12th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

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DEJIMA MESSE NAGASAKI

Report of Abstracts

Student Lectures / **354**

Jet and High pT

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Collaboration:

Category:

Student Lectures / **357**

Initial State and Early Time Dynamics

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Collaboration:

Category:

Student Lectures / **352**

Electromagnetic and Weak Probes

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Collaboration:

Category:

Plenary Session I / **317**

ALICE Collaboration Overview

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Collaboration:

ALICE

Category:

Plenary Session I / **316**

ATLAS Collaboration Overview

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Collaboration:

ATLAS

Category:

Plenary Session I / **315**

CMS Collaboration Overview

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Collaboration:

CMS

Category:

Plenary Session II / **319**

LHCb Collaboration Overview

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Collaboration:

LHCb

Category:

Plenary Session II / **318**

STAR Collaboration Overview

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Category:

Plenary Session II / **320**

PHENIX Collaboration Overview

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Collaboration:

PHENIX

Category:

Plenary Session II / **321**

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Collaboration:

sPHENIX

Category:

Plenary Session II / **356**

Women in Japanese STEM field

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Collaboration:

Category:

Parallel 4: high pt in small systems / 149

Search for jet quenching with high p_{T} hadron azimuthal anisotropy using subevent cumulants in pPb collisions at CMS

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Measurements at the LHC have provided evidence for collective behavior in high-multiplicity proton-lead (pPb) collisions through multiparticle correlation techniques. Yet, no conclusive evidence of jet quenching, indicating the energy loss of high-p_{T} partons as they traverse the medium, has been detected in pPb. This raises the intriguing question: How can a medium described by hydrodynamics, and that significantly modifies the distribution of final-state hadrons, yet has no significant impact on the distribution of high-pT particles? To investigate this, a comprehensive study of differential Fourier coefficients (v_n) in particle transverse momentum (p_{T}) and event multiplicity is presented in pPb collisions recorded by the CMS experiment at a nucleon-nucleon center-of-mass energy $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV. In particular, new measurements of p_{T}-differential multiparticle cumulants using the subevent method probes an extended phase space region up to a high particle p_{T}. Additionally, we compare the results between pPb and PbPb collisions in the same multiplicity window. This comparison will help assess similarities and differences in the medium's interaction with high-p_{T} particles in these two collision types.

Category:

Experiment

Collaboration:

CMS

Parallel 3: nPDF / 176

Improved constraints on nPDFs using dijet production in pPb collisions at 8.16 TeV with the CMS Detector

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Measurements of dijet production in heavy ion collisions can be used to probe the nuclear matter. In proton-lead collisions, the normalized average dijet pseudorapidity distributions can be used as a sensitive tool for constraining the nuclear modifications of parton distribution functions (nPDF) at different Q^2 scales and Bjorken-x. In such studies, it is possible to investigate, with a good precision, the shadowing, anti-shadowing and EMC effects. In this talk, the updated dijet average pseudorapidity measurements in pPb collisions at 8.16 TeV in various dijet transverse momentum ranges will be presented with the data samples collected with the CMS detector at the LHC. The measured distributions are compared to perturbative quantum chromodynamics calculations with different sets of proton and nuclear PDFs.

Category:

Experiment

Collaboration:

CMS

Parallel 2: heavy quark production / 171

Understanding initial and final states with charm meson pair and charm baryon production in pPb collisions with CMS

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Recent research suggested that hot nuclear matter phenomena also occur in small systems in the charm sector. To deepen the understanding of the source of such phenomena, we will present the charm hadron production in pPb collisions, focusing on the Λ_c-to-D^0 ratio in different multiplicities to examine the hadronization mechanisms. The results are also compared to the light and the strange sectors in different collision systems. To further investigate the initial state effects in nuclear collisions, we will report the first observation of double J/ψ production and the first measurement of double D meson productions in pPb collisions. . These new results impose important constraints on the models from initial to final states, providing essential information for understanding the heavy quark behaviors in small systems.

Category:

Experiment

Collaboration:

CMS

Parallel 1: jet substructure / 155

Radius dependent jet quenching measurements from ATLAS

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Measurements of jets that traverse a quark gluon plasma can provide in- sights into the jet energy loss in heavy ion collisions. Furthermore, considering jets of various radii can help elucidate how the parton energy is transferred to the medium as well as the corresponding medium response. This talk presents measurements of the nuclear modification factor and dijet momentum balance for anti-kt jets reconstructed with radius R = 0.2, 0.3, 0.5, 0.4, and 0.6, obtained with the ATLAS detector at the LHC. These measurements used 1.72 nb−1 of Pb+Pb data collected in 2018, and 260 pb−1 of pp data collected in 2017, both at a per-nucleon center of mass energy √sNN = 5.02 TeV. The measurements were unfolded in jet transverse momentum to correct for the jet energy reso-

lution. The measurements show a jet radius dependence of jet quenching and suppression. These measurements will improve the understanding of the jet energy loss process.

Category:

Experiment

Collaboration:

ATLAS

Parallel 4: high pt in small systems / **164**

ATLAS measurements of soft-hard correlations and anisotropy decorrelations in pp collisions

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This talk presents two recent ATLAS measurements of multi-particle correlations in pp collisions. The first investigates the relationship between the pp "ridge"and hard scattering processes. In particular, it is not known whether jets or their soft fragments are correlated with particles in the underlying event. To study this "soft-hard"correlation, measurements of two-particle correlations in pp collisions with two different particle-pair selections are presented. First, charged particles associated with jets are excluded from the correlation analysis. The measurement shows that excluding such particles does not affect the pp-ridge. In the second case, correlations are measured between particles within jets and charged particles from the underlying event. Particles associated with jets are found to not exhibit any significant azimuthal correlations with the underlying event, ruling out that hard processes contribute to the ridge. A second measurement of longitudinal decorrelation in pp collisions at 5 TeV and 13 TeV is also presented. This is the first time such measurements have been performed in pp collisions. Because non-flow effects are more significant in pp collisions, non-flow template subtraction procedures are applied. The results are quoted over a range of multiplicities and compared to measurements in Xe+Xe collisions. This gives the first detailed information on the correlation between longitudinal and transverse energy deposition in pp collisions.

Category:

Experiment

Collaboration:

ATLAS

Parallel 3: nPDF / **150**

Top quark pair production in Heavy Ion Collisions with the ATLAS experiment

Author: Iwona Grabowska-Bold[1]

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Measurements of top quarks in heavy-ion collisions are expected to provide novel probes of nuclear modifications to parton distribution functions as well as to bring unique information about the evolution of strongly interacting mat- ter. We report the observation of the top-quark pair production in proton-lead collisions at the centre-of-mass energy of 8.16 TeV in the ATLAS experiment at the LHC. Top-quark pair production is measured in the lepton+jets and the dilepton channels, with a significance well above 5 standard deviations in each channel separately. The results from the measurement of the nuclear modifica- tion factor RpA are also presented. If available, results from the measurement of top-quark production in Pb+Pb collisions will be presented and discussed.

Category:

Experiment

Collaboration:

ATLAS

Parallel 2: heavy quark production / **54**

Measurements of production of charm-hadron pairs in pp collisions with ALICE

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In hadron-hadron collisions at LHC energies, Multiple Parton Interactions (MPI), where multiple hard-parton scatterings can occur in the same collision, play a significant role. Among MPI scenarios, Double-Parton Scatterings (DPS) represent the simplest case. The DPS contribution to a given process with two final-states A and B can be expressed as the product of the cross-sections of the sub-processes involved for the independent production of A and B, divided by an effective cross section. The effective cross section, a phenomenological parameter, is related to the transverse overlap function between the partons of the proton. By investigating DPS, we gain insights into the evolution equations of Quantum Chromodynamics (QCD) concerning multi-parton distributions and potential correlations in color and spin degrees of freedom.

The production of heavy quarks (charm and beauty) occurs in hard-parton scatterings due to their large masses. Consequently, the study of DPS production can be performed via measurements of the production cross sections of charm-hadron pairs. In this contribution, we will discuss the latest measurements involving production of $\mathrm{D^0D^0}$, $\mathrm{D^0J/\psi}$, and $\mathrm{J/\psi J/\psi}$ pairs at midrapidity and forward rapidity in pp collisions, from Run 2 data samples at $\sqrt{s} = 13$ TeV and Run 3 data samples at $\sqrt{s} =$ 13.6 TeV, with the ALICE detector at the LHC.

Category:

Experiment

Collaboration:

ALICE

Parallel 1: jet substructure / **153**

Jet substructure measurements with small and large radius jets with ATLAS

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Measurements of jet substructure in heavy-ion collisions provide critical insights into the mechanisms of jet quenching within the hot and dense QCD medium created during these collisions, spanning a wide range of energy scales. This talk presents new measurements from the ATLAS Collaboration on jet suppression and substructure, employing the Soft-Drop grooming procedure in Pb+Pb and pp collisions at √sNN = 5.02 TeV. These precision measurements utilize vari- ous jet constituents, including charged particles and novel objects reconstructed from tracker and calorimeter data. Notably, measurements that exclusively uti- lize charged particles extend to a large radius of R = 1.0. Jet suppression is quantified with the nuclear modification factor RAA and is presented as a func- tion of jet transverse momentum pT, the opening angle of the hardest internal splitting rg, and the corresponding transverse momentum scale √d12. These results, when compared with theoretical models, enhance our understanding of jet quenching dynamics in the QCD medium, provide new insights into the medium's properties, and test the theoretical understanding of QCD dynamics in heavy-ion collisions.

Category:

Experiment

Collaboration:

ATLAS

Parallel 4: high pt in small systems / 103

Differential pi0 and photon modification in d+Au collisions

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Experiments at RHIC and LHC have found no observable evidence of jet quenching in small systems, with one exception —a recent measurement by PHENIX [2303.12899], which compared the yield of neutral pion and direct photon production in very central d+Au collisions. The argument is that the photon yields can be used to correct out any centrality bias effects, and thus the surprisingly strong signal observed by PHENIX in the pi0 measurement is attributable mainly to jet quenching. In a recent paper [2404.17660], I argue that the particular photon and pion events selected by PHENIX arise from proton configurations with significantly different Bjorken-x distributions, and thus are subject to different magnitudes of centrality-dependent modification from initial-state color fluctuation effects. Using the results of a previous global analysis of RHIC and LHC data [1709.04993], with no additional parameters or re-tuning, I show that potentially all of the pion-to-photon difference in PHENIX data can be described by a proton color fluctuation picture at a quantitative level before any additional physics from final-state effects is required. This finding reconciles the interpretation of the PHENIX measurement with others at RHIC and LHC into a consistent picture across experiments, in which there are strong constraints on the possible amount of jet quenching in small systems.

Category:

Experiment

Collaboration:

Parallel 3: nPDF / 106

PHENIX cold QCD and spin physics results

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The strong interaction, QCD, has been very successful in describing perturbative processes between high-energetic quarks and gluons, but nonperturbative quantities such as the (spin) structure of the nucleon and nuclei are generally not accessible from first principles. Parton distribution functions, PDFs, have to be obtained from experiment and in part from lattice simulations. The PDFs of the nucleon and nuclei form the cold QCD baseline needed for heavy ion collisions. When adding the spin structure of nuclear matter, even less is understood in terms of the spin decomposition of quark and gluon spins, and their orbital angular momenta. In recent years, particularly, transverse spin asymmetry measurements have also been performed on polarized proton-nucleus interactions. These measurements show a strong connection to low-x physics, as well as spin dependent modifications even in unpolarized nuclei via intrinsically transverse momentum dependent PDFs.
The recent cold QCD and spin related measurements by PHENIX, with emphasis on those that relate to nuclei will be presented.

Category:

Experiment

Collaboration:

PHENIX

Parallel 2: heavy quark production / 50

Studies of beauty-quark production, hadronisation and cold nuclear matter effects in pp and p-Pb collisions with ALICE

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Measurements of beauty-hadron production in ultrarelativistic hadronic collisions provide a fundamental tool for testing perturbative QCD calculations. Recent results at the LHC show that the beauty fragmentation function, as well as that of charm, is not universal across different collision systems. An extension of these studies to further energies, rapidities and collision systems has thus become crucial. Additionally, studies in p-Pb collisions allow us to shed light on the role of cold nuclear matter effects on beauty production and their impact on beauty-quark hadronisation. The ALICE experiment investigates the beauty sector via high-precision measurements of non-prompt D mesons and $\Lambda_{\rm c}^{+}$ baryons, and via the measurement of leptons from beauty-hadron decays.
In this presentation, the first studies of non-prompt/prompt production-yield ratios of charm hadrons in pp collisions at $\sqrt{s} = 13.6$ TeV from the LHC Run 3 data taking are reported. Moreover, the final results on non-prompt charm baryon-over-meson and meson-over-meson production yield ratios in pp collisions at $\sqrt{s}$ = 13 TeV and in p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV are shown, as well as the

nuclear modification factor of non-prompt D mesons and Λ_c^+ baryons in p-Pb collisions. The total $b\bar{b}$ production cross section at midrapidity in pp collisions is also presented. Finally, recent results on electrons from beauty-hadron decays are discussed.

Category:

Experiment

Collaboration:

ALICE

Parallel 1: jet substructure / **55**

Jet fragmentation and substructure correlations in pp and Pb–Pb at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV with ALICE

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Jet substructure observables are an effective probe of the QCD matter created in heavy ion collisions, studying various jet and medium interaction scales. Measurements of these observables have been typically limited to single dimensions, leaving unanswered questions about the interplay of momentum and angular components in the evolution of jets. Here we present two new multi-dimensional jet substructure measurements from the ALICE collaboration. The first is a measurement of Soft Drop groomed jets, reporting the first fully corrected correlation between z_{g} and R_{g} in pp and Pb–Pb collisions. The measurement is compared to a selection of models to explore the role of various jet quenching mechanisms and selection biases due to energy loss. We also report a differential measurement of jet fragmentation in small systems, specifically examining the transverse momentum (j_{T}) distributions of jet constituents for several z ranges in pp collisions. By comparing these z-dependent j_{T} distributions with theoretical predictions, we test our current understanding of jet fragmentation and hadronisation processes, exploring parton shower and hadronisation effects in vacuum and their possible modifications in small systems. These studies provide a comprehensive view of both the medium-induced modification of the jets and the jet evolution process and highlight the importance of multi-dimensional analyses in understanding QCD.

Category:

Experiment

Collaboration:

ALICE

Parallel 4: high pt in small systems / **20**

Exploring jet quenching effects via di-hadron correlations in 13 TeV proton-proton collisions with ALICE

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In high-energy collider physics, one of the most important questions is whether quark-gluon plasma (QGP) is formed in pp collisions. Recently, flow-like behaviours have been found in high-multiplicity pp collisions implying collectivity. Stronger evidence for the QGP formation in pp collisions would be signatures of jet quenching, which has not yet been observed. In this contribution, the results of jet quenching studies in pp collisions at $\sqrt{s_{\rm NN}} = 13$ TeV with di-hadron correlations will be presented. The correlations are measured for various $p_{\rm T}$ intervals as a function of charged-particle multiplicity. The results at high-multiplicity (HM) events show an azimuthal narrowing of the jets compared to the minimum bias (MB) events, although the difference between HM and MB becomes smaller at higher $p_{\rm T}$ intervals where the jets are narrower. These findings suggest a potential bias in the flow extraction, called the low-multiplicity (LM) template method, which assumes that the jet shape does not change between HM and LM events. The measurements are compared with various model calculations such as PYTHIA8, PYTHIA String shoving, EPOS, AMPT and JETSCAPE. Additionally, we report on the jet fragmentation functions in HM and MB events as well as preliminary results of di-hadron correlations from the LHC Run 3 pp collisions. Furthermore, the implications and interpretations of the results are discussed.

Category:

Experiment

Collaboration:

ALICE

Parallel 3: nPDF / 8

Nuclear PDFs from the nCTEQ collaboration

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Recently in the nCTEQ group we have performed a number of dedicated analyses investigating different important aspects related to nuclear parton distribution functions (nPDFs). This includes: analysis of the low-x distributions with help of p-Pb heavy quark(onium) data from the LHC; study of the high-x region by including JLAB DIS data and systematically investigating theoretical aspects related to this region, such as, target mass corrections or deuteron corrections; reanalysis of the available DIS neutrino data and others. All these efforts are now being combined into a new global nPDF analysis - nCTEQ24. In the current talk I will present preliminary results of this new analysis.

Category:

Theory

Collaboration:

Parallel 2: heavy quark production / 118

Charm production in LHCb fixed-target mode

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The novel fixed-target program pioneered by the LHCb experiment during the LHC Run 2 has been upgraded for Run 3 with a dedicated gas injection system, SMOG2. Featuring an improved gas confinement to increase the fixed-target luminosity and a new system that allows the injection of non-noble gases, SMOG2 enables the collection of large samples of pA and PbA fixed-target collisions, including high-statistics samples of charm hadrons. Charm production measurements with SMOG2 provide a unique ability to study and constrain cold nuclear matter effects in small and large collision systems at the same √sNN and also allow to probe the possible onset of hot nuclear matter effects. In this talk, new results of hidden and open charm production using the first data from the new SMOG2 system will be shown. The prospects for charm measurements in PbAr collisions will also be discussed.

Category:

Experiment

Collaboration:

LHCb

Parallel 1: jet substructure / 70

Isolating perturbative QCD splittings in heavy-ion collisions

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We propose a novel approach to investigate the evolution of jets in heavy-ion collisions by employing a combination of jet substructure measurements. Our method focuses on isolating the perturbative regime of jet evolution. As a proof of concept, we analyze the distribution of the hardest splitting above a transverse momentum scale, $k_{t,\mathrm{cut}}$, in high-p_T jets. For a $k_{t,\mathrm{cut}}$ that is significantly greater than any medium scale, the observable is determined by vacuum-like emissions. Therefore, it serves as a unique baseline independent of the medium modeling. Furthermore, a moderate $k_{t,\mathrm{cut}}$ enhances the sensitivity to energy loss, specifically highlighting the presence of a critical resolution angle. Finally, at low $k_{t,\mathrm{cut}}$, the observable becomes sensitive to induced emissions and medium response. We validate the generality of our findings using various heavy-ion event generators, including Hybrid, JetMed, Jewel, and Matter+LBT/MARTINI models. Consequently, these substructure measurements can serve as a valuable guideline for future model developments, effectively disentangling different medium contributions. Our study paves the way for the definition of jet observables that can be calculated from first principles, dominated by perturbative QCD, and within the experimental reach of Run3 at the LHC.

[1] L. Cunqueiro, D. Pablos, A. Soto-Ontoso, M. Spousta, A. Takacs, M. Verweij, arXiv:2311.07643

Category:

Theory

Collaboration:

Parallel 4: high pt in small systems / 16

Exploring light flavor hadronization in hard and soft events with event shape classifiers in small collision systems at the LHC with ALICE

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High-multiplicity pp collisions at LHC energies have revealed that small systems can exhibit QGP-like features, suggesting that light-flavor hadron production arises from complex mechanisms whose relative contributions evolve smoothly from low to high multiplicity collisions. Several analyses have recently been performed with event shape classifiers to separate soft and hard components, namely with transverse spherocity, relative transverse activity classifier, and charged-particle flattenicity.
This talk will present the charged and identified light flavour particle production as a function of event shape classifiers in pp collisions. These studies allow topological selection of events that are either "isotropic" (dominated by multiple soft processes) or "jet-like" (dominated by one or few hard scatterings). In addition, to get an insight into the underlying dynamics of ϕ meson production, this talk will highlight new results from ALICE comparing the ϕ meson production in and out of jets from pp collisions at $\sqrt{s} = 13.6$ TeV. The experimental results will be compared with the predictions from QCD-inspired models such as PYTHIA 8 and QGP-inspired models such as EPOS-LHC and EPOS4.

Category:

Experiment

Collaboration:

ALICE

Parallel 3: nPDF / 24

Evolution of structure functions at NLO without PDFs

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The increasingly precise experimental data from LHC have led to global extractions of parton distribution functions with significantly improved accuracy. While there are ways to approximate some

theoretical uncertainties like those arising from the choices of the factorization scale, alternative approaches to tame the remaining theoretical uncertainties may eventually be needed for precision phenomenology and searches for new physics. An option advocated here is to formulate the global analysis of QCD entirely in terms of Deep Inelastic Scattering (DIS) structure functions instead of PDFs. In this talk, we show how to write down the Q^2 dependence of DIS structure functions at NLO with three active quark flavours, what are the novel features with respect to the leading-order case discussed in Ref. [1], and how the independence of the factorization scale and scheme arises in practice. The steps towards the first PDF-free global analysis of QCD including LHC data are outlined.

