Muon detector with timing

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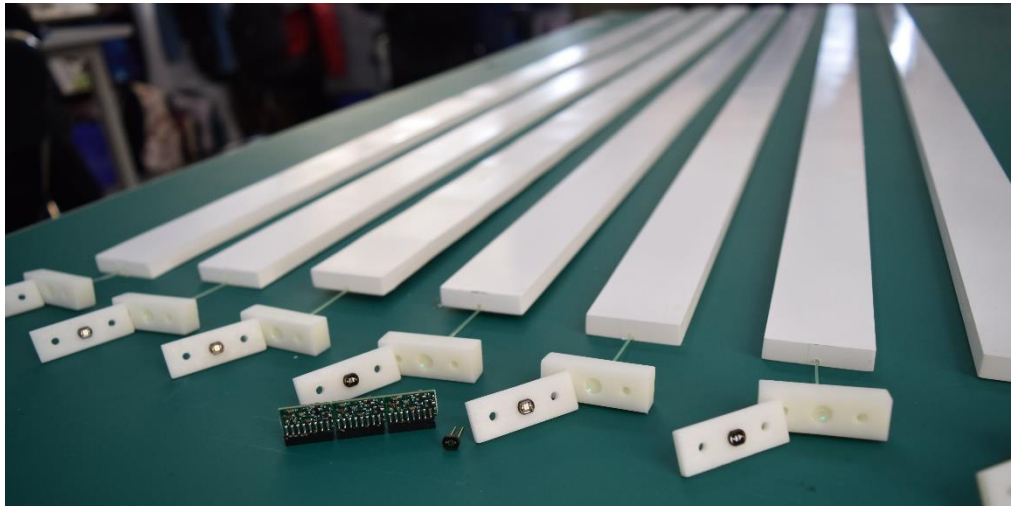
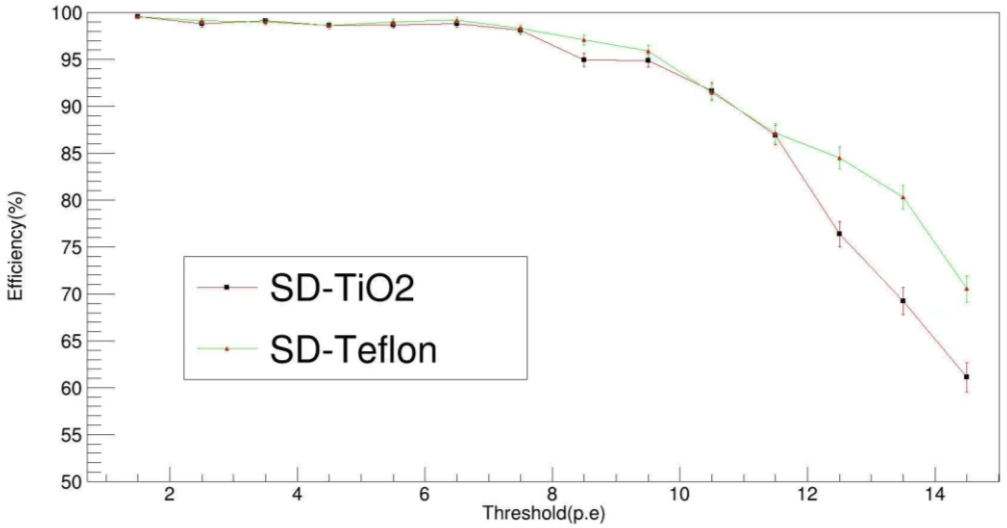
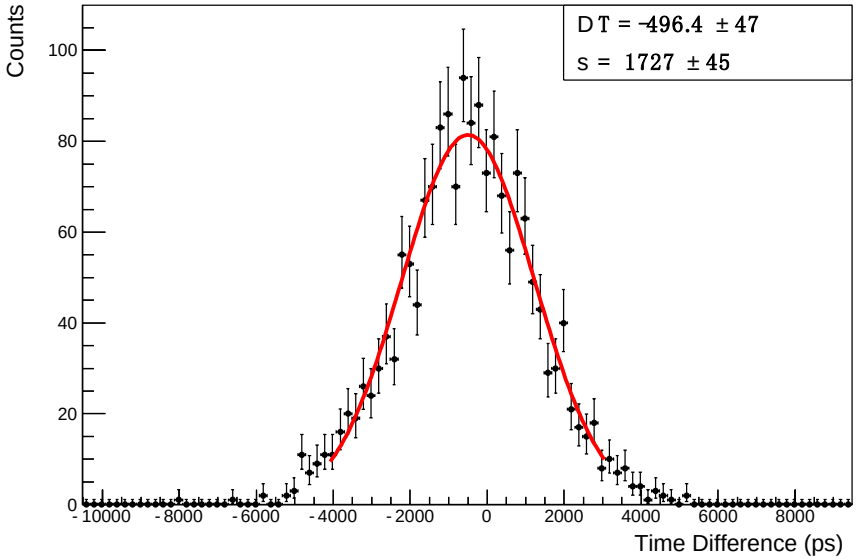
Performance of current Belle II KLM design

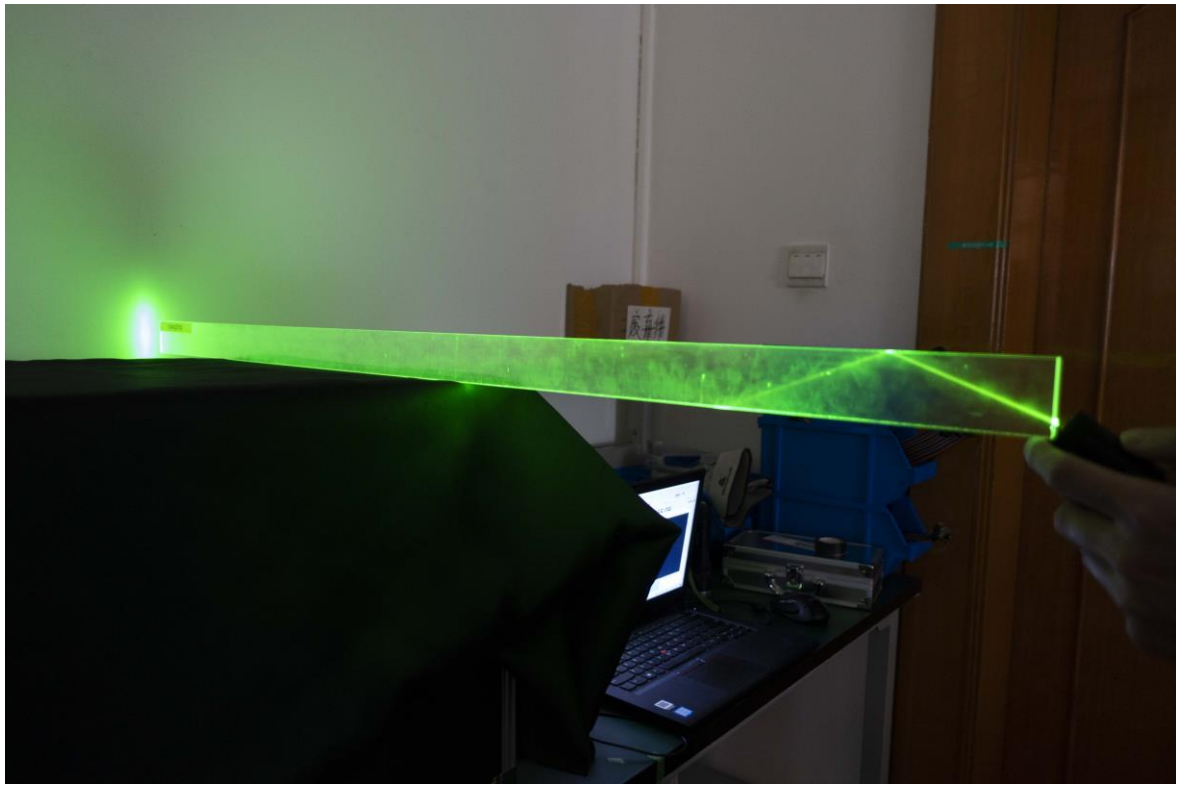




- CR testing with two strips.
- High efficiency, similar to the performance of the current Belle II KLM.
- Time resolution: $< 1.5ns$
- Number of photons collected from WLS fibre is limited.



Need new scintillator



New scintillator from Gaonengkedi Company.

- Longer attenuation length.
- Reasonable cost.
- Considering efficiency without fiber and reflective layer.
- New design for fast pream!

How about new NDL SiPM (Made in China)

Specifications

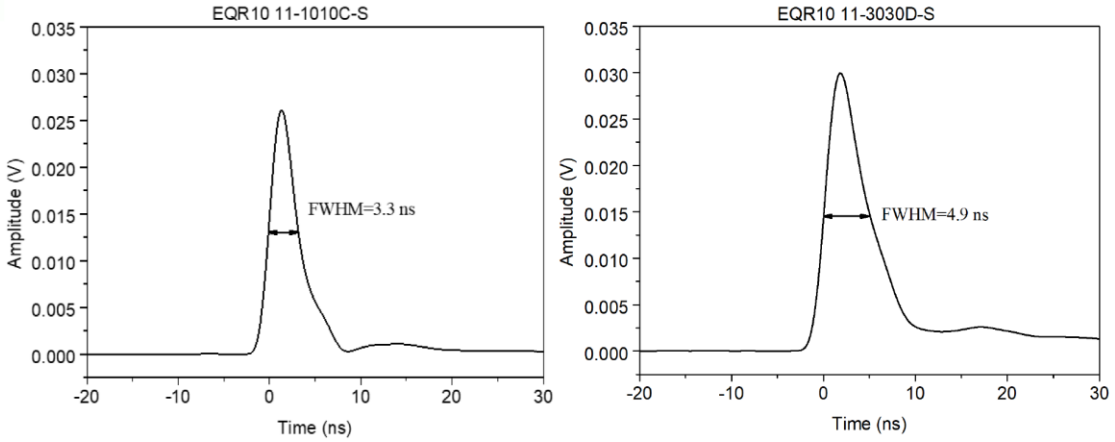
Type	EQR10 11-1010C-S	EQR10 11-3030D-S
Effective Pitch	10 μm	
Element Number	1×1	1×1
Active Area	1.0×1.0 mm^2	3.0×3.0 mm^2
Micro-cell Number	10000	90000
Breakdown Voltage (V_B)	26.4 ± 0.4 V	28.5 ± 0.5 V
Temperature Coefficient for V_B	21 mV / ℃	19 mV / ℃
Recommended Operation Voltage	V_B + 6 V	V_B + 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 ℃.

