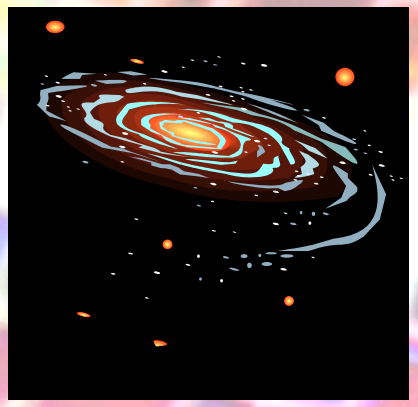
Radiation image sensor with SOI technology



Dec. 2, 2014, AISISS@TI Tech

Yasuo Arai

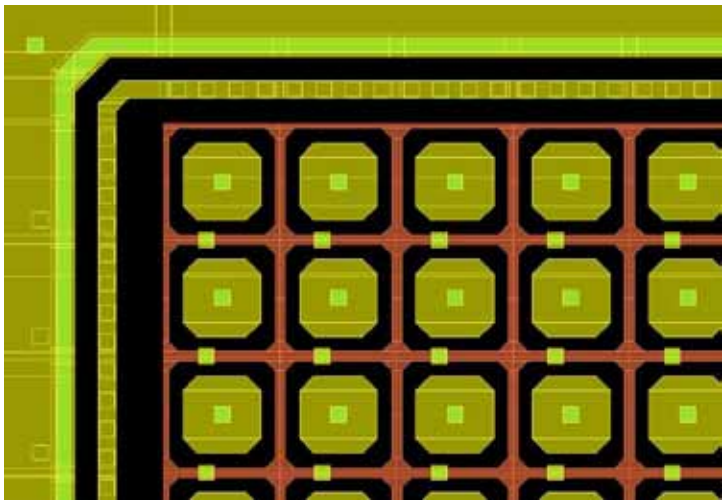
(High Energy Accelerator Research Organization, KEK)

yasuo.arai@kek.jp

http://rd.kek.jp/project/soi/

Outline

I. Introduction
II. SOI Pixel Process
III. SOIPIX Detectors
IV. Advanced R&D
V. Summary



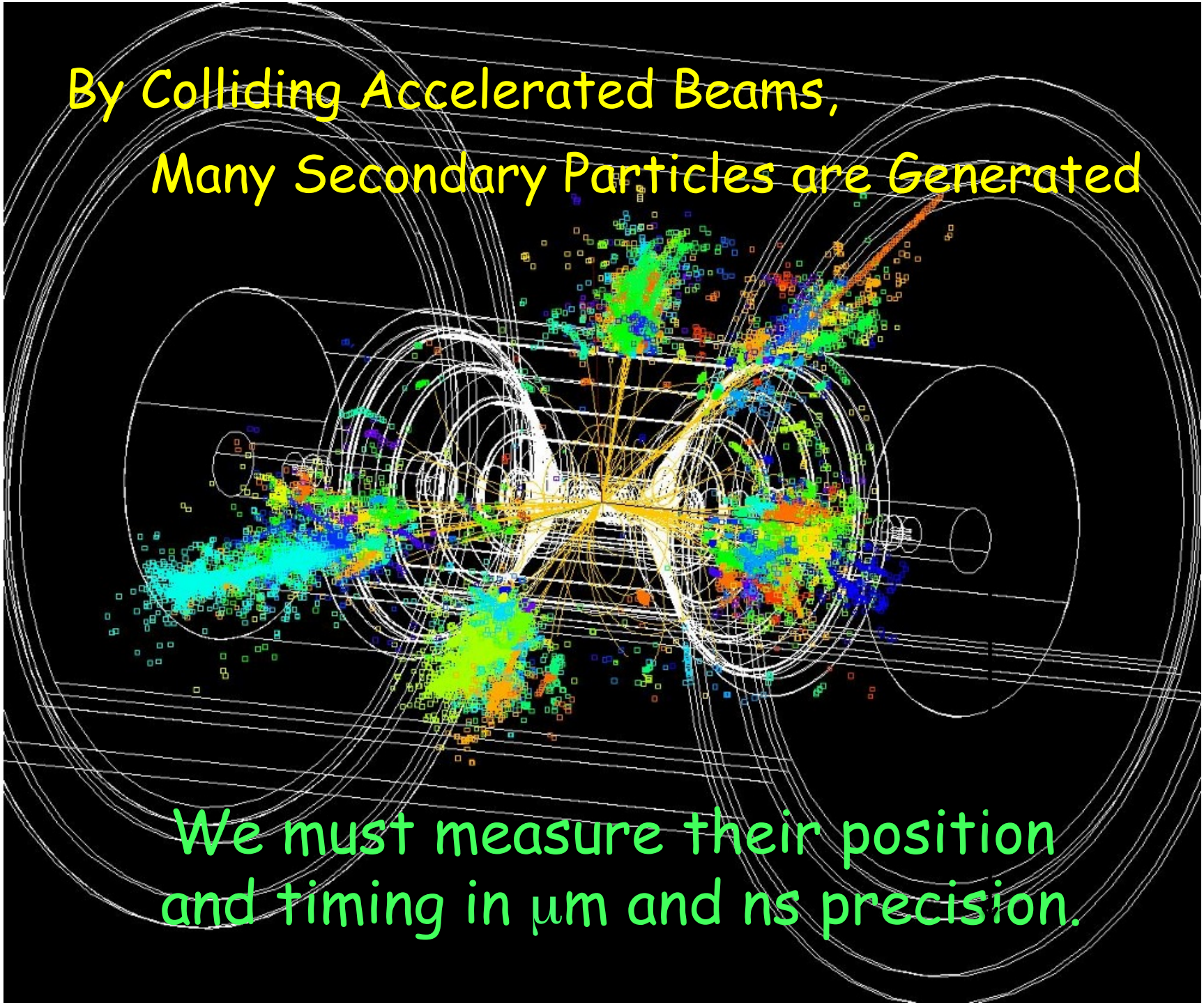
I. Introduction

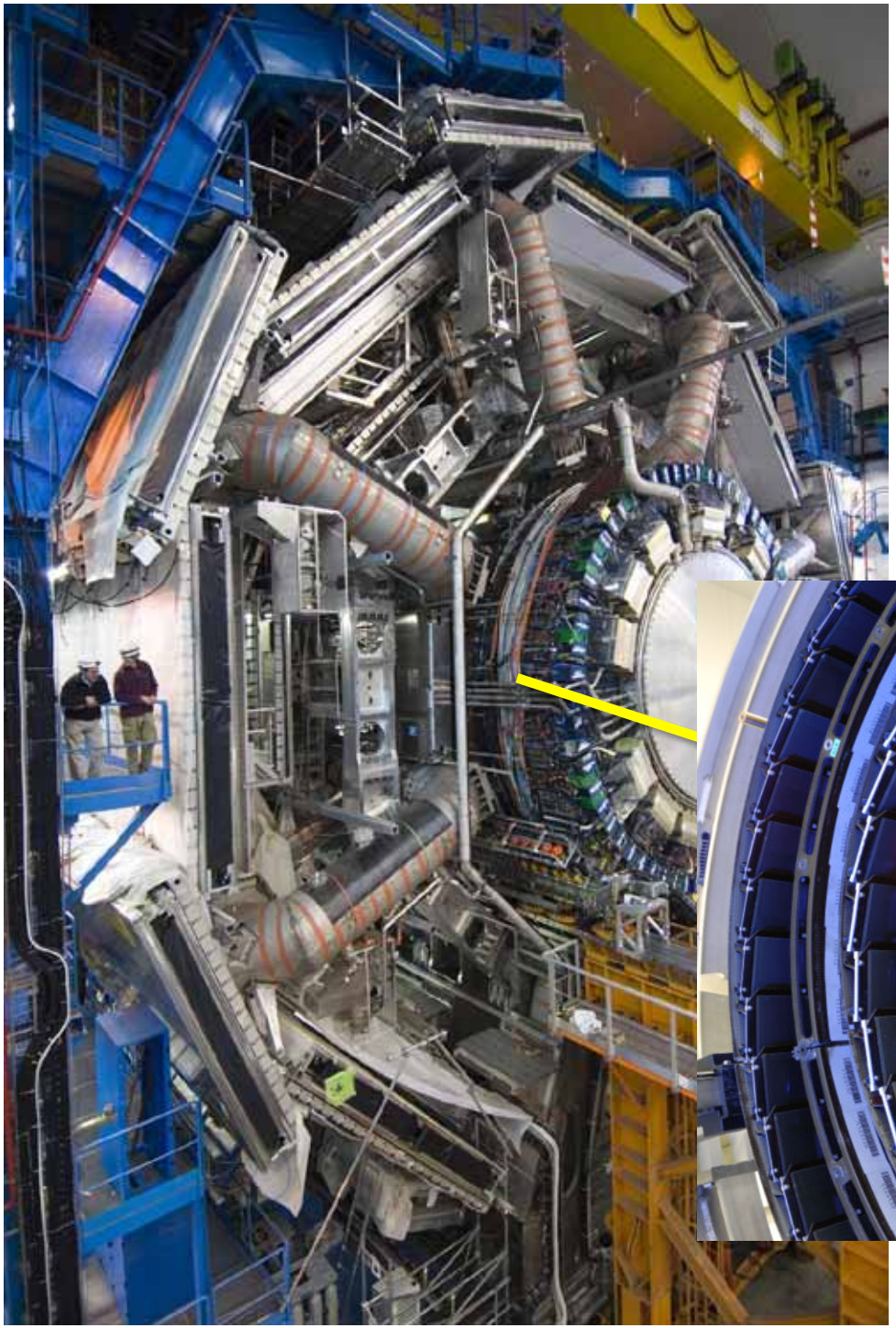
High Energy Accelerator Research Organization (KEK)

International Linear Collider Project

KEK Tokai
J-PARC
(30 GeV Proton)

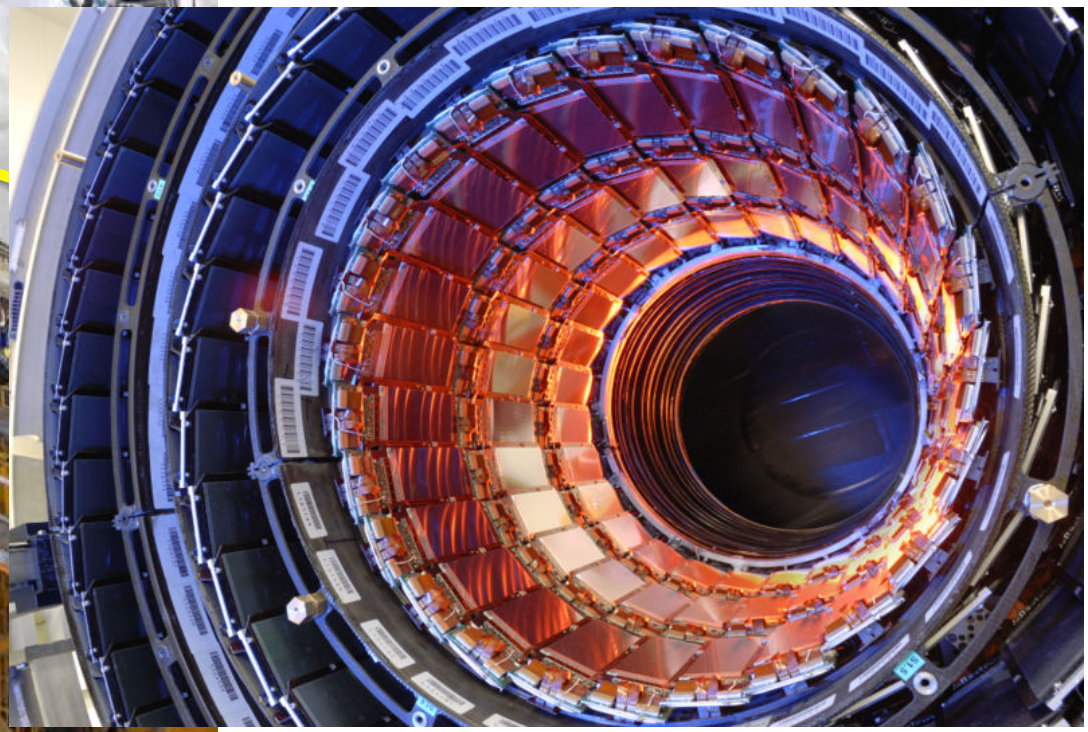
KEK Tsukuba
Super KEKB
(4 GeV e^+ - 7 GeV e^-)
Photon Factory
(2.5 & 6.5 Gev Sync. Rad.)