[1] T. Lappi, H. Mäntysaari, H. Paukkunen and M. Tevio, Evolution of structure functions in momentum space, Eur. Phys. J. C 84.1 (2024) [arXiv:2304.06998 [hep-ph]]

Category:

Theory

Collaboration:

Parallel 2: heavy quark production / **80**

Charm and beauty production at forward rapidity with ALICE

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In hadronic collisions, charm and beauty quarks are mainly produced in hard partonic scatterings due to their large masses. Thus, they are ideal tools to investigate various aspects of perturbative QCD. In addition, measurements in pp collisions represent a baseline for cold nuclear matter studies in p-A collisions, and for the characterization of the hot and dense medium, the quark-gluon plasma (QGP), formed in A-A interactions. In ALICE, it is possible to reconstruct dileptons both in the dielectron channel at midrapidity ($|y| < 0.9$) in the central barrel, and in the dimuon channel at forward rapidity ($2.5 < y < 4$) with the muon spectrometer. In particular, the continuum region between charmonium and bottomonium resonances, as well as that beyond bottomonia, are significantly populated by the semileptonic decays of hadron pairs containing charm or beauty quarks. In this contribution, a first measurement of heavy-flavor cross sections in pp collisions at $\sqrt{s} = 13$ TeV and forward rapidity will be presented. Additionally, the separate measurement of single muons from charm- and beauty-hadron decays in pp and Pb-Pb collisions from the LHC Run 3, collected with the upgraded ALICE apparatus exploiting the vertexing capabilities of the new Muon Forward Tracker (MFT), will also be reported.

Category:

Experiment

Collaboration:

ALICE

Parallel 1: jet substructure / **37**

Probing hadronization and quark-gluon plasma using collinear-drop jet observables at RHIC

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Deciphering jet substructure modification patterns in heavy ion collisions holds the key to finding the inner working of the quark-gluon plasma. In the past few years, significant progress was made to studying the modifications of soft-drop jet observables, which were designed to probe the hard jet substructure. Collinear-drop observables were constructed to enhance the sensitivity to soft jet substructure, with the flexibility of scanning through phase space in search of characteristic medium signatures. With the new runs at Relativistic Heavy Ion Collider, we provide resummed calculations of a set of collinear-drop observables, including the new class of flattened jet angularity, at next-to-leading logarithmic accuracies using soft-collinear effective theory. The significant hadronization effects as modeled in Pythia event generator are included through the transfer matrix approach. We also investigate the medium effects to collinear-drop observables in heavy ion collisions using Q-pythia and Jewel Monte Carlo simulations, as well as analytic calculations with glauber interactions. We discuss strategies of designing collinear-drop observables for testing jet-medium interaction mechanisms. In the end we present theoretical predictions for the upcoming STAR measurement results.

Category:

Theory

Collaboration:

Parallel 4: high pt in small systems / **215**

Multi-Observable Analysis of Jet Quenching Using Bayesian Inference

Authors: JETSCAPE Collaboration[None]; Peter Martin Jacobs[1]

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The JETSCAPE Collaboration presents a new, multi-observable study of jet transport in the QGP using Bayesian Inference, for the first time incorporating all available inclusive hadron and jet suppression data, and jet substructure data. The theoretical description of jet quenching is multi-stage, based on the MATTER and LBT models, with virtuality-dependent jet-medium interaction. Detailed hydrodynamic modeling of the QGP utilizes a previous Bayesian calibration. This study extends the previous JETSCAPE Bayesian Inference jet quenching analysis, which was based solely on inclusive hadron data. The multi-observable nature of the analysis enables exploration of correlations and differences between different probes and different kinematic ranges. Notably, tension is observed between calibrations based on hadron RAA for pT<30 GeV/c, and higher pT hadron and jet RAA data. This approach goes beyond the constraint of model parameters, testing the consistency with which the theoretical formulation describes a wide range of jet quenching data, and identifying those aspects of the formulation that are in tension with data. We also explore the constraints imposed by jet substructure data, beyond those of inclusive jet and hadron suppression measurements. These studies provide new insight into the mechanisms of jet interactions in matter and their theoretical description, and point to next steps in the field for comprehensive understanding of jet quenching as a probe of the QGP.

Category:

Theory

Collaboration:

JETSCAPE

Parallel 3: nPDF / 159

Polarization measurement and prospects at LHCb

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With its precise vertex reconstruction and particle identification capabilities, the LHCb detector is ideally suited to study the production and polarization of primary and secondary particles. In particular, as the origin of hyperon polarization from unpolarized proton-proton and proton-nucleus collisions is not yet fully understood, measurements in different collision systems and kinematic ranges must be provided. In this contribution, recent LHCb measurements of hyperon polarization in heavy-ion collider and in fixed-target modes are discussed, including their implications for hadronization modification in small collision systems and for transverse-momentum-dependent parton distributions and fragmentation functions.

Category:

Experiment

Collaboration:

LHCb

Parallel 2: heavy quark production / 120

First $D^0+\overline{D}^0$ measurement in heavy-ion collisions at SPS energies with NA61/SHINE

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The measurement of open charm meson production provides a tool for the investigation of the properties of the hot and dense matter created in nucleus-nucleus collisions at relativistic energies. In particular, charm mesons are of vivid interest in the context of the study of the nature of the phase-transition between confined hadronic matter and the quark-gluon plasma. Recently, the experimental setup of the NA61/SHINE experiment was upgraded with the high spatial resolution Vertex Detector which enables the reconstruction of secondary vertices from open charm meson decays.

In this presentation the first D^0 meson yields at the SPS energy regime will be shown. The analysis used the most central 20% of Xe+La collisions at 150A GeV/c from the data set collected in 2017. This allowed the estimation of the corrected yields (dN/dy) for $D^0+\overline{D}^0$ via its $\pi^{+/-}+K^{-/+}$ decay

channel at mid-rapidity in the center-of-mass system. The results will be compared and discussed in the context of several model calculations including statistical and dynamical approaches.

Category:

Experiment

Collaboration:

NA61/SHINE Collaboration

Parallel 1: jet substructure / 306

Leading order, next-to-leading order, and non-perturbative parton collision kernels: Effects on the jet substructures

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Jet energy loss is an important signature of the creation of QGP. High-precision energy-loss model is essential to independently verifying the QGP properties learned from soft particles. In this work, we study the phenomenological influence of the higher order collision kernels — the up-to-NLO one evaluated by EQCD and the non-perturbative (NP) one computed in lattice QCD — in the energy loss of hard parton, compared to the LO kernel using AMY.

We first optimize the energy loss modeling in MARTINI. Introducing formation time to the parton shower in the initial hard scattering is found to be essential for a simultaneous description of hadron and jet R_AA. It also improves jet shape at small angle and fragmentation function of leading hadrons. Discrepancy with data is observed at the soft sections of jet substructures, i.e. shape at large angles and the fragmentation function at small momentum fractions, which necessitates introduction of energy loss to high virtuality partons.

We then perform comprehensive parameter scans of MARTINI using LO, NLO, and NP kernels. Hadron and jet R_AA are calculated with AMY rates using the three kernels and the optimized parameter sets for the running coupling. The results exhibit remarkable similarities in their overall values, as well as pT and centrality dependences. Due to the differences in the soft radiation rates, sizable differences in the jet substructure is observed.

Refs: the authors, PRC106.064902; in progress.

Category:

Theory

Collaboration:

Parallel 7: early time dynamics / 231

Measurement of $dE_T/d\eta$ in Au+Au collisions at 200 GeV with sPHENIX at RHIC

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The transverse energy in heavy ion collisions is one of the key observables characterizing global properties of the Quark-Gluon Plasma (QGP). The transverse energy per unit pseudorapidity ($dE_T/d\eta$) probes the energy carried by the medium along the longitudinal direction, providing essential information related to the initial geometry and subsequent hydrodynamic evolution of the QGP. Such studies are facilitated using recent data collected by the sPHENIX detector during the RHIC commissioning run in 2023 with Au+Au collisions at nucleon-nucleon center-of-mass energy of 200 GeV. The sPHENIX calorimeter system, comprising Electromagnetic and Hadronic Calorimeter detectors, covers a wide rapidity acceptance region as well as the full azimuthal phase space. This setup provides the capability for high-resolution measurements of photons, electrons, jets, and hadrons, and also allows particularly detailed $dE_T/d\eta$ measurements with high precision. This talk reports the first measurements of $dE_T/d\eta$ with the sPHENIX detector, which are also the first results for that observable at RHIC using a hadronic calorimeter. The results are presented in various centrality intervals and compared to the latest theoretical models, which will impose strong constraints on centrality-dependent particle production and initial conditions of the collisions at RHIC energies.

Category:

Experiment

Collaboration:

sPHENIX

Parallel 8: high pt correlations / **166**

Study of full event energy-energy correlation in high-p_{T} Z tagged events in PbPb collisions in CMS

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The production of a Z boson provides a clean handle to control the population of events to be studied. By selecting muonic decays of Z bosons, we can isolate the effect of the recoiling process without potential bias from requiring isolation, as is the case for photons. Di-hadron correlations can naturally separate effects from different angular scales. Similar to the energy-energy correlator in jets where perturbative and non-perturbative regimes are separated, by studying analogous correlation in the full event, one can unravel potential larger-scale structures that may arise from the interaction of high-energy recoiling particles with the quark-gluon plasma. This talk will present the first measurement of the energy-weighted di-hadron correlation with the CMS collaboration using events tagged with a Z boson. The result provides interesting insight into the inner workings of the quark-gluon plasma.

Category:

Experiment

Collaboration:

CMS

Parallel 6: heavy quarks in medium / 219

Elliptic flow measurements of light and heavy flavor hadrons, and J/ψ in Au+Au collisions at forward rapidity with PHENIX

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Measurements of elliptic flow (v_2) of light and heavy flavor particles can provide key insight into the transport properties and collective behavior of QGP. The PHENIX experiment has a unique forward rapidity coverage at RHIC ($1.2 \leq |\eta| \leq 2.2$), and large muon datasets collected in 2014 and 2016 with Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, allowing for statistically significant heavy flavor v_2 measurements. Mid-rapidity data from RHIC indicate significant flow of open heavy flavor, while v_2 of J/ψ is consistent with zero within the large statistical uncertainty. At LHC energies, both open heavy flavor particles and J/ψ have non-zero v_2 measured in Pb+Pb and in p+Pb collisions. The influence of the initial and final state effects, charm thermalization and coalescence are under investigation both at RHIC and LHC. Most of the available RHIC measurements are at mid-rapidity. However, at forward rapidity the measurements sample different initial conditions, and the QGP has different temperature and pressure gradients, presenting an opportunity to disentagle competing effects. We present final results of v_2 of charged hadrons, muons from heavy flavor decays, and J/ψ, measured using the PHENIX muon arms from the combined high-statistics 2014 and 2016 Au+Au datasets. The results are compared to RHIC measurements at mid-rapidity and to measurements form LHC to provide a comprehensive picture of heavy flavor dynamics in QGP.

Category:

Experiment

Collaboration:

PHENIX

Parallel 5: jet substructure / 157

Identifying the onset of early-vacuum showers and medium-modified showers with the Lund jet plane in high-pT jets with CMS

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Jets are powerful probes used to improve our understanding of the strong force at short distances. The radiation pattern of jets can be visualized via the Lund jet plane, a two-dimensional representation of the phase space of intrajet emissions using the splitting angle ΔR and the relative transverse momentum of the emission relative to the emitter k_{T}. The Lund jet plane allows for the separation of nonperturbative and perturbative effects in a modular fashion, allowing for strong constraints in MC event generators and for robust comparisons with first-principles QCD calculations. In heavy ion collisions, the Lund jet plane in addition can be used to obtain a spacetime picture of the evolution of the jet shower as it traverses the quark-gluon plasma created in the collision. In this talk, we discuss new CMS jet substructure measurements in pp and PbPb collisions based on the Lund jet plane representation in inclusive jets with a $p_{\mathrm{T},jet} > 200$ GeV.

Category:

Experiment

Collaboration:

CMS

Parallel 8: high pt correlations / 158

Investigating initial state of heavy-ion and pp collisions using [pT] fluctuations and vn – [pT] correlations in ATLAS

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This talk presents recent studies of event-wise mean transverse momentum, [pT] that can help differentiate the interplay between the effect of radial collectivity, random thermal motion and deformation in nuclear geometry. In addition, the Pearson Correlation Coefficient (PCC) between flow, vn and [pT] , ρ(vn, [pT]), will be shown. The results bear on aspects of the initial state, such as nuclear deformation and initial momentum anisotropy. This talk presents new precise ATLAS measurements of [pT] cumulants up to 3rd order and vn – [pT] correlations in Xe+Xe, Pb+Pb and pp collisions. This measurement provides the first experimental handle to isolate initial state and medium evolution contributing to final state momentum fluctuations. The PCC coefficients show a non-monotonic dependence on centrality, [pT] and η, reflecting the fact that different aspects of the initial conditions affect different regions of the phase space. The ratio of ρ(v2, [pT]) be- tween the two systems in the ultra-central region suggests that 129Xe has large quadrupole deformation but with a significant triaxiality. The measurement of vn – [pT] correlation provides the first measurement of triaxiality in 129Xe using heavy ion collisions and provides new constraints to current models which fail to describe many of the observed trends in data. The measurement in high multiplicity pp collisions is compared to several models and provides information on the initial state contributions to the observed PCC.

Category:

Experiment

Collaboration:

ATLAS

Parallel 7: early time dynamics / 254

Quantifying the degree of hydrodynamic behaviour in heavy-ion collisions

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Exploiting the first measurements of the same ion species in O+O collisons at RHIC and LHC, we propose an experimentally acessible observable to distinguish whether collective behavior builds up through a hydrodynamic expansion of a strongly interacting QGP or through few rescatterings in a non-equilibrated dilute medium. Our procedure allows to disentangle the effects of the initial state geometry and the dynamical response mechanism on the total resulting anisotropic flow. We validate the ability of our proposed observable to discriminate between systems with different interaction rates using results from event-by-event simulations in RTA kinetic theory. As a proof of concept, we extract the degree of hydrodynamization for Pb+Pb collisions at LHC from experimental data.

Category:

Theory

Collaboration:

Parallel 6: heavy quarks in medium / **51**

Characterisation of heavy-quark propagation and thermalisation in QGP with ALICE

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Heavy quarks (charm and beauty) are useful probes for investigating the properties of the quark-gluon plasma (QGP) generated in ultrarelativistic heavy-ion collisions. Measurements of the nuclear modification factor R_{AA} of charm and beauty hadrons offer a means to characterize the in-medium energy loss of heavy quarks in the QGP. Insights into their participation in the medium collective motion are obtained through measurements of the elliptic-flow coefficient v_2. As heavy quarks traverse the QGP, the internal structure and energy of the resulting jet may be altered, while the parton shower can modify the plasma itself by injecting energy and momentum. Insights into these effects are obtained by measuring angular correlations involving heavy-flavour particles.

In this contribution, the latest findings from the LHC Pb-Pb Run 3 data are featured, showcasing the performance of v_2 measurements for both charm mesons and baryons. Measurements of the R_{AA} of charm hadrons and D^0-tagged jets in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV are shown, as well as the prompt- and non-prompt D meson v_2 coefficients. These measurements are compared to model predictions that incorporate various implementations of heavy-quark interaction and hadronisation with the QGP constituents. Additionally, angular correlations of heavy-flavour decay electrons with charged particles, and their alterations due to the QGP presence are presented.

Category:

Experiment

Collaboration:

ALICE

Parallel 5: jet substructure / **151**

First measurement of the jet axis decorrelation with photon-tagged jets in pp and PbPb at 5.02 TeV with CMS

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A search for medium-induced jet transverse momentum broadening is performed with isolated photon-tagged jet events in proton-proton (pp) and lead-lead (PbPb) collisions at nucleon-nucleon center-of-mass energy 5.02 TeV. The difference between jet axes as determined via energy-weight and winner-take-all clustering schemes, also known as the decorrelation of jet axes and denoted Δj, is measured for the first time in photon-tagged jet events. This observable is sensitive to both multiple scattering and large-angle scattering effects in the QGP. The pp and PbPb data samples were recorded with the CMS detector at the LHC and correspond to integrated luminosities of 1.69 nb^{-1} and 302 pb^{-1} respectively. Events are required to have a leading isolated photon with $60 < p_T^{\gamma} < 200$ GeV, which is correlated with anti-\kt $R = 0.3$ jets with $30 < p_T^{jet} < 100$ GeV opposite in azimuthal angle. Event selection on colorless high-pT bosons reduces the medium-induced survivor's bias present in inclusive jet measurements of Δj. The PbPb results are reported as a function of collision centrality and compared to pp reference data. Jets with $p_T^{jet} < 60$ GeV have consistent shape in PbPb relative to pp. However, jets with $p_T^{jet} > 60$ GeV in central PbPb show signs of narrowing relative to pp. The results are compared to the Jewel and Pyquen theoretical models, which include different methods of energy loss.

Category:

Experiment

Collaboration:

CMS

Parallel 8: high pt correlations / 161

Measurement of Azimuthal Anisotropy of High Transverse Momentum Charged Particles in Pb+Pb Collisions using Multi-particle Cumulants with the ATLAS Detector

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Heavy-ion collisions produce a hot, dense medium, and high-momentum par- tons from the collision traverse this medium while losing energy in it. Because of the initial geometry of the QGP, partons produced at different angles, with respect to the impact parameter, traverse different path lengths in the medium leading to azimuthal-angle dependence of the yields of high transverse momen- tum (pT) final-state particles. The magnitude of angular modulation is quanti- fied by the parameter vn with respect to the nth-order event plane. This talk presents new measurements of vn and its fluctuations as a function of pT and centrality using high-pT charged hadrons in data collected by ATLAS detector at √sNN = 5.02 TeV. The measurements cover a broad track pT range from 1 to 400 GeV over collision centrality 0–60% for vn where n = 2, 3, 4 using scalar product method. The v2 and v3 coefficients are also measured with the multi-particle cumulant methods to probe fluctuations in the vn distribution. A non-zero v2 is observed through all centrality bins at pT greater than 60 GeV. For the scalar-product method, both v3 and v4 are consistent with zero in a high- pT region. The v2 and v3 showed different behaviors toward the high-pT region when studied with different methods. Comparison between the methods with improved statistics will explore a higher pT range than current measurements and provide insights for the initial-state fluctuations and non-flow contributions.

Category:

Experiment

Collaboration:

ATLAS

Parallel 7: early time dynamics / 245

A Unified Adiabatic Description of Hydrodynamization in Kinetic Theory

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The far-from equilibrium dynamics of the pre-hydrodynamic quark-gluon plasma (QGP) formed in heavy ion collisions can be characterized by distinct stages, during each of which the system loses some memory of its initial condition, until only the hydrodynamic modes remain. This attractor behavior has been characterized previously in both strongly and weakly coupled descriptions. In particular, at weak coupling it has been found in kinetic theory descriptions in terms of self-similar scaling solutions for the particle distribution function, even at times well before hydrodynamization. However, even though it has been repeatedly observed, there has been an absence of an intuitive physical explanation of how and why attractor behavior occurs. The Adiabatic Hydrodynamization (AH) framework provides exactly such an explanation, showing that the attractor solution can be thought of as the ground state of an analog to quantum mechanical adiabatic evolution, provided we identify appropriate coordinate rescalings. Using the example of a simplified QCD kinetic theory in the small-angle scattering limit, we show how AH can explain both the early pre-hydrodynamic attractor and the later hydrodynamizing attractor in a longitudinally expanding gluon gas in a unified framework. By doing this, we provide a unified description of, and intuition for, all the stages of what in QCD would be bottom-up thermalization, starting from a pre-hydrodynamic attractor and ending with hydrodynamization.

Category:

Theory

Collaboration:

Parallel 6: heavy quarks in medium / 170

Measurement of collective flow of $D_{\rm s}^{\pm}$ and D^0 meson with CMS at 5.02 TeV

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The interaction of heavy quarks with the quark-gluon plasma (QGP) affects their azimuthal distribution and transverse momentum ($p_{\rm T}$) spectrum. Hence, azimuthal anisotropy coefficients (v_n) and nuclear modification factors (R_{AA}) of heavy flavor hadrons are vital probes to study QGP properties. This talk presents the first measurements of the elliptic (v_2) and triangular (v_3) flow coefficients

of $D_s^{\pm}$ mesons in lead-lead (PbPb) collisions at a center-of-mass energy of 5.02 TeV with the CMS experiment. These measurements are performed as a function of transverse momentum in different centrality classes, significantly increasing precision and expanding the kinematic range compared to existing results. The wide kinematic range and direct comparison with non-strange D mesons allow for the investigation of various charm quark flow generation mechanisms, particularly hadronization processes. Additionally, the first-ever $D_s^{\pm}$ meson v_3 measurement can probe the impact of initial states.

Category:

Experiment

Collaboration:

CMS

Parallel 5: jet substructure / **192**

Constraining the color-charge effects of energy loss with jet axis-based substructure studies in PbPb collisions at 5.02 TeV

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Jets are established tools for studies of the Quark Gluon Plasma (QGP) properties. In this talk, we present a new measurement of the jet substructure modification via the observable ΔR_{axis}, characterizing the distance between two types of jet axis constructed with the same jet constituents. We use E-scheme and WTA axes with different sensitivity to soft and semi-hard medium-induced radiation. The reported fully unfolded distributions present the first CMS measurements of the angular separation between such axes for anti-k_T $R = 0.4$ jets from 5.02 PbPb collisions for several collision centralities and jet p_T intervals. Significant modifications of ΔR_{axis} distributions are observed in central compared to peripheral collisions, indicating progressive narrowing of angular correlations that could be attributed to QGP-induced modifications of the internal jet structure. Alternatively, the narrowing could also be produced by the predicted color-charge dependence of energy loss, causing a larger migration of gluon-initiated jets towards lower final state energies. Assuming the modification is attributed to the difference in the quark/gluon energy loss, we provide complementary findings on gluon fraction limits from the MC-based template fit to the fully unfolded data. The new measurements access the jet substructure in the previously unassessed kinematic domain and provide new limits of color charge dependence of energy loss.

