ψ' production in nucleus-nucleus collisions at the CERN/SPS

Helena Santos for the NA50 Collaboration
E-mail: helena@lip.pt

Abstract. We report results on ψ' production in Pb-Pb interactions at 158 GeV/c per nucleon incident momentum, from data collected by the NA50 experiment at the CERN-SPS. A comparison with proton and Sulphur-induced collisions shows a similar ψ' production rate per nucleon-nucleon collision for S-U and Pb-Pb reactions, decreasing with increasing centrality and significantly lower than the rate measured from proton-induced reactions. This feature contrasts with J/ψ production which exhibits a similar behaviour for reactions induced by protons and by Sulphur nuclei and a significantly suppressed rate for Pb-Pb interactions.

1. Introduction

The study of charmonium production in ultrarelativistic heavy ion collisions has been addressed since the mid 80s by the NA38 Collaboration [1], followed in the 90s by NA50 [2]. The motivation is to search for the phase transition of nuclear matter from its normal state to a deconfined quark-gluon plasma, as predicted to occur, under extreme energy densities or temperature conditions, by non-perturbative QCD. In such a deconfined matter, it is expected that J/ψ is suppressed by Debye colour screening [3]. Indeed, experiment NA50 has shown that J/ψ production, in Pb-Pb collisions, is significantly suppressed with respect to the expectations derived from the rates measured in proton and Sulphur-induced reactions [2, 4]. The ψ', a more loosely bound state than J/ψ, could also dissociate at lower energy densities, although, because of its small binding energy, its production could as well be suppressed by standard nuclear interactions.

2. Data selection and analysis method

A detailed description of the NA50 apparatus can be found in [5]. Vector mesons are detected through their leptonic decays in an air gap toroidal magnet muon spectrometer. The centrality of the reaction is estimated with three independent detectors which measure the neutral transverse energy E_T, the beam spectators energy E_{ZDC} and the charged multiplicity produced in the interaction.

Pb-Pb data collected in the years 1998 and 2000 are used for the ψ' analysis reported here. Dimuons are selected in the rapidity window $2.92 \leq y_{lab} < 3.92$ ($0 \leq y_{CM} < 1$) and with a Collins-Soper angle $| cos\theta_{CS} | < 0.5$, resulting in an acceptance of around 14% in the dimuon invariant mass region of interest. On-target interactions are further selected requiring the appropriate correlation between hits in the two planes of the Multiplicity Detector. Double interactions are discarded by a shape analysis of the signal from the

Electromagnetic Calorimeter. Residual pileup events are rejected by a 2σ cut in the $E_T - E_{ZDC}$ correlation plot. More details are described in [4]. The total number of ψ' after data selection is 380 and 905, for the 1998 and 2000 data samples respectively.
The recorded events are analyzed as a function of the centrality of the reaction in which they were produced. For each centrality class separately, the analysis is performed as described hereafter. The opposite-sign dimuon mass spectrum results from four physical contributions (J/ψ, ψ', Drell-Yan and semi-leptonic $D\bar{D}$ decays) and from a combinatorial backround originating mostly from uncorrelated π and K decays. The combinatorial background is estimated from the like-sign muon pairs according to $N_{BG} = 2\sqrt{N^{++}N^{--}}$. The remaining components of the opposite-sign muon pair mass spectrum are estimated through a fit where the shape of each component is obtained by Monte-Carlo simulation, including the apparatus, the detection of the muons in the spectrometer and the event reconstruction and selection as used for real data. Drell-Yan and $D\bar{D}$ are generated at leading order by PYTHIA [6].

3. ψ' production in Pb-Pb collisions

At SPS energies, the NA38/NA51/NA50 experiments have verified that the Drell-Yan cross-section is proportional to the number of elementary nucleon-nucleon collisions, from p-p up to Pb-Pb interactions [7]. Therefore, and in order to cancel systematic errors like reconstruction and trigger inefficiencies or luminosity uncertainties, the ψ' production rate is normalized to Drell-Yan. As explained above, the fit to the dimuon invariant mass spectra leads to the ψ' and the Drell-Yan yields (the latter in the mass interval 4.2 - 7.0 GeV/c^2) and to the ratio $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$ which is proportional to the ψ' production cross-section per nucleon-nucleon collision. Fig.1 displays this ratio $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$ as a function of E_T and shows a suppression of the ψ' production rate which increases with increasing centrality. The relative behaviour of the two

