A study of TES X-ray microcalorimeter array with different absorber thickness towards the observation from 50 eV to 15 keV for STEM-EDS

Tasuku Hayashi, **H. Muramatsu, R. Konno, N. Y. Yamasaki, K. Mitsuda**
(Institute of Space and Astronautical Science, JAXA)
K. Maehata (Kyushu University)
T. Hara (National Institute for Materials Science)

LTD18, 25 July 2019 in MILANO

Microanalysis of astromaterials using STEM-EDS

Astromaterials are known to keep informations about early phase solar system!

Meteorites have

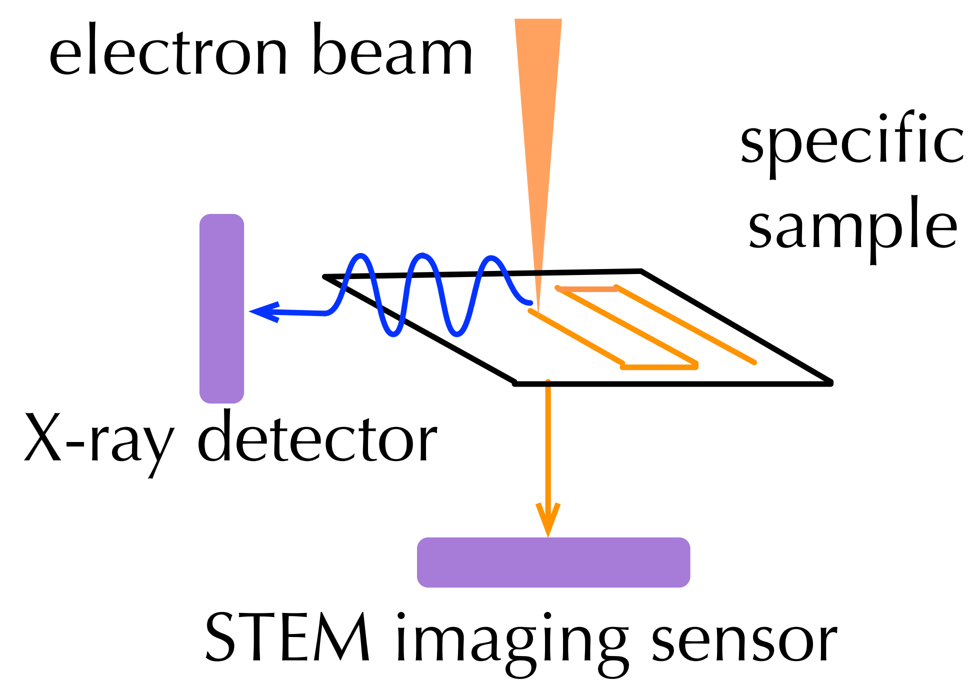
- sub-micro scale structures
- many elements such as **B**, C, O, **Si**, Mg, **Fe**…

Meteorite
or
Sample-return missions to asteroids

HAYABUSA2
& OSIRIS-REX

From the amount of B(=183eV) in the silicate, we can investigate the effect of solar wind.

We have to know the amount of B and Si by the quantitative analysis (W.FUJIYA+2016)



Method of Microanalysis

- STEM-EDS can obtain the image and composition from meteorites.

In order to improve the energy resolution for STEM-EDS, we have been developing the TES microcalorimeter array.

STEM : Scanning Transmission Electron Microscope

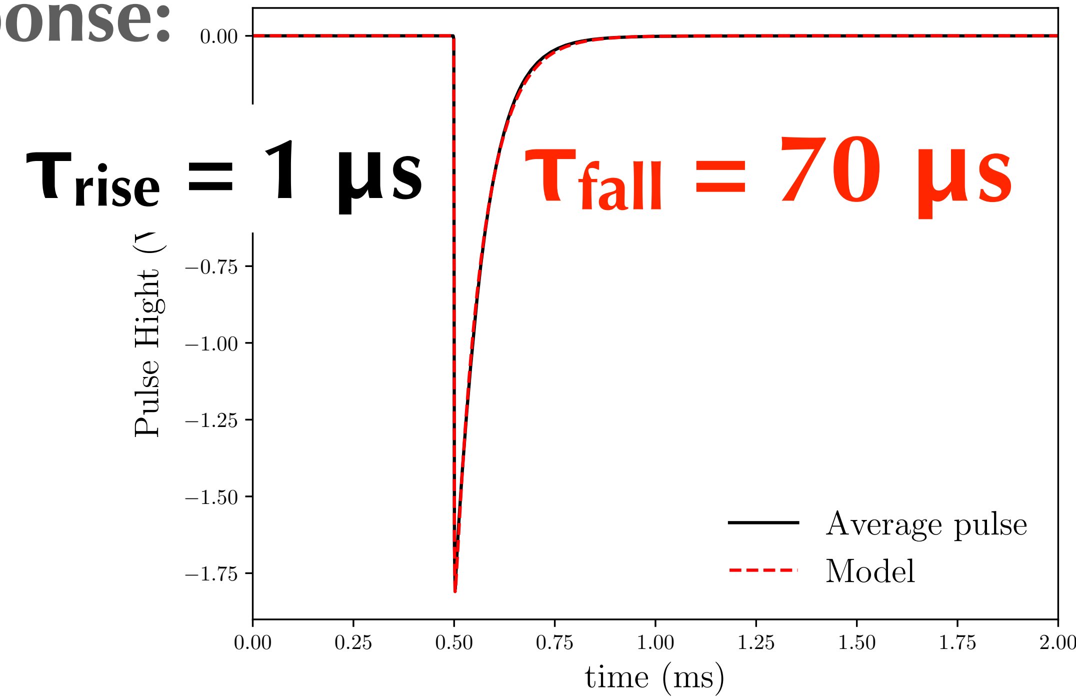
EDS : Energy Dispersive X-ray Spectroscopy

64 pixel TES array for STEM-EDS

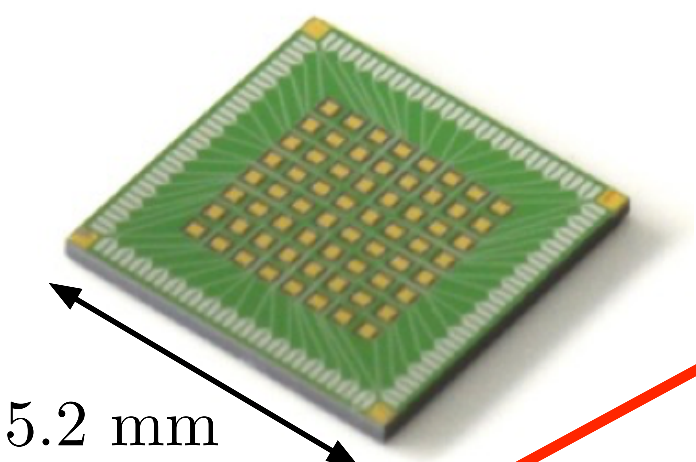
System requirements

1. High energy resolution : < 10 eV
2. High counting rate : < 5 kcps
3. Wide energy band : 0.05 - 15 keV

- Tc = 162 mK
- **Fast response:**

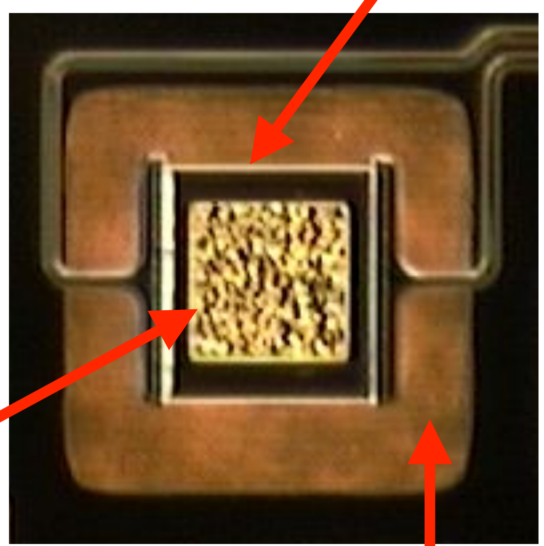


- Fabricated in house using the JAXA nano clean room



(Ti/Au=40/90 nm,180 um²)

