VCI 14TH VIENNA CONFERENCE ON INSTRUMENTATION
THE UNIVERSITY OF TOKYO

Feasibility Study of a Single Probe Compton Camera for Laparoscopic Surgery

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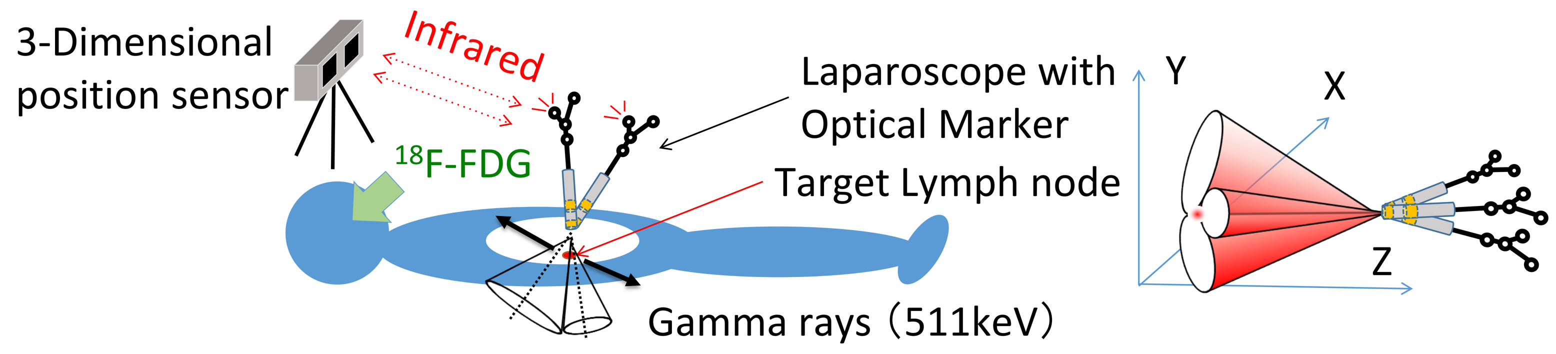
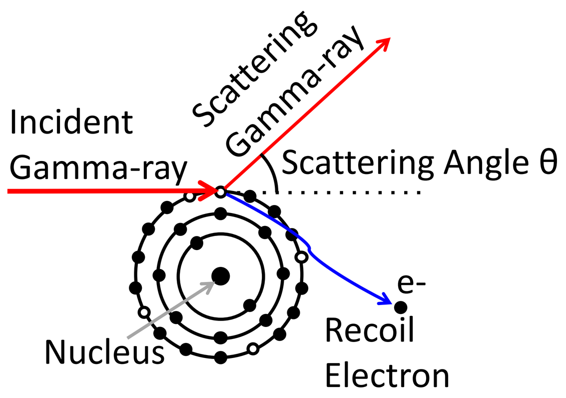
Compton Camera, which enables us to visualize gamma-ray source distribution by using Compton scattering, came to take interests in various research fields. As for clinical applications, compactness of Compton Camera will be attractive advantage to achieve intraoperative diagnosis using radioactive biomarker [Y.Nakamura, 2013].

For satisfying requirement to miniatualizing and simplification of radiation detector for laparoscope, we proposed novel imaging system using only one pair of scatterer and absorber. 3-Dimensional position sensor was also used to monitor detector's movement and to reconstruct image by multiplying Compton cones, which represents incident angles of gamma ray at each detector's position.

In Compton scattering, incident gamma rays collided electrons in material, and scattering gamma rays are generated. This scattering angle θ depends on recoiled electron's energy (E_{sc}) and incident gamma ray's energy (hν). Proposed Compton Camera reconstructed image by measuring these recoiled electron's energy and scattered gamma-ray's energy in various probe position, and multiplying Compton Cones on temporal axes.

