THE SEARCH FOR THE QUARK-GLUON PLASMA STUDY OF PRODUCTION OF CHARMED BOUND STATES IN PB-PB COLLISIONS AT 158 GEV/NUCLEON

presented by Albert Romana for the NA50 Collaboration

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The NA50 Collaboration has studied the production of dimuons originating from J/ψ, ψ' and Drell-Yan virtual photons in Pb-Pb collisions at 158 GeV/nucleon. The J/ψ production differs from what is expected when extrapolating from previously studied colliding systems. Going from peripheral to central collisions, the J/ψ suppression presents a sudden and clear drop-off which we refer here as an "anomalous suppression".

1 Introduction

Since 1986, the NA38 Collaboration [1] has studied the production of dimuons in ultrarelativistic heavy ion collisions, in a search for quark-gluon plasma (QGP) formation. In particular, J/ψ suppression was predicted to be a clear signature of QGP [2]. The J/ψ suppression which is measured with proton, oxygen and sulfur beams on several targets at the CERN SPS is now understood in terms of nuclear absorption. The study has been extended in 1995 and 1996 to Pb-Pb collisions by the NA50 Collaboration, which has used the same dimuon spectrometer as the NA38 experiment and performed a major upgrade of the beam detector, the active target system and the centrality detectors, as presented in section 2. Based on a new analysis method described in section 3, preliminary results on J/ψ, ψ' and Drell-Yan production are presented in section 4. We report here an anomalous J/ψ suppression in Pb-Pb collisions in comparison with the suppression observed in lighter systems. The data allow a detailed study of the suppression pattern in the Pb-Pb sample itself, showing a discontinuity around an E_t value of 40 GeV.

2 DESCRIPTION OF THE APPARATUS AND DATA TAKING CONDITIONS

The NA50 apparatus [3] consists of a muon spectrometer complemented by detectors used to define the incoming beam, recognize interactions in the target and measure the centrality of the collision. The description of the muon spectrometer can be found elsewhere [3]. Dimuons are detected with a good acceptance in the rapidity interval $2.92 \leq y_{lab} \leq 3.92$ (corresponding to $0 \leq y_{cm} \leq 1$) and $-0.5 \leq cos(\theta_{CS}) \leq 0.5$, θ_{CS} being the muon polar angle in the Collins-Soper frame, with a mass resolution of 3.2% at the J/ψ.

A 16-segment quartz beam hodoscope (BH), located 22 m upstream the target (where the beam transverse dimension is large) is used to count the incident ions and reject beam pile-up. The active target is made of 7 Pb subtargets with vertex identification and rejection of reinteracting fragments provided by quartz Cerenkov counters. Note that the length of all subtargets was 1 mm (19% of a Pb interaction length) in 1995 while it was increased to 2 mm for five of them (32% of a Pb interaction length) in 1996. The event centrality is estimated using three independent detectors : neutral transverse electromagnetic energy E_t is measured by means of a lead-scintillating fibers calorimeter ($1.1 \leq \eta_{lab} \leq 2.3$), subdivided in 6 azimuthal sectors and 4 rings; energy of non-interacting beam fragments E_{ZDC} is measured with a tantalum-quartz fibers zero degree calorimeter ($\eta_{lab} \geq 6.2$); charged multiplicity is obtained from a 2-plane high granularity silicon strip multiplicity detector ($1.5 \leq \eta_{lab} \leq 3.5$), completed in 1996.

The first production run took place in the fall of 1995, where 56 10^6 dimuon triggers were collected at an average intensity of 3.2 10^7 ions per burst, giving about 50 000 J/ψ events for analysis.

In 1996, the average intensity was increased to 5.4 10^7 ions per burst and the beam quality was improved, reducing significantly the out-of-target background. We were then able to collect about 170 10^6 triggers, among which 250 000 J/ψ events.

3 METHOD OF ANALYSIS

A first selection of events is made according to the following criteria : only one incident ion is detected by the BH, with no interaction in the BH itself, no signal is present in the halo counters surrounding the target, two and only two tracks are in the fiducial region of the spectrometer and both would be accepted in a reverse magnetic field, in order to have the same acceptance for any charge state of the muon pair.

