Development and Performance of Kyoto's X-ray Astronomical SOI pixel sensor Sensor

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T. Imamura, A. Iwata, T. Ohmoto, T. Maeda (A-R-Tec) for Chip Design

Publication

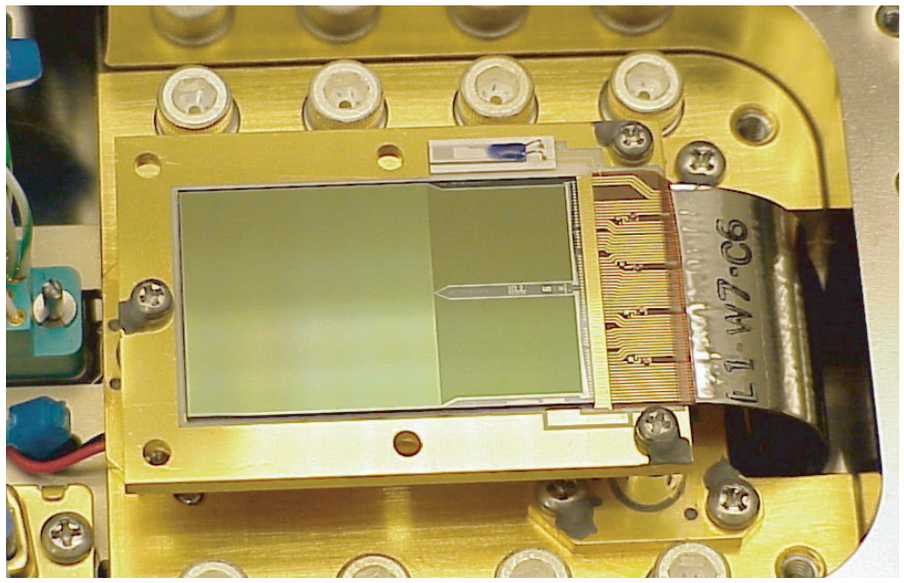
Ryu et al.	IEEE NSS 2010, Conf. Record	XRPIX1-CZ -FI
Ryu et al.	IEEE TNS 58, 2528 (2011)	XRPIX1-CZ-FI
Tsuru et al.	IEEE NSS 2011	Review
Ryu et al.	IEEE NSS 2011, Conf. Record	Event-Driven Readout system
Nakashima et al.	IEEE NSS 2011, Conf. Record	XRPIX-ADC1
Nakashima et al.	Physics Procedia 37, 1373 (2012)	XRPIX1-FZ-FI
Ryu et al.	IEEE TNS 60, 465 (2013)	XRPIX1b-CZ-FI, Inter-pixel cross-talk
Takeda et al.	IEEE TNS 60, 586 (2013)	Event-Driven Readout with XRPIX1b-CZ-FI
Tsuru et al.	SPIE Astro2012	Review
Nakashima et al.	NIM A, Accepted (2013)	XRPIX2
Matsumura	NIM A in Prep.	Charge Collection Efficiency

Talk Plan

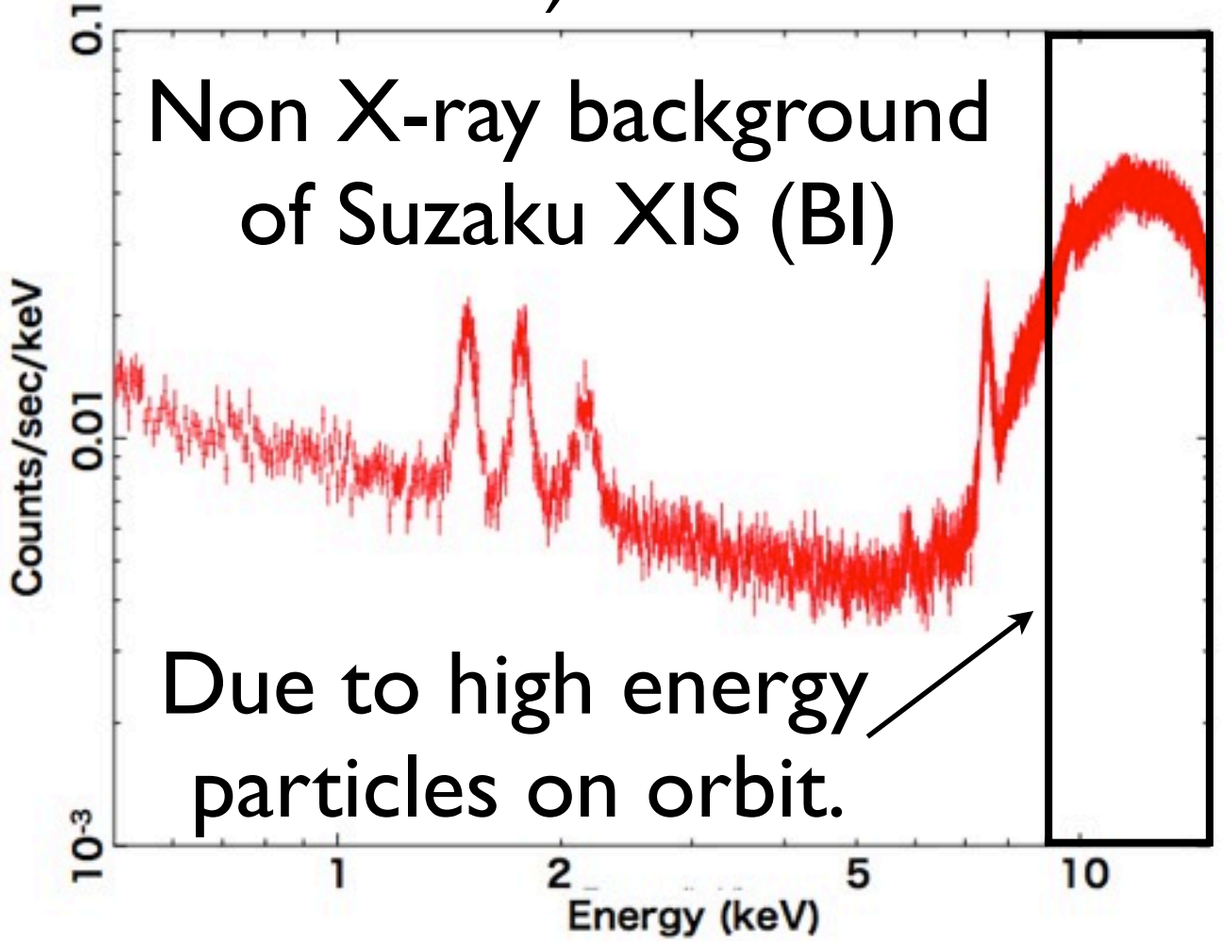
- "XRPIX"
  the Kyoto's X-ray Astronomical SOI pixel sensor
- Spectral Performance
- Depletion Layer
- Trigger output and Event Driven Readout
- Charge loss at the interface between the depletion layer and SiO2 insulator

The standard Imaging Spectrometer of modern X-ray astronomical satellites → X-ray CCD

Suzaku「すざく」 XIS



- Fano limited spectroscopy with the readout noise ~3e- (rms).
- Wide and fine imaging with the sensor size of ~20-30mm pixel size of ~30μm□
- High QE by BI and thick depletion (200μm for ASTRO-H).



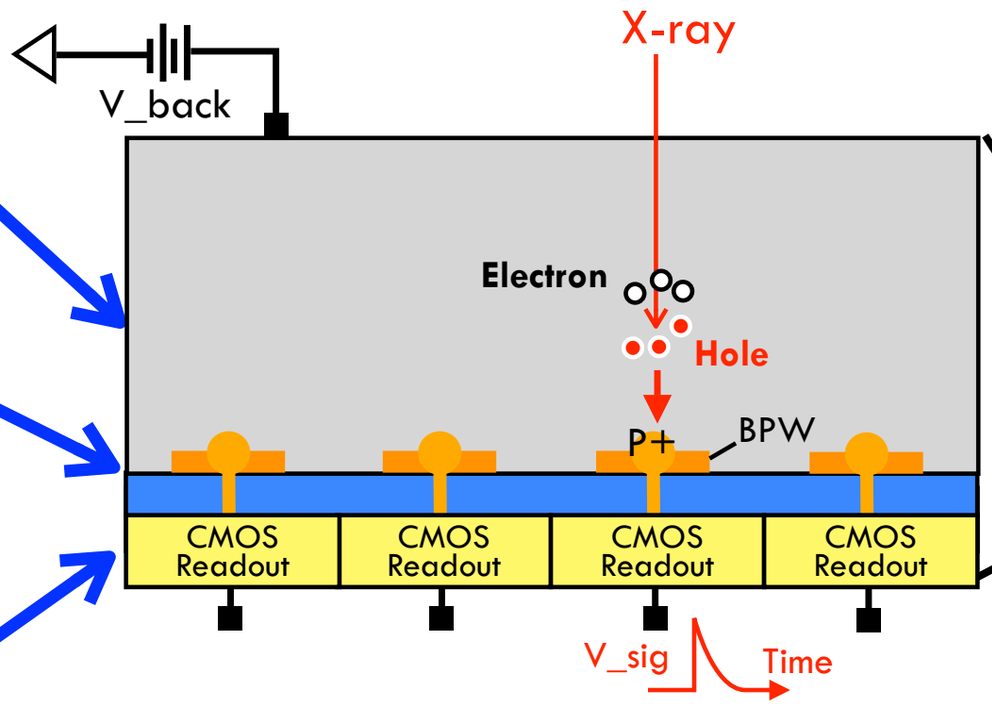
- Non X-ray background above 10keV is too high to study faint sources.
- The time resolution is too poor (~sec) to make fast timing obervation of time variable sources (eg. BH and NS).