Category:

Experiment

Collaboration:

CMS

Parallel 8: high pt correlations / **139**

Strangeness studies in LHCb fixed-target collisions

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Leveraging on the injection of noble gases into the LHC accelerator beam-pipe, LHCb has been collecting since 2015 proton- and lead-gas collisions, which give access to the poorly explored high-x and moderate Q2 kinematic region. In particular, studies of strangeness production provides information on hadronization and serve as important inputs to models of particle production in cosmic rays. In this contribution, recent results on strangeness production in fixed-target collisions at LHCb will be presented, including studies for hyperon production and polarization.

Category:

Experiment

Collaboration:

LHCb

Parallel 7: early time dynamics / 110

Jet momentum broadening beyond the jet quenching parameter from QCD kinetic theory

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The study of the initial nonequilibrium stages in heavy-ion collisions is an exciting research frontier. In particular, for jet quenching observables, jet-medium interactions during the initial stages have been argued to be one of the major theoretical uncertainties. To calculate the medium-induced gluon spectrum and jet energy loss, knowledge of the momentum broadening kernel is required, which is often used in a harmonic approximation with the jet quenching parameter $\hat{q}$. In this talk, I will present our results for the momentum-broadening kernel from the gluonic sector of QCD kinetic theory, which describes the probability for a jet parton to exchange a specific momentum with the medium. In particular, we find that at early times, processes with small-momentum exchange are more likely than in a corresponding thermal system, which reverses at large momenta. Our results for the kernel are consistent with the previous extraction of $\hat{q}$ while encoding more information and hence leading to a better description of jet quenching during the initial stages.

Category:

Theory

Collaboration:

Parallel 6: heavy quarks in medium / 188

Fluid-dynamic approach to heavy-quark diffusion in the quark-gluon plasma

Authors: Andrea Dubla[1]; Andreas Kirchner[None]; Eduardo Grossi[2]; Federica Capellino[3]; Silvia Masciocchi[4]; Stefan Floerchinger[5]

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Charm and beauty quarks are powerful tools to characterize the quark-gluon plasma (QGP) produced in heavy-ion collisions. Although they are initially produced out of kinetic equilibrium via hard partonic scattering processes, recent measurements of anisotropic flow of charmed hadrons pose the question regarding the degree thermalization of heavy quarks in the medium. Our recent work [1] has provided new insights into the level of thermalization of charm and beauty quarks in the QGP. In particular, by exploiting a mapping between transport theory and fluid dynamics, we have shown how a fluid-dynamic description of charm-quark diffusion in the QCD plasma is feasible at LHC energies. Inspired by recent lattice-QCD calculations, we will show how a partial thermalization within the lifetime of the QGP is expected also for beauty quarks.
We will present results for spectra of charm [2] and beauty hadrons obtained with a fluid-dynamic approach employing the conservation of a heavy-quark - antiquark current in the QGP. By introducing a weight parameter in the Equation of State for the beauty quark density and comparing our results with experimental measurements of open- and hidden-beauty hadron yields, we provide an estimate of the fraction of thermalized beauty quarks in the QGP.
This work is funded via the DFG ISOQUANT Collaborative Research Center (SFB 1225).
[1] Phys.Rev.D 106 3, 034021 (2022)
[2] Phys.Rev.D 108 (2023) 11, 116011

Category:

Theory

Collaboration:

Parallel 5: jet substructure / 195

Detection of jet shower width and survival bias effect with photon-tagged jet girth and groomed jet radius in pp and PbPb at 5.02 TeV with CMS

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This talk presents the first measurements of the groomed jet radius R_{g} and the jet girth g in events with an isolated photon recoiling against a jet in PbPb and pp collisions at the LHC at 5.02 TeV. The observables R_{g} and g provide a quantitative measure of how narrow or broad a jet is. Events are required to have a photon with transverse momentum $p_{\mathrm{T}}^{\gamma} > 100$˜GeV and at least one jet back-to-back in azimuth with respect to the photon and with transverse momentum p_{T}^{jet} such that $p_{\mathrm{T}}^{jet}/p_{\mathrm{T}}^{\gamma} > 0.4$. The measured R_{g} and g distributions are unfolded to the particle level, which facilitates the comparison between the PbPb and pp results and with theoretical predictions. It is found that jets with $p_{\mathrm{T}}^{jet}/p_{\mathrm{T}}^{\gamma} > 0.8$, i.e, those that closely balance the photon p_{T}^{γ}, are narrower in PbPb than in pp collisions. Relaxing the selection to include jets with $p_{\mathrm{T}}^{jet}/p_{\mathrm{T}}^{\gamma} > 0.4$ reduces the narrowing of the angular structure of jets in PbPb relative to the pp reference. This demonstrates that selection bias effects associated with jet energy loss play an important role in the interpretation of jet substructure measurements.

Category:

Experiment

Collaboration:

CMS

Parallel 6: heavy quarks in medium / 49

Investigating of charm-quark hadronisation into baryons and its collision-system dependence with ALICE

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Charm-baryon production measurements in proton-proton (pp) collisions at the LHC are fundamental tools to investigate the charm-quark hadronisation and to test pQCD calculations. Recent measurements in pp collisions have shown baryon-to-meson ratios significantly larger than those in e^+e^- collisions, challenging the validity of theoretical calculations based on the factorisation approach, which assumes universal charm fragmentation functions across collision systems. Additionally, these measurements allow for the study of possible hadronisation modifications in presence of nuclear-matter effects in larger collision systems (e.g. p-Pb).

In this contribution, preliminary results on the production of $\Sigma_c^{0,++}(2455)$ and $\Sigma_c^{0,++}(2520)$ baryon resonances in pp collisions at $\sqrt{s}$ = 13.6 TeV are presented. A first look at the Λ_c^+/D^0 production-yield ratios in the same collision system is also discussed. Additionally, the final ALICE results on the fragmentation fractions of charm quarks into hadrons in pp and p–Pb collisions from Run 2 data sample are presented, along with the final measurement of Ω_c^0 baryon from the semileptonic decay channel $\Omega^-e^+\nu_e$ in pp collisions at $\sqrt{s}$ = 13 TeV. The results are compared with predictions from novel theoretical models that consider different hadronisation mechanisms with respect to in-vacuum fragmentation.

Category:

Experiment

Collaboration:

ALICE

Parallel 8: high pt correlations / 196

Measurements of the light-by-light scattering and the Breit–Wheeler processes, and searches for axion-like particles in ultraperipheral PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

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Measurements of the light-by-light scattering (LbL, $\gamma\gamma \to \gamma\gamma$) and the Breit–Wheeler (B–W, $\gamma\gamma \to \mathrm{e}^+\mathrm{e}^-$) processes are reported in ultraperipheral collisions at 5.02 TeV using the 2018 CMS lead-lead data sample of $1.65\ \mathrm{nb}^{-1}$. Events with a pair of exclusively produced photons or electrons are selected, each with transverse energy $E_\mathrm{T}^{\gamma,\mathrm{e}} > 2$ GeV, pseudorapidity $|\eta^{\gamma,\mathrm{e}}| < 2.2$, pair invariant mass $m^{\gamma\gamma,\mathrm{ee}} > 5$ GeV, pair transverse momentum $p_\mathrm{T}^{\gamma\gamma,\mathrm{ee}} < 1$ GeV, and pair azimuthal acoplanarity $A_\phi < 0.01$. The measured B–W fiducial cross section, $\sigma_\mathrm{fid}(\gamma\gamma \to \mathrm{e}^+\mathrm{e}^-) = 271.5 \pm 1.9\ (\mathrm{stat}) \pm 18.3\ (\mathrm{syst})\ \mu\mathrm{b}$, as well as the differential distributions for various kinematic observables, are in agreement with standard model (SM) predictions. The observed significance of the LbL signal with respect to the background-only hypothesis is above five standard deviations. The fiducial LbL scattering cross section, $\sigma_\mathrm{fid}(\gamma\gamma \to \gamma\gamma) = 107 \pm 33\ (\mathrm{stat}) \pm 20\ (\mathrm{syst})\ \mathrm{nb}$, is consistent with SM predictions. Limits on the production of axion-like particles coupling to photons are set over the mass range $m_\mathrm{a} = 5$–100 GeV, including the most stringent limits in 5–10 GeV.

Category:

Experiment

Collaboration:

CMS

Parallel 7: early time dynamics / **94**

Jet quenching in the glasma stage of heavy-ion collisions

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The early glasma stage of heavy-ion collisions is characterized by strong color fields which deflect jet partons, resulting in sizable jet momentum broadening. An outstanding question is how this momentum broadening leads to jet quenching in the glasma and how important this quenching is for jet phenomenology. In this work we aim to answer these questions by performing the first calculation of medium-induced radiation in the glasma. We use a model for the glasma comprised of independent color domains where each domain has a constant color field that varies event by event. We evaluate the rate of soft-gluon radiation in this model by performing an exact calculation of the path integral for the emissions kernel. We show that the rate is governed by the interplay of synchrotron-like radiation in a single color domain and the destructive interference between different color domains, giving a rate that is highly sensitive to the size of domains. Finally, we discuss how our work can be extended to more realistic glasma profiles and applied to accurate modelling of jets in heavy-ion collisions.

Category:

Theory

Collaboration:

Parallel 5: jet substructure / **207**

Extraction of jet-medium interaction details through jet substructure for inclusive and gamma-tagged jets

Authors: JETSCAPE Collaboration[None]; Yasuki Tachibana[1]

[1] *Akita International University*

Through a comprehensive analysis with Monte Carlo simulations using a multi-stage jet evolution model, we demonstrate that by comparing the jet substructure modifications for inclusive jets and gamma-tagged jets, the virtuality dependence and flavor dependence in jet-medium interactions can be closely examined. Recent findings reveal that a reduction in jet-medium interaction at the early high-virtuality stage, where the jet resolves the medium at a very short distance scale [1], is crucial in explaining single particle energy loss and multiple inclusive jet observables simultaneously [2,3]. In particular, the Soft Drop observables for inclusive jets indicate that medium effects manifest primarily in the very soft components at a later stage, resulting in minimal modification to the hard splitting structure. This behavior is predominantly governed by the characteristics of gluon jets. For quark jets, interactions with the medium in the low virtuality region significantly influence the structure of hard splittings. Reflecting on this, we show that the medium modification of hard-splitting structures is more clearly visible in gamma-jet events via the Soft Drop observables.

[1] A. Kumar, A. Majumder, and C. Shen, PRC 101, 034908 (2020).
[2] A. Kumar et al. (JETSCAPE), PRC 107, 034911 (2023).
[3] Y. Tachibana et al. (JETSCAPE), arXiv:2301.02485.

Category:

Theory

Collaboration:

JETSCAPE

Parallel 8: high pt correlations / 175

Measurement of the tau $g-2$ factor in the ultraperipheral PbPb collisions recorded by the CMS experiment

Author: Arash Jofrehei[1]

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Measurements of the anomalous magnetic moment of leptons are good handles for precision tests of the Standard Model and hints of physics beyond the Standard Model. These measurements for electrons and muons are among the most precisely measured quantities in physics. However, due to the short lifetime of the tau lepton, its anomalous magnetic moment is not as precisely known and needs to be measured innovatively and collaboratively. The CMS experiment follows a comprehensive approach to measure this quantity in complementary phase spaces of ultraperipheral hadron collisions. We will report the latest measurements of the anomalous magnetic moment of the tau lepton using ultraperipheral PbPb collisions recorded by the CMS experiment.

Category:

Experiment

Collaboration:

CMS

Parallel 7: early time dynamics / **244**

Evolution of QCD jets in non equilibrium plasmas

Authors: Bin Wu[None]; Carlos Albert Salgado Lopez[1]; Sergio Barrera Cabodevila[2]; Xiaojian Du[3]

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In this work, we study the evolution of a jet, modelled as a linear perturbation of the distribution of quarks or gluons, in an out of equilibrium system of quarks and gluons. The hard probe and the bulk QCD matter are described in an unified approaching using QCD kinetic theory. This allows us to investigate the interplay between the hard and soft sectors of jets as well as those in the bulk. We shall focus on new features of jet evolution resulted from such an approach, contracting it with the conventional description using quenching weights. This study involves solving the Boltzmann Equation in Diffusion Approximation (BEDA) numerically, complemented with parametric estimates. Our results will also be compared with those using the Effective Kinetic Theory (EKT).

Category:

Theory

Collaboration:

Parallel 6: heavy quarks in medium / **236**

Recent LHCb probes for b-quark hadronization studies

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The differences in hadron chemistry observed at e+e- machines versus hadron colliders may indicate that the mechanisms by which partons evolve into visible matter are not universal. In particular, the presence of many other quarks produced in the underlying event may affect the hadronization process. With full particle ID, precision vertexing, and a high rate DAQ, the LHCb detector is uniquely well suited to study the hadronization of heavy quarks. In this contribution, LHCb data on hadronization of heavy charm and bottom quarks, including the first results on the b baryon-to-meson production ratio versus charged particle multiplicity, will be presented

Category:

Experiment

Collaboration:

LHCb

Parallel 5: jet substructure / **212**

Effects of hadronic reinteraction on jet fragmentation from small to large systems

Authors: Hendrik Roch[1]; JETSCAPE Collaboration[None]

[1] *FIAS*

The effect of the hadronic phase on jet quenching in nuclear collisions is largely an open question, although there are tantalizing hints from previous studies that the effects might be sizable. We have implemented a hadronic afterburner phase for jet fragmentation hadrons in the JETSCAPE framework using SMASH. We have applied the new setup to $e^+ + e^-$, $p+p$ and $A+A$ systems in order to study the effects of hadronic rescattering. For a quantitative analysis we compare simulations, with and without rescatterings of shower hadrons during the afterburner phase. We report here effects of hadronic rescattering on hadron spectra, event shape observables and jet observables as functions of collision system and multiplicity. We find sizable corrections for many observables, in particular for hadron-hadron correlation functions.

Category:

Theory

Collaboration:

JETSCAPE

Parallel 12: EM in early stages / **174**

Scaling of pre-equilibrium dilepton production in QCD Kinetic Theory

Authors: Oscar Jesús Garcia Montero[None]; Philip Plaschke[1]; Soeren Schlichting[2]

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The idea of using dilepton measurements to construct a phenomenology of the early pre-equilibrium phase of heavy-ion collisions has been recently posed [1,2]. Nevertheless, a full computation of pre-equilibrium radiation yields was still missing. In this work, we use QCD kinetic theory to compute dilepton production coming from the pre equilibrium phase of the Quark-Gluon Plasma created in high-energy heavy-ion collisions [3]. Additionally, we demonstrate that the dilepton spectrum exhibits a simple scaling in terms of the specific shear viscosity η/s and entropy density $dS/d\zeta \sim \left(T\tau^{1/3}\right)^{3/2}_{\infty}$, which can be derived from dimensional analysis in the presence of a pre-equilibrium attractor. Based on this scaling we present a useful scaling formula readily available for phenomenology. We then perform full event-by-event calculations of in-medium dilepton production. By comparison to thermal QGP radiation, as well as the Drell-Yann background [4], we determine the invariant mass range where the pre-equilibrium yield is the leading contribution.

References:
[1] M. Coquet, X. Du, J.-Y. Ollitrault, S. Schlichting, and M. Winn, Phys.Lett.B 821 (2021) 136626, arXiv: [2309.00555]
[2] F. Seck, B. Friman, T. Galatyuk, H. van Hees, E. Speranza, R. Rapp, and J. Wambach, arXiv: [2309.03189]
[3] O. Garcia-Montero , P. Plaschke, S. Schlichting, arXiv: [2403.04846]
[4] S. D. Drell and T.-M. Yan, Phys. Rev. Lett. 25, 316 (1970)

Category:

Theory

Collaboration:

Parallel 11: heavy quarkonia in medium / 83

Quarkonia production in proton-proton and Pb-Pb collisions with ALICE

Authors: ALICE Collaboration[None]; Yiping Wang[1]

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Charmonia are a valuable tool to investigate nuclear matter under extreme conditions, and particularly the strongly interacting medium formed in heavy-ion collisions. At the LHC energies, the regeneration process has been found to significantly impact the observed charmonium yields. In particular, the measurement of $\psi(2S)$ production relative to J/ψ in Pb-Pb collisions has a strong discriminating power between different regeneration scenarios. Additionally, the study of quarkonium production in proton–proton (pp) collisions represents the reference for interpreting results obtained in Pb–Pb collisions and it is a key measurement to distinguish among the quarkonium production models in pp and p–Pb. In this contribution, preliminary findings on the double ratio of $\psi(2S)$ -to- J/ψ between Pb-Pb and pp collisions and the inclusive J/ψ yield in pp collisions at $\sqrt{s}$ = 13 TeV measured by the ALICE Collaboration will be presented and compared with existing model calculations.

Category:

Experiment

Collaboration:

ALICE

Parallel 10: heavy quarks in medium / 61

The system-size dependence of the bottom-baryon-to-meson production in high-energy proton-proton collisions

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The latest measurement of bottom baryon-to-meson production ratio [1], Λ_b/B, in proton-proton collisions at the LHC, shows a continuous evolution from the saturation value toward the small value identified in electron-positron collisions as the system size reduces. We address this in a canonical ensemble statistical hadronization model, and demonstrate that the decreasing trend of Λ_b/B can be quantitatively understood in terms of the canonical suppression on the yield of Λ_b toward small system size caused by exact conservation of baryon number [2]. We have thereby proposed a plausible scenario for the origin of non-universality of heavy quark hadronization currently under hot debates.

[1] LHCb Collab., Phys. Rev. Lett. 132, 081901 (2024).
[2] Yuxuan Dai, Shouxing Zhao, and Min He, arXiv: 2402.03692 (2024).

Category:

Theory

Collaboration:

Parallel 9: jet EEC / **67**

Energy-energy correlators of inclusive jets from small to large collision systems with the ALICE experiment

Authors: ALICE Collaboration[None]; Anjali Nambrath[1]

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Jet substructure is a powerful tool for performing fundamental QCD tests in elementary particle collisions and offers unique insight into the microscopic structure of the QGP in heavy-ion collisions. Defined as the energy-weighted cross section of particle pairs inside jets, the two-point energy-energy correlator (EEC) is a novel jet substructure observable probing the correlation of energy flow within jets. In pp collisions, the angular dependence of the EEC cross section shows a distinct separation of the perturbative and non-perturbative regimes, revealing the partonic dynamics of jet formation and the confinement of partons into hadrons. There have also been an increasing number of theory studies predicting how the presence of the deconfined medium modifies the EECs with respect to the vacuum results. In this talk, we present the first measurements of the EECs for inclusive jets in p-Pb and Pb-Pb collisions at 5 TeV from the ALICE experiment. By comparing our results to a measured pp baseline, we can study the modifications in jet evolution caused by interactions with both a cold nuclear medium and the quark-gluon plasma.

Category:

Experiment

Collaboration:

ALICE

Parallel 12: EM in early stages / **201**

Effects on the dilepton radiation induced by a background magnetic field

Authors: Han Gao[None]; Xiang-Yu Wu[1]; Charles Gale[None]; Sangyong Jeon[None]

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Dilepton radiation is known to be an effective thermometer of the quark-gluon plasma (QGP) [1]. In this study, we explore the possibility of using dilepton radiations as a QGP magnetometer. We calculate corrections to dilepton production rate at finite baryon chemical potential, in the presence of a time-dependent magnetic field typically found in heavy-ion collisions. At first order, such a

correction includes the non-equilibrium effects from Faraday induction: electric fields induced by a decaying magnetic field, and the relative motion of the fluid with respect to the background magnetic field. We then compute the thermal dilepton spectra from Au+Au collisions at BES energies — $\sqrt{s_{NN}}$ =7.7, 19.6, 62.4 and 200 GeV —using a realistic (3+1)-dimensional multistage hydrodynamic simulation [2]. Other non-equilibrium effects, such as viscosities and baryon diffusion, are also considered. We find signals such as dilepton elliptic flow to be very sensitive to the strength and the lifetime of the magnetic field, as well as the intrinsic QGP conductivity. This study highlights the feasibility of using dileptons as probes for the electromagnetic properties of the QGP.

[1] Jessica Churchill, Lipei Du, Charles Gale, Greg Jackson, and Sangyong Jeon, Phys. Rev. Lett. 132 (2024) 4, 172301
[2] Lipei Du, Han Gao, Sangyong Jeon, and Charles Gale, Phys. Rev. C 109 (2024) 1, 014907

Category:

Theory

Collaboration:

Parallel 11: heavy quarkonia in medium / **117**

Charmonium production measurements in large systems at LHCb

Author: Chenzhi Dong[1]

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Modifications of quarkonia production in hadronic collisions provide an important experimental observable to probe the heavy quark interaction with the nuclear medium. The excited ψ(2S) state, with a relatively low binding energy, is especially sensitive to these effects. In this contribution, we will present a new LHCb result on ψ(2s)/J/ψ production in PbPb collisions, along with comparisons to the latest theoretical models.

