Development of Compton-PET hybrid imaging system with $CeBr_3$-SiPM arrays

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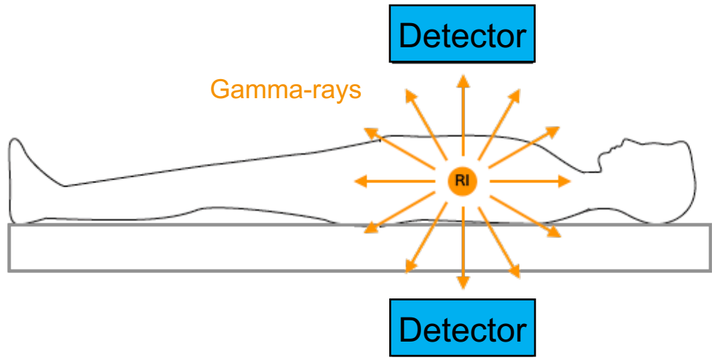
Research Background

Nuclear Medicine

One of medical specialty to diagnose and treat disease by injecting a radioactive agent into our body



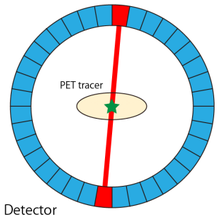
Conventional imaging modality・・PET * and SPECT **

* Positron emission tomography
** Single photon emission computed tomography

PET

- Positron emitter (511keV annihilation gamma-rays)
- Early detection of malignant tumors

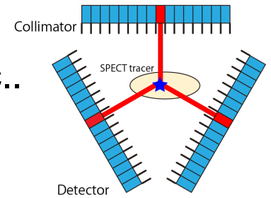
^{18}F-FDG etc..



SPECT

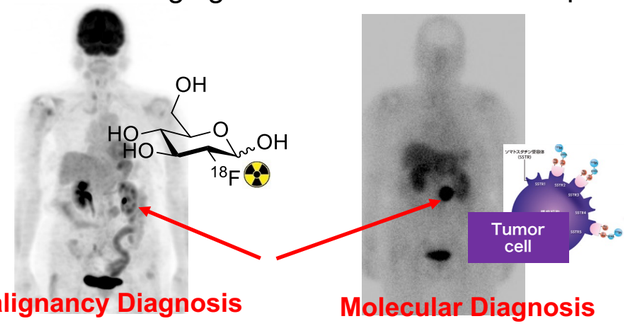
- Single photon emitters (～400 keV)
- Blood flow, molecular dynamics, antibody imaging

^{99m}Tc (141keV),^{67}Ga (300keV), ^{111}In (171,245keV) etc..



FDG-PET -> Glucose imaging

SPECT -> Receptor imaging



Malignancy Diagnosis

Molecular Diagnosis

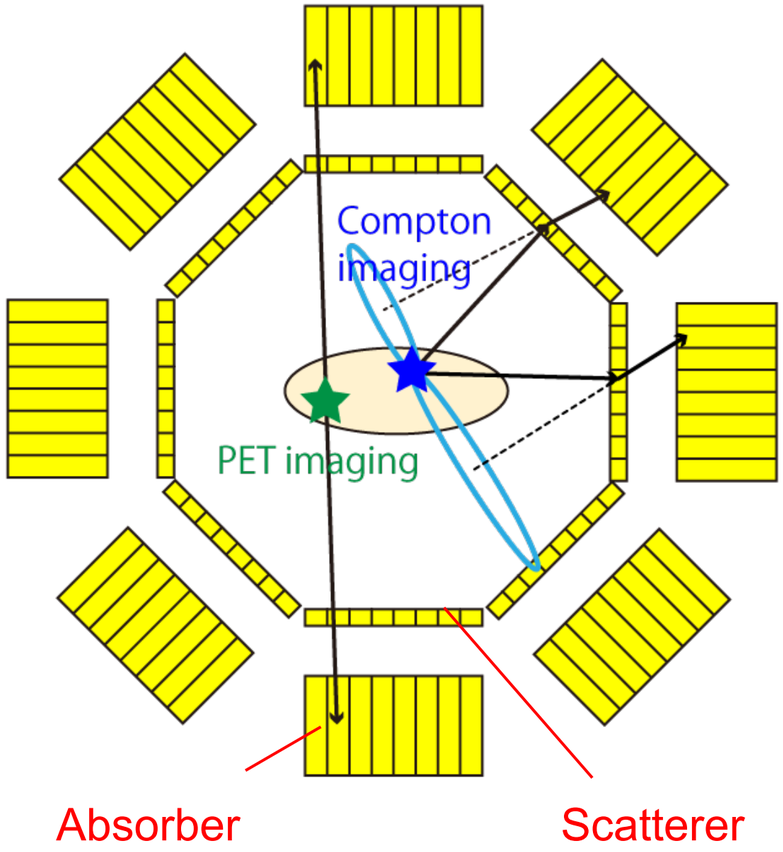
Simultaneous imaging of PET and SPECT nuclides

