Why is the J/ψ suppression enhanced at large transverse energy?

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Abstract

We study the ratio of J/ψ over minimum bias in Pb Pb collisions at SPS energy. The NA50 data exhibit a sharp turn-over at $E_T \sim 100$ GeV (close to the knee of the $E_T$ distribution) followed by a steady, steep decrease at larger $E_T$. We show that this behaviour can be explained by the combined effects of a small decrease of the hadronic $E_T$ in the J/ψ event sample (due to the $E_T$ taken by the J/ψ trigger), together with the sharp decrease of the $E_T$ distributions in this $E_T$ region (tail). This phenomenon does not affect the (true) ratio J/ψ over DY (obtained by the NA50 standard analysis), but does affect the one obtained by the so-called minimum bias analysis. A good agreement is obtained with the data coming from both analysis – as well as with the ratios of J/ψ and DY over minimum bias – in the whole $E_T$ region.

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1 Introduction

The NA50 collaboration has observed [1–3] an anomalous $J/\psi$ suppression in $Pb Pb$ collisions, i.e. a suppression significantly larger than the one expected from the extrapolation of $pA$ and $SU$ data. Furthermore, the shape of the ratio $J/\psi$ over $DY$ shows a clear change of curvature – from concave to convex – at $E_T \sim 100$ GeV close to the knee of the $E_T$ distribution followed by a steady decrease at larger $E_T$.

It is important for the discussion in this paper to distinguish between two types of analysis of the data [4]. One is the standard analysis, in which the ratio $J/\psi$ over $DY$ is measured. The other one is called the minimum-bias analysis. In the latter only the ratio of $J/\psi$ over minimum bias ($MB$) is measured – and is multiplied by a theoretical ratio $MB$ over $DY$, i.e.

$$\left(\frac{J/\psi}{DY}\right)_{MB \text{ analysis}} = \left(\frac{J/\psi}{MB}\right)_{exp.} \left(\frac{MB}{DY}\right)^{NA50}_{th}.$$  \hspace{1cm} (1)

Data for the true ratio $J/\psi$ over $DY$, i.e. obtained in the standard analysis, are only available up to the knee of the $E_T$ distribution. They give some indication of the change of curvature at $E_T \sim 100$ GeV mentioned above. However, the information on the behaviour of this ratio at larger values of $E_T$ comes entirely from the $MB$ analysis. In this analysis, the second factor in (1) is practically constant for $E_T > 100$ GeV and therefore the behaviour of the ratios $J/\psi$ over $DY$ and $J/\psi$ over $MB$ in this large $E_T$ region is practically the same.

In this paper we present a simple ansatz according to which the ratio $DY$ over $MB$ is not constant at large $E_T$ but decreases for $E_T > 100$ GeV, i.e. its behaviour is qualitatively similar to the one of the ratio $J/\psi$ over $MB$. As a consequence, the true ratio $J/\psi$ over $DY$ for $E_T > 100$ GeV is significantly flatter than the one obtained according to eq. (1) – and in good agreement with the predictions [5,6] based on comovers interaction, taking into account the fluctuations in the density of comovers at large $E_T$.

Our ansatz is based on the trivial observation that, in the $J/\psi$ event sample, $E_T \sim 3$ Gev is taken by the $J/\psi$ trigger and, thus, the transverse energy deposited in the calorimeter by the other hadron species will be slightly smaller than the corresponding one in the $MB$ event sample. This decrease is, of course, very small.
However, its effect on the ratio of $J/\psi$ over $MB$ at the tail of the $E_T$ distribution is much larger. A possible way to determine this hadronic $E_T$ loss is the following (see Section 2c for a more detailed discussion). Assume that one pair of participants, out of $n_A$, produces the $J/\psi$ and no other hadrons, except, of course, in the fragmentation regions of the collision of this pair (which will contain at least the two leading baryons). The binary collisions of the remaining $n_A - 1$ pairs are assumed to produce ordinary hadrons, exactly in the same way as in the $MB$ event sample.

