Evaluating the impact of PSF event types

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DESY.

Ciemat
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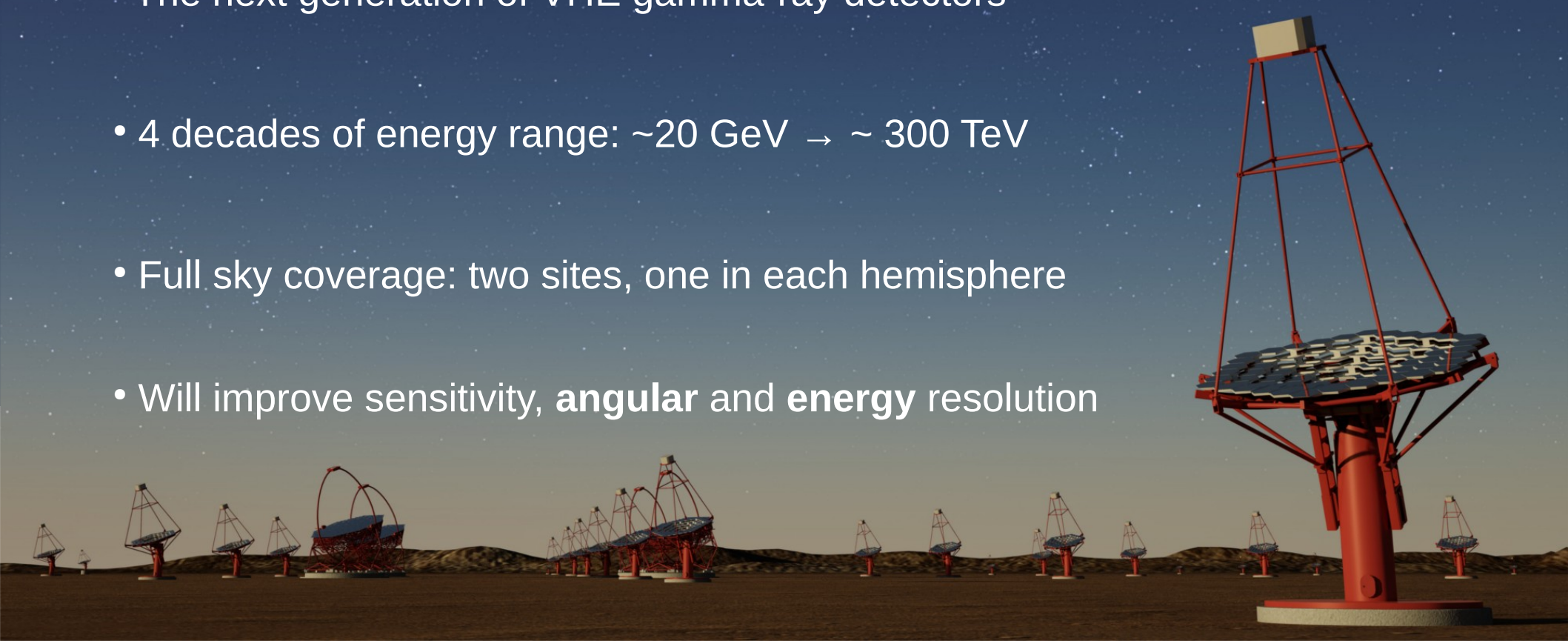
THE CHERENKOV TELESCOPE ARRAY

