Performance evaluation of recoil electron track detection with an electron tracking Compton camera using an SOI pixel sensor

R. Kato[1], H. Katagiri[1], M. Kagaya[2], N. Toujo[1], Y. Arai[3], A. Takeda[4], T. Tsuru[5]

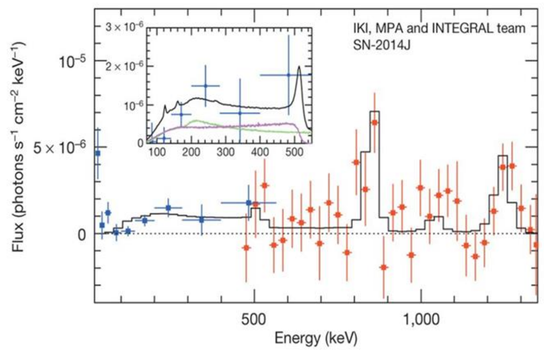
[1]Ibaraki University, [2]National Institute of Technology,Sendai College, [3]KEK, [4]University of Miyazaki, [5]Kyoto University

Abstract

We developed an electron tracking Compton camera using XRPIX2b semiconductor sensor and CsI(Tl) scintillator to verify the recoil electron detection performance of the XRPIX2b for sub-MeV gamma rays. Using this prototype, we measured the ^{22}Na of a 511 keV line gamma ray source and confirmed imaging of the recoil electron tracks. We verified the imaging capability for various gamma ray scattering angles and show the comparison with Monte Carlo simulations.

Background and objective

Spectral observation of sub-MeV line gamma rays is important in astrophysics, such as elucidating the origin of elemental synthesis. However, observations in this energy band have lagged by some decades because of difficulties in removing considerable detector background with a conventional Compton camera. One of the solutions is an electron tracking Compton camera because it enables high background rejection by detecting recoil electron tracks. Electron tracks detection in the sub-MeV region has not been demonstrated with this camera. Therefore, we developed an electron tracking Compton camera using a high energy resolution semiconductor sensor for sub-MeV.



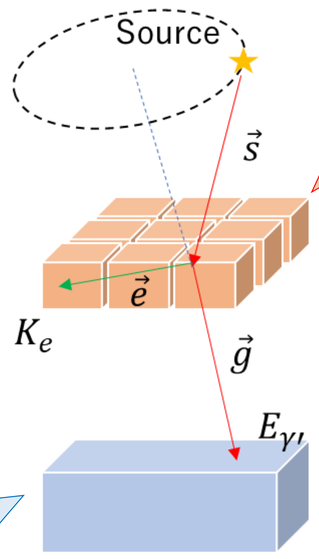
Cobalt-56 γ-ray emission lines from the type Ia supernova 2014J , E. Churazov et al.,2014

Materials and Methods

Electron tracking Compton kinematics

$$\vec{s} = \frac{E_{\gamma'}}{E_{\gamma'} + K_e}\vec{g} + \frac{\sqrt{K_e(K_e + 2m_e c^2)}}{E_{\gamma'} + K_e}\vec{e}$$

: Recoil electron energy (K_e) and direction ($\vec{e}$)
: Scattering gamma-ray energy ($E_{\gamma'}$) and direction ($\vec{g}$)
: Incident gamma-ray ($\vec{s}$)



Scintillation detector

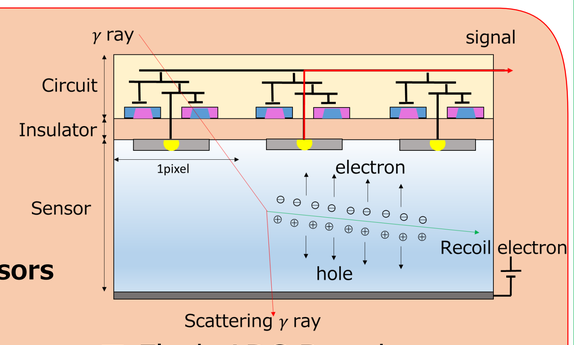
- CsI(Tl)crystal of 3.5×3.5cm

- Flash ADC Board

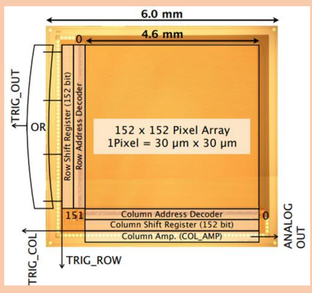
SOI pixel sensor

- Readout circuit combined with sensor
- Good time resolution
- High energy resolution for semiconductor
- Fine pixel