Target identification is based on an algorithm using the quartz Cerenkov blades in 1995. Because this method has a poor efficiency for peripheral collisions and thanks to better beam conditions in 1996, a new method has been developed, based on a contour-cut on the E$_t$-E$_{ZDC}$ correlation at a 2σ level (cf figure 1). This method allows to recover most of the lost peripheral collisions : for these events, no precise target assignment can be done, therefore both the transverse energy and the mass distribution suffer from a a slightly worse resolution (mass resolution at the J/ψ mass increases from 96 to 104 MeV/c^2 when going from intermediate to low centrality). In order to reject events produced out of target, a severe cut on the distance between each muon track and the beam axis is applied.

The invariant mass spectrum for opposite sign dimuons is shown in figure 2, for the 1995 data sample.

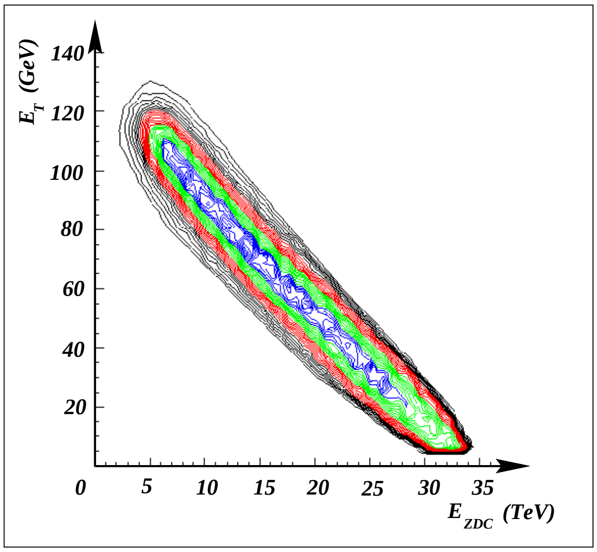

Figure 1: Et-EZDC correlation

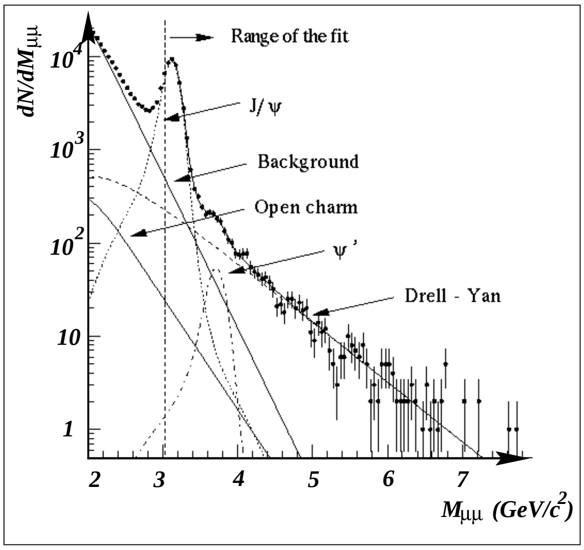

Figure 2: Fit of the mass spectrum

The contribution from two muons originating from uncorrelated meson decays (background) is evaluated with a standard procedure using the two like-sign samples of muon pairs. The signal to background ratio is larger than 10 at the J/ψ peak. The open charm semileptonic decays are primarily fitted in the intermediate mass region ($1.9 \leq M \leq 2.9$) using a shape distribution given by Pythia and allowing a charm-like excess. The mass spectrum is then fitted by adding the contributions of the J/ψ, ψ' and Drell-Yan, whose shapes are determined with a Monte-Carlo simulation.

$$\frac{dN^{+-}}{dM} = A_{J/\psi}\frac{dN^{J/\psi}}{dM} + A_{\psi'}\frac{dN^{\psi'}}{dM} + A_{DY}\frac{dN^{DY}}{dM} + \frac{dN^{D\bar{D}}}{dM} + \frac{dN^{bg}}{dM} \quad (1)$$

The fit (equation 1) is performed above 3.05 GeV/c^2 with five free parameters $A_{J/\psi}$, $A_{\psi'}$, A_{DY} and the mass and width of the gaussian part of the J/ψ shape. Mass and width of the ψ' are linked to those of the J/ψ.