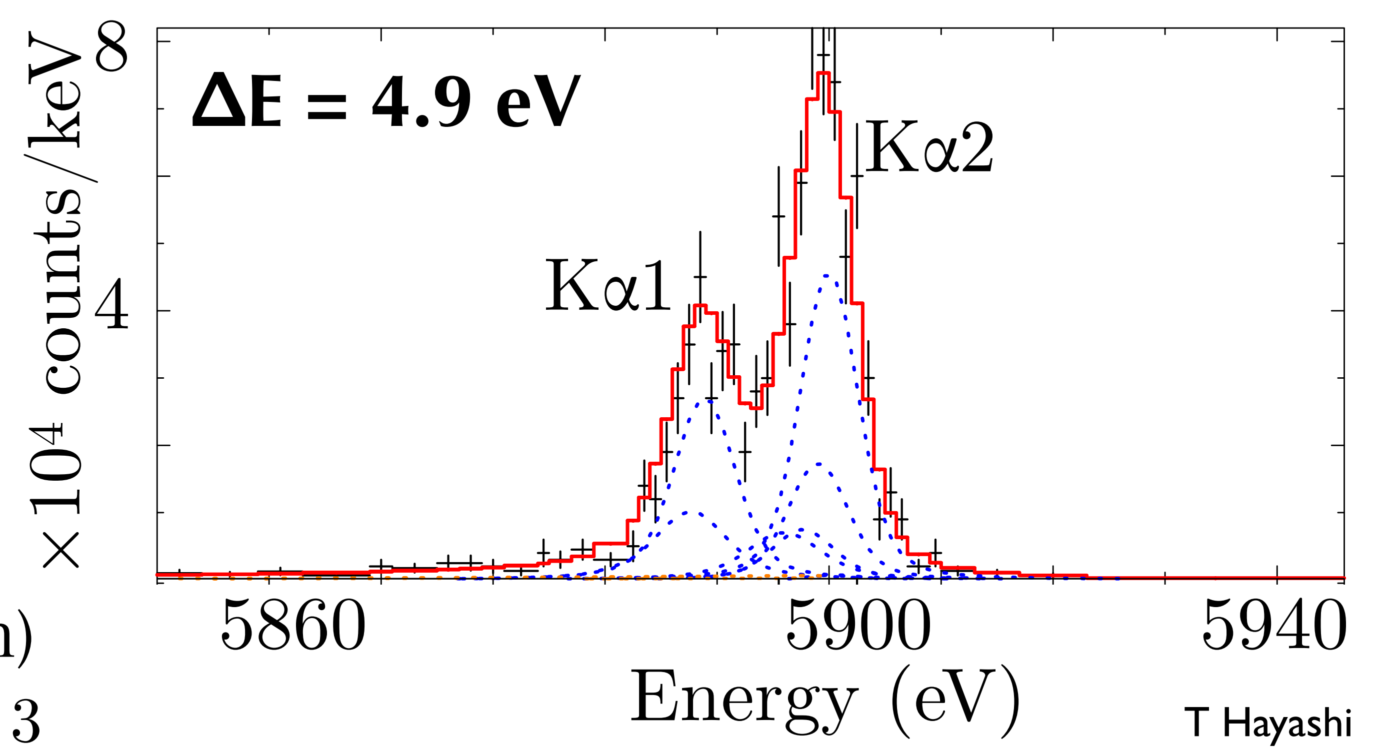
TES



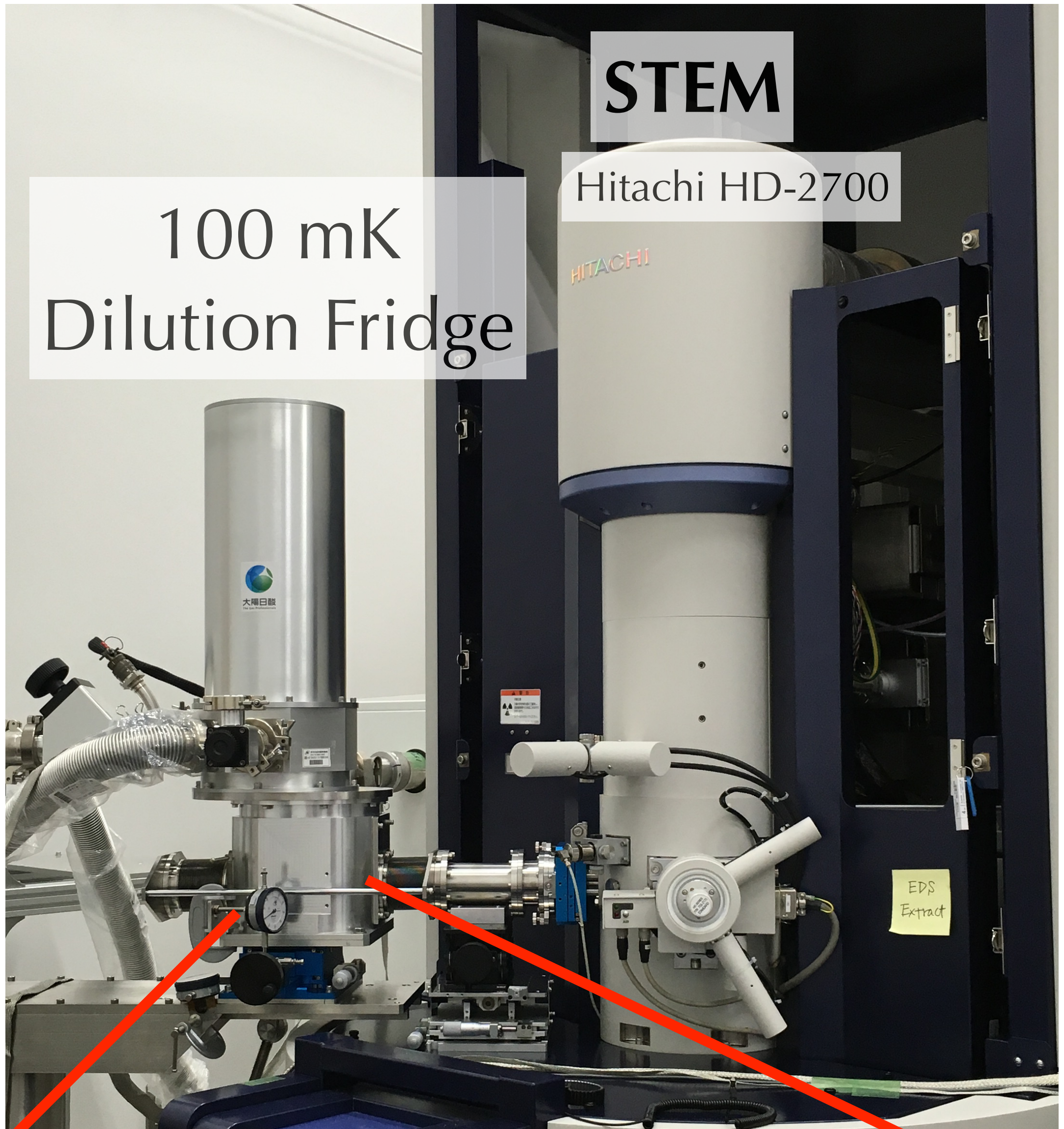
Au absorber
(120 um², t4.2 um)

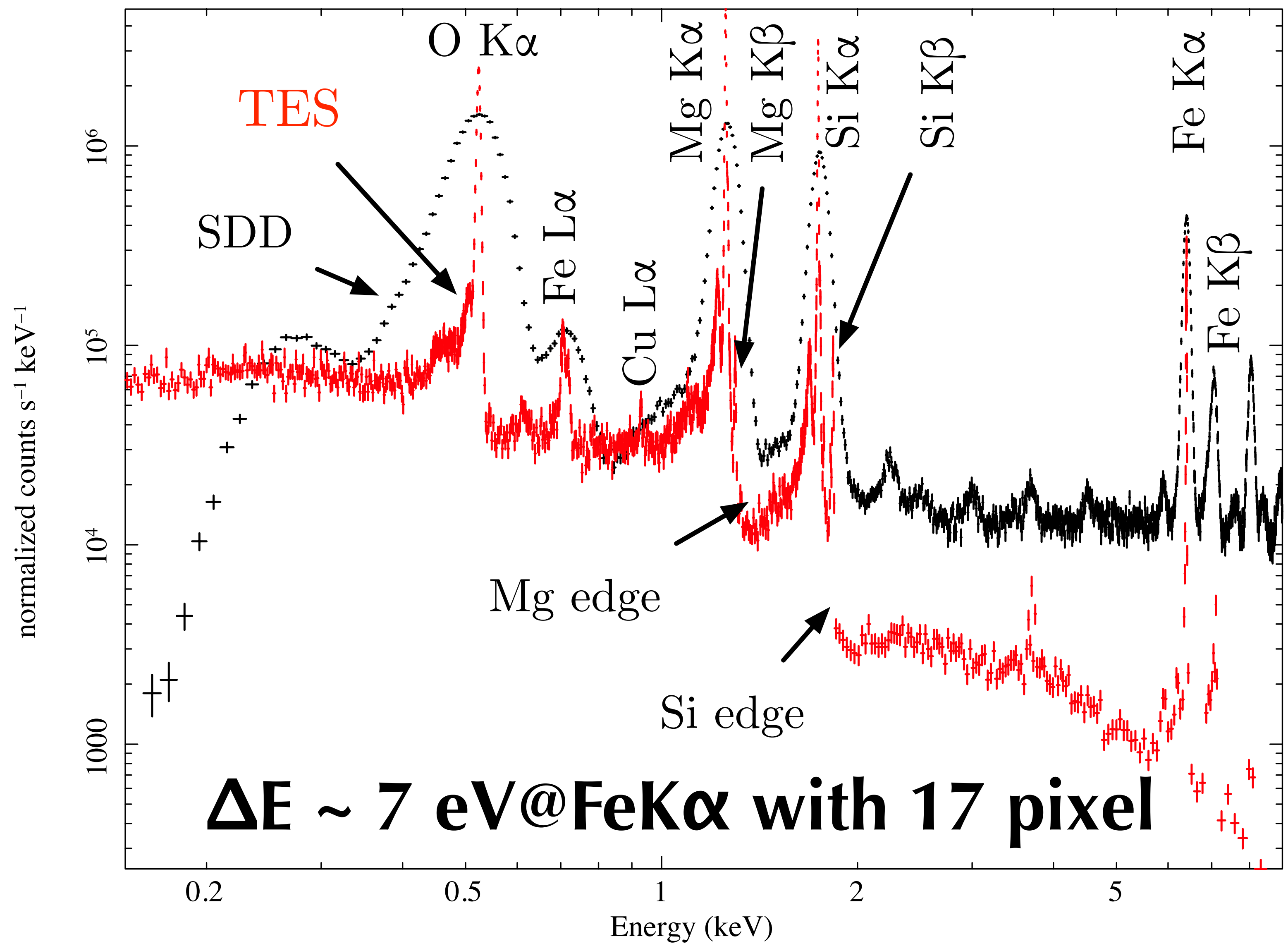
Membrane
(SiN_x/SiO_2=1/0.5 um)

- Single pixel performance @ JAXA lab environment



STEM TES EDS system and performance





We were able to…

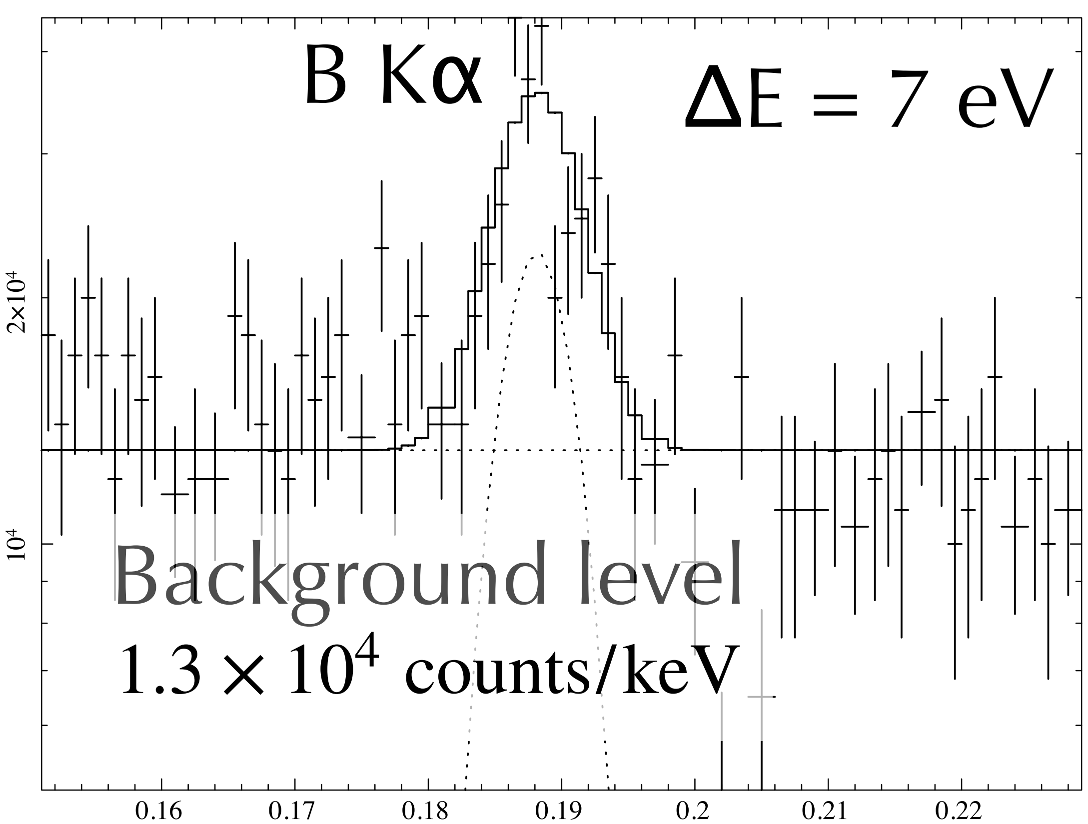
- ✓ detect an emission line of CuLα, SiKβ, MgKβ
- ✓ detect a self absorption of specimen
- ✓ resolve the continuum and the line emissions

