

Canonical Vs. Phenomenological Formulations of Spin Hydrodynamics

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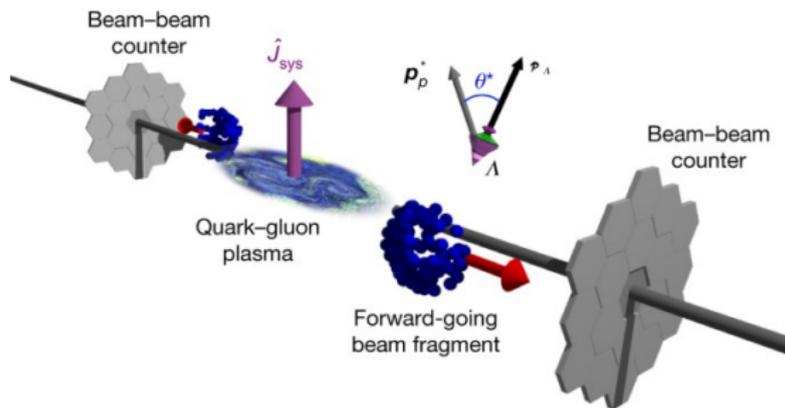
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STAR experiment at RHIC observed an alignment between global angular momentum of the colliding system and the average spin of Λ^0 baryons emitted from it [STAR, L. Adamczyk et al., Nature 548, 62 (2017)], indicating spin polarization of the produced matter along its vorticity direction.



A sketch of a Au + Au collision [STAR, L. Adamczyk et al., Nature 548, 62 (2017)]

Recently, several groups are investigating such phenomena trying to understand the QGP's vortical structure and hydrodynamics of spin DoF's.

Florkowski et al.1811.04409, Rischke et al.2005.01506, Becattini et al.2103.14621

Phenomenological spin-hydrodynamic framework [Hattori et al.1901.06615, Fukushima et al.2010.01608] is based on the conservation of the energy-momentum (EM) and total angular momentum (TAM) tensors

$$\partial_{\mu} T_{\text{ph}}^{\mu\nu} = 0 \quad , \quad \partial_{\mu} J_{\text{ph}}^{\mu\alpha\beta} = 0. \quad (1)$$

It commonly uses a simplified form of the spin tensor

$$T_{\text{ph}}^{\mu\nu} = \varepsilon u^{\mu} u^{\nu} - p \Delta^{\mu\nu} + T_{\text{ph}(1)}^{\mu\nu} \quad , \quad S_{\text{ph}}^{\mu\alpha\beta} = u^{\mu} S^{\alpha\beta} + S_{\text{ph}(1)}^{\mu\alpha\beta}. \quad (2)$$

On the other hand, the canonical spin-hydrodynamic framework [Daher et al.2202.12609] is also based on the conservation of EM and TAM tensors, but its spin tensor is totally anti-symmetric (which is a direct consequence of Noether's theorem applied to the Dirac Lagrangian)

$$S_{\text{can}}^{\mu\alpha\beta} = u^{\mu} S^{\alpha\beta} - u^{\alpha} S^{\mu\beta} + u^{\beta} S^{\mu\alpha} + S_{\text{can}(1)}^{\mu\alpha\beta}. \quad (3)$$

Using entropy-current analysis, we've shown that the canonical framework is not a well-defined initial value problem for an arbitrary set of hydrodynamics T , u^{μ} and $\omega^{\mu\nu}$.

Such a problem can be solved by a proper modification of the EM tensor resulting in an improved canonical framework

$$\tilde{T}_{can}^{\mu\nu} = (\epsilon + p)u^\mu u^\nu - pg^{\mu\nu} + T_{can(1)}^{\mu\nu} + \partial_\lambda(u^\nu S^{\mu\lambda}), \quad (4)$$

where $\partial_\lambda(u^\nu S^{\mu\lambda})$ is not a pseudo-gauge. On top of that, we were able to show that it is possible to construct explicitly a pseudo-gauge [Florkowski et al.1811.04409] leading directly from the improved canonical framework to the phenomenological one

$$T_{ph}^{\mu\nu} = \tilde{T}_{can}^{\mu\nu} + \frac{1}{2}\partial_\lambda(\Sigma^{\lambda\mu\nu} - \Sigma^{\mu\lambda\nu} - \Sigma^{\nu\lambda\mu}), \quad (5)$$

$$S_{ph}^{\lambda\mu\nu} = \tilde{S}_{can}^{\lambda\mu\nu} - \Sigma^{\lambda\mu\nu}, \quad (6)$$

$$\Sigma^{\lambda\mu\nu} = 2\Phi_{can(0)}^{\lambda\mu\nu} + \Sigma_1^{\lambda\mu\nu}, \quad (7)$$

where $\Phi_{can(0)}^{\lambda\mu\nu} = u^{[\mu} S^{\nu]\lambda}$. In addition, starting from the phenomenological formulation we can re-obtain the improved canonical framework.

- 1 We introduce the canonical framework with totally anti-symmetric spin tensor based on the natural continuous symmetries of the underlying field theory. Our work shows that the naive use of arbitrary forms of canonical currents conflicts with the principle of entropy production.
- 2 We show that this problem can be solved by an improved form of the canonical EMT without affecting the conservation equations. Such improvement is not a result of pseudo-gauge transformation as many author implicitly assume.
- 3 Using proper pseudo-gauge transformation, we show an equivalence between the improved canonical framework and the phenomenological framework of dissipative spin hydrodynamic.