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Energy and system dependence of nuclear modification factors of inclusive charged particles and identified light hadrons measured in p–Pb, Xe–Xe and Pb–Pb collisions with ALICE

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Abstract

We report recent ALICE results on primary charged particle and neutral meson production in pp, p–Pb, Pb–Pb and Xe–Xe collisions at LHC energies. In this article, measurements of the nuclear modification factors R_{AA} of primary charged particles and of light neutral mesons in Pb–Pb, in Xe–Xe and in p–Pb collisions in a wide p_T range and different centrality classes are discussed. We compare the nuclear modification factors obtained for different collision systems as a function of transverse momentum, collision centrality as well as charged particle multiplicity ($dN_{ch}/d\eta$). We also present comparison of experimental results to model calculations.

Keywords: Nuclear modification factor, inclusive charged particles, neutral mesons

1. Introduction

Partons originating from initial hard scatterings lose their energy in the hot and dense QCD matter produced in ultra-relativistic heavy-ion collisions, which result in suppression of high p_T hadrons reported by several experiments [1, 2, 3, 4, 5], known as "jet quenching". Light flavor hadrons are powerful probes to measure the suppression, because they can be measured in a wide transverse momentum (p_T) range with high precision. The modification of particle production at high p_T is quantified by the nuclear modification factor R_{AA}, which is the ratio of particle yields in AA collisions to that in pp collisions at the same center-of-mass energy scaled by the number of binary nucleon-nucleon collisions $\langle N_{coll} \rangle$,

$$R_{AA} = \frac{dN^{AA}/dp_T}{\langle N_{coll} \rangle \times dN^{pp}/dp_T} = \frac{dN^{AA}/dp_T}{\langle T_{AA} \rangle \times d\sigma^{pp}/dp_T} \tag{1}$$

where N^{AA} and N^{pp} are particle yields in AA and pp collisions and σ^{pp} is production cross section in pp collisions respectively. The nuclear overlap function $\langle T_{AA} \rangle = \langle N_{coll} \rangle / \sigma^{pp}_{INEL}$ is determined from the Glauber model of the nuclear collision geometry and σ^{pp}_{INEL} is the total inelastic nucleon-nucleon cross section [6].

2. Nuclear modification factors in p–Pb and Pb–Pb collisions
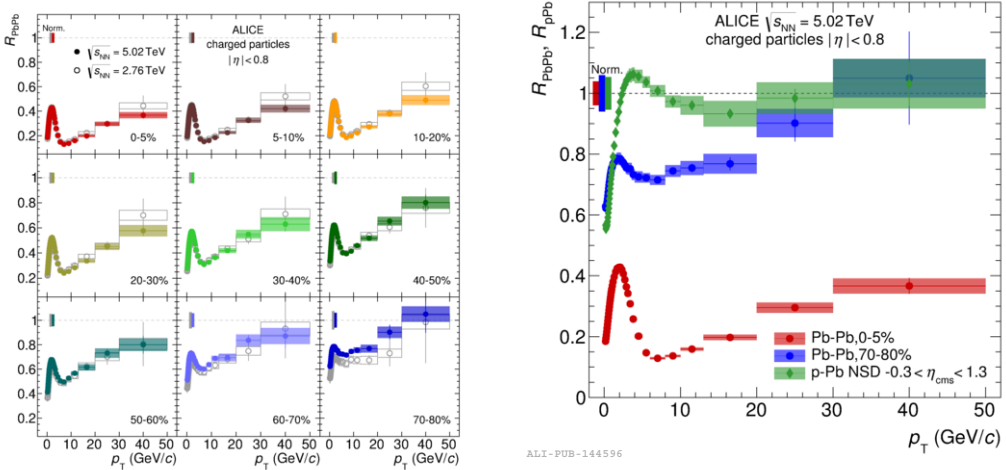

Fig. 1. Left : The transverse momentum dependence of the nuclear modification factor measured in Pb–Pb collisions for nine centrality classes. The new data at $\sqrt{s_{NN}}$ = 5.02 TeV are compared to the re-analyzed data at $\sqrt{s_{NN}}$ = 2.76 TeV [7]. Right : Nuclear modification factors of primary charged particles measured by ALICE in central (0-5%) and peripheral (70-80%) Pb–Pb collisions and in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [7].

