T 85: Cosmic Rays IV

Time: Thursday 16:15–17:45 Location: KS 00.006

T 85.1 Thu 16:15 KS 00.006

Simulating Cosmic-Ray Hadronic Interactions: Analytic vs. Monte Carlo — •Leonel Morejon — Bergische Universitaet Wuppertal, Wuppertal, Germany

Cosmic-ray hadronic interactions are important in explaining the production of very-high-energy photons and high-energy neutrinos arriving at Earth. For example, galactic neutrino emissions recently reported by IceCube, are expected to result from cosmic-ray interactions in the central region of the galaxy. Hadronic interactions can be modeled with Monte Carlo codes, but the computational effort to explore a variety of model parameters may produce limitations. Conversely, continuous production models exist and are faster to evaluate, but neglect the inherent stochasticity of these interactions.

An alternative approach is presented in this work, describing sequences of hadronic interactions analytically, using the precomputed tables for the products of individual interactions. This has the advantage of including stochastic effects in the sequence (unlike in continuous models) and reinteractions, while keeping the computation analytic, scalable and efficient. The correctness of this approach is verified by comparing to Monte Carlo simulations.

T 85.2 Thu 16:30 KS 00.006

Pythia 8/Angantyr and CORSIKA 8: Muon Puzzle and tuning* — •Chloé Gaudu for the CORSIKA8-Collaboration — Bergische Universität Wuppertal, Gaußstraße 20, 42119 Wuppertal

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 (EAS), widely referred to as the “Muon Puzzle”, observed by cosmic-ray experiments when comparing to predictions from commonly used hadronic interaction models. This puzzle might stem from limitations in modeling high-energy hadronic interactions, arising as model parameters are tuned to accelerator data probing lower energies than those relevant to EAS, thus requiring extrapolations into unmeasured phase space. With Pythia 8/Angantyr now fully integrated into the Corsika 8 particle-shower simulation code, analyses of EAS are feasible. Initial studies indicate that its default configuration fails to reproduce key measurements from the Pierre Auger Observatory. The Pythia 8/Angantyr model remains a promising candidate for shedding light on the Muon Puzzle, owing to its user-friendly tunability.

In this work, the first dedicated efforts to tune Pythia 8/Angantyr for air-shower physics using fixed-target measurements are presented. The tuned Pythia configuration is compared to its default configuration, to other hadronic interaction models used in cosmic-ray physics, and to existing experimental data, highlighting the impact of tuning on muon production and other relevant shower properties. **Supported by DFG (SFB 1491)*

T 85.3 Thu 16:45 KS 00.006

Constraints on the Atmospheric Muon Flux from Stopping and High-Energy Muons in IceCube — •Pascal Gutjahr[1,2], Lucas Witthaus[1,2], and Lene Van Rootselaar[1,2] — [1]TU Dortmund University, Dortmund, Germany — [2]Lamarr Institute, Dortmund, Germany

Atmospheric muons detected by the IceCube Neutrino Observatory provide a sensitive probe of cosmic-ray interactions in the atmosphere. These muons originate from conventional pion and kaon decays as well as from prompt decays of short-lived heavy hadrons, with the latter expected to become significant at the highest energies. This contribution presents an unfolding of the atmospheric muon energy spectrum in IceCube, combining low-energy stopping muons with high-energy through-going muons to cover a broad energy range from several hundred GeV to the PeV scale. Stopping muons, which lose all their energy in the ice, constrain the surface muon spectrum at TeV energies, while high-energy muons provide sensitivity to the prompt component. Event classification and energy reconstruction are performed using deep learning techniques to improve resolution and background rejection. The unfolded spectra are used to study the relative contributions of conventional and prompt muons and are compared to predictions.

T 85.4 Thu 17:00 KS 00.006

Testing newly released hadronic interaction models with KASCADE-Grande — •Donghwa Kang and Andreas Haungs for the KASCADE-Grande-Collaboration — Karlsruhe Institute of Technology (KIT)

KASCADE-Grande was designed to study the energy spectrum and mass composition of cosmic rays in the energy range from 10 PeV up to 1 EeV. The measurements revealed a knee-like structure in the heavy components at energies around 100 PeV, consistent with expectations from rigidity-dependent scenarios. In addition, a spectral hardening was observed in the light component near 120 PeV. With the recent release of updated post-LHC hadronic interaction models - QGSJet-III-01, EPOS.LHC-R, and Sibyll 2.3d - we test their validity using KASCADE-Grande data. In this contribution, we present the reconstructed all-particle energy spectra as well as the energy spectra of individual mass groups derived from shower size observables, using the newly released hadronic interaction models.

T 85.5 Thu 17:15 KS 00.006

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 cascades in arbitrary media, building on the long-standing foundation of CORSIKA 7. It has been completely redesigned as a modular, modern C++ framework, overcoming key limitations of its predecessor and providing a flexible platform for both established and emerging use cases. In addition to traditional air-shower simulations, CORSIKA 8 supports applications such as cross-media particle cascades and improved modeling of radio emission, especially propagation through complex media. The framework includes state-of-the-art descriptions of electromagnetic cascades via PROPOSAL and supports hadronic interactions with current and next-generation models, such as EPOS LHC-R, QGSJet-III, and Pythia 8. In this presentation, we will outline the design principles, current capabilities, and ongoing validation efforts of CORSIKA 8, and discuss its role as a versatile simulation tool for future astroparticle and particle-physics experiments.

T 85.6 Thu 17:30 KS 00.006

Classifying photon- and proton-induced air-showers with a transformer-based approach at the Pierre Auger Observatory — •Alexander Doeker, Marcus Niechciol, and Markus Risse for the Pierre Auger-Collaboration — Experimentelle Astroteilchenphysik, Center for Particle Physics Siegen, Universität Siegen

The Pierre Auger Observatory is the world's largest detector for ultra-high-energy (UHE) cosmic rays, capable of observing particles with energies exceeding 10^{20} eV. Only the most extreme cosmic events can accelerate particles to such energies. Detecting an accompanying flux of UHE photons would deepen our understanding of these extreme cosmic events, probe the GZK suppression mechanism, and potentially reveal signatures of exotic scenarios like super-heavy dark matter.

In this work, a transformer-based approach to classify simulated air showers induced by photons and protons will be presented. Transformer networks, with their ability to capture complex patterns in sequential data, offer a promising tool for distinguishing between these signals. The current transformer network uses the photomultiplier tube signals from the water Cherenkov detector stations of the surface detector array as its primary input.

This approach demonstrates the potential of transformer networks to enhance the identification of UHE photon events, possibly advancing our understanding of the most energetic phenomena in the universe.

Supported by the BMFTR Verbundforschung Astroteilchenphysik under project No. 05A23PS1.