INVESTIGATION OF CHARMONIUM STATES PRODUCTION IN p-A AND NUCLEUS-NUCLEUS COLLISIONS AT THE CERN SPS

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Abstract

Charmonium production in Pb-Pb collisions at 158 GeV/c per nucleon is investigated from the data, collected in year 2000, under improved experimental conditions with the target system placed in vacuum. The study of the transverse momentum distributions of J/ψ as a function of the centrality of the collision shows that the observed J/ψ suppression in Pb-Pb interactions is particularly significant mainly at low transverse momentum where it strongly depends on centrality. For peripheral Pb-Pb collisions, the transverse momentum dependence of the J/ψ suppression is qualitatively similar to the dependence observed in p-A and S-U collisions. Comparing peripheral and central Pb-Pb collisions, the data show a relative suppression in the whole p_T range although its amplitude significantly decreases with increasing transverse momentum.

Key-words: heavy ions collisions, charmonium suppression, transverse momentum dependence.

1. Introduction

Charmonium production has been measured by the NA50 Collaboration in Pb-Pb collisions at 158 GeV/c per nucleon and in proton-nucleus collisions at 400 and 450 GeV/c [1, 2]. The suppression of the J/ψ yield in ultrarelativistic heavy ion collisions is considered as a potential signature of the phase transition from normal nuclear matter to a deconfined state of quarks and gluons.

Normal nuclear absorption of J/ψ has been measured in proton-induced reactions. The corresponding cross-section, deduced in the frame of a Glauber calculation, amounts to 4.18 ± 0.35 mb [3]. It provides thereby the J/ψ normal nuclear absorption reference as a function of the path in nuclear matter that the produced $c\bar{c}$ pair has to go through the matter, a quantity which is directly related to the centrality of the collision. The main result of the NA50 experiment in the study of Pb-Pb collisions is that whereas peripheral Pb-Pb collisions approximately follow the normal nuclear absorption pattern, a departure from this normal behaviour is observed for semi-central reactions which increases in amplitude with increasing centrality. The Drell-Yan cross section is used as a reference one, since it exhibits linear scaling with $A \cdot B$, the product of the target and pojectile mass numbers, like the number of nucleon-nucleon collisions in the interaction. Becides, most of the systematic errors cancel out in the ratio of cross sections which is unsensitive, in particular, to the absolute incident flux uncertainty.

Preliminary results obtained from our latest data samples collected under improved experimental conditions can be found in [4, 5]. In this article we extend our analysis of J/ψ production and study the suppression as a function of the transverse momentum of the charmonium state.

2. Transverse momentum distribution of charmonium

To investigate in more detail the features of the reaction mechanism, we study the transverse momentum and transverse mass distributions of the J/ψ yield. In particular, the dependence, as a function of the centrality of the collision, of the mean square transverse momentum and of the slope of the M_T spectra were obtained and can be found in [6].

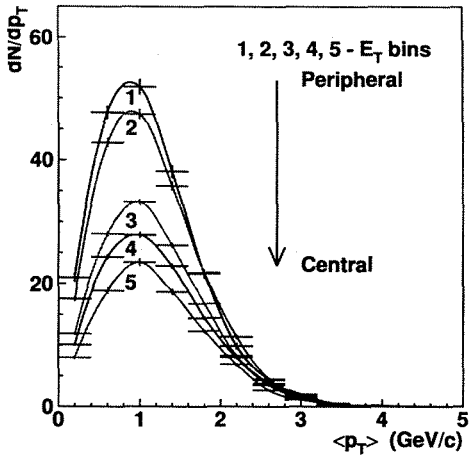

Figure 1: Ratio F of the J/ψ production cross section for Pb-Pb collisions at 158 GeV/c per nucleon as a function of the transverse momentum in GeV/c to the DY cross section for 5 E_T bins

When rescaled to the same energy and as a function of the mean length path of J/ψ in nuclear matter, the mean square transverse momentum of J/ψ exhibits the same behaviour for p-A, S-U and Pb-Pb collisions [7], which could be related to initial parton scattering. The data also show a change of the slope of the T dependence on the energy density near the value where the J/ψ production cross section starts to deviate from the normal absorption curve [8].