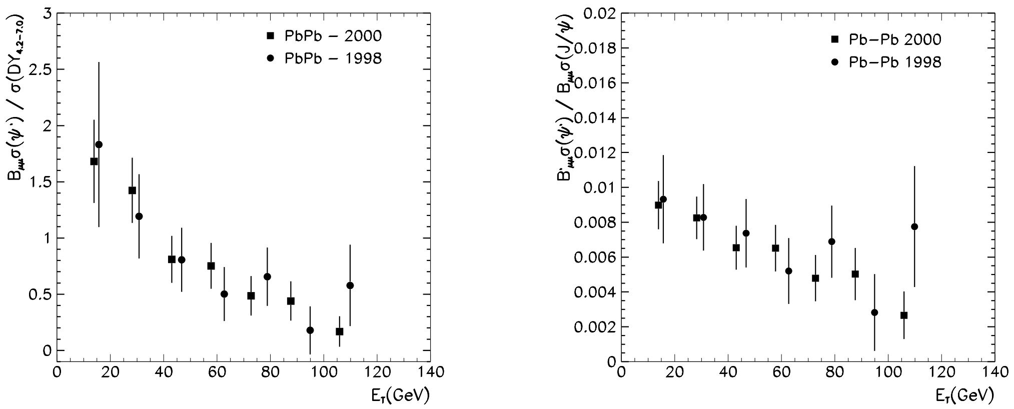

Figure 1. $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$(left) and $B'_{\mu\mu}\sigma(\psi')/B_{\mu\mu}\sigma(\psi)$(right) as functions of E_T, both for the Pb-Pb 1998 and 2000 data samples.

charmonium states as a function of E_T is presented in the right plot of fig.1. It shows that, in Pb-Pb interactions, the ψ' is more suppressed than the J/ψ when centrality increases.

4. Comparison with lighter systems

ψ' suppression in Pb-Pb collisions can be compared with results obtained both from proton-induced reactions by experiment NA50 and from S-U reactions studied by experiment NA38. Incident momenta were 400 and 450 GeV/c for protons and 200 AGeV/c for Sulphur. The first comparison (fig.2) gives the relative suppression of the two charmonium states as a function of the product of the projectile and target atomic mass numbers. The ratio $B'_{\mu\mu}\sigma(\psi')/B_{\mu\mu}\sigma(\psi)$ is parametrized by the power law $A^{\Delta\alpha}$, where α accounts for all nuclear effects suffered by the resonances. The measured non-zero negative value of this parameter shows that the ψ' is more absorbed than the J/ψ, already in p-A collisions [8, 9]. Furthermore, a strong suppression of the ψ' w.r.t. J/ψ is measured for the heavier systems, S-U and Pb-Pb.
In order to compare ψ' suppression between different systems, we use L, the average path crossed by the $c\bar{c}$ pair inside the nucleus. L is estimated within the Glauber model framework and the results are shown in the right plot of fig.2. We observe

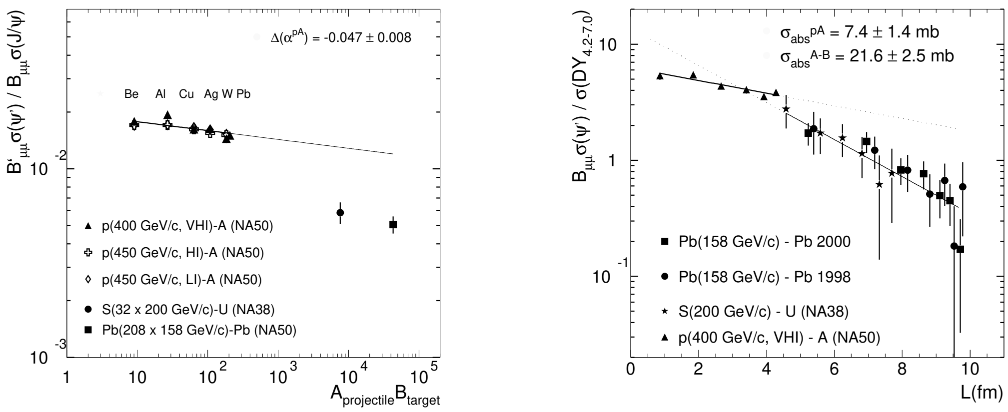

Figure 2. $B'_{\mu\mu}\sigma(\psi')/B_{\mu\mu}\sigma(\psi)$ as a function of A×B(left). $B_{\mu\mu}\sigma(\psi')/DY$ as a function of L(right).

incompatible behaviours for the ratio $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$ as a function of L, between p-A and A-B interactions. Using an exponential parametrization in L, $\exp(- < \rho L > \sigma_{abs})$, we obtain an absorption cross-section of 7.4 ± 1.4 mb for ψ' in p-A collisions, while in ion-ion interactions the value obtained is much higher, 21.6 ± 2.5 mb. Moreover, ψ' suppression is, as a function of centrality, the same in S-U and Pb-Pb interactions.

5. Comparison between J/ψ and ψ' productions

The most updated Pb-Pb results for the ratio $B_{\mu\mu}\sigma(J/\psi)/\sigma(DY)$ as a function of E_T [4] are shown in the left plot of fig.3. The absorption curve is deduced from p-A and S-U results [9] and the limited band accounts for the Drell-Yan rescaling uncertainty when passing from the S-U 200 AGeV to the Pb-Pb 158 AGeV energy domain. The figure shows that while peripheral collisions follow the absorption curve, there is a departure from this normal behaviour at mid-centrality followed by a steady decreasing trend; a pattern which qualitatively agrees with the theoretically predicted J/ψ dissociation in a partonic medium.

The right plot of fig.3 shows, for various interacting systems, the ratio of the measured charmonium yields to the corresponding expected values. The latter are computed as resulting only from normal absorption in nuclear matter, that is a full Glauber calculation with $\sigma_{abs}^{J/\psi} = 4.3 \pm 0.3$ mb, as extracted from a simultaneous fit to p-A and S-U interactions in the case of J/ψ , and $\sigma_{abs}^{\psi'} = 7.9 \pm 0.6$ mb as deduced only from p-A collisions in the case of ψ' (since this absorption cross-section value is incompatible with the one obtained in S-U reactions). The figure shows that the value of L at which departure from normal absorption occurs, is lower for ψ' than for J/ψ.

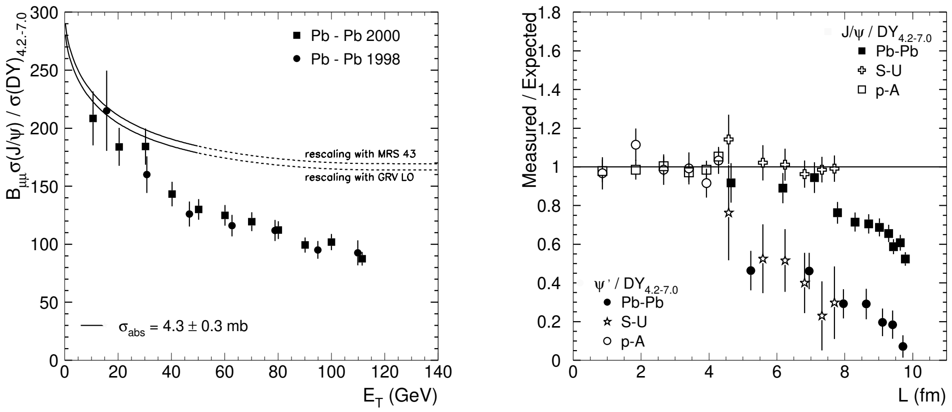

Figure 3. $B_{\mu\mu}\sigma(J/\psi)/\sigma(DY)$ as a function of E_T(left).
The ratio "measured value"/"expected value" for the relative yields $B_{\mu\mu}\sigma(J/\psi)/\sigma(DY)$ and $B'_{\mu\mu}\sigma(\psi')/\sigma(DY)$, as a function of L(right).

6. Conclusions

Between Pb-Pb peripheral and central collisions, ψ' is suppressed by a factor of 7, w.r.t. Drell-Yan, and by a factor of 2.5, w.r.t. J/ψ. The comparison with lighter systems shows that ψ' is much more suppressed in nucleus-nucleus than in proton-nucleus reactions and that the suppression pattern as a function of centrality is the same in S-U and Pb-Pb interactions. From the comparison between J/ψ and ψ', we conclude that anomalous suppression for the latter sets in for lower values of L.

Acknowledgments

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