

Transverse momentum spectra and nuclear modification factors of identified charged hadrons in p-Pb and Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE

Maria Vasileiou^{1,a} on behalf of the ALICE Collaboration

¹*National and Kapodistrian University of Athens, Faculty of Physics*

Abstract. The ALICE experiment has measured the production of identified light-flavour hadrons in p-Pb and Pb-Pb collisions at 5.02 TeV in a wide range of transverse momentum. The newest ALICE results on pion, kaon and proton transverse momentum spectra, yield ratios and nuclear modification factors will be presented and discussed in comparison to lower energy results. In particular, the production of identified hadrons in most central Pb-Pb collisions relative to pp collisions is found to be strongly suppressed at high transverse momenta ($p_T > 8$ GeV/c) whereas in p-Pb collisions the nuclear modification factors are consistent with unity. This indicates that the strong suppression of high- p_T hadrons measured in central Pb-Pb collisions is not due to an initial state effect but instead to the energy loss of partons traversing a hot and dense QCD medium.

1 Introduction

The deconfined state of quarks and gluons, the Quark-Gluon Plasma (QGP) predicted by Quantum Chromodynamics (QCD) [1, 2, 3, 4] can be studied in ultra-relativistic heavy-ion collisions. Hydrodynamic and statistical models have been very successful in describing the bulk matter created in heavy-ion collisions. The initial hot and dense matter expands, cools down and undergoes a phase transition from a partonic to a hadronic phase. During the expansion collective flow builds up. Statistical models succeed to describe the observed particle abundances. Hard partons propagating through the hot and dense medium are predicted to lose energy via multiple scattering and gluon radiation. As a result, the yield of final state hadrons at high transverse momentum will be suppressed compared to the reference value from a simple superposition of incoherent proton-proton collisions [5,6]. This observation is typically quantified in terms of the nuclear modification factor, defined as the ratio of the yield in Pb-Pb to the corresponding yield in pp collisions scaled by the number of binary nucleon-nucleon collisions. The ALICE experiment has measured a strong suppression of hadron production at high- p_T in central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, indicating that a dense and hot medium is created at the LHC energies.

2 ALICE detector

The ALICE detector [7] consists of a central barrel with a large solenoid providing a 0.5 T magnetic field for tracking and particle identification, a dimuon spectrometer equipped with a dipole magnet

^a Corresponding author: mvasili@phys.uoa.gr

with a 0.7 Tm field integral, and other forward detectors for triggering and centrality selection. The ALICE central barrel subdetectors have specific unique capabilities for measuring the production of strange and light-flavour hadrons over a wide range of transverse momentum, from pp and p-Pb interactions up to the highest multiplicity environment of the central Pb-Pb collisions. Tracking and vertexing are performed using the Inner Tracking System (ITS), consisting of six layers of silicon detectors, and the Time Projection Chamber (TPC). The two innermost layers of the ITS and the VZERO detector (scintillation hodoscopes placed on either side of the interaction region) are used for triggering. The VZERO also provides the centrality (multiplicity) class definition in Pb-Pb (pp, p-Pb) collisions, while the ITS and the TPC provide particle identification in the low and intermediate p_T region, respectively. The Time Of Flight detector (TOF) and the ring imaging Cherenkov detector (HMPID) are used for particle identification up to 6 GeV/c. Furthermore, the relativistic rise of the energy loss in the TPC gas can be used to extend the PID up to 12 GeV/c in Pb-Pb and up to 20 GeV/c in p-Pb collisions.

3 Results and discussion

3.1 Identified particle spectra and ratios

The transverse momentum spectra of primary charged particles are measured in the full azimuthal acceptance and within $|\eta| < 0.8$. The p_T spectra of identified pions, kaons and (anti)protons in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are shown for different centrality classes in Fig. 1. A hardening of the spectra is observed going from peripheral to central events. The effect is mass dependent, being more pronounced for heavier particles, and is characteristic of a radial flow. Similar hints of collectivity have been also observed in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV [8].