The data collected in year 2000 are of the high quality what allows a more detailed study of the J/ψ suppression as a function of the transverse momentum. We study the ratio of the J/ψ cross section to the Drell-Yan cross section (we consider here the Drell-Yan with invariant mass higher than 4.2 GeV/c^2), which is proportional to the J/ψ yield per nucleon-nucleon collision. Events are binned according to the neutral transverse energy E_T which is experimentally measured, on an event by event basis, by an electromagnetic calorimeter with laboratory pseudorapidity coverage in the range [1.1-2.3]. E_T is connected with the centrality of the collision in which dimuons are produced.

We plot on Fig.1 and Fig.2 the ratio F of the J/ψ to the DY cross section in the corresponding E_T bin as a function of transverse momentum p_T for 5 transverse energy bins (Fig.1) and as a function of the transverse energy E_T for 11 transverse momentum bins up to $p_T = 5.0$ GeV/c (Fig.2). The figures show that, whereas for low values of p_T there is a significant J/ψ suppression which strongly increases with centrality, when p_T increases, the dependence of the J/ψ normalized yield on centrality becomes weaker and weaker. In other words, the suppression observed on the integrated p_T yield from peripheral to central collisions originates mainly from the suppression of J/ψ with low p_T values. In order to better investigate this dependence we consider the ratio R_i of each p_T distribution corresponding to a given E_T bin i with respect to the first and most

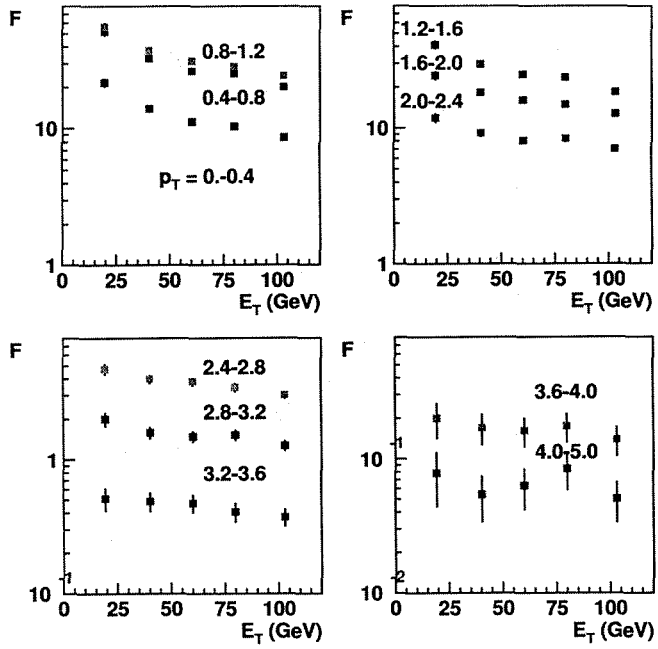

Figure 2: Ratio F of the J/ψ production cross section for Pb-Pb collisions at 158 GeV/c per nucleon in the p_T bins shown on the plots (in GeV/c) to the DY cross section, as a function of the measured neutral transverse energy in GeV

peripheral bin, namely:

R_i= (J/ψ_i / DY_i) / (J/ψ_1 / DY_1)

Fig.3 displays the four ratios R_i as a function of p_T. It shows that with respect to the most peripheral collisions, J/ψ becomes more and more suppressed, with increasing centrality but also with decreasing p_T values. For high p_T values, above 3.5 GeV/c, the suppression although still increasing with centrality, exhibits no significant p_T dependence for the central collisions.

