Development of 60μm pitch CdTe double-sided strip detector for FOXSI-3 rocket experiment

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CdTe semiconductor and diode device

Cadmium Telluride semiconductor :

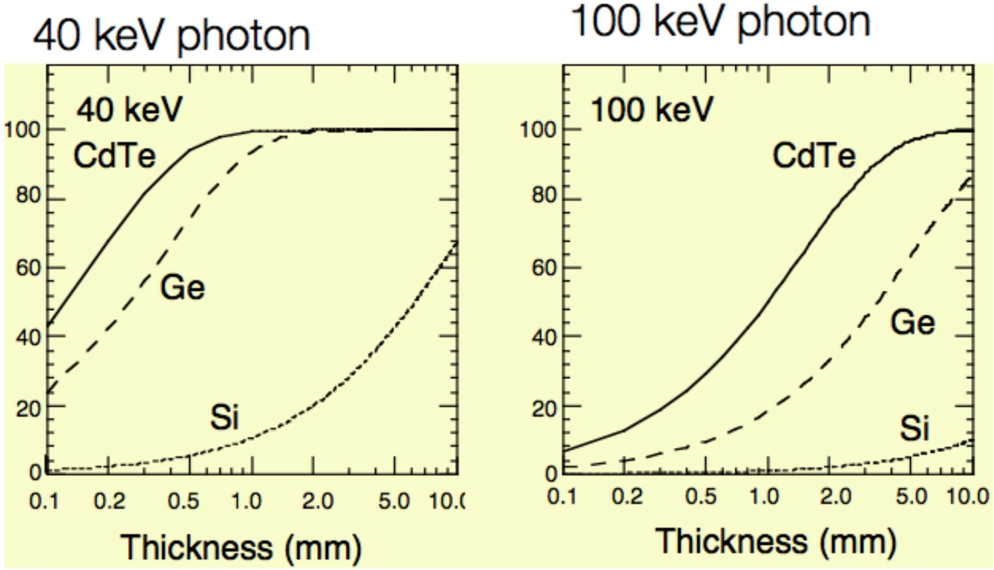
- High density
- Large atomic number

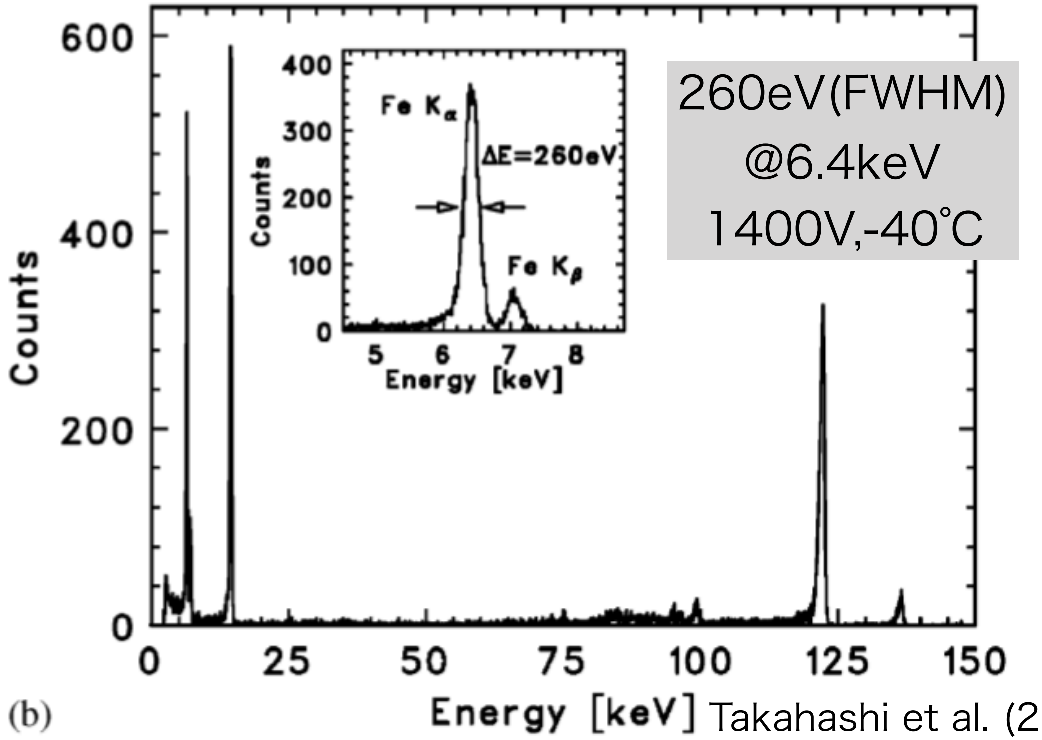
- High efficiency

Issue : small μτ product especially for holes

- Uniform & thin device
- Schottky Diode (Takahashi et al. 1998)

High bias voltage
full charge collection
+ high energy resolution



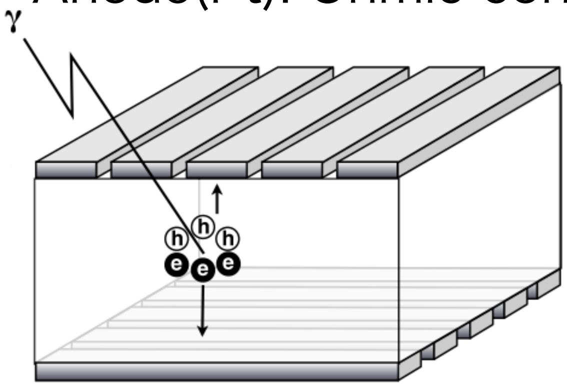


Takahashi et al. (2005)

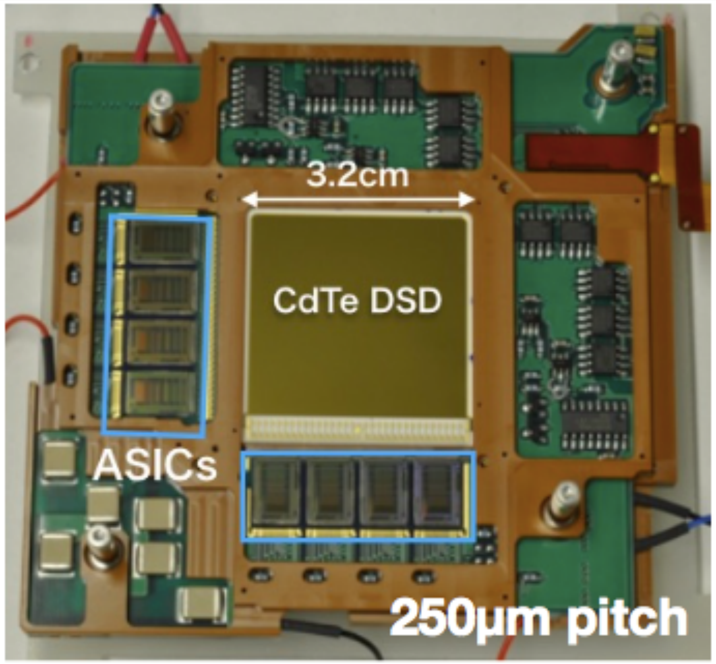
Application of CdTe Diode Double-sided Strip Detector

