NA50 results on Pb-Pb interactions at 158 GeV per nucleon

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We present a set of results obtained by experiment NA50 at the CERN SPS. In Pb-Pb collisions, the ϕ meson yield and the muon pair mass continuum in the invariant mass range (1.5 - 2.5 GeV/c^2) exhibit a significant enhancement which increases with the centrality of the collision. The measured J/ψ suppression pattern rules out conventional hadronic scenarios and provides evidence for quark-gluon deconfinement.

1. introduction

The NA38 and NA50 experiments measure muon pair production in coincidence with the transverse energy produced in ultrarelativistic heavy ion collisions. For the most central collisions, the energy density is sufficient to reach the critical temperature T_c [1] of the phase transition toward a plasma of quarks and gluons predicted by statistical QCD. Among several observables of interest in the description of the various stages of the evolution of the system, the dimuon measurement gives access to two of the possible signatures of this QGP, the J/ψ suppression and the ϕ enhancement. J/ψ suppression [2] has the unique advantage of being a potential direct measurement of the deconfinement, through the screening effect of the plasma on the $c\bar{c}$ pair, produced in hard processes in the earliest times of the collision. In spite of its lower mass, The ϕ production is also interesting as another possible signature of the quark gluon plasma formation[3,4], which could lead to some enhancement of the strangeness production, also observed in several experiments [5]. In addition the dimuon mass continuum displays peculiar features in heavy ion collisions which will be mentioned in this talk.

2. experimental setup

The NA38/NA50 detector [6,7] consists mainly of a muon spectrometer made of an absorber followed by a set of tracking chambers and hodoscopes located upstream and downstream a toroidal magnet.

For experiments using ion beams, where the measurement of the impact parameter is relevant, transverse energy produced in the collision is measured thanks to a Pb-fiber calorimeter. To avoid biases in this centrality measurement, a beam detector allows to reject pile up and projectile fragment reinteractions are minimized thanks to a segmented active target [6,7] . In NA50 [7] the energy produced at zero degree and the charged multiplicity are also measured, thanks to two additional detectors.

π and K mesons decays into muons are the main source of the combinatorial - and thus increasing with the square of the produced multiplicity - background in the measured muon pairs. With increasing masses of the colliding nuclei, it is then more and more important to add dense material as close as possible to the target, with a low atomic number in order to minimize multiple scattering and thus protect mass resolution. Depending on the compromise done between resolution and absorption different layouts have been used.

In order to be adapted to the hardest radiations conditions and to obtain extended measurement of centrality and associated quantities, the complete ion setup has been rebuilt for the measurements with Pb Beam [7]. New detector have been added, a silicon multiplicity detector and a Pb-fiber zero degree calorimeter. The angular aperture of the calorimeter has also been changed from a pseudorapidity domain 1.7-4.2 in NA38 to 1.5-2.3 in NA50. In the latter case the resolution on E_{ZDC} varies from $\sim$10% for peripheral collision to $\sim$20% for the most central ones, whereas for E_T the corresponding values are 10% and 7%. The energy per nucleon of the Pb beam is lower than the S one, 158 GeV instead of 200. The aperture of the spectrometer has been tuned in order to correspond to rapidity of measured dimuons between 0 and 1 in the nucleon nucleon center of mass.

The aim of these measurements was the study of the J/ψ production and the setup was optimized for these high masses domain. In particular the field in the magnet was increased by 7/4, and 80 cm of carbon at the end of the absorber were replaced by 80 cm of iron. These changes reduce the low masses acceptance and even suppress the measurement of their lowest transverse mass domain.

Pb-Pb data have been taken in 1995, 1996 and 1998. The main differences between these periods lie in the target thickness, corresponding respectively to 17, 30 and 7 per cent of interaction length, leading to different statistics (respectively 50000, 190000 and 40000 J/ψ produced) but also to different experimental conditions. From 1996, the range of transverse energies available has been improved thanks to the use of the correlation between E_T and E_{ZDC} in order to reject spurious events in the low Et region while avoiding the inefficiency of the target detector.

3. analysis

The background resulting from combinations of muons coming from uncorrelated decays has to be removed in the $\mu^+\mu^-$ spectra. It can be determined from the spectra of $\mu^+\mu^+$ and $\mu^-\mu^-$ which are also recorded and originates only from uncorrelated combinations. More details on the subtraction methods can be found in [10].

