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**RECENT RESULTS ON HEAVY-ION REACTIONS IN THE
SIS-ENERGY REGIME**

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Recent Results on Heavy-Ion Reactions in the SIS-Energy Regime ¹

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1. INTRODUCTION

Future heavy-ion reaction studies at RHIC and LHC aim at exploring the partonic degrees of freedom of hadronic matter at temperatures of several 100 MeV and almost vanishing net baryon densities. In contrast, experiments at SIS, i.e. in the 1 AGeV energy regime, focus on hadronic matter at temperatures below 100 MeV and baryon densities of 2-3 times normal nuclear matter density. Both experimental approaches are complementary as they allow rather different regimes in the phase diagram of hadronic matter to be studied. There are, nevertheless, several aspects of common interest, among them, e.g. the partial restoration of chiral symmetry. In general, investigations at low incident energies are required for a full, quantitative description of ultrarelativistic heavy-ion reactions as any initially formed quark-gluon plasma will go through a temperature and density range during the hadronization phase that can be directly studied at lower collision energies.

This overview over heavy-ion reactions in the SIS-energy range focuses on two aspects: (i) the global features of compressed hadronic matter generated in such collisions, and (ii) evidence for medium modifications of hadrons in this hot and dense nuclear medium.

2. GLOBAL PROPERTIES OF COMPRESSED HADRONIC MATTER

2.1. The space-time evolution of relativistic heavy-ion collisions

The characteristic features and the space-time evolution of relativistic heavy ion reactions in the SIS-energy regime are illustrated in fig.1 obtained from transport model calculations with the code IQMD: [1]. Two nuclei collide at 90 % light velocity and a high-density collision zone ($\rho_B \simeq 2\text{-}3 \rho_0$) is formed for a time of about 10 fm/c which is in the focus of our investigations. After violent nucleon-nucleon collisions the system explodes and is driven apart in an almost radial expansion. Part of the initial kinetic energy is converted into chaotic motion of hadrons and nuclear fragments, while some fraction of the energy goes into compression followed by a collective expansion of the system. Furthermore, some of the available energy is stored in the internal degrees of freedom of the nucleons. As composite systems of quarks and gluons, nucleons can be excited to short-lived resonance states which decay primarily by meson emission. Meson production studies thus allow the fraction of baryons excited during the high density phase of the nuclear collision to be deduced. To study these features of relativistic heavy-ion reactions, two experimental approaches have been pursued: (i) the investigation of nucleon and fragment emission patterns and (ii) the measurement of meson production. At GSI, both aspects have been addressed with the FOPI detector system, while the magnetic

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Figure 1. The space-time evolution (in time steps of $\approx 10 fm/c \approx 3 \cdot 10^{-23} s$) of a central nucleus-nucleus collision at 2 AGeV simulated within the IQMD-model [1].

spectrometer KaoS and the photon spectrometer TAPS have been employed for studying the emission of charged and neutral mesons, respectively. Results from these detector systems provide the basis of this overview.

2.2. Collective radial flow

Since the early days of heavy-ion reaction studies the search for collective phenomena has been a central issue: Are nucleus-nucleus reactions merely an ensemble of more or less independent nucleon-nucleon collisions or are there qualitatively new phenomena of collective character? The first collective effect established in heavy-ion reactions is the directed sideward flow [2] observed in non-central collisions where the presence of spectator matter defines a reaction plane. The spectators which do not experience first chance collisions because of lack of geometrical overlap are deflected sideways in the reaction plane by the exploding collision zone [3]. Recent developments with regard to this phenomenon have been reviewed at this conference by J.Y. Ollitrault [4].

An important achievement of the FOPI collaboration has been the first observation of azimuthally symmetric radial flow in central collisions of heavy nuclei [5]. If the expansion of the collision zone were a thermal motion, all particles - irrespective of their mass - would move with the same average kinetic energy determined by the temperature, i.e. $\langle E_{kin} \rangle \sim T$. In case of a purely collective motion all particles would move with the same velocity and, consequently, the average kinetic energy would increase proportional to the mass A , since $\langle E_{kin} \rangle = A \frac{m_0 v^2}{2} \sim A$. A superposition of both types of motion will give rise to a mass dependence $\langle E_{kin} \rangle \sim const + \alpha \cdot A$ as observed experimentally [6] in central events (fig.2). Although predicted long ago, the explosion of the collision zone could only be experimentally established after methods of selecting central collisions had been refined by, e.g. requiring a high degree of azimuthal symmetry of the event topology.

Subsequent studies by the FOPI [6] and EOS [7] collaborations for a large number of collision systems and bombarding energies have revealed a systematic increase of the transverse expansion velocity reaching a little more than 30 % velocity of light at 2 A GeV (see fig.3). This implies that 20 - 50 % of the initially available kinetic energy is converted into this collective expansion. For higher energies, AGS and SPS experiments

Figure 2. Average kinetic energy of nuclear fragments as a function of fragment mass for central Au-Au collisions at 250 A MeV. The figure is taken from refs. [3,6].

Figure 3. Systematics of transverse flow velocities for different collision systems and bombarding energies. The data have been compiled by N. Herrmann from refs. [6–11].

[8–11] indicate a saturation around $\beta_t \approx 0.4$.

2.3. Equilibration of the collision zone

An important question of heavy-ion reaction dynamics is whether an equilibrated system is formed in the collision. A prerequisite for such equilibration would be a complete mixture of nucleons from target and projectile which can be studied by colliding nuclei of the same mass but different neutron-to-proton ratios. If equilibration were reached fragments emitted from the collision zone should no longer exhibit the N/Z -ratio of the target or the projectile but rather one reflecting the mixing of target and projectile nucleons. The FOPI group [12] has studied the $^{96}_{44}\text{Ru} + ^{96}_{40}\text{Zr}$ reaction and the reference systems $^{96}_{40}\text{Zr} + ^{96}_{40}\text{Zr}$ and $^{96}_{44}\text{Ru} + ^{96}_{44}\text{Ru}$ which have different N/Z -ratios of 1.40 and 1.18, respectively. Preliminary analyses show that, with increasing centrality of the collision, the $t/{}^3\text{He}$ -ratio (taken as a measure for the N/Z -ratio) approaches the value expected for a complete mixture of projectile and target nucleons. This isotope ratio is thus a rather sensitive probe for studying the equilibration in relativistic heavy-ion reactions.

2.4. Particle production in nucleus-nucleus collisions

In the course of a heavy-ion reaction many nucleon-nucleon collisions occur which are energetic enough to excite the intrinsic degrees of freedom of the nucleons. As any composite system the nucleon exhibits a rich excitation energy spectrum with broad ($\Gamma \approx 100$ MeV) resonance states which decay primarily by meson ($\pi, \eta, K, \omega, \dots$) emission. The study of meson production is thus the appropriate approach to learn more about the conversion of the initial kinetic energy of the two colliding nuclei into internal excitations. π -emission from the lowest non-strange excited state of the nucleon, the $\Delta(1232)$ resonance, is the predominant source of pions in heavy-ion reactions at SIS energies. Higher lying, mostly overlapping resonances also emit pions but are less frequently populated. The η -meson plays a special role as it is a selective probe for the excitation of the $S_{11}(1535)$ resonance which is the only baryon resonance with a sizable ($\approx 50\%$) η -branching ratio.

Meson production in heavy-ion collisions has been studied over a wide energy and mass range. Resulting production probabilities per participant nucleon are shown in fig.4 as a function of the bombarding energy. To allow for a comparison of different particle species the bombarding energy per nucleon is divided by the threshold for producing the respective particle in free nucleon-nucleon collisions [13]. The production probabilities for π, η mesons fall close to one curve over 11 orders of magnitude. As shown more clearly

Figure 4. (a) left: meson production probability per participant nucleon as a function of the bombarding energy normalized to the meson production threshold in free nucleon-nucleon collisions; (b) expanded version of left hand panel showing the production probabilities for mesons with strange quarks; updated figures adapted from [13,14].

in fig. 4b, K^+ - and K^- - production probabilities are down by up to a factor 5 and the Φ -yield is even smaller compared to π, η -production.

