J/ψ, and low masses resonances production in hadron and heavy ions induced collisions around 200 GeV per nucleon

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Vector mesons production in hadron and ion induced ultrarelativistic collisions have been studied through their muonic decays by the NA38 and NA50 collaboration at CERN SPS. These measurements give access to the J/ψ production which has been proposed as a specific probe of deconfinement. Anomalous suppression of the J/ψ has indeed been observed recently in the Pb-Pb system. Preliminary results with increased statistic are presented here. Furthermore dimuon measurement gives access to lighter hadron ϕ, ρ and ω production. Evolution of their ratio $\phi/(\omega+\rho)$ and of their transverse mass distribution with respect to the system and of the centrality of the collision shows also a peculiar behavior in central Pb-Pb collisions.

1 introduction

The NA38 and NA50 experiment 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. A possible signature of this phase transition could be the J/ψ suppression [2] due to the screening effect of the plasma on the $c\bar{c}$ pair.

In the Pb-Pb system, anomalous suppression has indeed been observed [3,4] in the most central collisions where the energy density is maximal. The ψ' also shows a very strong suppression, already in the S-U system. These results will be presented in this talk, together with the ones related to low masses resonances ϕ ρ and ω.

The ϕ production is also interesting as another possible signature of the quark gluon plasma formation[5,6], which could lead to some enhancement of the strangeness production. Such enhancement is observed in several experiments [7], but could also be attributed to reinteraction effects in the hadronic gas phase following the primary stage where the plasma may eventually take place. In any case the additional information could be worth since the formation of the quark gluon plasma could be signalized by deviations from the pure hadronic gas scenario, and then the completeness of the description of the hadronic phenomenons is important.

2 experimental set-up

The NA38/NA50 detector [8,9] 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 reinteraction in the target are minimized thanks to a segmented active target[8,9] . In Na50 [9] the energy produced at zero degree and the charged multiplicity are also measured, thanks to two additional detectors.

The absorber optimization needs a particular care in ion measurements. π and K mesons decays into muons being the main source of a 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. Several set ups have then been considered in NA38, depending on the priority of the measurement. Concerning the absorber system we will only refer in the following to the part located in the aperture of the spectrometer, which is then relevant with regard to muon momentum resolution.

For NA50, the complete ion dedicated system has been rebuilt and the angular aperture of the spectrometer has been adapted to the beam energy in order to keep the same rapidity domain in the nucleon-nucleon center of mass. 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.

3 the NA38 set up

For J/ψ studies we will compare NA50 results to the systematic [10] obtained in NA38 using the standard na38 set up [8] and NA51.

For low masses studies the two inner parts of the Pb-fiber electromagnetic calorimeter had been replaced by 62 cm Al_2O_3 in order to minimize multiple scattering[15], and extend the available set of data with optimized low mass resolution that had previously been obtained[15] in the same conditions.

At the end of the ion period, one week was devoted to deuteron beam. As compared to protons, deuteron is interesting to check some eventual isospin effect. Beside it can be used at high intensity at 200 GeV per nucleon, without need of a cerenkov identification. 6 10^8 projectiles per burst were used. In one

week it was then possible to get a reasonable statistic with two targets and then to characterize the hadron induced behavior for low masses productions with the minimal experimental biases (detector, setup, analysis methods). Centrality is not measured with this beam, and then there is no need for calorimeter nor active target. The targets were simple cylinders matter whose lengths, 11cm for C and 2cm for U, were calculated in order to get same mass resolutions than the S-U ϕ set up, about 70 MeV. The targets were followed by 66.5 cm of Al_2O_3 and then by 480 cm of Carbon, as for the ion ϕ set up. More details on the set up and on the results can be found in preliminary versions of these results [12,13] in previous publications [14,15], and thesis[16].

