ULTRAPERIPHERAL J/Ψ AND DI-ELECTRON PRODUCTION AT RHIC (PHENIX)

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Ultra-relativistic protons and heavy ions carry with them strongly boosted electromagnetic fields, which act as an equivalent flux of photons. At impact parameters where hadronic collisions are not possible ($b > 2R_A$), the ions still interact through photon-ion and photon-photon collisions. These interactions are known as Ultra-Peripheral Collisions (UPC), and are expected to occur at high rates in hadron colliders such as RHIC, the Tevatron, and eventually the LHC. We present a measurement of the photonuclear production of J/Ψ and high-mass dielectrons with the PHENIX detector at RHIC.

1. Introduction

Measurements at HERA of exclusive vector meson photoproduction have contributed significantly to our understanding of the proton's structure. The use of Ultraperipheral Collisions (UPC), where the the nuclei do not overlap, can be used to extend these studies to hadron colliders, since photons are produced copiously from the boosted electro-magnetic fields of the hadrons. For instance, at the LHC the rates for $\gamma + p$ and $\gamma + Pb$ collisions will push beyond the HERA limits in a single one month run[1].

An additional benefit is that the cross-section for heavy vector meson ($J/\Psi or \Upsilon$) photoproduction depends *quadratically* on the gluon density [2,3]:

$$\left.\frac{d\sigma(\gamma + A \rightarrow V\, A)}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xG_A(x,Q^2)\right]^2 \quad (1)$$

with $Q^2 = M_V^2/4$ and $x = M_V^2/W_{\gamma+A}^2$. Also, the probability of rescattering or absorption of the $Q\overline{Q}$ pair as it traverses the nucleus can be probed in these collisions. The study of quarkonia production in $\gamma + A$ collisions at RHIC or LHC energies is thus considered an excellent probe of (i) the gluon distribution function $G_A(x, Q^2)$ in nucleons and nuclei, and (ii) vector-meson dynamics in nuclear matter.

2. Experimental Setup and Analysis

The data shown here were taken with the PHENIX detector at RHIC during the Run04 Au+Au run, at a beam energy per nucleon of $\sqrt{s_{NN}} = 200$ GeV. To reject hadronic interactions, which are a background to this measurement, a veto on coincident signals in the beam-beam counters (BBC) is used. Electrons are triggered with 2×2 tower sums in the EMC above a threshold of 0.8 GeV. However, high non-physics backgrounds are often generated by a heavy ion collider, such as particles coming from upstream beam-pipe interactions far from the collision vertex, and routinely trigger this relatively low EMC threshold. To overcome these backgrounds at the trigger level, in association with exclusive vector-meson production or dielectron continuum production, one also can require coulomb exchange from the strong field of quasi-real photons from the passing nuclei. These photons very effectively cause 1 or 2 neutron emission from the struck nucleus, and are triggered with the presence of an energy deposit in the Zero-Degree Calorimeters (ZDC). The trigger used in PHENIX is therefore

$$Trigger(UPC) = (EMC \geq 0.8GeV)(ZDC(N)||ZDC(S))(\overline{BBC}) \quad (2)$$

The lowest order diagram for these coulomb tagged J/Ψ production is shown in figure 1. Several calculations of the photoproduction calculation

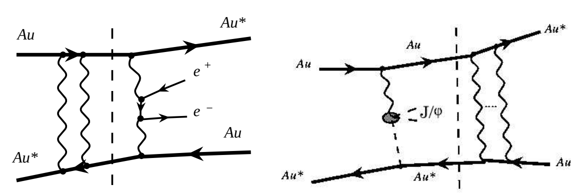

Figure 1. Lowest order Feynman diagrams for J/Ψ (left) and dielectron pair (right) production in $\gamma + \gamma$ and $\gamma + A$ processes accompanied by Au Coulomb excitation in ultra-peripheral Au+Au collisions.

with the coloumb exchange tag can be found in the literature [4,5,6]. The UPC triggered events constitute just 0.5% of the Au+Au hadronic event rate, putting it well below the maximum bandwidth of the DAQ.

Within this data sample electrons are identified using associations with the RICH, and track association with a good cluster in the EMC. More details on the analysis techniques can be found elsewhere [8,9].

