

# Development of Multi-Via (MVia) pixel with signal-charge division to realize high effective $10^5$ dynamic range for X-ray Free-Electron Laser applications

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# Outline

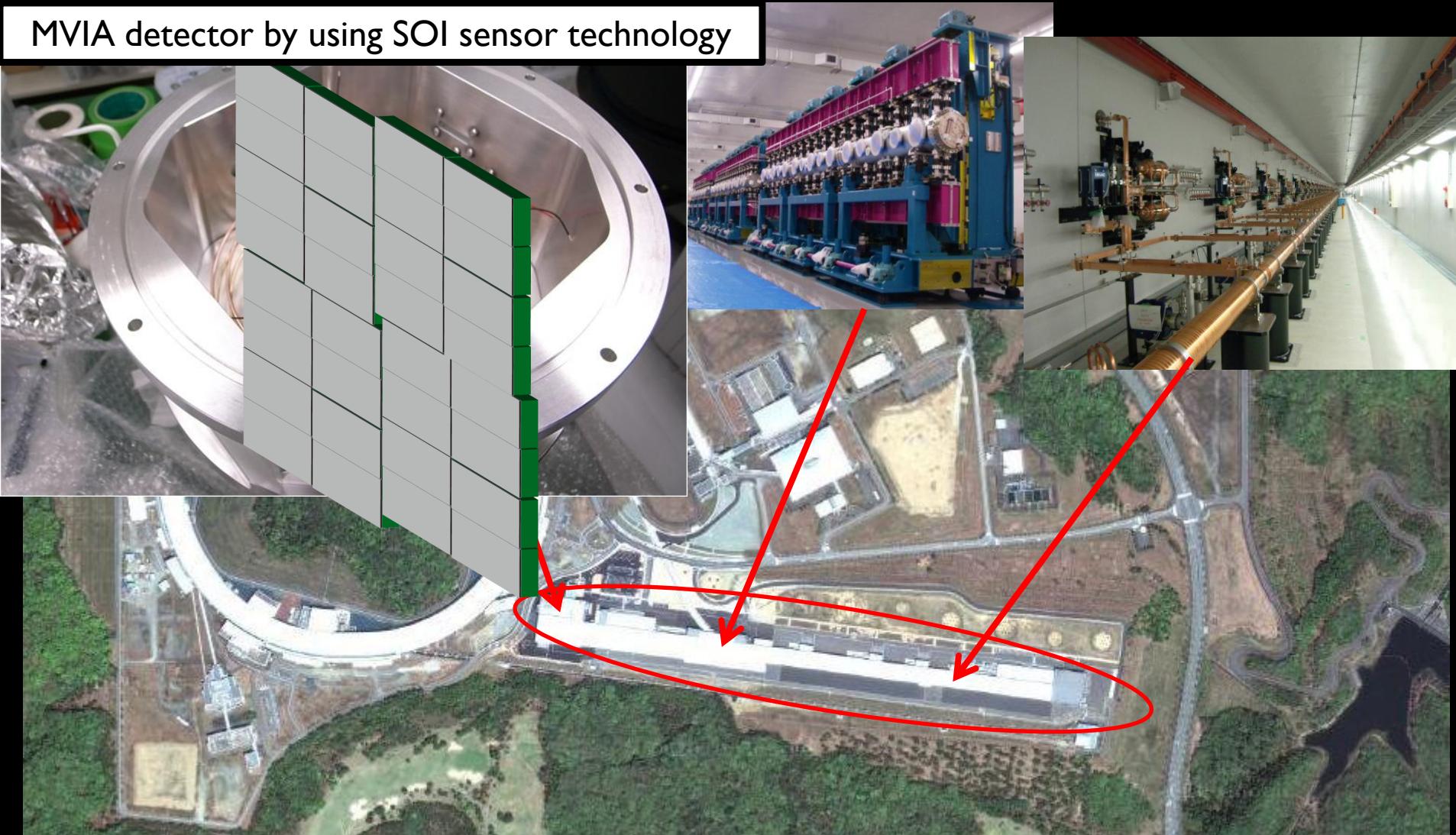
- X-ray Free Electron Laser Project at SPring-8
  - Detector Requirements
- Multi-via Pixel Concept
- Experimental Results
  - Gain
  - Depletion depth
  - Radiation hardness
- System Development

# SPring-8 in Japan

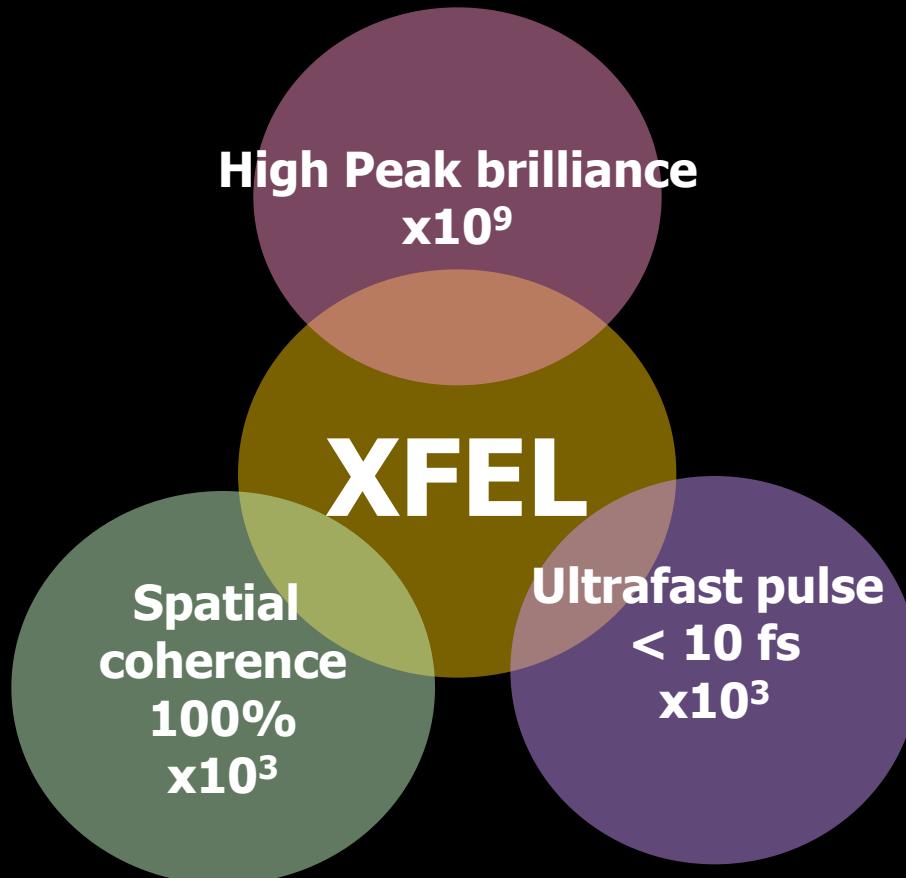


# SPring-8 XFEL (2011-)

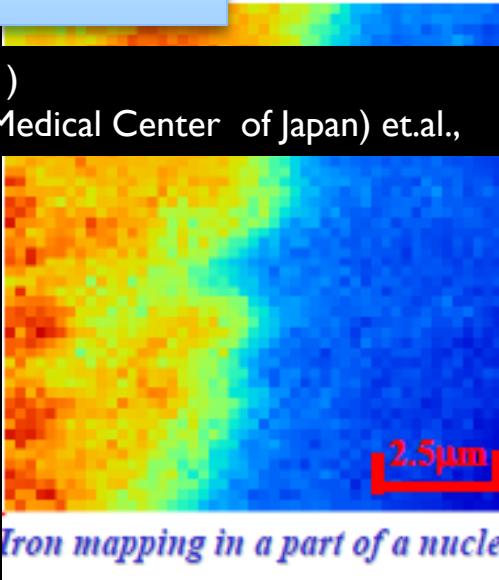
MVIA detector by using SOI sensor technology