Select XRPIX2b from SOI sensors

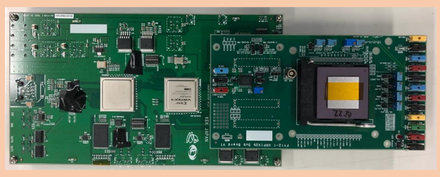


- XRPIX2b

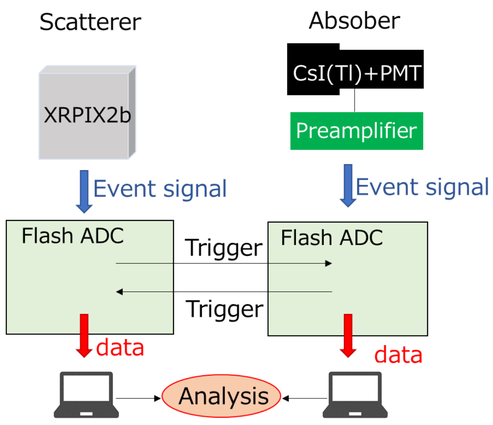


-> Effective area 4.3×4.3 mm
-> Sensor thickness 300 μm
-> Pixel size 30×30 μm
-> Pixel number 144×144
-> Event-driven read out
- This can acquire data only when an event comes.

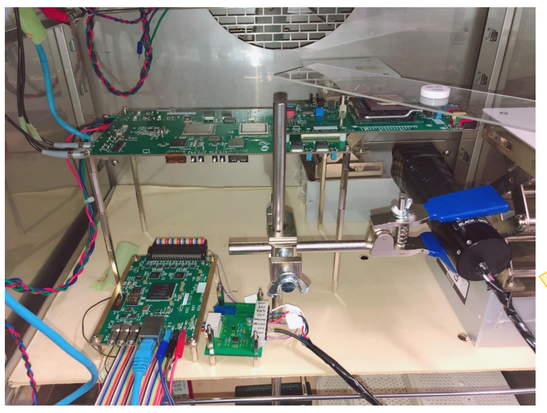
- Flash ADC Board with XRPIX2b control board



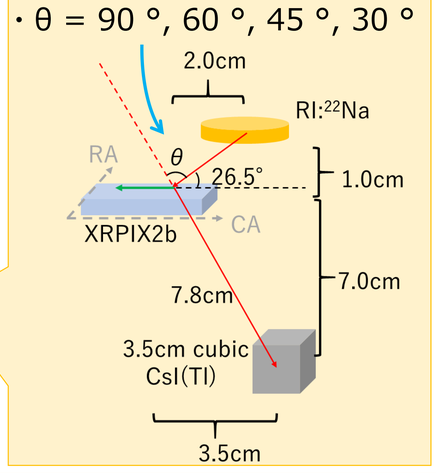
Coincidence Trigger logic



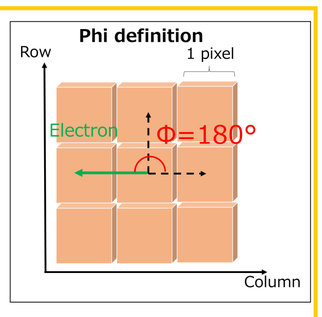
Measurement set up



- θ = 90 °, 60 °, 45 °, 30 °



- In a chamber at -20 ℃
- RI :^{22}Na emits 511 keV at 3.7×10^5 Bq
- Back bias voltage : 120V
- Recoil direction ø = 180°
- Recoil parallel to the XRPIX2b plane



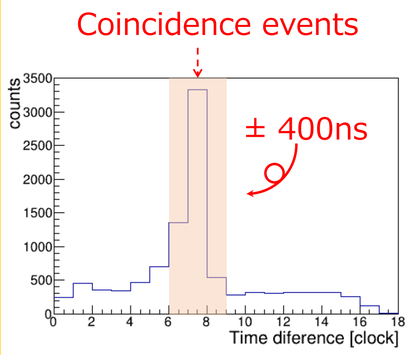
Simulation

We did a Monte Carlo simulation that reproduced the setup using a platform called GEANT4 to compare with measurements.

Analysis method and Result

Event selection

◈ Timing cut ◈

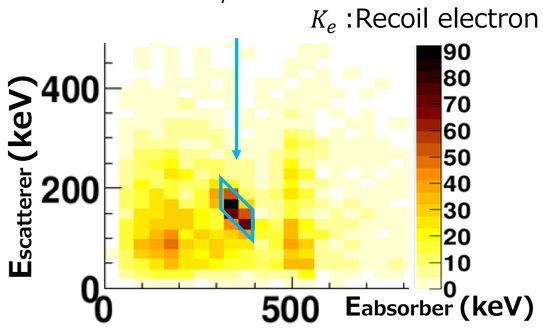


Time difference of SOI and CsI(Tl)