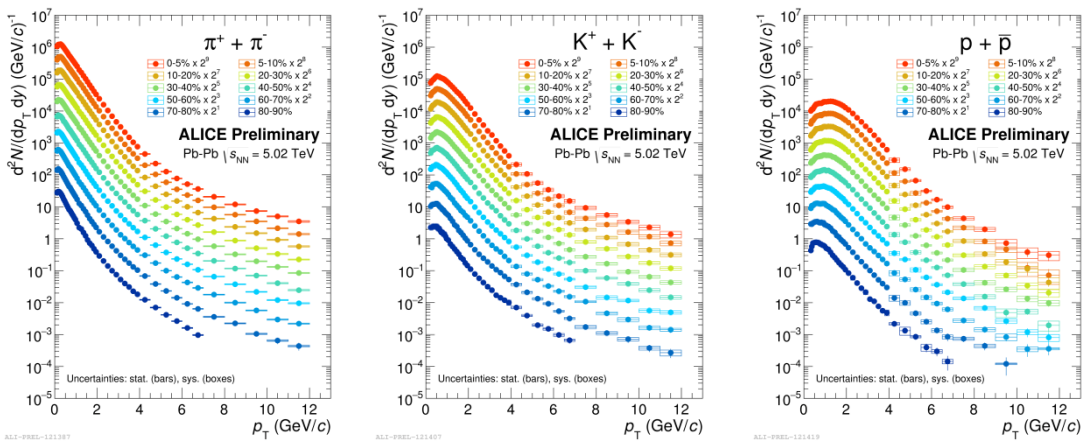


Figure 1. (Color online) Transverse momentum spectra of identified charged pions (left panel), kaons (center panel) and (anti)protons (right panel) for different centrality classes, as measured in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Statistical and systematic uncertainties are plotted as vertical error bars and boxes, respectively.

The p_T -differential proton-to-pion ratio is shown in Fig. 2 for different multiplicity/centrality classes in pp collisions at $\sqrt{s} = 7$ TeV and p-Pb, Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Across the three systems the ratios evolve with multiplicity in a quantitatively similar way. A depletion of the ratios at low p_T and an enhancement at intermediate p_T is observed. The proton-to-pion ratio as a function of p_T

for different centrality classes in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV has been also compared with measurements at $\sqrt{s_{NN}} = 2.76$ TeV [9].

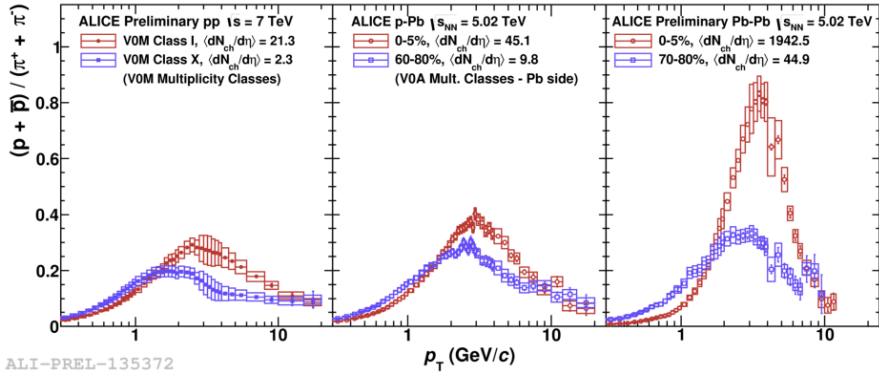


Figure 2. (Color online) p_T -differential proton-to-pion ratio for different multiplicity/centrality classes in pp collisions at $\sqrt{s} = 7$ TeV and p-Pb, Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

In order to quantify the freeze-out parameters a combined fit of the spectra with a Boltzmann-Gibbs blast-wave model [10] was performed, in the ranges 0.5-1 GeV/c, 0.2-1.5 GeV/c, 0.3-3 GeV/c for pions, kaons and protons, respectively. Figure 3 presents the results of blast-wave fits for pp collisions at $\sqrt{s} = 7$ TeV, p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV. In Pb-Pb collisions at 5.02 TeV the blast-wave parameters follow trends observed at lower energy, i.e. the value of the average transverse radial flow velocity increases with centrality, while the kinetic freeze-out temperature decreases.

