ϕ production in Pb-Pb collisions at 158 GeV/c per nucleon in the NA50 experiment.

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We report on the production of the ϕ, ρ and ω resonances in Pb-Pb collisions at 158 GeV/c per nucleon (CERN/SPS). These preliminary results correspond to the 1996 data taking of the NA50 experiment.

The $(\phi/\rho+\omega)_{\mu\mu}$ ratio is studied versus the centrality of the collision and versus the transverse mass of the resonances. The ϕ and $\rho+\omega$ multiplicities as a function of the number of participant nucleons (N_{part}) have also been measured. Finally the cross sections of the resonances are presented and the effective temperatures are extracted.

1 Introduction

The NA50 experiment is devoted to the search for the Quark-Gluon Plasma (QGP) in ultra-relativistic heavy ion collisions at the CERN/SPS. At large enough temperature and/or baryon density, the quarks and gluons are expected to behave as free objects within a new state of deconfined matter: the Quark-Gluon Plasma [1]. Among the QGP proposed signatures, the suppression of J/ψ production [2] and the enhancement of strangeness production are studied in the NA50 experiment.

The present paper concerns the latter signal which is studied in several other experiments [4, 5]. In the case of QGP formation, a strong enhancement of strange particle production, as compared to the yield expected from a hadron gas, has been predicted by J. Ralfelski and B. Müller [3]. In this experiment, we measure the ϕ meson production (an $s\bar{s}$ bound state) and compare it to the ρ and ω meson yields (combinaisons of $u\bar{u}$ and $d\bar{d}$), as proposed by A. Shor [6].

2 Apparatus

The ϕ, ρ and ω mesons are detected via their decay channel in $\mu^+\mu^-$.

The muon spectrometer is separated from the target (12 cm thick in 1996) by an hadron (mainly pions and kaons) absorber. A toroïdal magnet bends the trajectory of the muons, measured with eight multi wires proportional chambers (MWPC). Four scintillator hodoscopes provide the dimuon trigger.

A beam hodoscope (BH) counts the incident ions.

Three detectors estimate the centrality of the collision: the electromagnetic calorimeter measures the transverse energy (E_T) of the neutral particles (mainly π^0); the zero degree calorimeter collects the energy of the projectile spectators of the collision and the multiplicity detector.

The kinematical domains of acceptance are: $0 \leq y_{cm} \leq 1$, $-0.5 \leq \cos\theta_{C.S.} \leq 0.5$ and $0 \leq \varphi_{C.S.} \leq 2\pi$; where y_{cm} is the rapidity of the muon pair in the center of mass of the nucleon-nucleon collision and $\theta_{C.S.}$ and $\varphi_{C.S.}$ are the angles of one muon in the frame of the dimuon (Collins-Soper reference frame).

A detailed description of the dectector can be found in [7, 8].

The experimental set-up is optimized for J/ψ measurements, i.e. invariant dimuon masses higher than 2 GeV/c^2. For lower masses (ϕ, ρ and ω) the acceptance is limited to dimuons of transverse mass M_T (defined as $M_T = \sqrt{M^2 + p_T^2}$, where p_T is the dimuon transverse impulsion) greater than 1.5 GeV/c^2.

3 Data analysis

3.1 Experimental data processing

During the 1996 run, the intensity of the beam was about 5 10^7 ions per burst, which leads to a total of 4 10^{12} incident ions.

From the total number of opposite sign muon pairs ($N^{\mu^+\mu^-}$), we subtract the uncorrelated muon pairs due to μ-decay of π and K mesons. This combinatorial background is deduced from the like sign muon pairs ($N^{\mu^+\mu^+}$ and $N^{\mu^-\mu^-}$), and the number of opposite sign muon pairs corresponding to the signal is obtained using the usual formula:

$$N^{\mu^+\mu^-}_{signal} = N^{\mu^+\mu^-} - 2\sqrt{N^{\mu^+\mu^+}N^{\mu^-\mu^-}}$$

In the resonance mass region ($0.5 \leq$ M ≤ 1.2 GeV/c^2), the signal accounts for 27 % of the total number of $\mu^+\mu^-$ pairs. The mass resolution is of the order of 70 MeV/c^2, therefore the ρ and ω mesons cannot be separated.

