Signatures of chiral magnetic wave in heavy ion collisions

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Chiral magnetic wave[1)] is a collective hydrodynamic mode of chiral charge densities in the presence of background magnetic field, as a consequence of underlying triangle anomaly of QCD. It has a longitudinal dispersion relation along the direction of the magnetic field

$$\omega = \pm v_\chi k - i D_L k^2 + \cdots , \quad (1)$$

where the chiral magnetic velocity v_χ is completely fixed by the thermodynamic charge susceptibility χ as

$$v_\chi = \frac{eN_c B}{4\pi^2 \chi} , \quad (2)$$

whereas the sign in front of the first term in the dispersion relation depends on the chirality, that is, left-handed charge fluctuations propagate in the opposite direction to that of the right-handed charge fluctuations. Since off-central heavy ion collisions can create magnetic fields as large as $eB \sim m_\pi^2$ at RHIC and about ten times larger at LHC, they provide an interesting environment where one can potentially test possible experimental signatures of chiral magnetic wave.

One observable that might be affected by the chiral magnetic wave is the elliptic flows of early photons and dileptons, for which the recent experimental data from RHIC indicate a value larger than the current theory estimate without taking into account the presence of magnetic fields. Earlier studies have suggested possible enhancement of the elliptic flows of photons due to the magnetic field, but a proper account of possible effects coming from chiral magnetic wave was first examined in Ref.[2)] in the framework of AdS/CFT correspondence. We observed that the chiral magnetic wave can significantly modify the elliptic flows for the momentum $p < 1$ GeV. Also, the quadrupole to the elliptic flow square ratio, v_4/v_2^2, is largely different from a constant, violating a typical scaling $v_4 \sim v_2^2$ for charged hadrons. We also predicted a distinctive signature in the polarization of photons originating from chiral magnetic wave. Future experiments probing the momentum range $p < 1$ GeV will be interesting to potentially see such behaviors due to chiral magnetic wave.

Another observable of interest is the charge dependent elliptic flows of pions, $\Delta v_2 \equiv v_2(\pi^-) - v_2(\pi^+)$, which was recently measured at RHIC. The QCD plasma formed by heavy ion collisions naturally has a small average positive vector charge density as a remnant of the colliding two positively charged nuclei, but one can also select events with any sign of the net charge that exist via statistical fluctuations. Recalling that $Q_V = Q_L + Q_R$ and $Q_A = -Q_L + Q_R$ where $Q_{V,A}$ are vector (axial) charge densities and $Q_{L,R}$ are left (right)-handed chiral charge densities, the initial vector charge density with average zero axial charge corresponds to having equal amounts of chiral charges Q_L and Q_R. Chiral magnetic wave acting on these chiral charges will move them apart in opposite directions along the magnetic field, which leads to a net vector charge quadrupole moment that is proportional to the initial vector charge density. Based on this, we predicted in Ref.[3)] that this quadrupole moment, in conjunction with the radial flow developed by hydrodynamic evolution, will eventually result in Δv_2 proportional to the initial vector charge density,

$$\Delta v_2 = r A_\pm , \quad A_\pm = \frac{(N_+ - N_-)}{(N_+ + N_-)} , \quad (3)$$

with a positive slope parameter r, which has been confirmed by the experimental analysis of RHIC. The simulation in Ref.[3)] for r to compare with experimental value was crude, neglecting many realistic elements in heavy ion collisions, and in Ref.[4)] we significantly improved the simulation by implementing a realistic 2+1 dimensional hydrodynamic code with isothermal Cooper-Frye freeze out condition, as well as chiral phase transition effect on the chiral magnetic wave. Our result for r and its dependence on the impact parameter compare well with experiments, although our analysis does not exclude other contributions unrelated to triangle anomaly.

In Ref.[5)] we systematically classified possible P and CP odd observables in photon and dilepton emission rates. Since axial charge is P and CP odd, which is a unique characterization of it, these observables must be proportional to event-by-event fluctuations of axial charges in the QCD plasma formed in heavy ion collisions. Our observables are related to spin (helicity) alignments of the photons and dileptons, and we have shown that they probe the imaginary part of the chiral magnetic conductivity of the plasma at finite momenta, which ultimately arises from the underlying triangle anomaly of QCD.

References

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