ID: 318

Applications in biology, medicine, medical equipment: Session3

Imaging and spectral performance of a 60μm-pitch CdTe double-sided strip detector

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CdTe Semiconductor

Cadmium Telluride semiconductor

✓ High density & Large Atomic number

$\rho = 5.85\ \mathrm{g/cm^3}$, $Z_{\mathrm{Cd}} = 48$ $Z_{\mathrm{Te}} = 52$

→ **High detection efficiency**

✓ Large Bandgap Energy $E_{\mathrm{Gap}} = 1.44$ eV

→ **A portable experimental system**

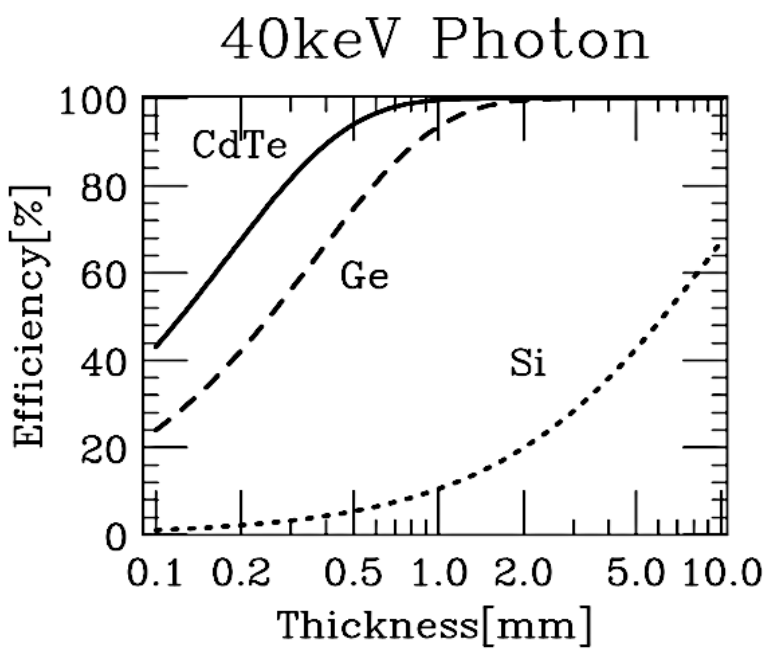
× Lower charge transport properties

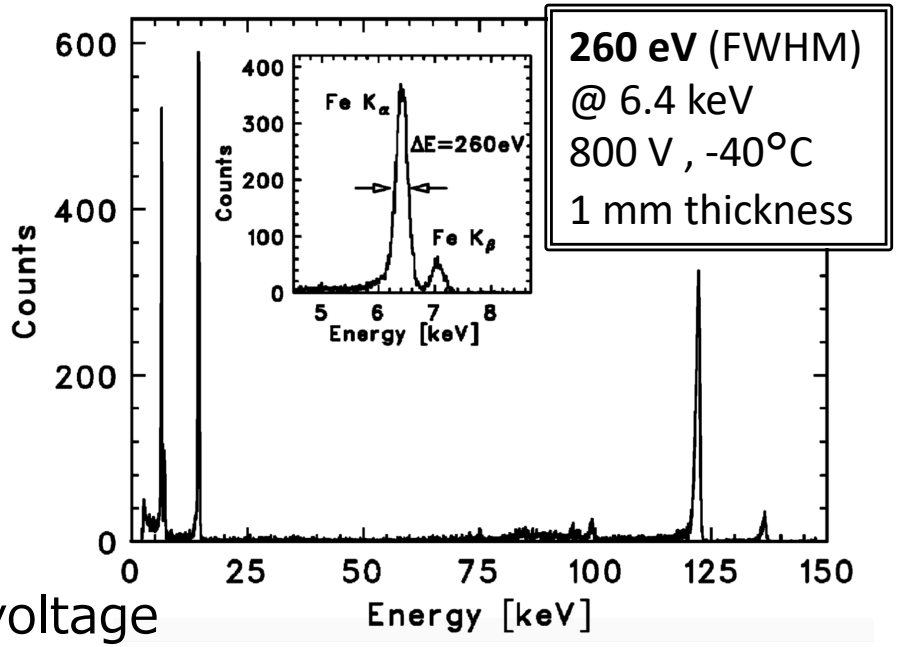
$(\mu\tau)_e = 2\times10^{-3}$ $(\mu\tau)_h = 1\times10^{-4}$ $[\mathrm{cm^2/V}]$

- Uniform & Thin device
- Schottky diode (Takahashi+ 1998)
- Guard ring (Nakazawa+ 2004)

Extremely low leakage current , High bias voltage

→ Full charge collection & High energy resolution

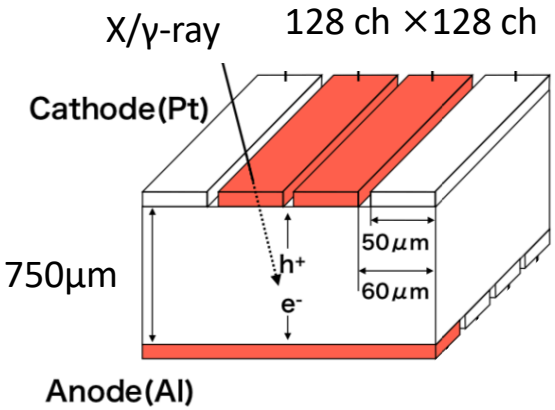




(Takahashi+ 1998,2005)
(Takahashi & Watanabe 2000)

CdTe-DSD and its Applications

CdTe Double-Sided Strip Detector (CdTe-DSD)



Strip electrodes orthogonally placed on both side

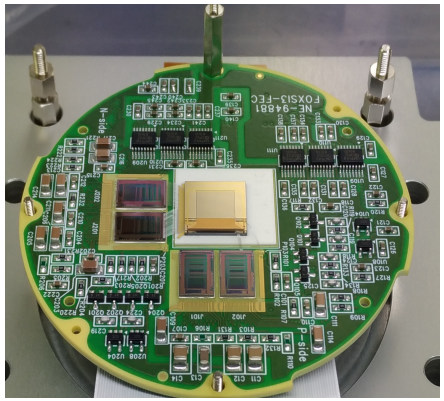
→ **Energy and 2-D position information**

Applications

✓ Non-destructive analysis (Katsuragawa+ 2018)

✓ Medical Application: in-vivo imaging
SPECT system for small animal (Takeda+ 2018)

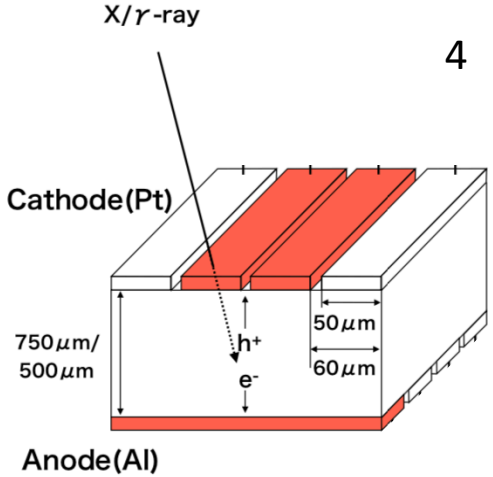
etc…



60 μm fine-pitch CdTe-DSD (128×128 strips)
for the FOXSI-3 Sounding Rocket experiment
(Steven+ 2016, Sophie+ 2019, Furukawa+ 2019)

