29th International Cosmic Ray Conference Pune (2005) **00**, 101-104

MAGIC Phase II

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MAGIC, the largest ground-based gamma ray telescope in the world, has been in scientific operation since summer 2004. The major motivation of the MAGIC project is to study high energy phenomena in the universe in the unexplored energy region between 10 GeV and 300 GeV. MAGIC-II, a two 17m telescope system with advanced photon detectors and ultra fast readout, is designed to lower the threshold energy further and to simultaneously achieve a higher sensitivity in the stereoscopic / coincidence operational mode. The construction of the second telescope will be completed in 2007. This allows simultaneous observations with the gamma ray satellite missions GLAST and AGILE with a sensitivity not achieved so far by ground-based gamma ray telescopes.

1. Introduction

MAGIC was designed back in 1995 with the very clear goal to lower the energy threshold in order to reveal the unexplored energy range between 10 GeV and 300 GeV [1]. The first MAGIC telescope has recently started operation and is now almost reaching its design performance [2]. MAGIC is the first instrument to explore a new energy regime, i.e. >30 GeV energy, with the ground-based imaging Cherenkov technique. We expect that many important physics results will be delivered by this first MAGIC telescope, and our understanding of gamma ray astrophysics in the energy range of a few tens GeV will become deeper. However, we are upgrading MAGIC to MAGIC-II by adding a second telescope and by improving the photon detectors and readout system in order to lower the energy threshold further and, simultaneously, to increase the sensitivity of the telescope. These intentions make sense if we consider the upcoming satellite mission, the Gamma ray Large Area Space Telescope (GLAST) [3]. Simultaneous observations by GLAST and MAGIC-II will provide us with more promising scientific results in the wide energy range of five decades, 100MeV-10TeV, and surely we can deepen our knowledge of the high energy phenomena in the Universe.

The physics objectives of MAGIC-II are widely distributed both in astrophysics and in fundamental physics. **AGNs and GRBs** are prime targets in MAGIC. The function of the fast repositioning (~20 seconds) and the lower threshold energy of 20 GeV will make MAGIC-II the best ground-based detector to study GRBs. Observation at a lower threshold allows us access to larger redshifts, and multiple AGNs up to redshifts ~2 will help to study the **Gamma Ray Horizon** (FSR) determined by the infrared background light, resulting in a better understanding of the cosmological evolution of galaxy formation. The chances for detecting **Quantum gravity** effects using time delays as a function of energy will improve with lowering the threshold, due to an increased number of potential time-variable gamma ray sources, and the larger distances of their positions. Especially GRBs are interesting sources to study this effect. Concerning a search for **Dark matter,** the continuum energy spectrum from neutralino annihilations can only be identified by the measurement with a low threshold.

The GLAST satellite is scheduled for launch in August 2007. Its mission duration will be at least 5 years. GLAST will have an effective collection area of ~ 1 m^2 and will be able to detect gamma rays with good energy and direction resolution above 100MeV. MAGIC-II can have a significant overlap with GLAST in the energy region between 20 to 100 GeV. This allows not only the systematic study of high energy sources in the wide energy range, but also the cross calibration of MAGIC and GLAST. GLAST has a wide field of view, which is a strong feature to discover new sources, transient sources like GRBs, and flaring AGNs. MAGIC-II has a large acceptance and provides a better sensitivity for the study of the spectrum and the rapidly changing light curve of AGNs and GRBs in a short time scale. For example, MAGIC-II can supply more precise light curves of high state AGNs after getting an AGN-flare-alert from GLAST. GLAST and MAGIC-II will perfectly complement each other.

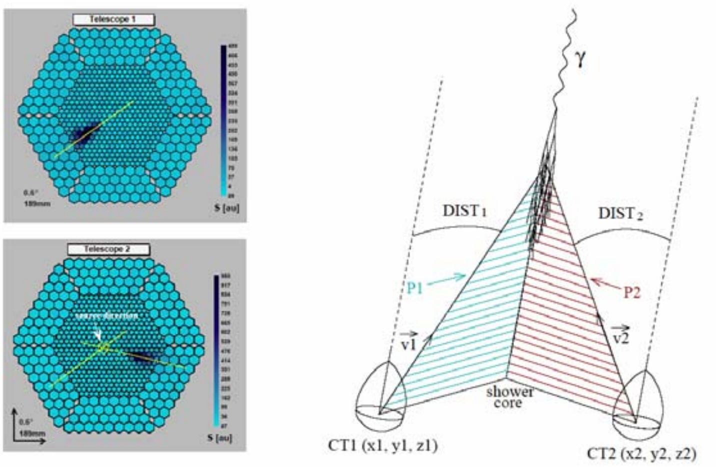

Figure 1: Left: reconstruction of the shower direction through the intersection of the major axes of the images in both telescopes. Right: reconstruction of the shower core position assuming that the shower axis is parallel to the pointing direction of the telescopes.

The HESS collaboration plans to upgrade to HESS-II by adding a 28m diameter telescope at the center of the HESS array. This installation will allow to access the energy domain of 10-20 GeV, and HESS-II has a quite similar sensitivity as MAGIC-II. HESS and MAGIC are located in the Southern hemisphere and Northern hemisphere, respectively. Therefore, the entire sky will be covered by low threshold, high sensitivity instruments. In spite of the difference of North and South, the close geographical longitudes of the HESS and MAGIC sites provide a unique opportunity to do a simultaneous observation of interesting variable sources [4]. Irrespective of whether a source is located in the Northern sky or in the Southern sky, one telescope will see it with 10-20 GeV threshold energy, and the other will see it at large zenith angle with high threshold energy but with huge acceptance. We can then study high energy gamma ray emission in the wide energy range between 10 GeV and 10 TeV. The rapidly changing light curve and the time variable spectrum can be studied in a systematic way. Of course, through these simultaneous observations HESS-II and MAGIC-II will be cross-calibrated perfectly.

2. MAGIC-II

The second 17m telescope is now under construction at the same site as the first telescope on the Roque de los Muchachos, La Palma, Canary Islands. The second telescope is configured to be situated at a distance of 80m from the first telescope. This distance was optimized after a detailed Monte Carlo simulation. The imaging camera is designed with advanced photon detector HPDs which have a quantum efficiency of 50% around 500nm [5]. The signals will be read out by ultra-fast FADC systems of 2.5 Gsamples/s [6] to reduce background photons from the night sky and to achieve a better gamma / hadron separation by taking into account the time profile of the Cherenkov light. We aim to lower the threshold energy by a factor of two with advanced photon detectors and an ultra fast readout system. The stereo configuration with two telescopes will increase the sensitivity to fainter sources and the quality of the experimental data.

The second telescope substantially increases the sensitivity to gamma rays and also increases the flexibility of the observations. One operational mode is a stereoscopic mode, which allows us to perform deep sky survey. The other is an independent / patrol operational mode, which allows us the fast scanning of different sources. With this mode, we can increase the chance to discover flaring AGNs (AGN patrol).

In the stereoscopic deep observation mode, there are two advantages; a better gamma / hadron separation, and a capability of geometrical reconstruction. The better gamma / hadron separation power will supply us with higher purity gamma ray samples and allow us to study the energy spectra of gamma rays from astronomical objects with higher precision or with less systematic errors. The geometry reconstruction will help to determine energies and arrival directions of individual gamma rays more precisely. The high purity gamma ray samples with geometrical information will also provide good understanding of the characteristics of low energy gamma ray showers experimentally; this will be invaluable information for the conceptual design of the next generation ultimate ground-based gamma ray telescope.

In Figure 2, the expected distributions of the image parameters obtained by Monte Carlo simulation are shown. The θ^2- distribution represents the angular resolution (θ is the space angle between the source position and the estimated shower direction). The angular resolution, defined as the error circle containing 50% of the events, can be expressed as $\theta_{50\%} \sim 0.20^{o}\ (100\mathrm{GeV/E})^{0.5}$ as a function of gamma ray energies. Mean scaled width and length will be used for gamma / hadron separation. Figure 3 shows the power of event identification. The horizontal axis shows the classification parameter “Hadronness” (0 = pure gamma, 1 = pure hadron). At a hadroness around 0.4, the quality factor reaches the maximum of ~7.

In Figure 4, the sensitivity of MAGIC-II to high energy gamma rays is shown in comparison with MAGIC-I, HESS, VERITAS and GLAST. The sensitivity of MAGIC-II is better by a factor of two than that of MAGIC-I. This means that we need a factor of four less observation time to get the same significance in MAGIC-II as in MAGIC-I, or, in other words, we can see four times more sources in a fixed time period.

