Performance verification and Calibration of the Soft X-ray Imager aboard ASTRO-H

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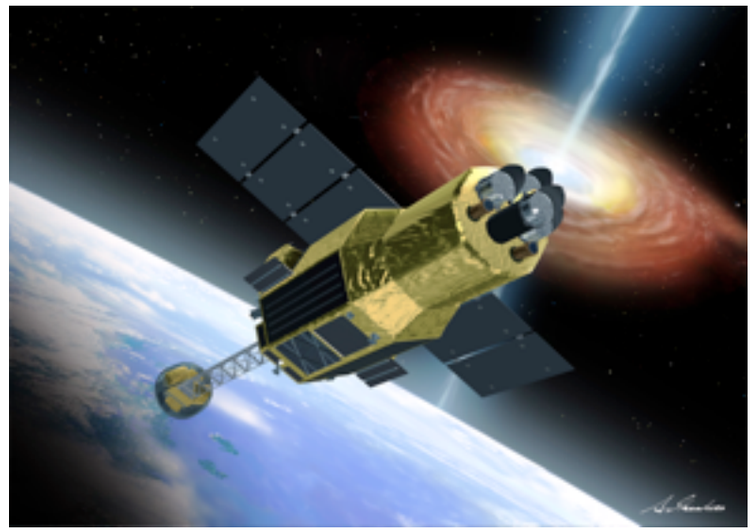
ASTRO-H

- The sixth Japanese X-ray astronomy satellite
- To be launched in 2015
- The only one next generation of large X-ray astronomy satellite @ 2015



Micro calorimeter
Energy resolution of 4 eV
Narrow FOV (3′×3′)

0.1 keV — 1 keV — 10 keV — 100 keV — 1 MeV

Soft X-ray Spectrometer (SXS)

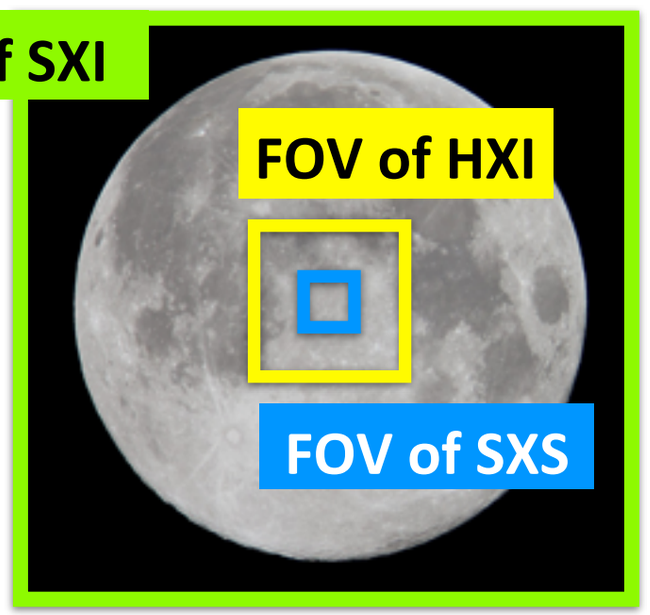
Soft X-ray Imager (SXI)

Hard X-ray Imager (HXI)

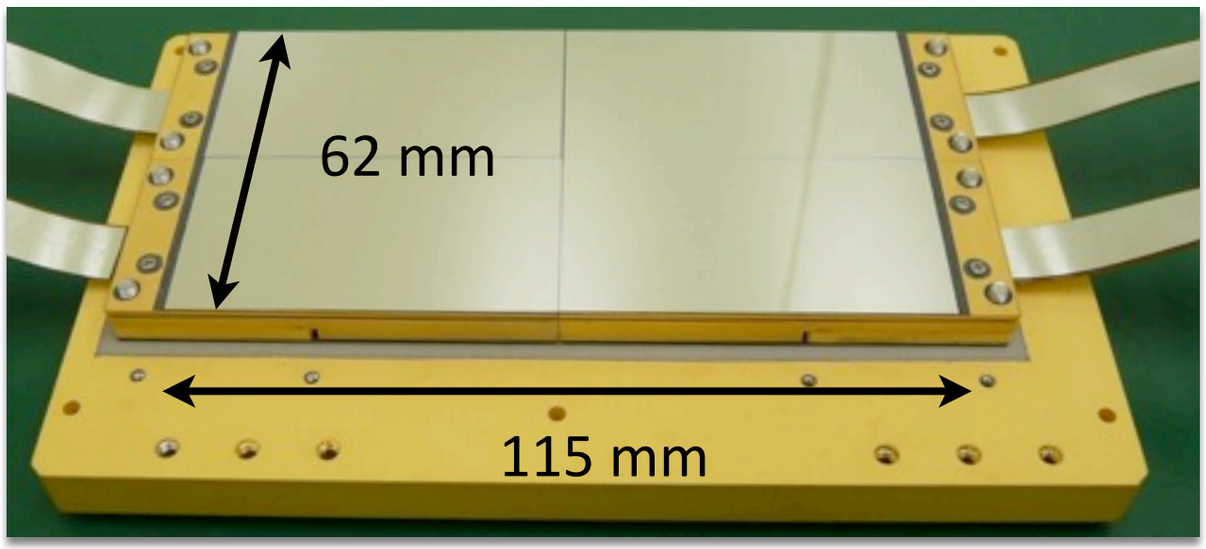
Soft Gamma-ray Detector (SGD)

Wide FOV (38′×38′)
Large effective area (< 12 keV)

Doppler shifts, fine structures
Simultaneous broadband observations (0.3–600 keV)



Soft X-ray Imager (SXI)

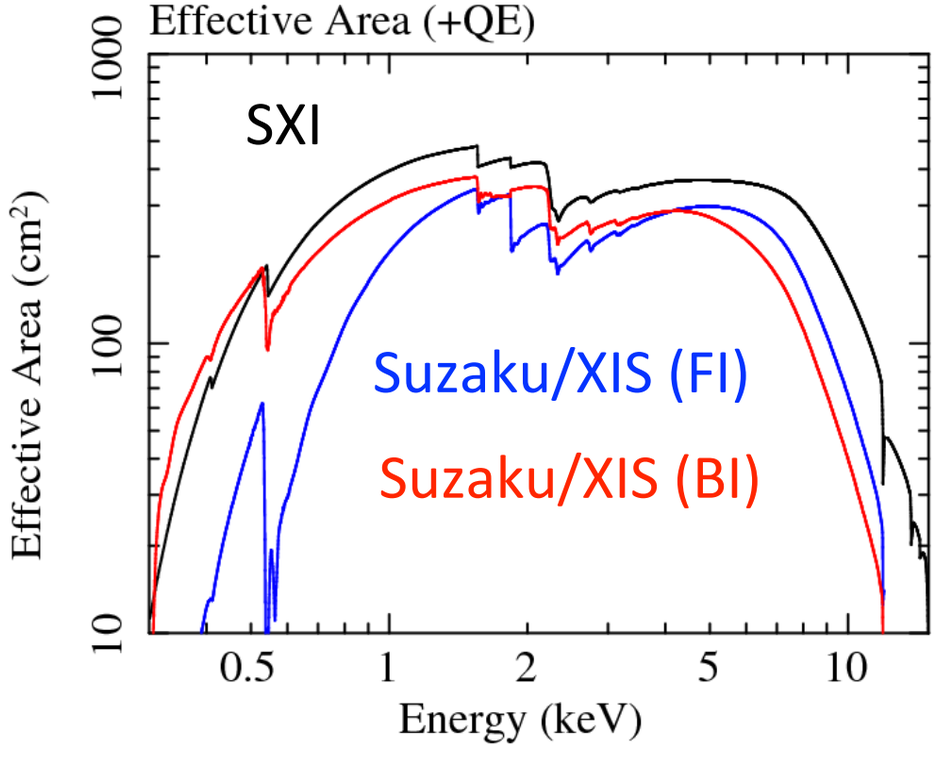


After onboard 2×2 binning

- 4 CCDs arranged in a 2 by 2 mosaic
- **P-channel back illuminated CCDs**
- **200 µm fully depleted**

➔ High quantum efficiency for X-rays in the wide range of 0.4-12 keV

CCD format	frame transfer
Pixel number /1device	640×640
Pixel size	48 µm×48 µm
Energy resolution (FWHM)@5.9 keV	requirement: 200 eV goal: 150 eV
Readout noise (a CCD + SXI system)	requirement: 10 e- achievement: 7 e-



Progress

- Flight model (FM) production has started. FM devices have already been selected.
- FM calibration is coming up.