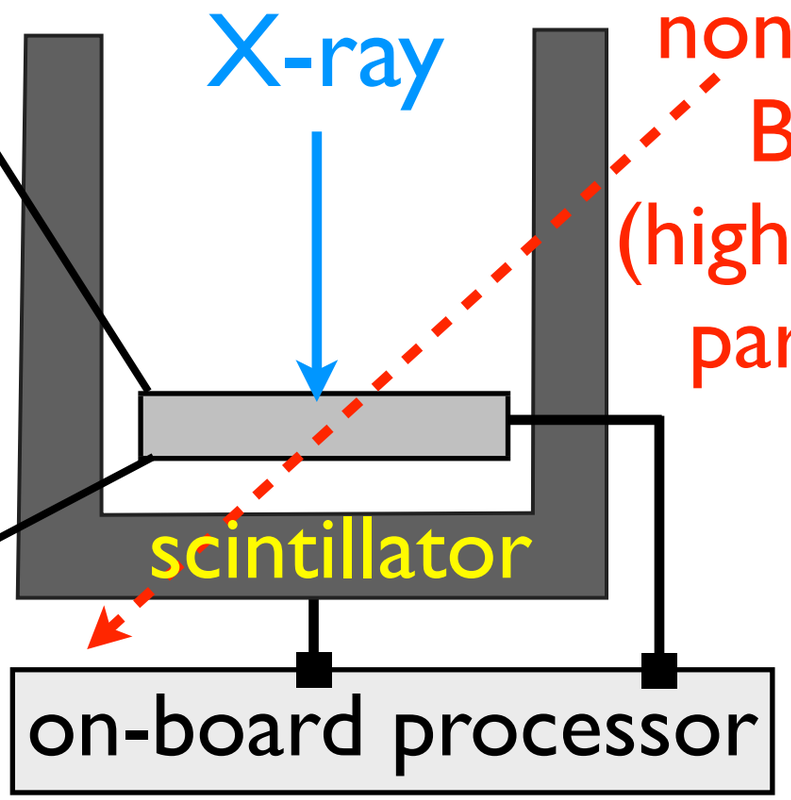
"XRPIX" = **Monolithic** SOI pixel sensor for future X-ray astronomical satellites

Sensor (high ρ, depleted Si)

Insulator (SiO2)

Fast CMOS (low ρ Si)





Our SOIPIX (XRPIX)

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

Very low BGD by anti-coincidence (1/100 of CCD at 20keV)

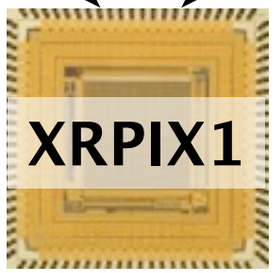
Target Spec.

Imaging	area > 25x25mm2, pixel ~ 30-60μm□ (1" @ F=9m)
Energy Band	0.3-40keV with BI (<0.1μm), and thick depletion (>250μm)
Spectroscopy	ΔE < 140eV @ 6keV, Fano limit (Req.<10e-, Goal < 3e-)
Timing	<1μsec
Dark Current	<2pA/cm2 (assuming working T = -40℃)
Function	Trigger signal & pixel address output, built-in ADC (option)
Non X-ray BGD	5e-5 c/s/keV/10x10mm2 at 20keV (1/100 of CCD)

