Evaluation of X-ray astronomical SOI CMOS pixel sensor aimed at improvement charge-collection efficiency

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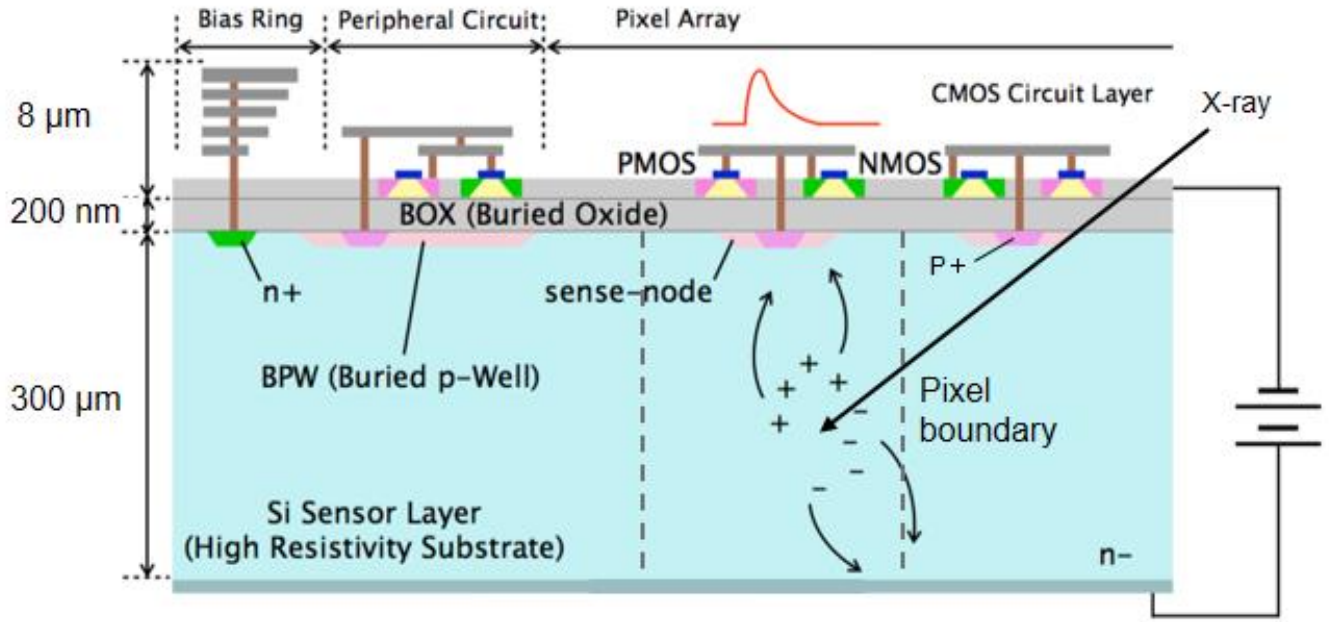
Contents

- Introduction
- Spectrum measurement by using XRPIX6H
- Subpixel response experiment
- Summary

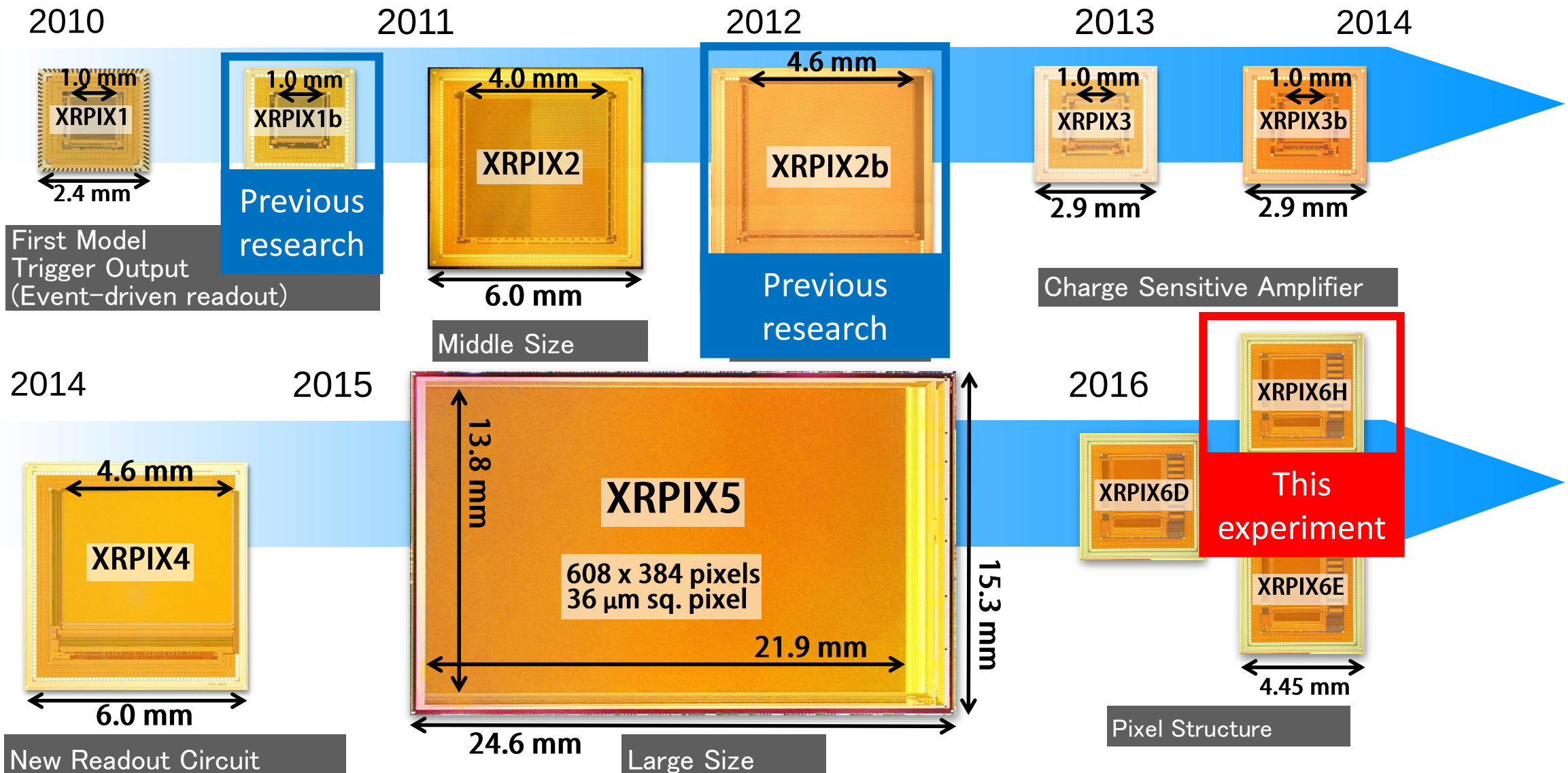
SOI pixel sensor for X-ray astronomical use



