

Spin alignment of vector mesons by glasma fields

Avdhesh Kumar*, Berndt Müller**, Di-Lun Yang*

*Institute of Physics, Academia Sinica, Taipei 11529, Taiwan



**Department of Physics, Duke University, Durham, North Carolina 27708-0305, USA

Based on PRD 108, 016020, arXiv:2304.04181, PRD 107, 076025, arXiv:2212.13354

Abstract

We explain how spin alignment of vector mesons can be induced by background color fields. Our study is based on the quantum kinetic theory of spinning quarks and antiquarks and incorporates the relaxation of the dynamically generated spin polarization. The spin density matrix of vector mesons is obtained by quark coalescence via the Wigner function and kinetic equation. Our approach predicts a local spin correlation that is distinct from the non-local expressions previously obtained in phenomenological derivations. We estimate the magnitude of such local correlations in the glasma model of the preequilibrium phase of relativistic heavy ion collisions. It is found that the resulting spin alignment could be greatly enhanced and may be comparable to the experimental measurement in order of magnitude. We further propose new phenomenological scenarios to qualitatively explain the transverse-momentum and centrality dependence of spin alignment in a self-consistent framework.

Dynamical spin polarization

Quantum kinetic theory: K. Hattori, Y. Hidaka, D.-L.. Yang, PRD100, 096011 (2019), JHEP 20, 070 (2020) Review : Y. Hidaka S. Pu, Q, Wang, D.-L. Yang, PPNP 127, 103989 (2022)

 $\mathcal{V}^{\mu}(p,x) = \frac{1}{4} \operatorname{tr}\left(\gamma^{\mu} S^{<}(p,x)\right), \quad \mathcal{A}^{\mu}(p,x) = \frac{1}{4} \operatorname{tr}\left(\gamma^{\mu} \gamma^{5} S^{<}(p,x)\right), \quad S^{<}(p,x) = \int d^{4}s \, \mathrm{e}^{-\frac{\mathrm{i}p \cdot s}{\hbar}} \langle \bar{\psi}(x-s/2) U(x-s/2,x+s/2) \psi(x+s/2) \rangle.$

L.O. solution (from the Kadanoff-Baym eq.): Power counting: $f_V \sim \mathcal{O}(\hbar^0), \tilde{a}^{\mu} \sim \mathcal{O}(\hbar).$ Kinetic equations : $p^{\mu} (\partial_{\mu} + eF_{\nu\mu}\partial_{p}^{\nu}) f_V = C[f_V]$ $\mathcal{V}^{\mu}(p,x) = 2\pi \delta(p^2 - m^2) \tilde{a}^{\mu} + \hbar e \tilde{F}^{\mu\nu} p_{\nu} \delta'(p^2 - m^2) f_V],$

$$p \cdot \partial \tilde{a}^{\mu} - \frac{e}{2} \hbar \epsilon^{\mu\nu\rho\sigma} p_{\rho} (\partial_{\sigma} F_{\beta\nu}) \partial_{p}^{\beta} f_{V} = -\frac{p_{0}(\tilde{a}^{\mu} - \tilde{a}_{eq}^{\mu})}{\tau_{R}} \qquad \text{(weak-coupling limit)}$$

$$\delta \tilde{a}^{i}(p,x) = \frac{\hbar e}{2p_{0}} \int_{-\infty}^{\infty} dx_{0}^{\prime} \Theta(x_{0} - x_{0}^{\prime}) \Theta(x_{0}^{\prime}) e^{-(x_{0} - x_{0}^{\prime})/\tau_{\mathrm{R}}} \left(p_{0} \partial_{0} B^{i}(x^{\prime}) + \epsilon^{ijk} p_{k} \partial_{0} E_{j}(x^{\prime}) \right) \partial_{p0} \tilde{f}_{V}, \qquad \delta \tilde{a}^{i}(p,x) = \tilde{a}^{i}(p,x) - \tilde{a}^{i}_{0} \Phi^{i}(x^{\prime}) + \epsilon^{ijk} p_{k} \partial_{0} E_{j}(x^{\prime}) = 0$$

Spin alignment of vector mesons





Primary contribution : 2-field correlations $\propto \langle B^{az}(X)B^{az}(X)\rangle_{X_0=0}$

Spin-alignment puzzle : negligible deviation of ρ_{00} from 1/3 from vorticity e.g. $\rho_{00} \approx \frac{1}{3} - \left(\frac{\omega}{T}\right)^2$, $\frac{\omega}{T} \sim 0.1\%$ at LHC energy. (from Λ polarization)

(Other corrections from hydrodynamic gradients such as the thermal-shear term should be of the same order.)

Other sources for spin polarization (alignment) beyond hydrodynamic gradients (in QGP)?



Spin alignment is led by spin correlations :

 $\langle \mathcal{P}_q^i \mathcal{P}_{\bar{q}}^i \rangle \neq \langle \mathcal{P}_q^i \rangle \langle \mathcal{P}_{\bar{q}}^i \rangle \implies \rho_{00} \neq 1/3 \text{ with } \langle \mathcal{P}_{q/\bar{q}}^i \rangle = 0 \text{ is possible }$

spin polarization of Λ could be unaffected (the sources for spin alignment may be fluctuating)

Generic spin density matrix from quark coalescence :

From the kinetic theory of ϕ mesons (rest frame, non-relativistic limit): A. Kumar, B. Müller, D.-L. Yang, PRD 108, 016020



Momentum dep. : boosting color fields

lasma : nisotropic lor fields) otropic otential :	$ ho_{00}$ –	$\frac{1}{3} \approx$	$\frac{\hbar^2 g^2 (v_x^2}{v_x^2}$	$\frac{-2v_y^2-1)e^{-2X_0^{\rm eq}/\tau_{\rm p}}}{72N_c^2n}$	$\overset{\circ}{\mathbf{R}} \int d\Sigma_X \cdot q \langle B^{az}(0, \mathbf{z}) \rangle \\ m^2 \int d\Sigma_X \cdot q f_{\mathrm{V}q}^{\mathrm{th}}(\epsilon_{\mathbf{q}/\mathbf{z}}) \rangle $	$egin{array}{lll} m{X} B^{az}(0,m{X}) angle_{0,m{X}} \ m{X} \ m{X}) & = \ m{X} \ m{X$	$(\partial_{\epsilon_{\boldsymbol{q}/2}} \tilde{f}_V(\epsilon_{\boldsymbol{q}/2}, 0))$
	$\rho_{00} - \frac{1}{3} \approx \frac{\hbar^2 g^2 (v_x^2 - 2v_y^2) e^{-2X_0^{\text{eq}}/\tau_{\text{R}}^{\text{o}}} \int d\Sigma_X \cdot q \langle B^a(0, \boldsymbol{X}) B^a(0, \boldsymbol{X}) \rangle (\partial_{\epsilon_{\boldsymbol{q}/2}} \tilde{f}_V(\epsilon_{\boldsymbol{q}/2}, 0))^2}{36N_c^2 m^2 \int d\Sigma_X \cdot q f_{\text{V}\boldsymbol{q}}^{\text{th}}(\epsilon_{\boldsymbol{q}/2}) f_{\text{V}\bar{\boldsymbol{q}}}^{\text{th}}(\epsilon_{\boldsymbol{q}/2})}$						
nomentum nisotropy)				small-P _T	large-P _T	central	non-central





RESEARCH POSTER PRESENTATION DESIGN © 2012 WWW.PosterPresentations.com