Polarization of vector meson and quarkonium in non-equilibrium

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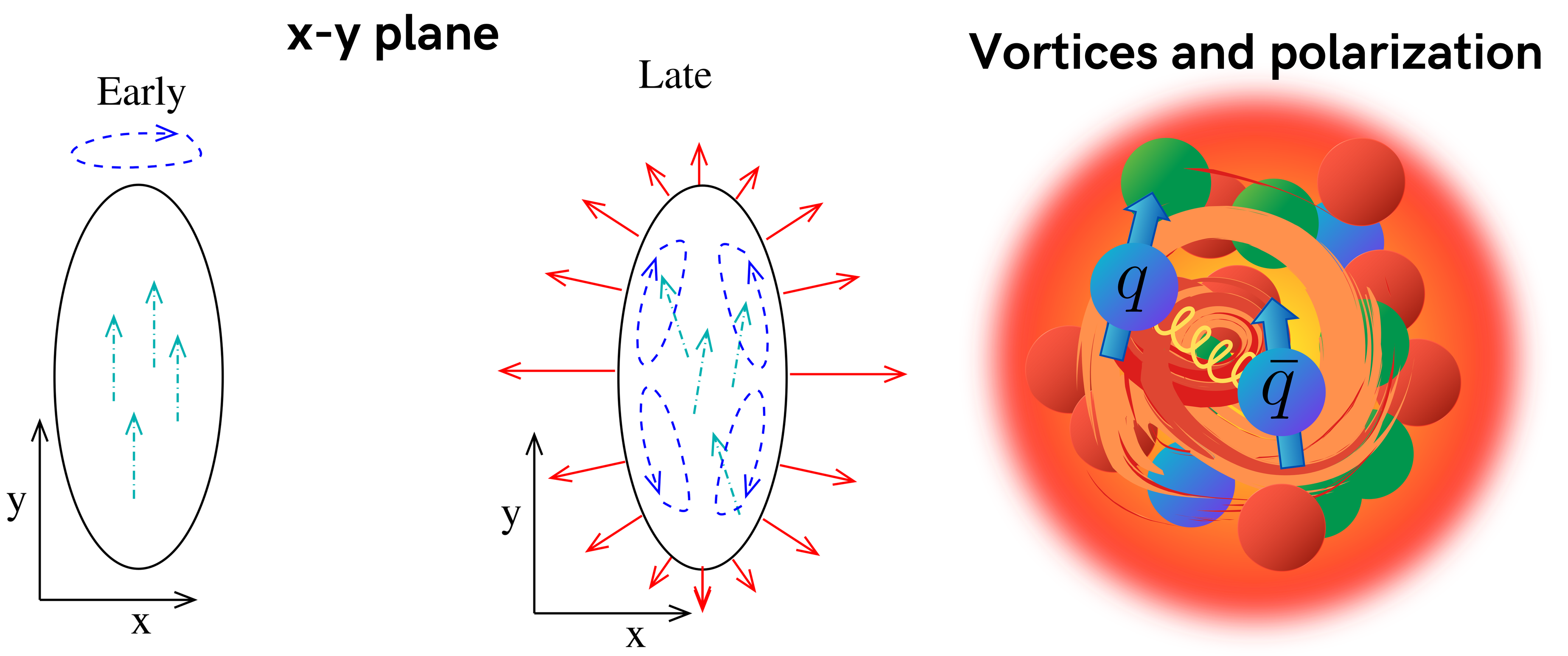
Abstract

We argue that spin alignment of hadrons of spin 1 and higher provide a unique window into the study of hydrodynamics with spin, because it is capable to probe non-equilibrium between spin density and vorticity. This happens because most of the full 3X3 density matrix is in principle accessible experimentally, and non-zero off-diagonal matrix elements can be directly linked to such non-equilibrium.