In this case, the $E_T$ loss in the $J/\psi$ event sample at $b \sim 0$ (where $n_A$ is close to 200) is about 0.5 %. In order to have a rough estimation of its effect on the $J/\psi$ over $MB$ ratio at the tail of the $E_T$ distribution let us consider the $E_T-b$ correlation $P(E_T, b) \propto \exp \left\{ -\frac{(E_T - E_T(b))^2}{2qa E_T(b)} \right\}$ With the values of the parameter given below (Section 2a) we find at $E_T = 130$ GeV:

\[
\frac{P_{MB}(E_T = 130 \text{ GeV}, b = 0)}{P_{J/\psi}(E_T = 130 \text{ GeV}, b = 0)} \simeq \frac{\exp \left\{ -(130 - E_T(0))^2/2qa E_T(0) \right\}}{\exp \left\{ -(130 - 0.995E_T(0))^2/2qa 0.995E_T(0) \right\}} = 1.3. \tag{2}
\]

Such an effect is close to what is needed in the model of refs. [5,6] in order to reproduce the data. This shows that a small variation in the value of $E_T(0)$ between the $J/\psi$ and the $MB$ event samples (0.5 %), produces a much larger effect in their ratio at the tail of the $E_T$ distribution.

A more precise calculation of the hadronic $E_T$ loss and of its effect on the ratio $J/\psi$ over $MB$ beyond the knee will be given below. However, independently of any details, we see that one should be very cautious in interpreting the experimental results on this ratio beyond the knee of the $E_T$ distribution.

Clearly, the effect discussed above will affect the ratio $DY$ over $MB$ in a similar way – while the ratio $J/\psi$ over $DY$ turns out to be practically unaffected. Of course, the ratio of $J/\psi$ over $DY$, obtained according to eq. (1), will be affected in the same way as the ratio $J/\psi$ over $MB$.

The plan of this paper is as follows. In Section 2a we describe a model for $J/\psi$ suppression based on comovers interaction with the comovers density computed in the Dual Parton Model (DPM). We show that in the rapidity region of the dimuon trigger, the charged multiplicity per participant increases with centrality, whereas in that of the $E_T$ calorimeter it is centrality independent. In Section 2b we introduce
fluctuations in the density of comovers beyond the knee of the $E_T$ distribution. In Section 2c we propose a simple ansatz to compute the loss in the average $E_T(b)$ of the $J/\psi$ event sample resulting from the trigger requirement. In Section 3 we present our results for the ratios $J/\psi$ over $MB$, $DY$ over $MB$ and $J/\psi$ over $DY$. As explained above the latter is found to be different in the standard analysis and in the $MB$ one. Conclusions are given in Section 4.

2 The model

a) Comovers interaction in the dual parton model

Here we summarize the model of $J/\psi$ suppression based on comovers interaction [5–8]. We use the centrality dependence of the comovers density obtained [9] in the Dual Parton Model (DPM) [10]. The model in this subsection can be used from peripheral collisions up to the knee of the $E_T$ distribution. To go into the tail of the distribution one has to introduce the modifications in Sections 2b and 2c.

The cross-section of $MB$, $DY$ and $J/\psi$ event samples are given by

\[ I_{MB}^{AB}(b) \propto \sigma_{AB}(b) \]  
\[ I_{DY}^{AB}(b) \propto \int d^2s \sigma_{AB}(b) n(b, s) \]  
\[ I_{J/\psi}^{AB}(b) \propto \int d^2s \sigma_{AB}(b) n(b, s) S_{abs}(b, s)S_{co}(b, s) \] .

Here $\sigma_{AB}(b) = \int d^2s \{1 - \exp[-\sigma_{pp} A B T_{AB}(b, s)]\}$ where $T_{AB}(b, s) = T_A(b) T_B(b - s)$ is the product of profile functions obtained from the Woods-Saxon nuclear densities [11]. Upon integration over $b$ we obtain the $AB$ total cross-section, $\sigma_{AB}$. The factor $n$ in (3) is given by

\[ n(b, s) = AB \sigma_{pp} T_A(s) T_B(b - s)/\sigma_{AB}(b) \] .

Upon integration over $s$ we obtain the average number of binary collisions $n(b) = AB \sigma_{pp} T_{AB}(b)/\sigma_{AB}(b)$.  