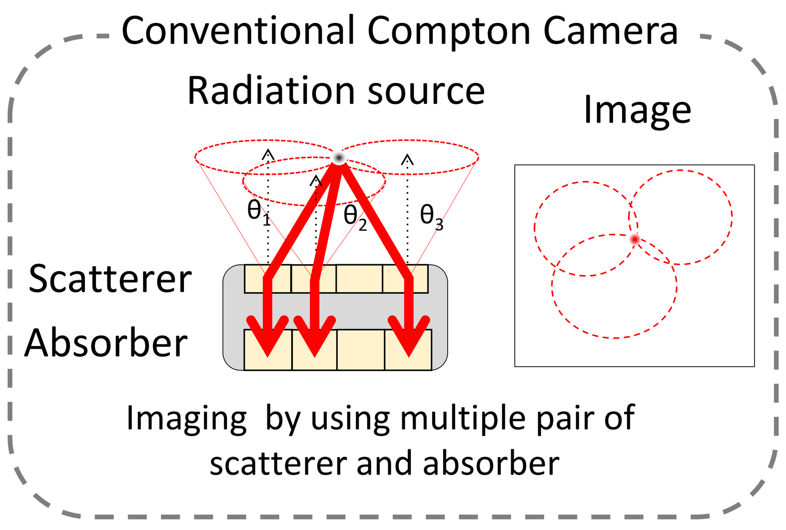
Requirement specification
- Small-sized (~ϕ13mm) detector
- 10 mm^2 spatial resolution at 30 mm depth

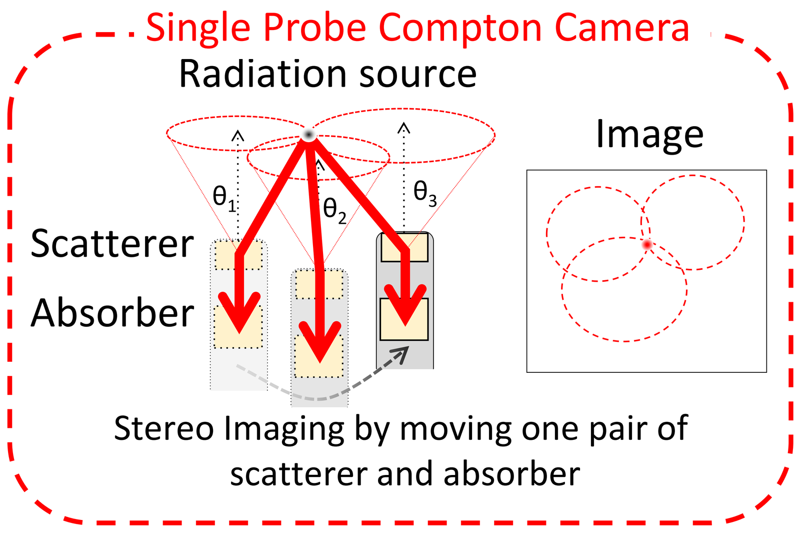




$$\theta = \arccos\left[1 + m_e c^2\left(\frac{1}{h\nu} - \frac{1}{E_{sc}}\right)\right]$$

E_{sc} : Recoil Electron's energy
hν : Incident Gamma ray's energy
$m_e c^2$: Rest Energy, 511 keV

