technische universität
dortmund

cherenkov
telescope
array

e5

Finding optimal hyperparameters for cleaning algorithms for the Cherenkov Telescope Array

Bachelor thesis half-time talk

Anno Knierim

July 15, 2022

E5b Astroparticle Physics
Department of Physics – TU Dortmund

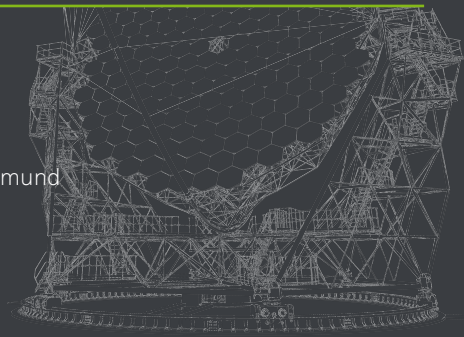


Table of contents

Introduction

The Cherenkov Telescope Array (CTA)

- 2 sites: CTA North and CTA South
- 3 types of telescopes:
  - Small-Sized Telescope (SST)
  - Medium-Sized Telescope (MST)
  - Large-Sized Telescope (LST)

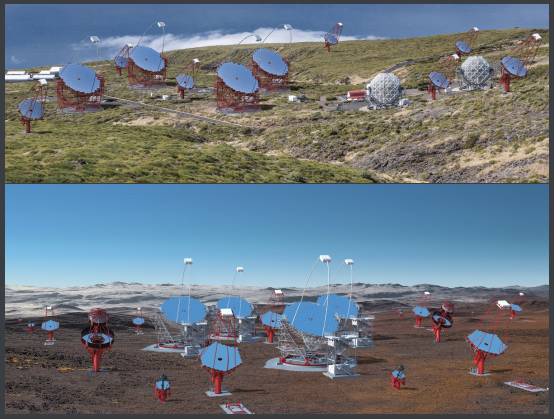
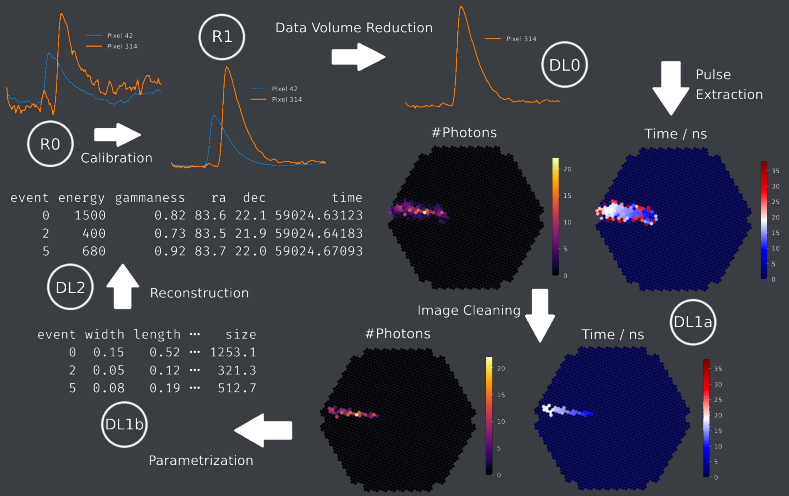


Image Credit: G. Pérez Diaz. CTA/ IAC. 2016. URL: https://www.cta-observatory.org/about/how-cta-works/ (visited on 07/10/2022).

ctapipe



Adapted from J. Hackfeld and M. Nöthe. "Analyzing the Data Volume Reduction for the LST-1 Prototype of the Cherenkov Telescope Array." MA thesis. Bochum, 2021.

Cleaning Algorithms

- `TailcutsImageCleaner`
- `MARSImageCleaner`
- `FACTImageCleaner`
- `TimeConstrainedImageCleaner`

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1. Select pixels that pass the `picture threshold`
2. Add pixels that pass the `boundary threshold`

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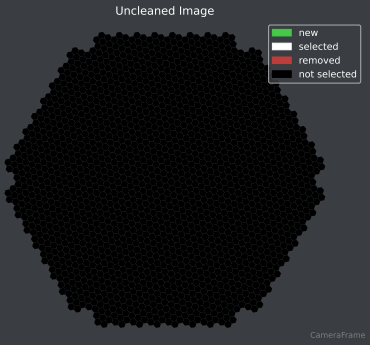

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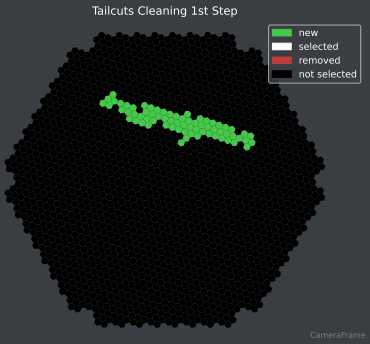

