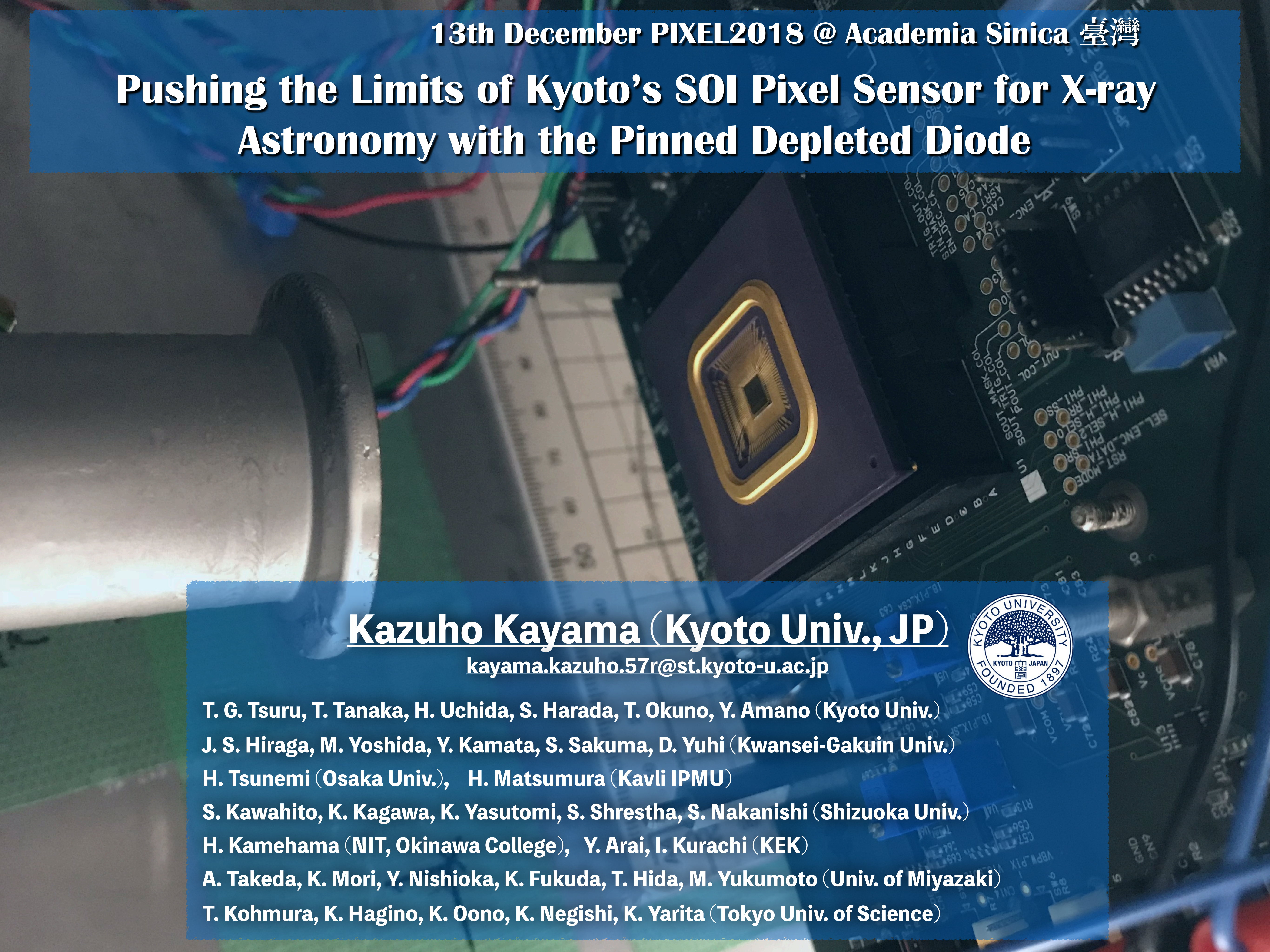


13th December PIXEL2018 @ Academia Sinica 臺灣

Pushing the Limits of Kyoto's SOI Pixel Sensor for X-ray Astronomy with the Pinned Depleted Diode

Kazuho Kayama（Kyoto Univ., JP）

kayama.kazuho.57r@st.kyoto-u.ac.jp

T. G. Tsuru, T. Tanaka, H. Uchida, S. Harada, T. Okuno, Y. Amano（Kyoto Univ.）

J. S. Hiraga, M. Yoshida, Y. Kamata, S. Sakuma, D. Yuhi（Kwansei-Gakuin Univ.）

H. Tsunemi（Osaka Univ.）, H. Matsumura（Kavli IPMU）

S. Kawahito, K. Kagawa, K. Yasutomi, S. Shrestha, S. Nakanishi（Shizuoka Univ.）

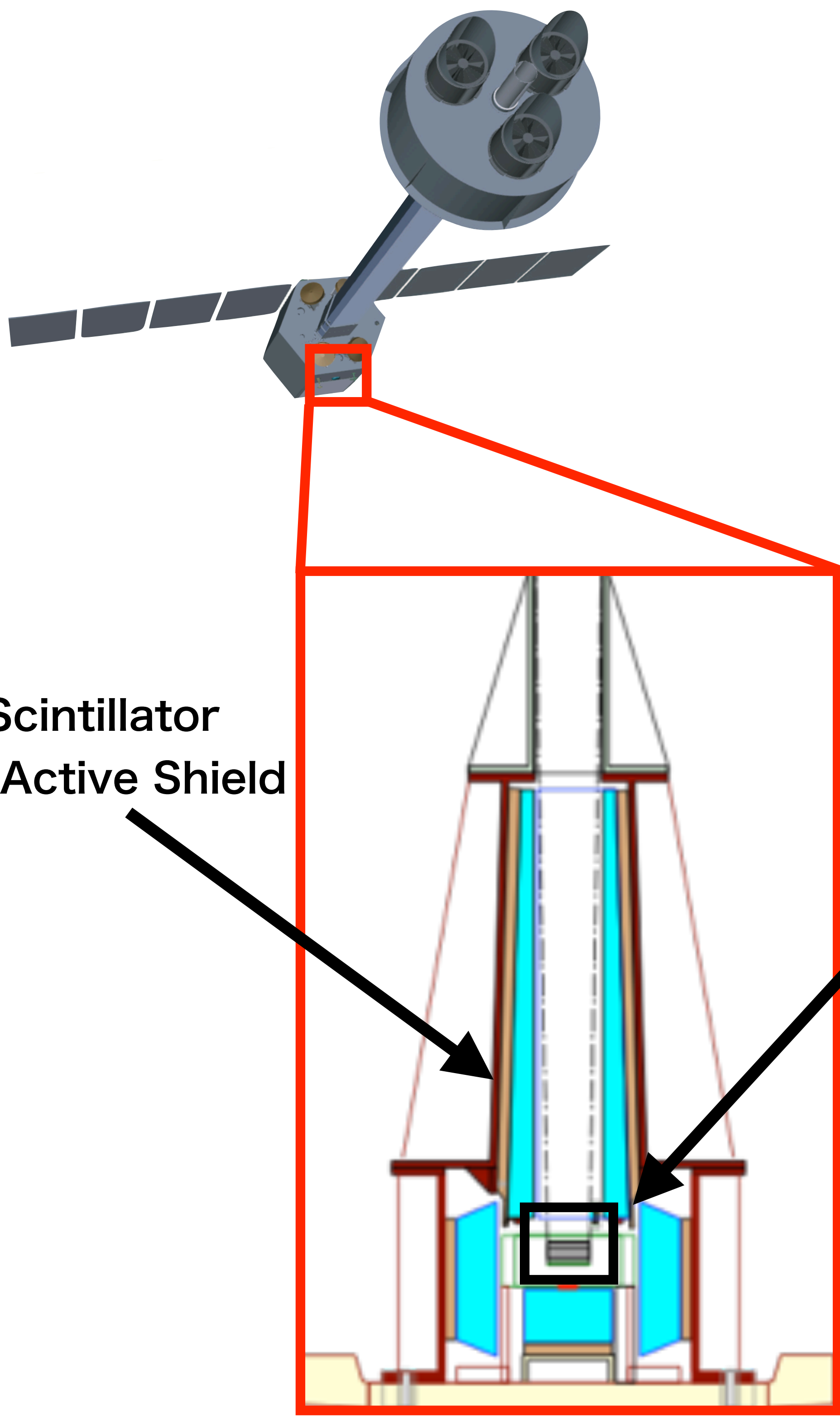
H. Kamehama（NIT, Okinawa College）, Y. Arai, I. Kurachi（KEK）

