Double Photon Emission Compton Imaging based on event-driven SOI and GAGG-SiPM detectors

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11th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking detectors - HSTD11

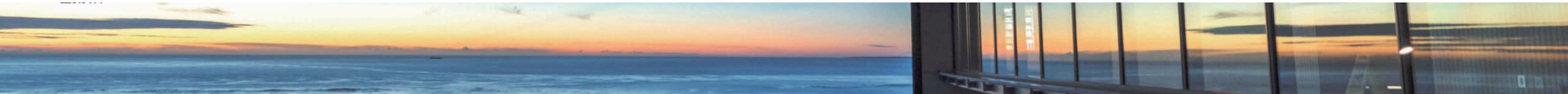
in conjunction with

2nd Workshop on SOI Pixel Detector - SOIPIX2017

OIST, Okinawa, Japan, Dec. 11-15, 2017

東京大学 THE UNIVERSITY OF TOKYO

OIST



Outline of Talk

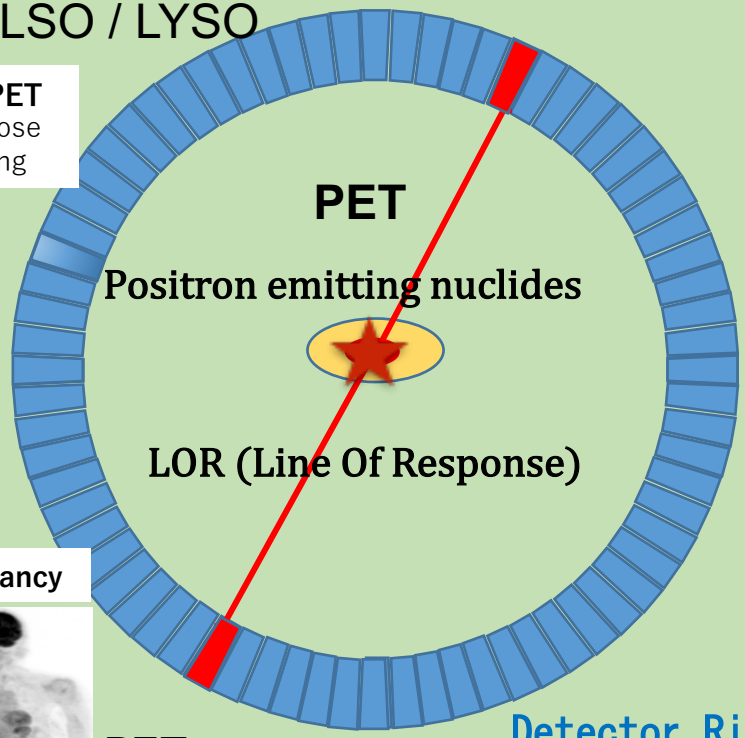
- Background – Nuclide Imaging
- Double Photon Coincidence Imaging (DPCI)
- SOI event-driven pixel detector
- Validation Experiment (Scintillator-SiPM based)
- Result
- Conclusion / Future work

Background – Nuclide Imaging

Ex) nuclide imaging in Nuclear Medicine

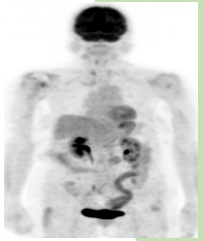
LSO / LYSO

FDG-PET
Glucose
Imaging



Detector Ring

Malignancy

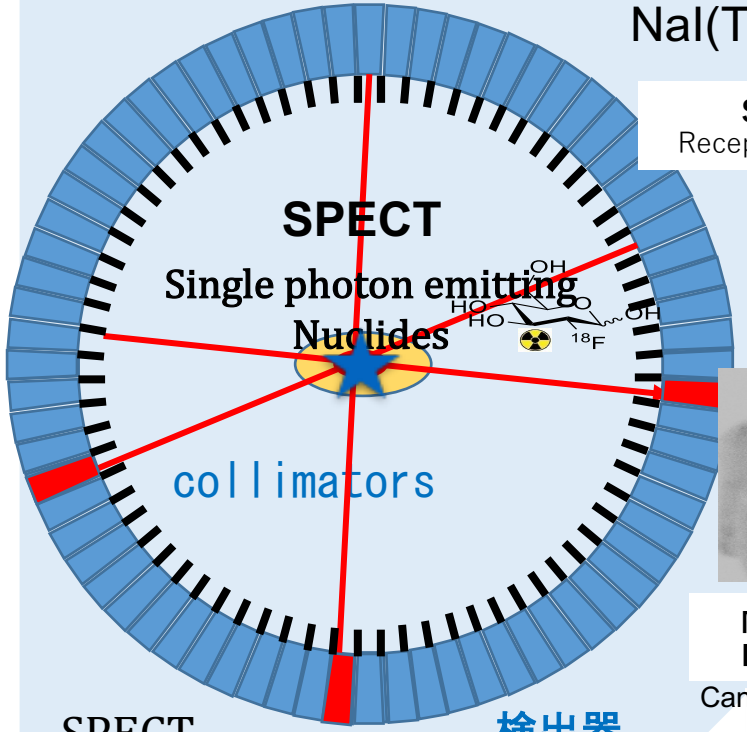


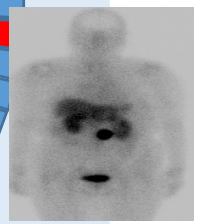
PET
(Positron Emission Tomography)

PET tracer (positron emitter)
18F-FDG 511 keV

NaI(Tl)

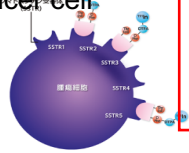
SPECT
Receptor Imaging





Molecular Diagnosis

Cancer cell



SPECT
(Single Photon Emission CT)

検出器

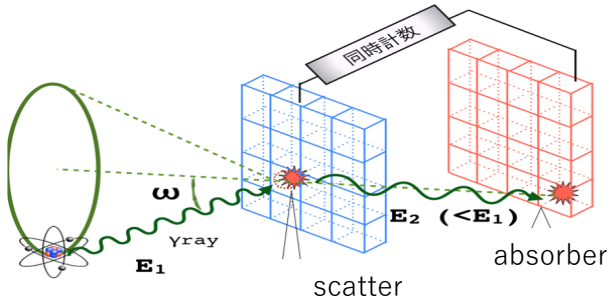
Single Photon Detection
99m-Tc, 111In 100 ~ 250 keV

Suffers from low image quality

Compton Imaging
(Not commercial yet)

$$\cos\omega = 1 + m_0c^2\,(E_1^{-1} - E_2^{-1})$$

Compton scattering kinetics

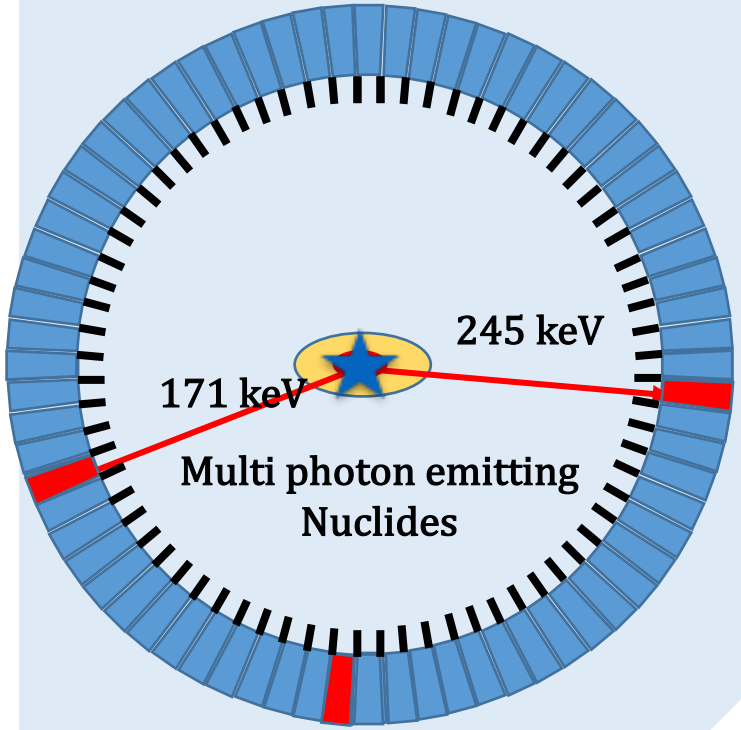


Compton Imaging

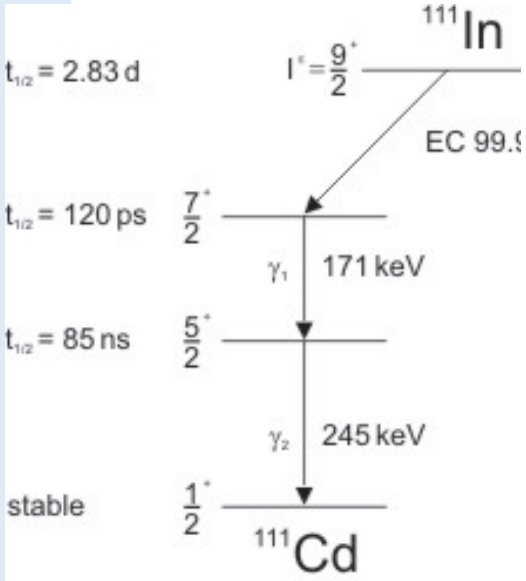
Single Photon Detection
Multi energy ~ MeV

Suffers from low SNR

Double Photon Coincidence Imaging Method (DPCI or DPECT)

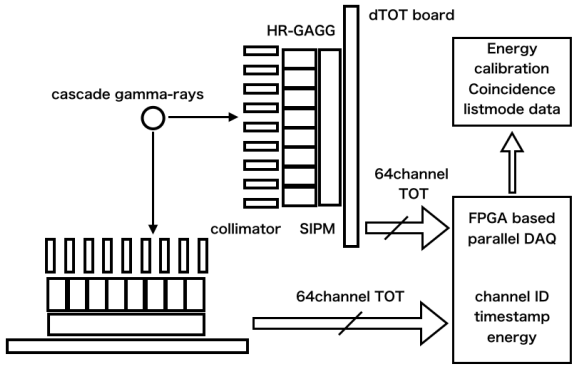


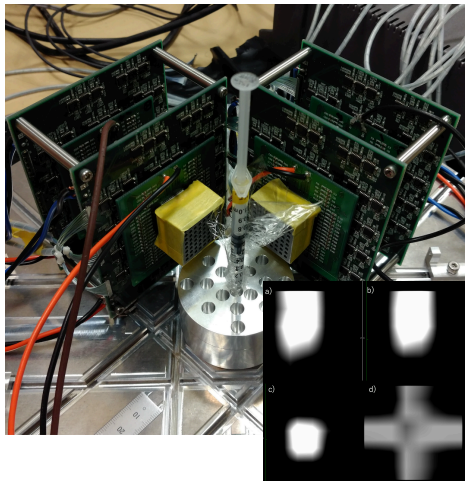
Angular Resolving Detector



cascade photon emitting
Nuclides

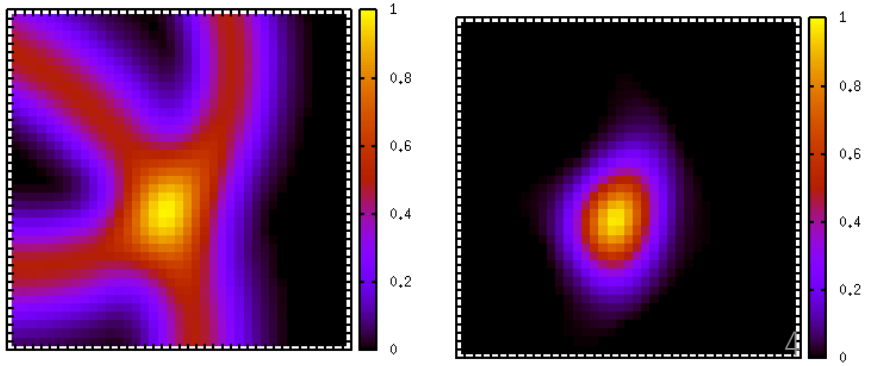
mechanical collimation (Gamma camera)





PSD11, JINST 2017 accepted, Shimazoe et. al.

