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EVIDENCE OF STRONG J/ψ AND ψ' SUPPRESSION IN HIGH ENERGY Pb-Pb INTERACTIONS

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Abstract

Preliminary results on cross sections for J/ψ, ψ' and Drell-Yan produced in Pb-Pb collisions at 158GeV/nucleon are presented as a function of centrality. A strong suppression of J/ψ and ψ' is observed compared with previous results obtained by NA38 and NA51 experiments, using the same dimuon spectrometer for lighter projectiles and different targets.

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Preliminary results on cross sections for J/ψ, ψ' and Drell-Yan produced in Pb-Pb collisions at 158GeV/nucleon are presented as a function of centrality. A strong suppression of J/ψ and ψ' is observed compared with previous results obtained by NA38 and NA51 experiments, using the same dimuon spectrometer for lighter projectiles and different targets.

1 INTRODUCTION

An ultrarelativistic fixed target heavy ion program is being developped at CERN/SPS since 1986, on the search of a new state of matter, the Quark Gluon Plasma (QGP) which is believed to occur in nuclear matter at sufficient high temperatures or densities. The exploratory program with lighter ions – oxygen and sulphur – ended in 1992, and a new program with lead beam started in late 1994.

One clear signal proposed, related to the early stage of QGP formation, is charmonia suppression by Debye colour screening effect [1].

The NA50 experiment studies vector meson production via their decays into muon pairs in Pb-Pb interactions at 158 GeV/nucleon as a function of the collision centrality. It follows the program started by NA38 collaboration on its first observations of J/ψ and ψ' suppressions using the same dimuon spectrometer with proton and light nuclei beams [2].

2 THE NA50 DETECTOR

The NA50 setup is mainly composed of a dimuon spectrometer, a segmented active target, three independent detectors giving the centrality of the collision, namely an electromagnetic calorimeter, a forward hadronic calorimeter (ZDC) and a multiplicity detector, and beam counters.

The dimuon spectrometer is the NA10 detector [3] with a hadron absorber composed of beryllium oxyde, carbon and iron (60 cm, 400 cm and 80 cm long respectively). It accepts muon pairs in the pseudo-rapidity interval $2.8< \eta <4.0$. The magnetic field is toroidal with a strength of 0.383 Tesla at 1 meter. The mass resolution for the J/ψ is 3.2%.

The target is divided in 7 subtargets 1 mm thick each leading to a total of 17% interaction length. An assembly of quartz blade pairs facing each subtarget position is used to identify the primary vertex and to reject offline any reinteraction.

The electromagnetic calorimeter is made of scintillating fibres embedded in lead in a 1:2 proportion and covers the pseudo-rapidity domain $1.1 < \eta < 2.3$. It measures the neutral transverse energy released in the interaction with a resolution of 5% for central Pb-Pb collisions. In the analysis presented here, it is the detector used to give information on the impact parameter of the collision (it has a nice linear correlation with the information provided by the ZDC, which detects the spectator fragments of the interacting projectile).

The incident flux of lead ions is permanently measured by a segmented beam detector made of quartz blades. The 1995 run, corresponding to this analysis, has an average intensity beam of about $3.5 \cdot 10^7$ ions/burst. These beam counters are also used offline for pile-up rejection.

3 DATA ANALYSIS

In the 1995 run, a sample of 50 million dimuon triggers was recorded. After track reconstruction, fiducial cuts on chambers and hodoscopes are applied; dimuon rejection if at least one muon travels through the iron magnet coils (to keep good mass resolution) or if one of the muon's charge image track would be lost (to insure dimuon acceptance irrespective of the charge for combinatorial background subtraction purpose) are performed; finally, events with no target identification, pile-up, upstream interactions, or beam halo, are also rejected.

