technische universität
dortmund

cherenkov
telescope
array

e5

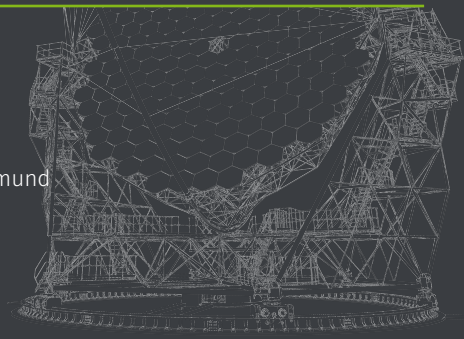
Finding optimal hyperparameters for cleaning algorithms for the Cherenkov Telescope Array

Bachelor thesis half-time talk

Anno Knierim

July 15, 2022

E5b Astroparticle Physics
Department of Physics – TU Dortmund



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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)

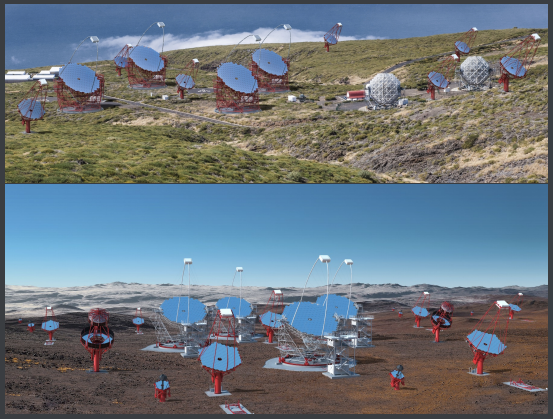
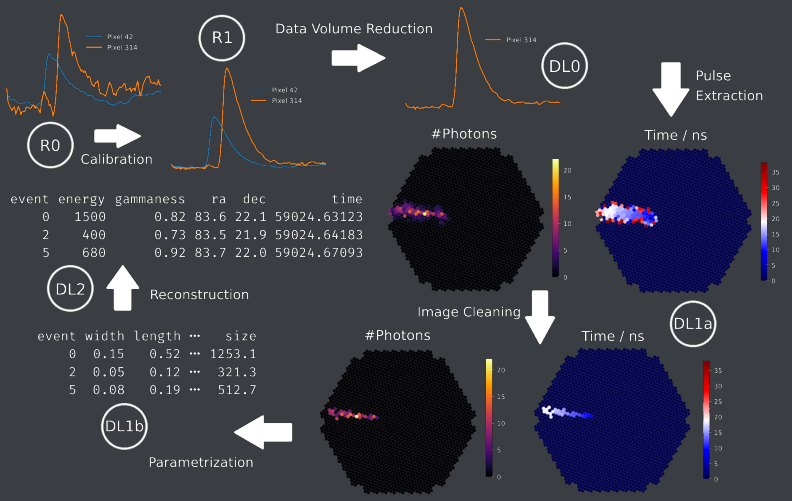


Image Credit: G. Pérez Diaz (CTA/IAC)

ctapipe



Adapted from J. Hackfeld and M. Nöthe

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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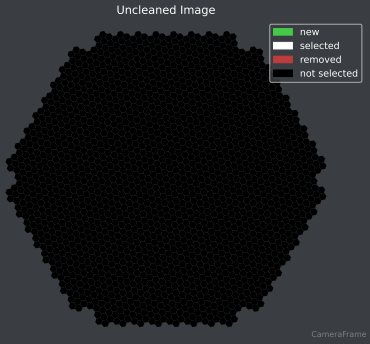

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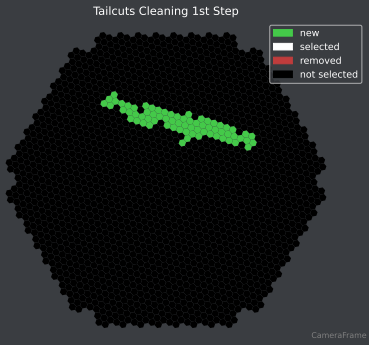

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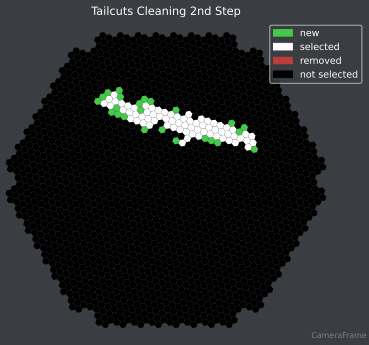

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Cleaning Algorithms

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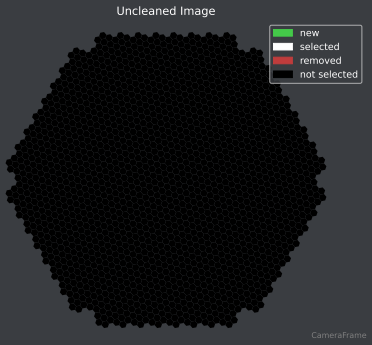
1. Select pixels that pass the `picture` and `boundary threshold`, analogous to `TailcutsImageCleaner`
2. Add pixels that are a neighbor of a neighbor of a core pixel, if they are above the `boundary threshold`

