Chemical Equilibration of Conserved Charges

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ABSTRACT

In a recent development the author along with his collaborators have developed a novel scheme to describe the chemical composition of hadronic yields observed in various experiments on high energy collisions of heavy-ions. The method not only makes an excellent estimate of the so-called freeze-out parameters but gives completely independent predictions of the chemical composition.

INTRODUCTION

Exploration of the phase diagram of matter interacting via the strong force has received considerable attention. Such matter in the form of quarks and gluons with very high temperatures is supposed to have existed in the early universe. Hadronic matter is supposed to exist inside theneutron stars. Their cores are also speculated to contain quark matter at small temperatures. In order to recreate such phases of matter, heavy-ion collisions are performed in the laboratories with very high energies. Among the primary remnants of such reactions are hadrons of various species. The chemical composition of these hadrons is expected to give valuable information about the phases through which the reactions took place.

Up until now chi-squared analyses of the hadron yields or their ratios have been performed with various versions of hadron gas models, the simplest of these being the ideal hadron resonance gas (HRG).

Recently it was proposed [1] that a better observable to analyze the experimental data would be the ratios of the various charges and anti-charges that are conserved in strong interactions.

METHOD

The number density of the various hadron species is taken in the simplest approximation to be that of the ideal gas of bosons or fermions, depending on the hadron species. The masses are taken to be the vacuum masses as tabulated by the Particle Data Group. This number density generally depends on temperature and the chemical potentials for the conserved charges, namely, baryon number, electric charge and strangeness. These parameters are the unknowns that are to be extracted by assuming that the number densities are proportional to the observed hadron yields. A common practice is to use hadron yield ratios to reduce the uncertainties of the proportionality factor. There are quite a few hadrons detected in each experiment at a given collision energy. For the four thermodynamic parameters one therefore needs four independent ratios. A common observation has been that the choice of such ratios influences the parametrization and hence may widely over-predict or under-predict the hadron ratios not used in the analyses. Therefore a chi-square analysis is performed to contain as much information of the experimental data as possible.

On the other hand we constructed the conserved charge numbers from the hadron yields and also the corresponding HRG densities, then determined their ratios and equated them. We found that the extraction of the thermodynamic parameters is much more reliable in this case if we vary the charge ratios concerned. The added advantage is that now each and every individual hadron yield ratio is predicted, because these were never considered in the fitting procedure.

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RESULTS

We have used the experimental data from AGS, SPS, RHIC, and LHC for our analysis. STAR BES data has also been used. For the HRG spectrum we have used hadrons up to 2 GeV mass that have known degrees of freedom. The details can be found in [1].

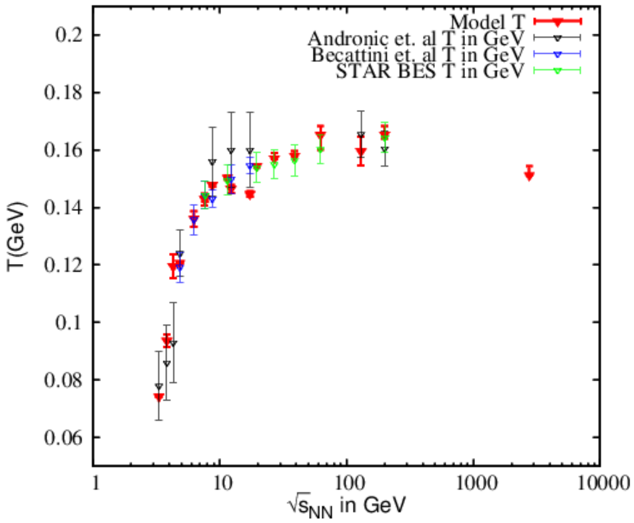

Fig.1: Variation of freeze-out temperature with center of mass energy.

