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Elliptic flow difference of charged pions in heavy-ion collisions

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Abstract

Recently, the STAR Collaboration at RHIC has presented experimental evidence for the correlation between the elliptic flow difference of charged pions and charge asymmetry as a possible signal of the chiral magnetic wave. We demonstrate that the STAR results can be understood within the standard viscous hydrodynamics.

Keywords: Quark–gluon plasma; Elliptic flow

Recently, the STAR Collaboration at RHIC has measured the difference in the elliptic flow parameter v_2 between π^+ and π^- on an event-by-event basis, and found a linear dependence on the charge asymmetry of the collision system $A_{ch} \equiv \frac{N_+ - N_-}{N_+ + N_-}$ [1]

$$\Delta v_2^\pi \equiv v_2(\pi^-) - v_2(\pi^+) = \Delta v_2^\pi(\text{base}) + r A_{ch}, \tag{1}$$

where $N_\pm$ is the multiplicity of positively (negatively) charged particles. This quantity has attracted much interest over the past several years as a possible signal of the so-called chiral magnetic wave (CMW) [2]. It has been argued that a strong magnetic field created in off-center

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heavy-ion collisions together with the chiral anomaly induce a quadrupole deformation of electric charges, resulting in the elliptic flow difference (1). The main predictions of the CMW are that Δv_2^π depends linearly on A_{ch}, and the slope parameter r is positive. Moreover, r has a characteristic peak as a function of the centrality. The STAR data are qualitatively similar to these expectations.

Of course, one has to thoroughly examine all the other 'non-exotic' mechanisms that can contribute to the difference (1) and subtract their contributions before finally claiming the discovery of the CMW in heavy-ion collisions. Some attempts in this direction have been made in [3,4], but these alternative scenarios are already disfavored by the data [1] (see, however, [5]). In this paper, we raise the possibility that the STAR data can actually be understood within the standard viscous hydrodynamics.

In a previous paper [6], we have analytically computed the difference Δv_2^π for the anisotropic Gubser flow [7] coupled with conserved currents and found that it is proportional to the shear viscosity η and the isospin chemical potential μ_I. The result is, neglecting numerically small corrections,

$$\frac{\Delta v_2^\pi}{v_2^{\pi,ideal}} \approx \frac{-\mu_I}{T}\frac{27}{80}K, \tag{2}$$

where $K \propto \eta/s$ is the Knudsen number (s is the entropy density) and T is the freezeout temperature. (The sign convention of Δv_2 here is different from [6].) In heavy-ion collisions, the mean value of μ_I is slightly negative because the colliding nuclei are neutron-rich. In place of μ_I, we may alternatively use the charge chemical potential μ_Q. Numerically, μ_I are μ_Q are close (cf., Ref. [8]), and we expect that the following discussion will be qualitatively similar in the two cases.

In order to establish the connection between (1) and (2), we classify events according to the value of A_{ch} and assign effective freezeout parameters in each bin of A_{ch}.[1] This can be done by using the statistical model of hadrons in which the multiplicity N_i of hadron species i is computed as [9]

$$N_i = \frac{g_i V}{2\pi^2}\sum_{k=1}^{\infty}(\mp 1)^{k+1}\frac{m_i^2 T}{k}K_2\left(\frac{km_i}{T}\right)\exp\left(k\frac{B_i\mu_B + I_i\mu_I + S_i\mu_S}{T}\right), \tag{3}$$

where V is the volume, m_i is the mass and g_i is the degeneracy factor.[2] The sign ∓ 1 corresponds to fermions/bosons. B, I, S are the baryon, isospin and strangeness quantum numbers, respectively, and $\mu_{B,I,S}$ are the corresponding chemical potentials. The asymmetry A_{ch} can be evaluated by summing over all charged hadrons $N_\pm = \sum_i N_\pm^i$ whose masses are below 2 GeV.[3]

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[1] To assign freezeout parameters for certain subevents is a common practice in heavy-ion collisions. For instance, T and μ are often plotted as a function of centrality at fixed energy. Experimentally, centrality is determined by multiplicity, and the idea here is that events with the same multiplicity are regarded as a statistical ensemble and chemical potentials can be independently assigned for this ensemble. Here we do the same, using A_{ch} bins instead of multiplicity bins. In the STAR measurements, the number of events in each bin of A_{ch} at fixed centrality is typically $\mathcal{O}(10^5)$.

[2] The temperature T here is the chemical freezeout temperature which in general differs from the kinetic freezeout temperature in (2). Here we assume that the two temperatures are equal or close to each other, following the early freezeout model [6] in which the formula (2) was derived. Note that in the same model the ratio μ_I/T in (2) is approximately constant during the time evolution.

[3] In practice, we include the $k = 1, 2, 3$ terms in the sum (3) for pions, $k = 1, 2$ terms for kaons and only the $k = 1$ term for all the other hadrons. We have checked that other higher k terms are negligible.