

A Cosmic ray test of FPCCD vertex detector

Tohoku - U (2019)
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Goal of test & what we did

[GOAL]

To evaluate the performance of FPCCD with Cosmic Ray

- to evaluate signal charge diffusion and position resolution
- Resolution goal of FPCCD is 1.5 μm for ILC
- Charge diffusion goal is within 2×2 pixel around hit position

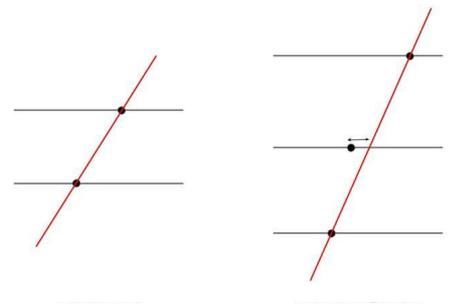
What we did ?

- Made measurement system with 4 FPCCDs ($6\mu\text{m} \times 15\mu\text{m}$)
- Start using measurement system
- Tried to evaluate the performance of FPCCD

Measurement system

[Need to run at least 3 CCDs at the same time]

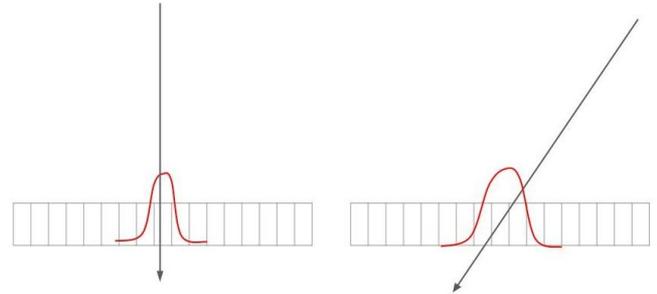
For tracking.
→ If we get only 2 points from 2 CCDs, a residual will be always 0.



We used 4 CCDs for this test.

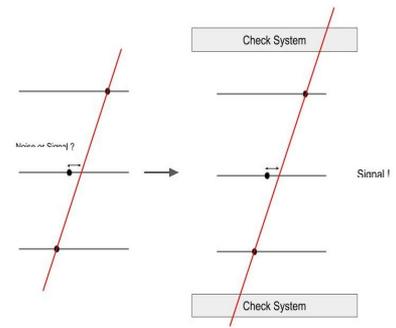
[Taking wider azimuthal angle signal]

To evaluate azimuthal angle dependency of diffusion.



[Check a signal is by cosmic rays or not]

We used hodoscope using the combination of MPPC + stick scintillator.



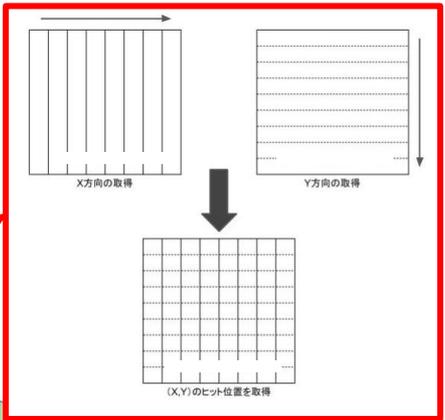
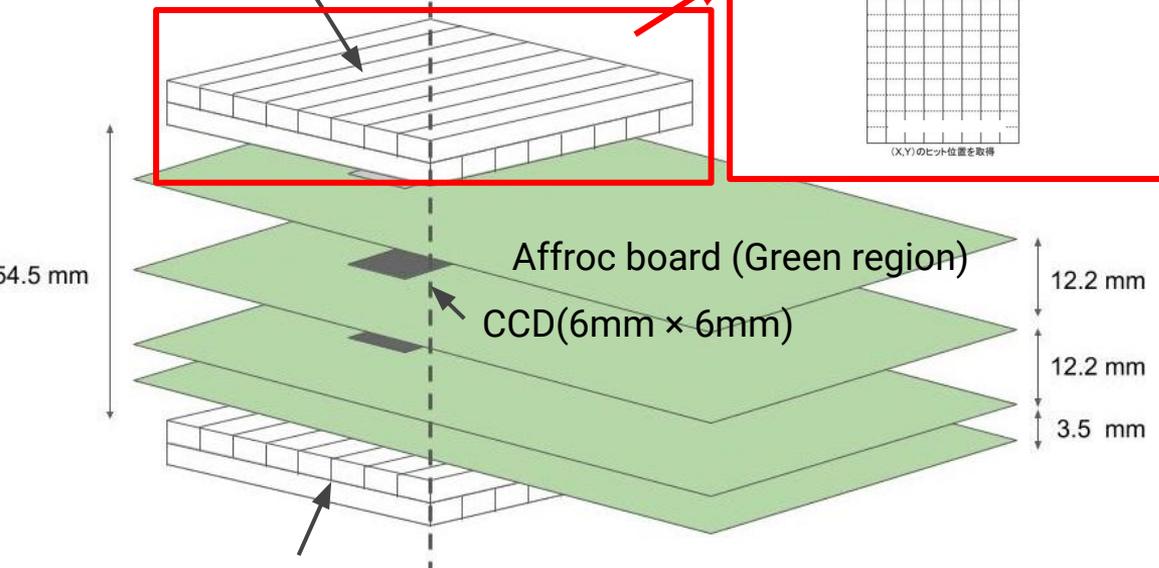
[Link the timing between check system and CCDs]

We needed to link the timing between signal from hodoscope and FPCCD.

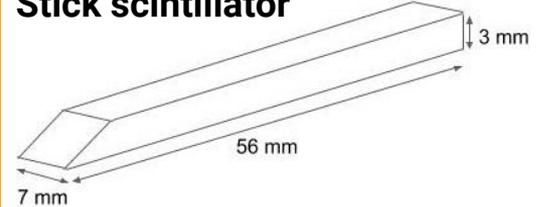
To get the timing, we used “Easiroc Module” for DAQ electronics for hodoscope. Modified firmware of EM is developed at Shinshu-U.

Measurement system

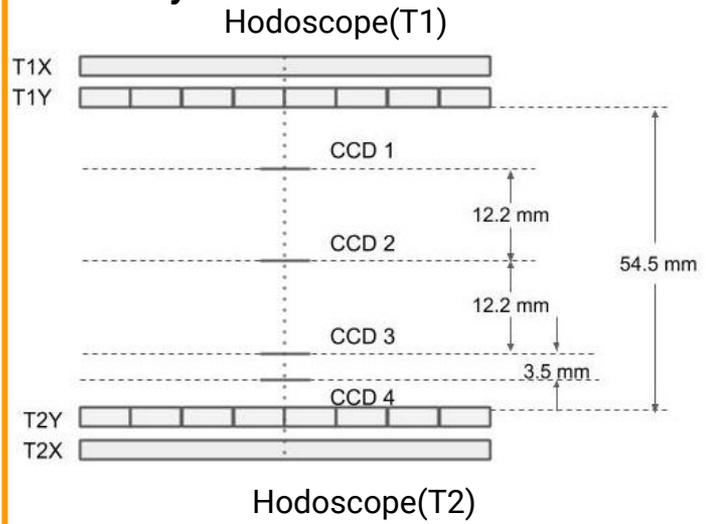
Hodoscope(T1)