Electric collimation (Compton imaging)



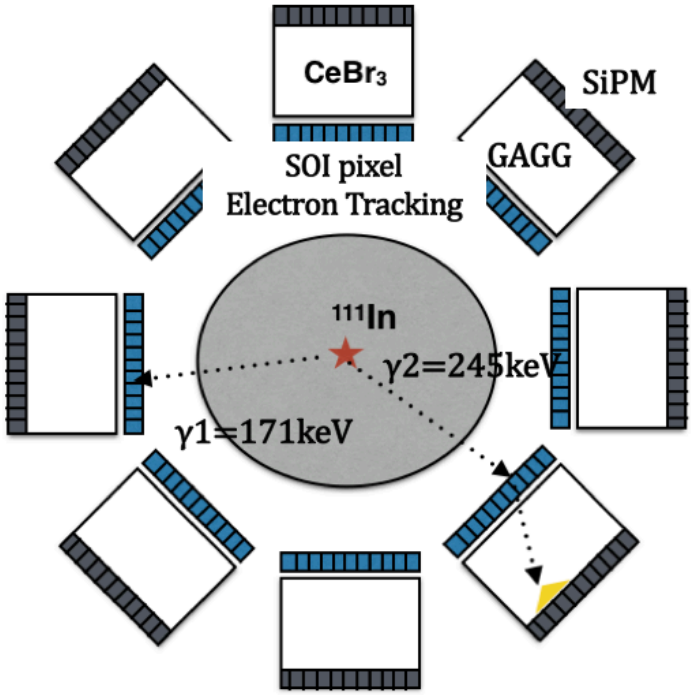
Coincidence Detection of Cascade Gamma-rays

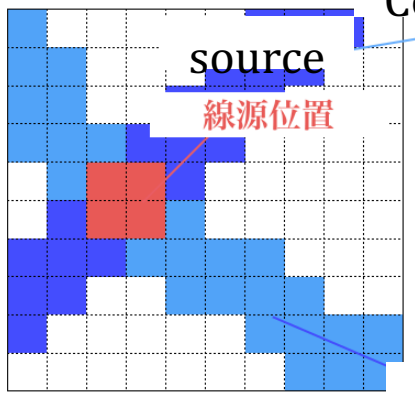
→ Localizes the source point into one point

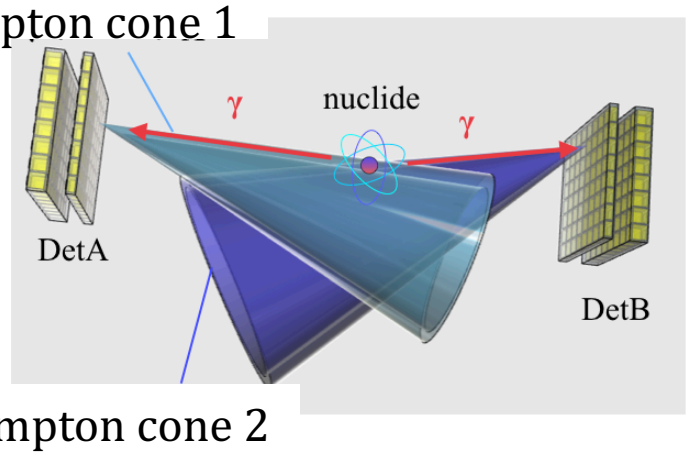
Double Photon Coincidence Imaging based on Compton Imaging

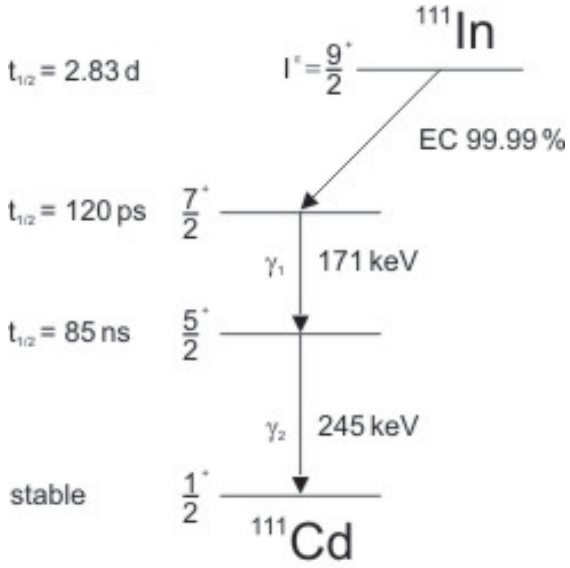
Compton imaging suffers from low SNR because of Compton cones

The intersection of two Compton cones localize the original source position with high sensitivity based on Compton kinematics









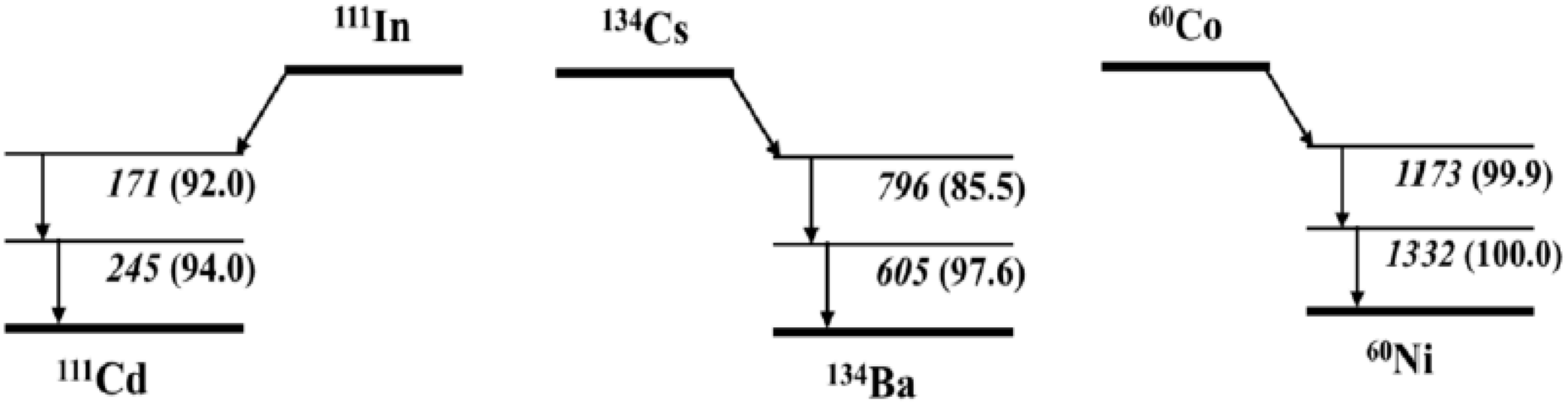
10 times higher SNR

Improvement of **spatial resolution**

Compared with conventional Compton imaging

New Nuclide Imaging Method for Medical Molecular Imaging without any collimator

Cascade gamma-ray nuclides candidates

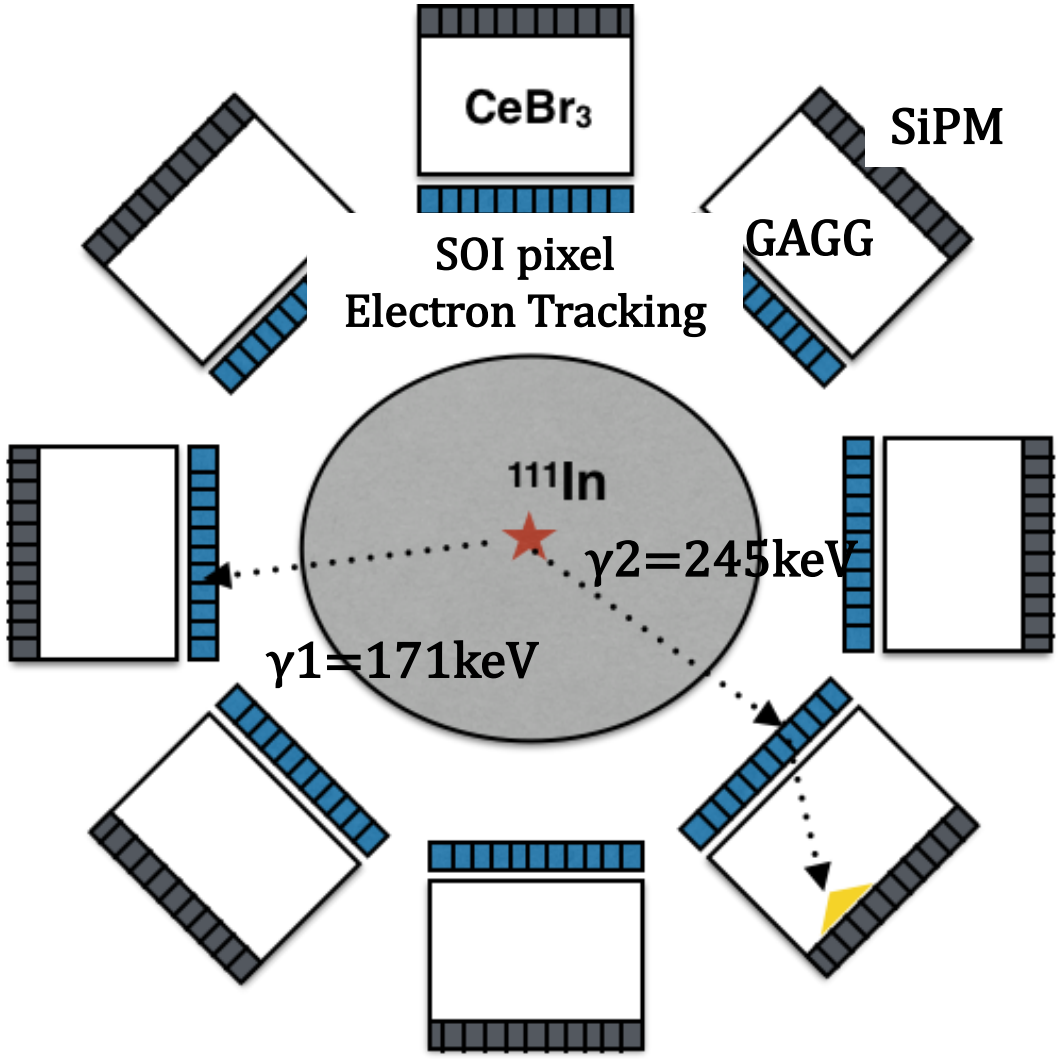


Double Photon Coincidence Imaging could applied to cascade gamma nuclides

111In (decay 2.8 days) = already available nuclide in SPECT diagnosis

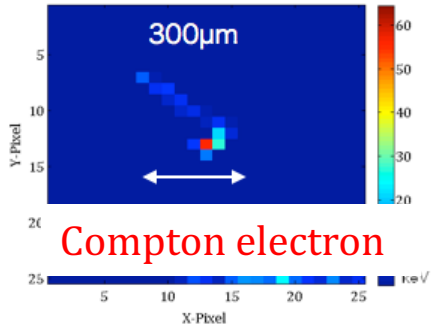
134Cs and 60Co = important nuclide in Nuclear Engineering and Physics

