LOOKING FOR BFKL RESUMMATION AND SATURATION 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 PbPb collisions at the LHC. We then give the predictions of the jet production cross section in dedicated detectors in the very forward region, such as the FOCAL detector of ALICE, as another probe of low-x dynamics and saturation.

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In this short paper, we will first discuss the possible observation of saturation phenomena in vector-meson ultra-peripheral (UPC) collisions at the LHC. In the second part of the paper, we will discuss the measurement of very forward jets especially in the FOCAL detector [1] to be installed by the ALICE Collaboration as an additional probe of saturation phenomena in the future.

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

In order to see saturation effects at the LHC, one needs to have measurements sensitive to a low scale below the saturation scale Q_{S}. This scale should also be large enough so that perturbative QCD calculations can be trusted. For protons, Q_{S} is of the order of 1 GeV as it was found at HERA. In order to enhance the value of Q_{S} by $A^{1/3}$, it is useful to consider probing the gluon in Pb instead of the proton. In that sense, γPb productions of c, b quarks, J/Ψ, Υ mesons are ideal probes for low-x physics and saturation

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since the scale is given by the mass of the vector meson or the heavy-quark mass. Measuring vector mesons at large rapidities allows for reaching low-x values of 10^{-4} or smaller while still being in the perturbative QCD domain and below Q_S.

Figure 1 displays the diagram corresponding to the production of vector meson in pPb and PbPb interactions. Our idea is thus to compute exclusive vector-meson production in γp (HERA, EIC, and pPb LHC) and γPb (EIC and PbPb LHC) interactions where pPb (resp. PbPb) collisions allow for 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 appear in PbPb interactions only [2].

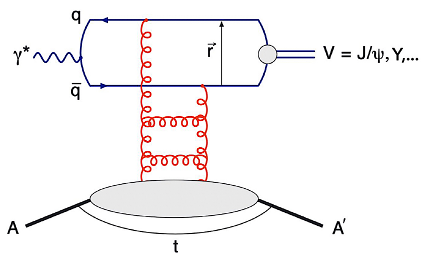

Fig. 1. Exclusive vector meson production in PbPb collisions.

To compute the vector-meson production cross section, we factorize the $\gamma \to q\bar{q}$ part from the dipole density in p or Pb as shown in Fig. 1 (the cross section is proportional to the gluon density squared $(xG)^2$ in the proton or Pb at Leading Order). We use the linear Balitsky–Fadin–Kuraev–Lipatov (BFKL) [3] and the non-linear Balitsky–Kovchegov (BK) [4] evolution equations including saturation effects to evolve the dipole densities. In addition, we take into account b impact parameter dependence in the dipole amplitude including a Gaussian dependence of the thickness function for protons and the Wood–Saxon formalism for Pb [5]. Taking into account the b-dependence of the dipole amplitude is crucial [2].

Figure 2, left and center, shows the results of our BFKL and BK calculations for γp and γPb interactions as a function of energy W for J/Ψ production (the "adjusted" BFKL predictions correspond to a fit of the α_S value to the vector meson data). They are compared with the data from the H1 [6] and ZEUS [7] collaborations at HERA at lower energies and from the CMS [8], ALICE [9], and LHCb [10] collaborations at the LHC in pPb and PbPb collisions. As expected, small differences between BK and BFKL predictions are observed for J/Ψ production in pPb (almost no saturation effects), whereas large differences are obtained between BK and BFKL calculations in PbPb collisions. PbPb data clearly favor saturation models (it even seems that saturation effects might be stronger than predicted by our calculations that can be due to higher order effects), and the linear BFKL behavior as a function of energy W is clearly disfavored. Figure 2, right, presents the nuclear suppression factor which shows again that data clearly favor saturation models.

