J/ψ photoproduction at RHIC using $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions

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High Energy Photonuclear Reactions

- Impact parameter (b) is larger than the sum of radii of participating nuclei
- The strong electromagnetic field of relativistic particles can be represented by a spectrum of equivalent photons

\[ \text{Weizsäcker-Williams (EPA) formula} \]
\[ \frac{dN_{\gamma}}{d\xi}(b > b_{min}) = \frac{\alpha_{em} Z^2}{\pi} \left( \frac{1}{\xi} - 2xK_0(x)K_1(x) - x^2(K_1^2(x) - K_0^2(x)) \right); \xi = \frac{E_{\gamma}}{E_A} \text{ and } x = \xi m_A b_{min} \]

Nucleus Form factor dependence is included in modified Bessel functions \( K_1 \) and \( K_0 \)

- High energy photons can have a point–like interaction like (e.g.: Compton scattering) or quantum fluctuate into vector meson (\( J^{pc} = 1^{-} \)) or fermion–antifermion pair

- The validity of EPA for heavy ions requires coherent emission of photons

\[ \text{Photon Kinematics} \]
\[ Q^2 = \left( \omega^2 / \gamma^2 + q^2_{\perp} \right) \lesssim 1/R_A^2 \quad \omega < \omega_{max} \approx \frac{\gamma}{R} \quad q_{\perp} \lesssim \frac{1}{R} \approx 30 \text{ MeV} \]

At RHIC energies \( \gamma = 108 \quad \omega_{max} \sim 3 \text{ GeV} \quad \text{In the CM system } \omega_{YN} (\text{max}) \sim 34 \text{ GeV} \]
Photoproduction of $J/\psi$

- Test perturbative Quantum Chromodynamics (pQCD)
  - The quarkonium mass, $m_v$, gives a perturbative scale even in the photoproduction limit, allowing us to study low-$x$ gluons in the nuclear target

$$x = \frac{M_V}{\sqrt{S_{NN}}} e^{\pm y} \sim 10^{-3} - 10^{-2} \text{ and } Q^2 \sim M_v^2$$

- At the RHIC energy regime we can study Pomeron exchange (or two gluon exchange without color transfer)

- To study nuclear ratio for the gluon density, $R_G$, (nuclear shadowing)
  - Paukkunen et al, talk at DIS 2009; JHEP 0904:065 (2009)

- Measurements of differential cross section as a function of rapidity($y$) and momentum transfer($t$) enable us to test theory predictions
• Large acceptance; TPC: $-1 < \eta < 1$ and $-\pi < \phi < \pi$
• Excellent PID; ToF and TPC dE/dx

by Maria & Alex Schmah
Lowest order Feynman diagram for exclusive J/ψ production in UPCs. The photons to the right of the dashed line are soft photons.

**STAR UPC trigger consists of:**

- 2 \leq TOF hits \leq 6
- Veto on small BBC tiles 2 < |\eta| < 5
- The strong fields associated with heavy ions at high energies lead to large probabilities for exchanging additional soft photons in the same event
- The soft photons excite nuclei to a Giant Dipole Resonance (GDR), which then decay by emitting neutrons in the forward/backward directions

✓ 1 \leq beam neutrons \leq 5 in both ZDCs
Data and Analysis cuts for J/ψ

- 38 Million Run10 200 GeV Au+Au UPC trigger events with $\int L = 1075 \mu b^{-1}$

Select events:

- [2–4] primary tracks in the TPC
- Z–vertex position; [−50, 50]cm
- An event vertex has two tracks associated to it (exclusive production)
- Require both tracks to be matched to Time of Flight (trigger)
- Background modeled with like–sign pairs
- Mass cuts
  - J/ψ: $3.0 < M_{inv} < 3.2$ GeV/c$^2$
- J/ψ rapidity distribution
  - coherent cut; $p_T < 0.15$ GeV/c
Pair $p_T$ Distribution

• **Blue:** unlike-sign pairs
• **Red:** background estimated with like-sign pairs
• The peak at low transverse momenta is consistent with coherent production
• For $J/\psi$ rapidity distribution analysis, only events with $p_T < 0.15$ GeV/c are used (coherent momentum cut ~ $\hbar/R_A$)
• Only statistical error bars are presented