Design of Double Photon Coincidence Imaging (DPCI) System

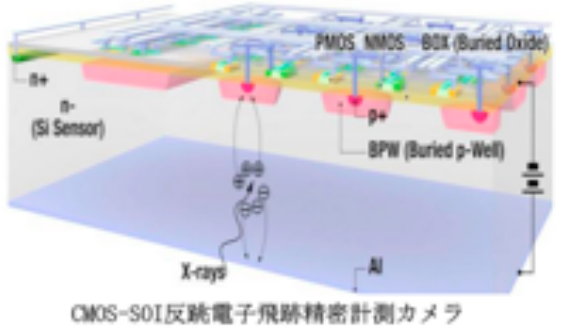


Event-Driven SOI pixels + GAGG/CeBr3+SiPM

Scatter: Event-Driven SOI pixels

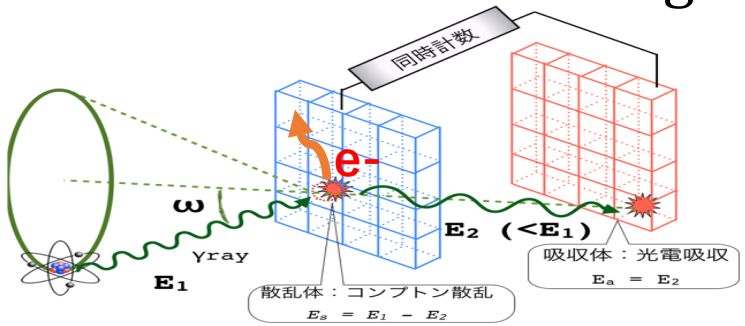


Compton electron

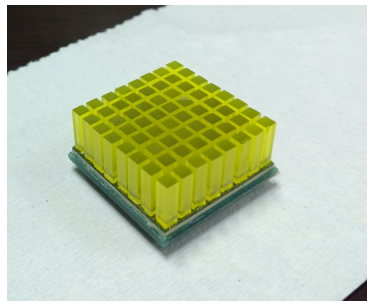


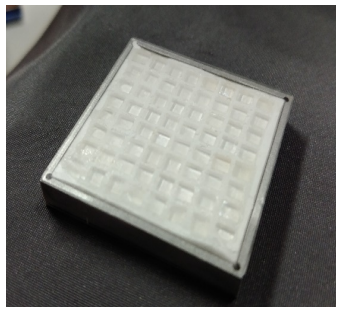
CMOS-SOI反跳電子飛跡精密計測カメラ

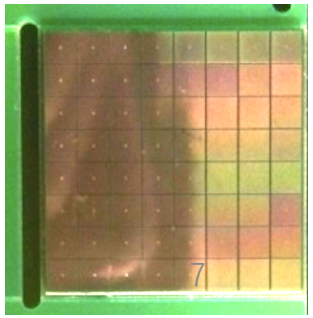
Electron tracking



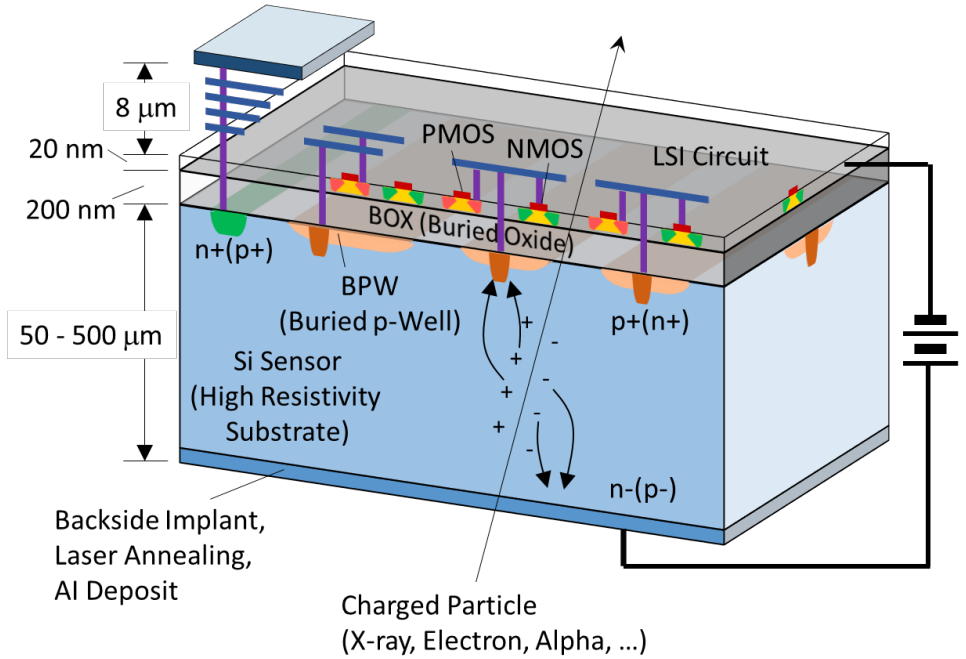
Absorber: GAGG/CeBr3 + SiPM

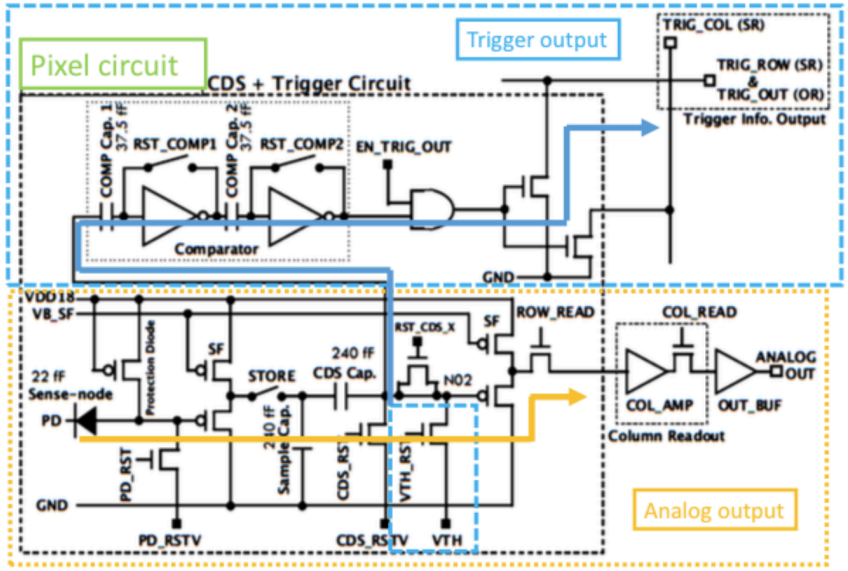






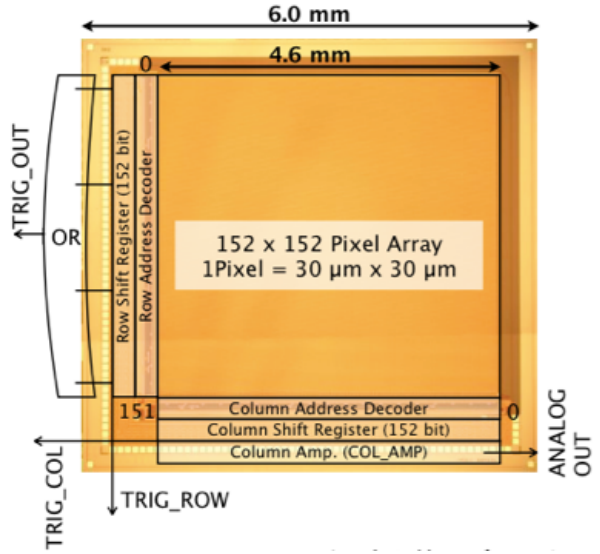
Event-Driven SOI Pixel sensor as scatter in C.C.



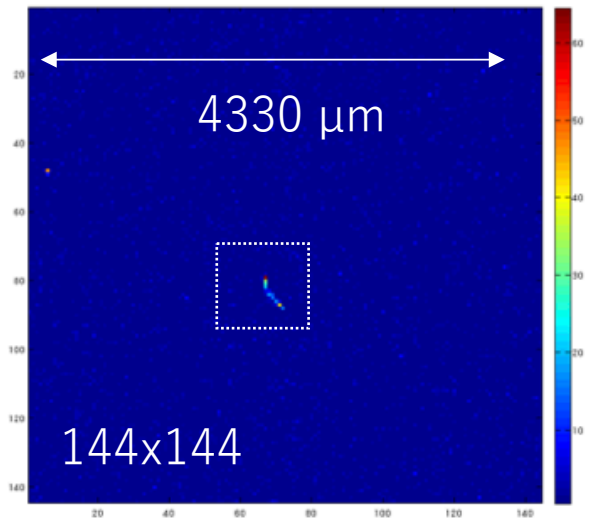


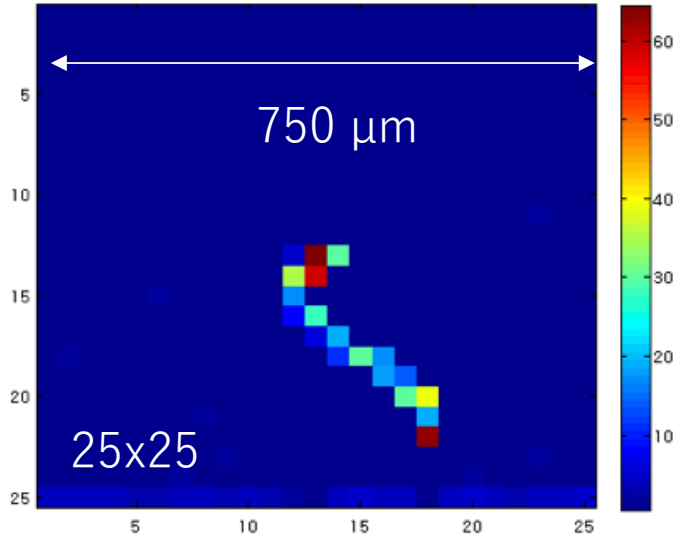
- Possibly small Pixel Size (~ 10 µm)
  - Electron Tracking capability
- Good detection efficiency
  - (Thick ~ 500 µm)
- Event-driven pixel detector
  - Coincidence Detection between absorber and scatter
- Pattern readout (~ 10kHz)
  - instead of frame readout
  - Event driven SOI Pixel sensor developed by Kyoto-U, Miyazaki-U and KEK for X-ray Astronomy (Poster of Dr. Takeda)

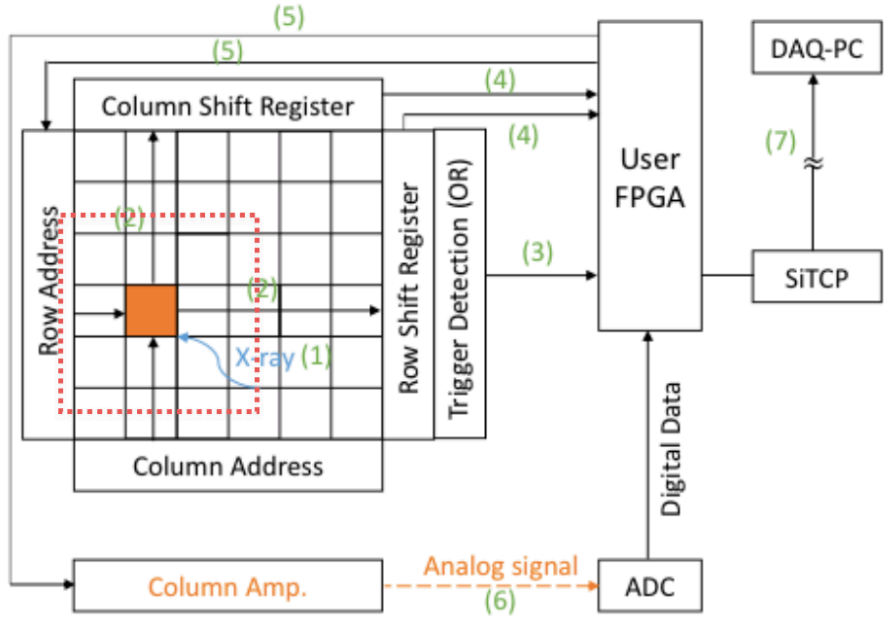
Event-Driven SOI recoil electron pattern readout



	NHR1(CZ)	NFZ
Chip Size	6.0 mm sq.	
Pixel Size	30 μm sq.	
BPW Size	12 μm sq.	
# of pixel ***	152 x 152	
Effective Pixel	144 x 144 (= 20,736)	
Effective Area	4.3 mm x 4.3 mm	
Thickness of Sensor ****	250 μm	500 μm
Resistivity	1.5 kΩ・cm	5 kΩ・cm
Power Supply *****	1.8V @ Core / 3.3V @ IO	
Back Bias (sensor)	5 - 500V <	







