重离子碰撞中整体极化的实验研究

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2023/7/24

报告提纲

01 物理图像介绍

02 重离子碰撞中“整体极化”效应的实验测量

- 超子极化
- 矢量介子自旋排列

03 总结和讨论

自旋极化：从经典到量子

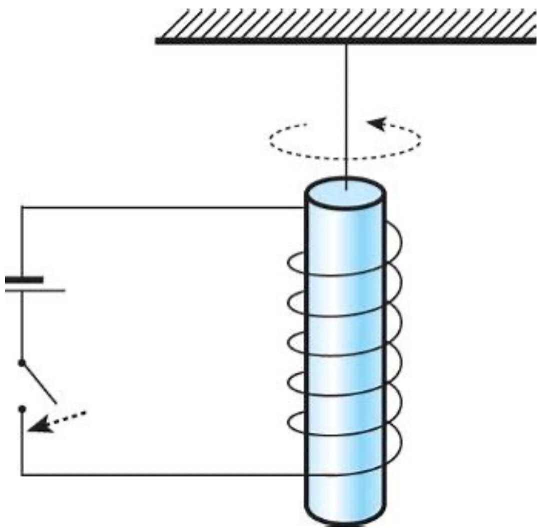
磁场、角动量与自旋的经典实验

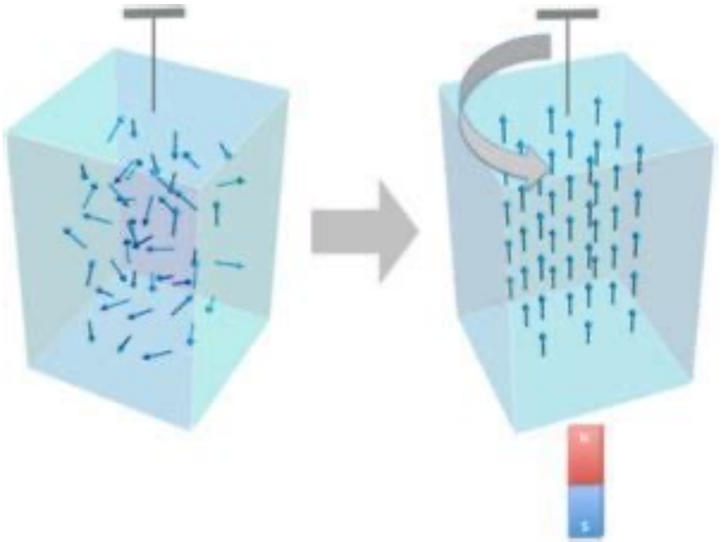
Einstein-de-Hass效应（Richardson效应），磁化后物体旋转，电子极化

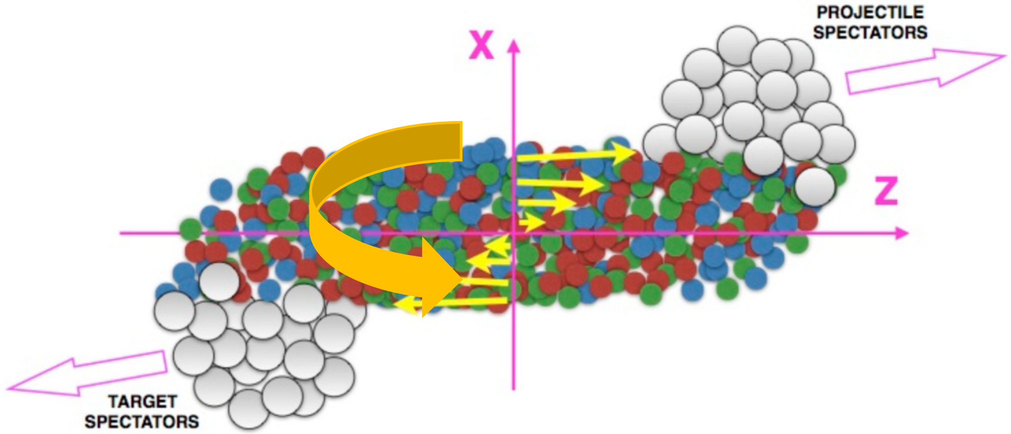
Einstein, de Haas, Deut. Phys. Gesellsch. Verhandlungen **17**,152 (1915); KNAW Proc. **181**, 696 (1915)
Richardson,Phys. Rev. **26**, 248 (1908)

Barnett效应，旋转后物体自发磁化

Barnett, Phys. Rev. **6**, 239 (1915); Science **30**, 413 (1909); Rev. Mod. Phys. **7**, 129 (1935)



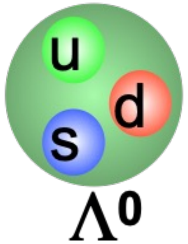




Liang, Wang Phys. Rev. Lett. **94**, 102301(2005); Phys. Lett. B **629**, 20 (2005)

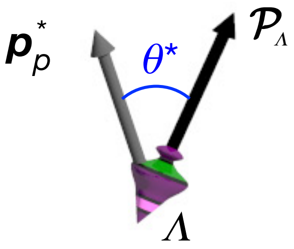
- 微观上，非对心相对论重离子产生了巨大的轨道角动量L，L通过流体涡旋的形式传递到QGP中，QGP中粒子通过轨道-自旋相互作用可以产生自旋极化
- 宏观上，自旋-涡旋耦合也能够产生自旋极化 Betz, Gyulassy, Torrieri Phys. Rev. C **76**, 044901 (2007); Becattini, Piccinini, Rizzo Phys. Rev. C **77**, 024906 (2008)

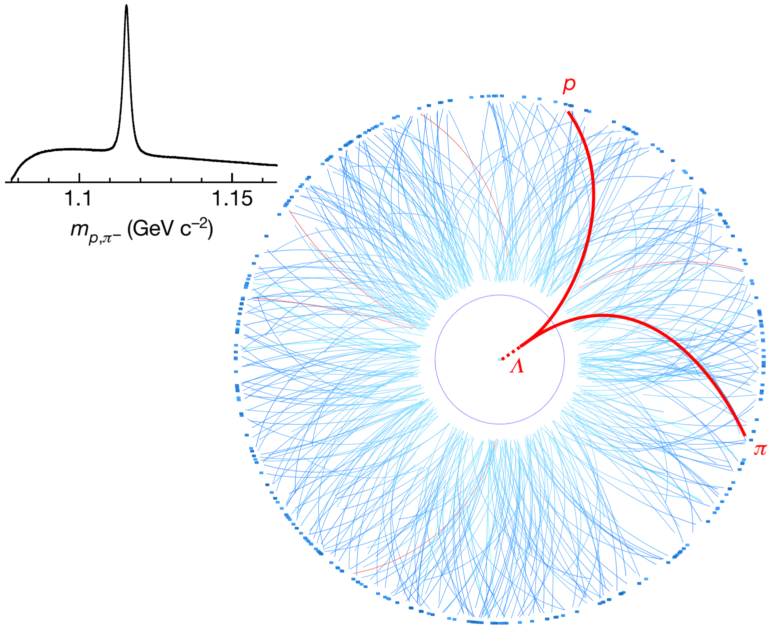
实验测量方法：超子极化

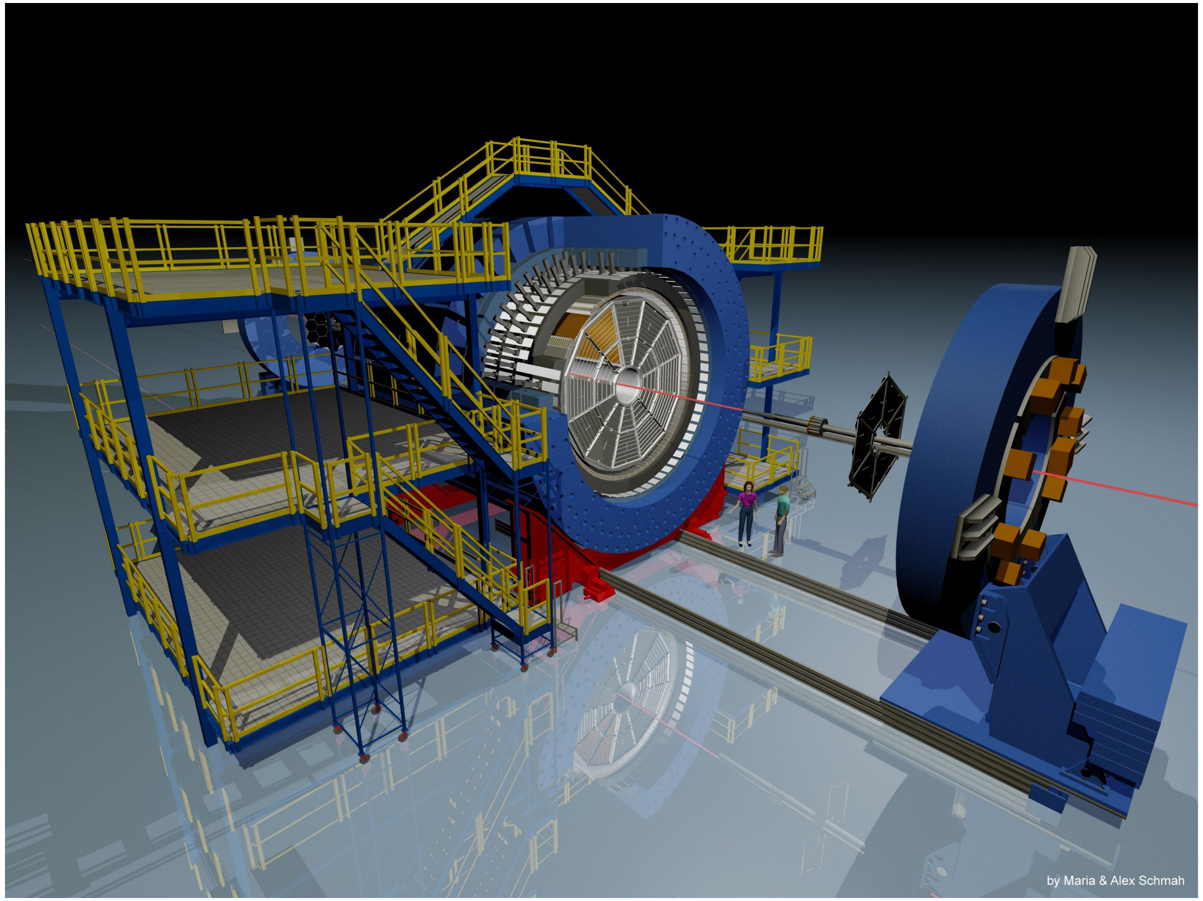


：弱衰变，宇称破缺，质子朝着Λ极化的方向飞出

$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}\left(1 + \alpha_H |\mathcal{P}_H| \cos\theta^*\right)$$





