# Development and Performance of X-ray Astronomical SOI pixel sensor

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Posters

Ryu et al. "Trigger-Driven Readout" NP3.M-90
Nakashima et al. "Analog to Digital Converter" NP3.M-92

Ryu-kun

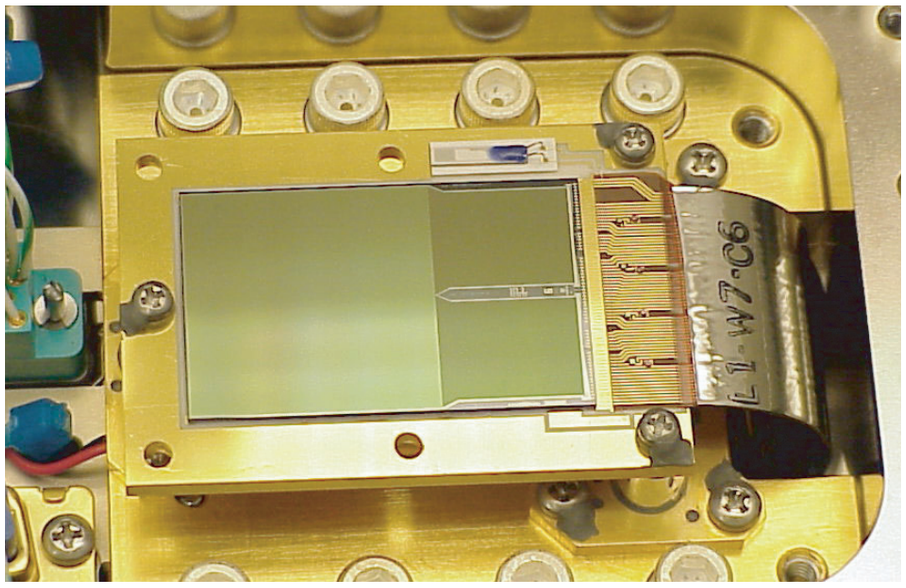
Nakashima-kun

Papers

Ryu et al. IEEE NSS 2010, Conf. Record (2010)
Ryu et al. IEEE TNS 58, 2528 (2011)
Nakashima et al. TIPP 2011 (2011) Submitted

# 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□

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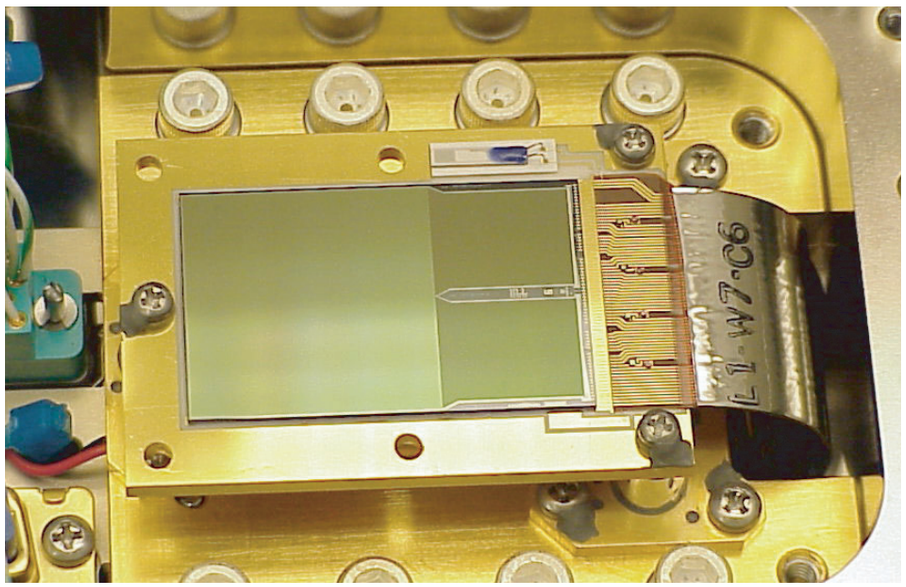
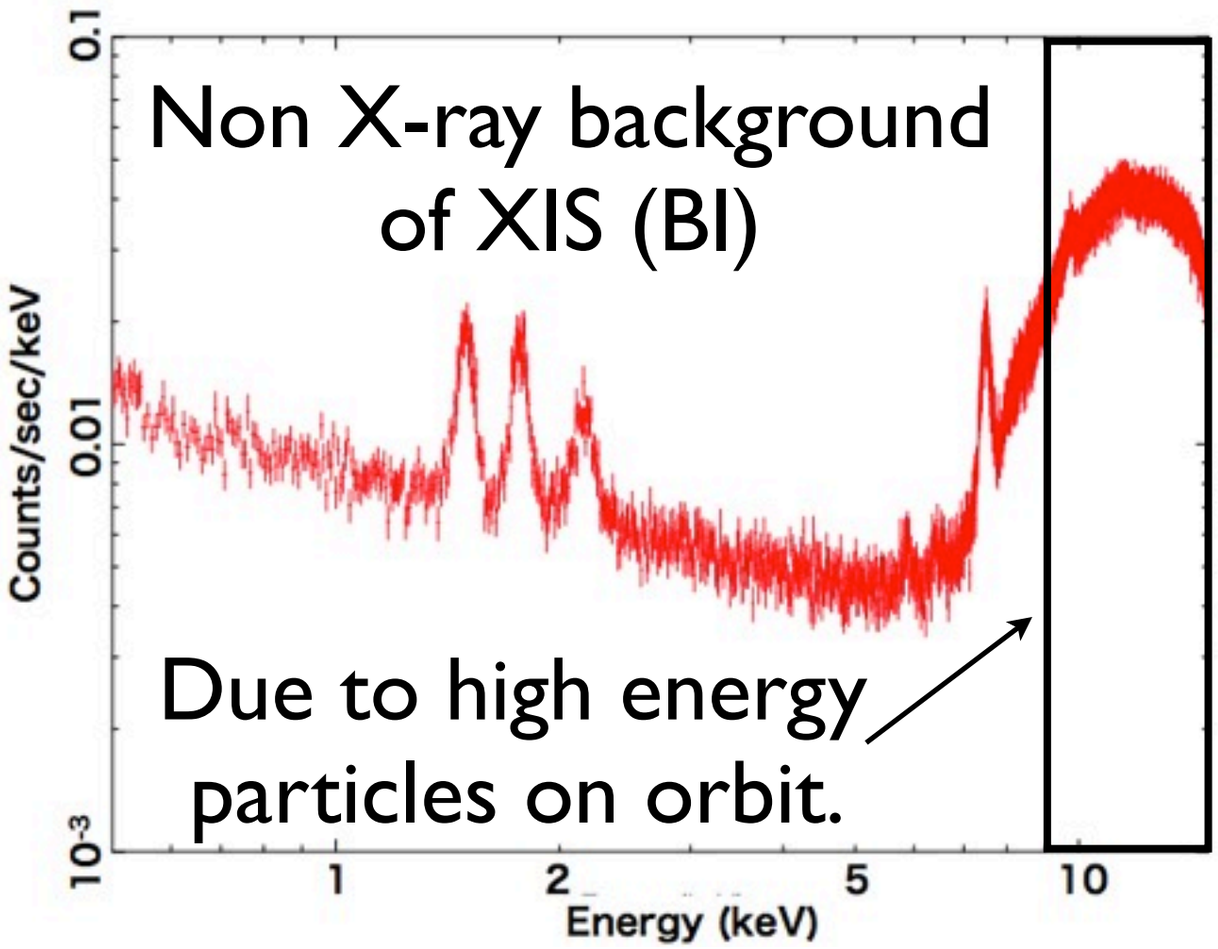


- Fano limited spectroscopy with the readout noise ~3e- (rms).
- Wide and fine imaging with the sensor size of ~20-30mm pixel size of ~30μm□

- 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 variable sources.

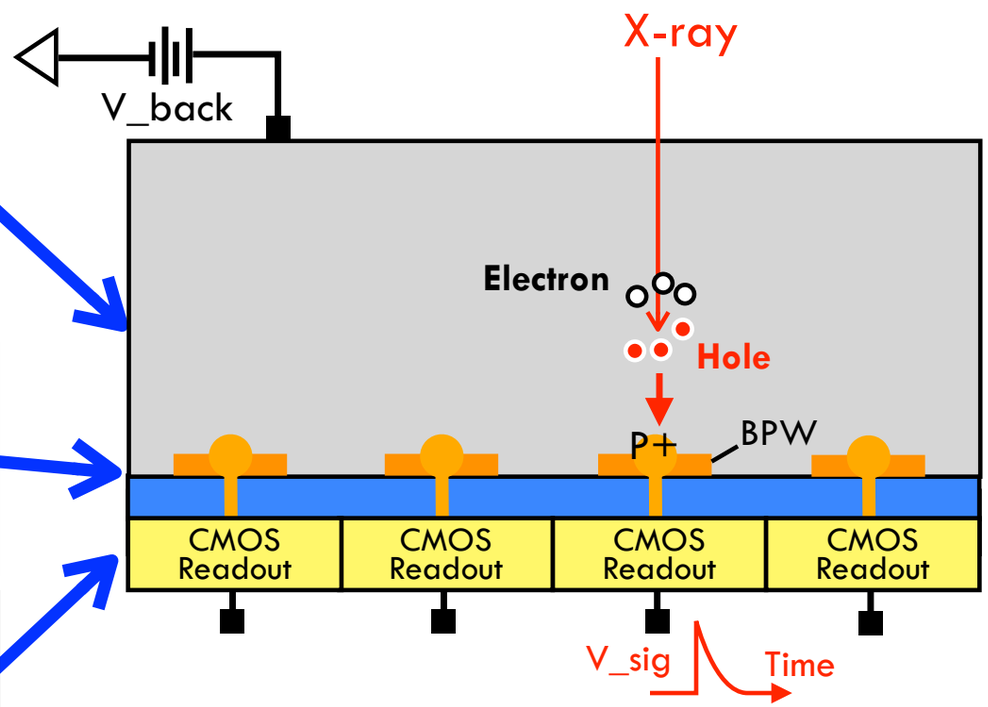


# “XRPIX” = SOI pixel sensor for future X-ray astronomical satellites

Sensor (high ρ, depleted Si)

Insulator (SiO2)

Fast CMOS (low ρ Si)




Our SOIPIX

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

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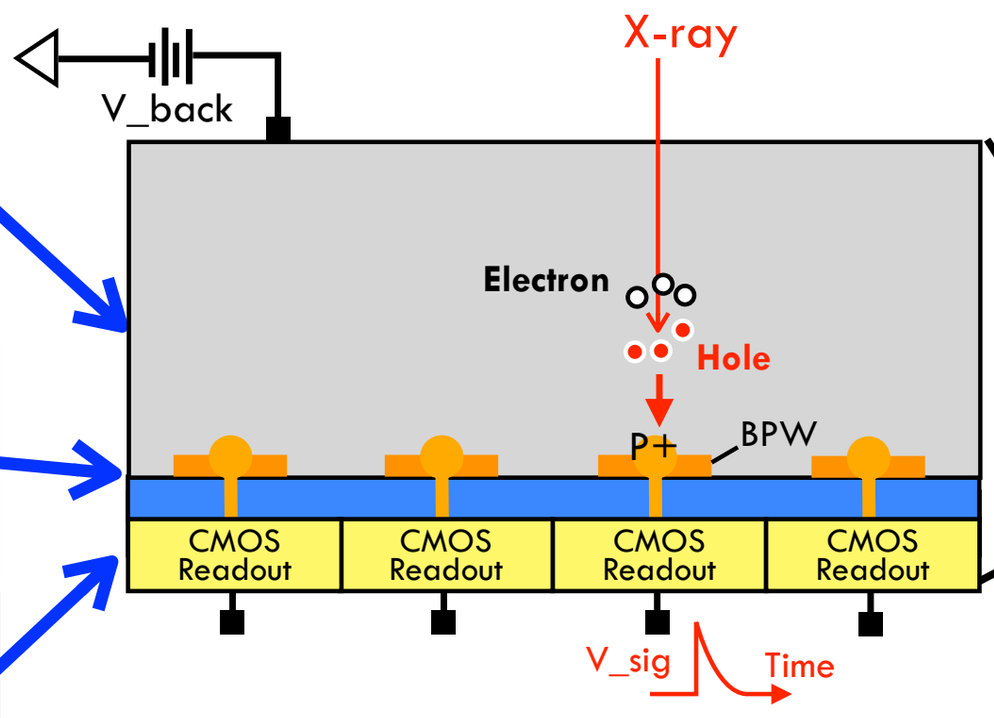


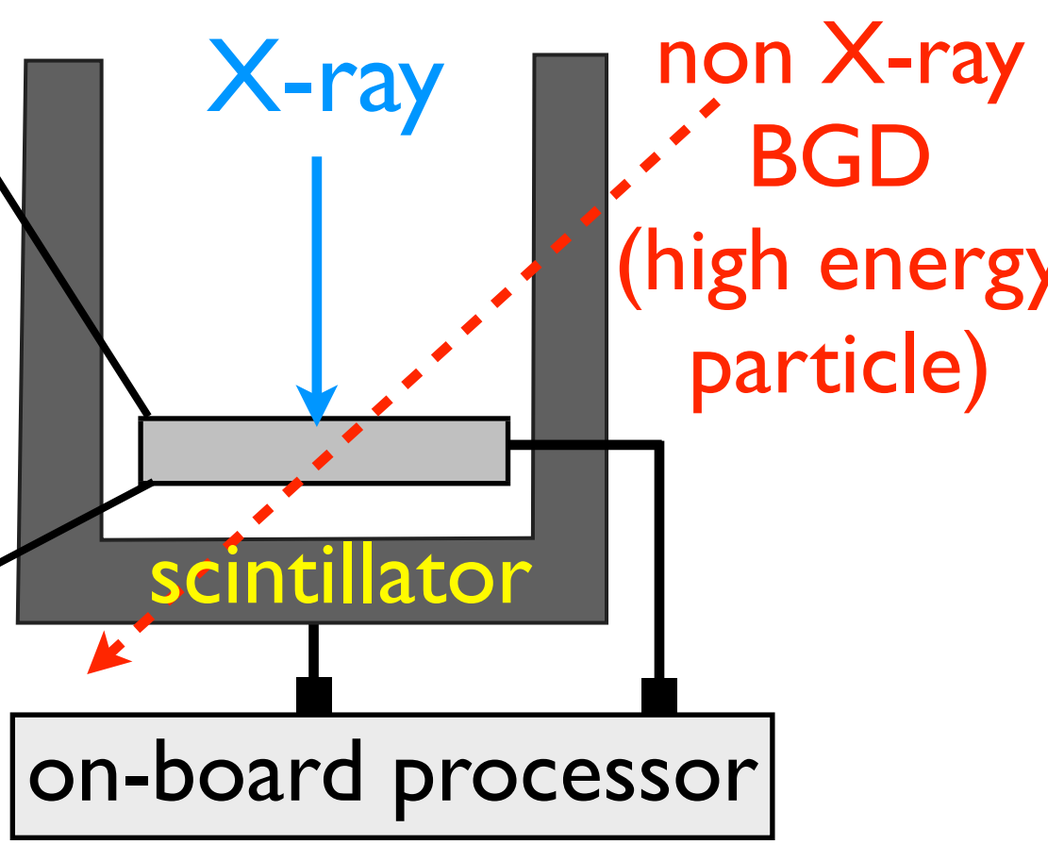


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Realize Very Low BGD by Anti-coincidence

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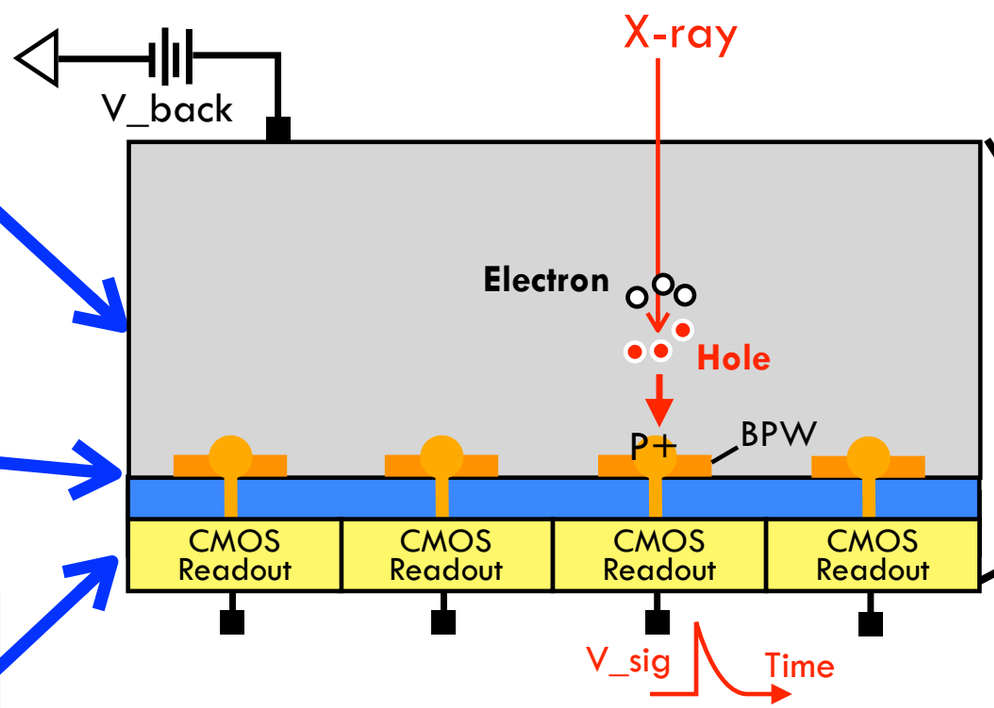
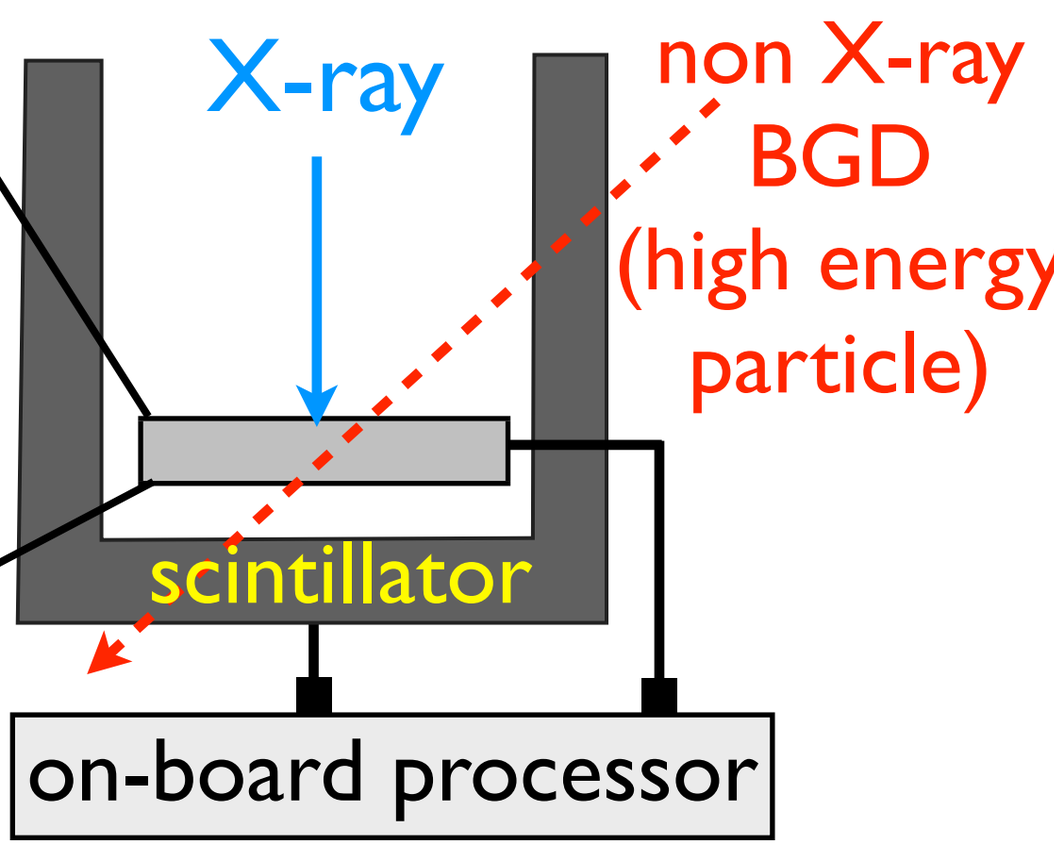