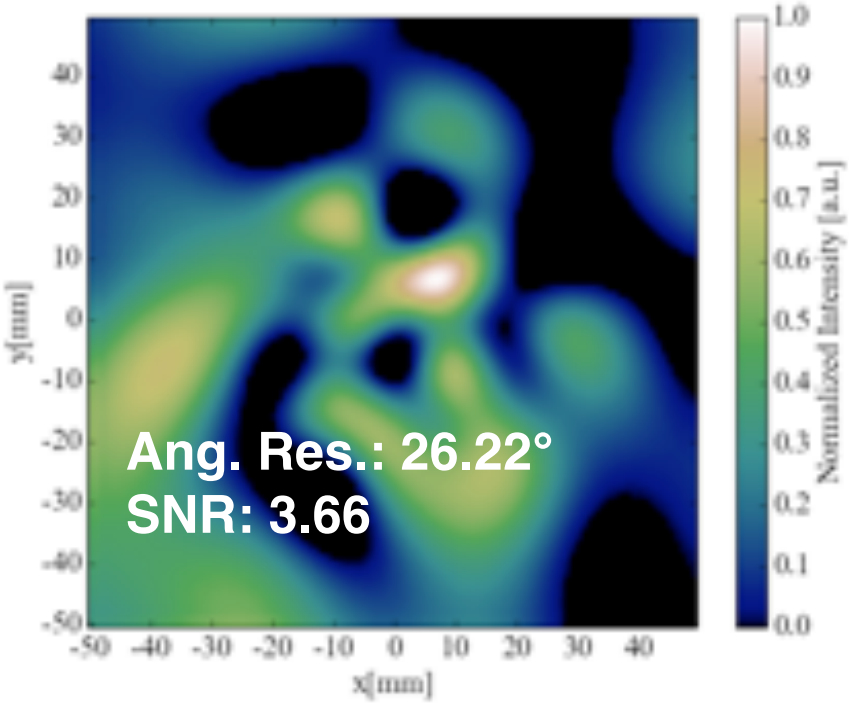
25 x 25 pixel pattern readout
Surrounding the triggered pixel

~ 30 times faster

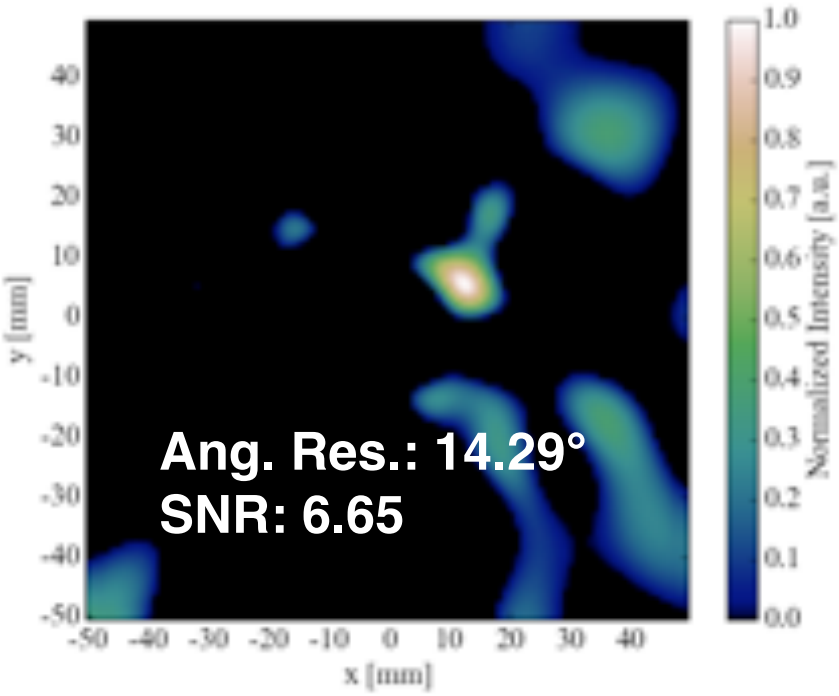
Shimazoe, K., et al. "Electron Pattern Recognition using trigger mode SOI pixel sensor for Advanced Compton Imaging." *Journal of Instrumentation* 11.02 (2016): C02030.

Event-Driven SOI based electron tracking

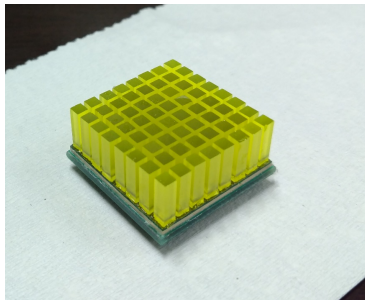
Without Electron Tracking

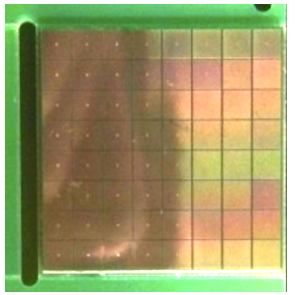


With Electron Tracking



1MBq Cs-137
distance=30mm



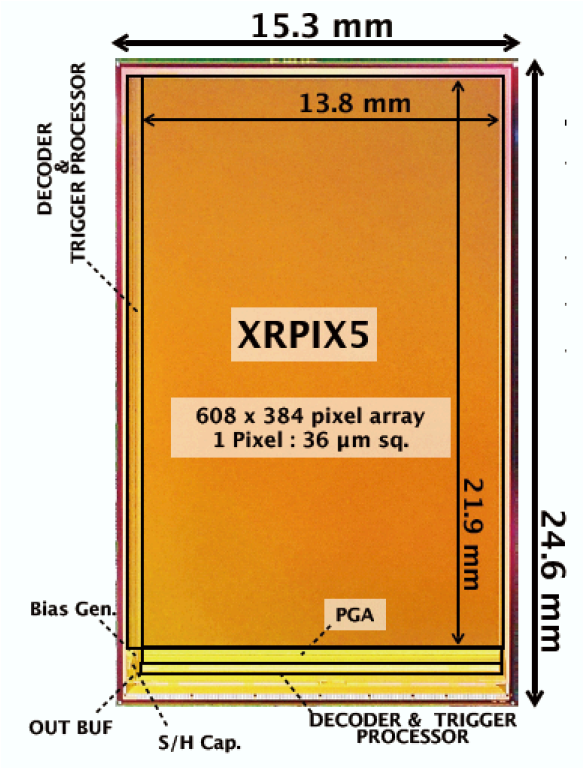


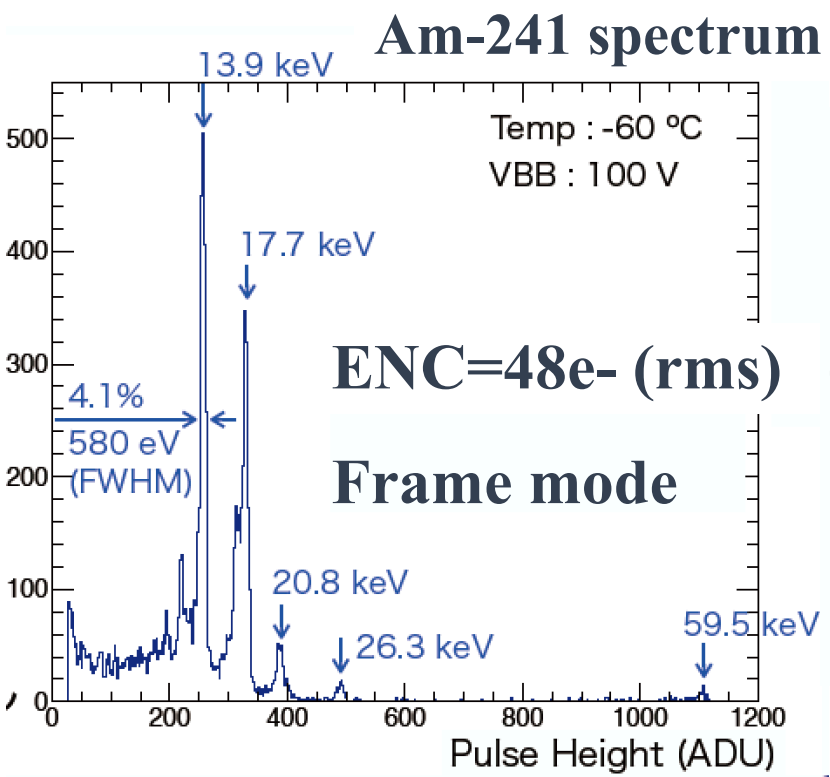
XRPIX2b + GAGG-SiPM (8x8 MPPC) Compton Camera

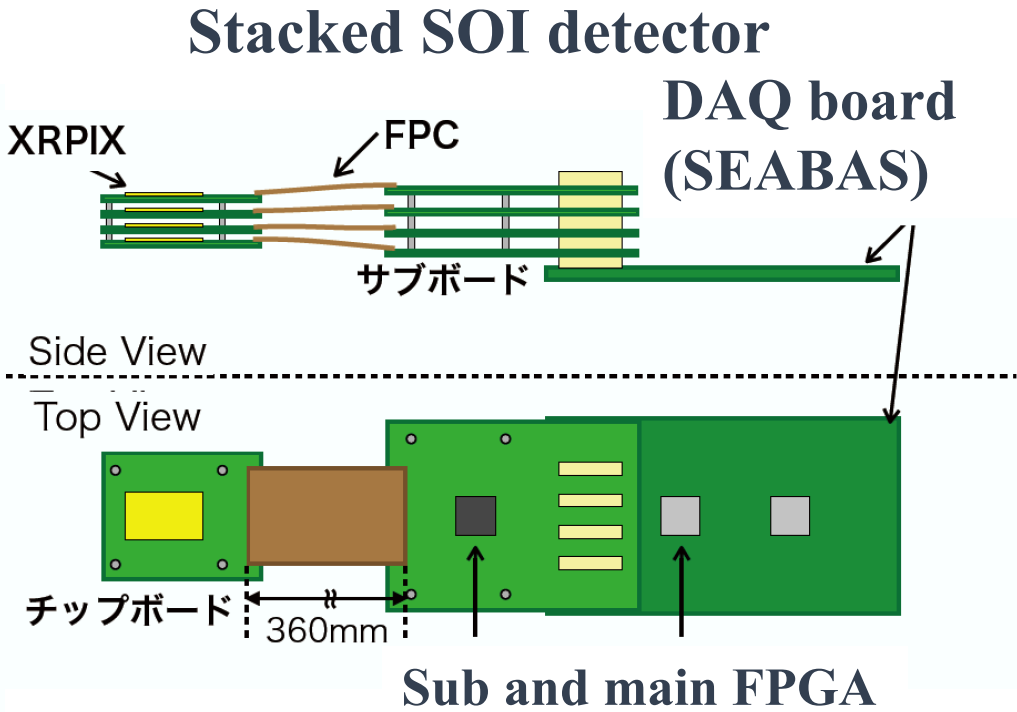
Coincidence event ~ 1 cps

Yoshihara, Y., Shimazoe, K. et. al. (2017). Development of electron-tracking Compton imaging system with 30-μm SOI pixel sensor. *Journal of Instrumentation*, *12*(01), C01045.

“Stacked” large event-driven SOI sensors







Large-size event-driven SOI by Dr. Takeda (Miyazaki U.)

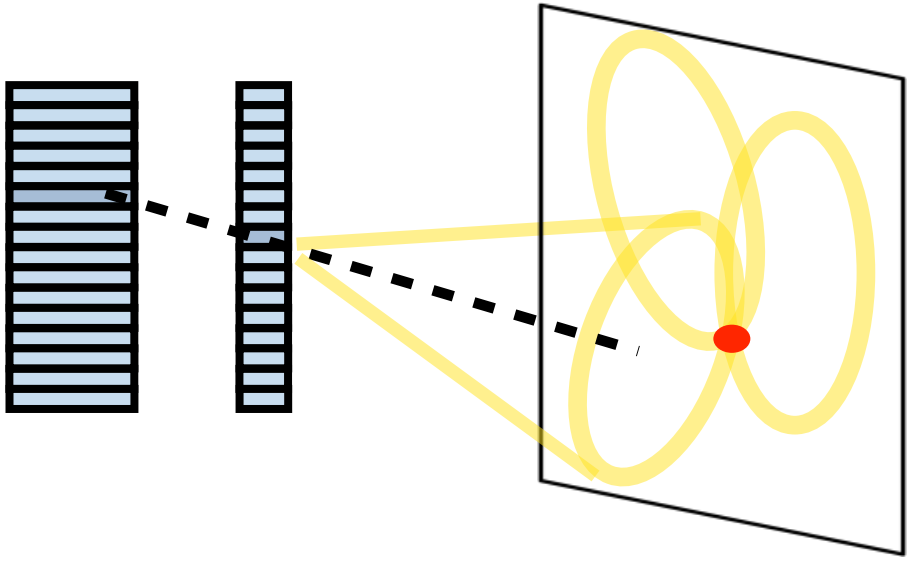
From Tachibana et. al. @ SOIPIX meeting

Collaborative development for astrophysics(Kyoto-U, Miyazaki-U), DPCI (UTokyo) and Light Wimp/Axion (Kobe-U,Utokyo)