A. Takeda, K. Mori, Y. Nishioka, K. Fukuda, T. Hida, M. Yukumoto（Univ. of Miyazaki）

T. Kohmura, K. Hagino, K. Oono, K. Negishi, K. Yarita（Tokyo Univ. of Science）

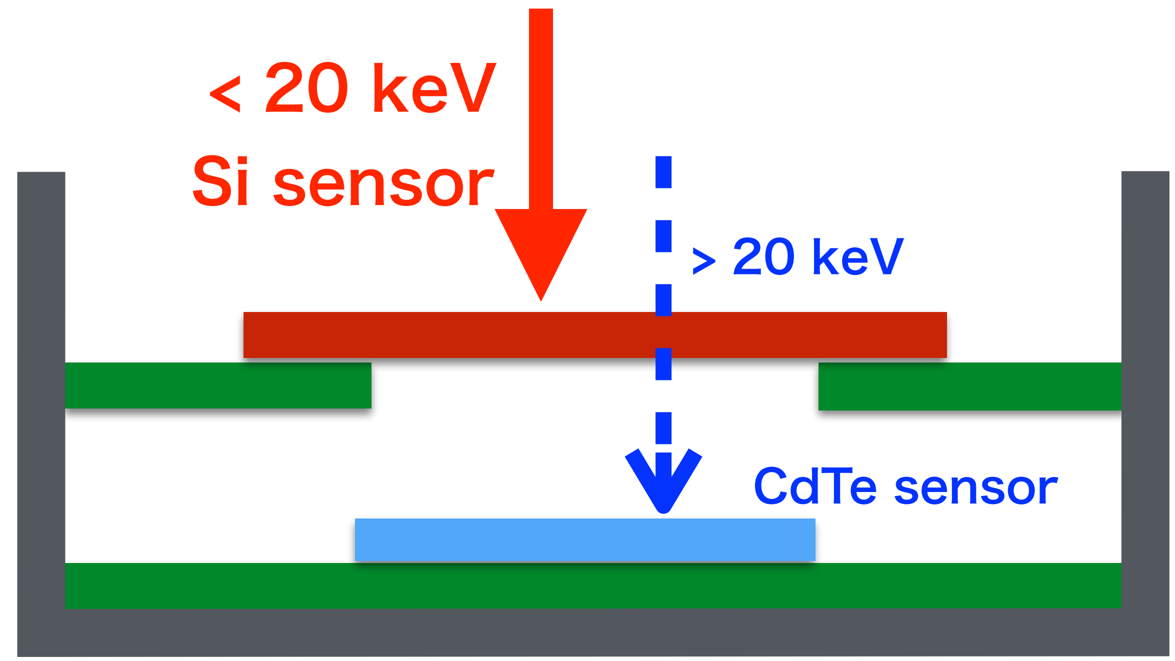
FORCE Satellite Mission

Focusing On Relativistic universe and Cosmic Evolution



Scintillator
for Active Shield

Wideband Hybrid X-ray Imager



★ Wide energy range : 1 - 80 keV (Requirement)
★ Si + CdTe hybrid detector

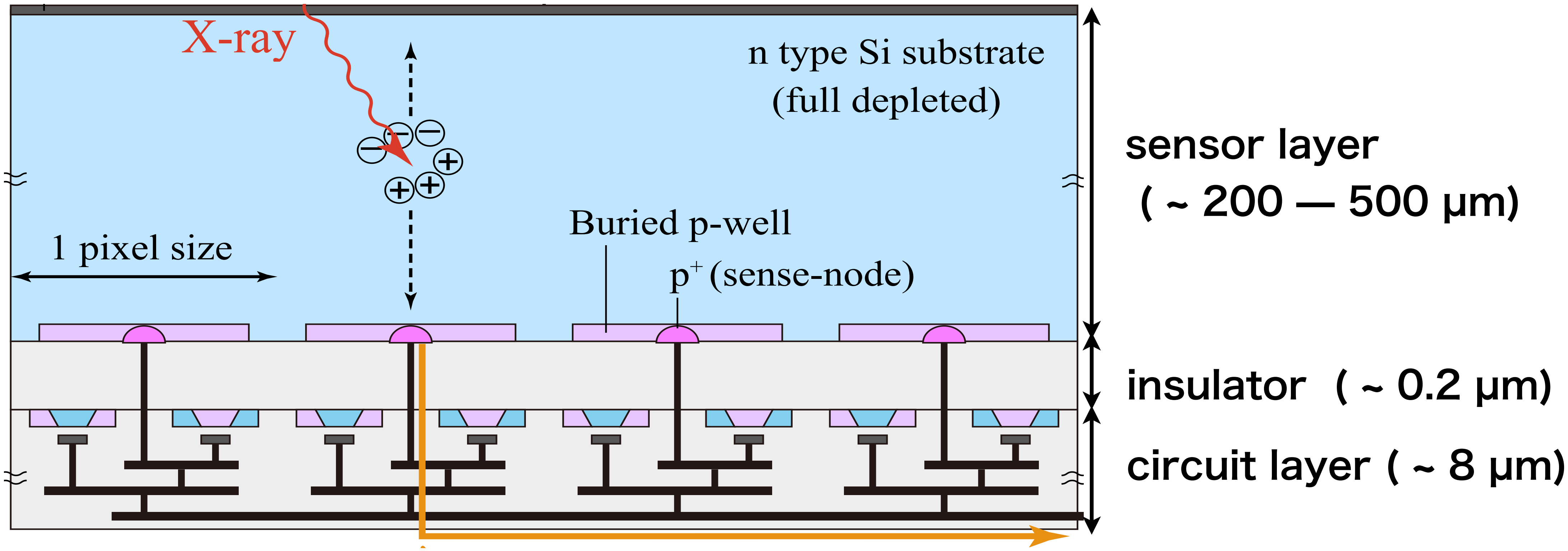
Requirement of Si sensor

- Energy resolution of < 300 eV(FWHM) @ 6 keV
- Time resolution of < 10 μs for anti-coincidence

We have been developing X-ray Si sensor for FORCE mission.

SOI Pixel Detector “XRPIX”

