MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK
Non-Thermal Astrophysics Division

SWGO

The forthcoming gamma-ray observatory SWGO will detect particle showers produced by high-energy cosmic rays and photons in the atmosphere. The charged particles in these showers produce Cherenkov light in SWGO's water-filled detector units. The Cherenkov light is detected by photomultiplier tubes (PMTs) — fast and highly sensitive light sensors — whose signals are digitised by high-speed electronics custom-designed at MPIK. Our group maintains several test setups for PMTs, electronics, materials and complete detector units, and is involved in software development for all aspects of the simulation, data acquisition and analysis chain.

Below are topics for potential Master's theses at MPIK.

Contact `felix.werner@mpi-hd.mpg.de` if you are interested or scan this QR code →

ELECTRONICS SIMULATION DEVELOPMENT AND VERIFICATION

Contact: `johannes.bennemann@mpi-hd.mpg.de`

Reconstruction of the particle showers' properties requires accurate simulations of all detector elements. The candidate would develop a computationally efficient simulation of the response of the combined PMT and electronics chain. Measurements of fast light pulses with different intensities and time profiles will be used to extract simulation parameters and templates, and to perform an end-to-end verification of the simulation.

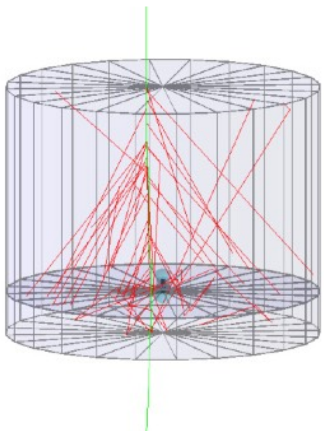
PMT MAGNETIC FIELD DEPENDENCY AND INHOMOGENEITY

The responses of the candidate PMTs for SWGO depend on the magnetic field environment and the position of illumination. The candidate would help design and build a dedicated test setup, qualify these effects and draw conclusions on the optimal orientation of the PMTs (and tolerances) for the specific magnetic field at the SWGO site.

ONLINE CALIBRATION ALGORITHMS

SWGO will consist of many thousands of detector units that will be exposed to changing weather conditions for more than a decade. Efficient operation requires a fully automated and robust approach to calibration and monitoring. The candidate would study and implement algorithms that estimate and adjust the operational parameters of the detector channels, and test them on the prototype detectors operating at MPIK.

DETECTOR CALIBRATION USING TAGGED MUONS



Cosmic rays are the main background for gamma-ray detectors. A key improvement over previous water Cherenkov detectors is to efficiently tag through-going muons, a signature of hadronic primary particles, using an additional detector layer. Our group has developed a machine learning algorithm that efficiently tags muons based on signals from such a dual-layer detector. The candidate would investigate how tagged muon signals can be used to infer changes in water transparency and wall reflectivity, and whether muons can be used for cross-calibration of channels.

15. January 2025

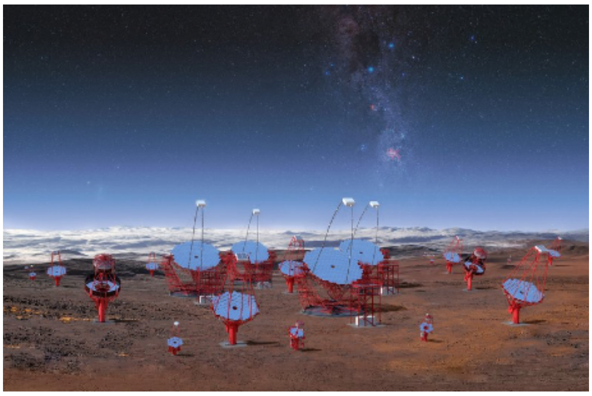
A HYBRID MACHINE LEARNING-LIKELIHOOD RECONSTRUCTION FOR SWGO

Contact: `georg.schwefer@mpi-hd.mpg.de`

Reconstructing the energy and arrival direction of the primary gamma-rays producing the air showers measured by SWGO is central to the operation and performance of the observatory. As demonstrated on other observatories, methods that combine machine learning with likelihood-based approaches are particularly promising options.