The mass spectrum can be fitted for the whole sample of data or for separate E$_t$ bins, typically 5 bins for the 1995 data and 15 bins for the 1996 data thanks to the higher statistics, in particular at low E$_t$.

4 THE RESULTS

4.1 The Drell-Yan dimuons

The measured Drell-Yan cross-section ($2.9 \leq M_{\mu\mu} \leq 8.0$) for Pb-Pb interactions at 158 GeV/nucleon is $\sigma_{DY}(Pb + Pb \rightarrow \mu^+\mu^-) = 1.49 \pm 0.03 \pm 0.11\ \mu b$. In order to compare this value with p-p and p-d at 450 GeV/c [4] and p-W and S-U values at 200 GeV/c, one has to rescale the results at the same beam momentum (158 GeV/c). An isospin correction has also to be applied in order to account for the isospin composition of the nuclei which is done according to equation 2 :

$$\sigma_{DY}^{AB}(corrected) = \sigma_{DY}^{AB}(measured) \times \frac{\sigma_{DY}^{pp}(theory)}{\sigma_{DY}^{AB}(theory)} \tag{2}$$

where $\sigma(theory)$ is a theoretical cross-section for the Drell-Yan process computed at the leading order using the MRS-43 set of parton distributions[8].

The power law of equation 3 which usually parametrises the nuclear dependence for hard processes production

$$\sigma(A+B) = \sigma(pp)(AB)^{\alpha} \tag{3}$$

is then fitted to the data and a value of $\alpha = 1.002 \pm 0.011$ is found, which indicates that no nuclear absorption affects the Drell-Yan process, as expected, and therefore that this process can be used as a reference for subsequent studies.

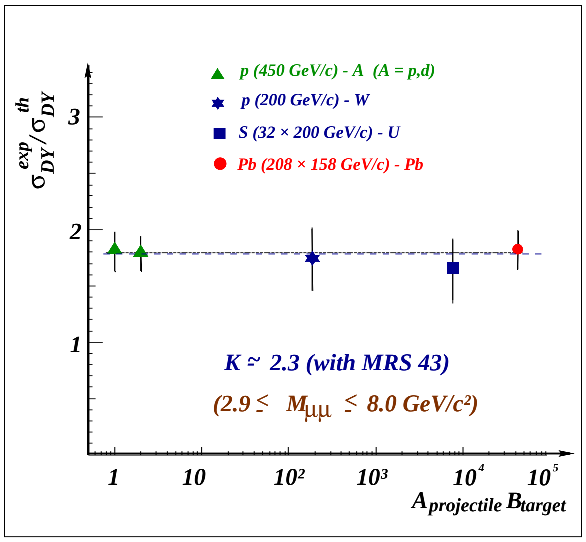

Figure 3: The Drell-Yan cross-section

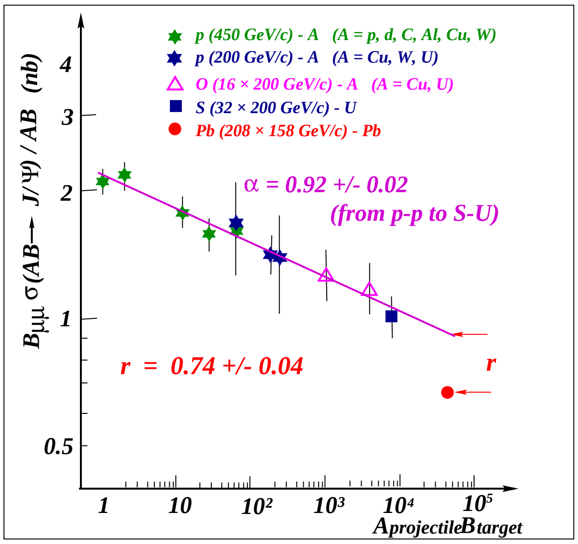

Figure 4: The J/ψ cross-section

4.2 The J/ψ cross-section

The scaling of the J/ψ cross-section times the branching ratio with AB is also well described by expression 3 from p-p to S-U collisions with $\alpha = 0.92 \pm 0.02$, as shown in figure 4. The 450 GeV/c and 200 GeV/c results are rescaled to 158 GeV/c using the Schuler parametrisation [7] and having checked that p-W results which were measured at both 450 and 200 GeV/c obey the rescaling law. These results indicate a nuclear effect which has been interpreted as absorption of the pre-resonant $c\bar{c}$ state in nuclear matter [6].