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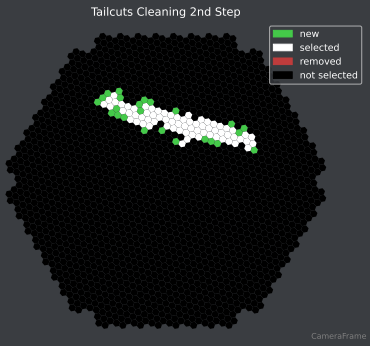

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Cleaning Algorithms

- `TailcutsImageCleaner`
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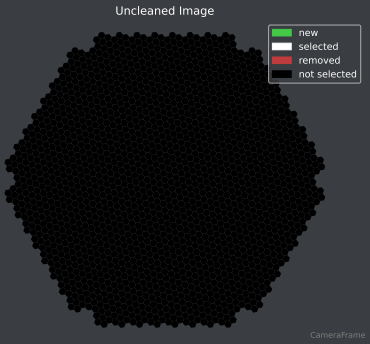
- `TimeConstrainedImageCleaner`

1. Select pixels that pass the `picture` and `boundary threshold`, analogous to `TailcutsImageCleaner`
2. Add pixels that are a neighbor of a neighbor of a core pixel, if they are above the `boundary threshold`

Cleaning Algorithms



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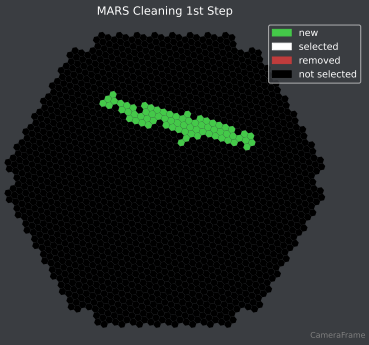

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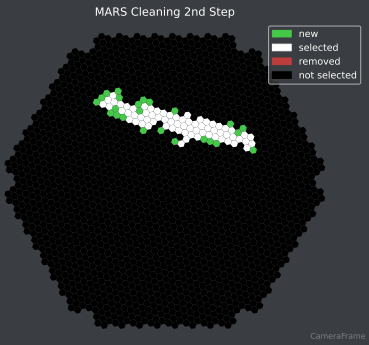

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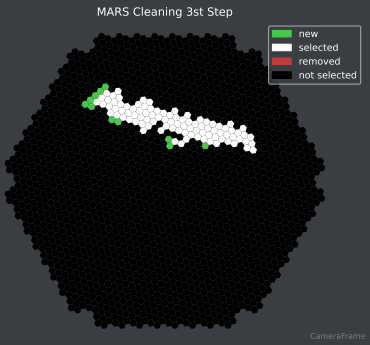

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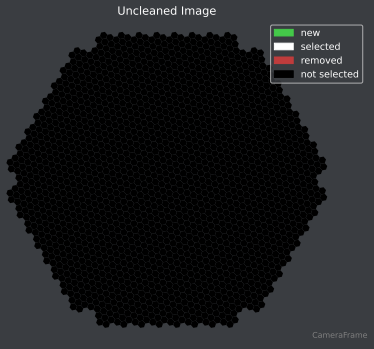
1. Find all pixels that contain more photons than the `picture threshold`
2. Remove pixels with less than ***N*** neighbors
3. Add remaining neighbors that are above the `boundary threshold`
4. Remove pixels that have less than ***N*** neighbors, that arrive within a given timeframe (here: **5** ns)
5. Remove pixels that have less than ***N*** neighbors
6. Remove pixels that have less than ***N*** neighbors, arriving within a given timeframe (same as in step 4)

Cleaning Algorithms



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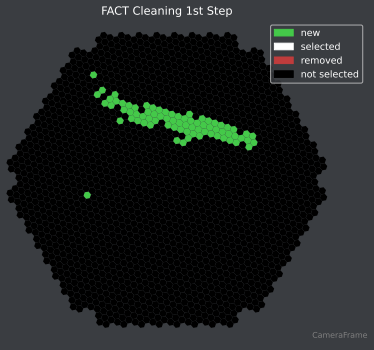

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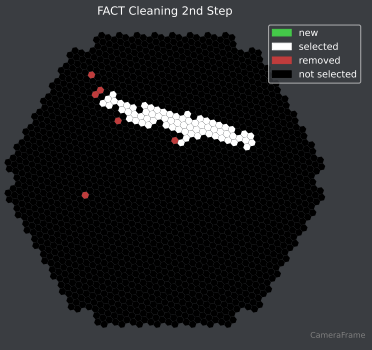

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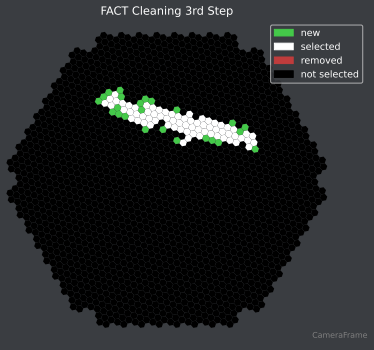

