Optimization of Angular and Energy Resolution of the AGILE γ-ray Detector

A. GIULIANI[1], P. LIPARI[2],C. PITTORI[3], M. TAVANI[1,4] AND D. ZANELLO[2]
[1]*IASF/CNR, Sez. Milano, V. Bassini 15, 20133 Milano - Italy*
[2]*Dip. Fisica Univ. Roma-I and INFN, P.le Aldo Moro 2, 00185 Roma - Italy*
[3]*Dip. Fisica Univ. Roma-II and INFN, V. Ric. Scientifica 1, 00133 Roma - Italy*
[4]*IASF/CNR, Sez. Roma, V. Fosso del Cavaliere, 00133 Roma - Italy*

ABSTRACT. In this article we present the preliminary results on the optimization studies for the angular and energy resolution of the AGILE Gamma-Ray Imaging Detector.

1. Introduction

The AGILE Gamma-Ray Imaging Detector (**GRID**) is sensitive in the 30 MeV–50 GeV energy range and it consists of a Silicon Tracker, a Cesium Iodide Mini-Calorimeter (MCAL) and a segmented Anticoincidence System. The AGILE instrument is described in detail in Tavani et al., 2003-2004. AGILE will have, among other features, an unprecedently large field of view (FOV) of $\sim$ 2.5 sr, larger than previous gamma-ray experiments by a factor ~ 5, and an excellent spatial resolution. The AGILE Si-Tracker makes a crucial use of the analog signal from the Si-microstrips; CERN testbeam results (Barbiellini et al., 2002) show that by using the analog readout, a spatial resolution of order of $\sim 40 \mu m$ can be achieved for a wide range of photon incidence angles.

2. AGILE Angular Resolution

Fig. 1 shows an example of a simulated γ-ray event converting in the Si-Tracker. A 100 MeV photon has the primary interaction in a tungsten converter layer. The superimposed lines correspond to Kalman filter reconstructed tracks. The Mini-Calorimeter hit bars are also shown. The γ-ray direction reconstruction is based on the physical process of pair production and is obtained from the identification and the detailed analysis of the e^+/e^- tracks stemming from a common vertex. In previous γ-ray space detectors this was done by applying a "2D projection method", that is by analyzing separately the two tracks projections in the ZX and ZY views. However, because of its large field of view and very good intrinsic spatial resolution, the simplified 2D projection method would not be a good approximation for AGILE. The AGILE Point Spread Function (PSF) is obtained by applying the AGILE REconstruction Method (AREM) (Pittori & Tavani, 2001), integrated with Kalman filter algorithms for track identification and fitting (Giuliani, 2001). AREM is a general method for γ-ray direction reconstruction applicable to high-resolution Si-Tracker detectors in space. AREM correctly addresses three points of the analysis which become relevant for off-axis incidence angles:
- intrinsic ambiguity in the identification of the 3D e^+/e^- tracks;
- proper identification of the 3D pair production plane and reconstructed direction;
- careful choice of an energy weighting scheme for the 3D tracks.

The Kalman filter-smoother algorithm is applied to find and fit tracks (Frühwirth, 1987). Unlike traditional pattern recognition algorithms, this technique always progressively updates the track-candidate information during the track-finding process, predicts as precisely as possible the next hit to be found along the trajectory. This capability is used to merge into an unique recursive algorithm the track-finding procedure and the fitting of track parameters. As shown in Fig. 2 the AGILE 3D PSF on-axis (at 68% c.r.) is expected to be better than that of EGRET by a factor of ~ 2 above 400 MeV.

