Gamma-Ray Imaging by Silicon Detectors in Space: Presentation of the AGILE Reconstruction Method and Kalman Filter Algorithms

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Abstract. We present the AGILE REconstruction Method (AREM) and the track finding optimization by Kalman filter algorithms. AREM is a method of γ-ray direction reconstruction to be applied to high-resolution Silicon Tracker detectors in space. It can be used in a "fast mode", independently on Kalman filters techniques, or in an "optimized mode", including Kalman filter algorithms for track identification. AREM correctly addresses three points of the analysis which become relevant for off-axis incidence angles: 1) intrinsic ambiguity in the identification of the 3-D e^+/e^- tracks and conversion plane; 2) proper identification of the 3-D reconstructed direction; 3) careful choice of an energy weighting scheme for the 3-D tracks. We present the preliminary results of the angular resolution obtained by analyzing simulated γ-rays in the AGILE detector. The excellent spatial resolution obtained by the AGILE Silicon Tracker allows to improve the angular resolution by a factor ~ 2 at energies $\gtrsim 400$ MeV with respect to previous spark chamber detectors (e.g. EGRET).

INTRODUCTION

AGILE (Astro-rivelatore Gamma a Immagini LEggero) is a Small Scientific Mission of ASI (Agenzia Spaziale Italiana) with a γ-ray imaging system based on state-of-the-art Silicon strip technology [1]. Thanks to the fast readout electronics and to the segmented anticoincidence system, AGILE will have, among other features, an unprecedently large field of view, ~ 3 sr (larger than previous γ-ray experiments by a factor ~ 5) and a very good intrinsic spatial resolution of the Si-Tracker (with a distance of 1.6 cm between contiguous planes). CERN testbeams show that, by using the analog information on the charge distribution released in Si-microstrips of pitch 121 μm, one can achieve a spatial resolution of order of ~ 40 μm [2]. For comparison, we recall here that the EGRET [3] spark chamber pitch was equal to 820 μm. The AGILE goal is to obtain the best sensitivity ever reached for off-axis events (up to $\sim 60°$), and an on-axis sensitivity comparable to that of EGRET despite the smaller dimensions and effective area. Therefore, the optimization of the angular resolution algorithms becomes a crucial point to fulfil the mission scientific objectives.

THE AREM METHOD

The γ-ray detection and direction reconstruction are based on the physical process of pair production, and are obtained from the identification and detailed analysis of the electron/positron tracks originating from a common vertex. Crucial to this task is a proper account of the effects of multiple Coulomb scattering and energy distribution between the e^+/e^- particles. The current customary simplification of analyzing separately the two tracks projections in the ZX and ZY Tracker views ("2-D projection method") induces two kinds of systematic error in the photon direction reconstruction:

A) the intrinsic ambiguity in the proper identification of the two 3-D tracks;

B) the problem of the identification of the true 3-D direction reconstruction.

Finally, we emphasize the importance of the:

C) choice of track weighting scheme.

In general, the photon energy is not evenly divided between the two particles. Since the direction of the most energetic particle is closer to that of the incident photon, an "energy-weighted" reconstructed direction should be computed[1]. As for the point A), we note that when the e^+/e^- pair hits simultaneously the active Tracker layers, the signal will correspond to two projected track points in each ZX and ZY view, but it could correspond to two possible couples of points in space, as shown in Fig. 1-A. This

