Latest results from NA50 on J/ψ suppression 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 and 1998 data taking periods. We used new event selection procedures, different analysis techniques and different event centrality estimators and we can now confirm and extend our preavious observation that the J/ψ is anomalously suppressed when going from peripheral to central Pb-Pb 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 transverse energy values above 40 GeV. The 1998 data provide a big improvement in the study of the most central region, where a second change in the pattern becomes visible. This suppression pattern is confirmed by an independent analysis which uses the zero degree energy (E_{ZDC}) as centrality estimator.

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 ion 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]. NA38 experiment 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 per nucleon using an upgraded version of the NA38 experimental apparatus. In this paper we present new (preliminary) results based on proton-induced interactions which lead to a more precise measurement of J/ψ normal absorption, we compare different analyses of the same Pb-Pb data in which centrality is estimated using different experimental variables, i.e. forward and transverse energy. Moreover the direct connection between E_{ZDC} and the geometry of the collision allows us to calculate, within a Glauber approach, the precise relation between E_{ZDC} and N_{part}.

EXPERIMENTAL SETUP AND DATA TAKING CONDITIONS

The main component of the NA50 experimental set-up is a muon spectrometer which covers a rapidity window corresponding to $2.8 \leq y_{lab} \leq 4.0$ $(0 \leq y_{cm} \leq 1)$. The centrality of each event 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 is 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–plane 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 [6]. A detailed description of data taking conditions can be found in [5].

THE $J/\psi/DY$ RATIO AS A FUNCTION OF E_T

We chose to use the Drell–Yan (DY) cross-section as a reference because 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 systematic errors which are equal for J/ψ and DY cancel in the ratio. This ratio is evaluated using two different analyses: the standard and the minimum bias analyses. In the first analysis method the number of J/ψ and DY are obtained by fitting the invariant $\mu^+\mu_-$mass spectrum above 2.9 GeV/c^2, taking into account the contribution of open charm semileptonic decays background, J/ψ, ψ', DY. In the second method, developed to overcome the problem of statisticl fluctuations in the Drell–Yan sample, the Drell–Yan spectrum is calculated from 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. For a detailed description of the two analyses see [5]. Fig.1a shows the J/ψ to Drell–Yan ratio, multiplied by the branching ratio of J/ψ into two muons, as a function of the transverse energy E_T for the 1996 and 1998 data sample both standard and minimum bias analyses. The transverse energy spectrum was divided in many bins, to study the dependence of the J/ψ over DY ratio on the centrality of the collisions. The two different set of data and the two analyses are in good agreement.

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 $b \sim 8\ fm$. In this plot the anomalous suppression can be observed within the same data sample, without any need of beam energy and isospin corrections necessary to compare different data sets. In order to compare different systems, characterized by different kinematical domains, the variable L has been introduced [8]. 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.1b. In this analysis we use new preliminary NA50 p-A data collected with proton beam impinging on several targets (Be, Al, Cu, Ag, W, and Pb). Two samples of events taken with different beam momentum (450 and