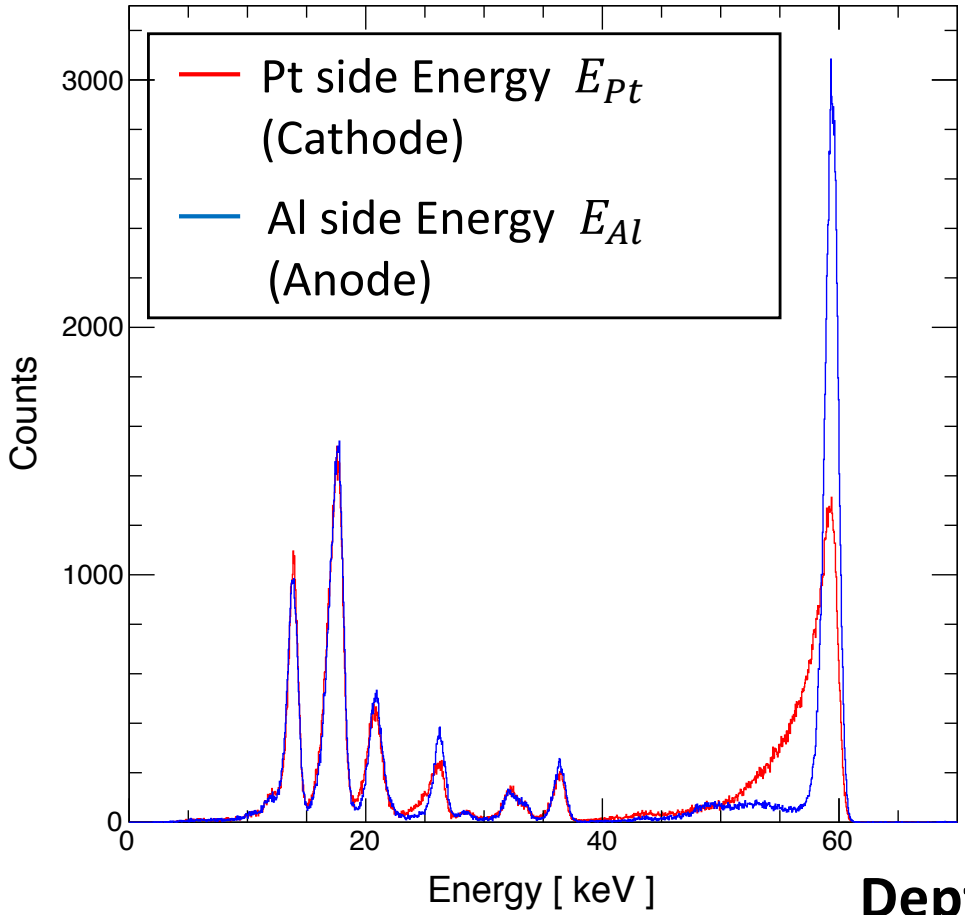
- **Depth of Photon Interaction**
- **Charge sharing event**

Energy Spectrum ^{241}Am



Gamma-ray spectra of ^{241}Am

Condition: Bias Voltage = 200 V
Operating Temperature = - 20 ℃



At high energy peak ~ 60 keV,
Pt (Cathode) side forms a tail structure

↑

Caused by low charge transport of holes

$(\mu\tau)_e = 2\times10^{-3}$ $(\mu\tau)_h = 1\times10^{-4}$ $[\mathrm{cm}^2/\mathrm{V}]$

- Low Energy photon $\lesssim$ 30 keV
  near the surface of Pt (Cathode)
- High Energy photon
  near the surface of Al (Anode)

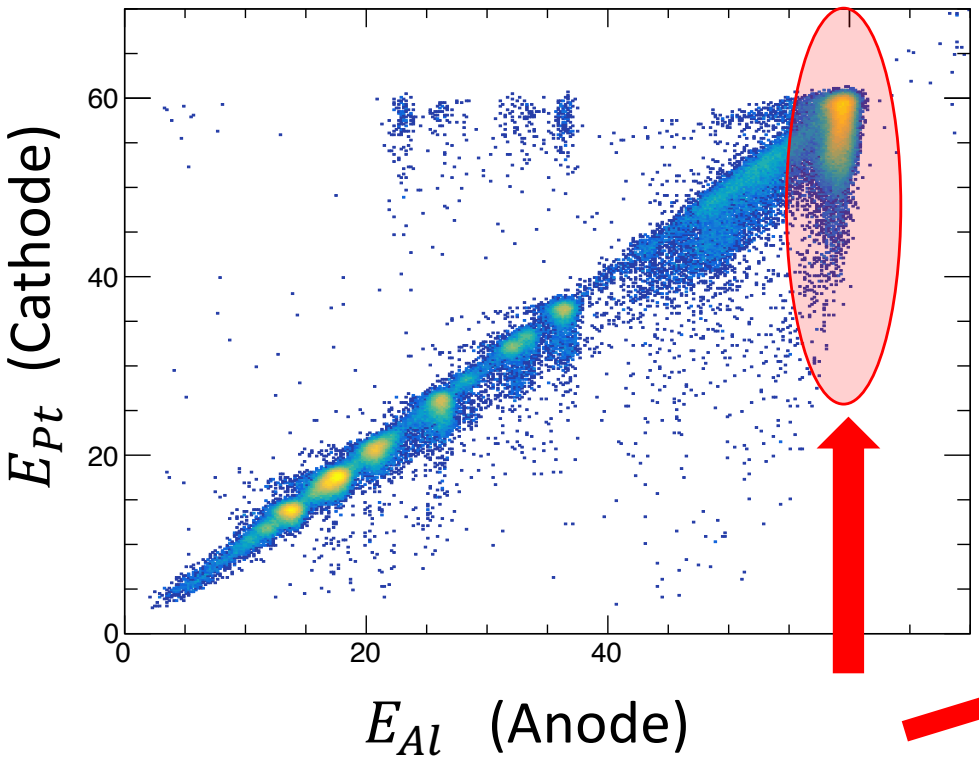
→ more holes can be trapped

Depth of Interaction correction is important !

Depth of Interaction Effect

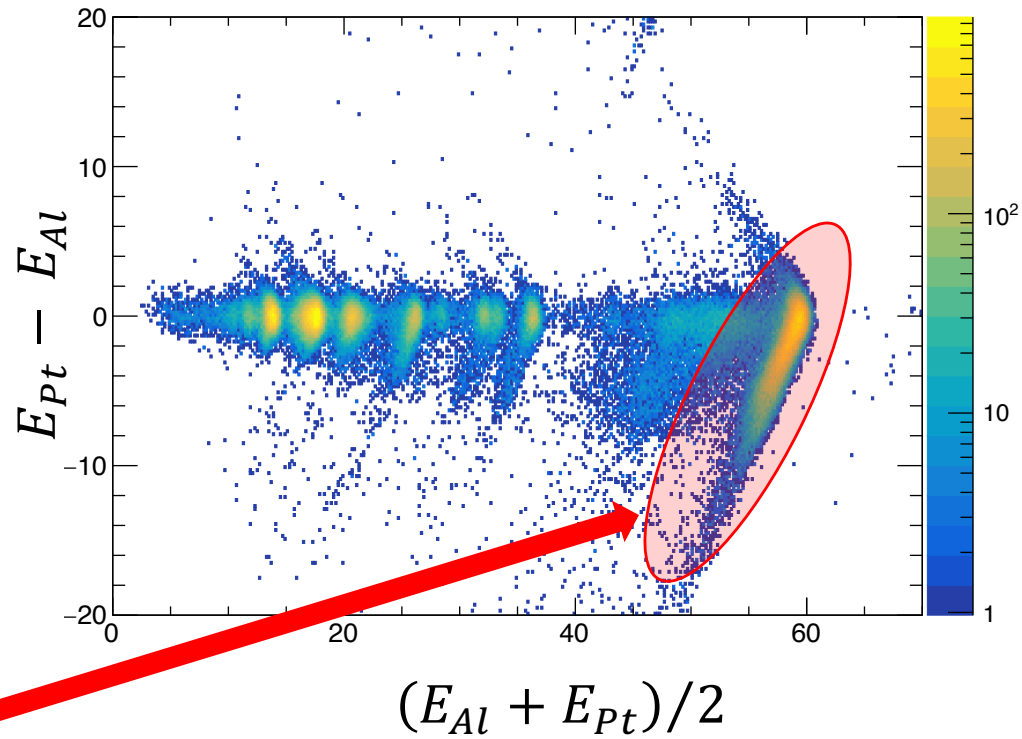
Al Side Energy (Anode) vs Pt Side Energy (Cathode)

