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?

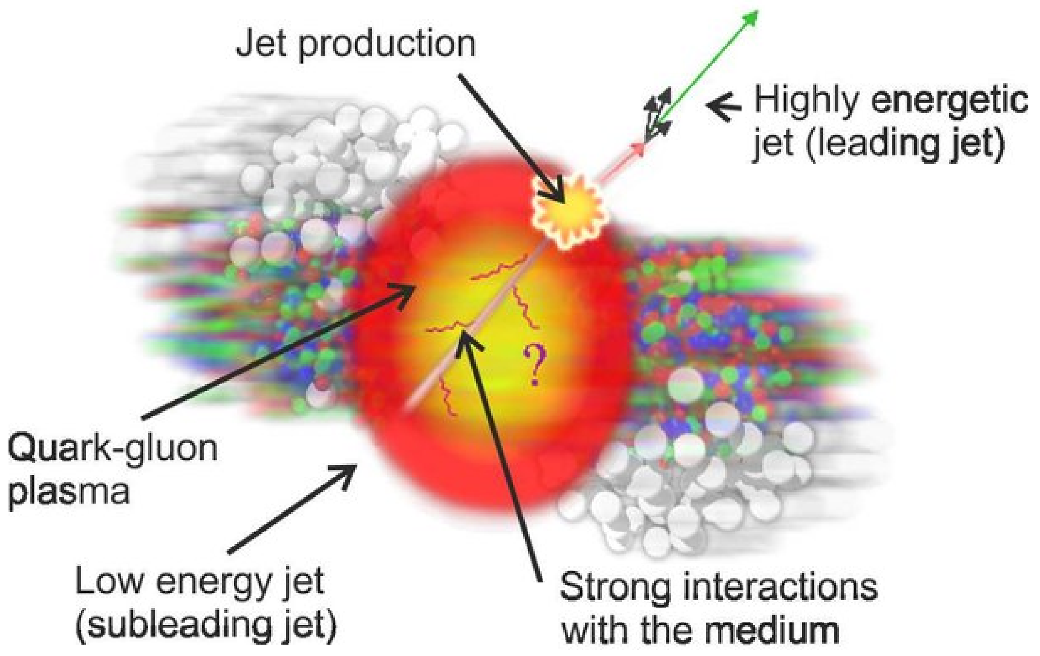

Figure 1: When a dijet pair is produced inside QGP, one of the jets may be absorbed by the hot dense matter [1].

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

Vorticity-Spin Coupling

- 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].

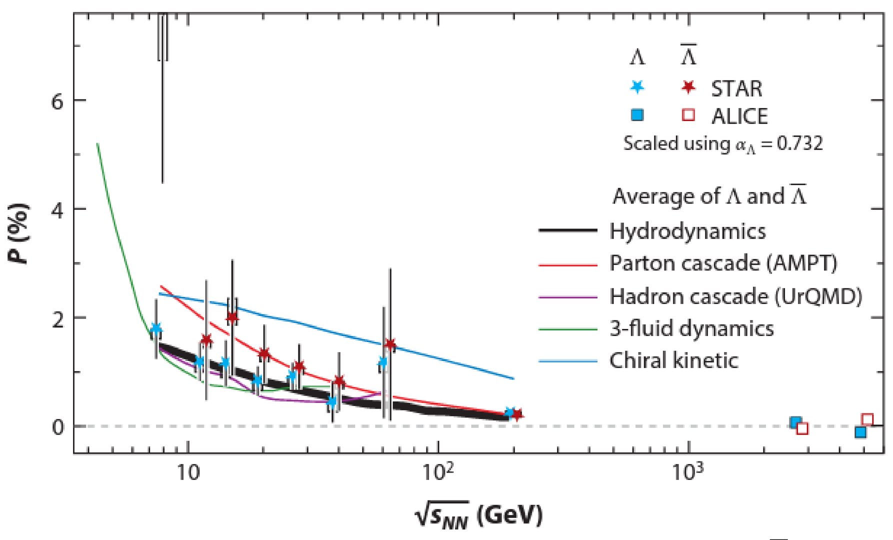

Figure 2: Energy dependence of Λ and $\bar{\Lambda}$ global polarization at midrapidity from midcentral Au+Au (20–50%) or Pb+Pb (15–50%) collisions. Comparison of experimental data to different models [3].

(Property of QGP) **Angular momentum** → Vorticity:

$$\varpi_{\mu\nu} = \frac{1}{2}(\partial_\nu \beta_\mu - \partial_\mu \beta_\nu)$$

Vorticity-Spin Coupling:

$$S^\mu(p) = -\frac{1}{8m}\epsilon^{\mu\rho\sigma\tau}p_\tau \frac{\int d\Sigma_\lambda p^\lambda n_F(1-n_F)\varpi_{\rho\sigma}}{\int d\Sigma_\lambda p^\lambda n_F}$$

→ **Hadrons' polarization** (Final Observable)

Vorticity Rings

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

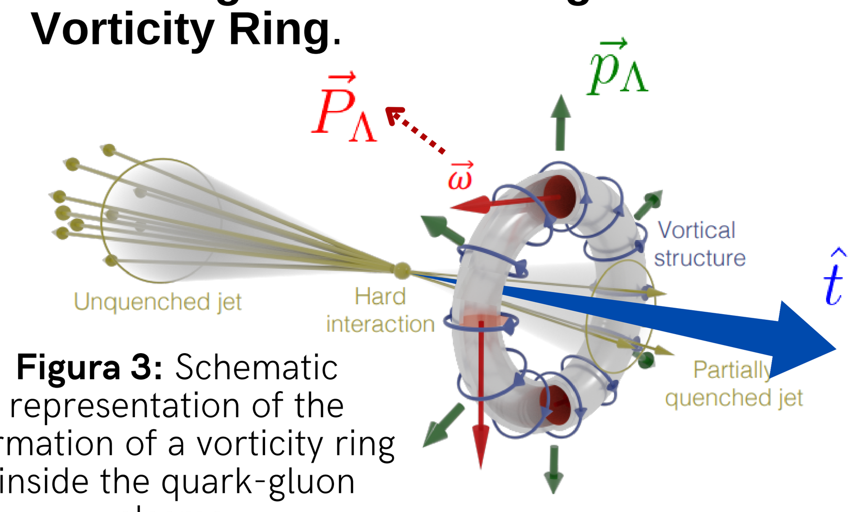

Figura 3: Schematic representation of the formation of a vorticity ring inside the quark-gluon plasma.

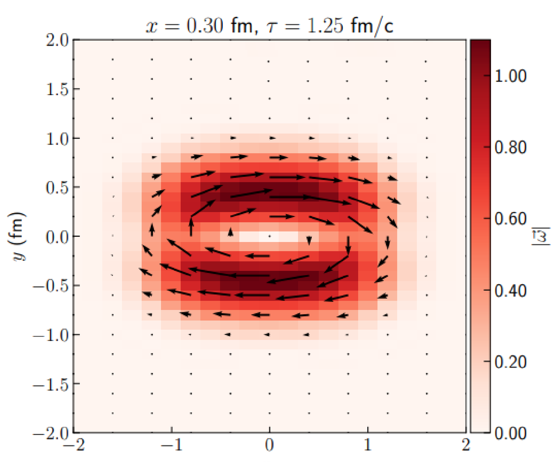

Figura 4: Vortex ring formed by a thermalized jet into a hydrodynamic evolution. The color gradiants show $|\vec{\omega}|$ and the arrows shows the y and z component of the vorticity vector.

- 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.

The Ring Observable:

$$\mathcal{R}^t_\Lambda = \left\langle \frac{\vec{P}_\Lambda \cdot (\hat{t} \times \vec{p}_\Lambda)}{|\hat{t} \times \vec{p}_\Lambda|} \right\rangle$$

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**

TRENTo:
- Pb-Pb @ 2.76 TeV;
- Smooth and Fluctuating Initial Conditions.

MUSIC 3+1D:
- Insertion of a hot source term simulating the quenched jet;
- Vorticity Ring formation.

iSS Sampler:
- Particlization proccess;
- Λ polarization.