By Colliding Accelerated Beams,
Many Secondary Particles are Generated
We must measure their position
and timing in μm and ns precision.

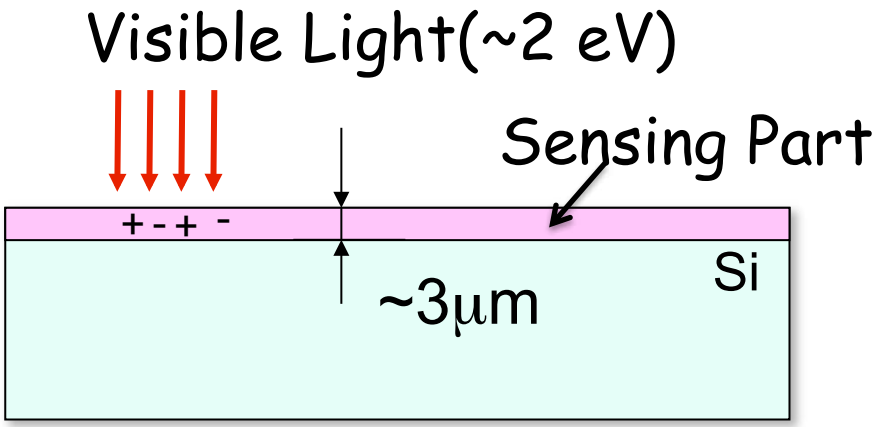


ATLAS Detector@CERN

Silicon Vertex Detector



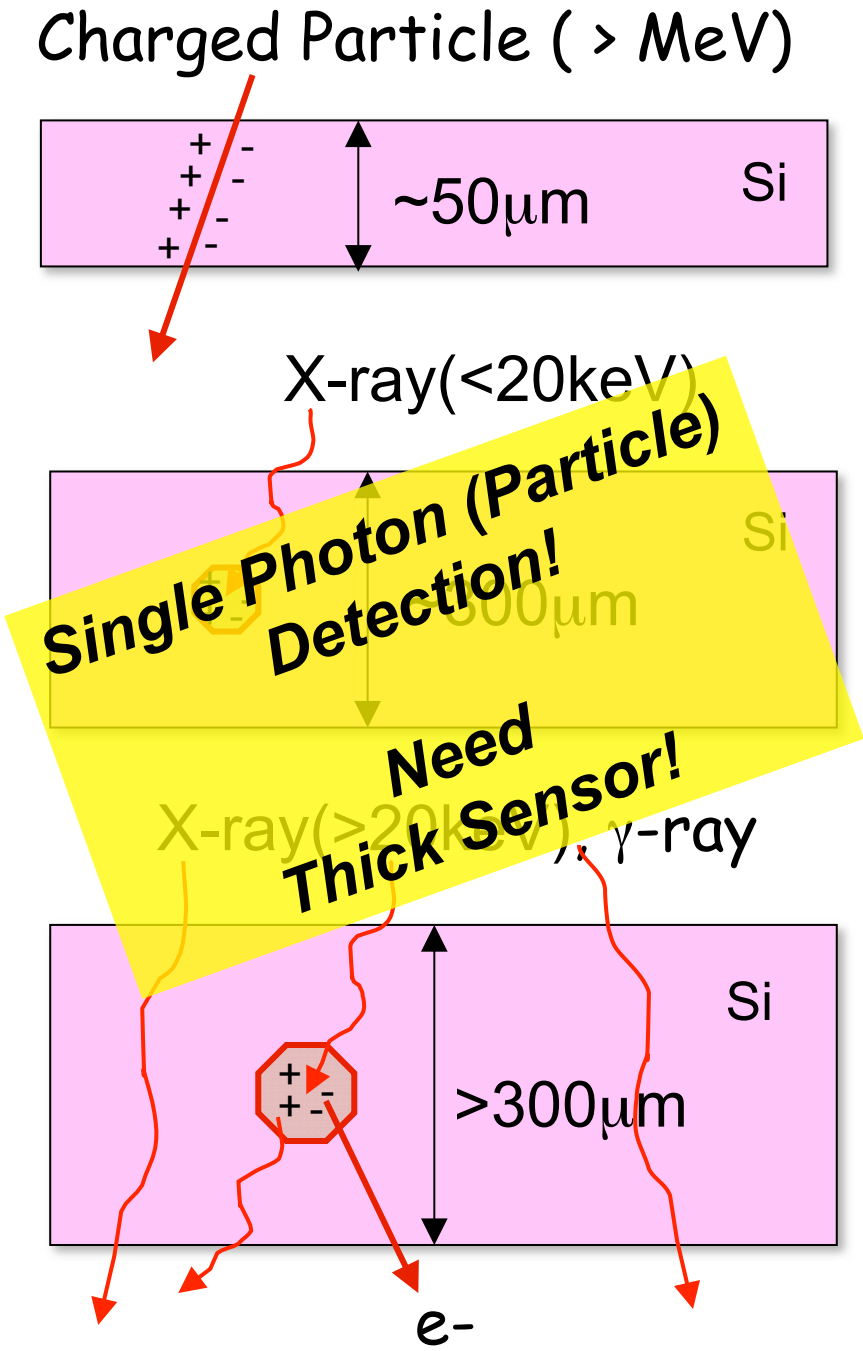
Radiation Detection in Si



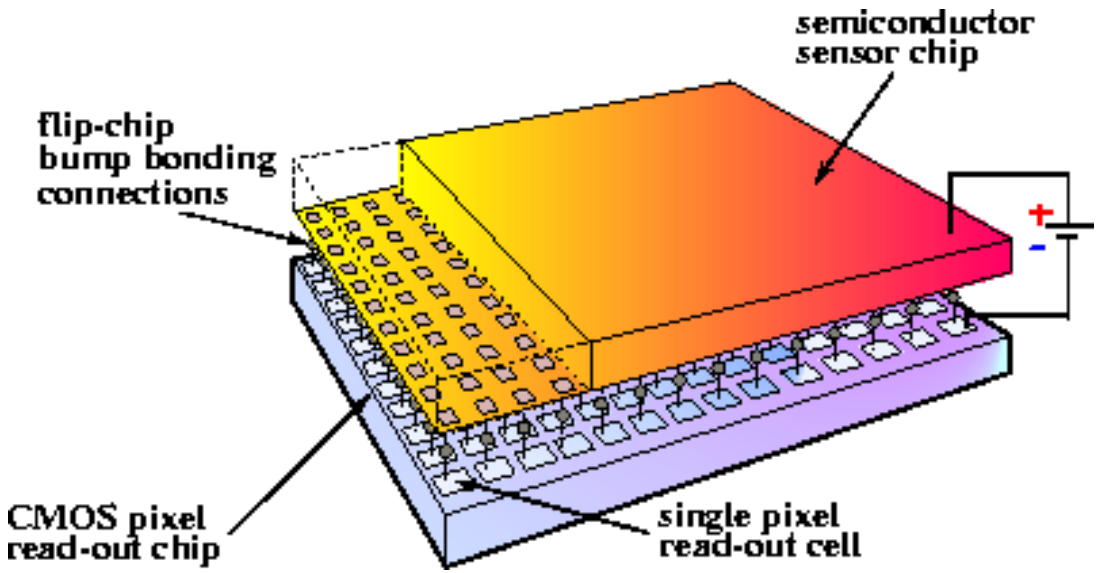
Visible Light ~ 1 e-h / 1 photon

High Energy Particle ~ 80 e-h / μm

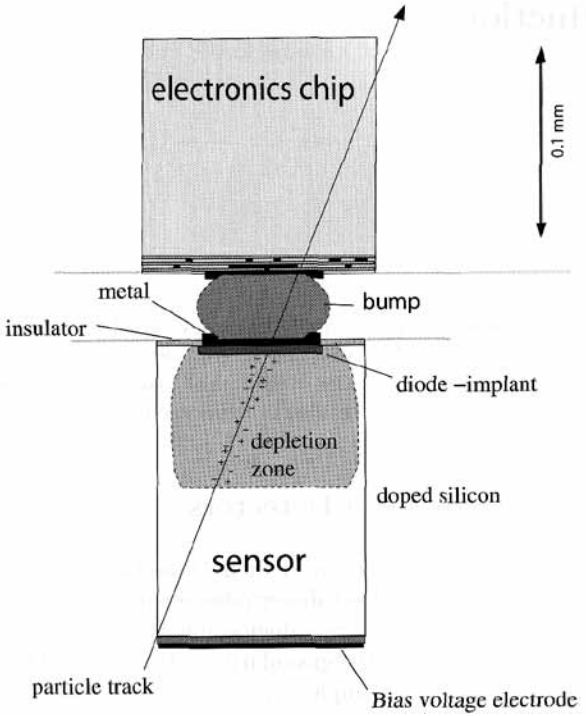
X-ray ~ 3000 e-h @10 keV



Present Advanced Pixel Radiation Sensor
(Sensor and LSI Hybrid with large number of bump bondings)

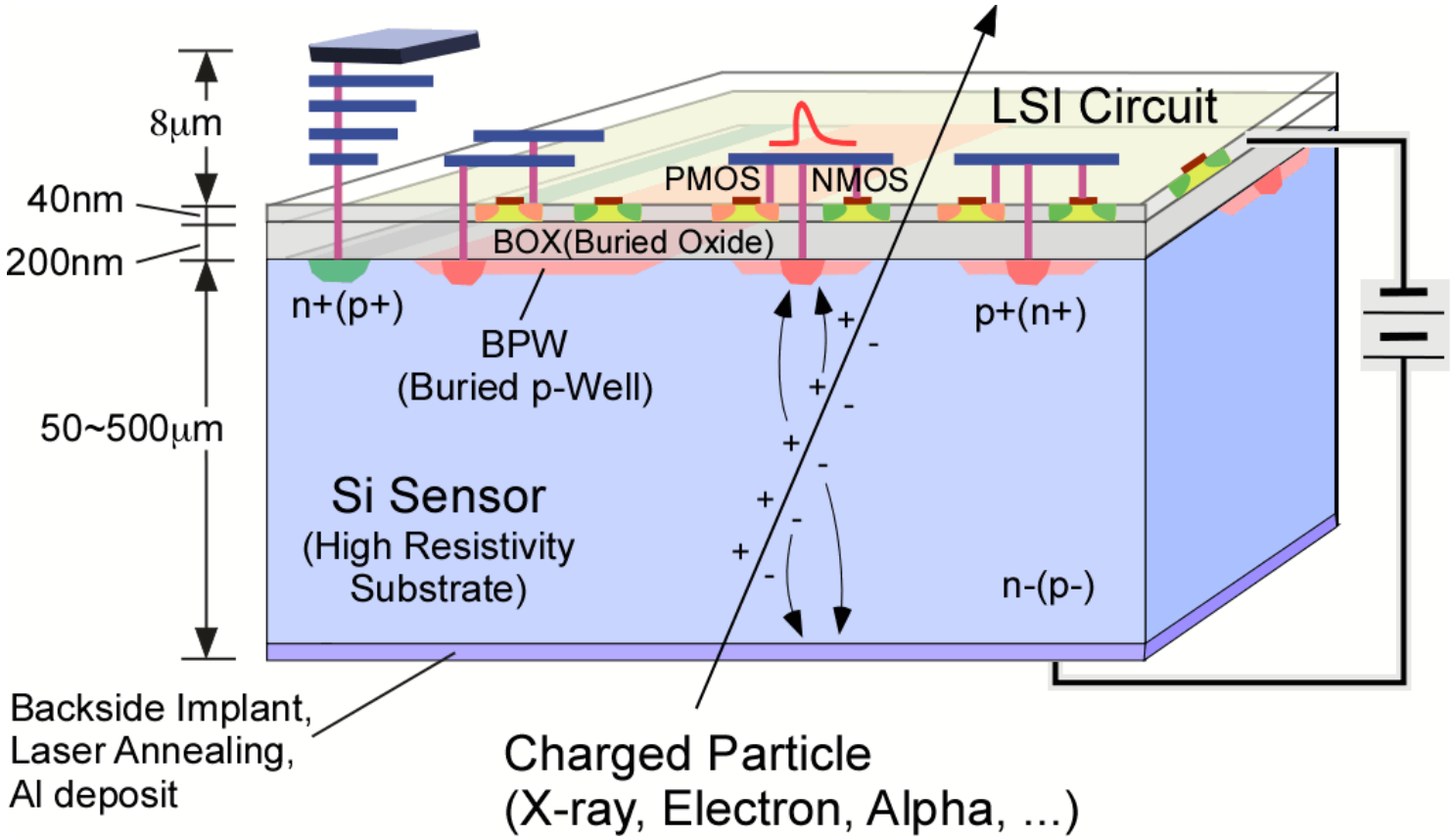


(from Medipix picture)



