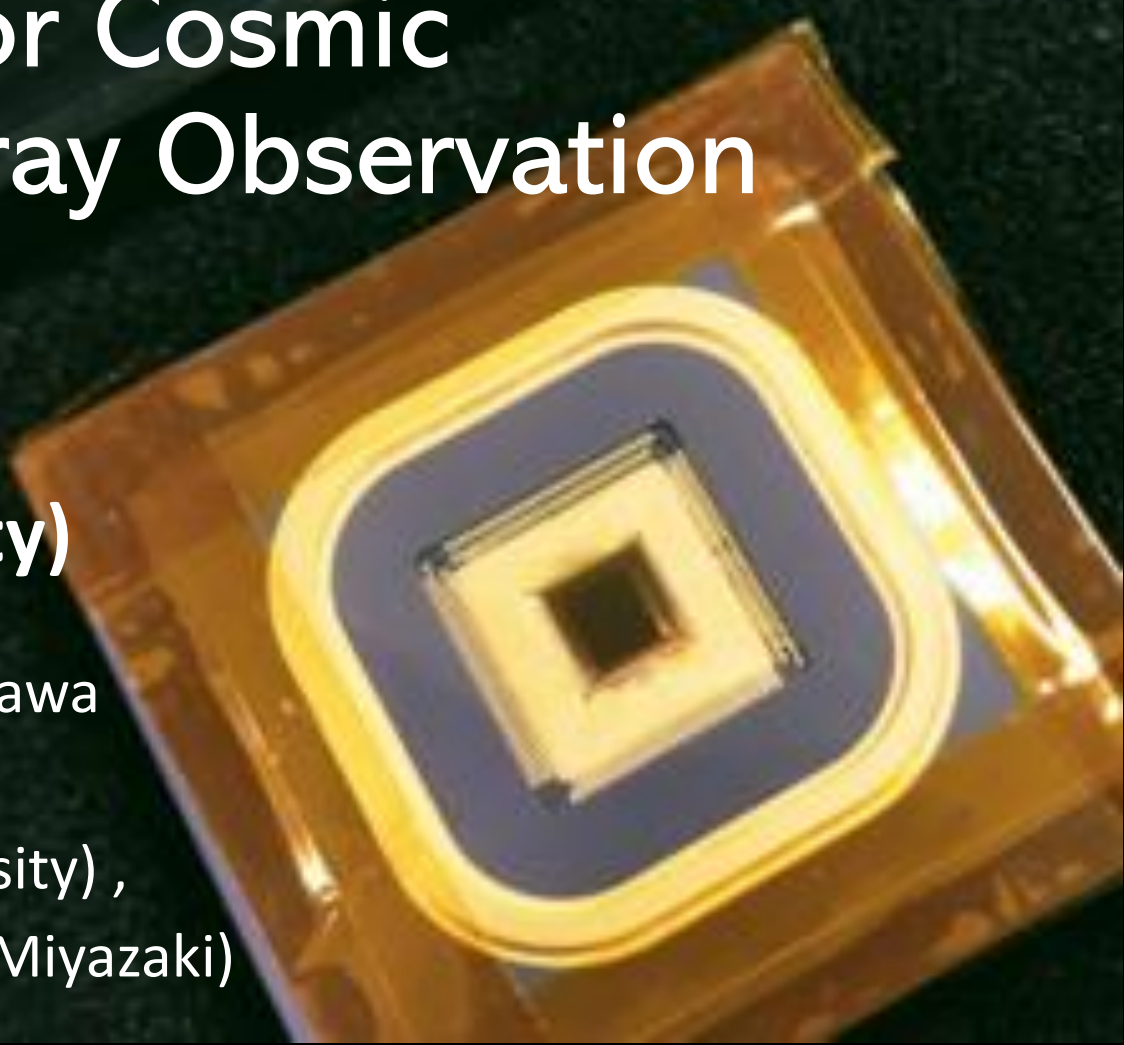
Performance Evaluation of Event-Driven SOI Pixel Detector *"XRPIX8.5"* for Cosmic MeV Gamma-ray Observation



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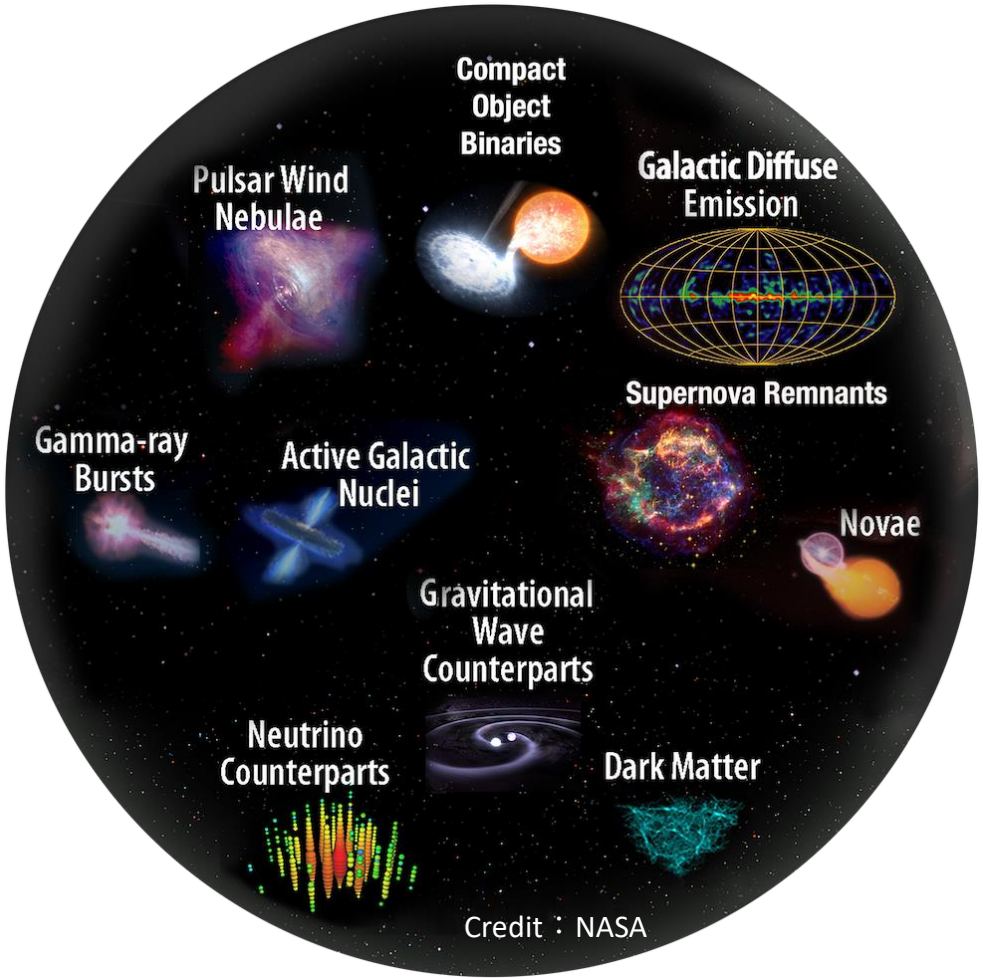
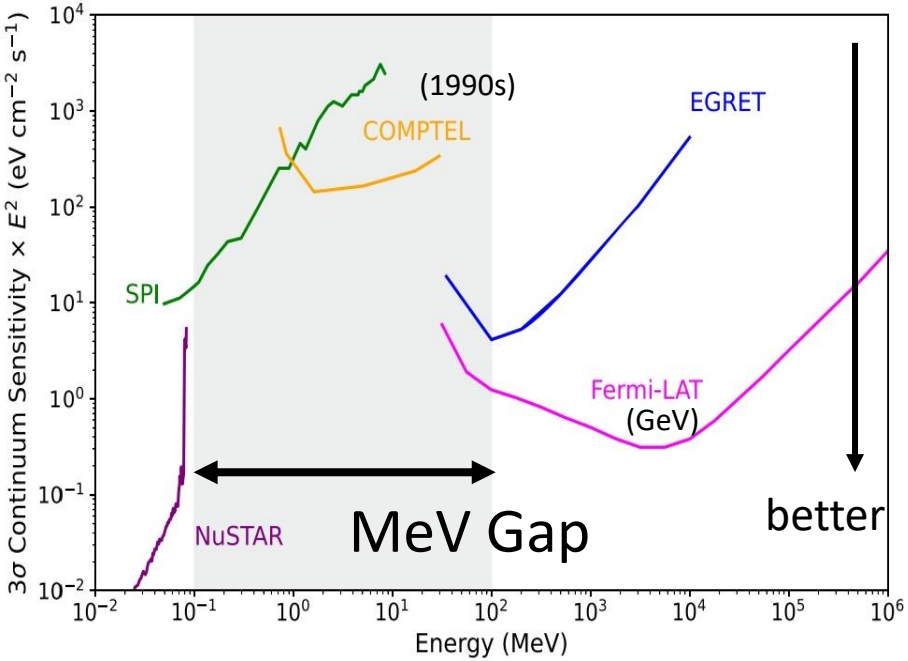
Introduction

