Master's Thesis

Advanced Muon Tagging For H.E.S.S.

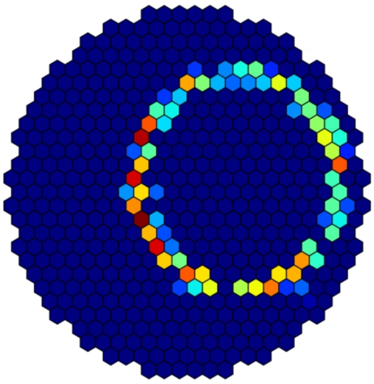

Abbildung 1: Image of a muon as observed by VERITAS, image credit: Muon Hunters 2.0 Team.

The High Energy Stereoscopic System (H.E.S.S.) is an array of Imaging Atmospheric Cherenkov Telescopes (IACTs) located in Namibia, that has been operated since 2004. It is designed to observe the γ-ray sky from $0.05 - 100$ TeV by observing the Extensive Air Showers (EAS) created when such photons interact in Earth's atmosphere. In order to calibrate the optics of the telescope, and to reduce the background from hadronic EAS, it is important to be able to identify cosmic ray muons present in H.E.S.S. data. These muons make characteristic ring images in IACT cameras when they pass along the telescope's optical axis (above), but these can be truncated depending on the muons trajectory.

This masters project will build upon the previous Muon Hunters 2.0 project by VERITAS (another IACT array, `https://arxiv.org/abs/2108.07771`). The student will build a basic pipeline to process low-level H.E.S.S. data, and then apply deep unsupervised learning techniques to filter out complete and partial muon rings from other EAS events. The aim will be to determine if deep learning alone can match the performance of techniques that require human labelling.

Skills acquired during this work:

- Open-Source Software Development Using *Python* and *PyROOT*
- IACT Data Analysis
- Deep Learning with *Keras*

Interested? Please get in touch:

- Dr. Samuel Spencer, samuel.spencer@fau.de
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- Dr. Alison Mitchell, alison.mw.mitchell@fau.de
  Büro 02.038, Nikolaus-Fiebiger-Str. 2

Erlangen Centre for Astroparticle Physics

Master Thesis Project

Gamma-ray astronomy searches for evidence of astrophysical particle accelerators - sources of energetic Cosmic Rays. Gamma-rays are detected via Extensive Air Showers (EAS) that develop in the Earth's atmosphere, cascades of particles producing Cherenkov light. The size of the EAS relates to the energy of the gamma-ray, such that atmosphere acts as a calorimeter for gamma-ray detection. The light from these Extensive Air Showers is detected by Imaging Atmospheric Cherenkov Telescopes (IACTs) such as the H.E.S.S. telescope array located in Namibia.

Variation of atmospheric conditions, e.g. by the presence of aerosols of cirrus clouds, can affect the amount of Cherenkov light detected. To correctly account for these effects, Lidar measurements are used, where a laser beam is fired into the atmosphere and the amount of light reflected from different altitudes is measured.

Correcting for Atmospheric Effects using a Lidar

This project will use Lidar measurements from the H.E.S.S. site to construct an altitude dependent transmission profile for the atmosphere under varying conditions. The level of natural variations and optimum correction methods will be investigated. Different approaches will be compared, in particular their result on the final gamma-ray performance metrics. Evaluation of the methods may use both on data from the H.E.S.S. telescopes and preliminary data for the forthcoming Cherenkov Telescope Array.

You will develop programming and data analysis skills, whilst studying the physics of particle interactions and the Earth's atmosphere.

Photo of a Lidar at the VLT ESO site, Paranal. Image credit: ESO/Y. Beletsky

Physics topics related to this work:

- Atmospheric Physics
- Gamma-ray Astronomy
- Imaging Atmospheric Cherenkov Telescopes

Skills acquired during this work:

- Python / C++ programming
- Gamma-ray data analysis
- Lidar instrument data analysis

Interested? Please get in touch:

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Dr. Rodrigo Guedes Lang, rodrigo.lang@fau.de

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Master's Thesis

Gamma-ray astronomy searches for evidence of astrophysical particle accelerators - sources of energetic Cosmic Rays. Pulsars are known to accelerate electrons and positrons to high energies ($\sim 10^{12}$ eV). These energetic particles stream away from the pulsar in a wind and occupy a region around the pulsar known as the nebula. Pulsar wind nebulae are among the most common astrophysical sources known in very-high-energy (VHE, $\sim 10^{12}$ eV) gamma-ray astronomy. This project will investigate a potential discovery of a new gamma-ray source - is there a nebula around the pulsar PSR J1828-1101?

