Anomalous J/ψ suppression in 158 GeV/c Pb-Pb interactions at the CERN SPS

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presented by C. Baglin for the NA50 collaboration:

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Abstract

Heavy ion production of J/ψ mesons has been studied at CERN for a decade, in search for the Quark-Gluon Plasma predicted by lattice-QCD. The suppression observed very early in O-Cu,O-U and S-U reactions has been shown to be eventually explained by nuclear absorption, and follow the same exponential behavior as the proton-nucleus reactions. The new Pb-Pb data deviate from this behavior very strongly, indicating the onset of a new regime in J/ψ suppression.

1 Introduction

Quarks and gluons are known to be confined within hadronic matter. In the frame of the Standard Model the early universe was a deconfined quark and gluon plasma (QGP). As it expanded and cooled down to its present configuration, a phase transition from QGP to confined matter occured at some stage. Within the QCD theory, lattice-calculations predict the existence of such a phase transition [1], which can possibly occur in heavy-nucleon collisions at the SPS energies. If a QGP were produced in these collisions, the resulting color screening would dissociate the $c\bar{c}$ pairs, therefore preventing their hadronization to a J/ψ meson. J/ψ-suppression has thus been proposed [2] as a signature of the QGP.

From 1986 to 1992 the CERN experiment NA38 has studied dimuon decays of charmonium produced in various $A_{projectile}B_{target}$ (nucleon-nucleus and/or nucleus-nucleus) reactions. Dimuons originating from the Drell-Yan (DY) process were naturally recorded at the same time; they were used as reference sample since this primary electromagnetic process cannot be affected by the QGP. From the early days of NA38, important decreases of the ratio J/ψ/DY were observed in all central ion-collisions [5]. A long series of subsequent theoretical efforts converged to a consistent interpretation of these results in term of nuclear absorption of a pre-resonance $c\bar{c}g$ state [4]

2 The Pb-Pb experiment: setup and data analysis

The muon spectrometer was that of NA38 [5] whose electromagnetic calorimeter was supplemented with a Zero Degree Calorimeter (ZDC), made of tantalum-imbedded Čerenkov quartz fibers and a silicon-strips multiplicity detector, for centrality measurements. To cope with the high level of radiation damage from the Pb-beam, the new beam hodoscope (BH), (for luminosity measurement and beam pile-up detection), was made of Čerenkov quartz blades. The system of 7 active Pb-subtargets (17% int. length) also used quartz Čerenkov blades, whose output signals were recorded for off-line determination of the interaction-subtarget and identification of possible secondary and/or pile-up interactions.

The data were taken in two successive november-runs 1995 and 1996 with the CERN Pb-beam (158 GeV/c per nucleon) at an average intensity of 3.5 10^7 ions per burst. This article reports on the analysis of the 1995 sample (about 20% of the total statistics). The opposite-sign mass spectrum is shown in figure 1 together with the Monte-Carlo determined individual contributions from J/ψ, ψ', DY and

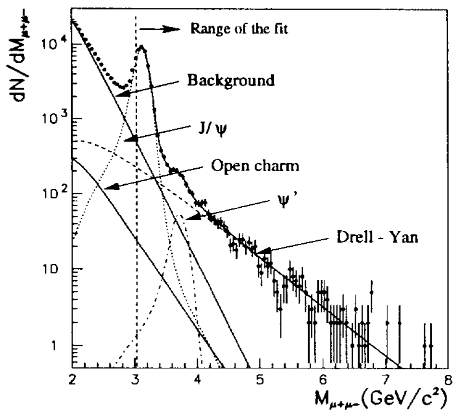

Figure 1: Opposite-sign dimuon mass spectrum.

open-charm decays as seen by the spectrometer. The same-sign dimuon spectra resulting from pure π and K decays were used to determine the background in opposite-sign dimuons. To minimize the effect of uncertainties in the open-charm contribution, we limited our analysis to dimuon masses above 2.9 GeV/c: the charm contamination is negligible in the J/ψ peak and less than 10% under the ψ'. The fit gives 49000 J/ψ, 350 ψ' and 630 DY events in the kinematical domain of the spectrometer: rapidity $3 < y < 4$ ($0 < y* < 1$ in the CM system) and $|cos\theta| < 0.5$ for the muon polar angle in the Collin-Soper frame.

