Mem. S.A.It. Suppl. Vol. 9, 374
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Memorie della
Supplementi

The MAGIC Telescope

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Abstract. The key problem of Cherenkov Astronomy is to detect a weak signal from a point source embedded in an overwhelming but isotropic sea of noise events generated by Cosmic Rays. The enormous improvement of the gamma-hadron separation achieved by IACT systems is briefly described. A short mention of the results obtained by some leader experiments in this field is given.

1. Introduction

For historical reasons we call *gamma ray* the electromagnetic radiation (photons) whose energy spans from 1 MeV to the highest observed energy which is of the order of 10^{20} eV.

In this paper, we shall focus on the energy interval just above the satellite limit, which is, up to now, of the order of 10 GeV. In particular the energy interval between 10 GeV and 1 TeV was, until recently, a sort of no man's land, where neither satellites nor ground based experiments were able to perform observations for opposite reasons. Now, for the first time, things are changing in the sense that future satellites (GLAST) will raise their significant sensitivity up to some hundred GeV, while, on the other side, ground based telescopes are rapidly lowering their energy threshold to a few tens of GeV. In particular, it is worth noticing that the Magic experiment can safely claim an energy threshold as low as $30 \div 40$ GeV. In spite of this rapid evolution ground based telescopes and the gamma ray Astronomy above 10 GeV are still currently referred to as *TeV Telescopes* and *TeV Astronomy*.

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2. TeV Astronomy

In the low energy band of the so-called TeV Astronomy, we will experience the simultaneous observations of satellite instruments (as GLAST) and ground based telescopes like MAGIC (Martínez 2003), HESS (Hofmann 2003), CANGAROO (Enomoto 2003) and VERITAS (Wakely 2003). While the former, by means of laboratory-tested detectors, detect γ by measuring the electromagnetic showers they produce in the detector itself, ground-based telescopes detect γ by measuring e.m. showers produced in the atmosphere.

In the first case we have an effective area of $\sim 1\,\mathrm{m}^2$ in the latter it is $\sim 10^{4\div5}\,\mathrm{m}^2$; in the former case detection of gamma rays is almost background free, in the latter the background due to atmospheric showers initiated by cosmic rays is largely dominant. Therefore, the main difficulty for ground-based gamma astronomy is to discriminate showers originated by CR, called *hadronic showers*, from showers originated by gammas, referred to as *electromagnetic showers*. Undoubtly, the problem of gamma-hadron separation is still a field in which much can be done and this makes

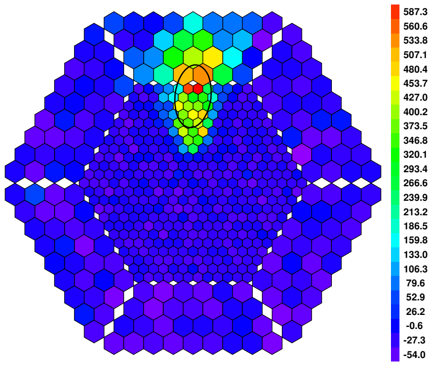

Fig. 1. Simulation of a gamma-initiated shower as seen by the MAGIC telescope.

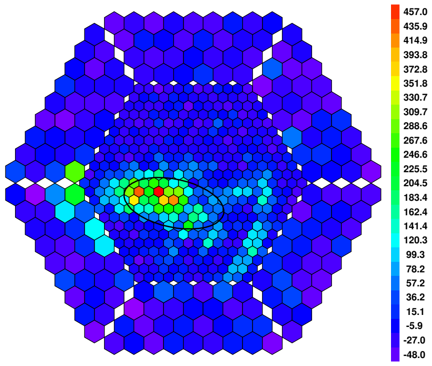

Fig. 2. Simulation of a proton-initiated shower as seen by the MAGIC telescope.

ground based TeV Astronomy a young branch of Astronomy.

3. The Imaging Technique

One measurement which discriminates hadronic showers (HS) from e.m. showers (ES) is the time profile of the Cherenkov pulse. However, the most efficient properties that allow us such a discrimination, are found in the geometric shape of the image in the camera. This is the reason why all ground based Telescopes are called IACT (Image Atmospheric Cherenkov Telescopes). Tipically, the topological structure of a HS is more dispersed while the ES has a more compact shape.