Cleaning Algorithms



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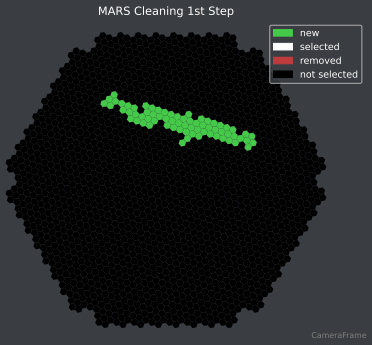

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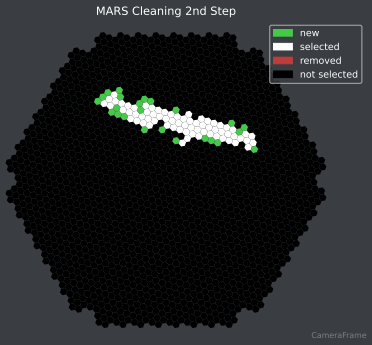

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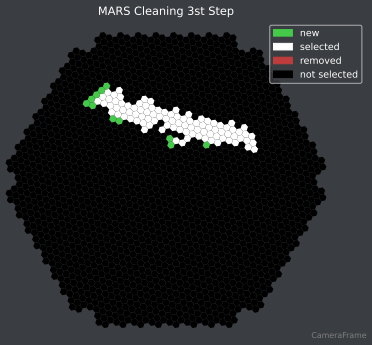

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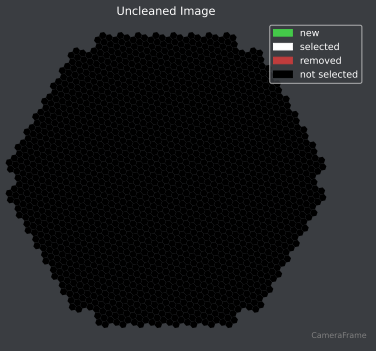
- `TimeConstrainedImageCleaner`

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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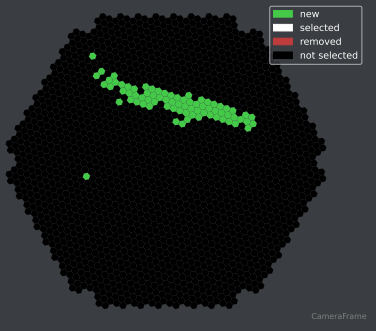

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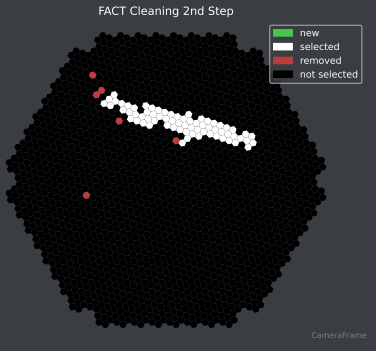

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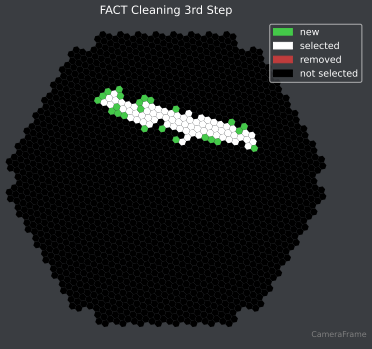

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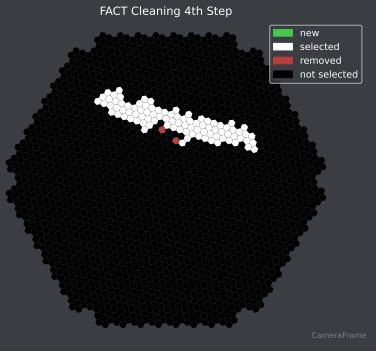

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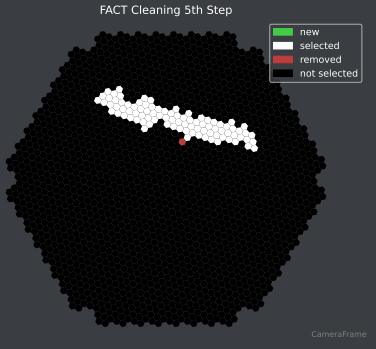

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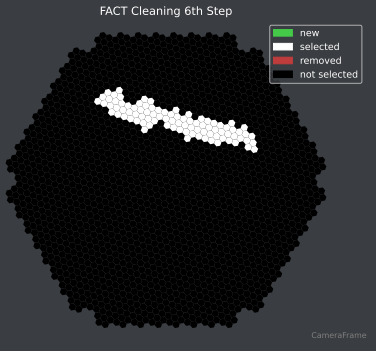

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1. Find all core pixels above the `picture threshold`
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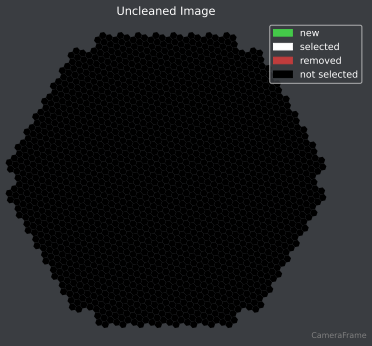

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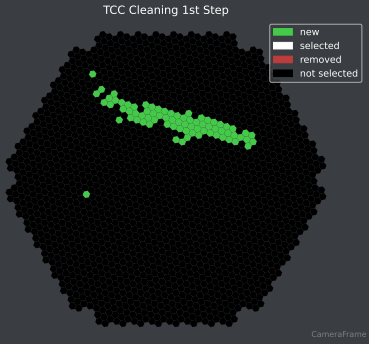

