Hadron Physics Research Group

Wigner Research Group

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Heavy-flavor jets and correlations 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 (Fig. 1), have been accepted for publication [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.

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 submitted for publication [2]. We also evaluated the partonic and hadronic contributions to heavy-flavor correlation patterns in detail [3]. Our group is responsible for the ALICE analysis of D-meson production in function of the transverse event-activity classifier R_T. In a manuscript currently under preparation, we further explore experimental possibilities of similar heavy-flavor measurements with hadron as well as jet triggers [4]. 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.

High-momentum hadron production in the ALICE experiment. — Our group played a leading role in the measurement of light-flavor meson and baryon production in inelastic pp collisions at a center-of-mass energy of $\sqrt{s}$=7 TeV and $\sqrt{s}$=13 TeV at midrapidity as a function of transverse momentum, using the ALICE detector at the CERN LHC [5]. A hardening of the spectra at high p_T with increasing collision energy was observed. These results serve as a benchmark test for perturbative QCD calculations beyond leading order as well as for fragmentation models, besides providing the baseline for potential nuclear modification in larger collision systems.

Particle production as a function of the underlying event. — We investigated the production of charged particles associated with high-p_T trigger particles at midrapidity in proton-proton collisions at $\sqrt{s}$=5.02 TeV in simulations, in function of R_T, which is sensitive to multiple-parton interactions (MPI). We point out a correlation between R_T and the leading p_T, caused by triggered samples being biased toward events with gluon-radiation. We also propose a refined event classifier, $R_{T,min}$, defined in the 'transverse-min' region (Fig. 2) that reduces contributions from initial- and final-state radiations of the main partonic scattering [6].
We implement a machine-learning-based regression technique via boosted decision trees to predict the impact parameter and transverse spherocity in Pb-Pb collisions at the LHC energies. In the absence of experimental measurements, we verify our method using realistic simulations, and we propose to implement this technique to obtain transverse spherocity from the known final state quantities in heavy-ion collisions [7]. Furthermore, we developed a method to quantify the underlying event based on the angular dependence of multiplicity classes and transverse-momentum spectra in high-energy pp collisions at LHC energies [8].

Jet structures in phenomenology and experiment. — We studied the structure of jets in proton-proton collisions at LHC energies using Monte Carlo simulations. We demonstrate that the radial jet profiles exhibit scaling properties with charged- hadron event multiplicity over a broad transverse-momentum range. Based on statistically motivated parametrizations of the jet profiles, we proposed that the scaling behavior stems from fundamental statistical properties of jet fragmentation [9]. We also observed that the charged-hadron multiplicity distributions scale with jet momentum (Fig. 3). This suggests that the Koba–Nielsen–Olesen (KNO) scaling holds within a jet. The in-jet scaling is fulfilled without MPI, but breaks down in case MPI is present without color reconnection. Our findings imply that KNO scaling is violated by parton shower or multiple-parton interactions in higher-energy collisions [10].
The analysis on the intrinsic structure of jets recorded by CMS has also been extended to include high pile-up runs, thus the statistical uncertainties decreased significantly. The first preliminary analysis note has been uploaded to the CERN Document Server.

Probing the semi-soft QCD regime with heavy flavor. — The event-activity differential investigation of particle production reveals the connection between the leading process and the underlying event (UE). It allows for the study of semi-soft vacuum-QCD effects potentially responsible for collectivity in events with higher activity, such as MPI. Flavor-dependent studies of these mechanisms can help separate color-charge and mass effects in jet production and fragmentation. We study UE-observables in inelastic proton-proton (pp) collisions at $\sqrt{s}$=13 TeV with identified light and heavy-flavor triggers using the PYTHIA 8 event generator, in function of the transverse momentum of the leading particle. We find that the underlying-event activity depends on the flavor of the trigger particle. We conclude that the observed effect can be attributed to differences in the interactions of gluon and quark jets with the UE [11].

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 [12]. Recently we extended our studies to charmed baryons with strange content to understand whether strangeness and charm enhancement stem from a common physical reason.

