

Quarkonia Photoproduction at Nucleus Colliders

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Abstract

Exclusive photoproduction of heavy quarkonia in high-energy ultraperipheral ion-ion interactions ($A \rightarrow V A$, where $V = J/\psi$; and the nucleus A remains intact) offers a useful means to constrain the small- x nuclear gluon density. We discuss [1] preliminary results on J/ψ photoproduction in A - A collisions at RHIC [2], as well as full simulation-reconstruction studies of photo-produced J/ψ in Pb-Pb interactions at the LHC [3].

1 Introduction

The gluon density, $xG(x;Q^2)$, at small fractional momenta $x = p_{\text{parton}}/p_{\text{proton}} \lesssim 0.01$ and low, yet perturbative, Q^2 is a subject of intensive experimental and theoretical activity. On the one hand, DGLAP analyses based on DIS e - p data cannot reliably determine xG (Fig. 1) [4] as it is only indirectly constrained by the $\log(Q^2)$ dependence of the quark distributions (F_2 scaling violations). On the other, there are well founded theoretical arguments [5] that support the inapplicability of linear QCD (DGLAP- or BFKL-type) evolution equations at low enough values of x , due to the increasing importance of gluon-gluon fusion processes ("parton saturation"). This regime is theoretically described e.g. in the Colour-Glass-Condensate [6] or "black-disk limit" [7] approaches. Our knowledge of the low- x gluon distribution in the nucleus is even more scarce. Nuclear DIS data only cover the range above $x \sim 10^{-2}$ (Fig. 2), and gluon saturation effects are expected to be much larger in nuclei than in the proton due to their larger transverse parton density.

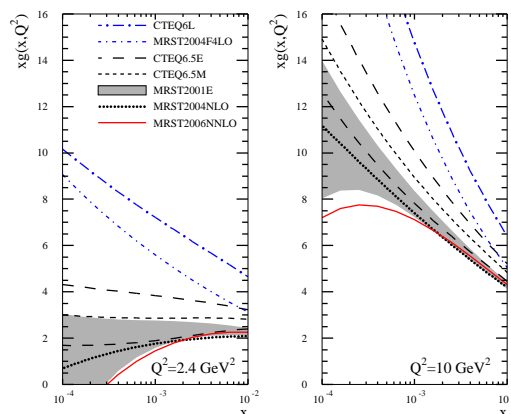


Figure 1: Comparison of recent parametrizations of the low- x gluon distribution at scales $Q^2 = 2.4$ (left) and 10 GeV^2 (right) [4].

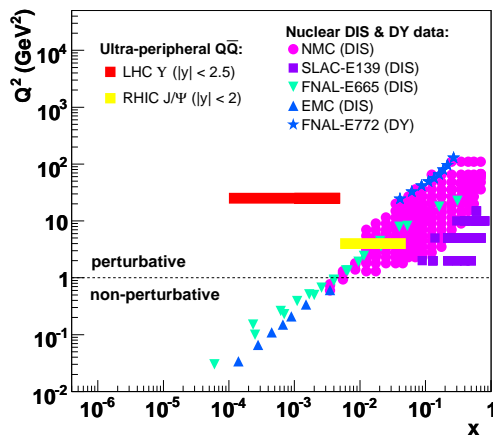


Figure 2: Kinematic $(x; Q^2)$ plane probed in e -, A collisions: DIS data compared to ultraperipheral $Q\bar{Q}$ photoproduction ranges.

2 $Q\bar{Q}$ photoproduction in ultra-peripheral A-A interactions

Exclusive quarkonia photoproduction offers an attractive opportunity to constrain the low- x gluon density at moderate virtualities, since in such processes the gluon couples directly to the c or b quarks (see Fig. 3) and the cross section is proportional to the gluon density squared (see [4] and refs. therein). The mass of the $Q\bar{Q}$ vector meson introduces a relatively large scale, amenable to a perturbative QCD (pQCD) treatment.

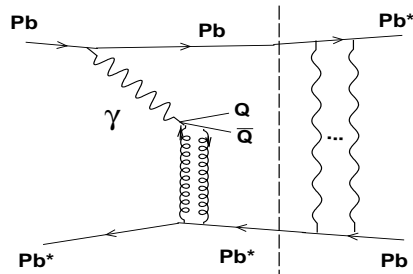


Figure 3: Schematic diagram for diffractive quarkonia photoproduction in A collisions.

