J/Ψ and Ψ' PRODUCTION IN LEAD-LEAD COLLISIONS AT 158×A GeV/c

Presented by N. De Marco[11] for the NA50 Collaboration

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Abstract

The cross sections for J/Ψ, Ψ' and Drell–Yan production in Pb–Pb interactions at 158 GeV per nucleon, presently studied at the CERN SPS by the NA50 experiment, are presented.

An anomalous J/Ψ suppression is observed in Pb–Pb collisions as compared to the previous results obtained by the NA38 experiment with proton and lighter ion beams.

1 Introduction

The NA50 experiment studies the production of vector mesons via their decays into muon pairs in high energy heavy ion interactions as a function of the collision centrality at the CERN SPS. The aim is to get evidence for the formation of a new state of matter, the Quark–Gluon Plasma (QGP), which lattice QCD predicts at sufficient high energy density. The dissociation of the J/Ψ and Ψ' resonances, which might result from Debye screening in a medium of deconfined quarks and gluons[1], is one of the most promising signatures of this new state of the matter. The NA50 experiment follows the exploratory program started in 1986 by the NA38 collaboration which studied J/Ψ, Ψ' and Drell–Yan production in collisions between protons, oxygen, sulphur on various heavy targets. This paper reports preliminary results obtained from the data collected in 1995 on J/Ψ, Ψ' and Drell–Yan production in Pb–Pb interactions at 158 GeV per nucleon.

2 NA50 experimental apparatus

The NA50 detector is an upgraded version of the previous NA38 apparatus. The $\mu^+\mu^-$ pair from the decay of the J/Ψ and Ψ' is detected by a magnetic spectrometer consisting of a hadron absorber, an air core toroidal magnet, 8 MWPCs and 6 hodoscopes for trigger. The muons are detected in the pseudo–rapidity interval $2.8 \leq \eta \leq 4.0$; the mass resolution obtained for J/Ψ is 3.2%.

The event centrality of 1995 data is estimated on an event by event basis by means of two independent detectors, covering different pseudo–rapidity intervals:
the electromagnetic calorimeter ($1.1 \leq \eta \leq 2.3$), which measures the neutral transverse energy produced in the interaction;
the zero degree calorimeter ($\eta \geq 6.3$), measuring the energy of beam spectator fragments.

Due to the small production cross sections (3 nb/nucleon[2] for J/Ψ and the small branching ratios in the $\mu^+\mu^-$ channel (6% for J/Ψ, 7.7 10^{-3} for Ψ')) high beam intensity and thick target are needed in order to make this kind of measurements. An incident beam of 3.5×10^7 Pb ions per burst has been used, providing on average 1000 dimuon triggers/burst. The incident Pb–ions are counted by a quartz beam hodoscope, which is also used to reject beam pile–up (of the order of 20%). The target is made of 7 Pb active subtargets (1 mm thick each, leading to a total of 17.5% interaction length) with vertex identification in order to reject reinteractions of spectator fragments, which could lead to an incorrect measurement of centrality.

3 Data taking conditions and analysis

During five weeks of run in November and December 1995 a sample of 60×10^6 dimuon triggers were recorded on tape and all these data are actually fully analysed.

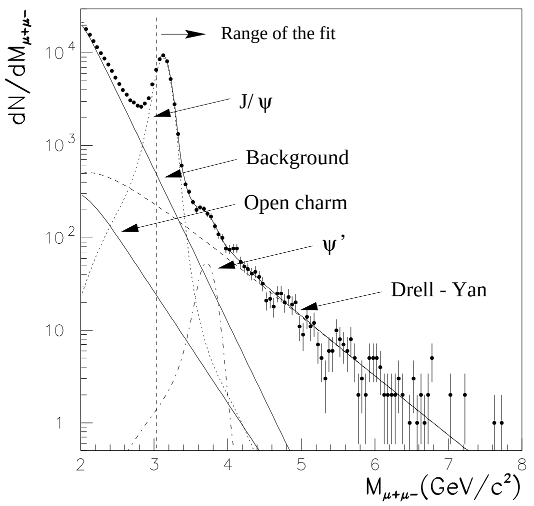

Figure 1: Muon pair invariant mass spectrum.

In October and November 1996 new data have been collected with higher beam intensity (5×10^7 Pb ions per burst) and a thicker target (30% interaction length). A total amount of about 160×10^6 dimuon triggers were recorded during this run; no preliminary results can be shown in this paper, since the analysis is still in progress.

