X線用を中心とする
最近のSOIピクセル検出器の開発の現状

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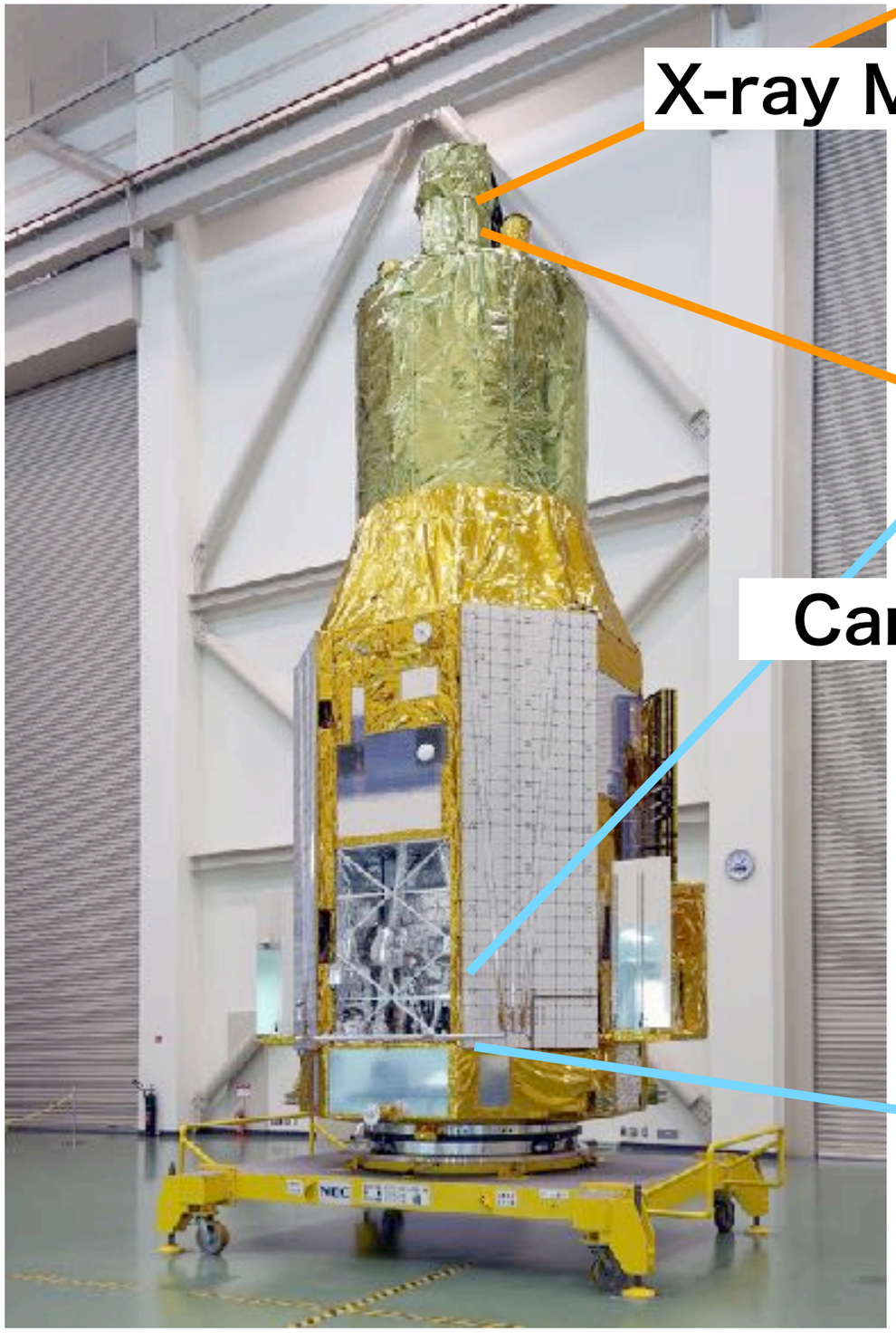
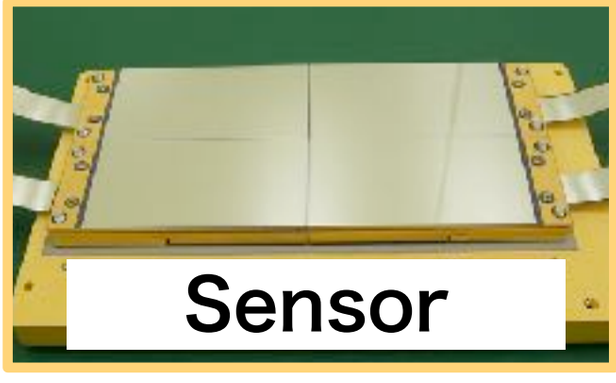
X-ray Imaging System



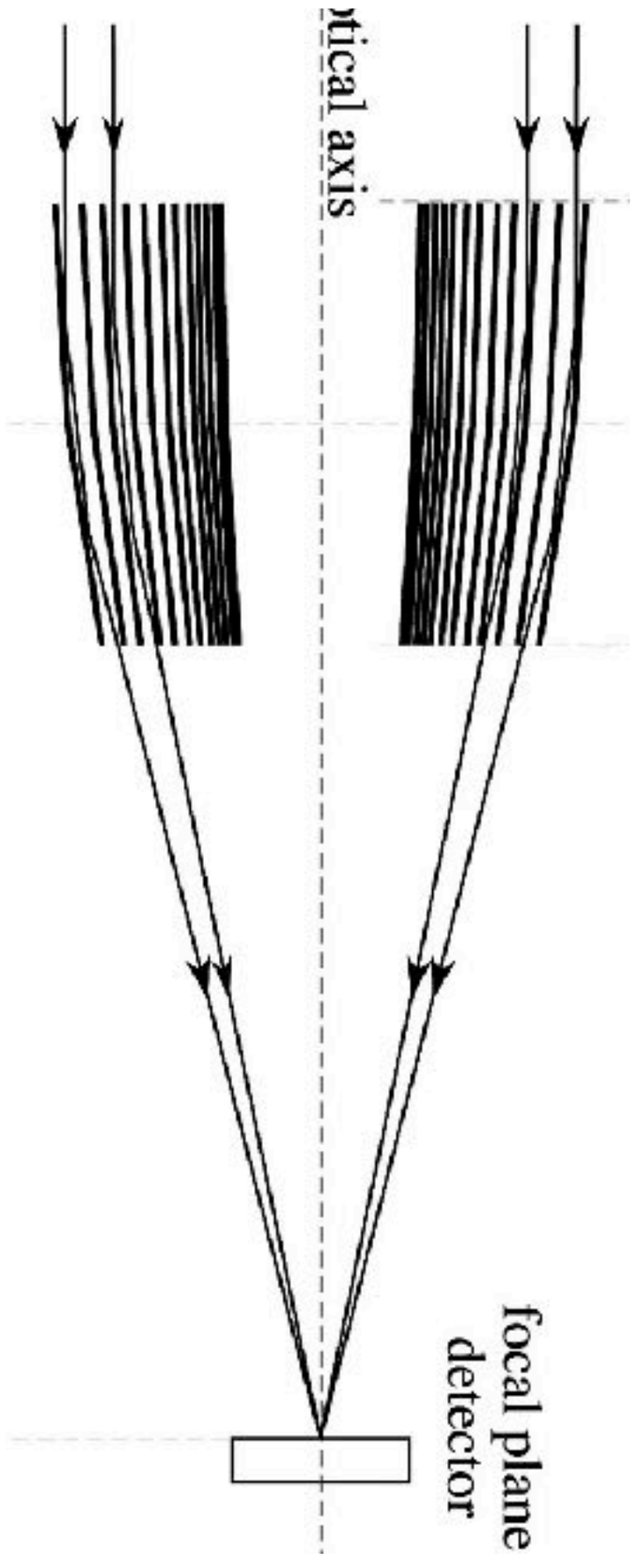
X-ray Mirror

Camera

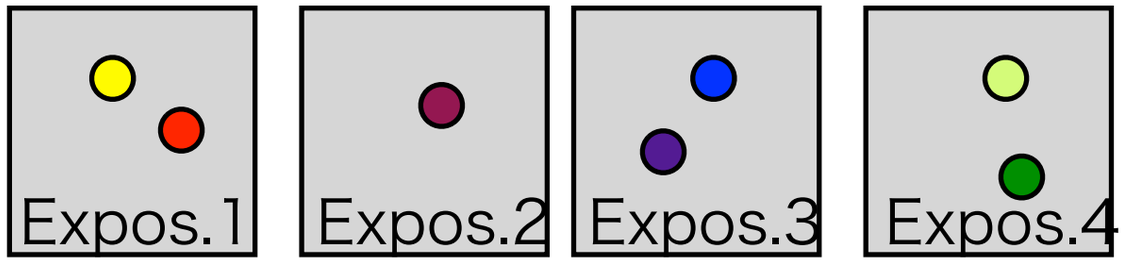


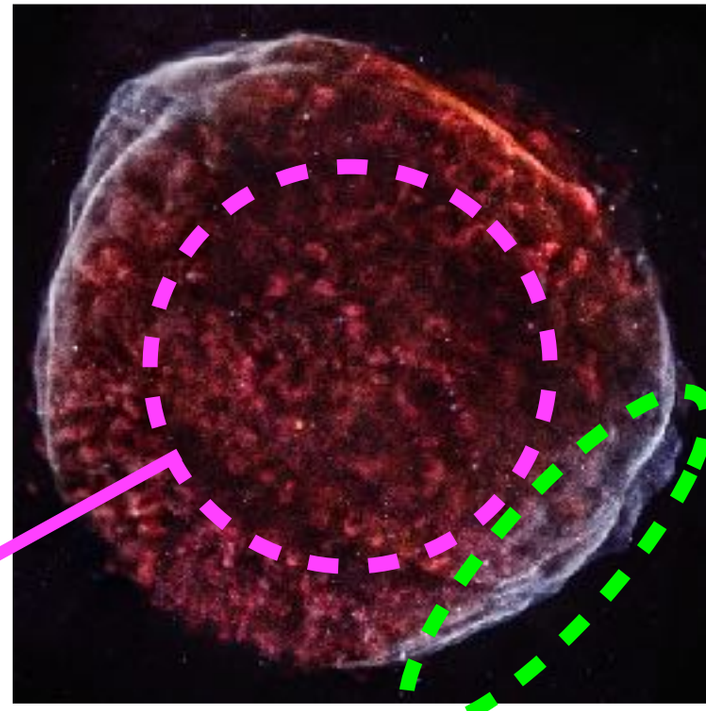
Sensor

http://astro-h.isas.jaxa.jp/diary/1329/
ttps://user.spring8.or.jp/sp8info/?p=2925



