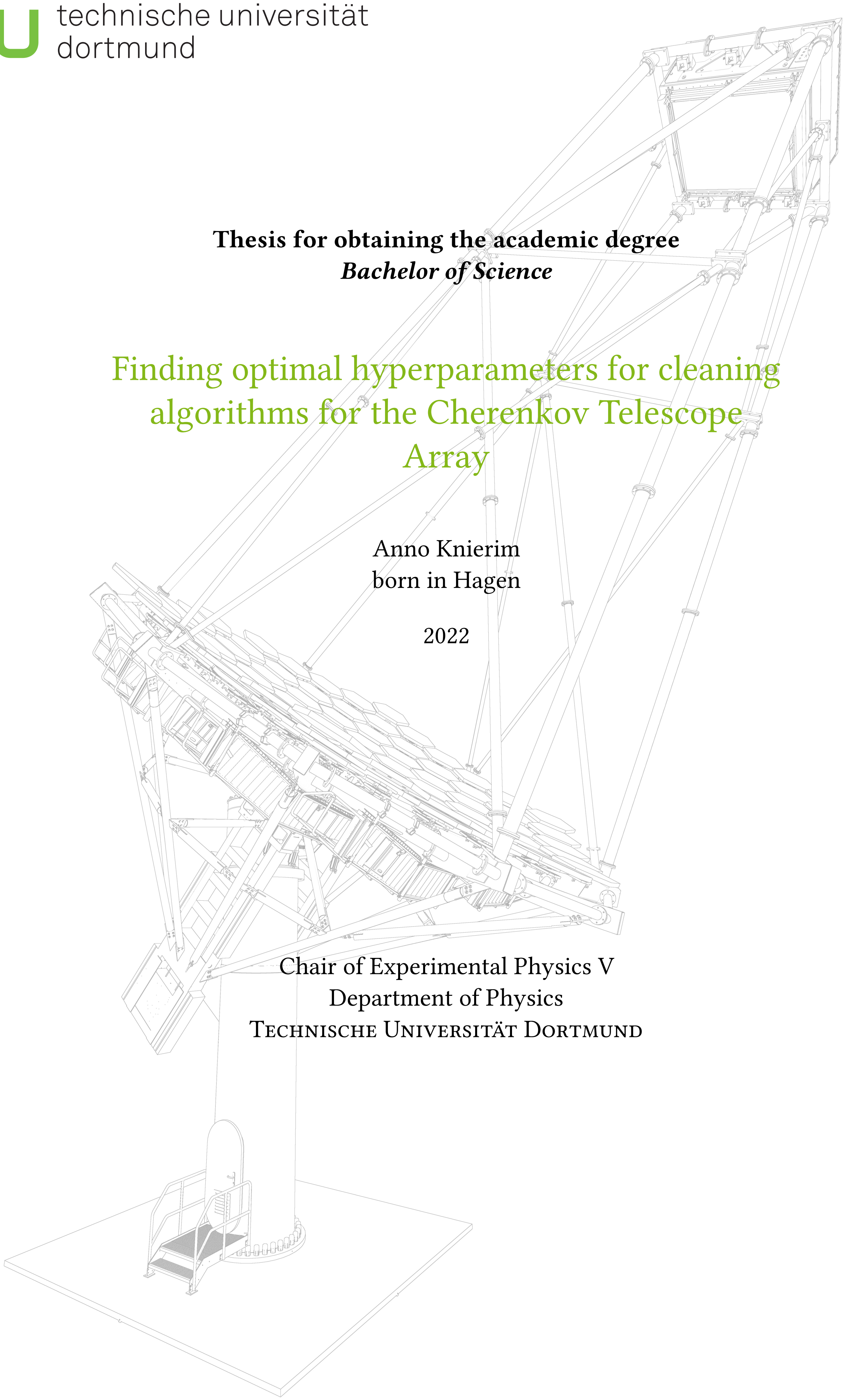
technische universität
dortmund



Thesis for obtaining the academic degree
Bachelor of Science

Finding optimal hyperparameters for cleaning algorithms for the Cherenkov Telescope Array

