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

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Jaroslav Adam
Czech Technical University in Prague
For the STAR Collaboration

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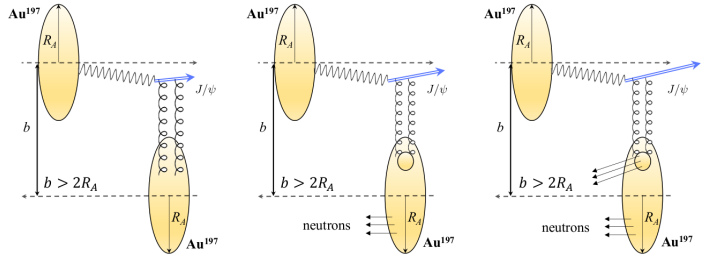
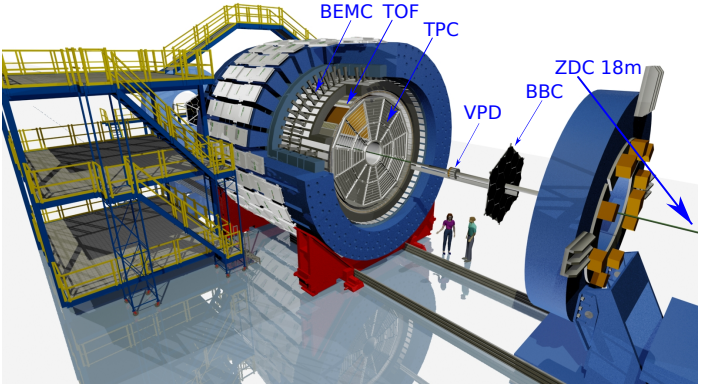
Introduction



- 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 $\gamma\gamma \to e^+e^-$ production at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV measured by STAR
- Coherent and incoherent J/ψ photoproduction and $\gamma\gamma \to e^+e^-$ 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

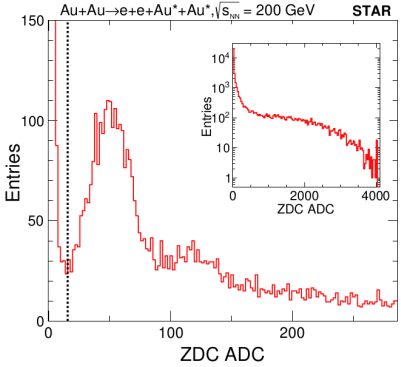
- Central tracking and particle identification, forward counters and neutron detection

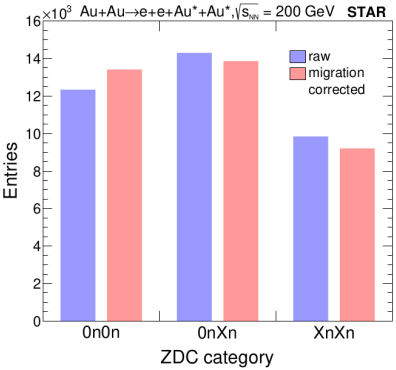


- Time Projection Chamber: tracking and identification in $|\eta| < 1$
- Time-Of-Flight: multiplicity trigger, particle identification and pile-up track removal
- Barrel ElectroMagnetic Calorimeter: topology trigger and pile-up track removal
- Beam-Beam Counters: scintillator counters in $2.1 < |\eta| < 5.2$, 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:





0n0n

No signal in ZDCs

0nXn

One ZDC has signal, the other is empty

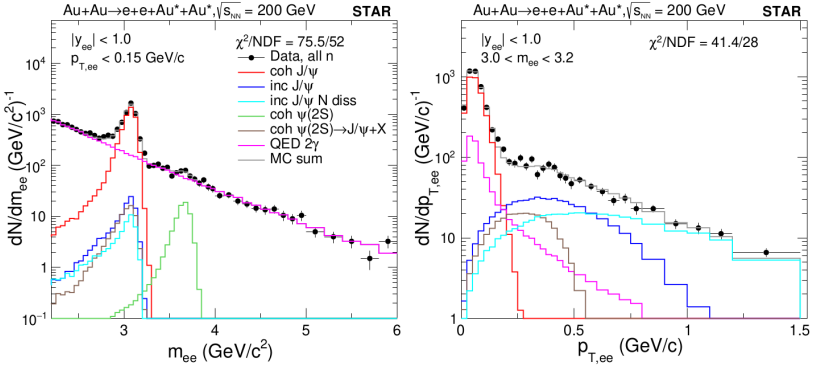
XnXn

Both ZDCs have signal

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

Mass and p_T of selected dielectron candidates

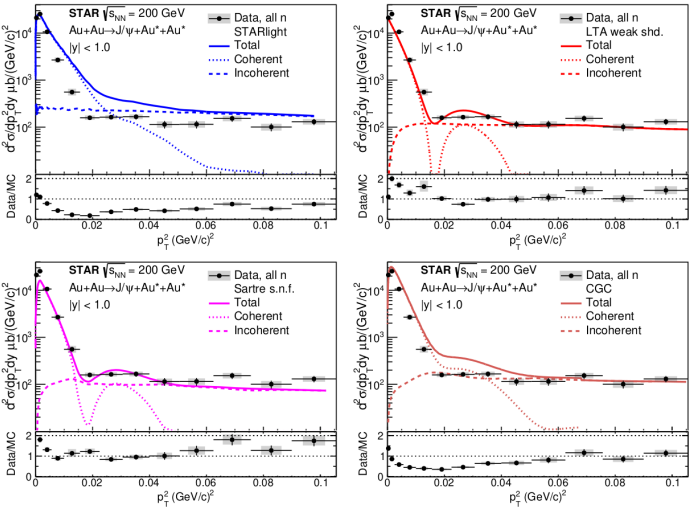
- Coherent enriched sample below p_T = 0.15 GeV
- No requirement on ZDC (*all n*)
- Fit by MC templates folded by complete detector simulation



- The templates include: coherent J/ψ and $\psi(2S)$, incoherent J/ψ w/o dissociation, feed-down from $\psi(2S)\rightarrow J/\psi$+X and QED $\gamma\gamma \rightarrow e^+e^-$
- 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 GeV
- Coherent peak at low p_T^2
- Incoherent photoproduction at larger p_T^2 (decreasing exponential)
- Better agreement with data is found for Sartre and LTA calculations in data/MC ratios

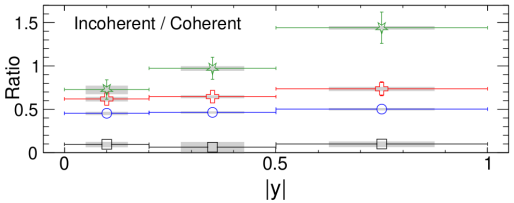


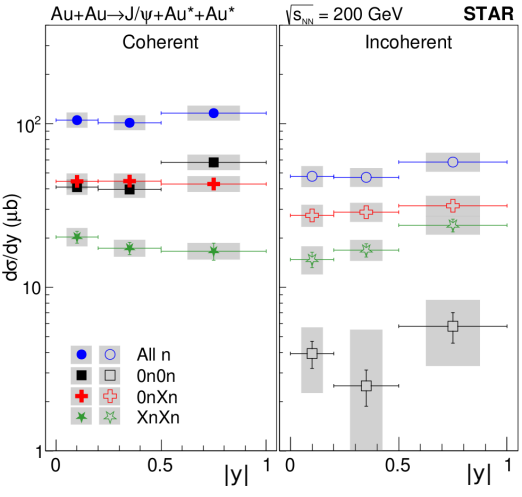
Additional 10% luminosity uncertainty is not shown

arXiv:2311.13632

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





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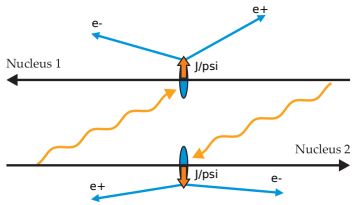
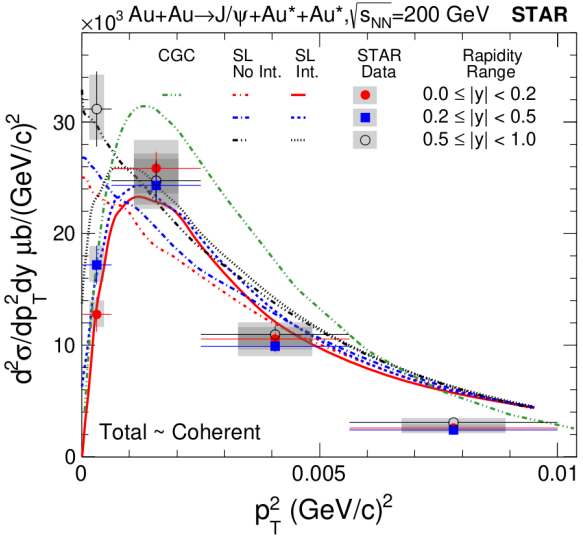
Interference in J/ψ photoproduction