Category:

Experiment

Collaboration:

LHCb

Parallel 10: heavy quarks in medium / **48**

The role of strangeness in heavy quark hadronisation from small to large collision systems with ALICE

Authors: ALICE Collaboration[None]; Fabio Catalano[1]

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Production measurements of strange hadrons originating from the hadronisation of charm quarks (prompt) and from beauty-hadron decays (non-prompt) offer a unique tool to study the heavy-quark hadronisation across different collision systems. The comparisons between the measurements of charm hadrons with and without a strange valence quark in proton-proton (pp) and proton-lead (p-Pb) collisions provide important tests for pQCD calculations and the possible influence of cold nuclear matter effects, respectively. In Pb-Pb collisions, the production of heavy-flavour hadrons with strange-quark content is sensitive to the hadronisation mechanisms of charm and beauty quarks in the quark-gluon plasma and to final-state effects.

This contribution discusses the final results of the ALICE Collaboration obtained by measuring strange D mesons in pp, p–Pb, and Pb–Pb collisions collected during the LHC Run 2. Additionally, the production measurements of prompt and non-prompt $\mathrm{D_s}^+$ mesons are compared to those of non-strange mesons across the different collision systems. The first measurements of the production of orbitally excited charm-strange mesons $\mathrm{D_{s1}^+}$, $\mathrm{D_{s2}^{*+}}$ in pp collisions and the measurement of prompt Ξ_c^0-baryon production are also reported. To conclude, the first studies of strange and non-strange D mesons with the data sample of pp collisions at $\sqrt{s} = 13.6$ TeV harvested from the start of LHC Run 3 are presented.

Category:

Experiment

Collaboration:

ALICE

Parallel 9: jet EEC / **163**

Study of energy-energy correlator of jets in PbPb collisions at CMS

Author: Jussi Viinikainen[1]

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Energy-energy correlator has the advantage of isolating physics of different angular scales, which has attracted a lot of interest recently to study it in heavy-ion environments. Any modification from proton-proton reference can reveal hints about the inner workings of the quark-gluon plasma. In this presentation we will present the first measurement of the energy-energy correlator of jets in heavy ion collisions using lead-lead data at 5.02 TeV collected by CMS. We observe significant modifications over the pp reference and discuss the implications of these observations, along with future directions.

Category:

Experiment

Collaboration:

CMS

Parallel 12: EM in early stages / **185**

Dilepton emission in heavy ion collisions and chemical equilibrium of QCD matter

Authors: Xiang-Yu Wu[1]; Lipei Du[1]; Charles Gale[None]; Sangyong Jeon[None]

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Dileptons are produced throughout the entire evolution history of the medium. Owing to their electromagnetic coupling to strongly interacting matter, dileptons traverse the QGP medium unaltered after their production and carry information about their space-time points of production. The emissivity is correlated with the quark abundance in the collision system as well. Therefore, dileptons provide a unique probe to study the pre-equilibrium phase of heavy ion collisions and to report on the chemical composition in the early stages.

In this talk, we will present the thermal dilepton production and dilepton anisotropic flow calculated using next-to-leading order (NLO) thermal QCD dilepton emission rate [1] in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV collision energy, at the LHC. Multistage modelling consisting of IP-Glasma+Kompost+MUSIC+URQMD [2] is used to simulate the dynamical evolution of heavy ion collisions. The relative contribution of the pre-equilibrium stage to dilepton observables is explored and discussed. In addition, the effect of chemical equilibrium of QCD matter is also presented and highlighted.

[1] Jessica Churchill, Lipei Du, Charles Gale , Greg Jackson , Sangyong Jeon, "Dilepton production at next-to-leading order and intermediate invariant-mass observables ", Phys.Rev.C 109 (2024) 4, 044915.
[2] Charles Gale, Jean-François Paquet, Björn Schenke , Chun Shen, "Multimessenger heavy-ion collision physics", Phys.Rev.C 105 (2022) 1, 014909

Category:

Theory

Collaboration:

Parallel 11: heavy quarkonia in medium / 242

Measurements of charmonium production in heavy-ion collisions at STAR

Author: Wei Zhang[None]

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In relativistic heavy-ion collisions, the dissociation of charmonium is considered an important evidence for the formation of the quark-gluon plasma (QGP). However, charmonia also experience the regeneration effect in the QGP, which acts against the dissociation process. With decreasing collision energy, the regeneration effect decreases quickly, providing leverage to disentangle the two competing effects. Additionally, it is expected that different charmonium states dissociate at different temperatures, with a suppression pattern ordered sequentially with the binding energy. Therefore, sequential suppression of different charmonium states will further help to study the thermodynamic properties of the QGP.

In this talk, we present the nuclear modification factor (R_{AA}) of J/ψ as a function of centrality and transverse momentum in Au+Au collisions at $\sqrt{\mathrm{s_{NN}}}$ = 14.6, 17.3, 19.6, and 27 GeV using the Beam Energy Scan Phase II data. Additionally, we investigate the energy dependence of J/ψ R_{AA} from RHIC to LHC energies in central heavy-ion collisions, including a comparison to model calculations. Furthermore, the first measurement of ψ(2S) production in isobaric collisions ($^{96}_{44}Ru$ + $^{96}_{44}Ru$ and

$^{96}_{40}Zr$ + $^{96}_{40}Zr$) at top RHIC energy, including the centrality and transverse momentum dependence of the ratio of $\psi(2S)$ yield over that of J/ψ, will also be presented.

Category:

Experiment

Collaboration:

STAR

Parallel 10: heavy quarks in medium / **184**

Probing the pre-equilibrium stage of heavy-ion collisions with charm quarks

Authors: Mayank Singh[1]; Manu Kurian[2]; Bjoern Schenke[3]; Sangyong Jeon[None]; Charles Gale[None]

[1] *Vanderbilt University*

[2] *RIKEN BNL*

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Charm quarks produced in the initial stages of relativistic heavy-ion collisions serve as crucial probes of the produced medium, including the pre-equilibrium and hydrodynamic stages of the evolution. We simulate relativistic heavy-ion collisions using a hybrid method that integrates a fluctuating IP-Glasma initial state with subsequent viscous hydrodynamics. Utilizing the MARTINI event generator, we simulate the initial production of heavy quarks, and employ Langevin dynamics to model their evolution within the medium. Studying the nuclear modification factor and flow coefficient of D-mesons in Pb+Pb collisions at 5.02 TeV, we focus on the sensitivity to the energy loss of charm quarks during the early stages of the collision. We further explore how charm observables are influenced by the momentum dependence of charm quark energy loss in the medium and the hadronization processes, including fragmentation and coalescence.

Category:

Theory

Collaboration:

Parallel 9: jet EEC / **210**

Energy-energy correlators of inclusive jets in heavy-ion collisions

Authors: JETSCAPE Collaboration[None]; Yayun He[1]

[1] *South China University of Technology*

Energy-energy correlators (EECs) have manifested an important probe to unveil the properties of QCD splitting in vacuum, which should be modified in the nuclear medium such as the quark-gluon plasma. By employing the recently developed multi-stage jet evolution framework JETSCAPE, we have investigated the nuclear modification of EECs of inclusive jets in heavy-ion collisions. We find EECs are significantly influenced by the splitting behaviors in the small angle region, and contributed

by the medium response in the large angle region. We also provide the theoretical predictions of nuclear EECs for ALICE and CMS measurements.

Category:

Theory

Collaboration:

JETSCAPE

Parallel 11: heavy quarkonia in medium / 82

Prompt/Non-prompt J/ψ production in proton-proton and Pb-Pb collisions with ALICE

Authors: ALICE Collaboration[None]; Yuan Zhang[1]

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Quarkonium production in high-energy hadronic collisions is sensitive to both perturbative and non-perturbative aspects of QCD calculations. The charmonium production cross section can be split into prompt and non-prompt components, the first corresponding to a direct production of charm (anticharm) quarks, the second originating from the decay of beauty hadrons. The latter is important to investigate the mass dependence of heavy-quarks in-medium energy-loss mechanism. In this contribution the recent measurement of prompt and non-prompt J/ψ carried out by the ALICE Collaboration in pp and Pb–Pb collisions at midrapidity ($|y|$ < 0.8) will be presented. Moreover, thanks to the installation of the new muon forward tracker (MFT), the prompt/non-prompt charmonia separation is possible in LHC Run 3 also at forward rapidity ($2.5 < y < 4$). The status of the new measurements will be presented and compared, where possible, with the available models.

Category:

Experiment

Collaboration:

ALICE

Parallel 10: heavy quarks in medium / 257

Medium-induced coherent gluon radiation and heavy flavor suppression in pA collisions

Authors: Greg Jackson[1]; Kazuhiro Watanabe[2]; Stephane PEIGNE[3]

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High-energy proton-nucleus (pA) collisions have provided intriguing playgrounds for disentangling various cold nuclear matter effects on hadron production. Multiple rescatterings in the cold nuclear target induce many soft gluons that have a long formation time, resulting in the modification of hadron production rates due to fully coherent energy loss (FCEL). Medium-induced FCEL has proven to be crucial in explaining heavy meson (J/ψ, D) nuclear suppression in pA collisions in a wide range of collision energy [1,2].

Understanding the qualitative and quantitative role of the FCEL effect for the quenching of hadron production rates in a wide kinematic range is a crucial task, requiring rigorous calculations of the medium-induced soft gluon radiation spectrum. This talk will present new results for the induced single soft gluon radiation spectrum beyond leading logarithmic accuracy, enhancing the predictive power of FCEL estimations in the phenomenology of hadron production in pA collisions. The general formula is valid in the full kinematic range of the underlying processes, quantifying the entanglement between the color components of the production amplitude [3]. We will discuss the impact of the newly induced spectrum on heavy flavor suppression in pA collisions.

[1] F. Arleo, S. Peigne, Phys. Rev. Lett. 109 (2012) 122301
[2] F. Arleo, G. Jackson and S. Peigne, JHEP 01 (2022) 164
[3] G. Jackson, S. Peigne and K. Watanabe, JHEP 05 (2024) 207

Category:

Theory

Collaboration:

Parallel 9: jet EEC / **108**

Probing the Short-Distance Structure of the Quark-Gluon Plasma with Energy Correlators

Authors: Zhong Yang[1]; Yayun He[2]; Ian Moult[None]; Xin-Nian Wang[3]

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Energy-energy-correlators (EEC's) are a promising observable to study the dynamics of jet evolution in the quark-gluon plasma (QGP) through its imprint on angular scales in the energy flux of final-state particles. We carry out the first complete calculation of EEC's using realistic simulations of high-energy heavy-ion collisions, and dissect the different dynamics underlying the final distribution through analyses of jet propagation in a uniform medium. The EEC's of γ-jets in heavy-ion collisions are found to be enhanced by the medium response from elastic scatterings instead of induced gluon radiation at large angles. In the meantime, EEC's are suppressed at small angles due to energy loss and transverse momentum broadening of jet shower partons. These modifications are further shown to be sensitive to the angular scale of the in-medium interaction, as characterized by the Debye screening mass. Experimental verification and measurement of such modifications will shed light on this scale, and the short-distance structure of the QGP in heavy-ion collisions.

Category:

Theory

Collaboration:

Parallel 16: Thermal EM / **45**

Direct photon production and correlations at low p_{T} in Pb–Pb collisions with ALICE

Authors: ALICE Collaboration[None]; Dmitri Peresunko[1]

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Measurements of direct photons can provide valuable information on the properties and evolution of the quark-gluon plasma (QGP); from the initial conditions to the pre-equilibrium, QGP, and the hadronic phase. In the ALICE experiment, photons that convert in the detector material are reconstructed down to low momentum using the excellent tracking capabilities. Furthermore, photons are reconstructed using the calorimeters. Using these methods we can measure the direct-photon production from a transverse momentum of 0.4 GeV/c, where thermal direct photons dominate, up to several GeV/c, where prompt photons take over.
In this talk we will present measurements in selected centrality classes of the direct-photon production in Pb—Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ and 5.02 TeV, as well as first significant results on direct-photon HBT at low momentum. Finally, the first results on photon reconstruction using LHC Run 3 data will be reported.

Category:

Experiment

Collaboration:

ALICE

Parallel 15: heavy quarks, spin polarization / **255**

A potential approach to the 𝒳(3872) thermal behaviour

Authors: Elena G. Ferreiro[1]; Miguel Angel Escobedo[None]; Nestor Armesto[None]; Víctor López Pardo[None]

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We study the potential of X(3872) at finite temperature in the Born-Oppenheimer approximation under the assumption that it is a tetraquark. We argue that, at large number of colors, it is a good approximation to assume that the potential consists in a real part plus a constant imaginary term. The real part is then computed adapting an approach by Rothkopf and Lafferty and using as input lattice QCD determinations of the potential for hybrids. This model allows us to qualitatively estimate at which temperature range the formation of a heavy tetraquark is possible, and to propose a qualitative picture for the dissociation of the state in a medium. Our approach can be applied to other suggested internal structures for the X(3872) and to other exotic states.

Category:

Theory

Collaboration:

Parallel 14: jet theory / **89**

Measurements of Baryon-to-Meson Ratios Inside Jets in Au+Au and p+p Collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

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Measurements at RHIC and the LHC show strongly enhanced inclusive hadron baryon-to-meson yield ratios at intermediate transverse momenta (p_{T}) in high-energy nuclear collisions compared to p+p baseline. This enhancement is attributed to strong hydrodynamic flow and parton recombination in the Quark-Gluon Plasma (QGP). Jet probes have been used extensively to gain insights into QGP properties, with substantial modifications to jet yields and internal structures seen across multiple measurements. Despite apparent medium-induced changes to jet fragmentation patterns, the LHC results indicate that in-jet baryon-to-meson ratios remain similar to that of p+p measurements and are significantly different from that of the QGP bulk.
To explore this behavior with the STAR detector at RHIC, we employ jet-hadron correlation and particle identification to measure in-cone baryon-to-meson yield ratios associated with fully reconstructed jets from Au+Au and p+p collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV. These in-jet ratios are studied as a function of jet radii, R $= 0.2, 0.3, 0.4$, and jet constituent p_{T} selections, $p_{\mathrm{T}}^{\mathrm{const}} > 2.0$ GeV/c, 3.0 GeV/c. Varying the jet radius and constituent p_{T} selection allows us to probe jets with different levels of QGP interaction. The in-jet baryon-to-meson ratios are compared between Au+Au and p+p to examine what effect the presence of QGP has on the hadronization process in jets.

Category:

Experiment

Collaboration:

STAR

Parallel 13: jet EEC / 95

Exploiting Two- and Three-point Charge-Energy Correlators at STAR as Probes of Jet Evolution

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The N-Point Energy correlator (ENC) is a jet substructure observable formed out of the distribution of angular distances between all particle groups of N constituents in a jet weighted by their energy product. This observable approximately separates non-perturbative and perturbative effects into the angular scales at which they dominate, reflecting a uniform distribution of hadrons at small angles and hard partonic splittings at large angles. Additionally, the energy scales at which hadron groups with different charge compositions form are sensitive to the hadronization mechanism, an effect shown in Monte-Carlo to be observable by charge-weighted ENCs.

We will present the first measurement of the projected three-point energy correlator (E3C) at RHIC, measured using pp data at $\sqrt{s}$ = 200 GeV from the STAR experiment, and its ratio to the two-point correlator (EEC). These ENC measurements are shown for several jet transverse momentum ranges in the charge inclusive sample as well as in the charge-selected samples. The quark-rich sample at RHIC compared to the LHC allows for enhancement of charge-odd non-perturbative effects that are suppressed for gluons. This in tandem with the lower jet momentum allows for the observation

window of these effects to move to more easily resolvable angular scales. Finally, first advancements towards study of the ENC in heavy-ion collision data at STAR are presented.

Category:

Experiment

Collaboration:

STAR

Parallel 16: Thermal EM / 240

Measurements of direct photons and dileptons at PHENIX

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Photons, both real and virtual, are one of the cleanest probes of high-density partonic matter produced in relativistic heavy-ion collisions as they carry unmodified information about the evolution of the system.
Leveraging the versatility of RHIC, PHENIX has measured low momentum direct photons across different collision systems ranging from p+p to Au+Au. An excess of direct photons, above those from hard scattering processes and consistent with thermal emission, has been observed in large collision systems. Additionally, measurements of azimuthal anisotropy of these photons help gain insight into the origins of these radiation and better constrain model calculations, thereby, elucidating the direct photon puzzle.
In addition to the direct photon measurements, in this talk, PHENIX presents the first measurement for disentangling the lepton pairs into heavy flavor decays, prompt pairs and background pairs based on the distance of closest approach to the interaction point in the intermediate mass range ($m_{\phi} < m_{ee} < m_{J/\psi}$) using p+p data at 200 GeV taken in 2015.

Category:

Experiment

Collaboration:

PHENIX

Parallel 15: heavy quarks, spin polarization / 168

Measurements of χ_c production in pPb collisions with CMS

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The nuclear modification of quarkonium state production is one of the smoking gun evidence of the deconfined QCD medium production in nuclear collisions. However, this modification does not solely originate from the medium dissociation but rather is a collection of effects from initial to

final states. To better understand the interplay of these effects nowadays, the production relation of different quarkonium states is explored with different attributes of the quarkonia. Excited charmonium production in pPb collision can be thought of as a controlled environment to understand these effects further. In particular, the production of the chi_c mesons can provide more information about the feed-down and binding energy dependence of the charmonia in the nuclear collision, as its mass lies in between the ground state and the $\psi(2S)$. In this talk, we present studies of the production of chi_c in pPb collisions performed by CMS. We report the relative production of $\chi_{c1,2}$ with respect to J/ψ. The analysis measures the cross section ratio as a function of particle transverse momentum and rapidity, and event activity. The results are compared with other measurements in LHC with different rapidity ranges and pp collision data and model calculation to further extend our understanding of χ_c state production in nuclear collision.

Category:

Experiment

Collaboration:

CMS

Parallel 14: jet theory / 56

Probing jet hadrochemistry and charged-particle jet radial profile modifications in pp and Pb–Pb collisions with ALICE

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Jet substructure measurements in heavy-ion collisions provide constraints on jet quenching and the medium response in the QGP. Though there has been remarkable progress in inclusive-charged-hadron jet substructure measurements, understanding the identified particle composition of jets and their modification in heavy-ion collisions remains elusive. Jet quenching models predict that the jet hadrochemical composition may be modified in heavy-ion collisions due to jet-medium interactions, as well as the medium response. Further, models including the jet wake from a hydrodynamic medium response predict an enhancement of soft particle productions at large angles from the jet axis. Measurements of identified particles in jets can help discriminate between various parton-QGP interactions. We present the first measurements of π, K, and p ratios within charged-particle-jets of various R and the underlying event as a function of particle transverse momentum and radial distance from the jet axis in pp and Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. These measurements leverage the excellent PID capabilities of ALICE over a wide momentum range. Additionally, we present results of the particle density profile, ρ, for charged particles in jets. We compare the results with theoretical models to understand soft particle production mechanisms and distinguish modified jet fragmentation from bulk effects.

Category:

Experiment

Collaboration:

ALICE

Parallel 13: jet EEC / 74

The two-point energy correlator in the QGP: from gamma+jet to inclusive jets

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Energy correlators have been proposed as a new approach to jet substructure in proton-proton and heavy-ion collisions. In this work, we extend our previous calculations of the two-point energy correlator of heavy-ion gamma-tagged jets to include several effects essential for understanding the behavior of this observable in inclusive heavy-ion jets measurements. Through a semi-analytic approach, we incorporate the hydrodynamic expansion of the QGP, jet broadening, selection bias due to energy loss, and provide a description of the confinement transition. Our outcomes offer a crucial first step toward bridging the gap between the experimental and theoretical study of energy correlators in heavy-ion collisions.

Category:

Theory

Collaboration:

Parallel 16: Thermal EM / 90

Thermal dielectron measurements in Au+Au collisions at BES-II energies with the STAR experiment

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Dielectrons, emitted during the evolution of the hot and dense QCD medium created in relativistic heavy-ion collisions, offer an effective probe of the hot medium properties, as they do not involve strong interactions. The dielectron emission rate is proportional to the medium's electromagnetic spectral function. In the dielectron mass range from 400 to 800 MeV/c^2, the spectral function probes the in-medium ρ meson propagator which is sensitive to the medium's properties including the total baryon density and the temperature. By measuring thermal dielectron production, we can study the microscopic interactions between the electromagnetic current and the medium. The RHIC Beam Energy Scan (BES) program provides a unique opportunity to systematically study dielectron production in a collision energy range where the total baryon density and temperatures are varying substantially.

In this talk, we will report on STAR measurements of thermal dielectron produced in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 7.7, 9.2, 11.5, 14.6 and 19.6 GeV. The results will include the thermal dielectron spectra, differential/total excess yield, and the temperature extracted from the low invariant mass range, as well as their collision energy dependence. In addition, these new preliminary results will be compared to the results from STAR BES-I and theoretical model calculations for the discussions of the physics implications.

Category:

Experiment

Collaboration:

STAR

Parallel 15: heavy quarks, spin polarization / 85

Quarkonium polarization in hadronic collisions with ALICE

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Polarization is a key observable to study the quarkonium production mechanism in elementary hadronic collisions. Its very small value measured at the LHC challenges the commonly-used theoretical models and it still represents a major standing issue in the field. In nuclear collisions, heavy quarks are produced at the initial stage collisions, on a time scale shorter than the QGP formation time, and they are sensitive to the large initial magnetic field and angular momentum of the medium produced in non-central events. We will present the measurements of quarkonium polarization in pp collisions at 13 TeV and in Pb-Pb collisions at 5.02 TeV, exploiting the large data samples collected by the ALICE Collaboration in LHC Run 2. Results will be compared with existing theoretical models and with recent results from the heavy-flavor sector. In addition, preliminary results from LHC Run 3 will be discussed.

