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# Transverse momentum distribution of $J/\psi$ produced in Pb - Pb and p-A interactions at the CERN SPS.

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Muon pairs produced in Pb-Pb interactions at 158 GeV/$c$ per nucleon and in p-A interactions at 400 GeV/$c$, together with older S-U results obtained at 200 GeV/$c$ are used to study the transverse momentum and transverse mass distributions of the J/$\psi$.

## 1. Introduction

The NA50 experiment is mainly devoted to the study of a specific signature of a quark-gluon phase transition, the predicted suppression of the charmonium state [1]. Indeed, the NA50 observation of an anomalous J/$\psi$ suppression [2,3,4] is a strong indication for the deconfinement transition. The study of the J/$\psi$ transverse momentum and transverse mass distributions could provide an additional information on the features of the phase transition of ordinary matter to quark-gluon plasma.

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## 2. Experimental conditions

The NA50 experimental setup is basically the muon spectrometer to measure the production of muon pairs as a function of the centrality of the collision. Dimuons are detected in the kinematical domain $2.92 \leq y_{\rm lab} \leq 3.92$ and $-0.5 \leq \cos\theta_{CS} \leq 0.5$. In our analysis the centrality of the collision is estimated from the neutral transverse energy, measured by an electromagnetic calorimeter [5].

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

## 3. Analysis

In order to take into account the contribution of the mass continuum events under the resonance peak, the invariant mass spectrum is fitted to the sum of the four physical contributions : $J/\psi$, $\psi'$, DY and $D\bar{D}$ plus combinatorial background originating from uncorrelated $\pi$ and K decays. This background is estimated from the samples of like-sign muon pairs. In the $J/\psi$ region, the continuum contribution amounts to less than 8 % of the total in the mass range $2.7 < M < 3.5$ GeV/$c^2$, and to 3 % in the narrower interval ($2.9 < M < 3.3$ GeV/$c^2$) used for 1996, 2000 year data analysis. These continuum events are mainly DY pairs.

To obtain $J/\psi$ transverse momentum distribution the $p_{\rm T}$ distribution of the muon pairs in the resonance mass region is corrected with $p_{\rm T}$ distribution for continuum taken as experimental distribution for dimuon mass below or above the $J/\psi$. The details of the analysis method could be found in [6].

## 4. Transverse momentum distributions

The $\langle p_{\rm T}^2 \rangle$ values for the $J/\psi$ 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 behaviour is the same - first increase and then tend to flatten when the centrality of the collision increases. The $\langle p_{\rm T}^2 \rangle$ values obtained from the 1995 and 1996 data are in good agreement all over the measured transverse energy range, but 2000 year data shows small ($\leq 4$ %) but systematic increase for peripheral events which could be accounted to the Pb-air interaction contamination in 1995 and 1996 year data. The $\langle p_{\rm T}^2 \rangle$ values of $J/\psi$ produced in collisions induced by light projectiles (p, O, S) [7,8,9] have been successfully interpreted in terms of initial-state parton multiple scattering [10,11]. In order to study more precisely the effect of initial state interactions, the $\langle p_{\rm T}^2 \rangle$ values for three energy data sets: p-A interactions at 400 GeV/$c$ , lighter projectiles nucleus collisions at 200 GeV/$c$ per nucleon together with the Pb-Pb data at 158 GeV/$c$ per nucleon are plotted in Fig. 2 as a function of the geometric length of matter in the initial state, $L$. The results are fitted according to the formalism of [11], $\langle p_T^2\rangle = \langle p_T^2\rangle_{pp} + a_{gN} \cdot L$. The slopes are compatible and the $\langle p_T^2\rangle_{pp}$ value grows with the beam energy. The result of a simultaneous fit to the three energy data sets with a common slope gives for $a_{gN}$ value $0.077 \pm 0.002$ $(\mathrm{GeV}/c)^2\mathrm{fm}^{-1}$. The fact that the $\langle p_T^2\rangle$ value depends on the beam energy is observed for the first time by the NA3 experiment with pion beams [7] and is in agreement with measured linear growing of $\langle p_T^2\rangle_{pp}$ with $\sqrt{s}$, total energy in the NN center of mass. The observed dependence of $\langle p_T^2\rangle$ values of J/$\psi$ as a function of centrality of the collision could simply result from parton initial state multiple scattering.

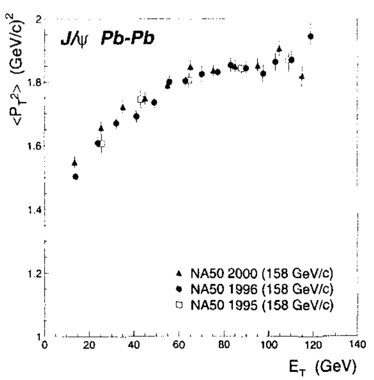


Figure 1. $\langle p_T^2\rangle$ of the J/$\psi$ as a function of the transverse energy for the several data taking periods. For the J/$\psi$, the circules correspond to the 1996 data sample, the open squares - to the 1995 and triangles to the 2000 data sample.

