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Results on leptonic probes from NA50

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The NA50 Collaboration has performed a new measurement of the J/ψ yield in Pb-Pb collisions at 158 GeV/nucleon in improved experimental conditions. Our preliminary analysis of the year 2000 data sample, while confirming the onset of anomalous suppression

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and the non saturation of the J/ψ / Drell-Yan cross-section ratio, shows that peripheral Pb-Pb interactions follow the normal nuclear absorption pattern, which has in turn been established more precisely thanks to high statistics p-A data.

1. INTRODUCTION

Charmonium production in heavy ion collisions provides a powerful tool to test whether deconfined matter was formed in the early stages of the reaction (see e.g. Ref. [1]). Detection of J/ψ and ψ' mesons through their leptonic decay to a pair of muons is particularly interesting since muons are not affected by strong interactions and, therefore, are insensitive to the hadronization step. The NA50 experiment is a high luminosity fixed target experiment at CERN, essentially dedicated to the study of dimuon production in Pb-Pb collisions at 158 GeV/nucleon laboratory energy. In this paper we present the measurement of the J/ψ yield as a function of collision centrality, from data collected in year 2000.

1.1. The NA50 apparatus

The NA50 apparatus (see Ref. [2]) consists of a set of beam and anti-halo counters, a set of three centrality detectors, and a hadron filter followed by a dimuon spectrometer, as illustrated in Fig. 1. The incoming ion beam is counted by a 16-slab quartz Beam Hodoscope (BH), while interactions occurring before the target are vetoed by dedicated scintillator counters. After the target, a couple of quartz counters can be used to tag interactions, while the centrality of the collision is measured by three detectors (see Fig. 2): the silicon Multiplicity Detector (MD) counts charged particles in the range $1.9 < \eta < 4.2$, the Electromagnetic Calorimeter (EMC) measures neutral transverse energy in the range $1.1 < \eta < 2.3$, and finally the Zero-Degree Calorimeter (ZDC) measures the forward energy carried by the beam spectator nucleons. The hadron filter consists of BeO, carbon and Fe absorbers and is followed by the dimuon spectrometer, composed of an air-core toroidal magnet in-between two sets of 4 MWPC each. The dimuon trigger is provided by 4 planes of scintillator hodoscopes, while a minimum bias (MB) trigger is defined by a minimal energy deposit in the ZDC.

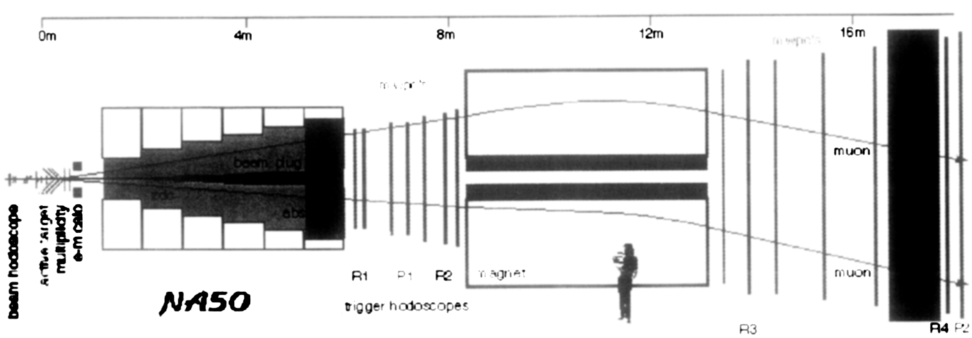

Figure 1. The NA50 spectrometer.

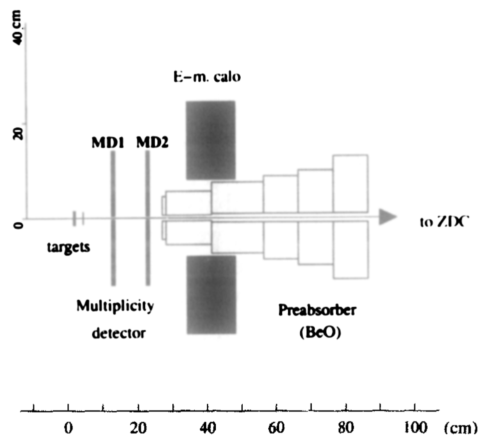

Figure 2. The NA50 target region.