X-ray Photon Counting

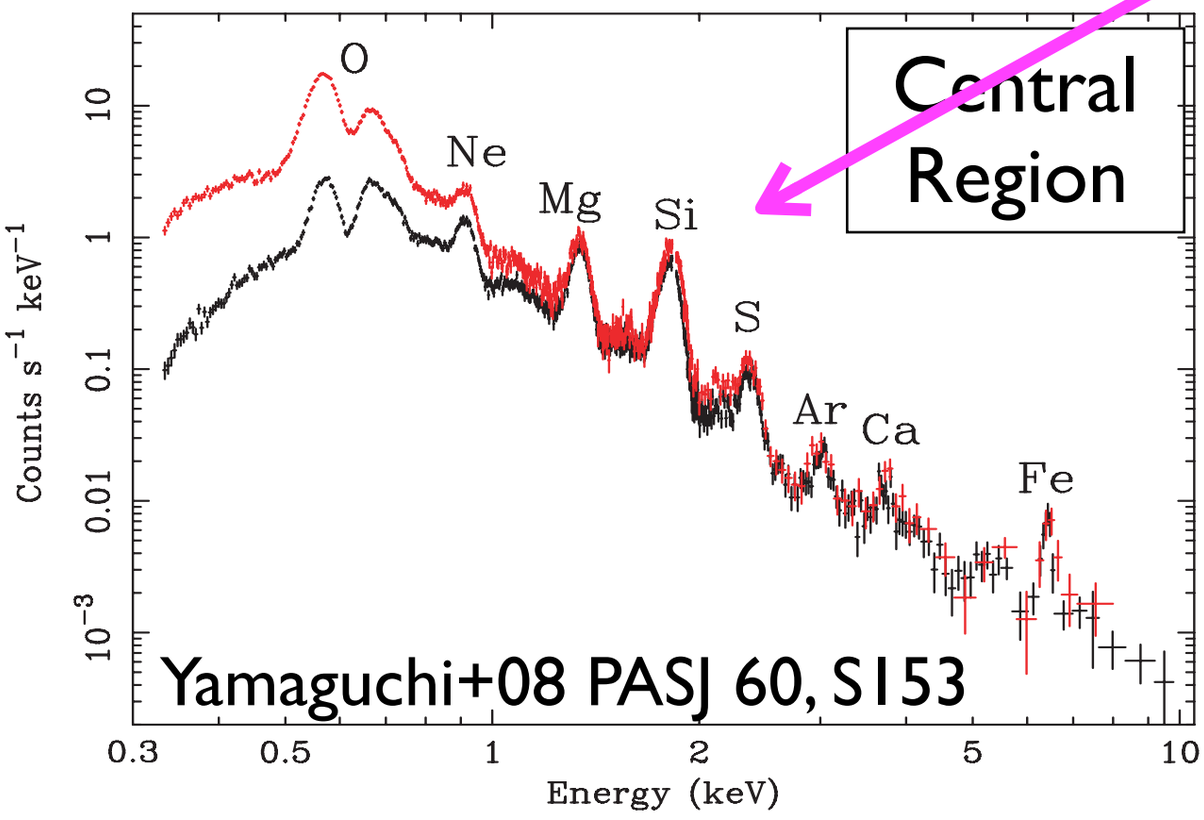


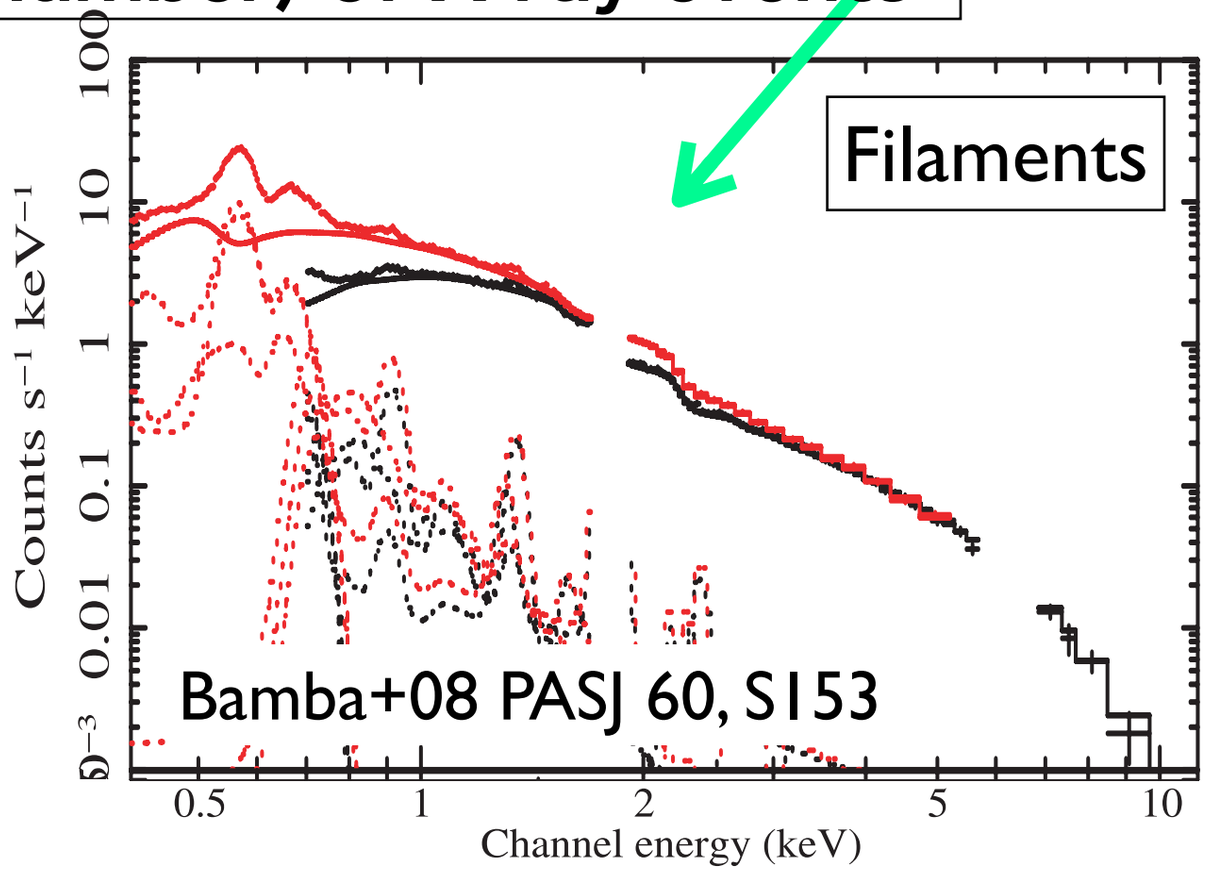


- Detect an X-ray photon as one-by-one event.
- Measure position, energy and time of each X-ray event.
- Make exposures of ~10^4 times.

Map of the number of X-ray events

Histogram of energy (electron number) of X-ray events



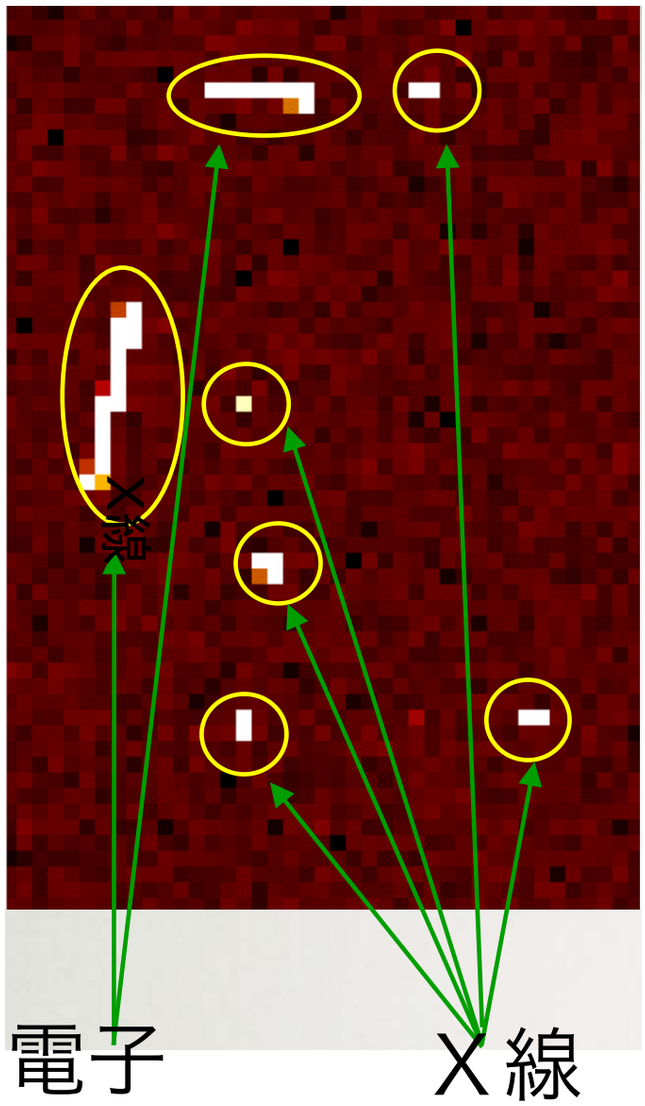


非X線バックグラウンド

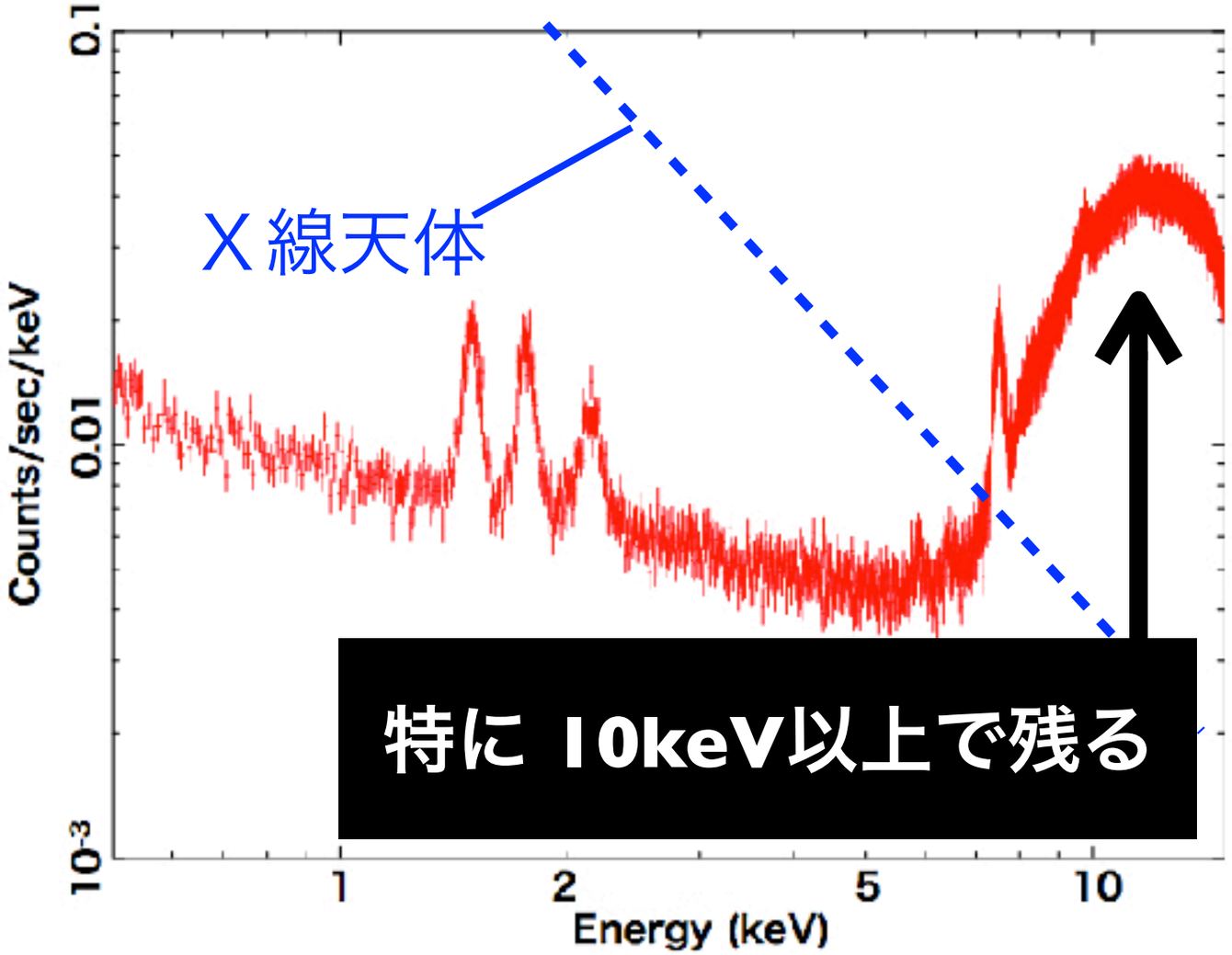
- 高エネルギー粒子が作るX線によるイベントと区別できない信号
- X線天体は暗い ⇒ 非X線バックグラウンドの除去が本質

「すざく」のデータ

生イメージ



除去後 ⇒ 完全には除去できない



高エネルギー粒子：トラックを作る
X線：広がりがコンパクト小さい (シングルまたは隣)

