Comment to 'The dependence of the anomalous J/ψ suppression on the number of participant nucleons'

A.P. Kostyuk[a,b], H. Stöcker[a], and W. Greiner[a]

[a] *Institut für Theoretische Physik, Universität Frankfurt, Germany*
[b] *Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine*

(November 15, 2005)

Abstract

The recently published experimental dependence of the J/ψ suppression pattern in Pb+Pb collisions at the CERN SPS on the energy of zero degree calorimeter E_{ZDC} are analyzed. It is found that the data obtained within the 'minimum bias' analysis (using 'theoretical Drell-Yan') are at variance with the previously published experimental dependence of the same quantity on the transversal energy of neutral hadrons E_T. The discrepancy is related to the moderate centrality region: $100 \lesssim N_p \lesssim 200$ (N_p is the number of nucleon participants). This could result from systematic experimental errors in the minimum bias sample. A possible source of the errors may be contamination of the minimum bias sample by off-target interactions. The data obtained within the standard analysis (using measured Drell-Yan multiplicity) are found to be much less sensitive to the contamination.

1

Recently, the NA50 collaboration published new data on the centrality dependence of the J/ψ suppression pattern in Pb+Pb collisions at CERN SPS [1]. The centrality of the collisions was estimated by measuring the energy of projectile spectator nucleons E_{ZDC} by a zero degree calorimeter. The purpose of the present comment is to compare the new data with the ones published by the NA50 collaboration previously [2–4], where the transverse energy of produced neutral hadrons E_T was used as the centrality estimator. It is shown that the two sets of data (for brevity, we shall call them 'E_{ZDC}-data' and 'E_T-data', respectively), having very similar qualitative behavior, seem, nevertheless, to be at variance on the quantitative level. This may point out a presence of systematic errors in one of the data sets.

In each data set, the J/ψ suppression pattern were obtained in two different ways: by the standard analysis and the minimum bias analysis. In the standard analysis, the ratio R of J/ψ multiplicity to the *physical* multiplicity of Drell-Yan pairs was calculated from the measured dimuon spectra. In the minimum bias analysis, the ratio R was obtained by dividing the experimentally measured ratio of the number of J/ψ events to the number of minimum bias events by the *theoretical* Drell-Yan' given by

$$\langle DY(E_T) \rangle = \frac{\int_0^\infty d^2 b P(E_T|b) \langle DY(b) \rangle P_{int}(b)}{\int_0^\infty d^2 b P(E_T|b) P_{int}(b)} \tag{1}$$

Here $\langle DY(b) \rangle$ is the average number of Drell-Yan dimuon pairs per Pb+Pb collision at impact parameter b. $P_{int}(b)$ is the probability that an interaction between two nuclei at impact parameter b takes place. Both quantities were calculated in the Glauber approach.

The E_T-distribution of events at fixed impact parameter b, $P(E_T|b)$, was assumed to have the Gaussian form with the central value and dispersion given by

$$\langle E_T(b) \rangle = q N_p(b) \qquad \sigma_{E_T}(b) = q \sqrt{a N_p(b)} \tag{2}$$

Here $N_p(b)$ is the average number of nucleon participants in a Pb+Pb collision at impact factor b calculated in the Glauber approach. The parameter values $q = 0.274$ GeV and $a = 1.27$ [5] were fixed from the minimum bias transverse energy distribution [4].

The E_{ZDC}-dependence of 'theoretical Drell-Yan' was found from the formula similar to (1). The E_{ZDC}-distribution $P(E_{ZDC}|b)$ was assumed to be a Gaussian with the central value and dispersion given by Eqs. (1) and (2) of Ref. [1].

It is obvious that in absence of essential systematic errors, the E_T- and E_{ZDC}-data should be consistent with each other. If there exists a parameterization of the b-dependence of the J/ψ multiplicity $\langle J/\psi(b) \rangle$, such that the E_T dependence of R computed from

$$R(E_T) = \frac{\int_0^\infty d^2 b P(E_T|b) \langle J/\psi(b) \rangle P_{int}(b)}{\langle DY \rangle_{E_T}} \tag{3}$$

agrees with the E_T-data, then the dependence of R on E_{ZDC}

$$R(E_{ZDC}) = \frac{\int_0^\infty d^2 b P(E_{ZDC}|b) \langle J/\psi(b) \rangle P_{int}(b)}{\langle DY \rangle_{E_{ZDC}}} \tag{4}$$

should agree with the E_{ZDC}-data without any additional parameter fit. And vice versa: a model fitted to the E_{ZDC}-data should automatically agree with the E_T-data.