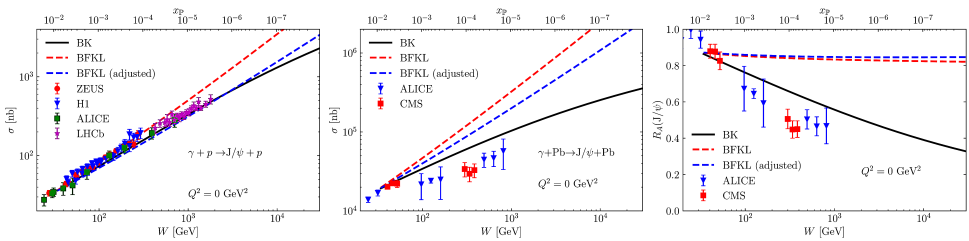

Fig. 2. Exclusive J/Ψ production as a function of the center-of-mass energy W. Left: Proton target. Center: Lead target. Right: Nuclear suppression factor.

In Fig. 3, left and center, there are presented the predictions for Υ production. As expected, since the mass of Υ is larger than the mass of the J/Ψ, we get smaller differences between BFKL and BK PbPb predictions. We also obtain a good agreement for the γp cross section. The prediction for the nuclear suppression factor is depicted in Fig. 3, right. Additional possible observables are the observation of ultra-peripheral production of $c\bar{c}$ and $b\bar{b}$ where we also expect a significant difference between BFKL and BK expectations.

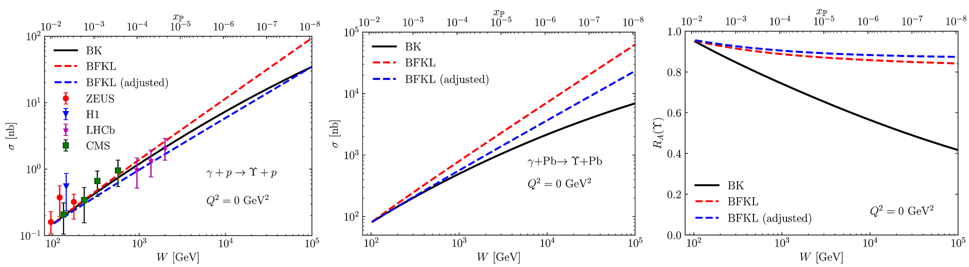

Fig. 3. Exclusive Υ production as a function of the center-of-mass energy W. Left: Proton target. Center: Lead target. Right: Nuclear suppression factor.

2. Very forward jet production at the LHC

In this section, we will discuss another observable that is sensitive to BFKL resummation and to saturation effects [11], namely the production of very forward jets in heavy-ion collisions, for instance in pPb interactions. In order to be sensitive to the gluon density on the Pb side at very low x (down to $\sim 10^{-5}$) where saturation effects could appear, it is needed to observe dijet production in the very forward region. In the following, we will thus consider jet measurements in the forward region of the CMS and ATLAS detectors called "forward CMS" kinematics [12] ($3.5 < y_{\rm jet} < 4.5$ and $p_{\rm T}^{\rm jet}$ between 10 and 20 GeV, 20 and 40 GeV or 40 and 80 GeV) and CASTOR/FOCAL [1] kinematics ($5.2 < y_{\rm jet} < 6.6$ and $p_{\rm T}^{\rm jet}$ between 5 and 10 GeV, or 10 and 20 GeV) [13].

We predict the forward jet cross section first by factorizing the photon into a $q\bar{q}$ pair from the $q\bar{q}$ scattering off a dense nuclear target, such as Pb. The dipole amplitude taken from the AAMQS parametrization (A non-linear QCD analysis of new HERA data at small x) [14] was fitted to HERA data. We then use the BK [4] equation to evolve the dipole density at small x. Since the AAMQS parametrization does not contain any b impact parameter dependence (which we need to get precise predictions at the LHC), we chose the b-dependence from IPSAT [15]. Our model is thus a mixture of AAMQS and IPSAT in order to use a b-dependent saturation model. The additional original aspect of our model is that we consider the sum of each proton and neutron Gaussian thicknesses as the Pb thickness

$$T(b) = \Sigma_{i=1}^{A} T_{p/n}(b_i - b)\,,$$

where the nucleon impact parameters, b_is, are generated stochastically.