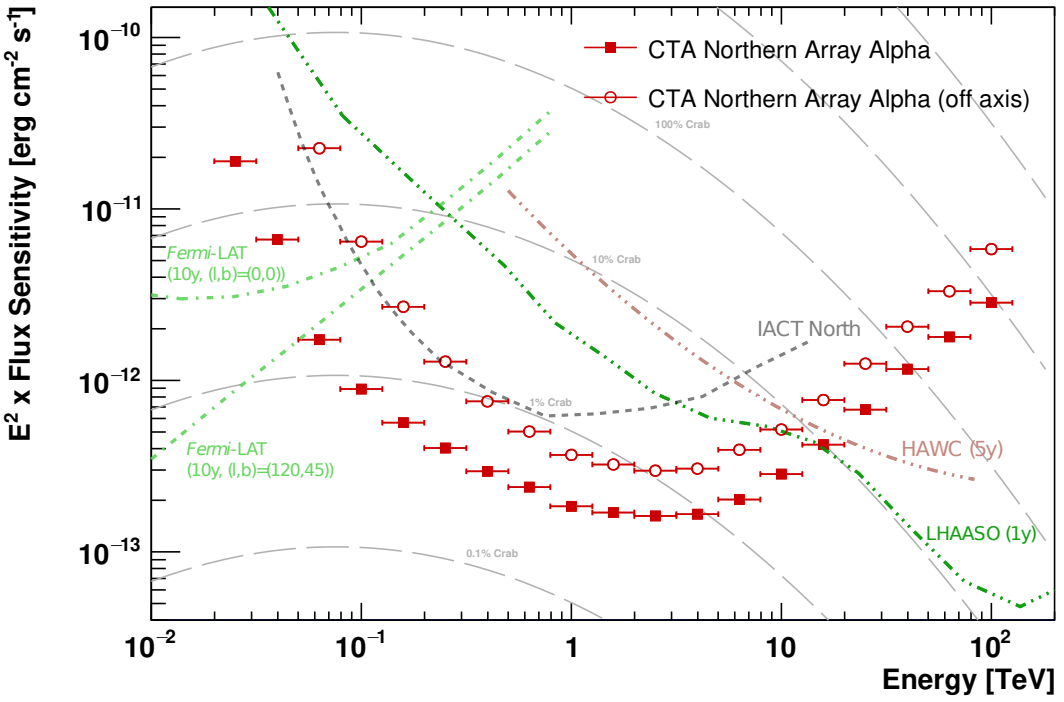
cherenkov telescope array

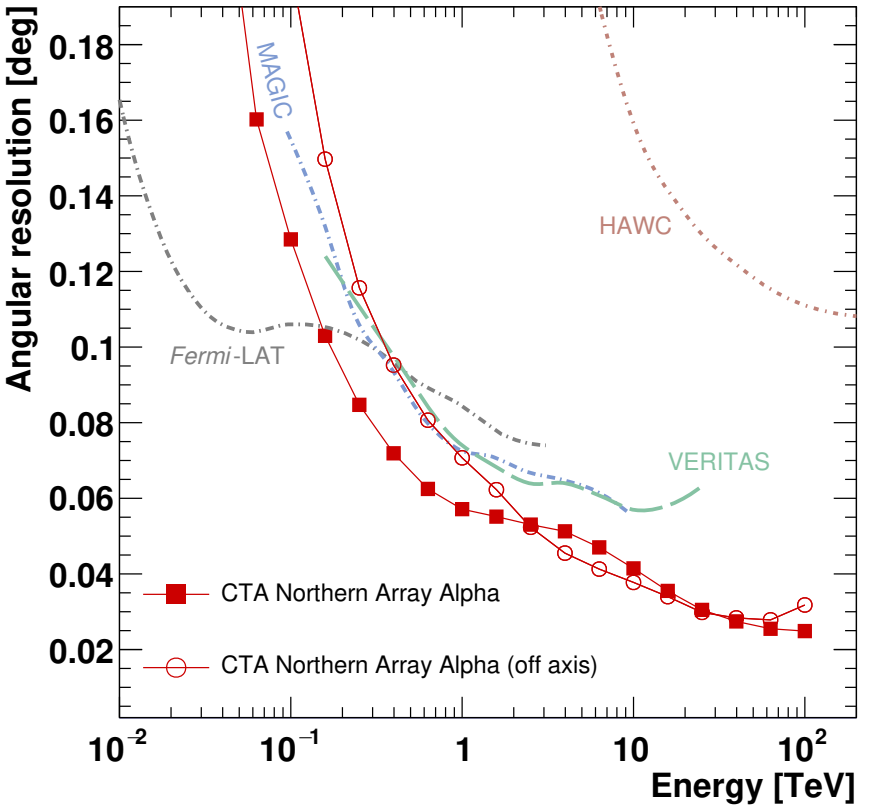
- The next generation of VHE gamma-ray detectors
- 4 decades of energy range: ~20 GeV → ~ 300 TeV
- Full sky coverage: two sites, one in each hemisphere
- Will improve sensitivity, **angular** and **energy** resolution



