Anomalous J/Ψ suppression in Pb-Pb collisions

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Abstract: Preliminary results on cross-sections for J/Ψ and Drell-Yan, produced in Pb-Pb collisions at 158 GeV/c per nucleon are presented. The ratio of cross-sections $B_{\mu\mu}\sigma_{J/\Psi}/\sigma_{DY}$ is studied as a function of centrality deduced from the transverse energy measurements.
A strong suppression is observed as compared to the previous results obtained by NA38 and NA51 using p, O and S projectiles.

Introduction

The study of J/Ψ production in ultra-relativistic heavy ion collisions has been developed at CERN-SPS since 1986 as one of the most promising signatures of the formation of a deconfined state of nuclear matter. The Quark-Gluon Plasma is expected to occur in the early stages of the collision, where the energy density is at its highest.
It has been proposed that the J/Ψ vector meson which is a resonance of the $c\bar{c}$ system could be suppressed by color screening effects in the QGP[1]. However, some "normal" suppression attributed to absorption of the charmonia in nuclear matter was observed and studied by the NA38 and NA51 experiments[2)3)] for p+A and S,O +U collisions. The NA50 experiment is an upgraded version of NA38 for the lead beam. Charmonia and Drell-Yan are observed via their decay into muon pairs. Drell-Yan is used as a reference for hard processes in heavy ions collisions. The centrality of the reaction is obtained by simultaneous measurements of neutral transverse energy, zero degree kinetic energy of the spectators and total charged multiplicities.
The final results for 1995 lead-lead data are presented and compared to the NA38 ones. Statistics was significantly increased in 1996 run by means of an enhanced luminosity and a thicker target. Regarding analysis, a new procedure for vertex identification has been used and is explained in the text. It increases the detection efficiency for peripheral collisions. These preliminary results are presented and compared to the previous ones. The transverse momentum distributions are also studied and preliminary plots for $\langle p_T^2 \rangle$ are compared to some theoretical predictions.

NA50 apparatus and experimental conditions

The $\mu^+\mu^-$ pair for the decay of the J/Ψ is detected by a magnetic spectrometer consisting of a hadron absorber and an air core toroidal magnet. The tracking is performed by 8 MWPC's triggered by 4 scintillator hodoscopes. The muons are detected in a rapidity interval of $2.8 < y < 4$. The mass resolution of the J/Ψ is 3.1%. An electromagnetic calorimeter and a very forward hadronic calorimeter ("Zero Degree Calorimeter") provide two independent estimates of the centrality of the collision. The electromagnetic calorimeter measures the neutral transverse energy in the pseudo-rapidity range
$1.1<\eta<2.3$. The ZDC measures the energy deposited by the spectator fragments left in the collision ($\eta > 6.2$). As will be seen later on, a strong correlation is obtained between these two measurements and is used in the 1996 data analysis.
Due to small cross-sections, high intensity beams and thick targets are needed to obtain reasonable statistics. The incident Pb ions are counted by a quartz beam hodoscope which is also used to reject beam pile-up which is of the order of 20%.
The target is made of 7 Pb subtargets leading to a total thickness of 17.5% interaction lengths (30 % in 1996). Each subtarget is followed by 2 associated quartz blades located off the beam axis and used to identify the primary vertex and reject events with secondary interactions.

Data taking and event selection

In 1995 a sample of 58. 10^6 dimuon triggers were recorded and the data[4)] are actually fully analyzed. In November 1996 new data have been collected with a higher beam intensity and a thicker target. A total amount of 170. 10^6 triggers were recorded. The analysis [5-6)] is still preliminary.

The off-line reconstruction program requires two well identified tracks. Furthermore, events with pile-up, upstream or beam halo interactions are also rejected. A subtarget identification is required to obtain a precise vertex identification. As a loss of efficiency was observed for peripheral collisions, an additional procedure was used for 1996 runs. A 2σ cut is applied on the (E_T-E_{zdc}) correlation plot in order to ensure that the event is produced in one of the subtargets. (E_T stands for transverse energy, E_{zdc} for the energy of the spectators). Strict fiducial cuts were applied to reject a low residual contamination from upstream interactions on air. Finally, a fiducial cut is applied for background substraction purposes in order to make the acceptance of the spectrometer independent of the sign of the charge of the two muons.