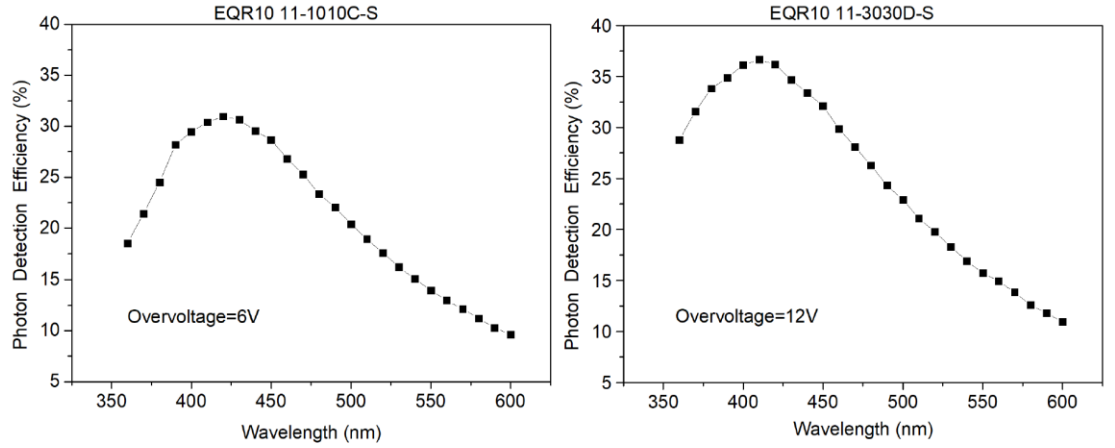
The EQR10 11-1010C-S can operate at 77 K.

Looks good.

Characteristics

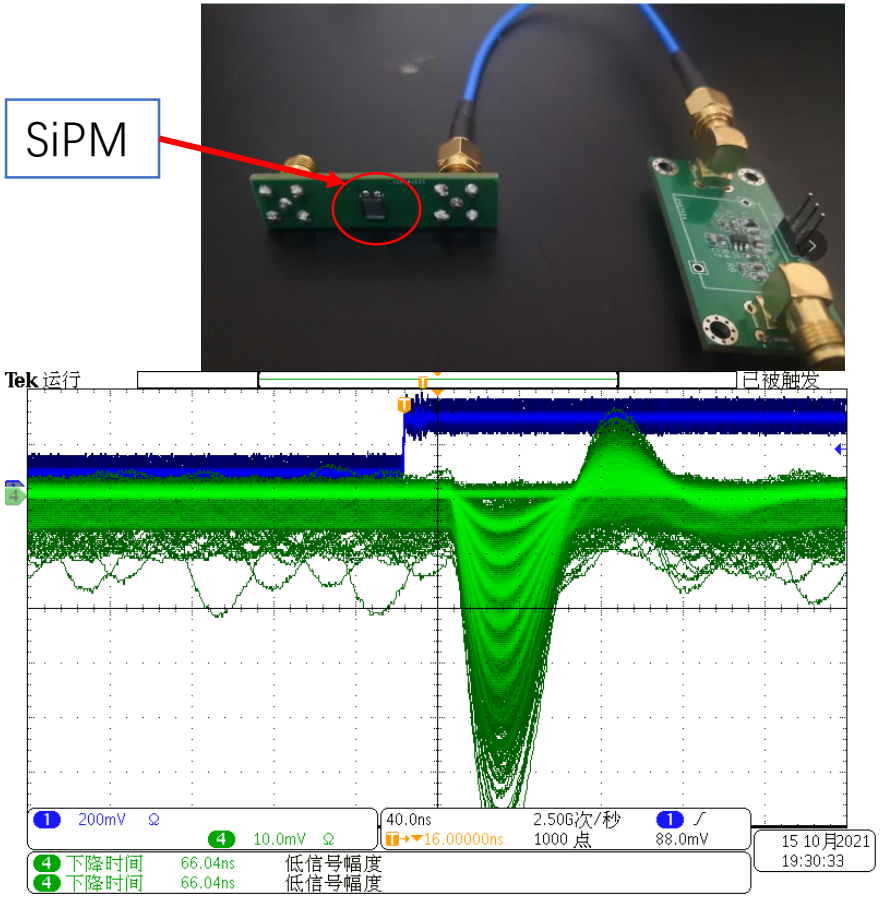


The single photoelectron pulse (amplified by a 40dB fast amplifier).



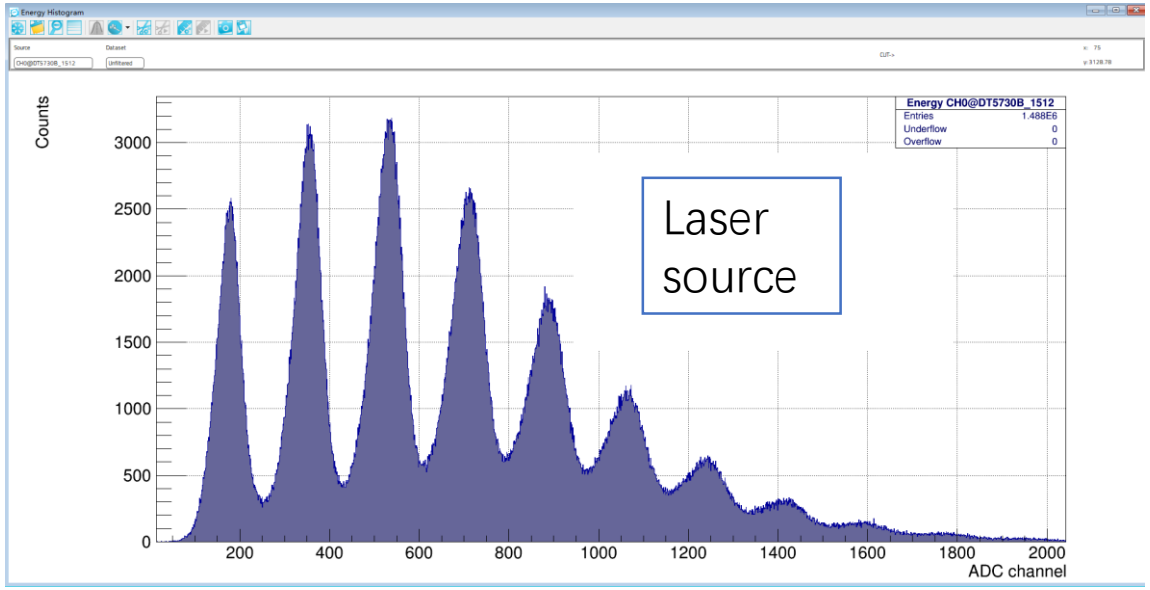
The PDE versus overvoltage and wavelength, deducted crosstalk and afterpulse and measured at 20 ℃ .

New design on the FE and NDL SiPM



Laser pulse triggering

Rising time: 15-20ns
Pulse width: 40-60ns



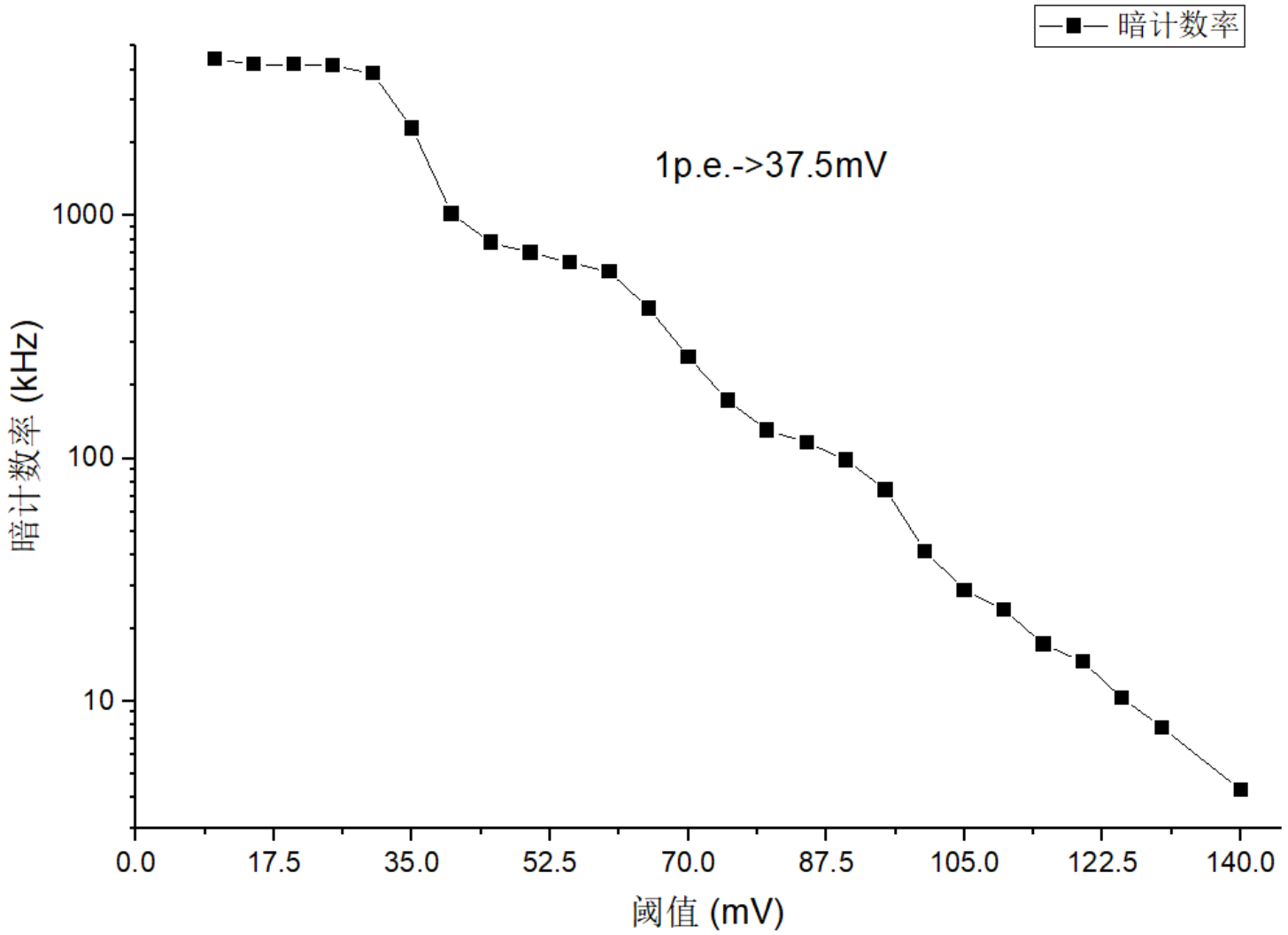
Very good p.e. peaks!

