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Production of π, K, p in inclusive UPC events in ALICE

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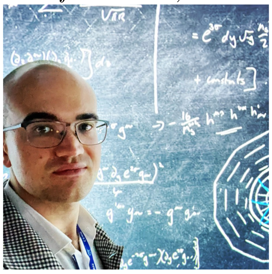

High-multiplicity proton–proton and proton–lead collisions at LHC energies feature signatures similar to those observed in Pb–Pb collisions, such as e.g. strangeness enhancement and collective expansion effects, which are traditionally attributed to the formation of the quark–gluon plasma. One way to study them is through the measurement of p_{T}-spectra for identified hadrons such as charged π, K and p, and the ratios of these spectra. To date, analyses in ultra-peripheral collisions have mostly focused on exclusive photonuclear vector meson production and on two-photon interactions. However, photonuclear interactions, in which the target nucleus breaks up, also occur and provide novel tests of collective phenomena in small systems. The p_{T}-spectra of identified pions, kaons and protons in these events have been measured by the ALICE experiment and compared to those obtained in other collision systems.

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1 Introduction

Ultraperipheral collisions (UPCs) are interactions of heavy ions at impact parameters larger than the sum of their nuclear radii, where the strong interaction is strongly suppressed and the intense electromagnetic fields of the ions act as sources of quasi-real photons [1,2,3]. These photons can interact either with other photons ($\gamma\gamma$ processes) or with the opposite nucleus elastically or inelastically (γA processes), providing a clean environment to study electromagnetic and photonuclear phenomena at high energies.

Most studies of UPCs at the LHC have so far focused on exclusive final states, such as vector meson photoproduction [4,5] or light-by-light scattering [6,7]. In contrast, inclusive UPC events — where the photon interacts with the nucleus leading to particle production with higher multiplicities — are less explored. Such γA interactions provide an opportunity to probe the parton structure of nuclei at low Bjorken-x, and to investigate whether signatures of collective phenomena may arise in small systems [8,9].

In this work, we present the first measurement of identified charged light hadron production (π, K, p) in inclusive UPC Pb–Pb collisions in the rapidity range $|y| < 0.9$ with the ALICE detector at the LHC. Transverse momentum spectra are extracted and particle ratios are studied as a function of p_{T}. These measurements provide a novel reference for constraining particle production mechanisms in photonuclear interactions, serve as a baseline for future studies of collectivity in UPC systems, and furthermore provide the opportunity to tune models for the future Electron-Ion Collider (EIC) [10].

2 Analysis methodology

The analysis is based on Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV collected with the ALICE detector during LHC Run 3. ALICE is a general-purpose heavy-ion experiment at the CERN LHC, designed to study the properties of strongly interacting matter at extreme energy densities [11]. Charged-particle tracking is performed using the Inner Tracking System (ITS), Time Projection Chamber (TPC) and time-of-flight (TOF) detectors, covering $|\eta| < 0.9$, with the particle identification (PID) relying on the specific energy loss ($\mathrm{d}E/\mathrm{d}x$) measured in the TPC and the time-of-flight information from the TOF detector [12].

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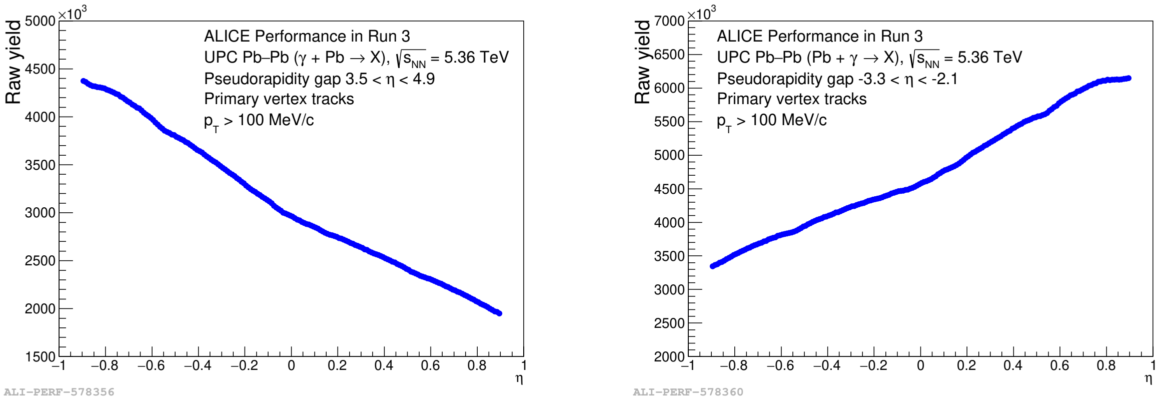
Inclusive photonuclear UPC events are selected through their characteristic single rapidity gap topology. The Forward Interaction Trigger (FIT) detectors, located on both sides of the interaction point, are used to veto hadronic activity on one side of the collision, while requiring activity on the opposite side. The Zero Degree Calorimeters (ZDCs) are simultaneously used to reject hadronic interactions on the photon-emitting side. Depending on which side of the interaction is vetoed, two topologies are defined—corresponding to a gap on the A side or on the C side of the ALICE detector (located opposite to and on the same side as the muon spectrometer, respectively)—which lead to asymmetric charged-particle pseudorapidity distributions. These two distributions are shown in Fig. 1a and 1b, for the gap A and gap C configurations, respectively, highlighting the asymmetric nature of the selected events as a function of pseudorapidity.