HESS J1828-111 : A New Pulsar Wind Nebula?

This project will analyse data from the H.E.S.S. experiment, where indications for a new gamma-ray source have been seen. The aim is to confirm the detection of this emission, characterise the properties and determine its origin. Can the new source - tentatively called "HESS J1828-111" based on its co-ordinates in the H.E.S.S. data - be described by a model of the expected behaviour from pulsar wind nebulae?

You will develop programming and data analysis skills, whilst gaining a deeper knowledge of the physics of pulsar wind nebulae.

Physics topics related to this work:

- High Energy Astrophysics
- Gamma-ray Astronomy
- Pulsar environments
- Imaging Atmospheric Cherenkov Telescopes

Skills acquired during this work:

- Python programming
- Gamma-ray data analysis
- Astrophysical source modelling

Composite multi-wavelength image of the Crab pulsar wind nebula.

Interested? Please get in touch:

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Erlangen Centre for Astroparticle Physics

Bachelor / Master's thesis

Gamma-ray astronomy searches for evidence of astrophysical particle accelerators - sources of energetic Cosmic Rays. Within our own Milky Way Galaxy, a wide variety of natural particle accelerators are known, including supernovae, pulsars and their environments, stellar clusters and binary star systems. To identify the origins of the most energetic Cosmic Rays in our Galaxy, a new facility, the Southern Wide-field Gamma-ray Observatory (SWGO), is being planned to observe the Southern sky. This project will investigate the potential SWGO has for studying different phenomena in the very-high-energy gamma-ray sky. Recent results from both the HAWC and LHAASO facilities have revealed exciting discoveries in the Northern sky - what could we see in the South?

Galactic Sources with SWGO

This project will simulate different source classes that we expect to encounter with SWGO in the Southern sky. The aim is to identify which areas SWGO will outperform other experimental facilities and consolidate the open questions where SWGO will excel. Possible projects may focus on simulating pulsar environments in various evolutionary stages, on stellar clusters, or on time-varying sources such as binary systems comprised of a massive star and a compact companion (White Dwarf, Neutron Star or Black Hole).

You will develop programming and data analysis skills, whilst gaining a deeper knowledge of the physics of various Galactic sources of cosmic rays.

Physics topics related to this work:

- High Energy Astrophysics
- Gamma-ray Astronomy
- Imaging Atmospheric Cherenkov Telescopes

Skills acquired during this work:

- Python programming
- Gamma-ray data analysis
- Astrophysical source modelling

Composite multi-wavelength image of the Crab pulsar wind nebula.

Interested? Please get in touch:

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Bachelor / Master's thesis

Gamma-ray astronomy is concerned with some of the highest energy signals from the universe. Ground-based instruments detect gamma-ray photons via the Extensive Air Showers that they generate in the Earth's atmosphere. A cascade of highly energetic particles produces Cherenkov emission as they pass through water tanks located at high altitudes. By reconstructing these Cherenkov light signals, the energy and direction of the original gamma-ray photon can be determined.

The Southern Wide-field Gamma-ray Observatory (SWGO), is a Water Cherenkov Detector facility being planned to observe the Southern sky. This project will develop new techniques for calibrating the efficiency with which water Cherenkov facilities - such as SWGO - measure Cherenkov radiation.

Light Efficiency Calibration of SWGO using Muons

This project will use simulations of muons within SWGO to develop a method of calibrating the light collection efficiency. The aim is to recover how well the expected light signal from muons can be characterised, and how sensitive this measurement is to degradations in efficiency. (For example via degradation of the photomultiplier tube or of the water quality.) Furthermore, inter-calibration of individual water tanks within the array may be explored.

