2025.

Suppression of high-momentum hadrons in collisions of light ions. — We took part in two new and important measurements at the CMS experiment with the goal to shed light on the onset of the quark-gluon plasma, a hot and dense state of nuclear matter, in collisions of ultrarelativistic small nuclei. Highly energetic quarks and gluons, collectively referred to as partons, lose energy as they travel through this matter, leading to suppressed production of particles with large transverse momenta (p_T). Conversely, high-p_T particle suppression has not been seen in proton-lead collisions, raising questions regarding the minimum system size required to observe parton energy loss. Oxygen-oxygen (OO) collisions examine a region of effective system size that lies between these two extreme cases. The CMS detector at the CERN LHC has been used to quantify charged-particle production in inclusive OO collisions at a nucleon-nucleon center-of-mass energy $\sqrt{s_{NN}}$ = 5.36 TeV for the first time via measurements of the nuclear modification factor (R_{AA}). The R_{AA} is derived by comparing particle production to expectations based on proton-proton (pp) data and has a value of unity in the absence of nuclear effects [1,2]. The R_{AA} is below unity with a minimum of 0.69 ± 0.04 around p_T = 6 GeV (Fig. 1-left). The data exhibit better agreement with theoretical models incorporating parton energy loss as compared to baseline models without energy loss.

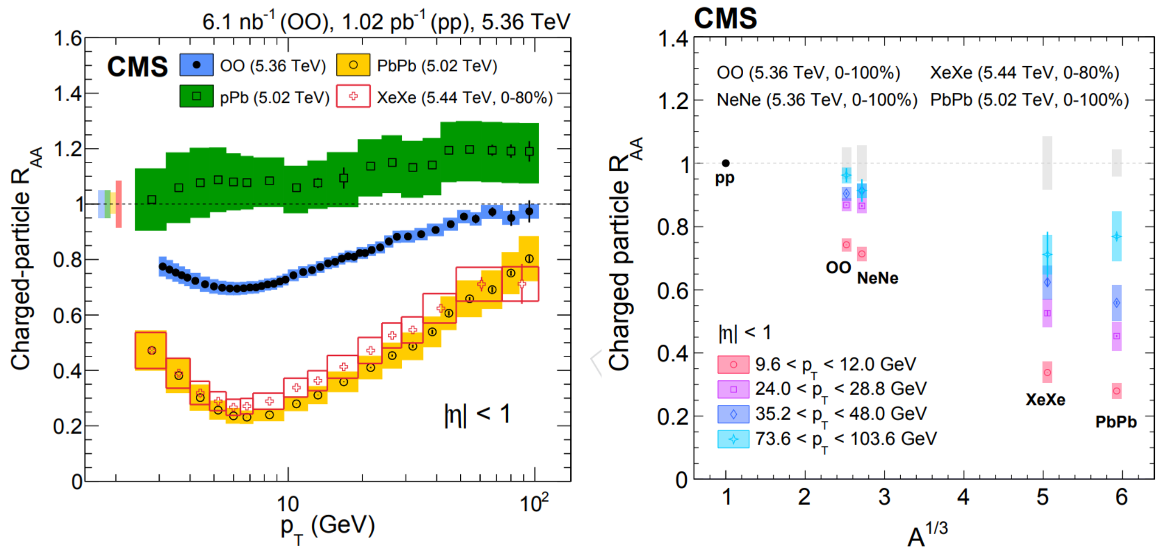

Figure 1. *Left: The charged-particle nuclear suppression for inclusive 5.36 TeV OO collisions, shown together with previous pPb, XeXe, and PbPb results (from Ref. [1]). Right: Charged-particle nuclear suppression, in intervals of p_T, as a function of the nucleon number A of the nucleus-nucleus colliding systems (from Ref. [3]).*

In another analysis, we presented a systematic study of high-p_T charged-particle suppression across different nucleus-nucleus collision systems, using the nuclear modification factor [3]. Previously published CMS R_{AA} measurements in oxygen-oxygen, xenon-xenon, and lead-lead collisions are recast with identical p_T intervals and are complemented by the first measurement of the charged-particle R_{AA} in neon-neon collisions at $\sqrt{s_{NN}}$ = 5.36 TeV. Presented as functions of charged-particle p_T and A (Fig. 1-right), the number of nucleons of a given colliding nucleus, the results span four collision systems and provide new quantitative constraints on the system-size dependence of nuclear suppression.

Thermodynamical string fragmentation and string density effects in jets. — It has been proposed to search for thermal and collective properties arising from parton-fragmentation processes by examining high jet charged-constituent multiplicities ($N_{j,ch}$) in proton-proton collisions. Previous studies did not reveal any conclusive evidence for the presence of radial flow. We expanded upon the proposed Monte Carlo study by eliminating selection biases associated with triggering on charged particle multiplicities. Furthermore, MPI are disabled to focus exclusively on jet fragments. We analyze pp collisions at $\sqrt{s}$=13 TeV simulated with PYTHIA 8, exploring different implementations of the generator: thermodynamical string fragmentation and the standard Lund fragmentation model. The impact of color-string junctions was also explored. Surprisingly, the thermodynamical string fragmentation together with the close-packing of strings mechanism predicts a hint of baryon enhancement in jets (Fig. 2).

