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

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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.
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.
Making the transformation to the lab frame

\[ \rho (n_3, n_8, \theta_r, \phi_r) = U (\theta_r, \phi_r) \rho (n_3, n_8) U^{-1} (\theta_r, \phi_r) \]

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

\[
\frac{1}{12} \left( 3 \left( n_8 - \sqrt{3} n_3 \right) \cos (2\theta_r) - \sqrt{3} n_3 + n_8 + 4 \right) = \rho_{00} \\
\frac{\left( n_8 - \sqrt{3} n_3 \right) \sin (\theta_r) \cos (\theta_r) \cos (\phi_r)}{\sqrt{2}} = r_{10} \\
- \frac{\left( \sqrt{3} n_3 + 3n_8 \right) \sin (\theta_r) \sin (\phi_r)}{3\sqrt{2}} = \alpha_{10} \\
\phi_r = -\frac{1}{2} \tan^{-1} \left( \frac{\alpha_{1,-1}}{r_{1,-1}} \right) \\
\]

Variable | Element
--- | ---
\(r_{10}\) | \(Re[\rho_{-10} - \rho_{10}]\)
\(\alpha_{10}\) | \(Im[-\rho_{-10} + \rho_{10}]\)
\(r_{1,-1}\) | \(Re[\rho_{1,-1}]\)
\(\alpha_{1,-1}\) | \(Im[\rho_{1,-1}]\)
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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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 $\omega$ an type Hamiltonian where $\omega J$ 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 $n_3$, $n_8$, $\theta_r$ and $\phi_r$.

The next step is to use a numerical code that to solve a diffusion equation coupled to the hydro output:

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