High-energy nuclear photoproduction studies are possible in Ultra-Peripheral Collisions (UPCs) of heavy-ions [8] in which the strong electromagnetic fields involved are equivalent to the exchange of quasi-real photons with maximum energies $\omega_{\max} \approx 3 \text{ GeV}$ (100 GeV) at RHIC (LHC). Correspondingly, the maximum photon-nucleus c.m. energies are of the order $W_A^{\max} \approx 35 \text{ GeV}$ (1 TeV) at RHIC (LHC). Thus, in A-A J/ψ (Υ) processes, the gluon distribution can be probed at values as low as $x = M_V^2/W_A^2 \approx 10^{-2}$ (10^{-4}) (Fig. 2). Gluon saturation effects are expected to reveal themselves through strong suppression of hard exclusive di-ratction relative to the leading-twist approximation [7]. While this suppression may be beyond the kinematics achievable for J/ψ

photoproduction in UPCs at RHIC, $x \approx 0.01$ and $Q_e^2 = M_V^2 = 4 \text{ GeV}^2$, it could be important in UPCs at the LHC [8].

3 J/ψ photoproduction in Au-Au at RHIC (PHENIX)

The PHENIX experiment has measured J/ψ photoproduction at mid-rapidity in Au-Au UPCs at $\sqrt{s_{NN}} = 200 \text{ GeV}$ in the dielectron channel [2]. The UPC events were triggered requiring (i) a cluster in the electromagnetic calorimeter (EMCal) above 0.8 GeV , (ii) a rapidity gap in one or both $3.0 < |j| < 3.9$ ranges, and (iii) at least 30 GeV energy deposited in one or both of the Zero-Degree Calorimeters (ZDCs). This last condition very efficiently selects ultra-peripheral events accompanied by forward neutron emission (X_n) coming from the electromagnetic dissociation of one (or both) Au nuclei, which occurs with a large probability, $P_{X_n} \approx 0.64$ (at $y = 0$) at RHIC energies [9]. Electron reconstruction is done combining the central tracking devices, Ring Imaging Cherenkov (RICH) counters, and the EMCal.

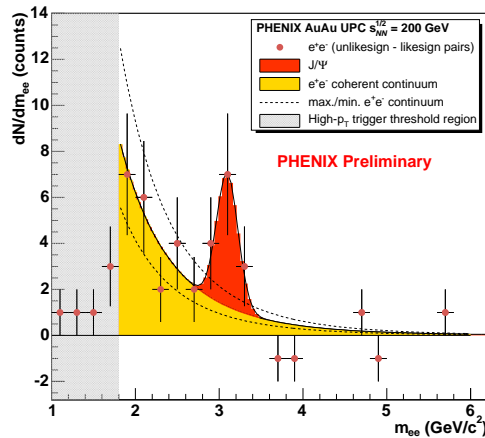


Figure 4: Invariant mass distribution of e^+e^- pairs measured in UPC Au-Au fitted to the combination of a J/ψ e^+e^- continuum plus a A-A J/ψ A signal [2].

The invariant mass distribution of all reconstructed e^+e^- pairs is shown in Fig. 4. The plot shows the expected $J/\psi \rightarrow e^+e^-$ continuum curve combined with a fit to a Gaussian at the J/ψ peak. The total number of J/ψ 's is 10 ± 3 (stat) ± 3 (syst.), where the systematic uncertainty is dominated by the dielectron continuum subtraction. Within the (still large) experimental errors, the preliminary J/ψ cross-section of $dN_{J/\psi}/dy|_{y=0.5} = 48 \pm 14$ (stat) ± 16 (syst) μb is consistent with various theoretical predictions [10, 11, 12, 13] (see Fig. 5, where the FGS and KST rapidity distributions have been scaled down according to [9] to account for the reduction of the yield expected when requiring coincident forward neutron emission). The band covered by the FGS predictions includes the J/ψ cross sections with and without gluon shadowing [11]. The current experimental uncertainties preclude yet any detailed conclusion regarding the nuclear gluon distribution. The possible contribution of an additional incoherent (\sim nucleon J/ψ) component (amounting to about 50% of the coherent (A) yield at $y = 0$ [11]) should be taken under consideration too.

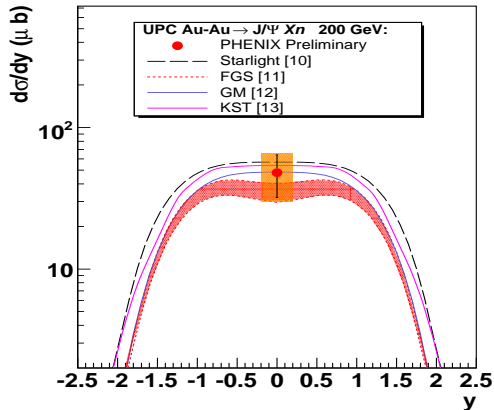


Figure 5: Preliminary cross-section of coherent J/ψ production at $y = 0$ in UPC Au-Au at $\sqrt{s_{NN}} = 200$ GeV compared to various theoretical calculations [10, 11, 12, 13].