Our SOIPIX

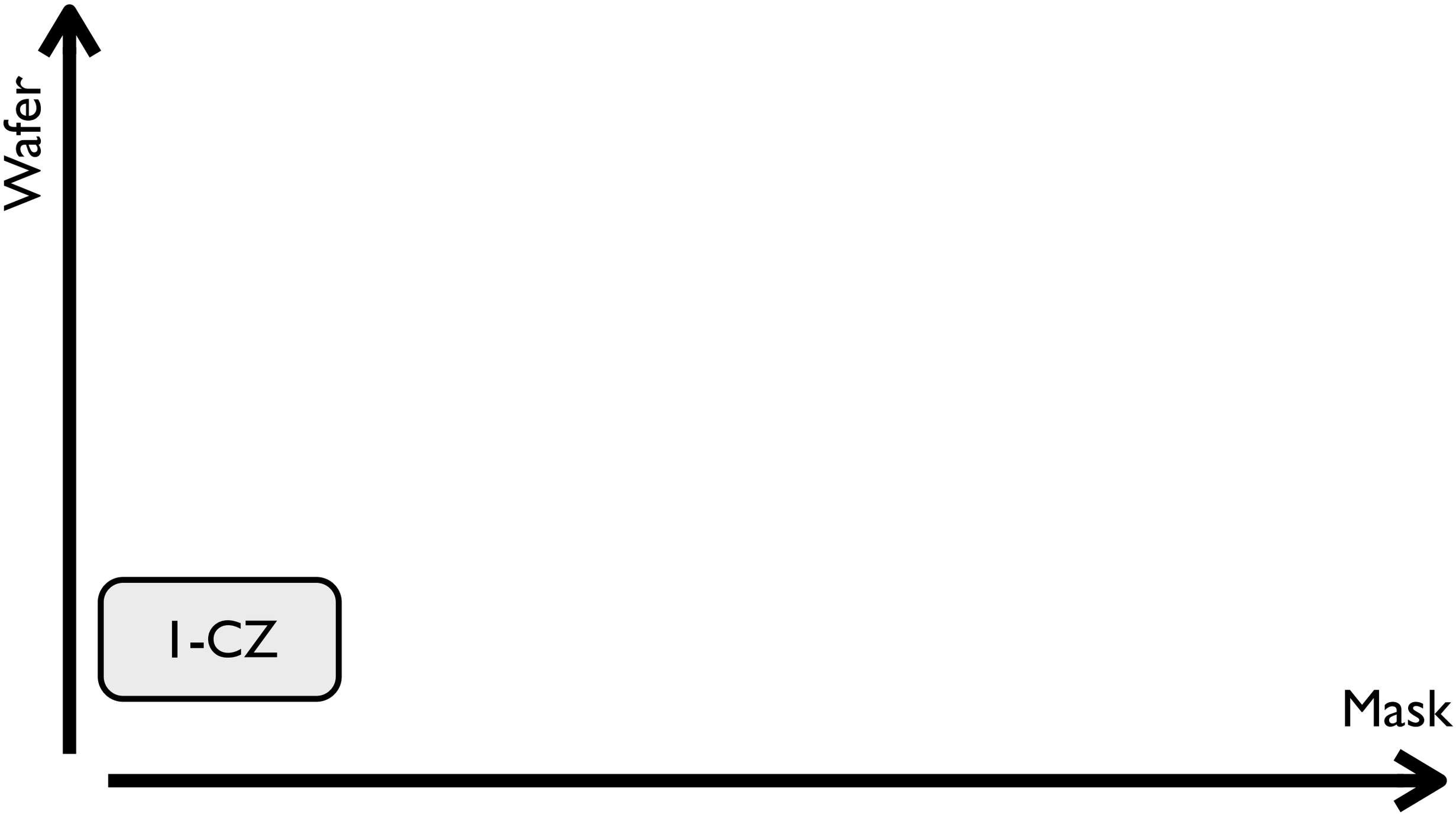
Each pixel has its own trigger and analogue readout CMOS circuit.

Realize Very Low BGD by Anti-coincidence

Target Specification

| | |
|---|---|
| Imaging | area > 25x25mm2, pixel ~ 30-60μm□ (1” @ F=9m) |
| Energy Band | 0.3-40keV with BI, and thick depletion (>300μm) |
| Spectroscopy | ΔE < 140eV @ 6keV, Fano limit (<10e-) |
| Timing | ~ 10μsec |
| Function | Trigger signal & pixel address output, built-in ADC |
| Non X-ray BGD | 5e-5 c/s/keV/10x10mm2 at 20keV (1/100 of CCD) |

# Road Map to the Goal



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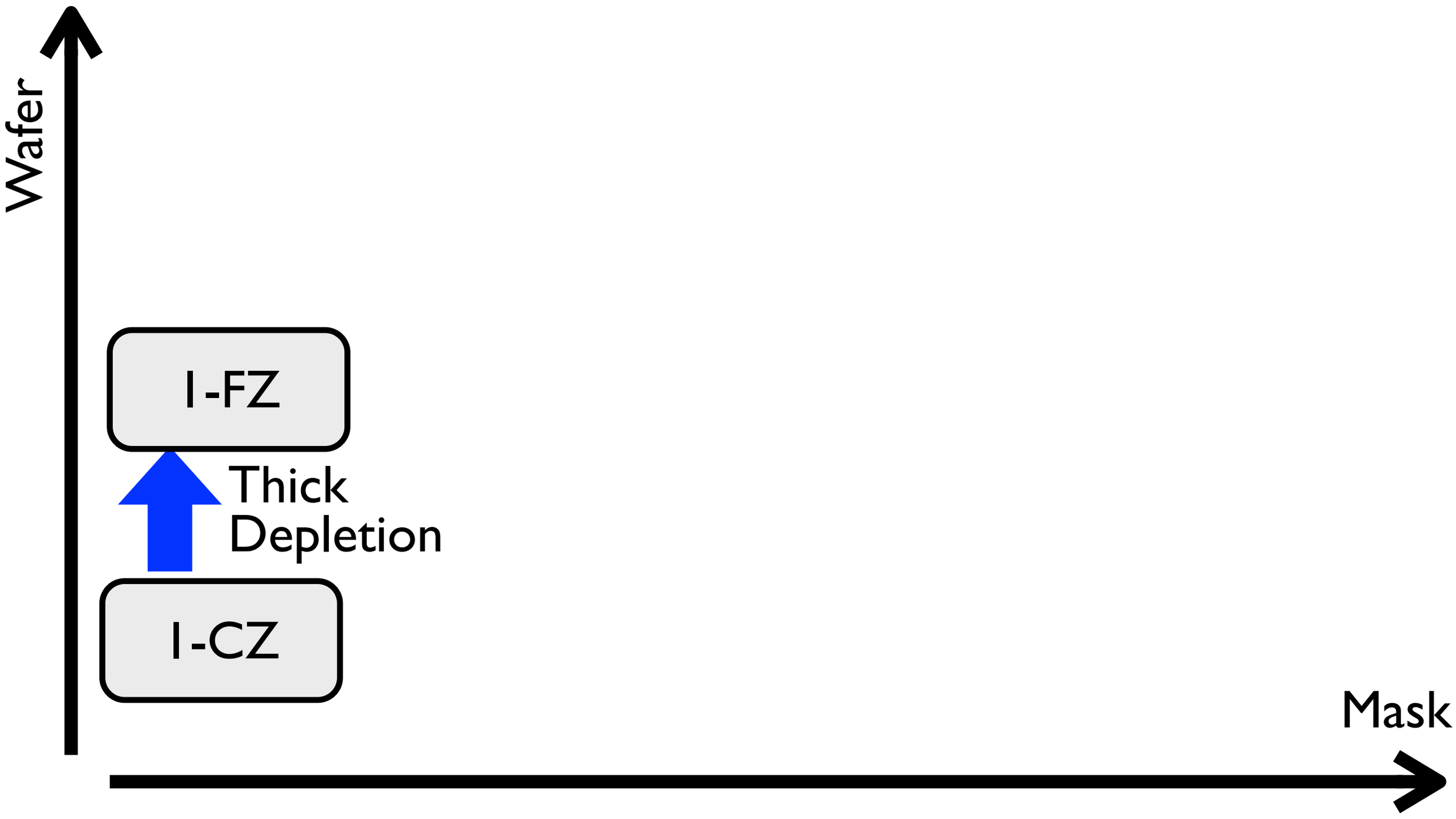

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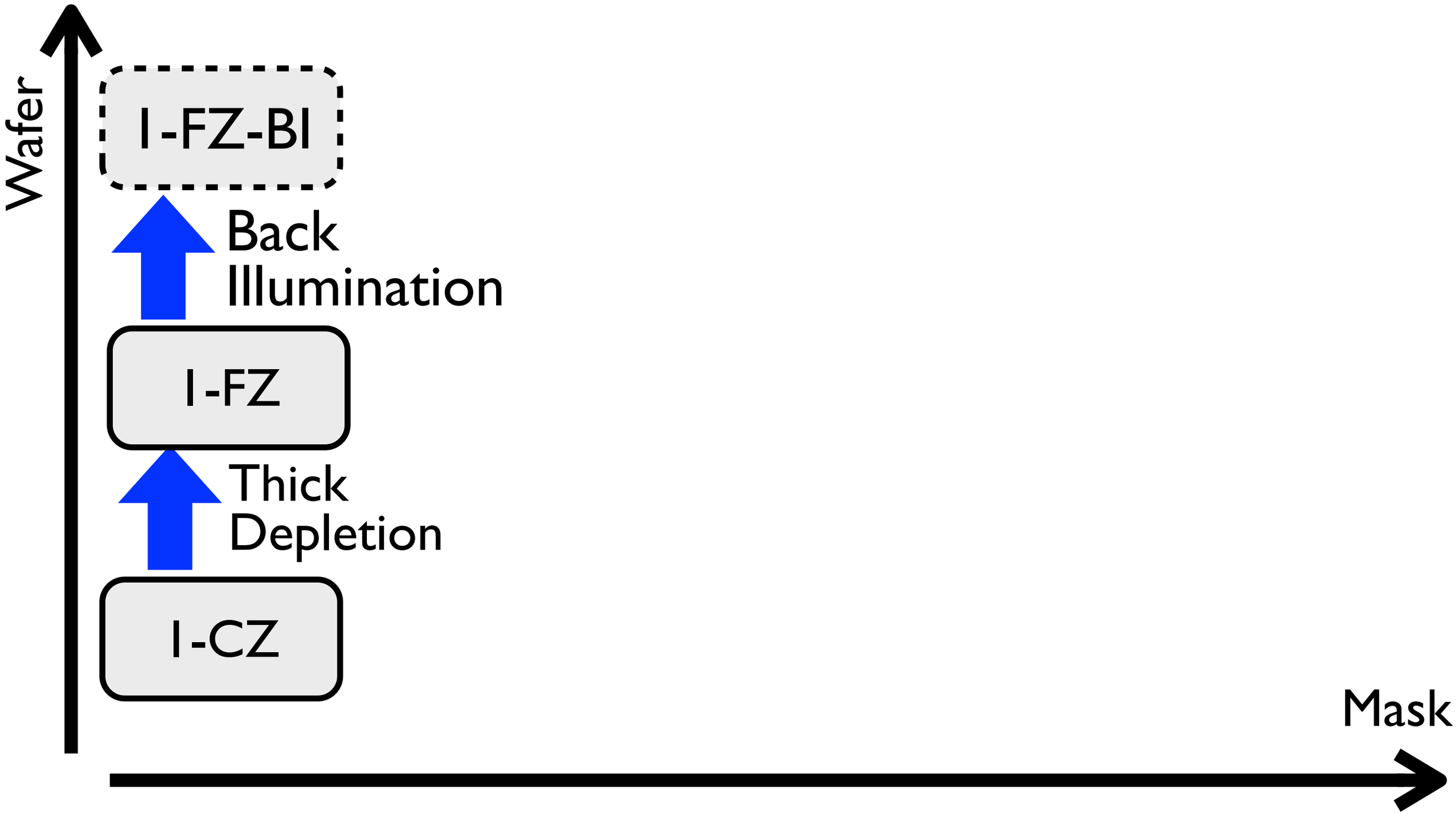

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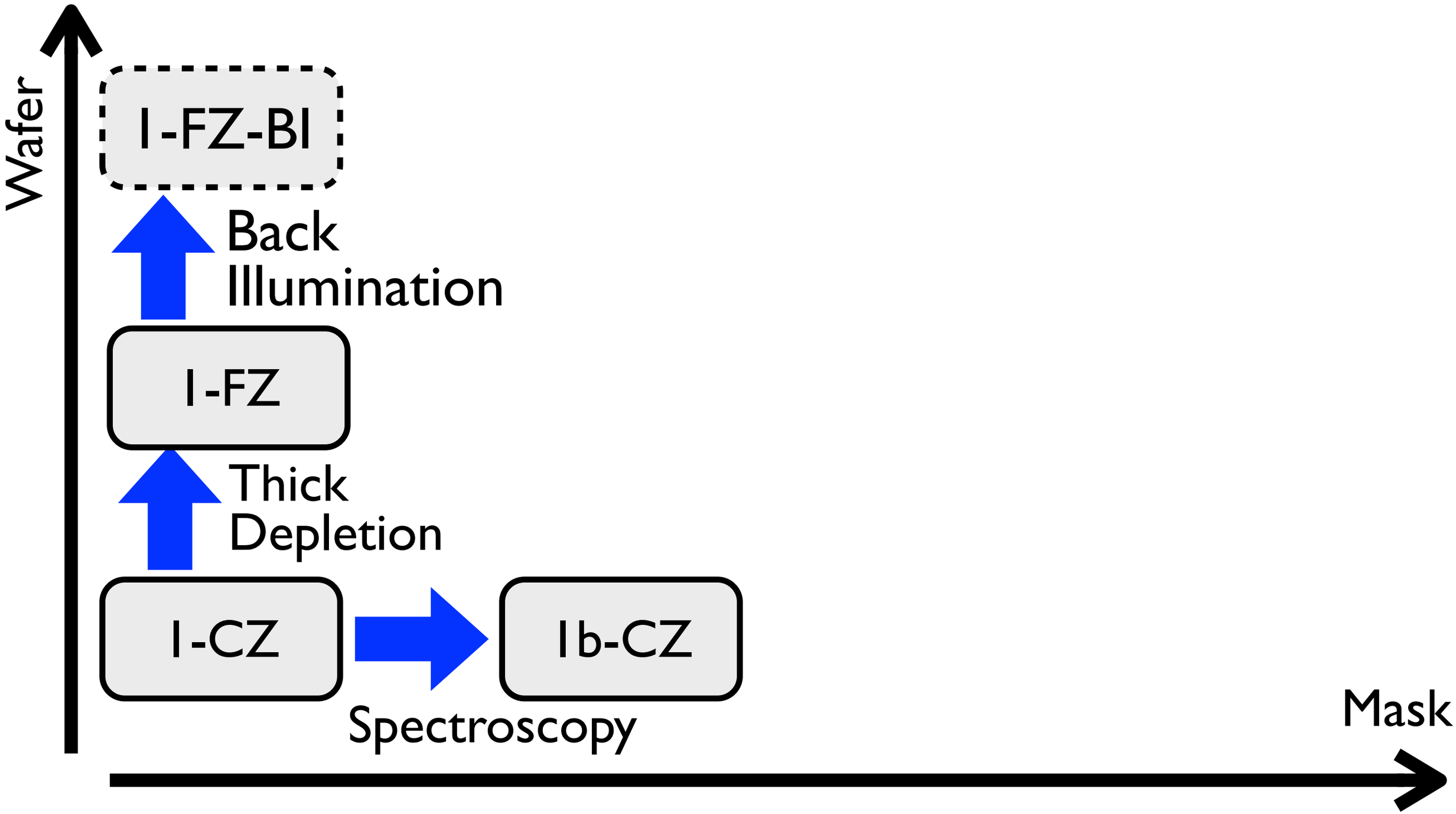

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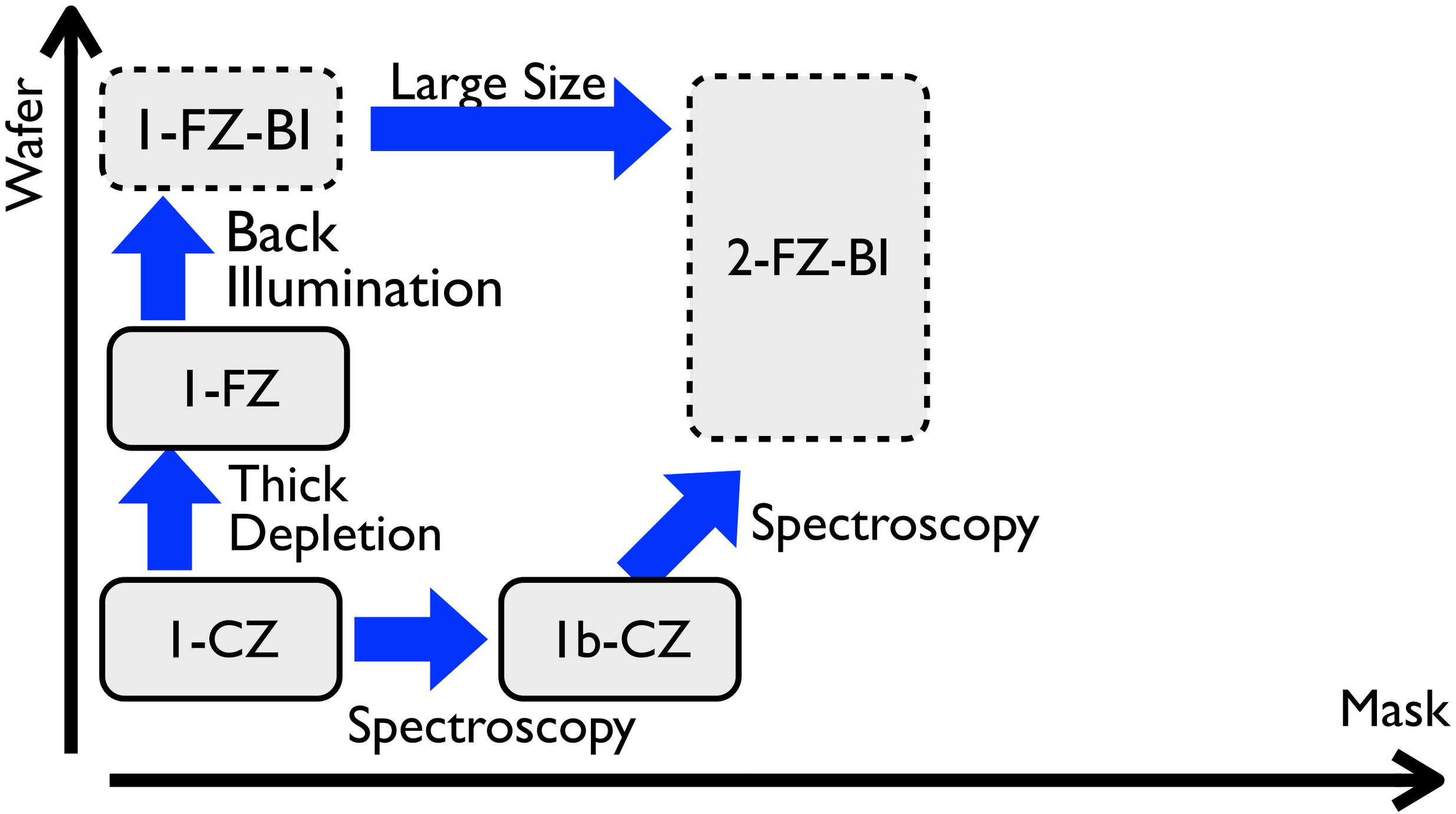