✓Improvement of diagnostic accuracy
✓Reduction in the number of inspections
→ Reduces the burden on patients

Principle of Compton-PET hybrid camera

■ New simultaneous multi-nuclide imaging method

Principle of Compton-PET hybrid camera



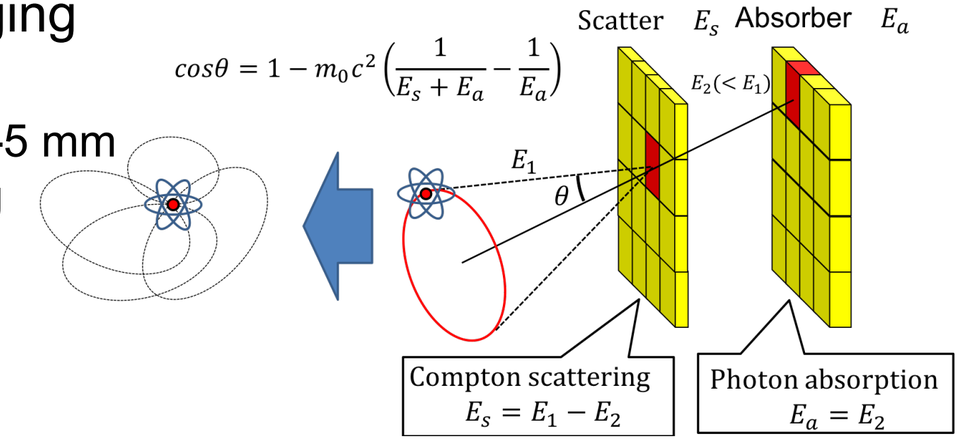
We proposed new simultaneous PET/SPECT imaging system:
Compton-PET hybrid camera [1]

2 Compton cameras (scatterer + absorber) in opposite directions
→ 1 module

- PET nuclide
  → Conventional PET imaging (Coincidence between cameras)
- SPECT nuclide
  → Compton imaging (Coincidence between scatterer and absorber)

Advantages of PET imaging

- High sensitivity
- High spatial resolution : 4-5 mm
- High quantitative imaging

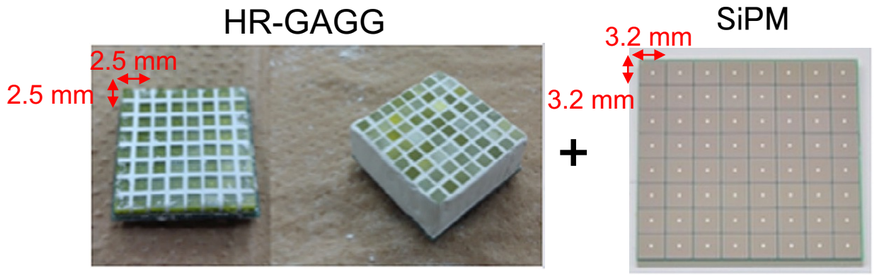


[1] K.Shimazoe et al., NIMA. **954**, (2020) 161499

Compton-PET hybrid camera with GAGG detectors

Detector

HR−GAGG+SiPM

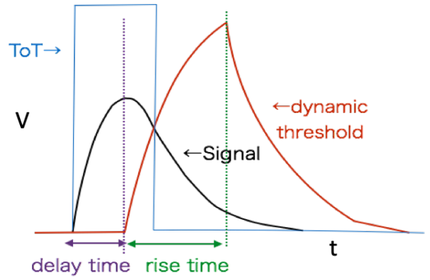


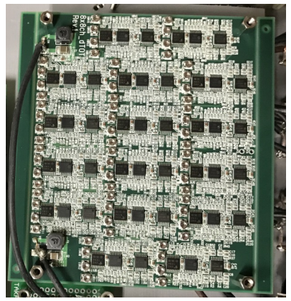
- 8 × 8 array HR-GAGG
- Scatterer : 2.5 mm × 2.5 mm × 1.5 mm
- Absorber : 2.5 mm × 2.5 mm × 9 mm

Coupled with 8 × 8 array SiPM
(Hamamatsu S-13361-3050N-08)

Signal processing

64 ch signals → parallel signal processing with **dynamic Time over Threshold (dToT)** method[2]



