

# Using the photons from the Crab Nebula seen by GLAST to calibrate MAGIC and the Imaging Air Cherenkov Telescopes

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## Abstract

In this article we discuss the possibility of using the observations by GLAST of standard gamma sources, as the Crab Nebula, to calibrate Imaging Air Cherenkov detectors, MAGIC in particular, and optimise their energy resolution. We show that at around 100 GeV the absolute energy calibration uncertainty of Cherenkov telescopes can be reduced to  $\lesssim 10\%$  by means of such cross-calibration procedure.

*Key words:* Gamma-ray astronomy, Cherenkov detectors

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## 1 Introduction

Full multiwavelength coverage over as wide an energy range as possible is needed to understand aspects of fundamental physics and astrophysics as well. An important observational window, between few tens and some hundreds GeV, is still largely unknown due to experimental detection difficulties, related

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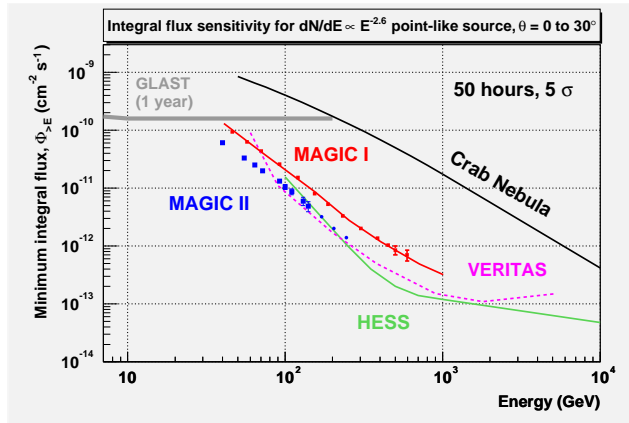


Fig. 1. Predicted sensitivities for some operating and proposed detectors. Note the wide overlap region between GLAST and present Cherenkov telescopes. As far as MAGIC is concerned, the solid, red line represents the predictions made by the full Montecarlo simulation and it is in good agreement with the sensitivity calculated from the first observations. The blue dots are the expected sensitivity for MAGIC II, where a second telescope, *clone* of the current MAGIC, will be built at  $\sim 85$  m of distance from MAGIC. Start of operation for MAGIC II is envisaged for the end of 2006, just before the scheduled launch of GLAST.

to the opacity of our atmosphere to gamma-rays. For this reason, observations have to be performed:

- on board of satellites orbiting outside our atmosphere (given the steep decrease of the gamma-ray flux, the limited size of the detectors, due to launching cost, sets an upper limit to the accessible energy region),
- detecting, on the ground, showers initiated by gamma-rays in the atmosphere (in this case, as the measurement of the gamma-ray properties are done exploiting the atmosphere as a calorimeter, there is a lower energy limit to the observable gamma-rays).

Among ground-based detectors, the so-called IACTs (Imaging Atmospheric Cherenkov Telescopes) are expected to reach the lowest energy thresholds. IACTs feature huge collection areas, an excellent angular resolution and good energy confinement even at very high energies. On the other hand, they suffer from low duty-cycles, small fields of view ( $<5^\circ$ ) and systematic calibration uncertainties in both energy and sensitivity. In fact, whereas current IACTs achieve an intrinsic energy resolution as low as 5%, the absolute energy scale remains quite elusive, as the energy reconstruction in the  $30 \div 300$  GeV range is dominated by uncertainties on Monte Carlo simulations and on atmospheric models[1].

In the next few years, two satellites with a payload dedicated to observation of gamma rays will be launched: AGILE[2], a small instrument expected to fly in 2005, and GLAST[3], a large detector whose launch is scheduled for the