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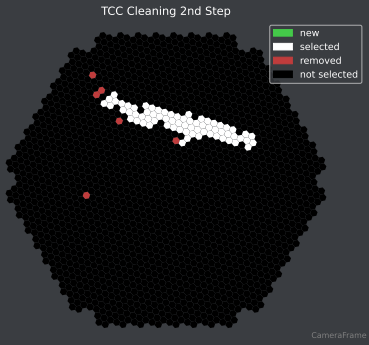

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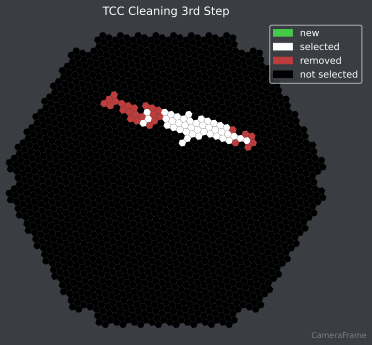

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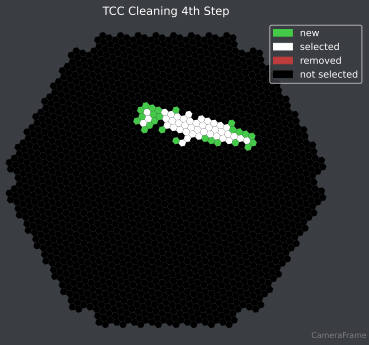

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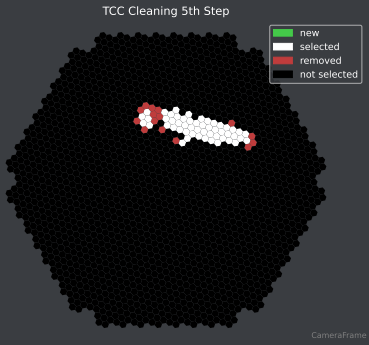

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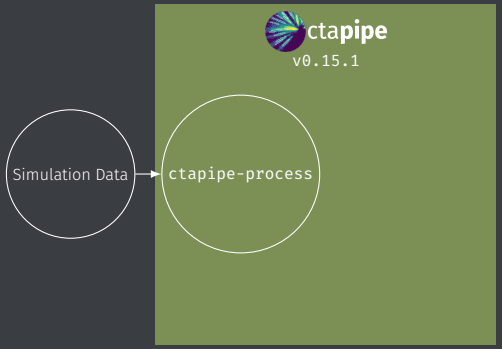
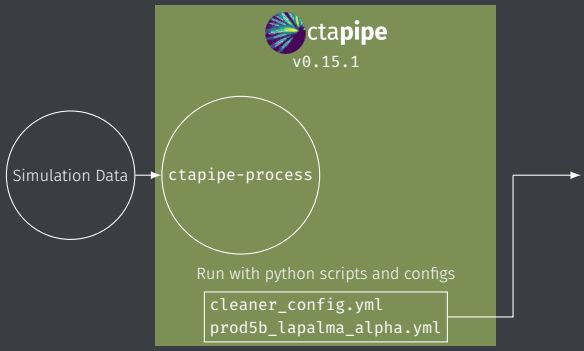
Data Processing with `ctapipe`


Simulation Data


ctapipe
v0.15.1
Simulation Data
ctapipe-process




```yaml
ImageProcessor:
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    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"]
```
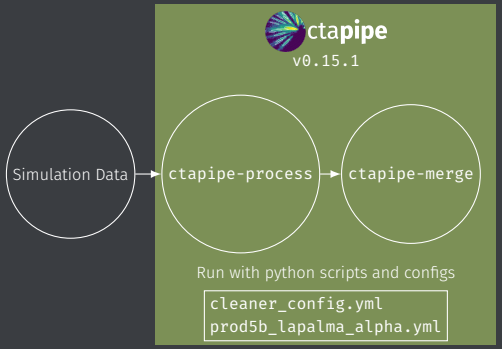
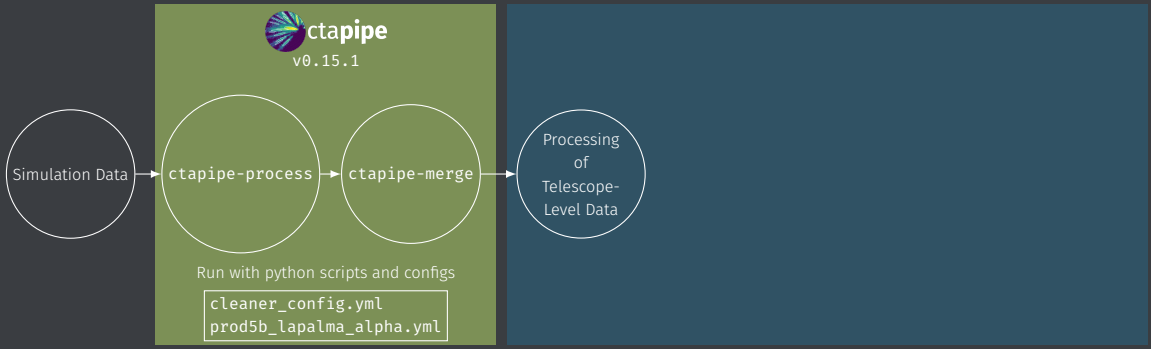
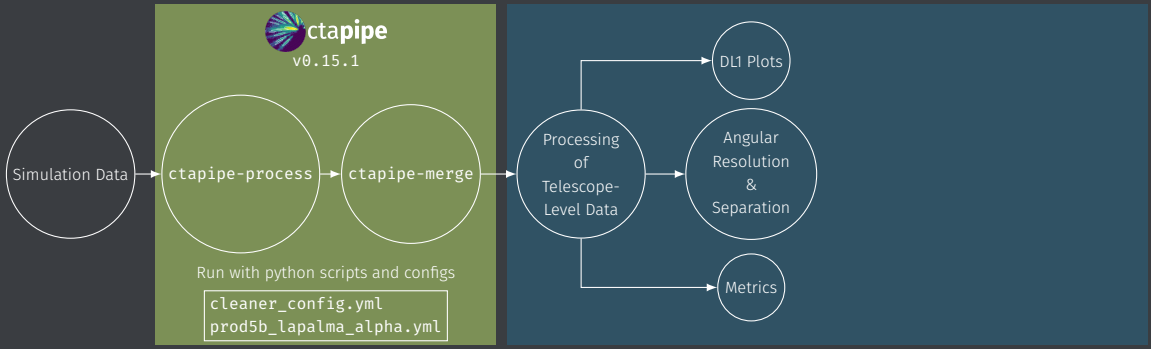


