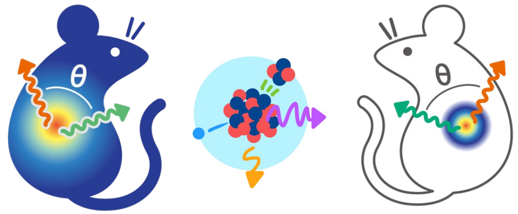


Development of trigger-mode fine-pitch silicon hybrid detectors for electron tracking Compton camera

[1]Kenji Shimazoe, [2]Mizuki Uenomachi, [3]Ayaki Takeda, [4]Setsuo Sato, [5]Daisuke Matsunaga, [5]Yuji Okubo, [5]Junichi Aoyama, [6]Makoto Motoyoshi

[1]The University of Tokyo, [2]Kyoto University, [3]Miyazaki University, [4]KEK, [5]HORIBA, [6]T-micro

PSD13: The 13th International Conference on Position Sensitive Detectors, 3 - 8 September 2023, Oxford, UK

Today's Talk

1. Introduction ~ Compton Imaging
2. Electron Tracking
3. Detector Configuration
4. Silicon detectors
5. ASIC & bump
6. Preliminary results
7. Summary

1. Compton Imaging
Wide band-multi color Imaging

THE UNIVERSITY OF TOKYO 東京大学

PET ·SPECT Imaging·Theranostics

- ✓ PET metabolism of malignancy
- ✓ SPECT labeling antibody

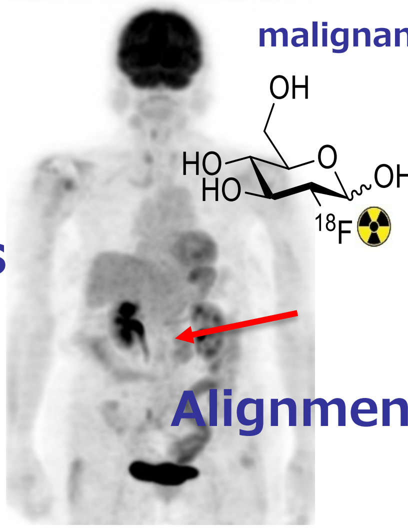
  currently separated diagnosis

  -> Organ movement, alignment by eyes

➡ **simultaneous multi molecule Imaging**

- ✓ Therapy α、β emitter

PET

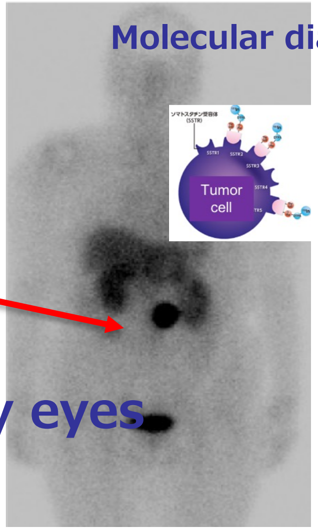


malignancy

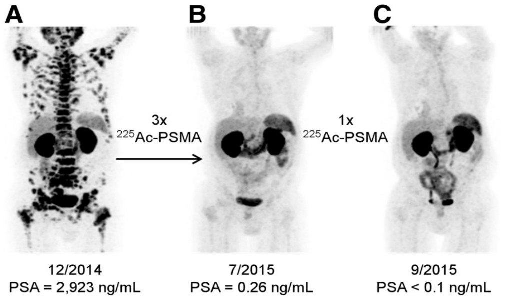
Alignment by eyes

SPECT

Molecular diagnosis



Therapy

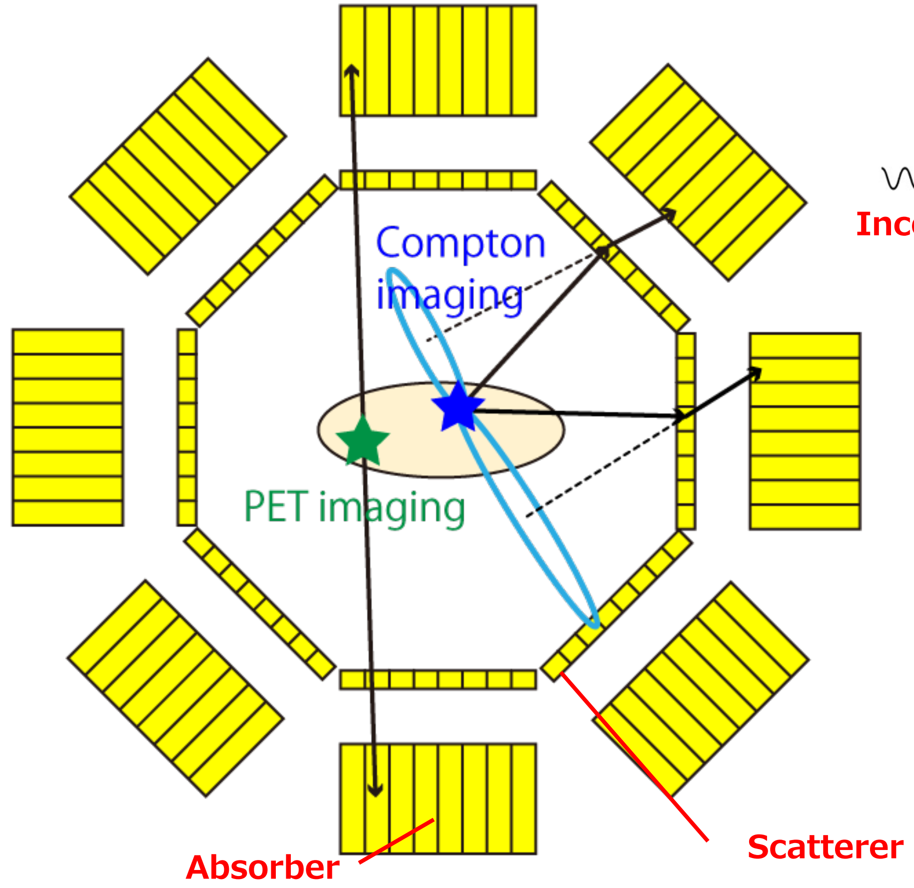


Kratochwil et al. J Nucl Med 2016;57:1941-1944

	Nuclide	Half life	Radiation: α･β	Radiation: γ-ray Energy	Clinical application
PET	^{18}F	110 m	β^+	511keV	Tumor/Brain imaging、Glucose imaging
SPECT	^{99m}Tc	6 h		141 keV	Brain, blood flow, tumor, etc.
	^{111}In	2.8 d		171, 245 keV	bone marrow imaging, etc.
Therapy	^{131}I (β)	8 d	606 kev	364 keV	thyroid cancer therapy, etc.
	^{225}Ac (α)	10 d	6-8 MeV	218, 440 keV	prostate cancer therapy, etc.

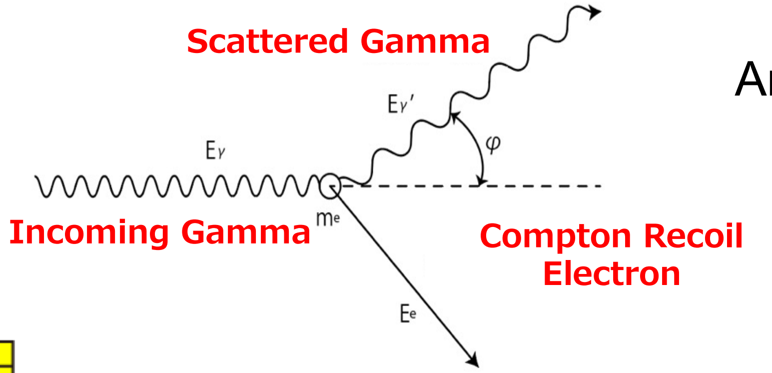
1. Compton+PET imaging

First Compton-PET
Hybrid Imaging Demonstration



Shimazoe, K. et al. NIMA 954 (2020): 161499.

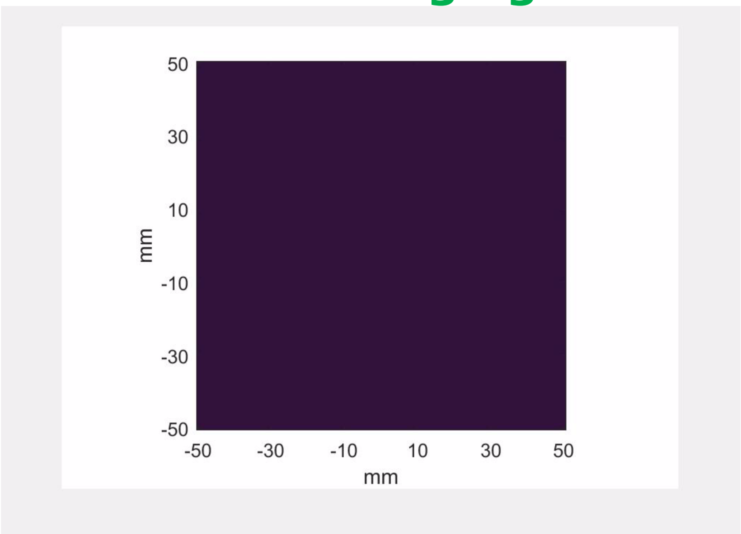
- **PET nuclides-> PET imaging**
- **SPECT / Therapy -> Compton Imaging**



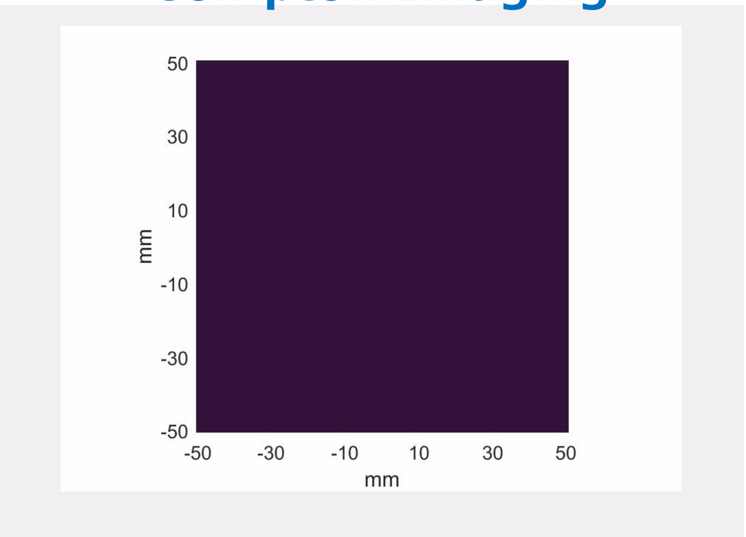
Angle is calculated by

$$\theta = \mathrm{acos}\left(1 - m_0 c^2 \left(\frac{1}{E_0 - E_{sca}} - \frac{1}{E_0}\right)\right)$$

