Ultra-peripheral collisions in STAR

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Abstract

A collision occurring at impact parameter larger than the sum of nuclear radii is denoted as an Ultra-Peripheral Collision (UPC). Such a collision is mediated by electromagnetic forces, because hadronic interactions are strongly suppressed. Ultra-relativistic heavy ions allow to study of photon-nucleus and photon-photon collisions, providing a sensitive probe of phenomena of gluon shadowing, nuclear diffraction and fundamental quantum electrodynamics. Here we report on the STAR measurements of coherent photoproduction of ρ^0 and J/ψ mesons and of exclusive photoproduction of e^+e^- pairs in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV

Keywords

ultra-peripheral collisions; STAR; ρ^0 photoproduction; diffraction; gluon shadowing.

1 Introduction

Electromagnetic fields of ultra-relativistic heavy ions are described as a flux of virtual photons. The flux of such photons is proportional to the square of the electric charge. Photoproduction of vector mesons in UPC is described by (i) photon fluctuation to a virtual quark-antiquark pair and (ii) interaction of the pair on the nuclear target. The ρ^0 and J/ψ mesons provide photoproduction reactions at different scales, given by their masses. Reviews of UPC physics can be found in Refs. [1, 2].

The diagram for ρ^0 photoproduction is shown in Fig. 1. In addition to the photoproduction process, one or both nuclei may excite to Giant Dipole Resonances (GDRs) [3] or higher resonances, as also shown in Fig. 1. Those resonances decay by emitting one more neutrons, which allows to tag the UPC events experimentally.
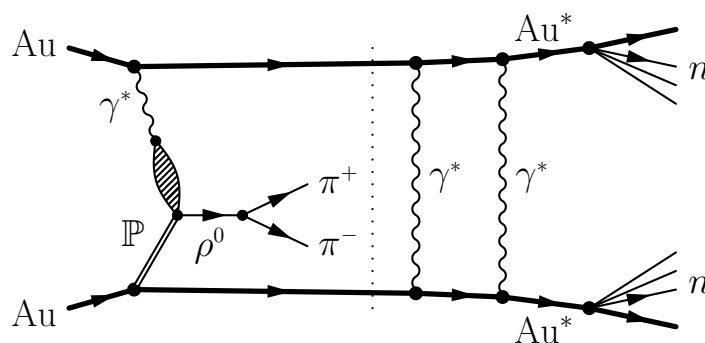

Fig. 1: Photoproduction of ρ^0 meson accompanied by additional photon exchange.

2 The STAR experiment at RHIC

UPC measurements at STAR [4] use tracking and particle identification in the Time Projection Chamber (TPC), covering central rapidities $|\eta| < 1$, the Time of Flight Detector (TOF) to select tracks belonging

to the current event, the Beam-Beam Counters (BBC) to veto non-UPC activity at forward (backward) rapidities $2.1 < |\eta| < 5.2$ and very forward Zero-Degree Calorimeters (ZDC), $|\eta| > 6.6$, to detect neutrons from additional photon excitations. The trigger for UPC is based on inputs from BBC, TOF and ZDC.

3   Coherent photoproduction of ρ^0 mesons

Coherent photoproduction occurs when the photon interacts with the whole nucleus. Recent results on coherent ρ^0 photoproduction are given in Ref. [4]. Theoretical calculations of coherent photoproduction cross section can be done with a quantum Glauber model [5].