The measured Pb-Pb cross-section, $B_{\mu\mu}\sigma_{J/\psi} = 21.9 \pm 0.3 \pm 1.6\ \mu b$, is significantly lower, a factor 0.74 ± 0.04, than the extrapolation obtained from the absorption fit line. This result suggests a new mechanism responsible for what has been quoted as "anomalous J/ψ suppression".

4.3 The J/ψ over Drell-Yan ratio

To investigate further charmonium suppression, we now consider the $B_{\mu\mu}\sigma_{J/\psi}\ /\ \sigma_{DY}$ ratio, since we have shown that the Drell-Yan production is proportional to the number of collisions. Moreover, this ratio is free from all particular systematic errors which affect J/ψ as well as

Drell-Yan production. Figure 5 shows this ratio as a function of E_t for the 1995 data sample in 5 bins and the 1996 data sample in 15 bins, extending to more peripheral collisions. In this figure, neither energy rescaling nor isospin correction are needed. Besides the good agreement between the two data sets, one observes a clear jump in the value of the ratio at $E_t \simeq 40$ GeV (where the E_t resolution is about 5 GeV), corresponding to an impact parameter $b \simeq 8fm$, with different patterns below and above the jump.

In order to compare with the NA38 data, i.e. different systems in collision, characterised by different kinematics and different experimental E_t coverages, a new variable is needed. We present results in figure 6 as a function of L, defined as the geometrical mean path length of the produced $c\bar{c}$ state through nuclear matter. L is computed via a Monte-Carlo program which, for a given impact parameter b, performs a weighted average over the possible production points using a standard Woods-Saxon nuclear density function ρ (equation 4) :

$$\bar{L}(b) = \frac{1}{\rho_0} < \rho L > \tag{4}$$

The averaged L for each transverse energy bin is computed via a relation between E_t and b (see [3]) and is essentially independent on the precise knowledge of the absolute E_t scale. All 450 and 200 GeV data presented in this figure are rescaled to 158 GeV and Drell-Yan cross-sections are corrected for isospin effects, using formula 2 and MRS 43 [8] as above. A good fit to the proton

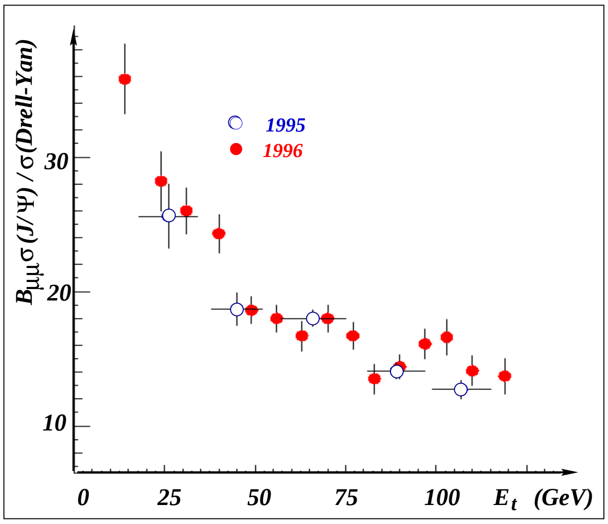

Figure 5: The ratio J/ψ / DY versus E_t

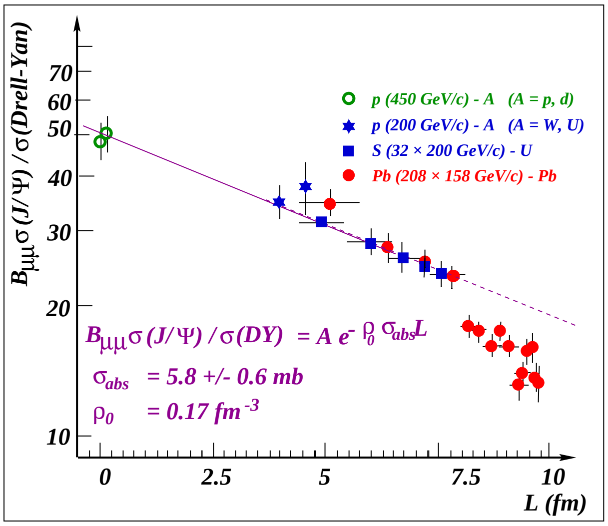

Figure 6: The ratio J/ψ / DY versus L

and S-U data is obtained with the absorption model described by equation 5 :