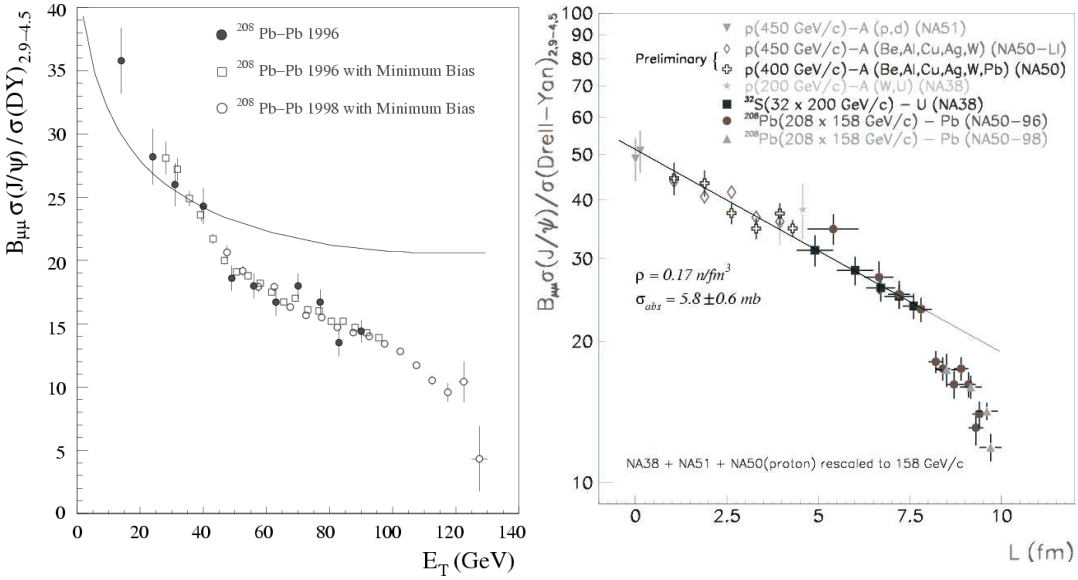

FIGURE 1. a) The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ ratio evaluated in different E_T bins using standard (full circles) and minimum bias analyses (open circles=1998, open squares=1996); b) The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ ratio versus L (1996 and 1998 Pb-Pb data and new preliminary p-A data from NA50)

400 GeV/c) and intensity ($\sim 5\cdot 10^8$ and $\sim 4\cdot 10^9$) are considered here. All 450 GeV/c, 400 GeV/c and 200 GeV/c data presented in the figure have been rescaled to 158 GeV/c using the Schuler parametrization [7] and the Drell–Yan cross sections have been corrected for isospin effect. The full line in Fig.1b 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 $\sigma_{abs} = 5.8 \pm 0.6\ mb$, which can be considered a first order approximation of the absorbtion cross section of charmonium in nuclear matter. From the figure it can be seen that while all the 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.

THE $J/\psi/DY$ RATIO AS A FUNCTION OF E_{ZDC}

The geometry of a nucleus–nucleus collision is characterized by the value of the impact parameter b, which can be deduced by the measured E_{ZDC} value. In fact, being placed on the beam line, the ZDC intercepts all the spectator nucleons, which are not affected by the collision and reach the detector with their initial energy. The resulting E_{ZDC} as a function of b can be, as a first approximation, obtained by the following equation:

$$\langle E_{ZDC}(b)\rangle \simeq 158 \times N_{spec}(b) = 158 \times \left(208 - \frac{N_{part}(b)}{2}\right) \tag{1}$$

where 158 GeV is the energy per spectator nucleon. The link between N_{part} (or N_{spec}) and the impact parameter b has been obtained with a calculation based on a Glauber model using Wood-Saxon nuclear density profiles. We plot in Fig.2 the distribution of N_{part} vs E_{ZDC} which is relevant for the J/ψ suppression analysis described hereafter. In Fig.3a we plot the result of the minimum bias analysis for the $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ ratio versus E_{ZDC}, both for 1996 and 1998 data. The two set of data are compatible. The result presented exhibit two clear changes of slope: the first one corresponds to the E_{ZDC} region around 26TeV (corresponding to $b \simeq 8 fm$, where we observe a departure from the trend of the normal absorption curve, while the second one is visible in the zone corresponding to the most central collisions. The pattern is even more evident if we divide the $J/\psi/DY$ ratio by the nuclear absorption curve, as shown in Fig.3b.

As reported in [10], one of the basic features of the suppression pattern in a deconfinement scenario is a well defined onset. In fact, all the approaches based on conventional suppression mechanisms predict a smoother trend as

