# Method of incident low-energy gamma-ray direction reconstruction in the GAMMA-400 gamma-ray space telescope



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# Method of incident low-energy gamma-ray direction reconstruction in the GAMMA-400 gamma-ray space telescope

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**Abstract.** The GAMMA-400 gamma-ray space-based telescope has as its main goals to measure cosmic γ-ray fluxes and the electron-positron cosmic-ray component produced, theoretically, in dark-matter-particles decay or annihilation processes, to search for discrete γ-ray sources and study them in detail, to examine the energy spectra of diffuse γ-rays — both galactic and extragalactic — and to study gamma-ray bursts (GRBs) and γ-rays from the active Sun. Scientific goals of GAMMA-400 telescope require fine angular resolution. The telescope is of a pair-production type. In the converter-tracker, the incident gamma-ray photon converts into electron-positron pair in the tungsten layer and then the tracks are detected by silicon-strip position-sensitive detectors. Multiple scattering processes become a significant obstacle in the incident-gamma direction reconstruction for energies below several gigaelectronvolts. The method of utilising this process to improve the resolution is proposed in the presented work.

## 1. Introduction

The GAMMA-400 scientific complex [1, 2] is designed to study cosmic γ-ray emissions in the energy range of 0.1 GeV to 3 TeV and acquire data that will allow us to determine the nature of dark matter in the Universe to develop a theory of the origin of high-energy cosmic rays. The GAMMA-400 instrument is designed to resolve energy spectra peculiarities, which are expected in gamma-ray emission from areas where hypothetical dark-matter particles decay or annihilate producing gamma rays. Temporal study of high-energy gamma-ray emission from discrete sources may shed light upon the nature of particle acceleration in these sources.

The design of the GAMMA-400 telescope is described in [2].

A method of gamma-ray direction reconstruction used in GAMMA-400 for higher energies [7] encounters a problem of low efficiency below 300 MeV since low-energy gammas suffer multiple scattering, which is not considered. This paper describes approach to reconstruct low-

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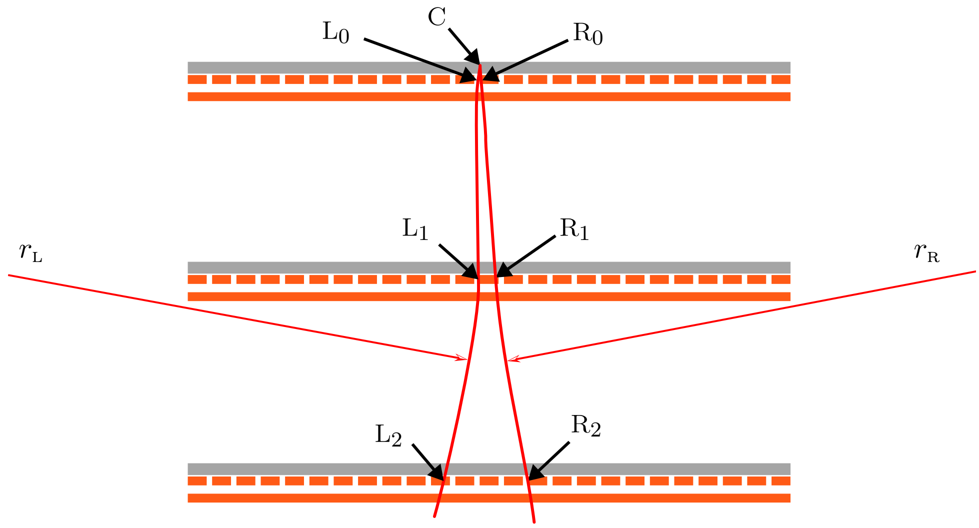


**Figure 1.** Schematic illustration of using the method involved. Here shown are the points in the converter-tracker used in the reconstrucion algorithm. C is a point in a tungsten layer where a conversion occured. $L_i$ and $R_i$ are strips where an electron or a positron hits a converter's silicon layer. Three consecutive layers directly below the converting tungsten layer are considered.

energy gamma-ray direction using only converter planes and utilising multiple-scattering process.

## 2. Reconstruction method

Events were selected with signals in all layers of time-of-flight system, with particles arriving from upper hemisphere in the instrument aperture.

When the energy of the incident gamma ray particle is $\lesssim 10\,\mathrm{GeV}$, an electron-positron pair produced in the primary conversion can be readily tracked individually.

Due to multiple scattering, electrons and positrons are deflected from initial direction and their trajectories can be fitted by a circular arc. As Monte-Calrlo simulation shows, mean curvature of an arc decreases due to multiple scattering with rise of kinetic energy because of more sizeable scattering of low-energy particles.

Beforehand, the relation between mean (actually, statistical mode by histogram) of radius of curvature and electron (positron) energy is calculated using Monte-Carlo simulation. The relation appears to be $r/\mathrm{m} = 5.5\,E/\mathrm{GeV}$.

It is clear that tracks of pair particles of higher energy (smaller curvature) lie closer to initial gamma-ray track. The idea is to find a somewhat 'weighted bisector' of pair tracks in each orientation with weights being estimated by a track curvature. We use here the fact that mean curvature due to multiple scattering decreases with rise of kinetic energy.

The method is the following.

- Find tungsten layer W in which a primary conversion occurs (no tracker signal above and >3 consecutive directly below in each X/Y orientation).
- Define the silicon layer (two strip planes) immediately below W to be number $i = 0$; others are assigned numbers 1 and 2 (see fig. 1).