Detection limit in the low energy band

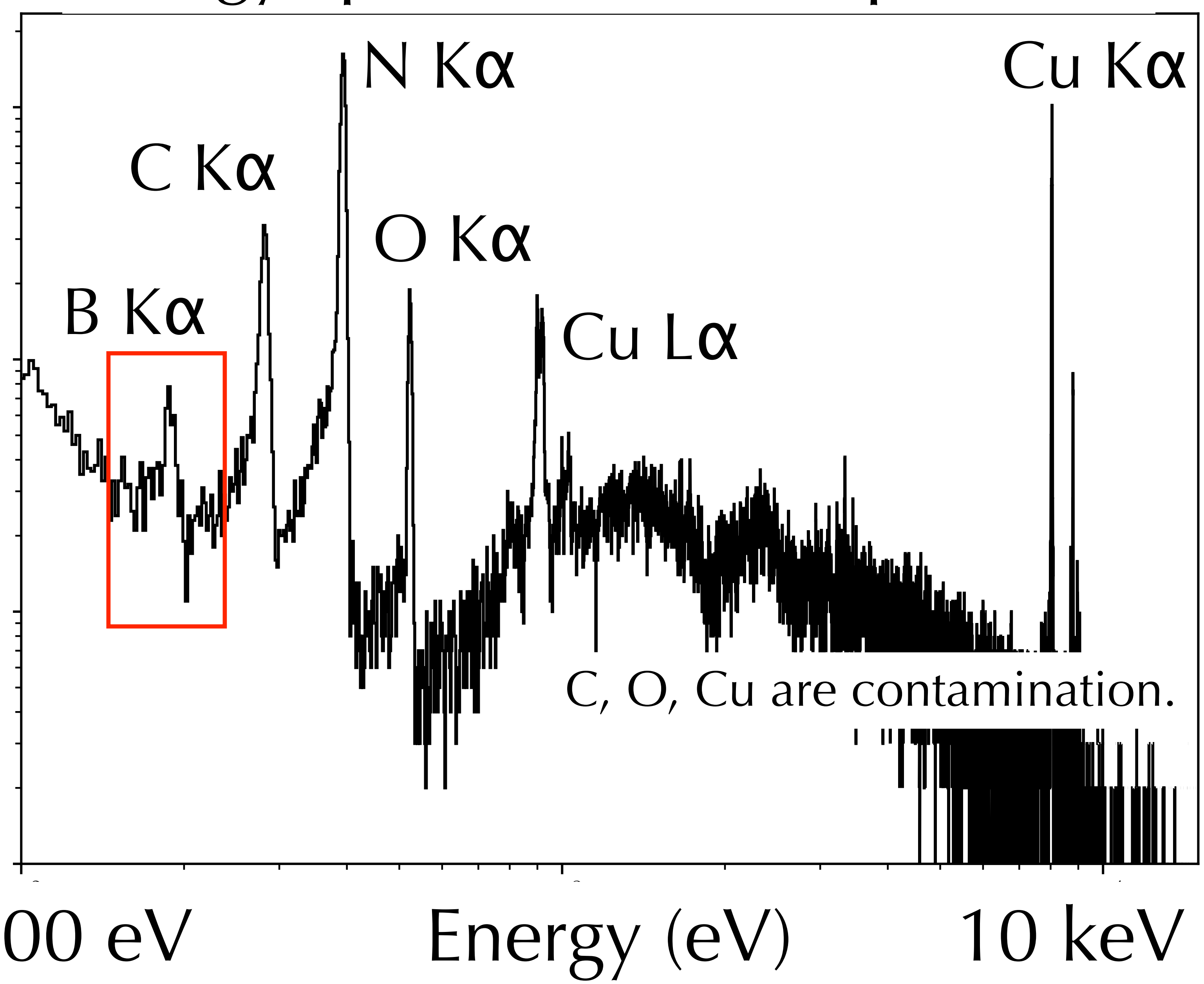
- In old system, it is difficult to detect a low energy X-ray below 300 eV.

Low energy band sensitivity is limited by

- the background level
- an absorption of the OBF (OBF:optical blocking filter)
- fluorescence yields of elements



Energy spectrum of BN specimen



Compatibility between the high and the low energy band

- We need to increase the signal to noise ratio by improving energy resolution, because other factors are difficult to change.

- To improve the DL 10% ΔE needs to improve below 4 eV

- Decreasing the C or Tc for improving ΔE

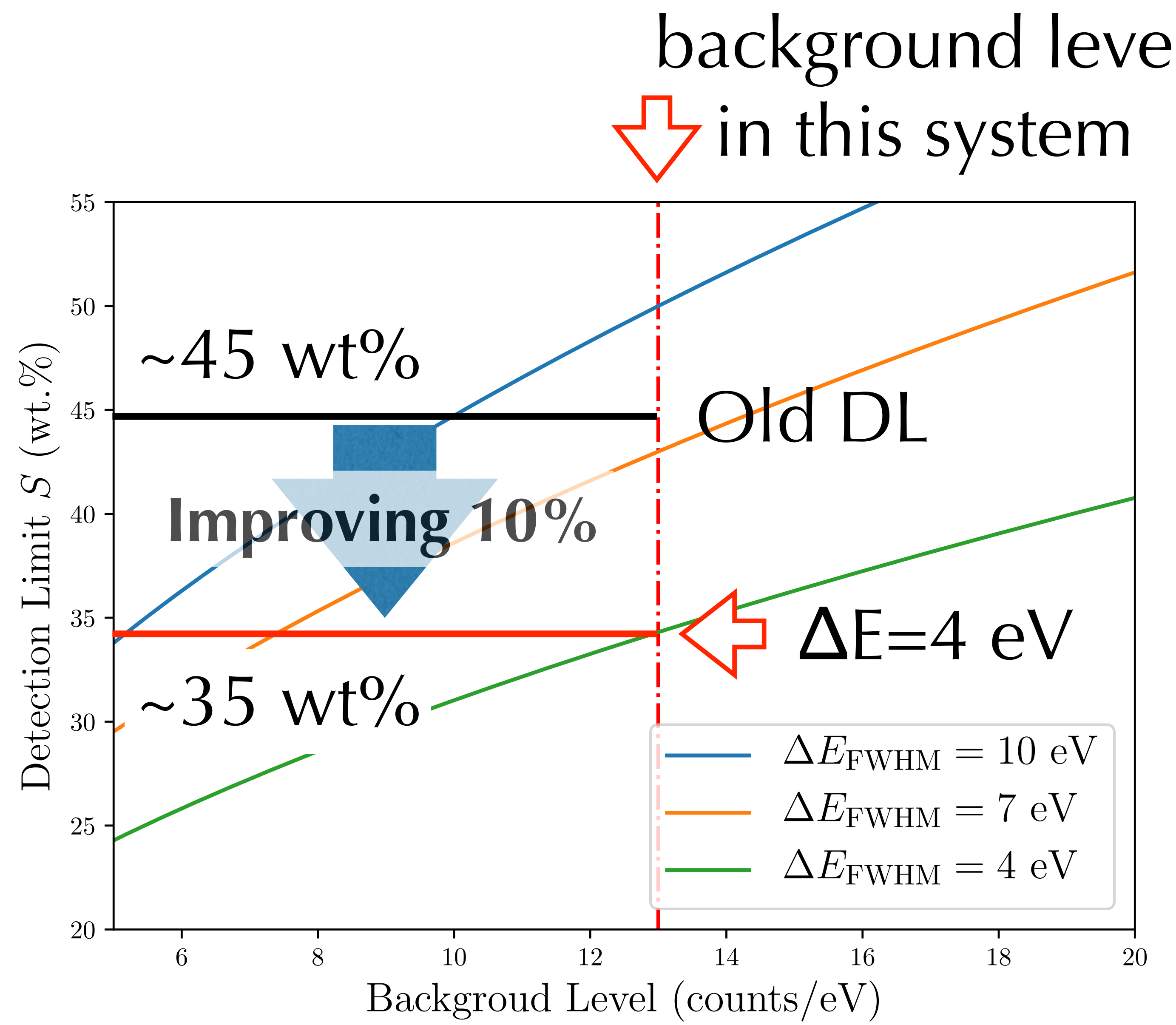
$$\Delta E \propto \sqrt{k_B T^2 C}$$

- However decreasing of C or Tc makes the energy band narrow

- **We set two different types of TES on single device for covering low energy band and high energy band**

$$S/N = \frac{S}{\sqrt{S + \Delta E b(1+\epsilon)/2.35}},$$

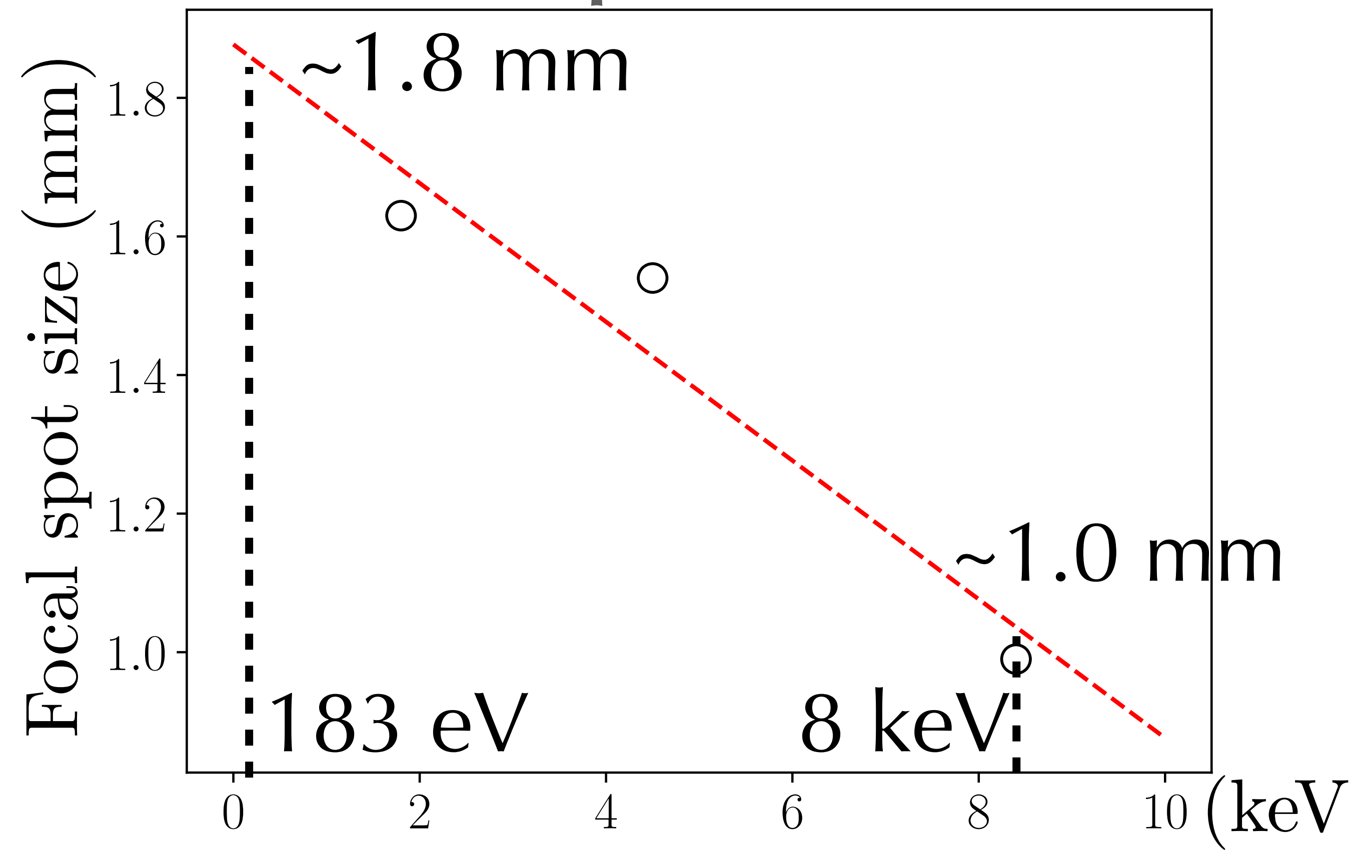
ΔE : energy resoltuion (eV),
b : Backgroud level (counts/eV),
S : signal intensity (counts), ϵ : fudge factor ~ 1