PET imaging

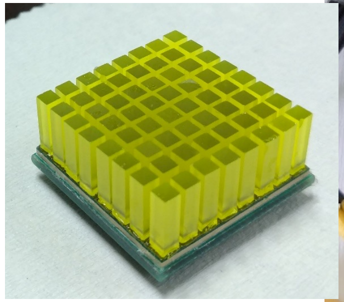


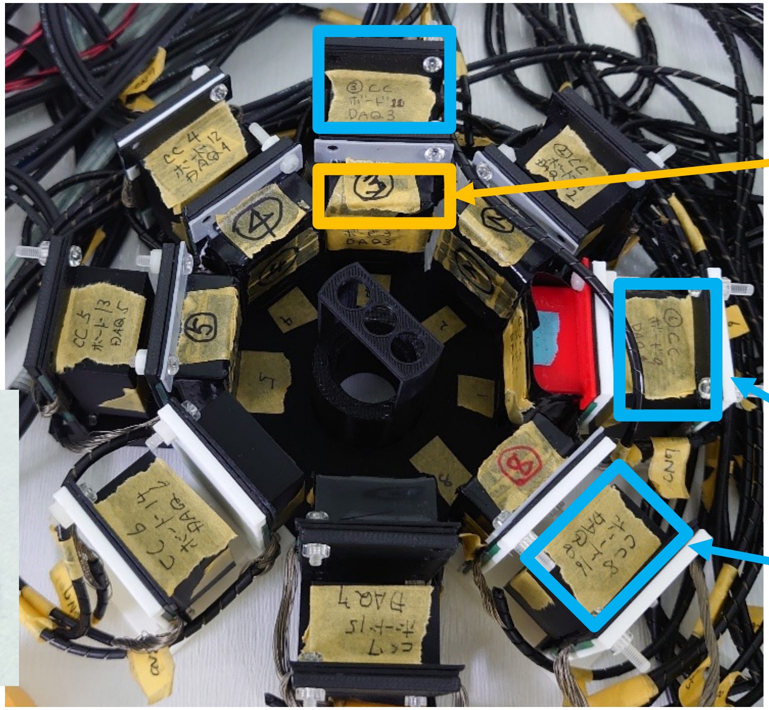
Compton Imaging



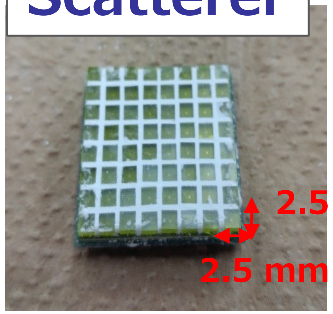
1. Compton-PET demonstrator

■ Detectors

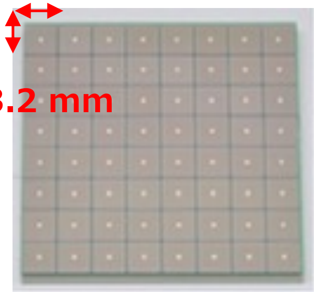




HR-GAGG **Scatterer**

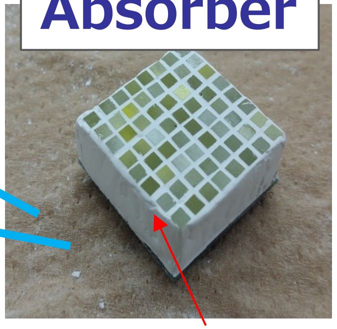


\+

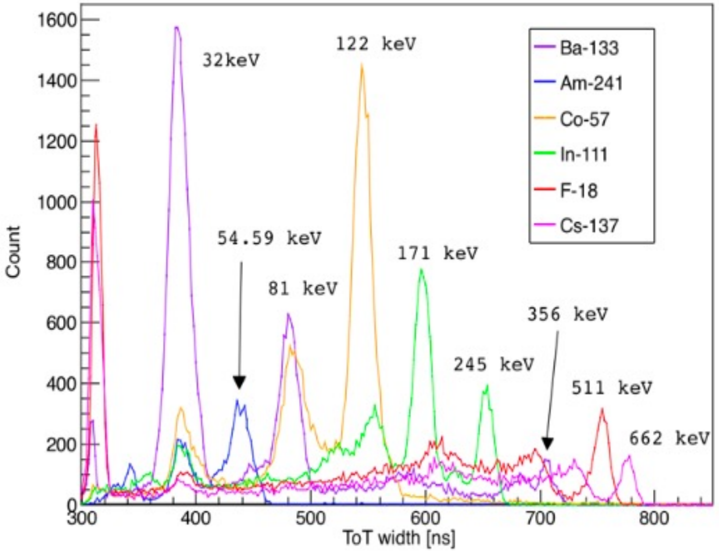


SiPM

HR-GAGG **Absorber**



$BaSO_4$ reflector

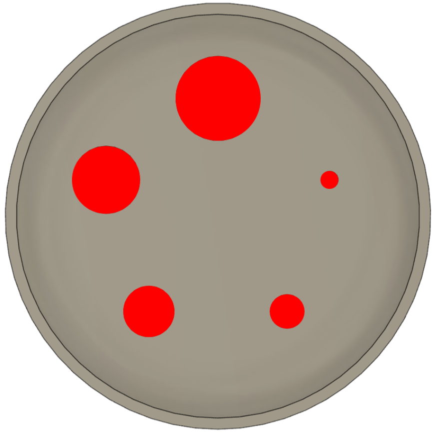


- **Scatterer/Absorber**
  8 × 8 array **HR-GAGG** ($\rho = 6.63\ g/cm^3$)
  : 2.5 mm × 2.5 mm × 1.5(sca) / 9(abs) mm
- **Silicon photomultiplier (SiPM)**
  8 × 8 array SiPM (Hamamatsu S-13361-3050N-08)
  : 3.2 mm × 3.2 mm

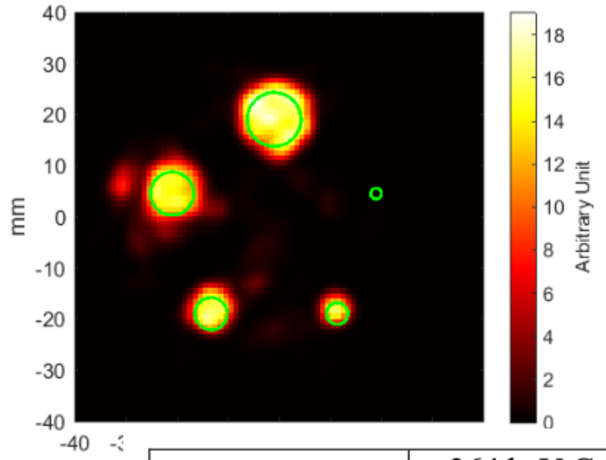
1. Compton-PET demonstrator

■ ^{18}F-FDG(PET) and Na^{131}I(Therapeutic) *phantom* Imaging

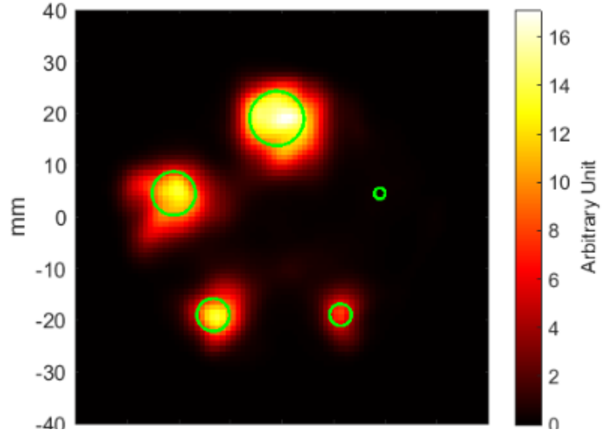
The diameters of the rods
15, 12, 9, 6, and 3 mm



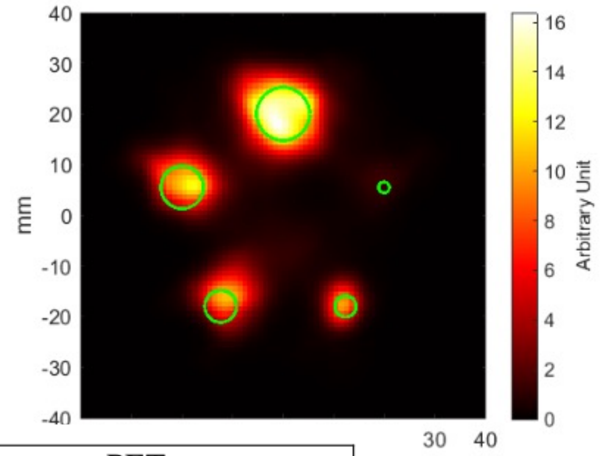
PET imaging
(511 keV)



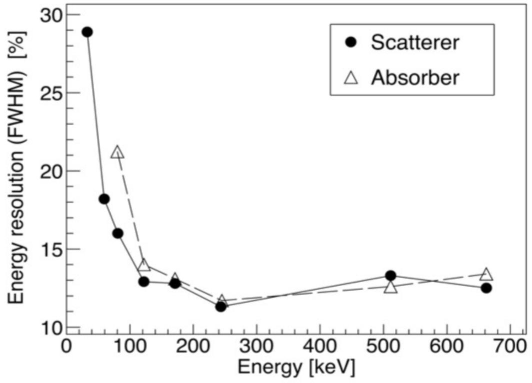
Compton imaging
(18F-FDG 511 keV)

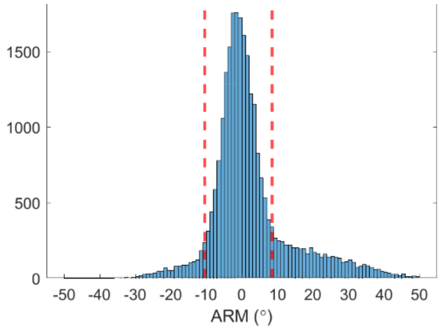


Compton imaging
(Na^{131}I 356 keV)

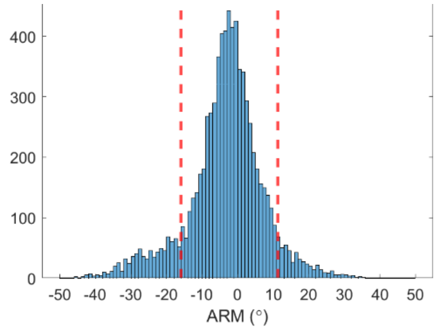


	364 keV Compton camera	511 keV Compton camera	PET
Sensitivity	2.0×10^{-5}	6.3×10^{-5}	1.2×10^{-4}





