Two particle correlations at RHIC
(RHIC エネルギーでの粒子相関)

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Abstract

High-energy heavy-ion collisions at AGS, SPS, and RHIC energies are studied by using a hadronic cascade model, JAM. We can well explain the hadronic yields at AGS and SPS energies. At RHIC, while low p_T observables are reasonably explained, we underestimate the yield and elliptic flow at high p_T and we cannot descibe the HBT radius behavior, R_{out}/R_{side}.

1 Hadronic Cascade Study of Heavy-Ion Collisions

In high-energy heavy-ion collisions, huge number of particles are created soon after the first contact of nuclei, and their interaction leads to formation of hot and dense matter. The prime aim of heavy-ion collision study is to elucidate the properties of this hot and dense matter. Since heavy-ion collisions are quite dynamical, it is not straight forward to pin down the "static" properties of matter formed during heavy-ion collisions. Hadronic cascade models describe the dynamics of heavy-ion collisions based on the elementary cross sections (and optionally on mean field for hadrons) without the assumption of equilibrium, and they have been successfully applied to heavy-ion collisions at lower energies than RHIC [1, 2]. Thus it is valuable to examine how hadronic cascade models work at RHIC, where QGP formation is strongly expected.

A hadronic cascade model, JAM, developed by Nara et al. [1], is one of the successful models, which well explains hadron p_T spectra at AGS and SPS energies. The picture of "pure" hadronic cascade is not enough already at SPS. For example, string interactions within the hadron formation time is known to be important for the description of stopping power at SPS. While strings are not pure hadrons, they do not directly form QGP because strings do not have colors. Thus we can regard strings as spatially extended hadrons. In JAM, string interactions with other hadrons are included within the formation time. The cross section within the formation time is reduced by a factor $\sim 2/3(1/2)$ for baryonic (mesonic) strings, based on an additive quark model picture for the quarks which belong to the initial state hadrons. At RHIC, partons play explicit roles in particle production through jet production and fragmentation, which are included in JAM by using the PYTHIA. The observation of jet production itself, which exists in the elementary processes, does not prove the formation of QGP, but the modification of the jet properties may reveal the state of hot and dense matter.

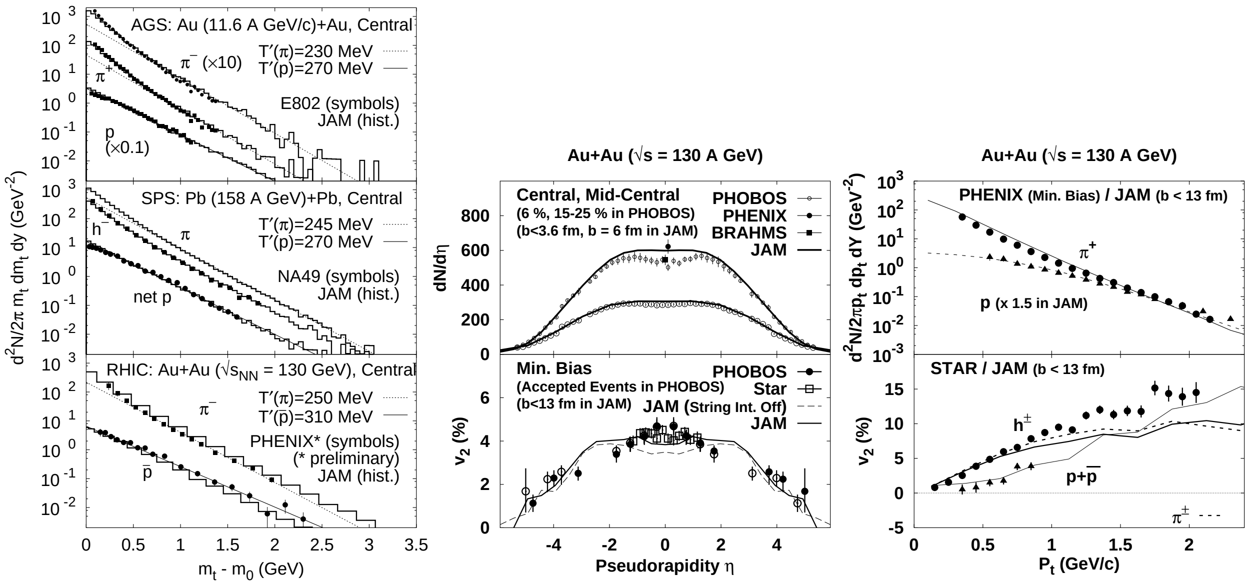

Figure 1: Results of hadronic cascade model JAM. Left: Hadron m_T spectra at AGS, SPS and RHIC energies. Middle: Pseudorapidity distribution (top) and elliptic flow (bottom) as a function of the pseudorapidity at RHIC. Right: p_T spectra (top) and p_T dependence of the elliptic flow (bottom) at RHIC.

In Fig. 1, we show several results of hadronic inclusive spectra and elliptic flows at AGS, SPS and RHIC energy heavy-ion collisions [3]. We find that the p_T spectra at AGS and SPS energies are well reproduced, At RHIC, while we can explain the data at low p_T, we underestimate the yield and the elliptic flow at high p_T. These findings are consistent with the formation of strongly interacting partonic state of matter in the early state of heavy-ion collisions at RHIC. In the present model, we include the secondary string and hadronic interactions, but partonic interactions are limited only in the initial jet production; partons from different hadron-hadron collisions do not interact before hadrons are formed. Thus we expect higher pressure in the early stage when partonic secondary interaction is taken into account.

In order to illustrate that the elliptic flow at high p_T is sensitive to the interactions in the early stage, we show the spatial eccentricity in the earlier stage in Fig. 2. Spatial eccentricity ε gives the driving force of the anisotropy in the momentum space, i.e., the elliptic flow v_2. In the early stage ($t < 3$ fm/c), ε is large enough, but the interaction is not strong enough to increase the elliptic flow effectively in the hadronic cascade model. High p_T particles leave the interaction region quickly, then spatial eccentricity goes down in the later stage. On the other hand, ε is large enough for slow particles even in the later stage, then we can explain the strength of v_2 in a hadronic picture at low p_T.

Results presented here imply that low p_T observables would be governed by later hadron dynamics. For high p_T, although the importance of partonic interactions is suggested, it would be necessary to examine the elementary cross sections and the multiple scattering scheme in the cascade processes before concluding the role of partonic interactions. In a present treatment, jet production is active only in the first NN collisions practically: All the hadron-hadron collisions are assumed to be independent, then once two nucleons are judged to collide with each other, these two nucleons do not see other hadrons before hadron formation except for

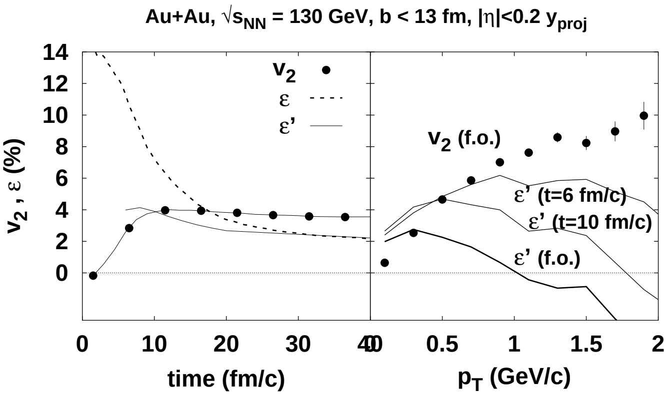

Figure 2: Left: Time dependence of v_2 and ε. Right: Time dependence of v_2 and ε as a function of p_T.

soft string interactions. This prescription gives a common attenuation factor to the initial flux independent on the momentum transfer, which contradicts to the observation of mass number scaling of hard processes such as Drell-Yang, and leads to the underestimate of high p_T particles rather than overestimate, for example in the HIJING model [4]. We are now trying to solve this problem, which is reported by Isse.