CTA performance evaluation

- We estimate CTA performance via MC simulations: see **O. Gueta** contribution!





CTA performance evaluation

- How are CTA IRFs calculated?

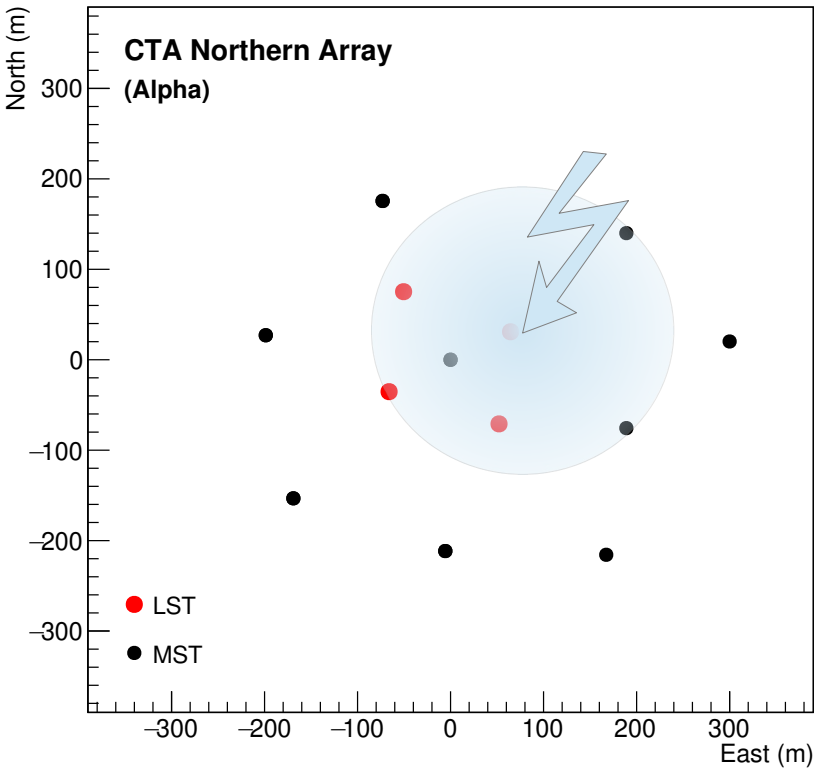
  1) Low-level analysis reconstruct shower parameters