In order to cut acceptance tails, the dimuon kinematical domain used in analysis is restrained to $0< y^* <1$ and to $-0.5< cos(\theta_{CS}) <0.5$, where y^* is the center of mass dimuon rapidity and θ_{CS} the muon polar angle in the Collins-Soper frame. The final acceptance obtained, which increases with mass, is $13.4\%, 15.8\%$ and 18.0% respectively for the J/ψ, ψ' and Drell-Yan ($M_{\mu\mu} > 4.5\ GeV/c^2$) events.

Fig. 1 shows the fit performed on the opposite sign pairs mass distribution and its four components namely J/ψ, ψ', Drell-Yan (DY) and background coming from uncorrelated π and K decays. In order not to deal with dimuons issued from charm meson semi-leptonic decays, fits are made for $M_{\mu\mu} > 2.9\ GeV/c^2$; in fact this is completely negligible for the J/ψ, but a contamination of about 8% still remains under the ψ' peak [4], which is taken in account when cross sections are evaluated.

The J/ψ, ψ' and DY shapes are given by a Monte Carlo program which includes the fully detector simulation. DY is calculated in the leading log approximation using GRV(LO) structure functions [5] and isospin effects (due

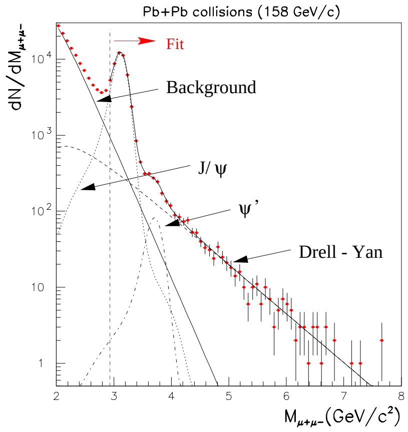

Figure 1: Mass distribution fit.

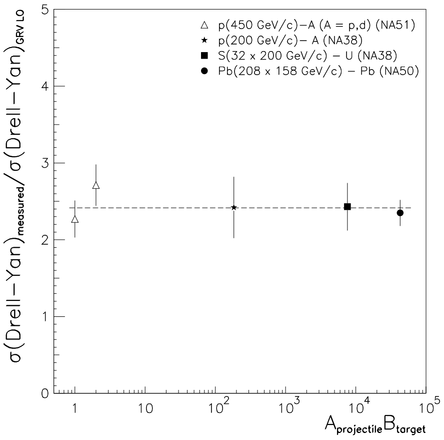

Figure 2: Drell-Yan K-factor as a function of target times projectile atomic numbers.

to the fact that $\sigma_{pp}^{DY} \neq \sigma_{nn}^{DY} \neq \sigma_{pn}^{DY} \neq \sigma_{np}^{DY}$) are taken in account when comparing A-B to p-A collisions.

4 CROSS SECTION RESULTS

Results on mass fits are corrected for acceptance; luminosity is calculated, and detector efficiencies and selection cut losses are evaluated; finally, we extract the following preliminary cross section values in the kinematical domain defined above: $B_{\mu\mu}\sigma_{J/\psi} = 19.0 \pm 0.2 \pm 1.4\ \mu b$, $\sigma_{DY} = 1.31 \pm 0.04 \pm 0.10\ \mu b$ for $2.9\ GeV/c^2 < M_{\mu\mu} < 4.5\ GeV/c^2$ and $B'_{\mu\mu}\sigma_{J/\psi'}/B_{\mu\mu}\sigma_{J/\psi} = (0.59 \pm 0.09)\%$, where in this last value the error is only statistical.

In Pb-Pb interactions the DY cross section value agrees completely with previous results obtained in p-A and S-U collisions (NA38 and NA51 experiments), considering a linear A dependence as expected for the Drell-Yan behaviour. This is shown in Fig. 2 in terms of K-factor measurements whose values are the same irrespective of the system; an overall fit gives K=2.44±0.14, having calculated DY in the leading log approximation with GRV(LO) structure functions. This result emphasizes that no significant bias in extracting absolute cross sections is present in our analysis.