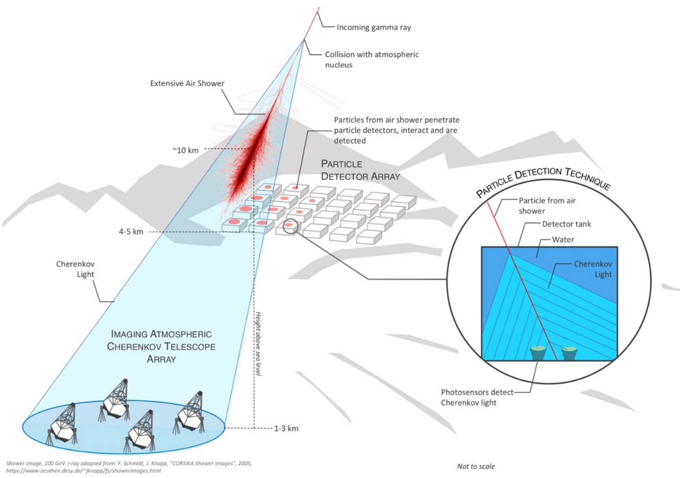
You will develop programming and data analysis skills, whilst gaining a deeper knowledge of the physics of extensive air showers and the detector.

Physics topics related to this work:

- Extensive Air Showers
- Water Cherenkov Detectors

Skills acquired during this work:

- Python and/or C++ programming
- Data analysis
- Calibration



Schematic showing the detection of Cherenkov radiation from an Extensive Air Shower.

Interested? Please get in touch:

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- Pedro Battista
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Erlangen Centre for Astroparticle Physics

Bachelor / Master’s thesis
in Hardware Development

The Cherenkov Telescope Array Observatory (CTAO) is the next generation of telescope systems to observe high-energy gamma rays. In line with CTAO, the ECAP/work group of Stefan Funk takes an active part in the development of a front-end electronics, based on the sampling (CTC) and trigger (CT5TEA) ASIC (application-specific integrated circuit) TARGET (TeV array readout and Event Trigger). This is to take over the digitization of silicon photomultiplier signals in the Small Size Telescope Cameras (SSTCam).

Bachelor thesis

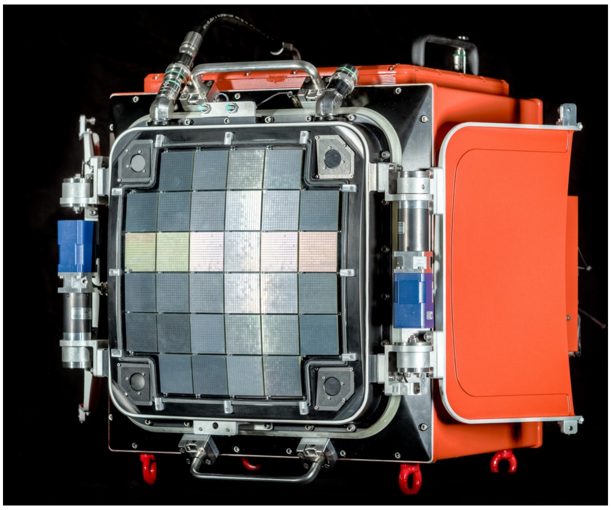
- Characterisation of trigger and read-out chain of the latest TARGET ASIC generation
- Optimization of the trigger threshold lookup generation for the SSTCam TARGET modules
- Developing a robust peak extraction algorithm for CTC
- In-depth study of the CTC’s ”cell 32 anomaly”

Master’s thesis

- Feasibility Study of Utilizing the CTC for read-out of a High Channel Count Phase Camera in the Einstein Telescope Experiment
- Online CTC ramp tuning for temperature variation compensation

Physics topics related to this work

- Ground based gamma ray telescopes
- State-of-the-art electronics



Skills acquired during this work

- Statistical analysis of data
- Programming in Python
- Understanding of electronics instruments

Interested? Please get in touch!

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Room 02.036, ECAP laboratory

Erlangen Centre for Astroparticle Physics

Bachelor thesis

in Hardware Development

Characterisation of trigger and read-out chain of the latest TARGET ASIC generation

The goal of this thesis is to understand the performance of the latest TARGET Trigger ASIC (CT5TEA). Several parameters can be tuned to achieve low noise and low trigger thresholds, which enables the detection of single photon pulses or a large dynamic range for multi-photon signals with high precision. The knowledge from previous versions can be used as a good starting point.

