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Energy Calibration of Cherenkov Telescopes using GLAST Data

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Abstract: We discuss the possibility of using the observations by GLAST of steady gamma sources, as the Crab Nebula and some selected AGNs, to calibrate the Imaging Air Cherenkov Telescopes (IACT) and improve their energy resolution. We show that at around 100 GeV, exploiting the features in the spectrum of the Crab Nebula, the absolute energy calibration uncertainty of Cherenkov telescopes can be reduced to $< 10\%$. Other reconstruction uncertainties can be taken care of, as soon as new sources become observable by GLAST and by Cherenkov telescopes. Results of the calibration technique can possibly be used to discriminate between VHE gamma-rays emitted by the Nebula and by the inner pulsar in pleryons.

Introduction

Full multiwavelength coverage of galactic and extragalactic sources 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 ~ 10 and ~ 100 GeV, is still largely unknown due to experimental detection difficulties; indeed , until now, this energy range stands between the highest energies significantly detected by satellites and the lowest energy threshold of ground based instruments.

Among ground-based detectors, IACTs are expected to reach the lowest energy thresholds ($75 \div 85$ GeV). On the one hand, IACTs feature huge collection areas, an excellent angular resolution and a good energy confinement. On the other hand, they suffer from a low duty-cycle, small fields of view ($< 5^\circ$) and systematic calibration uncertainties in both energy and sensitivity. In fact, whereas IACTs have an intrinsic energy resolution as low as $\sim 5\%$, the absolute energy scale remains quite elusive, as the energy reconstruction in the $30 \div 300$ GeV range is dominated by uncertain-

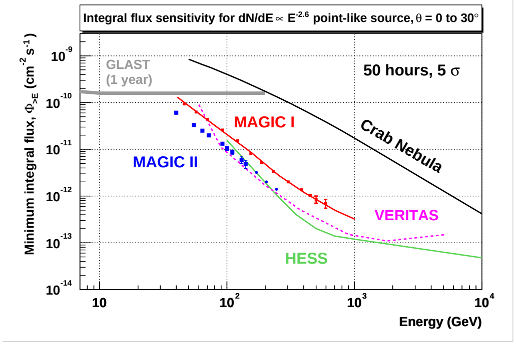

Figure 1: Predicted sensitivities for some operating and proposed detectors. Note the wide overlap region between GLAST and present Cherenkov telescopes. The blue dots are the expected sensitivity for MAGIC II, a second telescope, *clone* of the current MAGIC, that is being built at ~ 85 m of distance from MAGIC. Start of operation for MAGIC II is envisaged for the beginning of 2008, just around the scheduled launch of GLAST.

Table 1: Relative error on the determination of $E_{\rm brk}$ from the Crab Nebula. IACTs (MAGIC) are assumed to collect at least 50,000 gammas and the error on $E_{\rm brk}$ takes into account only the statistics as explained in the text.

$E_{\rm brk}$	GLAST	IACTs	IACTs+ GLAST
50 GeV	6.2%	40%	26%
100 GeV	8.2%	37%	22%
150 GeV	13%	35%	22%
200 GeV	17%	34%	24%

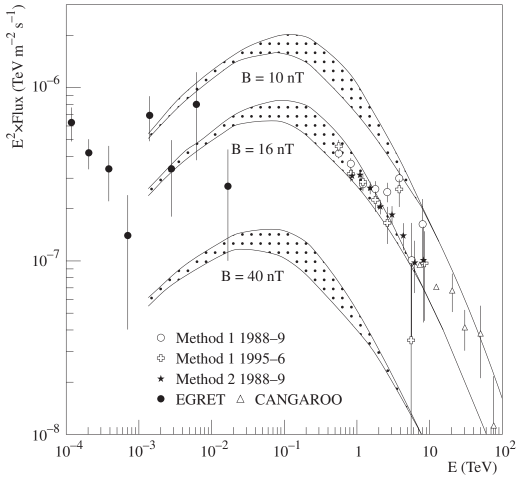

Figure 2: Expected gamma spectrum from Crab Nebula (from Hillas et al. 1998).

ties on Monte Carlo simulations and on the atmospheric model (Mohanty et al. 1998).

