Simulation Study on SOI based electron tracking Compton camera using deep learning method

K. Shimazoe[1], K. Toyoda[1], M.Uenomachi[1], Y.Yoshihara[1], H.Takahashi[1], A.Takeda[2], Y.Arai[3]

1. Department of Nuclear Engineering and Management, The University of Tokyo,
2. Miyazaki University 3. KEK

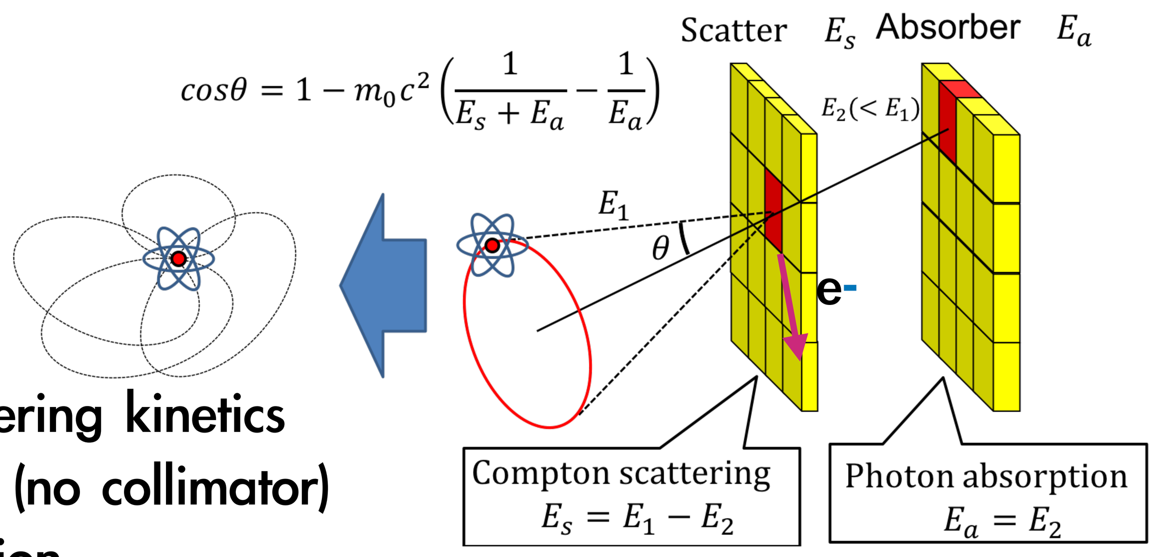
shimazoe@bioeng.t.u-tokyo.ac.jp

Introduction

A Compton Camera is a promising gamma-ray imaging method based on Compton scattering kinetics because of high Compton scattering probability for sub-MEV or higher energy gamma-ray imaging [1]. Several researches show the great capability of detecting nuclides in the applications of nuclear medicine, astrophysics and decommissioning [2][3][4], however, there are still demands for improving signal-to-noise ratio in Compton imaging. The conventional Compton imaging suffers from the artifact derived from the Compton cones and it is known the detection of ejected direction of recoil electrons could improve the signal to noise ratio in the image [5][6]. Our group have been working on the fine-pitch silicon-on-insulator (SOI) based electron tracking Compton camera and shows the improvement of SN in the experiment. In this study the extraction of ejected direction of recoil electron by using deep learning method are simulated and analyzed with Monte Carlo simulation for faster processing of data.

Principle

$$\cos\theta = 1 - m_0c^2\left(\frac{1}{E_s+E_a} - \frac{1}{E_a}\right)$$



Compton Camera

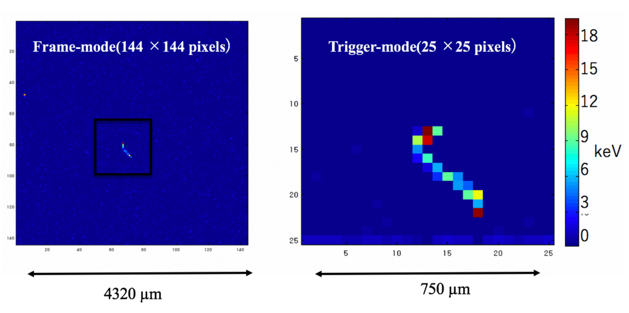
- Gamma-ray imaging
- Based on Compton scattering kinetics
- High detection efficiency (no collimator)
- Detection energy + position
  → scattering angle (Compton cone)
- Draw some Compton cones → Identify a position of source