～MeV gamma ray astronomy～



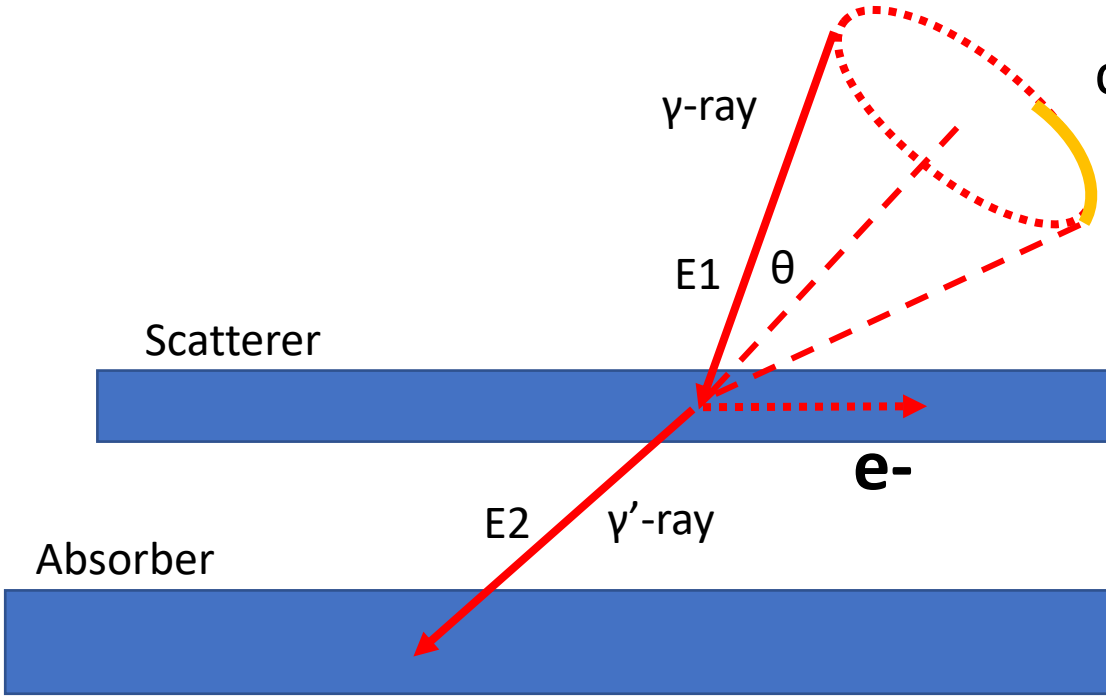
Sensitivity



Credit：Negro_2022_ApJ_927_225.pdf

New satellites for
MeV gamma-ray observations
are needed !

～ Electron-tracking Compton camera ～



$$\cos\theta = 1 - mc^2\left(\frac{1}{E_2} - \frac{1}{E_1}\right)$$

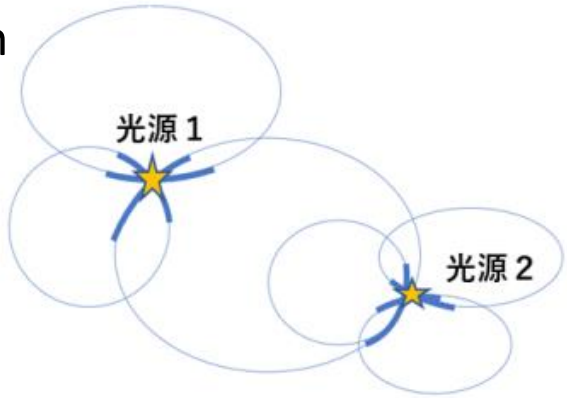
- deposit energy
- hit position

  -> Event circle

Scatter electron can narrow down gamma source location from a circle to an arc.

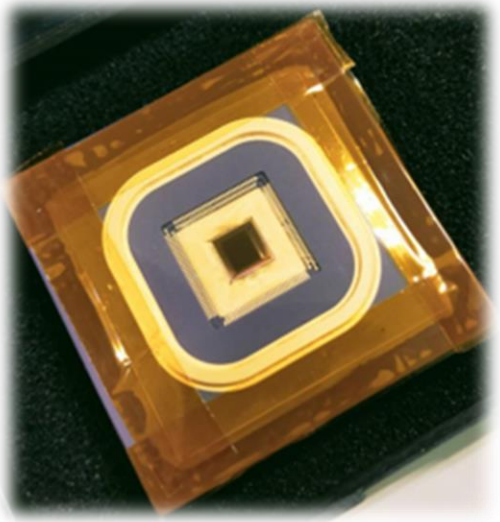
➡ **We can reduce background !**

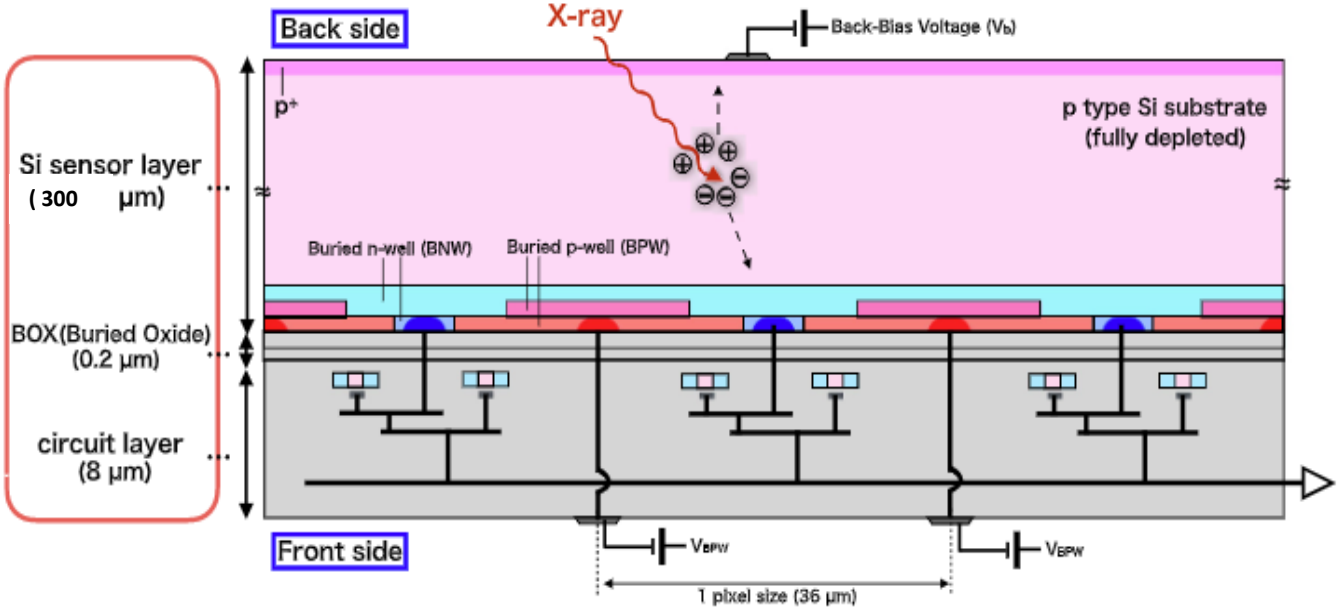
Pixel detector with a small pixel size are effective.
(Range of e- 500 um for 300 keV)



