602: A new measurement of the J/ψ production rate in Lead-Lead interactions at 158 GeV/c per nucleon

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Abstract. We present preliminary results of a new measurement of J/ψ production in Pb-Pb interactions at 158 GeV/c. As a function of centrality, the J/ψ production rate shows peculiar discontinuities which, if confirmed, could imply a sudden change in the state of the reacting medium.

1 Introduction

Ultra-relativistic heavy ion collisions at the CERN-SPS are used to study the possible formation of quark gluon plasma (QGP). Among several predicted signatures of this phase transition, charmonia suppression is expected to occur at the early stages of the collision. This suppression is attributed to color screening in the QGP [1]. However, some "normal" suppression is also produced by absorption in nuclear matter [2, 3].

Measurements of J/ψ , ψ' and Drell-Yan cross-sections are performed by the NA38 and NA50 experiments. Charmonia and Drell-Yan are observed via their decay into muon pairs. Drell-Yan is used as a reference as it is insensitive to strong interactions.

In the NA38 experiment, the studied collisions were induced by incident protons, oxygen or sulfur ions at 200 GeV/c per nucleon on different targets. A significant suppression of the J/ψ resonance in central collisions [4, 5] in O-A_{target} and S-U collisions has already been observed. It has triggered a considerable amount of theoretical work intended to explain the experimental results.

More recently, the NA50 experiment, an upgraded version of the NA38 experiment, used a lead beam with an energy of 158 GeV/c per nucleon on a fixed lead target. Data were collected in 1995 and 1996. Results from the 1995 data show a strong suppression of charmonia [6]. It thus provides new constraints for any theoretical explanation.

We present the final results for the 1995 lead-lead data and compare them to the NA38 results. As for the 1996 lead-lead experiment, a new event selection procedure enables to increase significantly the statistics of the events produced in peripheral collisions. This new selection is explained. The latest results of charmonia suppression in lead-lead are presented and compared with the previous ones and with the NA38 results.

2 Experimental details

The NA50 detector [7] which is an upgraded version of the NA38 apparatus [4], see Fig 1, consists of a dimuon spectrometer based on an air-core toroidal magnet. A set of proportional muon chambers and scintillator hodoscopes provide muon pair tracking and trigger. A hadron absorber made of carbon and a BeO pre-absorber are placed upstream from the first muon chamber. This spectrometer covers a pseudo-rapidity interval $2.8 < \eta < 4.0$. A mass resolution of 3.1% is obtained for the J/ψ .

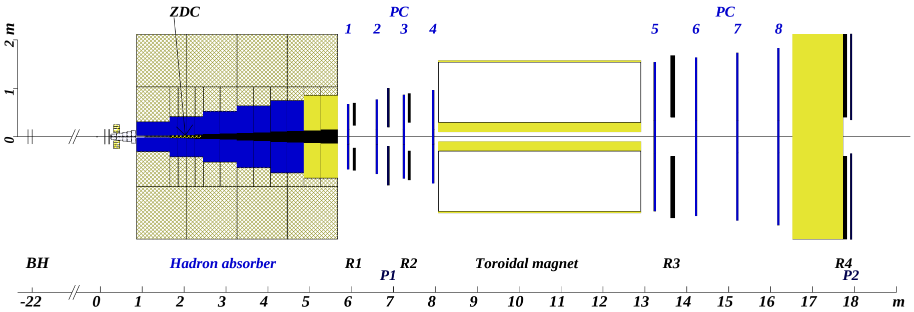

Fig. 1. Layout of the NA50 experiment.

The target is made of 7 lead subtargets in order to minimize secondary interactions. Its total thickness amounts to 30% of an interaction length (17.5% in 1995). A set of quartz blades allows the identification of the primary vertex. An electromagnetic calorimeter made of scintillating fibers embedded in lead measures the neutral transverse energy (E_T) produced in the collision. Its resolution is 5% for central Pb-Pb collisions. A "zero degree" calorimeter (ZDC) located along the beam axis and placed within the main muon absorber, downstream from the target, measures the energy carried out from the Pb-Pb reaction by the beam spectators. It is made of silica optical fibers embedded in a tantalum converter. Its energy resolution is 7% for 32.7 TeV incident Pb nuclei. The neutral transverse energy as well as the energy carried out by the beam spectators are used to estimate the centrality of the collision.

Events are selected for the final analysis if only one incident ion is detected, therefore avoiding pile-up effects. The tracking algorithm requires exactly two muon tracks in the acceptance of the spectrometer. The kinematical domain for the muon pair analysis is defined by a center-of-mass rapidity 0. $< y_{cm} <$ 1. and a polar decay angle in the Collins-Soper reference frame -0.5 $< cos(\theta) <$ 0.5 .

3 Pb-Pb 1995 results and comparison with NA38 results

The invariant mass spectrum for opposite sign muon pairs is shown in Fig 2 for masses above 2. GeV/c^2. The processes contributing to this spectrum are Drell-Yan , J/ψ , ψ' , D$\bar{\mathrm{D}}$ pairs and the background from mesons (π and K) decay. The π and K mesons decay leads also to like sign pairs which are used to estimate the background using the relation:

$$N^{Bckg} = 2 \times \sqrt{N^{++} \times N^{--}} \ ,$$

where N^{++} (N^{--}) is the number of pairs made of two positive (negative) charged muons. The signal to background ratio is larger than 10 at the J/ψ peak. There are roughly 5% non-J/ψ signal events under the J/ψ peak, mainly originating from Drell-Yan events since the $D\bar{D}$ contribution is expected to be unsignificant at a mass of 3. GeV/c^2.

The number of J/ψ , ψ' , and Drell-Yan events is obtained from a fit to the invariant mass spectrum. This fit is performed for masses above 3.05 GeV/c^2, using the maximum likelihood method with a superposition of four contributions as described hereafter:

$$\frac{dN^{+-}}{dM_{\mu^+\mu^-}} = A_{J/\psi}\frac{dN^{J/\psi}}{dM_{\mu^+\mu^-}} + A_{\psi'}\frac{dN^{\psi'}}{dM_{\mu^+\mu^-}} + A_{DY}\frac{dN^{DY}}{dM_{\mu^+\mu^-}} + \frac{dN^{Bckg}}{dM_{\mu^+\mu^-}} \ .$$

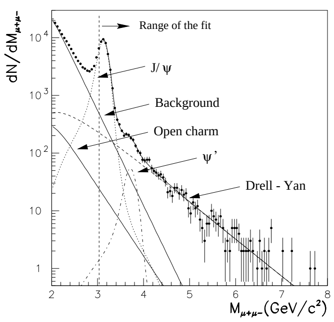

Fig. 2. Opposite sign muon pairs mass distribution in Pb-Pb collisions from the 1995 data collection.

The shape of the J/ψ , ψ' and Drell-Yan contributions are determined by Monte-Carlo simulations. Analytical functions are used to smooth the reconstructed simulated events as can be seen in Fig 2. The fit is performed with five free parameters including the three parameters $A_{J/\psi}$, $A_{\psi'}$, A_{DY} and the mass and width of the gaussian-like distribution for J/ψ . The corresponding parameters (mass, width) for the ψ' are related to those of the J/ψ according to the nominal mass difference and width ratio obtained from the Monte-Carlo simulation. Each contribution can be studied as a function of the centrality of the collision. For this purpose, we use the neutral transverse energy spectrum and divide it into equipopulated bins. The higher value bins account for the more central collisions.

Drell-Yan cross-section in A+B collisions is a superposition of primary independent nucleon-nucleon Drell-Yan components, expressed as $\sigma_{DY}^{AB} =$

$\sigma_{DY}^{NN} \times (A \times B)^{\alpha}$. All the measurements in NA38 as well as in Pb-Pb collisions experiment agree with an α value of 1 when taking into account isospin effects[1]. Thus, Drell-Yan scales as $(A \times B)$ as expected. This behaviour is illustrated in Fig 3(left) where the ratio of the measured Drell-Yan cross-section to the lowest order theoretical Drell-Yan value is shown as a function of $(A \times B)$. This ratio is expressed through the so-called K factor which is found to be around 2.5 in good agreement with the well known Drell-Yan theoretical calculations.

