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The production of J/Ψ in 200 GeV/A oxygen-uranium interactions ★

A. Bussiere
LAPP, Annecy-le-Vieux, France

NA38 Collaboration

M.C. Abreu [5], M. Alimi [6], C. Baglin [1], A. Baldit [3], G.P. Barreira [5], M. Bedjidian [6], P. Bordalo [5], S. Borenstein [4], J. Britz [8], A. Bussiere [1], P. Busson [4], A. Casaca [5], R. Cases [9], J. Castor [3], C. Charlot [4], B. Chaurand [4], D. Contardo [6], E. Descroix [6], A. Devaux [3], J. Fargeix [3], X. Felgeyrolles [3], P. Force [3], J.M. Gago [5], C. Gerschel [7], P. Gomez [5], P. Gorodetzky [8], J.Y. Grossiord [6], A. Guichard [6], J.P. Guillaud [1], R. Haroutunian [6], L. Kluberg [4], L. Kraus [8], G. Landaud [3], I. Linck [8], C. Lourenço [5], A. Maio [5], L. Peralta [5], M. Pimenta [5], J.R. Pizzi [6], C. Racca [8], S. Ramos [5], A. Romana [4], R. Salmeron [4], A. Sinquin [7], R. Sonderegger [2], J. Varela [5]

[1] LAPP, CNRS-IN2P3, F-74019 Annecy-le-Vieux, France
[2] CERN, CH-1211 Geneva 23, Switzerland
[3] LPC, Université de Clermont-Ferrand and CNRS-IN2P3, F-63170 Aubière, France
[4] LPNHE, Ecole Polytechnique and CNRS-IN2P3, F-91128 Palaiseau, France
[5] LIP, P-1699 Lisbon, Portugal
[6] IPNL, Université de Lyon and CNRS-IN2P3, F-69622 Villeurbanne, France
[7] IPN, Université de Paris-Sud and CNRS-IN2P3, F-91406 Orsay, France
[8] CRN, CNRS-IN2P3 and Université Louis Pasteur, F-67037 Strasbourg, France
[9] IFIC, E-46100 Burjasot, Valencia, Spain

Abstract. The dimuon production in 200 GeV/nucleon oxygen-uranium interactions is studied by the NA38 Collaboration. The production of J/Ψ, correlated with the transverse energy ET, is investigated and compared to the continuum, as a function of the dimuon mass M and transverse momentum PT. A value of 0.64 ± 0.06 is found for the ratio (Ψ/Continuum at high ET)/(Ψ/Continuum at low ET), from which the J/Ψ relative suppression can be extracted. This suppression is enhanced at low PT.

1 Introduction

NA38 is a dedicated experiment for the study of muon pairs produced in interactions of ultra-relativistic ions with dense matter. Several authors [1] have underlined the possibility that a phase transition could occur in such interactions, provided that the energy density reached is high enough. It would lead to a new state of matter, the quark-gluon plasma (quagma), which would exhibit specific observable properties.

Among the proposed signatures of the quagma, the production of lepton pairs has been advocated as one of the most direct [2], since it is not affected by the hadronization phase. More recently the suppression of the J/Ψ resonance has been predicted [3] and should provide a very clean signature. Moreover, this effect is expected to depend on the momentum of the dimuon [4]: the suppression should increase with decreasing momentum.

The results presented here are based on data taken with a 200 GeV/nucleon beam impinging on an uranium target. Muon pairs characteristics have been measured and correlated with the corresponding transverse energy produced in the collision.

The study of the data is still in progress and the results presented here reflect the status of the analysis at the time of the conference.

2 The experiment

The experiment was run at very high intensities (5–10)$\cdot 10^7$ ions/burst, requiring very fast electronics and an efficient pile-up rejection. The apparatus was triggered on muon-pairs at a rate of 500–1000 events per burst; a second level trigger, based on a CAB-microprocessor, rejected very low mass muon pairs, so that 250 events per burst could be reported on