The off–line reconstruction program requires two well identified tracks in the spectrometer. Furthermore events with no target identification, pile–up, upstream interactions or beam halo are also rejected. The above reconstruction criteria reject 55% of the raw events. Finally, for background subtraction purposes, a fiducial cut is applied, in order to make the acceptance of the spectrometer independent from the sign of the charge of the detected muons.

The dimuon kinematical domain used in the analysis is restricted to $0 \leq y_{cm} \leq 1$ (y_{cm} = center of mass dimuon rapidity) and to

$-0.5 \leq cos(\theta_{CS}) \leq 0.5$ (θ_{CS} = muon polar angle in the Collins–Soper frame), where the acceptance of the spectrometer is sizeable (above 10% of its maximum). The final acceptance of the spectrometer is 13.4% for J/Ψ, 15.8% for Ψ' and 18% for Drell–Yan events (with $M_{\mu\mu} \geq 4.5\ GeV/c^2$).

Fig. 1 shows the invariant mass spectrum of the opposite sign muon pairs, not corrected for acceptance. The main contribution to this sample is due to the combinatorial background originating from uncorrelated π and K decays, determined with a standard procedure using the like–sign sample of the muon pairs. After background subtraction the "signal" mass spectrum above $M \geq 3.05\ GeV/c^2$ is fitted as the superposition of three main contributions: J/Ψ, Ψ' and Drell–Yan. The small contribution due to the semi–leptonic decay of couples of charmed mesons ($D\bar{D}$), negligible for the J/Ψ, has been estimated of the order of 8% under the Ψ' peak. The shapes of the J/Ψ,Ψ' and Drell–Yan distributions are obtained by Monte–Carlo simulations, taking into account all the event selection criteria used by the reconstruction program. The selection criteria of the analysis lead to a final data sample containing roughly 50000 J/Ψ, 350 Ψ' and 650 Drell–Yan events with $M_{\mu\mu} \geq 4.\ GeV/c^2$.

4 Experimental results

Taking into account acceptance, luminosity, detector efficiencies and selection cut losses we evaluate the following cross section values:

$$B_{\mu\mu} \cdot \sigma_{J/\Psi} = 21.9 \pm 0.2 \pm 1.6\ \mu b$$

$$\sigma_{Drell-Yan} = 1.49 \pm 0.02 \pm 0.11\ \mu b \qquad (2.9 GeV/c^2 \leq M_{\mu\mu} \leq 8.0 GeV/c^2)$$

In order to check the systematic errors in our absolute cross section measurements the $\sigma_{Drell-Yan}$ in Pb–Pb interactions has been compared with previous results obtained in p–A and S–U collisions (NA38 and NA51 experiments). The Drell–Yan is understood as a hard process and is not affected by the surrounding nuclear matter in a nucleus–nucleus collision. This behaviour is usually quantified through the parametrization $\sigma_{Drell-Yan} \propto A_{projectile} \times B_{target}$, where $A_{projectile}$ and B_{target} are the projectile and the target atomic mass numbers.

In order to take into account different kinematical domains and incident beam energies, the comparison is therefore made using the so–called "K factor", which is the ratio between the measured value of the cross section and the lowest order Drell–Yan cross section computed at the appropriate center of mass energy and in the same kinematical domain, using the GRV–LO[2] set of parton distribution functions. The results, plotted in fig. 2 as a function of

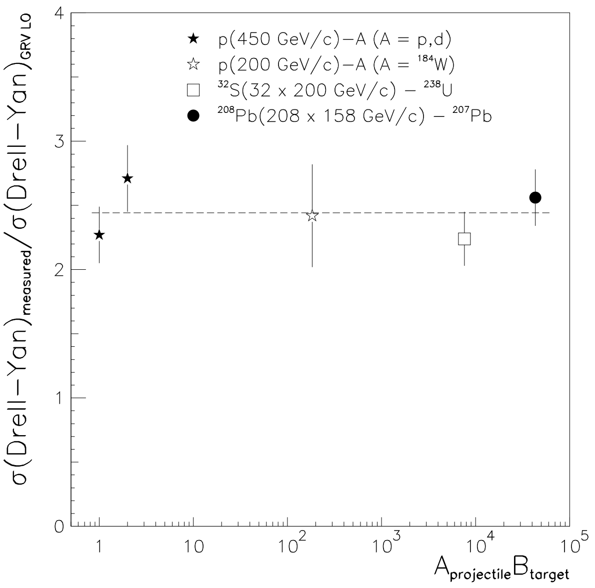

Figure 2: The Drell–Yan K–factor as a function of the product of the projectile and target atomic mass numbers.

the product of the target and projectile atomic mass numbers, show that the Pb–Pb data are in good agreement with the other measurements and are an indication that all the efficiencies and corrections needed for the determination of the absolute cross section values are well understood.