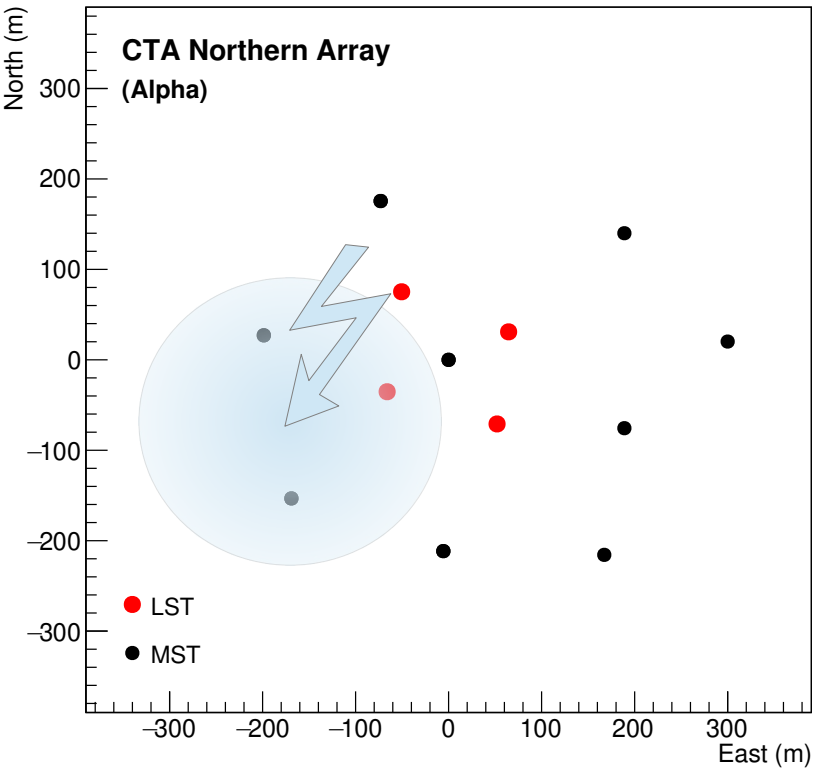
  2) Using all reconstructed events, we find the cuts that maximize sensitivity

  3) From the few surviving events, we compute IRFs

CTA performance: not all events are the same

- In the low-level analysis, we have a lot of information on the **quality** of each event:





All our knowledge on individual events is **lost** when computing IRFs.

CTA performance evaluation

- We propose changing this approach (as done in e.g. Fermi-LAT):

  1) Low-level analysis reconstruct shower parameters

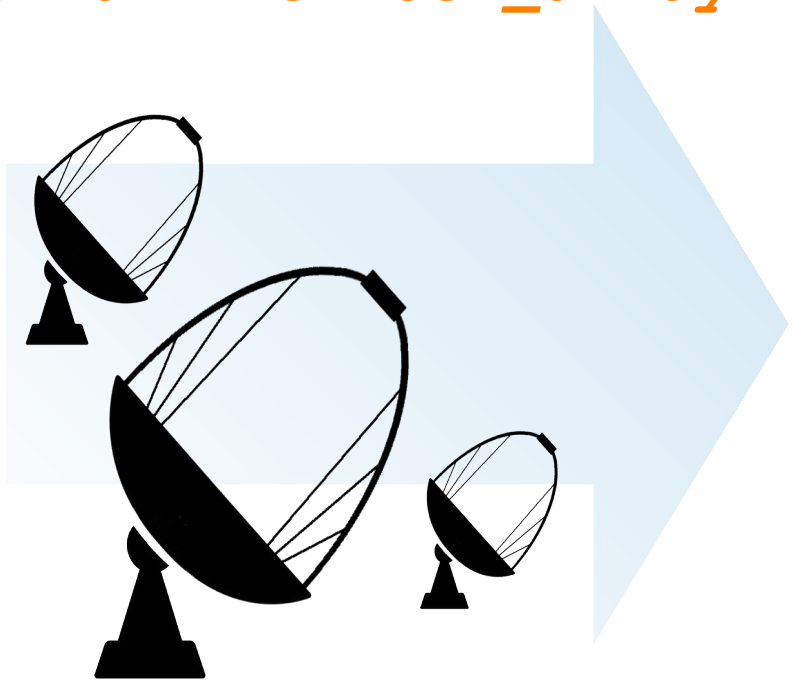
  2) Rank event “quality” and **separate** events into independent samples