From BH luminosity measurements, spectrometer acceptance and target detection efficiency calculations, the following cross-sections for the dimuon events have been obtained:

- $B_{\mu\mu}\sigma_{J/\psi} = 21.9 \pm 0.2 \pm 1.6\mu$b
- $\sigma_{DY} = 1.49 \pm 0.02 \pm 0.11\mu$b (for mass > 2.9 Gev)
- $B_{\mu\mu}\sigma_{\psi'}/B_{\mu\mu}\sigma_{J/\psi} = (0.59 \pm 0.09)\%$.

See ref [3] for details on the experimental procedure.

3 Comparison with previous experiments

p-p, p-nucleus and nucleus-nucleus collisions do not allow straightforward comparison of cross-sections. It is natural to divide the measured cross-sections by

$A_{projectile}B_{target}$, so as to obtain an average cross-section "per nucleon-nucleon collision" for each reaction.

First of all, as an experimental check, we have measured the well known K factor which relates the experimental value of the DY cross-section to the lowest order theoretical prediction calculated from a standard set of parton distribution functions [6]. This K factor is experimentally known to be independent from the reaction and from the incident momentum. The result $K = 2.56 \pm 0.04 \pm 0.18$ obtained from our data is in agreement with the other experiments.

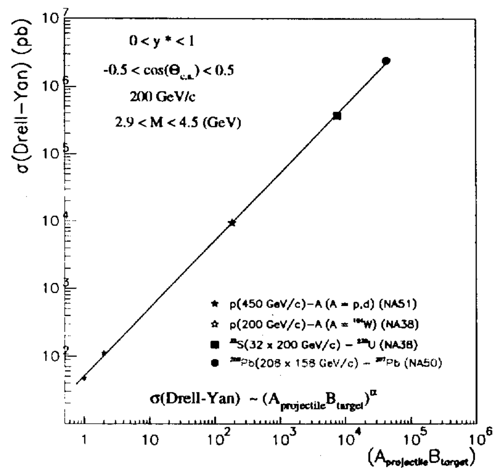

Figure 2: Drell-Yan cross-section vs. $A_{projectile}B_{target}$.

Figure 2 shows our DY cross-sections measured for various reactions with the same spectrometer. The data are observed to scale as $(A_{projectile}B_{target})^{\alpha}$ with $\alpha = 1.001 \pm 0.010$.

The NA38 p-nucleus J/ψ cross-sections have also been checked to follow the scaling law: $(A_{projectile}B_{target})^{\alpha}$ for each incident momentum separately and the exponent values are the same within experimental errors. The global fit to the whole set of NA38 p-nucleus data gives $\alpha = 0.92 \pm 0.015$, in good agreement with the other CERN and FNAL experiments. Our 450 GeV/c data can thus be rescaled to 200 GeV/c, and the rescaling factor obtained from the exponential fit is in agreement with the value given by the theoretical parametrization of J/ψ cross-sections [8].

Fig 3 shows $B_{\mu\mu}\sigma_{J/\psi}$ vs. $A_{projectile}B_{target}$: all NA38 data, including O-Cu, O-U and S-U results, fit very nicely with the same exponential behavior. The J/ψ

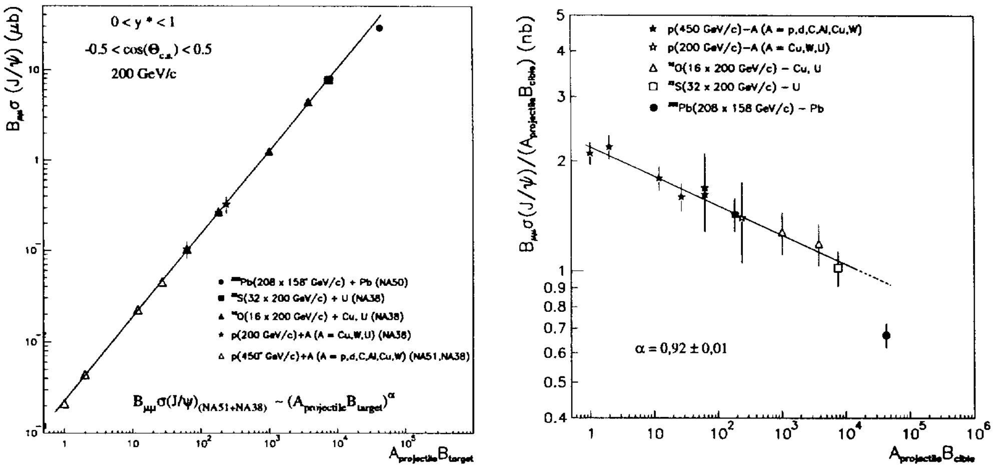

Figure 3: Left: J/ψ cross-sections as exponential function of $A_{projectile}B_{target}$ Right: same for the cross-sections "per nucleon-nucleon collision" (see the text).

suppression observed in NA38 can thus be regarded as the result of an unique absorption mechanism common to all reactions. (In the sequel this behavior is referred to as "normal" absorption.) Several authors [4] attribute the phenomenon to the absorption of a colored preresonant $c\bar{c}g$ state in the nuclear matter.

In order to extend the comparison to the new Pb-Pb data at 158 GeV/c, we have rescaled the J/ψ cross-section to 200GeV/c with the theoretical parametrization [8] before display in figure 3. The Pb-Pb J/ψ cross-section stands below the expected exponential line by a factor 0.74 ± 0.06 : the J/ψ suppression is significantly stronger for Pb-Pb than the "normal" suppression due to absorption in nuclear matter observed for lighter ions.

In the framework of [4] the normal J/ψ suppression can be parametrized as $\sigma(A_{projectile}B_{target} \rightarrow$ J/$\psi) \propto A_{projectile}B_{target}.exp(-\rho_0\sigma_{abs}\bar{L})$: where ρ_0 is the standard nuclear density, σ_{abs} is $\approx$ 6mb, and $\bar{L}$ is the path length of the $c\bar{c}g$ state in nuclear matter, averaged over the whole range of impact parameter. The straigth line in figure 3 corresponds to this parametrization. Since the DY cross-sections scale according to $A_{projectile}B_{target}$, the ratio J/ψ / DY, which is free from systematic errors related to the normalization procedure, can be used to compare the experimentally observed J/ψ suppression with the "normal" exponential behavior.

To pursue the analysis we subdivided our data sample, in equipopulated bins, as a function of the collision centrality. For this purpose an average impact pa-

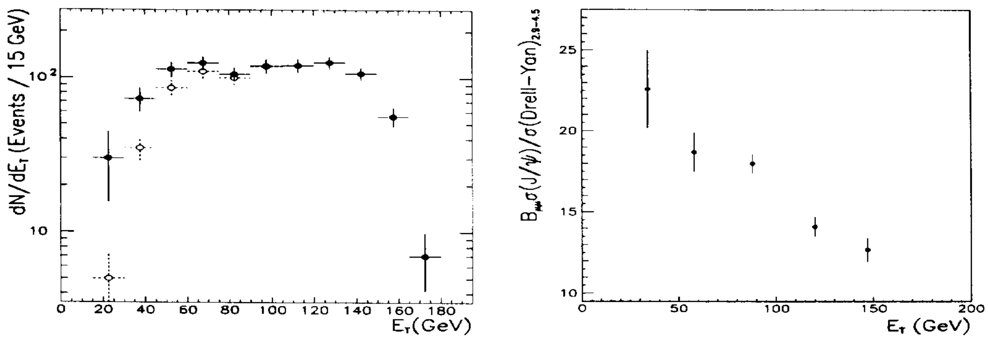

Figure 4: Left: Drell-Yan $E_{\rm T}$-distribution, the dotted symbols are prior to correction for target detection efficiency. Right: Ratio J/ψ / DY vs. $E_{\rm T}$.

rameter b has been determined from the transverse energy $E_{\rm T}$ of each event, as measured from the electromagnetic calorimeter. $E_{\rm T}$ is strongly (anti)correlated with the energy deposited in the ZDC. Figure 4 shows the $E_{\rm T}$-distributions for DY events and the ratio J/ψ / DY versus $E_{\rm T}$.

Figure 5 shows the ratio J/ψ / DY vs L(b), i.e. the path length in nuclear matter at impact parameter b. We see that for low L the Pb-Pb data agree with the S-U data; but the larger L values correspond to larger deviation from the "normal" exponential behavior. The average ratio of observed to expected values of $\sigma_{J/\psi}/\sigma_{DY}$ is 0.71 ± 0.03, about 10 standard deviations below "normal" suppression.

Figure 6 shows the ratio $\sigma_{\psi'}/\sigma_{J/\psi}$ vs. $A_{projectile}B_{target}$ for proton and ion-induced collisions. The proton data remain almost independent of incident momentum and target mass. The S-U cross-sections are significantly smaller. The new Pb-Pb data stand at least as low as the S-U data.

It also shows that $B_{\mu\mu}\sigma_{\psi'}/\sigma_{DY}$ has the same centrality($E_{\rm T}$)-dependence for Pb-Pb and S-U interactions. These remarks indicate that the ψ' undergoes additional suppression with respect to J/ψ for ion-induced reactions; several authors [4] attribute this effect to ψ' absorption by the comovers, which do not affect the J/ψ.

