EXPERIMENTAL STATUS OF J/ψ SUPPRESSION

THE NA50 COLLABORATION [$]

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. Capony*[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].

Talk presented by L. KLUBERG

The most recent results obtained by experiment NA50 show that the J/ψ cross-section per nucleon-nucleon collision in semi-peripheral Pb-Pb reactions is "normally" suppressed in the sense that it follows the trend already observed from p-p and up to the most central S-U reactions. A clear change of behaviour is observed for more central Pb-Pb collisions which could be due to the transition of normal nuclear matter to its predicted Quark-Gluon Plasma state.

1 Introduction

The most recent sample of Pb-Pb events collected by experiment NA50 has been used to test the original prediction made by T. Matsui and H. Satz [1] who claimed that J/ψ production would be suppressed if high energy heavy ion collisions led to the formation of a hot quark-gluon plasma (QGP). The behaviour of the J/ψ production cross section has been systematically studied in order to detect a possible fingerprint of the QGP phase transition predicted by non-perturbative QCD calculations.

2 Experimental features

The results reported here are based on a systematic study of muon pair production. All the data have been collected with a very similar setup and recomputed, when necessary for comparison purposes, to the same kinematical conditions, i.e. same incident momentum of the projectile, rapidity window [0.0, 1.0] and Collins-Soper angle $|cos\,\theta_{cs}| < 0.5$. The neutral transverse energy produced in the reaction is used as an estimator of its centrality. This measurement is done in the lab pseudo-rapidity range [1.7-4.1] for S-U reactions and [1.1, 2.3] in the case of Pb-Pb. In this last case, a "very forward" hadronic calorimeter measures also the energy for a pseudo-rapidity $y > 6.14$. This is a measurement of the total energy E_{ZDC} of the "spectator" nucleons, i.e., of the non-interacting nucleons of the incident projectile, which is directly related to the impact parameter of the reaction. A detailed description of the apparatus used for the collection of the various data samples can be found elsewhere [2,3,4].

3 Data selection and analysis

Reconstructed muon pairs are carefully selected in order to exclude, in particular, those which do not originate from the Pb target of the experiment or those where "spectator" reinteractions within the target itself lead to overestimate the transverse energy of the interaction. A selection based on the E_t -E_{ZDC} correlation together with a tagging algorithm using the specific instrumentation surrounding the target minimize, in fact, these two important contaminations.

The invariant mass distribution of the final sample of selected opposite-sign muon pairs allows, through a fit procedure, to desentangle its various components namely the J/ψ and ψ' resonances and the mass continuum. The continuum is made of pairs originating from Drell-Yan $q\bar{q}$ annihilation, from associated charm-anticharm production and subsequent semi-leptonic decay and, finally, from the background due to uncorrelated π and K meson decays,

4 Cross-sections

4.1 *"Normal" and "anomalous" J/ψ suppression*

The Drell-Yan muon pair cross-section behaves as expected from a hard process. It has been shown experimentally [5] that it is the sum of the cross-sections of the elementary nucleon-nucleon collisions both in proton-induced p-A collisions and in nucleus-nucleus interactions up to and including Pb-Pb.

It is known from past experiments that, in p-A reactions, the J/ψ cross-section scales like A^α, where A is the atomic mass number of the target and the exponent α is slightly smaller than 1. Measurements show that this "normal" behaviour still holds for O-Cu, O-U and S-U reactions. The results are plotted in Fig. 1. The power law $(A_{proj} \times B_{targ})^\alpha$, when fitted to all the results except for the value measured for Pb-Pb, exhibits an excellent agreement with the cross-sections obtained both for proton and for light ion-induced reactions. The fit leads to the value $\alpha = 0.92 \pm 0.01$ which is in good agreement with old p-A results. This observed proton-like behaviour, which extends up to S-U reactions, can be considered as the model-independent reference for "normal" J/ψ suppression. Departing from this "normal" behaviour, the cross-section obtained for Pb-Pb is a factor $R_K = 0.74 \pm 0.06$ smaller than the value naively extrapolated from all the other measurements. This unexpected and clear disagreement with the "normal" proton-like behaviour has been named "anomalous J/ψ suppression" by the NA50 Collaboration.

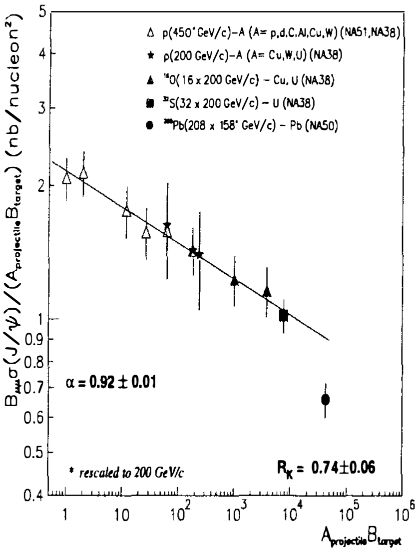

Figure 1: The J/ψ cross section per nucleon-nucleon collision as a function of the product $A_{proj} \times B_{targ}$. The data, when necessary, have been rescaled to 200 GeV/c per nucleon incident momentum and to the cms pseudo-rapidity range [0.0 - 1.0] according to the procedure described in detail in [5].