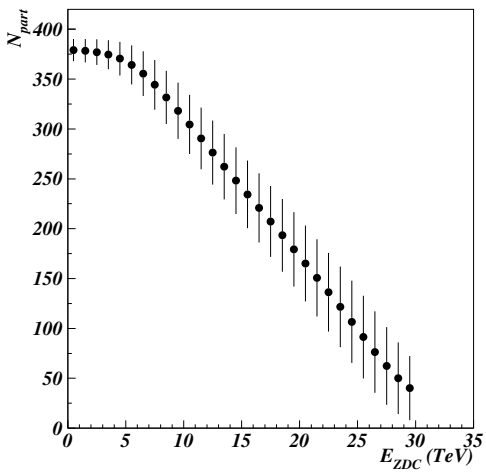

FIGURE 2. Correlation between N_{part} and E_{ZDC}

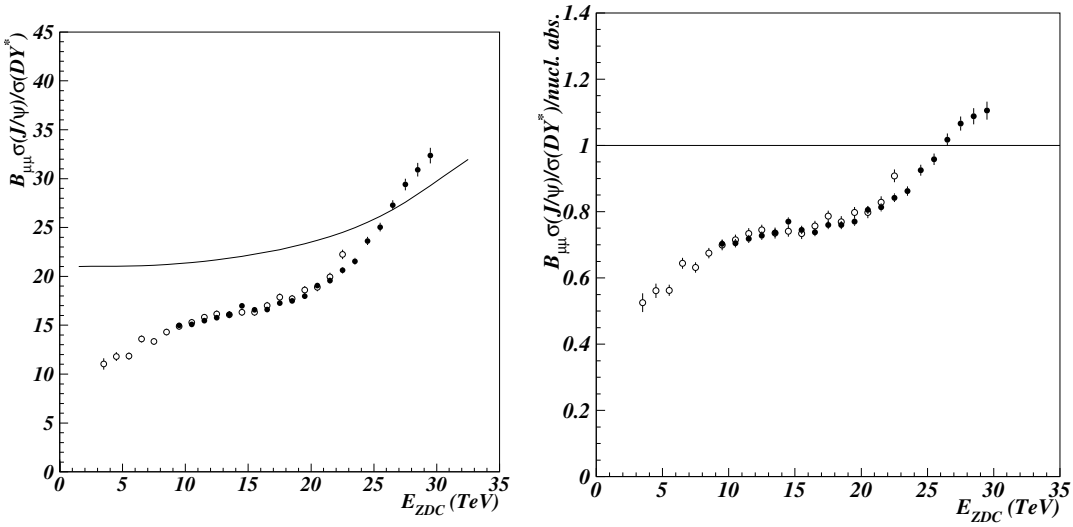

FIGURE 3. a) The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ ratio versus E_{ZDC} (full circles are 1996 and open circles 1998 Pb-Pb data, both obtained with a minimum bias analysis); b) The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ divided by the nuclear absorption curve vs E_{ZDC}

a function of centrality. A priori we do not know which is the variable governing the onset of the anomalous J/ψ suppression. Hence, given the strict correlation between E_{ZDC} and N_{part}, we check if the double step pattern shown in Fig.3b is compatible with two sharp drops in the J/ψ yield occurring at well defined N_{part} values (N_1 and N_2). Taking into account the N_{part} versus E_{ZDC} correlation, and the finite resolution on E_{ZDC} due to the detector response, we calculate $\sigma_{J/\psi}/\sigma_{Drell-Yan}$ vs E_{ZDC}. Making a fit to the data we obtain for N_1 and N_2 the values of 122 and 334. The curve resulting from the fit nicely describe the data pattern, as we show in Fig.4. We also performed a study of the region around N_1 introducing a gaussian-smeared onset of the J/ψ suppression. We vary the σ of the gaussian function and check what is the χ^2/ndf resulting from the fit. This number is roughly constant up to σ_{N_1}=25 then it steadely increases. This result clearly suggest an onset of the anomalous suppression occurring in a very limited centrality range. A more detailed description of this analysis can be found in [9].

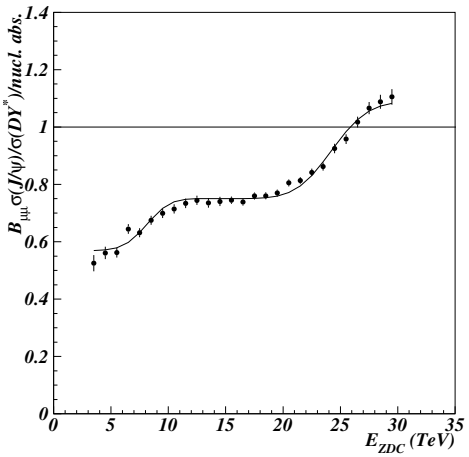

FIGURE 4. The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ divided by the nuclear absorption curve vs E_{ZDC}, fitted assuming two sharp absorption mechanism of free amplitude occurring at N_{part}=122 and N_{part}=334

CONCLUSIONS

The J/ψ over Drell–Yan patterns plotted versus two different centrality variables are very similar. They show two drops in the J/ψ yield corresponding to $E_T \sim 45$ *GeV* ($E_{ZDC} \sim 26$ *TeV*) and $E_T \geq 90$ *GeV* ($E_{ZDC} \sim 9$ *TeV*). The quantitative comparison of the two results is far from being trivial. Qualitatively, one can compare the values of the impact parameter corresponding to the anomalous suppression onset point extracted from the two analyses. These values are roughly in agreement and are of the order of 8 fm. The connection between E_{ZDC} and the number of participants has been investigated in detail using a Glauber model of the Pb–Pb collisions. We have shown that our data imply a very steep onset of the anomalous J/ψ suppression, having taken into account the effect of the experimental resolution of E_{ZDC} on N_{part}. This observed suppression rules out all existing models based on conventional hadronic scenarioes, where the suppression pattern is predicted to be smoother and saturate for central collisions, and can be considered as a strong indication of the transition to a deconfined state of matter.

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