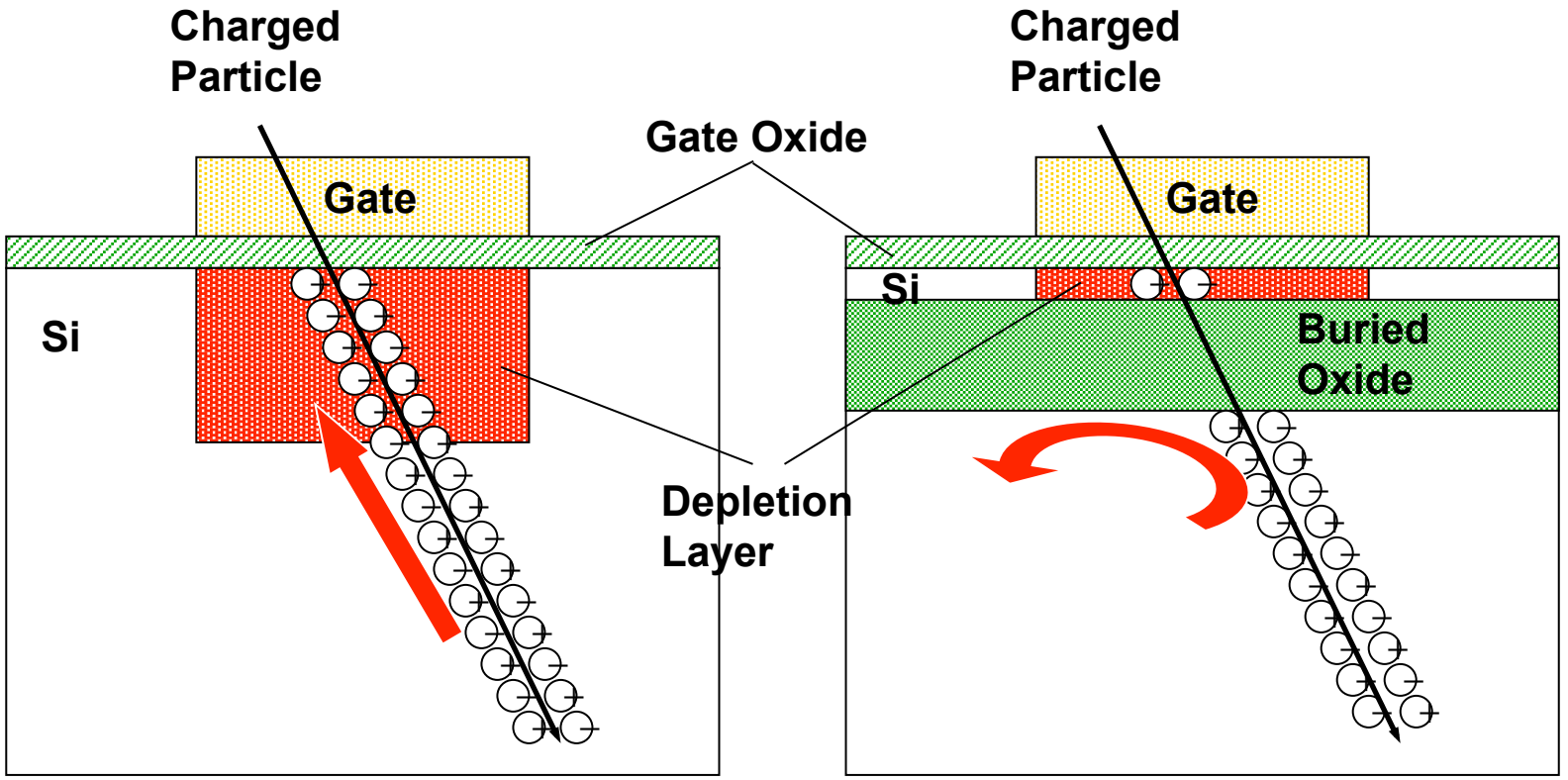
- Large number of metal bump bondings.
- Performances are limited by the bump size.
- Large unwanted materials which bend particle track.

Silicon-On-Insulator Pixel Detector (SOIPIX)



Monolithic Detector having fine resolution of silicon process and high functionality of CMOS LSI by using a SOI Pixel Technology.

High Soft Error Immunity



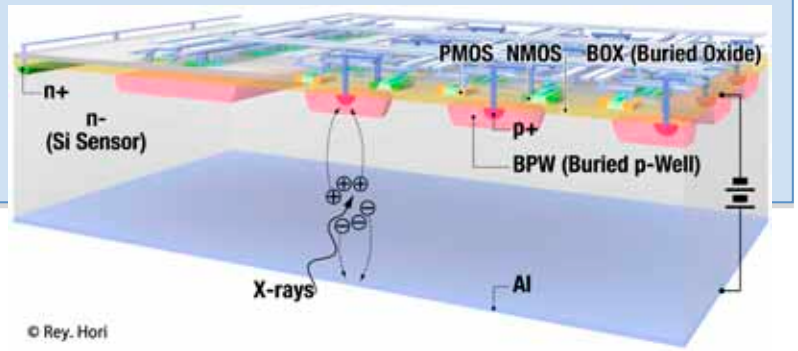
Bulk Device

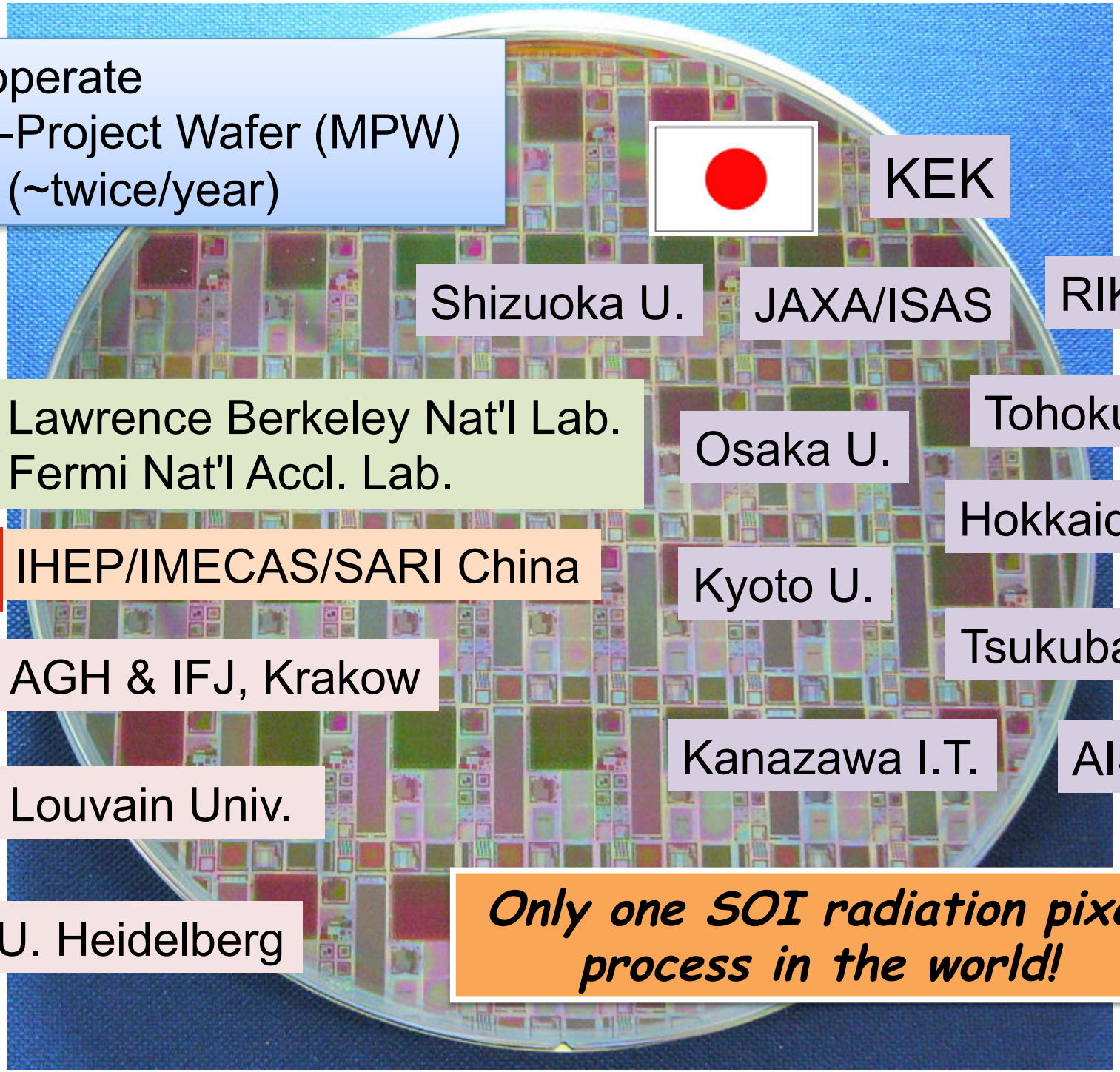
SOI Device

SOI has higher soft error immunity due to its ultra thin body Silicon.

Feature of SOI Pixel Detector

- No mechanical bonding. Fabricated with semiconductor process only, so high reliability, low cost are expected.
- Fully depleted thick sensing region with Low sense node capacitance.
- On Pixel processing with CMOS transistors.
- Can be operated in wide temperature (1K-570K) range, and has low single event cross section.
- Based on Industry Standard Technology.





We operate
Multi-Project Wafer (MPW)
run. (~twice/year)

KEK

Shizuoka U.

JAXA/ISAS

RIKEN

Lawrence Berkeley Nat'l Lab.
Fermi Nat'l Accl. Lab.

Tohoku U.

Osaka U.

Hokkaido U.

IHEP/IMECAS/SARI China

Kyoto U.

Tsukuba U.

AGH & IFJ, Krakow

Kanazawa I.T.

AIST

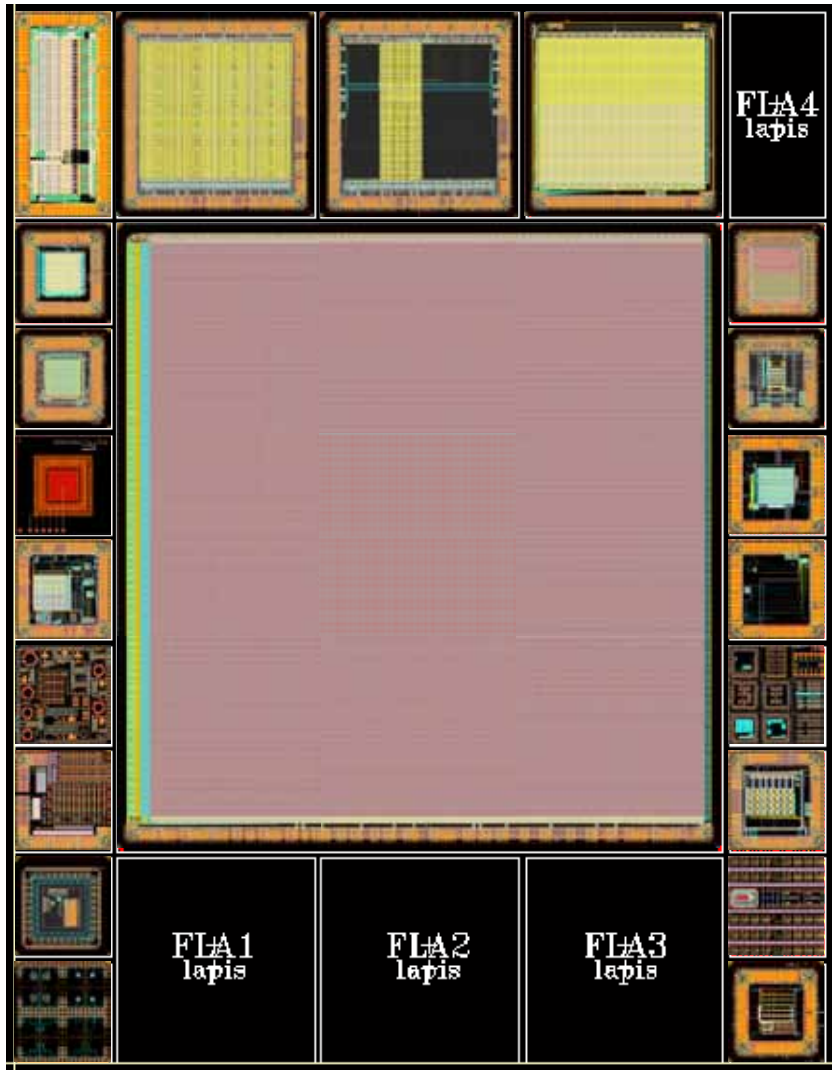
Louvain Univ.

