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Drell-Yan process in $p+Pb$ collisions at the LHC

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We study the initial-state interactions (non-coherence) and nuclear shadowing (coherence) effects in the Drell-Yan pair production process in $p+Pb$ collisions at the LHC energies. The analysis of the nuclear suppression, $R_{pA} < 1$, has been performed in the color dipole approach in the large coherence length approximation. The Z^0 boson contribution relevant at large dilepton invariant masses has been included. We showed that the initial-state interactions cause a strong suppression at large p_T, large dilepton masses and forward rapidities leading to a breakdown of QCD factorisation that can be verified by LHC measurements. The nuclear effects on the correlation function $C(\Delta\phi)$ in azimuthal angle $\Delta\phi$ between dilepton pair and a forward pion have been discussed as well. We predict a characteristic double-peak structure of $C(\Delta\phi)$ for very forward pions and large-mass dilepton pairs.

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In this contribution, we discuss the Drell-Yan (DY) pair production process in $p+Pb$ collisions at the LHC in the framework of color dipole approach [1] where the contribution of Z^0 boson was included in addition to the virtual photon one relevant at large dilepton invariant masses that are measured at the LHC. It is worth noticing that the DY process represents an ideal tool for studies the initial-state interactions (ISI) effects in proton-nucleus and nucleus-nucleus collisions due to the absence of final-state interactions and fragmentation associated with energy loss or absorption.

The large-mass DY pair production process in proton-proton collisions at the LHC has been studied within the color dipole approach in Ref. [2], and a good agreement with the corresponding ATLAS and CMS data has been found. In the dipole picture, the DY process looks as Bremsstrahlung of a virtual gauge boson G^* by a projectile quark where the produced $|qG^*\rangle$ Fock state interacts with a target nucleon. Such interaction can be represented via the universal dipole cross section $\sigma^N_{q\bar{q}}(\vec{r})$ given in terms of a trasverse separation $\vec{r}$ within the qG^* pair.

On nuclear targets, the coherence effects are controlled by the coherence length l_c which can be interpreted as the mean lifetime of $|qG^*\rangle$ Fock state. It was demonstrated in Ref. [3] that the coherence length is larger than the nuclear radius $l_c \gtrsim R_A$ for the LHC kinematics, and, therefore, the long coherence length (LCL) limit can be safely used. Otherwise, the universal Green function formalism should be employed to account for finite l_c effects [4]. The LCL limit enables us to incorporate the nuclear shadowing effects via a simple eikonalization of the dipole cross section.

As long as the lowest Fock state $|qG^*\rangle$ is taken into account, the eikonalization of the dipole cross section accounts for the quark shadowing only. The gluon shadowing (GS) dominating at very small x_2 and thus becoming significant at the LHC can be incorporated as a correction also represented in terms of the dipole cross section [5].

Besides the coherence effects (such as quark and gluon shadowing), we study the effective energy loss induced by the ISI effects. The latter are expected to cause a significant suppression of the nuclear DY cross section when reaching the kinematical limits, $x_L = 2p_L/\sqrt{s} \to 1$ and/or $x_T = 2p_T/\sqrt{s} \to 1$, and were analysed in Ref. [6]. The ISI effects explain the nuclear suppression at large p_T in particle production at RHIC as well as at forward rapidities in fixed-target experiments where the coherence effects are not allowed due to a low collision energy. More details on the color dipole formalism, gluon shadowing, and ISI mechanism can be found in Ref. [3] and in references therein.

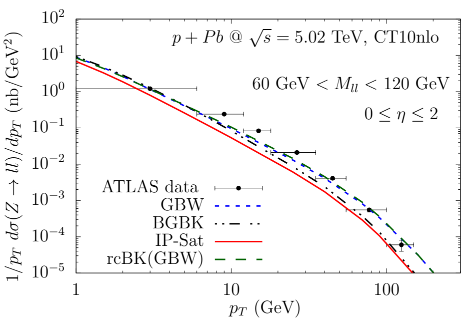

Figure 1: The DY dilepton p_T distribution in $p+Pb$ collisions versus data from the ATLAS Collaboration [7].

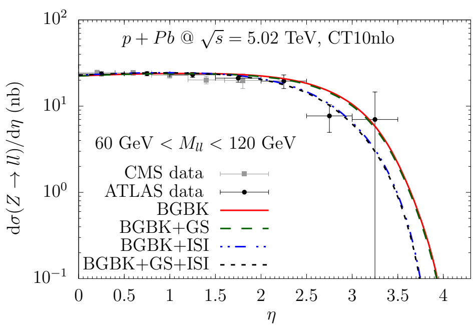

Figure 2: The DY dilepton η distribution in $p+Pb$ collisions versus data from the CMS Collaboration [8].

In Fig. 1 the DY nuclear cross sections in $p+Pb$ collisions at $\sqrt{s}=5.02$ TeV are shown for various dipole parameterisations in comparison with the ATLAS data and a good agreement has been found. The rapidity distributions in Fig. 2 are compared to the CMS and ATLAS data and include the quark shadowing only (red solid) as well as the gluon shadowing (green dashed) and the ISI effects (blue dots-and-dashed) and both (black dashed).

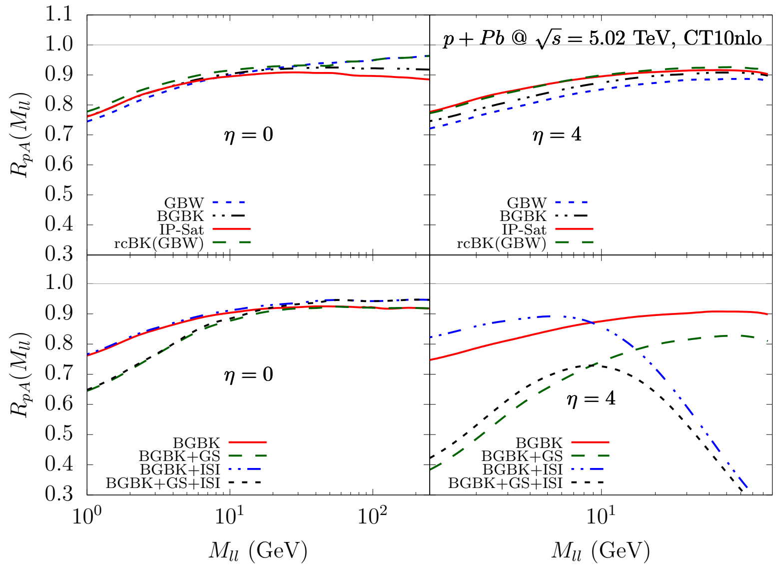

Figure 3: The dilepton invariant mass dependence of the nucleus-to-nucleon ratio $R_{pA}(M_{l\bar{l}})$.

The results for the nucleon-to-nucleus ratio as a function of dilepton invariant mass $R_{pPb}(M_{l\bar{l}})$ at the LHC are presented in Fig. 3. In the top panels, we compare the corresponding quantity for various parameterisations for the dipole cross section. The magnitude of the saturation effects decreases at large dilepton invarint masses and increases at forward rapidities. In the bottom panels, we additionally take into account the GS corrections and ISI effects. As can be expected, the GS contribution decreases with the dilepton invariant mass and increases at forward rapidities. On the other hand, the ISI effects are negligible at midrapidity, but dominate for large dilepton invariant masses and at forward rapidities. This behaviour enables us to disentangle the coherence and non-coherence sources of the nuclear suppression.

In Fig. 4 we show predictions for the nuclear ratio $R_{pPb}(p_T)$ for dilepton invariant mass range $60 < M_{l\bar{l}} < 120$ GeV for different rapidities. We found that for this mass range the nuclear shadowing (coherence effects) appears to be important only at small p_T and mainly at forward rapidities. The ISI effects are relevant at forward rapidities and lead to a considerable suppression.

In the current study, we investigated the DY pair production process off nuclear targets at the LHC within the color dipole approach. We focused on study of the coherence effects (such as quark and gluon shadowing) and non-coherence effects (ISI effects). It was demonstrated that our predictions are in a good agreement with the available LHC data. We found that the nuclear modification factor as a function of the dilepton invariant mass, $R_{pA}(M_{l\bar{l}})$, is a good probe for both the coherence and non-coherence sources of suppression allowing to reduce or eliminate the GS-

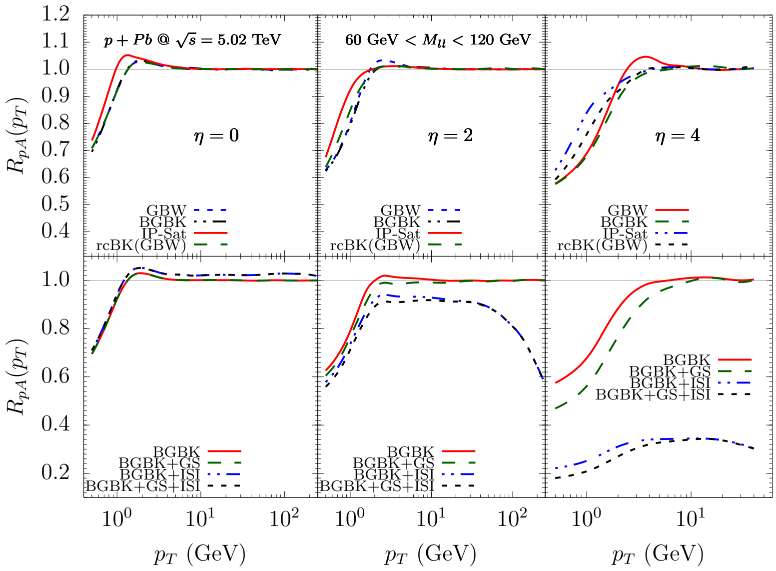

Figure 4: The transverse momentum dependence of the nucleus-to-nucleon ratio $R_{pA}(p_T)$.

ISI mixing since the shadowing corrections dominate at small Bjorken-x in the target while the ISI effects cause a significant suppression at large transverse momenta p_T and invariant masses $M_{l\bar{l}}$.

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