# Transverse Momentum Dependence of J/Ψ Production at Forward Rapidity in $\sqrt{s_{NN}}$ = 200GeV Cu+Cu Collisions

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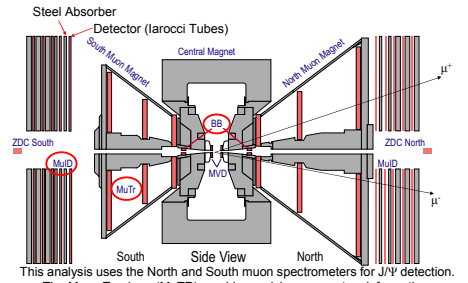
## Goal and Motivation

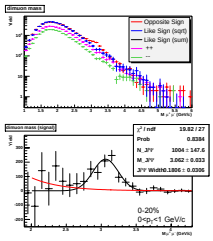
- **To use J/Ψ as a probe of the hot dense matter created in heavy ion collisions.** Since charm is dominantly produced in initial hard scattering, the J/Ψ has become an industry standard tool for studying heavy ion collisions.
- **J/Ψ measurements are crucial to understanding charmonium production**, which is important for studying color deconfinement and color screening associated with a QGP. The J/Ψ is also expected to be sensitive to recombination effects. The species dependence of any initial or final state effects will be essential to forming a comprehensive understanding of the created environment.

## The PHENIX Experiment




This analysis uses the North and South muon spectrometers for J/Ψ detection. The Muon Trackers (MuTR) provide precision momentum information. The Muon Identifiers (MuID) separate penetrating muons from strongly interacting hadrons. The MuIDs also serve as local LVL1 trigger detectors. The Beam-Beam Counters (BB) are minimum bias trigger detectors used for centrality and vertex determination.

## Signal Extraction




Raw J/Ψ yields are extracted via bin counting in the corrected invariant mass spectrum. The estimated combinatorial background, $2\sqrt{N_{++}N_{--}}$, is subtracted from the opposite sign spectrum. The J/ Ψ yield is then estimated by the total remaining counts from the mass range of 2.6-3.6 GeV/c.

Various fits to the J/Ψ mass region are used to estimate the systematic due to any remaining contribution in the mass window from sources such as Drell-Yan, open cham, and acceptance induced shape effects. An example of a double Gaussian + exponential fit is shown left.

From the variation of these fits, the 1 RMS systematic uncertainty on our signal extraction is estimated as 10%.

## Analysis Details

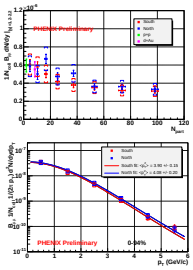
•This analysis used MuID Local Level 1 triggered data set consisting of over 4 billion sampled events per arm after good run selection. To remain consistent with trigger requirements, only muons which penetrate the entire MuID are analyzed.

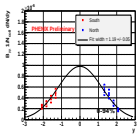
•The data set was filtered offline using a MuID+MuTR Level 2 trigger algorithm.

•Our acceptance x efficiency is estimated using simulated J/Ψ's from PYTHIA embedded into real minimum bias events. These are ran through the full trigger and reconstruction software.

• Fully corrected yields are studied as a function of centrality, rapidity and transverse momentum.

•The figures below demonstrate the good agreement between fully corrected yields from the separate arms in multiple kinematic variables.

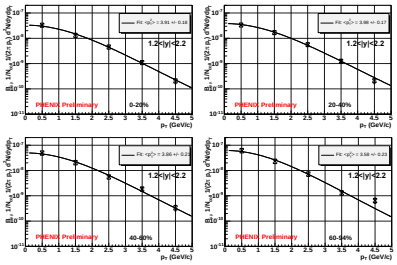



Main contributors to estimated systematic error

| | |
|---|---|
| Error on #MB triggers/events | 1% |
| Vertex, bunch crossing checks | 3% |
| Acc*Eff: MC input distributions (vtx, pt, y), cuts | 5% |
| Mutr bad FEM handling | 2% |
| Muid efficiency | 5% |
| Run to run variations | 8% |
| Signal extraction | 10% |

## $P_T$ Spectra



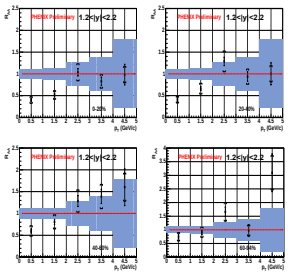

Here we present the invariant yields of J/Ψ as a function of transverse momentum for several classes of centrality.

Yields are corrected for finite bin width.

Also shown is a fit to $f(p_t) = A(1+(p_t/B)^2)^{-6}$, where $B^2/4 = \langle p_t^2 \rangle$.