Outline

1. Performance Verification of Engineering Model (EM) Device
(which is almost the same as FM devices)

Measurement items for performance verification

- [x] Energy resolution
- [x] Energy gain
- [x] Charge trail
- [x] CTI

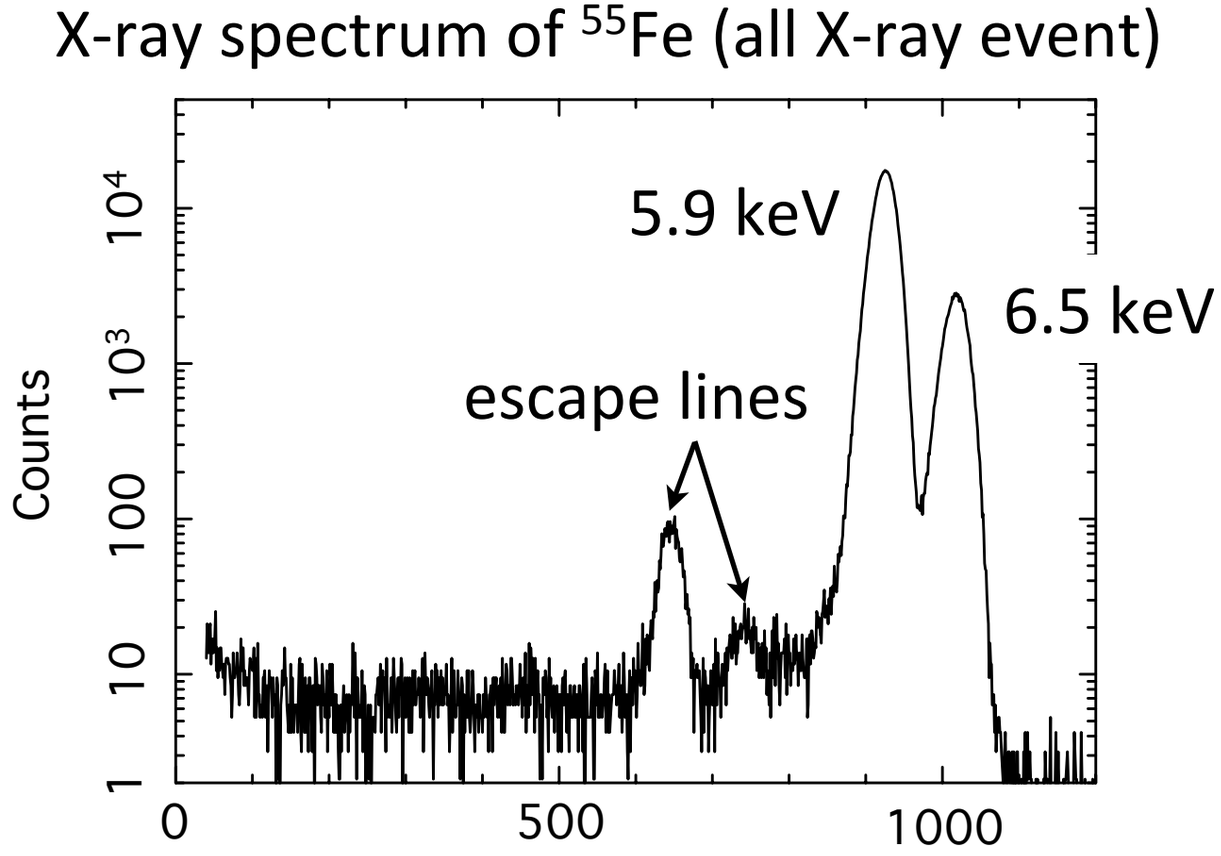
} Topics of this talk

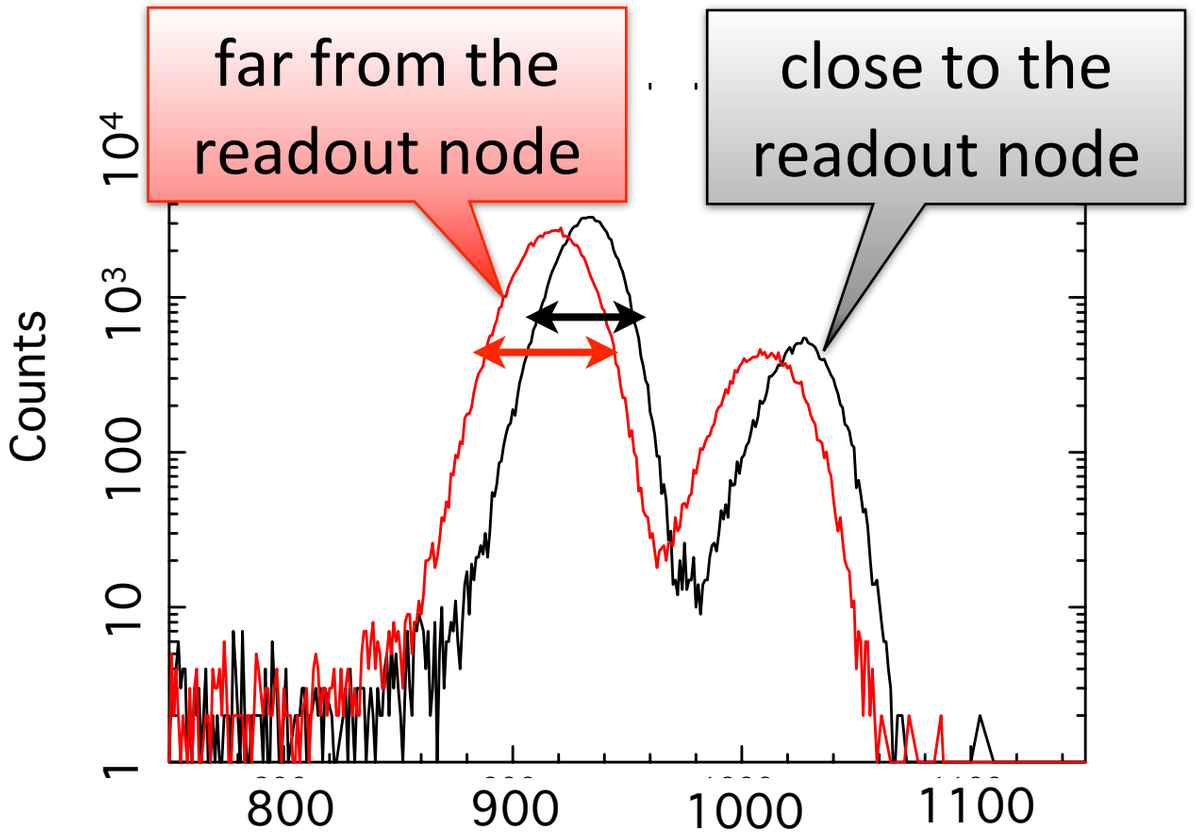
- [ ] Quantum efficiency
- [ ] Dark current
- [ ] Hot pixel / bad column
- [ ] etc...