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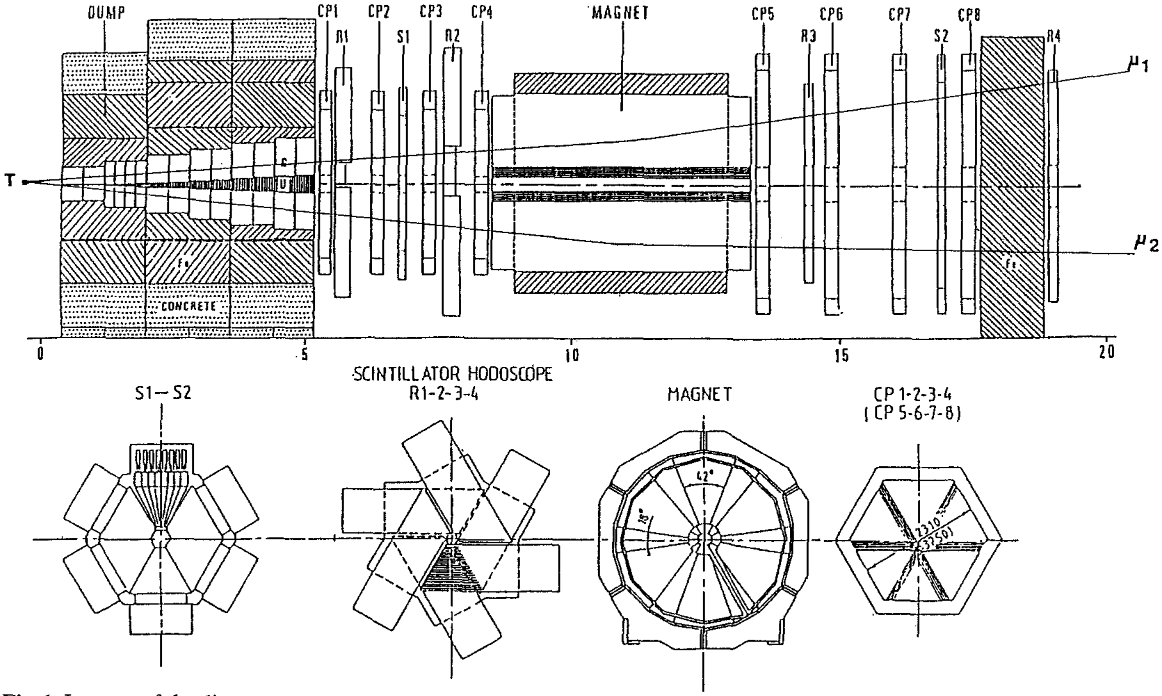

Fig. 1. Lay-out of the dimuon spectrometer

tape with acquisition livetime higher than 90%. The apparatus consists of a muon spectrometer, an electromagnetic calorimeter, a multiple active target and specific beam detectors [5].

2.1 The spectrometer

Figure 1 shows the lay-out of the spectrometer, already used at CERN in the NA10 experiment [6]. The muons produced at the target T are detected by two sets of four multiwire proportional chambers, CP1–CP4 and CP5–CP8, located respectively upstream and downstream of a magnet. Four hodoscopes, R1–R4, made of plastic scintillators, provide the trigger. The magnet is an air-core toroid with hexagonal symmetry, which determines the geometrical structure of all the other components of the apparatus. A 4.8 m long absorber, located after the target, is used as a muon filter and allows also to dump the non-interacting part of the incident beam. Dimuons of mass larger than 0.5 GeV/c^2 are detected in the pseudo-rapidity range $2.8<\eta<4$ in the laboratory. For the J/Ψ, the mass resolution is 5% and the acceptance 7%.

2.2 The electromagnetic calorimeter

The 12 cm long compact calorimeter has an outer radius of 12 cm and a central hole of 2.5 cm in diameter. It is made of scintillating fibers (1 mm diameter) embedded in lead in a 1/2 volume ratio ($X_0 = 8.3$ mm). It is segmented in 30 cells, in a five rings arrangement covering the pseudo-rapdity range $2<\eta<4.2$ and exhibits the same hexagonal symmetry as the spectrometer. The energy resolution is $0.25/\sqrt{E}$.

2.3 The multiple active target

Ten uranium subtargets (1 mm thick, 1×3 mm^2), 24 mm apart, are surrounded by 24 ring-scintillators, as shown in Fig. 2. For each interaction, the energy deposited in each scintillator is measured, allowing the identification of the subtarget, where the interaction took place, and the rejection of events with a secondary interaction.

2.4 The beam detectors

As a consequence of the high intensity required by the experiment, pile-up rejection is mandatory in order to eliminate biased energy measurements. This is achieved by the use of two kind of detectors in the incident beam, as shown in Fig. 2.

A beam hodoscope, made of two parallel planes of 14 and 16 scintillators respectively, is located 33 m upstream of the target, at a place where the beam spot is large enough to allow individual identification of the incoming ions. An efficient pile-up rejection is obtained by flagging events with more than one incident ion within the 20 ns gate of the ADC's.