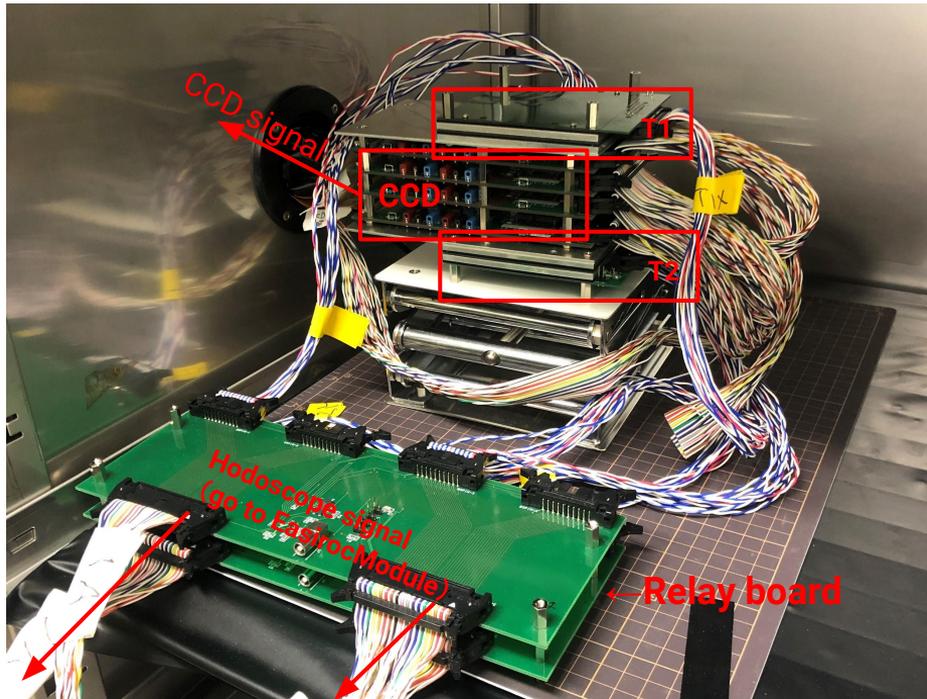
Stick scintillator



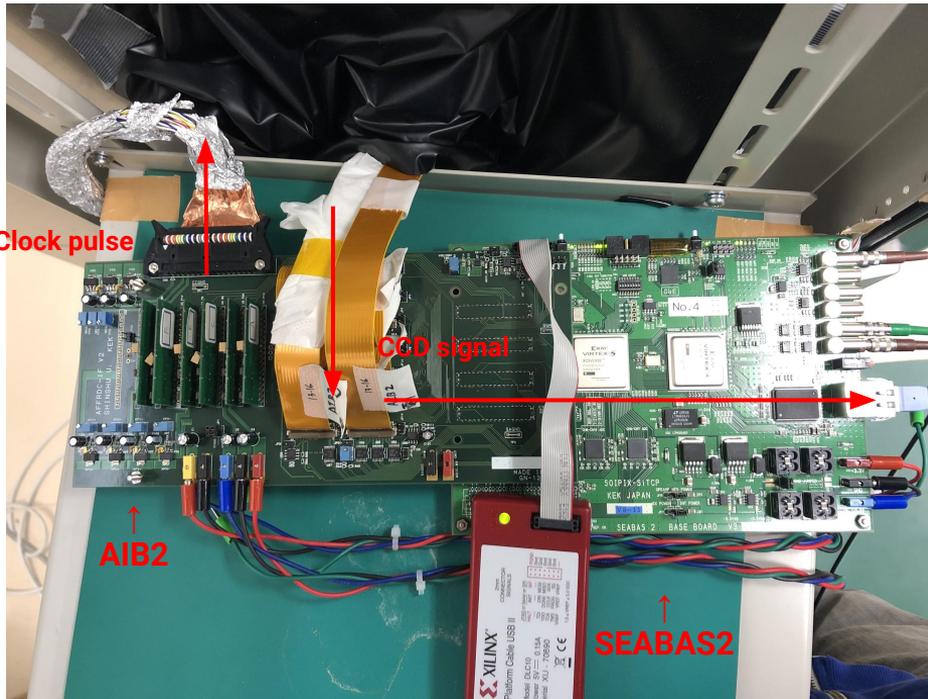
Geometry



Setup



Inside of **Constant temperature bath**



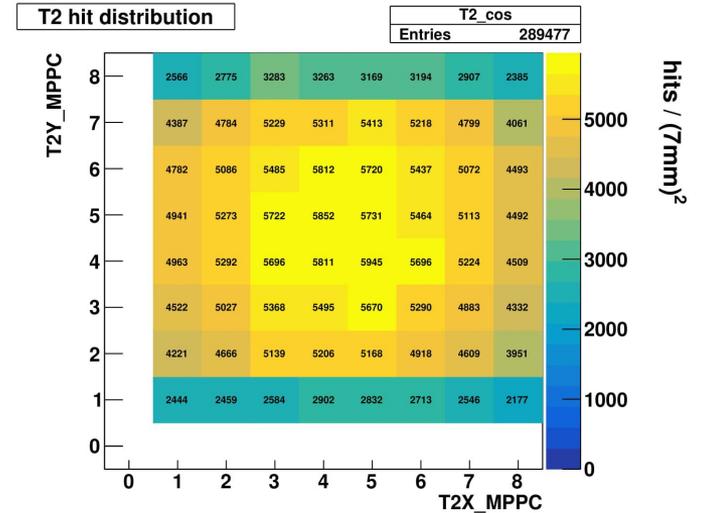
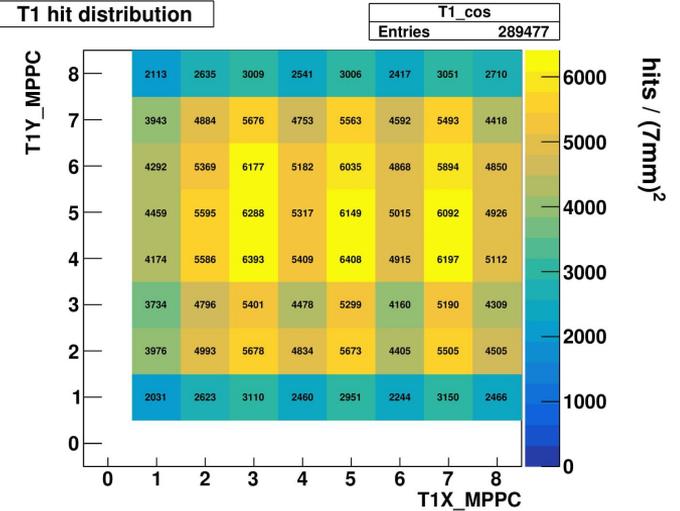
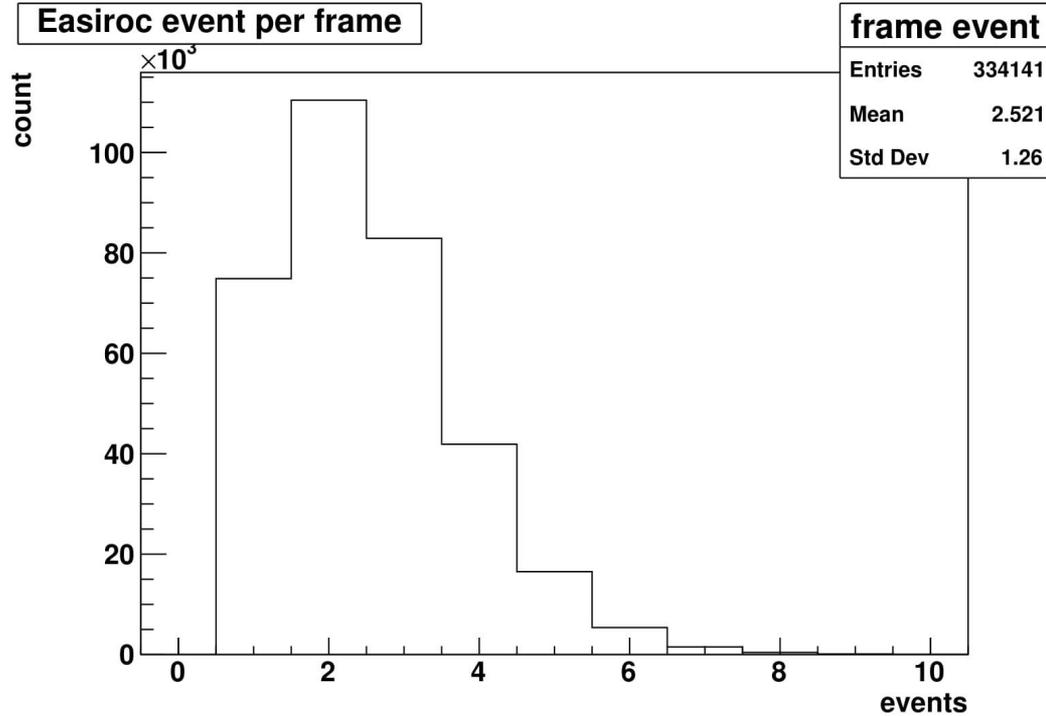
Outside of **Constant temperature bath**