Charged particles are measured by the Inner Tracking system (ITS) and the Time Projection Chamber (TPC) in the central barrel of the ALICE apparatus [8, 9]. Concerning identified particles, this article covers the production of neutral mesons while results for other identified particles are presented in [10]. Neutral mesons are measured by two types of electro-magnetic calorimeters, which are EMCal and Photon Spectrometer (PHOS) as well as via photon conversions ($\gamma \rightarrow$ ee) in detector materials at the mid-rapidity. The fully corrected p_T spectra of primary charged particles in the kinematic range of $0.15 < p_T < 50$ GeV/c and $|\eta| < 0.8$ have been measured in pp and Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV, and in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE [7]. A significant improvement of systematic uncertainties related to the tracking efficiency motivated the reanalysis of data in pp and Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV and p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. Fig. 1 (left) shows nuclear modification factors of primary charged particles as a function of p_T in nine centrality classes. Nuclear modification factors have a strong centrality dependence and are similar at the two collision energies. As p_T spectra become harder at higher collision energy, this similarity in R_{AA} indicates larger parton energy loss in a hotter and denser QCD medium produced at the higher collision energy. Fig. 1 (right) shows R_{pA} compared to R_{AA} in 0-5% and 70-80% centrality classes for Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. R_{pA} is consistent with unity at high p_T, which demonstrates that the strong suppression observed in central Pb–Pb collisions is related to the formation of a hot and dense QCD medium. In addition, R_{AA} of π^0 have been measured in $0.4 < p_T < 30$ GeV/c in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV, as shown by Fig. 2 (left). One of its advantages compared to inclusive charged particles is well defined fragmentation function for an identified hadron. Thus, understanding the production of identified hadrons in pp collisions is also important baseline in this study. The maximum p_T reach is extended to 30 GeV/c, compared to previous results at $\sqrt{s_{NN}}$ = 2.76 TeV [11, 12]. R_{AA} of π^0 at two collision energies is also similar, as well as that of primary charged particles. Furthermore, the behavior of R_{pPb} at high p_T is the same as that of primary charged particles (Fig. 2 (right)). We also present a comparison of the measured R_{AA} of π^0 with theoretical models in Fig. 2 (left). The model calculations by Djordjevic et al. [13, 14] and Vitev et al. [15, 16] give a quantitatively good description of p_T and centrality dependence of R_{AA}.
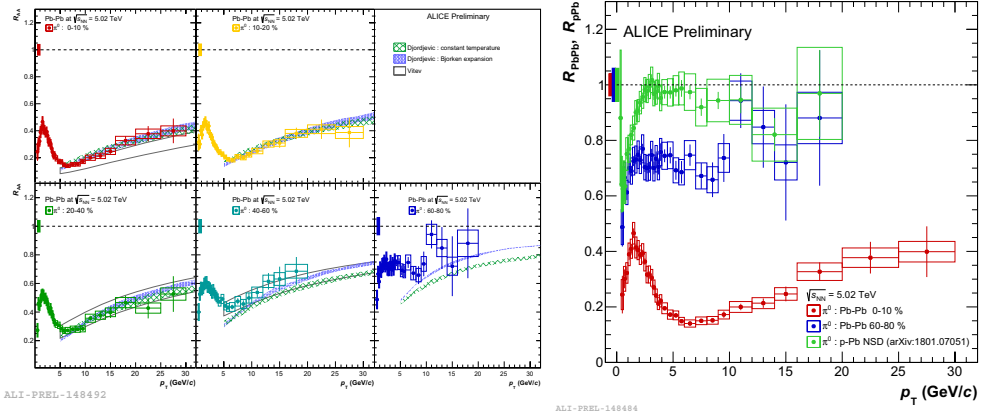
Fig. 2. Left : Nuclear modification factors of π^0 as a function of p_T in different centrality classes compared to theoretical models [13, 14, 15, 16] in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. Right : Nuclear modification factors of π^0 in central (0-10%) and peripheral (60-80%) Pb–Pb collisions and in minimum-bias p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [17].