Anno Knierim
born in Hagen

2022

Chair of Experimental Physics V
Department of Physics
Technische Universität Dortmund

Reviewer:	Prof. Dr. Dr. Wolfgang Rhode
Co-reviewer:	Dr. Dirk Wiedner
Submission date:	7 September 2022

This thesis is set in Libertinus (Serif, Sans and Math) and Fira Code
typeset using LaTeX with LuaTeX from TeXLive 2021.
Title graphic by **TITLE GRAPHIC AUTHOR**.

Abstract

The abstract is a short summary of the thesis in English, and together with the German summary, it has to fit on this page.

Kurzfassung

Hier steht eine Kurzfassung der Arbeit in deutscher Sprache inklusive der Zusammenfassung der Ergebnisse. Zusammen mit der englischen Zusammenfassung muss sie auf diese Seite passen.

Contents

Gamma-Ray Astronomy

1

In recent years, gamma-ray astronomy has become an important research field in astroparticle physics. The term gamma-rays is generally denoted as photons with energies above 100 keV [7]. Due to this high-energy nature, gamma rays pose some of the most powerful cosmic rays (CR) in the universe and since they travel in straight lines, it is possible to pinpoint their sources accurately.

For the past two decades, ground-based Imaging Air Cherenkov Telescope (IACT) experiments like the Major Atmospheric Gamma-Ray Imaging Cherenkov (MAGIC) telescopes, the Very Energetic Radiation Imaging Telescope Array System (VERITAS) and the High Energy Stereoscopic System (H. E. S. S.) have been monitoring these very-high-energy gamma rays (VHE gamma rays) to gain an understanding of their production.

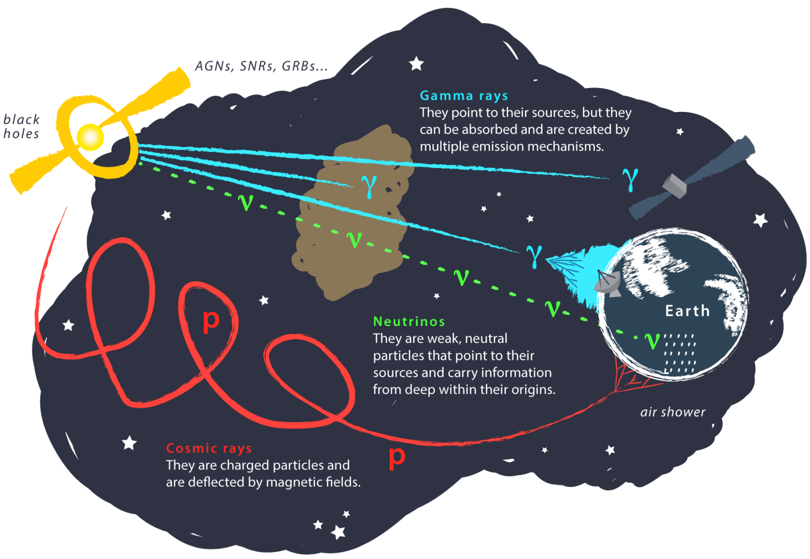


Figure 1.1: Different types of cosmic rays on their way to Earth. Charged particles like protons and electrons are deflected by magnetic fields and therefore making it hard to pinpoint the source. Only the origin of photons and neutrinos can be reconstructed directly since they are uncharged particles and therefore travel in straight lines. However, photons can be absorbed or created in multiple mechanisms. Since neutrinos only rarely interact with matter via the weak force, their detection is significantly harder than for photons [3].