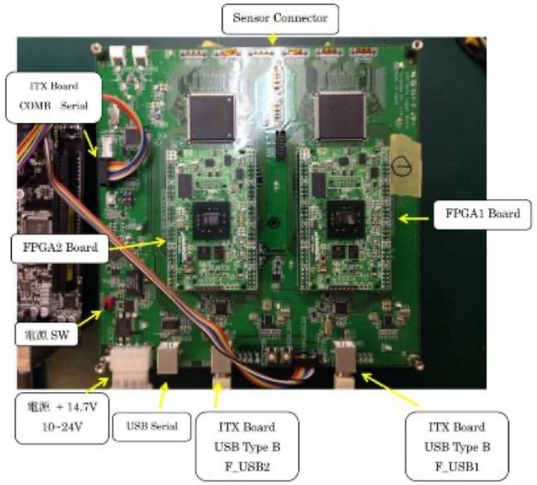


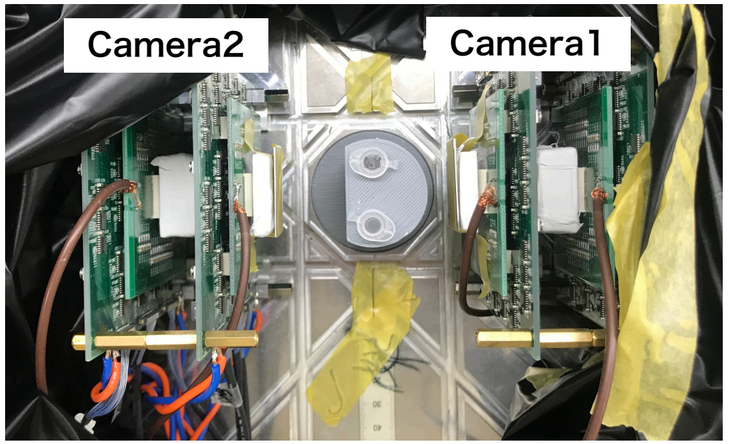
- Digitally acquire the energy information as the time width
- Improved linearity between ToT and energy

Data Acquisition (DAQ) system

- 144 ch parallel ToT DAQ
- 400 MHz (Xilinx Kintex7)
- List mode data

(Channel, time stamp, ToT width)



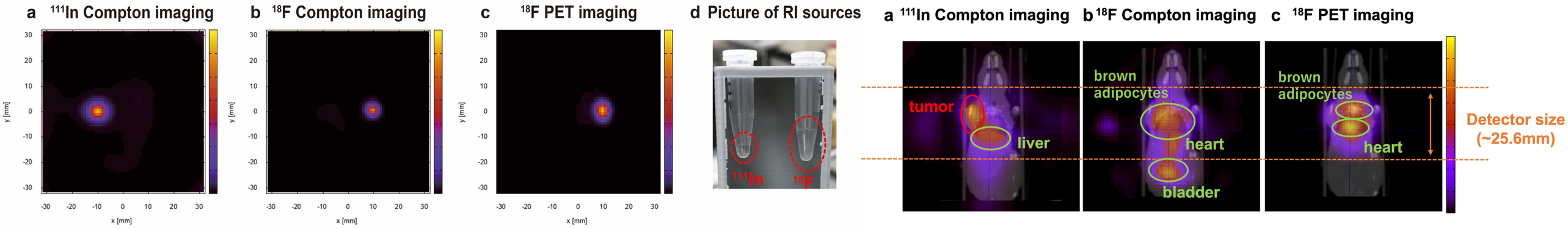


[2] K.Shimazoe et al., IEEE trans. On Nuc. Sci. Vol59, No.6, pp3213-3217, (2012)

Compton-PET hybrid camera with GAGG detectors

Demonstration of simultaneous imaging of PET nuclide (^{18}F–FDG) and SPECT nuclide (^{111}In) [3]

Simultaneous *in vivo* imaging of 18F-FDG and ^{111}In anti-body



Problem

・Poor time resolution (～50 ns) → Limited mainly in the signal processing circuit

Objective

Development of new system with higher time resolution and Evaluation of basic performance

[3] M.Uenomachi et al., ” Simultaneous in vivo imaging with PET and SPECT tracers using a Compton-PET hybrid camera” , 11.1, Scientific Reports (2021) 1-11

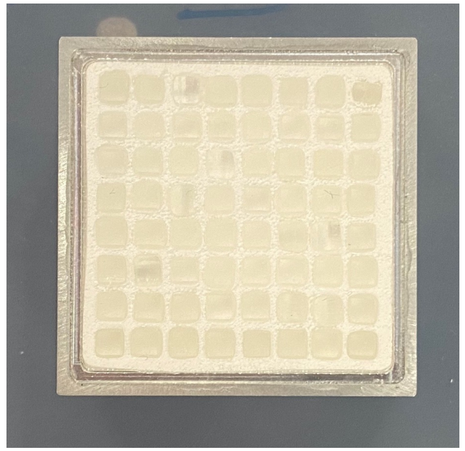
Development of new system with $CeBr_3$ pixel detectors