## Nuclear Modification Factor

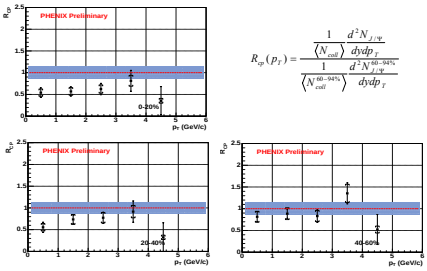
$$R_{AA}(p_T) = \frac{\frac{1}{\langle N_{coll}\rangle}\frac{d^2N^{AA}_{J/\Psi}}{dydp_T}}{\frac{1}{\sigma^{NN}_{inel}}\frac{d^2\sigma^{NN}_{J/\Psi}}{dydp_T}}$$




Blue band indicates uncertainty on p+p reference

The nuclear modification factor, $R_{AA}$, reveals a factor of ~2 suppression at low $p_T$ for the most central event class. The large suppression is not present in the most peripheral data. The high $p_T$ data appear consistent with, or slightly enhanced over, binary collision scaling at all centralities, BUT the large error on the p+p reference precludes any strong statement.

## $R_{CP}$

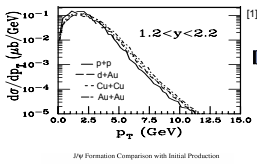



$$R_{cp}(p_T) = \frac{\frac{1}{\langle N_{coll}\rangle}\frac{d^2N_{J/\Psi}}{dydp_T}}{\frac{1}{\langle N^{60-94\%}_{coll}\rangle}\frac{d^2N^{60-94\%}_{J/\Psi}}{dydp_T}}$$

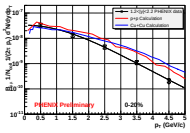
Similarly, one can compare production of a given centrality class to production in peripheral events via $R_{CP}$. This has the advantages that some systematics cancel, and a higher statistics reference is used. Some nuclear effects may still be present in the peripheral bin.

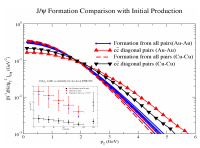
A suppression of up to a factor of ~2 is evident up to a $p_T$ of ~3 GeV/c in the most central events. The suppression is greatly reduced in the 40-60% most central collision. Due to current errors, the behavior at high $p_T$ is still ambiguous.

## Comparisons and Discussion

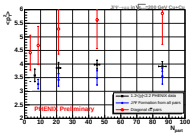



[1]




[2]




Here the data are compared to some of the few direct theoretical calculations for the $p_T$ dependence of J/Ψ in $\sqrt{s_{NN}}$ = 200 GeV Cu+Cu collisions. The upper left plot shows the result of a NLO calculation[1] using a $\langle k_T^2 \rangle_p$=1.77 GeV$^2$ plus additional broadening due to multiple scattering. In the upper right, the calculations for Cu+Cu and p+p have been overlaid with the PHENIX measurement. The data is reproduced reasonably well at low $p_T$, but yields are significantly over predicted above ~2 GeV/c. A similar NLO calculation[2] gives results for "diagonal pairs" in the lower left plot. The diagonal pairs produce systematically larger values of $\langle pT^2 \rangle$; consistent with the previous calculations. A recombination component is then added to the calculation as indicated by "all pairs". The recombination component narrows the $p_T$ distribution. As shown in the bottom right figure, the recombination model produces systematically low values of $\langle pT^2 \rangle$ as compared to the PHENIX data. This seems to support that a recombination component may be present. This recombination model has consequences for rapidity shape which are discussed in A. Rakotozafindrabe's poster.

[1] R. Vogt ,*"Shadowing and Small x Physics on J/Ψ Production at RHIC"*, PHENIX muon workshop, Santa Fe, NM, June 13, 2005
[2] R. L.Thews, *"Quarkonium Formation from Heavy Quark Recombination"*, PHENIX muon workshop, Santa Fe, NM, June 13, 2005

## Summary and Outlook

- Over 10K J/Ψ→μ⁺μ⁻ were measured by PHENIX in RHIC Run V Cu+Cu.
- A clear suppression of up to a factor of ~2 in yield per binary collision has been observed at low $p_T$ for central collisions with respect to p+p and peripheral Cu+Cu.
- This suppression is greatly reduced, if at all present, in peripheral collisions.
- The examined theoretical NLO calculations predict a harder than observed $p_T$ spectrum, but large theoretical uncertainties exist.
- The examined recombination model appears to overcompensate as the predicted $\langle p_T^2 \rangle$ is systematically low.
- The outlook is promising for differentiating production scenarios in the future.

## Related Posters

**Cu+Cu→J/Ψ→μ⁺μ⁻:**
#201 A. Rakotozafindrabe
Acc x Eff, Rapidity
#208 D. Silvermyr
Centrality
#129 A. Bickley
62 GeV

**Cu+Cu→J/Ψ→e⁺e⁻ (mid-rapidity)**
#181 K. Das

**Au+Au→J/Ψ→μ⁺μ⁻:**
#130 M. Brooks
#145 M. Kweon
#171 V. Tram

**Au+Au→J/Ψ→e⁺e⁻ (mid-rapidity)**
#187 T. Gunji
#148 A. Lebedev
#178 D. d'Enterria

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