# SPring-8 X-ray Free-Electron Laser



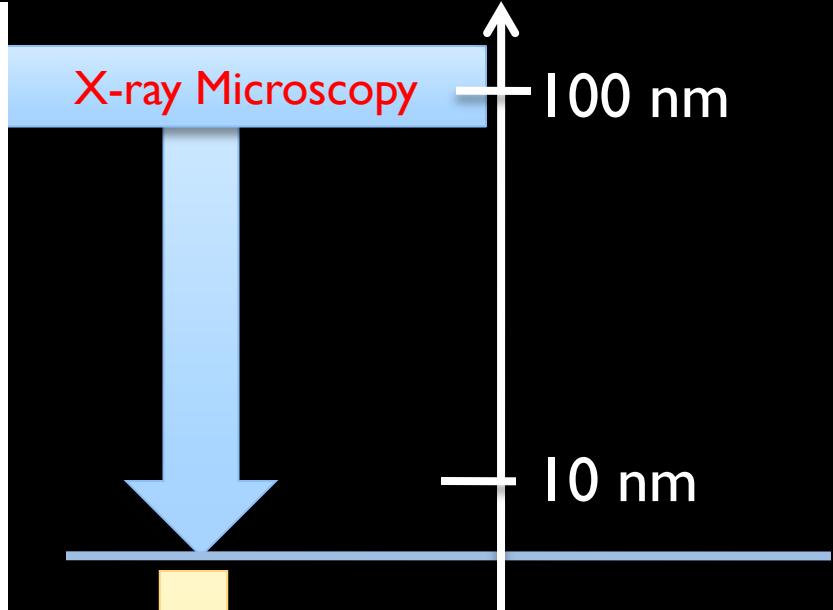
# Elemental Mapping of Cell



Yamauchi Lab.,(Osaka Univ.)

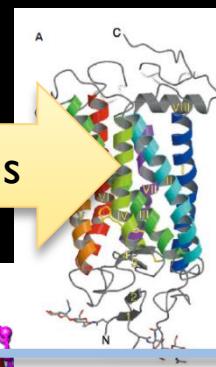
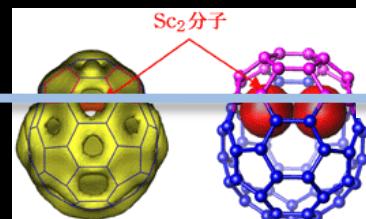
Dr. Shimura (International Medical Center of Japan) et.al.,

## X-ray Microscopy



## X-ray Diffraction

Ultrafast motion of atoms



Miyano et.al., Science Vol. 289 (2000) 739.

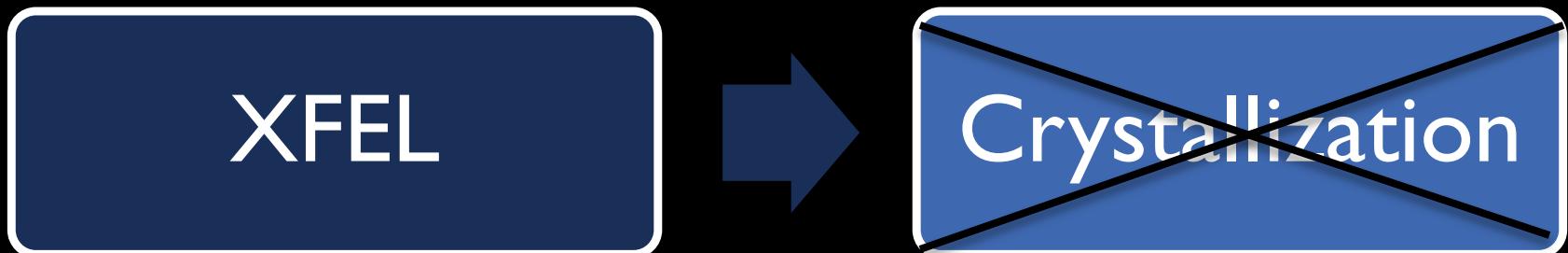
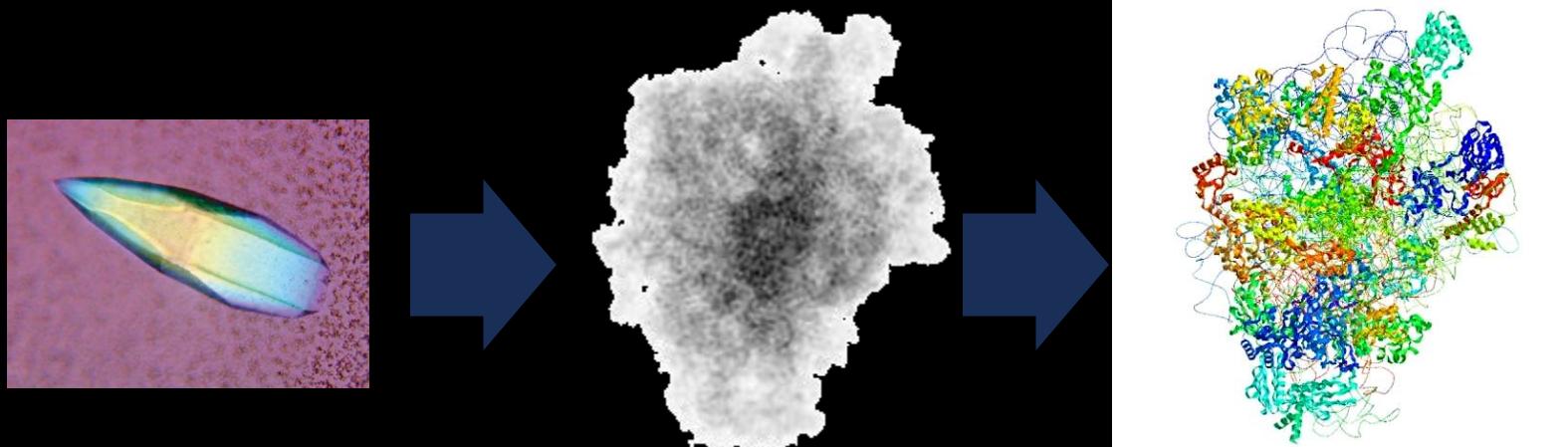
0.1 nm

1 nm

10 nm

100 nm

# Look at atomic structure in microscopy way Coherent X-ray Imaging by XFEL



# Spring-8 XFEL X-ray 2D detector Requirements

## X-ray Source Characteristics

- 60 Hz
- Variation in each shot
  - Pulse intensity, Sample variation, etc.

## Requirements

- Frame rate > 60 Hz
- Single Photon Detection Capability
  - *What would be the definition?*
- Device life > 1 year