ctapipe
v0.15.1
Simulation Data
ctapipe-process
ctapipe-merge
Run with python scripts and configs
cleaner_config.yml
prod5b_lapalma_alpha.yml


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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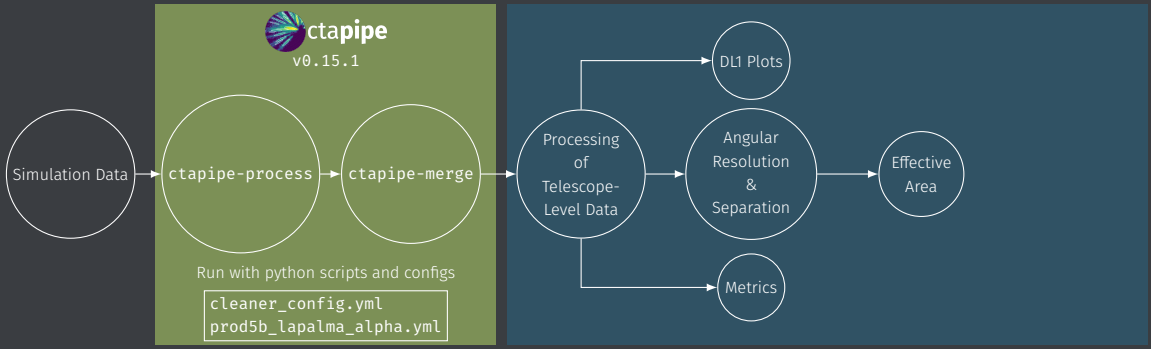
Processing of Telescope-Level Data
DL1 Plots
Angular Resolution & Separation
Metrics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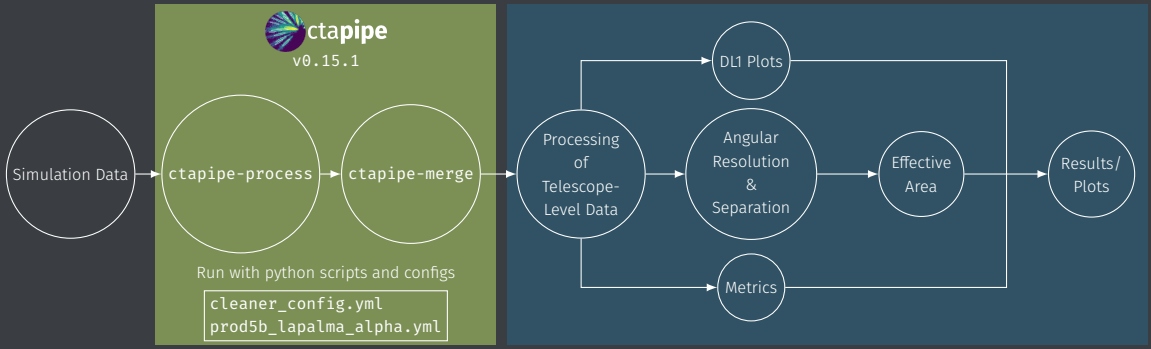
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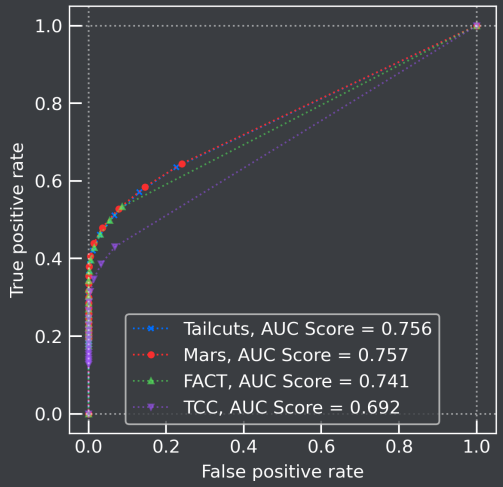
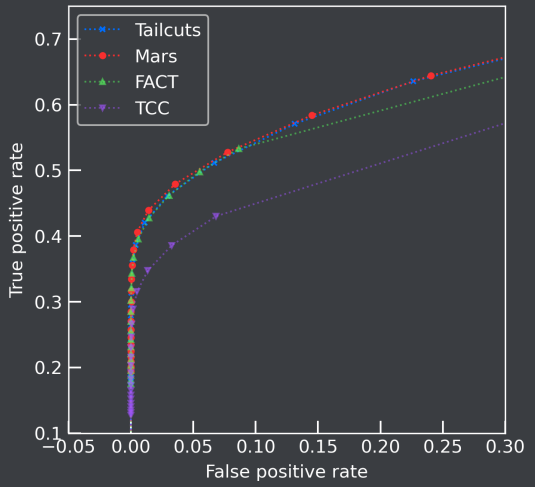
prod5b_lapalma_alpha.yml
Processing of Telescope-Level Data
DL1 Plots
Angular Resolution & Separation
Effective Area
Results/ Plots
Metrics