- Correction for the effects of charge transfer
  - Increase of charge transfer inefficiency (CTI)
  - Charge trail
- Energy resolution after correction

2. Energy and Temperature Dependence of the CTI

Spectra of SXI and Problems





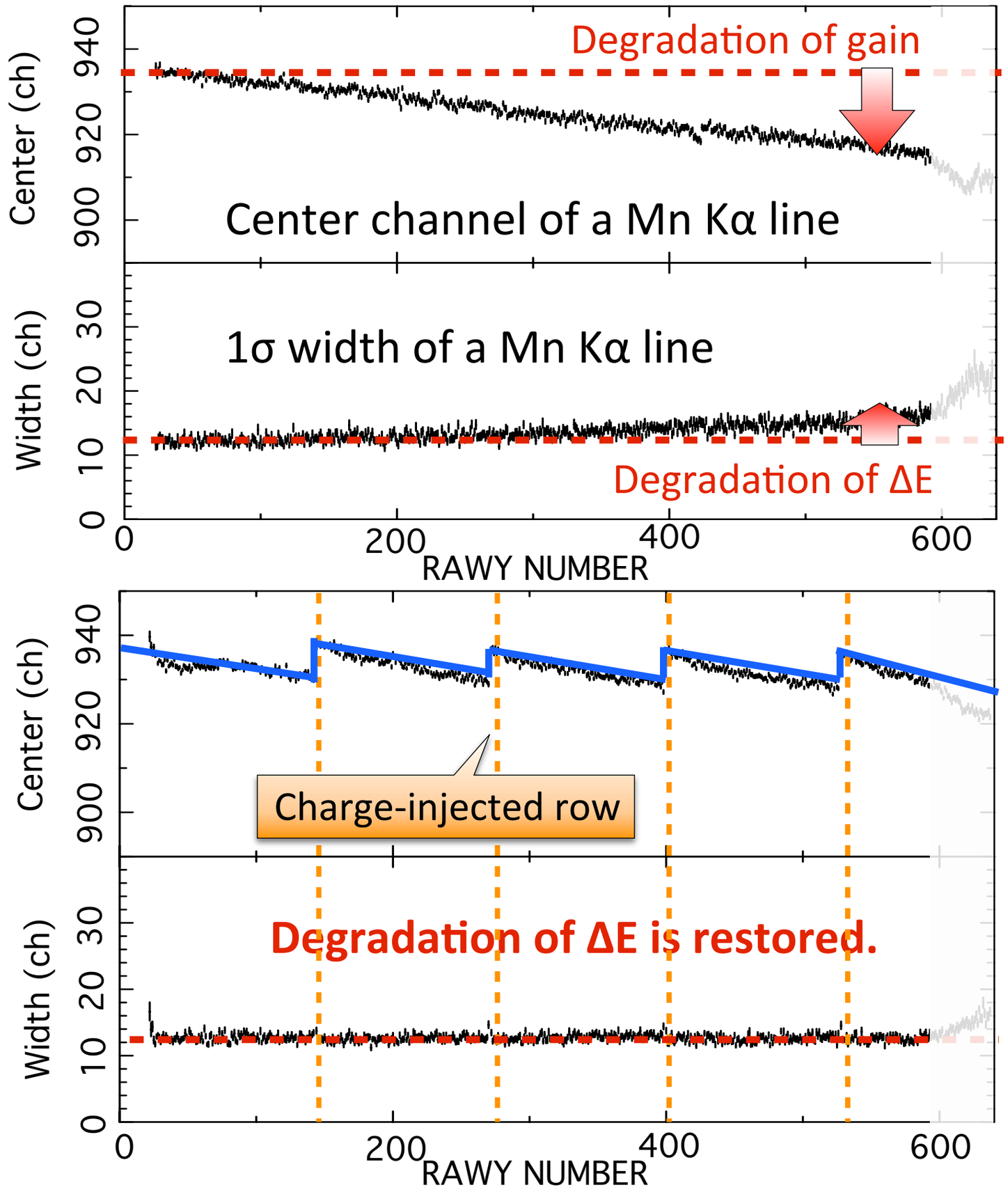
	requirement	goal	measurement
Energy resolution (FWHM)@5.9 keV	200 eV	150 eV	210 eV

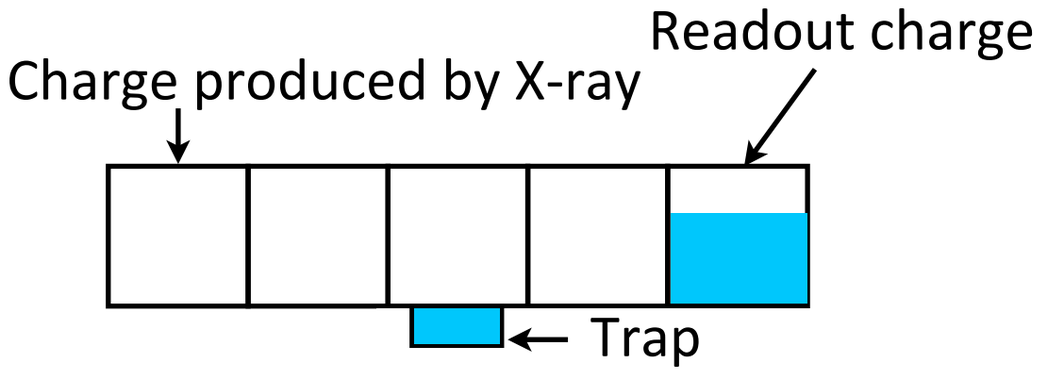
Increase of the charge transfer inefficiency (CTI)

- The gain and energy resolution get worse.