Selection criteria are aimed to select events with just two tracks from the decay $\rho^0 \to \pi^+\pi^-$. The invariant mass distribution of $\pi^+\pi^-$ pairs is shown in Fig. 2, with a fit by a modified Söding parameterization [6]. The fit includes Breit-Wigner resonances for ρ^0 and for ω mesons, where the contribution of the ω is needed to get an acceptable fit.
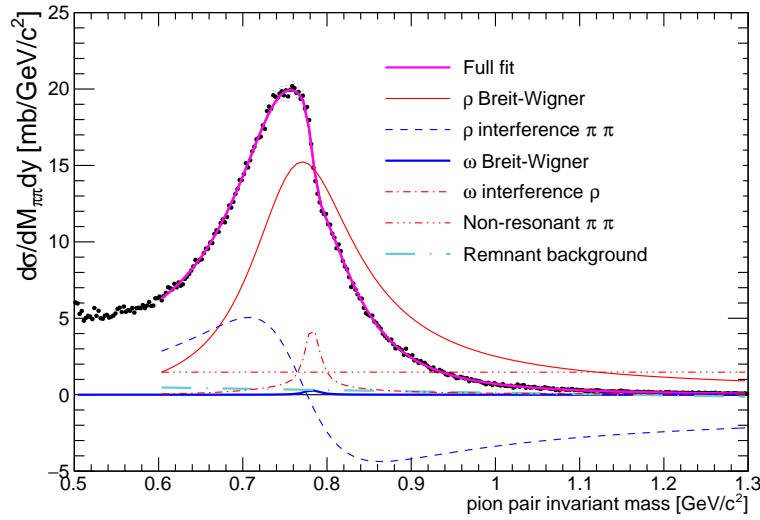

Fig. 2: Invariant mass of selected $\pi^+\pi^-$ candidates with transverse momentum $p_T < 100$ MeV/c [4].

Relative amplitudes of non-resonant $\pi^+\pi^-$ and ρ^0 (B/A), and of ω and ρ^0 (C/A) are shown in Fig. 3 as a function of $\pi^+\pi^-$ rapidity. The rapidity is kinematically related to the photon energy; the rapidity distribution therefore provides energy dependence of the ratios. The only previous data on C/A come from the DESY-MIT experiment [7] at lower photon energies corresponding to rapidity $y = -2.5$. The ratio C/A is well described by STARlight [8].

The coherent ρ^0 cross section as a function of $-t$ in Fig. 4 shows characteristic diffractive dips. Two categories of neutron emission are present, 1n1n for one neutron emitted on each side and XnXn for at least one neutron on each side. The positions of diffractive dips at $-t = 0.018 \pm 0.005$ GeV^2 and $-t = 0.043 \pm 0.01$ GeV^2 are correctly predicted by a quantum Glauber calculation without nuclear shadowing correction [5]. A fit by an exponential function is performed below the first peak; the slope of the fit is proportional to the nuclear size, and the result is consistent with ALICE data [9] at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV. The inset in Fig. 4 for very small $-t$ shows the effect of destructive interference between production on the two nuclei.

4   Photoproduction of J/ψ

Photoproduction of J/ψ occurs at a harder scale given by the mass of the J/ψ. The process is described by two-gluon exchange, where the photon fluctuates to a dipole of a $c\bar{c}$ pair and the dipole interacts with the target nucleus. Coherent J/ψ photoproduction has recently been measured at the LHC [10, 11].
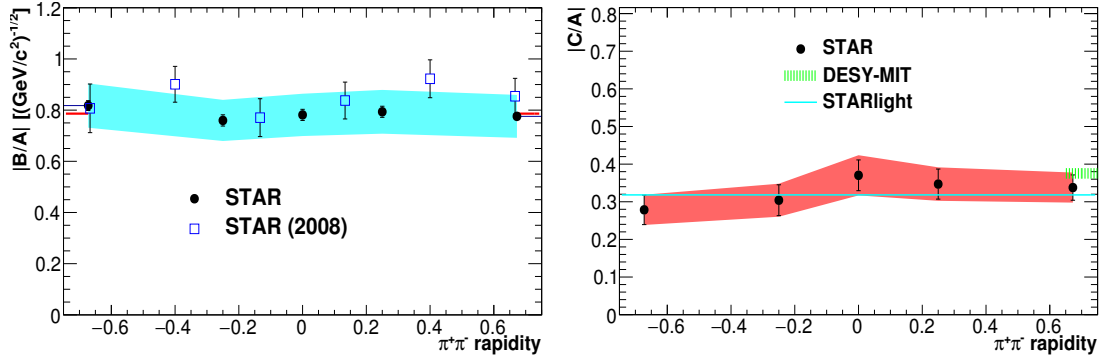
Fig. 3: Ratios of amplitudes of non-resonant $\pi^+\pi^-$ and ρ^0 (top) and ω and ρ^0 (bottom) [4]. The red line is the rapidity-averaged result.
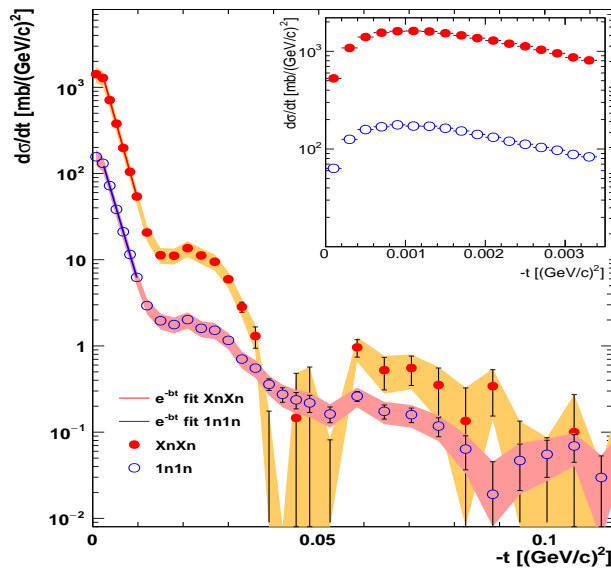

