Searching for QGP: the J/ψ probe in the NA50/CERN experiment

Presented by Sérgio Ramos[6,b]

NA50 Collaboration

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Abstract. The J/ψ production in 158 A GeV Pb-Pb interactions is studied as a function of centrality. Its pattern, after a first sharp variation around E_T= 40 GeV, continues to fall down and exhibits a curvature change around E_T= 90 GeV. This trend excludes any conventional hadronic model and is in agreement with a deconfined quark-gluon phase scenario.

INTRODUCTION

A phase transition from ordinary hadronic matter to a new state of deconfined quarks and gluons is predicted for temperatures above $T_c \sim 150$ MeV by non-perturbative Quantum ChromoDynamics [1] and is thus expected to be achieved in heavy ion collisions at the CERN-SPS. In this context, experiment NA50 searches for a specific signal for deconfinement, the predicted suppression of charmonia production, the $c\bar{c}$ bound states being prevented to be formed by the colour screening potential in the very dense medium [2].

I EXPERIMENTAL SETUP AND DATA SELECTION

The NA50 apparatus mainly consists of a muon spectrometer, a segmented active target and three independent centrality detectors: an electromagnetic calorimeter which measures the neutral transverse energy (E_T) produced in the interaction, a zero degree calorimeter measuring the very forward hadronic energy (E_{ZDC}) of the spectator nucleons and a silicon strip multiplicity detector [3].

Data taking conditions in all periods were the same, apart from the total thickness of the target and the number of its sub-targets. The segmented lead target was made, in 1996, of 7 sub-targets with a total thickness of 12 mm corresponding to 30 % interaction length; due to its low efficiency to fight re-interactions in Pb-Pb central collisions, its total thickness was reduced to 3 mm (7 % λ_I) in 1998, with only one sub-target (thus improving detectors' resolution).

The active target algorithm being inefficient for peripheral collisions, a contour-cut selection (correlation $E_T - E_{ZDC}$) [4] was applied to the huge 1996 statistics in order to recuperate low E_T events. But, because of the re-interactions problem at high E_T in 1996, the 1998 run was devoted to the detailed study of the suppression pattern in central collisions, and as the in-target over off-target events ratio was much less favorable, no attempt was made to recover the lost low E_T events (thus preventing any contamination of the final sample by Pb-air events).

The kinematical domain used, $2.92 \leq y_{lab} \leq 3.92$ and $|cos\ \theta_{CS}| < 0.5$ leads, in the mass region of interest, to acceptances of the order of 15%. The muon pairs selected for the analysis satisfy the standard NA50 criteria [3].

II ANALYSIS AND RESULTS

The physical ingredients taken into account, besides J/ψ and ψ' resonances and the Drell-Yan mechanism, are the background and the open charm ($D\bar{D}$) contributions. The background is mainly due to uncorrelated π and K decays into muons. It is computed from the like-sign mass distributions using $N_{BG} = 2\sqrt{N^{++}N^{--}}$.

The opposite sign muon pair invariant mass distribution (Fig. 1) is fitted according to the following procedure in order to determine the amounts of its different

components. The shapes of the muon pairs originating from J/ψ and ψ' decays and from the Drell-Yan process are obtained from a simulation of the NA50 detector using the same reconstruction and selection criteria as used for the real data. Drell-Yan contribution is calculated at the leading order and uses the MRSA structure functions, which take into account the $\bar{u}/\bar{d}$ asymmetry as measured by NA51 experiment [5]. The $D\bar{D}$ shape is taken from Pythia and its normalisation is obtained by fitting the data in the range $2.2 < M_{\mu\mu} < 2.9$ GeV/c^2. Finally, the amplitudes of J/ψ, ψ' and Drell-Yan contributions are obtained from a fit to the experimental data above $M_{\mu\mu} > 2.9$ GeV/c^2.

