

# Transverse momentum of dimuons produced in p-Cu, p-U, $^{16}\text{O}$ -Cu, $^{16}\text{O}$ -U and $^{32}\text{S}$ -U collisions at 200 GeV per nucleon

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**TRANSVERSE MOMENTUM OF DIMUONS PRODUCED IN  
p-Cu, p-U,  $^{16}\text{O-Cu}$ ,  $^{16}\text{O-U}$  and  $^{32}\text{S-U}$   
COLLISIONS AT 200 GeV PER NUCLEON**

**NA38 Collaboration**

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Abstract : The NA38 experiment measured the muon pair production in interactions of p and  $^{16}\text{O}$  with Cu and U and in  $^{32}\text{S-U}$  collisions at 200 GeV per nucleon incident energy. The transverse momentum distribution of the  $J/\psi$  and of muon pairs in the mass continuum ( $1.7 < M_{\mu\mu} < 2.7 \text{ GeV}/c^2$ ) has been studied, taking into account the acceptance and smearing effects of the apparatus. For the  $J/\psi$ , the average values of the transverse momentum  $\langle P_T \rangle$  and  $\langle P_T^2 \rangle$  show a clear increase with the energy density reached in  $^{16}\text{O}$  and  $^{32}\text{S}$  induced reactions, which is not observed for muon pairs in the mass continuum. Such a behaviour is in agreement with quark-gluon plasma models. However, models based on parton multiple scattering in the initial state are also able to reproduce the data.

The NA38 collaboration measured the dimuon production in p-Cu, p-U,  $^{16}\text{O}$ -Cu,  $^{16}\text{O}$ -U and  $^{32}\text{S}$ -U reactions at 200 GeV per nucleon, in correlation with the neutral transverse energy  $E_T^0$  produced in the interaction, which reflects the centrality of the collision. It has been observed<sup>[1]</sup> that the  $J/\psi$  yield relative to the dimuons in the mass continuum decreases with increasing  $E_T^0$ . In addition<sup>[2]</sup>, this effect was found to be enhanced at low transverse momentum  $P_T$ . Such a behaviour is in agreement with the predictions of quark-gluon plasma (QGP) models<sup>[3]</sup> in which the colour screening effect prevents the binding of the  $c - \bar{c}$  pair, depending on its transverse momentum<sup>[4]</sup>. It is therefore important to study the  $P_T$  dependence of  $J/\psi$  production as a function of  $E_T^0$ .

Measurements were performed at the CERN SPS, using the highest available intensity (up to  $10^7$  ions/s). The spectrometer detected muon pairs in the lab rapidity range  $2.8 < y < 4.1$ , in correlation with  $E_T^0$ , the neutral transverse energy deduced from the energy flow measured by an electromagnetic calorimeter in the pseudorapidity range  $1.7 < \eta_{lab} < 4.1$ . More details on the experimental set-up and event selection criteria can be found elsewhere<sup>[1,2]</sup>.

Only dimuons with invariant mass  $M_{\mu\mu} \geq 1.7 \text{ GeV}/c^2$  are considered here. In this mass region, the signal in the opposite sign (OS) dimuon spectra originates mainly from  $J/\psi$  and  $\psi'$  meson decays, semi-leptonic decays of  $D\bar{D}$  pairs, and from the Drell-Yan mechanism. For each kinematical variable, the number  $N_{Bk}^{+-}$  of background pairs coming from pion and kaon decays is estimated from the like sign (LS) pair spectra, using the formula :

$$N_{Bk}^{+-} = 2\sqrt{N^{++}N^{--}}$$

where  $N^{++}$  ( $N^{--}$ ) is the number of  $\mu^+\mu^+$  ( $\mu^-\mu^-$ ) pairs in the corresponding distribution. In the following,  $J/\psi$ 's are defined as events with mass between 2.7 and 3.5  $\text{GeV}/c^2$ , and continuum dimuons as events outside this mass interval.

In order to study the transverse momentum distributions of  $J/\psi$ 's and continuum dimuons, the acceptance and smearing effects of the apparatus are taken into account. This treatment is performed by the means of transfert matrices obtained from the simulation of the NA38 detector<sup>[2]</sup>. The  $P_T$  distributions of the OS muon pairs are parametrized according to :

$$P_T e^{-\left(\frac{P_T}{P_{T0}}\right)^\beta}$$

A fit through the acceptance and smearing matrices, taking into account the background contribution in the OS spectra, leads to the parameters  $P_{T0}$  and  $\beta$  of this phenomenological  $P_T$  distribution for  $J/\psi$ 's and for muon pairs in the mass continuum. The average values  $\langle P_T \rangle$  and  $\langle P_T^2 \rangle$  deduced from the resulting distributions are gathered in table 1 for proton and ion induced reactions. As one can see from these results, for the  $J/\psi$ , the values obtained for proton induced reactions are not compatible with those corresponding to ion-uranium collisions.

