J/ψ AND ψ' PRODUCTION IN THE NA38 EXPERIMENT

NA38 Collaboration:
M.C. Abreu[4], C. Baglin[1], A. Baldit[2], C. Barrière[2], M. Bedjidian[8], P. Bordalo[4], A. Bussière[1], J. Castor[2], T. Chambon[2], B. Chaurand[6], D. Contardo[8], E. Descroix[8], A. Devaux[2], O. Drapier[8], B. Espagnon[2], J. Fargeix[2], R. Ferreira[4], P. Force[2], L. Fredj[2], J. Gago[4], C. Gerschel[5], P. Gorodetzky[7], B. Grosdidier[7], J.Y. Grossiord[8], A. Guichard[8], J.P. Guillaud[1], R. Haroutunian[8], D. Jouan[5], L. Kluberg[6], R. Kossakowski[1], G. Landaud[2], D. Lazic[7], P. Liaud[1], C. Lourenço[4], L. Luquin[2], F. Malek[8], R. Mandry[8], R. Mazini[7], L. Peralta[4], J.R. Pizzi[8], C. Racca[7], S. Ramos[4], A. Romana[6], B. Ronceux[1], R. Salmeron[6], S. Silva[4], P. Sonderegger[3], X. Tarrago[5], J. Varela[4], F. Vazeille[2].
(1) LAPP-Annecy; (2) LPC-Clermont-Ferrand; (3) CERN-Geneva; (4) LIP-Lisbon; (5) IPN-Orsay; (6) LPNHE-Palaiseau; (7) CRN-Strasbourg; (8) IPN-Lyon.

Presented by Faïrouz Malek
IPN-Lyon, IN2P3-CNRS, Université Claude Bernard Lyon I,
43 Bd du 11 Novembre 1918, F-69622 Villeurbanne-Cedex, France.

Abstract

We present a summary of the results obtained from 1986 to 1991 for the J/ψ suppression in p-Cu, p-U, O-Cu, O-U and S-U collisions at 200 GeV/c per nucleon. We also present results on the production ratio $\psi'/J/\psi$ in p-A and S-U collisions as a function of the centrality of the collision. We compare this ratio with those obtained in p-A collisions by other experiments.

1 Introduction

We have studied collisions of heavy ions such as O-Cu, O-U and S-U at an incident energy of 200 GeV per nucleon and compared to several p-A collisions carried out in similar conditions. This study is done in order to signal the possible formation of a Quark Gluon Plasma (QGP). As was first predicted by Matsui and Satz [1], charmonium production is suppressed in the case of QGP formation. The NA38 experiment measures the dimuon production and in particular the J/ψ and ψ' production through their dimuon decay channel. The muons were measured with a toroidal field spectrometer in the laboratory rapidity range {2.8-4.1}, in correlation with the neutral transverse energy E_T emitted in the collision and measured with a calorimeter in the laboratory pseudo-rapidity range {1.7-4.1} [2]. The energy density ϵ, reached in the collision, is calculated from E_T using the well-known Björken formula $\epsilon = \frac{3<E_T>}{A_T \tau_0 \Delta y}$ [3], where the overlap area of the colliding nuclei A_T is deduced from a geometrical model [4], the formation time is assumed to be $\tau_0 = 1\ fm/c$ and the rapidity interval of the calorimeter is $\Delta y = 2.4$.

Both the opposite sign (OS) as well as the like sign (LS) muon pairs are measured. The OS pairs come from the decay of J/ψ, ψ', Drell-Yan, semi-leptonic decay of $D\bar{D}$ pairs, decay of low mass vector mesons and combinatorial background due to uncorrelated decays of π's and K's. The LS muon pairs are produced from the π's and K's decay and are used to estimate the background in the OS spectra [5].