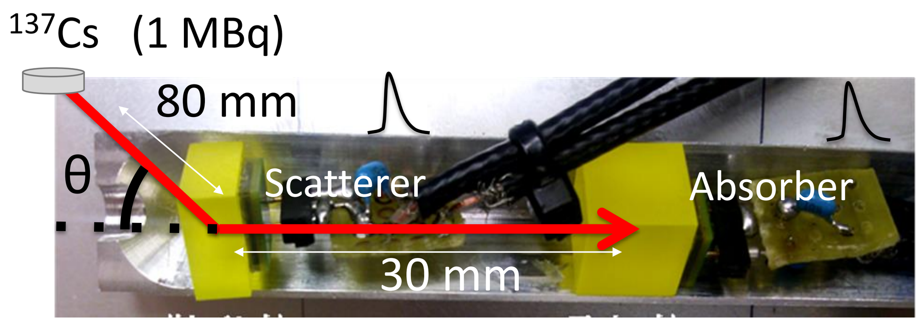




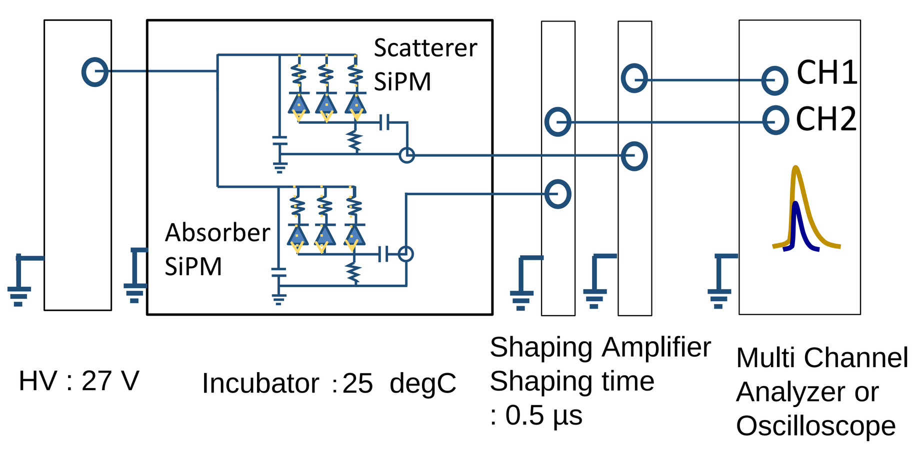
Purpose : Feasibility Study of Compton Imaging Probe Using Position Sensor

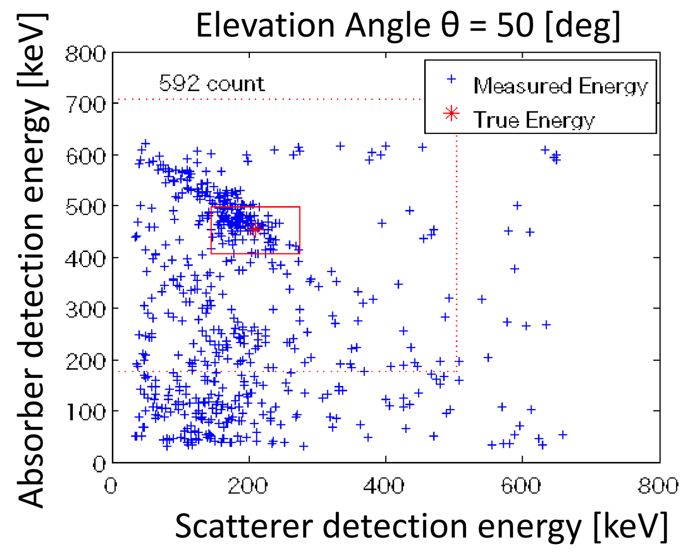
Single Probe Compton Camera

Compton scattering angle was calculated from detected energy values using scintillation detectors. Each detector size was decided by insert hole size of forceps (10 ~ 15 mm diameter). Used GAGG crystal size is follow, scatter scintillator size is 10 × 10 × 5 [mm^3] and absorber scintillator is 10 × 10 × 10 [mm^3]. GAGG has a good property of high density (6.3 g/cm^3) and good chemical stability. The distance between these detectors is 30 [mm]. Scintillation light is detected by Silicon Photomultiplier (SiPM, KETEK PM6660 6 × 6 mm^2). To inspect detector's performance, energy resolution and intrinsic detection efficiency were measured. Intrinsic detection efficiency was calculated by measured coincidence counts for 10 minutes. Energy resolution of scatterer detector was 11.4 % at 662 keV with ^{137}Cs. Detection efficiency was 0.016 % at θ = 50 [deg], and counting loss which comes from lower recoil electron's energy than detection threshold caused sensitivity deterioration at lower elevation angle θ.