$CeBr_3$ Scintillator

	HR-GAGG	$CeBr_3$
Light yield (photon/MeV)	40,000~50,000	~70,000
Decay time (ns)	~400	20
Energy resolution (%)	≤ 5 (APD)	~4 (PMT)
Density (g/cm^3)	~6.3	5.2
Other	・No intrinsic γ-ray background ・No hygroscopicity	・Quite-small intrinsic γ-ray background ・Hygroscopicity

Ref : C&A Home page(https://www.c-and-a.jp/index_jp.html)

8x8 array pixel $CeBr_3$



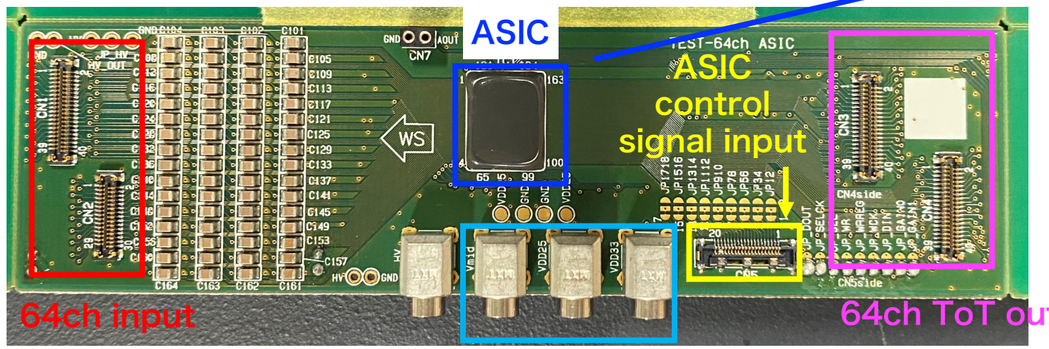
- 3.2 mm pitch
- Thickness:3 mm
- $BaSO_4$ reflector
- Hermetically sealed in an aluminum package with a quartz window
- Fabricated by Tohoku Univ. (Japan)
- Couple with SiPM (Hamamatsu S-13361-3050N-08)

$CeBr_3$ scintillator can achieve both high time resolution and energy resolution

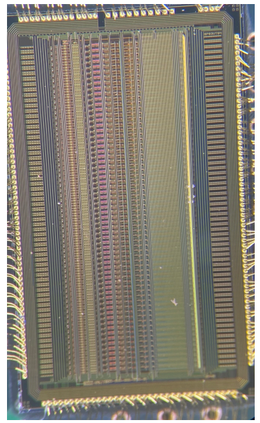
Development of new system with $CeBr_3$ pixel detectors

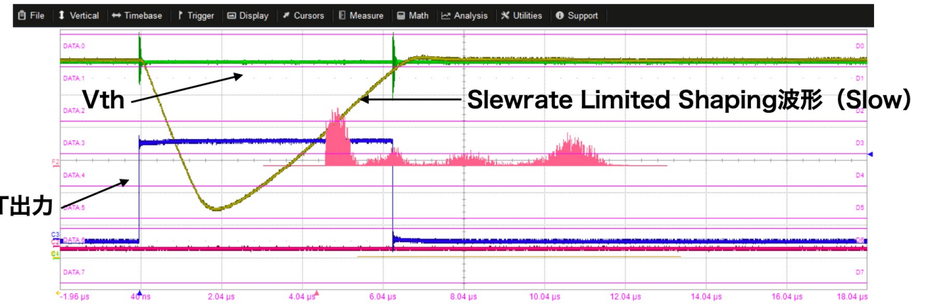
New signal processing circuit

64ch slew rate limited ToT ASIC



ASIC power supply (2.5V, 1.25V)
IC chip power supply (3.3V)