4 photoproduction in Pb-Pb at the LHC (CMS)

At the LHC energies, the cross section for J/ψ photoproduction in UPC Pb-Pb at $\sqrt{s_{NN}} = 5.5$ TeV is of the order of 150 μb [10, 14]. Inclusion of leading-twist shadowing effects in the nuclear PDFs reduces the yield by up to a factor of two, $\sigma = 78 \mu\text{b}$ [14]. Even larger reductions are expected in calculations including gluon-saturation (Colour Glass Condensate) effects [15].

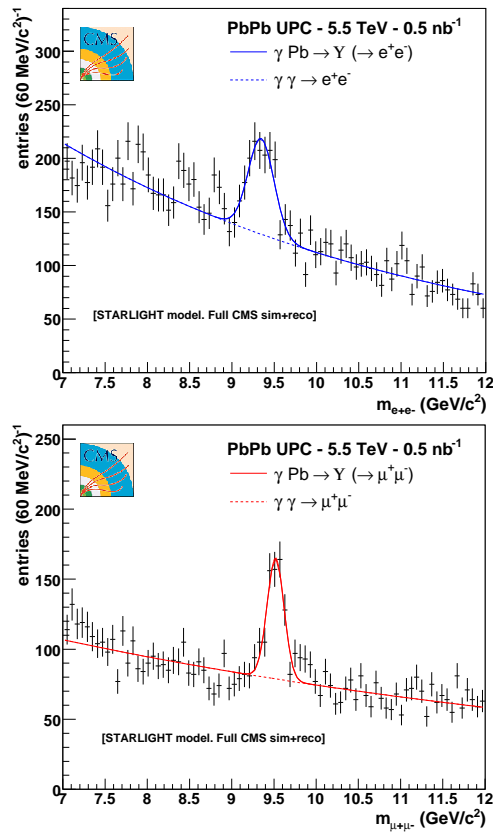


Figure 6: Expected e^+e^- (top) and $\mu^+\mu^-$ (bottom) invariant mass distributions from $Pb-Pb$ UPC at $\sqrt{s_{NN}} = 5.5$ TeV in CMS. The signal ($J/\psi \rightarrow l^+l^-$, signal) and $J/\psi \rightarrow l^+l^-$ (background) in UPC Pb-Pb at $\sqrt{s_{NN}} = 5.5$ TeV in CMS.

Full simulation+ reconstruction studies [3]

of input distributions generated with the starlight MC [10] have shown that CMS can measure $\sigma(e^+e^- \rightarrow \psi(2S))$ within $|j| < 2.5$, in UPCs tagged with neutrons detected in the ZDCs [16], with large efficiencies ($\epsilon_{\text{rec}} \sim 20\%$). Figure 6 shows the reconstructed $dN/dm_{T\perp}$ around the mass (only the ground-state, $1S$), of the bottomonium family was generated). The signal over continuum background is around one for both decay modes. The total expected number of events, normalised to the nominal 0.5 nb^{-1} Pb-Pb integrated luminosity, is ~ 500 , and the p_T resolution is good enough to separate the coherent (peaked at very low p_T , $M_V = 30 \text{ MeV}/c$) from the incoherent components. With such a statistics, detailed p_T studies can be carried out, that will help constrain the low- x gluon density in the nucleus.

5 Summary

High-energy quarkonia photoproduction provides a particularly useful means to constrain the poorly known low- x gluon distribution of the nucleus in the clean environment of ultra-peripheral (electron-positron) ion-ion collisions. Gluon saturation effects in the small- x domain of the nuclear wavefunction are expected to result in a suppression of hard exclusive di-jet yields relative to linear QCD expectations. We have presented preliminary PHENIX results of exclusive J/ψ photoproduction in 200-GeV Au-Au interactions, as well as the perspectives of the CMS experiment in 5.5-TeV Pb-Pb collisions at the LHC. In the absence of strong non-linear QCD effects, around 500 photo-produced J/ψ will be reconstructed in the CMS acceptance with nominal integrated luminosities.

Acknowledgments

My gratitude to the organisers of photon '07 conference (in particular Gerhard Baur and

Maarten Boonekamp) for their kind invitation and for the stimulating programme. Special thanks due to Joakim Nystrand for providing the starlight predictions and for useful discussions, as well as to Mark Strikman for informative exchanges. Work supported by the 6th EU Framework Programme contract MEIF-CT-2005-025073.

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