Scatterer scintillator size : 10 × 10 × 5 (mm^3)
Absorber scintillator size : 10 × 10 × 10 (mm^3)





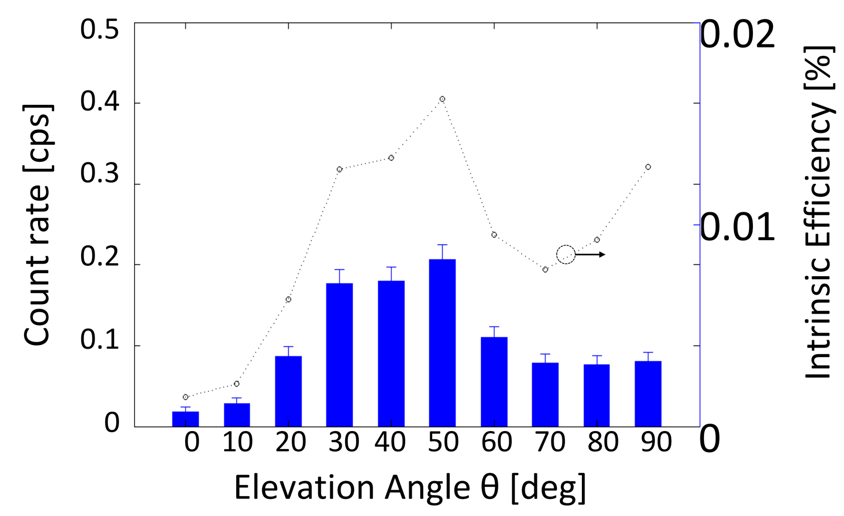
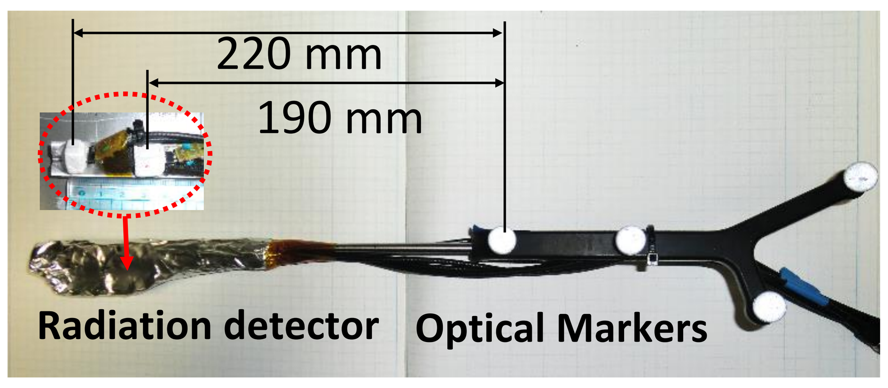
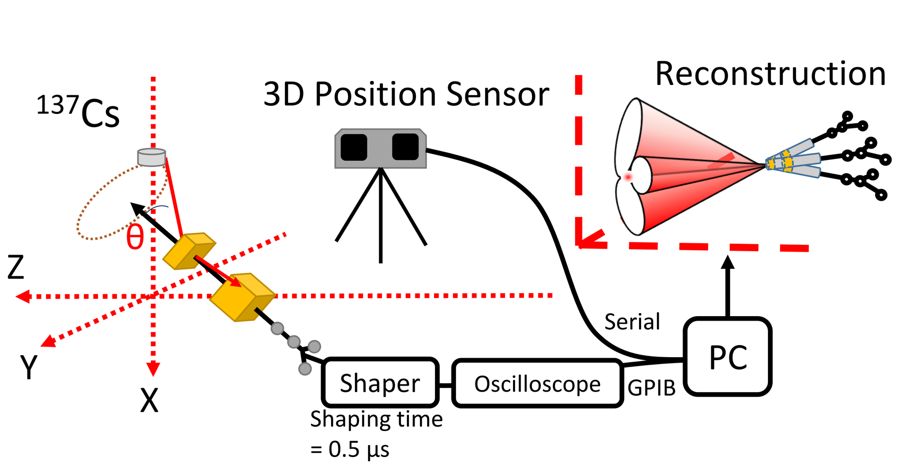
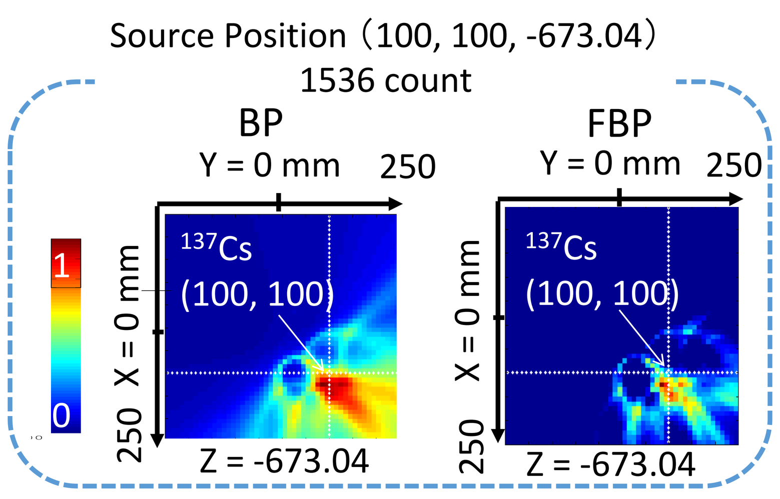


