The production of ϕ , ω and ρ mesons in p, d, S and Pb-induced reactions at the CERN SPS

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Abstract. From proton, deuteron, S and Pb-induced reactions, experiments NA38 and NA50 have measured muon pair production with various targets. In particular, the production rates of the ϕ , ω and ρ mesons have been simultaneously extracted and compared. Preliminary partial results of the most recent Pb-Pb measurement done in year 2000 by NA50 are presented here. They are also included in the comparison with the results obtained with lighter interacting nuclei.

1. Introduction

The NA38 and NA50 experiments measure muon pair production in ultrarelativistic heavy ion collisions as a function of the centrality of the interaction, estimated from the transverse energy produced in the reaction. For central Pb-Pb collisions, the energy density and the temperature could reach the critical values [1] leading nuclear matter, through a phase transition, to a state of deconfined quarks and gluons (QGP) as predicted by non-perturbative QCD. In this frame, experiments NA38 and NA50 have found and extensively investigated an abnormal J/ψ suppression [2, 3, 4, 5]. Charmonium suppression is considered as a signature of QGP through its screening effect on the colour potential which, normally, holds together the c and $\bar{c}$ quarks in bound states [6]. In this talk we study and present results on ϕ production, another possible signature of QGP formation [7, 8], considered as a particular case which allows to test the much older prediction of strangeness enhancement [9] in a QGP.

2. Experimental setup

The NA38/NA50 detector [2, 10] consists of a muon spectrometer made of a muon filter followed by a set of tracking chambers and trigger hodoscopes located upstream and downstream from an air-gap toroidal magnet. The transverse energy produced in the ion collisions is measured with a Pb-scintillating fiber electromagnetic calorimeter. A beam detector (with rejection of internal interactions) allows to reject pile up of incoming ions within the 20ns gate used by the calorimeter. In the most recent measurement of year 2000, only one target was used. The target identification detector is supplemented with a specific offline algorithm which is based on two silicon strip planes located downstream from the target [11] and primarily devoted to a charged particle multiplicity measurement. A Ta-quartz fiber zero degree hadronic calorimeter measures the zero degree energy, mainly due to the energy deposited by the incident ion nucleon spectators. The electromagnetic calorimeter and several additional detectors are also used for background (off-target interactions) and pile up rejection. After the offline track reconstruction, based on the tracker proportional chambers, a set of selection cuts is applied to reject bad quality and off-target reconstructed muons.

For the last Pb-Pb measurement, the target was put in the vacuum, allowing therefore the unambiguous detection of very peripheral reactions, thanks to the complete suppression of the contaminating Pb-air interactions. Another improvement resulted from the use of the Beam Hodoscope for triggering "minimum-bias" events, which allowed, for the recording of the data, the same time reference for dimuon and minimum-biased events. It is worthwhile noting the significant difference between the 1995, 1996 and 1998 Pb-Pb data collections which used targets with a thickness of 17, 30 and 7% of an interaction length respectively. In the year 2000 run, the target thickness was 4 mm, corresponding to 9,3% of an interaction length. As compared to the setup used in experiment NA38 and in order to improve the J/ψ measurement in Pb-Pb collisions, the NA50 setup used a magnetic field increased by a factor 7/4 and, moreover, 80 cm of iron replaced carbon at the downstram end of the absorber. As a consequence, the acceptance of the apparatus for low mass dimuons was significantly reduced, in particular for low transverse masses. All the NA38 data considered here are taken with a low Z pre-absorber setup very similar to the Pb-Pb one, which optimizes the balance between the early absorption of the produced π and K mesons and muon multiple scattering induced by the absorber. The latter leads to a mass resolution of the order of 70 MeV/c^2 which, although not sufficient to extract separately the ρ and the ω , is still small enough to separate the ϕ from the sum ($\rho + \omega$).

