What is the Role of Higher Baryonic Resonances in AA Collisions at AGS energies?

Yasushi NARA*, Naohiko OTUKA *,** Akira OHNISHI **
and Tomoyuki MARUYAMA*

* *Advanced Science Research Center, Japan Atomic Energy Research Institute, Tokai, Naka, Ibaraki 319-11, Japan*
** *Division of Physics, Graduate School of Science, Hokkaido University, Sapporo 060, Japan*

(Received August 31, 1997)

Thermal evolution of hadronic resonance matter in ultrarelativistic nucleus-nucleus collisions is studied in the framework of cascade models. We investigate the role of higher baryonic resonances during the time evolution in (ρ, T) diagram of hot and dense hadronic matter at AGS energies. Although final hadronic spectra do not strongly depend on the number of higher resonances included in the calculation, it is shown that they prevent the temperature from going beyond 200 MeV.

§1. Introduction

Exploration of various phases of hadronic matter is one of the main goals of heavy-ion physics. At AGS energies(10-15AGeV), the hot and dense hadronic resonance matter is of primary interest. In recent years, it has become experimentally clear that the nuclear stopping power in the collision of heavy systems such as gold on gold collision is large enough to create a form of baryon rich hadronic matter at this energy region.1) Transport model calculations such as RQMD,2) ARC,3) QGSM,4) ART,5) which reproduce the experimental particle spectrum, suggest that the baryon density reaches about 6-10 ρ_0.

The expected number density of hadrons are so high that hadrons collide with each other frequently, and various baryon and meson resonances will be created abundantly. Then, if the formation rate of hadron resonances balances their decay, they are expected to modify the thermal evolution of the hadronic matter from a simple picture of nucleon and pion gas. It is valuable to note that incorporating all the hadron resonances is not trivially good to describe heavy-ion collisions and/or statistical properties of hadronic matter; if all the resonances are included with exponentially increasing level densities with mass, there appears a limiting temperature over which hadronic matter cannot be heated.6) On the other hand, the treatment based only on the ground state hadrons (octed mesons and baryons) is not enough in a classical treatment. For example, Venugopalan and Prakash have shown that the thermal properties of interacting pion gas, including the distortion of pion wave function, can be simulated by free resonance gas below the temperature around pion mass.7) In a classical treatment, however, this distortion effects are usually neglected, then explicit treatment of resonances becomes necessary. In this paper, we study the time evolution during heavy-ion collisions at AGS energy based on the hadronic cascade approach, and elucidate the roles of higher baryon resonances on the thermal evolution of hot and dense hadronic matter.

The basic idea of the cascade models is to understand the complex processes of heavy-ion collisions from a incoherent superposition of two-body elementary collisions. Thus it is essential to use good inputs, *i.e.* cross sections which well describe the elementary processes such as *pp* collision. In this paper, we compare the following two models which are different in the number of hadronic degrees of freedom (DOF). Model-A is mainly based on the isobar model⁹⁾ and string model⁸⁾,¹⁰⁾ in a similar way to RQMD.²⁾ We have included all the observed baryon resonances up to 2 GeV and strings in Model-A, which assumes that particle production occurs through hadron resonances and strings. In Model-B, three kind of baryon resonances (Δ, $N^*(1440)$ and $N^*(1535)$) are treated in a similar way to Model-A, and other particle productions are described in a direct production scheme. The basic idea for this model is the same as that of ART.⁵⁾ These two models reproduce elementary reactions equally well. However, in heavy-ion collisions, we expect some difference between them, since the available numbers of degrees of freedom are different.

§2. Hadron spectra and thermal evolutions

In Fig. 1, we show calculated results of rapidity and transverse mass distributions of protons and pions with experimental data¹¹⁾,.¹²⁾ Both of the two models reproduce the single hadron spectrum data equally well. For example, they describe the formation of baryon rich hadronic matter as can be seen in the rapidity distributions, and the calculated transverse slope parameters of pions are almost the same as the experimental data. These results are consistent with previous works,²⁾,³⁾,⁵⁾ and it seems that the statistical property or the DOF does not affect the final single hadron spectra.

