Cross-calibration and combined analysis of the CTA-LST prototype and the MAGIC telescopes

Y. Ohtani[1], A. Berti[2,3], D. Depaoli[3], F. Di Pierro[3], D. Green[2], L. Heckmann[2], M. Hütten[2], T. Inada[1], R. López-Coto[4], E. Medina[3], A. Moralejo[5], D. Morcuende[6], G. Pirola[3], M. Strzys[1], Y. Suda[7] and I. Vovk[1] for the CTA LST project and MAGIC Collaboration

[1]ICRR, the University of Tokyo, Japan, [2]Max Planck Institute for Physics, Germany, [3]INFN Sezione di Torino, Italy, [4]INFN Sezione di Padova, Italy, [5]IFAE, Campus UAB, Spain, [6]Universidad Complutense de Madrid, Spain, [7]Hiroshima University, Japan

ABSTRACT

The prototype Large Size Telescope (LST-1) proposed for Cherenkov Telescope Array (CTA) was inaugurated in October 2018 in the northern hemisphere site of CTA, La Palma (Spain). MAGIC is a system of two Cherenkov telescopes of the current generation, located approximately 100 m away from LST-1. Since LST-1 and MAGIC can observe the same air shower events, we can cross-calibrate both telescope systems and ultimately improve the sensitivity by performing the combined analysis. We present the first detection of an astronomical source, the Crab Nebula, with combined observation of LST-1 and MAGIC.

Supported by:

1. Introduction

CTA will be the next generation gamma-ray observatory. LST-1 proposed for CTA was inaugurated in the northern site, La Palma, and is in its commissioning phase. Since LST-1 and MAGIC are located ∼100 m apart and can observe the same air shower events, it is possible to cross-calibrate the telescopes by comparing the estimated energy of gamma rays event by event. Also, by performing combined analyses, we can reconstruct the shower geometry more accurately, leading to better energy and angular resolutions, and a better discrimination of cosmic-ray background events. Thus, as a part of the commissioning of LST-1, we performed joint observations with LST-1 and MAGIC. Also, we have developed Monte Carlo (MC) simulations and a pipeline for the analysis of such joint observation data. In this work, we present the analysis technique and the results of the cross-calibration and combined analysis of the Crab Nebula data.

2. Event coincidence with timestamps

Since LST-1 and MAGIC trigger and readout systems are independent, the events triggering both systems need to be matched in the offline analysis. We have developed an algorithm to find the coincident events based on their individual timestamps. In this algorithm, the coincidence window is defined by the LST-1 events, and the MAGIC-stereo events falling within the window are recognized as coincident events. We also introduce a time offset to LST-1 events, which compensates for the systematic difference of the timestamps between the telescope systems. An example of search for coincident events is shown in Fig. 1, where a result of a scan over time offsets is shown.

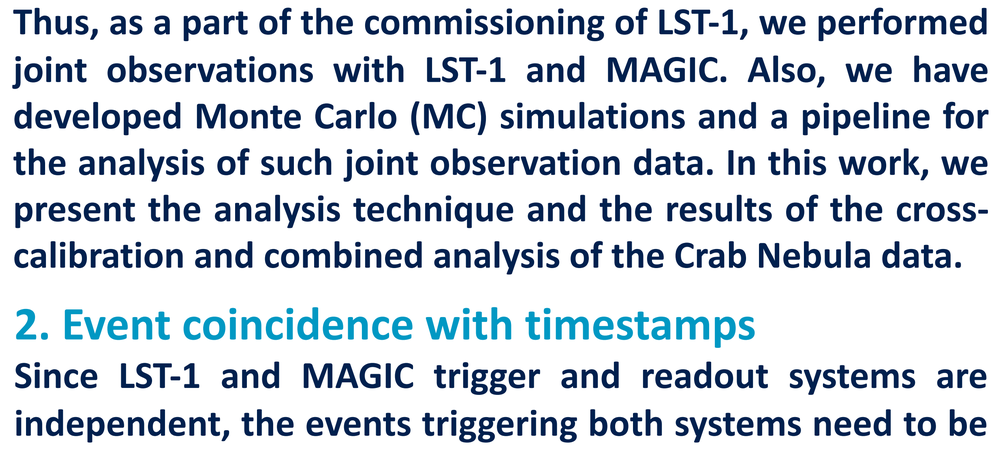

Fig. 1: Example of searching for the coincidence with timestamps

3. Inter-telescope cross-calibration

We use Crab Nebula data taken on 17th January 2020 with exposure of 1.5 hours at low zenith angles from 7 to 20 degrees. The data are at first analyzed independently in each telescope system with corresponding analysis pipelines. Then, the coincident events are searched by the developed algorithm and MAGIC standard analysis cuts are applied to extract gamma-candidate events. Finally, in total 1360 gamma-candidates are extracted. The expected contamination in the selected samples from background cosmic-ray events is ∼20%. The comparison of the estimated energy is shown in Fig. 2. The energy is well correlated, and the mean discrepancy is estimated to be $5\% \pm 1\%$. Considering the systematic uncertainty of the MAGIC energy scale, this result indicates that the accuracy of the LST-1 energy estimation is comparable to that of the MAGIC estimation.