~ SOI Pixel Detector "XRPIX" ~

- Developed for X-ray astronomy
- It can selectively read out only the area hit by X-rays.
- Sensor layer : **~300 um** Pixel size : **36 um sq.** Number of pixels : 94 × 94
  -> It is expected to measure electron tracks for gamma rays with the energy of several hundred keV.
- Full depletion are possible at room temperature (XRPIX8.5).
- FWHM = 1.7 keV @ 59.5 keV , Am-241



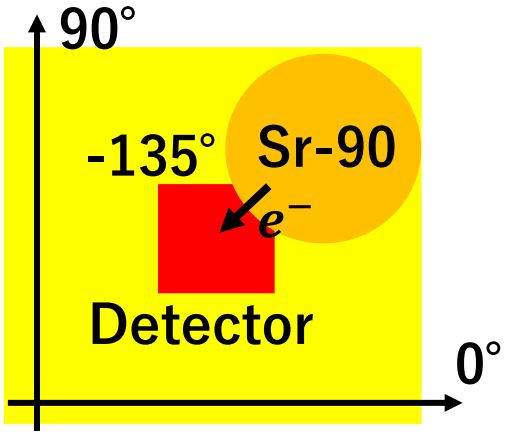


Goal

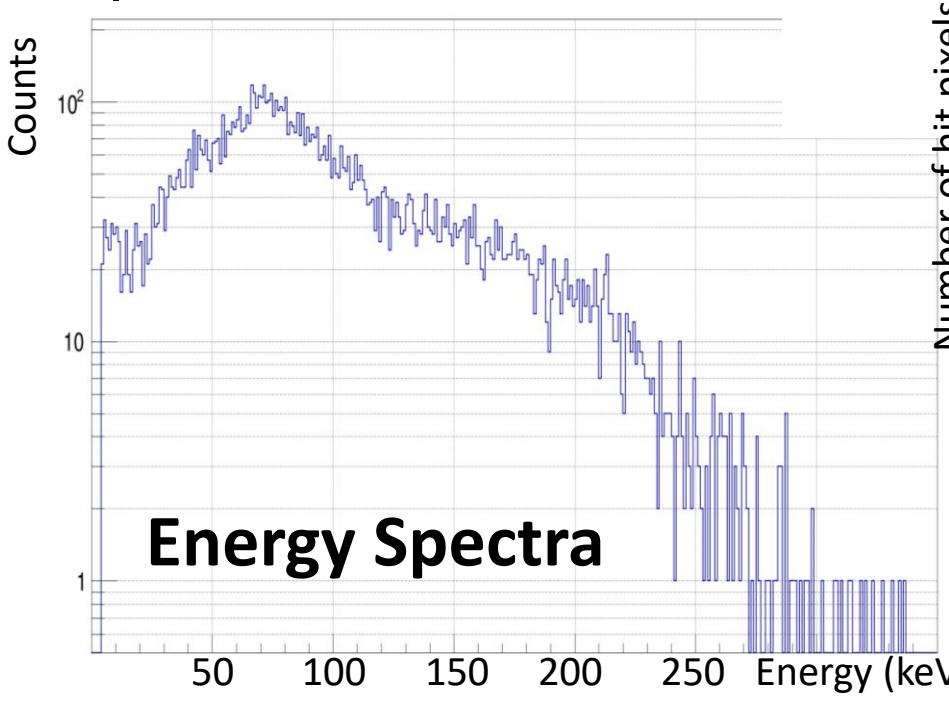
Capture scattered electron tracks with XRPIX8.5
and evaluate their effect on Compton reconstruction.

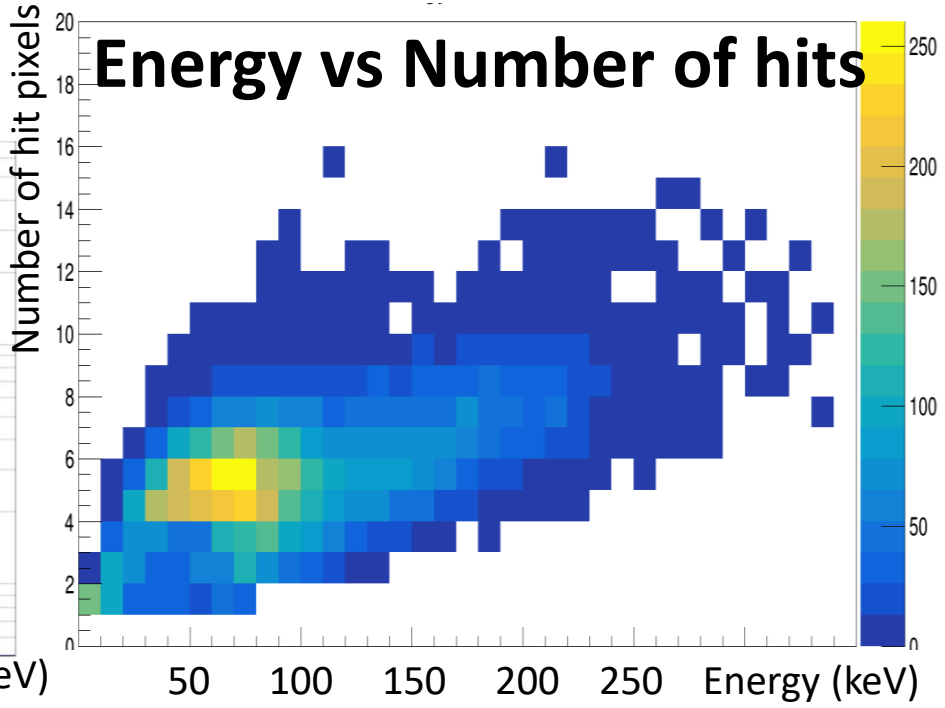
The direction of electron track

Top view of Set up



- To develop an algorithm for determining the initial momentum direction of electrons, We obtained samples of electron tracks with a known direction.
- Sr-90
- Back Bias : 200 V (~ fully depletion)
- We positioned the radiation source to induce anisotropy in the beta radiation.



