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Simulation studies of MACE-I: Trigger rates and energy thresholds

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ABSTRACT

The MACE (Major Atmospheric Cherenkov Experiment) is an upcoming Very High Energy (VHE) γ-ray telescope, based on imaging atmospheric Cherenkov technique, being installed at Hanle, a high altitude astronomical site in Ladakh, India. Here we present Monte Carlo simulation studies of trigger rates and threshold energies of MACE in the zenith angle range of 0°–60° for on-axis γ-ray coming from point source and various cosmic ray species. We have simulated the telescope's response to γ-rays, proton, electron and alpha initiated atmospheric Extensive Air Showers (EAS) in the broad energy range of 5 GeV to 20 TeV. For γ-rays we consider power law and log parabolic spectra while other particles are simulated with their respective cosmic ray spectrum. Trigger rates and threshold energies are estimated for the trigger configuration of 4 Close Cluster Nearest Neighbour(CCNN) pixels as implemented in MACE hardware, in combination with single channel discriminator threshold ranging from 6–10 photo electrons (pe). We find that MACE can achieve the γ-ray trigger energy threshold of $\sim$ 17 GeV (4 CCNN, 9 pe) at 0° zenith angle for power law spectrum. The total trigger rate at 0° zenith is expected to be $\sim$650 Hz, with protons contributing $\sim$ 80% to it. For the zenith range of 0°-40° we find that the telescope can achieve γ-ray trigger threshold energies of $\sim$22 GeV at 20° zenith angle and $\sim$40 GeV at 40° zenith angle. Integral rates are also almost constant for this zenith angle range. At zenith angle of 60°, trigger energy threshold increases to $\sim$173 GeV and total integral rate falls down to $\sim$305 Hz.

1. Introduction

The successful journey of VHE γ-ray astronomy started with the discovery of Tera-electronVolt (TeV) γ-ray photons from Crab nebula by the Whipple observatory using Imaging Atmospheric Cherenkov Telescope (IACT) [1] . It gave astronomers a new tool to observe the universe through the VHE γ-ray window. The Whipple 10 m telescope went on to discover the first extra galactic TeV source, Markarian 421, which is an Active Galactic Nucleus (AGN) [2]. CAT and CANGAROO established the reliability of this new technique by reproducing VHE observations from Crab, Markarian 421 and Markarian 501 [3,4]. In India, efforts were made to detect VHE γ-rays during early eighties by setting up Ooty, Gulmarg and Panchmarhi telescopes. In mid 90s the TACTIC (TeV Atmospheric Cherenkov Telescope with Imaging Camera) telescope, based on imaging atmospheric Cherenkov technique was installed at Mt. Abu, Rajasthan [5]. Presently TACTIC is used to monitor AGNs.

The next major breakthrough in the ground based γ-ray astronomy came when the HEGRA collaboration, by using an array of small IACTs, was able to achieve not only a low energy threshold of 500 GeV but also an angular resolution of 0.1° [6]. HESS, VERITAS and MAGIC telescopes extended an IACT observable energy window from 100 GeV to 10 TeV [7–9] By using large reflector stereoscopic IACTs. Their sensitivities and angular resolutions in this energy band have made an IACT array, the most powerful system for VHE γ-ray observations. The number of sources discovered in 100 GeV to 10 TeV band now exceeds 150.[1]

The TeV catalogue now contains a variety of galactic sources like pulsars, binaries, SNRs, PWNe and extra galactic sources like blazars, radio galaxies, starburst galaxies etc. However this catalogue is dominated by blazars and PWNe. Larger samples of VHE observations are required for reliable understanding of VHE emissions from sources of other categories. The *Fermi*/LAT telescope, aboard *Fermi* satellite, has discovered $\sim$3000 sources in the 100 MeV–10 GeV energy range. Most of these sources exhibit power

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[1] http://tevcat.uchicago.edu/.

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law spectra and their expected VHE flux is very low (see 3FGL[2]). Although LAT has detection capability up to 500 GeV, sensitivity beyond 10 GeV is not sufficient to detect weak GeV/TeV γ-ray flux [10] from the observed MeV sources. The first Fermi catalogue of > 10 GeV sources (1FHL[3]) has only 514 sources and there is a strong possibility to detect more sources with IACTs because of their better sensitivity in the 10 s of GeV energy range. As per the recently published second Fermi/LAT γ-ray pulsar catalogue [11], 117 γ-ray pulsars have been detected. The observed spectra in Fermi/LAT energy range for all these pulsars exhibit spectral cut-off around few GeVs. But the detection of pulsed γ-rays up to 400 GeV from Crab pulsar and pulsed γ emission above 50 GeV from Vela pulsar indicate the presence of a separate component at GeV–TeV energies [12,13]. So many more pulsars can be expected to have such GeV–TeV emission and hence IACTs with energy threshold less than 50 GeV are very useful in pulsar studies. Rapid variability on the time scales of few minutes has been observed in γ-ray emission from BL Lac and FSRQ objects [14,15] by IACTs. However the number of such observations is low. For better understanding of such phenomena more observations are required with detailed temporal and spectral studies. This requires better flux sensitivity and low energy threshold telescopes.

Hence, in view of this requirement of "low energy threshold high sensitivity IACT", a new imaging telescope MACE with reflector of diameter 21 m is being installed, at an altitude of 4270 m, at Hanle, India. As will be shown in the following sections, MACE is expected to have trigger threshold energy as low as $\sim$ 20 GeV.