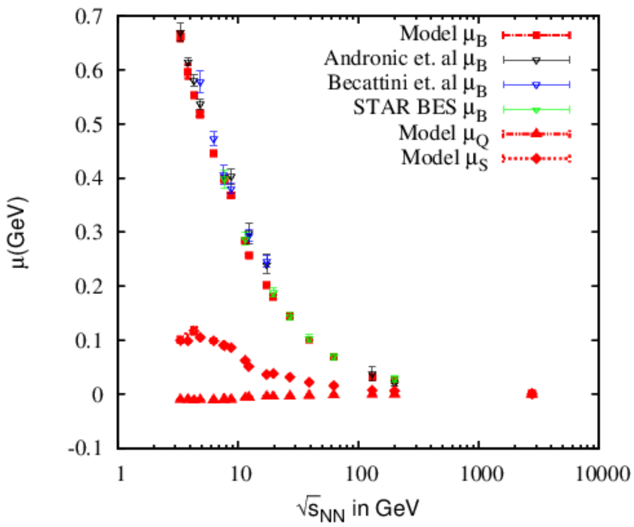

Fig.2: Variation of chemical potential with center of mass energy.

The freeze-out temperature and chemical potentials are shown in Fig. 1 and Fig. 2 respectively. We have also shown for comparison other estimates available from the literature: Andronic et.al. [2], Becattini et.al. [3] and STAR BES [4]. Even though there are differences in the various model assumptions they all seem to be in general agreement.

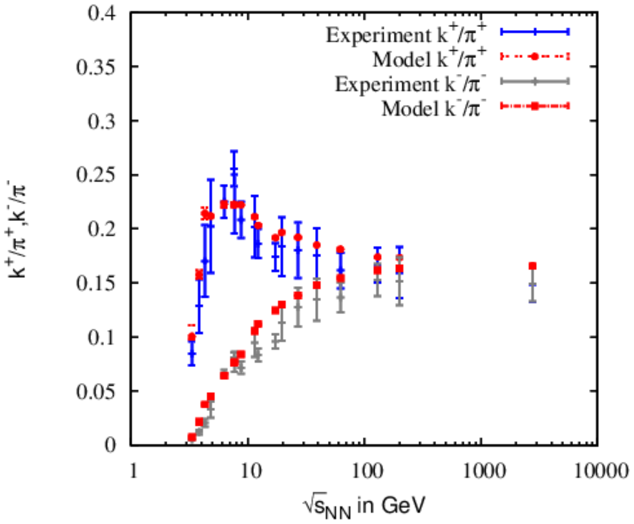

Fig.3: Variation of kaon to pion ratio with center of mass energy.

The significance of our method can be seen from the prediction of the individual hadron ratios. One important ratio is that of kaons to pions as shown in Fig. 3. We note that, although the underlying mechanism of the observation of a peak in the positive kaon to positive pion ratio is not predicted by the HRG model, the agreement with the experimental data is quite satisfactory. Also we reiterate that these individual ratios were not used in our analysis.

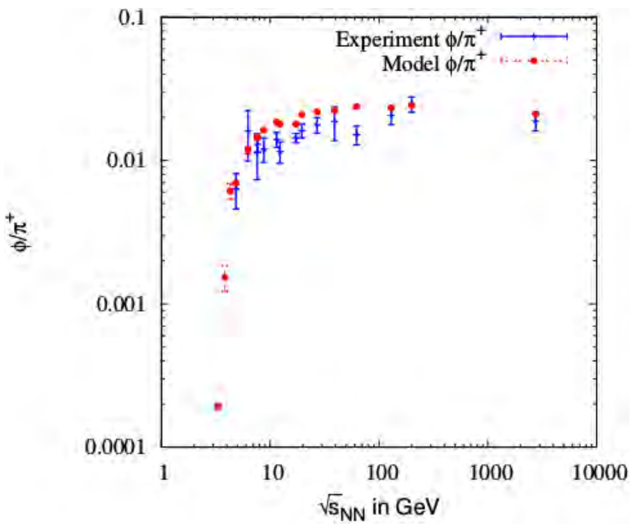

Fig.4: Variation of phi to pion ratio with center of mass energy.

We further show the phi and pion ratio in Fig. 4. The phi particle was itself never used in our analysis. Yet our model predictions match nicely with the experimental data.

SUMMARY

We have discussed a novel analysis technique for the hadron yield data reported by us in [1]. The technique was built with the charges completely conserved under strong interactions. The resulting reduction in uncertainties due to the specific choice of individual hadron ratios as observed in traditional analysis is significant. At the same time the agreement of various predicted hadron ratios, some of which also contained hadrons never used in the analysis, seems to be a strong indicator of chemical equilibration of conserved charges in heavy-ion collision experiments.

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