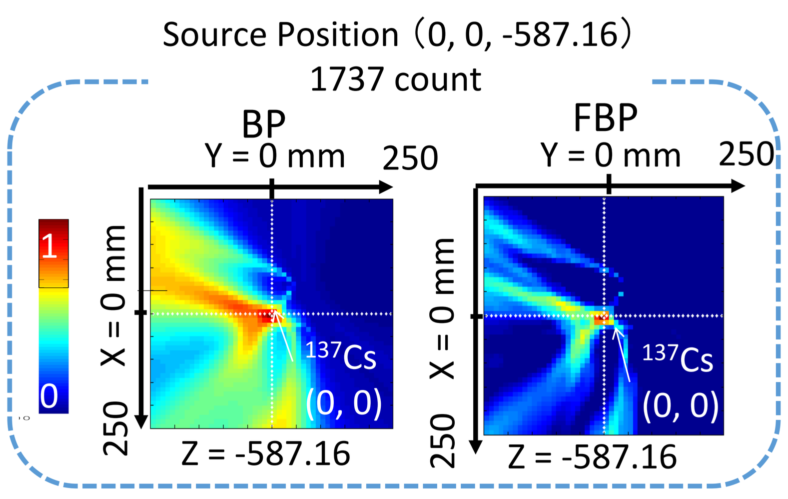
Image Reconstruction Using Position Sensor

We designed prototype imaging-probe including radiation detectors and optical markers. 3-Dimensional (3D) Position sensor (NDI POLARIS Vicra) measure spatial coordinates of detector positions by tracking attached optical markers. Compton scattering events are recognized by the logical product trigger established with oscilloscope. If scatterer and absorber detector's output over the threshold voltage at the same time, oscilloscope start recording each output pulse waveform. After both waveforms are recorded, POLARIS start transferring the each detector's spatial position to personal computer (PC). 5000 coincidence events are recorded with moving probe around the radiation source. The sum of scatterer and absorber energy is used for judge if background event or Compton scattering event. Acquired energy and position data sets are used to reconstruct back projection image (BP) by multiplying Compton Cones which projected at each detector's position. Filtered back projection method (FBP) which was taking into account point spread function was also used. Although reconstructed images had artifacts around the source point, we can distinguish source position by proposed method. And spatial resolution of 30 ~ 60 mm (FWHM) was acquired at FBP image.



