Vector resonances spin alignment as a probe of spin hydrodynamics and freeze-out

Presented by:
Kayman Jhosef Carvalho Gonçalves
kaymang@ifi.unicamp.br

In collaboration with:
Donato Giorgio Torrieri

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https://arxiv.org/abs/2104.12941

IFGW Instituto de Fisica Gleb Wataghin
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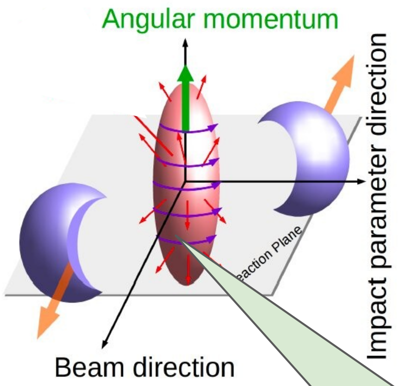
Polarization in QGP

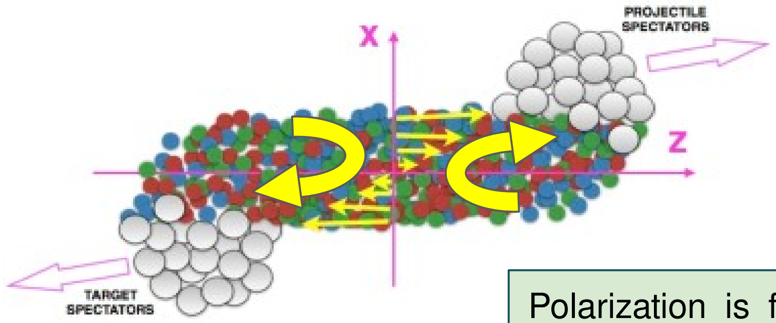
[3]

Fireball



x-z plane

[4]



[3]https://phys.org/news/2020-08-evidence-vector-meson-alignment-heavy-ion.html
[4] https://www.groundai.com/project/vorticity-and-particle-polarization-in-heavy-ion-collisions-experimental-perspective/1

As QGP is a fluid with low viscosity, so we can have vortices and from it makes particles polarized.

Polarization is first created in the reaction plane direction but the transversion expansion makes vorticity in the longitudinal direction too.

Vortices → **Angular momentum** → **Particles polarized**

Theoretical Uncertainty

What we can learn about particle production models using the alignment in quark-gluon plasma (QGP) :

1. Cooper-Frye Model

   1.1 If spin and vorticity are in equilibrium, one expects that Cooper-Frye is a good estimate.

   1.2 This means that the density matrix is not a coherent state.

2. Coalescence Model

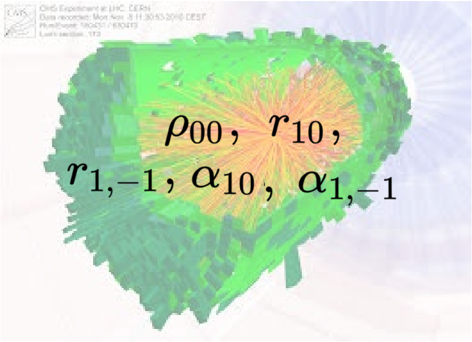
   2.1 If spin and vorticity are not in equilibrium, so coalescence model is a good estimation.

   2.2 This means that the density matrix is a coherent state.

The connection between theory and experiment

Making the transformation to the lab frame

$$\rho\left(n_3, n_8, \theta_r, \phi_r\right) = U\left(\theta_r, \phi_r\right) \rho_8\left(n_3, n_8\right) U^{-1}\left(\theta_r, \phi_r\right)$$



From this density matrix, we can obtain the following system equation:

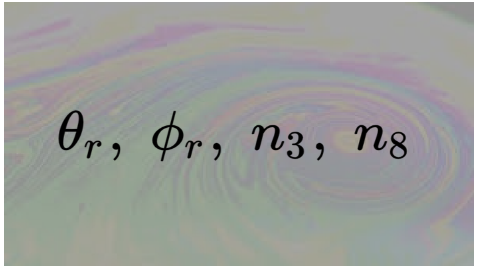
$$\frac{1}{12}\left(3\left(n_8 - \sqrt{3}\, n_3\right)\cos\left(2\theta_r\right) - \sqrt{3}\, n_3 + n_8 + 4\right) = \rho_{00}$$

$$\frac{\left(n_8 - \sqrt{3}\, n_3\right)\sin\left(\theta_r\right)\cos\left(\theta_r\right)\cos\left(\phi_r\right)}{\sqrt{2}} = r_{10}$$

$$-\frac{\left(\sqrt{3}\, n_3 + 3n_8\right)\sin\left(\theta_r\right)\sin\left(\phi_r\right)}{3\sqrt{2}} = \alpha_{10}$$

$$\phi_r = -\frac{1}{2}\tan^{-1}\left(\frac{\alpha_{1,-1}}{r_{1,-1}}\right)$$

Variable	*Element*
r_{10}	$Re[\rho_{-10} - \rho_{10}]$
α_{10}	$Im[-\rho_{-10} + \rho_{10}]$
$r_{1,-1}$	$Re[\rho_{1,-1}]$
$\alpha_{1,-1}$	$Im[\rho_{1,-1}]$