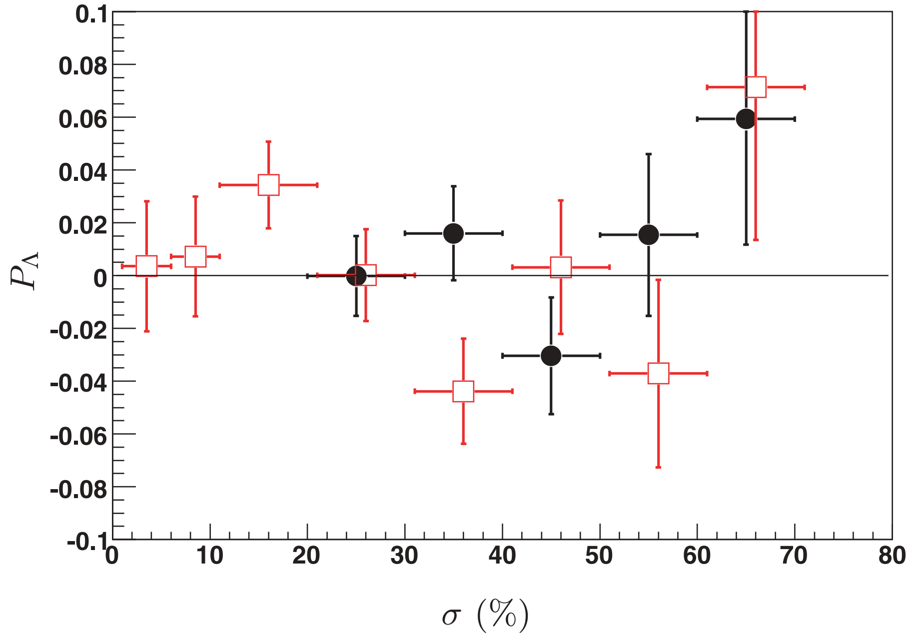


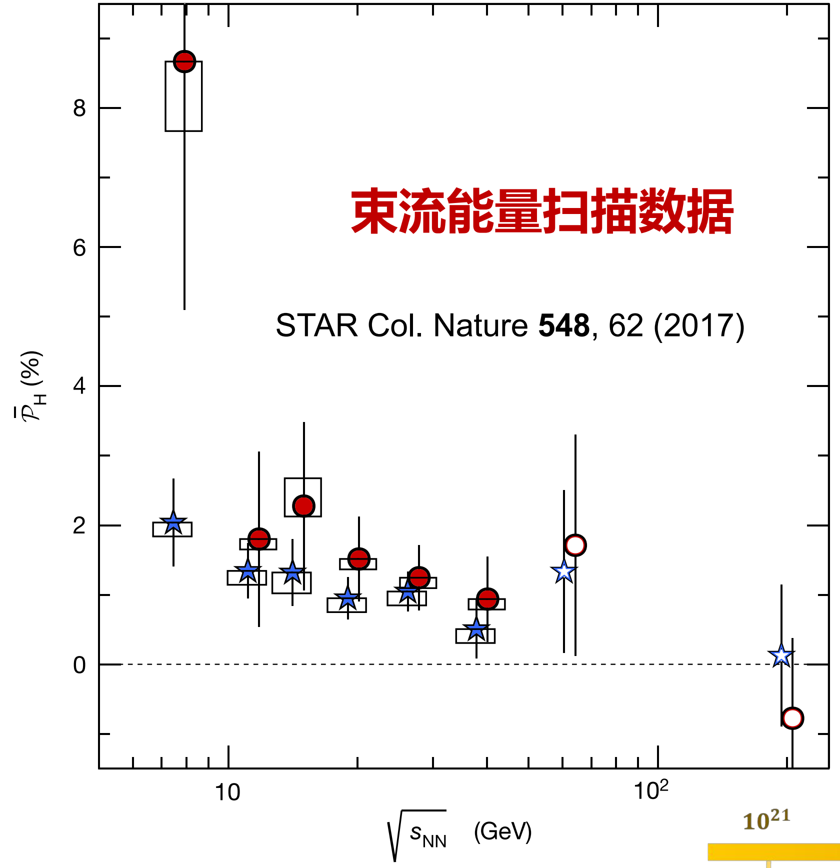
$$P_H = \frac{8}{\pi\alpha_H}\frac{\langle \sin(\Psi_1^{obs} - \phi_p^*)\rangle}{\mathrm{Res}(\Psi_1)}$$

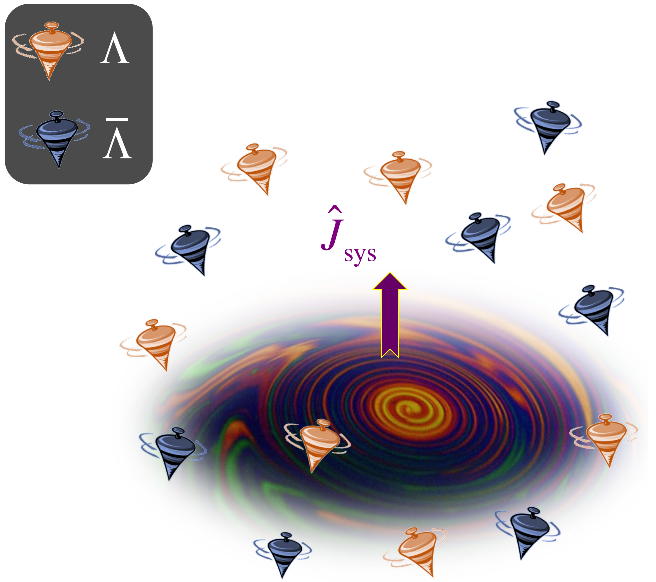
Λ极化测量

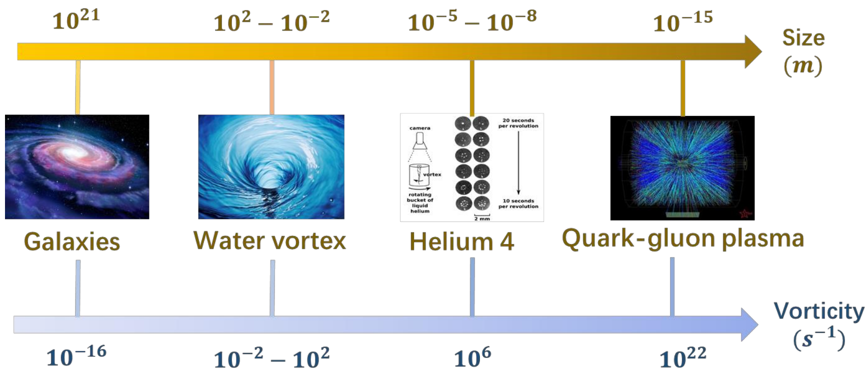
200GeV 数据

STAR Col. Phys. Rev. C **76**, 024915 (2007)









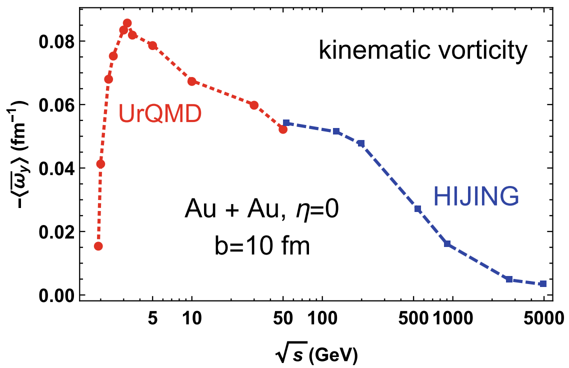
- Λ超子的整体极化高达2%

$$\omega \approx k_B T(\overline{\mathcal{P}}_{\Lambda'} + \overline{\mathcal{P}}_{\bar{\Lambda}'})/\hbar$$

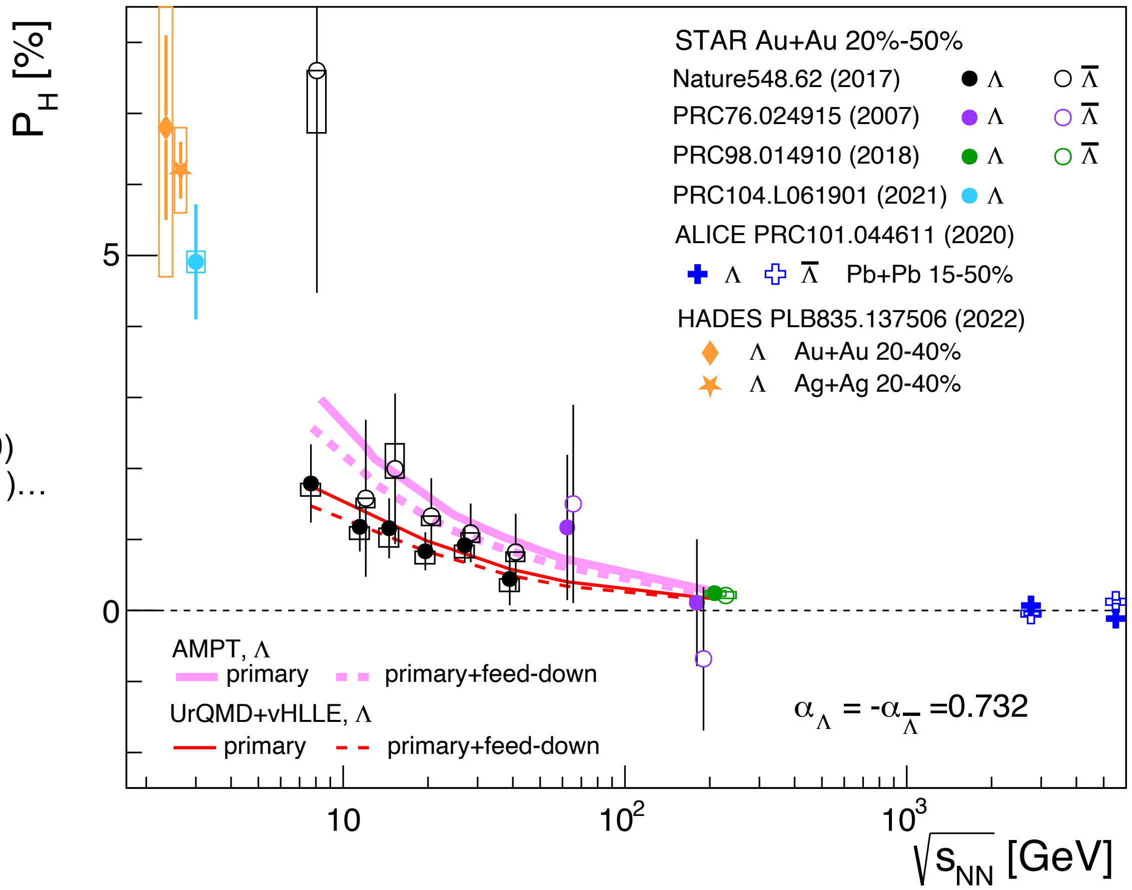
- Λ超子整体极化测量给出了研究QGP涡旋的途径，(9±1) x10^{21} s^{-1}

超子极化的束流能量依赖

- Measurements in different Exps.
  -clear signal, vorticity is the driven force?



Deng et al., Phys. Rev. C **101**, 064908 (2020)
Guo et al., Phys. Rev. C **104**, L041902 (2021)…



- Measurements extend to multistrange

Lee and Yang, Phys. Rev. 108, 1645 (1957)

$$\mathbf{P}_\Lambda^* = \frac{(\alpha_\Xi + \mathbf{P}_\Xi^* \cdot \hat{\boldsymbol{p}}_\Lambda^*)\hat{\boldsymbol{p}}_\Lambda^* + \beta_\Xi \mathbf{P}_\Xi^* \times \hat{\boldsymbol{p}}_\Lambda^* + \gamma_\Xi \hat{\boldsymbol{p}}_\Lambda^* \times (\mathbf{P}_\Xi^* \times \hat{\boldsymbol{p}}_\Lambda^*)}{1 + \alpha_\Xi \mathbf{P}_\Xi^* \cdot \hat{\boldsymbol{p}}_\Lambda^*}$$

$$\mathbf{P}_\Lambda^* = C_{\Xi^-\Lambda}\mathbf{P}_\Xi^* = \frac{1}{3}(1 + 2\gamma_\Xi)\mathbf{P}_\Xi^*.$$

$$\mathbf{P}_\Lambda^* = C_{\Omega^-\Lambda}\mathbf{P}_\Omega^* = \frac{1}{5}(1 + 4\gamma_\Omega)\mathbf{P}_\Omega^*.$$

$$\langle P_\Xi \rangle = 0.47 \pm 0.10(\text{stat}) \pm 0.23(\text{syst})\%$$

$$\langle P_\Omega \rangle = 1.11 \pm 0.87(\text{stat}) \pm 1.97(\text{syst})\%$$

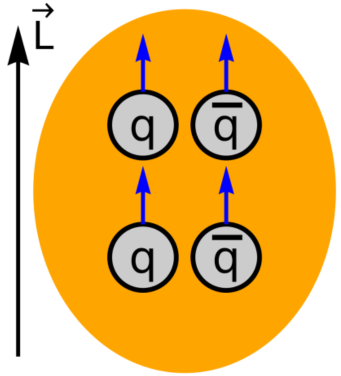
STAR Col. Phys. Rev. Lett. **126**, 162301 (2021)

矢量介子自旋极化

- Vector meson ($J=1^-$) spin alignment
  - ✓ Spin tensor polarization
  - ✓ Different probabilities among three spin states

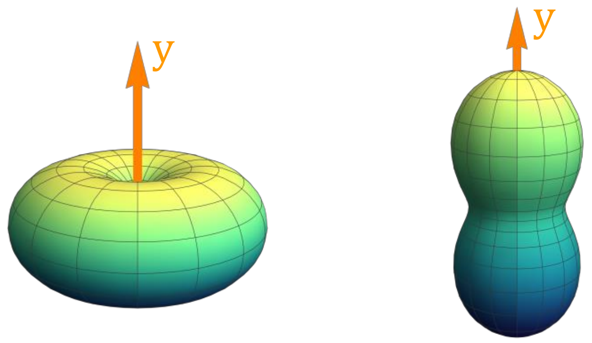
$$\rho^V = \begin{pmatrix} \rho_{11} & \rho_{10} & \rho_{1-1} \\ \rho_{01} & \rho_{00} & \rho_{0-1} \\ \rho_{-11} & \rho_{-10} & \rho_{-1-1} \end{pmatrix}$$