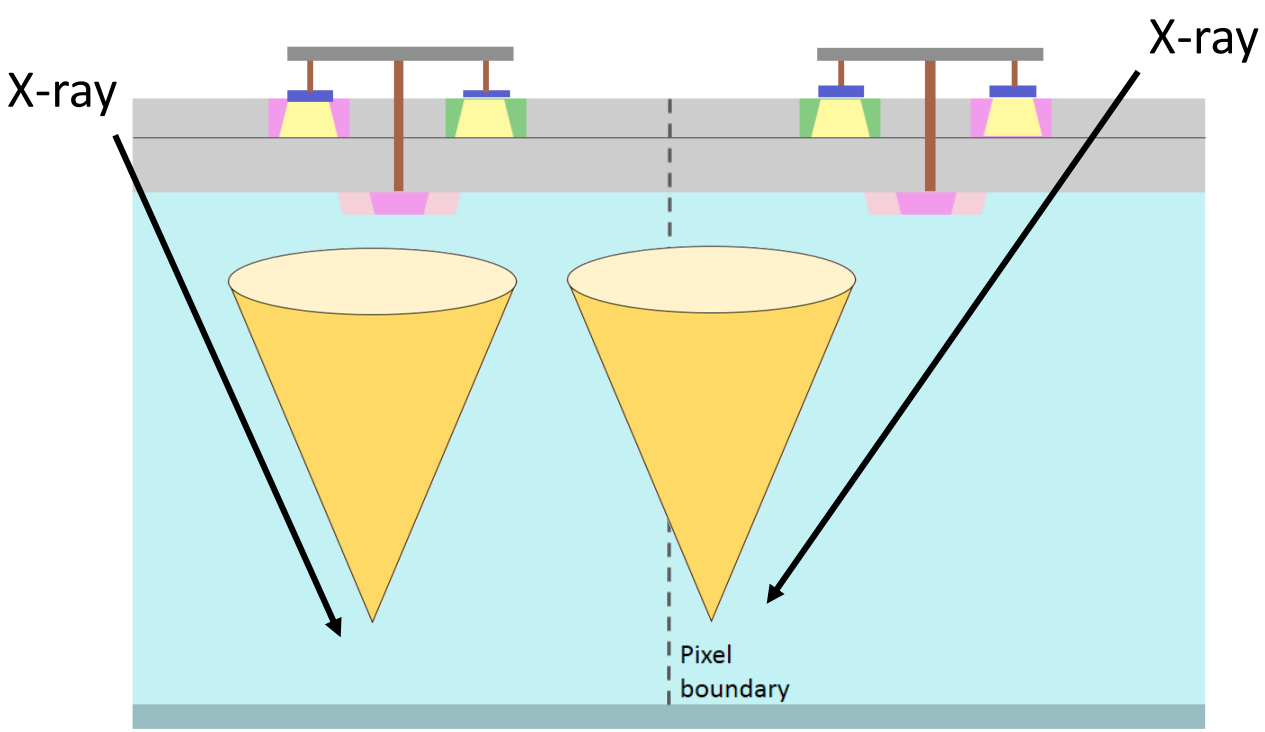
Cross section of our device “XRPIX”

- XRPIX is a monolithic active pixel sensor with Silicon-On-Insulator (SOI) CMOS Technology.
- Two substrate are formed monolithically and have a different resistivity.
- The thick depletion layer and advanced signal processing are compatible. → Ideal for X-ray astronomical use