ARM = 9.49°
@ 511 keV

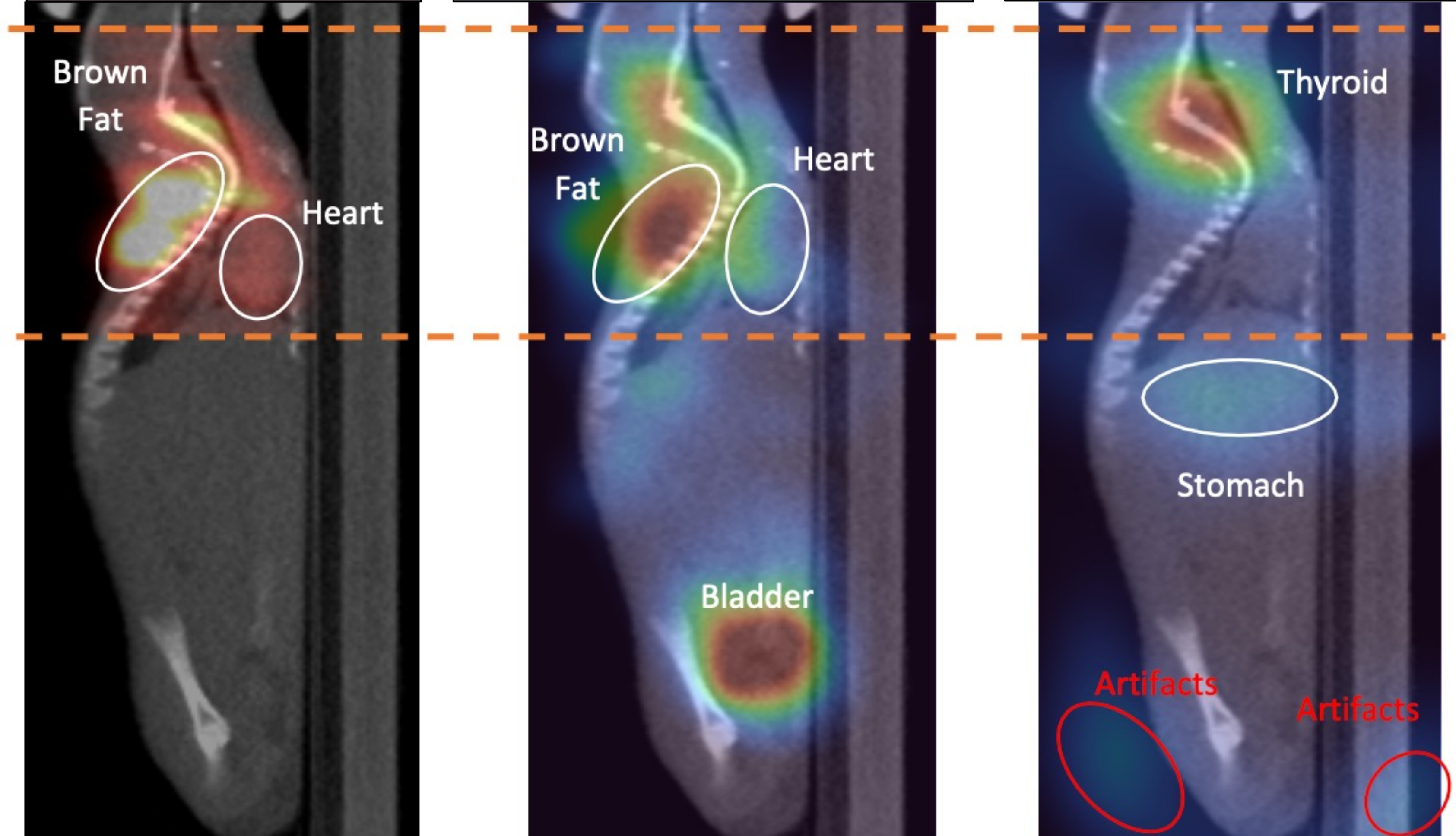


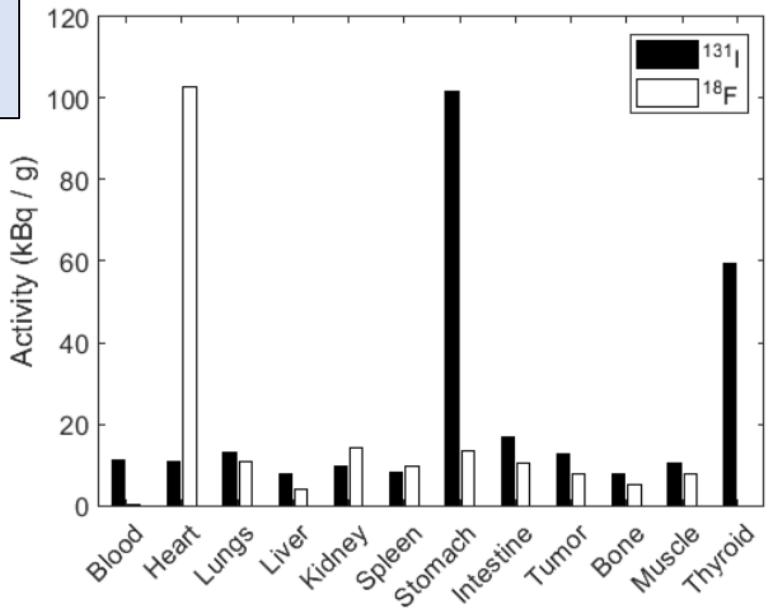
ARM = 12.3°
@ 356 keV

1. Compton-PET demonstrator

■ ^{18}F-FDG(PET) and Na^{131}I(Therapeutic) *in vivo* Imaging

PET imaging (511 keV)	Compton imaging (18F-FDG 511 keV)	Compton imaging (Na^{131}I 356 keV)





Accumulation in Organs

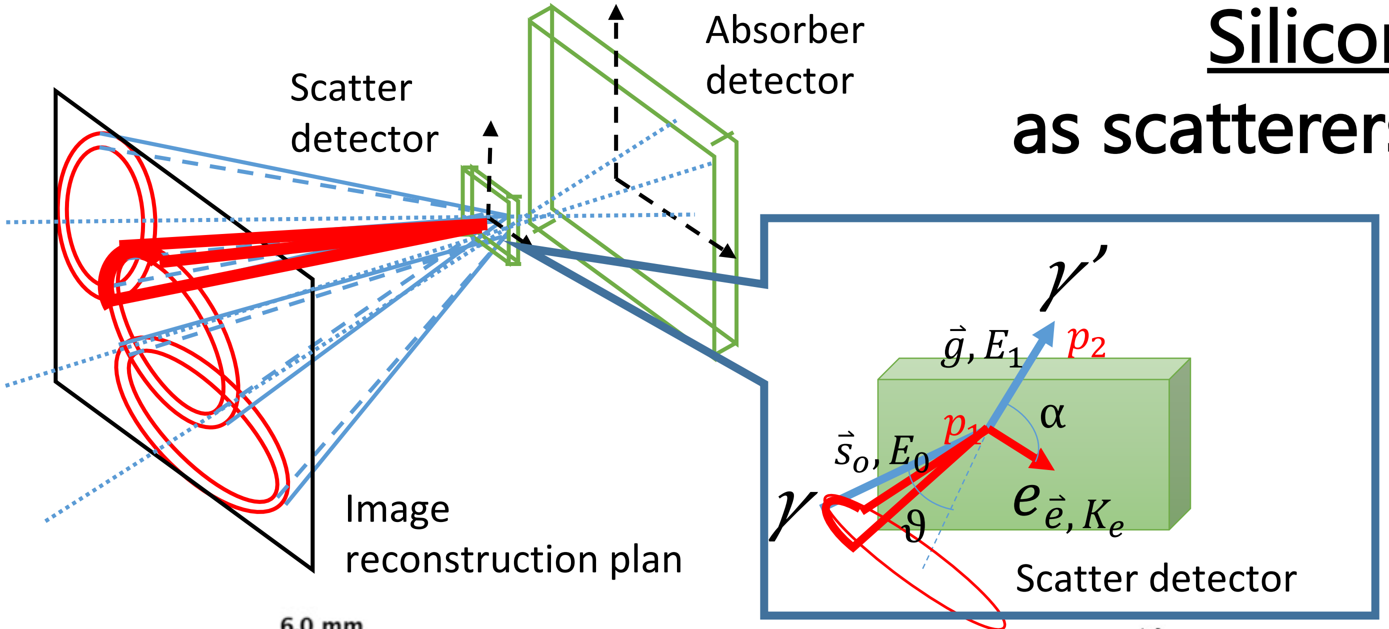
current limitation

angular resolution ~ 9°

Artifact, low SNR

Uenomachi, M., et al. *Scientific reports* 11.1 (2021): 17933.

2. Electron Tracking in Silicon

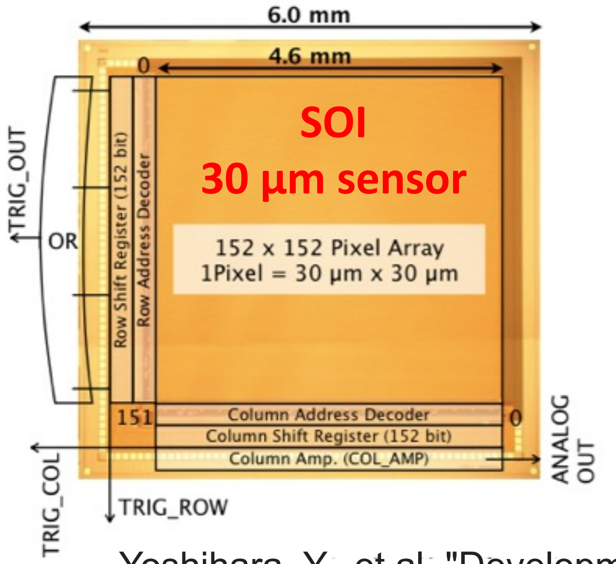


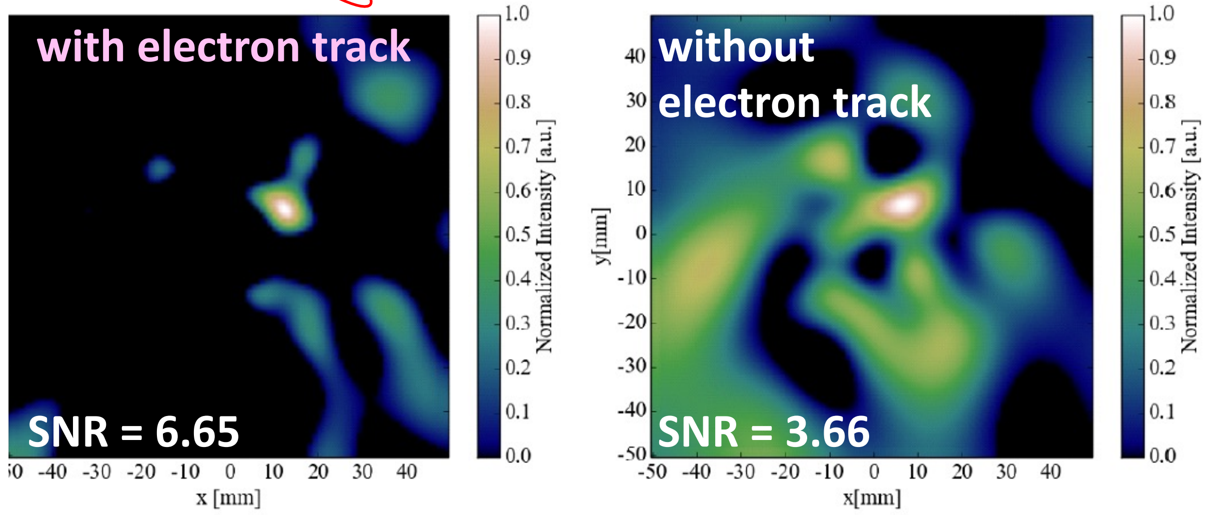
Silicon pixel detectors
as scatterers in Compton Imaging

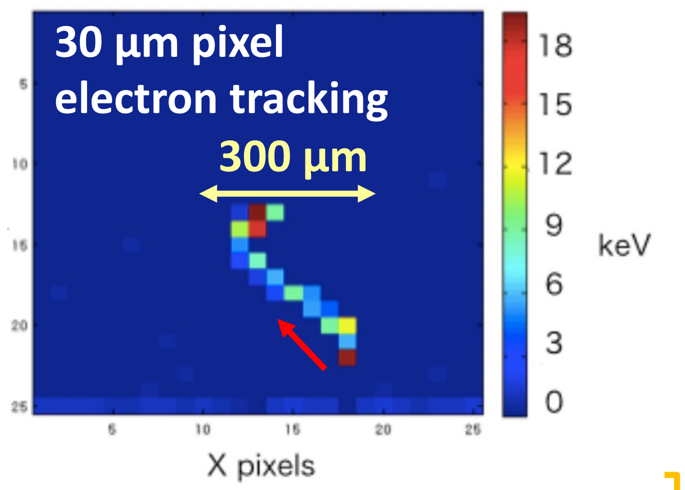
Better energy resolution, angular resolution ~ 1°

Electron tracking capability for better SBR

⇒Next talk (Dr. Uenomachi @ Kyoto U.)

