STRANGENESS ENHANCEMENT IN RELATIVISTIC NUCLEAR COLLISIONS†

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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 observed enhancement of the $\phi/(\rho_o + \omega)$ ratio observed in relativistic heavy ion collisions at CERN, might be due to 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.

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1. Why strangeness enhancement ?

Since the topic of strangeness enhancement is perhaps not very familiar to everyone, I will start with a very short discussion of the theoretical and experimental situations.

Enhanced strangeness production has been proposed as a possible signature of quark-gluon plasma (QGP) formation. To understand this [1, 2], let us first consider the production of strange hadrons in proton-proton collisions. As protons contain no s quarks, strange particles are produced in association with an antistrange-particle. For example

$$pp \longrightarrow p\Lambda K^+ \quad (1)$$
$$pp \longrightarrow pp\Lambda\bar{\Lambda} \quad (2)$$
$$pp \longrightarrow ppp\bar{\Lambda}K^- \quad (3)$$

The threshold energy for the first reaction is $M_\Lambda - M_p + M_K \sim 0.7$ GeV in the p-p center-of-mass system. In the same way, the threshold energy for the second reaction is 2.2GeV and for the third 2.5 GeV. In contrast, in QGP (with partially restored chiral symmetry), the threshold for strangeness creation is $2m_s \sim$ 300-400 MeV. Therefore, it is expected that strangeness is easier to create in QGP than in pp collisions.

In fact, strangeness is also higher in a thermally and chemically equilibrated hadronic gas than in pp collisions. However the approach to chemical equilibrium in that case is slow and it is thought that not enough time is available for strangeness to build up. Therefore, strangeness enhancement remains a possible signature of QGP formation.

2. Experimental results

Results on strange particle production have been obtained by various collaborations at the A.G.S. in Brookhaven and the S.P.S. at Cern. Table 1 contains a summary of these experiments and their results (see e.g. [3] and [4] for more details).

Table 1: Summary of results on strangeness production in heavy ion collisions.

Place	Collab.	Nuclei	Results on strangeness prod.	Exp. and theor. ref.
BNL E=14.5 GeV A	E802	Si+Au	-$K^+/\pi^+ > K^+/\pi^+_{pp}$ $K^-/\pi^- > K^-/\pi^-_{pp}$ -K/π increses with $p_\perp$	E:[5] T: [6, 7, 8, 9, 10, 11]
	(E810)			
CERN E=200 GeV A	NA34	S+W	- no excess of K/π low $p_\perp$ data central events not selected	ET:[3]
	NA35	O+Au	- K^0_s/h^-,Λ/h^-,Λ equal to pAu	E:[12]
		S+S	- K^0_s/h^-,Λ/h^-,$\Lambda \sim 2\times$ pS - K^+, K^- not enhanced?	T:[13] E:[14]
	(NA36)			
	NA38	O+U,S+U	- no excess of K/π - $\phi/cont.$ increases with E_t	E:[15] E:[16] T:[17, 18]
	WA85	S+W	- $\bar{\Lambda}/mult.$, $\Lambda/mult.$ cst with mult. - $\bar{\Lambda}/\Lambda$ equal to pW but $\bar{\Xi}^-/\Xi^-$ >.	E:[19], [20]

As can be seen the experimental situation is not very clear with some collaborations obtaining an enhancement and others none. There is a clear need for more experimental data and more theoretical reflection to unify these findings.

3. ϕ-enhancement of NA38

In this section, I present a possible explaination of the ϕ enhancement seen by NA38. This collaboration studies [16] the ϕ and $\rho_0 + \omega$ production in relativistic heavy ion collisions. They detect dimuons coming from 1) resonance decays, e.g., $\phi \to \mu^+ \mu^-$, 2) continuum processes, e.g., $q\bar{q} \to \mu^+ \mu^-$ (Drell-Yan) (continuum is designated thereafter by c) and 3) background, e.g. $\pi^\pm\pi^\pm \to \mu^\pm \mu^\pm$. To reduce the background, which is very important at low invariant mass, cutoffs are introduced: only muon pairs with $p_t > p_t^{cut}$ GeV and $p_z > p_z^{cut}$ GeV are kept. Two different sets of cutoffs were used: p_t^{cut}=1.3 GeV and p_z^{cut}=26 GeV or p_t^{cut}=1.1 GeV and p_z^{cut}=19 GeV. The background muon pairs are then eliminated from the signal (resonances and continuum) by doing:

$$N_{signal}(\mu^+\mu^-) = N(\mu^+\mu^-) - 2\sqrt{N(\mu^+\mu^+)N(\mu^-\mu^-)}. \quad (4)$$

