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HEAVY ION PHYSICS

Local Thermalization in d + Au collisions

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Abstract. The extent of a locally equilibrated parton plasma in d + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV is investigated as a function of centrality in a nonequilibrium-statistical framework. Based on a three-sources model, analytical solutions of a relativistic diffusion equation are in precise agreement with recent data for charged-particle pseudorapidity distributions. The moving midrapidity source indicates the size of the local thermal equilibrium region after hadronization. In central d + Au collisions it contains 19% of the produced particles.

Keywords: Relativistic diffusion model, Charged-hadron rapidity distributions, Approach to thermal equilibrium.
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1. Introduction

In order to investigate analytically the gradual thermalization occuring in the course of particle production at the highest available energies in heavy-ion collisions, we propose nonequilibrium-statistical methods. The approach is tailored to identify the fraction of produced particles in local thermal equilibrium from their distribution functions in pseudorapidity. It yields indirect evidence for the extent and system-size dependence of a locally equilibrated parton plasma.

Recently pseudorapidity distributions of primary charged particles have become available [1] as functions of centrality in d + Au collisions at a nucleon-nucleon center-of-mass energy of 200 GeV. They are investigated within a nonequilibrium-statistical framework that is based on analytical solutions of a Relativistic Diffusion

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Model (RDM), and the results for this very asymmetric system are compared to Au + Au at the same nucleon-nucleon center-of-mass energy, where the formation of a locally equilibrated subsystem appears to be more likely.

2. Relativistic Diffusion Model

Our analytical investigation is based on a linear Fokker-Planck equation (FPE) for three components $R_k(y,t)$ of the distribution function in rapidity space [2, 4, 5, 10, 3]

$$\frac{\partial}{\partial t}R_k(y,t)=\frac{1}{\tau_y}\frac{\partial}{\partial y}\Big[(y-y_{eq})\cdot R_k(y,t)\Big]+\frac{\partial^2}{\partial^2 y}\Big[D_y^k\cdot R_k(y,t)\Big] \tag{1}$$

with the rapidity $y = 0.5 \cdot ln((E+p)/(E-p))$. The diagonal components D_y^k of the diffusion tensor contain the microscopic physics in the respective Au-like (k=1), d-like (k=2) and central (k=3) regions. They account for the broadening of the distribution functions through interactions and particle creations. In the present investigation the off-diagonal terms of the diffusion tensor are assumed to be zero. The rapidity relaxation time τ_y determines the speed of the statistical equilibration in y-space.

As time goes to infinity, the mean values of the solutions of Eqs. (1) approach the equilibrium value y_{eq}. We determine it from energy- and momentum conservation [6, 7] in the system of Au- and d-participants and hence, it depends on impact parameter. This dependence is decisive for a detailed description of the measured charged-particle distributions in asymmetric systems:

$$y_{eq}(b)=1/2\cdot ln\frac{< m_1^T(b)> exp(y_{max})+< m_2^T(b)> exp(-y_{max})}{< m_2^T(b)> exp(y_{max})+< m_1^T(b)> exp(-y_{max})} \tag{2}$$

with the beam rapidities $y_b = \pm y_{max}$ and the mean transverse masses $< m_{1,2}^T(b) >$ that depend on the impact parameter b. The average numbers of participants $N_{1,2}(b)$ in the incident gold and deuteron nuclei are calculated from the geometrical overlap. The results are consistent with the Glauber calculations reported in [1] which we use in the further analysis. The corresponding equilibrium values of the rapidity vary from y_{eq} = - 0.169 for peripheral (80-100%) to y_{eq} = - 0.944 for central (0-20%) collisions. They are negative due to the net longitudinal momentum of the participants in the laboratory frame, and their absolute magnitudes decrease with impact parameter since the number of participants decreases for more peripheral collisions.