4
The factors $S_{\text{abs}}$ and $S_{\text{co}}$ in (4) are the survival probabilities of the $J/\psi$ respectively due to nuclear absorption and comovers interaction. They are given by

$$S_{\text{abs}}(b, s) = \frac{1 - \exp(-AT_A(s) \sigma_{\text{abs}})) [1 - \exp(-B T_B(b - s) \sigma_{\text{abs}})]}{\sigma_{\text{abs}}^2 AB T_A(s) T_B(b - s)} \tag{7}$$

$$S_{\text{co}}(b, s) = \exp \left[ -\sigma_{\text{co}} \frac{3}{2} N_{yDT}^\text{co}(b, s) \ell n \left( \frac{3}{2} N_{yDT}^\text{co}(b, s) N_f \right) \right] \tag{8}$$

In (8), $N_{yDT}^\text{co}(b, s)$ is the density of charged comovers (positives and negatives) in the rapidity region of the dimuon trigger and $N_f = 1.15$ fm$^{-2}$ is the corresponding density in $pp$. The factor $3/2$ in (8) takes care of the neutrals. In the numerical calculations we use $\sigma_{\text{abs}} = 4.5$ mb and $\sigma_{\text{co}} = 1$ mb.

In order to compute the density of comovers we use the DPM formalism developed in [9]. The density of charged particles is given by a linear superposition of the density of participants and the density of binary collisions with coefficients calculable in DPM. For $A = B$ we have

$$N_y^\text{co}(b) = n_A(b) \left[ N_{\mu(b)}^{\mu^- - \mu^+}(y) + N_{\mu(b)}^{q\bar{q} - q\bar{q}}(y) + (2k - 2) N_{\mu(b)}^{q_s - \bar{q}_s}(y) \right]$$

$$+ \left[ (n(b) - n_A(b)) 2k N_{\mu(b)}^{q_s - \bar{q}_s}(y) \right] \tag{9}$$

Here $n_A(b, s)$ is given by

$$n_A(b, s) = A T_A(s) [1 - \exp \{ -\sigma_{pp}, B T_B(b - s) \}] / \sigma_{AB}(b) \tag{10}$$

Upon integration over $s$ of (10) we obtain the average number of participants of $A$ (or participant pairs for $A = B$). $k = 1.4$ is the average number of inelastic collisions in each $NN$ collision and $\mu(b) = k n(b)/n_A(b)$ is the total average number of collisions suffered by each participant. The first term in (9) is the charged plateau height in one $NN$ collision, resulting from the superposition of $2k$ strings, multiplied by the average number of participant pairs $n_A$. This would be the only contribution if each participant of $A$ would interact with only one participant of $B$. The second term in (9) contains the contributions resulting from the extra collisions of each

$^2$This value is in between the ones obtained from fits of the $pA$ data of the NA38 [18] and of E866 [19] Collaborations, and is consistent with both sets of data.
participant. Since in DPM there are two strings per inelastic collision, this second term, consisting of strings stretched between sea quarks and antiquarks, completes the total average number of strings – equal to $2kn$. The string multiplicities in (9) are obtained from a convolution of momentum distribution functions and fragmentation functions. All relevant equations and the values of the parameters needed for their calculation are given in [9]. Their numerical values for several values of $b$ are listed in Table 1 – for the rapidity regions of both the dimuon trigger and the $E_T$ calorimeter.

The results, in the rapidity regions of both the dimuon trigger and the $E_T$ calorimeter, are shown in Fig. 1. We see that the charged multiplicity per participant increases with centrality in the rapidity region of the dimuon trigger. This increase is slightly smaller than the one in the central region $-0.5 < y^* < 0.5$ [4,12]. However, it is still significant. On the contrary, in the rapidity region of the calorimeter, the same quantity is practically independent of centrality and we recover here the behaviour expected in the wounded nucleon model [13].

In order to compute $S^{co}(b, s)$, eq. (8), we need the density of comovers at each $b$ and $s$. In this case $n_A \neq n_B$ and we have to use the general DPM formulae (eqs. 6.1 and 6.15 of [10]). We have [8]

$$N^{co}_y(b, s) = [N_1 n_A(b, s) + N_2 n_B(b, b - s) + N_3 n(b, s)] \theta (n_B(b, b - s) - n_A(b, s)) + [N'_1 n_A(b, s) + N'_2 n_B(b, b - s) + N'_3 n(b, s)] \theta (n_A(b, s) - n_B(b, b - s)) .$$

(11)

The values of the coefficients $N_i$ and $N'_i$ are given in Table 2 [1]. By comparing the values in Tables 1 and 2 we see that for $n_A = n_B$ we recover eq. (10).