◈ Energy cut ◈

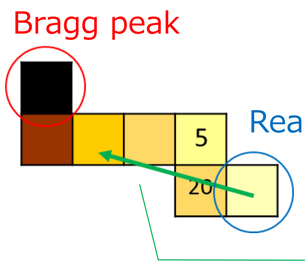
- Total : $E_{\gamma'} + K_e$ ±40 keV
- Absorber : $E_{\gamma'}$ ± 40 keV

$E_{\gamma'}$:Scattering gamma-ray
K_e :Recoil electron



Spectrum of SOI and CsI(Tl)

Recoil direction analysis



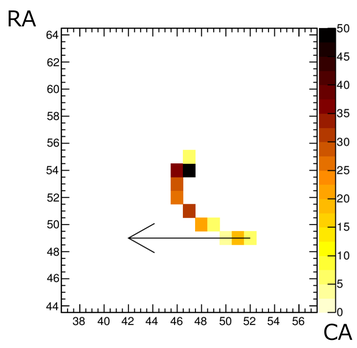
The reaction point is defined as the pixel farthest from the Bragg peak.

Reaction point

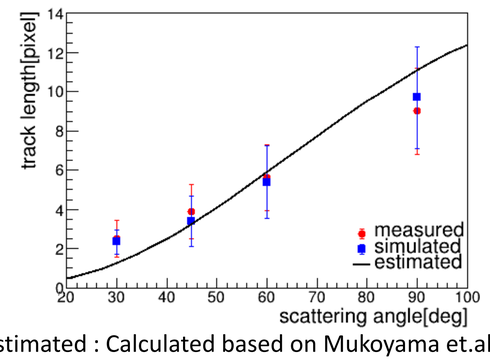
The recoil direction is defined by the direction of the energy centroid of 8 pixels around the reaction point.

Result

◈ Track image ◈

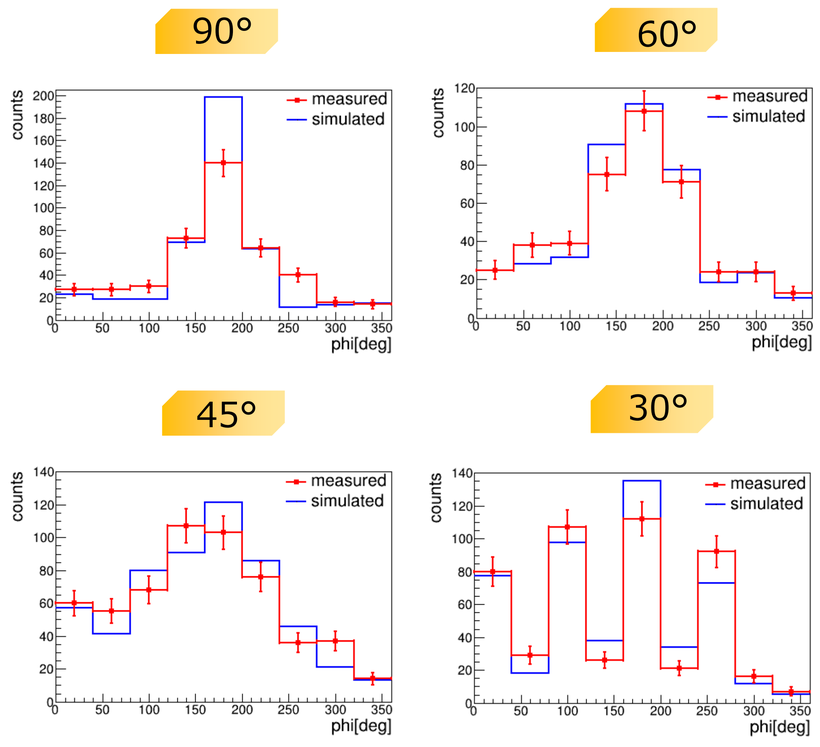


◈ Track length as scattering angle ◈



estimated : Calculated based on Mukoyama et.al 1976.

◈ Phi distribution ◈



-> Succeeded in imaging recoil electron tracks.
-> At 90° and 60°, appeared a peak at the Φ = 180°.
-> The measured shows a smiler tendency to the simulated.

Discussion & Summary

- **We succeeded in imaging recoil electron tracks in 511keV. Comparison of the measured and the simulated gave almost equal results. This confirmed that the prototype was working properly.**
- The difference in 90 degree scattering in the phi distribution is thought to be because the diffusion effect of the electron cloud in XRPIX2b sensor was not included in the simulation.
- **Considering the phi distribution and track length, this prototype with 30 μm pitch pixels cannot correctly specify the recoil direction if the scattering angle is less than 45 degrees, that is, the track length is less than 100 μm.**
- In the future, the track detection performance of rotation angle and depth angle will be confirmed.