Vol. 3 (2010) *Acta Physica Polonica B Proceedings Supplement* No 4

HEAVY FLAVOR PRODUCTION AT RHIC*

Jaroslav Bielcik

FNSPE, Czech Technical University in Prague, Prague, Czech Republic
Nuclear Physics Institute AS CR v.v.i., Prague, Czech Republic

(Received August 9, 2010)

The strong suppression of hadrons with large transverse momentum (p_{T}) in central Au+Au collisions observed at RHIC is generally interpreted as a consequence of energy loss of energetic partons in the hot and dense matter before fragmenting. The study of heavy quark production is testing our understanding of this scenario. The recent results on heavy flavor measurements from the STAR and PHENIX experiments at RHIC will be presented. The total charm production cross-section extracted in $d+\mathrm{Au}$, Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV scales with the number of binary collisions. The high p_{T} non-photonic electron spectra show an unexpectedly strong suppression in central Au + Au collisions. Current theoretical models do not explain this observation satisfactory. The relative contribution of charm and bottom decays to non-photonic electrons was experimentally extracted. The measurements of J/Ψ and Υ production are considered as a leading probe of Quark Gluon Plasma (QGP) properties. Recent STAR and PHENIX results in quarkonia sector will be presented and discussed.

PACS numbers: 13.20.Gd, 14.40.Pq, 13.75.Cs, 12.38.–t

1. Introduction

Relativistic heavy ion collisions allow to produce in the laboratory conditions that were present in the Universe shortly after Bing Bang. In such collisions nuclear matter is heated up to high energy densities and temperatures. Lattice QCD predicts the phase transition from confined hadrons to deconfined quarks and gluons at an energy density of about 1 GeV/fm^3 and at temperature of about 170 MeV. This state of nuclear matter is currently studied in experiments at RHIC. Several interesting observations were already done [1, 2]. The most important are: high-p_{T} hadron suppression

* Presented at the Workshop "Excited QCD 2010", Tatranská Lomnica/Stará Lesná, Tatra National Park, Slovakia, January 31–February 6, 2010.

and back-to-back di-hadron suppression in central Au + Au collisions, large hadron elliptic flow (v_2) and its quark number scaling, and J/Ψ suppression. The observed hadron suppression ("jet quenching") is generally interpreted as a result of energy loss of light partons traversing the hot and dense nuclear matter. Heavy quarks are expected to be created during the initial energetic part of collision and therefore are a good probe of flavor dependence of parton energy loss and properties of QGP. The mass dependent dead-cone effect suggests that energy loss of heavy quarks should be reduced [3]. Due to temperature dependence of quark–antiquark bounding potential in quarkonia their systematic measurement in heavy ion collisions serves as a thermometer of hot nuclear matter.

2. Open heavy flavor

Open heavy flavor (containg c or b quark) can be best studied directly by reconstruction of open heavy flavor hadrons, such as D^0, $D^{\pm}$, D^*, D_s or B^0, $B^{\pm}$ via their hadronic decay channels. Due to longer lifetime of these hadrons displaced vertex detectors can be used to reduce the combinatorial background in the reconstruction. Unfortunately, none of the current RHIC experiments is equipped with such detectors. Despite of this, the large geometric acceptance of the STAR experiment enabled to directly reconstruct D mesons in several collision systems (d + Au [4], Cu + Cu [6], and Au + Au [5]). Other method to access open heavy flavor mesons is the measurement of electrons from their semileptonic decays. In this method it is neccessary to subtract all other contributions from inclusive electron spectra. The resulting non-photonic electron spectrum is then a sum of electrons from charm and beauty decays.

Both STAR and PHENIX have reported measurement of the total charm production cross-section. STAR is using a combined fit of three spectra: D^0, charm muon and charm non-photonic electrons at low $p_{\rm T}$ as is shown in Fig. 1. PHENIX is extracting the charm cross-section using extrapolation from non-photonic electron measurements. Although only 15% of kinematical range is covered, due to low material budget around beampipe, PHENIX is able to measure a clean electron sample. The extracted total charm production cross-sections from both experiments are shown in Fig. 2 [7] for various collision systems as a function of averaged number of binary collisions. Both STAR and PHENIX values show scaling with the number of binary collisions as expected for hard processes, but the results differ by a factor close to two. The calculation of charm cross-section from NLO pQCD has large systematic errors and both experimental values are in the calculated range. The PHENIX experiment has also a good capability to measure muon transverse momentum spectra at forward rapidity. In Fig. 3 the measured muon spectra in $p+p$ collisions at $\sqrt{s} = 200$ GeV with $\langle y \rangle = 1.65$ are shown [8]. The calculations from FONLL pQCD underestimate the measured spectra by a factor of four at low $p_{\rm T}$ to a factor of two at high $p_{\rm T}$.