Based on: V. H. Ribeiro et al, arXiv:2305.02428 [hep-ph]
W. M. Serenone et al, Phys. Lett. B ,820, 126500 (2021)

Bibliography

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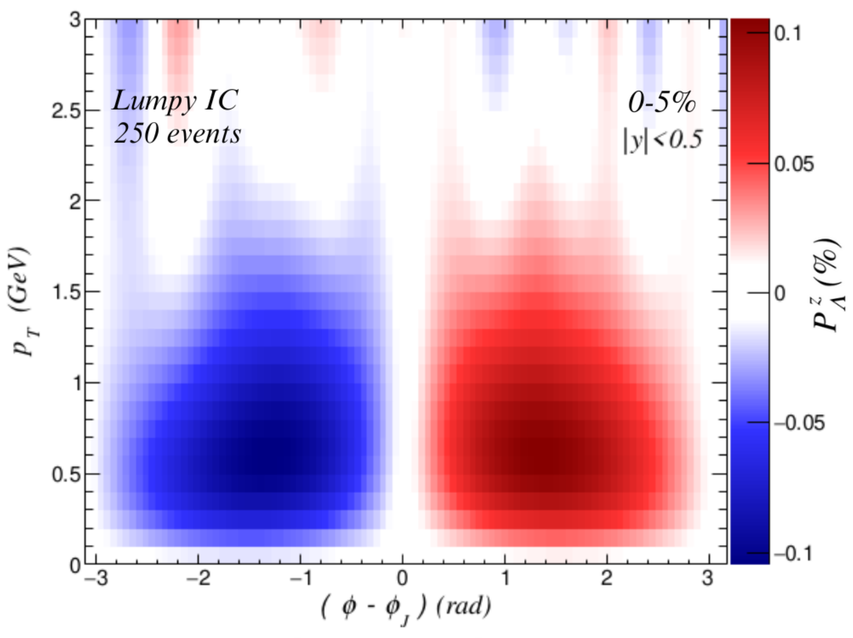
Results and Conclusions

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)***

Figura 4: Longitudinal polarization of Λ particles as a function of transverse momentum (p_T) and azimuthal angle relative to jet's direction ($\phi - \phi_J$)

- **Smooth vs. Ebe**

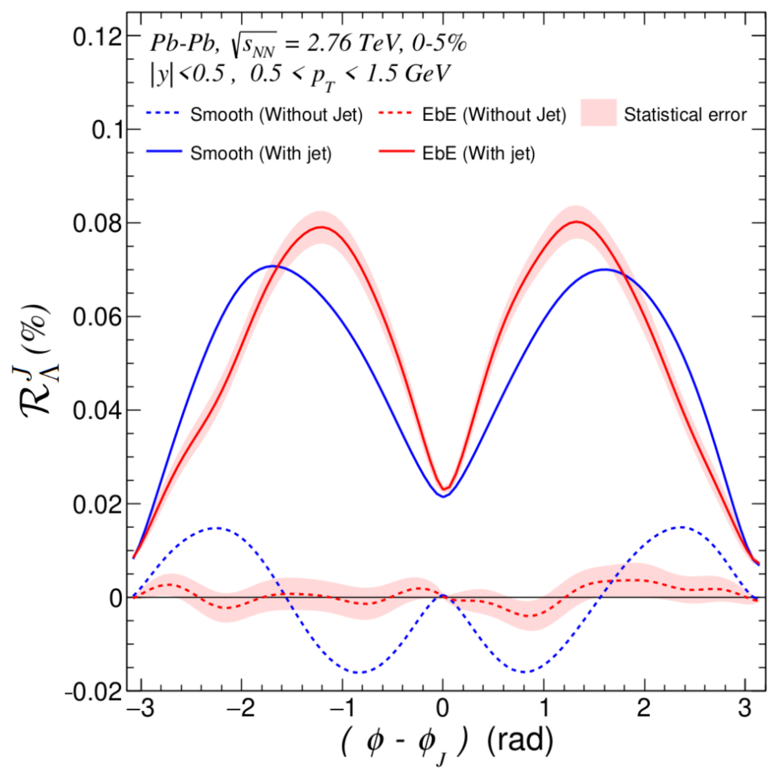
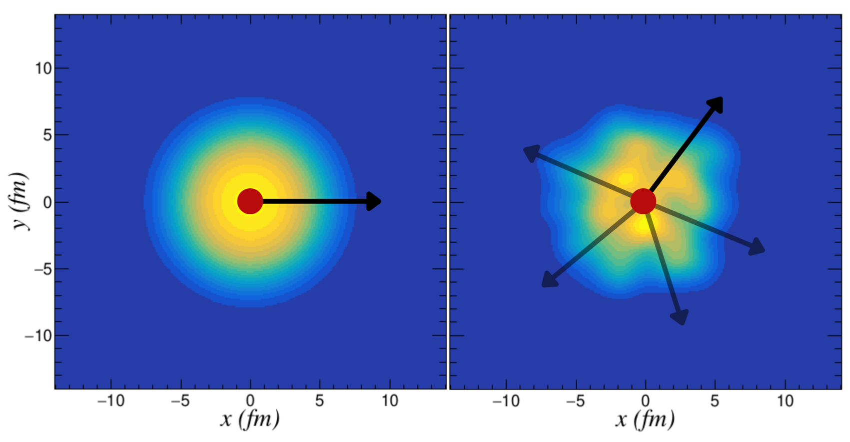