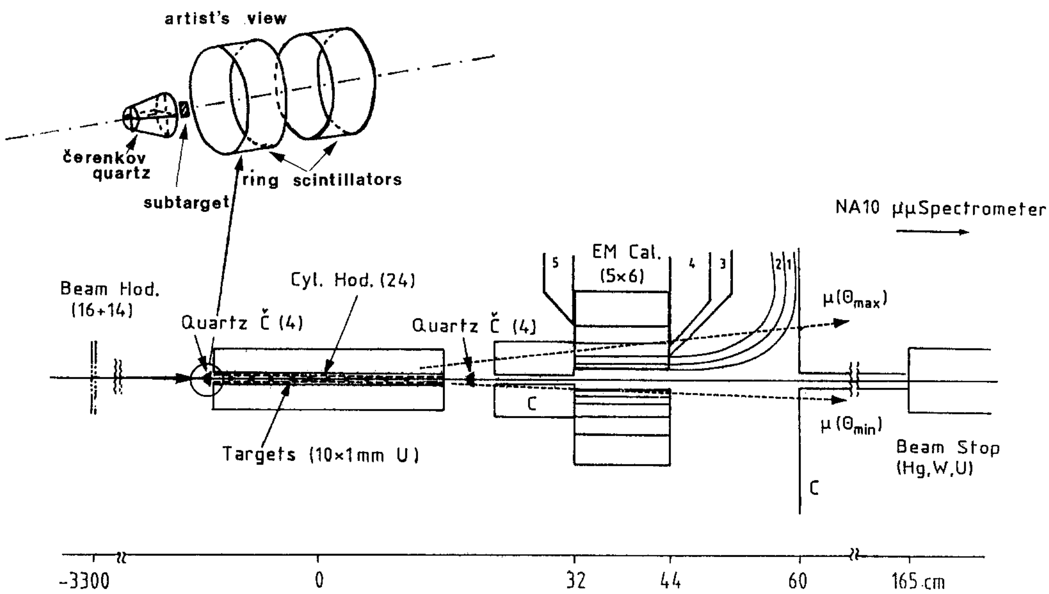

Fig. 2. Lay-out of the electromagnetic calorimeter, the multiple active target and the beam detectors

Upstream and downstream of the active target, Fig. 2, two quartz Cerenkov counters, immune to the high radiation level, are used for pile-up rejection, in conjunction with the beam-hodoscope. Their azimuthal segmentation in four quadrants allows a precise centering of the beam on the very small subtargets.

Three sets of scintillator-telescopes, perpendicular to the beam-line, located around the target, are used to monitor the interaction rate.

3 Data reduction

Data were taken in the fall of 1986 with a first period of 200 GeV protons on uranium. This was followed by an oxygen-ion period at 200 GeV/nucleon and 60 GeV/nucleon, during which data were taken for oxygen-uranium and oxygen-copper interactions. Table 1 summarizes the characteristics of the beams and the number of reconstructed muon pairs for the various running conditions. The present analysis is based on a total of $2.5*10^6$ reconstructed muon pairs of any sign produced in oxygen-uranium collisions at 200 GeV/nucleon.

The data reduction for the subsample of events taken at $5*10^7$ ion/burst gives 450 K opposite-sign and 320 K like-sign pairs, after applying the following criteria, which reject 62% of the events:

Pile-up (42%): only one incident ion.

Target (17%): one subtarget identified and no secondary interaction.

Trigger and vertex (3%): trigger conditions satisfied and calculated z-vertex in the target.

Table 1. Beam characteristic and number of reconstructed muon-pairs for the 1986 data

Beam	Energy (GeV/A)	Intensity (Ion/Burst)	Events ($\mu\mu$)
p+U	200	$5*10^7$	$6*10^5$
O+U	200	$5*10^7$	$2*10^6$
O+U	200	10^8	$5*10^5$
O+Cu	200	$5*10^7$	$8*10^5$
O+U	60	$5*10^7$	$6*10^5$

The sample of like-sign muon pairs is dominated by muons originating from π and K decays. It is used to determine the number of background events in the sample of opposite-sign pairs. The prompt dimuon signal is then given by the well known formula:

$$\text{signal} = (\mu^+\mu^-) - 2\sqrt{(\mu^+\mu^+)*(\mu^-\mu^-)}.$$

Figure 3 shows the mass spectra for the opposite-sign and like-sign muon-pairs, and for the prompt dimuon signal. One should notice that the background is large in the raw spectra for low mass events, but is very small in the J/Ψ region. On the final mass spectrum, the J/Ψ resonance shows-up clearly above a steeply decreasing continuum originating mainly from Drell-Yan pairs and charmed particles decays.

The corresponding distributions of transverse neutral energy ET are shown on Fig. 4, for the opposite-sign, the like-sign pairs and for the signal. The shape of the distribution shows a depression in the low energy region, because our trigger favours collisions with a large number of participant nucleons.

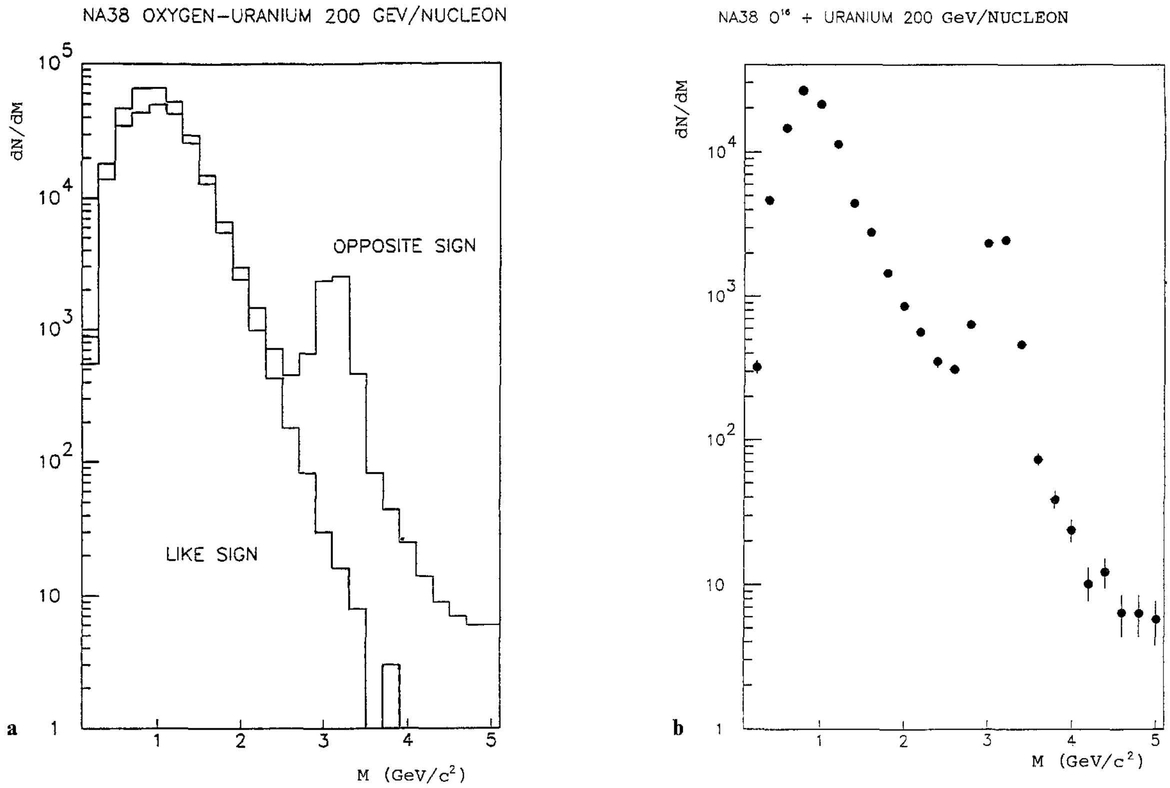

Fig. 3a, b. The mass spectra for the opposite-sign and like-sign muon pairs **a** and for the dimuon signal **b**

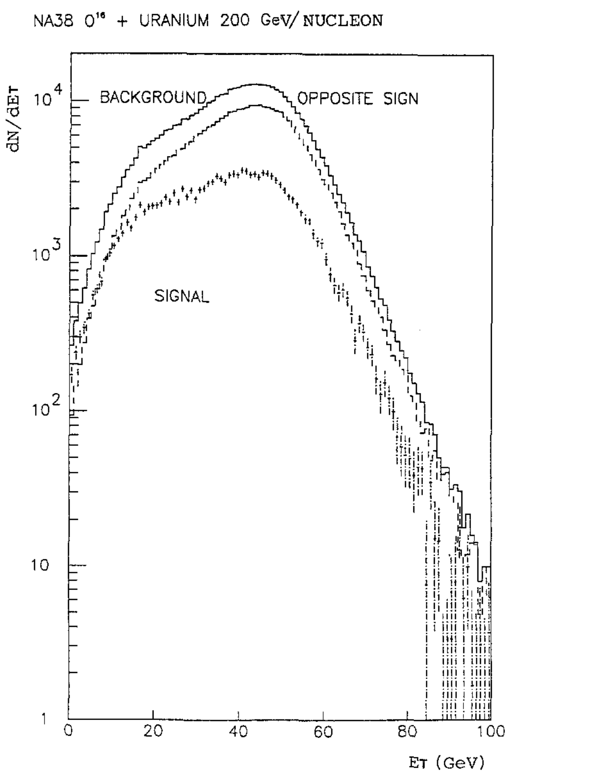

Fig. 4. The measured transverse energy distributions for the opposite-sign and like-sign (background) pairs, and for the signal. These distributions contain 5% of events satisfying the additional trigger condition $ET > 40$ GeV

The measured transverse energy corresponds to about one half of the total transverse energy (neutral energy plus one third of the charged hadronic energy) in the covered pseudo-rapidity range. It should be noted that the values quoted for the transverse energy are "raw values" uncorrected for acceptance and smearing. The measured transverse energy will be used mainly as an indicator of the energy density of the interaction, although it is obviously correlated to the centrality of the collision.

4 Analysis and results

The analysis presented here is a preliminary study of the J/Ψ production relative to the continuum, as a function of the transverse energy in the collision. The predicted J/Ψ suppression would imply a decrease of the relative yield of the resonance with increasing energy density which, in our experiment, is estimated from the neutral transverse energy ET. In order to get rid of the low energy resonance region (rho, omega, phi), the analysis is limited to muon pairs of mass larger than 1.7 GeV/c^2, a region where we can fit the shape of the continuum with a simple formula. We are then left with about 15000 events, roughly one half in the J/Ψ mass region ($2.7 < M < 3.5$ GeV/c^2) and one half in the continuum ($1.7 < M < 5.3$ GeV/c^2).

