Measurement of an Excited Charmonium State and the Study of $J/\psi$ Polarization in PHENIX Experiment at RHIC

Celebrating the November Revolution!

Marisilvia Donadelli for the PHENIX Collaboration

Physics Institute
University of Sao Paulo
Brazil

marisilvia@if.usp.br
mari@rcf.rhic.bnl.gov
Quarkonia production in pp collisions

- Heavy quarks predominantly generated in hadronic collisions via gluonic diagrams and production can be calculated in perturbative QCD.

- Details of quarkonia hadronization process remain unclear. Color neutralization is a non perturbative process and several models have been proposed:
  - NRQCD;
  - Color Evaporation Model;
  - Color Singlet Model.
Charmonium Signals at PHENIX

- **Central Arms**: Hadrons, photons, electrons;
  - $J/\psi \rightarrow e^+e^-$; $\psi' \rightarrow e^+e^-$; $\chi_c \rightarrow e^+e^-\gamma$;
  - $|\eta|<0.35$;
  - $p_e > 0.2$ GeV/c;
  - $\Delta\phi = \pi$ (2 arms x $\pi/2$)

- **Forward rapidity Arms**: Muons
  - $J/\psi \rightarrow \mu^+\mu^-$
  - $1.2 < |\eta| < 2.2$
  - $p_\mu > 1$ GeV/c
  - $\Delta\phi = 2\pi$
Electron Identification at PHENIX

- Electron candidates are charged tracks identified by RICH and with position and energy measured by EmCal;
- Dielectron events are selected by additional logical trigger;
- The numbers of $J/\psi$ and $\psi'$ candidates are obtained by counting the unlike-sign dielectron pairs in a fixed mass window after subtracting the like-sign pairs.

$\Psi'$ [3.5-3.9] GeV/c$^2$
**J/ψ cross section at PHENIX**

PHENIX Run5 p+p data [PRL98:232002,2007] began to constrain shape of cross section vs rapidity & $p_T$

Total cross section calculated by integration of different fits to $y$ dependence

Inclusive measurement: includes feed down

Different models fit to the p+p data returning a total cross section:

$BR \sigma(p+p\rightarrow J/\psi+X) = 178 \pm 3{\text{(stat)}} \pm 53{\text{(sys)}} \pm 18{\text{(norm)}} \text{ nb}$

Brand new yield measurement from larger luminosity Run6 agrees with published results!

\[
\frac{d\sigma}{dy}\bigg|_{|y|<0.35} = 45.3 \pm 1.0{\text{(stat)}} \pm 5.4{\text{(sys)}} \pm 4.5{\text{(global)}} \text{ nb}
\]

Run5 Result = $44.0 \pm 1.4{\text{(stat)}} \pm 5.7{\text{(sys)}} \pm 4.4{\text{(global)}} \text{ nb}$
• The number of $\psi$ particles were selected by direct counting after like sign background subtraction.
• The $e^+e^-$ invariant mass distribution was fitted with templates generated from Monte Carlo simulation of continuum contribution (correlated D and B mesons and Drell-Yan), besides internal and external radiations.

\[
B_{\psi \rightarrow e^+e^-} \sigma_{\psi} \big|_{|y|<0.35} (p_T < 7 \text{GeV/c}) = 0.88^{+0.30}_{-0.20} \text{(stat)} \pm 0.12 \text{(sys)} \text{nb}
\]
$\psi'$ to $J/\psi$ cross sections ratio measurement at PHENIX

$\frac{B \sigma_{\psi'}}{B \sigma_{J/\psi}} = 0.019 \pm 0.005 \pm 0.002$

\[ \frac{(BR\psi'\rightarrow e^+e^-)\sigma(\psi')}{(BRJ/\psi\rightarrow e^+e^-)\sigma(J/\psi)} < 0.38 \text{ 90\% CL} \]

11/10/08

Marisilvia Donadelli - PANIC 2008
Feed down fraction of $J/\psi$ from $\psi'$ in PHENIX

- $R(\psi') = 8.6 \pm 2.5\%$ PHENIX [QM08];
- $R(\psi') = 8.0 \pm 2.0\%$ from the lattice [Phys. Rev.D64:094015]
- $R(\psi') = 8.1 \pm 0.3\%$ from average of world data [hep-ph/0809.2153v1]

- PHENIX preliminary
  - $BR(\psi'\rightarrow e^+e^-)\sigma(\psi')/BR(J/\psi\rightarrow e^+e^-)\sigma(J/\psi) = 0.019 \pm 0.005$ (stat) $\pm 0.002$ (syst)

- PDG 2008 values
  - $BR(J/\psi\rightarrow e^+e^-) = 5.94 \pm 0.06\%$
  - $BR(\psi'\rightarrow e^+e^-) = 0.743 \pm 0.018\%$
  - $BR(\psi'\rightarrow J/\psi + X) = 56.9 \pm 0.9\%$

- $\sigma(\psi')/\sigma(J/\psi) = 0.15 \pm 0.04$

- Feed-down fraction of $J/\psi$ from $\psi'$ is $0.086 \pm 0.025$. 
Why polarization matters...