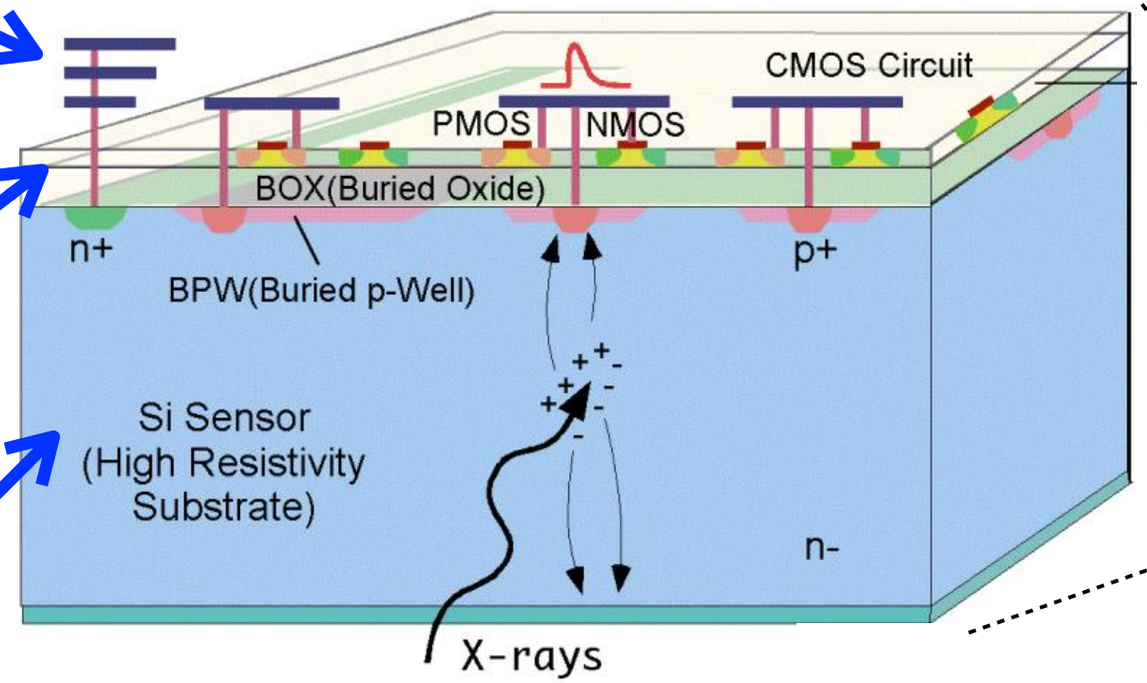
⇒ 広がりで区別する

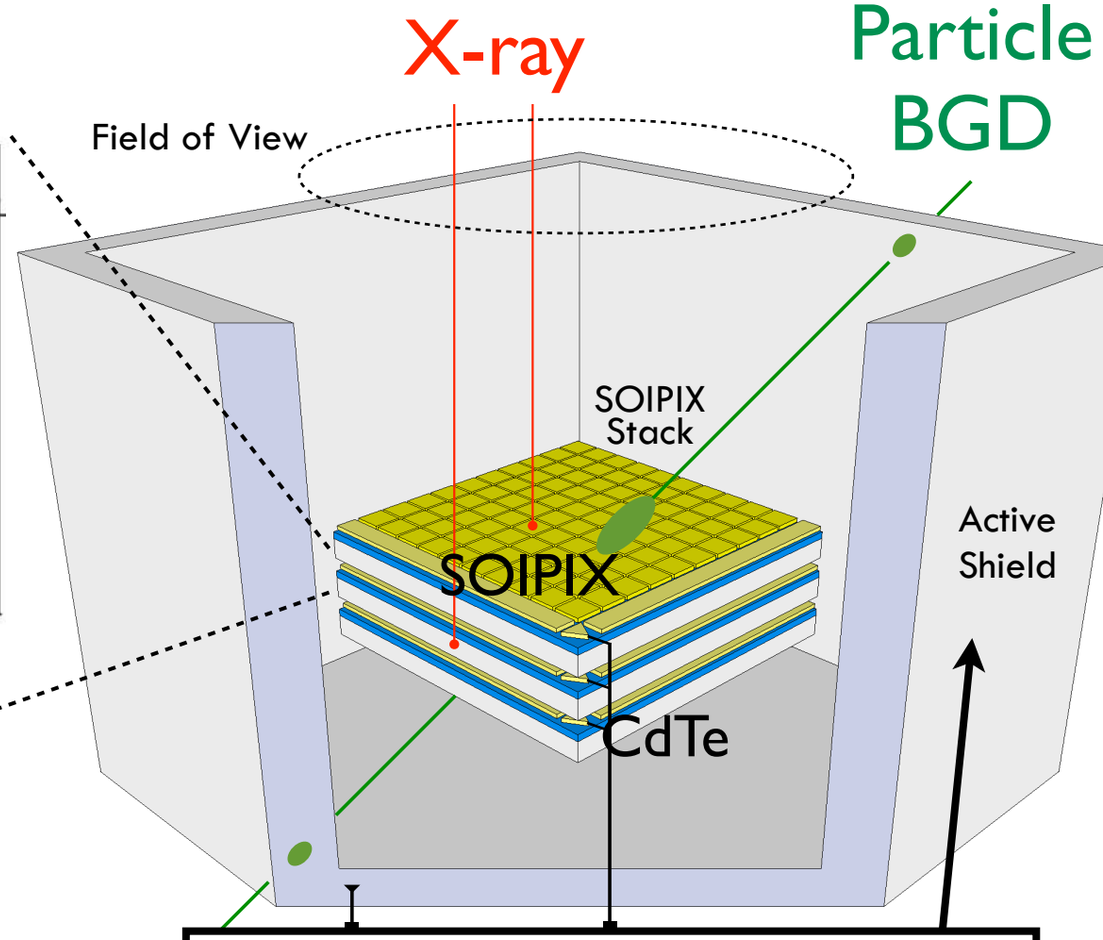
"XRPIX" = SOI pixel sensor for X-ray Astronomy

CMOS (low ρ Si)

Insulator (SiO2)

Sensor (high ρ Si)





Anti-coincidence Shield
by Scintillators
Rate ~10kHz

Each pixel has its own trigger logic and analogue readout CMOS circuit.

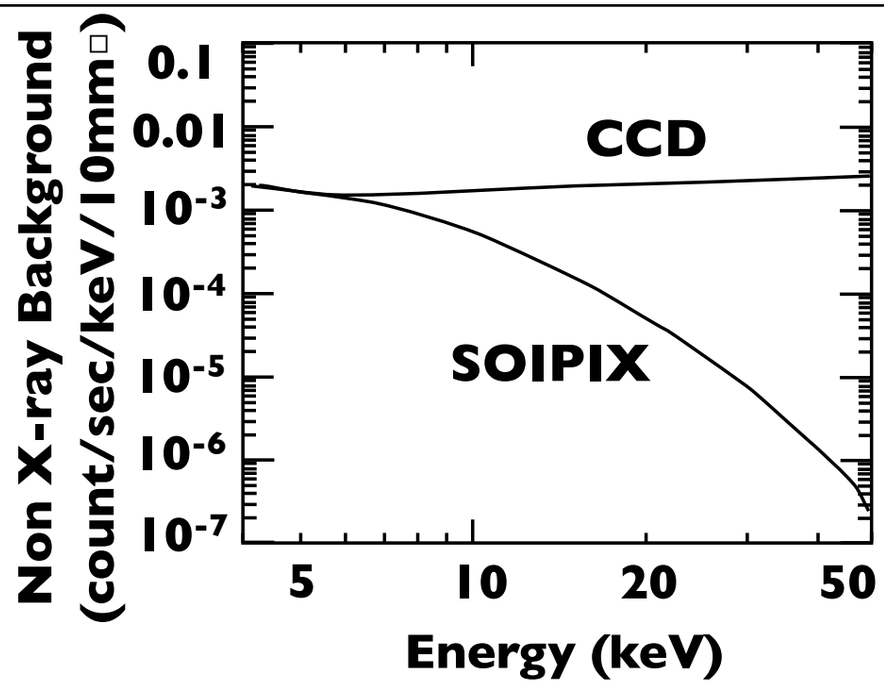
- realize very low non-Xray BGD by anti-coincidence with surrounding scintillators
- event rate from the scintillators is about ~10kHz
- XRPIX is required to have time resolution much faster than ~10kHz.

Target Specification of the Device

Imaging	area ~ 15x45mm^2 pixel ~ 30-60μm□ (1" @ F=10m)
Energy Band	Req. 1-40 keV, Goal 0.5-40 keV Backside Illumination Req. <1μm, Goal 0.1μm Full Depletion Req. >250μm
Spectroscopy	ΔE : Req. < 300eV, Goal < 140eV @ 6keV ENC: Req. <10e-, Goal < 3e- ← **Most Difficult**
Time Resolution	< 10μsec for the anti-coincidence with the rate of ~10kHz
Max Count Rate	> 2kHz / detector for observation of bright X-ray sources
Non X-ray BGD (anti-coincidence)	1/100 of CCD at 20 keV (5e-5 c/s/keV/10x10mm2)

same performance as CCD

new features with X-ray SOIPIX



XRPIX1: Pixel Circuit

Trigger

Comparator

VDD18

GND18

Trigger output

Analog Readout

Analog output

VDD18

SF1

STORE

CDS

SF2

COL_AMP

OUT_BUF

G=1

G=1

Sensor

Sensor C

Sample C
100fF

CDS C
100fF

Sample /Store

GND18

PD_VRST

CDS _VRST

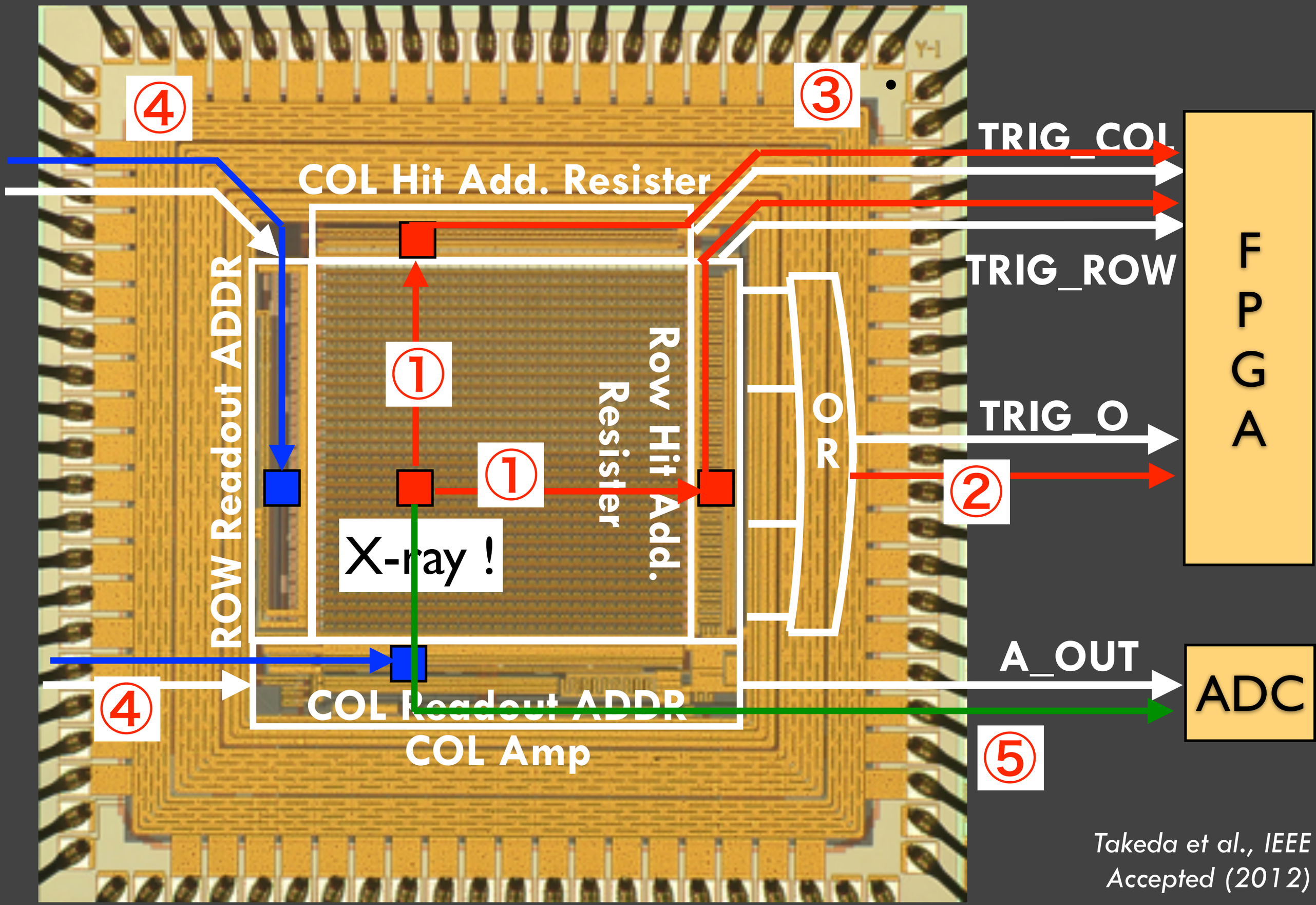
VTH

TEST_ECA

EOXX

Ryu+2011 IEEE/TNS 58, 2528

XRPIX1b-CZ : Event Driven Readout



Takeda et al., IEEE Accepted (2012)