Introduction

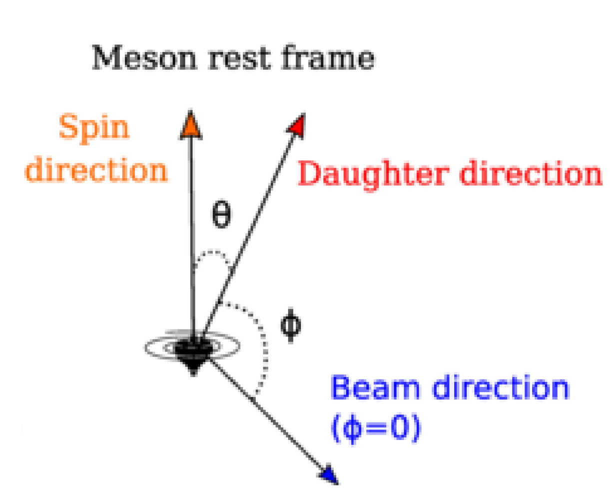


- Polarization is first created in the reaction plane direction but the transversion expansion makes vorticity in the longitudinal direction too.
- **The vorticity and spin are not necessarily in equilibrium.**

Quarkonium Polarization

- The particle angular distribution is given by:

$$\frac{dN}{d\Omega} = \frac{1}{8\pi}\Big[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta - 2Re\rho_{-1,1}\sin^2\theta\cos(2\phi)\Big] - 2Im\rho_{-1,1}\sin^2\theta\sin(2\phi) + \sqrt{2}Re(\rho_{-1,0}-\rho_{0,1})\sin(2\theta)\cos\phi + \sqrt{2}Im(\rho_{-1,0}-\rho_{0,1})\sin(2\theta)\sin\phi\Big]$$



$$\rho_{00} = \frac{1+\lambda_\theta}{3+\lambda_\theta}, r_{1,-1} = \frac{\lambda_\phi}{3+\lambda_\theta}, r_{10} = \frac{\lambda_{\theta\phi}}{3+\lambda_\theta}$$

Methods and results

Is it possible to know about the degree of equilibrium between spin and vorticity?

- The density matrix from SU(3) group:

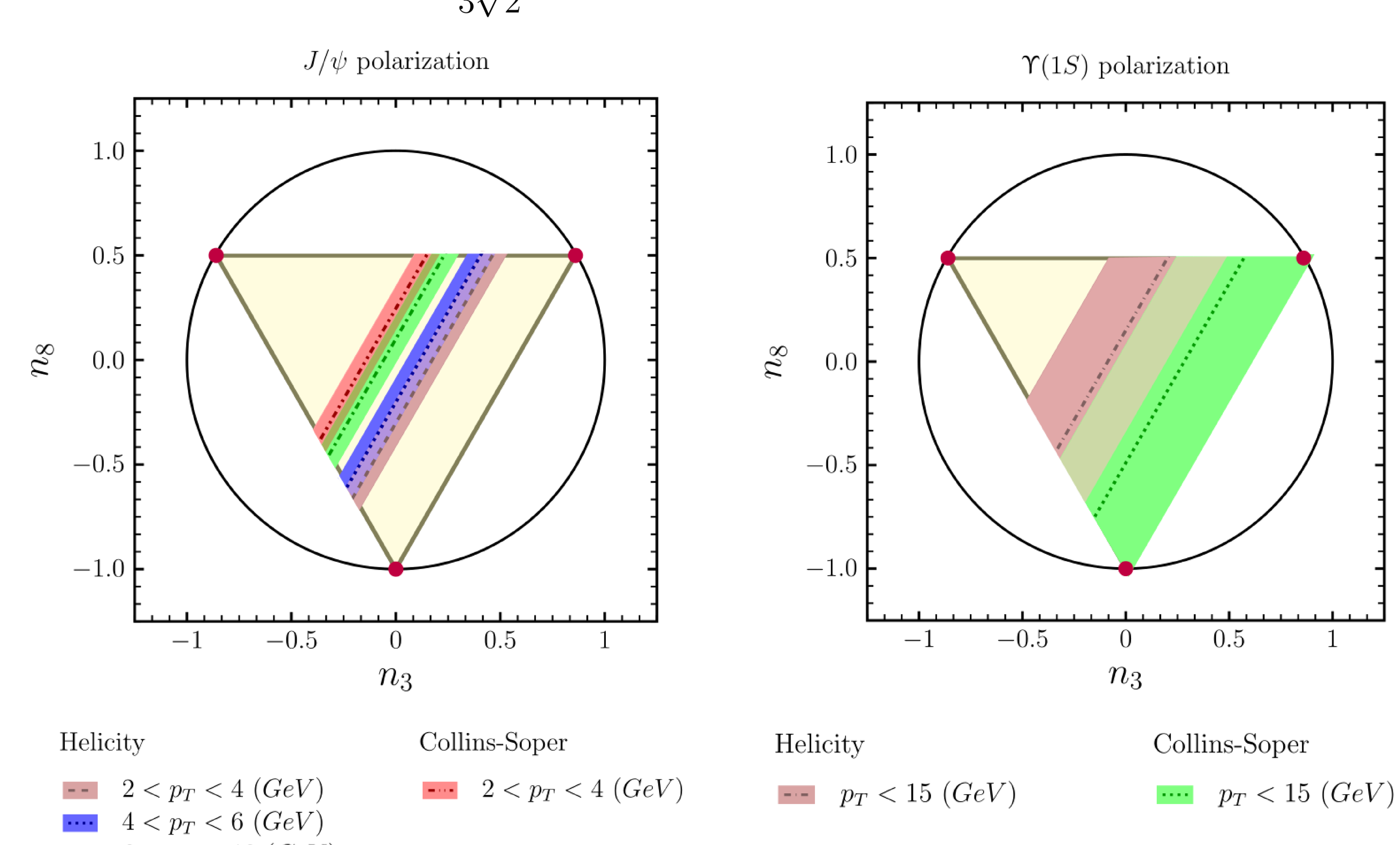
$$\rho_8(n_3,n_8) = \frac{1}{3}\begin{pmatrix} 1+\sqrt{3}\,n_3+n_8 & 0 & 0 \\ 0 & 1-\sqrt{3}\,n_3+n_8 & 0 \\ 0 & 0 & 1-2n_8 \end{pmatrix} \text{ and } \rho = U(\theta_r,\phi_r)\,\rho\,U^{-1}(\theta_r,\phi_r)$$