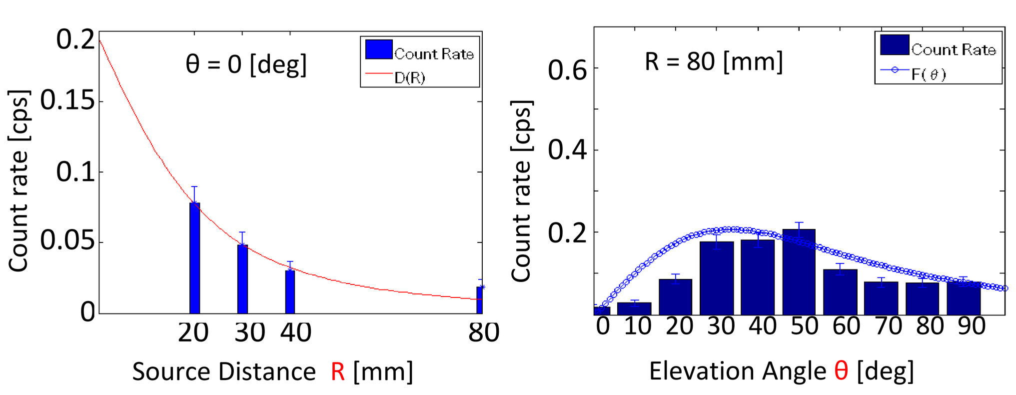


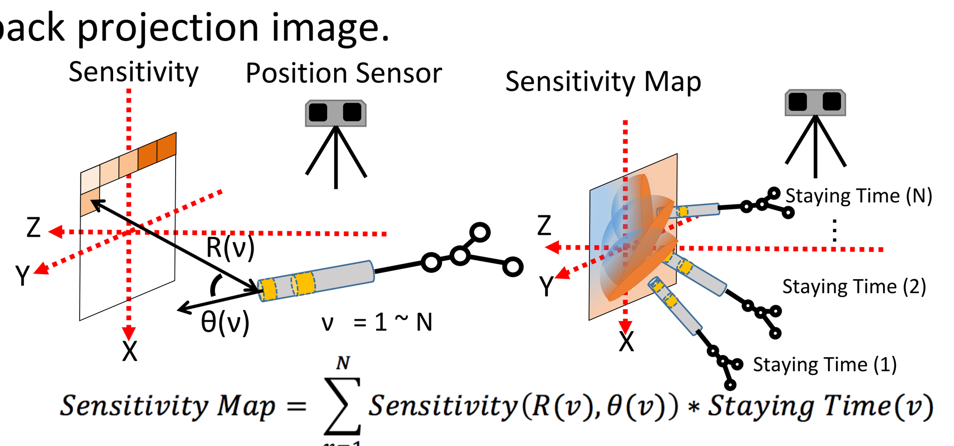




Sensitivity Calibration

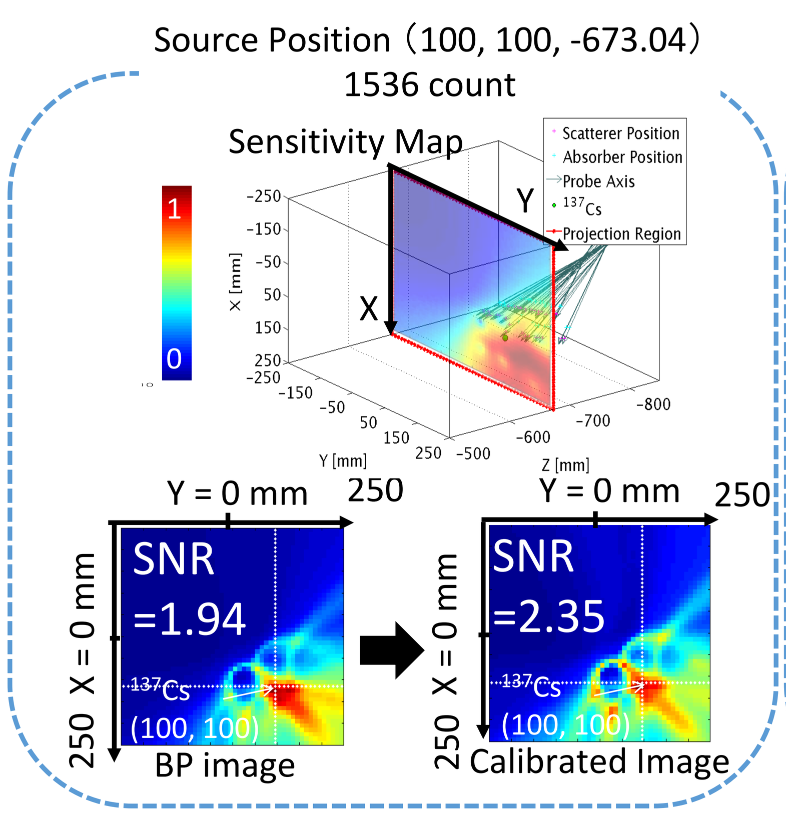
To calibrate difference of probe sensitivity at each elevation angle θ and distance R toward radiation source, sensitivity distribution on projected image was calculated. The staying time at each probe positions were also recorded and total sensitivity map in the projected image was acquired as cumulative sum of sensitivity. N means total event counts, and the signal to noise ratio (SNR) was defined as mean image intensity divided by the standard deviation of square region of 200 mm around source position. Calibrated image showed SNR improvement of 20 ~ 30 % toward back projection image.