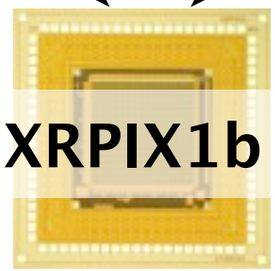
XRPIX Series – Road Map –

2010 2011 2012 2013 2014

1.0mm 1.0mm 4.0mm 4.5mm 1.0mm 1.0mm



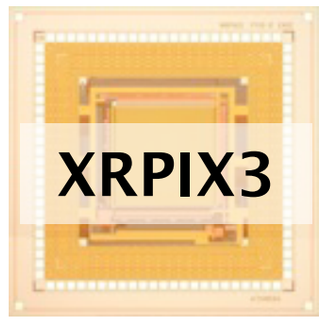
2.4 mm



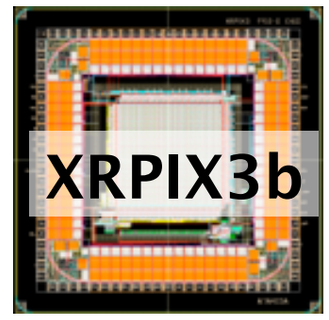
2.4 mm

6.0 mm

6.0 mm



2.9 mm



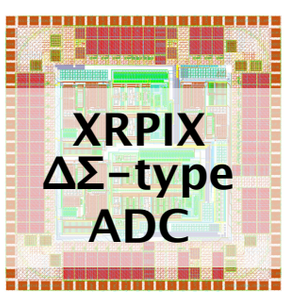
2.9 mm

First Model Trigger Output

Middle Size

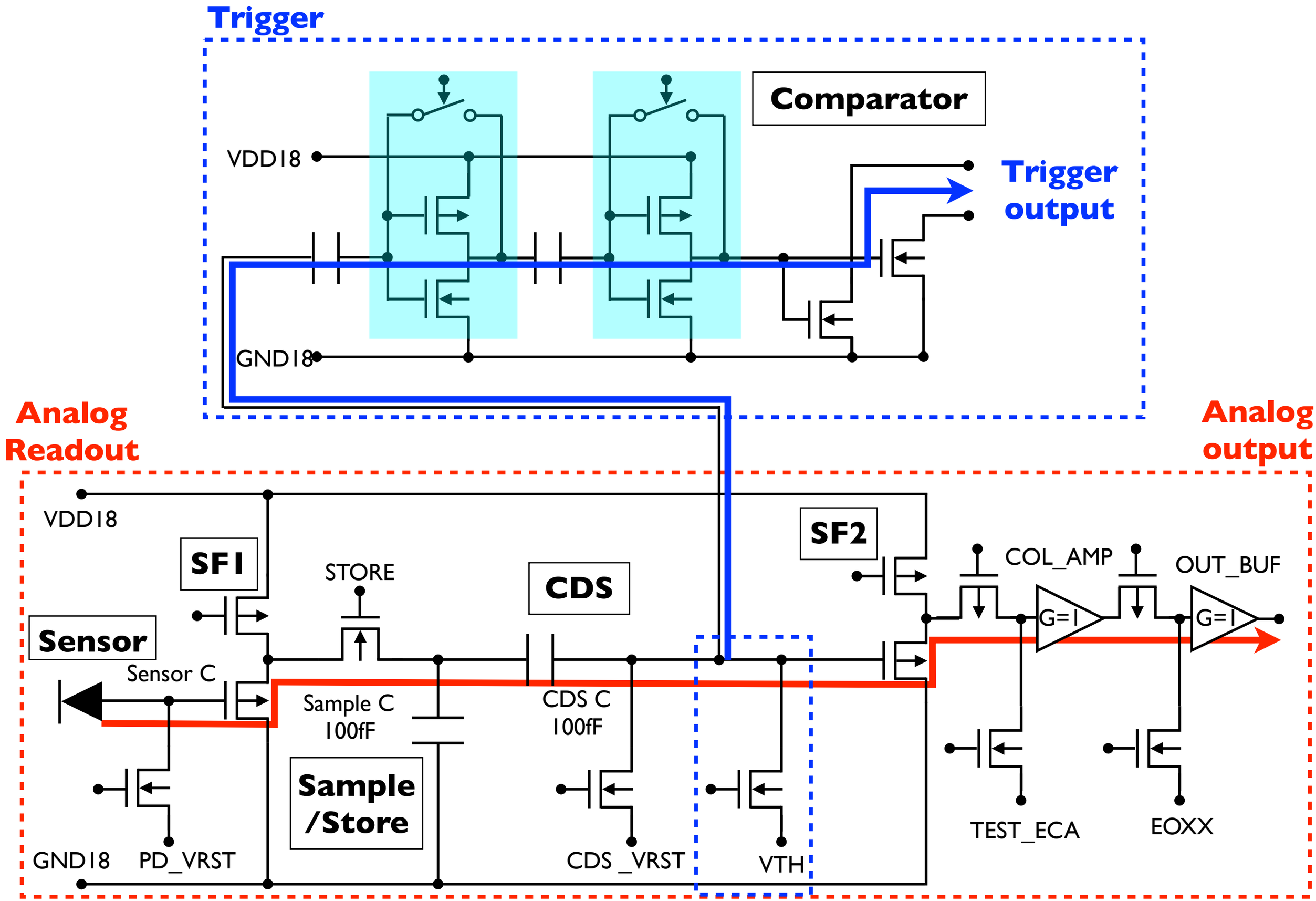
Buttable

Charge Sensitive AMP

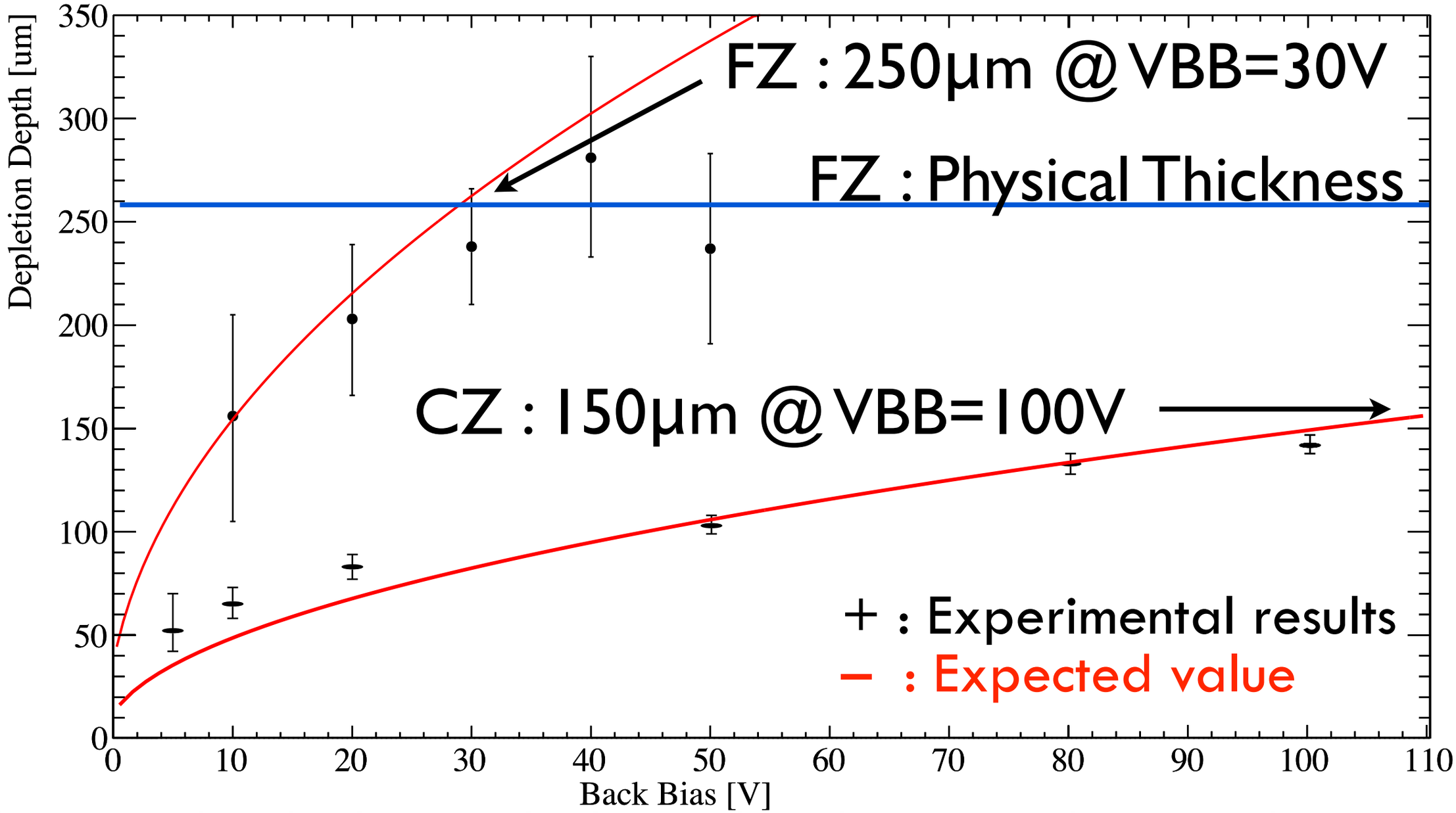


2.4 mm

XRPIX1: Pixel Circuit



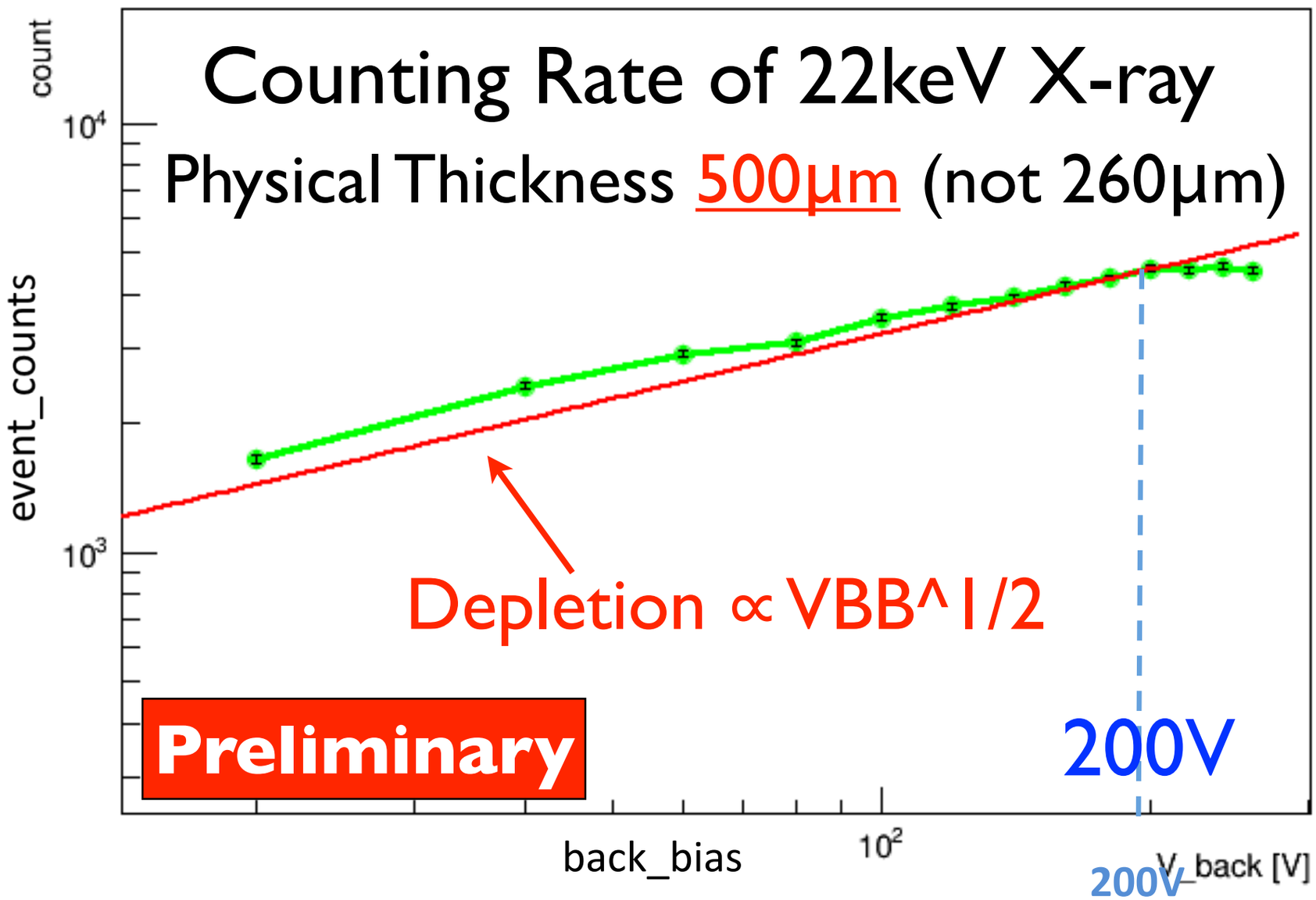
XRPIX1-CZ (0.7kΩcm), -FZ(2010) (7kΩcm): Depletion Depth



- Measure the depletion thickness by observing the ratio between the counting rates of two energies X-rays having different attenuation lengths.
- CZ: Depletion thickness of 150μm at VBB=100V.
- FZ: Full depletion is achieved at VBB=30V.