• Measurement system is placed in $-40\text{ }^{\circ}\text{C}$ **constant temperature bath**.
• Exposure time : 10s, readout time : about 0.6 s → "1 frame"

RUN 39 days

Working check of Hodoscope

[COINCIDENCE] T1 and T2



Used frame for analysis

[Hit pixel]

Max ADC value pixel in each CCD

And get information of 5×5 pixels around hit pixel. (Use later)

[Target CCD hit pattern]

(ccd1,2,3,4), (ccd1,2,3), (ccd2,3,4)

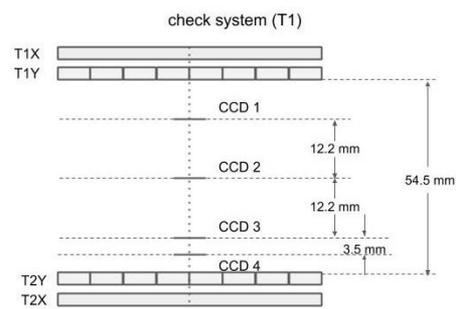
[Restriction]

1. Only 1 hit in each CCD
2. Success linear FIT (and cut by χ^2)
→ to use only CLEAN event for the evaluation.

Total #target hit pattern : 4172

#final used frame : 259

In 39 days

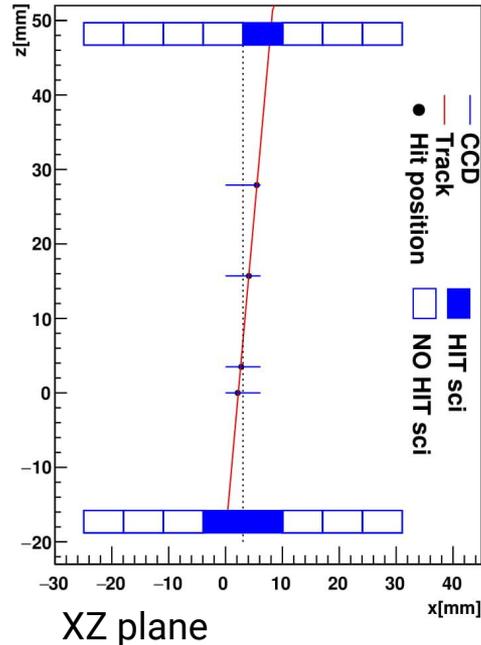


Left : geometry

below : frame example

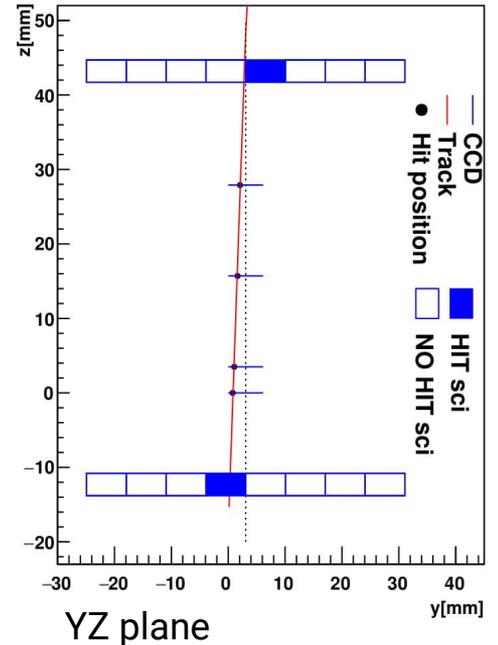
XZ plane [crun13 erun 3 frame250]

χ^2 / ndf	1.714 / 2
Prob	0.4244
p0	8.525 ± 0.3599
p1	-19.11 ± 1.384



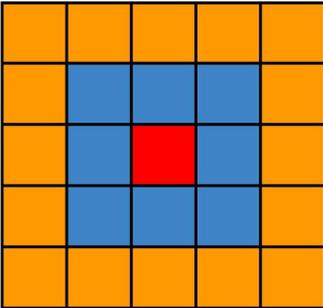
YZ plane [crun13 erun 3 frame250]

χ^2 / ndf	6.801 / 2
Prob	0.03336
p0	21.81 ± 1.844
p1	-18.48 ± 2.719

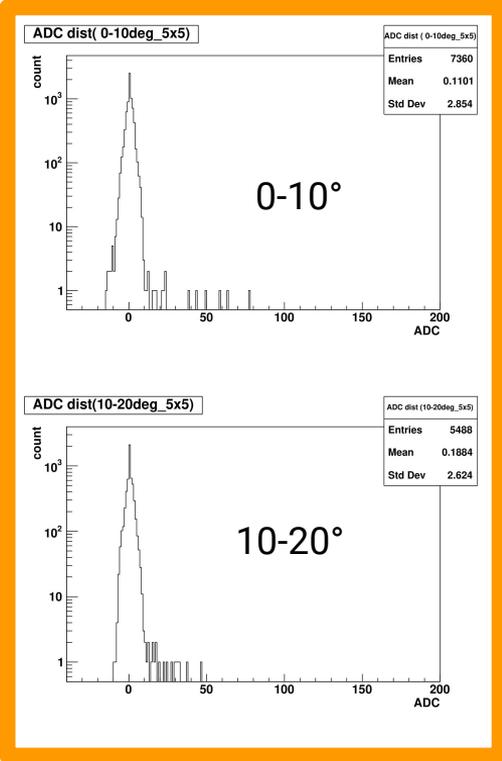
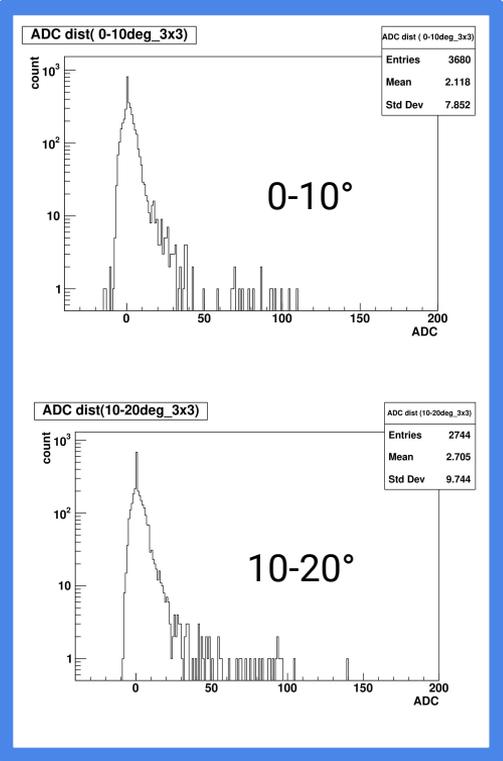
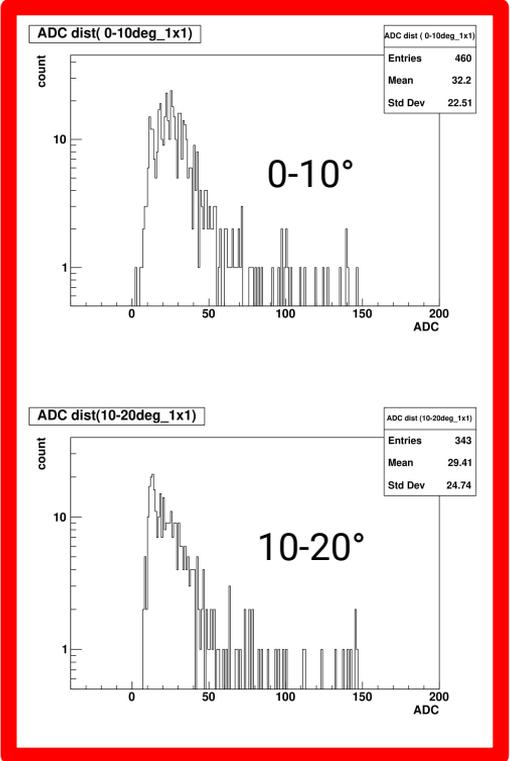


Evaluation of Charge diffusion from ADC value

The pictures below are histograms of each angle region.
ADC value of each area is filled to corresponding histograms.