Optimization of the trigger threshold lookup generation for the SST Cam TARGET modules

For CTAO, the ECAP will produce, commission and calibrate in the order of 1,600 TARGET modules for the envisaged 42 SST Cams. One of the main calibration topics is the generation of a trigger threshold lookup. Clever routines and/or new methods need to improve the time needed for this step.

Developing a robust peak extraction algorithm for CTC

For the energy reconstruction of a gamma ray event, it is important to accurately determine the number of detected Cherenkov photons. This number is proportional to the amplitude and intergral of the voltage pulse measured in the Silicon Photomultiplier. Extracting these is crucial to the success of CTAO. To archive the best possible signal to noise ratio, a matched filter shall be implemented for the peak extraction. As there will be 42 SST Cams build with 32 TARGET modules each, it is important to know how sensitive the algorithm is to variations and environmental factors.

In-depth study of the CTC's "cell 32 anomaly"

To avoid uncontrollable amounts of data, the CTC ASIC uses a ring buffer to temporally store the data before it is digitized (if a trigger hits). One issue of this ring buffer is, that the 31st sample modulo 32 shows a different behaviour, limiting the resolution of the Analog to Digital Converter and therefore the resolution of the SST Cam. The task would be to localise the cause of this behaviour in the ASIC and to fix it.

Interested? Please get in touch!

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Erlangen Centre for Astroparticle Physics

CTAO

Master’s thesis

in Hardware Development

Feasibility Study of Utilizing the CTC for read-out of a High Channel Count Phase Camera in the Einstein Telescope Experiment

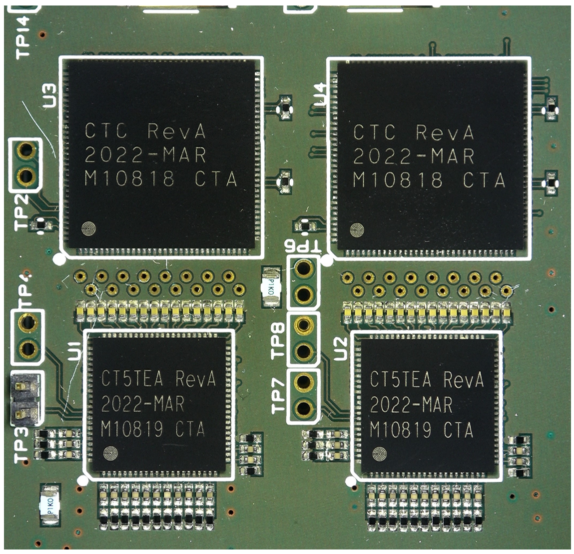
The proposed thesis aims to explore the feasibility of adapting the low-cost CTC ASIC for use in the Einstein Telescope, a next-generation gravitational wave detector. The ASIC in question features a sampling rate of 1 GSa/s and 16 channels. This thesis will investigate its potential application in reading out a high channel count phase camera, specifically one with up to 4096 channels, composed of a fiber array, high gain transimpedance amplifiers, and photodiodes, designed to measure the phase of a laser wavefront.

Online CTC ramp tuning for temperature variation compensation

The CTC has shown a great temperature dependency, which could be localised in the Analog to Digital Converter, where the sample gets compared to a rising voltage ramp, while a clock counts the time until the ramp crosses the sampled value. The slope of the ramp changes with temperature, leading to higher or lower values of the clock. Additional to that, the slope of the ramp voltage changes with the voltage of the sampled value. Past approaches calibrated the whole ASIC including the ring buffer, which is computationally and data intensive. For the data out of CTAO, the calibration needs to be as accurate as simple to run on a server which host over 42 SSTs.

Interested? Please get in touch!

