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Transverse momentum spectra and the nuclear modification factor of charged particles with ALICE

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Abstract. The observed suppression of particle production at high transverse momentum in nucleus-nucleus collisions at high energies is an effect of the energy loss of partons as they propagate through the hot and dense deconfined QCD medium. The measurement of transverse momentum spectra of primary charged particles in Pb–Pb collisions and the comparison to the measurement in pp collisions are important to study the properties of the deconfined medium. In 2015, pp and Pb–Pb collisions have been recorded at the LHC at the energy of $\sqrt{s_{NN}} = 5.02$ TeV. The inclusive charged particle production is measured with the ALICE detector in the pseudo-rapidity range $|\eta| < 0.8$ and in the transverse momentum range $0.15 < p_{\rm T} < 40$ GeV/c. The spectra in Pb–Pb, determined for several centrality intervals, are compared to the reference spectrum in pp collisions by calculating the nuclear modification factor $R_{\rm AA}$. The data are compared to measurements at the lower collision energy of 2.76 TeV and to model predictions.

1. Introduction

The charged particle production has been measured in different collisions systems and at several beam energies. Experiments at RHIC have found, from the measurements of the transverse momentum spectra in p+p and Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV [1, 2], that the high-$p_{\rm T}$ particle production in heavy-ion collisions is suppressed compared to the production measured in pp. Bjorken had earlier introduced the idea that such an observation is related 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 final particles. The ALICE experiment has observed a stronger suppression of hadron production at high-$p_{\rm T}$ in central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [4], indicating the creation of a denser and hotter medium comparing to RHIC energies. This modification is typically quantified in terms of the nuclear modification factor:

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

where ${\rm d}N_{\rm AA}/{\rm d}p_T$ and σ_{pp} represent the yield in nucleus-nucleus collisions and the total inelastic 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 σ_{inel}^{NN}. 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.


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2. Analysis

The preliminary results reported here are based on an analysis of 25×10^6 pp collisions and 3.3×10^6 Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV recorded with the ALICE detector during late 2015 that represents approximately 25% and 3% of the total data collected, respectively. Events are triggered using the V0A and V0C detectors, which have full azimuthal coverage and the pseudorapidity coverage of $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$, respectively. For the measurement of charged particle spectrum, secondary particles are rejected by requiring a minimum distance of the particle tracks to the reconstructed primary vertex. Primary particles are selected in Monte Carlo and they are defined as all prompt charged particles produced in the collision including all decay products, except the products from weak decays of light flavour hadrons. The charged particles are reconstructed using the Inner Tracking System (ITS) and the Time Projection Chamber (TPC). In Pb–Pb collisions the sum of amplitudes measured in V0A and V0C is used to estimate the collision centrality [5]. A detailed description of the ALICE detector, its sub-systems, and the performance have been reported in [6].