シリコンピクセル検出器のアメリカ・ヨーロッパの状況

X-ray Surveyor / Lynx

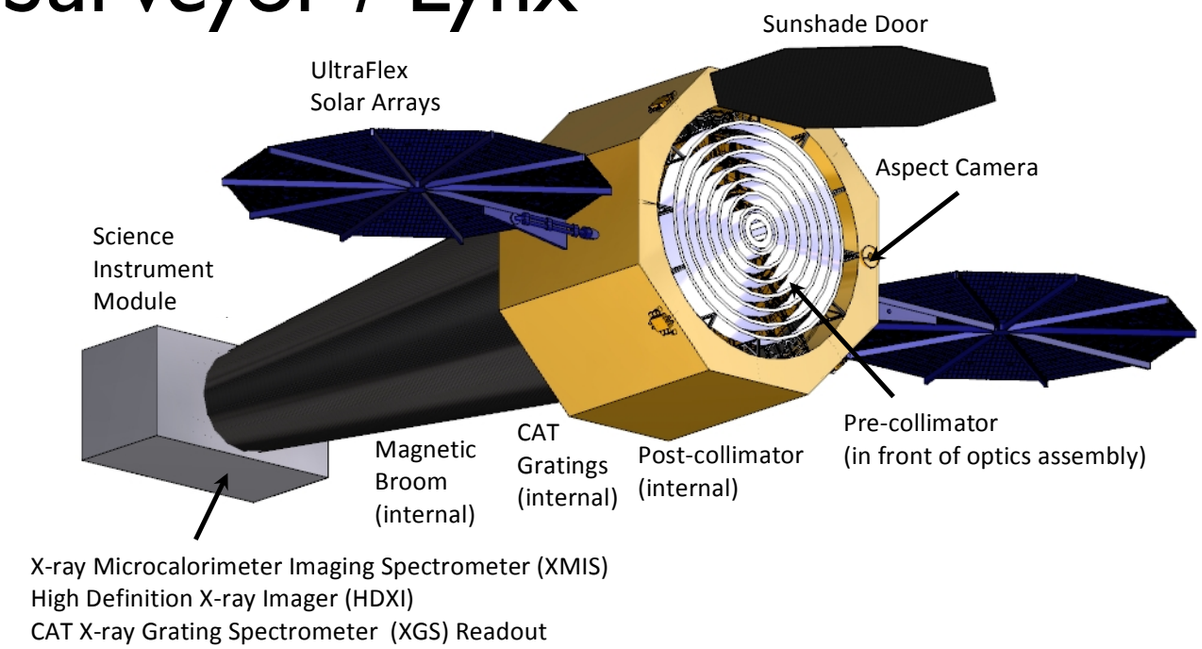
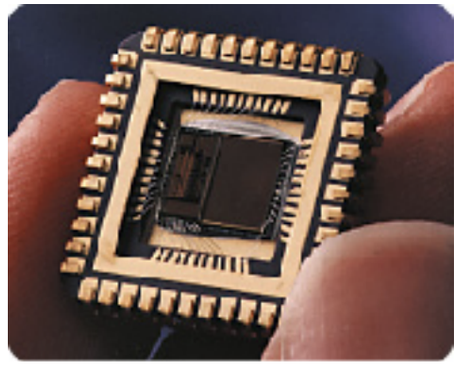
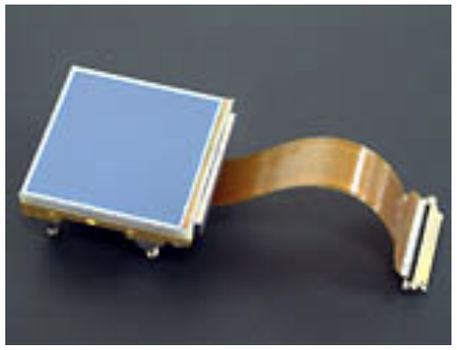


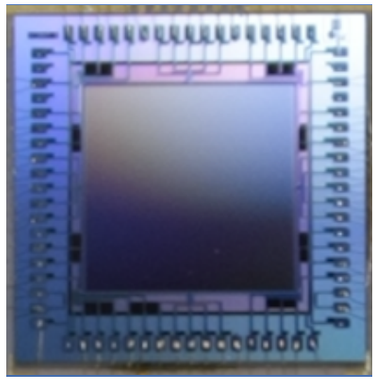
Figure 1. Artist's conception of the *X-ray Surveyor* baseline mission concept.

Bulk CMOS



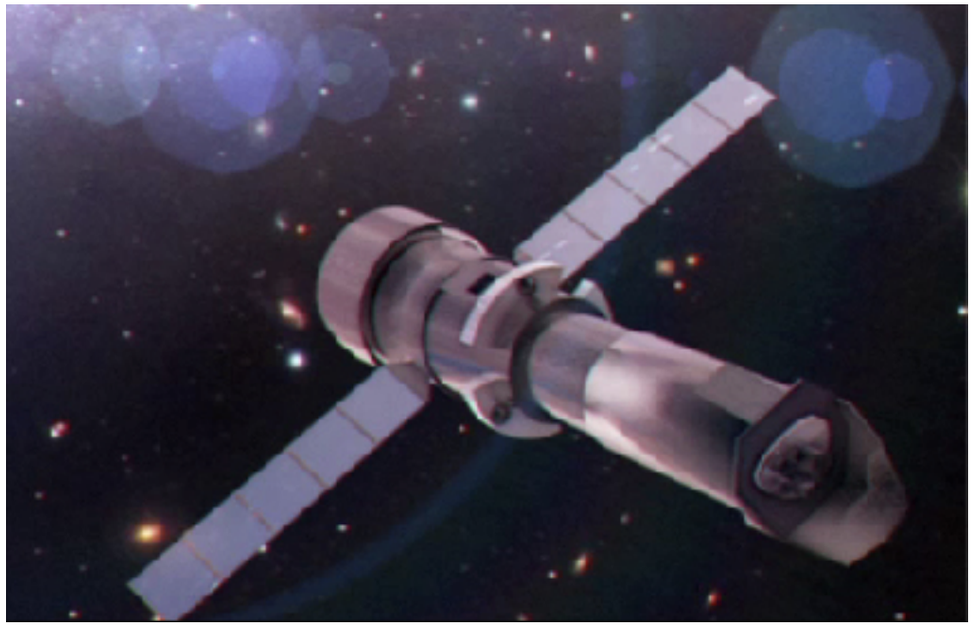
Hybrid

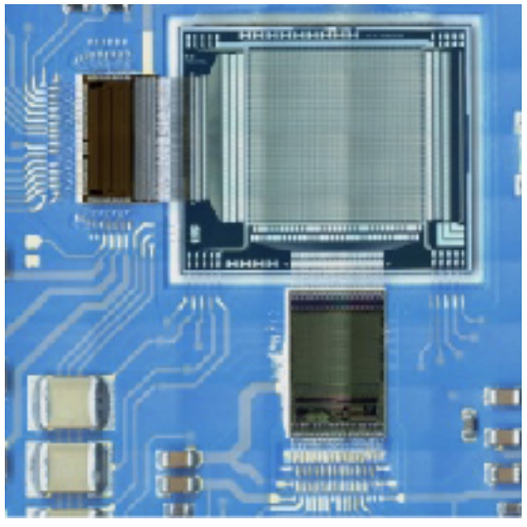




Digital CCD with CMOS output

Athena





DEPFET

いずれも軟Ｘ線 (<10keV)を重視

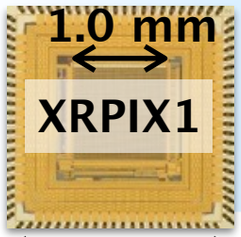
X線SOIPIXはワイドバンド

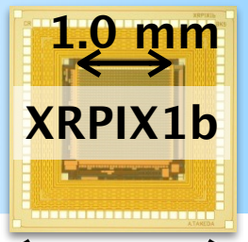
トリガ送出機能を持つのはX線SOIPIXのみ

Results from the developments

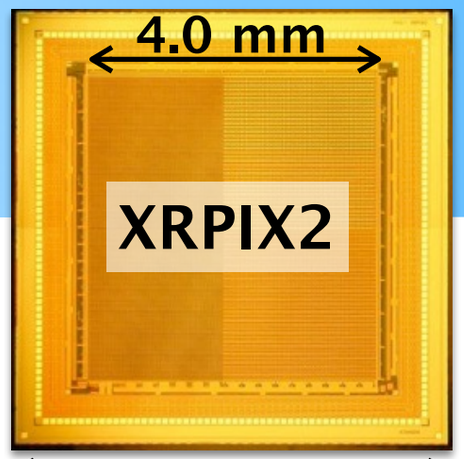
History of XRPIX Series

2010 2011 2012 2013 2014



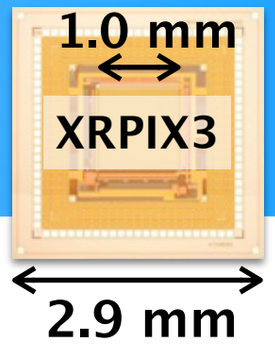


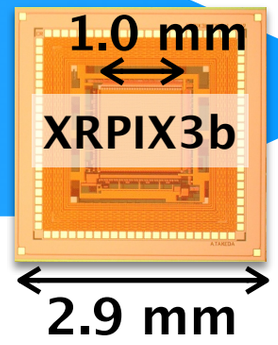
First Model
Trigger Output
(Event-driven readout)



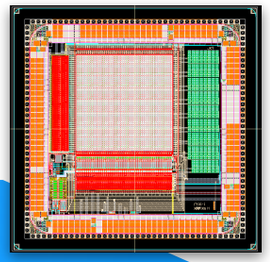
Middle Size

Buttable

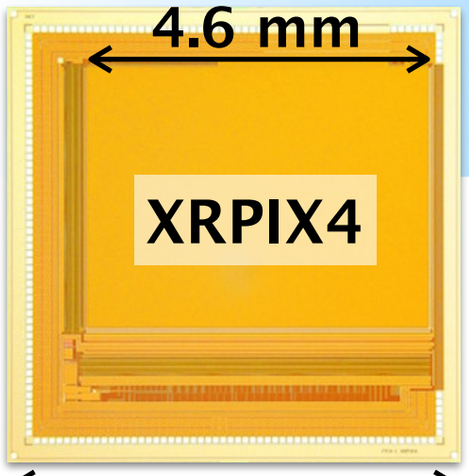




Charge Sensitive
Amplifier

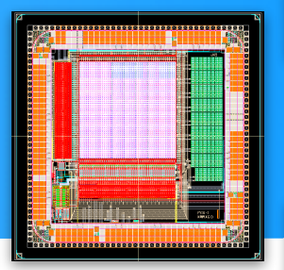


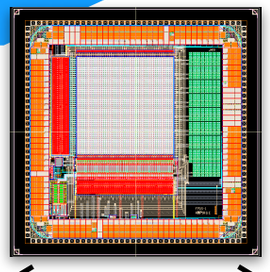
2014 2015 2016



New Readout Circuit

Large Size !!