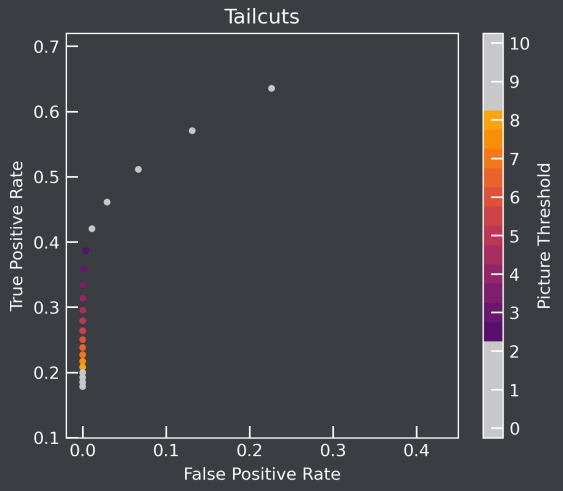
Results

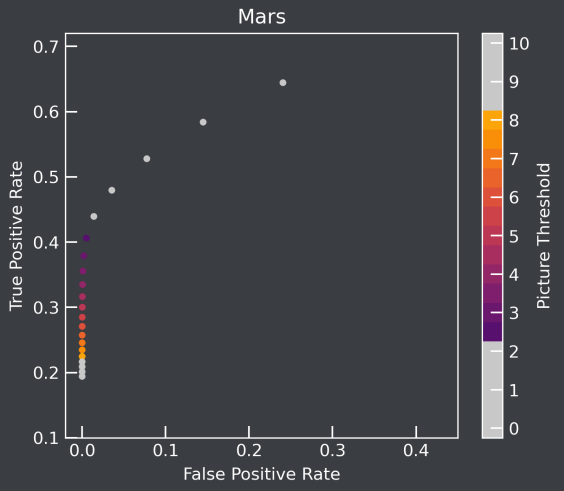
ROC Curves


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

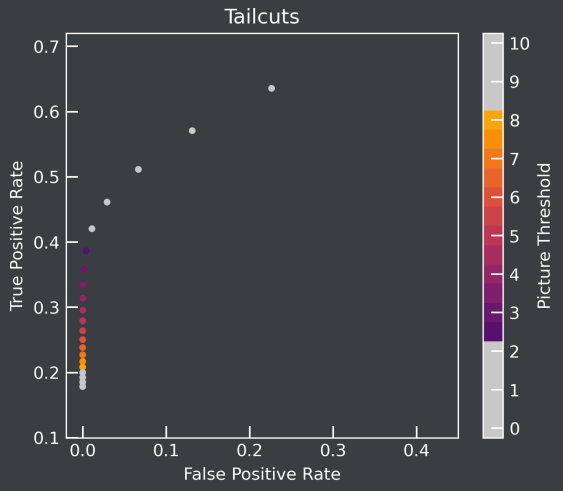

Tailcuts
Mars
FACT
TCC
True positive rate
False positive rate

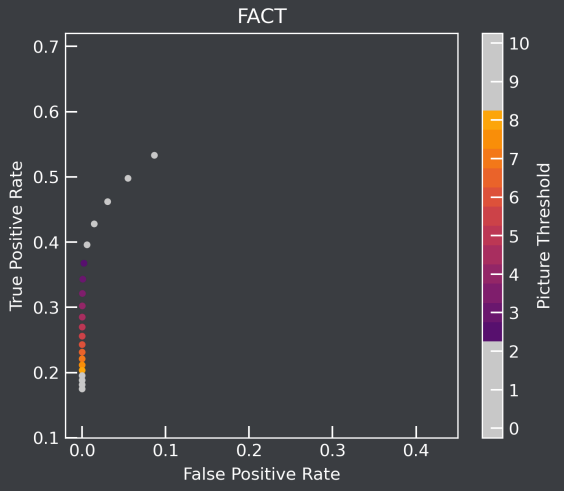
ROC Curves with Picture Thresholds



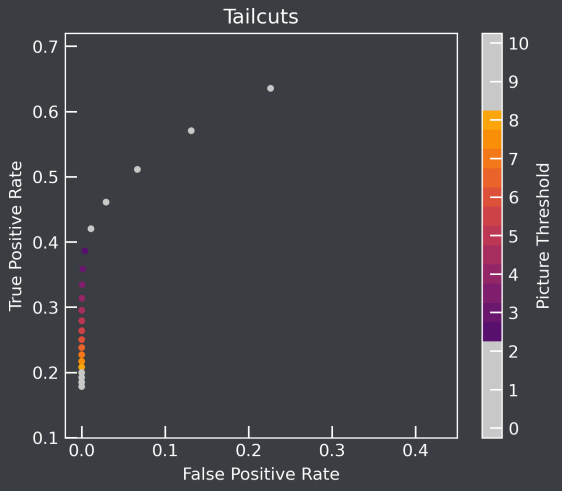


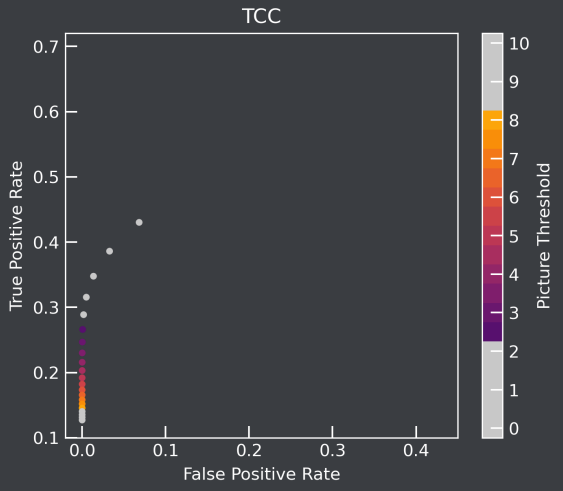