Watanabe et al. 2009

Anode(Pt): Ohmic contact

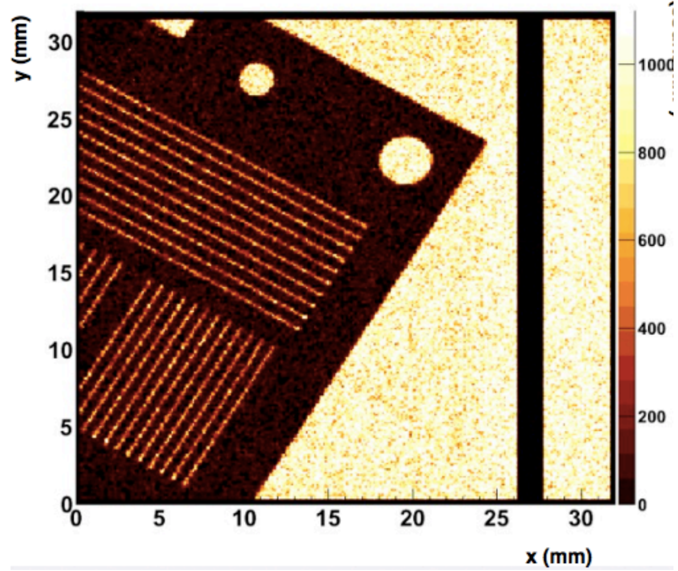


Cathode(Al): Schottky contact



Astrophysical Application

- Hard X-ray Imager(HXI) onboard Hitomi(ASTRO-H) satellite
- FOXSI rocket mission



Medical Application

- Small animal SPECT system (OIST/JAXA)

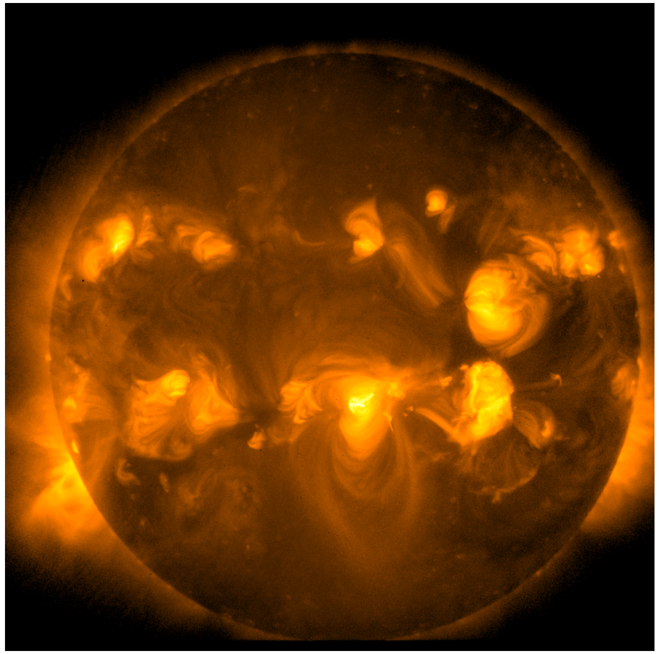
Hard X-ray study of the Sun

<u>Observation Target : the Sun</u>

Corona and flare

<u>Scientific Aim</u>

- Coronal Heating
  (thermal emission)
- Particle Acceleration
  (non-thermal emission)



Soft X-ray image by Hinode (NAOJ/JAXA)

→**Sensitive Hard X-ray imaging and spectral observation is the key especially for small scale flares study (micro and nano)**

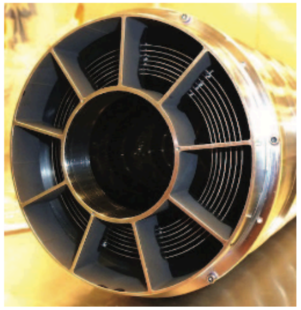
So far
only Indirect Imaging
e.g. RHESSI spacecraft (Rotational Modulation collimator)

<u>No direct imaging in hard X-ray band for solar mission</u>

FOXSI rocket mission

FOXSI experiment
(UCB/SSL, NASA, UMN, ISAS/JAXA)
Direct Imaging Spectroscopy
with Focusing Optics in Hard X-ray