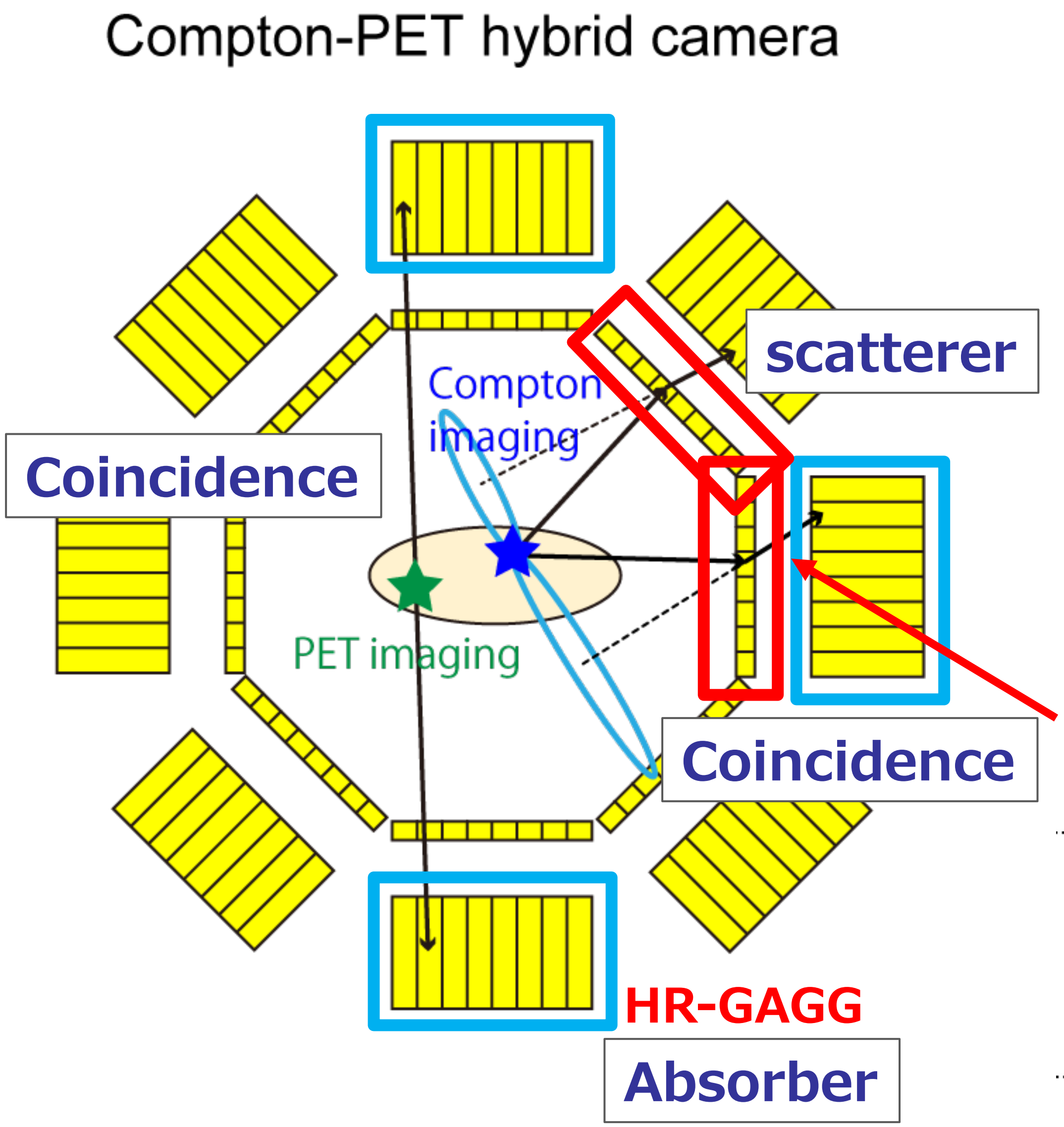






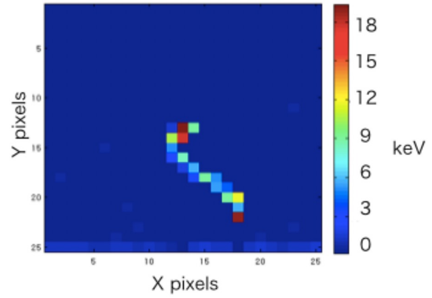
Yoshihara, Y., et al. "Development of electron-tracking Compton imaging system with 30-µm SOI pixel sensor." JINST 12.01 (2017): C01045.

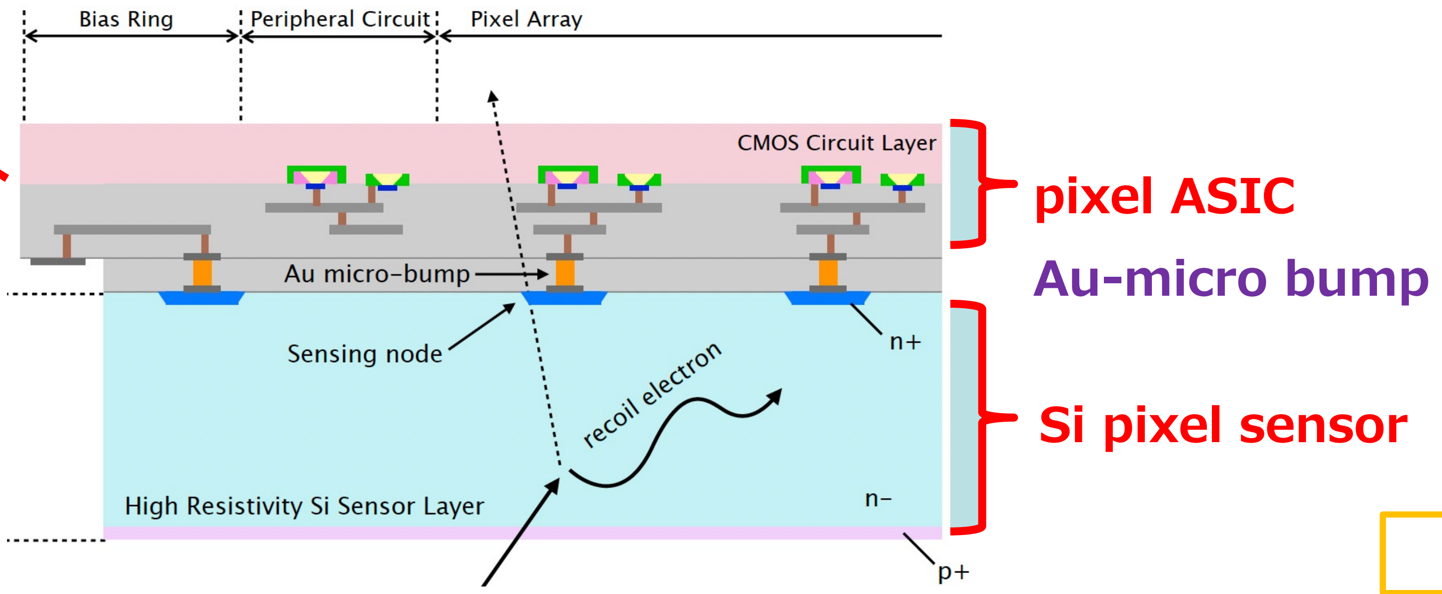
3. Detector Configuration



HR-GAGG ⇒ Si hybrid detectors as Compton scatterer

- Coincidence detection (Asynchronous trigger)
- spectroscopy
- ~ 100 kHz for medical imaging
- Recoil electron pattern readout



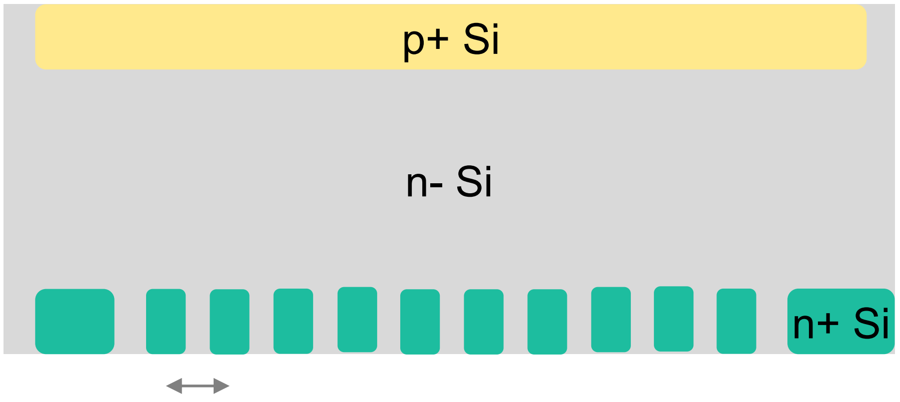


4. Silicon pixel Detectors

東京大学 THE UNIVERSITY OF TOKYO

HORIBA (HORIBA. JAPAN)

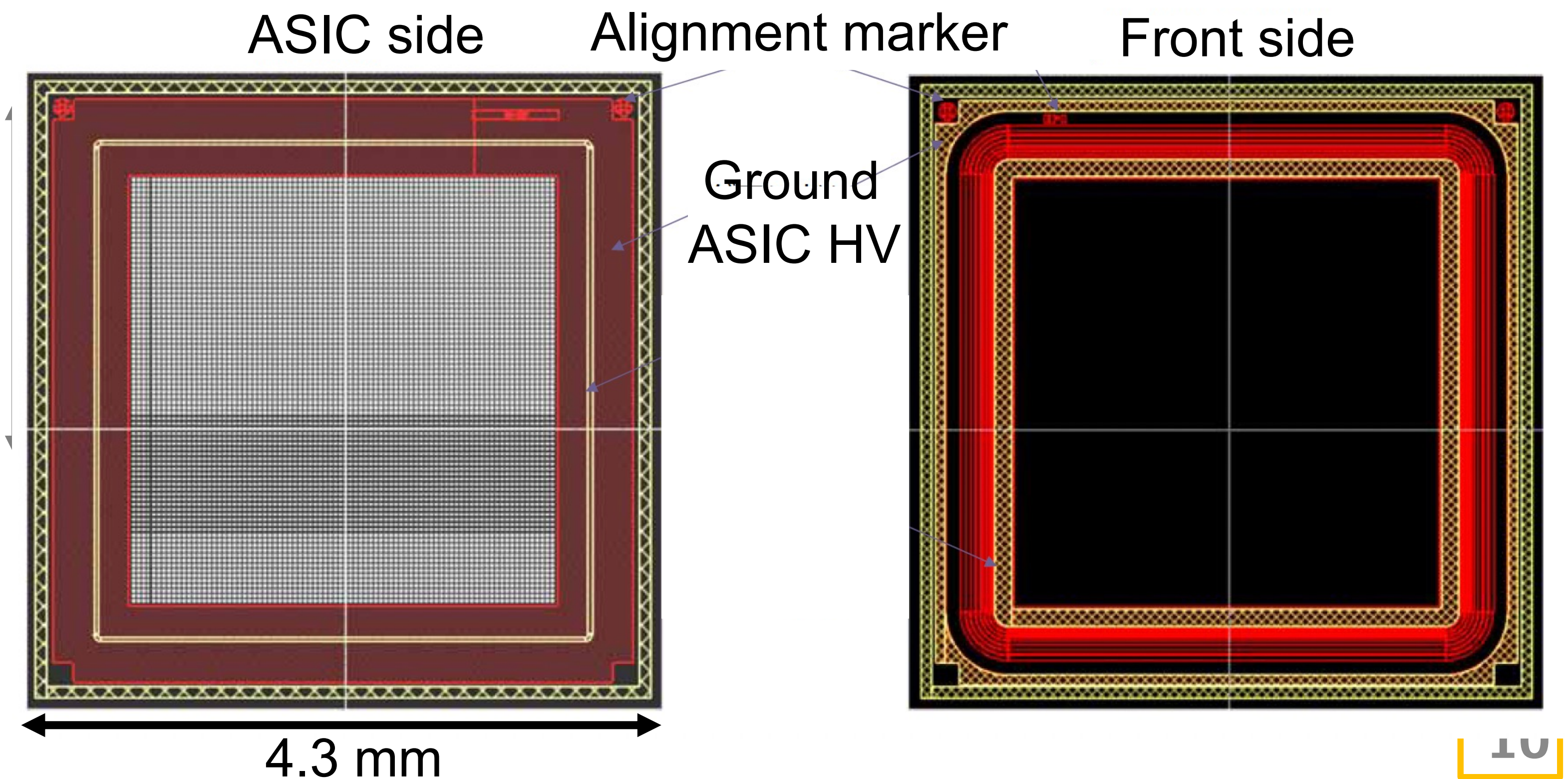
Name	Pixel size	No. of Pixel	PAD opening	Chip size	output coupling	Metal
V1-B V1-A	18 μm	168 x 168 192 x 192	φ4 μm	4.3 x 4.3 mm	DC	Al(Si 1%)
V2-B	36 μm	84 x 84	φ6 μm	4.3 x 4.3 mm	DC	Al(Si 1%)