general XRPIX structure



“XRPIX” = series of SOI pixel sensors for X-ray detection

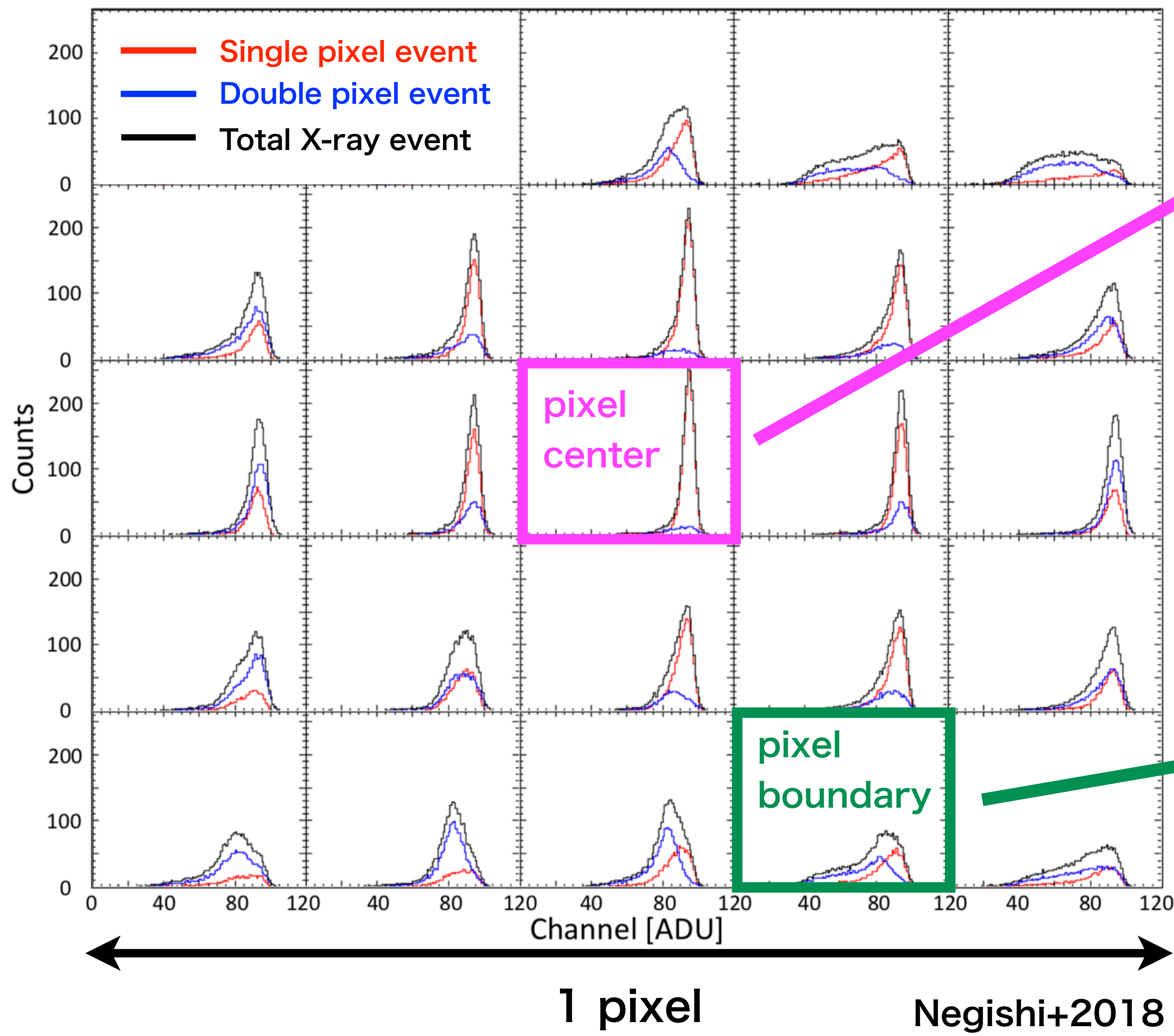
XRPIX Advantages

- ✳ **No mechanical bump bonding**
  → High Density, Low Parasitic Capacitance, High Sensitivity
- ✳ **Standard CMOS circuit can be built**
  → Trigger output function for good time resolution
- ✳ **Based on industrial standard technology**

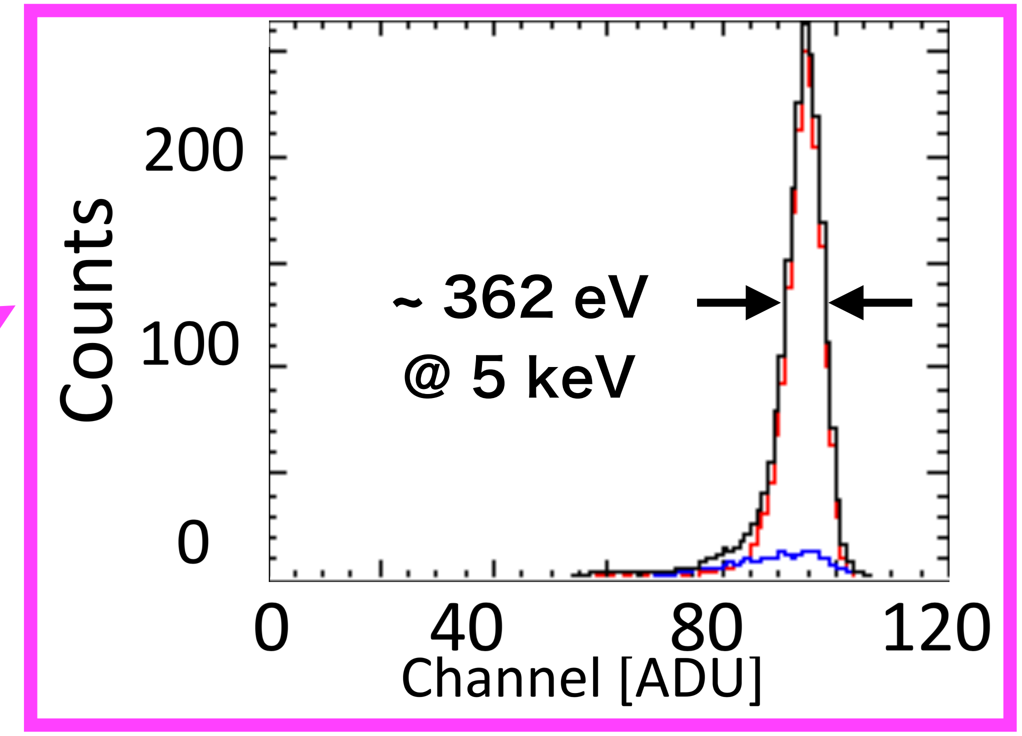
Previous devices have two known problems related to charge collection efficiency.

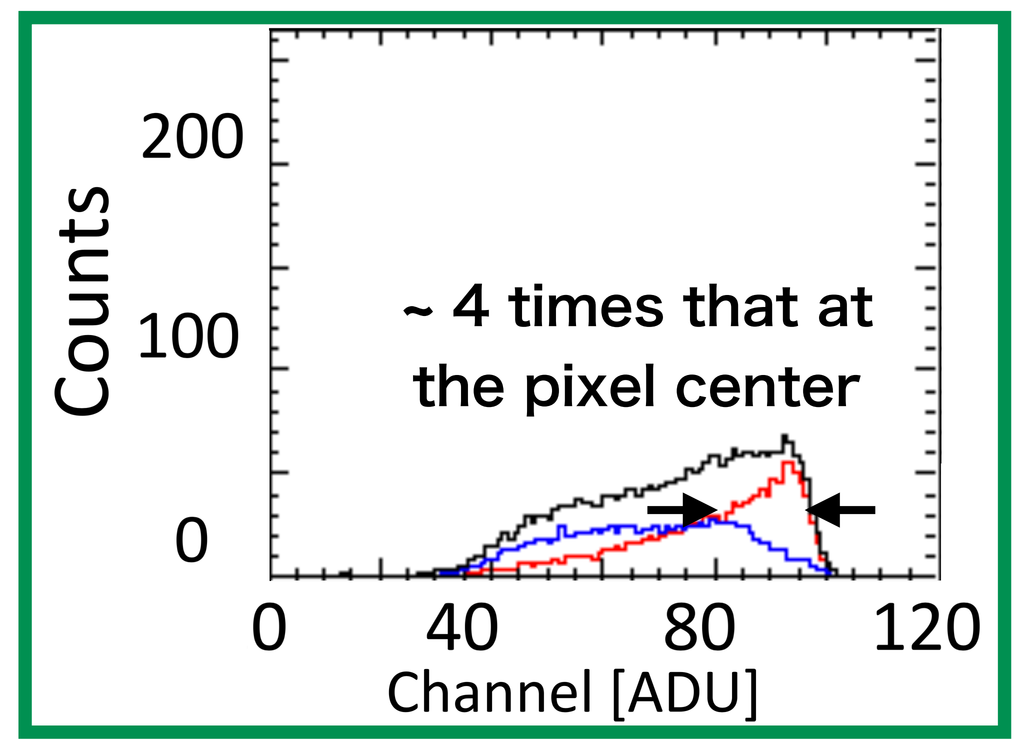
4 Spectrum Resolution Difference at Sub-Pixel

Energy spectrum folded in one pixel at 5 keV.



Negishi+2018





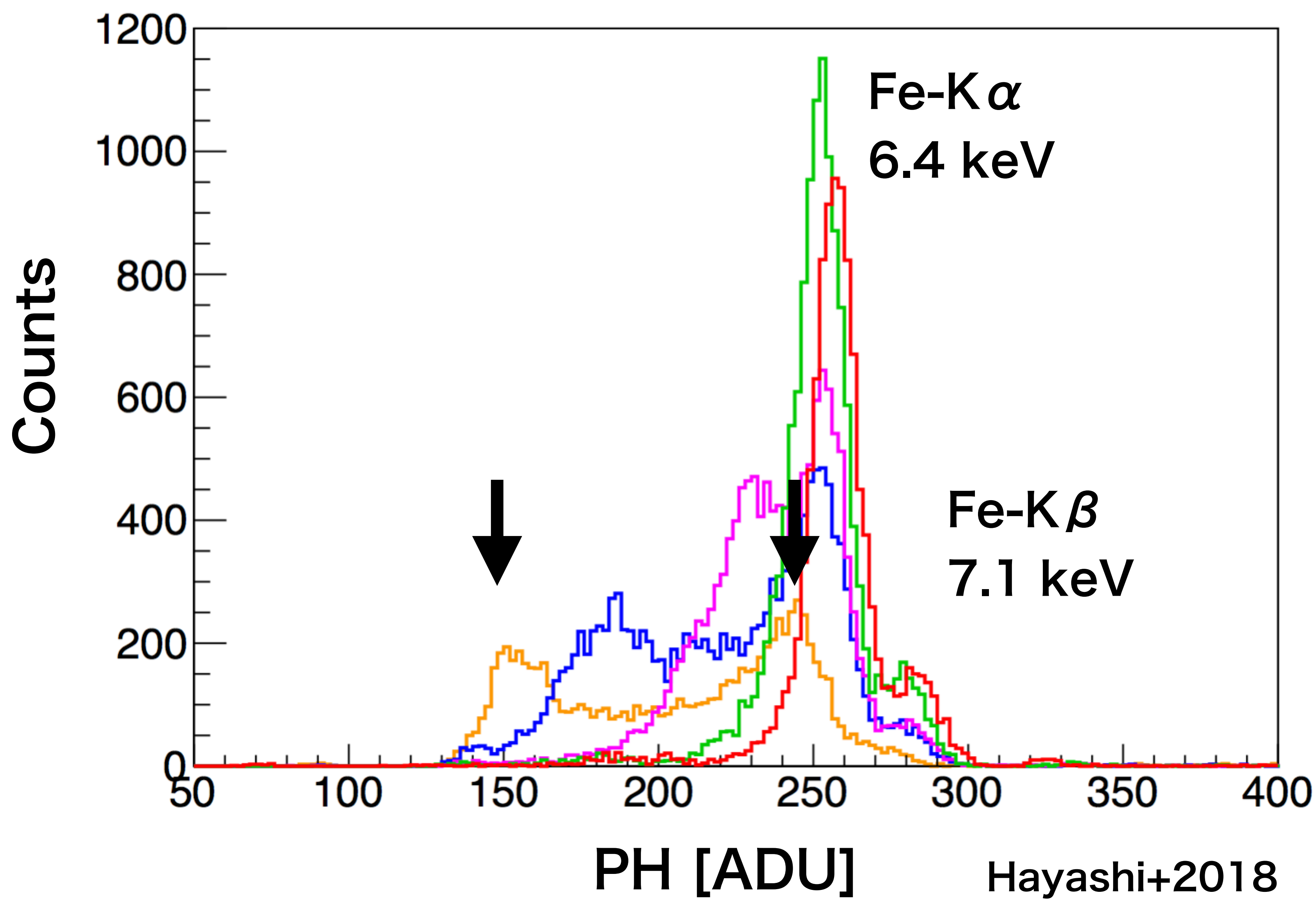
- Tail structure near pixel boundaries.
- The energy resolutions at pixel boundaries are ~ 4 times larger than that at the pixel center.

Spectrum Shape is Related To T_{STORE}

We define T_{STORE} as exposure time after the trigger comes out

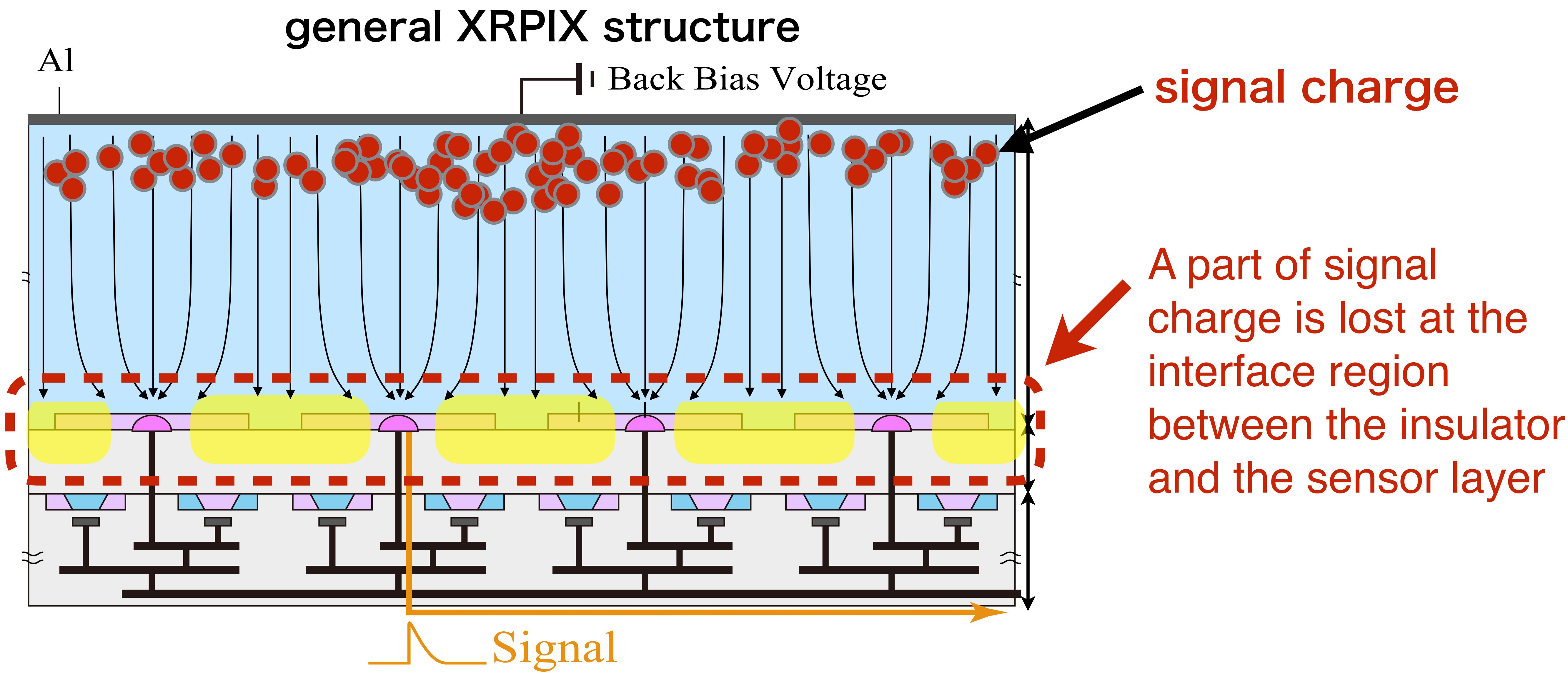
T_{STORE} ~ 320 ns
T_{STORE} ~ 1.2 μs
T_{STORE} ~ 10 μs
T_{STORE} ~ 100 μs
T_{STORE} ~ 1 ms

FORCE mission require T_{STORE} < ~ μs



- Fake peak appears when the T_{STORE} is short.
- We speculate that the charge collection efficiency is different at X-ray incident position in the same pixel.

Signal Charges are Trapped at the Interface

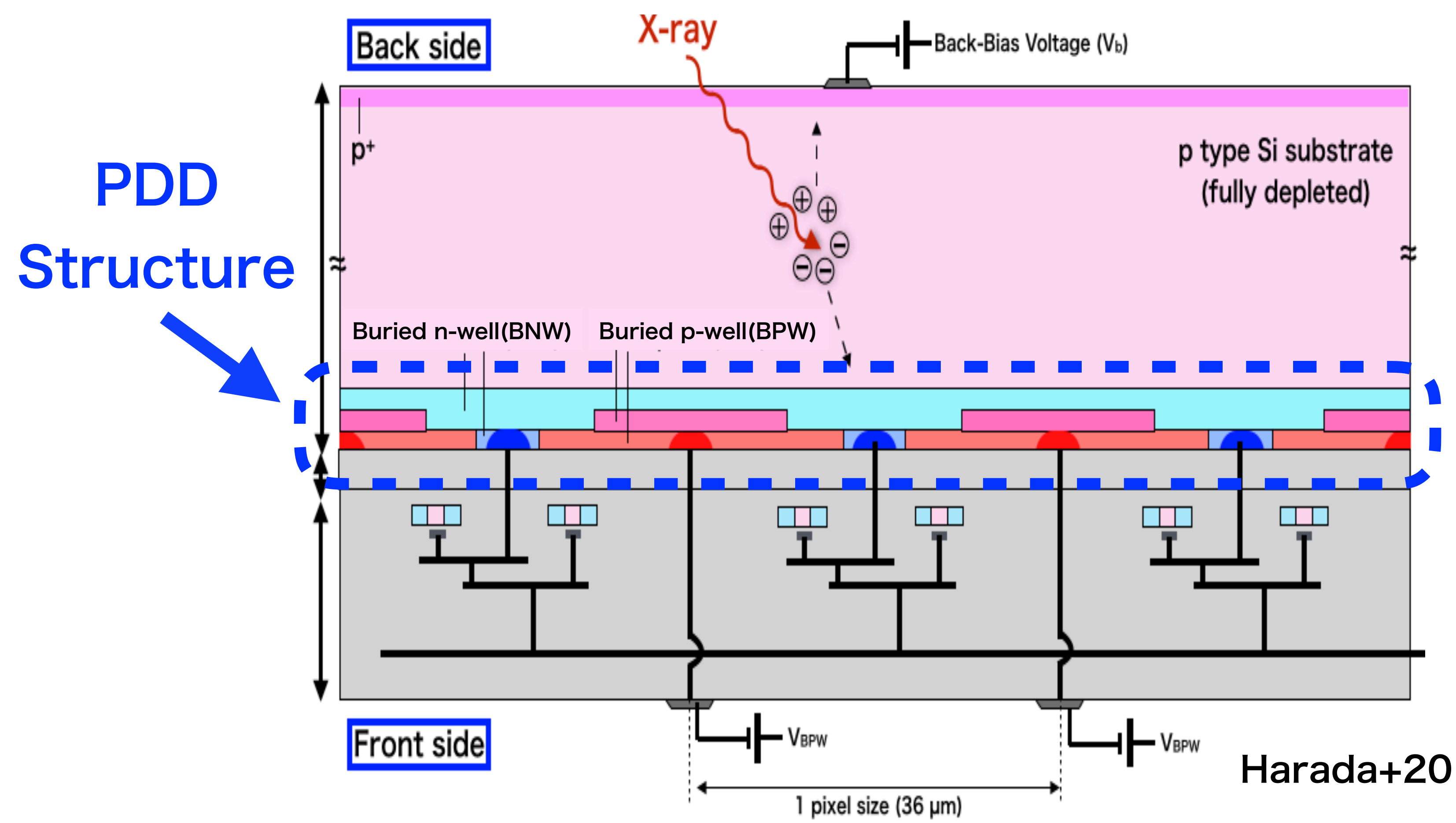


We speculate that both of those problems are due to the signal charges are trapped at the interface between the sensor layer and SiO_2 layer