Hard X-ray telescopes + CdTe focal plane detect

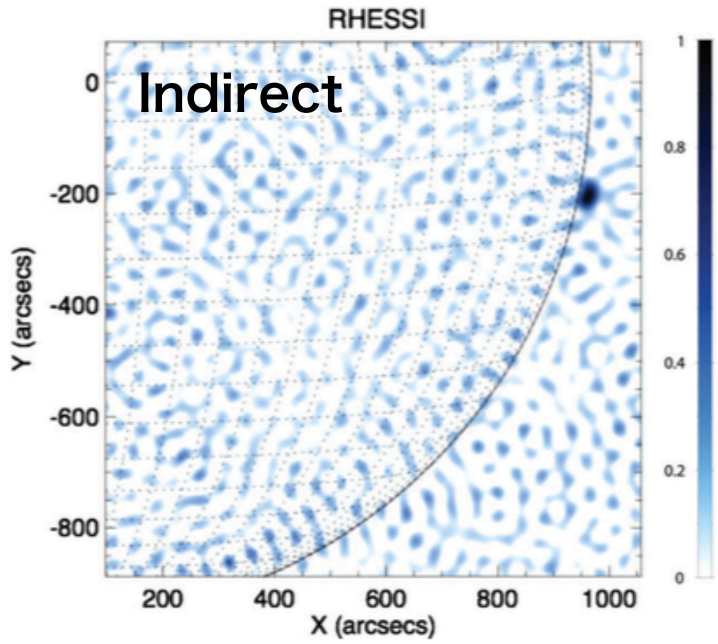


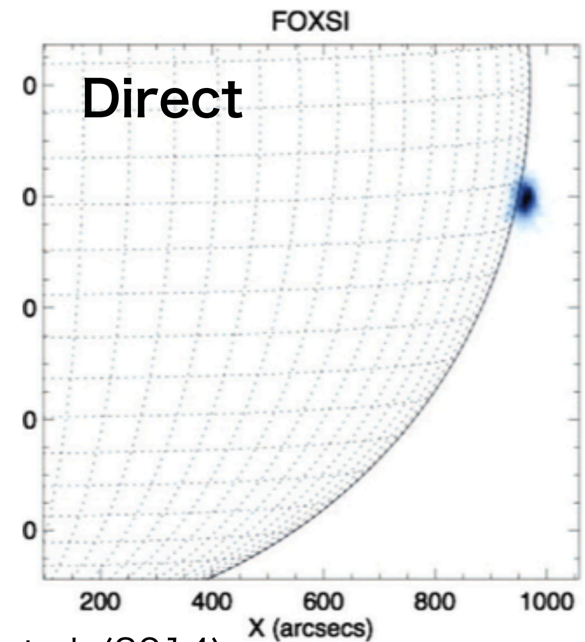
FOXSI's hard X-ray telescope clearly identified a micro-flare with high S/N ratio

Telescope

Focal plane detector

Angular resolution :
5 arcsec (FWHM)
50μm on focal plane





Krucker et al. (2014)

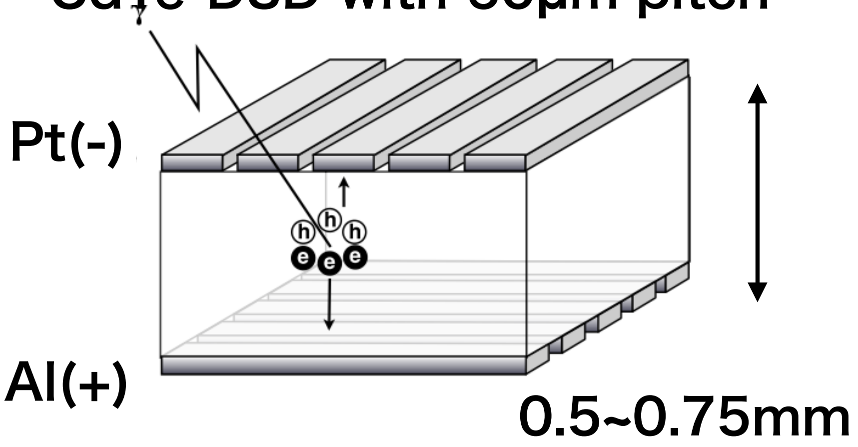
FOXSI-3 CdTe-DSD for larger effective area

FOXSI-1 (2012)
- Si detector×7

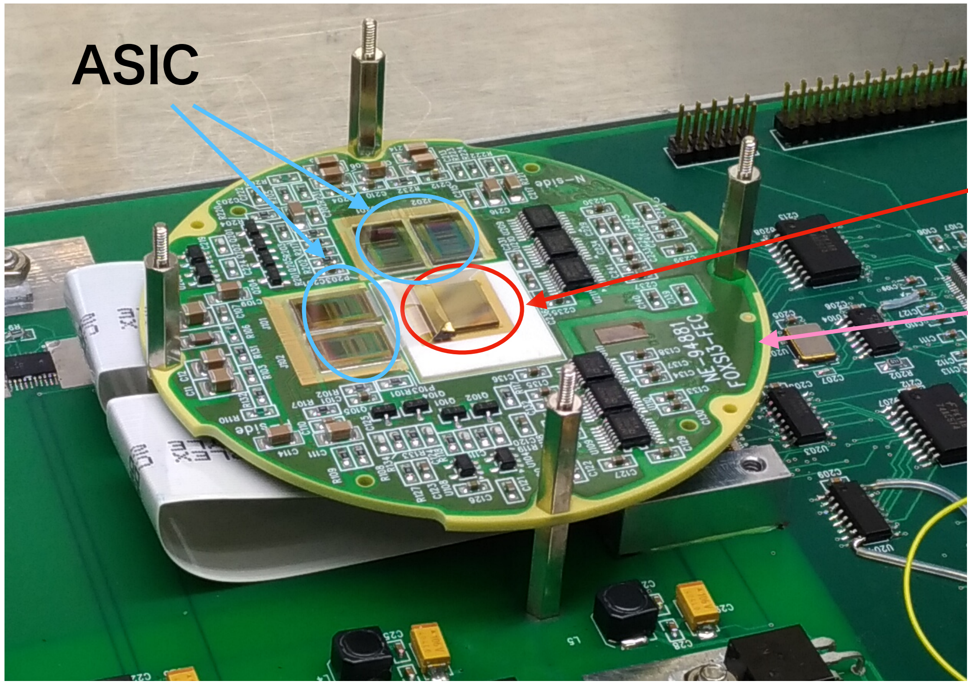
FOXSI-2 (2014)
- Si detector×5
- CdTe-DSD×2