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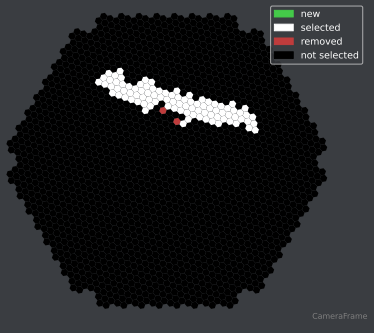

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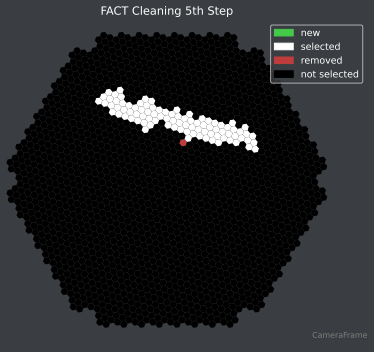

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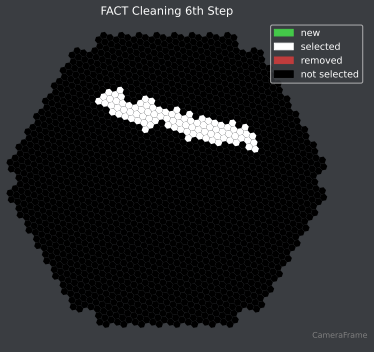

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1. Find all core pixels above the `picture threshold`
2. Remove pixels with less than ***N*** neighbors
3. Keep all pixels that arrive within a time limit of the average arrival time (`time_limit_core`: **4.5** ns)
4. Find all neighbboring pixels above the `boundary threshold`
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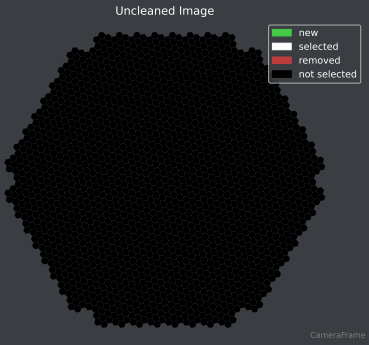

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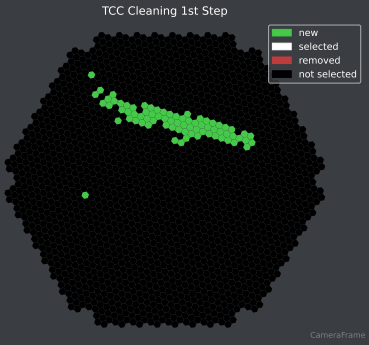

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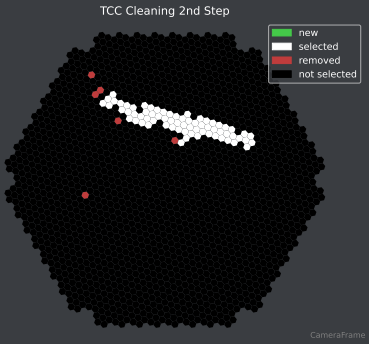

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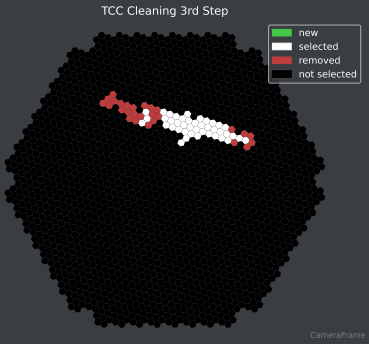

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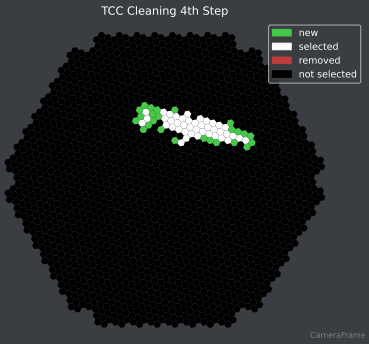

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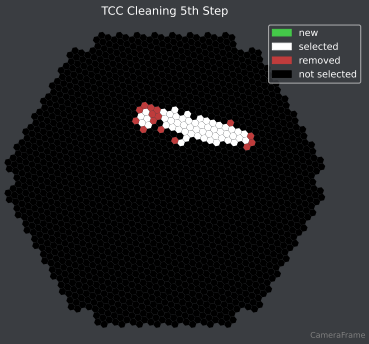