Under development

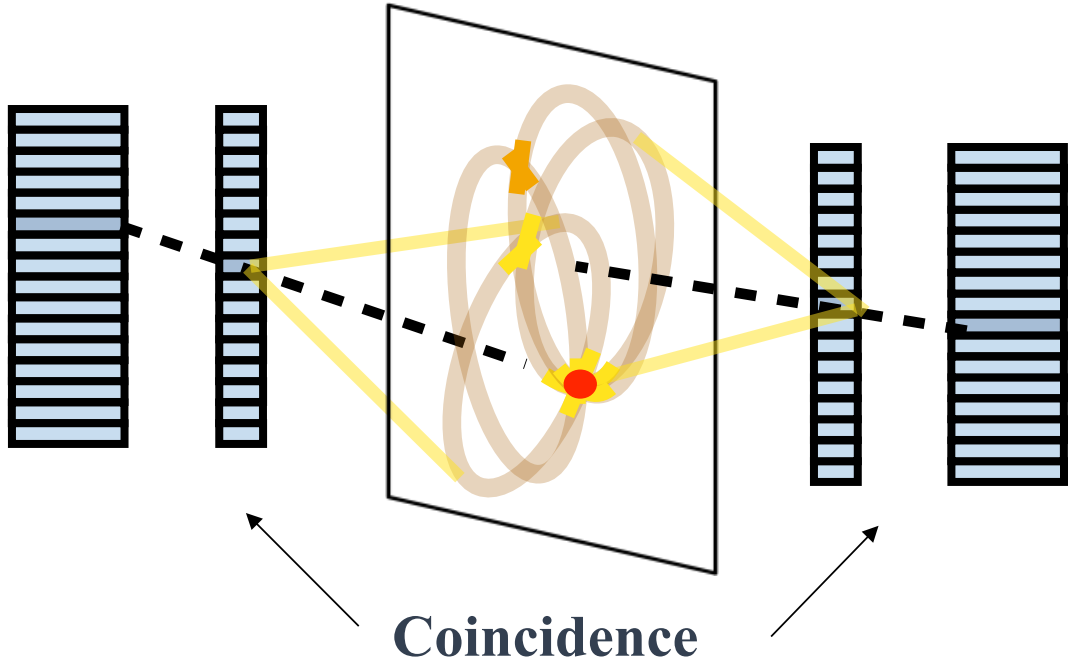
Experimental principle validation of DPCI

Single Photon Compton Imaging



(Filtered) Back Projection of cones

Double Photon Compton Imaging



Back Projection of intersection normalized product of two cones

GAGG-SiPM Compton Camera

8×8 array of HR-GAGG + SiPM

HR-GAGG (density 6.3g/cc, ~50000 photons/MeV Zeff=52 C&A)

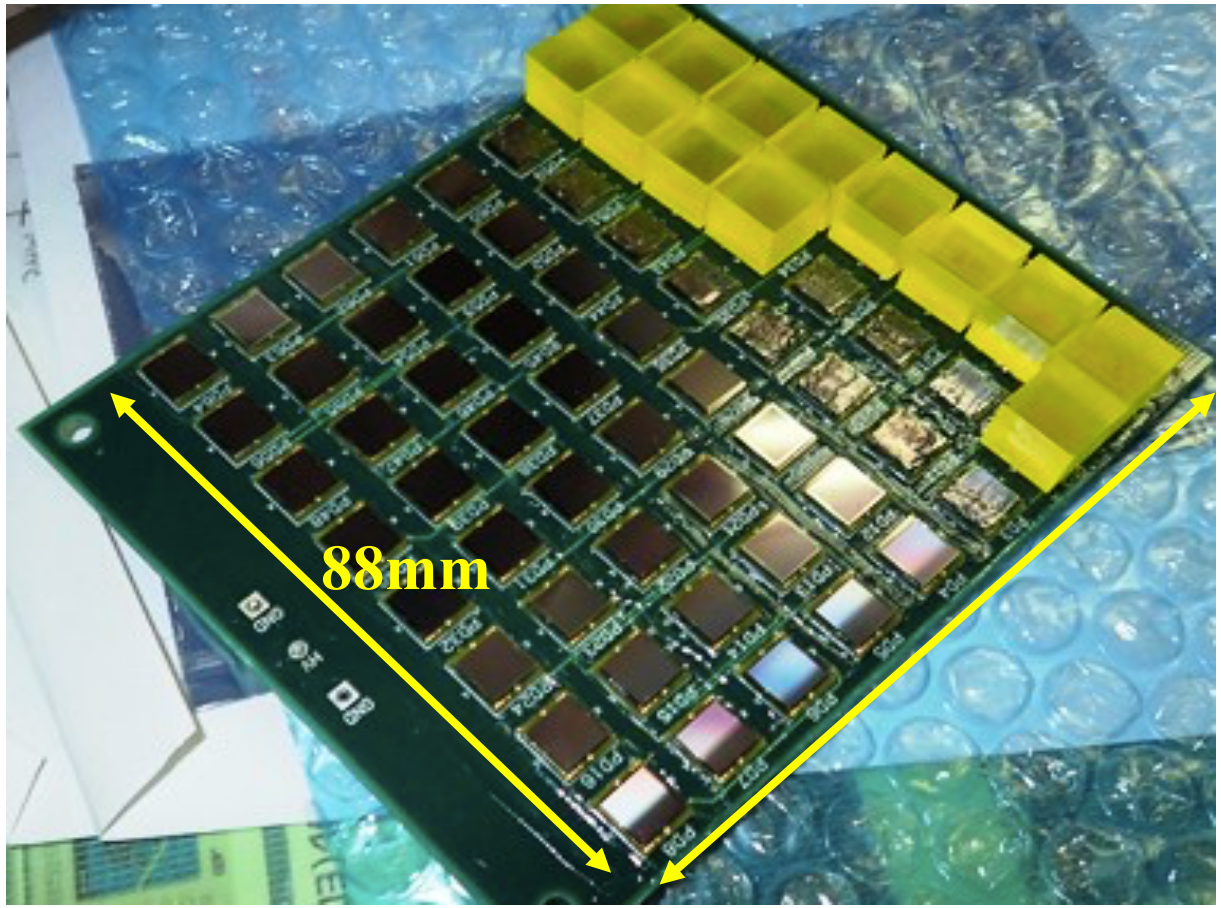
SiPM (PM6660 KETEK 6mm effective area)

5×10×10mm (scatter)

10×10×10mm (absorber)

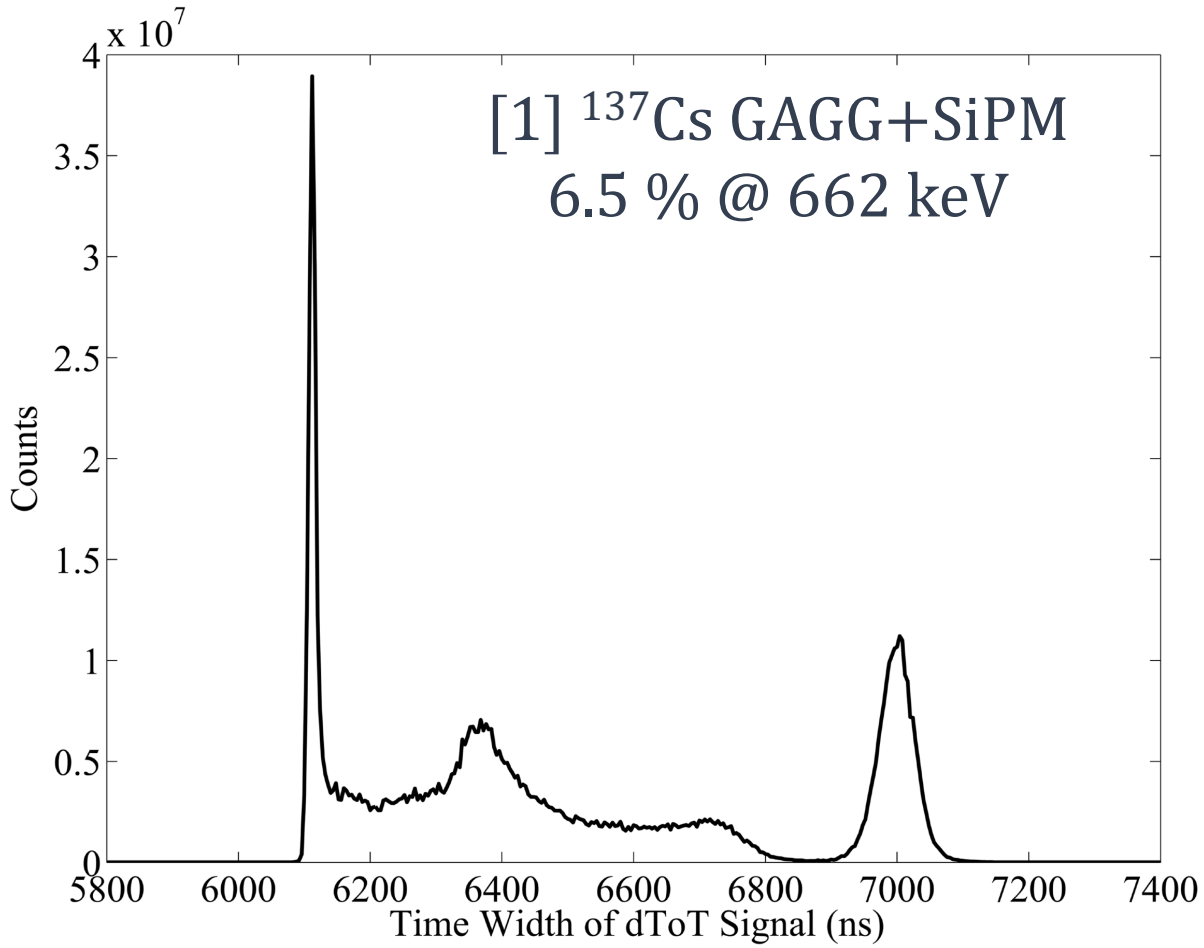
Signal processing

- dynamic Time-over-Threshold (dTOT) based readout [1]

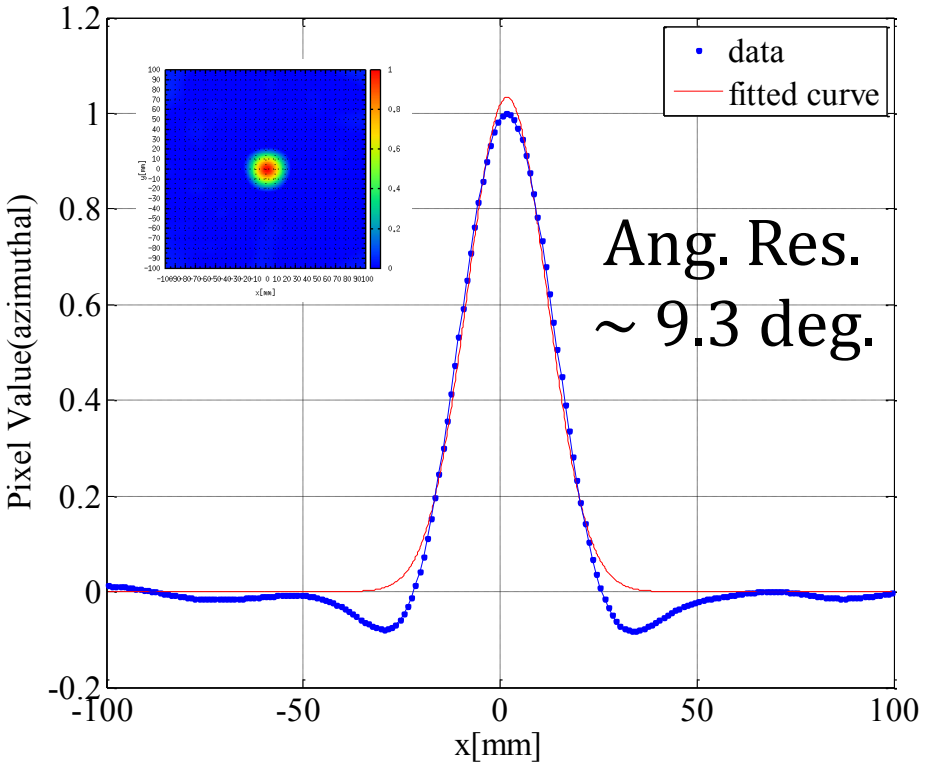


[1]K. Shimazoe et al., (2012) Dynamic Time Over Threshold Method, IEEE trans. on Nuc. Sci. Vol.59 No.6 2012.12