2 J/ψ production

In Fig. 1. we show a typical mass distribution obtained with the OS dimuons in the mass range 1.7 $<M_{\mu^+\mu^-} <$ 6.5 GeV/c^2 where the resonances J/ψ and ψ' are easily identified. The J/ψ resonance is defined to be in the mass range 2.7 $<M_{\mu^+\mu^-} <$ 3.5 GeV/c^2, the spectrometer resolution being 10% (FWHM). In this figure are shown the background due to the uncorrelated π's and K's decays (dashed line), the continuum of Drell-Yan and semi-leptonic $D\bar{D}$ pair decay (dotted line) and the fit to the whole mass spectrum (full line). Taking into account the acceptance and smearing effects of the apparatus, we are able to obtain the J/ψ and continuum dimuon production at the vertex [6]. While the high mass continuum is supposed to come from the pure Drell-Yan mechanism, the low mass continuum is also populated with muon pairs coming from the semi-leptonic decays of $D\bar{D}$ pairs. Because of statistics, we use the mass continum in the range {1.7-2.7} as a normalization reference in order to study the J/ψ production.

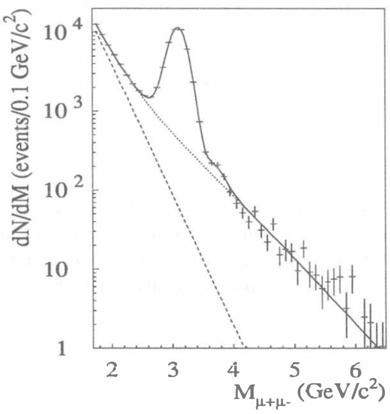

Fig. 1. Opposite sign dimuon mass distribution measured in S-U collisions, 1991 data (part of the statistics)

2.1 $B\sigma_{J/\psi}/\sigma_{cont}$ as a function of the energy density ϵ

From the method described above, one can obtain the ratio $B\sigma_{J/\psi}/\sigma_{cont}$ where σ_{cont} is the continuum production cross section and $B\sigma_{J/\psi}$ the J/ψ production cross section into the dimuon decay channel. The E_T distribution was divided into several bins, corresponding to different impact parameters of the collisions. This ratio, $B\sigma_{J/\psi}/\sigma_{cont}$, has been calculated as a function of the energy density ϵ. It is plotted in Fig. 2 for different data aquisition periods and set-ups.

We can observe that the ratio $B\sigma_{J/\psi}/\sigma_{cont}$ decreases with increasing energy density ϵ. The cross sections are compatible with the atomic number dependance $(A_{proj}.A_{targ.})^{\alpha}$ where $\alpha = 0.91 \pm 0.04$ for the J/ψ [7]. This is an indication that the J/ψ is suppressed. This suppression was predicted to occur in the case of QGP formation but it can also be explained by absorption in nuclear matter [8]. More definite conclusions must wait for larger statistics.

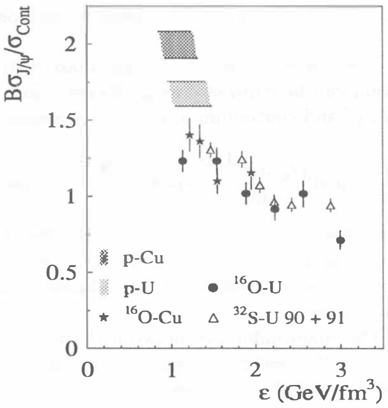

Fig. 2. $B\sigma_{J/\psi}/\sigma_{cont}$ *as a function of* ϵ

2.2 $< P_T >$ and $< P_T^2 >$ behaviour of the J/ψ and the continuum

In Fig. 3 and 4 we show $< P_T >$ and $< P_T^2 >$ distributions of the J/ψ and the continuum respectively, as a function of the energy density ϵ [9]. This behaviour is expected in the case of QGP formation where the J/ψ's of smaller $< P_T >$ are more suppressed [10]. It is also predicted in case of parton multiple scattering in the initial stage of the reaction [11, 12]. It is expected in particular that the slope of the $< P_T >$ distribution is larger for the J/ψ than for the continuum and the slope of the $< P_T^2 >$ distribution for the J/ψ is equal to 9/4 of the continuum one. Our experimental data are in agreement with these predictions [13].