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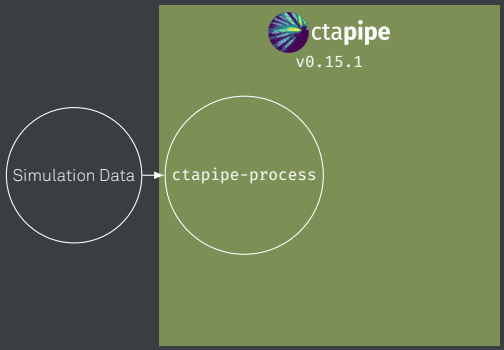
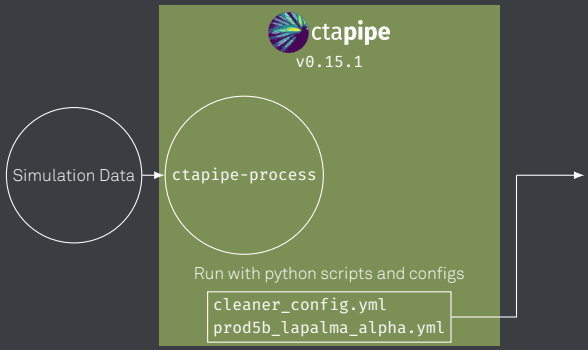
Data Processing with **ctapipe**


Simulation Data

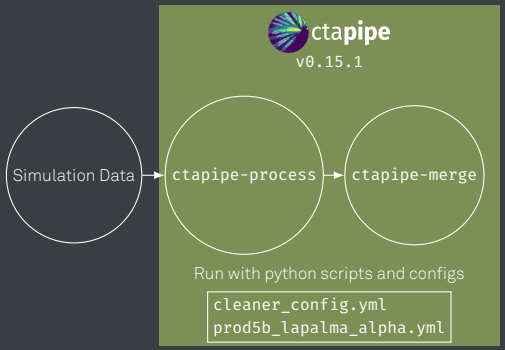

ctapipe
v0.15.1
Simulation Data
ctapipe-process

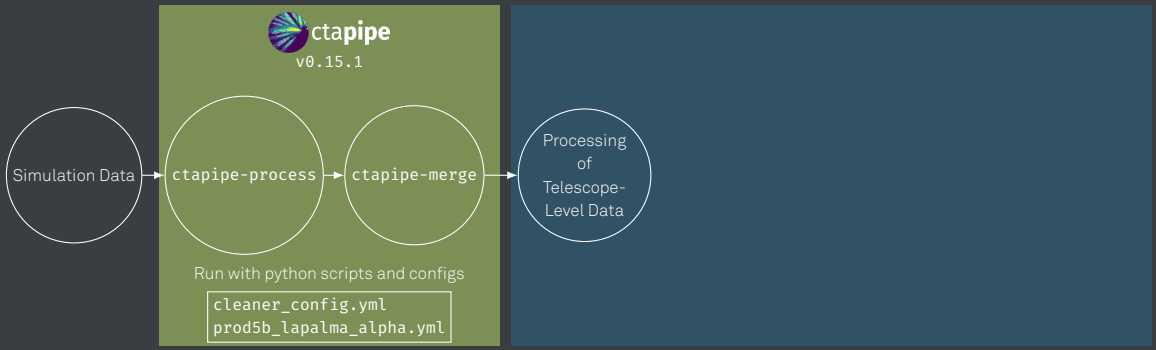


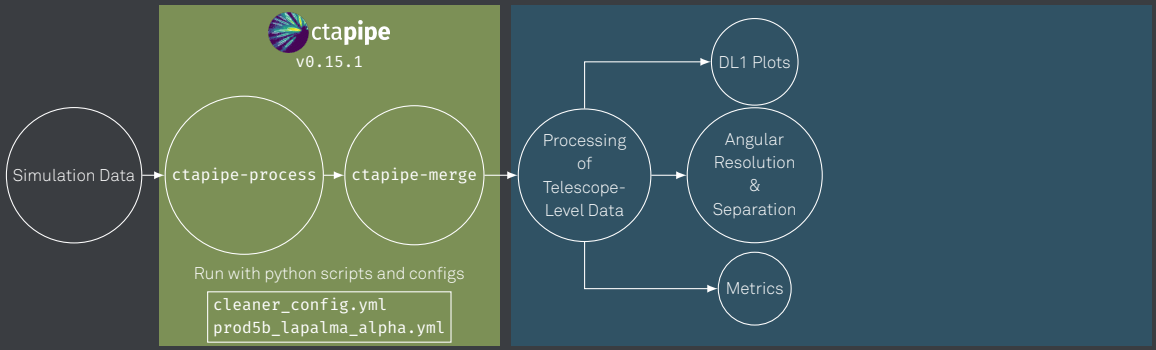

```yaml
ImageProcessor:
  image_cleaner_type: MARSImageCleaner

    MARSImageCleaner:
      picture_threshold_pe:
        - [type, "LST*", 8.5]
        - [type, "MST*NectarCam", 9.0]
      boundary_threshold_pe:
        - [type, "LST*", 4.75]
        - [type, "MST*NectarCam", 4.5]
      keep_isolated_pixels: false
      min_picture_neighbors: 2

    ImageQualityQuery:
      quality_criteria:
        - ["enough_pixels", "np.count_nonzero(image) > 2"]
        - ["enough_charge", "image.sum() > 50"]
```


