# Image reconstruction from Compton scattering data

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**Abstract** A new image reconstruction method was developed for a Compton camera. A simulation to determine a γ-ray source position was performed by using the simulation tool, GEANT4. An image reconstruction was made in two steps. First, a three dimensional image was constructed and projected in one selected plane, then the points from each ellipse was picked up by taking the peak points of a density distribution of crossing points between the ellipse and the first step image. The second step procedure improved the accuracy and the spatial resolution of a position determination significantly, comparing with the image obtained by only the first step. The accuracy and the resolution for a point source were obtained to be about 0.02 mm and (1.35±0.15) mm, respectively. The same procedure was applied to an imaging of the distributed γ-ray source.

**Keywords** Compton scattering event, Position sensitive germanium detector, Image reconstruction

**CLC numbers** TL814, O571.32$^+$3

## 1 Introduction

Recently, a multitracer technology[1] was developed in RIKEN using an intermediate energy heavy ion beam. A multitracer involves many radioisotopes and the resultant γ-ray energy spectrum is complicated showing many peaks. The PET and SPECT are most widely used as γ-ray cameras. However they cannot be used for the multitracer application because of their poor energy resolutions. A Compton camera was developed using two position sensitive germanium (Ge) detectors[2] of 20 mm thick. The cathodes of these Ge detectors are divided into 25 segments of an equal size, 10mm×10mm×10mm. The signals from these segments give the interaction positions as well as the energy information. The energy resolution of the Ge detectors is good enough to analyze γ-ray spectra from a multitracer.

The idea of Compton camera was originally proposed by Everett *et al.*[3] and by Singh[4]. A Compton camera always consists of two Ge detectors, of which the front and rear one is called scatter and absorption detector, respectively. High position sensitivity is required for both detectors. The information collected in a Compton event includes the location where an incoming γ-ray is scattered, the energy transferred to a recoil electron, and the direction of the Compton scattered γ-ray. The scatter angle can be computed from the transferred energy; thus, for a given event, the origin of the primary γ-ray can be determined to lie somewhere on a cone-surface. Therefore, a Compton camera does not require the lead collimator which is inevitable for SPECT, thus resulting in an increase of efficiency of γ-ray detection. The first prototype of the Compton camera was made in 1983 by Singh and Doria[5]. Since then, many contributions have been made to its development, such as the image reconstruction methods and the fabrication of detectors. The data reconstruction is one of the big challenges and a difficult task for the development of a Compton camera. One potential 3D image reconstruction technique is the conventional Fourier deconvolution, which is based on projecting cone surfaces into the image space to establish a data matrix and then deconvoluting the projected data matrix with the point spread function that was previously determined for the image system.[6,7] In this article, a new image reconstruction method, based on the back-projection procedure is proposed. The results show that the position of a point source can be identified with an accuracy of less than 0.02 mm using this new method. Another example of a distributed γ-ray source's imaging is also presented.

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## 2 Methodology

The design and optimization of the camera parameters are realized using Monte Carlo simulation techniques. Moreover the Monte Carlo simulation also provides realistic data for reconstruction purposes. A dedicated and versatile Monte Carlo simulation framework is under construction based on GEANT 4.[8] The used Compton camera in our laboratory consists of two position sensitive planar Ge detectors. The method including the geometry of the two detectors is illustrated in Fig.1. Two detectors are placed parallel to each other and the distance between them is 60 mm.