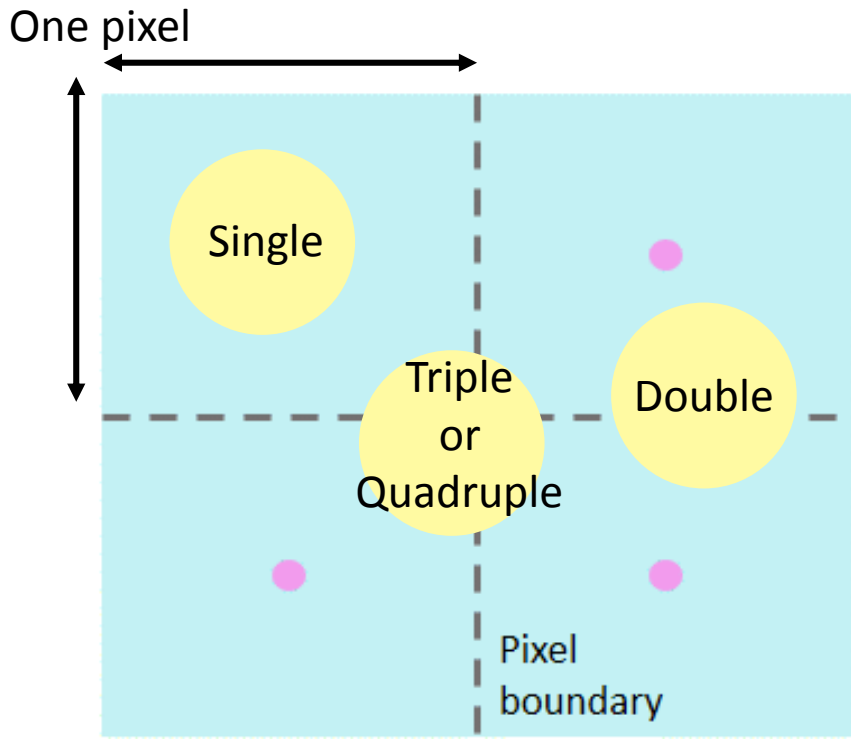
History of XRPIX Series



Charge sharing



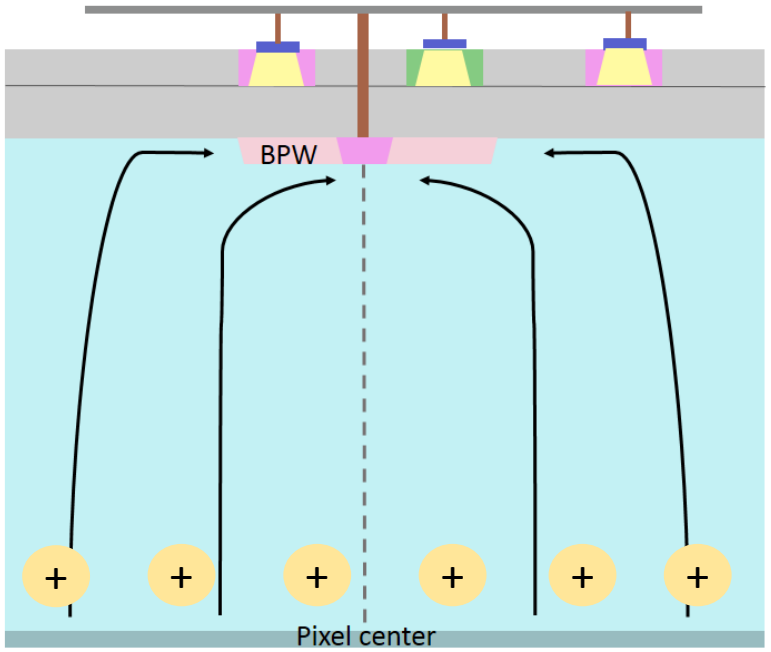
Cross section of imaging area



Top view of left figure

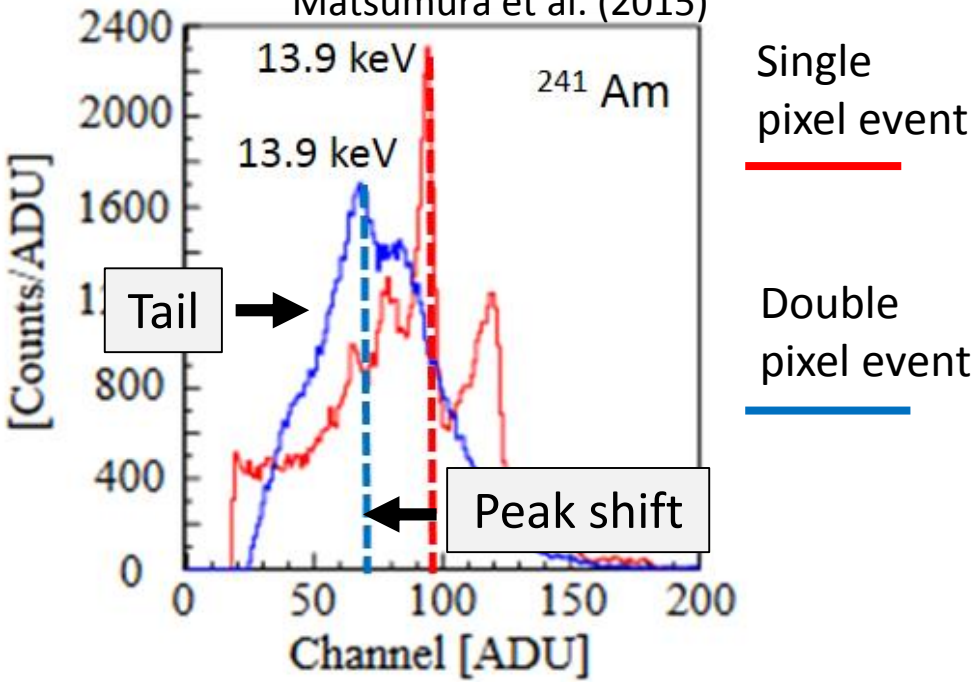
・Depending on the intra-pixel position where X-ray is photo-absorbed , electric charges generated are collected by a single pixel or shared by multiple pixels

The effects of in-pixel circuitry on the sensor layer



Cross section of one pixel

Matsumura et al. (2015)