ctapipe
v0.15.1
Simulation Data
ctapipe-process
ctapipe-merge
Run with python scripts and configs
cleaner_config.yml
prod5b_lapalma_alpha.yml


ctapipe
v0.15.1
Simulation Data
ctapipe-process
ctapipe-merge
Processing of Telescope-Level Data
Run with python scripts and configs
cleaner_config.yml
prod5b_lapalma_alpha.yml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cleaner_config.yml
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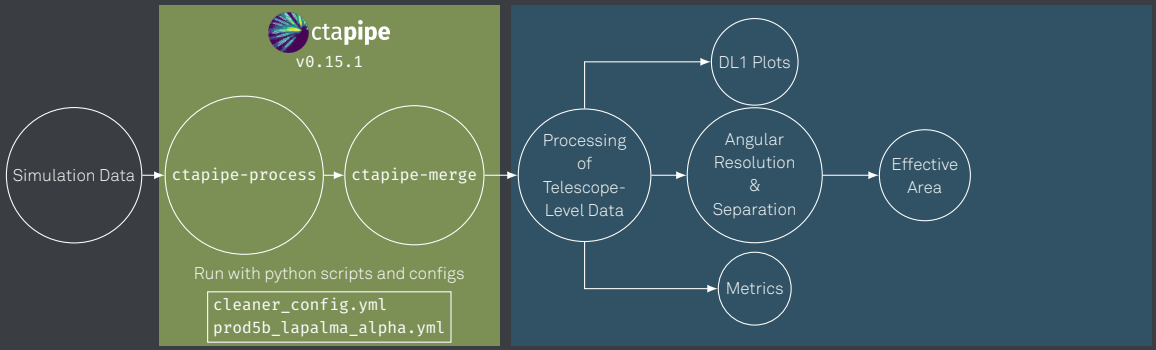
Processing of Telescope-Level Data
DL1 Plots
Angular Resolution & Separation
Metrics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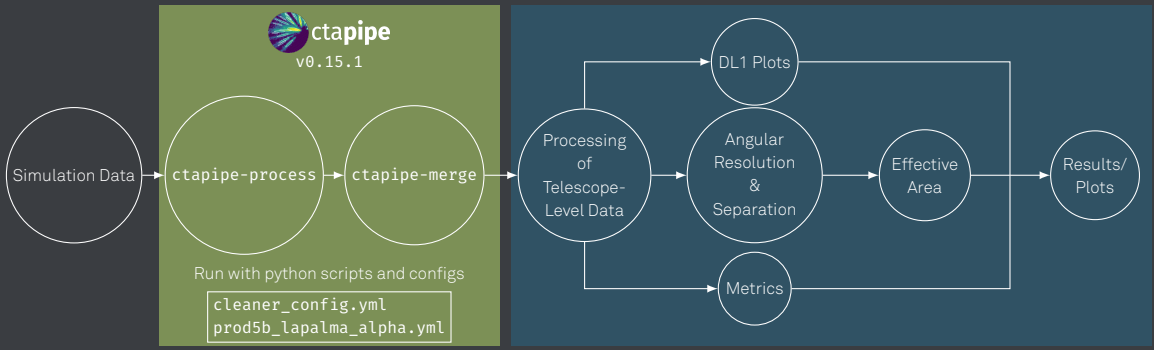
Processing of Telescope-Level Data
DL1 Plots
Angular Resolution & Separation
Effective Area
Metrics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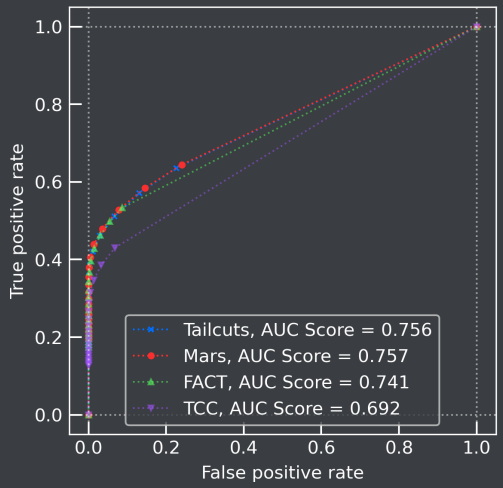
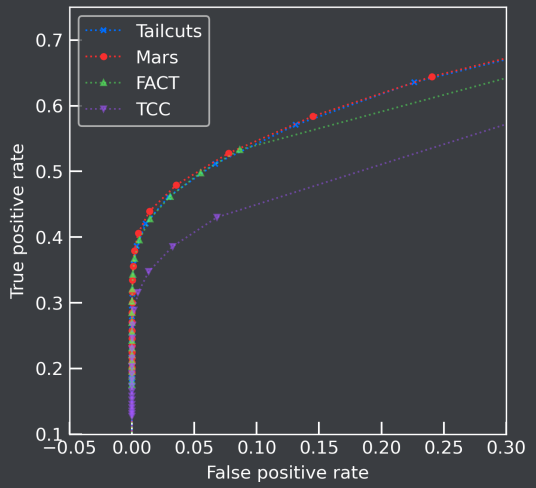
Angular Resolution & Separation
Effective Area
Results/ Plots
Metrics