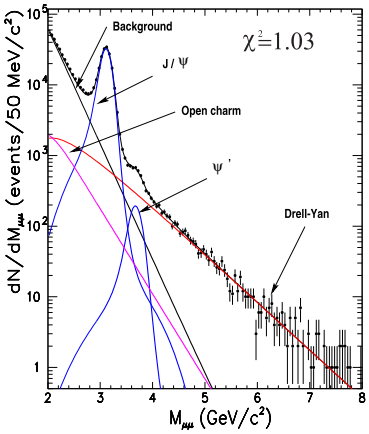

FIGURE 1. Fit to the mass spectrum

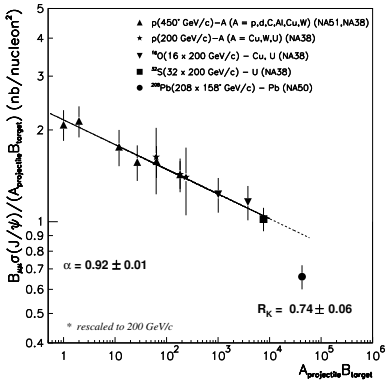

FIGURE 2. ψ/AB as a function of $A_{proj} \cdot B_{tgt}$

A systematic study of Drell-Yan behaviour, ranging from p-p and some p-A systems to S-U and Pb-Pb, proves that its cross-section behaves normally and is proportional to the number of elementary nucleon-nucleon collisions (i.e., the product A·B) [6]. Thus, it can be used as a reference in the study of J/ψ production.

Fig. 2 shows the J/ψ cross-section per nucleon-nucleon collision as a function of $A_{proj} \cdot B_{tgt}$: p-A collisions at 450 GeV/c (rescaled to 200 GeV/c), and proton, oxygen and sulphur induced reactions at 200 GeV/c. The common trend observed from p-p to S-U allows a single parametrization; using a power law, one obtains:

$$\sigma^{\psi} \propto (A\ B)^{\alpha} \quad \Rightarrow \quad \alpha = 0.92 \pm 0.01 \quad .$$

The Pb-Pb point (which error bar includes a 7 % systematic error contribution) is several standard deviations under the expected value. One concludes that J/ψ is anomalously suppressed in lead-lead, as compared to other reactions.

The J/ψ cross-section per nucleon-nucleon collision can also be evaluated from the ratio of the J/ψ to Drell-Yan cross-sections. This ratio is almost free of systematic errors, which are common to both samples (only 1.5% left). Fig. 3 shows it, for a large range of systems (from p-p and several p-A to S-U and Pb-Pb), as a function L, the path length of the pre-resonant $c\bar{c}g$ state in nuclear matter (which allows a common description of the very different interacting systems) [4].

A simple exponential parametrization applied to the lighter systems (previous NA38 [7–9] and NA51 [5] data ranging from p-p to S-U): $B_{\mu\mu}\sigma^{\psi}/\sigma^{DY} \propto e^{-\rho L \sigma_{abs}}$

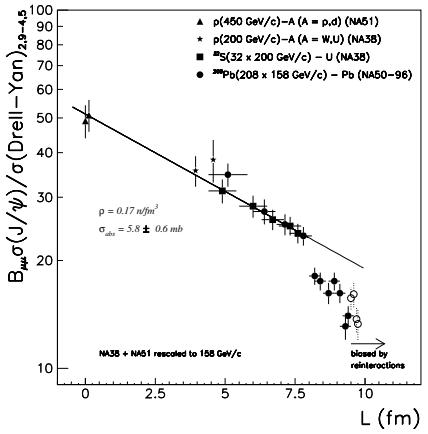

FIGURE 3. ψ/DY as a function of L

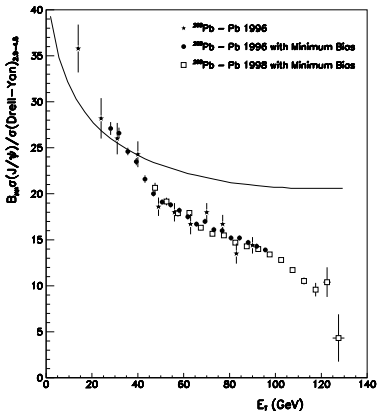

FIGURE 4. ψ/DY as a function of E_T

gives an absorption value of the $c\bar{c}g$ state in nuclear matter of $\sigma_{abs} = 5.8 \pm 0.6$ mb (full calculation gives 6.4 ± 0.5 mb). Whereas the more peripheral Pb-Pb points lie on the absorption curve, the more central ones show a sudden 20% drop at L = 8 fm, suggesting the onset of another J/ψ suppression mechanism.