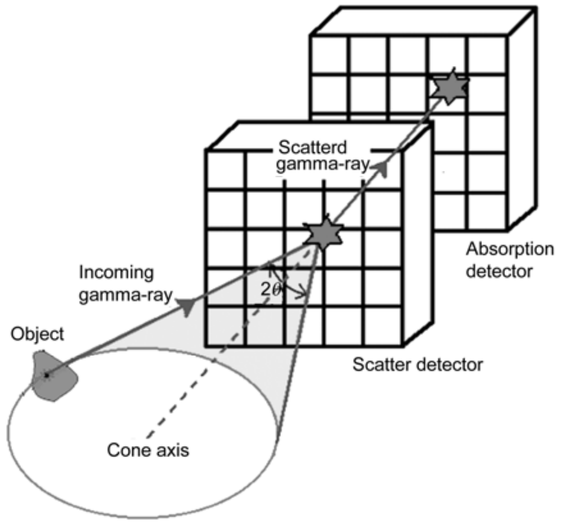


**Fig.1** Illustration of a recorded Compton scattering event by a proposed Compton camera.

An incoming gamma ray is scattered by an electron in the scatter detector and is subsequently absorbed in the absorption detector. If the deposited energies and the interaction points in two segmented Ge detectors are recorded, one can calculate a vertical angle of a cone, on whose surface the origin of the incoming gamma ray should exist. The half angle of the vertical angle of a cone, which is equal to the Compton scattering angle, $\theta$, can be obtained according to Compton scattering kinematics:

$$\cos\theta = 1 + m_0c^2\left(\frac{1}{E_\gamma} - \frac{1}{E_\gamma - E_1}\right)$$

where $E_\gamma$ is the incoming γ-ray energy, $E_1$ is the energy deposited in the scatter detector and $m_0c^2$ is the rest energy of electron. Therefore, the origin of a γ-ray can be constrained on the surface of a well-defined cone. When multiple Compton scattered events happen, these cones will cross at the source location. Thus, the simplest image reconstruction can be made by a direct projection of the cones on a plane.

In order to simplify the mathematical procedure, one can use an image plane, which is placed in parallel to the scatter detector at a certain distance and defined as *X-Y* plane, to carry out a two-dimensional imaging. Distances between planes and the scatter detector are selected in the region, which is determined as a most likely region of the source location by checking a simple back-projection. A *Z*-axis is defined as a perpendicular axis with respect to the detector surface. The intersection of the cone with the image plane generates an ellipse. If a single point source of activity is considered, a succession of Compton scattering events will generate a number of ellipses which have a common point of intersection as shown as the dark point in Fig.2, thereby defining the image point. This procedure is repeated on some planes at different distances and finds a plane with the largest density of crossing points in a pixel. This method, known as a back-projection one, can reproduce the source location. However the image background is also high, because the entire back-projected ellipse was recorded to reconstruct the image. Actually, only one point of each projected ellipse is at the origin of the incoming gamma ray, while all the other recorded points form a huge background. Thus, the back-projection method has two major drawbacks: limiting spatial resolution and blurring other image positions.

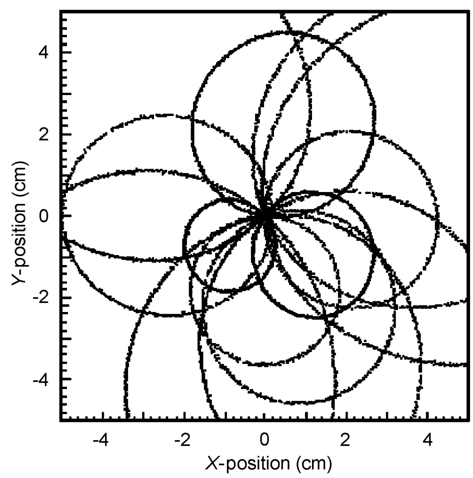


**Fig.2** Twelve ellipses generated from the intersection of Compton scatter cone with the image plane for a point source.

In our new method, a second step is introduced to select one point for each ellipse. After the image is made in the first step, each ellipse is overlapped with the image. Then a density of the points is projected along the whole ellipse and the peak point position of the density distribution is only selected for final image reconstruction. By applying this procedure for all ellipses, one gets an image with far lower background comparing with that made by only the first step. This new method is called the two-step back-projection (TSBP) method. The procedure is shown in Fig.3. A selected ellipse is overlapped with a first step image shown in Fig.3 (a). Fig.3 (b) displays the density distribution of the selected ellipse. The position of the peak, marked by the letter "*A*" shown in Fig.3(b), was obtained for the image reconstruction.

