PROCEEDINGS OF SCIENCE

Recent results of extra-galactic observations with the MAGIC telescope system

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MAGIC is a system of two 17m Cherenkov telescopes, sensitive to very high energy (VHE) γ-rays between 50 GeV up to several tens of TeV. Thus MAGIC is ideally suited to connect the VHE energy spectra to those of the Fermi-LAT, which is sensitive to γ-rays up to 300 GeV, but whose collection area is too small to detect the low flux levels of many of the sources beyond few tens of GeV. Also MAGIC-I mono results will be reported. The variety of sources discussed in this proceeding includes clusters of galaxies, radio galaxies, quasars and BL Lac objects.

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[1] For the MAGIC Collaboration

1.Introduction

The MAGIC telescopes are situated on the Roque de los Muchachos on the canary island La Palma, 28°N, 18°W at a height of 2200 m. They are separated by 85 m and work in a coincidence trigger mode. Thanks to the 3D shower reconstruction a two times better integral sensitivity above 250 GeV (0.8% of the Crab Nebula flux in 50 h of observation) is achieved. Differentially the sensitivity improved especially below 100 GeV (see figure 1 for details), where a lower background rate (factor ~10) significantly reduces the systematic errors. The angular resolution (defined as the sigma of a 2D Gaussian) is 0.07° on an event to event basis. The energy resolution (above 300 GeV) improved to 15% [1]. The detailed performance of the MAGIC stereo system will be discussed in a forthcoming publication.

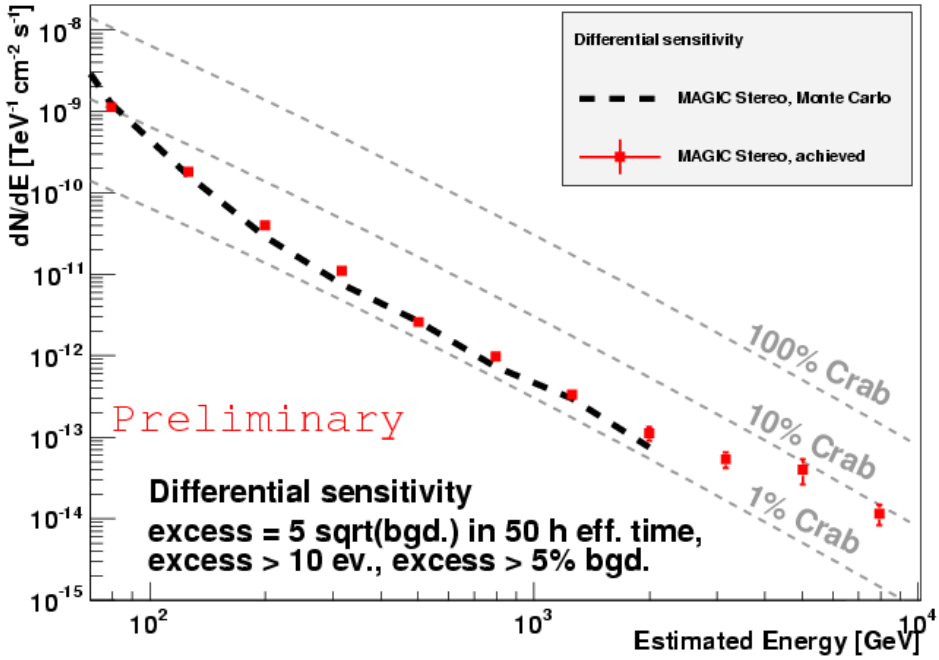

Figure 1: Differential sensitivity of the MAGIC telescope system. The measured data is shown as red squares, and Monte Carlo simulations are shown as dashed line for comparison.

2.The 3C 66A/B region

The intermediate energy peaking BL Lac object 3C66A and the radio galaxy 3C66B are located just 6 arc minutes apart in the sky. During MAGIC-I mono observations in 2007 a significant excess coincident with the position of 3C 66B was discovered [2], however 3C66A could not be excluded as the source of the VHE γ-rays at a high confidence level. Between December 2009 and January 2010 the region was re-observed in stereoscopic mode during an optical high state of [3]. Significant (5.2 σ) γ-ray emission >100 GeV was detected in 2.3h, consistent with the position of 3C 66A (Fig. 2). We rule out the emission to come from 3C 66B at 3.6 σ (syst. and stat. errors). The 2009/10 spectrum is softer and consistent with the

VERITAS measurements. We conclude that 3C 66A was detected in 2009/10, while 3C 66B still qualifies as a plausible source of the 2007 VHE γ-ray detection.