U. Heidelberg

Only one SOI radiation pixel process in the world!

II. SOI Pixel Process

MPW Run Mask
24.6 x 30.8 mm

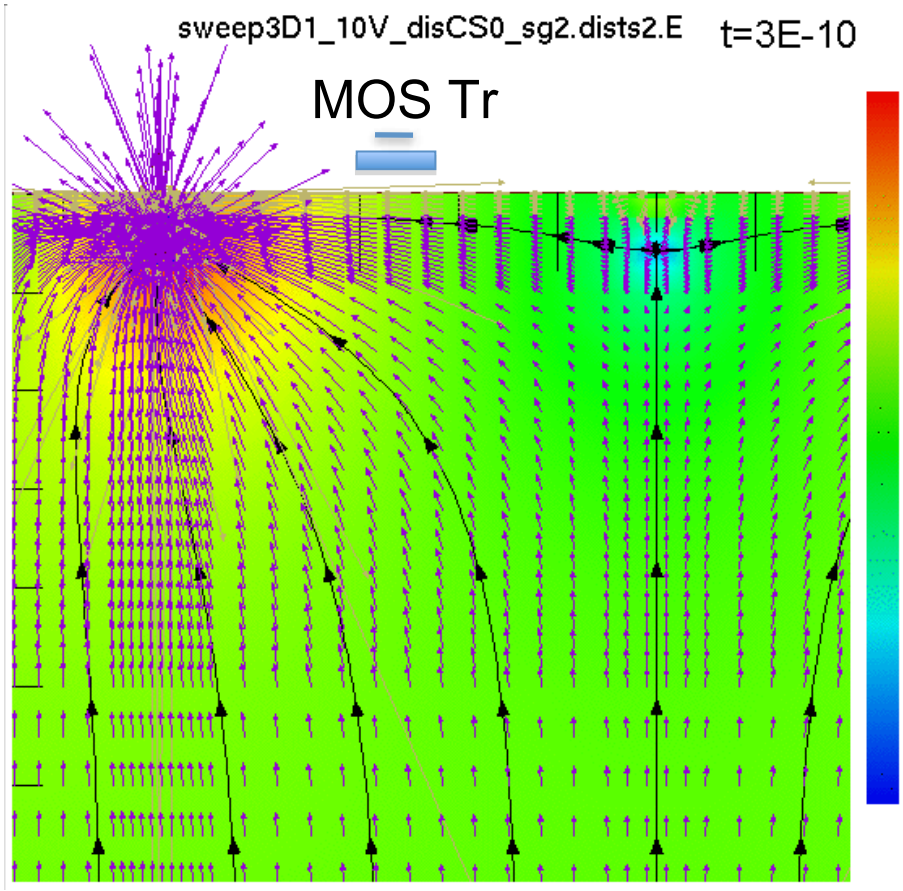


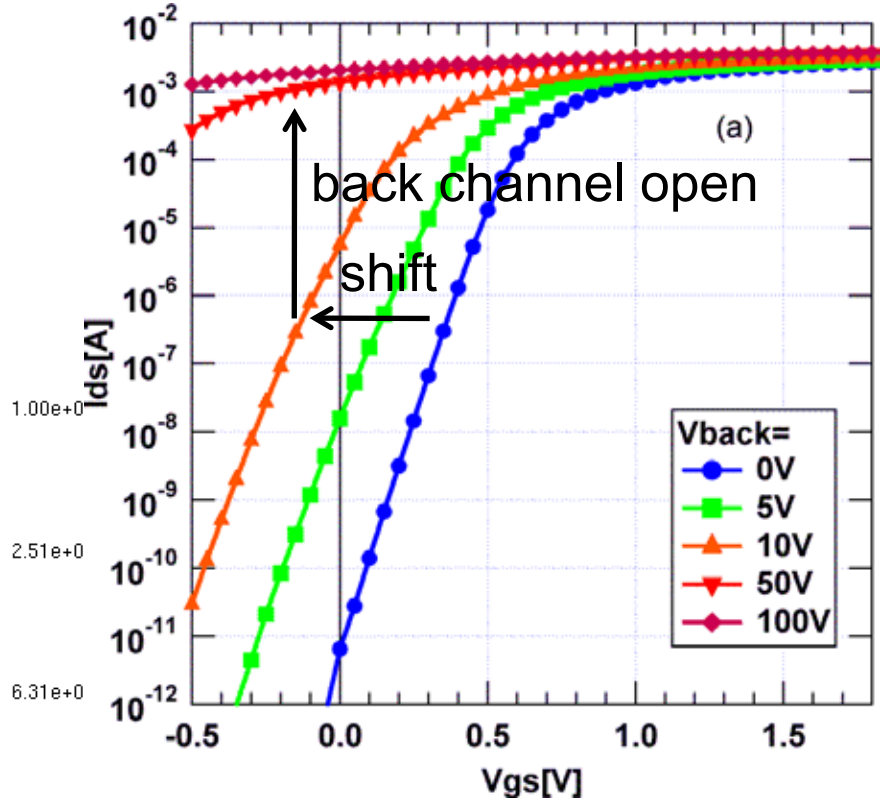
Lapis Semi.(*) 0.2 μm FD-SOI Pixel Process

Process	0.2μm Low-Leakage Fully-Depleted SOI CMOS 1 Poly, 5 Metal layers. MIM Capacitor (1.5 fF/um^2), DMOS Core (I/O) Voltage = 1.8 (3.3) V
SOI wafer	Diameter: 200 mmϕ, 720 μm thick Top Si : Cz, ~18 Ω-cm, p-type, ~40 nm thick Buried Oxide: 200 nm thick Handle wafer: Cz (n) ~700 Ω-cm, FZ(n) ~7k Ω-cm, FZ(p) ~25 k Ω-cm etc.
Backside process	Mechanical Grind, Chemical Etching, Back side Implant, Laser Annealing and Al plating

(*) Former OKI Semiconductor Co. Ltd.

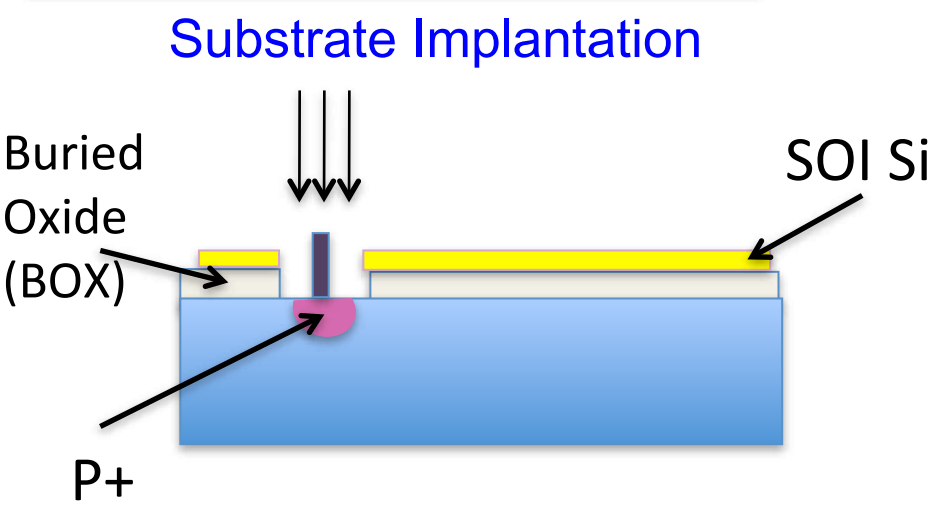
Main Issue in the SOIPIX:
Back-Gate Effect

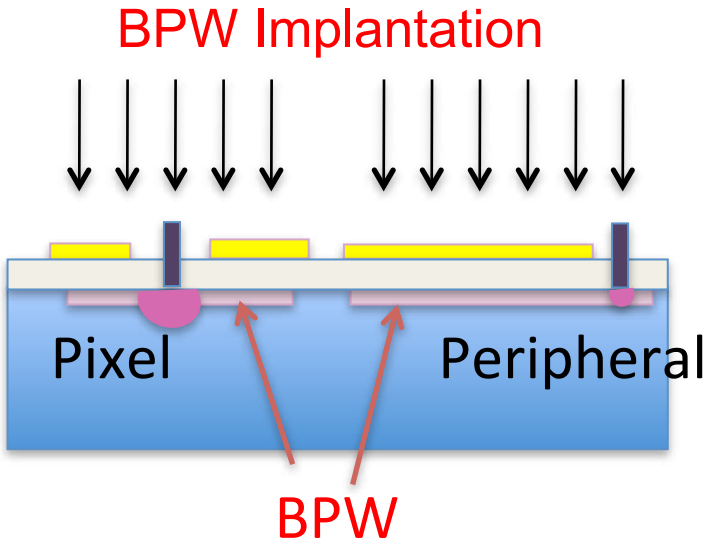




Detector Voltage act as a Back Gate of the Transistors, and open back channel.

Buried p-Well (BPW)





- Cut Top Si and BOX
- High Dose

- Keep Top Si not affected
- Low Dose

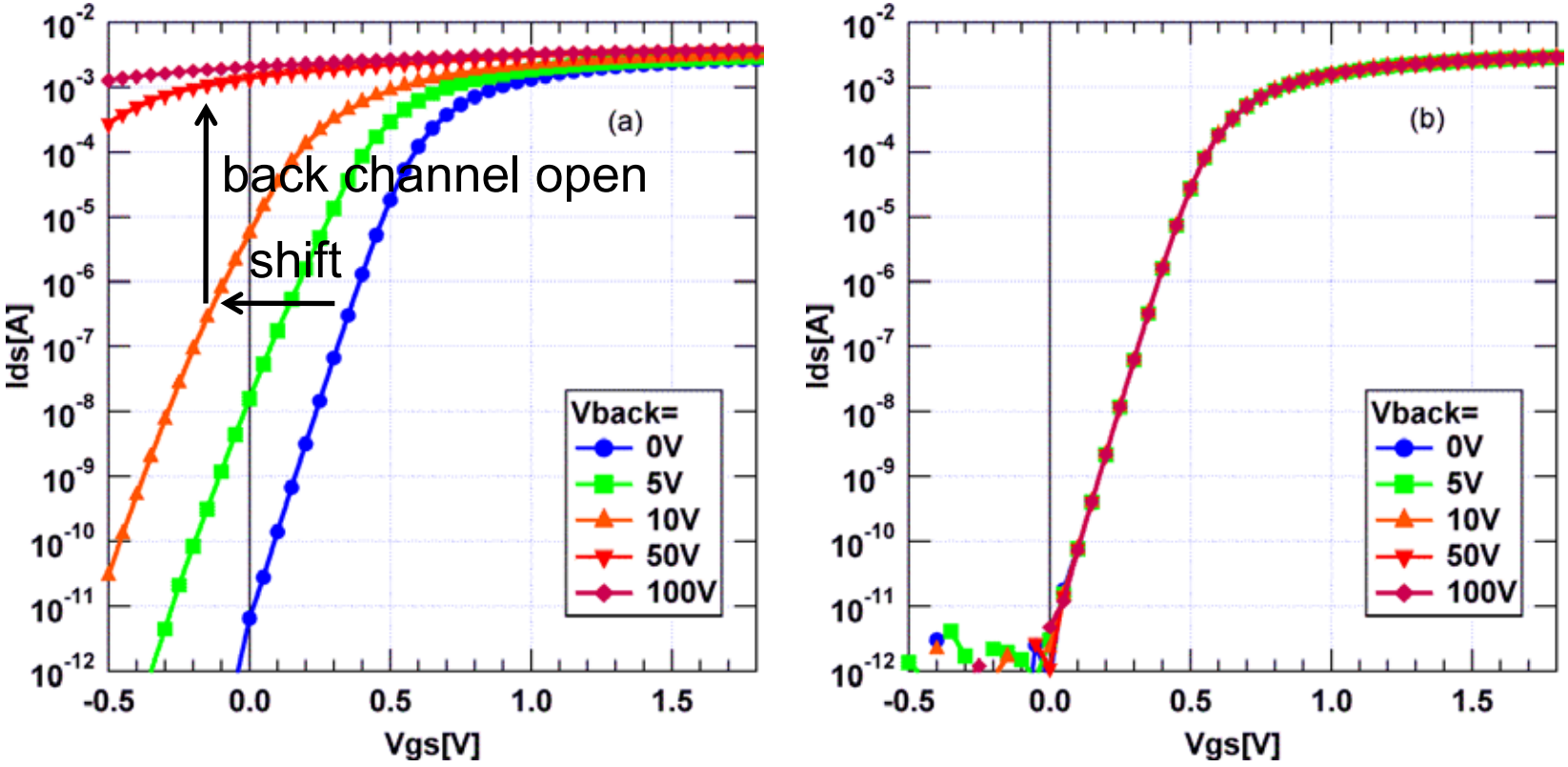
- Suppress the **Back Gate Effect**.
- Shrink pixel size without loosing sensitive area.
- Increase break down voltage with low dose region.
- Reduce electric field in the BOX which improve radiation hardness.

