Study of J/ψ suppression in Pb-Pb collisions at the CERN SPS.

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Abstract

We report on a search for a phase transition from ordinary nuclear matter to a state of deconfined quarks and gluons as predicted by lattice QCD calculations. One of the most clean signatures of this state of matter is predicted to be the suppression of the J/ψ production. The NA50 experiment measures, at CERN SPS, the dimuon production in Pb–Pb collisions at an incident momentum of 158 GeV/c per nucleon. The J/ψ production, detected via its decay into muon pairs, is studied as a function of the centrality of the collision. For peripheral collisions the J/ψ production cross section can be described in terms of nuclear absorption, inferred from numerous measurements extending from p-p to S-U. The central events show an anomalous suppression, which cannot be described by models based on hadronic scenarios. Latest results on these measurements are reported.

The heavy ion program is focalized on the search of a state of matter where the quarks and gluons are deconfined, i.e. the quark-gluon plasma (QGP). This phase is predicted by non-perturbative lattice QCD calculations to occur above a critical temperature T_C, of the order of 200 MeV. The ultrarelativistic heavy ion collisions are a unique tool for the discovery of the QGP, since they can provide the extremely high temperatures and energy densities needed for the phase transition. The charmonium suppression, due to the color screening, is generally believed to be one of the most promising signatures for the deconfinement. In this paper we report the most recent results (1996 and 1998 data samples) about the measurement of the J/ψ suppression in Pb-Pb collisions as a function of the centrality, performed by the NA50 collaboration.

NA50 is basically a dimuon spectrometer. The muon pairs are deflected by an air-core toroidal magnet, and tracked by a set of 8 multi-wire proportional chambers. An hadron absorber is placed between the spectrometer and the active target, composed by seven subtargets connected to a system of Cherenkov counters that identify the subtarget where the interaction took place and tag the reinteracion events, that occur when a fragment coming from a primary collision in the target interacts with a downward target nucleus. These events bias the transverse energy measurement and have to be rejected in the off-line analysis.

To estimate the centrality of the collision we use an electromagnetic calorimeter, that measures the transverse energy E_T of the collision, a multiplicity detector, and a zero-degree calorimeter (ZDC) that measures the energy E_{ZDC} carried by the non interacting spectator nucleons. Further details can be found in [1].

The goal of the 1996 data taking was to obtain a high statistics sample, to have access to the most peripheral collisions. For this purpose, we used a thick target ($30\%\lambda_I$) and a high intensity beam. This target setup causes a higher probability of having reinteractions, that bias the high transverse energy region. For the 1998 data taking the target setup was optimized for a more accurate study of the high E_T spectrum. We thus adopted the choice of a single thin target ($7\%\lambda_I$), thus reducing strongly the amount of reinteraction events.

The data selection is made in order to have a clean sample of dimuons originating in the target. The events on target can be selected by the active target system, or by the correlation between E_T and E_{ZDC}. The former is a powerful tool for the rejection of the off-target events, but is inefficient for peripheral collisions, since the small signal in the Cherenkov counters is indistinguishable from the delta rays produced by the non-interacting lead ions crossing the target. Indeed, it will not reconstruct the most peripheral collisions and will not detect most of the reinteraction events, in which at least one of the interactions is most probably peripheral. To recover the most peripheral events we thus adopted, for the 1996 data selection, the selection criterion based on the correlation between E_T and E_{ZDC}: the events are accepted if they lie within two standard deviations from the average value of the correlation, cleaning most of the off-target events. For the 1998 data sample, the bigger contamination by events in air led us to the choice of the target algorithm selection, with severe cuts on the Cherenkov counters thresholds. This limits our transverse energy range, for this data sample, to $E_T > 40$ GeV.

Another powerful tool in the selection of the on-target collisions is a severe check of the muon track quality. Tracks pointing to a common vertex in the target region are selected.

We study the ratio $B_{\mu\mu}\sigma^{J/\psi}/\sigma^{DY}_{(2.9-4.5\ GeV)}$ by making a fit to the invariant mass spectra. Five components are present: the combinatorial background, the open charm, the J/ψ, the ψ', and the Drell-Yan process. We determine the amount of background, due to simultaneous, uncorrelated decays of pions and kaons into muons, from the like-sign muon pairs sample, using the standard formula $N^{BG} = 2\sqrt{N^{++}N^{--}}$. We determine the shape of the other components by a Monte Carlo simulation, and fit the mass spectrum leaving the normalizations as free parameters. Further details about the data selection and the fit procedure can be found in [2, 3].

