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Abstract

Enhanced strangeness production in nuclear collisions has been proposed as a possible signature of quark-gluon plasma formation: in particular, the ϕ production might increase. We find, however, that the enhancement of the $\phi/(\rho_o+\omega)$ ratio by a factor of ca. 3 observed by NA38 (for $p_\perp \geq 1.1$ GeV) can be explained by the smaller size of the ϕ absorption cross section and that the enhancement of the ϕ to continuum ratio could be an artifact of the p_t cutoff applied to the data.

1. INTRODUCTION

An enhanced production of strange particles has long been advocated as a signature for quark-gluon plasma formation [1]. A particular way to study this effect [2] is to measure the production ratio of the vector mesons ϕ with respect to $\rho_0+\omega$, $\phi/(\rho_0+\omega)$. In ordinary collisions (i.e. collisions not leading to quark-gluon plasma formation), this is a small number because the production of vector mesons with hidden flavor is inhibited (OZI rule). On the other side, during the hadronization of a quark-gluon plasma, ϕ's can be produced copiously via the coalescence of s and $\bar{s}$ quarks, so $\phi/(\rho_0+\omega)$ may reach several times its value in ordinary collisions.

The collaboration NA38 [3] has studied the ϕ and $\rho_0+\omega$ production through their muonic decay in relativistic heavy ion collisions. To reduce the background which is very important at low invariant mass and for acceptance reasons, cutoffs are introduced: only pairs where each individual muon has $p_t > p_t^{cut}$ GeV and $p_z > p_z^{cut}$ GeV are kept. Two different sets of cutoffs were used: p_t^{cut}=0.7 GeV and p_z^{cut}=13 GeV or p_t^{cut}=0.6 GeV and p_z^{cut}=9.5 GeV. (For simplicity we assume that the mesons detected have $p_t \geq 2\,p_t^{cut}$ = 1.3 or 1.1 GeV.) With these cutoffs, the ratios $\phi/(\rho_0+\omega)$ and ϕ/c (where c designates the continuum in the mass range 1.7-2.4 GeV) increase with the transverse energy, E_t, while $(\rho_0+\omega)/c$ remains approximatively constant. Given that higher E_t's are expected to correspond to more central collisions and higher particle densities, these observations could signal the appearance of a quark-gluon phase.

Let us point out, however, that in calculations of strangeness enhancement with quark-gluon plasma formation, thermal and chemical equilibrium is usually assumed (see, e.g., [2,4]). A quark or gluon has an average momentum of order $\sim (mT)^{1/2}$ if $T < m$ and $\sim T$ if $T > m$, therefore too little energy to give rise to a high p_t meson with a recoiling particle at the phase transition. To create high p_t particles from a QGP, one probably has to use evaporation mecanisms such as described in [5] and it is not clear that $\phi/(\rho_0+\omega)^{QGP}_{high\ p_t} \gg \phi/(\rho_0+\omega)^{pp}_{high\ p_t}$.

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2. Φ-ENHANCEMENT OF NA38 AT HIGH P_t

Presently, there exist two non-plasma explanations of the high p_t ϕ enhancement seen by NA38. Koch et al. [4] suppose that $(\rho_0+\omega)/c$ is independent of E_t because these particles are in chemical equilibrium in the hot hadronic gas. With some additional approximations, they are able to reproduce the shape of $\phi/(\rho_0+\omega)$ as a function of E_t, which means that production of ϕ's in secondary collisions in the hot hadronic gas exceeds absorption. In contrast, our approach [6] is based on the observation that massive particles at high p_t are hard to create in secondary collisions in the hot hadronic gas, because there is not sufficient energy available, but can easily be absorbed in the rescattering processes. The increase of $\phi/(\rho_0+\omega)$ then follows from the fact that the absorption cross section of the ϕ is smaller than that of the ρ_0 or ω.

We are also able to reproduce the ϕ/c and $(\rho_0+\omega)/c)$ data (not done in [4]). The increase of ϕ/c comes from the following fact. A cutoff in transverse momentum is applied to the data, i.e. only vector mesons with momentum greater that p_t^{cut} are recorded. On the other side, it is known than transverse momentum distributions flatten as E_t increases (Cronin effect) so they are more and more particles above the cutoff as E_t increases[1]. This causes an artificial increase in the yields. For the ϕ, absorption is small and may be overcome by this increase; for the $\rho_0+\omega$, absorption is higher and may be balanced by the increase. Let us check that in order of magnitude the two mecanisms identified above (absorption and increase due to cutoff) are efficient enough to reproduce the experimental data.