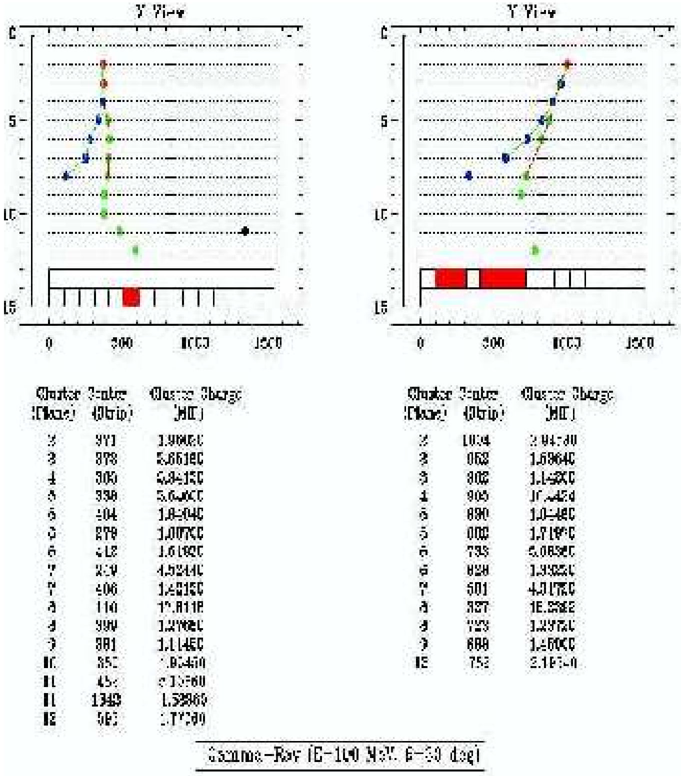

Fig. 1. Example of a simulated 100 MeV γ-ray photon converting in the AGILE Si-Tracker. The analog readout allows the determination of the total charge deposited in the Si-microstrips. The tables show the values of the deposited charges (in MIP units) per cluster.

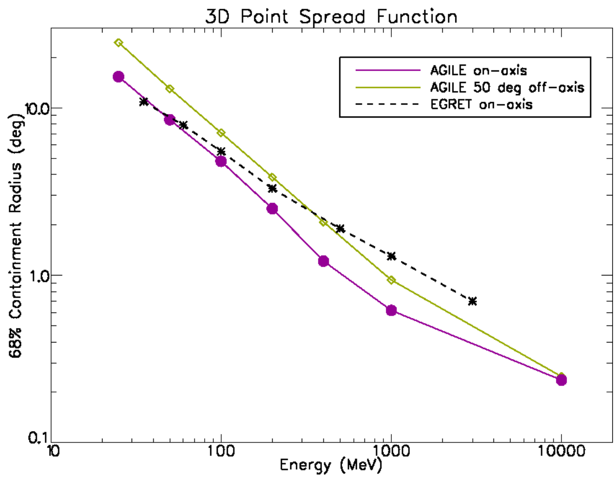

Fig. 2. EGRET on-axis 3D PSF (Thompson et al., 1993) compared with the simulated AGILE 3D PSF on-axis and at 50^o off-axis.

3. Energy Reconstruction from multiple scattering in the Tracker

We find that the AGILE Tracker by itself, because of its excellent spatial resolution, can provide a good estimate of the incident photon energy from the multiple scattering of e+/e- passing through the converter planes (Giuliani et al, 2004). The root mean square (rms) angular deviation of electrons due to multiple scattering with atomic nuclei of the material follows the Molière formula:

$$\theta_{rms} = \frac{13.6}{E_e[MeV]}\sqrt{\frac{z}{X_0}}\left(1 + 0.038 \ln \frac{z}{X_0}\right) \tag{1}$$

where z is the thickness, X_0 is the radiation length of the material and E_e is the electron energy. It is therefore possible to evaluate the energy by measuring the scattering angles of the track.

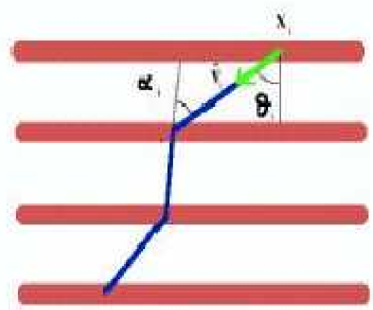

Fig. 3. Scattering angles definitions in 3D.

The AGILE Tracker energy reconstruction method (Giuliani et al. 2004) consists of three steps that we briefly summarize here. Step 1: a standard 2D Kalman Filter is applied to fit the tracks. We obtain a first estimate of the track energies by an iterative algorithm. Step 2 consists in 3D track association and reconstruction. Finally in step 3, by χ^2 optimization, we derive a refined estimate of the track energy by taking into account the real 3D thickness crossed by the e+/e- pair and the corresponding energy losses.

4. A Spectral Simulation

Fig. 4 shows the preliminary energy response matrix obtained by using our method, described in the previous section. The simulated counts have been rebinned to obtain 8 energy channels with energies between 10 MeV and 50 GeV.