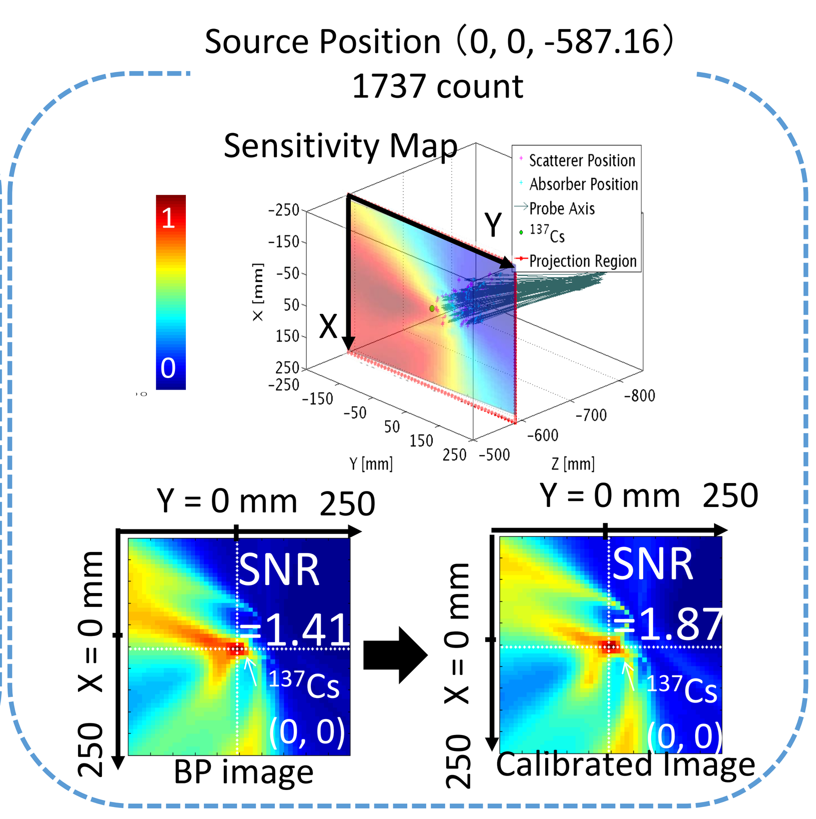




$$\text{Sensitivity Map} = \sum_{v=1}^{N} \text{Sensitivity}(R(v), \theta(v)) * \text{Staying Time}(v)$$

$$\text{Calibrated Image} = \text{Back Projection Image} * \text{Sensitivity Map}^{-1}$$





Conclusion

- ✓ Single Compton camera using position sensor was proposed
- ✓ Reconstruction results indicated proposed method enables visualization of radiation source region with spatial resolution of 30 ~ 60 mm (FWHM)
- ✓ The difference of detector sensitivity at each elevation angle and distance toward radiation source appeared as artifacts in the projection images, and sensitivity calibration showed SNR improvement of 20 ~ 30 % toward back projection image