J/ψ suppression as a function of the energy of the zero degree calorimeter: can it discriminate between deconfining and comovers interaction models?

A. Capella and D. Sousa

Laboratoire de Physique Théorique, UMR 8627 CNRS, Université Paris XI, Bâtiment 210, 91405 Orsay Cedex, France

Abstract

The ratio of J/ψ over Drell-Yan cross-sections as a function of the energy of the zero degree calorimeter in Pb Pb collisions has been computed in a comovers interaction model and compared with the results of a deconfining model. The predictions of the two models are different both for peripheral events and for very central ones. These differences are analyzed and the results of the models confronted with available data – not only for Pb Pb but also for pA and SU collisions.
1 Introduction

The NA50 interpretation of the data on $J/\psi$ suppression in $pA$, $SU$ and $PbPb$ collisions is as follows [1]. The $pA$, $SU$ and peripheral $PbPb$ data (up to $E_T \sim 35 \div 40$ GeV), are well described with nuclear absorption alone with an absorptive cross-section $\sigma_{abs} = 6.4 \pm 0.8$ mb. At $E_T \sim 40$ GeV there is a sudden onset of anomalous suppression. A second accident occurs at $E_T \sim 90 \div 100$ GeV, close to the knee of the $E_T$ distribution, where a change of curvature in the shape of the suppression is observed – followed by a steep fall-off. However, at variance with this view, the most peripheral point in $PbPb$ has consistently lied above the NA50 nuclear absorption curve – which extrapolates $pA$ and $SU$ data. This tendency is now confirmed by the preliminary data on the $J/\psi$ suppression versus the energy, $E_{ZDC}$, of the zero degree calorimeter. Here several peripheral points lie above the NA50 nuclear absorption curve and, more important, they exhibit a steeper suppression pattern. It is, therefore, important to study these data and to compare them with the results of deconfining and comover interactions models. This comparison is also of interest in the large $E_T$ region. Indeed, the NA50 data for $PbPb$ collisions at large $E_T$ can be described either in a deconfining model [4] or as a result of the interaction with comovers [5].

Our purpose here is to confront with each other the results of two specific models, namely a deconfining [4] and a comovers interaction [5] model – and to compare them with experiment. In the first model [4], one requires either two sharp thresholds, as in [6], or a single threshold smoothed with an arbitrary function. Both in this model and in the comovers one [5], it is necessary to introduce the fluctuations in $E_T$ [7] in order to reproduce the fall-off of the data at large $E_T$ (beyond the “knee” of the $E_T$ distribution). It has been shown in [4] that the effect of the $E_T$ fluctuations is significantly larger in the deconfining scenario than in the comovers approach. This leads to agreement with the large $E_T$ data in the first case – while the fall-off obtained in the comovers approach is too weak [5, 7]. However, all data beyond the knee have been obtained in the so-called Minimum Bias ($MB$) analysis, where only the ratio of $J/\psi$ to $MB$ cross-sections is measured and it is divided by a theoretical ratio of $DY$ to $MB$ cross-sections, i.e.

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

In the theoretical model used by the NA50 collaboration [8], the ratio $(DY/MB)_{th}$ satu-

*For reviews of deconfining and comover interaction models, see [2]. Alternative models have also been proposed [3].
rates at large $E_T$. In contrast, it has been argued in [5] that this ratio also falls at large $E_T$. This is due to the shift in $E_T$ between the $DY$ and $MB$ event samples, resulting from the $E_T$ taken by the dimuon. This shift is very small (of the order of a few per mil) and, therefore, has no visible effect up to the knee of the $E_T$ distribution – where this distribution is rather flat. However, it does have a sizeable effect in the tail, due to the very steep fall-off of the distribution. Actually, experimental data on the ratio $DY/MB$ are available [8]. They do show a fall-off at large $E_T$, but the statistical errors are large. Obviously, the same effect should be present in the ratio $J/\psi$ over $MB$ and would cancel out in the true ratio of $J/\psi$ to $DY$ cross-sections – i.e. the one obtained in the so-called standard analysis. However, it does not cancel in $R_{MB}$ because this effect is not included in the theoretical model for the last factor in the r.h.s. of Eq. (1), used by the NA50 collaboration [3]. When this effect, as estimated in [3], is taken into account, the comovers approach does describe the data for $R_{MB}$, whereas, in the deconfining model [4], the fall-off beyond the knee is too strong. This is shown in Fig. 1 where the dashed lines are the results in the comovers model [3] with and without $E_T$ loss. The upper solid line is the result obtained in the deconfining model [4]. In this model one calculates the true ratio of $J/\psi$ to $DY$ differential cross-sections – not $R_{MB}$. Therefore, this line should be compared with the results in the standard analysis. To compare with the data in Fig. 1, which where obtained with the $MB$ analysis, one should take into account the $E_T$ loss. Incorporating this effect, following the prescription [5], one obtains the lower full curve in Fig. 1.

Clearly, a good way to avoid this problem is to measure $R_{MB}$ as a function of $E_{ZDC}$. Indeed, the main contribution to $E_{ZDC}$ is due to the energy of the spectator nucleons – which is not affected by the presence or absence of the dimuon trigger.

The plan of this paper is as follows. In Section 2 we derive the $E_T - E_{ZDC}$ correlation. It turns out that this correlation allows to relate to each other the $MB$ experimental distributions in the two variables – $E_T$ and $E_{ZDC}$. In Section 3 we compute the $J/\psi$ suppression versus $E_{ZDC}$ and compare it with the one measured in $E_T$, and with the results of the deconfining model [4]. In Section 4, we compute the $J/\psi$ suppression in $pA$ and $SU$ in the comovers approach and compare the normalization in these systems with the one in $PbPb$. The scenario for $J/\psi$ suppression resulting from the comovers model is described in the Conclusions and confronted with the deconfining one.
2 $E_T$ - $E_{ZDC}$ correlation.

In the models [4], [5], one determines the $J/\psi$ suppression as a function of the impact parameter, $b$. However, $b$ is not measurable and the NA50 collaboration uses, as a measure of centrality, either $E_T$ or $E_{ZDC}$. It is, therefore, necessary to determine both quantities as a function of $b$. Since $E_T$ is proportional to the multiplicity, the relation between $E_T$ and $b$ results from the determination of the multiplicity at each $b$ in the rapidity region of the $E_T$ calorimeter. In the comovers model [5] this is done [9] in the Dual Parton Model (DPM). More precisely, we put:

$$E_T(b) = \frac{1}{2} q N_{yca}^{co}(b) \quad .$$

Here $N_{yca}^{co}$ is the charged multiplicity in the rapidity region of the $E_T$ calorimeter. The factor $1/2$ is introduced because only the energy of neutrals is measured by the calorimeter. Thus the coefficient $q$ is close to the average energy per particle. However, the difference between multiplicities of positive negatives and neutrals as well as the efficiency of the $E_T$ calorimeter do affect the value of $q$. This value can be determined from the position of the “knee” of the $E_T$ distribution of $MB$ events measured by the NA50 collaboration. We obtain $q = 0.62$ GeV [5] (see below).

The energy of the zero degree calorimeter is given by

$$E_{ZDC}(b) = [A - n_A(b)] E_{in} + \alpha n_A(b) E_{in} \quad .$$

Here $A - n_A(b)$ is the number of spectator nucleons of $A$ and $E_{in} = 158$ GeV is the beam energy. While the first term in the r.h.s. of Eq. (3) gives the bulk of $E_{ZDC}$, the latter corresponds to the contamination by secondaries emitted very forward [10] – assumed to be proportional to the number of participants, $n_A(b)$. Here also the value of $\alpha$ can be precisely determined from the position of the “knee” of the $E_{ZDC}$ distribution of the $MB$ event sample measured by NA50 [10]. We obtain $\alpha = 0.076$.

Eqs. (2) and (3) give the relation between $b$ and $E_T$ and $b$ and $E_{ZDC}$, respectively. These relations refer to average values and do not contain any information about the tails of the $E_T$ or $E_{ZDC}$ distributions. Eqs. (2) and (3) also lead to a correlation between (average values of) $E_T$ and $E_{ZDC}$. This correlation is shown in Fig. 2, and gives a good description of the experimental one [8]. We see from Fig. 2 that the $E_T - E_{ZDC}$ correlation is close to a straight line† and therefore can be accurately extrapolated beyond the knee.

†This is due to the fact that $N_{yca}^{co}(b)$ in Eq. (2) is practically proportional to $n_A(b)$ (see Fig. 1 of [8]).
of the $E_T$ and $E_{ZDC}$ distributions. It turns out that this extrapolation describes the data quite well\(^4\). Let us discuss this point in detail. It is well known that the correlation $E_T - b$ can be described by a Gaussian:

$$\begin{equation}
P(E_T, b) = \frac{1}{\sqrt{2\pi qaE_T(b)}} \exp \left[-\frac{(E_T - E_T(b))^2}{2qaE_T(b)}\right]
\end{equation}
$$

with $q = 0.62$ GeV and $a = 0.60$ \(^5\). The resulting $MB$ distribution is indistinguishable from the solid line of \cite{10} (1998 data). The $MB$ distribution of the 1996 data \cite{10} is reproduced with $q = 0.62$ GeV and $a = 0.852$ \(^5\).

Applying the $E_T - E_{ZDC}$ correlation resulting from Eqs. (2) and (3) we obtain the $E_{ZDC}$ distribution of $MB$ events shown in Figs. 3. We see that the NA50 data are well described, not only up to the knee, but also in the tail of the distribution. The turnover in the data at large $E_{ZDC}$ is due to the fact that they have not been corrected for efficiency. The comparison of Figs. 3a and 3b is quite instructive. In Fig. 3a it seems that the calculated curve has too much curvature and overshoots the data at small $E_{ZDC}$. However, this is no longer the case in Fig. 3b. Here, on the other hand, there is some discrepancy in the region $6 < E_{ZDC} < 12$ TeV – which is not present in Fig. 3a. Finally, the calculated curve is slightly too broad at the tail in Fig. 3a and too narrow in Fig. 3b. From this comparison, we conclude that Eq. (4), supplemented with the $E_T - E_{ZDC}$ correlation of Fig. 2, gives a good description of the $E_{ZDC}$ distribution when both the 1996 and the 1998 data are considered.

The consequences of this result are quite interesting. Indeed, the $E_T - E_{ZDC}$ is essentially a correlation between multiplicity (which in the rapidity region of the calorimeter is practically proportional to the number of participants) and number of spectators. Hence it cannot be affected by the dimuon trigger\(^4\). Therefore, not only the $MB$, but also the $E_{ZDC}$ distributions of $J/\psi$ and $DY$ event samples can be obtained from the corresponding ones versus $E_T$ applying the $E_T - E_{ZDC}$ correlation. This is an important result since it allows to relate to each other the $J/\psi$ suppression versus $E_T$ and versus $E_{ZDC}$ (obtained

---

\(^4\)One can understand the physical origin of this extrapolation if one assumes that a fluctuation in $E_T$ is essentially due to a fluctuation in $n_A$ – which, in turn, produces a corresponding fluctuation in $E_{ZDC}$, via Eq. (3).

\(^5\) At first sight these sets of values look very different from the ones used by the NA50 Collaboration. Nevertheless, they reproduce the same $E_T$ distribution. This is due to the fact that the product $qa$, which, according to eq. (3), determines the width of the distribution, is very similar in the two cases. As for the difference in the values of $q$ it is just due to its definition, which is different in the two approaches (eq. (2), in our case).

\(^\dagger\) Except in the tails, where the $E_T$ loss affects the $E_T$ distributions of $J/\psi$ and $DY$ without changing the $E_{ZDC}$ ones.
with a different calorimeter) and check their consistency.

