Prototype Open Event Reconstruction Pipeline for the Cherenkov Telescope Array

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Abstract

The Cherenkov Telescope Array (CTA) is the next-generation gamma-ray observatory currently under construction. It will improve over the current generation of imaging atmospheric Cherenkov telescopes (IACTs) by a factor of five to ten in sensitivity and it will be able to observe the whole sky from a combination of two sites: a northern site in La Palma, Spain, and a southern one in Paranal, Chile. CTA will also be the first open gamma-ray observatory. Accordingly, the data analysis pipeline is developed as open-source software. The event reconstruction pipeline accepts raw data of the telescopes and processes it to produce suitable input for the higher-level science tools. Its primary tasks include reconstructing the physical properties of each recorded shower and providing the corresponding instrument response functions. `ctapipe` is a framework providing algorithms and tools to facilitate raw data calibration, image extraction, image parameterization and event reconstruction. Its main focus is currently the analysis of simulated data but it has also been successfully applied for the analysis of data obtained with the first CTA prototype telescopes, such as the Large-Sized Telescope 1 (LST-1). `pyirf` is a library to calculate IACT instrument response functions, needed to obtain physics results like spectra and light curves, from the reconstructed event lists. Building on these two, `protopipe` is a prototype for the event reconstruction pipeline for CTA. Recent developments in these software packages will be presented.

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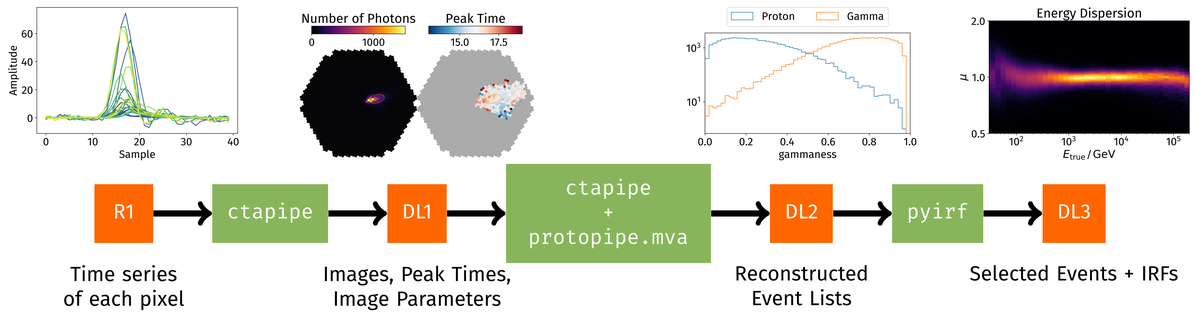
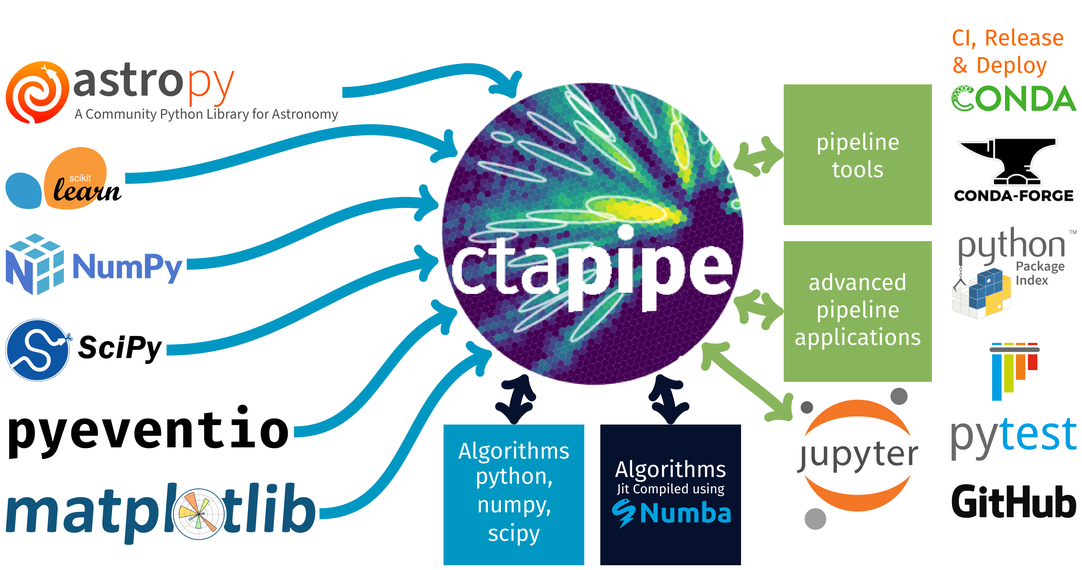
Pipeline Steps and Intermediate Results





ctapipe – from raw data to reconstructed event properties

`ctapipe` is an open-source package for event reconstruction of imaging atmospheric Cherenkov telescope (IACT) data and related functionality. In the classical analysis approach for IACTs, this pipeline is performed in a four step procedure of: **Image Extraction:** Extract the number of photons and the peak time from each pixel time series of all telescopes that recorded a signal for a given air shower. **Image Cleaning:** Select pixels that are likely to contain a Cherenkov signal, discard pixels likely containing only noise. **Image Parametrization:** Calculate parameters suitable for use by the event reconstruction algorithms. Essentially, this step is a dimensionality reduction from the full pixel data to less but more descriptive features. `ctapipe` supports the classical Hillas parametrization, descriptive statistics of images and peak times, morphological features like the number of isolated pixel groups after cleaning and features describing the containment of the shower in the camera. **Event Property Reconstruction** The final step is to reconstruct the physical properties of the primary particle which induced the air shower. This step combines the data from all selected telescope images to reconstruct the shower's geometry and predict the particle's energy and type (the latter two are currently performed within `protopipe`). `ctapipe` implements several algorithms to solve these tasks, based on geometrical approaches, machine learning and the template-based `ImPACT` algorithm.
Additionally, ctapipe offers visualization and IO functionality, including a plugin system that makes it possible to implement readers for data formats not supported by ctapipe directly.

pyirf – library for instrument response functions and sensitivity

To deduce properties of the gamma-ray source from IACT data, reconstructed events have to be accompanied by the instrument response functions (IRFs). The IRFs describe the full measurement process by giving the conditional probability of observing a gamma ray with the properties reconstructed by the event reconstruction given its true properties. The IRFs have to be calculated on labeled data, usually obtained from extensive Monte Carlo simulations. `pyirf` is a python library to compute the IRFs from such labeled, reconstructed event lists and to export them into the open Gamma-Astro-Data-Format, which is an evolving standard for IACT event lists and IRFs using the FITS format.
`pyirf` also offers functionality to calculate the flux sensitivity of an instrument and to optimize the event selection criteria to obtain the best sensitivity.

protopipe – full pipeline with support for large scale analyses

`protopipe` is a set of tools to perform the full event reconstruction of CTA data up to IRF production based based on `ctapipe` and `pyirf`. It's development aims at superseding the historical pipelines used for production of the current public IRFs for CTA but also at testing and migration of new algorithms and analysis approaches into `ctapipe` and `pyirf`. `protopipe` implements in fact some parts of the pipeline not yet fully implemented in `ctapipe`, e. g. the `protopipe.mva` package which allows for training and testing machine learning models used in event property reconstruction. Thanks to a dedicated interface based on the CTADIRAC middleware, it allows for its application at large scale by supporting massive parallel processing on the DIRAC grid.

For more details and references, please refer to the proceeding.

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