Fig. 4: Cross section for coherent ρ^0 vs. $-t$ for 1n1n and XnXn events [4].

Nuclear gluon shadowing at low Bjorken-x can be studied using the data on coherent J/ψ photoproduction by extracting the nuclear suppression factor S, defined as a ratio of measured photon-nucleus cross section to a calculation in impulse approximation. The effect of shadowing is observed as a partial depletion of the nuclear (w.r.t. nucleon) gluon density. Previous experimental and theoretical results on $S_{\rm Pb}$ are given in Fig. 5. STAR probes the gluon distribution at $x \approx 0.015$.

Selection criteria for $J/\psi \to e^+e^-/\mu^+\mu^-$ are similar to those for ρ^0, to get events with just two tracks corresponding to dilepton pairs. In this case the very central rapidity region $|y| < 0.02$ is excluded to prevent cosmic background. The data provide a clean J/ψ signal and expected background from two-photon production of dilepton pairs.

The cross section of J/ψ as a function of transverse momentum is shown in Fig. 6. A coherent peak at low p_T is followed by a tail from incoherent production at higher values of p_T. Shape of the coherent peak in the region $p_T < 0.15$ GeV/c is consistent with STARlight estimation.

5 Two-photon production of electron-positron pairs

The photoproduction reaction $\gamma\gamma \to e^+e^-$ is a probe of quantum electrodynamics and the description of fields by a flux of virtual photons. The cross section of $\gamma\gamma \to e^+e^-$ is given by Breit-Wheeler for-

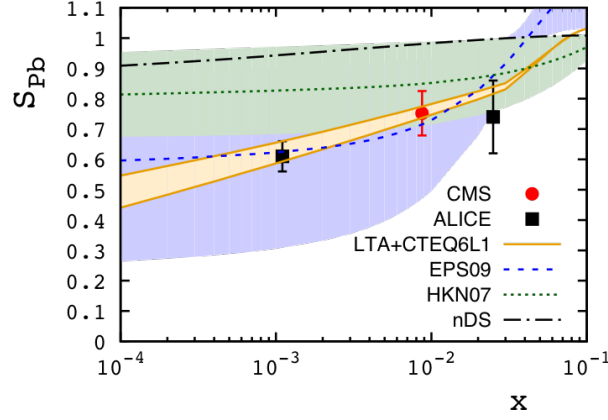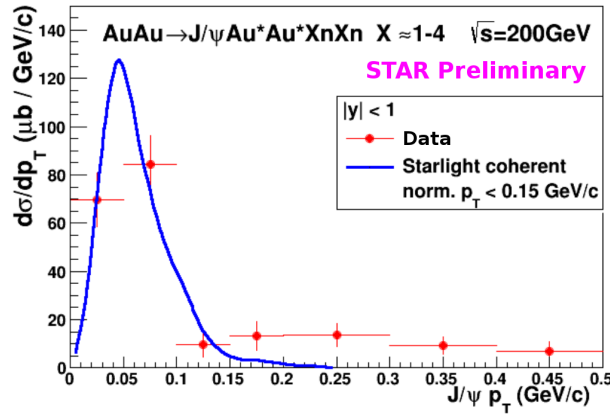**Fig. 5:** Nuclear shadowing obtained from the LHC data and comparison to theoretical models [12].

