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Transverse momentum distributions of charged particles in pp and nuclear collisions with ALICE at the LHC

Edgar Perez Lezama[*†]
GSI Helmholtzzentrum für Schwerionenforschung
Johann Wolfgang Goethe Universität
E-mail: eperezle@cern.ch

The charged-particle transverse momentum spectrum in pp collisions is an important observable for testing perturbative QCD calculations and serves as a reference for heavy-ion collisions to study the properties of deconfined matter created in nucleus-nucleus (AA) collisions. The study of inclusive charged particle spectra gives information on parton energy loss in the medium created in AA collisions, leading to a suppression of hadron production at high transverse momentum (p_{T}). This effect can be investigated by calculating the nuclear modification factor, defined as the ratio between the p_{T} spectrum measured in nucleus-nucleus collisions and a reference spectrum in pp collisions scaled by the number of binary collisions. ALICE has measured pp collisions over a large energy range $\sqrt{s}$ =13, 7, 5.02 and 2.76 TeV, p-Pb at $\sqrt{s_{\mathrm{NN}}}$ =5.02 TeV, Xe-Xe at $\sqrt{s_{\mathrm{NN}}}$ =5.44 TeV and Pb-Pb $\sqrt{s_{\mathrm{NN}}}$ =5.02 TeV and 2.76 TeV. We show the p_{T} spectra in pp and nuclear collisions as well as the nuclear modification factors with an exceptional precision as compared to previous results.

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[*]Speaker.
[†]for the ALICE Collaboration

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1. Introduction

The charged particle production has been measured in different collisions systems and in several experiments. The measurements of the transverse momentum spectra in pp and AuAu collisions at $\sqrt{s_{\rm NN}} = 130$ GeV, at RHIC experiments [1, 2], have shown that the high-$p_{\rm T}$ particle production in heavy-ion collisions is suppressed compared to the production measured in pp. Bjorken proposed that suppression of jets or high-$p_{\rm T}$ particles is associated to parton energy loss in the hot and dense QCD medium created in the collision of heavy-ions [3], which leads to a modification of transverse momentum distributions of the particles in the final state. The ALICE experiment has observed a stronger suppression of hadron production at high-$p_{\rm T}$ in central Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV[4] with respect to RICH at lower energies. This proves that a denser and hotter medium is created with respect to the medium created at RHIC energies. This observation is typically quantified in terms of the nuclear modification factor, defined as:

$$R_{\rm AA} = \frac{1}{\langle T_{\rm AA}\rangle} \frac{{\rm d}N_{\rm AA}/{\rm d}p_{\rm T}}{{\rm d}\sigma_{pp}/{\rm d}p_{\rm T}} \tag{1.1}$$

where ${\rm d}N_{\rm AA}/{\rm d}p_T$ and σ_{pp} represent the yield in nucleus-nucleus collisions and the cross section in pp collisions, respectively. $\langle {\rm T_{AA}} \rangle$ is the nuclear overlap function, expressed as the ratio of the number of binary nucleon-nucleon collisions $\langle {\rm N_{coll}} \rangle$ obtained from a Glauber model and the inelastic nucleon-nucleon cross section $\sigma^{\rm NN}_{inel}$. If the Pb–Pb collisions are a simple superposition of elementary pp collisions the $R_{\rm AA}$ is expected to be equal to unity, while $R_{\rm AA} < 1$ indicates a suppression of charged-particle production compared to binary-collision scaling.

2. Analysis

The results reported here are based on the analysis of 1.1×10^6 Xe–Xe collisions at $\sqrt{s_{\rm NN}} =$ 5.44 TeV and 20×10^6 Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV recorded with the ALICE detector during late 2017 and 2015, respectively. The primary charged particles are reconstructed using the ITS (Inner Tracking System) and the TPC (Time Projection Chamber). In Pb–Pb collisions the sum of amplitudes measured in V0A and V0C detectors is used to estimate the collision centrality [5]. Since ALICE did not record pp collisions at $\sqrt{s} = 5.44$ TeV, the pp reference was obtained using the power law interpolation method between the measurements at $\sqrt{s} = 5.02$ TeV and 7 TeV. The scaling of the cross section at a fixed $p_{\rm T}$ is approximated to a power law in the collision energy, i.e. ${\rm d}\sigma/{\rm d}p_{\rm T}(\sqrt{s}) \propto \sqrt{s}^n$.

The corrections applied to the data are calculated using the combined information of MC simulations based on PYTHIA8 or HIJING generators, and data. To account for the differences in the particle composition between event generators and data, the charged-particle reconstruction efficiency ($\sim 70\%$) was calculated from the particle-dependent efficiencies weighted by the relative abundances of each particle measured in pp at 7 TeV and Pb–Pb collisions at 2.76 TeV. The correction for contamination by secondary particles, produced from weak decays or secondary interactions, is estimated using the transverse impact parameter distributions ($\rm DCA_{\it xy}$) of particles in data and MC. This correction is important only at low $p_{\rm T}$ ($\sim 8\%$), while the correction for $p_{\rm T}$-resolution is relevant only at high-$p_{\rm T}$.

3. Results

The transverse momentum distribution for primary charged particles has been measured for Pb–Pb and Xe–Xe collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV and 5.44 TeV, respectively. The differential cross section has been measured for INEL pp collision at $\sqrt{s} = 5.02$ TeV. The $R_{\rm AA}$ at central collisions 0-5% has a minimum at $p_{\rm T} = 6-7$ GeV/c and an almost linear rise for larger momenta. Similar $p_{\rm T}$ dependence of $R_{\rm AA}$ is observed for Pb–Pb and Xe–Xe collisions, but the suppression of high-momentum particles is apparently stronger in Pb–Pb for the same centrality class.

