Transverse momentum distributions of J/ψ mesons produced in p-A and Pb-Pb interactions at the CERN SPS

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The NA50 experiment has measured the transverse momentum and transverse mass distributions of J/ψ mesons produced in p-A and in Pb-Pb collisions, of incident energies 400 GeV and 158 GeV/nucleon, respectively. In the present paper we study how these distributions change with the centrality and energy of the collisions. The study includes points previously measured by the NA3 and NA38 experiments.

The NA50 experiment is mainly devoted to the study of a specific signature of the quark-gluon phase transition, the predicted suppression of the charmonium states [1]. Indeed, the NA50 observation of an anomalous J/ψ suppression [2] strongly indicates that the deconfinement transition takes place in Pb-Pb collisions, at the SPS energies, for impact parameters smaller than ~ 8 fm. The study of the J/ψ transverse momentum and transverse mass distributions could provide additional information on the features of this phase transition.

The NA50 experimental setup is basically devoted to the measurement of dimuon production as a function of the centrality of the nuclear collisions. Dimuons are detected in the kinematical domain defined by $2.92 < y_{\rm lab} < 3.92$ and $-0.5 < \cos\theta_{CS} < 0.5$. In our analysis, the centrality of the collision is estimated from $E_{\rm T}$, the neutral transverse energy measured by an electromagnetic calorimeter [3].

Pb-Pb data taking conditions were similar in all periods reported here, except for the total thickness of the target. A segmented lead target made of 7 subtargets was used for the 1996 (1995) data taking periods with a total target thickness of 12 mm (7 mm), corresponding to 30 % (17 %) of an interaction length. During year 2000, a single lead target of 4 mm (9.33 % of $\lambda_{\rm int}$) was placed in vacuum, to reduce the contamination from Pb-air interactions, in the peripheral Pb-Pb collisions event sample. The total number of collected J/ψ events for the 1995, 1996 and 2000 Pb-Pb runs is 50 000, 190 000 and 110 000, respectively. The results on p-A interactions reported hereafter are based on data collected in the year 2000, with a high intensity ($\sim 4 \cdot 10^9$ p/burst) proton beam, of 400 GeV, on several targets (Be, Al, Cu, W and Pb). The number of collected J/ψ events is 40 000, 50 000, 47 000, 51 000 and 71 000, respectively.

In order to subtract the contribution of the dimuon mass continuum under the J/ψ peak, the invariant mass spectrum is fitted to the superposition of the four physical contributions, J/ψ, ψ', Drell-Yan and muon pairs from the simultaneous semileptonic decay of $D\bar{D}$ pairs, plus the combinatorial background contribution from uncorrelated π and K decays. This background is estimated from the samples of like-sign muon pairs. In the J/ψ region, the continuum contribution amounts to less than 8 % of the total in the mass range $2.7 < M < 3.5$ GeV, and to 3 % in the narrower interval $2.9 < M < 3.3$ GeV used in the data analysis of the 1996 and 2000 data sets. These continuum events are mainly Drell-Yan dimuons.

To obtain the J/ψ transverse momentum distributions, the $p_{\rm T}$ distribution of the muon pairs in the resonance mass region is corrected with the $p_{\rm T}$ distribution measured for the continuum dimuons with mass just below or above the J/ψ peak. The details of the analysis method can be found in Ref. [4].

The $\langle p_{\rm T}^2\rangle$ values for the J/ψ obtained from the 1995, 1996 and 2000 Pb-Pb data samples are plotted in Fig. 1, as a function of $E_{\rm T}$. The overall behavior is the same in the three data sets, with a fast increase followed by a flatter evolution for the more central collisions. The $\langle p_{\rm T}^2\rangle$ values obtained from the 1995 and 1996 data are in good agreement over the measured transverse energy range, but the 2000 year data points are slightly (< 4 %) but systematically higher in the most peripheral events. This is probably due to the Pb-air interaction contamination in the 1995 and 1996 year data. The $\langle p_{\rm T}^2\rangle$ values of J/ψ mesons produced in collisions induced by light projectiles (p, O, S) [5,6] have been successfully interpreted in terms of initial-state parton multiple scattering [7,8]. In order to study more precisely the effects of initial state interactions, the $\langle p_{\rm T}^2\rangle$ values obtained in p-A interactions at 200 and 400 GeV, and in O-Cu, O-U and S-U collisions at 200 GeV per nucleon, are plotted together with the Pb-Pb data at 158 GeV per nucleon in Fig. 2, as a function of L, the length of nuclear matter traversed in the initial state.