Single pixel event

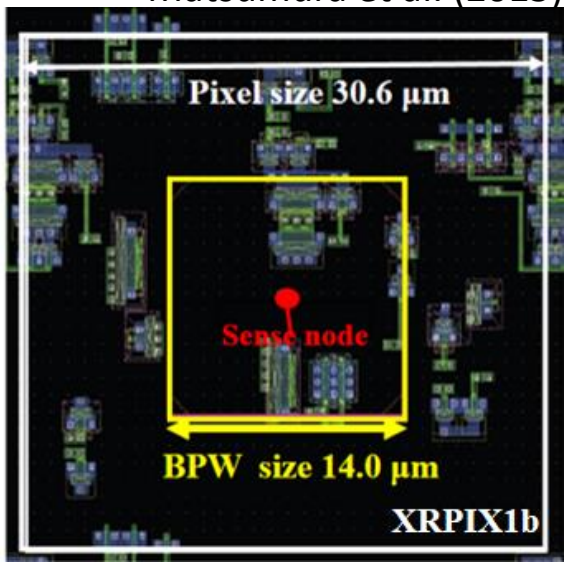
Double pixel event

Spectrum of Am X-ray obtained with XRPIX1b

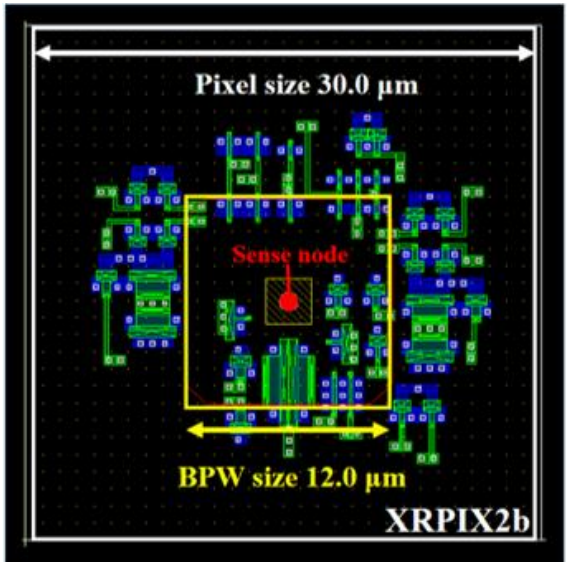
- The BPW formed at pixel center fixes potential to suppress the back-gate effect.
- The in-pixel circuitry placed outside the BPW distorts the electric field of the sensor layer.
- The circuitry causes charge loss at the pixel boundary and peak shift in the spectra of multi pixel event.

Rearranging the placement of in-pixel circuitry

Matsumura et al. (2015)



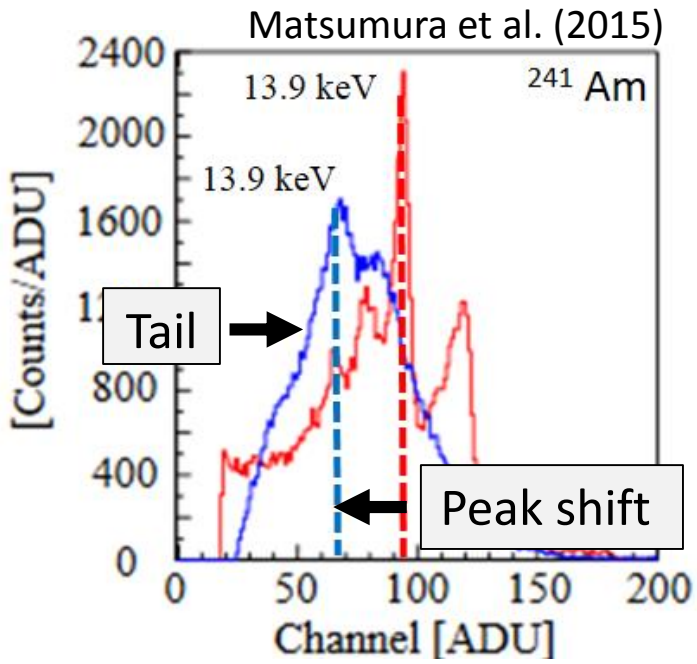
In-pixel circuitry placement of XRPIX1b



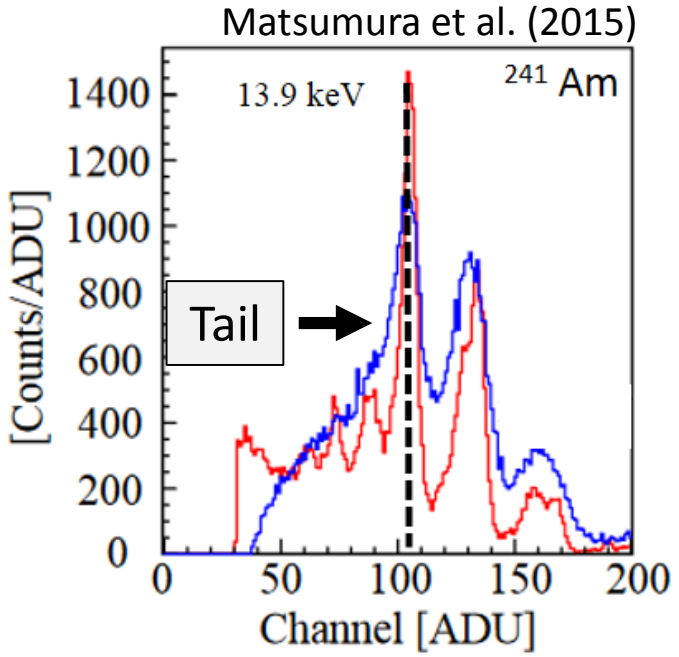
In-pixel circuitry placement of XRPIX2b

- There is the circuitry at the pixel boundary in XRPIX1b.
- In XRPIX2b, the placement of the circuitry is re-arranged near the BPW
- The aim is improving the Charge-Collection Efficiency (CCE) at the pixel boundary.