Prof. Stefan Funk, s.funk@fau.de
Room 02.036, ECAP laboratory



Erlangen Centre for Astroparticle Physics

Master's Thesis

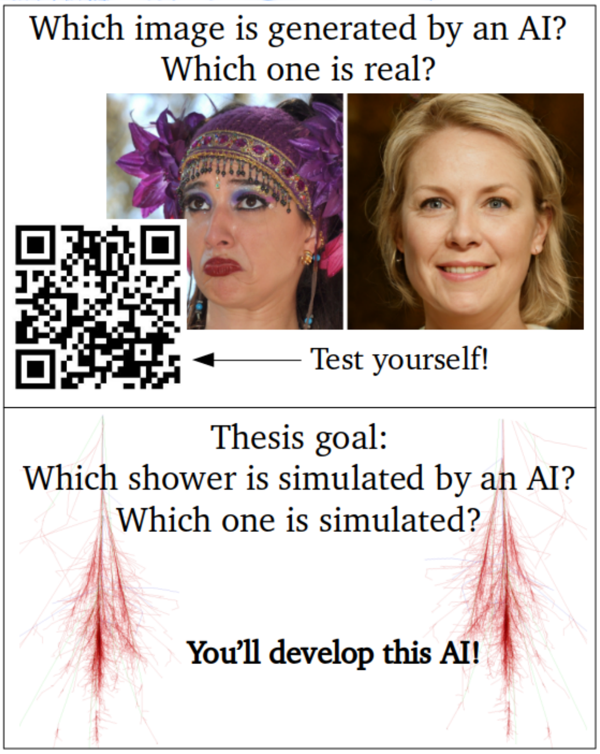
Artificial intelligence (AI) has become an integral part of our daily lives, revolutionizing industries and enhancing our capabilities in countless domains. With recent breakthroughs in deep learning, AI has demonstrated its immense potential to tackle complex challenges. We are now at an exciting juncture where we can harness the power of AI to accelerate knowledge discovery in fundamental science using novel algorithms with unprecedented performance.
Modern experiments and observatories detect an enormous amount of data, requiring large amounts of simulations which are time-consuming and computationally expensive. With the recent progress in deep learning, we can accelerate such simulations using generative models.

Accelerating Air Shower Simulations using Deep Neural Networks

In this master's thesis, we aim to develop an algorithm that accelerates the generation of air shower simulations, simulated using CORSIKA, through the use of state-of-the-art network architectures like generative adversarial networks or diffusion models. Air showers are cascades of particles generated when high-energy cosmic rays interact with the Earth's atmosphere. Since, in theory, each particle interaction has to be simulated, the generation of air showers is time-consuming.

By leveraging deep neural networks, we can generate these simulations much faster and more efficiently than traditional methods, paving the way for cost-efficient algorithms that not only accelerate the generation of air shower simulations but also enables to enhances their accuracy by increasing their details without an increase in computational costs.

As a member of our research group, you will work alongside passionate physicists and machine learning enthusiasts, and we offer you access to a powerful GPU computing cluster. Take advantage of this opportunity to combine your passion for physics and AI while contributing to the scientific community!



Top: www.whichfaceisreal.com, photographs from the FFHQ dataset, generated image from www.thispersondoesnotexist.com. Bottom: Fabian Schmidt

Physics topics related to this work:

- Development of deep learning algorithms
- Simulation of particle cascades

Skills acquired during this work:

- Python coding skills
- Expertise in machine learning, deep learning, and data science

Interested? Please get in touch:

- Dr. Jonas Glombitza, jonas.glombitza@fau.de
- Prof. Dr. Stefan Funk, s.funk@fau.de

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Master's Thesis

Are you fascinated by the ever-expanding possibilities of Artificial Intelligence (AI) and its impact on our daily lives? Are you passionate about unraveling the mysteries of physics?
We invite you to embark on a cutting-edge journey as we explore the application of AI in the context of physics challenges. With recent breakthroughs in deep neural networks, AI has reached new heights, demonstrating its immense potential to tackle complex challenges. Modern experiments and observatories produce an enormous amount of data, often too vast and complex for traditional analysis methods to fully comprehend. With AI, we can analyze this vast trove of information with unprecedented efficiency and accuracy.