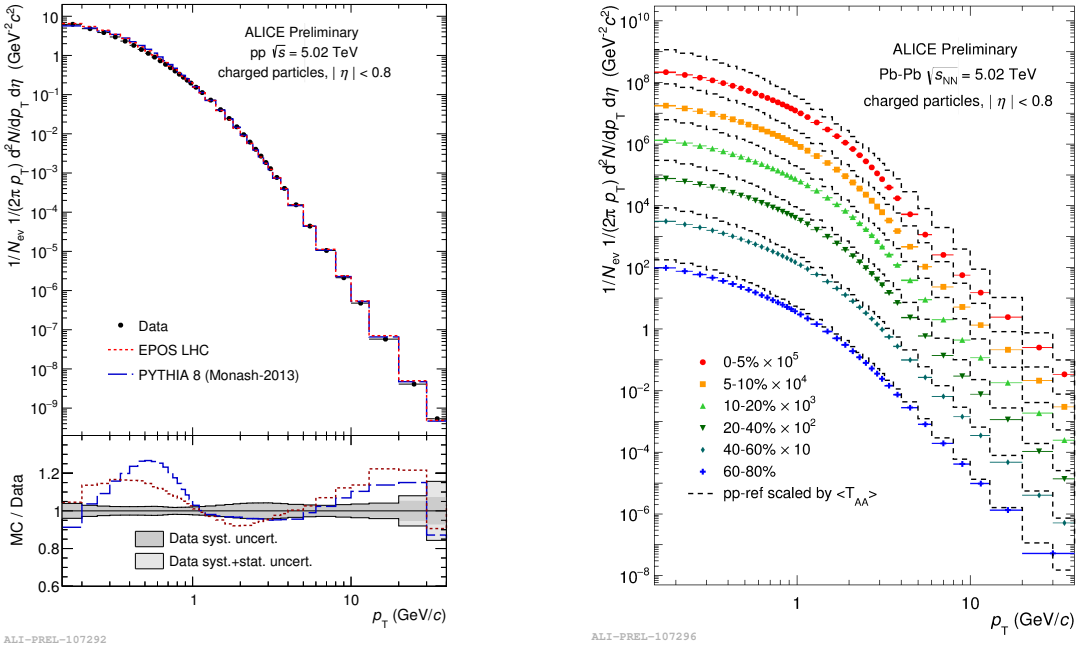


Figure 1. Transverse momentum distribution of charged particles. **Left:** For pp collisions at $\sqrt{s} = 5.02$ TeV, compared to PYTHIA8 and EPOS calculations [7, 13] and the ratio Monte Carlo to data in the lower panel. **Right:** For Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV, for six centrality classes. The dashed curves correspond to the measured $p_{\rm T}$ distribution in pp collisions scaled by $\langle {\rm T_{AA}} \rangle$.

All corrections applied to data are calculated using Monte Carlo simulations from PYTHIA8 [7] for pp and HIJING [8] for Pb–Pb collisions with particle transport via a GEANT3 [9] simulation of the ALICE detector. 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[10] and Pb–Pb collisions at 2.76 TeV[11, 12]. The correction for contamination by secondary particles produced from weak decays or secondary interactions is important only at low transverse momentum ($\sim 10\%$), $p_{\rm T} < 1$ GeV/c, while the correction for $p_{\rm T}$-resolution is important at high $p_{\rm T}$ ($\sim 2\%$), $p_{\rm T} > 10$ GeV/c.

3. Results

The transverse momentum distribution has been measured for pp and Pb–Pb collisions at the same energy per nucleon for Pb–Pb at $\sqrt{s_{\rm NN}} = 5.02$ TeV. Figure 1 (left) shows the distribution for pp collisions measured in the range of 0.15 GeV/$c \leq p_{\rm T} <$ 40 GeV/c and $|\eta| < 0.8$. The data is compared to Monte Carlo calculations performed with PYTHIA8 (Monash-2013 tune) [7] and EPOS LHC [13], both describing the data reasonably well at intermediate $p_{\rm T}$. However, it is interesting to note that models overestimate the production at low and high transverse momentum by a similar amount $\sim$ 20%. The Pb–Pb transverse momentum distribution is shown in Figure 1 (right) for six centralities together with the pp cross section scaled by the nuclear overlap function.

Figure 3 shows the $R_{\rm AA}$ as a function of $p_{\rm T}$ for six centralities. The solid symbols correspond to the measurement at $\sqrt{s_{\rm NN}} = 5.02$ TeV while the open symbols represent the published measurement at $\sqrt{s_{\rm NN}} = 2.76$ TeV [4]. For the six centralities, the measurements for both energies show similar behavior within systematic uncertainties. In central collisions (0–5%) a strong suppression is observed, with a minimum at $p_{\rm T} \sim 7$ GeV/c and a significant rise for $p_{\rm T} >$ 7 GeV/c. For peripheral collisions (60–80%) $R_{\rm AA}$ exhibits a moderate suppression (~0.6-0.7). The similarity of the $R_{\rm AA}$ measured at 2.76 TeV and 5.02 TeV could be a hint of a stronger energy loss in the hotter and denser medium taking into account that the spectra are harder at 5.02 TeV than at 2.76 TeV.

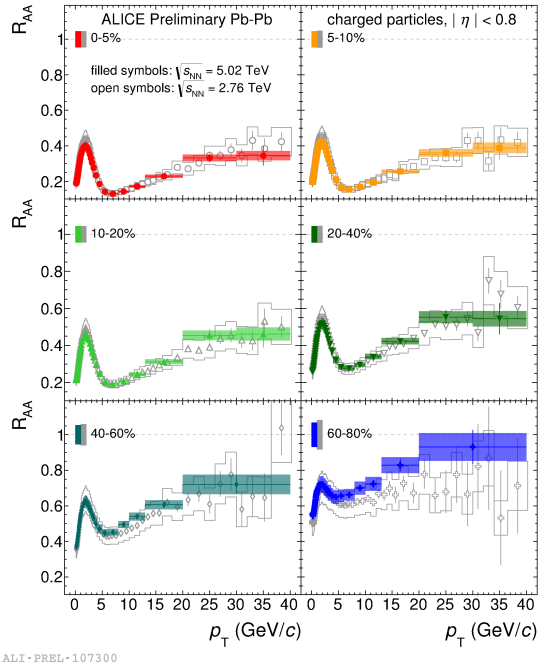


Figure 2. The nuclear modification factor ($R_{\rm AA}$) as a function of $p_{\rm T}$ for six centralities. Filled symbols represent the measurement at $\sqrt{s_{\rm NN}} = 5.02$ TeV and empty symbols correspond to $R_{\rm AA}$ at $\sqrt{s_{\rm NN}} = 2.76$ TeV [4]. The normalisation uncertainty is shown for both energies as a box around unity for both energies.

Figure 3 (left) compares the $R_{\rm AA}$ at $\sqrt{s_{\rm NN}} = 5.02$ TeV to model predictions from Djordjevic et al. [14] and Majumder et al. [15]. The two models succeed in describing the $R_{\rm AA}$ measurement at high-$p_{\rm T}$, for the 0–5% centrality range. On the right panel of Figure 3, the measurement of

the $R_{\rm AA}$ for the 0–10% centrality is compared to predictions by Vitev et at. [16] which achieve a good description of data.

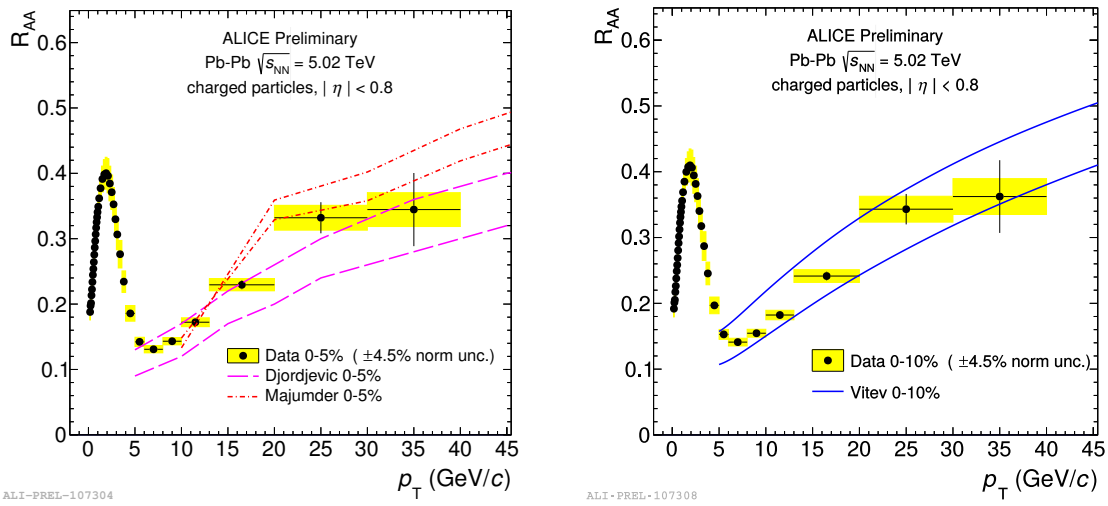


Figure 3. The nuclear modification factor measured at $\sqrt{s_{\rm NN}} = 5.02$ TeV for 0–5% (left) and 0–10% (right) compared with model calculations [14, 15, 16].

4. Summary

The nuclear modification factor in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV was found to be similar to the measurement at 2.76 TeV. A maximal suppression was observed around 6-7 GeV/c for the most central collisions (0–5%) which becomes smaller as centrality increases. The $R_{\rm AA}$ was compared with three models and they succeed in describing the general features of the measurement for a transverse momentum $p_{\rm T}$ >5 GeV/c. The full dataset is currently being analyzed. In addition, an improved analysis method will be applied to the $\sqrt{s_{\rm NN}} = 2.76$ TeV dataset, which is expected to reduce the systematic uncertainties and increase precision in the comparison with the higher collision energy.

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