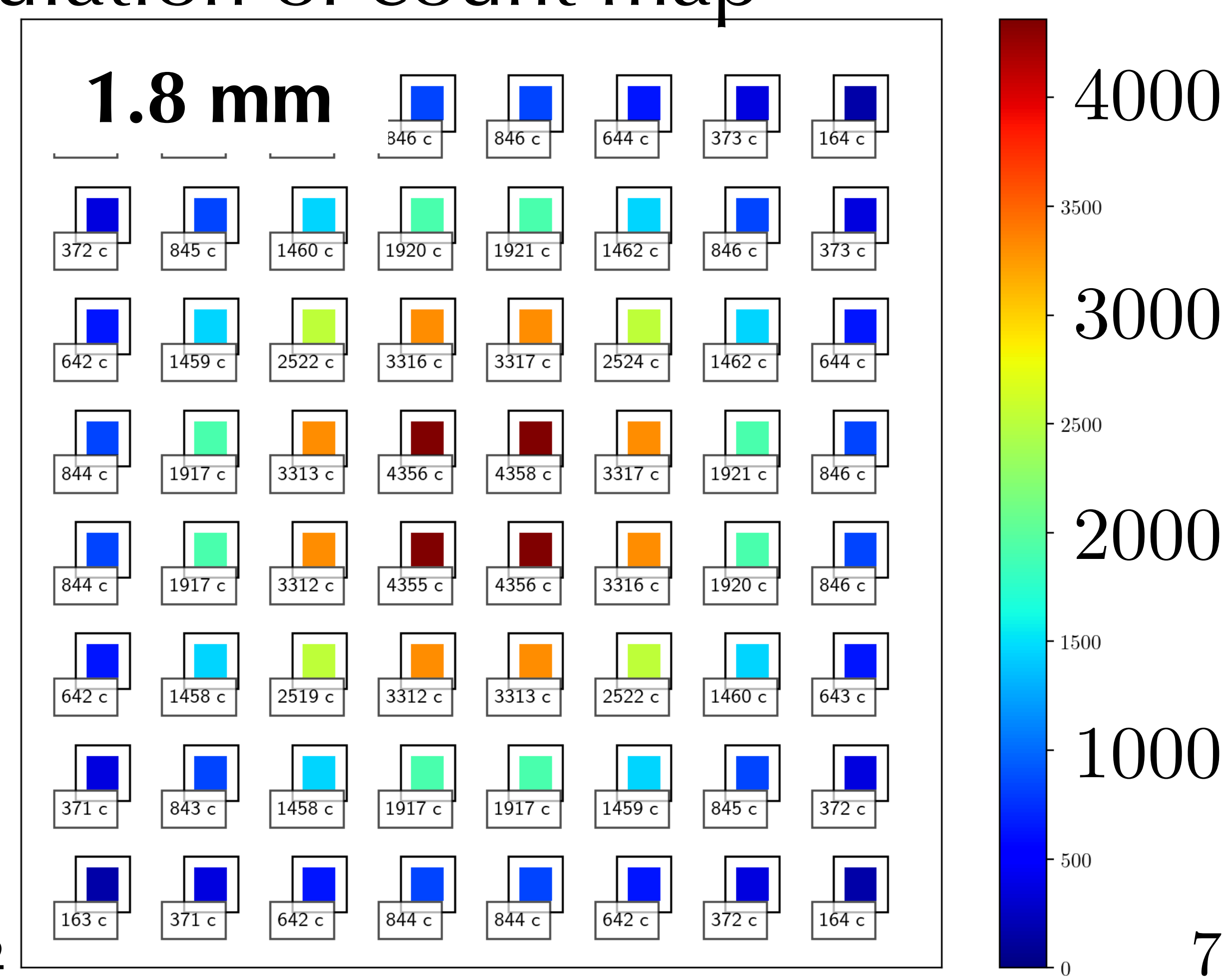
Broadening of X-ray on the TES chip

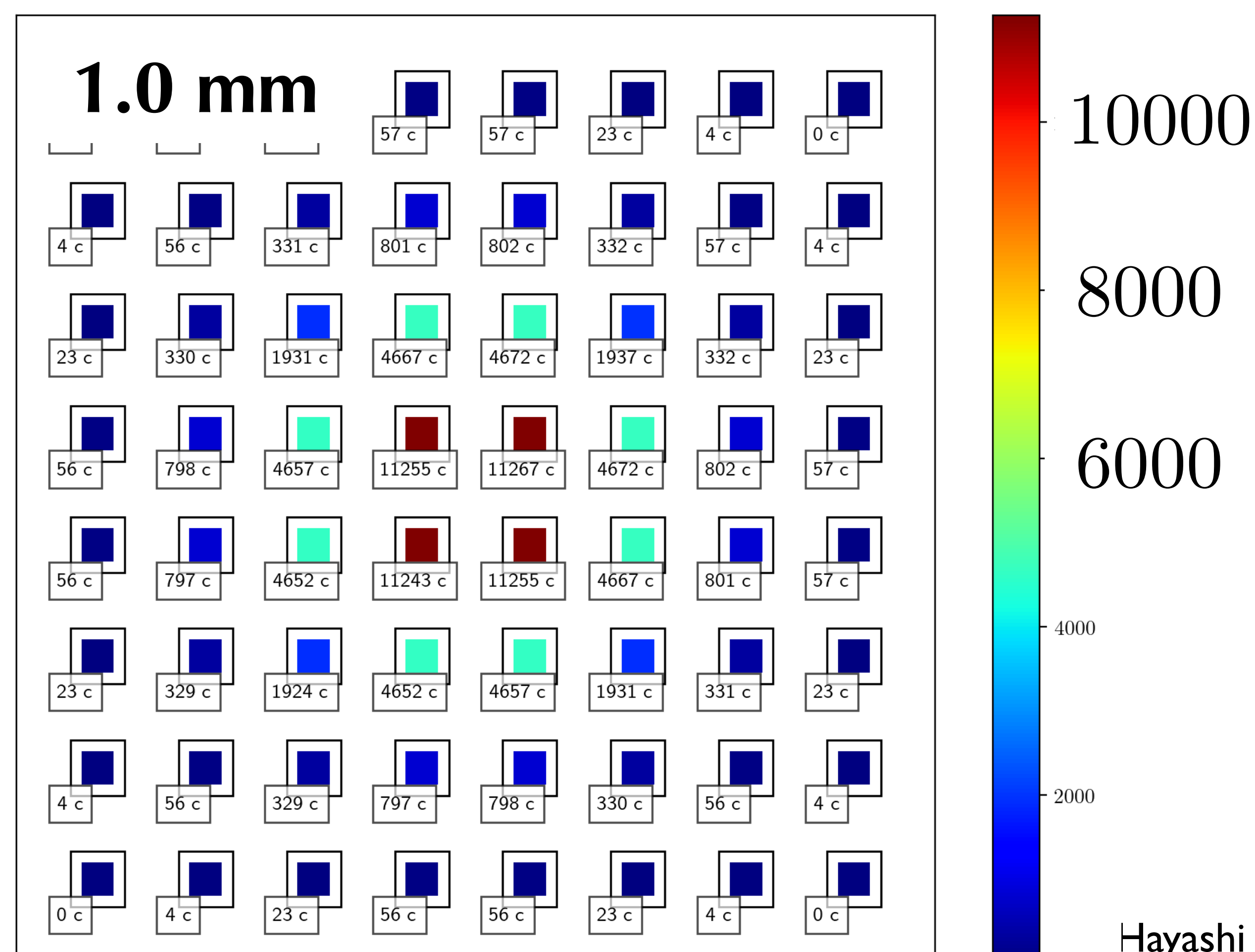
Takano et al., 2017

- An X-ray photon from specimen is collected by **poly-capillary optics**
- **The refraction of the poly-capillary depends on the energy**
- Spread of the low energy X-ray is broader than high energy on TES chip



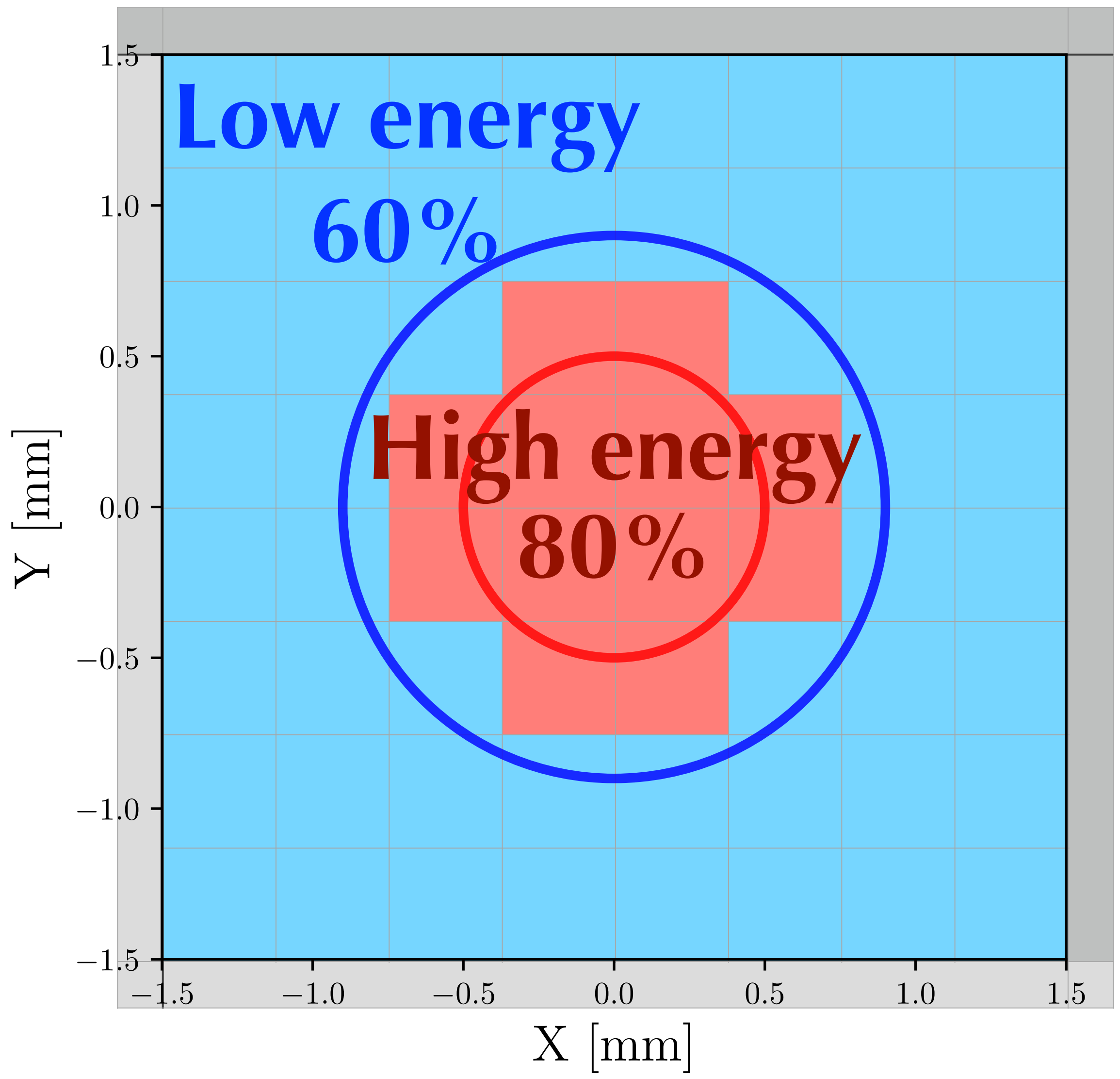
Simulation of count map



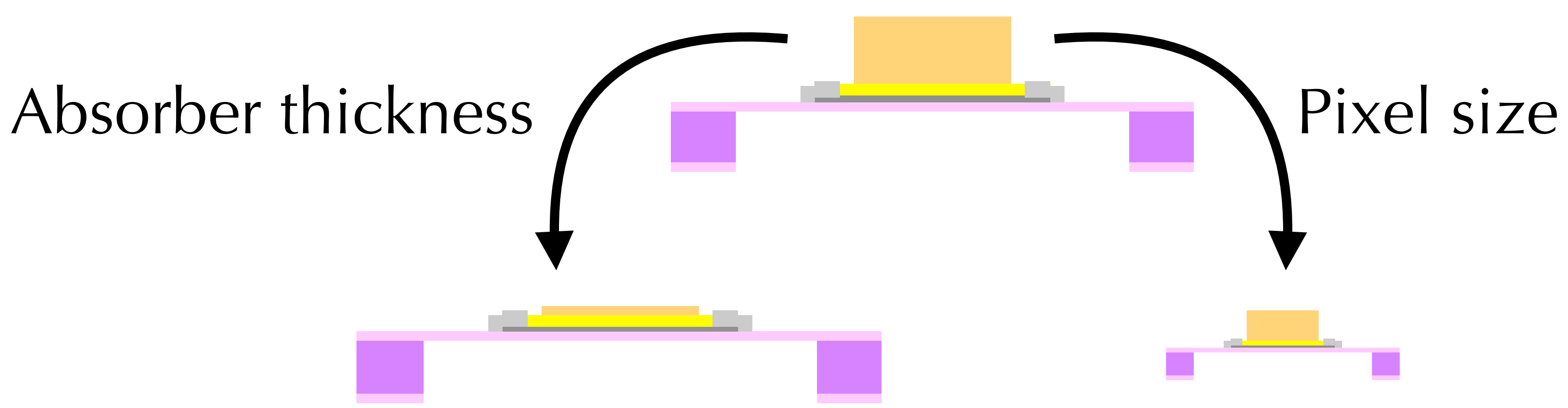


Concept design

- In high energy bands, the centroid 12 pixels occupied about 80% of total counts.
- In low energy bands, the outside 52 pixels occupied about 60% of total counts.
- In order to satisfy both high and low energy, the TES for low energy needs to be located at the outer side on the chip