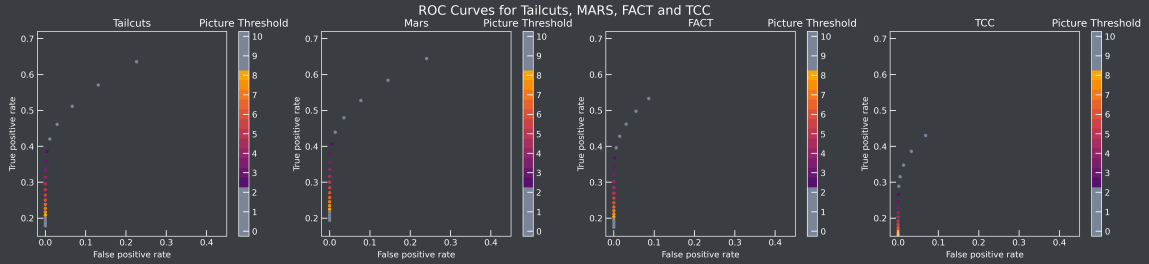
Results

ROC Curves

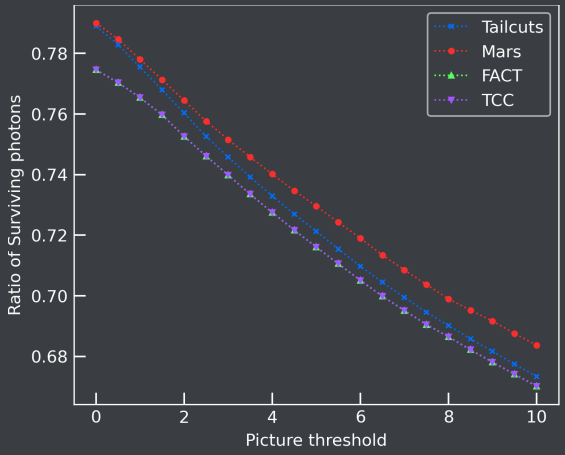

ROC Curves for Tailcuts, Mars, FACT and TCC
True positive rate
False positive rate
Tailcuts, AUC Score = 0.756
Mars, AUC Score = 0.757
FACT, AUC Score = 0.741
TCC, AUC Score = 0.692

