Hadron Physics Research Group

Wigner Research Group

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Heavy-flavor jets with the ALICE experiment. — The production of heavy-flavor jets in proton-proton collisions serves as a fundamental test of perturbative QCD, while p-Pb (Pb-Pb) measurements provide information about the effects of the cold (hot) nuclear matter. Our group plays a key role in several experimental measurements within the ALICE Heavy Flavor Jets and Correlations physics analysis groups. The final results on the production cross-section and b-jet fractions in $\sqrt{s}$=5.02 TeV in pp and p-Pb collisions, as well as the nuclear modification factor in p-Pb collisions, have been published [1]. With the excellent particle tracking capabilities of the ALICE detector, these results extend to unprecedentedly low momenta (p_T>10 GeV/c) and pave the way to the understanding of flavor-dependent jet fragmentation as well as nuclear modification.

Heavy-flavor correlations in the experiment and in phenomenology. — Correlation measurements of D mesons with charged hadrons reveal the heavy-flavor jet structure at intermediate momenta. We are one of the main contributors to the D-h correlation measurements in pp collisions at $\sqrt{s}$=13 TeV by the ALICE experiment, recently published [2]. Our group is responsible for the ALICE analysis of D-meson production in function of the transverse event-activity classifier R_T. In a recent paper, we further explore experimental possibilities of similar heavy-flavor measurements with hadron as well as jet triggers (Fig. 1) [3]. Furthermore, our group participates in the peak shape analysis of heavy-flavor electron to hadron correlations in $\sqrt{s}$=5 TeV pp and p-Pb collisions. This work will become part of a later ALICE publication.

Unveiling the effects of soft multipaton interactions using novel event classifiers. — Nowadays, event classifiers as well as event shape variables have been considered as efficient tools to study the characteristics of high-energy proton-proton collision events at the LHC. For example, the event selection based on the charged-particle multiplicities at forward pseudorapidities helped to discover the strangeness enhancement in high-multiplicity proton-proton collisions at the ALICE experiment. However, it turned out that the obtained results suffer from significant selection bias due to presence of mutl-jet events. This makes it difficult to interpret the results from e.g. jet-quenching searches in small collision systems. To overcome the unwanted bias a novel event classifier is introduced which considers a self-normalized quantity using charged-particle multiplicities in a broad phase space region measurable experimentally. In Monte Carlo models we explore the sensitivity of this classifier to the “hardness” of the event and its sensitivity to soft multi-parton interactions [4]. The results from such phenomenological studies are being verified in the ALICE experiment using data from the Run 2 data taking period of the LHC. Good understanding of the effects is essential to plan long-term measurements in the Run 3 period and beyond.

Scaling properties of light and heavy-flavor jets. — In an earlier work we showed that Koba–Nielsen–Olesen (KNO)-like scaling is fulfilled inside the jets, which indicates that KNO scaling is violated by complex vacuum quantum chromodynamics (QCD) processes outside the jet development, such as single and double parton scattering or softer multiple parton interactions. In a subsequent publication we investigated the scaling properties of heavy-flavor jets using Monte-Carlo simulations. We found that while jets from leading-order flavor-creation processes exhibit flavor-dependent patterns, heavy-flavor jets from production in parton showers follow inclusive-jet patterns. This suggests that KNO-like scaling is driven by initial hard parton production and not by processes in the later stages of the reaction [5].

Interpreting the charm-baryon enhancement. — The enhancement of charmed baryons, observed in pp collisions at the LHC, questions the validity of the factorization approach in heavy-flavor production. Based on the comparative use of several event-activity classifiers in simulations with color-reconnection beyond leading color approximation, we proposed methods to identify the source of the observed enhancement. We also conclude that in the scenario under investigation the excess charmed Λ_c^+-baryon production is primarily linked to the underlying event activity and not to the production of jets (Fig. 2) [6]. More recently we investigated the production of charmed baryons with different isospin and strangeness content, and proposed methods based on event-activity classifiers to probe the source of the charm baryon enhancement. We conclude that in the considered model class, the isospin of the charmed baryon state has a strong impact on the enhancement pattern. Using the observables we propose in our manuscript in preparation, upcoming high-precision experimental data will be able to differentiate between mechanisms of strangeness and charm enhancement.

Image reconstruction for proton CT. — Proton CT can be used to measure the energy loss of individual protons and reconstruct the relative stopping power (RSP) distribution of the patient. We developed a novel algorithm for the image reconstruction as we first time applied the Richardson–Lucy iteration cycle for pCT with a simplified probability density based interaction calculation. We also investigated the energy dependence of the RSP which represents a theoretical limitation for the accuracy of the pCT imaging. We concluded that this dependence does not limit the applicability of pCT systems, but the measurement accuracy of the state of the art prototypes are close to this theoretical limit.