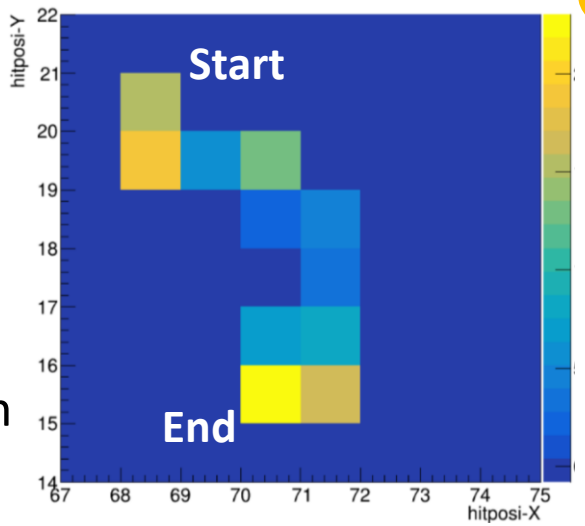


Algorithm to determinate the direction of electrons

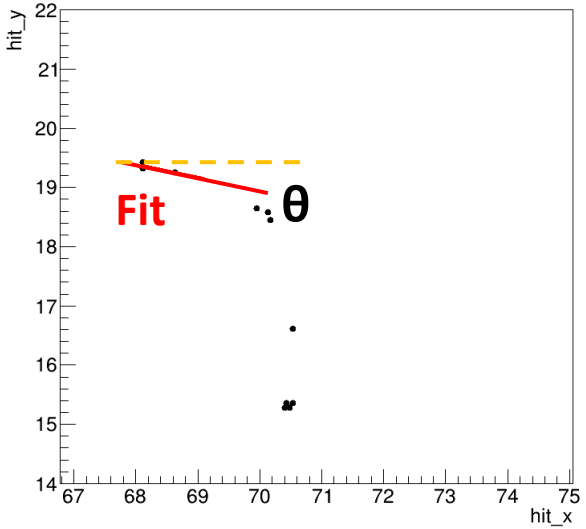
1. Charge centroid method

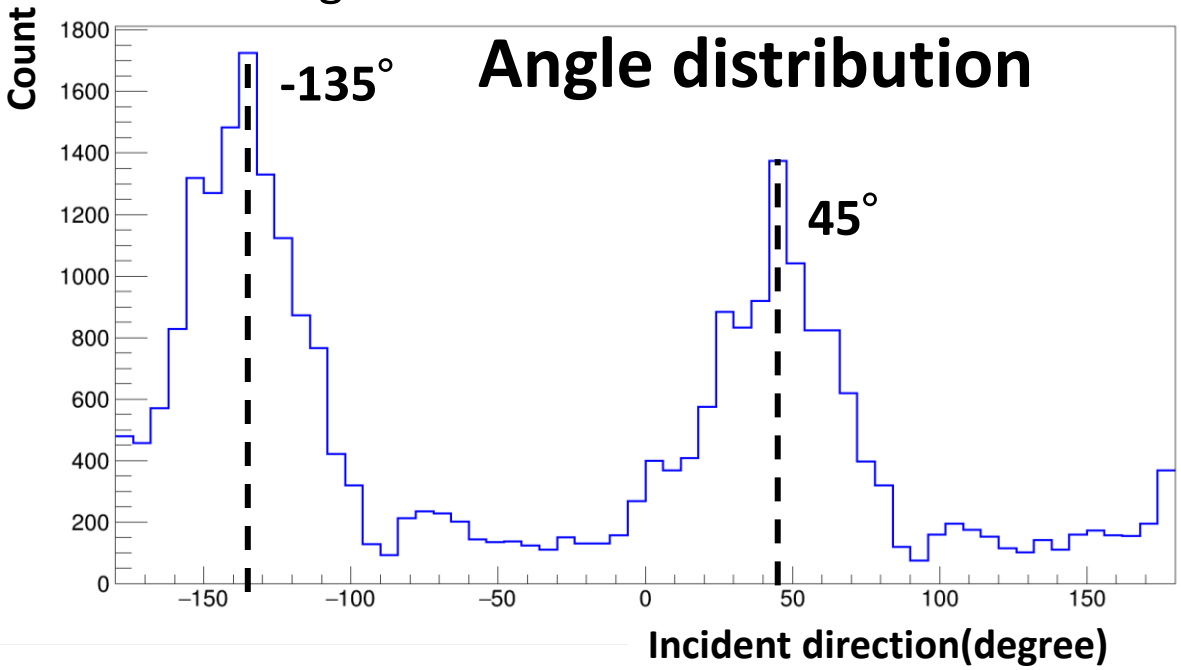
$$Corrected\ position = \frac{\Sigma(original\ position \times pulse\ height)}{\Sigma(pulse\ height)}$$

2. Determine the start point as the point farthest from the position with the maximum pulse height (Bragg peak).



3. Fit three points around the start point with a straight line.



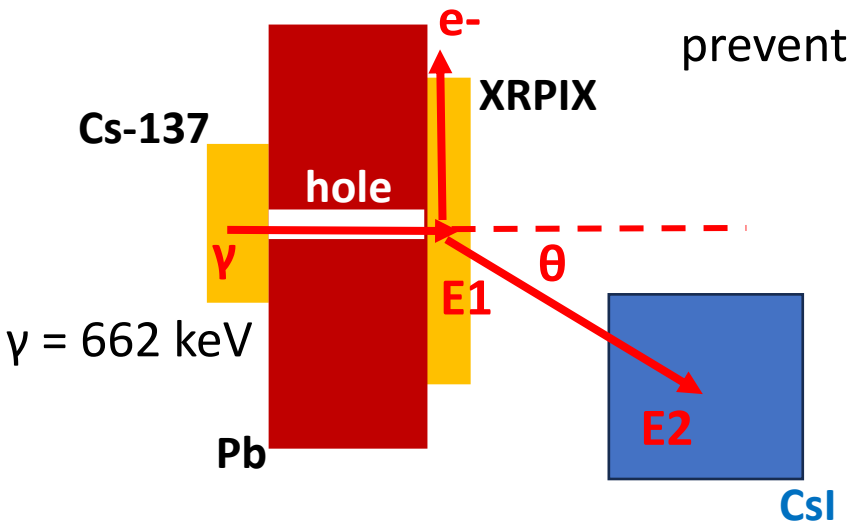


- There are two peaks.
  -135° -> Targeted direction
  45° -> Error peak
  (start ↔ end)

Compton Reconstruction

Set up of Experiment

Top view

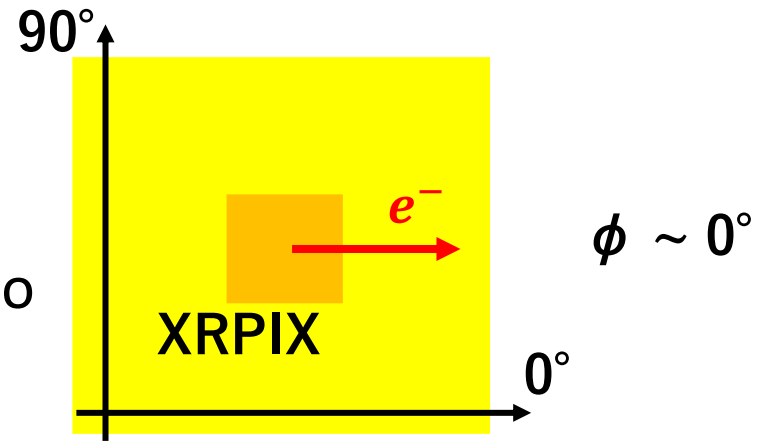


Lead serves to collimate gamma rays, preventing them from reaching CsI directly.

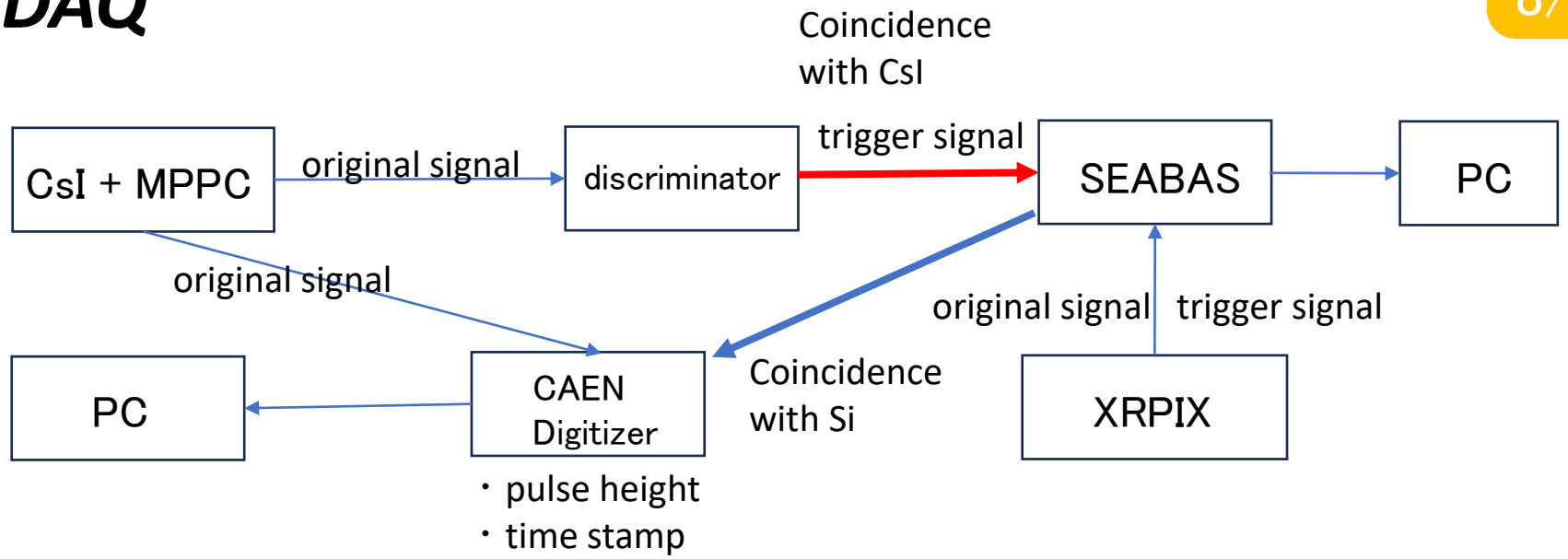
Scatter Angle	35 deg	60 deg
E1 (keV)	149	265
E2 (keV)	513	401

$$\gamma' = \frac{\gamma}{1 + \frac{\gamma}{mc^2}(1 - \cos\theta)} \; keV$$

The azimuth angle was set to aim at 0 deg.



