Latest results from NA50 on J/ψ suppression and multiplicity distributions in Pb-Pb collisions at 158 GeV/c

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Abstract

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. We used new event selection procedures and different analysis techniques and we can now confirm and extend our preavious observation that the J/ψ is anomalously suppressed going from peripheral to central collisions. 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 p-p 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 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. A second goal of the NA50 collaboration is the study of the particle multiplicity distributions using the silicon multiplicity detector (MD). Very preliminary results on pseudorapidity distributions $dN/d\eta$ as a function of centrality defined by the forward energy E_{ZDC} and by the neutral transverse energy are now available and will be presented as well.

1 Introduction

Non perturbative Quantum Chromodynamics calculations predict that under extreme conditions of temperature and energy density a phase transition occurs from ordinary nuclear matter to a deconfined state of quarks and gluons: the Quark-Gluon Plasma (QGP). Such extreme conditions should be achieved in ultrarelativistic heavy ions collisions and the deconfined phase should be characterized by the appearance of theoretically predicted signatures. In 1986 Matsui and Satz predicted that the suppression of charmonium states should be an unambiguous probe of deconfinement [1]. The formation of the $c\bar{c}$ bound states would be suppressed in the QGP due to the screening of the attractive color force which binds the two quarks together (Debye screening). J/ψ and ψ' resonances are produced in the very early stage of the collision and are expected to weakly interact with the other hadrons, so that they can carry informations about the existence of a deconfined status.

Experiment NA38 at CERN SPS has studied those vector meson resonances in the $\mu^+\mu^-$ decay channel, using proton, Oxygen and Sulphur beams on several targets.

J/ψ production was observed to be suppressed monotonically and continously from the lighter to the heavier interacting nuclei and this result is fully consistent with an ordinary nuclear absorbtion model. The NA50 experiment studies Pb–Pb collisions at 158 GeV/c^2 using an upgraded version of the NA38 experimental apparatus. The results presented here concern the high mass region of the dimuon mass spectrum, where the main contribution are due to the dimuons coming from the Drell–Yan process and from the leptonic decay of the J/ψ and ψ'. Data refer to 1995, 1996 and 1998 NA50 run periods.

2 Experimental setup and data taking conditions

A schematic overview of the NA50 experimental set-up is shown in fig.1. The main component is a muon spectrometer which 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 covered rapidity window is $2.8 \leq y_{lab} \leq 4.0$ $(0 \leq y_{cm} \leq 1)$. The centrality of each event

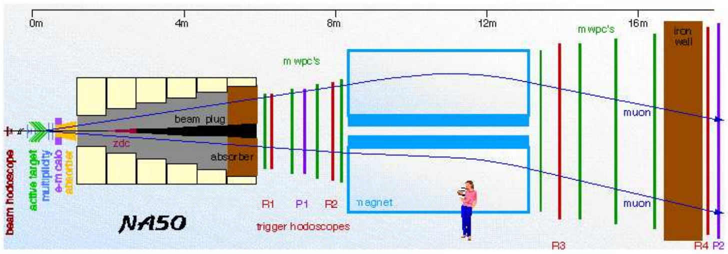

Figure 1: NA50 experimental setup

is measured independently using three different detectors: the electromagnetic calorimeter (EMC), the zero degree calorimeter (ZDC) and the multiplicity detector (MD). The EMC, made of lead and scintillating fibres, measures the neutral transverse energy released in the acceptance window $1.1 \leq \eta_{lab} \leq 2.3$. The ZDC made of quartz fibres embedded in Tantalum slabs and measures the very forward energy (i.e. the energy of the spectator nucleons in the acceptance window $\eta_{lab} \geq 6.3$ [4]). A two planes high granularity silicon strip detector measures the multiplicity of charged particles in the acceptance window $1.5 \leq \eta_{lab} \leq 3.5$.

In addition NA50 uses a quartz beam hodoscope (BH) in order to count incident ions, located approximately 33 m upstream the target. This detector is also used to detect pile–up events. The detectors are described in a more detailed way in [2]. The setup was very similar for the 1995, 1996 and 1998 ion runs, except for the number of subtargets and their thickness [5]. A brief summary of the runs is given in the table below.