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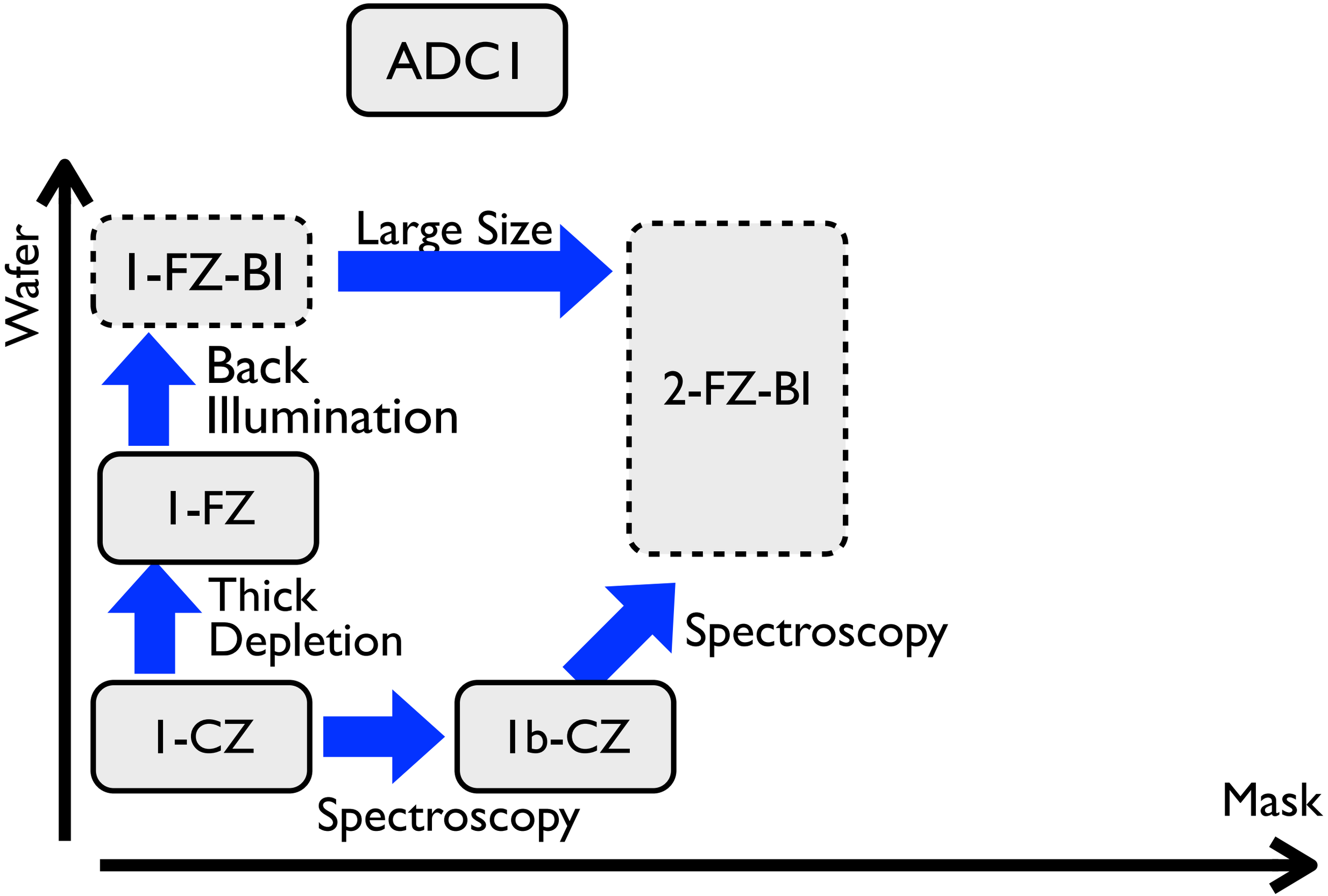

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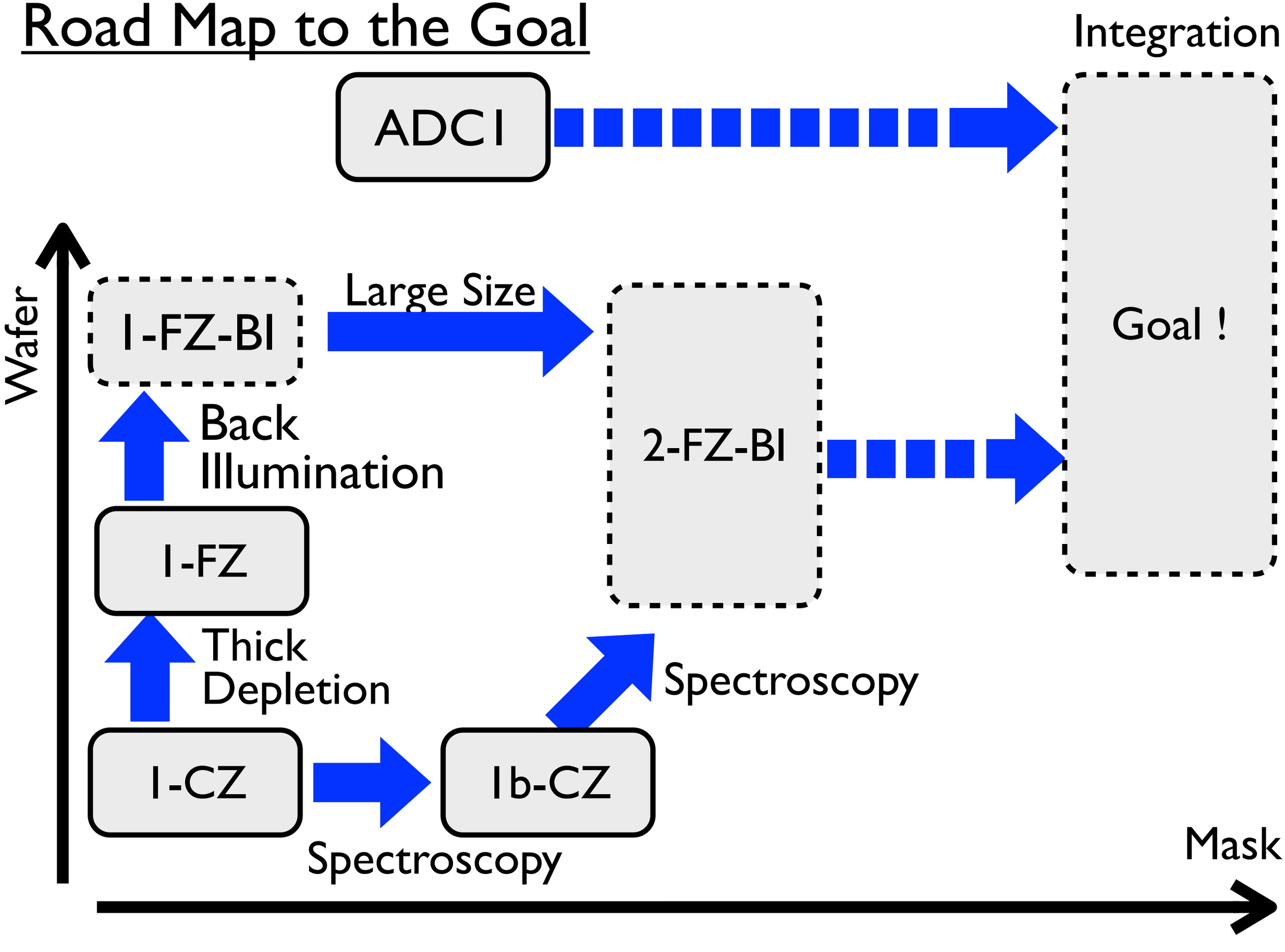
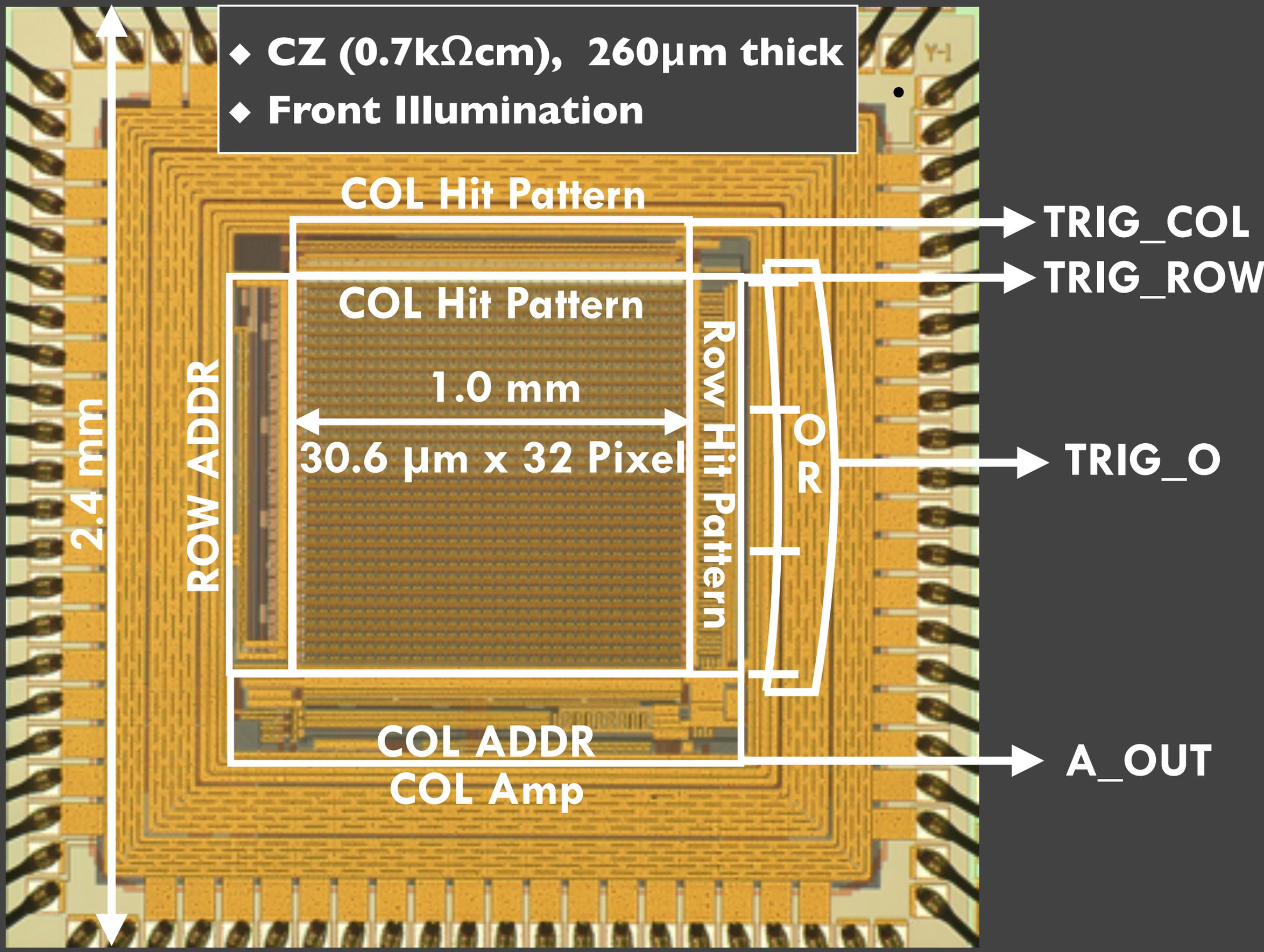
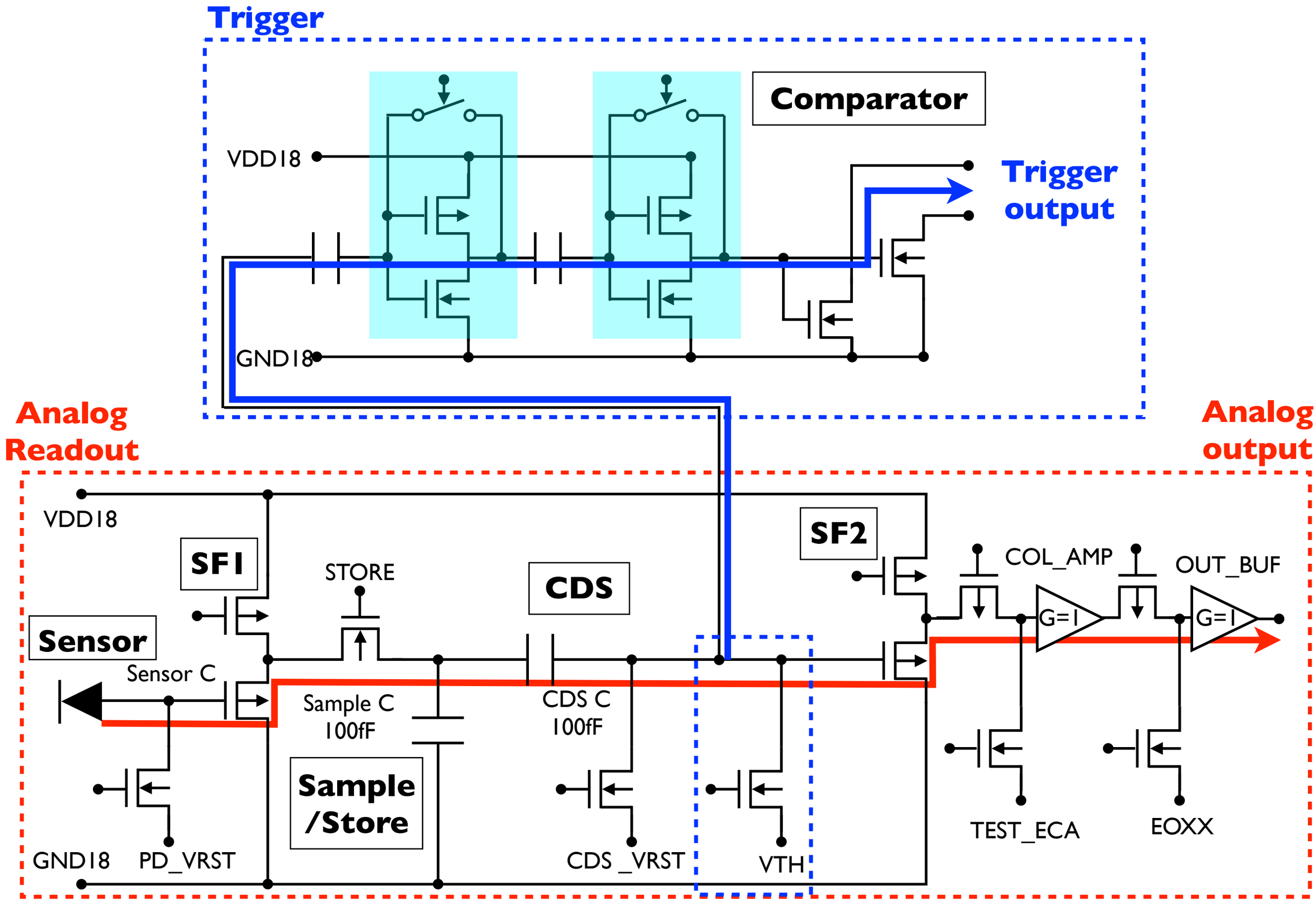


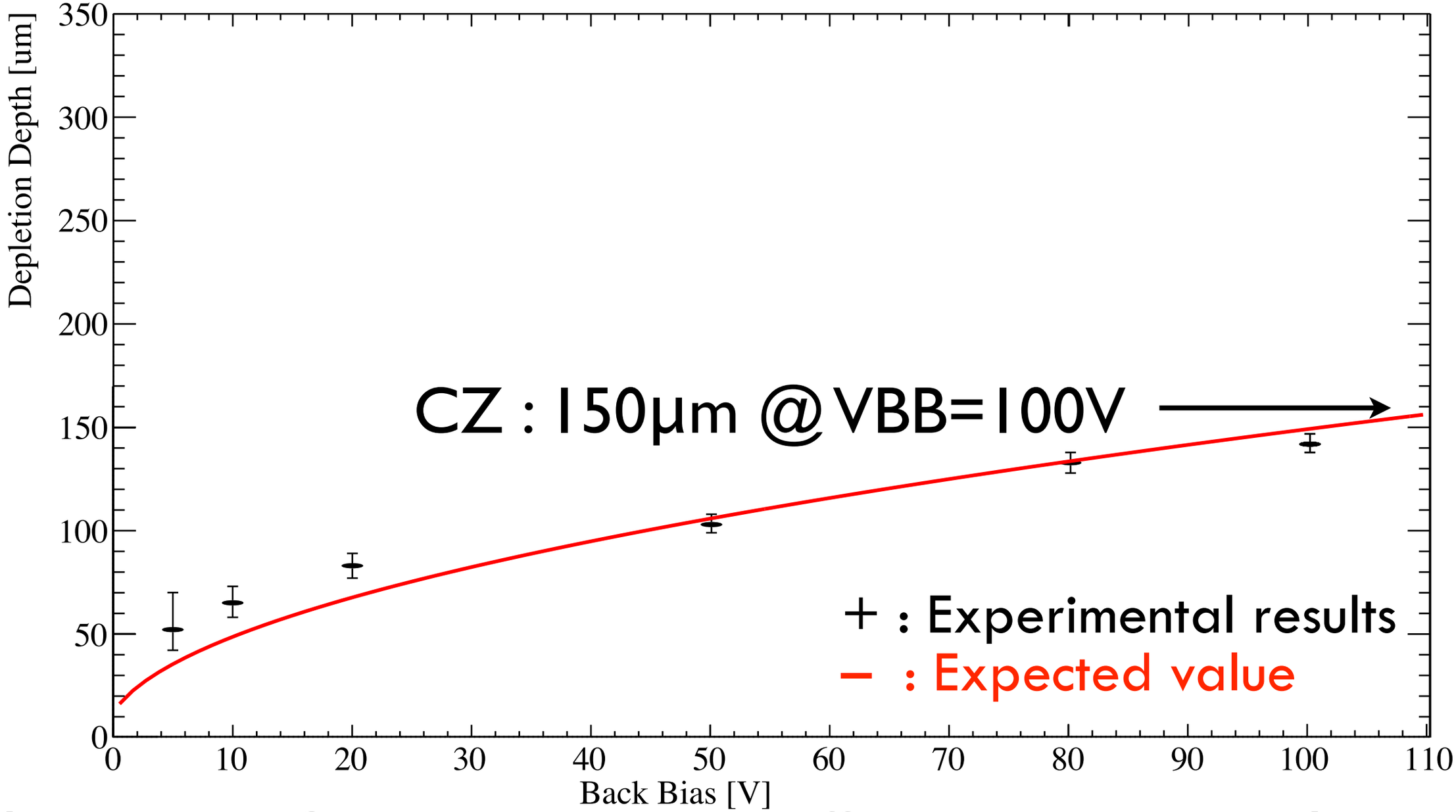
# XRPIX1-CZ (X-Ray PIXel detector - CZochralski)



# XRPIX1: Pixel Circuit



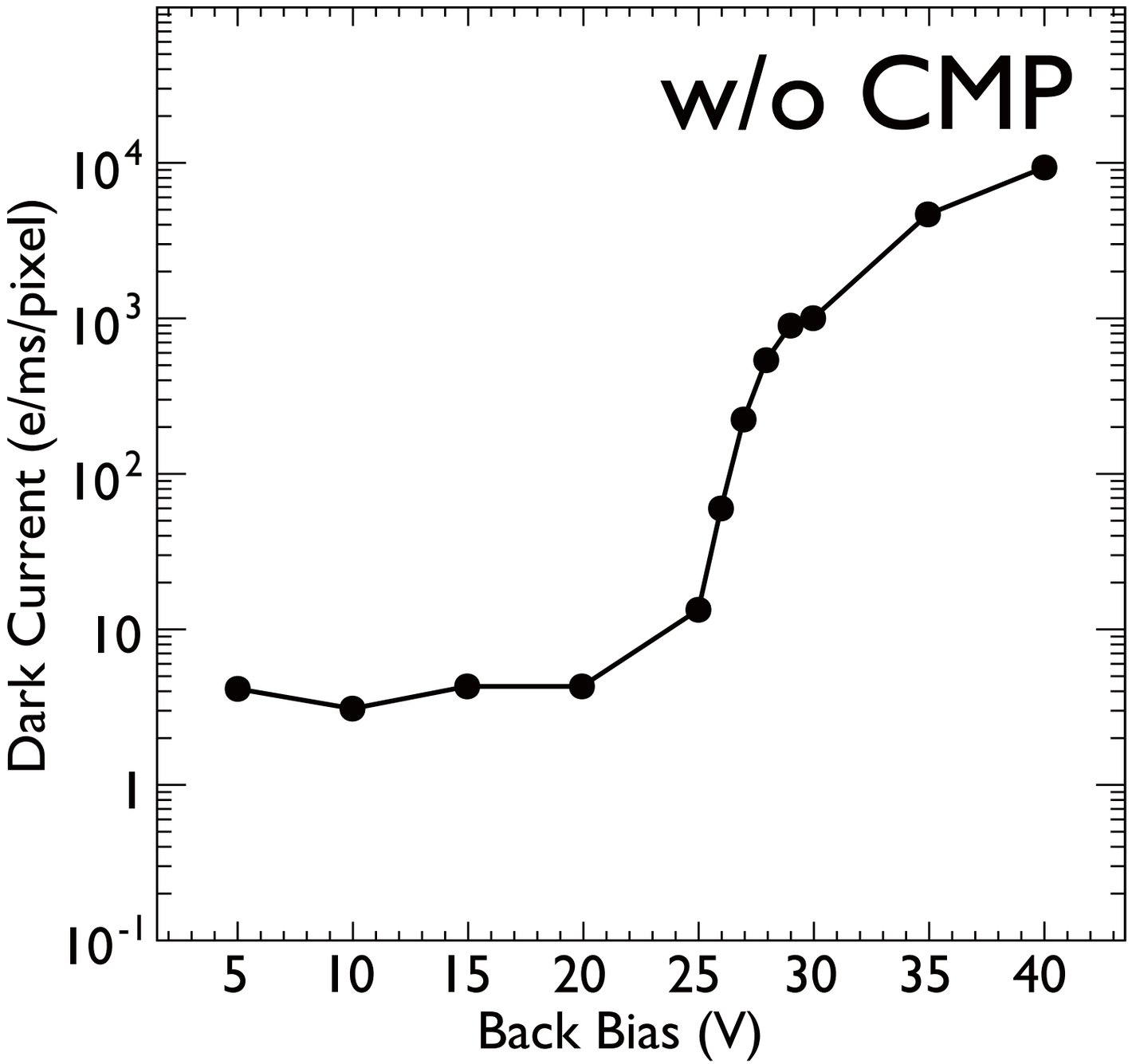
# XRPIX1-CZ (0.7kΩcm): Depletion Depth




- 17 keV and 8 keV X-rays have different attenuation lengths.
- Measure the depletion thickness by observing the ratio between the counting rates of the two energies X-rays.
- The data follow the expectation well.