Fig. 3 displays $B_{\mu\mu}\sigma_{J/\psi}$ per nucleon as a function of the product $A_{projectile} \cdot B_{target}$ for different types of collisions (NA38, NA50 and NA51 experiments).

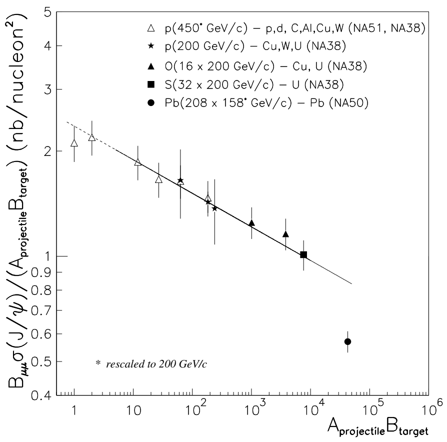

Figure 3: J/ψ cross section per nucleon as a function of target times projectile atomic numbers.

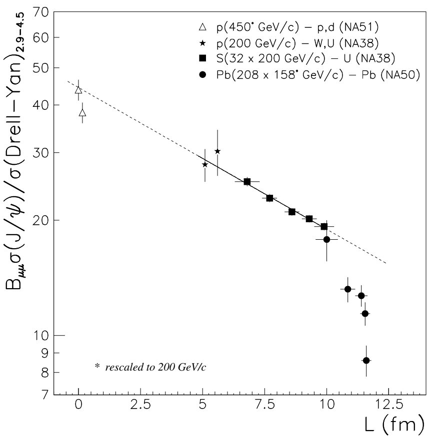

Figure 4: Cross section ratio J/ψ over Drell-Yan as a function of mean path in nuclear matter.

The results corresponding to incident beam momenta different from 200 GeV/c are rescaled to this energy using the Schuler parametrisation [6] $(1-M_{\mu\mu}/\sqrt{s})^{12}$. The error bars include also systematics. The exponential fit performed to the NA38 points shows that data from p-p to S-U are well described by the power law $(A_{projectile} \cdot B_{target})^{\alpha}$ with $\alpha = 0.91 \pm 0.02$, in agreement with other experiments [7]. However, our value resulting from Pb-Pb collisions is quite below with respect to this law, putting in evidence an additional J/ψ suppression.

Another way to observe this strong J/ψ suppression is using an absorption model of the form $\sigma_o exp(-n_o L \sigma_{abs})$ where n_o=0.14 fm^{-3}) is the usual nuclear density, σ_{abs} is the absorption cross-section and L is the average path length through nuclear matter crossed by the pre-resonant state $c\bar{c}g$, calculated within a geometrical model in the hard spheres approximation. In this absorption model, and using $\sigma_{J/\psi}/AB$ values measured by NA38 collaboration, we obtain $\sigma_{abs} = 6.3 \pm 1.2$ mb. This high value is in agreement with p-p and p-d results (NA51) but is not sufficient to describe the amount of J/ψ suppression observed in Pb-Pb.

To study charmonia production as a function of centrality, we have divided our data in different transverse energy bins which are correlated with impact parameter b or with the variable L, as quoted in Table 1. As σ_{DY} has a linear A·B dependence, and in order to reduce significantly error bars, results are presented in terms of cross section ratios $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY}$ (major systematic errors cancel when performing these ratios). Fig. 4 displays this ratio as a function of L together with results obtained from NA38 and NA51 experiments where, as usual, the values have been rescaled to 200 GeV/c and σ_{DY} is corrected for isospin. Once again, previous data are well fitted by the absorption model with $\sigma_{abs} = 6.2 \pm 0.7\ mb$, but in Pb-Pb collisions deviations with respect to this model increase dramatically with centrality. In fact, if the most peripheral point in Pb-Pb interactions agrees well with the most central point in S-U collisions, when increasing centrality the J/ψ is more and more suppressed: a factor of 0.52±0.05 is reached when comparing the most central bin to the value expected by extrapolation of the nuclear absorption model using the measured σ_{abs}. Still comparing to this absorption model, the integrated $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY}$ value shows an overall suppression of 0.71±0.03 which is 9.7 standard deviations away from the expected value.