In order to extract the contributions of the resonances and of the continuous components, fits are performed on the dimuon mass spectra. For the high [7] and intermediate masses studies 4 components are considered for the signal, J/ψ, ψ', Drell Yan and D$\bar{\text{D}}$, plus one for the background, whereas for low masses studies 3 components are considered ϕ, $\rho + \omega$ and a phenomenological exponential-like continuum.

From input distributions in mass, rapidity , $\cos\Theta_{cs}$ and transverse mass, a complete simulation of the detection of the muon pairs is made through a Monte-Carlo program, allowing to correct for smearing and acceptance effects. From the fits of the mass spectra the amount of dimuons produced in the kinematical available domain (M_T bin, $0. < Y_{cdm} < 1.$, $-0.5 < \cos\theta < 0.5$) can then be deduced for each component.

Cross sections are estimated from these numbers normalized thanks to the number of incidents particles measured by the beam hodoscope for the ion beams, and by a set of gaseous detectors called argonion for the deuteron and proton beams.

4. results

4.1. ϕ and ω

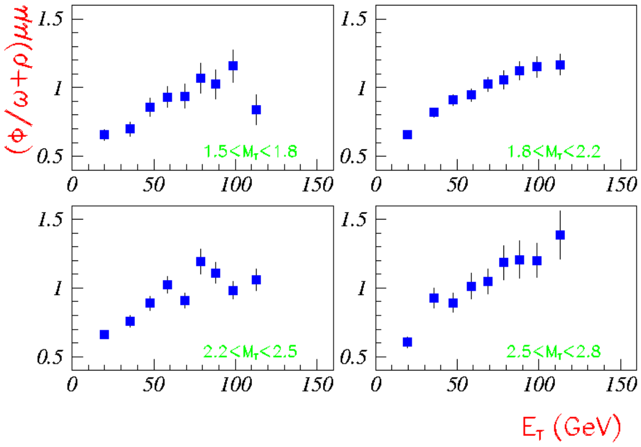

Figure 1. ratio ϕ/ω as a function of E_T in the Pb-Pb system, for several M_T domains

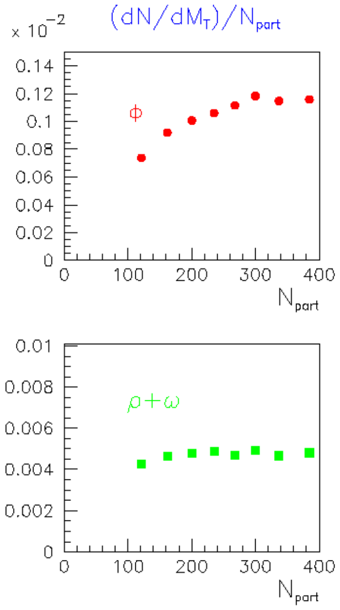

Figure 2. ϕ and $\omega + \rho$ multiplicities divided by the number of participant nucleon N_{part}

The ratio ϕ/ω is of particular interest with regard to strangeness production, as a possible direct measurement of $s\bar{s}/u\bar{u}+d\bar{d}$ production in similar kinematical conditions. As a ratio it does not depend on the luminosity and is less sensitive to the acceptance uncertainties than an absolute observable.

In picture 1 this ratio is presented in the Pb-Pb system as a function of the transverse energy for several transverse mass domains. One observes a continuous increase of the ϕ with respect to the ω . The study of the ϕ and ω multiplicities with respect to the number of participant nucleons (figure 2) confirms that the ϕ/ω increase is due to an enhancement of the ϕ . These results [11] have been extracted from the 1996 data set where the E_T range and the statistics have been extended compared to the 1995 previous analysis. These previous results [12] were concluding also to the increase of ϕ/ω , in the Pb-Pb system but also when comparing central Pb-Pb collisions to central S-U ones. Extended comparisons of the procedures and acceptance calculations and cross checks are going on inside NA50 in order to take advantage of the complete NA50 measurement about this increase, at the level of several tenths, but measured at the border of the detector acceptance for Pb-Pb. This should help clarify the comparison between NA49 strangeness and ϕ production measurements [5] regarding the saturation of the strangeness production between sulfur and lead, and the ϕ M_T slope. In NA50, $T_\phi = 227 \pm 10$ MeV and $T_\omega = 224 \pm 10$ MeV without visible dependence on centrality. This appears consistent with the Ω M_T slope measured in WA97, but not with the ϕ one from NA49. It should then influence our global understanding of the strange and multistrange production in heavy ion collisions.