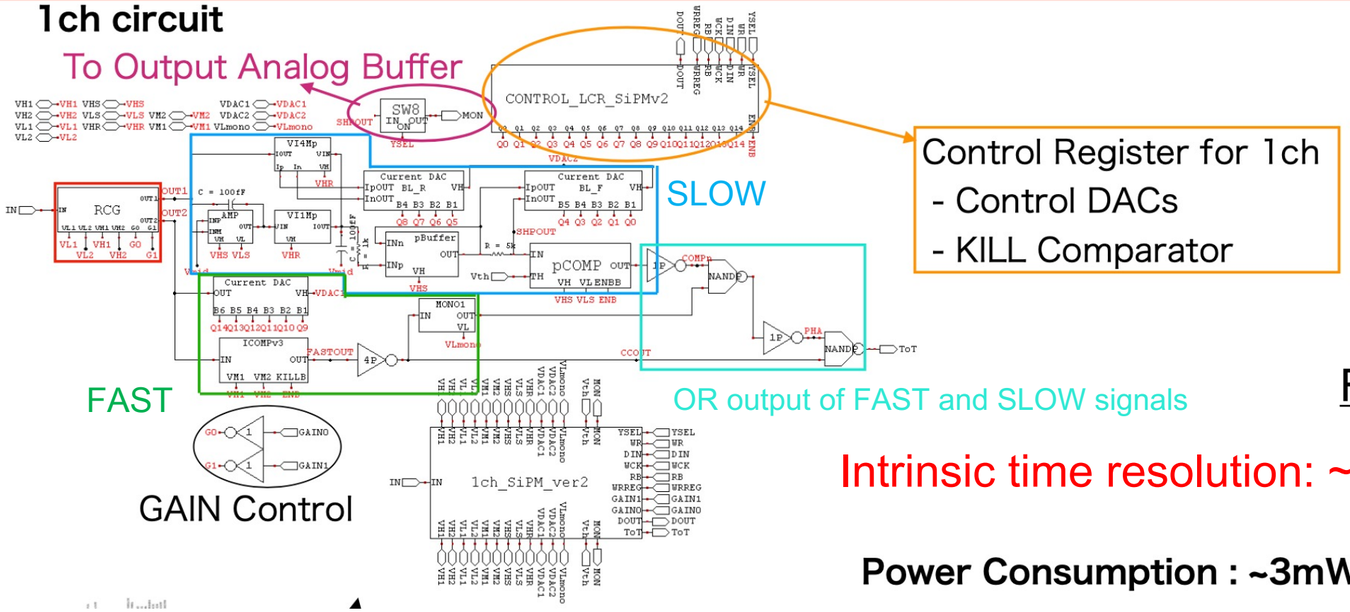




FAST circuit :
- Timing output
- Generates a pulse with constant width by setting the current threshold

SLOW circuit :
- Energy information（ToT）output
- Generates a ToT pulse by comparing a slew rate limited signal and a constant voltage (Linearity○)

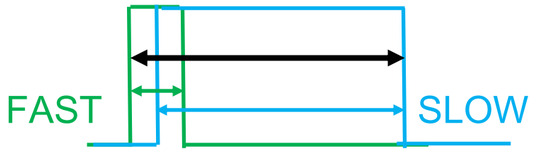
1ch circuit



Final digital output→ OR output of FAST and SLOW signals

Intrinsic time resolution: ~55 ps (FWHM)