By assuming an equilibrated system of hadronic matter that emits pions and η -mesons, the hadrochemical composition of the system can be analyzed within a thermal model at chemical freeze out. This point is reached in the expansion of the collision zone when the baryon density has dropped so far that inelastic collisions among hadrons (i.e. particle species changing reactions) die out and the hadrochemical composition of the system is no longer changed. Following reference [9], the system at chemical freeze out is regarded as a hadron gas consisting of $\pi, \eta, N, \Delta(1232), N^*(1440), N^*(1535)$, higher lying baryon resonances and deuterons in chemical and thermal equilibrium; the density of each constituent is then given by two parameters, the temperature T and the baryochemical potential μ_B :

$$\rho(\mu_B, T) = \frac{g}{(2\pi\hbar)^3} \int 4\pi p^2 f(pR) dp \int \frac{A(m) dm}{\exp[(E - \mu_B B)/T] \pm 1} \quad (1)$$

where g is the spin-isospin degeneracy, $A(m)$ the resonance mass distribution and $f(pR)$

a finite volume correction. The $\pm$ sign refers to the different statistics for bosons or fermions, respectively.

From the π^0 production probability per participant nucleon $\pi^0 / \langle A_{part} \rangle$, the production ratio η/π^0 [15], and the production rates of π, Δ, p, d [16] the parameters μ_B and T have been determined for different collision systems and bombarding energies using (1). The results are shown in the phase diagram of hadronic matter (fig.5). The figure

Figure 5. Phase diagram of hadronic matter: temperature T and baryochemical potential μ_B derived from particle production ratios in nucleus-nucleus reactions are plotted for different bombarding energies [9,11,15,16]. The solid curve through these data points represents the curve for chemical freeze out of hadronic matter. Open data points represent parameter pairs for thermal freeze out and are connected by the corresponding freeze out curve (dashed). This version of the figure has been prepared by U. Heinz [17].

also contains (T, μ_B) -determinations from particle production experiments at AGS and SPS energies [9,11]. The data points are connected by the (chemical) freeze out curve of hadronic matter.

Thermal freeze out occurs when elastic collisions between mesons and baryons die out. As elastic cross sections in the relevant energy regime are larger than those for inelastic reactions, thermal freeze out takes place later when the baryon density has dropped even further. Temperatures at thermal freeze out can be derived from fits to particle spectra if the distortion due to the radial expansion of the collision zone is simultaneously taken into account, using the transverse velocities from the systematics of fig.3. At SPS energies the information from HBT-measurements has also been used [11]. Corresponding data points have been included in the phase diagram of fig.5. The dashed curve represents the resulting curve for thermal freeze out of hadronic matter. It should be noted that at SIS energies the parameters for thermal and chemical freeze out are very similar.

The phase diagram illustrates that at freeze out the collision system is near the phase transition to the quark-gluon-plasma for AGS and SPS energies while in the SIS energy

regime only moderate temperatures below 100 MeV are reached and freeze out occurs at baryon densities of $\rho_B \approx 0.3-0.6 \rho_0$.

Having determined the (T, μ_B) -values, the population of all baryon resonances can be calculated within the thermal model using eq.(1). At 2 AGeV about 15% of the nucleons are found to be excited to resonance states. Although knowledge about the collision system at freeze out, i.e. in the end phase of the heavy-ion reaction, is very valuable it is the main aim to learn more about the high-density phase of the reaction. This information is difficult to access via strongly interacting probes as they decouple from the system only when the baryon density has already dropped. Leptons, to be discussed in section 3.2, provide a direct view of the hot and dense medium. Some information from hadronic probes can nevertheless be obtained by comparison to model calculations [1,18] which indicate that the number of excited baryons in the high-density phase is about twice as large as at freeze out. This leads to an estimated resonance population of $\approx 30\%$ at 2 AGeV. Combining the information on baryon density and resonance population, one derives a baryon resonance density of $\rho_{res} \approx 0.3\rho_b \approx 0.3 \cdot 2.5\rho_0 \approx 0.8\rho_0$. This implies an average spacing among baryon resonances of about 2 fm which is within the range of the strong interaction. The density of resonances is thus so high that they start interacting among each other which suggests to characterize the system as *resonance matter* [19].