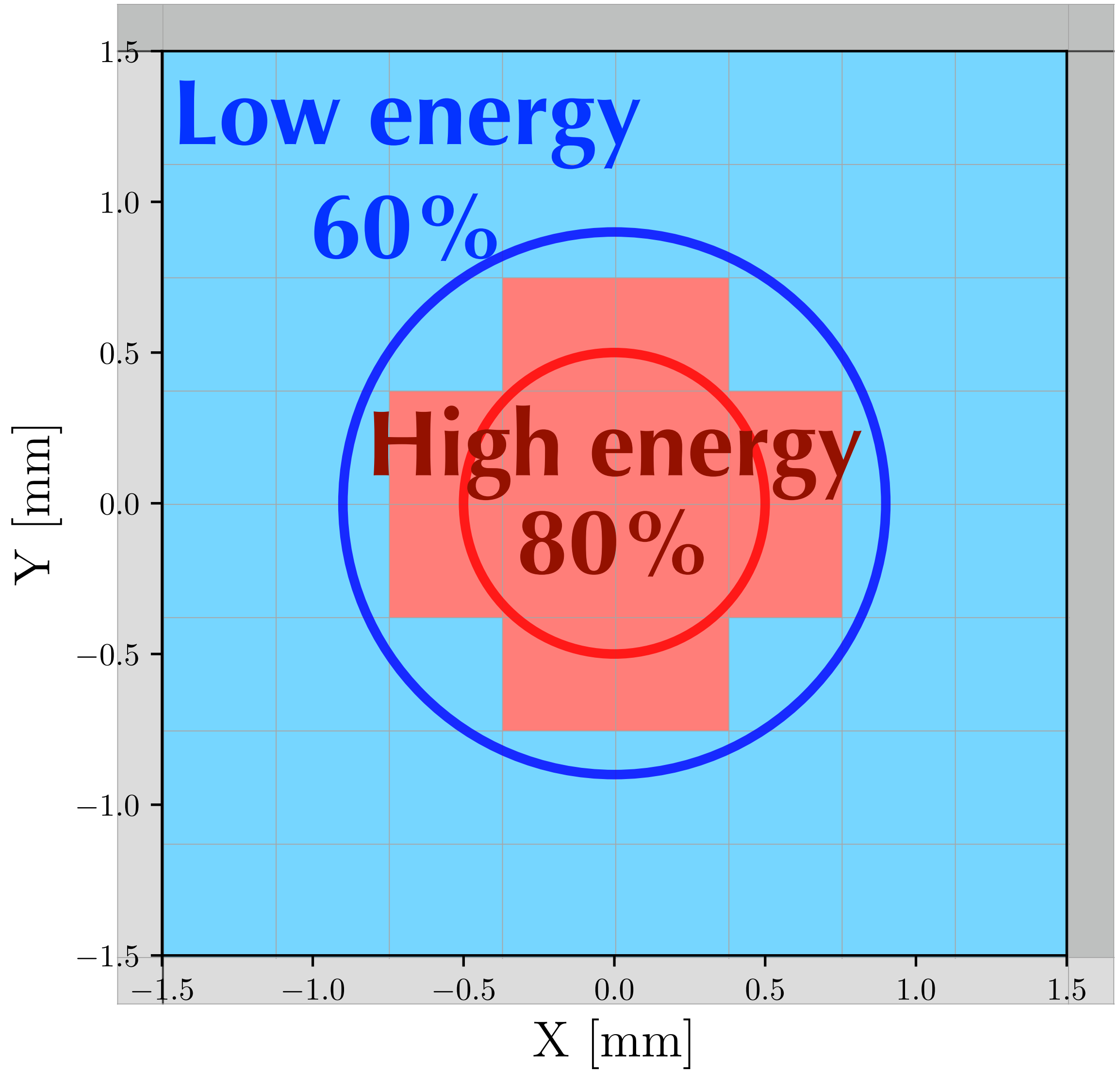


Which TES for low E is better
the small size TES or thin absorber TES?

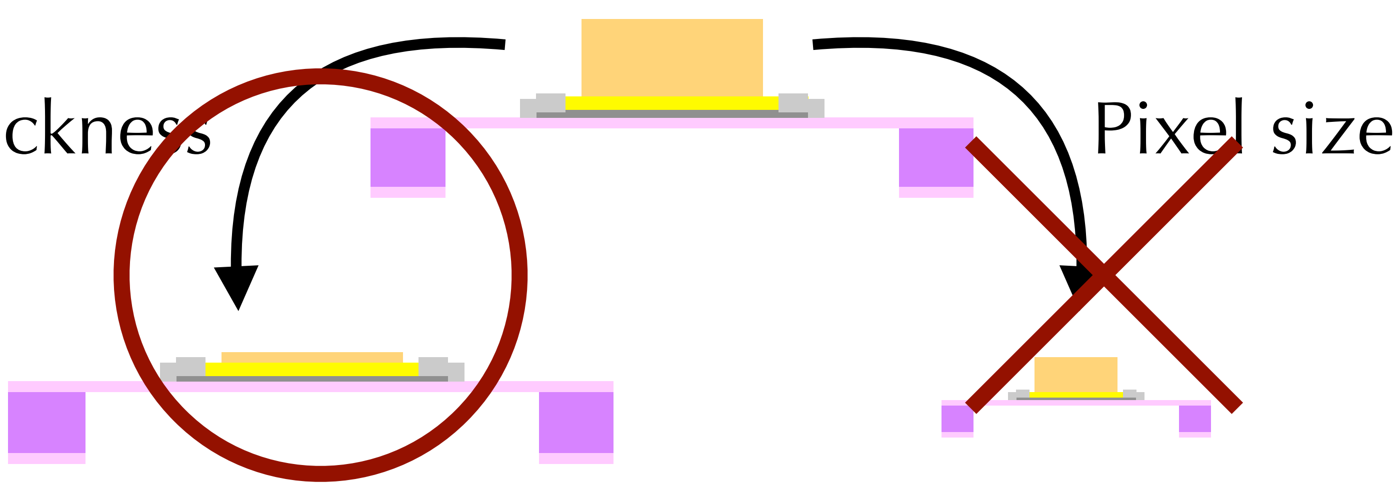


Concept design

- In high energy bands, the centroid 12 pixels occupied about 80% of total counts.
- In low energy bands, the outside 52 pixels occupied about 60% of total counts.
- In order to satisfy both high and low energy, the TES for low energy needs to be located at the outer side on the chip



Which TES for low E is better
the small size TES or thin absorber TES?

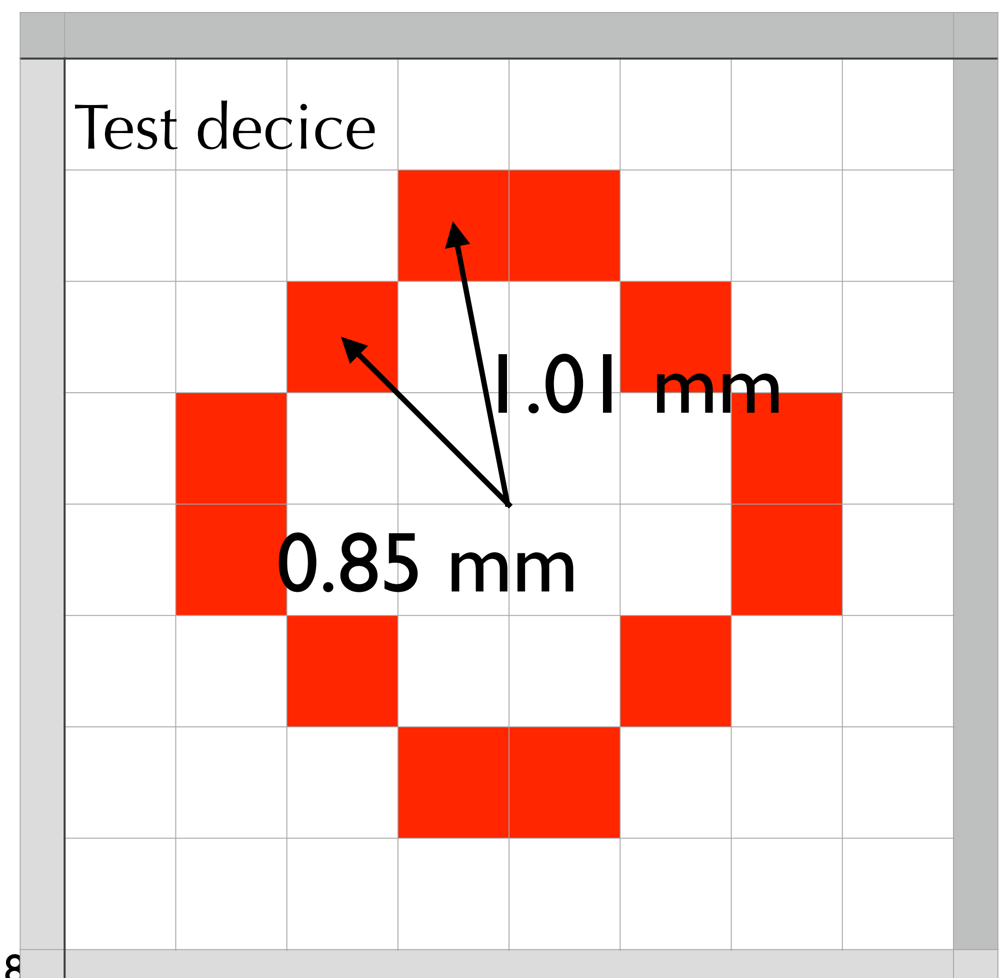


We suggested TES with two different absorber thickness without changing pixel size