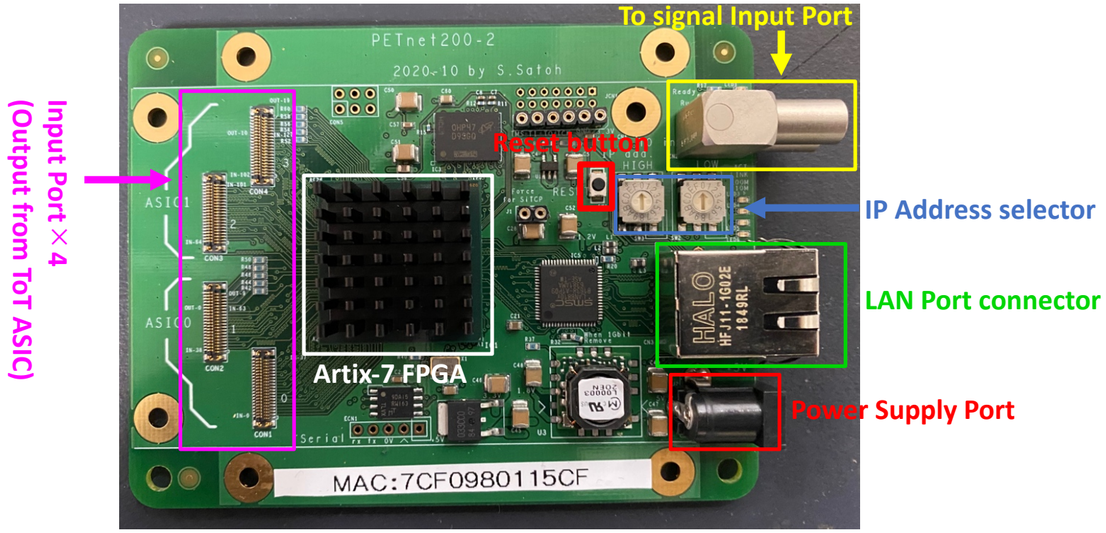
Power Consumption : ~3mW



Development of new system with $CeBr_3$ pixel detectors

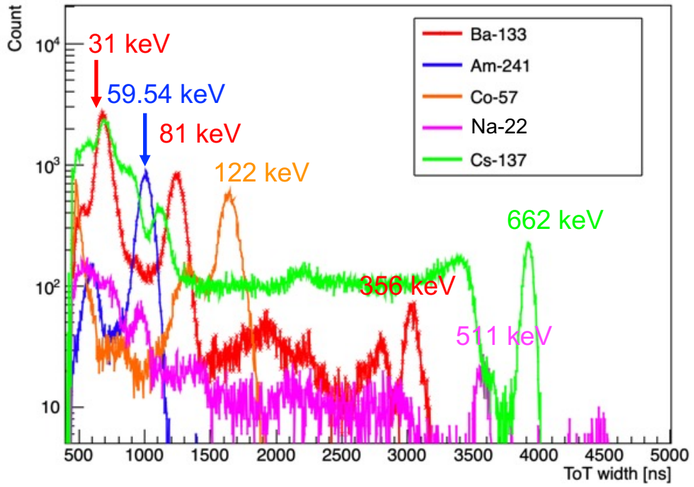
New DAQ [4]

- 128 ch parallel ToT DAQ
- Time resolution: 62.5 ps (Old DAQ : 2.5 ns)
- List-mode data

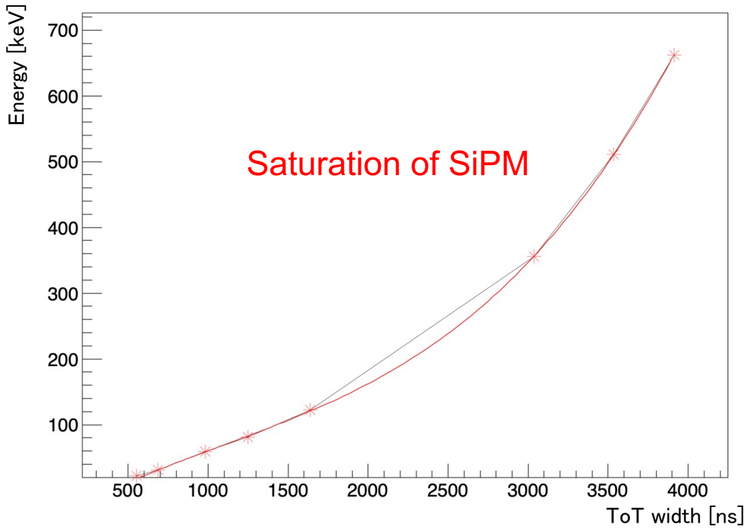


[4] S.Sato et al., ” Development of multichannel high time resolution data acquisition system for ToT-ASIC” , IEEE Trans. On. Nucl. Sci. (2021)

