Recent Results on Charmonia Production in the PHENIX Experiment at RHIC

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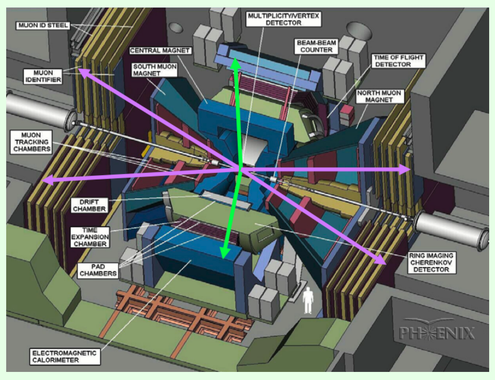
Introduction

- Charmonia production is predicted to be sensitive to the formation of the quark gluon plasma (QGP) in relativistic heavy ion collisions via competing mechanisms such as color screening and/or quark recombination.
- During the past RHIC data taking periods, a large amount of data has been collected on heavy charmonia production in p+p , d+Au, Cu+Cu and Au + Au collisions, at a center of mass energy per nucleon-nucleon collision $\sqrt{s_{NN}} = 200$ GeV .
  - Measurements performed using heavy ion collisions such as Cu+Cu and Au + Au allow to study effects of the QGP;
  - Measurements performed in d+Au are necessary to study possible effects of the nuclear matter on the resonance production in absence of a QGP;
  - Measurements performed in p+p collisions are used as a reference for heavier nuclei measurements.

J/ψ detection in PHENIX



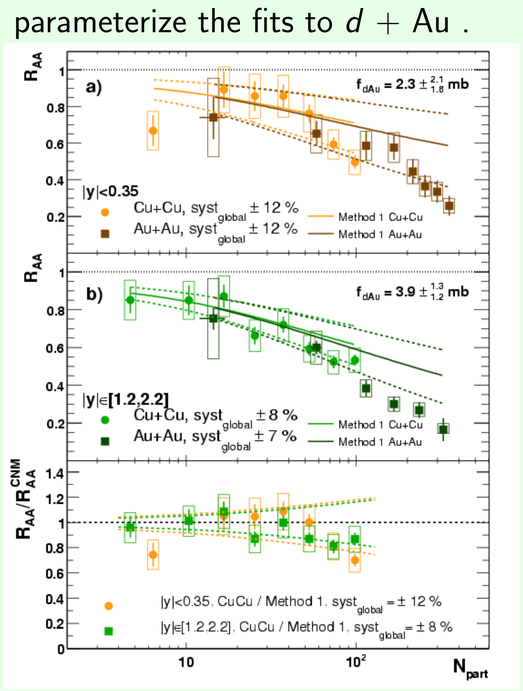
Central Arms:
- $J/\psi \rightarrow e^+e^-$;
- $|\eta| < 0.35$;
- $p_e > 0.2$ GeV/c;
- $\Delta\phi = \pi$ (2 arms $\times \pi/2$)

Forward Rapidity Arms
- $J/\psi \rightarrow \mu^+\mu^-$;
- $1.2 < |\eta| < 2.2$;
- $p_\mu > 1.0$ GeV/c;
- $\Delta\phi = 2\pi$

Global Detectors
- Beam-Beam Counter (BBC);
- Zero Degree Calorimeter (ZDC);
- Reaction Plane Detector (RxNP).

J/ψ production in Cu+Cu and Au + Au collisions.

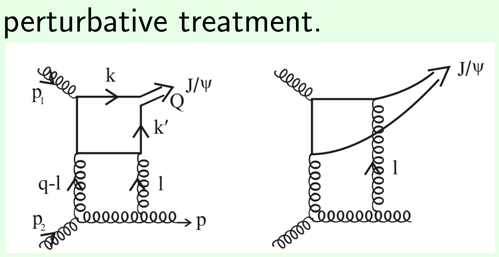
- The J/ψ R_{AA} in Cu+Cu and Au + Au collisions is found to decrease significantly when going from peripheral to central collisions **[PRL101, 122301 (2008)]** and **[PRL 98, 232301 (2007)]**. It matches well between the two systems when the number of nucleons that take part in the collision (*N_part*) is identical. For central Au + Au collisions, this decrease exceeds what can be inferred from CNM effects both at mid-rapidity ($y < |0.35|$), and forward rapidity ($|y| \in [1.2,2.2]$). The suppression is found to be larger at forward than at mid-rapidity, which is unexpected if one only considers mechanisms such as color-screening and interaction with comovers, so that other mechanisms, such as recombination must play a role.
- Measured R_{AA} values for Cu+Cu is seen to be consistent with the cold nuclear matter projection within about 15% uncertainties up to N $\sim$ 50. Cold nuclear matter estimates based on ad hoc data-driven model to parameterize the fits to d + Au .