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

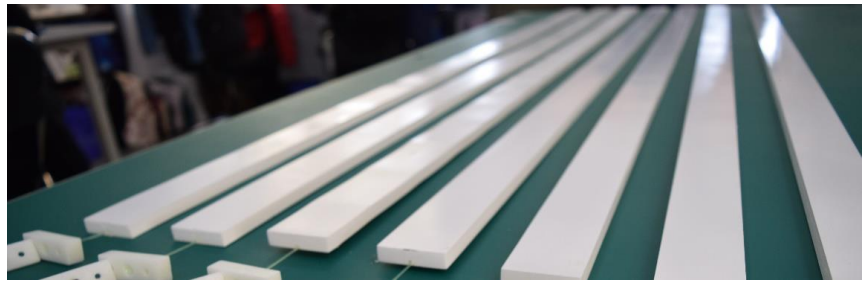
Dark Count Rate NDL-EQR15

Single p.e.：37.5mV

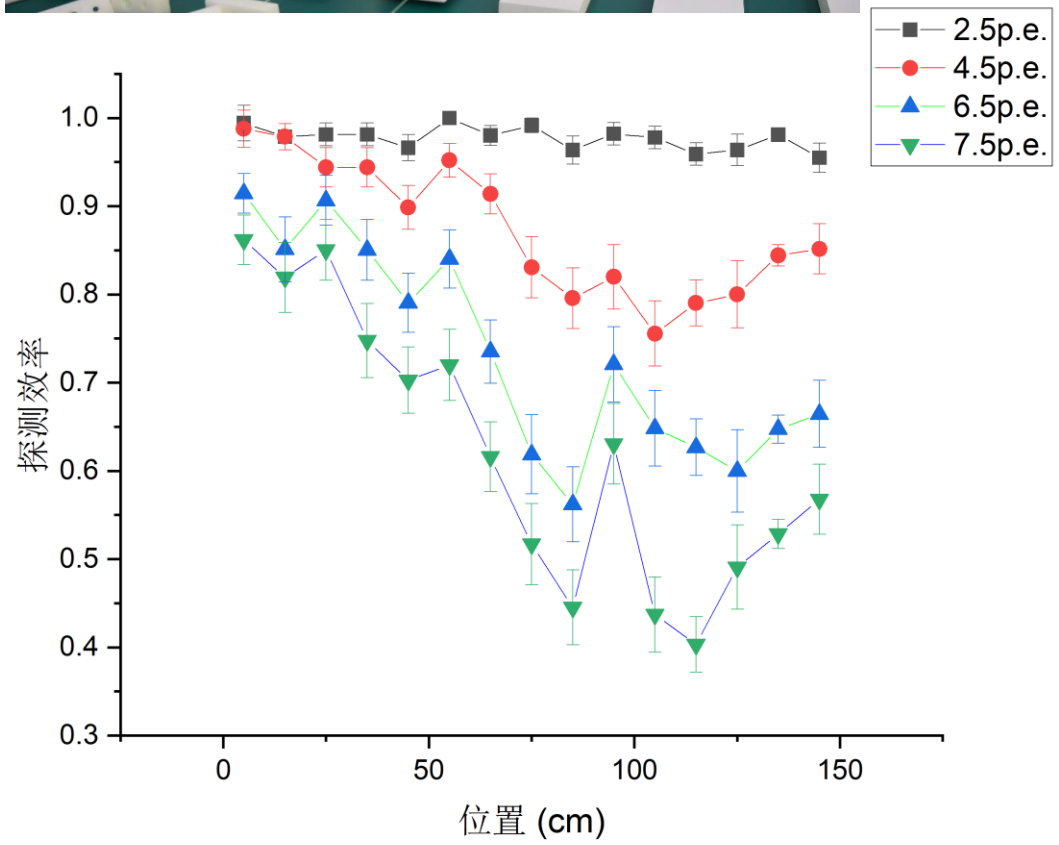
Threshold>6p.e. DCR<10 Hz
Threshold>7p.e. DCR<1 Hz



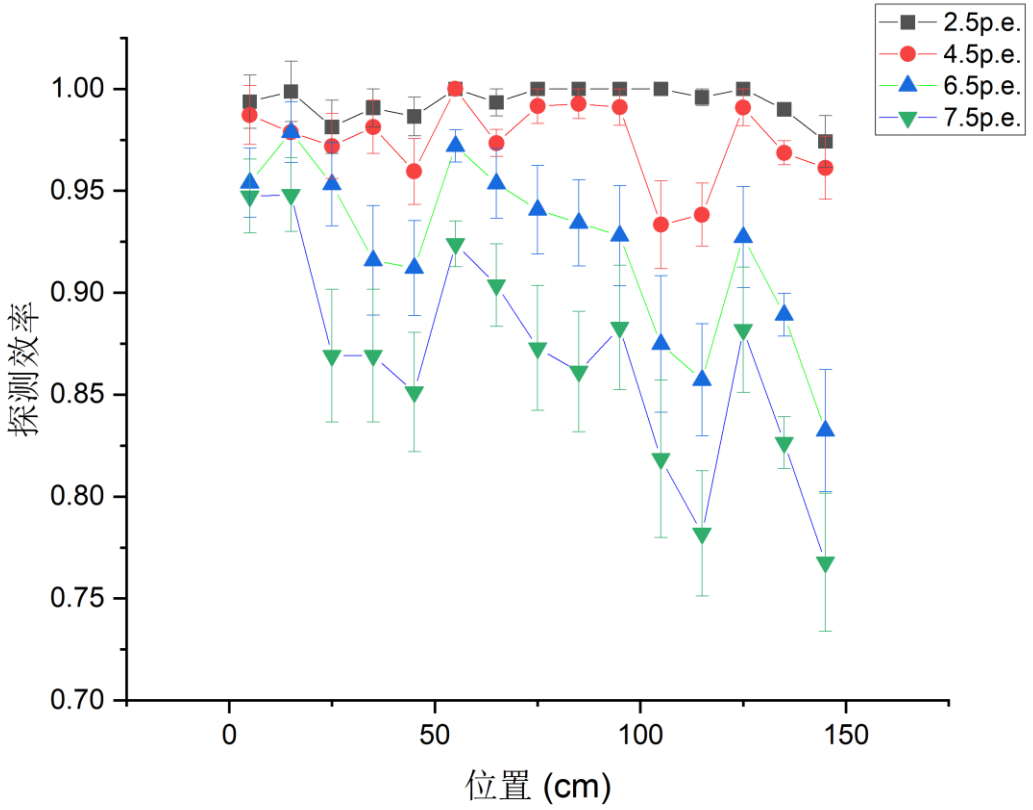
Efficiency NDL-EQR15



- The efficiency is high enough.
- Still needs improvement on coupling, light collection, etc.