Fabrication of a test device with two different type absorbers

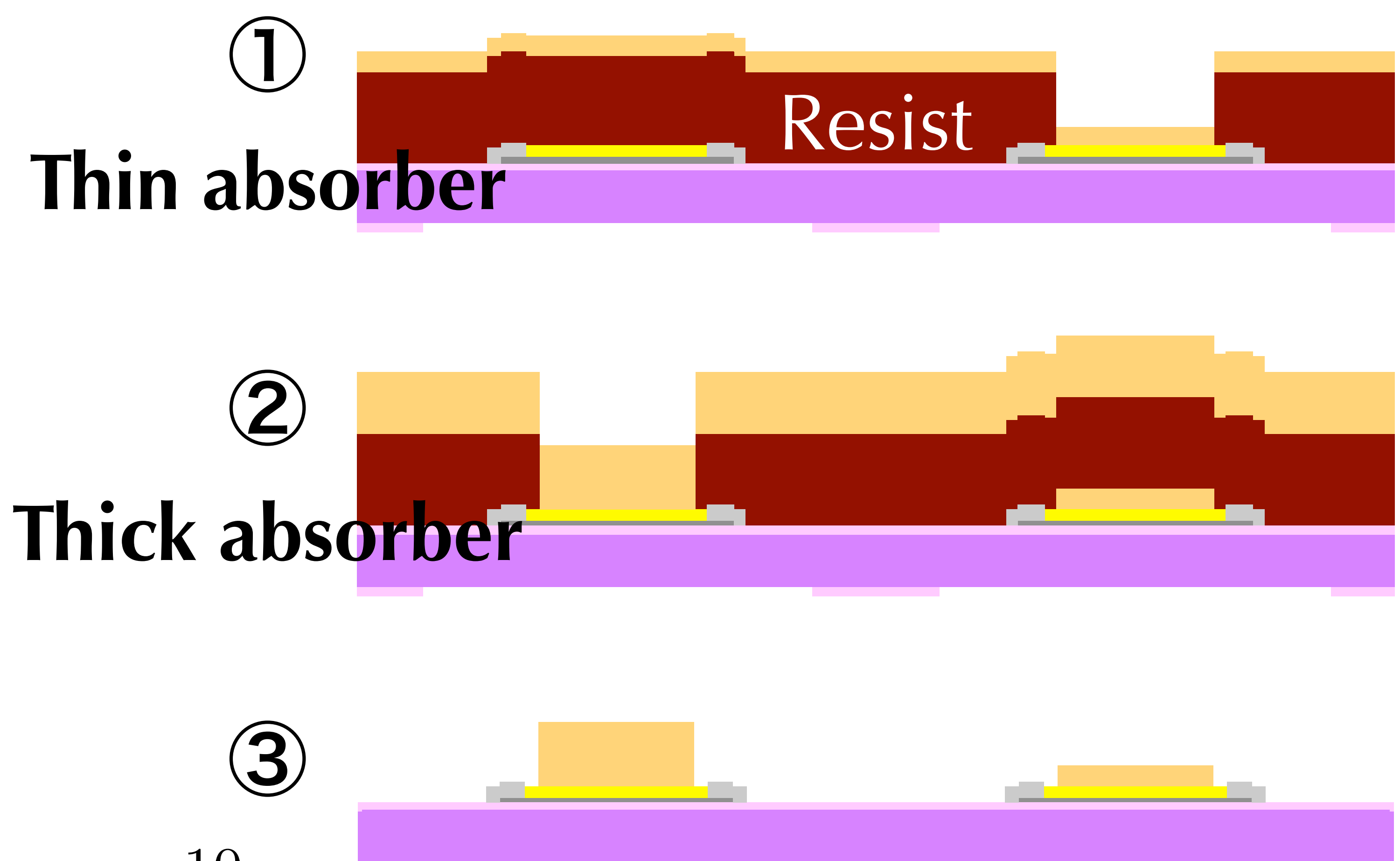
- We set the thin absorber of 300 nm to satisfy requirement of the ΔE, Esat
- For demonstration, we located the 12 thin absorbers to occupy about 20% of total counts.
- In order to realize two different type absorbers, the thin absorber was formed first and then the thick absorber was formed.

Location Map of thin absorber



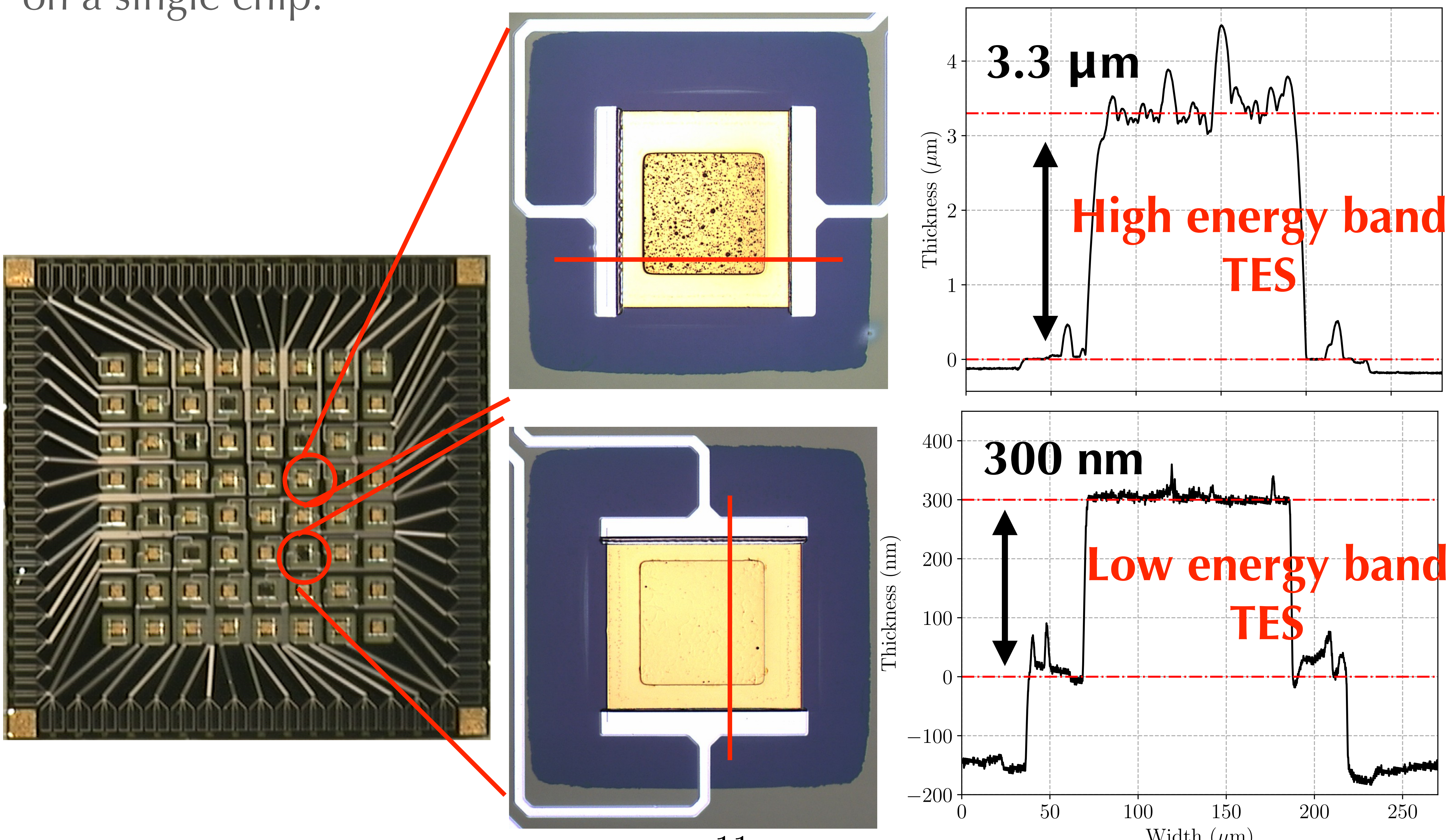
Fabrication process of absorber

by EB evaporator and the lift off process.



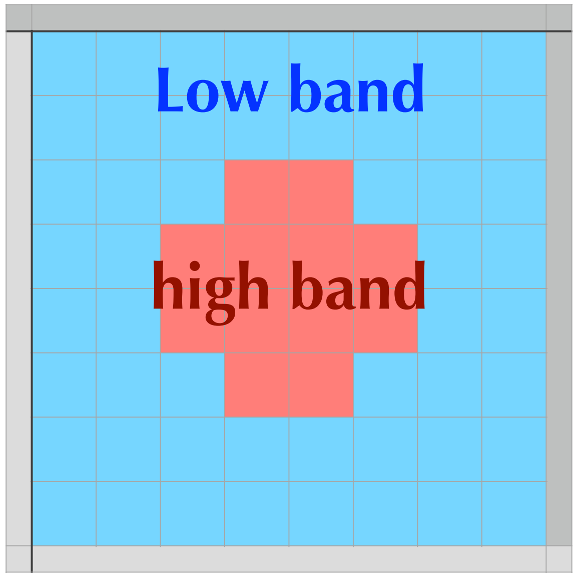
Fabrication results

- ✓ We were able to fabricate two different type absorbers with the target thickness
- ✓ We established the process that fabricate the thin absorber and thick absorber on a single chip.



Conclusion

- Towards the microanalysis of astromaterials for our solar system, we have been developing the STEM-TES-EDS system.
- In the low energy band below 500 eV, old system is low sensitivity.
- **We suggested the concept design of TES with two different absorber thickness to increase sensitivity in low energy band.**
    - TES pixels of the low E band were located out side.
    - TES pixels of the high E band are centroid 12 pixel.
    - We controlled the absorber thickness to degrease C without changing the geometry of pixel.



- We fabricated test device to confirm the performance of the TES with 2 different type absorber thickness.

Future plans

- We'll fabricate the concept design TES and evaluate its performance by EDS system.
- We would like to analyze the Hayabusa-2 sample using this new system at 2020!

Thank you for your attention!

