Charmonia States Suppression and Transverse Momentum Distribution in Pb-Pb Collisions at the CERN SPS

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Abstract. We present the results of experiment NA50 on the production of charmonia states in Pb-Pb collisions at 158 GeV/c per nucleon. For the most peripheral collisions the experimental data agree with ordinary nuclear absorption as deduced from proton and light nuclei induced collisions. For central collisions, we observe an anomalous suppression which significantly departs from normal nuclear absorption and which could result from Debye color screening in a deconfined quark-gluon phase. The dependence of the transverse momentum distributions on the centrality of the Pb-Pb collision is also investigated.

INTRODUCTION

The data on the suppression of charmonia states in lead-lead collisions obtained by the NA50 collaboration at 158 GeV/c per nucleon [1] have attracted considerable attention in the search for experimental evidence of formation of deconfined matter.

The set of results obtained by both experiments NA38 and NA50 shows two different regimes for J/ψ absorption in nuclear matter. Ordinary nuclear absorption due to charmonium-nucleon interactions explains the production in proton and light ion induced reactions. On the other hand, for the more central Pb-Pb collisions, a significantly stronger absorption is observed which could be the indication of a new physics at the subnucleon level. It could be naturally explained by Debye color screening in a deconfined quark-gluon phase [2] which could account, at least qualitatively, for the peculiar pattern of the J/psi production rate as a function of energy density (see Fig.1). Other attempts to describe the observed pattern and based on the interaction of the charmonium state with the comovers produced in the collision lead to a significantly poorer agreement with the data [1].

The study of the transverse momentum distributions of the charmonia states, recently published [3], could shed some extra light on the underlying suppression mechanism.

DATA COLLECTION AND ANALYSIS

The data were collected with a thoroidal magnetic field muon spectrometer used to detect and measure the muon pair originating from the charmonium decay. The centrality of the collision was characterized by an electromagnetic calorimeter measuring

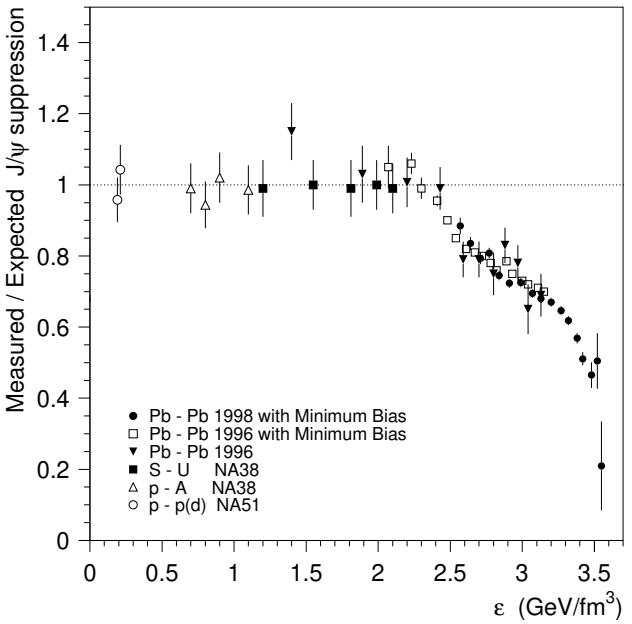

FIGURE 1. Measured J/ψ production yield, normalized to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data are shown as a function of the energy density reached in the several collision systems.

the neutral transverse energy produced in the reaction, a "zero degree calorimeter" measuring the energy of the projectile spectator nuclei and a charged particle multiplicity detector. An active target system with seven lead subtargets was used to increase the yield of events. The dimuon background originated from uncorrelated pion and kaon decays was estimated and subtracted using the data of like-sign muon pairs. The final number of J/ψ events was about 190000 in 1996 and 50000 in 1995.

Muon pairs originating from the Drell-Yan process and from the semileptonic decays of pairs of charmed D and $\bar{D}$ mesons produce a physical invariant mass continuum which is estimated from a fit to the dimuon mass distribution. The raw muon pair p_{T} distributions of the charmonium resonaces is corrected using the fitted yields and the experimental p_{T} distributions for dimuon masses below and above the J/ψ and ψ′ resonances. For the J/ψ, the systematic uncertainty of the $\langle p_{\mathrm{T}}^2 \rangle$ value due to the subtraction of the mass continuum amounts to only 2%. Details of the analysis method can be found in the recent publication [3].

DISCUSSION

The p_{T} distributions determined for the J/ψ, ψ′ and Drell-Yan mass intervals and integrated over the impact parameters have similar structure with a broad maximum near 1 GeV/c and decreasing by three orders of magnitude at about 4 GeV/c.

