CHARMONIA PRODUCTION AT THE CERN/SPS

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We present the final results of experiment NA50 on charmonia production in Pb-Pb interactions at 158 A GeV. A strong increasing suppression is observed with increasing centrality, for both the $J/\psi$ and $\psi'$ resonances. We also present new developments regarding the $J/\psi$ and $\psi'$ normal nuclear absorption determinations deduced from proton-nucleus data only. Their comparison with Pb-Pb results allows us to conclude that the $J/\psi$ anomalous suppression sets in at mid-centralities while the S-U results show a reasonable agreement with the p-A behavior. The $\psi'$ suffers a significantly stronger suppression already in S-U interactions, which continuously increases in the Pb-Pb system, and is completely incompatible with the expected behavior deduced from p-A collisions.
1 Introduction

The aim of the NA50 experiment is to search for a transition from normal hadronic nuclear matter to a quark-gluon plasma (QGP) phase of deconfined quarks and gluons. Theory has predicted that $J/\psi$ suppression in ultrarelativistic heavy ion collisions would unambiguously sign such a transition. We present here the latest and final results on charmonia production in Pb-Pb interactions at 158 A GeV from data collected by the experiment at the CERN SPS. The apparatus, optimized for the detection and study of muon pairs produced in heavy ion collisions, is well adapted to identify and measure, through its leptonic decay, the production of charmonium in such collisions. The study has been extended to proton-nucleus reactions which provide the appropriate reference for any possible new feature specific of heavy ion collisions.

Charmonia resonances are measured by the NA50 spectrometer through their decay into a pair of muons in the $2.92 < y_{lab} < 3.92$ and $|\cos(\theta_{CS})| < 0.5$ kinematical window. The muon spectrometer, made of an air core toroidal magnet in-between two sets of four multiwire proportional chambers and two trigger hodoscopes, allows to trigger the experiment on the detection of two muons simultaneously produced in the target region and to measure their trajectories and momenta. A hadron absorber placed downstream from the target is used as a muon filter for the spectrometer. In the NA50 Pb-Pb configuration of the setup, the detector also provides, on an event-by-event basis, the centrality of the interaction as measured by three different devices: an electromagnetic calorimeter (EMC), a forward hadronic calorimeter (ZDC) and a multiplicity detector (MD). Charmonia production in Pb-Pb collisions can thus be studied as a function of three different centrality estimators: $E_T$, the neutral transverse energy; $E_{ZDC}$, the beam spectators energy; and $N_{ch}$, the charged particles multiplicity. The different sources which contribute to the dimuon samples collected in the experiment are extracted from a simultaneous fit to the invariant opposite-sign dimuon mass spectra, obtained for each centrality bin, where all known physical sources are included. Drell-Yan dimuons, the only contribution for the very high mass part of the spectrum, are used as a reference since their production cross-section scales linearly with the number of nucleon-nucleon collisions, as experimentally shown. Results are normally presented as ratios of charmonia to Drell-Yan cross-sections, with the advantage that, since Drell-Yan is measured using the same invariant mass spectrum as the $J/\psi$ and $\psi'$ resonances, most of the systematic errors cancel out in these ratios. The drawback of this procedure is the relatively small Drell-Yan sample which becomes the major source of statistical uncertainties.