I_{ds}-V_{gs} and BPW

w/o BPW

with BPW=0V

NMOS

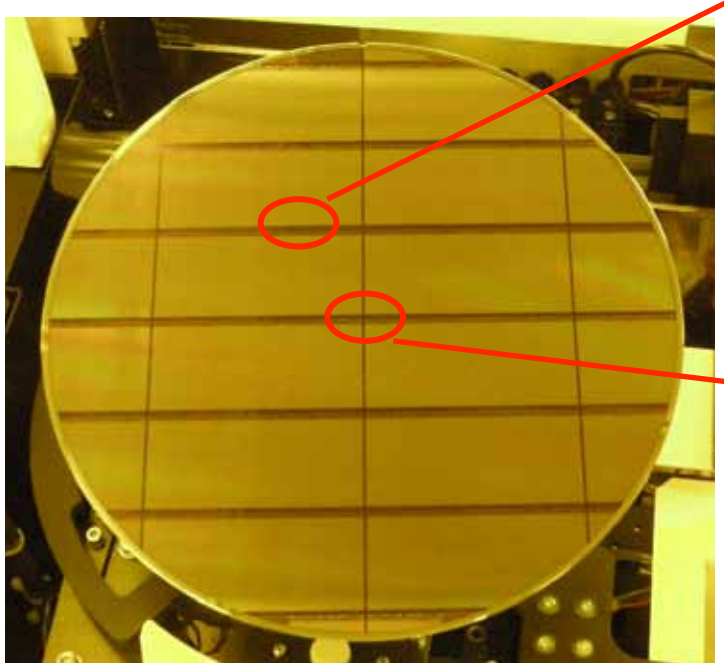


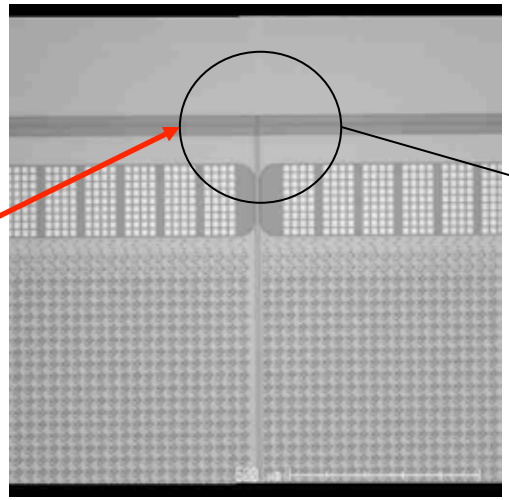
Back-gate effect is completely suppressed by the BPW.

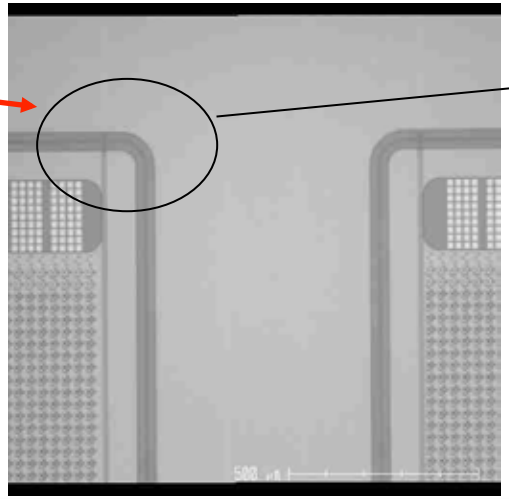
Stitching Exposure for Large Sensor

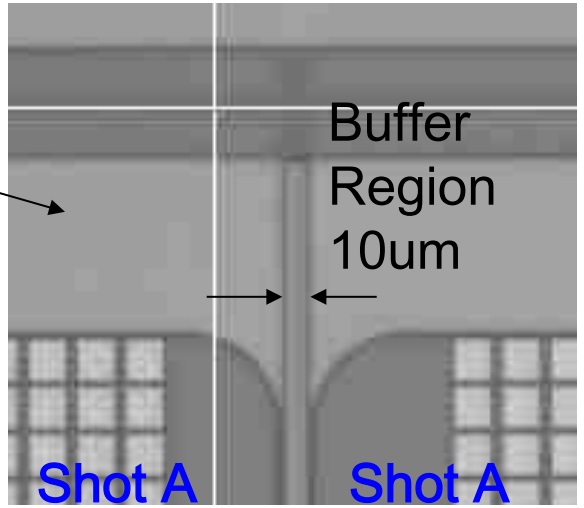
SOPHIAS by RIKEN

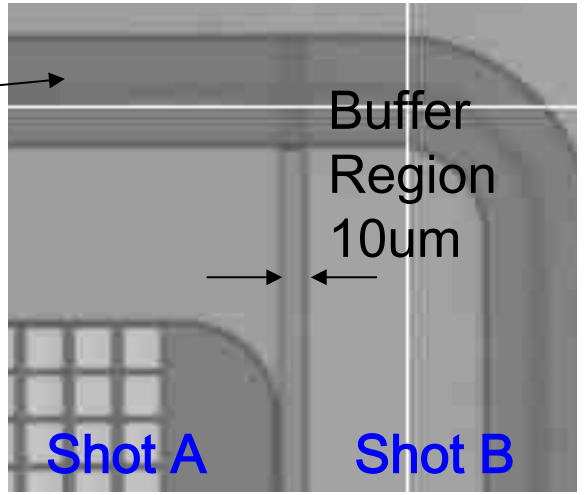
Produce 26.7 mm x 64 mm Sensing Area (3 Stitching).





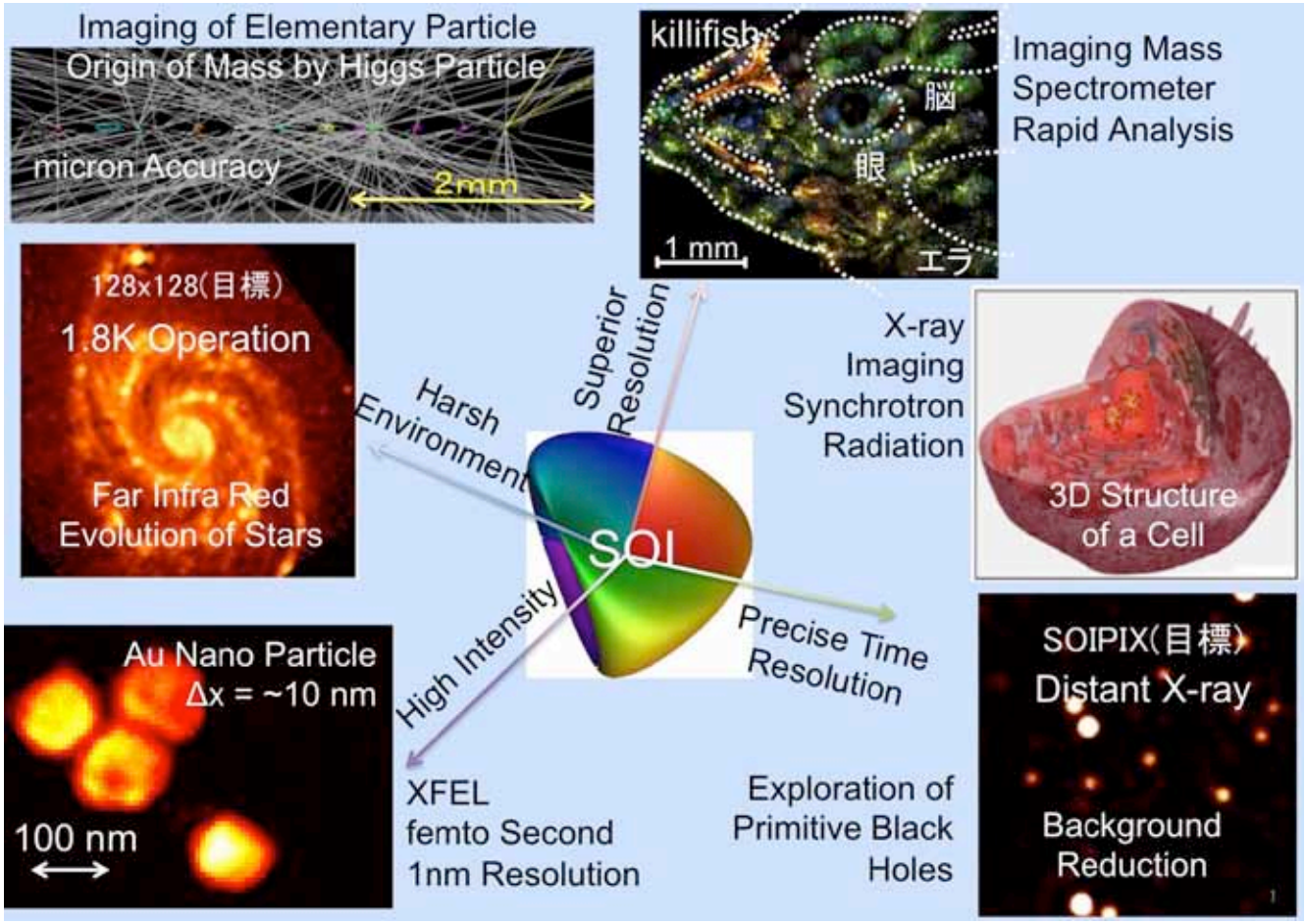






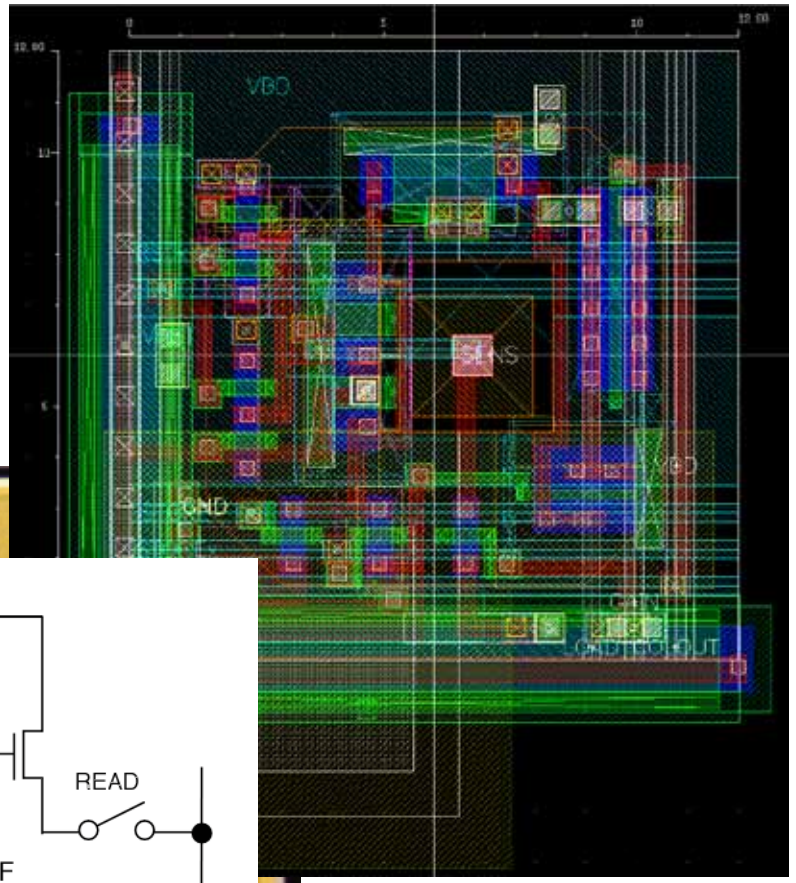
- Width of the Buffer Region can be less than 10um.
- Accuracy of Overwrap is better than 0.025um.