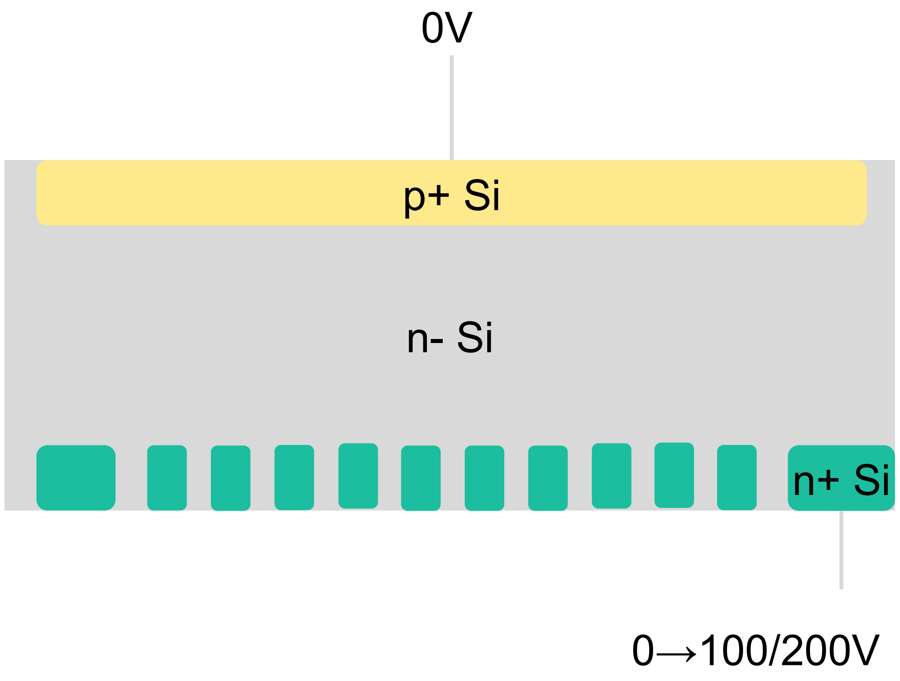
pitch： 18 μm or 36 μm

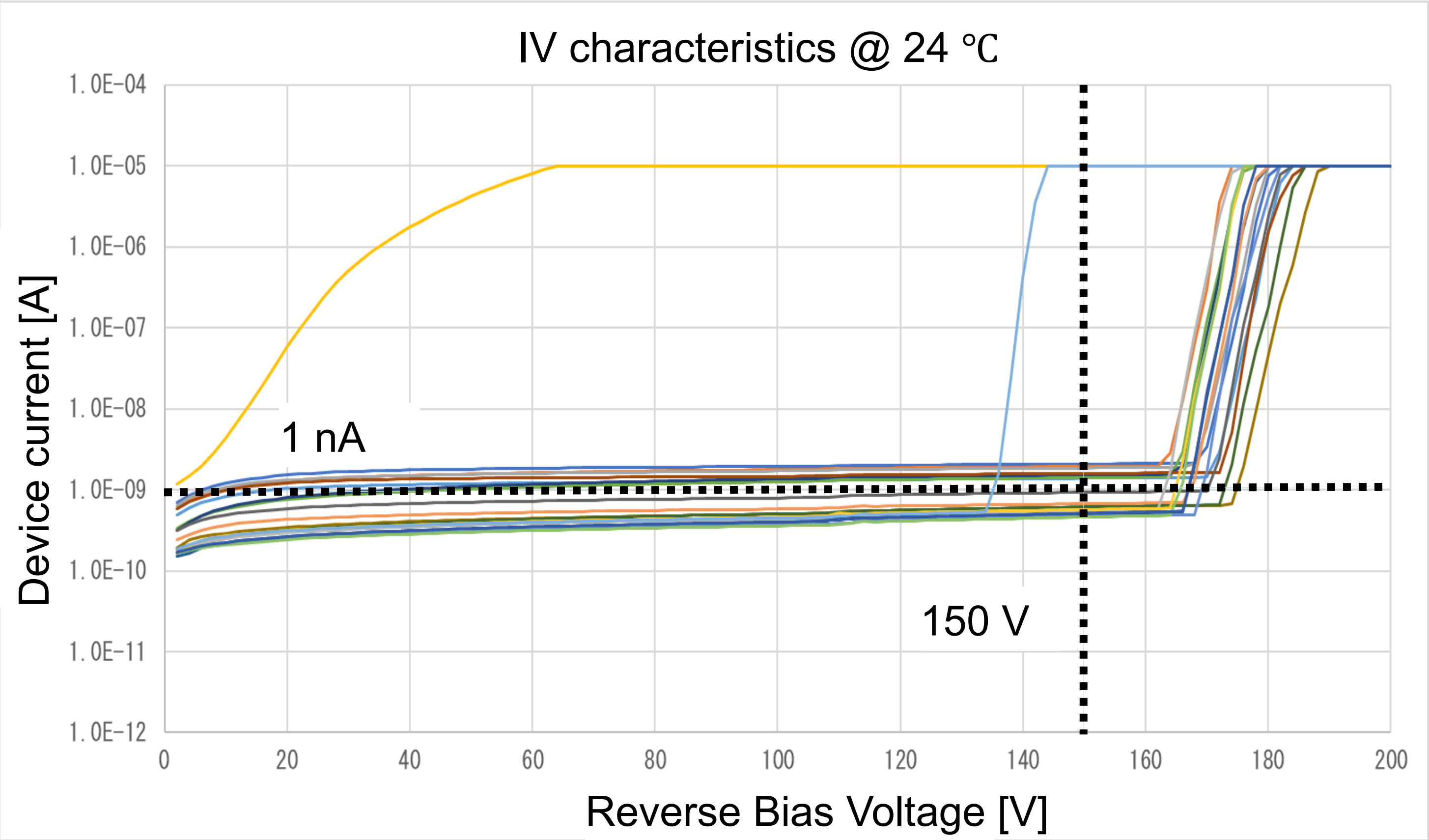
Wafer thickness： 450 μm

Resistance: 6-8 kΩ



4. Silicon pixel Detectors





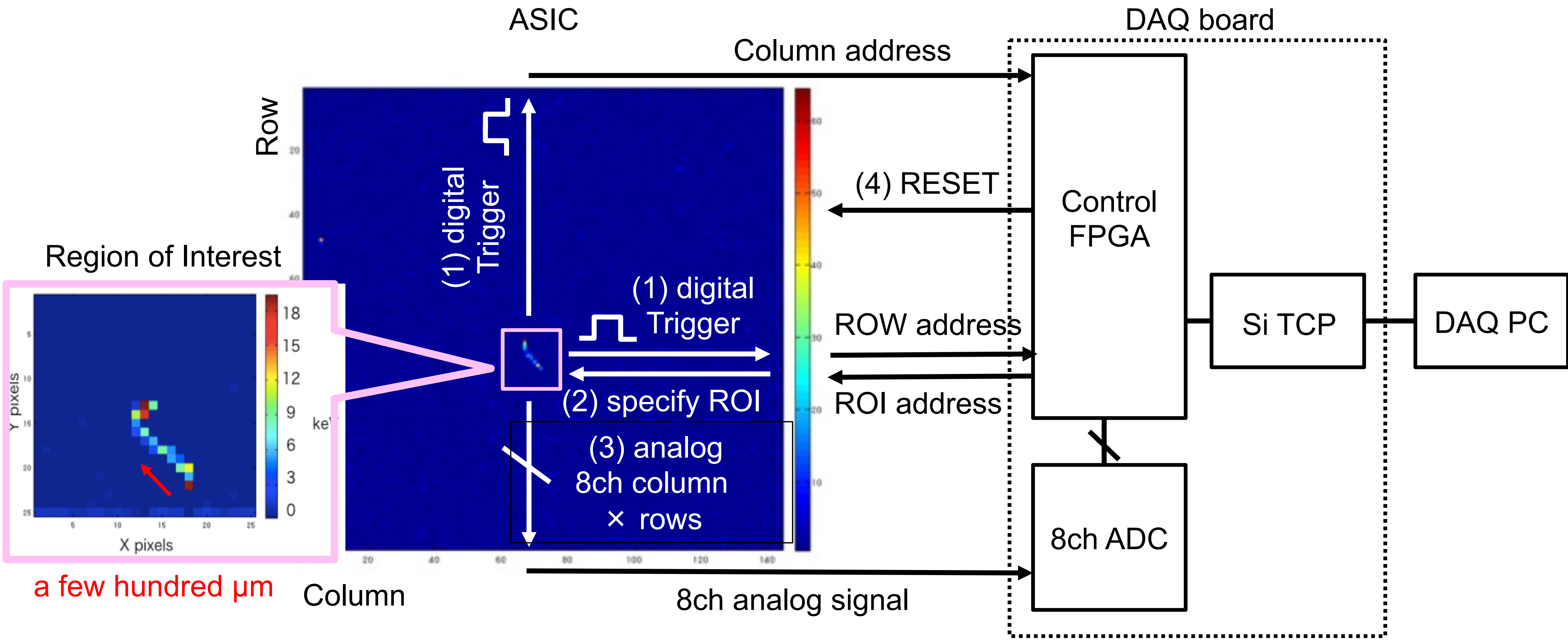
Sensing nodes are pixelized (18 or 36 μm)

Resistance: 6-8 kΩ

Thickness : 450 μm

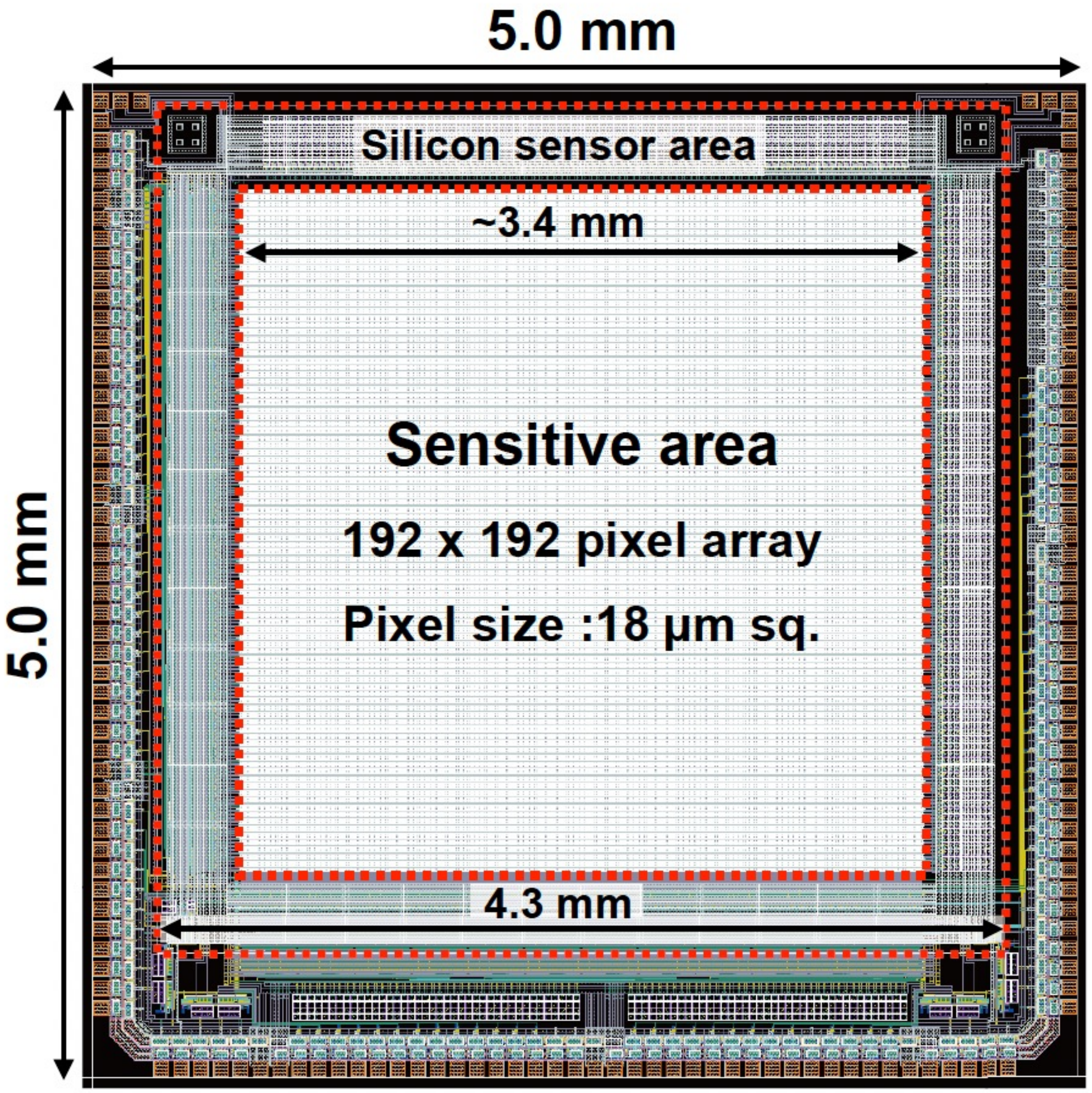
Measurement temperature：24℃
p+ Si is grounded、n+ Si is changed from 0 V to 200V