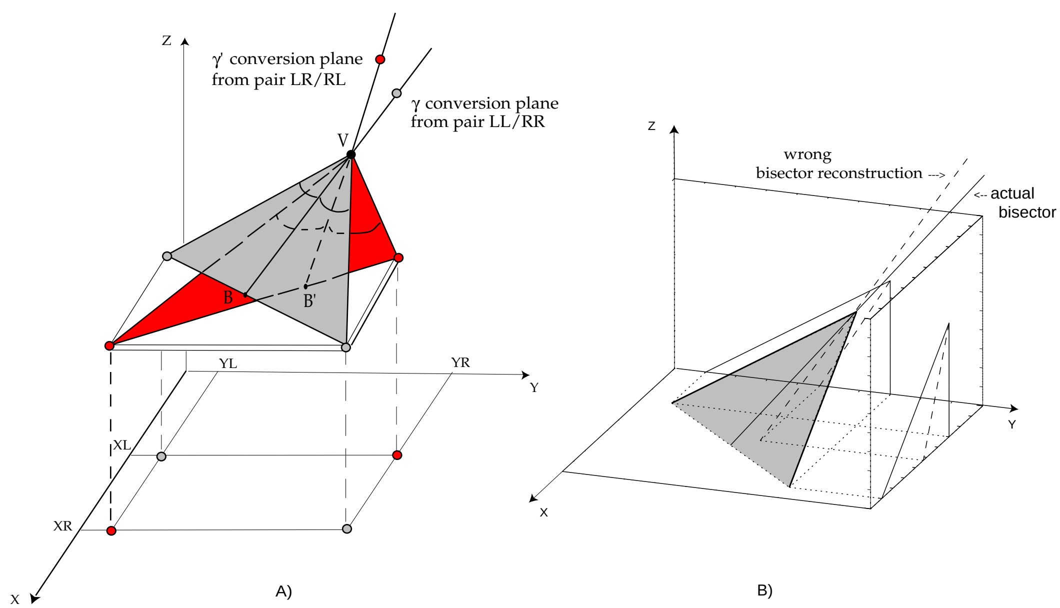

FIGURE 1. A) The "conversion plane problem": a correct event reconstruction in 3-D implies solving the coordinate track ambiguity and making the right choice for one out of two possible conversion planes. B) The "projection problem": the projections of the bisector on the ZX and ZY planes are different from the bisectors of the projections of the tracks.

[1] For simplicity, in the following we illustrate points A) and B) in case of an even energy sharing, i.e., when the photon direction coincides with the bisector.

gives rise to an ambiguity in the conversion plane identification. In terms of projected views the "conversion plane problem" can be phrased as: "Does the track to the left in the ZX view correspond to the left track in the ZY view - pair LL/RR? Or does it correspond to the track to the right - pair LR/RL?"

The "projection problem", point B), stems from the fact that in previous γ-ray experiments, after the identification of the two projected tracks in each view, the next step was to take their (eventually weighted) bisectors and compose them to obtain the reconstructed γ-ray direction. As illustrated in Fig. 1-B, this procedure is not correct since the true 3-D bisector (solid line in the shaded conversion plane) is different from the one obtained from the two bisecting lines in each projected view (dashed line from dashed projections). As shown in ref.[4], this systematic effect increases for increasing off-axis angles and large opening angles, up to values of $\sim 0.5^{\circ}$. In the case of EGRET data[2], this effect is hidden by the relatively low spark chamber intrinsic resolution, but it would have a significant impact for AGILE. Furthermore, with high resolution Si-detectors it is possible to estimate the e^{+}/e^{-} energies from a few MeV to the GeV scale, by measuring deviations due to multiple scattering effects. This fact allows to properly define the weight of each track for the direction reconstruction (point C).

As described in detail in ref.[5], AREM is a 3-D reconstruction method, which takes into account these three points of the analysis. It provides a general baseline, to be optimized for each particular γ-ray instrument, for the photon direction reconstruction algorithms. Several approaches are under study: *(i)* first n-Planes Resolution, using only information from the first hit planes (2PR, 3PR, ...), *(ii)* algorithms based on the Kalman filter [6] for an optimal use of the information from all hit planes. In the following, we present some preliminary results of our analysis.

PRELIMINARY RESULTS

The Monte Carlo simulations of the AGILE-GRID imaging performance were done using the GEANT 3.21 code [7]. In Fig. 2 and in Fig. 3 we show, as an example, the 3-D Point Spread Function (PSF) obtained by using only information from the first 3 hit Tracker planes (3PR) for near-on-axis events at $E_{\gamma} = 1$ GeV and $E_{\gamma} = 200$ MeV . In Fig. 4 we show the 3-D PSF distribution profiles obtained from the AGILE Kalman filters algorithms (AKF) for several angles and energy values. The 3PR provides a satisfactory PSF for near on-axis events, compatible with AKF, even though with a lower reconstruction efficiency (85% vs. 97% at 1 GeV ; 76% vs. 94 % at 200 MeV). The AKF provides a good event reconstruction with very high efficiency (above 90% for $E_{\gamma} > 200$ MeV) for a variety of incidence angles. Finally, in Fig. 5 we compare the preliminary AGILE angular resolution, between 0° and 50° off-axis, with that of EGRET on-axis. The figure shows the 3-D 68% containment radius as a function of energy. The AGILE 3-D PSF is better than that of EGRET by a factor of ~ 2 above 400 MeV. We expect to further improve this performance, expecially at low energies, by a more accurate study

[2] We warmly thank the EGRET team, in particular D.L. Bertsch and D. Thompson, for many discussions and for allowing us to perform a test of our reconstruction algorithms on EGRET calibration data.