XRPIX6h
XRPIX6e
XRPIX6D

4.45 mm

Pixel Structure

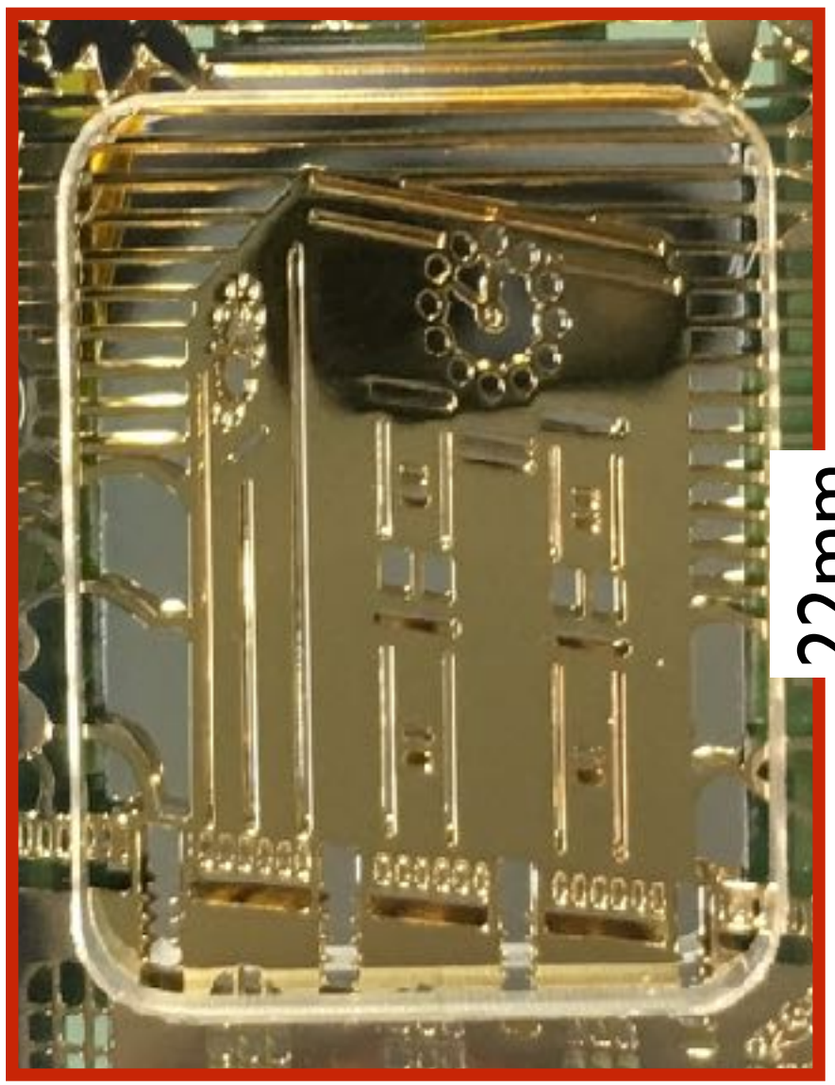
Imaging in Event-Driven Mode

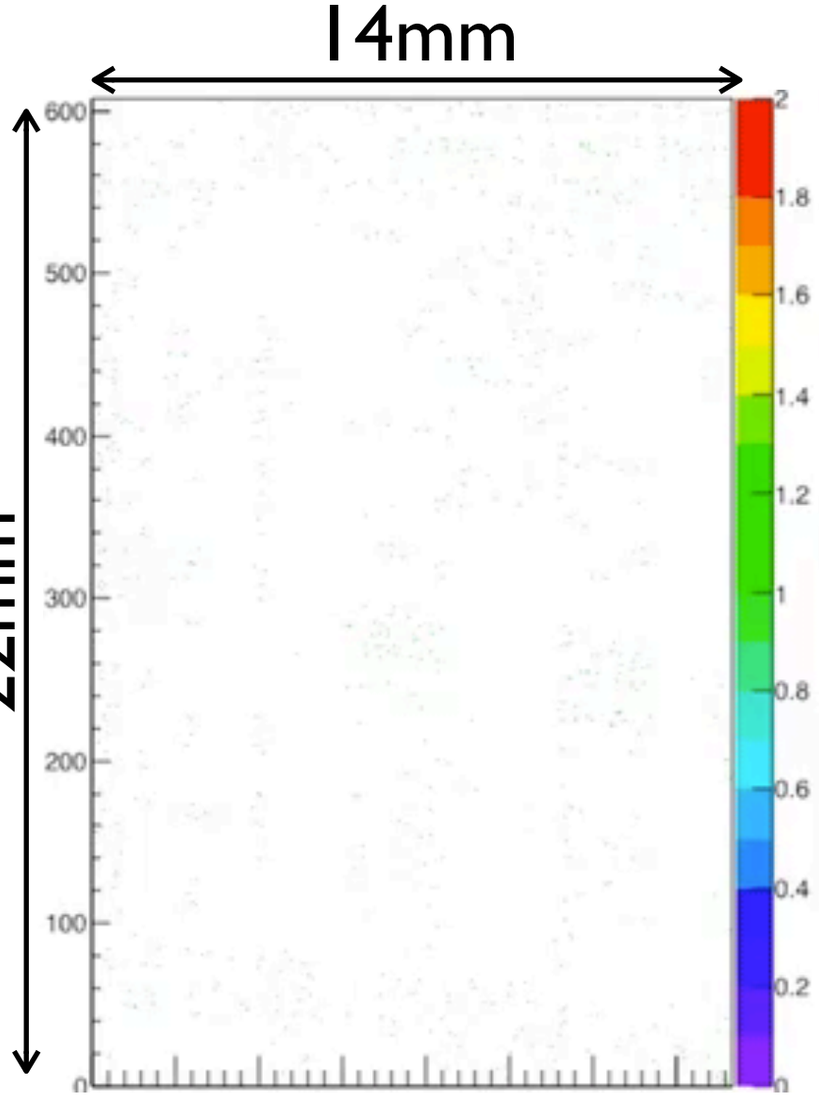
透かし彫り栞/金

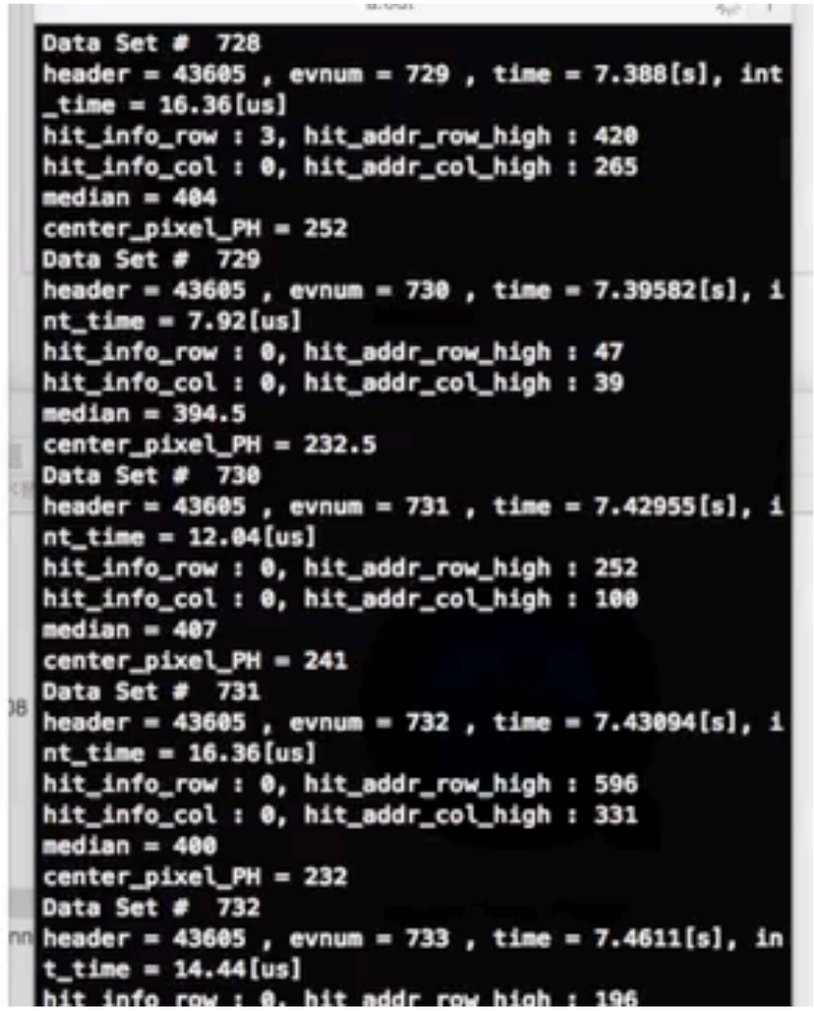
SIZE:W35×H85mm

◆純金表面加工◆時計台を透かし彫りにした実用性の高いアイテムです。 860 円

https://www.u-coop.net/kyodai/goods/indicate.php?mode=detail&id=27&category=6





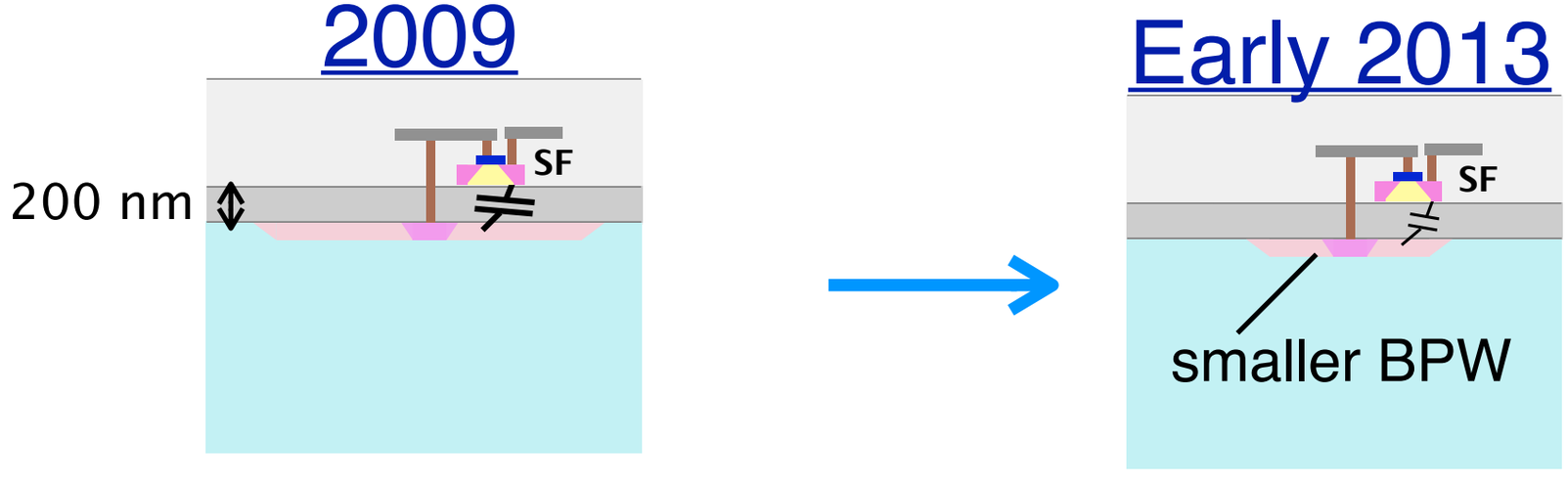


Cd-109, Vbb=10V, Room Temp. (movie in10 times speed)

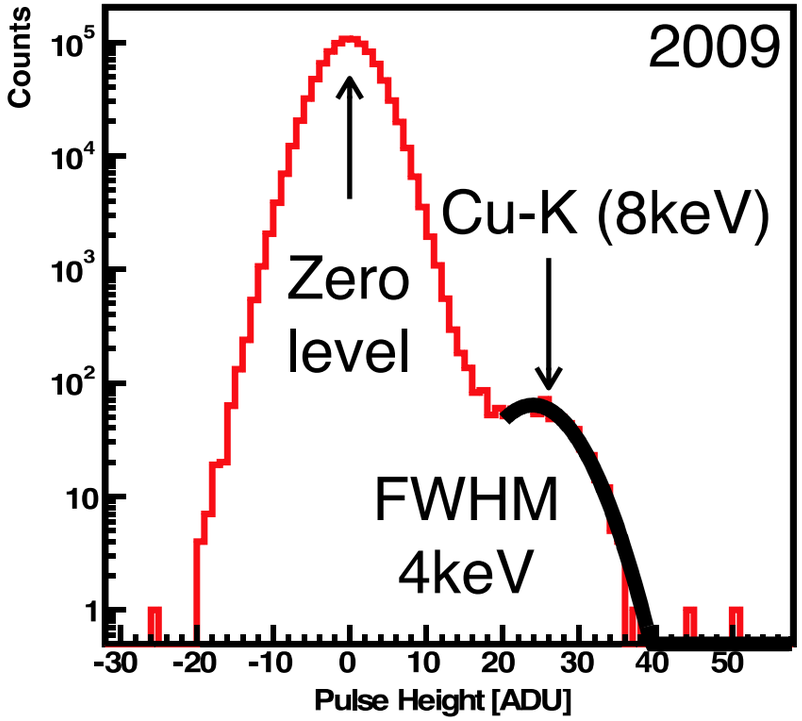
Capability of event rate > 500Hz is Confirmed

Improvement of Spectral Performance in Frame Mode

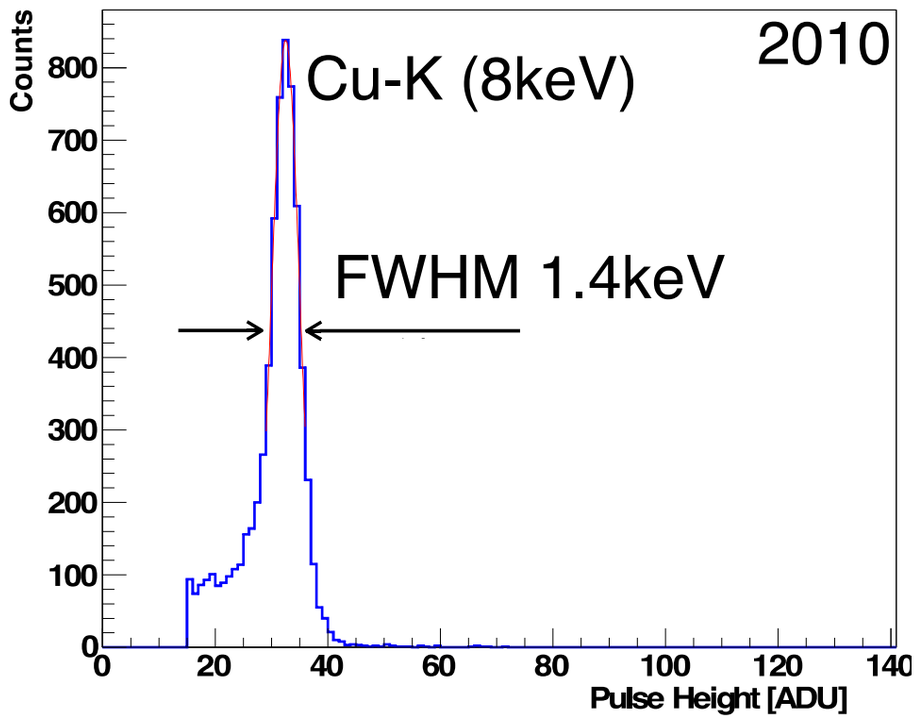
Increase the node-gain by applying
smaller BPW (parasitic Capacitance).