3 J/ψ suppression versus E\textsubscript{ZDC}.

We show in Fig. 4 the results for the ratio of J/ψ to DY cross-sections versus E\textsubscript{ZDC} obtained in the deconfining model [4] and in the comovers model [5]. The curves are obtained from the corresponding ones versus \(E_T\) (upper solid and dashed curves in Fig. 1), applying the \(E_T - E\textsubscript{ZDC}\) correlation given by Eqs. (2) and (3) and shown in Fig. 2. We keep the absolute normalizations unchanged. No \(E_T\) loss is incorporated in these calculations (see below).

Comparing the data with the model predictions, we see that a better description of the small \(E\textsubscript{ZDC}\) region is obtained when the \(E_T\) fluctuations are taken into account. This was to be expected since the fluctuations in \(E_T\) and \(E\textsubscript{ZDC}\) are related to each other via the \(E_T - E\textsubscript{ZDC}\) correlation – as shown in Fig. 2.

As discussed above, the effect of the \(E_T\) loss is not included here since \(E\textsubscript{ZDC}\) is not affected by the dimuon trigger\(^\dagger\). Nevertheless, the curve obtained in the comovers approach does describe the most central data while it failed to describe the data versus \(E_T\) at large \(E_T\) (see Fig. 1). This result lends support to the interpretation in ref. [5] – namely that this discrepancy is due to the \(E_T\)-loss induced by the J/ψ trigger.

We also see in Fig. 4 that the fall-off for central events is stronger in the deconfining than in the comovers model. The present data do not allow to discriminate between them. However, this should be possible when the shape and absolute normalization of the data are better known - possibly with the 2000 NA50 data.

Turning to the large \(E\textsubscript{ZDC}\) region (peripheral events), we see that the data favor the comovers model. Indeed, it is clear that, in the present data, the ratio \(R_{MB}(E\textsubscript{ZDC})\) at large \(E\textsubscript{ZDC}\) falls more steeply than the NA50 nuclear absorption curve – fitting \(pA\) and \(SU\) data. If confirmed, this would clearly disfavor the deconfining model – where nuclear absorption is assumed to be the only source of suppression below the deconfining threshold. On the contrary, such a feature is expected in a comovers approach, and is clearly seen in Fig. 4.

An important observation from Fig. 4 is the fact that the pattern of J/ψ suppression

\(^\dagger\)Actually, some effect of the \(E_T\) loss could be present in the J/ψ suppression versus \(E\textsubscript{ZDC}\) via the second term of Eq. (3). However, this effect should be rather small due to the large rapidity separation of the dimuon trigger and the zero degree calorimeter.
in the NA50 data is different in $E_{T}$ and $E_{ZDC}$ – at least in the region $9 \lesssim E_{ZDC} \lesssim 14$ TeV. This is at variance with the results in Section 2, according to which the shapes of the two curves should be the same. More precisely, if the shape of the $J/\psi$ suppression in $E_{ZDC}$ is different from the one in $E_{T}$ for whatever reason (for instance, due to the different calorimeters), the shape of the $MB$ distribution in the two variables should also be different – and it is not. This point needs to be clarified. It should be noted here that the ratio of $J/\psi$ to $DY$ differential cross-sections obtained in the standard analysis \cite{10}, although consistent with the one obtained in the $MB$ analysis, do not show any sign of a different pattern with respect to the one versus $E_{T}$. This is illustrated in Fig. 5 where the standard analysis data are compared with the same theoretical curves of Fig. 4. Note also that in the $MB$ analysis the absolute normalization is not measured. It is determined from the one obtained with the standard analysis. This determination can not be precise due to the uncertainty in the shape of the $J/\psi$ suppression discussed above. Actually, the adjustment of the absolute normalization has been done \cite{10} in the region $8 < E_{ZCD} < 17$ TeV – where the difference in the shape of the $E_{T}$ and $E_{ZDC}$ distributions is the largest.

Further insight in the comparison of comovers and deconfining models can be gained by studying the $J/\psi$ suppression in lighter systems.