## Optimization Parameters

- Quantum Efficiency (Q.E.)
- Full Well (FW) Capacity
- Pixel Size

# Motivation

*What is limiting the Full Well Capacity?*

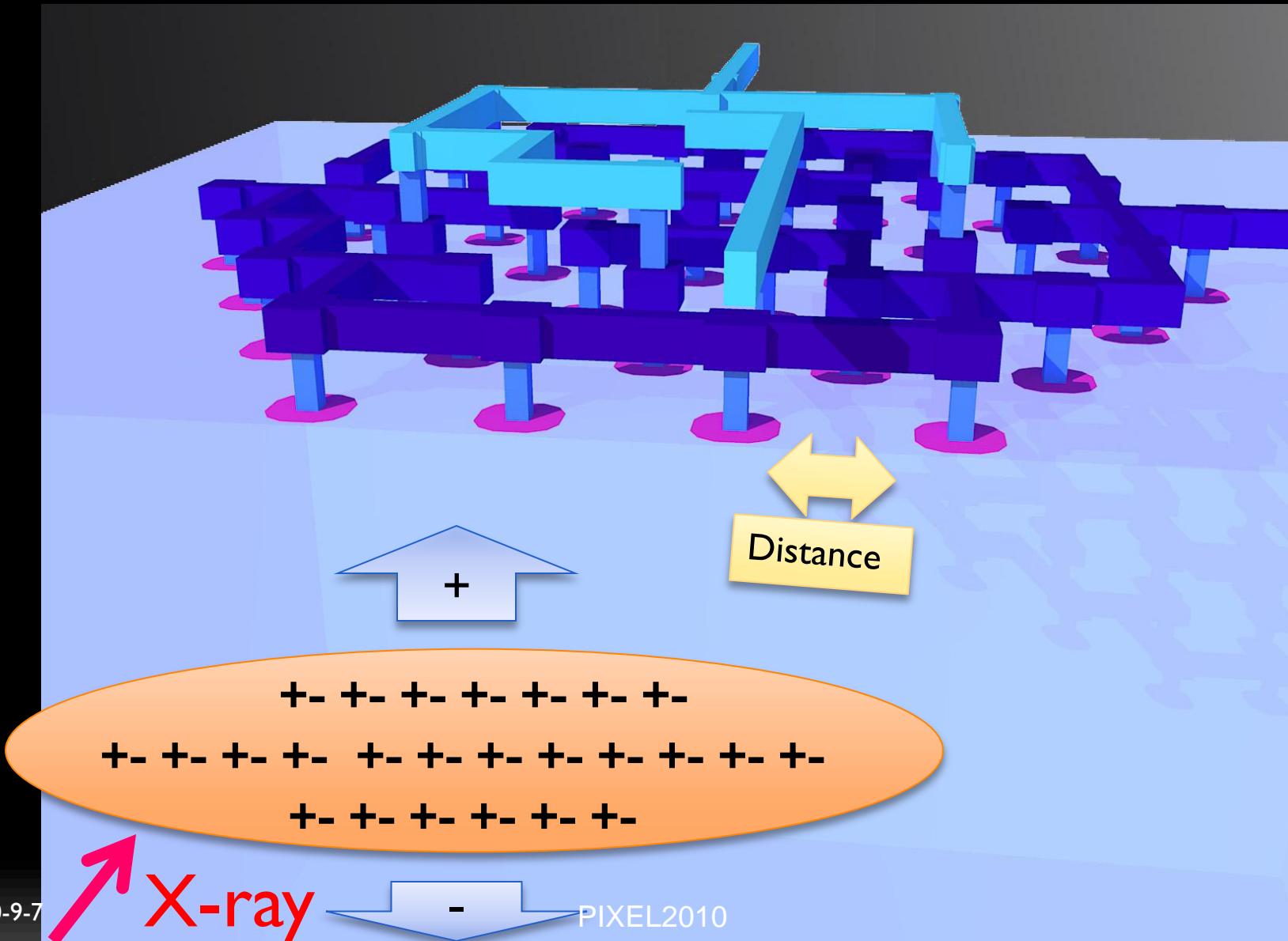
## Charge generated by single x-ray photon

- For 6-12 keV,
- 1600-3200 electrons
- In optical region
- $\sim 1$  electron

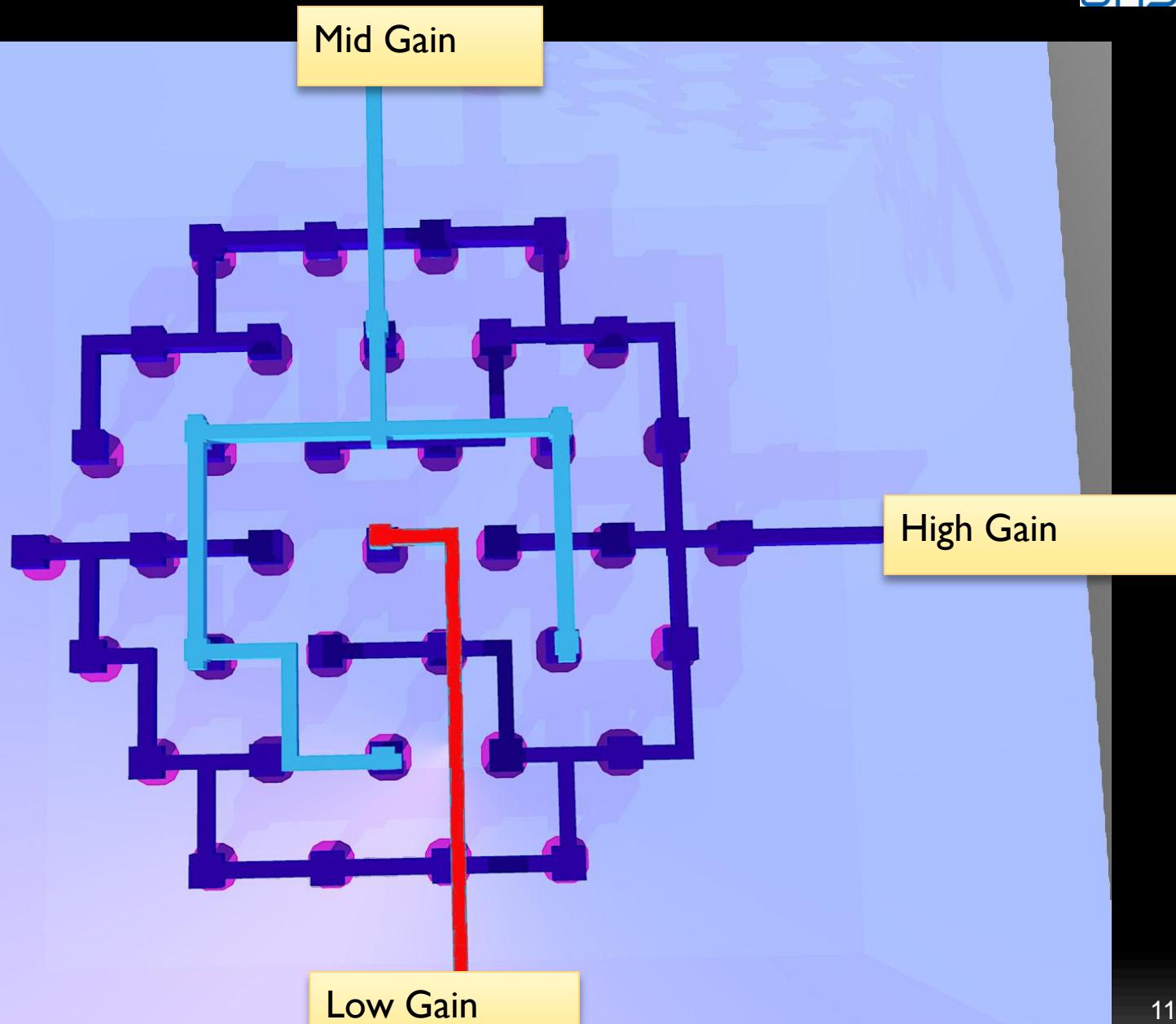
Charge/photon ratio: too large  $\rightarrow$  smaller full well