2 IACTs and the Cherenkov Telescope Array

Most modern gamma-ray observations are performed with IACTs, which are ground-based telescopes or arrays of telescopes that use the Cherenkov light emitted by Extensive Air Shower (EAS) in the atmosphere. Since they are ground-based, IACTs are taking advantage of the Earth's atmosphere to get a larger effective area than space-based instruments. This is especially true for energies above 100 GeV, where the gamma-ray flux is low compared to lower energies. The cosmic ray flux is shown in Figure 2.1.

confirm values

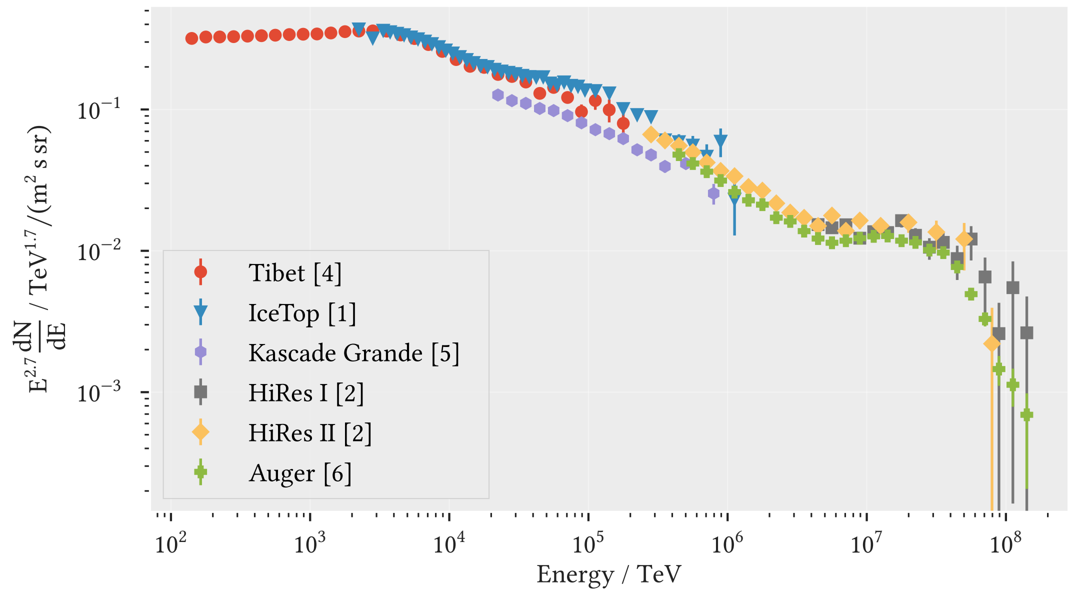


Figure 2.1: The cosmic ray flux as a function of energy. The flux is given in 1/(s m^2 sr).

PLACEHOLDER, MAYBE USE A DIFFERENT PLOT?

The Cherenkov Telescope Array (CTA) is a new generation of IACTs that will consist of two sites, one of which will be built at the Observatorio del Roque de los Muchachos (ORM) on the Canarian island of La Palma while the other site will be built in the southern hemisphere at the European Southern Observatorys (ESO) Paranal Observatory in the Atacama desert of northern Chile.