*Nakashima et al., 2011, submitted*

# XRPIX1-FZ (7kΩcm): Dark Current from Rough Backside Surface




*Nakashima et al., 2011, submitted*

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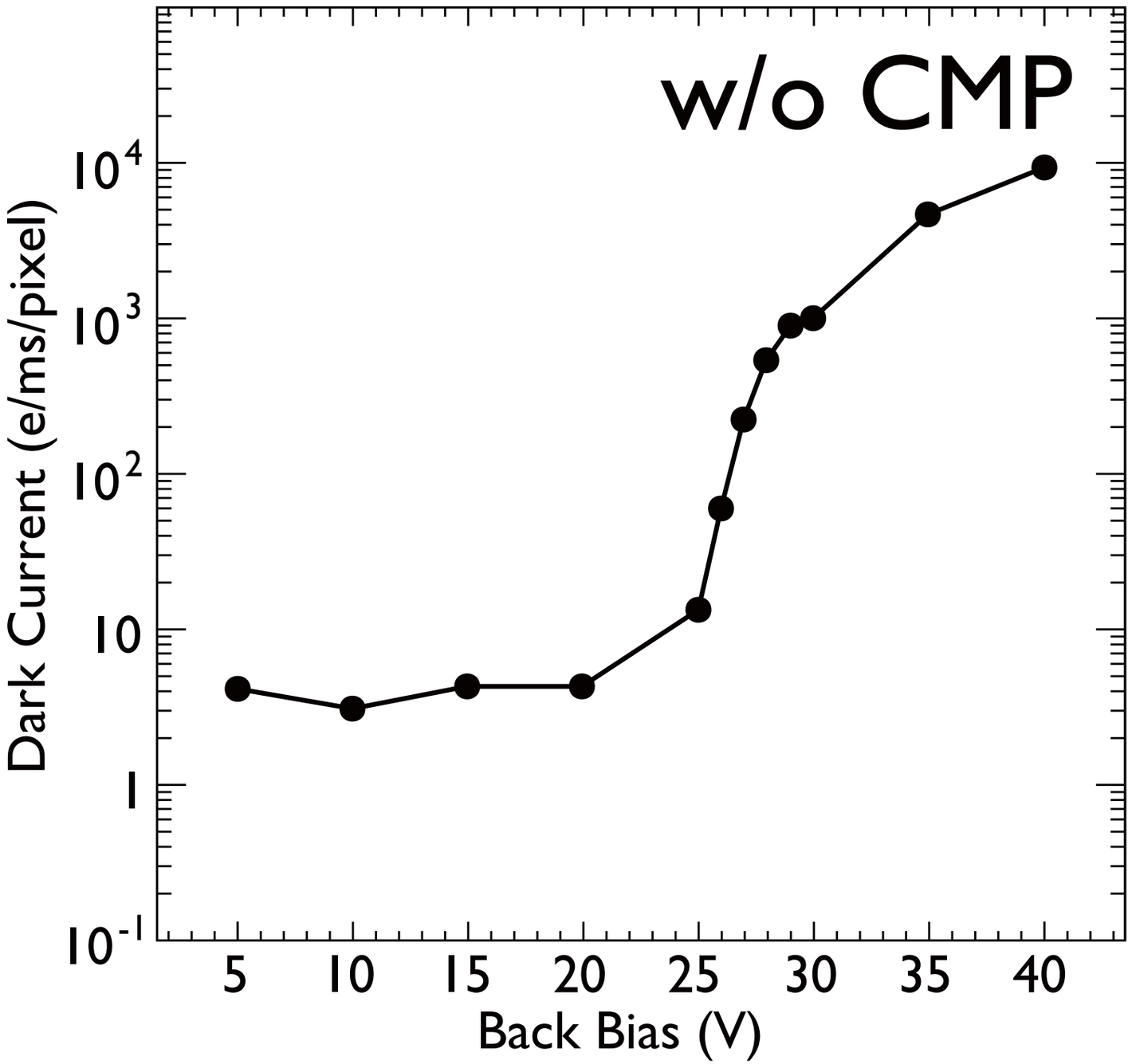
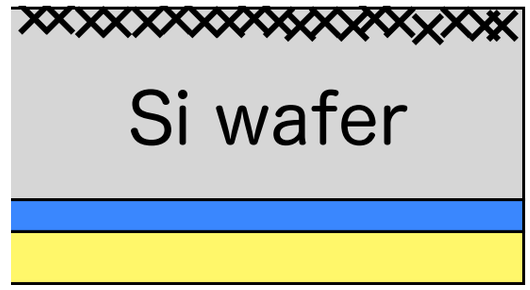



Depletion Layer Reaches the backside at 25V

Rough backside




Before CMP

*Nakashima et al., 2011, submitted*

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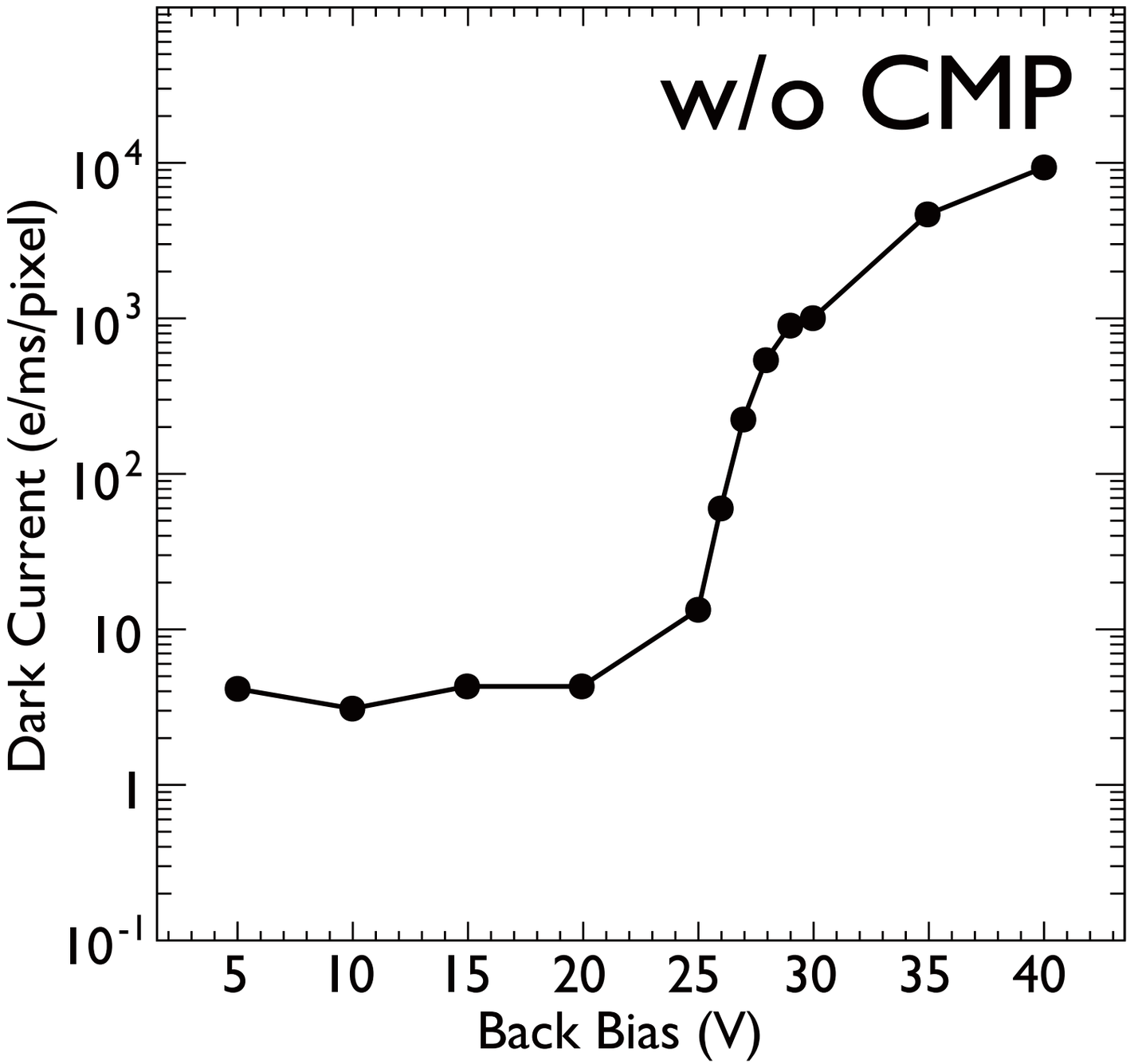


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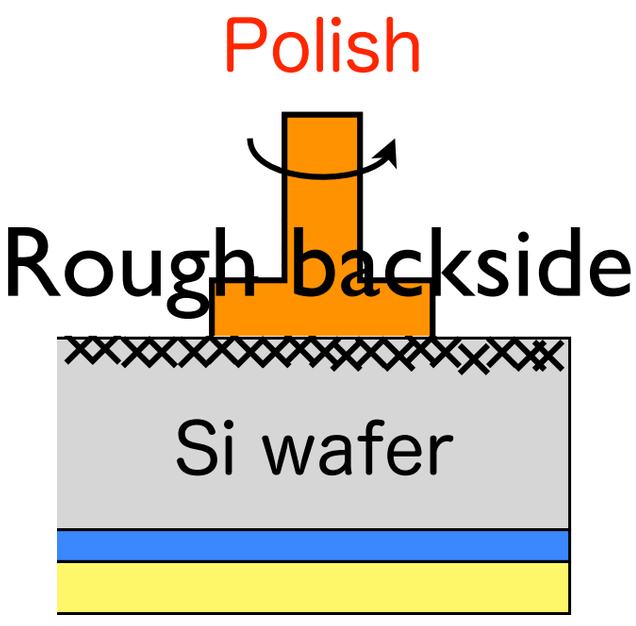
Chemical Mechanical Polish (CMP)

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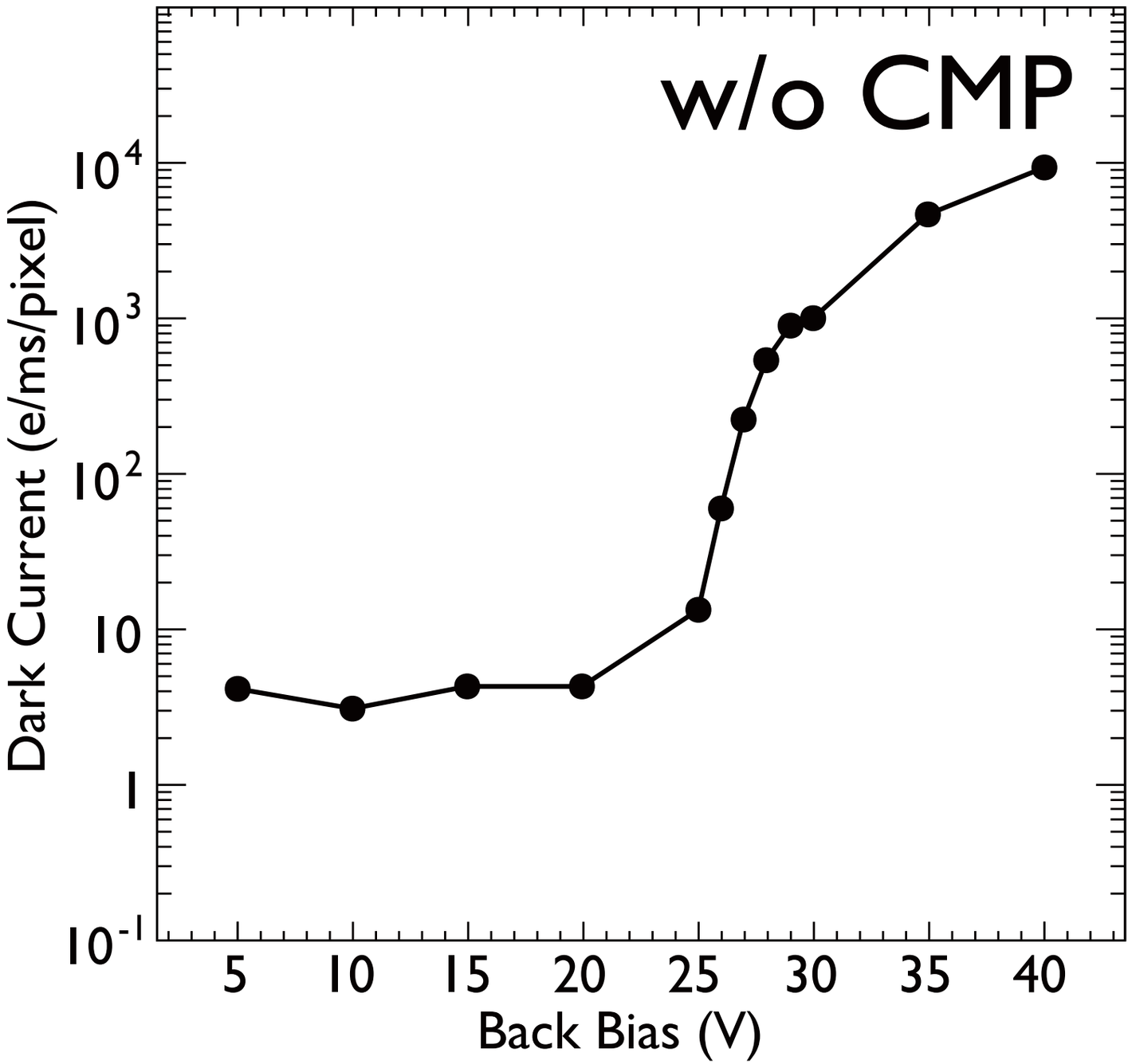


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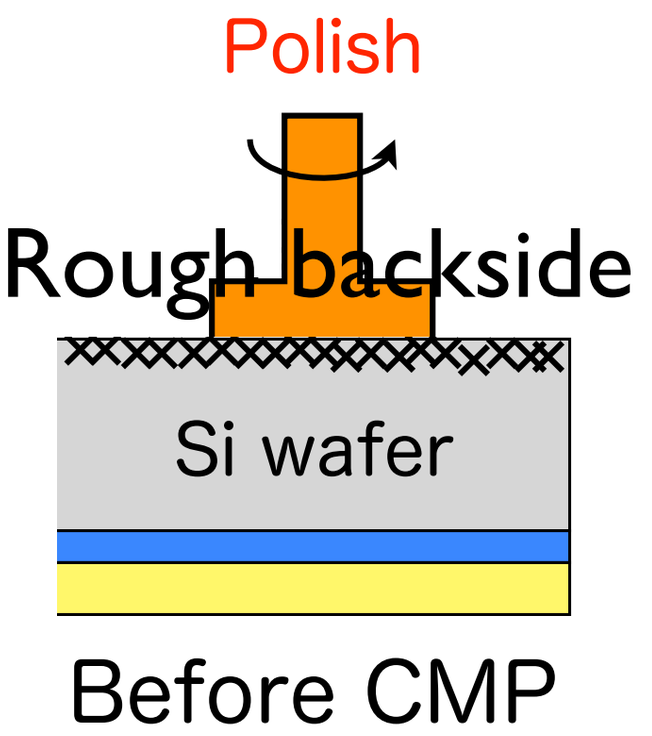


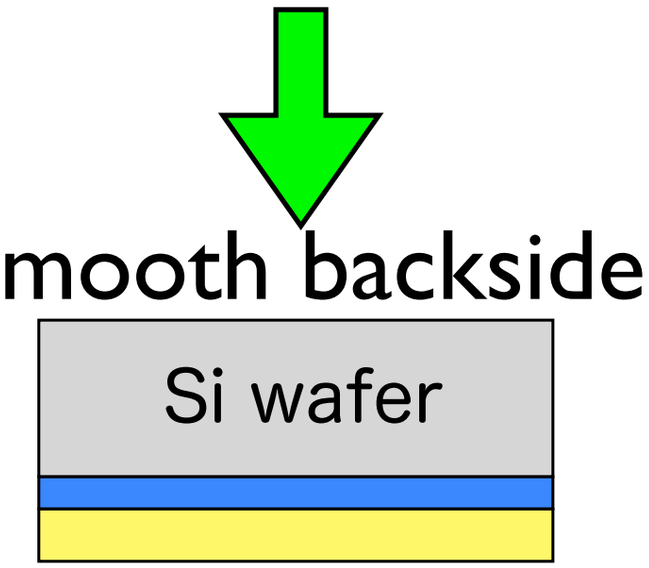


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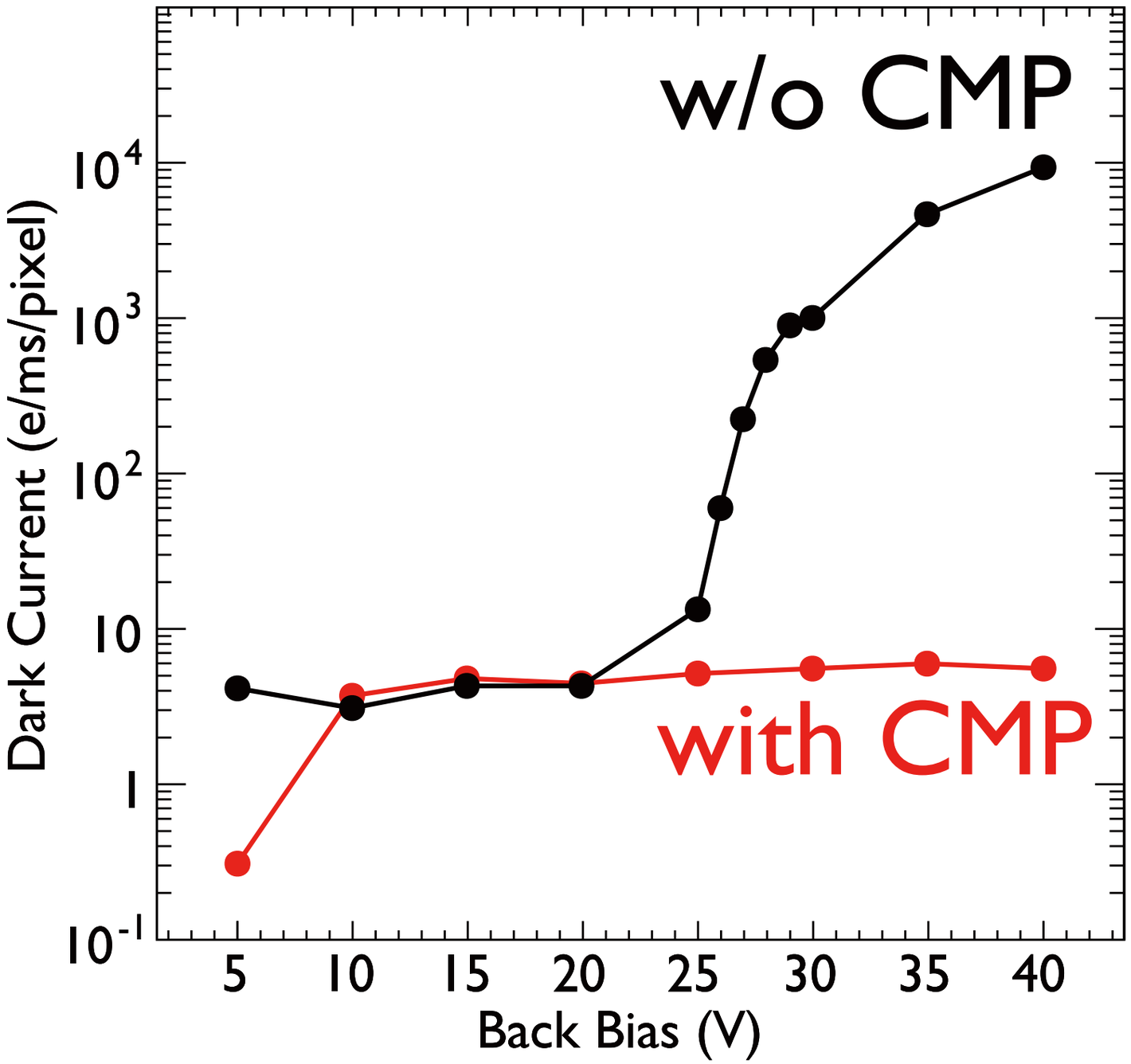