The nuclear dependance of charmonia production in A+B collisions is also expressed through the expression $\sigma_{J/\psi}^{AB} = \sigma_{J/\psi}^{NN} \times (A \times B)^{\alpha}$. The α value is found to be around 0.91 for all NA38 data as shown in Fig 3(center) where the J/ψ cross-section per nucleon-nucleon collision is plotted as a function of $(A \times B)$. Relatively to the $(A \times B)^{0.91}$ dependence, the 1995 Pb J/ψ cross-section is lower by a factor 0.74$\pm$0.06 and thus exhibits an unexpected abnormal behaviour [6]. In order to compare the J/ψ cross-sections from different systems at different incident energies, all the values have been rescaled to the same energy, using the so-called Schuler parametrization [9], $\sigma = \sigma_0(1 - \frac{M_{\mu\mu}}{\sqrt{s}})^{12}$, $\sqrt{s}$ standing for the center of mass energy per nucleon. The energy dependence for Drell-Yan is given by analytical calculations. Since Drell-Yan scales as $(A \times B)$, we study the J/ψ /Drell-Yan cross-sections ratio which is proportional to the J/ψ "cross-section per nucleon-nucleon collision".

This ratio is shown in Fig 3(right) as a function of the mean length of the path of the charmonia through nuclear matter, $\bar{L}$. $\bar{L}$ is calculated using the standard three-parameter Woods-Saxon potential as explained in reference [8]. In the framework of the absorption model, the J/ψ cross-section is proportional to $e^{-\rho_0 \bar{L} \sigma_{abs}}$, where σ_{abs} is the nuclear absorption cross-section. As clearly seen in this figure, except for the Pb data, all the other data decrease exponentially with $\bar{L}$ leading to an absorption cross-section of 6.2$\pm$0.7 mb. The last Pb bin lies a factor 0.62$\pm$0.04 below the absorption line, off by 10 standard deviations from the absorption expectation. It has to be noticed that the Pb-Pb data and the proton data are rescaled to 200 GeV/c.

4 1996 Pb-Pb results

A new event selection has been applied in order to increase the statistics of peripheral collisions. Indeed, applying the usual event selection criteria which includes the identification of the primary vertex leads to a sample of

[1] As the Drell-Yan mechanism depends on the isospin of the nucleon, the measured Drell-Yan cross-section is corrected to account for the relative amount of interacting protons and neutrons . The Drell-Yan corrected cross-section is equivalent to the Drell-Yan cross-section we would have measured for the same two nuclei made only of protons and is therefore expected to scale exactly with the number of nucleon-nucleon collisions.

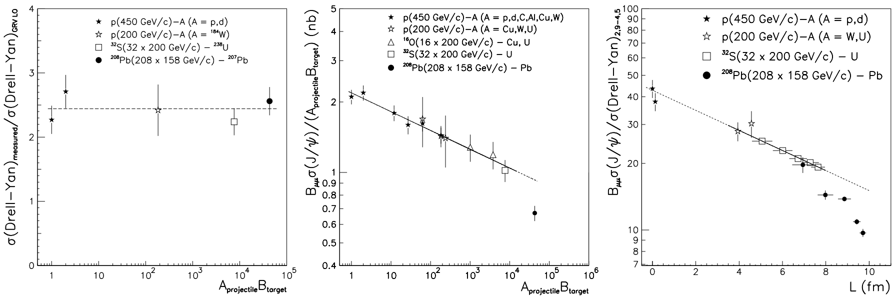

Fig. 3. Pb-Pb data from 1995 measurement compared to NA38 data: (left) Drell-Yan K factor as a function of $A \times B$. (center)J/ψ cross-section per nucleon-nucleon collision as a function of $A \times B$. (right)J/ψ cross-section per nucleon-nucleon collision as a function of $\bar{L}$. Data are rescaled to 200 GeV/c.

events where most "very peripheral collisions" are missing due to the target algorithm low efficiency below an E_T around 40 GeV. This is clearly seen on the plot of E_T versus E_{ZDC} in Fig 4(left). Therefore, a new selection has been implemented which accepts all the events lying in a 2σ region of the E_T versus E_{ZDC} average correlation. Events which are not identified by the target algorithm are checked to be produced in the target region. Fig 4(right) shows the accepted events for the J/ψ mass range in the E_T versus E_{ZDC} plot.