Nakashima et al.,
2012, Physics
Procedia 37, 1373

XRPIX1b-FZ(2012)-FI (7kΩcm) : Depletion Depth

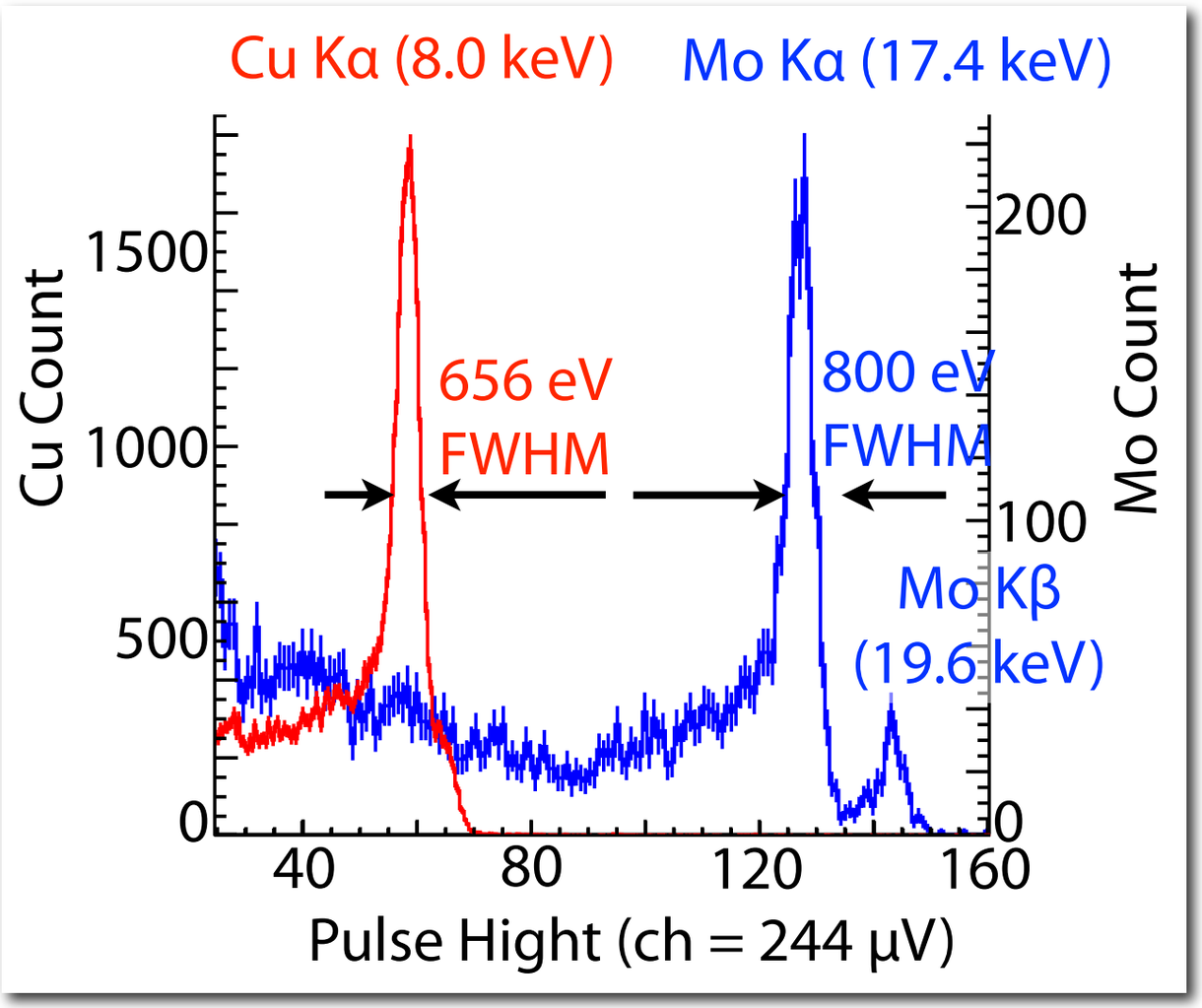


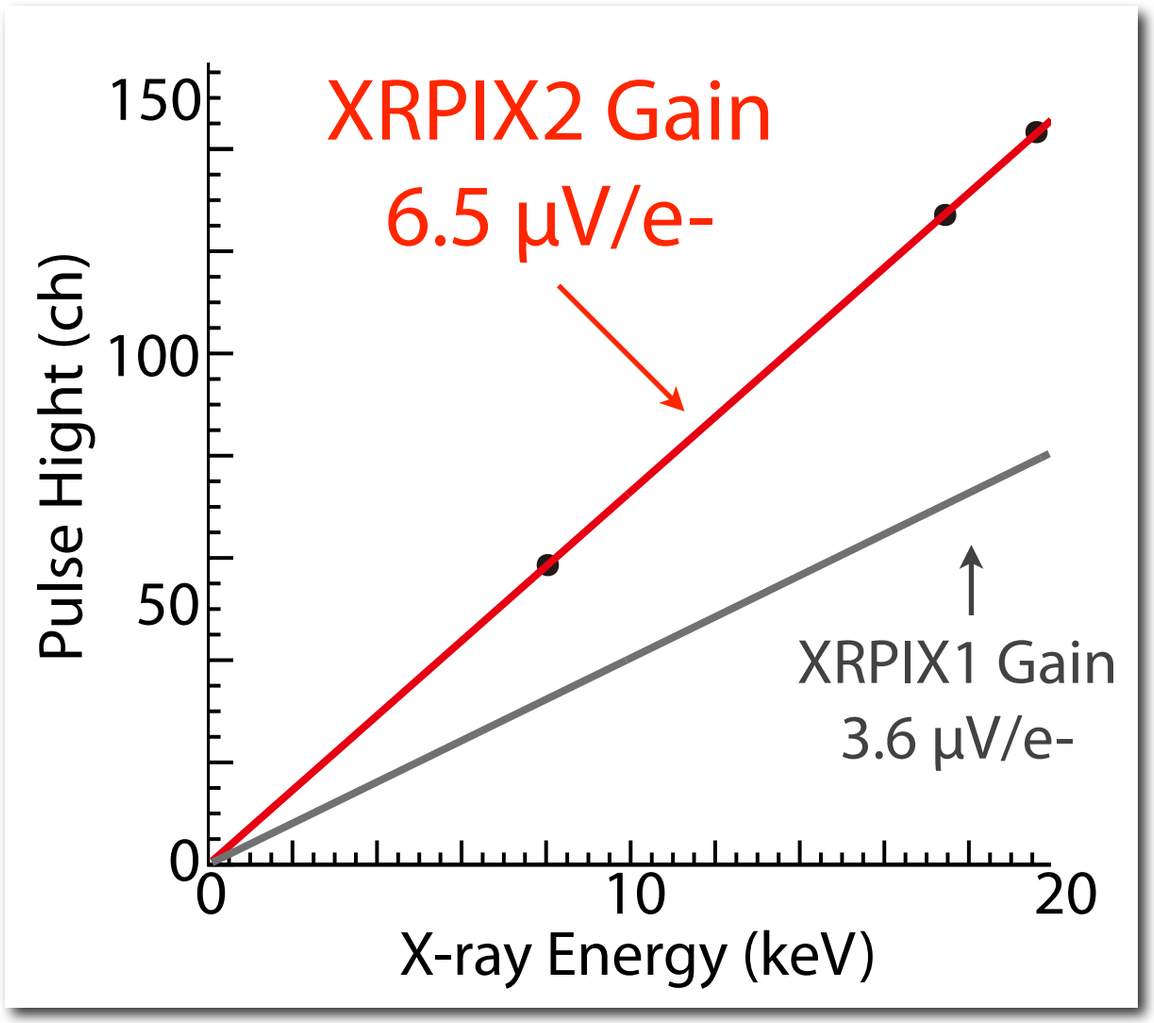
- Counting Rate of 22keV X-ray (Cd-109) as a function of VBB. (Attenuation Length = 1200μm > Physical Thickness = 500μm.)
- The data follow the expected slope of depletion ∝ VBB^1/2.

- Full Depletion of 500μm is reached at VBB=200V.

20130502_matsumura.pdf

XRPIX2-CZ-FI (Small Pixel) : Spectrum in the frame mode

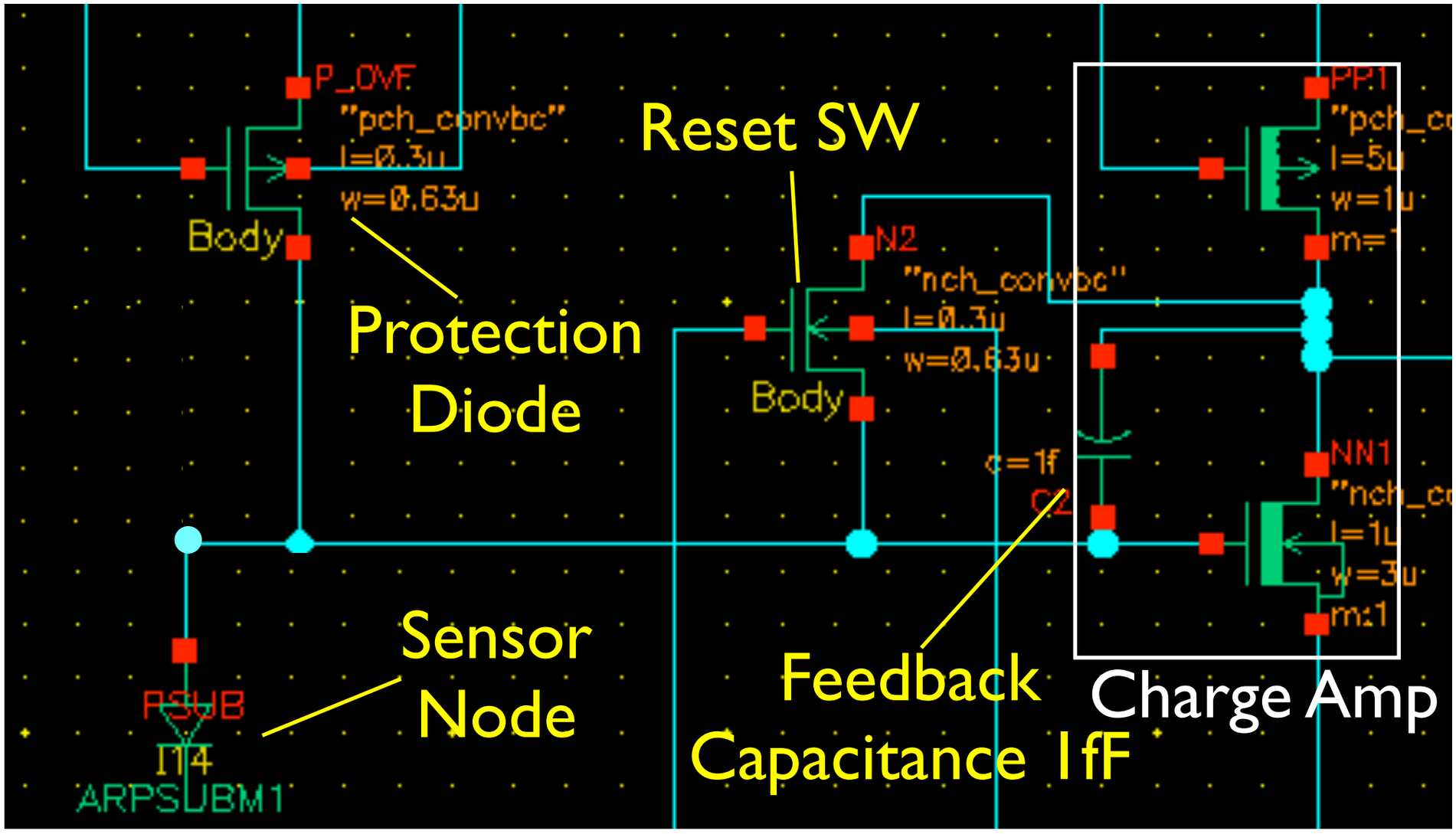




	Observed	Readout Noise	Fano Noise	Pixel-Pixel Gain Dispersion 1%	Sum
Cu Kα	656 eV	548 eV (FWHM) 64 e-(rms)	139 eV	255 eV	620 eV
Mo Kα	800 eV		205 eV	553 eV	805 eV

