Measurements of exclusive J/ψ photoproduction in Au+Au ultra-peripheral collisions at RHIC

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Exclusive coherent and incoherent J/ψ photoproduction in Au+Au ultra-peripheral collisions (UPC) are measured at $\sqrt{s_{\rm NN}} = 200$ GeV using the STAR detector. Measurements of the differential cross sections as functions of rapidity y and $p_{\rm T}^2 \approx -t$ of the J/ψ are reported. Results for different combinations of neutron emission, detected in zero degree calorimeters, are also presented. The different neutron emissions enable the resolution of the photon energy ambiguity inherent in UPCs, allowing measurement of the coherent cross section of $\gamma + {\rm Au} \to J/\psi + {\rm Au}$ as a function of the photon-nucleon center-of-mass energy $W_{\gamma {\rm N}}$. For the first time at the top RHIC energy, the momentum transfer $-t$ of J/ψ photoproduction is measured up to 2.25 $({\rm GeV/c})^2$, where the large $-t$ region is dominated by incoherent production. The incoherent J/ψ photoproduction measurements strongly suggest the presence of sub-nucleonic shape fluctuations in heavy nuclei, which is a major step forward towards understanding the initial-state dynamics of heavy-ion collisions. Both the coherent and incoherent J/ψ cross sections are found to be strongly suppressed relative to those of $\gamma + p \to J/\psi + p$. Within the kinematic range $x_{\rm parton} \sim 0.015 - 0.03$, the reported data provide important experimental constraints for nuclear parton distribution functions. The outlook for significantly improved measurements during the final RHIC runs in 2023-2025 is discussed. These measurements also demonstrate the potential opportunities and challenges of performing gluon tomography measurements via coherent vector meson production at the upcoming Electron-Ion Collider.