Eqs. (2) to (10) allow to compute the impact parameter distributions of the $MB$, $DY$ and $J/\psi$ event samples. Experimental results for these quantities are plotted as a function of observable quantities such as $E_T$ – the energy of neutrals deposited in the calorimeter. Using the proportionality between $E_T$ and multiplicity, we have

$$E_T(b) = \frac{1}{2} q N^{co}_{y, cal}(b) .$$

(12)

Here the multiplicity of comovers is determined in the rapidity region of the $E_T$
calorimeter. The factor 1/2 is introduced because $N^{\text{co}}$ is the charged multiplicity whereas $E_T$ refers to neutrals. In this way $q$ is close to the average transverse energy per particle, but it also depends on the calibration of the calorimeter. The correlation $E_T - b$ is parametrized in the form

$$P(E_T, b) = \frac{1}{\sqrt{2\pi qaE_T(b)}} \exp\left\{-(E_T - E_T(b))^2/2qaE_T(b)\right\} \; .$$  \hspace{1cm} (13)

The $E_T$ distributions of $MB$, $DY$ and $J/\psi$ are then obtained by folding eqs. (3)-(5) with $P(E_T, b)$, i.e.

$$I^{MB,DY,J/\psi}_{AB}(E_T) = \int d^2b \; I^{MB,DY,J/\psi}_{AB}(b) \; P(E_T, b) \; .$$  \hspace{1cm} (14)

The parameters $q$ and $a$ are obtained from a fit of the $E_T$ distribution of the $MB$ event sample. Note that since $N^{\text{co}}_{\text{cal}}(b)$ is proportional to the number of participants (see Fig. 1) our fit is identical to the one obtained \[7\] using the wounded nucleon model. Actually, we obtain identical curves to the ones in Fig. 1 of ref. \[1\] – where the $E_T$ distributions of $MB$ events of 1996 and 1998 are compared with each other. The values of the parameters for the 1996 data are $q = 0.62$ GeV and $a = 0.825$. For the 1998 data, the tail of the $E_T$ distribution is steeper, and we get $q = 0.62$ GeV and $a = 0.60$\[4\]. In the following we shall use the latter values. Indeed, according to the NA50 Collaboration \[4\], the 1996 data (thick target) at large $E_T$ are contaminated by rescattering effects – and only the 1998 data should be used beyond the knee.

b) Comovers fluctuations

The model described above allows to compute the $E_T$ distribution of $MB$, $DY$ and $J/\psi$ event samples between peripheral $AB$ collisions and the knee of the $E_T$ distribution. Beyond it, most models, based on either deconfinement or comovers interaction, give a ratio $J/\psi$ over $DY$ which is practically constant – in disagreement with NA50 data. A possible way out was suggested in \[5\]. The idea is that, since $E_T$ increases beyond the knee due to fluctuations, one can expect that this is also

\[4\] Note that the same value of the parameter $a$ is used in the $MB$, $DY$ and $J/\psi$ event sample. A priori there could be some differences in the fluctuations for hard and soft processes.
the case for the density of comovers. Since \( N_{y_{DT}}^{co} \) does not contain this fluctuation it has been proposed to introduce the following replacement in eq. (8):

\[
N_{y_{DT}}^{co}(b, s) \rightarrow N_{y_{DT}}^{Fco}(b, s) = N_{y_{DT}}^{co}(b, s) \ F(b)
\tag{15}
\]

where \( F(b) = E_T/E_T(b) \). Here \( E_T \) is the measured value of the transverse energy and \( E_T(b) \) is its average value given by eq. (12) – which does not contain the fluctuations.

The replacement (15) assumes that the fluctuation in \( N_{y}^{co} \), in the rapidity region of the dimuon trigger, is identical to the fluctuation in \( E_T \) measured by the calorimeter. Since these two regions do not overlap, the two fluctuations could be weakly correlated. However, this is not the case in string models where multiplicity fluctuations are mainly due to fluctuation in the number of strings (rather than to multiplicity fluctuations within individual strings). This introduces long-range rapidity correlations [14] (see also [15] for a discussion on this point).

It has been shown in [16] that, introducing the fluctuations given by (15) in a deconfining approach, one can describe the NA50 data, at large and intermediate values of \( E_T \), either with two sharp deconfining thresholds or with a gradual onset of \( J/\psi \) suppression (rather than a sharp one)\(^5\).