# Multi-Via Concept for XFEL

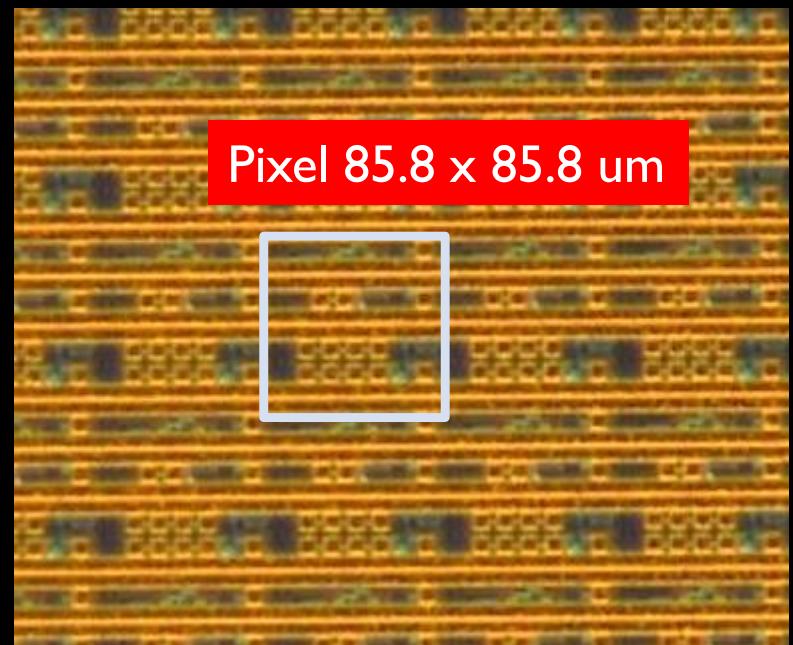
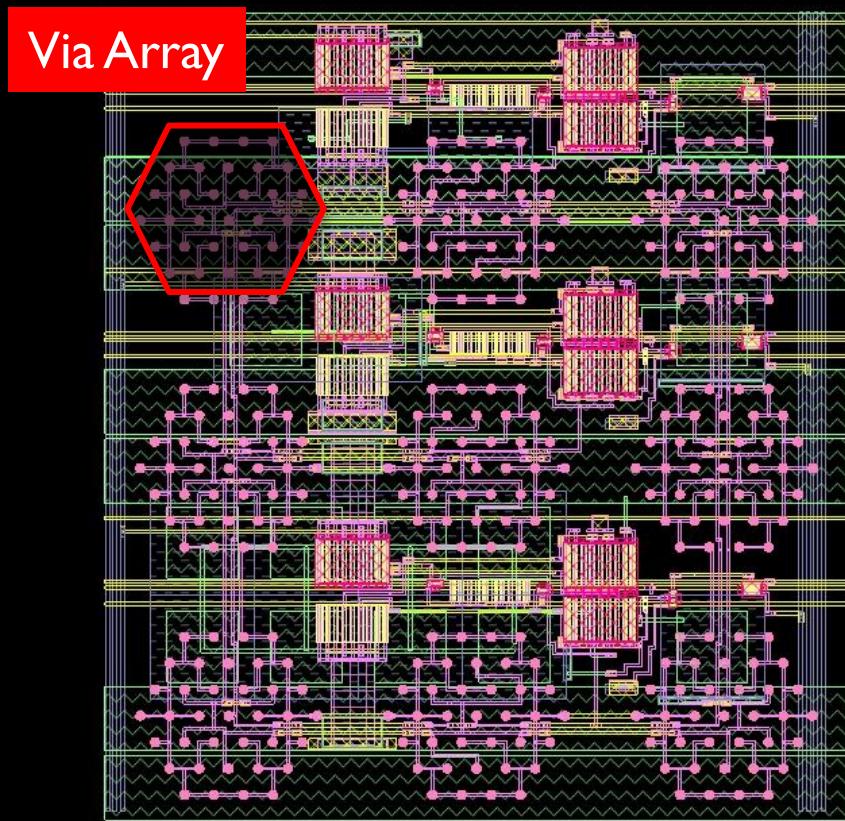
## 3.2 um pitch via



