Anomalous J/ψ suppression in In-In collisions at 158 GeV/nucleon

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J/ψ suppression has been studied by the NA60 experiment in Indium-Indium collisions. A new analysis technique, based only on the J/ψ sample, allows to accurately study the centrality dependence of J/ψ production. The observed pattern indicates that a suppression is already present in In-In collisions, setting in at $\sim$ 90 participant nucleons. A comparison with the available theoretical models is also presented.

J/ψ suppression is generally considered as one of the most direct signatures of quark-gluon plasma formation [1]. The study of this probe has been extensively carried out, at the CERN SPS, by the NA38 and NA50 experiments [2], exploiting several colliding systems, like p-A, S-U and Pb-Pb. The study of the centrality suppression pattern observed in Pb-Pb collisions indicates that, above a certain centrality threshold, the J/ψ yield is lower than expected from the "nuclear absorption" curve derived from p-A data. However, several of the questions raised by the J/ψ behaviour have still to be clarified. For example, it is important to understand if systems lighter than Pb-Pb already present an anomalous J/ψ behaviour. The comparison between different colliding systems should allow to understand which is the variable driving the J/ψ suppression, e.g. the local energy density or the density of participants or the length L of nuclear matter crossed by the charmonium state. This information should help to disentangle the different theoretical models predicting the disappearance of the J/ψ. The new and accurate measurements provided by NA60 will help answering these and other questions.

The NA60 experimental apparatus complements the muon spectrometer inherited from NA50 with a completely new target region, composed of a beam tracker and a vertex telescope placed in a 2.5 T dipole magnet. A Zero Degree Calorimeter provides an estimate of the centrality of the collisions, by measuring the energy released by the projectile nucleons which have not interacted in the target. A more detailed description of the experimental apparatus can be found in [3]. The reconstruction of the muon tracks in the muon spectrometer is affected by the multiple scattering and energy loss fluctuations due to the crossing of the muons through the hadron absorber. To overcome this limitation, NA60 measures the tracks before the hadron absorber, by means of the vertex telescope. The matching, in coordinate and momentum space, of the tracks reconstructed in the muon spectrometer with those reconstructed in the vertex telescope results in an improvement of the dimuon mass resolution and in an accurate determination of the origin of the muons. Details on the matching technique can be found in [4].

In the 5 weeks long run of year 2003, we run with beam intensities around 5×10^7 ions per 5-seconds burst on 7 Indium targets, 1.5 mm thick each, placed in vacuum. To extract the J/ψ yield we select dimuons in the phase space window $0 < y_{\rm cms} < 1$ and $-0.5 < \cos\theta_{\rm CS} < 0.5$, where $\theta_{\rm CS}$ is the polar decay angle of the muons in the Collins-Soper reference frame. The vertex measurement provided by the vertex telescope allows to keep only dimuons produced in In-In interactions. The matching of the muon tracks is not mandatory for the J/ψ analysis, since the J/ψ peak is clearly visible on top of the underlying continuum. However, the matching requirement allows to have a precise measurement of the dimuon vertex, reduces the combinatorial background under the J/ψ peak (from $\sim 3\,\%$ to $\sim 1\,\%$), and improves the J/ψ mass resolution from ~ 105 to $\sim 70\,$MeV. As a drawback, the matching rate of $\sim 70\,\%$ (per dimuon), reduces the available statistics. Therefore, in the following, the matching will be required only if the reduced statistics will not represent a major limit to the accuracy of the results. After the event selection, without requiring the matching, we are left with $\sim 43\,000$ J/ψ and ~ 300 Drell-Yan events with mass above 4.2 GeV/c^2.

Two different analyses have been performed to investigate the centrality dependence of the J/ψ production in Indium-Indium collisions. They correspond to two different ways of normalizing the J/ψ yield. The first technique, the so-called "standard analysis" is based on a normalization to the Drell-Yan (DY) events. Drell-Yan can be considered as a reference since it is a hard process, its production cross section scales as the number of binary collisions, and does not suffer final state effects.