E_{Al} vs E_{Pt}



Energy Average vs Energy Difference

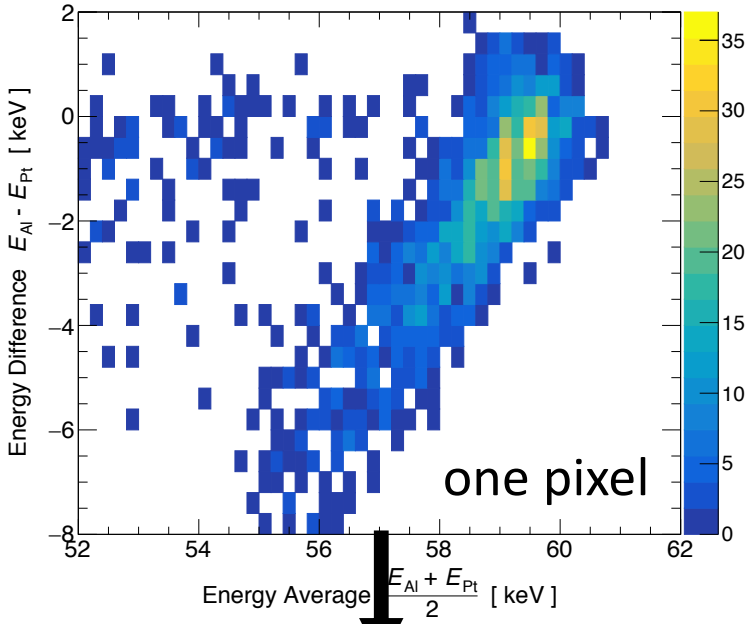
$\frac{E_{Al} + E_{Pt}}{2}$ vs $E_{Pt} - E_{Al}$



Structure caused by charge loss of holes

This caused a tail of spectrum at high energy peak

Definition of "Angle θ"

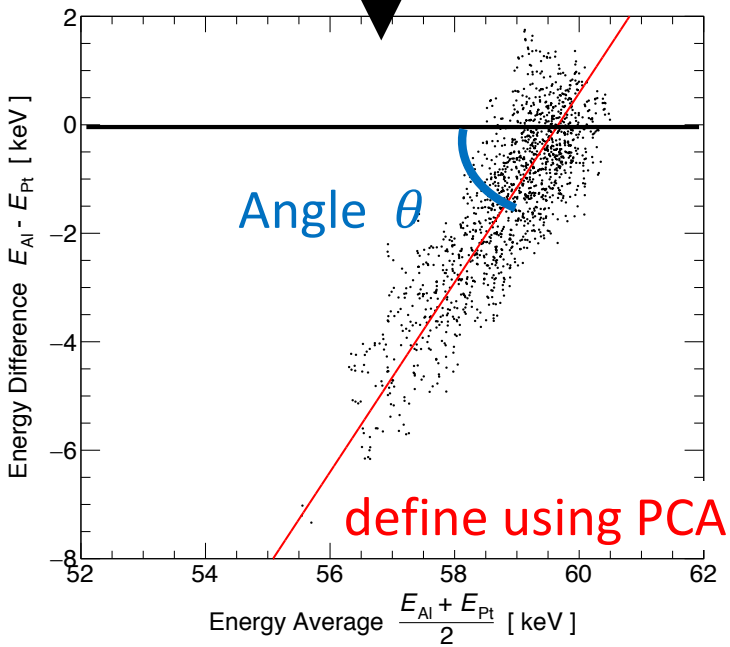


1) Pick up one pixel, and draw "Energy Average " and "Energy Difference"

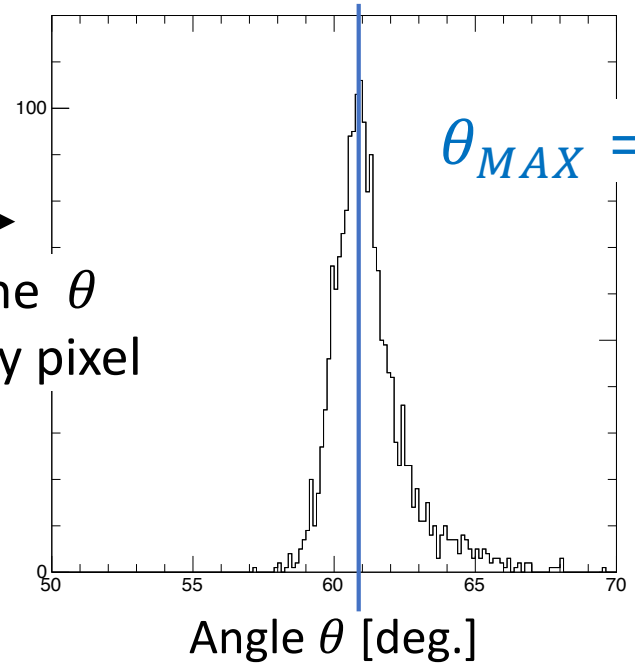
2) Distribute counts randomly in each bin (bin which counts less than 3 are ignored)

3) Define "Angle θ" using Principal Component Analysis (PCA)

repeat 1) - 3) using every pixel (128ch×128ch)

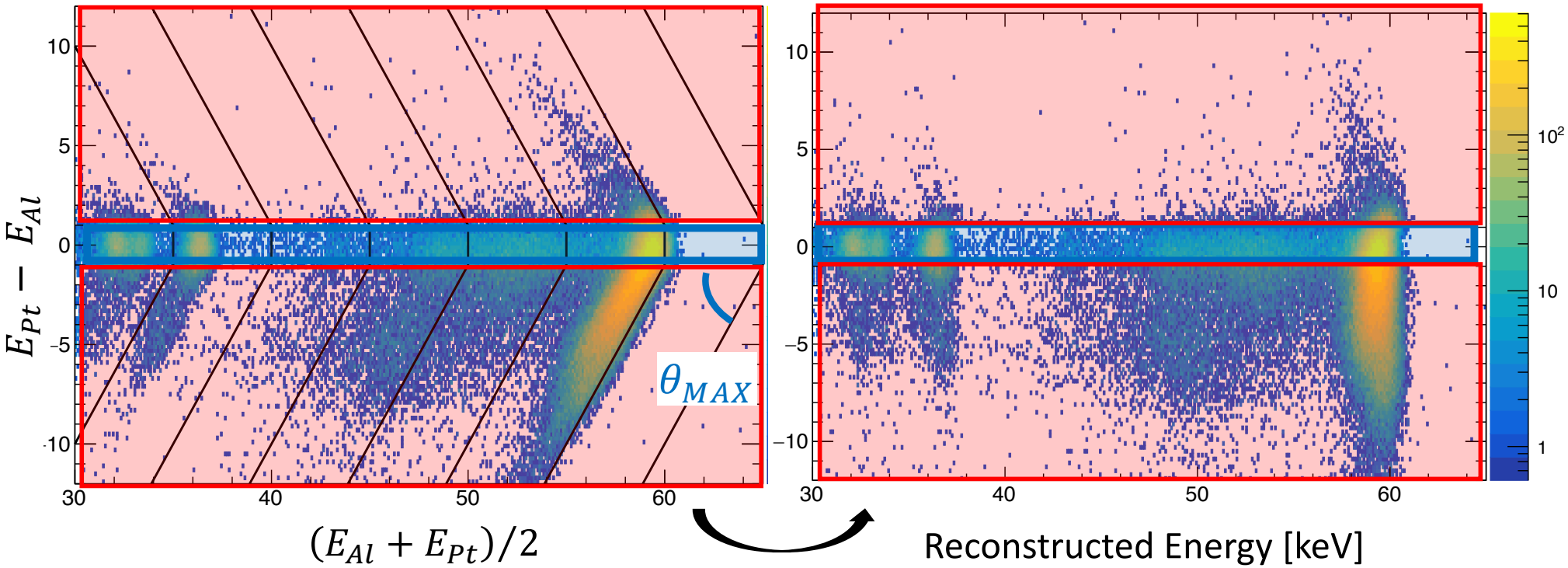


define θ every pixel



$\theta_{MAX} = 60.94$ deg.