Clear signal for coherent production seen in $p_T$ distribution

Daughter tracks are not constrained to TOF

$J/\psi$ is generated at rest, daughters decay back to back

2010 AuAu 200 GeV data

Only acceptance corrected

Statistical error only
• J/ψ particles are identified using an invariant mass reconstruction
• After like sign background subtraction, we fit the data with an exponential for $e^+e^-$ continuum, a Gaussian for J/ψ signal and a polynomial background
• We reconstruct 78 J/ψ mesons after correcting for $e^+e^-$ continuum background
• Only statistical error bars are shown
Cross section normalization uses the following formula:

\[
\frac{d\sigma}{dy} = \frac{N_{J/\psi}}{\varepsilon_{\text{trigg}} \cdot \text{Acc} \cdot \Delta y \cdot \frac{1}{BR} \cdot \frac{1}{L_{\text{int}}}} \cdot \text{Trigger correction}
\]

- \(N_{J/\psi}\) = Background corrected Vector meson count
- \(BR\) = Branching ratio
- \(L_{\text{int}}\) = Integrated luminosity
- \(\Delta y\) = Histogram bin width
- \(\varepsilon_{\text{trigg}}\) = Trigger efficiency
- \(\text{Acc}\) = Acceptance
- \(\varepsilon\) = Tracking efficiency

Trigger correction: Correct cross section for detecting up to \(X\) \{1,2,3, \ldots\} neutrons in both ZDCs

- STAR 2010 UPC_Main trigger detected up to 5 neutrons in both ZDCs
- The cross section was corrected for losing events which emitted more than 5 neutrons
- The correction was done using a mutual heavy ion dissociation model \(A.\ Pshenichnov\ et\ al.,\ Physical\ Review\ C,\ 64,\ 024903\)

Table 2: Comparison between ZDC data collected with the UPC and the RELDIS calculation.

<table>
<thead>
<tr>
<th>Neutrons</th>
<th>Data (%)</th>
<th>RELDIS (%)</th>
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<tr>
<td>0</td>
<td>28.9</td>
<td>29.5</td>
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<tr>
<td>1</td>
<td>30.2</td>
<td>30.2</td>
</tr>
<tr>
<td>2</td>
<td>18.2</td>
<td>18.2</td>
</tr>
<tr>
<td>3</td>
<td>29.7</td>
<td>29.7</td>
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<tr>
<td>4</td>
<td>28.9</td>
<td>28.9</td>
</tr>
<tr>
<td>5</td>
<td>27.7</td>
<td>27.7</td>
</tr>
</tbody>
</table>

Figure 35: The left panel shows the results of the Mutual electromagnetic dissociation calculation by Pshenichnov et al. (RELDIS) as cross section values for all possible combinations of number of neutrons and other hadrons emitted towards East and West ZDCs.

Model cross section values for all possible combinations of number of neutrons and other hadrons emitted towards East and West ZDCs.
Comparisons

Xn : X [1,2,3, ... number of neutrons on either ZDC]

- Using Starlight we scale STAR XnXn cross section to Xn (a 3.64 factor)

- Scaled STAR Xn cross section has been compared with PHENIX data with statistical errors only


- STAR & PHENIX data have been compared with Starlight predictions

- Systematic error is not included

- J/ψ differential cross section measurements for ALICE and CMS at 2.76 TeV

- LHC data are compared to Starlight and other theory predictions

- Both LHC and RHIC data are approximately a factor of 2 below the Starlight prediction
Summary and outlook

• We have analyzed 38 million UPC trigger events from 2010 Au+Au 200 GeV data set ($\int L=1075 \mu b^{-1}$)

• After applying offline analysis cuts, and subtracting $e^+e^-$ continuum, STAR measures a $<XnXn>$ cross section of $\sim 12 \mu b^{-1}$ (78 coherently produced $J/\psi$ particles)

• We report the efficiency corrected differential cross section for UPC $J/\psi$ production

• STAR data were compared with theory prediction and other experimental measurements for $J/\psi$ photo-production

• Both RHIC and LHC measurements are approximately a factor of two below Starlight predictions

• Systematic uncertainties need to be estimated