$J/\psi$ suppression at SPS and RHIC in the comovers approach

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(presented by A. Capella)

The NA50 collaboration data on the $J/\psi$ suppression are compared with the results obtained in a comovers approach based on the Dual Parton Model (DPM). Predictions for the $J/\psi$ suppression versus the charged multiplicity – measured in the rapidity region of the dimuon trigger – are given for SPS and RHIC energies.

The NA50 collaboration has observed an anomalous $J/\psi$ suppression in $Pb Pb$ collisions i.e. a suppression that exceeds the one expected from the extrapolation of the $pA$ and $SA$ data, and exhibits an interesting centrality pattern. These data [1] have been interpreted either as the result of one (or two) deconfining phase transition(s) or as due to the interaction with comovers. Our aim is to examine to what extent the observed pattern can be reproduced in the latter approach. Here, the $J/\psi$ survival probability is the product of two factors $S_{abs}(b,s) \cdot S_{co}(b,s)$. The first factor represents the suppression due to nuclear absorption of the $c\bar{c}$ pair. Its expression, given by the probabilistic Glauber model, is well known. It contains a parameter, the absorptive cross-section $\sigma_{abs}$. The second factor $S_{co}(b,s)$ represents the suppression resulting from the interaction with comovers. Its expression [2–4] is

$$S_{co}(b,s) = \exp \left\{ -\sigma_{co} N_{yDT}(b,s) \ln \left[ \frac{N_{yDT}^{CA}(b,s)}{N_f} \right] \right\}.$$ (1)

Here $N_{yDT}^{CA}$ represents the density of comovers (positive negative and neutrals) in the rapidity region of the dimuon trigger ($0 < y^* < 1$). We determine it in the Dual Parton Model (see Eq. (3) below). $N_f = 1.15$ fm$^{-2}$ is the corresponding density in $pp$, and $\sigma_{co}$ is an averaged interaction cross-section. In the calculations below we take $\sigma_{co} = 1$ mb and $\sigma_{abs} = 4.5$ mb.

In this way we can compute the $J/\psi$ suppression at each impact parameter. However, experimentally, the ratio of $J/\psi$ over DY is plotted as a function of either $E_T$ or the energy of the zero degree calorimeter $E_{ZDC}$. $E_T$ is the transverse energy of neutrals deposited in the NA50 calorimeter, located in the backward hemisphere ($1.1 < y_{lab} < 2.3$). Using the...
proportionality between $E_T$ and multiplicity, we have

$$E_T(b) = \frac{1}{3} q N_{\text{yco}}(b).$$

Here the multiplicity of comovers is determined in the rapidity region of the NA50 calorimeter. The factor 1/3 is introduced because only the energy of neutrals is recorded. In this way $q$ is close to the transverse energy per particle, but it contains also the calibration of the calorimeter. From a fit to the $E_T$ distribution we obtain $q = 0.6$ GeV.

An alternative determination of $q$ is obtained from the measured correlation between $E_T$ and $E_{ZDC}$ (see below). The latter is defined as $E_{ZDC}(b) = [A - n_A(b)] E_{in}$. Here $n_A$ is the number of participants of nucleus, $A - n_A$ the number of spectators, and $E_{in} = 158$ GeV is the beam energy. We see from Eqs. (1) and (2) that, in order to describe the centrality dependence of the $J/\psi$ suppression, it is paramount to have a good description of the $b$ dependence of $N_{\text{yco}}$ – both in the rapidity region of the dimuon trigger and in the one of the $E_T$ calorimeter. The $b$-dependence of charged multiplicity at mid-rapidities has been measured at SPS and RHIC. It has been shown in [5] that these data are well described in DPM, where the multiplicity is given by a linear combination of the number of participants and the number of binary collisions

$$N_{\text{yco}}(b) = A_y(b) n_A(b) + B_y(b) n(b)$$

with coefficients that depend on $b$ and $y$ and can be calculated in the model. Their values at mid-rapidities are given in [4]. Using Eq. (3), with coefficients calculated in the rapidity region of the calorimeter, we obtain a good description of the measured $E_T - E_{ZDC}$ correlation with $q = 0.6$ GeV (Fig. 1)\footnote{In [2–4] an approximation was made in which the dependence on $b$ of the coefficients $A$ and $B$ was dropped. Moreover, a two-string approximation was used for each $NN$-collision. It turns out that these approximations have a very small effect on the ratio $J/\psi$ over DY at each $b$. However, they do change the correlation between $b$ and $E_T$ – or between $E_T$ and $E_{ZDC}$. As a consequence, an extra term in the r.h.s. of Eq. (2) was needed in [3,4] in order to reproduce this correlation.}. The correlation $E_T - b$ is given by $P(E_T, b) \propto \exp\{-(E_T - E_t(b))^2/2qaE_T(b)\}$ with $q = 0.6$ GeV and $a = 0.88$.

The model allows to compute the ratio $J/\psi$ over DY versus either $E_T$ or $E_{ZDC}$ from peripheral collisions up to the knee of the $E_T$ distribution. To go beyond it, we have to introduce the fluctuations responsible for the tail of the $E_T$ distribution (Eq. (2) gives only the average value of $E_T$ at each $b$). They have been introduced in [4] in the model by multiplying $N_{\text{yco}}(b)$ in Eq. (2) by $F(b) = E_T/E_{T}(b)$, where $E_T$ is the measured value of the transverse energy.

The results are presented in Fig. 2a and compared with the NA50 data. We see that from peripheral collisions up to the knee of the $E_T$ distribution, the data are well described. However, beyond the inflexion point at the knee, the decrease in the data is sharper than in the model. Note, however, that the data beyond the knee are obtained with the so-called minimum bias (MB) analysis. Only the ratio $J/\psi$ over MB is measured and it is multiplied by a theoretical ratio DY/MB. In the model, this ratio (as well as the ratio $J/\psi$/MB) is essentially flat beyond the knee – due to the fact that the tail of the $E_T$ distribution of hard ($J/\psi$, DY) and soft (MB) processes is assumed to be the same. In sharp contrast...
with this behaviour, the measured ratio \( J/\psi \) over MB has a very pronounced turn-over at the knee. It is most important to determine whether such a turn-over is due to an increase in the \( J/\psi \) suppression, or, on the contrary, to a small difference in the widths of the tails of the \( E_T \) distributions of soft and hard processes. In the latter case a similar turn-over would also be present in the ratio DY/MB – resulting in a flatter behaviour of the ratio \( J/\psi \) over DY beyond the knee. On the theoretical side the calculation beyond the knee is also subject to uncertainties. In particular, the rapidity regions of the dimuon trigger and the \( E_T \) calorimeter are far apart and the fluctuations in the two regions could be different. In view of that, it would be very interesting to measure the \( J/\psi \) suppression versus charged multiplicity – with the dimuon and multiplicity triggers sitting in the same rapidity region. The results of the model \[ \] for SPS and RHIC are shown in Fig. 3.

The NA50 collaboration has presented new data on the \( J/\psi \) suppression versus \( E_{ZDC} \). In so far as a theoretical model describes well the \( E_T – E_{ZDC} \) correlation, a set of data can be plot versus either variable without further constraints on the model. However, the new data are important since they include many peripheral points. The results of the model are presented in Fig. 2b. The centrality dependence of the \( J/\psi \) suppression is reasonably well reproduced. However, the absolute normalization used in Fig. 2a is here 10 % too large. (Note that the normalization of the data in Fig. 2b is not measured. It has been fixed \[ \] from the one in Fig. 2a using only points in the range \( 60 < E_T < 100 \) GeV). This point has important consequences for the interpretation of the data. Indeed, it is obvious from a comparison of figures 2a and 2b that, if the relative normalization of the two sets of data were correct, the onset of the anomalous suppression in \( E_{ZDC} \) would take place at a value of \( b \) significantly larger than in \( E_T \). This problem is solved with the change of normalization discussed above. However, in this case there would be several experimental points sitting above the NA50 nuclear absorption curve. More important, independently of their absolute normalization, the data of Fig. 2b for \( E_{ZDC} < 28 \) TeV exhibit a \( J/\psi \) suppression significantly steeper than the NA50 absorption model – indicating that the anomalous suppression is already present in very peripheral collisions, where the density is significantly lower than the maximal one in S-U.

In conclusion, the NA50 data on the \( J/\psi \) suppression from peripheral collisions up to the knee of the \( E_T \) distribution can be described in a comovers approach. (In contrast, both the NA50 absorption model and the model \[ \] fail to reproduce the peripheral data). Beyond the knee the obtained suppression is too small. However, in this region the theoretical uncertainties are large and the data contain a theoretical input that has to be checked experimentally.

This work was supported by NATO grant PSTCLG 977275.

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Figure 1. $E_T - E_{ZDC}$ correlation.

Figure 3. Ratio $J/\psi$ over DY normalized to $pp$ versus charged multiplicity in Pb-Pb collisions at $p_{lab} = 158 \text{ AGeV}/c$, both in the range $0 < y^* < 1$, (full line) and at $\sqrt{s} = 200 \text{ AGeV}$ in the range $-0.5 < y^* < 0.5$ (dotted line).

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Figure 2. a): Ratio $J/\psi$ over DY versus $E_T$ compared to NA50 data [1]. The full curve is the theoretical prediction. b): Ratio $J/\psi$ over DY versus $E_{ZDC}$ compared to preliminary results presented by NA50 [1]. The full line is obtained from the full line in a) using the calculated $E_T - E_{ZDC}$ correlation and changing the normalization by a factor 0.92 (see text). The dashed line is obtained computing for each $b$, the value of $E_{ZDC}$ and the value of the ratio $R$ – with the same change in normalization. In both figures the dotted line is the NA50 absorption model, fitting pA and SU.