ϕ and $\rho + \omega$ vector-mesons produced in lead induced collisions

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Abstract

The experiment NA50 studies the strangeness production by means of the $BR^{\phi}_{\mu\mu}\sigma_{\phi}/(BR^{\rho}_{\mu\mu}\sigma_{\rho} + BR^{\omega}_{\mu\mu}\sigma_{\omega})$ cross-sections ratio in relativistic heavy ion collisions with respect to proton and light ion collisions. New results for Pb+Pb interactions at 158 A GeV/c are presented (1998 data) and analyzed with a different method.

The $BR^{\phi}_{\mu\mu}\sigma_{\phi}/(BR^{\rho}_{\mu\mu}\sigma_{\rho} + BR^{\omega}_{\mu\mu}\sigma_{\omega})$ ratio shows an increase with the number of participants, in agreement with previous results.

The inverse slope parameter extracted from the M_T universal scaling is also studied.

1. Introduction

Strangeness enhancement as a signal for the phase transition from hadronic to deconfined quark and gluon matter has been searched for since a long time ago [1]. The enhanced production in relativistic heavy ion collisions of the hidden strange vector-meson ϕ, normalized to the production of non-strange neutral vector-mesons $\rho + \omega$ is one of the searched signatures for this phase transition [2].

The experiment NA50 from CERN/SPS (and its predecessor NA38), investigates the muon pairs coming from Pb+Pb collisions at 158 GeV/nucleon (p+W, d+d, d+U, S+S, S+Cu and S+U at 200 GeV/nucleon). The experiment is optimized to measure the J/ψ, so the mass resolution in the low mass region $M_{\mu\mu} \leq 1.2$ GeV/c^2 is not optimal, preventing to distinguish the ρ from the ω resonances, with close mass poles (the mass resolution is ≈ 70 MeV/c^2 in the ϕ mass).

2. Experimental apparatus

The data taken by NA50 during 1996 was obtained using a high intensity lead beam, accelerated at 158 GeV/nucleon, and 7 sub-targets with a total lenght of 12 mm. In this analysis, the lead data taken in 1998 with only one sub-target 3 mm thick is studied.

The NA50 setup is explained in detail elsewhere [3]. Only a short description will be made here. The experiment consists of an active target, a zero degree and an electromagnetic calorimeter, a multiplicity detector and a muon spectrometer which includes an air-core toroidal magnet. In this data taking period one sub-target was used, the interactions in target being recognized by means of quartz blades. The electromagnetic calorimeter (EM) allows to measure the neutral transverse energy produced in each collision; while the zero degree hadronic calorimeter (ZDC), located around the beam line, inside the absorber, measures the spectators energy. The huge amount of π and K particles produced is reduced to a minimum with the absorber placed in front of the EM calorimeter. The spectrometer consists of two sets of multiwire proportional chambers and trigger hodoscopes, with the magnet placed in between. The bending angle of the muon tracks gives a measure of their transverse momentum. An iron wall located upstream from the last trigger hodoscope ensures only muon triggers.

3. Method of analysis

The 20 million events recorded reduce to about 3 million after selection cuts. The selection of events requires that the interaction is seen by the target blades. Events coming from the halo beam and events produced in the beam detector are rejected. The extrapolation of tracks back to the target region is required to pass within σ from the beam line, in the target plane. The image cut, consisting of a selection of tracks that would have been accepted if their charge would be opposite, is also performed, in order to normalize the population of like-sign muon pairs, allowing for a correct background subtraction.

The combinatorial background of uncorrelated muons coming from π and K decays is subtracted using the like-sign muon pairs. This background is estimated according to the expression:

$$N^{bkg} = 2\sqrt{N^{\mu^+\mu^+}\ N^{\mu^-\mu^-}} \quad . \tag{1}$$

Kinematical cuts consist of requiring $0.25 \leq M_{\mu\mu} < 2.5$ GeV/c^2, $0.05 \leq Y^{CM} < 1.05$, $P_{T\ \mu\mu} < 3.5$ GeV/c and $-0.5 \leq \cos\theta_{CS} < 0.5$ (θ measured in the Collins-Soper reference frame). A diagonal cut in the plane E_T *versus* E_{ZDC} is also applied, in order to keep only those events within 2σ from the maximum correlation between the two energy measurements.