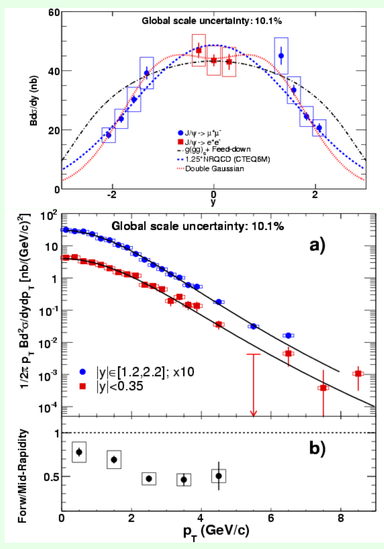
Charmonium Cross Section Calculations

Methods to calculate the cross section include:

- Non-relativistic QCD (NRQCD) **[PLB167 (1986) 437, PRD43 (1991) 196, PRD51 (1995) 1125]**. Effective field theory where the production is a combination of singlet and octet states.
- Color Evaporation Model (CEM) **[Int. J. Mod. Phys. A 10 (1995) 3043]**. Production is a empirical fraction of $Q\bar{Q}$ heavy quark cross section integrated over 2mc and 2mD . Color octet turns to singlet by soft gluon evaporation.
- pQCD w/ 3-gluon fusion: [Eur. Phys. J. C 39, 163171 (2005)]. Formation done by (gg)8+g fusion. Complete perturbative treatment.

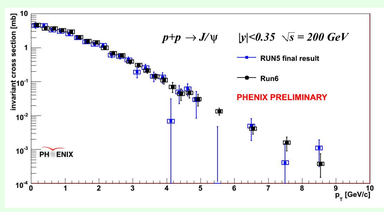


J/ψ in Run5 p+p collisions [PRL98, 232002 (2007)]



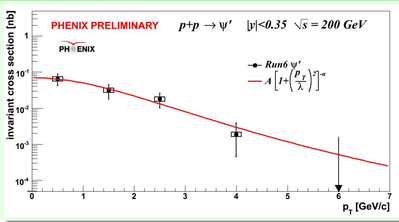
- PHENIX Run5 p+p data **[PRL98:232002,2007]** began to constrain shape of cross section vs rapidity and p_T.
- These data slightly favour a flatter rapidity distribution at mid-rapidity than most model calculations which have shapes similar to the NRQCD calculation (dashed curve) in the figure. A pQCD calculation **[Eur. Phys.J. C39163]** that includes explicit treatment of the third gluon, necessary to give the final colour singlet state, gives good agreement with the cross sections and polarization seen in other measurements, but does not reproduce the steep fall off at large rapidity of the PHENIX results.
- Inclusive measurement: includes feed down.
- J/ψ Total cross section times branching ratio: 178±3(stat)±53(syst)±18(norm) nb
- The distribution is harder at mid-rapidity than for forward rapidity with: $\langle p^2{}_T \rangle = 4.14 \pm 0.18^{+0.30}{}_{-0.20}$ (mid-rapidity) and 3.59±0.06±0.16(forward rapidity) GeV/c^2.