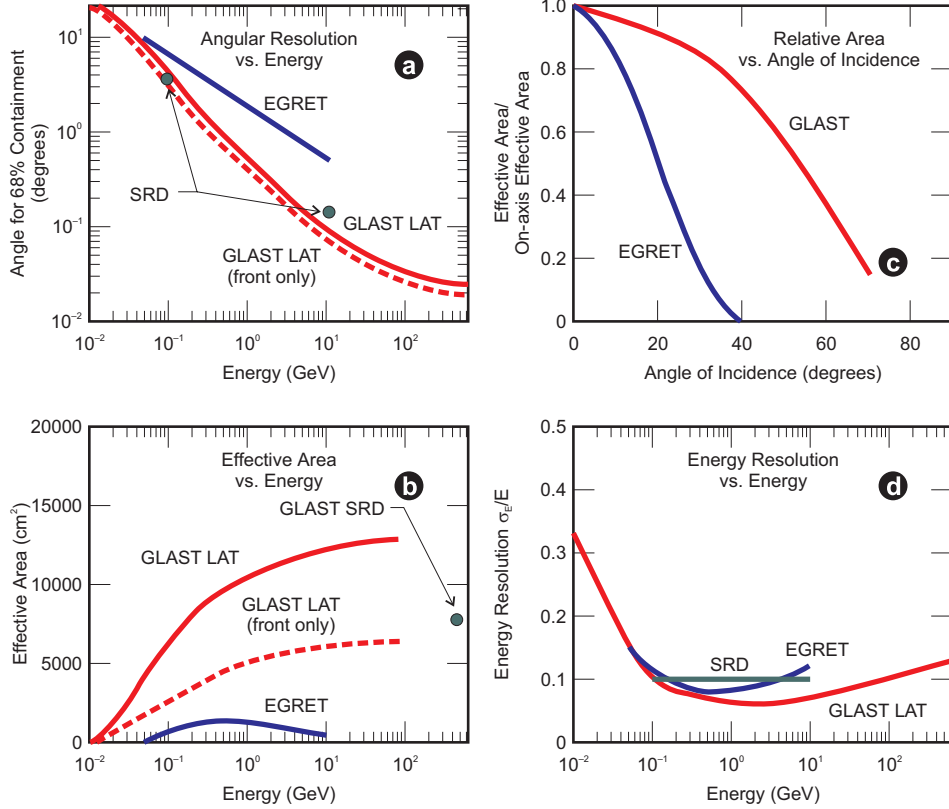


Fig. 2. Full *Instrument Response Functions* (IRFs) of the GLAST LAT (taken from [http://www-glast.slac.stanford.edu/software/IS/glast\\_lat\\_performance.htm](http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm)).

beginning of the year 2007. GLAST will operate in a complementary manner to ground-based experiments and provide ground-based observers with alerts for transient sources, as new imaging Cherenkov telescopes are built to slew toward a source within few tens of seconds following a prompt notification.

Satellites as AGILE or GLAST, contrary to IACTs, are calibrated in a well-controlled laboratory environment, using test beams of electrons and gammas, and a relative uncertainty of  $\sim 10\%$  or better is expected (see Figure 2d). After GLAST launch, while LIDARs can provide IACTs with regular measurements of atmospheric transmission, GLAST observations of steady sources at the highest energies can be used to reduce systematic errors in the absolute energy scale determination of IACT events.

Four major IACTs for the observation of gamma rays, designed as arrays of 10-meter class mirrors with finely pixelized imaging cameras, just started running: MAGIC[4] and VERITAS[5] in the northern hemisphere; HESS[6] and CANGAROO-III[7] in the southern one. In particular MAGIC, which started operations in October 2003 at La Palma, Canary Islands, consists of a single 17 m  $\varnothing$  tessellated mirror. As the largest instrument, it can access the lowest threshold, and has the widest overlap with satellites (see Figure 1 from [8]). Its actual energy threshold is expected to be, at regime, as low as 30 GeV,

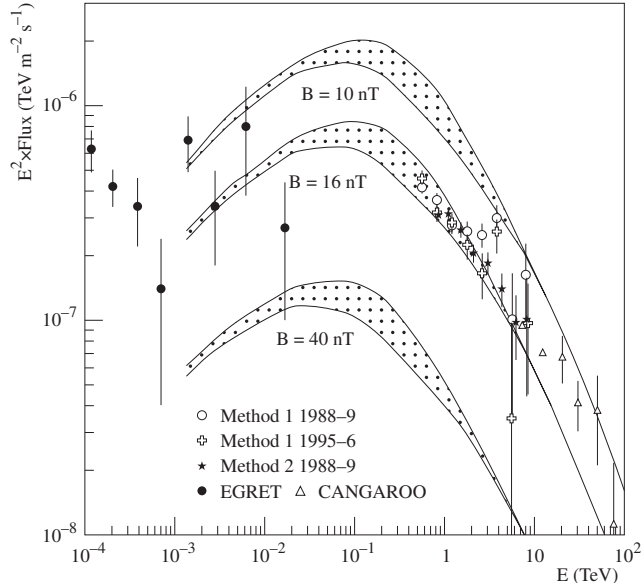


Fig. 3. Expected gamma spectrum from Crab Nebula.

although an even lower threshold of few GeV is not excluded, provided a new high quantum efficiency camera is implemented. Standing the present panorama, MAGIC can benefit most from GLAST data.

In this paper, we discuss the possibility of using GLAST observations of a standard gamma source, the Crab Nebula, to calibrate the Imaging Air Cherenkov detectors, MAGIC in particular, in order to extract the maximal information from the GeV region.

The paper is organised as follows. After this introduction, in Section 2 we estimate the number of photons from Crab Nebula seen by GLAST. In Section 3 we outline a possible strategy for cross-calibration based on the observations by GLAST. Finally, in Section 4 we draw our conclusions.

## 2 Detection of Crab Nebula by GLAST

The performance of GLAST was studied by means of a full simulation based on Geant4[9]. The on-axis effective area of GLAST as a function of energy is shown in Figure 2b (from Ref. [3]), with an average value for the GLAST Large Area Telescope (LAT) of about  $1.3 \text{ m}^2$  around 100 GeV.