CTI = the fraction of charge loss per transfer

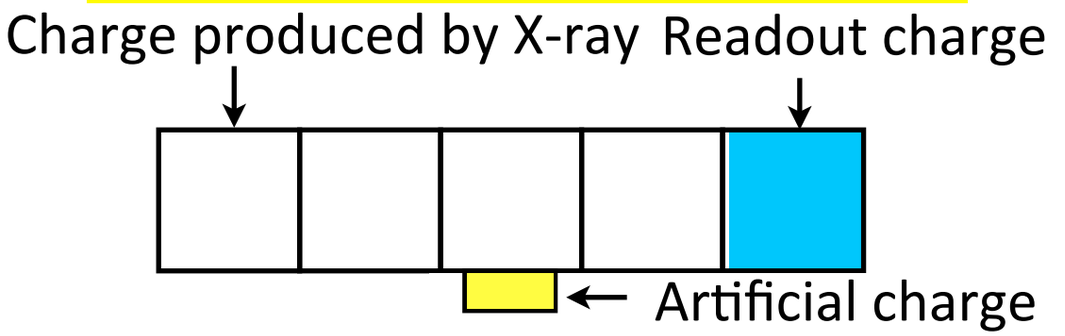
Increase of CTI and Charge Injection



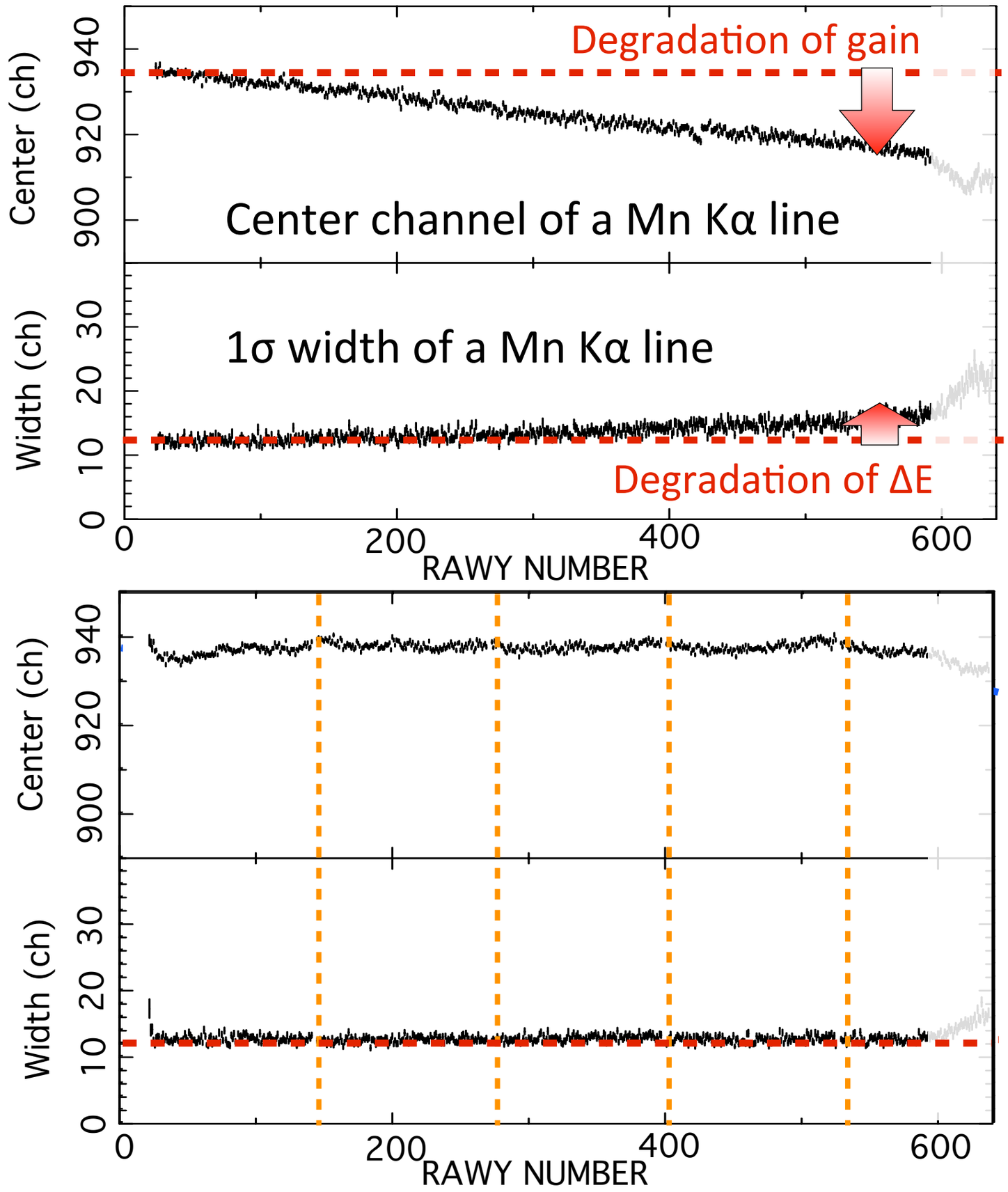


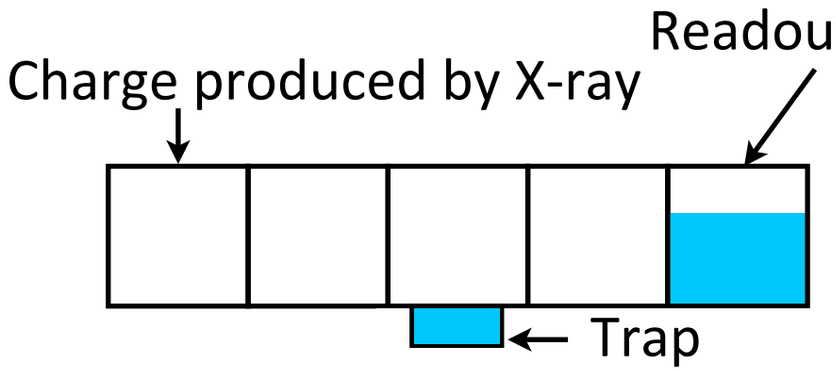
Charge traps cause increase of the charge transfer inefficiency (CTI).

Artificial charge injection (CI)



Increase of CTI and Charge Injection





Charge traps cause increase of the charge transfer inefficiency (CTI).

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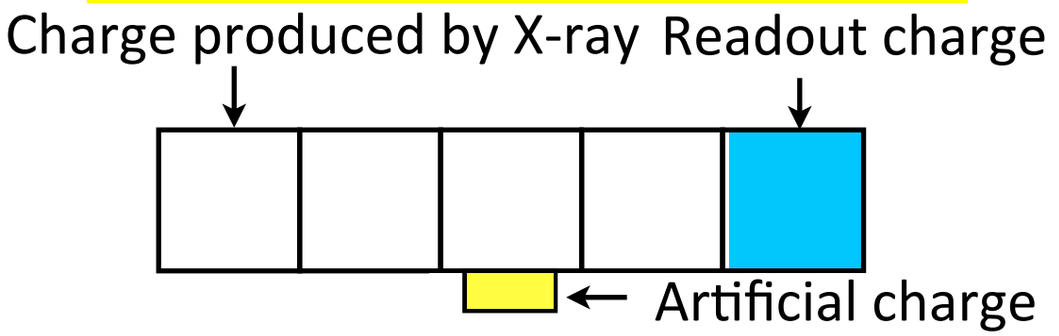
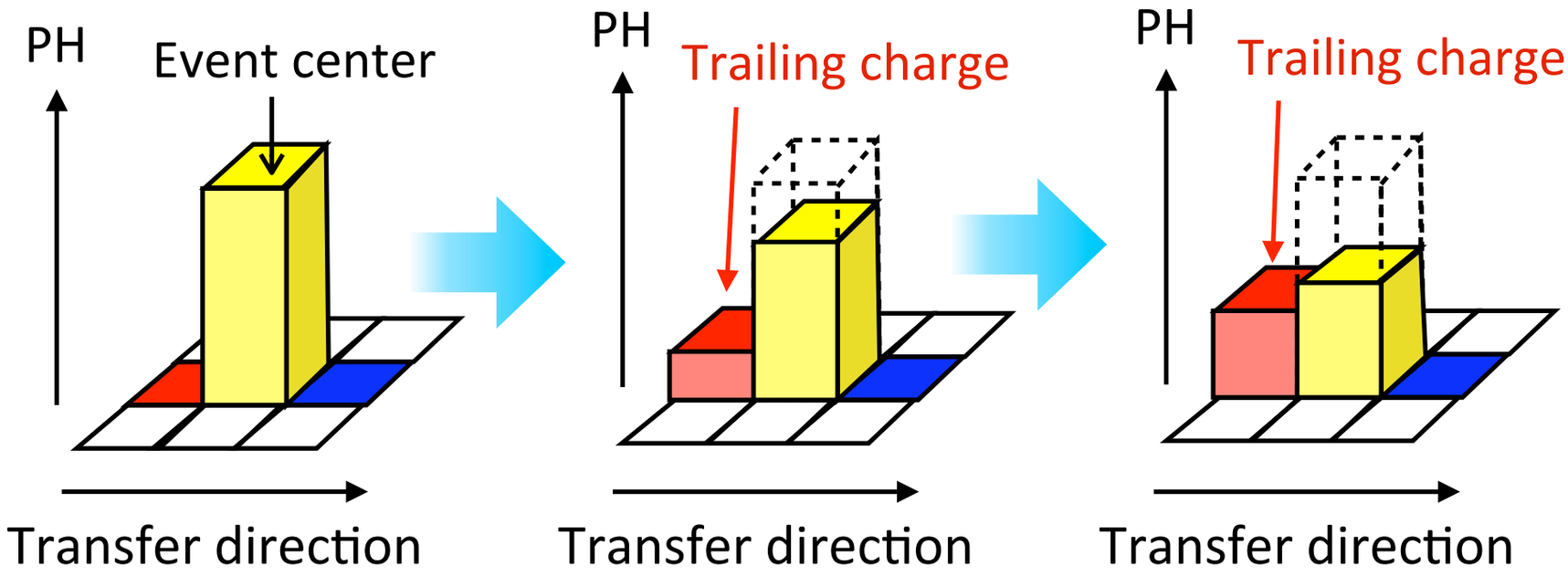


The artificial charge is detrapped.