Category:

Experiment

Collaboration:

ALICE

Parallel 14: jet theory / 252

EFT-based factorization of jet quenching observables in heavy ion collisions

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Using an open quantum system EFT approach we derive a factorization formula for the cross-section of inclusive jet production in heavy ion collisions as a series with an increasing number of independently radiating subject functions resolved by the Quark Gluon Plasma medium, convolved with perturbative matching coefficients. In a strongly coupled system, each term in this series is a distinct non-perturbative object that depends on jet measurements such as its radius and transverse momentum as well as medium scales, temperature, and size. This approach provides a systematic formalism for computing higher-order corrections of energy loss observables.

Category:

Theory

Collaboration:

Parallel 13: jet EEC / 36

EECs in heavy ions and in the Lund plane

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We study the jet EEC in heavy ions, exploring the modification to its LL structure due the presence of the medium. We present exact analytic results for the gamma->qqbar channel, showing that, at low jet energies, the medium enhancement is rather moderate. We complement our study with a MC analysis, where energy loss effects are seen to compete with the modification to the splitting function. Finally, we introduce the notion of LundEEC which takes as input Lund primary declusterings instead of particles. We discuss its logarithmic structure and argue that this IRC definition gives a better handle on non-perturbative effects.

Category:

Theory

Collaboration:

Parallel 16: Thermal EM / 131

Measurements of thermal dielectron and QGP temperature in isobar collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV

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Lattice QCD predicts a phase transition from hadronic matter to the Quark-Gluon Plasma (QGP) at high temperature and small baryon chemical potential. Thermal dileptons can be produced throughout the entire evolution of a collision and do not involve strong interactions. As a result, they can carry information about their emission source, and are therefore suggested as the ideal probes of hot medium created in the heavy-ion collision. In particular, the invariant mass distribution of thermal dielectrons is not subjected to blue-shift effects, which enables the extraction of the average temperature of the hot QCD medium at different stages of the evolution.

In this talk, measurements of the dielectron invariant mass spectra in Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV with the STAR experiment will be presented. The average temperature extracted from the thermal dielectron in the low-mass and intermediate-mass regions will be shown as a function of $N_{\rm part}$. Furthermore, comparisons to previous results and the physics implications will also be discussed.

Category:

Experiment

Collaboration:

STAR

Parallel 15: heavy quarks, spin polarization / 52

Investigation of charm hadronisation and early magnetic field in ultrarelativistic heavy-ion collisions via D^{*+}-meson spin alignment with ALICE

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The production of hadrons containing charm and beauty quarks has been extensively studied in hadronic collisions, improving the understanding of the hadronisation mechanisms. One aspect of the transition of the heavy quark to the final-state hadron not yet settled regards the spin properties of particles produced in the quark hadronisation. In proton–proton (pp) collisions, the observation of a polarisation of heavy-flavour vector mesons would imply a spin-dependent fragmentation function of the fragmenting heavy quark.

Heavy quarks are produced at the initial stage of heavy-ion collisions. In the presence of a large angular momentum and initial magnetic field, they can be polarised. The quark polarisation is expected to be transferred to the hadron during the hadronisation process, and it can be probed by measuring the ρ_{00} parameter of the spin density matrix element of spin-1 hadrons.

We will present the final measurement of the ρ_{00} of D^{*+} mesons in pp collisions obtained with data collected by ALICE during the LHC Run 2, and preliminary results on the extension to a wider transverse-momentum interval with the first samples collected in Run 3. The measurement is performed for promptly produced D^{*+} mesons and those originating from B-meson decays.

The first measurement of prompt D^{*+}-meson ρ_{00} in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV will also be presented and compared with the J/ψ polarisation measurement.

Category:

Experiment

Collaboration:

ALICE

Parallel 14: jet theory / 197

Jet Drift in Heavy Ion Collisions

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We introduce a sub-eikonal anisotropic contribution to jet-broadening, “jet drift”, that couples to the flow of the medium, showing that this effect results in a deflection of hard partons, and thus jets, in the direction of the medium flow. Next, we study this effect in both toy models and a full-fledged

hybrid transport simulation of √s = 5.02 TeV PbPb collisions at the LHC, tracking trajectories of hard partons with perturbative energy loss and drift. We show that sub-eikonal anisotropic effects, including flow-mediated jet drift, are sensitive to properties of the medium that traditional eikonal isotropic effects are insensitive to, demonstrating that including these effects leads to modifications to jet and hard particle observables that survive averaging over events. We show that jet drift leads to an enhancement of the elliptic flow (v2) of hard particles and discuss the implications for jet substructure and medium response effects.

Category:

Theory

Collaboration:

Parallel 13: jet EEC / 308

First measurement of the energy-energy correlator in the back-to-back limit using archived ALEPH e+e- data at 91.2 GeV

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Measurements of hard probes in e^+e^- collision data are essential components of parallel studies of hard probes in proton-proton and heavy-ion collisions as e^+e^- collisions offer a true reference for such systems free from any hadronic initial state effects. Recently, one class of hard-probe observables that has seen a resurgence of interest for studying vacuum QCD are the projected N-point energy correlation function (ENCs) of particles within jets. This is primarily due to a clear separation of scales these observables provide, which is useful for studying both perturbative and non-perturbative QCD in the collinear limit. An analogous class of observables can be used to study QCD in the back-to-back (Sudakov) limit, but in hadronic collisions, such studies have additional experimental difficulties. In this talk, we will discuss recent ENC measurements from Archived ALEPH e^+e^- data taken at LEP at $\sqrt{s} = 91.2$ GeV spanning, for the first time, both the collinear to the back-to-back limit of QCD as well as the transition between these two regimes. These results can be used to extract a value of the strong coupling constant (α_s) in addition to performing precision tests of pQCD with generators. The ENCs prove to be highly discriminative observable when compared to models, with the different generators showing a large spread in their predictions.

Category:

Experiment

Collaboration:

ALEPH

Parallel 16: Thermal EM / 46

Direct photon measurement in small systems and thermal radiation from QGP with ALICE

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Electromagnetic probes are a unique tool for studying the space-time evolution of the hot and dense matter created in ultra-relativistic heavy-ion collisions. Dielectron pairs are emitted during the entire evolution of the medium created in such collisions, allowing the extraction of the real direct photon fraction at vanishing mass, providing access to thermal radiation from the early hot stages of the collision. The measurement of dielectron and direct photon production in minimum-bias pp collisions serves as a crucial baseline for the studies in heavy-ion collisions, whereas pp collisions with high charged-particle multiplicities allow the search for interesting phenomena such as the possible presence of QGP in small systems.
This talk will present the final LHC Run 2 ALICE results on the direct-photon production using dielectron pairs in central Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The results are compared to theoretical models that include hot medium effects such as thermal radiation and chiral symmetry restoration. Different approaches to disentangle the background from semi-leptonic heavy flavour decays are presented and discussed. To study the possible onset of the formation of a hot medium, we also report the results on the direct-photon production in pp collisions at $\sqrt{s}$ = 13 TeV as a function of the charged-particle multiplicity. For the first time at LHC energies we observe a significant yield of direct photons in pp collisions at low p_{T}.

Category:

Experiment

Collaboration:

ALICE

Parallel 15: heavy quarks, spin polarization / **84**

J/ψ photoproduction and polarization in peripheral Pb-Pb collisions with ALICE

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Ultrarelativistic heavy-ion collisions generate a powerful electromagnetic field that produces photonuclear reactions. Recently, coherent J/ψ photoproduction has been observed in nucleus–nucleus (A–A) collisions with nuclear overlap, based on the measurement of an excess of J/ψ production with respect to hadron-production expectations at very low p_{T}. In this context, a polarization measurement can confirm the electromagnetic origin of the very low p_{T} J/ψ yield excess, since the produced quarkonium is expected to inherit the transverse polarization of the incoming photon. ALICE can measure inclusive and exclusive quarkonium production down to p_{T} = 0. In this contribution, preliminary measurements of the y-differential cross section and the polarization analysis of coherently photoproduced J/ψ in peripheral Pb–Pb collisions will be presented together with recent results on coherent J/ψ photoproduction as a function of centrality. Comparison with models will be shown when available.

Category:

Experiment

Collaboration:

ALICE

Parallel 14: jet theory / 33

Jet entropy as a probe of jet collimation

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As QCD jets fragment in vacuum, the entropy of their hardest constituents increases proportionally to the subjet multiplicity. When the cascade takes place in the presence of a dense QCD plasma, the entropy growth is slowed down due to the transport of the jet's energy to the medium. This feature is connected to the quenching of active color sources inside the jet, collimating the partonic cascade.

Category:

Theory

Collaboration:

Parallel 13: jet EEC / 66

Extracting the anomalous dimensions of energy-correlators in charged jets in pp collisions at 13 TeV with ALICE

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The projected N-point Energy Correlators (ENCs) are a novel tool to probe jet substructure in hadronic collisions by exploring the energy flow within jets. Defined as the energy-weighted correlations of N tracks as a function of their angular separation, these correlators reveal the multiscale nature of jets. Jet evolution from perturbative, hard-scattered partons to non-perturbative sprays of hadrons is imprinted in the slopes of the ENCs. The lower charged-particle jet p_{T} range between 20 and 80 GeV/c accessible at ALICE makes these observables especially interesting as it allows one to probe both pQCD and npQCD effects. The ratio, E3C/E2C, exhibits sensitivity to the running of the strong coupling constant, α_{S}, while being robust to detector effects. In this talk, we will present the measurement of the E2C, E3C and the sensitivity of the E3C/E2C ratio to α_{S} via their anomalous dimensions in pp collisions at 13 TeV. Additionally, we will present an outlook for measuring the E3C/E2C ratio in Pb-Pb collisions. The jet p_{T} range at ALICE offers a unique phase space to study jet-medium interactions. We will show how the E3C/E2C ratio can probe the QGP due to its robustness to the uncorrelated heavy-ion background while retaining its sensitivity to medium effects.

Category:

Experiment

Collaboration:

ALICE

Parallel 20: future facilities / **189**

The NA60+ experiment at SPS.

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A new apparatus, NA60+, is proposed for measuring muon pairs in the center-of-mass region from 5 to 17 GeV at CERN SPS in a variety of collisional systems from Pb+Pb and down to p+Be. The physics scope of the new detector will cover topics from the measurement of thermal radiation coming from the hot and dense medium to chiral symmetry restoration, strangeness, and charm production.

The proposed detector consists of a vertex spectrometer based on novel technology, allowing the production of large silicon sensors and a large-acceptance muon spectrometer based on gaseous detectors. With its high beam intensity, the new apparatus provides access to rare observables that have been scarcely studied until now. The new detector will come into operation after the Long Shutdown 3 of the LHC (past 2029) and is aimed at the first data-taking with Pb and proton beams. In this contribution, we review the project and recent R&D effort, including the technical aspects and the studies of the physics performances for the observables.

Category:

Experiment

Collaboration:

NA60+

Parallel 19: heavy quarkonia production / **190**

Quarkonia and Open Heavy Flavour Hadrons in High Energy pp Collisions - Collectivity and the Importance of Correlations between Heavy Quark ($Q\bar{Q}$) Pairs

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Quarkonia and Open Heavy Flavour Hadrons in pp Collisions.
Collectivity and the Importance of Correlations between Heavy Quark (Q ̄Q) Pairs.

Several heavy quark observables, like the meson to baryon ratio and the elliptic flow indicate that the interaction of the produced particles with heavy quarks play an important role. Correlations between $Q\bar{Q}$ pairs show the complexity of the production process which should manifest itself also in the production of $Q \bar Q states.
Employing the EPOS4HQ approach we discuss heavy quark observales in pp collisions. There energy densities are reached, which in AA collisions lead to the formation of a QGP. Employing the same critical energy density in pp collisions the enhancement of the heavy meson to baryon ratio as well

as the collective flow find a natural explanation. Agreement with the transverse momentum spectra for charm and bottom mesons as well as Bc is also found.
Extending our study to the correlations we find that the measured azimuthal correlations are due to LO and NLO pQCD processes, which are therefore accessible to experiment. These correlations influence also the formation of quarkonia, which we treat in the recently advanced Wigner density approach [1]. We study the dependence of quarkonium production on this pQCD processes and show that the different pQCD processes influence the single particle spectra of charm and bottom mesons, although in a quite different way.
[1] J. Zhao et al, arXiv:2312.11349 [hep-ph]

Category:

Theory

Collaboration:

Parallel 18: heavy quarks, hard, jet / **148**

Measurements of heavy-flavor azimuthal correlations and b-jet suppression in 5.02 TeV Pb+Pb collisions with ATLAS

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High energy partons are known to lose energy when passing through the hot and dense medium produced in heavy ion collisions. This energy loss is expected to depend on the mass of the fragmenting parton. For light partons, energy loss via gluon bremsstrahlung is expected to dominate, while for heavy-quarks, collisional energy loss may play a more important role. Comparisons between the suppression b-jets and inclusive jets are therefore needed to understand the impact of parton mass on the energy loss. An alternative method for probing the interactions of heavy quarks with the plasma is the study of the correlations between heavy quark pairs. In this talk, we also report final results on the measurements of azimuthal angle correlations of muons produced via heavy-flavor decays and results on the b-tagged jet production. The measurements are performed in pp and Pb+Pb collisions at √sNN = 5.02 TeV using the ATLAS detector at the LHC. The measurement of azimuthal angle correlations of muons is performed differentially in centrality for muons with |η| < 2.4 and pT > 4 GeV. Studies of the shapes of the azimuthal-angle correlations between the two muons are performed and compared between pp, Pb+Pb data and MC event generators. The b-jet suppression is evaluated in terms of nuclear modification factor, RAA. A detailed quantification of the differences between the b-jet RAA and the inclusive jet RAA is also provided together with comparisons to theory.

Category:

Experiment

Collaboration:

ATLAS

Parallel 17: jet R_AA, correlation / **96**

Measurement of jet v_1 to study path length dependent jet energy loss in heavy-ion collisions at $\sqrt{s_{NN}}$ = 200 GeV by STAR

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A path length asymmetry along impact parameter direction (x) exists for hard probes in heavy-ion collisions at finite rapidity, as the Quark Gluon Plasma (QGP) bulk is tilted in reaction plane, while the hard scattering profile is not˜\cite{ref1}. Jet v_1 and $\langle p_x \rangle$ measurements provide access to path length dependent energy loss of partons in the QGP. Such a measurement has several advantages. Energy loss can be measured without measurements in p+p collisions. Event-by-event fluctuations in geometry and energy loss do not contribute to v_1 (and $\langle p_x \rangle$), unlike to the elliptic anisotropy, v_2. Non-flow contributions are also minimal as measurements use reaction plane determined from spectators.

In this talk we present the first measurement of jet v_1 and $\langle p_x \rangle$ in heavy-ion collisions using Au+Au and Ru+Ru, Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV by STAR. Centrality, jet $p_{\rm T}$ and radius dependence of the observables will be shown. We will also present an evaluation of the initial path length asymmetry utilizing models describing the measured pseudorapidity dependence of particle production in asymmetric collisions. The measurements open up a new avenue to study path length dependent energy loss of partons in QGP and its mass, flavor and fragmentation dependences.

Category:

Experiment

Collaboration:

STAR

Parallel 17: jet R_AA, correlation / 162

Search for jet quenching using high-multiplicity pPb collisions at the CMS Experiment

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High-energy jets are produced by the fragmentation of partons (quarks and gluons) that underwent hard scattering in the early stages of a collision. For quite a number of years, jets have been successfully used to probe the properties of the special form of matter, the quark gluon plasma (QGP), formed in high-energy heavy ion collisions. One of the most recognized signatures of the QGP, the jet quenching phenomenon, has been evidenced by a wide range of LHC measurements from lead-lead collisions. More recently, experimental results through multiparticle correlation techniques provided some evidence of possible QGP formation in the smaller colliding systems, such as high-multiplicity proton-proton and proton-lead collisions, but confirmation of the jet quenching expected for QGP remains elusive for such collisions. In this talk, systematic measurements of jet properties are presented for data collected by the CMS experiment at the LHC in high-multiplicity collisions to search for hot medium production or effects of cold nuclear matter at top LHC energies.

Category:

Experiment

Collaboration:

CMS

Parallel 20: future facilities / 182

Time-of-flight PID upgrade at CMS for hard probes in dense QCD matter at the high-luminosity LHC era

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The intriguing phenomena emerging in the high-density quantum chromodynamics (QCD) matter are being widely studied in the heavy ion program at the LHC and will be understood more deeply during the high-luminosity LHC (HL-LHC) era. The CMS experiment is under the Phase 2 upgrade towards the HL-LHC era. Among others, a new timing detector is proposed with its timing resolution for minimum ionization particles (MIP) to be 30 ps. The MIP timing detector (MTD) will also provide the particle identification (PID) ability with a large pseudorapidity acceptance covering up to $|\eta| < 3$ through time-of-flight (TOF). Combining MTD with a new wide-acceptance tracker ($|\eta| < 4$) and high-granularity calorimetry ($|\eta| < 5$), CMS will enable deeper studies of high-density QCD matters in ultrarelativistic heavy ion collisions. Taking advantage of upgraded detector capabilities, new opportunities in probing the quark-gluon plasma with hard probes will be presented, such as investigating the (3+1)-dimensional evolution of heavy flavor quark dynamics and particle composition inside jets over a wide angular range. The latest status and progress of the MTD project will also be presented.

Category:

Experiment

Collaboration:

CMS

Parallel 19: heavy quarkonia production / 203

Measurement of J/ψ multiplicity dependent production in p+p $\sqrt{s}$ = 510 GeV with STAR at RHIC

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The investigation of quarkonium production allows for the study of the properties of strongly interacting matter, such as interactions with the quark-gluon plasma (QGP) and nucleonic gluon content. While such probes are essential, a detailed description of the quarkonium production mechanism is not yet completely understood. Proposed explanatory mechanisms, including multi-parton interactions, string screening, and higher gluon radiation are discussed, as well as the guidance this measurement and related probes provide to model calculations. Within the QGP, understanding the interplay between suppressed production and regenerative recombination may directly benefit from a heightened understanding of the underlying production mechanisms.

Herein we present dielectron channel measurements of J/ψ production of $1.5 < p_T < 12$ GeV/c at mid rapidity (|y| < 1.0) as a function of charged particle multiplicity. Specific observables include

multiplicity dependent transverse momentum spectra and self-normalised J/ψ yields. The presented analysis utilizes the largest to date analyzed sample of quarkonia the STAR experiment has obtained from p+p collisions in the dielectron channel. Consistent with measurements at 200 GeV, 7 TeV and 13 TeV, a faster-than-linear rise is observed for which models converge at low values of normalized multiplicity. Their divergence at higher values emphasizes the potential for improvement from extending the measurement range.

Category:

Experiment

Collaboration:

STAR

Parallel 18: heavy quarks, hard, jet / **172**

Hadronization and Energy Loss of Beauty Quark from Flavor-Identified B-Hadrons R_{AA} in pp, pPb, and PbPb Collisions with CMS

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Beauty quarks are unique probes for studying quark-gluon plasma (QGP) properties. One of the most important issues and limiting factors in understanding their energy loss and diffusion in the QGP is their hadronization. Additionally, whether they experience energy loss in the smallest systems remains an open question. We present newresults on the nuclear modification factors (R_{AA}) of $\mathrm{B_s^0}$ and $\mathrm{B^+}$ mesons in proton-proton and lead-lead collisions at 5.02 TeV, and the $\mathrm{B^+}$ meson in proton-lead (pPb) collisions at 8.16 TeV, using CMS detector data. These measurements span an extended transverse momentum range and different charged particle multiplicities, shedding light on beauty quark diffusion, energy loss, and hadronization mechanisms. The results in pPb collisions are in agreement with fixed-order next-to-leading logarithmic calculations, and the results in the highest multiplicity pPb collisions show no suppression or enhancement due to medium effects within the current precision. Additionally, we compared the $\mathrm{B^+}$ and $\mathrm{B_s^0}$ R_{AA} results with $\mathrm{B_c^+}$ meson results, observed for the first time in nucleus-nucleus collisions, suggesting enhanced R_{AA} via recombination of beauty and charm quarks, which is larger than that between beauty and strange quarks.

Category:

Experiment

Collaboration:

CMS

Parallel 20: future facilities / **135**

Prospects for heavy-ion data-taking with the LHCb Upgrade II

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Owing to its spectrometer acceptance, complementary to the other LHC experiments, and to its excellent tracking and particle identification, LHCb has been performing since the LHC Run2 a unique heavy-ion programme. By exploiting instead the injection of gases in the LHC accelerator beam-pipe, LHCb has been simultaneously acquiring data in fixed-target mode. The sum of the two configurations already gives unique inputs to theoretical models. With the foreseen LHCb Upgrade II, to be operated from Run5, even more possibilities will be opened by the increased detector granularity, the timing capabilities and the new instrumentation. In this contribution, a full overview of the heavy-ion opportunities with LHCb Upgrade II, as discussed in a recent workshop with theoreticians, will be presented and discussed.