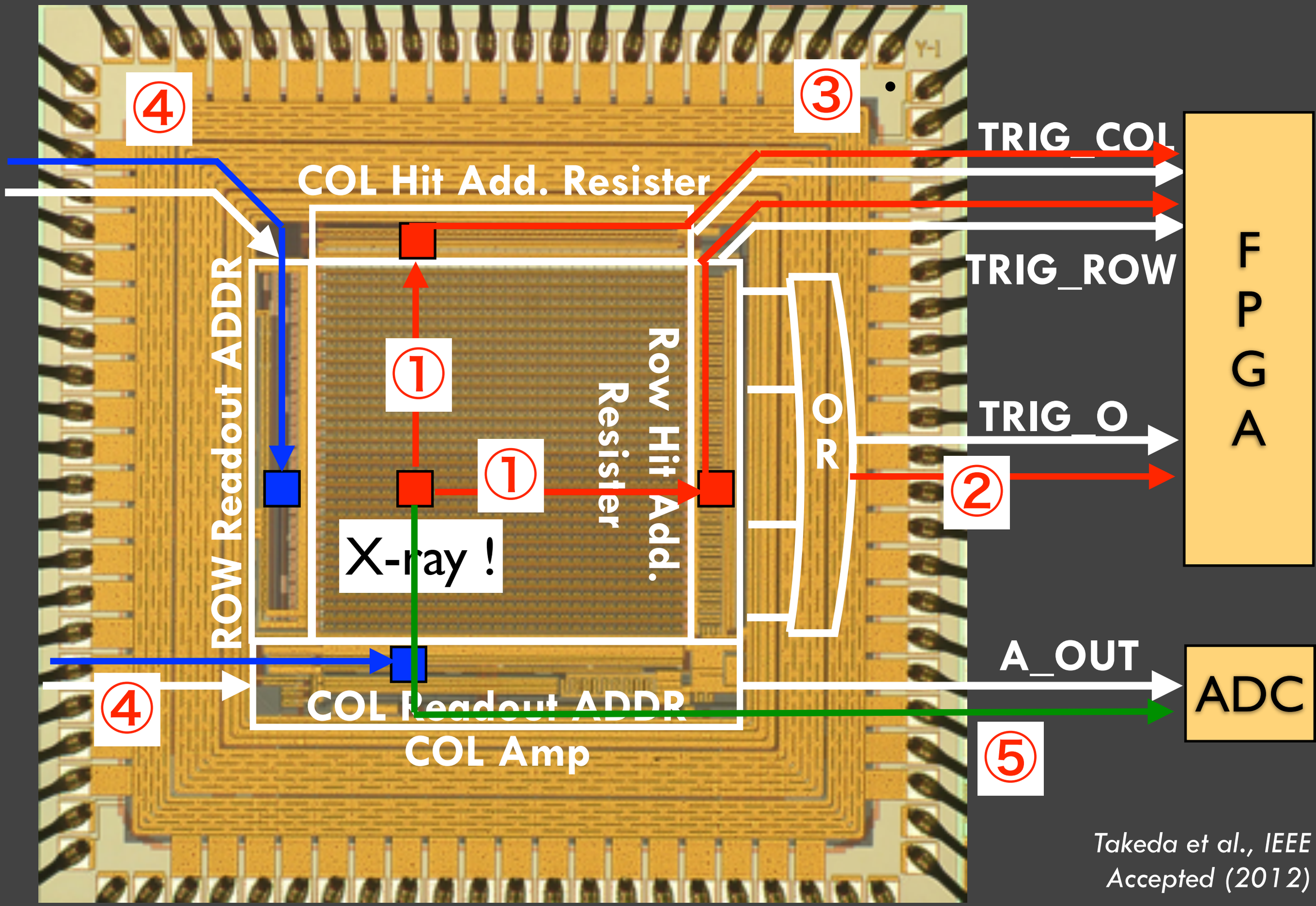
Nakashima et al., 2012, NIM A submitted

XRPIX3/3b : Pre Amp in Each Pixel



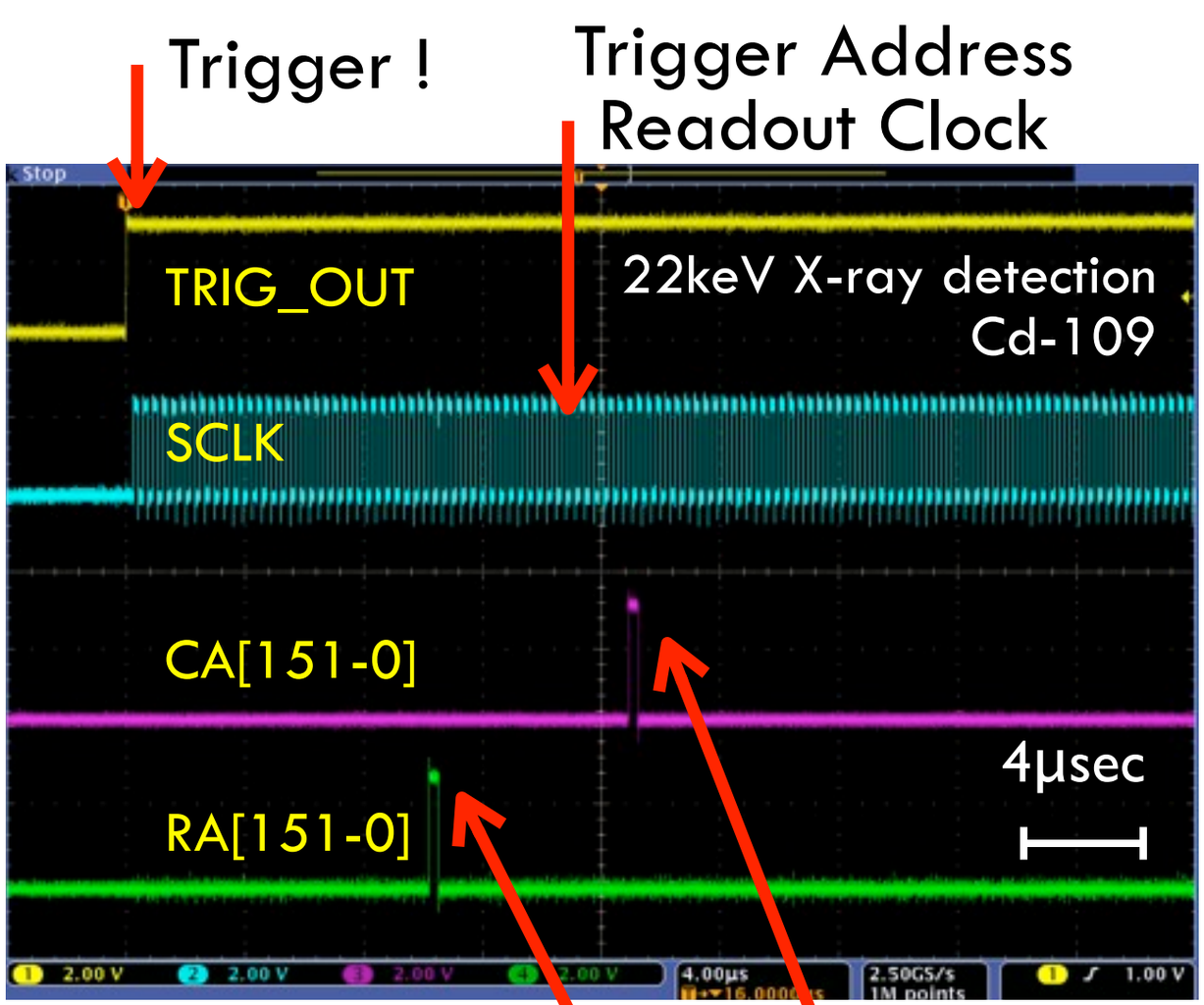
- A charge sensitive amp (CSA) in every pixel in order to increase the gain and improve energy resolution.
- CSA is basically the same that developed in another SOIPIX (PIXOR).
- Gain ~50 μV/e, higher by a factor of ~10.
- Readout noise = 64e (rms) → Now testing