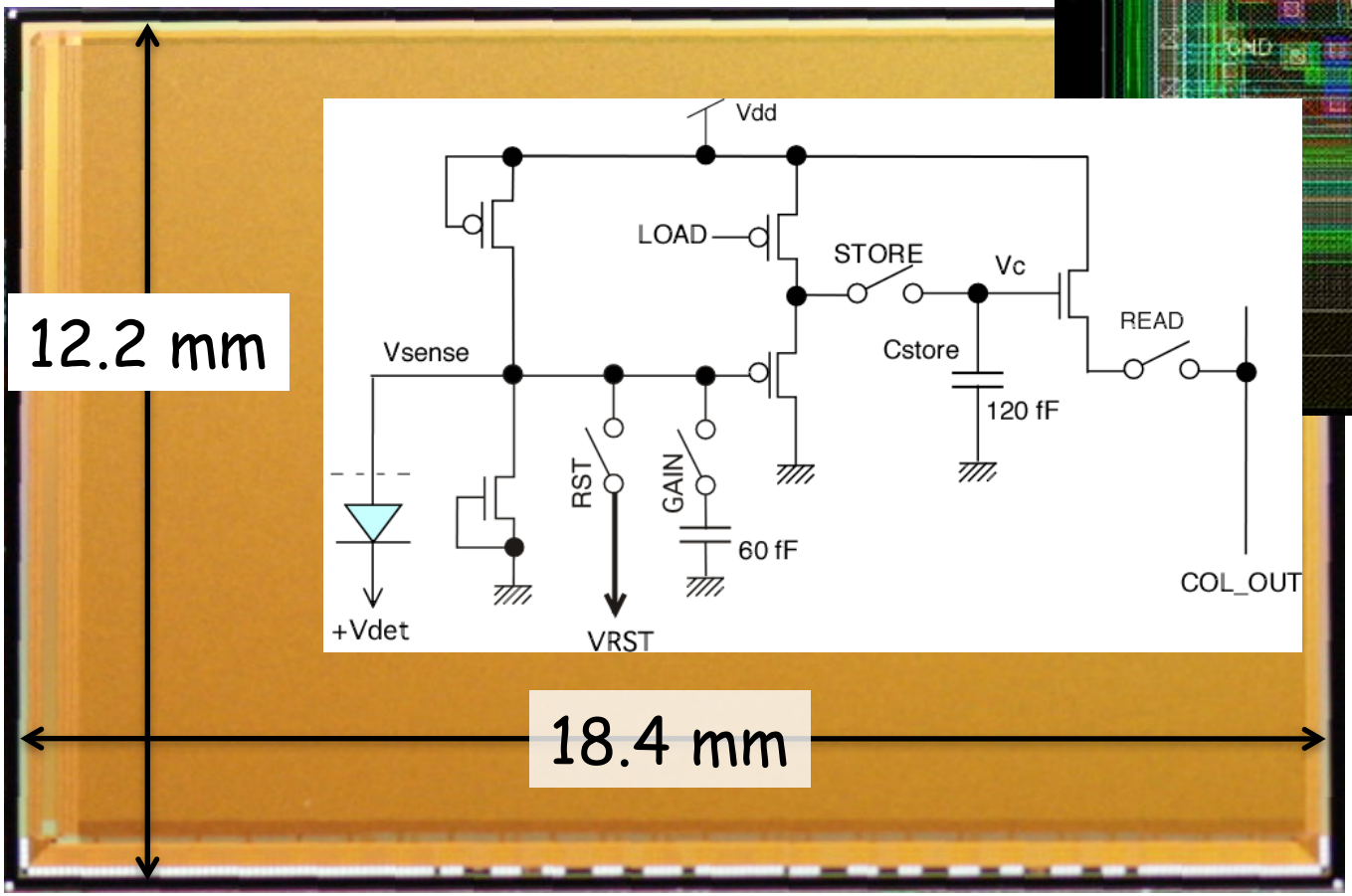
III. SOIPIX Detectors



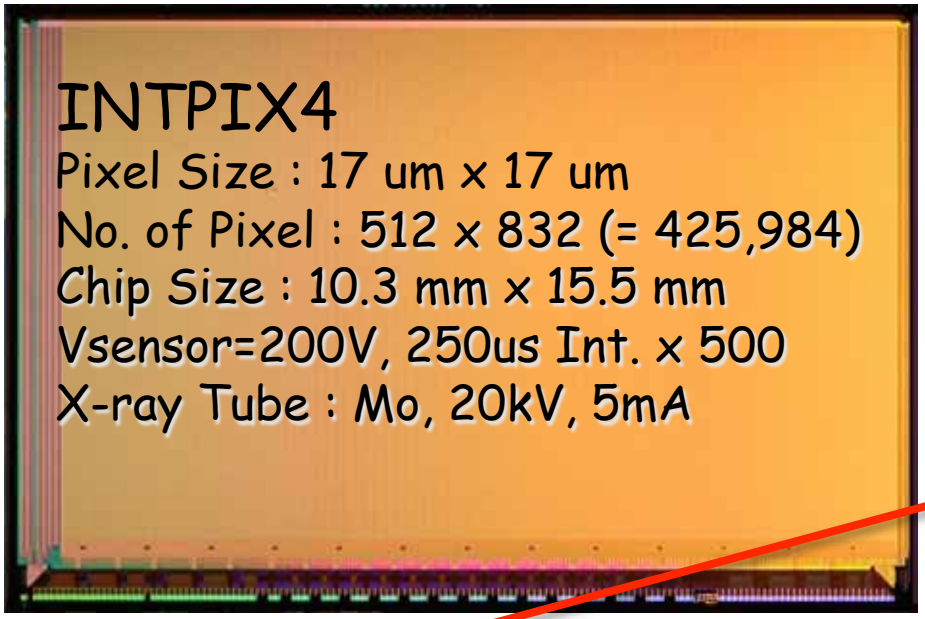
An example of SOIPIX: Integration Type Pixel (INTPIX)

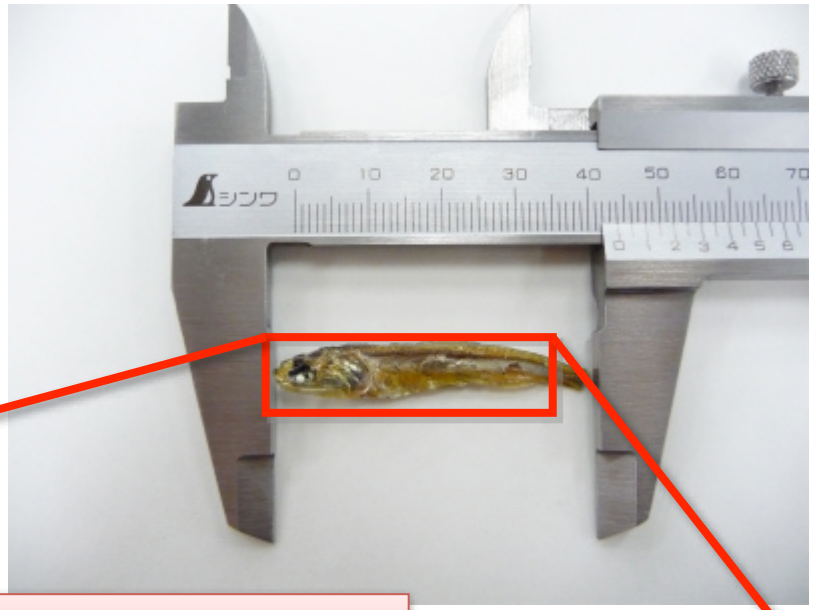
Pixel Size : 12x12 μm^2
896x1408 (~1.3 M) pixels、
11 Analog out port、Column CDS.