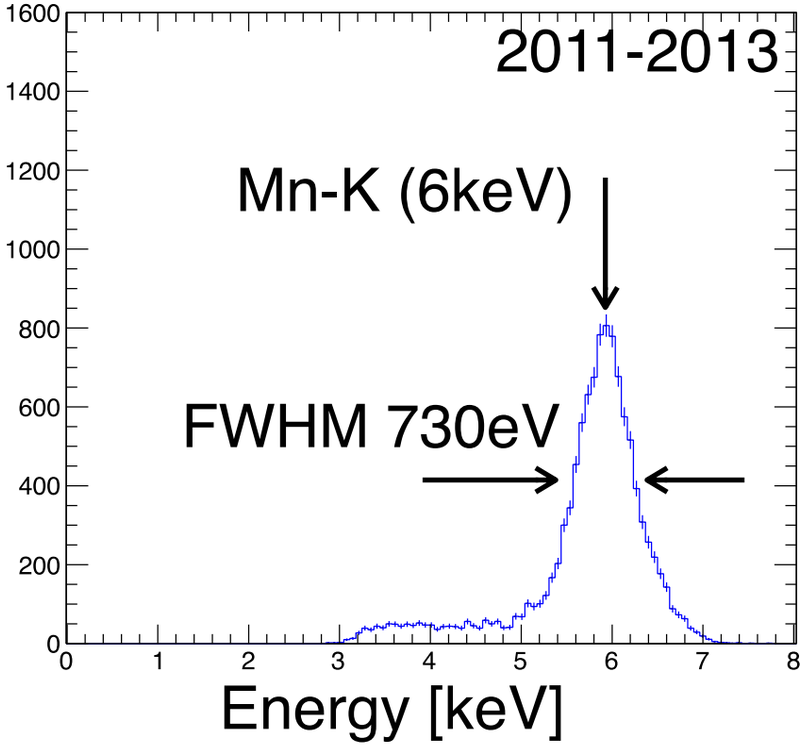
20121217
国立天文台
可視赤外観測技術
ワークショップ



ENC ~600e (rms)



ENC ~130e (rms)

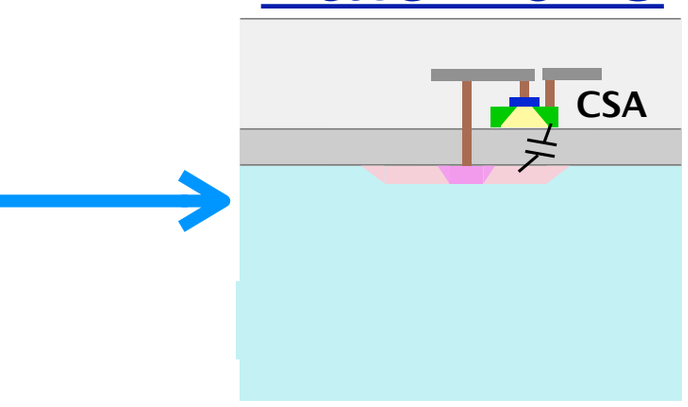


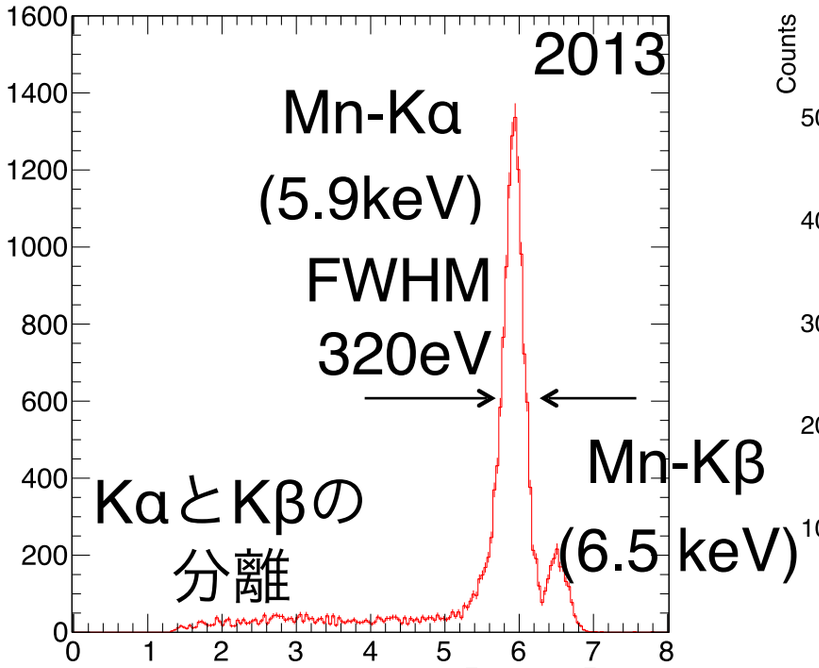
ENC ~68e (rms)

Improvement of Spectral Performance in Frame Mode

Introduction of in-pixel charge-sensitive amplifier

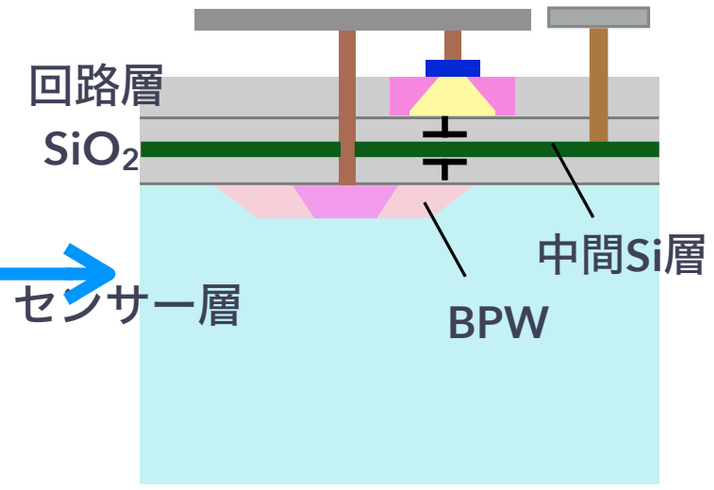
Late 2013

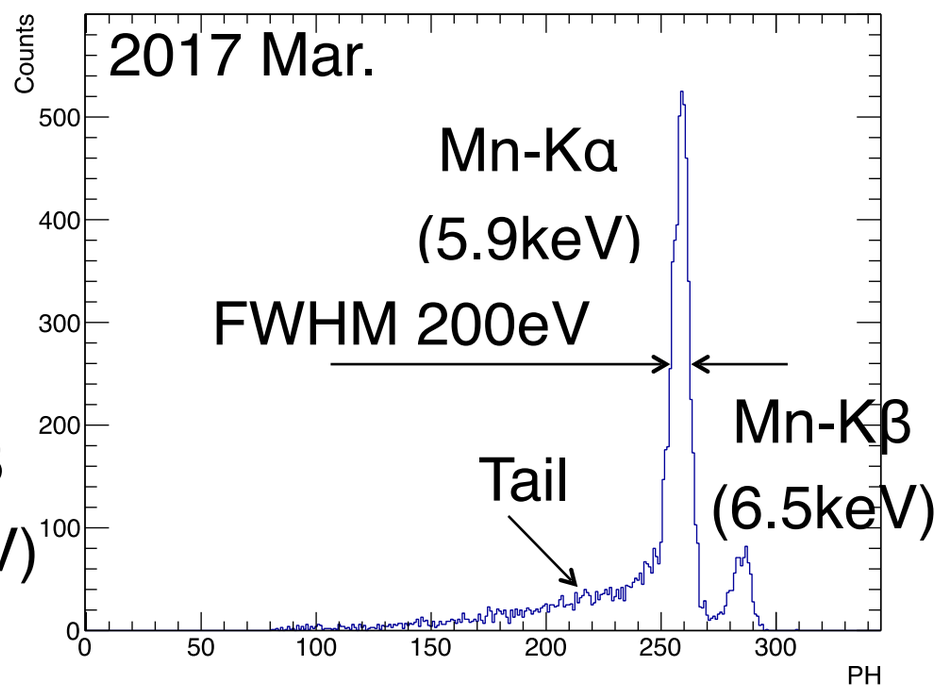




ENC ~35e (rms)

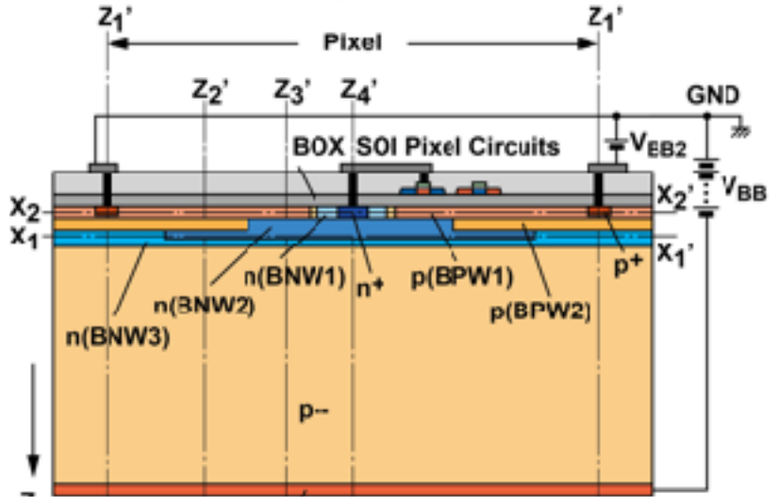
Introduction of Double SOI wafer

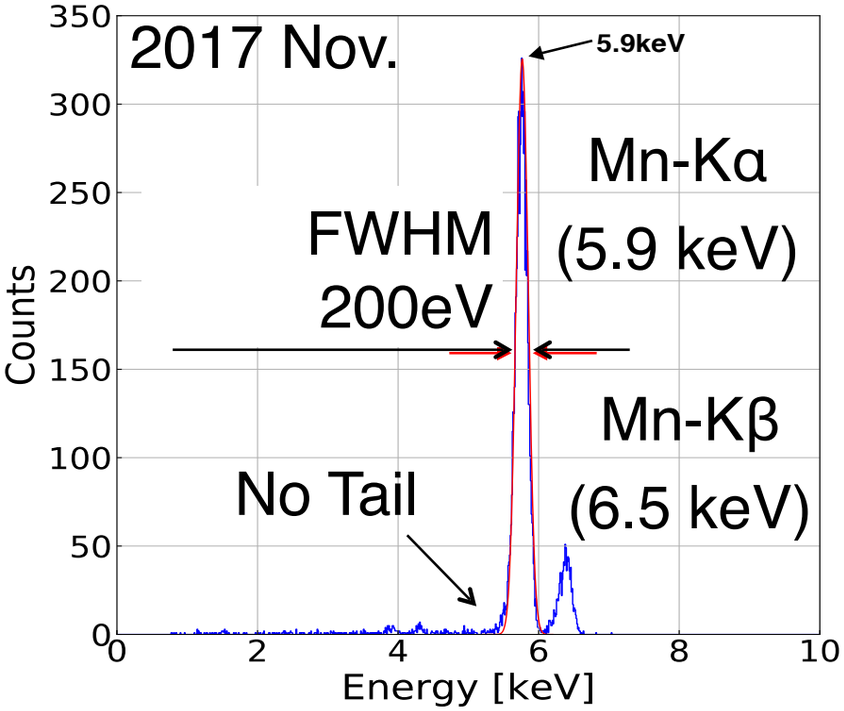




ENC ~16e (rms)