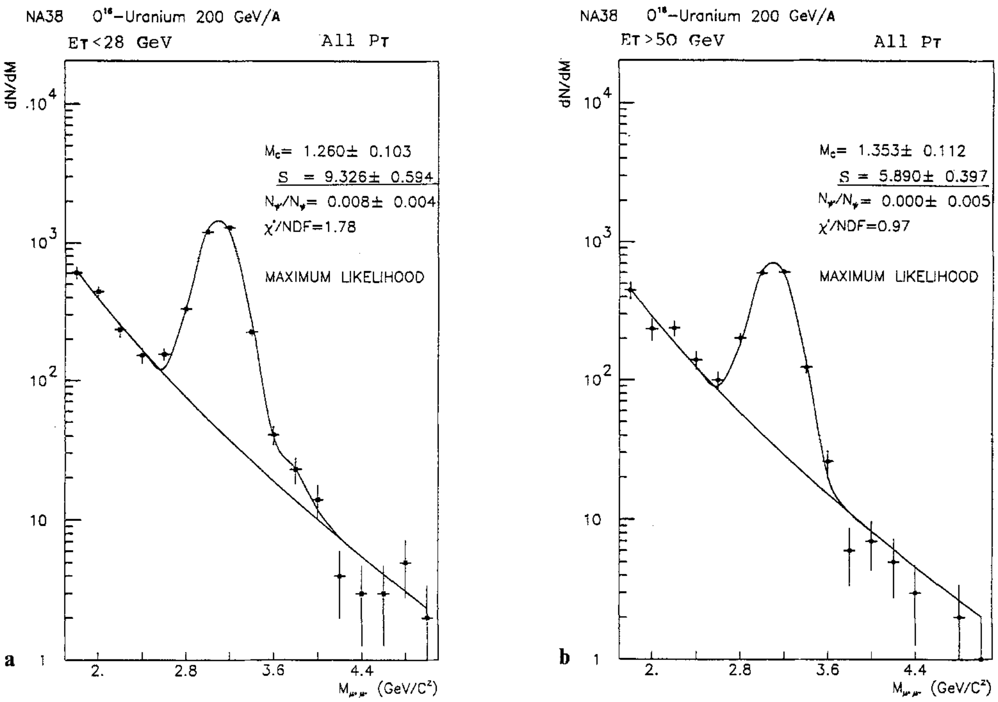

Fig. 5a, b. The fitted mass spectra for events with low transverse energy **a** and for events with high transverse energy **b**

Table 2. Fitted values of the continuum slope Mc and the ratio $S = N\psi/Nc$ in the range $2.5 < M < 3.5$ GeV/c²

	a) All *PT*	
ET	*Mc*	*S*
All *ET*	1.21 ± 0.05	8.3 ± 0.3
$ET < 28$ GeV	1.26 ± 0.1	9.3 ± 0.6
$28 < ET < 40$	1.30 ± 0.1	7.9 ± 0.5
$40 < ET < 50$	1.15 ± 0.1	7.4 ± 0.5
$ET > 50$ GeV	1.35 ± 0.1	5.9 ± 0.4

	b) $PT > 1$ GeV/c		b) $PT < 1$ GeV/c	
ET	*Mc*	*S*	*Mc*	*S*
All *ET*	1.62 ± 0.1	10.9 ± 0.6	1.03 ± 0.05	6.8 ± 0.3
$ET < 28$ GeV	1.83 ± 0.3	10.6 ± 0.9	1.01 ± 0.1	8.7 ± 0.8
$28 < ET < 40$	1.77 ± 0.3	9.9 ± 0.9	1.07 ± 0.1	6.5 ± 0.6
$40 < ET < 50$	1.58 ± 0.3	11.8 ± 1.2	0.91 ± 0.1	5.7 ± 0.5
$ET > 50$ GeV	1.37 ± 0.3	7.6 ± 0.8	1.33 ± 0.2	4.6 ± 0.5

The mass spectrum has been fitted with the superposition of an exponential multiplied by $1/M^3$ for the continuum and two gaussians for the resonances J/Ψ and Ψ' according to the following expression:

$$\frac{dN}{dM} = Nc\left\{\frac{e^{\frac{-M}{Mc}}}{Cc*M^3} + \frac{N\psi}{Nc}\left[\frac{e^{\frac{-(M-M\psi)^2}{2\sigma^2\psi}}}{C\psi} + \frac{N\psi'}{N\psi}\,\frac{e^{\frac{-(M-M\psi')^2}{2\sigma^2\psi'}}}{C\psi'}\right]\right\}$$

where Cc, $C\psi$ and $C\psi'$ are normalization factors, $M\psi$, $M\psi'$, $\sigma\psi$ and $\sigma\psi'$ are the masses and widths of the resonances, Mc is related to the slope of the continuum, $N\psi/Nc$ is the ratio of the J/Ψ over the continuum and $N\psi'/N\psi$ is the ratio of the Ψ' over the Ψ. In a check of the reconstruction procedure, the fitted mass of the J/Ψ is $M = 3.102 \pm 0.003$ GeV/c², and its width $\sigma = 0.155 \pm 0.003$ GeV/c² agrees with the calculated mass resolution of the spectrometer.

In the following, $M\psi$, $M\psi'$, $\sigma\psi$ and $\sigma\psi'$ are fixed and the three fitted parameters are Mc, $N\psi/Nc$ and $N\psi'/N\psi$. This last ratio appears to be meaningless, because of the poor statistics on the Ψ'. In order to look for the predicted J/Ψ suppression with increasing ET, we study the ratio S of the fitted number of J/Ψ events relative to the fitted number of events in the continuum, in the mass range $2.5 < M < 3.5$ GeV/c²*.