3. HADRON PROPERTIES IN THE HOT AND DENSE NUCLEAR MEDIUM: BREAKING AND RESTORATION OF CHIRAL SYMMETRY

In the previous section an overview has been given of the global properties of compressed hadronic matter produced in relativistic nucleus-nucleus collisions: information on the collective behaviour, the equilibration of the collision zone, the excitation of intrinsic degrees of freedom and the achievable baryon densities and temperatures has been summarized. In the following we will discuss whether in this type of hadronic medium the properties of hadrons may change. This question is related to the breaking and partial restoration of chiral symmetry which has recently attracted much attention, both theoretically and experimentally. In a chirally symmetric world all quarks would be massless. Chiral symmetry holds approximately for u- and d-quarks with current masses of a few MeV but is explicitly broken for s-quarks with current masses of around 150 MeV. Chiral symmetry breaking effects are thus expected in particular for pseudoscalar K-mesons with open strangeness. Model calculations, briefly sketched in the following chapter, predict changes of the kaon mass with increasing baryon density and effects on kaon propagation in the nuclear medium. In addition, there are theoretical predictions for a partial restoration of chiral symmetry with increasing baryon density and temperature which may lead to a dropping of vector meson (ρ, ω, Φ) masses (see section 3.2.).

3.1. Medium effects on Kaons

Starting from effective chiral perturbation theory an in-medium dispersion relation for kaons can be derived ([20–25] and references therein). The total energy is not only given by the K-mass and momentum as for free kaons but there are additional terms due to the

Figure 6. Effective masses of K^+ and K^- mesons in symmetric nuclear matter as a function of the baryon density ρ in units of the normal nuclear matter density ρ_0 . The figure is taken from ref. [21]. The solid curves include Pauli blocking, binding and Fermi motion while the dashed curves show the additional effects of nucleon-nucleon correlations [22].

interaction of kaons with the medium:

$$\omega_K^\pm(p, \rho_b) = \sqrt{m_K^2 + p^2 - \frac{\Sigma_{KN}}{f_K^2} \rho_s + \left(\frac{3\rho_B}{8f_K^2}\right)^2} \pm \frac{3\rho_B}{8f_K^2} = U_s + U_v + \sqrt{m_K^2 + p^2} = \sqrt{m_K^{*2} + p^2} \quad (2)$$

The so-called $KN\Sigma$ -term reflects the explicit chiral symmetry breaking due to the non-zero strange quark mass. The additional terms can be rewritten as a scalar and vector potential or they can be absorbed into effective kaon masses which - due to different signs in the additional terms - behave differently for K^+ and K^- as a function of baryon density (fig.6). While the effective K^+ mass varies only little, a dramatic decrease in the K^- -mass is predicted, dropping to 50-60% of the free K^- -mass at $2.5 \rho_0$, a baryon density reached in central collisions at SIS energies. An experimentally observable consequence would be an enhanced K^- -yield as it would be energetically much easier to produce K^- -mesons in dense hadronic matter (when leaving the collision zone K^- -mesons acquire their free mass from the total energy in the system). In addition, the propagation of kaons in the nuclear medium would be modified. The scalar and vector potentials give rise to an additional force acting on kaons once they are produced and move within the collision zone, leading to a specific flow behaviour. There are thus two theoretical predictions which can be tested experimentally. First evidence for this scenario has indeed been provided in recent experiments [26,27] with the KaoS spectrometer and the FOPI detector at GSI.

