Recent results on heavy quarkonia production in p+p and heavy ion collisions at RHIC [1]

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1 Introduction

Heavy quarkonia 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 quarkonia production in p+p, d+Au, Cu+Cu and Au+Au collisions, at a center of mass energy per nucleon-nucleon collision $\sqrt{s_{\rm NN}} = 200$ GeV/c. Measurements performed in p+p collisions are used as a reference for heavier nuclei measurements. Measurements performed in d+Au are necessary to study possible effects of the nuclear matter on the resonance production in absence of a QGP. Finally, measurements performed using heavy ion collisions such as Cu+Cu and Au+Au allow one to study the effects of the QGP.

2 J/ψ production in p+p collisions

The J/ψ production cross-section has been measured as a function of the J/ψ rapidity (y) in p+p collisions at $\sqrt{s_{\rm NN}} = 200$ GeV/c [2] (Fig. 1 left). It is compared to various models that depend on the parton distribution function (pdf) prescription, and the J/ψ formation mechanism. Although the statistics is highly improved with respect to earlier measurements, the experimental uncertainties do not allow to discriminate between most of these models. The best fit to the data is used to derive the integrated J/ψ production cross-section, which, compared to other measurements at different energies, can reasonably well be described by perturbative QCD calculations (Fig. 1 right). The dependency over the J/ψ transverse momentum $p_{\rm T}$ has also been measured by both the PHENIX and the STAR collaboration at

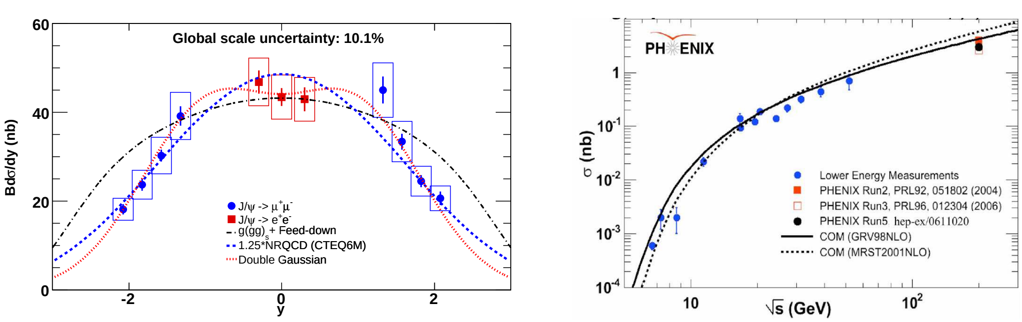

Figure 1: Left: J/ψ production cross-section as a function of y in p+p collisions at $\sqrt{s_{\rm NN}} =$ 200 GeV. Right: total J/ψ production cross-section as a function of collision energy.

RHIC. The STAR collaboration extends the p_T reach of the measurement up to 13 GeV/c, which puts new constraints on production mechanisms.

3 J/ψ production in d+Au collisions

The study of p+A or d+A collisions allows to evaluate the impact of the surrounding nucleons on the J/ψ production in contrast to p+p collisions. To quantify this impact one forms the J/ψ modification factor R_dA by taking the ratio of the cross-section in d+A collisions to the cross-section in p+p, and additionally dividing it by N_coll the number of nucleon-nucleon collisions equivalent to one d+A collision at a given impact parameter. Since the production of J/ψ involves the scattering of partons with large momentum transfer, such a ratio is expected to be equal to unity in absence of any medium effect. No QGP is expected to be formed in d-A collisions. Deviations of R_dA from unity are therefore inferred to so-called cold nuclear matter (CNM) effects. Such effects include 1) shadowing effects that originate from the modification of the incoming parton distribution functions in a nuclei as opposed to a nucleon; 2) the scattering of the incoming partons and J/ψ precursors 3) the absorption of the J/ψ by the surrounding hadrons. Several models exist that describe the first effect and its dependence over the J/ψ rapidity and transverse momentum, whereas the other two effects are described empirically by a break-up cross-section (σ_breakup) that is fitted to the data.