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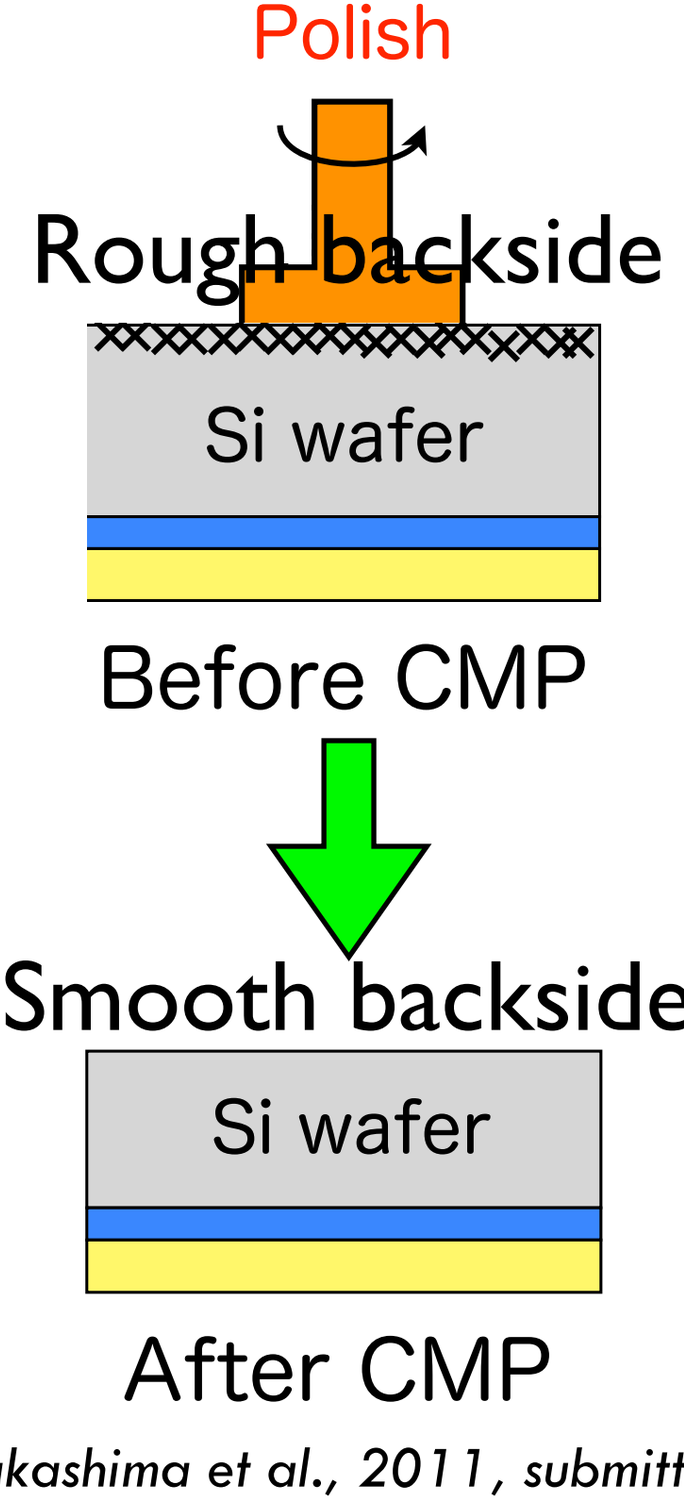


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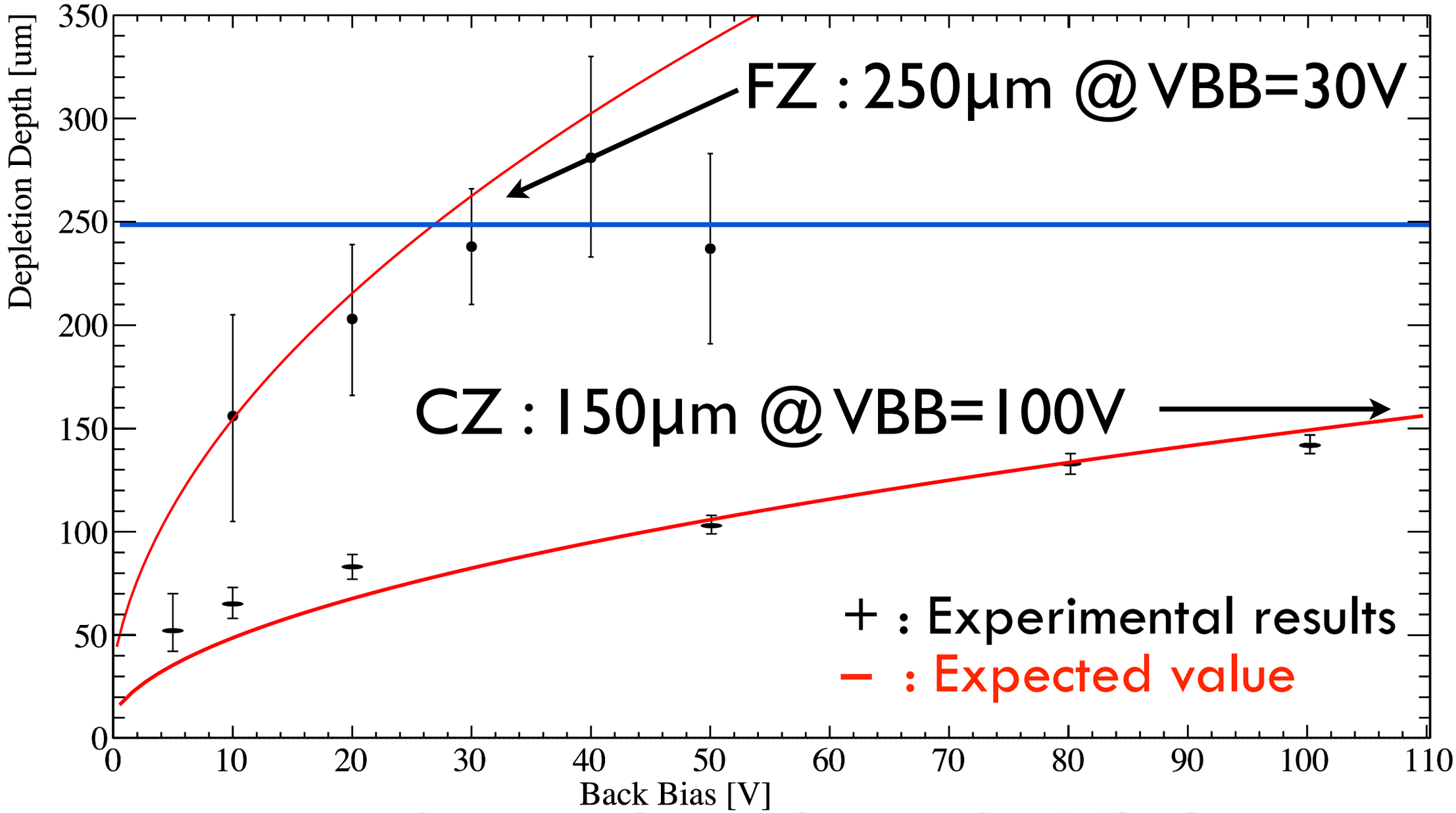
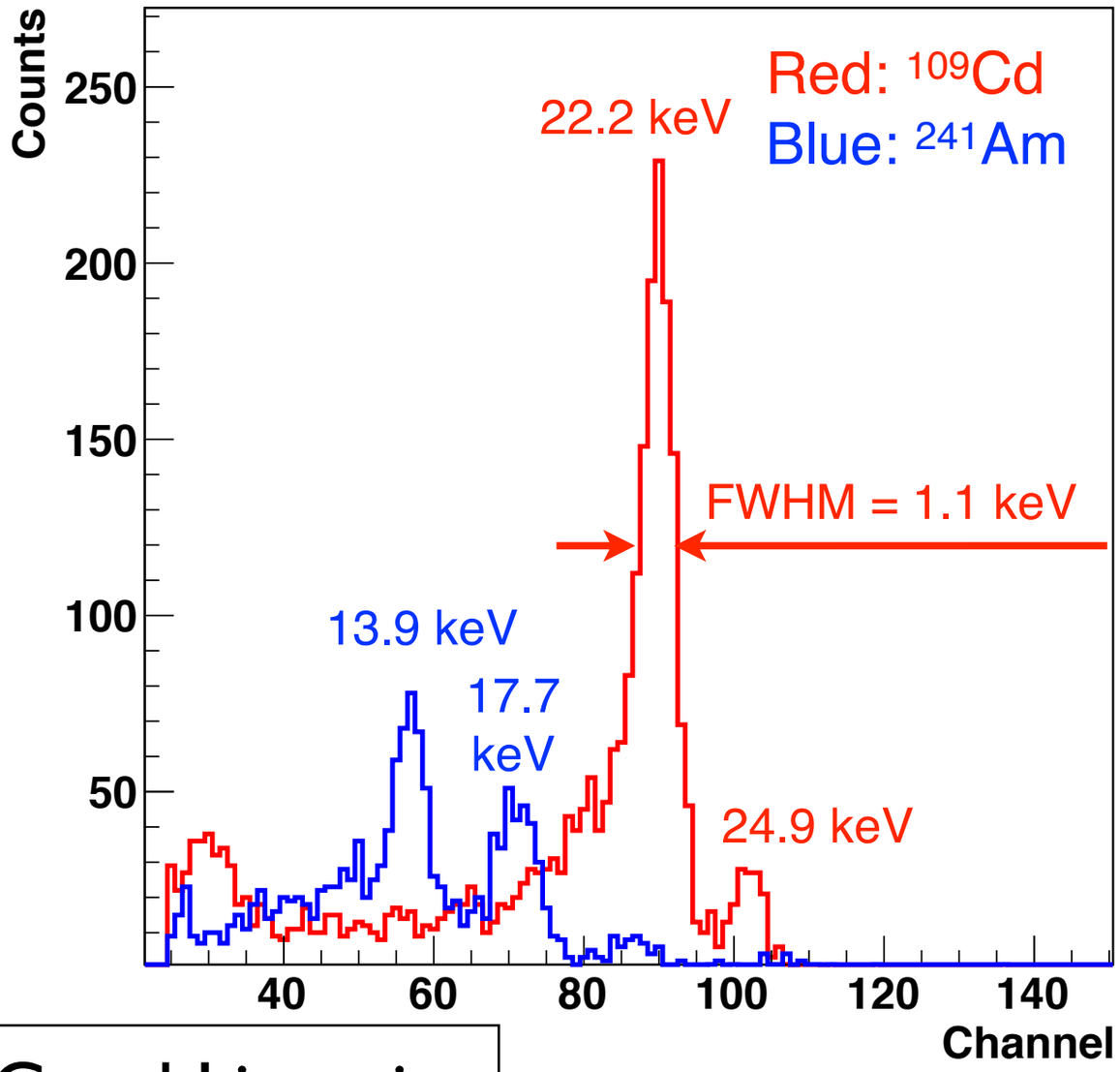
# XRPIX1-FZ (7kΩ): Depletion Depth

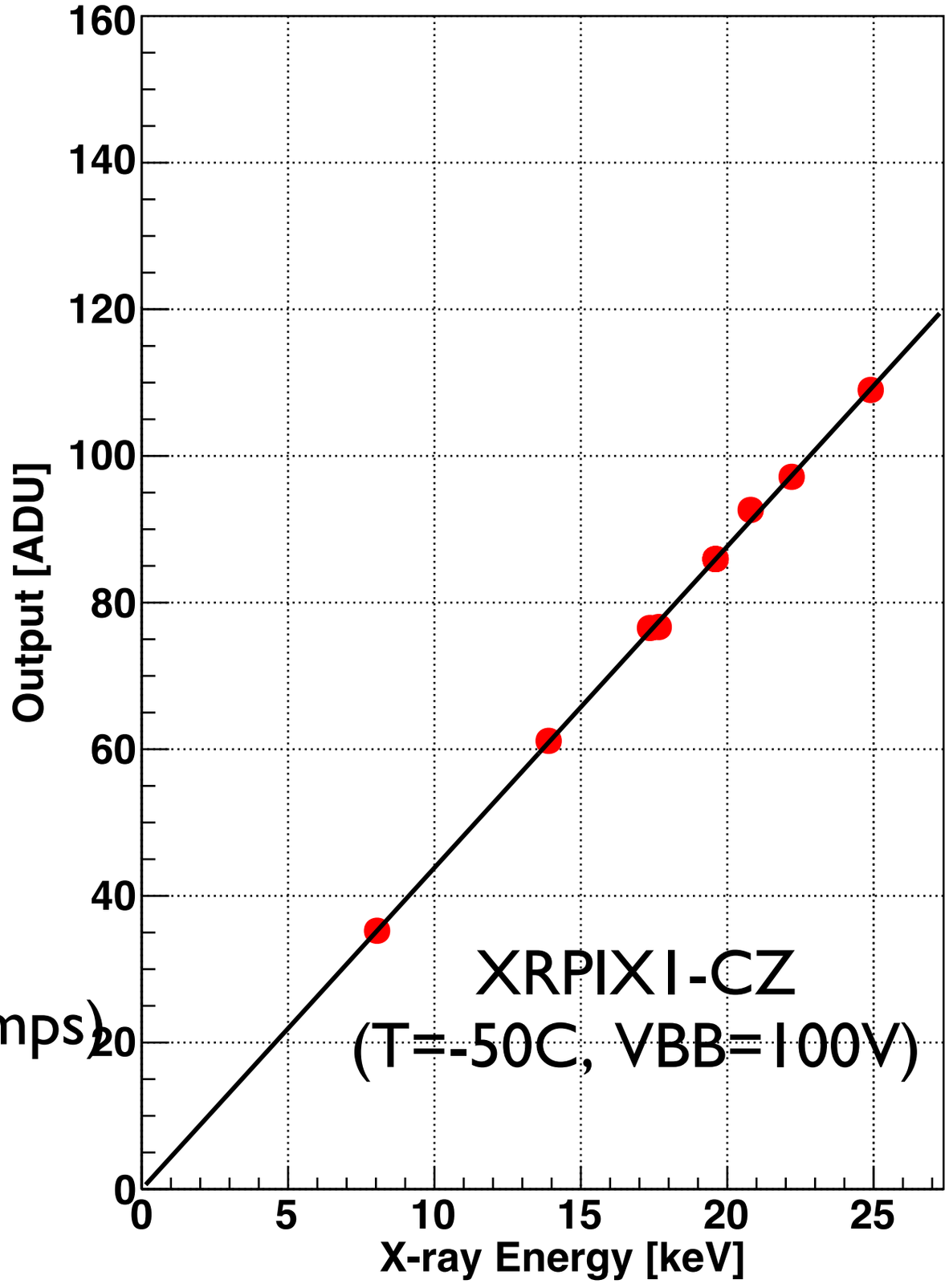



- The thickness of the depletion layer of XRPIX1-FZ reaches ~250μm at 30V and stops its growth there.
- The 250μm is nearly equal to the hi-ρ Si thickness (260μm).
- Full depletion is achieved at VBB=30V.

*Nakashima et al., 2011, submitted*

# XRPIX1-CZ : X-ray Spectra in frame mode




**Good Linearity**

Sensitivity = 4.0 μV/e- (including SF, amps)
Sensor C = 34 fF

**Energy Resolution**

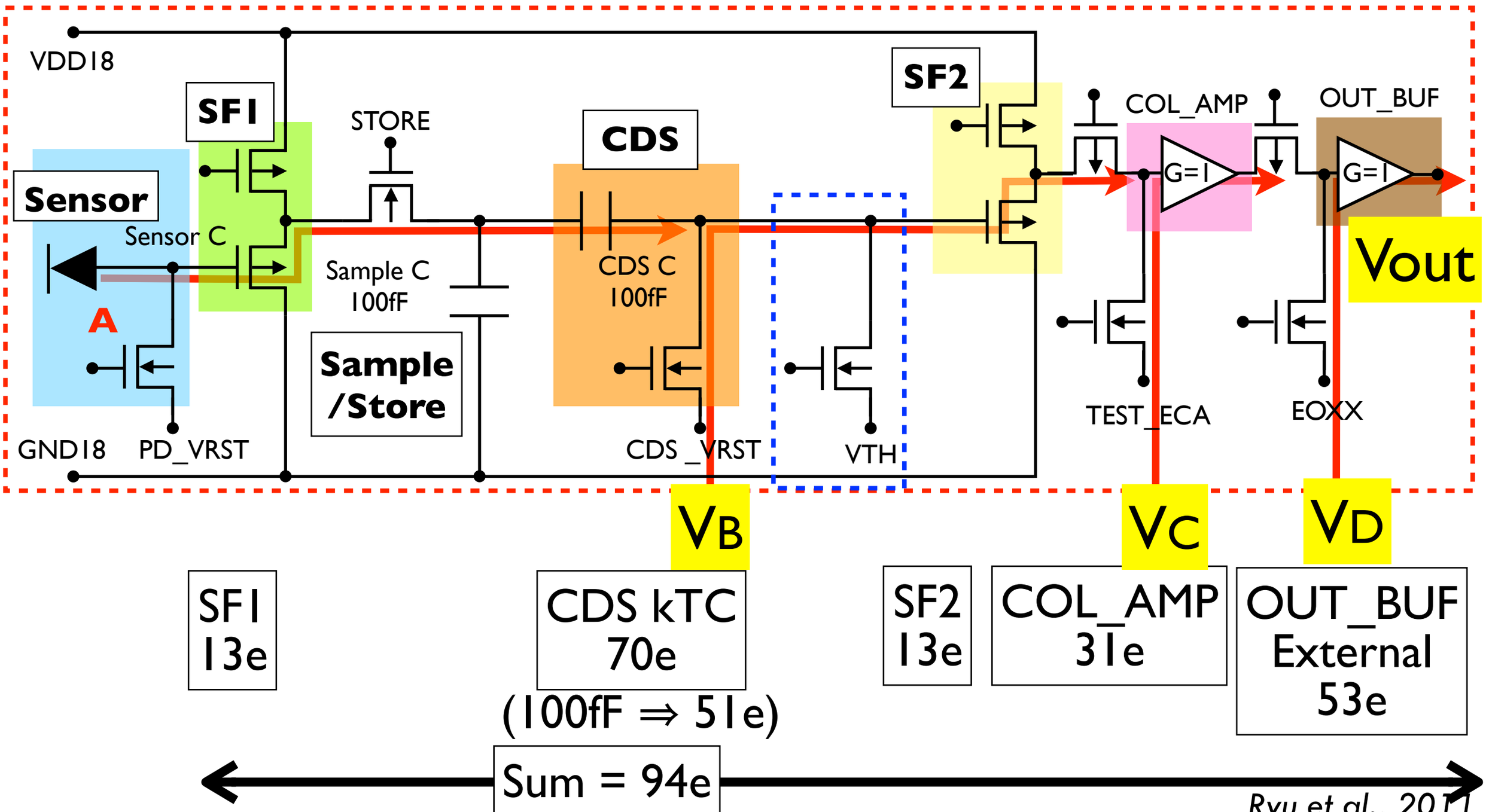
ΔE = 1.1-1.2keV (FWHM) » Fano limit
Readout Noise = 100e- (rms)

*Ryu et al., 2011*

# XRPIX1-CZ : Readout Noise

- See if the readout noise of 100e- (rms) is explained by the sum of circuit noises or not.
- Measure the noise of individual circuit element through several DC voltage input points.

The sum of these noise are almost consistent with the observed readout noise of 100e.

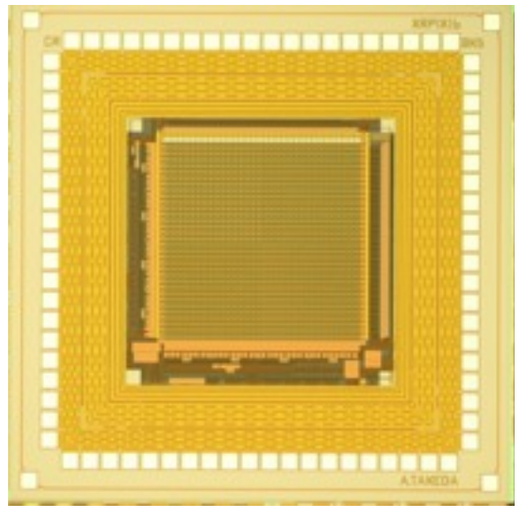



*Ryu et al., 2011*

# XRPIX1 → XRPIX1b

Purpose

Improvement of Spectroscopic performance



- Block 1
  - Increase C_CDS from 100fF to 400fF to reduce the reset noise generated at the CDS circuit.
- Block 2, 3
  - Reduce the area of BPW to 45% to obtain higher gain.
  - BPW (buried p-well) suppressing back gate effect dominates the capacitance at the sensor node.