A deconvolution method is used to obtain dimuon mass and transverse momentum distributions in terms of the produced variables, i.e., to correct the measured quantities from the effects of the smearing and limited acceptance introduced by the apparatus. This deconvolution method relies on a Monte-Carlo simulation. Mass spectrum is generated using three classical Breit-Wigner functions for the ρ, ω and ϕ vector-mesons, with mass poles and total widths given by the PDG [4]. The physics continuum coming from Dalitz decays of η, $\eta\prime$ and ω, Drell-Yan and semi-leptonic decays of D and $\bar{D}$ particles is parameterized by a decreasing exponential. The transverse momentum distribution is simulated using a Bessel function with $T = 236$ MeV. Dimuon rapidity in the center-of-mass frame is given by a Gaussian function centered at zero, with width $\sigma = 1.25$, as measured by the NA49 experiment for the ϕ resonance [5]. The dimuon $\cos\theta$ distribution is generated according to $(1 + \cos^2\theta)$. These generated distributions are adjusted to the experimental data applying weights in each kinematical bin, using an iterative procedure. The convergence is obtained after 2 iterations, when the modified distributions tracked through the detector agree with the experimental ones.

The data is deconvoluted to obtain the distributions as functions of the produced variables, using an acceptance with smearing function, given by:

$$Acceptance \otimes Smearing = \frac{Reconstructed\ events|_{measured\ variable}}{Generated\ events|_{generated\ variable}} \quad (2)$$

A P_T cut of $P_T \geq 1.4$ GeV/c is applied, in order to have an acceptance in the resonances' mass region higher than 1%.

4. Results

The mass spectra corrected for acceptance and smearing are fitted with a 5 free-parameter function:

$$\mathcal{F} = P_1\ BW^{\rho} + P_1 P_2\ BW^{\omega} + P_1 P_3 (1 + P_2)\ BW^{\phi} + P_4\ e^{-P_5 M} \quad (3)$$

using the masses and natural widths for ρ, ω and ϕ resonances as given in the PDG. The cross-sections ratio $BR^{\phi}_{\mu\mu}\sigma_{\phi}/(BR^{\rho}_{\mu\mu}\sigma_{\rho}+BR^{\omega}_{\mu\mu}\sigma_{\omega})$ in the dimuon channel (from now on abbreviated to $\phi/(\rho+\omega)$) is given by P_3. Figure 1 presents an example of the mass spectrum fit, for the transverse momentum integrated region $1.4 \leq P_T < 3.5$ GeV/c.

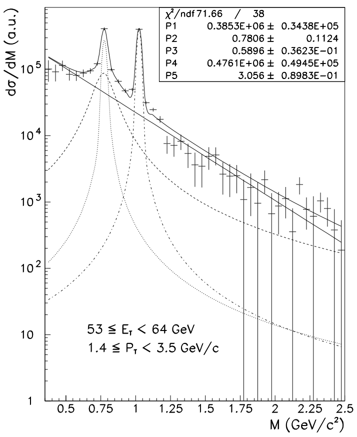

Figure 1. Example of a mass spectrum fit.

The relative production of the ϕ vector-meson is studied in 4 P_T bins. Here a low transverse energy cut is applied ($E_T \geq 42$ GeV), to avoid possible contamination from the interactions with air in the very peripheral collisions' region. As can be seen in figure 2 for Pb+Pb and also for proton and sulphur induced collisions [6], the ratio $\phi/(\rho + \omega)$ doesn't depend on the dimuon transverse momentum. This ratio is higher for heavier systems, as expected [6].

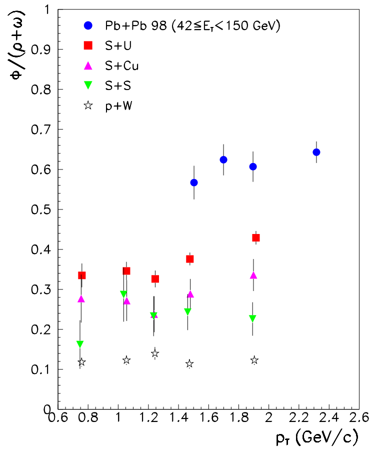

Figure 2. Cross-sections ratio $\phi/(\rho+\omega)$ as a function of the dimuons' transverse momentum. Also shown are the results from NA38 for sulphur and proton induced collisions.