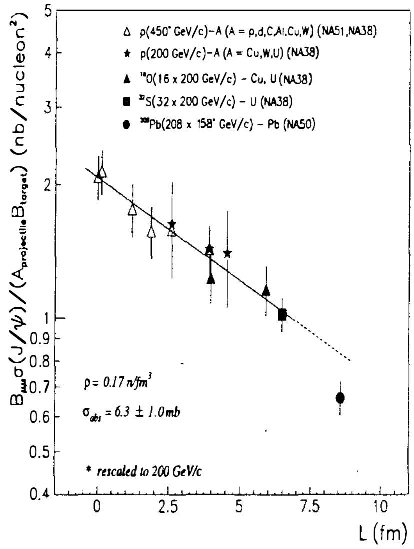

Figure 2: Same as figure 3 as a function of the average nuclear path L.

4.2 *Interpretation of the "normal" J/ψ suppression*

As seen above and except for Pb-Pb interactions, the J/ψ cross-section follows the power law behaviour $(A_{proj} \times B_{targ})^{\alpha}$ with an exponent $\alpha < 1$. It can thus be written as:

$$\sigma(AB \rightarrow J/\psi) \propto (AB) exp(-\rho_0 \sigma_{abs} L) \quad (1)$$

The product AB, which is proportional to the number of elementary nucleon-nucleon collisions in A-B reactions, accounts for the probability of $(c\bar{c})$ creation. The decreasing exponential accounts for the $(c\bar{c})$ "absorption" probability, with cross-section σ_{abs}, in collisions with the nucleons encountered along its path through nuclear matter. The number of such nucleons per unit surface, at a given impact parameter b, is given by $\rho_0 L(b)$ where L is the path of nuclear matter of average density ρ_0. The integral can be "geometrically" calculated and extends over all the possible $c\bar{c}$ paths for a given b. Fig. 2 shows the same cross-sections per nucleon-nucleon collision as Fig. 1 plotted as a function of L. A simple exponential fit to the data of expression (1) leads to $\sigma_{abs} = 6.3 \pm 1.0$ mb when the Pb cross-section is excluded from the fit [a]. The absorption-type suppression analytically described by equation (1) provides an excellent agreement with the data. On the other hand, this simple absorption pattern is clearly unable to account for the Pb-Pb cross-section.

5 The J/ψ suppression pattern in Pb-Pb

The new suppression pattern has been investigated in detail with the data collected in 1996.

[a] It should be noted that a more refined treatment of the collision geometry (see Ref. [6]) leads to an absorption cross-section $\sim$ 13% higher than the value obtained in the simplified procedure described here.

The centrality of the reaction is estimated from the neutral transverse energy E_t measured by the electromagnetic calorimeter or, equivalently, from $L(b)$, L in short, which is a function of both the interacting objects and the impact parameter of the reaction.

The ratio of the J/ψ to the Drell-Yan cross-sections is proportional to the J/ψ cross-section per nucleon-nucleon collision. In a first step, the values obtained for p-p, p-d, p-W, p-U and S-U (this last integrated over E_t) are fitted with the absorption-type decreasing exponential of equation (1) according to

$$\sigma(\mathrm{J}/\psi\ )\ /\ \sigma(Drell-Yan) \propto exp(-\rho_0 \sigma_{abs} L) \qquad (2)$$

