Hydrodynamic Flow at RHIC

Peter F. Kolb\textsuperscript{1,2,a}

\textsuperscript{1} Institut für Theoretische Physik, Universität Regensburg
D-93040 Regensburg, Germany
\textsuperscript{2} Department of Physics, The Ohio State University
174 West 18th Avenue, Columbus, OH 43210, USA

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Abstract. We review the apparently hydrodynamic behaviour of low transverse momentum particles ($p_T \leq 1.5 \text{ GeV/c}$) produced in central and semi-central ($b \leq 7 \text{ fm}$) heavy ion collisions at RHIC. We investigate the impact parameter dependence of various observables, elaborating on radial and elliptic flow and particle multiplicities. We also discuss possible ambiguities in the initialization of the hydrodynamic system and present observables that should allow for their resolution.

Keywords: relativistic heavy ion collisions, flow, hydrodynamic model

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1. Introduction and Motivation

The first measurements at RHIC systematically investigated the centrality dependence of an observable focused on elliptic flow (the anisotropic particle emission from the collision) \cite{1}, followed by the centrality dependence of the absolute (charged) particle yield per unit of pseudorapidity \cite{2} and the produced transverse energy per unit of pseudorapidity \cite{3}. Such systematic studies of the influence of the collision centrality are of fundamental interest, as they represent a powerful tool to gain a detailed understanding of the collision dynamics:

Firstly, non-central collisions offer additional observables due to their deformed, almond shaped overlap region, which can lead to angular dependencies (relative to the reaction plane) of final state observables which do not appear in central collisions with azimuthal symmetry \cite{4}. Large anisotropies arise only if there is strong rescattering already in the first moments ($\sim \text{ fm}/c$) of the collision, and (anisotropic) pressure gradients are building up, determining the subsequent evolution of the matter. Curiously the stronger forces in the direction of steepest pressure gradients lead to more transport of matter in those directions and thus eventually even out the...
differences between the radial gradients in the short and long direction of the initial almond. Thus anisotropies that are observable in the final state are built up early and in the hottest stages of the collision, as the cause of these anisotropies disappears during the system’s evolution (on a timescale of less than \( \sim 4 \text{ fm/c} \) [5–7]). In contrast to this self-quenching effect, e.g. for elliptic flow, other dynamical quantities such as radial flow continue to grow until freeze-out and carry information about the full expansion stage. We explore the influence of the initial spatial anisotropies in terms of a hydrodynamic picture, which represents the limiting case of maximum response to the initially produced pressure gradients due to strong (infinite) rescattering already in the early stages of the expansion. Such an approach was shown to be appropriate at RHIC energies [8] and is valuable to understand the global (macroscopic) characteristics of the expansion stage of an ultrarelativistic heavy ion collision.

Secondly, changing the centrality leads to a varying number of participating nucleons and a changing size of the interaction region. The amount of energy deposited in the collision region as well as the energy density in the system will be largest in central collisions and decrease with increasing impact parameter. Thus by varying the centrality, one is able to scan the initial energy density and in this fashion can measure excitation functions even without varying the beam energy. It is crucial, however, to disentangle such ‘centrality excitation functions’ from the geometric effects introduced by the varying excentricity of the system. In this spirit we investigate the centrality dependence of particle production per participating nucleon pair and transverse energy carried by the emitted hadrons to learn about soft and hard scattering contributions in the initial processes.

In Section 2, we introduce the underlying assumptions of hydrodynamic models and focus especially on different initialization scenarios. We present our results and comparisons to experimental data in Section 3, which covers a discussion of particle spectra and radial flow, elliptic flow, multiplicities and transverse energy. Section 4 contains a brief summary. In the Appendix we study the effect of boost-invariance on the pseudorapidity dependence of multiplicities and elliptic flow. This helps to understand the corresponding shapes of the recently presented experimental data [9] around midrapidity.

2. Hydrodynamics and Initialization

Hydrodynamics is a macroscopic approach to describe the dynamical evolution of the expansion stage of a heavy ion collision. It is a phenomenological model that, by describing the evolution of thermodynamic fields like energy density, pressure, temperature and flow fields, circumvents the necessity of introducing unknown microscopic parameters (e.g. in-medium cross sections or string tensions) as required for microscopic descriptions of such systems.

In the hydrodynamic description the nuclear equation of state enters the model quite naturally as the connection of pressure or temperature to energy and particle