Category:

Experiment

Collaboration:

LHCb

Parallel 19: heavy quarkonia production / **116**

Charmonium production measurements in small systems at LHCb

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Charmonium production in hadronic collisions is an important experimental observable that sheds light on the heavy quark interaction with the nuclear medium. While the bound quarkonium states undergo dissociation and recombination in PbPb collisions, in pPb collisions they can experience a combination of initial and final state effects such as shadowing and comover breakup. A full description of charmonia production from small to intermediate system is hence crucial to disentangle these from medium effects. In this contribution, recent LHCb measurements of $\psi(2s)/J/\psi$ production in pp and in pPb as a function of multiplicity will be shown and discussed. Also, the first LHC measurement of χc production and nuclear modification will be included

Category:

Experiment

Collaboration:

LHCb

Parallel 18: heavy quarks, hard, jet / **25**

The impact of glasma on heavy quark spectra and correlations

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Co-authors: Vincenzo Greco [2]; Tuomas Lappi [1]; Heikki Mäntysaari [1]; David Müller [3]

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We study the effect of the early stage of heavy-ion collisions on the transport of heavy quarks, by extracting two-particle correlations and nuclear modification factor [1]. We perform numerical simulations for both the temporal evolution of the initial state Glasma fields and the propagation of classical test particles in these background fields [2].

Firstly, we simulate how $Q\overline{Q}$ pairs initially produced back-to-back propagate in the Glasma and compute their two particle correlations $\mathcal{C}(\Delta\phi, \Delta\eta)$. Such a quantity is relevant for experimentally measured $D\overline{D}$ correlations. We extract the azimuthal $\sigma_{\Delta\phi}$ and rapidity $\sigma_{\Delta\eta}$ correlation widths. We study the initial quark p_T and Glasma saturation momentum Q_s dependence and notice dramatic decorrelations for moderate p_T and Q_s values.

Secondly, we initialize heavy quark p_T-spectra according to FONLL heavy quark production and measure how the Glasma affects the nuclear modification factor R_{AA}. We find that the Glasma shifts the initial spectra from low to high-p_T, causing an enhancement in R_{AA} at larger-p_T. We investigate how this is affected by varying Q_s, along with switching between proton PDFs and nuclear nPDFs in the FONLL calculation.

[1] D. Avramescu, V. Greco, T. Lappi, H. Mäntysaari, D. Müller - in preparation
[2] D. Avramescu, V. Băran, V. Greco, A. Ipp, D. Müller, M. Ruggieri - Phys. Rev. D 107, 114021

Category:

Theory

Collaboration:

Parallel 17: jet R_AA, correlation / 79

Deciphering the nonintuitive enhancement of recoil jets in heavy-ion collisions

Authors: Helen Caines[1]; Li Yi[2]; Maowu Nie[2]; Rongrong Ma[3]; Shanshan Cao[2]; Yang He[None]

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Jet quenching is recognized as critical evidence for the existence of the quark-gluon plasma (QGP) and serves as an essential probe to study its transport properties. Measurements of hadron-triggered semi-inclusive recoil jets has gained popularity due to its capability to probe jets over an extended phase space at low transverse momenta (p_T) and large radii. Recent ALICE measurements showed that the I_{AA}, yield ratio of recoil jets between heavy-ion and p+p collisions, rises with jet p_T and exceeds unity at high p_T, contradicting conventional expectations that jet quenching should result in I_{AA} values less than one. In this talk, we re-examine the surface bias and study the effects of energy losses for both trigger hadrons and recoil jets on I_{AA}, employing the Linear Boltzmann Transport (LBT) model to simulate jet-medium interactions. Our findings suggest that a large portion of hadron triggers undergo substantial energy loss despite also experiencing a slight surface bias. This energy

loss of the trigger hadrons elevates the I_{AA} baseline, evaluated by removing energy loss for recoil jets, to be greatly larger than unity. This *enhancement of the baseline* implies that the measured I_{AA} values larger than unity could still signal jet quenching, aligning with other related experimental observations.

References
Y. He, M. Nie, S. Cao, R. Ma, L. Yi and H. Caines, Phys. Lett. B 854 (2024) 138739

Category:

Theory

Collaboration:

Parallel 20: future facilities / **60**

OmniFoldHI: Advanced ML Unfolding for Heavy-Ion Data

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To compare collider experiments, measured data must be corrected for detector distortions through a process known as unfolding. As measurements become more sophisticated, the need for higher-dimensional unfolding increases, but traditional techniques have limitations. To address this, machine learning-based unfolding methods were recently introduced. In this work, we introduce OmniFoldHI, an improved version of the well-known algorithm [1], tailored for heavy-ion analyses. OmniFoldHI incorporates background counts, detector acceptances, efficiency, and uncertainties for real-analysis applications, and it works for an arbitrary number of observables. Besides removing detector effects, we demonstrate that unfolding can be used to subtract the underlying event, which is crucial for jet-quenching analyses and phenomenology. With these enhancements, OmniFoldHI functions effectively even without additional background subtraction. To illustrate its capabilities, we apply OmniFoldHI to unfold up to a 5-dimensional jet-substructure observable, comparing it to traditional techniques and quantifying uncertainties. We present model-independent results, with training and testing performed using different event generators. We show that OmniFoldHI reproduces the maximum likelihood estimate and provide mathematical proof of the ML unfolding algorithm.

[1] Andreassen et. al, Phys. Rev. Lett. 124, 182001 (2020)

Category:

Theory

Collaboration:

Parallel 19: heavy quarkonia production / **235**

Exotic hadron production in pp and pPb collisions at LHCb

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In the last decade, hadron spectroscopy has unveiled a wealth of states that do not have the properties expected of particles composed of 2 or 3 valence quarks. Foremost among these is the X(3872), which is thought to contain a ccbar pair plus two light quarks. In heavy ion collisions, these multiquark states are especially sensitive to a range of phenomena that can suppress or enhance their production. With a full range of precision vertexing, tracking, and particle ID capabilities covering forward rapidity, the LHCb experiment is especially well suited to measurements of both prompt and non-prompt exotic hadrons. This talk will present recent LHCb measurements of exotic hadrons, including the first measurement of the nuclear modification factor of the exotic hadron X(3872) in pPb collisions.

Category:

Experiment

Collaboration:

LHCb

Parallel 18: heavy quarks, hard, jet / **204**

Holographic Heavy Quark Energy Loss in the Hybrid Model

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To date, holographic calculations have provided separate descriptions for the rates of energy loss either for ultrarelativistic massless quarks and gluons or for infinitely massive quarks in strongly coupled plasma, with the latter calculation valid for $\sqrt{\gamma} < M/(\sqrt{\lambda}T)$, where γ is the Lorentz boost factor for a heavy quark with velocity v and mass M moving through plasma with 't Hooft coupling λ and temperature T. These two calculations should apply sequentially in the description of the energy loss of a heavy quark that starts out ultrarelativistic, loses energy, slows down, becomes non-relativistic at later times, and ultimately comes to rest and diffuses in the strongly coupled plasma. We provide an ansatz for uniquely incorporating both regimes to give an approximate but unified description of how a heavy quark that is initially ultrarelativistic loses energy all the way until it comes to rest. We implement this ansatz in the Hybrid Strong/Weak Coupling Model. With this new, consistent, treatment of heavy quark energy loss at strong coupling, we confront our predictions for the suppression R_{AA} and azimuthal anisotropies v_2 of B- and D- mesons, as well as B- and D- tagged jets, with available experimental data. Via a new holographic calculation, we also investigate the regimes of validity of the ansatz that we employ.

Category:

Theory

Collaboration:

Parallel 17: jet R_AA, correlation / **57**

New measurements of inclusive jet suppression and jet v_2 in Pb–Pb collisions with ALICE

Authors: ALICE Collaboration[None]; Aimeric Landou[1]

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We report new ALICE measurements of inclusive charged-particle jet yield suppression R_{AA} and jet azimuthal anisotropy v_2 in Pb–Pb collisions. The R_{AA} measurement is carried out in central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, with uncorrelated background corrected statistically using an event-mixing approach. The charged-particle jet R_{AA} measurements have high precision over a broad kinematic range, including very low jet p_{T}, for jet resolution parameters $R = 0.2$ to 0.5. Comparison of these R_{AA} measurements and their R dependence to theoretical calculations provide new insight into jet quenching phenomenology and its underlying mechanism. We also report measurements of inclusive charged-particle jet v_2 in semi-central Pb–Pb collisions using new Run 3 data, quantifying the jet yield dependence relative to event-plane orientation that may probe the pathlength dependence of jet energy loss.

Category:

Experiment

Collaboration:

ALICE

Parallel 24: future facilities / **12**

ALICE 3 physics programme and detector R&D

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The ALICE Collaboration has proposed a completely new apparatus, ALICE 3, for the LHC Runs 5 and 6 (LoI, arXiv:2211.02491). The detector consists of a large pixel-based tracking system covering eight units of pseudorapidity, complemented by multiple systems for particle identification, including silicon time-of-flight layers, a ring-imaging Cherenkov detector, a muon identification system, and an electromagnetic calorimeter. Track pointing resolution of better than 10 micron for p_T >200 MeV/c can be achieved by placing the vertex detector on a retractable structure inside the beam pipe. ALICE 3 will, on the one hand, enable novel studies of the quark-gluon plasma and, on the other hand, open up important physics opportunities in other areas of QCD and beyond. The main new studies in the QGP sector focus on low-p_T heavy-flavour production, including beauty hadrons, multi-charm baryons and charm-charm correlations, as as well as on precise multi-differential measurements of dielectron emission to probe the mechanism of chiral-symmetry restoration and the time-evolution of the QGP temperature. Besides QGP studies, ALICE 3 can uniquely contribute to hadronic physics, with femtoscopic studies of the interaction potentials between charm mesons and searches for nuclei with charm, and to fundamental physics, with tests of the Low theorem for ultra-soft photon emission. The presentation will cover the detector concept, the physics performance, and the status of detector R&D.

Category:

Experiment

Collaboration:

ALICE

Parallel 23: heavy quarkonia production / 167

First observation of the multiplicity dependence of $\sigma_{\psi(2S)}/\sigma_{J/\psi}$ in pPb collisions with CMS and its implication regarding comover effects in small systems

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The substantial masses of charm hadrons make them exceptional tools for the study of quantum chromodynamics (QCD), providing quantitative insights into QCD dynamics for systems having high parton densities and/or temperatures. Final-state effects, including interactions with co-moving particles or quark coalescence, may modify the hadronization of heavy quarks. To study these effects, we report the first measurement of prompt and non-prompt separated $\psi(2S)$-over-J/ψ cross-section ratios as a function of the charged-particle multiplicity in proton-lead (pPb) collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV. For the first time in the pPb collision system, a multiplicity dependence of this ratio is clearly observed for prompt charmonium production with a significance of over 5 sigma. The rapidity-dependence of this observable is studied, and results are compared with a model incorporating comover interactions. These measurements constrain hadronization models of heavy quarks in nuclear collisions and support a picture in which co-moving particles may dissociate the weakly-bound excited state of charmonia more than the ground state throughout the system's evolution.

Category:

Experiment

Collaboration:

CMS

Parallel 22: heavy quarks hard, jet / 217

Bayes-DREENA: Integrated QGP Parameter Inference from High-pt and Low-pt Data

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High-pt theory and data are traditionally used to study the interactions of high-pt partons with the Quark-Gluon Plasma (QGP). Conversely, bulk QGP properties are typically inferred from low-pt data and models. Our approach unifies these domains through a finite-temperature dynamical energy loss (DREENA) framework, enabling a comprehensive QGP properties assessment using high-pt

and low-pt data. Through this method, we constrain the early evolution of the QGP, examine the temperature dependence of the shear viscosity to entropy density ratio, and demonstrate the importance of including heavy flavor data in containing bulk QGP properties. By incorporating Bayesian inference within the DREENA framework, we show that utilizing light and heavy-flavor high-pt data together with low-pt data yields parameter distributions that are within the bounds of those inferred solely from low-pt data but are much better constrained. Therefore, integrating DREENA within a formal statistical framework (Bayes-DREENA) allows for more accurate inferences of QGP properties and leverages a broader range of available data.

Category:

Theory

Collaboration:

Parallel 21: jets in small systems / **271**

Measurement of high pT direct photon and neutral pions in small collision systems at PHENIX

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Collective effects like elliptic and triangular flow have been observed in small system collisions and found to be consistent with the formation of quark-gluon plasma (QGP) droplets. Corresponding changes in the nuclear modification factor, R_{xA} however, became controversial, because they depend on certain model assumptions when mapping event activity on collision geometry. Using direct photons as "standard candle", i.e. assuming that $R_{xA}^{\gamma^{dir}} = 1$ holds for any system at high transverse momenta, the PHENIX experiment introduced a new R_{xA} based solely on experimentally measured quantities. In the highest event activity d+Au collisions this new double ratio $R_{xA,EXP}^{\pi^0} = (\gamma^{dir}/\pi^0)_{pp}/(\gamma^{dir}/\pi^0)_{xA}$ still shows a 20% suppression of the π^0 production. By comparing to recent results in other systems and collision energies, as well as to model calculations we will examine whether and how the role of final state (QGP) and initial state effects on this observation can be disentangled.

Category:

Experiment

Collaboration:

PHENIX

Parallel 21: jets in small systems / **58**

Measurements of jet quenching using hadron-jet observables at ALICE

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Measurements of jets recoiling from a trigger hadron are useful probes of jet quenching, where jets are modified in the presence of a QGP. In particular, the spectrum of jets as a function of the separation angle $\Delta\phi$ is a good indicator of jet quenching effects such as azimuthal broadening. In this talk, we present measurements of this hadron-jet observable in high multiplicity (HM) pp collisions at $\sqrt{s} = 13$ TeV, where it is theorised a QGP could form. A novel data-driven subtraction of the combinatorial background is used, extending the low $p_{\mathrm{T,jet}}$ reach of the measurement. We find that although HM pp events do exhibit some azimuthal broadening, this effect is reproduced in simulations that do not model jet-quenching effects. We also present the first preliminary results of a non-multiplicity dependent hadron-jet measurement from Run 3 pp data from ALICE. The higher statistics data enables more precision in investigating other recoil jet properties, such as jet substructure, that test higher-order pQCD effects.

Category:

Experiment

Collaboration:

ALICE

Parallel 24: future facilities / **11**

Design and expected performance of the ALICE ITS3 tracker upgrade

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During LHC LS3 (2026-28) ALICE is replacing its innermost three tracking layers by a new detector, "ITS3". It will be based on newly developed wafer-scale monolithic active pixel sensors, which are bent into truly cylindrical layers and held in place by light mechanics made from carbon foam. Unprecedented low values of material budget (0.07% per layer) and closeness to interaction point (19 mm) lead to a factor two improvement in pointing resolutions from very low p_T (O(100 MeV/c), achieving, for example, 20 μm and 15 μm in the transversal and longitudinal directions, respectively, for 1 GeV/c particles. After a successful R&D phase 2019-2023, which demonstrated the feasibility of this innovational detector and lead to the Technical Design Report (https://cds.cern.ch/record/2890181), the final sensor and mechanics are being developed right now. This contribution will review the conceptual design and the main R&D achievements, as well as the current activities and road to completion and installation. It concludes with a projection of the improved physics performance, in particular for heavy-flavour mesons and baryons, as well as for thermal dielectrons, that will come into reach with this new detector installed.

Category:

Experiment

Collaboration:

ALICE

Parallel 23: heavy quarkonia production / **23**

Tetraquark Production by Intrinsic Charm

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A number of new four-quark states containing from one to four c or $\bar{c}$ quarks have been observed recently. Many of these new states have been discovered at the LHC. The production of these states via intrinsic charm in the proton is investigated. The tetraquark masses obtained in this approach, agree well with the measured masses. These calculations can provide some insight into the nature of the tetraquark candidates, whether as a bound meson pair or as a looser configuration of four individual partons which can influence their interactions in nuclear medium, such as in heavy-ion collisions. The kinematic distributions
of these states as a function of y and pT are also studied. The possible cross sections for these states are also considered.

This work was performed under the auspices of the U.S. DoE by LLNL under Contract DE-AC52-07NA27344 and supported by LDRD projects 21-LW-034 and 23-LW-036 and the HEFTY Topical Collaboration.

Category:

Theory

Collaboration:

HEFTY

Parallel 22: heavy quarks hard, jet / 146

Collinear ccbar enhancement in medium

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We derive the characteristic behaviour of the splitting function of a gluon to ccbar inside of a jet and focus on the medium modification. In the Baier-Dokshitzer-Mueller-Peigné-Schiff and Zakharov formalism one determines the modifications of parton splittings in the hot QCD plasma that arise from medium-induced gluon radiation. We study the modification of the g->c-cbar splitting function in the kinematic range accessible at the LHC runs 3&4. In addition to the characteristic momentum broadening of the c-cbar pair, we find that interactions with the medium also enhance the rate of c-cbar production both with Monte-Carlo reweighting and JetMed simulations. We propose an experimental signature through the rate of jets containing two D0 mesons in heavy-ion over proton-proton collisions.

Category:

Theory

Collaboration:

Parallel 24: future facilities / 10

ALICE Forward Calorimeter upgrade (FoCal): physics program and expected performance

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The FoCal is a high-granularity forward calorimeter to be installed as an ALICE upgrade during the LHC Long Shutdown 3 and take data in Run 4.
It will cover a pseudorapidity interval of $3.2 < \eta < 5.8$, allowing to explore QCD at unprecedented low Bjorken-x of down to $\approx 10^{-6}$ – a regime where non-linear QCD dynamics are expected to be sizable.
The FoCal consists of a compact silicon-tungsten sampling electromagnetic calorimeter with pad and pixel readout to achieve high spatial resolution for discriminating between isolated photons and decay photon pairs. Its hadronic component is constructed from copper capillary tubes with scintillator fibers.
The detector design allows measuring a multitude of probes, including direct photons, jets, as well as photo-production of vector mesons in ultra-peripheral collisions and angular correlations of different probes.
After the recent completed of the Technical Design Report (https://cds.cern.ch/record/2696471), the FoCal project is entering the production phase in view of installation in 2028.
We will give an overview of the FoCal physics programme, of the detector design and of its expected performance using results from recent test beams of small-scale prototypes.

Category:

Experiment

Collaboration:

ALICE

Parallel 23: heavy quarkonia production / 243

NJ/ψ and $N\eta_c$ interactions from lattice QCD

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The interaction between the nucleon and charmonia (J/ψ and η_c) is expected to deepen our understanding of various aspects in nonperturbative QCD ranging from the origin of nucleon mass to J/ψ suppression in heavy-ion collisions and properties of hidden-charm pentaquark states. Here, we present the first lattice QCD studies on low-energy NJ/ψ and $N\eta_c$ interactions based on (2+1) flavor configurations with nearly physical pion mass $m_\pi = 146$ MeV. The interactions, extracted from the spacetime correlations of nucleon and charmonium system by using HAL QCD method, are found to be attractive in all distances and manifest a characteristic long-range tail, which is consistent with the two-pion exchange interaction between a nucleon and a color-dipole. The resulting scattering lengths are around 0.4 fm, 0.3 fm and 0.2 fm for NJ/ψ with spin $1/2$, with spin $3/2$, and $N\eta_c$, respectively. Our results are order of magnitude larger than those from the photo-production experiments assuming the vector meson dominance.

Category:

Theory

Collaboration:

Parallel 22: heavy quarks hard, jet / 288

Energy-energy correlators of heavy and light flavor jets in heavy-ion collisions

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Energy-energy correlators (EECs) have been proposed as excellent jet substructure observables for studying the space-time structure of the jet shower and disentangling the different properties of the quark-gluon plasma. The EEC distributions of charged hadron jets, D-tagged and B-tagged jets from PYTHIA 8 exhibit that the EEC of heavy meson jets in small angle is much smaller than that of charged hadron jets. Within a linear Boltzmann transport model which includes both elastic and inelastic interactions between jet partons and medium constituents, we explore the contributions from energy loss, jet-induced medium response and medium-induced gluon radiation to the the final EEC distribution of both heavy and light flavor jets at different angles. Comparing to pp result, the energy correlation between shower partons are suppressed at the whole region of angles due to energy loss. After combining the contributions from medium response and radiated gluons, the total correlators get enhanced at both large angles and very small angles. The enhancement at large angles comes from the correlations between shower partons and medium response, while the enhancement at very small angles comes from the correlations between shower partons and radiated gluons. Within this framework, we provide the medium-modified EEC for charged hadron jets, D-tagged jets and B-tagged jets in Pb+Pb collisions at 5.02 TeV. The effect of hadronization process on EEC distribution will also be discussed.

Category:

Theory

Collaboration:

Parallel 21: jets in small systems / 209

Correlations between hard probes and bulk dynamics in small systems

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Experimental exploration of small systems has produced several observables that indicate the existence of non-negligible correlations between hard and soft dynamics. When studying heavy ion collisions, the initial conditions and early stages of the bulk evolution are assumed independent of the dynamics of jets and high-p_T partons. For such large systems, the production of rare high-p_T probes is a small perturbation, but for small systems hard probes extract a significant fraction of the

energy and momentum from the collision. This becomes unavailable for, and thus strongly affects, bulk evolution.
We investigate correlations between hard probes and bulk dynamics in small systems. We use a multi-stage approach where the hard scatterings are sampled first, followed by an initial state shower, yielding the energy and momenta of the originating hard partons, which are then subtracted from the incoming nucleons. The remaining energy is used for soft-particle production, modeled by 3D-Glauber + hydrodynamics. We present results for the nuclear modification factor as a function of event activity, azimuthal correlations between hard probes and soft particles, and transverse energy (at large rapidities) as a function of the jet p_T. Our results demonstrate that hard-soft correlations are crucial to understand the dynamics in small systems. The X-SCAPE framework allows for systematic studies of the interplay between flow and non-flow correlations in small systems.

Category:

Theory

Collaboration:

JETSCAPE

Parallel 26: medium response / **142**

Jet quenching and medium response using photon+jet events in ATLAS

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Partons traversing the hot and dense medium of deconfined color charges produced in collisions of heavy nuclei are expected to lose their energy primar- ily through medium-induced gluon bremsstrahlung. As a result, the amount of induced energy loss is expected to depend on the QCD color charge carried by the parton, i.e. depend on whether it is a quark- or a gluon-initiated jet. In this talk, photon+jet events taken with the ATLAS detector in Pb+Pb and pp are used to constrain the color-charge dependence of jet energy loss. First, ATLAS presents the finalized result on the nuclear modification factor RAA for photon-tagged jets. By comparing this measurement to the RAA for inclu- sive jets, one can exploit the known difference in the quark-/gluon-initiated jet fraction between these two samples and extract the QCD color-charge depen- dence. Second, ATLAS presents the finalized measurement of photon plus two jet production in Pb+Pb collisions as compared to pp, where the configuration of quark+gluon jet pair opposite the photon is expected to dominate. Measurements of the total jet-to-photon pT ratio, the two-jet pT asymmetry, and the jet opening angle are presented, providing novel information on the parton-QGP interaction. Results are compared to a suite of theoretical calculations.

Category:

Experiment

Collaboration:

ATLAS

Parallel 27: UPC / **100**

Measurements of photon-induced J/ψ azimuthal anisotropy in isobar collisions at STAR

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Ultra-strong electromagnetic field in relativistic heavy-ion collisions could be quantized as a large flux of linearly polarized quasi-real photons. These photons can interact with nuclei or nucleons, leading to vector meson production ($\gamma + A \rightarrow V + A$). Notably, azimuthal asymmetries between the pair momentum and the daughter momentum could arise from the linear polarization of incident photons correlated with spin interference effect. On the other hand, the decay daughters of these vector mesons inherit polarization information of the photons, which is related to the initial collision geometry. Thus, the measurement of azimuthal anisotropy of these decay daughters offers a novel and direct probe into both the initial collision geometry and the polarization characteristics of the photons.

In this presentation, we will report the angular modulation measurements of the photon-induced J/ψ pair production in Ru+Ru and Zr+Zr ultra peripheral collisions at $\sqrt{s_{NN}}$ = 200 GeV. Additionally, we will also present the measurements of the azimuthal anisotropy with respect to the event plane (v_2) of electrons decayed from photon-induced J/ψ in non-central collisions from the same collision systems.
Our results offer novel insights into both the collision geometry and spin interference effect.

Category:

Experiment

Collaboration:

STAR

Parallel 28: hard EM / 65

Measuring isolated prompt photon production in small and large collision systems with ALICE

Authors: ALICE Collaboration[None]; Gustavo Conesa Balbastre[1]

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This talk presents a comprehensive study of isolated prompt photon production in pp, p–Pb and Pb–Pb collisions by ALICE, including new analyses which elucidate the low-x structure of matter and the impact of fragmentation photons on the prompt photon cross section. The first measurement of the prompt photon-nuclear modification factor $R_{\rm pA}$ in p–Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV is presented. A measurement of $R_{\rm pA}$ at $\sqrt{s_{\rm NN}}$ = 8.16 TeV is also presented, which probes cold nuclear matter effects down to $x \approx 2.9.10^{-3}$. In addition, the first ALICE measurement of prompt photon production in centrality-selected Pb–Pb collisions is presented – extending the low-x reach of previous measurements by about a factor two. This measurement is carried out for the first time with multiple isolation cone radii, which quantifies the contribution of fragmentation photons to the total physical cross section. These data provide new input for constraining nuclear PDFs, and for disentangling cold nuclear matter and hot QCD medium effects.

Category:

Experiment

Collaboration:

ALICE

Parallel 25: jets with heavy quarks / **193**

Dead cone effect and charm quark mass effects in high-pT D-jets with the CMS experiment

Author: Jelena Mijuskovic[1]

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The mass of heavy quarks modifies the radiation pattern of heavy-quark jets in comparison to their light quark counterparts, since the heavy quark mass effectively regularizes the soft and collinear divergences that would normally dominate the partonic cascade formation. This leads to the depletion of collinear gluon emissions relative to the heavy quark, an effect known as the dead cone effect. The dead cone of heavy-quark jets has been identified as a possible venue to isolate medium-induced radiation in a phase-space region where calculations are viable and where the large underlying event of a heavy-ion collision is absent. Previous measurements based on the construction of an angle-ordered tree of intrajet emissions have shown that it is possible to expose the dead cone experimentally. Novel jet substructure observables and algorithms are used to isolate hard and collinear emissions in the dead cone region with an improved sensitivity to charm quark mass effects using D^0-tagged jets in pp collisions at 5.02 TeV. For the first time, the substructure of charm quark jets with a p_{T} greater than 100 GeV is analyzed, in a regime that should be relatively insensitive to non-perturbative effects. It is shown that the sensitivity to quark mass effects is present even at high p_{T}. This result also serves as a baseline for future measurements in heavy-ion collisions.

Category:

Experiment

Collaboration:

CMS

Parallel 26: medium response / **154**

Searching for jet-induced diffusion wakes of quark gluon plasma via jet- track correlations in heavy ion collisions with the ATLAS detecto

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Hard-scattered partons traversing the medium produced in heavy-ion colli- sions lose energy by interacting with the medium. Simultaneously, the medium is modified in this interaction, exchanging energy and momentum with the parton. A typical modification of the medium in this process

includes an enhancement of the medium particles in the direction of the parton (the so-called wake) and a depletion (the so-called diffusion wake) in the opposite direction. In this talk, we present jet-track correlations in photon-jet and di-jet events measured in Pb+Pb collisions at 5.02 TeV with the ATLAS detector to search for diffusion wake signals. The results for photon-jet events do not show a significant diffusion wake signal within the current uncertainties. We provide upper limits on the probability, and the CoLBT theory prediction is found to be consistent with the data within the 68% confidence interval. The signals in di-jet events are also interpreted in terms of theoretical predictions, within the statistical significance of the data

Category:

Experiment

Collaboration:

ATLAS

Parallel 27: UPC / 134

Ultra-peripheral collisions at LHCb

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Ultra-peripheral collisions provide a unique environment to study pomeron- and photon-induced reactions with heavy nuclei. These interactions can produce a wide range of final state particles, from light vector mesons to heavy quarkonia, and probe potentially exotic phenomena. LHCb's particle ID capabilities provide unique opportunities to study hadronic final states in ultra-peripheral collisions. We will present recent LHCb results from ultra-peripheral heavy ion collisions and discuss how these impact our understanding of low-x parton interactions

Category:

Experiment

Collaboration:

LHCb

Parallel 28: hard EM / 53

Electroweak vector-boson production in hadronic collisions with ALICE

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Electroweak W and Z bosons, produced in hard-scattering processes at the early stage of hadronic collisions, are excellent probes of their initial state. The W and Z measurements in pp collisions represent a stringent test of perturbative QCD calculations, and provide important input for the determination of parton distribution functions (PDFs). In p-Pb and Pb-Pb collisions, these measurements can constrain the nuclear PDFs and test the binary-scaling for hard processes.

Electroweak W and Z bosons are studied with ALICE in pp, p-Pb, and Pb-Pb collisions via their leptonic decays in the muon and electron channels at forward rapidity ($-4.0 < \eta < -2.5$) and midrapidity ($|\eta| < 0.8$), respectively. The measurements in p-Pb and Pb-Pb collisions at forward rapidity give access to low Bjorken-x values, a phase-space region poorly constrained by other heavy-ion experiments.

A review of the W- and Z-boson results and their comparison to model calculations are presented, with particular emphasis on those recently obtained in pp collisions at midrapidity. That concerns differential measurements of the production cross sections, nuclear modification factors and lepton-charge asymmetry as a function of rapidity, transverse momentum, collision centrality and charged-particle multiplicity. The production of W bosons in association with hadrons as a function of the charged-particle multiplicity in pp collisions is discussed as well.

Category:

Experiment

Collaboration:

ALICE

Parallel 28: hard EM / 214

Interplay of prompt and non-prompt photons in photon-triggered jet observables

Authors: Chathuranga Sirimanna[None]; JETSCAPE Collaboration[None]

Prompt photons are important yet challenging to observe in relativistic heavy-ion collisions, as they are produced in the early stages and traverse almost the entire QGP medium without interaction. Experimental analyses typically employ isolation cuts, in the hope to identify prompt photons. Most theoretical studies consider only events with actual prompt photons, assuming no contribution from isolated non-prompt photons to reduce computational cost. For the first time, we present a study that compares simulation results generated using inclusive (bremsstrahlung) and prompt-photon events with multiple experimental observables for both $p-p$ and $Pb-Pb$ collisions at 5.02 TeV. Simulations are carried out using the multi-stage JETSCAPE framework tuned to describe the quenching of jets and hadrons. Isolated non-prompt photons are generated in hard photon bremsstrahlung, where the photon is radiated at a sufficient angle to the jet. Several photon triggered jet and jet substructure observables show significant contributions from inclusive photons, yielding an improvement in comparison with experimental data. Novel photon triggered jet substructure observables are also expected to show new structures, yet to be detected in experiment. This effort examines the significance of isolated non-prompt photons using parameters tuned for a simultaneous description of the leading hadron and jet spectrum, and thus provides an independent verification of the multistage evolution framework.

Category:

Theory

Collaboration:

JETSCAPE

Parallel 25: jets with heavy quarks / 156

Probing bottom quark mass effects in jet substructure with CMS using a novel technique to cluster the b-hadron decays

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The substructure of bottom quark jets is of substantial interest, both in vacuum and in medium, in terms of understanding radiation emitted from heavy quarks. Unfortunately, the decays of b hadrons, which are typically cascading, obscure the parton level branching, by filling the radiative dead cone. To circumvent this, one may study exclusive b-hadron decays, but one then sacrifices the vast majority of the b-jet cross section. We have implemented a technique to partially reconstruct the b-hadrons by aggregating their charged hadron decay products, dramatically improving the sensitivity to the underlying QCD splitting. Using this technique, we report the first measurements of the soft drop groomed momentum fraction and jet radius for b-jets, as well as the b-jet charged fragmentation function.

Category:

Experiment

Collaboration:

CMS

Parallel 26: medium response / 125

Visualizing How Jet Structure Shapes Jet Wakes

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We begin by using Hybrid Model calculations to reproduce experimental results published by ATLAS in 2023 on R_{AA} for $R = 1$ jets in Pb+Pb collisions. These jets are identified via first reconstructing anti-k_t $R = 0.2$ subjets and then reclustering them. Following ATLAS, we investigate how R_{AA} for these large-radius jets depends on the angle between the two subjets involved in the final clustering step of the $R = 1$ jet. We also study the dependence of R_{AA} for these jets on the resolution length of QGP, which suggests that measurements like those pioneered by ATLAS can constrain this property of QGP.

We make further use of this setup by analyzing the response of the medium to the passage of large-radius $R = 2$ jets containing two $R = 0.2$ subjets, produced in gamma-jet events, and identified as above. We introduce novel jet-shape observables that allow us to visualize the angular shape of the soft hadrons originating from the wakes that wide jets with two skinny subjets excite in the droplet of QGP, as a function of the angular separation between the subjets. We find that even when the two hard subjets are 0.8 to 1.0 radians apart, a single broad wake is produced. When the two subjets are even farther apart the presence of two sub-wakes is revealed. We show that the way in which jet structure shapes jet wakes can be visualized with similar clarity in experiments by measuring the observables we have introduced using only those hadrons with low transverse momenta.

Category:

Theory

Collaboration:

Parallel 27: UPC / 15

Probing the nucleus and nucleons with vector mesons in ultra-peripheral collisions in ALICE

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The strong electromagnetic fields associated with heavy-ions at the LHC lead to large cross sections for exclusive photoproduction of vector mesons in ultra-peripheral collisions (UPCs). Photoproduction of charmonium probes the distribution of gluons in the target nucleus. Earlier studies of charmonium photoproduction have focussed on measuring the production cross sections and rapidity distributions. More information can, however, be obtained from differential distributions, such as $\mathrm{d}\sigma/\mathrm{d}t$ at different rapidities. This enhances the sensitivity to the gluon distribution and opens up the possibility to extract also the spatial distribution of gluons. It may also contribute to a better understanding of the interplay between nuclear shadowing and gluon saturation. The energy dependence of the photoproduction cross section can be extracted by studying vector meson production in coincidence with neutron emission. Because of the interference betweeen the production sources (the two nuclei), vector meson production also serves as a two-slit interferometer at subatomic length scales. The interference can be probed by studying the azimuthal angular distributions. The latest results from ALICE on photoproduction of vector mesons will be presented.

Category:

Experiment

Collaboration:

ALICE

Parallel 28: hard EM / 173

Revealing the medium-recoil effect with high-p_{T} Z boson tagged underlying event distribution in PbPb collisions at CMS

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Effects such as medium-induced radiation and medium response could contribute to the enhancement of low-p_{T} particles. The low p_{T} particles are shown to be essential in the energy-momentum balance of dijet and photon/Z-jets. In this presentation, we utilize the Z boson reconstructed within the dimuon channel, which does not interact with the quark-gluon plasma (QGP) throughout the decay chain before interacting with the detector. Identification of muons does not require an isolation requirement and thus does not introduce bias into the underlying event distribution. This feature

enables the selection of a single quark-enriched high-p_{T} parton and study the modification of the underlying events associated with this probe. We present the first measurement of the Z boson-tagged underlying event spectra as well as track-track correlation over a large acceptance with respect to the Z boson, using lead-lead data recorded by the CMS detector at 5.02 TeV. This new result can provide an unambiguous signal of the medium-recoil effect, and it could be sensitive to the equation of state and the speed of sound of the quark-gluon plasma and other potential novel effects.

Category:

Experiment

Collaboration:

CMS

Parallel 25: jets with heavy quarks / **285**

Flavor hierarchy of parton energy loss in quark-gluon plasma from a Bayesian analysis

Authors: Guang-You Qin[1]; Shanshan Cao[2]; Wen-Jing Xing[2]

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The quenching of light and heavy flavor hadrons in relativistic heavy-ion collisions probes the color and flavor dependences of parton energy loss through a color-deconfined quark-gluon plasma (QGP), and thus offers an important test of QCD-based calculation at extremely high density and temperature. By combining a next-to-leading order perturbative QCD calculation of parton production, a general ansatz of parton energy loss functions and parton fragmentation functions, we calculate the nuclear modification of various hadron species – charged hadrons, D mesons and B-decayed J/ψ – over a wide transverse momentum regime. Comparing our calculations to the experimental data using the Bayesian statistical analysis, we perform a first simultaneous extraction of the energy loss functions of gluons (g), light quarks (q), charm quarks (c) and bottom quarks (b) inside the QGP. We find that the average parton energy loss at high energies follows the expected hierarchy of $\langle\Delta E_g\rangle > \langle\Delta E_q\rangle \sim \langle\Delta E_c\rangle > \langle\Delta E_b\rangle$, while the parton energy loss distribution can further test the QCD calculations of parton interaction with the dense nuclear matter.
We also find that the reduction of experimental uncertainties can significantly improve the precision of the extracted parton energy loss functions inside the QGP.

Ref: Wen-Jing Xing, Shanshan Cao and Guang-You Qin, Phys.Lett.B 850 (2024) 138523

Category:

Theory

Collaboration:

Parallel 26: medium response / **296**

Jet transport in QGP fluid

Authors: Tan Luo[1]; Carlos Albert Salgado Lopez[2]; Yayun He[3]; Xin-Nian Wang[4]

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Particles associated with the jet will be deflected from their initial direction due to the scatterings with the thermal partons flowing in the QGP fluid. Such deflections depend on the energy of the jet, the local energy gradient, and the local flow velocity. In general, the soft particles will drift towards the direction of the flowing medium, away from the center of the jet cone where the hard particles are located, leading to an intra-jet asymmetry coupled with flow, which can be used to extract the properties of the QGP medium. In this work, we first calculate the intra-jet asymmetry distribution in both transverse and longitudinal directions and investigate their dependence on path length, viscosity, and jet multiplicity. Such asymmetry is also observed in the jet chemical structure. We then extract the average radial flow velocity distribution via the intra-jet asymmetry distribution and compared it with the hydrodynamic simulation results. Our approach can be further used to localize the initial production position of the jet without specified requirements of the jet direction. As we apply jet localization to gamma-jet and dijet events, we find an improvement in the localization accuracy of dijet events due to the interplay between QGP flow and the diffusion wake induced by the backside jet.

Category:

Theory

Collaboration:

Parallel 27: UPC / 13

A new class of ultra-peripheral collisions in ALICE: inelastic photonuclear interactions and open charm photoproduction

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The study of ultra-peripheral collisions (UPCs) has so far mostly focussed on exclusive production of a single vector meson or a dilepton pair, while the nuclei have remained in their ground state or have only been slightly excited. There is, however, also the possibility to study a more general class of UPCs involving a photonuclear interaction where the target nucleus is broken up, gamma+A −> X. These interaction can be divided into resolved processes, where the photon fluctuates to a qqbar pair (typically a vector meson) which interacts hadronically with the target, and direct processes where a bare photon interacts with a parton. The former process resembles proton-nucleus collisions, and it gives the dominant contribution to the the cross section. The latter includes charm production through photon-gluon fusion. Experimentally, these interactions can be identified by requiring rapidity gaps, void of particles, on the side of the photon-emitting nucleus. The latest results from ALICE on inelastic photonuclear interactions will be presented.

Category:

Experiment

Collaboration:

ALICE

Parallel 32: hadronization / 17

Probing light nuclei production mechanism by measuring nuclei production in and out of jets with ALICE at the LHC

Authors: ALICE Collaboration[None]; Chiara Pinto[1]

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The production mechanism of (anti)nuclei in ultrarelativistic hadronic collisions is under intense debate in the scientific community. Two successful models used for the description of the experimental measurements are the statistical hadronisation model and the coalescence approach. In the latter, multi-baryon states are assumed to be formed by coalescence of baryons that are close in phase-space at kinetic freeze-out. Due to the collimated emission of nucleons in jets, the available phase-space is limited, hence the production of nuclear states by coalescence in jets is expected to be enhanced with respect to the production in the underlying event. In this contribution, the results for the coalescence parameter B_2, that quantifies the formation probability of deuterons by coalescence, in and out of jets measured in both pp and p–Pb collisions are presented in comparison with predictions from the coalescence model.

Category:

Experiment

Collaboration:

ALICE

Parallel 31: UPC / 180

First measurement of the D^0 production in photonuclear ultra-peripheral heavy ion collisions with CMS to probe low-x nuclear matter

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The study of heavy-quark photoproduction in ultraperipheral collisions (UPC) of heavy ions provides a new tool to characterize the production mechanisms of heavy-quarks with high experimental and theoretical control, and constrain the properties of nuclear matter in a wide region of the (x, Q^2) with perturbatively-produced hard probes. In this talk, we will present the first measurement of the production yield of D^0 mesons as a function of their transverse momentum and rapidity performed in ultraperipheral heavy ion collisions at 5.36 TeV, performed by CMS using the first heavy ion data from the LHC Run 3. The results are compared to recent calculations that describe the production of charm photoproduction in UPC and exploit different modeling of the nuclear parton distribution functions (nPDFs). These results will provide new insights into the nPDFs of gluons down to low x and Q^2 and pave the way for high-accuracy measurements of the heavy-quark production and shower evolution in the clean experimental environment that characterize photonuclear collisions.

Category:

Experiment

Collaboration:

CMS

Parallel 30: jets in early stages / **220**

Deformation of Jets Induced by Ambient Medium Flow

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The evolution of jets showers in high energy nuclear collisions is influenced in various ways by the presence of a surrounding medium. The interaction of jet constituents with the medium can happen during the partonic stage of the jet, during hadronization, and even during its hadronic stage. We will demonstrate how flow of the ambient medium in a direction transverse to the jet can introduce both dipole and quadrupole defomations. We analyze the corresponding n=1 and n=2 harmonic deformations of the transverse structure of jets using the method of Q-vectors. We discuss how the harmonic coefficients and their preferred angles evolve when the ambient environment of jets changes from the vacuum to a parton medium without flow and finally to a medium with various rates of transverse flow. We have conducted a systematic study using both partonic and hadronization effects of the medium on jets. While quadrupole deformations are naturally present even in the vacuum, we find that the existence of sizable dipole deformations, and a correlation of the angles of dipole and quadrupole deformations could constitute clear experimental signals for the presence and size of transverse flow.