The values were fitted according to $\langle p_{\rm T}^2\rangle = \langle p_{\rm T}^2\rangle_{pp} + a_{gN} \cdot L$ [8]. The three slopes are compatible, and the $\langle p_{\rm T}^2\rangle_{pp}$ values increase with the beam energy. The result of a simultaneous fit to the three energy data sets with a common slope gives $a_{gN} = 0.077 \pm$

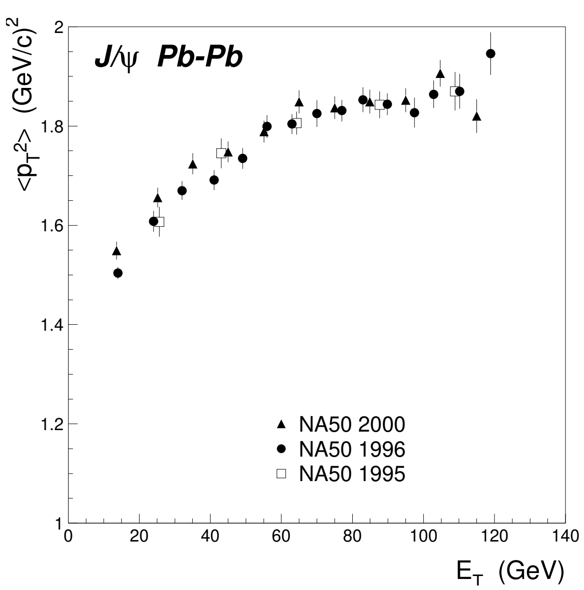

Figure 1. $\langle p_{\mathrm{T}}^2 \rangle$ of the J/ψ as a function of the transverse energy, as measured in the several Pb-Pb data taking periods.

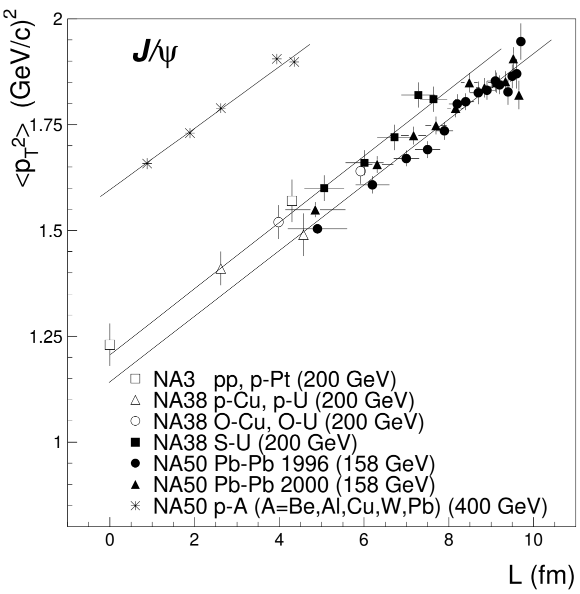

Figure 2. $\langle p_{\mathrm{T}}^2 \rangle$ values of the J/ψ as a function of the length of matter traversed in the initial state, for three different energies.

0.002 (GeV/c)^2/fm.

We see that $\langle p_{\mathrm{T}}^2 \rangle_{pp}$ increases linearly with $\sqrt{s}$, the total energy in the nucleon-nucleon center of mass system, as seen by the NA3 experiment with pion beams [5]. The observed dependence of the J/ψ $\langle p_{\mathrm{T}}^2 \rangle$ values as a function of the centrality of the collision may be due to initial state multiple scattering of the partons.

The J/ψ transverse mass distributions have also been studied. They were fitted with the analytical function $1/T \cdot M_{\mathrm{T}}^2 \cdot K_1(M_{\mathrm{T}}/T)$, where K_1 is the modified Bessel function and the inverse slope, T, may be related to the effective temperature of the system, in thermal models of particle production [9].