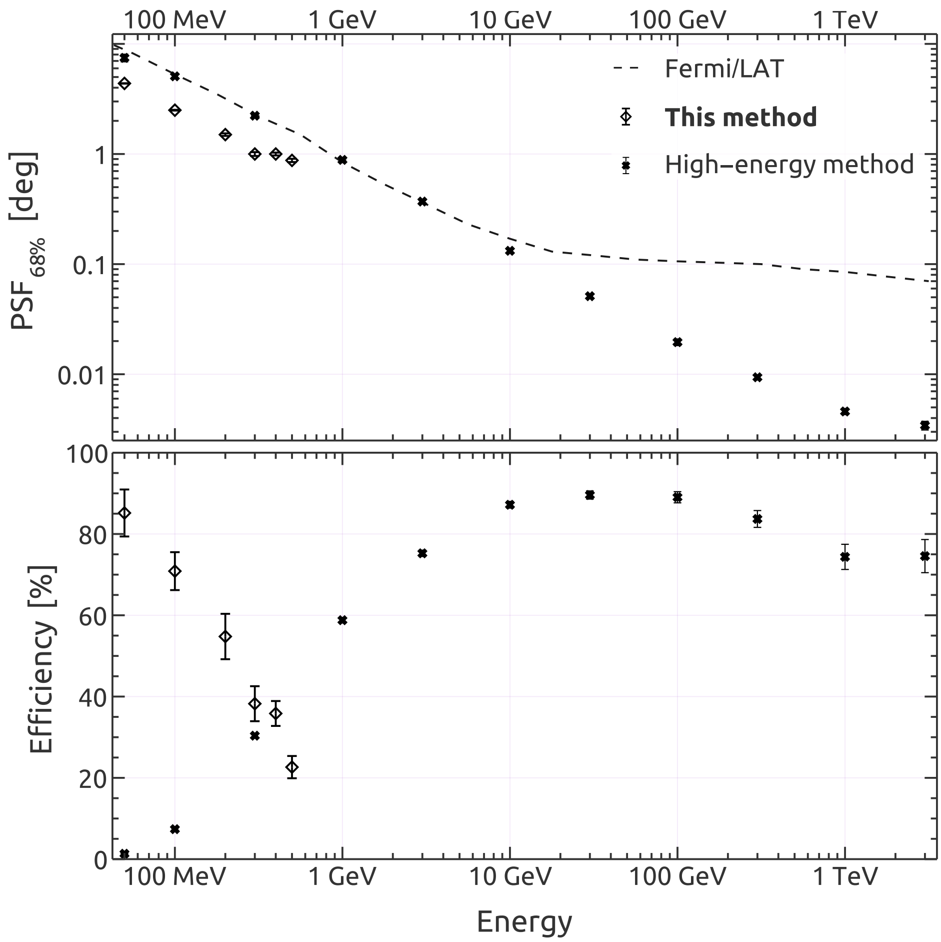


**Figure 2.** Angular resolution (PSF 68% containment) and reconstruction efficiency versus initial-gamma energy, as obtained by the method involved (diamonds ⋄). Also shown are: the result by the method used with higher energies [7] (crosses ✖) and the Fermi-LAT data [8] (dashed line - - -).

- Obtain coördinate $X_{\mathrm{C}}$ of the conversion point C. To do this, first approximations of the two directions are computed via weighted linear fit. We fit points $\mathrm{L}_0$, $\mathrm{L}_1$, $\mathrm{L}_2$ (last weight being 10 times smaller), and the fitted line intersects W layer at point $\mathrm{C}_{\mathrm{L}}$ ($\mathrm{C}_{\mathrm{R}}$ got similarly).
- Radii of curvature $r_{\mathrm{L}}$ and $r_{\mathrm{R}}$ (see fig. 1) are defined to be the radii of circles passing the three points, $(\mathrm{L}_0, \mathrm{L}_1, \mathrm{L}_2)$ and $(\mathrm{R}_0, \mathrm{R}_1, \mathrm{R}_2)$ respectively. They serve as a rough estimation of electron (positron) energy using pre-calculated relation between $r$ and $E$. Thus, we have now estimations $E_{\mathrm{L}}$ and $E_{\mathrm{R}}$. Now, point C is defined by

$$X_{\mathrm{C}} = \frac{E_{\mathrm{L}} X_{\mathrm{C_L}} + E_{\mathrm{R}} X_{\mathrm{C_R}}}{E_{\mathrm{L}} + E_{\mathrm{R}}}$$

- Now that we have got the $4^{\mathrm{th}}$ point on both tracks, the linear fit described above is re-done with new point triples: $(\mathrm{C}, \mathrm{L}_0, \mathrm{L}_1)$ and $(\mathrm{C}, \mathrm{R}_0, \mathrm{R}_1)$. Just as before, the lower point's weights are reduced tenfold. Two straight lines are obtained with angles $\alpha_{\mathrm{L}}^{\mathrm{X}}$ and $\alpha_{\mathrm{R}}^{\mathrm{X}}$ from the vertical. The angle

$$\alpha_{\mathrm{X}} = \frac{E_{\mathrm{L}} \alpha_{\mathrm{L}}^{\mathrm{X}} + E_{\mathrm{L}} \alpha_{\mathrm{R}}^{\mathrm{X}}}{E_{\mathrm{L}} + E_{\mathrm{R}}}$$

together with similarly evaluated $\alpha_Y$ is considered as a direction of the incident gamma $\big(\tan(\alpha_X), \tan(\alpha_Y), 1\big)$.

In fig. 2, angular resolution (PSF 68% containment) is shown. It is sligthly better then that for the standard method [7] used for high energies and has relatively high efficiency at low energies ($\leq 300\,\mathrm{MeV}$). The Fermi-LAT PSF size [8] is shown for a comparison.

## 3. Conclusion

The mehod proposed leads to fine angular resolution with having reconstruction efficiency relatively high at energies below 300 MeV.

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