Energy Reconstruction Method



1) $|E_{Pt} - E_{Al}| < 0.5$ keV

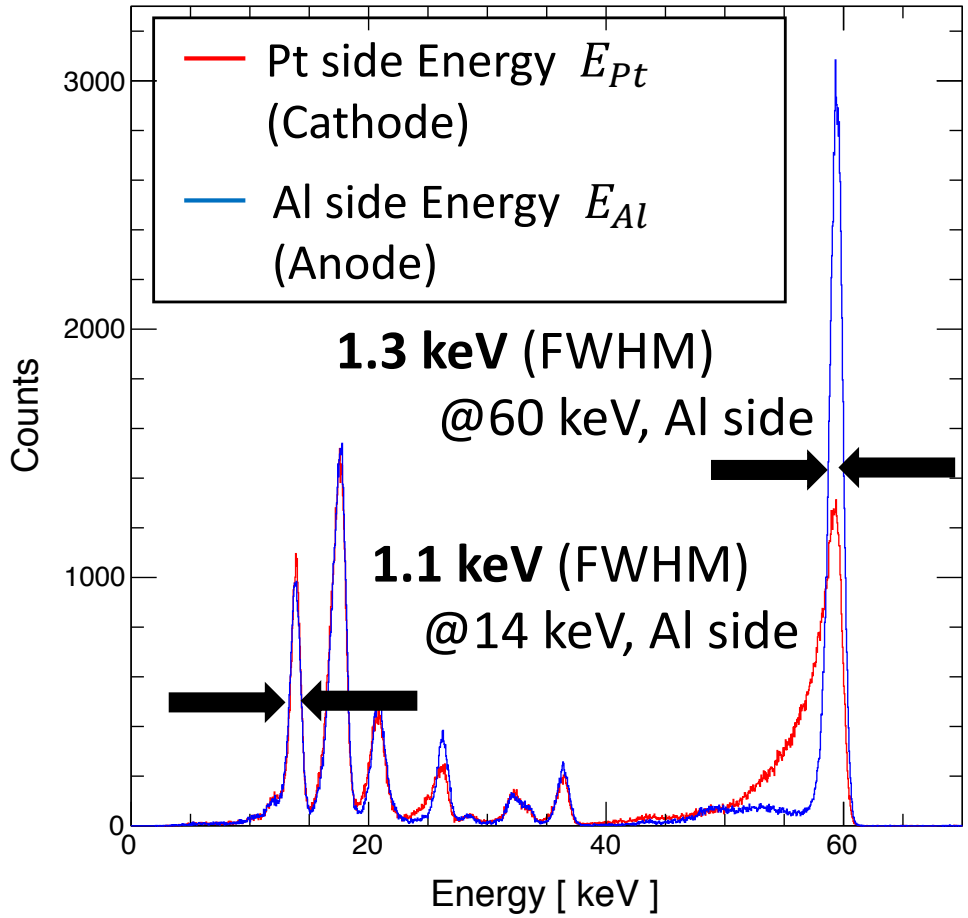
Simply using Energy Average $\frac{E_{Al} + E_{Pt}}{2}$ as a reconstructed energy

2) $|E_{Pt} - E_{Al}| > 0.5$ keV

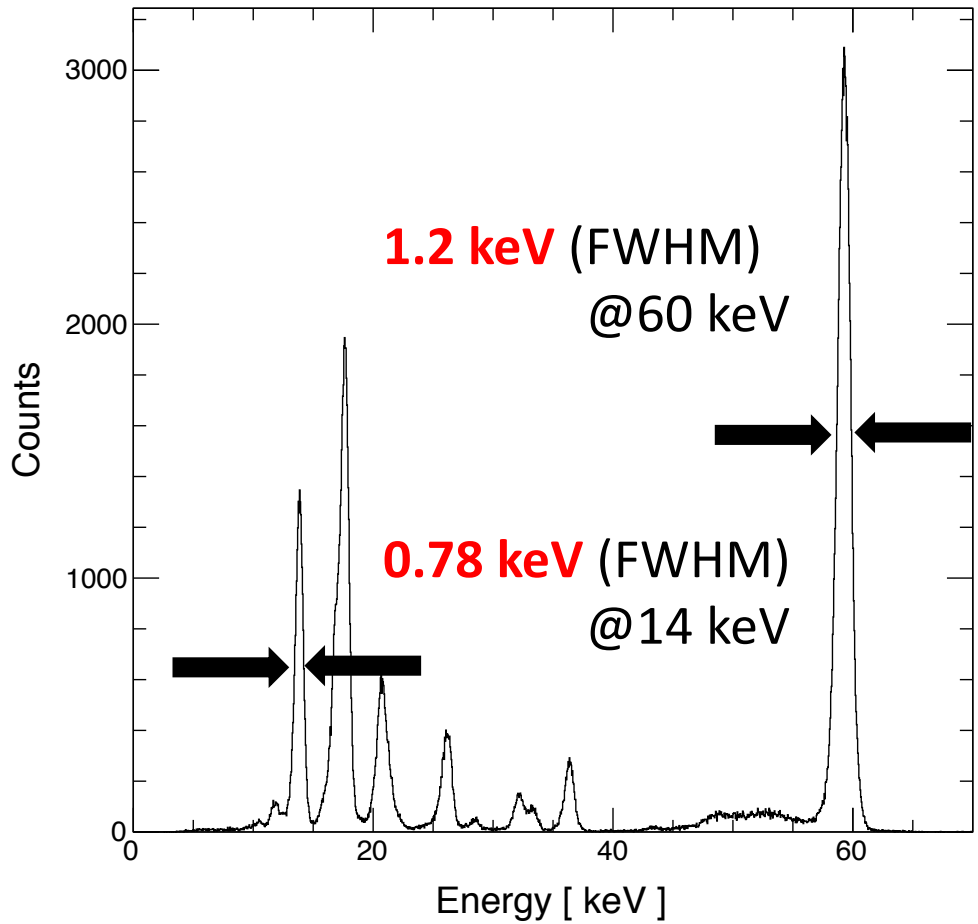
Correct tail structure using straight line of angle θ_{MAX} and calculate a reconstructed energy

Reconstructed Energy Spectrum

Pt & Al side Energy



Reconstructed Energy



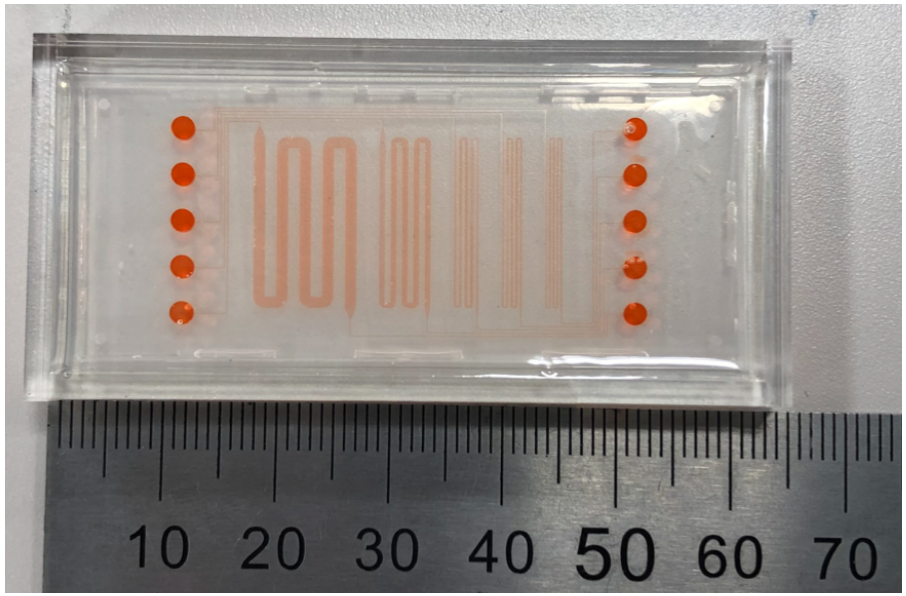
Energy resolution is improved by using both side of energy information
Tail structure at high energy peak is properly corrected

Radioisotope for Evaluating Imaging Performance

Purpose: Obtain a sub-strip position resolution (< 60 μm)

1 mm is too big !