J/ψ measurement in Run6 p+p collisions with PHENIX Central Arms $|\eta| < 0.35$



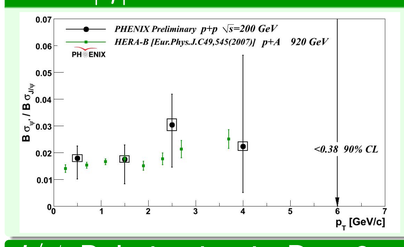
- Brand new yield measurement from larger luminosity in Run6 agrees with published results.
- J/ψ Total cross section times dielectron branching ratio: 45.3±1.0(stat)±5.4(syst)±4.5(global) nb
- J/ψ 41.0±0.9(stat)±4.9(syst) nb $p_T < 7$GeV/c
  $\langle p^2{}_T \rangle = 4.06 \pm 0.13$(uncorr) $\pm$ 0.11(corr) $p_T < 5$GeV /c
  $\langle p^2{}_T \rangle = 4.48 \pm 0.14$(uncorr) $\pm$ 0.12(corr) $p_T < 7$GeV /c
  $\langle p^2{}_T \rangle = 4.60 \pm 0.15$(uncorr) $\pm$ 0.11(corr)

ψ' measurement in Run 6 p+p collisions with PHENIX Central Arms $|\eta| < 0.35$



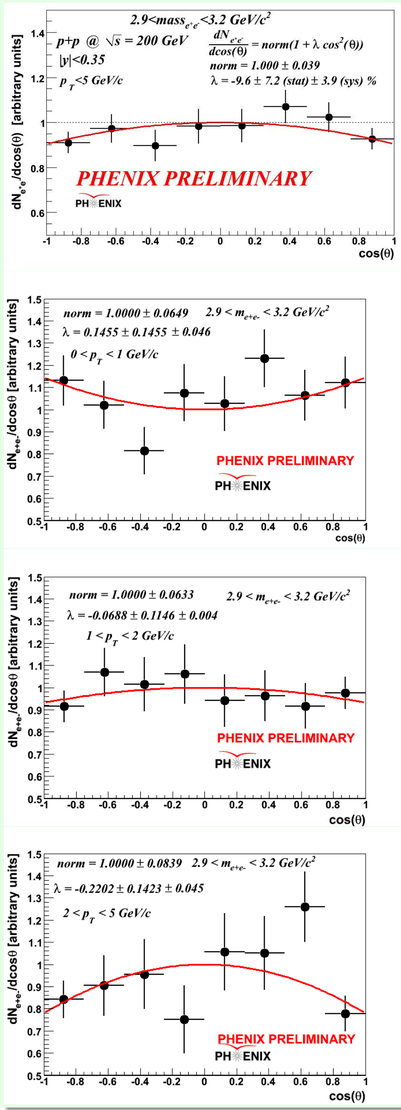
- **First ψ' measurement at RHIC!**
- ψ' Total cross section times dielectron branching ratio: $0.88^{+0.30}{}_{-0.20}$(stat)±0.12(syst) nb $p_T < 7$GeV/c
  $\langle p_T{}^2 \rangle = 4.56\ ^{+}1.46_{-1.15}$ (uncorr)± 0.13(corr) $p_T < 5$GeV /c
  $\langle p_T{}^2 \rangle = 7.13\ ^{+}2.0_{-2.6}$ (uncorr) $\pm$ 0.26(corr) $p_T < 7$GeV /c

ψ' to J/ψ cross sections ratio measurement in Run 6 p+p collisions with PHENIX Central Arms $|\eta| < 0.35$



Good agreement with HERA-B fixed target experiment.
ψ' to J/ψ cross sections ratio = 0.019±0.005 (stat)±0.002(sys)

J/ψ Polarization in Run 6 p+p collisions with PHENIX Central Arms $|\eta| < 0.35$



$dN/dcos(\theta) = A[1+ \lambda cos^2\theta]$
θ is the angle between the positive lepton momentum direction and the J/ψ momentum direction in its rest frame
$\lambda > 0$ transverse polarization
$\lambda < 0$ longitudinal polarization

- NRQCD predicts:
  - transverse for octet states with $p_T >> M_{J/\psi}$;
  - longitudinal for singlet states with $p_T >> M_{J/\psi}$.
- CEM expects no polarization;
- 3-gluon fusion expects transverse polarization for low p_T and longitudinal for $p_T >> M_{J/\psi}$.
- 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 [Phys. Rev. Lett. 100, 032006 92008]