PROCEEDINGS OF SCIENCE

Coherent J/ψ photoproduction in ultra-peripheral collisions at STAR

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Ultra-peripheral nucleus-nucleus collisions (UPC) are mediated by strong electromagnetic fields, offering the opportunity to study photon-nucleus processes at RHIC. Coherent J/ψ photoproduction is of particular interest for its sensitivity to nuclear gluon distribution. The J/ψ mesons are heavy enough to be described by perturbative Quantum Chromodynamics (pQCD), where coherent cross section, at the first order, is proportional to the square of the nuclear gluon distribution. This makes coherent J/ψ cross section an ideal probe to phenomena of gluon saturation and nuclear gluon shadowing.

Here we present a brief overview of the topic and preliminary results of exclusive coherent J/ψ photoproduction in Au+Au UPC at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV at central rapidity $|y| < 1$, where the photoproduction was tagged at the trigger level by forward neutrons emitted as a result of electromagnetic excitation of the nuclei.

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1. Introduction

As an ultra-peripheral collision (UPC) we denote a collision taking place at impact parameter large enough to avoid the short range strong interactions. Such impact parameters are approximately greater than the sum of nuclear radii. Thanks to that the collision is mediated by strong electromagnetic forces. We can describe the field as a flux of quasi-real photons, which intensity is proportional to the square of the charge of the colliding ions.

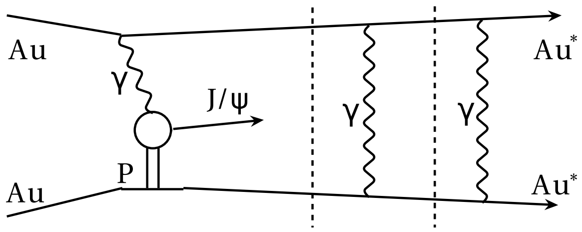


Figure 1: Photoproduction of J/ψ meson with additional photon exchange

Coherent photoproduction of vector mesons, Figure 1, in photo-nuclear interactions is of particular interest, because it is sensitive to gluon distribution of the target nucleus at low-x. The coherent process occurs when the photon couples coherently to the entire nucleus. Colliding nuclei are typically left intact by the photoproduction process, but may be excited by independent Coulomb excitation to emit very forward neutrons. Experimentally the J/ψ mesons are measured in their dielectron decays, $J/\psi \to e^+e^-$. Natural background to this process is two-photon production of dielectron pairs, $\gamma\gamma \to e^+e^-$. Physics of ultra-peripheral collisions is reviewed in Ref. [1, 2, 3].

2. Photoproduction of heavy vector mesons

Relatively large mass makes it possible to describe photoproduction of heavy vector mesons, such as the J/ψ, by means of perturbative QCD (pQCD). At the leading order the process is described by exchange of two gluons in a color singlet state. Momentum fraction of the probed gluons is given by the mass of the J/ψ ($M_{J/\psi}$) and the photon-nucleus center-of-mass energy, $W_{\gamma\mathrm{A}}$, as $x = (M_{J/\psi}/W_{\gamma\mathrm{A}})^2$. It is shown [4], that the photoproduction cross section is proportional to the square of nuclear gluons density at the scale Q^2 given by the mass of the J/ψ as $Q^2 = M^2_{J/\psi}/4$.

One of the possibilities to calculate the differential coherent J/ψ cross section as a function of rapidity and of the square of momentum transfer at the target nucleus, t, is based on the Glauber approach [5], implemented in the STARLIGHT event generator. Input to this calculation is experimental photon-nucleus cross section and Woods-Saxon nuclear profile, the cross section is then found by the vector meson dominance and convolution with the photon flux.

The next possibility which allows to introduce non-linear QCD phenomena via the Color-Glass Condensate is based on the dipole model [6, 7]. In the rest frame of the nucleus, the photon fluctuates into a quark-antiquark dipole, which then scatters off the nucleus, forming the final vector meson. The dipole models predict to observe characteristic diffractive minima and maxima in the coherent cross section measured as a function of $|t|$.