Microchannel phantom (^{57}Co 800kBq)

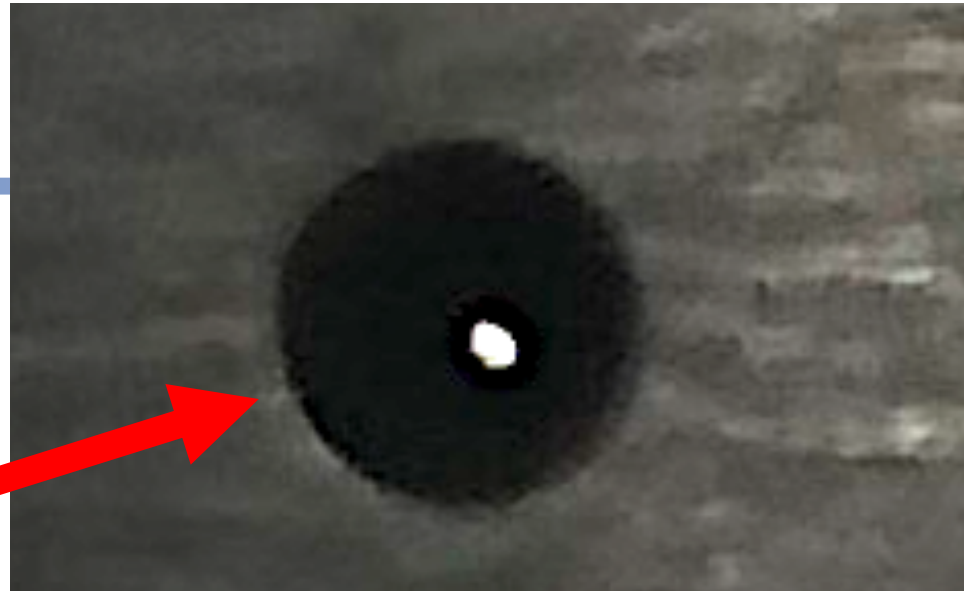


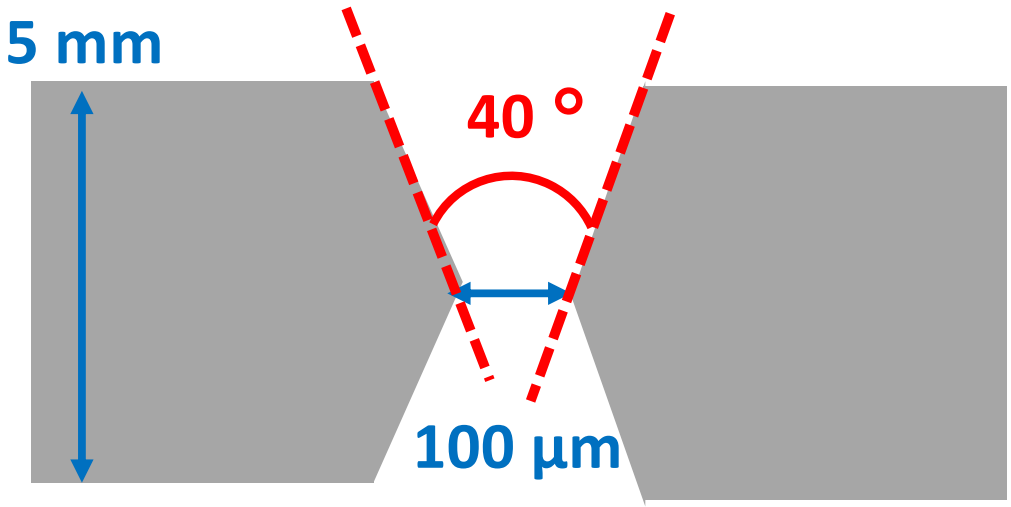
(in collaboration with the Japan Radioisotope Association)

A new type of **sealed radioisotope** (RI) with from **0.167 mm to 1 mm pattern** structure

→ It is suitable for testing how accurately we can reconstruct the fine structure of target sources in a laboratory easily

100 μm Pinhole





100 μm knife-edge Pinhole

5 mm thick Tungsten
Opening angle ：40 degree

For high energy photon,
effective pinhole diameter is a little bigger

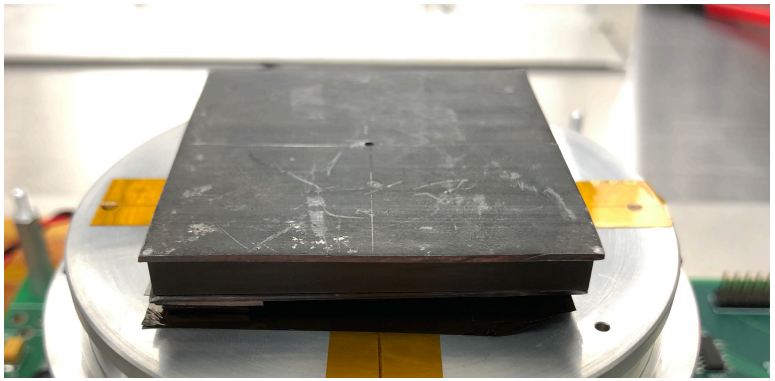
14 keV：105 μm　　30 keV： 120 μm

(90% Absorption)

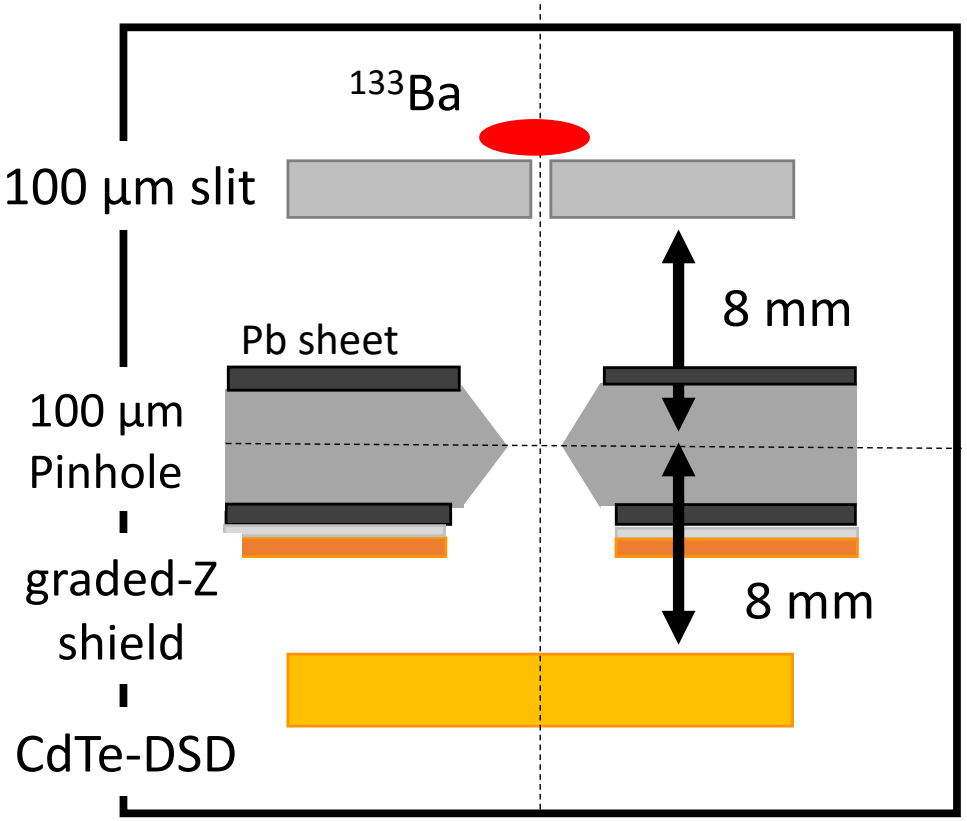
100 μm strip Setup

To make 100 μm size RI source,

- **^{133}Ba point radioactive source** (diameter = 1 mm)
- **100 μm slit** made by 0.5 mm thickness tungsten