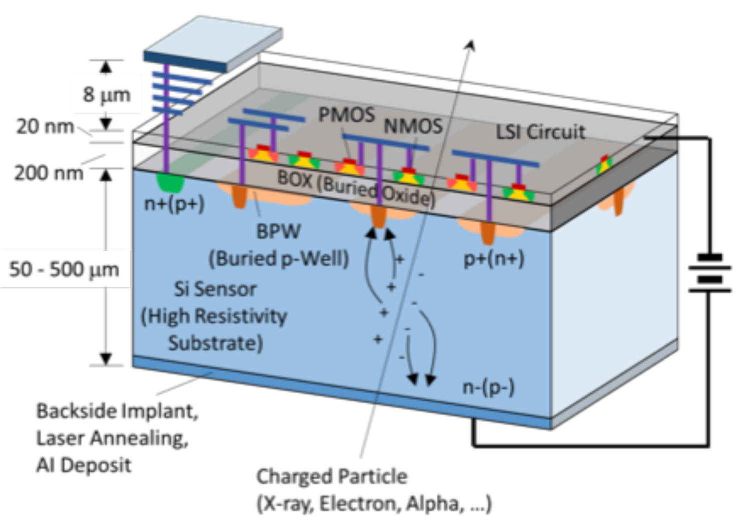
Conventional : Low SN ratio caused by Compton cones
Recoil electron tracking is one way to improve

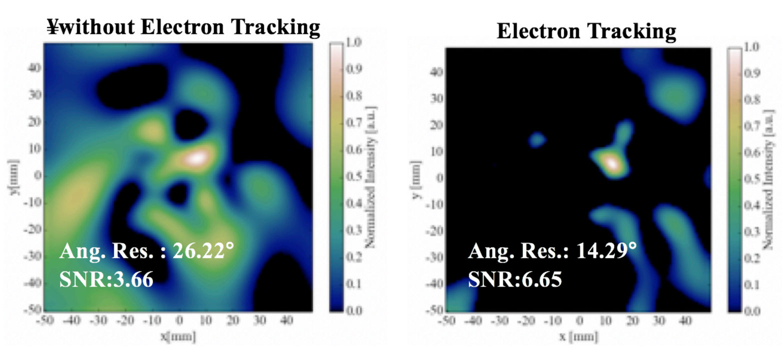
SOI

Electron Tracking in SOI pixel detector

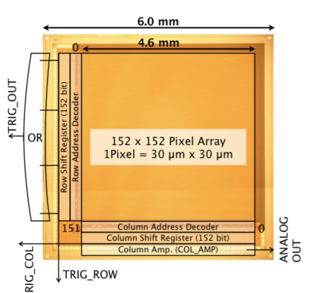
Fine-pitch SOI pixel sensor with trigger output capability is useful in electron tracking Compton imaging







	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 <	



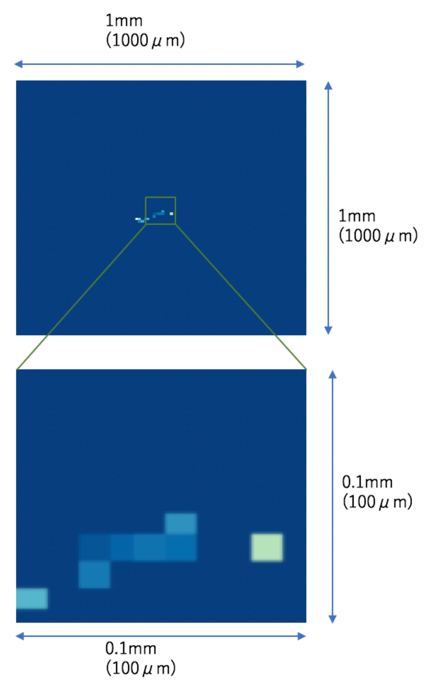
Electron tracking with SOI detector improves the SN and angular resolution

