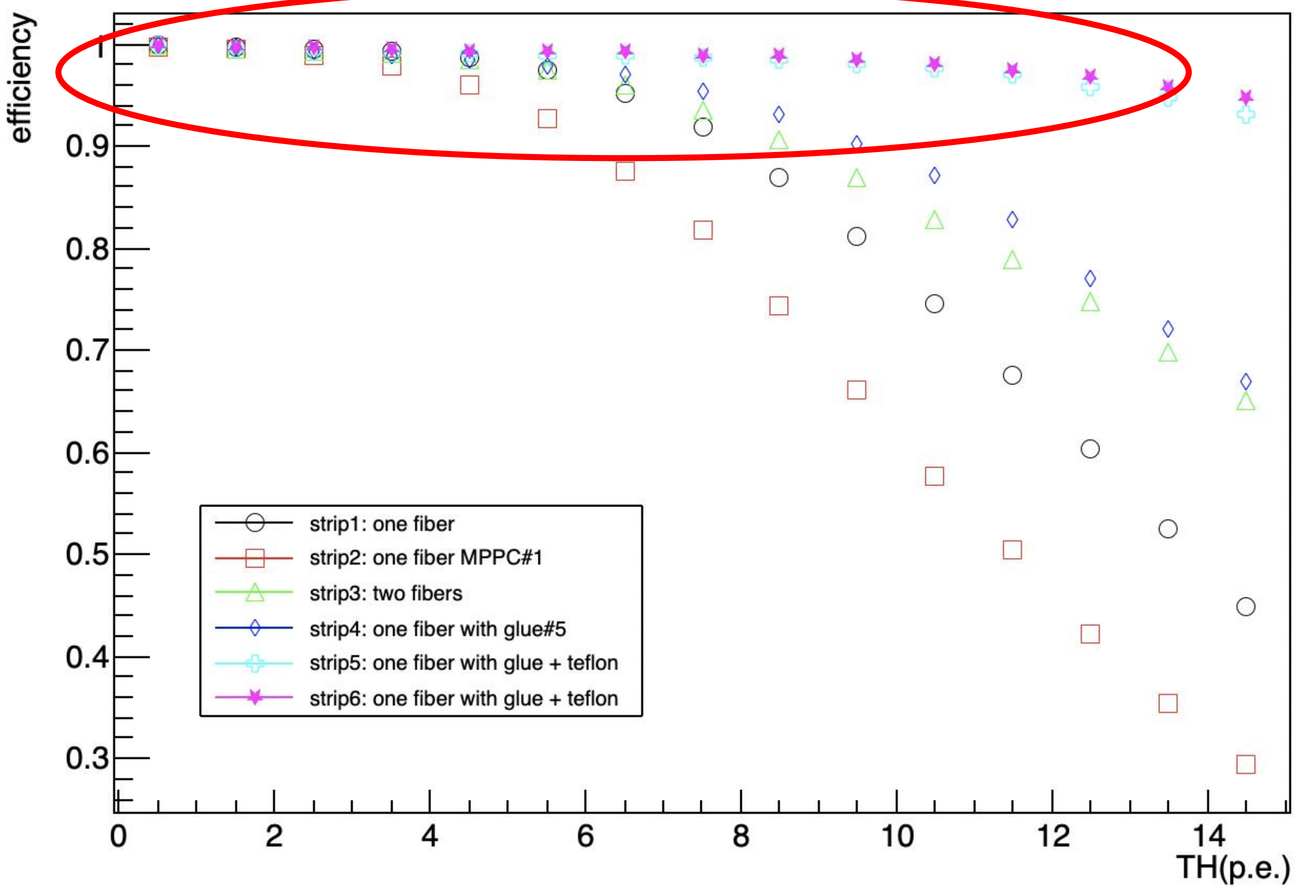


1 p.e. : 2.7mV

Efficiency measurement

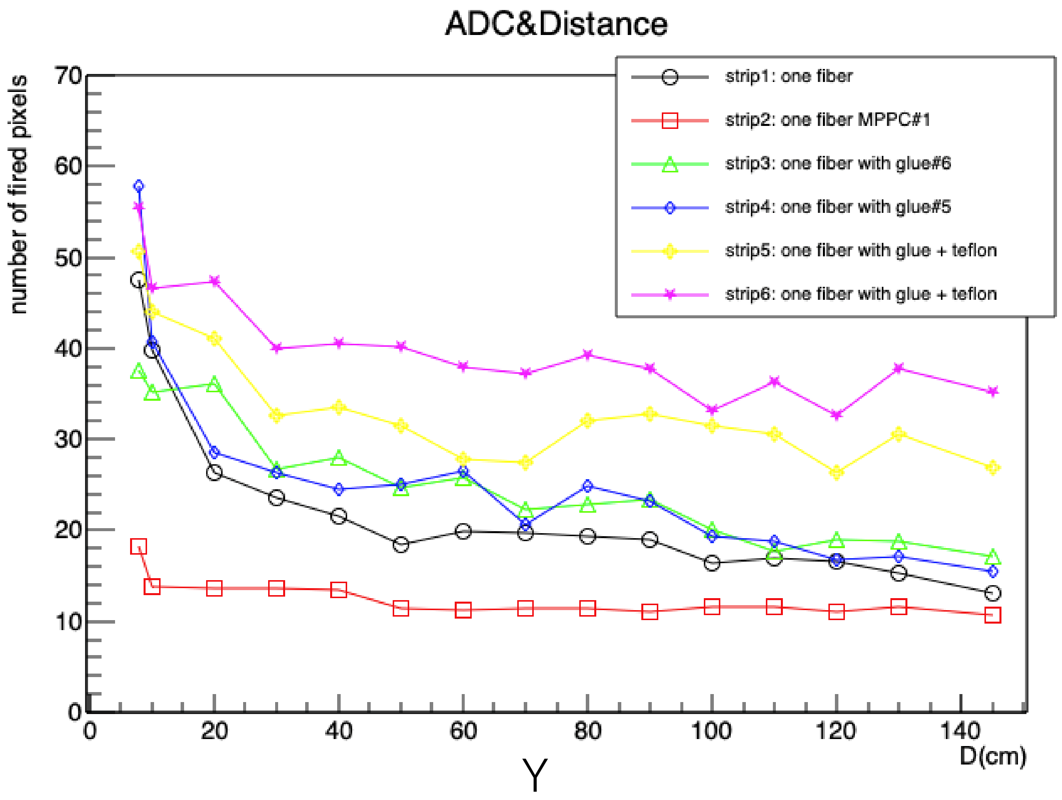


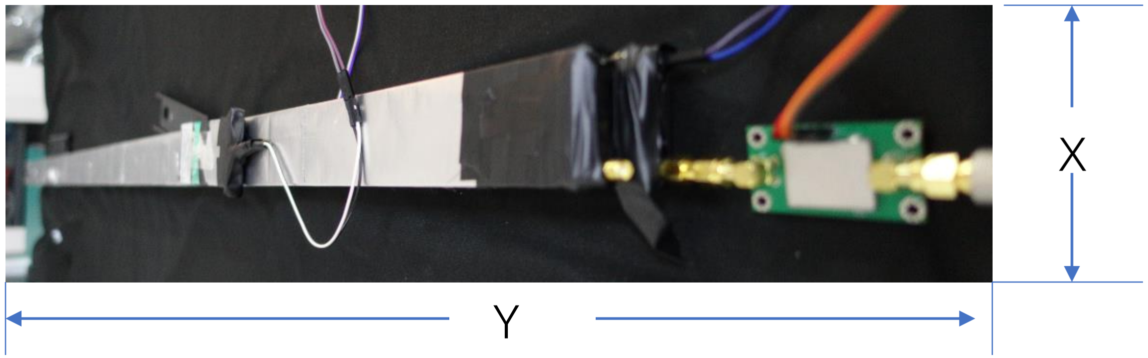
Optical glue and Teflon covering

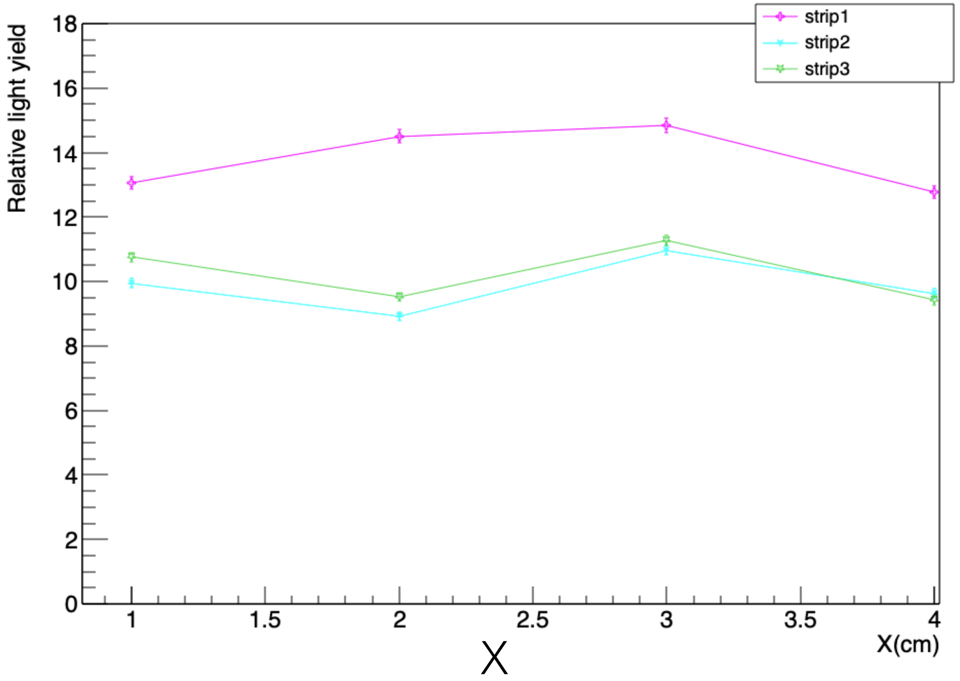


> 98% at threshold of 10 p.e. !

Light collection with different position







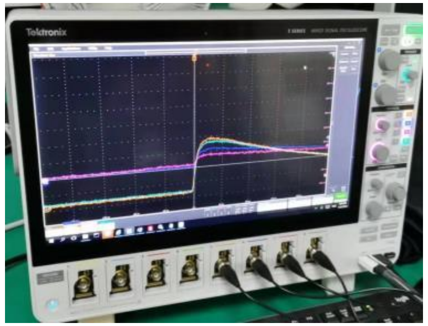
- ➢ Wavelength-shifting fiber keeps good photon collection at long distance.
- ➢ The time resolution should be better. Not measured yet.

- ➢ The relative light yield on the transverse hit position.

Time resolution of scintillator + SiPM

ch1、ch4

Ch2、ch3



Time resolution:

T2,T3: $132.0 \pm 3.3ps$

T1,T2: $127.2 \pm 2.7ps$

T3,T4: $119.5 \pm 2.0ps$

T1,T3: $199.2 \pm 4.5ps$

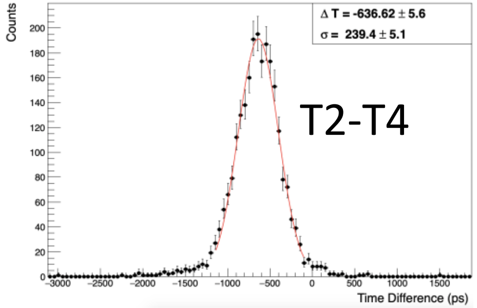
T2,T4: $169.3 \pm 3.6ps$

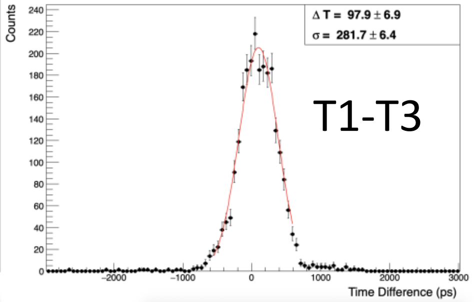
T1,T4: $222.1 \pm 4.4ps$

top to bottom： 1， 2， 3， 4

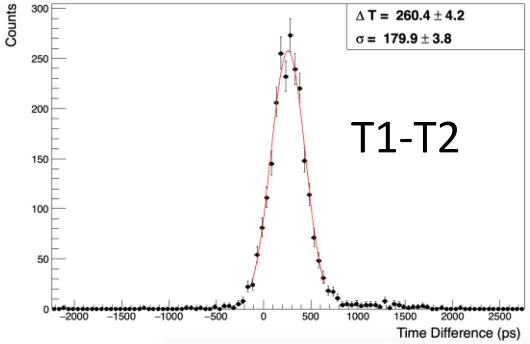
T2 and T3 with distance of ~4 cm

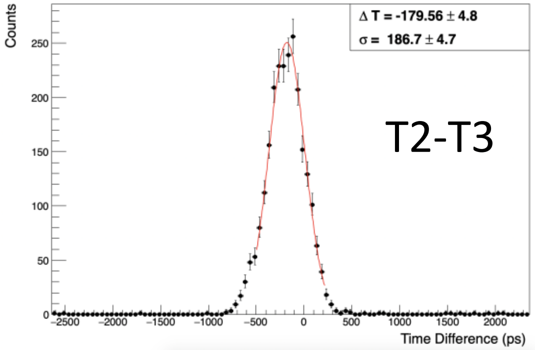
T1 and T4 with distance of ~10 cm

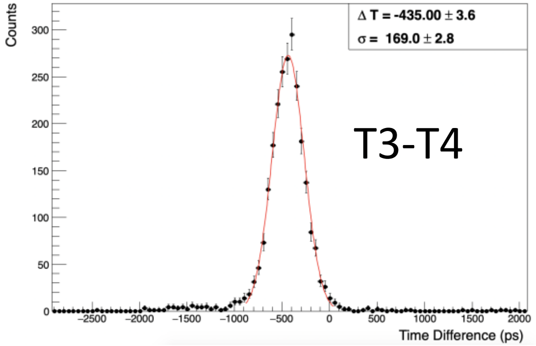


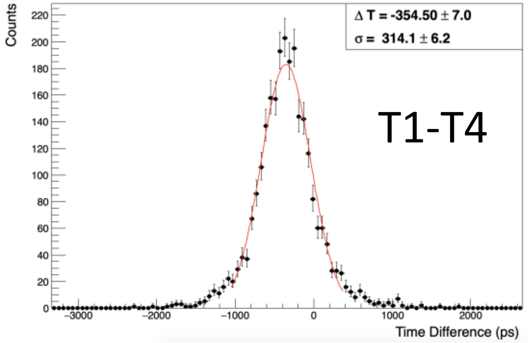


- Caused by photon propagation & cosmic ray angle effect

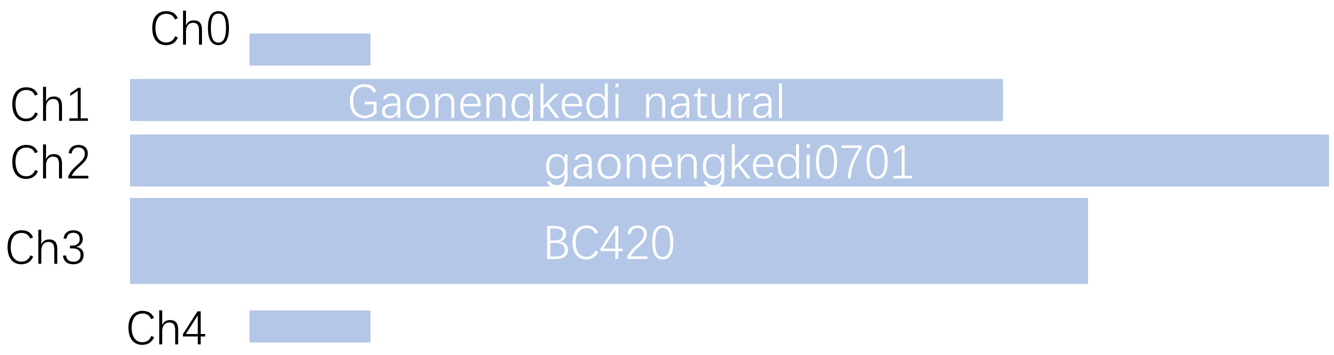




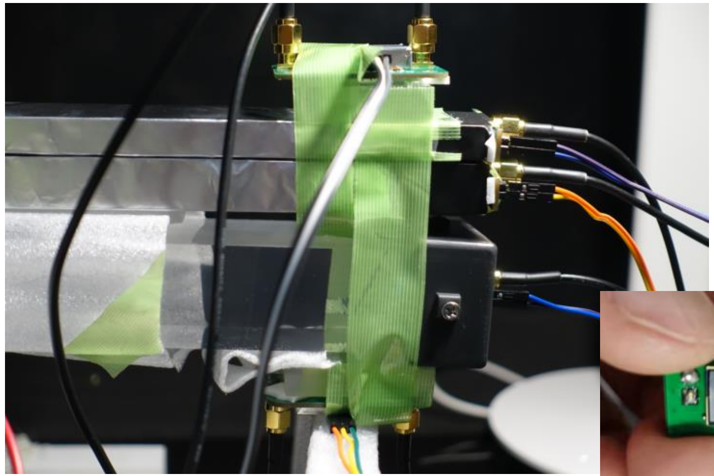


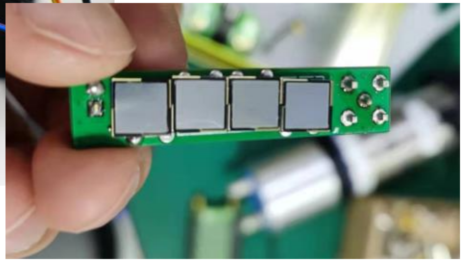


Time resolution with shorter trigger strips



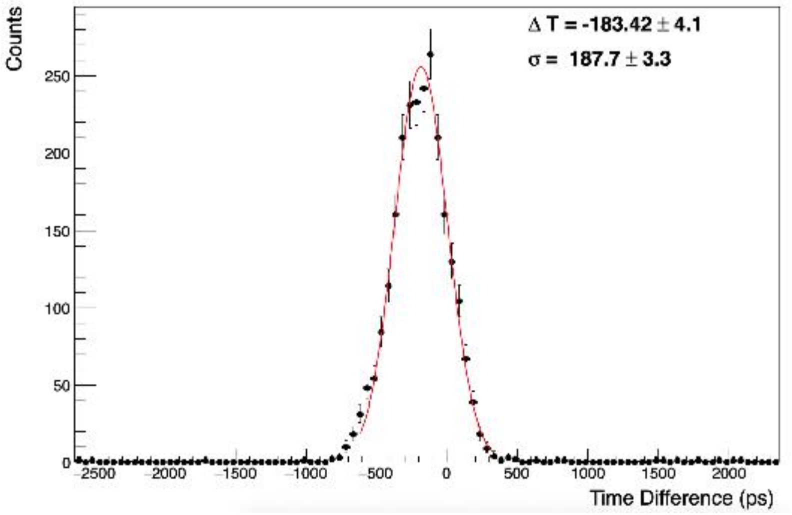
- Threshold： ADC0&&ADC4>50
- Trigger: 4 cm strips

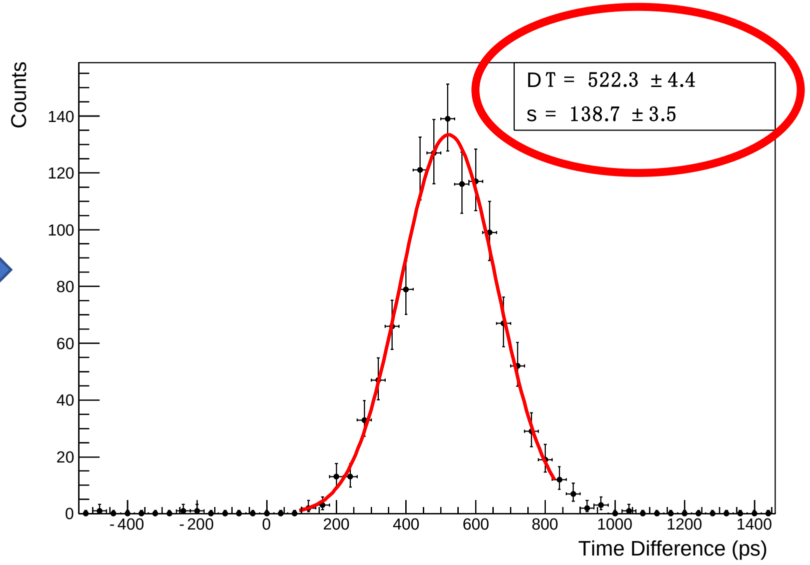




$6mm \times 6mm$
MPPCs

T23

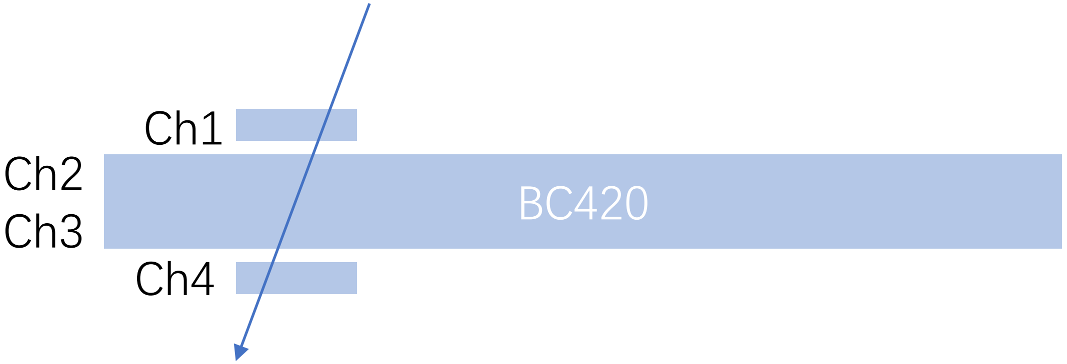


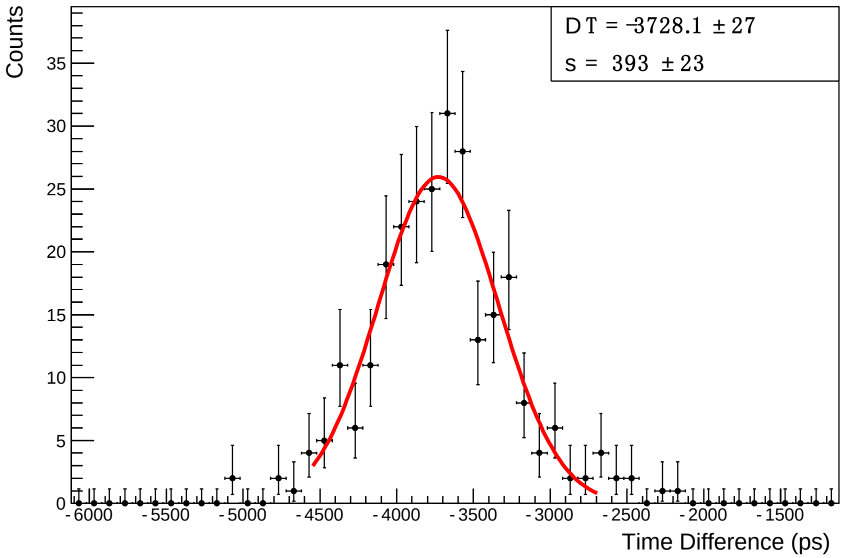


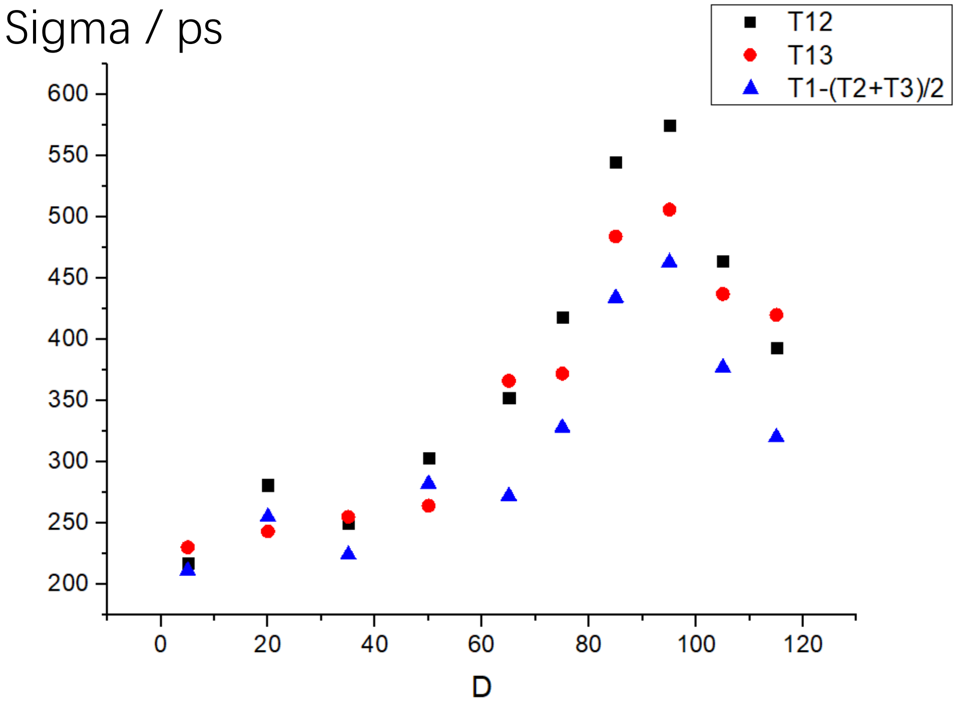
Time resolution getting better with shorter trigger strips for better position resolution of CR

Time resolution at different position

Trigger at different positions



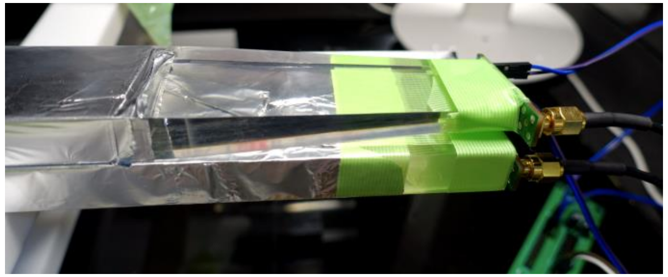




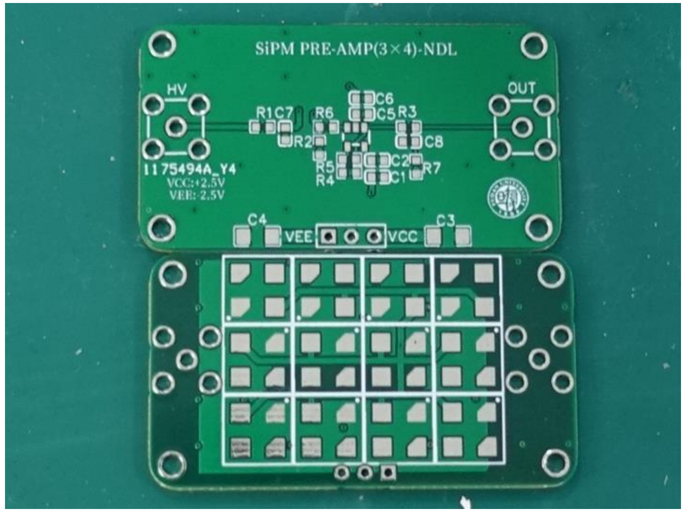
- ✓ Time resolution gets worse with longer distances, with signal getting much smaller.
- ✓ Need to improve the light collection.

Design and test for good timing at far position

To improve time resolution at far end
Improve photon collection
- thicker scintillator (need light guide);
- Array with more SiPMs (2×4、3×4);
- Or readout at both ends.

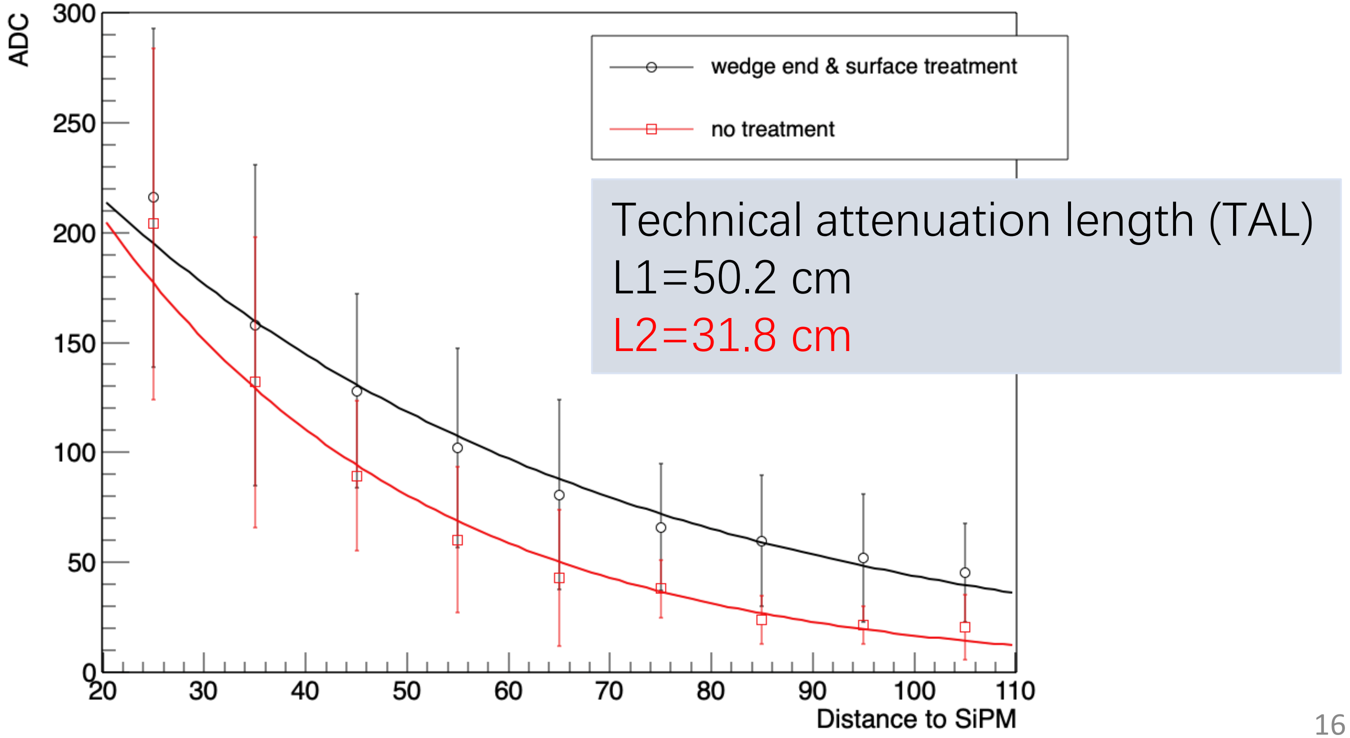



$3.2cm \times 4cm \times 150cm$
Full polish, with light guide shape at both ends.



PCB for SiPM-preamplifier

To be tested……



Summary

The regular design:

- Good performance of the current design for efficiency.
- Light collection is improved with NDL SiPMs.
- Setup and FE are good enough for a muon detector.
- The next steps:
  - A module prototype with several layers, and then CR testing.
  - Start the BE design for digitization.
  - Both need budget!

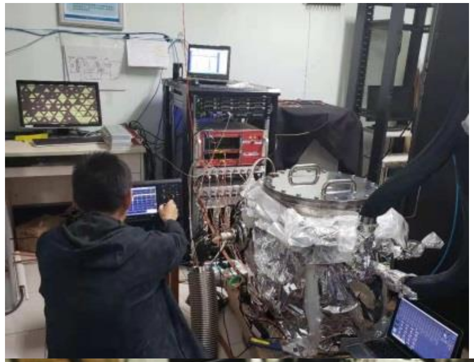
TOF-like design:

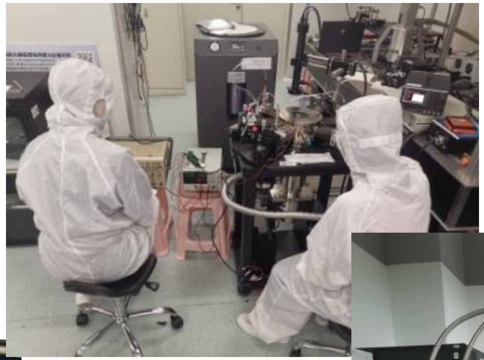
- Time resolution of about 100 ps has been obtained at near end.
- Study of time resolution at different position is ongoing.
- We are trying to improve time resolution at far end.

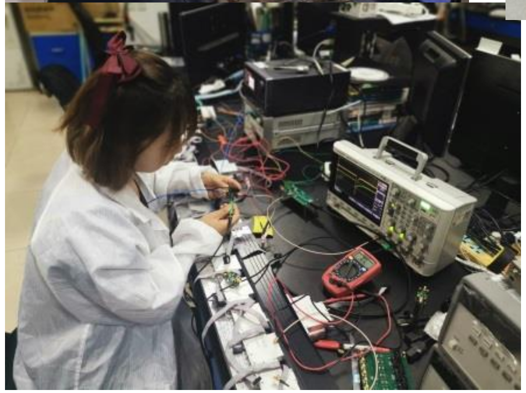
Thank you!

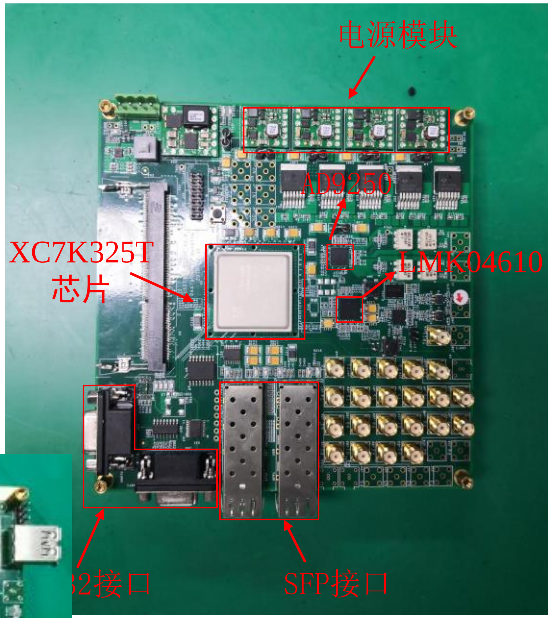
Lab for nuclear electronics at 上海理工

- University of Shanghai for Science and Technology
- Distance between Fudan and USST: 8km
- A large and stable lab, very good equipments
- PI: Dr. Qibin zheng (郑其斌), got Ph.D from USTC
- Need funding to start the R&D.

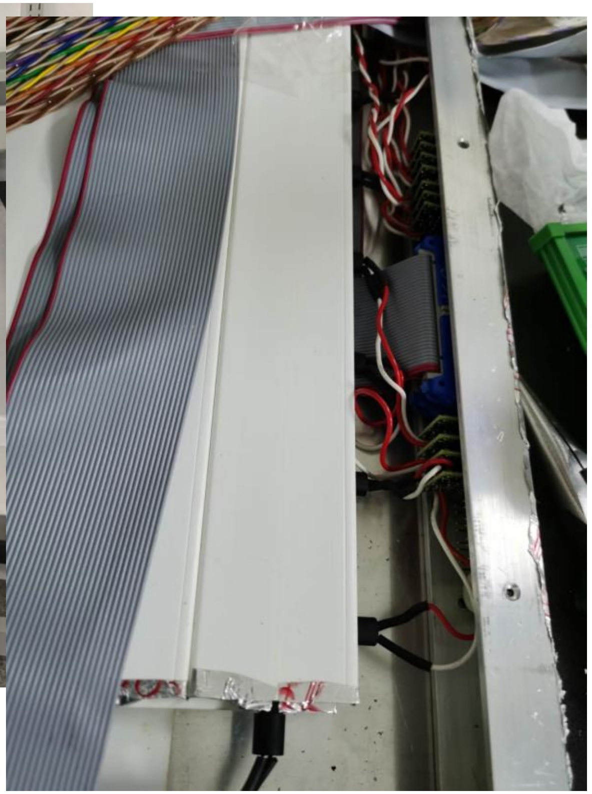








Reference of Belle II KLM

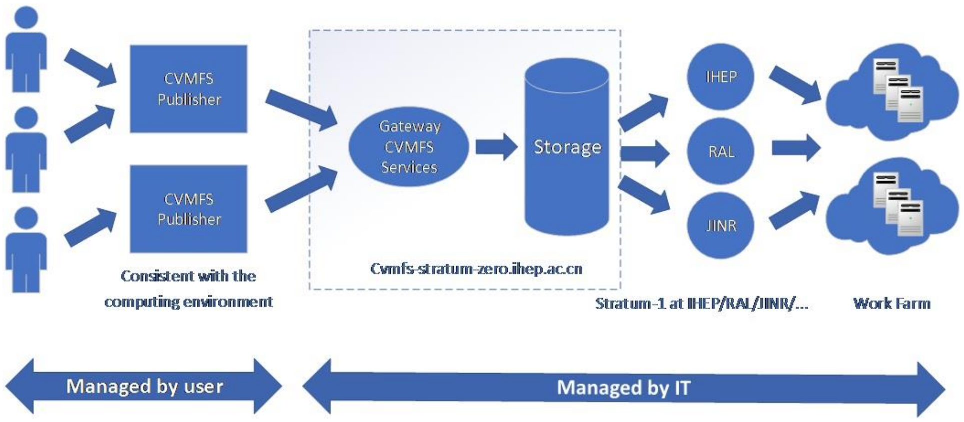


Back up

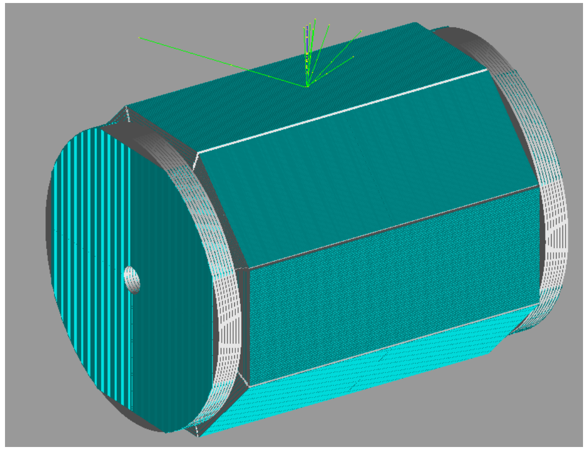
Implement of muon detector in CEPCSW

Scintillator + SiPM readout

- Structure
  - Geometry
  - Scintillator parameters
  - WLS fiber
- Simulation
  - Detector efficiency for muon
  - Behavior of long-lived particle
  - Tail of hadron cluster from HCAL
  - Spatial resolution
  - Time resolution



CEPCSW installed

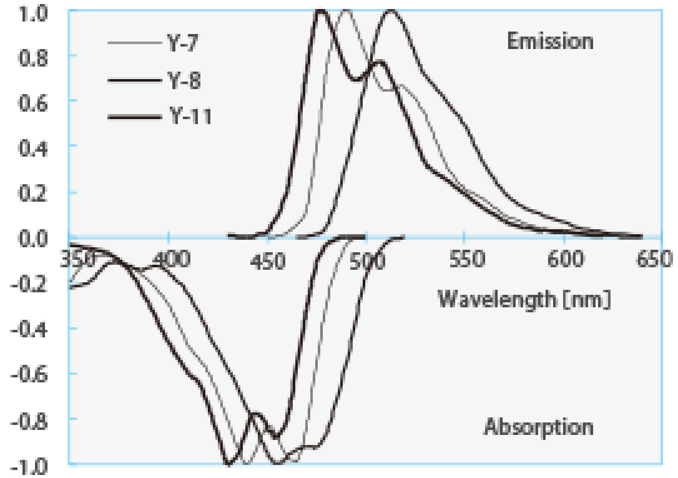


40 GeV $\mu^{\pm}$ hits

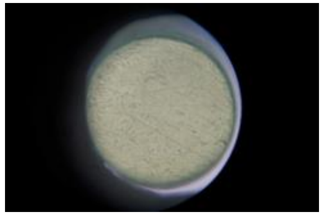
Two kinds of WLS fiber

- Wavelength-shifting fibers

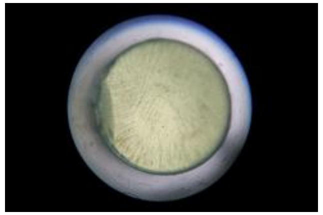
Saint-Gobain WLS Fiber
1.0mm Dia.