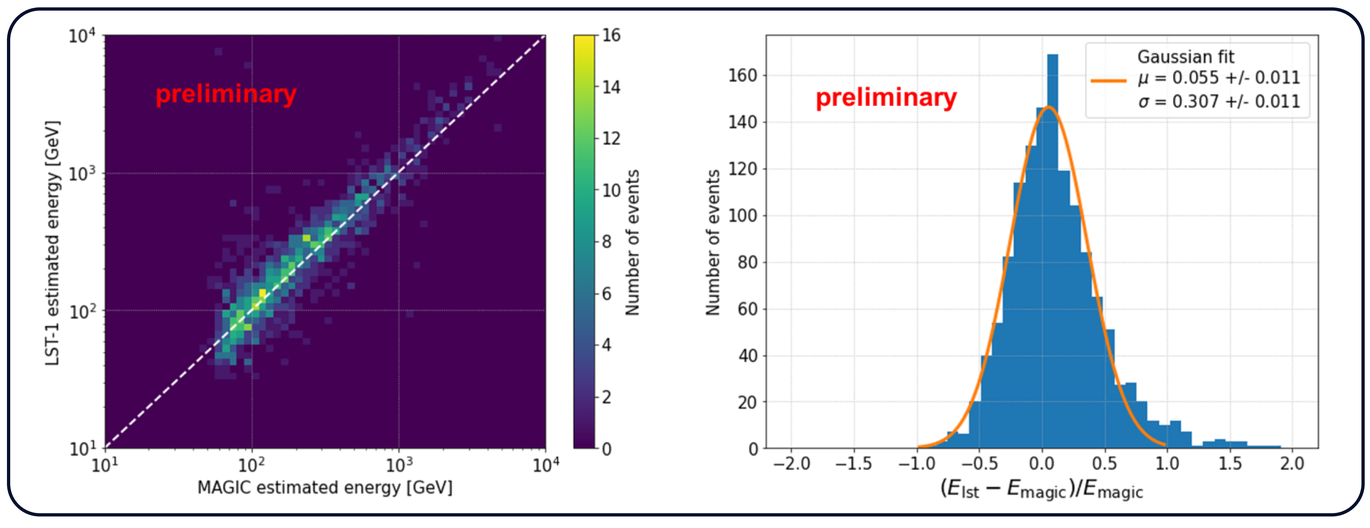

Fig. 2: Comparison of the estimated energy of the gamma-candidate events. Left panel shows the event-wise comparison, and right panel shows relative difference distribution

4. Combined analysis of Crab Nebula data

We have developed a pipeline dedicated to perform the combined analysis of LST-1 and MAGIC events. It reconstructs the geometrical shower parameters using the three shower images obtained by LST-1, MAGIC-I and MAGIC-II. The combined analysis improves the accuracy of the reconstruction of the geometrical parameters compared to that using only the two MAGIC telescopes.

We present the preliminary results of the combined analysis of Crab Nebula data, taken on 18th November 2020 at middle zenith angles from 35 to 45 degrees. The gamma-ray signal from the Crab Nebula after the background suppression is shown in Fig. 3. It shows that the Crab Nebula is detected with the statistical significance of 18.1σ with the observation time of 36.6 minutes. We also estimated the energy threshold to be ∼185 GeV from the MC simulation.

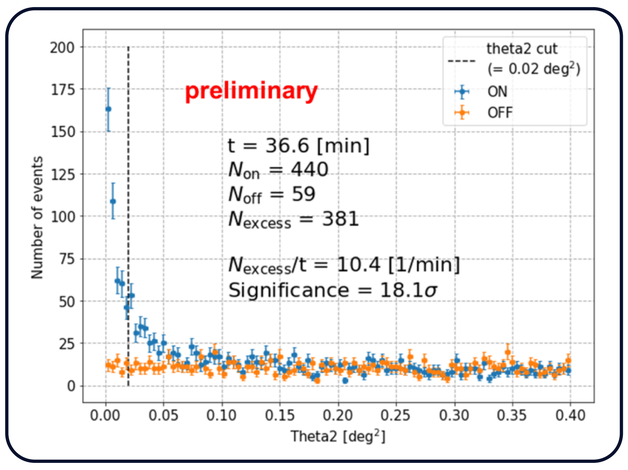

Fig. 3: Angular distribution from the Crab Nebula and an off position

ACKNOWLEDGEMENTS

We gratefully acknowledge financial support from the agencies and organizations listed here: (CTA) www.cta-observatory.org/consortium_acknowledgments (MAGIC) https://magic.mpp.mpg.de/acknowledgments_ICRC2021