Inelastic shadowing of secondary $\pi^\pm$, $K^\pm$, $p$, and $\bar{p}$ produced in $p+\text{Pb}$ collisions at LHC energy

G.H. Arakelyan$^a$, C. Merino$^b$, Yu.M. Shabelski$^c$ and A.G. Shuvaev$^c$

$^a$Alikhanyan National Scientific Laboratory (Yerevan Physics Institute)
Yerevan, 0036, Armenia

$^b$Departamento de Física de Partículas, Facultade de Física
and Instituto Galego de Física de Altas Enerxías (IGFAE)
Universidade de Santiago de Compostela, Galiza, Spain

$^c$Petersburg Nuclear Physics Institute
NCR Kurchatov Institute
Gatchina, St.Petersburg 188300 Russia

Abstract

The inclusive spectra of secondaries produced in soft (minimum-bias) $p+\text{Pb}$ collisions at LHC energy are calculated in the frame of the Quark-Gluon String Model, by including the inelastic screening corrections (percolation effects). These effects are expected to be quite large at the very high energies, and they should drive down the spectra in the midrapidity region more than 2 times, at $\sqrt{s_{NN}}=5$ TeV.

PACS. 25.75.Dw Particle and resonance production

1 Introduction

We compare the results obtained in the frame of the Quark-Gluon String Model (QGSM) with the experimental data for the inclusive densities of different secondaries obtained by the CMS collaboration for $p+\text{Pb}$ at $\sqrt{s_{NN}}=5$ TeV (see [1] for a more detailed version of this work).

In [2, 3] it was shown that in the frame of the QGSM one can obtain a reasonable description of the experimental data on the inclusive spectra of secondaries produced in $d+\text{Au}$ collisions at $\sqrt{s_{NN}}=200$ GeV (RHIC), by accounting of the inelastic corrections, which are related to the multipomeron interactions. These corrections lead to the saturation of the inclusive density of secondary hadrons in the soft (low $p_T$) region, where the methods based on perturbative QCD cannot be used. The effects of the inelastic shadow corrections should increase with the initial energy, becoming large at the LHC energies.

1Presented by C. Merino (carlos.merino@usc.es) at the Low-$x$ Meeting 2017, Bisceglie, near Bari (Italy), June 13$^{th}$-18$^{th}$, 2017.
In principal, two possibilities exist to explain the origin of the inelastic nuclear screening: either it comes from the diagrams with Pomeron interactions, or from the interactions of the produced secondaries with another hadrons. In the first case, the inelastic screening effects should be the same for different secondaries, while for the second one they should be different.

2 QGSM inclusive spectra of secondary hadrons with inelastic screening effects in p+A collisions at very high energies

In order to produce quantitative results for the inclusive spectra of secondary hadrons, a model for multiparticle production is needed. It is for that purpose that we have used the QGSM [4, 5] in the numerical calculations presented below. QGSM is based on the Reggeon calculus and on the 1/N_c (or 1/N_f) expansion in QCD, where N_c and N_f are the numbers of colors and light flavors, respectively.

Both the high energy hadron-nucleon and hadron-nucleus interactions are treated in the QGSM as proceeding via the exchange of one or several Pomerons. The elastic and inelastic processes result from cutting through or between Pomerons [6]. Each Pomeron corresponds to a quark-gluon cylinder diagram. The cut through the cylinder produces two showers of secondaries (color strings) [7]. The decay of these strings generates new quark-antiquark pairs that lead then to the production of secondary hadrons.

For the nucleon target, the inclusive density dn/dy of a secondary hadron h has the form [4]:

\[ \frac{dn}{dy} = \frac{1}{\sigma_{inel}} \cdot \frac{d\sigma}{dy} = \frac{x_E}{\sigma_{inel}} \cdot \frac{d\sigma}{dx_F} = \sum_{n=1}^{\infty} w_n \cdot \phi_n^h(x) \]  

(1)

where the functions \( \phi_n^h(x) \) determine the contribution of diagrams with \( n \) cut Pomerons, and \( w_n \) is the probability for this process to occur [8]. Here we neglect the diffractive dissociation contributions, since it would only be significant in the fragmentation regions, i.e at large \( x_F \).