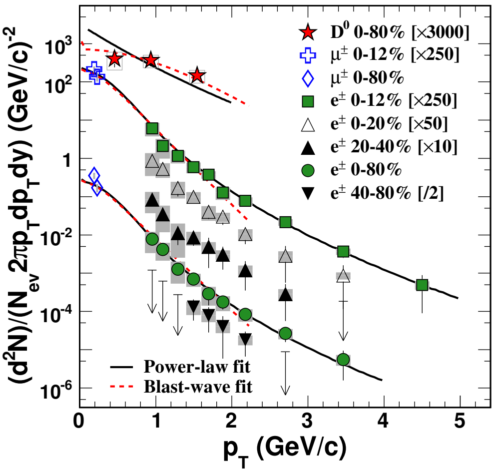

Fig. 1. Total charm production cross-section measurement in STAR using a combined fit of D^0, muon and non-photonic electron spectra in Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV [5].

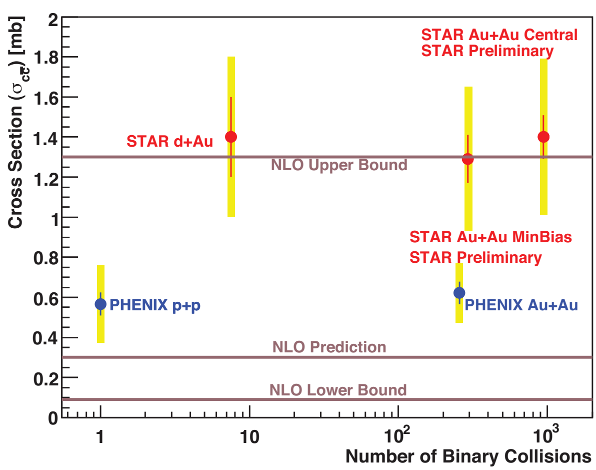

Fig. 2. Measured total charm production cross-section as a function of average number of binary collisions for $\sqrt{s_{NN}} = 200$ GeV energy by the STAR and PHENIX experiments. The yellow band shows the systematic error of the measurement. The horizontal lines show the NLO pQCD prediction and its lower and upper limit. Taken from [7].

The nuclear effects to particle production can be expressed by a nu-

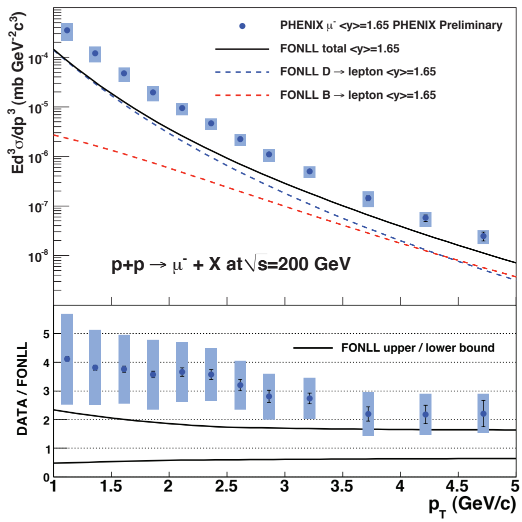

Fig. 3. Measurement of transverse momentum spectra of muons at forward rapidity $\langle y\rangle = 1.65$ in $p+p$ collisions at $\sqrt{s} = 200$ GeV by PHENIX. The ratio of data and FONLL pQCD calculations is shown in the bottom panel. Taken from [8].

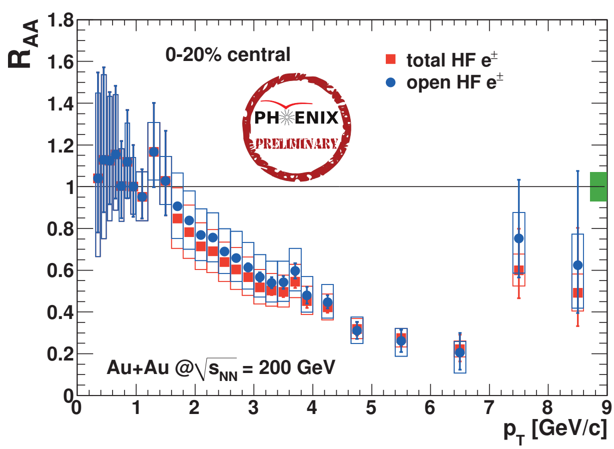

Fig. 4. Nuclear modification factor of non-photonic electrons measured by the PHENIX experiment in 0–20% central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The contributions from photonic background and other than open heavy flavor decays were subtracted. Taken from [8].

clear modification factor (R_{AA}). R_{AA} is a ratio of the measured yield in heavy ion collision to the yield from $p+p$ collisions scaled by an averaged number of binary collisions. In Fig. 4, the nuclear modification factor of non-photonic electrons is shown for 0–20% most central Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV as measured by PHENIX [8]. Contribution from other than open heavy flavor decays was subtracted. It was expected that a smaller suppression of charm and beauty quarks relative to light quarks would lead to a smaller suppression of non-photonic electrons relative to hadrons. However, $R_{AA} = 0.2$ was observed for high-$p_{\rm T}$ non-photonic electrons, similar to that for hadron suppression. Similar results were also measured by STAR. It has been shown that at $p_{\rm T} = 5$ GeV/c the contribution of bottom decays to the spectrum is significant and thus the observed large suppression is puzzelling.