Since we added the b-dependence part in AAMQS following IPSAT, the first step is obviously to check that we still describe the measurement of the proton structure function F_2 at HERA and negligible differences are observed between our model and AAMQS [13]. In Fig. 4, we compare the saturation scales given by our model for different heavy ions and for three different values of x (including the b-dependence) and the naive one with the usual $A^{1/3}$-dependence, and we see that we get lower saturation scales. Figure 5 displays the nuclear modification factors as a function of the az-

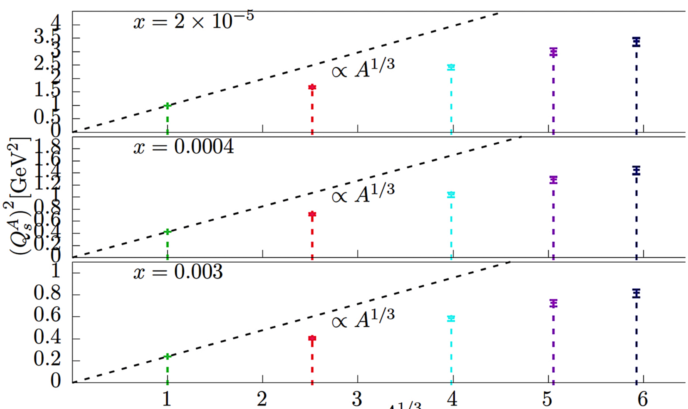

Fig. 4. Saturation scale $(Q_{\rm S}^A)^2$ (colored bars) *versus* naive expectations ($A^{1/3}Q_{\rm S}^2$).

imuthal angle between the two forward jets for two detector configurations, namely CASTOR/FOCAL on the left and FORWARD CMS on the right for different domains in jet p_T. As expected, Pb and Xe lead to similar decorrelations, and decorrelation is higher at higher jet y and lower p_T. Figure 6 compares our result with the naive expectation, and large differences are obtained especially in the CASTOR/FOCAL acceptance. Once installed, it will be important to compare our predictions with data from FOCAL in ALICE.

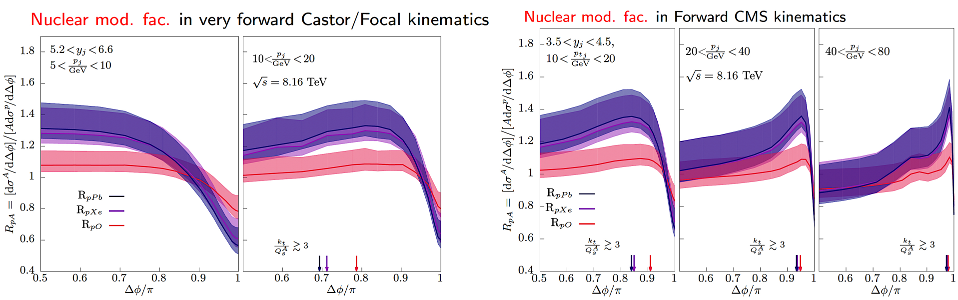

Fig. 5. Nuclear modification factors for two detector configurations (CASTOR/FOCAL and FORWARD-CMS) for different p_T intervals.

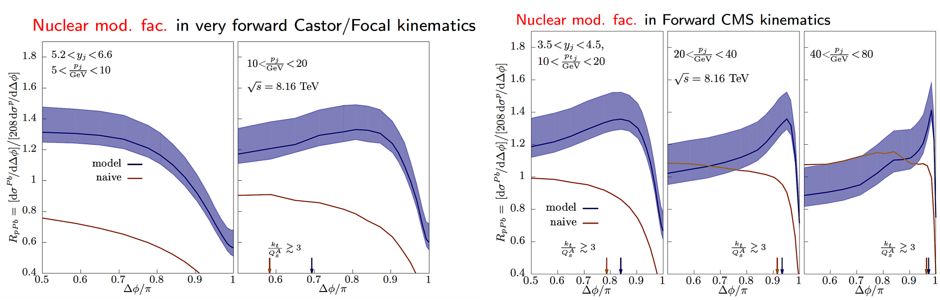

Fig. 6. Nuclear modification factors for two detector configurations (CASTOR/FOCAL and FORWARD-CMS) for different p_T intervals compared with the naive expectations.

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 the second part of this report, we computed the prediction for very forward jet cross sections as a function of the azimuthal angle between the two jets for different heavy ions using a full impact dependence approach. It leads to a lower decorrelation between jets and to a lower saturation scale than the simple $A^{1/3}$-dependence.

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