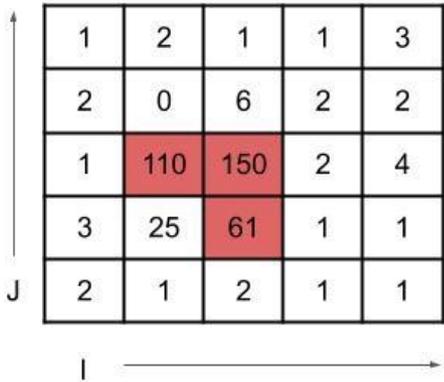
1x1 : center pixel (hit position)
3x3 : 1 pixel outer area (8 pix)
5x5 : most outer pixels (16 pix)



Evaluation of Charge diffusion

[Goal] within 2x2 pixel around hit pixel
 [Size] 6um x 15um t
 [Method]

1. Sum ADC value of 5x5 pixels
2. Count #pixels which contribute **ADC > 10% of SUM**

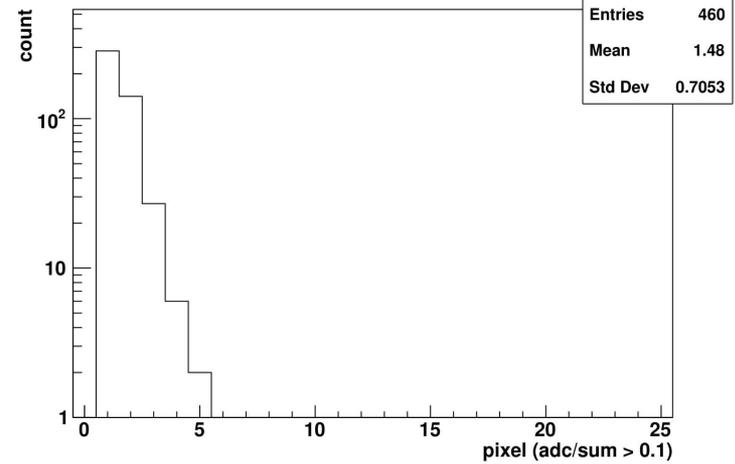


[EXAMPLE]
 SUM = 381 ,
 #charge diffusion pixel = 3

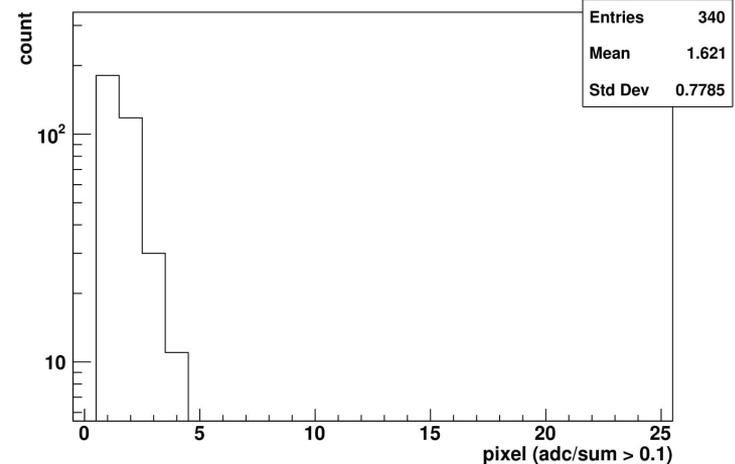
Evaluate the diffusion with the method above...

- **Max #pixel = 4** (azimuthal angle < 20°)
- We can estimate mean value of #pixel will be larger if azimuthal angle is large.

pixel .vs hit_angle(0-10deg)



pixel .vs hit_angle(10-20deg)



Evaluation of Position Resolution

[Resolution goal] 1.5 μm

Residuals between **Tracking** & **hit pixel** are filled for this evaluation.

Calculate σ of gaussian fit.

$$\sigma = 0.064 \pm 0.002 \text{ [mm]}$$

We used this σ as position resolution.

→ σ is about 10 times larger than pixel size of FPCCD
(6 $\mu\text{m} \times 6\mu\text{m}$).

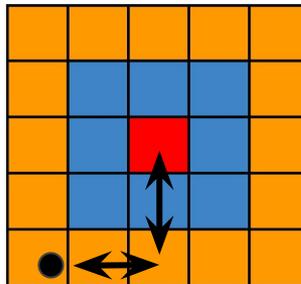
Why σ was large ?

[Bad alignment]

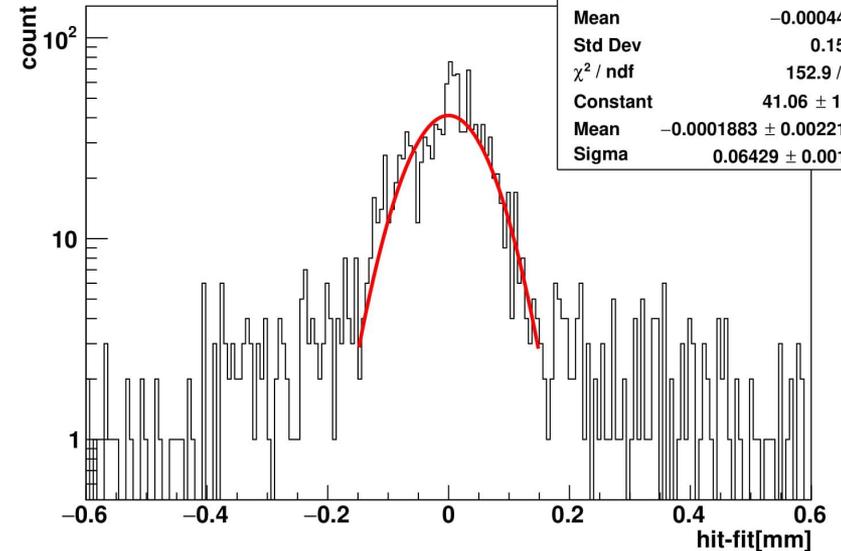
- max 60 μm position aberration.

[Glass cover on CCD (1 mm)]

- Max 3 μm positional aberration will be caused by multiple scattering in the case of 4 GeV cosmic muon at 12.2 mm distance.



Hist_Dif Line-Hitpos (all)



- : Hit position
- : Tracking point
- ↔ : Filled residual(both X & Y)

What we need to do

[Improvement of Analysis]

We should try to use more events (frame) for analysis,
We are using only “clean” frames with the frame restriction.

Needed work

- Development of better method to use multi hit frame (in 1 CCD)
- Development of alignment adjustment method.