In 1995, the above criteria rejects 55% of the raw events.

Data analysis

The invariant mass spectra for opposite sign muons pairs is shown in fig.1 for masses above 2 GeV/c^2. It is fitted with a superposition of five contributions: J/ψ, ψ', Drell-Yan, open charm and the combinatorial background. So the following relationship was used :

$$\frac{dN^{+-}}{dM} = A_{J/\Psi}\frac{dN_{J/\Psi}}{dM} + A_{\Psi'}\frac{dN_{\Psi'}}{dM} + A_{DY}\frac{dN_{DY}}{dM} + \frac{dN_{D\bar{D}}}{dM} + \frac{dN_{bg}}{dM}$$

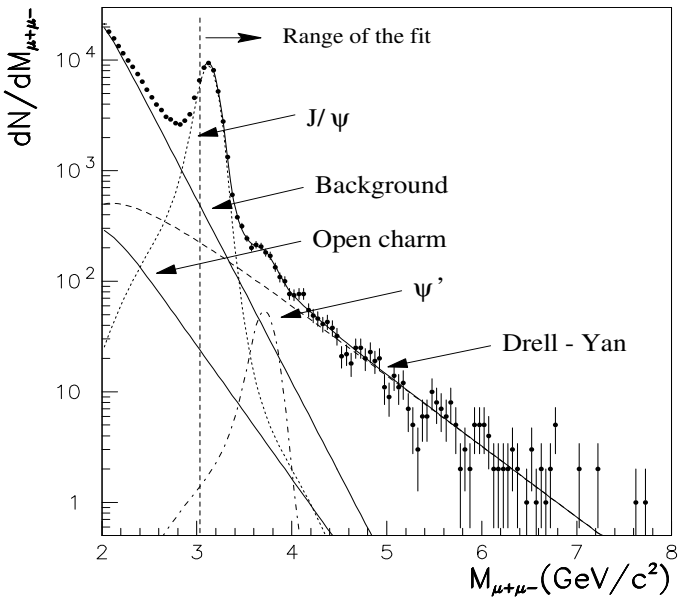

Figure 1

The background originates from pion and kaon decays. It is totally determined using the like-sign sample of the muons pairs. The shape of the distributions for J/Ψ, Ψ' and D.Y. are obtained from Monte Carlo simulations. The $dN^{D\bar{D}}/dM$ is the open charm contribution obtained from p+B_{target} extrapolations. In order to compare NA50 and NA38 results, the J/Ψ data obtained at 158 GeV/c per nucleon were scaled up to 200 GeV/c /nucleon according to a simple Schuler parametrisation [7)].

The D.Y. cross-sections for different $A_{projectile}$+B_{target} systems are determined taking into account isospin effects. The cross-sections are normalized to p-p collisions as:

$$\sigma = \left(\sigma_{AB}^{exp} / \sigma_{AB}^{GRVLO}\right) * AB * \sigma_{pp}^{GRVLO}$$

where σ_{pp}^{GRVLO} represent the calculated cross-section at the lowest order for pp collisions and σ_{AB}^{GRVLO} is a linear combination of the elementary σ_{pn}^{GRVLO}, σ_{pp}^{GRVLO} and σ_{nn}^{GRVLO}

1995 final results

Drell-Yan results

D.Y. cross-sections in A+B collisions are calculated as a superposition of elementary nucleon-nucleon D.Y. cross-sections and expressed as $\sigma_{DY}^{AB} = (AB)\,\sigma_{DY}^{NN}$

The D.Y. process corresponds to an electromagnetic fusion of a $q\bar{q}$ pair through a massive photon decaying in $\mu^+\mu^-$ pair. Then no absorption in the nuclear medium has to be considered.

As expected for hard processes, all the measurements in NA38 as well in the Pb-Pb collisions experiment scale as (AB). This behavior is illustrated in fig.2.a where the usual K-factor is plotted as a function of (AB) and is seen to be in agreement with the well-known D.Y. theoretical calculations of the lowest order.

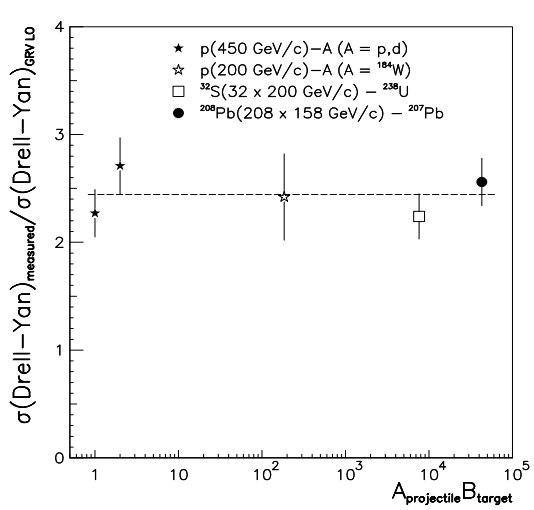

Figure 2a

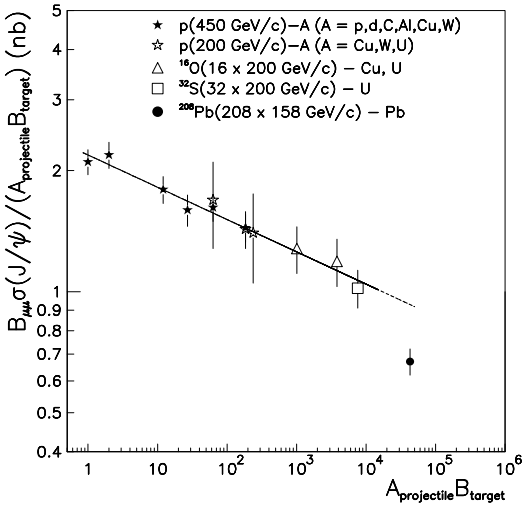

Figure 2b

J/Ψ production results

The nuclear dependence of charmonia production is also calculated as

$$\sigma_{J/\Psi}^{AB} = (AB)^{\alpha}\ \sigma_{J/\Psi}^{NN}$$

Early experiments have observed nuclear effects for the J/Ψ production . The value of α was found from a fit to NA38 and NA51 data to be $\alpha = 0.91 \pm 0.02$. As can be seen in fig.2.b the J/Ψ result for Pb-Pb is smaller than the extrapolation given by the $(AB)^{0.91}$

law shown in the same figure by the solid line. This suggests an anomalous J/Ψ suppression by a factor of 0.74 ± 0.04 from the absorption prediction[8-9] expected value.
The measurements of the ratio $\sigma^{J/\Psi}/AB$ can be replaced by the measurement of $\sigma^{J/\Psi}/\sigma^{D.Y.}$ which is independent of luminosity and of most of the systematic normalization errors. In the framework of the absorption model for particles passing through nuclear matter the survival probability for J/Ψ can be written to the first order as

$$\sigma^{J/Y} \propto (AB) \exp(-\rho_0 \sigma \bar{L})$$

where (AB) accounts for the $c\bar{c}$ creation probability in A-B collisions and the decreasing exponential takes into account the absorption along the $c\bar{c}$ mean free path $\bar{L}$ through nuclear matter of mean density ρ_0.
Dividing the data samples into five neutral transverse energy intervals, the average value of the impact parameter b for each bin can be calculated from a « wounded nucleons » procedure. The corresponding value $\bar{L}(b)$ can be calculated from the average value of the $c\bar{c}$ production positions for each transverse energy bin.
The ratio $\sigma^{J/\Psi}/\sigma^{D.Y.}$ for all the previous data and for Pb-Pb data is plotted versus the centrality parameter L in fig.3.

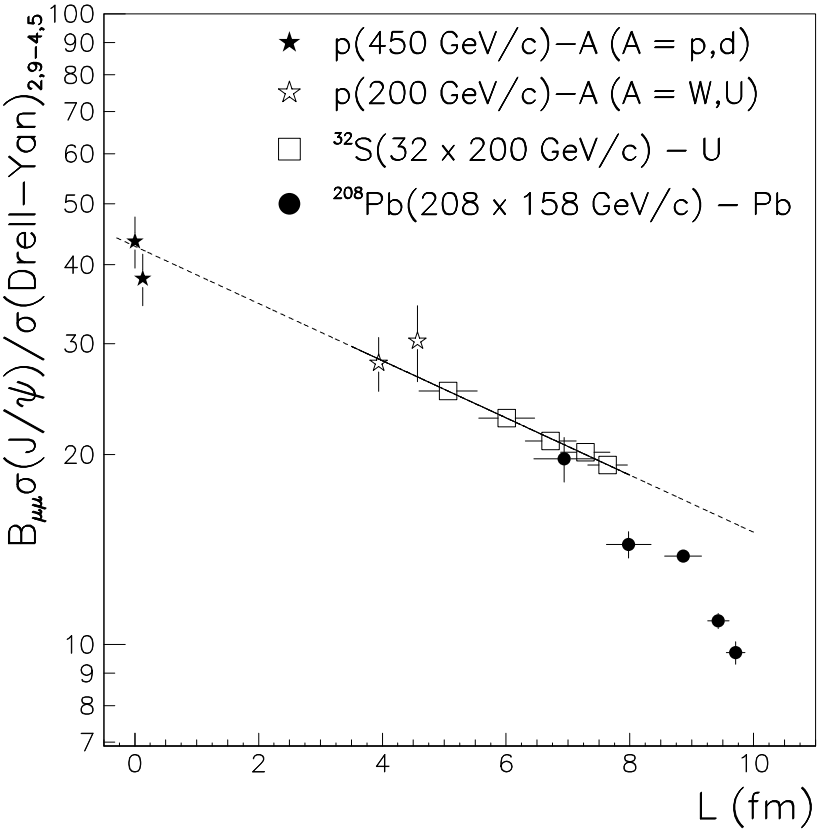

Figure 3

From the fit of NA51 and NA38 data, an absorption cross-section $\sigma_{abs} = 6.2 \pm 0.7$ mb is extracted using a 3 parameters Woods-Saxon nuclear densities. The exponential behavior, shown as a solid line, breaks down for the Pb-Pb data showing a strong dependence of this effect with the centrality of the collision. For L > 7.5 fm the J/Ψ is

suppressed by factors between 0.81 ± 0.03 and 0.62 ± 0.04 respective to nuclear absorption law.

Preliminary 1996 results

As previously mentioned a new procedure using the (E_T-E_{zdc}) correlation plot was applied for vertex identification in order to increase the efficiency for the most peripheral bins. This effect is clearly seen in fig.4 where on the left hand side, the events are selected with the usual target algorithm. On the right hand side the events are selected either by the same algorithm or by the new procedure. The plots clearly show an increased efficiency for peripheral bins in the later case.