4.2. intermediate mass continuum

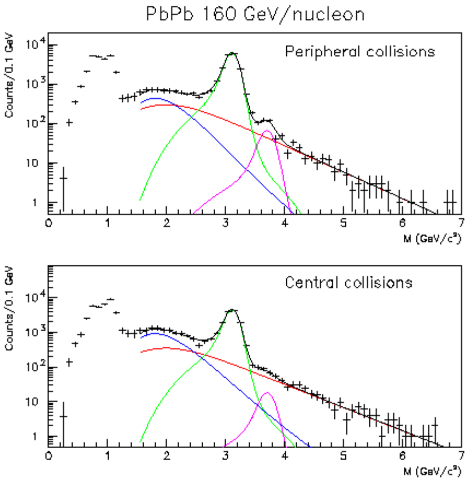

Figure 3. Dimuons mass spectra for low and high E_T bins in Pb-Pb collision, displaying the various contributions considered in the fit and showing the increase of the D$\bar{\mathrm{D}}$ like component.

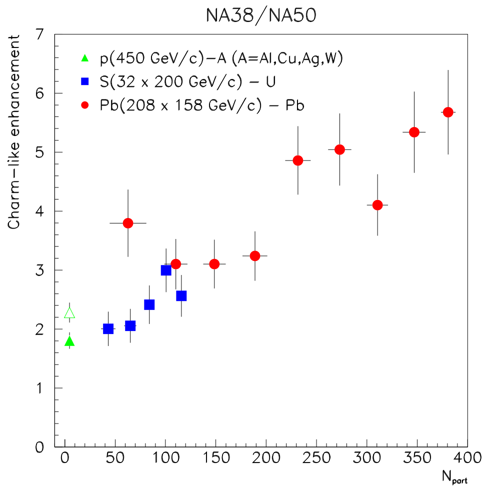

Figure 4. Evolution of measured/expected D$\bar{\mathrm{D}}$ like component as a function of the number of participant nucleons, from protons to ions induced collisions, arbitrary normalized to 1 for protons

Figure 3 displays two complete dimuon mass spectra, for peripheral and central collisions in the Pb-Pb system. The various components considered in the fit are shown. The Drell Yan contribution is determined by the high mass dimuon yield. The background component is mostly fixed by the muon pair of the same signs, as described previously. J/ψ and ψ' resonances contribute significantly only in their restricted mass domains, so in the intermediate mass range only the D$\bar{\mathrm{D}}$ component is significantly free.

D$\bar{\mathrm{D}}$ open charm and Drell Yan are hard processes, their cross section scales as the number of nucleon-nucleon collisions. Their ratio should be constant, irrespective of the system considered. This picture is verified for the Drell Yan, whereas the D$\bar{\mathrm{D}}$ component has to be increased relatively to Drell Yan in order to reproduce the continuum production in the mass range 1.5-2.5 GeV/c^2, and this excess is increasing with the centrality (figure 3). Picture 4 shows the evolution as a function of the number of participant nucleons [13].

The kinematical distribution of the excess is consistent with D$\bar{\mathrm{D}}$ production as expected from the PYTHIA code, suggesting that this excess is due to an open charm enhancement. This will be checked by the NA60 experiment. Alternative explanations [13,14] could be rescattering of D mesons in nuclear matter, or production of thermal dileptons.