Let us turn now to the comparison of the thermodynamical evolution of hot and dense hadronic matter. We define the temperature by the ratio of the pressure to the number density in the local rest frame, assuming that the local thermal equilibrium is always achieved for transverse motion. Here the pressure is defined by the two transverse diagonal component of the hadronic energy-momentum tensor. Theses quantities are extracted from the cascade simulation by using Gaussian smeared test particle method in a covariant way.¹³⁾ From the simulation calculation, we find that the energy density in Model-A during the time evolution is approximately the same as that in Model-B, while the temperature of Model-A is much lower than Model-B. This may be explained as follows: In Model-A, since the energy is stored in the hadron mass through the resonance formation, each hadron moves relatively slowly and the pressure becomes smaller. On the other hand, colliding energy is directly converted to the kinetic energies of hadrons in Model-B, and these kinetic energies increase the pressure and the temperature rapidly.

From this analysis, it is suggested that the thermal evolution of the system depends on the DOF, although the final single hadron spectra are not largely affected. This insensitivity may be related to the flow. It is well known that the hydrodynamical model can reproduce the single hadron spectra with various initial conditions of

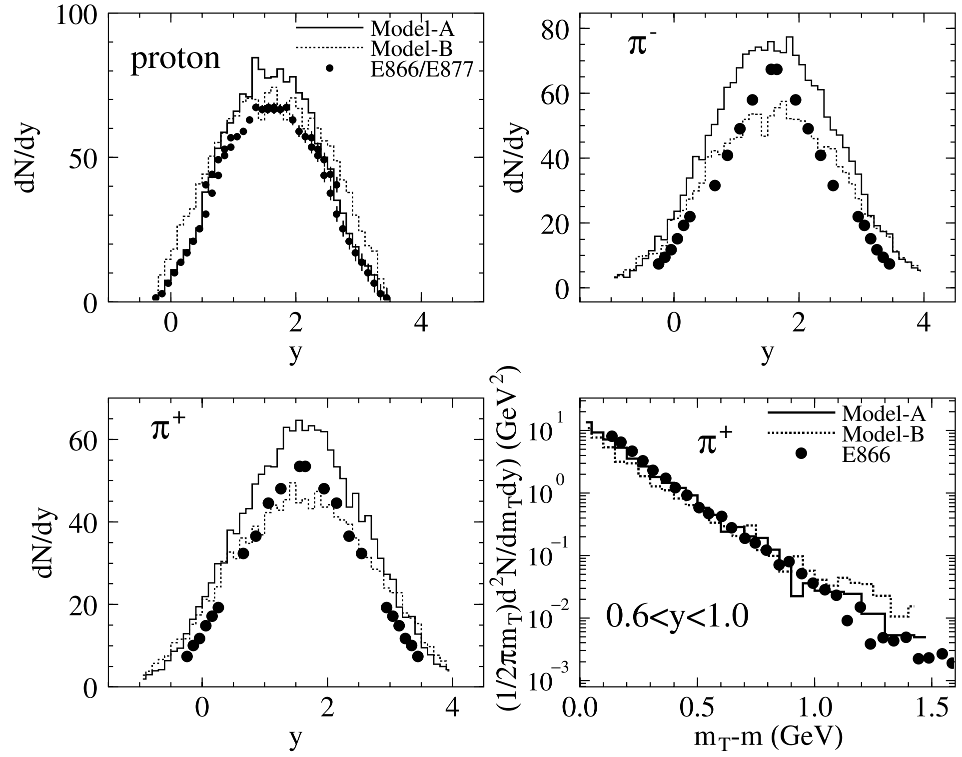

Fig. 1. Comparison of calculated rapidity and transverse mass spectra with the experimental data of E866 and E877 in Au+Au collision at P_{lab} = 11.6GeV/c. Solid and dotted histogram show the calculated results with Model-A and Model-B, respectively.

the temperature and flow; the combination of high T and small flow or small T and large flow leads to very similar final distributions. Since the flow is sensitive also to the Equation of State (EoS), we study the dependence of EoS in the next section.