Schilling, Seyboth, Wolf Nucl. Phys. B **15**, 397 (1970)



$$\begin{aligned}\frac{\mathrm{d}N}{\mathrm{d}\Omega} = \frac{3}{8\pi}\Big[&(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta \\ &- 2\mathrm{Re}\rho_{-1,1}\sin^2\theta\cos(2\phi) - 2\mathrm{Im}\rho_{-1,1}\sin^2\theta\sin(2\phi) \\ &+ \sqrt{2}\mathrm{Re}(\rho_{-1,0}-\rho_{01})\sin(2\theta)\cos\phi \\ &+ \sqrt{2}\mathrm{Im}(\rho_{-1,0}-\rho_{01})\sin(2\theta)\sin\phi\Big], \qquad (13)\end{aligned}$$

Chen, Liang, Ma, Wang Science Bulletin **68**, 874 (2023)



$\rho_{00} < 1/3$ $\rho_{00} > 1/3$

Integrate over azi. angle

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta} = \int_0^{2\pi} \mathrm{d}\phi \frac{\mathrm{d}N}{\mathrm{d}\Omega}$$

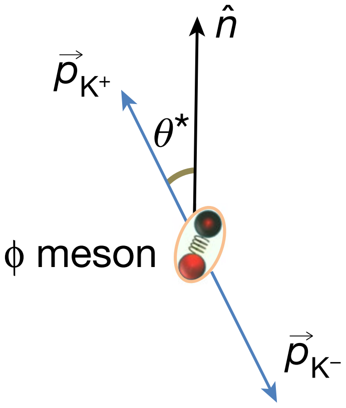
$$= (3/4)[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta].$$

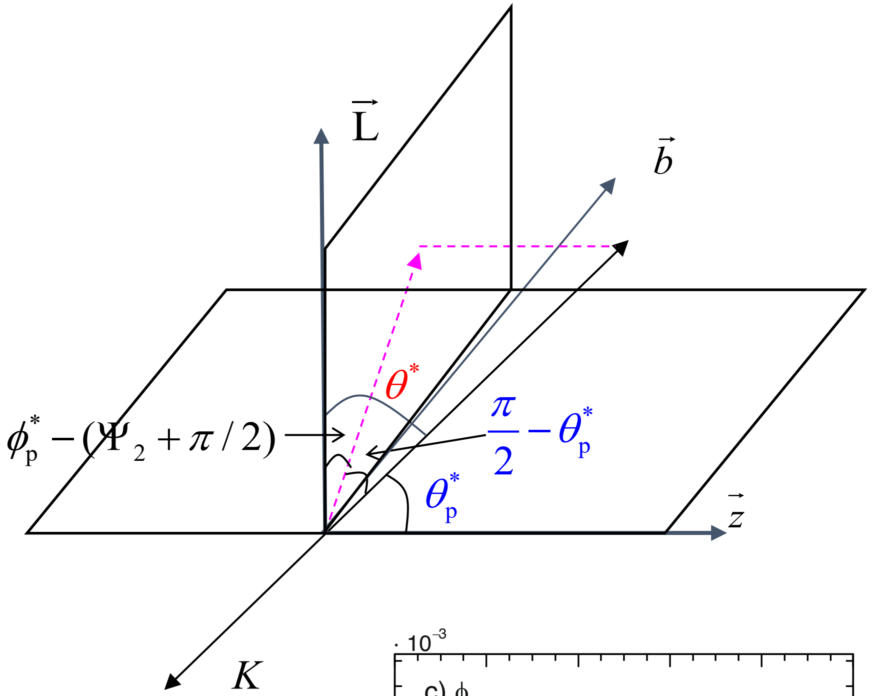
实验测量方法：矢量介子

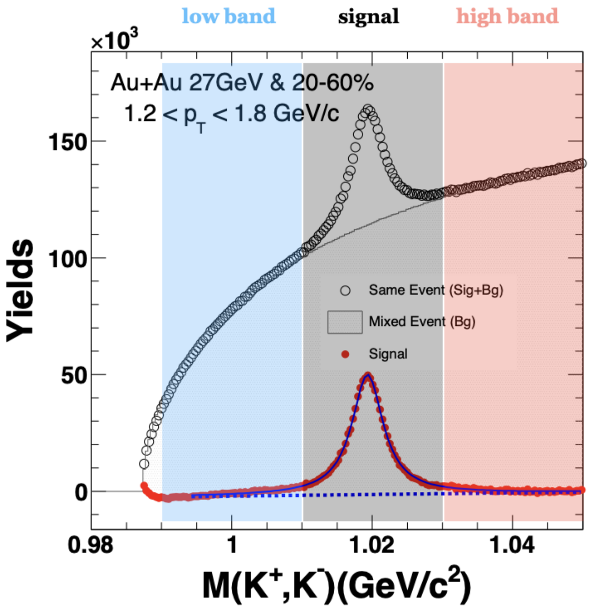
- 系统轨道角动量方向，反应平面的法线，实验通过带电粒子在实验室系的运动方向集合构建事件平面

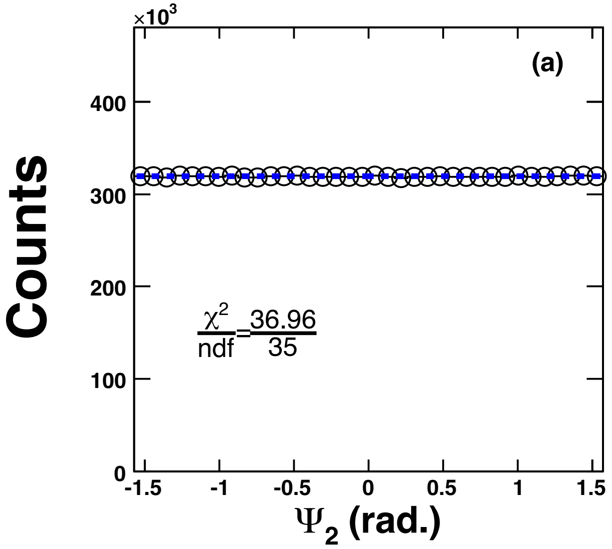
$$\Psi_2 = \frac{1}{2}\left[\tan^{-1}\frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)}\right]$$

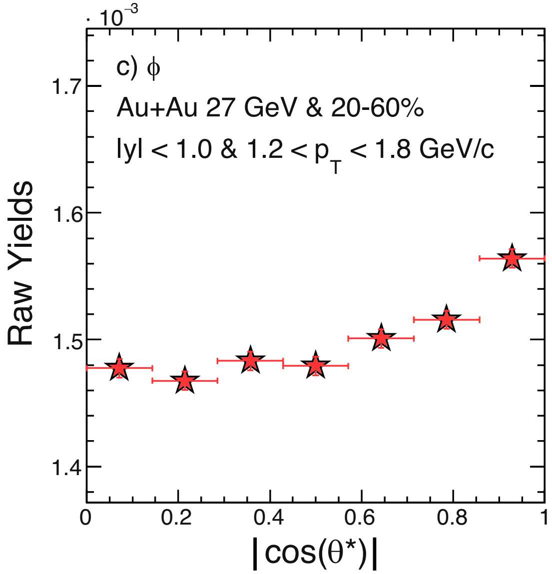
$$\cos\left(\theta^*\right) = \sin\left(\theta_p^*\right)\sin(\phi_p^* - \Psi_2)$$











实验测量修正

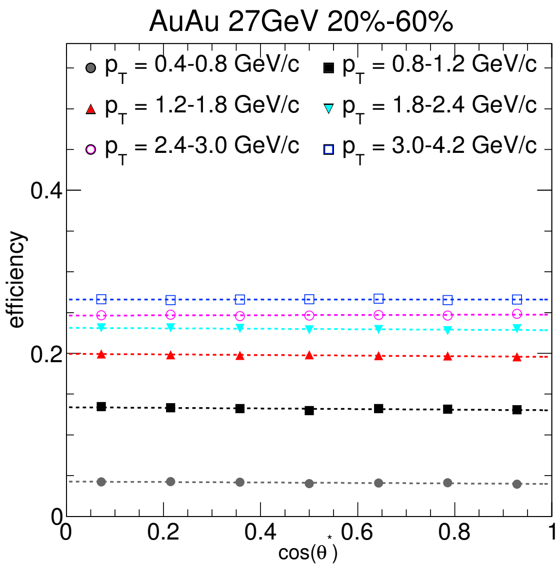
- 修正：探测效率TPC+ToF，**接受度修正(F)**，事件平面分辨率(R)

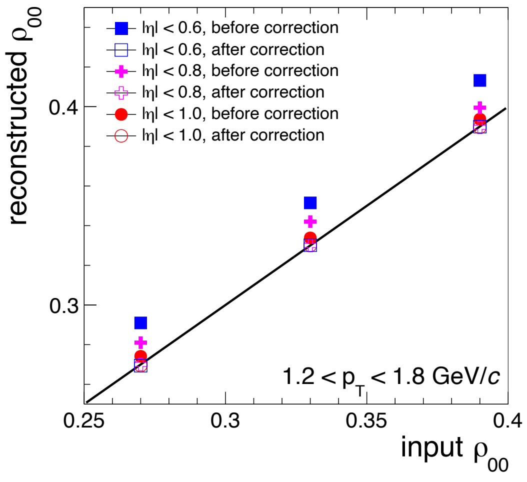
$$\left[\frac{dN}{d\cos\theta^*}\right]_{|\eta|} \propto \left(1+\frac{B'F}{2}\right) + (A'+F)\cos^2\theta^* + \left(A'F-\frac{B'F}{2}\right)\cos^4\theta^*,$$

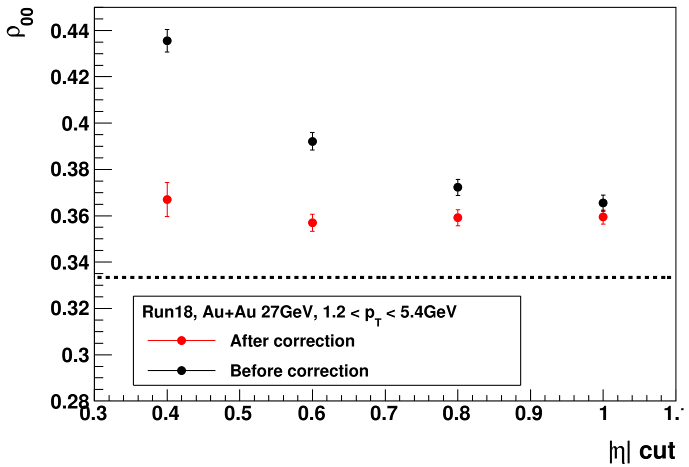
$$A' = \frac{A(1+3R)}{4+A(1-R)}, \quad B' = \frac{A(1-R)}{4+A(1-R)},$$

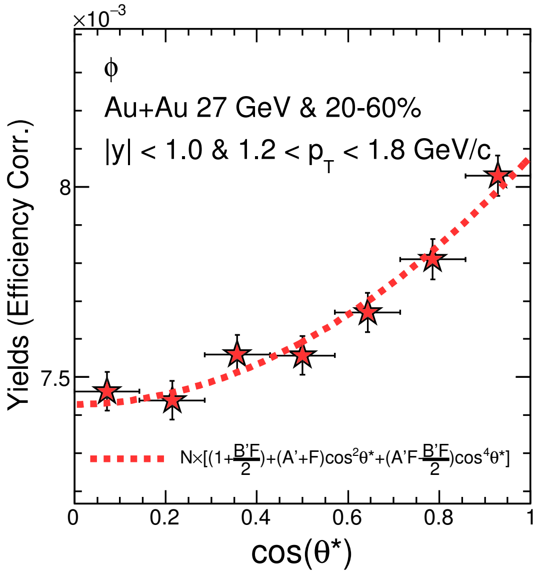
$$A = \frac{3\rho_{00}-1}{1-\rho_{00}},$$

Tang, Tu, Zhou Phys. Rev. C 98, 044907 (2018)
Shen, Chen, Lin, Chin. Phys. C 45, 054002 (2021)