Category:

Theory

Collaboration:

Parallel 29: jets with heavy quarks / **232**

J/ψ production within a jet in high-energy proton-proton and nucleus-nucleus collisions

Author: Shan-Liang Zhang[1]

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Within the framework of leading power factorization formalism of nonrelativistic quantum chromodynamics, we calculate the jet fragmentation function for J/ψ production in proton-proton (pp) collisions ranging from $\sqrt{s} = 500$ GeV to 13 TeV. The reasonable agreements between theory and experimental data indicate that J/ψ production within a jet is mainly dominated by gluon fragmentation. Such a mechanism can be further tested by the predicted jet transverse momentum and radius dependence of jet fragmentation function. Based on the satisfying description of pp baseline, we carry out the first theoretical investigation on medium modification on J/ψ production within jet in heavy-ion collisions at the Large Hadron Collider, using a linear Boltzmann transport model

combined with hydrodynamics for the simulation of jet-medium interaction. The consistency with the experimental measurement on nuclear modification factor $R_{\rm AA}$ by CMS collaboration reveals that the gluon jet quenching is the driving force for the suppression of J/ψ production in jet. Furthermore, we make predictions for the dependence of $R_{\rm AA}$ on the jet transverse momentum and jet radius R, which can be tested in future measurements to further constrain the flavor dependence of jet quenching.

Category:

Theory

Collaboration:

Parallel 32: hadronization / **102**

Probing hadronization with the charge correlator ratio in pp and Ru+Ru/Zr+Zr collisions at $\sqrt{s_{\rm NN}} = 200$ GeV at STAR

Author: Youqi Song[None]

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Jet substructure observables can reveal details of the parton fragmentation and hadronization processes that create a jet. We measure a new substructure observable, the charge correlator ratio (r_c), that characterizes the fraction of string-like fragmentation by distinguishing the charge signs of leading and subleading charged particles within jets. This can further our understanding of non-perturbative QCD and provide tests for phenomenological hadronization models. Moreover, by measuring r_c with jets created in heavy-ion collisions, we probe for potential modifications of the hadronization process due to the presence of the Quark Gluon Plasma.

We present the first fully corrected results of r_c at RHIC, in $\sqrt{s} = 200$ GeV pp collisions recorded by the STAR detector, and compare them with Monte Carlo predictions. Additionally, we present progress on the first measurement of r_c in heavy-ion collisions, with $\sqrt{s_{\rm NN}} = 200$ GeV Ru+Ru and Zr+Zr collisions.

Category:

Experiment

Collaboration:

STAR

Parallel 31: UPC / **145**

Results on photon-induced processes in ultra-peripheral Pb+Pb collisions with ATLAS

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In ultra-relativistic heavy-ion collisions, copious rates of γγ processes are expected through the interaction of the large electromagnetic fields of the nu- clei, which enables the production of particles

such as leptons, virtual axion-like particle, magnetic monopoles, or can lead to light-by-light scattering via loop diagrams, and even higher-order processes where additional photons are ex- changed. In ultra-peripheral collisions (UPCs), characterized by large impact parameter between the nuclei, the outgoing leptons, photons, or monopoles, exhibit back-to-back production in the transverse plane which provides precise and efficient identification. This talk presents recent measurements of dilepton production as well as new measurements that assess the rate of additional pho- ton exchange which leads to vector meson or forward neutron production. The study of these secondary photon exchanges can give detailed insights into the photon flux and field configuration as well as the geometry of the collisions. Also presented is a more recent search for monopole-pair production in UPCs with monopole masses ranging from 2–100 GeV. The results are compared with a leading-order model of spin-1/2 particle production from photon–photon fusion and a recently developed semi-classical model that includes non-perturbative cross section calculations.

Category:

Experiment

Collaboration:

ATLAS

Parallel 30: jets in early stages / **137**

The imprints of hydrodynamics in jet quenching

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In this talk, we present a novel extension to the theory of jet quenching, incorporating the effect of both the flow and anisotropy of matter undergoing hydrodynamic evolution. The interplay between these two vectorial magnitudes results in a significant rescaling of fundamental objects, like the jet quenching parameter. Depending on the relative direction of the two vectors, the energy loss gets severely modified. The new contribution is not subleading in energy, and thus it could transform our understanding of jet-medium interactions drastically. First, we show the effect of this interplay for both the jet momentum broadening and medium induced branching, treating the interaction within the opacity expansion. We further discuss the extension to the dense regime and the resummation of multiple scatterings. Finally, we discuss phenomenological implications that the presented results have for a realistic imaging of the QGP created in HICs.

Category:

Theory

Collaboration:

Parallel 29: jets with heavy quarks / **130**

Energy correlators for gluon splitting to heavy quarks

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Energy correlators inside of high energy jets provide a powerful tool to image the intrinsic and emergent angular scales of QCD. They have the potential to provide unprecedented insight on the interplay between vacuum scales inside of a jet and its medium modification. However, as with traditional jet substructure, experimentally these correlators will mix different angular features associated with quark and gluon jets. We show that energy correlators of jets containing a gluon splitting to heavy quarks can resolve this problem, by providing clean experimental access to two- and three-point correlators with known parton flavors through jets tagged with heavy hadrons. We demonstrate the unique capabilities of this process for two- and three-point energy correlators for the gluon splitting to heavy quarks in vacuum, and calculate the medium modification of the two-point correlator.

Category:

Theory

Collaboration:

Parallel 30: jets in early stages / 208

Open heavy flavor in evolving anisotropic matter

Authors: Joao Lourenco Henriques Barata[None]; Xoán Mayo López[1]; Andrey Sadofyev[2]; Carlos Albert Salgado Lopez[3]

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We derive the leading modifications of the transverse momentum broadening and medium-induced gluon spectrum in anisotropic flowing matter for the case of a heavy leading quark. We show that the broadening and radiation patterns develop new directional dependence due to an interplay of the quark mass and matter flow, absent in the massless case. In turn, the interplay of the medium anisotropy with the quark mass also leads to a considerable modification of the hydrodynamic gradient corrections to the soft-gluon spectrum. These results allow constructing heavy-flavor observables sensitive to the medium structure and evolution, constituting the next step toward tomographic studies of the quark-gluon plasma in heavy-ion collisions.

Category:

Theory

Collaboration:

Parallel 32: hadronization / 181

Probing Hadronization Through Jet Substructure Analysis

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Understanding the hadronization mechanism in Quantum Chromodynamics (QCD) remains a significant challenge due to its non-perturbative nature. Hadronization is typically described via phenomenological models in Monte Carlo event generators (such as PYTHIA and HERWIG), whose parameters need to be tuned to data. This work leverages jet substructure to probe underlying features of these frameworks, offering new insights into the hadronization process. While jets were originally proposed to circumvent non-perturbative effects, we show that their substructure can be a powerful tool to investigate these phenomena. Specifically, we demonstrate that the charge correlation ratio, which is sensitive to hadronization effects, can be enhanced by selections on jet substructure, particularly by analyzing the relative placement of splittings that resolve the leading charged particles within the clustering tree. Our findings reveal remarkable differences between widely used hadronization models, contributing to a better understanding of hadronization and opening new avenues for exploring non-perturbative QCD.

Category:

Theory

Collaboration:

Parallel 31: UPC / 198

Detecting fluctuating gluonic structure via energy-dependent incoherent J/ψ photoproduction in PbPb at 5.02 TeV with the CMS experiment

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In heavy ion ultraperipheral collisions (UPCs), the production of J/ψ through photon-nuclear interactions is of particular interest, as its cross section is highly sensitive to the properties of gluons within heavy nuclei. Photons can interact with the nucleus coherently (involving the entire nucleus) or incoherently (with individual nucleons). While coherent interactions probe the average gluon densities of the nucleus, incoherent interactions offer unique sensitivity to the local gluon density fluctuations at the nucleonic or subnucleonic levels. Studies of incoherent J/ψ photoproduction hold promise for shedding new light on the dynamic evolution of fluctuating gluonic structures within nuclei and potentially uncovering the onset of gluon saturation towards the small-x limit. By applying the forward neutron tagging technique, we will present the first measurement of incoherent J/ψ photoproduction cross section as a function of the photon-nucleon center-of-mass energy (40-400 GeV) in PbPb UPCs. Furthermore, we will examine the cross section ratios between incoherent and coherent \rm{J}/\psi.$Additionally, we will reveal the nuclear suppression factor of incoherent$\rm{J}/\psi$and draw comparis$o
Finally, we will discuss the relevant physics implications of these results.

Category:

Experiment

Collaboration:

CMS

Parallel 29: jets with heavy quarks / 237

Probing QCD dynamics with jet substructure in LHCb kinematics

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Jet production at the LHC provides an invaluable probe of QCD dynamics ranging from initial-state parton distributions to final-state jet fragmentation functions. High-precision perturbative calculations for jet substructure have recently become available, allowing direct comparison of experimental measurements to theory. Measurements of jet substructure therefore offer a direct test of first-principles theoretical prescriptions for jet formation and fragmentation in perturbative QCD. Selecting jets containing a heavy-flavor hadron extends tests of QCD fragmentation to a regime where parton mass and color factors play a crucial role, probing the limits of modern perturbative calculations. Comparing inclusive heavy-flavor jet production to jets associated with a Z boson probes initial state effects. At the same time, performing measurements using a novel jet flavor tagging algorithm allows tests of perturbative QCD at unprecedented theoretical precision. The LHCb Collaboration presents recent jet substructure results at forward rapidity in pp collisions at center-of-mass energy $\sqrt{s}$ = 13 TeV. These jet fragmentation studies are compared to theoretical predictions, providing new insight on QCD dynamics at forward rapidity and at low and moderate values of jet transverse momentum

Category:

Experiment

Collaboration:

LHCb

Parallel 32: hadronization / 22

Studying the interaction between charm and light-flavor mesons with ALICE

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In the last years, several exotic hadrons have been observed in the charm sector; such particles cannot be interpreted as conventional baryons or mesons and are thought to be either quark bags or molecular states. To unveil their nature, it is crucial to experimentally constrain the strong force that governs the interaction between the charm hadrons and other hadrons, for instance, by measuring the scattering parameters. This knowledge is also essential for the study of ultrarelativistic heavy-ion collisions. In fact, during the hadronic phase of the system expansion, the charm hadrons can interact with the other particles produced in the collision via elastic and inelastic processes. These interactions modify the heavy-ion observables, and to disentangle this effect from the signatures of the quark–gluon plasma formation, the scattering parameters of the charm hadrons with light-flavor hadrons are required. This contribution presents the first experimental study of the final-state strong interaction between open-charm and light-flavor mesons. The measurement is performed using the

femtoscopy method applied to high-multiplicity proton-proton collisions at $\sqrt{s}$ = 13 TeV, collected by the ALICE Collaboration. The Dπ and D*π scattering lengths are also determined for the first time. Additionally, predictions on femtoscopic results in the charm sector of the future ALICE 3 experiment are presented

Category:

Experiment

Collaboration:

ALICE

Parallel 31: UPC / **177**

First measurement and observation of exclusive coherent bottomonia photoproduction in PbPb at 5.02 TeV with the CMS experiment

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Photonuclear interactions in ultraperipheral heavy-ion collisions can be used to improve our understanding of gluonic nuclear structure In particular, coherent photoproduction of vector mesons are processes sensitive to the gluon distribution of the target nucleus, especially at small values of the parton momentum fraction x, where the onset of gluon saturation effects is expected. A systematic study of exclusive vector meson production allows us to probe cold nuclear matter with different color dipole sizes, thus with different sensitivities to gluon saturation effects. In the case of heavy quarkonia production, the heavy quark masses set a sufficiently large scale that allows for an interpretation in terms of perturbative quantum chromodynamics calculations. In this talk, the first measurement and observation of exclusive coherent Y(1S) photoproduction in PbPb collisions by the CMS experiment will be presented. The measurement is compared to calculations based on small-x linear or nonlinear evolution.

Category:

Experiment

Collaboration:

CMS

Parallel 30: jets in early stages / **92**

Quark antenna in early stage anisotropic QCD matter

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The states of matter produced in the early stage of heavy ion collisions can be highly anisotropic. If such a feature is sufficiently pronounced, one should expect the final particle distribution inside jets to reflect it in the form of non-trivial angle correlations. In this talk, we discuss a first step in exploring such correlations by studying how a $q\bar{q}$ state branching from an initial unpolarized gluon couples to the anisotropies of an underlying static QCD medium. The medium anisotropy is captured by allowing the jet quenching parameter to take different magnitudes in two orthogonal directions in the plane transverse to the jet axis.
We find that the final particle distribution is sensitive to the medium anisotropy in the form of an azimuthal angle modulation, and more importantly, that this effect couples directly to the helicity/spin of the final states, offering a novel way to extract the details of the underlying matter which is not accessible with standard jet observables. We show how such features can be extracted from the Fourier decomposition of the particle distribution, from azimuthally dependent energy-energy correlators and from final state transverse spin polarization measures. We further discuss how to incorporate these effects into the description of other hard probes of the medium.

Category:

Theory

Collaboration:

Parallel 29: jets with heavy quarks / **99**

Charm Meson Tagged Jets in Au+Au Collisions at $\sqrt{s_{\rm NN}} = 200$ GeV

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Hard-scattered partons produced early in heavy-ion collisions are used to probe the properties of the QGP (Quark-Gluon Plasma). These partons lose energy in the QGP either through elastic collisions, or through medium-induced gluon \textit{bremsstrahlung}, which is the dominant mode of energy loss for gluons and light quarks. Theoretical calculations predict that at low momentum ($p_{\rm T}$), this radiative energy loss is suppressed for heavy quarks (charm, bottom). At RHIC energies, with excellent secondary vertex resolution in the STAR experiment, these low $p_{\rm T}$ charm-tagged jets are readily accessible.

In this talk, we present several measurements of $D^0(c\bar{u})$-tagged jets of different resolutions in Au+Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV at STAR. We report the yields and nuclear modification factors as functions of $p_{\rm T,Jet}$, fragmentation function ($z = \frac{\vec{p}_{\rm T,D^0}\cdot\vec{p}_{\rm T,Jet}}{|\vec{p}_{\rm T,Jet}|}$), and generalized angularities ($\lambda^{\kappa}_{\beta} = \sum_{\rm const\in Jet}\left(\frac{p_{\rm T,const}}{p_{\rm T,Jet}}\right)^{\kappa}\Delta r_{\rm constJet}$) for these jets in the QGP. In addition, we present the radial profile of the D^0 mesons in these jets. Together, these measurements can help us put significant constraints on theories predicting parton flavor and mass dependence of energy loss in the medium.

Category:

Experiment

Collaboration:

STAR

Parallel 32: hadronization / **287**

Unraveling the final state interaction and correlation inside high multiplicity jet at LHC

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The recent CMS measurements of high multiplicity jets have revealed intriguing structures in two-particle correlations within jets with over 80 charged tracks, which may suggest the existence of final state interactions other than those considered in current parton shower programs. We investigate whether two final-state interaction mechanisms that may become important when the phase-space density of partons in a jet becomes large: 1) partonic rescattering 2) two-to-one merging of patron pairs of small invariant mass. We implement such processes approximately after Pythia8 shower and carefully model the spacetime structure and track the color information in these final state interactions. We analyze the impact of these two effects on particle correlation inside jet as measured by CMS. This study may shed light on understanding QCD hard processes in the high-multiplicity limit.

Category:

Theory

Collaboration:

Parallel 31: UPC / 147

Measurement of dijet production in ultraperipheral Pb+Pb collisions with ATLAS

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In relativistic heavy ion collisions, the charged ions produce an intense flux of equivalent photons. Thus, photon-induced processes are the dominant inter- action mechanism when the colliding nuclei have a transverse separation larger than the nuclear diameter. In these ultra-peripheral collisions (UPCs), the pho- ton provides a clean, energetic probe of the partonic structure of the nucleus, analogous to deep inelastic scattering. This talk presents a measurement of jet production in UPCs performed with the ATLAS detector using high-statistics 2018 Pb+Pb data. Events are selected using requirements on jet production, rapidity gaps, and forward neutron emission to identify photo-nuclear hard- scattering processes. The precision of these measurements is augmented by studies of nuclear break-up effects, allowing for detailed comparisons with the- oretical models in phase-space regions where significant nuclear PDF modifica- tions are expected but not strongly constrained by existing data.

Category:

Experiment

Collaboration:

ATLAS

Parallel 30: jets in early stages / 31

Initial stage jet momentum broadening and energy loss in tBLFQ formalism

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We study the energy loss and momentum broadening of a high energy quark jet in the high density gluon medium created right after the collision of two ultrarrelativistic heavy nuclei, the Glasma. Using the light-front QCD Hamiltonian formalism, we compute the real-time evolution of the quark jet. We thereby treat the jet as a fully quantum state, and describe the Glasma as an evolving classical color background field. Notably, in this formalism, the fields are quantized on the equal light-front time surface of the jet and in the associated light-cone gauge, whereas the existing studies of the Glasma field are usually formulated in a different gauge, the Glasma's temporal gauge. For the first time, we carried out the gauge transformation of the Glasma fields from its temporal gauge to the jet's light-cone gauge. In this work, we will focus on jets at approximately mid-rapidity. By evolving the jet state within the Glasma, we analyze various observables with the obtained jet wavefunction.

Category:

Theory

Collaboration:

Parallel 29: jets with heavy quarks / 39

Differential measurements of in-jet fragmentation of charmed mesons and baryons in pp collisions with ALICE

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Despite being a key component of the factorisation theorem used for the calculation of heavy-flavour hadron production, fragmentation functions remain poorly understood due to their non-perturbative nature and must instead be evaluated based on experimental data. Recent measurements comparing charm baryon and meson production in hadronic collisions at low and intermediate transverse momenta have revealed significant deviations from the expected electron-positron and electron-proton baselines, challenging the assumed universality of fragmentation.

To gain a precise understanding of possible novel hadronisation mechanisms involved in hadronic collisions, we present a series of charm-tagged jet-fragmentation studies. These measurements extend the previous single-hadron measurements by exploring the interplay between the final-state charmed hadron and the originary charm quark produced in the hard-parton scattering. Using a larger sample of pp data collected by ALICE during the LHC Run 3, we report a measurement of the longitudinal jet momentum fraction carried by Λ_c^+ baryons compared to that carried by D^0 mesons. We explore these observables differentially as a function of the surrounding colour-charge multiplicity. We also investigate the angular component of fragmentation by comparing the radial

displacement of these final state baryons and mesons from the jet axis, giving us a handle on the differences between baryon and meson confinement.

Category:

Experiment

Collaboration:

ALICE

Plenary Session III / **322**

Open Heavy Flavor: Theory

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Collaboration:

Category:

Plenary Session III / **323**

Open Heavy Flavor: Experiment

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Category:

Plenary Session III / **324**

Quarkonia Theory: From Open Quantum System to Classical Transport

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Collaboration:

Category:

Plenary Session III / **325**

Quarkonia: Experiment

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Collaboration:

Category:

Plenary Session IV / **347**

Future Facilities: Heavy-ion physics at the LHC

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Collaboration:

Category:

Plenary Session IV / **348**

Future Facilities: Electron Ion Collider

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Collaboration:

Category:

Plenary Session IV / **349**

Future Facilities: SPS

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Collaboration:

Category:

Plenary Session IV / **350**

Future Facilities: J-PARC

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Collaboration:

Category:

Plenary Session V / **374**

Jets: Jet modification and medium response

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Plenary Session V / **375**

Jets: Hard-soft correlation

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Plenary Session V / **376**

Jets: In-medium parton evolution with finite size effects

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Plenary Session VI / **329**

Jets: Experimental overview

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Collaboration:

Category:

Plenary Session VI / **330**

Jets: Substructures and energy-energy correlator

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Collaboration:

Category:

Plenary Session VI / **331**

Jets: Hard-jet correlation

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Collaboration:

Category:

Plenary Session VI / **332**

Theory+Experiment Approach: Bayesian analysis with jet MC models

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Collaboration:

Category:

Plenary Session VII / **333**

Electromagnetic and Weak Probes: Theory

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Collaboration:

Category:

Plenary Session VII / **334**

Electromagnetic and Weak Probes: Experiment

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Collaboration:

Category:

Plenary Session VII / **335**

Nuclear PDFs

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Collaboration:

Category:

Plenary Session VII / **336**

Early Time Dynamics

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Collaboration:

Category:

Plenary Session VII / **337**

Ultra-peripheral collisions: Achievements and future prospects

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Collaboration:

Category:

Plenary Session IX / **338**

Lattice and Effective Field Theory for Hard Probes

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Collaboration:

Category:

Plenary Session IX / **339**

Machine Learning for the analysis of hard probes

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Collaboration:

Category:

Plenary Session IX / 340

Quantum Computation for Jets in Heavy Ion Collisions

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Collaboration:

Category:

Plenary Session X / 341

Conference Highlight: Jets and high pT

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Collaboration:

Category:

Plenary Session X / 342

Conference Highlight: Heavy flavors

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Collaboration:

Category:

Plenary Session X / 343

Conference Highlight: Initial state and early time dynamics

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Collaboration:

Category:

Plenary Session X / 344

Conference Highlight: Electroweak Probes

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Collaboration:

Category:

Plenary Session X / 345

Next Hard Probes (Vanderbilt)

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Collaboration:

Category: