Motion/shear induced J/psi spin alignment

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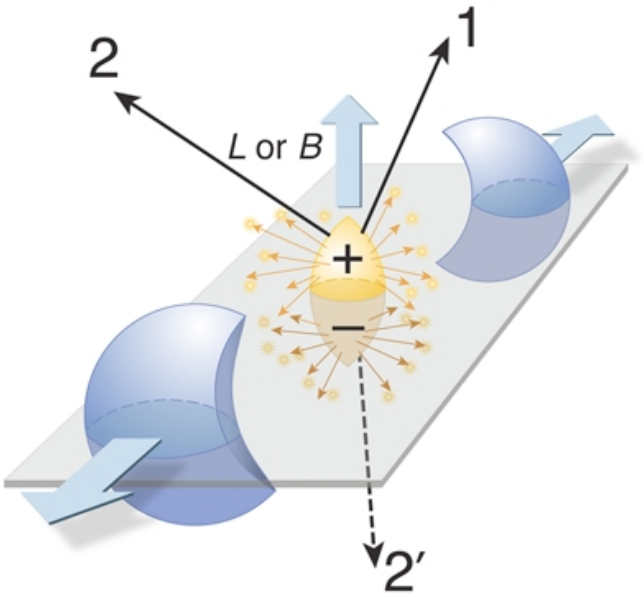
梁宇浩 , SL, to appear

Outline

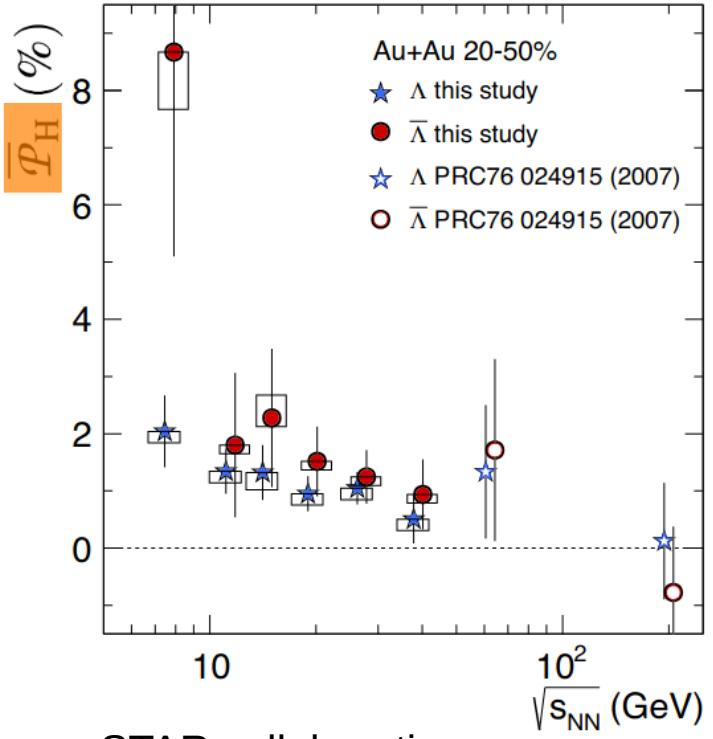
- Spin phenomena in heavy ion collisions
- Vector meson spin alignment from medium induced spin correlation
- Spin correlation from chromoB fluctuation: motion and shear
- Application to J/psi spin alignment
- Extension to phi spin alignment
- Summary and outlook