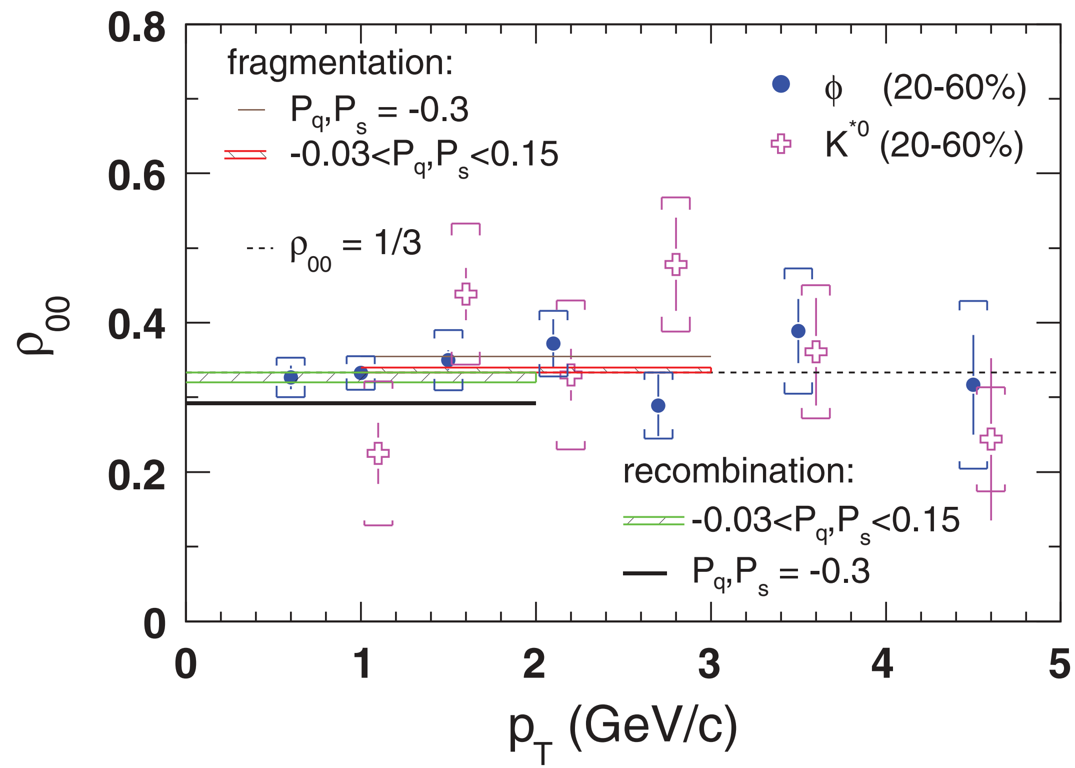




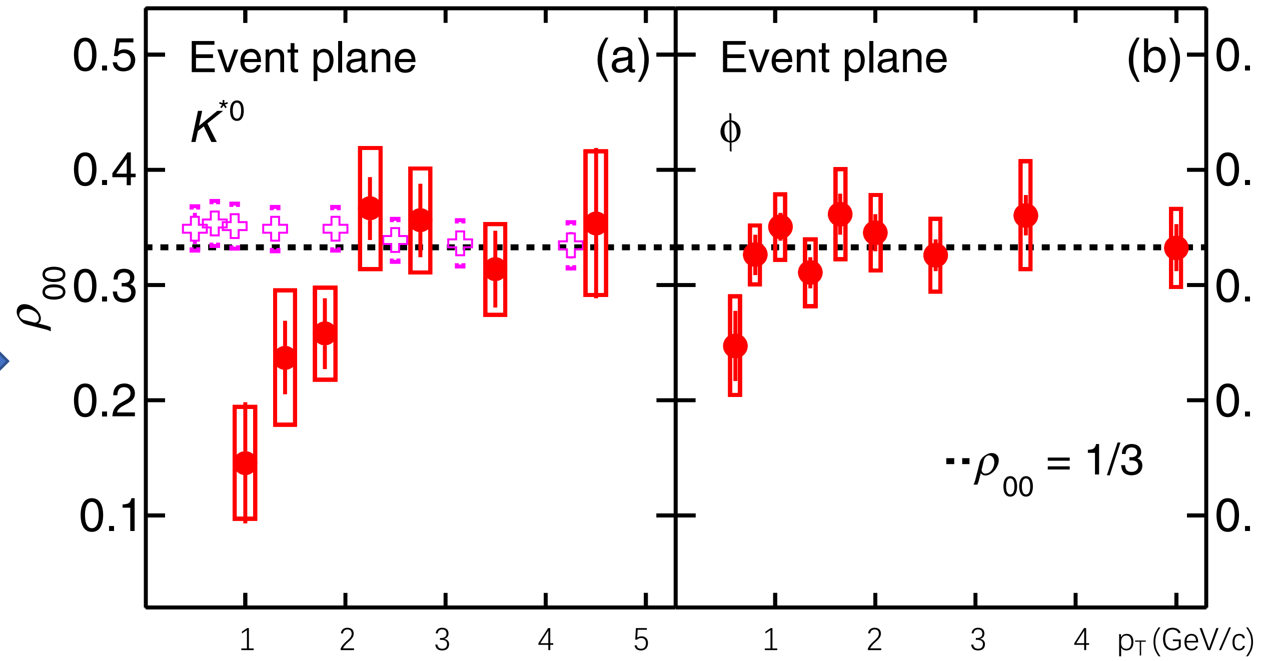


Experimental measurements: φ,K*

STAR Col. Phys. Rev. C **77**, 061902® (2008)



ALICE Col. Phys. Rev. Lett. **125**, 012301 (2020)

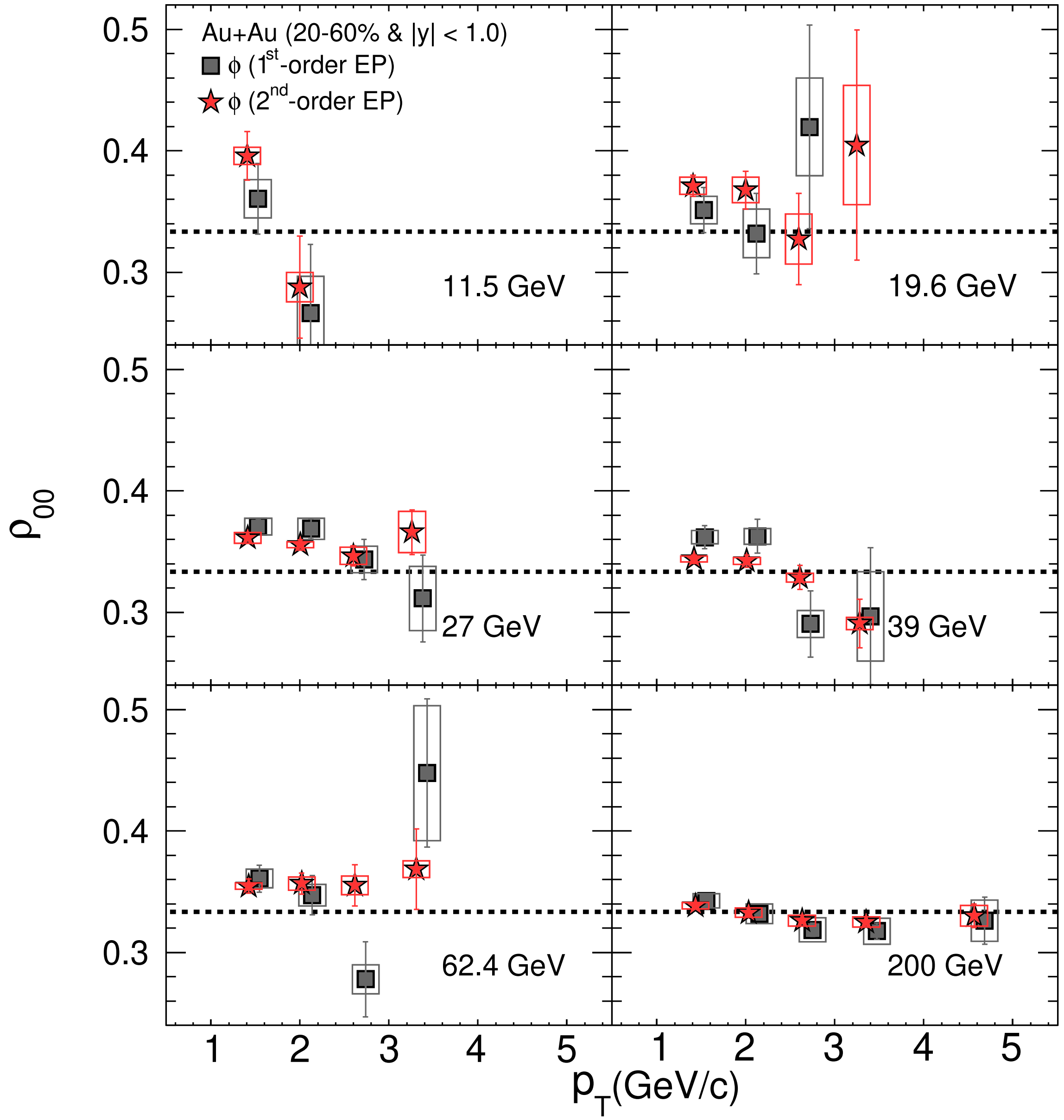


($|y|<0.5$) in Pb-Pb collisions at a center-of-mass energy ($\sqrt{s_{NN}}$) of 2.76 TeV with the ALICE detector. ρ_{00} values are found to be less than 1/3 (1/3 implies no spin alignment) at low transverse momentum ($p_T < 2$ GeV/c) for K^{*0} and ϕ at a level of 3σ and 2σ, respectively. No significant spin alignment is

- Early data suffer from large uncertainties
- Updated measurements seem to provide evidence of spin-orbital angular momentum interactions

(Note: acceptance effect should be carefully studied at 1 GeV/c)