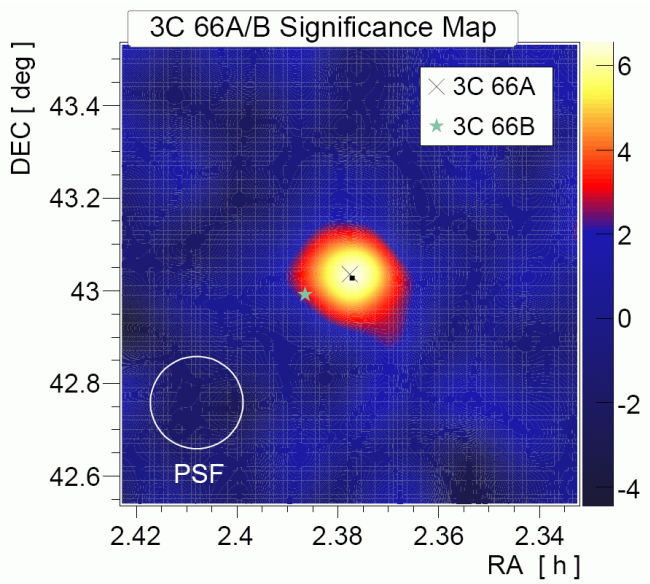

Figure 2: Sky map of the 3C 66A/B region. The source extension is consistent with a point source (the white circle in the lower left corner shows the expected extension of point source for the analysis energy threshold of 100 GeV). The fitted excess position is consistent with the blazar 3C 66A [3].

3.Observations of the Perseus cluster of galaxies

Observations were conducted in mono (2008: 25 h, 2009/10: 28 h) and stereo mode (~21 h in 2009/10). The cluster is rich in physics interests ranging from Dark Matter searches, interaction of cosmic-rays and individual sources such as the head-tail radio galaxy IC 310 [4], [5]. An initial search for γ-ray emission induced by the cosmic-rays of the cluster [6] did not succeed in the detection (see Fig. 3). 14 h of new data were taken in winter 2010, in which the central radio galaxy NGC 1275 has been detected below 400 GeV [7] at a significance of 5.2σ with a flux of 0.03 crab units (CU). The MAGIC detection happened during a period of increased γ-ray activity of NGC 1275 reported by the Fermi/LAT collaboration [8].

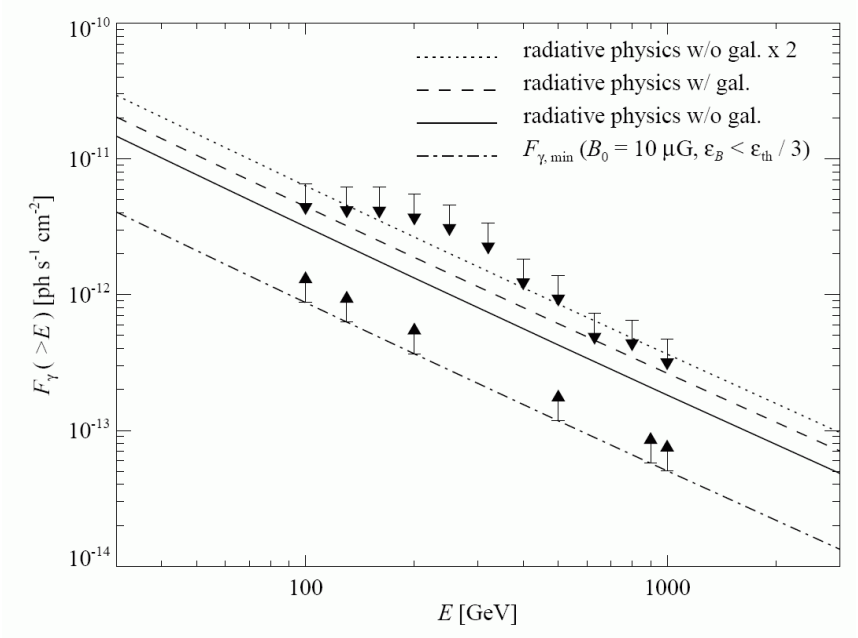

Figure 3: Comparison between MAGIC-I upper limits and model predictions depending on the cosmic-ray density in the Perseus cluster [6].

4.Markarian 421 flare on January 14th 2010

When the well known blazar Mrk 421 entered a high state (2.5 CU) in January 2010, MAGIC was able to measure its spectrum from 50 GeV until 5 TeV in just one night (~2.5h of stereoscopic data, see Fig. 4 for details). No significant variability was found during the observation. The spectrum is consistent with a power law with a cut-off.