§3. Flow

The strength of transverse flow is known to be very sensitive to the EoS of hadronic matter. Maximum resonance to nucleon ratio for Au+Au collision at impact parameter b= 4 fm is calculated to be about 40% at 10GeV/A incident energy. Therefore, the effect of resonance potential may strongly affect the strength of transverse flow. We study this effect by changing the resonance potentials. Fig. 3 shows the directed transverse flow calculated by BUU. The effect of EoS as well as resonance potential on the strength of the transverse flow can be seen, where Soft EoS1 corresponds to the result of calculation employing the resonance potential depth -30MeV at saturation density ρ_0, while in the case of Soft EoS2, all resonance potential is switched off.

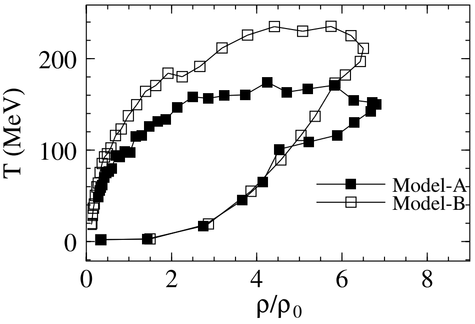

Fig. 2. Time evolution of baryon density and effective temperature in Au+Au 11.6*A*GeV/*c* from 0 fm/*c* to 25 fm/*c* by 0.5 fm/*c* step. The solid line is for Model-A and the dashed line is for Model-B.

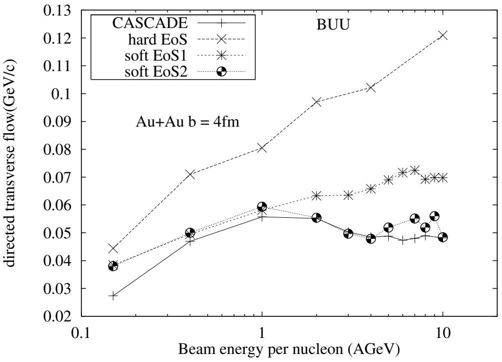

Fig. 3. Incident energy dependence of the directed transverse flow in Au+Au, b=4fm.

§4. Summary

Au+Au collisions at AGS energy have been analyzed with the two types of hadronic cascade models which are modeled either including higher baryonic resonances and strings or three baryonic resonances and direct particle productions. Both models give similar results for the proton and pion rapidity/transverse distributions in Au+Au collision. We have made a comparison with both models concerning to some macroscopic quantities, i.e. baryon density, energy density and "temperature" with Gauss smeared test particle method. Although energy density is almost the same in both models, Temperature in Model-A is lower than Model-B as predicted by the statistical model consideration. Finally, by solving BUU equation, it has been shown that the effect of resonance potential on the transverse flow is rather large.

References

1) Quark Matter 95, Nucl. Phys. **A590**, (1995); Quark Matter 96, Nucl. Phys. **A610**, (1996).
2) H. Sorge, H. Stöcker, and W. Greiner, Ann. Phys. (N. Y.) **192** (1989), 266; H. Sorge *et al.*, Phys. Lett. **B243** (1990), 7.
3) Y. Pang, T.J. Schlagel, and S.H. Kahana, Phys. Rev. Lett. **68** (1992), 2743; T.J. Schlagel, Y. Pang, , and S.H. Kahana, BNL-4840 October (1992); S.H. Kahana, Y. Pang, , and T.J. Schlagel, BNL-48888 February (1993).
4) L. Bravina *et al.*, Phys. Rev. **C 51**, (1994), 21161.
5) B.A. Li and C.M. Ko, Phys. Rev. **C52** (1995), 2037.
6) R. Hagedorn and J. Ranft, Nuovo Cim. Suppl. **6** (1968), 169.
7) R. Venugopalan and M. Prakash, Nucl.Phys. **A546** (1992), 718.
8) B. Andersson, G. Gustafson, and B. Nilsson-Almquist, Nucl. Phys. **B281** (1987), 289.
9) R.M. Sternheimer and S.J. Lindenbaum, Phys. Rev. **123** (1961), 333.
10) B. Nilsson-Almquist and E. Stenlund, Computer Phys. Comm. **43** (1987), 387.

11) F.Videbaek et al. (E866 Collaboration), Nucl. Phys. **A590** (1995), 249c.
12) R.Lacasse et al. (E877 Collaboration), nucl-ex/9609001 (1996).
13) C. Fuchs and H. H. Wolter, Nucl. Phys. **A589** (1995), 732.