FOXSI-3 (2018,summer)
- CdTe-DSD×6
- Si CMOS sensor

CdTe-DSD with 60μm pitch

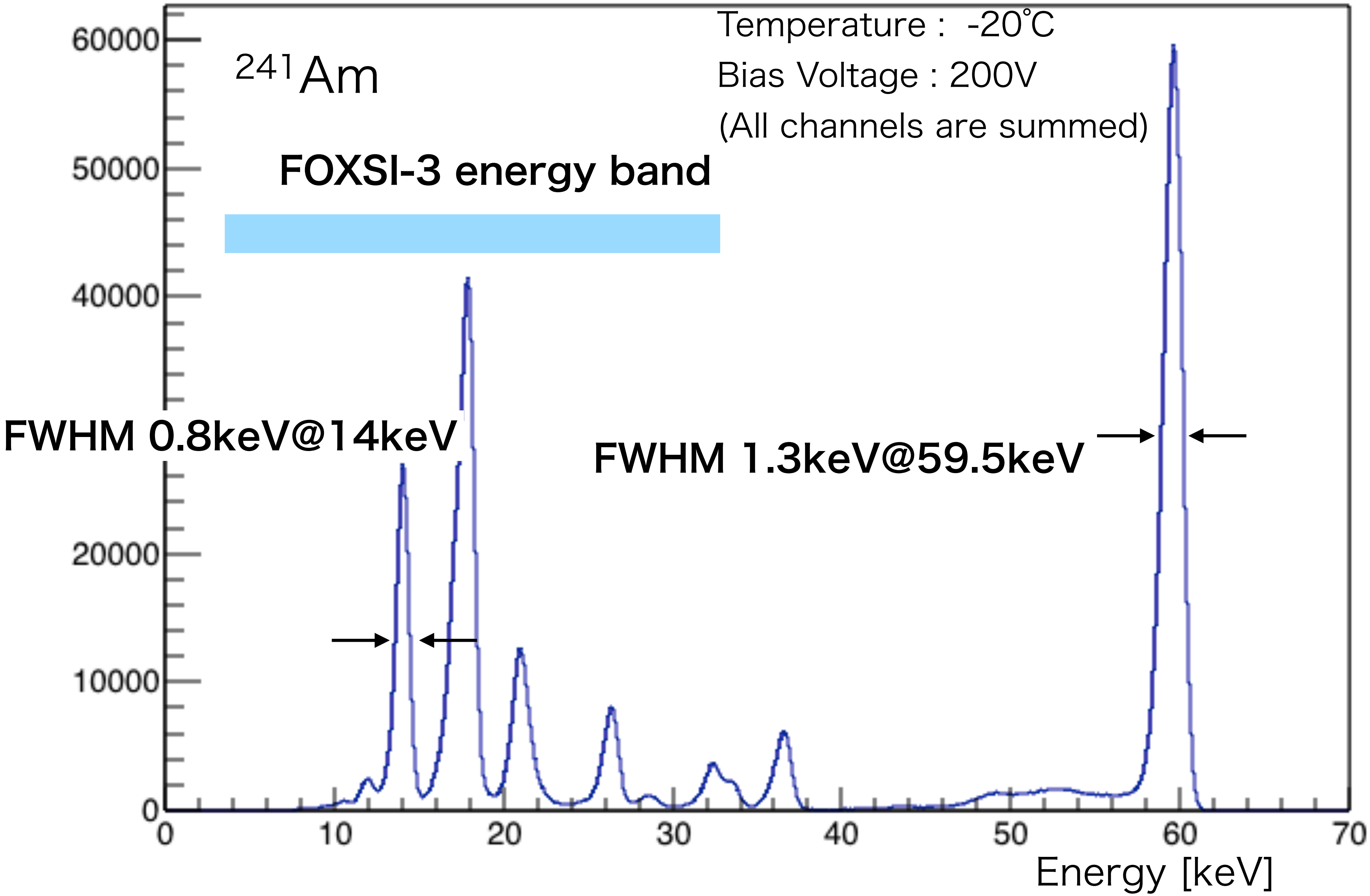


New prototype detector for FOXSI-3



FOXSI-3 Prototype

(1)Spectral Performance



FOXSI-3 Prototype

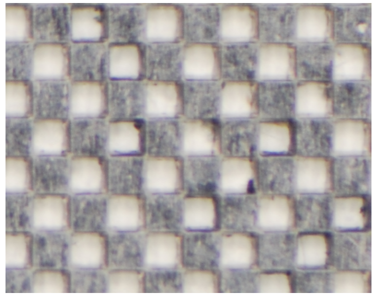
(2)Imaging Performance

Charge integration image

||

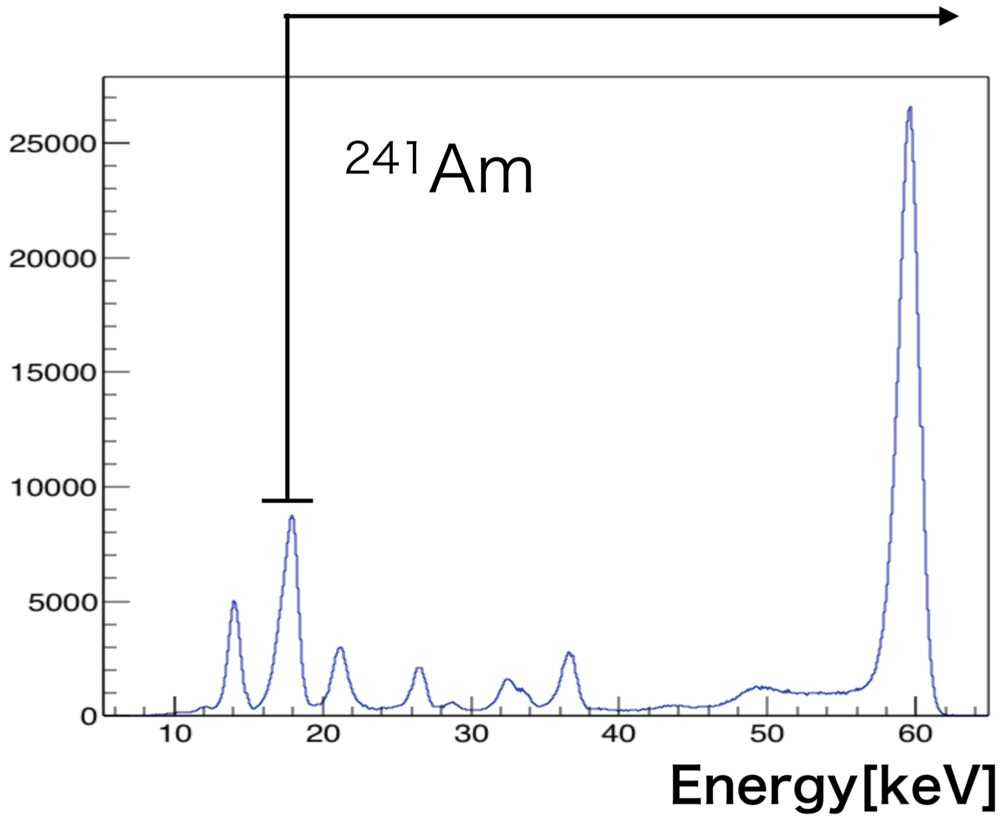
<Energy selected image>