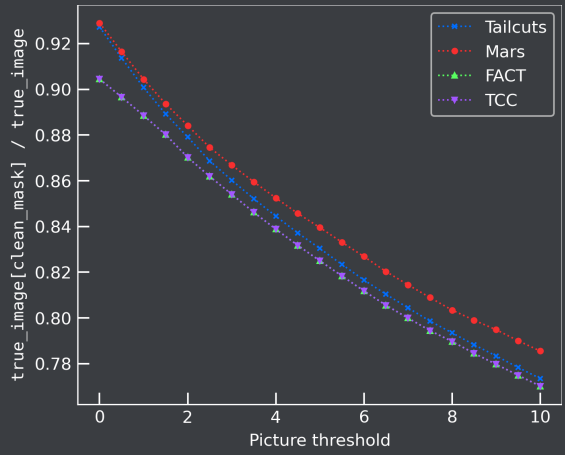

Tailcuts
Mars
FACT
TCC
True positive rate
False positive rate

Picture Thresholds

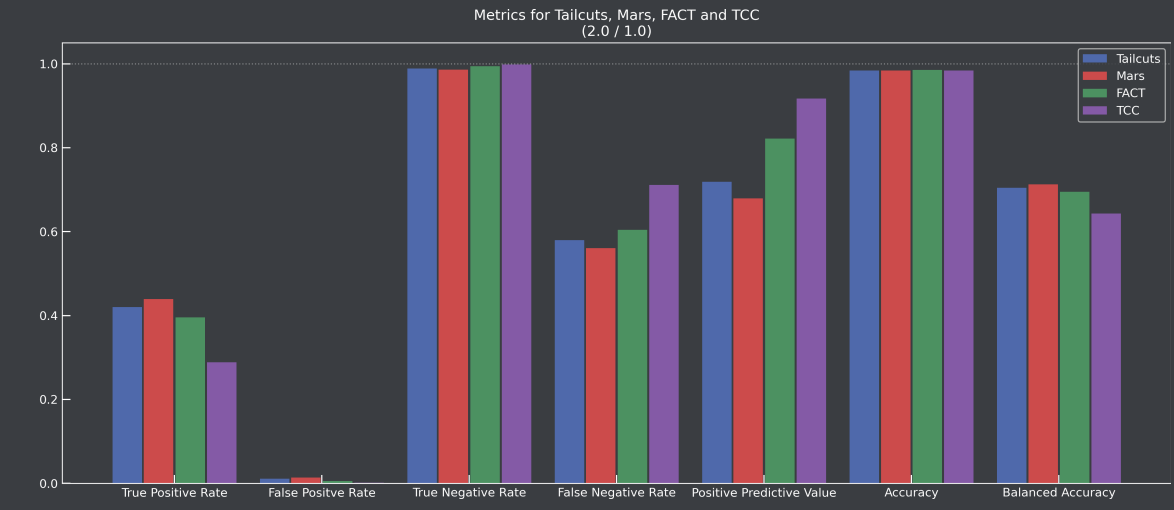


Ratio of Surviving Pixels

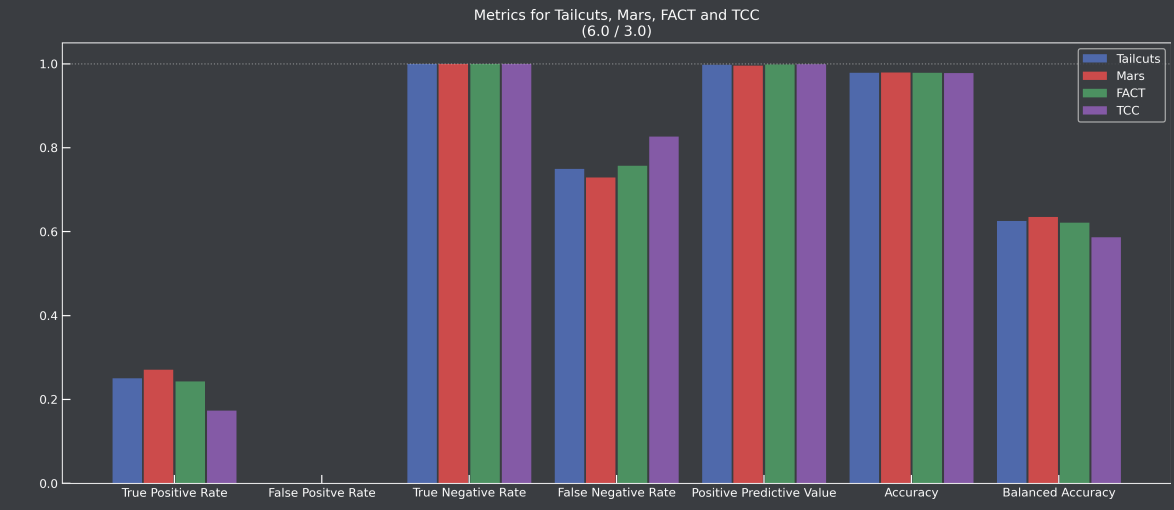




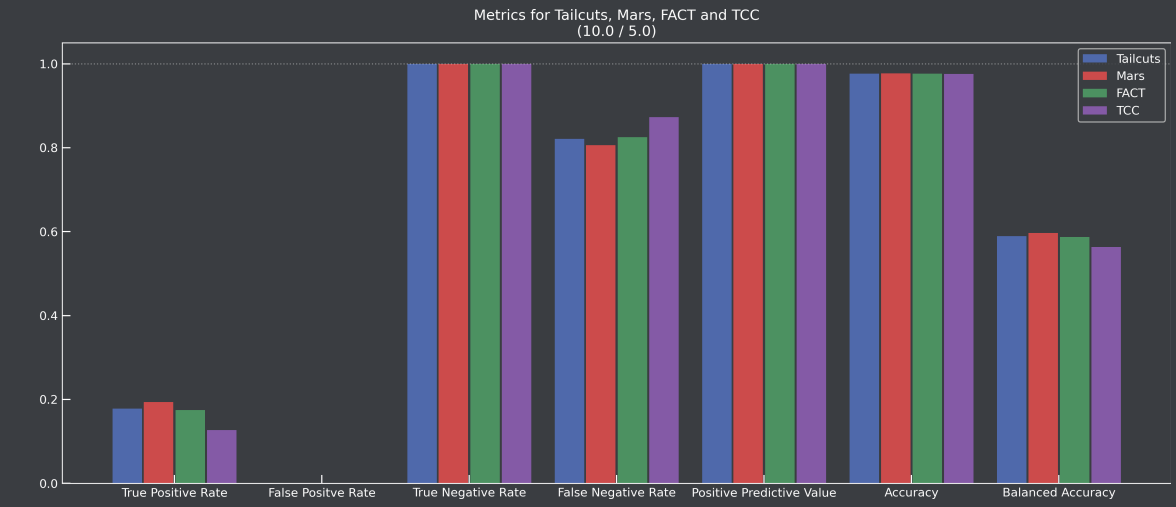
Metrics


Metrics for Tailcuts, Mars, FACT and TCC
(2.0 / 1.0)
Tailcuts
Mars
FACT
TCC
1.0
0.8
0.6
0.4
0.2
0.0
True Positive Rate
False Positve Rate
True Negative Rate
False Negative Rate
Positive Predictive Value
Accuracy
Balanced Accuracy