The fit leads to $\sigma_{abs} = 6.1 \pm 0.7$ mb in perfect agreement with the value obtained from absolute cross-sections. For Pb-Pb interactions, the 1995 data show that the ratio is lower than the value given by the exponential behaviour by a factor $R_K = 0.71 \pm 0.03$, a result in good agreement again with the value obtained from absolute cross-sections, although with a significantly smaller error. The departure from the pattern followed by lighter interacting nuclei can only be attributed to the J/ψ sample of events; the Drell-Yan events enter marginally the absolute cross-section analysis and show, furthermore, a completely "normal" absolute integrated cross-section (see section 4.1). With the 1996 Pb-Pb independent data sample, after complete reanalysis of the results obtained for p-p, p-d, p-W, p-U and S-U, the corresponding numbers are $\sigma_{abs} = 5.8 \pm 0.7$ mb and $R_K = 0.75 \pm 0.04$ supporting the robustness of the results. The ratio $\sigma(\mathrm{J}/\psi\ )\ /\ \sigma(DY)$, computed from the most recent 1996 data, is plotted in Fig. 3 as a function of the transverse energy E_t . Whereas for E_t <40 GeV the suppression pattern does agree with an absorption-type mechanism, there is a clear departure from this pattern for E_t >50 GeV. The drop occurs within an E_t bin of about 10 GeV wide. It suggests a rather "sudden" onset of the anomalous suppression regime within an energy density range of 2-3 GeV/fm^3. Fig. 4 shows the same ratio of cross-sections as a function of L . The exponential fit to the proton and sulphur experimental data, also shown in the figure, accounts for the "normal" absorption-type behaviour. Here again and for the most peripheral Pb-Pb collisions, J/ψ production exhibits an excellent agreement with the trend inferred from lighter projectiles and targets. The agreement holds for $L \leq 8$ fm, the value reached for the most central S-U reactions. For $L \geq 8$ fm, the data show a clear departure from the "normal" absorption-type pattern as deduced from the experimental results obtained with lighter projectiles or targets.

Both Fig. 3 and Fig. 4 do exhibit significant fluctuations for the highest E_t or L values. A close comparison of the results obtained with the 1995 and 1996 data show a quite good agreement except for E_t >100 GeV where the 1995 results are lower. This very high E_t range is where unidentified re-interactions within the total target thickness lead to overestimate the transverse energy E_t for these events. The result is a non-negligible E_t migration bias which spuriously increases the value of the ratio of J/ψ to Drell-Yan cross-sections for the highest E_t values. The assumption is based on the fact that the total target thickness was 7 mm in 1995 and 12 mm in 1996 so that the potential bias should be smaller in 1995, as experimentally seen.

6 The "minimum bias" analysis method

As a consistency check of the results presented above, an alternative analysis method has been developed. The use of "minimum bias" events in place of the Drell-Yan events leads to significantly lower statistical errors but different systematic uncertainties. The results obtained with this new method support the measurements and conclusions summarized above. The specific data selection and the detailed description of the analysis procedure can be found in Ref. [7].

The method is based on the use of the Drell-Yan E_t distribution (noted hereafter as $(\mathrm{d}N/\mathrm{d}E_\mathrm{T})_{\mathrm{DY}*}$) as obtained from the minimum bias experimental distribution according to:

$$(\mathrm{d}N/\mathrm{d}E_\mathrm{T})_{\mathrm{DY}*} \ = \ (\mathrm{d}N/\mathrm{d}E_\mathrm{T})^{\mathrm{exp}}_{\mathrm{MB}}\ \Theta(E_\mathrm{T})$$

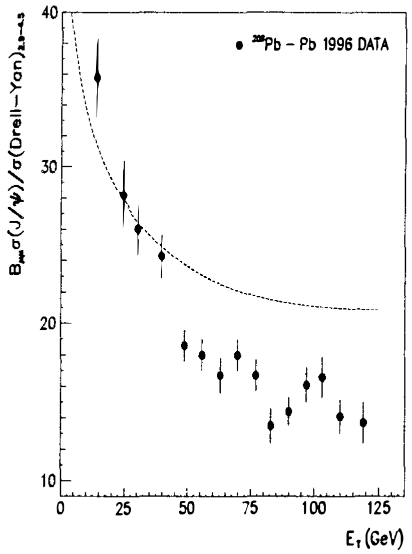

Figure 3: Ratios of J/ψ to Drell-Yan cross-sections as a function of the transverse energy E_t . The Drell-Yan cross-section is arbitrarily computed in the mass range [2.9-4.5] GeV/c^2. The dotted curve shows the "normal" absorption curve as fitted from the results obtained with lighter projectiles or targets.

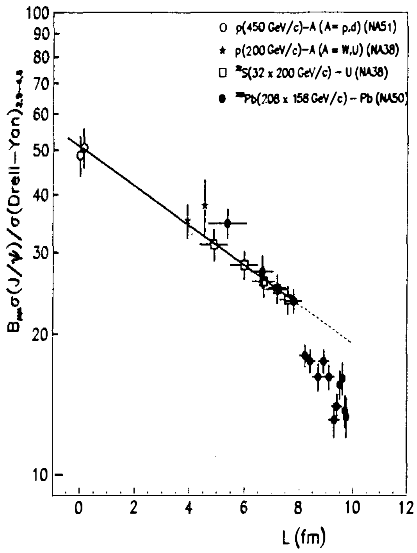

Figure 4: Ratios of J/ψ to Drell-Yan cross-sections as a function of the average nuclear path L . The Drell-Yan cross-section is arbitrarily computed in the mass range [2.9-4.5] GeV/c^2. The data, when necessary, have been rescaled to 158 GeV/c per nucleon incident momentum and to the cms pseudo-rapidity range [0.0 - 1.0].

with

$$\Theta(E_{\mathrm{T}}) \;\propto\; (\mathrm{d}N/\mathrm{d}E_{\mathrm{T}})^{\mathrm{th}}_{\mathrm{DY}} \;/\; (\mathrm{d}N/\mathrm{d}E_{\mathrm{T}})^{\mathrm{th}}_{\mathrm{MB}}$$

standing for the ratio of the analytical expressions of the transverse energy distributions of Drell-Yan and minimum bias events. This ratio depends on 2 parameters obtained from a fit to the experimental data.

Fig. 5 shows the ratio of cross-sections $\sigma_{J/\psi} / \sigma_{DY*}$ for the different E_t bins superimposed on the values obtained with the standard method. The analysis is limited to values above $E_{\mathrm{T}} = 26$ GeV due to a contamination of off-target interactions which affects, in particular, the more peripheral minimum bias events. The shapes obtained by both analyses are compatible. In particular, an excellent agreement is observed between the two sets of points in the energy range $30 < E_{\mathrm{T}} < 55$ GeV, where a clear drop of the J/ψ yield is observed.

7 Conclusions

J/ψ suppression has been measured in Pb-Pb interactions at 158 GeV/c per nucleon incident momentum. As a function of centrality, peripheral events do exhibit the normal behaviour firmly established for lighter projectile or targets. A drop of about 20% signs the onset of an "anomalous" suppression in the E_t range between 40 and 50 GeV, corresponding to an impact parameter between 7.3 and 8.3 fm and an average energy density roughly within the range [2.0 - 2.8] GeV/fm^3.

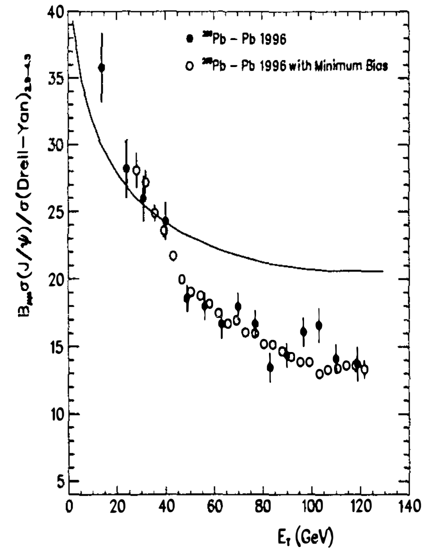

Figure 5: Comparison of the ratios $\sigma_{J/\psi} / \sigma_{DY}$ and $\sigma_{J/\psi} / \sigma_{DY*}$ based respectively on Drell-Yan and minimum bias events. The curve shows the same ratio for normal nuclear absorption, as plotted in Fig. 4.

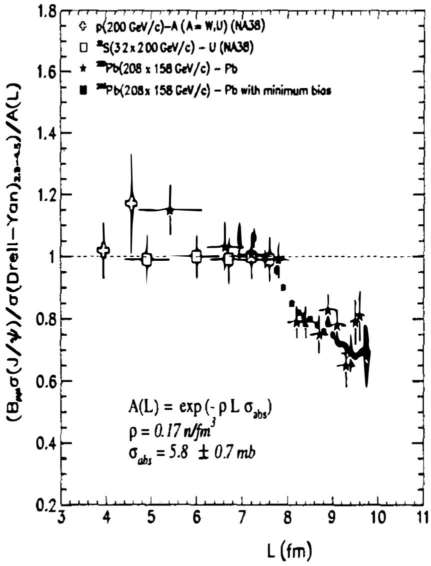

Figure 6: The $\sigma_{J/\psi} / \sigma_{DY}$ ratios divided by the normal nuclear absorption suppression inferred from experimental results obtained with lighter projectile or targets.

The onset of the anomalous behaviour is clearly seen in Fig. 6. The observed threshold could be attributed to a QGP screening-type effect which would induce the "melting" of the χ states that partially contribute, through their decay, to the J/ψ sample of events collected by the experiment.

References

1. T. Matsui and H. Satz Phys. Lett. B 178 (1986) 416.
2. C. Baglin *et al.*, Phys. Lett. B 220 (1989) 471.
3. M.C. Abreu *et al.*, Phys. Lett. B 410 (1997) 327.
4. M.C. Abreu *et al.*, Phys. Lett. B 438 1998 35.
5. M.C. Abreu *et al.*, Phys. Lett. B 410 (1997) 337.
6. D. Kharzeev et al., Z. Phys. C 74 (1997) 307.
7. M.C. Abreu *et al.*, Phys. Lett. B 450 (1999) 456.

$ [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