Global polarization of Λ



$$L_{ini} \sim 10^5 \hbar \rightarrow S_{final}$$

Liang, Wang, PRL 2005, PLB 2005

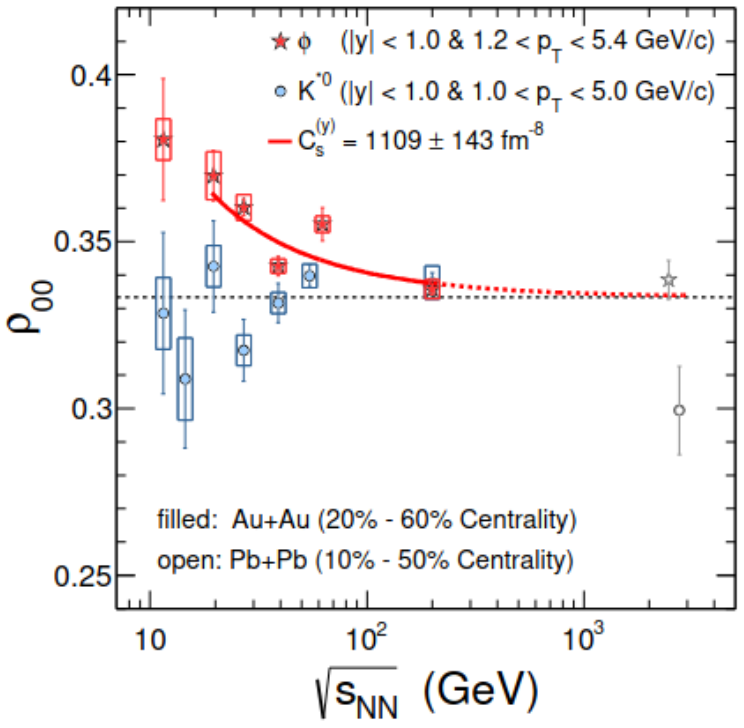


STAR collaboration, Nature 2017

$$e^{-\beta(H_0 - \mathbf{S}\cdot\boldsymbol{\omega})}$$

Becattini et al, PRC 2017

Global spin alignment of phi



STAR, Nature 2023

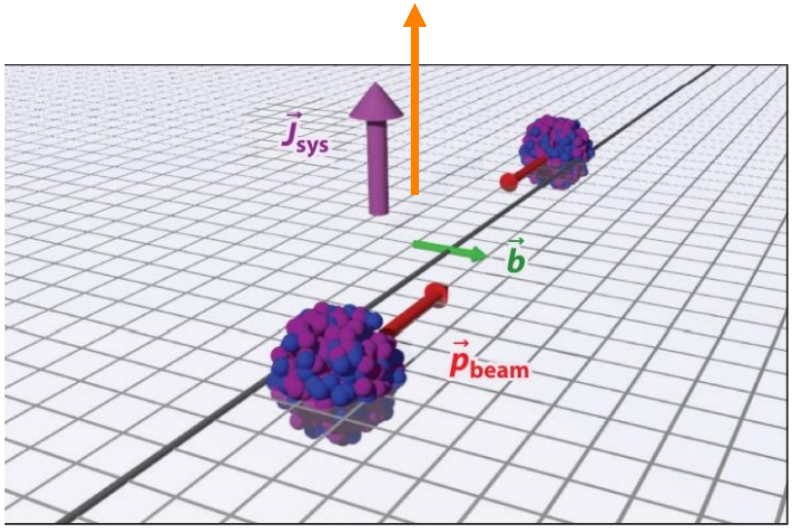
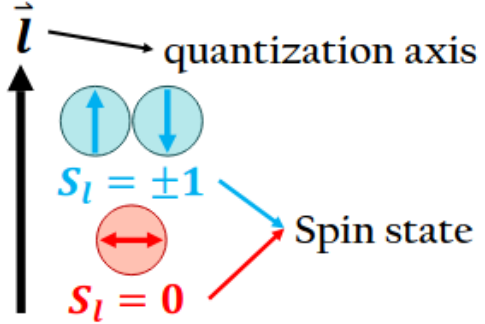


Figure from F. Becattini-Michael A. Lisa, AR 2020

quantization axis: n

$$\rho = \begin{pmatrix} \rho_{11} & \rho_{1,0} & \rho_{1,-1} \\ \rho^*_{1,0} & \rho_{00} & \rho_{0,-1} \\ \rho^*_{1,-1} & \rho^*_{0,-1} & \rho_{-1,-1} \end{pmatrix}$$



Theoretical proposals for spin alignment

- Fluctuations
- Vorticity, shear
- Electromagnetic fields
- In-medium spectral splitting

Sheng, Oliva, Liang, Wang, Wang, PRL 2023
Kumar, Muller, Yang, PRD 2023
Li, Liu, 2022
Wagner, Weickgenannt, Speranza, PRR 2023
Sheng, Zhao, Li, Becattini, Hou, PRD 2024
Zhao, Sheng, Li, Hou, JHEP 2024
Xu, Huang, PRD 2024
Chen, Fu, Huang, Ma, PRL 2025
Chen, SL, PRD 2025
De Moura, Goncalves, Torrieri, PRD 2023
Liang, SL, CPC 2025
Yan, SL, 2025

Spin alignment from constituent polarization

Non-relativistic quark model

$$\mathcal{P}_\Lambda = \mathcal{P}_s$$

$$\rho_{00} - \frac{1}{3} = -\frac{4}{9}\mathcal{P}_s\mathcal{P}_{\bar{s}}$$

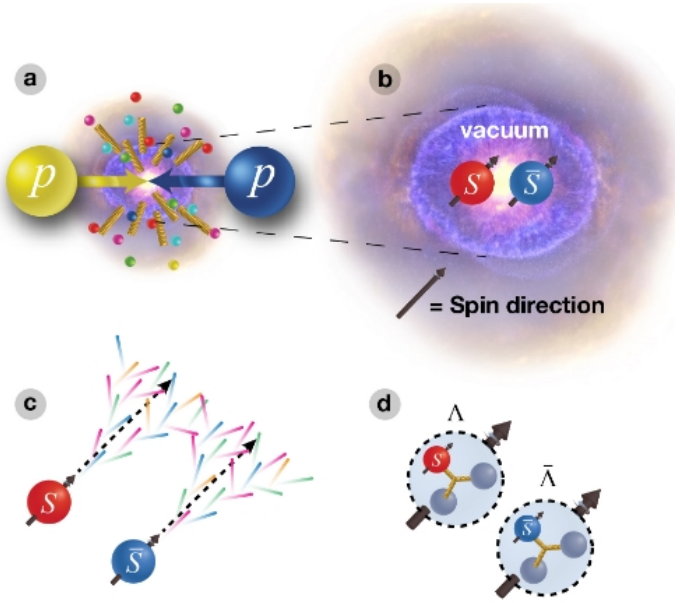
Liang, Wang, PLB 2005
Yang, Fang, Wang, Wang, PRC 2018

