LST-1 telescope performance and preliminary data analysis

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cherenkov telescope array

ABSTRACT

Large Size Telescope (LST) is the biggest of the three main telescope types of CTA. Having the largest reflector of 23 m diameter, the LSTs will lower the energy threshold of the whole observatory down to about 20 GeV and will be crucial for the CTA sensitivity up to about 200 GeV. As the first telescope for CTA, a fully equipped LST-1 was installed and inaugurated at the CTA-N site in La Palma in October 2018.

We present a mono-performance estimation of the LST-1 prototype together with a preliminary analysis of the data from the first Crab observation campaign conducted during the author's stay at Institut de Fisica d'Altes Energies (IFAE) of Universitat Autònoma de Barcelona at the end of 2019 in the cooperation with members of the LST Consortium.

The LST-1 telescope

LST-1 telescope located at La Palma (Fig. 1) is mounted on an alt-azimuthal mount, its parabolic mirror (23 m in diameter) consists of 198 hexagonal facets (1.51 m flat to flat) and its focal length is 28 m. The camera for LST has 1855 PMTs, grouped in 265 modules with seven pixel units each [1].

Figure 1: The LST-1 telescope

Shower reconstruction

For the data reconstruction and reduction, cta-lstchain [2] is being developed. At the time of our analysis the full reconstruction chain had not yet been fully implemented and thus the presented analysis is based on a custom reconstruction code. For arrival direction and energy reconstruction, Random Forest (RF) algorithm from scikit-learn Python library [3] was applied on CORSIKA [4] + sim_telarray [5] Monte Carlo simulations of point and diffuse gammas and diffuse proton background pre-processed up to Hillas parameters [6]. The mono performance was evaluated for different analysis cuts on intensity, leakage, number of islands (listed in brackets in figures below in the same order), and the impact of the shower timing on the performance was assessed. The parameters of RF were grid searched and the stability of each model was 5-fold cross-validated.

The energy resolution which can be reached in mono reconstruction for optimal parameters of Random Forest is 15% above 1 TeV (Fig. 2) with energy bias better than 10% between 80 GeV and 30 TeV. In case of arrival direction reconstruction the perpendicular distances of the true source position from the shower centroid were reconstructed resulting in 68% containment of the point-spread function better than 0.2 deg in the core energy range (see Fig. 3).

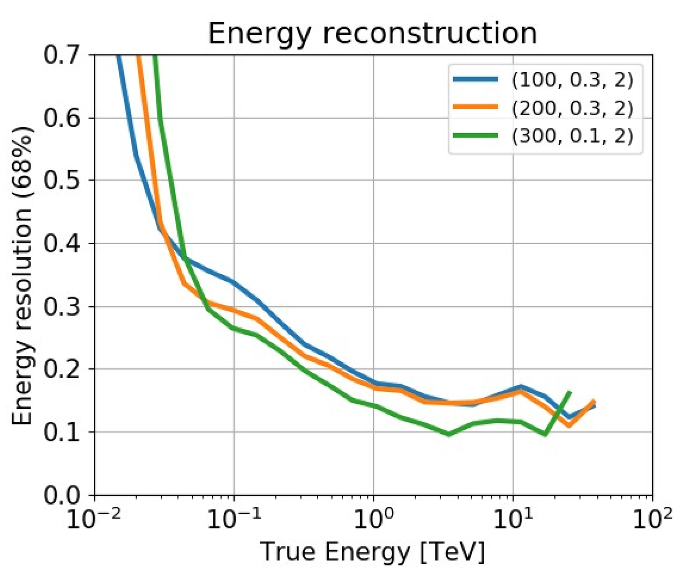

Figure 2: Energy resolution of LST-1 in mono regime for 20 deg zenith angle.