Figura 5: The ring observable as a function of the azimuthal angle relative to jet's direction for different scenarios.



Jet pointing +x̂ | Randomization of jet direction

- 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.**

- **Systematic study**

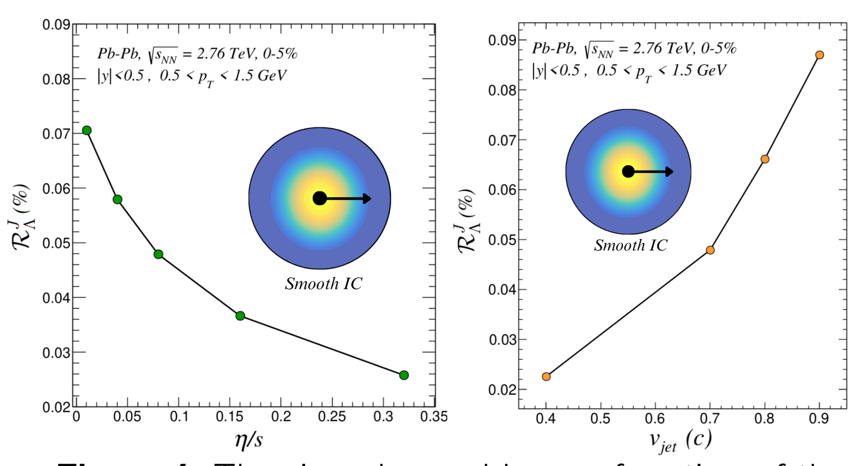


Figura 6: The ring observable as a function of the shear viscosity (left) and jet's velocity (right).

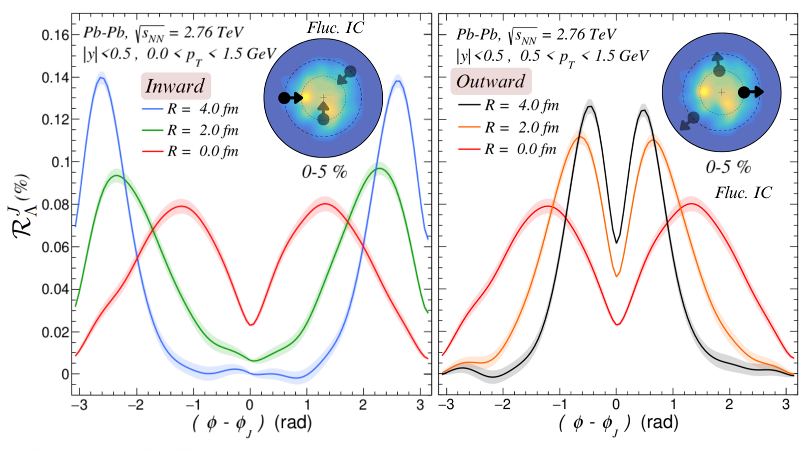


Figura 7: The ring observable as a function of the azimuthal angle relative to jet's direction for different scenarios of insertion position.

