CENTRALITY DEPENDENCE OF THE J/ψ SUPPRESSION IN ULTRARELATIVISTIC Pb-Pb COLLISIONS

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The study of the dimuon yield in 158 GeV/c Pb-Pb collisions, carried out by the NA50 collaboration, has revealed the existence of an anomalous J/ψ suppression, a predicted signal for the transition from ordinary nuclear matter towards a Quark-Gluon Plasma.

1 Introduction

Several signals have been proposed as signatures of the formation of a deconfined state of matter in heavy ion collisions. In particular, Matsui and Satz predicted that the formation of a QGP would screen the colour binding potential, preventing the c and $\bar{c}$ quarks to form charmonia states and, therefore, leading to a measurable suppression of the J/ψ yield. The $c\bar{c}$ states, composed of heavy quarks, can only be produced at the earliest times in the collision evolution, in hard processes (gluon fusion) that happen early enough to probe the formation of the QGP. Besides, tightly bound states as the J/ψ meson are not easy to break in the relatively soft interactions they may suffer while crossing the surrounding (hadronic) matter.

At the CERN SPS, the NA38, NA51 and NA50 experiments have extensively studied J/ψ production in proton–nucleus and nucleus-nucleus collisions, to establish a detailed production pattern that can be used to probe the existence of the deconfined phase predicted by QCD.

The NA38/NA51 experiments, thanks to an extensive set of experimental data obtained with proton, oxygen and sulphur beams on several targets, have indeed observed a J/ψ suppression which increases continuously and monotonically from the lighter to the heavier interacting nuclei. The same behaviour is observed in sulphur-uranium collisions as a function of the centrality of the reaction [1]. The observed suppression exhibits a completely smooth increasing pattern which is fully consistent with ordinary nuclear absorption of the charmonium states by the nucleons of the interacting nuclei. Within the framework of the Glauber model, the data lead to a J/ψ absorption cross-section of 6.4±0.8 mb (the so-called "normal" absorption) which accounts for the observed suppression in a range which extends from pp up to central SU reactions.

2 The NA50 experiment: data analysis and results

The NA50 experiment has extended the study of the J/ψ suppression to PbPb collisions. The experimental setup used by NA50 is based on a muon spectrometer. Muon pairs produced in the pseudorapidity interval $2.8 < \eta_{lab} < 4.0$ are deflected by an air gap toroidal magnet and tracked by a set of multiwire proportional chambers. A very forward ("zero degree" or ZDC) hadronic calorimeter covers rapidities higher than 6.3 and measures the energy, E_{ZDC}, of the spectator (non-interacting) nucleons from the incoming Pb projectile, giving an estimation of the collision centrality. Futhermore, an electromagnetic calorimeter measures E_T, the neutral transverse energy produced in the reaction in the range $1.1 < \eta_{lab} < 2.3$, giving an independent (but correlated with E_{ZDC}) evaluation of the centrality.

As a first result, the J/ψ cross-section measured in PbPb collisions at 158 GeV/c per nucleon has been found to be a factor 0.71±0.03 below the value extrapolated from the NA38 data according to pure nuclear absorption. This observation, often referred to as "anomalous J/ψ suppression", was the first evidence that, contrarily to what happens in S-U interactions, in PbPb collisions there is an onset of a very dense state of matter with specific properties [2].

A powerful tool to investigate the origin of the anomalous J/ψ suppression is the study of the pattern of such suppression as a function of the centrality of the collision. In fact, theoretical models of the J/ψ suppression based on its absorption by interactions with the surrounding hadronic (confined) matter predict a smooth decrease of the J/ψ production yield from peripheral to central PbPb interactions, with a saturation of the suppression in the most central collisions. To investigate such issue, the NA50 collaboration has collected two more J/ψ samples in PbPb collisions.

In the first run (1996) a high statistics sample has been collected, using a $0.3\lambda_I$ thick target. In this way, after data analysis, about 190000 J/ψ events in the kinematical region $0 < y_{CM} < 1$, $-0.5 < \cos\theta_{CS} < 0.5$, where the acceptance of the spectrometer is significantly different from zero, have been obtained. In the second run (1998) a much thinner target ($0.07\lambda_I$) has been used, since preliminary analysis of the 1996 data had showed that the sample of very central PbPb collisions were contaminated by a non–negligible contribution of uncorrectly recognized peripheral events. Such events originated from reinteractions of a nuclear fragment in the thick target, leading to a bias in the centrality measurement. This bias can be showed to cause an underestimation of the J/ψ suppression for very central events.

The NA50 results are usually presented as the ratio, versus centrality, $\sigma_{J/\psi}/\sigma_{DY}$ between the J/ψ and Drell-Yan cross sections (the so-called "standard analysis"). Since Drell-Yan is a hard process, its cross section in nucleus-nucleus collisions scales as the product of the mass numbers of the target and projectile nuclei. Therefore the ratio $\sigma_{J/\psi}/\sigma_{DY}$ is equivalent to the J/ψ cross section per nucleon-nucleon collision. Furthermore, being the ratio of two measured quantities, $\sigma_{J/\psi}/\sigma_{DY}$ is free from systematic errors connected with the evaluation of beam luminosities and detection inefficiencies. The centrality variable used to present the data is the mean length L of the path traversed by the $c\bar{c}$ pair through nuclear matter. Using such variable, calculated by means of the Glauber model from the measured E_T distribution, it is possible to compare results obtained for PbPb collisions with the outcome of previous investigations with lighter systems. The result is shown in Fig. 1.

