Open-beauty production in $pPb$ collisions at $\sqrt{S_{\text{NN}}} = 5$ TeV: effect of the gluon nuclear densities

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Abstract

We present our results on open beauty production in proton-nucleus collisions for the recent LHC $pPb$ run at $\sqrt{S_{\text{NN}}} = 5$ TeV. We have analysed the effect of the modification of the gluon PDFs in nucleus at the level of the nuclear modification factor. Because of the absence of measurement in $pp$ collisions at the same energy $\sqrt{S_{\text{NN}}}$, we also propose the study of the forward-to-backward yield ratio in which the unknown proton-proton yield cancel. Our results are compared with the data obtained by LHCb collaboration and show a good agreement.

Keywords: quarkonium production, heavy-ion collisions, cold nuclear matter effects

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1. Introduction

The recent $pPb$ run at 5 TeV which has taken place at the CERN LHC provides exciting measurements that need to be interpreted from the phenomenological point of view. In particular, the LHCb collaboration has released the first result of the nuclear matter effects on beauty production in $pPb$ collisions at 5 TeV at the LHC through the study of non-prompt $J/\psi$. Since the data cover the low $p_T$ region down to zero, they really constitute a direct access to open beauty production in $pPb$ collisions.$^1$

In these proceedings, we follow the lines of our previous studies devoted to the investigation of the cold nuclear matter effects, as the nuclear attenuation and the modification of the gluon densities, on quarkonium production in proton-nucleus collisions, both at RHIC [1, 2, 3, 4, 5] and LHC [6, 7] energies.

In the following, we present our results on the nuclear modification factor and on the forward-to-backward ratio for open-beauty production using LO pQCD for $bb$ production and the nuclear PDF (nPDF) fit EPS09 and nDSg at LO accuracy.

$^1$It is important to keep in mind that the $J/\psi$’s are produced by weak decay way outside the nucleus.
2. Theoretical framework

As for our precedent studies on prompt $J/\psi$ and $\Upsilon$ production in proton-nucleus collisions at RHIC and LHC energies, we have used our probabilistic Glauber Monte-Carlo framework, JIN [8], which allows us to encode different mechanisms for the partonic production and to interface these production processes with different cold nuclear matter effects, such as the shadowing, in order to get the production cross sections for $pA$ and $AA$ collisions.

As far as the open beauty partonic production is concerned, we have used the LO calculations from [9] which applies for the production of $b\bar{b}$ quarks in proton-proton collisions.

Other approaches, as the successful NLO prediction of the FONLL [10] which describes well the beauty production at Tevatron and LHC energies can obviously also be used. However, a comparison of our LO result with more refined theoretical approaches [11] shows that the LO description is sufficient to describe the low $p_T$ cross section up to $1 - 2m_b$.

Consequently, we believe that a LO evaluation is sufficient to determine the proton-proton production kinematics to be used in our Glauber code. Note that, in order to compare our results on $b$ quarks with the data for $J/\psi$ from $b$, we will make the approximation that they occur at the same rapidity. This approximation is reasonable as can be seen on Fig. 1 which shows the rapidity correlation between the rapidity of the $B$ and that of the $J/\psi$ decay product.

Figure 1: (Colour online) Rapidity correlation between $B$ hadrons and the $J/\psi$ coming from their decay at 5 TeV.
We note however that the approximation that the production kinematics of the $J/\psi$ be similar to that of the $b$ quark is only justified because one integrates on $p_T$. One would have to be much more careful if we wanted to analyse $p_T$ dependent effects.

Our results for $J/\psi$ from $b$ production in proton-proton collisions, integrated over $p_T$ and compared to the experimental data from LHCb Collaboration at 7 [12] and 8 TeV [13], are shown in Fig. 2. We have introduced the uncertainty related to the choice of the factorisation scale, $\mu_F$, also referred to as $Q$, that we have taken to be $(0.75, 1, 2) \times m_T$. We obtain a good agreement, as expected.

![Figure 2: (Colour online) Differential production cross-section as a function of $y$ integrated over $p_T$, for $J/\psi$ from $b$ at 7 TeV (up) and 8 TeV (down) compared to experimental data [12, 13]. The effect of the unknown factorisation scale is taken to be $(0.75, 1, 2) \times m_T$ (lower, central and upper curves).](image)

In which concerns the nuclear modification of the gluon PDFs, we have employed the parametrisations EPS09 [14] and nDSg [15] at LO accurary. The spatial dependence of the nPDF has been taken into account in our approach, assuming an inhomogeneous shadowing proportional to the local density [16, 17]. For the results presented here, this $b$-dependence does however not enter.

As in [7], we use the central curve of EPS09 as well as four specific extremed curves (minimal/maximal shadowing, minimal/maximal EMC effect) which reproduce the enveloppe of the gluon nPDF uncertainty encoded in EPS09 LO.
3. Results

As for any hard probes, the suppression of the open beauty can be characterised by the nuclear modification factor, $R_{pA}$—the ratio of the yield in $pA$ collisions to the yield in $pp$ collisions at the same energy multiplied by the average number of binary collisions in a typical proton-nucleus collision, $\langle N_{\text{coll}} \rangle$:

$$R_{pA} = \frac{dN_{pA}}{\langle N_{\text{coll}} \rangle dN_{pp}}.$$  

(1)

If a nuclear effect is at work, it leads to a deviation of $R_{pA}$ from unity.

![Graph](image)

Figure 3: (Colour online) Open-b nuclear modification factor (up) and its forward-to-backward (down) ratio in $pPb$ collisions, at $\sqrt{s_{NN}} = 5$ TeV versus $y$ using 5 extremal curves of the EPS09LO nPDF set and nDSg and compared to experimental results extracted from LHCb Collaboration[18].

It is nevertheless fundamental to insist on the fact that, in the absence of a yield measurement in $pp$ collisions in the same kinematical condition (e.g. the c.m.s. energy), $N_{pp}$, the normalisation of such a factor depends on an interpolation which introduces in additional systematical
uncertainties. Because of this, it is interesting to look at an additional observable, the forward-to-backward ratio, defined as

$$R_{FB}(y_{CM}) \equiv \frac{dN_{pA}(y_{CM})}{dN_{pA}(-y_{CM})} = \frac{R_{pPb}(y_{CM})}{R_{pPb}(-y_{CM})}, \tag{2}$$

in given rapidity and/or $P_T$ bins. Since the yield in $pp$ is symmetric in $y_{CM}$, it drops out of the double ratio in the l.h.s. of Eq. (2).

In Fig. 3, we present our results on open beauty for the nuclear modification factor $R_{pA}$ and the forward-to-backward ratio $R_{FB}$ for $pPb$ collisions at 5 TeV. These values can be compared to the measurements by the LHCb collaboration. LHCb has reported [18] differential cross-sections for $J/\psi$ from $b$ as a function of $y$, both for $pA$ and $Ap$ collisions. From them, we have extracted the corresponding forward-to-backward ratio, to be compared with our results. As can be observed in Fig. 3, the measured values of $R_{pPb}$ seem to disfavour the presence of antishadowing. Indeed, the nDSg fit, which does not exhibit an antishadowing excess, matches the data points better.

However, we would like to stress that $R_{pPb}$ is sensitive to the interpolated $pp$ cross section. To avoid this uncertainty, one may only want to focus on the comparison with the data for $R_{FB}$. In such a case, one does not see any tension with EPS09.

4. Conclusions

We have presented our results for the open beauty nuclear modification factor in $pPb$ collisions and its forward-to-backward ratio, $R_{FB}$, at $\sqrt{s_{NN}} = 5$ TeV as functions of $y$. Our results directly follow from the effects encoded in the nPDF which we have used and can be compared to the LHCb data.

As for now, the precision of the measurement is limited by the collected statistics during the one month 2013 $pPb$ run, and by the absence of a $pp$ reference. Nevertheless, a comparison at the level of $R_{pPb}$ hints at an absence of gluon antishadowing, whereas a sole comparison at the level of $R_{FB}$ does not hint at any disagreement.

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