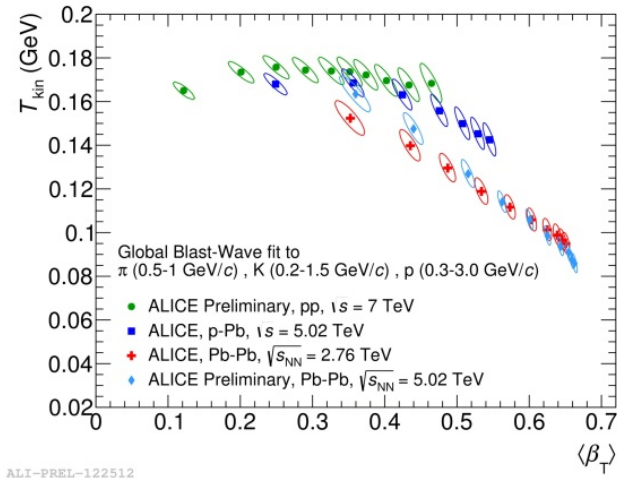


Figure 3. (Color online) Results of blast-wave fits for pp, p-Pb and Pb-Pb collisions. Charged particle multiplicity/centrality increases from left to right. Uncertainties from the global fit are shown as ellipses.

In pp and p-Pb collisions there is a similar evolution of the parameters towards high multiplicity. The largest radial flow velocity is observed in central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and is measured to be higher than at 2.76 TeV. In Figs. 4a and 4b the p_T -integrated yield ratios of kaons and

protons relative to pions, respectively, are shown as a function of the density of charged particles at midrapidity for pp ($\sqrt{s} = 7$ TeV) [11], p-Pb ($\sqrt{s_{NN}} = 5.02$ TeV) [8] and Pb-Pb ($\sqrt{s_{NN}} = 2.76$ [12] and 5.02 TeV) collisions. A continuous evolution of the ratios is observed. The comparison of the new data from Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the measurements at lower energy shows no significant energy dependence within uncertainties.

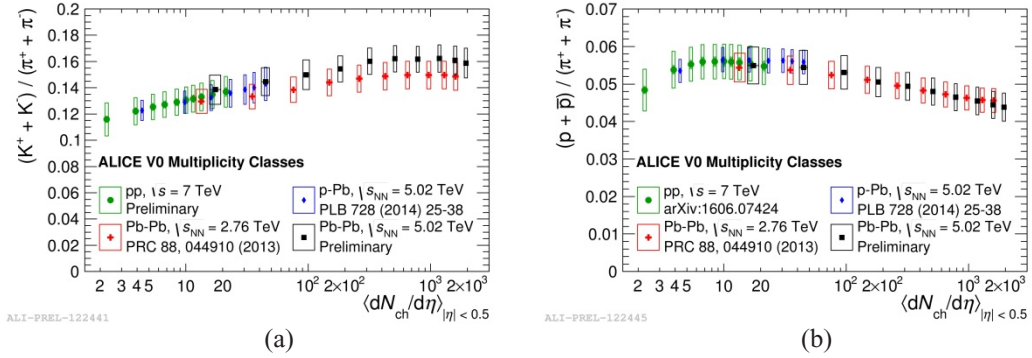


Figure 4. (Color online) p_T -integrated yields of kaons (a) and protons (b) scaled to the ones of pions as a function of the charged particle density for pp ($\sqrt{s} = 7$ TeV), p-Pb ($\sqrt{s_{NN}} = 5.02$ TeV) and Pb-Pb ($\sqrt{s_{NN}} = 2.76$ and 5.02 TeV) collisions.

3.2 Nuclear modification factors

The nuclear modification factors in Pb-Pb (R_{AA}) and p-Pb (R_{pPb}) collisions are given by:

$$R_{AA} = \frac{d^2 N_{AA}/dndp_T}{\langle N_{coll} \rangle d^2 N_{pp}/dndp_T}, \quad R_{pPb} = \frac{d^2 N_{pPb}/dndp_T}{\langle N_{coll} \rangle d^2 N_{pp}/dndp_T}, \quad (1)$$

where N_{AA} (N_{pPb}) and N_{pp} represent the charged particle yield in Pb-Pb (p-Pb) and pp collisions, respectively, and $\langle N_{coll} \rangle$ is the average number of binary nucleon-nucleon collisions.