ROC Curves with Picture Thresholds



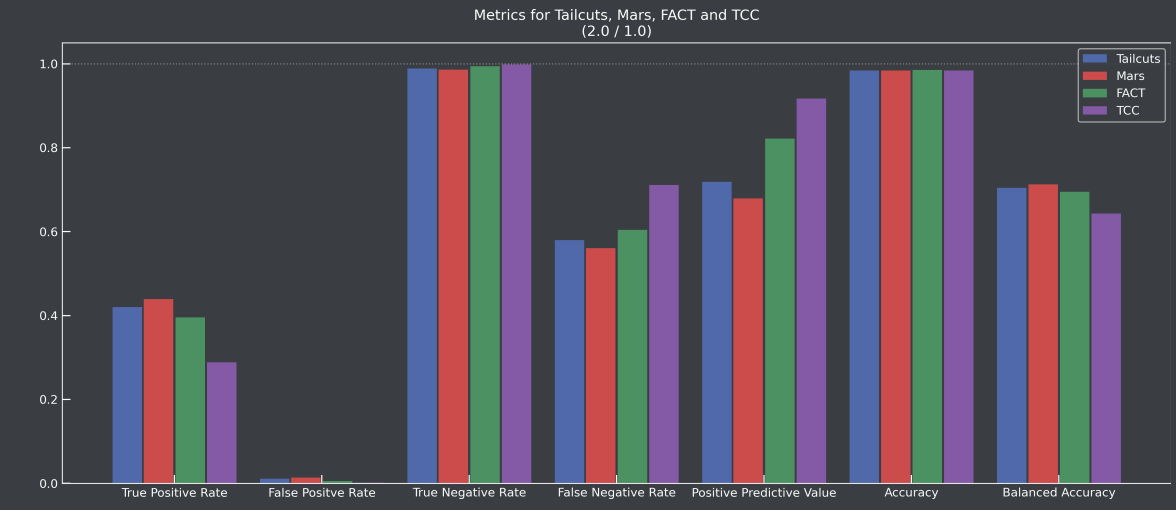


ROC Curves with Picture Thresholds

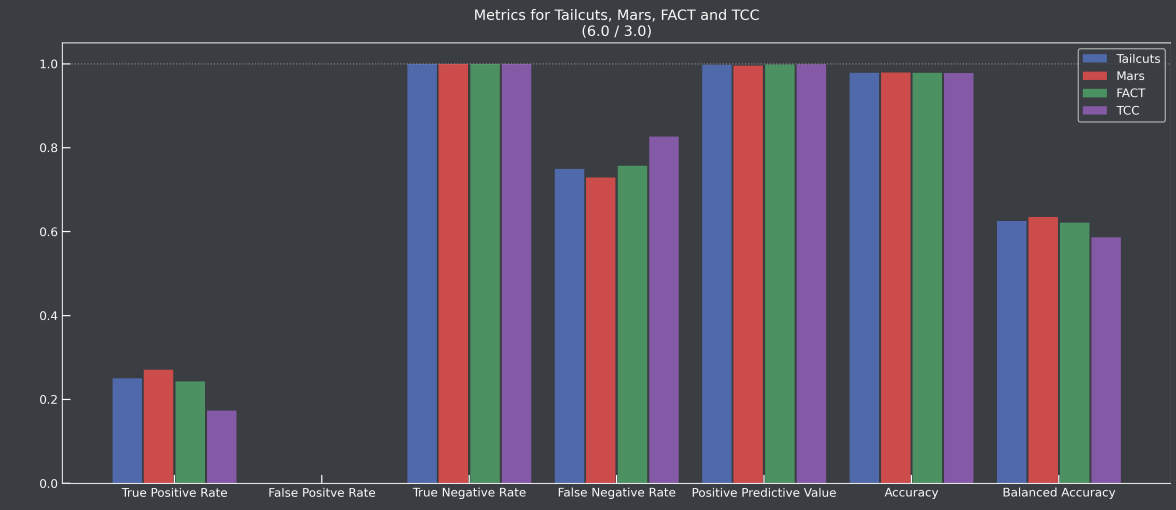




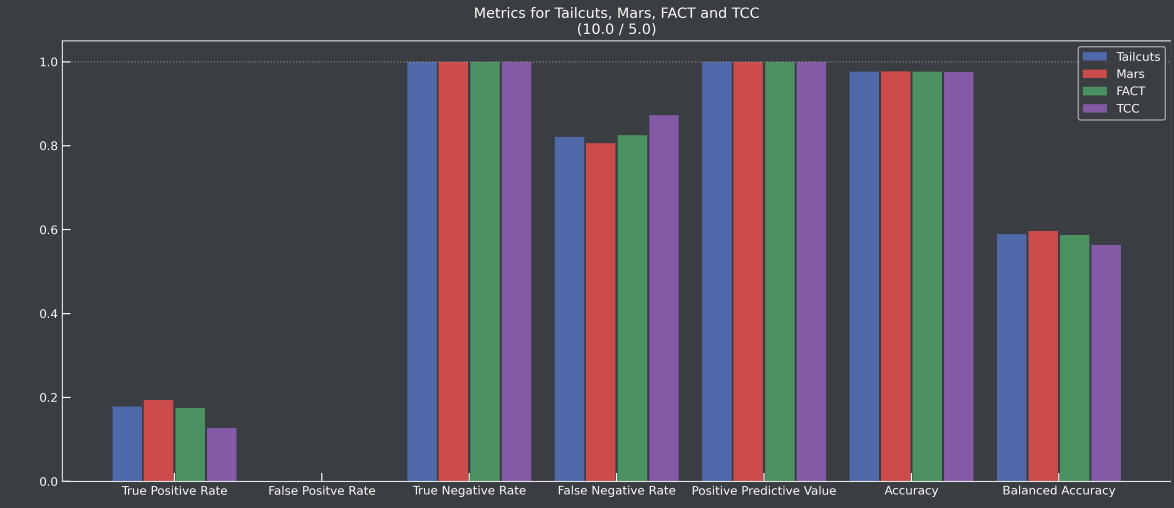
Metrics


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

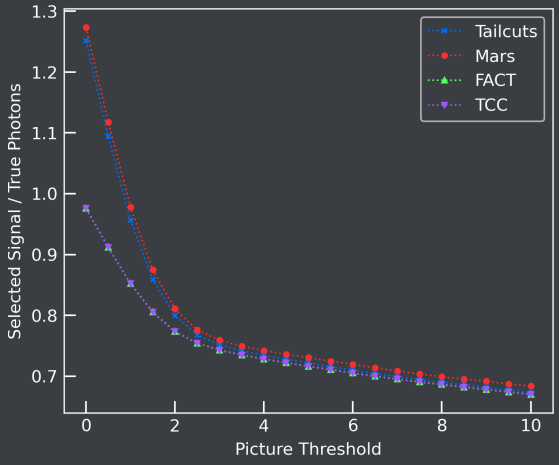
Metrics

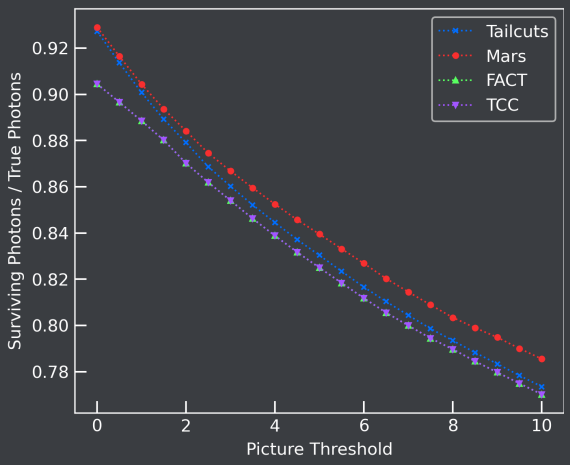

Metrics for Tailcuts, Mars, FACT and TCC
(6.0 / 3.0)
Tailcuts
Mars
FACT
TCC
1.0