[Evaluation of angle dependency of charge diffusion]

We want to evaluate larger angle diffusion

- try to use 2CCD hit frame
- need more precise tracking with check system

Needed work

- Development of 2CCD hit tracking method with check system hit information

[Hardware improvement]

Removing glass cover from CCD, more careful use of CCD etc

Needed work

- Clean environment is need for removing glass cover of CCD

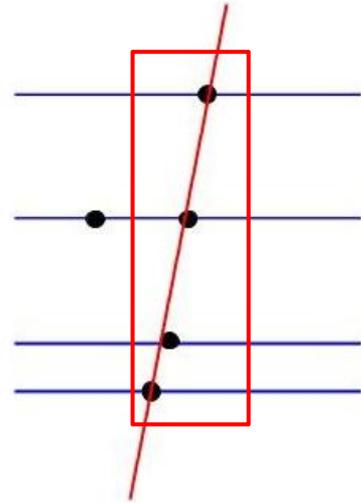


Image of multiple hit frame in 1 CCD

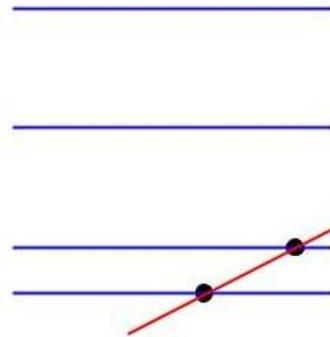


Image of 2 CCD hit frame

Summery

We made a measurement system with 4 FPCCDs for cosmic ray test, and use it first time.
We tried to evaluate the performance of FPCCD using cosmic ray.

Hodoscope

We used combination of MPPC+Stick scintillator for hodoscope, and Easiroc Module for readout electronics.

We need more precise tracking method using hit position information from this hodoscope.

Signal charge diffusion

We could get the signal by cosmic ray which have small azimuthal angle ($< 20^\circ$).

Charge diffusion was only 4 pixels around hit pixel.

We need to evaluate charge diffusion by larger azimuthal angle cosmic rays.

Position resolution

The position resolution σ which calculated from histogram of residual between tracking line and actual hit was

$$\sigma = 0.064 \pm 0.002$$

The reason why bad resolution is

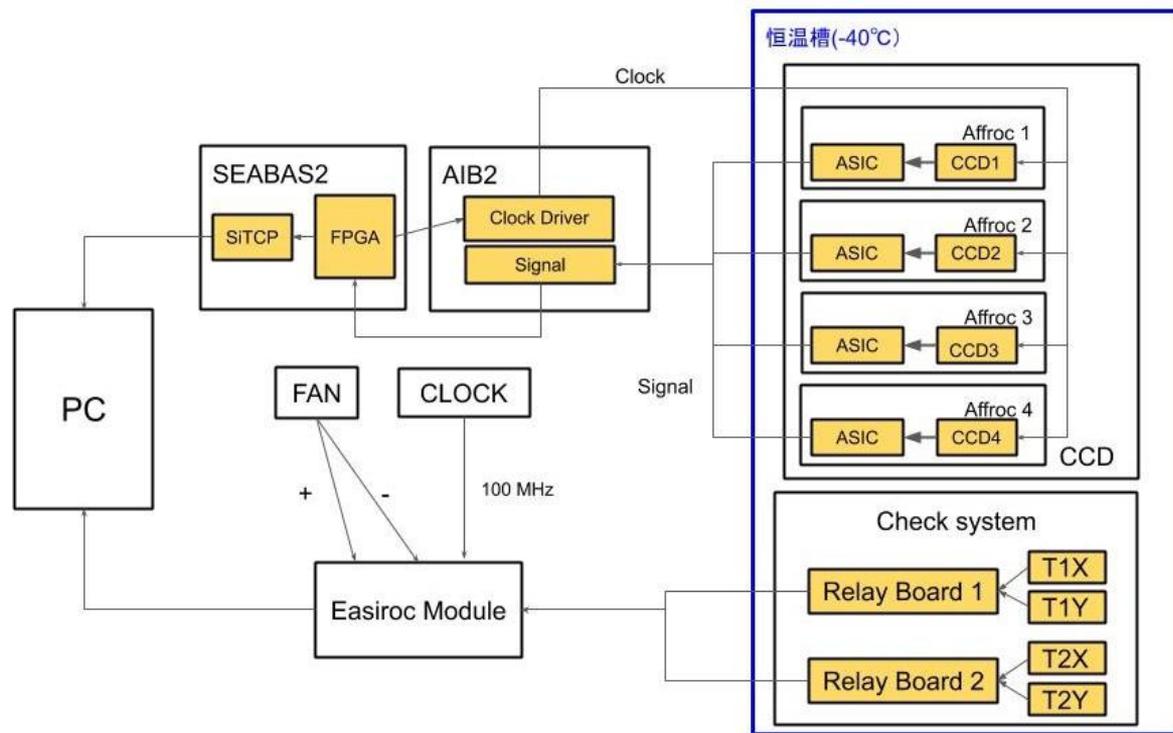
- bad alignment
- glass cover of FPCCD

What we need to do ?

1. Improvement of analysis method to use frames which has multiple hit in 1 CCD and for alignment adjustment
2. Development of more precise tracking method using hodoscope signal.
3. Removing glass cover on FPCCD

BACK UP

Setup

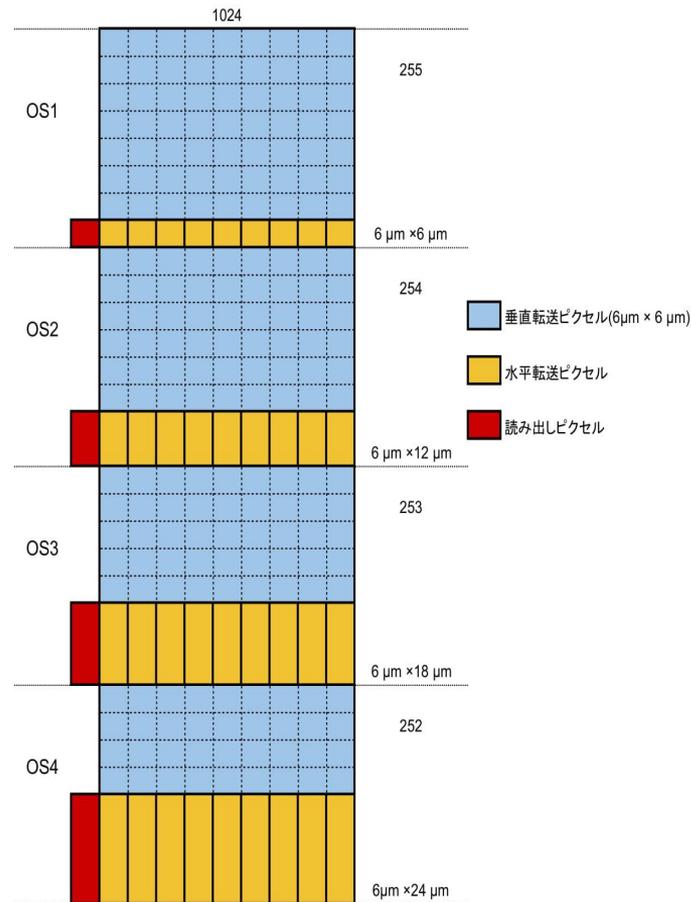
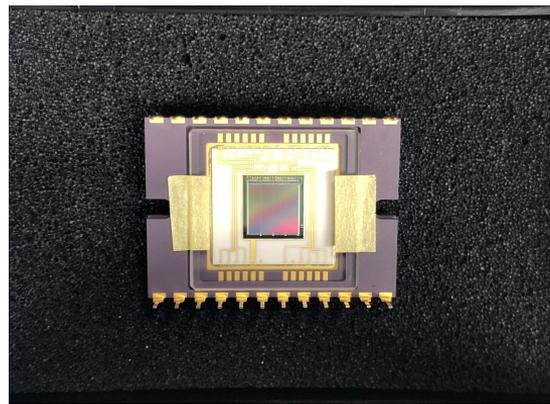
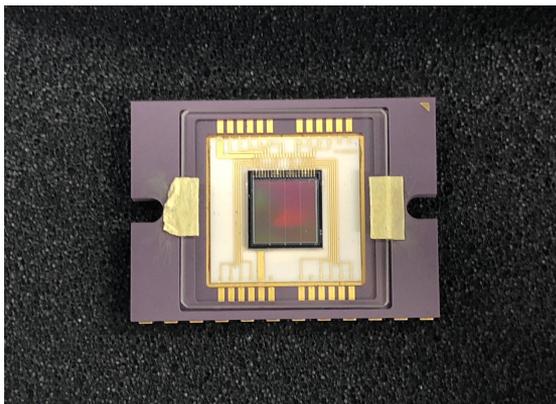