The J/Ψ production cross section in Pb–Pb interactions can be therefore compared with previous measurements obtained with different beam and target combinations with the same spectrometer[3]. The cross sections per nucleon–nucleon collision are shown in fig. 3; in order to be compared, all results are rescaled when necessary to the same incident beam momentum (200 GeV/c) using the Schuler parametrization[4], and to the same kinematical domain. The correction factor for the Pb–Pb data is 1.32, leading to a J/Ψ cross section per nucleon–nucleon collision of 0.67 ± 0.05 nb. All the measured cross sections, except the Pb–Pb data, fit a power law $(A \cdot B)^{\alpha}$ with $\alpha = 0.92 \pm 0.015$. The Pb–Pb result is smaller than the expected value by more than 5 standard deviations, putting in evidence an additional J/Ψ suppression. The "normal" J/Ψ suppression has suggested in the past[5] to define a parameter L, which represents the mean length of the path of the $c\bar{c}$ system through nuclear matter.

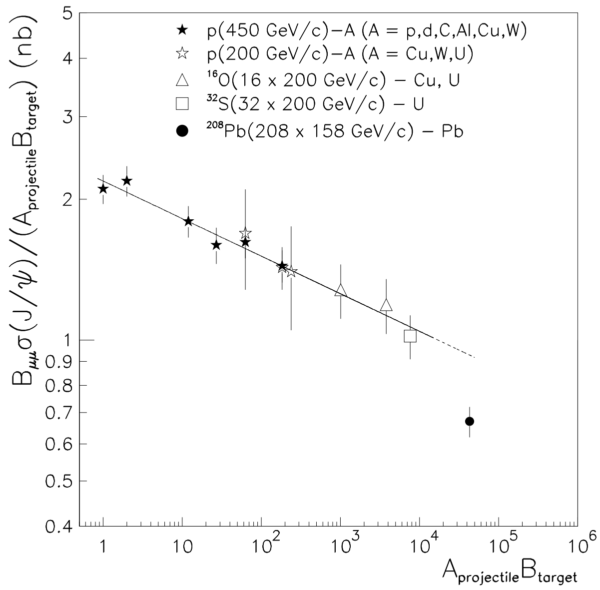

Figure 3: The J/Ψ cross section per nucleon–nucleon collision as a function of the product of the projectile and target atomic mass numbers.

The J/Ψ production cross section can therefore be written as:

$$\sigma(AB \to J/\Psi) \propto (AB)e^{-\rho_o \bar{L}\sigma_{abs}}$$

where the exponential accounts for the $c\bar{c}$ survival probability. σ_{abs} stands for the $c\bar{c}$ absorption cross section, ρ_o=0.17 fm^{-3} is the standard nucleon density in nuclear matter, $\bar{L}$ is averaged over all the possible values of impact parameter b. For a given colliding system, L(b) has been calculated from simple geometrical considerations assuming a Woods–Saxon form[6] for the nuclear density. A fit of this expression to the experimental data leads to
σ_{abs} = 6.2 $\pm$ 1.1 mb, when the Pb cross section is excluded from the fit.

The behaviour of the J/Ψ production cross section in Pb–Pb interactions can be further investigated as a function of the centrality of the collision.