→ **"Sawtooth function"**

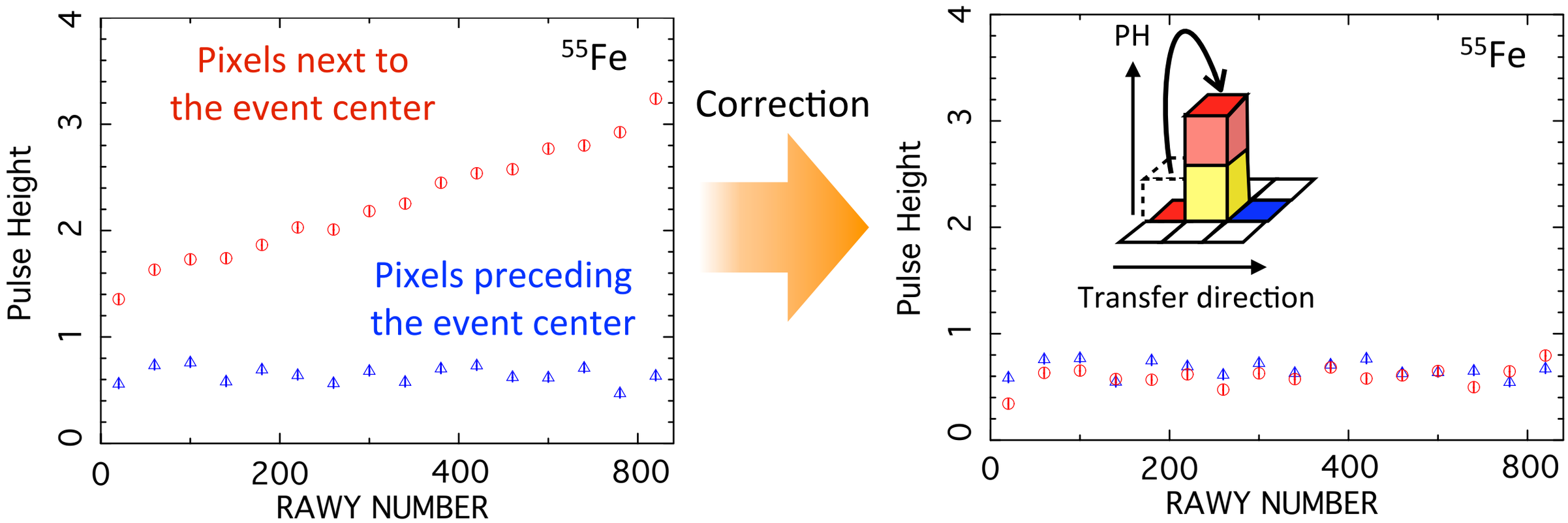
Correction

Charge trail and Its Correction

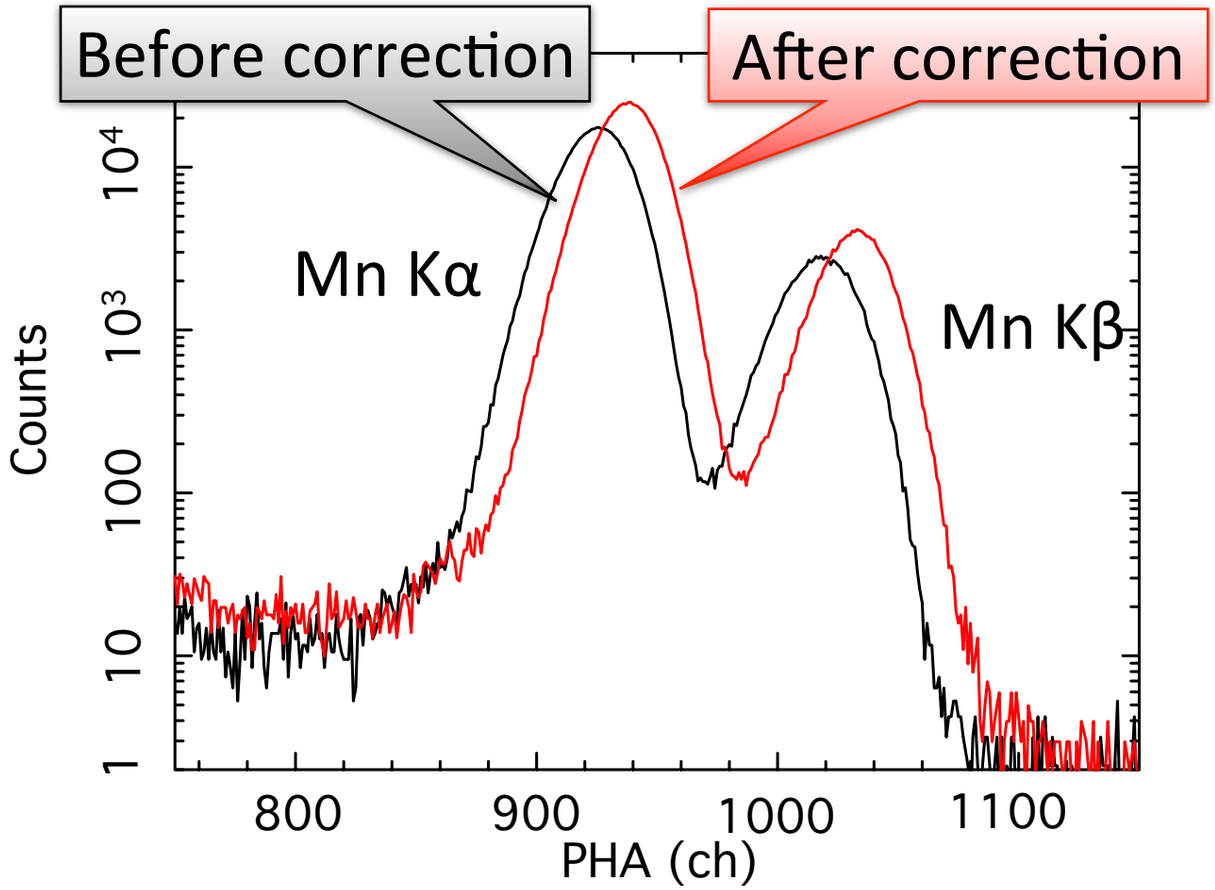


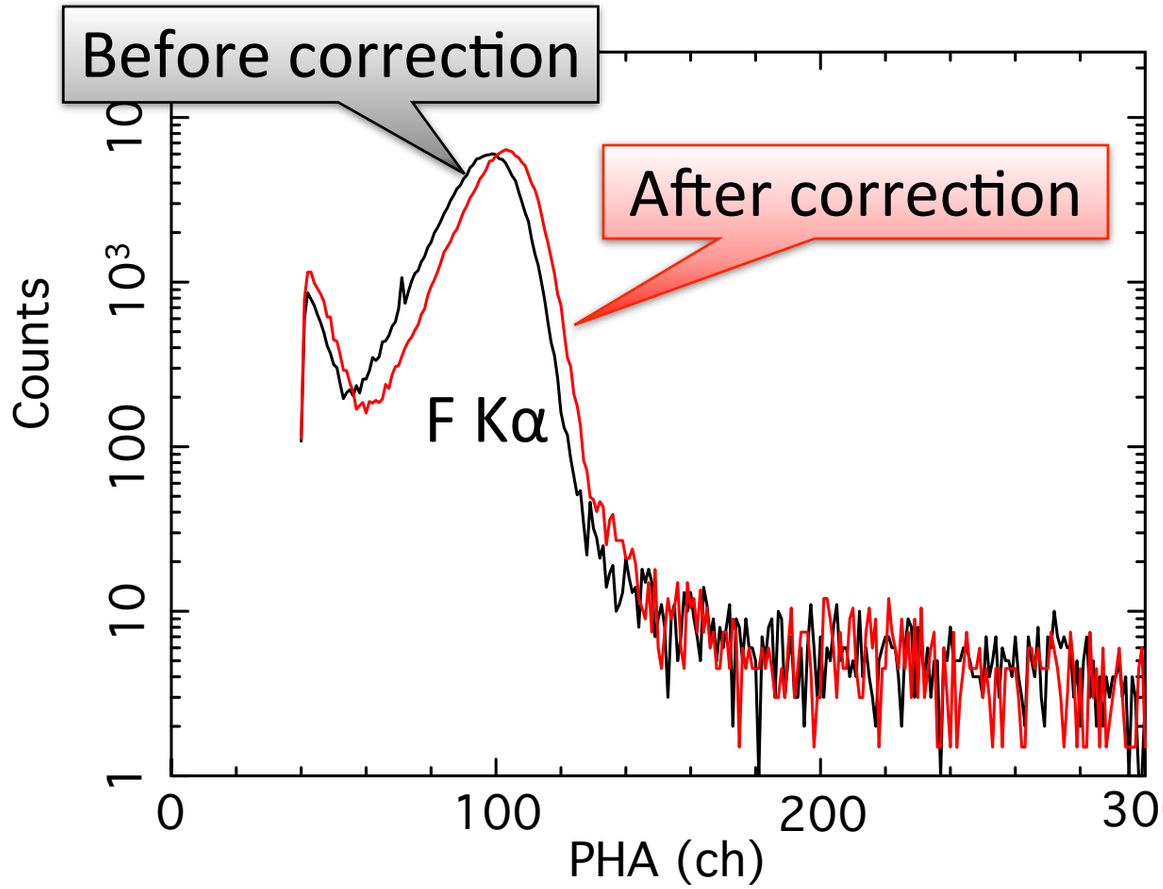
A part of charge is trapped during the transfer.