# Multi-Via Concept for XFEL

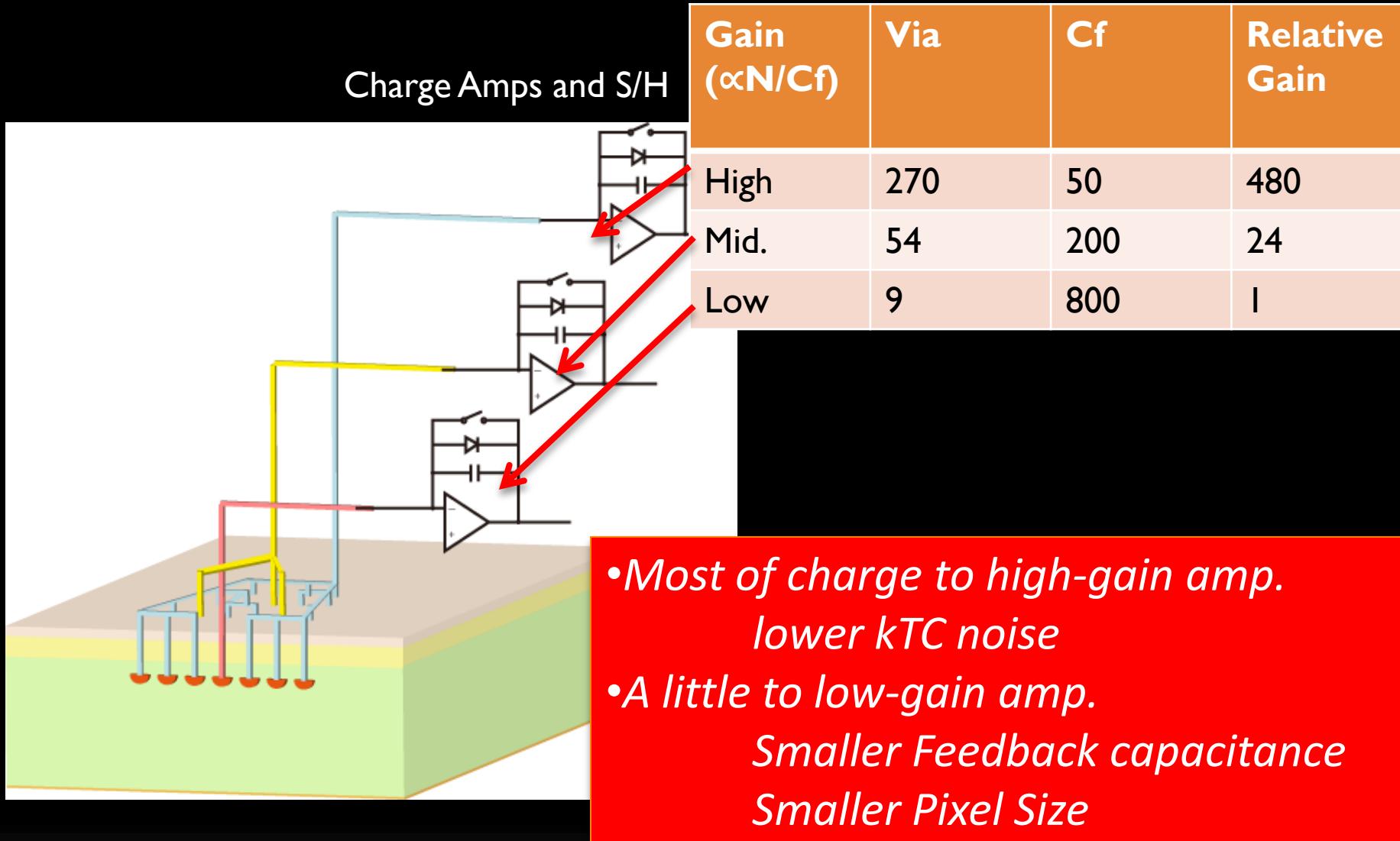


# Layout in 2009-1 chip



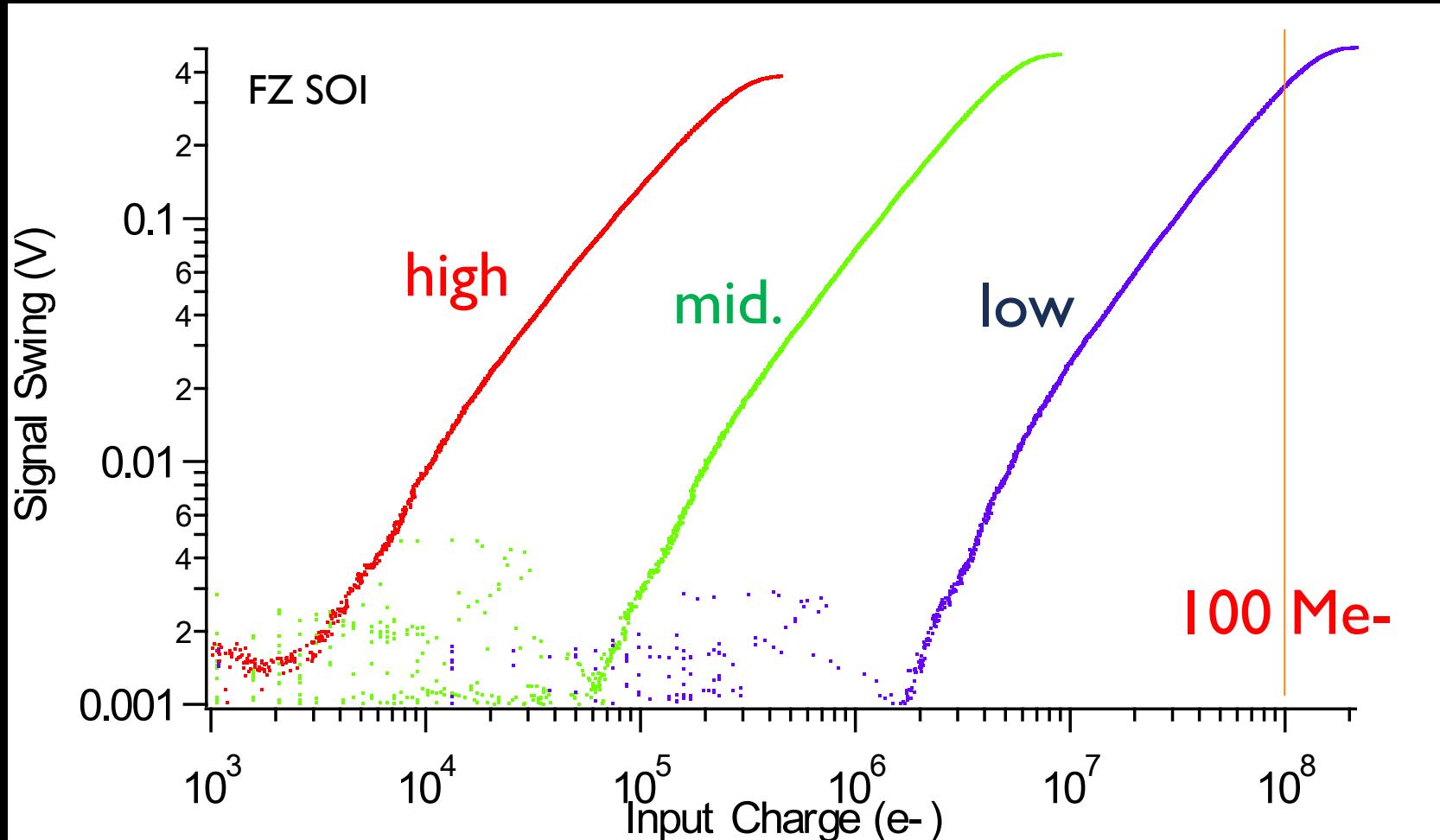
A TEG with  $32 \times 32$  pixels  
( $5 \times 5 \text{ mm}^2$ )

# Pixel Core



# Signal gain of FY09-1 chip

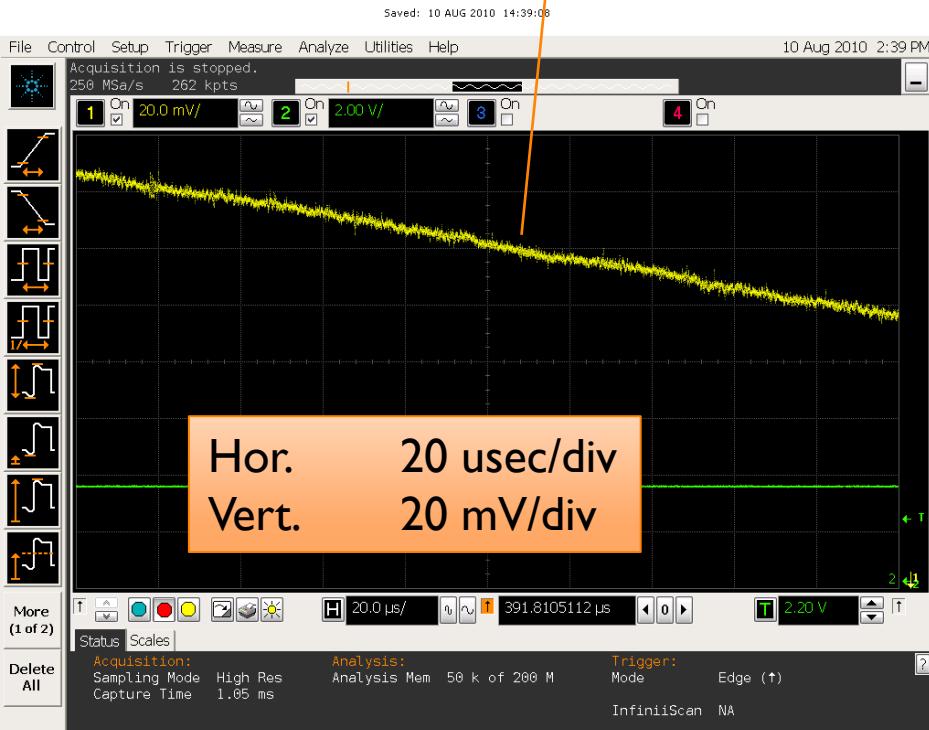
*Experiment with electrical input*



# MVIA with FZ SOI wafer

2010-8-10 : taken by Omodani

Leak Current

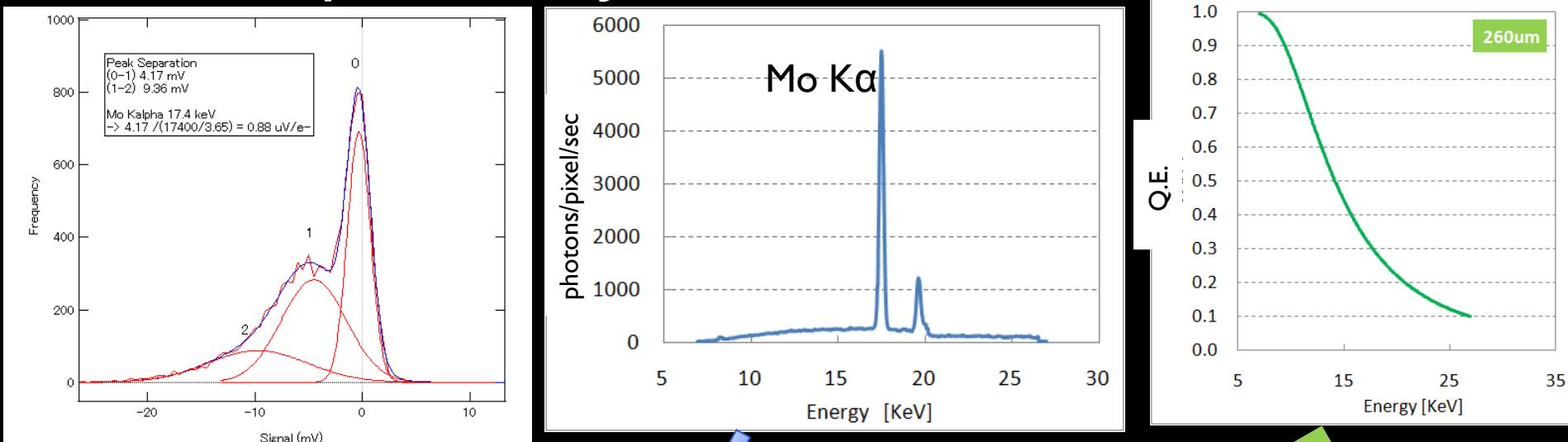


Single Photon of Mo K (18-19 keV)



# Depletion Depth Measurement

*preliminary bias 23 V for FZ SOI*



$$V_{obs} \doteq G_{det} \int N_0(E_{ph}) QE(E_{ph}, W_{depletion}) \frac{E_{ph}}{W} dE_{ph}$$

Inputs to the equation:

- 0.88 uV/e- for high gain
- 83 mV/msec
- Mo K $\alpha$  60 %
- $E_{ph, effective} = 15.3 \text{ keV}$
- Henke table