7 Pinned Depleted Diode Structure

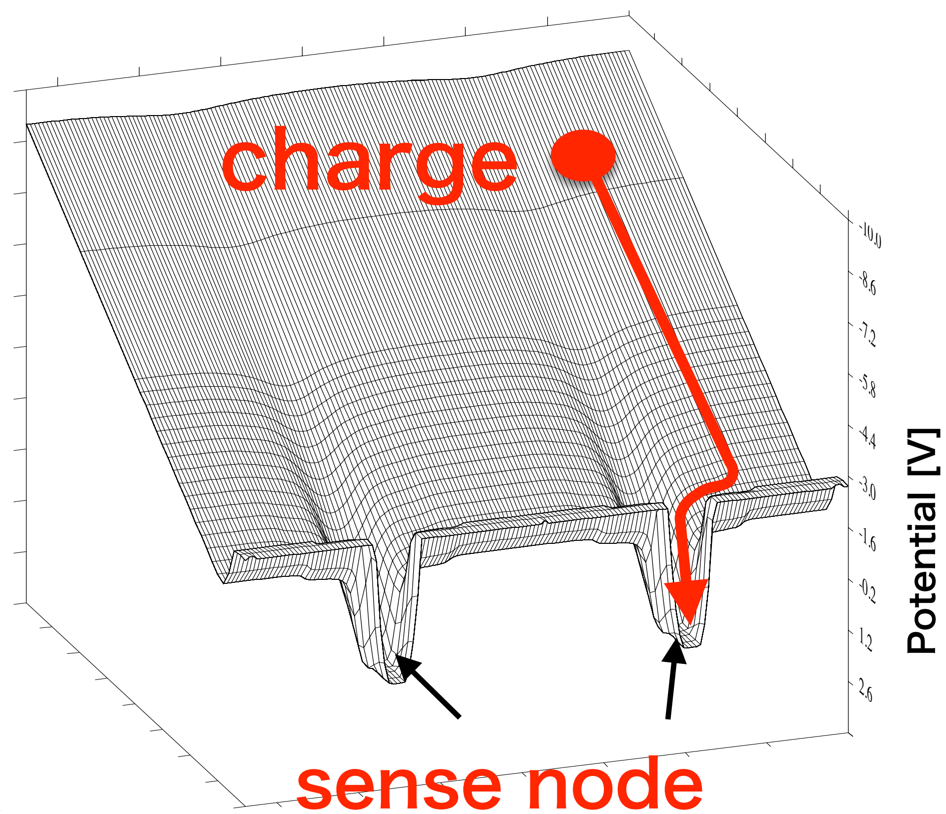
Pinned Depleted Diode (PDD) Structure (Kamehama+2018) is employed to mitigate the issues in our previous devices

XRPIX with PDD structure



Harada+2018

Electric field simulation

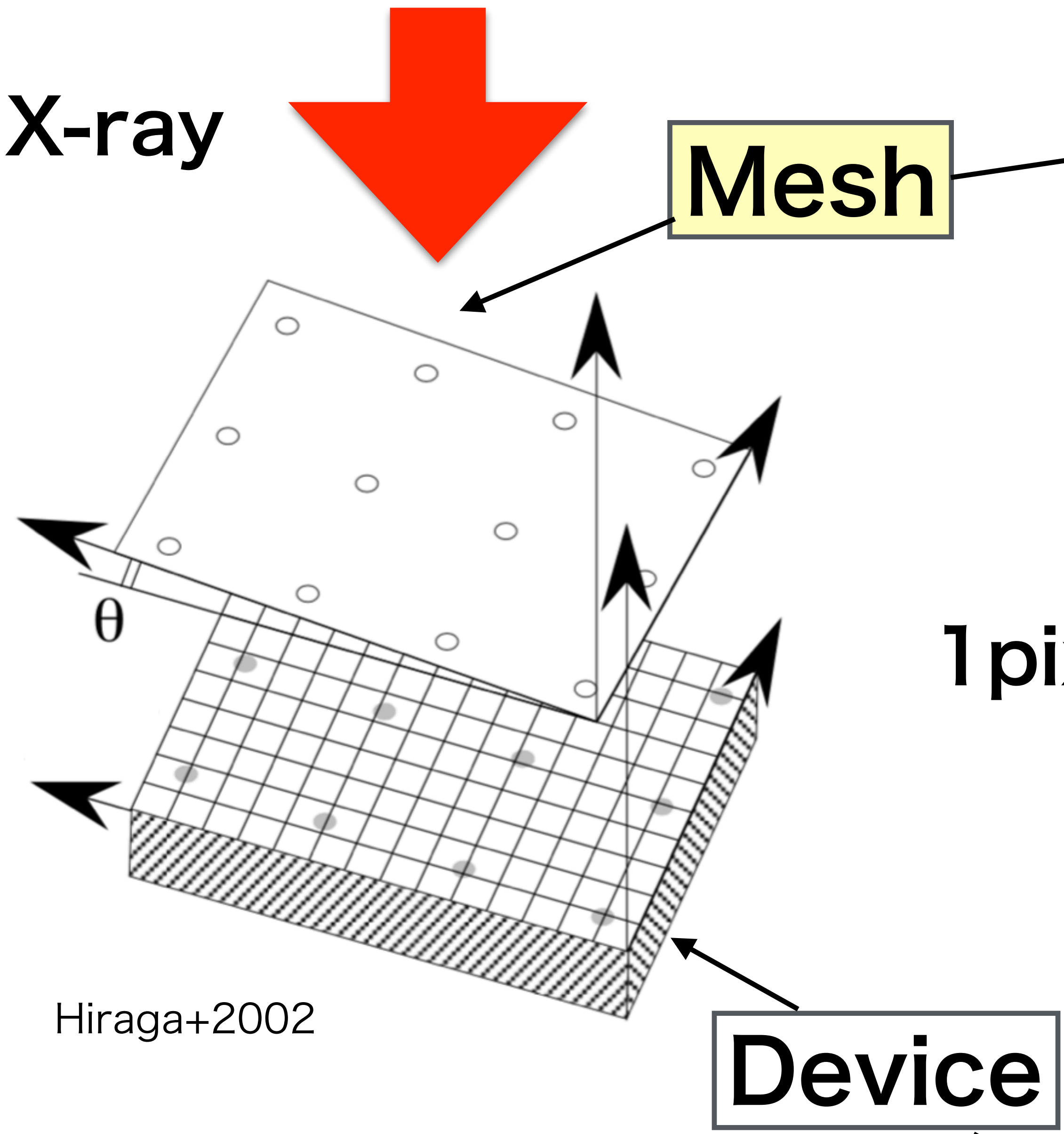


* Highly doped buried p-well acts as shield layer to reduce noise.
* Signal charges are transported through stepped buried n-well to the sense node without touching the interface between the sensor layer and SiO_2 layers