5. ASIC design concept



➢ **Asynchronous trigger and selective readout of electron track**

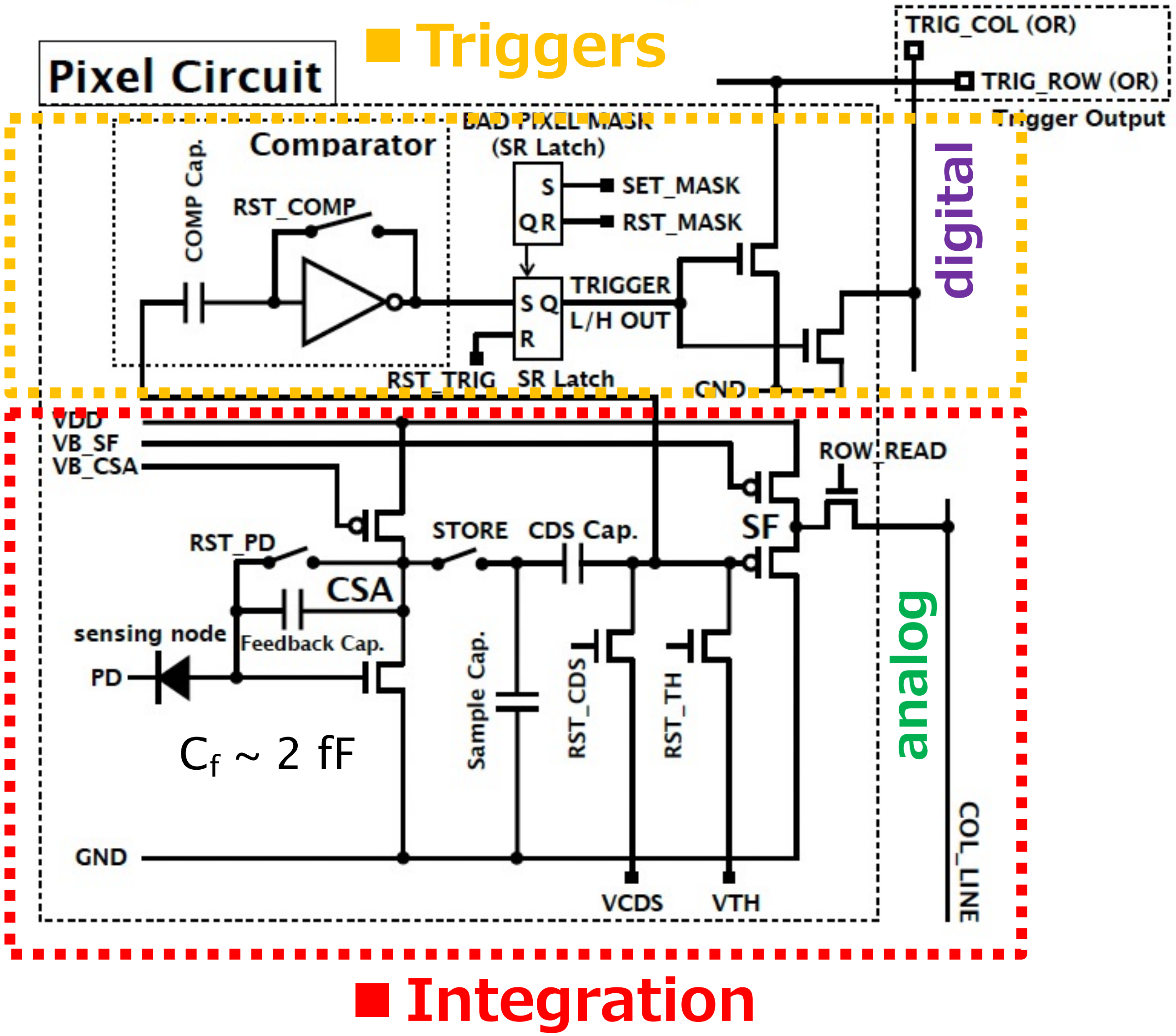
5. ASIC prototype chip design

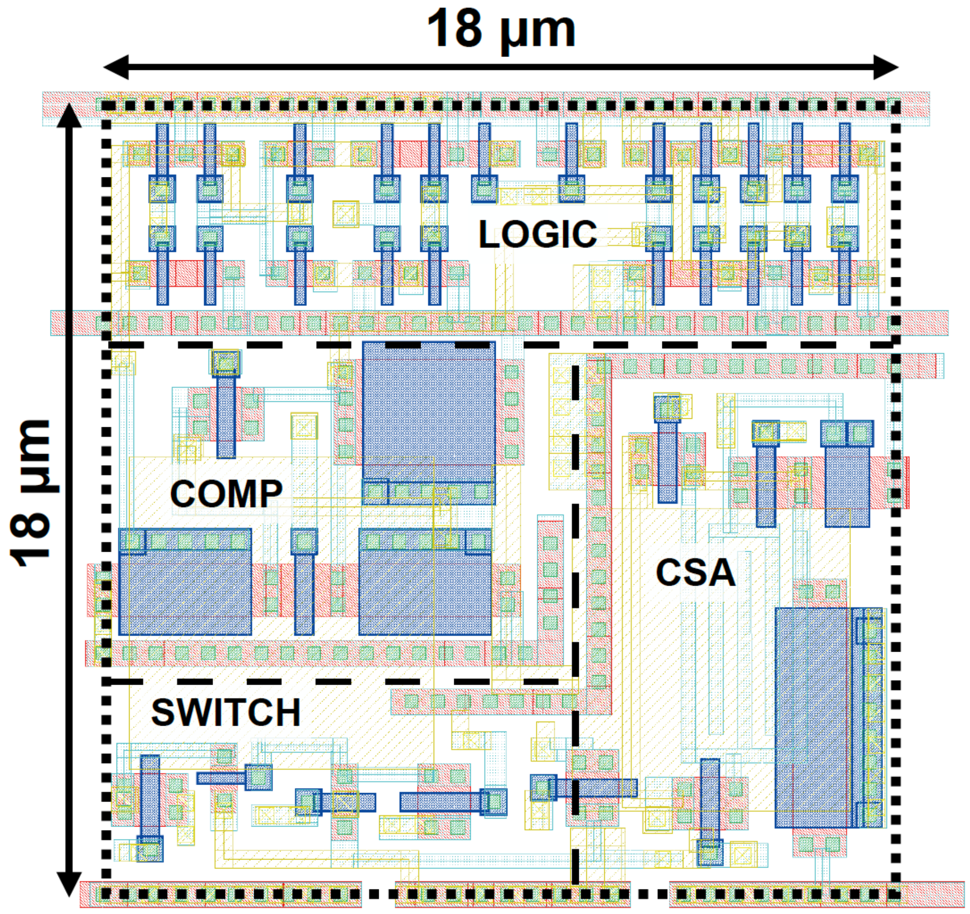


Components

- Process: TSMC 0.25 μm
- Chip size: 5.0 mm × 5.0 mm
- # of Pixel: 192 (V) × 192 (H)
- Pixel size: 18 μm × 18 μm
- Sensitive area: 3.4 mm × 3.4 mm

5. ASIC pixel design





- ✓ Charge sensitive amplifier (CSA)
- ✓ Correlated double sampling (CDS)
- ✓ Inverter chopper type comparator

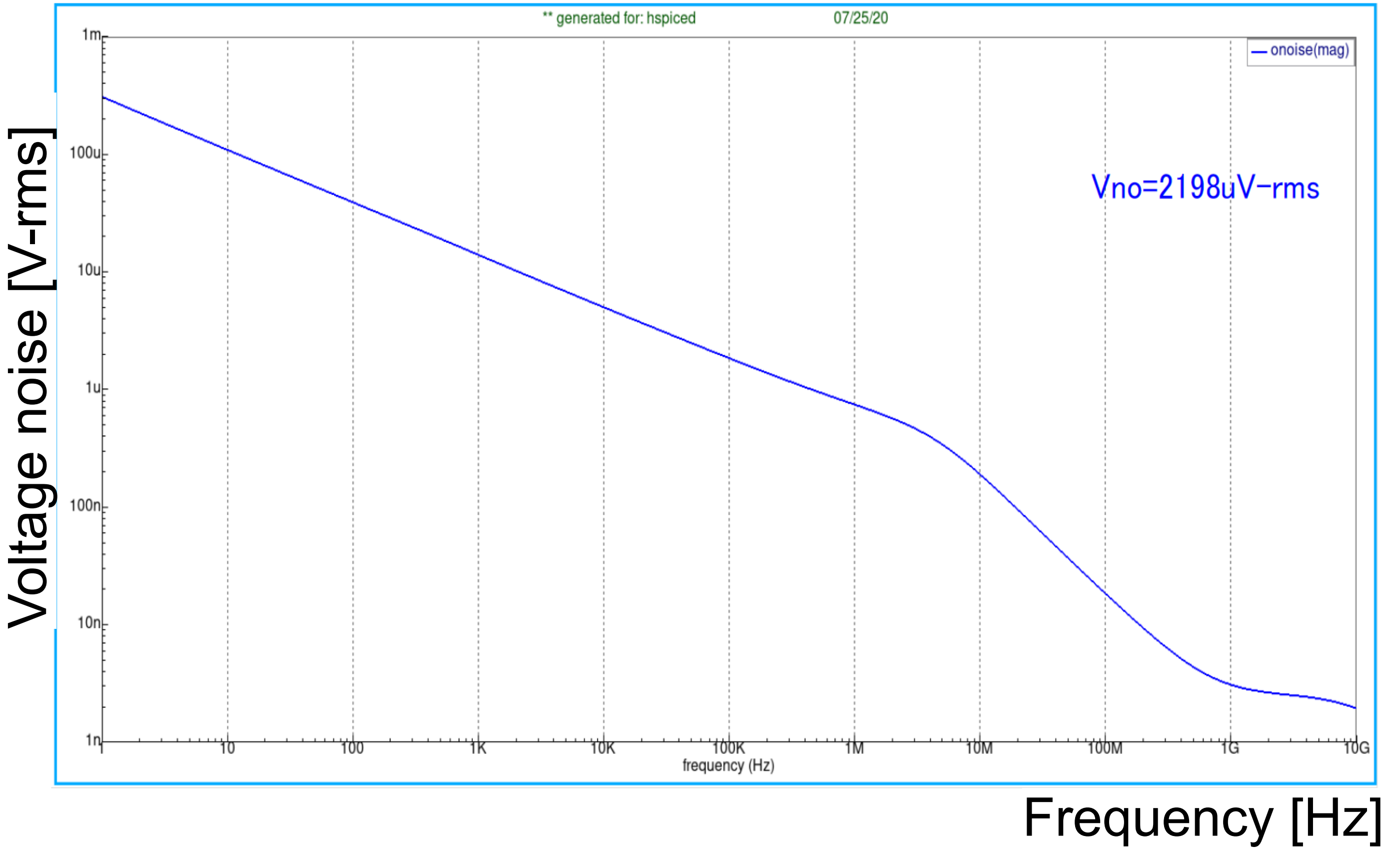
5. ASIC design simulation

Input NMOS transistor Flicker noise is dominant (75.2 %)

35 e- rms

CSA output noise spectrum

Input DC level: 0.525 V



(32_NC)(23072001)