Introducing the replacement (15) in the comovers model of Section 2a, we obtain a change of curvature in the ratio \( J/\psi \) over \( DY \) at \( E_T \sim 100 \text{ GeV} \). However, its decrease at larger values of \( E_T \) is smaller than the experimental one. In the next section, we introduce a new mechanism which increases the \( J/\psi \) suppression at large \( E_T \), in the \( MB \) analysis.

c) \( E_T \) loss of ordinary hadrons induced by the \( J/\psi \) trigger

As discussed in the Introduction, due to energy conservation, the production of a \( J/\psi \) in the dimuon trigger produces a decrease of the \( E_T \) of ordinary hadrons in

\(^5\)Note, however, that this model does not describe the data at low \( E_T \). Moreover, according to the analysis of [6], it should also fail to describe the preliminary data [2] on the \( J/\psi \) suppression versus the energy \( E_{ZDC} \) of the zero degree calorimeter for peripheral collisions. Indeed, it was shown in [6] that these data confirm the low \( E_T \) shape of the data versus \( E_T \). Moreover, this new data require the anomalous suppression to be present for very peripheral \( Pb Pb \) collisions.
the $J/\psi$ event sample – as compared to its value in the $MB$ one. As discussed there, this effect is strongly amplified in the tail of the $E_T$ distribution. The size of this hadronic $E_T$ loss is very small. However, its exact value is difficult to compute since we do not know in detail the rapidity region affected by the about 3 GeV of $E_T$ taken by the $J/\psi$. We propose the following ansatz. Let us single out the $NN$ collision in which the $J/\psi$ is produced and let us assume that in this collision no hadrons, other than the $J/\psi$, are produced in the central rapidity interval $-1.8 \lesssim y_* \lesssim 1.8$ – which includes the regions of the $E_T$ calorimeter and of the dimuon trigger. Of course, ordinary hadrons, in particular the two leading baryons, will be produced in the two fragmentation regions of this collision. With this assumption, eq. (12) has to be replaced by

$$E_T(b) = \frac{1}{2} q \left\{ (n_A(b) - 1) \left[ N_{qq}^{P-qq_T}(y) + n_{\mu(b)}^{q-p-q_T}(y) + (2k - 2)N_{Nq}\mu(y) \right] 
+ (n(b) - n_A(b)) 2k N_{\mu(b)}^{q-q_{\mu}}(y) \right\}$$

(16)

One could think that the hadronic $E_T$ loss resulting from the replacement of eq. (12) by eq. (16) is the maximal possible one. Actually, this is not the case. Indeed, it could happen that the $J/\psi$ trigger produces a decrease of the average energy of the other collisions involving either one of the two nucleons of the binary collision which produces the $J/\psi$. In (16) we have assumed that this is not the case and that all these extra collisions produce exactly the same hadronic multiplicity as in the $MB$ case. One could instead assume that no ordinary hadrons are produced in these extra collisions either, i.e. that one pair of participants produces only the $J/\psi$ and no other hadrons (in the central rapidity interval defined above). In this case (12) should be scaled down by a factor $(n_A(b) - 1)/n_A(b)$, i.e.

$$E_T(b) = \frac{1}{2} q \frac{n_A(b) - 1}{n_A(b)} N_{yca}(b)$$

(17)

Both possibilities, eqs. (16) and (17), will be discussed in the next section\textsuperscript{6}. Of course, for the $MB$ event sample we use eq. (12) without any change.

In order to see how the hadronic $E_T$ loss in the $J/\psi$ event sample, given by eqs. (16) and (17), compares to the $E_T \sim 3$ GeV taken by the $J/\psi$, we have calculated

\textsuperscript{6}The same changes should also be made in $N_{yca}^{co}$ but, obviously, their effect is negligibly small.
the charged multiplicity per participant pair in the rapidity region $-1.8 < y^* < 1.8$ – which includes both the dimuon trigger and the $E_T$ calorimeter. Using the values in Table 1 we obtain 6.6. Multiplying it by 1.5 to include the neutrals and assuming an average $E_T$ per particle of 0.5 GeV we obtain an average $E_T$ loss of $E_T \sim 5$ GeV. This is the average $E_T$ loss induced by eq. (15), where the contribution of one participant pair to the hadronic $E_T$ has been removed. At $b = 0$, where $n_A$ is close to 200, it amounts to about 0.5 % of the total $E_T$ produced in the above rapidity interval. From, the values in Table 1, one can also see that the average $E_T$ loss induced by (16) is about one half of the above value, i. e. $E_T \sim 2.5$ GeV – corresponding to about 0.25 % of the total $E_T$ in the considered rapidity interval. Therefore an average $E_T$ loss of $E_T \sim 3$ GeV would be somewhere in between the ones obtained with the ansatzs in eqs. (16) and (17).