Partial improvement of the CCE



Spectrum of Am X-ray obtained with XRPIX1b



Spectrum of Am X-ray obtained with XRPIX2b

Single pixel event

Double pixel event

- Peak shift disappeared however Tail had been appearing in spectrum of XRPIX2b.
- Require further improvement → Development of XRPIX6H

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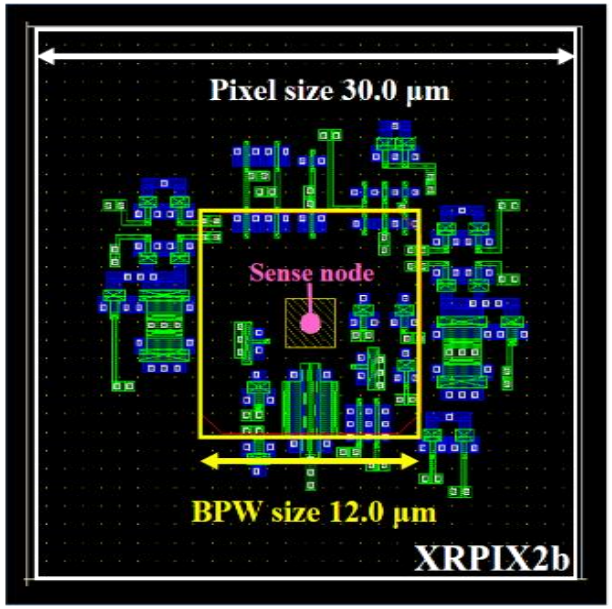
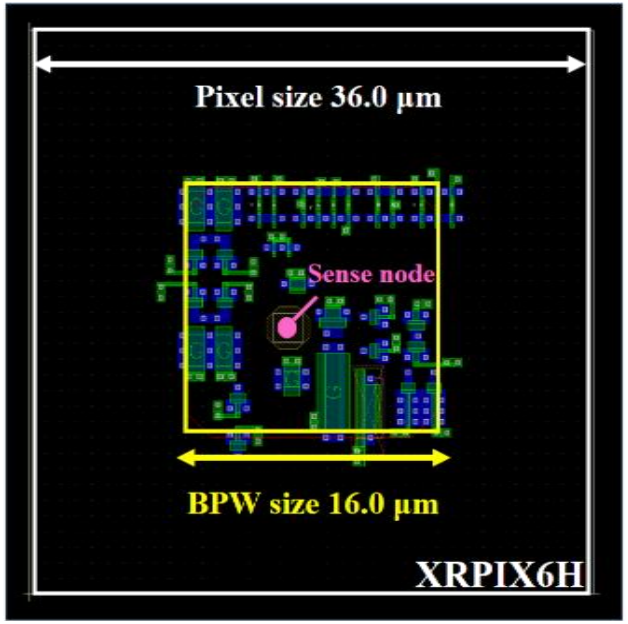
The difference between XRPIX2b and XRPIX6H



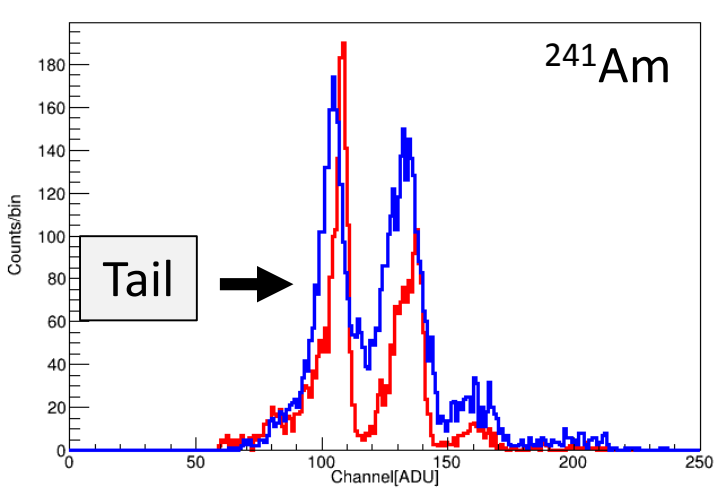
In-pixel circuitry placement of XRPIX2b



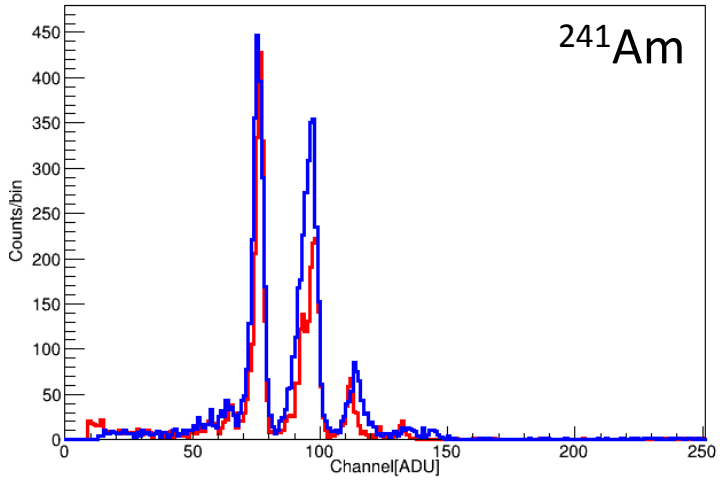
In-pixel circuitry placement of XRPIX6H

- There is the circuitry outside the BPW in XRPIX2b.
- Rearrange the placement of the circuitry inside the BPW in XRPIX6H.
- Aiming the further improvement the CCE at the pixel boundary.