Improved reconstruction algorithms using Deep Neural Networks

This thesis work focuses on the improved reconstruction of Air Showers detected by Imaging Atmospheric Cherenkov Telescopes (IACTs), like the Cherenkov Telescope Array. Air Showers are cascades of particles generated when high-energy cosmic rays collide with the Earth's atmosphere. The accurate reconstruction of these events is crucial for understanding the nature and origins of cosmic rays. By leveraging state-of-the-art network architectures and advanced machine learning techniques, you will be at the forefront of developing innovative approaches for the precise reconstruction of Air Showers.

As part of our research group, you will work with passionate physicists with a strong background in machine learning, gaining expertise in data science and event reconstruction. Moreover, you will have access to powerful computing resources, including NVIDIA A100 and NVIDIA A40 GPUs, ensuring that you have the necessary tools to execute your research fast and efficiently.

Physics topics related to this work:

- Development of deep learning algorithms
- Experimental detection of astroparticles

Skills acquired during this work:

- Python coding skills
- Expertise in machine learning, deep learning, and data science

Interested? Please get in touch:

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- Prof. Dr. Stefan Funk, s.funk@fau.de
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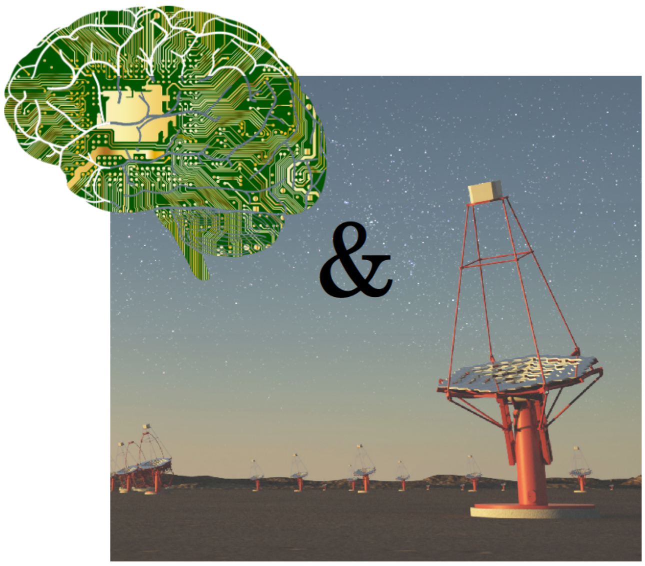


Modification of private work by G. Perez, IAC
and https://www.pngwing.com/en/free-png-bppox

ERLANGEN CENTRE
FOR ASTROPARTICLE
PHYSICS

Master’s Thesis

Super Resolution applied to Cherenkov Telescope Camera Images

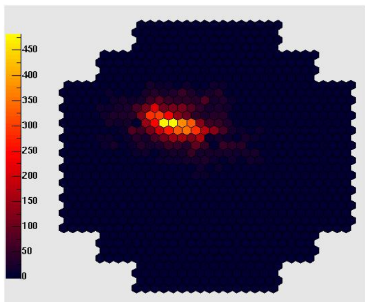
In this master’s thesis, you will use of machine learning (AI) techniques to develop an algorithm to increase the resolution of the Cherenkov telescope camera to enable more sophisticated analyses of the recorded image data.

Using the H.E.S.S. experiment air showers induced by highly energetic photons from outer space are imaged using Imaging Air Cherenkov Telescopes (IACTs), equipped with a dedicated camera system. The obtained images are characterized by analytical parameters describing the signal shape that carries information about the primary particle, its energy, and its origin. The reconstruction quality is, among other factors, limited by the resolution of the instrument’s camera. In this work, you will develop a machine learning architecture based on generative models to transform a low-resolution image into a realistic high-resolution image. By increasing the image resolution, you will enhance the details of the cosmic signal, opening the potential for more precise analyses of the recorded data.

As part of our research group, you will work with passionate physicists with a strong background in machine learning, gaining expertise in data science and event reconstruction. Moreover, you will have access to powerful computing resources, including NVIDIA A100 and NVIDIA A40 GPUs, ensuring that you have the necessary tools to perform your research.