Initial stages and transport properties in high-energy hadron collisions. — We used the Color String Percolation Model (CSPM) to explore the initial stage of high energy nucleus-nucleus and nucleon-nucleon collisions and determine the thermalized initial temperature of the hot nuclear matter at an initial time ∼ 1 fm/c. For the first time, the temperature and the energy density of the hot nuclear matter have been obtained from the measured charged particle spectra using ALICE data for PbPb collisions at 2.76 and 5.02 TeV and pp collisions at 13 TeV. The dimensionless quantity ε/T^4 is evaluated to obtain the number of degrees of freedom (DOF) of the deconfined phase. We observe two features hitherto not reported: the existence of two temperature ranges in the behavior of the PbPb system DOF, and a clear departure from the LQCD results regarding the maximum number of DOF, which reaches values in agreement with the Stephan-Boltzmann limit for an ideal gas of quarks and gluons [13].
We also investigated the jet transport coefficient at LHC energies in the CSPM approach, and we found a good agreement between CSPM results and the JET collaboration calculations [14].
Furthermore, we evaluated the effect of nuclear density profile on the global properties in O+O collisions at the Large Hadron Collider using a multi-phase transport model [15].

Performance analysis of the CMS Zero Degree Calorimeters (ZDC). — We published a paper on the subject [16]. In this paper we present our studies of the CMS ZDC using proton-lead collisions measured in 2016. First, we developed a template fitting method, which can be used to extract accurate values of the ZDC signals in the presence of collisions preceding our main signal. We also improved the Monte Carlo simulation of the ZDC, including the modeling of Cherenkov photons. We have shown that the properties of the measured ZDC signals can be reproduced by this simulation and can be used to match the gains of the ZDC channels. As a result, we measured the energy distribution of neutrons emitted from the collisions at shallow angles; we have found peaks corresponding to single, double and triple neutron events (Fig. 4). Finally, we studied the effect of multiple simultaneous collisions and derived a Fourier deconvolution formula to correct the measured energy distribution in the ZDC. The corrected spectrum can be used to determine the centrality of p-Pb collisions.

Medical applications of high energy detector technologies. — We participate in the Bergen pCT collaboration, formed for the development of a sampling calorimeter to be used for imaging in cancer therapy. Irradiation of cancer tumors using hadron beams results in a more advantageous dose distribution than X-ray irradiation. Most commonly proton beams are used, but there are investigations with heavier hadrons like Helium [17]. The calorimeter is built from alternating tracker and absorber layers, based on the ALPIDE detector. The first detector layers have been produced and are being tested now. In parallel, we are in the development of a data and image reconstruction algorithm based on machine learning techniques [18] and analytical methods [19]. We expect the first real test results in the near future.

Development of detectors for current and future experiments. — We are participating in the development of the cooling system of the third generation of the Inner Tracking System of the ALICE experiment. The new detector will greatly reduce material budget with the use of the new flexible silicon detector technology. The future ALICE 3 experiment that will replace the current detector system will be fully based on semiconducting technology. We contribute to its development with performance studies that will make part of the Letter of Intent.
The CMS DOROS (Diode ORbit and OScillation) detectors, playing a crucial role as part of Beam Position Monitors, are designed to measure the exact position of the proton beams, while the instantaneous luminosity can be estimated by monitoring the occupancy of the CMS Pixel Detector system. We worked on improvements of the signals from both detectors to increase performance for the upcoming Run 3 data taking period.