We compare Pb-Pb collisions with p-A reactions where the J/ψ survival probability is affected by normal nuclear absorption only. In this case, when the J/ψ yield is parametrized according to A^α, nuclear absorption leads to a value of α lower than unity reflecting the absorption of the $c\bar{c}$ pair within the target. Now we perform more complex study when the survival probability as a function of p_T is considered. Within the frame of the same NA50 experiment, we have therefore made a study of the J/ψ yield p_T dependence for 400 GeV p-induced reactions on 6 different target nuclei: Be, Al, Cu, Ag, W and Pb. We have considered the same 11 p_T bins and have measured the ratio F in each of them for the six different targets. We have used the above A^α parametrization of the J/ψ cross section separately in each of the 11 p_T bins in order to perform a p_T dependent analysis. The results are shown in Fig.4.

The results of the J/ψ production study in p-A reactions are illustrated in Fig.5. They

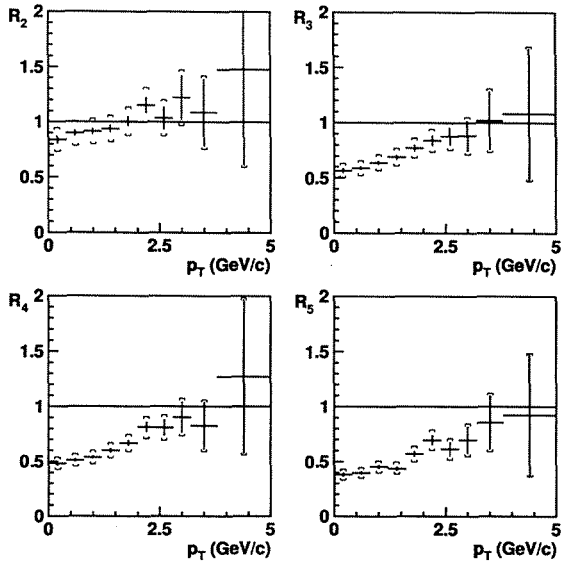

Figure 3: Ratios R_i of the J/ψ transverse momentum distribution normalized to the DY cross section in the E_i bin $2< i< 5$ to the first E_1 bin. The solid error bars on each data point are the statistical errors of the J/ψ yield ratios. The error bars with systematic errors from the DY cross section ratios are given as brackets

show that whereas for low values of p_T J/ψ production as a function of the atomic mass number A increases less than proportionally to A (Drell-Yan is proportional to A and both are proportional to the number of nucleus-nucleus collisions) leading to a value of α lower than unity, for high p_T values J/ψ production increases faster than A so that the corresponding value of α is higher than 1. There is a kind of normal nuclear absorption for the lower p_T values but the magnitude of this absorption decreases with increasing p_T then vanishes and turns to overproduction for high p_T already above 2 GeV/c. This is, in fact, a wellknown behaviour observed since long in the production of hadrons and known as the Cronin effect.

For comparison we show in Fig.6 the data for S-U collisions as obtained from the NA38 experiment, where the effect of absorption is seen for low p_T (R<1), together with some hints of enhancement for high p_T (R>1) suggesting, within errors, a behaviour similar to the Cronin effect observed in p-A collisions. The Pb-Pb data can be rebinned using only 3 bins of transverse energy in order to minimize statistical fluctuations. Fig.7 shows that for the most central Pb-Pb collisions and with respect to the most peripheral bin, the suppression exists for all values of p_T. The centrality dependence decreases with increasing p_T. For the highest p_T values, no overproduction is observed: there is always an absorption which increases with centrality, although less pronounced than for small p_T and which, moreover, does not exhibit any significant p_T dependence.