ALICE 3: cooling system development for the inner tracking system. — One of the main motivations behind the inner tracking system (ITS) development is to minimize the material budget of this detector with a drastic cut on the support and cooling structure. The sensitive detector will be a self-supporting blended, large silicon layer. The minimal material budget cooling system is forced airflow. The high power consumption parts of the detector layer require more effective cooling. In a novel concept, the carbon foam rings of the support structure will be used as heat exchangers. The main contribution of our group is the characterization of this material, which is challenging because of the non-Fourier thermal behavior of the foam. We are further involved in the numerical simulations and test measurements of the prototype detector.

Estimating the elliptic flow using machine learning techniques. — In this work, carried out jointly with the Heavy-Ion workgroup, we explore the prospects of using deep learning techniques to estimate elliptic flow (v_2) in heavy-ion collisions at the RHIC and LHC energies. A novel method is developed to process the input observables from particle kinematic information. Predictions from the proposed deep neural network (DNN) are compared to both simulation and experiment. It seems to preserve the centrality and energy dependence of v2 for LHC and RHIC energies. The DNN model is also quite successful in predicting the pT dependence of v_2, and keeps the robustness and prediction accuracy when subjected to noise [7].

Jet substructure. — We continued working on the analysis on the intrinsic structure of jets recorded by the CMS. Studying a large data sample from 2017, we were able to acquire information on the extreme corners of the phase space. The promising preliminary studies show which model is favored by the recorded data, although a detailed supervision of the results is needed to get to the final conclusion.

Pomeron physics. — We have finished the study of central exclusive production of charged hadron pairs in pp collisions at a center-of-mass energy of 13 TeV, using joint CMS and TOTEM data. The differential cross sections as functions of the polar scattering angle between the outgoing protons and of several squared four-momenta are measured in a wide region of scattered proton transverse momenta. A rich structure of interactions related to double pomeron exchange emerges, and the dynamics of the nonresonant continuum is determined. Based on an extensive model tuning effort, various physical quantities related to pomeron cross sections, pomeron-proton and pomeron-hadron form factors, trajectory slopes and intercepts, as well as coefficients of the supposed diffractive eigenstates of the proton are determined.

Detection of forward neutrons. — Studying forward neutrons at LHC energies can help in the understanding of cosmic rays through the tuning of models. Analyzing data from the Zero Degree Calorimeter of CMS for different collision geometries (p+p, p+Pb, Pb+p), we studied the time-dependent signals of various detector layers. We developed a technique to properly handle overflows using previously determined fits. After this first treatment the few-neutron peaks are clearly visible.

High-precision luminosity measurements. — The Beam Position Monitors (BPMs) placed close to the CMS detector measure the positions of the circulating beams. The exact location is crucial for the calibration of the luminosity during special Van der Meer (VdM) scans. In order to synchronize the measured data between the different BPMs, we need to determine the exact length-scale for each detector. We joined the efforts of the CMS BRIL (Beam Radiation, Instrumentation and Luminosity) team to study the results of the BPMs recorded in 2018. The shape of the incoming bunches in x direction differs from that in the y direction. The task of xy correlation analyses is to measure the non-factorizability of the directions, and to correct for this effect. Besides code refactoring, we started to work on the recent (2022) data.

References

[1] ALICE Collaboration, JHEP 01 (2022) 178

[2] ALICE Collaboration, Eur.Phys.J.C 82 (2022) 4, 335

[3] Gyulai L, Sándor Sz, Vértesi R, Particles 5 (2022) 3, 235

[4] Ortiz A et al. incl. Bencédi Gy, arXiv:2211.06093v1 (2022)

[5] Varga Z, Vértesi R, Symmetry 14 (2022) 1379

[6] Varga Z, Vértesi R, J. Phys. G: Nucl. Part. Phys. 49 (2022) 075005

[7] Mallick N, Prasad S, Mishra A N, Sahoo R, Barnaföldi G G, Phys.Rev.D 105 (2022) 11, 114022