4 $J/\psi$ suppression in pA and SU.

Let us compute the ratio $J/\psi$ over $DY$ in $SU$ at 200 GeV/c per nucleon in the model \cite{9}. We use, of course, the same values of the parameters as in $PbPb$ : $\sigma_{abs} = 4.5$ mb and $\sigma_{co} = 1$ mb. To get this ratio versus $b$, the only new ingredient is the multiplicity of comovers – which is again computed in DPM, in the way described in \cite{9}. In this case, only $R(E_{T})$ is available ($R(E_{ZDC})$ has not been measured in $SU$). In $SU$, data do not extend beyond the knee of the $E_{T}$-distribution. Therefore, effects such as $E_{T}$ fluctuations or $E_{T}$ loss are not relevant here. To compute $R(E_{T})$, we also need the $E_{T} - b$ correlation which is parametrized as in Eq. (4). The parameters $q$ and $a$ have been obtained from a fit of the $E_{T}$-distribution of $DY$ given in \cite{11}. We obtain $q = 0.69$ GeV and $a = 1.6$.

Our results are shown in Fig. 6a. We see that the $E_{T}$ dependence of the suppression is reproduced – in spite of the fact that our $\sigma_{abs}$ is smaller than in the NA50 nuclear absorption model. This is due to the suppression by comovers. Actually, the effect of the comovers in $SU$ is comparatively small for all values of $E_{T}$. However, its contribution
increases with $E_T$ and compensates for the difference in the values of $\sigma_{abs}$ in the two approaches.

A recent reanalysis of the $pA$ data at 450 GeV \cite{12} leads to a value $\sigma_{abs} = 4.7 \pm 0.8$ mb in good agreement with the one used in the comovers approach. This value is significantly lower than the one, $\sigma_{abs} = 6.4$ mb, used in the NA50 nuclear absorption curve. A value $\sigma_{abs} = 4$ mb is used in the deconfining model of ref. \cite{13}. However, within the deconfining approach such a value of $\sigma_{abs}$ has the drawback of producing a $J/\psi$ suppression pattern in SU which is flatter than the data – unless, of course, one reduces substantially the value of the threshold, thereby introducing some anomalous suppression in SU.

Let us now discuss the absolute normalization of the curve in Fig. 6a which is 46.8. This number has to be compared with the ratio of $J/\psi$ to $DY$ pp cross-sections, rescaled at 200 GeV, which is 46.6 ± 5 \cite{14}. This nice agreement between $pp$ and SU tends to indicate that the $pA$ data will also be reproduced (see also \cite{13}). This is indeed the case, as shown in Fig. 6b.

Our result gives an $A$-dependence between $pp$ and $pU$ $A^\alpha$ with $\alpha = 0.943$. This is to be compared with the NA38 value $\alpha = 0.919 \pm 0.015$ \cite{14} and with the E866 \cite{16} one $\alpha = 0.955 \pm 0.02 \pm 1 \%$ systematics.

We can now compare the absolute normalization of our curve for $pp$, $pA$ and SU (46.8) with the corresponding one for $PbPb$ (59.4). As we see, there is a 27% difference. According to the NA50 estimates \cite{17}, 9% of this difference is due to the rescaling from SU at 200 GeV to Pb Pb at 158 GeV. This factor 1.09 contains both energy and isospin corrections\cite{**}. Therefore, it remains a real discrepancy of about 17% in the relative normalization of $pp$, $pA$ and SU, on the one hand, and $PbPb$ on the other hand. This point needs clarification.