Investigation of direction extraction with automated deep learning method

Experimental Setup

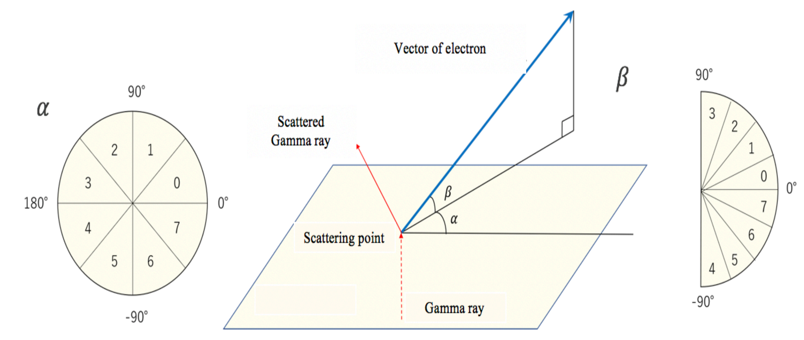
Data Generation

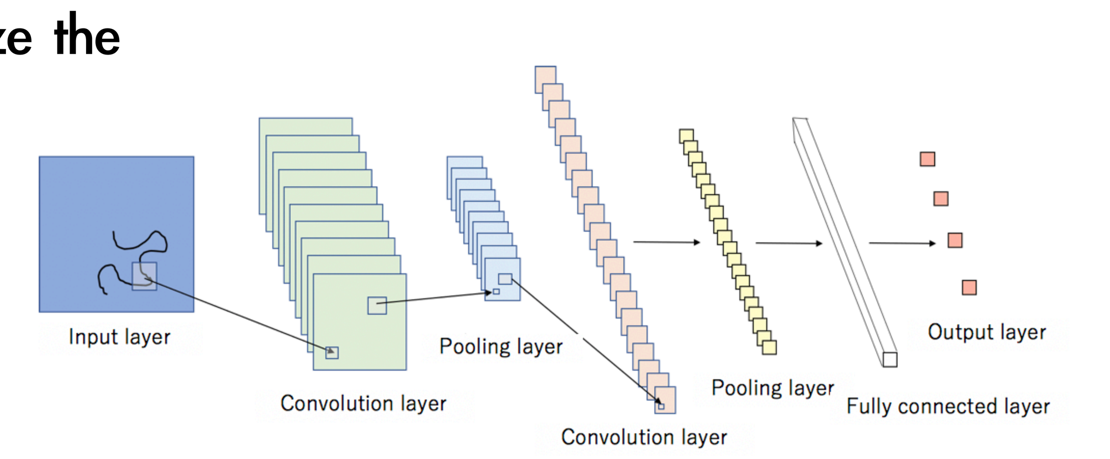
1. 662 keV gamma photons are injected to the center
2. silicon detector with 10 μm and 30 μm pixel
3. Deposited energy is recorded in 2D
4. Data are classified into 8 categories each in alpha (horizontal) and beta (vertical) angle of scattering
5. Around 80000 data for teaching
   With Geant4 Monte Carlo simulation



Convolutional Neural Network

Deep learning with multi-layer
Combination of convolutional layer to extract the local characteristics and pooling layer to minimize the size



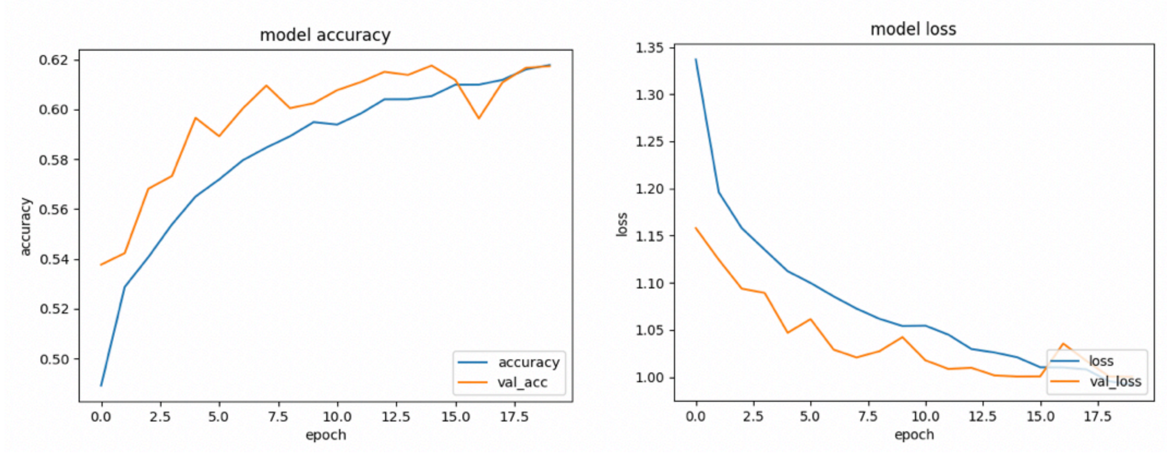


Evaluation

1. Around 40000 data are used to evaluation the accuracy of estimated direction in 8 categories
2. Using the unknown image as input to estimate the direction
3. Accuracy is defined by (no. of correct forecast data)/ (no. of all data)
4. SPD (Scatter Plane Deviation) is evaluated
5. Image is reconstructed with and without electron tracking

Results

After teaching is finished the unknown images are used as input to estimate the direction in alpha and beta. Around 15 epoch is required for estimation.



