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Y. Pang, T.J. Schlagel and S.H. Kahana

Physics Department
Brookhaven National Laboratory
Upton, New York 11973

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ARC - A Relativistic Cascade

Y. Pang, T. J. Schlagel and S. H. Kahana

Department of Physics, Brookhaven National Laboratory, Upton, NY 11973, USA

Abstract

A general purpose relativistic cascade code ARC has been developed to study ion-ion collisions. As a first application of ARC we study Si+Au collisions at 14.6 GeV/c using two hadronic models which use the same two-body data as input, but with different assumptions about the way particles are produced. Comparison with data from experiment E802 suggests the importance of baryonic resonances in nucleus-nucleus collisions at BNL-AGS energies.

1. INTRODUCTION

Relativistic ion-ion collision experiments at the BNL-AGS are performed with the hope of creating transient states of hot nuclear matter at high baryon density. Current experiments involve proton or light nucleus projectiles on various targets [1-3], but soon true heavy ion collisions will be possible. Although data from these experiments can be simulated qualitatively by RQMD [4], several key features of the data require further study, among them the inverse slopes of the transverse mass distribution of protons, the rapidity distribution of protons and pions, and the K^+/π^+ ratio.

In experiments at AGS energies, the binding energy of the nucleus is small compared to the center of mass energy of the first collision ($\sqrt{s} = 5.4$ GeV). But the average pion multiplicity for the first nucleon-nucleon collisions (~ 3) suggest the energy may not be high enough for hadronic string models to be a good approximation [5]. Can a "pure" hadronic picture describe the AGS data?

To answer this question, two hadronic models were studied using a relativistic cascade (ARC) recently developed at BNL [6]. The first is the *direct production model*, in which nucleons and pions are the degrees of freedom. The second is the *resonance model*, which allows the production, decay and rescattering of baryon resonances throughout the cascade. Both models reproduce qualitative features of the AGS data. A detailed comparison with E802 data [7] clearly favors the resonance model over the direct production model.

2. DIRECT PRODUCTION MODEL

In the direct production model we consider only nucleons and pions. There are three types of hadron-hadron collisions:

$$\begin{aligned} NN &\rightarrow NN + \pi's \\ N\pi &\rightarrow N + \pi's \\ \pi\pi &\rightarrow \pi's \end{aligned} \tag{1}$$

where N stands for either a proton or a neutron. The CERN-HERA compilation [8] has extensive listings of cross sections for the first two types of collisions, including the energy dependence and many of the production channels. $\pi\pi$ collisions can be obtained by studying $\pi N \rightarrow \pi\pi N$ [9]. The momentum distribution of the secondaries are chosen through Monte-Carlo sampling of the Lorentz invariant phase space, with two additional weight factors: limited transverse momentum and leading particle behavior. The initial phase space distribution for the nuclei are Wood-Saxon distributions in space, and a Fermi distribution in momentum. The inclusion of kaons does not effect the gross behavior of protons and pions.

The rapidity distribution dN/dy for p , π^+ , K^+ , and K^- are shown in Figure 1 for Si + Au at 14.6 GeV/c and an impact parameter ≤ 3 fm. Comparison with E802 data are shown in Figure 2a, using the experimental acceptance [10]. In each rapidity bin, the transverse mass spectra dN/dm_T^2 are fit to an exponential in m_T . The exponential is then integrated over all m_T to give the extrapolated rapidity distribution $(dN/dy)_{\text{ext}}$. For protons, $(dN/dy)_{\text{ext}}$ is close to dN/dy , while for pions $(dN/dy)_{\text{ext}}$ is always lower than dN/dy , with the amount depending on the rapidity bin.

The direct production model reproduces most of the qualitative features of the experimental data, but fails on all quantitative comparisons. We tried different ways to implement the concept of formation time τ for the secondaries. With $\tau \approx 1$ fm/c no significant difference is seen, while an infinite formation time results in fewer π 's and K 's, and at the same time a lower inverse m_T slope for the protons. Therefore, adjustment of the formation time does not improve the direct production model in comparison with E802 data.

3. RESONANCE MODEL

In the resonance model, π 's are mostly produced through the production of one or two baryon resonances in nucleon-nucleon collisions. In this work we used only the lowest mass Δ resonance. For example, in the three- π production channel we use

$$NN \rightarrow \Delta\Delta\pi. \quad (2)$$

Elastic πN scattering proceeds through a Δ resonance. We make the assumption that, except for the difference in mass, Δ interacts the same way as N . Deviations from this assumption will be studied later. Detailed balance gives

$$\Delta N \rightarrow NN, \quad \Delta\Delta \rightarrow \Delta N \quad \text{and} \quad \Delta\Delta \rightarrow NN \quad (3)$$

which provides a mechanism for pion absorption.

The choice of this model is based on the following observation: i) π 's produced in pp collisions at 14.6 GeV/c come from about 2/3 resonances and 1/3 from continuum; ii) at lower energies, one- π and two- π production is dominated by resonances; iii) Δ is the strongest resonance at lower energies. In the resonance model, $NN \rightarrow NN + \pi$'s gives higher average p_T to the protons than to the pions as observed in pp collisions at these energies. An interesting fact is that the Δ in (2) has a larger p_T than the nucleon, one of its decay product. This is the result of relativistic kinematics.

In Figure 1 we show the dN/dy for the resonance model. The distributions for protons and pions are quite different than those for the direct production model. Decreased rescattering of π 's, which are mostly bound in Δ 's, result in lower multiplicity for both

Figure 1: Rapidity distribution for the direct production (lines) and resonance production (symbols) models.

Figure 2: The extrapolated rapidity distribution, inverse m_T slope and K^+/π^+ ratios for a) the direct production model and b) the resonance production model. The symbols show E802 data [7].

Figure 2

the protons and pions in the E802 rapidity window, shown in Figure 2a. Most of the protons in this window are from the target. Higher p_T from the rescattering of Δ 's contribute to the larger inverse m_T slope. The number of K^+ 's are about the same as in the direct production model and are produced mostly in baryon-baryon and meson-meson collisions. In the resonance model, most of the energy is still carried by the baryonic resonance after the collision, so subsequent collisions occur at high energies throughout the cascade, while in the direct production model the energy is immediately released in the form of pions. For this reason, the baryon-baryon contributes more to the K production in the resonance model.

Variations of the resonance model were studied to learn the sensitivity to the final dN/dy and inverse m_T slopes in Si+Au collisions. We find that as long as the ratio between resonance and continuum pion production is fixed, changes in the details of two-body processes produce only small changes in nucleus-nucleus collisions. The inverse processes (3) lowers the pion multiplicity near the target rapidity. Inclusion of ρ -meson resonance made no significant changes in the visible E802 region. Lower numbers of π 's and K 's in comparison to the E802 data could be due to the use of an impact parameter cut rather than simulation of the multiplicity trigger and/or oversimplification of the resonance structure.

4. CONCLUSIONS

Further study with a more realistic resonance structure is clearly needed for the resonance model. Nevertheless, we see that a hadronic picture with resonances describes the E802 data reasonably well. Since E802, E810 and E814 compliment each other in their choice of detectors, together they offer a wide coverage of rapidity, p_T and particle identification. A detailed analysis of these experiments is necessary to gain insight into the relevant two-body processes. This will enable us to make reasonable predictions of the hadronic background for the upcoming Au+Au experiments. Only after we fully understand the contributions and uncertainties of the background can we make definitive statements on signatures of other interesting physics.

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