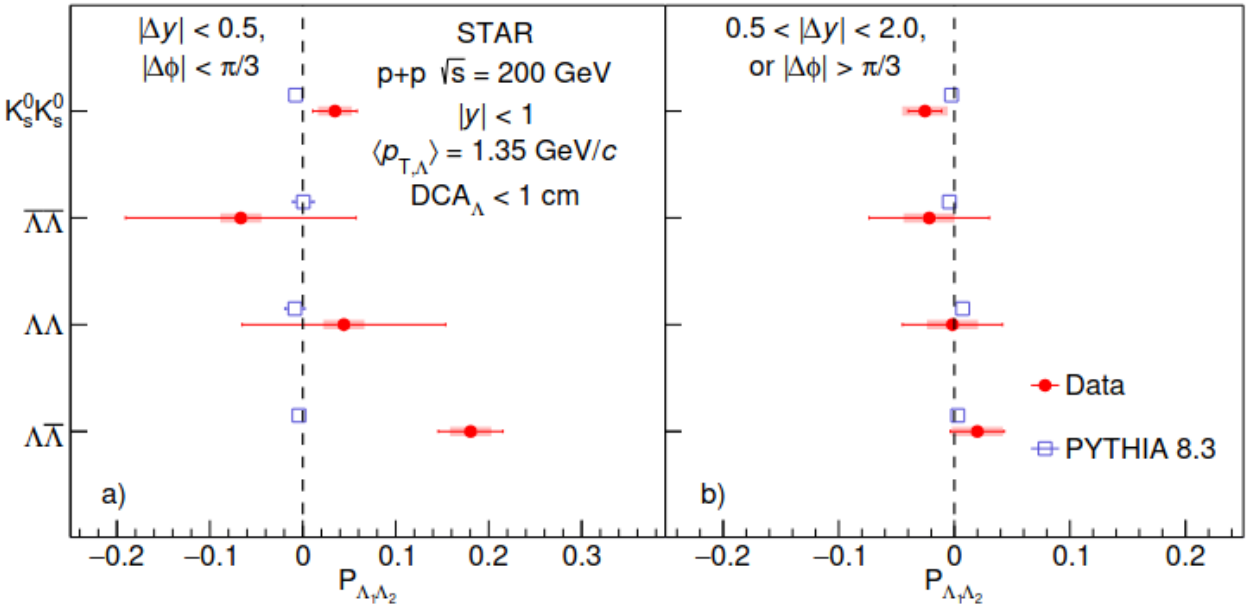
polarization too small to explain alignment,
need spin correlation

$$\langle \mathcal{P}_q \mathcal{P}_{\bar{q}} \rangle \neq \langle \mathcal{P}_q \rangle \langle \mathcal{P}_{\bar{q}} \rangle$$

Sheng, Oliva, Wang, PRD 2020
Sheng, Wang, Wang, PRD 2020
Sheng, Oliva, Liang, Wang, Wang, PRL 2023, PRD 2024
Lv-Yu-Liang-Wang-Wang, PRD 2024

Spin correlations from experiments





$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^\star} = \frac{1}{2}[1+\alpha_1\alpha_2 P_{\Lambda_1\Lambda_2}\cos\theta^\star]$$

STAR, Nature 2026

Spin correlation of Λ pair from vacuum
(not correlated with event plane)

What about spin correlation from medium?

Possible medium induced spin correlation

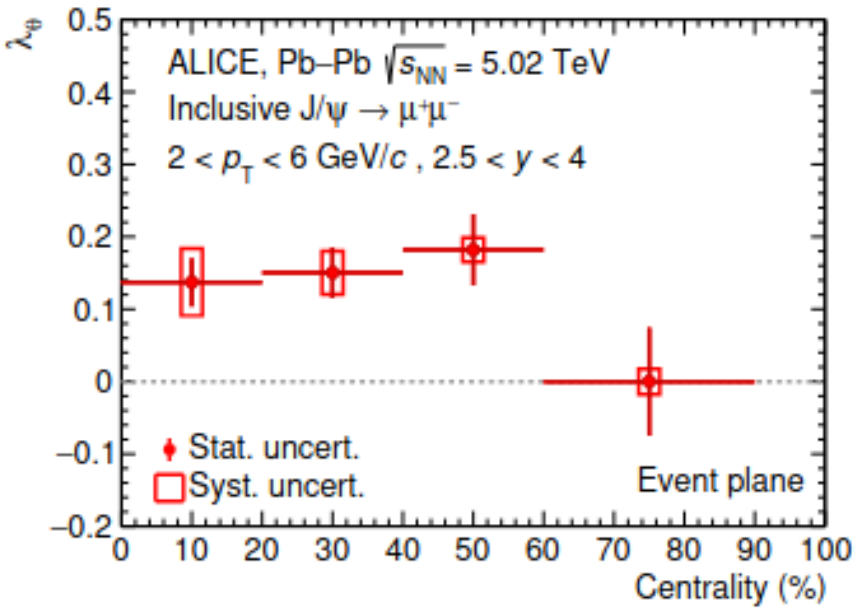
- phi field fluctuation

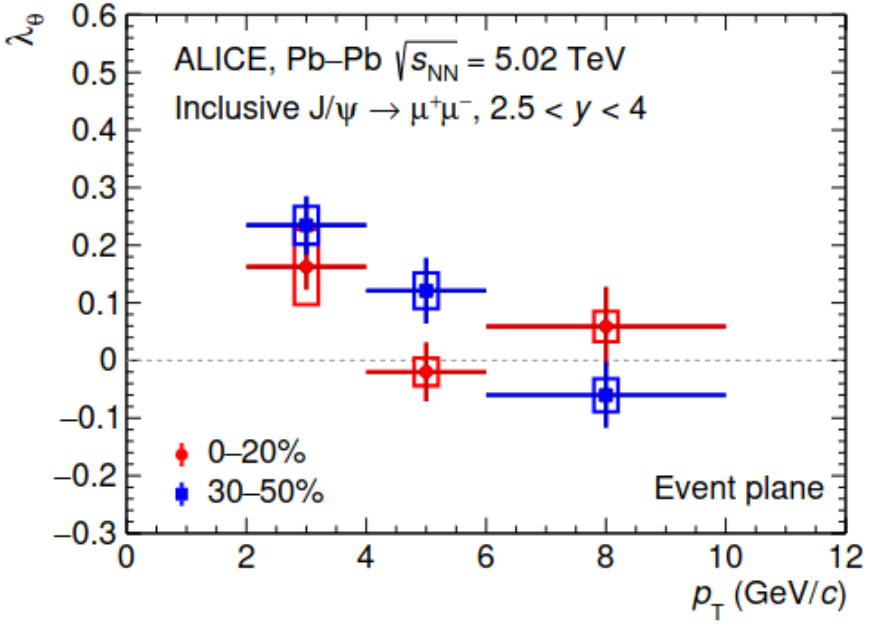
Sheng, Oliva, Wang, PRD 2020
Sheng, Wang, Wang, PRD 2020
Sheng, Oliva, Liang, Wang, Wang, PRL 2023, PRD 2024

- chromomagnetic field fluctuation

Muller, Yang, PRDs 2023
Chen, SL, PRD 2025

Global spin alignment of J/psi





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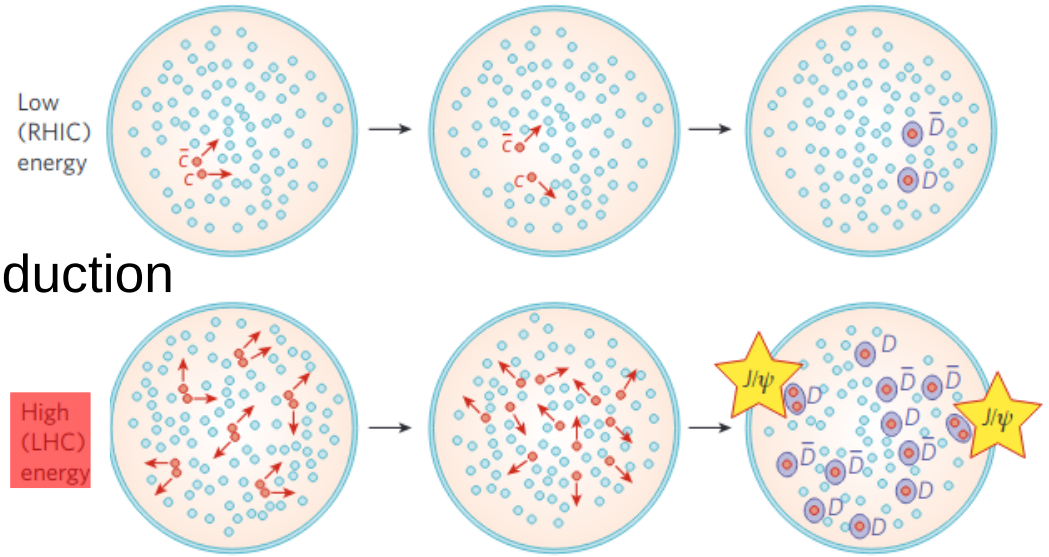
$$\lambda_\vartheta = \frac{1-3\rho_{00}}{1+\rho_{00}} \qquad \rho_{00} < 1/3$$

opposite sign to phi

J/psi dynamics in QGP

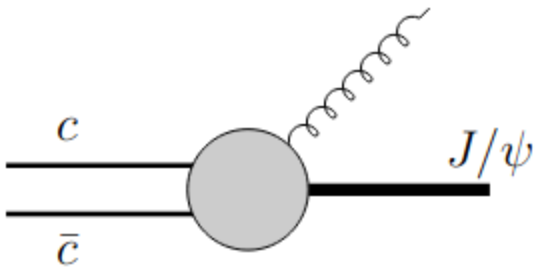


early production

dissociation dominate

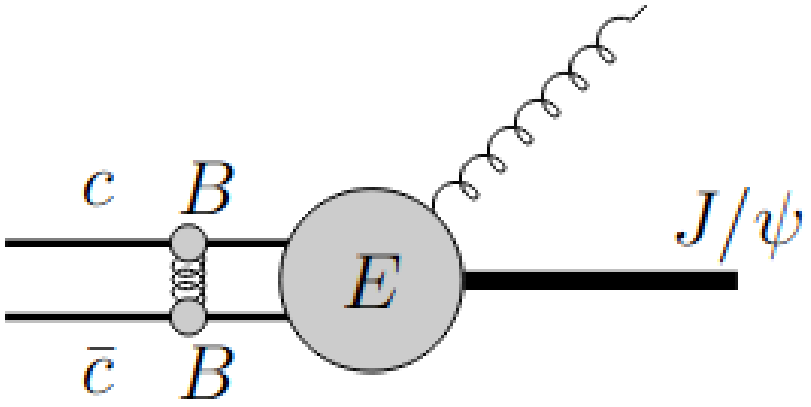
regeneration dominate

Braun-Munzinger, Stachel,
Nature 2007



color octet → singlet

Spin alignment from chromo-B fluctuations

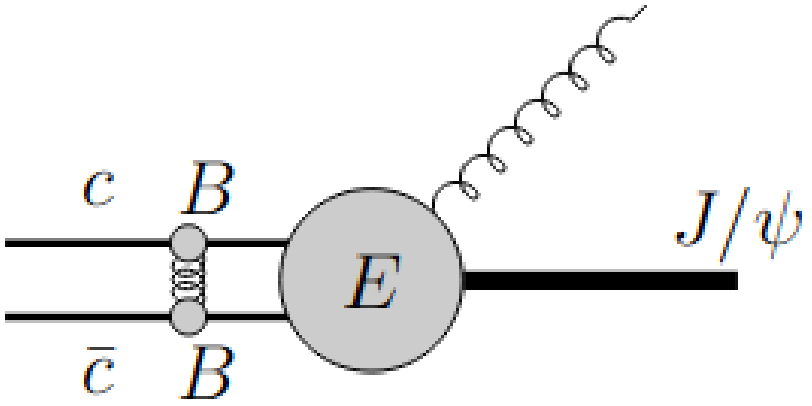


chromo-B vertices: spin correlation

chromo-E vertex: spin blind

→ Spin alignment of singlet from octet

Octet-chromo-B coupling



$$\Delta H \sim \sigma_c \cdot B \left(-\sigma_{\bar{c}} \cdot \bar{B}\right)$$

$$\langle 11|\Delta H|11\rangle = \langle 1-1,|\Delta H|1-1|\rangle \sim -B_n \bar{B}_n$$

$$\langle 10|\Delta H|10\rangle \sim 2B_n \bar{B}_n - \mathbf{B}\cdot\bar{\mathbf{B}}$$

$$B_n = \mathbf{B}\cdot\hat{n}$$

$\hat{n}$ quantization axis

Spin dependent interaction from anisotropic chromo-B fluctuaiton

Thermodynamics of octet with chromo-B source

$$\rho_{\lambda\lambda} \propto e^{-\beta \Delta H_\lambda} \qquad \lambda = 1, -1, 0$$

$$\Delta H \sim \sigma_c \cdot B \left(-\sigma_{\bar{c}} \cdot \bar{B}\right)$$

$$\langle 11|\Delta H|11\rangle = \langle 1-1, |\Delta H|1-1|\rangle \sim -B_n \bar{B}_n \qquad B_n = \mathbf{B} \cdot \hat{n}$$

$$\langle 10|\Delta H|10\rangle \sim 2B_n \bar{B}_n - \mathbf{B} \cdot \bar{\mathbf{B}}$$