3. The STAR experiment at RHIC

For UPC measurements at STAR [8] we use tracking at midrapidity, $|\eta| < 1$, and particle identification provided by the Time Projection Chamber (TPC). To veto any additional non-UPC activity, we use the Barrel Electromagnetic Calorimeter (BEMC), covering approximately same midrapidity region as the TPC, and the Beam-Beam Counters (BBC) at the forward and backward rapidities, $2.1 < |\eta| < 5.2$. Forward neutrons from mutual Coulomb excitation are detected by the Zero Degree Calorimeters (ZDC), $|\eta| < 6.6$. The trigger for UPC processes is based on BEMC, BBC and ZDC.

4. Trigger and data selection for coherent J/ψ

Selection criteria for coherent J/ψ are aimed to select events with only two tracks from the J/ψ dielectron decay. The situation is schematically shown in Figure 2. Assuming very low transverse momentum p_T of the J/ψ, the tracks are oriented in a back-to-back topology. The trigger for the J/ψ is set for such events with back-to-back pattern in the BEMC, limited activity in the TOF, and for no signals in both BBCs. The trigger also requires showers in both ZDCs.

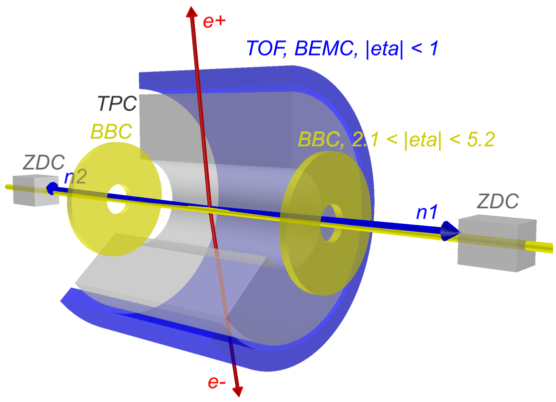


Figure 2: Measurement of dielectron decays of the J/ψ with the STAR detector

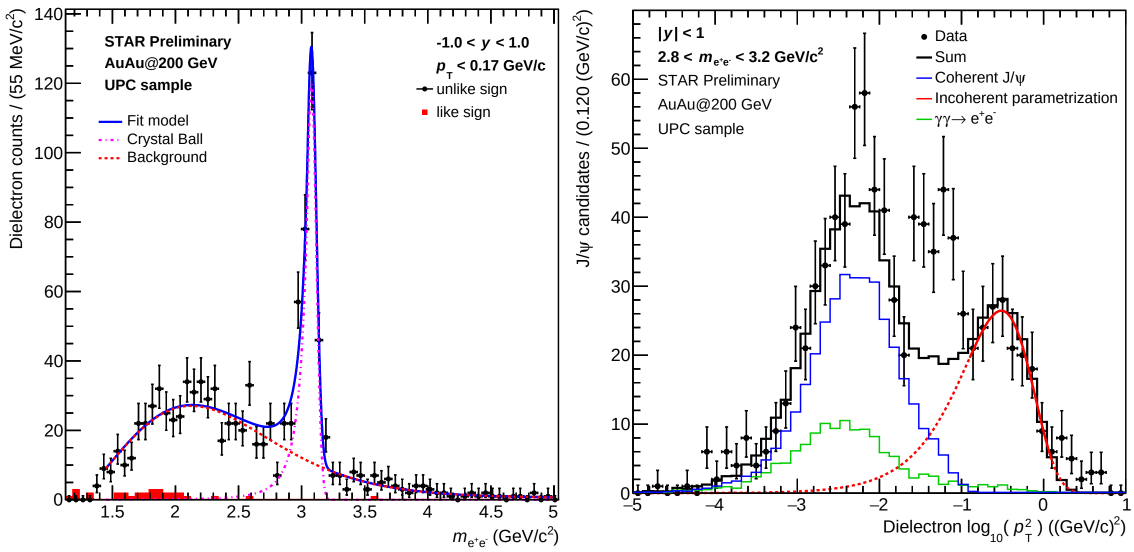
5. Signal extraction

Invariant mass of all selected e^+e^- pairs is shown in Figure 3a. The pairs correspond to a coherent-enriched sample at $p_T < 0.17$ GeV/c. The distribution shows a clean J/ψ signal atop the expected background from the $\gamma\gamma \to e^+e^-$. Background from like-sign $e^\pm e^\pm$ combinations is also given in the plot, the amount is negligible and occurs at masses lower than the J/ψ.