New Measurements φ,K*⁰@non-central collisions

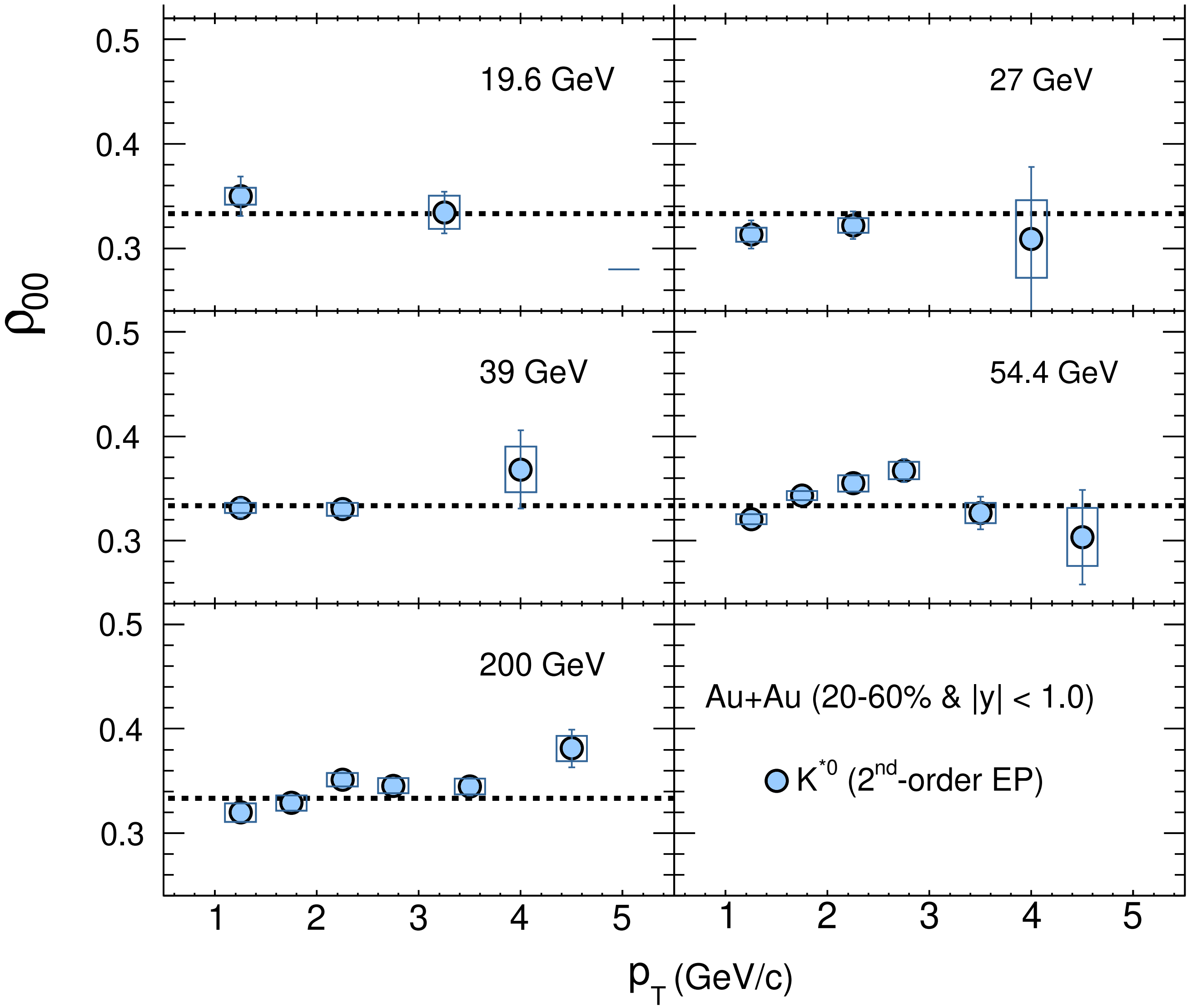


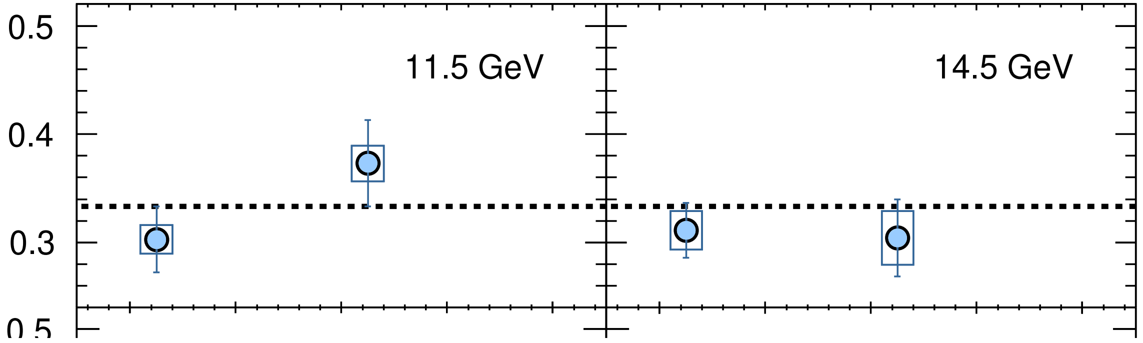
- New measurements extend the study to lower energies with high statistics, @200 GeV, a factor of ~50 more event statistics analyzed.
- We see that the signal for the φ meson occurs mainly within ~1.0-2.4 GeV/c; at larger p_T the results can be regarded as being consistent with 1/3 within ~2σ or less.

* 1st order EP: ZDC or BBC
* 2nd order EP: TPC

STAR Col. Nature **614**, 244 (2023)

New Measurements φ,K*0@non-central collisions

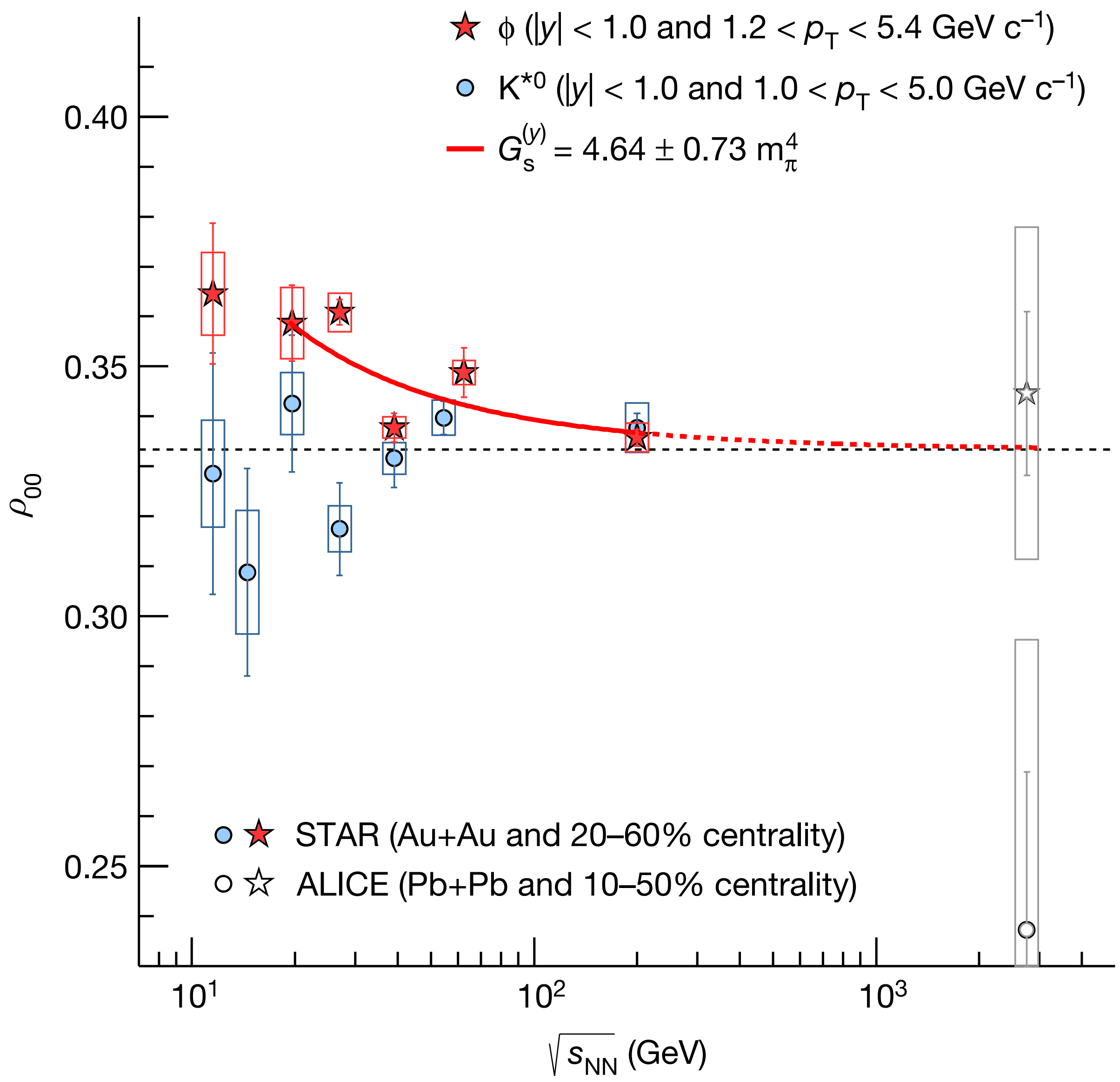




- K^{*0} is a combination of K^{*0} and anti-K^{*0}
- Independent analysis
- Different from the φ meson data, the K^{*0} data is largely consistent with 1/3, within statistics and systematical uncertainties

STAR Col. Nature **614**, 244 (2023)

Results averaged over p_T



1) φ-meson is significantly above 1/3 for sqrt{s}≤ 62 GeV

2) K* is largely consistent with 1/3

3) Averaged over 62 GeV and below:

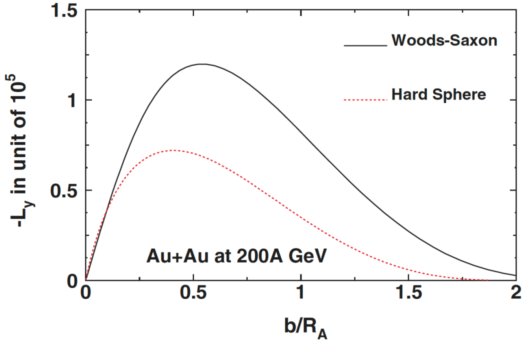
- 0.3541 ± 0.0017 (stat.) ± 0.0018 (sys.) for φ
- 0.3356 ± 0.0034 (stat.) ± 0.0043 (sys.) for K*

* Different approaches are used in the combinatorial bg. analysis

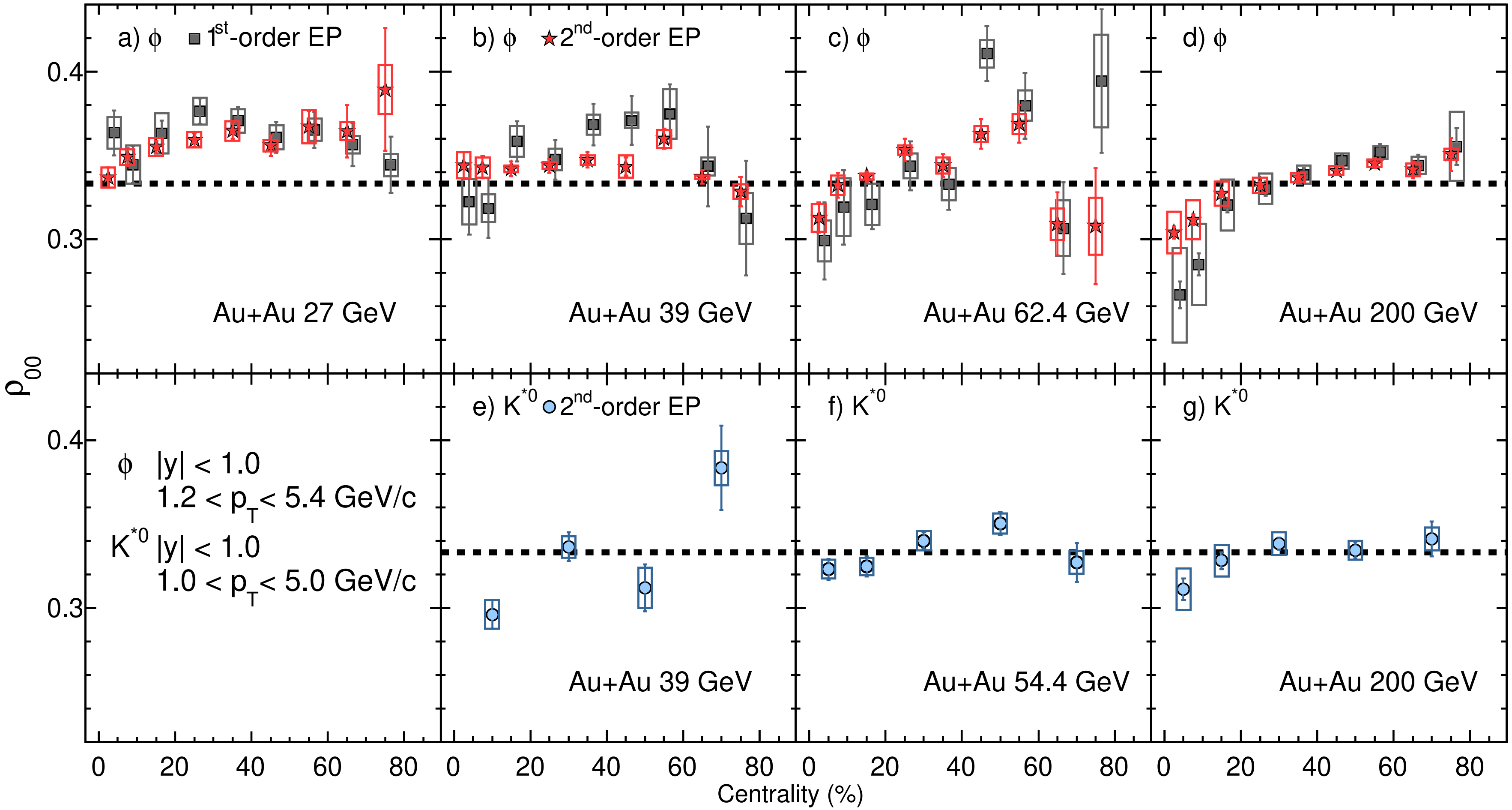
STAR Col. Nature **614**, 244 (2023)

Study the fine structure vs. centrality

STAR Col. Nature 614, 244 (2023)



Gao, Chen, Deng, Liang, Wang, Wang
Phys. Rev. C **76**, 044901 (2007)



At high energies (≥62.4 GeV) for φ, and (≥39 GeV) for K^{*0}, ρ_{00} in central collisions tends to ≤1/3. This might be caused by transerve local spin alignment and a contribution from the helicity polarization of quarks.

Expectations of ρ_{00} from theory

$$\rho_{00}^{\phi} \approx \frac{1}{3} + c_{\omega} + c_{\varepsilon} + c_{\mathrm{EM}} + c_{\phi} + c_{\mathrm{LV}} + c_{h} + c_{\mathrm{TC}} + c_{\mathrm{shear}}$$

$c_{\omega}, c_{\varepsilon}$：涡旋场磁分量和电分量的贡献，CLVisc流体计算$\sim 10^{-4}$

c_{EM}：电磁场的贡献，PHSD输运模拟$\sim 10^{-5}$

c_{LV}：QGP膨胀的各向异性导致的局域涡旋场贡献，< 0

c_{h}：拓扑荷涨落或夸克净螺旋度非零的贡献，< 0

c_{TC}：湍流色场的贡献，< 0

c_{shear}：剪切张量的贡献，QGP中自旋极化能达到1%，或< 0

[1]. Yang et al., Phys. Rev. C **97**, 034917 (2018)
[2]. Sheng et al., Phys. Rev. D **101**, 096005 (2020)
[3]. Xia et al., Phys. Lett. B **817**, 136325 (2021)
[4]. Gao, Phys. Rev. D **104**, 076016 (2021)
[5]. Muller, Yang, Phys. Rev. D **105**, L011901 (2022)
[6]. Li, Liu, arXiv:2206.11890,
Wagner, Weickgenannt, Speranza, arXiv:2207.01111

How to explain the large ρ_{00} of φ-meson?