3 Data Preprocessing

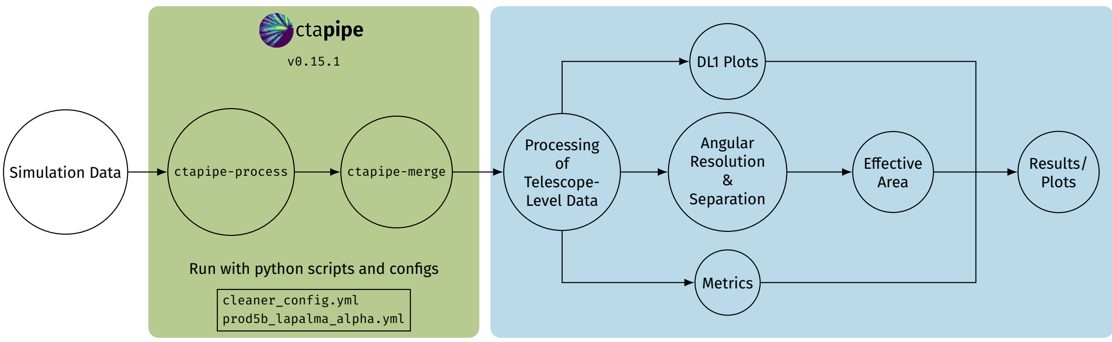


Figure 3.1: Data Preprocessing

```python
def metrics(events, output_file_metrics, unique_file_id):
    """Calculates the metrics for the given telescope type.

    Parameters:
    -----------
    events: astropy.table.Table
        The events table. Must contain the following columns:
        - true_image: The true image of the event.
        - image: The event image containing background noise.
    output_file_metrics: pathlib.Path
        The path to the output file for the metrics.
    unique_file_id: int
        The unique file id for the input file.
    """

    # initialize the metrics calculator
    metrics_calc = TprFprCalculator(
        true_image=events["true_image"],
        image=events["image"],
        clean_mask=events["image_mask"]
    )

    # calculate the metrics
    metrics_data = metrics_calc.tpr_fpr()

    # write metrics data to DataFrame and then to a file
    metrics = pd.DataFrame(data=metrics_data)
    metrics.insert(loc=0, column='unique_file_id', value=unique_file_id)
    metrics.to_csv(
        output_file_metrics,
        index=False,
        mode='a',
        header=not output_file_metrics.exists()
    )
```

4 Finding Optimal Hyperparameters for the Cleaning Algorithms

4.1 Cleaning Algorithms

Write about cleaning algorithms

4.2 Hyperparameters

Write about the hyperparameters

5 Results

Conclusions and Outlook 6

Bibliography

1. M. G. Aartsen et al. (IceCube Collaboration). “Measurement of the cosmic ray energy spectrum with IceTop-73.” *PhysRevD* 88, 042004, 2013, page 042004.
   DOI: 10.1103/PhysRevD.88.042004. ARXIV: 1307.3795 [astro-ph.HE]
2. R. U. Abbasi et al. “First Observation of the Greisen-Zatsepin-Kuzmin Suppression.” *PRL* 100, 101101, 2008, page 101101.
   DOI: 10.1103/PhysRevLett.100.101101. ARXIV: astro-ph/0703099 [astro-ph]
3. J. A. Aguilar, J. Yang, and S. Bravo. *Neutrinos and gamma rays, a partnership to explore the extreme universe*. IceCube/WIPAC. 2016.
   https://icecube.wisc.edu/news/view/455 visited on 2022-08-05
4. M. Amenomori et al. “The All-Particle Spectrum of Primary Cosmic Rays in the Wide Energy Range from 10^{14} to 10^{17} eV Observed with the Tibet-III Air-Shower Array.” *Astrophysical Journal* 678, 2008, pages 1165–1179.
   DOI: 10.1086/529514. ARXIV: 0801.1803 [hep-ex]
5. M. Bertaina et al. “KASCADE-Grande energy spectrum of cosmic rays interpreted with post-LHC hadronic interaction models.” In: *Proceedings of the 34th International Cosmic Ray Conference*. Vol. 34. ICRC 2015. 2015, 359, page 359.
   DOI: 10.22323/1.236.0359
6. F. Fenu and Pierre Auger Collaboration. “The cosmic ray energy spectrum measured using the Pierre Auger Observatory.” In: *Proceedings of the 35th International Cosmic Ray Conference*. Vol. 301. ICRC 2017. 2017, 486, page 486
7. S. Funk. “Ground- and Space-Based Gamma-Ray Astronomy.” *Annual Review of Nuclear and Particle Science* 65:1, 2015, pages 245–277.
   DOI: 10.1146/annurev-nucl-102014-022036. https://doi.org/10.1146/annurev-nucl-102014-022036