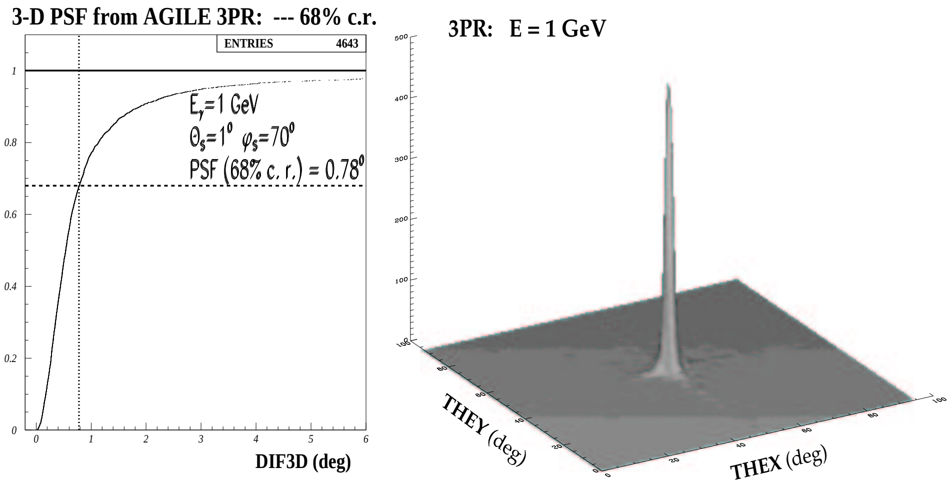

FIGURE 2. AGILE-GRID on-axis 3-D PSF from the 3PR reconstruction for 1 GeV photons. The left panel curve represents the integral distribution of the difference between true and reconstructed direction of each photon.

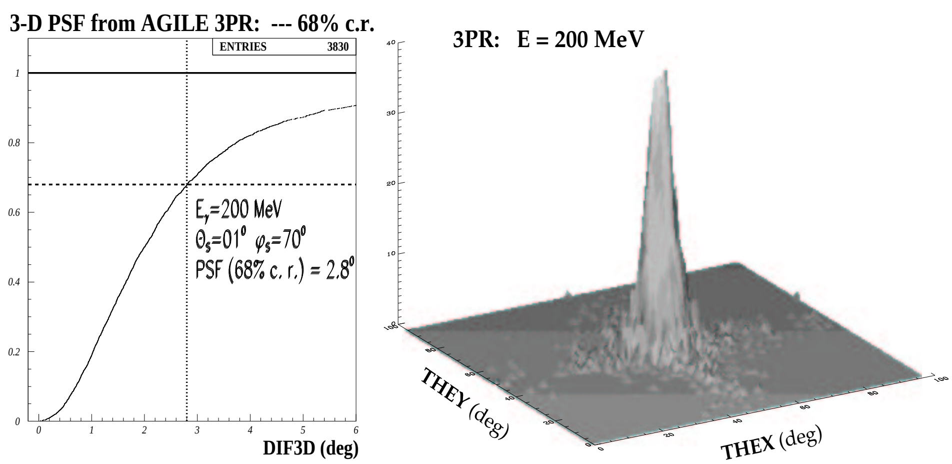

FIGURE 3. AGILE-GRID on-axis 3-D PSF from the 3PR reconstruction for 200 MeV photons.

of the charge deposition in the Si-microstrips, and by an optimization of the energy determination and weighting scheme based on extensive Monte Carlo simulations.