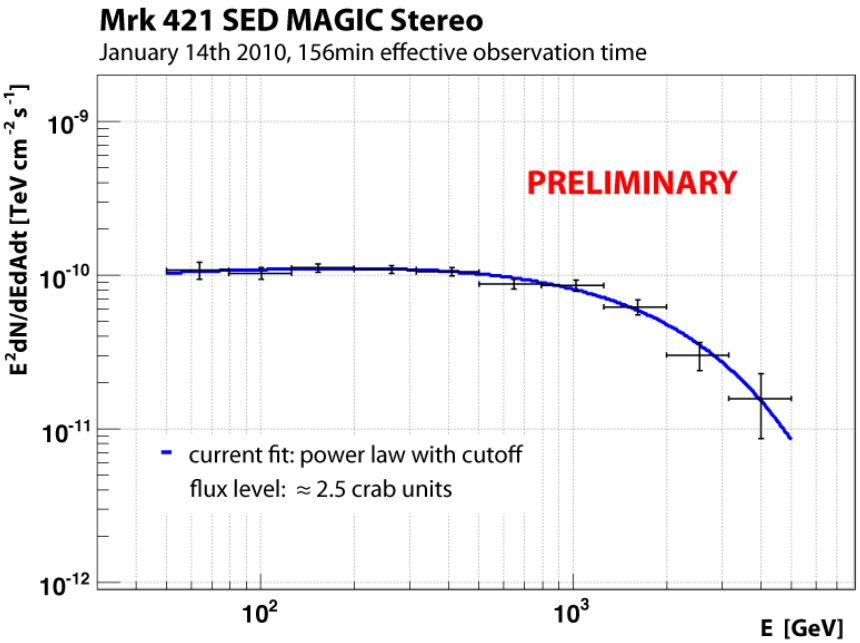

Figure 4: Spectral energy distribution during the Mrk421 flare. Observation details are given in the figure.

5.Stacked analysis of non-detected high- and intermediate-frequency peaked blazars

Between 2004 and 2009 a sample of 28 X-ray selected blazars with an X-ray flux larger than 2 μJy at 1 keV in the redshift range from 0.018 to 0.361 was observed with the MAGIC telescope at energies above 100 GeV [9]. Seven among them were detected and the results of these observations are discussed elsewhere. For the remaining 21 blazars which were not detected the individual flux upper limits lie between 1.6% and 13.6% of the integral flux from the Crab Nebula. Applying a stacking method to the sample of non-detections with a total of 394.1 hours exposure time, evidence for an excess with a cumulative significance of 4.9 standard deviations is found. It is not dominated by individual objects or flares, but increases linearly with the observation time as for a constant source with an integral flux level of ~1.5% of that observed from the Crab Nebula above 150 GeV. The differential energy spectrum is well described by a power law with index -3.16 ± 0.51 (Fig. 5). Some of the blazers have successively been discovered by H.E.S.S., MAGIC and VERITAS, which confirms them as VHE γ-ray emitters. After removing these sources from the sample an excess of 3.8 σ remains. This hints at additional sources in the sample.

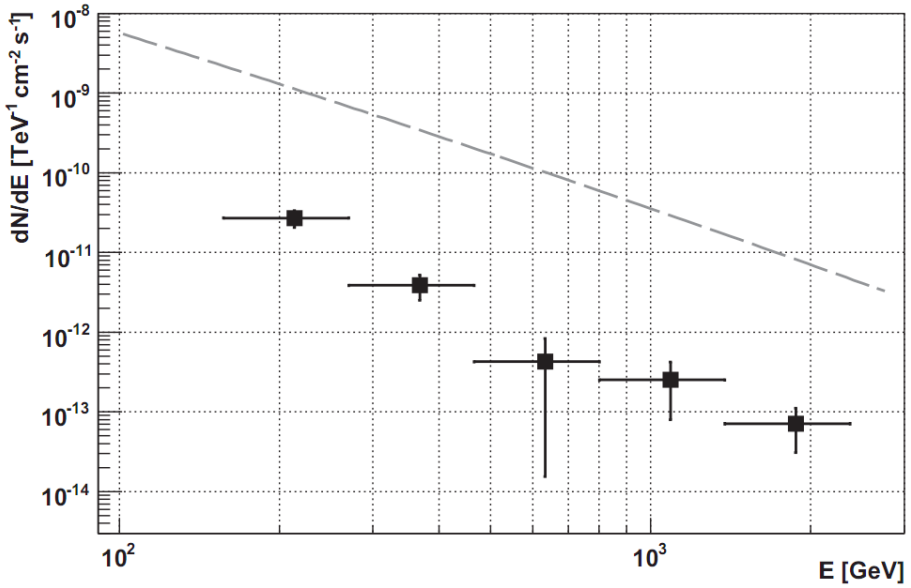

Figure 5: The spectrum of the stacked, X-ray selected blazar sample between 150 GeV and ~2 TeV is shown as filled black squares. The observed distribution is compatible with a simple power law with index -3.16 (see text). For comparison the Crab Nebula spectrum is also shown as grey dashed line.