$$B\sigma_{J/\psi} \ / \ \sigma_{DY} = exp(-\rho_0 \sigma_{abs} L) \qquad with \qquad \sigma_{abs} = 5.8 \pm 0.6\ mb \tag{5}$$

One observes that the peripheral Pb-Pb points are fully compatible with the absorption model while a sharp drop is visible at L $\simeq$ 8 fm, suggesting that the absorption by participant nucleons cannot be the only mechanism responsible for the observed J/ψ suppression.

4.4 The ψ' over Drell-Yan ratio

The $B_{\mu\mu}\sigma_{\psi'} \ / \ \sigma_{DY}$ ratio can provide complementary information on the mechanisms at work for charmonium suppression since the ψ' has a larger radius and hence a lower threshold for break-up than the J/ψ. This ratio is presented in figure 7 for proton-nucleus, S-U and Pb-Pb collisions as a function of L, with the absorption line of equation 5 superimposed to the data.

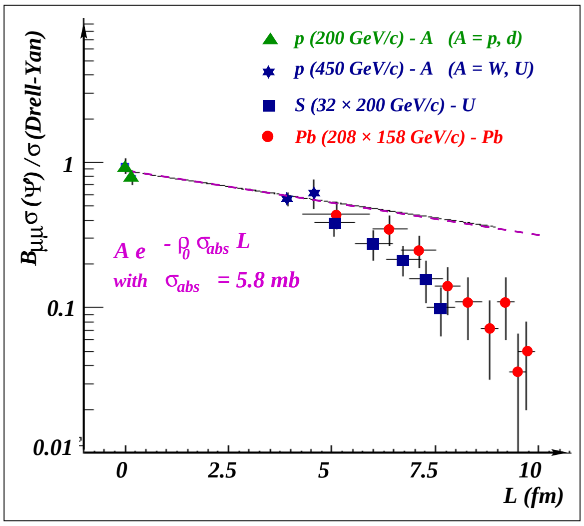

Figure 7: The ratio ψ' / DY versus L

While p-nucleus data are compatible with the J/ψ absorption law, both S-U and Pb-Pb ratios depart from it with a very similar suppression pattern starting at lower L values than the J/ψ one. This suggests that a common mechanism for ψ' suppression could be at work in S-U and Pb-Pb collisions.

Absorption by comovers (hadrons produced in the vicinity of the $c\bar{c}$ state) has been proposed as a candidate suppression mechanism both for J/ψ and ψ' [9]. In this model, the absorption cross-section of the $c\bar{c}$ state by participant nucleons is somehow smaller and the interaction cross-section with the comovers is significantly different for the J/ψ and the ψ'.

However, the sharp decrease of the J/ψ / DY ratio at L $\simeq$ 8 fm is not reproduced satisfactorily by this model, whereas a threshold effect in the J/ψ production may be understood in the case of formation of a quark-gluon plasma.

5 Conclusions

The NA38 experiment has measured dimuon production in p-A, O-U and S-U interactions. The J/ψ suppression measured from p-p to S-U can be understood in terms of absorption (of the $c\bar{c}$ state in the nuclear matter and/or of the resonance itself by comovers).

In Pb-Pb interactions (NA50 experiment) an anomalous J/ψ suppression is measured : the E$_t$ integrated cross-section is reduced by a factor 0.74 $\pm$ 0.04 with respect to the expected one and the $B_{\mu\mu}\sigma_{J/\psi}$ / σ_{DY} ratio shows a clear discontinuity at E$_t$ $\simeq$ 40 GeV (L $\simeq$ 8 fm).

The ψ' suppression relative to Drell-Yan behaves similarly in S-U and Pb-Pb collisions.

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