Heavy quarks and quarkonia

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This paper is a review of the latest results on heavy flavor production presented during the Quark Matter 2005 conference in Budapest. The measurements of J/ψ production performed at CERN SPS by NA60 are discussed together with the latest NA50 results. Surprisingly, none of the models that have been shown to account for NA50 Pb+Pb data is able to reproduce NA60 In+In points. The PHENIX experiment at RHIC also presented results on J/ψ production. When interpreting these results, several cold nuclear effects have to be taken into account, as J/ψ absorption by interactions with nucleons, or modification of parton distribution functions in the nuclei. The interpretation of RHIC data is still unclear, but a precise study of J/ψ rapidity and transverse momentum distributions could help to discriminate the different models. In addition, data on open charm have been presented by RHIC experiments. Some implications of these new results for J/ψ production are also discussed.

INTRODUCTION

The original title of this presentation was 'Review of electromagnetic probes'. Although in principle, only direct photons and lepton pairs are strictly speaking electromagnetic probes of the medium created in the collisions, this name is usually given to all photon and lepton signals, including indirect ones. A lot of new results on this topic have been shown during this conference. Among these, PHENIX [1] observes an excess of photons produced in central Au+Au collisions, as compared to pQCD prediction. This signal is the first observation at RHIC which is compatible with thermal emission [2]. Another interesting result is the dimuon invariant mass spectrum shown by the NA60 collaboration [3]. This result confirms, with a better mass resolution, the observation of an excess of dileptons in the ρ mass region [4]. As these two striking results have been reviewed by C. Gale in his presentation [5], this paper will focus on another source of lepton signals, namely production of heavy quarks and quarkonia.

1. J/ψ and ψ' production at CERN SPS

The NA50 collaboration has recently published a complete re-analysis of the p+A data used to establish the baseline for the measurement of J/ψ anomalous suppression [6]. The main changes since previous publications are:

- new data sets are included in the analysis,

- S+U measurements are not included in the determination of J/ψ nuclear absorption,
- all the corrections needed to rescale the different data samples to each other, such as $\sqrt{s}$ scaling, corrections for different kinematical domains, correction for isospin (including neutron halo), have been revisited and updated to ensure consistency.

The new value of J/ψ nuclear absorption cross-section obtained by NA50 for p+A collisions is $\sigma_{abs}(J/\psi) = 4.18 \pm 0.35$ mb. This value allows to calculate the expected ratio of J/ψ production cross-section to the one of Drell-Yan muon pairs (DY), as a function of the average path L of the resonance through nuclear matter. The latest result obtained by NA50 is similar to the one published previously: for S+U and for the most peripheral Pb+Pb collisions, this ratio is compatible with the expected curve. A clear departure is seen for mid-centrality Pb+Pb interactions. This 'anomalous' J/ψ suppression increases with centrality.

J/ψ production in In+In collisions has been studied by the NA60 collaboration, and can now be compared to this anomalous suppression pattern. NA60 has presented the ratio (J/ψ)/DY as a function of centrality, together with an analysis of J/ψ only [7]. The standalone J/ψ analysis does not suffer from the poor statistics of the Drell-Yan samples, allowing to split the data in many centrality intervals. The drawback of this method is that the absolute normalization is not known and has to be derived from the (J/ψ)/DY ratio. As for NA50 data, a clear departure from the expected behavior is observed in the range $80 < N_{part} < 100$, N_{part} being the number of participant nucleons of the collision. For higher centralities, the ratio of measured J/ψ to normal nuclear absorption is flat.

1.1. Possible interpretations

Two observations can be made from the NA50/NA60 combined plots [7]:
- The amplitude of the anomalous suppression observed in In+In interactions is compatible with the one seen in Pb+Pb reactions,
- the onset of the anomalous suppression seems to take place around the same value of $N_{part} \simeq 100$ for both In+In and Pb+Pb. This point also roughly corresponds to the same energy density $\epsilon \simeq 1.5$ GeV/fm^3 for both systems. On the contrary, the same ratios plotted against L show that the cause of the suppression pattern is not directly linked the the simple thickness of nuclear matter traversed by charmonia.

A clear plateau is observed in In+In J/ψ data. If confirmed, this stepwise feature will be very hard to understand in the frame of any model involving only continuous variations of the cause of the suppression, as absorption by co-movers [8]. In addition, it is important to notice that even very dramatic changes of the suppression factor [9] are partially washed out by finite-size effects and experimental resolutions, and hardly lead to very steep patterns in the final spectra.

None of the models proposed to account for Pb+Pb measurements is able to reproduce In+In data [7]. These models are of two kinds, involving or not color deconfinement. The absorption of J/ψ by co-moving hadrons [8] overpredicts the suppression observed in In+In by NA60. The model proposed by Grandchamp *et al.* [10] simultaneously takes into account charmonium dissociation in a QGP and regeneration of J/ψ from c and $\bar{c}$ quarks present in the medium. This prediction almost follows In+In data up to $N_{part} = 120$, but fails to reproduce the plateau. Finally, the model based on percolation [9] predicts a strong decrease of J/ψ production that is similar to the one observed, but that occurs at a very different value of N_{part}.

Concerning the ψ', the pattern seems quite different: both S+U and Pb+Pb data show a departure from the curve corresponding the the absorption cross-section measured in p+A: $\sigma_{abs}(\psi') = 7.6\pm1.1$ mb [6]. This additional suppression takes place in very peripheral collisions already, and does not exhibit any discontinuous behavior. Moreover, both S+U and Pb+Pb data seem to follow the same suppression pattern as a function of L. As it is different from what is observed in p+A, this suppression cannot be due to simple ψ' absorption in nuclear matter. The difference between J/ψ and ψ' patterns in S+U and Pb+Pb could correspond to a higher temperature achieved in Pb+Pb collisions, that would be sufficient to dissolve both ψ' and χ_c, whereas the conditions reached in S+U would only prevent the formation of the less bound ψ' [9].

1.2. J/ψ absorption by nuclear matter

The A dependence of J/ψ production in p+A interactions is often referred to as 'normal nuclear absorption' of J/ψ, and is associated to the absorption cross-section $\sigma_{abs}(J/\psi)$. This parameter is of key importance in the determination of the expected J/ψ production in nucleus-nucleus collisions. Indeed, at least three different effects are involved in the nuclear dependence of J/ψ production:

- Absorption of J/ψ in nuclear matter: in fact, it is important to notice that part of the observed J/ψ's are not directly produced, but arise from the decay of higher mass $c\bar{c}$ states [11] (ψ' and χ_c). Therefore, the measured 'nuclear absorption cross-section' is some average value that accounts for the absorption of these several resonances as they travel through the average thickness L (corresponding to a given impact parameter b) of nuclear matter. Thus, this effective cross-section can vary with the proportions of the different states contributing to the detected J/ψ's. Even for a given resonance, it can also vary with $\sqrt{s}$, as Lorentz contraction causes the overlap time of the nuclei to vary with respect to the resonance formation time. In addition, the contribution from open beauty decay is negligible up to RHIC energies, but might be important at LHC.

- The modification of parton distribution functions in nuclei also leads to a modification of $c\bar{c}$ production cross-section in p+nucleus collisions. This effect, often referred to as 'shadowing', could also depend on the impact parameter [12] and is difficult to disentangle experimentally from nuclear absorption. This will be further discussed in section 2.2.

- Energy loss of the incident gluons before they create the $c\bar{c}$ pair could also lead to a variation of J/ψ production cross-section [13]. It is often argued that $c\bar{c}$ production is a hard process, which implies that no energy loss by soft gluons is involved in the creation process. Let us remark that as $c\bar{c}$ production in p+A is not strictly proportional to A anyway (at least due to nuclear absorption), a precise comparison with other production processes, such as photo-production in nuclei [14], is needed [15]. Indeed, as the $\sqrt{s}$ dependence of $c\bar{c}$ production cross-section is very steep at low $\sqrt{s}$, the influence of initial energy loss, if any, could be more important at low energies. This same influence would be even more important for beauty production, as the threshold energy is higher. Concerning this last point, recent NA50 data on Υ production [16] show that it scales as A^{α}, with $\alpha = 0.98\pm0.08$. This value is very close to 1, but the error is still large. If confirmed with a better precision, this result would indicate that the Υ resonance is weakly absorbed in nuclear matter, and that initial energy loss of partons before they create the $b\bar{b}$ pair is not seen at SPS energies (at $\sqrt{s} \simeq 42$ GeV, HERA-B measured $\alpha = 0.99 \pm 0.05$ [17]).

All these contributions are superimposed in the very simple approximation of the σ_{abs} parameterization, and cannot be evaluated separately with p+A or d+A data alone. The value of σ_{abs} can be used together with a full Glauber calculation to estimate the expected J/ψ production cross-section as a function of L or b. It is important to notice that even a full Glauber calculation is an approximation in this case, as part of the effects hidden behind σ_{abs} do not depend strictly on L or on the local ρL term. Moreover, all these contributions depend on the momentum fraction x of the incident partons, and therefore on x_f. Only the precise measurement of open charm production in the same kinematical domain would help solve this problem, as open charm is not affected by nuclear absorption. This measurement requires either the reconstruction of the charmed mesons from their decay particles, or the detection of the offset of the decay vertex with respect to the primary nucleus-nucleus collision. Both STAR and PHENIX experiments have reported on indirect measurements of charm production from non-photonic single electrons [18,19]. This channel does not allow to precisely measure the yield of low transverse momentum (p_T) particles, that constitute the bulk of the production cross-section. So far, only STAR has published results on open charm production through reconstruction of D mesons [20] at RHIC. Concerning offset measurements, NA60 data are still under analysis, and a PHENIX silicon detector upgrade is scheduled for 2008 [21].

2. From SPS to RHIC energies

Great care must be taken when comparing charmonium results obtained at SPS with those obtained at RHIC, as several parameters change with the higher incident energy:

- Charm production cross-section is higher by a factor of ≈ 100. This opens the door to $c\bar{c}$ recombination that can regenerate J/ψ's from uncorrelated charmed quark pairs [22]. Indeed, up to 20 to 40 $c\bar{c}$ pairs can be produced in a central Au+Au collision at RHIC, and local charm densities can cause this so called 'off-diagonal' contribution to be dominant in a given kinematical domain, as will be discussed in section 2.3.

- The different beam energy also corresponds to a different domain of momentum fraction x of the gluons leading to $c\bar{c}$ production. Thus, the modification of parton distribution functions inside the incident nuclei can lead to very different shadowing effects as compared to SPS data.

- Although the inclusive open charm production in Au+Au collisions at RHIC is measured to be proportional to the number of binary nucleon-nucleon collisions [18,19], it has been observed that high p_T charm production is suppressed, as expected in case of energy loss of charm quarks in the dense medium. In addition, STAR and PHENIX both reported the observation of a positive flow parameter V_2 of non-photonic electrons that is compatible with a significant flow of charmed particles. This two features were not expected and should be included in the models that predict the contribution of recombined $c\bar{c}$ pairs in the observed J/ψ spectra.

- If formed in the collisions, the quark-gluon plasma region should be bigger and longer-lived at RHIC as compared to SPS. This should be taken into account in all models involving dissolution of $c\bar{c}$ bound states by color screening in a deconfined medium. In addition, the anisotropic flow observed in hadron production may have consequences on all models developed to understand the J/ψ anomalous suppression at RHIC.

- The energy density is often considered as the most relevant variable to compare J/ψ suppression in different nucleus-nucleus collisions, in the frame of QGP models. It should be noticed that this variable does not take into account any variation of the hot region volume in different collision geometries. Furthermore, dissociation of charmonium states in a deconfined medium does not occur at a precise time. The relevant parameter should take into account the integral of the $c\bar{c}$ pair history in a variable energy density region, from the time at which it is produced to the time at which it eventually binds into a charmonium. Increasing $\sqrt{s}$ by a factor of 10 not only changes the initial energy density, but also the 'geometry' along the time axis, e.g. due to the different overlap time of the two colliding nuclei. Thus, comparing SPS and RHIC results as a function of $< \epsilon >$ calculated with a different 'formation time', may not reflect the change in the average effective energy density seen by the $c\bar{c}$ pair.

2.1. J/ψ production in PHENIX

The PHENIX collaboration has reported on J/ψ production measured in Cu+Cu and Au+Au collisions at RHIC [23], in central (J/$\psi \rightarrow e^+e^-$) and forward/backward (J/$\psi \rightarrow \mu^+\mu^-$) rapidity regions. Proton+proton data is used as a reference [24], and d+Au collisions have been studied to measure cold nuclear effects, namely shadowing and J/ψ absorption in nuclear matter. A suppression by a factor of 3 is observed between p+p and central Au+Au data, with respect to the simple scaling with the number of binary collisions. Although SPS and RHIC results cannot be compared without taking several different effects into account, as discussed earlier, it is important to notice that this raw suppression factor is very similar to the one observed by NA50. This situation may be accidental, but we must keep in mind that within the precision of present measurements, any claim about a difference in J/ψ suppression between SPS and RHIC would be based on a difference in the expected suppression.

2.2. Possible interpretations

PHENIX J/ψ data can be compared with different models proposed in the literature:

- Shadowing and nuclear absorption have been calculated by R. Vogt [12], and compared with PHENIX d+Au data [24]. The rapidity distribution of J/ψ measured in d+Au collisions is asymmetric. This asymmetry can be interpreted as the combination of shadowing and almost rapidity-independent absorption effects. In this frame, the data indicate that $\sigma_{abs} < 3$ mb, as the value $\sigma_{abs} = 1$ mb leads to a much better description of the measured J/ψ yield. Let us remark that according to this model, the flat ratio R_{dA} observed at negative rapidities is interpreted as the superposition of nuclear absorption and anti-shadowing that almost exactly compensate each other. To extrapolate to Au+Au collisions, the momentum of the two gluons are then taken from the parton distribution function in the two different x ranges corresponding to the rapidity considered for J/ψ. Nuclear absorption is included, depending on the centrality interval of interest. This model accounts for all the Au+Au data points except the most central one, for both central and forward rapidities. The main problem in this interpretation is that it is experimentally impossible at present, to disentangle nuclear absorption and shadowing. The asymmetry observed in d+Au collisions could indeed be due to the rapidity dependence of J/ψ nuclear absorption [25]. In this case, the maximum absorption factor in central

Au+Au collisions, that can be derived from d+Au data would be around 0.65 instead of 0.55.

- Models assuming J/ψ dissociation in the QGP [26] predict surviving probabilities of the J/ψ that are clearly below the observed one. The co-mover model [27], also overpredicts the suppression at RHIC. It is important to notice that although all these models nicely reproduce NA50 Pb+Pb data at SPS energy, they have not been tuned to reproduce NA60 In+In measurements. Therefore, one should wait until the authors have the opportunity to check whether it is possible to account for all SPS data before drawing any firm conclusion concerning the agreement of these models with results at RHIC energy.

- recent lattice QCD calculations [28] predict that only ψ' and χ_c states should be dissolved in a QGP at a temperature around T_c. According to these calculations, the more tightly bound J/ψ would dissolve only around 1.5 to 2 T_c. This could probably explain why the J/ψ suppression measured at RHIC is not greater than the one observed at SPS, provided all cold nuclear effects are of similar amplitude.

- Another interesting hypothesis that has been proposed is the possibility to regenerate J/ψ's from the numerous $c\bar{c}$ present in the medium. Although the models leading to a very dramatic increase of J/ψ production in central Au+Au data had already been ruled out by previous results [29], several predictions are found in good qualitative agreement with the new data [26,30]. Nevertheless, it seems difficult to believe that the weak J/ψ suppression observed at RHIC is due to a strong suppression and a regeneration that almost compensate each other. Fortunately, the process of J/ψ production by charm recombination is very different from the hard gluon-gluon fusion mechanism at work in p+p collisions, and leads therefore to very specific kinematical distributions that could help solve this puzzle, as discussed in the next paragraphs.

2.3. Rapidity distributions and charm recombination

One of the main characteristics of recombined J/ψ's [22] is a rapidity distribution which is peaked at $y = 0$. This feature arises from the square of the charm density that drives the statistical $c\bar{c}$ recombination. In the model from Thews *et al.*, the starting charm distribution is taken from pQCD, which is shown to correctly reproduce the rapidity distribution of J/ψ measured by PHENIX for p+p interactions. The model leads to a clear peak at $y = 0$ for the 'off diagonal' J/ψ contribution. It has been argued that the absence of peak at $y = 0$ in the J/ψ rapidity distributions observed in Au+Au and Cu+Cu collisions at RHIC rules out recombination models. It is important to notice that this is not true if, for some reason, the rapidity distribution of open charm produced in these collisions if much flatter than the J/ψ one measured for p+p interactions. Present observations of single muon spectra [31] may indicate such a trend.

The conclusion is that the absence of peak at $y = 0$ in J/ψ rapidity distributions does not favor the recombination scenarios, although the precise measurement of open charm production over the full p_T and rapidity ranges covered by PHENIX would help to establish the input distributions that are needed in this approach.

2.4. What can be learned from transverse momentum distributions ?

At SPS energies, it has been observed that the J/ψ p_T distribution is modified in nucleus-nucleus collisions as compared to proton-nucleus interactions. Furthermore, the anomalous J/ψ suppression observed by NA50 takes place at low transverse momentum [6]. This is in qualitative agreement with QGP models, in which high transverse momentum $c\bar{c}$ pairs can escape the deconfined region before forming a resonance [32,33]. Nevertheless, this modification is also understood as multiple scattering of initial partons before they produce the $c\bar{c}$ pair [34]. This mechanism is called 'Cronin effect', and leads to an increase of $< p_T^2 >$ that is proportional to L. The resulting $< p_T^2 >_{A+A}^{J/\psi}$ of J/ψ in A+A collisions is usually parameterized as:

$$< p_T^2 >_{A+A}^{J/\psi} = < p_T^2 >_{p+p}^{J/\psi} + \rho L \sigma_{gN} \Delta < p_T^2 >_{gN} \quad (1)$$

where $< p_T^2 >_{p+p}^{J/\psi}$ is the value corresponding to p+p interactions, ρ is the nuclear density, and $\Delta < p_T^2 >_{gN}$ is the average $< p_T^2 >$ acquired by a gluon scattering on a nucleon (indeed on the partons inside a nucleon), with a cross-section σ_{gN}. Such an effect must also be present at RHIC, and should lead to a similar behavior, although the amplitude of the $< p_T^2 >$ increase may depend on $\sqrt{s}$. The transverse momentum distributions of both direct and recombined J/ψ's at RHIC have also been predicted [22]. The broadening parameter $< k_T^2 >$ of charm quark transverse momentum distribution is adjusted to reproduce p+p data. The transverse momentum distributions are then predicted for both diagonal and off-diagonal $c\bar{c}$ pairs in Au+Au collisions. The J/ψ suppression factor is also considered to vary with p_T, to take into account the high p_T pairs which can escape the plasma [33]. The net result is a curve representing $< p_T^2 >$ for diagonal J/ψ, that is far above the measured values. The predicted $< p_T^2 >$ is in much lower if recombined J/ψ's are dominant, which seems in better agreement with PHENIX data. Although these comparisons seem to strongly favor a contribution from $c\bar{c}$ recombination, it is important to notice that the predicted $< p_T^2 >$ value of diagonal J/ψ is not in agreement with PHENIX d+Au measurement. Even without knowing the precise correspondence between N_{coll} and L, two simple estimates of the maximum $< p_T^2 >$ value of J/ψ's in the most central Au+Au collisions can be obtained the following way:

- From NA50 results [6], we can see that $< p_T^2 >_{p+p}^{J/\psi}$ depends on $\sqrt{s}$, but we can assume that $\sigma_{gN} \Delta < p_T^2 >_{gN}$ does not (although the limited range of SPS energies somewhat weakens this assumption). In this case, NA50 result indicates that $\rho L \sigma_{gN} \Delta < p_T^2 >_{gN} \simeq 0.75$ (GeV/c)^2 for central Pb+Pb collisions. PHENIX measured $< p_T^2 >_{p+p}^{J/\psi} = 2.51 \pm 0.21$ (GeV/c)^2 and $< p_T^2 >_{p+p}^{J/\psi} = 4.20 \pm 0.76$ (GeV/c)^2 for forward/backward and central rapidities respectively at RHIC [24]. The maximum values expected in the most central Au+Au collisions without recombination would then be $< p_T^2 >^{J/\psi} \simeq 3.3$ (GeV/c)^2 (forward/backward) and $< p_T^2 >^{J/\psi} \simeq 5$ (GeV/c)^2 ($y = 0$).

- The previous extrapolation could be too naive, and the hypothesis that $\sigma_{gN} \Delta < p_T^2 >_{gN}$ does not depend on $\sqrt{s}$ is not favored by E866 data [35]. A more precise estimate can be obtained by comparing PHENIX p+p and d+Au data. For $y = 0$, $< p_T^2 >$ decreases from proton-proton to deuteron-gold collisions. This in indeed incompatible with Cronin effect, and may be due to large experimental uncertainties. For forward and backward rapidities, the values of $< p_T^2 >$ measured in d+Au collisions are 4.28 ± 0.31 (GeV/c)^2 and 3.63 ± 0.25 (GeV/c)^2 respectively. From NA50, we can take the value of L as ≈ 4 fm for average d+Au (in fact p+Pb or p+W) collisions, and ≈ 9 fm for central Au+Au (in fact Pb+Pb) ones. This extrapolation leads to a maximum value expected in the most central Au+Au collisions without recombination of $< p_T^2 >^{J/\psi} \simeq 2.5 + (4 - 2.5) * 9/4 \simeq 5.75$ (GeV/c)^2, which is in very good agreement with PHENIX data.

The conclusion is that the comparison of $< p_T^2 >$ values predicted in reference [22] with PHENIX data cannot be considered as a strong indication for $c\bar{c}$ recombination at RHIC.