The event centrality can be deduced either from the neutral transverse energy E_T measured with the e.m. calorimeter or from the energy of the spectator nucleons or fragments of the projectile by means of the zero degree calorimeter[7]. These two measured quantities are both strongly correlated to the impact parameter of the collision b. In order to compare the Pb–Pb data to

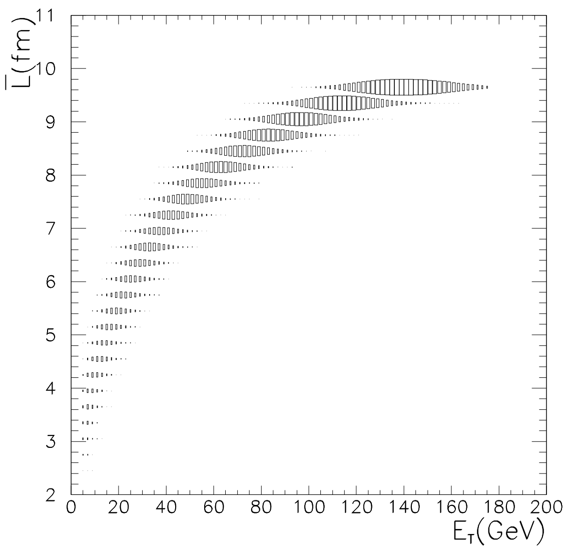

Figure 4: Correlation between E_T and $\bar{L}$ calculated for Pb–Pb collisions at 158 GeV/c.

the previous measurements E_T has been used to estimate the event centrality. The Pb–Pb data have been divided into 5 E_T bins. A selection of the events in E_T is equivalent not only to a selection in b but also in L, as visible in fig. 4.

The accuracy of our results can be improved if we consider the ratio of J/Ψ to Drell–Yan cross sections, since it is insensitive to all systematic errors. Moreover the Drell–Yan cross section is known to scale with the number of nucleon–nucleon collisions. The ratio of J/Ψ to Drell–Yan cross sections in Pb–Pb interactions is plotted in fig. 5 as a function of $\bar{L}$ in each of the 5 E_T bins and compared with previous results from NA38 and NA51 experiments. The measured Drell–Yan cross sections have been corrected in order to take into account isospin effects. The p–A and A–A data up to S–U are well fitted by an exponentially decreasing law, leading to an absorption cross section of 6.2 ± 0.7 mb. This exponential behaviour breaks down for the Pb–Pb data, showing a strong dependence of this effect with the centrality of the collision. In fact the most peripheral Pb–Pb data agrees quite well with the most central S–U data, while, increasing centrality, the J/Ψ becomes more and more suppressed. The

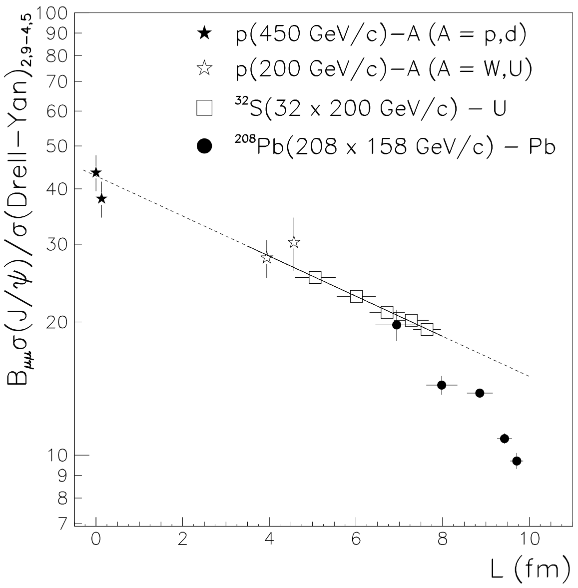

Figure 5: The ratio of J/Ψ to Drell–Yan cross sections as a function of $\bar{L}$.

measured integrated J/Ψ to Drell–Yan ratio ($B_{\mu\mu}\sigma_{J/\Psi}/\sigma_{Drell-Yan} = 12.4 \pm 0.2 \pm 0.2$, corresponding to an average $\bar{L}$=8.6 fm) lies 9 standard deviations away from the expected value, extrapolated from the exponential fit.

Finally the Ψ' to J/Ψ ratio has been measured:

$$B'_{\mu\mu} \cdot \sigma_{\Psi'}/B_{\mu\mu} \cdot \sigma_{J/\Psi} = (0.59 \pm 0.09)\%$$

In fig. 6 this ratio is plotted as a function of product $A_{projectile} \times B_{target}$ together with previous measurements obtained in p–A and S–U collisions. While for proton–nucleus interactions the ratio is constant with A with an average value of (1.8±0.1)%, in Pb–Pb and already in S–U Ψ' appears more suppressed than J/Ψ.