**Show results from block 2 today**

| | |
|---|---|
| 1<br>44D_CDS<br>(400fF) | 2<br>44M_BPW<br>(45%) |
| 3<br>44D_BPW<br>(45%) | 4<br>44D_ORG<br>(BPW100%,<br>CDS=100fF) |

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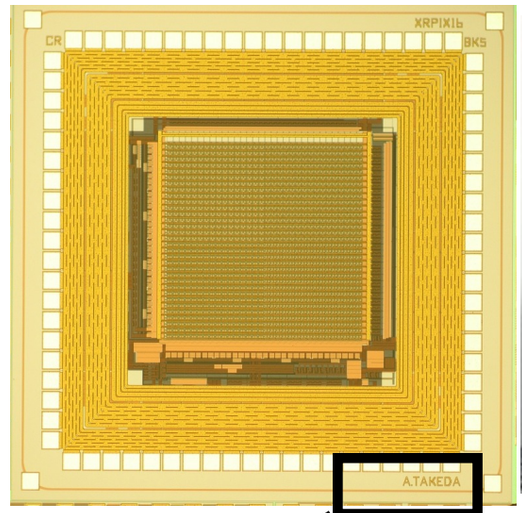


Designed by A.TAKEDA (KEK)

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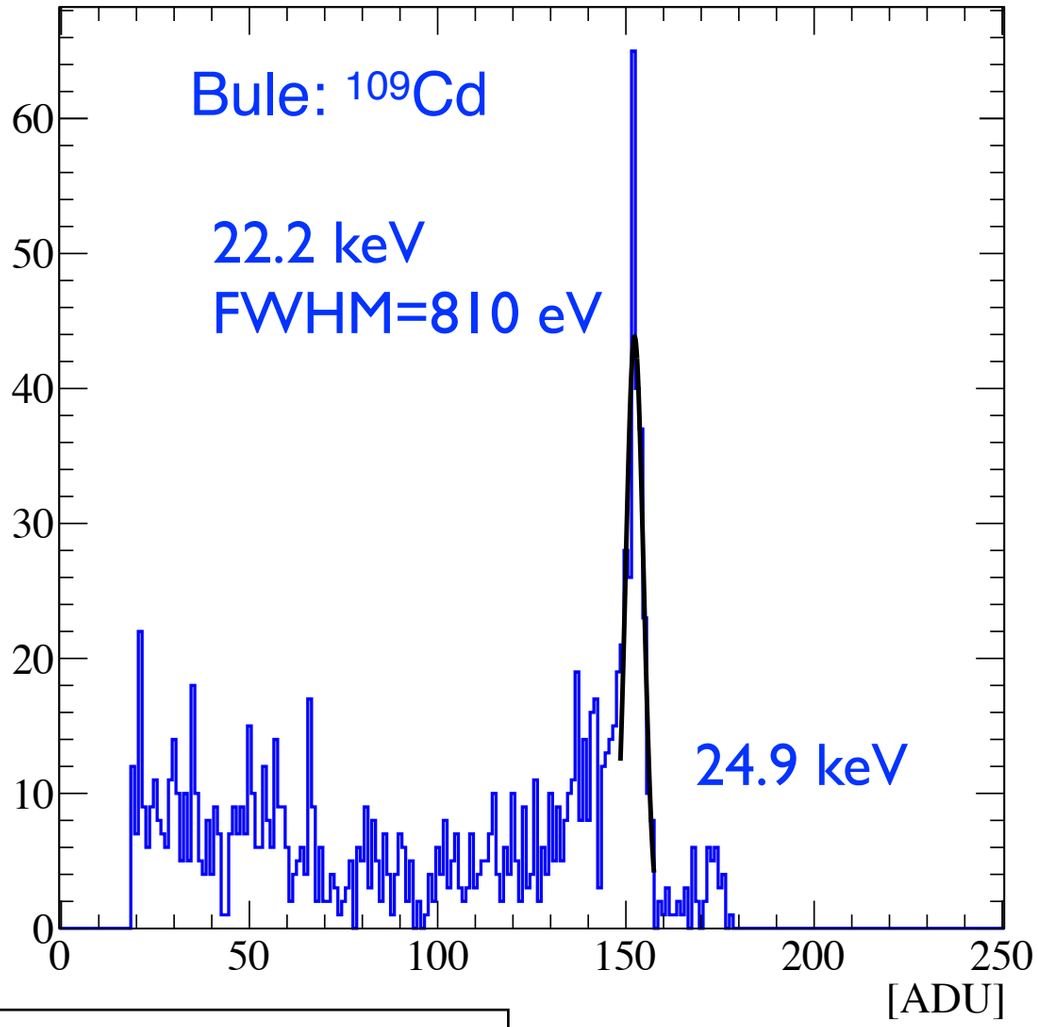
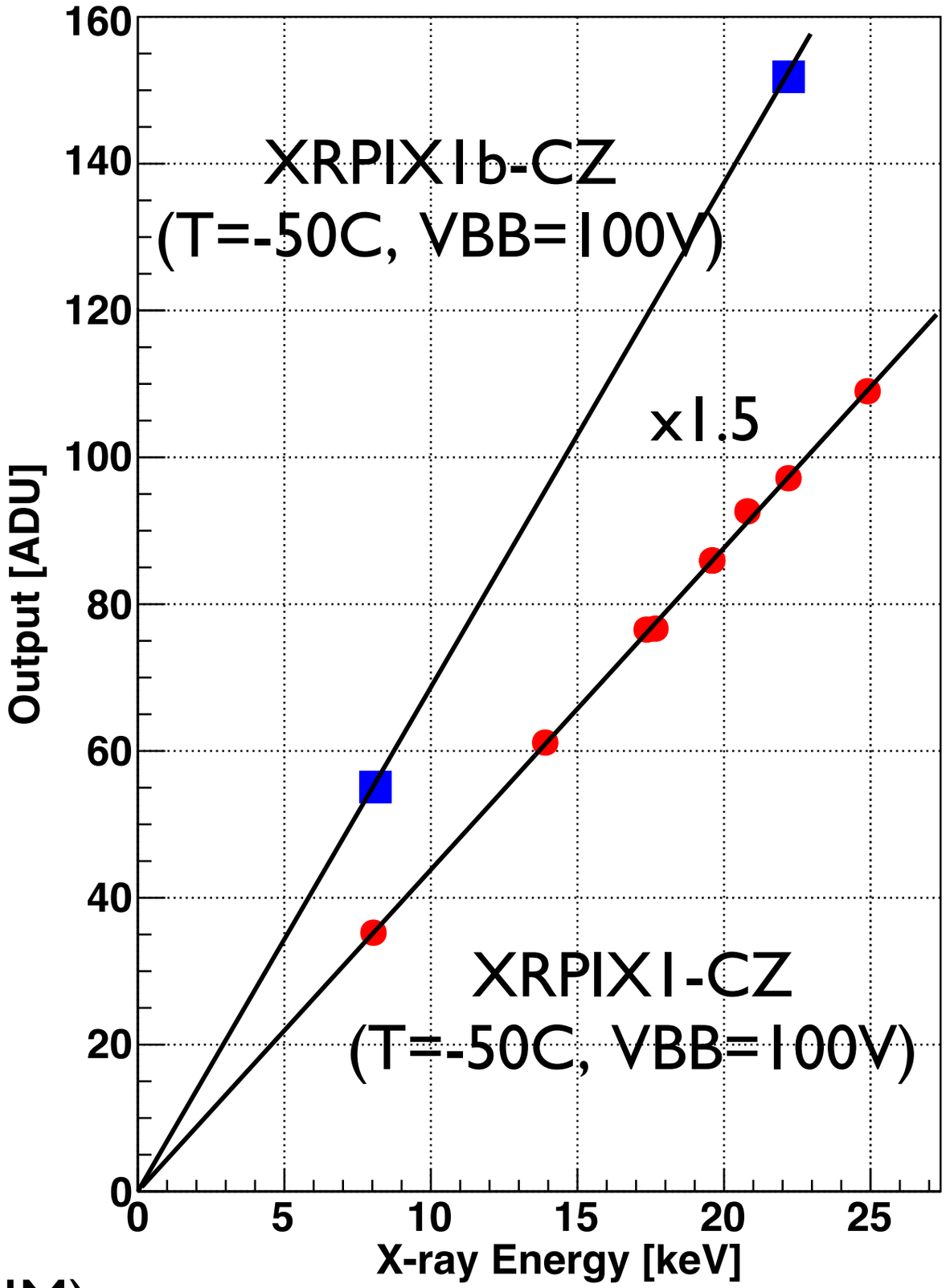
| 3<br>44D_BPW<br>(45%) | 4<br>44D_ORG<br>(BPW100%,<br>CDS=100fF) |

# XRPIX1-CZ→1b-CZ : X-ray Spectra in frame mode




Gain Increased

Sensitivity = 4.0 →6.1μV/e-

Sensor C = 34 → 23fF

Better Energy Resolution

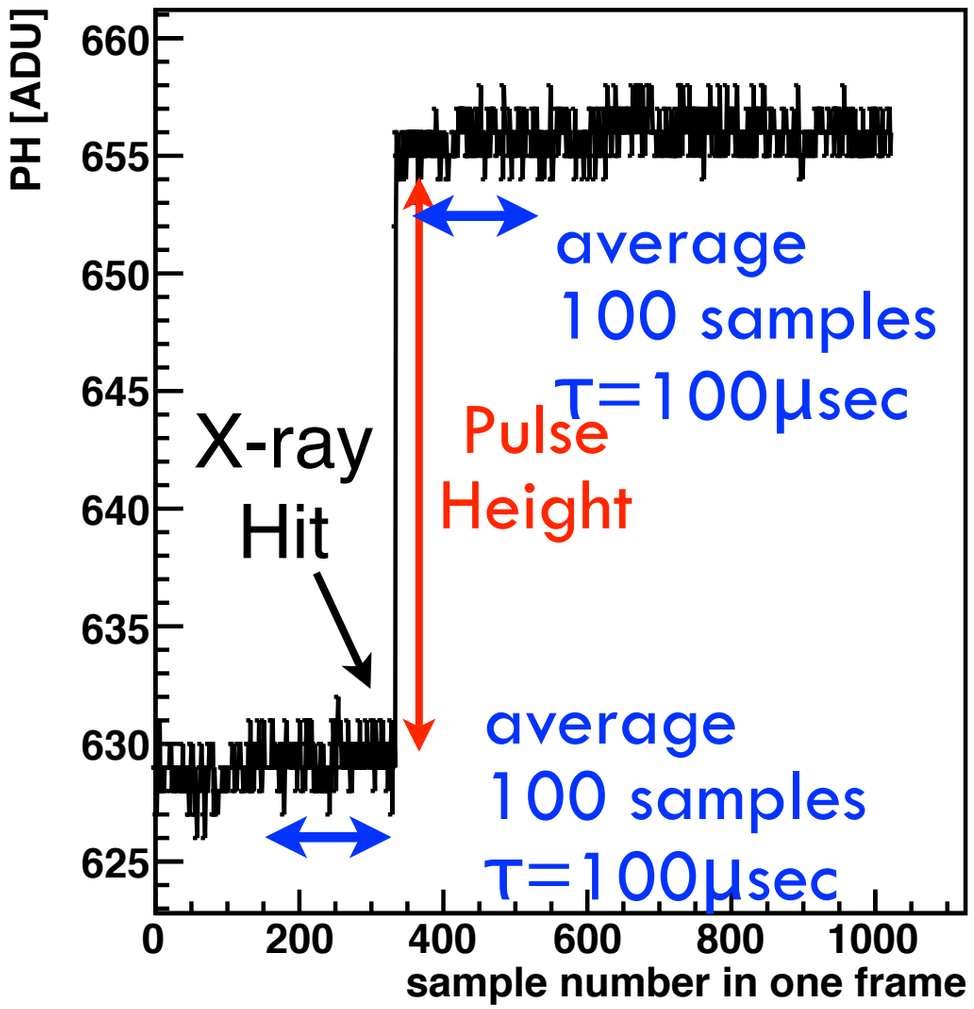
ΔE = 1.1-1.2keV → 0.8-1.1 keV(FWHM)

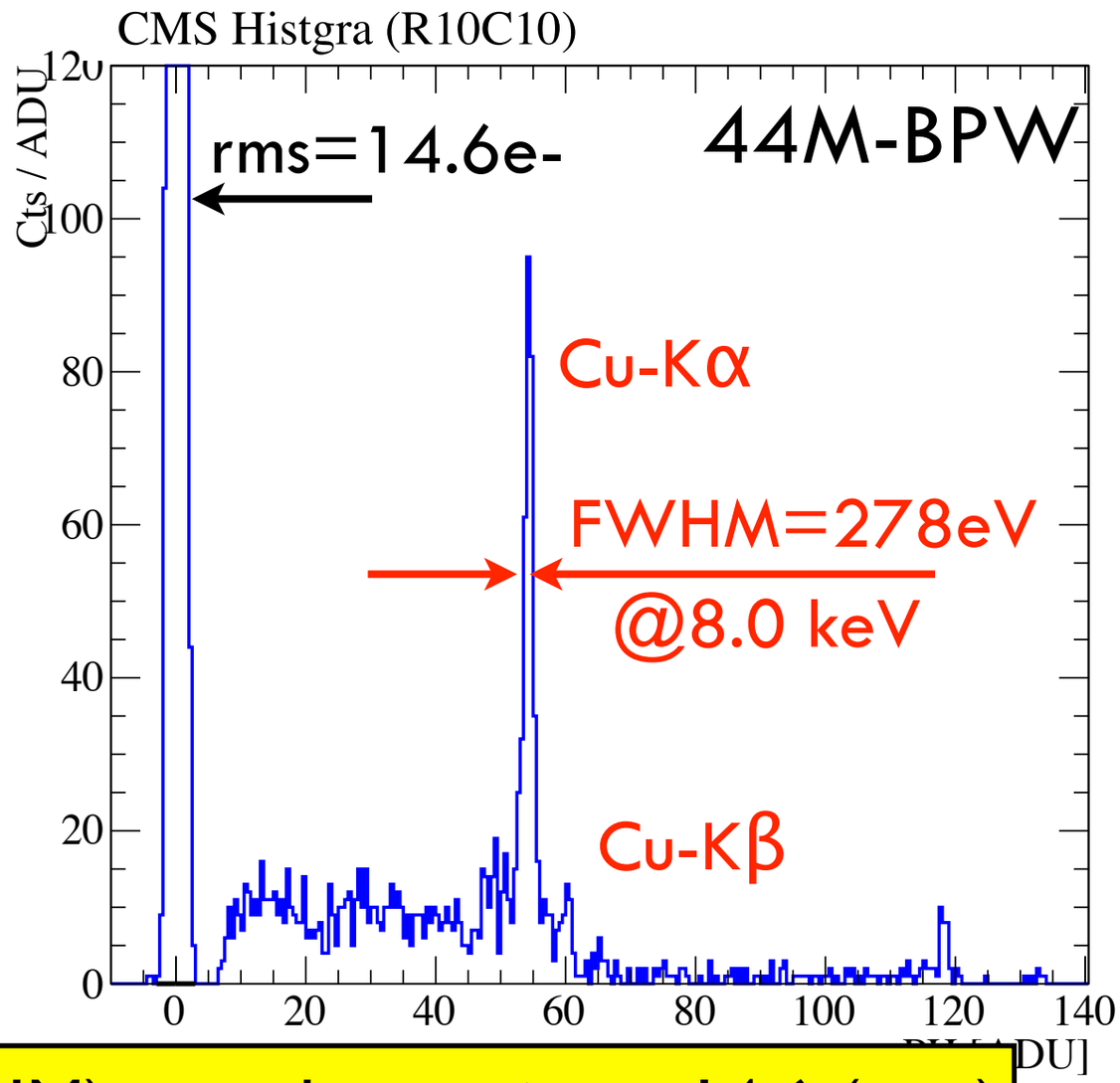
Readout Noise = 100e- → 74e- (rms)

Second dominating source of C of sensor node.

# XRPIX1b-CZ : Single Pixel Readout

- In order to study the limit of the spectroscopic performance.

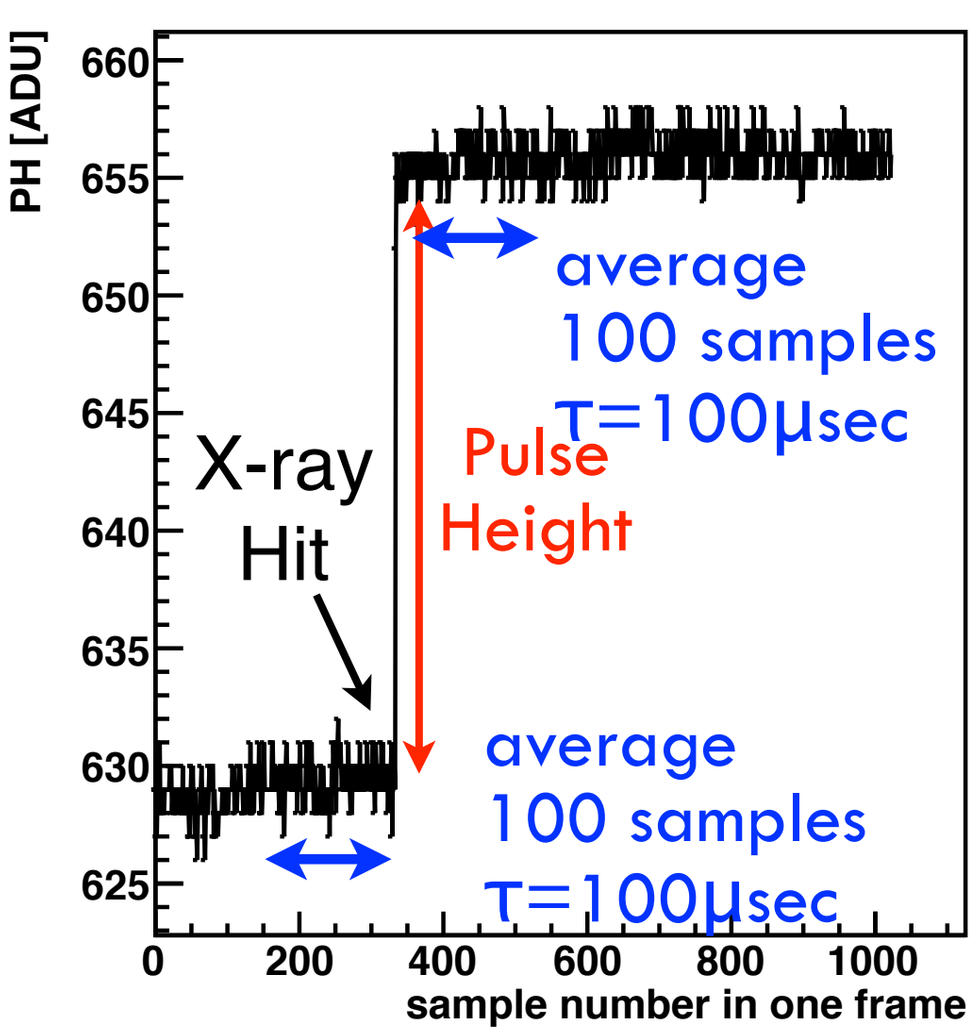


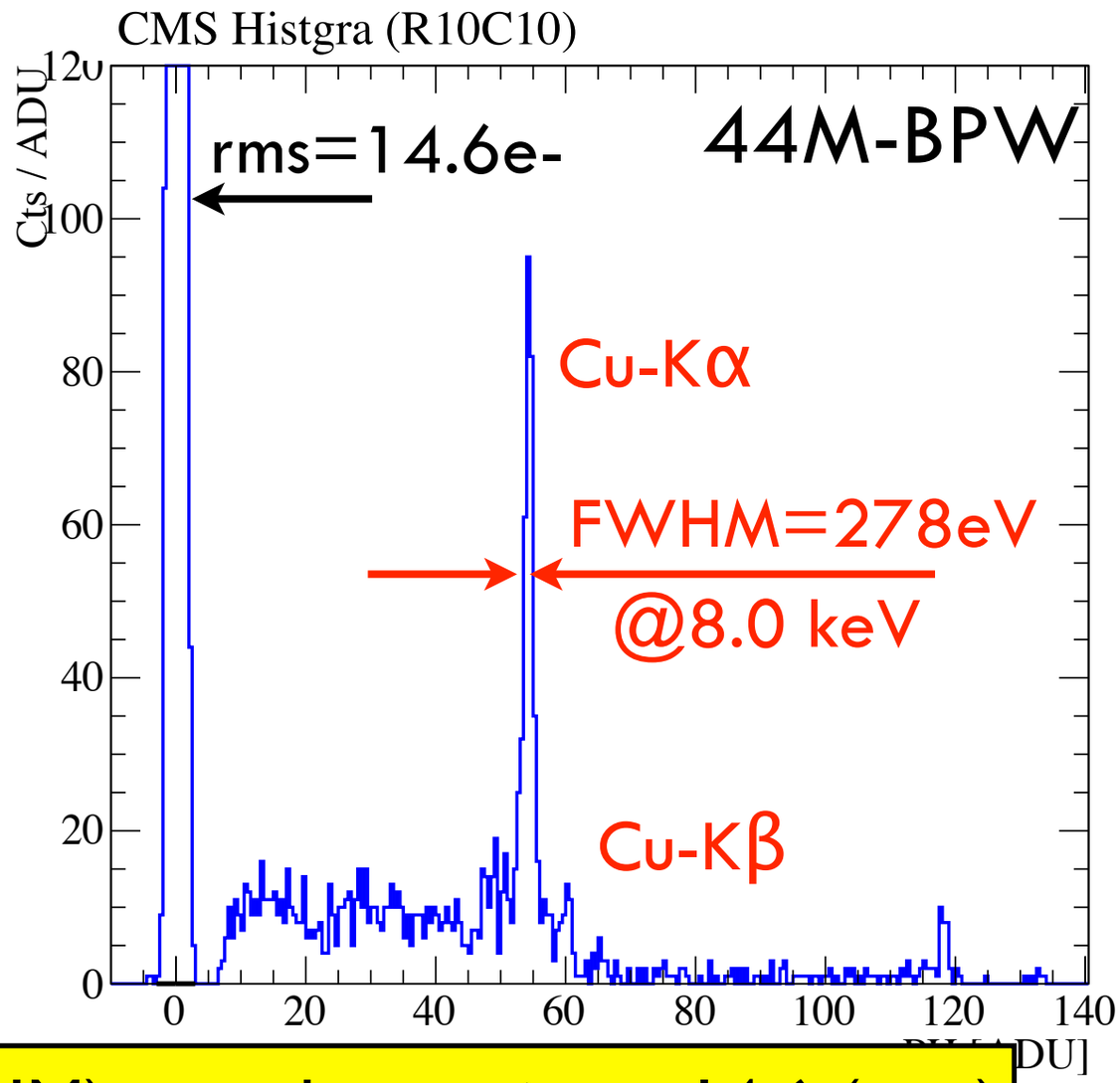




ΔE = 278eV @ 8.0keV (FWHM),  readout noise = 14.6 (rms)

# XRPIX1b-CZ : Single Pixel Readout

- In order to study the limit of the spectroscopic performance.
- Observe the waveform of analogue output from a single pixel by fixing the readout address without clocking (Single Pixel Readout like a SSD).

