

# Observable implications of geometrical and dynamical aspects of freeze-out in heavy ion collisions

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Using an analytical parameterization of hadronic freeze-out in relativistic heavy ion collisions, we present a detailed study of the connections between features of the freeze-out configuration and physical observables. We focus especially on anisotropic freeze-out configurations (expected in general for collisions at finite impact parameter), azimuthally-sensitive HBT interferometry, and final-state interactions between non-identical particles. Model calculations are compared with data taken in the first year of running at RHIC; while not perfect, good agreement is found, raising the hope that a consistent understanding of the full freeze-out scenario at RHIC is possible, an important first step towards understanding the physics of the system prior to freeze-out.

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## I. INTRODUCTION

The first data from collisions between heavy nuclei at the Relativistic Heavy Ion Collider (RHIC) have generated intense theoretical efforts to understand the hot, dense matter generated in the early stage of the collision [1]. Testing these theoretical ideas relies on comparison to experimental observables. Leptonic [2] or electromagnetic [3] observables are believed to probe directly the early, dense stage of the collision. Most of the early data from RHIC, however, have been on hadronic observables. Measurements of hadrons at high transverse momentum ( $p_T$ ) [4] have generated much excitement, as they may provide useful probes of the dense medium produced at RHIC [5]. However, the medium itself decays largely into the soft (low- $p_T$ ) hadronic sector.

Soft hadronic observables measure directly the final “freeze-out” stage of the collision, when hadrons decouple from the bulk and free-stream to the detectors. Freeze-out may correspond to a complex configuration in the combined coordinate-momentum space, with collective components (often called “flow”) generating space-momentum correlations, as well as geometrical and dynamical (flow) anisotropies. A detailed experimental-driven understanding of the freeze-out configuration is the crucial first step in understanding the system’s prior evolution and the physics of hot colored matter.

In this paper, we explore in detail an analytic parameterization of the freeze-out configuration, which includes non-trivial correlations between coordinate- and momentum-space variables. We discuss the connections between the physical parameters of the model and observable quantities. If the model, with correct choice of physical model parameters, can adequately reproduce several independent measured quantities, then it might be claimed that this “crucial first step,” mentioned above, has been performed.

A consistent reproduction of all low- $p_T$  observations at RHIC is not achieved in most physical models which

aim to describe the evolution of the collision. In particular, it is difficult to reproduce momentum-space measurements while simultaneously describing the freeze-out coordinate-space distribution probed by two-particle intensity interferometry measurements [6] (also known as Hanbury-Brown-Twiss or HBT [7] measurements). Hadronic cascade models predict a too weak momentum azimuthal anisotropy and too large source sizes [8]. Hydrodynamic transport models describe successfully transverse mass spectra and elliptic flow but fail at describing pion source radii [9]; some hydrodynamic models have successfully reproduced pion source radii [10], but only with different model parameters than those used to reproduce spectra and elliptic flow [11]. Similarly, sophisticated hybrid transport models (e.g. AMPT [12]) require different model parameters [13] to reproduce data on elliptic flow [15] and HBT [16]. Good reproduction of observed values has been achieved in models which adjust parameters to fit data within a given freeze-out scenario, such as in the Buda-Lund hydro approach [17]. The work presented here falls into this latter category.

The parameterization used in this paper (“blast-wave parameterization”) is similar in form to the freeze-out configuration obtained from hydrodynamic calculations [18], but we treat the physical parameters of the configuration (e.g. temperature) as free parameters. Our main goal is simply to quantify the driving physical parameters of freeze-out at RHIC, and the dependence of observables on these parameters.

Further motivation for exploring freeze-out configurations of the type discussed here, is that they implicitly assume a “bulk” system which may be described by global parameters (temperature, flow strength, etc). Discussions of a “new phase of matter” and its “Equation of State” are only sensible if indeed such assumptions hold. Comparison of blast-wave calculations with several independent measurements, then, is a crucial consistency check of these assumptions (though, of course, a successful comparison still would not constitute a proof of their validity).

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