Jet-medium interactions through vortex ring formation inside the QGP


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Introduction

- Among the results from relativistic heavy-ion collisions, two of the most studied are the jet energy loss and the fluid behavior of the system formed after the collision.
- Both results are well established, but considerable uncertainty exists about the fate of the energy lost by the jet.

- What happens to the energy lost by a quenched jet and absorbed into the medium?
- How can the answer for the previous question help in the study of QGP and its interactions?

Figure 1: When a dijet pair is produced inside QGP, one of the jets may be absorbed by the hot dense matter [1].

- To find answers, we linked the jet quenching phenomenon with hydrodynamic theory and hadron’s polarization.

- Recently it was observed that the polarization of Λ hyperons presents a preference to be oriented according to the global vorticity of the system [2].

Vorticity-Spin Coupling

- The vorticity at midrapidity from midcentral Au+Au collisions is predominantly negative (anti-clockwise) [2].
- The Λ polarization presents a similar anisotropy which is expected to be set up by the shear stress of the vorticity ring, introduced by the quenching jet.

Figure 2: Energy dependence of Λ and ¯Λ global polarization at midrapidity from midcentral Au+Au (20-50%) or Pb+Pb (15-50%) collisions. Comparison of experimental data to different models [3].

Vorticity Rings

- We showed that the deposition of energy-momentum of a quenched jet into the medium generates flow gradients that give rise to an structure that we call Vorticity Ring.

Figure 3: Schematic representation of the formation of a vortex ring inside the quark-gluon plasma. The jet is quenched and the Λ hyperons are emitted in a specific direction, due to the vorticity of the ring, which can be measured experimentally using the polarization of the Λ hyperons.

- Due to the vorticity of the ring, this phenomenon can be measured experimentally using the polarization of the Λ hyperons, which will align according to that vorticity.

- We also propose an experimental observable responsible for filtering the contributions of polarization that was induced by the thermalization of the jet.

Methodology

- To obtain the results of this work, we applied a hybrid chain computer simulation composed of three main stages:

  - TRENTo
  - MUSIC 3+1D
  - iSS Sampler

  - Pb-Pb @ 2.76 TeV;
  - Smooth and Fluctuating Initial Conditions.
  - Insertion of a hot source term simulating the quenched jet;
  - Vorticity Ring formation.
  - Particleization process;
  - Λ polarization.

Results and Conclusions

In this work, we studied the sensitivity of the polarization induced by the thermalized jet to different parameters. The results are shown in the plots below.

- **Polarization distribution**
  - The signal of polarization induced by jet-medium excitations is concentrated in low $p_T$ region.
  - The signal in the high $p_T$ region is induced by the anisotropic expansion of the system (elliptic flow).

Figure 4: Longitudinal polarization of Λ particles as a function of transverse momentum $p_T$ and azimuthal angle relative to jet’s direction for different scenarios.

- **Smooth vs. Ebe**
  - The randomization of the jet’s direction suppresses the influence of background polarization.
  - Both analyses are qualitatively similar and present the same order of magnitude.

Figure 5: The ring observable as a function of the azimuthal angle relative to jet’s direction for different scenarios.

- **Systematic study**
  - The signal calculated through the Ring Observable is sensitive to shear viscosity of the medium; momentum of the quenched jet; position and direction of the energy-momentum currents.

Figure 6: The ring observable as a function of the shear viscosity (left) and jet’s velocity (right).

- The signal calculated through the Ring Observable is sensitive to shear viscosity (left) and jet’s velocity (right).

Figure 7: The ring observable as a function of the azimuthal angle relative to jet’s direction for different scenarios of insertion position.

- Signal consistent with zero in events without jet insertion;
- Jet-medium excitations induce non-zero measurements;
- The Ring Observable is robust with different types of scenarios studied.

Figure 8: The ring observable as a function of the impact parameter for different scenarios of analysis.

- The Ring Observable is a powerful tool to probe jet-medium interactions and QGP dynamics.
- The signal of the observable is robust with respect to different scenarios.

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2 Polarization and Vorticity in the QGP, Annu. Rev. Nucl. Part. Sci. 2020; 70:395-423