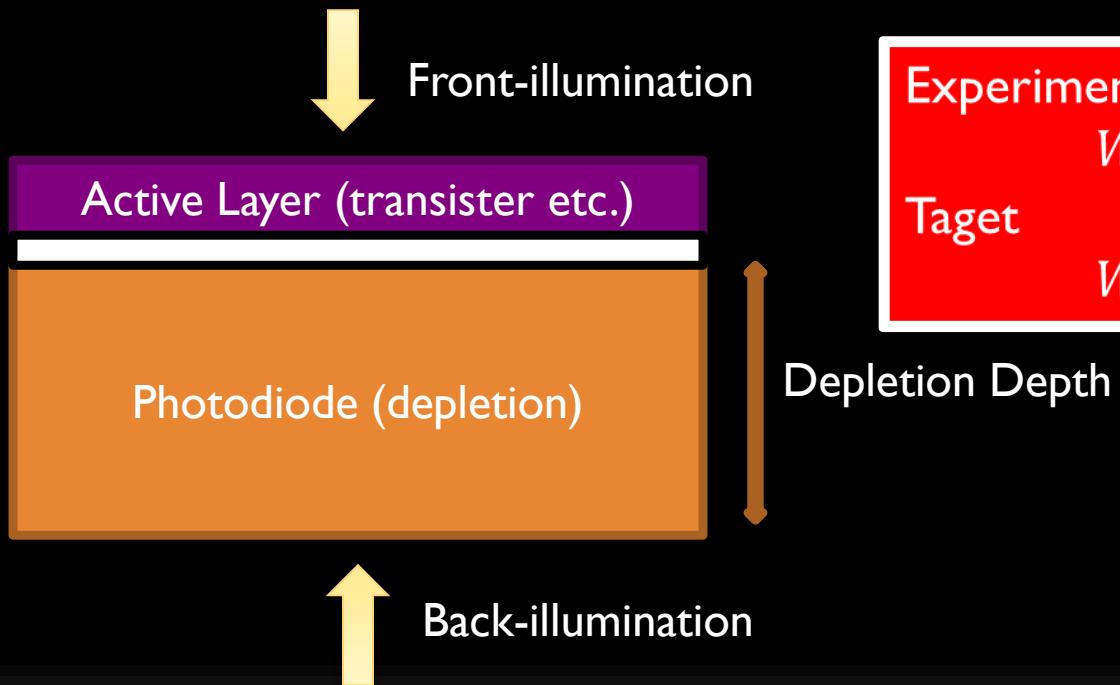
Experiment  
 $QE_{exp} = 38.4 \%$

Theory for 260 um  
 $QE_{theory} = 37\%$

# Radiation Damage and Q.E.

## Thicker Depletion solve both the issues

- Annual Fluence 30 Mrad
  - Active Layer radiation hardness: 150 krad



### Experiment

$W_{depletion} = 260 \text{ um}$  @ bias 23 V

### Target

$W_{depletion} = 500 \text{ um}$  @ bias 85 V

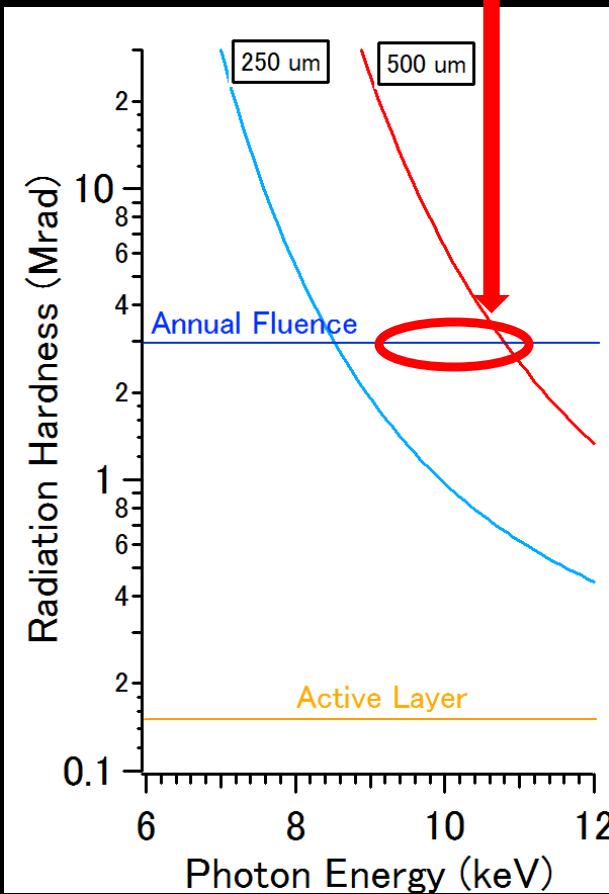
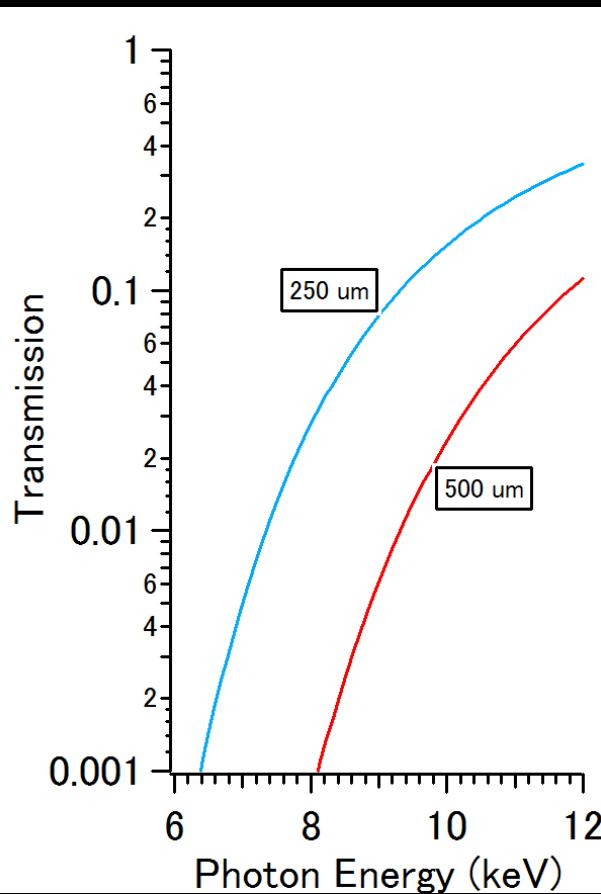
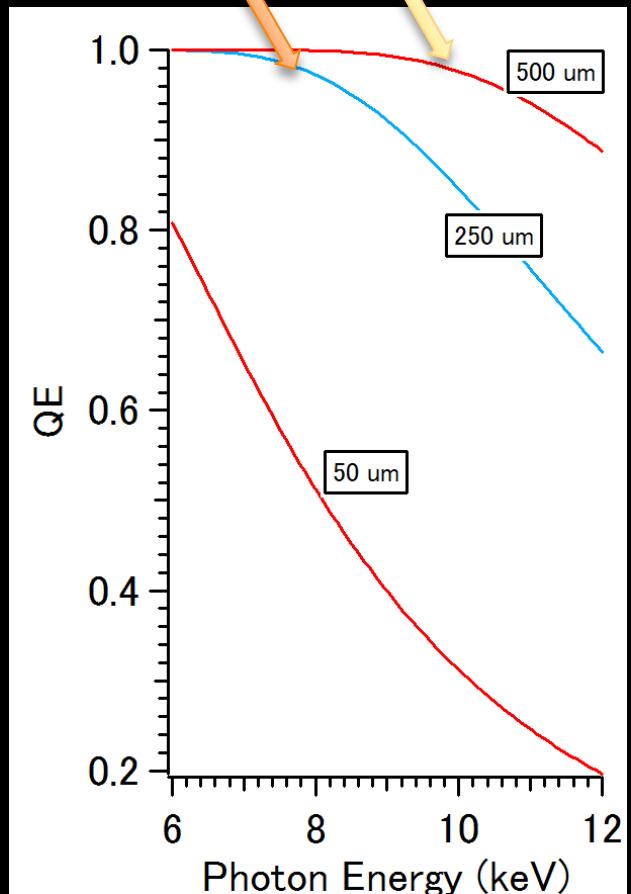
# Q.E. and Radiation Hardness vs. Depletion Depth ( $W_{depletion}$ ), and Photon Energy

CZ wafer

FZ wafer

$$W_{depletion} \propto \sqrt{V/N}$$

Phase I target



# SYSTEM Development

Phase I: Single module detector

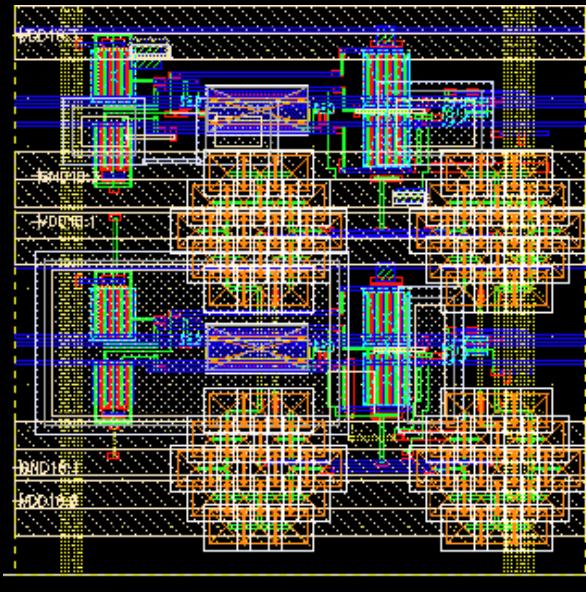
2010.4-2011.3

Phase II: Tiled Detector

2011.4-2012.3

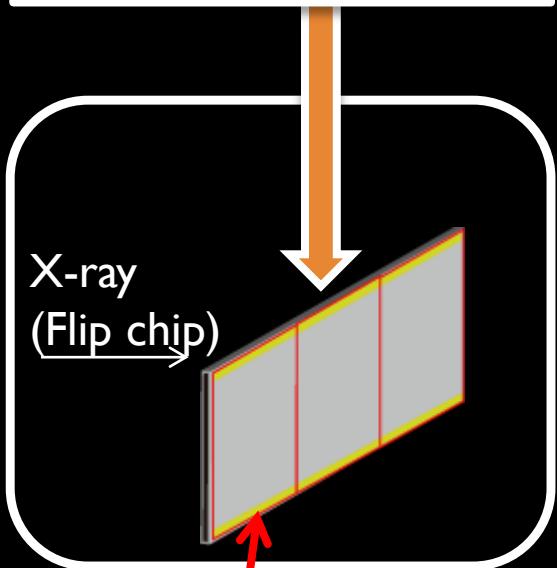
# 50 x 50 $\mu\text{m}$ Dual Gain MVIAs pixel

Pixel	Shape	50 µm square
	Type	2 gain Multi-via pixel
	Noise	100 e- (0.061 eq. photon@6 keV)
	Full Well	50 Me- (30 000 eq. photons@6 keV)
	Depletion Depth	> 500 µm



# MVIA Detector (Dual Gain)

Die has 3 reticule domains.



I/O pads for wire-bonding

		Target Performance
Sensor	Size (max)	32 mm x 64 mm
	Pixel Number	640 x 426 (273k) / reticule 640 x 1278 (818 k) / die
	Input (address)	5 Serial line @ 100 MHz
	Input (timing)	3 (start, store, idle start)
	Input (bias)	1
	Output node	2 / reticule (high & low) 6 / module
	off-chip ADC	6 ch ADC (ENOB 11bit) 20 MS

# Packaging

## Die (32 mm x 64 mm)

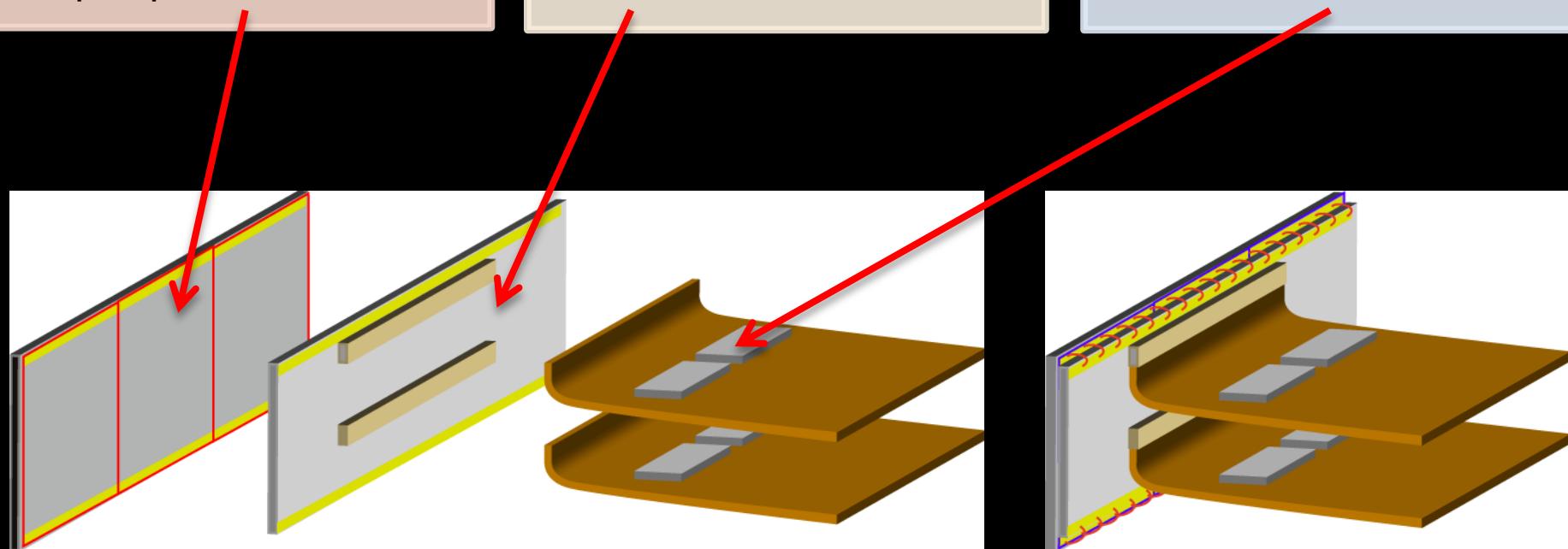
- 3 reticule units
- I/O pad on top and bottom
- Flip chip

## Package

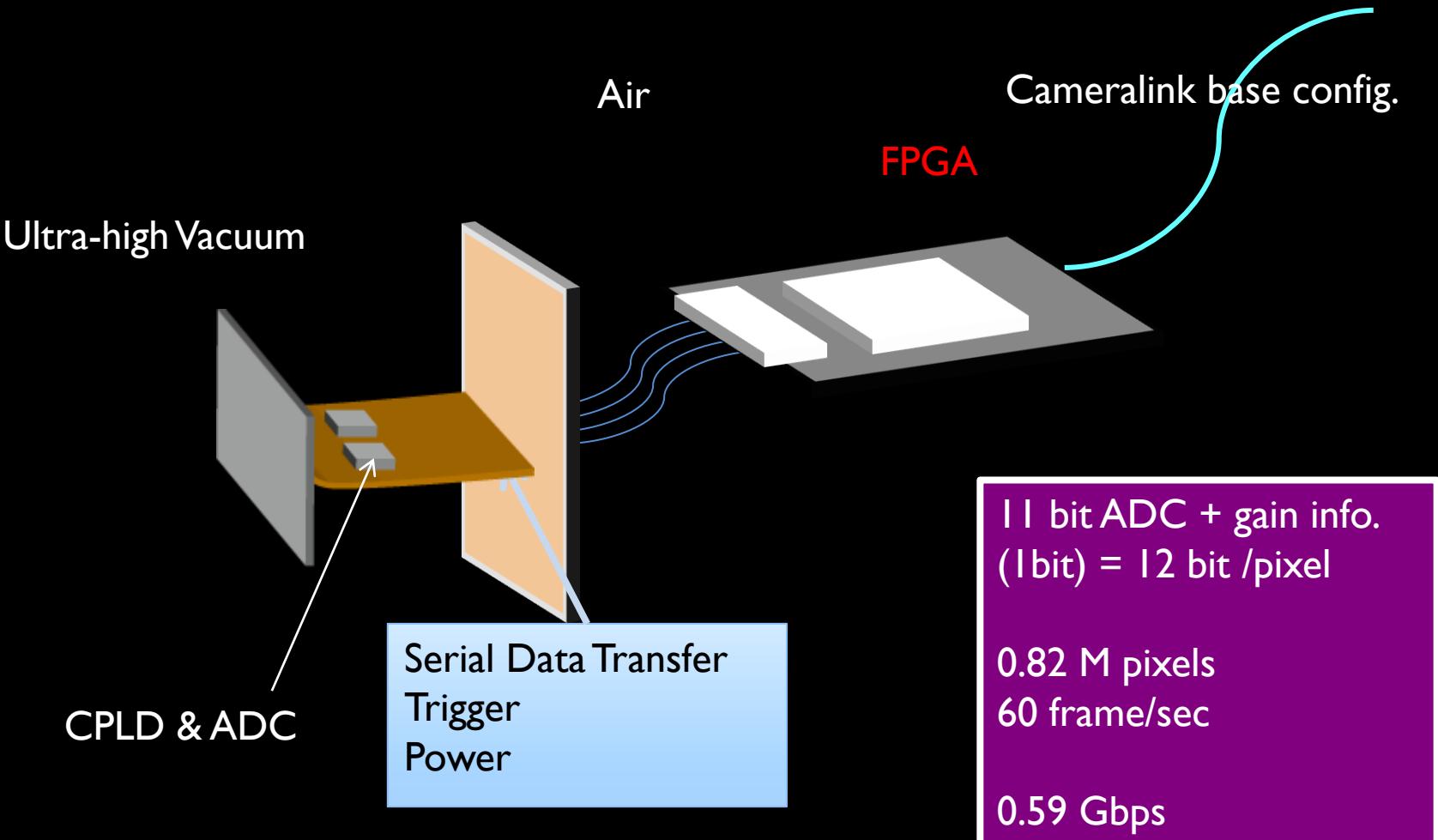
- low height profile to meet industry standard