However the dependence of $\langle p_T^2 \rangle$ on the centrality of the collision is different for charmonia states and for the Drell-Yan process as can be seen on Fig.2.

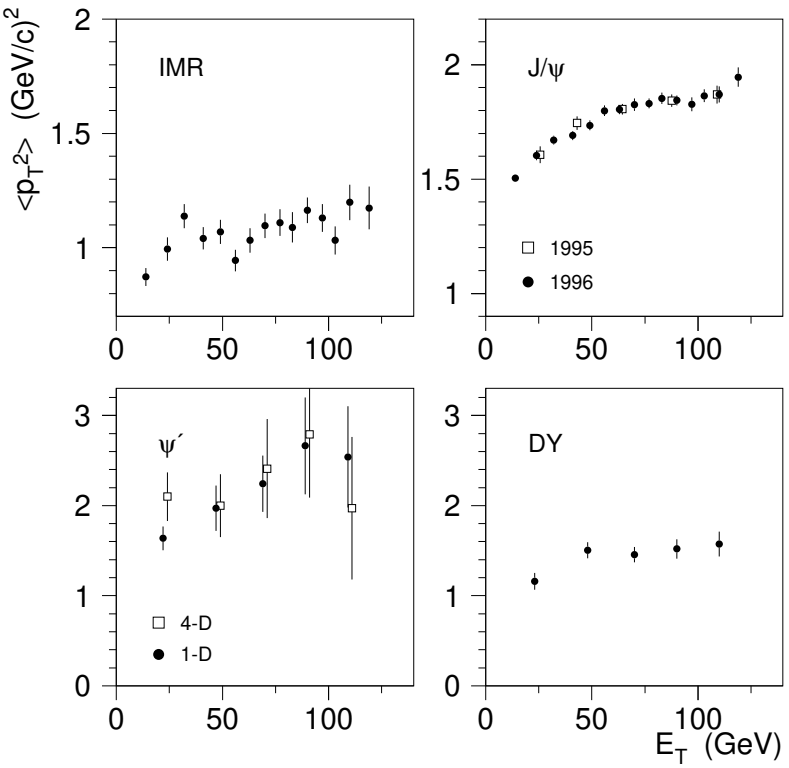

FIGURE 2. $\langle p_T^2 \rangle$ as a function of the transverse energy for several muon pair mass intervals. For the J/ψ the 5 open squares correspond to the 1995 data sample. The error bars are only statistical. For the ψ', both the 1-D and 4-D deconvolution results are shown.

For J/ψ production, the $\langle p_T^2 \rangle$ value first increases and then tends to flatten for more central collisions. The same trend is seen for ψ', however with much worse statistical accuracy. For the Drell-Yan process, $\langle p_T^2 \rangle$ is almost independent on the centrality of the collision, as it could be assumed for the hard process based on nucleon-nucleon interaction. The most interesting feature is a considerably higher value of $\langle p_T^2 \rangle$ for ψ' than for J/ψ.

The nice agreement between the results obtained from the 1995 and 1996 data for the J/ψ suggests that the target thickness does not induce any significant effect on $\langle p_T^2 \rangle$. On the other hand, systematic effects due to the method used for correcting smearing and acceptance due to the apparatus are small, as deduced from the comparison, shown for the ψ' on Fig.2, of the results obtained from two different methods.

In Fig.3 we plot the ratios $R_i(p_T)$ between the p_T distributions obtained in the E_T bin i and the same distribution obtained in the first E_T bin. The normalization to the Drell-Yan process was used as in the case of the production cross section analysis [1]. It is clearly seen that the suppression is stronger for low p_T .

The transverse mass distribution was fitted with the exponential function $M_T \cdot exp(-(M_T - M)/T)$, and T-values were determined for different E_T intervals.