The specific form of the functions \( \phi_n^h(x) \) is given by the convolution of the diquark and quark distributions with the fragmentation functions, both being determined by Regge asymptotics. [9, 10]

The probabilities \( w_n \) in Eq. (1) are the ratios of the cross sections corresponding to \( n \) cut Pomerons, \( \sigma^{(n)} \), to the total non-diffractive inelastic pp cross section, \( \sigma_{nd} \) [8].

The contribution of multipomeron exchanges in high energy pp interactions results in a broad distribution of \( w_n \) (see [11]). In the case of interaction with a nuclear target, the Multiple Scattering Theory (Gribov-Glauber Theory) is used, which allows to treat the interaction with the nuclear target as the superposition of interactions with different numbers of target nucleons (see a more detailed description in [1], and references therein).
The average value of the number of target nucleons with whom the proton interacts, $\nu$, has the well-known form:

$$\langle \nu \rangle = \frac{A \cdot \sigma_{pp}^{inel}}{\sigma_{prod}}.$$  \hspace{1cm} (2)

We use the numerical values $\sigma_{pp}^{inel} \simeq 72 \text{ mb}$ and $\sigma_{pPb}^{prod} \simeq 1900 \text{ mb}$ at $\sqrt{s_{NN}} = 5 \text{ TeV}$, so that

$$\langle \nu \rangle_{p+Pb} \approx 7.9.$$  \hspace{1cm} (3)

In the calculation of the inclusive spectra of secondaries produced in $pA$ collisions, the possibility of one or several Pomeron cuts in each of the $\nu$ blobs of the proton-nucleon inelastic interactions should be considered.

The QGSM gives a reasonable description \[12, 13\] of the inclusive spectra of different secondaries produced in hadron-nucleus collisions at energies $\sqrt{s_{NN}} = 14 - 30 \text{ GeV}$. The situation drastically changes at RHIC energies, where, from a theoretical point of view, the authors of ref. \[2\] claimed that the suppression factor in the inclusive density for $Pb-Pb$ collisions when taken into account saturation effects was of about 2. Later, this effect was experimentally confirmed when comparing the theoretical inclusive densities without saturation effects to the corresponding RHIC experimental data for $Au-Au$ collisions \[14, 15\].

However, all estimations are model dependent. In particular, the calculations of inclusive densities and multiplicities, both in $pp$, and in heavy ion collisions (with accounting for inelastic nuclear screening), can be fulfilled in the percolation theory \[16\].

The percolation approach assumes two or several Pomerons to overlap in the transverse space and to fuse in a single Pomeron. Given a certain transverse radius, when the number of Pomerons in the interaction region increases, at least part of them may appear inside another Pomeron. As a result, the internal partons (quarks and gluons) can split, leading to the saturation of the final inclusive density. This effect persists with the energy growth until all the Pomerons will overlap \[16\].

In order to account for the percolation effects in the QGSM, it is technically more simple \[3\] to consider in the central region the maximal number of Pomerons $n_{max}$ emitted by one nucleon (see \[3\] for details). By doing this, the QGSM calculations of the spectra of different secondaries integrated over $p_T$, as functions of initial energies, rapidity, and $x_F$, become rather simple and very similar to those in the percolation approach.

In the following calculations, the value $n_{max} = 21$ has been used at the LHC energy $\sqrt{s_{NN}} = 5 \text{ TeV}$. This value can be regarded as the normalization of all the charged secondaries multiplicities in the midrapidity region to the ALICE data \[17\].

The predictive power of our calculation applies for different sorts of secondaries in midrapidity region. If the inelastic nuclear screening comes mainly from the Pomeron interactions, as it was discussed above, the screening effects would be the same for all the secondaries.

In the following calculations, one additional effect is also taken into account, namely the transfer of the baryon charge to large distances in rapidity space through the string
junction effect \[18\] [19]. This transfer leads to an asymmetry in the production of baryons and antibaryons in the central region that is non-zero even at LHC energies (see \[19\] for the details of the calculation of these effects).

3 Rapidity spectra of different secondaries at LHC energies

To compare the calculated effect of nuclear screening with the experimental data, the adequate description of the secondary production on nucleon, as well as on nuclear targets is needed.