The ratio between the J/ψ and the DY cross sections is extracted by fitting the opposite-sign dimuon mass spectrum to a superposition of different contributions. The dimuon mass region above 2 GeV contains the J/ψ and the ψ' resonances sitting on a continuum composed of DY dimuons and muon pairs from the simultaneous semi-muonic decay of D and $\overline{\rm D}$ mesons, besides the combinatorial background from π and K decays, estimated from the measured like-sign pairs. The "signal" contributions are evaluated through Monte Carlo simulation, using Pythia as event generator, with "GRV94LO" parton distribution functions. Besides giving the shapes of the processes contributing to the J/ψ mass region, these simulations also provide the J/ψ and DY acceptances, $A_{{\rm J}/\psi} \sim 12.4\,\%$ and $A_{DY(2.9-4.5)} \sim 13.2\%$ for the data collected with the muon spectrometer current of 6500 A. The J/ψ over DY ratio is insensitive to most experimental inefficiencies and to the integrated luminosity. However, because of the very low statistics of high-mass DY events, only three centrality bins can be performed. From the comparison with the previous results (Fig. 1(a)), we can conclude that a suppression of the J/ψ production is indeed present already in Indium-Indium collisions. However, the small number of bins prevents an accurate study of the J/ψ centrality dependence.

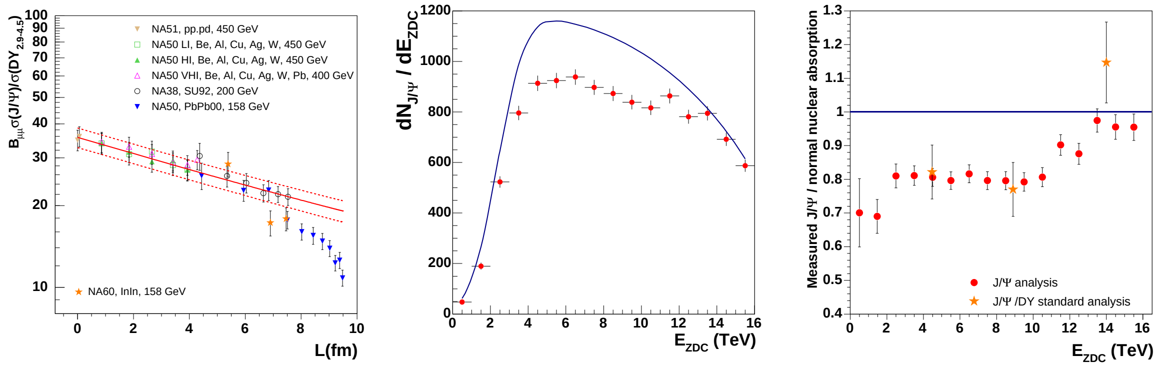

Figure 1. (a) J/ψ / DY standard analysis vs. L, compared with the NA50 and NA38 results; (b) measured J/ψ compared to the normal nuclear absorption curve, vs. E_{ZDC}; (c) ratio between the J/ψ points and the absorption curve (stars: standard analysis).

The second analysis procedure is based on the idea of directly comparing the measured J/ψ sample with a theoretical distribution, based only on the nuclear absorption, obtained within a Glauber model. The matching of the muon tracks is now required, since we are not limited, in this analysis, by the small DY statistics. The J/ψ events correspond to the signal, after the combinatorial background subtraction. Since this analysis has no intrinsic absolute normalization, we normalize it to the results of the standard analysis. In Fig. 1(b) the result of the direct J/ψ analysis is shown as a function of the energy released in the ZDC (E_{ZDC}). Fig. 1(c) shows the ratio between the J/ψ points and the absorption curve. This analysis technique allows a detailed study of the centrality dependence of the J/ψ suppression: an onset of the anomalous suppression is clearly visible at ~ 12 TeV (corresponding to $N_{\mathrm{part}} \sim 90$), followed by a flat behaviour for central collisions. Further information can be acquired comparing the J/ψ analysis with the results previously obtained by the NA38 and NA50 experiments, as a function of different centrality variables. NA60 obtains the centrality estimators from E_{ZDC}, using the Glauber model and taking into account the detector resolution. In Fig. 2 the ratio between the J/ψ and the absorption curve is shown as a function of L, N_{part}, and the Bjorken energy density, estimated using the event generator VENUS.