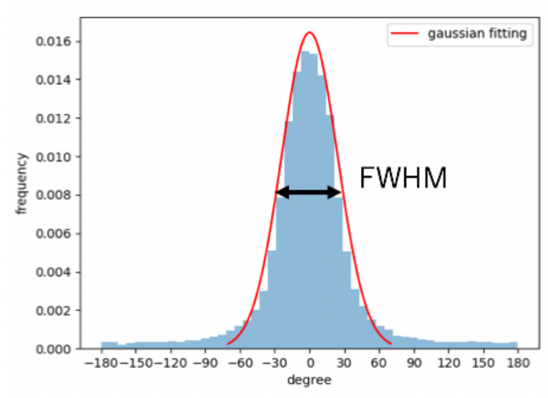
a. Tables shows the accuracy of alpha and beta angle (one angle corresponds to 45 deg. In alpha And 22.5 deg in beta) with CNN

b. 10 μm pixel shows the higher accuracy in estimation of alpha angle

c. SPD (FWHM of accuracy) is around 36 degree in beta.
SPD with 10μm pixel is 57.5 deg. and with 30μm pixel is 73 deg. In alpha (horizontal) angle

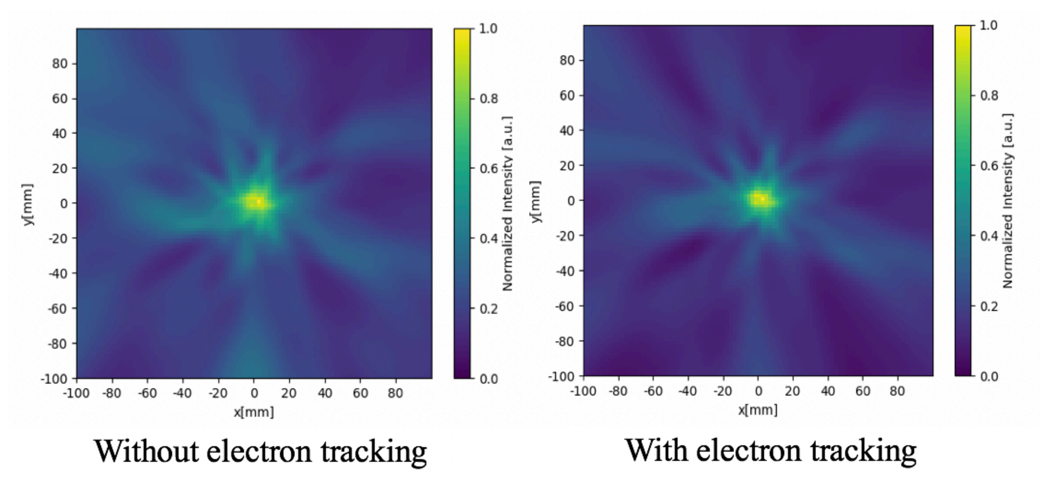
Method	Pixel Size	α	β	SPD(α)	SPD(β)
CNN	10μm	61.76%	48.48%	57.5	36.3
CNN	30μm	47.52%	49.51%	73.0	35.6

Comparison of 10 and 30 μm pixel



SPD evaluation

Compton Image reconstruction (preliminary) is done with electron tracking and without electron tracking using simulated data. Electron tracking shows slightly better signal-to-noise ratio and spatial resolution.



Electron	SNR(X)	SNR(Y)	PR(X)	PR(Y)
Without	3.99	3.47	32.3mm	26.4mm
With	4.83	5.15	30.4mm	23.6mm

SNR and spatial resolution (FWHM) in reconstructed image

Conclusions

- Deep learning method could be useful to estimate the direction of ejected recoil electron with SPD of a 58 degree and 36 degree in alpha and beta angle, which will accelerate the processing in et-Compton imaging
- Reconstructed image shows better SNR and resolution with e.t.
- Further investigation is required including the effect of noise in pixel.
- Silicon based et-Compton imager is in development

Reference

[1] J.E.Gormley et al., Nucl. Instr. and Meth. A. 397, pp440-447, (1997)
[2] Y.Shikaze et al., Journal of Nucl. Sci. and Tech. Vol 53, Issue 12, pp1907-1918, (2016)
[3] S.Takeda et al., NIMA Vol. 787, pp207-211, (2015)
[4] Sato, Yuki, et al. Journal of Nuclear Science and Technology55.9 (2018): 965-970.
[5] Y.Yoshihara et al, Null. Instr. and Meth. A. 873, pp51-55, (2017)
[6] Shimazoe, K., et al. 11.02 (2016): C02030.