  3) Using all reconstructed events, we find the cuts that maximize sensitivity

  4)From the few surviving events, we compute IRFs

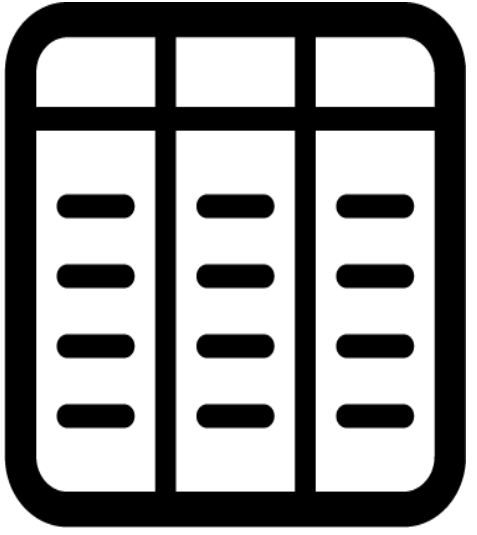
CTA event types implementation

Corsika[2] *+ simtel_array*[3]



DL2 tables

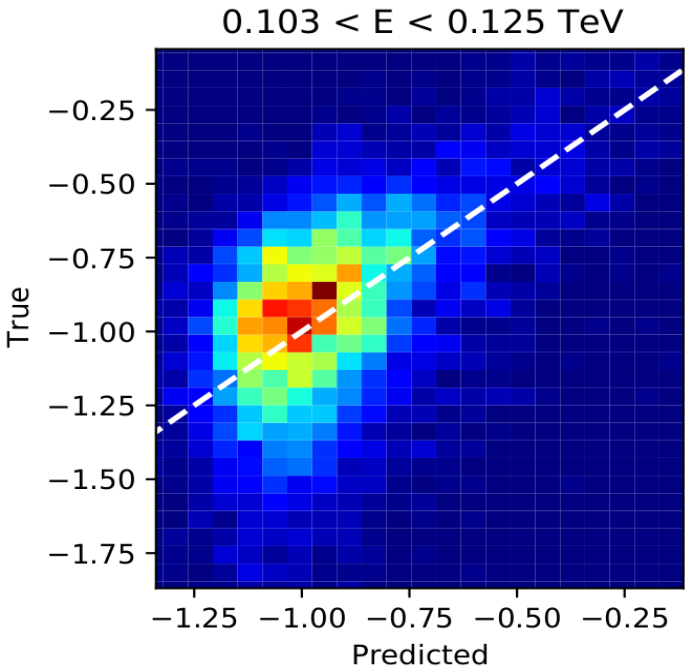
eventDisplay[4]



CTA event types implementation

PSF prediction & partitioning

iact_event_types[5]