XRPIX1b-CZ : Event Driven Readout

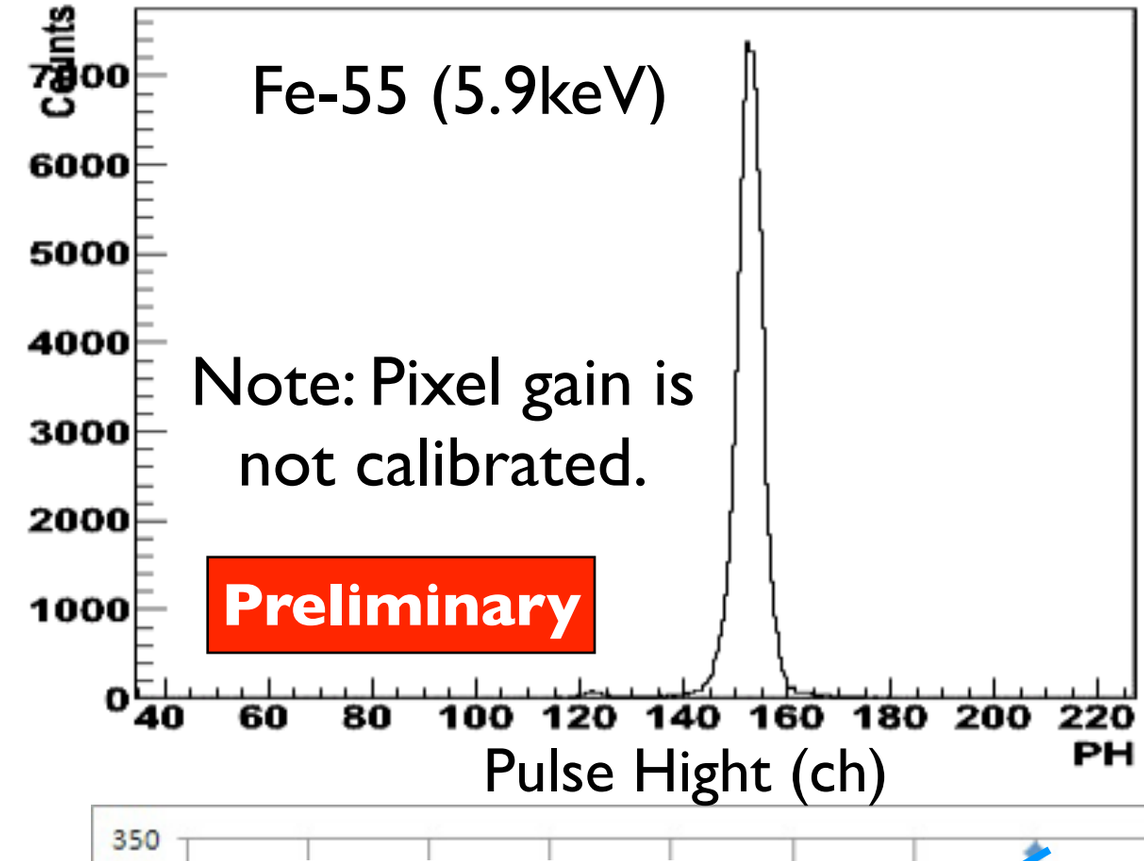


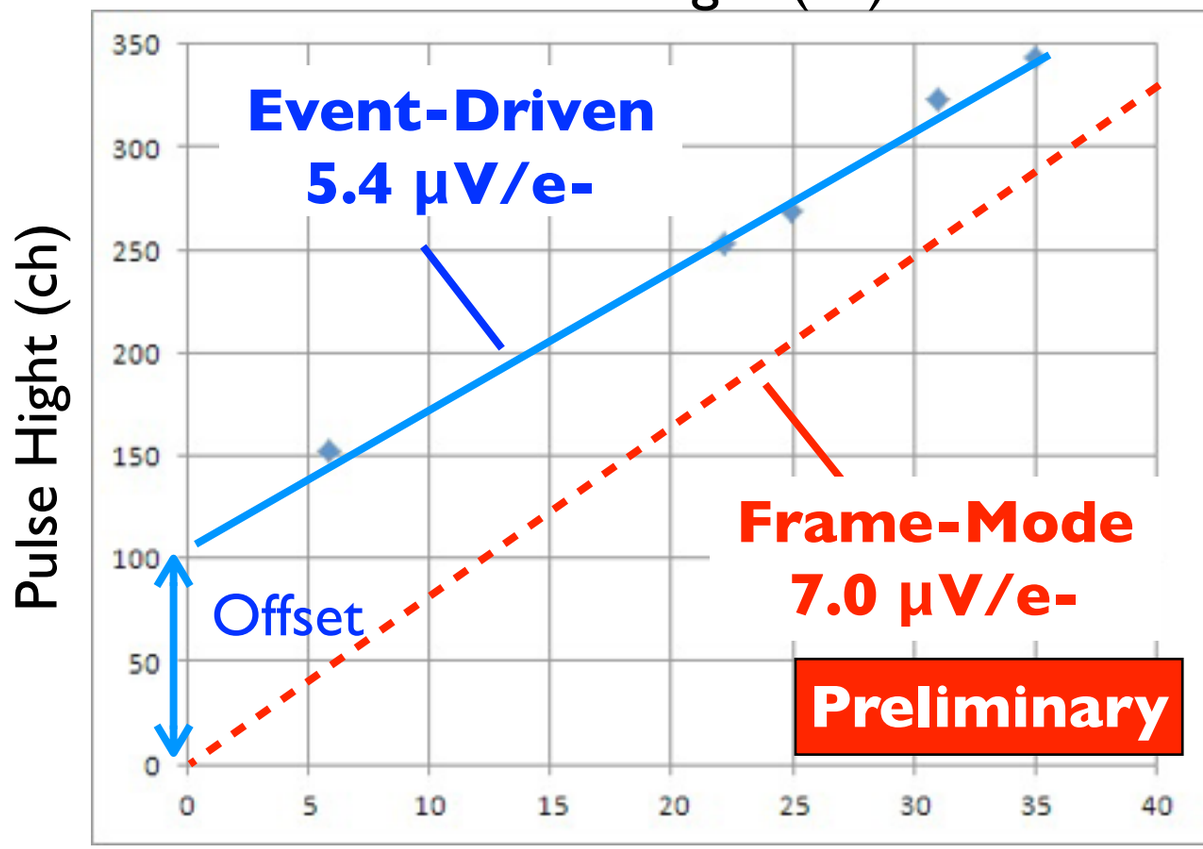
Takeda et al., IEEE Accepted (2012)

XRPIX2b-CZ : Event-driven Readout Mode



- Event-driven mode basically operates.
- Capacity of event rate >1kHz.
- The gain is different. There is offset.
- Due to interference between analog and digital circuits



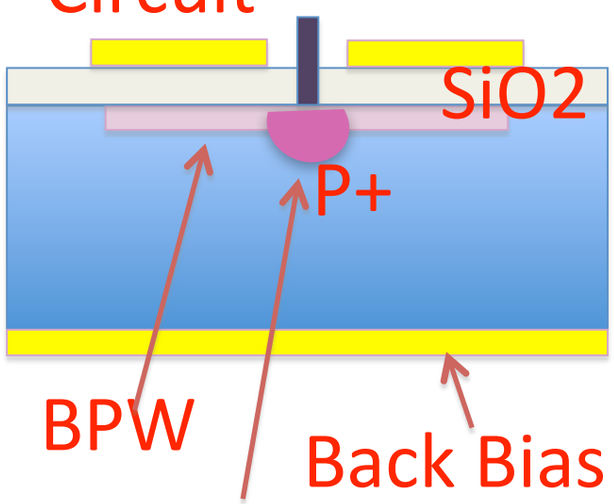


Takeda et al., IEEE (2013)