Physics topics related to this work:

- Development of deep learning algorithms
- Analysis of IACT images



IACT image detected with one of the H.E.S.S. telescopes

Skills acquired during this work:

- Python coding skills
- Expertise in machine learning and deep learning
- Precise analysis of data

Interested? Please get in touch:

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Master’s Thesis

Relativity has been one of the most widely tested theories ever and yet it has survived every experimental test so far. Nevertheless, several novel high-energy models either accommodate or assume some deviation of relativity via Lorentz invariance violation (LIV). This effect is expected to become significant only at the highest energies and, thus, astroparticles play a crucial role in searching for signals of LIV.

Estimating the potential of SWGO to study Lorentz invariance violation

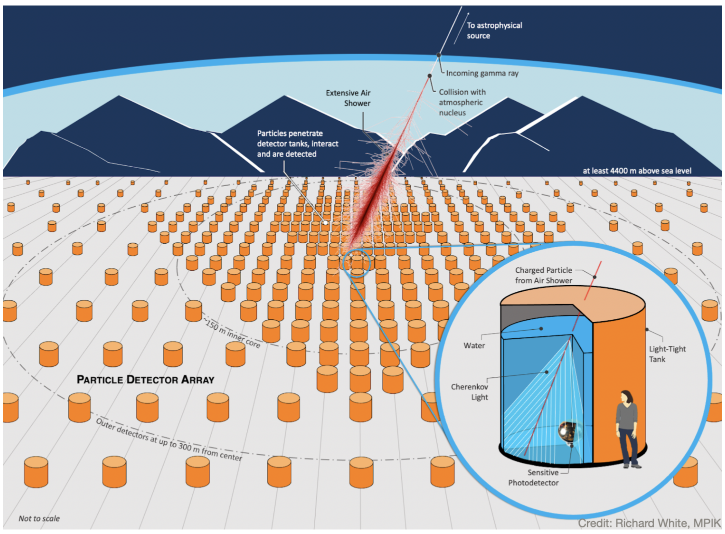
Over the last years, the potentiality of using astroparticles as a probe for LIV has been extensively proved. In particular, very-high-energy (VHE) gamma rays play an important role in this search due to their high energy, long travel distance (which leads to accumulation of the effects), and exceptional experimental precision. Several phenomenological tests of LIV using data from the current generation of experiments have been performed. No signal of LIV has been detected, leading to the most restrictive limits on the energy range of validity of relativity imposed up to date. The Southern Wide-field Gamma-ray Observatory (SWGO) is a planned future ground-particle-based experiment to be built high in the Andes currently in the research and development phase. The aim of this thesis is to estimate the potential of SWGO to study LIV, in particular by calculating the expected level of imprint in data coming from a modified interaction of gamma rays with the extra-galactic background light (EBL) and/or from photons of different energy having a different “speed of light” due to LIV.

Physics topics related to this work:

- Lorentz invariance violation
- Propagation of gamma rays and the EBL
- Ground-based gamma-ray observatories

Skills acquired during this work:

- Phenomenological interplay between theoretical and experimental physics
- Data analysis techniques



Scheme of SWGO
Credits: Richard White, MPIK.

Interested? Please get in touch:

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Master thesis

The High Energy Stereoscopic System (H.E.S.S.) is an Imaging Atmospheric Cherenkov Telescope (IACT) that measures gamma rays with energies above about 100 GeV. H.E.S.S. consists of four medium-size and one large-size telescopes. H.E.S.S. has detected numerous point-like and slightly extended sources. However, detection of sources with extension exceeding a few degrees is challenging due to small field of view (less than 5 degrees diameter) and large residual background from cosmic ray showers. In order to study such sources one needs a background model that covers the full H.E.S.S. field of view rather than to use the on-off analysis method, which is used for small-size sources.

Development of H.E.S.S. background model with deep learning

A method for data-driven background determination from high-latitude observations has been developed: background model is derived by averaging the data outside of the known sources of high-energy gamma rays. This method however requires a choice of binning in several variables, such as energy and zenith angle, which leads to high systematic uncertainties at small and high energies. The project is to determine the background model using deep learning methods, more specifically a decoder that takes some input parameters, e.g., energy and zenith angle, and outputs a map representing the expected background.

Physics topics related to this work:

- High-energy astrophysics
- Observation of very high energy gamma rays with IACTs

Skills acquired during this work:

- Programming in Python
- Deep learning methods

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