Glossary

CR cosmic rays. 1

CTA Cherenkov Telescope Array. 2

EAS Extensive Air Shower. 2

ESO European Southern Observatory. 2

H. E. S. S. High Energy Stereoscopic System. 1

IACT Imaging Air Cherenkov Telescope. 1, 2

MAGIC Major Atmospheric Gamma-Ray Imaging Cherenkov. 1

ORM Observatorio del Roque de los Muchachos. 2

VERITAS Very Energetic Radiation Imaging Telescope Array System. 1

VHE gamma rays very-high-energy gamma rays. 1

Appendix

Hier könnte ein Anhang stehen, falls Sie z. B. Code, Konstruktionszeichnungen oder Ähnliches mit in die Arbeit bringen wollen. Im Normalfall stehen jedoch alle Ihre Resultate im Hauptteil der Bachelorarbeit und ein Anhang ist überflüssig.

Acknowledgements

Eidesstattliche Versicherung

(Affidavit)

Name, Vorname
(surname, first name)

Matrikelnummer
(student ID number)

☐ Bachelorarbeit
(Bachelor's thesis)

☐ Masterarbeit
(Master's thesis)

Titel
(Title)

Ich versichere hiermit an Eides statt, dass ich die vorliegende Abschlussarbeit mit dem oben genannten Titel selbstständig und ohne unzulässige fremde Hilfe erbracht habe. Ich habe keine anderen als die angegebenen Quellen und Hilfsmittel benutzt sowie wörtliche und sinngemäße Zitate kenntlich gemacht. Die Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

I declare in lieu of oath that I have completed the present thesis with the above-mentioned title independently and without any unauthorized assistance. I have not used any other sources or aids than the ones listed and have documented quotations and paraphrases as such. The thesis in its current or similar version has not been submitted to an auditing institution before.

Ort, Datum
(place, date)

Unterschrift
(signature)

Belehrung:
Wer vorsätzlich gegen eine die Täuschung über Prüfungsleistungen betreffende Regelung einer Hochschulprüfungsordnung verstößt, handelt ordnungswidrig. Die Ordnungswidrigkeit kann mit einer Geldbuße von bis zu 50.000,00 € geahndet werden. Zuständige Verwaltungsbehörde für die Verfolgung und Ahndung von Ordnungswidrigkeiten ist der Kanzler/die Kanzlerin der Technischen Universität Dortmund. Im Falle eines mehrfachen oder sonstigen schwerwiegenden Täuschungsversuches kann der Prüfling zudem exmatrikuliert werden. (§ 63 Abs. 5 Hochschulgesetz - HG -).

Die Abgabe einer falschen Versicherung an Eides statt wird mit Freiheitsstrafe bis zu 3 Jahren oder mit Geldstrafe bestraft.

Die Technische Universität Dortmund wird ggf. elektronische Vergleichswerkzeuge (wie z.B. die Software „turnitin") zur Überprüfung von Ordnungswidrigkeiten in Prüfungsverfahren nutzen.

Die oben stehende Belehrung habe ich zur Kenntnis genommen:

Official notification:
Any person who intentionally breaches any regulation of university examination regulations relating to deception in examination performance is acting improperly. This offense can be punished with a fine of up to EUR 50,000.00. The competent administrative authority for the pursuit and prosecution of offenses of this type is the Chancellor of TU Dortmund University. In the case of multiple or other serious attempts at deception, the examinee can also be unenrolled, Section 63 (5) North Rhine-Westphalia Higher Education Act (*Hochschulgesetz, HG*).

The submission of a false affidavit will be punished with a prison sentence of up to three years or a fine.

As may be necessary, TU Dortmund University will make use of electronic plagiarism-prevention tools (e.g. the "turnitin" service) in order to monitor violations during the examination procedures.

I have taken note of the above official notification:*

Ort, Datum
(place, date)

Unterschrift
(signature)

***Please be aware that solely the German version of the affidavit ("Eidesstattliche Versicherung") for the Bachelor's/ Master's thesis is the official and legally binding version.**