GLAST, contrarily to IACT, is calibrated in a well-controlled laboratory environment using test beams and a relative uncertainty of $\sim 10\%$ or better is expected. After GLAST launch, while LIDARs can provide IACTs with regular measurements of atmospheric transmission, GLAST observations of higher energies sources can be used to reduce systematic errors in the absolute energy scale determination of IACT events.

Calibrating IACTs with GLAST using the Crab

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 (see, *e.g.* The GLAST Science Document). As its field of view is around 2.4 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° on average, and the effective area is correspondingly reduced by a factor of 0.8 (for GLAST performance: *http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm*).

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 2 (from Hillas et al. 1998). 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 $E_{\rm brk}$ 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 larger difference between the indexes will make the spectral feature more prominent and allow a more precise determination of $E_{\rm brk}$. The value of $E_{\rm brk}$ is expected to be around 100 GeV.

The position of this spectral break, well determined by GLAST, can be used to calibrate IACTs.

The number of photons from Crab Nebula between 10 and 300 GeV 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 $E_{\rm brk}$. $E_{\rm brk}$ is evaluated assuming the actual energy resolution of GLAST (see column GLAST).

As far as IACTs are concerned, we used the Crab data provided by MAGIC at energies above 100 GeV. Recent data below this value confirm the bending of the spectrum (Albert et al. *in preparation*). The column headed IACTs refers to the total scale uncertainty of MAGIC and is the sum in quadrature of the absolute scale uncertainty ($\sim$

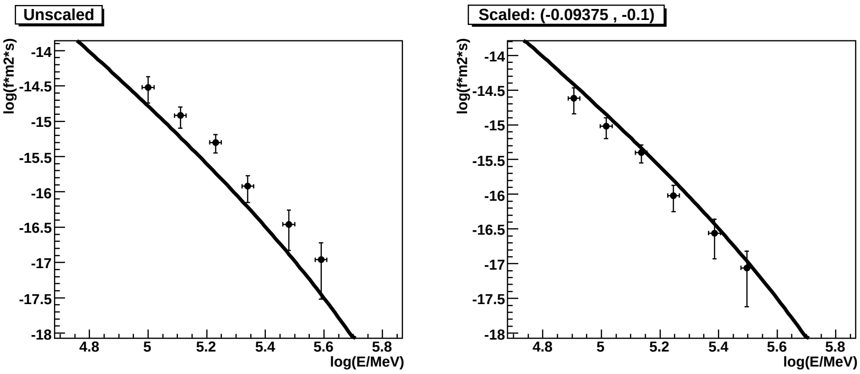

Figure 3: Spectrum of PG 1553+113 as estimated by using the GLAST performance data for one year (line), MAGIC data from (Albert et al. 2007) (left) and scaled (right). Constraints on scale factors are set by the reconstructed spectrum of PG 1553+113, 1ES 1218+30.4 and the Crab Nebula.

30%) and the intrinsic one, whereas the last column refers to the total scale uncertainty of MAGIC when using GLAST information on the position of $E_{\rm brk}$.

Calibrating IACTs with GLAST using AGN spectra

Beside the Crab, many other sources, typically AGNs, do show a featured spectrum. Their power-law spectrum is in fact folded with an exponential cutoff due to the absorption by the Metagalactic Radiation Field. The position of this cutoff, if reconstructed both by GLAST and IACTs, can be used to reduce the absolute scale uncertainty as in the case of the Crab. But they can also help in reducing other possible systematic misbehaviors: there can be in fact some scaling error in reconstructing the fluxes or the energies. For this purpose, we used the data collected on PG 1553+113 (Albert et al. 2007) and 1ES 1218+304 (Albert et al. 2006). Estimating the GLAST observation from its performance and comparing it with the data obtained by IACTs, one can infer the two scale factors that should affect flux and energy. As can be seen from Fig. 3, just two AGNs and the Crab Nebula are enough to constrain these factors with uncertainties comparable with the actual ones. The numbers quoted in the caption of the right plot in Fig. 3 correspond to the logarithm of the scaling factors to be applied to MAGIC estimates for energy and flux, corresponding to a rescaling of $\sim$ 0.81 for the energy scale and $\sim$ 0.79 for the fluxes.

Conclusions

We showed how to reduce the uncertainties in the spectrum reconstructed by the IACTs. This approach was proven to be comparable with the current estimates of the systematic errors affecting the measurements. As the GLAST catalogue will embrace more and more sources, these errors will get smaller allowing us to observe the sky at very high energies with unprecedented precision.

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