Improvement of spectral shape



Spectrum of ^{241}Am X-ray obtained with XRPIX2b



Spectrum of ^{241}Am X-ray obtained with XRPIX6H

Single pixel event

Double pixel event

- Tail disappear in spectrum of Double pixel event.
- It is suggested that the CCE at pixel the boundary was improved in XRPIX6H

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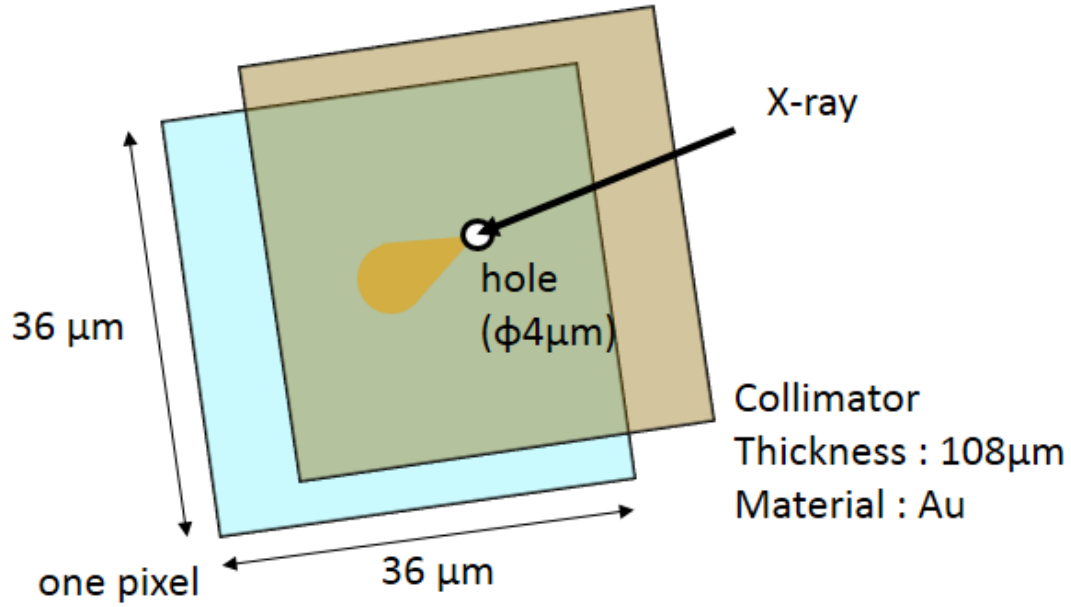
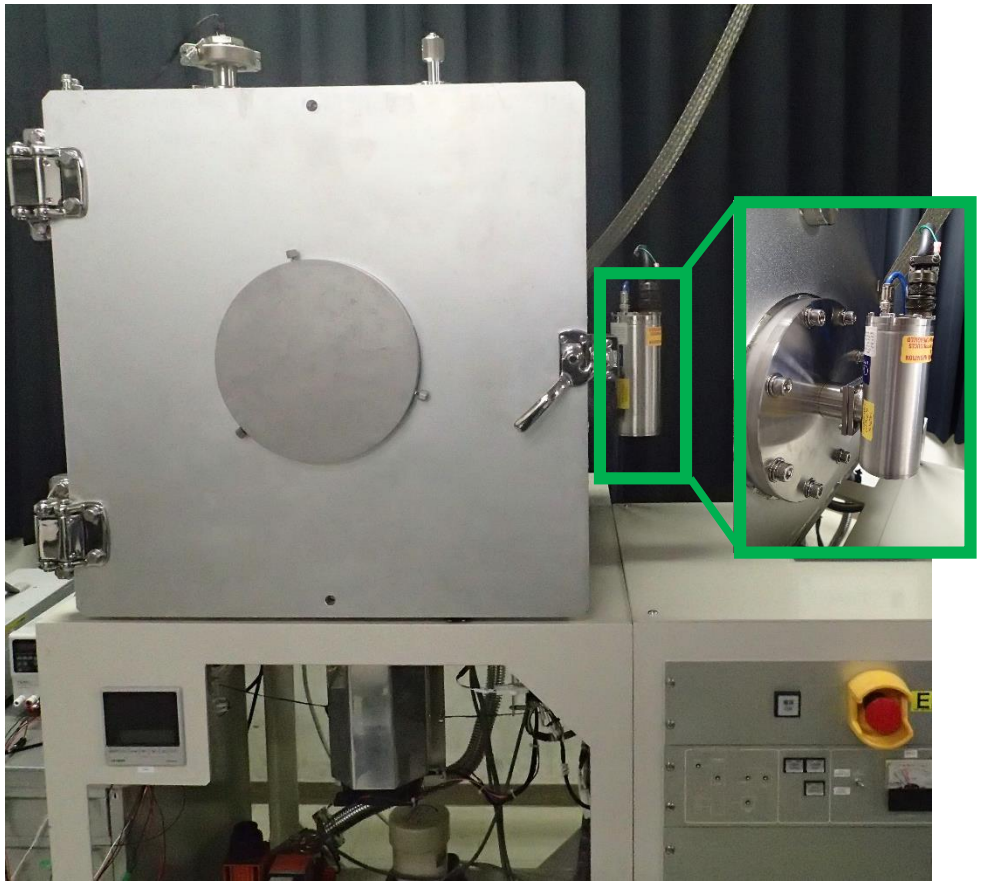
Subpixel response experiment

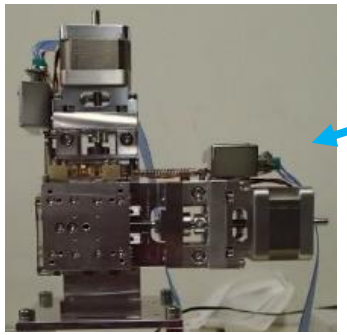


- Irradiate the small part of one pixel with collimated X-ray beam.
- Move the device by positioning automatic stage.
- This experiment enables us to decide relative incident position in one pixel.