3. Nuclear modification factors in Xe–Xe collisions

The fully corrected p_T spectra of primary charged particles have been measured in Xe–Xe collisions at $\sqrt{s_{NN}}$ = 5.44 TeV [18] in the same kinematic range as in Pb–Pb collisions. The pp reference is interpolated from p_T spectra in pp collisions at $\sqrt{s}$ = 5.02 and 7 TeV by using a power-law parameterization in order to determine nuclear modification factors. The nuclear modification factor exhibits a strong centrality dependence with a minimum at p_T = 6-7 GeV/c and an almost linear rise in the higher p_T region. In particular, the yield in the most central collisions (0-5%) is suppressed by a factor of about 6 at minimum with respect to the scaled pp reference. R_{AA} reaches a value of 0.6 at the highest p_T interval of 30-50 GeV/c. A similar characteristic p_T dependence of R_{AA} is observed in both Xe–Xe and Pb–Pb collisions. Fig. 3 (left) shows the comparison of R_{AA} between Xe–Xe and Pb–Pb collisions for the same charged particle multiplicity $\langle dN_{ch}/d\eta \rangle$ ranges and their ratios. In the most central Xe–Xe collisions (0-5%), the nuclear modification is consistent with that in 10-20% central Pb–Pb collisions over the entire p_T range. While a similar R_{AA} is found for comparable charged particles multiplicity $\langle dN_{ch}/d\eta \rangle$, the respective mean number of participants $\langle N_{part} \rangle$ are significantly different. $\langle N_{part} \rangle$ is 236 ± 2 in the 0-5% centrality class in Xe–Xe, but 263 ± 4 in the 10-20% centrality class in Pb–Pb collisions [19, 20]. In the 30-40% Xe–Xe (40-50% Pb–Pb) centrality class, agreement of R_{AA} is also found within uncertainties at similar $\langle N_{part} \rangle$ of 82 ± 4 (86 ± 2). A detailed comparison of nuclear modification factors as a function of $\langle dN_{ch}/d\eta \rangle$ in Xe–Xe and Pb–Pb collisions for three selected p_T regions is shown in Fig. 3 (right). A remarkable similarity in R_{AA} between Xe–Xe and Pb-Pb collisions is observed for $\langle dN_{ch}/d\eta \rangle$ > 400. In a simplified radiative energy loss model, the average energy loss is proportional to the energy density and to the square of path length L in the medium $\langle \Delta E \rangle \propto \varepsilon \cdot L^2$ [21]. Therefore, the comparison of the measured R_{AA} in two different collision systems can provide insight into path length dependence of medium-induced parton energy loss.

4. Summary

In summary, nuclear modification factors of primary charged particles and π^0 mesons have been measured in a wide p_T range at mid-rapidity in various centrality classes and different collision systems and energies. R_{AA} shows similar value at two collision energies, indicating the presence of a hotter and dense QCD matter at higher collision energy. R_{pA} which is consistent with unity at high p_T demonstrates that the strong suppression observed in central Pb–Pb collisions is related to formation of hot and dense QCD medium. The measured R_{AA} is compared to theoretical models. The model calculations by Djordjevic et
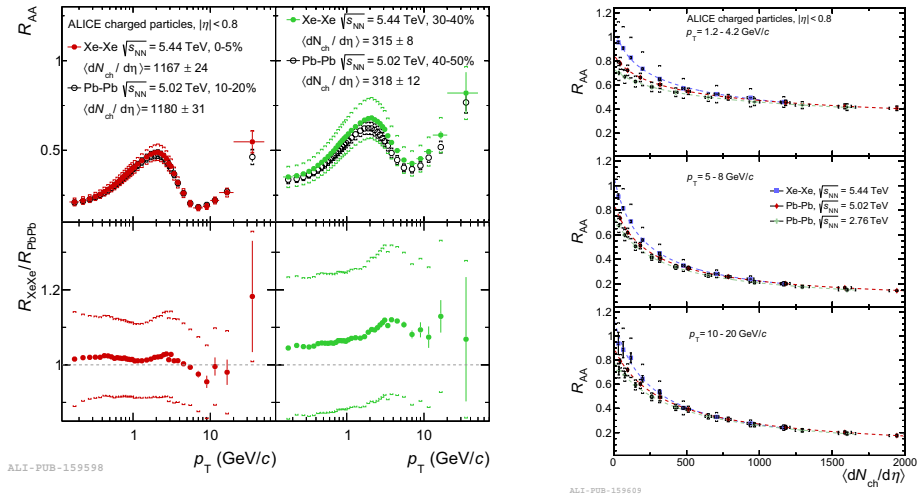
Fig. 3. Left : The nuclear modification factors in Xe–Xe collisions and Pb–Pb collisions for similar values in $\langle dN_{ch}/d\eta \rangle$ for the 0-5% and 30-40% Xe–Xe centrality classes [18]. Right : Comparison of the nuclear modification factor in Xe–Xe and Pb–Pb collisions integrated over identical regions in p_T as a function of $\langle dN_{ch}/d\eta \rangle$ [18].

al. [13, 14] and Vitev et al. [15, 16] give a quantitatively good description of the data. A similar R_{AA} is observed in Xe–Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV in centrality classes corresponding to similar charged particle multiplicities. This comparison of R_{AA} in two collision systems can provide insight into the path length dependence of medium-induced parton energy loss.

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