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The major upgrade of the MAGIC telescopes, Part II: A performance study using observations of the Crab Nebula

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ABSTRACT

MAGIC is a system of two Imaging Atmospheric Cherenkov Telescopes located in the Canary island of La Palma, Spain. During summer 2011 and 2012 it underwent a series of upgrades, involving the exchange of the MAGIC-I camera and its trigger system, as well as the upgrade of the readout system of both telescopes. We use observations of the Crab Nebula taken at low and medium zenith angles to assess the key performance parameters of the MAGIC stereo system. For low zenith angle observations, the standard trigger threshold of the MAGIC telescopes is ~ 50 GeV. The integral sensitivity for point-like sources with Crab Nebula-like spectrum above 220 GeV is $(0.66 \pm 0.03)\%$ of Crab Nebula flux in 50 h of observations. The angular resolution, defined as the σ of a 2-dimensional Gaussian distribution, at those energies is $\lesssim 0.07°$, while the energy resolution is 16%. We also re-evaluate the effect of the systematic uncertainty on the data taken with the MAGIC telescopes after the upgrade. We estimate that the systematic uncertainties can be divided in the following components: $< 15\%$ in energy scale, 11%–18% in flux normalization and ± 0.15 for the energy spectrum power-law slope.

1. Introduction

MAGIC (Major Atmospheric Gamma Imaging Cherenkov telescopes) consists of two 17 m diameter Imaging Atmospheric Cherenkov Telescopes (IACT). The telescopes are located at a height of 2200 m a.s.l. on the Roque de los Muchachos Observatory on the Canary Island of La Palma, Spain (28°N, 18°W). They are used for observations of particle showers produced in the atmosphere by very high energy (VHE, $\gtrsim 30$ GeV) γ-rays. Both telescopes are normally operated together in the so-called stereoscopic mode, in which only events seen simultaneously in both telescopes are triggered and analyzed [15].

Between summer 2011 and 2012 the telescopes went through a major upgrade, carried out in two stages. In summer 2011 the readout systems of both telescopes were upgraded. The multiplexed FADCs used before in MAGIC-I [32] as well as the Domino Ring Sampler version 2 used in MAGIC-II (DRS2, [45]) have been replaced by Domino Ring Sampler version 4 chips (DRS4, [43,40]). Besides lower noise, the switch to DRS4 based readout allowed to eliminate the $\sim 10\%$ dead time present in the previous system due to the DRS2 chip. In summer 2012 the second stage of the upgrade followed with an exchange of the camera of the MAGIC-I telescope to a uniformly pixelized one [39]. The new MAGIC-I camera is equipped with 1039 photomultipliers (PMTs), identical to the MAGIC-II telescope. Each of the camera pixels covers a field of view of 0.1°, resulting in a total field of view of $\sim 3.5°$. The upgrade of the camera allowed to increase the area of the trigger region in MAGIC-I by a factor of 1.7 to the value of $4.8°^2$. In the first part of this article [17] we described in detail the hardware improvements and the commissioning of the system. In this second part we focus on the performance of the upgraded system based on Crab Nebula observations.

The Crab Nebula is a nearby (~ 1.9 kpc away, [46]) pulsar wind nebula, and the first source detected in VHE γ rays [49]. A few years ago, the satellite γ-ray telescopes, AGILE & Fermi-LAT observed flares from the Crab Nebula at GeV energies [44,1]. However so far no confirmed variability in the VHE range was found. Therefore, since the Crab Nebula is still considered the brightest steady VHE γ-ray source, it is commonly referred to as the "standard candle" of VHE γ-ray astronomy, and it is frequently used to evaluate the performance of VHE instruments. In this paper we use Crab Nebula data to quantify the improvement in performance of the MAGIC telescopes after the aforementioned upgrade. In Section 2 we describe the different samples of Crab Nebula data used in the analysis. In Section 3 we explain the techniques and methods used for the processing of the MAGIC stereo data. In Section 4 we evaluate the performance parameters of the MAGIC telescopes after the upgrade. In Section 5 we discuss the influence of the upgrade on the systematic uncertainties of the measurements and quantify them. The final remarks and summary are gathered in Section 6.

2. Data sample

In order to evaluate the performance of the MAGIC telescopes, we use several samples of Crab Nebula data taken in different conditions between October 2013 and January 2014. Notice that, as MAGIC is located in the Northern Hemisphere, the Crab Nebula is observable only during the winter season. The data were taken in the standard L1–L3 trigger condition (see [17]). The data selection was mostly based on zenith angle dependent rate of background events surviving the stereo reconstruction. Other measurements: LIDAR information, observation logbook, daily check of weather and hardware status [30] are also used as auxiliary information. All data have been taken in the so-called wobble mode [29], i.e. with the source position offset by a fixed angle, ξ, from the camera center in a given direction. This method allows to estimate the background from other positions in the sky at the same offset ξ. Most of the results are obtained using the data taken at low zenith