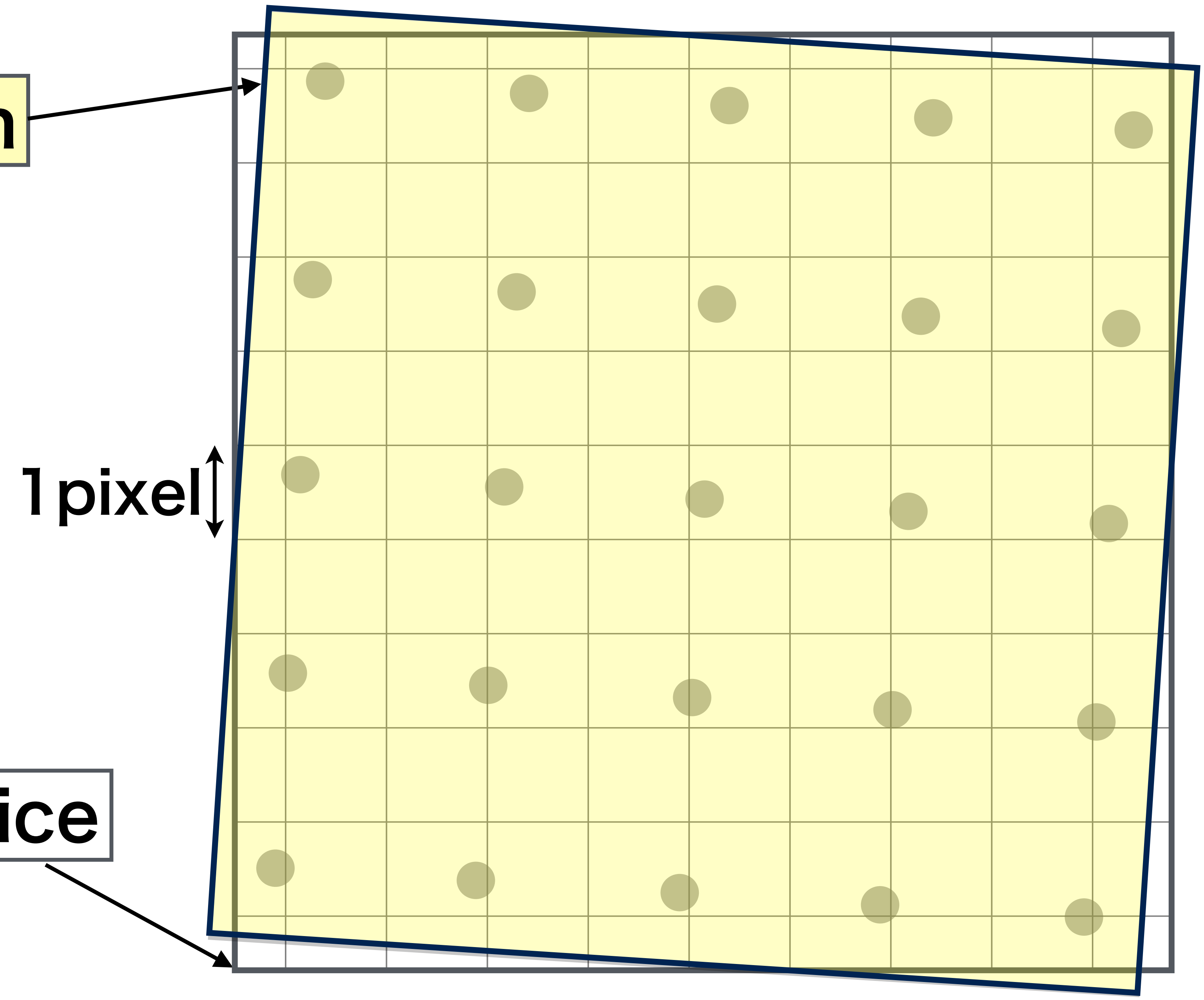
To solve those problems we have developed XRPIX6E with PDD structure

Mesh Experiment

Tsunemi+1997



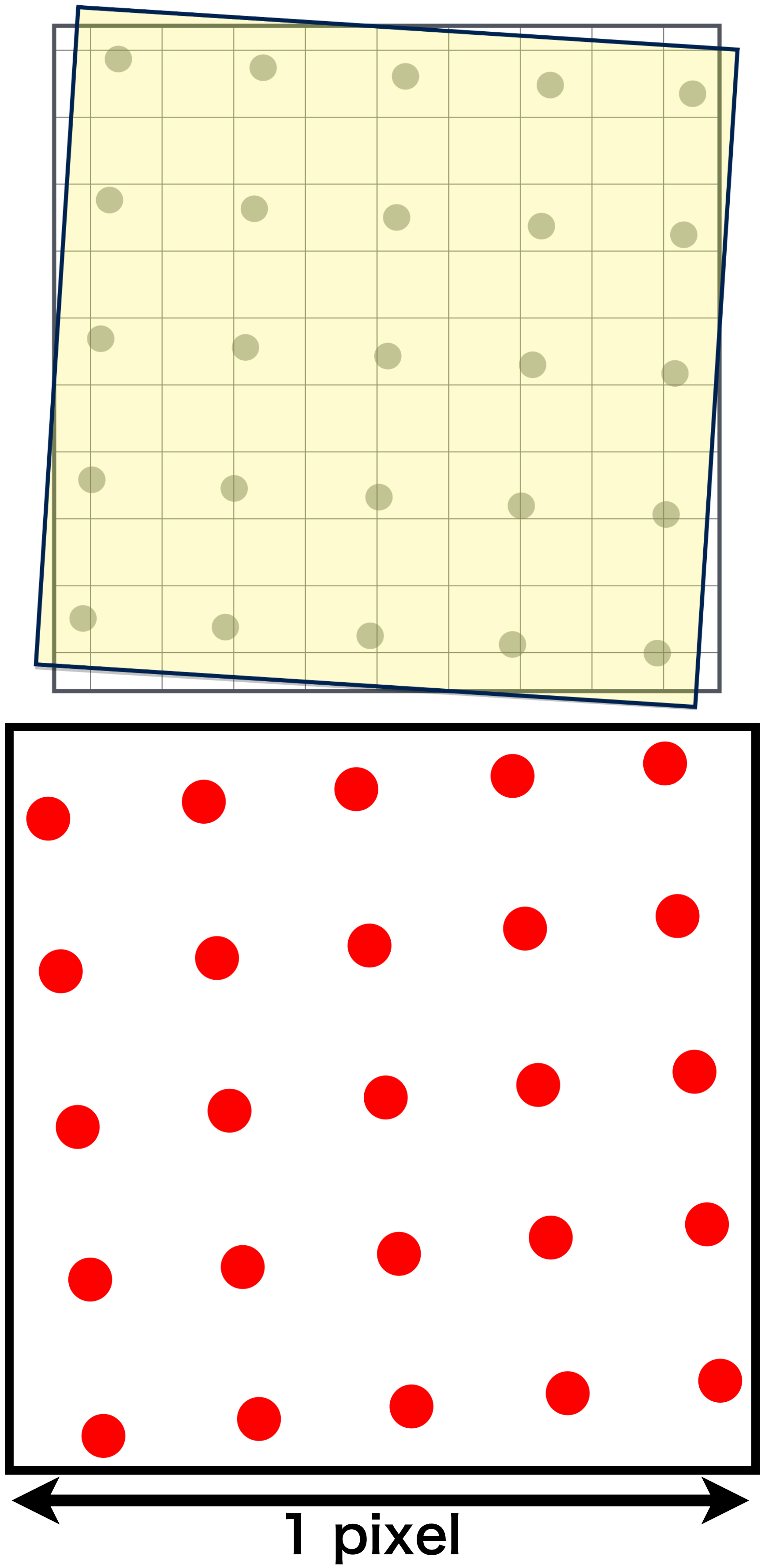
Hiraga+2002



Placing a thin metal mesh with evenly spaced holes, the hole pitch is multiple to the detector pixel size, parallel to the detector surface and tilted by a small angle.
→The hole shadows on the detector gradually shift positions from pixel to pixel