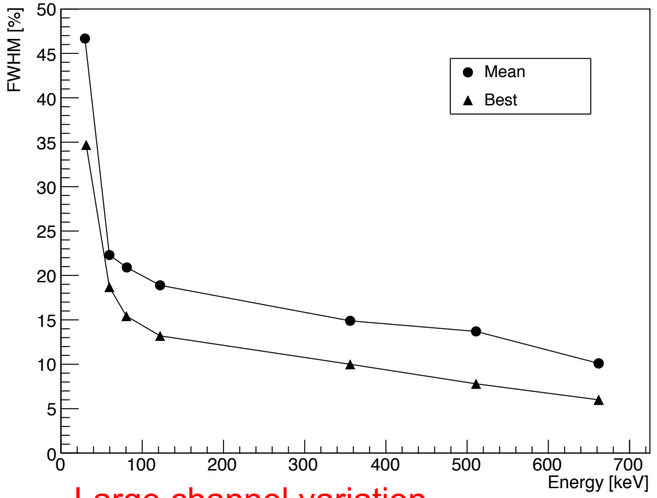
ToT Spectra



Linearity



Energy resolution

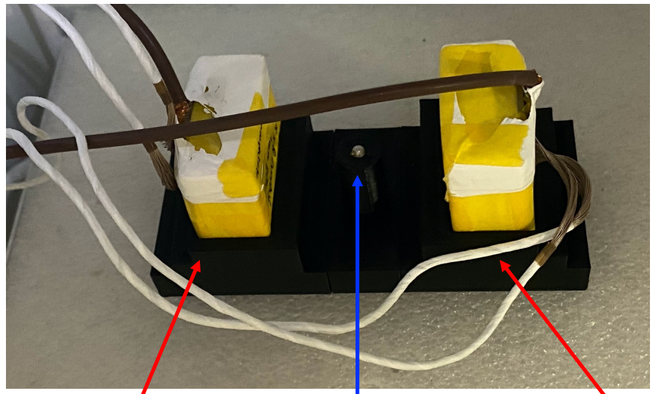


Large channel variation

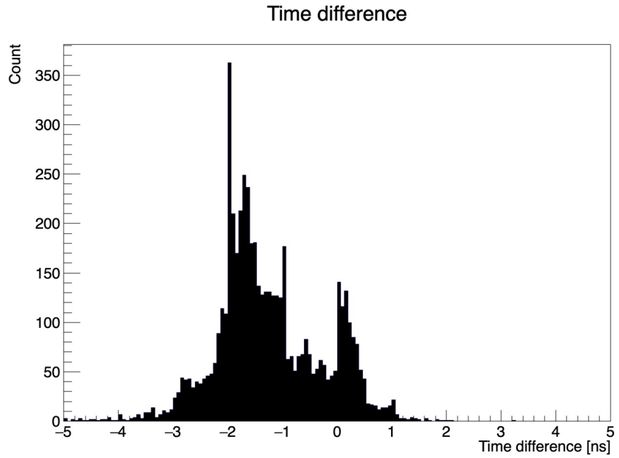
Time resolution, PET imaging

Experimental setup

- Two 8x8 array $CeBr_3$ detectors (thickness 3 mm) placed in opposite directions for measurement
- Source：^{22}Na point source
- Distance from source to detector：30 mm
- SiPM bias : 55.0V
- Temperature：25℃



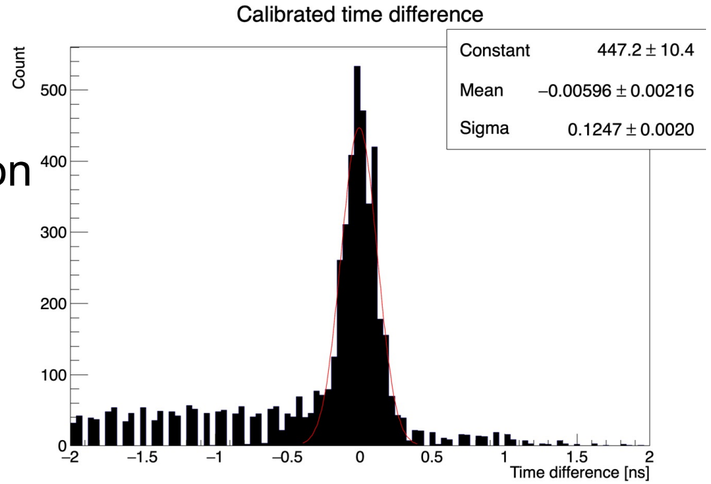
Time resolution



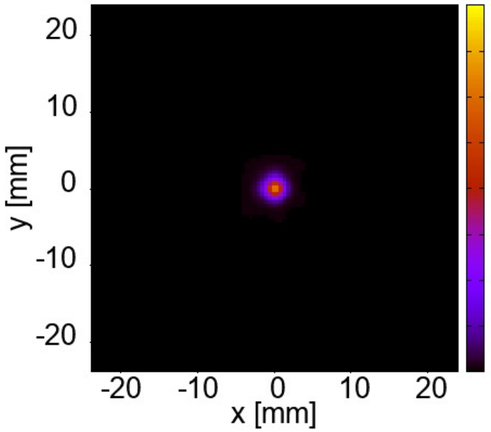
Offset depending on the combination of pixels

After offset calibration

Correct only combinations with statics of 50 or more



PET imaging (BP)

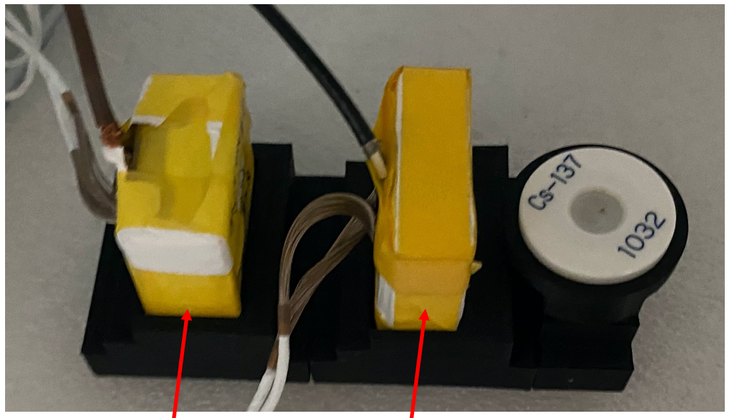


Time resolution: ~293 ps (FWHM)　Spatial resolution : ～2.1 mm (FWHM)