2 $J/\psi$ and $\psi'$ nuclear absorption: The normal references

$J/\psi$ normal nuclear absorption is deduced from the analysis of a large set of proton-nucleus data, collected at 450 GeV and 400 GeV and covering a wide range of nuclear sizes. A simultaneous Glauber analysis of the ratios $B_{\mu\mu} \sigma(J/\psi)/\sigma(DY_{2.9-4.5})$ from three different NA50 p-A data sets, together with the pp and pd results obtained by the NA51 Collaboration, lead, for the normalization and absorption cross-section of the $J/\psi$ resonance through nuclear matter, to fitted values of 57.5±0.8 (at 450 GeV) and $\sigma_{abs}(J/\psi)=4.2±0.4$ mb, respectively. These values, when used as inputs in a Glauber model, allow to compute the expected $J/\psi$ production in a Pb-Pb system. Since there are no data allowing to perform a $\sigma_{abs}(J/\psi)$ systematic study as a function of $\sqrt{s}$, we assume that the previous $\sigma_{abs}(J/\psi)$ value holds at 158 GeV. The normalization of the absorption curve at the Pb-Pb energy is obtained by rescaling the $J/\psi$ and Drell-Yan contributions separately. The $J/\psi$ scaling factor is obtained through the analysis of the $B_{\mu\mu} \sigma(J/\psi)/A$ values, for which there are data available at 200 GeV, obtained by the NA38 and NA3 experiments. From a simultaneous Glauber fit at the different energies (see left panel of figure), we measure $\sigma_{abs}(J/\psi)=4.1±0.4$ mb, a value in excellent agreement with the one extracted using the ratios $B_{\mu\mu} \sigma(J/\psi)/\sigma(DY_{2.9-4.5})$. We extract 0.319±0.025 as the factor which scales
down the $J/\psi$ production cross-section from 450 to 200 GeV$^5$. The additional scaling needed to go from 200 to 158 GeV (0.737±0.006) is deduced using a phenomenological description of the $\sqrt{s}$ dependence of the cross-section$^1$ $\sigma_\psi = \sigma_0 (1 - M_\psi/\sqrt{s})^n$. All the available experimental data have been fitted, leading to $n=12.8±0.3$. The $x_F$ correction also needed (1.020±0.013) is computed$^6$ based on a $x_F$ distribution parametrized as a function of $\sqrt{s}$. The Drell-Yan process is scaled down from 450 to 158 GeV (0.387±0.010) using a LO calculation with the same parton distribution functions (GRV 94 LO) as the one used in the Pb-Pb and p-A data analysis. The $\psi'$ normal nuclear absorption is deduced from the ratios $B_{\mu\mu}'\sigma(\psi')/\sigma(DY)$ which, fitted with the same Glauber approach as used for the $J/\psi$, give 1.08±0.05 and 7.6±1.1 mb, for the normalization and $\psi'$ absorption cross-section, respectively. The corresponding absorption curve at 158 GeV is obtained using the same scaling factors as for the $J/\psi$.

3 $J/\psi$ anomalous suppression

The ratio $B_{\mu\mu}\sigma(J/\psi)/\sigma(DY_{2.9-4.5})$ measured in Pb-Pb is now compared with the nuclear absorption curve obtained following the procedures explained in the previous section. The results are presented as a function of centrality and averaged, for each separate centrality region, from data collected in years 1998 and 2000. Indeed, a good statistical compatibility between both data sets has been obtained, after reanalyzing the already published 1998 data with the same criteria as used for the 2000 analysis. A comparison as a function of any of the three centrality estimators shows the same $J/\psi$/DY pattern: a clear departure from the normal nuclear absorption curve at mid-centrality values and a suppression which then increases with increasing centrality (see right panel of figure$^1$). All available data (p-A, S-U and Pb-Pb) can be plotted as a function of $L$, the average path length crossed by the $c\bar{c}$ pair through nuclear matter, which makes possible a direct comparison from pp up to the most central Pb-Pb region. We observe that the S-U $B_{\mu\mu}\sigma(J/\psi)/\sigma(DY_{2.9-4.5})$ results show a reasonable compatibility with other lighter systems while the Pb-Pb central measurements are anomalously suppressed (see left panel of figure$^2$).

4 $\psi'$ suppression

The $\psi'$ results are extracted from the same opposite sign dimuon mass spectra as the $J/\psi$. However, this is a more delicate analysis due to the small $\psi'$ cross-section and to the overlap of several dimuons sources in the $\psi'$ mass region, which can strongly influence the results of the fit. The difficulties increase with centrality since the $\psi'$ is more and more suppressed with respect to those other sources. Careful systematic studies have been performed. We observe a strong
Figure 2: The ratios $J/\psi$/DY as a function of $L$ (left panel) and $\psi'$/DY as a function of $L$ (center panel). The same ratios divided by the expected values deduced from p-A collisions (right panel).

suppression of the $\psi'$ in Pb-Pb collisions. If the direct ratio between the two charmonia states is used to compare both suppression patterns, we observe a factor $\sim 2.5$ higher suppression for the $\psi'$ resonance, between peripheral and central collisions. Once again, the $L$ variable is used to put together the ratios $\psi'/DY$ for various systems as a function of centrality, which leads to the conclusion that a strong $\psi'$ suppression (with respect to p-A) sets-in already in S-U collisions and that the same continuous pattern is observed for Pb-Pb interactions (see center panel of figure 2).

5 Conclusions

We have presented final results from NA50 on charmonia production in Pb-Pb collisions using the Drell-Yan process as reference. The comparison of ion induced $J/\psi$ production yields with the expected behavior inferred from proton-nucleus collisions shows a reasonable compatibility of S-U and peripheral Pb-Pb measurements with the normal nuclear absorption curve. $J/\psi$ anomalous suppression sets-in at mid-centrality and systematically increases for smaller impact parameter interactions. The $\psi'$ production in Pb-Pb follows the S-U pattern as a function of centrality but is completely incompatible with the behaviour expected from proton-nucleus reactions. Dividing the measured charmonia to DY ratios by the expected normal nuclear absorption curves, we conclude that the $\psi'$ suppression sets-in earlier with respect to the $J/\psi$ suppression and presents, for the same centrality values, lower surviving probabilities (see right panel of figure 2).

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