GAGG-SiPM Compton Camera



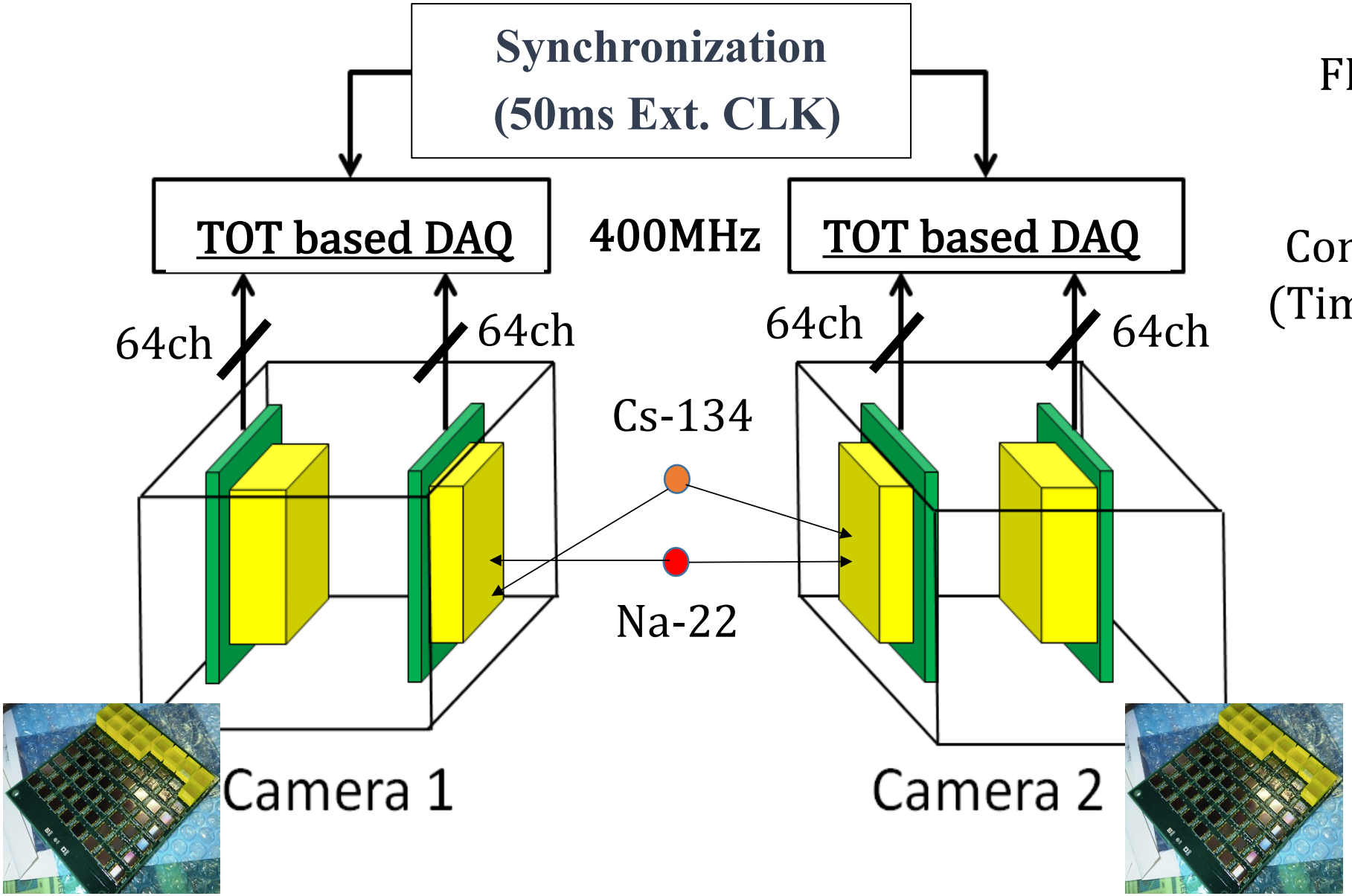
[2] ^{137}Cs image with back projection



Det. Eff. = 1.6 %
@662 keV

[1] J. Jiang et al., (2015). Journal of Nucl. Sci. and Tech. Vol. 53, No. 7, 1067-1075
[2] Y. Shikaze et al., (2016). Journal of Nucl. Sci. and Tech. Vol. 53, No. 12, 1907-1918

Experimental system for DPCI



TOT based DAQ :

FPGA (Kintex 7 XC7K70T-1FBG484C)

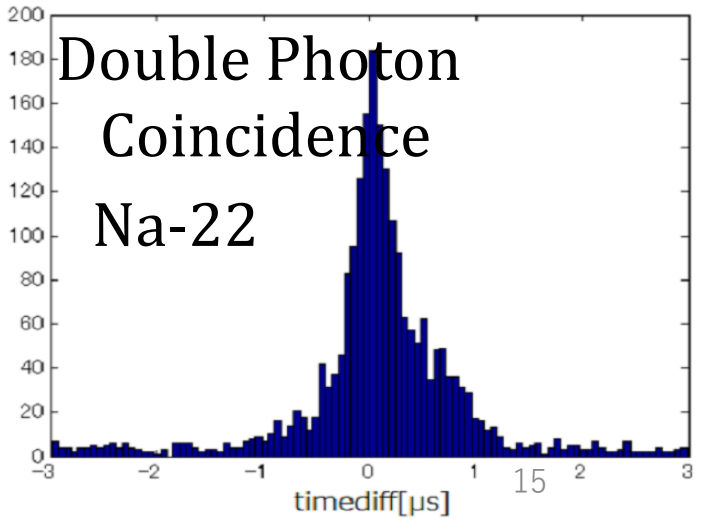
@ 400 MHz sampling

Continuous parallel readout

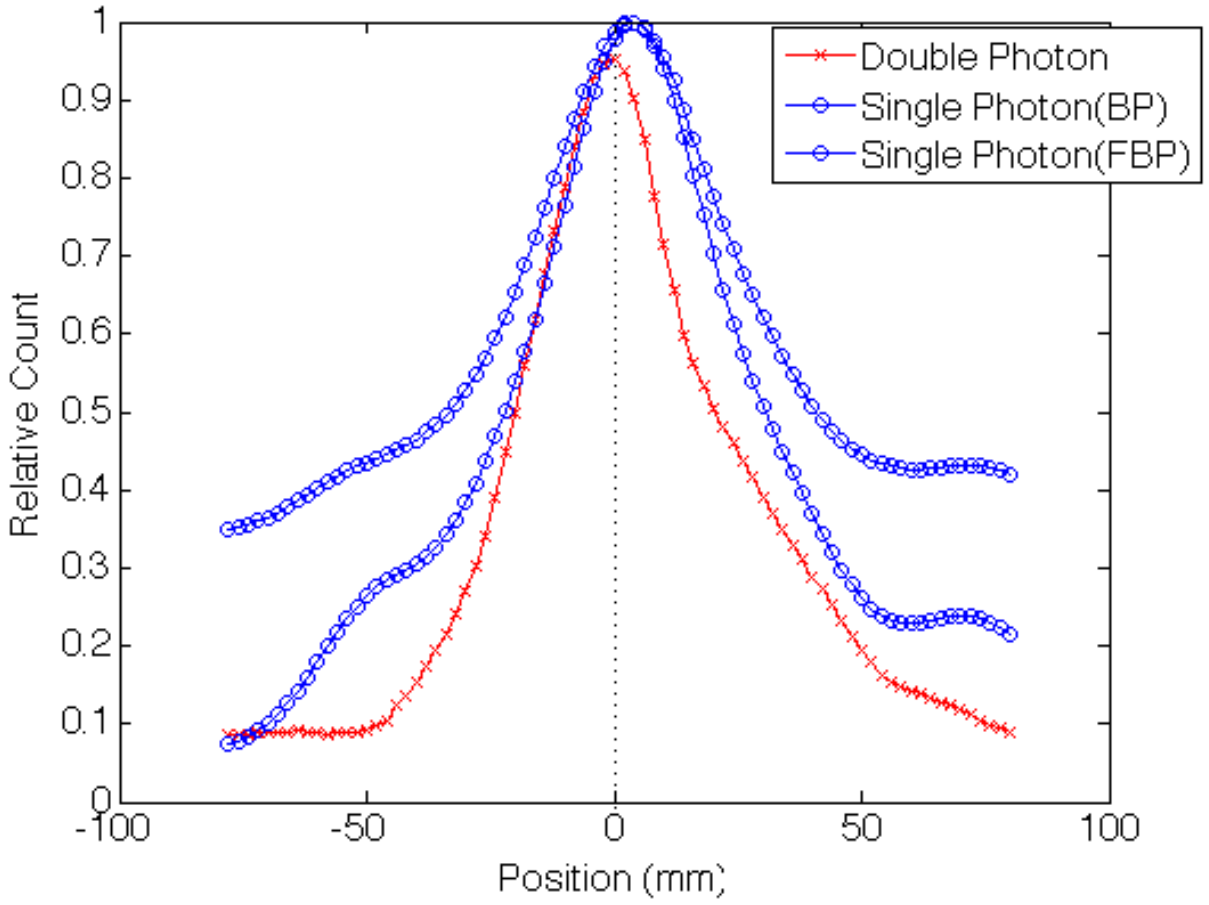
(Timestamp, channel, Energy)