Mesh Experiment

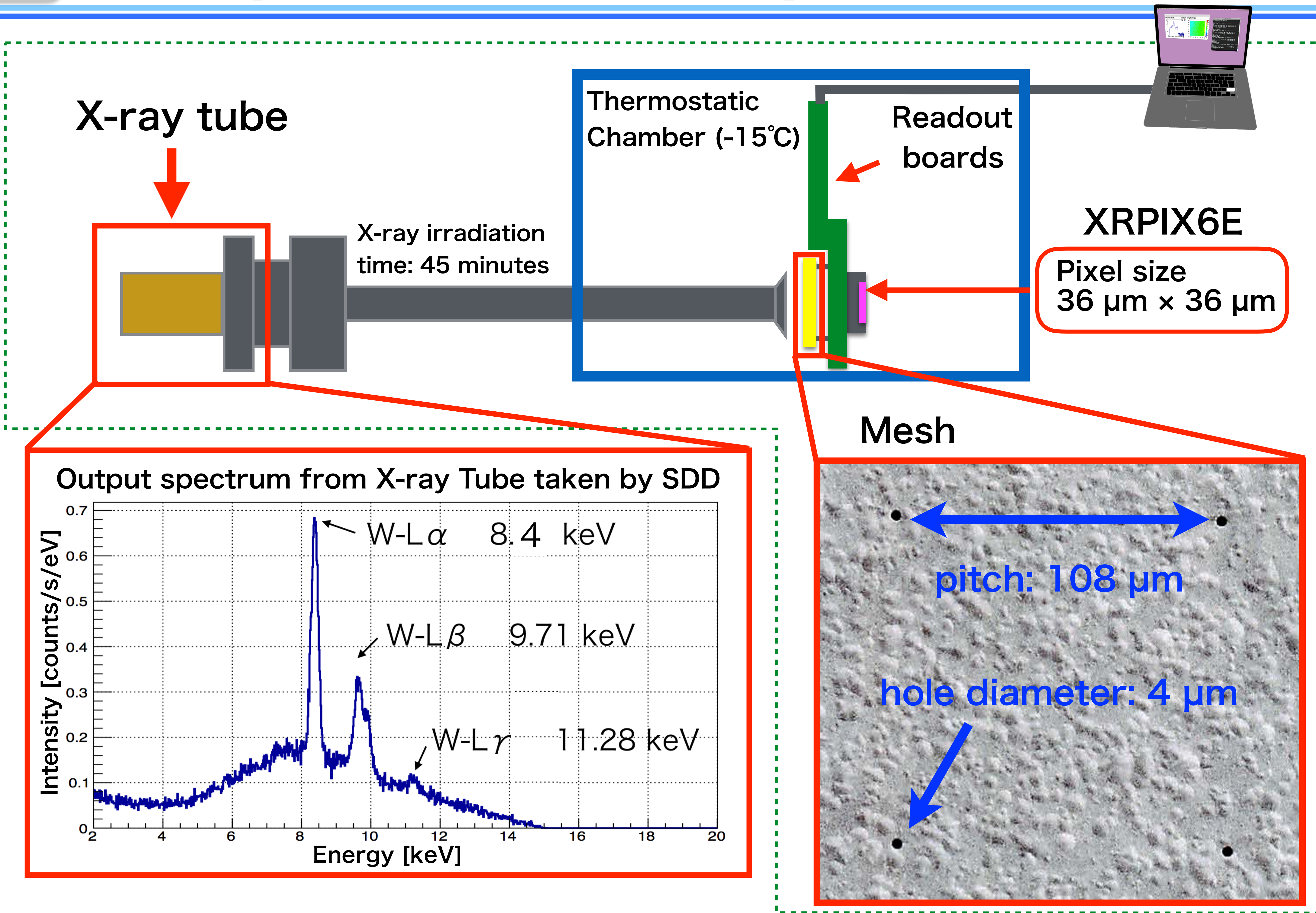
Tsunemi+1997



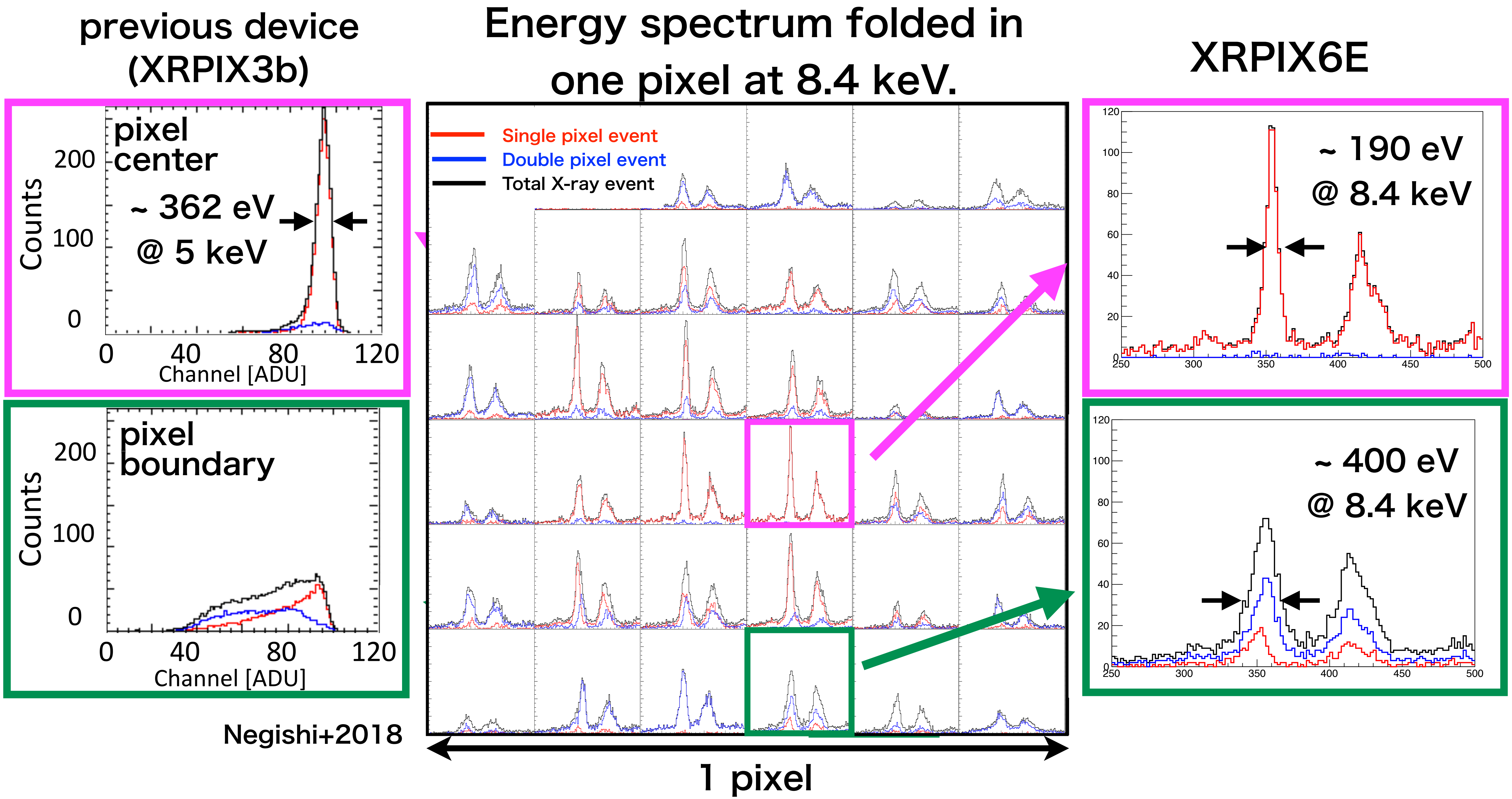
- X-ray incident position on the detector is restricted by the mesh hole.
- Large number of pixels represent an expanded one pixel structure.
- We can easily determine the incident position on the pixel from the hole shadow on the detector.

This technique enables us to evaluate the sub-pixel resonance.

Experimental Setup



Spectrum Resolution as Sub-Pixel

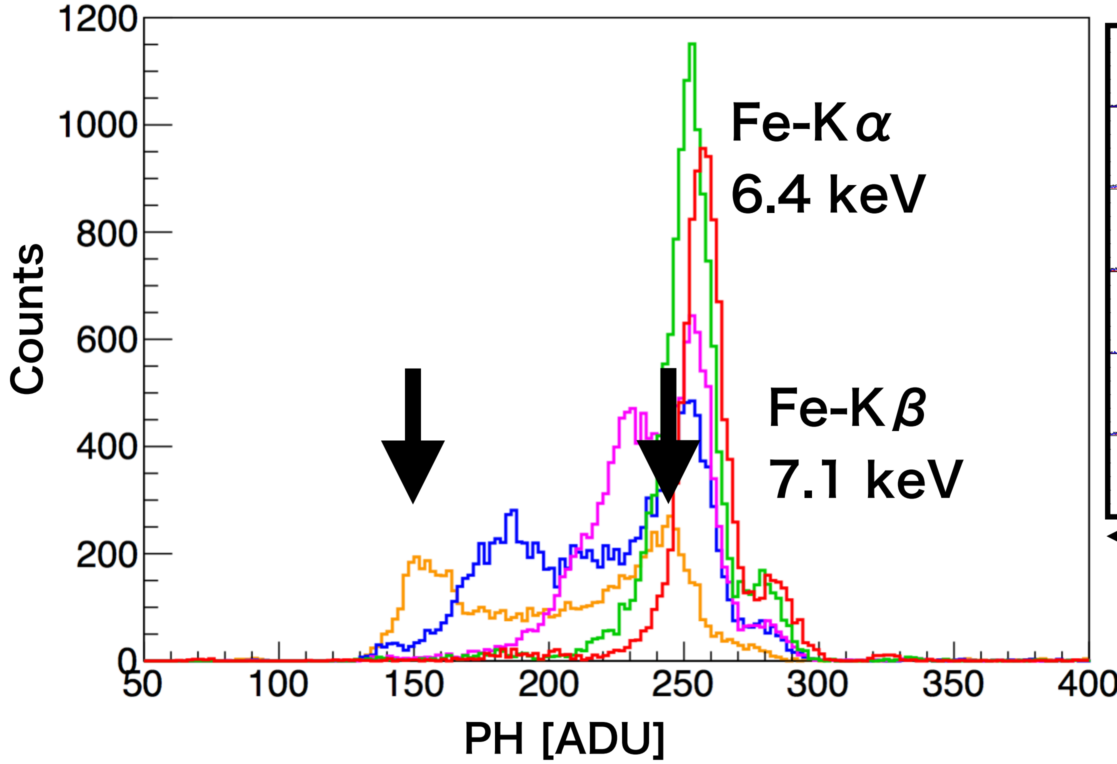


- No tail structure is seen near pixel boundaries of XRPIX6E
- Energy resolutions near pixel boundaries are ~ 2 times larger than that at the pixel center.