4 Summary and Conclusions

J/ψ, ψ' and DY production cross-sections have been measured for Pb-Pb and compared to p-p, p-nucleus, O-Cu,O-U, and S-U collisions measured with the same spectrometer. The Pb-Pb data presented in this report represent only 20% of the

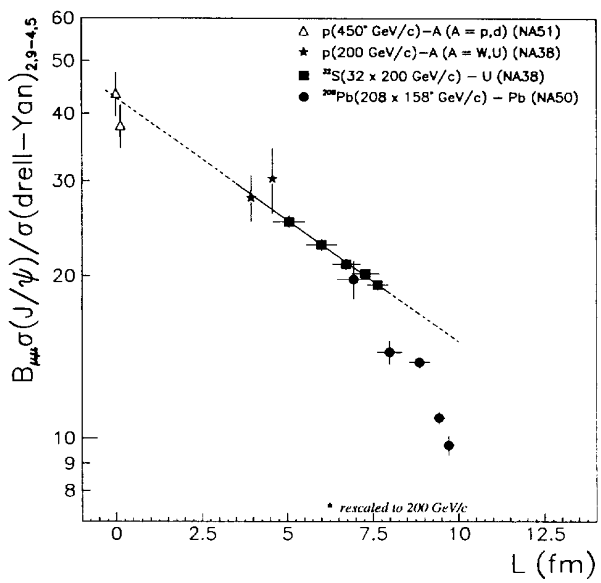

Figure 5: J/ψ/DY vs. centrality.

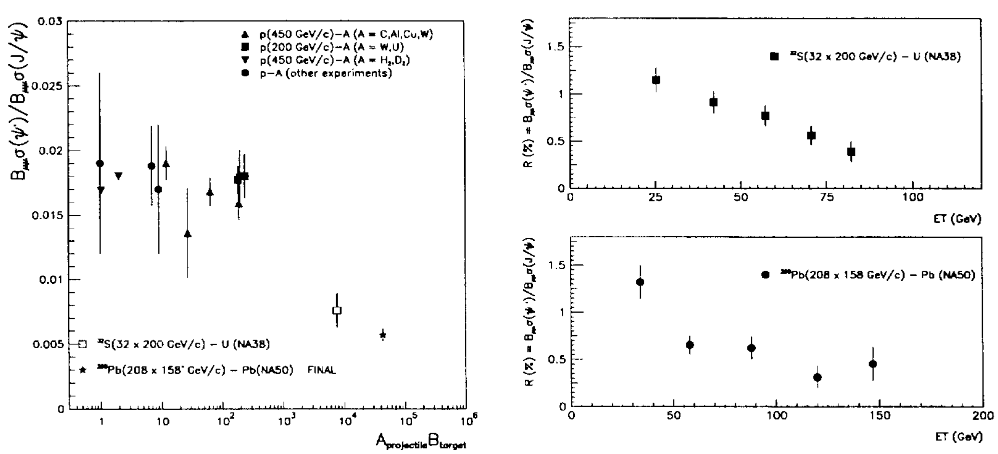

Figure 6: Ratio of ψ' to J/ψ integrated cross-sections (left) and versus E_{T} in S-U and Pb-Pb collisions (right).

total statistics. Nevertheless some important points can be stressed:

- DY cross-sections scale as $(A_{projectile}B_{target})^{\alpha}$ with $\alpha = 1$.
- J/ψ cross-sections exhibit the same exponential behavior with $\alpha = 0.92 \pm 0.015$ for all collisions, with the noticeable exception of Pb-Pb:
  - $\sigma_{J/\psi}/\sigma_{DY}$ is a factor 0.71 ± 0.03 below the value extrapoled from the other reactions.
  - Study of event samples corresponding to different centrality bins show that the deviation from previous reactions increases with centrality.
  - For lowest centrality the Pb-Pb data are in agreement with the other ion-collisions.
- $\sigma_{\psi'}/\sigma_{J/\psi}$ is constant for proton-induced reactions but considerably smaller for S-U and Pb-Pb collisions. Both ion-collisions show the same centrality dependence.

After the first presentation of our Pb-Pb results, some theorists have attributed the anomalous J/ψ suppression to the onset of a new absorption mechanism [8]. Others attempted to attribute it to the normal interaction with hadronic comovers [9]; up to now they can roughly reproduce the general trend, but miss the detailed distribution of experimental data.

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