- Measurement system is placed in -40 °C constant temperature bath. (Blue box in above picture)
- Exposure time 10s, readout time 0.6 s (1 frame)

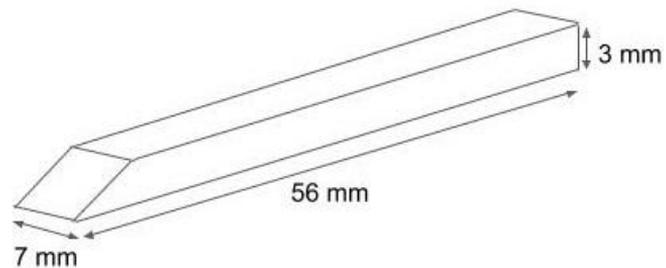
RUN 39 days

Spec of FPCCD

	OS1	OS2	OS3	OS4
垂直転送ピクセル	6 μm \times 6 μm			
水平転送ピクセル	6 μm \times 6 μm	6 μm \times 12 μm	6 μm \times 18 μm	6 μm \times 24 μm
ピクセル数	1024 \times 255	1024 \times 254	1024 \times 253	1024 \times 252
有感層厚	15 μm			
型番	CPK1-14-CP502-9,11,25,37			

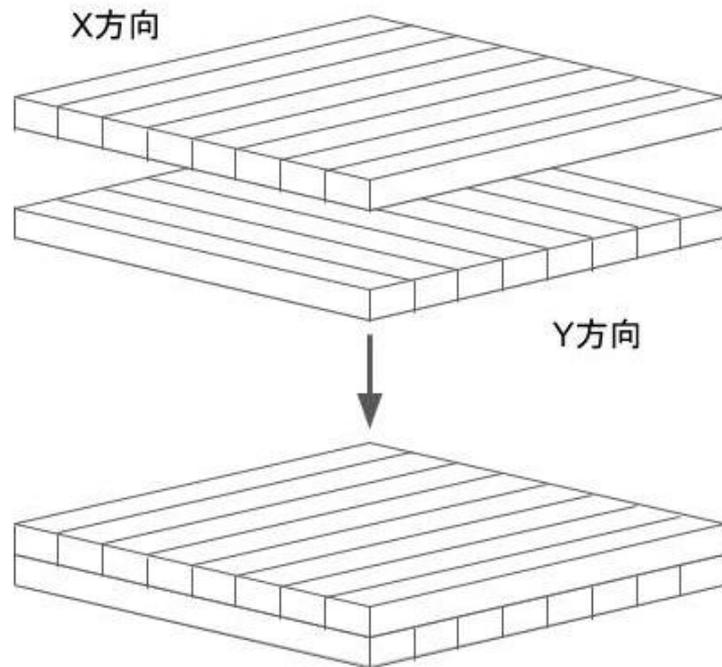
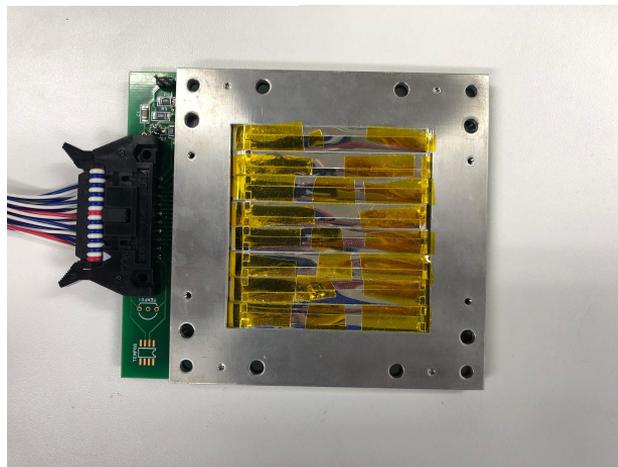


Check system



above : Stick scintillator

Right : MPPC board
board 105 mm × 90 mm
Sci 56 mm × 56 mm



Modified firmware of EasirocModule

Developed at Shinshu-U

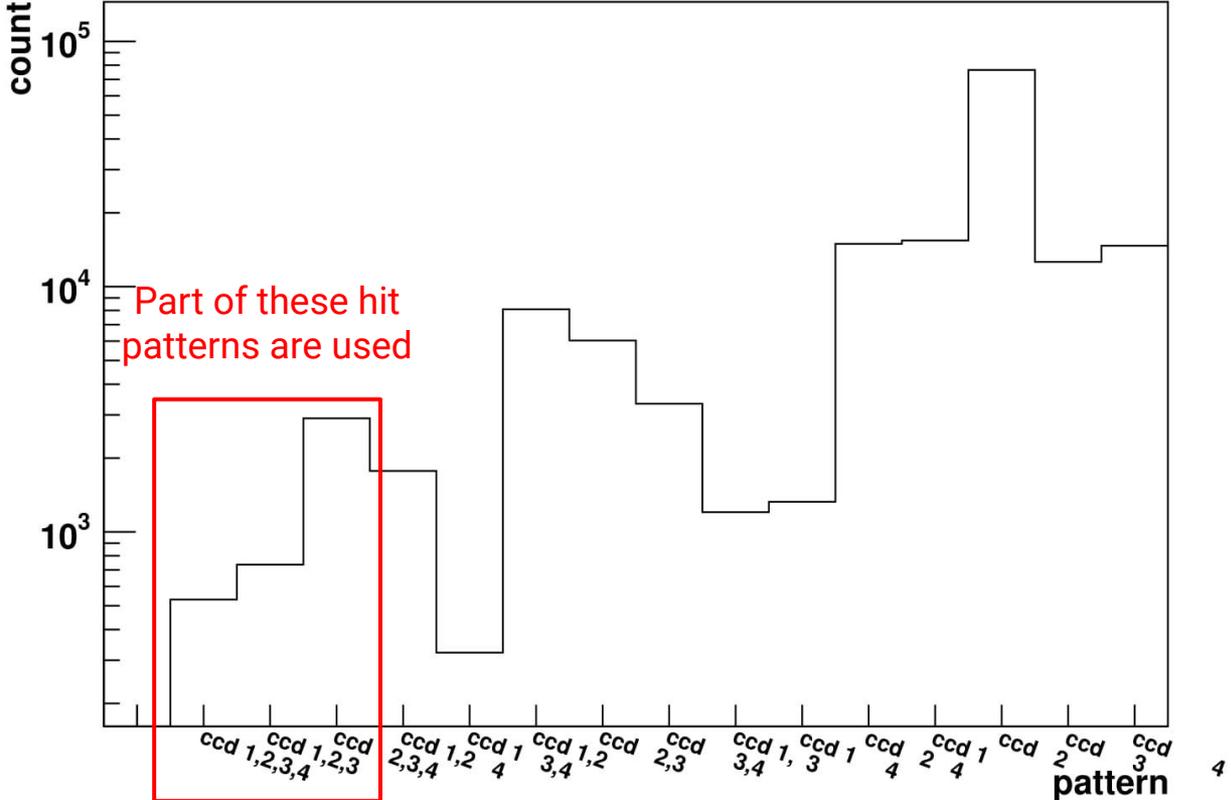
[Added function]

- Inner coincidence
- Synchronization of 2 Easiroc Module
(This function is used to get timing information.)
- Data taking timing control with veto signal.