The fit is performed using the Crystal Ball function [9] for the J/ψ and with the following empirical parametrization for the $\gamma\gamma \to e^+e^-$:

$$f_{\gamma\gamma\to e^+e^-}(m) = (m - c_1)e^{\lambda(m-c_1)^2 + c_2 m^3} \tag{5.1}$$

where the λ, c_1 and c_2 constants are free parameters to the fit.



(a) (b)

Figure 3: Reconstructed mass (a) and $\log_{10}(p_T^2)$ (b) of selected e^+e^- candidates

The signal of coherent J/ψ is obtained by subtracting background from $\gamma\gamma \to e^+e^-$ and from incoherent J/ψ.

The amount of $\gamma\gamma \to e^+e^-$ background is constrained using the mass fit in Figure 3a. The parametrization in Equation 5 is integrated over the region of the J/ψ, giving thus the expected number of the $\gamma\gamma \to e^+e^-$ events. Particular p_T shape of the $\gamma\gamma \to e^+e^-$ background component was provided by STARLIGHT.

The incoherent background component was obtained by fitting the $\log_{10}(p_T^2)$ distribution in Figure 3b. The distribution is taken for the J/ψ candidates, defined as events within the J/ψ mass region $2.8 < m_{e^+e^-} < 3.2$ GeV/c^2. The fit is performed using:

$$f_{\text{incoherent}}(p_T^2) = A \cdot e^{-bp_T^2} \tag{5.2}$$

where A and b are the free fit parameters. The fit was done over the incoherent region, shown as a straight line in Figure 3b. The formula in Equation 5.2 was given in terms of $\log_{10}(p_T^2)$ to perform the fit.

Figure 3b also shows the shape of $\gamma\gamma \to e^+e^-$ background, already normalized according to the mass fit, and the shape of coherent J/ψ, as simulated using STARLIGHT and folded by a complete detector simulation.

6. Coherent J/ψ cross section as a function of t

Coherent J/ψ cross section at midrapidity ($|y| < 1$) and as a function of $|t|$ was calculated as:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}|t|\mathrm{d}y} = \frac{N_{J/\psi}^{\text{coh}}}{A \times \varepsilon \cdot \mathscr{B} \cdot \mathscr{L}} \cdot \frac{1}{\Delta|t|\Delta y} \tag{6.1}$$

where $N^{\rm coh}_{J/\psi}$ is the number of coherent candidates after subtracting the $\gamma\gamma \to e^+e^-$ and incoherent background in a given bin of $|t|$, $A \times \varepsilon$ is detection acceptance and efficiency, $\mathscr{B}$ is branching ratio of J/ψ dielectron decays, $\mathscr{L}$ is an integrated luminosity of the data sample and $\Delta|t|$ and Δy is the width of $|t|$ and rapidity intervals.