DAQ



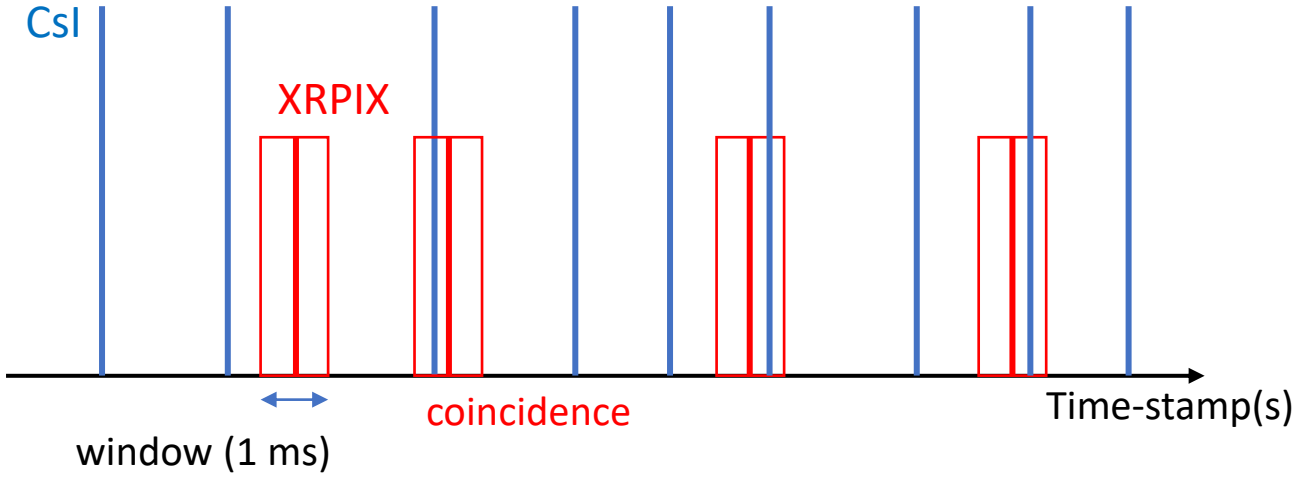
SEABAS is a circuit that receives original signals from XRPIX and trigger signals from MPPC and synchronizes them.

the digitizer receives the MPPC original signal and the XRPIX trigger signal.

We need …

1. Selecting Compton event on SEABAS
2. Matching the time of two independent systems

Time offset determination for Pairing

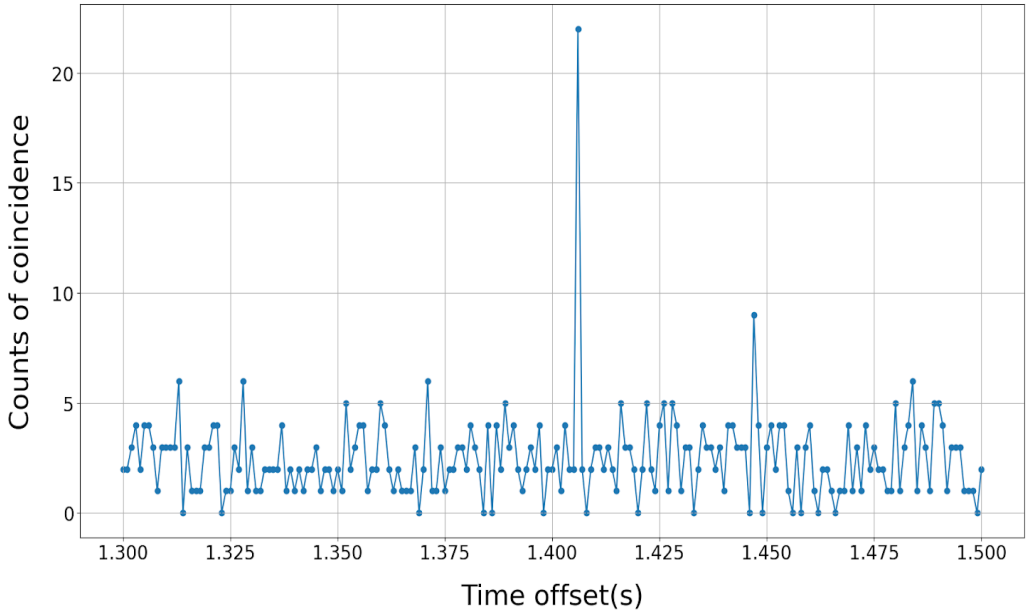


Create a 1 ms window for the XRPIX trigger signal.

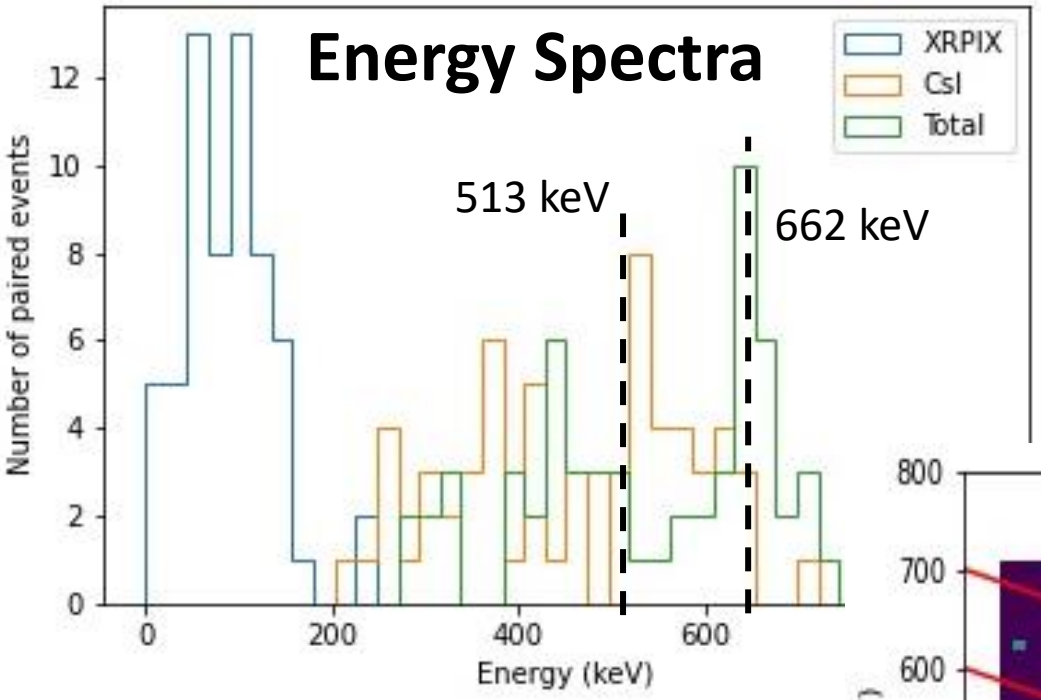
This is shifted in 10 us steps.

If there is a CsI trigger signal in the created window, it is considered a coincidence event.

Count up the number of coincidence events for each shift and use the amount of shift at the highest number as the time offset.