Introduction of Pinned Depleted Diode



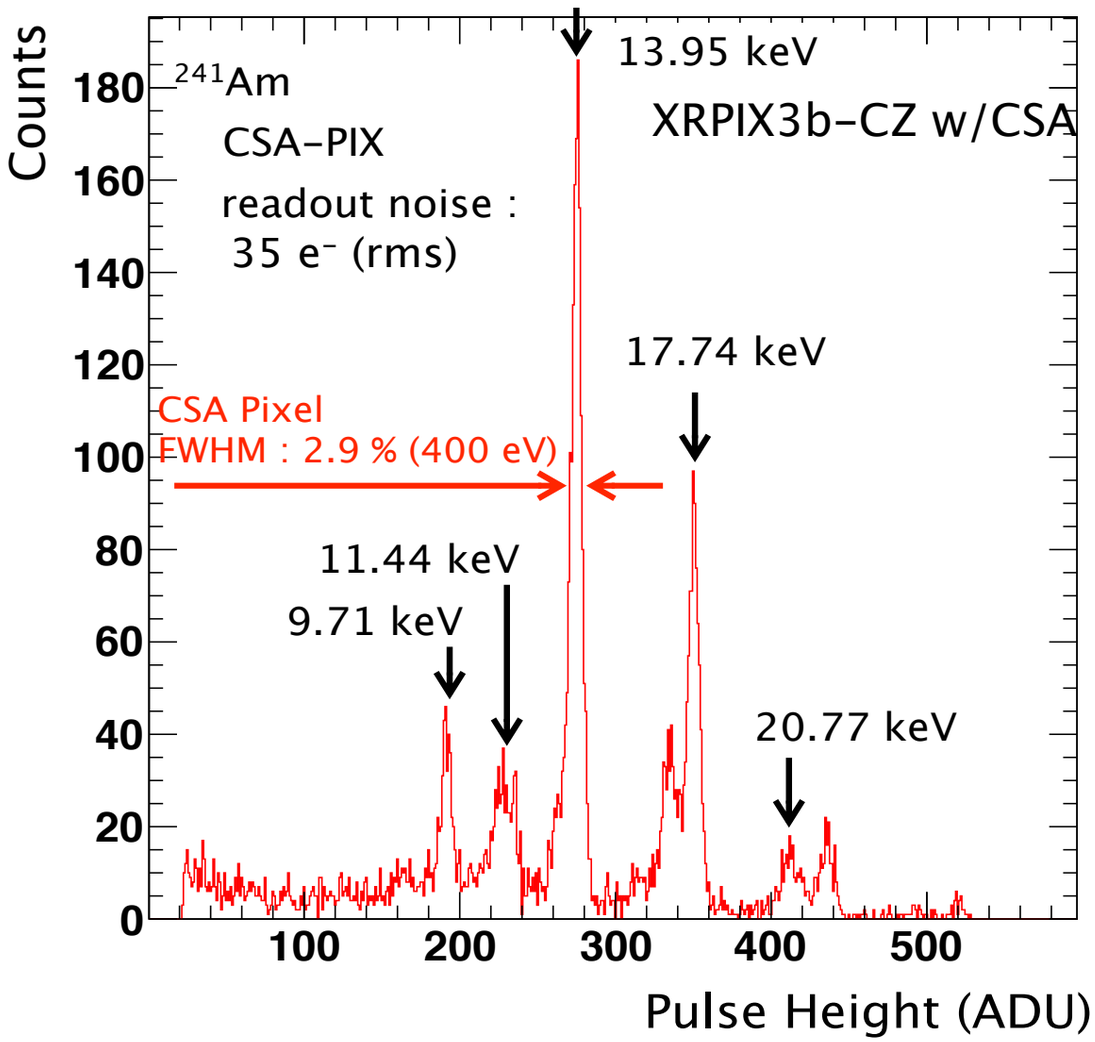


ENC ~10e (rms)