The vector mesons V (where V=$\phi, \rho_0+\omega$) are embedded in a gas of average particle density $\bar{\rho}$ from an initial time t_0 to a final (average) time t_f. Neglecting the production of V mesons and (temporarely) expansion, the rate of change of the density of V's is $d\rho_V/dt \sim \sigma^V_{abs} \times \bar{\rho} \times \rho_V$, from which we obtain the simple exponential dependence

$$\frac{N_\phi(t_f)}{N_{\rho_0+\omega}(t_f)} \sim \frac{N_\phi(t_0)}{N_{\rho_0+\omega}(t_0)} \exp[\bar{\rho}(\sigma^{\rho_0,\omega}_{abs} - \sigma^{\phi}_{abs})(t_f - t_0)] \tag{1}$$

Inserting the assumptions $\bar{\rho} \simeq \rho_{nucl.matt.} = 0.17$ fm^{-3} and $t_f - t_0 \simeq R/c_s \simeq 5$ fm (if c_s, the sound speed, is $\sim c/\sqrt{3}$ and R is the oxygen radius), one sees that the ϕ production compared to that of $\rho_0+\omega$ is enhanced by a factor 3-8, when going from peripheral collisions where no absorption is expected ($N_\phi(t_f)/N_{\rho_0+\omega}(t_f) \sim N_\phi(t_0)/N_{\rho_0+\omega}(t_0)$) to central ones, provided that the initial production ratio $N_\phi(t_0)/N_{\rho_0+\omega}(t_0)$ does not change with centrality or E_t. This increase is consistent with the NA38 data described above. The incertitude in our estimate comes from the error bars on the absorption cross sections but the ratio in Eq. 1 is also sensitive to the roughly estimated value of $\bar{\rho}$ and $(t_f - t_0)$, so a more detailed model including expansion is really needed.

To calculate the effect of the cutoff, we parametrize the p_t-distribution as $dN/dp_t^2 \propto \exp(-\beta m_t)$, where m_t is the transverse mass of the particle with mass m. The slope parameter β decreases with increasing A in pA collisions or E_t in A-B collisions. Since the cutoff was applied to the p-U data but not to the continuum, we obtain (neglecting absorption)

$$\frac{N_V}{N_c} \sim \frac{N_V^{pU}}{N_c^{pU}} \exp[(\beta^{pU} - \beta(E_t))(m_t^{cut} - m)] \tag{2}$$

From NA38 J/Ψ data (see e.g. [7]), one gets $\Delta\beta \sim 1.1 \pm 0.4$ GeV^{-1}. Therefore we expect the V/c ratio to be enhanced by 1.8-2.6 when going from peripheral to central collisions.

[1]The slope of the continuum stays approximately constant with increasing E_t (see e.g. [7]) and no cutoff is applied to the continuum.

This enhancement may be enough to explain the NA38 data for ϕ/c, for which absorption is small. The observed $(\rho_0+\omega)/c$ ratio however is almost constant. This is understandable since absorption in that case is important, so should be included in Eq. 2 and, as already mentioned, may balance the enhancement due to the p_t cutoff.

In Ref. 6 we obtained, applying the Bjorken hypothesis for expansion,

$$\frac{N_\phi/N_{\rho_0+\omega}}{N_\phi^{pU}/N_{\rho_0+\omega}^{pU}} \simeq (x_\phi/x_{\rho_0+\omega})^{1.5E_t/\pi R^2} \qquad (3)$$

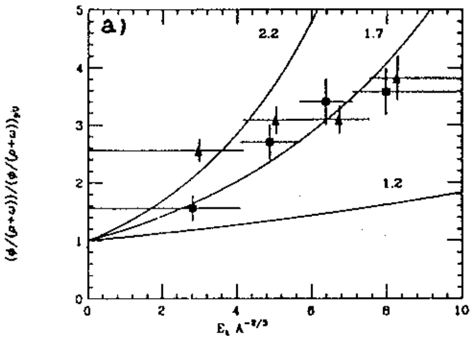
(here we used that experimentally the rapidity density is $\sim 1.5E_t$ with E_t in GeV) and

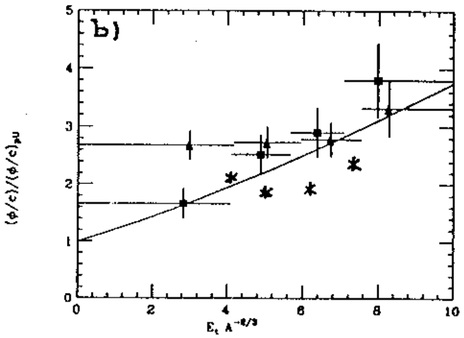
$$\frac{N_V/N_c}{N_V^{pU}/N_c^{pU}} \simeq e^{(\beta^{pU}-\beta(E_t))(m_t^{cut}-m)} \times (x_V)^{1.5E_t/\pi R^2}, \qquad (4)$$