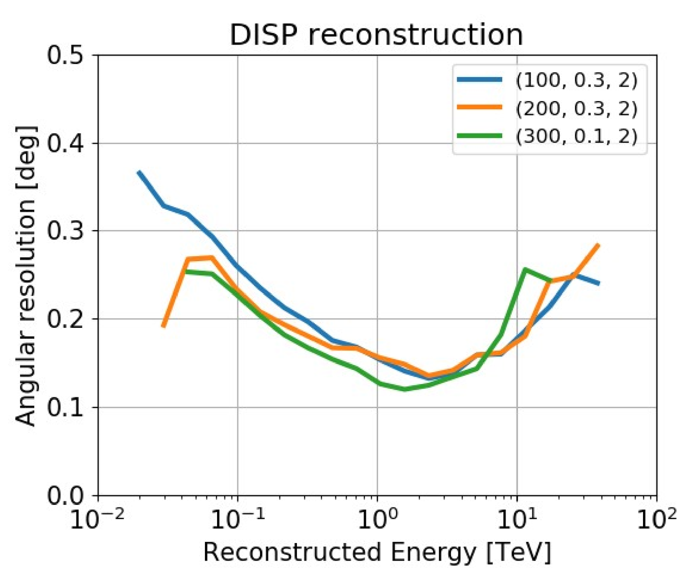

Figure 3: Angular resolution of LST-1 in mono regime for 20 deg zenith angle.

Gamma/hadron separation and sensitivity

In typical IACT observations, the trigger rate from diffuse cosmic-rays background is about 1000× or more higher than the trigger rate from gamma ray photons and therefore a strong background suppression is necessary. In this analysis, we used Random Forrest classifier from scikit-learn Python library [2], trained on diffuse protons and gammas. Optimal separation gives the Area Under Receiver Operating Characteristic (ROC) curve AUC = 0.88 for medium cuts. ROC AUC as a function of the reconstructed energy is shown in Figure 4.

The reconstruction pipeline was applied on all simulated point gammas and diffuse protons, and the reconstructed events were then used to evaluate differential sensitivity of the LST-1 shown in Figure 5. The energy dependent cuts on event 'gammaness' and the signal region radius were optimized to reach the best possible sensitivity and these cuts were used in the real data analysis.

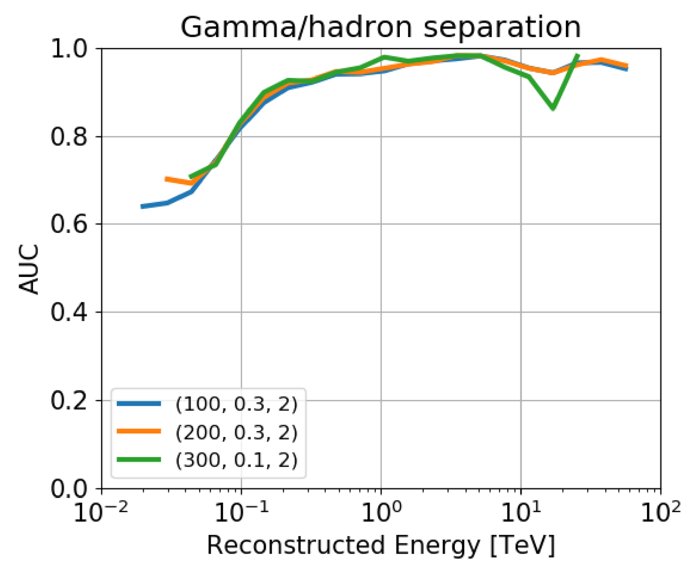

Figure 4: Area under ROC curve as a function of reconstructed energy for all quality cuts.

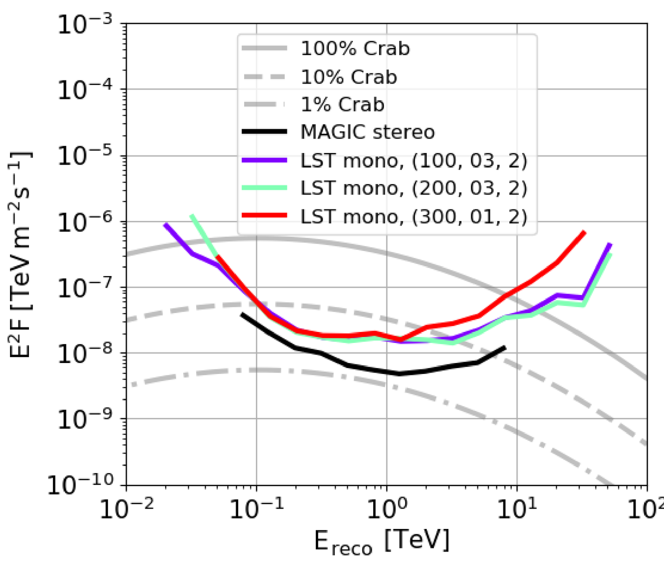

Figure 5: Differential sensitivity of the LST-1 in mono regime compared for three sets of quality cuts.