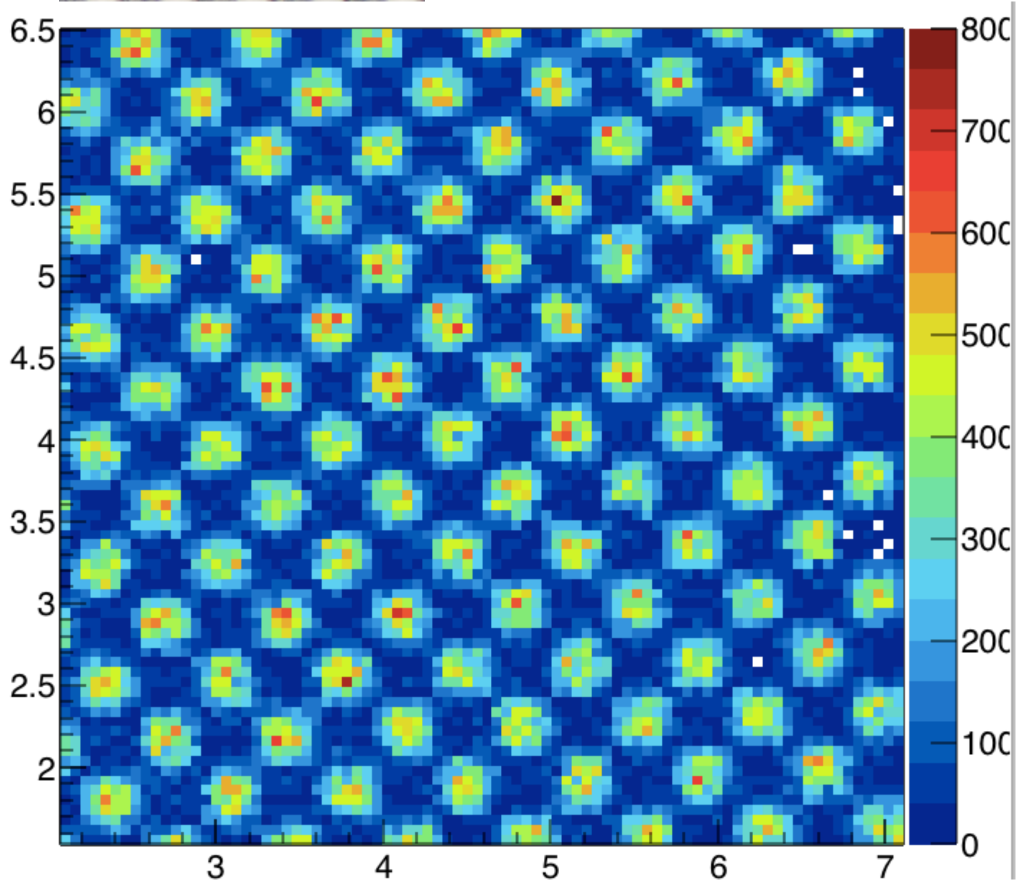
ΔE~1keV



Tungsten Mask

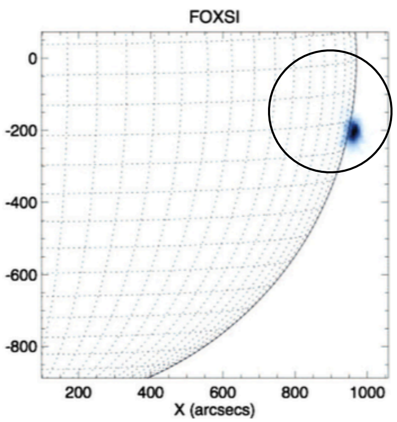
- pattern size 300μm
- thickness 300μm





FOXSI-3 Prototype

(2)Imaging Performance



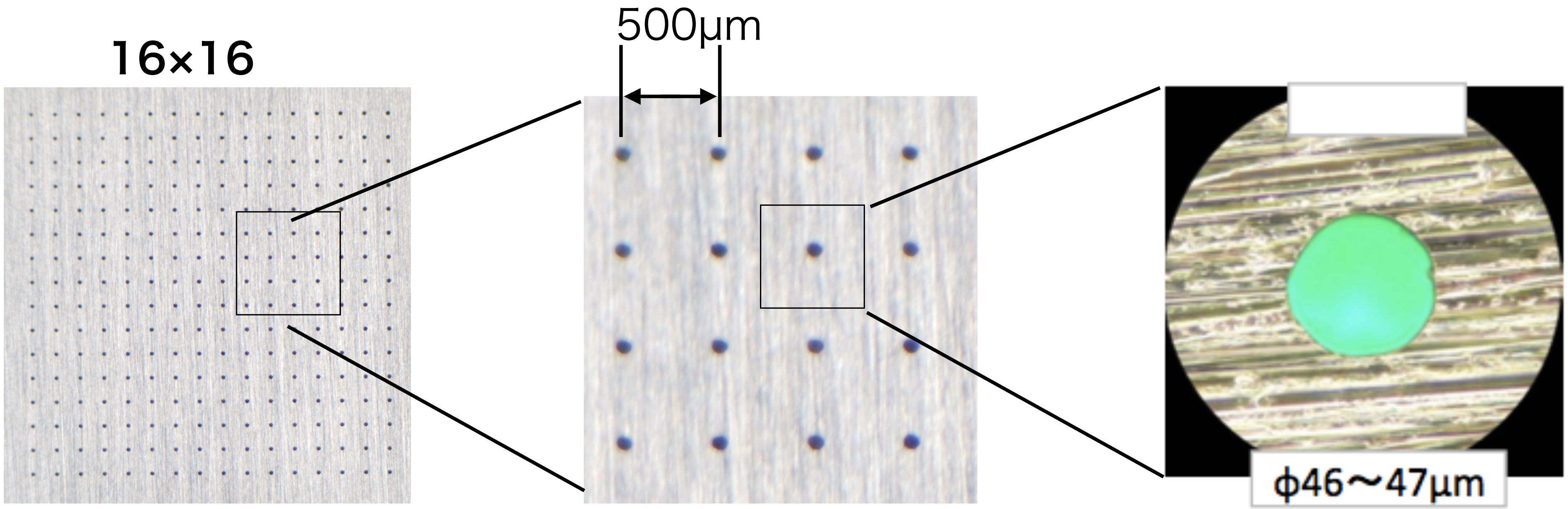
What we need is the spectrum of this region

→ photo counting image

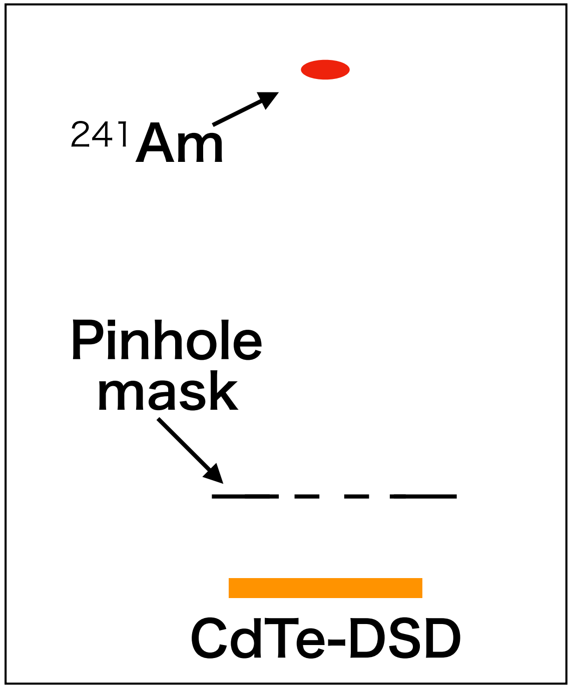
Issue : Verification of imaging performance