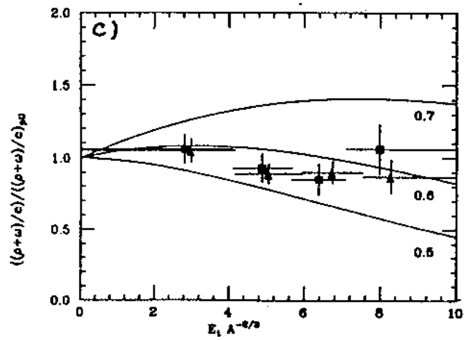
where $x_V \equiv (\tau_0/\tau_f)^{<\sigma_{abs}^V v_{rel}>}$. In figures a-c, we show the values of x_V needed to reproduce the data. Note that $x_\phi = 1$ and $x_{\rho_0+\omega)} = 0.6$ are compatible with $x_\phi/x_{\rho_0+\omega)} = 1.7$. The τ_f we extract is $\sim 2\tau_0$. The standard assumption, $\tau_0 \sim 1$ fm, thus gives a lifetime $\tau_f \sim 2$ fm which is considerably shorter than R/c, but is compatible with the time it takes for a high p_t meson traveling outwards in the interaction region to meet a rarefaction wave traveling inwards. Whether such a short lifetime is sufficient for rescattering processes to lead to chemical equilibrium [4] is questionable.

The short ρ-lifetime, $\tau_\rho = 1.32$ fm/c, corresponds to a time ~ 2 fm in the gas local rest frame, i.e. of order τ_f. Therefore, adding ρ-decay (cf. [8]) only affects our results slightly. Measuring τ_f should soon be possible by improving the experimental resolution and separating the ρ from the ω [8].

Figures: a) Ratio $\phi/(\rho_0+\omega)$ as a function of $E_t/A^{2/3}$ (Eq. 3) for various values of $x_\phi/x_{\rho_0+\omega}$ (see text for definition). The NA38 (high p_t) data for O are represented by filled squares and for S by filled triangles. b) Ratio ϕ/c as a function of $E_t/A^{2/3}$ (Eq. 4) for $x_\phi = 1$ (or $\sigma_{abs}^\phi \sim 0$). c) Ratio $(\rho_0+\omega)/c$ as a function of $E_t/A^{2/3}$ (Eq. 4) for various values of $x_{\rho_0+\omega}$.







3. NEW Φ RESULTS

The NA38 and NA34-3 collaborations have recently presented results for ϕ and $\rho_0+\omega$ at lower p_t [9,10]. The lower momentum cutoff of NA38 is now 0.6 GeV, and they find that the inverse slope of the ϕ (resp. $\rho_0+\omega$) transverse momentum distribution increases by 24 MeV (resp. 20 MeV) from p-U to S-U, but by only 10 MeV (resp. 5 MeV) between the lowest transverse energy bin and the highest. If we turn to the ϕ/c S-U data in fig.b, we see that most of the increase in strangeness is between p-U and the lowest energy bin. There is little increase between the lowest energy bin and the highest. Therefore new results on the p_t transverse slope are in qualitative agreement with our model. To make this quantitative, we have evaluated Eq. 4 with the new ϕ slopes (rather than those of the J/Ψ) and the results are shown by stars in fig. b.

For NA38, the new $\phi/(\rho_0+\omega)$ ratio increases by ~1.7 between p-W and the lowest transverse energy and by 1.5 between the lowest and highest transverse energy bins. NA34-3 has similar results with an increase by a factor 2.3 between p-W and the low multiplicity bin in S-W. The increase of $\phi/(\rho_0+\omega)$ going from low to high multiplicity bins is 1.4. If this is still the situation after the error bars are improved, one would have to conclude that either the $\phi/(\rho_0+\omega)$ increase is due to some new hadronic effect or that the quark-gluon plasma was created already in the low transverse energy or low multiplicity bin.

NA34-3 also presented results on ϕ/c and $(\rho_0+\omega)/c$ ratios. Within the experimental uncertainty these are independent of multiplicity. One should, however, note that the continuum here is that below the ϕ and $\rho_0+\omega$ (not that below the J/ψ as for NA38) and this continuum may not be constant in shape with increasing multiplicity.

4. CONCLUSION

Absorption in nuclear matter plus the Cronin effect may explain the high p_t NA38 data without strangeness enhancement. There are now indications both from NA38 and NA34-3 that $\phi/(\rho_0+\omega)$ also increases with transverse energy or multiplicity for low p_t particles but most of the increase is between pA and the low transverse energy or multiplicity bin which cannot yet be explained by any hadronic gas model. It might be an indication of the formation of a QGP but this is not expected at low transverse energy or multiplicity. More precise data is needed to resolve these questions.

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