Figure 5 shows the fitted mass spectra for the events with low transverse energy ($ET < 28$ GeV) and for those with high transverse energy ($ET > 50$ GeV). Table 2a displays the fitted value of the parameter

* At the presentation at the conference, the interval used for the determination of S was misquoted as $2.7 < M < 3.5$ GeV/c²

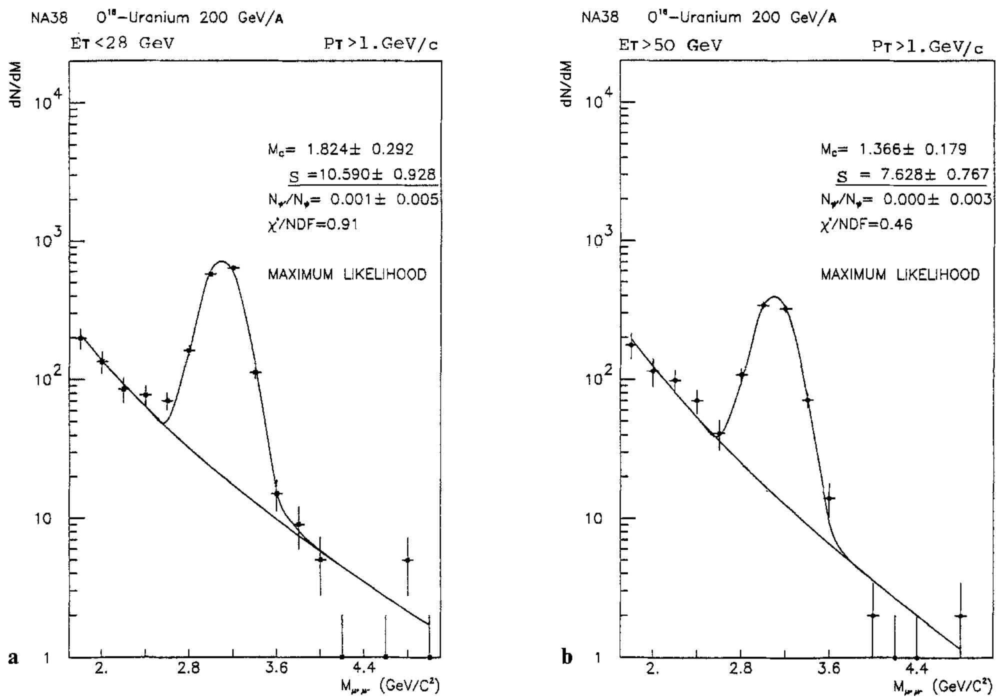

Fig. 6a, b. Same as Fig. 5 but for events with high transverse momentum

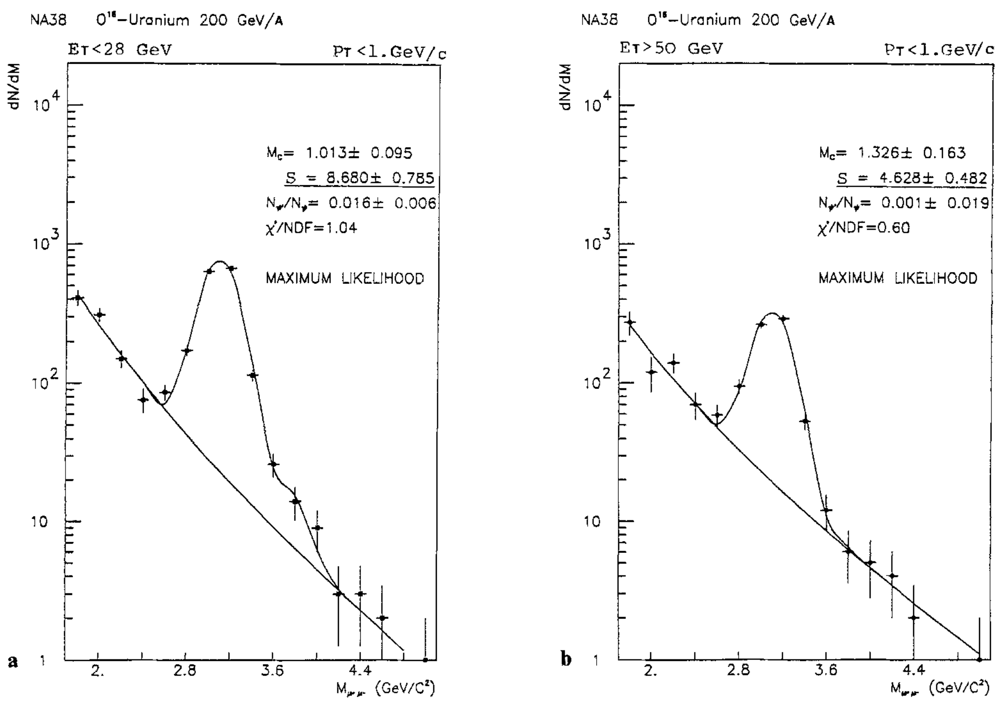

Fig. 7a, b. Same as Fig. 5 but for events with low transverse momentum

Mc and the ratio S in four ET bands, choosen to be roughly equally populated. It shows a net decrease of S with increasing ET: the J/Ψ-suppression appears from the ratio of the values of S for the extreme ET bands

$$(S \text{ at high } ET)/(S \text{ at low } ET) = 0.64 \pm 0.06.$$

On the contrary, the slope of the continuum Mc remains constant, within errors, as ET increases. It should be noted that the S values presented here do