The nuclear modification factor in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV as a function of p_T is shown in Fig.5 for six centralities and compared with measurements at $\sqrt{s_{NN}} = 2.76$ TeV [13]. We observe a similar behavior of the R_{AA} within systematic uncertainties. In central collisions (0-5%) a strong suppression is observed, with a minimum at $p_T \sim 7$ GeV/c and a significant rise for $p_T > 7$ GeV/c. For peripheral collisions (60-80%) R_{AA} exhibits a moderate suppression ($\sim 0.6-0.7$). No significant evolution of the R_{AA} with the collision energy is found. The nuclear modification factor in 0-5% central Pb-Pb collisions is compared in Fig 6 (left) to the predictions from Djordjevic et al. [14] and Majumber et al., [15]. Figure 6 (right) shows R_{AA} for 0-10% central Pb-Pb collisions and a prediction from Vitev et al. [16]. The measurement is in good agreement with all three model predictions within their uncertainties. Figure 7 presents the identified hadron R_{pPb} compared to that for inclusive charged particles in non-single diffractive (NSD) p-Pb events at $\sqrt{s_{NN}} = 5.02$ TeV [8]. The nuclear modification factors at high- p_T are consistent with unity within uncertainties, suggesting that final state effects do not play a role. In the transverse momentum range from 3 to 6 GeV/c, the R_{pPb} for (anti)protons is above unity. This mass dependence of the nuclear modification factor is consistent with radial flow. A similar pattern has been observed at RHIC [17]. In Fig. 8 the nuclear modification factors in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV are shown for pions, kaons and (anti)protons as a function of p_T for different centrality classes. Results indicate that all particle species are equally suppressed for all centralities at p_T above 8 GeV/c. So, a light-flavour independent energy loss at high- p_T is measured, as observed also at 2.76 TeV [18].

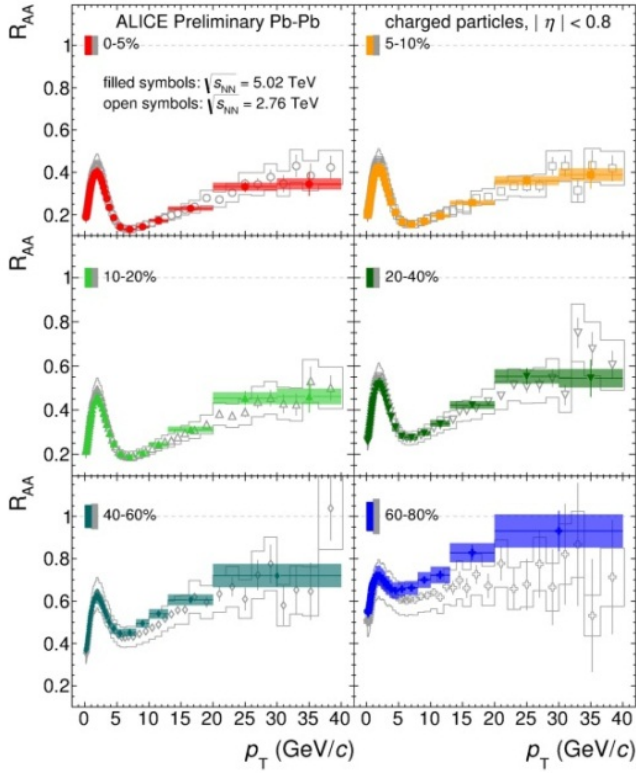
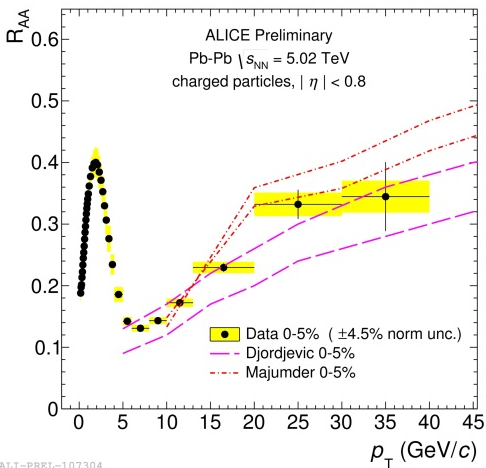
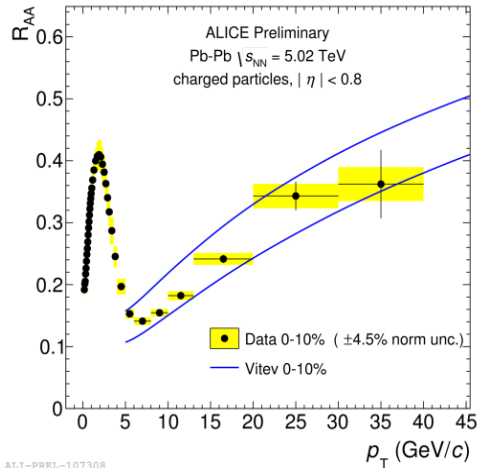