3 Numerical results and comparison with experiment

a) Ratio $J/\psi$ over $MB$

The results for the ratio $J/\psi$ over $MB$ versus $E_T$ in $Pb Pb$ collisions at 158 GeV are shown in Fig. 2 and compared with NA50 preliminary data [2]. The dotted curve is the result of the model as presented in Section 2a, i.e. without the effect of the fluctuations, eq. (13), or that of the $E_T$ loss induced by eqs. (16) or (17). The dashed line is the result obtained with the fluctuations but without the $E_T$ loss. The dashed-dotted and the solid curves are the results obtained when both effects are taken into account using eqs. (16) and (17), respectively, for the $E_T$ loss. We see that the turn-over and subsequent decrease are well reproduced. Note that the calculation of the dashed, dashed-dotted and full lines does not involve any new free parameter.

7 The points obtained with the standard analysis are not included in Fig. 2 since they are not experimental measurements of the ratio $J/\psi$ over $MB$. These points extend to lower values of $E_T$ than the ones obtained in the $MB$ analysis. Unfortunately, we see from Fig. 7 of [4] that, at low $E_T$, the measured values of $DY$ over $MB$ deviate from the theoretical ones.
b) Ratio $DY$ over $MB$

As mentioned in Section 2c the effect of the $E_T$ loss should also be present in the case of the $DY$ event sample – where a dimuon of average mass close to that of $J/\psi$ is produced. We use in this case the same prescriptions, eqs. (14)-(17), as for $J/\psi$. The results for this ratio versus $E_T$ in $Pb Pb$ collisions at 158 GeV are presented in Fig. 3 and compared to 1996 NA50 data \[4\]. The dotted line is obtained without introducing the $E_T$ loss. We see that the ratio tends to saturates at large $E_T$. The dashed-dotted and solid curves are obtained using the $E_T$ loss given by eqs. (16) and (17), respectively. We observe a turn-over and a subsequent decrease at large $E_T$, qualitatively similar to the one in $J/\psi$ over $MB$ ratio, but smaller in magnitude due to the absence, here, of the comover interaction – and, hence, of the effect of the fluctuations. It is interesting that the data, although having large statistical errors, also seem to indicate a turn-over. In any case, they are consistent with our results\[8\].

A test of our mechanism could be provided by a measurement of the ratio open charm over $MB$ beyond the knee. The presence of a similar turn-over beyond the knee would strongly support our interpretation.

c) Ratio $J/\psi$ over $DY$

The results of our model for this ratio, versus $E_T$, in $Pb Pb$ collisions at $\sqrt{s} = 158$ GeV, are shown in Fig. 4 and compared to NA50 data \[1\] – both for the true $J/\psi$ over $DY$ ratio (labeled with $DY$), and for the one obtained with the $MB$ analysis (labeled Min. Bias). The results of the model for the true ratio are given by the dotted line (without fluctuations) and the dashed line (with fluctuations). The latter is practically the same as the ones obtained in \[4\] and \[5\]. In both cases the $E_T$ loss mechanism introduced above was not present. However, our results for the true ratio $J/\psi$ over $DY$ do not change, since the effect due to the $E_T$ loss cancels, to a high accuracy, in this ratio. We see that our results are in good agreement with

\[8\]Note that the ration $DY$ over $MB$ has been measured in 1996. The NA50 Collaboration does not consider the 1996 data to be reliable beyond the knee due to possible contamination of rescattering in the (thick) target. However, from the comparison of 1996 and 1998 data on the ratio $J/\psi$ over $MB$, we can expect that, using a thin target, the $DY$ over $MB$ ratio beyond the knee would be smaller than with a thick one.
the NA50 data for this ratio – which do not extend beyond the knee. The other data in Fig. 4 are obtained with the MB analysis, summarized by eq. (11) – where the last factor is given by eq. (14), and, therefore, does not contain the $E_T$ loss induced by eqs. (16) or (17). Using our results (Section 3a) for the ratio $J/\psi$ over $MB$ and multiplying it by the ratio $(MB/DY)^{\text{NA50}}_{th}$ we obtain the dashed-dotted and solid curves in Fig. 4. The agreement with the NA50 data obtained with the MB analysis is substantially improved.