Coincidence detection

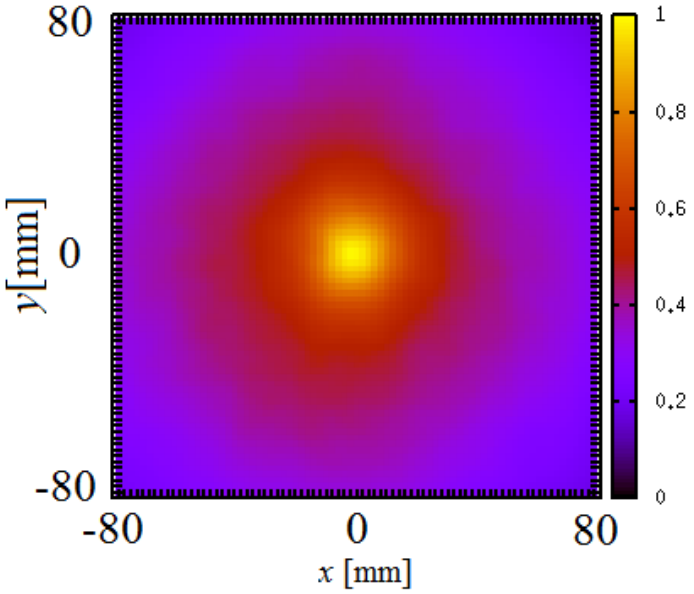
In software



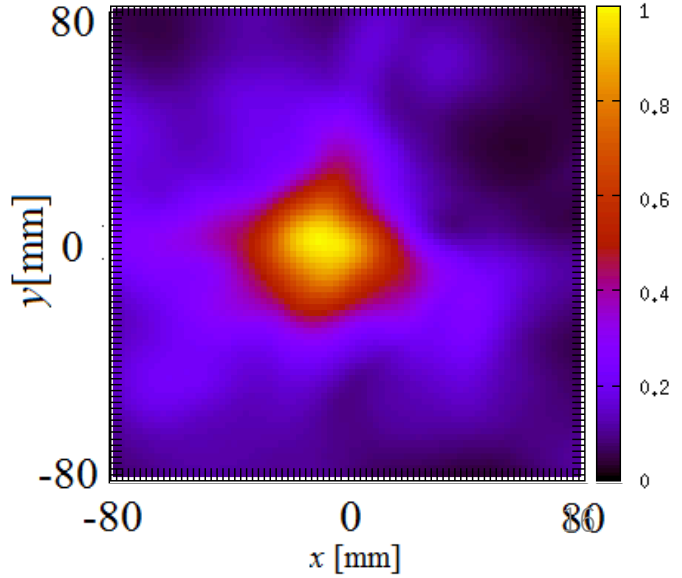
^{134}Cs point source imaging by DPCI



Single Photon 232509 events



Double Photon 214 events

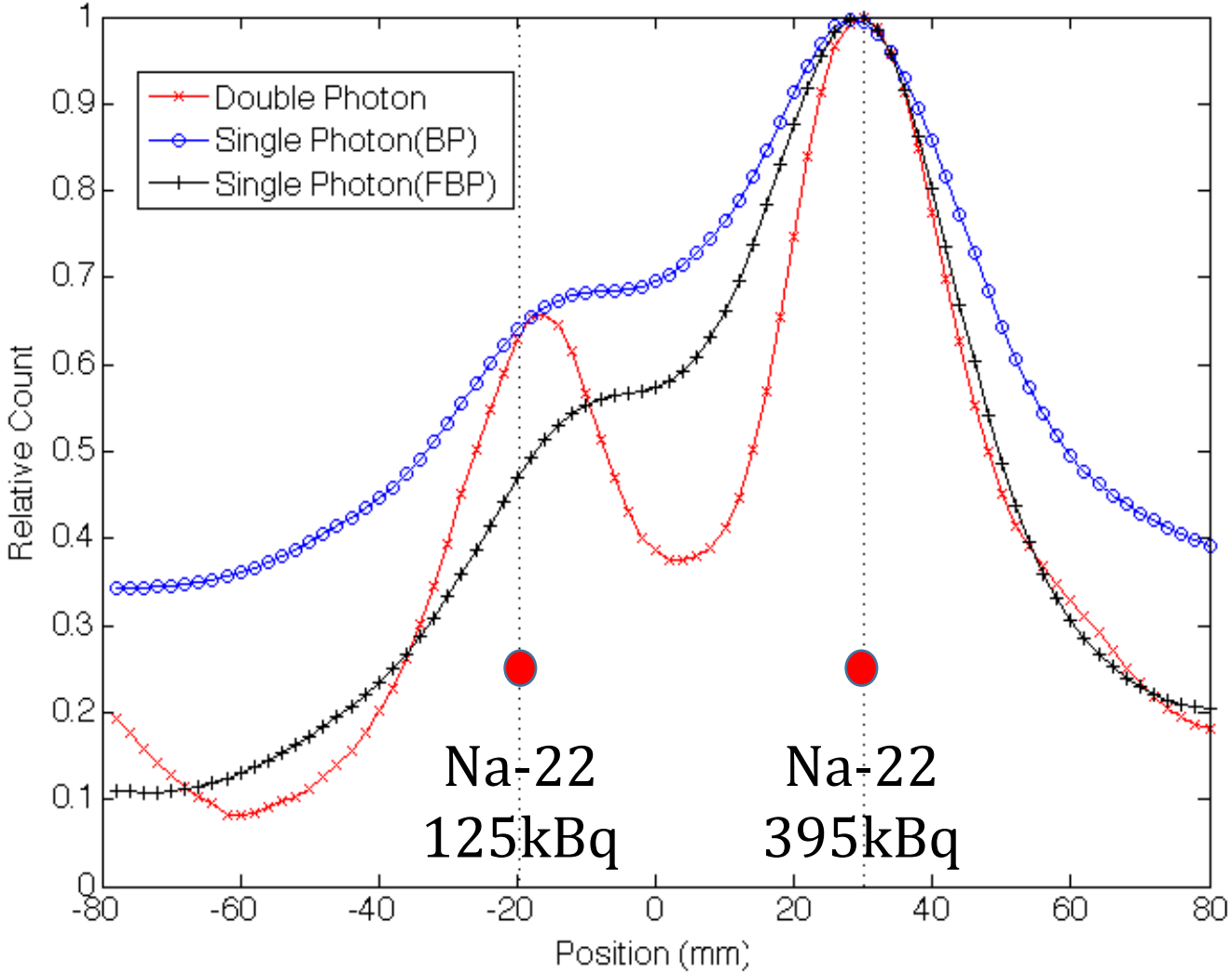


SNR (Single/Double): 2.38 / 9.10

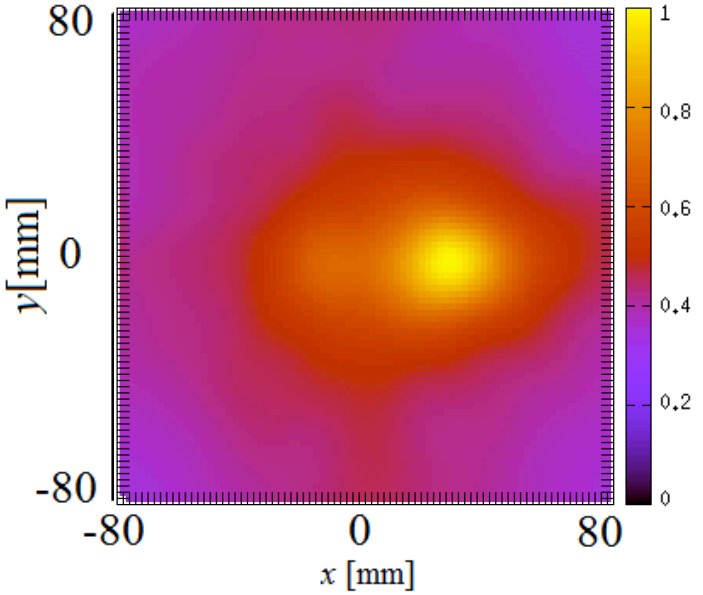
Spatial resolution(mm) (Single/Double): 38.1 / 32.7 (mm)