1.2. Published results on charmonium production

NA50 has already published results on the J/ψ / Drell-Yan cross-section ratio in Pb-Pb collisions obtained from the 1995 data sample [2,3], from the 1996 data sample [4] and from the 1998 data sample [5], using mainly transverse energy as the centrality measure. In all cases the so-called standard analysis method, which uses only dimuon triggers, has been used; for the 1996 and 1998 data, the Minimum Bias trigger has also been used. Recently, NA50 has published an analysis of the 1996 and 1998 data using the forward energy as the centrality variable [6].

From these Pb-Pb data, collected during years 1995-1998, the anomalous J/ψ suppression, i.e. a rather sharp decrease of the J/ψ / Drell-Yan cross-section ratio at $E_T \simeq 40$ GeV, was established (see Fig. 3); furthermore, no saturation of the ratio at high E_T was observed. It must be noted that the normal absorption curve (dotted line in Fig. 3) has been established using data obtained by the NA51 experiment in p-p and p-d systems [7]

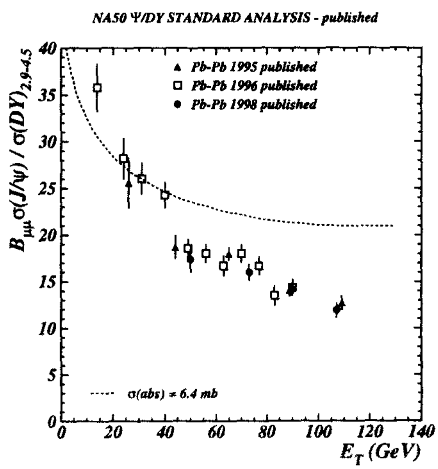

Figure 3. Published results for the J/ψ / Drell-Yan cross-section ratio vs. E_T.

and by the NA38 experiment in p-A and S-U systems [8,9]; the NA38 p-A data suffered from somewhat low statistics.

A deeper understanding of the Pb-Pb data revealed that at low E_{T} there could be a substantial contamination from Pb-air interactions. We also realized that the numerical values we have published were sensitive to the exact parametrisation we used for the Parton Distribution Functions (PDFs). This happens because different PDFs give slightly different shapes for the Drell-Yan mass distribution. Since we leave the normalization of the Drell-Yan spectrum as a free parameter, we always reach a good description of the mass region above the resonances. However, we get different extrapolations into the mass interval $2.9 < M < 4.5$ GeV/c^2, that we have used so far to report the Drell-Yan cross-sections. The data points in this mass region cannot help distinguishing between the different shapes, because that window is mostly populated by the charmonium resonances. Since we used the GRV 92 LO PDFs for the published analysis of the S-U data and for the 1995 Pb-Pb data, while we used the MRS A (LQ) PDFs (MRS number 43 in the PDFLIB package) for later data analyses, there is a systematic discrepancy between the corresponding results. This discrepancy becomes evident when 1996 and 1998 data are corrected or reanalysed according to the best of our present knowledge (see section 2.1).

1.3. Experimental conditions for the year 2000 run

We devoted the year 2000 data taking period to investigate further whether Pb-Pb peripheral collisions (before the onset of anomalous suppression) were really compatible with the results obtained from lighter collision systems, and to collect more statistics on several p-A systems, in order to establish a more precise normal absorption curve.

In order to ensure the most favourable experimental conditions, several measures were taken for the Pb-Pb run: (i) the target region was put under vacuum up to and including the BeO preabsorber; (ii) a new method to detect double interactions was developed, based on the EMC; (iii) a new target identification method was adopted, based on the two planes of the MD. Data were taken with the 158 GeV/nucleon beam at $1\text{-}1.4{\cdot}10^7$ ions/s and with a 4 mm Pb target.

The data selection proceeded as follows. First of all, parasitic interactions of the incident Pb ion in the BH were rejected using auxiliary scintillator counters; then, double interactions were rejected by a temporal analysis of the signal in the EMC, allowing us to retain events with either one or two incident ions detected in the BH, within a given time window. Some residual pileup events visible on the E_{T}-E_{ZDC} correlation (Fig. 4) were then rejected by a simple diagonal band cut (in the figure, the $\pm3\sigma$ lines are presented).

The location of the primary interaction was determined by requiring a good correlation between hits on the first and second plane of the MD, as seen from the target position; this method works for $E_T > 3$ GeV, and reaches full efficiency at $E_T \simeq 15$ GeV. It retains for further analysis more peripheral events than the traditional target identification algorithm, based on Cherenkov counters surrounding the target. Muons originating after the target (e.g. in the BeO preabsorber, or in the ZDC) are rejected by a cut on the transverse distance between the extrapolated muon track at the target position and the beam line. We reach a quite effective rejection of the out-of-target events, which are especially numerous in the most peripheral E_{T} bin at masses below the J/ψ (see Fig. 5).

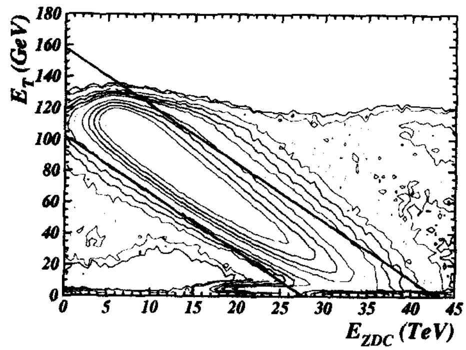

Figure 4. Correlation between transverse and forward energy, showing a $\pm 3\sigma$ diagonal band.

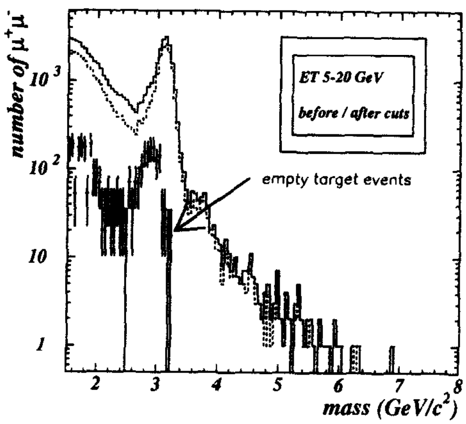

Figure 5. Invariant mass for peripheral interactions before (full line) and after (dashed line) target cuts.

1.4. Normal nuclear absorption of charmonium

To establish the pattern of normal nuclear absorption, data were collected with the NA50 apparatus using the CERN SPS 450 GeV proton beam and five nuclear targets [10].

The Drell-Yan cross section scales linearly with the product $A \times B$ of the projectile and target mass numbers, as shown in Fig. 6, where the so-called K-factor is reported for the new p-A data, along with previous pp, pd and S-U measurements, made by NA51 [7] and NA38 [8,9]. The K-factor is quite constant, including the Pb-Pb data, allowing us to use the Drell-Yan cross-section as a reference process, even for subsamples of different centrality in the case of S-U and Pb-Pb interactions.

Figure 7 shows the J/ψ / Drell-Yan cross-section ratio measured by NA51 in pp and

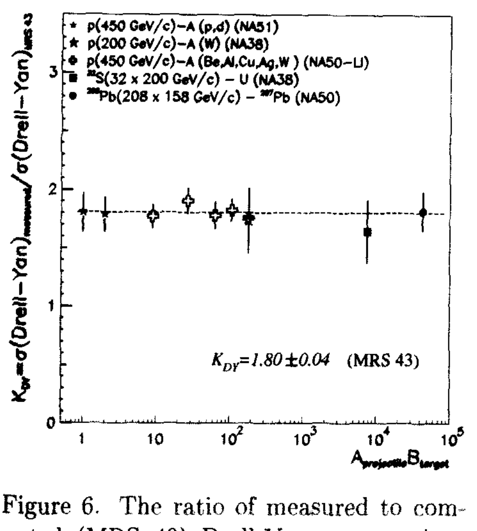

Figure 6. The ratio of measured to computed (MRS 43) Drell-Yan cross-sections from NA51, NA38 and NA50 experiments.

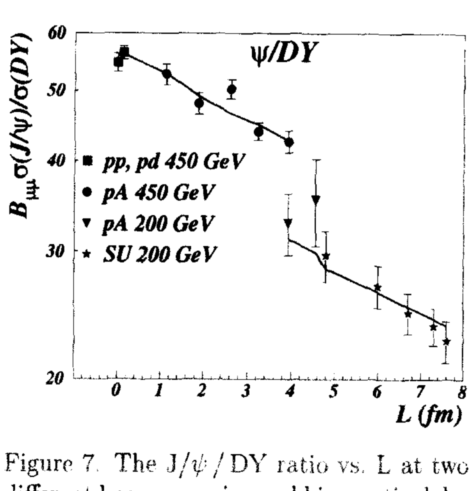

Figure 7. The J/ψ / DY ratio vs. L at two different beam energies and kinematical domains, from NA51, NA38 and NA50 data.