REFERENCES

1. Tavani, M. et al., ed.by M. McConnell, AIP Conf. Proc. 510, 2001, p. 746; and these Proceedings.

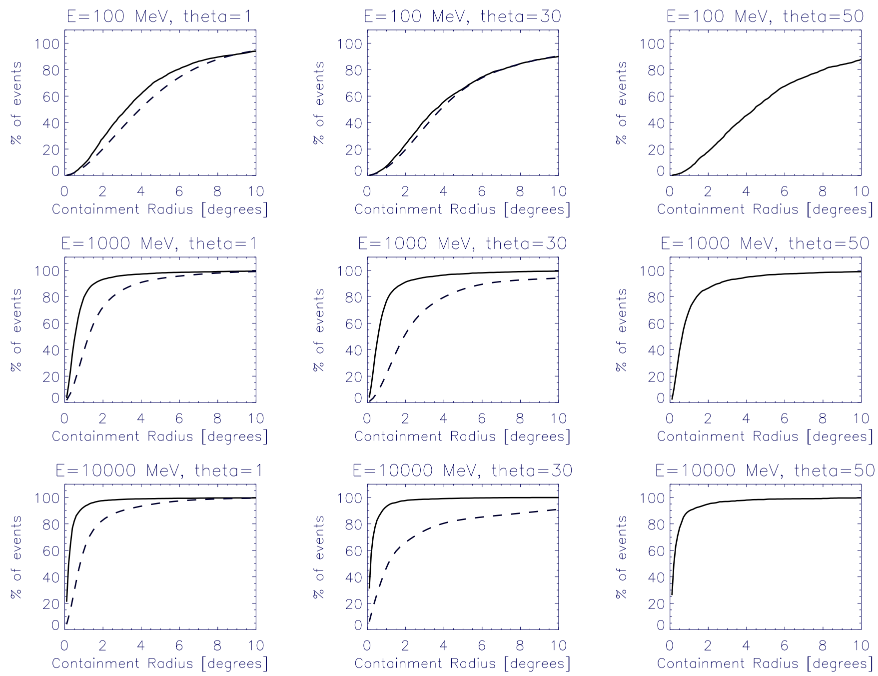

FIGURE 4. 3-D integral PSF profiles obtained with the AGILE-GRID Kalman filters algorithms (solid curve) compared to the corresponding EGRET values (dashed curve) when available (public data).

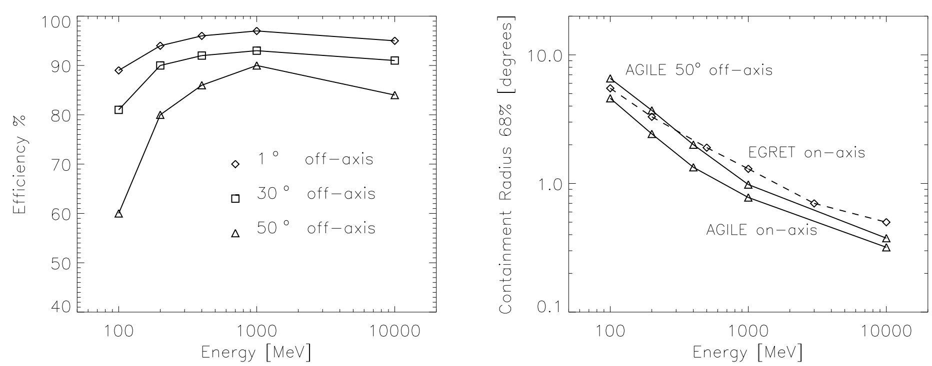

FIGURE 5. Left panel: Reconstruction efficiency of the AGILE Kalman filters algorithms for different off-axis directions. Right panel: Preliminary results for the AGILE 3-D containment radius (68%).

2. Barbiellini, G. et al., these Proceedings.
3. Thompson, D.J. et al., ApJSS, **86**, 629 (1993).
4. Giuliani, A., “Studio e Ottimizzazione della Risoluzione Angolare del Telescopio Spaziale per Astronomia Gamma AGILE”, Laurea Dissertation, Università degli Studi di Pavia (2001).
5. Pittori, C., and Tavani, M., Gamma-Ray Imaging by Silicon Detectors in Space, Rome 2 preprint ROM-2F/2001/12, Rome, I-00133 (2001).
6. Frühwirth, R., NIM A, **262**, 444 (1987).
7. Cocco, V., Longo, F., and Tavani, M., AGILE Internal Tech. Note, AGILE-SIM-TN-001, Issue n.2 (2000), and preprint in preparation.