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 $J/\psi$ as a function of the centrality of the collision shows that the observed $J/\psi$ 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 $J/\psi$ 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 $J/\psi$ 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 $J/\psi$ has been measured in proton-induced reactions. The corresponding cross-section, deduced in the frame of a Glauber calculation, amounts to $4.18 \pm 0.35$ mb [3]. It provides thereby the $J/\psi$ 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 projectile mass numbers, like the number of nucleon-nucleon collisions in the interaction. Besides, 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 $J/\psi$ 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 $J/\psi$ 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].
When rescaled to the same energy and as a function of the mean length path of $J/\psi$ in nuclear matter, the mean square transverse momentum of $J/\psi$ 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 $J/\psi$ 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 $J/\psi$ suppression as a function of the transverse momentum. We study the ratio of the $J/\psi$ 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 $J/\psi$ 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 $J/\psi$ 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 $r$ there is a significant $J/\psi$ suppression which strongly increases with centrality, when $r$ increases, the dependence of the $J/\psi$ 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 $J/\psi$ with low $r$ 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 $J/\psi$ 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:

$$R_i = \left( \frac{J/\psi_i}{DY_i} \right) / \left( \frac{J/\psi_1}{DY_1} \right)$$

Fig. 3 displays the four ratios $R_i$ as a function of $p_T$. It shows that with respect to the most peripheral collisions, $J/\psi$ 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 $J/\psi$ survival probability is affected by normal nuclear absorption only. In this case, when the $J/\psi$ yield is parametrized according to $A^\alpha$, nuclear absorption leads to a value of $\alpha$ lower than unity reflecting the absorption of the $c\bar{c}$ pair within the target. Now we perform a more complex study when the survival probability as a function of $p_T$ is considered. Within the framework of the same NA50 experiment, we have therefore made a study of the $J/\psi$ 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 $A^\alpha$ parametrization of the $J/\psi$ 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 $J/\psi$ production study in p-A reactions are illustrated in Fig. 5. They
Figure 3: Ratios $R_i$ of the $J/\psi$ 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 $J/\psi$ 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 $p_T$, $J/\psi$ 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 $\alpha$ lower than unity, for high $p_T$ values $J/\psi$ production increases faster than $A$ so that the corresponding value of $\alpha$ 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 $J/\psi$ 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 $J/\psi$ yield is parametrized according to $A^\alpha$.

Figure 5: Parameter $\alpha$ obtained from the fit of the proton-nucleus $J/\psi$ production cross sections as a function of the transverse momentum (GeV/c).
Figure 6: Ratios $R_i$ of the $J/\psi$ 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 $J/\psi$ 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 $J/\psi$ suppression pattern on $p_T$ for Pb-Pb collisions is somewhat different from what is observed in the case of normal nuclear $J/\psi$ 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 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.

References