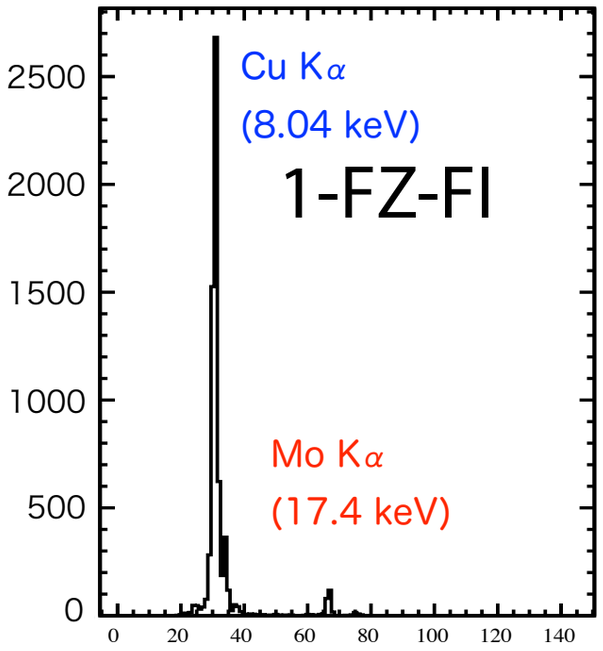
XRPIX1/2-CZ : Charge Loss

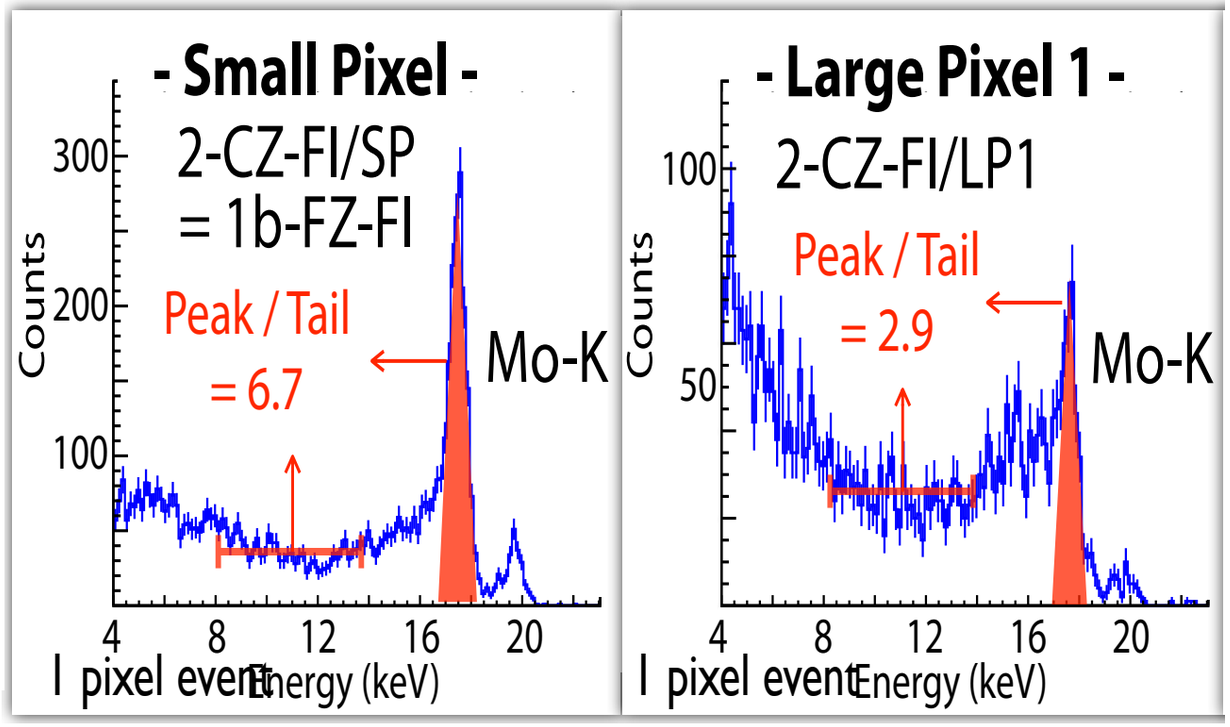
BPW : Buried p-well

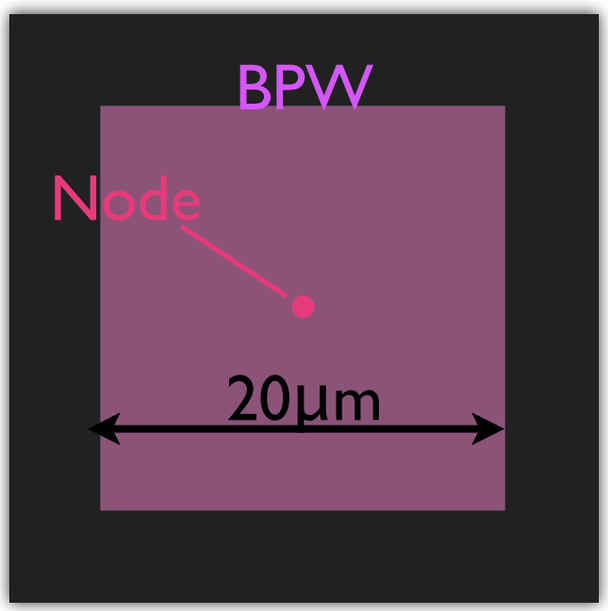
Pixel structure



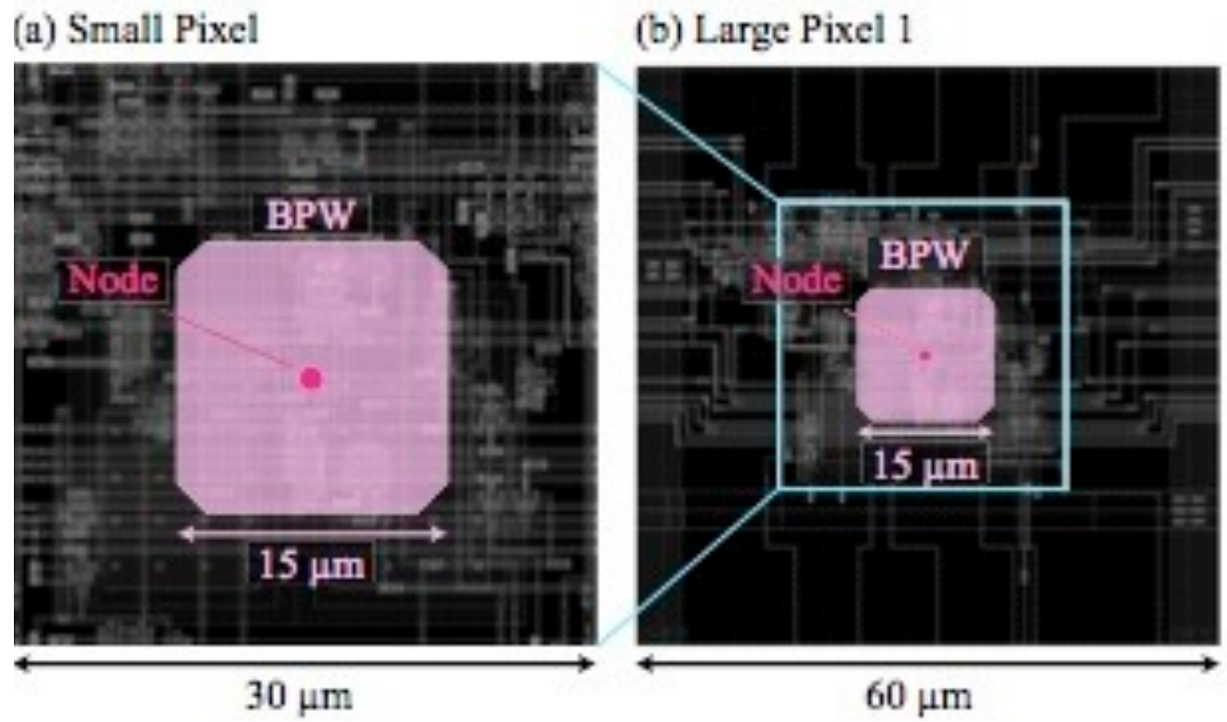
- Suppress the back gate effect of Tr.
- Also act as a part of charge collecting node.
- Increase parasitic capacitance.
- A large BPW reduces node gain.







3μV/e



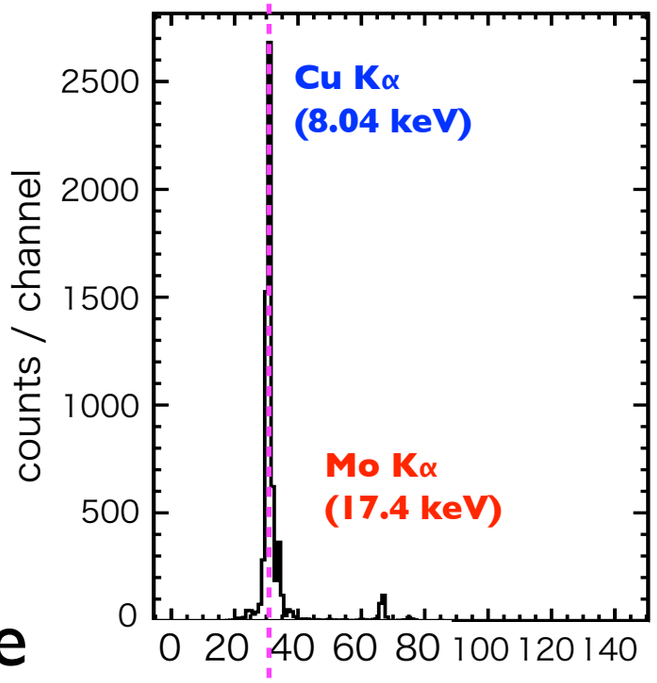
6μV/e 6μV/e

A part of signal charge is lost somewhere.

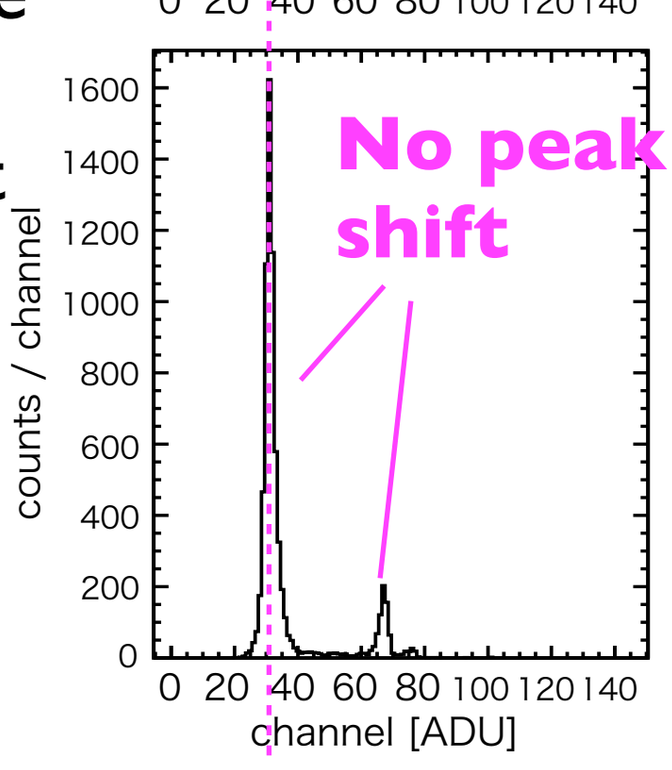
Charge Loss

Large BPW (20.9μm)