CCD hit pattern distribution

CCD hit pattern

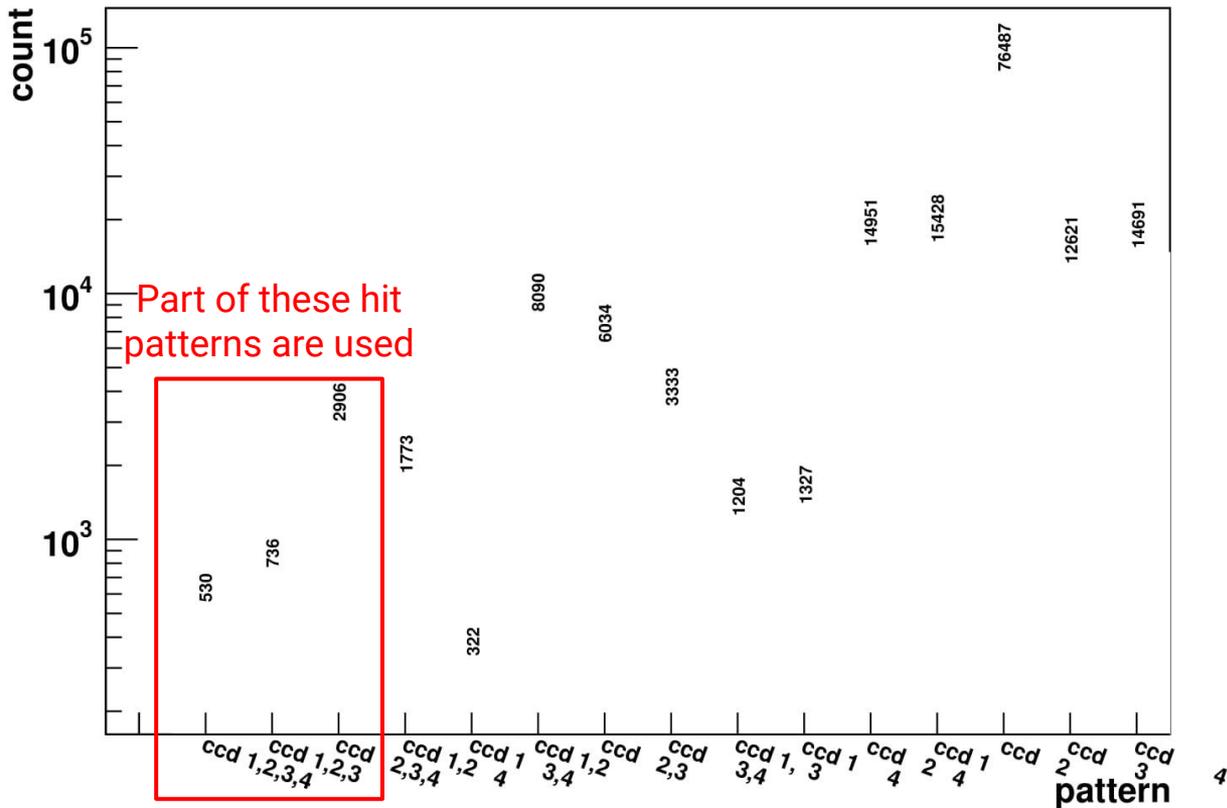
CCD hit pattern
Entries 160433



CCD hit pattern distribution

CCD hit pattern

CCD hit pattern
Entries 160433

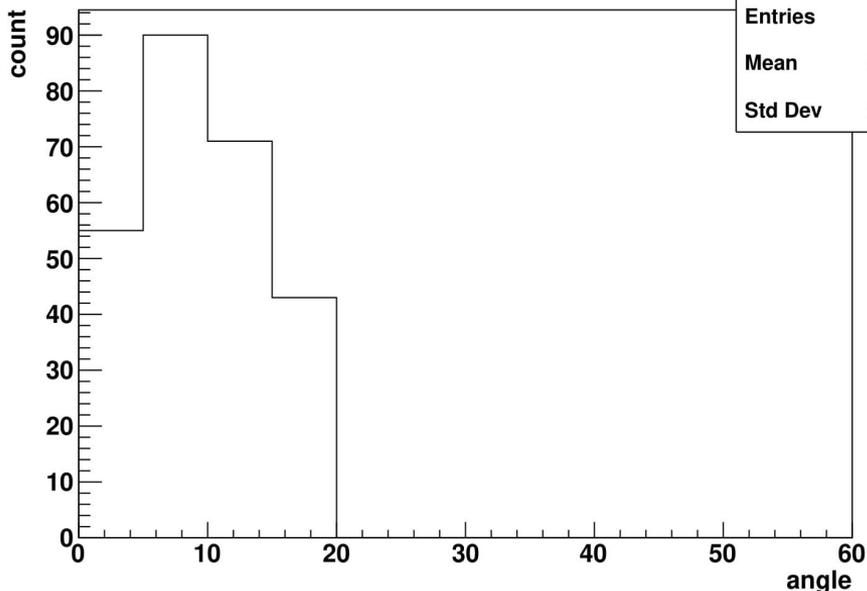


Angle distribution & ADC sum (CCD)

Left : Angle is limited under 20° because of the geometry.

Right : ADC sum distribution of 5×5 pixel.

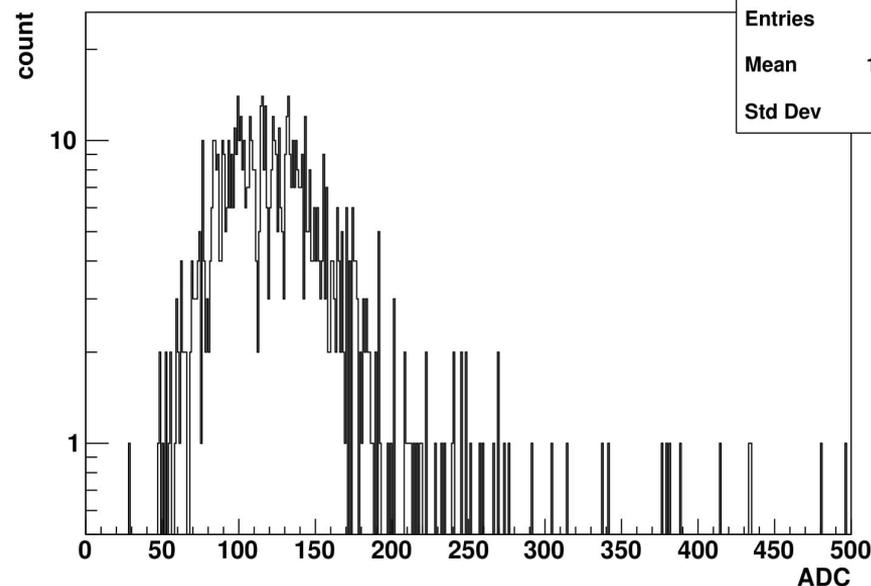
CCD angle dist



CCD angle

Entries	259
Mean	9.604
Std Dev	4.772

ADC sum (all_lim)



ADC sum (all_lim)