During the first year, GLAST will observe the sky in survey (scanning) mode, therefore a uniform exposure at a 90% level can be conservatively assumed[10]. As its field of view is around  $2.4 \text{ sr}$ , *i.e.*,  $\sim \frac{1}{5}$  of the full sky, GLAST will observe every source, and in particular the Crab Nebula, for  $\frac{1}{5}$  of a year. Most of the time the source will be off-axis by  $40^\circ$  on average, and the effective area is

Table 1

Number of photons from Crab Nebula detected by GLAST in one year and relative error on the determination of  $E_{\text{brk}}$ . MAGIC is assumed to collect 50,000 gammas in 50 hours and the error on  $E_{\text{brk}}$  takes into account only the statistics as explained in the text.

$E_{\text{brk}}$ (GeV)	Gammas seen by GLAST	$\delta E_{\text{brk}}/E_{\text{brk}}$	
		GLAST	MAGIC
50	3763	6.2%	4.0%
100	3249	8.2%	3.5%
150	2988	12.7%	2.9%
200	2818	17.2%	5.2%

correspondingly reduced by a factor of 0.8 as seen in Figure 2c.

The spectrum of the Crab Nebula in the overlap region is poorly known: under different hypotheses on the magnetic field in an Inverse Compton scenario, it changes according with Figure 3 (from Ref. [11]). The variation in spectral index, from lower to higher energies, can be used to define a unique energy scale. In fact, the spectrum can be parameterised with two different spectral indexes: one fitting data at low energies and one at higher energies. We can define  $E_{\text{brk}}$  as the energy at which the two power laws meet. Let us assume, conservatively, that the low energy spectral index is 2.0 and the high energy one is 2.7. A bigger difference between the indexes will mark even more the spectral feature and make the determination of  $E_{\text{brk}}$  easier. The value of  $E_{\text{brk}}$  is of the order of magnitude of 100 GeV. *The position of this spectral break, well determined by GLAST, can be used to calibrate MAGIC.*

The number of photons from Crab Nebula between 10 and 300GeV detected in the first year by GLAST in survey mode (with a 90% data efficiency allowing for South Atlantic Anomaly passages, data downlink failures etc.), depends on  $E_{\text{brk}}$ . The actual value obtained from the simulation, as a function of  $E_{\text{brk}}$ , is listed in Table 1.

### 3 Calibration Strategy for IACT

We simulated the observation by GLAST in the range from 10 to 300 GeV and assumed the energy resolution in Figure 2d. The photon samples followed the spectra expected from Crab Nebula at different values of  $E_{\text{brk}}$  and with the multiplicities of Table 1.

The value of  $E_{\text{brk}}$  was then estimated from each sample by minimising the residual values, properly weighted, of the simulated data from some *template*

distributions that mimicked the Crab spectrum at different values of  $E_{\text{brk}}$ . The error on the determination of  $E_{\text{brk}}$  was calculated from the spread of the central values of the estimate obtained from 100 independent Monte Carlo samples. The relative errors on  $E_{\text{brk}}$  obtained with such a procedure are listed in the column headed GLAST of Table 1.

On the other side, we simulated for MAGIC a total flux of 50,000 gamma photons coming from the Crab Nebula in 50 hours of observation time. The estimate of 1000 gammas/hour should be easily attainable at regime. To unfold the simulated distribution we filled a migration matrix using the full Monte-carlo simulation and then applied it to the simulated spectrum. Applying the same algorithm for the determination of  $E_{\text{brk}}$  we obtain the relative error for MAGIC as listed in the last column of Table 1.

This error is taking into account only the statistics, and it is quite lower than the GLAST one.

The spectral feature  $E_{\text{brk}}$ , as seen by GLAST, can be used to calibrate MAGIC: the value of  $E_{\text{brk}}$  as determined by MAGIC should be offset to match GLAST value. In this way the absolute scale uncertainty in the region between 30 and 200 GeV will not exceed GLAST one, *i.e.*, it will go from about 6% to 17%. Higher values of  $E_{\text{brk}}$  will be hardly reconstructed by GLAST due to the steep decrease in the power-law spectrum, as can be inferred from the rapidly increasing values of  $\delta E_{\text{brk}}/E_{\text{brk}}$  as a function of  $E_{\text{brk}}$ .

## 4 Conclusions

We showed in this paper that we can use GLAST observations of a standard gamma source, as the Crab Nebula, to calibrate the absolute energy scale of Imaging Air Cherenkov detectors and MAGIC in particular. In this way, the absolute energy uncertainty of Cherenkov telescopes, at around 100 GeV, can be reduced to  $\lesssim 10\%$ . A spectral break at higher energies will be harder to measure and of little help to IACTs. Nevertheless, other features, as the exponential cutoff of AGN spectra, due to the interaction of AGN gammas with the extragalactic infrared background, can also be well-suited for IACT calibration, provided they can be observed by GLAST and IACTs in the same energy range.

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