- **uniformity**
- **charge splitting**

Calibration by using a high precision tungsten mask

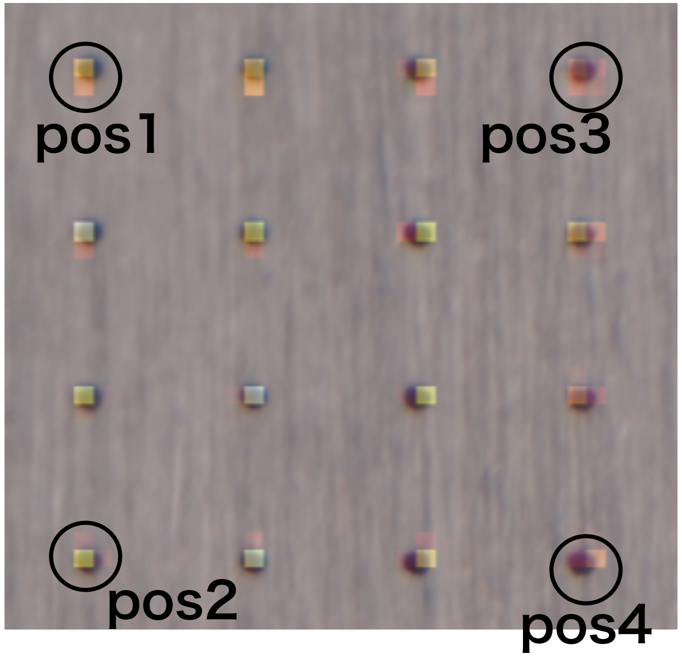


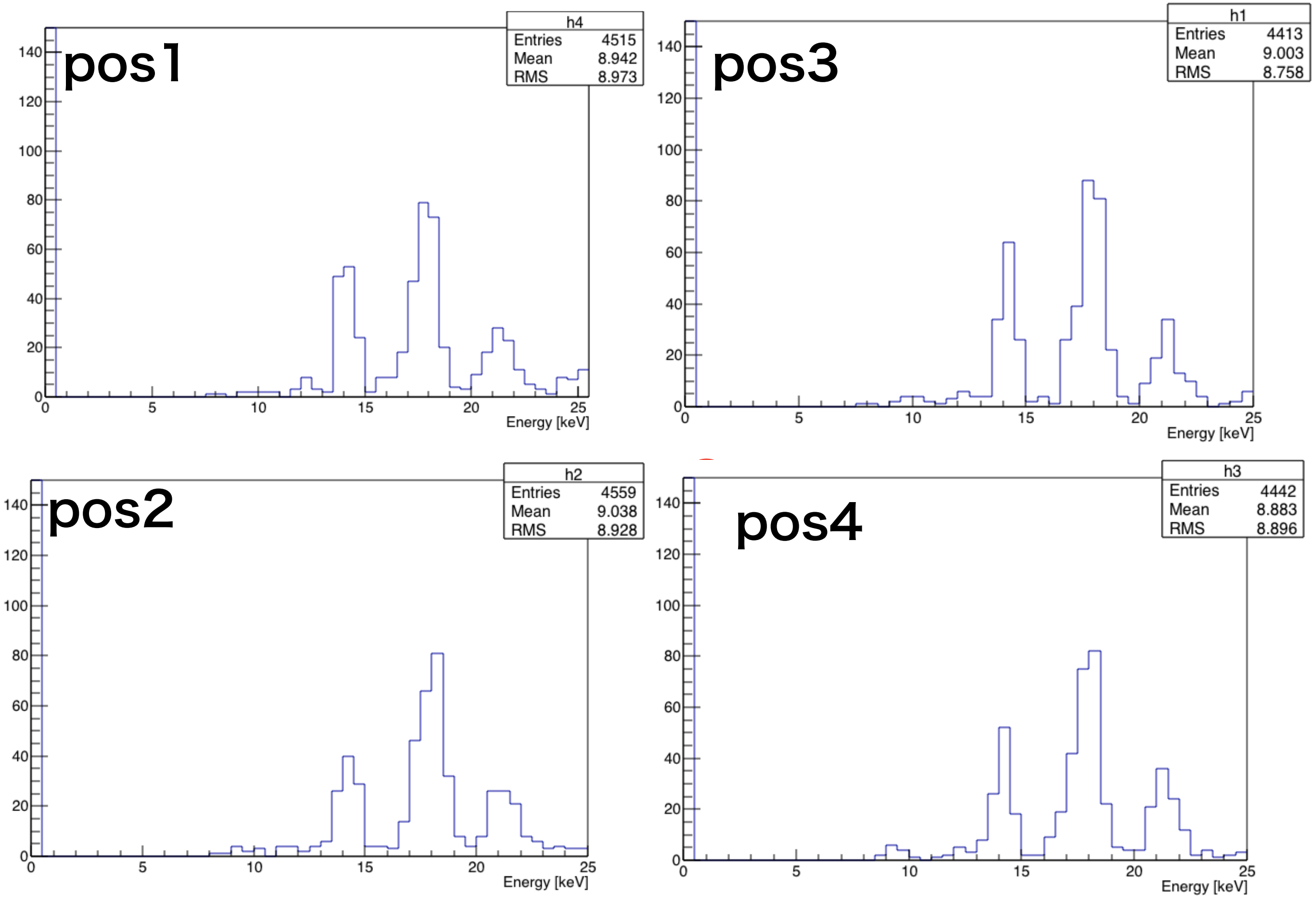
(2)Imaging Performance



uniformity over the detector plane

multi-pinholes are efficient for studying position dependence of the performance



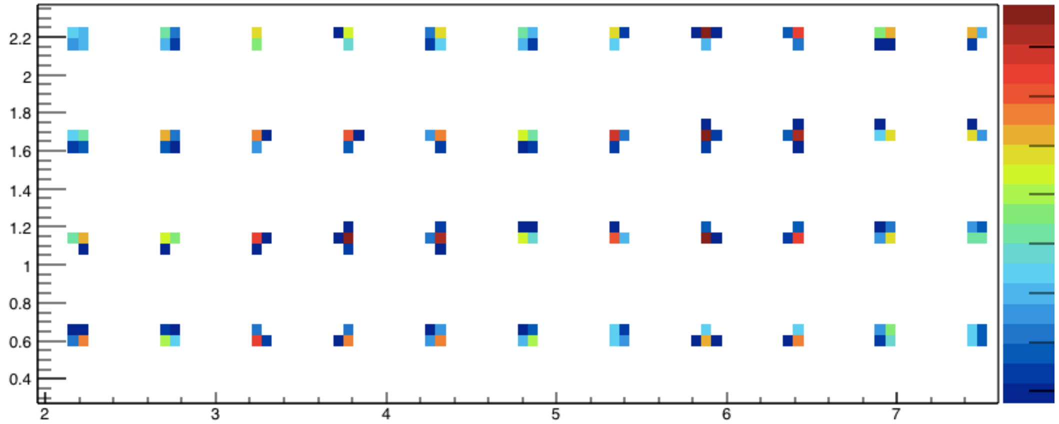


Energy resolutions are almost constant

FOXSI-3 Prototype

(2)Imaging Performance

Image of the pinhole mask(Integration)

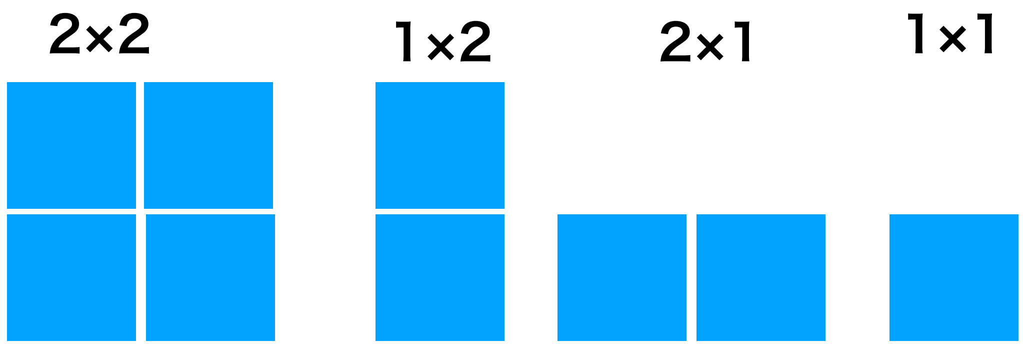


- Charge splits even at 18 keV
- Need to find an algorithm to get an accurate position

Toward sub-strip resolution