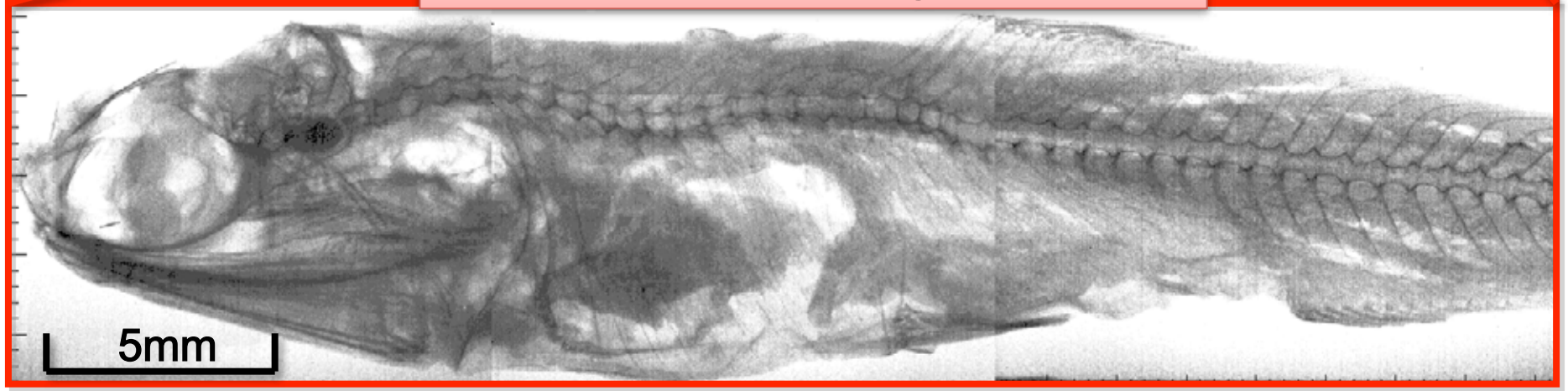


INTPIX5





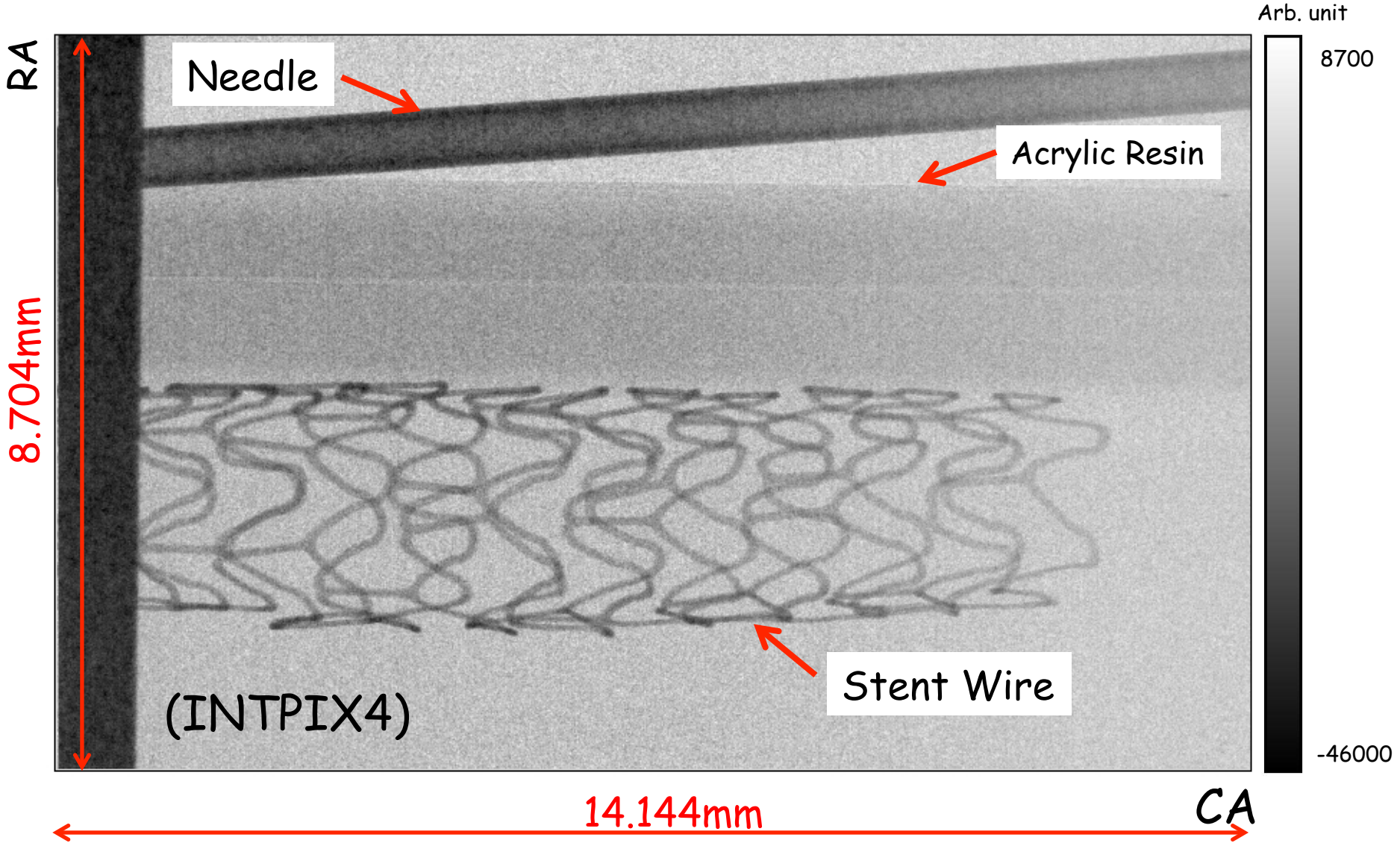
Fine resolution & High Contrast



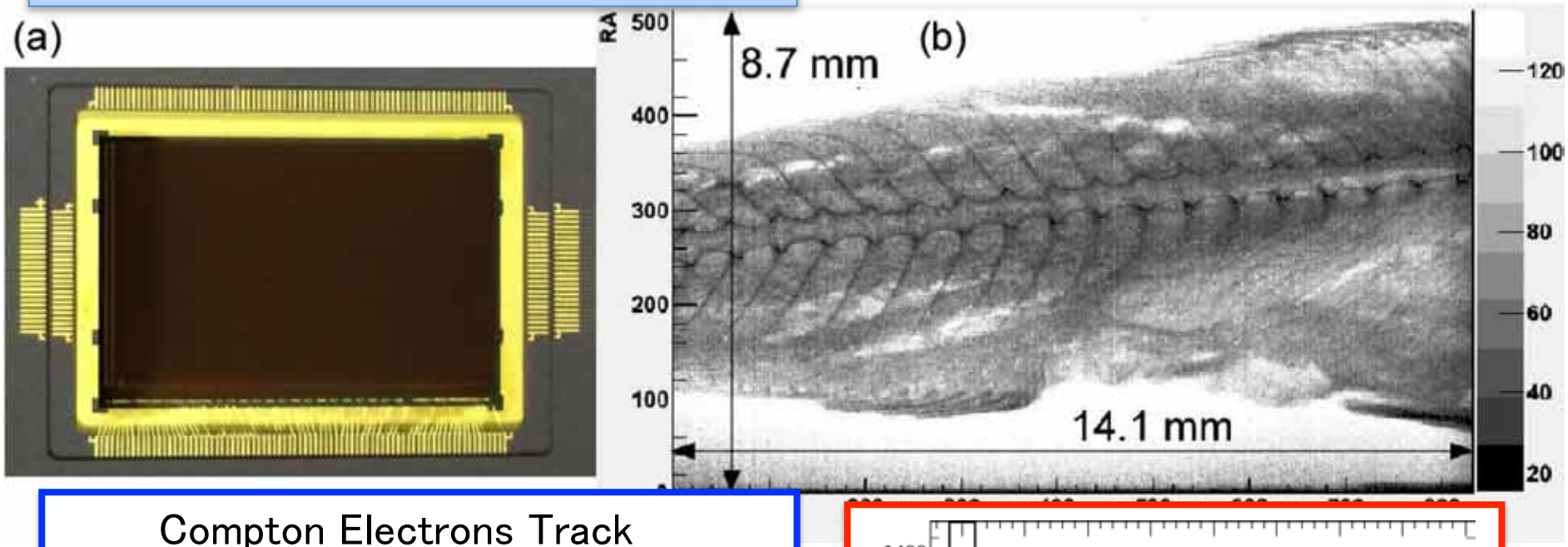
X-ray Image of a small dried sardine taken by a INTPIX4 sensor (3 images are combined).

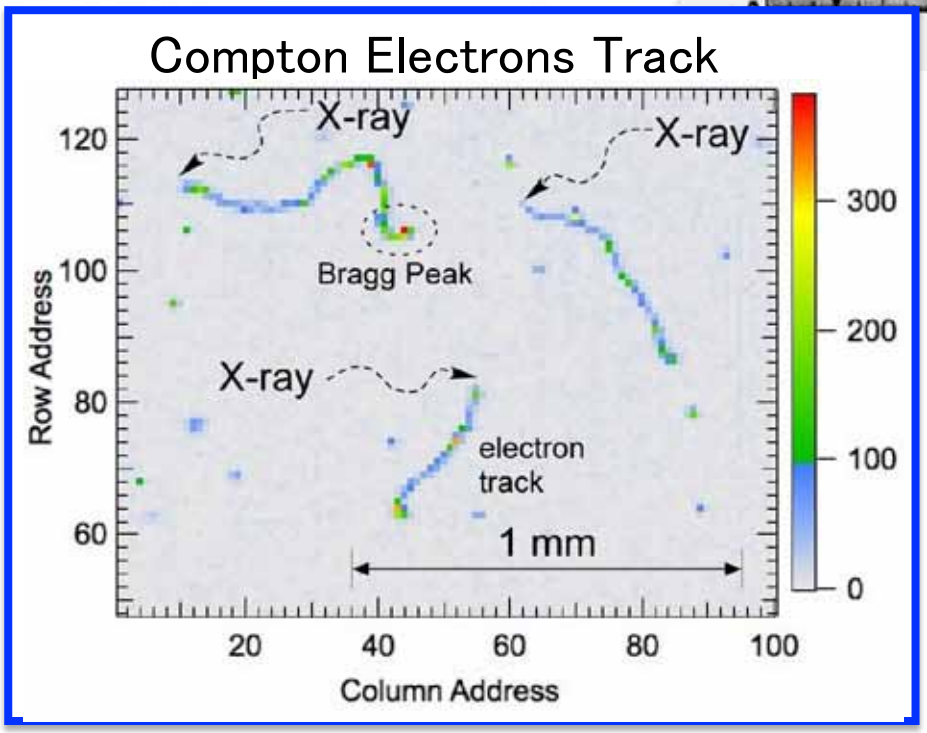
Examples of X-ray Image with the SOIPIX

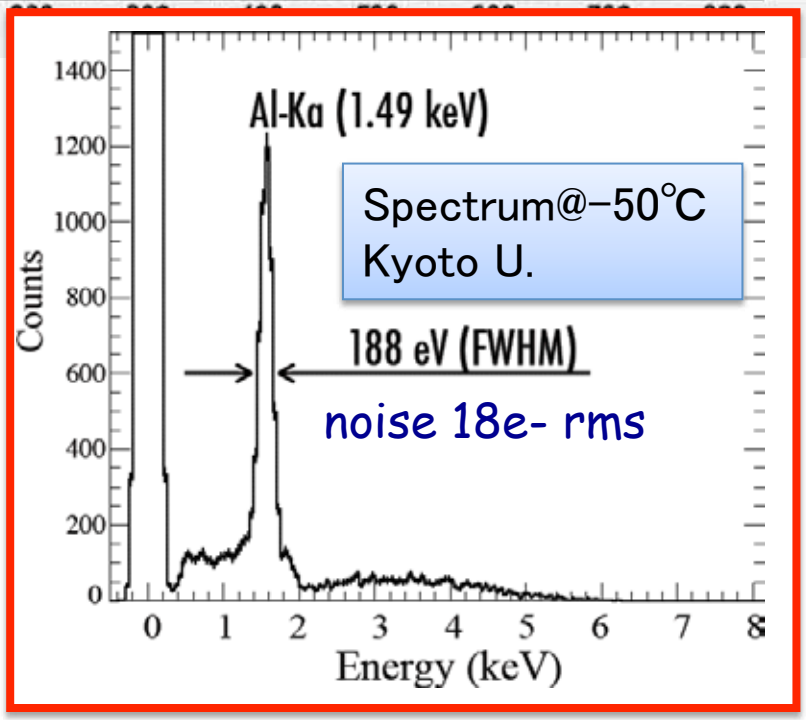
PF-AR NE7A 33.3keV
Acrylic resin 40mm
200us x 250 frames