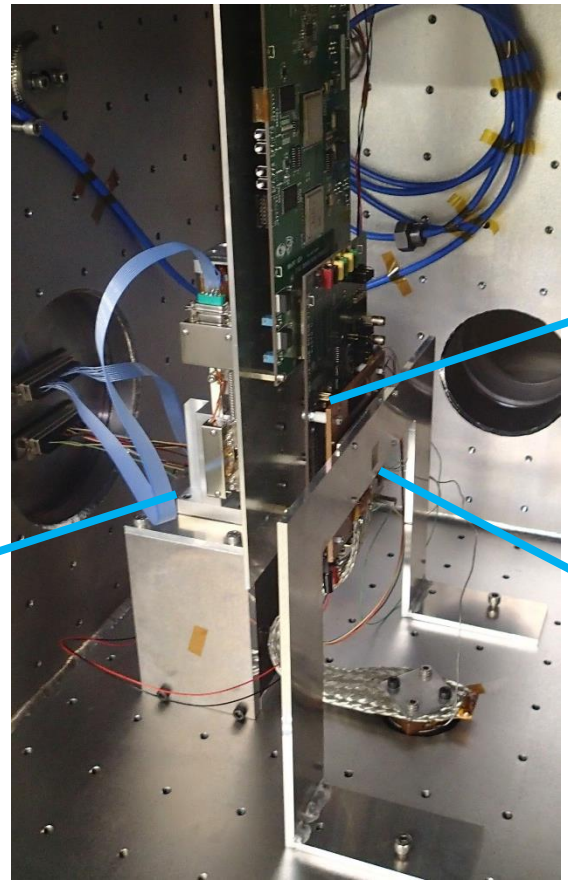
Experimental setup



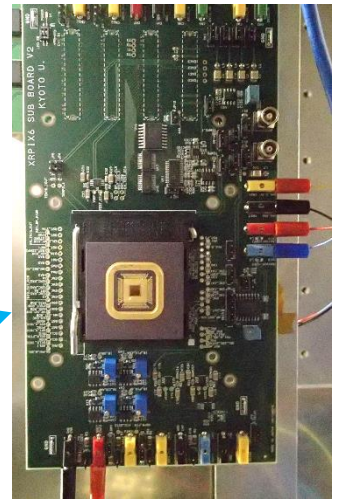
Experimental setup



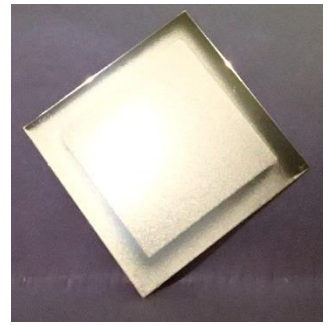
The automatic positioning stage



Inside the vacuum chamber

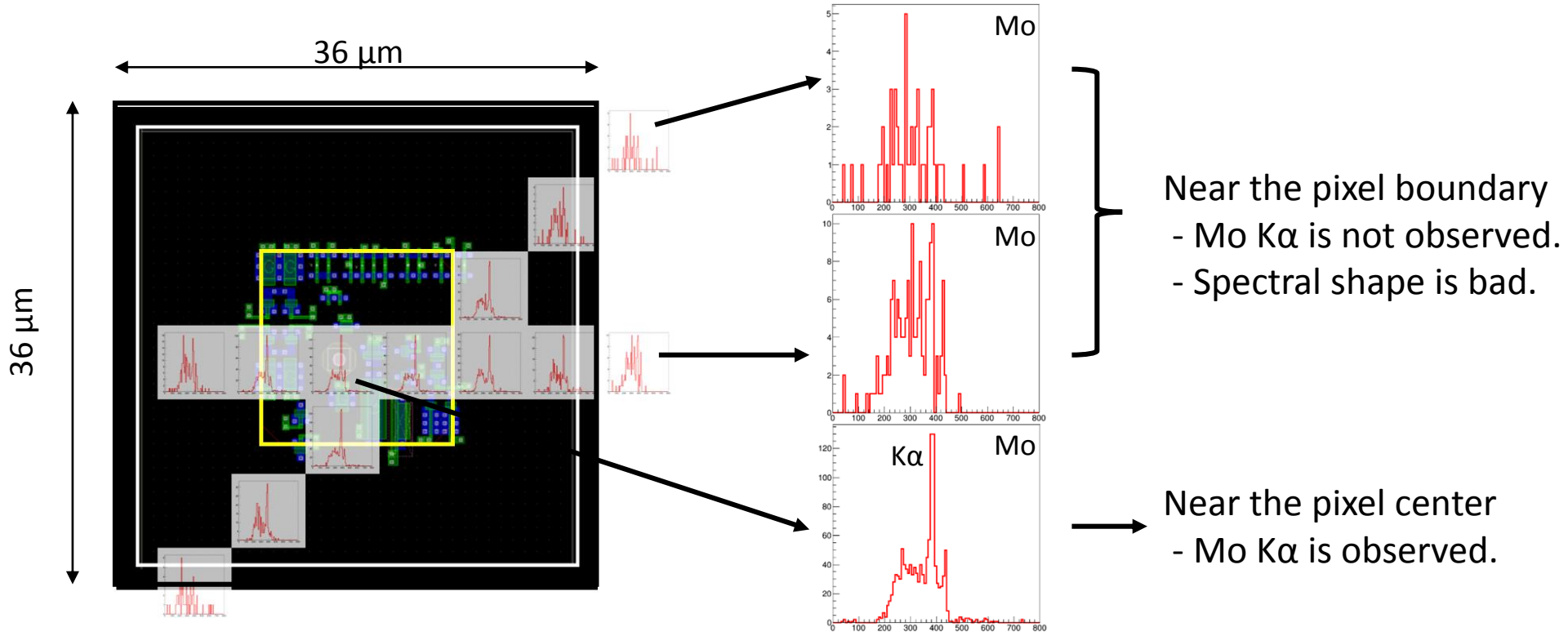


The device and the board



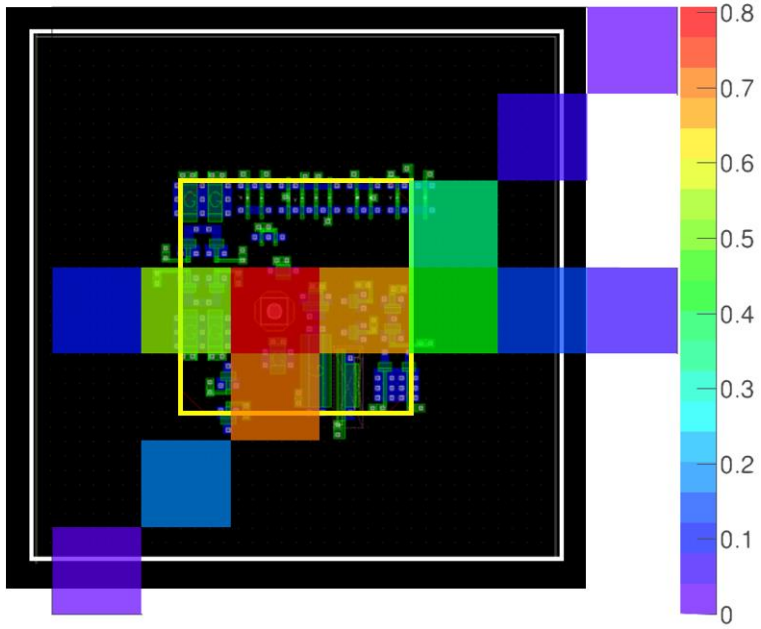
The collimator

Spectra in each position

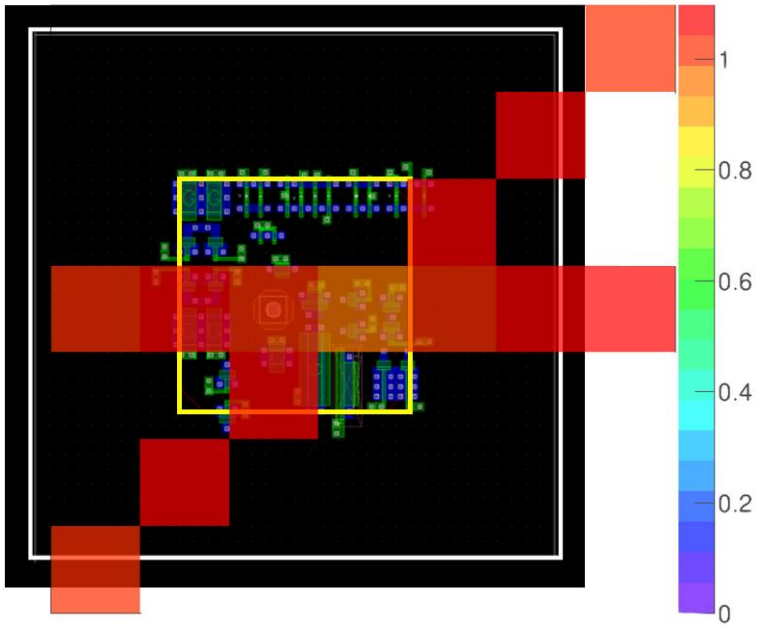


- Spectral shape is different and rate of single pixel event change in each position.
- The position-dependence of the spectrum is seen in one pixel.

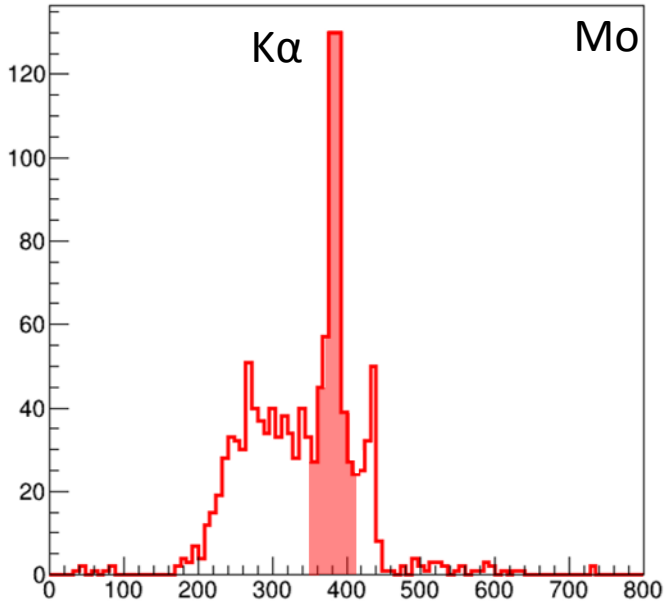
Countmap in each position



Count map of single pixel event



Count map of all pixel event



- The fraction of single pixel event is the highest at the pixel center and decreases toward the pixel boundary.
- Although the ratio between the single and multi pixel events changes, total number of events does not change

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Summary

・We have been developing the active pixel sensor with SOI CMOS technology for X-ray astronomical use.

・We developed the XRPIX6H in which the in-pixel circuitry is spatially arranged inside the BPW

・XRPIX6H shows little difference between single and double pixel event spectra

・Sub-pixel response experiment confirms that the fraction of single pixel event is the highest at the pixel center and decreases toward the pixel boundary.

- These results show the CCE at the pixel boundary is improved