Figure 5. (Color online) The nuclear modification factor (R_{AA}) as a function of p_T for six centralities. Filled symbols represent the measurement at $\sqrt{s_{NN}} = 5.02$ TeV and empty symbols correspond to the measurement at $\sqrt{s_{NN}} = 2.76$ TeV. The normalization uncertainty is shown as a box around unity for both energies.



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Figure 6. (Color online) The nuclear modification factor R_{AA} measured at $\sqrt{s_{NN}} = 5.02$ TeV for 0-5% (left) and 0-10% (right) compared with model calculations.

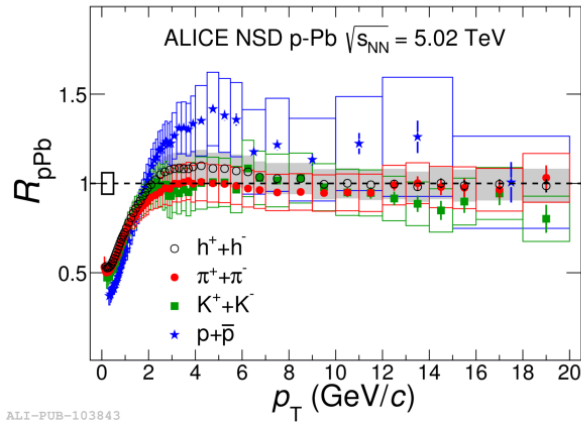


Figure 7. (Color online) The nuclear modification factor R_{pPb} as a function of p_T for different particle species. The statistical and systematic uncertainties are shown as vertical error bars and boxes, respectively. The total normalization uncertainty is indicated by a vertical scale of the empty box at $p_T = 0$ GeV/c and $R_{pPb} = 1$. The result for inclusive charged hadrons is also shown.

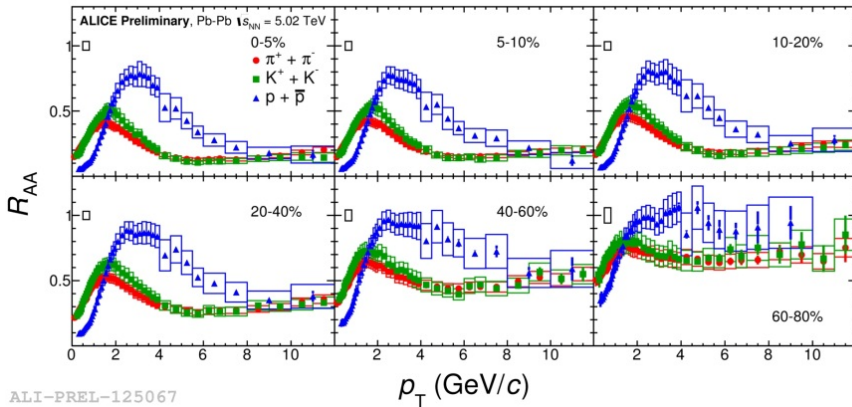


Figure 8. (Color online) Nuclear modification factors (R_{AA}) measured in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV for identified pions, kaons and protons as a function of p_T for different centrality classes.

4 Conclusions

Measurements of charged particle transverse momentum spectra, yield ratios and nuclear modification factors in p-Pb and Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV by the ALICE collaboration are presented. A slightly higher expansion velocity is measured in central Pb-Pb collisions at 5.02 TeV than at 2.76 TeV. Thus, a stronger radial flow is observed at the higher energy. In Pb-Pb collisions proton-to-pion and kaon-to-pion relative abundances exhibit no significant energy dependence. A strong suppression of high- p_T particles is measured in central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. No suppression is observed for high- p_T particles in minimum bias p-Pb collisions. This indicates that the measured

suppression of high- p_T hadrons in central Pb-Pb collisions is due to parton energy loss in the hot and dense QCD medium. The nuclear modification factor R_{AA} shows no significant evolution with the collision energy.

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