This result is compatible within errors with a previous one, using a different analysis' method(non-deconvoluted) of the lead data taken by NA50 in 1996 [7].

The influence of the ρ vector-meson line shape in the fit results is studied, using different Breit-Wigner functions to parameterize this resonance (ω and ϕ are much less sensitive to the Breit-Wigner function used, due to their narrow width). Besides the classical Breit-Wigner function, a relativistic one is used in the fit (as suggested by [8]). As can be seen in figure 3, the cross-sections ratio $\phi/(\rho + \omega)$ as a function of P_T is not sensitive to these different line-shapes for the ρ, the values differing by less than 2%.

The same ratio as a function of P_T, per transverse energy regions, is globally in agreement with the integrated one, but the large fluctuations don't allow to draw any further conclusion.

The ϕ relative production as a function of the transverse energy is also studied in 4 P_T regions (figure 4), showing a slight increase of the ratio with the centrality of the collisions, more apparent in the last P_T bin, where statistic fluctuations are less important. In this figure, the first two E_T bins for each P_T region are also presented, although they have a contamination from interactions with air, not yet fully evaluated. This contamination is not expected to be too large, since there is a good agreement, even in the 2 first bins, between the lead results from 1996, with a target extending through 12 cm, and those from 1998, with only 1 subtarget 3 mm thick (figure 6, right). Since no dependence of the ratio with P_T is seen, data can safely be integrated in transverse momentum, thus allowing a study as a function of the centrality, with higher statistics. The number of participant nucleons in the collisions N_{part} is evaluated using the Glauber model, for each E_T bin, from the corresponding mean E_T value. The result is presented in figure 5, together with those obtained by the experiment NA38 with lighter systems. The two low E_T bins for lead are shown as open circles, for completeness.

The strangeness production increases smoothly with N_{part} and seems to saturate for

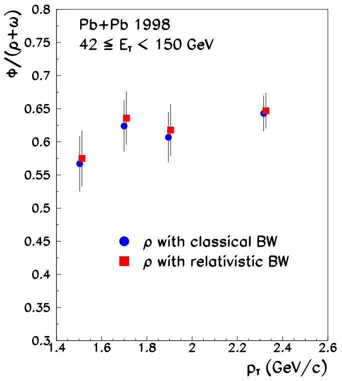

Figure 3. Cross-sections ratio $\phi/(\rho+\omega)$ as a function of P_T. Using 2 different ρ line-shapes, a classical Breit-Wigner function or a relativistic one, does not influence significantly the ratio.

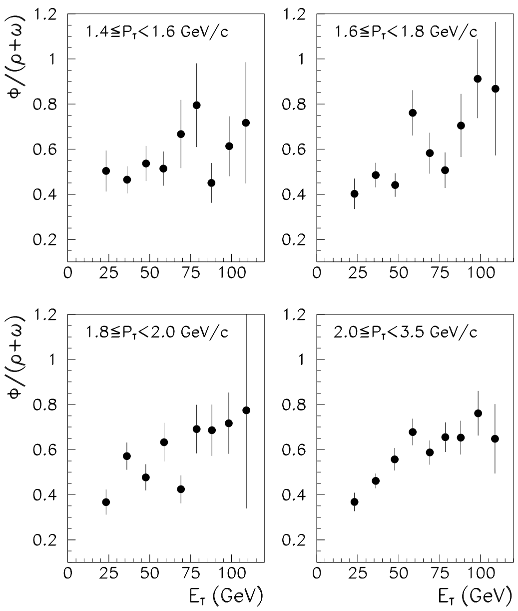

Figure 4. Cross-sections ratio $\phi/(\rho+\omega)$ as a function of the transverse momentum, for P_T regions.

$N_{part} \approx 200$. The sulphur data follow the behaviour of the lead data, and the ratio increases with AB, as expected.