In order to investigate this effect as a function of the centrality, the same procedure is applied for different  $E_T^0$  intervals. For proton-copper and proton-uranium collisions, no analysis as a function of  $E_T^0$  is performed, as  $E_T^0$  and impact parameter are in this case loosely correlated. For each  $E_T^0$  bin, the energy density reached in the collisions is

estimated using the Bjorken formula :

$$\varepsilon = \frac{3 \langle E_T^0 \rangle}{\Delta\eta \tau_0 \bar{S}}$$

where  $\langle E_T^0 \rangle$  is the mean neutral transverse energy measured in the pseudorapidity range  $\Delta\eta$ , and  $\bar{S}$  is the mean overlap area of the colliding nuclei at the time  $\tau_0=1\text{fm}/c$ .

all $E_T^0$	Continuum		$J/\psi$	
	$\langle P_T \rangle$	$\langle P_T^2 \rangle$	$\langle P_T \rangle$	$\langle P_T^2 \rangle$
p-Cu	$0.83 \pm 0.03$	$0.94 \pm 0.05$	$1.04 \pm 0.02$	$1.41 \pm 0.04$
p-U	$0.84 \pm 0.03$	$0.96 \pm 0.06$	$1.06 \pm 0.02$	$1.49 \pm 0.05$
$^{16}\text{O-Cu}$	$0.84 \pm 0.03$	$0.94 \pm 0.06$	$1.08 \pm 0.01$	$1.52 \pm 0.04$
$^{16}\text{O-U}$	$0.85 \pm 0.02$	$0.98 \pm 0.05$	$1.12 \pm 0.01$	$1.64 \pm 0.03$
$^{32}\text{S-U}$	$0.87 \pm 0.02$	$1.06 \pm 0.05$	$1.14 \pm 0.01$	$1.69 \pm 0.03$

Table 1 : Values of  $\langle P_T \rangle$  and  $\langle P_T^2 \rangle$  obtained after correction for acceptance and smearing, for  $J/\psi$ 's and for muon pairs in the mass continuum.

The values of  $\langle P_T \rangle$  and  $\langle P_T^2 \rangle$  as a function of  $\varepsilon$  are plotted in figure 1 for the  $J/\psi$ , and in figure 2 for continuum events. As shown in figure 1, for the  $J/\psi$ ,  $\langle P_T \rangle$  and  $\langle P_T^2 \rangle$  display a clear increase with  $\varepsilon$ . Such a behaviour is not seen in the case of continuum dimuons, for which the values of  $\langle P_T \rangle$  and  $\langle P_T^2 \rangle$  obtained in ion-nucleus collisions are, within statistics, compatible with those measured in p-Cu and p-U reactions.

Figures 1 and 2 : Values of  $\langle P_T \rangle$  (a) and  $\langle P_T^2 \rangle$  (b) as a function of the energy density  $\varepsilon$ , for the  $J/\psi$  (1) and for events in the mass continuum (2).

To study the transverse momentum dependence of the  $J/\psi$  suppression, the ratio  $R(P_T)$  of the transverse momentum distributions corresponding to the two extreme  $E_T^0$  bins is calculated. Each distribution is normalized to the number of continuum events in the  $J/\psi$  mass range, in the corresponding  $E_T^0$  interval :

$$R(P_T) = \frac{\left(\frac{1}{N_C} \frac{dN^\psi}{dP_T}\right)_{High E_T^0}}{\left(\frac{1}{N_C} \frac{dN^\psi}{dP_T}\right)_{Low E_T^0}}$$

This ratio is shown in figure 3 as a function of  $P_T$ . One can see that  $R$  increases with  $P_T$ , indicating that the  $J/\psi$  suppression is enhanced for low transverse momentum values. Such an increase is expected from quark-gluon plasma models, which predict, in addition, a saturation of  $R$  with  $P_T$ . However, other interpretations<sup>[5]</sup>, based on parton multiple scattering in the initial state, and  $J/\psi$  absorption in a dense hadron gas, are also able to account for the data. In these models, the multiple scattering in the entrance channel allows the incident partons to acquire transverse momentum, leading, for the  $J/\psi$ , to a value of  $\langle P_T^2 \rangle$  which increases with the centrality of the collision. In this frame,  $R(P_T)$  should not saturate with  $P_T$ . Unfortunately, the available statistics do not permit to distinguish between both models.

Figure 3 :  $R(P_T)$  for  $^{16}O-Cu$ ,  $^{16}O-U$  and  $^{32}S-U$  collisions, deduced from the fitted  $P_T$  distributions (solid lines), and calculated directly from the data (error bars).

Another analytical form of the  $J/\psi$   $P_T$  distribution, using the transverse mass parametrization :

$$P_T e^{-\frac{\sqrt{P_T^2 + M_\psi^2}}{T}}$$

leads to the values of the parameter  $T$ , presented in figure 4. The  $\epsilon$  dependence of this parameter, usually considered as a temperature in thermal models, has been fitted according to  $T = a \epsilon^{1/b}$ . With  $T$  expressed in GeV, the results of the fit (represented by the solid line in figure 4) are :

$$a = 0.212 \pm 0.002 \text{ and } b = 3.9 \pm 0.4$$

Figure 4 : Values of the parameter  $T$ , as a function of the energy density  $\epsilon$

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