- New idea: local correlation of φ-meson fields, like electric charges in motion can generate an EM fields, strange quarks in motion can generate an effective φ-meson field

Sheng, Oliva, Wang Phys. Rev. D **101**, 096005 (2020);
Sheng, Wang, Wang Phys. Rev. D **102**, 056013 (2020)

- Quarks polarized by spin-orbital interaction

$$\rho_q = \sum_{rs} \int d^3\mathbf{x} \int [d^3\mathbf{p}][d^3\mathbf{q}] e^{-i\mathbf{q}\cdot\mathbf{x}} \times f^q_{rs}(\mathbf{x},\mathbf{p}) \left| r, \mathbf{p}+\frac{\mathbf{q}}{2} \right\rangle \left\langle s, \mathbf{p}-\frac{\mathbf{q}}{2} \right| ,$$

Quark Recombination

$$\rho^{\phi}_{00}(\mathbf{x},\mathbf{p}) \approx \frac{1}{3} - \frac{2}{3}\left\langle P^y_q(\mathbf{x}_1,\mathbf{p}_1)\, P^y_{\bar{q}}(\mathbf{x}_2,\mathbf{p}_2)\right\rangle + \frac{2}{9}\left\langle \mathbf{P}_q(\mathbf{x}_1,\mathbf{p}_1)\cdot \mathbf{P}_{\bar{q}}(\mathbf{x}_2,\mathbf{p}_2)\right\rangle ,$$

Greco, Ko, Levai, Phys. Rev. Lett. **90**, 202302 (2003)
Fries, Muller, Nonaka, Bass, Phys. Rev. Lett. **90**, 202303 (2003)
Hua, Yang Phys. Rev. Lett. **90**, 212301 (2003) …

How to explain the large ρ_{00} of φ-meson?(cont.)

- Polarization by a meson field can accommodate large deviation for φ-meson ρ_{00} at midcentral collisions

$$\mathbf{P}_{q/\bar{q}} = \frac{1}{2}\boldsymbol{\omega} + \frac{1}{2m_s}\boldsymbol{\varepsilon}\times\mathbf{p} \pm \frac{g_\phi}{2m_s T}\mathbf{B}_\phi \pm \frac{g_\phi}{2m_q E_p T}\mathbf{E}_\phi \times \mathbf{p},$$

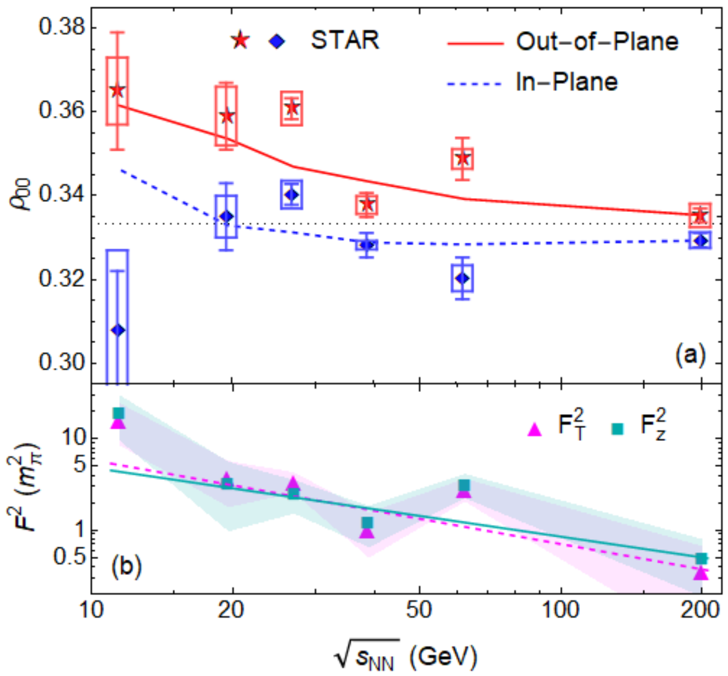
Sheng, et al., arXiv:2205.15689; 2206.05868

$$\left\langle (g_\phi \mathbf{B}^\phi_{x,y}/T_{\mathrm{h}})^2 \right\rangle = \left\langle (g_\phi \mathbf{E}^\phi_{x,y}/T_{\mathrm{h}})^2 \right\rangle \equiv F_T^2$$

$$\left\langle (g_\phi \mathbf{B}^\phi_{z}/T_{\mathrm{h}})^2 \right\rangle = \left\langle (g_\phi \mathbf{E}^\phi_{z}/T_{\mathrm{h}})^2 \right\rangle \equiv F_z^2$$

represented the fluctuations of transerve and longitudinal fields

$$\rho^\phi_{00}(t,\mathbf{x},\mathbf{p}) \approx \frac{1}{3} + C_1\left[\frac{1}{3}\boldsymbol{\omega}'\cdot\boldsymbol{\omega}' - (\boldsymbol{\epsilon}_0\cdot\boldsymbol{\omega}')^2\right] + C_2\left[\frac{1}{3}\boldsymbol{\varepsilon}'\cdot\boldsymbol{\varepsilon}' - (\boldsymbol{\epsilon}_0\cdot\boldsymbol{\varepsilon}')^2\right] - \frac{4g_\phi^2}{m_\phi^2 T^2}\left\{C_1\left[\frac{1}{3}\mathbf{B}'_\phi\cdot\mathbf{B}'_\phi - (\boldsymbol{\epsilon}_0\cdot\mathbf{B}'_\phi)^2\right] + C_2\left[\frac{1}{3}\mathbf{E}'_\phi\cdot\mathbf{E}'_\phi - (\boldsymbol{\epsilon}_0\cdot\mathbf{E}'_\phi)^2\right]\right\}, \quad ($$



Meson fields and global polarization

- Meson field effect explains the polarization difference between Λs

PHYSICAL REVIEW C **99**, 021901(R) (2019)

Rapid Communications

Λ and $\bar{\Lambda}$ spin interaction with meson fields generated by the baryon current in high energy nuclear collisions

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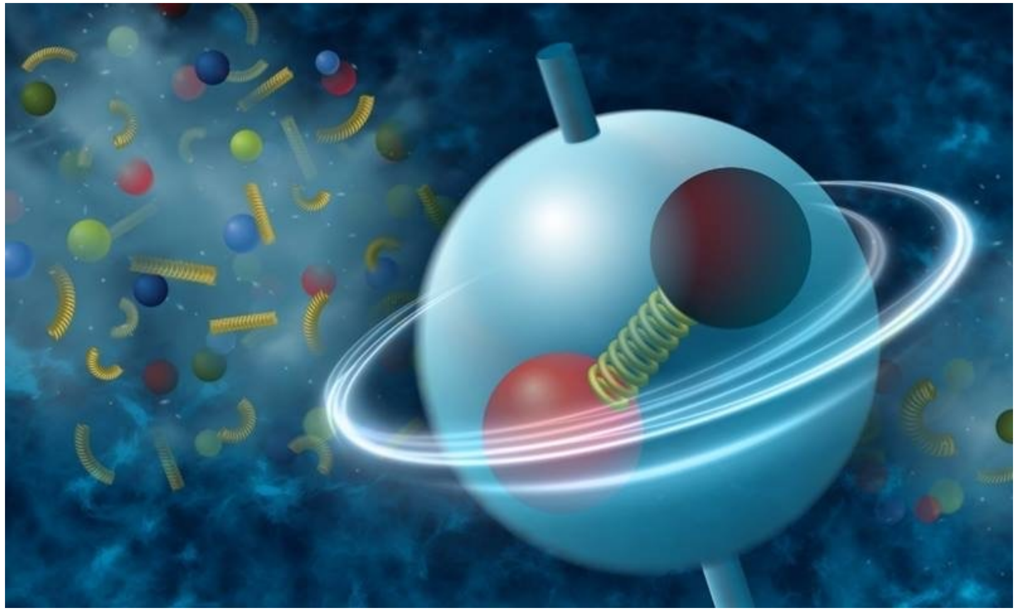
[2]*School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455, USA*

(Received 1 August 2018; revised manuscript received 12 December 2018; published 19 February 2019)

We propose a dynamical mechanism which provides an interaction between the spins of hyperons and antihyperons and the vorticity of the baryon current in noncentral high energy nuclear collisions. The interaction is mediated by massive vector and scalar bosons, which is well known to describe the nuclear spin-orbit force. It follows from the Foldy-Wouthuysen transformation and leads to a strong-interaction Zeeman effect. The interaction may explain the difference in polarizations of Λ and $\bar{\Lambda}$ hyperons as measured by the STAR Collaboration at the BNL Relativistic Heavy Ion Collider. The signs and magnitudes of the meson-baryon couplings are closely connected to the binding energies of hypernuclei and to the abundance of hyperons in neutron stars.

DOI: 10.1103/PhysRevC.99.021901

$$H^{V}_{\text{spin-orbit}} = \frac{g_{V\Lambda}}{2m_\Lambda^2}\frac{1}{r}\frac{\partial V_0}{\partial r}\boldsymbol{S}\cdot\boldsymbol{L}, \qquad H^{\sigma}_{\text{spin-orbit}} = \frac{g_{\sigma\Lambda}}{2m_\Lambda^2}\boldsymbol{S}\cdot\nabla\sigma\times\boldsymbol{p},$$



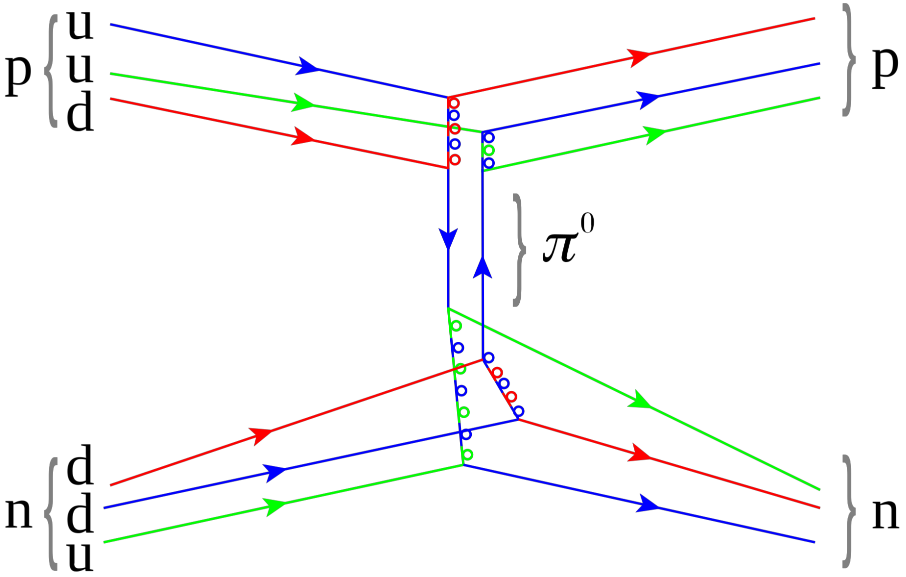
Some follow-ups on the topics:

- “The value of the polarization is very sensitive to interplay of thermal vorticity and meson-field term” Ivanov, Soldatov Phys. Rev. C 105 (2022), 034915
- “A local spin correlation could be greatly enhanced” Kumar, Muller, Yang arXiv:2304.04181, “spin alignment of vector mesons by glasma fields”

- The effect is orders of magnitude larger than the one arising from electromagnetic fields

Meson fields and strong interaction

Yukawa, *Proc. Phys. Math. Soc. Jap.* **17** (1935) 48

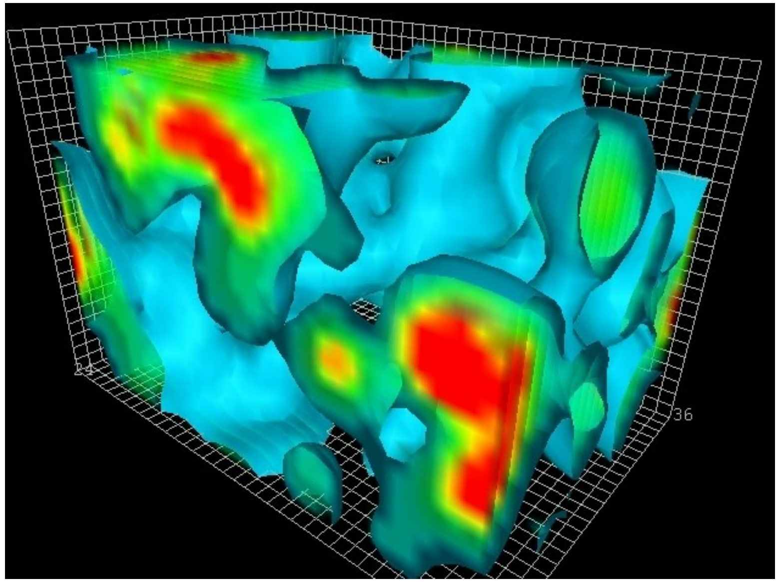


"The transition of a heavy particle from neutron state to proton state is not always accompanied by the emission of light particles, i. e., a neutrino and an electron, but the energy liberated by the transition is taken up sometimes by another heavy particle…"