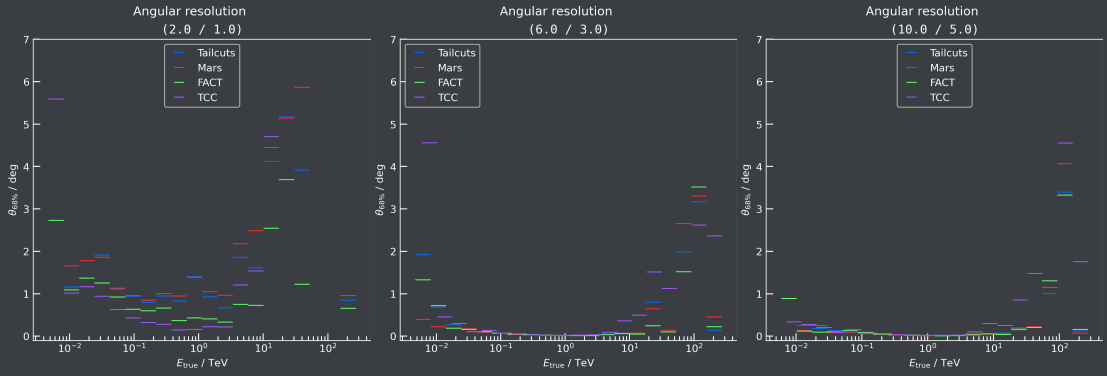
Metrics


Metrics for Tailcuts, Mars, FACT and TCC
(6.0 / 3.0)
Tailcuts
Mars
FACT
TCC
1.0
0.8
0.6
0.4
0.2
0.0
True Positive Rate
False Positve Rate
True Negative Rate
False Negative Rate
Positive Predictive Value
Accuracy
Balanced Accuracy

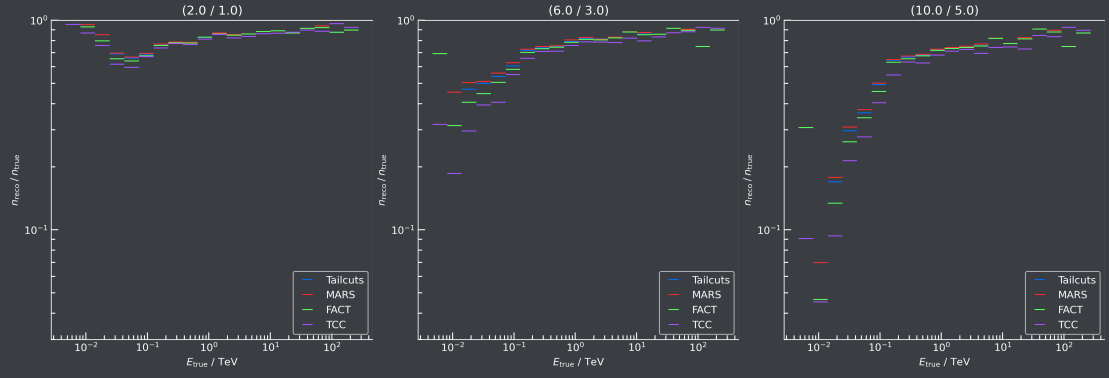
Metrics


Metrics for Tailcuts, Mars, FACT and TCC
(10.0 / 5.0)
Tailcuts
Mars
FACT
TCC
1.0
0.8
0.6
0.4
0.2
0.0
True Positive Rate
False Positve Rate
True Negative Rate
False Negative Rate
Positive Predictive Value
Accuracy
Balanced Accuracy

Angular Resolution



Effective Area



Outlook and Summary

Outlook

- Compare cleaners for other parameters than the `picture` and `boundary thresholds`
  - → Use `sklearn.model_selection.Parametergrid` to find the best parameters for each cleaner
- Instead of letting the `picture threshold` vary from **0** to **10**, use quantiles
- Vary the `boundary thresholds` as **0.25**, **0.33**, **0.5** and **0.75** of the `picture threshold`

Problems

- Run time and number of datasets increase with the number of parameters
  - → For `TailcutsImageCleaner` and `MarsImageCleaner` alone, this results in **32** possible combinations of parameters:

```
params = {
    "picture_quantiles": (0.9, 0.99, 0.995, 0.999),
    "boundary_threshold_ratio": (0.25, 0.33, 0.5, 0.75),
    "min_number_picture_neighbors": (1, 2)
    }
```

  - → Add only two parameters for `FACTImageCleaner` and this number increases to 64 possible combinations

```
fact_params["time_limit"] = (2, 5)
```

Summary

- So far, a `picture threshold` of ≈ **6.0** seems to be the best choice w.r.t. the metrics
  - → Has to be tested again for combinations with other parameters
- Testing other ratios than **0.5** for the `boundary thresholds` seems to be a rational next step
- Testing combinations of the other available parameters should help finding the optimal parameters for each cleaner