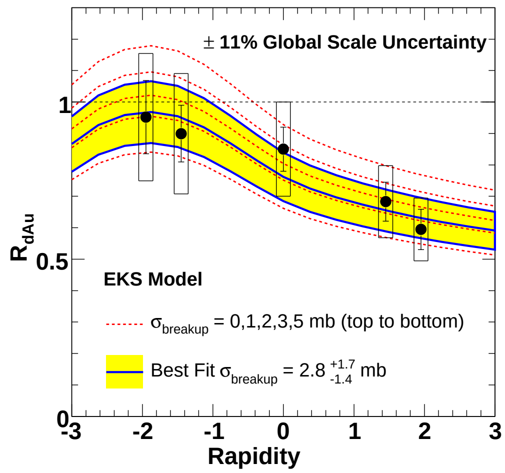

Figure 2: J/ψ R_dA as a function of rapidity in d+Au collisions at $\sqrt{s_\mathrm{NN}} = 200$ GeV.

Figure 2 shows the J/ψ $R_\mathrm{d+A}$ as a function of the J/ψ rapidity. The curves correspond to calculations that rely on one shadowing model, on top of which several values for σ_breakup are tested. These curves allow to derive the breakup cross-section that best describes the data and the corresponding error that properly accounts for all experimental uncertainties, as described in [3]. Once these are known, one can extrapolate the resulting CNM effects to A-A collisions and see whether any additional suppression is observed.

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

The formation of a QGP can impact the J/ψ production yields via several mechanisms such as: 1) a Debye-like screening of the c and $\overline{c}$ pair by the surrounding light quarks in the dense colored medium [4]; 2) the dissociation of the J/ψ's precursors by interaction with the surrounding partons (also called co-movers); 3) the formation of J/ψs by statistical recombination of c quark pairs that do not originate from the same parton scattering. The first two effects lead to a reduction of the number of J/ψs observed in the final state with respect to expectations from p+p and CNM effects. On the other hand the third effect would lead to an enhancement of this number proportional to the square of the number of $c\bar{c}$ pairs produced in the collision. At RHIC, 10 to 20 such pairs have been measured for central (i.e. head-on) 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 [5, 6] (Fig. 3). It matches well between the two systems when the number of nucleons that participate to the collision ($N_{\rm part}$) is identical. For central Au+Au collisions, this decrease exceeds what can be inferred from CNM effects, both at mid-rapidity ($y = 0$), and at forward rapidity ($y \in [1.2, 2.2]$). On the other hand, the suppression is found to be larger at forward rapidity than at mid-rapidity, which is unexpected if one only consider mechanism such as color-screening and interaction with co-movers, so that other mechanisms, such as recombination, must play a role.

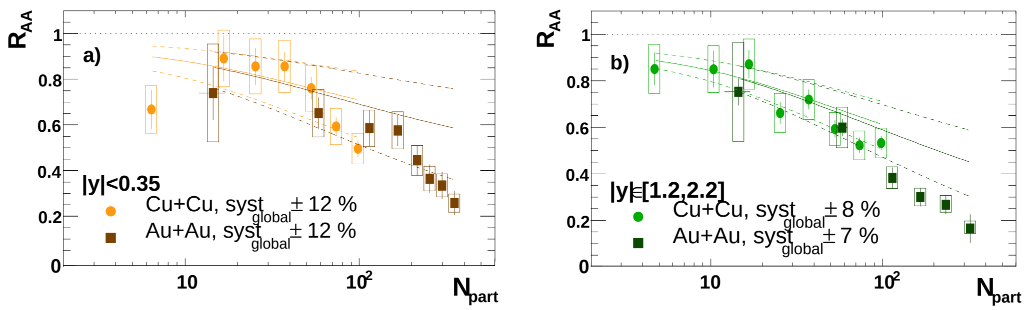

Figure 3: J/ψ $R_{\rm AA}$ as a function of $N_{\rm part}$ in $Cu + Cu$ and $Au + Au$ collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. Left: at mid rapidity; right: at forward rapidity.