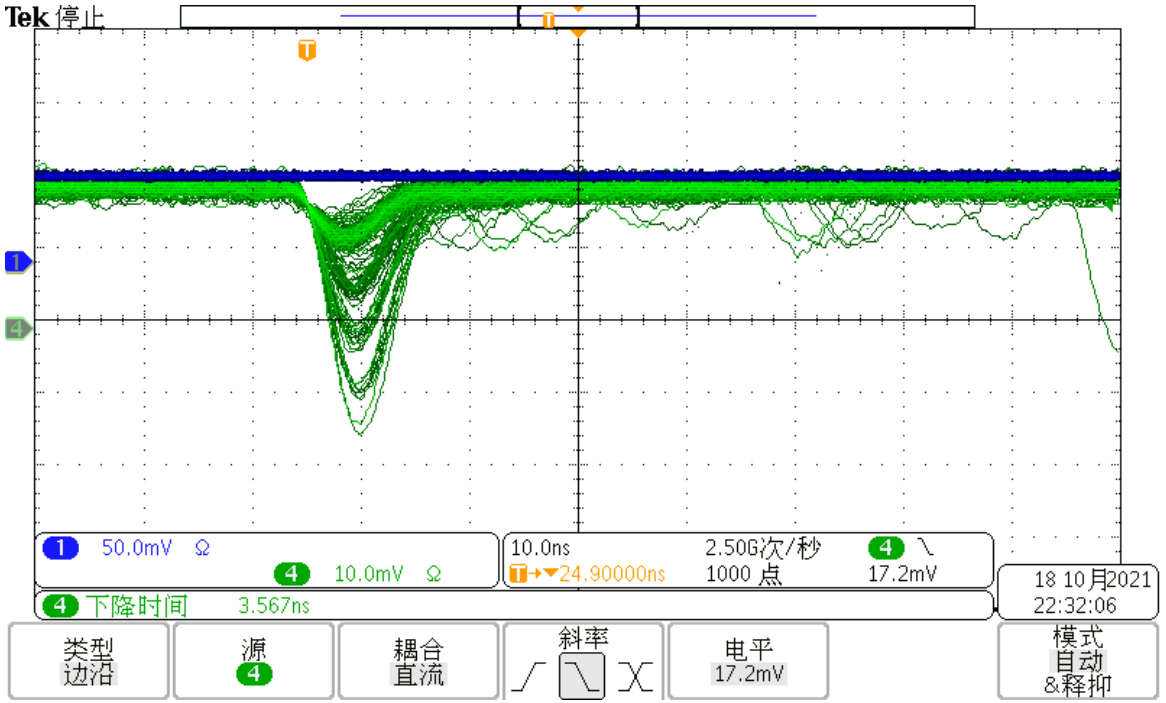
W/o optical glue

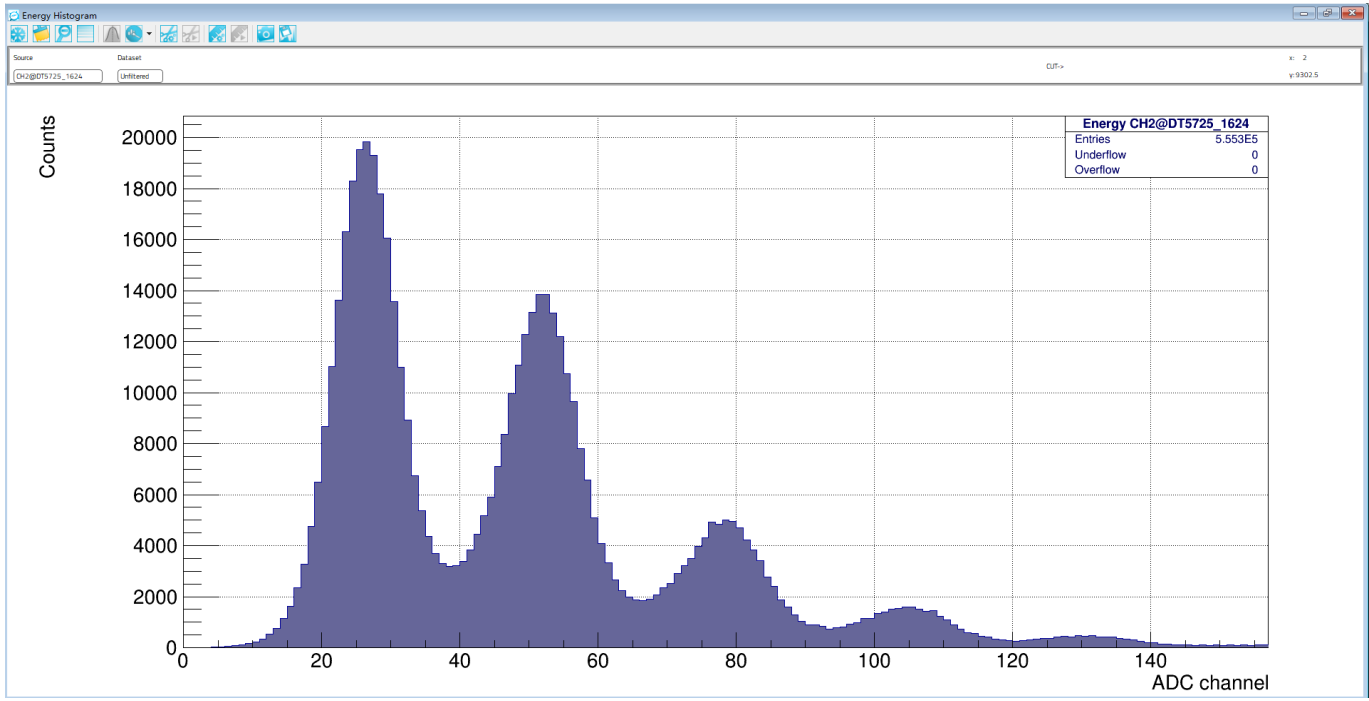


With optical glue

Pulse from NDL SiPM (1.0mm*1.0mm)

Using fast pream

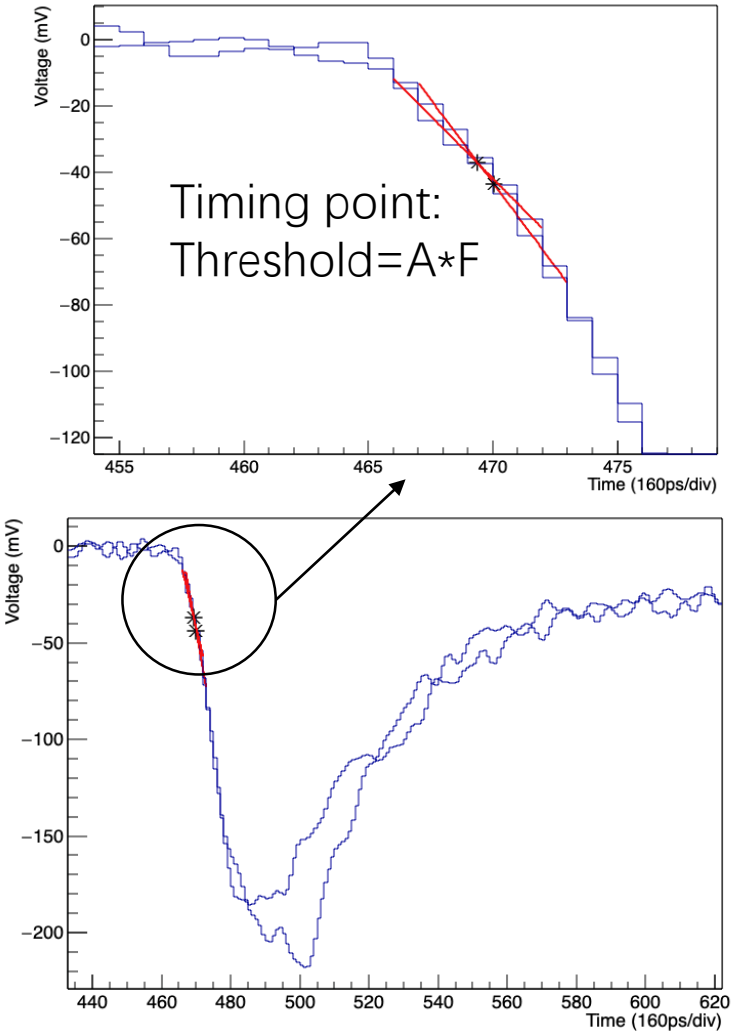


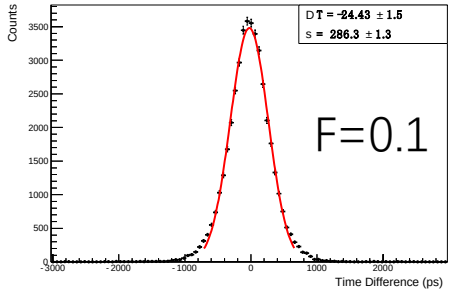


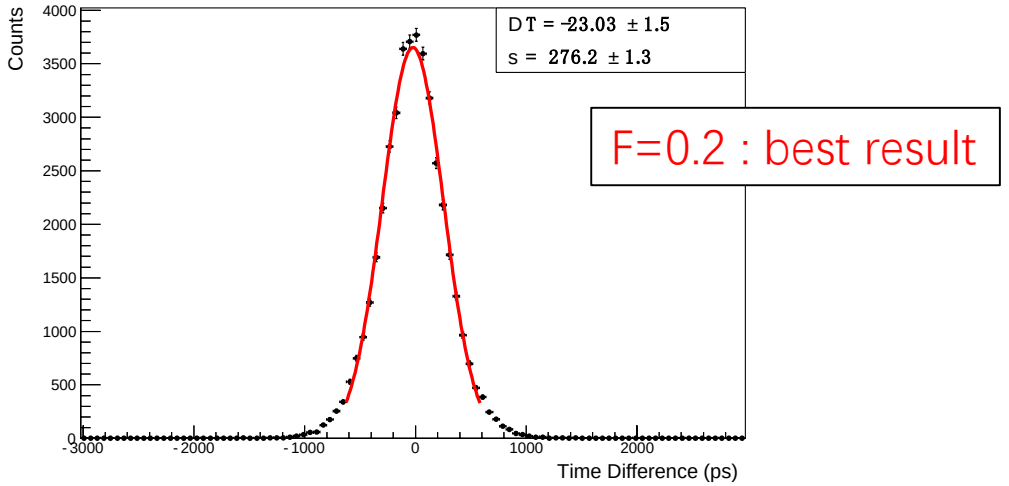
Rising time: ~3.5 ns!