The aim of this thesis is to adapt and apply such a recently developed method to SWGO simulations and assess its performance.

CTA



Cherenkov Telescope Array (CTA) is a flagship astronomical facility which will have transformational impact in the gamma-ray domain and broadly in high energy astrophysics. In 2025, construction of the first small and medium size telescopes of the southern part of CTA will begin in Chile. For both types of telescope, MPIK will supply the Cherenkov cameras - custom-built, high-sensitivity, high-speed cameras that are currently undergoing design finalisation. Extensive darkroom testing is underway to prepare the hardware, software and procedures to rapidly get the cameras ready for science operation once they are installed in the field.

Below are topics for potential Master's theses at MPIK.

Contact jim.hinton@mpi-hd.mpg.de if you are interested or scan this QR code →

PERFORMANCE & ROBUSTNESS VERIFICATION OF THE LOSSY EVENT COMPRESSION
Contact: felix.werner@mpi-hd.mpg.de

The high-speed cameras of the Cherenkov Telescope Array will produce hundreds of petabytes of high-precision event data per year. Our group is developing an efficient and robust data reduction algorithm to ensure that only scientifically useful data is stored in the long term. The candidate would study how variations in detector performance and observing conditions affect the scientific performance using simulations and data.

SUPPRESSING BACKGROUND FOR CTA USING GOODNESS-OF-FIT VARIABLES
Contact: georg.schwefer@mpi-hd.mpg.de

Most images recorded by Imaging Air Cherenkov Telescopes do not originate from the air showers produced by gamma-rays, but by air showers from protons and other nuclei. Suppression of this background is crucial for the performance of the telescopes.

A possible parameter that could be used to improve this separation is the goodness-of-fit of the measured images to expected gamma-ray image templates

The goal of this thesis is to construct such a goodness-of-fit variable using machine learning-based inference techniques and to test its impact on the background suppression.

USING IMAGE TIMINGS TO IMPROVE GAMMA-RAY RESOLUTION
Contact: georg.schwefer@mpi-hd.mpg.de

Imaging Atmospheric Cherenkov Telescopes record the Cherenkov light produced by air showers from high-energy gamma rays in the atmosphere. In order to reconstruct the energy and arrival direction of the original gamma ray, often only the time-integrated image of the air shower is used. The timing of the recorded shower can however also include valuable information for the reconstruction.

The goal of this project is to extend a recent machine-learning based reconstruction method beyond the use of the time-integrated image to also include the timing information and to assess the impact on the reconstruction performance.

IMPROVING GAMMA-RAY RESOLUTION THROUGH MULTI-STEP IMAGE FITTING

Contact: `georg.schwefer@mpi-hd.mpg.de`

Imaging Atmospheric Cherenkov Telescopes record the Cherenkov light produced by air showers from high-energy gamma rays in the atmosphere. Reconstructing the energy and arrival direction of the primary gamma-rays is central to the operation and performance of the observatory. A well-established reconstruction method involves fitting expected gamma-ray image templates to the measured images. These fits however require good fitting seeds in order to perform well. One possibility is to use a multi-step fit, where a simpler analytical template is fit in a first step. The goal of this thesis is to explore this multi-step fitting method and assess its performance compared to previous fitting seeds.

STATISTICAL METHODS AND DATA ANALYSIS SOFTWARE DEVELOPMENT

Contact: `quentin.remy@mpi-hd.mpg.de`

Gammapy is a community-developed, open-source Python package for gamma-ray astronomy built on Numpy, Scipy and Astropy. It is the core library for the CTA Science Tools but can also be used to analyse data from existing imaging atmospheric Cherenkov telescopes (IACTs), such as H.E.S.S., MAGIC and VERITAS. It also provides some support for Fermi-LAT, HAWC and SWGO analyses.

The goal of this project is to contribute to the ongoing developments of gammapy extending the analysis methods available and testing them on HESS and HAWC data, or CTA simulations. The work will focus on new statistical utilities including for example Bayesian Inference using nested sampling, regularization and multivariante priors, generalized degree of freedom and cross-validation for model selection. If you did not run away after reading the previous sentence and like writing code, then you should definitely contact us, will be fun I swear.