CTA event types implementation

PSF prediction & partitioning

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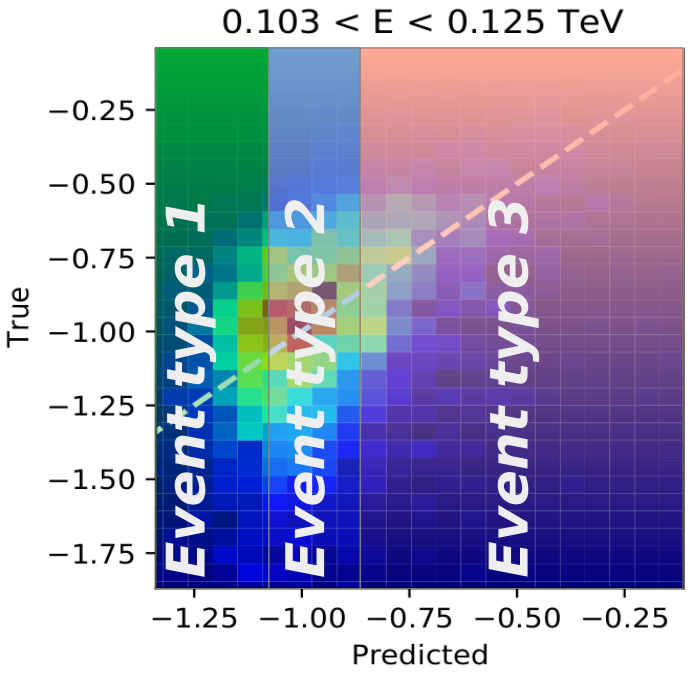
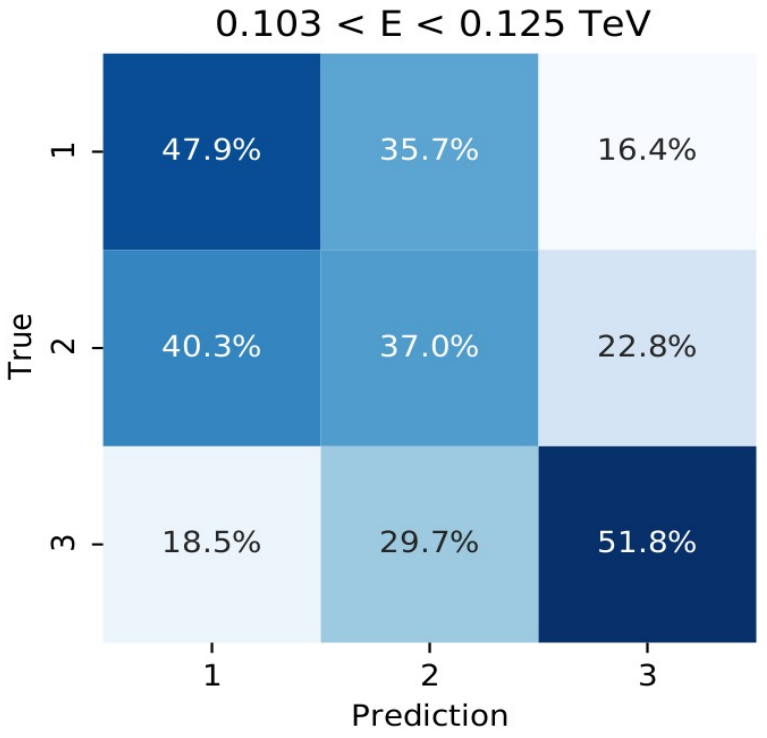


Event type evaluation

iact_event_types[5]



CTA event types implementation

PSF prediction & partitioning

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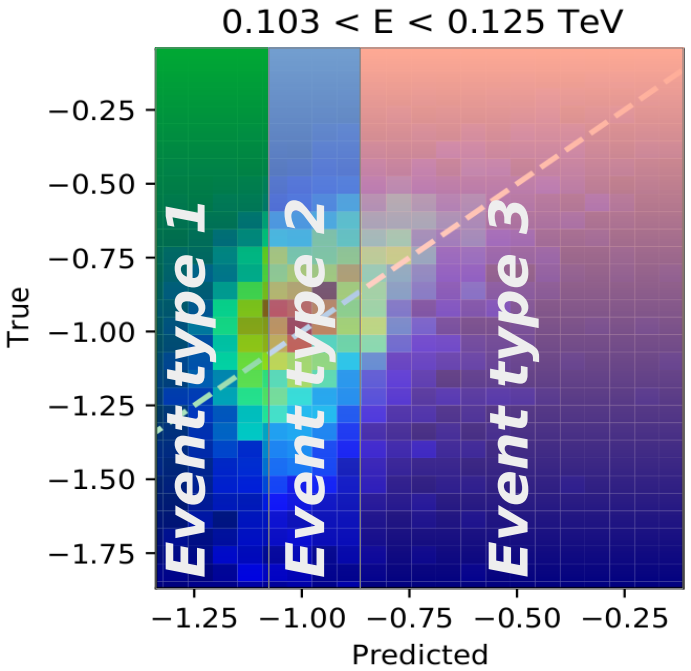