3. Results

The invariant mass distribution and p_T distribution are shown in fig. 2. The J/Ψ mass is measured to be $m_{J/\Psi} = 3.095 \pm 130$ MeV, in agreement with the PDG value. The number of J/Ψ reconstructed is $N_{J/\Psi} = 10 \pm 3(stat) \pm 3(syst)$.

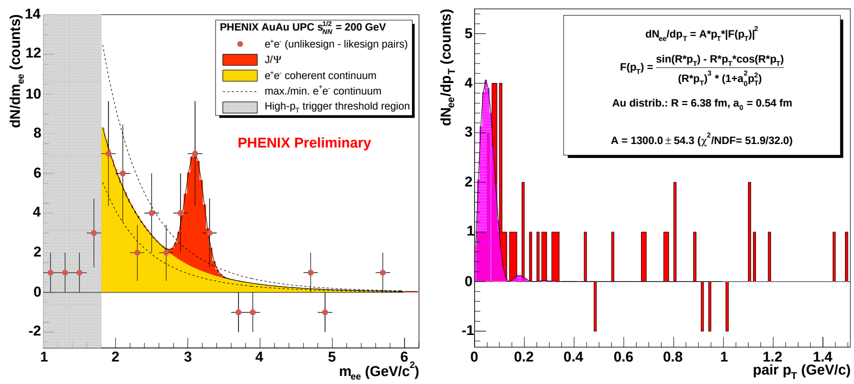

Figure 2. The invariant mass distribution of e^+e^- pairs in UPC Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The distribution is fit with a gaussian J/Ψ signal and a power-law di-electron continuum. The dashed curves are the maximum and minimum continuum contributions considered in this analysis. The right figure is the p_T distribution of di-electron pairs, and is overlaid with the nuclear form factor for gold.

The final cross-section for coherent J/Ψ photoproduction at midrapidity in UPC Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and accompanied by Au breakup is:

$$\left.\frac{d\sigma_{UPC\ J/\Psi}}{dy}\right|_{|y|<0.5} = \frac{1}{BR_{J/\Psi\rightarrow\ ee}} \cdot \frac{N_{J/\Psi}}{Acc \cdot \varepsilon_{reco} \cdot \varepsilon_{trig} \cdot L_{int}} \cdot \frac{1}{\Delta y} \tag{3}$$
$$= 48. \pm 14.\ (\text{stat}) \pm 16.\ (\text{syst})\ \mu b.$$

The theoretical calculations for coherent production, in which the photons interaction with the nucleus as a whole, are based on factorizations of the equivalent photon flux, the nucleus form factor, the nucleus gluon distribution, parameterizations of photonuclear production from HERA data, and assumptions on the J/Ψ+N scattering cross-section. In the case of incoherent production, the interactions of the equivalent photon with individual nucleons in the nucleus is taken into account. More data will be needed to evaluate the differences between the different theoretical calculations.

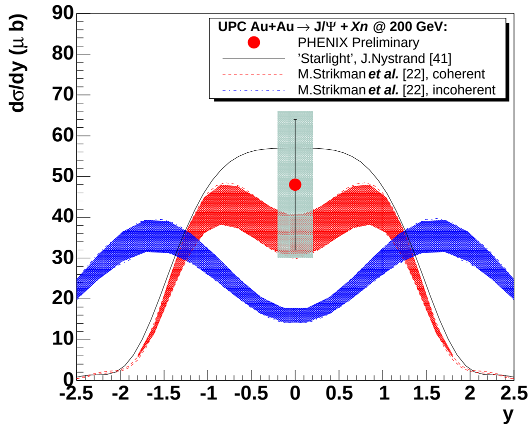

Figure 3. J/Ψ cross-section from UPC production in Au+Au collisions. The cross-section is compared to various theoretical calculations [5,7]. The curves from ref. [7] are scaled by the nuclear breakup probability from Coulomb excitation of 0.64.

Future Au+Au runs will see a 10-fold increase in statistics at RHIC, as well as the possibility to extend measurements to higher rapidity with $J/\Psi \rightarrow \mu^+\mu^-$ into the PHENIX muon arms. The incoherent signal is expected to dominate at forward rapidities. Besides the UPC program at RHIC, these measurements can be pursued at the LHC, where the $\gamma + p$ and $\gamma + A$ luminosities, as well as the center of mass energy, will be over 10 times higher.

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