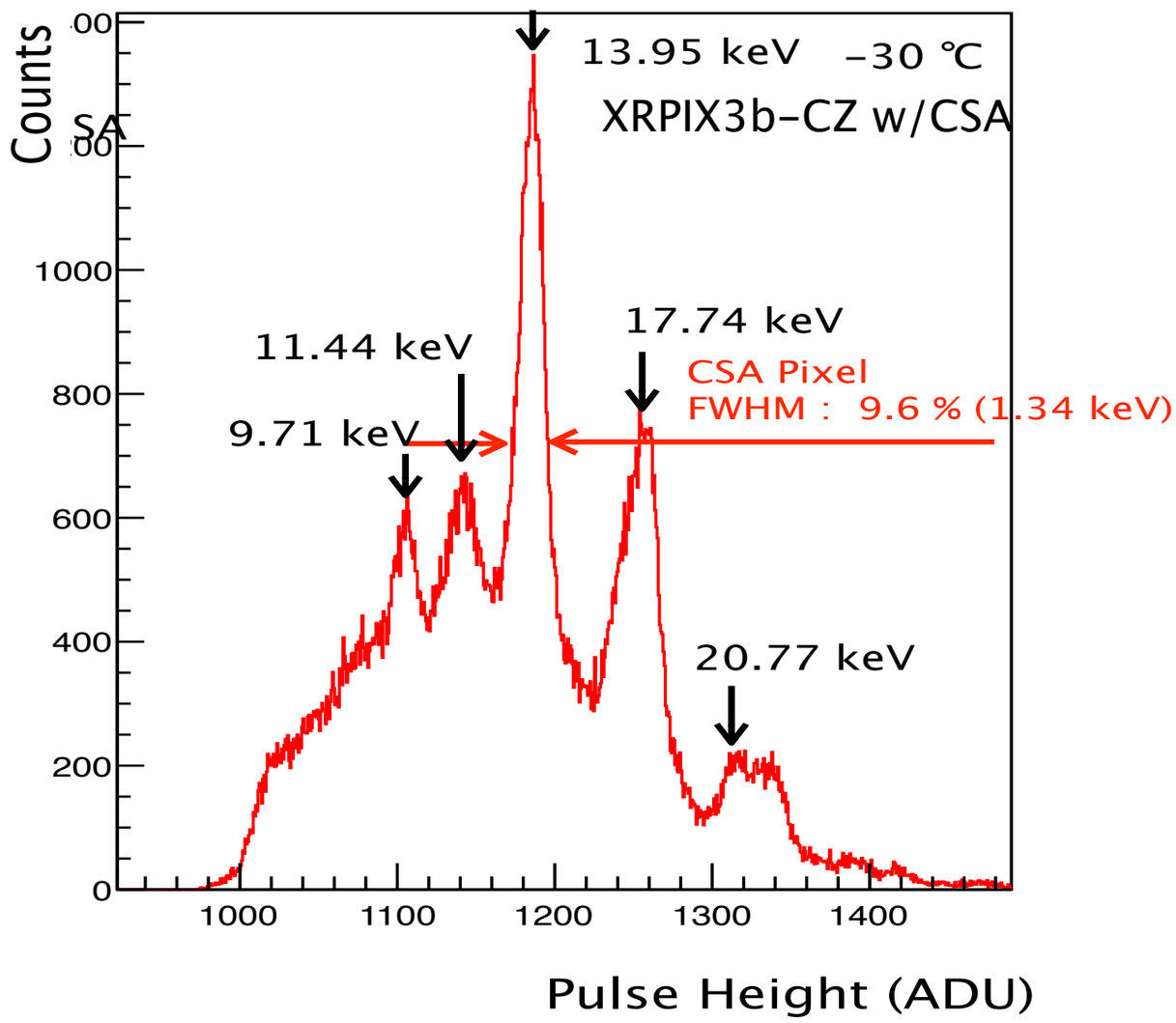
Kamehama, Kawahito+17

Comparison of Frame and Event-Driven Modes

Frame readout mode



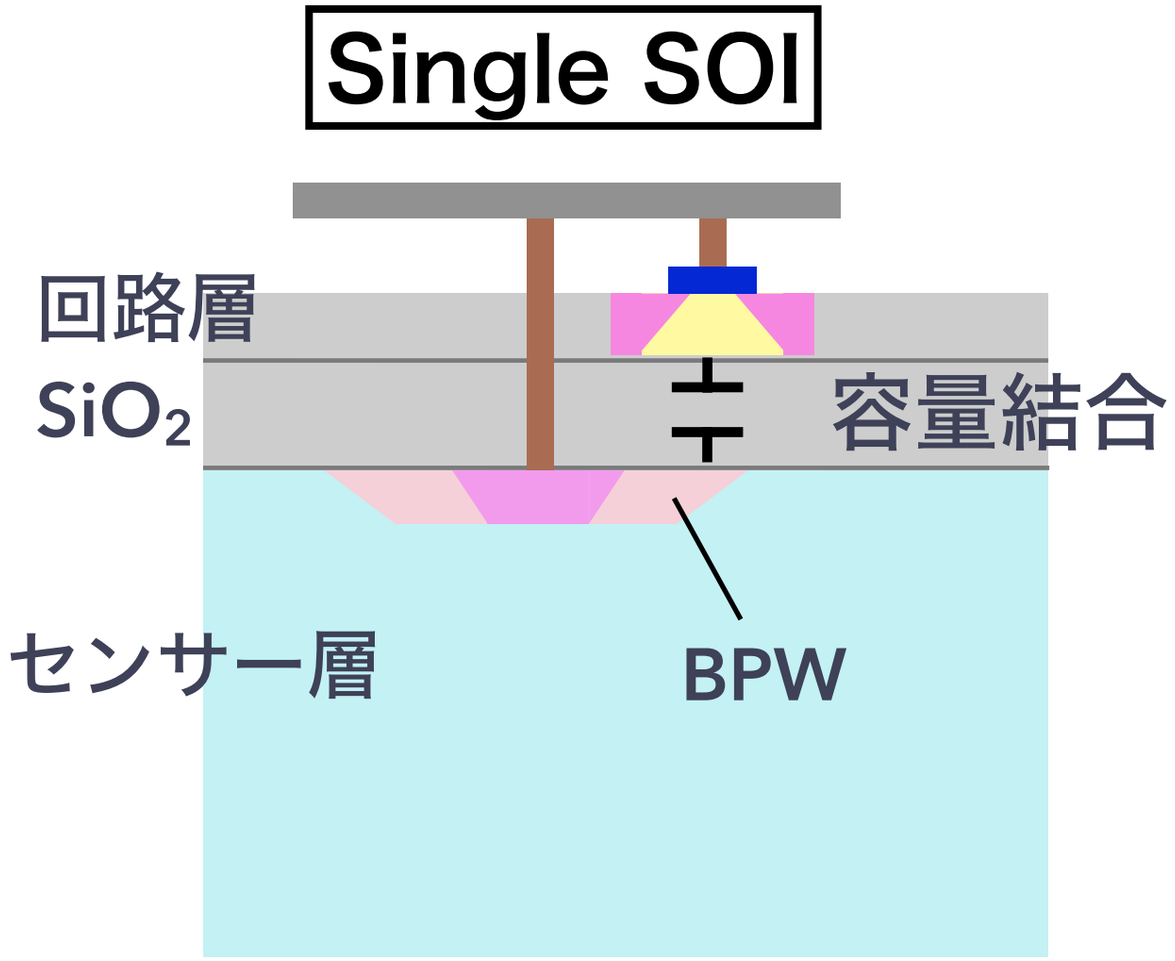
Event-Driven readout mode

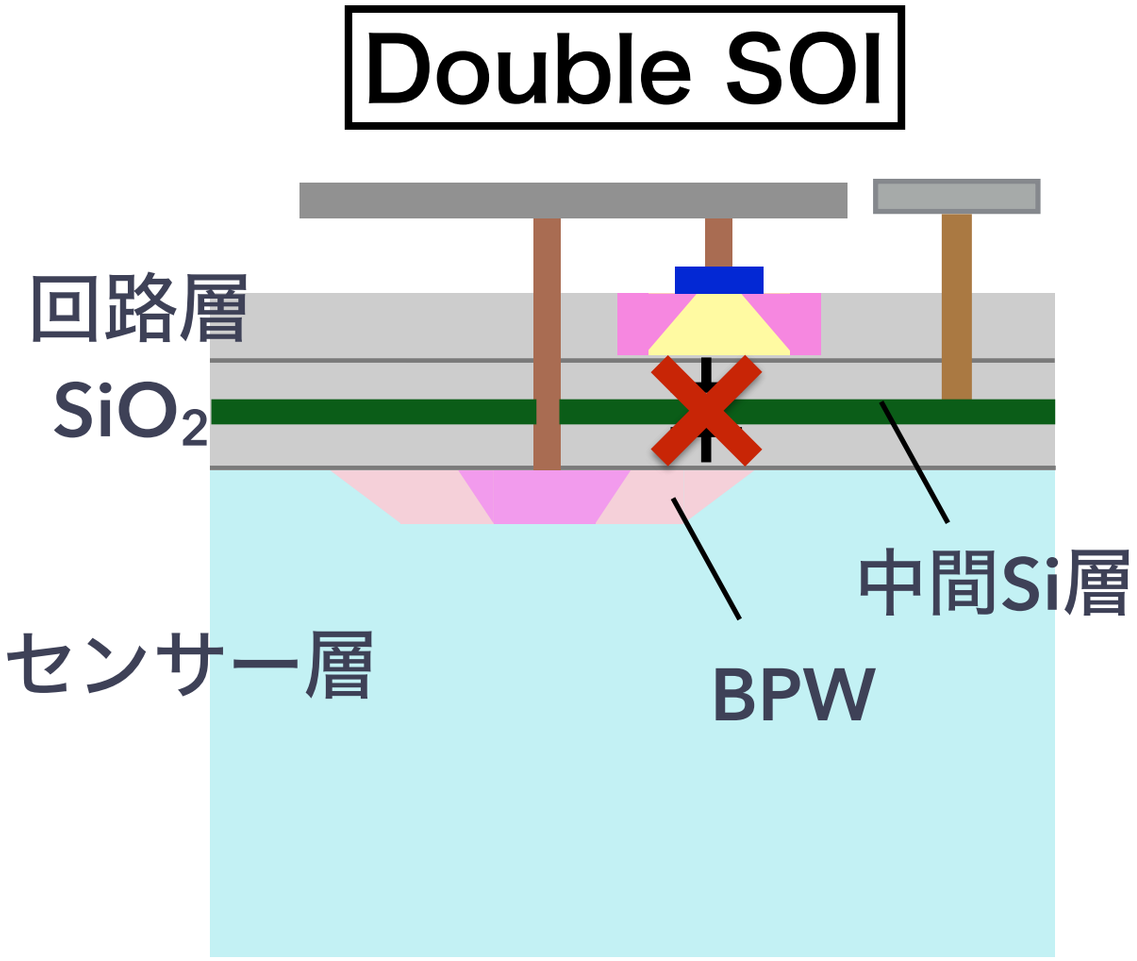


- Operation of in-pixel digital circuit influences the analog signal in the event-driven readout mode.
- crosstalk between digital circuit and BPW (electrically connecting to the sense-node) ⇒ “Double SOI”

Takeda+2015 JINST, Takeda+2013 IEEE/NSS, Takeda Ph.D Thesis, 20140814_takeda_v0.pdf

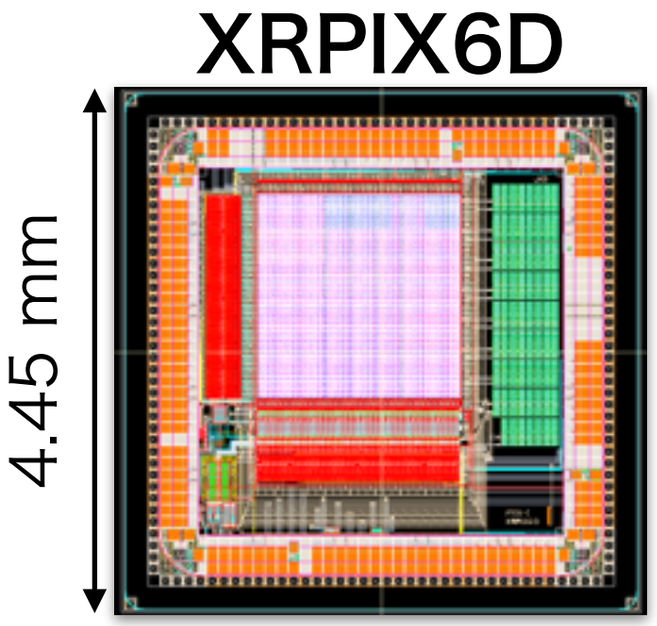
Double SOI 構造の導入





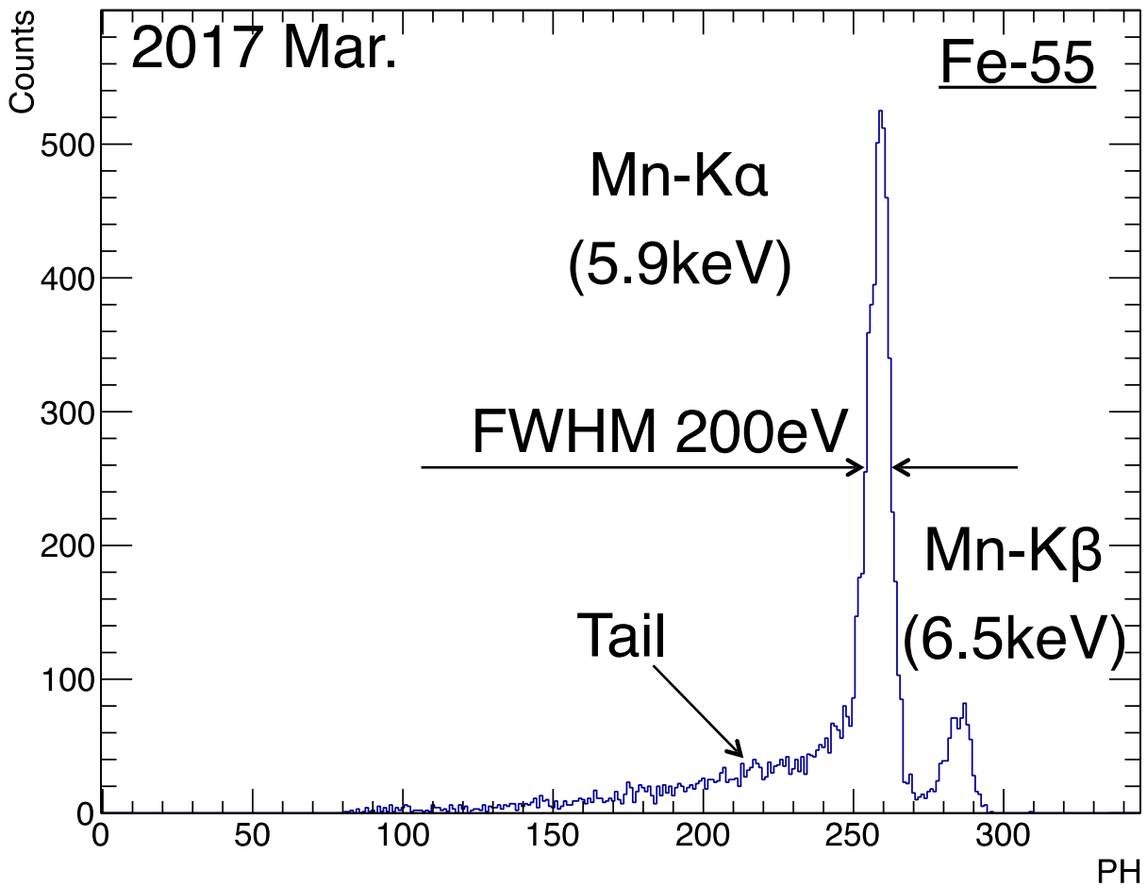
中間 Si に電圧をかけ、電磁シールドとして機能させる (Ohmura et al. 2016)

-> BPWとデジタル回路の干渉を切る

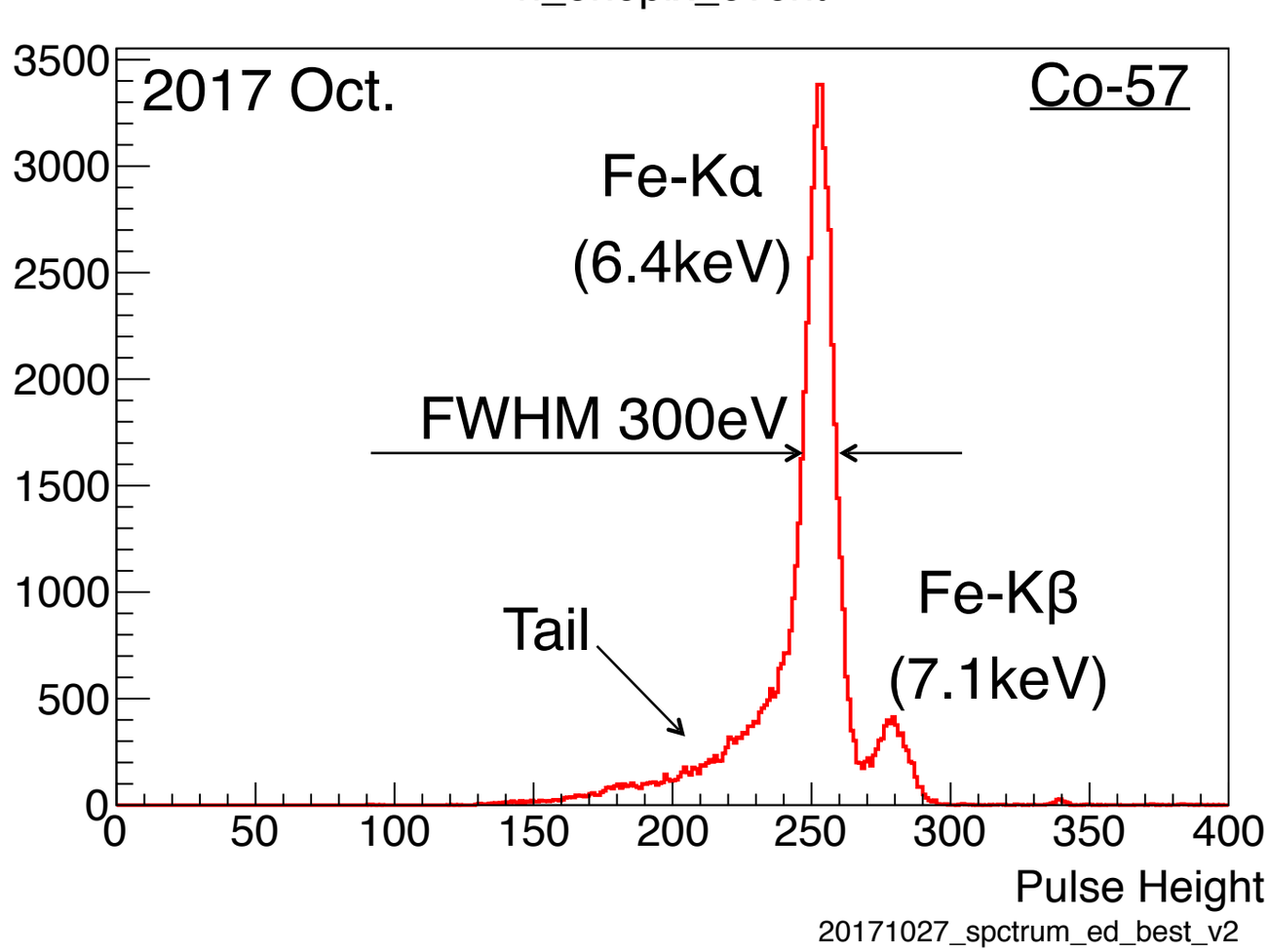


Event-Drive Mode with DSOI

Frame readout mode



Event-Driven readout mode



Event-Driven と Frame でほぼ同じ性能が得られつつある

Hayashi, Takeda+2017

まとめ

- ミッシングブラックホール探査を主目的とする，
  イベント駆動型X線SOIPIX「XRPIX」を開発

- 大面積・低ノイズを達成し，さらなる性能向上へ

- 裏面照射・厚い空乏層 (~500um)，高速読み出し，
  3D構造（センサ層，回路層）は役に立つ？

⇒ お問い合わせは，鶴まで，お気楽にどうぞ．