

An overview of the MACE Telescope

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The Major Atmospheric Cherenkov Experiment (MACE), located at Hanle, Ladakh, India (32.8°N, 78.9°E; 4270 m a.s.l.), was commissioned [1] by Bhabha Atomic Research Centre to detect very high energy (VHE) gamma-rays from astrophysical sources, such as active galactic nuclei, pulsars, and gamma-ray bursts. Its primary goal is to probe the mechanisms of particle acceleration in extreme astrophysical environments, and to search for signatures of new physics such as dark matter annihilation and axion-like particles. MACE employs a 21 m diameter quasi-parabolic light collector with a 25 m focal length, composed of 356 panels, each containing four 488 mm × 488 mm spherical aluminum facets with SiO₂ coating. Active mirror control system equipped with actuators ensures proper mirror panel alignment. The camera at the focal plane consists of 1088 photomultiplier tubes (PMTs), organized into 68 Camera Integrated Modules (CIMs), each with 16 channels. The central 36 CIMs define the trigger region, covering a field of view of $\sim 2.6^\circ \times 3.0^\circ$, while the full optical field of view extends to $\sim 4.3^\circ \times 4.0^\circ$. The event trigger is generated through two level system, where a first level trigger checks the coincidence of threshold crossing pulses within a CIM. The second level trigger detects the events which are spread over pixels in two or more neighboring CIMs. Further, the PMT pulses are amplified in low and high gain channels and digitized using a DRS4 chip operating at 1 GSPS.

The performance of the telescope was evaluated using 15 h of Crab Nebula and 12 h of OFF-source observations acquired between November 2022 and February 2023 [2]. The analysis was conducted using the in-house developed MACE Analysis Package (MAP). Good agreement was found between Monte Carlo simulations and the data in terms of event rates and Hillas image parameters. The energy threshold is estimated to be ~ 80 GeV, with energy resolution improving from $\sim 34\%$ at threshold to $\sim 21\%$ above 1 TeV. The PSF improves from 0.20° to 0.08° across this energy range. The differential spectrum of Crab nebula between 80 GeV and 5 TeV is well fitted by a log-parabolic model and is consistent with results from other telescopes (Fig 1). The integral flux sensitivity is estimated to be $\sim 9.6\%$ of the Crab Unit above 80 GeV for 50 h of observation. Further improvements, particularly by incorporating the photon arrival time information and new image cleaning method [3], are underway to enhance the sensitivity at lower energies.

Since commissioning, MACE has demonstrated stable technical performance. It has detected VHE gamma-ray emission from nearby blazars Mrk 421, Mrk 501, and 1ES 1959+650. MACE observations of Mrk 501 from June 27 to July 23, 2022, together with near-simultaneous observations of MAGIC, captured an extended flaring activity from the blazar. The low-state spectral energy distribution (SED) was modeled using a one-zone Synchrotron Self Compton (SSC) framework, whereas neither one-zone nor two-zone SSC models adequately reproduced the high-state emission. Observations of 1ES 1959+650 commenced on June 14, 2023, following an optical alert (ATel 16083) from the 0.5 m CDK-astrograph in Hettstadt, Germany. Preliminary analysis of data from June 14–22 revealed a >5 sigma signal on June 17. A Swift-XRT alert (ATel 16087) also reported a strong X-ray flare on June 16. MACE has also detected an enhanced gamma-ray activity from Markarian 421, on March 16, 2024, with an integral flux of 70% of the Crab Nebula.

MACE detected two distinct VHE flares from NGC 1275 on December 21, 2022, and January 10, 2024 [4]. The SEDs were modeled using SSC framework, indicating similar physical conditions during both flares with a slight shift in the electron energy distribution. Constraints on optical depth during MACE observations suggest a maximum jet viewing angle of $\sim 30^\circ$ (See Fig. 2). Subsequently, MACE detected another enhanced activity of NGC 1275 on January 25, 2025 with a statistical significance of 5.2 sigma, during its regular monitoring program of the source from December 2024 to February 2025 (Atel 17020). In January 2025, MACE detected a VHE gamma-ray flare from the flat-spectrum radio quasar (FSRQ) OP 313 (Atel 17003), the most distant blazar detected in the VHE regime to date. As one of only ten FSRQs detected at VHE energies, and considering its high redshift ($z=0.997$), this observation is important for studies of external Compton processes and for constraining the extragalactic background light. Furthermore, based on MACE observations of six high-redshift ($z>0.3$) blazars, 99% confidence level upper limits on their integral flux above 80 GeV were derived [5].

In this talk, an overview of the MACE telescope, including technical features, scientific results, and future observational programs will be presented.

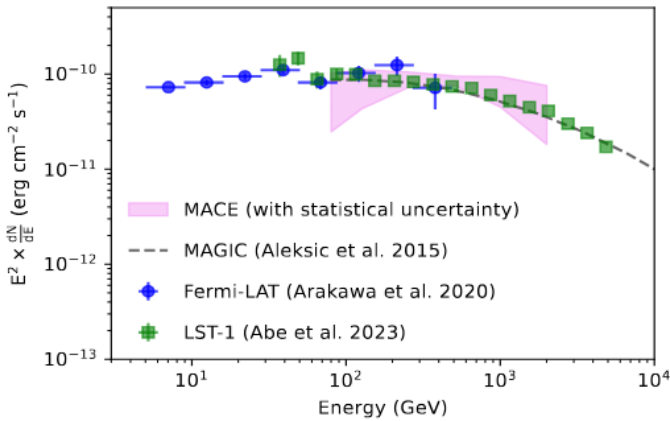


Fig 1: The Spectral energy distribution of the Crab Nebula obtained by MACE (pink shaded) and its comparison with that obtained by other experiments.

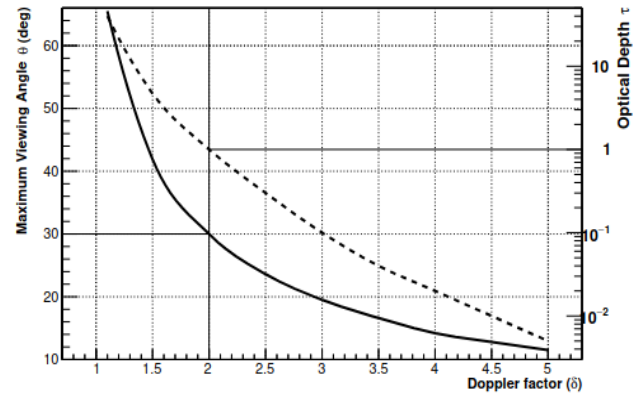


Fig 2: The maximum viewing angle (solid line) and optical depth (dotted line) for different Doppler factor values of NGC 1275. The black thin lines mark optical depth of 1 at a jet viewing angle of 30 degree.

References:

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3. M. Khurana et al., Galaxies, 13(1), 14 (2025)
4. S. Godambe et al., Astrophysics Journal Letters, 974, 31 (2024)
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