First, we have obtained the QGSM description of $\pi^\pm$, $K^\pm$, $p$, and $\bar{p}$ productions in $pp$ collisions at LHC energies, and then we have compared the results of our calculations with the experimental data by the CMS Collaboration \[20, 21\] and by the ALICE Collaboration \[22, 23, 24\]. The experimental data by the ALICE Collaboration are approximately 20–30% lower than those published by the CMS Collaboration, but in spite of this disagreement between ALICE and CMS data our QGSM result is qualitatively compatible with both experimental samples (see \[1\] for the details of this analysis).

One has to note that the experimental point by the ALICE Collaboration \[17\], $dn_{ch}/d\eta = 16.81 \pm 0.71$ at $\sqrt{s_{NN}} = 5$ TeV, has been used \[11\] to normalize the QGSM calculations for the case of nuclear targets, the agreement of our calculations with this result being reached at $n_{max} = 21$, where the theoretical value is of $dn_{ch}/d\eta = 16.28$ (see ref. \[11\]).

The experimental data for $p+Pb$ collisions by the CMS Collaboration on the inclusive densities of different secondaries, $\pi^\pm$, $K^\pm$, $p$, and $\bar{p}$ \[20\] are presented in Table 1, where they are compared with the results of our QGSM calculations. The agreement for every secondary particles is good, what it means that the experimental nuclear shadowing factor is the same for different secondaries, as it is assumed in our calculations.

Also in Table 1, we present the QGSM results for the $pp$ collisions at the same energy. The ratios of particle yields in $p+Pb$ and $pp$ collisions are equal to $3.6–3.7$, i.e they are two times smaller than the values of $\nu_{p+Pb}$ in Eq. 3. In the absence of inelastic nuclear screening, the ratio $r = pPb/pp$ in the midrapidity region should be equal to $\nu_{p+Pb}$ \[25\], that is, to the average number of the inelastic collisions of the incident proton in the target nucleus. Thus, we can see that the inelastic nuclear screening factor is little larger than 2, and it is practically the same for all considered secondaries.

We have also calculated the hyperon and antihyperons production in $pp$ and $p+Pb$ collisions at the same energy $\sqrt{s_{NN}} = 5$ TeV. The ratios of the inclusive densities of all secondary hyperons and antihyperons produced on Pb and hydrogen targets are practically the same as for secondary mesons production, with a $\sim 5\%$ accuracy (see \[1\]), what would indicate that the main contribution to the processes of hyperon and meson production has a similar nature.
Table 1: Experimental data on $dn/dy$, $|y| \leq 1$ by the CMS Collaboration [20] of charged pions, kaons, $p$, and $\bar{p}$ production in central $p+Pb$ collisions at $\sqrt{s_{NN}}=5$ TeV, together with the corresponding QGSM results. The parameter $r$ is the ratio of the particle yields in $p+Pb$ and $pp$ reactions. The results of the QGSM calculations for $pp$ collisions are also given.

4 Conclusion

The inelastic nuclear screening corrections at LHC energies have proved to be really large, and the QGSM approach for high energy inelastic $pp$, $p$-nucleus and nucleus-nucleus collisions with multiparticle production, provides a natural explanation of the independence of the nuclear screening effects on the type of the produced particles in the central region of inclusive spectrum, as the nuclear screening effects are practically the same for $\pi^{\pm}$, $K^{\pm}$, $p$, and $\bar{p}$ production.

If confirmed experimentally for high energy inelastic $pp$, $p$-nucleus and nucleus-nucleus collisions with multiparticle production, this fact would indicate that the interaction of secondaries in the final state would be negligibly small.

Acknowledgements

The authors thank B.Z. Kopeliovich for his valuable comments.

C.M. wants to congratulate Christophe Royon and all the organizers for the nice environment for talks and discussion at the conference, and to thank Nicola Minafra for his help during the whole stay in Bisceglie.

This work has been supported by Russian RSCF grant No. 14-22-00281, by the State Committee of Science of the Republic of Armenia, Grant-15T-1C223, by Ministerio de Ciencia e Innovaci´ on of Spain under project FPA2014-58293-C2-1-P and FEDER, and the Spanish Consolider-Ingenio 2010 Programme CPAN (CSD2007-00042), and by Xunta de Galicia, Spain (2011/PC043).

References

[1] G.H. Arakelyan, C. Merino, Yu.M. Shabelski, and A.G. Shuvaev, Phys. Rev. D95, 7, 074013 (2017), and [arXiv:1604.01918[hep-ph]].