Crab observation campaign

We present a preliminary analysis of the first scientific data from the LST-1 prototype keeping in mind several caveats, natural for the commissioning phase of the telescope. 269/154 mins of ON/OFF observation were taken on zenith angles between 7 and 40 deg. The event timestamps were not available at the time of the first Crab campaign and therefore the aim of the first analysis is only to detect the source and to evaluate the detection significance. For that purpose, all runs were merged to get a single data set. Data were processed using our pipeline and the optimal selection cuts were applied. In Figure 6, the θ^2 distribution is shown with the normalized rate of the OFF events. The excess in the ON data is clearly visible and the significance of source detection for the full 269 minutes interval of observation is $\sigma_{Li\&Ma} = 30.4$. In Figure 7, there is shown a reconstructed 2D significance map of the vicinity of the Crab Nebula (located at the origin (0, 0) of coordinates) in the camera frame.

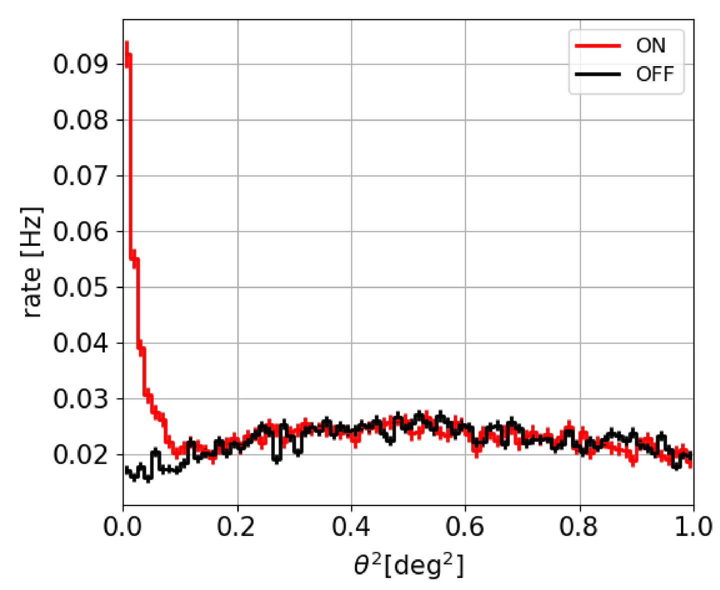

Figure 6: θ^2 distribution of ON and OFF events for the complete Crab data set from the first observation campaign.

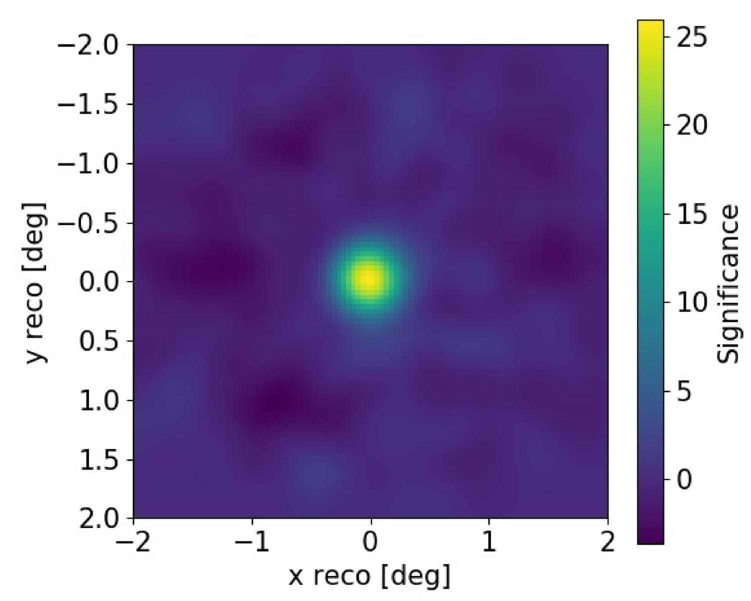

Figure 7: 2D significance map of the sky in the vicinity of the Crab Nebula.

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