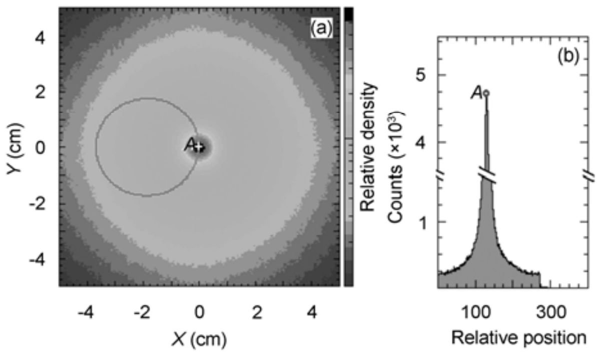


**Fig.3** (a) *X*-*Y* coordinates of a point source reconstructed by using the back-projection method. One of the ellipses is also shown; (b) Density distribution of a Compton scattering event (see text in detail).

## 3 Preliminary results

The following is two examples of reconstructions by the TSBP method. One is that of a point source of $^{137}$Cs shown in Fig.4. A source was placed at 60 mm apart from the surface of a scatter detector. By using a peak fitting of the *X*-axis slice or the *Y*-axis with Gaussian function, the accuracy and the resolution (FWHM) for a position determination of the point source were found to be about 0.02 mm and (1.35$\pm$ 0.15) mm, respectively. Fig.4(a) shows the result of a simple back-projection (SBP). The FWHM of the peak is about 6 mm. The other example is a source distributionn that is seen in Fig.5. A $^{137}$Cs activity is uniformly painted in the form of a letter "H". The size of "H" is 50 mm high and 25 mm wide, respectively. Events of 4,306,163 were analyzed. Fig.5(a) and Fig.5(b) exhibit the results from SBP and TSBP respectively. It is clear that both position resolution and background are significantly improved with the new reconstruction method.

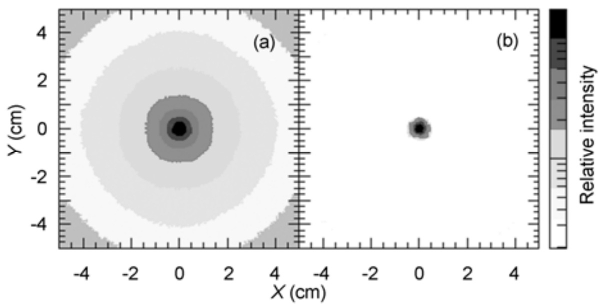


**Fig.4** *X*-*Y* distributions of reconstructed coordinates for a point source of $^{137}$Cs (662 keV): (a) using the back-projection method; (b) using the TSBP method.

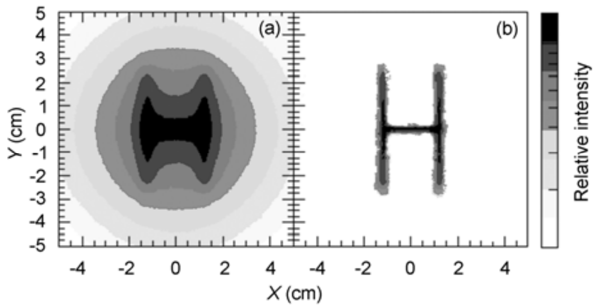


**Fig.5** *X*-*Y* coordinates of a uniform intensity source in the form of the letter H. The size of the character H is 50mm× 25mm. 4,306,163 events were used for the image: (a) using the back-projection method; (b) using the TSBP method.

## 4 Summary

In summary, a new image reconstruction method, TSBP, was proposed. With this procedure, the specific resolution was significantly improved by a factor of 4 and the background was greatly reduced comparing with that obtained by SBP method. The computer simulation was made for the Compton camera composed of two-segmented Ge detectors. This camera has an energy resolution high enough for the multi-tracer usage.

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