Statistics of multi-strip events at 18 keV

	1 strip	2 strip	>3 strip
Al	54.4%	43.7%	1.9%
Pt	61.6%	32.9%	5.5%



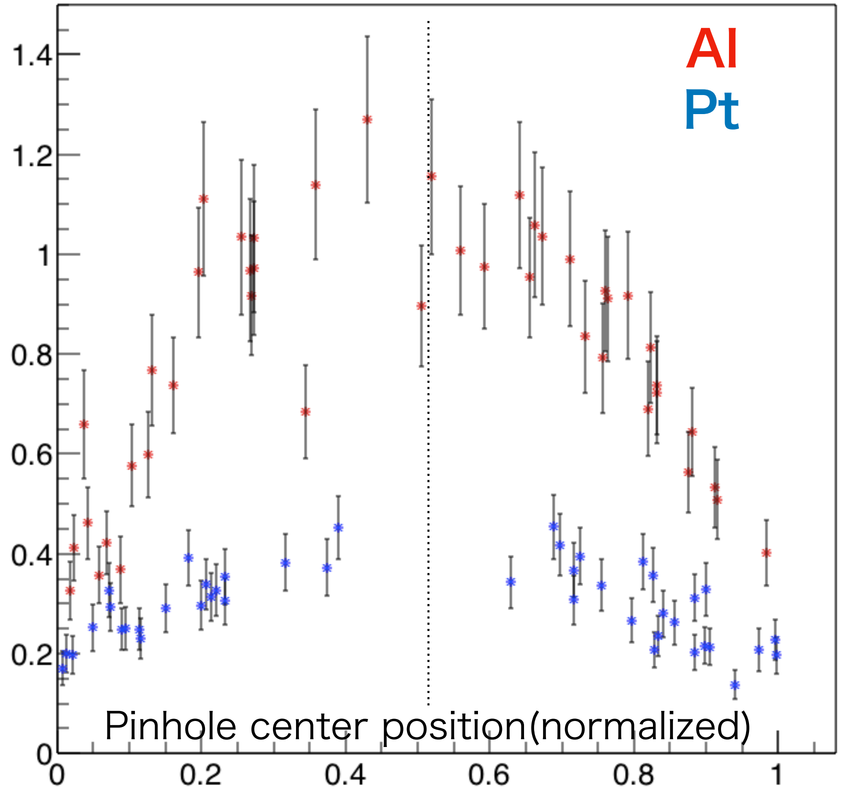
FOXSI-3 Prototype

(2)Imaging Performance

Multi-pinhole mask enables us to study the feature of double-strip events, quantitatively

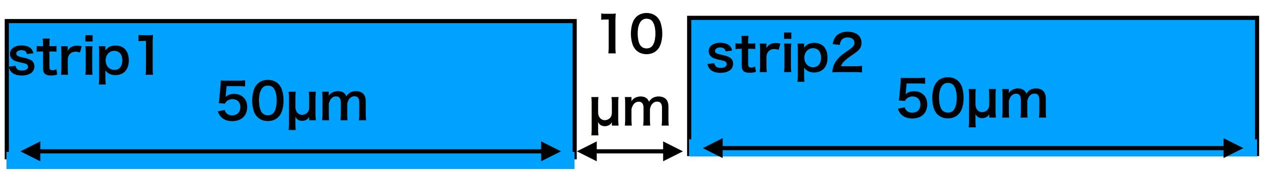
$$\frac{\text{\# of double strip events}}{\text{\# of single strip events}}$$

at 18 keV



double strip ratio reflects interaction position, and therefore double-strip events contain information on sub-strip position

- should be energy dependent
- calibration is going on for the launch of FOXSI-3 in Aug 2018