2 Two-particle correlations at RHIC energy

In the previous section, we have demonstrated that several low p_T observables are well explained in hadronic cascade models even at RHIC energy. Now we would like to address the HBT puzzle at RHIC. When the lifetime of the source is not negligible, two-particle momentum correlations in the "out" direction are believed to dissappear at lower relative momentum than in the "side" direction. In terms of the source size, the "out" radius should be larger than the "side" radius, because the former contains the lifetime contribution. However, the measured out radius is generally smaller than the side radius at RHIC, especially at high p_T region, $p_T \sim 500$ MeV/c. This problem is now referred to as the HBT puzzle, and it is one of the biggest question at low p_T. Since the hadronic cascade model is successful in the momentum range of interest $p_T < 600$ MeV/c, it would be valuable to compare the calculated results with the data.

Two particle momentum correlation function is defined as

$$\boldsymbol{C(p,q) \equiv \frac{P(p_1,p_2)}{P(p_1)P((p)_2)}\ ,\quad p_1 = p + q/2\ ,\quad p_2 = p - q/2\ .}$$

Because of the symmetrization of boson wave functions, two particle detecting probability $P(p_1,p_2)$ is enhanced by a factor of $1+\cos q(x_1-x_2)$, leading to the enhancement of $C(p,q)$ at low q.

In Fig. 3, we show the calculated HBT radii in comparison with the STAR data [7]. When we adopt the particle time $t=(t_1+t_2)/2$ as in Ref. [5], HBT radius data are roughly reproduced at very low p_T, but we cannot explain the behavior of radii in the high p_T region (Left panel). Next we propagate the particle freezed-out first until the later time in the two particle CM system, $t=t_>^{CM}$ in a similar way to Ref. [6], then the description of R_{side} and R_{long} become better (Right). However we overestimate R_{out} in both of the cases.

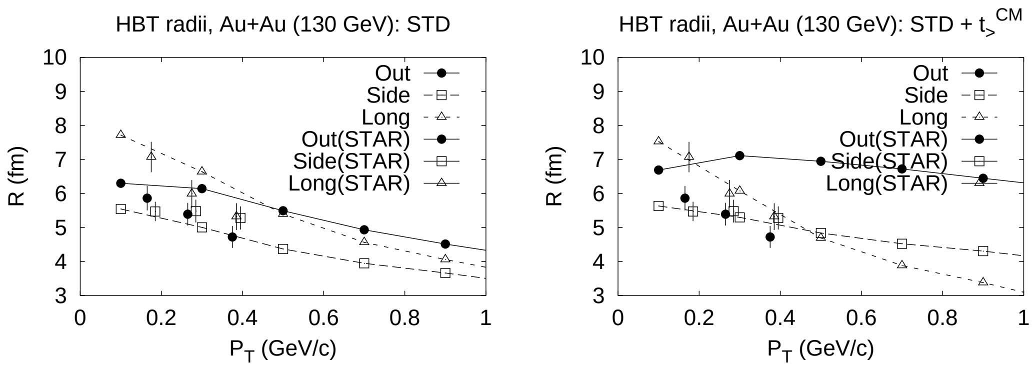

Figure 3: Left: Time dependence of v_2 and ε. Right: Time dependence of v_2 and ε as a function of p_T.

3 Summary

In this report, we have demonstrated that hadronic cascade models which explain the data at AGS and SPS energies would work also at RHIC for low p_T ($p_T < 0.5$ GeV/c) observables such as the hadron yield and the elliptic flow. However, it seems that we underestimate the pressure in the early stage at RHIC, as seen in the underestimate of hadron yield and elliptic flow at high p_T.

For HBT radii, we cannot solve the puzzle in a straightforward manner. By selecting the particle time at which the correlation is created, side and longitudinal radii can be explained, but we cannot reproduce the behavior $R_{out}/R_{side} < 1$ at $p_T > 0.2$ GeV/c.

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