4.3. J/ψ

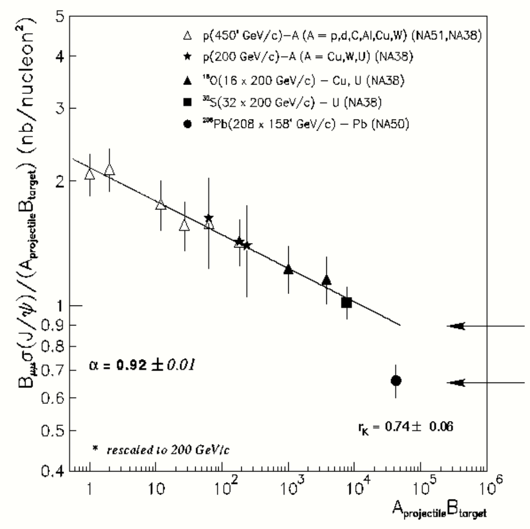

Figure 5. J/ψ production cross section as a function of the atomic masses of target and projectile A×B

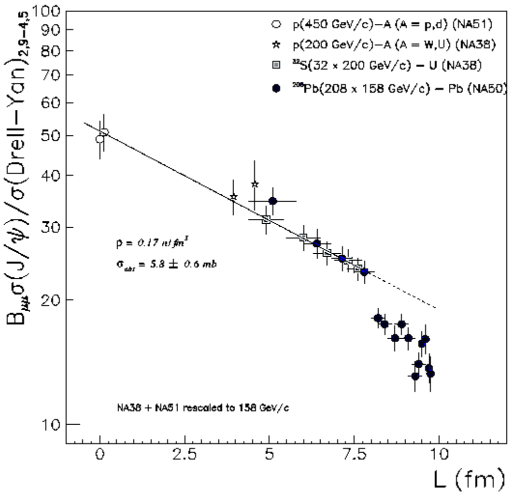

Figure 6. Ratio J/ψ over Drell Yan for various systems and centralities, presented as a function of L, average thickness of the participant zone

The cross section for the J/ψ production is displayed in figure 5 for various systems. Some results have been rescaled [7] to take into account the changes of beam energy. From p-p to S-U the cross section displays a regular decrease as a function of the size of the colliding system. Expressed through the product A×B of the two atomic mass numbers it is found compatible with the usual parameterization $(A \times B)^{\alpha}$, with $\alpha = 0.92 \pm 0.01$ which is also compatible with the value obtained by FNAL experiment E772 [9].

The value of the cross section in Pb-Pb collisions $21.9 \pm 0. \pm 1.6 \mu b$ is found to be significantly lower than the one expected from the absorption fit line. This "anomalous" suppression suggests the existence of a new mechanism in Pb-Pb collisions. On the contrary the Drell Yan cross section , not shown here, displays a very regular behavior proportional to A×B from pp to Pb-Pb, sustaining the anomaly in J/ψ result. Furthermore as it is insensitive to the strong interaction it furnishes a natural reference, for the studies as a function of centrality which are displayed in figure 6. Here the centrality is represented by the variable L, average thickness of the participant zone as deduced from Et thanks to a geometrical model (see [15] and references therein for more details). Again while a common behavior exists from p-p to S-U and the most peripheral Pb-Pb points, the most central Pb-Pb collisions display an additional suppression, on the average -25%± 0.04 with respect to the expectation. These 1996 results [15] are in agreement with the previous 1995 results with lower statistic [7,8]. Looking at the Pb-Pb results alone and as a function of Et (figure 7) we still see a very different pattern for the lowest Et points, suggesting a threshold effect between two regimes, occurring around Et=40 GeV.

Most of the J/ψ/DY uncertainty comes from the statistical fluctuations of the Drell-Yan

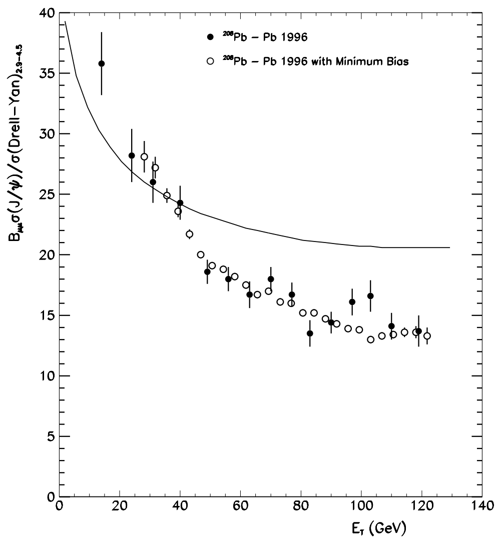

Figure 7. J/ψ over Drell Yan as a function of the transverse energy Et in the Pb-Pb system