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

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

$$\rightarrow$$

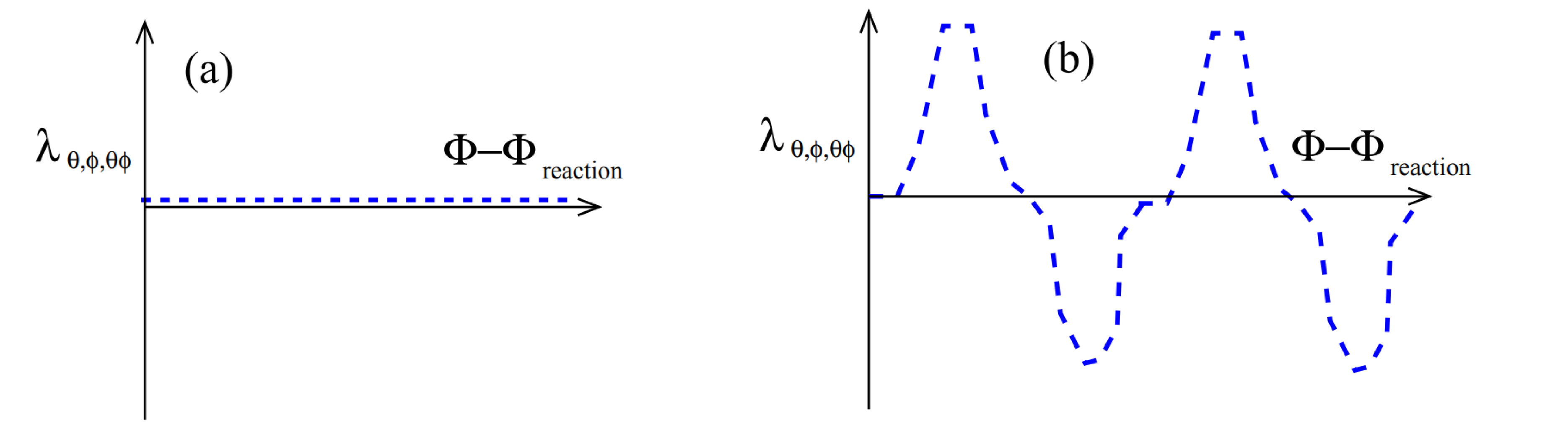
$$\frac{1}{12}(3\tilde{n}\cos(2\theta_r) + \tilde{n} + 4) = \rho_{00}$$
$$\frac{\tilde{n}\sin(\theta_r)\cos(\theta_r)\cos(\phi_r)}{\sqrt{2}} = r_{10}$$
$$\phi_r = 0$$