Entries	803
Mean	128.4
Std Dev	51.8

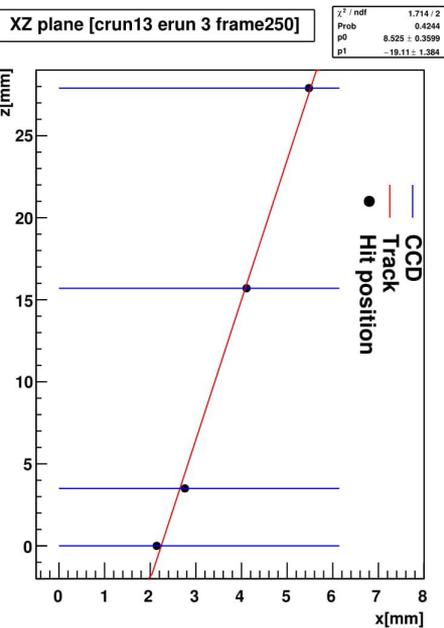
Azimuthal angle

ADC sum

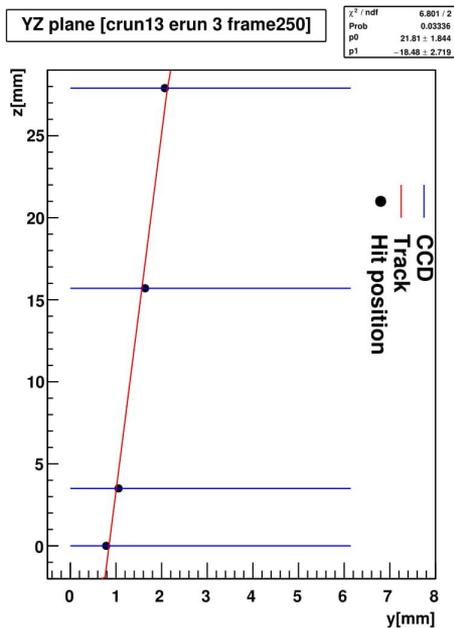
I checked FPCCD is **WORKING**.

Frame example

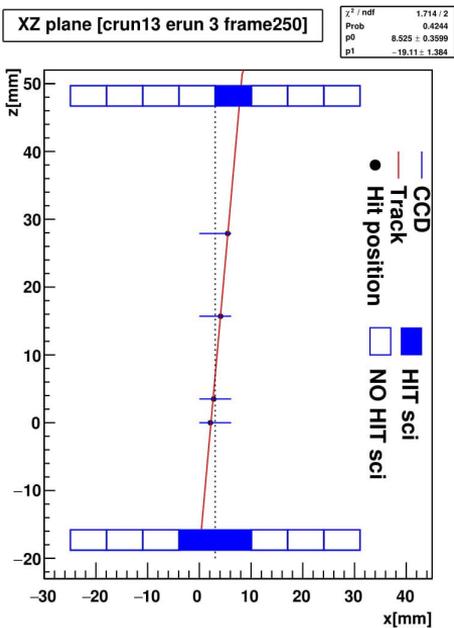
XZ plane (CCD only)



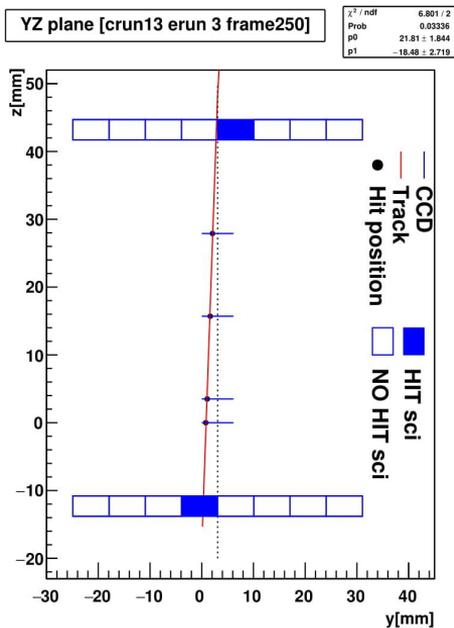
YZ plane (CCD only)



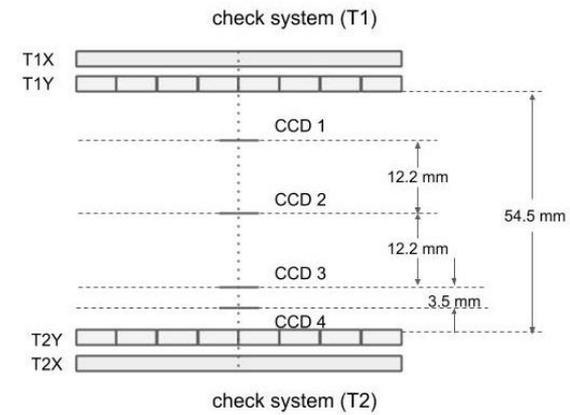
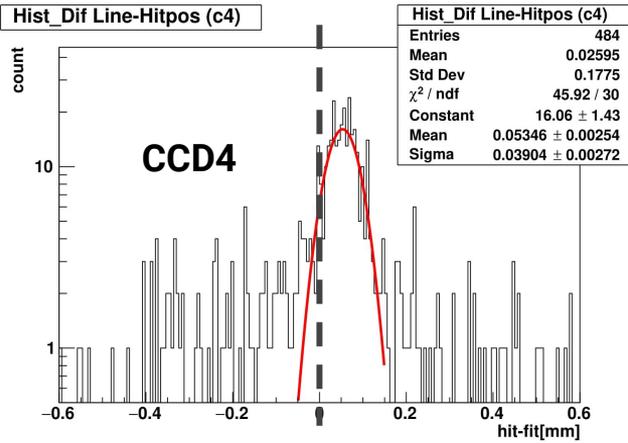
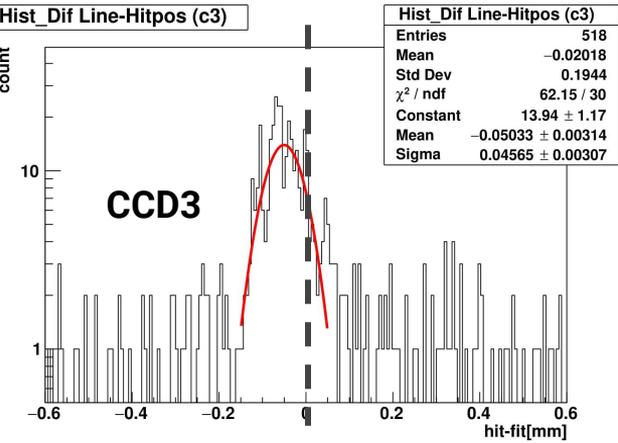
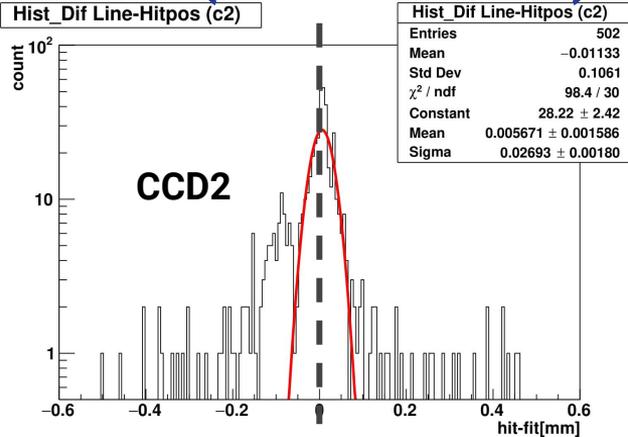
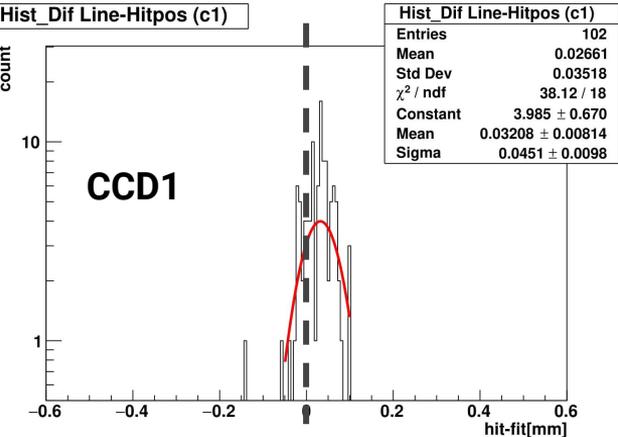
XZ plane (whole)



YZ plane (whole)



Distribution of residual (Each CCD)



Alignment of CCD3 & CCD4 was TERRIBLE...