Charmonium production in Pb – Pb collisions at 158 AGeV

Roberta Arnaldi for the NA50 collaboration

Universitá di Torino and INFN Torino, Italy

Received XXX

M.C. Abreu[7,a], B. Alessandro[12], C. Alexa[4], R. Arnaldi[12], J. Astruc[9], M. Atayan[14], C. Baglin[2], A. Baldit[3], M. Bedjidian[13], F. Bellaiche[13], S. Beolè[12], V. Boldea[4], P. Bordalo[7,b], A. Bussière[2], L. Capelli[13], V. Caponi[2], L. Casagrande[7], J. Castor[3], T. Chambon[3], B. Chaurand[10], I. Chevrot[3], B. Cheynis[13], E. Chiavassa[12], C. Cicalò[5], M.P. Comets[9], N. Constans[10], S. Constantinescu[4], J. Cruz[7], A. De Falco[5], N. De Marco[12], G. Dellacasa[1], A. Devaux[3], S. Dita[4], O. Drapier[13,6], L. Ducroux[13], B. Espagnon[3], J. Fargeix[3], S.N. Filippov[8], F. Fleuret[10], P. Force[3], M. Gallio[12], Y.K. Gavrilov[8], C. Gerschel[9], P. Giubellino[12], M.B. Golubeva[8], M. Gonin[10], A.A. Grigorian[14], J.Y. Grossiord[13], F.F. Guber[8], A. Guichard[13], H. Gulkanyan[14], R. Hakobyan[14], R. Haroutunian[13], M. Idzik[12,c], D. Jouan[9], T.L. Karavitcheva[8], L. Kluberg[10], A.B. Kurepin[8], Y. Le Bornec[9], C. Lourenço[6], P. Macciotta[5], M. Mac Cormick[9], A. Marzari-Chiesa[12], M. Masera[12], A. Masoni[5], S. Mehrabyan[14], M. Monteno[12], S. Mourgues[3], A. Musso[12], F. Ohlsson-Malek[13,d], P. Petiau[10], A. Piccotti[12], J.R. Pizzi[13], W.L. Prado da Silva[12,e], G. Puddu[5], C. Quintans[7], C. Racca[11], L. Ramello[1], S. Ramos[7,b], P. Rato-Mendes[12], L. Riccati[12], A. Romana[10], I. Ropotar[6], P. Saturnini[3], E. Scomparin[6,f], S. Serci[5], R. Shahoyan[7,g], S. Silva[7], M. Sitta[12], C. Soave[12], P. Sonderegger[6,b], X. Tarrago[9], N.S. Topilskaya[8], G.L. Usai[5], E. Vercellin[12], L. Villatte[9], N. Willis[9].

[1] Universitá del Piemonte Orientale, Alessandria and INFN-Torino, Italy.
[2] LAPP, CNRS-IN2P3, Annecy-le-Vieux, France.
[3] LPC, Univ. Blaise Pascal and CNRS-IN2P3, Aubière, France.
[4] IFA, Bucharest, Romania.
[5] Università di Cagliari/INFN, Cagliari, Italy.
[6] CERN, Geneva, Switzerland.
[7] LIP, Lisbon, Portugal.
[8] INR, Moscow, Russia.
[9] IPN, Univ. de Paris-Sud and CNRS-IN2P3, Orsay, France.
[10] LPNHE, Ecole Polytechnique and CNRS-IN2P3, Palaiseau, France.
[11] IRS, Univ. Louis Pasteur and CNRS-IN2P3, Strasbourg, France.
[12] Università di Torino/INFN, Torino, Italy.
[13] IPN, Univ. Claude Bernard Lyon-I and CNRS-IN2P3, Villeurbanne, France.
[14] YerPhI, Yerevan, Armenia.

a) also at UCEH, Universidade de Algarve, Faro, Portugal
b) also at IST, Universidade Técnica de Lisboa, Lisbon, Portugal
c) now at Faculty of Physics and Nuclear Techniques, University of Mining and Metallurgy, Cracow, Poland
d) now at ISN, Univ. Joseph Fourier and CNRS-IN2P3, Grenoble, France
e) now at UERJ, Rio de Janeiro, Brazil
f) on leave of absence from Università di Torino/INFN, Torino, Italy

g) on leave of absence of YerPhI, Yerevan, Armenia

The NA50 experiment at CERN SPS studies charmonia and Drell–Yan production in the $\mu^+\mu^-$ decay channel at 158 AGeV. The data collected in Pb–Pb collisions during 1995, 1996 and 1998 run periods show that the J/ψ is anomalously suppressed in central collisions. This observed suppression pattern can be considered as a strong indication of the production of Quark-Gluon Plasma.

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.

The suppression of charmonium states has been predicted to 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 suppression has been observed to increase 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 is an upgrade version of NA38 and studies Pb–Pb collisions at 158 GeV/c^2.

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 experiment is shown in Fig.[1].

It consists mainly of 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 event centrality is measured independently by means of three detectors.

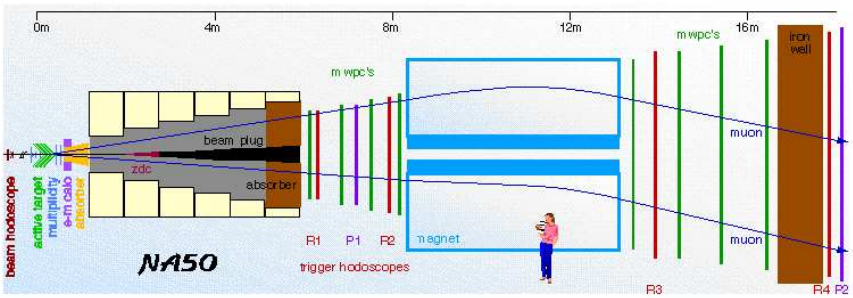

Fig. 1: NA50 experimental setup

The electromagnetic calorimeter, 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 very forward calorimeter ("Zero Degree Calorimeter" or ZDC) is made of quartz fibres embedded in Tantalum slabs and measures 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 $1.5 \leq \eta_{lab} \leq 3.5$.

Incident ions are counted by a quartz beam hodoscope (BH), located approximately 33 m upstream the target. This detector is also used to detect pile–up events. For a more detailed description of the detectors see [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

Since the Drell–Yan (DY) cross-section scales as the number of primary nucleon–nucleon collisions from p–p up to Pb–Pb collisions without showing sizeable nuclear effect, this process can be used as a reference [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.

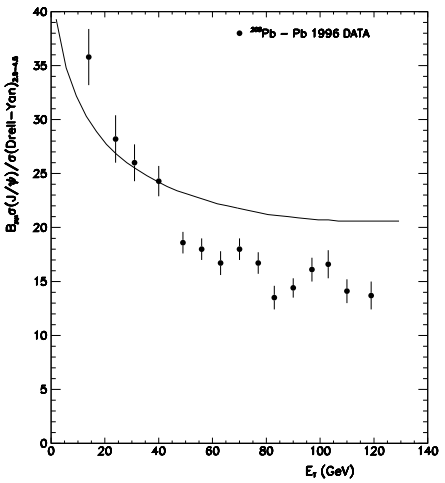

Fig. 2: The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ ratio versus E_T

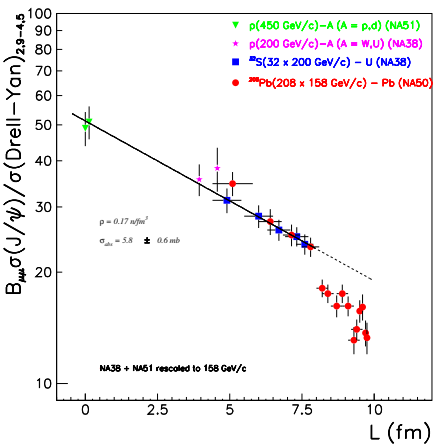

Fig 3: The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ ratio versus L

Fig. [2] 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 data sample. The transverse energy spectrum has been divided in 15 bins, to study the dependence of the J/ψ over DY ratio from the centrality of the collisions. 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. [3]. 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. [3] 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 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.