(a) Gap on the A side (activity on the C side).

(b) Gap on the C side (activity on the A side).

Figure 1: Charged-particle pseudorapidity distributions in inclusive Pb–Pb UPC events for the two single-gap topologies. The asymmetry reflects the photon direction and validates the event selection.

Particle identification on the tracks selected for analysis is then performed by comparing the specific energy loss measured in the TPC and the time-of-flight measured in the TOF to the expected values for different mass hypotheses. The difference between measured and expected signals is expressed in terms of the number of standard deviations ($N\sigma$). Signal extraction is carried out in the range $|N\sigma_i^j| < 5$, where the indices i and j refer to the particle species (π, K, p) and detector (TPC or TOF), respectively.

The $N\sigma$ distributions are then fitted to extract the yields of the particle species. This approach allows for the signal extraction in the ranges $0.1 < p_{\mathrm{T}} < 1$ GeV/c, $0.2 < p_{\mathrm{T}} < 0.6$ GeV/c, and $0.3 < p_{\mathrm{T}} < 0.9$ GeV/c for pions, kaons, and protons respectively in the TPC, and in the ranges $0.3 < p_{\mathrm{T}} < 1.9$ GeV/c, $0.4 < p_{\mathrm{T}} < 1.8$ GeV/c, and $0.5 < p_{\mathrm{T}} < 2$ GeV/c in the TOF. In the overlap regions, the TPC and TOF spectra are combined using a weighted average based on their statistical uncertainties.

The extracted raw yields are then corrected using detailed Monte Carlo simulations, with samples produced with STARlight [3], interfaced to DPMJET III 19.3.7 to simulate the photonuclear interaction and nuclear breakup [13,14], which is referred to below as STARlight+DPMJET.

3 Results

Transverse momentum spectra of π, K, and p were measured for the rapidity range $|y| < 0.9$ in inclusive photonuclear Pb–Pb UPC events, using combined TPC and TOF identification up to $p_{\mathrm{T}} \approx 2$ GeV/c. The corrected p_{T}-spectra are shown in Fig. 2, together with predictions from the STARlight+DPMJET event generator framework. While the model provides a good description of the pion production over the full measured p_{T} range, it does not agree very well with the kaon and proton yields. The kaon normalisation is reasonable but the kaon shape is not properly reproduced, while the protons are overestimated.

The mean transverse momentum $\langle p_{\mathrm{T}} \rangle$ of each particle species is extracted from the measured spectra. Figure 3 shows $\langle p_{\mathrm{T}} \rangle$ as a function of the particle mass, obtained solely from the UPC spectra. A clear mass ordering is observed, similar to what is typically seen in hadronic collisions.

In addition, the evolution of $\langle p_{\mathrm{T}} \rangle$ with event multiplicity is compared to that observed in other collision systems, as shown in Fig. 4. The $\langle p_{\mathrm{T}} \rangle$ values measured in inclusive photonuclear Pb–Pb UPC

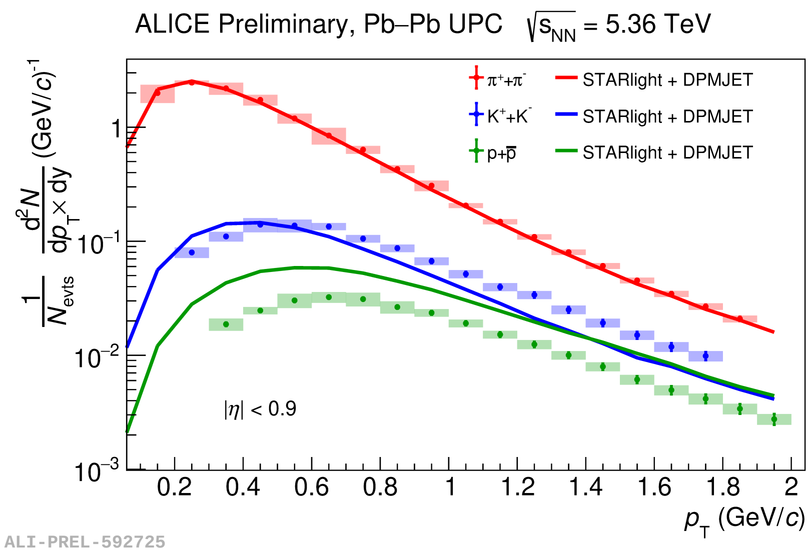


Figure 2: Transverse momentum spectra of π, K, and p in inclusive Pb–Pb UPC events, compared to STARlight+DPMJET predictions.