3. Some open questions

Several open questions should be addressed in a near future to better understand present J/ψ data, among which:

- An increase of $< p_T^2 >$ is observed at SPS with collision centrality. Is it related to high transverse momentum pairs that can escape the QGP, or is it due to pure Cronin effect ? Indeed, Cronin effect, together with dissociation in a QGP has also been proposed to lead to a saturation, or even a decrease of $< p_T^2 >$ for most central nucleus-nucleus collisions [36]. If due to high $c\bar{c}$ pairs escaping the QGP, higher $< p_T^2 >$ values of produced J/ψ at RHIC could lead to a smaller anomalous suppression, if not compensated by the bigger size of the deconfined region.

- The anisotropic flow of hadrons observed at RHIC [37] should be taken into account in the co-mover model [27]. The observed positive V_2 could lead to a more efficient J/ψ absorption by co-movers in the reaction plane as compared to the out-of-plane direction. In this case, J/ψ's surviving to interaction with co-moving hadrons would exhibit a negative value of parameter V_2.

- Recent data [38] indicated that charm quarks could have a positive anisotropic flow parameter V_2. If confirmed, this would have a strong influence on the yield of recombined J/ψ's if any, as it increases the charm quark density in the reaction plane. In addition, if off-diagonal $c\bar{c}$ pairs are dominant, the V_2 parameter of J/ψ would be positive and would even lie on the 'partonic flow' curves showing V_2/n as a function of p_T/n, with $n = 2$.

Conclusion

A lot of theoretical progresses have been accomplished since the first prediction of J/ψ suppression by T. Matsui and H. Satz [39]. On the experimental side, a lot of new data are now available, at two different incident beam energies. Nevertheless, it seems that no clear picture has emerged so far, which could help to understand all experimental observations at the same time. To go further in the interpretation of the observed J/ψ yields, the first step is to solve the SPS puzzle. It is almost certain that the different models proposed will be able to account for both NA50 and NA60 data in a near future, although the very flat pattern observed by NA60 in In+In collisions should be hard to reproduce. The analysis of NA60 p+A data is also needed to provide a precise measurement of J/ψ absorption cross-section that allows to get rid of the uncertainties introduced by $\sqrt{s}$ scaling of NA50 p+A points. It is important to notice that the simultaneous interpretation of J/ψ and ψ' data obtained at SPS is mandatory to validate any model. The second step is the comparison with RHIC data. The most important point is the clarification on the expected 'normal' J/ψ yield measured in nucleus-nucleus collisions. This would require a better theoretical knowledge of shadowing and nuclear absorption phenomena, as well as precise d+Au and d+Cu measurements. Then, two different hypotheses must be investigated, depending whether directly produced J/ψ's can be suppressed or not in the QGP phase. If only χ_c and ψ' are dissociated at the temperatures reached in RHIC nucleus-nucleus collisions, no $c\bar{c}$ recombination is needed to reproduce the data. If direct

J/ψ's are also suppressed, either by color screening in the deconfined medium or by interactions with co-moving particles, $c\bar{c}$ recombination or coalescence is necessary to account for the excess of J/ψ observed with respect to the strong predicted suppression. Nevertheless, rapidity distributions of J/ψ do not favor this hypothesis. This is also the case for the evolution of $< p_T^2 >$ with collision centrality, which is found to be compatible with a naive extrapolation of pure Cronin effect from p+p and d+Au data, as it it observed at SPS energies. Therefore, the simplest interpretation of the presently available data could be as follows: only the ψ' is suppressed in S+U collisions at SPS. In addition, In+In and Pb+Pb collisions at the same incident energy both lead to anomalous suppression of the χ_c state, reducing the observed J/ψ yield by 30 to 40%. The same amount of suppression is observed by PHENIX because direct J/ψ's do not suffer anomalous suppression at RHIC energies. This would revive the interest of J/ψ production measurement in heavy-ion collisions at LHC, for which the temperature would be sufficient to dissolve direct J/ψ's. Nevertheless, several measurements could help to confirm or rule out this simple scenario before LHC experiments start: precise measurements of rapidity and transverse momentum distributions are needed to constrain the different models. The measurement of anisotropic flow parameter V_2 of J/ψ would be very interesting to better understand the origin of detected charmonia. The possible suppression of ψ' at RHIC should be investigated. Most of all, precise measurements of open charm production in the same rapidity regions would provide a probe of cold nuclear effects and would be the ultimate reference for J/ψ suppression studies.

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