	Element	Source	Output Noise [uVrms]	[%]	ENC [e]
1	xpix.mn0	fn	1905.8	75.2	30.31
2	xpix.mn0	id	848.8	14.9	13.50
3	xpix.mp0	id	601.9	7.5	9.57
4	xpix.mn2	id	227.8	1.1	3.62
5	xbias_csa.mn3	fn	153.0	0.5	2.43
6	xbias_csa.mn2	fn	132.5	0.4	2.11
7	xpix.mp0	fn	127.5	0.3	2.03
8	xbias_csa.mp0	fn	84.1	0.1	1.34
9	r_shot	rs	24.8	0.0	0.39
10	xpix.xc3.rp	rs	14.8	0.0	0.23
11	xpix.xc3.rp	rs	14.8	0.0	0.23
12	xbias_csa.mn3	id	10.7	0.0	0.17
13	xpix.xc_cds.rs	rs	10.6	0.0	0.17
14	xbias_csa.mn2	id	9.2	0.0	0.15
15	xpix.mn2	rd	7.3	0.0	0.12
16	xbias_csa.mp0	id	6.9	0.0	0.11
17	xpix.mn0	rs	5.1	0.0	0.08
18	xpix.mn2	rs	4.0	0.0	0.06
19	xpix.mp0	rs	1.5	0.0	0.02
20	xpix.mn4	rd	1.1	0.0	0.02
21	xpix.mn4	rd	1.1	0.0	0.02
22	xpix.mn0	rd	1.0	0.0	0.02
23	xpix.mn1	rd	1.0	0.0	0.02
24	xpix.mp2	rd	0.8	0.0	0.01
25	xpix.mp2	rs	0.6	0.0	0.01
26	xpix.mp0	rd	0.6	0.0	0.01
27	xpix.mp7	rd	0.5	0.0	0.01
28	xpix.mp7	rd	0.5	0.0	0.01
29	xbias_csa.mn1	id	0.4	0.0	0.01
30	xbias_csa.mn1	fn	0.4	0.0	0.01
	Total		2198.3	100.0	34.97

※Noise[uVrms] : Integrated Noise

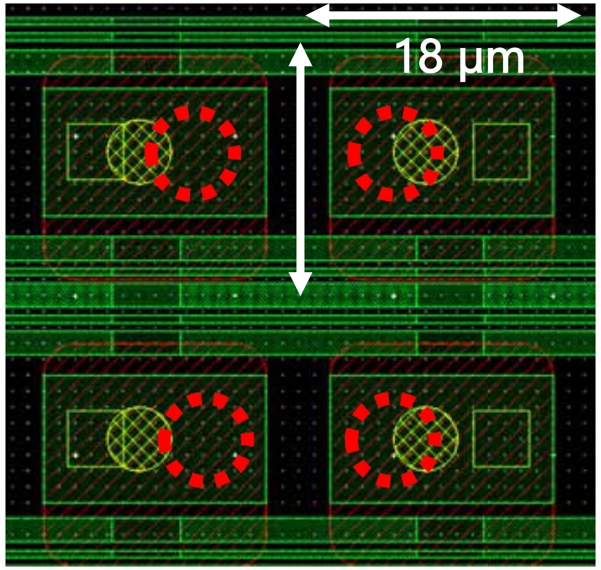
※Noise[%] : % of total noise power

5. ASIC-Si Au bumps

(Tohoku MicroTec Co., Ltd. JAPAN)

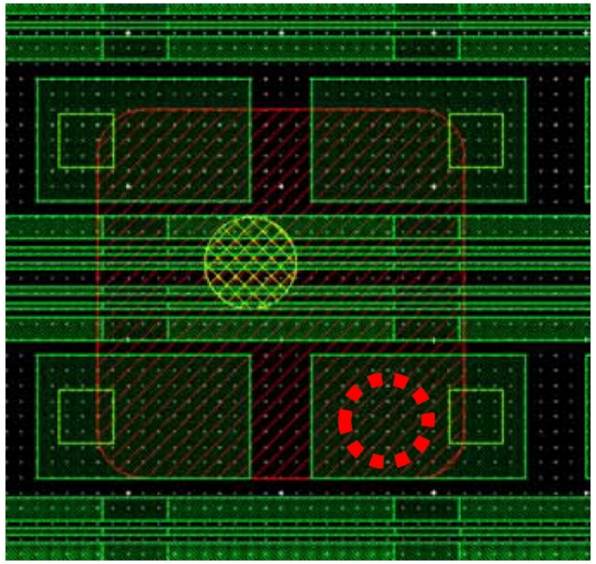
micro bump size ~ ϕ 5 μm   micro bump position

ASIC side



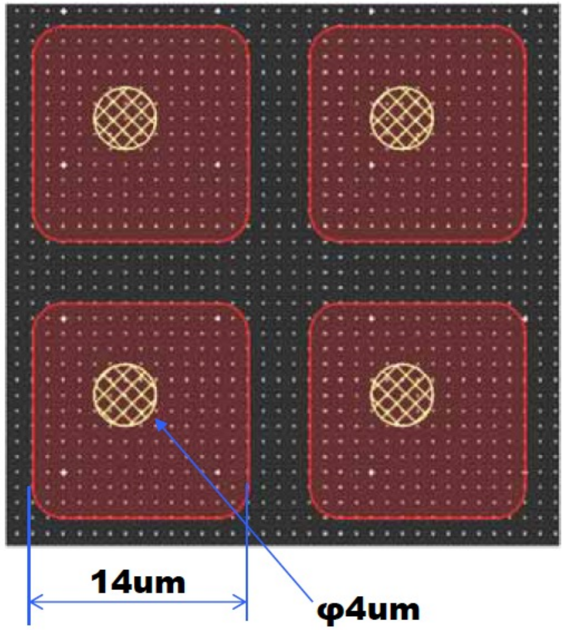
18 μm type (1:1)

ASIC side

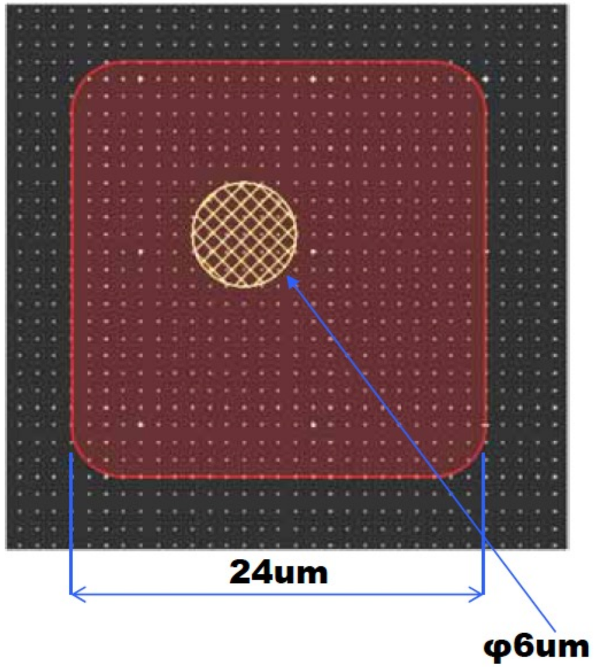


36 μm (1:4)

18 μm sensor side



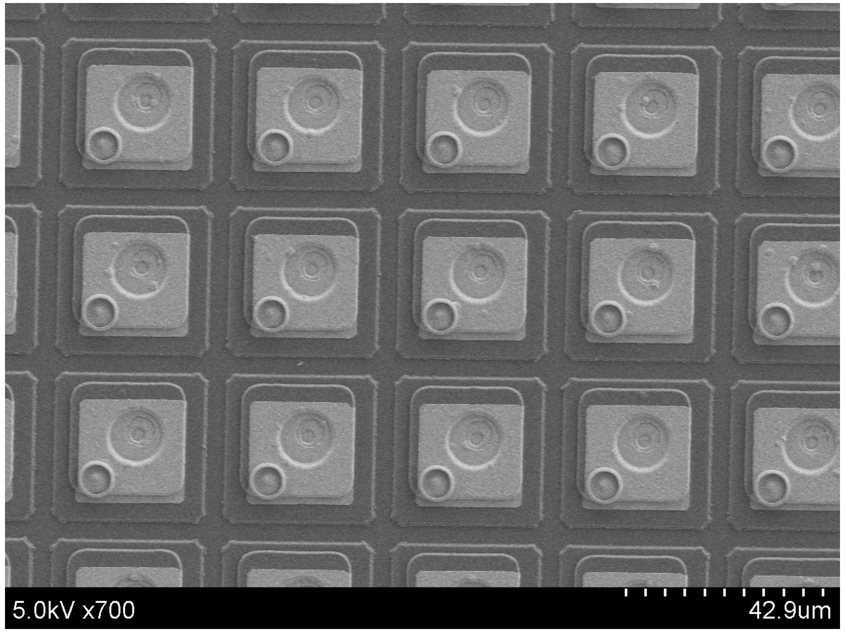
36 μm sensor side



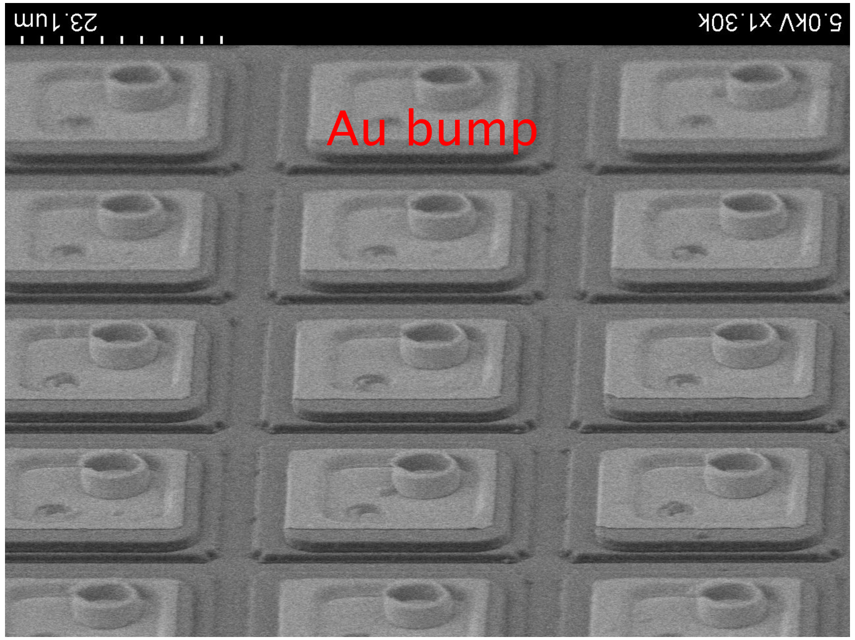
green: ASIC metal, yellow: passivation opening, Red: sensor metal

5. UBM and Au micro bump

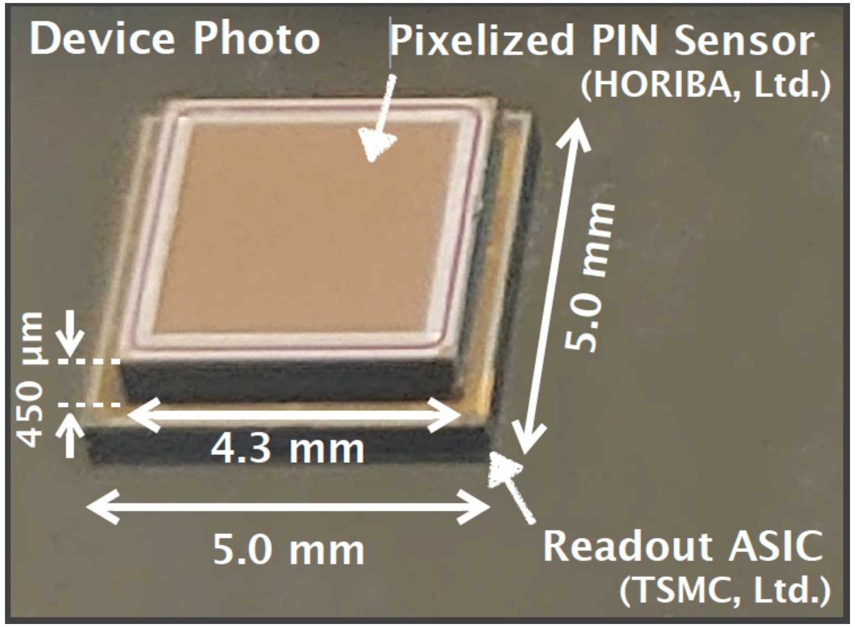
(Tohoku MicroTec Co., Ltd. JAPAN)



SEM picture from TOP (36 μm type)



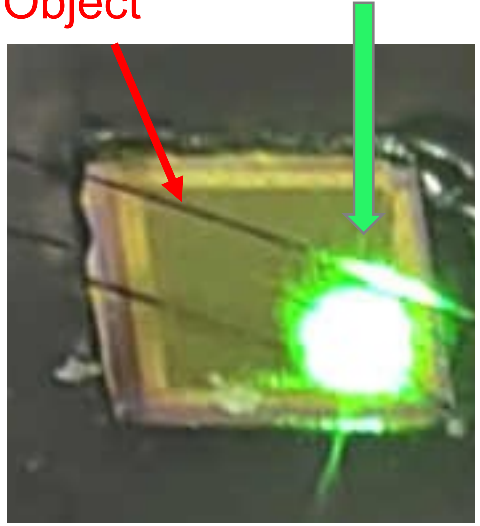
SEM picture from SIDE

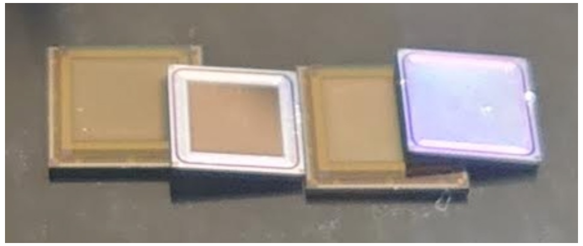


Connected ASIC and sensor

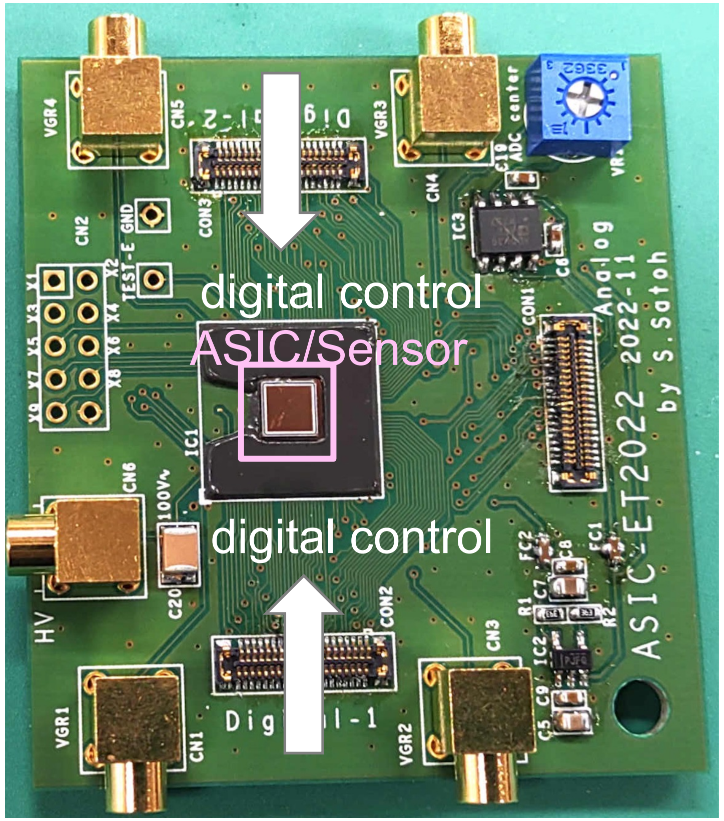
6. Preliminary results

Data Acquisition Setup





CHIP board

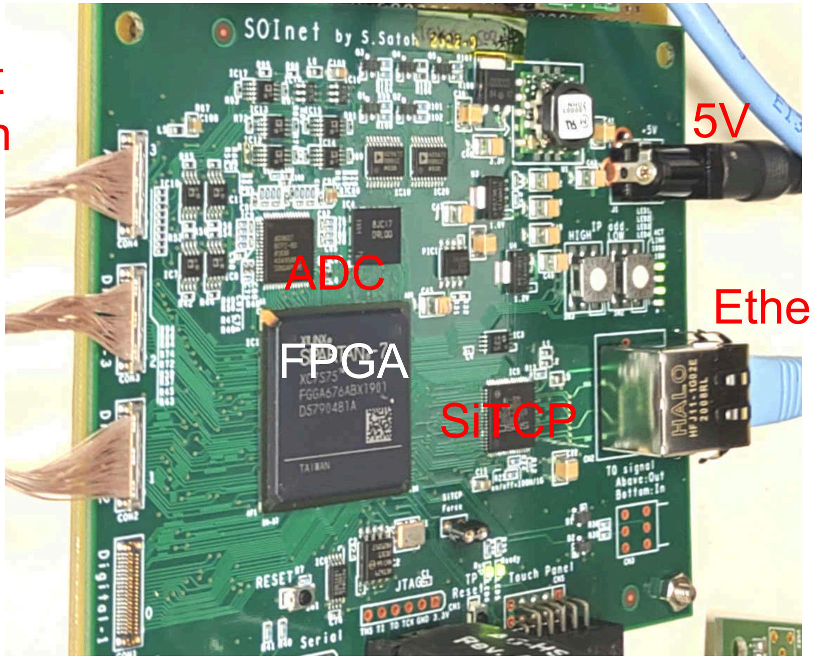


ASIC 2.5V operation

analog out
× 8ch × n

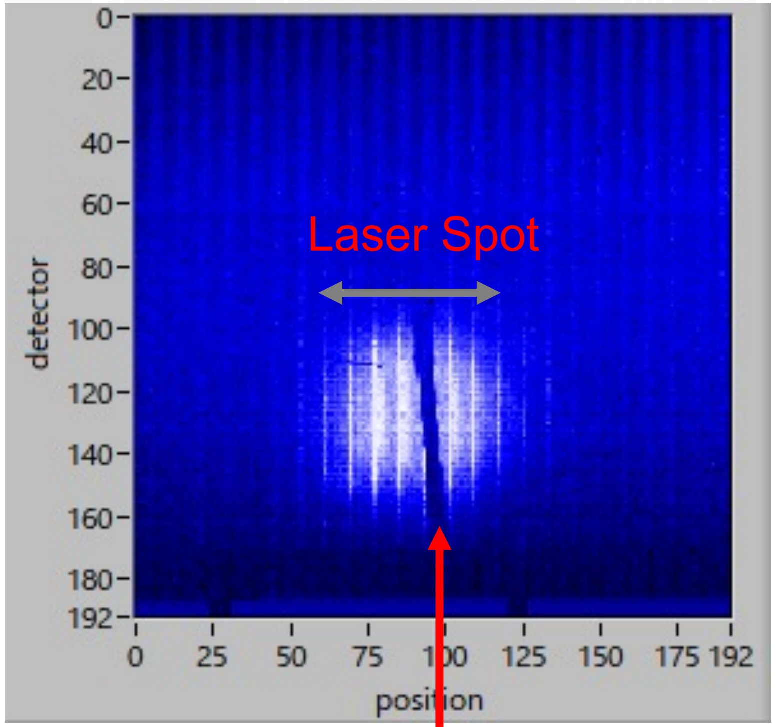
digital IO

DAQ board

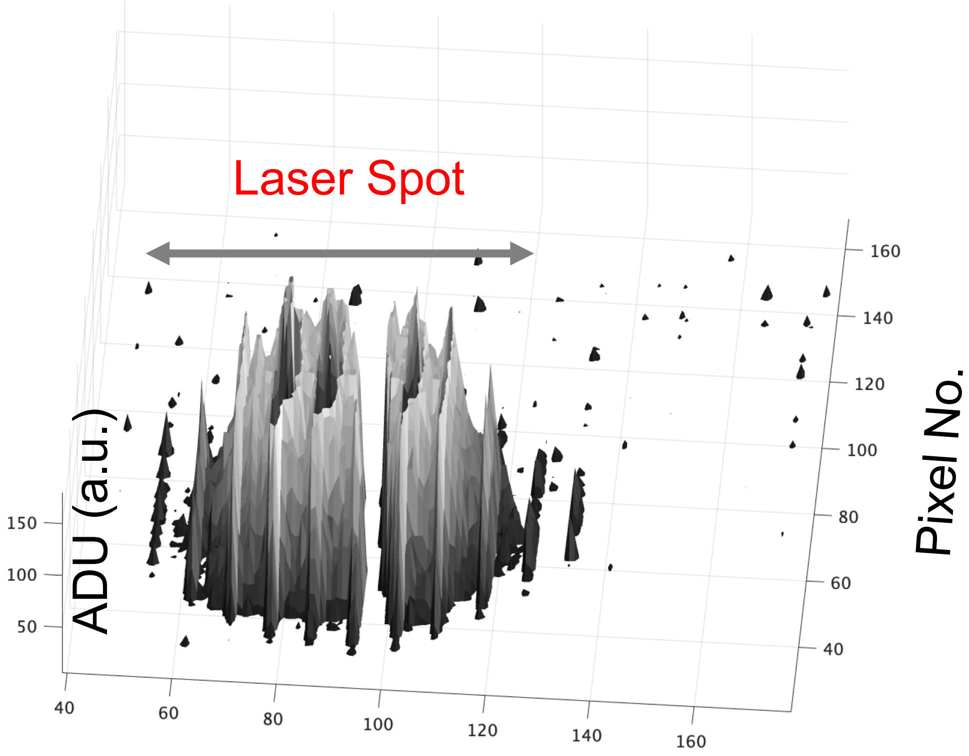


6. Preliminary results

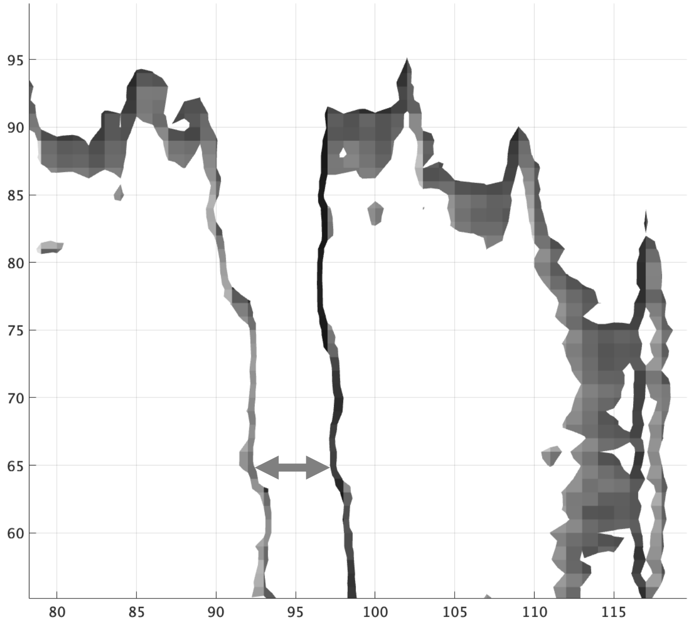
Preliminary image..



Object



Pixel No. (1=18 µm)



80 - 90 µm

Object (hair)

7. Summary

We are developing fine-pitch silicon hybrid pixel sensor as scatterers in electron tracking Compton Imager with spectroscopy and coincidence detection capability

18 μm/36 μm pixel silicon sensor ~ 150 V, <1 nA
Trigger-mode 18 μm pixel ASIC ~ 35 e- rms (250 nm TSMC)
Au - micro bump bonding technology
3.4 mm sensitive area, 5 mm ASIC size in the first prototype
preliminary image acquired

We are re-connecting ASIC/sensor for further experiment..
spectroscopic performance, trigger function etc..

Thank you for your kind attention!