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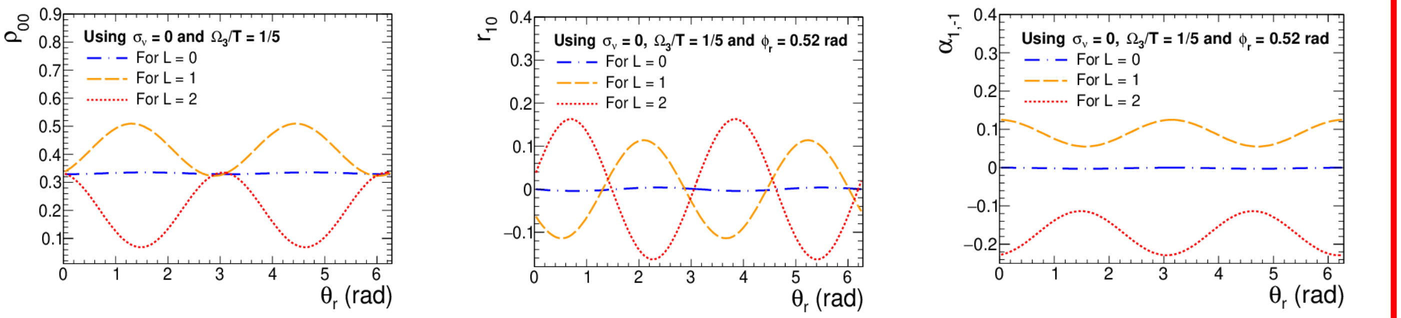
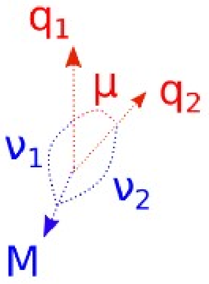
Coalescence model

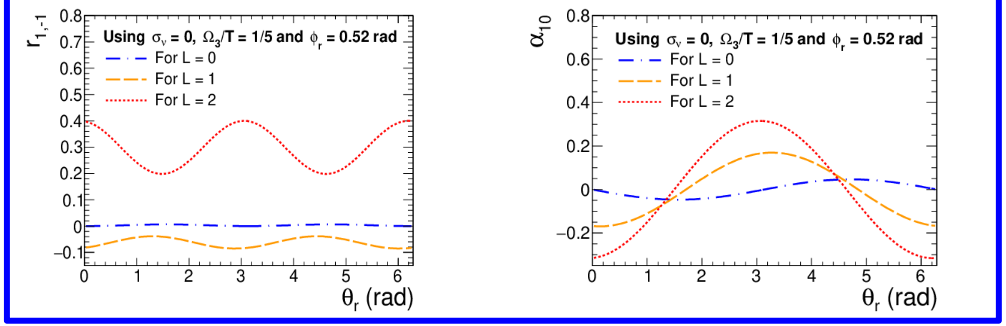
Matrix density for meson with vortice is given by:

$$(\hat{\rho}^M)_{mn} = \sum_{ijkl} (P^L_{12})_{ijklmn} U_S(\phi_r,\theta_r)\left(U_\omega(\mu_1,\nu_1)\rho^1(\Omega)U_\omega^{-1}(\mu_1,\nu_1)\right)_{ij} \times \left(U_\omega(\mu_2,\nu_2)\rho^2(\Omega)U_\omega^{-1}(\mu_2,\nu_2)\right)_{kl} U_S^{-1}(\phi_r,\theta_r)$$

The density matrix coefficients are given by:







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$\alpha_{1,-1}$	$Im[\rho_{1,-1}]$

Conclusions and Perspectives

- If spin and vorticity are in equilibrium, one expects that Cooper-Frye is a good estimate. This means that SU(3) element is not a coherent state, but rather a superposition of Eigenstates of ω an type Hamiltonian where ω_J is the total angular momentum.
- If spin and vorticity are not in equilibrium, so coalescence model is a good estimation. This means that the density matrix is a coherent state for some choice n_3, n_8, θ_r and ϕ_r .
- The next step is to use a numerical code that to solve a diffusion equation coupled to the hydro output: