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Looking for saturation in UPC vector meson and $c\bar{c}$, $b\bar{b}$ production at the LHC

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We first describe the possible observation of saturation effects in the measurement of ultra-peripheral vector meson production (J/Ψ and Υ) in Pb Pb collisions at the LHC. In addition, we give predictions concerning $c\bar{c}$ and $b\bar{b}$ quark productions using the color glass condensate framework that could lead to an independent observation of gluon recombination effects.

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We first present the possible observation of saturation phenomena in J/Ψ and Υ vector meson production in ultra-peripheral (UPC) collisions at the LHC. In a second part of the paper, we will discuss the possible measurement of $c\bar{c}$ and $b\bar{b}$ at the LHC as an additional possible observation of saturation.

1 Exclusive vector meson production at the LHC as a probe of gluon saturation

To get some evidence for saturation at the LHC, one needs to probe the structure of the dense object, for instance Pb, at very small x, the fraction of the Pb momentum carried away by the interacting gluon. The measurement should also be sensitive to scales lower than the saturation scale Q_S, but large enough to be above the perturbative scale (∼1 GeV) to trust perturbative calculation. Q_S in the proton was estimated at HERA energies to be of the order of 1 GeV. In order to increase significantly the value of Q_S by $A^{1/3}$, it is useful to probe the gluon density not in protons, but in heavier objects such as Pb ions. The mass of J/Ψ mesons, which gives the scale at which one probes the structure of the heavy ion, is ideal to probe the high gluon density regime (and thus saturation effects) in Pb Pb collisions since it is below Q_S and above 1 GeV. On the contrary, because of its higher mass, saturation effects are expected to be smaller for ultra-peripheral Υ production. The production of charm and beauty is also expected to be sensitive to saturation effects.

Fig. 1 displays the diagram of the production of vector meson in γPb interactions. We will compute the exclusive vector meson production in γp (HERA, EIC and pPb LHC) and γPb (EIC and Pb Pb LHC) interactions where p Pb (resp. Pb Pb) collisions allow probing the gluon density in the proton (resp. Pb), a quasi-real photon being emitted by one of the Pb ions. We expect that saturation effects will be large only in the case of Pb Pb interactions [2].

As shown in Fig. 1, we factorize the $\gamma \to q\bar{q}$ contribution from the dipole density in proton or Pb to compute the J/Ψ and Υ ultra-peripheral cross section (UPC). At leading order, the cross section is proportional to the gluon density squared in the probe object (p or Pb). We compare the W energy evolution of the dipole densities using either the linear Balitsky-Fadin-Kuraev-Lipatov (BFKL) [3] or the non-linear Balitsky-Kovchegov (BK) [4] evolution equations. We also take into account the b impact

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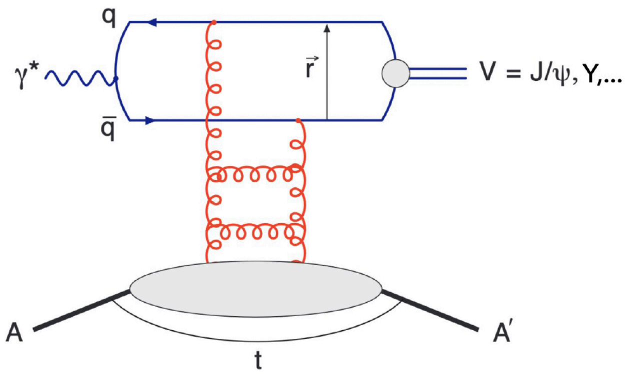

Figure 1 – Exclusive vector meson production in Pb Pb collisions.

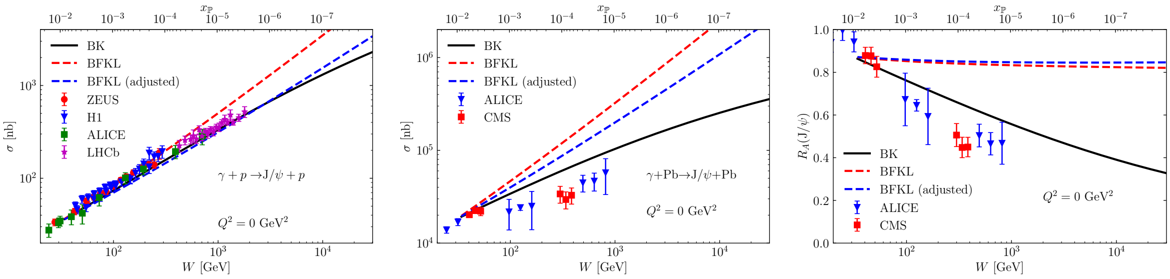

Figure 2 – Exclusive J/Ψ production as a function of the center-of-mass energy W. Left: Proton target, Center: Lead target, Right: Nuclear suppression factor.

parameter dependence in the dipole amplitude including a gaussian dependence of the thickness function for protons and the Wood-Saxon formalism for Pb [5], which is fundamental to obtain precise predictions in γ proton interactions (the effect of the b dependence is found to be weaker in the case of γ Pb interactions since Pb is a larger object compared to a proton).

Fig. 2, left and center, shows respectively the J/Ψ UPC production cross section as a function of energy W using either the BFKL or the BK evolution for the dipole densities calculations for γp and γPb interactions (the "adjusted" BFKL predictions correspond to a fit of the α_S value to the vector meson data). The predictions are compared with measurements from the H1 [6], ZEUS [7] collaborations at HERA at lower energies and from the CMS [8], ALICE [9], LHCb [10] collaborations at the LHC in p Pb and Pb Pb collisions. Small differences between BFKL and BK are obtained for γp cross sections since one probes the gluon in the proton where no large saturation effect is expected whereas large differences are obtained for γPb cross sections. Data clearly favor the BK evolution equation. It even seems that saturation effects might be stronger than predicted by our calculations that can be due to higher order effects. Fig. 2, right, displays the nuclear suppression factor which leads to similar conclusions.

In Fig. 3, left and center, we show the results of the calculation for Υ production for γp and γPb interactions using the BFKL and BK evolution. As expected, since the mass of Υ is larger than the mass of the J/Ψ, we get smaller saturation effects in PbPb interactions. We also obtain a good agreement for the γ p cross section. The prediction for the nuclear suppression factor is depicted in Fig. 3, right.

2 $c\bar{c}$ and $b\bar{b}$ production cross sections

Another method to probe saturation effects is to look for the production of $c\bar{c}$ and $b\bar{b}$ in pPb and PbPb collisions. We use a similar approach as for the vector meson production, namely we compute the production cross section using either the BFKL or BK evolution equation for the dipole amplitude [11].

In Fig. 4, we display the inclusive (left) and diffractive (right) $c\bar{c}$ (in red) and $b\bar{b}$ (in blue) production cross sections for γp interactions. The BFKL predictions are in dashed lines and the BK ones including saturation effects in full line. As expected, the differences between both approaches are small (slightly

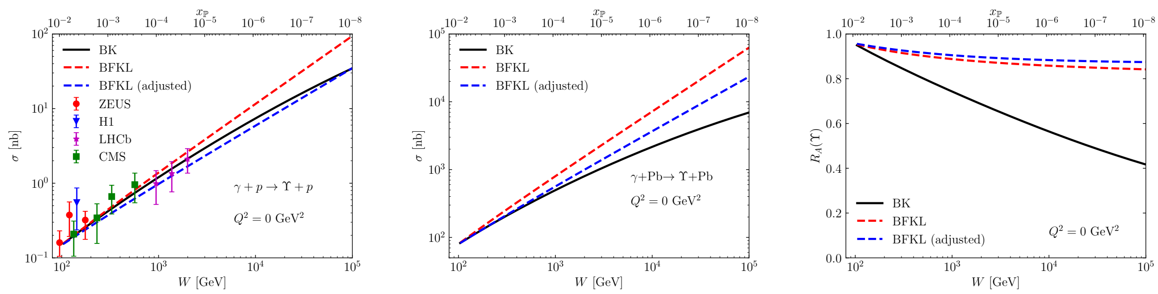

Figure 3 – Exclusive Υ production as a function of the center-of-mass energy W. Left: Proton target, Center: Lead target. Right: Nuclear suppression factor.

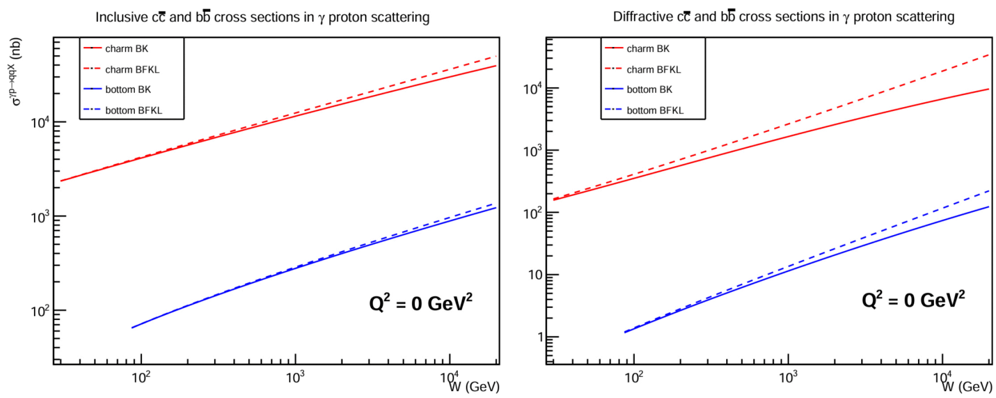

Figure 4 – Inclusive (left) and diffractive (right) $c\bar{c}$ (in red) and $b\bar{b}$ (in blue) production cross sections for γp interactions. The BFKL predictions are in dashed lines and the BK ones including saturation effects in full line.

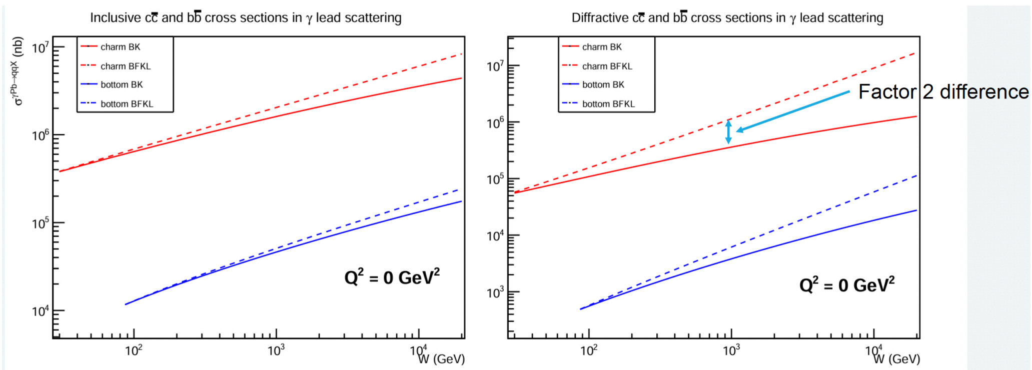

Figure 5 – Inclusive (left) and diffractive (right) $c\bar{c}$ (in red) and $b\bar{b}$ (in blue) production cross sections for γPb interactions. The BFKL predictions are in dashed lines and the BK ones including saturation effects in full line.

larger for diffractive events where Pb is intact after interaction since diffractive cross sections are sensitive to the gluon density squared). In the case of γPb interactions, the differences between BFKL and BK are found to be large as shown in Fig, 5 (typically a factor of about 2 is found between the BFKL and BK evolutions for charm production at an energy of about 1 TeV). It will be worth to perform directly this measurement at the LHC and compare with the expectations.

In Fig. 6, we also give the ratio of the diffractive to total $c\bar{c}$ and $b\bar{b}$ using the BK evolution equation. We note the high percentage of diffractive events, of the order of 20%, especially in the case of γPb interactions. This measurement will represent a clean test of CGC models.

To conclude, we first compared the γp and γPb exclusive productions of J/Ψ and Υ vector mesons including the BFKL and BK evolution equations with data, and data clearly favor saturation models to describe γ-Pb interactions. Predictions with and without saturation are similar for proton interactions. In a second part of this report, we mentioned that It will also be worth measuring $c\bar{c}$ and $b\bar{b}$ production at the LHC especially in diffractive events that lead to large differences with and without saturation.

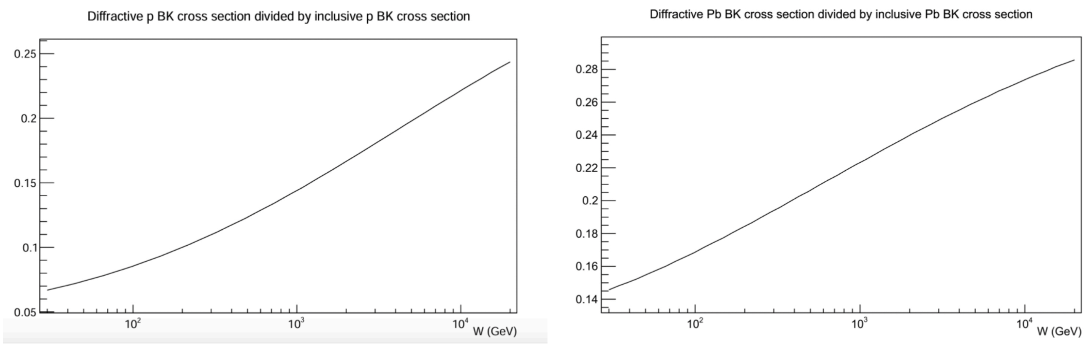

Figure 6 – Ratio of the diffractive to the inclusive $c\bar{c}$ production cross sections as predicted by the BK evolution for γp (left) and γPb (right) interactions.

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