Deep-learning-driven event reconstruction applied to simulated data from a single Large-Sized Telescope of CTA

cherenkov telescope array

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ABSTRACT The dominant background for Imaging Atmospheric Cherenkov Telescopes (IACTs) is comprised of air shower images produced by cosmic hadrons, with typical noise-to-signal ratios of several orders of magnitude. The standard technique adopted to differentiate between images initiated by gamma rays and those initiated by hadrons is based on classical machine learning algorithms, such as Random Forests, that operate on a set of handcrafted parameters extracted from the images. Likewise, the inference of the energy and the arrival direction of the primary gamma ray is performed using those parameters. State-of-the-art deep learning techniques based on convolutional neural networks (CNNs) have the potential to enhance the event reconstruction performance, since they are able to autonomously extract features from raw images, exploiting the pixel-wise information washed out during the parametrization process. Here we present the results obtained by applying deep learning techniques to the reconstruction of MC simulated events from a single, next-generation IACT, the Large-Sized Telescope (LST) of the Cherenkov Telescope Array (CTA). We use CNNs to separate the gamma-ray-induced events from hadronic events and to reconstruct the properties of the former, comparing their performance to the standard reconstruction technique. Three independent implementations of CNN-based event reconstruction models have been utilized in this work, producing consistent results.

Introduction

The Large-Sized Telescope (LST) is a new generation IACT of CTA, designed to reach the lowest achievable energy thresholds down to tens of GeV. In this contribution we present the results obtained applying convolutional neural networks (CNNs) to the reconstruction of full simulated events as recorded from a single LST, comparing the outcome to the standard analysis technique.

Classical event reconstruction for LST

The full event reconstruction consists of:

1. **Separate gamma-ray** initiated shower images from hadronic ones
2. Reconstruct **energy** of gamma rays
3. Reconstruct **arrival direction** of gamma rays

Usually, the images are cleaned and sets of parameters containing relevant information are extracted; using these parameters, the Random Forest (RF) technique accomplishes the task.

A new approach: CNNs

Cleaning and parametrization introduce loss of information. This analysis could be then improved skipping these steps and using CNNs, in order to exploit the maximum information contained in all the pixels but not in the parameters.