In this paper we present results of Monte Carlo simulation studies of trigger rates and energy thresholds for MACE. We organise this paper in the following manner. In Section 2, we give brief description of the Hanle site and MACE telescope including the details of its camera electronics. The details of air shower and detector simulations will be described in Section 3, whereas estimation of Night sky background (NSB), calculation of Single Channel Rate (SCR) and Chance Coincidence Rate (CCR) are discussed in Section 4. The calculation of the effective collection area, trigger rate and energy threshold are shown in Section 5. Main results for different zenith angles are given in Sections 6 and 7, while the conclusions are presented in Section 8. The analysis, sensitivity and expected performance of MACE telescope is being studied and will be reported in the second paper.

2. MACE telescope

The MACE is, a large-size imaging atmospheric Cherenkov telescope, presently being installed at Hanle in the Ladakh region of North India.

2.1. Site

The MACE is being built with a prime target of achieving low energy threshold. At any energy, the efficient detection of γ ray event using IACT has 2 basic requirements (i) sufficient number of photoelectrons in all the recorded events, for reliable parameterisation of an image (ii) accidental trigger rate due to NSB should be limited to < 5% of cosmic ray rate. For a given energy event, number of photoelectrons collected in an event depends on the light collector area and altitude of the telescope. The lateral distributions of Cherenkov photon density for γ ray of energy 10 GeV, for 2 altitudes of Mount Abu and Hanle are shown in Fig. 1. One can see from the figure that the Cherenkov photon density (up to core distance of $\sim$100 m) of $\sim$0.5 photons m^{-2}, observed

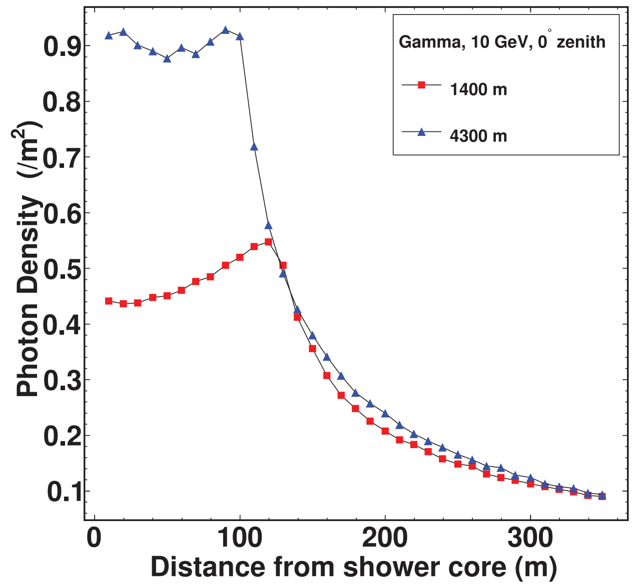

Fig. 1. Lateral distributions of Cherenkov photon density for γ ray showers of energy 10 GeV, for 0° zenith, at altitude of 1400 m and 4300 m.

at Mount Abu where TACTIC telescope is currently operating, increases to $\sim$0.9 photons m^{-2} at Hanle. Such increase in Cherenkov photon density due to EAS with increasing altitude lowers energy threshold of an IACT for a given telescope configuration. Installing an IACT at higher altitude has the added advantage that the density of Cherenkov photons for γ-ray shower increases significantly with altitude when compared to increase in the Cherenkov photon density of hadronic showers. In addition, at energies below 200 GeV, there is a dramatic decrease in the amount of Cherenkov light produced in cosmic ray showers. This leads to large difference in the Cherenkov photon density of γ-ray and cosmic ray showers at energies below 200 GeV [16] and hence higher threshold energies for cosmic rays. Advantage of installing an IACT at high altitude has also been discussed in [17] and results presented there indicate that stereoscopic array of 20 m diameter IACTs, installed at an altitude of $\sim$5 km can achieve a γ ray threshold energy of 5 GeV. Experimental data collected with HAGAR (High Altitude GAmma Ray) telescope installed at Hanle also shows a reduction in γ ray energy threshold by a factor of $\sim$4 when compared to the energy threshold of $\sim$700–800 GeV for the PACT (Panchmarhi Array of Cherenkov Telescopes) installed at an altitude of $\sim$1075 m [18].

Keeping in view these advantages of high altitude, we have chosen Hanle site for the MACE telescope. Hanle is known to be a very good astronomical site and the 2 m optical Himalayan Chandra Telescope (HCT) is already operating at this site. The exact coordinates of the site are 32°46′46″ N, 78°58′35″ E. From the world map shown in Fig. 2, it is evident that MACE telescope fills up the longitudinal gap between different major IACTs operating worldwide and hence, along with other IACTs, it will be very useful for exploring the VHE γ-ray sky, in particular for continuous monitoring campaigns of flaring sources. The altitude of this site is 4270 m and that makes it the highest altitude IACT in the world. Important site characteristics are noted in Table 1.

2.2. Telescope details

The MACE telescope will deploy a tracking light collector of 21 m diameter and 25 m focal length. The light collector will be made up of 356 mirror panels of 984 mm × 984 mm size fixed at a square pitch of 1008 mm on a paraboloid shape basket made

[2] http://www.asdc.asi.it/fermi3fgl/.
[3] http://fermi.gsfc.nasa.gov/ssc/data/access/lat/1FHL/.