Theory and Experiment in High Energy Physics

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Book of Abstracts

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Modified black hole with extra dimensions as an unusual dark matter candidate

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There are two branches of 1+(3+n) dimensional spacetimes with (1+3)-dimensional part corresponding to spherically symmetric spacetime and with Euclidean symmetry in n extra dimensions which satisfy vacuum Einstein field equations. One branch is a trivial extension of the Schwarzschild spacetime around a gravitating body, while the second branch is nontrivial. The extra dimensions may be compactified, so that, in principle, these solutions may be relevant in our (1+3)-dimensional Universe, perhaps providing a new dark matter candidate. We will discuss some unusual features of the nontrivial case, based on the Newtonian limit, Kretschmann scalar invariant, and conserved energy defined through the Landau-Lifshitz stress-energy pseudotensor.

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Event-activity-dependent beauty-baryon enhancement in simulations with color junctions

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Recent results from ALICE and CMS show a low-transverse-momentum enhancement of charm baryon-to-meson production ratios over model predictions based on e^+e^- collisions. Several mechanisms are proposed to understand this phenomenon. New measurements by the LHCb and ALICE experiments show a similar enhancement in the beauty sector. We explore this enhancement in terms of event activity using the color-reconnection beyond leading order approximation model. We propose sensitive probes relying on the event shape that will allow for the differentiation between the proposed beauty-production scenarios using freshly collected LHC Run-3 data, and we also compare these to predictions for charm. Our results will contribute to a deeper theoretical understanding of the heavy-flavor baryon enhancement and its relation to baryon enhancement in general.

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Saturation within the reach of the LHC: Incoherent J/ψ production at large |t|

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We identify a new way of pinpointing the presence of saturation effects in the LHC data by looking at incoherent J/ψ production at large |t|. We use an energy-dependent hotspot model to show that saturation effects are manifested through a fall-off of the incoherent vector meson production cross

section. This fall-off comes from the reduced variance of possible target configurations due to parton overlap at Mandelstam-t scales, where individual hotspots become important.

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Extra dimensions in strong gravitational field

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Studying the effects of an extra compactified spatial dimension on the phase space of massive particles and the photon. We investigate the dispersion relation within the Kaluza-Klein model, in a spherically symmetric, static spacetime. Modifications to the scalar curvature of phase space due to gravity and the scalar field appearing in the model are considered.

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From zero-temperature unitarity to quantum Boltzmann equation

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Within the classical Boltzmann approach, we include all number-changing processes in which the particle participates, typically decays or scatterings. At higher orders, other types of reactions may become relevant as well. We formulate a diagrammatic unitarity-based algorithm to complete the set of contributing reactions. Initially, the particles are treated as classical point-like objects whose interactions are described through zero-temperature quantum field theory. Remarkably, the algorithm automatically accounts for the effects of thermal corrections. The framework will be demonstrated by including anomalous thresholds leading to thermal mass and wave function renormalization effects.

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Modified Characteristics of Hadronic Interactions in Ultra-high-energy Cosmic-ray Showers

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Data from multiple experiments suggest that the current interaction models used in Monte Carlo simulations do not correctly reproduce the hadronic interactions in air showers produced by ultra-high-energy cosmic rays (UHECR), in particular –but not limited to –the production of muons during the showers. We have created a large library of UHECR simulations where the interactions at the highest energies are slightly modified in various ways –but always within the constraints of the accelerator data, without any abrupt changes with energy and without assuming any specific mechanism or dramatically new physics at the ultra-high energies. We find that even when very different properties –cross-section, elasticity and multiplicity –of the interactions are modified, the resulting changes in some air-shower observables are still mutually correlated. Thus not all possible combinations of changes of observables are easily reproduced by some combination of the modifications. Most prominently, the recent results of the Pierre Auger Observatory, which call for a change in the prediction of both the muon content at ground and the depth of the maximum of longitudinal development of the showers, are rather difficult to reproduce with such modifications, in particular when taking into account other cosmic-ray data. While some of these results are related to the assumptions we place on the modifications, the overall lessons are general and provide valuable insight into how the UHECR data can be interpreted from the point of view of hadronic physics

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Event-activity dependence of heavy-flavor production at the ALICE experiment

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Heavy-flavor production at the LHC offers valuable tests of quantum chromodynamics calculations, owing to the large masses of heavy quarks. Measurements of charm production as a function of event activity reveal new features of charm production and fragmentation, providing insights to the interplay between soft and hard processes. In addition, charm production in heavy-ion collisions addresses flavor-dependent quark transport properties in both hot and cold nuclear matter, helping to clarify the roles of coalescence and fragmentation in heavy-flavor hadron formation.
In this contribution, we present recent measurements from the ALICE experiment on charm production as a function of charged-particle multiplicity in pp collisions at various energies, including measurements of the charm baryon-to-meson production yield ratios in pp, p–Pb and Pb–Pb collisions. New results of D0 production in pp collisions as a function of the transverse spherocity of the event, as well as of the transverse event-activity classifier RT, are also presented.