	1995	1996	1998
Beam Intensity (Pb/burst)	$3.2 \star 10^7$	$5.4 \star 10^7$	$5.1 \star 10^7$
Target thickness	$17\%\lambda_I$	$30\%\lambda_I$	$7\%\lambda_I$
Number of subtargets	7	7	1
Number of triggers	$58 \star 10^6$	$170 \star 10^6$	$80 \star 10^6$
J/ψ events	53400	190000	~ 40000
Drell-Yan events ($M_{\mu\mu} > 4.2\ \ GeV/c^2$)	630	2100	~ 500

3 Experimental results

3.1 The standard $J/\psi/DY$ analysis

We chose to use the Drell–Yan (DY) cross-section as a reference becauses it scales as the number of primary nucleon–nucleon collisions from p–p up to Pb–Pb collisions without showing sizeable nuclear effect, see [3]. In this way the ratio J/ψ over DY is free from all systematic errors. The number of J/ψ and DY are obtained by fitting the invariant mass spectrum above 2.9 GeV/c^2. In this mass region the contribution of open charm semileptonic decays background, J/ψ, ψ', DY have been taken into account. Fig.2 shows the J/ψ to Drell–Yan

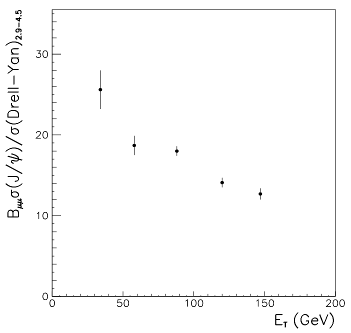

Figure 2: The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ ratio versus E_T evaluated in 1995 data

ratio, multiplied by the branching ratio of J/ψ into two muons, as a function of the transverse energy E_T for the 1995 data sample. The transverse energy spectrum was divided in 5 bins, to study the dependence of the J/ψ over DY ratio from the centrality of the collisions. In 1996 the target thickness was increased with respect to the preavious year (see tab.1) in order to increase the statistics and the number of E_T bins. In fig.3 the same ratio is plotted in

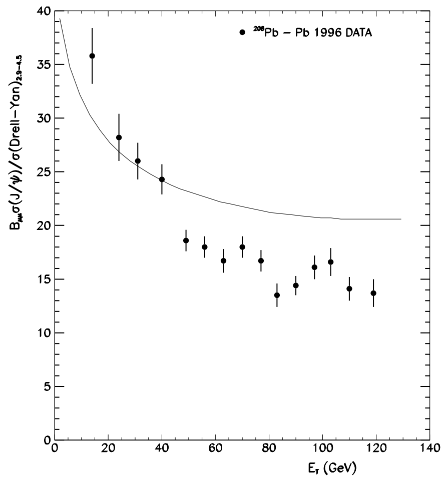

Figure 3: The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ ratio evaluated in 1996 data

15 bins of E_T. The full line refers to a fit, made in the frame of the Glauber model, to the lighter interacting systems and it describes the ordinary nuclear absorbtion of charmonia ($\sigma_{abs} = 6.4 \pm 0.8\ mb$). A clear departure from this "normal" trend can be seen at around $E_T \sim 45\ GeV$ corresponding to an impact parameter $b \sim 8\ fm$. It is the first time that the anomalous suppression can be observed within the same data sample, without any need of beam energy and isospin corrections necessary to compare differents data sets. In order to compare different systems, characterized by different kinematical domains, the variable L has been introduced [7]. L is defined as the lenght of nuclear matter the $c\bar{c}$ traverses, while escaping from the interaction region, and it is computed by means of a Monte Carlo program based on the Glauber formalism. The result can be seen in fig.4. All 450 GeV/c^2 and 200 GeV^2 data presented in the figure have been rescaled to 158 GeV/c^2 using the Schuler parametrization [6] and the Drell–Yan cross sections have been corrected for isospin effect. The full line in fig.4 is a simple exponential fit $e^{-\rho_0 \bar{L} \sigma_{abs}}$ to p–p up to S–U data, using $\rho_0 = 0.17\ fm^{-3}$. The exponential fit leads to $\sigma_{abs} = 5.8 \pm 0.7\ mb$, which can be considered a first order approximation of the absorbtion cross section of charmonia in nuclear matter. From the figure it can be seen that while all the