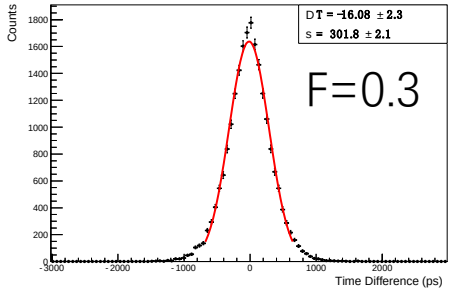
Optimization of CFD algorithm

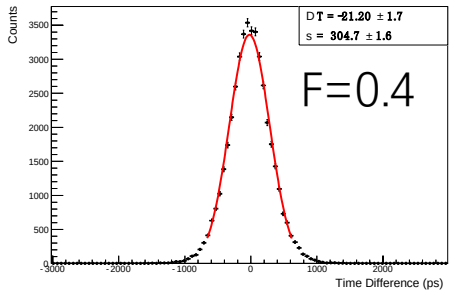
Choose the best fraction (F) for timing

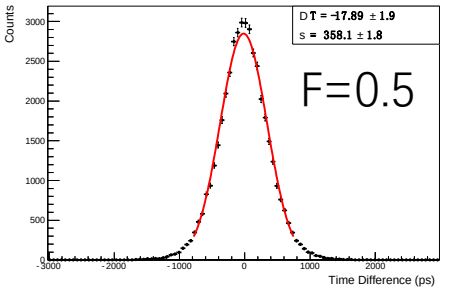






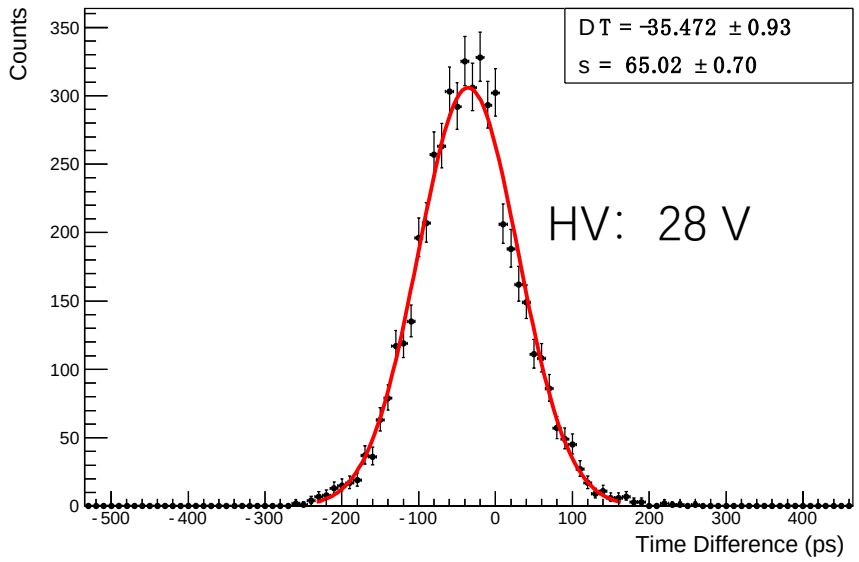


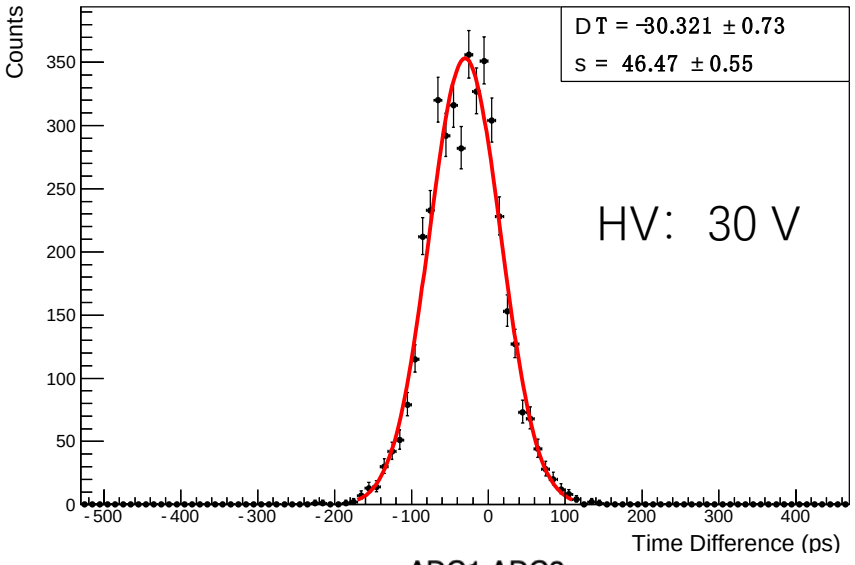


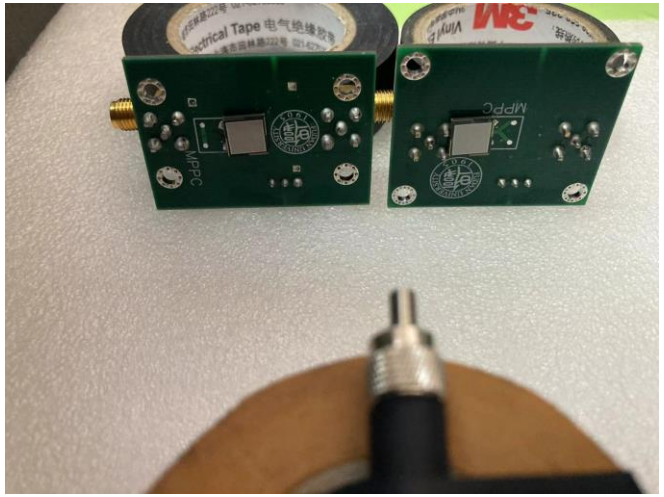


Time difference between ch1&ch2

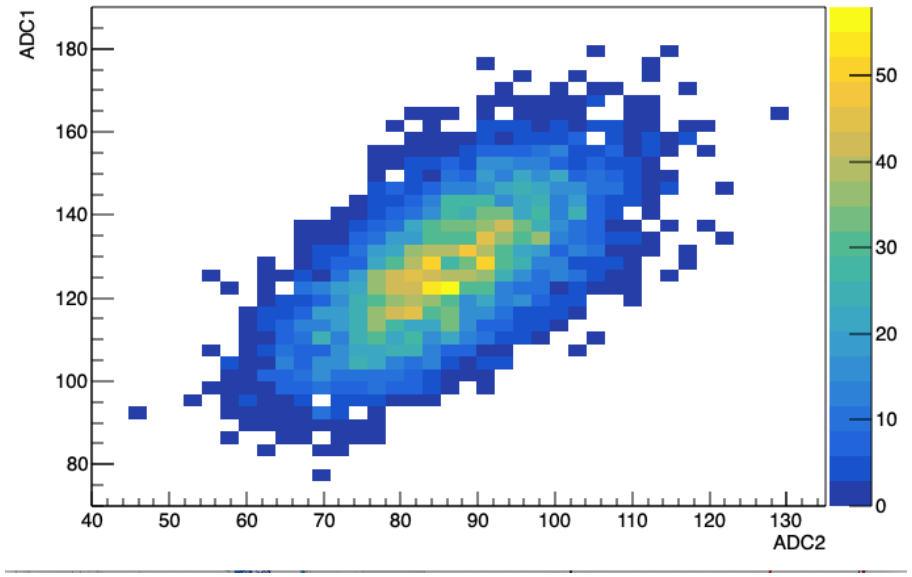
New NDL SiPM with $6mm \times 6mm$

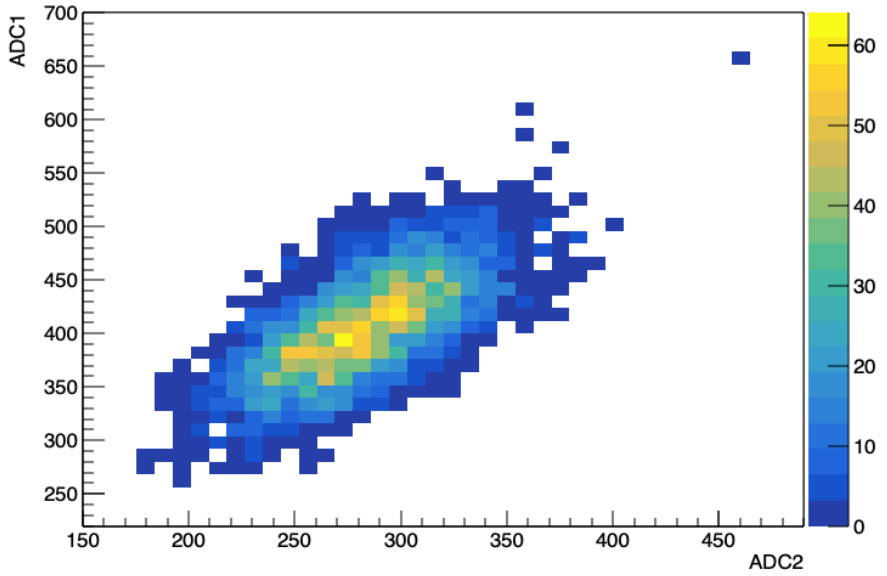






Keep laser constant



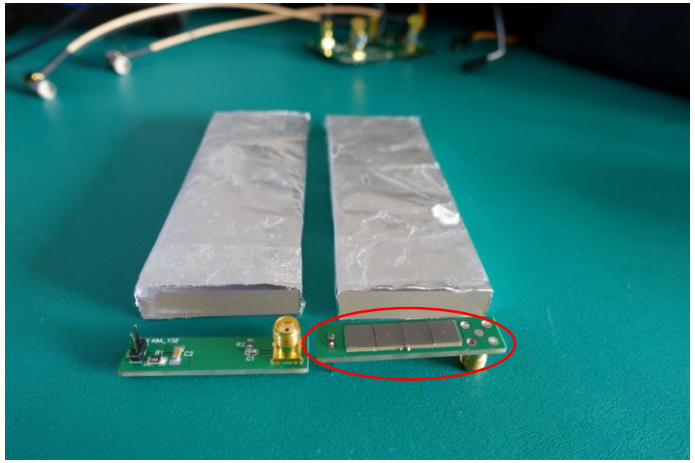


HV/ V	Pedestal	ADC	σ of time difference
28	1.2	140, 90	65
30	2.9	400,270	46

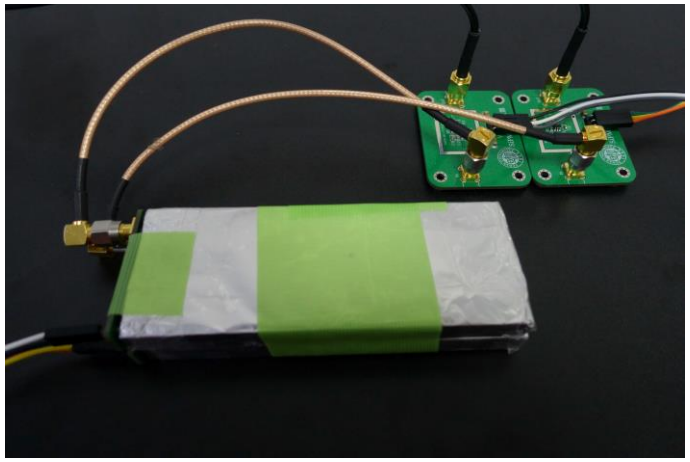
Time resolution = $\sigma/\sqrt{2}$

New design for good timing