Conclusions

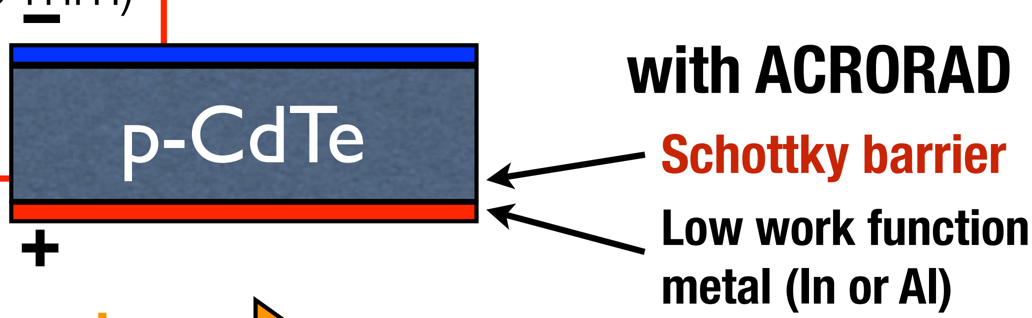
- Hard X-ray imaging and spectral observation is the key to understand the nature of the solar activity,
- The prototype of CdTe Diode Double-sided Strip Detector(CdTe-DSD) with fine 60μm pitch for FOXSI-3 has been developed and tested
- Energy resolution of 0.8 keV(FWHM)@14 keV is achieved
- With a high precision multi-pinhole mask, imaging performance better than 60μm have been verified.
- Flight detectors have been manufactured
- Calibration is going on for the launch of FOXSI-3 in Aug 2018

High Resolution CdTe

1. Make Uniform & Thin device (0.5 – 2.0 mm)
2. Establish Schottky contact
3. Study Optimum Operating Condition

Takahashi et al. 1998

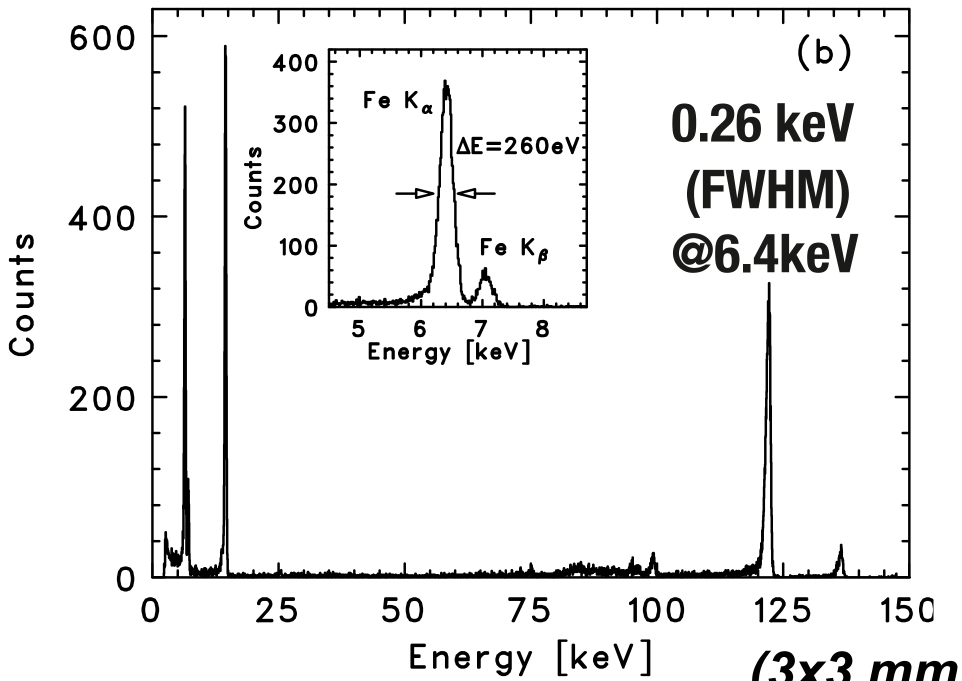
with ACRORAD



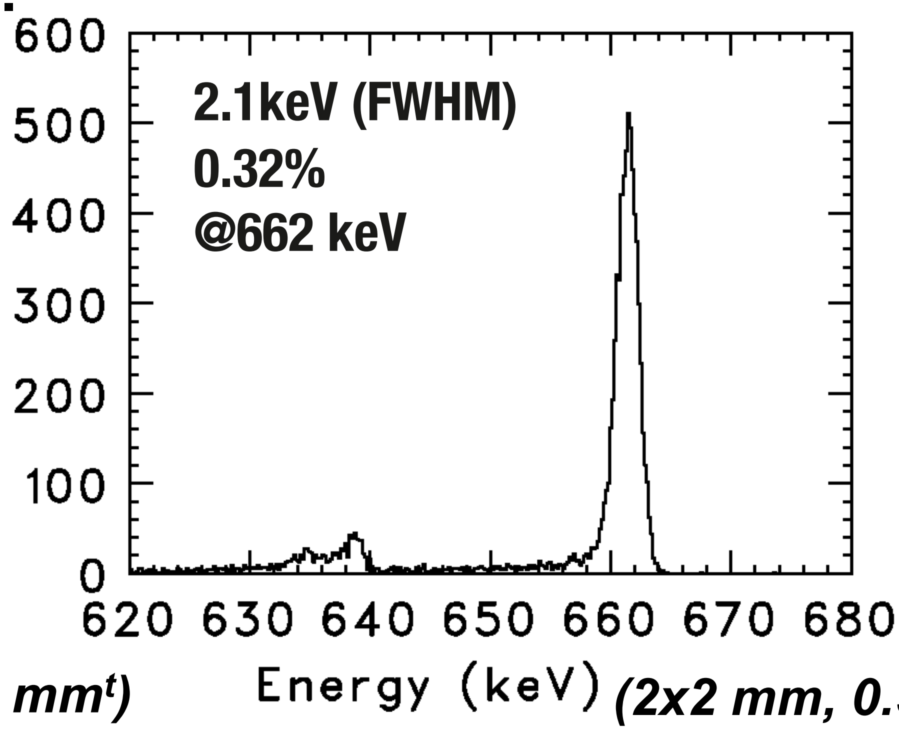
- **Extremely low leakage current**
- **High bias voltage**

Full charge collection (NO TAIL)

Best spectra we presented 10 years ago.



(3x3 mm, 1 mm^t)



(2x2 mm, 0.5 mm^t)

TABLE I

PROPERTIES OF THE SEMICONDUCTORS

semi-conductor	density $[g/cm^3]$	Z	E_{gap} [eV]	ϵ [eV]	X_0 [cm]
Si	2.33	14	1.12	3.6	9.37
Ge	5.33	32	0.67	2.9	2.30
CdTe	5.85	48,52	1.44	4.43	1.52
CdZnTe	5.81		1.6	4.6	
HgI_2	6.40	80,53	2.13	4.2	1.16
GaAs	5.32	31, 33	1.42	4.3	2.29

E_{gap} : band gap energy
ϵ : an ionization potential
X_0 : radiation length

Takahashi & Watanabe, 2000