Latest Results from NA50 on J/ψ Suppression in Pb-Pb Collisions

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The main goal of the NA50 experiment is to study the J/ψ suppression pattern in Pb-Pb interactions, at 158 GeV/c per nucleon at the CERN SPS. We present here the results from the 1996 (final) and 1998 (preliminary) data taking periods. They confirm and extend our previous observation that the J/ψ is anomalously suppressed from peripheral to central collisions. With new event selection procedures and different analysis techniques, we observe that in peripheral collisions the J/ψ cross section per nucleon-nucleon collision agrees with the pattern inferred from a wide range of measurements with lighter systems, from pp up to S-U. When the collisions become more central a clear departure from this behaviour is observed. The 1996 data show a sudden drop in the J/ψ production yield for E_{T} values above 40 GeV, where E_{T} is the neutral transverse electromagnetic energy released in the colision and measured in the EM calorimeter. The 1998 data provide a big improvement in the study of the most central region, where a second change in the pattern becomes visible.

1. Introduction

The deconfinement of quarks and gluons above a certain critical temperature, T_c, is predicted by Lattice Quantum ChromoDynamics calculations. The formation of a new state of deconfined matter, the Quark-Gluon Plasma (QGP), is expected in ultrarelativistic heavy ion collisions, where temperature and energy density could reach the required values. The suppression of charmonia production was predicted as a signature for QGP formation, making the measurement of J/ψ yields one of the most promising probes of deconfined matter [1]. The suppression of the J/ψ and ψ' states in the QGP can be interpreted as due to the colour (Debye) screening of the $c\bar{c}$ binding potential or due to interactions of the resonances with gluons hard enough to overcome the $c\bar{c}$ binding energy. Being produced in the hard parton interactions ocurring in the early stages of the Pb-Pb collisions and being relatively insensitive to final state effects, the J/ψ resonance brings very pertinent information about the existence or not of a deconfined state.

The NA38 experiment, at the CERN SPS, collected rather detailed information on charmonia and Drell-Yan production in collisions induced by proton, Oxygen and Sulphur beams, using several targets. It was observed that the J/ψ production yield is smoothly suppressed from the lighter to the heavier systems [2–4]. Moreover, the suppression increases within Sulphur-Uranium collisions from peripheral to more central events. The smooth pattern observed in the S-U collisions has been shown to be fully compatible with the ordinary nuclear absorption already present in the p-A systems [5].

The NA50 experiment is an upgraded version of NA38, optimised for the lead beam operation. The data taken in 1995, with Pb-Pb collisions at 158 GeV/c per incident nucleon, have shown [6,7] that the J/ψ production yield is anomalously suppressed in the Pb-Pb system. The measured absolute J/ψ cross-section lies a factor 0.71 ± 0.03 below the expect value, based on the reference provided by the data collected with the lighter systems. Furthermore, the suppression becomes stronger in the most central collisions.

In this paper we present the latest results of this study, from the data samples taken in 1996 and 1998. Two different analysis methods will be presented.

2. Experimental setup

A schematic view of the NA50 experiment is shown in Fig. 1. The apparatus is optimized to detect and reconstruct the muon pairs produced in Pb-Pb collisions. It complements the muon spectrometer with an EM calorimeter and a ZDC, to measure the transverse and forward energy, thereby getting a measure of the centrality of the reaction. There is also a set of silicon strip detectors that measure the charged particle multiplicity. The NA50 active target system can have up to 7 sub-targets. Two quartz blades located off the beam axis on the left and right side of each sub-target position identify the sub-target where the primary interaction has occurred. It is also possible to identify and reject events where spectator fragments suffer a second interaction ("re-interact") in a downstream sub-target.