Efficiency (eff. counts) (Single/Double): 232509 / 214

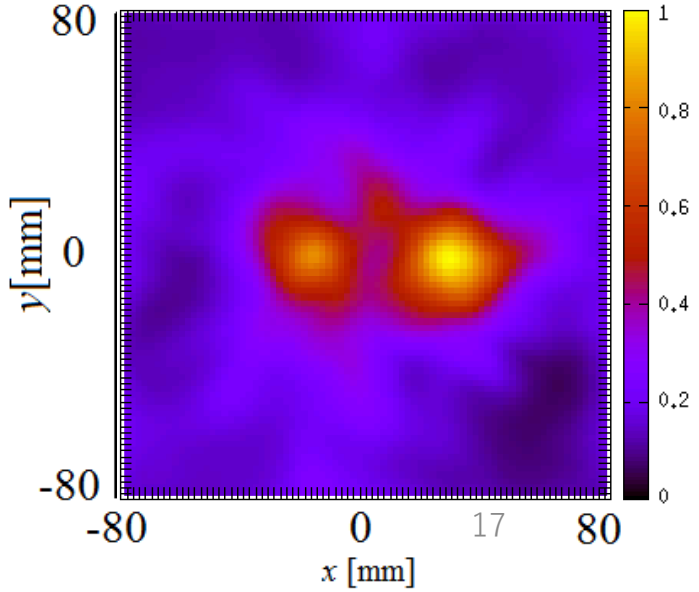
Multiple source Imaging ^{22}Na by DPCI



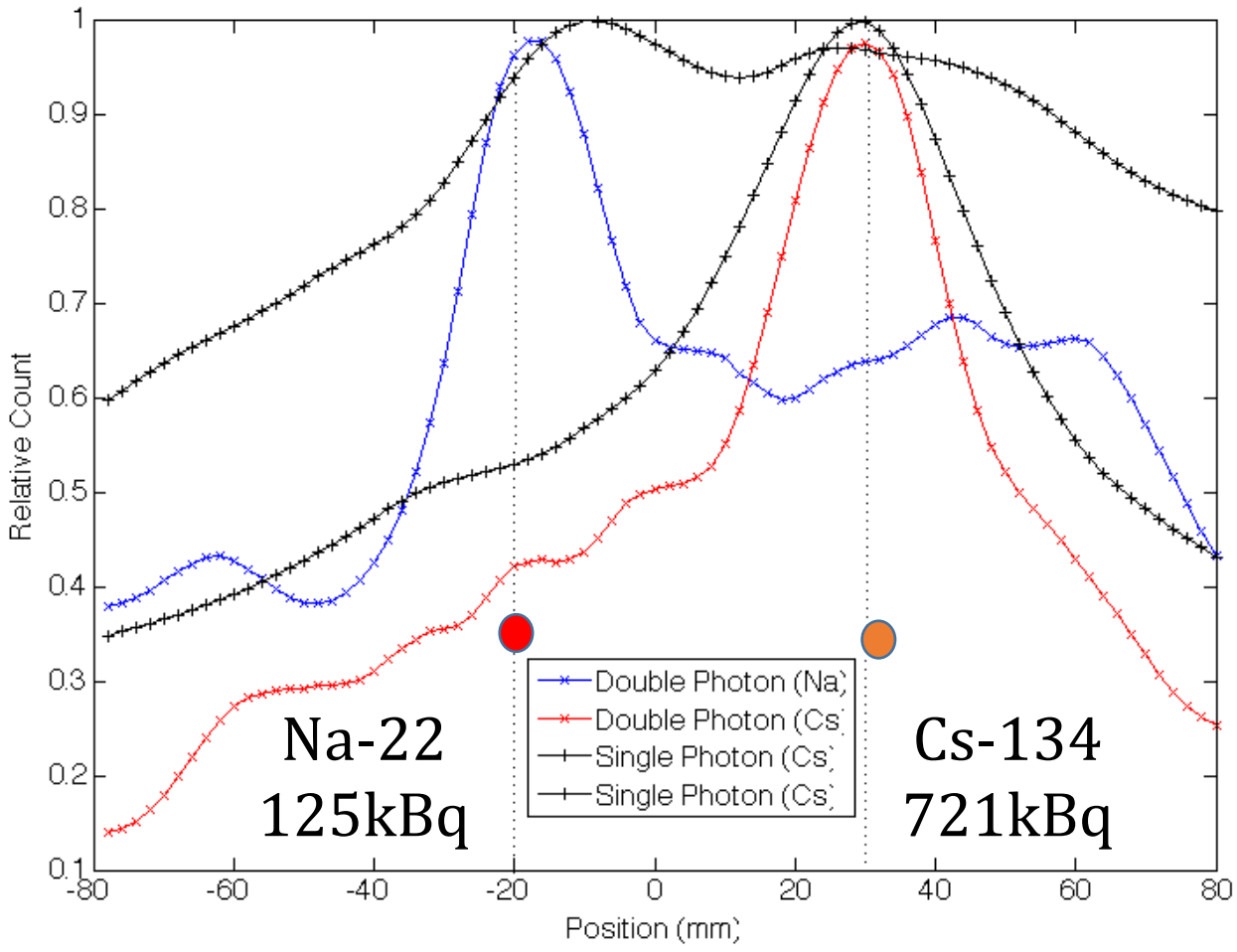
Single
Photon
5468 events



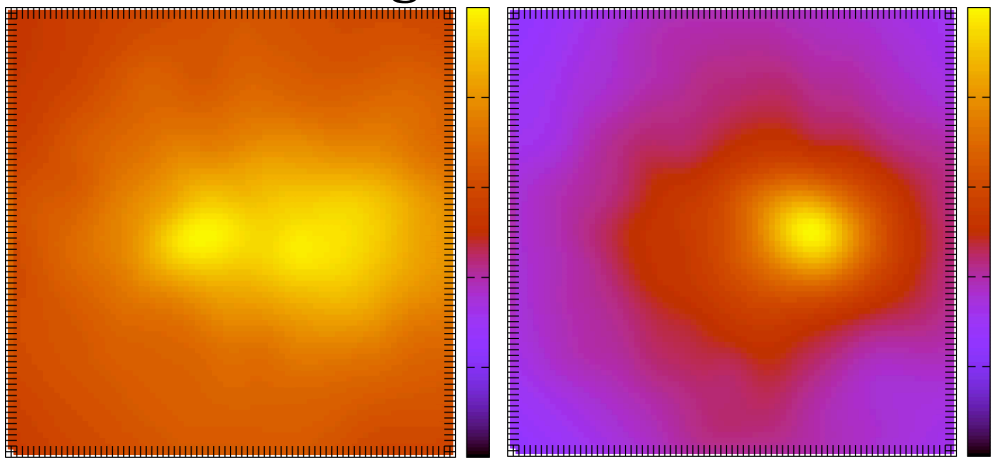
Double
Photon
715 events



Multiple nuclide Imaging ^{22}Na and ^{134}Cs by DPCI

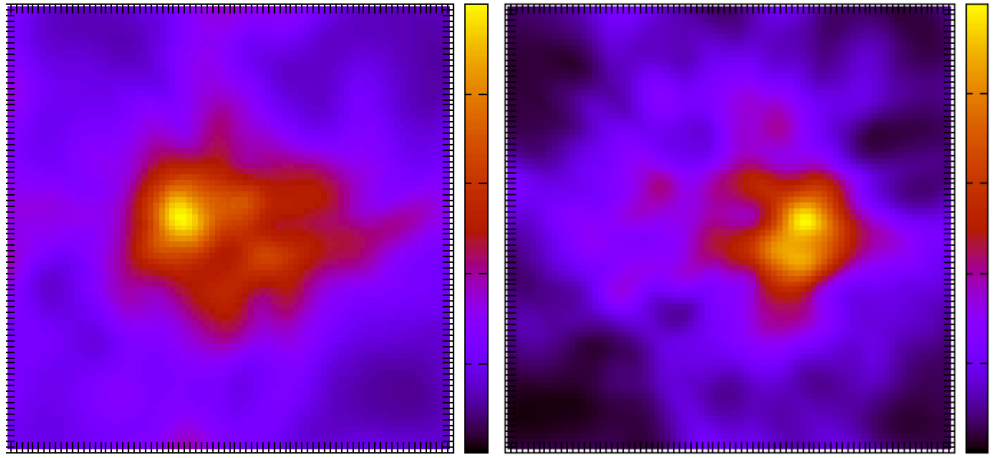


Single Photon



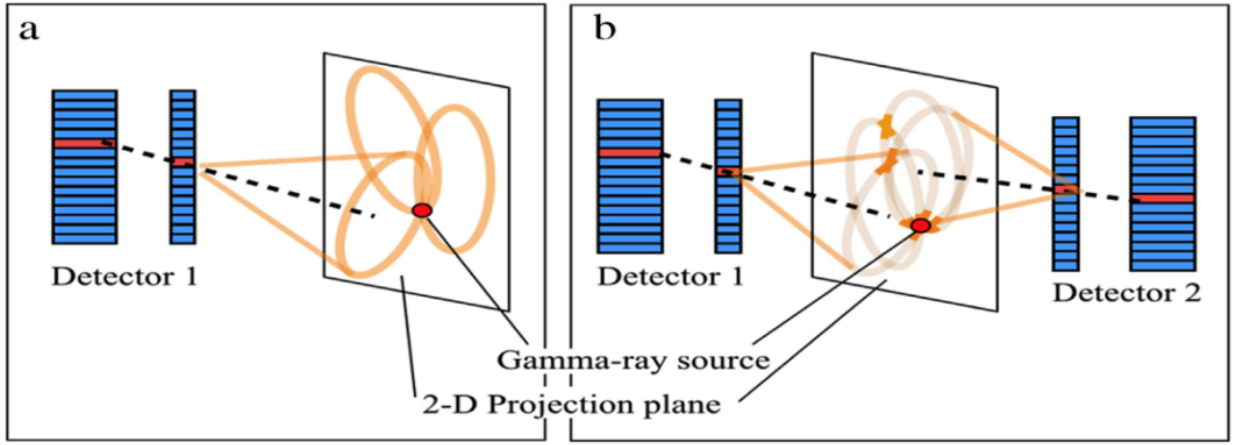
4088 cnts 3548 cnts

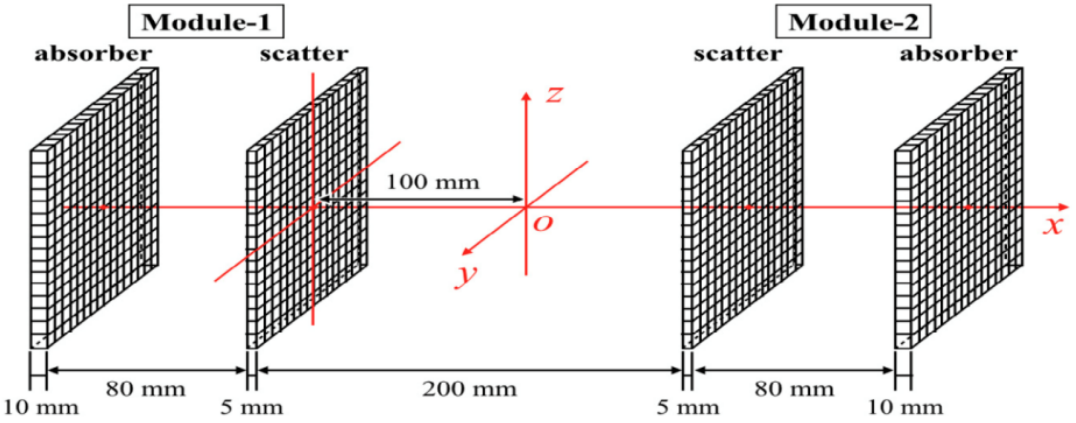
Double Photon

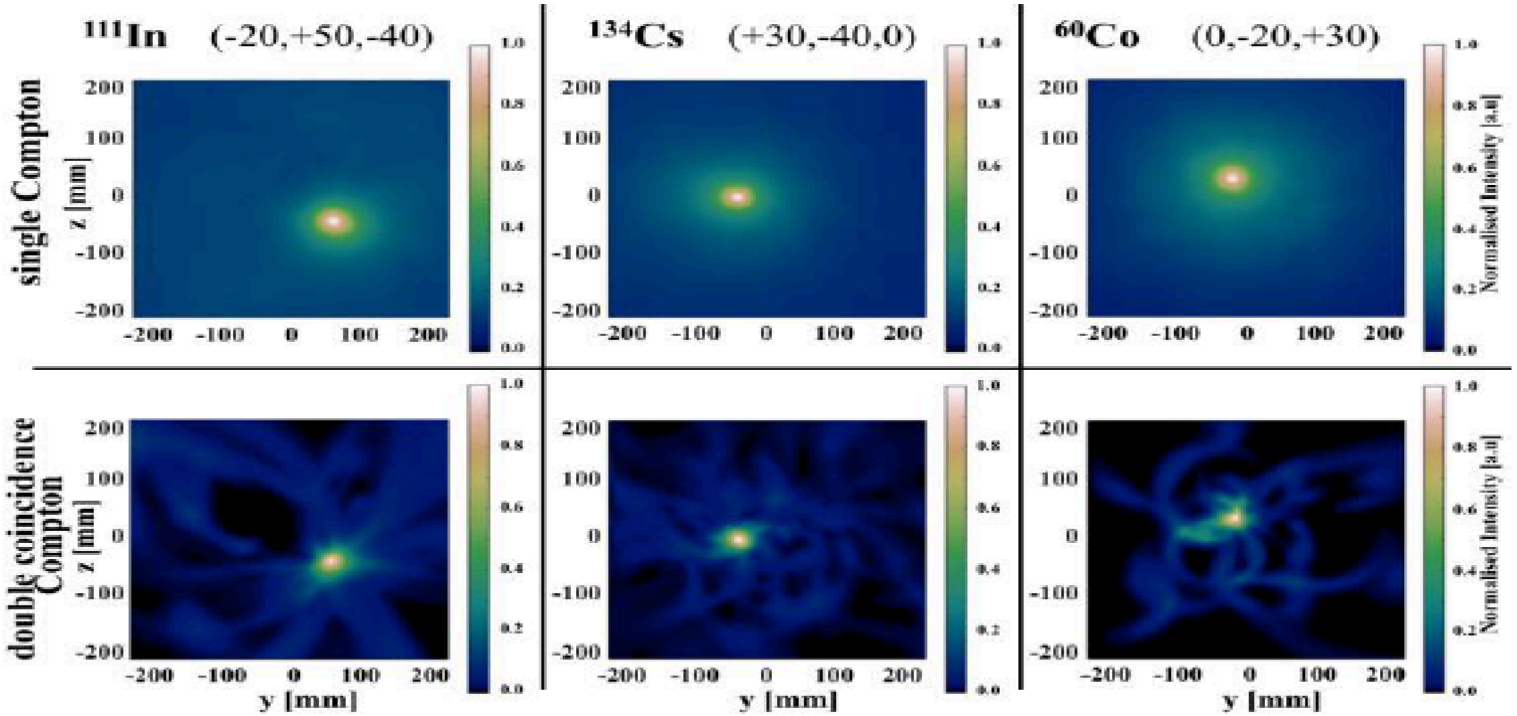


593 cnts 268 cnts

Validation by GEANT4 simulation



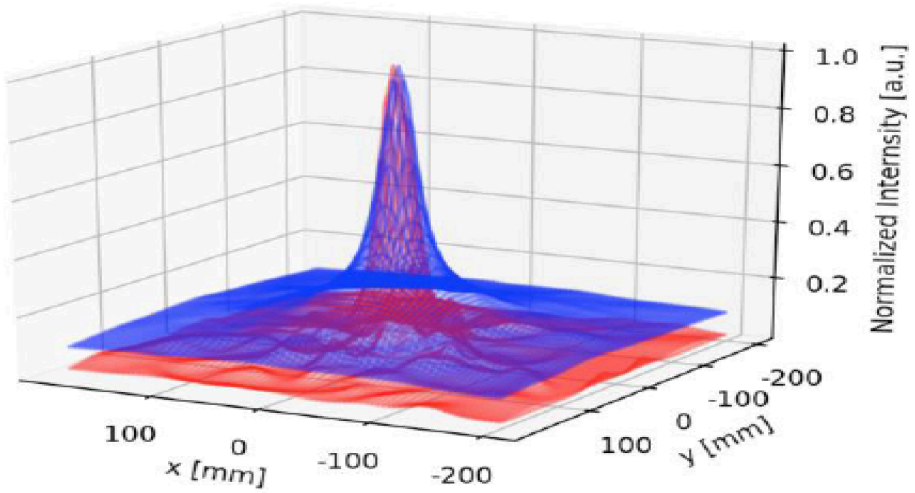


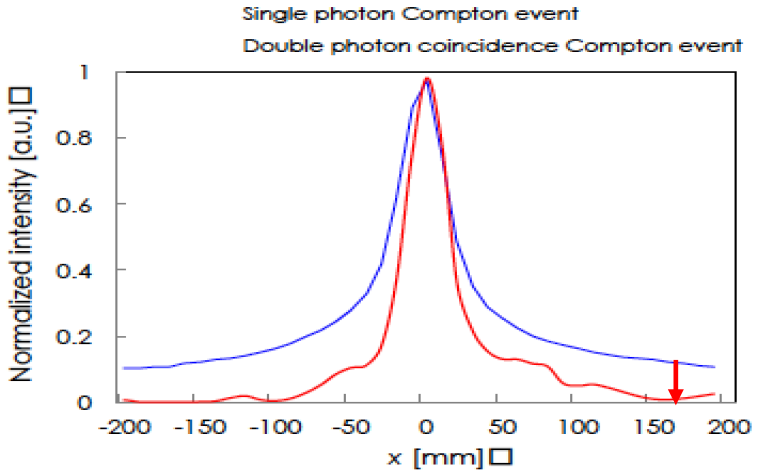


Single
Compton Imaging

Coincidence
Compton Imaging

Validation by GEANT4 simulation





Significant

Background reduction & SN increase

Comparison between the single photon Compton imaging method and the double photon Compton imaging method.

The single photon Compton imaging method	Emergence efficiency	Spatial resolution [mm]	SNR
^{111}In	2.78×10^{-3}	42.46–43.28	6.68
^{134}Cs	3.33×10^{-3}	44.39–46.57	6.51
^{60}Co	2.43×10^{-3}	51.45–52.68	6.34
The double photon coincidence Compton imaging method	**Emergence efficiency**	**Spatial resolution [mm]**	**SNR**
^{111}In	3.56×10^{-6}	28.13–29.87	35.97
^{134}Cs	5.67×10^{-6}	31.92–34.18	29.59
^{60}Co	3.09×10^{-6}	26.61–36.30	32.57

Yoshihara, Y., Shimazoe, K., Mizumachi, Y., & Takahashi, H. (2017). Evaluation of double photon coincidence Compton imaging method with GEANT4 simulation. *NIMA*

Conclusion and Future work

- New method (Double Photon Coincidence Imaging) is experimentally validated for high sensitive imaging

- Double Photon Coincidence Imaging could useful for cascade gamma-ray imaging, such as In-111, Cs-134 and Co-60 etc.

- Stacked SOI event-driven pixel detector be developed as scatter
- will contribute better angular resolution, background reduction

- event-driven SOI and GAGG-SiPM system will be tested for Double Photon coincidence imaging with electron tracking capability in future