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Angular power spectrum in publically released ALICE events

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Abstract

We study the particles emitted in the fireball following a Relativistic Heavy Ion Collision with the traditional angular analysis employed in cosmology and earth sciences, producing Mollweide plots of the number and p_t distribution of a few actual, publically released ALICE-collaboration events and calculating their angular power spectrum. We also examine the angular spectrum of a simple two-particle correlation. While this may not be the optimal way of analyzing heavy ion data, our intention is to provide a one to one comparison to analysis in cosmology. With the limited statistics at hand, we do not find evidence for acoustic peaks but a decrease of C_l that is reminiscent of viscous attenuation, but subject to a strong effect from the rapidity acceptance which probably dominates (so we also subtract the $m = 0$ component). As an exercise, we still extract a characteristic Silk damping length (proportional to the square root of the viscosity over entropy density ratio) to illustrate the method. The absence of acoustic-like peaks is also compatible with a crossover from the QGP to the hadron gas (because a surface tension at domain boundaries would effect a restoring force that could have driven acoustic oscillations). Presently we do not understand a depression of the $l = 6$ multipole strength; perhaps ALICE could reexamine it with full statistics.

Keywords: Heavy ion collisions; Cosmic microwave background; Angular correlations; Angular power spectrum

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1. Introduction

The phase diagram of Quantum Chromodynamics is one of the guiding goals of much of the worldwide nuclear-particle physics efforts. Currently, the picture in which, at low baryon-density, the Quark-Gluon-Plasma (QGP) cools into a hadron medium through a smooth crossover finds wide support fundamented in lattice gauge theory computations [1–3]. Additionally, studies of damping in the plasma and later hadron phase have been vigorously pursued [4–6].

Empirical evidence for the crossover, other features of the phase diagram, or transport coefficients are less straightforwardly obtained, since experimental data show the conditions at the freeze out surface.[1] For example, there is raging discussion on whether the critical end point of a first order phase transition present at larger baryon chemical potential has or has not been located [8,9].

It is therefore very reassuring when actual empirical evidence in support of the supposed phase diagram accrues, particularly the crossover at small baryon density, as for example the scaling of moments of the distribution for baryon-number fluctuations with volume (or as proxy, number of participants) [10,11]. And we have relatively solid evidence that the ratio of viscosity to entropy density is low [12,13] and not too far above the renowned $1/(4\pi)$ bound [14].

Part of this contribution, based on a number of events publically released by the ALICE collaboration, is to observe that the absence of acoustic peaks in the angular spectrum of p_t and related fluctuations (in addition to a clear effect of the rapidity acceptance cut) might be an additional hint of that crossover nature, and perhaps also attest attenuation (analogous to Silk damping in cosmology). This work follows on the footsteps of several others [15–18] that exploit the similarity between the primeval cosmological explosion and Relativistic Heavy Ion Collision Experiments (RHIC-E). We continue developing analysis methods, and, especially, try to apply them to study ALICE data in the public domain, setting the stage for studies with higher statistics.

The methods advocated here may not be the most precise or best suited ones to obtain the physical answers, but we also want to provide a one to one correspondence with the results reported in cosmology, that are very well known in the broader physics community and beyond, providing an unequivocal point of comparison for heavy-ion physics.

The main analysis tool for the Cosmic Microwave Background (CMB) radiation is the angular spectral analysis used to describe temperature fluctuations in the sky at different angular resolution. The spherical harmonic transform is an appropriate analysis method as the radiation is distributed over the celestial sphere. It has not escaped the attention of the RHIC-E community that the same method can be applied to radiation coming from *within* a sphere as opposed to entering it; some studies have provided Mollweide plots [19] of particle distributions or angular spectra generated by Monte Carlo simulations.

To discuss RHIC-E, we need an appropriate coordinate system that matches the one used in cosmology. A natural one orients the OZ axis along the beamline, and the polar angle θ is measured therefrom; this can be traded for the rapidity $y \equiv \tanh^{-1}(v_\parallel) = \tanh^{-1}\left(\frac{p_\parallel}{E}\right)$. Particles (90% of them pions) have coordinates $(p_\parallel, \mathbf{p}_t)$ or equivalently, (p_t, y, ϕ). Most often, rapidity is approximated by pseudorapidity $\eta \equiv -\ln\left(\tan\frac{\theta}{2}\right)$ that is more directly read from the pion track in such instruments as the time projection chamber of the ALICE experiment.

[1] It is generally believed that the freeze out happens after the system spends some time in a hadronic phase, but certain numerical fits [7] suggest that there is little or no final state rescattering among hadrons after the collision, meaning that chemical freeze out would occur right upon exiting the QGP.