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The ATLAS Forward Proton Time-of-Flight Detector System

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The Time-of-Flight (ToF) detectors in the ATLAS Forward Proton (AFP) system are designed to determine the primary vertex z-position of the pp -> pXp processes by comparing thearrival times measured in the ToF for the two intact protons in the final state. We present performance studies in terms of efficiencies and timing resolutions using high-statistics, low, and moderate pile-up data collected during the ATLAS Run 2 and Run 3 periods.

In Run 2, low efficiencies of a few percent are observed, and the resolutions of the two ToF detectors measured individually are 21 ps and 28 ps. This results in an expected precision of 5.3 ± 0.6

mm for the vertex reconstruction resolution provided by the ToF. This value aligns with the results from subsequent statistical analysis of the distribution of differences between the vertex z-positions reconstructed by the ATLAS central detector and the ToF. This distribution comprises a background component from combinatorics due to non-negligible pile-up and a significantly narrower signal component (6.0 ± 2.0 mm) from events where protons from the same interaction are detected in the ToF.

For Run 3, the ToF detector underwent major upgrades in electronics, optics, and mechanics, resulting in a substantial improvement in detection efficiency exceeding 80%. There was a slight, but not critical, degradation in its timing capabilities, leading to a vertex reconstruction precision at the level of 10 mm.

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Hydrodynamic description of direct photon spectrum and elliptic flow

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In high energy heavy ion collisions a new state of matter, the strongly coupled quark gluon plasma is formed that exhibits the similar properties as our Universe had just a couple of microseconds after the Big Bang, hence such collisions are usually referred as Little Bangs. Subsequent investigations showed that the created medium is a nearly perfect fluid whose time evolution can be described by hydrodynamic models. The distribution of the hadrons that are created in the freeze-out after a rapid expansion carry information about the final state. On the other hand, with penetrating probes, e.g., with direct photons, one can model the time evolution of the quark gluon plasma. I present a hydrodynamic model that was inspired by an analytical solution of relativistic hydrodynamics, calculate the invariant transverse momentum spectrum and the elliptic flow of direct photons and compare our results to data to obtain the value of the model parameters. Based on the the results we give an estimation for the initial temperature of the plasma.

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Comparison of eccentric waveform models on a HTC cluster

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In this study, we rigorously compare two advanced numerical models, CBWaves and SEOBNRE, which utilize the post-Newtonian and effective one-body frameworks to simulate eccentric binary systems. To thoroughly investigate the discrepancies between these models, we conducted an extensive series of 260,000 simulations—20,000 for non-spinning binaries and 240,000 for spinning configurations—across a finely tuned parameter space. The grid points, defined by the mass ratio $\nu \equiv m_1/m_2 \in [0.1, 1]$, gravitational mass $m_i \in [10M_\odot, 100M_\odot]$, spin magnitude $S_i \in [0, 0.6]$, and constant initial eccentricity e_0, allow for a comprehensive exploration of these systems. In my presentation, I will unveil the key insights derived from this detailed analysis, revealing the critical differences in the waveforms produced by these two models.

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Searches for QCD instantons with forward proton tagging

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We study the possibility to observe heavy (Minst > 60 GeV) QCD instantons at the LHC in events with one or two tagged leading protons including fast simulation of detector and pile-up effects. We show that the expected instanton signal in a single-tagged configuration is strongly affected by central detector and pile-up effects. For double-tagged approach, where larger integrated luminosities and hence larger pile-up contaminations need to be considered, the combinatorial background overwhelms the expected signal. We suggest that additional time information about tracks at central and forward rapidities would be crucial for potential improvements.