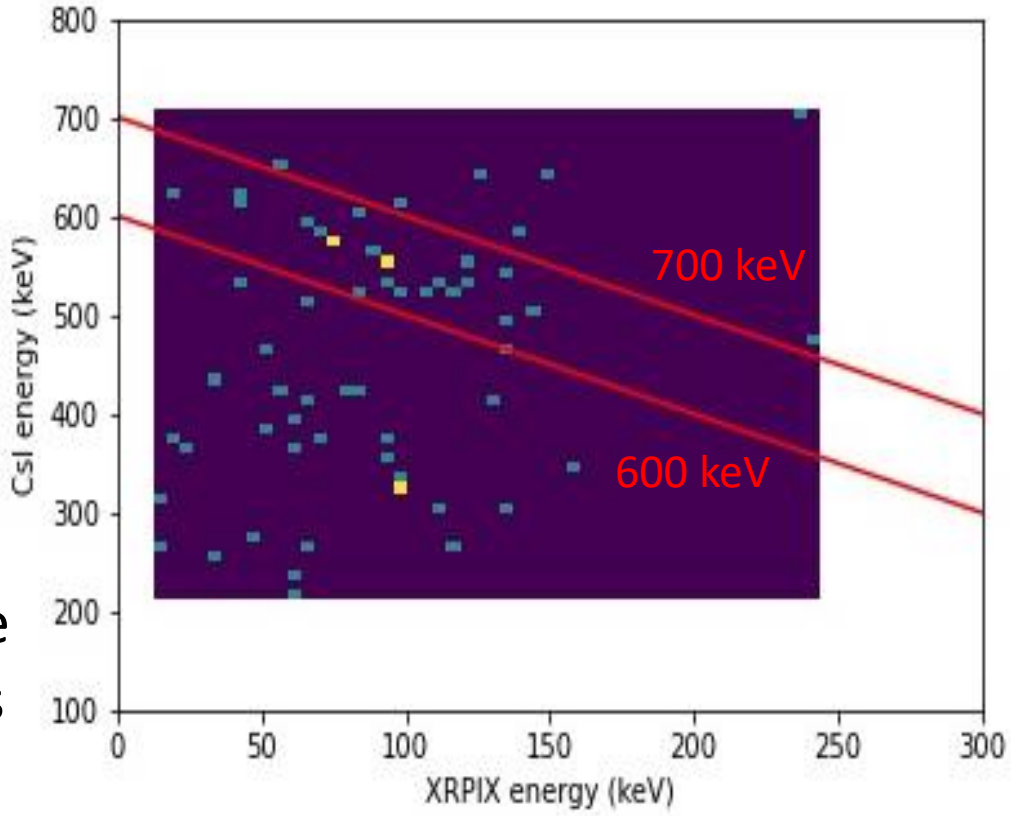
Result Ⅰ. Scattering Angle : 35 degree



γ = 662 keV

θ ∼ 35 deg

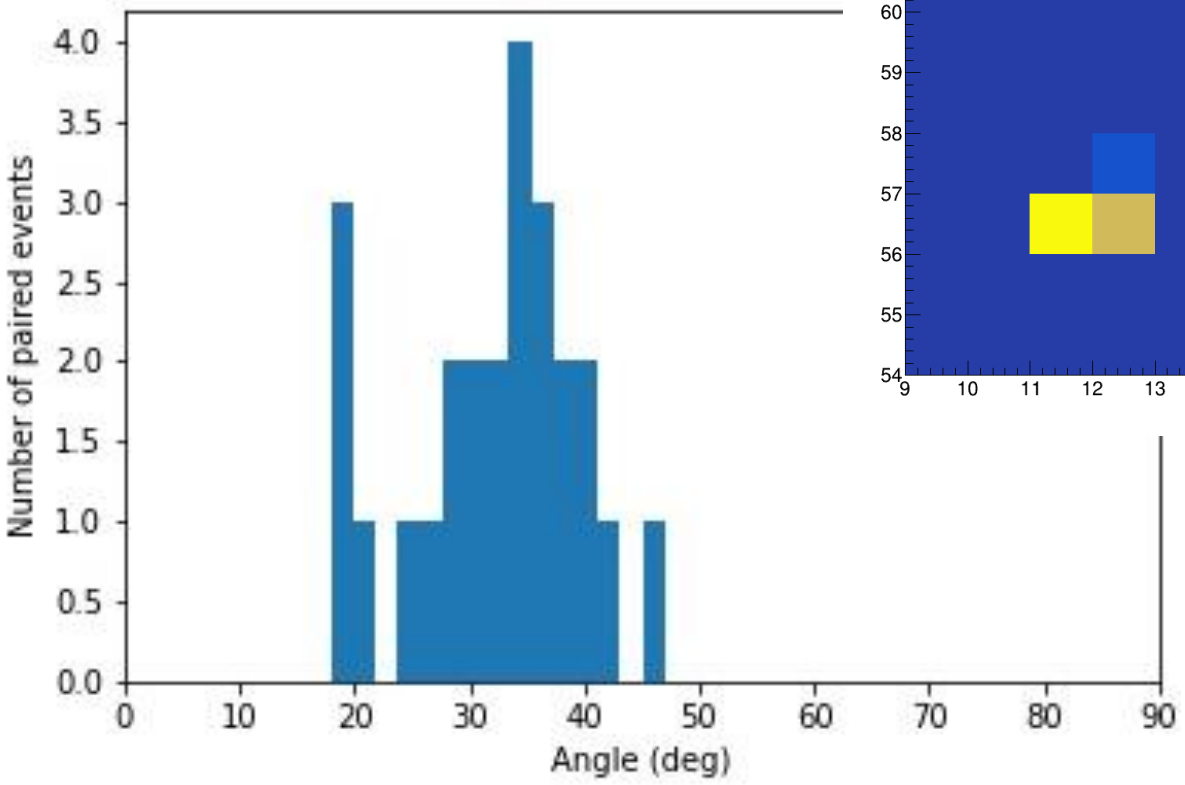
γ’ ∼ 513 keV

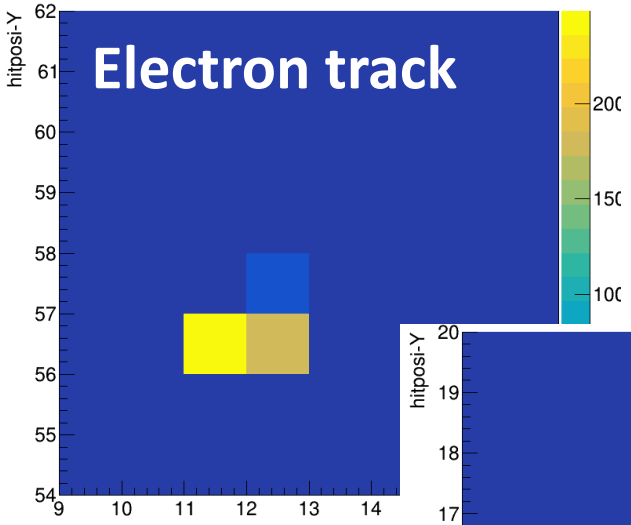


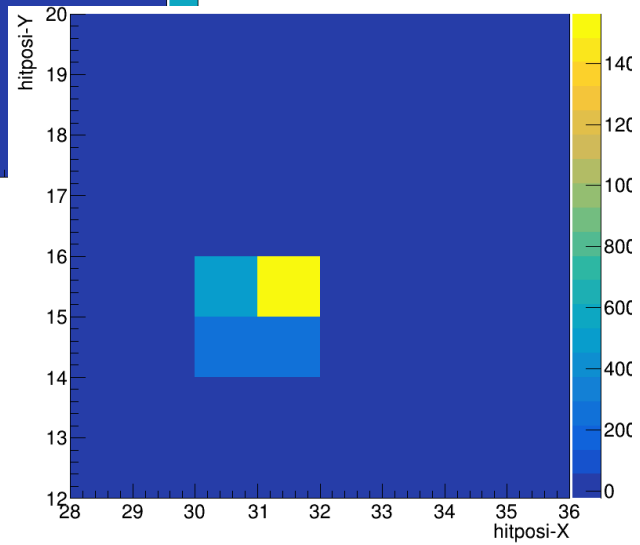
The peak at 662 keV was identified in the combined XRPIX and CsI energy spectrum.

The event rides on a straight line where the sum of both energy is 662 keV.

Scatter Angle distribution



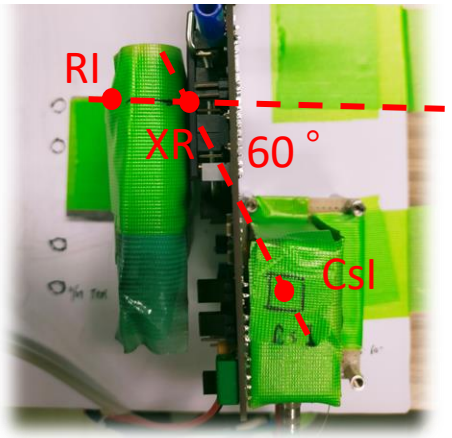




The events are distributed around the targeted 35 deg.