- 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.

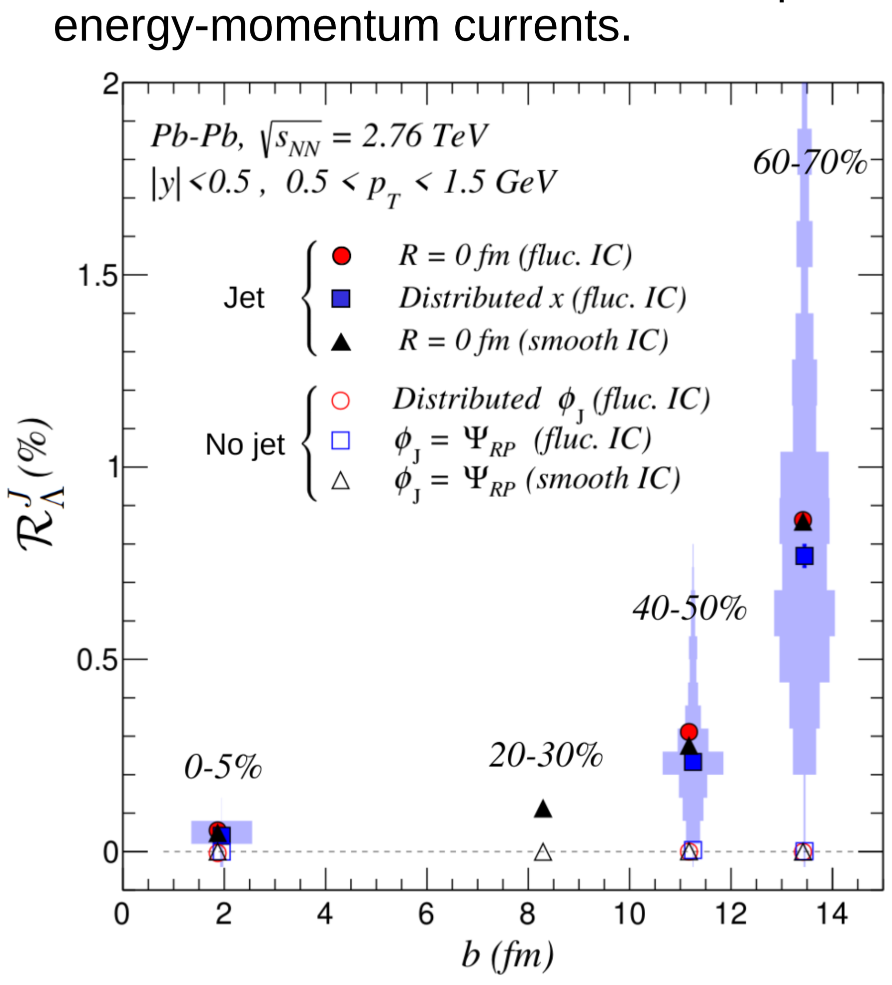
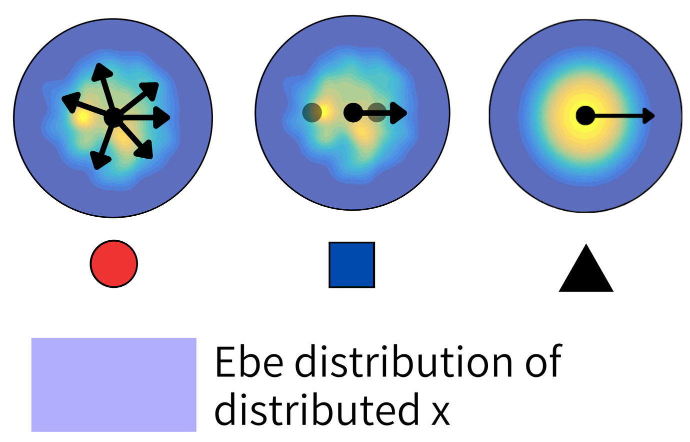


Figura 8: The ring observable as a function of the impact paramenter for different scenarios of analysis.



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

- **The Ring Observable is a poweful 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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