The signal mass spectra below 2 GeV/c^2, is made of four contributions: ϕ, ρ, ω and a mass continuum. The continuum originates from different physical processes: Dalitz decays ($\eta, \eta' \to \mu^+\mu^-\gamma$ and $\omega \to \mu^+\mu^-\pi^0$), "Drell-Yan" process ($q\bar{q}$ annihilation extrapolated to low masses), semi-leptonic decays of $D\bar{D}$... [9]

To extract the number of produced resonances from these spectra, simulations are used as detailed hereafter.

3.2 Simulations

In order to account for the acceptance and the smearing introduced by the set-up, we use generation functions for the different components of the mass spectra.

The ϕ and ω mass distributions are generated according to Breit-Wigner functions. For the broad ρ resonance, we take the same distribution as in the HELIOS/3 experiment [10] which is a parametrization of the Breit-Wigner formula including a non resonant background under the ρ. For the continuum mass generation, we use a phenomenological shape parametrised as $1/M^\alpha e^{-m/\beta}$.

The transverse mass of the three resonances and of the continuum is generated according to the Hagedorn distribution [11]: $M_T K_1(M_T/T)$, where K_1 is a modified Bessel function.

The rapidity distribution of the four components is taken as a gaussian function.

The simulated events are tracked through the apparatus and reconstructed using the same procedure as applied to the experimental data. Then, the parameters of the generation functions are adjusted in order to have experimental distributions reproduced by the reconstructed ones.

3.3 Mass spectra fits

Finally we perform a fit of the mass spectra to extract the number of produced resonances:

$$\frac{dN}{dM} = A_{\rho+\omega}[F_\rho(M) + F_\omega(M)] + A_\phi F_\phi(M) + A_{cont}F_{cont}(M)$$

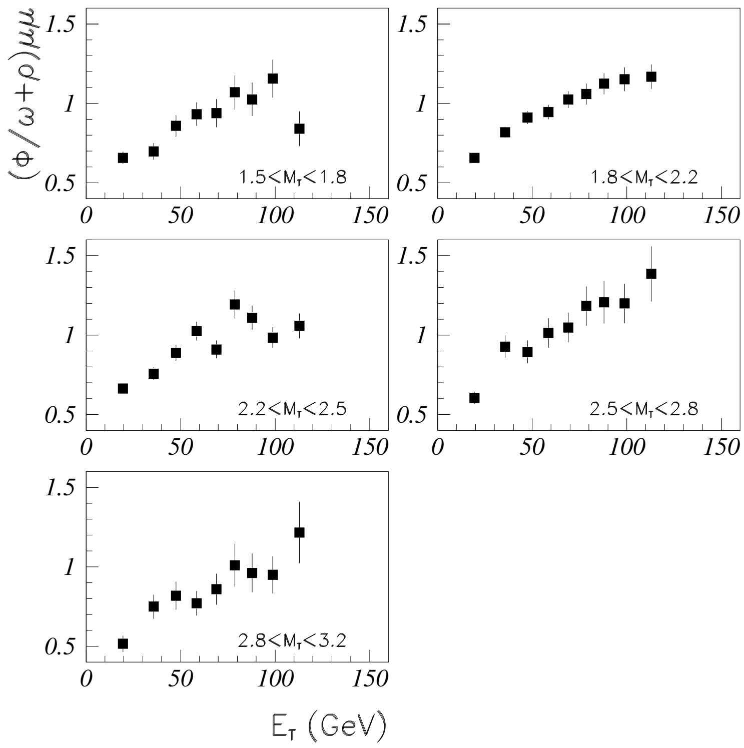

Figure 1: *The* $(\frac{\phi}{\rho+\omega})_{\mu\mu}$ *ratio versus* E_T *for five* M_T *bins.*