The quarkonium state in rotating reference frames

- The Schrödinger equation in rotating reference frames to describe quarkonium in a vortice. **(For more details, see poster 523 on Heavy Flavor by Paulo Moura).**

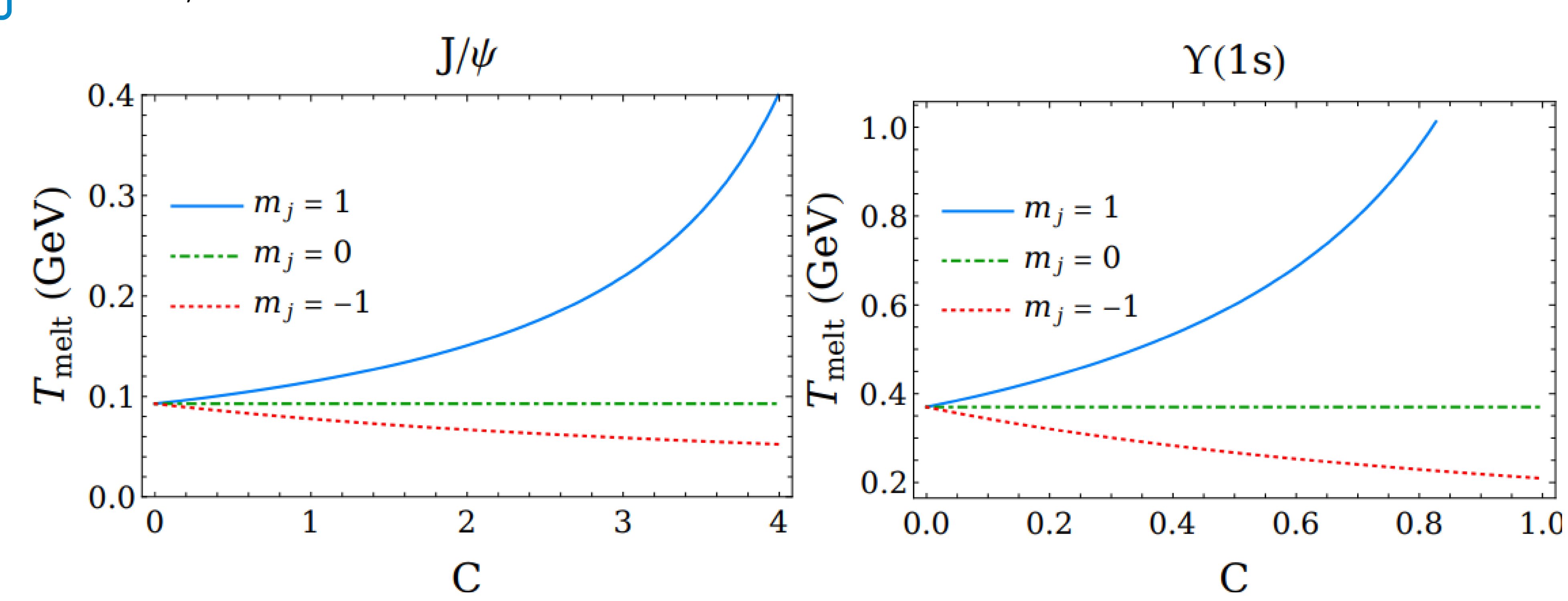
- A schematic illustration of how we expect the $\lambda_{\theta,\phi,\theta\phi}$ coefficients to evolve with the reaction plane. The estimate of these coefficients using blast wave model for charmonium is $\lambda_\theta = 0.021,\ \ \lambda_\phi = 0.023,\ \ \lambda_{\theta\phi} = 0.012$.



- We can use a semi-classical estimate to obtain the melting temperature, which is described in detail in [2], so:

$$T_{\rm melt} = 0.840\sqrt{\frac{2\alpha_{eff}}{9\pi}}\left[\frac{1}{\mu} - \frac{m_j C}{\pi}\right]^{-1}$$

- Then,

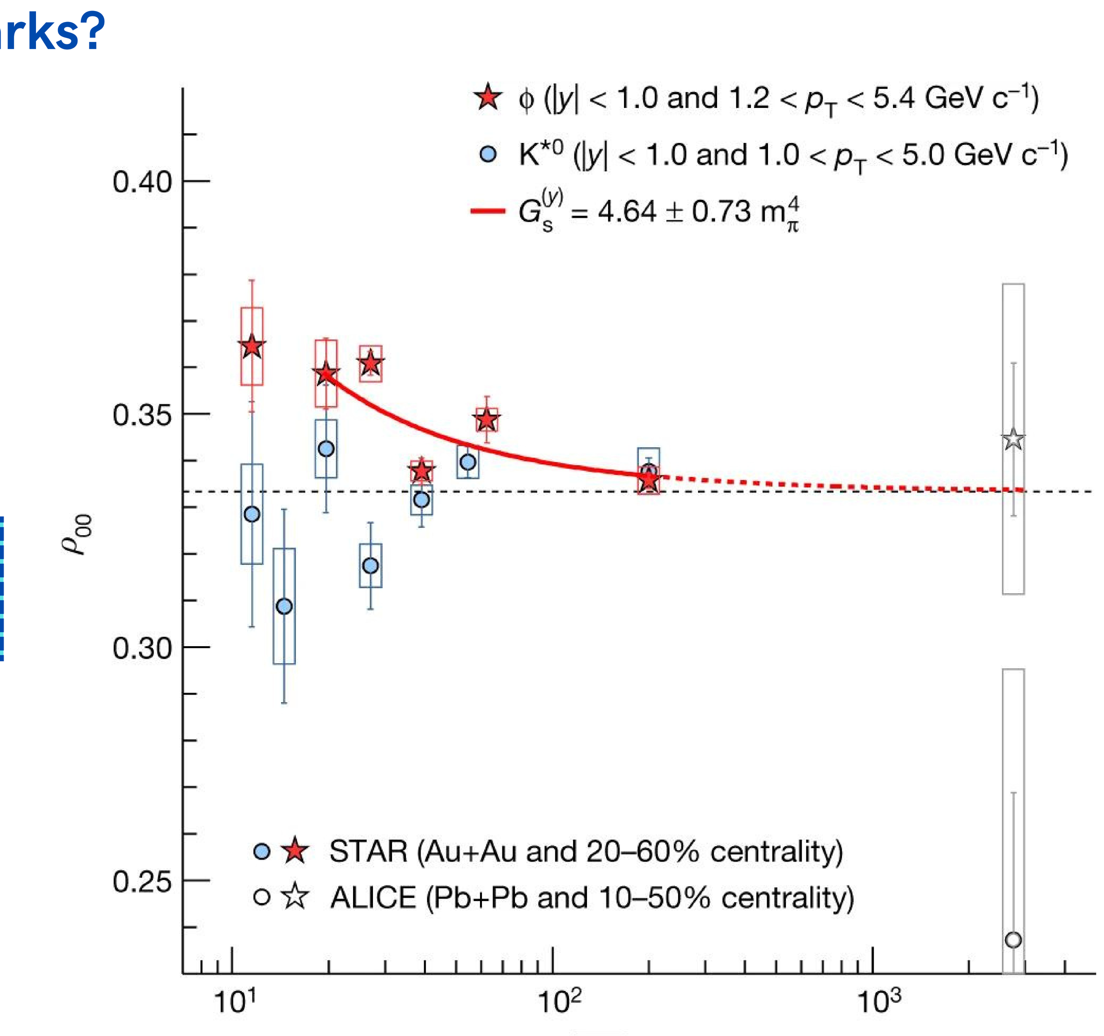


Is it possible to apply our model to the meson ϕ, which is formed of strange and anti-strange quarks?

- We can use together the melting temperature with density matrix definition to spin 1, where is given by:

$$\hat{\rho} = e^{-\beta\hat{H}}, \beta = \frac{1}{T}$$

WORK IN PROGRESS



Conclusion and prospects

We have used the techniques developed in [1] on the experimental Quarkonium polarization measurement in Pb-Pb collisions. Speculatively considering the ϕ a quarkonium state could explain the strong alignment signal, though some phenomenological work is needed to confirm if such a model is viable.

References

[1] Kayman J. Gonçalves and Giorgio Torrieri Phys.Rev. C 105, 034913.
[2]Paulo Henrique De Moura, Kayman J. Gonçalves, and Giorgio Torrieri Phys. Rev. D 108, 034032

Acknowledgments

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