$\hat{n}$ quantization axis

chromo-B fluctuation: chemical potential of spin correlation

Anisotropic fluctuation → Spin alignment of octet

Parametric estimation

$$\rho_{\lambda\lambda} \propto e^{-\beta \Delta H_\lambda} \qquad \lambda = 1, -1, 0$$

$$\Delta H \sim \sigma_c \cdot B \left(-\sigma_{\bar{c}} \cdot \bar{B}\right)$$

$$\langle 11|\Delta H|11\rangle = \langle 1-1, |\Delta H|1-1|\rangle \sim -B_n \bar{B}_n \qquad B_n = \mathbf{B} \cdot \hat{n}$$

$$\langle 10|\Delta H|10\rangle \sim 2 B_n \bar{B}_n - \mathbf{B} \cdot \bar{\mathbf{B}}$$

$\hat{n}$ quantization axis

$$\rho_{00} - \frac{1}{3} \sim \frac{\langle B^2 \rangle_{\text{aniso}}}{\langle B^2 \rangle} \beta^2 \mu_c^2 \langle B^2 \rangle \sim \frac{\langle B^2 \rangle_{\text{aniso}}}{\langle B^2 \rangle} \frac{g^2 T^2}{m_c^2}$$

source dynamic

Source of anisotropy: motion

$$\langle B_i B_j \rangle \sim \langle E_i E_j \rangle \propto \delta_{ij}$$ QGP frame: isotropic

$$\mathbf{B}' = \gamma(\mathbf{B} - \mathbf{v} \times \mathbf{E})$$

$$\langle B'_i B'_j \rangle = \gamma^2 \langle B_i B_j \rangle + \gamma^2 \langle (\mathbf{v} \times \mathbf{E})_i (\mathbf{v} \times \mathbf{E})_j \rangle$$

$$\frac{\langle B'^2 \rangle_{\text{aniso}}}{\langle B'^2 \rangle} \propto (\hat{v} \cdot \hat{n})^2 - \frac{1}{3}$$ J/psi frame: anisotropic

$\hat{n}$ quantization axis

陈志顺 , SL, PRD 2025

Source of anisotropy: shear

$$\langle B_i B_j \rangle \sim c_1 \delta_{ij} + c_2 \sigma_{ij}$$

magnetic component of gluon EM tensor $T_{ij} \sim \langle E_i E_j \rangle + \langle B_i B_j \rangle$

$$(\partial_t + \hat{\boldsymbol{p}} \cdot \boldsymbol{\nabla}_{\boldsymbol{x}})\, f_s(\boldsymbol{x}, \boldsymbol{p}, t) = -C_s^{2\leftrightarrow 2}[f] - C_s^{\text{“}1\leftrightarrow 2\text{”}}[f]$$

$$f = f(p \cdot u) + \delta f \qquad \delta f = (\cdots) f'(p \cdot u) \sigma_{ij} \hat{p}_i \hat{p}_j$$

Arnold, Moore, Yaffe, early 00s

collision dependent $c_2 \propto \eta$ $T_{ij} \sim \eta \sigma_{ij}$

$$\frac{\langle B^2 \rangle_{\text{aniso}}}{\langle B^2 \rangle} \propto -\frac{\eta}{s} \frac{\sigma_{ij} \hat{n}_i \hat{n}_j}{T}$$

Sign of spin alignment

$$\rho_{00} - \frac{1}{3} \sim \frac{\langle B^2 \rangle_{\rm aniso}}{\langle B^2 \rangle} \beta^2 \mu_c^2 \langle B^2 \rangle \sim \frac{\langle B^2 \rangle_{\rm aniso}}{\langle B^2 \rangle} \frac{g^2 T^2}{m_c^2}$$

motion

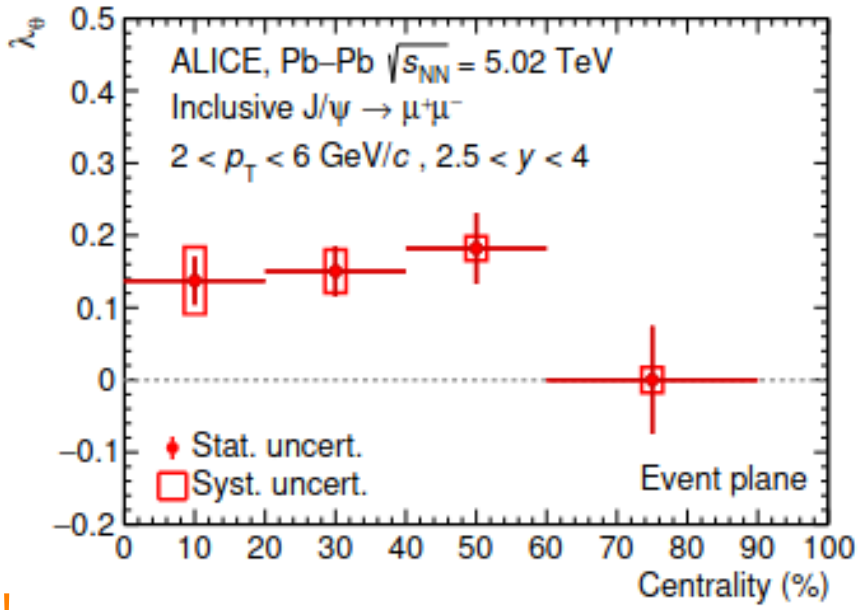
$$\frac{\langle B'^2 \rangle_{\rm aniso}}{\langle B'^2 \rangle} \propto (\hat{v} \cdot \hat{n})^2 - \frac{1}{3} \simeq -\frac{1}{3}$$ @forward rapidity

$$\rho_{00} < 1/3$$ Nonvanishing in central collisions!

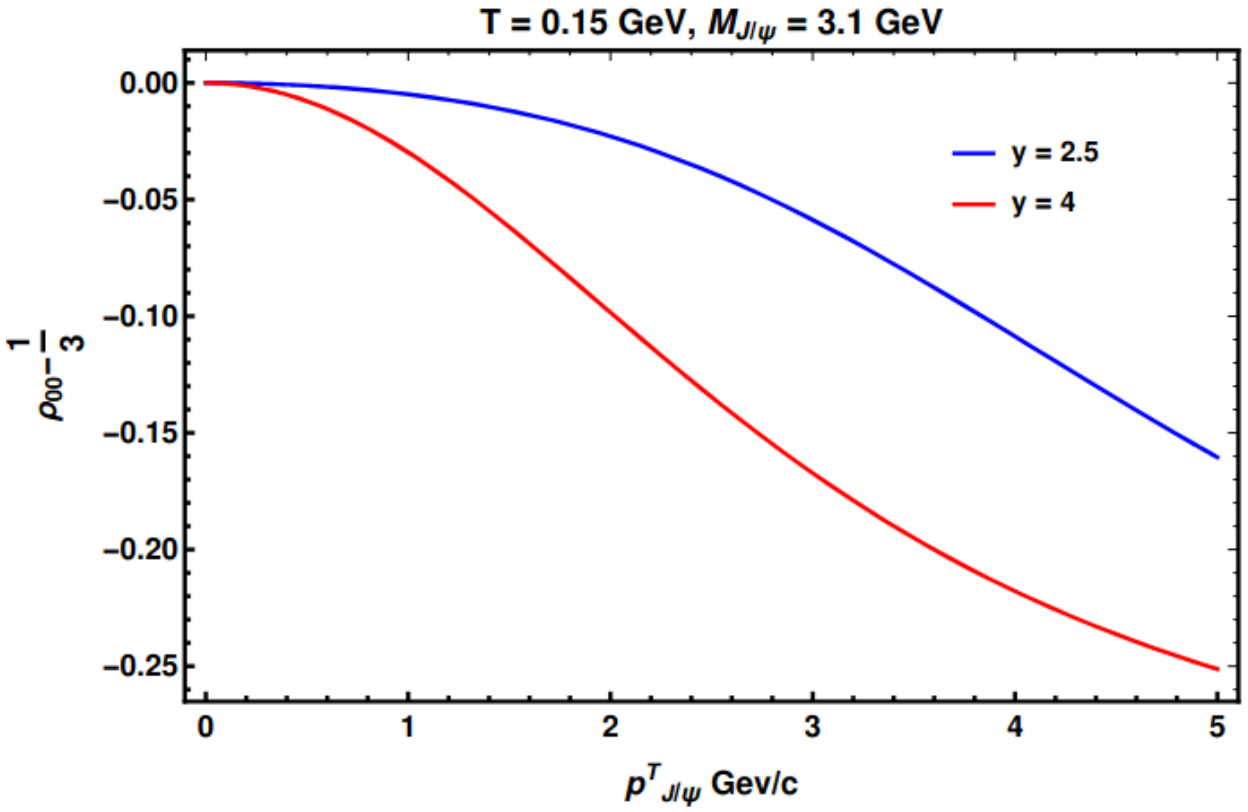
shear

$$\frac{\langle B^2 \rangle_{\rm aniso}}{\langle B^2 \rangle} \propto -\frac{\eta}{s} \frac{\sigma_{ij} \hat{n}_i \hat{n}_j}{T}$$