## 5 Conclusions

The deconfining – NA50 scenario, has been described in the first lines of this work. The alternative scenario obtained in the comovers model \cite{3} is summarized in Fig. 7. The curves in Fig. 7 are obtained from the ones in Figs. 1 ($PbPb$), 6a (SU) and 6b ($pp$ and

\*\*N. Armesto (private communication) has recalculated these corrections. He has confirmed the NA50 results concerning isospin. However, he finds an energy dependence of the $DY$ practically identical to the one of $J/\psi$ estimated by NA50 – leading to a ratio of $J/\psi$ to $DY$ cross-sections practically energy independent. This would solve the problem with the rescaling in energy used by NA50 in which the central value for the ratio $J/\psi$ over $DY$ in $pp$ decreases between 158 GeV (48.9) and 200 GeV (46.6) and increases from 200 to 450 GeV (54.7).
\( pA \), using the relation between \( A \) and \( L \) (in \( pA \)) and \( E_T \) and \( L \) (in \( SU \) and \( PbPb \)) given by NA38-NA50. In this Figure we see that there are two different curves for \( pA \) (dashed line) and \( SU \) (full line). This is due to the effect of the comovers. Contrary to nuclear absorption, which is a universal function of \( L \), the comovers contribution at a given value of \( L \) is different in different systems. In particular, its effect turns out to be negligible in \( pA \). As already seen in Fig. 6a and 6b the agreement with the data is good, both in \( pA \) and \( SU \). The \( PbPb \) data are not shown in this Figure. They follow quite well the shape of the theoretical curve (dashed line), as demonstrated in Fig. 1 (lower dashed line). However, their absolute normalization is 17% higher than the theoretical one, as discussed above. In the comovers model, the \( J/\psi \) suppression in \( PbPb \) is larger than the one in \( SU \) (at the same \( L \)) and significantly steeper - indicating an important anomalous suppression, present even in the most peripheral events. The data do support the latter result – which favors the comovers scenario. For central events, it lends support to the interpretation of ref. [5], according to which the discrepancy between the comovers model and \( R_{MB} \), eq. (1), is due to the \( E_T \) loss induced by the \( J/\psi \) trigger. Indeed, the data versus \( E_{ZDC} \) (which are not affected by this \( E_T \) loss) are well reproduced. Hopefully, a clear-cut discrimination between the deconfining and comovers scenarios will be possible with the 2000 NA50 data.

**Acknowledgments**

We thank N. Armesto, E. G. Ferreiro, A. Kaidalov and C. A. Salgado for discussions and E. Scomparini for information on the NA50 data. D. S. thanks Fundación Barrie de la Maza for financial support. This work was supported in part by the European Community-Access to Research Infrastructure Action of the Improving Human Potential Program.
References

[1] NA50 collaboration, A. Romana in Proceedings International Workshop on the Physics of the Quark-Gluon Plasma, Palaiseau, France, 4-7 September 2001, to be published; O. Drapier, ibid.

[2] C. Gerschel and J. Hufner, Ann. Rev. Nucl. Part. Sci. 49, 255 (1999).
R. Vogt, Phys. Rep. 310, 197 (1999).
H. Satz, Rep. Prog. Phys. 63, 1511 (2000).

[3] J. Qiu, J. P. Vary, X. Zhang, hep-ph/9809442;
A. K. Chandhuri, preprint Variable Energy Cyclotron Center, Calcutta, India (September 14, 2001).

[4] J. P. Blaizot, P. M. Dinh and J. Y. Ollitrault, Phys. Rev. Lett. 85, 4012 (2000).

[5] A. Capella, A. Kaidalov and D. Sousa, preprint LPT 01-42, nucl-th/0105021, to be published in Phys. Rev. C.

[6] M. Nardi and H. Satz, Phys. Lett. B442, 14 (1999);
D. Kharzeev, C. Lourenço, M. Nardi and H. Satz, Z. Phys. C74, 307 (1997).

[7] A. Capella, E. G. Ferreiro and A. Kaidalov, Phys. Rev. Lett. 85, 2080 (2000).

[8] NA50 collaboration, M. C. Abreu et al, Phys. Lett. B450, 456 (1999).

[9] A. Capella and D. Sousa, Phys. Lett. B511, 185 (2001).

[10] NA50 collaboration, M. C. Abreu et al, Phys. Lett. B477, 28 (2000); Phys. Lett. B521, 195 (2001).

[11] NA38 collaboration, M. C. Abreu et al, Phys. Lett. B449, 128 (1999).

[12] NA50 Collaboration, R. Shahoyan in Proc. XXXVIIth Rencontres de Moriond, Les Arcs (France), March 2002.

[13] A. K. Chandhuri, preprint Variable Energy Cyclotron Center (June 25, 2001).

[14] NA38 collaboration, M. C. Abreu et al, Phys. Lett. B466, 408 (1999);
NA51 collaboration, M. C. Abreu et al, Phys. Lett. B438, 35 (1998).

[15] N. Armesto and A. Capella, Phys. Lett. B430, 23 (1998).
[16] FNAL E537 Coll., M. Leitch et al., Phys. Rev. Lett. **84**, 3256 (2000).

[17] M. Gonin, private communication.
Figure Captions

*Fig. 1:* Ratio of $J/\psi$ to $DY$ cross-sections versus $E_T$ in $Pb\ Pb$ collisions at 158 GeV per nucleon in the deconfining model [4] (solid) and in the comovers model [5] (dashed). In both cases the upper (lower) curves are obtained without (with) $E_T$ loss.

*Fig. 2:* The correlation $E_T - E_{ZDC}$ obtained from Eqs. (2) and (3) and its extrapolation to the tails of these distributions (see main text).

*Fig. 3:* $E_{ZDC}$ distribution of $MB$ events obtained from Eq. (4) applying the $E_T - E_{ZDC}$ correlation of Fig. 2. The data in Fig. 3a were taken in 1998 [10] and those in Fig. 3b were taken in 1996 [10].

*Fig. 4:* Ratio of $J/\psi$ to $DY$ cross-sections versus $E_{ZDC}$ in $Pb\ Pb$ collisions at 158 GeV per nucleon in the deconfining model [4] (solid) and in the comovers model [5] (dashed). These curves are obtained from the corresponding ones versus $E_T$ (upper solid and dashed lines in Fig. 1) applying the $E_T - E_{ZDC}$ correlation of Fig. 2. The dotted line is obtained without $E_T$ fluctuations. The data, obtained with the minimum bias analysis, are from ref. [10]. The NA50 nuclear absorption curve [10] is also shown.

*Fig. 5:* Same theoretical curves as in Fig. 4, compared with the data obtained in the standard analysis [10].

*Fig. 6a:* The ratio of $J/\psi$ to $DY$ cross-sections as a function of $E_T$ in $SU$ collisions at 200 GeV per nucleon obtained in the comovers model [4]. The data are from [11].

*6b:* The ratio $J/\psi$ over $A$ in $pp$ and $pA$ collisions at 450 GeV as a function of $A$ obtained in the comovers model [5]. The data are from [14].

*Fig. 7:* The ratio of $J/\psi$ to $DY$ cross-section versus $L$ [8] for $pp$, $pA$ (dotted line) and $SU$ at 200 GeV (solid line) and $PbPb$ (dashed line) at 158 GeV, obtained in the comovers model [8] with a common normalization 46.8. Note that this normalization is not calculable in the model. The data are from [11], [14].
Fig. 1

$R(\psi/\text{DY})$ vs. $E_T$ (GeV)
Fig. 2

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2}
\caption{Graph showing the relationship between $E_T$ (GeV) and $E_{ZDC}$ (GeV).}
\end{figure}
Fig. 3a

![Graph showing dN/dE_{ZDC} vs. E_{ZDC} (TeV)]

- The x-axis represents $E_{ZDC}$ (TeV).
- The y-axis represents $dN/dE_{ZDC}$.
- The graph shows data points and a trend line indicating the distribution of $dN/dE_{ZDC}$ with increasing $E_{ZDC}$.
- The data points are labeled as "1998 Data."
Fig. 3b

\[ \frac{dN}{dE_{ZDC}} \]

\[ E_{ZDC} \text{(TeV)} \]

1996 Data
Fig. 4
Fig. 6

(a) 

(b) 

$R((J/\psi)/D\gamma)$

$\sigma(J/\psi)/A$ (nb/nucleon)$^2$