In principle, the comparison between different colliding systems as a function of different centrality variables should allow to understand which is the variable driving the J/ψ suppression, disentangling between different theoretical models. S-U, Pb-Pb and In-In results do not overlap if plotted as a function of the L variable, as expected, since L is closely related to the normal nuclear absorption. As it can be observed in Fig. 2, it is more difficult to disentangle among the other centrality variables, since a significant comparison would require Pb-Pb points with reduced error bars.

The good quality of the Indium data allows a quantitative comparison with the available theoretical predictions. These models predict a J/ψ suppression based on the nuclear absorption and comovers interactions [5], dissociation and regeneration in both quark-gluon plasma and hadron gas [6], and suppression of the χ_c (and therefore of the J/ψ's

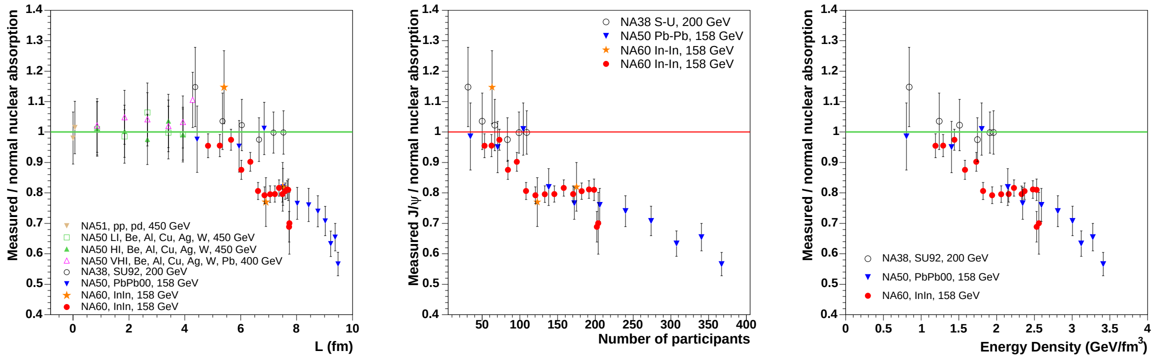

Figure 2. Ratio between the J/ψ data points and the absorption curve as a function of several centrality estimators: (a) L, (b) N_{part}, (c) energy density.

coming from χ_c decays) in a percolation scenario [7]. These models have been tuned on the p-A, S-U and Pb-Pb results obtained by NA38 and NA50. The smearing induced by the ZDC experimental resolution on the centrality estimator is taken into account before comparing the theoretical predictions with the data. Fig. 3 shows that none of the available predictions properly describes the observed suppression pattern.

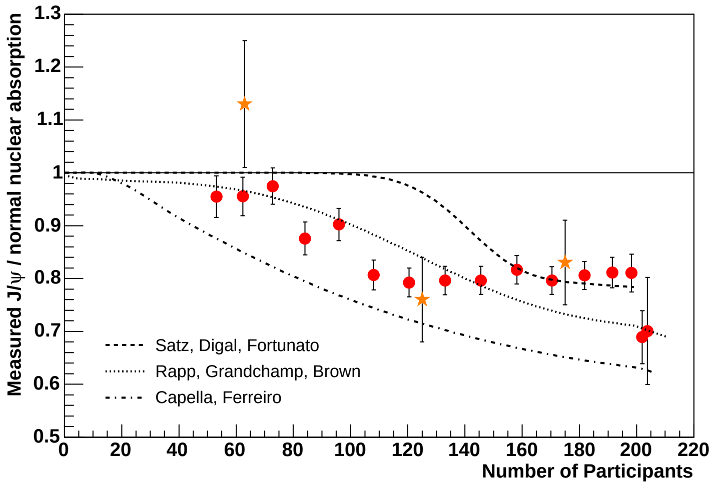

Figure 3. Comparison between the theoretical predictions and the measured J/ψ suppression pattern. The curves include the smearing due to the ZDC experimental resolution.

In conclusion, this preliminary analysis of the NA60 data shows that the J/ψ is already suppressed in In-In collisions. The centrality pattern, well defined by a new analysis only based on the J/ψ sample, indicates that the suppression sets in at $N_{\mathrm{part}} \sim 90$.

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