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Welcome

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Arrival Day, Registration, Discussion

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Discussions

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Leptogenesis in unified models

We shall briefly review the motivation for considering thermal leptogenesis within unified models and comment on the prospects of accommodating the measured value of the baryon-to-antibaryon asymmetry of the Universe in minimal calculable scenarios of the SU(5)xU(1) and SO(10) type.

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Overview IEAP activities

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Institute of Experimental and Applied Physics, Czech Technical University in Prague is active in many research projects. The talk will overview main activities of the institute in the fundamental physics experiments, theory, R&D projects in the field of detector development and applications in imaging.

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Exclusive π^0 muoproduction at COMPASS

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Hard Exclusive Meson Production is a very promising reaction to access Generalized Parton Distributions (GPDs). Measurements of the cross section for hard exclusive neutral-pion muoproduction on the proton were performed at COMPASS in 2016 and 2017 at the M2 beamline of the CERN SPS using 160\,GeV/c longitudinally polarised μ^+ and μ^- beams scattering off a 2.5 m long liquid hydrogen target. Results were obtained in a wide kinematic region with the photon virtuality Q^2 up to 8 (GeV/c)^2 and the Bjorken variable x_B ranging from 0.016 to 0.45. We will report on the virtual-photon proton cross section averaged over the μ^+ and μ^- cross sections and on its dependence on the squared four-momentum transfer between initial and final proton in the range $0.08\,(\mathrm{GeV}/c)^2 < |t| < 0.64\,(\mathrm{GeV}/c)^2$ and on the azimuthal angle between the scattering plane and the π^0 production plane. Fitting the azimuthal dependence yields the sum of the contributions by transversely and longitudinally polarised photons as well as transverse-transverse and longitudinal-transverse interference contributions. The COMPASS results provide input to constrain GPDs, in particular chiral-odd (“transversity”) GPDs.

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Machine Learning applications in high energy physics

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Recent advancements in machine learning have enabled the application of these techniques in high energy physics, yielding significant benefits. Artificial intelligence not only offers potential solutions to long-standing challenges but also aids in enhancing physical models by identifying and analyzing hidden correlations through innovative approaches.

The large-scale experiments at the LHC generate vast amounts of data annually, posing numerous technical challenges. However, AI technologies can assist in nearly every facet of these investigations, from optimizing DAQ triggers to performing advanced physics analyses. Additionally, related fields, such as designing future accelerators or advancing hadron therapy for cancer treatment, can also benefit from these applications.

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Hard diffraction in ATLAS

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Hard diffraction processes, characterized by the exchange of a color-neutral object (such as a Pomeron) between colliding protons, offer a unique window into the interplay between perturbative and non-perturbative QCD. In particular, the study of hard diffraction is of significant interest, as these processes occur at high momentum transfer (Q^2) and probe the mechanisms underlying diffractive interactions in the perturbative regime. Such measurements provide crucial insights into the nature of the Pomeron and the partonic structure involved in diffraction.

The feasibility of these measurements is greatly enhanced by the ATLAS Forward Proton (AFP) detectors, which are optimized to detect protons scattered at small angles while retaining most of their initial energy—a characteristic signature of diffractive interactions, where the proton may remain intact after the collision. By tagging these forward-scattered protons, AFP allows for a clean identification of diffractive events. Combined with the comprehensive particle detection and reconstruction capabilities of the ATLAS detector, this setup provides a robust framework for studying diffractive processes.

These studies enhance our understanding of the Pomeron's role in high-energy collisions and provide valuable insights into the structure of protons in diffractive interactions. The findings have important implications for both theoretical models of diffraction and future experimental developments in particle physics.

In my talk, I will introduce the AFP detector system and discuss the feasibility of measuring hard diffractive processes, specifically those involving jets and open charm production.

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Anisotropic flow fluctuation as a possible signature of clustered nuclear geometry in O-O collisions at the LHC

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Nuclei having 4n number of nucleons are theorized to possess clusters of α particles (4He nucleus). The Oxygen nucleus (16O) is a doubly magic nucleus, where the presence of an α-clustered nuclear structure grants additional nuclear stability. In this study, we exploit the anisotropic flow coefficients to discern the effects of an α-clustered nuclear geometry w.r.t. a Woods-Saxon nuclear distribution in O-O collisions at √sNN=7 TeV using a hybrid of IP-Glasma + MUSIC + iSS + UrQMD models. In addition, we use the multi-particle cumulants method to measure anisotropic flow coefficients, such as elliptic flow (v2) and triangular flow (v3), as a function of collision centrality. Anisotropic flow fluctuations, which are expected to be larger in small collision systems, are also studied for the first time in O−O collisions. It is found that an α-clustered nuclear distribution gives rise to an enhanced value of v2 and v3 towards the highest multiplicity classes. Consequently, a rise in v3/v2 is also observed for the (0-10)\% centrality class. Further, for α-clustered O−O collisions, fluctuations of v2 are larger for the most central collisions, which decrease towards the mid-central collisions. In contrast, for a Woods-Saxon 16O nucleus, v2 fluctuations show an opposite behavior with centrality. This study, when confronted with experimental data may reveal the importance of nuclear density profile on the discussed observables.