To check, whether the two sets of the NA50 data indeed possess the above property, we used three different models to parameterize $\langle J/\psi(b)\rangle$. Two of them, the models A and B (see below), were fitted to the E_T-data presented in Fig. 4 of Ref. [4] and then were compared with the 'minimum bias' E_{ZDC}-data from Fig.5 of Ref. [1]. The third one, the model C, was fitted to the 'minimum bias' E_{ZDC}-data and compared with the E_T-data.

Model A is essentially the statistical coalescence model (SCM) [6,7], which assumes that charmonia are created at the final stage of the heavy ion reaction from the charmed quark-antiquark pairs produced in hard parton collisions at the initial stage. The free parameters of the SCM (see Ref. [8] for details) are $\sigma_{c\bar{c}}^{NN}$, the in-medium modified [9] cross section of open charm production in nucleon-nucleon collisions, and η, the fraction of dimuon pairs, originating from J/ψ decays, that satisfies the kinematical conditions of the NA50 spectrometer.

The SCM is known to be applicable only for sufficiently large systems ($N_p > 100$). To parameterize the data in the low E_T region, we assumed a smooth transition between the normal nuclear suppression (NNS) to the statistical coalescence model:

$$\langle J/\psi(b)\rangle = \exp\left[-\zeta N_p^2(b)\right]\langle J/\psi(b)\rangle_{NNS} + \left\{1 - \exp\left[-\zeta N_p^2(b)\right]\right\}\langle J/\psi(b)\rangle_{SCM}. \qquad (5)$$

This introduces an additional free parameter ζ. The value of NNS cross section was fixed at $\sigma_{abs} = 6.4$ mb.

The drop of $R(E_T)$ at $E_T \gtrsim 100$ GeV appears in SCM due to fluctuations of the thermodynamical parameters and due to E_T losses in the dimuon event sample relative to the minimum bias one [10].

A good fit of the E_T-data ($\chi^2/\text{dof} = 1.10$) is obtained with

$$\sigma_{c\bar{c}}^{NN} = 3.67~\mu\text{b} \qquad \eta = 0.129 \qquad \zeta = 1.04 \cdot 10^{-4}~. \qquad (6)$$

Model B is the geometrical model of charmonium suppression [11,12]. It is assumed that all charmonia suffer the normal nuclear suppression with the cross section σ_{abs}. Then all excited charmonium states are destroyed in the region, where the nucleon participant density in the plane transverse to the collision axis exceeds the value n_1. This suppresses the J/ψ yield by a factor $X < 1$, because excited charmonia contribute to the final J/ψ multiplicity through their decays. No charmonium state survives in the region, where the participant density exceeds the value n_2. Fluctuations of E_T result in additional suppression at $E_T \gtrsim 100$ GeV [12]. E_T losses are ignored.

To make our parameterization as good as possible we treated not only n_1 and n_2, but also σ_{abs} and X as free parameters. A very good fit ($\chi^2/\text{dof} = 0.95$) is obtained at

$$\begin{aligned} n_1 &= 2.97~\text{fm}^{-2} & n_2 &= 4.05~\text{fm}^{-2} \\ \sigma_{abs} &= 5.16~\text{mb} & X &= 0.366 \end{aligned} \qquad (7)$$

In spite of the fact that the underlying ideas of the models A and B are very different, the fits are completely consistent with each other everywhere, except the low E_T region, where only two points with large statistical errors are available (see Fig. 1).

The both parameterizations are, however, in obvious disagreement with the 'minimum bias' E_{ZDC}-data: $\chi^2/\text{dof} = 12.1$ and $\chi^2/\text{dof} = 11.5$ for the models A and B, respectively. The strongest discrepancy is observed in the domain $100 \lesssim N_p \lesssim 200$ (see Fig. 2).

It must be noted that the effects that were responsible for the drop of the ratio R at $E_T \gtrsim 100$ GeV, the fluctuations and E_T losses, do not influence the E_{ZDC} dependence. Therefore, neither of the models is able to reproduce the drop of $R(E_{ZDC})$ at $E_{ZDC} \lesssim 9$ TeV.

Let us go the opposite way, i.e. we fit the E_{ZDC} data and check, whether the fit agrees with the E_T data. For this purpose, the model C will be used.

Model C was proposed by NA50 collaboration in Ref. [1]. The idea is similar to the model B, but the parameter that controls the charmonium suppression is not the nucleon participant density, but rather the number of participants. It is assumed that at $N_p > N_{p1}$, the J/ψ yield is suppressed by the factor of $X_1 < 1$ relative to the normal nuclear suppression value. At $N_p > N_{p2}$ the remaining J/ψ yield is additionally suppressed by the factor X_2. A minimum of χ^2 is reached at

$$
\begin{array}{lll}
N_{p1} = 122 & N_{p2} = 335 & \sigma_{abs} = 5.47\text{mb} \\
X_1 = 0.670 & X_2 = 0.752 &
\end{array}
\tag{8}
$$

Although the quality of the fit is not very good ($\chi^2/\text{dof} = 2.73$), the model satisfactory reproduces the shape of the E_{ZDC} data, including the drop of the ratio R at $E_{ZDC} \lesssim 9$ TeV.

Comparing the model C with the E_T data reveals strong disagreement: $\chi^2/\text{dof} = 13.3$. The strongest discrepancy is again related to the region $100 \lesssim N_p \lesssim 200$ (see Fig. 1). At large E_T, although the drop of R at $E_T \gtrsim 100$ GeV is present on the curve, it does not reproduce the behavior of the data. Account for E_T losses in the dimuon sample (similar to [13,10]) somewhat improves agreement with the data, but still the shape of the drop is not reproduced.

The above consideration demonstrates that the two sets of the NA50 data on the centrality dependence of the J/ψ suppression pattern: the E_T-dependence in Fig. 4 of Ref. [4] and the E_{ZDC}-dependence in Fig. 5 of Ref. [1] are at variance with each other. This could mean that at least one of the two sets may contain sizable systematic errors.

In our opinion, the E_{ZDC}-data obtained within the minimum bias analysis are very likely to contain essential systematic errors because of possible contamination of the minimum bias sample by off-target interactions. In the data analysis procedure of Ref. [1], empty target runs were used to remove the contribution of the off-target interactions. This approach, however, does not take into account possible influence of target on the shape of the contamination. In fact, spectator fragments from an off-target collision may interact with the target. On the other hand, the spectator fragment from a normal collision with a target nuclei may experience off-target interactions before they are registered by the zero degree calorimeter. Therefore, in presence of the target, the off-target contribution may be shifted downwards in E_{ZDC}.

Indeed, the minimum bias E_T distribution perfectly agrees with the Glauber model (see Fig. 1 of Ref. [4]).[1] In contrast, the agreement of the E_{ZDC} minimum bias distribution seems to be not so perfect. Unfortunately, the authors of Ref. [1] do not quote the value of χ^2/dof, which characterizes the quality of the fit of the minimum bias E_{ZDC} distribution (shown in

---

[1] Disagreement is observed only in the low E_T region, because the efficiency of the target algorithm is less than unity there.

Fig.1 of Ref. [1]). Nevertheless, it is seen from the plot, that the experimental points lie slightly above the theoretical curves in the region $25 \gtrsim E_{ZDC} \gtrsim 18$ TeV (which corresponds to $100 \lesssim N_p \lesssim 200$). Although the difference does not exceeds even the size of the point symbols, it, nevertheless, indicates a sizable discrepancy, because of the logarithmic scale of the vertical axis of the plot. Note, that at low E_{ZDC}, i.e. in the region of the 'second drop' of the E_{ZDC}-data, the theoretical models are also in disagreement with the data. Therefore, the discrepancy of the two sets of data in the region $100 \lesssim N_p \lesssim 200$ and the drop of the ratio $R(E_{ZDC})$ at $E_{ZDC} \lesssim 9$ TeV may have a common origin: contamination of the minimum bias sample by off-target interactions.

The standard analysis data appear to be less sensitive to the off-target contamination. In fact, the models A and B are consistent with the standard analysis E_{ZDC}-data (presented in Fig. 3 of [1]): $\chi^2/\text{dof} = 0.85$ and $\chi^2/\text{dof} = 0.83$, respectively (see Fig. 3). No definite conclusion is possible because of the large statistical errors. The model C may be also considered to be consistent with the standard analysis data with slightly worse but still quite satisfactory fit quality: $\chi^2/\text{dof} = 1.10$. Nevertheless, no contradiction between E_T and E_{ZDC} is seen in the recently presented by the NA50 collaboration standard analysis data from the year 2000 run, which have essentially smaller error bars [14]. This allows to conclude that the minimum bias sample seem to be more sensitive to the off-target contaminations than the dimuon one.

The discrepancy between E_T and E_{ZDC} data are unlikely to be related to interactions of Pb nuclei and their fragments with air. In fact, comparing of the data collected in the year 2000 with the target in vacuum [14] with the data from previous runs [1–4] indicates that interactions with air influence both E_T and E_{ZDC} data and that the influence is related mostly to the peripheral domain $N_p \lesssim 100$.

The contaminations at moderate centrality, $100 \lesssim N_p \lesssim 200$, may come from interactions of reactions fragments with nuclei in zero degree calorimeter. If such an interaction takes place, a fraction of the produced particles (those having large transversal momenta) may leave the calorimeter without deposing their energy in it. This could cause sizable losses of zero-degree energy, which result in distortion of the shape of the minimum bias sample. Therefore, the mentioned problem will likely persist even in the new vacuum data, if they are analyzed within the 'minimum bias' procedure, unless losses of the zero degree energy are taken into account.

We conclude, that the new data on the E_{ZDC} dependence of the J/ψ suppression pattern in Pb+Pb at the CERN SPS [1] are at variance with the other data published by the same collaboration [2–4]. This problem is related only to the data obtained within the 'minimum bias' analysis. A possible source of the discrepancy might be distortion of the minimum bias sample most likely by losses of zero degree energy because of interactions of reaction fragments with nuclei inside the zero degree calorimeter.
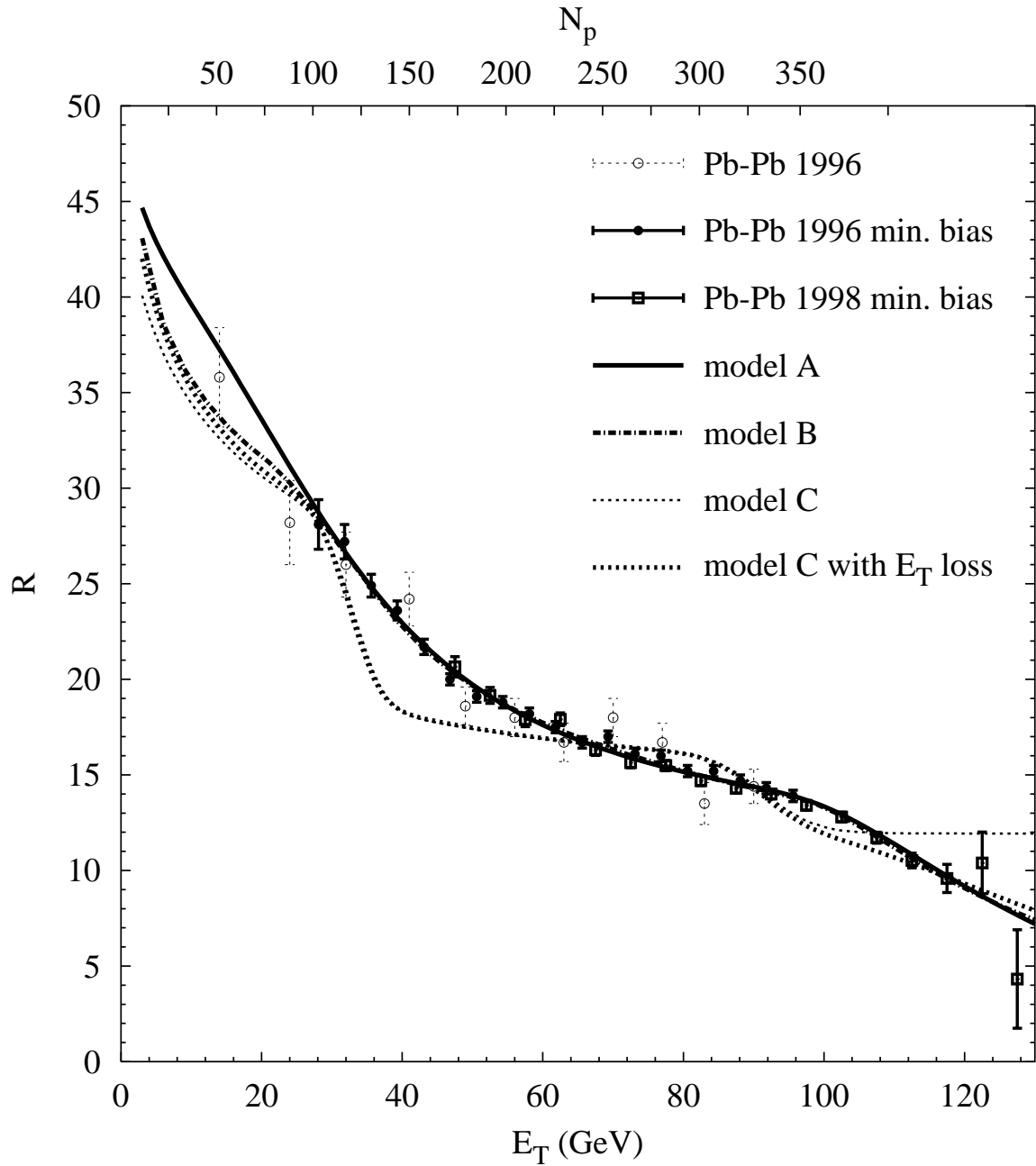
FIG. 1. The dependence of the J/ψ to Drell-Yan ratio R on the transverse energy E_T. The corresponding average number of participant nucleons N_p are shown on the upper axis. The points with error bars are the NA50 data. The lines correspond to different parametrizations. Models A an B are fitted to the E_T data set. Model C being fitted to the E_{ZDC} data set (see Fig. 2) demonstrates disagreement with the E_T data.
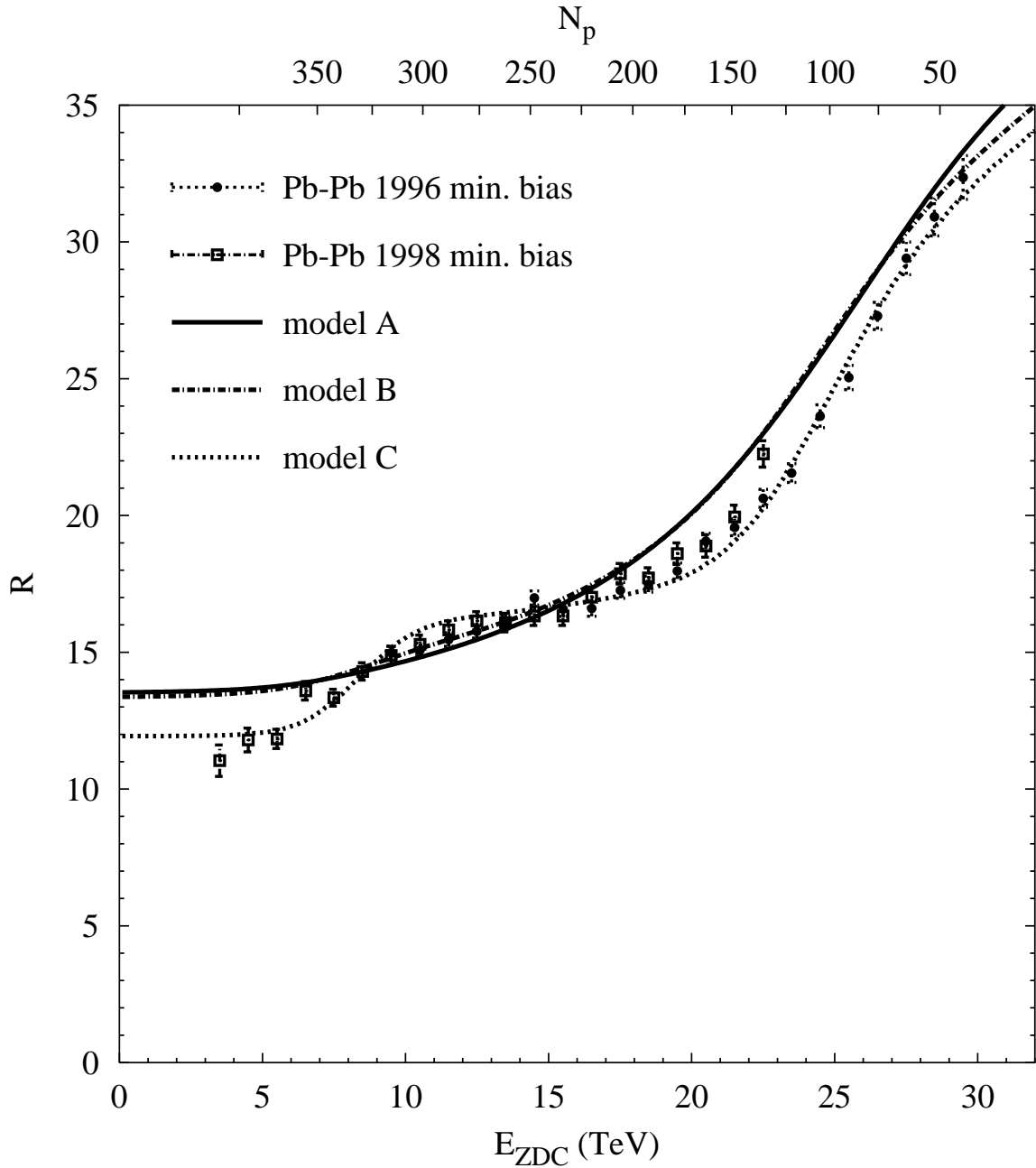
FIG. 2. The dependence of the J/ψ to Drell-Yan ratio R on the energy of zero degree calorimeter E_{ZDC}. The corresponding average number of participant nucleons N_p are shown on the upper axis. The points with error bars are the NA50 'minimum bias' analysis data. The lines correspond to different parameterizations. Model C is fitted to the E_{ZDC} data set. Models A and B being fitted to the E_T-data (see Fig. 1) demonstrate disagreement with the E_{ZDC} data.
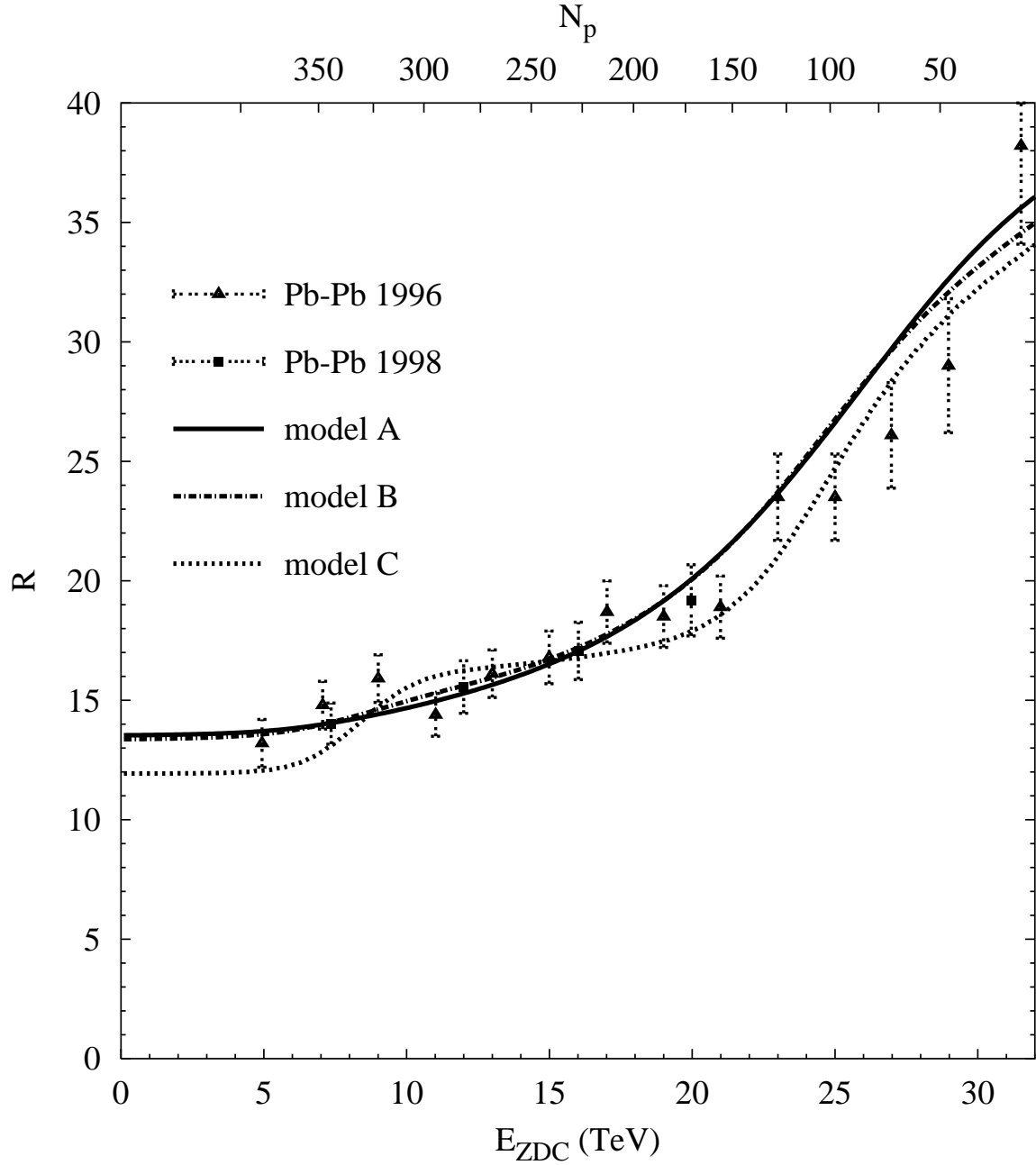
FIG. 3. The dependence of the J/ψ to Drell-Yan ratio R on the energy of zero degree calorimeter E_{ZDC}. The corresponding average number of participant nucleons N_p are shown on the upper axis. The points with error bars are the NA50 standard analysis data. The lines correspond to different parametrizations. Models A and B are fitted to the E_T-data (see Fig. 1) Model C is fitted to the 'minimum bias' E_{ZDC} data (see Fig. 2). Due to rather large statistical errors, all three models may be considered to be consistent with the standard analysis data.

REFERENCES

[1] M. C. Abreu *et al.* [NA50 Collaboration], Phys. Lett. B **521** (2001) 195.

[2] M. C. Abreu *et al.* [NA50 Collaboration], Phys. Lett. B **410** (1997) 337.

[3] M. C. Abreu *et al.* [NA50 Collaboration], Phys. Lett. B **450** (1999) 456.

[4] M. C. Abreu *et al.* [NA50 Collaboration], Phys. Lett. B **477** (2000) 28.

[5] B. Chaurand, quoted in Ref. [12].

[6] P. Braun-Munzinger and J. Stachel, Phys. Lett. B **490**, (2000) 196 [nucl-th/0007059].

[7] M. I. Gorenstein, A. P. Kostyuk, H. Stöcker and W. Greiner, Phys. Lett. B **509** (2001) 277 [hep-ph/0010148];
J. Phys. G **27** (2001) L47 [hep-ph/0012015].

[8] A. P. Kostyuk, M. I. Gorenstein, H. Stöcker and W. Greiner, Phys. Lett. B **531** (2002) 195 [arXiv:hep-ph/0110269];
A. P. Kostyuk, J. Phys. G **28** (2002), 2047 [arXiv:hep-ph/0111096].

[9] A. P. Kostyuk, M. I. Gorenstein and W. Greiner, Phys. Lett. B **519** (2001) 207 [hep-ph/0103057].

[10] A. P. Kostyuk, M. I. Gorenstein, H. Stöcker and W. Greiner, arXiv:hep-ph/0204180.

[11] J. P. Blaizot and J. Y. Ollitrault, Phys. Rev. Lett. **77** (1996) 1703 [arXiv:hep-ph/9606289].

[12] J. Blaizot, M. Dinh and J. Ollitrault, Phys. Rev. Lett. **85** (2000) 4012 [nucl-th/0007020].

[13] A. Capella, A. B. Kaidalov and D. Sousa, Phys. Rev. C **65** (2002) 054908 [arXiv:nucl-th/0105021].

[14] L. Ramello [NA50 Collaboration], Talk given to the International Conference "Quark Matter 2002", Nantes, France, July 18-24, 2002.