It is found that the ratios $\phi/(\rho_0+\omega)$ and ϕ/c increase with the transverse energy, E_t, respectively by a factor ~ 2 and $1.5 - 2.5$ while $(\rho_0 + \omega)/c$ remains approximatively constant (see fig. 1a-c). 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.

As of today there exist however two non-plasma explainations of these results. Koch et al. [17] suppose that $(\rho_0 + \omega)/c$ is flat with 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 overcomes their absorption. In contrast, the approach developped by H.Heiselberg and myself [18] starts from the remark that high p_t massive particles must be hard to create in secondary collisions in the hot hadronic gas but can be absorbed. 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 [17]). 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 that for light particles, the transverse momentum distribution flattens as E_t increases (this is the so-called Cronin effect. See for exemple in this conference proceedings, the NA38 data about $\pi + K$ [21]) 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. In [18], we developed a more detailed model to reproduce the experimental data. Here I will just show in order of magnitude that 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

[1] The slope of the continuum stays approximatey constant with increasing E_t (see for exemple NA38 data in this proceedings [22]) and no cutoff is applied to the continuum. For particles created in hard processes such as the J/Ψ, there is also an increase of $\langle p_t \rangle$ with E_t but it is not experimentally clear that it also corresponds to a flattening of the transverse momentum distribution [22]. It cannot be excluded that this is also the case for high transverse mass vector mesons.

and expansion, the rate of change of the density of V's is

$$\frac{d\rho_V}{dt} \sim \sigma^V_{abs} \times \bar{\rho} \times \rho_V \tag{5}$$

so

$$\frac{N_\phi(t_f)}{N_{\rho_0+\omega}(t_f)} \sim \frac{N_\phi(t_0)}{N_{\rho_0+\omega}(t_0)} \exp[\bar{\rho}(\sigma^{\rho_0,\omega}_{abs} - \sigma^\phi_{abs})(t_f - t_0)] \tag{6}$$

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.

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)

$$\frac{N_V}{N_c} = \frac{N_V^{pU}}{N_c^{pU}} \exp[(\beta^{pU} - \beta(E_t))(m_t^{cut} - m)] \tag{7}$$

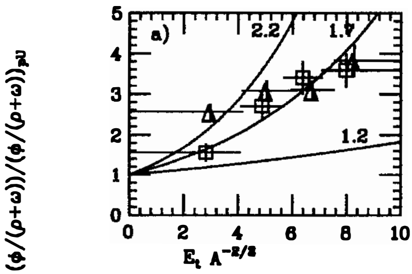
From NA38 J/Ψ data, one gets $\Delta\beta \sim 1.50 \pm 0.25$ GeV^{-1}. From their $K + \pi$ data, one gets $\Delta\beta \sim 0.33$ GeV^{-1}. Therefore we expect the V/c ratio to be enhanced by a factor $\sim$ 1.2-3.6 when going from peripheral to central collisions. This enhancement may be enough to 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. (7) and, as alredy mentioned, may balance the enhancement due to the p_t cutoff.

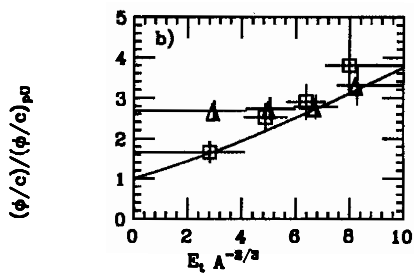
In summary, though other effects might be at work, absorption in nuclear matter (which decreases N_V with E_t) plus Cronin effect (which increases N_V with E_t above some p_t cutoff) may explain the NA38 data. (No strangeness enhancement is needed and indeed we expect the creation of high p_t massive mesons at midrapidity in secondary collisions to be rare.) One possible way to know whether there is a Cronin effect in the momentum distribution of the observed vector mesons would be to plot ϕ/c in a high E_t bin divided by the same quantity in a low E_t bin (at some value of the cutoff) as a function of the cutoff. If absorption is small, this ratio should increase. This is currently being investigated [23]. If indeed there is a cutoff effect in the data, it should be removed before one can really talk of strangeness enhancement. This may be tricky to do so a more promising line of work would be to extract data without p_t cutoff. This is also currently under investigation [23].