Event type 1

Event type 2

Event type 3

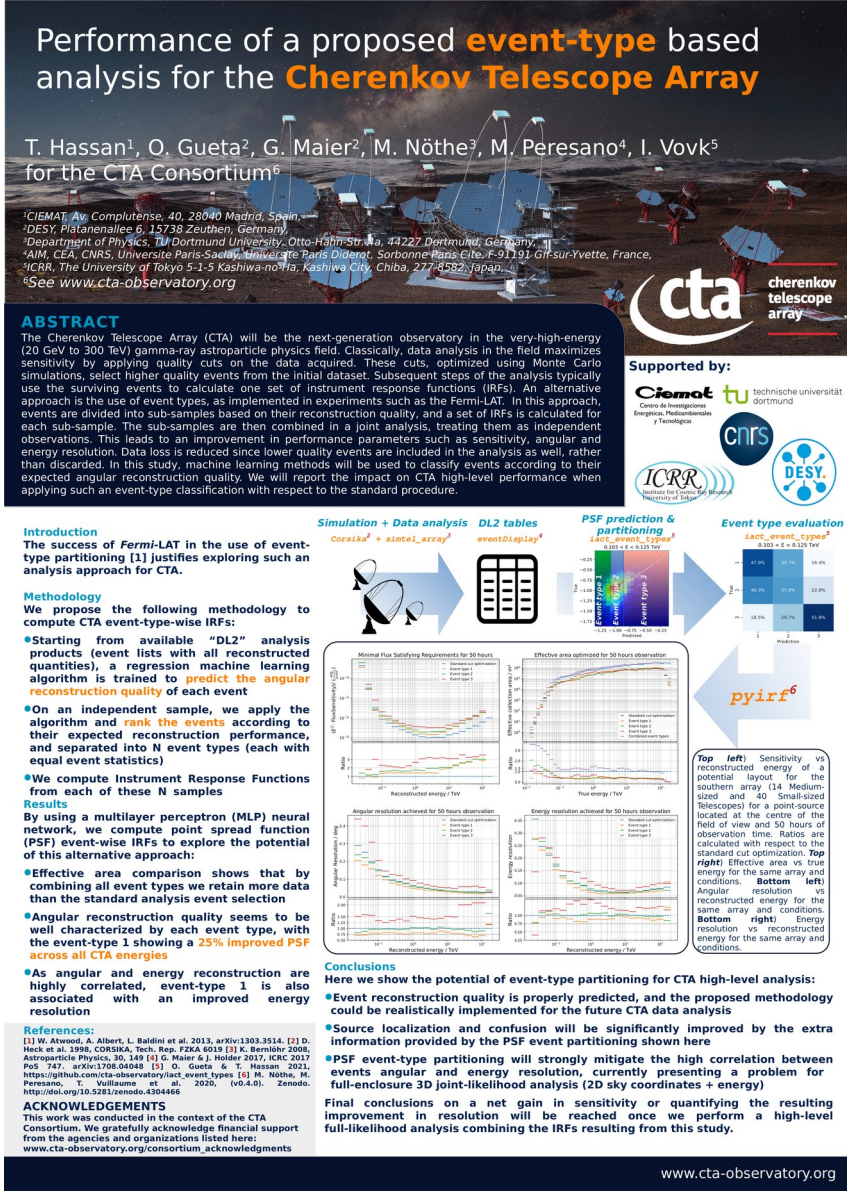
PSF event types for CTA

- Very promising results, shown in the poster!