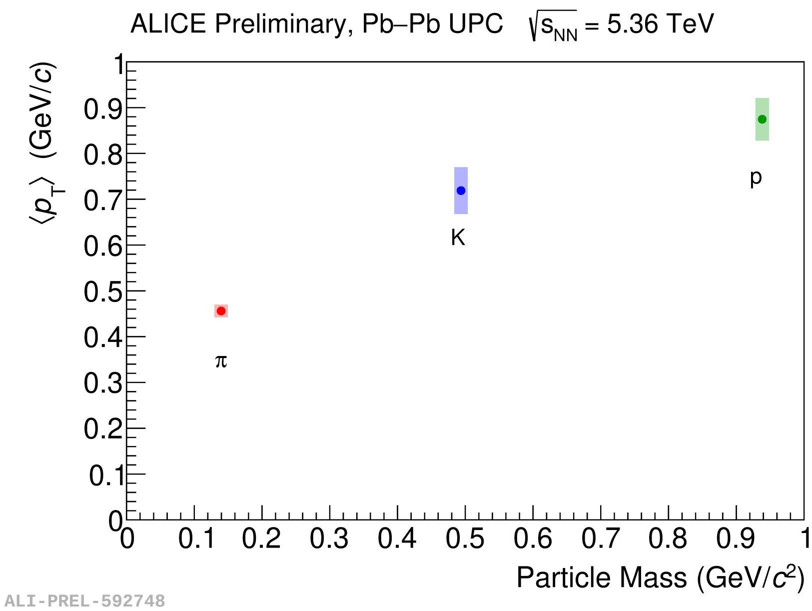


Figure 3: Mean transverse momentum $\langle p_{\mathrm{T}} \rangle$ as a function of the particle mass, extracted from UPC spectra.

events are found to be close to the values measured in pp collisions. This behaviour confirms the expected reduced collective dynamics in photonuclear interactions, which produce lower final-state multiplicities and softer transverse momentum spectra. These measurements extend the system-size evolution observed from Pb–Pb to pp collisions one step further, establishing inclusive UPCs as the smallest collision system accessible at the LHC.

4 Discussion and Conclusions

The production of identified light charged hadrons, i.e. π, K, and p, in inclusive photonuclear Pb–Pb UPC events has been measured in the rapidity range $|y| < 0.9$ with the ALICE detector during LHC Run 3. These results represent the first measurement of identified hadron spectra in this collision system.

The comparison of the measured p_{T}-spectra to STARlight+DPMJET predictions shows good agreement for pions, while kaon and proton yields are significantly underestimated by the model. This indicates

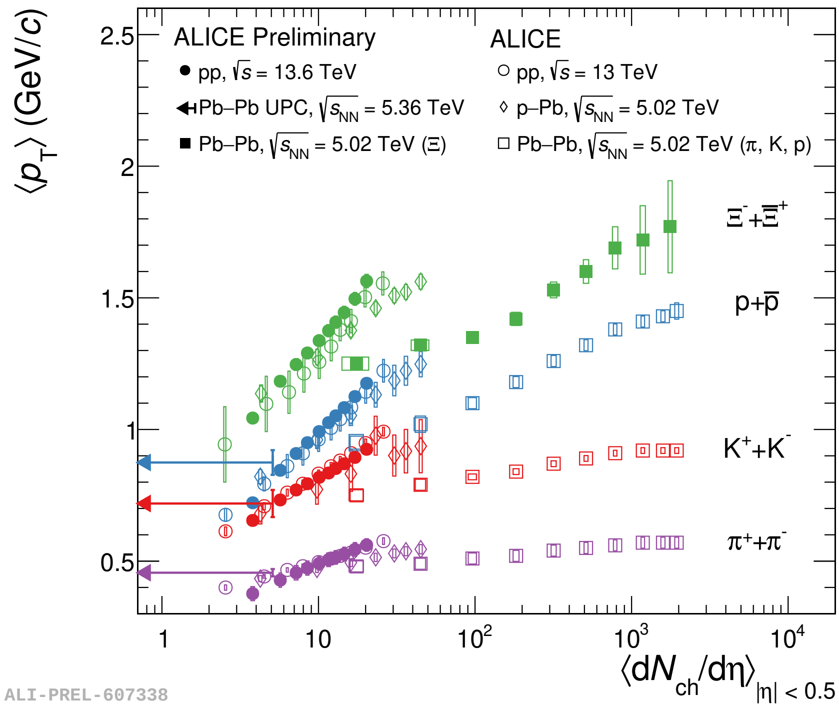


Figure 4: Mean transverse momentum $\langle p_{\mathrm{T}} \rangle$ as a function of event multiplicity in UPC events, compared to other collision systems.

that STARlight+DPMJET does not fully capture the mechanisms governing strangeness and baryon production in photonuclear interactions, and highlights the need for improved modelling in these processes.

When compared to hadronic Pb–Pb collisions, the $\langle p_{\mathrm{T}} \rangle$ values observed in UPCs are lower at similar multiplicities, and closer to those measured in pp collisions. This confirms the expected lower final-state activity of photonuclear events, and provides an essential baseline for future studies of collective effects in small, photon-induced systems.

These measurements offer a new experimental window on the dynamics of particle production in photonuclear interactions, and will serve as an important reference for ongoing efforts to refine the modelling of inclusive UPC events at the LHC, while also tuning the models for future measurements at the EIC.

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