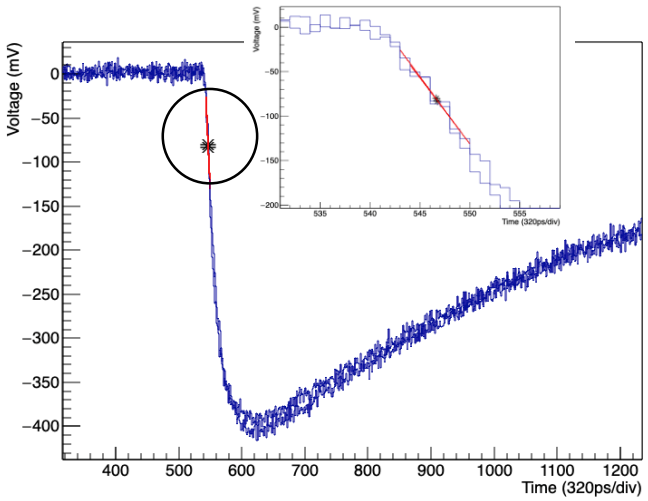
Scintillator+4SiPMs+new pream



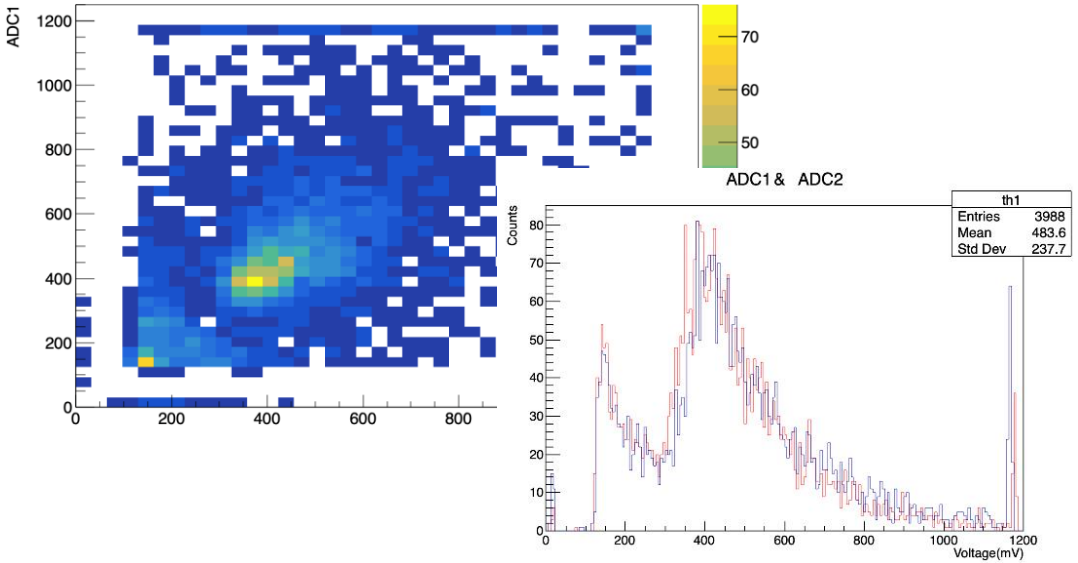
ADC1:ADC2



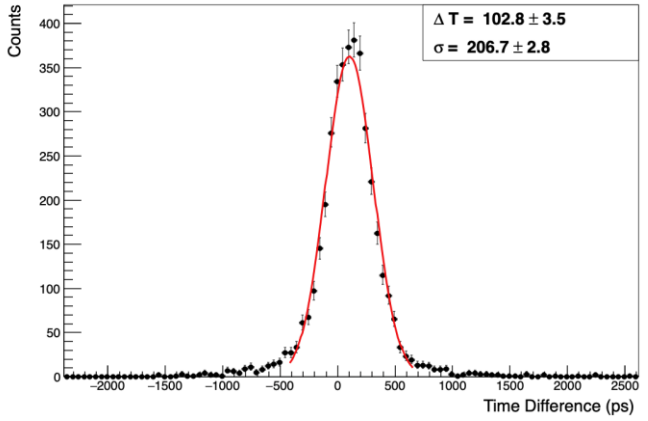
Two strips: $4cm \times 1cm \times 10cm$



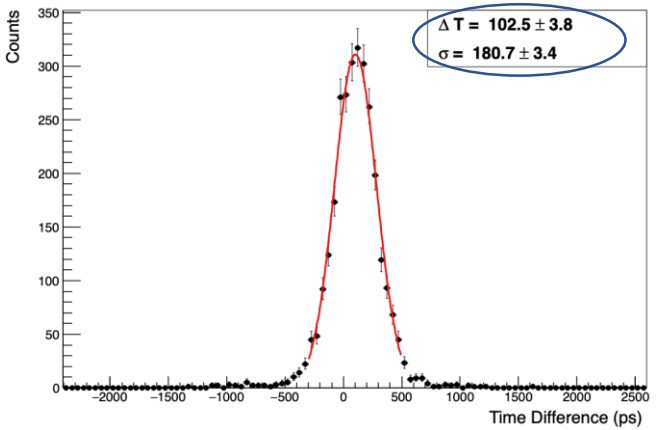
Pulse shapes



Is a charge measurement possible?



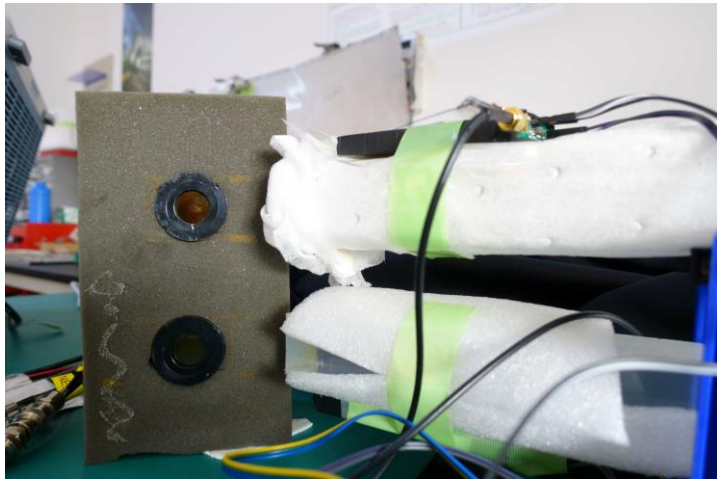
Time resolution:
(146.2 ± 2.0) ps



ADC>300

(127.8 ± 3.0) ps

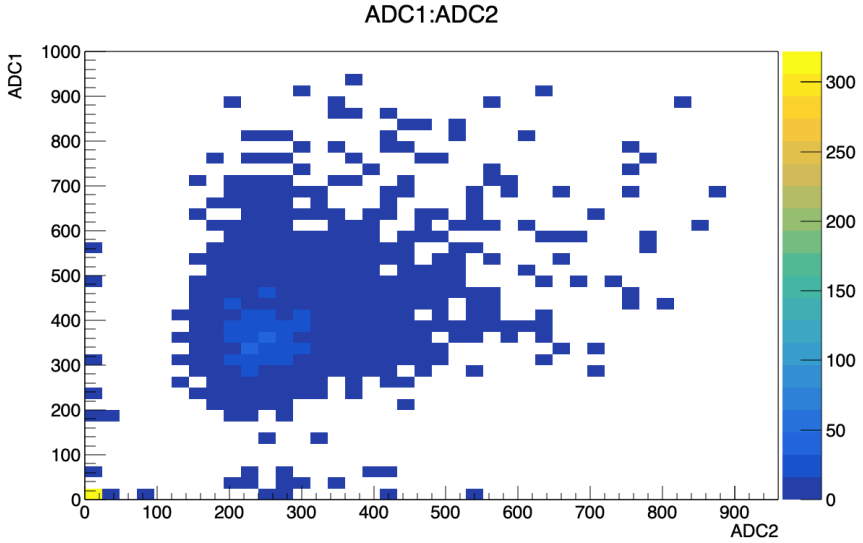
Testing with two long Santi-Gobain scintillators

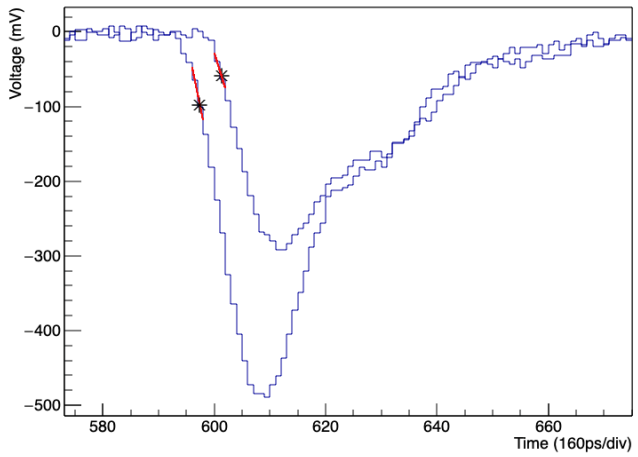


Two MCP-PMT

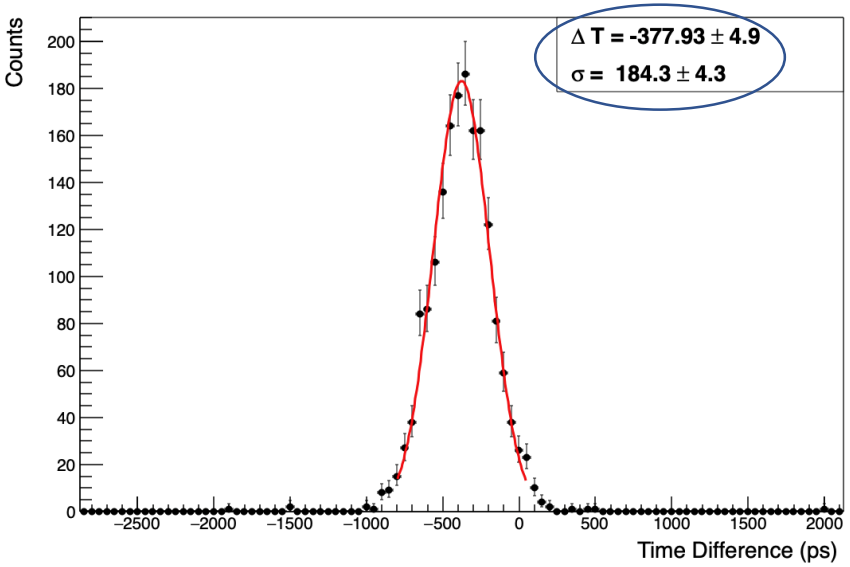
Trigger strips at near end:
$4cm \times 1cm \times 10cm$

Two long strips from IHEP
with excellent time resolution:
$3cm \times 5cm \times 1m$

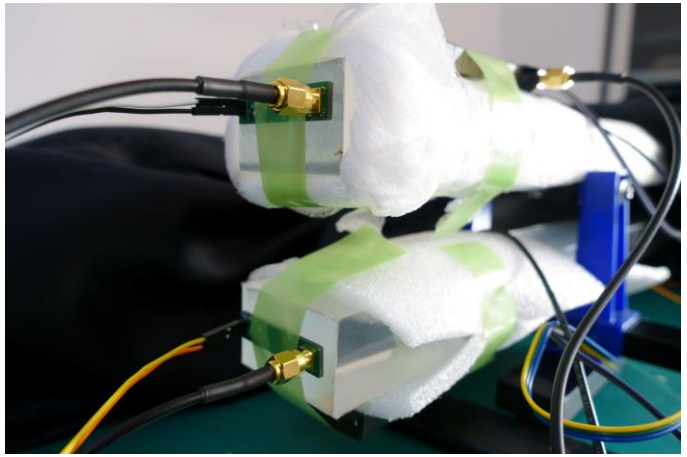


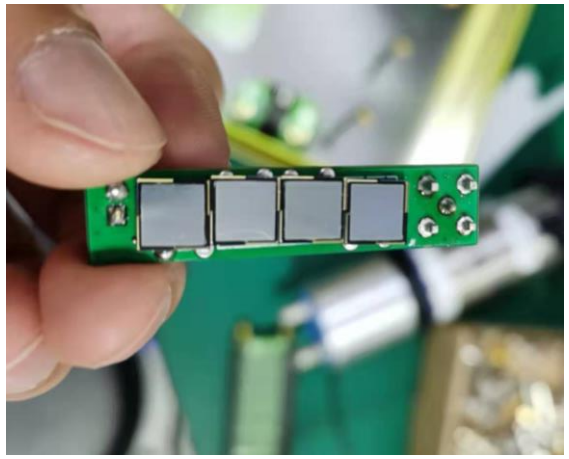


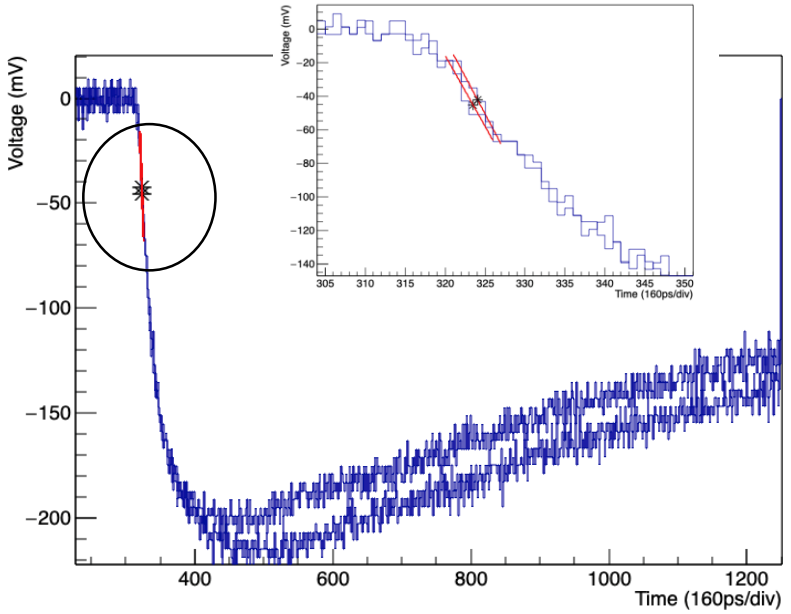
Time resolution: $< 130ps$



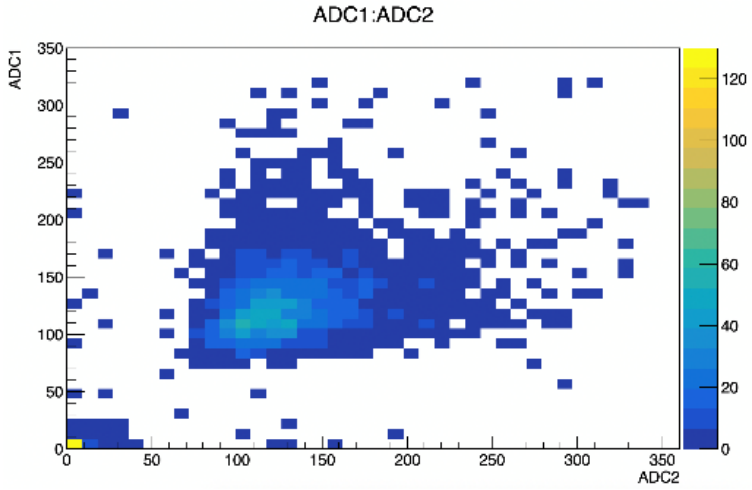
Santi-Gobain scintillators and SiPMs

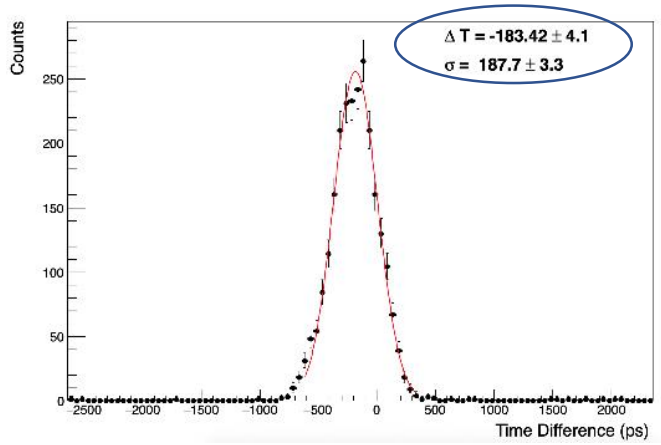






A combination of 4 pieces of $6mm \times 6mm$ SiPMs as the photon sensor.



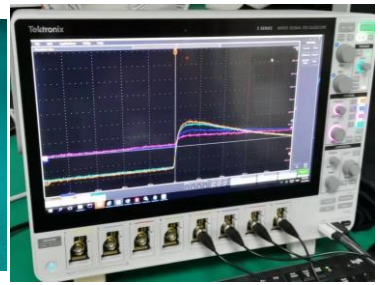


Almost a same performance as MCP-PMT for timing!!!

ADC>30

Effect from the velocity of cosmic rays!

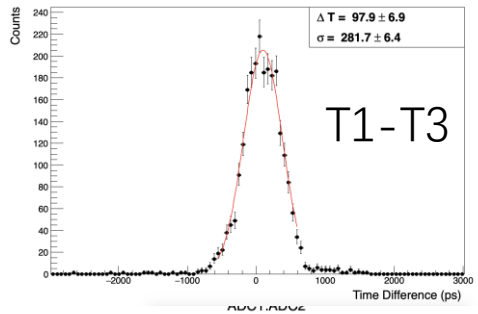
+

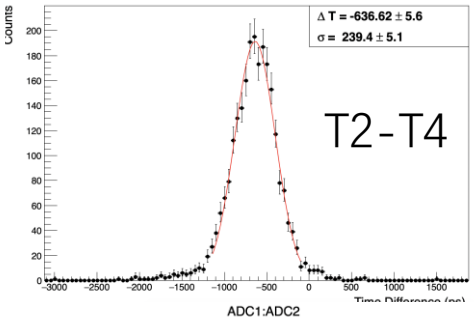


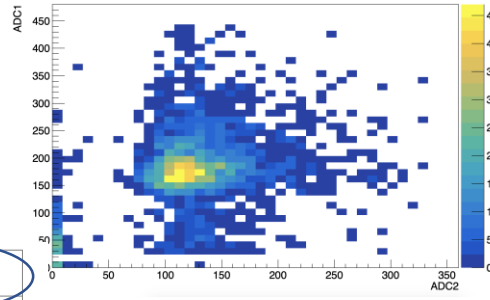
T1, T4

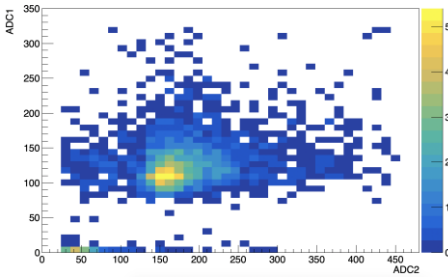
T2 and T3 with distance of $\sim 4cm$
T1 and T4 with distance of $\sim 10cm$

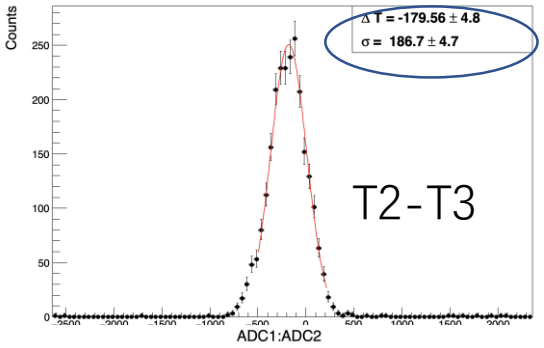
T1 close to T2, T4 close to T3

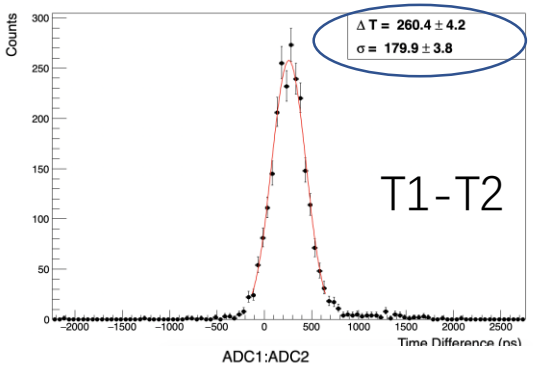


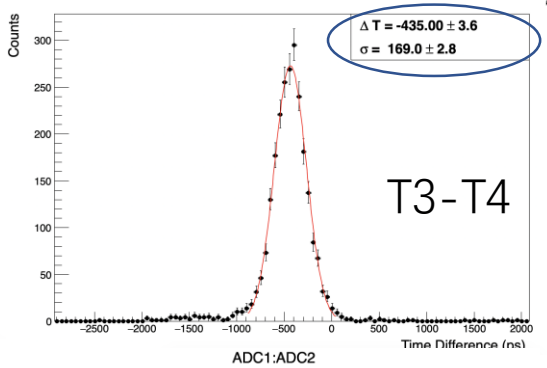


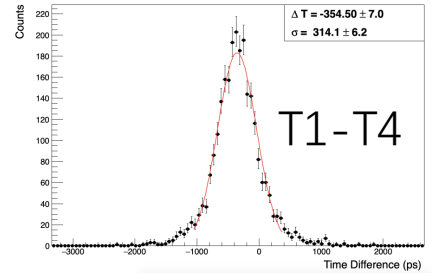


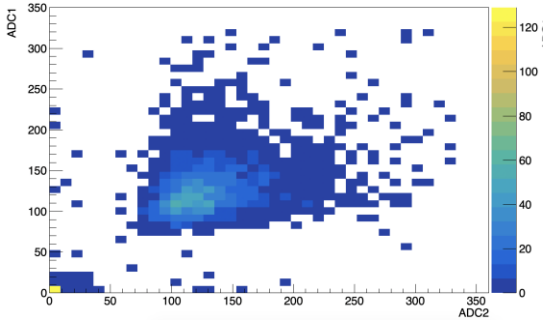


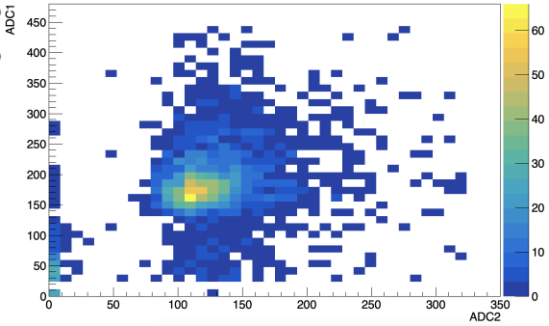


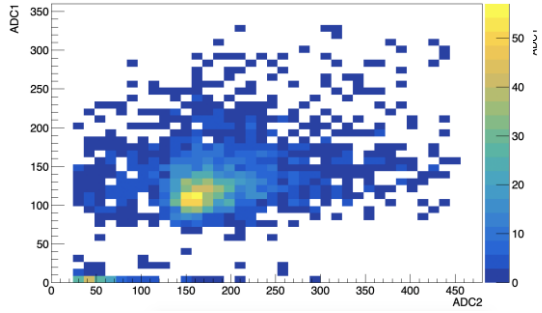


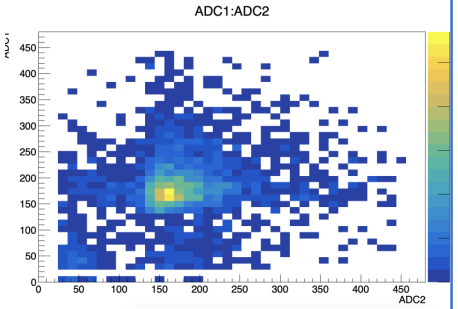












Time resolutions:

T2,T3: $132.0 \pm 3.3ps$

T1,T2: $127.2 \pm 2.7ps$

T3,T4: $119.5 \pm 2.0ps$

T1,T3: $199.2 \pm 4.5ps$

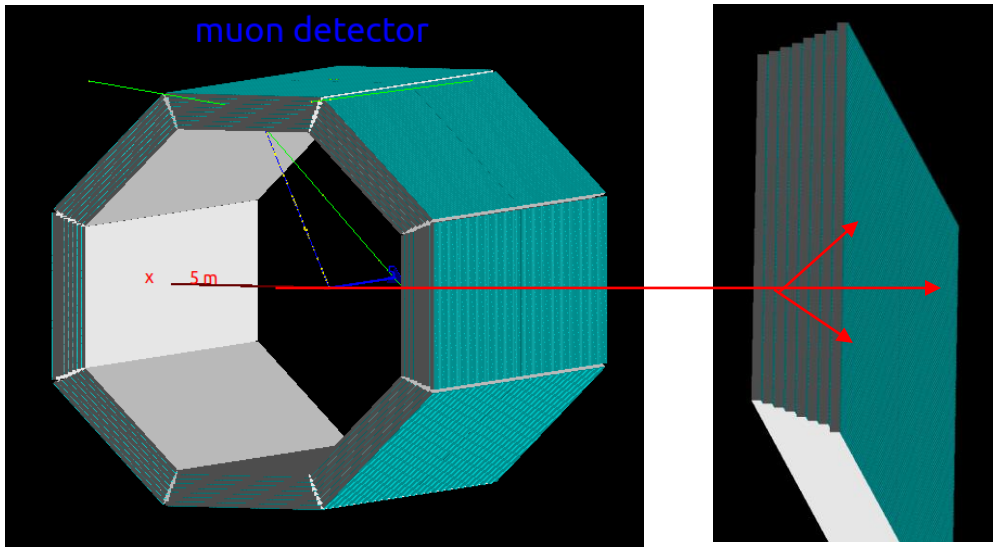
T2,T4: $169.3 \pm 3.6ps$

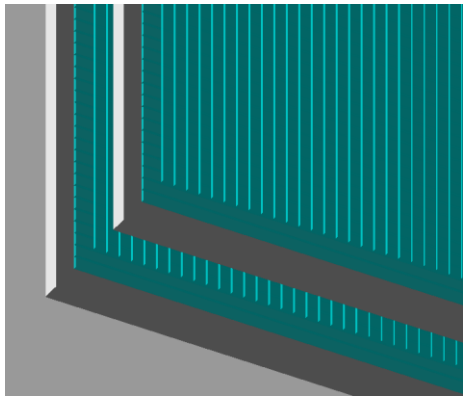
T1,T4: $222.1 \pm 4.4ps$

- Increase of time resolution is due to the velocity of CR.
- Velocity of CR should be taken into account.

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

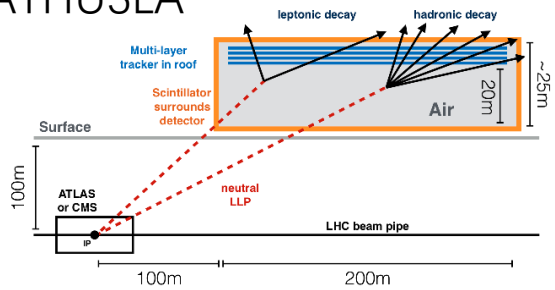


Fig. 1: Simplified detector layout showing the position of the $200\,\mathrm{m} \times 200\,\mathrm{m} \times 20\,\mathrm{m}$ LLP decay volume used for physics studies. The tracking planes in the roof detect charged particles, allowing for the reconstruction of displaced vertices in the air-filled decay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

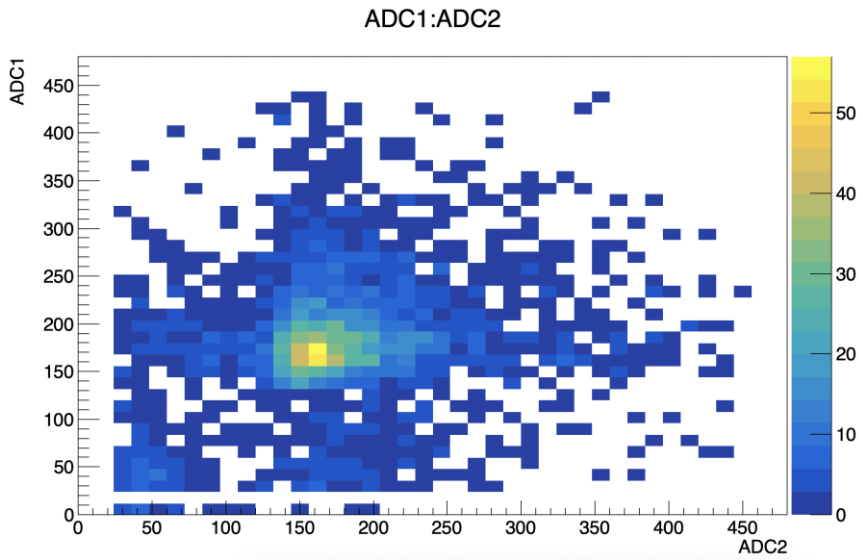
Summary

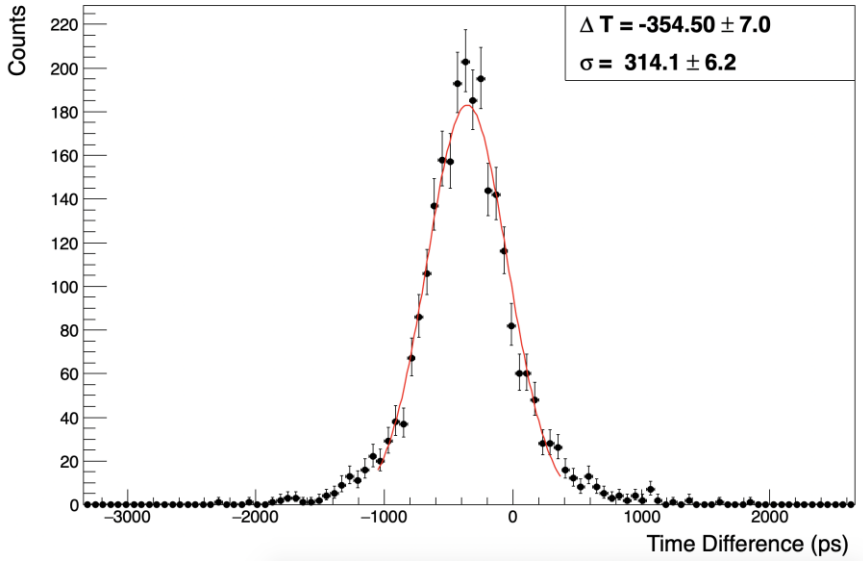
- Good performance of the current KLM design for efficiency.
- Short strips of new scintillator from Gaonengkedi Company shows a similar time resolution as Saint-Gobaint scintillator.
- Photon sensor with a combination of 4 $6mm \times 6mm$ SiPMs shows a good performance.
- Time resolution of about $130ps$ has been obtained with short strips.
- CR testing with 4 scintillator shows the effect of velocity of cosmic rays.
- A crazy/naïve idea for a detector with timing? We can extend the search for new physics, such as LLP.

Thank you!

Back up

Time resolution: 5*3/natural+6629PZx25





T1-T4

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