pd collisions and by NA50 in p-A collisions, at 450 GeV, in the kinematical domain $-0.5 < \cos\theta_{CS} < 0.5$ and $-0.4 < y_{cm} < 0.6$, together with NA38 data for p-W, p-U and S-U systems at 200 GeV per nucleon, in the kinematical domain $-0.5 < \cos\theta_{CS} < 0.5$ and $0 < y_{cm} < 1$. The results are plotted as a function of the average path length of nuclear matter encountered by the $c\bar{c}$ after its formation, L, a useful variable to compare the normal nuclear absorption in different systems. The continuous line represents a Glauber calculation in which the free parameters were the separate normalizations for the two kinematical conditions and a common value for the J/ψ absorption cross-section, which turned out to be $\sigma_{abs} = 4.4 \pm 0.5$ mb.

2. RESULTS FROM THE YEAR 2000 RUN

2.1. Centrality dependence of the J/ψ / DY cross-section ratio

Data were analyzed using the standard NA50 analysis method: (i) fit to $\mu^+\mu^+$ and $\mu^-\mu^-$ mass spectra to determine combinatorial background from π and K decays; (ii) fit to $\mu^+\mu^-$ mass spectra to extract J/ψ ψ', Drell-Yan and Open Charm yields; (iii) acceptance correction, thus obtaining $B_{\mu\mu}\sigma(J/\psi)/\sigma(DY)$.

This method presents the advantages of cancellation of most experimental efficiencies (by taking the ratio of two dimuon processes) and of absolute normalization (contrary to the Minimum Bias method), allowing a straightforward comparison to normal absorption in lighter systems. However, the low statistics of high mass Drell-Yan events gives larger error bars with respect to the Minimum Bias method.

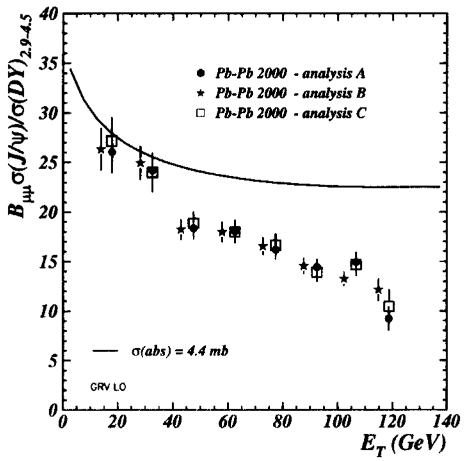

Figure 8. The J/ψ / DY ratio vs. E_T.

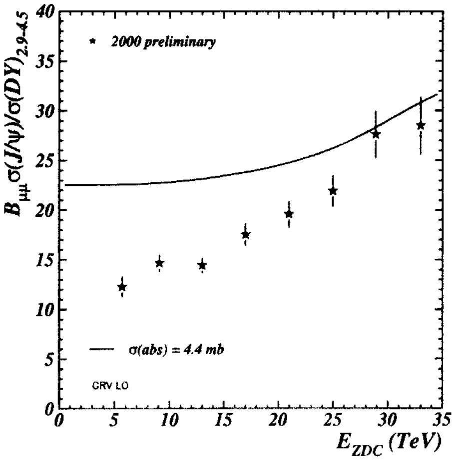

Figure 9. The J/ψ / DY ratio vs. E_{ZDC}.

The preliminary results from the Pb-Pb data collected in year 2000 are presented in Figs. 8 and 9, for the standard analysis (dimuon trigger only) and using two centrality estimators, E_T and E_{ZDC}; the GRV LO set of PDFs has been used for the extraction of the Drell-Yan cross-section in the mass range 2.9–4.5 GeV/c^2.

Figure 8 shows the results from three independent data analyses, as a function of the transverse energy; each analysis uses slightly different selection criteria and fit methods, agreeing between each other within a few percent. We see that the J/ψ production in peripheral Pb-Pb collisions follows indeed the pattern of normal nuclear absorption, as deduced from p-A and S-U collisions, using an absorption cross-section of 4.4 mb and normalizing it with the appropriate energy and isospin corrections, for the Pb-Pb system at 158 GeV/nucleon. The departure from the normal absorption pattern at $\sim$40 GeV, and the non saturation at high E_T, already observed in previously published data, are confirmed. The same observations can be made about the analysis as a function of E_{ZDC}, shown in Fig. 9. More results about transverse momentum distributions are reported in Ref. [11].

Turning now to a detailed comparison with our previously published results, we present in Fig. 10 the preliminary year 2000 data vs. E_T (including the analysis vs. E_{ZDC}, converted to E_T), together with the 1995 published data [2,3] and a reanalysis of our 1998 data, all made using the GRV LO PDFs. In Fig. 11 we present the preliminary year 2000 data vs. E_{ZDC} together with our published 1996 and 1998 data [6], again using the GRV LO PDFs. There is, in general, quite a good agreement between the year 2000 data and previous results, with the exception of the most peripheral data points in Fig. 11, probably due to the contamination of Pb-air interactions in the 1996 data set.

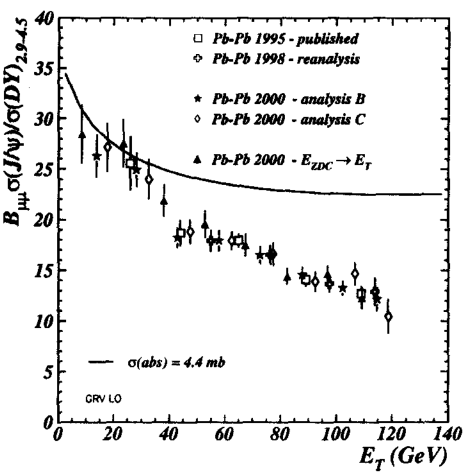

Figure 10. The J/ψ / DY ratio vs. transverse energy for the 2000 and previous years runs.

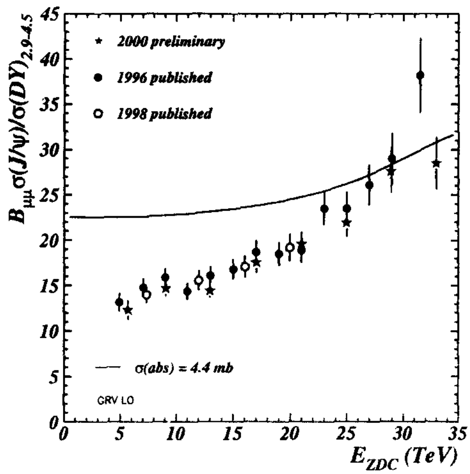

Figure 11. The J/ψ / DY ratio vs. forward energy for the 1996, 1998 and 2000 runs.

The year 2000 data have also been analyzed using the MRS 43 PDFs for the calculation of the Drell-Yan mass distribution and its relative acceptance, instead of the GRV LO PDFs. The result (Fig. 12) shows that the same pattern of suppression vs. E_T is obtained, although with different values of the cross-section ratio. We report also our published 1996 result, rescaled by 3.5 % to take into account a systematic effect due to the event selection cuts used at the publication time, and a reanalysis of our 1998 [illegible] the MRS 43 PDFs. We conclude that, when coherently compared, also the [illegible] MRS 43 analyses agree reasonably well with the preliminary year 2000 results

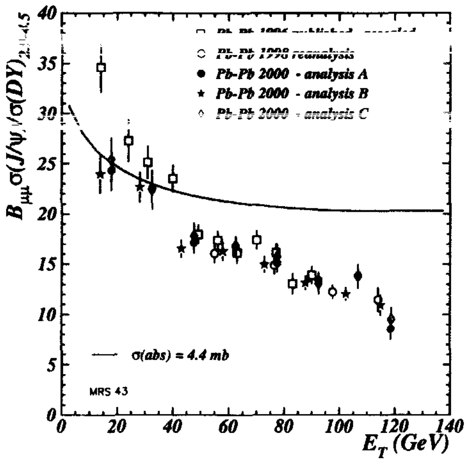

Figure 12. The J/ψ / DY ratio vs. E_T ratio using the MRS 43 parametrisation of the parton distribution functions.

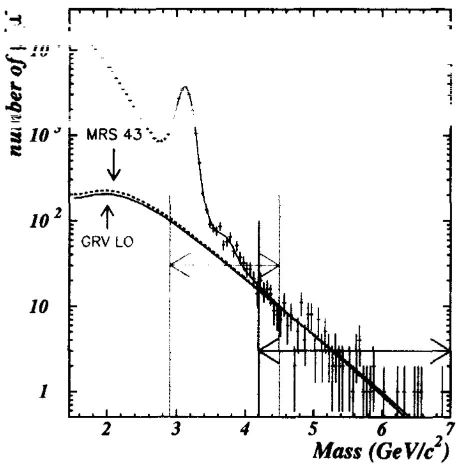

Figure 13. Comparison of fits to the Drell-Yan component, using GRV LO and MRS 43 PDFs.

The reason for the discrepancy between the GRV LO and the MRS 43 analyses comes from the fact that the cross section $\sigma_{DY}(2.9-4.5)$, which we use as a denominator in the cross-section ratio, depends on the extrapolation of dN_{DY}/dM from the high mass region, where Drell-Yan is directly measurable, to the region under the resonances (Fig. 13).

2.2. A new Drell-Yan reference

As shown in Fig. 13, the extrapolation of Drell-Yan from the high mass region to the region under the resonances induces a PDF-dependence on our results, of about 10 % in the Drell-Yan yield between GRV LO and MRS 43. To overcome this problem, we have defined a new Drell-Yan reference in the higher mass region $4.2 < M_{\mu\mu} < 7.0$ GeV/c^2.

We present in Figs. 14 and 15 the new cross-section ratio, namely $\sigma(J/\psi)/\sigma_{DY}(4.2\text{-}7.0)$, as a function of E_T. In Fig. 14 we see that the two analyses of year 2000 data performed with GRV LO and MRS 43 PDFs practically coincide, using new Drell-Yan reference. Of course, the conclusions on the pattern of the J/ψ suppression, quoted above, remain valid: only the scale of the cross-section ratio has changed. In the same figure, we also show the result of a cross-check performed by simply counting the number of J/ψ and of high mass Drell-Yan events. We see a very good consistency with the usual result, obtained by fitting the invariant mass spectra. Finally, a comparison of year 2000 results with several data analyses from previous data taking periods, made either with GRV LO or MRS 43 PDFs, is presented in Fig. 15, using the new Drell-Yan reference. It shows again a rather good compatibility between our most recent data sample and the previous ones (except for the most peripheral points collected in year 1996).

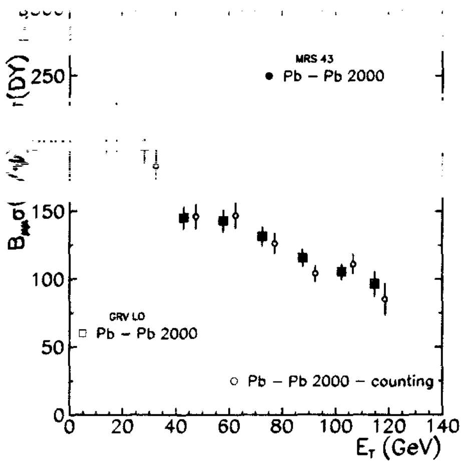

Figure 14. The J/ψ / DY(4.2-7.0) ratio for year 2000 data.

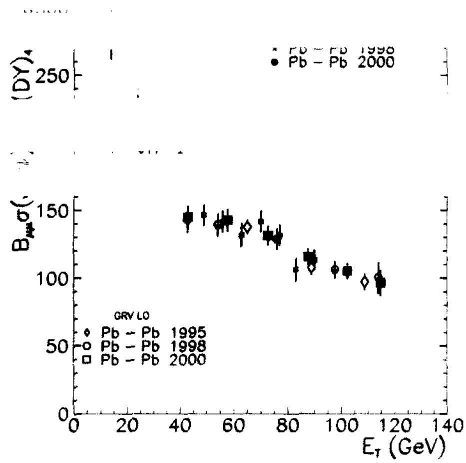

Figure 15. The J/ψ / DY(4.2-7.0) ratio for several data sets.

3. CONCLUSIONS

We have analyzed the most recent NA50 Pb-Pb data sample (collected in year 2000) which was taken in improved experimental conditions, which allowed us to extend the standard analysis of the J/ψ / Drell-Yan cross section ratio down to very peripheral interactions. We have used two different centrality estimators, namely transverse energy and forward energy. Our preliminary analysis confirms the threshold effect, i.e. the departure from normal nuclear absorption (determined with greater precision using the most recent NA50 p-A data, together with published NA51 and NA38 results), and also the steady decrease observed for the most central collisions. Furthermore, the new data confirm that peripheral Pb-Pb interactions (impact parameter $b > 8.5$ fm) follow the normal nuclear absorption pattern, deduced from the study of p-A and S-U collisions.

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