The obtained inverse slopes are plotted in Fig. 3 as a function of the energy density reached in the collision, ϵ, calculated in the framework of the Bjorken model [10]. For all the colliding systems we have studied, the effective temperature seems to increase linearly as a function of the energy density, with compatible T values at $\epsilon = 0$. A simultaneous fit with a common initial T for the three energy data sets gives $T(\epsilon = 0) = 179 \pm 2$ MeV, while the slope increases linearly with $\sqrt{s}$.

Figure 4 shows the dependence of T on ϵ, after having rescaled all the data sets to the same energy, 158 GeV. For the peripheral Pb-Pb collisions, we only use the points from the data collected in year 2000, not biased by Pb-air collisions. We can see that the linear increase of T with ϵ becomes flatter when we approach the most central Pb-Pb collisions, with the slopes changing from $(22 \pm 1) \cdot 10^{-3}$ fm^3 to $(12 \pm 3) \cdot 10^{-3}$ fm^3.

In conclusion, the Pb-Pb data collected in three different years, with different experimental setups, shows a common trend in what concerns the evolution with collision centrality of the $\langle p_{\mathrm{T}}^2 \rangle$ and of T, the inverse slope of the transverse mass distributions: a strong initial increase followed by a flatter behavior. At least in the lighter collision systems, including peripheral Pb-Pb interactions, the observed pattern of $\langle p_{\mathrm{T}}^2 \rangle$ may be

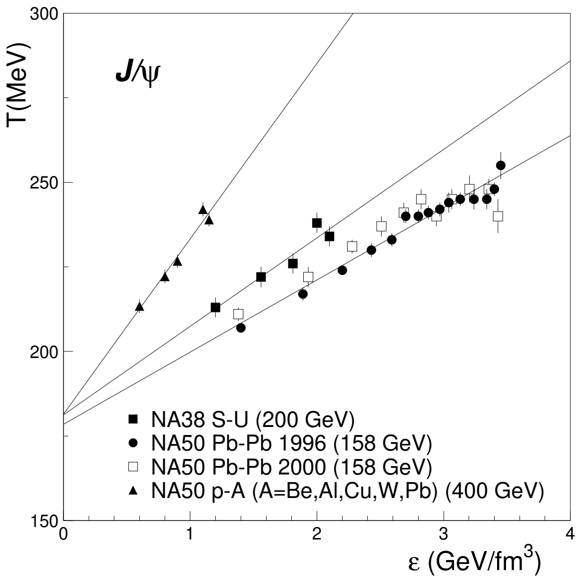

Figure 3. Inverse slope parameter, T, of the J/ψ as a function of the energy density. The lines are linear fits to the data points, for each beam energy.

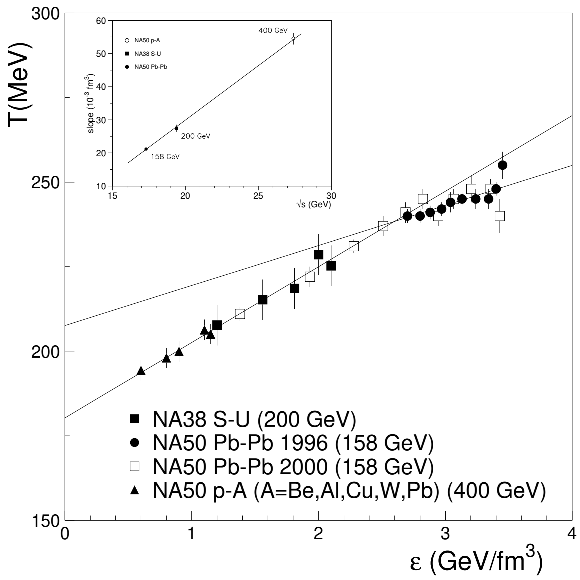

Figure 4. Same as previous figure, after rescalling all data sets to 158 GeV. The inset shows the slopes of the linear fits (Fig. 3) vs. $\sqrt{s}$.

explained in terms of initial state parton multiple scattering.

After taking into account the different energies of the collected data sets, all the collision systems show a very similar linear dependence between T and the energy density reached in the collisions, with the same value of T at $\epsilon = 0$. However, the Pb-Pb pattern seems to indicate a change in the slope of the linear increase of T with ϵ, for the most central Pb-Pb collisions.

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