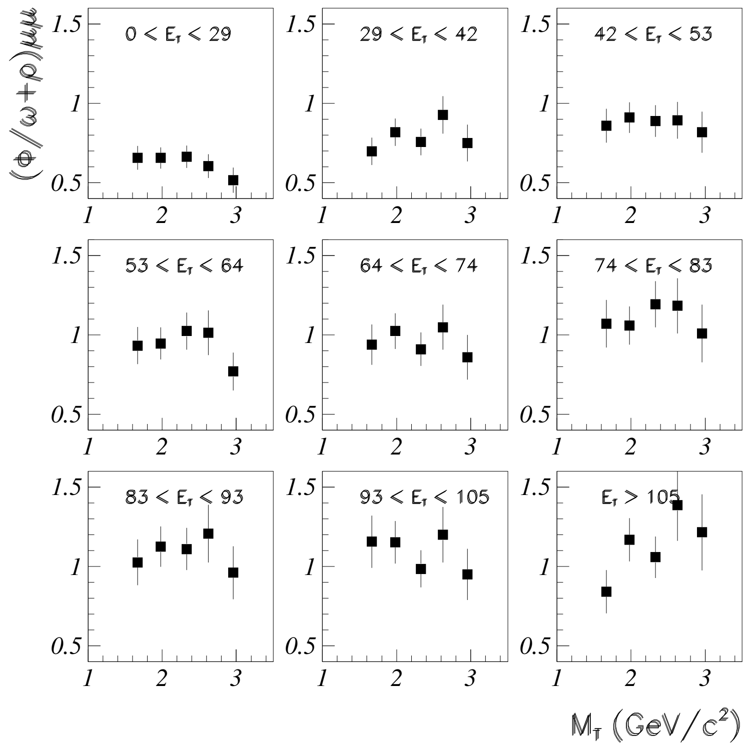

Figure 2: *The* $(\frac{\phi}{\rho+\omega})_{\mu\mu}$ *ratio versus* M_T *for nine* E_T *bins.*

where the F are the reconstructed distributions. We have five free parameters: the three A amplitudes and the mass values of the ϕ and the ω.

From these fits, we get about 130000 reconstructed ϕ mesons for the total sample of events.

4 Results of the ϕ and $\rho + \omega$ productions

4.1 $(\phi/\rho + \omega)_{\mu\mu}$ ratios

We first study the $(\phi/\rho + \omega)_{\mu\mu}$ ratio of the number of ϕ divided by the number of $\rho + \omega$ produced resonances which decay into $\mu^+\mu^-$, acceptance corrected, that is also the ratio of the cross sections multiplied by the corresponding $\mu^+\mu^-$ branching ratio.

In Figure 1 this ratio is plotted versus the transverse energy (E_T) of the collison for five transverse mass (M_T) bins. The error bars are only statistical. The global systematic error has been estimated by varying generation parameters (as the inverse slope parameter T of the components, the ρ and continuum mass shapes...) and amounts to 10%. We observe, for each M_T bin, an increase of the ratio with the centrality of the collision.

Figure 2 shows the same ratios versus M_T for nine E_T bins (with total error bars: statistical and systematic). We see an approximately flat trend which indicates a similar M_T dependence for the ϕ and $\rho + \omega$ productions.

The $(\frac{\phi}{\rho+\omega})_{\mu\mu}$ ratio is displayed in Figure 3, for the whole M_T domain ($1.5 \leq M_T \leq 3.2$ GeV/c^2) as a function of N_{part}, the number of participant nucleons in the collision. For each E_T bin, N_{part} is deduced from the E_T mean value using the Glauber model. The error bars plotted on the figure are only statistical; the systematic error is equal to 9.5 %. We observe a smooth increase of the ratio by about a factor 1.7 from the most peripheral to the most central collisions.

The observed behaviour can in principal be due to an increase of the ϕ production or to a decrease of the $\rho + \omega$ production. The multiplicity study allows to clarify this issue.

4.2 ϕ and $\rho + \omega$ multiplicities

The multiplicity of a particle is the number of produced particles per Pb-Pb collision. For each E_T bin, the number of Pb-Pb collisions is deduced from the Minimum Bias spectrum collected with a pure interaction trigger. In the left part of Figure 4, the ϕ and $\rho + \omega$ mutiplicities are presented versus N_{part} for the whole M_T domain. For both ϕ and $\rho + \omega$, we observe an increase versus N_{part}. To further quantify this increase, we have divided the multiplicities by N_{part}, as displayed on the right side of Figure 4. Whereas these quantities show a linear behavior for $\rho + \omega$, we note an additional increase of about 50% for the ϕ.

From the studies of the ratios and multiplicities, we do not observe a saturation of the ϕ production for a number of participant nucleons greater than one hundred, as seen in the WA97 experiment for strange baryons and antibaryons [4]. It is also worth noting that the behavior of the ratio and of the ϕ multiplicity/N_{part} is similar to the K/π ratios observed in the NA49 experiment at the CERN/SPS [5] and in the E866 experiment at the BNL/AGS [13].

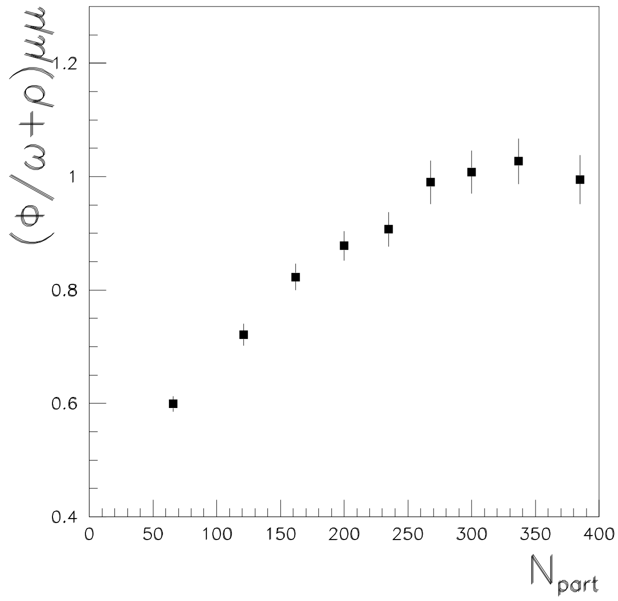

Figure 3: *The* $(\frac{\phi}{\rho+\omega})_{\mu\mu}$ *ratio versus the number of participant nucleons for 1.5* $\leq M_T \leq$ *3.2 GeV/*c^2*.*

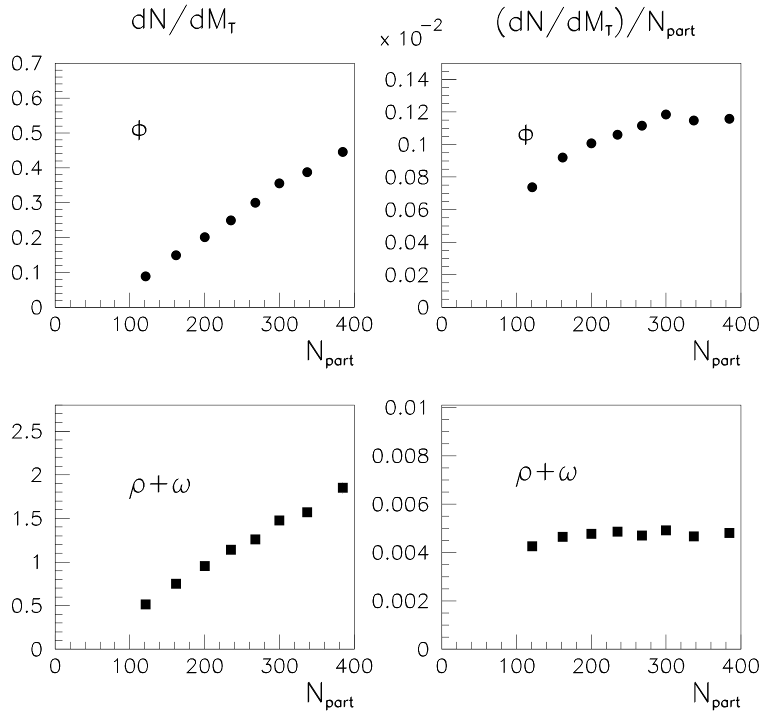

Figure 4: *Multiplicities and multiplicities per participant nucleon for the* ϕ *and* $\rho+\omega$ *(the first point has been omitted due to air contamination for the corresponding minimum bias value).*

5 Cross sections and effective temperatures of ϕ and $\rho + \omega$

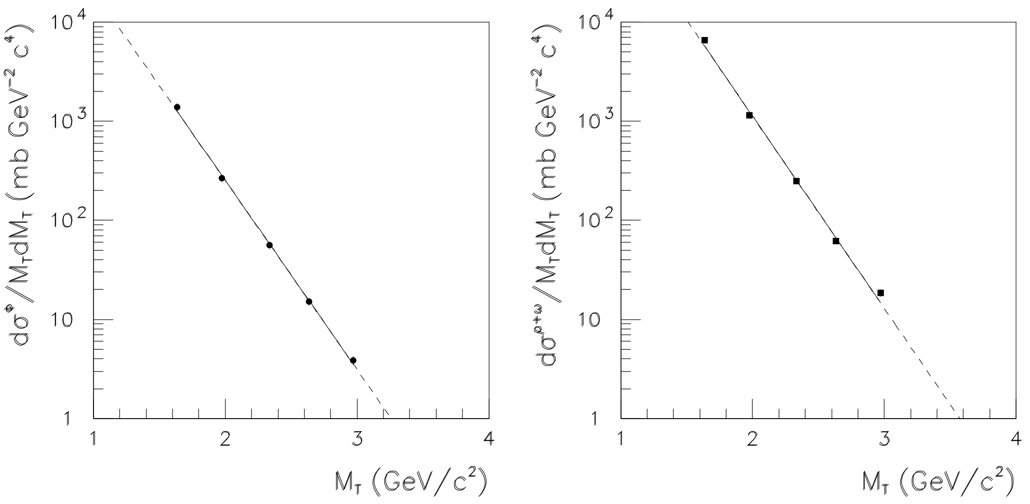

Figure 5: *Adjustement of the cross section distributions versus M_T for ϕ and $\rho + \omega$, for the whole E_T domain.*

The ϕ and $\rho + \omega$ cross sections are studied versus the transverse mass M_T. A fit of these distributions with the function $M_T e^{-M_T/T}$ is performed in order to extract the values of the effective temperatures (or apparent temperatures). For the whole E_T domain, the fits are presented in Figure 5 from which we obtain: $T_\phi = 227 \pm 10$ MeV and $T_{\rho+\omega} = 224 \pm 10$ MeV. The same fits are done for each E_T bin. The effective temperatures appear to be independent of the centrality of the collision (Figure 6) as observed in the WA97 experiment [4].

Similar to the Ω and $\bar{\Omega}$ baryons, the ϕ is made of strange quarks only. It is therefore worthwhile noting that our T_ϕ value, like the $T_{\Omega+\bar{\Omega}}$ studied in the WA97 experiment, departs from the linear trend of the apparent temperature versus mass as measured by several other experiments [4].

6 Summary

The $(\phi/\rho + \omega)_{\mu\mu}$ ratios display a smooth increase with the centrality of the collision. The same ratios are independent of M_T. The multiplity of $\rho + \omega$ is linear with N_{part} whereas for the ϕ a stronger increase is observed. From the ratio and multiplicity studies, the ϕ production does not exhibit any saturation for N_{part} greater than 100.
The values obtained for the effective temperatures are: $T_\phi \approx 227$ MeV and $T_{\rho+\omega} \approx 224$ MeV.

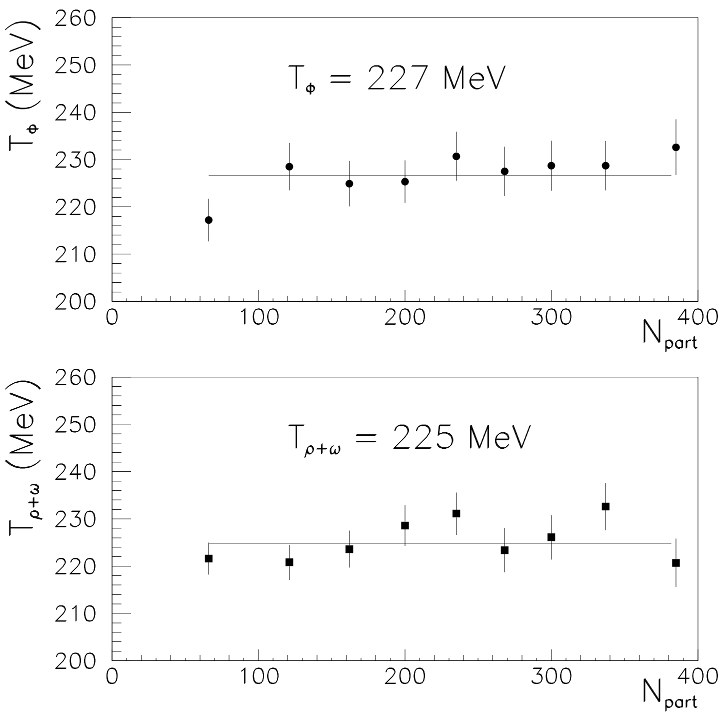

Figure 6: *Effective temperatures of ϕ and $\rho+\omega$ versus N_{part}.*

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