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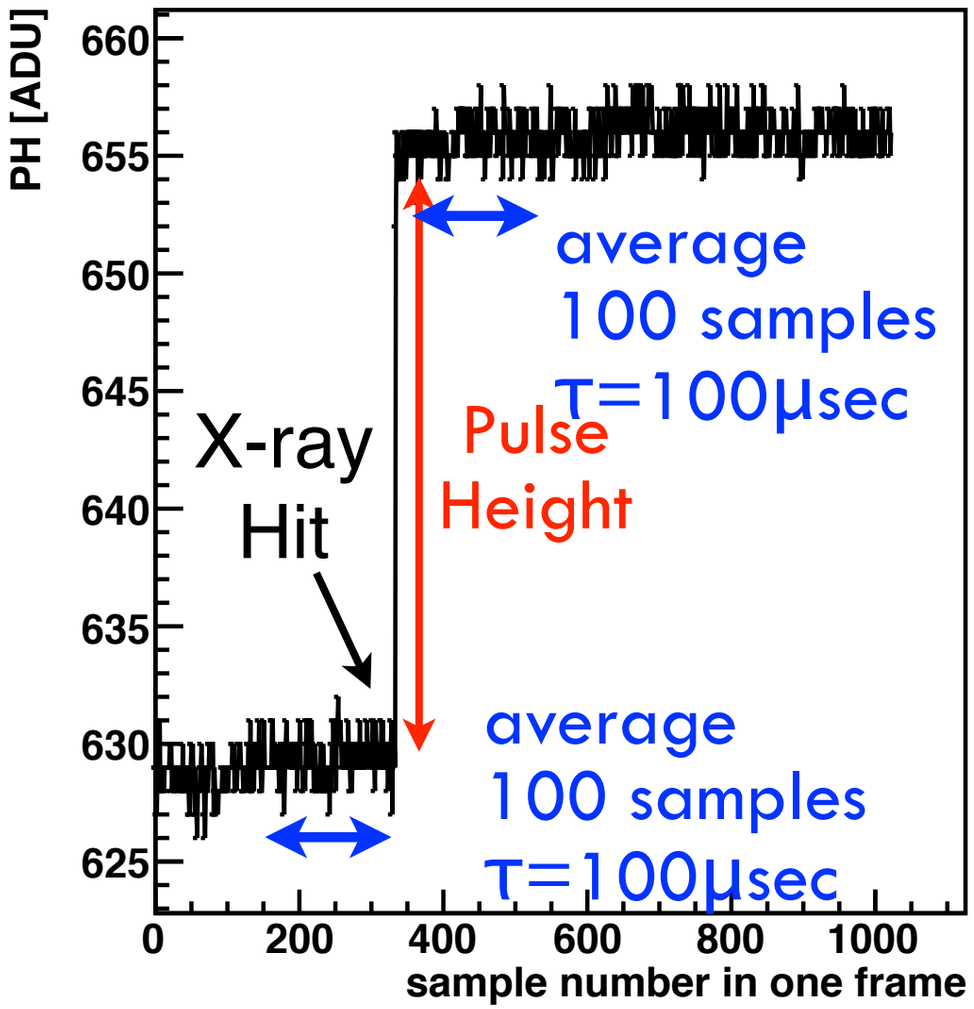
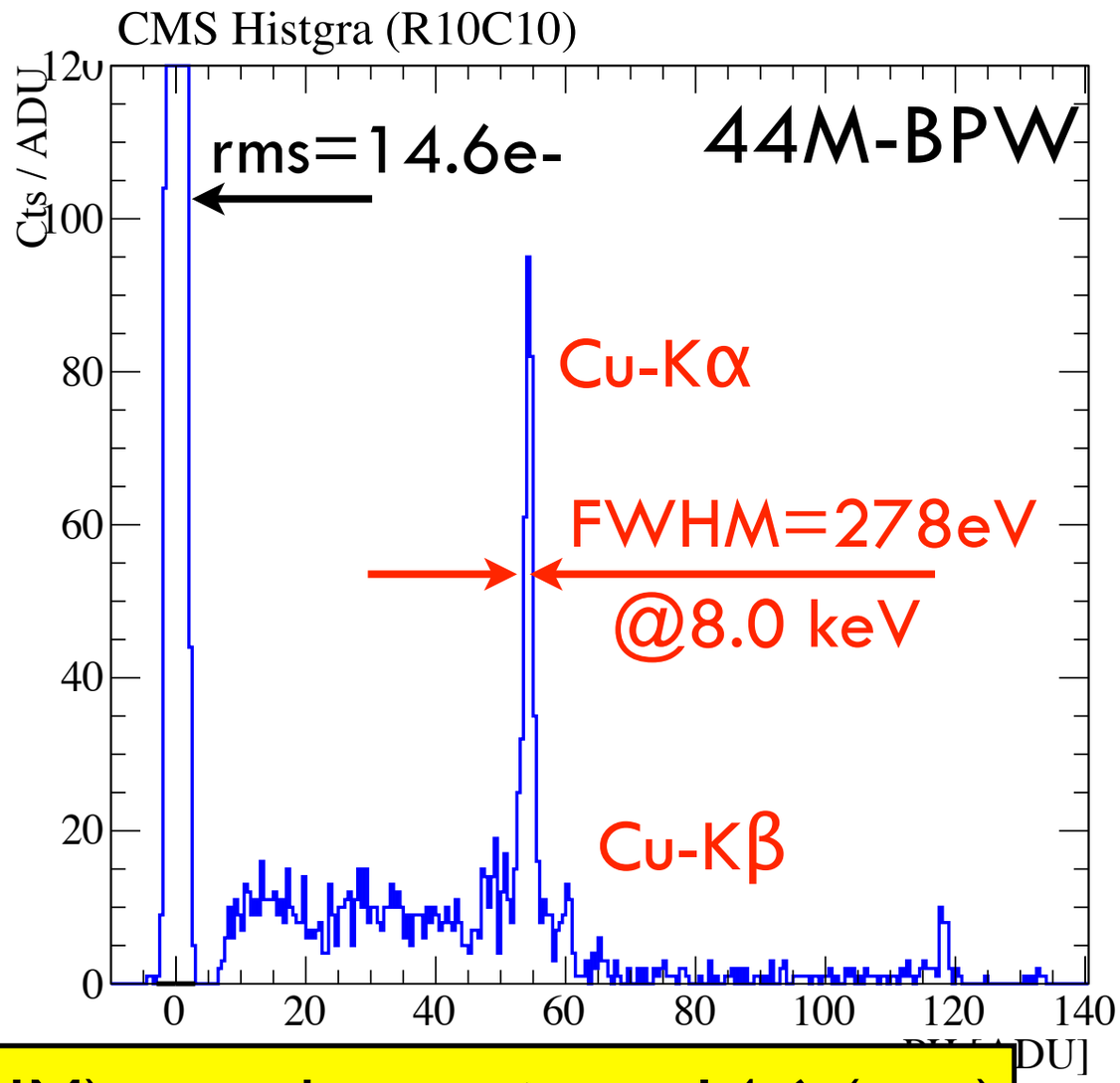
- In order to study the limit of the spectroscopic performance.
- Observe the waveform of analogue output from a single pixel by fixing the readout address without clocking (Single Pixel Readout like a SSD).
- Detect an X-ray as a "step" and measure the pulse height. → X-ray spectrum.

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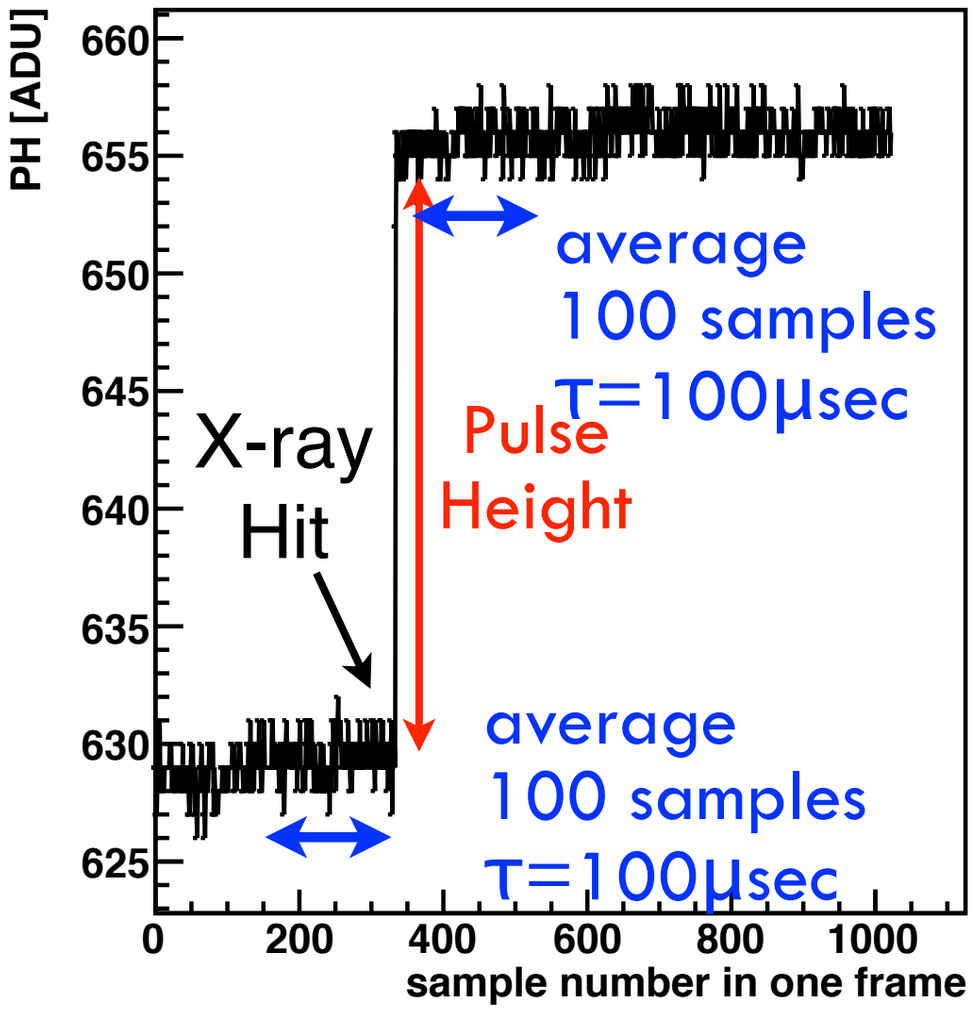
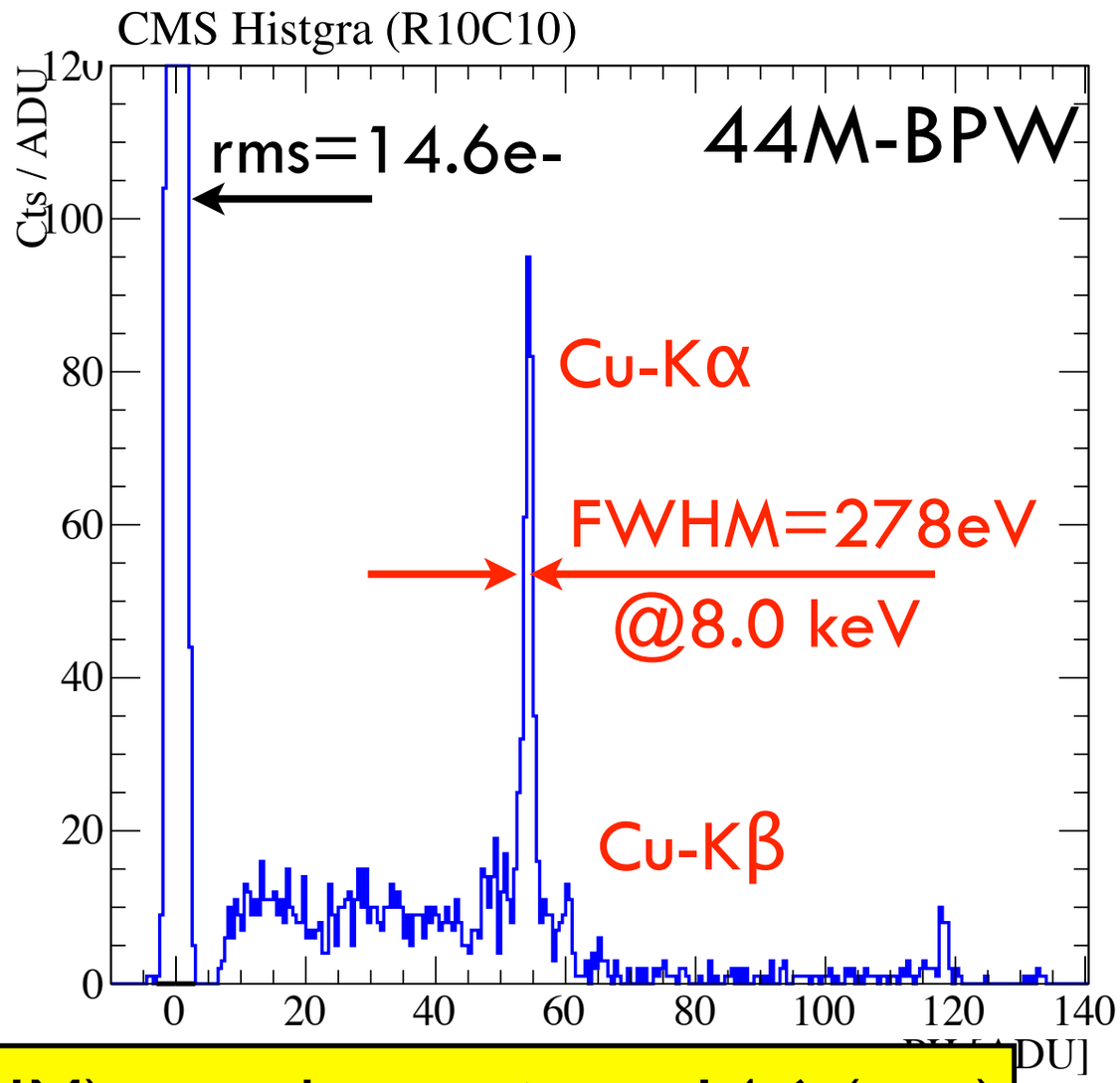
- No reset during the measurement → Free from the reset noise

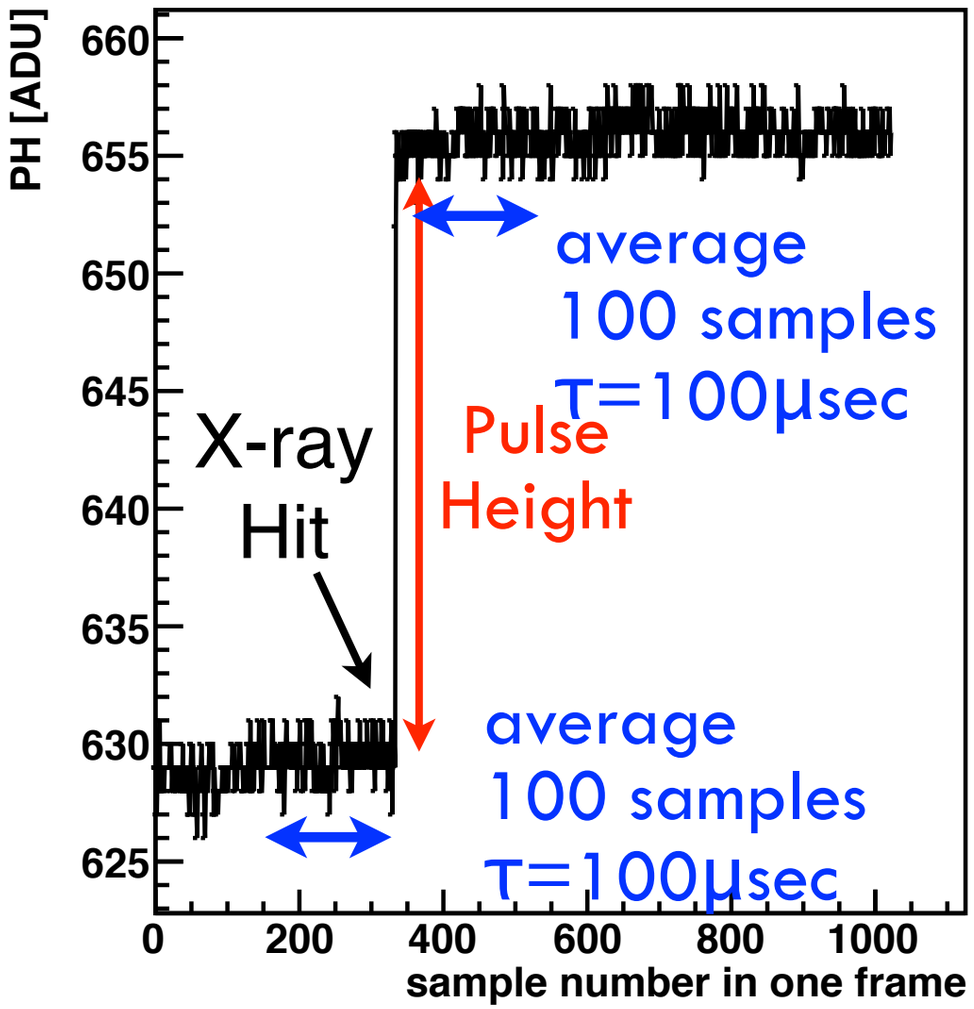


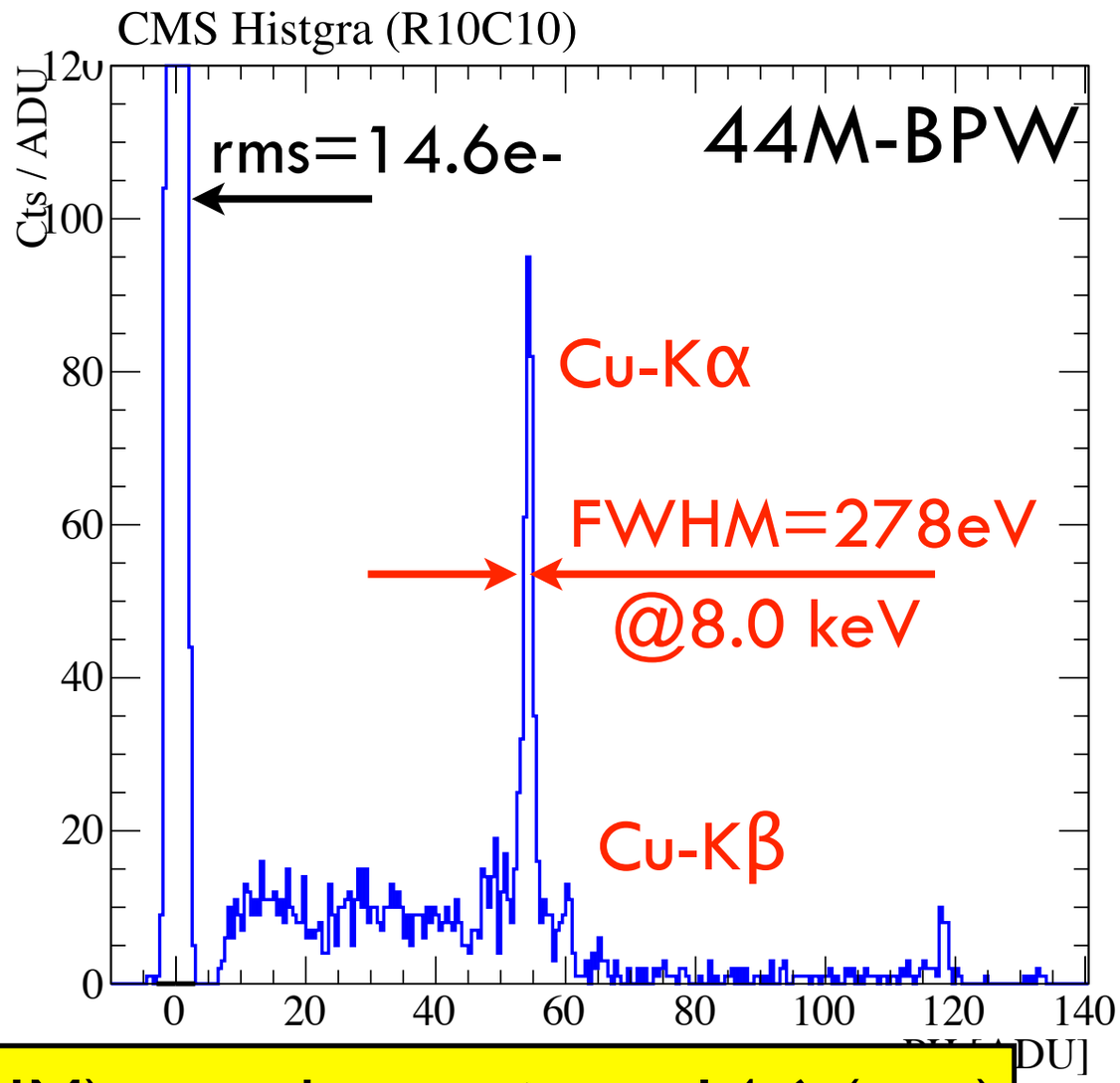




ΔE = 278eV @ 8.0keV (FWHM), readout noise = 14.6 (rms)