6.Other recent observation results

In June 2010 MAGIC detected a γ-ray flare of the distant flat spectrum radio quasar PKS 1222+216 (z = 0.432), reported in a dedicated talk at this conference [10]. Two new sources were discovered during a follow up of promising Fermi-LAT source candidates: 1FGL J2001.1+4351 (see [11]) and (after an optical trigger) the high frequency peaked BL Lac B3 2247+381 (z = 0.1187, [12]) with a flux of 0.02 CU above 150 GeV. No extended emission was

found around the blazars Mrk 421 and 501 (Fig. 6), which can be used to constrain the extra-galactic magnetic field [13]. From Mrk 501, field strengths of $4.0 \times 10^{-15} < B < 1.3 \times 10^{-14}$ G are therefore strongly disfavoured.

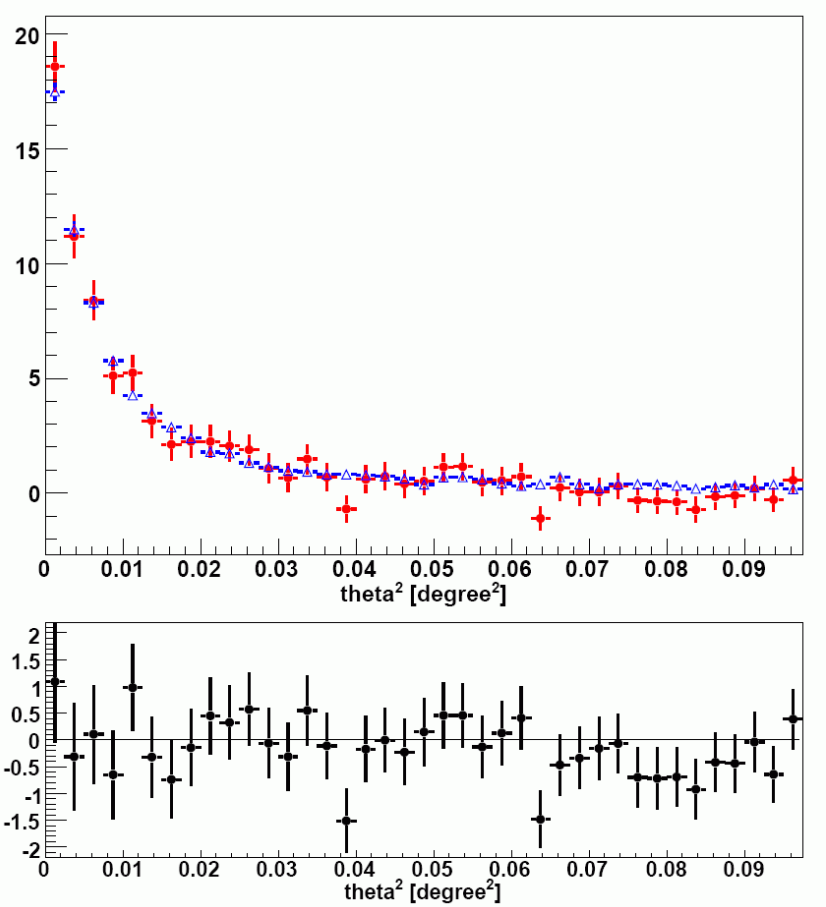

Figure 6: *Top*: Comparison between Mrk 501 MAGIC-I data (red) and a point-like excess distribution from the Crab Nebula (blue). *Bottom*: Difference between both distributions [13].

7.Conclusion

The MAGIC stereo system is working extremely well, actively extending our knowledge of the extra-galactic VHE γ-ray universe. Compared to the monoscopic observations the discovery frequency of AGNs in VHE γ-rays has significantly increased, thanks to the improved sensitivity, the high energy γ-ray catalogue provided by the Fermi satellite and optical triggers issued by the Tuorla blazar monitoring program. After a planned camera and readout upgrade during summer 2011, MAGIC will further extend its capabilities.

8.Acknowledgements

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