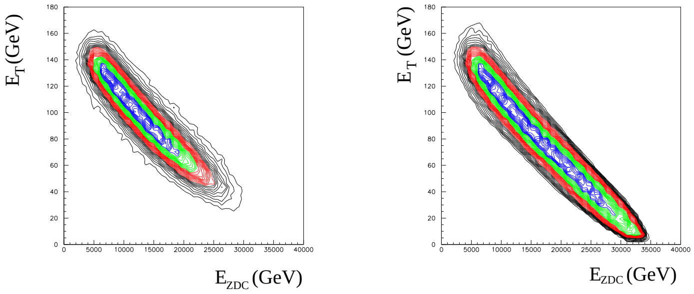

Fig. 4. (left) Correlation between the measured neutral transverse energy and the energy measured by the "zero degree" calorimeter for all events with an identified vertex. (right) Same plot for the J/ψ mass region after the new event selection.

The analysis is performed as explained above. The data sample allows to devide the events into 15 E_T bins. Fig 5(left) shows the ratio $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY}$ as a function of E_T for the 1996 Pb measurement as well as for the 1995 data. We observe that new and previous results are fully compatible. Both sets of data confirm that J/ψ is suppressed strongly as a function of the centrality of the collision. In addition, we observe a discontinuity at E_T around 50 GeV. The ratio $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY}$ as a function of $\bar{L}$ is plotted in Fig 5(right) for the 1996 Pb measurement and is compared with the NA38 results. It is important to notice that, in this plot, the NA38 data are rescaled to 158 GeV/c. The NA38 data together with the values from lead-lead collisions corresponding to the 4 most peripheral bins are fitted by an exponentially decreasing law as described above and lead to an absorption cross-section of 6.2 ± 0.7 mb. As clearly seen, the most central collisions lie far below the absorption line, showing a strong suppression of the J/ψ . The 4 more peripheral Pb-Pb bins span a region from $\bar{L}$=5 fm to $\bar{L}$=7 fm and the J/ψ /Drell-Yan ratio is found to be identical to the one obtained in S-U collisions. There is a discontinuity from this absorption line to central Pb-Pb collision bins at $\bar{L} \simeq 7.5$ fm. The second set of points corresponding to the most central Pb-Pb collisions could suggest a second discontinuity at around $\bar{L} \simeq 9$ fm. The most central bin corresponds to an impact parameter of 2 fm and lies 0.65 ± 0.04 below the absorption line.

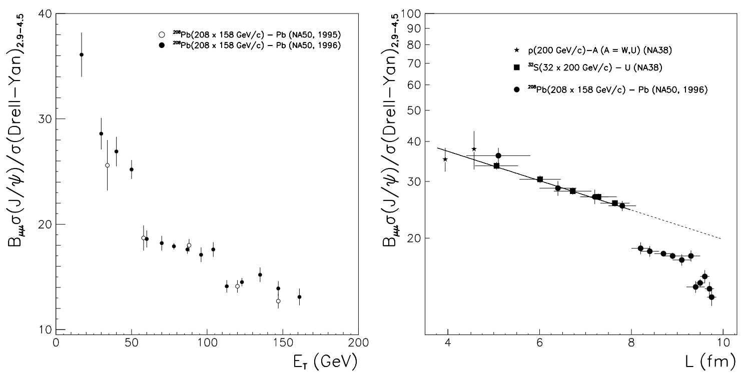

Fig. 5. (left) $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY}$ as a function of E_T for the 1996 Pb-Pb data compared to the 1995 Pb-Pb data. (right) Same ratio as a function of $\bar{L}$ from the 1996 Pb-Pb measurement compared to the NA38 data which are rescaled to 158 GeV/c.

5 Conclusion

The new measurement of the J/ψ production rate in Pb-Pb interactions at 158 GeV/c is consistent with previous results obtained in the same experiment. It confirms the strong suppression observed for central collisions. From peripheral to central collisions, J/ψ production is suppressed by a factor of about 2 relatively to Drell-Yan . As opposed to the results obtained with lighter incident ions, the Pb-Pb results deviates significantly from classical nuclear absorption predictions. We observe, in addition, a significant discontinuity between peripheral and central collisions which could suggest a threshold effect. A second but less significant discontinuity is suggested by the data in the most central collisions region leading to a possible two-step suppression behaviour.

It has to be stressed that the new results reported here are only preliminary and need further confirmation from a more complete analysis.

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