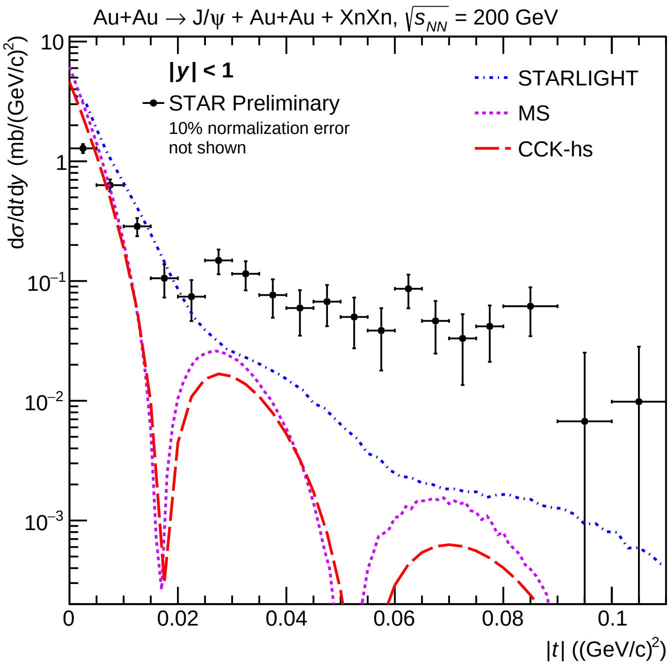


Figure 4: Coherent J/ψ photoproduction cross section as a function of $|t|$

Figure 4 shows the measured coherent J/ψ cross section in Au+Au ultra-peripheral collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV with neutron emission (denoted as XnXn). The data show a diffractive dip at around $|t| = 0.02$ GeV^2, which is consistent with the previous analysis on coherent ρ^0 photoproduction [8].

The data are compared to several theoretical predictions. The slope at very low $|t|$, below the first diffractive minimum, is correctly described by STARLIGHT [5]. Dipole-based models by Mäntysaari and Schenke (MS) [6] and by Cepila, Contreras and Krelina (CCK) [7] correctly predict the position of the diffractive dip.

7. Conclusions

The STAR experiment has provided the first measurement on the $|t|$ dependence of coherent J/ψ cross section at $\sqrt{s_{\rm NN}}$ = 200 GeV. The data were collected using a dedicated trigger aimed for back-to-back dielectron from J/ψ decays in the ultra-peripheral collisions.

The data show a diffractive structure, correctly predicted by models based on the dipole approach.

References

[1] C. A. Bertulani, S. R. Klein, and J. Nystrand, "*Physics of ultra-peripheral nuclear collisions*," *Ann.Rev.Nucl.Part.Sci.* **55** (2005) 271–310, [nucl-ex/0502005].

[2] A. Baltz *et al.*, "*The Physics of Ultraperipheral Collisions at the LHC*," *Phys.Rept.* **458** (2008) 1–171, [0706.3356].

[3] S. Klein and J. Nystrand, "*Ultraperipheral nuclear collisions*," *Phys. Today* **70** no.~10, (2017) 40–47.

[4] M. Ryskin, "*Diffractive J/ψ electroproduction in LLA QCD*," *Z.Phys.* **C57** (1993) 89–92.

[5] S. R. Klein, J. Nystrand, J. Seger, Y. Gorbunov, and J. Butterworth, "*STARlight: A Monte Carlo simulation program for ultra-peripheral collisions of relativistic ions*," *Comput. Phys. Commun.* **212** (2017) 258–268, [1607.03838].

[6] H. Mäntysaari and B. Schenke, "*Probing subnucleon scale fluctuations in ultraperipheral heavy ion collisions*," *Phys. Lett.* **B772** (2017) 832–838, [1703.09256].

[7] J. Cepila, J. G. Contreras, and M. Krelina, "*Coherent and incoherent* J/ψ *photonuclear production in an energy-dependent hot-spot model*," *Phys. Rev.* **C97** no.~2, (2018) 024901, [1711.01855].

[8] **STAR** Collaboration, L. Adamczyk *et al.*, "*Coherent diffractive photoproduction of rhoZero mesons on gold nuclei at 200 GeV/nucleon-pair at the Relativistic Heavy Ion Collider*," *Phys. Rev.* **C96** no.~5, (2017) 054904, [1702.07705].

[9] J. Gaiser, *Charmonium Spectroscopy From Radiative Decays of the J/ψ and ψ'*. PhD thesis, SLAC, 1982. www.slac.stanford.edu/cgi-wrap/getdoc/slac-r-255.pdf.