relevant in off-central collisions

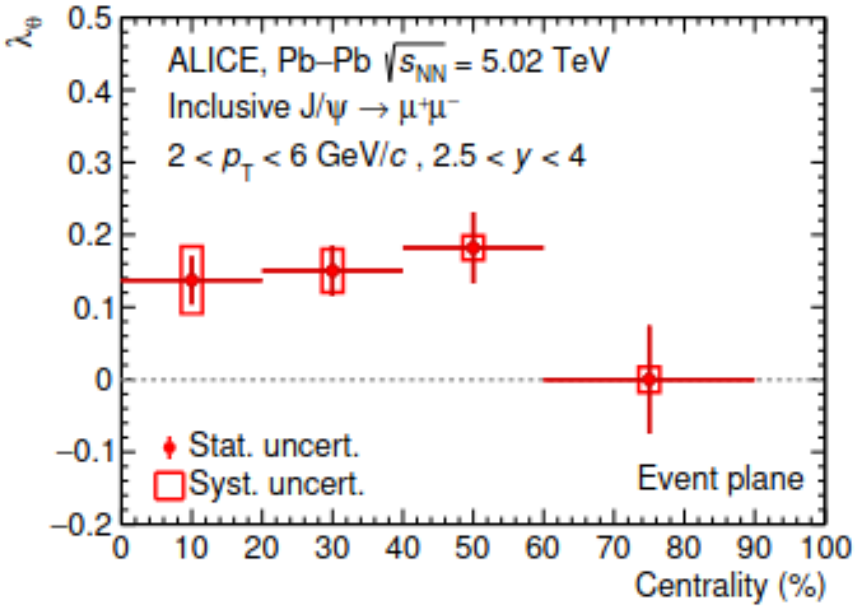


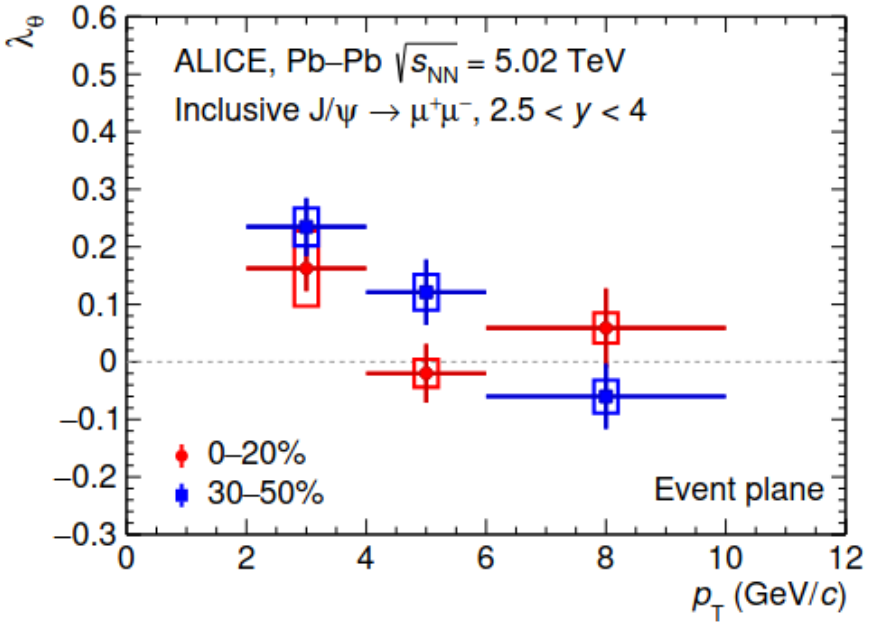
J/psi spin alignment



central collision, motion effect only

Applicable regions of the mechanism





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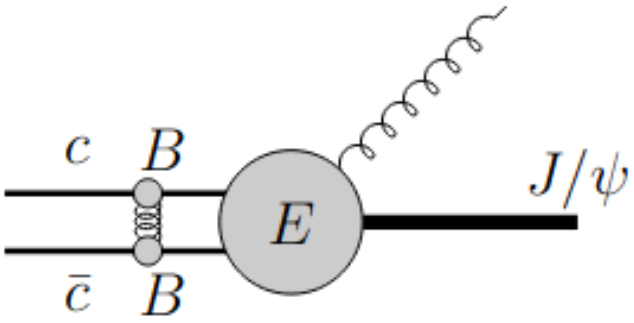
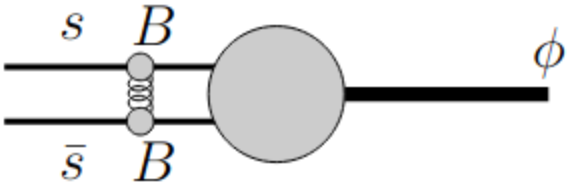
- Not too pheripheral (no medium effect)
- Not too large p_T (dissociation dominance)

Application to phi spin alignment?





$$t^a_{ji} t^a_{lk} = \frac{1}{2}\left(\delta_{il}\delta_{kj} - \frac{1}{N_c}\delta_{ij}\delta_{kl}\right)$$

singlet octet

$\rho_{00} > 1/3$

more works needed

Summary & Outlook

- J/psi spin alignment from medium induced spin correlation
- Spin correlation and in-medium chromo-B field fluctuation
- Sources of anisotropic fluctuations: motion and shear
- Possible extension to phi spin alignment

Thank you!