Demonstration of Compton imaging

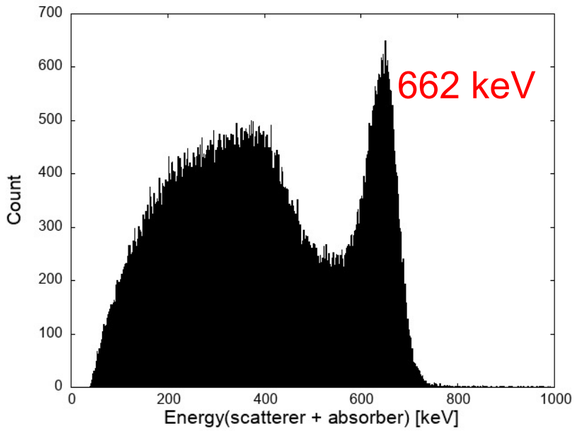
Experimental setup

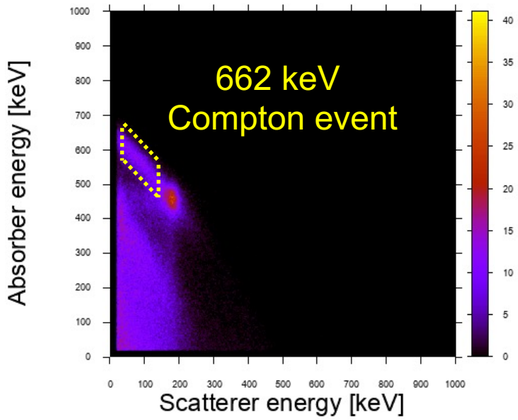
- 8x8 array $CeBr_3$ detector (Thickness 3 mm) placed as scatterer and absorber
- Source : ^{137}Cs (662 keV)
- Distance from scatterer surface to absorber surface : 40 mm
- Distance from source to camera : 30 mm
- SiPM bias : 55.0V
- Temperature : 25℃



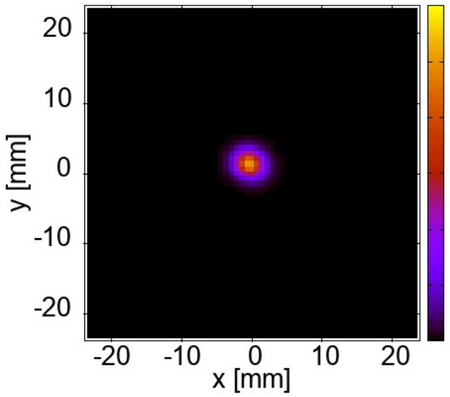
Absorber (Thickness 3 mm) Scatterer(Thickness 3 mm)

Coincidence event

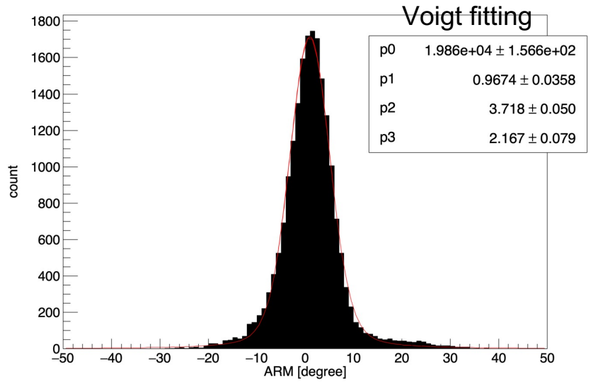




Compton imaging (MLEM)



ARM



Spatial resolution : ～3.1 mm (FWHM) ARM : 10.0 degree (FWHM)

Summary and future works

■ Development of new imaging system with $CeBr_3$ pixel detectors

Conventional system: Signal processing circuit of time resolution 50 ns + DAQ of time resolution 2.5 ns
→ New system : Signal processing circuit of time resolution 55 ps + DAQ of time resolution 62.5 ps

■ Evaluation of basic performance

- Energy resolution : Best ~6.0 % @ 662 keV, Mean ~10.1% @ 662 keV
  → Large channel variation
- Time resolution : 293 ps (FWHM) by correcting offsets between channels
- Succeeded to conduct PET and Compton imaging

■ Future works

- Development of a prototype Compton-PET hybrid camera with two $CeBr_3$ Compton cameras
- Demonstration of simultaneous PET and Compton imaging with a prototype system

Thank you for listening