Vol. 1 (2008) *Acta Physica Polonica B Proceedings Supplement* No 3

IF QUARKONIA COULD TALK: FROM SPS TO RHIC*

Abigail Bickley

National Superconducting Cyclotron Laboratory, Michigan State University
East Lansing, Michigan 48824-1321, USA

(Received October 16, 2008)

Quarkonia provide a direct probe of hard parton interactions that occur in nucleon–nucleon collisions. Because the heavy quark pairs interact with the medium produced in heavy ion collisions, information regarding the properties of the collision environment is accessible through the quarkonia that escape. Quarkonia are useful probes of the collision medium because they are sensitive to the modification of the QCD confining potential. Measurements of quarkonia produced in $p+p$, $p+A$ and $d+A$ collision systems provide reference information necessary for understanding their production mechanisms and for disentangling cold nuclear matter effects present in heavy ion data. Studies of heavy ion collisions can be used to quantify in-medium modifications. Experimental results from both the SPS and RHIC are presented in the context of the available theoretical interpretations.

PACS numbers: 13.85.Ni, 14.40.Gx

1. Introduction

Heavy quarks are predominantly produced in hadronic collisions via hard parton–parton collisions. These interactions occur during the early stages of the collision, hence the in-medium modifications experienced by the quarks reflect the high energy densities created in the collision. A variety of theoretical models have been proposed to describe the hadronization mechanism of quarkonia. However, a detailed understanding of the process has not been achieved. The color-singlet model, which produces color singlet $c\bar{c}$ pairs in the same quantum state as the J/ψ, underestimates the production cross section by more than an order of magnitude [1]. Color octet models add the contribution of octet state $c\bar{c}$ pairs that hadronize through the emission of soft gluons. These models predict a large transverse polarization of the J/ψ at high transverse momentum that is not observed in the experimental data [2]. Color evaporation models use a phenomenological approach

* Presented at the XXXVII International Symposium on Multiparticle Dynamics, Berkeley, USA, August 4–9, 2007.

in which charmonium states are formed in proportions determined by experimental data for any $c\bar{c}$ pair that has a mass below the $D\bar{D}$ threshold. Hadronization occurs through the emission of soft gluons. A perturbative QCD approach involving 3-gluon mechanisms in which hadronization occurs via the fusion of a symmetric color-octet state with an additional gluon has successfully reproduced the observed Jψ cross section and polarization [3]. However, PHENIX measurements of J/ψ production as a function of rapidity in 200 GeV $p+p$ collisions provide a challenge for this model [4].

In the 1980's Matsui and Satz proposed that color screening would result in a suppressed yield of J/ψ particles in the presence of a deconfined collision medium [5]. Hence, J/ψ suppression was considered to be a signature of quark–gluon plasma formation. The importance of competing effects such as recombination, gluon dissociation, shadowing and normal nuclear absorption have since been recognized to play a role as well. Suppression models assume heavy quarkonia are formed only during initial hard parton collisions and any subsequent interactions in the medium only result in an additional loss of yield. In contrast, recombination models treat heavy quark pairing as a reversible process in which heavy quarks that were not created together can partner to form quarkonia during the evolution of the medium. Recombination becomes relevant at RHIC and LHC energies where sufficient $c\bar{c}$ pairs are formed to permit J/ψ regeneration. Because it is not possible to distinguish directly produced J/ψ from those resulting from feeddown from χ_c and ψ' decay, the effect of the medium on these higher mass resonance states must be considered. As a result of the differing melting temperatures of the ψ', χ_c and J/ψ states, it has been proposed that the observed J/ψ yield could be used as a thermodynamic probe of the collision medium [6]. The utility of this probe depends on whether the melting points of the resonance states are sufficiently different to be resolved experimentally. Current lattice calculations provide differing predictions of the quarkonia melting temperatures [7, 8].

2. Experimental results

The study of J/ψ produced in $p+p$ collisions provides an important avenue for testing quarkonia production mechanisms and simultaneously provides a baseline reference to which collisions of heavy ions can be compared. Recent PHENIX results from 200 GeV $p+p$ collisions have shown that the rapidity distribution of the J/ψ cross section experiences a steep drop at forward rapidity. Many production models including the 3-gluon pQCD approach [3] have difficulty reproducing this feature [4]. Results from $p+A$ and $d+A$ collisions allow the influence of cold nuclear matter effects to be determined. Data collected at the SPS from $p+A$ collisions show good agreement between the observed J/ψ cross section and Glauber model simulations [9]. Data collected at RHIC from d+Au collisions are consistent with assumptions of weak gluon shadowing and an absorption cross section of 1–3 mb [10]. Results from the upcoming 2008 RHIC d+Au run are expected to provide more stringent constraints on the initial state effects.

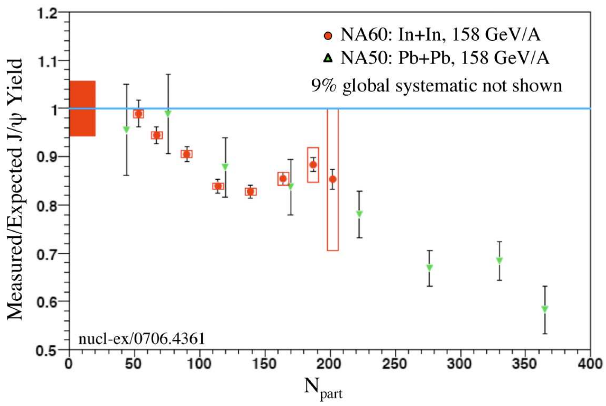

Fig. 1. Ratio of measured over expected J/ψ yield relative to cold nuclear matter results in NA50 Pb+Pb (circles) and NA60 In+In (triangles) collisions [11, 12].