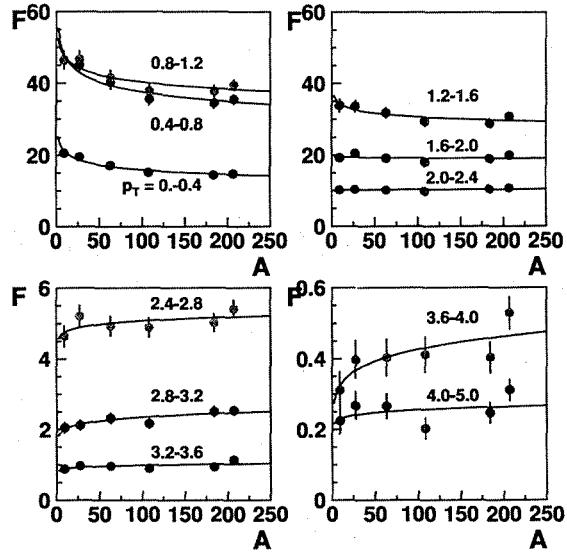

Figure 4: Ratio F of the J/ψ production cross section for proton-nucleus collisions at 400 GeV/c in the p_T bins shown on the plots (in GeV/c) to the DY cross section, as a function of the atomic number of the target nucleus. The J/ψ yield is parametrized according to A^α

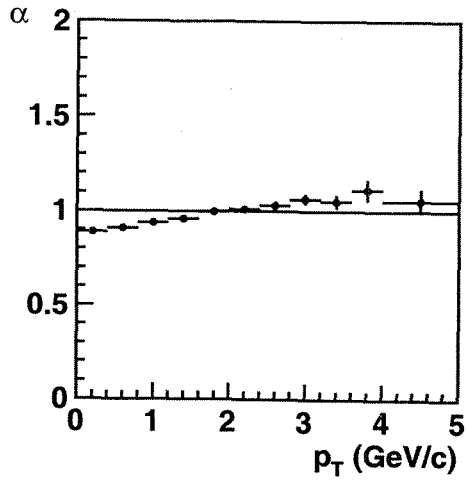

Figure 5: Parameter α obtained from the fit of the proton-nucleus J/ψ production cross sections as a function of the transverse momentum (GeV/c).

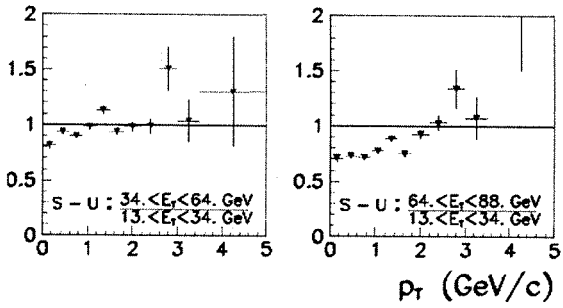

Figure 6: Ratios R_i of the J/ψ transverse momentum distribution normalized to the DY cross section for S-U collisions from the NA38 experiment for the case of three E_T intervals

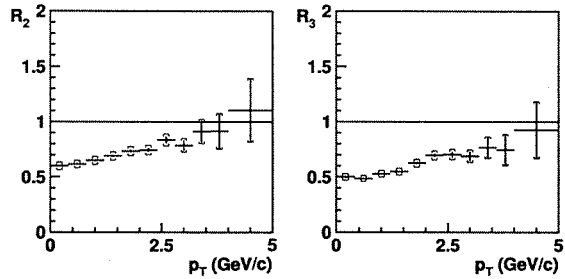

Figure 7: Ratios R_2 and R_3 of the J/ψ transverse momentum distribution normalized to the DY cross section for the second and third centrality bins with respect to the first and most peripheral one, in the case of three E_T intervals, for Pb-Pb collisions. The error bars have the same meaning as on Figure 3

3. Conclusions

The dependence of the J/ψ suppression pattern on p_T for Pb-Pb collisions is somewhat different from what is observed in the case of normal nuclear J/ψ absorption from p-induced reactions. In the latter case we see the change from absorption to enhancement with the increase of transverse momentum. For Pb-Pb collisions and for the whole p_T range, only absorption is observed with increasing centrality. Moreover, the data show that absorption is is significantly stronger for low p_T and almost p_T independent for the most central collisions and for the highest values of the transverse momentum.

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