The probability of charge trailing per pixel transfer =1.5×10^{-6}

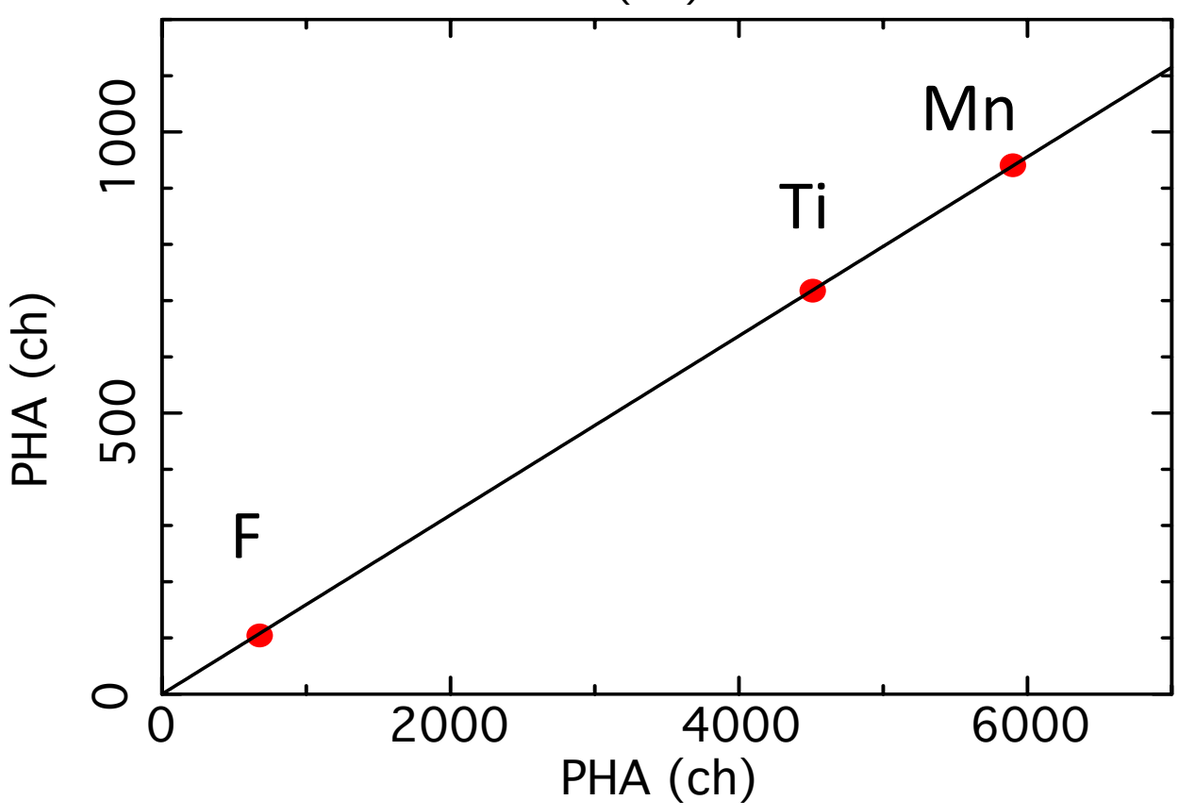


Spectra after Correction





Energy resolution (FWHM)	Mn Kα	F Kα
Before correction	210 eV	133 eV
After correction	186 eV	115 eV



Outline

1. **Performance verification of EM device**
   (which performance is equivalent to FM devices)
   - Correction of the effects of charge transfer
     - Increase of charge transfer inefficiency (CTI)
     - Charge trail
   - Energy resolution after correction

Measurement items of ground calibration

- ☑ Energy resolution
- ☑ Energy gain
- ☑ Charge trail
- ☑ CTI

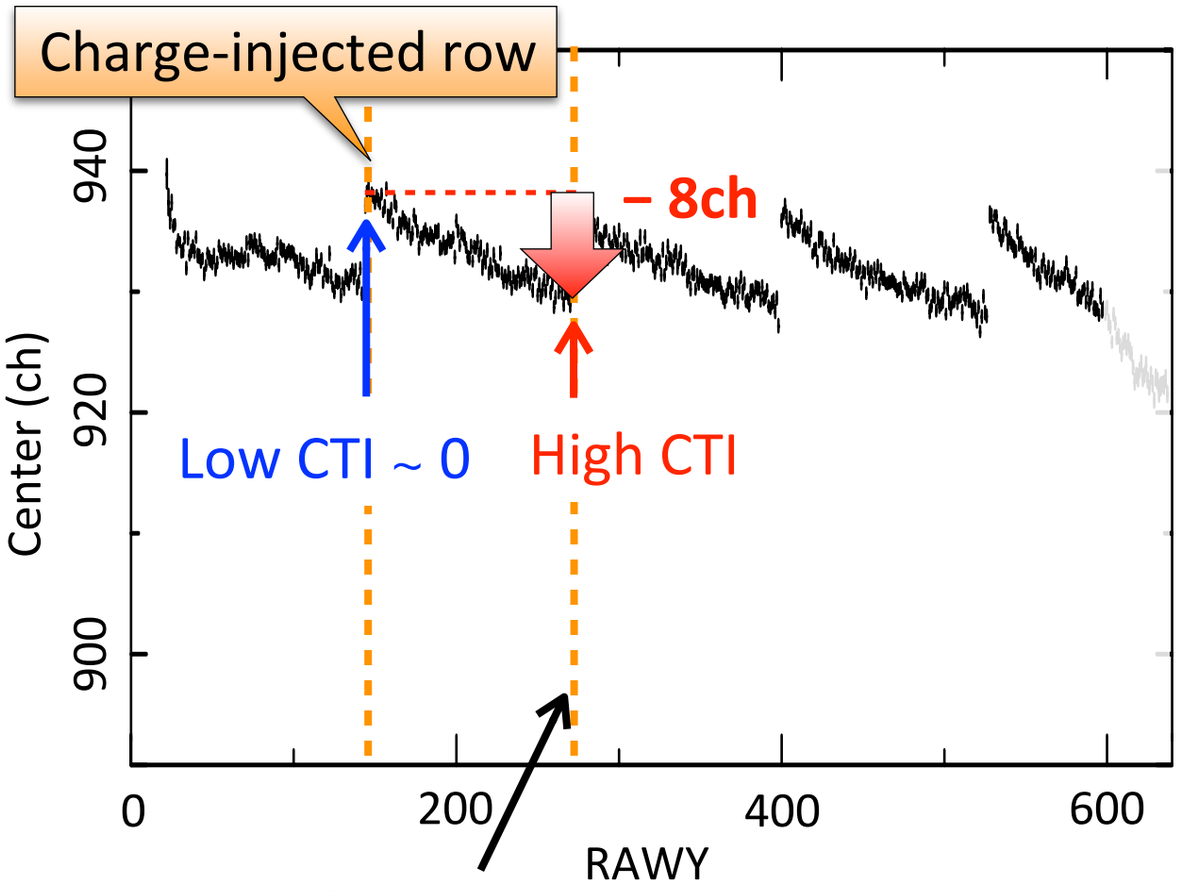
} We performed these calibration on EM device.

