On the Calibration of the Energy Scale of Cherenkov Telescopes using F*ermi* and Pulsars

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<u>Summary:</u> A new method is proposed to calibrate the energy scale of Imaging Atmospheric Cherenkov telescopes (IACT) using the pulse profiles of pulsars detected by *Fermi* and IACTs.

The energy estimation of gamma-rays detected with IACTs such as H.E.S.S., MAGIC, and VERITAS relies solely on Monte Carlo simulations. A calibration of these instruments with a "standard candle" has so far been difficult due to the lack of a source with a spectrum that had been measured by a calibrated instrument. With *Fermi* LAT it is now possible to measure gamma-ray spectra of some sources with high precision into the VHE (above 100 GeV) regime, the domain of IACTs. A calibration seems to be possible in the near future, which opens up the question on how to do it best. It has been argued that the Crab Nebula is the best source to perform this task, because it is the strongest steady VHE source known, and it has a relatively hard spectrum that extends well into the energy range accessible by *Fermi*. The lack of narrow features in the photon spectrum of the Crab nebula, however, makes a precise determination of the absolute energy scale difficult. The steep cutoffs observed in the gamma-ray spectra of pulsars above a few GeV, on the other hand, provide a distinct feature that can be used to determine the absolute energy scale of an IACT. The measurement of the photon spectrum of a pulsar with an IACT is not an easy task because of the steeply falling spectrum and the steeply rising effective area of IACTs around 100 GeV. Here, I propose a new method to calibrate IACTs that makes use of energy dependent features in the pulse profiles of pulsars. The method is explained using the example of the Crab pulsar with available *Fermi* and MAGIC data.

Energy Estimation of Gamma-Rays detected with IACTs

Energy is estimated from a few parameters:

- The number of detected Cherenkov photons
- Length and width of the recorded shower image
- Reconstructed impact location of the gamma-ray
- ...

Parameters are compared to Monte Carlo simulated gamma-ray parameters

Energy of recorded event
= Energy of best fit MC gamma-ray sample

Many variables are not taken account or efficiencies are unknown:

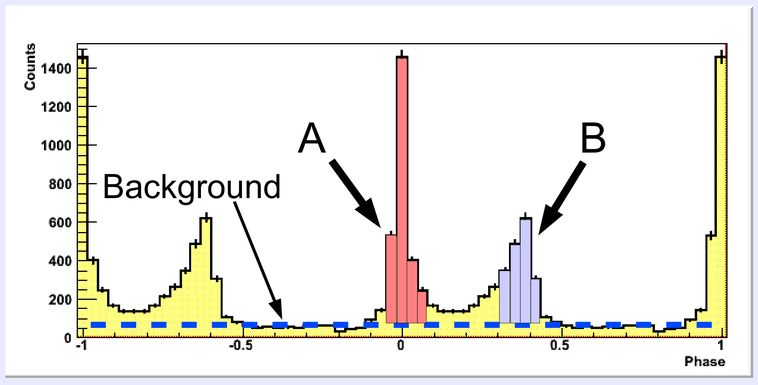
- Daily and seasonal changes in the atmosphere
- Some slowly changing characteristics of the telescope
- ...

→ ~20% uncertainty on the energy scale

The Parameter *R*:

Idea: Use energy dependent features in pulse profiles of pulsars to estimate the absolute energy scale.

- Many gamma-ray pulsars have two peaks
- Define quantity that is independent of detector efficiencies



Pulse profile of the Crab Pulsar above 1 GeV compiled from *Fermi* data. The red and blue regions around the main- and inter-pulse are used as region A and B in the definition of the parameter *R*. The background is estimated between phase 0.5 and 0.88.

$$R = (A-B) / (A+B)$$

A and B are the areas under the main- and inter-pulse corrected for the unpulsed background.

R depends only weakly on the efficiency of the detector

Analysis

The method is illustrated using the example of the Crab Pulsar, which is presently the only pulsar detected by an IACT.

***Fermi* event selection and analysis:**

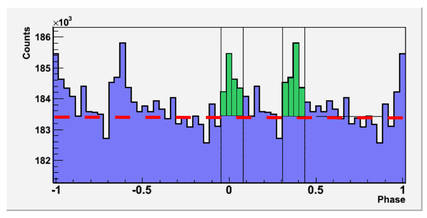
- Data from launch until September 2009
- Radius of ROI <1.5 deg
- Zenith angle <105 deg
- Barycentering with gtbary *Fermi* science tools v9r15p2
- Phase folding with ephemerides from Jodrell Bank [2]

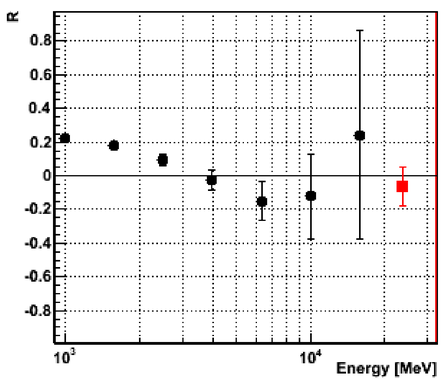
VHE detection:

The detection and the analysis of the Crab pulsar above 25 GeV by MAGIC is described in [1]. For convenience and illustration the published pulse profile is used here. The selection of region A and B around the main- and inter-pulse, respectively was chosen such that it matches with the binning of the published pulse profile (see pulse profile in the results section).

Results

The right panel shows the pulse profile of the Crab Pulsar above 25 GeV taken from [1]. The background is estimated between phase 0.5 and 0.9 (red dashed line). Region A is defined by the green area around phase 0 and region B is defined by the green area around phase 0.45. The value *R* is 0.07+-0.11.





The derived value *R* for the VHE pulse profile is shown by the red data point in the left figure.

The black points give the *R* values from the *Fermi* data.

Note that these are points of all events with energy higher than the energy at which they are plotted.

A feature is evident in the *Fermi* data between 2 GeV and 3 GeV where *R* changes from positive to negative.

Another crossover might occur above 10 GeV, which could be used to calibrate the energy scale of an IACT.

The statistics accumulated by *Fermi* are not yet sufficient to apply this method claim but four more years of *Fermi* data could be enough to see a feature above 10 GeV.

Discussion

Presented is a new approach to calibrate the energy scale of IACTs.

The method is promising but a calibration using the Crab pulsar is presently not possible because of insufficient overlap between *Fermi* and IACTs.

Future Improvements:

- More events accumulated with *Fermi* above 10 GeV.
- Cherenkov Telescope arrays with a lower energy threshold (AGIS, CTA)
- Additional Pulsars: Vela and Geminga

References

[1] Albert et al. (MAGIC Collaboration) 2008, Science 21, 1221-1224
[2] http://www.jb.man.ac.uk/~pulsar/crab.html