Table 1: E_T regions and related mean values for centrality studies.

E_T bin (GeV)	$< E_T >$ (GeV)	$< b >$ (fm)	$< L >$ (fm)
5 – 45	35	8.3	10.00
45 – 70	59	6.8	10.85
70 – 105	88	5.0	11.40
105 – 135	120	3.3	11.55
135 – 175	149	1.8	11.60

In Fig. 5 we plot the cross section ratio $B'_{\mu\mu}\sigma_{\psi'}/B_{\mu\mu}\sigma_{J/\psi}$ as a function of $A_{projectile} \cdot B_{target}$ together with other system's results. In Pb-Pb collisions, as already observed in S-U reactions, ψ' is more suppressed than J/ψ as compared to p-A systems, where the ratio is constant with A, with a mean value of 1.76%±0.04% independent of c.m.s. energy. This cannot be interpreted only by the usual absorption of the pre-resonant $c\bar{c}g$ state in nuclear matter, which should be the same as obtained in p-A collisions, irrespective of the final charmonium state.

Hadronic comovers, also formed in the interactions, may dissociate the ψ' in a confined medium, due to its low binding energy [8]. This could explain the increasing $B'_{\mu\mu}\sigma_{\psi'}/B_{\mu\mu}\sigma_{J/\psi}$ suppression behaviour with centrality as observed in NA38 experiment (see figure 6a), but NA50 preliminary results (Fig. 6b) show no significant dependence of the $B'_{\mu\mu}\sigma_{J/\psi'}/B_{\mu\mu}\sigma_{J/\psi}$ ratio as a function of the measured neutral transverse energy (E_T).

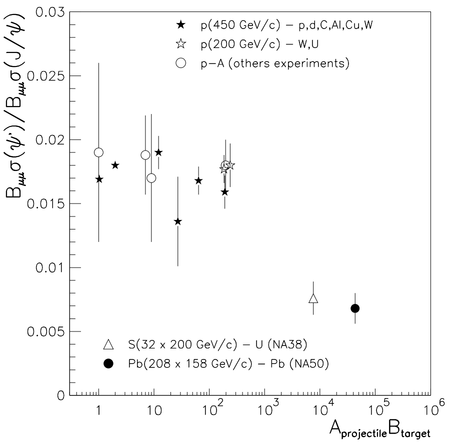

Figure 5: $\psi'/(J/\psi)$ cross section ratios as functions of target times projectile atomic numbers.

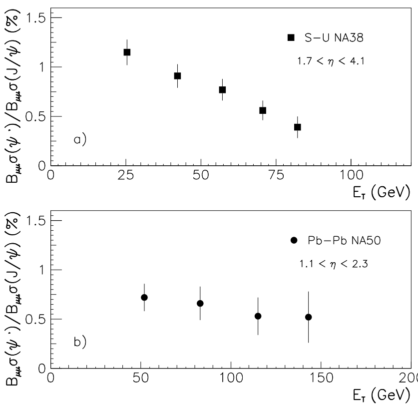

Figure 6: $\psi'/(J/\psi)$ cross section ratios as a function of neutral transverse energy.

5 CONCLUSION

We have measured J/ψ and ψ' cross sections in the dimuon decay channel in Pb-Pb collisions at 158 GeV/nucleon and found a huge additional suppression as compared to what is expected in the framework of an absorption model. After first NA50 communications [9], several theoretical tentatives came up in order to explain our results either in terms of QGP formation [10] or in more conventional hadronic approaches [11]. While the latter, considering charmonium absorption by comovers, cannot describe fully our available data, the former need the consideration of a deconfined medium to account for the observed anomalous suppression.

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