This work was supported in part by N.S.F. grant PHY 84-15064 in the U.S.A. and F.A.P.E.S.P. in Brazil.

REFERENCES

[1] B.Müller. "The Physics of Quark-Gluon Plasma", Springer-Verlag (1985).
[2] P.Koch, B.Müller, and J.Rafelski. Phys.Rep. 142 (1986) 1.
[3] R.A.Salmeron. Lecture at the Winter School on Quark-Gluon Plasma, Puri, Orissa, India, 5-16 December 1989.
[4] H.C.Eggers and J.Rafelski. Preprint AZPH-TH/90-28.
[5] T.Abbott and others (E802). Z.Phys.C 38 (1988) 135; Nucl. Phys. A 498 (1989) 67c; Phys. Rev. Lett. 64 (1990) 847.
[6] J.Cleymans, H.Satz, E.Suhonen, and D.W. von Oertzen. Phys. Lett. B242 (1990) 111.
[7] P.Lévai, B.Lukács, and J.Zimányi. Preprint KFKI-1989-47/A, Budapest.
[8] U.Heinz, P.Koch, E.Schnedermann, and H.Weigert. Preprint TPR-90-31, to appear in: "Phase Structure of Strongly Interacting Matter", Springer-Verlag, Lecture Notes in Physics.
[9] H.W. Barz, B.L. Friman, J.Knoll, and H.Schulz. Nucl. Phys. A498 (1989) 161c; To appear in Nucl. Phys. A.
[10] C.M. Ko and L.Xia. Nucl. Phys.Lett. A498 (1989) 561c.
[11] R.Matiello, H.Sorge, H.Stöcker, and W.Greiner. Phys. Rev. Lett. 63 (1989) 1459.
[12] A.Bamberger etal. (NA35) Z.Phys.C 43 (1989) 25; Nucl.Phys.A498 (1989) 375c; preprint IKF90-2; contribution in the Proceedings of the International Quark Matter Conference, Menton 90.
[13] F.Grassi and Y.Hama. Work in progress.
[14] M.Kowalski (NA35). Proceedings of the Rencontres de Moriond, Les Arcs, France (1991).
[15] M.C.Abreu etal. (NA38) Z.Phys.C 38 (1988) 129; Nucl.Phys.A498 (1989) 249c.
[16] M.C.Abreu etal. (NA38). To appear in the Proceedings of the International Europhysics Conference on High Energy Physics, Madrid 89; to appear in the Proceedings of the XXVth "Rencontres de Morond", Les Arcs 90; to appear in the Proceedings of the International Quark Matter Conference, Menton 90; A.Baldisseri Ph.D. Thesis, May 90.
[17] P.Koch, U.Heinz, and J.Pišút. Phys.Lett. B243 (1990) 149; Z.Phys.C 47 (1990) 477.
[18] F.Grassi and H.Heiselberg. Submitted to Phys.Lett.B.
[19] S.Abatzis etal. (WA85). Phys. Lett.B244 (1990) 130.
[20] D.Evans (WA85). Proceedings of the Rencontres de Moriond, Les Arcs, France (1991).
[21] L.Peralta (NA38). Proceedings of the Rencontres de Moriond, Les Arcs, France (1991).
[22] O.Drapier (NA38). Proceedings of the Rencontres de Moriond, Les Arcs, France (1991).
[23] C.Gershel and D.Jouan (NA38). Private communication.





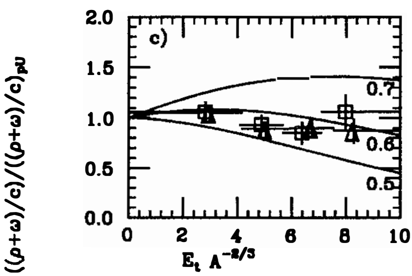


Fig. 1a–c: NA38 data for O+U (squa es) and S+U (triangles) Theoretical fits from [18].