3.2 The minimum bias analysis

The statistical fluctuations in the J/ψ over Drell–Yan ratio are essentially due to the small number of Drell–Yan events.

In order to overcome this problem and to confirm the obtained result, an alternative independent analysis has been 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 doesn't 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.[4] is shown, as a function of centrality, the comparison between the standard analysis (closed circles) and the minimum bias one (open circles) for the 1996 data sample. 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.

The 1998 run has been devoted to clarify the behaviour in the high E_T region, since the 1996 data sample seems to be affected by reinteractions problem due to the target thickness (30% λ_i in 1996). 1998 data have been collected with a 7% λ_i target.

In Fig. [5] the preliminary 1998 results obtained with the minimum bias analysis are presented together with the results of the two analysis on 1996 data. For

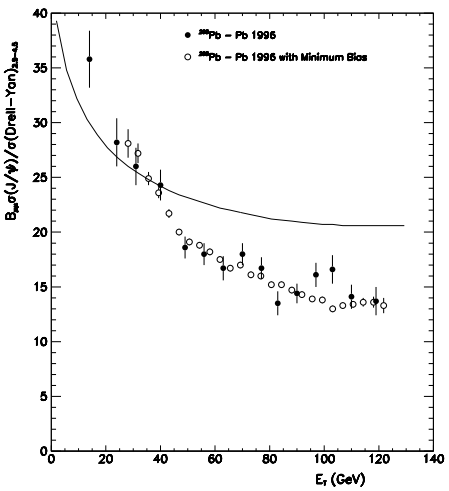

Fig.4: Comparison between the ratio $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ obtained with the standard analysis(closed circle) and the minimum bias one (open circle) for the 1996 data.

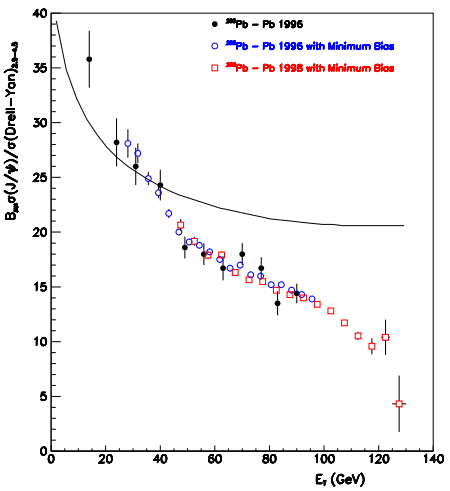

Fig 5: The $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{Drell-Yan}$ results for 1996 and 1998 data versus E_T.

$E_T \geq 90\ GeV$ 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

4 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.

R. Arnaldi acknowledges financial support from the "Fondazione Angelo Della Riccia" (Firenze, Italy)

References

[1] T. Matsui and H. Satz, Phys. Lett. **B 178** (1986) 416.

[2] M.C. Abreu *et al.* (NA50 Coll.), Phys. Lett. **B 410** (1997) 327.

[3] M.C. Abreu *et al.* (NA50 Coll.), Phys. Lett. **B 410** (1997) 337.

[4] R. Arnaldi *et al.*, NIM **A 411**, (1998) 1.

[5] F. Bellaiche *et al.*,NIM **A 398**, (1997) 180.

[6] G.A. Schuler, CERN-TH 7170/94 (hep-ph/9403387)

[7] C. Gerschel and J. Hüfner, Z.Phys, **C 56**, (1992) 71.

[8] M.C. Abreu *et al.* (NA50 Coll.), Phys. Lett. **B 450** (1999) 456.