- Particles and fields are two fundamental forms of matter in our natural world
- At low energy scales, strong interactions is often characterized by mesons as effective dof of quarks and gluons, whose existence was proposed by Yukawa

  "Now such interaction between the elementary particles can be described by means of a field of force, just as the interaction between the charged particles is described by the electromagnetic field."
- As the energy scale increases, other meson fields carrying strangeness quantum number may come into play

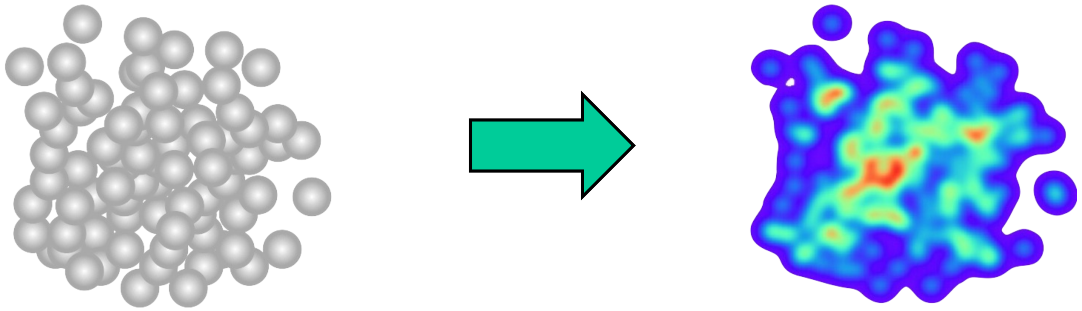
Strong interaction and fluctuation



QCD真空不平静 D. Leinweber

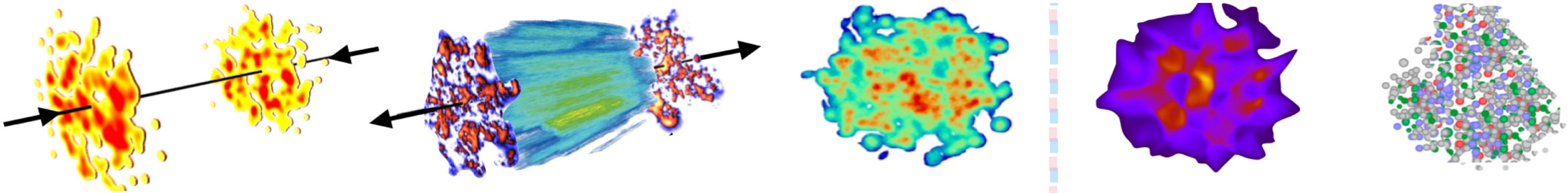
http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/QCDvacuum/

相对论能标下的原子核：超强色场



Gribov, Levin, Ryskin Nucl. Phys. B **188**, 555 (1981)

Mclerran, Venugopalan Phys. Rev. D **49**, 2233 (1994)



相对论重离子碰撞的初态不平静　**胶子凝聚GCP/夸克胶子等离子体QGP不平静**　**强子化过程不平静**

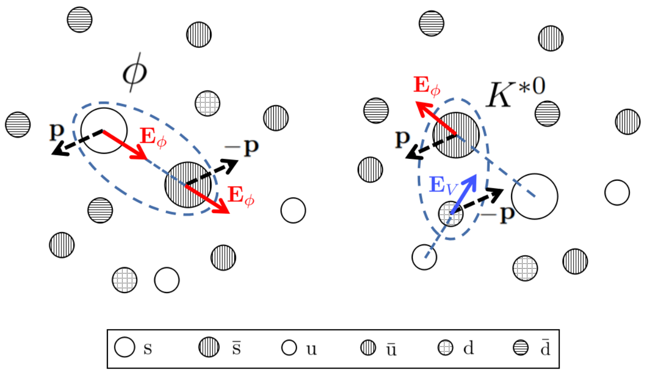
→ 这些涨落可能导致了强作用场的时空关联效应

Summary

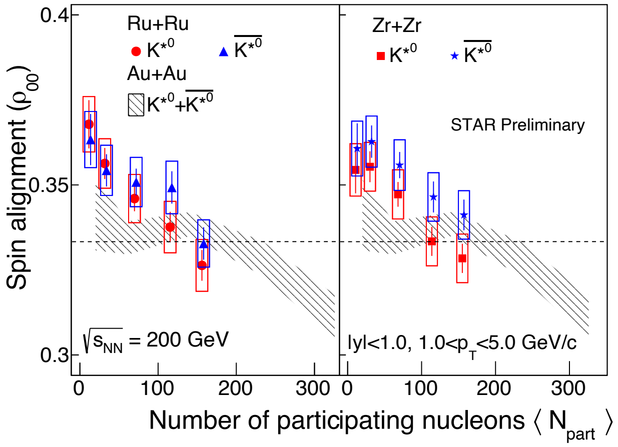
- STAR has observed a large global spin algiment for φ-meson, which cannot be explained by conventional mechanisms. However, it can be accommodated by a model with strong force field.
- For the K*0 meson, experimental data suffer from large statistical error and cannot yield a conclusion currently
- Vector meson global spin alignment, together with the hyperon polarization, established the new effect of QGP global polarization

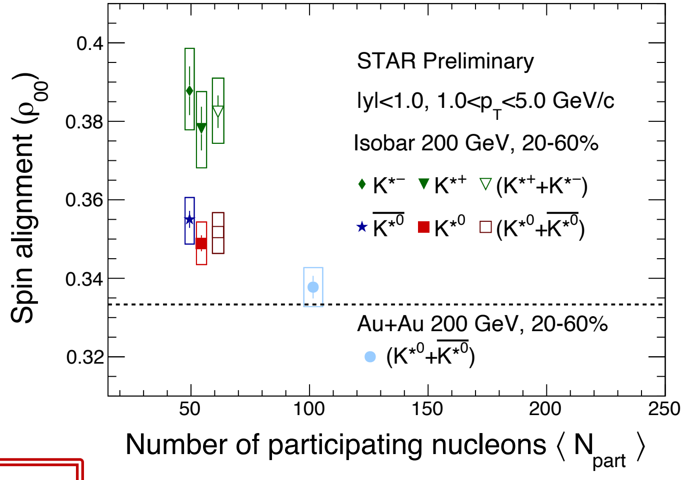
Discussion

- The strong force fields explanation is subject to debate and further verification

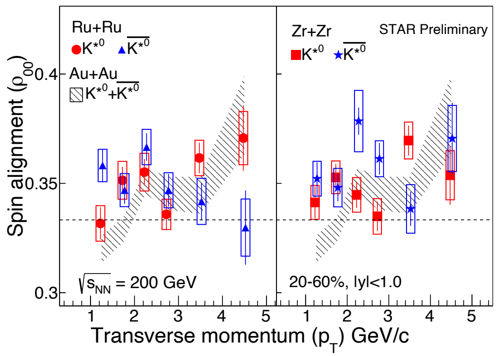


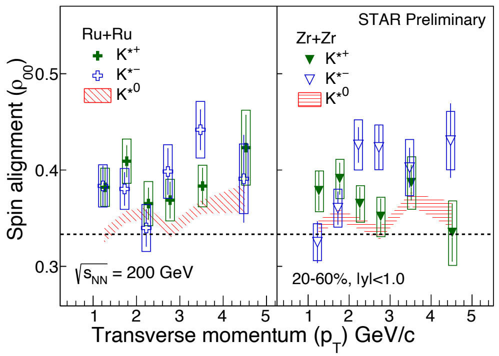
Little field correlation for K^{*0}, causing $\langle P_{\bar{q}} P_q \rangle$ to diminish.





Singha for STAR, QM22



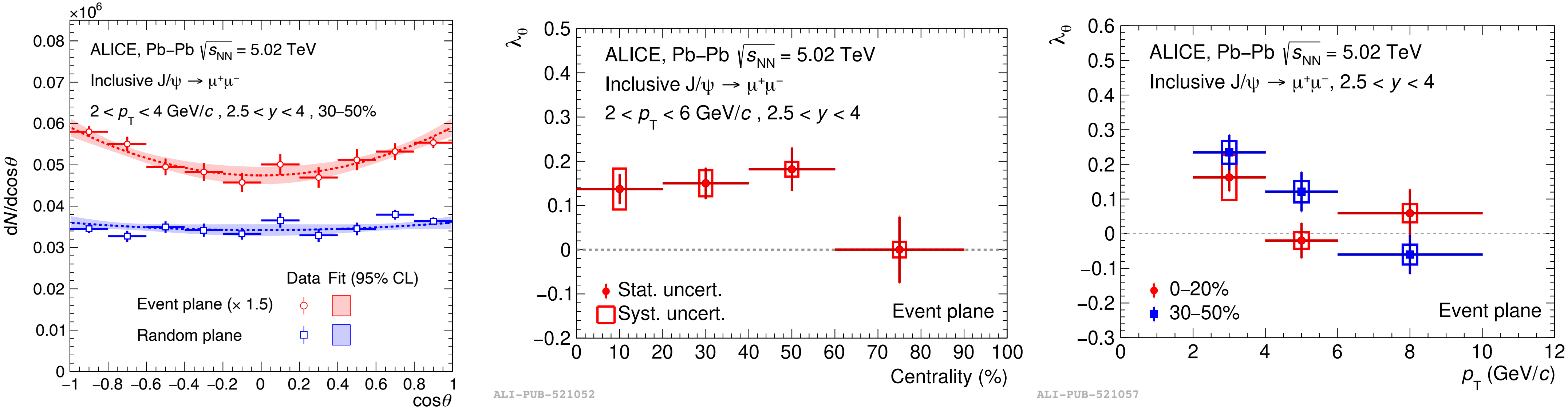


- K^{*0} is larger than 1/3 at smaller N_{part}, it is comparable to Au+Au at a similar N_{part}
- Charged K^* is larger than 1/3, it is larger than neutral K^* with 3.9σ

Due to the interaction between the B-field and the magnetic moment of constituent quarks, one naively expects the neutral K* to be larger than that of charge K*

Discussion (cont.)

- Same flavor: J/ψ-meson, at large rapidity, LHC observed a signal with 3.9σ (arXiv: 2204.10171).