- We achieve a **25-30% improved resolution** for a subset of CTA events

- Event reconstruction quality is properly predicted, and the methodolofy could be implemented for CTA

- Source localization and confusion will significantly improve by the extra information provided by the IRF PSF partitioning tested here



Performance of a proposed **event-type** based analysis for the **Cherenkov Telescope Array**

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ABSTRACT

The Cherenkov Telescope Array (CTA) will be the next-generation observatory in the very-high-energy (20 GeV to 300 TeV) gamma-ray astroparticle physics field. Classically, data analysis in the field maximizes sensitivity by applying quality cuts on the data acquired. These cuts, optimized using Monte Carlo simulations, select higher quality events from the initial dataset. Subsequent steps of the analysis typically use the surviving events to calculate one set of instrument response functions (IRFs). An alternative approach is the use of event types, as implemented in experiments such as the Fermi-LAT. In this approach, events are divided into sub-samples based on their reconstruction quality, and a set of IRFs is calculated for each sub-sample. The sub-samples are then combined in a joint analysis, treating them as independent observations. This leads to an improvement in performance parameters such as sensitivity, angular and energy resolution. Data loss is reduced since lower quality events are included in the analysis as well, rather than discarded. In this study, machine learning methods will be used to classify events according to their expected angular reconstruction quality. We will report the impact on CTA high-level performance when applying such an event-type classification with respect to the standard procedure.

Supported by:

Introduction

The success of *Fermi*-LAT in the use of event-type partitioning [1] justifies exploring such an analysis approach for CTA.

Methodology

We propose the following methodology to compute CTA event-type-wise IRFs:

- **Starting from available "DL2" analysis products (event lists with all reconstructed quantities), a regression machine learning algorithm is trained to predict the angular reconstruction quality of each event**
- **On an independent sample, we apply the algorithm and rank the events according to their expected reconstruction performance, and separated into N event types (each with equal event statistics)**
- **We compute Instrument Response Functions from each of these N samples**

Results

By using a multilayer perceptron (MLP) neural network, we compute point spread function (PSF) event-wise IRFs to explore the potential of this alternative approach:

- **Effective area comparison shows that by combining all event types we retain more data than the standard analysis event selection**
- **Angular reconstruction quality seems to be well characterized by each event type, with the event-type 1 showing a 25% improved PSF across all CTA energies**
- **As angular and energy reconstruction are highly correlated, event-type 1 is also associated with an improved energy resolution**

Simulation + Data analysis — DL2 tables — PSF prediction & partitioning — Event type evaluation

***Top left*) Sensitivity vs reconstructed energy of a potential layout for the southern array (14 Medium-sized and 40 Small-sized Telescopes) for a point-source located at the centre of the field of view and 50 hours of observation time. Ratios are calculated with respect to the standard cut optimization. *Top right*) Effective area vs true energy for the same array and conditions. Bottom left) Angular resolution vs reconstructed energy for the same array and conditions. Bottom right) Energy resolution vs reconstructed energy for the same array and conditions.**

Conclusions

Here we show the potential of event-type partitioning for CTA high-level analysis:

- **Event reconstruction quality is properly predicted, and the proposed methodology could be realistically implemented for the future CTA data analysis**
- **Source localization and confusion will be significantly improved by the extra information provided by the PSF event partitioning shown here**
- **PSF event-type partitioning will strongly mitigate the high correlation between events angular and energy resolution, currently presenting a problem for full-enclosure 3D joint-likelihood analysis (2D sky coordinates + energy)**

Final conclusions on a net gain in sensitivity or quantifying the resulting improvement in resolution will be reached once we perform a high-level full-likelihood analysis combining the IRFs resulting from this study.

References:

[1] W. Atwood, A. Albert, L. Baldini et al. 2013, arXiv:1303.3514. [2] D. Heck et al. 1998, CORSIKA, Tech. Rep. FZKA 6019 [3] K. Bernlöhr 2008, Astroparticle Physics, 30, 149 [4] G. Maier & J. Holder 2017, ICRC 2017 PoS 747. arXiv:1708.04048 [5] O. Gueta & T. Hassan 2021, https://github.com/cta-observatory/lact_event_types [6] M. Nöthe, M. Peresano, T. Vuillaume et al. 2020, (v0.4.0). Zenodo. http://doi.org/10.5281/zenodo.4304466

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