4 the NA50 set up

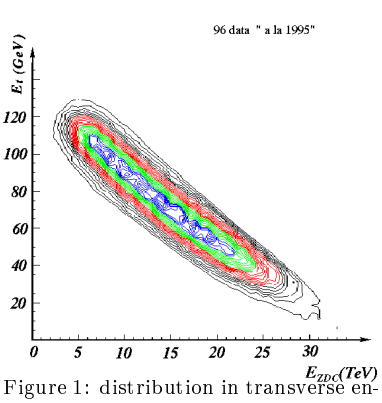

Figure 1: distribution in transverse energy Et and zero degree energy Ezdc of events for which the subtarget has been identified

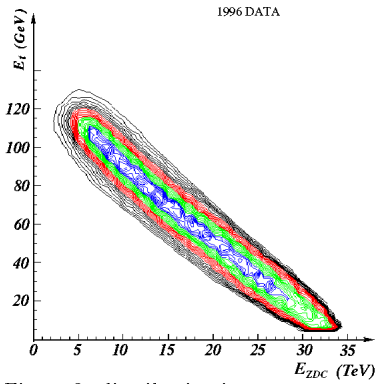

Figure 2: distribution in transverse energy Et and zero degree energy Ezdc of events without condition on the target recognition

In order to be adapted to the hardest radiations conditions and to obtain extended measurement of centrality and associated quantities, the complete setup has been rebuilt for the measurements with Pb Beam[9]. 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 the lowest transverse mass domain. Beside this strategical choice, new detector have been added, a silicon multiplicity detector and a Pb-fiber zero degree calorimeter[9].

The energy per nucleon of the beam is lower with Pb than with S or d, 158 GeV/c 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.

In this talk we will consider results obtained for the J/ψ production and also for the low masses resonances ϕ, ρ and ω. Pb-Pb data have been taken in 1995 and 1996, the later having 4 times more statistic thanks to the increase of the target thickness and of the beam intensity. For the analysis of these 1996 datas, the range of transverse energies available has been improved thanks to the use of the correlation between Et and Ezdc in order to reject spurious events in the low Et region (figure 2) where the target recognition is inefficient(figure 4). These 1996 results are still preliminary but are consistent with the 1995 published ones [9,10]. Concerning the low mass resonances, only the 1995 datas have been analyzed.

5 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 [17,18].

In order to extract the contributions of the resonances and of the continuous components, fits are performed on the dimuon mass spectrum. For the high mass studies [9] 4 components are considered for the signal, J/ψ, ψ', Drell Yan and D$\bar{\text{D}}$, whereas for low masses studies [12] 3 components are considered ϕ, $\rho + \omega$ and a phenomenological exponential-like continuum.

From the input mass, rapidity , $\cos\Theta_{cs}$ and transverse mass distributions, a complete simulation of the detection of the muon pairs is made through a Monte-Carlo program.

This simulation then takes into account smearing and acceptance effects and so allows to correct the results. From the fits of the mass spectra, performed in various Mt domains for the low masses studies, the amount of *produced*, i.e. without apparatus effects, dimuons 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 the measured numbers of muons, corrected for acceptance as explained previously, and normalized thanks to the number of incidents particles measured by the beam hodoscope for the Sulfur beam, and by a set of gaseous detectors called argonion for the deuteron

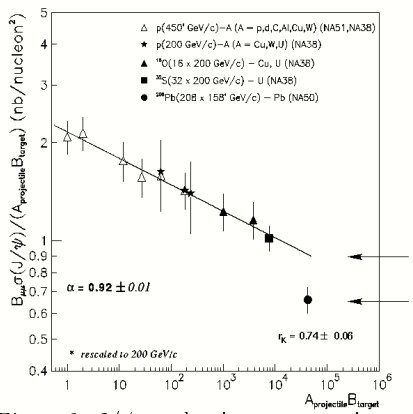

Figure 3: J/ψ production cross section as a function of the atomic masses of target and projectile A×B

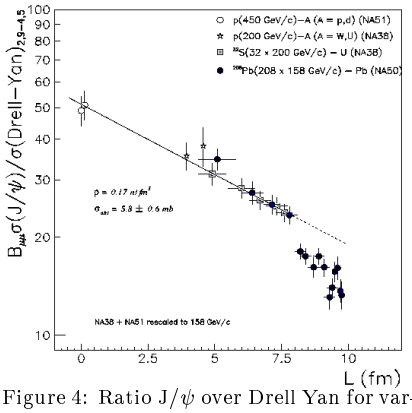

Figure 4: Ratio J/ψ over Drell Yan for various systems and centralities, presented as a function of L, average thickness of the participant zone

beams.