To test the spectral capabilities of the AGILE energy reconstruction method, we simulate an observation of a point source for 10^6 sec at 30 degree off-axis with background induced by mid-latitude diffuse γ-ray emission. The source spectrum is described by a power law:

$$F = k\left(\frac{E[\mathrm{MeV}]}{100}\right)^{\alpha} \tag{2}$$

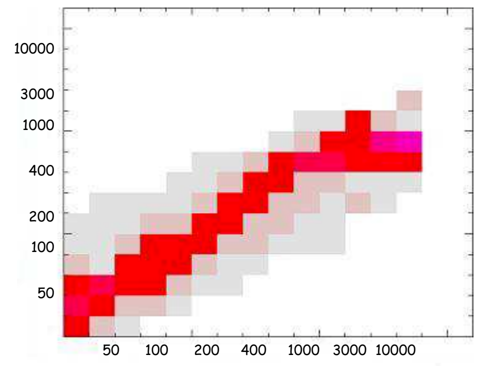

Fig. 4. Preliminary AGILE Response Matrix using Si-Tracker information only.

with input photon index $\alpha = 2$ and differential flux $k = 1.5 \times 10^{-9}$ ph cm^{-2} s^{-1} MeV $^{-1}$ at $E = 100$ MeV . The reconstructed fit values (at 90% conf. lev.) are:

$$\alpha = 1.99 \tag{3}$$

$$k = 1.56 \times 10^{-9} \text{ ph cm}^{-2} \text{ s}^{-1} \text{ MeV }^{-1} \tag{4}$$

The preliminary results obtained for the spectral resolution are shown in Fig. 5.

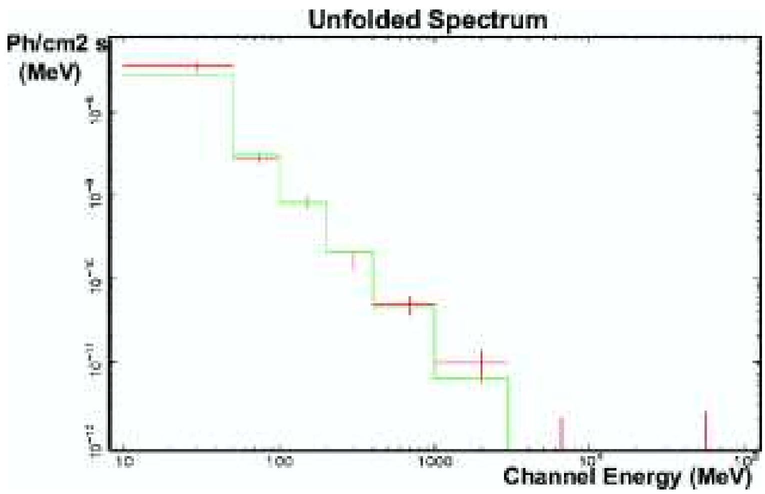

Fig. 5. Preliminary AGILE spectral deconvolution for the simulated observation of a point source for 10^6 sec at 30 degree off-axis from Tracker-only information.

5. Conclusions

We find that a γ-ray tracking detector with spatial resolution capabilities such as those of AGILE can be used to determine the incoming photon energy with resolution of the order $\Delta E/E \sim 0.8$ at 400 MeV , by using Si-Tracker information only. Improving the energy resolution implies the application of a method that fully integrates the Tracker with the Mini-Calorimeter information, this work is in progress (Pittori et al, 2004).

References

Barbiellini G. et al.: 2002, Nuclear Instruments and Method in Physics Research A 490, 146.

Frühwirth R.: 1987, Nuclear Instruments and Method in Physics Research A 262, 444.

Giuliani A.: 2001, Laurea Dissertation, Università degli Studi di Pavia `http://www.mi.iasf.cnr.it/ giuliani/public/tesi`.

Giuliani et al: 2004, *in progress*.

Pittori C. and Tavani M.: 2001, Nuclear Instruments and Method in Physics Research A 488, 295.

Pittori et al: 2004, *in progress*.

Tavani M. et al.: 2003, *Science with AGILE*, AGILE Doc. AP-25, `http://agile.mi.iasf.cnr.it`.

Tavani M. et al.: 2004, these proceedings.

D.J. Thompson et al.: 1993, these Astroph. J. Suppl. 86, 629.