T 58: Cosmic Rays III

Time: Wednesday 16:15–18:00 Location: VG 3.102

T 58.1 Wed 16:15 VG 3.102

CORSIKA 8: A modern and universal framework for particle cascade simulations — •Marvin Gottowik for the CORSIKA8-Collaboration — Karlsruher Institut für Technologie, Institut für Astroteilchenphysik, Karlsruhe, Germany

CORSIKA 8 represents a major advancement in the simulation of particle showers, building on the well-established foundation of CORSIK 7. It has been entirely rewritten as a modular and modern C++ framework, addressing the limitations of its predecessor to provide a flexible platform designed to satisfy current and novel use cases. This includes applications beyond traditional air-shower scenarios, such as cross-media particle cascades and enhanced radio emission calculations. For the first time, both the endpoint formalism and ZHS algorithm can be applied to the same simulation, demonstrating convergence to within 2 % on the radiation energy for high-precision simulations. A first official "physics-complete" version has been released, supporting hadronic interactions with current-generation models and the electromagnetic cascade with PROPOSAL 7.6.2. In this presentation, we will discuss the design principles, current capabilities, and validation efforts of CORSIKA 8, highlighting its potential applications for future experiments.

T 58.2 Wed 16:30 VG 3.102

Inclined Air Showers with Corsika 8 and Pythia 8: Cracking the Muon Puzzle One Shower at a Time — •Chloé Gaudu for the CORSIKA8-Collaboration — Bergische Universität Wuppertal, Gaußstraße 20, 42119 Wuppertal, Germany

The field of air shower physics seeks to understand the development of cosmic-ray interactions with the Earth's atmosphere. A key challenge in this field is the discrepancy in the muon content of extensive air showers observed by cosmic-ray experiments, such as the Pierre Auger Observatory, compared to predictions from state-of-the-art hadronic interaction models. This discrepancy, commonly referred to as the *Muon Puzzle*, stems from limitations in modeling high-energy hadronic interactions. The Pythia 8 interaction model emerges as a promising candidate for shedding light on the Muon Puzzle, owing to its user-friendly tunability and recent advancements in the Angantyr module, which enhances its handling of nuclear interactions. With Pythia 8 now partially integrated into the Corsika 8 particle-shower simulation code, preliminary analyses of the muon content in air showers are feasible.

This work is a comparative analysis of inclined air showers induced by proton primaries at 10^{19} eV, using Corsika 8 with Pythia 8 and current state-of-the-art alternatives, focusing on how differences in hadronic interaction models are reflected in shower observables. The preliminary results offer valuable insights into how Pythia 8 can advance our understanding of the Muon Puzzle and point to directions for future developments. **Supported by DFG (SFB 1491)*

T 58.3 Wed 16:45 VG 3.102

Simulating radio emission of extensive air shower with real noise for deep learning reconstruction at the Pierre Auger Observatory* — •Sven Querchfeld and Julian Rautenberg for the Pierre-Auger-Collaboration — Bergische Universität Wuppertal, Gaußstraße 20, 42119 Wuppertal

The ErUM-Wave project aims to develop an AI model to reconstruct 3-dimensional wave fields with the goal to predict the propagation of seismic waves based on only a few measurements. To test the transferability of the developed method to other fields, it will be applied to the propagation of radio waves in the atmosphere. These waves are produced by cosmic ray-induced air showers measured with the Pierre Auger Observatory. As part of the AugerPrime upgrade, each Water Cherenkov Detector (WCD) has been equipped with an additional radio antenna, enlarging the radio detection (RD) technique to the entire array, covering 3000 km^2. Realistic simulations of detector signals require realistic noise. With its unpredictable characteristics this needs to be extracted from real measured data. For vertical shower the particle footprint that triggers the station read-out is much larger than the radio footprint on the ground. We select noise data from outer stations which are not expected to have any radio-signal. The set of simulated events using the CoREAS extension of CORSIKA with this extracted realistic noise added will be used for first test of AI models to reconstruct the 3-dimensional wave propagation.