Examples of SOIPIX Imaging



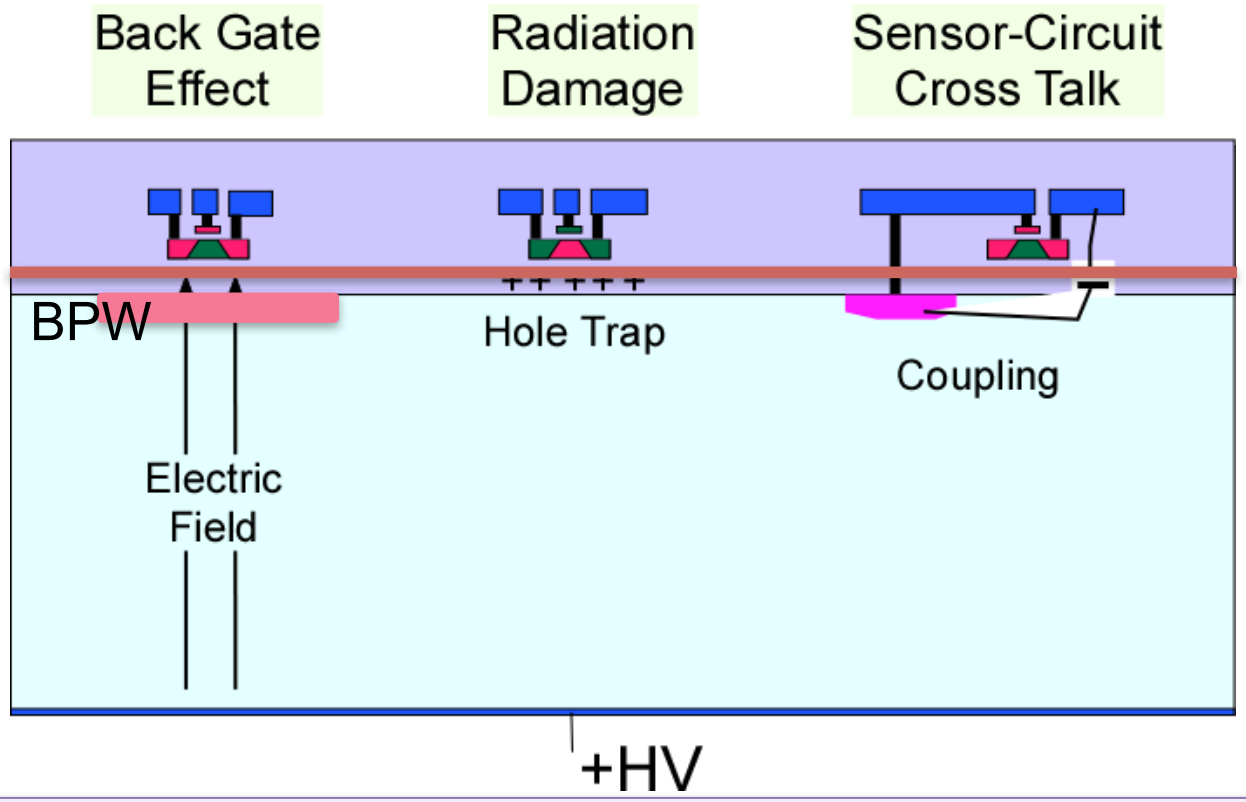




IV. Advanced R&D

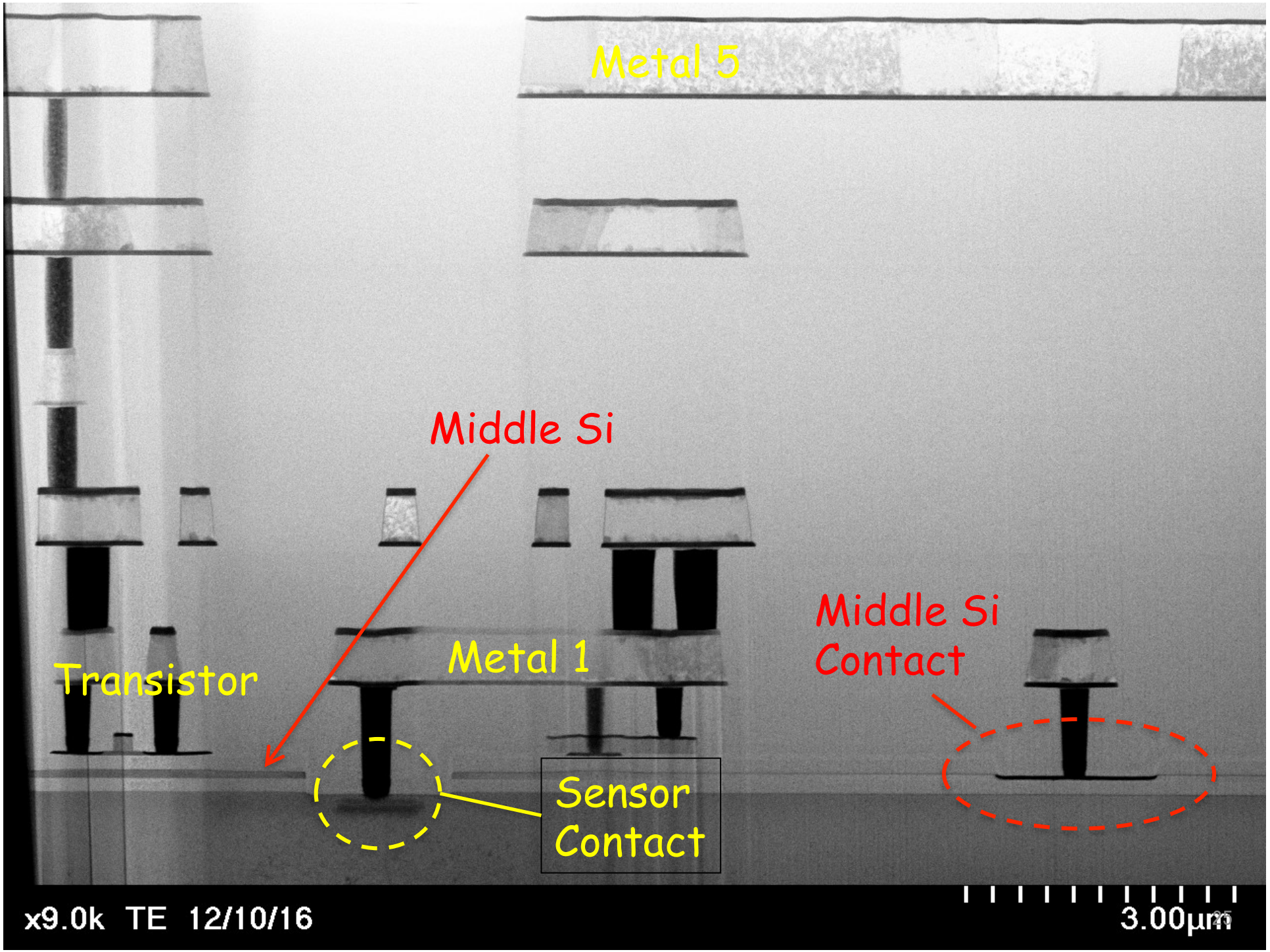
Double SOI wafer

Sensor and Electronics are located very near. This cause ..

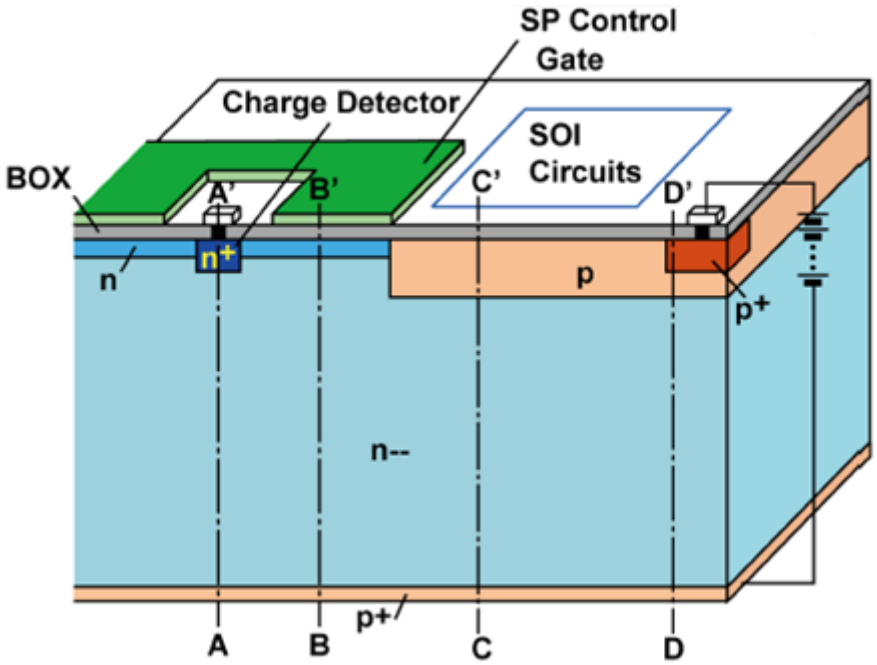


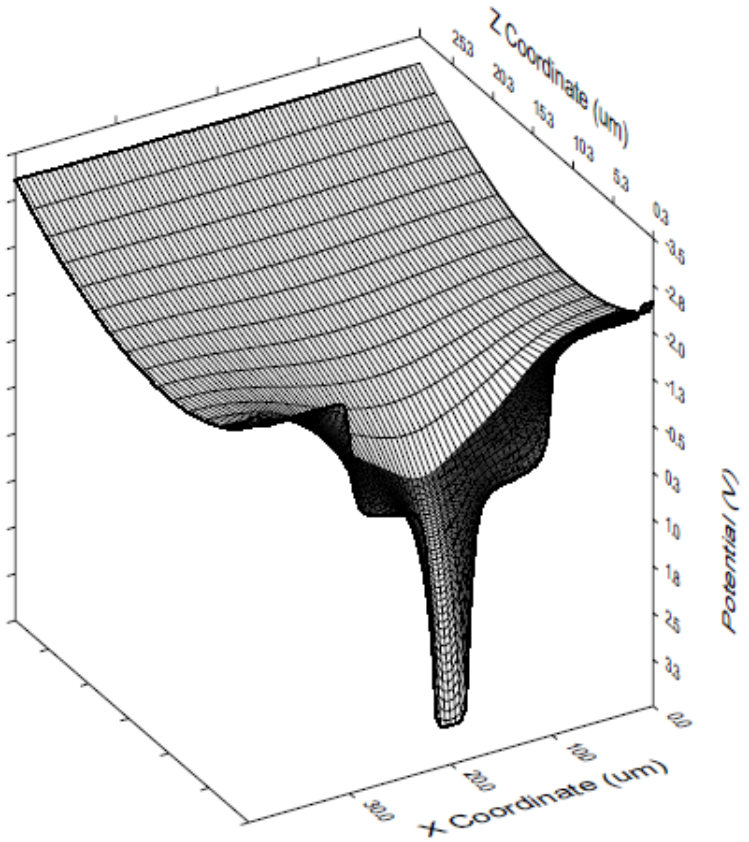
At first, we successfully introduced BPW layer to remove the back gate effect.

Then we newly introduced additional conductive layer under the transistors to reduce all effects (→ Double SOI).


Metal 5
Middle Si
Transistor
Metal 1
Middle Si
Contact
Sensor
Contact
x9.0k TE 12/10/16
3.00µm

New Sensor Structures





- Deplete from Back Side
- Very Low Input Capacitance
- Lower Leakage current
- Better charge collection

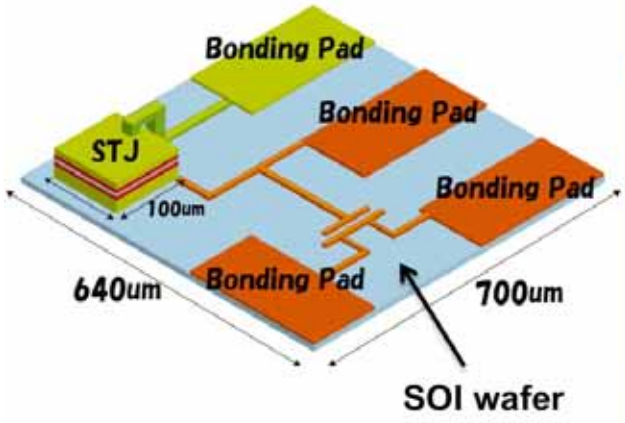
Shizuoka Univ.

STJ (Superconducting Tunnel Junction) on SOI

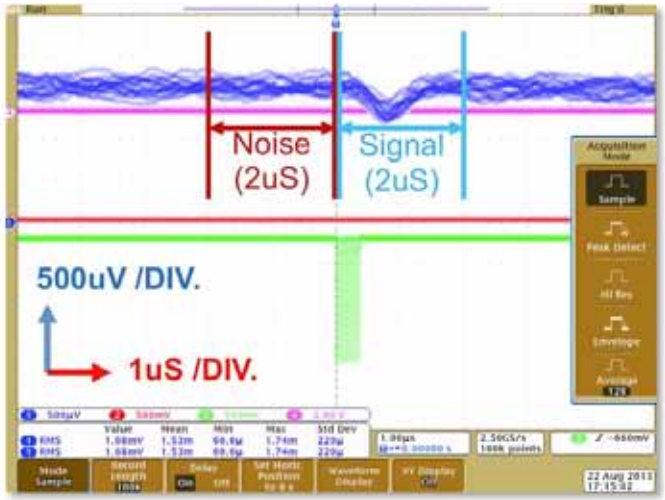
Tsukuba Univ. : Detection of Far Infra Red Photon

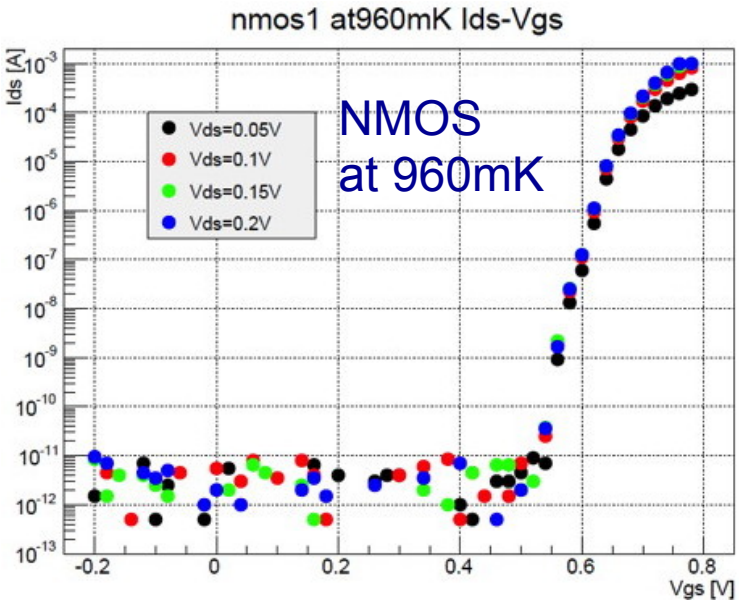
SOI transistors work at temperature below 1K.

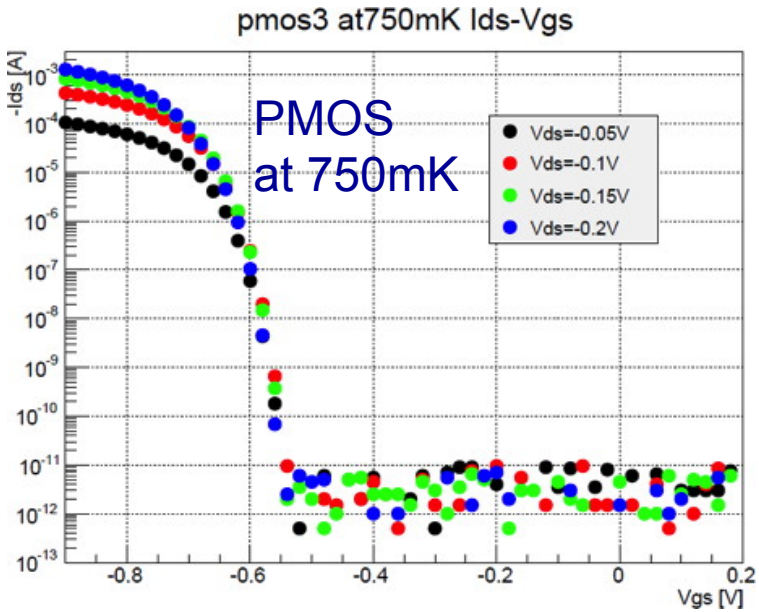
By building STJ sensors on SOI, multiple channel readout becomes possible!



Signal from Nb/Al STJ on SOI







V. Summary

- SOI Pixel process which integrate both radiation sensors and readout circuits in a single die is developed.
- The SOIPIX is a promising technology to achieve fine-resolution, high-performance, and cost-effective radiation image sensor.
- We operate regular MPW runs twice per year for Japanese and overseas academic users.
- In addition to use in the high-energy physics, there are many SOI detector projects for medical, material science and astro-physics applications.
- We appreciate any help or advices from the experts of the imaging devices.