Quarkonia production in heavy ion collisions is used to study the properties of the produced medium. The NA50 and NA60 experiments have studied J/ψ production in Pb+Pb and In+In fixed target collisions, respectively, at a beam energy of 158 GeV$/n$. In-medium modification of the J/ψ production is evaluated by comparing the observed cross section with the level of suppression expected from the Glauber calculation used to reproduce the cold nuclear matter effects in light ion collisions. A trend of increased J/ψ suppression with increasing collision centrality is observed, Fig. 1. The PHENIX collaboration has measured the J/ψ production cross section in Au+Au collisions at a center of mass collision energy of 200 GeV [13]. Initial and final state effects are distinguished by forming the nuclear modification factor, R_{AA}, in which the J/ψ cross section measured in the heavy ion collision system is scaled by the number of binary collisions and the J/ψ cross section observed in $p + p$ collisions at the same energy, Fig. 2. The curve shown in Fig. 2 represents the level of normal nuclear absorption expected to be present in the mid-rapidity Au+Au collisions based upon the absorption cross sections consistent with the d+Au data [14]. The data show a larger degree of suppression in central Au+Au collisions than is expected solely from nuclear absorption effects. A comparison of the NA50 and PHENIX results reveals that a statistically consistent degree of suppression is observed despite the large difference in the collision energies [15].

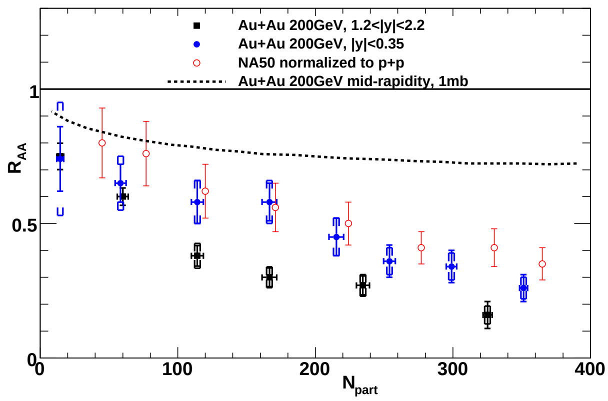

Fig. 2. J/ψ nuclear modification factor *versus* number of collision participants in 200 GeV Au+Au collisions compared to a cold nuclear matter calculation [13, 14].

3. Conclusions

In light of the high quality experimental J/ψ data available, detailed tests of production mechanisms and in-medium modifications of quarkonia are now possible. Thus far a comprehensive model of the J/ψ production mechanism has not been successful at reproducing the experimental data. However, the 3-gluon pQCD approach shows the most promise provided the PHENIX rapidity distribution can be accommodated. Several explanations have been proposed to account for the observation that the level of J/ψ suppression is similar in heavy ion collisions at the SPS and RHIC. It is possible that recombination is present at RHIC energies thus boosting the observed J/ψ yield. However, the predicted narrowing of the J/ψ rapidity spectra due to the recombination mechanism appears to be weak. Sequential melting of the $c\bar{c}$ resonance states has also been proposed as a possible explanation of the similarity between the SPS and RHIC results. However, it is unclear from the lattice calculations whether the central collision temperatures achieved at RHIC are sufficient to melt the J/ψ. Future measurements of J/ψ flow and cold nuclear matter effects from the 2007 and 2008 RHIC runs are expected to shed further light on quarkonia production.

REFERENCES

[1] J.P. Lansberg, *Int. J. Mod. Phys.* **A21**, 3857 (2006).
[2] CDF Collaboration, *Phys. Rev. Lett.* **99**, 132001 (2007).
[3] V.A. Khoze, *et al.*, *Eur. Phys. J.* **C39**, 163 (2005).
[4] A. Adare, *et al.*, *Phys. Rev. Lett.* **98**, 232002 (2007).

[5] T. Matsui, H. Satz, *Phys. Lett.* **B178**, 461 (1986).
[6] F. Karsch, D. Kharzeev, H. Satz, *Phys. Lett.* **B637**, 75 (2006).
[7] S. Datta *et al.*, *J. Phys. G* **30**, S1347 (2004).
[8] A. Mocsy, P. Petreczky, *Phys. Rev.* **D77**, 014501 (2008) [`arXiv:0705.2559 [hep-ph]`].
[9] B. Alessandro, *et al.*, *Eur. Phys. J.* **C48**, 329 (2006).
[10] S. Adler, *Phys. Rev. Lett.* **96**, 012304 (2006).
[11] B. Alessandro *et al.*, *Eur. Phys. J.* **C39**, 335 (2005).
[12] R. Arnaldi, *et al.*, `arXiv:0706.4361v1 [nucl-ex]`.
[13] A. Adare, {etal, *Phys. Rev. Lett.* **98**, 232301 (2007).
[14] R. Vogt, *Acta Phys. Hung.* **A25**, 97 (2006) [`nucl-th/0507027`].
[15] J. Nagle, `arXiv:0705.1712v1 [nucl-ex]`.