The PHENIX Cu+Cu and Au+Au data can be reasonably well reproduced at both rapidities using models involving the mechanisms mentioned above on top of CNM effects (see notably [7]). However the contribution and the magnitude of these mechanisms are largely unconstrained by the data. Additional measurements have been made available by the STAR collaboration in Cu+Cu collisions at high $p_{\rm T}$ that suggest (with large experimental uncertainties) that the nuclear modification factor gets closer to unity in this region.

5 Other heavy quarkonia and B mesons

The results shown in previous sections do not distinguish between primordial J/ψs and J/ψs from heavier resonances decays, such as $\psi\prime$, χ_C and B. Since the interaction of such resonances with a QGP might differ from the J/ψ interactions, it is worthwhile to constrain by which amount these decays contribute to the observed J/ψ yields. Several measurements have been performed by the PHENIX collaboration in that sense and the corresponding preliminary results are listed in table 1. They are compared to theoretical calculations and although the experimental uncertainties are large, a good agreement is observed in all cases.

One should also mention that the STAR collaboration reported the first observation of Υ in p+p and Au+Au collisions at $\sqrt{s}$ = 200 GeV/c. So far only the di-lepton invariant mass distributions have been reported. These will be used to derive a first cross-section and a nuclear modification factor for the Υ at RHIC. This represents the first measurement at an intermediate energy prior to the coming similar measurements at the LHC.

	measurement (PHENIX preliminary)	theoretical prediction
$B \rightarrow$ J/ψ	0.036 ± 0.025	0.02 ± 0.01
$\psi\prime \rightarrow$ J/ψ	0.086 ± 0.025	0.08 [8]
$\chi_c \rightarrow$ J/ψ	< 0.42 (90 % C.L.)	0.30 [8]

Table 1: Contribution from excited charmonia resonances and B mesons to the J/ψ production in p+p collisions at $\sqrt{s} = 200$ GeV/c

6 First measurement of the J/ψ elliptic flow in Au+Au collisions

The elliptic flow v_2 is the second coefficient of the Fourier transform of the produced particles azimuthal distribution with respect to the collision reaction plane. It characterizes the azimuthal anisotropy of the particle emission with respect to this plane. A positive v_2 was measured for light hadrons, that is attributed to the initial anisotropy of the pressure gradient in the overlapping region of the colliding nuclei.

Similarly, a positive v_2 was also observed for heavy flavored mesons (Ds and Bs). v_2 being an additive quantity, J/ψs produced by the recombination of uncorrelated $c\bar{c}$ pairs should therefore also carry a significant v_2, as opposed to J/ψs produced at the early stages of the collision.

The J/ψ v_2 was first measured by PHENIX in Au+Au collisions at mid-rapidity ($|y| < 0.3$) for mid-central collisions (Fig 4). Experimental uncertainties are very large, which makes it impossible to draw firm conclusions and discriminate between models.

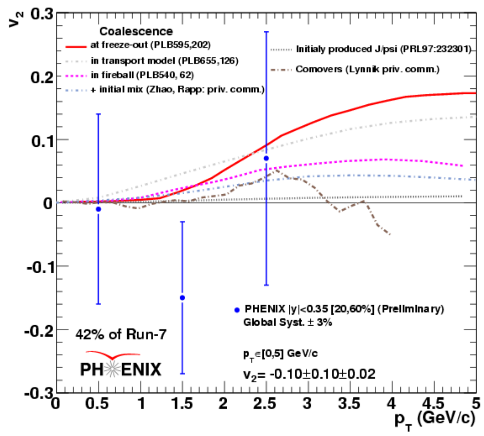

Figure 4: J/ψ v_2 at $|y| < 0.35$ for [20,60%] in centrality, as a function of p_T

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