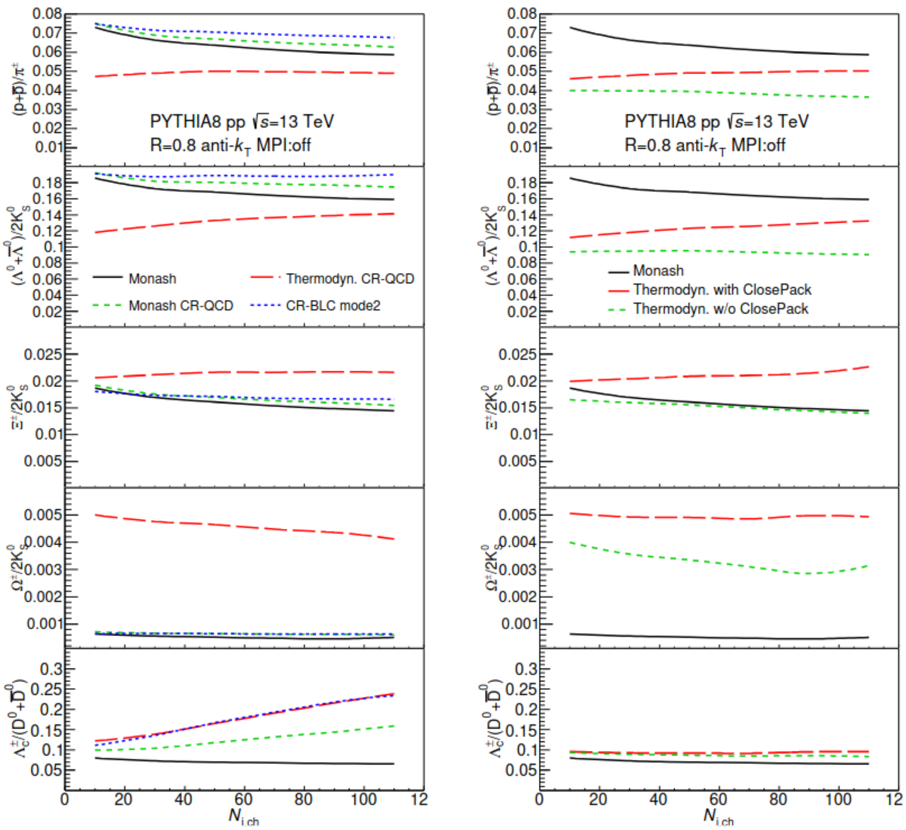

Figure 2. *Baryon-to-meson ratios as a function of the jet charged-constituent multiplicity. Results for pp collisions at √s = 13 TeV simulated with different PYTHIA settings. The different colour-reconnection schemes (left) and the effect of thermodynamical string fragmentation with and without close packing (right) are compared to the Monash tune.*

Additionally, the light-flavor baryon-to-meson ratios as a function of j_T exhibit similarities across all PYTHIA 8 implementations, and hint at radial flow-like effects. In contrast, the ratio of heavy-flavor hadrons (Λ_c^+/D^0) at low j_T as a function of $N_{j,ch}$ shows a trend similar to that observed as a function of charged-particle multiplicity in minimum-bias data, suggesting that color-string junctions may play a crucial role in heavy baryon production in jets. The same mechanism also predicts a j_T-integrated Λ_c^+/D^0 ratio that increases with increasing $N_{j,ch}$. Interestingly, for the lowest $N_{j,ch}$ value, such a ratio is consistent with the e^+e^- limit, suggesting that jet multiplicity is a potential way to explore more dilute systems covering the multiplicity gap between e^+e^- and pp collisions. [4].

Evolution of the hot dense matter at LHC energies with the Tsallis-thermometer — We analyzed the transverse momentum distributions of the identified light- and heavy-flavour hadrons from pp, p-Pb and Pb-Pb collisions in the ALICE experiment, covering the center-of-mass energy range between 2.76 TeV and 13 TeV, within a non-extensive statistical framework. We found that formation of mesons is mass ordered, with heavier particles formed in earlier stages of collisions. Baryons, on the other hand, were found to be formed at later timescales compared to mesons with similar masses. We determined that the spectrum formation proper time of pions is significantly larger compared to all the other hadrons: ~3 times of kaons and ~33 times that of D mesons. We also estimated the heat capacity of the system based on the common non-extensivity parameter and relative fluctuation values, which yielded a system-wide lower boundary C>5. The upper limit corresponding to light mesons implies a largely thermalized system, while heavier hadrons are strongly non-extensive regardless of the system size. [5].

As a continuation of our study we analyze identified hadron spectra in pp collisions at $\sqrt{s}$ = 13 TeV measured by ALICE, classified by multiplicity, flattenicity, and spherocity. These results, expected to be published in 2026, will highlight the ability of the Tsallis-thermometer to capture both multiplicity and event-shape effects, linking soft and hard processes in small systems.

The underlying event and heavy-flavor baryon enhancement. — Recent experiments from the LHC show an enhancement of charmed baryons compared to expectations. This questions the previously assumed universality of heavy-flavor jet fragmentation across different collisional systems. We investigated the production of charmed baryons in proton–proton collisions at LHC energies with flattenicity-dependent production of the D_0 and the Λ_c and concluded that flattenicity reflects underlying-event activity well, with relatively weak correlation to the event multiplicity. Similar conclusions could be drawn in the beauty sector with Λ_b and B^+. We compared several PYTHIA8 tunes to highlight those capable of reproducing measured data. These results have been published [6].

Development of the Muon Identification Detector for ALICE 3. — The MID for the ALICE3 experiment [7] will be essential for detail-rich open as well as hidden heavy-flavor measurements though the muonic decay channel. This way, exotic hadrons as well as the microscopic dynamics of the quark-gluon plasma can be explored. While the bulk of the work has been carried out by the Innovative Detector Development group, we contribute to the efforts mainly with modeling of the detector response using the GEANT 4 software package, with a focus on multiwire proportional chamber (MWPC) technology. We also play a role in the coordination of the detector simulation efforts [8].

Jet fragmentation. — The intrinsic properties of jets produced in high-energy proton–proton collisions provide valuable insight into the fragmentation processes following the hard scattering interaction. We continued the analysis of proton–proton data collected with the CMS detector, nearing completion of the final results.

Detection of forward neutrons and high-precision luminosity measurements at CMS. — Continuing our analyses on the ZDC, we examined the proton-proton reference run taken in 2024 and worked on calibrating the detectors using the following, early heavy ion data set. This included adapting and refining the previously used simulation analysis to the collaboration-wide software environment and cross-checking the detector geometry description. We contributed in the commissioning of the detectors extended with another pair of detectors that used the originally dummy readout channels of the ZDC. We also monitored the behaviour of the ZDC as a trigger and the radiation damage of both sets of detectors throughout the data taking period.

We also continued working on the XY factorization analysis, obtaining the bias for the proton-proton data set recorded in 2024. Besides further refactoring of the existing code and adapting it for the newly introduced data settings, we improved the methodology in the analysis. This included applying an extra correction against the time-evolution of the beam to homogenize the input data, adding new 2D fit models (able to describe square-like shapes) to the base set and choose the best-performing one for each data sample. The final correction values on the visible cross-section with respect to time we provided per bunch-crossing. The corresponding uncertainties also account for an extra systematic uncertainty coming from the wide spread of predictions of well-behaving but not best-performing models describing the given data samples.

Jet substructure measurements in the ALICE experiment. — Jet substructure in heavy-ion collisions is a rapidly evolving area with lots of intriguing new measurements. We continue our involvement in jet-substructure measurements from the ALICE experiment [9].

Heavy-flavor production in the ALICE experiment. — We analyzed prompt D mesons in proton--proton (pp) collisions at $\sqrt{s}$=13 TeV, measured by the ALICE experiment at mid-rapidity. The analysis investigates the relative yields of D^0 mesons as functions of transverse event-activity classifier R_T. The R_T-dependent production of D mesons provides a simple yet effective way to quantify the underlying event. A publication of the measured data is planned as a collaborational paper during 2025. The results improve our knowledge on charm production mechanisms and the role of multi-parton interactions in small collision systems. The results are also compared with PYTHIA 8 simulations with and without color string junctions, providing a reference for further studies.

Multi-parton interactions in pp collisions using charged-particle flattenicity. — We contined the exploration of the origin of small-system collectivity using a novel event classifier, flattenicity, that quantifies the shape of the event using experimental information from both azimuthal and forward/backward pseudorapidity directions [10]. We have been working on the analysis of Run 3 data taken by the ALICE experiment which provides us one order of magnitude larger statistics with respect to previous run periods of the LHC. We have also been analyzing data taken during the summer of 2025 when – for the first time at the LHC – proton-oxygen, oxygen-oxygen, and neon-neon (light-ion) collisions were provided [11]. Preliminary results are expected in 2026.

Pseudorapidity densities with the Muon Forward Tracker in the ALICE experiment — The measurement of multiplicity of primary charged particles created in a high-energy heavy-ion collision is among the basic ones used to characterise the system and its geometry created in the collision. The calculated charged-particle density produced per unit of pseudorapidity dN/dη can be used to constrain particle production mechanisms and the initial energy density of the system. We performed the first measurement of charged-particle pseudorapidity density at forward rapidity with the Muon Forward Tracker (MFT) detector in Pb-Pb collisions $\sqrt{s_{NN}}$ = 5.36 TeV. The MFT is a new Si-tracking detector in Run 3, which covers the forward pseudorapidity region $-3.6 < \eta < -2.5$ [12]. Preliminary results are expected in 2026.

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