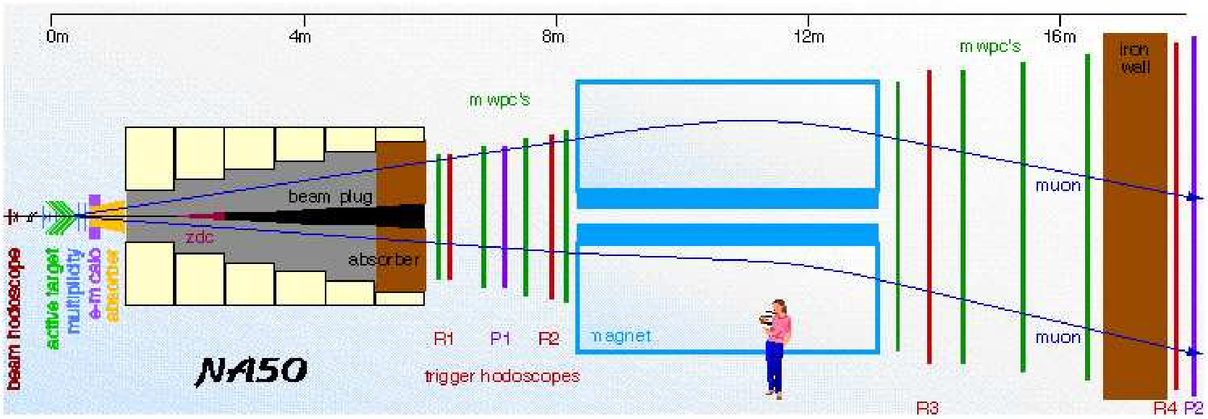

Figure 1. The NA50 apparatus.

The muon spectrometer includes a hadron absorber, an air gap toroidal magnet, 8 multiwire proportional chambers for muon tracking and a system of 6 scintillator hodoscopes for triggering purposes. The muons are detected with good acceptance in the rapidity window $2.8 < y_{\mathrm{lab}} < 4.0$ ($0 < y_{\mathrm{cm}} < 1$).

The event centrality is measured by three independent detectors. An electromagnetic calorimeter, made of lead and scintillating fibres, measures the neutral transverse energy, E_{T}, released by the interaction in the acceptance window $1.1 < \eta_{\mathrm{lab}} < 2.3$. A very forward calorimeter [8] ("Zero Degree Calorimeter" or ZDC), made of quartz fibres embedded in a Tantalum matrix, covers the acceptance $\eta_{\mathrm{lab}} > 6.3$ and measures the energy E_{ZDC} of the spectator (non interacting) nucleons. A 2-plane high granularity silicon strip detector measures the rapidity distribution and multiplicity of charged particles in the acceptance window $1.5 < \eta_{\mathrm{lab}} < 3.5$. The incident lead ions are counted by a quartz beam hodoscope, BH, located approximately 33 m upstream of the target, which is also used to reject beam pile-up. See Ref. [9] for a more detailed description of the detector components.

3. Results from the 1996 data taking period

The aim of the 1996 data taking period was the increase, with respect to 1995, of the number of collected high mass muon pairs, and a better study of the more peripheral collisions. A target system subdivided into 7 sub-targets was employed, but with a total thickness of 12 mm (30 % of λ_I) rather than the 7 mm (7 % of λ_I) used in 1995. Moreover, the better quality of the beam allowed to profit from the high intensity while reducing the number of interactions occurring outside the target. These ("out of target") contaminating events have been estimated from the analysis of special runs taken with no target. They are less than 3 % of the events with $E_{\mathrm{T}} < 50$ GeV and negligible for higher transverse energies. A total of 170 million events were recorded on tape, including about 10 % of (prescaled) minimum bias events, with the only requirement of a non-zero energy deposit in the ZDC.

The data were selected [9] to obtain a clean sample of dimuon events coming from the target. We can summarize the main steps of the selection procedure as follows:

- Dimuon trigger, based on the scintillator hodoscopes
- Pileup rejection. Events in which two ions arrive within 20 ns are tagged by the Beam Hodoscope for offline rejection. They amount to 28 % of the total sample of events.
- No interactions in the Beam Hodoscope itself.
- No signals on the beam halo counters, to prevent interactions upstream of the target.
- Selection of Pb-Pb collisions in the target.

The target algorithm is based on the signals coming from the quartz blades associated to each sub-target, and it efficiently rejects most of the off-target events [11]. Nevertheless, this cleaning tool is inefficient at low multiplicities, introducing considerable event losses for the most peripheral interactions and sometimes failing in the identification of the re-interaction events, where usually at least one of the interactions is very peripheral. Thus a new selection method has been introduced to recover events in the peripheral collision region, consisting in a contour cut at 2σ from the average on the correlation between the transverse energy (E_{T}) and the zero degree calorimeter energy (E_{ZDC}). This cut selects only Pb-Pb collisions in the target region, as shown by the analysis of the "empty target" runs. The response of the target algorithm is not required, but is used when possible.

Figure 2 shows the effect of this new selection (upper picture) in the E_{T}–E_{ZDC} two-dimensional distribution of the J/ψ events (1996 data). The lower picture corresponds to the events selected when the target algorithm is imposed.

The number of J/ψ and D-Y events is evaluated fitting the invariant mass spectrum of the opposite sign muon pairs. This spectrum is shown in Fig. 3 for the 1996 data sample.

We consider the five contributions: J/ψ, ψ', D-Y, open charm (simultaneous $D\bar{D}$ semileptonic decays) and combinatorial background. This last component is due to π and K decays and is estimated from the sample of like-sign muon pairs. The normalisation of the open charm component is determined from a fit to the mass region $2.2 < M < 2.9$ GeV.

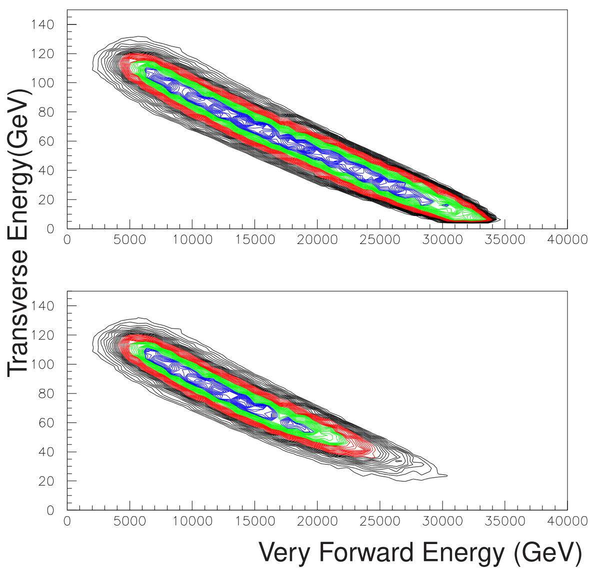

Figure 2. Correlation between E_{T} and E_{ZDC} for events selected with the contour cut (top) and for events selected with the target algorithm (bottom).

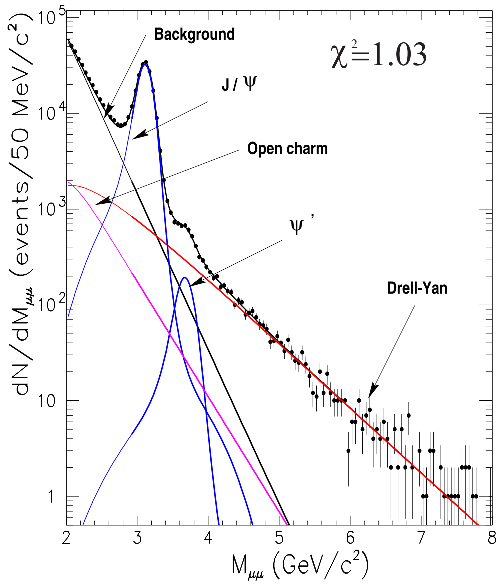

Figure 3. Invariant mass spectrum for the opposite sign muon pairs collected in 1996.

The global fit is performed for dimuon masses above 2.9 GeV with the number of J/ψ, ψ' and D-Y events as free parameters. The excellent fit quality reflects a clean event selection and a good agreement between the data and the sum of the contributions considered.

From the high statistics sample collected in 1996 we have measured the ratio between J/ψ and D-Y production cross sections in 15 different regions of neutral transverse energy, as shown in Fig. 4. The line in this figure provides a good representation of the J/ψ production yield in the lighter systems, from p-A to S-U, as measured by the NA38 and NA51 experiments [2–4]. This line describes the “ordinary” nuclear absorption, with an absorption cross section of 6.4 ± 0.8 mb [10]. The most peripheral points (first four bins) are in good agreement with this curve, while a clear departure is observed for E_{T} values above 40 GeV.

Figure 5 compares the 1996 and the 1995 [12] data, using only five bins. A good agreement is observed except for the most central collisions (highest E_{T} bin). This difference could be due to re-interaction events not identified and, therefore, not rejected. In these events, the measured E_{T} integrates the neutral transverse energy released in two collisions, overestimating the centrality of the interaction that produced the dimuons. The corresponding migration of events from mid to high E_{T} values bias the observed J/ψ suppression pattern. This effect is more pronounced in the 1996 data sample, where a thicker target was used, increasing the probability of having re-interaction events.

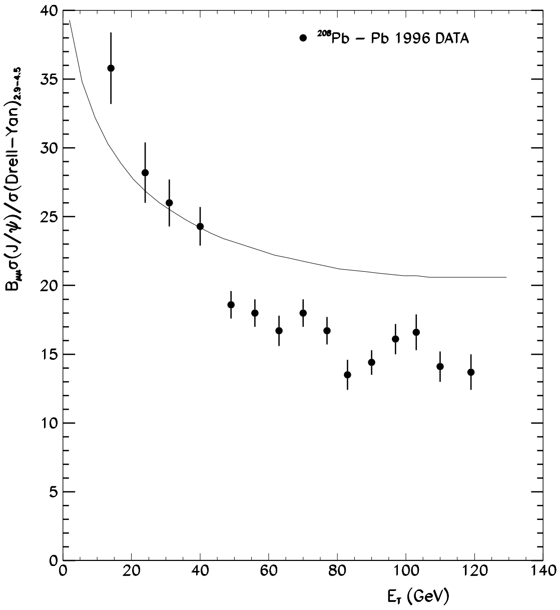

Figure 4. J/ψ over D-Y ratio for the 1996 data. The curve represents the “ordinary” nuclear absorption, properly describing the data from lighter systems.

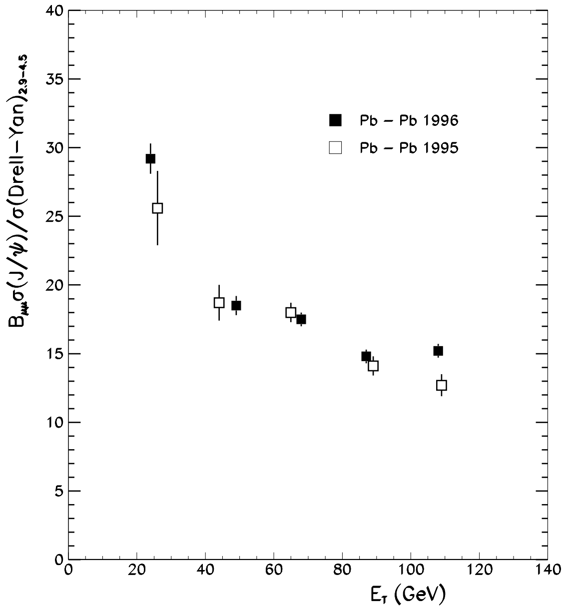

Figure 5. Comparison between 1996 and 1995 data. The difference at high E_{T} could be due to re-interaction events.

4. Results from the 1998 data taking period

The aim of the 1998 data taking period was the study of the Pb-Pb interactions in the high E_{T} region, to better understand the the J/ψ suppression pattern in the most central collisions. The experimental setup was very similar to the one used in the 1996 run, but with only one Pb target, 3 mm thick (7 % λ_I).

A total of 80×10^6 events were collected in two months of data taking. The data selection steps are essentially the same as those previously described. However, due to the short time available, a fine tuning of the target algorithm remains to be done. For the analysis presented here, we have simply used a cut on the signal coming from the Cherenkov counter corresponding to the used subtarget position. This way we obtain a rather clean sample of events coming from the target, at the price of rejecting good events in the low E_{T} region. In the future we will also be able to study those peripheral events but for the moment we concentrate our analysis on the more central events, where we suspect that the 1996 event sample was biased due to the excessive target thickness. After the selection procedure we keep a sample of around 40 000 J/ψ events.

Figure 6 shows the dimuon invariant mass spectrum for the 1998 sample. The fitting procedure is the same as for the 1996 data. In order to compare this data sample to the previous ones, we have calculated the ratio of J/ψ to D-Y cross-sections in four E_{T} intervals. The result is shown in Fig. 7, where the diamonds represent the 1998 data. The first three points, up to 85 GeV, are in good agreement with both other data samples, while the highest transverse energy point ($E_{\rm T}$ around 110 GeV) is closer to the value measured with the 1995 setup. This confirms that the different behaviour of the 1996 data (thicker target) at high $E_{\rm T}$ is due to a bias introduced by events with re-interactions not properly recognized, as anticipated in Ref. [13].

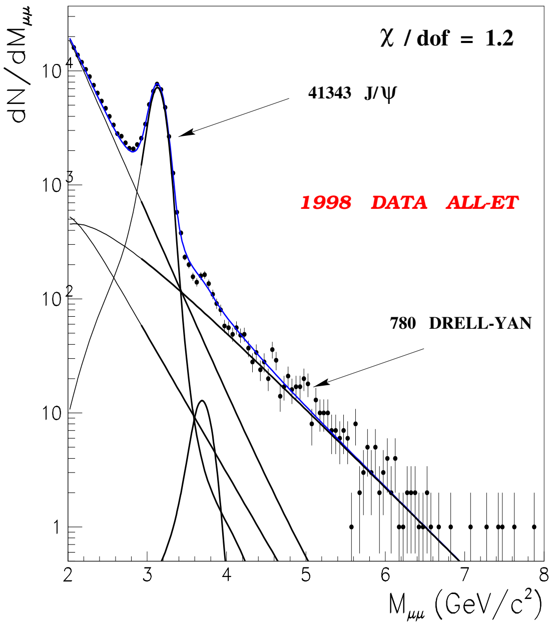

Figure 6. Dimuon invariant mass spectrum for the 1998 data sample.

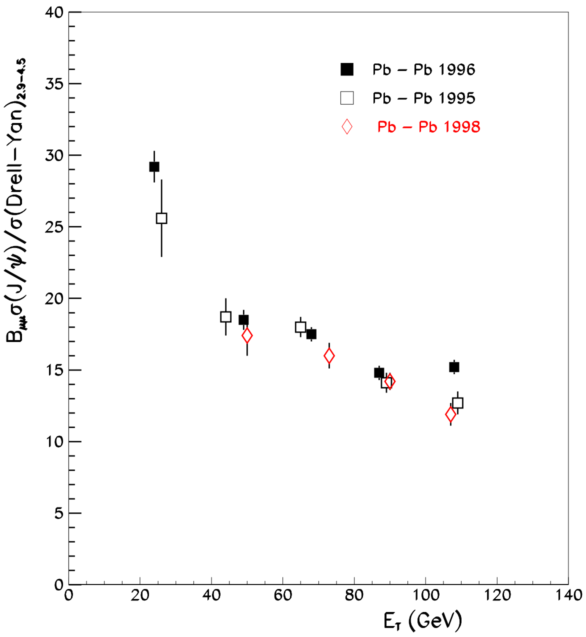

Figure 7. The J/ψ over D-Y cross section ratios for 1995 (open squares), 1996 (full squares) and 1998 (open diamonds) data samples.

5. The Minimum Bias Analysis

The centrality evolution, in Pb-Pb collisions, of the J/ψ suppression pattern has also been evaluated with the use of a minimum bias event sample as the reference. With this method we can significantly reduce the statistical fluctuations, essentially due to the small number of high mass Drell-Yan events. The minimum bias events are collected, with a prescaling factor, at the same time as the standard dimuon events, but with a trigger which is completely independent from the dimuon trigger, simply requiring that some energy has been deposited in the Zero Degree Calorimeter.

In order to compare the results of this new analysis to the previous figures, we have obtained the shape of the Drell-Yan $E_{\rm T}$ distribution, $N^{*}_{DY}(E_{\rm T})$, from the statistically precise minimum bias $E_{\rm T}$ distribution, $N^{\rm exp}_{MB}(E_{\rm T})$.

In fact, we can write the theoretical Drell-Yan and minimum bias $E_{\rm T}$ distributions, $N^{\rm th}_{DY}(E_{\rm T})$ and $N^{\rm th}_{MB}(E_{\rm T})$, in terms of the probability, $P(E_{\rm T}, b)$ that a given $E_{\rm T}$ is measured for a collision with impact parameter b. The analytical function $P(E_{\rm T}, b)$ depends on two

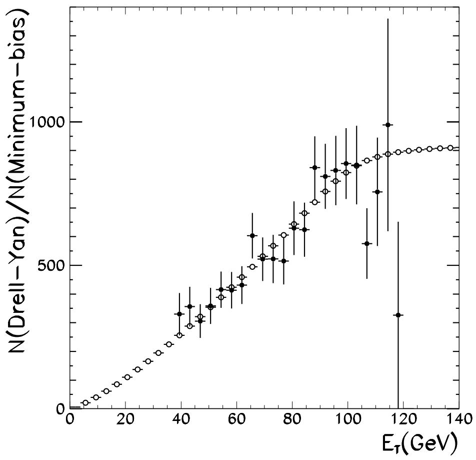

Figure 8. Ratio of Drell-Yan to minimum bias E_{T} distributions, from theory (open circles) and from the 1998 data sample (full circles).

parameters which are fitted to the experimental E_{T} distributions. More details on this procedure can be found in Refs. [10,14].

The ratio of N_{DY}^{th} to N_{MB}^{th} is approximately equal to the number of nucleon-nucleon collisions, $N_{AB}(b)$, evaluated in the Glauber model, with the nuclear density described by a three parameter Woods-Saxon distribution. This ratio is shown in Fig. 8 (open circles), together with the experimental 1998 data (full circles). The good agreement between the shapes of the two distributions confirms that we can use $N_{DY}^{*}(E_{\mathrm{T}})$ as a new reference in the study of the J/ψ yield. To compare the shape of the new curve with the "standard" J/ψ to D-Y ratio, we normalise them in the E_{T} window 55–75 GeV.

An important feature of this analysis method is that, due to the large statistics of the minimum bias reference, the target algorithm can be used for subtarget identification, despite the event losses (the statistical error in the J/ψ yield remains small). Moreover, the numbers of minimum bias events and of dimuon events in the mass interval 2.9–3.3 GeV (after combinatorial background and underlying continuum subtraction) are now obtained, in each E_{T} bin, with a simple counting technique, rather than with sophisticated fit procedures. Most systematical uncertainties still cancel in this ratio of two measured quantities, but new systematic effects may be introduced by the use of two different triggers chains. This issue is currently under detailed investigation.

Figure 9 displays the J/ψ suppression pattern for the 1996 data, as obtained with the two methods. The empty circles, corresponding to the minimum bias analysis, are limited to E_{T} values above 26 GeV, because of the contamination from events originating outside the target. This contamination, non-negligible for the most peripheral collisions, is much more important for the minimum bias events than for the dimuon triggers.

The set of points obtained with the new analysis, practically free from statistical fluctuations, agrees very well with the J/ψ suppression pattern previously obtained with the direct analysis, at least up to E_{T} around 90 GeV.

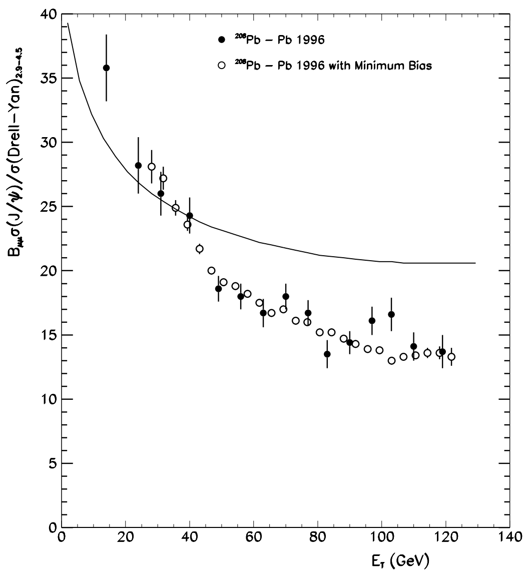

Figure 9. J/ψ to D-Y ratio from the 1996 data with the standard analysis (filled circles) and with the minimum bias analysis (empty circles).

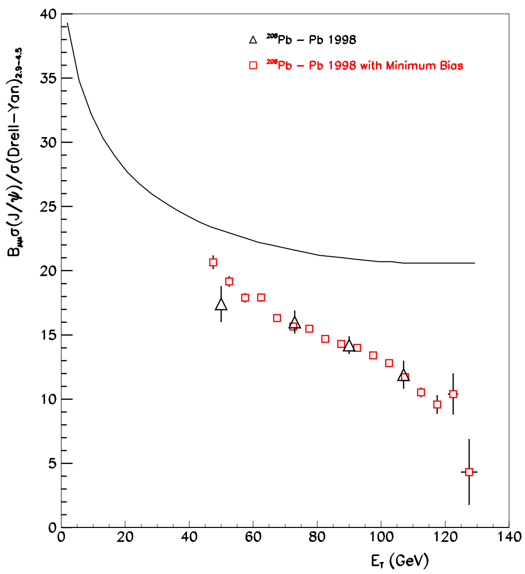

Figure 10. Analogous to Fig. 9 but for the (preliminary) 1998 data. The curve represents the normal nuclear absorption.

The comparison between the two analysis for the 1998 data sample is shown in Fig. 10. The two sets of points are in very good agreement. This figure shows quite clearly that the measured data points depart from the normal absorption curve in a very pronounced way, strongly suggesting a second drop in the J/ψ suppression pattern for $E_{\rm T}$ values above 90 GeV.

6. Summary and conclusions

In 1996 and 1998 the NA50 collaboration has collected two high statistics samples of Pb-Pb events at an incident momentum of 158 GeV/c per nucleon. The main goal was to study J/ψ production with respect to the Drell-Yan process as a function of the centrality of the reaction. The experimental setup was the same during the two data taking periods except for the thickness of the targets.

The numbers of J/ψ and Drell-Yan events were evaluated from a fit to the dimuon invariant mass spectra, for the different $E_{\rm T}$ intervals. Comparing the results obtained with the 1995, 1996 and 1998 data samples, we observe a difference in the highest $E_{\rm T}$ range, indicating the existence of unrecognized re-interaction events, mainly in the 1996 event sample.

A second analysis, based on the minimum bias event sample and not affected by statistical fluctuations in the Drell-Yan events, is in agreement with the first one and allows a more detailed study of the evolution of the J/ψ yield as a function of centrality.

In Fig. 11 the 1996 and 1998 data are combined to summarize the presently available

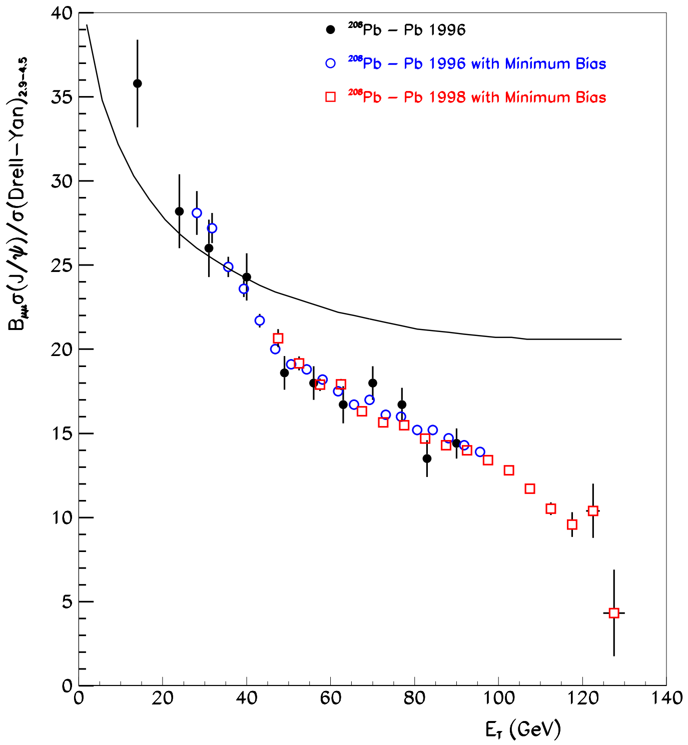

Figure 11. J/ψ suppression pattern, as a function of E_{T}, from the measurements done in 1996 and 1998.

NA50 results on J/ψ suppression in Pb-Pb collisions. The highest E_{T} values of the 1996 data set are not included in view of the bias caused by the re-interaction events. The results obtained with the standard analysis of the 1996 data (full circles) are compared to the points resulting from the minimum bias analysis of the 1996 (empty circles) and 1998 (empty squares) data samples.

The suppression pattern in peripheral Pb-Pb collisions is in agreement with the reference established by the data collected with lighter projectiles. At E_{T} values around 40 GeV a drop in the J/ψ yield is clearly observed. It can only be due to the J/ψ events, since only they are common to the “standard” and “minimum bias” analyses. The analysis of the 1998 event sample, shown in this conference for the first time and still in a preliminary stage, has revealed a second drop in the suppression pattern, for E_{T} values above 90 GeV. If this observation is confirmed after more extensive data analysis, the observed behaviour rules out all existing models based on conventional hadronic scenarios, where the suppression pattern is predicted to saturate at high E_{T}.

We would like to thank all the SPS staff, and particularly L. Gatignon, for the excellent machine operation and beam tuning.

This work was partially supported by Fundação para a Ciência e a Tecnologia and by INTAS grant 96-0231. One of the authors (L. Casagrande) acknowledges financial support from the EC (TMR programme) under contract number ERBFMBICT961204.

REFERENCES

1. T. Matsui and H. Satz, Phys. Lett. **B 178**(1986) 416.
2. M.C. Abreu *et al.* (NA51 Coll.) Phys. Lett. **B 438** (1998) 35.
3. M.C. Abreu *et al.* (NA38 Coll.) Phys. Lett. **B 444** (1998) 516.
4. M.C. Abreu *et al.* (NA38 Coll.) Phys. Lett. **B 449** (1999) 128.
5. M.C. Abreu *et al.* (NA38 Coll.), accepted by Phys. Lett. B, CERN-EP/99-113.
6. M. Gonin *et al.* (NA50 Coll.) Nucl. Phys. **A 610** (1996) 404c.
7. M.C. Abreu *et al.* (NA50 Coll.), Phys. Lett. **B 410** (1997) 337.
8. R. Arnaldi *et al.*, Nucl. Instr. Meth. **A 411** (1998) 1.
9. M.C. Abreu *et al.* (NA50 Coll.), Phys. Lett. **B 410** (1997) 327.
10. D. Kharzeev *et al.*, Zeit. fur Phys. **C 74** (1997) 307.
11. F. Bellaiche *et al.*, Nucl. Instr. Meth. **A 398** (1997) 180.
12. L. Ramello *et al.* (NA50 Coll.), Nucl. Phys. **A 638** (1998) 261c.
13. M.C. Abreu *et al.* (NA50 Coll.), Phys. Lett. **B 450** (1999) 456.
14. C. Baglin *et al.* (NA38 Coll.), Phys. Lett. **B 251** (1990) 472.