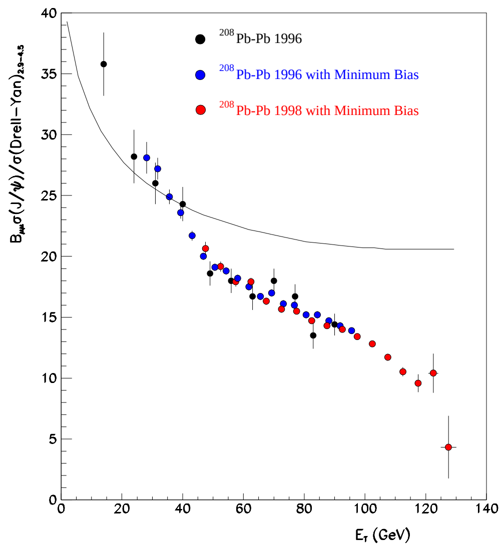

Figure 8. J/ψ/DY ratio as a function of E_T , for the standard and minimum bias analysis in their respective relevant domains (see text). The curve is the ordinary nuclear absorption from figure 6.

component which is defined by the high mass dimuons. A fit of the Drell Yan multiplicity allows to improve the situation, keeping the main trend of the Drell-Yan production , with negligible statistical fluctuations. Nevertheless it requires the dN_{coll}/dE_T distribution which is obtained by a different trigger (Zero Degree Calorimeter) than the dimuons, and might suffer different biases, in particular at high E_T (reinteraction in target, low E_{ZDC}) and low E_T (target selection using muon track). This analysis superimposed on the J/ψ/DY ratio of picture 7 confirms the rapid change of regime in the appearance of the anomalous J/ψ suppression. A similar conclusion arises from J/ψ/DY as a function of E_{ZDC} . In the "knee" region of the E_T distribution, above 100 GeV, the J/ψ/DY ratio is slightly increasing. It could be linked to an increase of unrecognized reinteractions with the target thickness. This could mix intermediate impact parameter collisions with central ones, causing inverted behaviour in the observables.

So in 1998 [16] was performed a measurement with only one target. Decreasing the target thickness has also the effect of increasing the relative importance of the Pb-air collisions which occur in the vicinity of the target. Measurements performed without target found this contribution negligible for transverse energies higher than 40 GeV. Only such events are thus considered in the 1998 data analysis, furthermore asking for an identification by the target detector which also reduces this Pb-air contribution.

The J/ψ/DY dimuon ratio (not shown here) is found smaller for the 1998 data than for the 1995 ones, confirming the presence of reinteractions in 1996. The minimum bias analysis allows a detailed study of the J/ψ/DY behaviour, despite of the limited statistic of the 1998 data set. This confirms the continuous decreasing trend of the J/ψ/DY ratio at high E_T , and even suggests a second drop in the J/ψ suppression pattern, around 90 GeV. Figure 8 then displays a very peculiar pattern for the J/ψ suppression in the Pb-Pb system, in itself but also compared to results obtained with lighter systems: an anomalous suppression for the most central collisions, occurring with two sudden changes of regime around 40 and 90 GeV, which suggests strongly the occurrence of some underlying critical phenomenon.

5. summary

The dimuon measurements performed by NA38, NA50 and NA51 for various systems ranging from p-p to Pb-Pb has brought to the fore different regimes in the production of charmonia. In proton and light ions induced reactions, J/ψ is suppressed in a way compatible with nuclear absorption. The J/ψ production leaves the standard behaviour only For the most central Pb-Pb collisions, displaying an anomalous additional suppression in a way suggesting a threshold effect. This is difficult to reproduce in the framework of standard hadronic models ([17,18],[16] and references therein), a new suppression mechanism needs to be introduced. Moreover a two step-wise pattern emerges from the experiment, consistent with a deconfinement scenario: first the χ_c melts, causing the disapearance of its corresponding J/ψ decay products and the first drop in the J/ψ production. Then with the increase of the energy density for the most central PbPb collision, directly produced J/ψ also melt, causing the second drop.

Beside these striking results suggestive of a deconfinement pattern, dimuon measurements have also given rise to peculiar observations for the low masses resonances and the intermediate mass continuum.

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