- ☐ Quantum efficiecy
- ☐ Dark current
- ☐ Hot pixel / bad column
- ☐ etc...

2. **Energy and Temperature Dependence of the CTI**

Energy Dependence of CTI (CI-on)

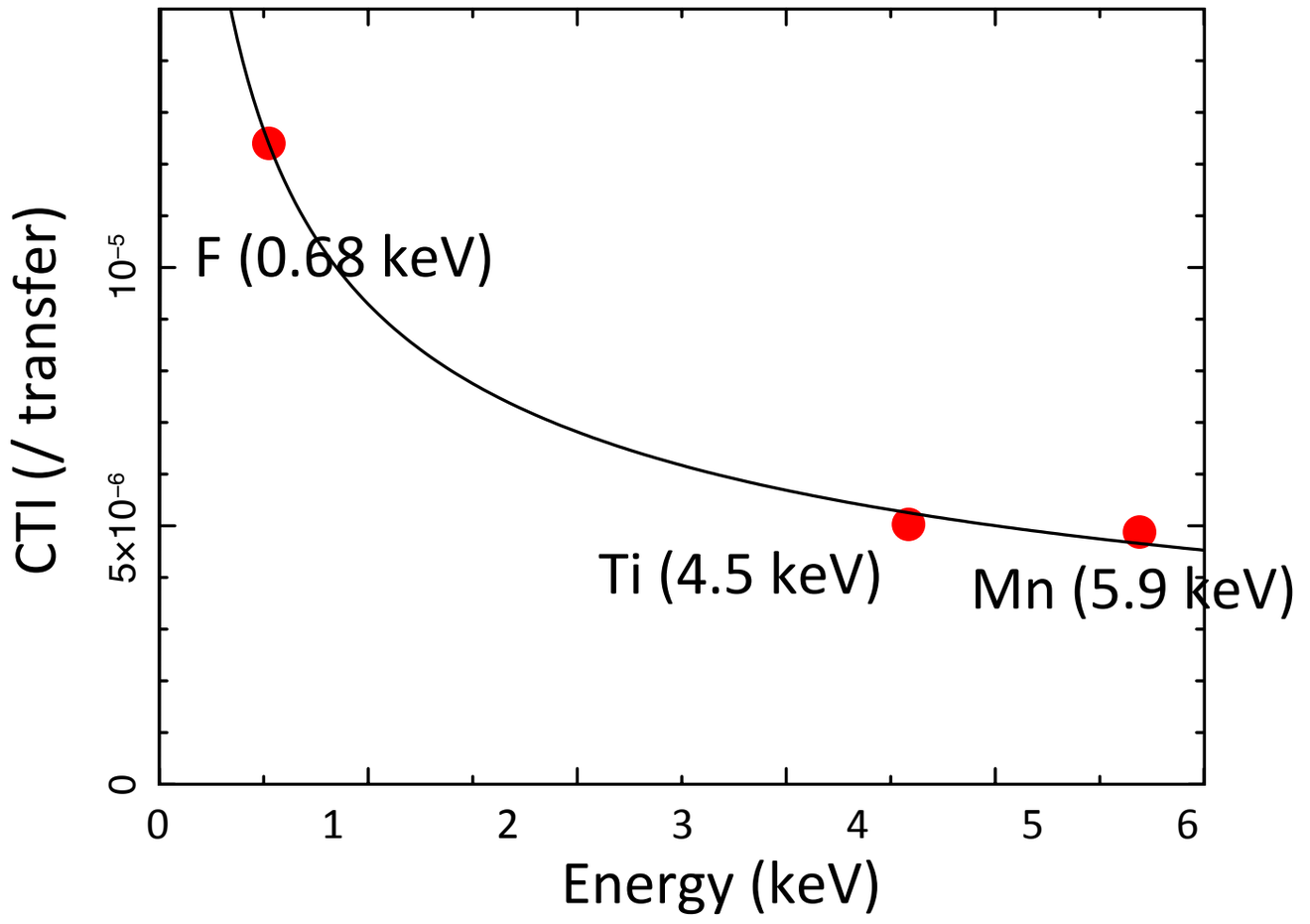
Measurement of CTI (^{55}Fe)



Transfer number ~1800
(including frame store region)

just before the CI row

CTI (/transfer) ~ 4.9 ×10^{-6}



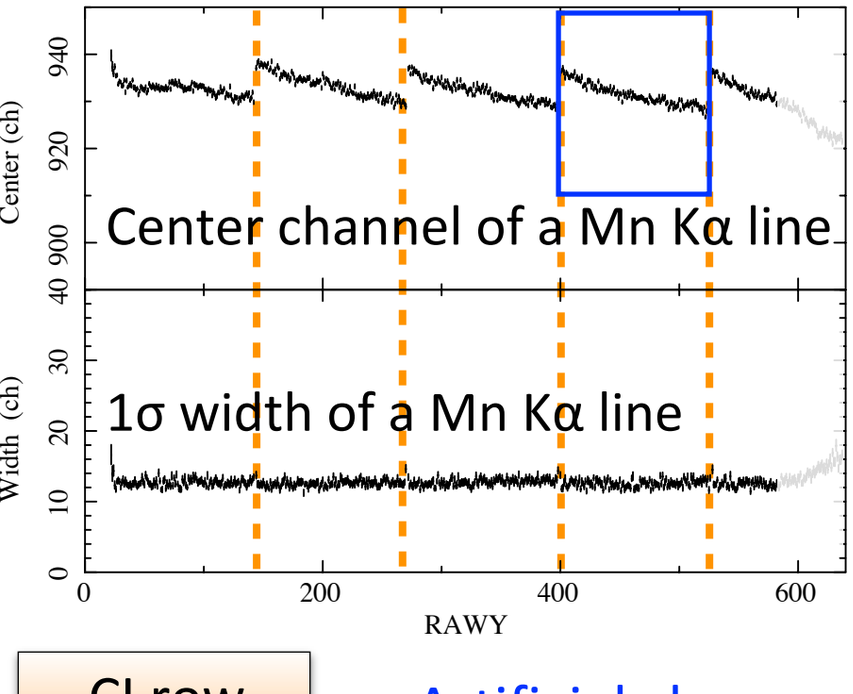
Model:

$$CTI = CTI_0 \times \left(\frac{E}{6\ keV}\right)^{-\beta}$$

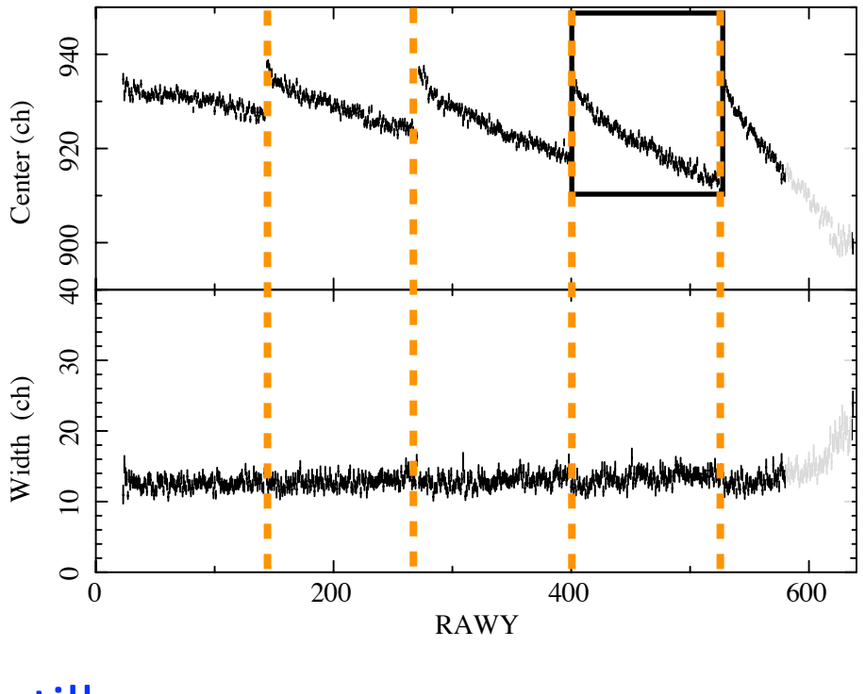
β = 0.45
$CTI_0 = 4.7 \times 10^{-6}$

Temperature Dependence of CTI

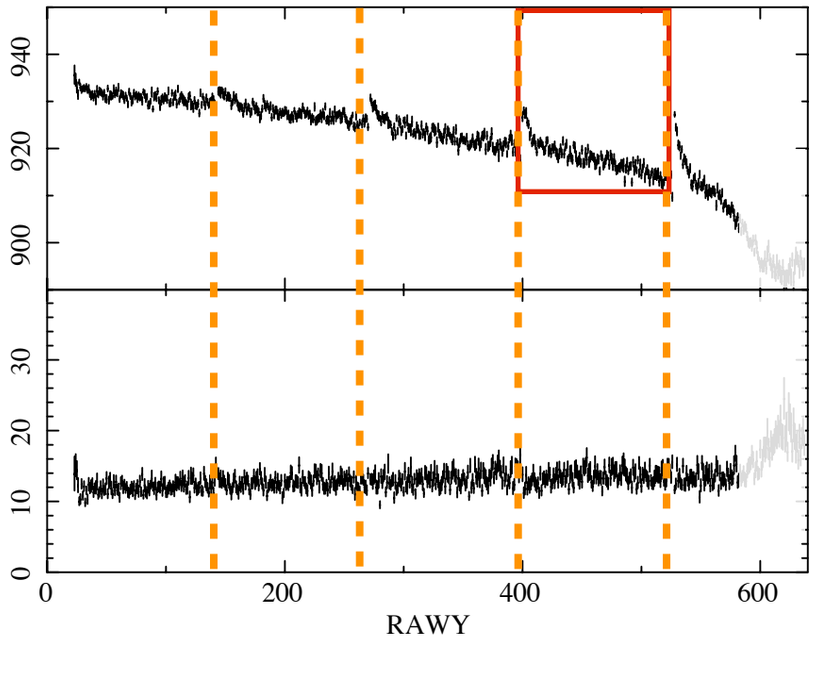
^{55}Fe @ −120℃

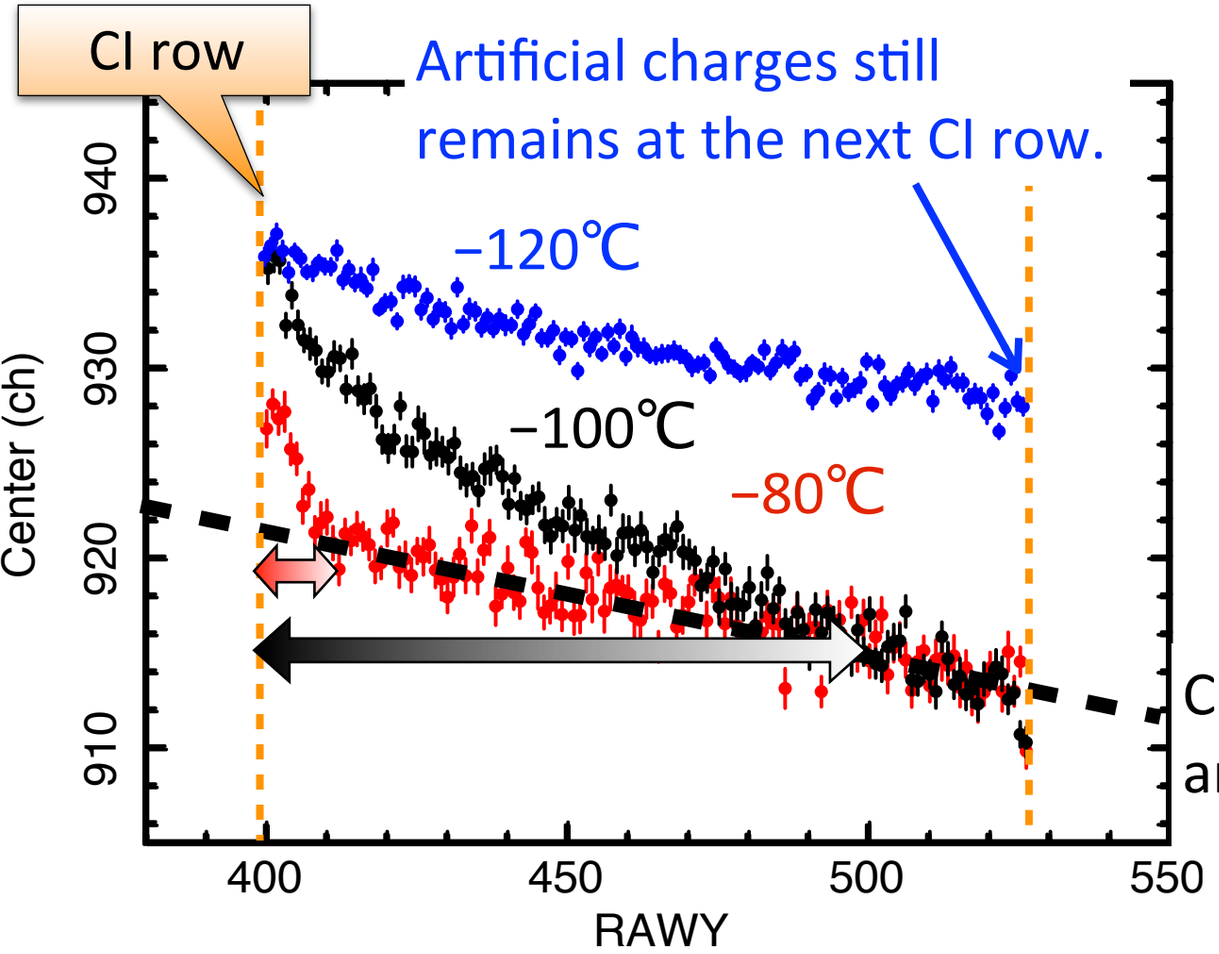


^{55}Fe @ −100℃



^{55}Fe @ −80℃





Artificial charge is detrapped.
Time scale depends on temperature.

$$\tau(T) \propto \exp[E_T/kT]$$

E_T : Trap energy level

(*Scientific Charge-coupled Devices,* J. R. Janestick)

$$\tau(-100℃) / \tau(-80℃) \sim 10$$

$$\rightarrow E_T \sim 0.3 \text{ eV}$$

Summary

1. Performance verification of EM device

- We performed corrections of increase of CTI and charge trail
- Energy resolution after correction

  210 eV → 186 eV (@5.9 keV)

  133 eV → 115 eV (@0.68 keV)
- Linear relationship between the energy and pulse height

2. Energy and Temperature Dependence of the CTI

- CTI depends on the energy as $\propto E^{-\beta}$

  → β=0.45
- Detrapping time scale of artificial charge depends on temperature
- Trap energy level ~ 0.3 eV