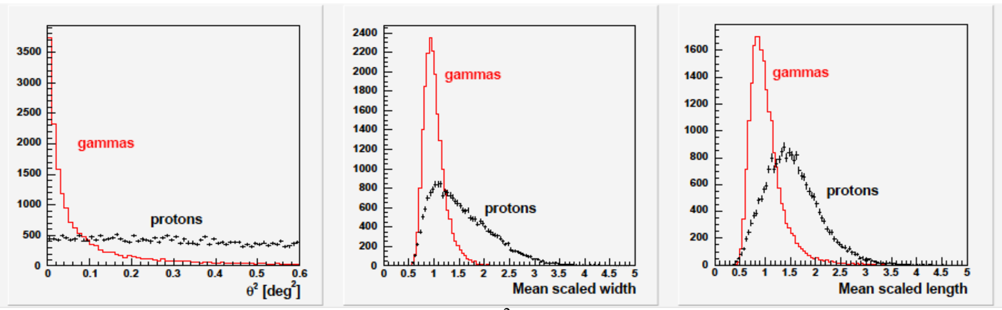

Figure 2: The distributions of image parameters, θ^2, mean scaled Width and Length for MAGIC-II.

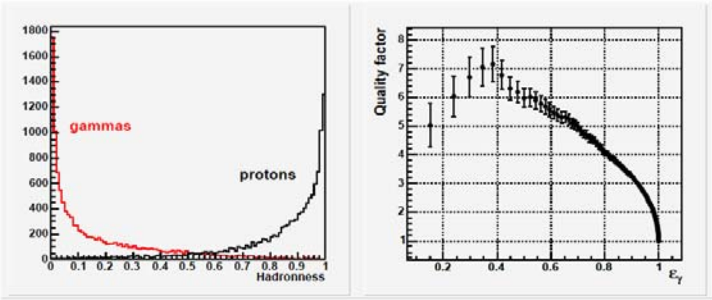

Figure 3: Event classification using the Random Forest method in MAGIC-II. Left: hadronness distribution for gammas and protons. Right: quality factor (see text) as a function of the gamma efficiency for different upper cuts in the hadronness.

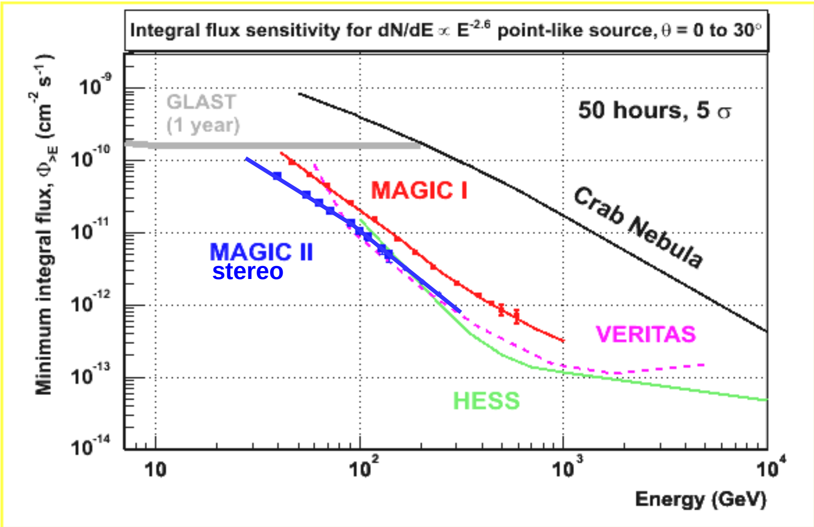

Figure 4: Sensitivities of the current MAGIC-I and MAGIC-II (two telescope system with advanced photon detector) are shown in the comparison with GLAST, HESS, and VERITAS. MAGIC-II improves the sensitivity by a factor of two compared to MAGIC-I. Around 30 GeV, the sensitivity of MAGIC-II in 50 hrs will cross the one of GLAST in 1 yr.

4. Acknowledgements

The authors thank other collaborators in MAGIC and Dr. M. Altmann for valuable discussions. We would like to thank the IAC for excellent working conditions. The support of the German BMBF and MPG, the Italian INFN and the Spanish CICYT is gratefully acknowledged.

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