The electron track is short and direction determination is not possible since the scattering angle is small and the deposit energy on XRPIX is small.

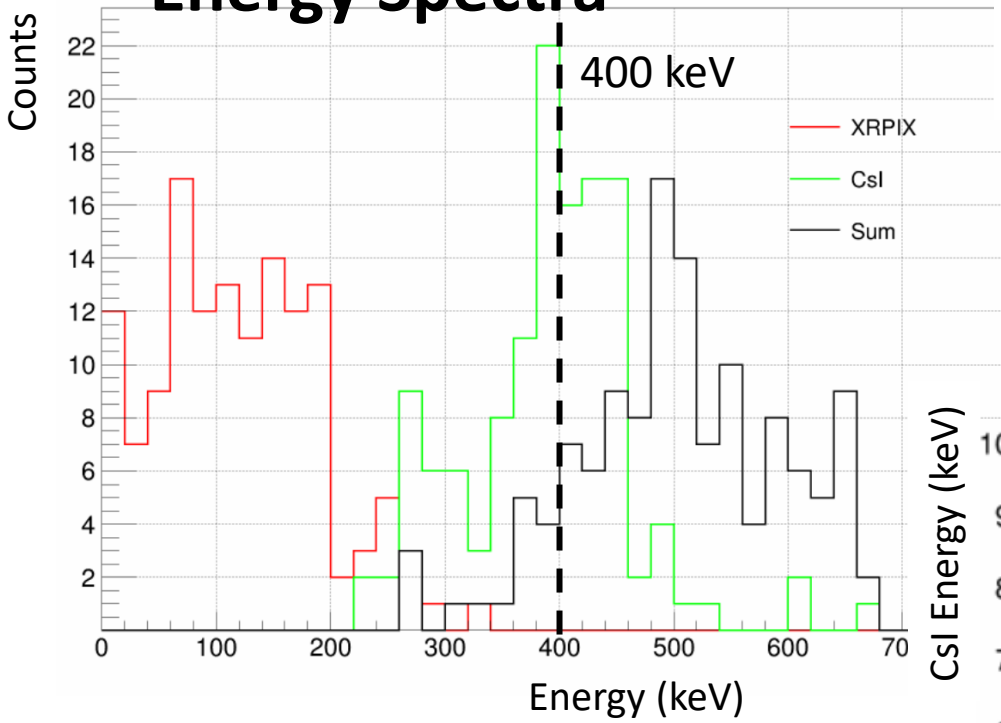
-> Increase the scattering angle.



Next 60 degree ->

Ⅱ. Scatter Angle : 60 degree

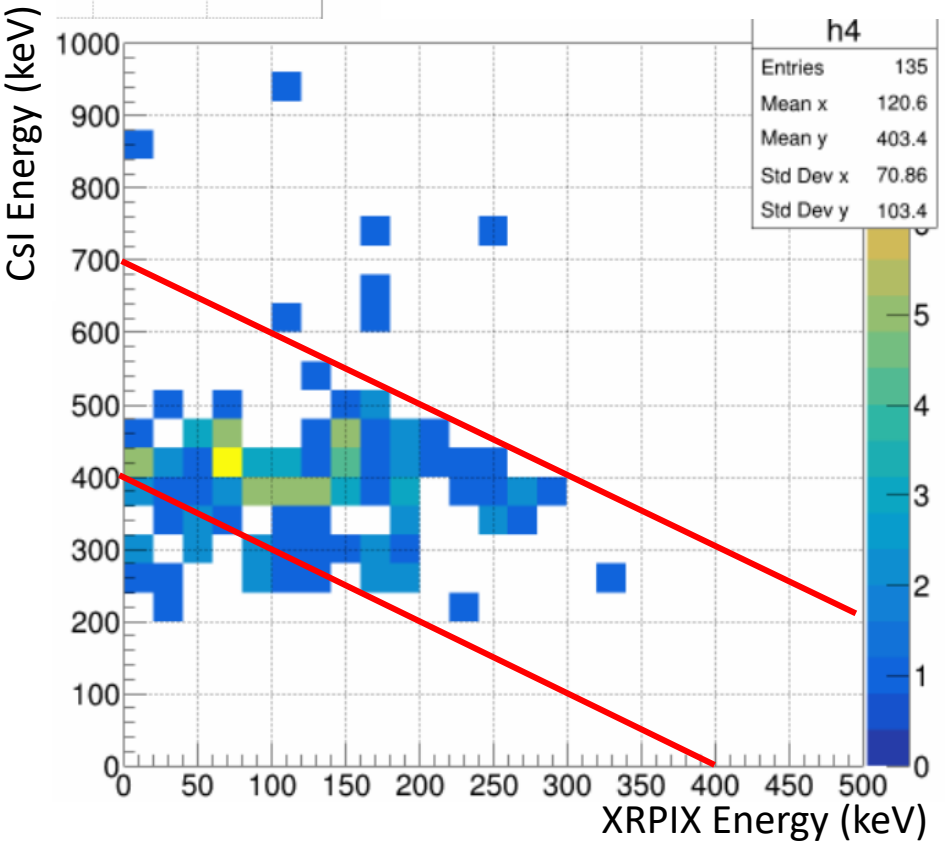
Energy Spectra



γ = 662 keV

θ ～ 60 deg

γ’ ～ 401 keV

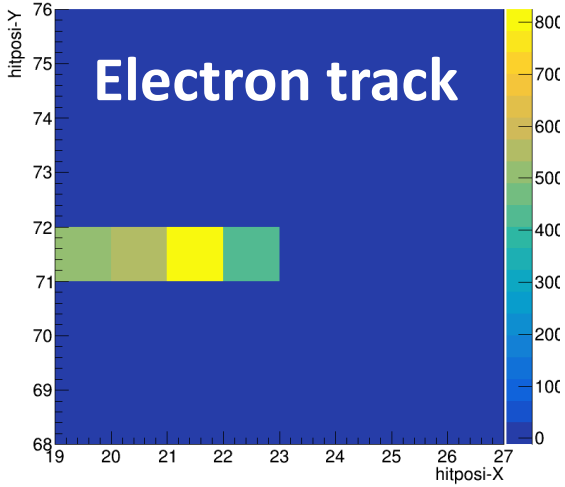


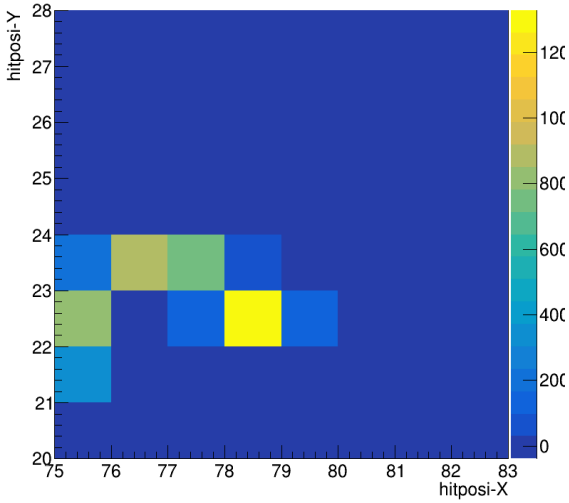
The energy of CsI is distributed around 400 keV.

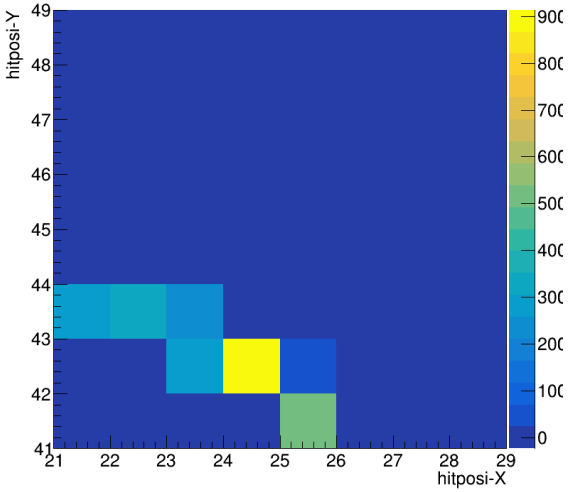
The energy spectrum of total energy is not distributed at 662 keV.