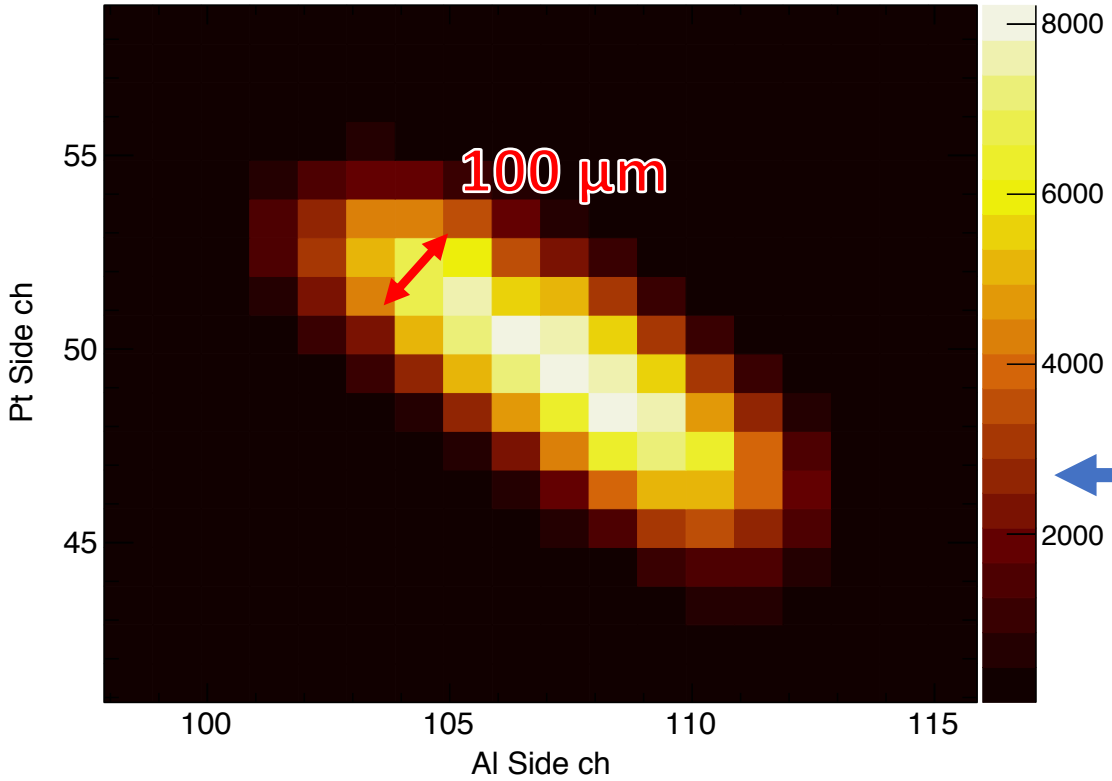
To suppress background
Pb-Sn-Cu graded–Z shield
was installed under the pinhole

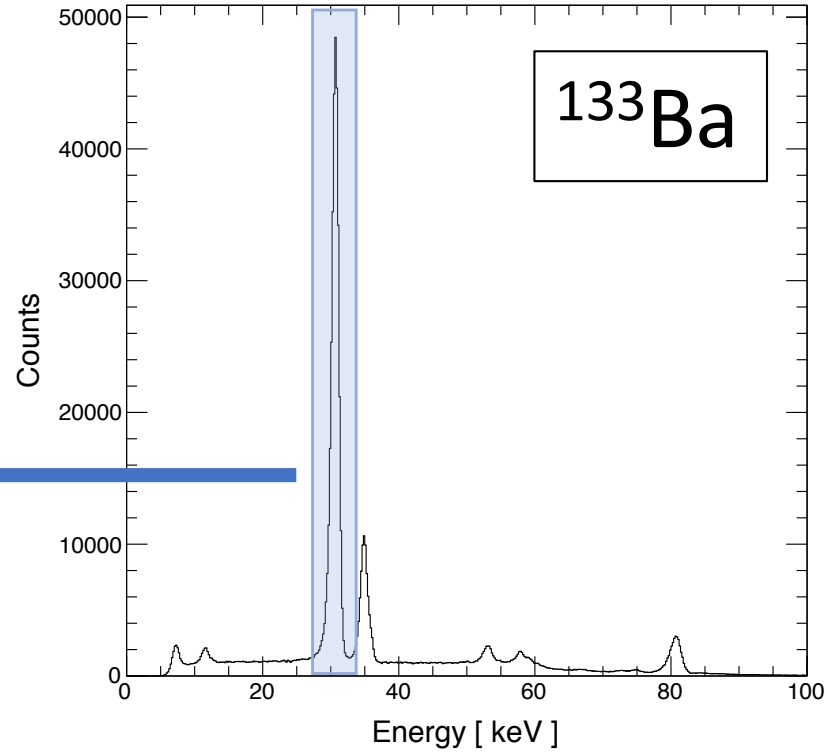


Temperature chamber (-10℃)

Strip Resolution Image

effective pinhole width：120 μm
@30 keV (90% Absorption)



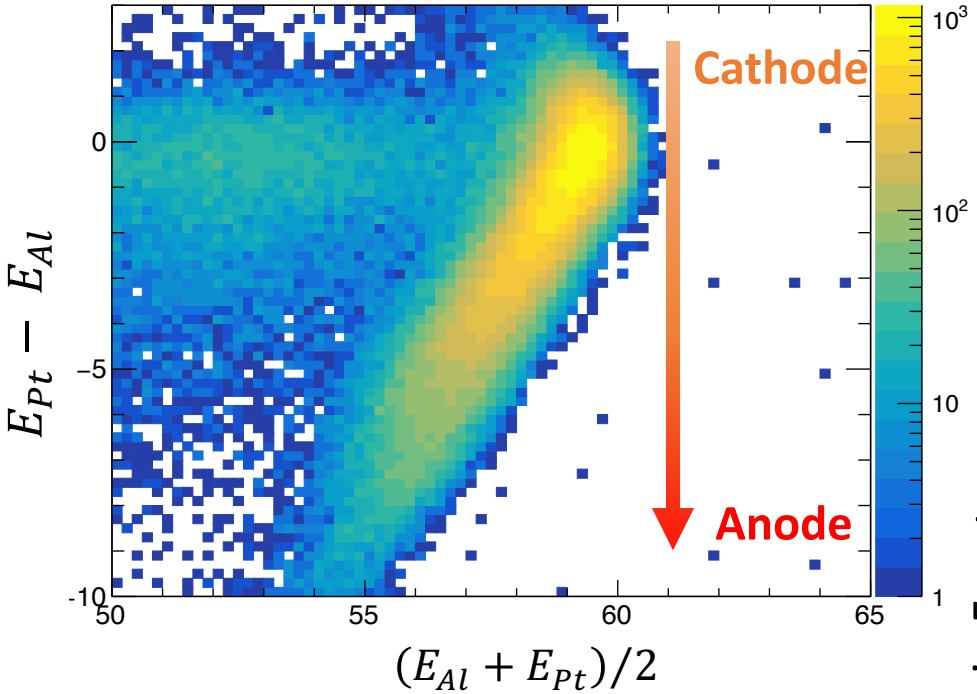


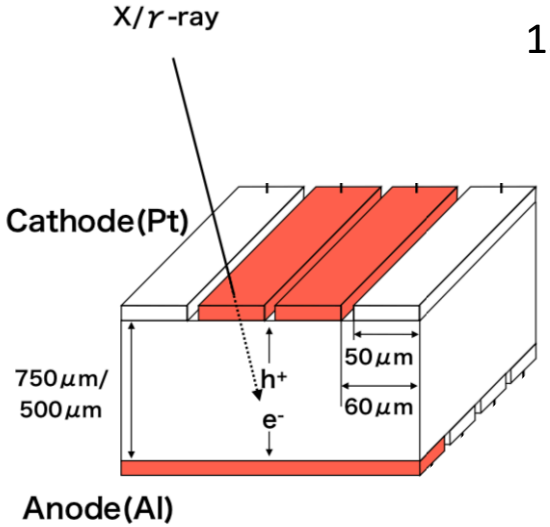
Reconstruct image using 28-32 keV Energy events