The sensitivity of $\phi/(\rho+\omega)$ to the ratio ω/ρ is studied. Fixing it to the value given by the ratio of their branching ratios into electrons [4] (assuming that the ratio into muons is the

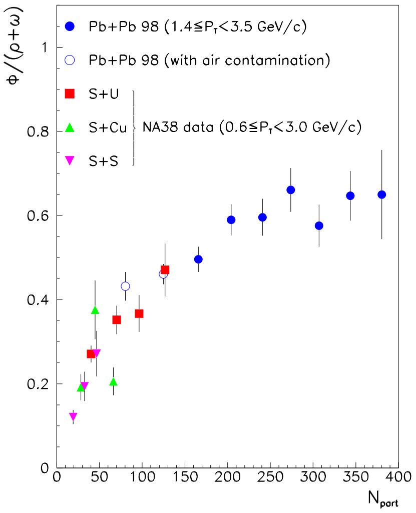

Figure 5. Cross-sections ratio $\phi/(\rho + \omega)$ as a function of N_{part}, integrated in the whole P_T domain of the analysis. Also shown are the results from NA38 with lighter systems.

same), $\omega/\rho = 1.6$, $\phi/(\rho + \omega)$ increases systematically (although in agreement within errors with the free ω/ρ results), and the quality of the mass fits deteriorates (figure 6). When ω/ρ is let free, the mean value is $\langle \omega/\rho \rangle = 0.76$.

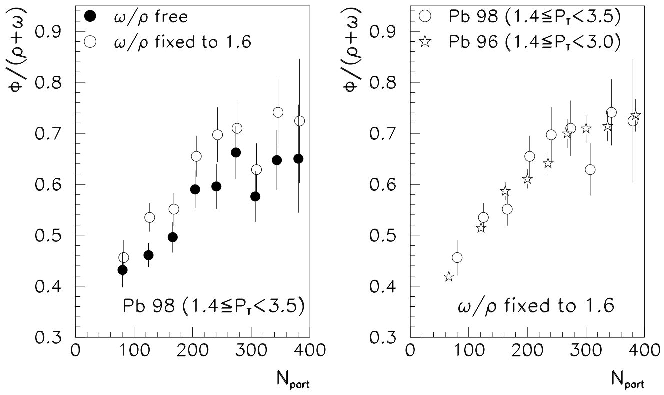

Figure 6. Cross-sections ratio $\phi/(\rho + \omega)$ as a function of N_{part}. Comparison of the results when letting ω/ρ free, or fixing it to 1.6 (left). Comparison of this analysis' result with ω/ρ fixed, with the one obtained by another analysis method for the 1996 data sample(right).

The cross-sections ratio $\phi/(\rho + \omega)$ obtained in this analysis with ω/ρ fixed is perfectly compatible with the result from another analysis for 1996 data sample [7] that also used $\omega/\rho = 1.6$ - although this other analysis used a completely different method.

To obtain the resonances' effective temperatures, the mass spectra are fitted with a function similar to eq. 3, but where the free parameters give directly the resonances' normalizations. The number of $\rho+\omega$ and the number of ϕ obtained in this way are divided by their corresponding transverse mass bin width. The resonances inverse slopes are obtained assuming a universal M_T scaling:

$$\frac{d\sigma}{dM_T} \propto M_T^{3/2}\ e^{-M_T/T} \tag{4}$$

where T is the inverse slope parameter, or effective temperature. The cross-section error bars include a very preliminary estimate of the systematic error, amounting to $\approx 10\%$ for $\rho + \omega$ and 2% for ϕ.

The temperature fits are presented in figure 7, giving $T_\phi = 216.7 \pm 4.2$ MeV and $T_{\rho+\omega} = 218.0 \pm 15.5$ MeV.

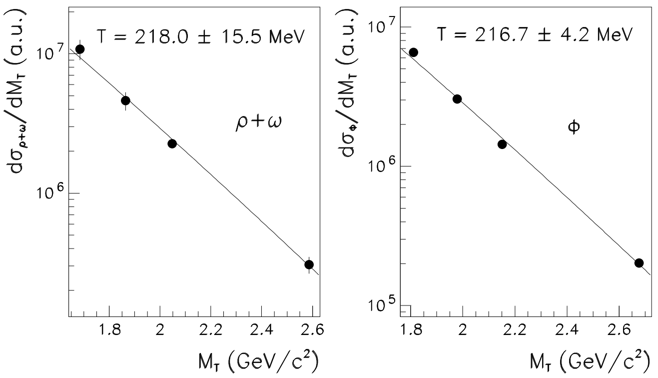

Figure 7. Resonances' M_T distribution as a function of M_T, integrated in the E_T domain $42 \leq E_T < 150$ GeV, fitted with a function $M_T^{3/2}\ e^{-M_T/T}$.

The study of the effective temperature as a function of centrality is presented in figure 8, together with the results from NA38 for sulphur induced collisions. No evolution is seen with N_{part}, for any of the resonances.

The inverse slope parameters obtained in this analysis are in perfect agreement with the previous ones [7]. They are also compatible with the theoretical result using the MICOR model [9] (the MIcroscopical COalescence Rehadronization model considering thermalized massive quark matter).

If the (also commonly used) fit function $M_T\ e^{-M_T/T}$ is used instead of eq. 4, the values $T_{\rho+\omega} = 230 \pm 17$ MeV and $T_\phi = 228 \pm 5$ MeV are obtained. This ϕ inverse slope on the leptonic channel is much lower than the one reported by the NA49 experiment on the hadronic decay channel ($\phi \to K^+K^-$), $T_\phi = 305 \pm 15$ MeV (see ref. [10]). Recent theoretical studies explain this difference by final state interactions of the decay kaons [11]. All the results presented here are preliminary, and systematic errors are still being evaluated.

5. Summary

NA50 studies the Pb+Pb collisions at 158 GeV/nucleon, using one single target 3 mm thick. The low mass region is analyzed with a simple multi-dimensional deconvolution method, to

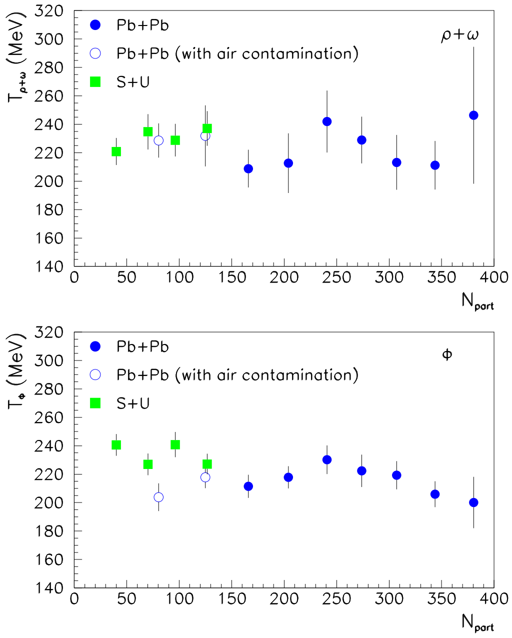

Figure 8. Inverse slope parameter T as a function of N_{part}, for $\rho+\omega$ (up) and for ϕ (down). Also presented are the inverse slopes obtained in S+U collisions (NA38).

study the production of the ϕ relative to the ρ and ω vector-mesons. The cross-sections ratio $BR^{\phi}_{\mu\mu}\sigma_{\phi}/(BR^{\rho}_{\mu\mu}\sigma_{\rho}+BR^{\omega}_{\mu\mu}\sigma_{\omega})$ is studied in 4 high P_T regions, showing no dependence on the dimuon transverse momentum.

The cross-sections ratio $BR^{\phi}_{\mu\mu}\sigma_{\phi}/(BR^{\rho}_{\mu\mu}\sigma_{\rho}+BR^{\omega}_{\mu\mu}\sigma_{\omega})$ increases with the centrality of the collisions, showing a slight raise followed by a saturation both in E_T and in the N_{part} variables. The comparison with the results from the NA38 experiment using sulphur beam, shows that $BR^{\phi}_{\mu\mu}\sigma_{\phi}/(BR^{\rho}_{\mu\mu}\sigma_{\rho}+BR^{\omega}_{\mu\mu}\sigma_{\omega})$ increases when going from lighter to heavier systems.

The inverse slope parameter is centrality independent and has the same value for $\rho+\omega$ and for ϕ, $\approx 220-230$ MeV, when measured through the dimuon decay channel.

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