Fig. 6: J/ψ cross section as a function of p_T. Error bars represent statistical uncertainties.

mula [13], and the cross section for e^+e^- pairs in nucleus-nucleus collisions is obtained by convolution of elemental cross section with photon fluxes of the nuclei [8]. Selection criteria for e^+e^- pairs are similar to those of the ρ^0 mesons, to get two-track events in an otherwise empty detector (except very forward neutrons). About 13000 of e^+e^- candidates were selected and only $\sim$10 like-sign candidates are present in the data, manifesting thus a very clean signal.

The distributions of invariant masses and p_T of selected e^+e^- candidates are shown in Fig. 7. There is exponential decrease of the yield with increasing mass of the e^+e^- pairs, given by the nature of the cross section. Also a signal of $J/\psi \rightarrow e^+e^-$ is present. The p_T distribution is consistent with an expected peak at low-p_T.

6 Conclusions

The STAR experiment has measured coherent photoproduction of ρ^0 mesons using a high statistics sample of $\rho^0 \rightarrow \pi^+\pi^-$ events [4]. Ratios of amplitudes of non-resonant $\pi^+\pi^-$ and ρ^0 and of ω and ρ^0 have been measured as a function of $\pi^+\pi^-$ rapidity. In the case of ω to ρ^0 amplitude, the only previous data were obtained at much lower photon energies. The cross section of coherent ρ^0 as a function of $-t$ shows diffractive dips, which were compared to a theoretical Glauber prediction.

Currently work is in progress in obtaining the cross sections of J/ψ and e^+e^- pairs, with newly reconstructed data samples. The results will help in the understanding of nuclear effects on gluon density in the transition region from shadowing to non-shadowing in the case of the J/ψ, and the mechanism of
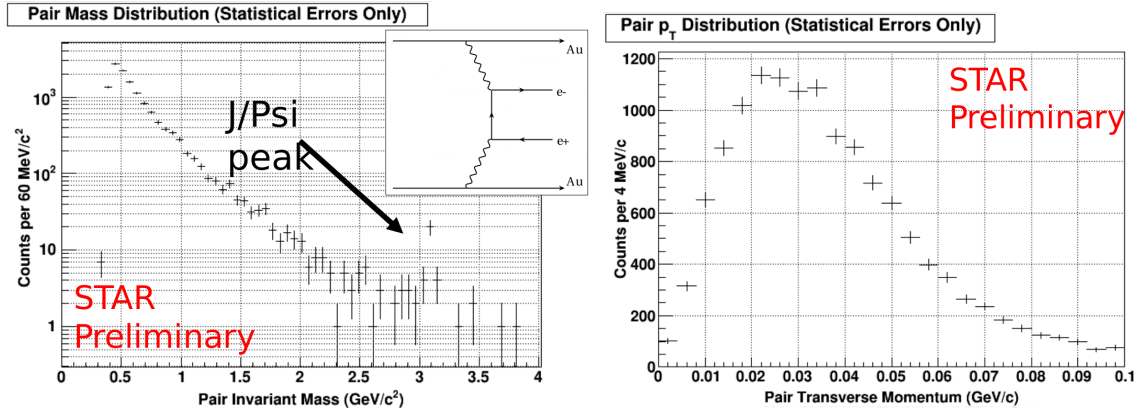
Fig. 7: Uncorrected e^+e^- invariant mass distribution (left) and transverse momentum (right) of selected electron-positron candidates. The diagram in the inset shows $\gamma\gamma \to e^+e^-$ production in Au+Au.

photon fluxes in the case of the e^+e^- pairs.

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