60 μm strip resolution is insufficient to image 100 μm slit

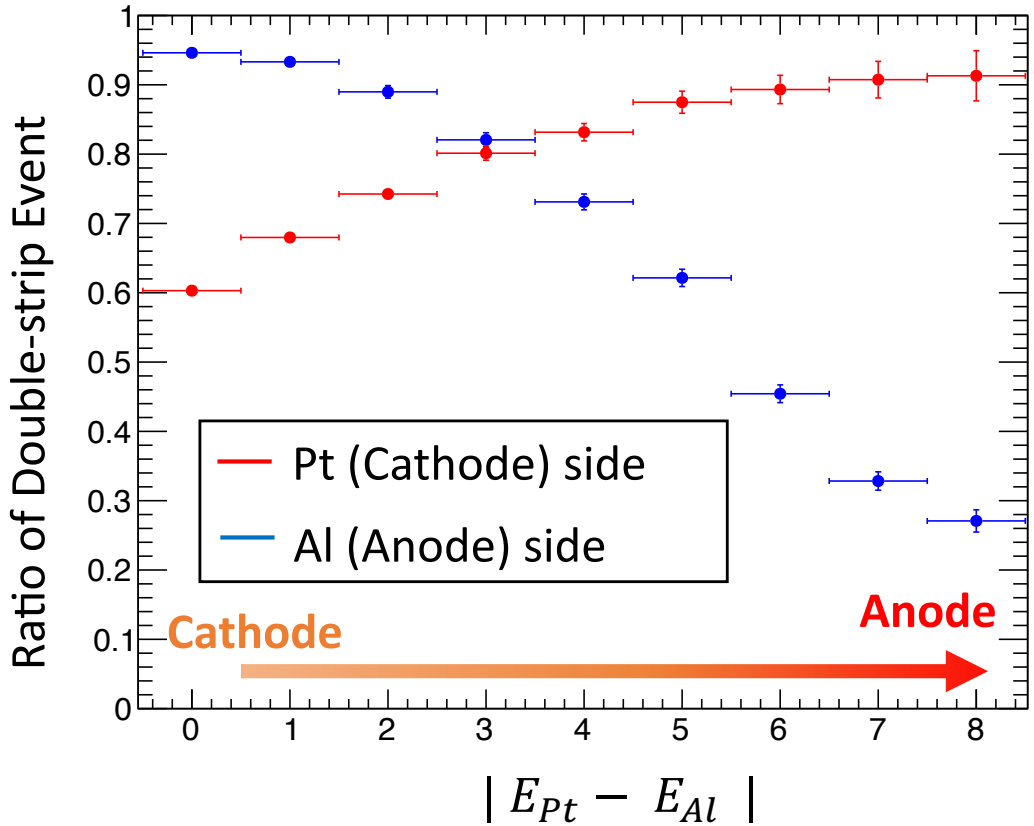
To realize sub-strip resolution, **charge sharing information** between the adjacent channel should be considered

Interaction Depth vs Charge Sharing





Ratio of Charge sharing



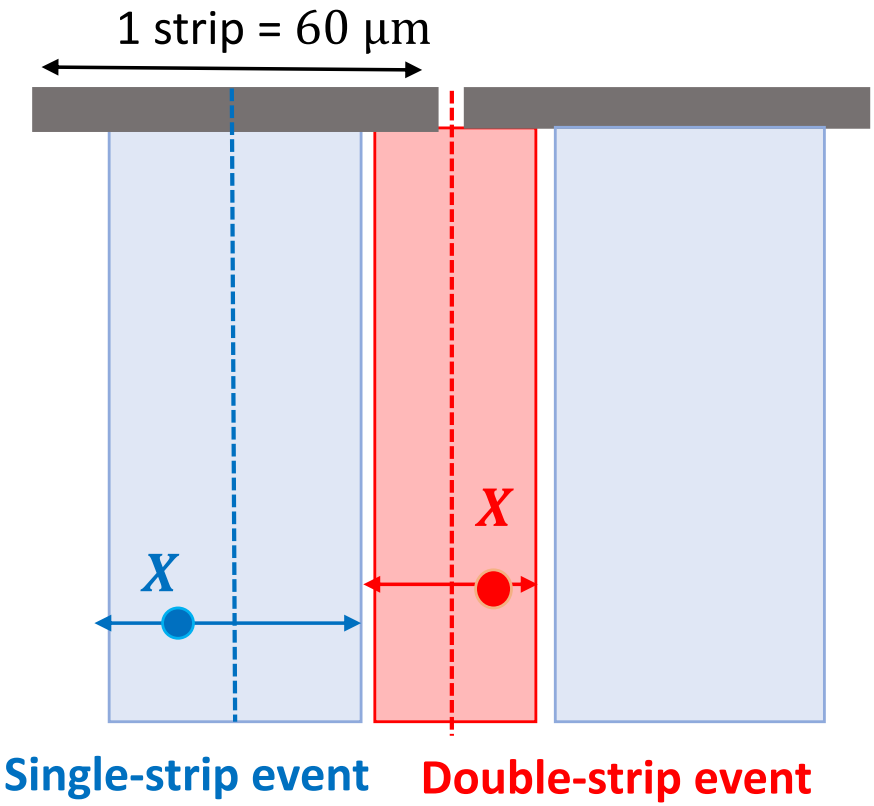
$E_{\mathrm{Al}} \gg E_{\mathrm{Pt}}$ ← holes are trapped
= interact near the surface of Al (Anode)

As Photon interacts deeper,
Pt charge sharing events increase

→ Charge cloud is spreading

Position Reconstruction Method

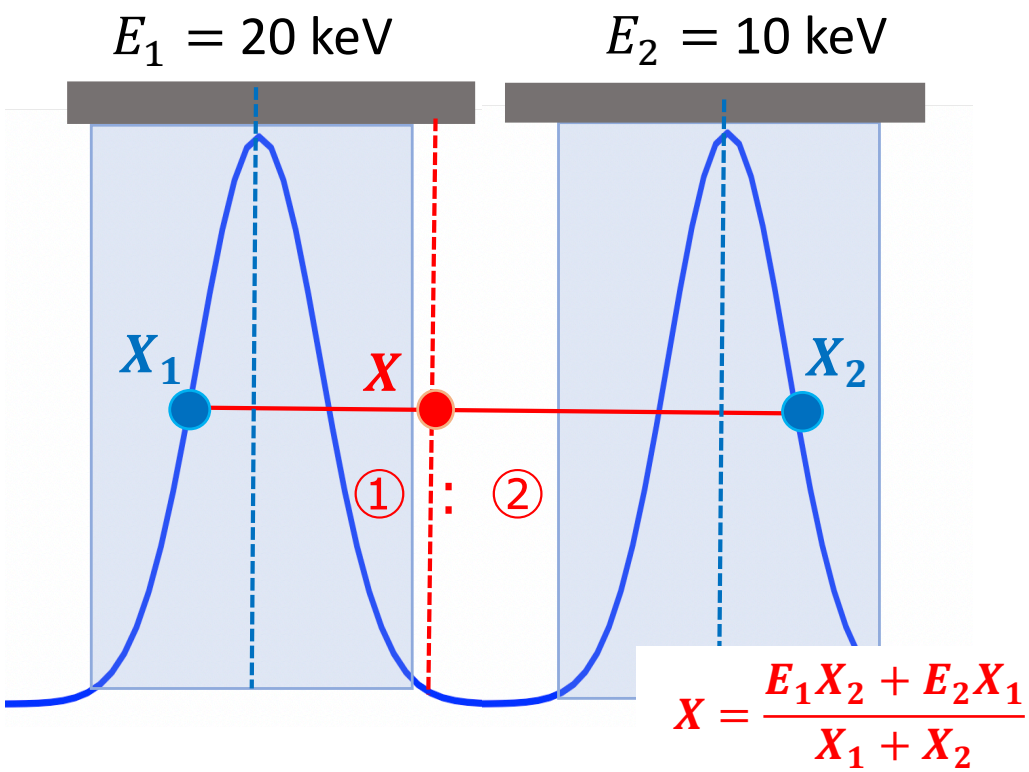
Previous Methods (Furukawa+ 2019)



