Réunion PHENIX-France, June 27-30, 2005 á Etretat

J/ψ suppression at $\sqrt{s} = 200$ GeV

Elena G. Ferreiro

Universidad de Santiago de Compostela, Spain

Contents:

1. **Introduction**
2. **The model**
3. **Numerical results**

hep-ph/0505032, with A. Capella

INTRODUCTION: Un petit peu de histoire...

• The J/ψ production in proton-nucleus collisions is suppressed with respect to the characteristic A^1 scaling of lepton pair production (Drell-Yan pairs).

•This suppression is interpreted as a result of the multiple scattering of a pre-resonance $c - \overline{c}$ with the nucleons of the nucleus: nuclear absorption.

• The NA50 collaboration has observed the existence of anomalous J/ψ suppression in $Pb - Pb$ collisions: the suppression clearly exceeds the one expected from nuclear absorption.

Different causes for the yield suppression:

• Such a phenomenon was predicted by Matsui and Satz as a consequence of **deconfinement in a dense medium**.

• It can also be described as a result of final state interaction of the $c-\overline{c}$ pair with the dense medium produced in the collision: **comovers interaction**.

• We have described the results at SPS energies using nuclear absorption $+$ comovers interaction: $\sigma_{abs} = 4.5$ mb , $\sigma_{co} = 0.65$ mb

• Our goal: Make predictions for the yield of J/ψ per binary nucleon-nucleon collision in $AuAu$ and $CuCu$ collisions at $\sqrt{s} = 200$ GeV.

We use the same value of the comovers cross-section, $\sigma_{co} = 0.65$ mb

We introduce different possibilities for the absorptive cross-section

Shadowing is introduced in both the comovers and the J/ψ yields

• A comparison with the results at CERN-SPS, including a prediction for $InIn$ collisions, is also presented.

THE MODEL:

• Ratio of the J/ψ yield over the average number of binary nucleon-nucleon collisions in AB collisions:

$$R_{AB}^{J/\psi}(b) = \frac{dN_{AB}^{J/\psi}(b)/dy}{n(b)} = \frac{dN_{pp}^{J/\psi}}{dy} \frac{\int d^2s \; \sigma_{AB}(b) \; n(b,s) \; S^{abs}(b,s) \; S^{co}(b,s)}{\int d^2s \; \sigma_{AB}(b) \; n(b,s)} \quad (1)$$

$\sigma_{AB}(b) = 1 - \exp[-\sigma_{pp} AB T_{AB}(b)]$ where $T_{AB}(b) = \int d^2s T_A(s) T_B(b-s)$, $T_A(b)$= profile function obtained from Wood-Saxon nuclear densities

$$n(b,s) = AB \; \sigma_{pp} \; T_A(s) \; T_B(b-s)/\sigma_{AB}(b)$$

$\Rightarrow$ upon integration of $n(b,s)$ over d^2s we obtain the average number $n(b)$ of binary nucleon-nucleon collisions at fixed impact parameter b

• S^{abs} and S^{co}= survival probability due to nuclear absorption and comovers interaction

• J/ψ yield in the absence of interactions ($S^{abs} = S^{co} = 1$) scales with the number of binary nucleon-nucleon collisions.

In this case $R_{AB}^{J/\psi}$ coincides with the J/ψ yield in pp collisions.

NUCLEAR ABSORPTION

From the probabilistic Glauber model:

$$S^{abs}(b,s) = \frac{[1-\exp(-A\ T_A(s)\ \sigma_{abs})][1-\exp(-B\ T_B(b-s)\sigma_{abs})]}{\sigma_{abs}^2\ AB\ T_A(s)\ T_B(b-s)} \quad (2)$$

This formula can break down at high-energy due to the increase of the coherence length.

In the limit of $s \to \infty$:

$$(1/\sigma_{abs})\left[1-\exp\left(-\sigma_{abs}\ A\ T_A(b)\right)\right] \Rightarrow A\ T_A(b)\exp\left[-\frac{1}{2}\sigma_{c\bar{c}-N}\ A\ T_A(b)\right] \quad (3)$$

Two changes:

- Change in the expression
- σ_{abs} is substituted by the total $c\bar{c} - N$ cross-section $\sigma_{c\bar{c}-N}$

If $\sigma_{c\bar{c}-N} \sim \sigma_{abs}$: Small change from low energies to asymptotic ones.
The two expressions coincide at the first and second order in the development of the exponential.

If $\sigma_{c\bar{c}-N} >> \sigma_{abs}$: The J/ψ suppression due to final state interaction within the nucleus will be larger at high energies.

The latter possibility seems to be ruled out by preliminary data on dAu collisions which show a rather small suppression at mid-rapidities.

COMOVERS INTERACTION

• Survival probability $S_{co}(b,s)$ of the J/ψ due to comovers interaction:

It is obtained by solving the gain and loss differential equations which govern the final state interactions with the co-moving medium:

$$\tau \frac{dN^{J/\psi}(b,s,y)}{d\tau} = -\sigma_{co}\ N^{J/\psi}(b,s,y)\ N^{co}(b,s,y) \tag{4}$$

$N^{J/\psi}$ and N^{co} are the densities (i.e. number per unit of transverse surface) of J/ψ and comovers (charged + neutral)

• We neglect a gain term resulting from the recombination of c and $\overline{c}$ into J/ψ.

This is natural in our approach since the cross-sections for recombination (gain) is expected to be substantially smaller than σ_{co}.

The possibility of such a recombination, giving sizable effects at RHIC energies, has been considered by several authors:
P. Braun-Munzinger and J. Stachel; R. L. Thews, M. Schrodter and J. Rafelski; L. Grandchamp and R. Rapp; A. P. Kostyuk, M. I. Gorenstein, H. Stoecker and W. Greiner

It will be most interesting to see whether the data confirm or reject such an effect.

We neglect transverse expansion.

We assume a dilution in time of the densities due to longitudinal motion which leads to a τ^{-1} dependence on proper time τ.

The solution is invariant under the change $\tau \to c\tau$
$\Rightarrow$ the result depends only on the ratio τ_f/τ_0 of final over initial time.

Using the inverse proportionality between proper time and densities:

$$\tau_f/\tau_0 = N^{co}(b, s, y)/N_{pp}(y)$$

$\Rightarrow$ we assume that the interaction stops when the densities have diluted, reaching the value of the pp density at the same energy.

At $\sqrt{s} = 200$ GeV and $y^* \sim 0$, $N_{pp}(0) = \frac{3}{2}\frac{(\frac{dN^{ch}}{dy})^{pp}_{y^*=0}}{\pi R_p^2} \sim 2.24$ fm^{-2}.
At CERN-SPS $N_{pp}(0) \sim 1.15$ fm^{-2}

The corresponding increase in the $AuAu$ densities is the same
$\Rightarrow$ the average value of τ_f/τ_0 is about the same at the two energies $\sim 5 \div 7$

The solution of eq. (4):

$$\tau \frac{dN^{J/\psi}(b,s,y)}{d\tau} = -\sigma_{co}\ N^{J/\psi}(b,s,y)\ N^{co}(b,s,y)$$

is given by

$$S^{co}(b,s) \equiv \frac{N^{J/\psi(final)}(b,s,y)}{N^{J/\psi(initial)}(b,s,y)}$$

$$= \exp\left[-\sigma_{co}\ N^{co}(b,s,y) \ell n \left(\frac{N^{co}(b,s,y)}{N_{pp}(0)}\right)\right] \tag{5}$$

Comovers interactions: Partons or hadrons?

We can divide our suppression factor

$$S^{co}(b,s) \equiv \frac{N^{J/\psi(final)}(b,s,y)}{N^{J/\psi(initial)}(b,s,y)} = \exp\left[-\sigma_{co}\, N^{co}(b,s,y)\ell n\left(\frac{N^{co}(b,s,y)}{N_{pp}(0)}\right)\right]$$

where the log term corresponds to:

$$\ell n\left(\frac{N(b,s,y)}{N_{pp}(y)}\right) = \ell n\left(\frac{\tau_f}{\tau_0}\right)$$

in two parts:

Partonic: From initial density $N(b,s,y) = \frac{dN/dy}{\pi R_A^2} \sim \frac{1000}{\pi R_A^2}$ to $\frac{dN/dy}{\pi R_A^2} \sim \frac{300}{\pi R_A^2}$, or equivalently from $\tau_0 = 1$ fm to $\tau_p = 3.36$ fm

Hadronic: From partonic density $\frac{dN/dy}{\pi R_A^2} \sim \frac{300}{\pi R_A^2}$ to $N_{pp}(y) = \frac{dN/dy}{\pi R_{pp}^2} = 2.24$ fm^{-2}, or equivalently from $\tau_p = 3.36$ fm to $\tau_f = 5 - 7$ fm

We find that:

75% of the effect takes place in the partonic phase

25% of the effect takes place in the hadronic phase

i) Comovers density in the dual parton model

In order to compute the survival probability S^{co} we need the comovers density N^{co} at initial time τ_0.

In the DPM

$$N^{co}_{NS}(b,s,y) = \frac{3}{2}\,\frac{dN^{ch}_{NS}}{dy}(b,s,y) = \frac{3}{2}\left[C_1(b)\ n_A(b,s) + C_2(b)\ n(b,s)\right] \quad (6)$$

$n_A(b,s) = A\ T_A(s)\left[1 - \exp\left(-\sigma_{pp} B\ T_B(b-s)\right)\right]/\sigma_{AB}(b)$
$n(b,s) = AB\ \sigma_{pp}\ T_A(s)\ T_B(b-s)/\sigma_{AB}(b)$
The factor 3/2 takes care of the neutrals.

The coefficients $C_1(b)$ and $C_2(b)$ are obtained from string multiplicities which are computed in DPM as a convolution of momentum distributions functions and fragmentation functions.

These functions are universal, i.e. the same for all hadronic and nuclear processes $\Rightarrow$ We use the same expressions as at CERN energies.

b	C_1^{AuAu}	C_2^{AuAu}	C_1^{CuCu}	C_2^{CuCu}	C_1^{PbPb}	C_2^{PbPb}	C_1^{InIn}	C_2^{InIn}
0	1.0274	1.7183	1.0330	1.8196	0.7102	0.3975	0.7480	0.4312
1	1.0276	1.7206	1.0334	1.8239	0.7115	0.3987	0.7485	0.4317
2	1.0278	1.7228	1.0338	1.8320	0.7152	0.4020	0.7527	0.4357
3	1.0286	1.7340	1.0342	1.8437	0.7208	0.4070	0.7599	0.4428
4	1.0293	1.7448	1.0347	1.8592	0.7283	0.4136	0.7696	0.4526
5	1.0302	1.7574	1.0352	1.8787	0.7376	0.4218	0.7810	0.4646
6	1.0310	1.7722	1.0357	1.9014	0.7488	0.4320	0.7945	0.4793
7	1.0320	1.7908	1.0361	1.9258	0.7617	0.4445	0.8112	0.4985
8	1.0330	1.8121	1.0364	1.9505	0.7764	0.4597	0.8290	0.5198
9	1.0340	1.8374	1.0364	1.9754	0.7929	0.4776	0.8475	0.5430
10	1.0349	1.8665	1.0363	2.0006	0.8112	0.4985	0.8664	0.5681
11	1.0357	1.8990	1.0360	2.0259	0.8308	0.5220	0.8855	0.5949
12	1.0362	1.9308	1.0356	2.0515	0.8503	0.5466	0.9046	0.6235
13	1.0364	1.9580	1.0349	2.0772	0.8673	0.5698	0.9233	0.6536

Table 1: Values of C_1 and C_2 in eq. (6) as a function of the impact parameter b. The second and third columns correspond to $AuAu$ collisions and the forth and fifth to $CuCu$ collisions both at $\sqrt{s} = 200$ GeV. The values, calculated in the range $-0.35 < y^* < 0.35$, are given per unit rapidity. The following columns refer to $PbPb$ and $InIn$ at $p_{lab} = 158$ GeV/c and are computed in the rapidity range of the NA50 dimuon trigger $0 < y^* < 1$.

• We see from Table 1 that C_2 is significantly larger than C_1 at RHIC energies.

$\Rightarrow$ DPM multiplicities: closer to a scaling with the number of binary collisions rather than to a scaling with the number of participants.

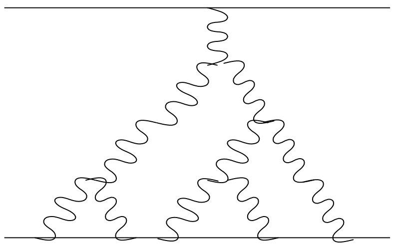
• With increasing energies the ratio C_2/C_1 increases and one obtains a scaling in the number of binary collisions.

This is a general property of Gribov's Reggeon Field Theory which is known as AGK cancellation – analogous to the factorization theorem in perturbative QCD and valid for soft collisions in the absence of triple Pomeron diagrams.

It is well known that this behaviour is inconsistent with data which show a much smaller increase with centrality.

Such a discrepancy is due to **shadowing** which is important at RHIC energies and has not been taken into account in eq. (6). This is precisely the meaning of label NS (no shadowing) in this equation.

ii) Shadowing corrections



Our approach contains dynamical, non linear shadowing
It is determined in terms of diffractive cross sections
It would lead to saturation at $s \longrightarrow \infty$
Controled by triple pomeron diagrams
Contribution to diffraction: positive
Contribution to the total cross-section: negative

Reduction of multiplicity from shadowing corrections in AB collisions:

$$S_{sh}^{ch}(b,s,y) = \frac{1}{1 + A\ F_h(y)\ T_A(s)}\ \frac{1}{1 + B\ F_h(y)\ T_B(b-s)} \qquad (7)$$

Function F: Integral of the triple P cross section over the single P one:

$$F_h(y) = 4\pi \int_{Y_{min}}^{Y_{max}} dY \frac{1}{\sigma_P} \left. \frac{d^2\sigma^{PPP}}{dY\,dt} \right|_{t=0} = C\left[\exp\left(Y_{max}\right) - \exp\left(Y_{min}\right)\right] \quad (8)$$

$Y = \ln(s/M^2)$, $M^2 =$ squared mass of the diffractive system

Particle produced at $y = 0 \Rightarrow$
$Y_{max} = \frac{1}{2}\ln(s/m_T^2)$, $Y_{min} = \ln(R_A m_N/\sqrt{3})$, $C =$ triple pomeron coupling
For charged particles $m_T = 0.4$ GeV and for a J/ψ $m_T = 3.1$ GeV

b (fm)	$Shadow(ch)$	$Shadow(J/\psi)$
0.	0.4959	0.7482
1.	0.4962	0.7485
2.	0.4973	0.7493
3.	0.5003	0.7513
4.	0.5058	0.7550
5.	0.5145	0.7607
6.	0.5268	0.7687
7.	0.5423	0.7792
8.	0.5649	0.7928
9.	0.5954	0.8109
10.	0.6318	0.8321
11.	0.6830	0.8599
12.	0.7447	0.8909
13.	0.8072	0.9200

Shadowing corrections for Au+Au collisions at RHIC

The shadowing produces a decrease of the comovers density

$$N^{co}(b,s,y) = N^{co}_{NS}(b,s,y)\ S^{ch}_{sh}(b,s,y) \tag{9}$$

Two effects:

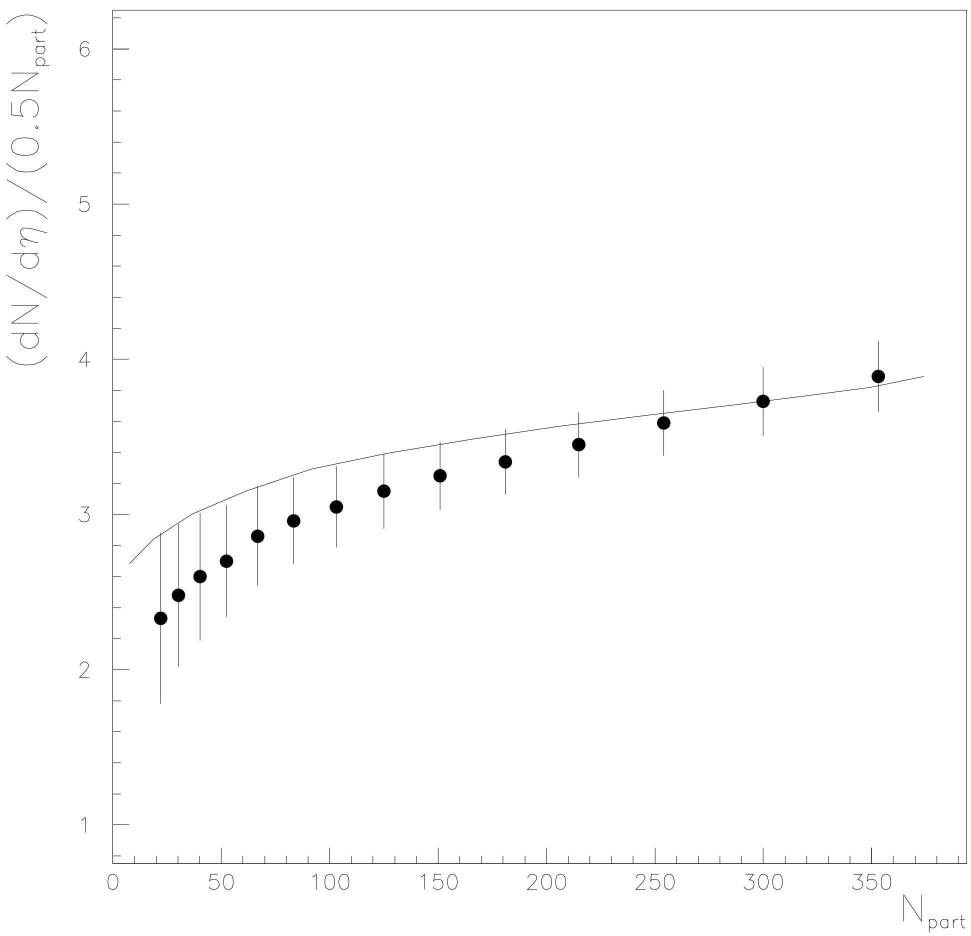
• The J/ψ survival probability S^{co} **increases** due to the shadowing corrections on comovers.

• But the shadowing produces also a **decrease** of the J/ψ yield: The J/ψ suppression $R^{J/\psi}_{AB}$ is given by eq. (1) with the following replacement in its numerator

$$n(b,s) \to n(b,s)\ S^{J/\psi}_{sh}(b,s,y) \tag{10}$$

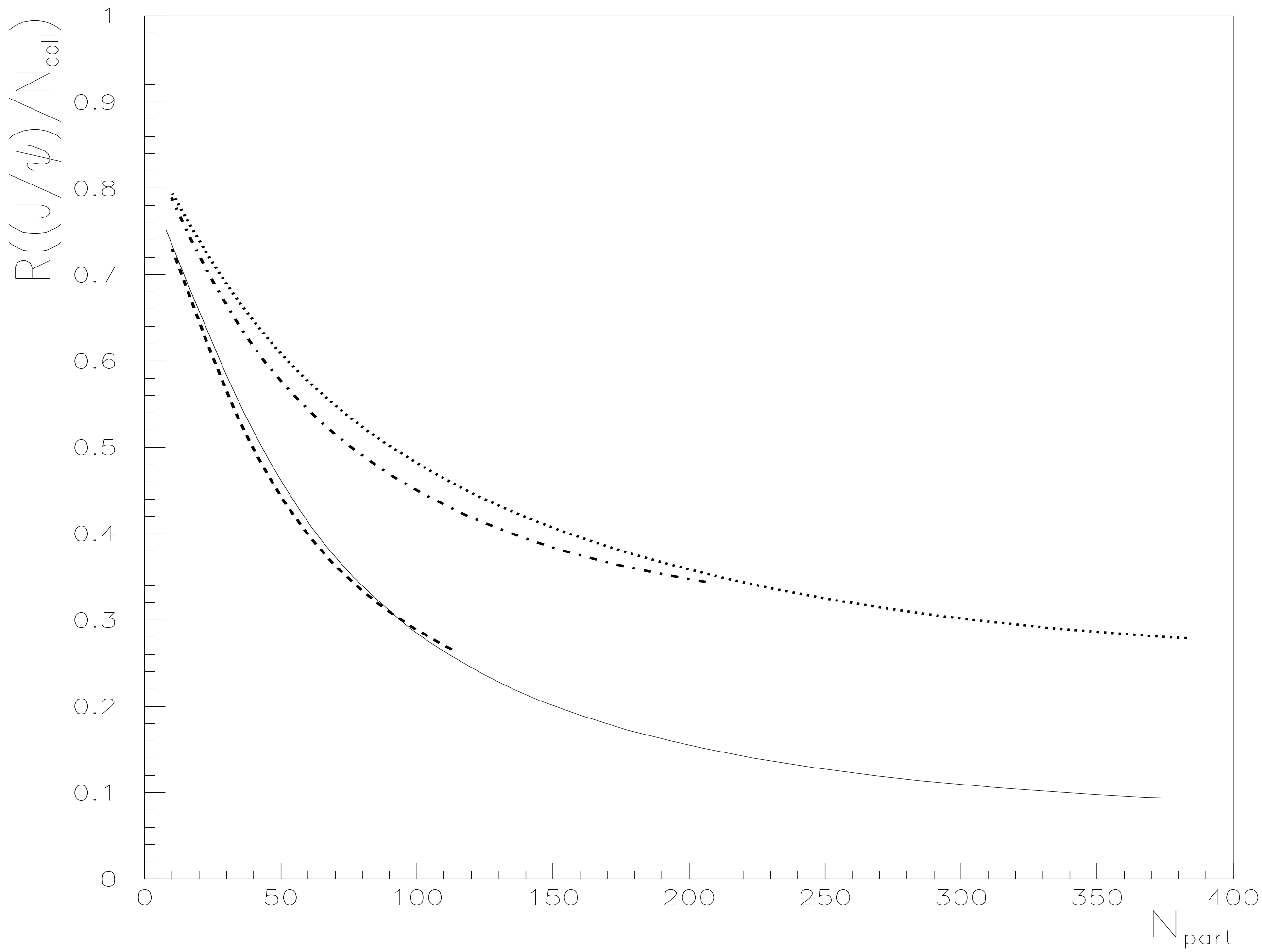
Shadowing $\Rightarrow$ The J/ψ yield in the absence of ($S^{abs} = S^{co} = 1$) does not longer scales with the number of binary collisions.

NUMERICAL RESULTS

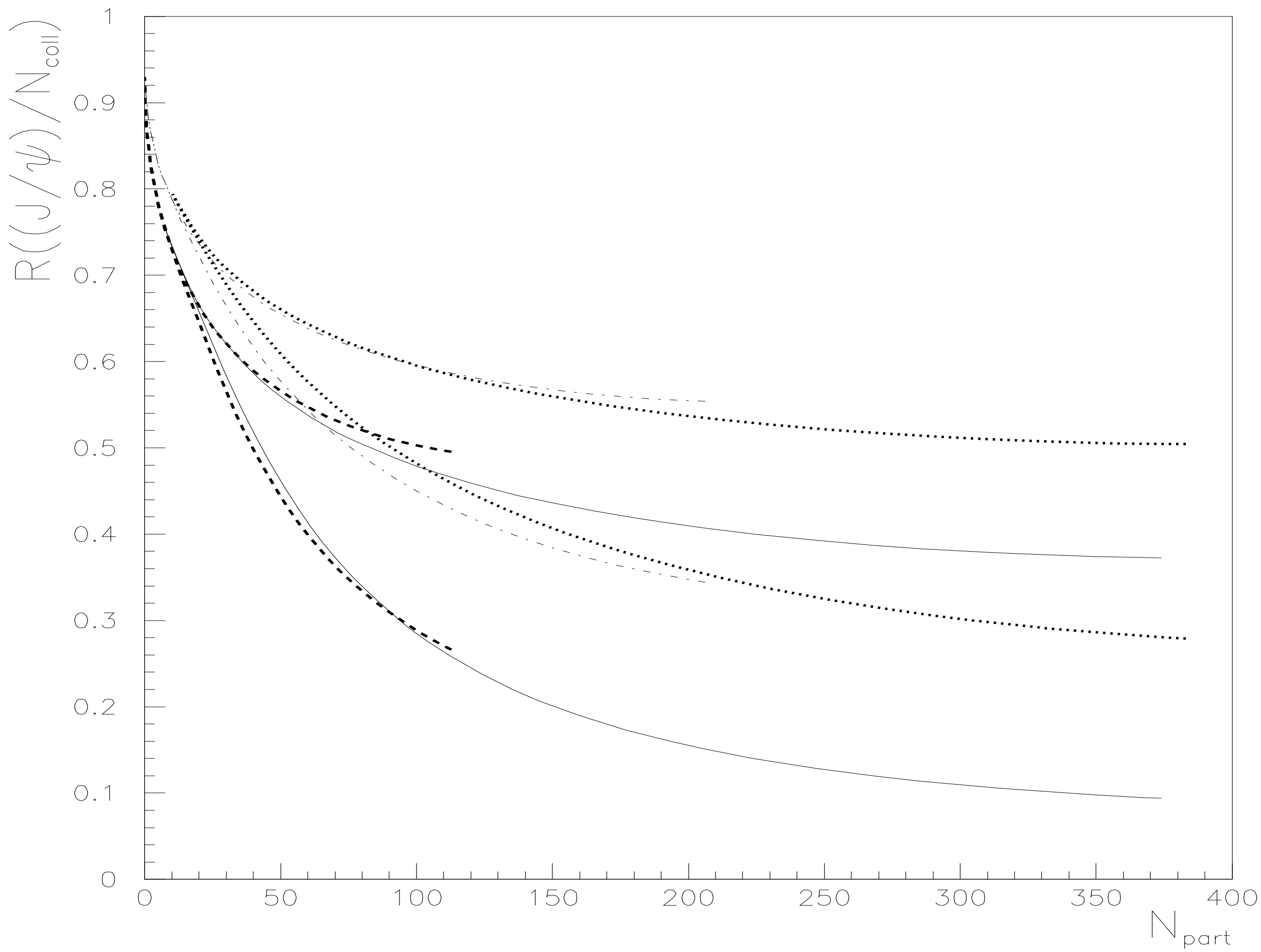


$$\frac{dN^{ch}}{dy}(b,y) = \int d^2s \frac{dN^{ch}_{NS}}{dy}(b,s,y)\ S^{ch}_{sh}(b,s,y)\ . \qquad (11)$$

An increase by a factor 1.13 between $\sqrt{s} = 130$ GeV and $\sqrt{s} = 200$ GeV for central collision was predicted in in agreement with present data.



$R_{AB}^{J/\psi}(b)$ for $AuAu$ collisions at $\sqrt{s} = 200$ GeV (full curve), $CuCu$ collisions at $\sqrt{s} = 200$ GeV (dashed curve), $PbPb$ at $p_{lab} = 158$ GeV/c (dotted curve) and $InIn$ at $p_{lab} = 158$ GeV/c (dashed-dotted curve). $\sigma_{co} = 0.65$ mb and $\sigma_{abs} = 4.5$ mb. The normalization, the same for all four curves, is arbitrary: $dN_{pp}^{J/\psi}/dy = 1$ in eq. (1).



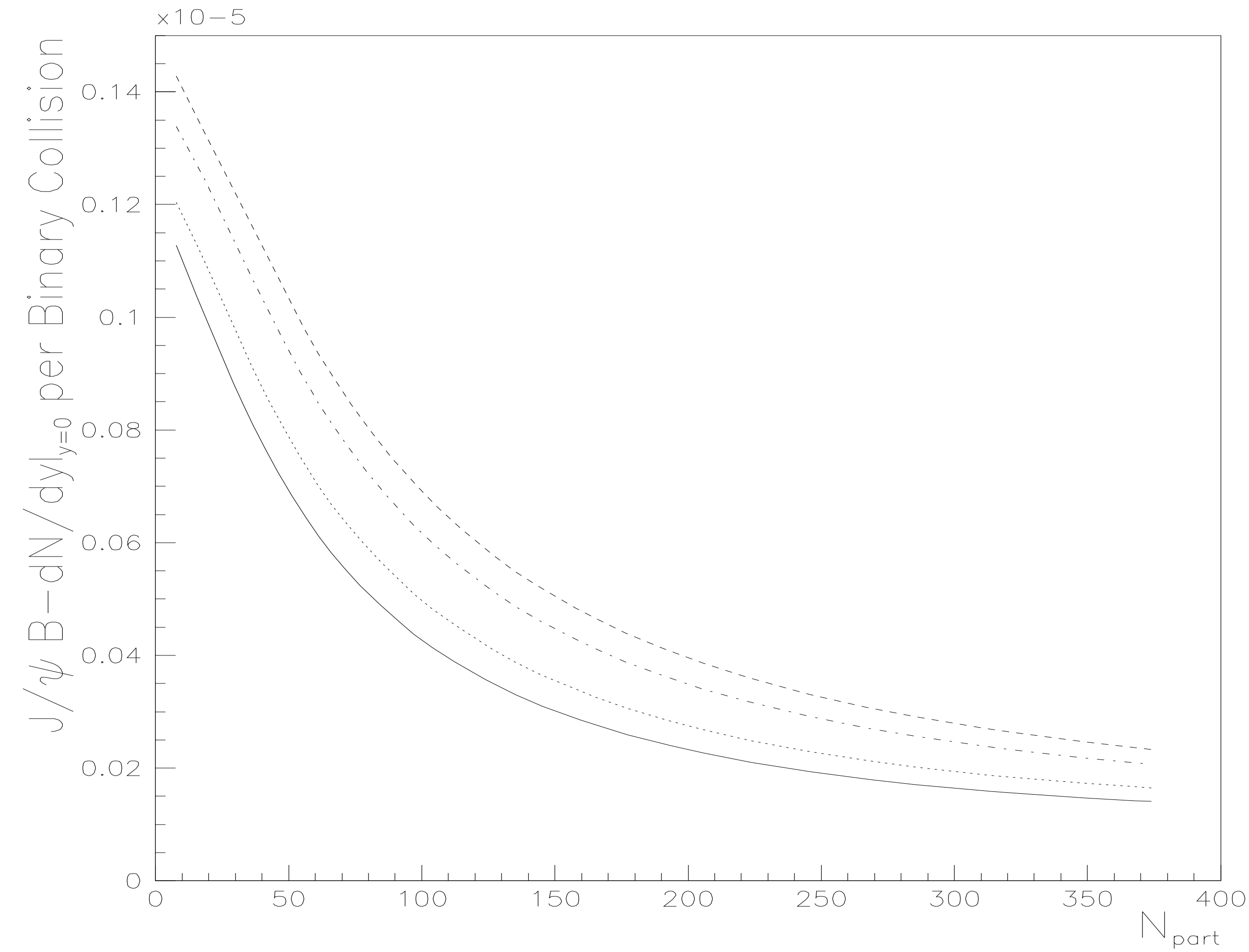
$R((J/\psi)/N_{coll})$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
400
N_{part}

At a given energy, the results for the lighter systems are rather close to the ones for the heavier ones, at the same values of N_{part}.

The J/ψ suppression is much larger at RHIC energies and reaches a factor 10 for central $AuAu$ collisions.

The results for $PbPb$ are identical to those already published except that before the ratio J/ψ over DY was plotted versus E_T.

We don't include here the effect of the fluctuation in the comovers multiplicity since, in a plot versus N_{part}, such a situation does not arise.



$R_{AB}^{J/\psi}(b)$ for $AuAu$ collisions at $\sqrt{s} = 200$ GeV multiplied by the dilepton branching ratio, normalized to the value in pp collisions. From up to down: $\sigma_{co} = 0.65$ mb and $\sigma_{abs} = 0$ mb (dashed curve), $\sigma_{co} = 0.65$ mb and $\sigma_{abs} = 1$ mb (dotted-dashed curve), $\sigma_{co} = 0.65$ mb and $\sigma_{abs} = 3$ mb (dotted curve), $\sigma_{co} = 0.65$ mb and $\sigma_{abs} = 4.5$ mb.

The suppression for central collisions varies between a factor of 6 for $\sigma_{abs} = 0$ and a factor of 10 for $\sigma_{abs} = 4.5$ mb.

Even in the former case the suppression is twice as large as the one obtained in a QCD based nuclear absorption model.

CONCLUSIONS

In a comovers interaction framework we have computed the yield of J/ψ per binary nucleon nucleon collision versus the number of participants in $PbPb$ and $InIn$ collisions at CERN-SPS ($p_{lab} = 158$ GeV/c) and in $AuAu$ and $CuCu$ at $\sqrt{s} = 200$ GeV.

At RHIC energies shadowing corrections to both the J/ψ and the comovers multiplicities are very important and have been included in the calculations.

We have found that, at a given energy, the J/ψ suppression for the lighter and heavier systems are similar, at the same value of N_{part}.

We have also found that the J/ψ suppression at RHIC is significantly larger than at SPS:
For central $AuAu$ collisions it reaches a factor of 10 for $\sigma_{abs} = 4.5$ mb and a factor 6 for $\sigma_{abs} = 0$.

The value of σ_{abs} has to be determined from the dAu data. Preliminary results favor a rather small value, $\sigma_{ab} \approx 1$ mb.

Finally,
an important difference between the J/ψ suppression pattern in a comovers interaction model and in a deconfining scenario is that, in the former case, the anomalous supression sets in smoothly from peripheral to central collisions – rather than in a sudden way when the deconfining threshold is reached.

The NA50 results have not allowed to disentangle these two possibilities.

However, at RHIC energies, the relative contribution of the comovers is strongly enhanced in our approach, and a clear cut answer to this important issue should be obtained.