3.1.1. Tentative evidence for medium effects in subthreshold kaon production

Kaon and antikaon production in heavy-ion reactions has been studied by the KaoS collaboration [26]. Fig. 7a shows a comparison of K^+ and K^- spectra taken in Ni + Ni collisions at 1.0 and 1.8 AGeV, respectively. The incident energies have been chosen to obtain the same available energy below the production threshold in free nucleon-nucleon reactions. At these equivalent energies the production cross sections for K^+ and K^- mesons are roughly the same. This is surprising as for the same available energy in free proton-proton collisions (see fig.7b) the K^- -production cross sections is lower by more than an order of magnitude compared to K^+ -production over a wide energy range, established in recent measurements at COSY [28]. In the heavy-ion reaction one would expect the K^- -yield to be even further reduced because of strong K^- absorption in nuclear matter, while the mean free path for K^+ mesons is comparable to the dimensions of a nucleus.

Figure 7. Cross sections for K^+ - and K^- - production in (left) Ni-Ni and (right) p-p reactions. The incident energies for the nucleus-nucleus reactions correspond to the same energy below the nucleon-nucleon production threshold. The figure is taken from [26].

Consequently, the observation of equal cross sections for K^+ and K^- mesons at equivalent energies rather implies a strong K^- enhancement in nucleus-nucleus reactions, which may be first evidence for a possible lowering of the K^- mass in the medium. Transport model calculations [29] which take all secondary K-producing reactions into account and assume a lowering of the K^- mass as in fig.6 find good agreement with the nucleus-nucleus data.

3.1.2. Tentative evidence for medium effects in kaon propagation

Recent theoretical work [30] has suggested that in-plane flow of strange particles may provide additional information on the in-medium properties of these particles. The FOPI-collaboration [27] has studied the in-plane flow of Λ 's and kaons in comparison to the well known sideward flow of protons. Despite of associated production at the same point in space and time Λ 's and K^+ mesons exhibit a completely different flow behaviour. As shown in fig.8 Λ 's flow with the protons while K^+ mesons show almost no flow at all. Theoretically this can be accounted for by assuming nonvanishing scalar and vector potentials acting on the kaons. Any deviation of kaon flow from that of the baryons is a measure for the repulsiveness of the kaon potential. Model predictions for the kaon potential in the nuclear medium can be further tested by studying the variation of the kaon flow with the kaon momentum and the centrality of the nucleus-nucleus-reaction. Furthermore, as the signs of the potentials are different for K^+ and K^- mesons, differences in the flow behaviour of kaons and antikaons are anticipated. Corresponding experimental investigations require an improvement of the momentum acceptance and particle identification capability of the FOPI detector; an upgrade with a high resolution time-of-flight barrel is under consideration.

In summary, recent calculations provide an almost quantitative reproduction of both initially surprising, experimental observations, the enhanced K^- -yield and the almost vanishing flow of K^+ mesons. Crucial model tests will be possible as soon as improved experimental data will become available in the near future.

Figure 8. Directed sideward flow for protons, Lambdas and Kaons: the average transverse momentum projected onto the reaction plane is plotted as a function of the normalized rapidity [27]. $Y^{(0)} = -1, 0, 1$ refers to target-, mid-, and projectile rapidity, respectively.

3.2. Medium effects for vector mesons

Vector meson (ρ, ω, Φ) masses in the medium may be affected by a possible restoration of chiral symmetry at high-densities and temperatures. In the chiral limit all quark masses would be zero and - being massless - quarks would maintain their helicity and chirality in all interactions with gluons. The order parameter for the transition from the real world

Figure 9. The chiral condensate calculated within the Nambu Jona-Lasinio model as a function of temperature and baryon density [31].

where the chiral symmetry is broken to a chirally symmetric scenario is the so-called chiral condensate $\langle q\bar{q} \rangle$. This quantity has been calculated within the Nambu Jona-Lasinio model and is shown in fig.9 as a function of temperature and baryon density [31].