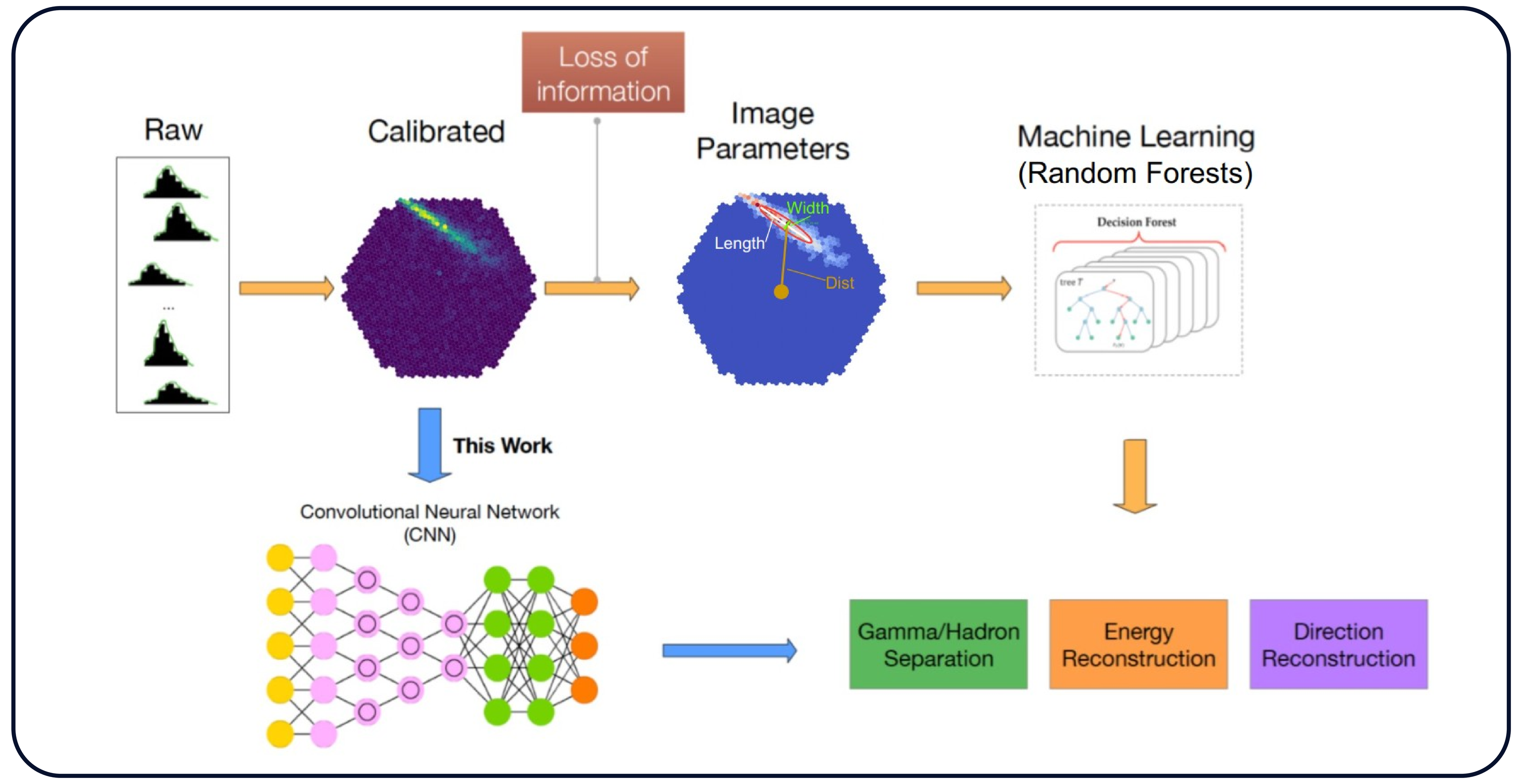

Fig. 1: classical event reconstruction compared to the CNN-based approach

Setup

Three independent CNN-based solutions have been implemented: (i) **PdVGG**, with single-task approach (one-network-per-task) based on the VGG architecture, (ii) **CTLearn-TRN**, a single-task architecture based on ResNets, (iii) **γ-PhysNet DA,** a multi-task architecture (one-network-for-all) also based on ResNets. Each experiment has been conducted 10 times to assess stability of the method.

The dataset comprises *full simulated images* of protons, gamma rays and electrons. *Diffuse* gamma rays have been used for training, *pointlike* gamma rays for test. Three different image selection cuts were used, based on image intensity: *low-cuts* (images containing more than 50 photoelectrons), *mid-cuts* (200) and *high-cuts* (1000).

Results

Instrument Response Functions (IRFs) have been computed with optimizations for the best sensitivity. Despite some small difference, the three CNNs lead to very similar results. Comparing to the RFs, a better **sensitivity** is reached at energies below 1 TeV and above 3 TeV, while the performance is worse in the 1-3 TeV window.

Concerning the **effective collection area** and **energy resolution**, slightly better performances are achieved below 200 GeV and around 700 GeV, while the curves show the same trend at higher energies. CNNs clearly perform better in the **angular resolution**, where the RFs are overtaken up to more than 40% for energies below 200 GeV - which is the target energy range of the LST.

Although results are obtained on simulations and RFs have been recently optimized to reach better performances, CNNs demonstrate to be an effective and reliable tool for LST event reconstruction to be further investigated.

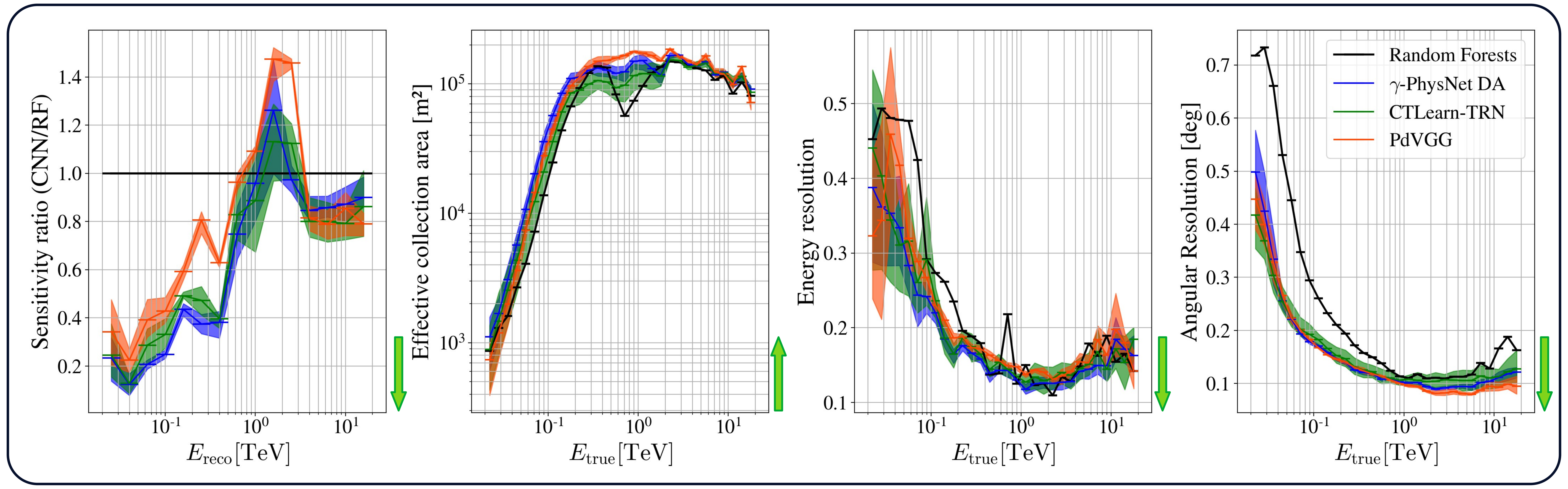

Fig. 2: Comparison between IRFs obtained with CNNs and RFs using *low-cuts*. Green arrows indicate whether higher or lower is better. Error bands are the 16th and 84th percentiles around the median of ten curves obtained training the CNNs ten times.

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REFERENCES

See proceeding #771 at this conference for more details: https://pos.sissa.it/395/771/

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