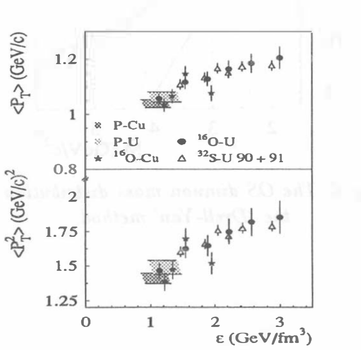

Fig. 3. $< P_T >$ *and* $< P_T^2 >$ *for* J/ψ

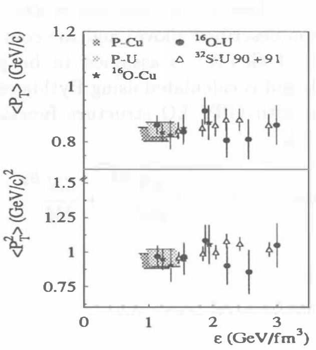

Fig. 4. $< P_T >$ *and* $< P_T^2 >$ *for continuum*

3 Study of the ψ' and J/ψ relative productions

Some recent theoretical models [8] showed that in the case of QGP formation and/or absorption in nuclear matter, the ψ' should be more suppressed than the J/ψ as a function of the energy density, for heavy ion collisions. The reasonable statistics collected in S-U allows us to study the ratio $B'\sigma_{\psi'}/B\sigma_{J/\psi}$. Two different methods were used to get such a ratio.

The shape of the OS dimuon mass distribution can be expressed as a superposition of J/ψ, ψ' and continuum production processes :

$$\frac{dN}{dM} = p_1 A^{J/\psi} \frac{dN}{dM}^{J/\psi} + p_2 A^{\psi'} \frac{dN}{dM}^{\psi'} + f(cont),$$

where the p's are free parameters and the A's the acceptances. The J/ψ and ψ' functions were obtained from a detailed simulation of the NA38 detector.

The main difference between the two methods is the *continuum* parametrization. The first method [14] describes the OS continuum, above 1.7 GeV/c^2, in a purely phenomenological way, as the superposition of two exponentials (see Fig. 5),

$$f(cont) = p_3 \, e^{-M/p_4} + p_5 \, e^{-M/p_6}.$$

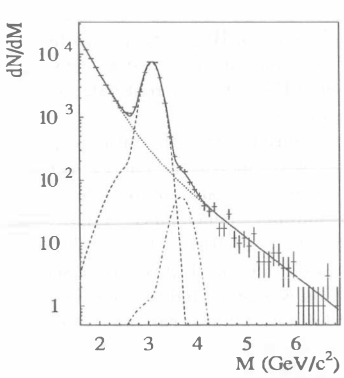

Fig. 5. The OS dimuon mass distribution in the 'phenomenological' method.

To minimize the number of free parameters in view of the available statistics, one of these exponentials is previously fitted to the mass region above 4.1 GeV/c^2 in the case of the S-U mass spectra (integrated in E_T), and then fixed in the fits of p-A and S-U per E_T bin.

In the second method [15], the LS muon pairs are used to get the "combinatorial background" (as done in the analysis of the J/ψ suppression described above) and the continuum above 3 GeV/c^2 is assumed to be pure Drell-Yan and is calculated using Pythia event generator with GRV LO structure functions, (see Fig. 6),

$$f(cont) = p_3 \, A^{DY} \frac{dN}{dM}^{DY} + \frac{dN}{dM}^{Bg}.$$

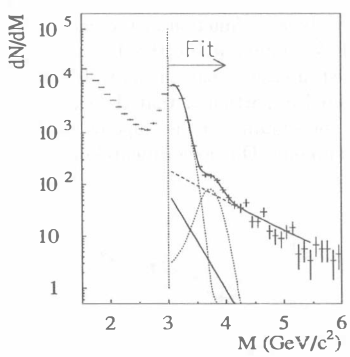

Fig. 6. The OS dimuon mass distribution in the 'Drell-Yan' method.

Reaction	$< E_T >$ (GeV)	$B'\sigma_{\psi'}/B\sigma_{J/\psi}$ (%)
p-W	$3.2^{(*)}$	1.71 ± 0.20
p-U	3.5	1.85 ± 0.40
S-U	27.1	1.19 ± 0.17
	51.5	1.02 ± 0.16
	74.9	0.89 ± 0.18
	99.9	0.74 ± 0.18

Table 1: *Table 1. $B'\sigma_{\psi'}/B\sigma_{J/\psi}$ (%) with its statistical errors as a function of $< E_T >$ (GeV). (*) This value (not measured) has been obtained from an extrapolation method.*

The mean values of the ratios $B'\sigma_{\psi'}/B\sigma_{J/\psi}$ obtained from the two methods are given in Tab.1, and plotted in Fig. 7, as a function of the neutral transverse energy E_T for p-W, p-U and S-U collisions. The systematic errors are estimated to be of the order of 20%. The ratio $B'\sigma_{\psi'}/B\sigma_{J/\psi}$ is seen to decrease by a factor of 2 from p-A to S-U and to decrease by 40% from peripheral to central S-U collisions. In Fig. 8, we compare the NA38 results with those obtained by other experiments [16]. Here, the values are plotted as a function of the parameter L, the length of nuclear matter in the final state [12]. This length is calculated from the measured mean transverse momentum $< P_T^2 >$ [13]. While in p-A collisions it seems that the J/ψ and ψ' resonances suffer the same influence from the nuclear matter, in S-U collisions the ψ' is suppressed relatively to the J/ψ with increasing centrality.

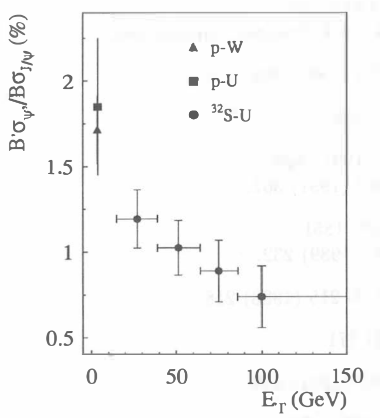

Fig. 7. $B'\sigma_{\psi'}/B\sigma_{J/\psi}$ as a function of E_T

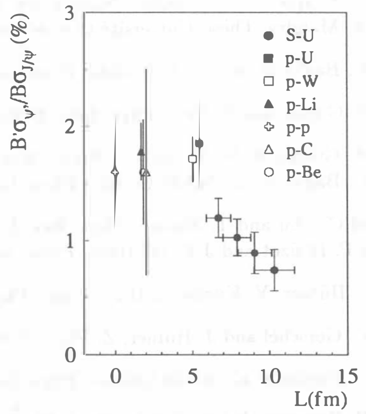

Fig. 8. $B'\sigma_{\psi'}/B\sigma_{J/\psi}$ as a function of ϵ from NA38 and other experiments

4 Conclusion

We have shown that the ratio $B\sigma_{J/\psi}/\sigma_{cont}$ decreases with increasing energy density. The atomic number dependence of the J/ψ cross section suggests that the J/ψ is suppressed. We have also shown that the ratio $B'\sigma_{\psi'}/B\sigma_{J/\psi}$ decreases from p-A to S-U and as a function of the S-U collision centrality.

A clear distinction between QGP formation and nuclear absorption in ultra-relativistic heavy ion collisions requires further statistics. This situation will be improved in the near future since an important amount of data taken in 1992 is currently being analysed. The future of this type of physics will continue with a new experiment, NA50, which will study Pb-Pb collisions at 160 GeV/c per nucleon. These collisions will allow the study of bigger thermalized volumes and somewhat higher energy densities.

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