Spectrum Shape is Related to TSTORE

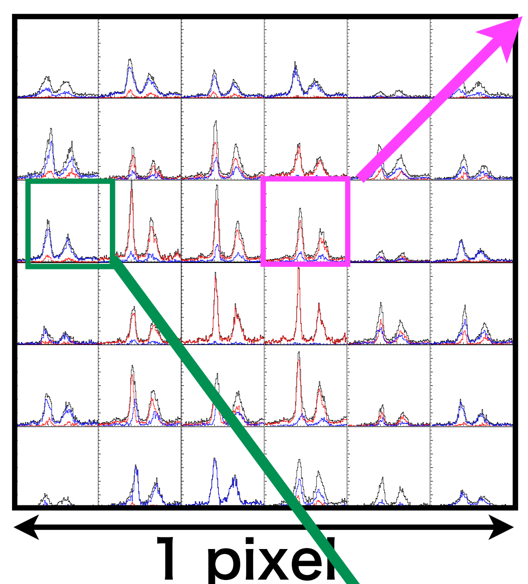
XRPIX6D

TSTORE ~ 320 ns
TSTORE ~ 1.2 μs
TSTORE ~ 10 μs
TSTORE ~ 100 μs
TSTORE ~ 1 ms

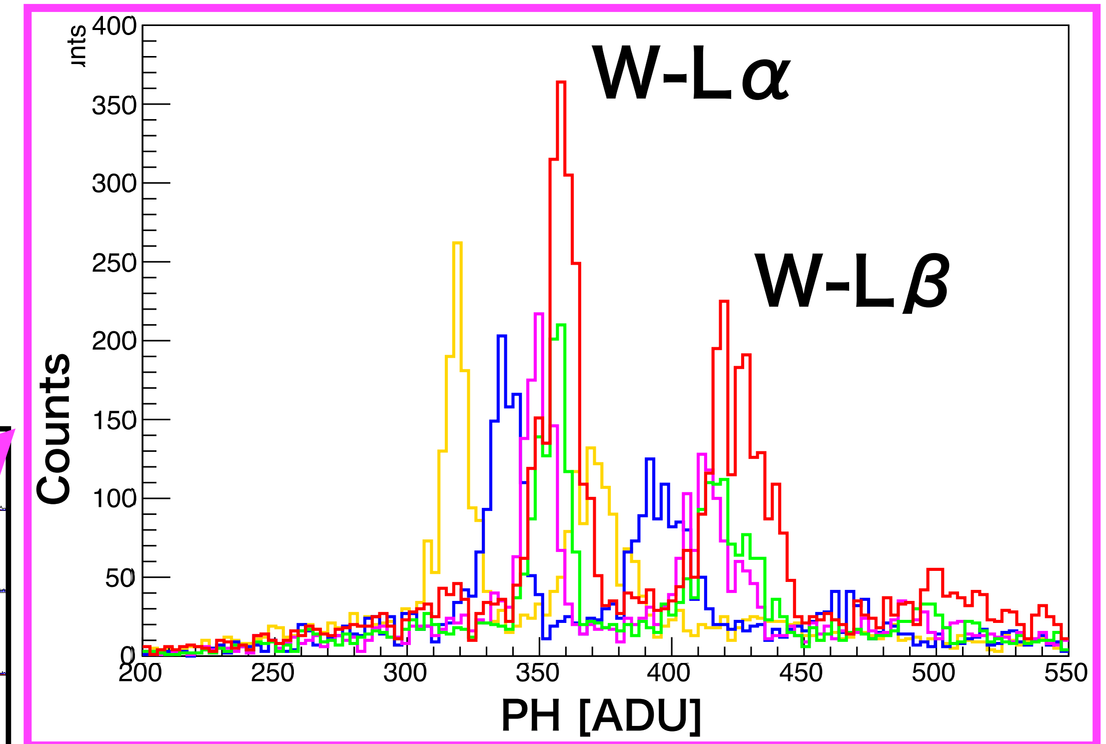


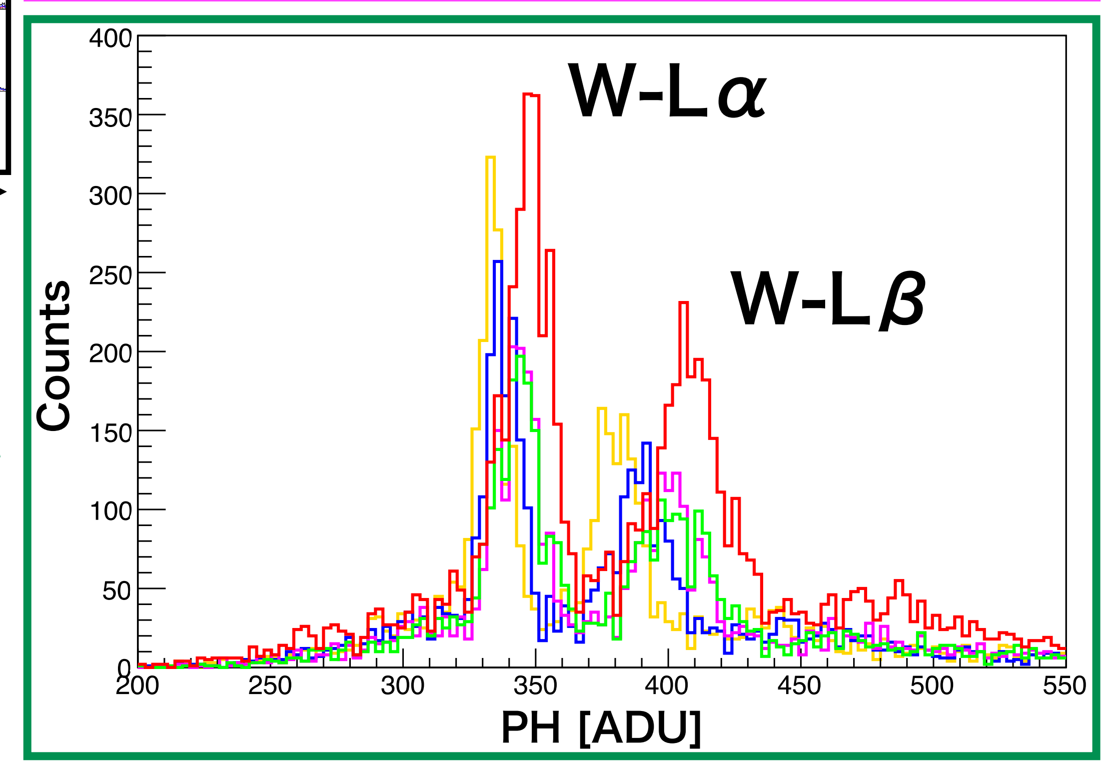
Hayashi+2018

TSTORE ~ 320 ns
TSTORE ~ 500 ns
TSTORE ~ 750 ns
TSTORE ~ 1 μs
TSTORE ~ 10 μs



XRPIX6E





Fake peak not appears at the pixel center and pixel boundaries when the TSTORE is short.

Summary

* We performed the mesh experiment to evaluate the X-ray response at the sub-pixel level for XRPIX6E with the PDD structure.
* No tail structure is seen near pixel boundaries of XRPIX6E.
* Energy resolution at the pixel center is about 190 eV.
* Energy resolutions near pixel boundaries are ~ 2 times larger than that at the pixel center.
* Fake peak not appears at the pixel center and pixel boundaries.
* These results indicate that charges are efficiently collected even near pixel boundaries. We thus conclude that the PDD structure of XRPIX6E solved the previously-known problems related to the charge collection efficiency.

PIXEL 2018

SOIPIX Silicon-On-Insulator Pixel Detector Project

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京都大学 KYOTO UNIVERSITY