A straightforward consequence of the above results is that the data of the standard and MB analysis are different at large $E_T$ and, therefore, should not be put on the same figure. The latter should be shown only as a ratio $J/\psi$ over $MB$ (which is the measured quantity in this analysis). A plot of the $J/\psi$ over $DY$ ratio should include only data obtained in the standard analysis.

Another consequence of our approach is that the decrease, beyond the knee, of the ratio $J/\psi$ over $DY$ in the MB analysis, as a function of $E_{ZDC}$ (the energy of the zero degree calorimeter), should be less pronounced than the corresponding one versus $E_T$. This is due to the fact that the main contribution to $E_{ZDC}$ is proportional to the number of spectators, which is not affected by the presence of the $J/\psi$ trigger. The data [2,3] seem to indicate that this is indeed the case [6].

4 Conclusions

The idea of using the $J/\psi$ over $MB$ ratio as a measure of the $J/\psi$ suppression was first introduced in ref. [17]. While this allows to improve considerably the statistics, it can only be safely used from peripheral collisions up to the knee of the $E_T$ distribution. Beyond it, this ratio is very sensitive to small differences between the average $E_T$ of the $J/\psi$ and $MB$ event samples. We have argued that such a difference is indeed present due to the $E_T$ taken by the $J/\psi$ trigger.

We have introduced a simple, physically sound, ansatz to evaluate this $E_T$ loss in the $J/\psi$ event sample (as compared to its value in the $MB$ one) and have shown that with this ansatz the NA50 data for the ratio $J/\psi$ over $MB$ can be reproduced. In our model, this mechanism does not affect the true ratio $J/\psi$ over $DY$ – i.e. the one obtained by the standard analysis. However, it does affect this ratio in the case
of the minimum bias analysis. Agreement is obtained with the NA50 data for this ratio, in both analysis.

An unavoidable consequence of our approach is that the ratio $DY$ over $MB$ should also exhibit a turn-over close to the knee of the $E_T$ distribution followed by a subsequent decrease. Actually, the 1996 NA50 data [4] provide some indication of such a turn-over. Our results are in agreement with these data.

Independently of the details of our implementation of the hadronic $E_T$ loss in the $J/\psi$ event sample, the analysis presented here indicates that it is premature to interpret the NA50 data at large $E_T$ (beyond the knee of the $E_T$ distribution) as a manifestation of a phase transition to a new state of matter. Actually, we have shown that a model based on comovers interaction provides a good description of the NA50 data in the whole $E_T$ region.

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Figure Captions:

**Figure 1.** Charged multiplicity per unit-rapidity and per participant pair versus number of participants in Pb Pb collisions at 158 GeV, in the rapidity regions of the dimuon trigger and of the $E_T$ calorimeter.

**Figure 2.** The ratio $J/\psi$ over $MB$ versus $E_T$ in Pb Pb collisions at 158 GeV. The dotted curve is obtained without $E_T$ fluctuations and $E_T$ loss. The dashed line contains the $E_T$ fluctuations (eq. (15)) and no $E_T$ loss. The dashed-dotted and solid lines are obtained when both effects are taken into account, using, respectively, eqs. (16) and (17) for the $E_T$ loss. The data (in arbitrary units) are from refs. [2,3].

**Figure 3.** Same as Fig. 2 for the ratio $DY$ over $MB$. The dotted curve is obtained without $E_T$ loss. The dashed-dotted and solid curves are obtained with $E_T$ loss using eqs. (16) and (17), respectively. The data are from ref. [4].