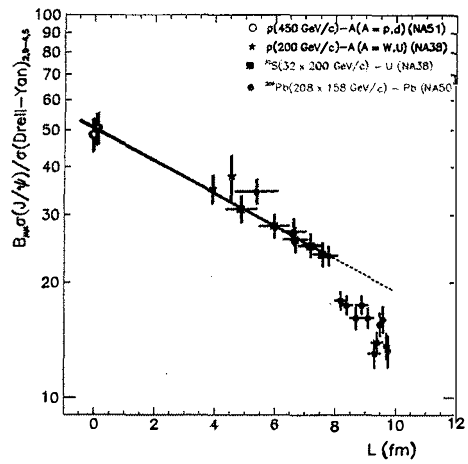

Figure 1: Ratios of the J/ψ to Drell-Yan cross-sections as a function of the mean nuclear path length L. NA38/NA51 data have been rescaled to 158 GeV/c.

While peripheral PbPb points (L <8 fm) give a result in good agreement with the "normal" scaling of the J/ψ cross section per nucleon-nucleon collision, at $L \simeq$8 fm (corresponding to a value of the impact parameter $b \simeq$8 fm) a sharp onset of the anomalous J/ψ suppression can be seen[3].

The accuracy of the measurement of the suppression pattern within the PbPb data sample is essentially limited by the Drell-Yan statistics. To overcome this problem an alternative independent analysis method has been developed. In this analysis instead of using the *measured* Drell-Yan events as a reference for the study of the J/ψ suppression, the centrality distribution of the Drell-Yan events is *calculated* starting from the huge available sample of "minimum bias" events, collected by requiring only a minimum deposition of energy in the ZDC. The analysis uses the very similar structure of the centrality distribution for minimum bias (MB) and Drell-Yan events (DY) in nucleus-nucleus collisions, that allows to calculate the E_T (or the E_{ZDC}) distribution of the DY and MB events, knowing the probability $P(E_T, b)$ ($P(E_{ZDC}, b)$) that a given E_T (E_{ZDC}) is measured for a collision with impact parameter b. The other ingredient used in the calculation is $N_{AB}(b)$, the number of binary nucleon-nucleon collisions, which is calculated using the Glauber model with the nuclear density described by a three parameter WoodsSaxon distribution. Based on these relations, the Drell-Yan distribution $(dN/dET)_{DY^*}$ has been obtained directly from the minimum bias experimental distribution according to:

$$(dN/dE_T)_{DY^*} \;=\; (dN/dE_T)^{exp}_{MB} \cdot \; (\; (dN/dE_T)^{th}_{DY} \; / \; (dN/dE_T)^{th}_{MB}) \qquad (1)$$

The results of the minimum bias analysis, for PbPb collisions, are shown in Fig.2. For the results as a function of E_T, the values from the standard analysis have been superimposed.

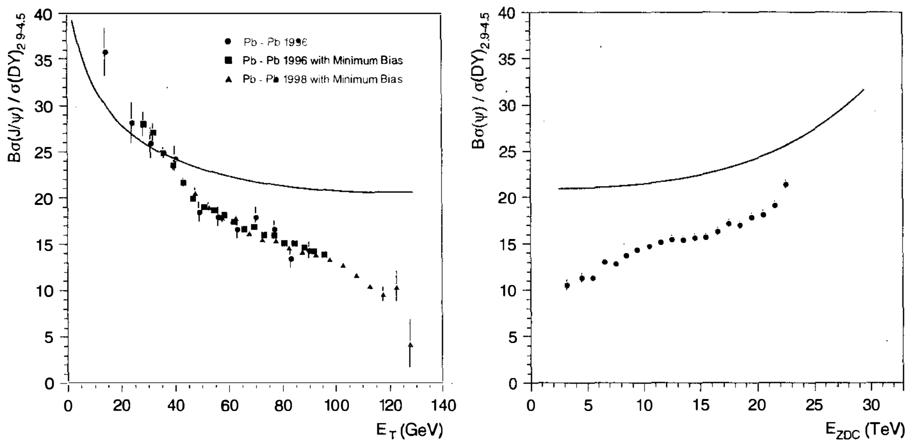

Figure 2: (left) $\sigma_{J/\psi}/\sigma_{DY}$ as a function of E_T, obtained with the standard and minimum bias analysis of the 1996 and 1998 data samples. The curve represents the J/ψ suppression due to ordinary nuclear absorption. (right) $\sigma_{J/\psi}/\sigma_{DY}$ as a function of E_{ZDC}, obtained with the minimum bias analysis on the 1998 data.

In the E_T plot, for the more central collisions (E_T >95 GeV) only the points from the analysis of the 1998 data are shown, since the 1996 sample is biased in this region because of the reinteraction problem. The results shown in Fig.2 are in disagreement with models basd on a hadronic absorption scenario, since such models can not reproduce both the sharp threshold observed at E_T ~35 GeV and the second smoother step at E_T ~90 GeV. On the contrary the observed pattern can be naturally understood in a QGP-based scenario. In such case in fact the first drop in the suppression pattern can be attributed to the melting of the loosely bound (binding energy ~ 250 MeV) χ_c state in the plasma (NA50 can not tag the $\chi_c \rightarrow J/\psi + \gamma$ decay and sees only the decay J/ψ), while the strongly bound, directly produced J/ψ melt only for very central collisions, giving the second drop in the observed pattern[4]. The anomalous J/ψ suppression E_{ZDC} pattern, very similar to the one observed as a function of E_T, qualitatively confirms this scenario.

References

1. M.C. Abreu *et al* (NA38 collaboration), *Phys. Lett.* B **466**, 408 (1999)
2. M.C. Abreu *et al* (NA50 collaboration), *Phys. Lett.* B **410**, 337 (1997)
3. M.C. Abreu *et al* (NA50 collaboration), *Phys. Lett.* B **450**, 456 (1999)
4. M.C. Abreu *et al* (NA50 collaboration), *Phys. Lett.* B **477**, 28 (2000) and references to theoretical models therein