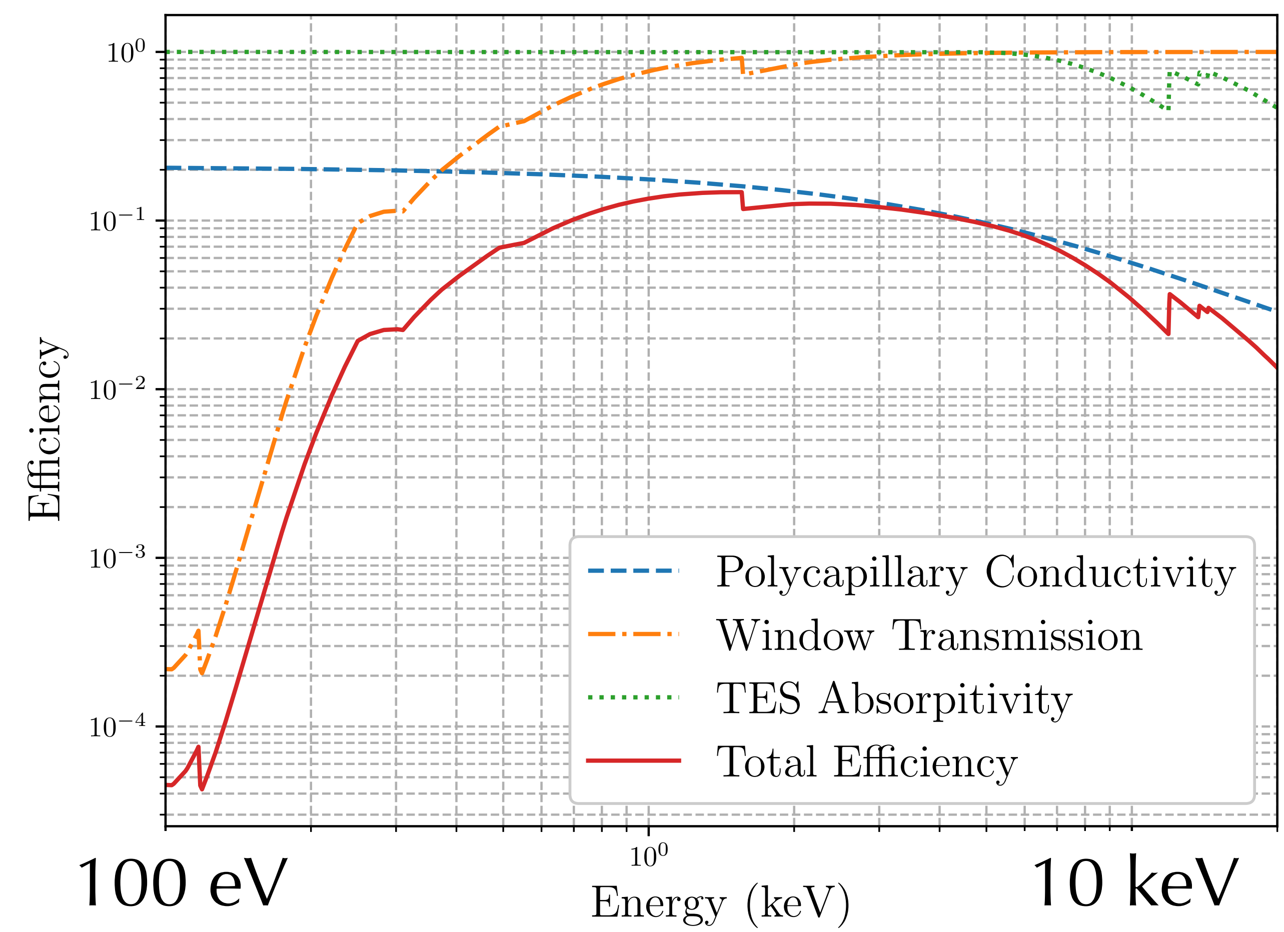
Detection Efficiency

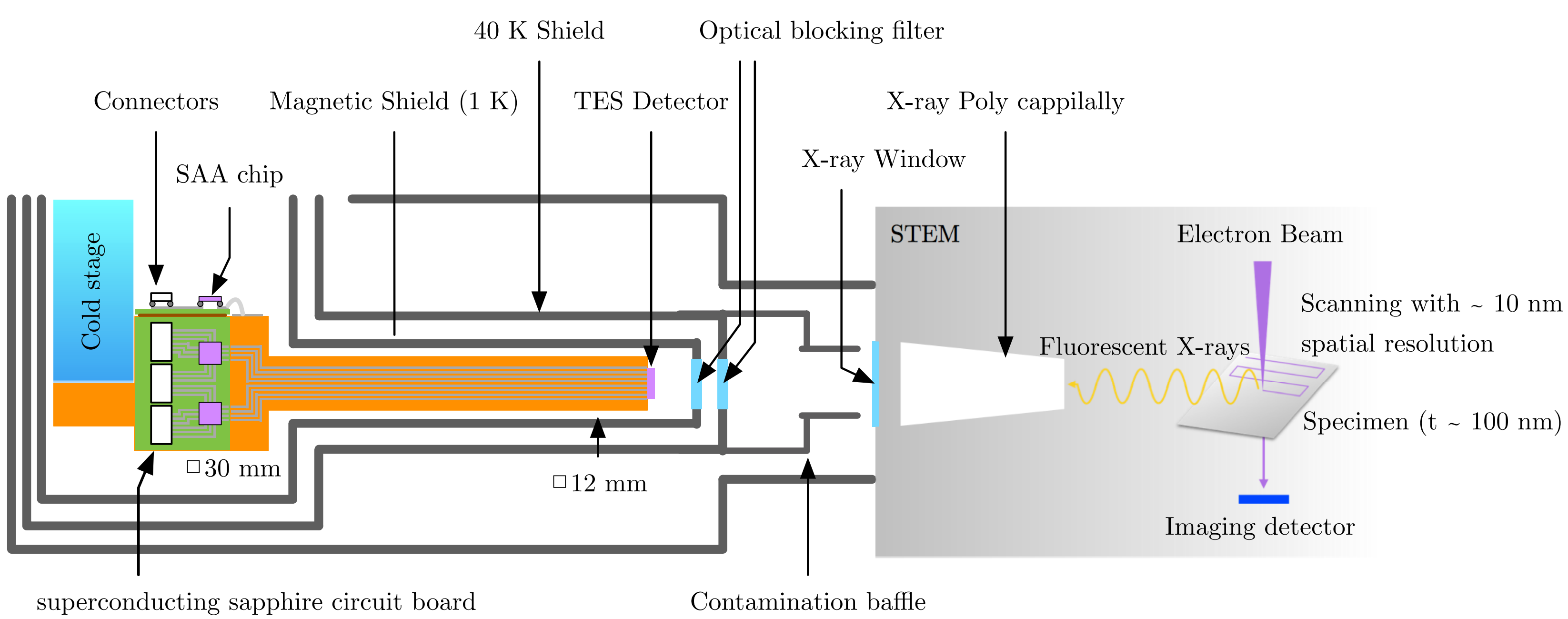
- We calculated the detection efficiency by considering optical path
- The florescent X-rays emitted from the sample

→ X-ray poly capillary (throughput)

→ X-ray window/filters (Transmission efficiency of Al/polyamide)

→ Detection efficiency of the TES (quantum efficiency of Au)



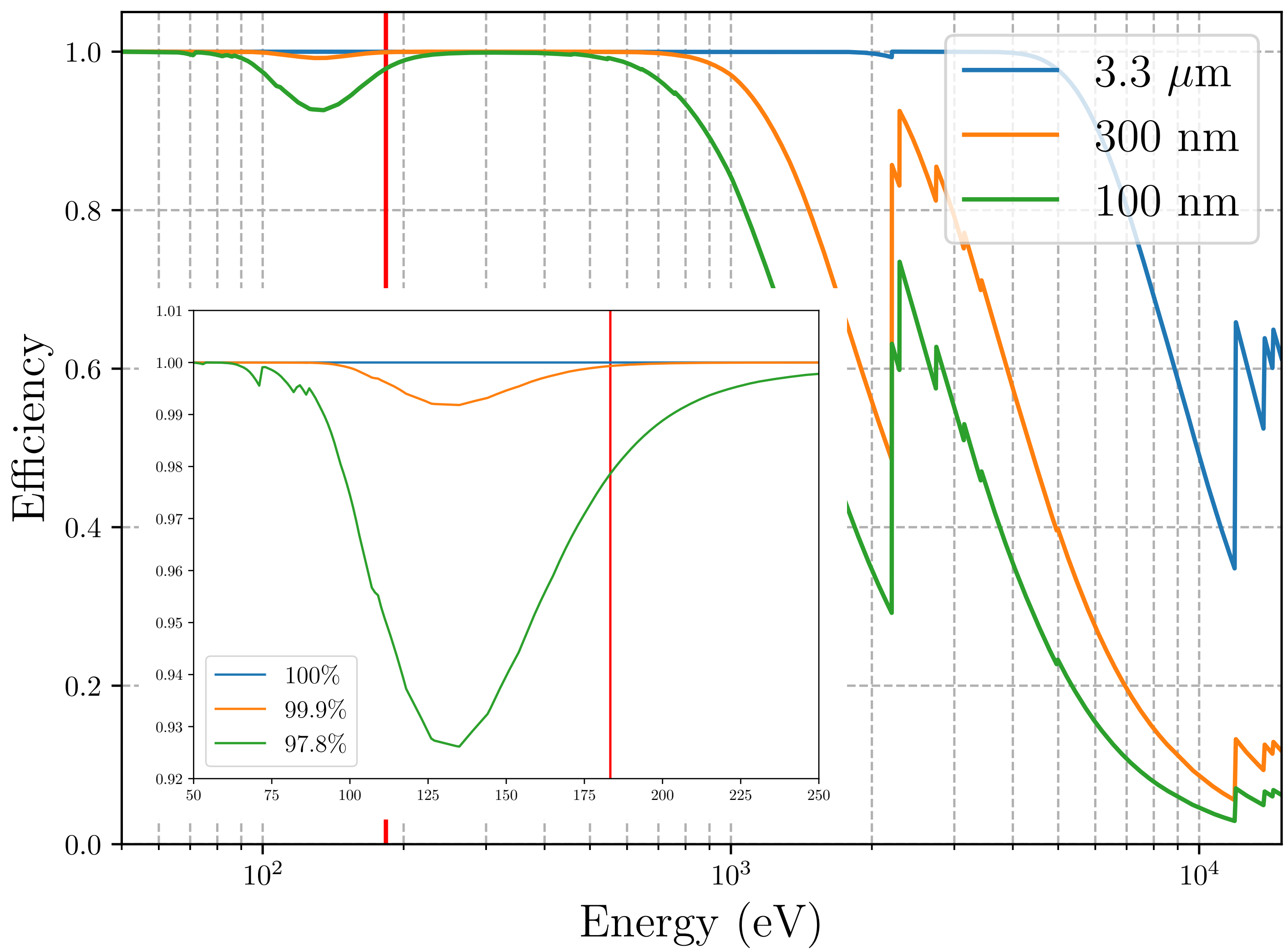


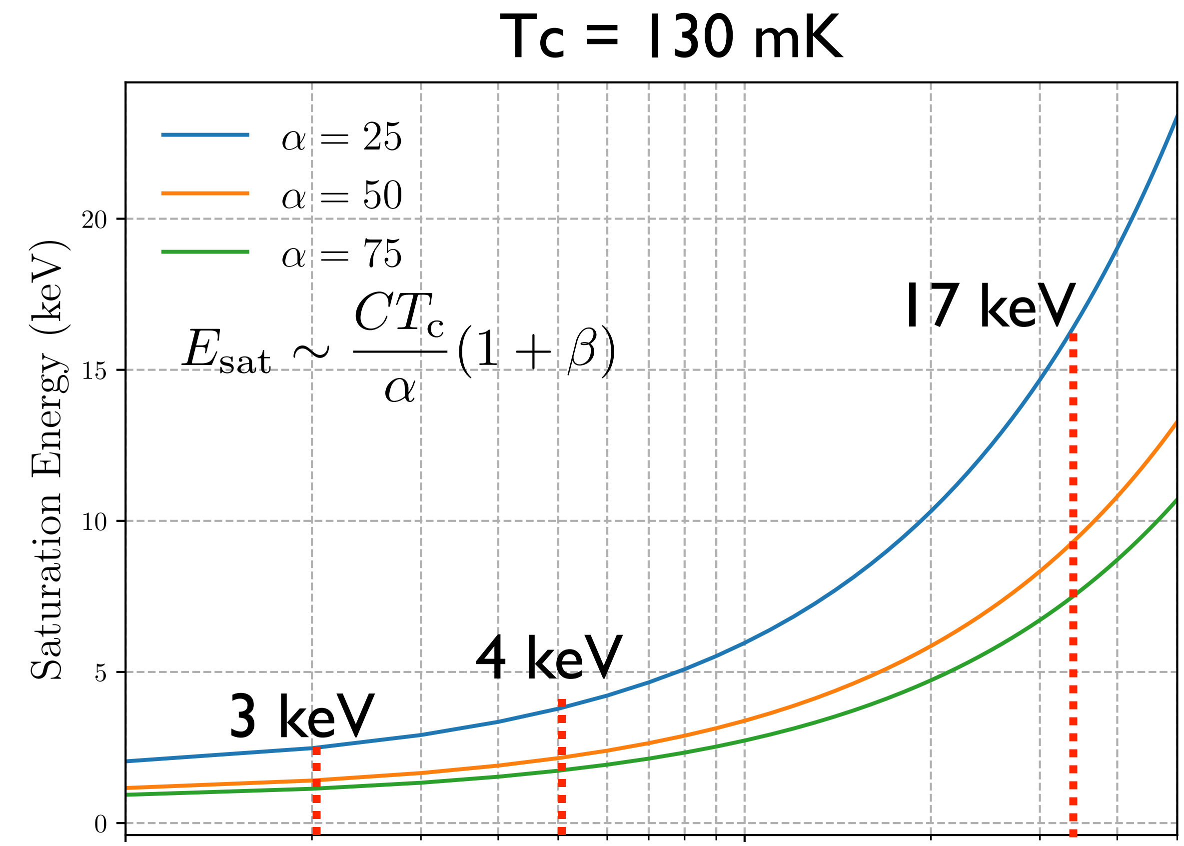
Optimization of the thin absorber thickness