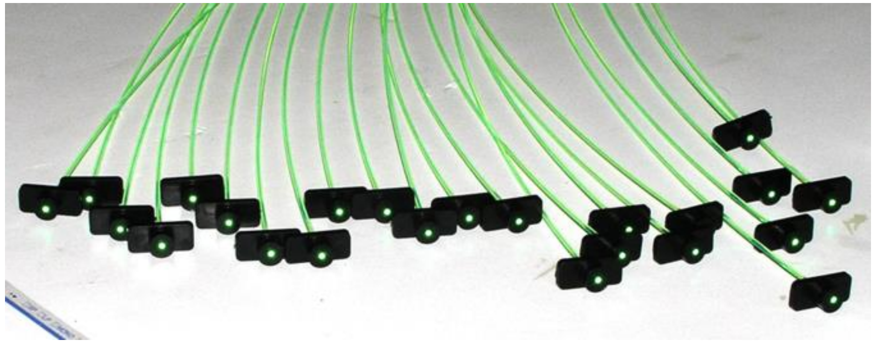
Blue to Green Shifter (Kuraray)



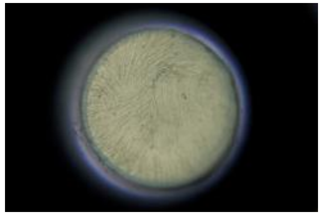
- File



- 1000 grit sandpaper



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

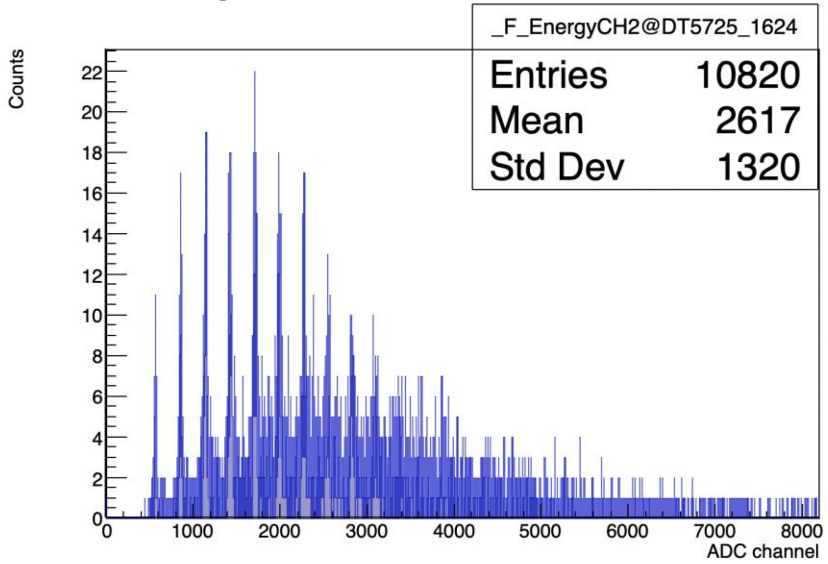


- 1500 grit sandpaper

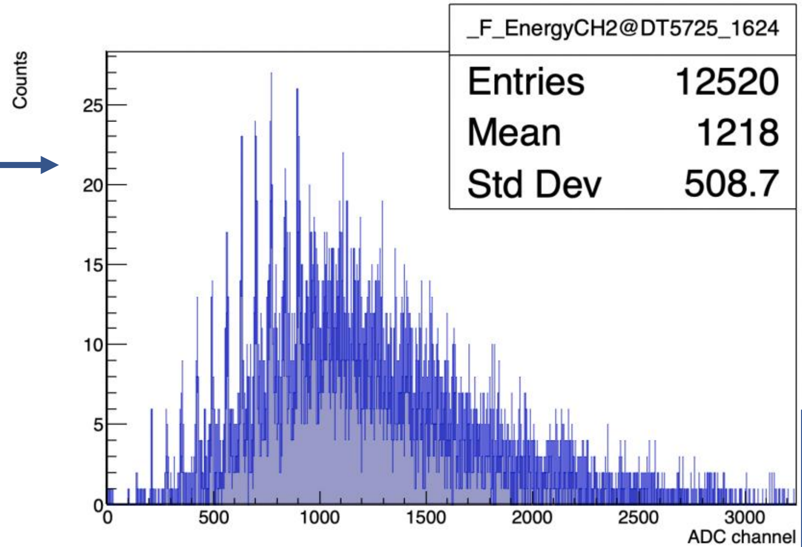
- 2000 grit sandpaper

Comparison of two WLS fibers

Choosing better fiber



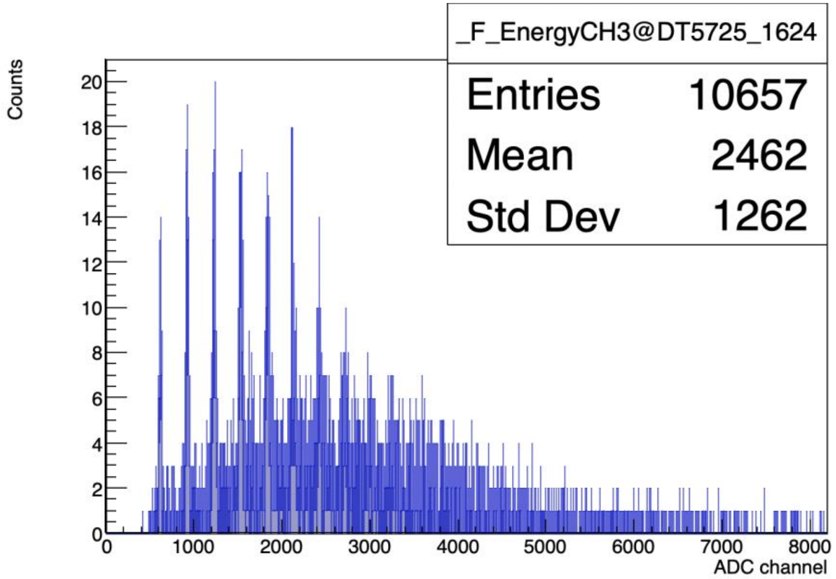
SD#1



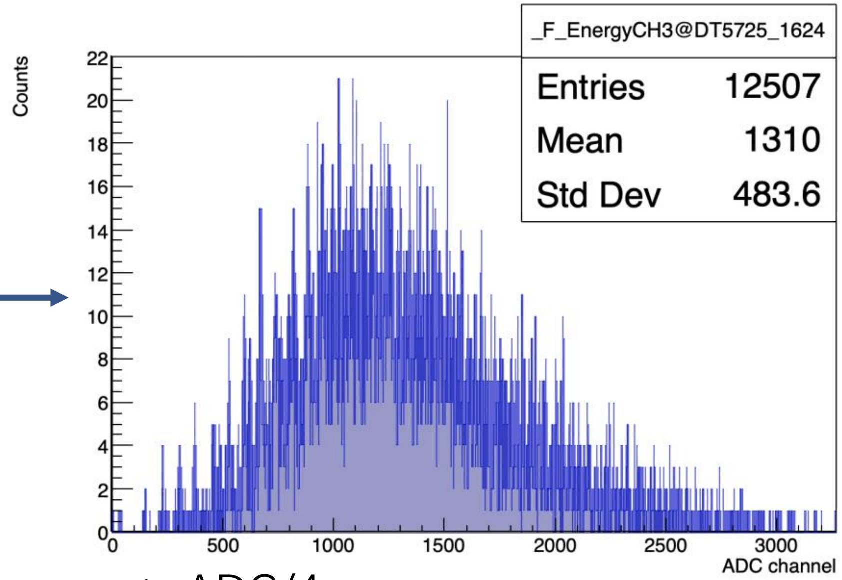
Better light yield

Left: saint_gobain
Right: kuraray

scintillator: 150cm



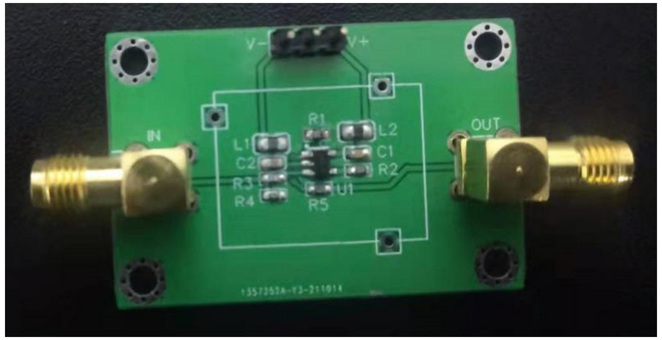
SD#2

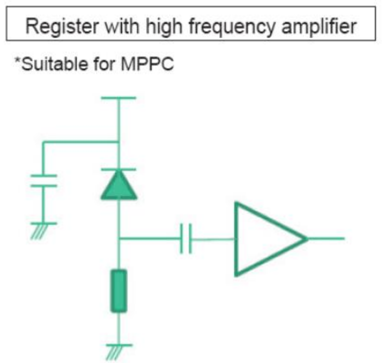


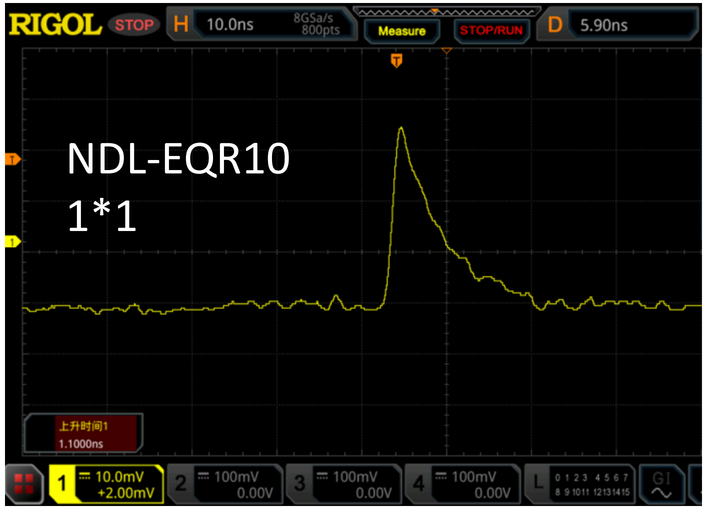
*: ADC/4

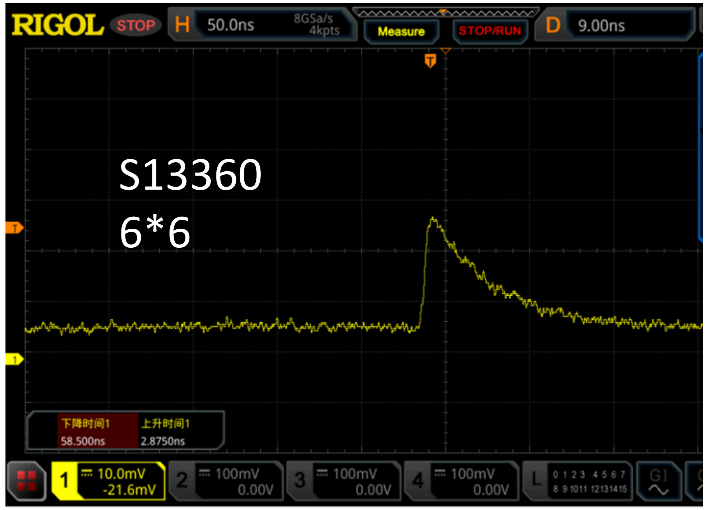