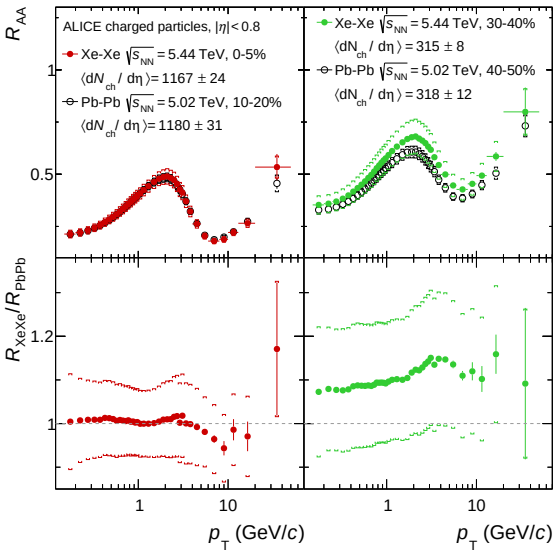

Figure 1: Comparison of nuclear modification factors in Xe-Xe (full points) and Pb-Pb (open points) collisions for similar ranges of mean multiplicity, 0-5% (left) and 30-40% (right) Xe-Xe centrality classes. The brackets represent the systematic plus normalization uncertainties and the vertical lines the statistical errors.

The nuclear modification factors from Xe–Xe and Pb–Pb collisions and their ratios at similar average multiplicity $\langle {\rm d}N_{\rm ch}/{\rm d}\eta \rangle$ are shown in Figure 1. In central Xe-Xe collisions $(0-5\%)$, the average multiplicity is $\langle {\rm d}N_{\rm ch}/{\rm d}\eta \rangle = 1167 \pm 24$, while for Pb-Pb collisions in 10-20% centrality range is $\langle {\rm d}N_{\rm ch}/{\rm d}\eta \rangle = 1180 \pm 31$. The ratio of the nuclear modification factor at similar average multiplicity (bottom panels of Fig.1) shows a remarkable agreement between both systems. In the comparison of 30-40% Xe-Xe and 40-50% Pb-Pb, the ratio is approximately flat and the systematic uncertainties cover the ratio at unity. The compatibility in the nuclear modification factors at similar values of average multiplicity is in agreement with results from the study of fractional momentum loss of high-$p_{\rm T}$ partons at RHIC and at the LHC. The ratios at similar multiplicities supports the idea that the $R_{\rm AA}$ ratios in the same centrality classes is not a meaningful comparison, since the average multiplicities or the medium sizes are not comparable between the two systems. A comparison of the $R_{\rm AA}$ as a function of $\langle {\rm d}N_{\rm ch}/{\rm d}\eta \rangle$ in Xe–Xe and Pb–Pb collisions for three different regions of $p_{\rm T}$ (low, medium, and high) is shown in Figure 2. A remarkable agreement in the $R_{\rm AA}$ is observed between Xe–Xe and Pb–Pb collisions when compared at similar multiplicity ranges, for $\langle {\rm d}N_{\rm ch}/{\rm d}\eta \rangle > 400$. The observed similarity in the $R_{\rm AA}$ at high-$p_{\rm T}$ is consistent with the

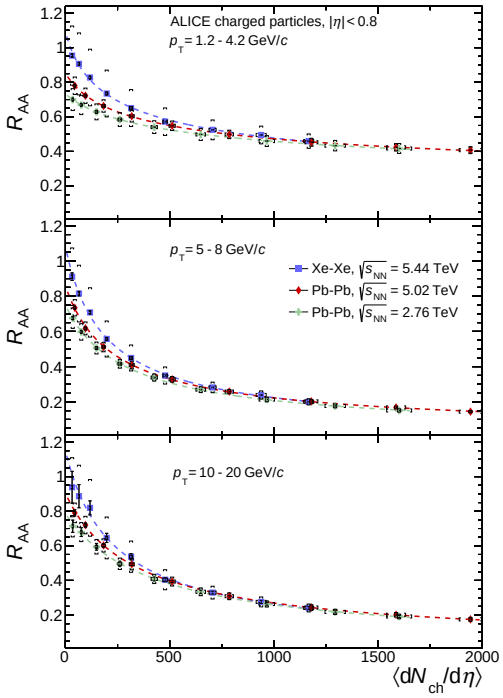

Figure 2: Comparison of the nuclear modification factor in Xe-Xe and Pb-Pb collisions integrated over three p_{T} regions as a function of $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$. The horizontal bars correspond to the RMS of the distribution in each bin. The dashed line is a power law fit to the data only for guidance purposes.

quadratic path length dependence of medium induced radiative energy loss, assuming a simplified radiative energy loss scenario and when assuming identical medium thermalization times.

4. Summary

The charged particle transverse momentum distributions have been measured for pp and Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and Xe–Xe collisions at $\sqrt{s_{\mathrm{NN}}} = 5.44$ TeV. The ratio of R_{AA} between Pb-Pb and Xe-Xe shows a good agreement for multiplicities of $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle \approx 1170$. The compatible R_{AA} in both systems at high-p_{T} is consistent with a quadratic path length dependence of medium energy loss.

References

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