The ratio of J/ψ to Drell-Yan cross-sections has also been studied as a function of E_T, for the different data taking periods, in Pb-Pb collisions. Two methods are used. Drell-Yan (and J/ψ) is extracted from the standard fit procedure described above, or it may be evaluated from the very large minimum bias sample (thus reducing significantly statistical errors) obtained with the independent ZDC calorimeter trigger, by a procedure described in [10].

The 1996 minimum bias analysis confirms the results of the standard analysis. They are shown in Fig. 4 in the domain where re-interactions are negligible. The 1998 data, showed here through the minimum bias method, are in agreement with 1996 analyses and reaches higher E_T values. The solid line presented in the figure corresponds to the ordinary nuclear absorption fit to lighter systems data (from p-p to S-U) using $\sigma_{abs} = 6.4$ mb. The overall displayed distribution exhibits, besides a 20% drop at 40 GeV (the one showed at L = 8 fm), an inflexion point at 90 GeV followed by a steady steep decrease.

III DISCUSSION AND CONCLUSION

The J/ψ pattern as a function of centrality is showed again in Fig. 5 together with conventional hadronic models (see [11] and Refs. therein) which assume charmonia absorption by comoving hadrons. It clearly rules out any hadronic model, as all them show a smooth decrease, with shapes similar to the absorption curve fitted to our data, without any drops or inflexion points. On the other hand, our data agree with the trend expected in the framework of quark-gluon plasma formation.

In order to further describe the J/ψ suppression pattern and in view of putting together all available systems, from p-p to Pb-Pb, we studied it as a function of the energy density ϵ, estimated by the Bjorken's model (for p-A collisions the RQMD cascade model [12] calculation was used), corrected for the rapidity interval of our E_T measurement ($1.1 < y < 2.3$). The result is shown in Fig. 6 (see also [11]).

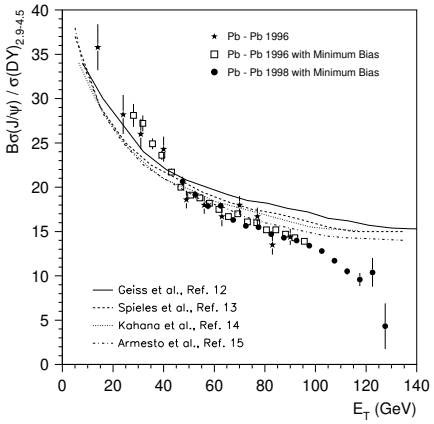

FIGURE 5. ψ/DY as a function of E_T: Comparision with hadronic models

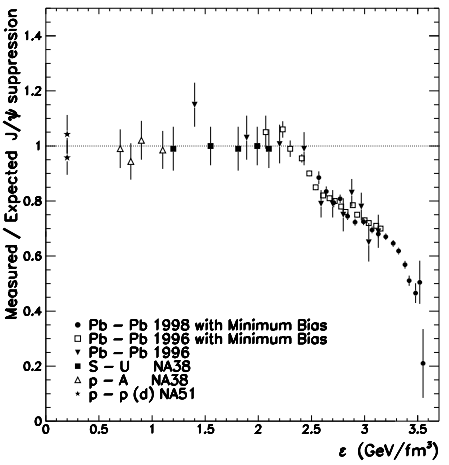

FIGURE 6. ψ suppression as a function of ϵ

The data represent the measured J/ψ to Drell-Yan cross-section ratios (for p-A the direct J/ψ cross-sections per nucleon-nucleon collision were used) normalized to our fitted absorption curve to lighter systems [7–9].

The stepwise suppression pattern shows a sudden drop at 2.3 GeV/fm^3 and an inflexion point at 3.1 GeV/fm^3 followed by a steady steepy decrease. It rules out any conventional hadronic model and can be explained in the framework of quark-gluon plasma formation as successive melting of χ , then ψ , charmonium states.

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