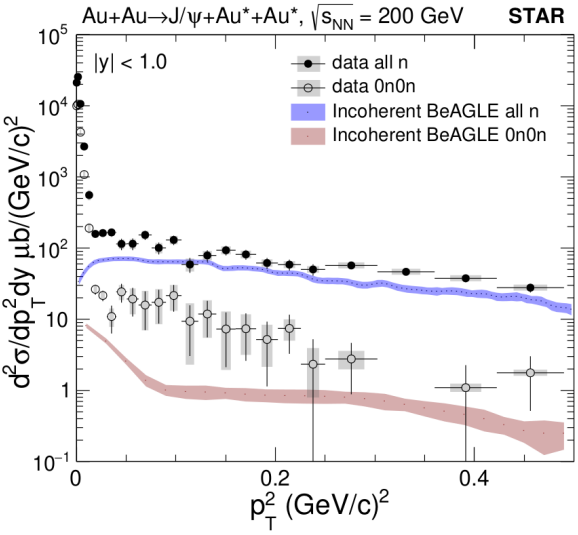
- Region of the lowest $p_T^2 < 0.01$ GeV^2, almost all production is coherent
- Bins in rapidity, *all n* neutron category
- Interference due to the symmetry of Au+Au collisions
- Suppression by more than 0.5 in the lowest p_T^2 bin
- Calculations which include the interference agree with the data



arXiv:2311.13632, drawing adapted from Phys.Today 70 (2017) 10, 40-47

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



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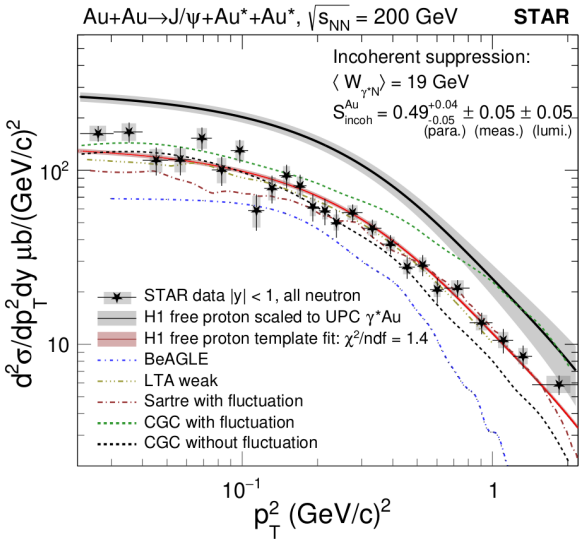
Cross section of incoherent J/ψ photoproduction

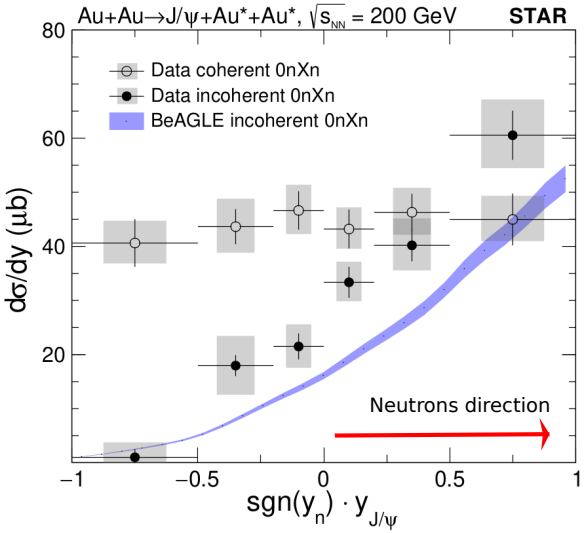
- Cross section vs. p_T^2 above 0.02 GeV^2, full mid-rapidity, *all n* class
- Comparison to H1 *ep* data scaled to the given $W_{\gamma N}$
- Fit to STAR data with H1 template, only the normalization is a free parameter
- Incoherent cross section is suppressed vs. photoproduction off a free proton
- Cross section dependence on p_T^2 between the bound and the free proton is similar



arXiv:2311.13632

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



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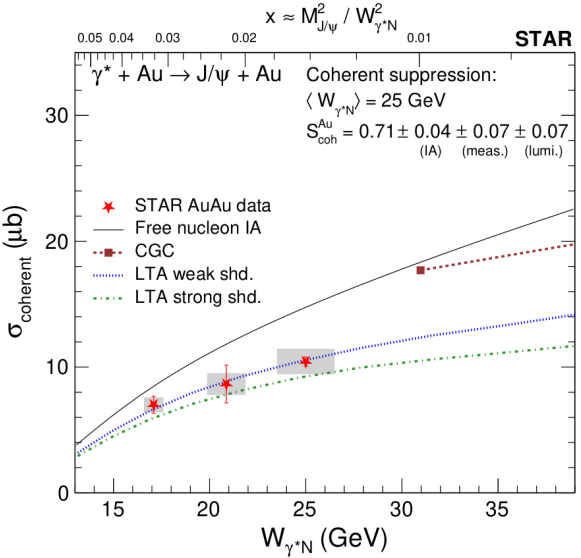
Coherent J/ψ photoproduction vs. $W_{\gamma N}$