0.8
0.6
0.4
0.2
0.0
True Positive Rate
False Positve Rate
True Negative Rate
False Negative Rate
Positive Predictive Value
Accuracy
Balanced Accuracy

Metrics

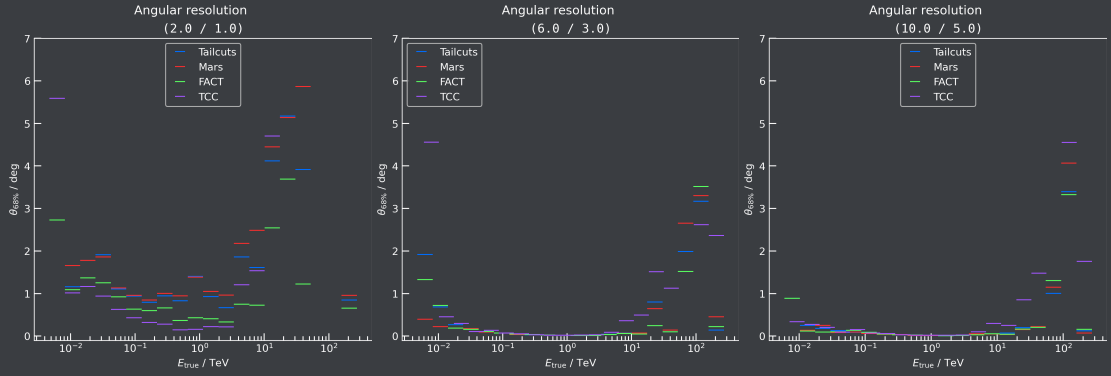

Metrics for Tailcuts, Mars, FACT and TCC
(10.0 / 5.0)
Tailcuts
Mars
FACT
TCC
1.0
0.8
0.6
0.4
0.2
0.0
True Positive Rate
False Positve Rate
True Negative Rate
False Negative Rate
Positive Predictive Value
Accuracy
Balanced Accuracy

