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Comments about the electromagnetic field in heavy-ion collisions

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Received 7 October 2013; received in revised form 10 May 2014; accepted 13 May 2014

Abstract

In this article we discuss the properties of electromagnetic fields in heavy-ion collisions and consequences for observables. We address quantitatively the issue of the magnetic field lifetime in a collision including the electric and chiral magnetic conductivities. We show that for reasonable parameters, the magnetic field created by spectators in a collision is not modified by the presence of matter.

Keywords: Magnetic field; Electromagnetic probes; Chiral magnetic wave

1. Introduction

The experiments with heavy-ion collisions of ultra-relativistic energies probe not only matter in extreme temperatures and densities, but also under action of an extremely strong electromagnetic field with magnitude of the hadronic scale, $eB \sim m_\pi^2$ [1,2].

The magnetic field is a key ingredient for many observables related to local parity and charge parity violation [1]. The lifetime of the magnetic field, which is needed to describe the observed data of the elliptic flow dependence for positive and negative charged particles on the asymmetry, within the framework of the Chiral Magnetic Wave must be as large as 4 fm/c [3]. However, the photon azimuthal anisotropy measured at the top RHIC energy can be described by the magnetic field at a time scale of a few 0.1 fm/c [4]. This apparent discrepancy demands theoretical studies

http://dx.doi.org/10.1016/j.nuclphysa.2014.05.008
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of the time dependence of the magnetic field. In this article we consider effects of finite conductivity on the lifetime. We also discuss the dependence of the magnetic field on the collision energy and draw some conclusion on photon azimuthal anisotropy for RHIC and LHC energies.

2. The electro-magnetic field in heavy-ion collision

The Maxwell equation describing the time evolution of the electromagnetic field in a collision reads

$$\frac{\partial \vec{B}}{\partial t} = -\vec{\nabla} \times \vec{E}, \tag{1}$$

$$\frac{\partial \vec{E}}{\partial t} = \vec{\nabla} \times \vec{B} - \vec{j}; \tag{2}$$

where the electromagnetic current can be decomposed in two pieces:

$$\vec{j} = \vec{j}_{\rm ext} + \vec{j}_{\rm int}, \tag{3}$$

the internal current, $\vec{j}_{\rm int}$, and the external one of the colliding nuclei, $\vec{j}_{\rm ext}$. The latter we will treat in the eikonal approximation neglecting effects of the proton deceleration and/or stopping. For later convenience we separate the electromagnetic field also in the "external" and "internal", e.g.

$$E = E_{\rm ext} + E_{\rm int}, \tag{4}$$

where the external electromagnetic field satisfies the equations

$$\frac{\partial \vec{B}_{\rm ext}}{\partial t} = -\vec{\nabla} \times \vec{E}_{\rm ext}, \tag{5}$$

$$\frac{\partial \vec{E}_{\rm ext}}{\partial t} = \vec{\nabla} \times \vec{B}_{\rm ext} - \vec{j}_{\rm ext}; \tag{6}$$

while for the internal we get

$$\frac{\partial \vec{B}_{\rm int}}{\partial t} = -\vec{\nabla} \times \vec{E}_{\rm int}, \tag{7}$$

$$\frac{\partial \vec{E}_{\rm int}}{\partial t} = \vec{\nabla} \times \vec{B}_{\rm int} - \vec{j}_{\rm int}. \tag{8}$$

This representation is especially convenient for numerical calculations due to the following reasons. First, there is no need in solving the first couple of equations for the external components with the singular source terms, because the solution can be obtained by boosting the electric field of both nucleus. Second, the singularities of the sources are spread by the fields, which leads to a better convergence of a numerical scheme.

In the matter rest frame, the internal current may include the contribution from the Ohmic conductivity

$$\vec{j}_{\rm Ohm} = \sigma \vec{E} \tag{9}$$

and the one induced by the QED anomaly

$$\vec{j}_{\rm anom} = \sigma_\chi \vec{B}, \tag{10}$$