5 Conclusions

J/Ψ suppression has been predicted to be a signature for deconfinement ten years ago[1]. It seems now established that all J/Ψ and Ψ' production data up to S–U interactions can be described in a conventional hadronic scenario. The

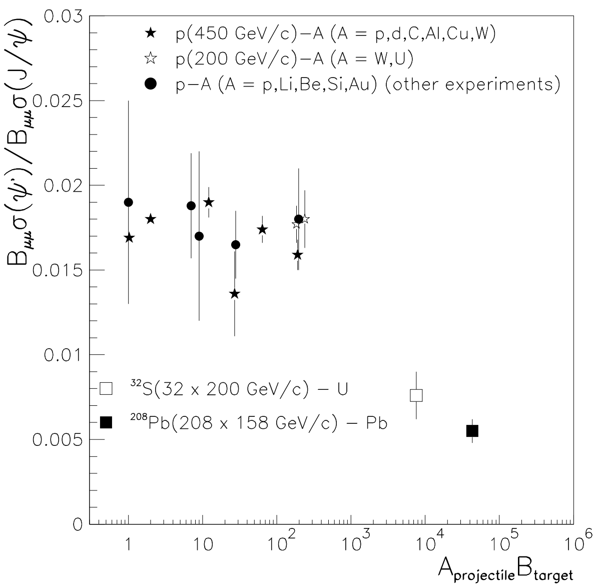

Figure 6: The ratio of Ψ' to J/Ψ cross sections as a function of the product product of the projectile and target atomic mass numbers.

J/Ψ and Ψ' suppression in p–nucleus is actually understood as the absorption of the pre–resonant $c\bar{c}g$ state[8], which would become later the J/Ψ or the Ψ' resonance. The A independence in p–A interactions of the Ψ' to J/Ψ ratio seems to confirm that the absorption occurs before the formation of the physical J/Ψ and Ψ' resonances.

In nucleus–nucleus interactions up to S–U, J/Ψ suppression can be accounted for by the pre–resonance absorption in nuclear matter, but this model fails to describe the Pb–Pb data. Two different interpretations of this J/Ψ "anomalous" suppression have been proposed in the literature. One is the Quark–Gluon Plasma (QGP) scenario in which J/Ψ suppression in Pb–Pb interactions signal the onset of deconfinement[9,10,11,12], the other is a conventional hadronic interpretation[13,14,15] in which an additional J/Ψ suppression mechanism is introduced, due to final state interaction of the resonant J/Ψ state with co–moving hadrons. The additional Ψ' suppression observed in S–U and Pb–Pb (fig. 6) can be described in the frame of a co–mover absorption model[9]; in fact because of its low binding energy (60 Mev) the Ψ' can be readily dissociated by hadron co–movers. However the co–mover models do not presently describe quantitatively all the available J/Ψ and Ψ' data in p–A and nucleus–nucleus collisions.

New data collected in 1996 will soon become available. Moreover precise mesurements in p–Al and p–W interactions have been recently performed, in order to further constrain theoretical models.

1. T.Matsui and H Satz, *Phys. Lett.* B **178**, 416 (1986).
2. H. Gluck, E. Reya and A. Vogt, *Phys. Lett.* B **306**, 391 (1993).
3. C. Baglin et al., *Phys. Lett.* B **270**, 105 (1991); *C. Lourenço, Ph.D. Thesis, Universidade Técnica de Lisboa(1995).*
4. G.A. Schuler, CERN–TH/94–7170.
5. C. Gerschel and J. Hufner, *Z. Phys.* C **56**, 71 (1992).
6. C. W. de Jager et al., *Atomic data and nuclear data tables 14(1974) 485.*
7. E.Chiavassa et al., *Nucl. Instrum. Methods* A **367**, 267 (1995).
8. D.Kharzeev and H. Satz, *Phys. Lett.* B **366**, 316 (1996).
9. D.Kharzeev et al., CERN–TH/96–328, preprint.
10. J.-P. Blaizot and J.-Y. Ollitrault, *Phys. Rev. Lett.* **77**, 1703 (1996).
11. C.Y. Wong, *Nucl. Phys.* A **610**, 434c (1996).
12. N. Armesto et al., *Phys. Rev. Lett.* **77**, 3736 (1996).
13. S. Gavin et al., *Phys. Rev. Lett.* **78**, 1006 (1997).
14. N. Armesto and A. Capella, hep–ph/9705275, preprint.
15. W. Cassing et al., hep–ph/9705257, preprint to appear in *Nucl. Phys.* A.