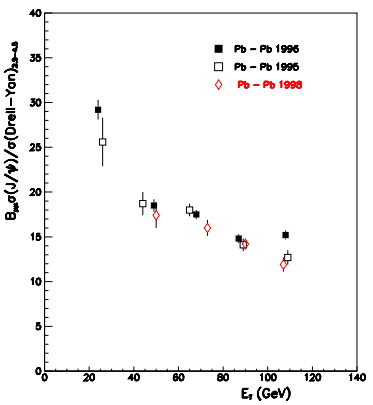

Figure 1. Ratio between the ψ cross section (times branching ratio in muon pairs) and the Drell-Yan cross section for three data samples.

In fig. 1 the J/ψ / DY ratio as a function of the transverse energy is shown for the '95, the '98 and the '96 data taking, plotted in 5 bins to compare to the other two data sets. Above 100 GeV a discrepancy can be noted between the latter, taken with a ticker target, and the other two. This effect is caused by a bias in the 1996 data due to reinteraction events. In the following, the '96 results at $E_T > 100$ GeV will not be considered.

An alternative way to study the J/ψ suppression is to estimate the Drell-Yan E_T distribution by means of a sample collected with a minimum bias trigger, that occurs whenever a non-zero energy is detected in the ZDC. This method has the basic advantage of reducing the statistical error, which is almost entirely due to the fluctuations in the Drell-Yan sample. Moreover, an independent sample is used for the denominator. Finally, a fit to the mass spectra is no more needed: the J/ψs are defined as the events with $2.9 < m < 3.3$ GeV. A small correction (of the order of 5%) is applied to account for the Drell-Yan events under the J/ψ peak. On the other hand, besides the fact that two different triggers are applied for the numerator and the denominator, the quality of the track reconstruction cannot be applied as a criterion for the off-target events recognition. A contamination of interactions in air is thus present for low E_T, so that the 1996 results will be limited to $E_T > 20$ GeV.

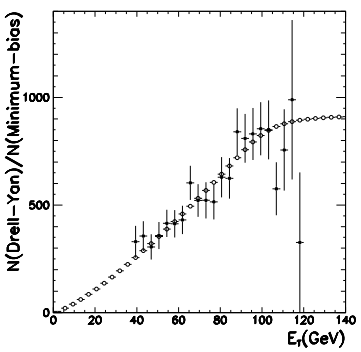

Figure 2. Ratio between the Drell-Yan and minimum bias calculated (open circles) and measured (black circles) E_T distributions.

The analysis is based on the very similar structures for the transverse energy distributions in minimum bias (MB) and Drell-Yan (DY) events. They can be parametrized according to: $f_{MB} = (dN/dE_T)^{th}_{MB} \propto \int P(E_T, b) b db$, and $f_{DY} = (dN/dE_T)^{th}_{DY} \propto \int N_{AB} P(E_T, b) b db$, where N_{AB} is the number of collisions and $P(E_T, b)$ is the correlation function between E_T and the impact parameter b, depending on two parameters that can be fitted to the experimental distributions [4, 2]. The Drell-Yan E_T distribution can thus be estimated from the measured MB one according to $(dN/dE_T)^{est}_{DY} = (dN/dE_T)^{meas}_{MB} \times f_{DY}/f_{MB}$. In fig. 2 the open circles represent the calculated ratio f_{DY}/f_{MB}. They show a good agreement with respect to the ratio of the measured distributions (black circles).

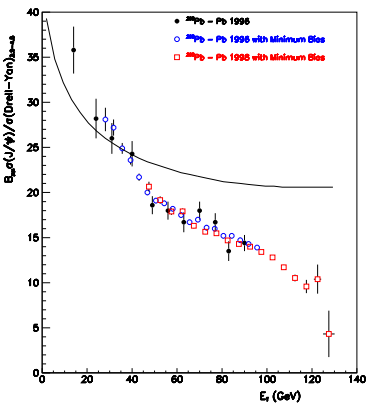

Figure 3. $J/\psi/DY$ cross sections ratio as a function of E_T.

Figure 3 shows the comparison between the minimum bias and direct analysis. The MB results are normalized in the range $55 < E_T < 75$ GeV. The most peripheral collisions are well described by the absorption curve, calculated for an absorption cross section of 6.4 mb, in the frame of the Glauber model [5], using the NA38 and NA51 data [6]. A sudden change of the suppression pattern occurs at 40 GeV, confirmed by the minimum bias analysis. A second change of slope is visible at high E_T.

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