# XRPIX1b-CZ : Single Pixel Readout

- In order to study the limit of the spectroscopic performance.
- Observe the waveform of analogue output from a single pixel by fixing the readout address without clocking (Single Pixel Readout like a SSD).
- Detect an X-ray as a "step" and measure the pulse height. → X-ray spectrum.
- No reset during the measurement → Free from the reset noise
- Reduce noises other than the reset noise by introducing LPF.
  high_v(100 samples average) - low_v(100 samples average) → LPF with τ=100μs



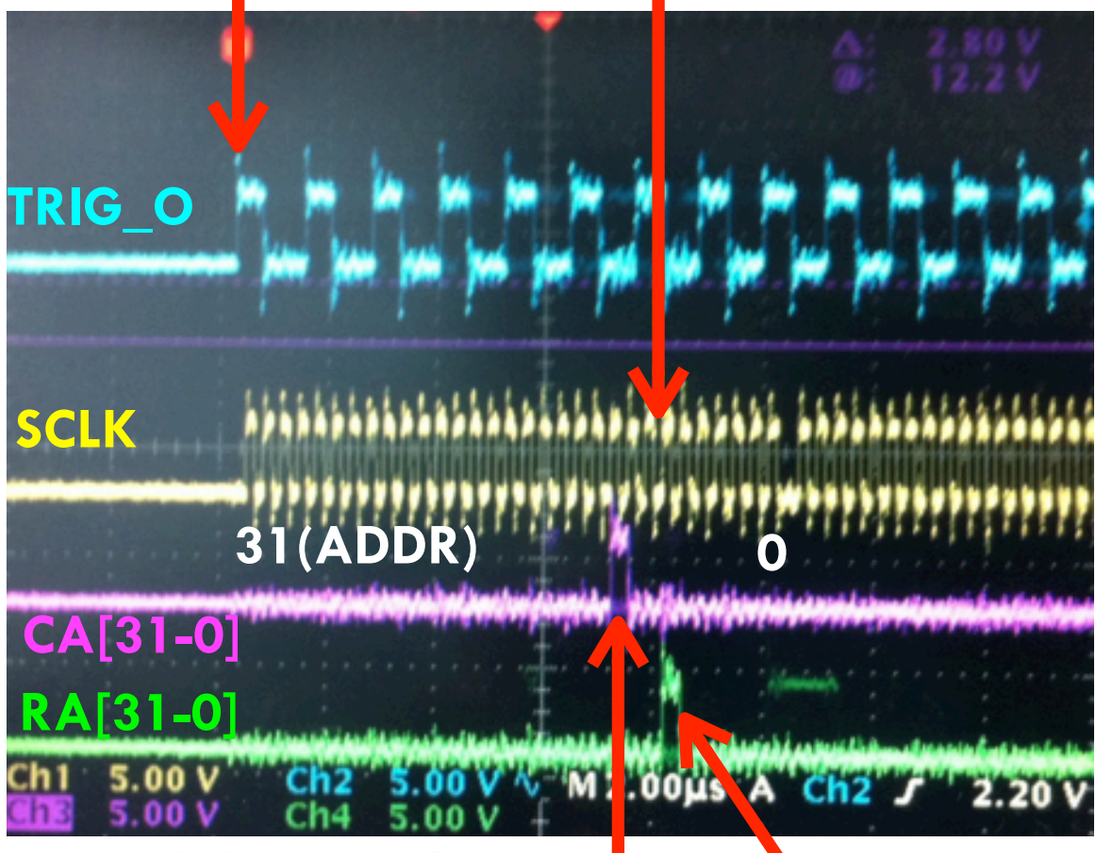

ΔE = 278eV @ 8.0keV (FWHM),  readout noise = 14.6 (rms)

# XRPIX1b-CZ : Trigger Driven Readout

See Ryu's poster (NP3.M-90) in detail

Trigger !

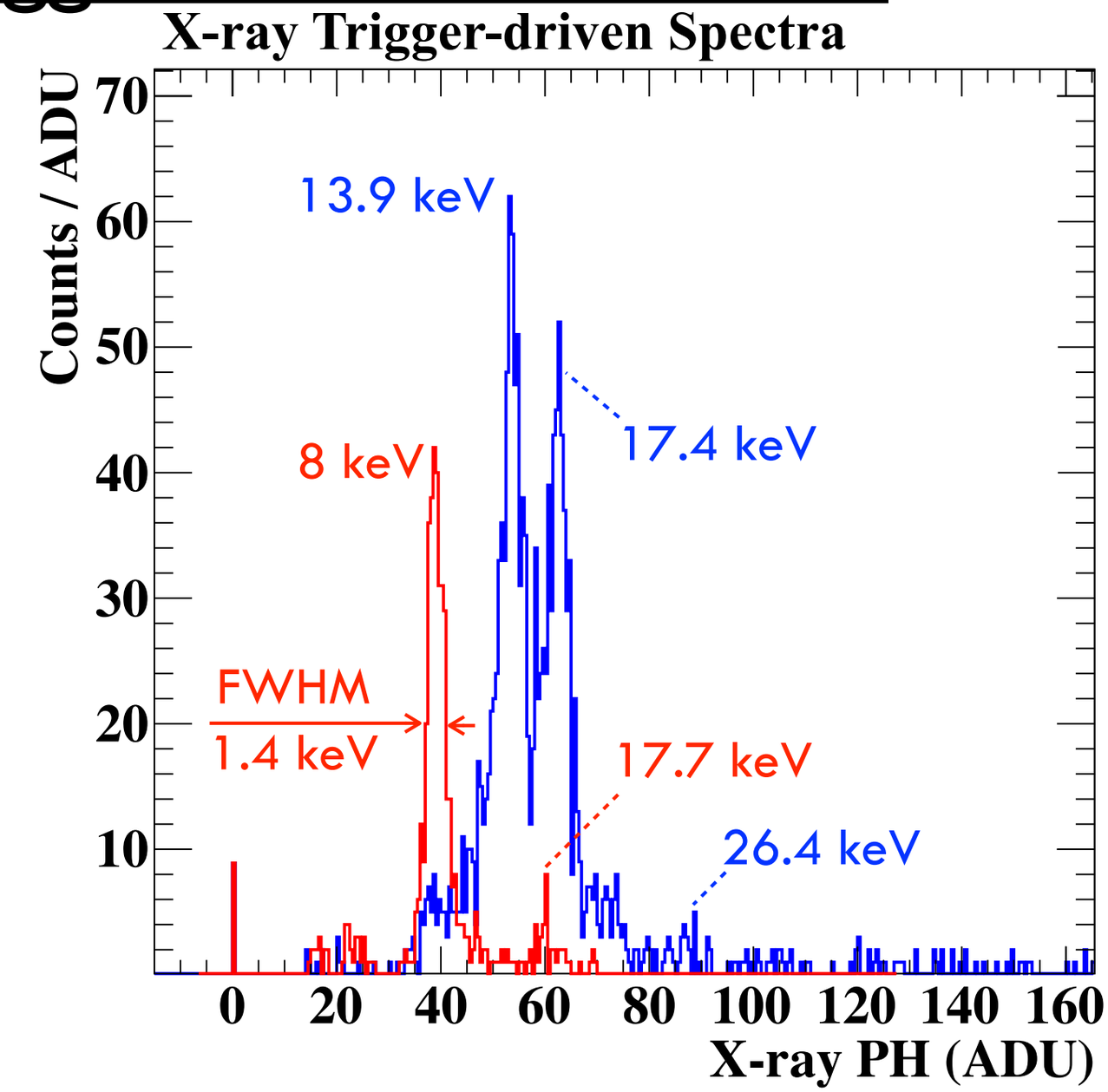
Trigger Address Readout Clock




Address of Triggered Pixel

Row

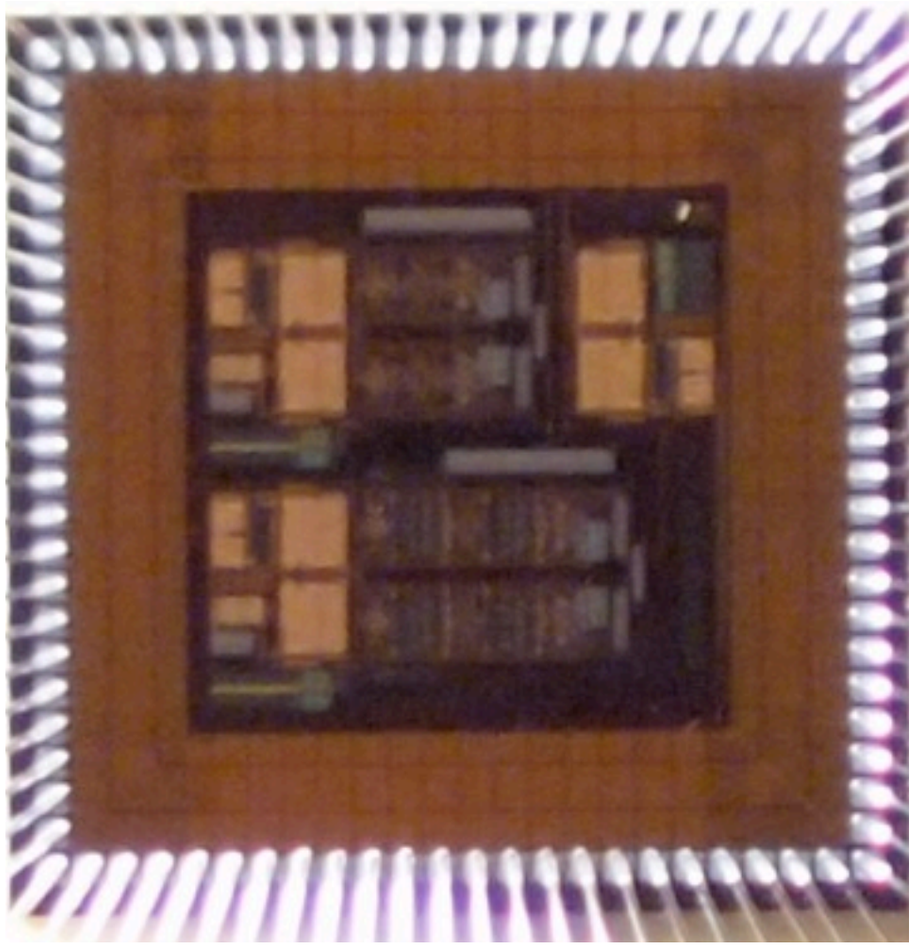
Column




Trigger-driven mode basically operates as designed.

- When X-ray is detected, the device outputs trigger signal.
- Address of the triggered pixel is output according to clock from FPGA.
- ADC reads out the analog signal of only the triggered pixel.

# XRPIX-ADC1



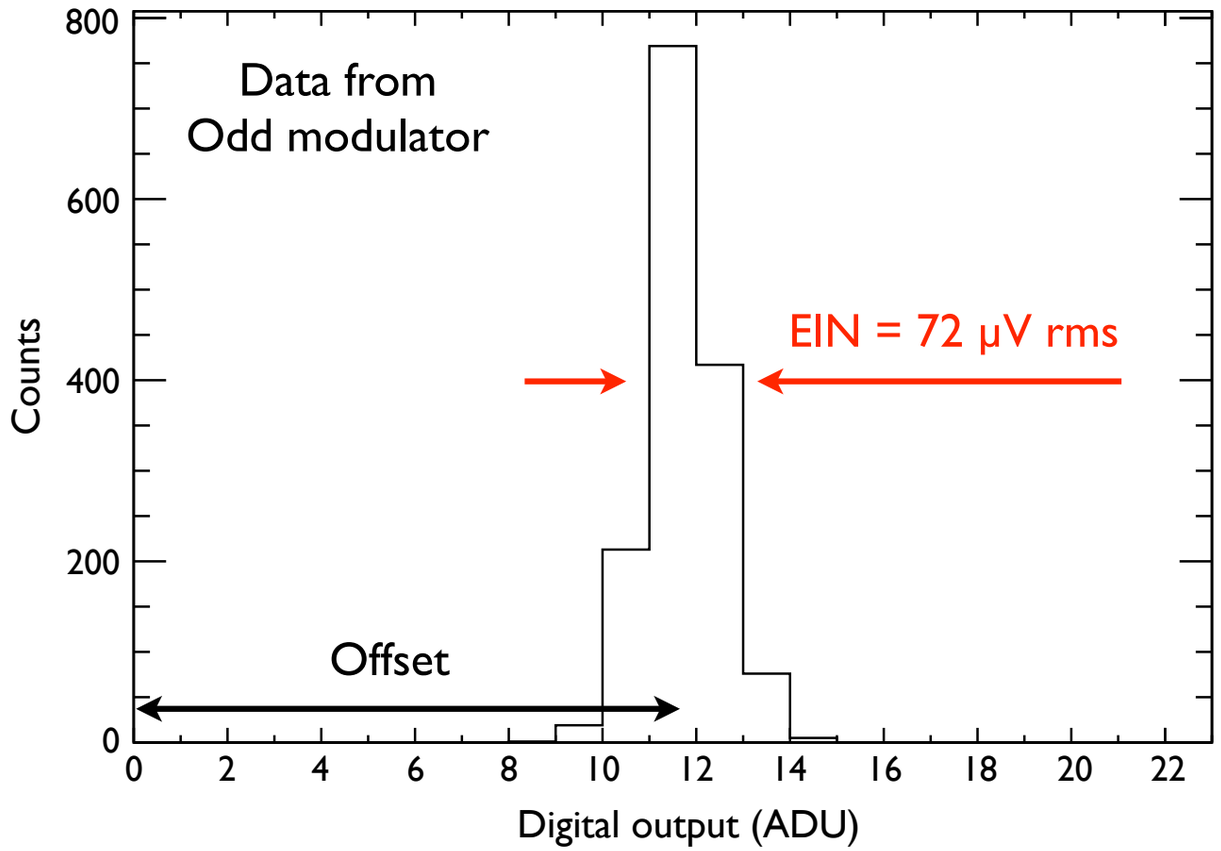



**Fig. 6.** Histogram of digital output in the case of GND input.

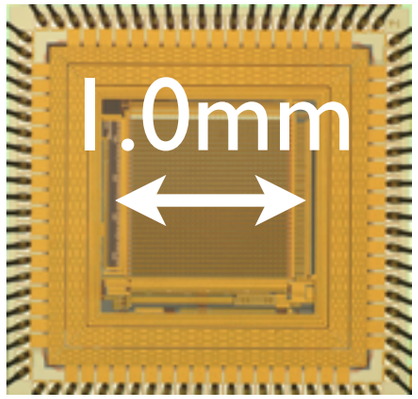
- ΔΣ type (over sampling type)
- SOI version of the ASIC developed for X-ray CCD camera onboard ASTRO-H (next Japanese X-ray satellite).

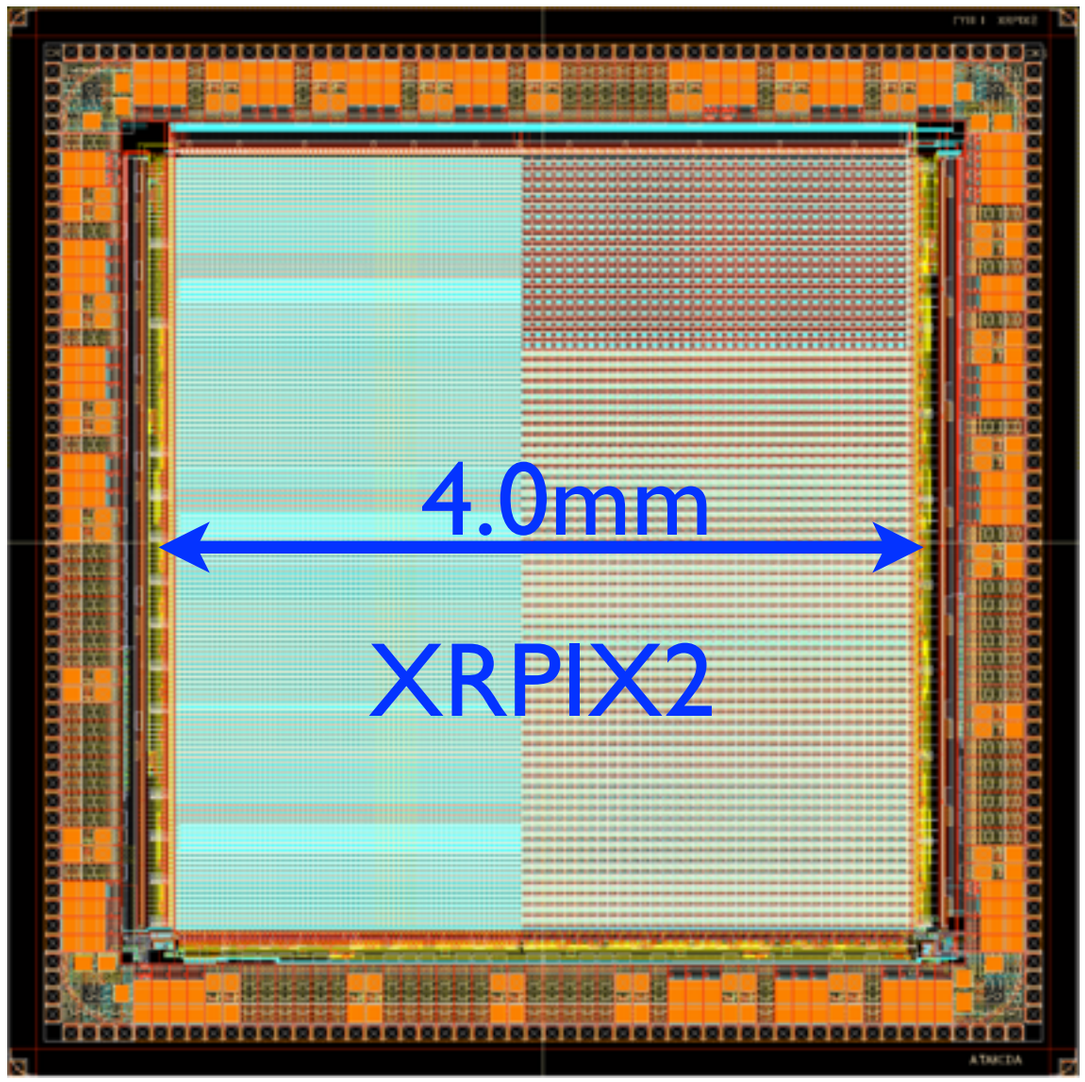
- It is working.
- Making performance test now.

See Nakashima's poster (NP3.M-92) in detail.

# XRPIX2 : New Device

XRPIX1, 1b




- Large Size, Large Format
- 60μm□ : Single pixel can cover the whole charge cloud to reduce charge sharing effect.
- Make the capacitance at the readout node smaller (Area of BPW = 1/4 of XRPIX1).
- Make further increase of C_CDS to reduce the reset noise.
- Just submitted last week.

Designed by A.TAKEDA (KEK)

# Thank you.


**A-R-Tec**
**Analog and RF Technologies**