6 results

6.1 J/ψ

The cross section for the J/ψ production is displayed in figure 5 for various systems. Some results have been rescaled [9] 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 parametrisation $(A \times B)^{\alpha}$, with $\alpha = 0.92 \pm 0.01$ which is also compatible with the value obtained by FNAL experiment E772 [19].

The value of the cross section in Pb-Pb collisions $21.9 \pm 0. \pm 1.6 \mu b$ is found, after rescaling to 200 GeV/c thanks to the Schuler parametrisation [20], to be significantly lower than the one expected from the absorption fit line. This suggests that a new mechanism is responsible from this "anomalous" suppression. 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 and furnishing furthermore a natural reference, as it is insensitive to the strong interaction, for the studies as a function of centrality which are displayed in figure 4. 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 [11] and references therein for more details). Again while a common

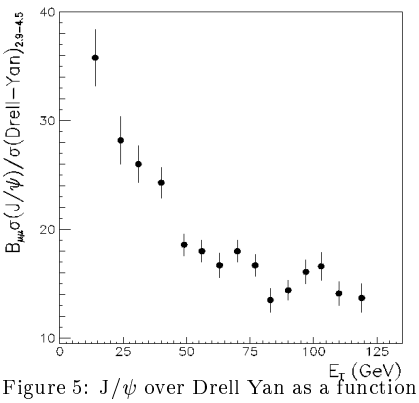

Figure 5: J/ψ over Drell Yan as a function of the transverse energy Et in the Pb-Pb system

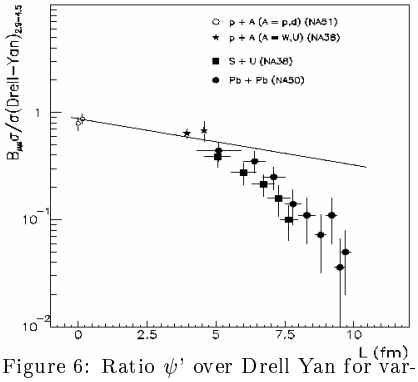

Figure 6: Ratio ψ' over Drell Yan for various systems and centralities, presented as a function of L, average thickness of the participant zone

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%$\pm$ 0.04 with respect to the expectation. These preliminary results are in agreement with the previous 1995 results with lower statistic [9,10]. Looking at the Pb-Pb results alone and as a function of Et (figure 6.1 we still see a very different pattern for the lowest Et points, suggesting a threshold effect between two regimes, occuring around Et=50 GeV.

This suppression is associated with an increase of the $< P_T^2 >$, saturating for the most central Pb-Pb collisions, in contrast with what is observed for S-U [11]

6.2 ψ'

The ψ' over Drell Yan ratio is displayed in picture 6 as for the J/ψ, but exhibit a very different behavior. There is still a regular decrease in p induced reactions, but the change of regime appears sooner than for the J/ψ, already at the S-U level, and S-U and Pb-Pb show additionnal suppressions which are compatibles within errors. The ψ' has a smaller binding energy than the J/ψ, so the ψ' is expected to be suppressed in mediums where the J/ψ is less affected, either by screening effect or by collisions with comovers. It is nevertheless not obvious that the pure hadronic model could explain consistently the various regimes exhibited in proton, sulfur and Lead induced reactions by the J/ψ and the ψ' [21]

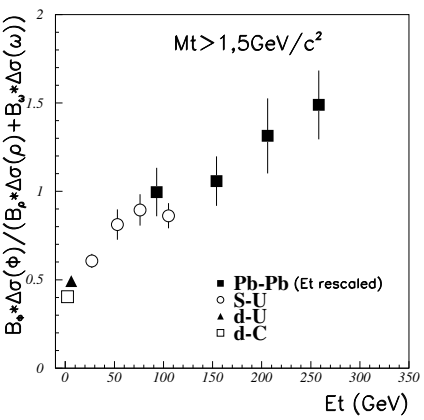

Figure 7: Evolution of $\phi/(\omega+\rho)$ as a function of the transverse energy, for $M_T > 1.5 Gev/c^2$

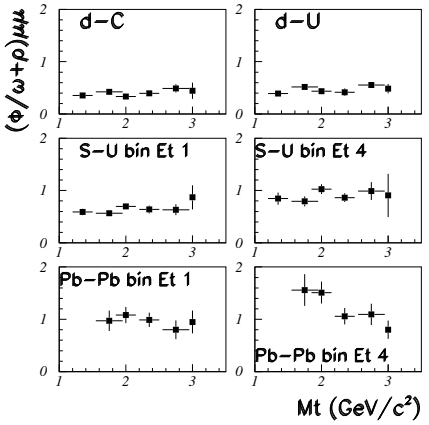

Figure 8: $\phi/(\omega+\rho)$ as a function of the transverse mass for different systems and centrality.

6.3 ϕ ρ and ω

The ratio $\phi/\rho+\omega$ 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. In addition it is not dependent on the luminosity nor sensitive to the acceptance uncertainty.

In picture 6.2 this ratio is presented for the various systems, as a function of the transverse energy. This variable is mainly used for convenience, and is only indicative for Pb-Pb since an extrapolation has to be used, but could be linked to volume effects which may be important for these rather low masses productions.

For production with transverse mass above 1.5 GeV/c^2, i.e. in the kinematical domain available in Pb-Pb, the ratio increases as a function of the system mass, or with centrality in S-U. In Pb-Pb the same behavior is also visible, both on the average and versus Et. Nevertheless contrarily to S-U this increase with centrality is only existing for the lowest Mt domains. This is indirectly visible in picture 8, where the ratio $\phi/\rho+\omega$ looks flat with respect to the transverse mass, except for the most central Pb-Pb collisions which display a very different and then very atypical behavior.

Thanks to cross sections it is possible to get another piece of information. The evolution in the experimental window displays a different rate for ion and for deuteron induced reactions. The rates of increases of the ϕ and $\rho+\omega$ cross sections between the various systems A-B, parametrized as $(AB)^{\alpha}$ in order to

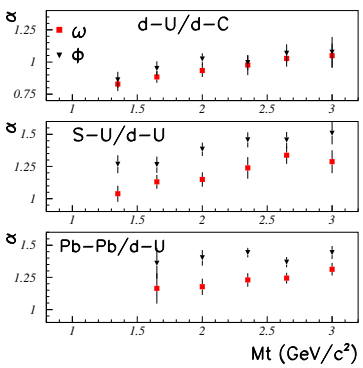

Figure 9: α parameter (see text) measuring the increase rate of the cross section between different systems. Note the change of vertical scale.

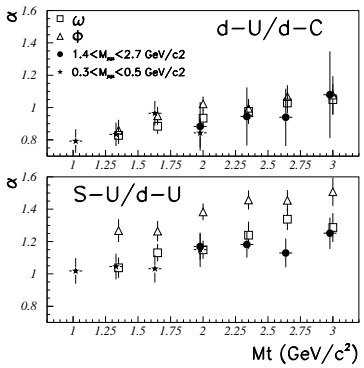

Figure 10: same as 9 where α parameters for the dimuon mass continuum on both sides of the resonances have also been added.

get a common scale, are presented in picture 9. For both components there is an increase of the rate with Mt (Cronin effect). With deuteron projectile ϕ and $\rho + \omega$ are very similar whereas in ion induced reactions we observe again the additional increase of the ϕ, already noticed thanks to the ratio. Rates obtained for Pb-Pb are close to the ones obtained for S-U. This suggests that the smaller increase observed on the average between S-U and Pb-Pb than between d-U and S-U, say 1.5 with respect to 2., could be due to the smaller lever arm. Between deuteron and ion induced reactions there is also an increase of the $\rho + \omega$ α parameter. This increase may be linked to the change of direction of the shift of the rapidity distribution when going from an increase of the target to an increase of the projectile.