single pixel event

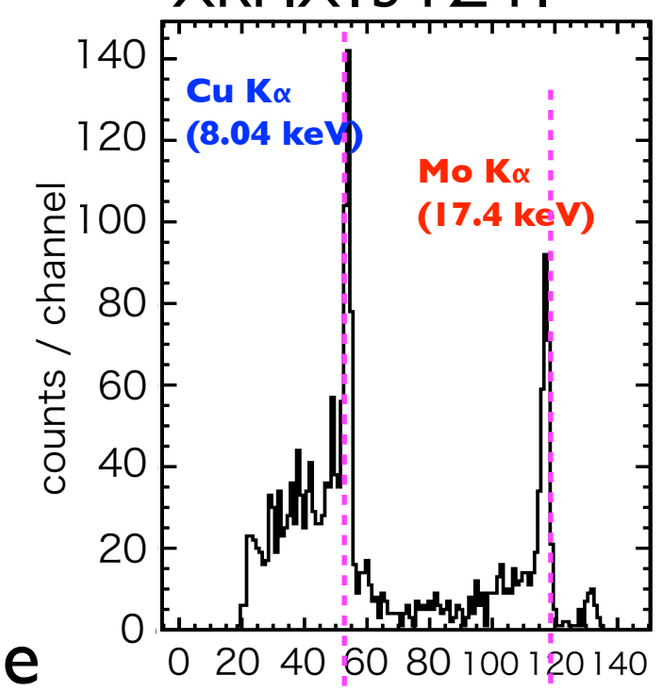


double pixel event

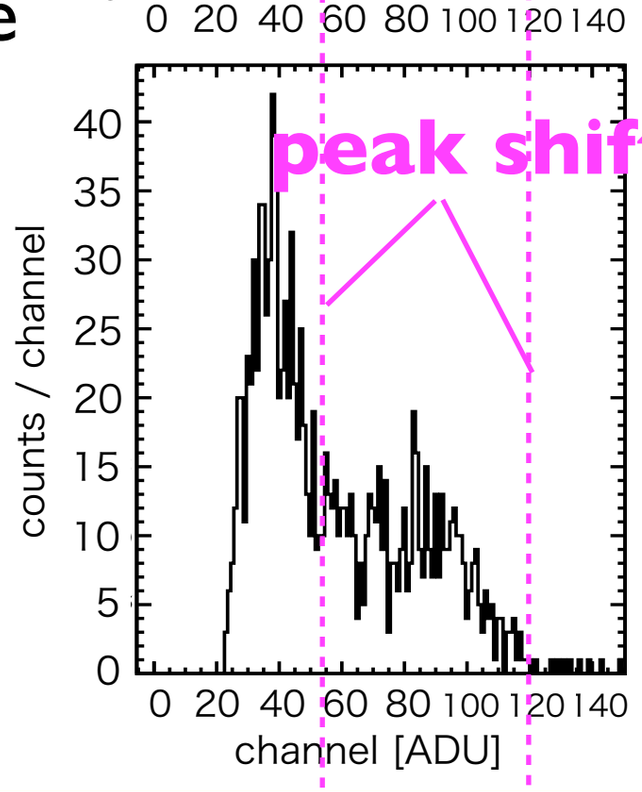


Small BPW (14.0μm)

single pixel event

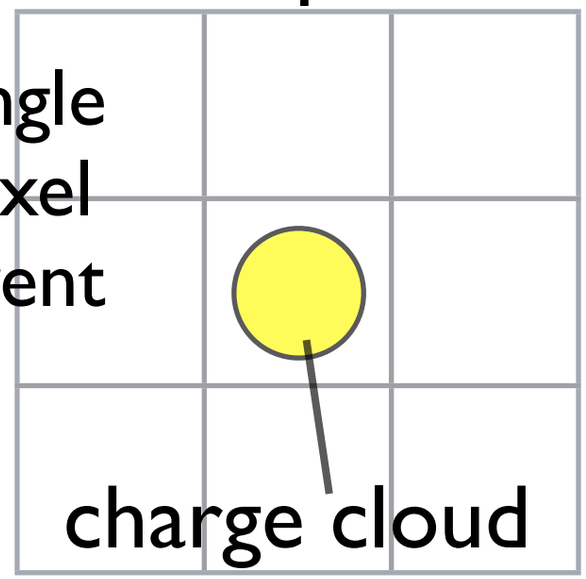


double pixel event

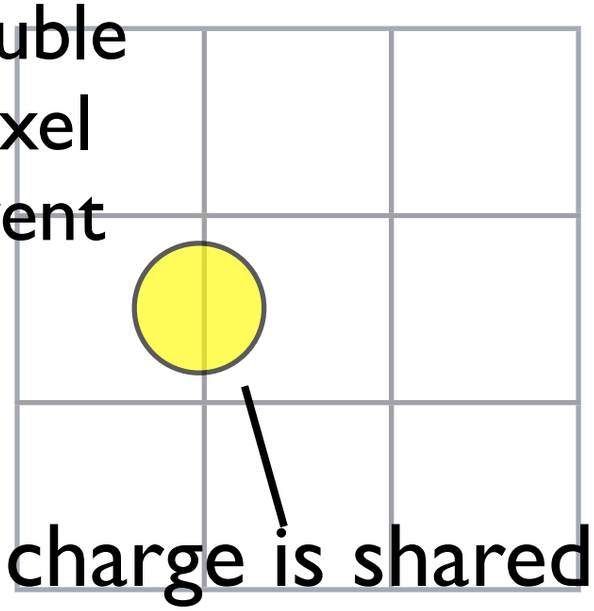


Top view of 3x3 pixels

single pixel event



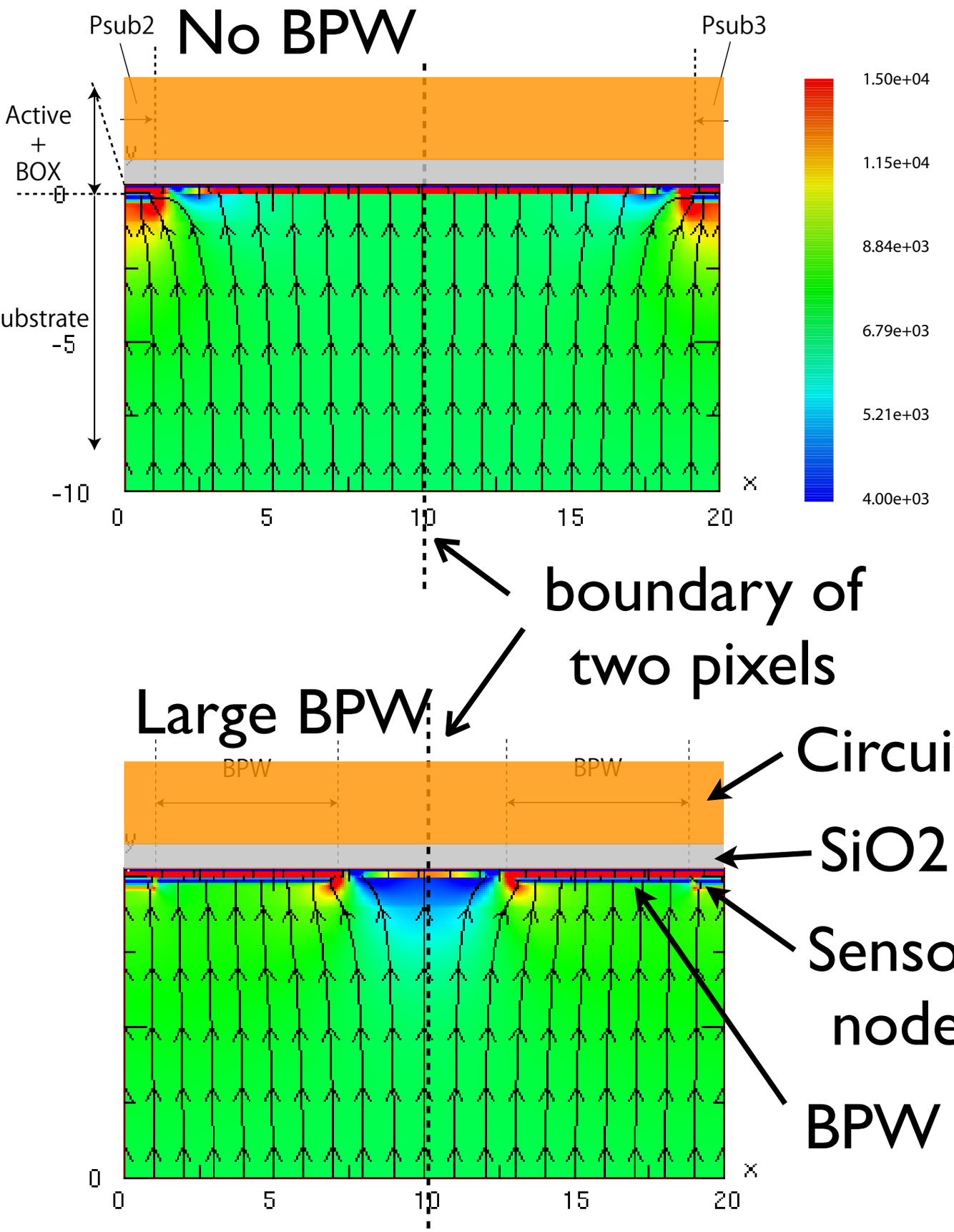
double pixel event



Matsumura+13
HSTD9

The charge loss occurs in the region of pixel boundary.

Charge Loss at interface between Si and SiO2



- Electric field penetrates into SiO2 insulator.
- Signal charge moves to the interface region between depleted Si and SiO2 insulator.
- The signal charge would be trapped and lost at the interface.
- Pencil X-ray beam test in SPring-8.

Y. Ono, master thesis "Research and development of the PIXOR (PIXel OR) semiconductor detector for the high energy experiments based on the SOI technology" (unpublished, in Japanese) http://epx.phys.tohoku.ac.jp/eeweb/paper.html

Summary

- Developing monolithic SOI sensor 'XRPIX' for future X-ray Astronomical Satellites.
- Realize the event driven readout mode and very low non-X-ray BGD by the function of the trigger signal output.
- Depletion region ~500μm.
- The readout noise ~60e- → Charge Sensitive Amp.
- The event driven readout basically operates.
- Signal charge would be lost at the interface between the depleted Si and SiO2 insulator. → Pencil X-ray mean test.

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A-R-Tec
Analog and RF Technologies