This is because XRPIX is less sensitive to 260 keV.

Electron track direction distribution

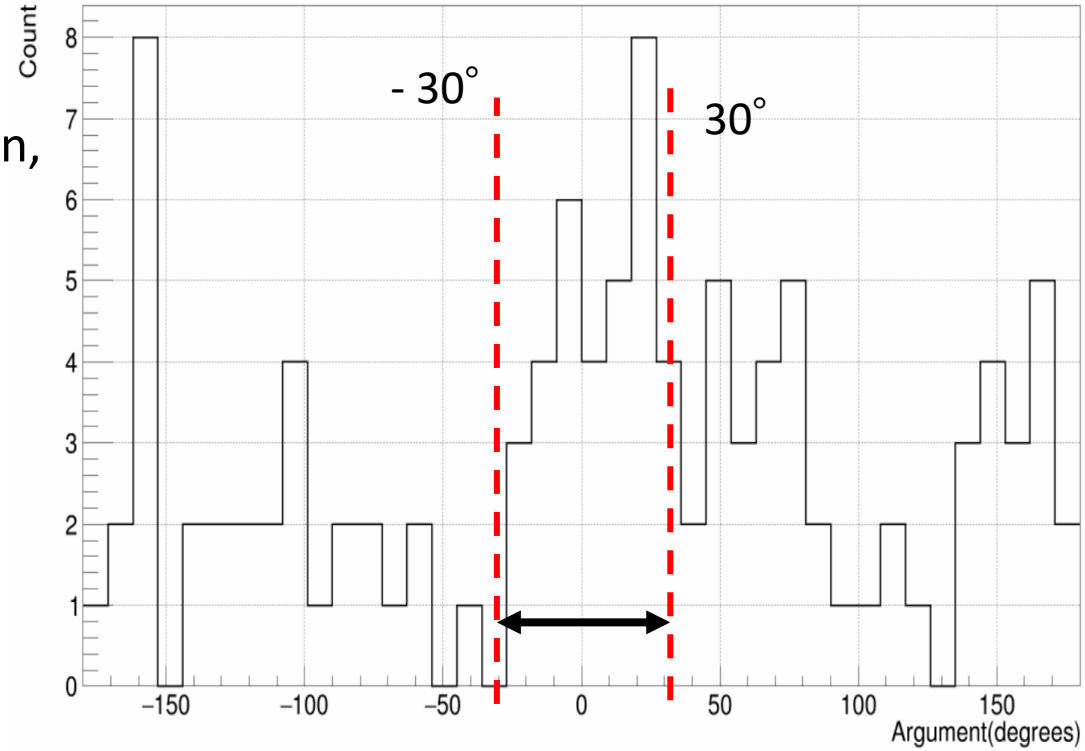




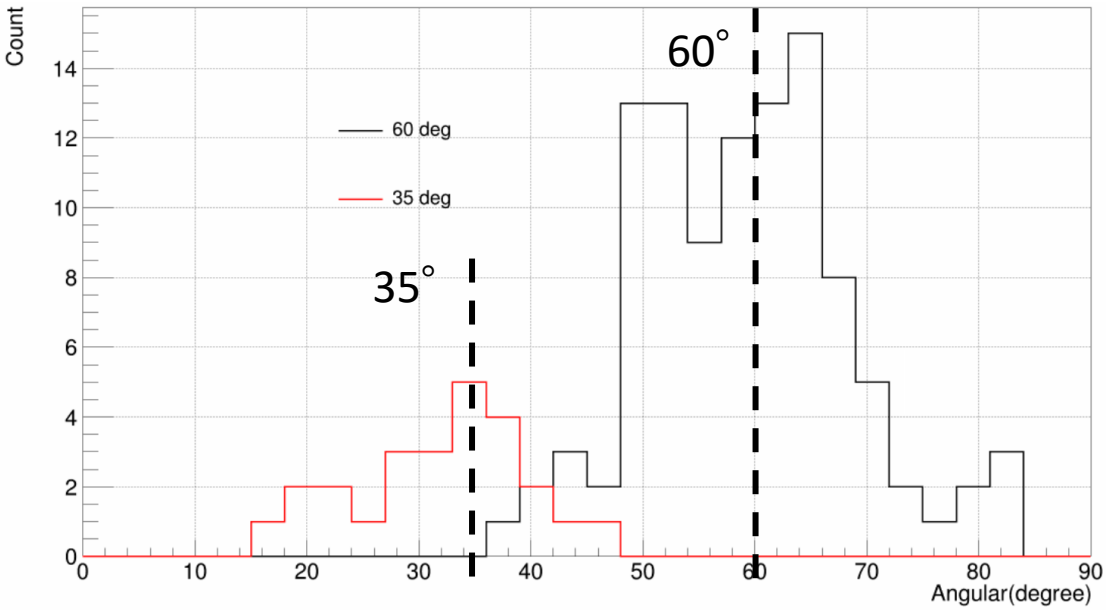


Electron tracks in the 0 deg direction, the targeted azimuthal direction, were found.

Select events where the electron track direction is around 0 deg ($\pm$ 30 deg)



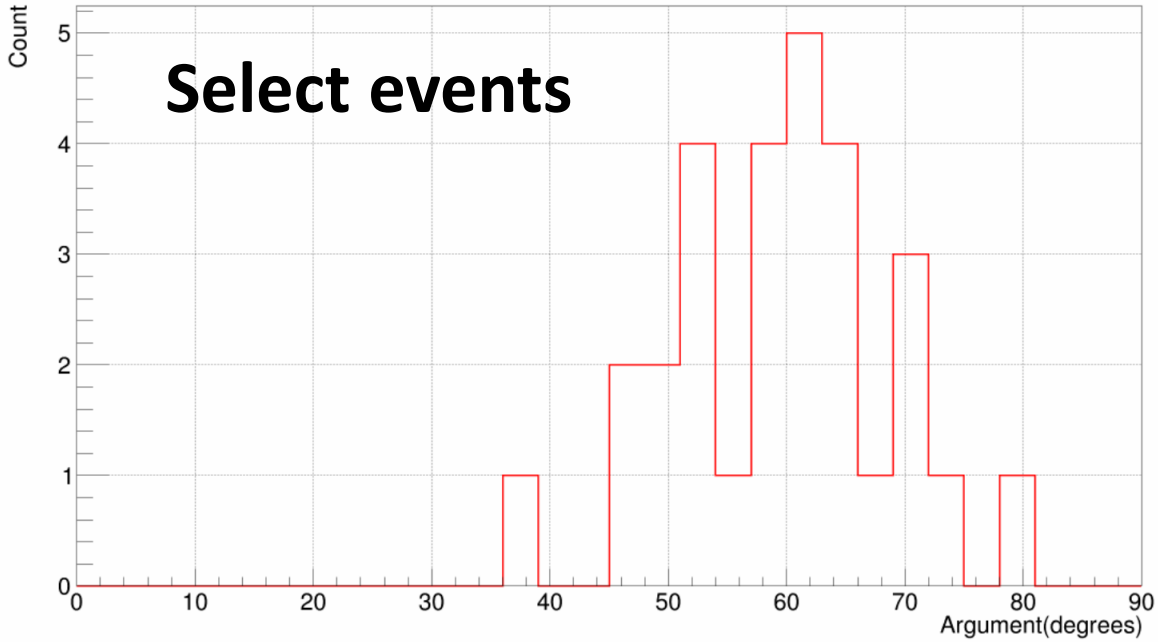
Scatter Angle distribution



The events are distributed around the targeted 60 deg.

Corresponding events could be found.

Angle distribution is more clearly !



Summary and Future work

The direction of electron track

- XRPIX has sensitivity to the direction.
- Investigate the errors and improve the algorithm.

Compton Reconstruction

- We have succeeded in conventional Compton reconstruction.
- We were able to identify Compton events corresponding to the electron track in the targeted direction.
- Create an event circle from each deposited energy and hit position.
- Evaluate angular resolution taking into account geometric errors and other factors.

Thank you for your attention !