Charmonium and e^+e^- photoproduction in UPCs at STAR

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Introduction



- Results from very recent PRL and PRC submissions arXiv:2311.13637 and arXiv:2311.13632 on photoproduction in Au+Au will be shown here
- Exclusive J/ψ , $\psi(2S)$ and $\gamma\gamma \rightarrow e^+e^-$ production at $\sqrt{s_{\rm NN}}$ = 200 GeV measured by STAR
- Coherent and incoherent J/ψ photoproduction and γγ → e⁺e⁻ pair production associated with neutron emission
- $\psi(2S)$ photoproduction and its ratio to J/ψ cross section
- Coherent J/ψ cross section vs. photon-nucleus CM energy without photon energy ambiguities

The STAR experiment

• Central tracking and particle identification, forward counters and neutron detection



- Time Projection Chamber: tracking and identification in $|\eta| < 1$
- Time-Of-Flight: multiplicity trigger, particle identification and pile-up track removal
- Barrel ElectroMagnetic Calorimeter: topology trigger and pile-up track removal
- Beam-Beam Counters: scintillator counters in 2.1 < $|\eta|$ < 5.2, forward veto
- Zero Degree Calorimeters: detection of very forward neutrons, $|\eta| > 6.6$

Neutron tagging by ZDCs

- Single-neutron at 50 ADC, full range up to ~80 neutrons
- Separation between no activity and at least one neutron (dashed line)
- Classes for neutron emission corrected for migrations:

No signal in ZDCs

0n0n



Additional class all n as a sum of all, 0n0n, 0nXn and XnXn (meaning no requirement on ZDC)

is empty

Mass and p_T of selected dielectron candidates

- Coherent enriched sample below p_T = 0.15 GeV
- No requirement on ZDC (all n)
- Fit by MC templates folded by complete detector simulation



- The templates include: coherent J/ψ and ψ(2S), incoherent J/ψ w/o dissociation, feed-down from ψ(2S)→J/ψ+X and QED γγ → e⁺e⁻
- Fit results are used to extract signal of individual processes

J/ψ photoproduction cross section in -t ($\approx p_T^2$)

- Mid-rapidity |y| < 1, average $W_{\gamma N} = 25 \text{ GeV}$
- Coherent peak at low p_T^2
- Incoherent photoproduction at larger p²_T (decreasing exponential)
- Better agreement with data is found for Sartre and LTA calculations in data/MC ratios



Additional 10% luminosity uncertainty is not shown

Rapidity dependence of J/ψ photoproduction cross section

- Coherent and incoherent photoproduction and their ratio
- Enhancement of incoherent cross section with neutron emission
- Neutrons in the coherent process are emitted by additional Coulomb excitation
- Neutrons in the incoherent process are also the result of hard scattering





Interference in J/ψ photoproduction



- Region of the lowest $p_T^2 < 0.01 \text{ GeV}^2$, almost all production is coherent
- Bins in rapidity, *all n* neutron category
- Interference due to the symmetry of Au+Au collisions
- Suppression by more than 0.5 in the lowest p_T^2 bin
- Calculations which include the interference agree with the data

arXiv:2311.13632



J/ψ photoproduction with no neutron emission

- No neutron emission (0n0n) and neutrons in both ZDCs (*all n*)
- For coherent process, change between (*all n*) and 0n0n makes difference in photon flux (40% ratio in cross section)
- Additional neutron emission with incoherent process (cross section ratio 10-20%)
- First data on incoherent J/ψ with nuclear breakup; important to tune models for e+A at the EIC, e.g. BeAGLE model on the plot



Cross section of incoherent J/ψ photoproduction

- Cross section vs. p²_T above 0.02 GeV², full mid-rapidity, *all n* class
- Comparison to H1 ep data scaled to the given $W_{\gamma N}$
- Fit to STAR data with H1 template, only the normalization is a free parameter
- Incoherent cross section is suppressed vs. photoproduction off a free proton
- Cross section dependence on p²_T between the bound and the free proton is similar



Coherent and incoherent 0nXn neutron class

- Neutron emission in one side, no ZDC hit in the other (0nXn class)
- Positive rapidity y is defined along the direction of produced neutron(s)
- No effect of neutron direction to coherent process (independent Coulomb nuclear excitation)
- Increase in incoherent production in the neutron direction (nuclear breakup directly in incoherent process)
- BeAGLE calculation gives same increasing trend as the data, first experimental validation



Coherent J/ψ photoproduction vs. $W_{\gamma N}$

- Values for σ_{coherent} are obtained after solving the two-way ambiguity by making use of the forward neutrons (0n0n, 0nXn, XnXn)
- Significant suppression w.r.t. the Impulse Approximation (IA) is observed
- LTA with weak shadowing describes the data



Nuclear suppression factor

- Coherent suppression *S*^{Au}_{coh} is determined relative to the IA
- Incoherent suppression S^{Au}_{incoh} is a ratio of all n cross section to HERA parametrization for free protons
- Stronger incoherent suppression is found than in the coherent case
- Bands for LTA model span between weak and strong shadowing
- CGC is shown at its kinematic limit for x > 0.01



arXiv:2311.13637

Coherent $\psi(2S)$ photoproduction vs. rapidity

- Coherent ψ(2S) and J/ψ cross section in bins of |y| and their ratio
- Case of all n neutron category
- The ratio is correctly predicted by STARlight





arXiv:2311.13632

Cross section of $\gamma\gamma ightarrow e^+e^-$ pair production

- Cross section as a function of dielectron mass
- Individual neutron emission categories
- New data up to m_{ee} of 6 GeV, addition to previous results at lower masses



 Models are consistent with data in all neutron categories, confirming relation between photon flux and neutron emission in mutual Coulomb excitation

arXiv:2311.13632

Summary

- Set of neutron emission categories 0n0n, 0nXn and XnXn for coherent and incoherent J/ψ photoproduction as a function of p²_T and |y| and for γγ → e⁺e⁻ production
- Resolution for photon energy ambiguity for coherent J/ψ cross section as a function of photon-nucleus center-of-mass energy
- Notable dependence of incoherent production on neutron direction, no such dependence for coherent production
- Strong direction correlation between incoherent J/ψ and forward neutrons, while no such correlation is seen between coherent J/ψ and forward neutrons
- RHIC + STAR kinematics probes region of nuclear modification effects to gluon density
- Importance to tuning eA models for the EIC

BACKUP

Trigger and selection criteria for $J/\psi ightarrow e^+e^-$

Au+Au data sample

- Data taking in 2016
- Integrated luminosity 13.5 nb⁻¹
- Approx. 24 imes 10⁶ UPC J/ψ triggers

Trigger definition

- BEMC energy depositions of ${\approx}0.7~\text{GeV}$ in back-to-back azimuthal sextants
- TOF multiplicity from 2 to 6 hits
- No signal in both BBCs

Event selection

• No more than 6 significant energy deposits in BEMC

Selection for single tracks

- Track extrapolates to BEMC energy deposit
- At least 15 TPC points and at least 11 points for dE/dx

Requirements for track pair

- Vertex is within 100 cm of STAR nominal interaction point
- d*E*/dx *e* and π hypotheses as $\chi^2_{ee} = n^2_{\sigma,e1} + n^2_{\sigma,e2} < 10$ and $\chi^2_{ee} < \chi^2_{\pi\pi}$
- Opposite sign