**Figure 4.** Same as Fig. 2 for the ratio $J/\psi$ over $DY$. The data are from ref. [1]. The data labeled with $DY$ are for the true $J/\psi$ over $DY$ ratio (standard analysis). They should be compared with the dotted and dashed lines obtained, respectively, without and with $E_T$ fluctuations. The effect of the $E_T$ loss cancels in the true ratio $J/\psi$ over $DY$. The data labeled Min. Bias are obtained with the $MB$ analysis (see eq. (1)) and should be compared with the dashed-dotted and solid lines, obtained with the $E_T$ loss given by eqs. (16) and (17), respectively.

Table Captions:

**Table 1.** Values of $N_{\mu(b)}^{qq-Pq^T} + N_{\mu(b)}^{q-\bar{q}^T}$ (second column) and $N_{\mu(b)}^{q-\bar{q}}$ (third column) for charged particles in eq. (11), for various values of the impact parameter ($b$) (first column), integrated in $y$ in the rapidity region of the dimuon trigger $0 < y^* < 1$. The forth and fifth columns are the same quantities integrated in the rapidity region of the $E_T$ calorimeter ($-1.8 < y^* < -0.6$), and divided by its length (1.2 units).

**Table 2.** Values of the coefficients $N_i$ and $N'_i$ in eq. (11), integrated in rapidity in the region $0 < y^* < 1$ for various values of the impact parameter $b$. 

15
Fig. 1

\[ \frac{1}{0.5N_{\text{par}}} \frac{dN^{ch}}{dy} \]

- \[ 0. < y' < 1. \]
- \[ -1.8 < y' < -0.6 \]
Fig. 2

\[ R(\langle J/\psi \rangle)/M_B \] (a.u.)

\[ E_T \] (GeV)

- \textbf{Pb–Pb 1996 Min. Bias}
- \textbf{Pb–Pb 1998 Min. Bias}
Fig. 4

![Graph showing R(J/ψ/DY) vs. E_T (GeV) with different data sets for Pb-Pb collisions labeled Pb-Pb 1996 with DY, Pb-Pb 1998 with DY, Pb-Pb 1996 Min. Bias, and Pb-Pb 1998 Min. Bias.](image)
\[
\begin{align*}
N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P} &= 0.994 + 0.142 = 1.136 \\
N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P} &= 0.751 + 0.087 = 0.838 \\
N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P} &= 0.144 + 0.088 = 0.232 \\
N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P} &= 0.784 + 0.092 = 0.876 \\
N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P} &= 0.154 + 0.097 = 0.251 \\
N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P} &= 0.878 + 0.106 = 0.984 \\
N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P} &= 0.178 + 0.118 = 0.296 \\
N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P} &= 0.195 + 0.134 = 0.329
\end{align*}
\]

Table 1

| $b$ (fm) | $N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P}$ | $N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P}$ | $N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P}$ | $N_{\mu(b)}^{qq^P-\bar{q}^T} + N_{\mu(b)}^{q\bar{q}^P-qq^P}$ |
|----------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| 0        | 0.994                                           | 0.142                                           | 0.751                                           | 0.087                                           |
| 2        | 1.002                                           | 0.144                                           | 0.760                                           | 0.088                                           |
| 4        | 1.024                                           | 0.148                                           | 0.784                                           | 0.092                                           |
| 6        | 1.057                                           | 0.154                                           | 0.823                                           | 0.097                                           |
| 8        | 1.105                                           | 0.164                                           | 0.878                                           | 0.106                                           |
| 10       | 1.167                                           | 0.178                                           | 0.952                                           | 0.118                                           |
| 12       | 1.241                                           | 0.195                                           | 1.040                                           | 0.134                                           |

Table 2

| $b$ (fm) | $N_1$  | $N_2$  | $N_3 = N'_3$ | $N'_1$  | $N'_2$  |
|----------|--------|--------|---------------|---------|---------|
| 0        | 0.5896 | 0.1210 | 0.3970        | 0.3743  | 0.3363  |
| 2        | 0.5937 | 0.1222 | 0.4018        | 0.3772  | 0.3387  |
| 4        | 0.6038 | 0.1250 | 0.4134        | 0.3844  | 0.3444  |
| 6        | 0.6192 | 0.1295 | 0.4323        | 0.3954  | 0.3533  |
| 8        | 0.6405 | 0.1358 | 0.4601        | 0.4107  | 0.3656  |
| 10       | 0.6671 | 0.1443 | 0.4988        | 0.4300  | 0.3814  |
| 12       | 0.6961 | 0.1541 | 0.5470        | 0.4513  | 0.3989  |