T 58.4 Wed 17:00 VG 3.102

Studies on Monte Carlo generator tuning for cosmic-ray induced air shower simulations — •Michael Windau and Kevin Kröninger — TU Dortmund, Fakultät Physik

Monte Carlo (MC) generators are a fundamental tool in particle and astroparticle physics. To achieve a high-quality simulation of physical processes, the hadronic interaction model of the generator must be tuned efficiently. The free parameters of MC generators are optimized with the help of experimental data and Bayesian methods. One area of application for MC generators is the simulation of cosmic-ray induced air showers in the Earth's atmosphere. Since hadronic interactions have a direct influence on the composition of secondary particles in shower formations, tuning the parameters of these hadronic models has an impact on crucial observables such as the muon number.

In this talk, studies on the tuning of the Monte Carlo generator PYTHIA for cosmic-ray induced air showers, using data from air shower experiments, are presented.

T 58.5 Wed 17:15 VG 3.102

Uncertainties in Atmospheric Interactions — •Alicia Fattorini for the IceCube-Collaboration — TU Dortmund, Dortmund, Germany

Many astrophysical measurements rely on assumptions about the absolute atmospheric flux of cosmic rays and their interaction in our atmosphere. While cosmic ray detectors such as Pierre AUGER measure cosmic rays via their secondary emissions in the atmosphere, neutrino detectors such as IceCube, and IACTs such as MAGIC are subject to a background consisting of particles from the same interactions. For all these experiments, it is particularly important to understand the processes in the atmosphere and to be able to determine the flux of the emitted secondary particles. This work focuses on uncertainties in the processes occurring in the atmosphere where secondary particles are produced in cosmic ray-induced air showers, and in the cosmic ray flux itself. The aim is to estimate the normalization of the measured spectra and to determine the origin of the systematic uncertainties.

T 58.6 Wed 17:30 VG 3.102

comparing hadronic interaction models with air shower parameters at the IceCube Neutrino Observatory — •Fahim Varsi[1], Mark Weyrauch[2], Dennis Soldin[3], and Timo Peter Lemmer[1] for the IceCube-Collaboration — [1]Karlsruhe Institute of Technology, Institute of Experimental Particle Physics, Karlsruhe, Germany — [2]Karlsruhe Institute of Technology, Institute for Astroparticle Physics, Karlsruhe, Germany — [3]Department of Physics and Astronomy, University of Utah, Salt Lake City, USA

The IceCube Neutrino Observatory studies cosmic-ray extensive air showers (EASs) using a surface array of ice-Cherenkov detectors, known as IceTop, by detecting the electromagnetic component and low-energy (~GeV) muons of EASs. A new reconstruction method, utilizing different lateral distribution functions (LDFs) for the electromagnetic and muonic components of the detector signals, is applied to estimate the shower size and low-energy muon content of EASs on an event-by-event basis. However, due to systematic uncertainties in high-energy hadronic interaction models, the simulated predictions of these EAS parameters show a significant dependence on the high-energy interaction models. Consequently, a detailed study of these systematic uncertainties in the reconstructed parameters provides insights into model-dependent variations in cosmic-ray air shower studies. In this work, we compare the EAS parameters reconstructed using three hadronic interaction models: Sibyll 2.1, QGSJet-II.04, and EPOS-LHC, and the results will be presented at the conference.

T 58.7 Wed 17:45 VG 3.102

Impact of adding simulations of ultra-heavy cosmic rays on neural network-based estimators using surface detector data of the Pierre Auger Observatory — •Steffen Hahn for the Pierre-Auger-Collaboration — Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

To understand the physics of ultra-high-energy cosmic rays (UHECRs), an accurate estimate of the masses of UHECR is crucial. Direct detection of UHECRs is not feasible and requires the study of air showers induced by the interaction of UHECRs with the atmosphere. The surface detector stations of the Pierre Auger Observatory (Auger) measure the front of such cascades, called the shower footprint. Analyzing the spatio- temporal information of these shower footprints is highly nontrivial. Neural networks (NNs) offer a convenient way to exploit the correlations in the footprints and improve the reconstruction of high-level shower observables. However, simulations of UHECRs face limitations due to incomplete understanding of the high-energy hadronic interactions. The most prominent discrepancy is the muon puzzle – a systematic deficit of muons in simulations which complicates the application of simulation-trained NNs to Auger data. Typically, training data sets for Auger consist of a mix of proton, iron, and intermediate-mass nuclei. Since the number of muons produced in an air shower correlates with the mass of the UHECR, varying the mass composition in the training dataset could impact the transition to measurements. In this contribution, we show how the inclusion of heavier UHECRs affects NN-based estimators in simulations and measurements.