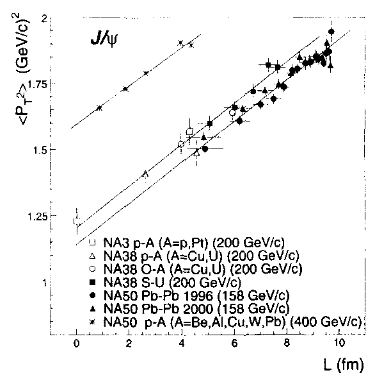


Figure 2. $\langle p_T^2\rangle$ values of the J/$\psi$ as a function of the geometric length of matter, L, traversed in the initial state for three energy data sets. The lines are linear fits to the data points, one for each beam energy.

## 5. Transverse mass distribution

The transverse mass distributions of the J/$\psi$ have also been studied in order to allow a comparison with thermal model [12]. The $M_T$ distributions are fitted with the analytical function, $1/T \cdot M_T^2 \cdot K_1(M_T/T)$, where $K_1$ is the modified Bessel function and the inverse slope, $T$, is related to the effective temperature of the system in thermal model. The inverse slope, $T$, is plotted in Fig. 3 as a function of the energy density, $\epsilon$, reached in the collision, calculated in the frame of the Bjorken model [13]. For all colliding systems effective temperature behaves linearly as a function of energy density, $T = T(\epsilon = 0) + Tslope \cdot \epsilon$, with the compatible initial $T$ value at $\epsilon$=0. Simultaneous fit with a common initial $T$ for three energy data sets gives $T(\epsilon = 0) = 179 \pm 2\ MeV$ and second parameter, Tslope, which linearly grows with $\sqrt{s}$. Taking into account the energy dependence for $T$ all the data are rescaled to the same 158 GeV/c and plotted as a function of $\epsilon$ in the Fig. 4. For Pb-Pb only peripheral Pb-Pb 2000 year data, not biased by the Pb-air contamination are used for fitting with common initial $T(\epsilon = 0)$ value. For all colliding systems $T$ grows linearly with the energy density and gives $Tslope = (22 \pm 1) \cdot 10^{-3}\ fm^3$ except the most central Pb-Pb collisions where more flat behaviour could be seen with $Tslope$ (central) $= (12 \pm 3) \cdot 10^{-3}\ fm^3$.

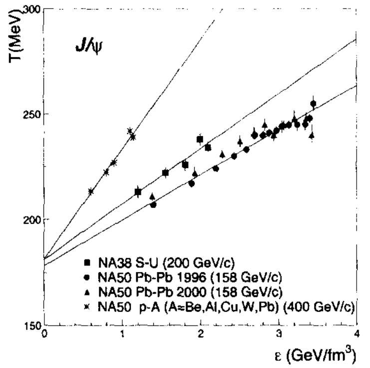


Figure 3. Inverse slope parameter, $T$, of the J/$\psi$ transverse mass distributions, plotted as a function of the energy density.

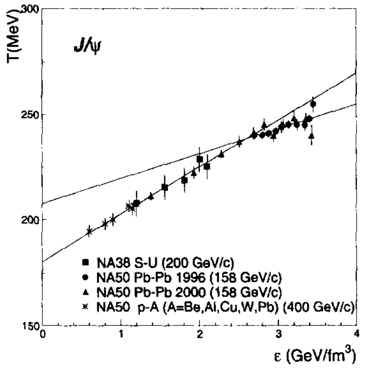


Figure 4. Inverse slope parameter, $T$, of the J/$\psi$ transverse mass distributions, rescaled to the 158 GeV/c, plotted as a function of the energy density.

## 6. Conclusions

In Pb-Pb collisions the $\langle p_T^2 \rangle$ values and the inverse slope parameter, $T$, for J/$\psi$ exhibit a similar trend as a function of $E_T$: an initial increase followed by a flatter behaviour.

The observed dependence of $\langle p_T^2 \rangle$ as a function of centrality of the collision shows that its behaviour could simply result from parton initial state multiple scattering.

The inverse slope, $T$, of the transverse mass distributions behaves linearly as a function of the energy density, reached in the collision, with the same initial T value at $\epsilon$=0. This behaviour is quite similar for all the colliding systems except for the most central Pb-Pb collisions which deviate from the general pattern and exhibit a flatter $\epsilon$ dependence.

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