Let us show some simulated events for HS and ES of comparable energy (Figg. 1, 2, simulations by Magic Collaboration). The study of topological properties of the two kinds of events has led to the definitions of several parameters, most of them are the original Hillas Parameters (Hillas 1985), and we can see the distributions of the values of the parameters for the two kinds of showers.

In the two examples of simulated events, we can notice two main features:

1. the shape of the gamma shower image is more compact, more or less elliptic and the major axis of the ellipse points towards the centre of the camera; this last feature indicates that the direction of the shower is parallel to the pointing of the telescope;
2. shape of the hadronic shower image is irregular as if it was composed by different sub-images, and the overall direction of the shower, still given by the direction of the major axis of the *ellipse* which confines the event, is distributed randomly as is expected from a background event.

In Fig. 3, some of the most important parameters used to describe the main features of the image of the shower: width, length, distance and alpha.

In particular, the alpha parameter has a clear deviation from the uniform distribution expected for isotropic background events, when the shower direction approximates the direction from the point source that is under observation. An example can be seen in Fig. 4,

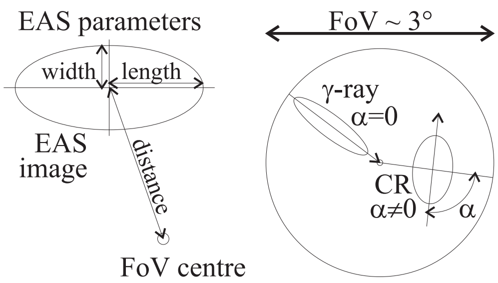

Fig. 3. Some of the main Hillas parameters.

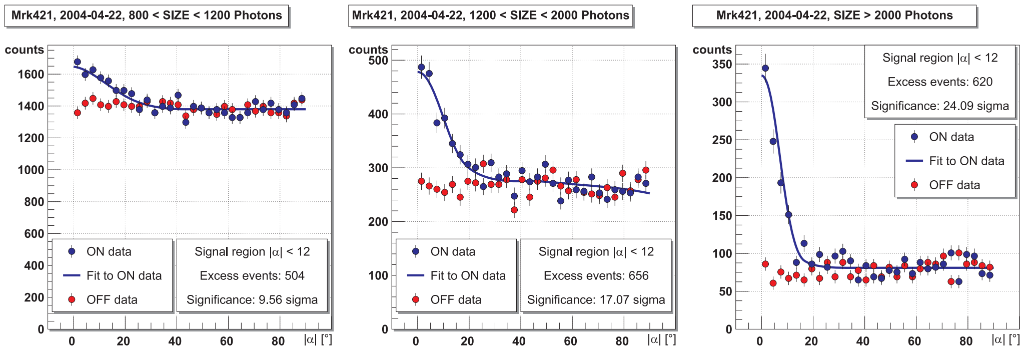

Fig. 4. The *alpha* distribution of the events collected pointing at Mkn 421, showing a peak toward the source direction ($\alpha \sim 0°$). Data from 155-minutes of acquisition taken on April 22$^{\text{nd}}$, 2004. The histogram of *alpha* for on- and off-source observations, are relative to different bin in *size*: 800–1200 (left), 1200–2000 (center) and more than 2000 photons (right).

where the alpha distribution of the Mkn 421 is shown.

In blue we can see the alpha distribution of events on the telescope camera for a point source, and the distribution of events for an isotropic background *source*.

Two Hillas parameters have a particular importance in the figure: *alpha* and *size*. *Alpha* is related to the actual direction of the primary particle that initiated the shower, thus an excess in *alpha* must be seen in the direction of a source. *Size* is the number of photons making up the image and is related to the energy of the primary particles (the more energetic is the particle, more photons appear in the image).

The three figures show that the Mkn 421 flare was well detected by MAGIC at different energies, and the excess seen in the first figure with *size* ranging from 800 to 1200 photons is consistent with an energy well below 100 GeV.

The relevant progress made in the study of the gamma-hadron separation has led to consider a particular combination of the different Hillas (and non Hillas) parameters, called *hadronness*, describing the actual shape of the image. Using the *hadronness*, the probability of being wrong in deciding whether an image is produced by a gamma or by a hadron has been fairly lowered.