It is still a matter of debate whether the predicted and undisputed decrease of the chiral condensate implies a corresponding drop in vector meson masses. This scenario can, however, be tested experimentally since temperatures and baryon densities can be achieved in heavy-ion reactions at SIS and SPS energies for which a dramatic decrease in $\langle q\bar{q} \rangle$ is expected (see fig.9). The best way to measure the in-medium mass of a vector

Figure 10. e^+e^- invariant mass spectra measured by the DLS collaboration [35] in inclusive heavy-ion reactions (left) at 1 AGeV [35] and in p+p collisions (right) [41]. For comparison e^+e^- pairs from π^0 - and η - Dalitz decays derived from measured meson yields and production systematics are indicated [43–45]. The figure has been prepared by R. Holzmann and is taken from [46].

meson is to detect its e^+e^- or $\mu^+\mu^-$ decay branch since leptons can leave the compressed interaction zone undistorted. The mass of the vector meson can thus be reconstructed from the 4-momentum vectors of the two leptons. The vector meson produced in the nucleus-nucleus collision has, however, to be sufficiently short-lived to decay within the high-density phase ($\Delta t \leq 10 fm/c$) of the reaction before the collision zone expands. From this point of view the ρ meson ($\tau = 1.8 fm/c$) is ideally suited while the corresponding measurement for ω ($\tau = 23 fm/c$) and Φ ($\tau = 45 fm/c$) mesons depends on additional in-medium broadening effects which reduce the decay time.

Corresponding experiments have already been performed at the CERN-SPS and the BEVALAC, studying dilepton emission in central S-Au and Pb-Au collisions at 160 AGeV [32–34] and inclusive Ca+Ca and C+C collisions at 1 AGeV [35]. In both cases, an enhancement of the dilepton yield compared to e^+e^- and $e^+e^-\gamma$ Dalitz decay contributions from known hadronic sources is observed in the invariant mass range above 200 MeV. As an example, the DLS-data [35,41] are shown in fig.10. Different scenarios have been considered for the interpretation of the observed enhancements. One class of transport

model calculations assumes dropping vector meson masses correlated with a decrease of the chiral condensate with temperature and density [25,29]; i.e. the dilepton excess in the mass range from 200-600 MeV is attributed to e^+e^- decays of ρ mesons which are shifted down in mass. An alternative interpretation based on in-medium many body effects which cause a broadening and distortion of the ρ -meson spectral function has also been suggested [38-40]. While both scenarios provide an almost quantitative description of the CERES data [32,33], none of them can reproduce the dilepton enhancement reported by the DLS collaboration [35,41,42].

This intriguing situation calls for more efforts theoretically and experimentally. At GSI this line of research will be taken up with the High Acceptance Di-Electron Spectrometer (HADES), which features a lepton pair acceptance of 20-40%, a mass resolution of 1% and a high countrate capability (10^6 interactions/s). The detector system is presently being installed by a European collaboration and first commissioning experiments are planned for 1998/99.

Using the π -beam at GSI [47], which will become available in 1998, HADES will also allow the measurement of the ω -mass at normal nuclear matter density [48,49] where - according to fig.9 - a shift in mass by 10-20% might be expected. The kinematics of the $\pi^-p \rightarrow n\omega$ reaction on a bound proton allows for almost recoilless ω -production in nuclei. The interpretation of this measurement can be based on much more solid theoretical ground as it does not rely on extrapolations to higher energies and temperatures.

4. CONCLUSIONS

Although heavy-ion reactions in the 1 AGeV energy range have intensively been studied for almost 25 years, new and unexpected results have recently been obtained. Following the global characterization of hadronic matter in the collision zone by studying the emission patterns of nucleons and nuclear fragments and by systematic investigations of meson production, first indications for in-medium effects of pseudoscalar and vector mesons have been observed. Enhanced K^- -production, kaon flow and enhanced dilepton yields are the signatures which will have to be studied further experimentally and theoretically to fully establish details of these medium modifications. In this effort, essential contributions are expected from the research program of the HADES and FOPI detectors at GSI.