The main source of background in the opposite-sign muon pair sample, where resonant mesons are found, originates from π and K decays into muons. This is a combinatorial background which increases with the square of the produced multiplicity. It is reflected in the like-sign muon pair sample where it can be estimated from [12].

3. Analysis methods

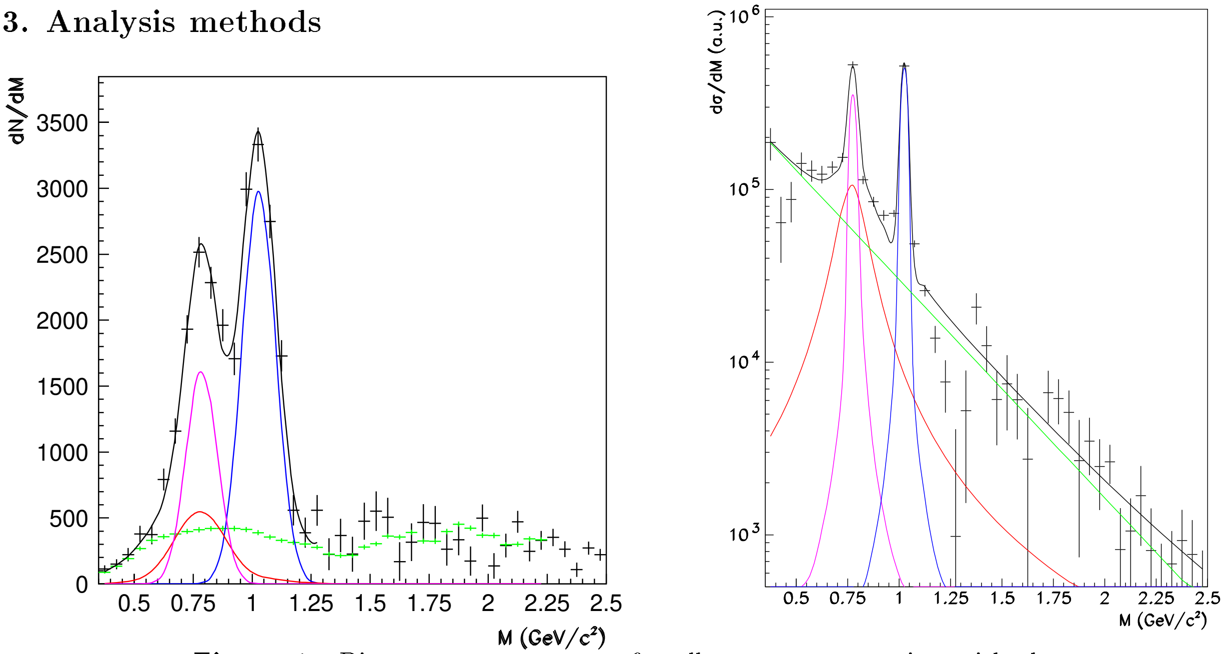

Figure 1. Dimuon mass spectrum for all transverse energies, with the various contributions considered in the fit. Left: fit on raw invariant mass distribution affected by acceptance and resolution. Right: fit performed after correction of these apparatus effects.

A wide range of systems has been explored in NA38 and NA50: d-C, p-W, d-U, S-S, S-Cu, S-U at an incident beam energy of 200 GeV/u and, finally, Pb-Pb at 200 GeV/u. All the studies have been made within the same center of mass rapidity window. Independent data analyses have been performed on these systems, using two different methods. Both use the same simulation of the detector which allows to correct each signal component for smearing and acceptance effects in the explored kinematical domains in either P_T or M_T bins (see below), within the rapidity window $0. < Y_{cms} < 1.$, with the Collins-Soper angle in the range $-0.5 < \cos\theta < 0.5$ and over full azimuthal coverage. In these simulations ([13, 14] and references therein) Breit-Wigner shapes are considered for the ϕ , ρ and ω resonances, and an exponential shape is taken to analytically describe the mass continuum. Transverse momentum distributions of dimuons are thermal-like, while a gaussian centered at mid-rapidity is used for rapidity distributions.

In the first method(fig.1-left), the experimentally obtained muon pair invariant mass spectrum is fitted with the simulated shapes (see above) of its various components. The procedure leads to the amplitude of each of these components which are then corrected for acceptance. The ratio $(\omega/\rho)_{\mu\mu}$ is fixed considering that the ω and ρ^0 cross sections are the same, when a simple Breit-Wigner shape is considered for the ρ^0. In fact the production of ρ is sensitive to its production process [15], and mass-dependent. We therefore introduce a $1/M^4$ factor, avoiding in particular an unphysical long tail at high masses but some effect is also expected at low masses. This uncertainty on the exact ρ shape - which could in addition be modified in high energy nucleus-nucleus collisions - is a limit on the precision of the ρ component corrected for acceptance but does not apply to the ω . In this sense, the ω extraction, which furthermore is making the most of the $(\rho+\omega)_{\mu\mu}$ peak height, could be considered potentially less sensitive to hypotheses on the ρ shape.

The second method is more elaborated: from simulations and experimental spectra a matrix for acceptance and smearing correction is built in an iterative process [16, 17]. This matrix is then applied to the experimental spectra, leading to spectra corrected for acceptance and smearing that can then be fitted by physical shapes.

The transverse variable is another difference between the two methods. The first one uses the transverse mass M_T , while the second one uses the transverse momentum P_T . Using M_T is less convenient than using P_T or $(M_T - M_0)$, it was aiming at a more direct estimate of ϕ/ω in M_T bins. In some thermodynamical models, this ratio could depend mainly on the strangeness saturation factor γ_s/γ_q [18, 19]. ϕ and ω acceptances main features are similar as a function of M_T , in the NA38 and NA50 setups. NA38 (S-U) acceptances are higher than NA50 (Pb-Pb) ones by a factor 3 at high M_T , and this difference increases up to a factor 30 in the lowest M_T bin considered for NA50. This leads to a very low acceptance (0.25% typically) in this domain, but most of the relative effect between NA38 and NA50, a factor 10 due to the magnetic field, has been checked to be perfectly consistent between simulation and experiment [20].

Results are presented for $M_T > 1.5$ GeV/c^2 for the M_T study, and for $P_T > 1.4$ GeV/c or $P_T > 0.6$ GeV/c respectively for Pb-Pb and the other systems considered in the P_T studies.

4. Results

The ratios $\phi/(\omega + \rho)$ are presented in fig.2 integrated over the transverse variable. $\phi/(\omega + \rho)$ increases with the size of the interacting nuclei and, for Pb-Pb interactions, with centrality. In addition it shows no dependence on the transverse variable, M_T or P_T , in the domains considered here.

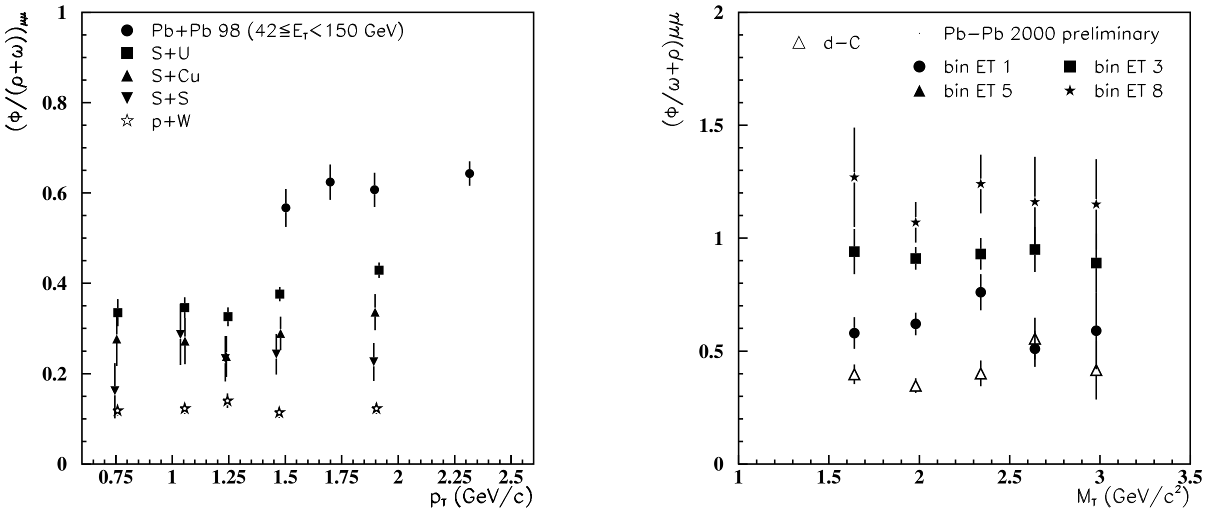

Figure 2. The ratio $\phi/(\omega+\rho)$ as a function of P_T or M_T and of the centrality of the collision (values cannot be directly compared between figures).

As can be seen from fig.3, the ratio $\phi/(\omega+\rho)$ exhibits a quite continuous single behaviour, increasing as a function only of the number of participant nucleons N_{part} , independently of the size of the interacting nuclei. This increase can be attributed indeed to the production of the ϕ as can be deduced from the study of the multiplicity per participant which shows an increase for the ϕ and a flat behaviour for the $\rho+\omega$ [14]. and is also supported by the evolution of the increase rate of cross sections between hadron and ion induced productions [22] for S-U.

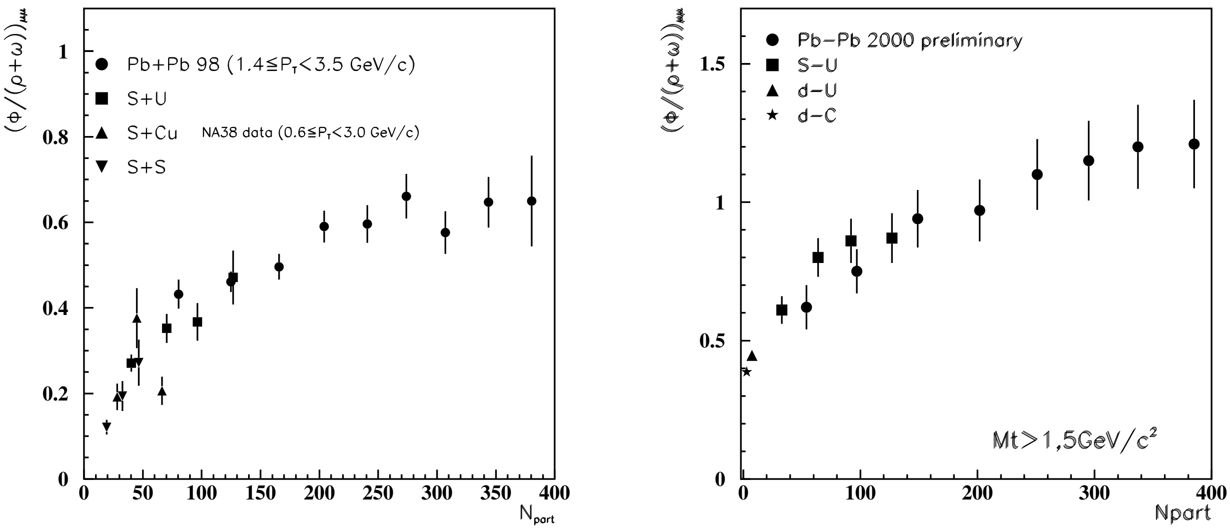

Figure 3. The ratio $\phi/(\omega+\rho)$ as a funtion of the number of participating nucleons N_{part} .

For Pb-Pb interactions, a fit of the M_T distribution of the ϕ with the function $dN/dM_T = M_T exp(-M_T/T)$ leads, for the effective temperature T, to an average value of 228 $\pm$ 10 MeV [14] and shows a weak dependence of T on the centrality of the collision. The values compare with the ones we obtain for lighter interacting nuclei. They range from 190 to 230 MeV from p-W to S-U interactions but are obtained with the slightly different analytical function $dN/dM_T = M_T^{3/2} exp(-M_T/T)$ [21, 13] which leads to 10 MeV lower slopes. They differ from the value of $305 \pm 15 MeV\ M_T$ obtained by experiment NA49 [23].

In summary, the ratios $\phi/(\omega + \rho)$ studied for a wide range of interacting nuclei, from d-C to Pb-Pb, show that ϕ production increases strongly as a function of the size of the nuclei and also as a function of the centrality of the reaction. The dependence becomes flatter for a number of participant nucleons higher than 150 in Pb-Pb interactions. These observations should be completed in the future by comparisons of T values and cross-sections (for the latter and for multiplicities, a sizeable systematic uncertainty arises from large variations of the B.R. to dimuons reported in successive reviews by the PDG) for all the considered interacting systems. Such extension to lighter systems as well as new NA50 results from the year 2000 run could help understanding the apparent differences with the NA49 results.

References

[1] F.Karsch, *Nuclear Physics A* **590** (1995) 367c.
[2] M.C. Abreu et al., *Physics Letters B* **410** (1997) 327.
[3] M.C. Abreu et al., *Physics Letters B* **410** (1997) 337.
[4] M.C. Abreu et al., *Physics Letters B* **450** (1999) 456.
[5] M.C. Abreu et al., *Physics Letters B* **477** (2000) 28.
[6] T.Matsui and H.Satz, *Physics Letters B* **178** (1986) 416. H.Satz, *Nucl. Phys.* A **681**, 2001 (3)c.
[7] A.Shor, *Physical Review* **54** (1985) 1122.
[8] P.Koch, B.Muller, J.Rafelski, *Phys. Rep.* **142** (1986) 167.
[9] J.Rafelski and B.Muller, *Phys. Rev. Lett.* **48**, (1982) 1066.
J.Rafelski and B.Muller, *Phys. Rev. Lett.* **56**, (1986) 2334.
[10] C.Baglin et al., *Physics Letters B* **220** (1989) 471.
[11] L.Ramello/NA50 collaboration, Quark matter 2002 conference proceedings. *Nucl Phys A* **715** (2003) 243c.
[12] C.Baglin et al., to be published. see for instance D.Jouan et al., preprint IPNO-DRE-02-015, or S.Constantinescu, S.Dita, D.Jouan, preprint IPNO-DRE-96-01
[13] C.Quintans/NA50, J. Phys. G **28**, no.7 (2002) 1809.
[14] B. Alessandro et al., *Physics Letters B* **555** (2003) 147.
[15] J.D.Jackson, *Nuovo Cimento* **34A** (1964) 1644.
[16] M.C.Abreu et al., *Nucl. Instrum. Methods* A **405**, 139-152 (1998)
[17] Caterina Quintans, Study of the $\rho + \omega$ and ϕ vector-meson production in lead-induced collisions at 158 GeV/nucleon, PhD Thesis, Instituto Superior Técnico, Lisboa (2002).
[18] J.Rafelski, these proceedings
[19] F.Becattini, J. Phys. G **25**, 287-294 (1999)
[20] L.Villatte, thèse PARIS VII, Université Denis Diderot (2001)
[21] J.Astruc, thèse de l'université PARIS VI, 9 Juillet 1997, IPNO-T-97-31
[22] D.Jouan/NA38-NA50, *Nucl. Phys.* A **638**, 483c (1998)
[23] V.Friese, these proceedings