Things go definitely better if we consider the stereoscopic mode with two identical Magic telescopes. The new situation is shown in Fig. 5, and the improvement is mainly due to the improved angular separation.

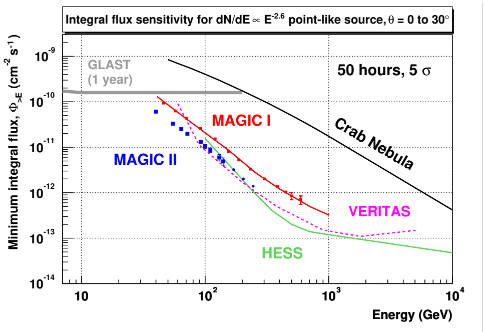

Fig. 5. Predicted sensitivities for some operating and proposed detectors. Note the wide overlap region between GLAST and present Cherenkov telescopes.

4. Status and future perspectives of Cherenkov Telescopes

The present status of Cherenkov telescopes shows an increasing interest and investment in this field of astronomy. Experimental apparatuses for VHE astronomy are scattered all over the world and most of them are based on the IACT technique, like: Cangaroo, Hess, Magic, Stacee, Tactic and Veritas.[1]

[1] For a very comprehensive review of the experimental situation and the status of VHE observations

The scientific case is increasingly important, featuring both galactic and extragalactic sources. Among the former ones the study of supernovae remnants show the remarkable development of VHE Astronomy, in particular due to the high degree of detail that the Hess Collaboration has achieved by exploiting the excellent angular resolution given by the stereoscopic technique.

For the first time supernovae remnants do not appear as point sources but a detailed map of intensity with the local spectral indices is given. However, the gamma spectrum does not allow us to disentangle the pion-decay component from other electro-magnetic mechanisms producing gamma radiation and related to high-energy electrons, and the proof on the origin of CR is still not complete.

Among extragalactic sources, the AGN (BL-Lac) physics is of the highest importance both for testing the modelling of these sources, for determining their luminosity function and for testing the diffuse infrared-optical extragalactic background radiation (EBL). High-energy gamma radiation is absorbed by the diffuse EBL by pair production.

The EBL can be tested by observing the VHE spectra of distant and powerful sources. If the threshold conditions for pair production, are satisfied VHE gamma are absorbed by infrared-optical EBL through the process:

$$\gamma + \gamma \longrightarrow e^+ + e^-$$

This process produces an exponential cut-off in the energy spectrum of the sources. The determination of the cut-off energies in the energy spectra of a source of given red-shift allows us to estimate the energy density of background light of different wavelength as a function of red shift.

This would be the only way, up to now, to have a local estimate of the energy density of EBL instead of the cumulative column measurements available until now. The Magic telescope is particularly suitable for this purpose owing to the lowest energy threshold and the highest sensitivity. As an example of the excellent performance of the Magic telescope it is worth noticing the recent discovery of the one of the furthest AGN positively detected in VHE gamma ray region, 1ES1218+304 at a redshift of $z = 0.184$.

see Reneè Ong , Rapporteur Talk OG1 presented at the 29th ICRC in Pune, India.

5. Conclusions

The energy interval between 10GeV and 300GeV which was out of the reach by satellite-borne instruments and ground based Telescopes until a few years ago, can now be explored by present generation Cherenkov Telescopes. The superposition with new satellite born instruments (Agile and Glast) will be very fruitful. The possibility of further improvement of these techniques is still very high.

Also the mutual cooperation among different Telescopes for common calibration and observation programs, is necessary for a general development. In addition, the Multi-Wavelength campaign between Gamma Telescopes and other ranges of the electro-magnetic spectrum (X-rays, optical and radio) will open fundamental opportunities. For all these reason VHE Gamma-ray Astronomy can be considered the most vital and innovative branch of Astronomy in these years.

Acknowledgements. The construction of the MAGIC Telescope was made possible by the financial contributions of the Italian INFN, the German BMBF and the Spanish CICYT, to whom goes our grateful acknowledgement. We would also like to thank the IAC for the excellent working conditions provided at El Roque de los Muchachos.

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