Randomly assigned according to
Uniform probability distribution

The width of two region
= Ratio of Single/Double-strip event number

Improved Methods



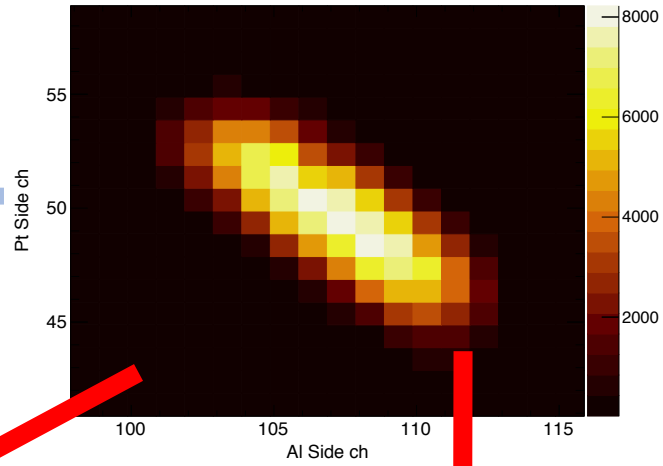
Randomly assigned according to
Gaussian probability distribution

Double-strip event
= Energy-weighted center of
each strip position of X_1 and X_2

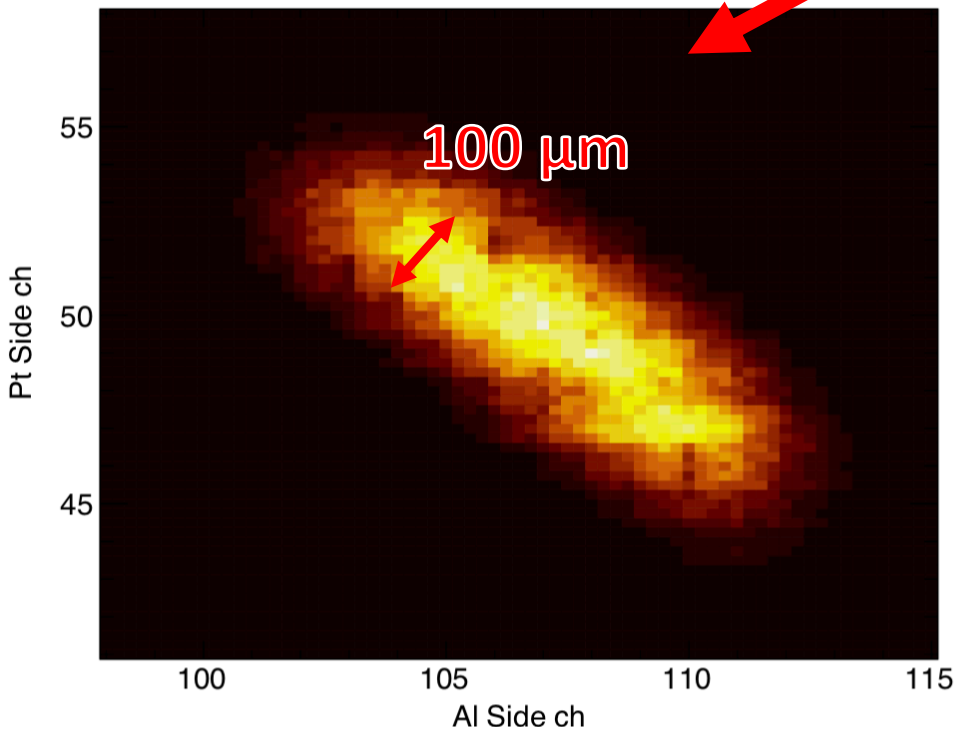
Sub-strip Resolution Image

100 μm slit image was properly reconstructed !

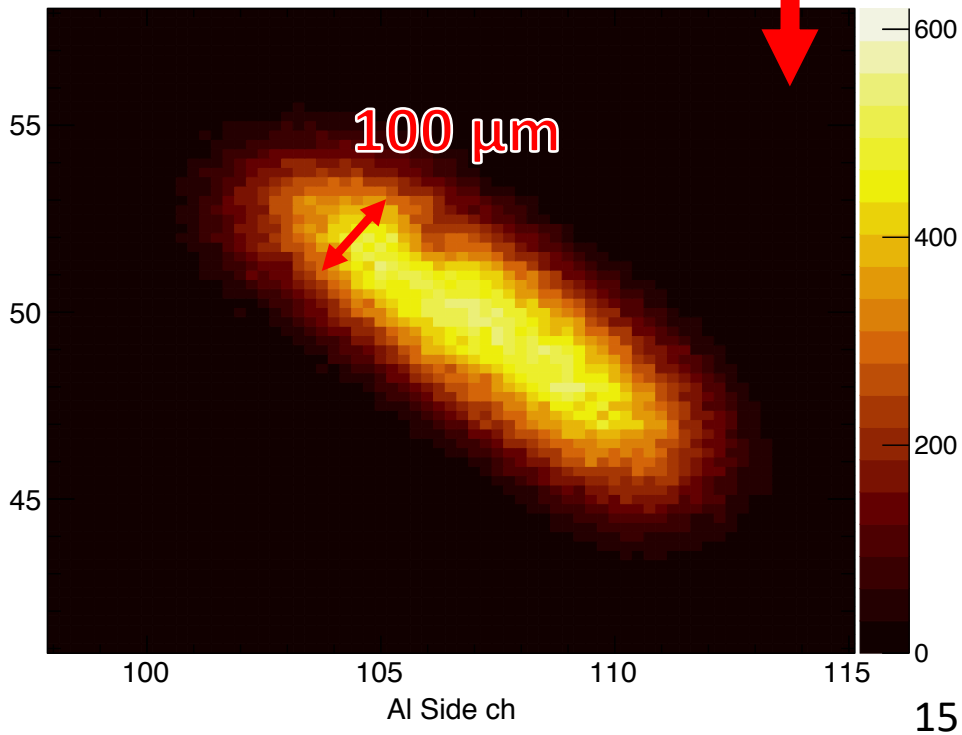
By using **charge sharing information** sub-strip resolution was confirmed



Previous Methods



Improved Methods



Summary

60 μm fine-pitch CdTe-DSD for the FOXSI-3 Sounding Rocket experiment

Spectral Performance

Tail structure of Pt side (Cathode) at high energy peaks

↓ Depth of Interaction correction

- Correct tail structure properly
- **1.2 keV** (FWHM)@60 keV, **0.78 keV** (FWHM)@14 keV

Imaging Performance

Using an information of charge sharing between the adjacent channel

↓

100 μm slit image was properly reconstructed

→ sub-strip resolution was confirmed