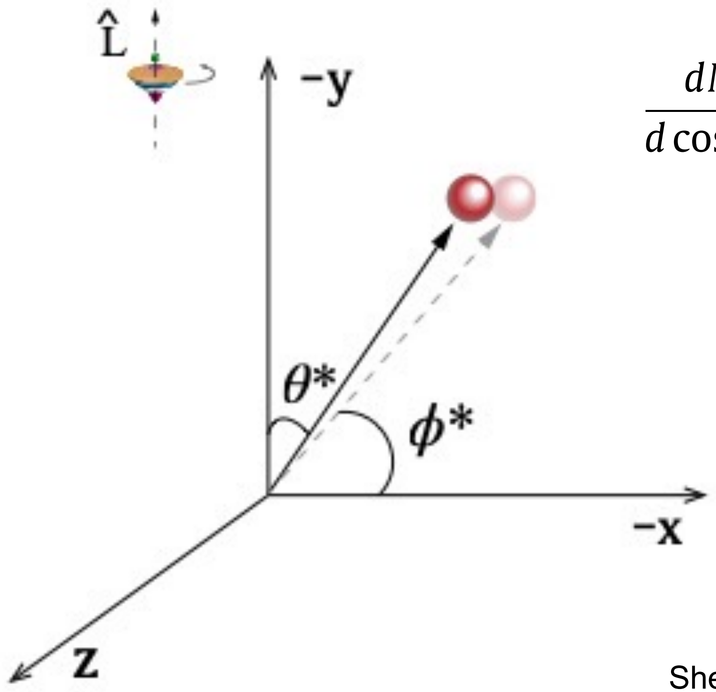
- ρ-meson (rescattering vs. regeneration may dilute the effect)

Shen, Chen, Lin, Chin. Phys. C **45**, 054002 (2021)

Discussion (cont. 2)

- In HIC collisions, the direction of magnetic field and OAM are correlated, which may have an effect on CME and global spin alignment

[*CME: interplay between chirality imbalance of quarks and intense magnetic field]

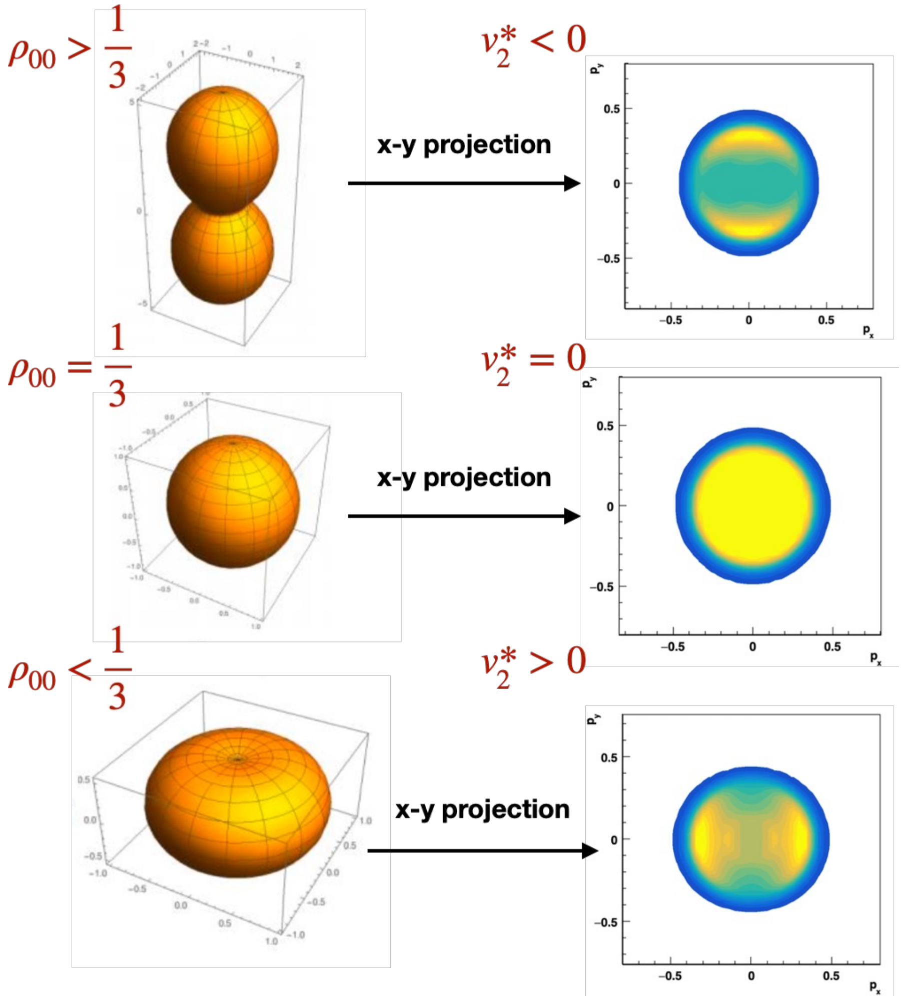


$$\frac{dN}{d\cos\theta^*} = \frac{3}{4}\left[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*\right],$$

$$\frac{dN}{d\phi^*} = \frac{1}{2\pi}\left[1 - \frac{1}{2}(3\rho_{00}-1)\cos 2\phi^*\right],$$

$$\therefore v_2^* = -\frac{3\rho_{00}-1}{4}$$

Shen, Chen, Tang, Wang, Phys. Lett. B **839**, 137777 (2023)



*Assumed the direction of OAM and the magnetic field are both perpendicular to the reaction plane

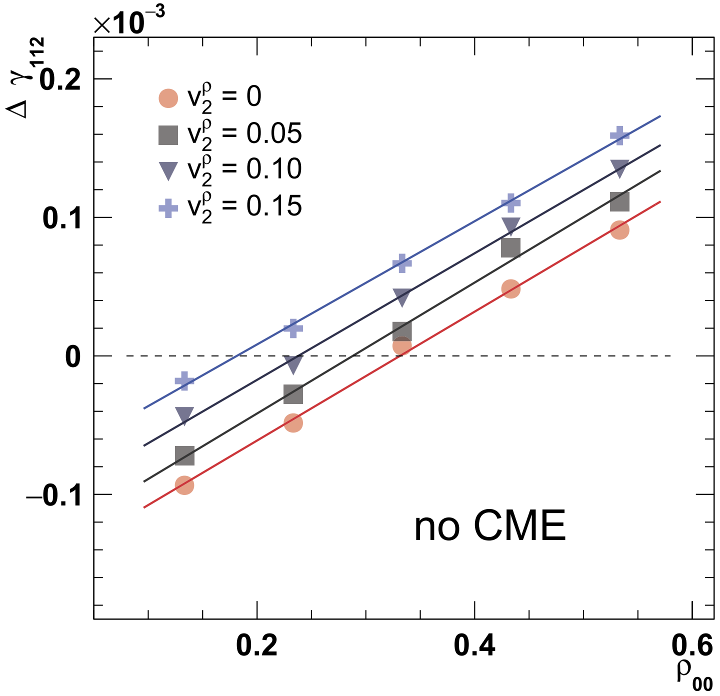
Discussion (cont. 3)

- Take the CME-sensitive observable γ_{112} as an example,

$$\gamma_{112} \equiv \left\langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \right\rangle$$

$$\gamma_{112}^{OS} = \langle \cos(\phi_+ + \phi_- - 2\Psi_{RP}) \rangle$$
$$= \langle \cos\Delta\phi_+ \rangle \langle \cos\Delta\phi_- \rangle + \frac{N_\rho}{N_+N_-}\mathrm{Cov}(\cos\Delta\phi_+, \cos\Delta\phi_-)$$
$$- \langle \sin\Delta\phi_+ \rangle \langle \sin\Delta\phi_- \rangle - \frac{N_\rho}{N_+N_-}\mathrm{Cov}(\sin\Delta\phi_+, \sin\Delta\phi_-),$$

Shen, Chen, Tang, Wang, Phys. Lett. B **839**, 137777 (2023)



- In the rest frame of ρ-meson, we calculate the covariance terms

$$\mathrm{Cov}(\cos\phi_+^*, \cos\phi_-^*) = -\left\langle \cos^2\phi_+^* \right\rangle + \left\langle \cos\phi_+^* \right\rangle^2$$
$$= -\frac{1}{2} + \frac{1}{8}(3\rho_{00} - 1),$$
$$\mathrm{Cov}(\sin\phi_+^*, \sin\phi_-^*) = -\left\langle \sin^2\phi_+^* \right\rangle + \left\langle \sin\phi_+^* \right\rangle^2$$
$$= -\frac{1}{2} - \frac{1}{8}(3\rho_{00} - 1).$$

$$\Delta\gamma_{112} = \frac{N_\rho}{N_+N_-}\left[\frac{1}{8}(f_c + f_s)(3\rho_{00} - 1) - \frac{1}{2}(f_c - f_s)\right]$$
$$= \frac{N_\rho}{8N_+N_-}\left[2f_0 + \sum_{n=1}^{\infty}(c_n + s_n)(v_2^\rho)^n\right](3\rho_{00} - 1)$$
$$- \frac{N_\rho}{2N_+N_-}\sum_{n=1}^{\infty}(c_n - s_n)(v_2^\rho)^n.$$

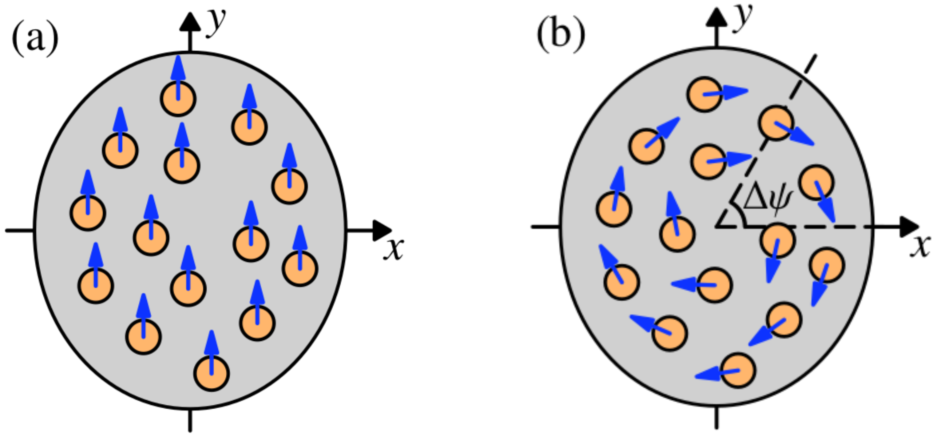
$$\Rightarrow \quad \Delta\gamma_{112}^* = \frac{N_\rho}{N_+N_-}\frac{3\rho_{00} - 1}{4},$$

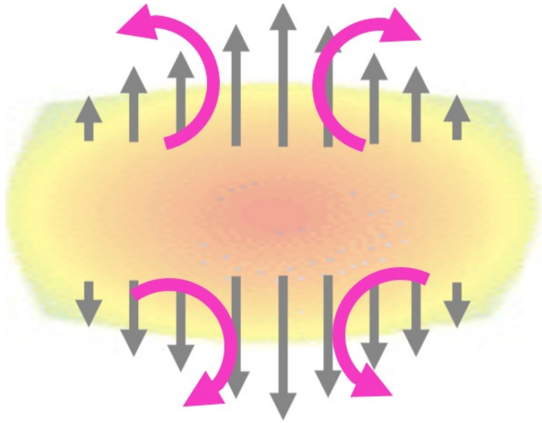
- Global spin alignment of ρ-meson is a crucial component in the background estimation for the CME measurements involving pions

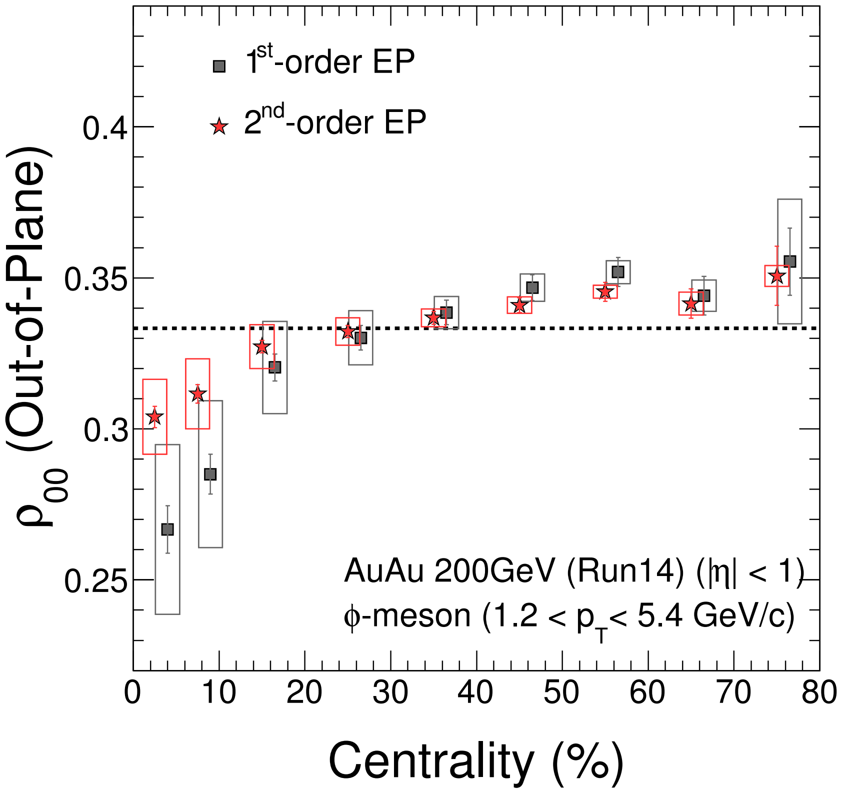
Discussion (cont.4)

Global vs. Local polarization

Xia et al., Phys. Rev. C **98**, 024905 (2018)
Phys. Lett. B **817**, 136325 (2021)







Global polarization

$$\rho_{00} = \frac{1 - P_y^2}{3 + P_y^2}$$

Local polarization

$$\rho_{00} = \frac{1 - P_y^2 + P_x^2 + P_z^2}{3 + P_y^2 + P_x^2 + P_z^2}$$

- Local vorticity structure generates a local polarization?
- Is the contribution from local spin alignment dominant in central collisions and at higher energies?