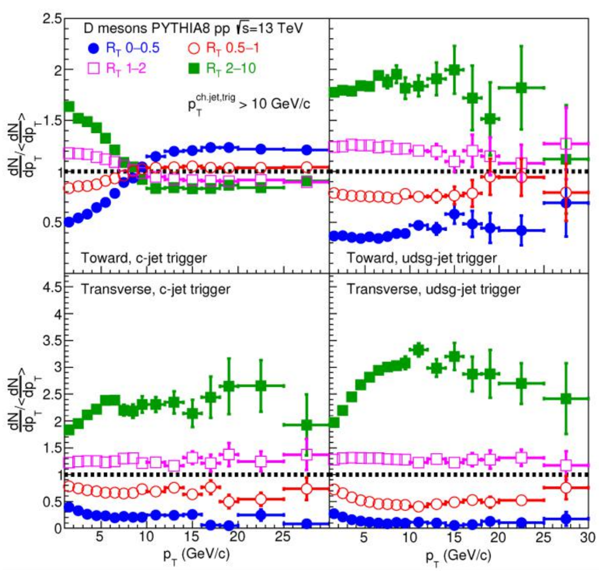

Figure 1. Per-trigger D-meson production ratios with charm-jet triggers as well as light-jet triggers, as a function of pT for different *R*T classes in the toward and transverse regions, over the *R*T-integrated per-trigger yield.

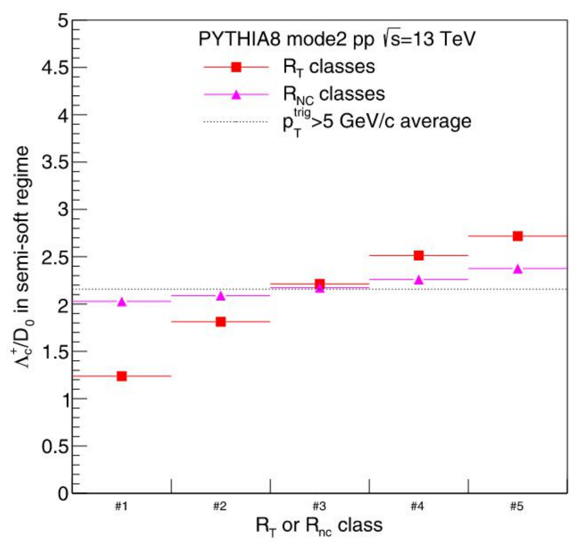

Figure 2. Λ+c to D 0 ratios integrated over the coalescence regime 2 < pT < 6 GeV/c as a function of RT and RNC bins for hadron-triggered data. The dashed line represents the average of triggered events.

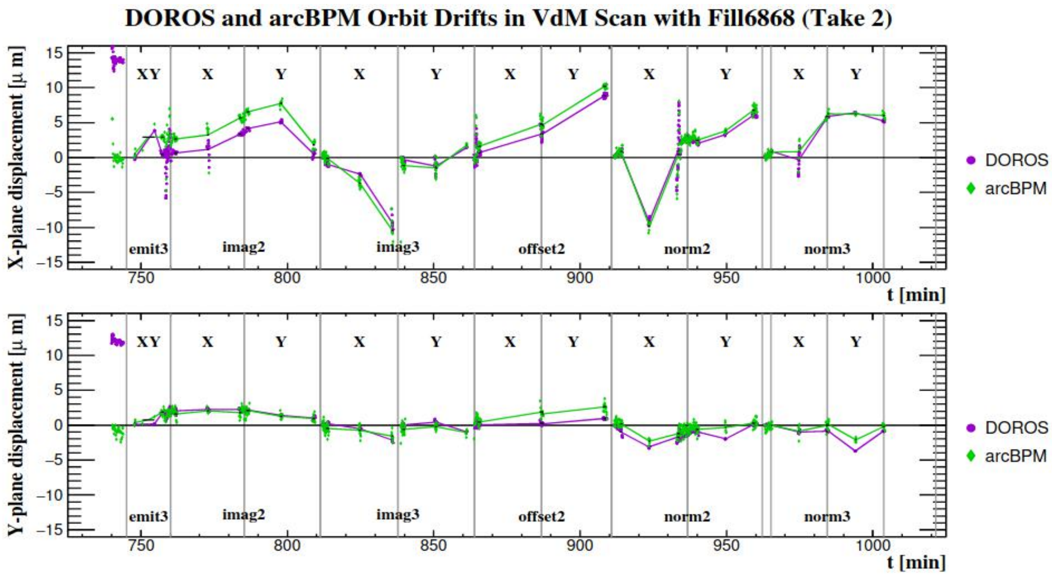

Figure 3. Nominal beam displacements in the transverse plane for head-on collision steps observed by the Beam Position Monitors during a Van der Meer scan program. The precise beam position is essential for the luminosity calibration. The lines correspond to the interpolation between the head-on positions measured before, during and after the individual scans, they are used for estimating the linear orbit drift correction for each scan step.