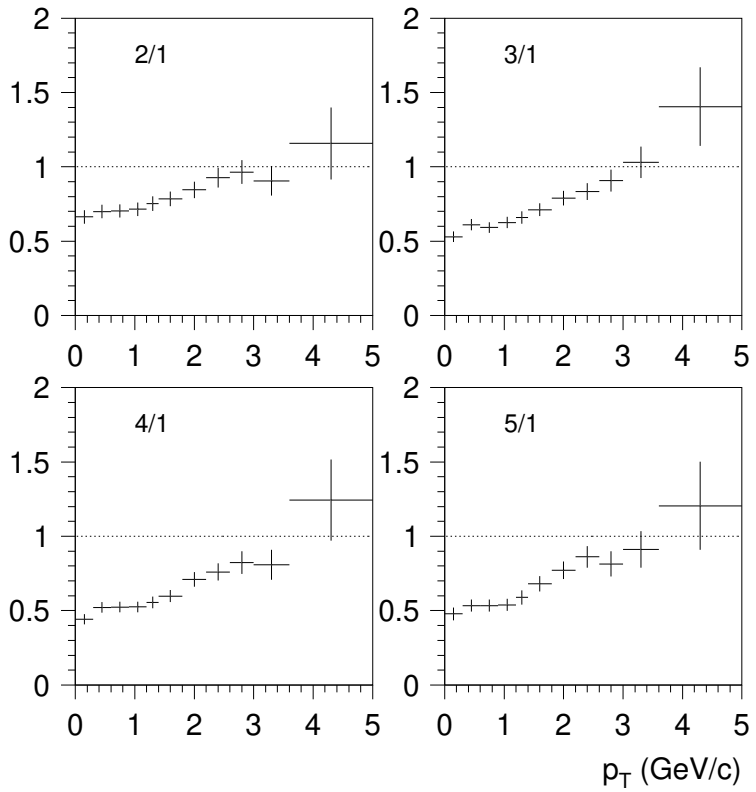

FIGURE 3. Ratios between the J/ψ p_{T} distributions in the E_{T} bin i (i = 2, 3, 4, 5) and in the first E_{T} bin, $R_i(p_{\mathrm{T}})$.

Fig.4 shows an increase of T from peripheral to semi-peripheral collisions followed by a plateau when centrality increases further up.

We can note that for J/ψ production the T-values for very central events are higher than it was predicted for the phase transition to quark-gluon plasma in lattice calculations [4]. A small increase of T for the most central events cannot be confirmed statistically. The estimate of the T-value for the most central ψ′ events is of the order of 180 MeV.

CONCLUSIONS

The observation by experiment NA50 of a two step pattern behaviour for the production of J/ψ as a function of centrality could be interpreted as a result of the Debye color screening in a quark-gluon plasma formed during the collision.

The study of the transverse momentum as a function of the centrality of collision reveals additional information. The interpretation of effects like larger $\langle p_{\mathrm{T}}^2 \rangle$ for ψ′ production, larger J/ψ suppression for low p_{T}, large temperature for more central collisions still needs to be worked out. A combined theoretical analysis of charmonia

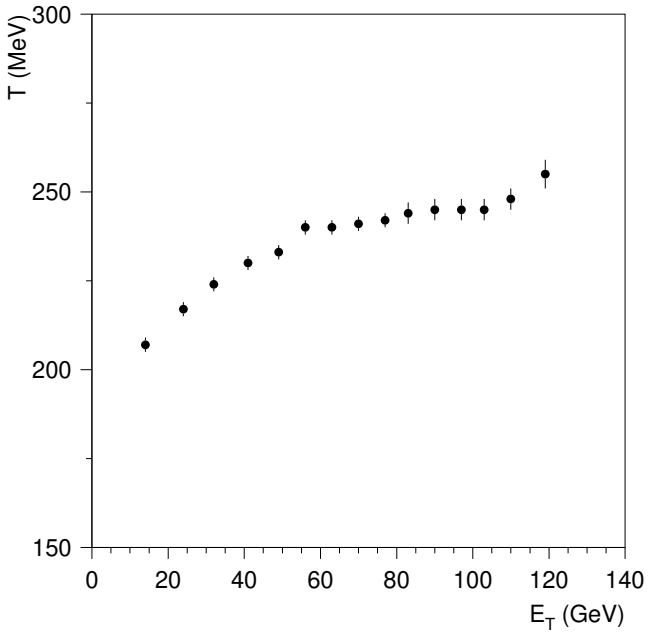

FIGURE 4. Inverse slope parameter, T, of the J/ψ transverse mass distributions, plotted as a function of the transverse energy.

states suppression and transverse momentum distributions is also needed.

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REFERENCES

1. Abreu, M. C. e. a., *Phys. Lett.*, **B477**, 28–36 (2000), na50 Collaboration.
2. Matsui, T., and Satz, H., *Phys. Lett.*, **B178**, 416–422 (1986).
3. Abreu, M. C. e. a., *Phys. Lett.*, **B499**, 85–96 (2001), na50 Collaboration.
4. Boyd, G. e. a., *Nucl. Phys.*, **B469**, 419–444 (1996).

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