- Measurements of polarization (the commonly used term to denote spin alignment) provide one of the most significant tests of models of charmonia production:
  - Color Evaporation Model: no polarization [hep-ph/9403387]
  - s-channel cut contribution to $J/\psi$ hadroproduction: at low and mid-range $p_T$ at Fermilab and RHIC: longitudinally polarized [Phys. Rev. Lett. 100, 032006 92008]
The observable

- $J/\psi$ polarization can be studied through the angular distributions of the decay lepton pairs.
- $\theta$ is the angle between the lepton momentum in $J/\psi$ rest frame, (helicity frame) and $J/\psi$ momentum in the laboratory frame.

Parametrization of the angular distribution

\[
\frac{d\sigma}{d\cos\theta} \propto 1 + \lambda \cos^2\theta
\]

- $\lambda = 1$ (transverse polarization)
- $\lambda = 0$ (no polarization)
- $\lambda = -1$ (longitudinal polarization)
Upsilon polarization measurement in D0

Comparison for Y1S, data (points) and MC (solid histogram) with $2 < p_T < 4$ and muon kinematic distributions.
The previous measurement by CDF of the polarization of $\Upsilon_{1S}$ with rapidity $y < 0.4$ is consistent with equal to zero [PRL88,161802]. No explanation why CDF and D0 results are different.
J/Ψ polarization parameter measurement in pp collisions at PHENIX

\[ p_T < 5 \text{ GeV/c} \]

\[ 2.9 < \text{mass}_{e^+e^-} < 3.2 \text{ GeV/c}^2 \]

\[ p^+p \at \sqrt{s} = 200 \text{ GeV} \]

\[ |y| < 0.35 \]

\[ p_T < 5 \text{ GeV/c} \]

\[ \lambda_{J/Ψ} = -9.6 \pm 7.2 \text{ (stat)} \pm 3.9 \text{ (sys)} \% \]

- J/ψ candidates were selected in the mass window [2.9-3.2] GeV/c² after same sign pairs background subtraction.
- The acceptance corrected cosθ distribution is the measured distribution divided by the acceptance obtained from simulation.
p_T dependent J/ψ polarization parameter in pp collisions at PHENIX

\[ p+p \rightarrow J/\psi \quad @ \sqrt{s}=200 \text{ GeV} \quad |y|<0.35 \]

\[ \lambda_{J/\psi} \]

11/10/08

Marisilvia Donadelli - PANIC 2008
Summary

• PHENIX presented J/ψ production measurement (up to 10 GeV/c) in Run 6pp with excellent agreement with the previous Run 5 published results [PRL98:232002,2007] and also the first ψ ′ production measurement (up to 7 GeV/c) at RHIC.
• The ψ ′ to J/ψ production ratio result shows good agreement with the HERA-B fixed target experiment.
• For the J/ψ polarization measurements in PHENIX, there is a very small chance that the polarization for the highest p_T point is zero or transverse in agreement with recent CSM + 4 point function prediction.
• These data not only constrain production models for heavy quarkonia, but also provide a critical baseline for:
  • deuteron + nucleus collisions, to study cold nuclear matter effects;
  • heavy ion collisions, to study enhancement or suppression in the QGP.
Back up slides
Some hadroproduction models of charmonia

CEM  

NRQCD + COM  
PRL74, 3327 (1995)

kT factorization  
[PRD63, 077501 (2001)]

Predictions for proton-antiproton collisions at $\sqrt{s} = 1.8$ TeV

CSM+4p  
PRL100, 032006 (2008)

Predictions for pp collisions at $\sqrt{s} = 200$ GeV

Marisilvia Donadelli - PANIC 2008

11/10/08
\[ R_{\chi_c} = \frac{1}{\sigma(J/\psi)} \sum_{j=1}^{2} \sigma(\chi_{cJ}) BR(\chi_{cJ} \rightarrow J/\psi \gamma) \]

< 0.42 (90% C.L., PHENIX preliminary)

\( R(\chi_c) = 30\% \pm 8.0 \) Lattice [Phys.Rev.D64:094015]

PDG 2008 values
- \( BR(\chi_{c0} \rightarrow J/\psi + \gamma) = 1.32 \pm 0.11\% \)
  - neglected
- \( BR(\chi_{c1} \rightarrow J/\psi + \gamma) = 35.9 \pm 1.9\% \)
- \( BR(\chi_{c2} \rightarrow J/\psi + \gamma) = 20.3 \pm 1.0\% \)
Prior to PHENIX polarization measurement....

**J/Ψ polarization parameter in E866**

$p_T < 5$ GeV/c @ 800 GeV proton interactions with hydrogen and deuterium targets

**J/Ψ and Ψ' polarization parameters in CDF**

5 < $p_T$ < 30 GeV/c @ 1.96 TeV proton-antiproton collisions