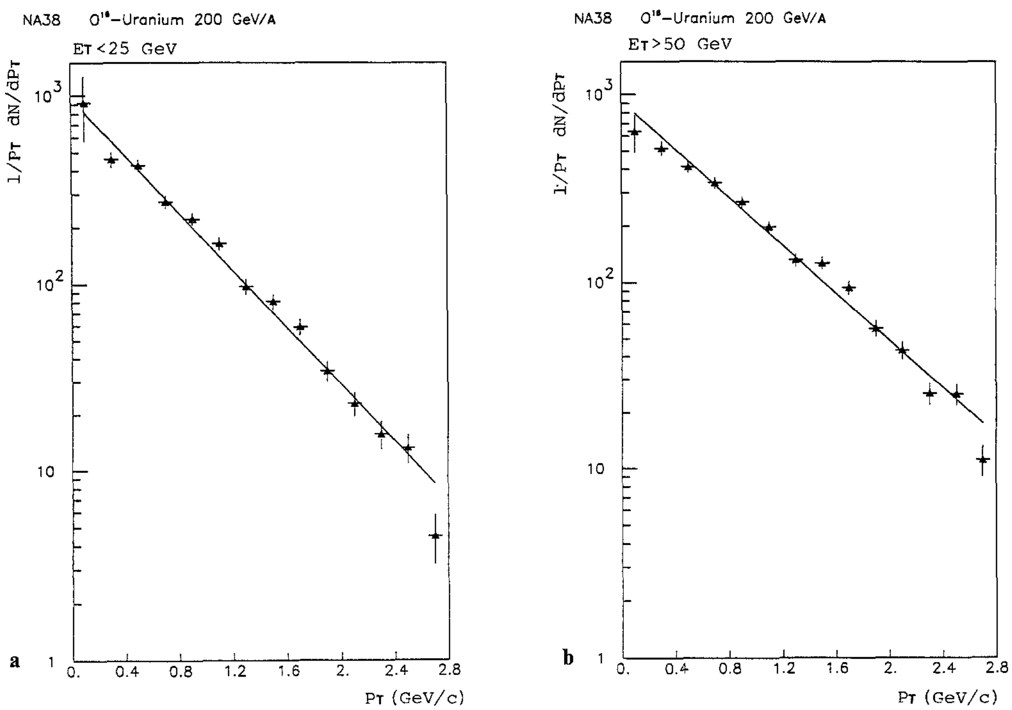

Fig. 8a, b. The PT distributions, in the J/Ψ mass range $2.7<M<3.5$ GeV/c^2, for events with low transverse energy **a** and for events with high transverse energy **b**. The lines correspond to simple exponential fits through the data

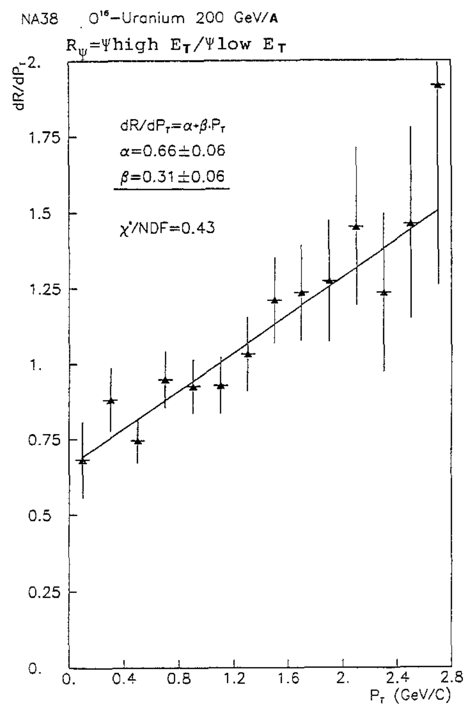

Fig. 9. The ratio (Ψ high ET/Ψ low ET) as a function of PT

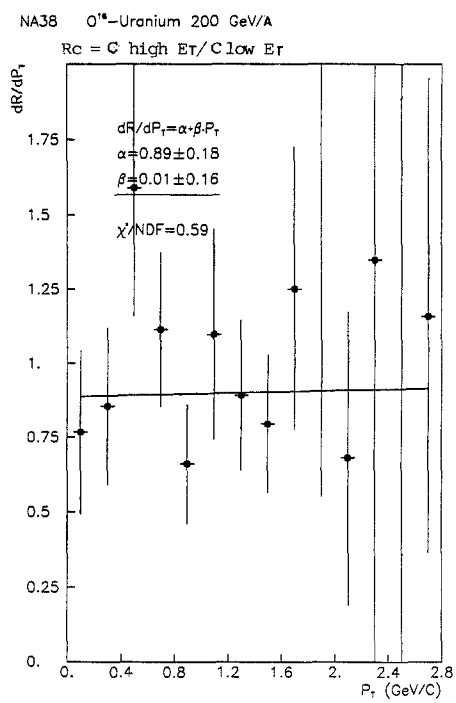

Fig. 10. The ratio (C high ET/C low ET), for the continuum events with $M>1.6$ Gev/c^2, excluding the J/Ψ region