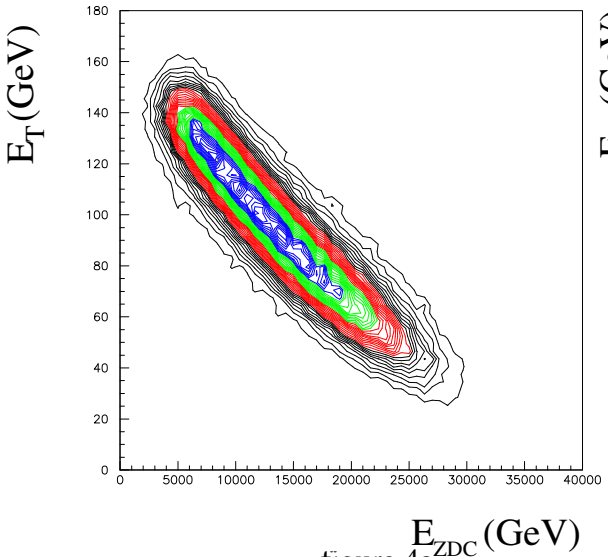

figure 4a

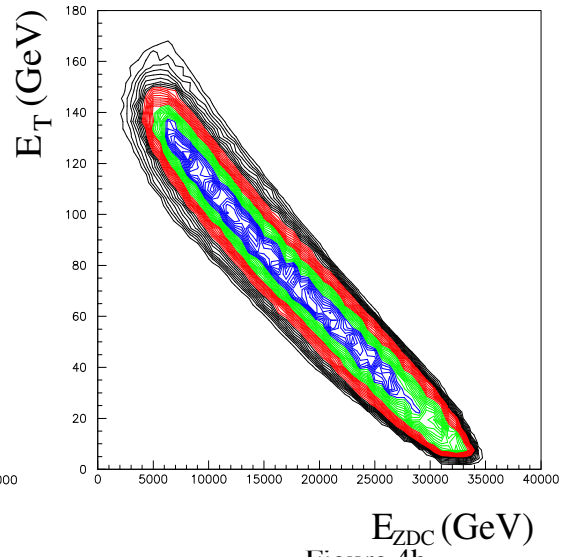

Figure 4b

Events are subdivided in 15 E_T classes. The preliminary new ratio (J/Ψ)/D.Y. extracted in this way are presented in Fig 5.a together with the 1995 data as a function of the transverse energy E_T .

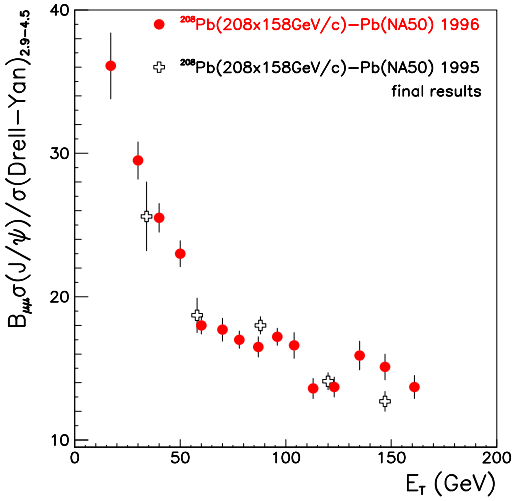

Figure 5a

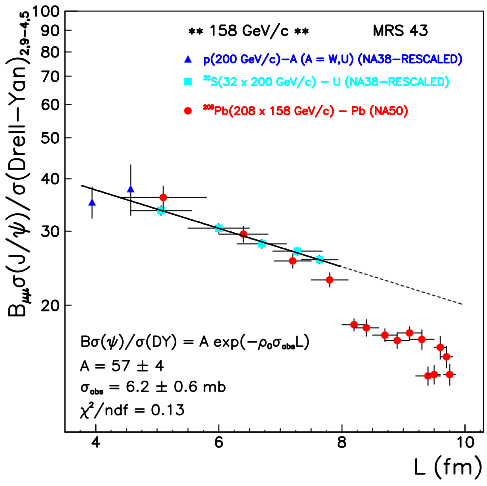

Figure 5b

A clear agreement between the two sets of measurements can be observed. The new data confirm a suppression increasing with the centrality and a discontinuity around at E_T = 50 GeV. The same ratio is plotted in fig.5b versus the parameter of centrality L, for NA38 and NA50 systems. It can be seen that the Pb-Pb peripheral data are compatible with the S+U results fitted by the absorption law. The change observed at L ≅ 7.5-8 fm (b ≅ 8.6 fm) (namely a departure from the classical absorption law)shows evidence of an anomalous suppression in the central collisions

The transverse momentum distributions have been analysed in terms of their moments $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ [6]. Using a 4-D method [10] to take into account acceptance and smearing, the dN/dp_T distributions are extracted for each transverse energy bin. and the mean value of the width of the distributions are deduced. The results for the mean squared transverse momenta $\langle p_T^2 \rangle$ are plotted in fig 6 versus the transverse energy for respectively NA38 and NA50 experiments.

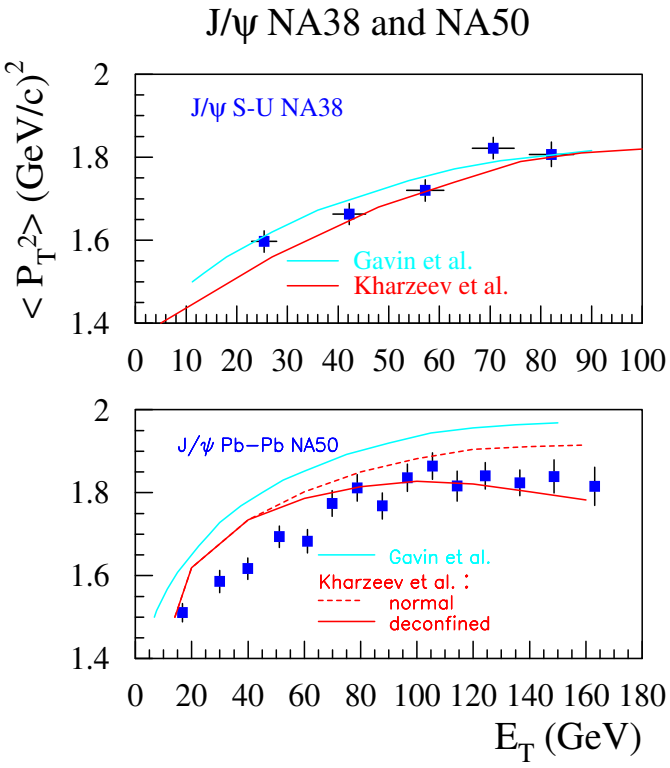

Figure 6

A smooth continuous broadening of the $\langle p_T^2 \rangle$ values is observed as function of increasing centrality. The natural explanation for this behavior in heavy ion collisions compared with pp collisions, is initial state parton scattering. Assuming gluon fusion as being the dominant process for the creation of a $c\bar{c}$ pair, successive interactions with nucleons in the nuclear medium broaden the intrinsic momentum distribution of the concerned gluons. The broadening will be proportional to the number of collisions and can be expressed by the following relation[9]:

$$\langle p_T^2 \rangle_{AB} = \langle p_T^2 \rangle_{NN} + \rho\, \sigma_{gN}\, L\, \langle p_T^2 \rangle_{gN}$$

where the term $\rho\ \sigma_{gN}\ L$ is roughly the number of collisions and $\langle p_T^2 \rangle_{gN}$ the average broadening of the intrinsic gluon p_T distribution per collision. Using the (L-E_T) correlation one can predict the observed monotonic increase of $\langle p_T^2 \rangle_{AB}$ with E_T. The saturation of the (L-E_T) correlation for central collisions leads to the flattening of the plot observed for Pb Pb collisions which corresponds then to geometrical effects. The results of the calculations[11-12] for a "normal medium" and the hypothesis of a

deconfinement are shown in the same figure. The hypothesis of anomalous suppression due to an eventual phase transition results in a decrease of the $\langle p_T^2 \rangle$ at large E_T values. Calculations used p-A data and the NA38 data to fix the model parameters.

Conclusions

A preliminary analysis of the new 1996 data on J/Ψ production in Pb-Pb collisions is performed for the full statistics and is shown to be compatible with previous results of the same experiment. It confirms the strong anomalous suppression observed for central collisions (b < 8.5 fm)respective to the classical nuclear absorption prediction.
The high statistics allows to subdivide data in 15 centrality bins. A discontinuity is seen around b ~ 8.5 fm. Peripheral collisions give results in agreement with those of NA38 and follow the absorption law.
A first analysis of the transverse momenta distributions shows a monotonic increase of the mean squared transverse momentum which flattens out for large L values in the case of Pb-Pb data.

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