Design of fast preamplifier

Resistor sampling and negative feedback amplifier circuit









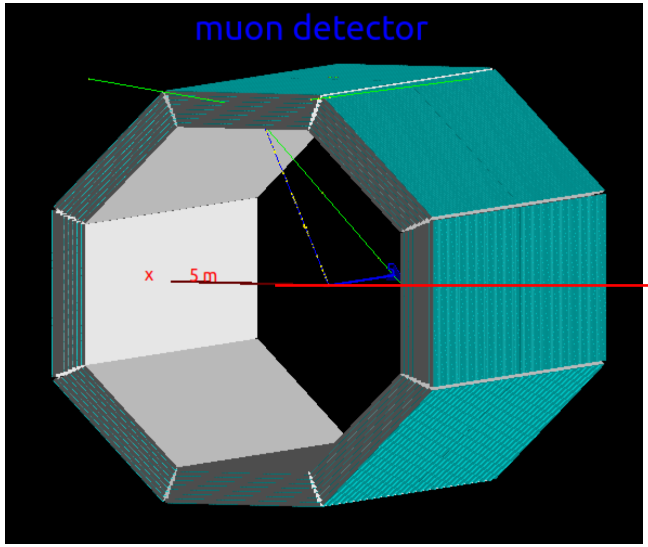
Rise time： 1-2ns
HWHM： 3-4ns

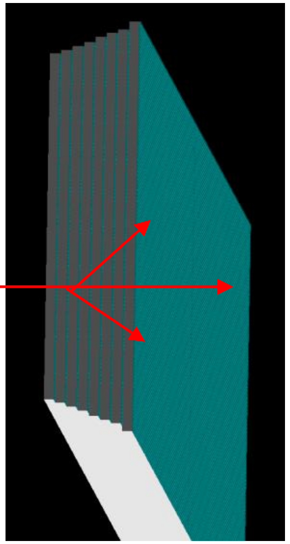
Rise time： 2-4ns
HWHM： 6-8ns

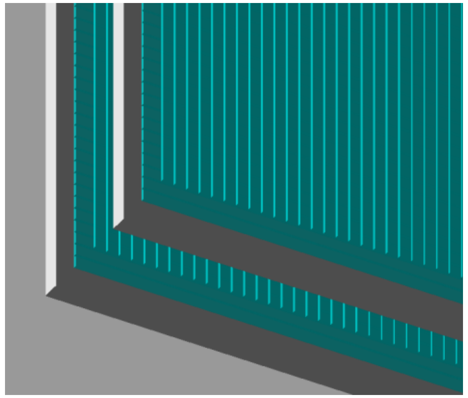
Rise time： 5-10ns
HWHM： 40-60ns

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

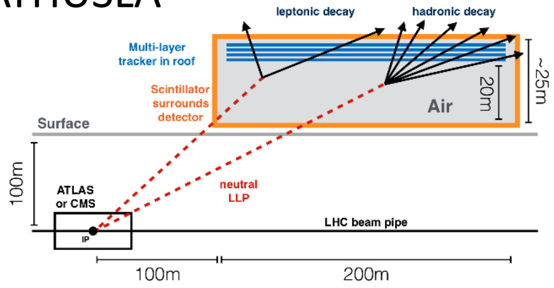


Fig. 1: Simplified detector layout showing the position of the 200 m × 200 m × 20 m LLP decay volume used for physics studies. The tracking planes in the roof detect charged particles, allowing for the reconstruction of displaced vertices in the air-filled decay volume. The scintillator surrounding the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