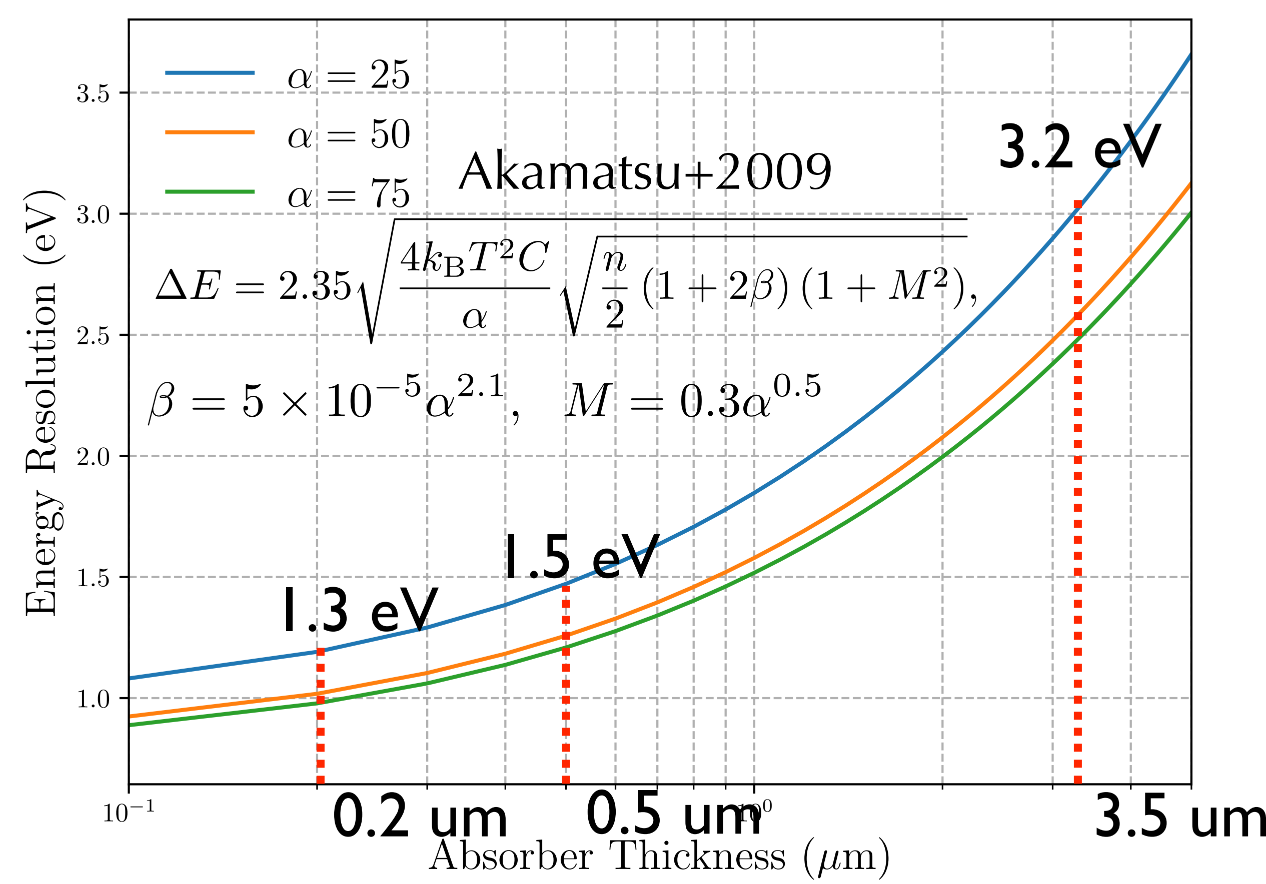
Requirements for thickness

- Esat > 2.0 keV (B (Li) - Si)
- ΔE < 2 eV
- Quantum efficiency > 99%

- There is an absorption edge of Au at 0.15 keV
- We adopted thickness of 300 nm

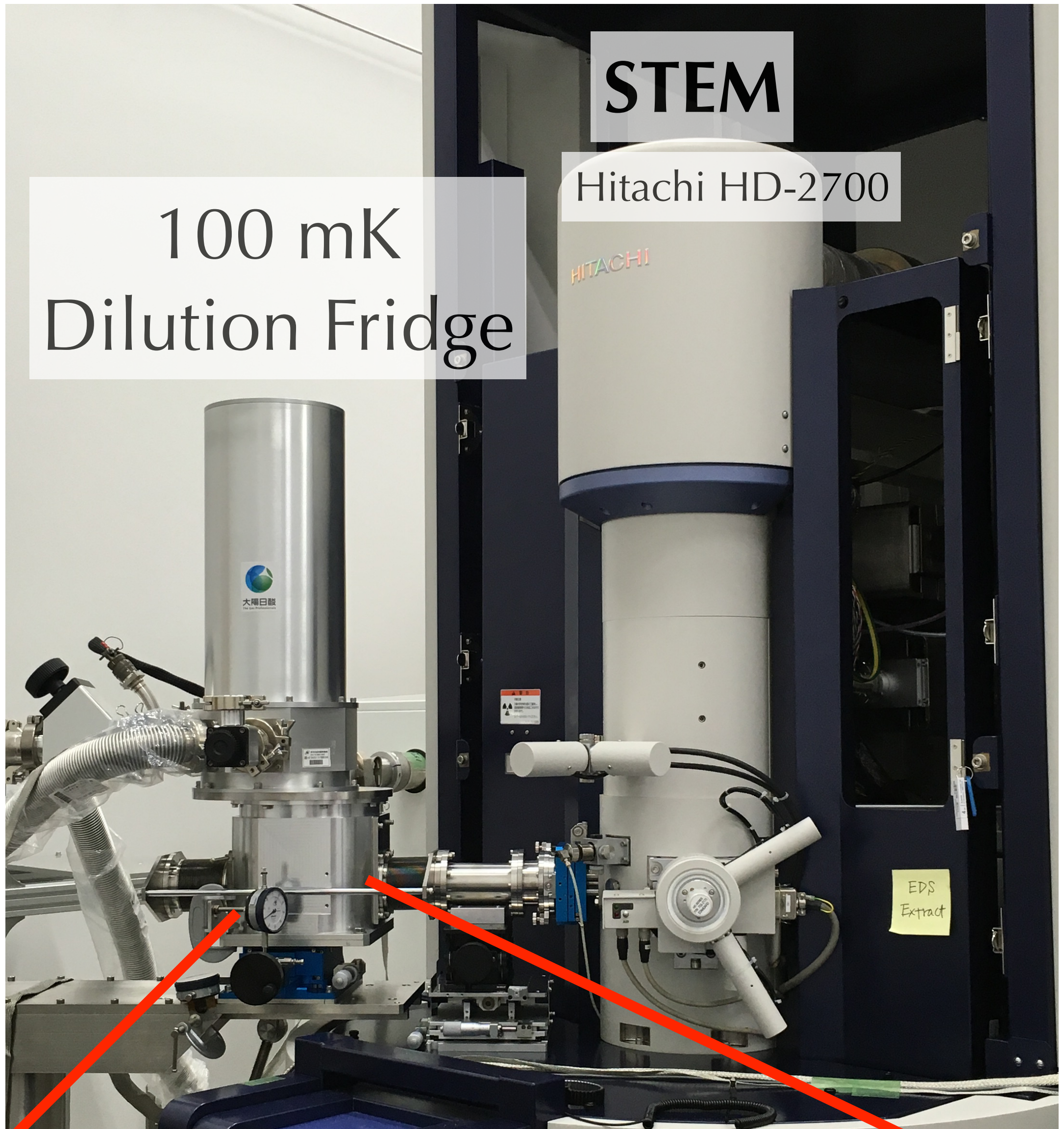


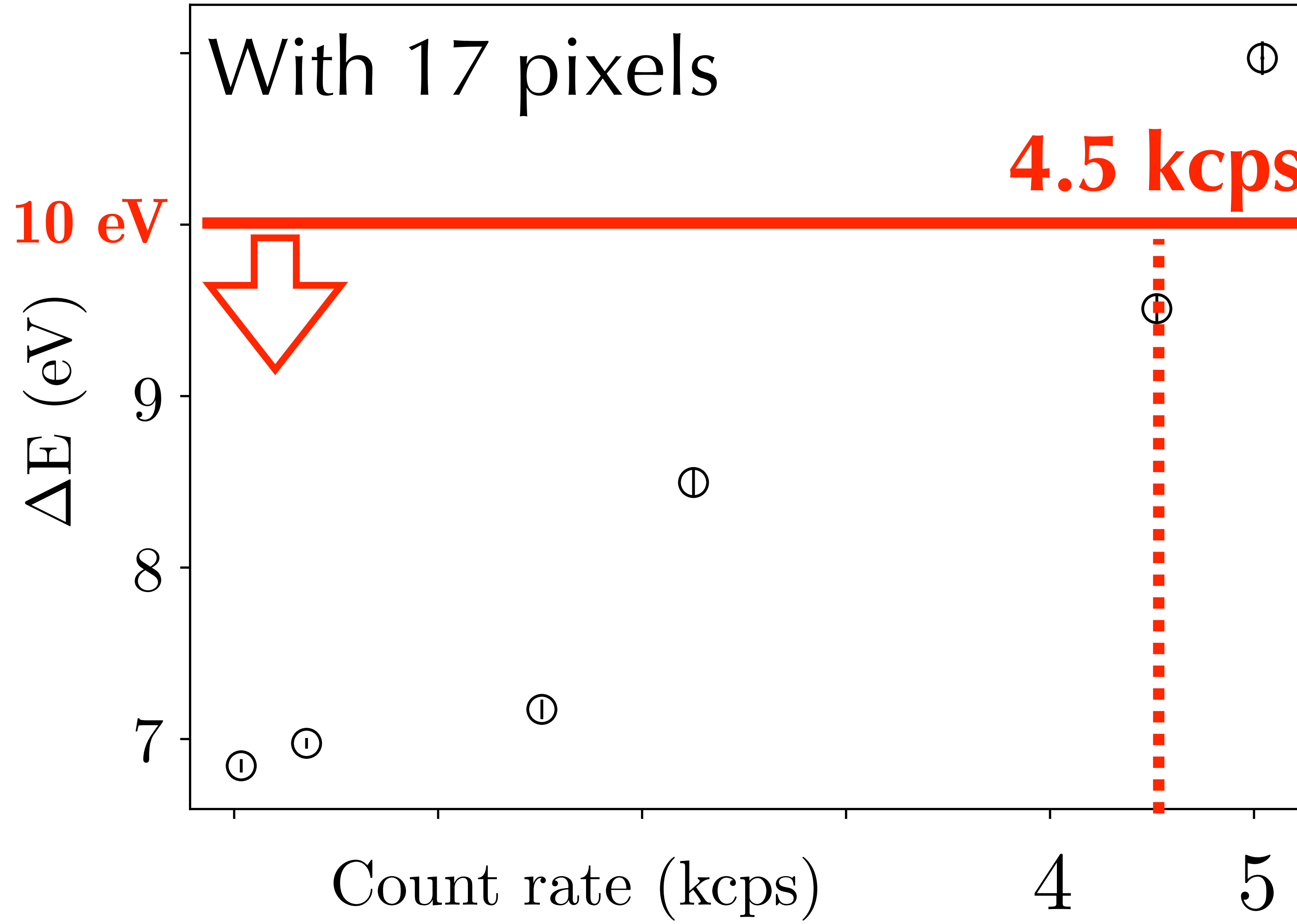




T Hayashi

STEM TES EDS system and it's performance





We were able to…

- ✓ detect an emission line of CuLα, SiKβ, MgKβ
- ✓ detect a self absorption of specimen
- ✓ resolve the continuum and the line emissions
- ✓ **ΔE < 10 eV @AlKα under 4.5 kcps**