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REFERENCES

1. S.A. Bass et al., Phys. Lett. B335 (1994) 289 and private communication
2. H.A. Gustafsson et al., Phys. Rev. Lett. 52 (1984) 1590
3. W. Reisdorf and H.G. Ritter, Ann. Rev. Nucl. Part. Sci. 47 (1997)
4. J.Y. Ollitrault, this conference

5. S.C. Jeong et al., Phys. Rev. Lett. 72 (1994) 3468
6. W. Reisdorf et al., Nucl. Phys. A 612 (1997) 493
7. M.A. Lisa et al., Phys. Rev. Lett. 75 (1995) 2662
8. J. Stachel, Nucl. Phys. A610 (1996) 509c
9. P. Braun-Munzinger et al., Phys. Lett. B 344 (1995) 43, Phys. Lett. B365 (1996) 1
10. I.G. Bearden et al., Phys. Rev. Lett. 78 (1997) 2080
11. NA49 - collaboration, to be published, and R. Stock, Nucl. Phys. A 630 (1998)
12. Y. Leifels, private communication
13. V. Metag, Prog. Part. Nucl. Phys. 30 (1993) 75
14. N. Herrmann, Nucl. Phys. A610 (1996) 49
15. R. Auerbeck et al., to be published, and private communication
16. B. Hong et al., Phys. Lett. B 407 (1997) 115
17. U. Heinz, summary talk at this conference
18. S. Teis et al., Z. Phys. A356 (1997) 421
19. U. Mosel and V. Metag, Nucl. Phys. News 4 (1993) 25
20. A.E. Nelson and D. Kaplan, Phys. Lett. B192 (1987) 193
21. W. Weise, Nucl. Phys. A610 (1996) 35c
22. T. Waas et al., Phys. Lett. B379 (1996) 34 and Nucl. Phys. A617 (1997) 449
23. J. Schaffner-Bielich et al. Nucl. Phys. A 625 (1997) 325
24. G.Q. Li et al., Phys. Rev. Lett. 79 (1997) 5214
25. C.M. Ko and G.Q. Li, J. Phys. G.: Nucl. Part. Phys. 22 (1996) 1673
26. R. Barth et al., Phys. Rev. Lett. 79 (1997)
27. J.L. Ritman et al., Z. Phys. A352 (1995) 355
28. J. T. Balewski et al. Phys. Lett. B 338 (1996) 859 and Phys. Lett. B , in press
29. W. Cassing et al., Nucl. Phys. A614 (1997) 415
30. G.Q. Li et al., Phys. Lett. B329 (1994) 149
31. S. Klimt et al., Phys. Lett. B249 (1990) 386
32. G. Agakichiev et al., Phys. Rev. Lett. 75 (1995) 7
33. I. Ravinovich et al., this conference
34. C. Lourenco , Nucl. Phys. A610 (1996) 552c and A. De Falco et al., this conference
35. R. Porter et al., Phys. Rev. Lett. 79 (1997) 1229, and this conference
36. G.Q. Li et al., Phys. Rev. Lett. 75 (1995) 4007
37. W. Cassing et al. Phys. Lett. B363 (1995) 35
38. B. Friman and H.J. Pirner, Nucl. Phys. A617 (1997) 496
39. R. Rapp et al., Nucl. Phys. A617 (1997) 472 and J. Wambach, this conference
40. W. Peters et al., Nucl. Phys. A, in press (nucl-th/ 9711004)
41. W.K. Wilson et al., Phys. Rev. C57 (1998)
42. W. Cassing et al., Nucl. Phys. A619 (1997) 413
43. R. Auerbeck et al., Z. Phys. A358 (1997)
44. F.D. Berg et al., Phys. Rev. Lett. 72 (1994) 977
45. E. Chiavassa et al., Z. Phys. A 342 (1992) 107 and Nuovo Cimento A 107 (1994) 1195
46. R. Holzmann et al., Phys. Rev. C 56 (1997) R2920
47. V. Metag, π -N Newsletter 11 (1995) 159
48. W. Schön et al., Acta Phys. Polonica B27 (1996) 2959
49. Ye.S. Golubeva et al., Nucl. Phys. A625 (1997) 832