Beside, the same treatment applied to the continuum at lower and higher masses than the resonances (figure 6.3) suggests that it could behave similarly to the $\omega + \rho$, in d-C, d-U and S-U. This could be the sign of some special meaning of the transverse mass in the low mass dimuons production process, directing both the change of slopes of the kinematical distributions and the abundancies of the particles.

7 summary

The dimuon measurements performed by NA38, NA50 and NA51 for various systems ranging from p-p to Pb-Pb has brought to fore different regimes in the production of charmonia. In proton induced reactions, J/ψ and ψ' are

suppressed in a way compatible with nuclear absorption. In Sulfur induced reactions, the ψ' displays a very strong additionnal suppression, which is compatible with the one observed in Pb-Pb when the average thickness of the participant zone is considered. The J/ψ production leaves the proton induced behaviour only for the most central Pb-Pb collisions, in a way suggesting a threshold effect for this anomalous suppression. This set of effects provides a constraining frame for models which could make difficult for the hadronic model to reproduce them all simultaneously (see [21,22] and references therein).

In the same experiment, increase of ϕ production with respect to $\rho+\omega$ has also been observed, furthermore displaying an atypical behavior with respect to Mt. This sustains the idea that the most central Pb-Pb collisions lead to unusual effect, which is also seen in the stabilisation of the Pt distribution of J/ψ.

1. F.Karsch, *Nucl. Phys. A* **590** (1995) 367c.
2. H.Satz, *Nucl. Phys. A* **590** (1995) 63c.
3. M.C.Abreu et al., *Physics Letters B* **410** (1997) 337
4. A.Romana/NA50, proceedings of the 1998 Rencontres de Moriond, les Arcs, France, March 1998
5. A.Shor, *Phys. Rev.* **54** (1985) 1122
6. P.Koch, B.Muller, J.Rafelski, *Phys. Rep.* **142** (1986) 167.
7. G.Odyniec, strangeness production in relativistic nuclear collisions, proceedings of the Quark Matter 97 Conference, Tsukuba, Dec 1-5, 1997
8. C.Baglin et al., *Physics Letters B* **220** (1989) 471;
   C.Baglin et al., *Physics Letters B* **255** (1991) 459
9. M.C. Abreu et al., *Physics Letters B* **410** (1997) 327-336
10. M.C. Abreu et al., *Physics Letters B* **410** (1997) 337-343
11. L.Ramello/NA50, Charmonium production in Pb-Pb interactions, proceedings of the Quark Matter 97 Conference, Tsukuba, Dec 1-5, 1997
12. D.Jouan/NA38-NA50, APH N.S., Heavy Ion Physics 4 (1996) 155-165
13. P.Bordalo/NA38, AIP conference proceedings 340, Tucson AZ january 1995, p. 152
14. C.Baglin et al., *Physics Letters B* **272** (1991) 449-454
15. C.Baglin et al., *Physics Letters B* **368** (1996) 230-238
16. J.Astruc, these de l'universite paris 6, 9 Juillet 1997, IPNO-T-97-31
17. S.Constantinescu, S.Dita, D.Jouan, preprint IPNO-DRE-96-01
18. S.Papillon, these de l'université Paris 7, 11 mars 1991, IPNO-T-91-03
19. D.M.Adle et al., *Phys. Rev. Lett.* **66**, 133 (1991).
20. G.A.Schuler, CERN-TH.7170/94 (hep-ph/9403387), 1994.
21. C.Y.Wong, *Nucl. Phys.* A **630**, 487 (1998), and this workshop
22. D.Kharzeev, Theoretical interpretations of J/ψ suppression: a summary, proceedings of 1997 quark matter conference, tsukuba, Dec 1-5, 1997