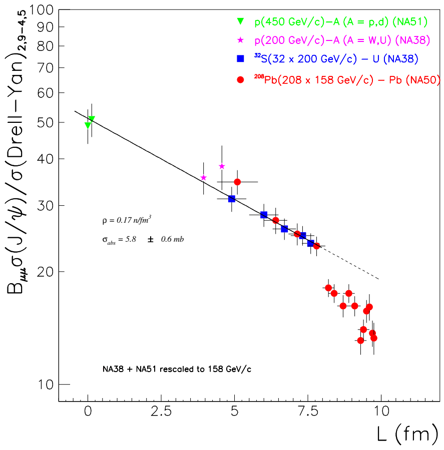

Figure 4: The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ ratio versus L

results from p–p up to peripheral Pb–Pb collisions can be described with the same absorbtion behaviour, the central Pb–Pb points show a clear departure from this trend. However, the points shown in fig.3 still suffer from low statistics of Drell–Yan events. The effects of this problem are clearly visible in the region of intermediate E_T, where the trend of the ratio seems to be flat, but statistical fluctuations are present.

3.2 The minimum bias analysis

In order to overcome the problem of the statistical fluctuations in the J/ψ over Drell–Yan ratio and to confirm the obtained result, an alternative independent analysis was developed [8]. The sample of Drell–Yan events is now replaced by the huge sample of minimum bias events, that is the sample collected with a beam trigger which fires when a minimum amount of energy is measured in the Zero Degree calorimeter. The J/ψ sample is the same used in the standard analysis. This method does not use the fitting procedure, but the numbers of events for the ratio are obtained directly from a simple counting technique. This analysis is based on the very similar structure of the transverse energy distributions for minimum bias (MB) and Drell–Yan events in A–B collisions. The theoretical shapes for both spectra(N^{th}_{MB} and N^{th}_{DY}) can be evaluated in the framework of the Glauber model and the ratio of N^{th}_{MB} and N^{th}_{DY}

$$\frac{N^{th}_{MB}}{N^{th}_{DY}} \sim N_{AB}$$

is approximately equal to the number of the nucleon–nucleon collisions, N_{AB}. The "new" Drell–Yan N_{DY} can be obtained according to:

$$N_{DY} = N_{MB} * N_{AB}$$

To compare the minimum bias analysis and the standard one, a normalization has been made in the E_T window 55–75 GeV. In fig.5 the comparison between

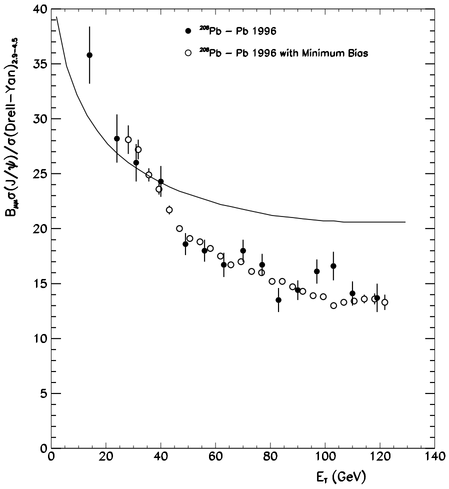

Figure 5: Comparison between the ratio $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ obtained with the standard analysis(closed circle) and the minimum bias one (open circle) for the 1996 data.

the standard analysis (closed circles) and the minimum bias one (open circles) for the 1996 data sample is shown, as a function of centrality. It can be seen that, because of the bigger minimum bias sample,the new analysis is affected by much lower statistical fluctuations and a finer E_T binning is possible. The minimum bias analysis is limited to E_T values above 26 GeV, because of 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 J/ψ over Drell–Yan pattern obtained with those two independent analysis show a good agreement at least up to $E_T = 90\ GeV$. This leads to establish that the drop can only be due to a reduced J/ψ production cross section.

3.3 Re–interation problems

The 1998 run was devoted to clarify the behaviour in the high E_T region, since the 1996 data sample seems to be different from the 1995 ones in this region. This problems was interpreted in terms of downstream reinteractions of a spectator fragment produced in a primary periferic interaction. This event has a J/ψ over Drell–Yan ratio corresponding to a peripheral interaction (i.e. high), but, if the fragment reinteracted in one of the down–stream subtargets, the E_T would be the sum of the contribution of the 2 interactions, and the event wuold be classified as a central one. In 1996 this problem was important because the target thickness (30% λ_i), so the 1998 data have been collected with a 7% λ_i target. In fig.6 the standard analysis results in 5 E_T bins for three different data taking periods is shown. The difference in the ratio J/ψ over Drell–Yan in the last bin is clearly due to the increasing thickness of the target.

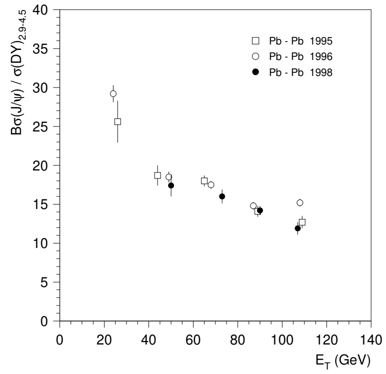

Figure 6: The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ results with standard analysis for 1995, 1996 and 1998 data versus E_T.

3.4 Final results

In fig.7 the preliminary 1998 results obtained with the minimum bias analysis are presented together with the results of the two analysis on 1996 data. For $E_T \geq\ 90\ GeV$ only the 1998 data are shown, because they are not biased by reinteractions. The 1998 pattern confirms the results obtained in 1996, but exhibits a further suppression for the more central events.

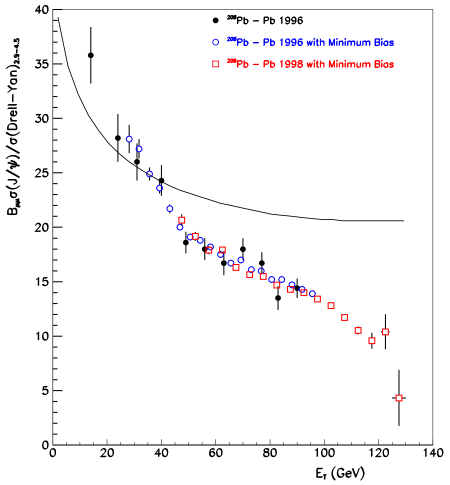

Figure 7: The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ results for 1995, 1996 and 1998 data versus E_T.

4 Preliminary results on multiplicity distributions

A small sample of the 1998 data ($\approx$ 40000 events) collected by the multiplicity detector was analyzed in order to obtain the charged multiplicity distributions. The data were divided in 6 centrality bins as a function of the very forward energy measured by the ZDC. In order to take into account the hardware problems of the detector (inefficiency caused by delay jitter between the trigger of the experiment and MD trigger, crosstalk between channels) and the physical effects which affect the measurement (multiple occupancy, Landau distribution of the energy loss in the silicon) some correction were applied. In addition, delta electrons were subtracted by means of GEANT simulations and corrections for gamma conversions and secondary interactions were applied on the basis of GEANT+VENUS simulations. In order to evaluate correctly the η coverage of the different modules of the detector, a preliminary alignment procedure based on spatial hits distribution was implemented. The uncertainty on this procedure plus the one of the method used to evaluate cross–talk effects may result in a systematic error of 25%. In fig.8 preliminary results for multiplicity distributions in 6 E_{ZDC} bins are shown. The error bars account for statistical errors only.

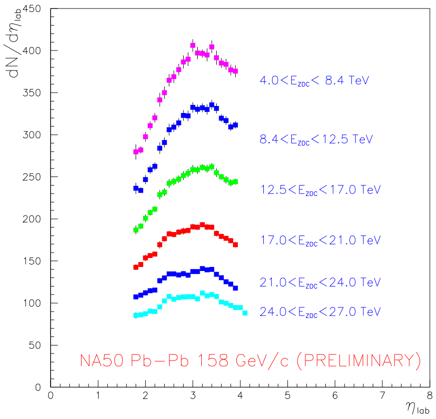

Figure 8: Pseudorapidity distribution of the N_{ch} in six centrality bands

5 Conclusions

The J/ψ over Drell–Yan patterns obtained with two different analysis techniques are very similar. They show a decreasing trend in the J/ψ production cross section as a function of centrality (E_T). Two drops are visible at $E_T \sim 45\ GeV$

and $E_T \geq 90\ GeV$. This observed suppression rules out all existing models based on conventional hadronic scenarioes, where the suppression pattern is predicted to saturate at high E_T, and can be considered as a strong indication of the production of Quark Gluon Plasma.

Very preliminary results about multiplicity distribution in six centrality bands were presented.

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