3. Quarkonia

The J/Ψ suppression in heavy ion collisions is considered to be a sensitive probe of color deconfinment in QGP. There are several other competing processes influencing the measured yield, including Cold Nuclear Matter effects (nuclear interaction break up, shadowing) and recombination. Therefore complex measurements are needed to interpret the suppression data properly. For example, the measurement of J/Ψ suppression at high-$p_{\rm T}$ is sensitive to differences in predictions of various models. In Fig. 5 the nuclear modification factor of J/Ψ as a function of transverse momentum for Cu + Cu collisions at $\sqrt{s_{NN}} = 200$ GeV collisions measured by STAR and PHENIX is shown [9]. R_{AA} for J/Ψ is seen to increase with increasing $p_{\rm T}$. The average of the two STAR data points at high-$p_{\rm T}$ at 0–20% centrality is $R_{AA} = 1.4 \pm 0.4\,(\text{stat.})\, \pm 0.2\,(\text{syst.})$. This disfavors the theoretical model of quarkonium dissociation in strongly coupled liquid using the AdS/CFT approach. On the other hand, the two-component model with finite J/Ψ formation time describes the increasing trend of the J/Ψ R_{AA} well.

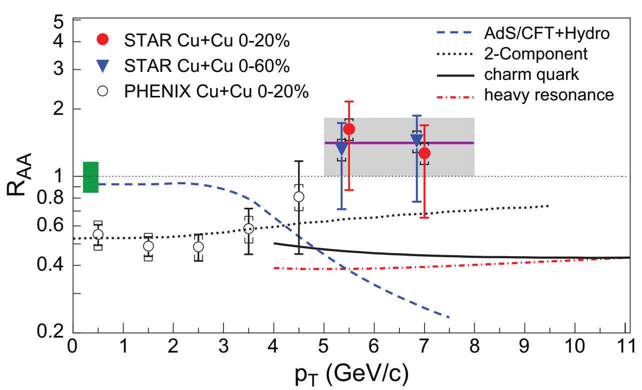

Fig. 5. The measurement of R_AA *versus* $p_{\rm T}$ in Cu + Cu collisions at $\sqrt{s_{NN}} = 200$ GeV by STAR and PHENIX. The lines show model predictions. Taken from [9].

The measurement of the Υ production in heavy-ion collisions is of great interest, because it is expected that Υ(1S) state does not dissociate at RHIC energies, but Υ(2S,3S) do. Both STAR and PHENIX reported measurements in p+p [10], d+Au [11] and Au+Au [12] collisions. The extracted production cross-section in p+p collisions is consistent with world trend. No cold-nuclear matter effects in d + Au were observed. The upper limit on R_{AA} at 90% confidence level was determined to be 64%. A higher precision measurement of R_{AA} is needed to draw finite conclusions.

4. Conclusions

The heavy flavor results from RHIC set important constraints on modeling of the hot and dense nuclear matter created in heavy-ion collisions. The strong suppression of heavy quarks is observed in central Au + Au collisions. The indication of no suppression at high p_{T} for J/Ψ is observed, which can help to discriminate the models of J/Ψ production. The Υ program has started succesfully.

This work was supported by grant INGO LA09013 of the Ministry of Education, Youth and Sports of the Czech Republic and by the Grant Agency of the Czech Technical University in Prague.

REFERENCES

[1] J. Adams *et al.* [STAR Collaboration], *Nucl. Phys.* **A757**, 102 (2005).

[2] K. Adcox *et al.* [PHENIX Collaboration], *Nucl. Phys.* **A757**, 184 (2005).

[3] Y.L. Dokshitzer, D.E. Kharzeev, *Phys. Lett.* **B519**, 199 (2001).

[4] J. Adams *et al.* [STAR Collaboration], *Phys. Rev. Lett.* **94**, 062301 (2005) [`arXiv:nucl-ex/0407006`].

[5] B.I. Abelev *et al.* [STAR Collaboration], `arXiv:0805.0364 [nucl-ex]`.

[6] S. Baumgart [STAR Collaboration], submitted to *Eur. Phys. J.* **C**.

[7] J.C. Dunlop, *Nucl. Phys.* **A830**, 419C (2009) [`arXiv:0907.4619 [nucl-ex]`].

[8] A. Dion [PHENIX Collaboration], *Nucl. Phys.* **A830**, 765C (2009) [`arXiv:0907.4749 [nucl-ex]`].

[9] B.I. Abelev *et al.* [STAR Collaboration], *Phys. Rev.* **C80**, 041902 (2009) [`arXiv:0904.0439 [nucl-ex]`].

[10] B.I. Abelev *et al.* [STAR Collaboration], `arXiv:1001.2745 [nucl-ex]`.

[11] H. Liu [STAR Collaboration], *Nucl. Phys.* **A830**, 235C (2009) [`arXiv:0907.4538 [nucl-ex]`].

[12] E.T. Atomssa [PHENIX Collaboration], *Nucl. Phys.* **A830**, 331C (2009) [`arXiv:0907.4787 [nucl-ex]`].