not include any acceptance correction and depend on the mass interval adopted for their determination. However, the ratio of S values in different ET intervals should be independent of such a correction and other systematic effects.

In order to look for a possible dependence of the J/Ψ suppression on the transverse momentum PT of the dimuon, the data have been divided into low-PT events ($PT<1$ GeV/c) and high-PT events ($PT>1$ GeV/c). The above fitting procedure has

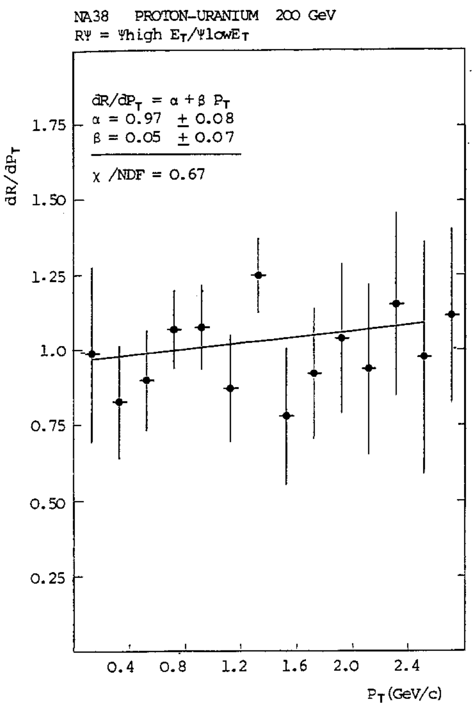

Fig. 11. Same as Fig. 9, but for proton-uranium data

been applied to both PT samples. The results are shown on Fig. 6 for $PT>1$ GeV/c, and Fig. 7 for $PT<1$ GeV/c. The values of S for $PT<1$ GeV/c and $PT>1$ GeV/c are given in Table 2b. The ratios (S at high ET/S at low ET) are 0.72 ± 0.11 for $PT>1$ GeV/c and 0.53 ± 0.08 for $PT<1$ GeV/c, showing that the J/Ψ suppression is enhanced for low PT.

The dependence of the J/Ψ suppression on the transverse momentum PT has also been investigated by studying the PT distribution of events in the mass range corresponding to the J/Ψ, $2.7<M<3.5$ GeV/c^2. In fact these distributions, though dominated by true J/Ψ events, are contaminated by a small amount of continuum (from 7% at low-ET to 11% at high-ET). These PT distributions, displayed on Fig. 8 for the low ET and the high ET bins, show a steeper shape for low ET. The ratio of these two PT distributions, $R\psi = (\Psi$ high $ET)/(\Psi$ low $ET)$, is plotted on Fig. 9, as a function of the PT of the J/Ψ. The ratio increases with increasing PT, indicating that the J/Ψ suppression is more pronounced at low PT. A linear fit through the ratios leads to a slope of 0.31 ± 0.06.

The same study of the ET dependence of the PT distributions has been performed for the events in the continuum with mass larger than 1.6 GeV/c^2, excluding the J/Ψ region ($2.7<M<3.5$ GeV/c^2). Figure 10 shows the ratio $Rc =$ (Cont high ET)/(Cont low ET) which is clearly independent of PT, reflecting the fact that the PT distribution of the continuum does not depend on transverse energy.

Finally a comparison has been made with the proton-uranium data at 200 GeV. The ratio $R\psi = (\Psi$ high $ET)/(\Psi$ low $ET)$ is plotted on Fig. 11, for the J/Ψ region ($2.7<M<3.5$ GeV/c^2), as a function of PT. The ratio is found to be independent of PT, as in Fig. 10 (the corresponding slopes are both compatible with zero).

5 Conclusion

The dimuon production in 200 GeV/nucleon oxygen-uranium interactions, studied by the NA 38 collaboration, shows that:

i) The ratio Ψ/Continuum (our parameter S) decreases with increasing ET.

ii) The J/Ψ relative suppression can be expressed as:

$$(S \text{ at high } ET)/(S \text{ at low } ET) = 0.64 \pm 0.06.$$

iii) This J/Ψ suppression is enhanced at low PT.

The fact that the PT-distribution of the continuum does not depend on ET is an indication for J/Ψ suppression rather than continuum enhancement.

Although this effect has been predicted as a signature of quagma formation, it is not excluded that collective or nuclear effects could explain, at least partly, our experimental results.

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