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CoLoRFul for hadron collisions: Integrating the counterterms

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In order to numerically compute scattering cross sections in QCD, one needs to deal with various kinematic divergences that appear at intermediate stages of the calculation. One way of doing this is by setting up an IR subtraction scheme. In this talk we give an update on the status of extending the CoLoRFul subtraction scheme, which has been successfully used in the past for processes with only final-state hadrons, to hadron-hadron collisions. In particular we discuss the analytic computation of the integrated counterterms.

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Cosmological evolution of a PQ field with small self-coupling and its implications for ALP DM

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Axion-like particles (ALPs) are often considered good candidates for dark matter (DM). Several mechanisms for generating the relic abundance of ALP DM have been proposed, involving processes that may occur either before, during, or after cosmic inflation. In all cases, the potential of the corresponding Peccei-Quinn (PQ) field plays an important role. We investigate the radiative, thermal, and space-time curvature corrections to the PQ field dynamics in scenarios where the potential has very small self-coupling. We focus on toy models with a quasi-supersymmetric spectrum and discuss how accounting for these corrections is crucial for accurately estimating the relic abundance of ALP DM.

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Deviation of observable quantities in rapid and slow-rotation approximation of neutron stars

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In the present study, we have extended our earlier investigation of the breakdown of the slow-rotation approximation to fast rotation by taking into consideration a range of EoS models in order to probe the impact of stiffness in the departure of the two dynamical models. We aimed to construct sequences of rigidly rotating equilibrium configurations at various rotation frequencies up to the Keplerian frequency in order to probe the limitations imposed by the mass-sheding limit and the onset of secular axisymmetric instability. We performed the computations to obtain the slow rotating stellar models by an own implementation of the Hartle–Thorne approximation, while for obtaining the fast-rotating models we relied on the rotstar code, which is part of the LORENE library where

a multi-domain spectral method is applied to solve the field equations decomposed into a system of five quasi-linear elliptic equations.

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Reheating in α-attractors

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α-attractors is a very promising class of inflationary models, utilizing non-canonical form of the kinetic term to solve the problem of flatness of the potential. This mechanism has significant implication for the dynamics of the (p)reheating.

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Speed of Sound in Dense Matter

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Gravitational waves offer exciting opportunities to study bulk properties of dense matter and challenge theoretical models of dense equations of state (EoS). NJL-type models widely employed in the COMPOSE database for studying neutron stars have the known problem that the speed of sound fails to approach the conformal limit. We investigate how a dynamical chiral quark model, which implements non-local interactions among quarks resolves the issue. Additionally, the influence of diquark on the QCD phase diagram is also investigated.

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Volume Concepts in the Thermodynamics of Black Holes

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Volume is a coordinate-dependent quantity in General Relativity. Therefore, when it comes to thermodynamics of black holes, volume and its conjugate pressure are not used as thermodynamic variables. In this presentation we study how different types of volume concepts can be used in black hole descriptions in a thermodynamically consistent way and show the consequences taking results from literature into account. We study especially the phase structure of Anti-de Sitter–Kerr type black holes and their Hawking–Page phase boundaries. The main aim of this project is to find out how one can put the thermodynamic volume piece into place in the great puzzle of the theory of black holes.

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Self-excited gravitational instantons

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The finite Euclidean action solutions known as instantons play an important role in non-perturbative understanding of Yang-Mills theory. In this talk, I will introduce a novel approach to constructing gravitational instantons using the teleparallel formulation of general relativity, which has an interesting feature of expressing the action of general relativity as an exterior product of the torsion and excitation forms. This allows us to define a new class of self-excited solutions, where these two forms are equal. These solutions closely resemble the BPST instantons in Yang-Mills theory, as their action reduces to a topological Nieh-Yan term, with axial torsion taking the role of the Chern-Simons current, allowing us to define a gravitational analogue of the winding number.

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Analysis of AFP ToF data from early LHC Run-3

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The analysis of the early LHC Run-3 data was performed. Efficiencies for the ATLAS Forward Proton (AFP) Time-of-Flight (ToF) detector were studied. In addition, these performance studies of the ToF data included the proton-proton vertex reconstruction using matching of ToF and central ATLAS vertex position. After a calibration, a preliminary resolution of the vertex reconstruction was determined with a low-mu ATLAS run.

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Dark physics constraints from NA62

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It is generally believed that in the particle world, the Standard Model cannot be accepted
as the ultimate theory. In this talk, we summarize searches for Beyond Standard Model Physics that attempt to reveal presence of dark particles in the NA62 Experiment.

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Domain Walls and Gravitational Waves

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I will discuss cosmological domain walls with a review of their evolution and how they produce gravitational waves. Particular attention will be devoted to melting domain walls which are described by tension red-shifting with the expansion of the Universe, so that this network eventually fades away completely. These melting domain walls emit gravitational waves with the low-frequency spectral shape favoured by the recent NANOGrav 15 yrs data. This scenario involves a feebly coupled scalar field, which can serve as a promising dark matter candidate. This ultra-light dark matter has mass below 0.01 neV which is accessible through planned observations thanks to the effects of superradiance of rotating black holes. This talk is based on recent works: arXiv:2104.13722, arXiv:2112.12608, arXiv:2307.04582 and arXiv: 2406.17053.

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Overview of the ATLAS Forward Proton detector

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A key focus of the physics program at the LHC is the study of head-on proton-proton collisions. However, an important class of physics can be studied for cases where the protons narrowly miss one another and remain intact. In such cases, the electromagnetic fields surrounding the protons can interact producing high-energy photon-photon collisions. Alternatively, interactions mediated by the strong force can also result in intact forward scattered protons, providing probes of quantum chromodynamics (QCD). To aid identification and provide unique information about these rare interactions, instrumentation to detect and measure protons scattered through very small angles is installed in the beam pipe far downstream of the interaction point. The ATLAS Forward Proton (AFP) 'Roman Pot' Detector is described, covering Tracking and Time-of-Flight Detectors and the associated electronics, trigger, readout, detector control, and data quality monitoring.

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Overview of the Past, Present, and Future of the Pierre Auger Observatory: Advantages and limitations concerning accelerator data

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The Pierre Auger Observatory is the world's largest facility for detecting ultrahigh-energy cosmic rays that has been operating for nearly 20 years. The hybrid concept of the detector allows accurate estimations of the energy spectrum, mass composition, and arrival directions of cosmic rays, which are crucial for identifying the origin and nature of the highest energy particles arriving at Earth. With the data from the Auger Observatory, it is possible to explore particle physics in regions of phase space inaccessible by the existing man-made accelerators and probe the hadronic interactions at energies nearly two orders of magnitude higher than those attainable at the Large Hadron Collider. In this contribution, we review the current status and a selection of the key results of the Pierre Auger Observatory. We discuss the existing limitations in exploring the universe's most energetic phenomena and the future perspectives, including the ongoing enhancements provided by the upgrade of the Observatory.

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ATLAS QCD jet measurements

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This talk discusses recent QCD jet measurements from the ATLAS experiment at the LHC collider using proton–proton collisions at 13 TeV. The first measurement deals with the cross-section ratios between several inclusive jet multiplicity configurations (2,3,4,5 jets configurations). The ratio for three to two jet production, R_{32}, provides sensitivity to strong coupling parameters. The higher ratios (R_{43}, R_{42} and R_{54}) are measured for the first time experimentally to serve as a reference for future theoretical developments of high-precision QCD predictions with high jet multiplicities. Second, the Lund subjet multiplicities measurement is discussed to probe and test the current and future parton shower MC algorithms. The third measurement deals with the transverse energy-energy correlation TEEC and its azimuthal asymmetry ATEEC. This measurement is used for the strong coupling parameter extraction to probe QCD prediction at the TeV scale. The extraction profits from new state-of-the-art NNLO pQCD calculations significantly reduce theoretical uncertainty. The final measurement focuses on event isotropies in multijet events as new and generalized event-shape observables, allowing new possibilities for investigating QCD radiation and new opportunities for MC tuning.

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Concluding Remarks

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