The FPE can be solved analytically in the linear case with constant D_y^k. The initial conditions for produced hadrons are taken as δ-functions at the beam rapidities, supplemented by a source centered at the equilibrium value y_{eq}. This value is equal to zero for symmetric systems, but for the asymmetric d + Au case its deviation from zero according to Eq.(2) is decisive in the description of particle production.

With $\delta-$function initial conditions for the Au-like source (1), the d-like source (2), and the equilibrium source (eq), we obtain exact analytical diffusion-model solutions as incoherent superpositions of the distribution functions $R_k(y,t)$ because the differential equation is linear. The total number of charged particles in each centrality bin N_{ch}^{tot} is determined from the data. The average number of charged particles in the equilibrium source N_{ch}^{eq} is a free parameter that is optimized together with the variances and τ_{int}/τ_y in a χ^2-fit of the data using the CERN minuit-code.

3. Comparison with RHIC-data

For central collisions (0-20%) of d + Au, the charged-particle yield is dominated by hadrons produced from the Au-like source, but there is a sizeable equilibrium source that is more important than the d-like contribution. This thermalized source is moving since y_{eq} has a finite negative value for d + Au, whereas it is at rest for symmetric systems. The total yield is compared to PHOBOS data [1] which refer to the pseudorapidity $\eta = -ln[tan(\theta/2)]$ since particle identification was not available. As a consequence, there is a small difference to the model result in y-space ($y \approx \eta$) which is most pronounced in the midrapidity region. It is removed when the theoretical result is converted to η-space through the Jacobian

$$J(\eta, \langle m\rangle/\langle p_T\rangle) = \cosh(\eta) \cdot [1 + (\langle m\rangle/\langle p_T\rangle)^2 + \sinh^2(\eta)]^{-1/2}. \quad (3)$$

Here we approximate the average mass $< m >$ of produced charged hadrons in the central region by the pion mass m_π, and use a mean transverse momentum $< p_T >$ $= 0.4$ GeV/c.

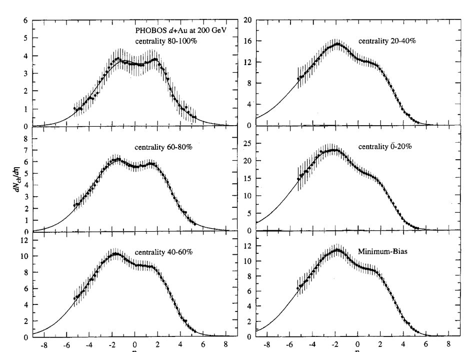

Fig. 1. Charged-hadron pseudorapidity spectra in the 3-sources Relativistic Diffusion Model (RDM), solid curves [3], compared to d + Au PHOBOS data.

The model calculations are converted to η-space and compared with PHOBOS data for five centrality cuts [1] and minimum bias [11] in Figure 1. The minimization procedure yields precise results so that reliable values for the relative importance of the three sources for particle production, and for $\tau_{int}/\tau_y (\simeq 0.4$ in central collisions) can be determined [3]. The observed shift of the distributions towards the Au-like region in more central collisions, and the steeper slope in the deuteron direction as compared to the gold direction appear in the Relativistic Diffusion Model as a consequence of the gradual approach to equilibrium.

The magnitude of the equilibrium source in central d + Au collisions at the highest RHIC energy is about 19% of the total yield. Comparing this with a previous result [10] for Au + Au in the three-sources-RDM [5, 10], we note that the equilibrium source for particle production tends to be larger in the heavy system. However, it turns out that the determination of the number of particles in the midrapidity source is not unique for symmetric systems.

4. Conclusion

We have investigated charged-particle production in d + Au collisions at $\sqrt{s_{NN}}=$ 200 GeV as function of centrality within the framework of an analytically soluble three-sources mode. Excellent agreement with recent PHOBOS pseudorapidity distributions has been obtained. Only the midrapidity part (19% in central collisions) of the distribution function reaches equilibrium. Although this fraction increases towards more peripheral collisions, the formation of a thermalized parton plasma prior to hadronization can probably only be expected for central collisions.

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