Ratio of Surviving Photons

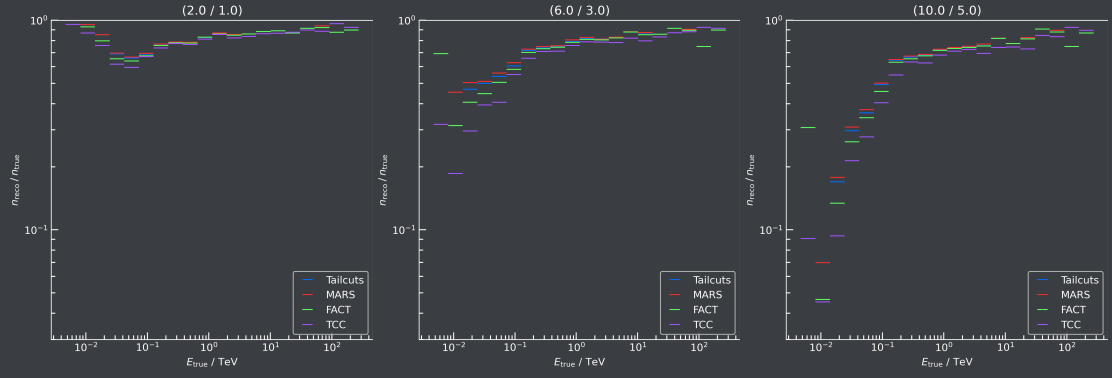




Angular Resolution



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:

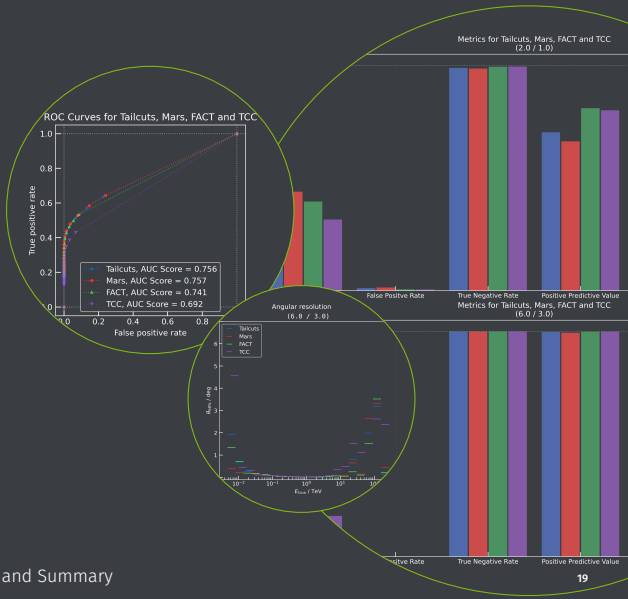
```
params = {
    "picture_quantiles": (0.9, 0.99, 0.995, 0.999),
    "boundary_threshold_ratio": (0.25, 0.33, 0.5, 0.75),
    "min_number_picture_neighbors": (1, 2)
    }
```

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

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

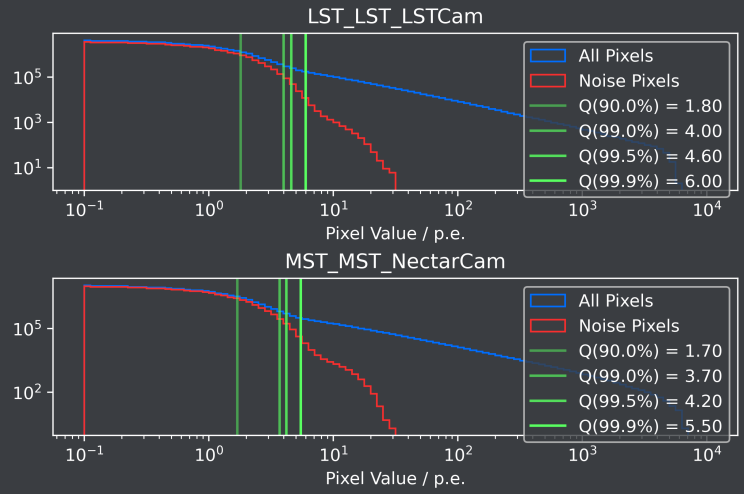
Summary

- So far, a `picture threshold` of ≈ **6.0** seems to be the best choice w.r.t. the metrics
- Until now only the `picture threshold` has been tested (with a `boundary threshold ratio` of **0.5**)
  - → Testing the other available parameters should help in finding optimal parameters for each cleaner
- `MARSImageCleaner` seems to have a slight advantage over the other cleaners (with the above parameters)



Backup

- Quantiles plots for LST and MST



Backup

- Surviving Signal / True Photons and Surviving Photons / True Photons