- 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



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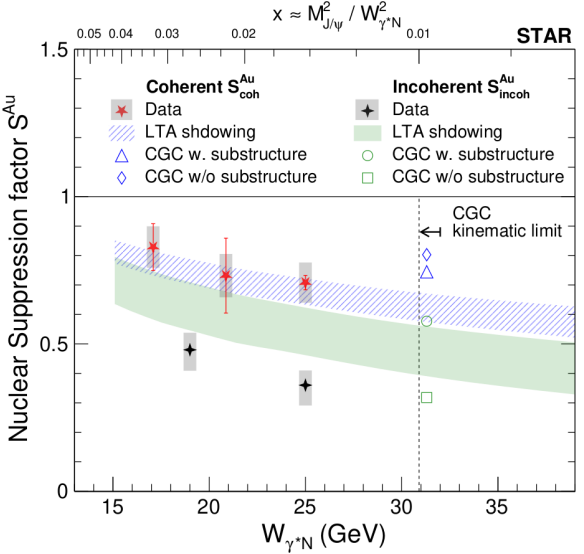
Nuclear suppression factor

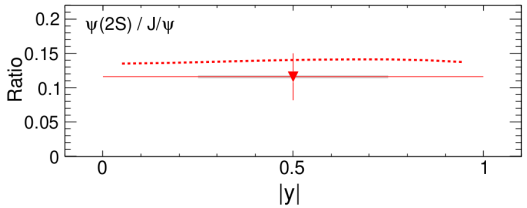
- Coherent suppression $S_{\mathrm{coh}}^{\mathrm{Au}}$ is determined relative to the IA
- Incoherent suppression $S_{\mathrm{incoh}}^{\mathrm{Au}}$ is a ratio of *all n* cross section to HERA parametrization for free protons
- Stronger incoherent suppression is found than in the coherent case
- Bands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

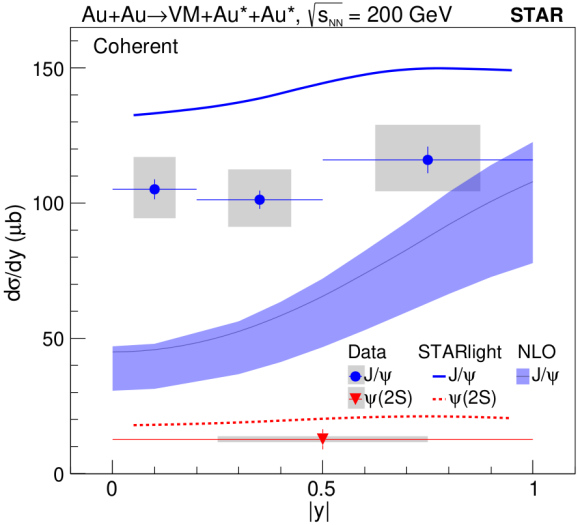


arXiv:2311.13637

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

- Coherent $\psi(2S)$ 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





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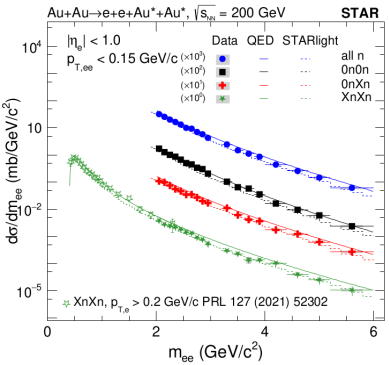
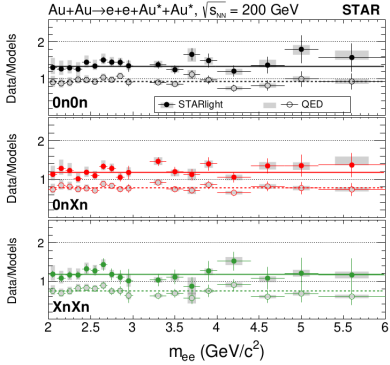
Cross section of $\gamma\gamma \to e^+e^-$ pair production

- 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 p_T^2 and $|y|$ and for $\gamma\gamma \to e^+e^-$ production
- Resolution for photon energy ambiguity for coherent J/ψ cross section as a function of photon-nucleus center-of-mass energy
- 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 *e*A models for the EIC

BACKUP

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

Au+Au data sample

- Data taking in 2016
- Integrated luminosity 13.5 nb^{-1}
- Approx. 24×10^6 UPC J/ψ triggers

Trigger definition

- BEMC energy depositions of $\approx$0.7 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 $\mathrm{d}E/\mathrm{d}x$

Requirements for track pair

- Vertex is within 100 cm of STAR nominal interaction point
- $\mathrm{d}E/\mathrm{d}x$ 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