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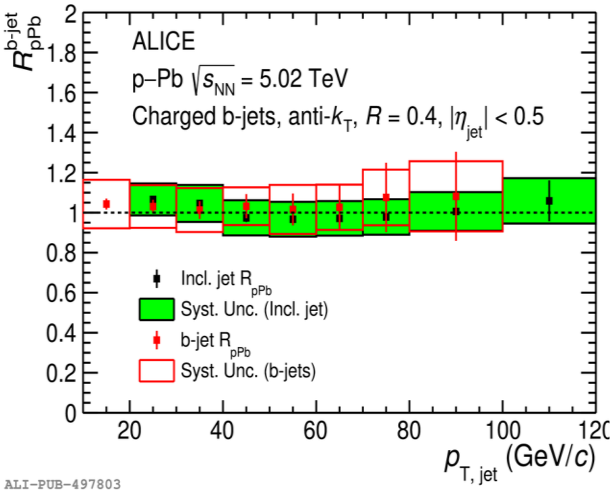

Figure 1. The nuclear modification factor of b-jets compared to inclusive jets.

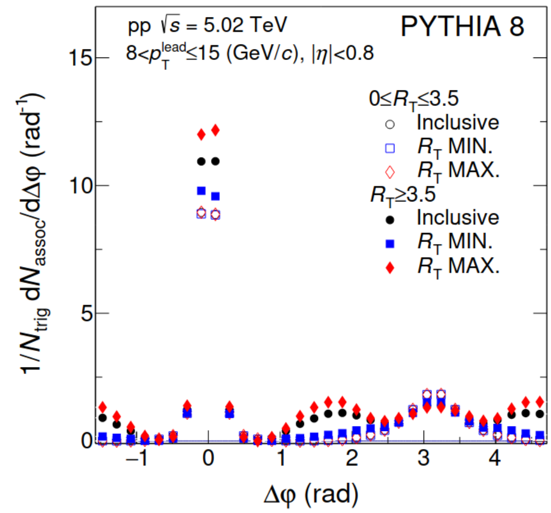

Figure 2. Charged particle yield in function of Δϕ, in the transverse, trans-max and trans-min regions for low and high transverse activity.

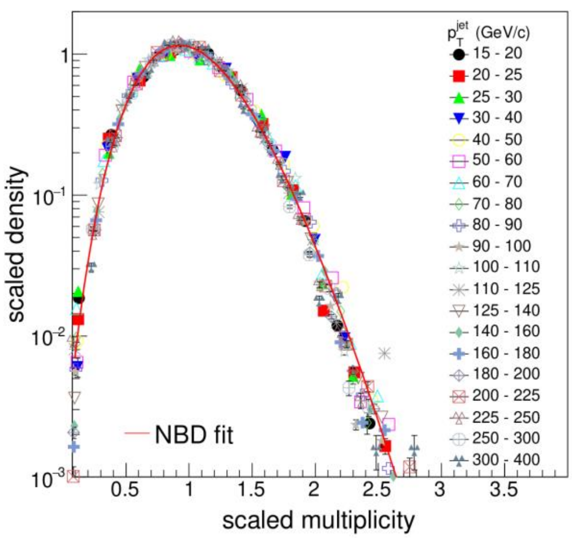

Figure 3. Multiplicity distributions in different p_T^{jet} windows, scaled by their means, with an NBD fit.

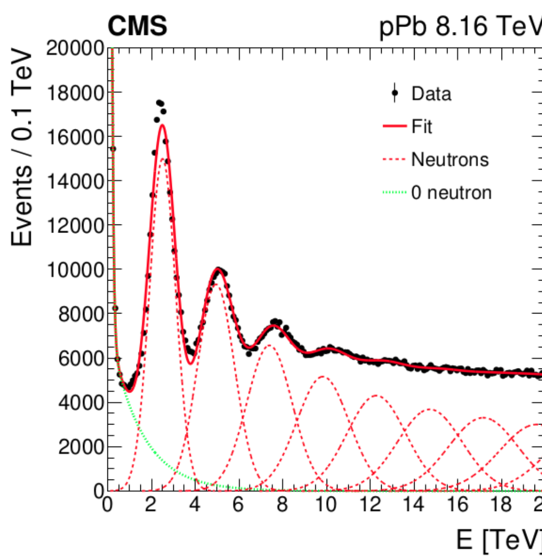

Figure 4. The measured ZDC energy distribution. The three prominent peaks correspond to single, double and triple neutron events.