## Analog Front-end

- ADC and Control Logic onto flexi cables

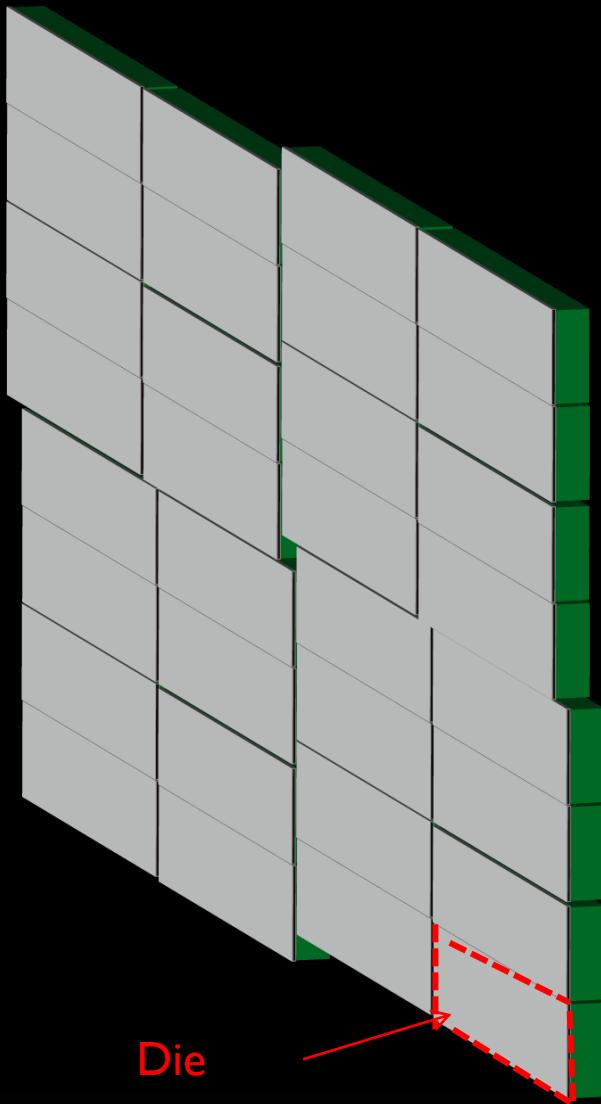


# MVIA Phase I (-2012.3)



# MVIA Detector (-2013.3)

## 32 Array



		Target Performance
System	Image Area	256 mm x 256 mm
	Tiling	4 x 8
	Pixel Number	5.1 k x 5.1 k
	Dead area	< 0.8 mm
	Vacuum	<10^-7 Pa
	Cooling	Water

# Conclusion

- X-ray Free Electron Laser Project at SPring-8
  - Detector Requirements
- Multi-via Pixel Concept
  - Charge division for higher dynamic range
- Experimental Results
  - Gain
  - Depletion depth
    - 260 um achieved
    - 500 um anticipated
  - Radiation hardness
    - 30 Mrad (Si) with some limitation
- System Development

# Collaborators

- KEK  
Yasuo Arai, and SOIPIX collaboration
- Private Sector
  - OKI Semiconductor
  - Rohm
  - A-R-Tec Corp
  - Kyocera

# Detector Development Members



# SPARE SLIDES

2 SLIDES 2 SLIDES

# Remaining Issues

IR drop in large area format

# IR drop

## Power consumption

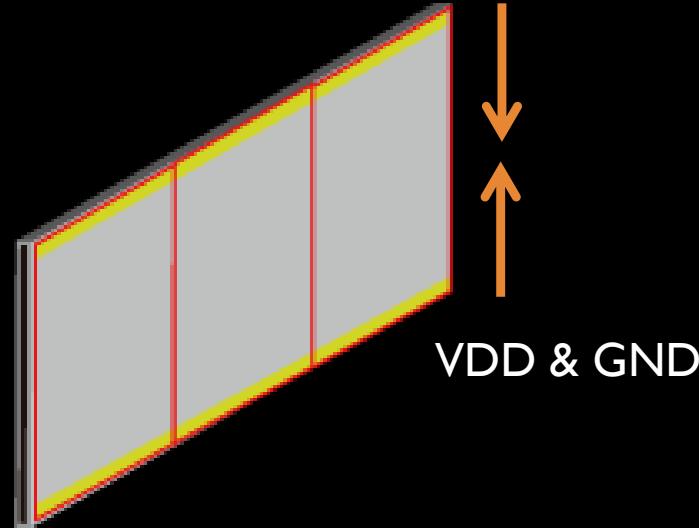
- Each amp. 100  $\mu$ A 1.8V
- 2 amp/pixel

## Heat

- 300W (peak)
- Operation < 0.1 % yield 0.3W

## IR drop

- 0.5V with current process



Add 5<sup>th</sup> Metal Layer

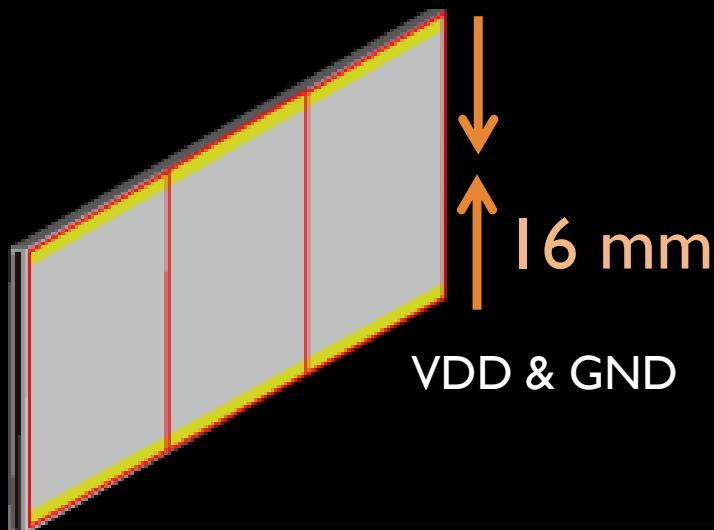
Lower current operation

Quasi differential output

IR drop < 130 mV

# 2010-1 Submission

- Experiment the large area format to solve
  - IR drop
  - dummy output



RIKEN  
MVIA chip

