CRITICAL FLUCTUATIONS AND CORRELATIONS OF QUARK SPIN IN HOT AND DENSE QCD MATTER

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ArXiv: 2410.20704

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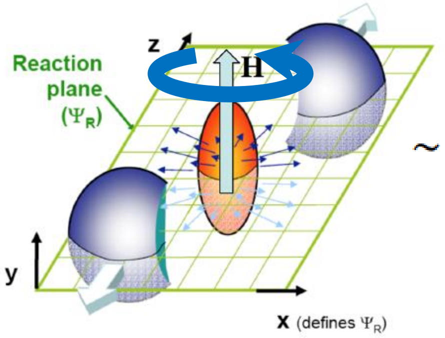
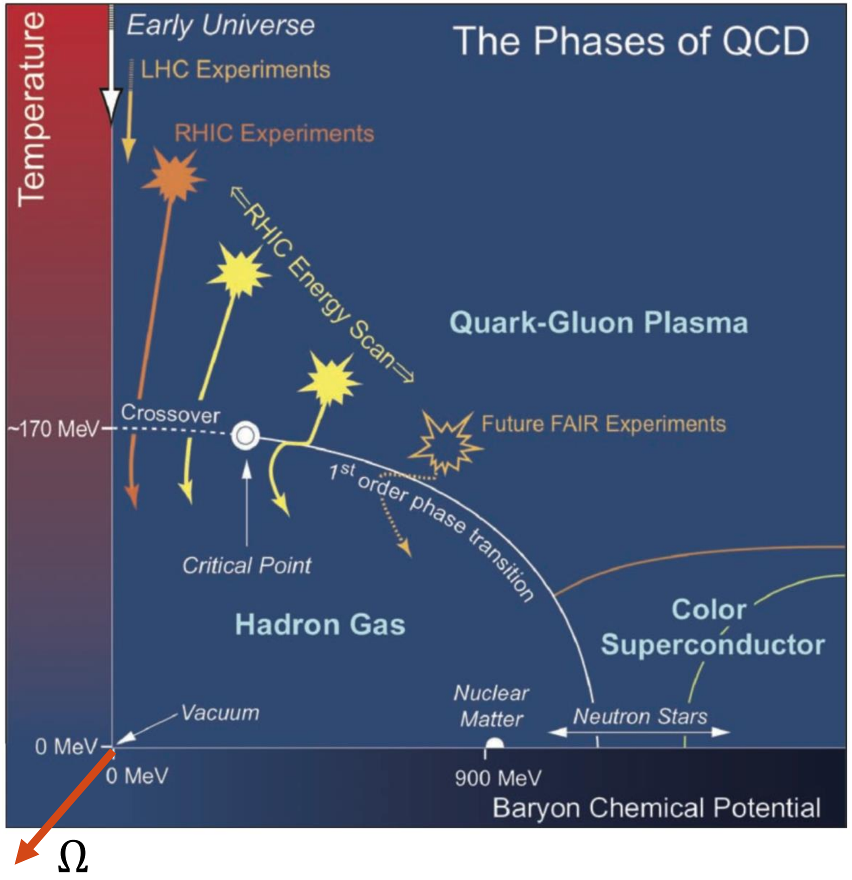
ROTATION RELATED STUDIES



$\sim 10^{21}/s$ at RHIC

- Spin polarization/alignment

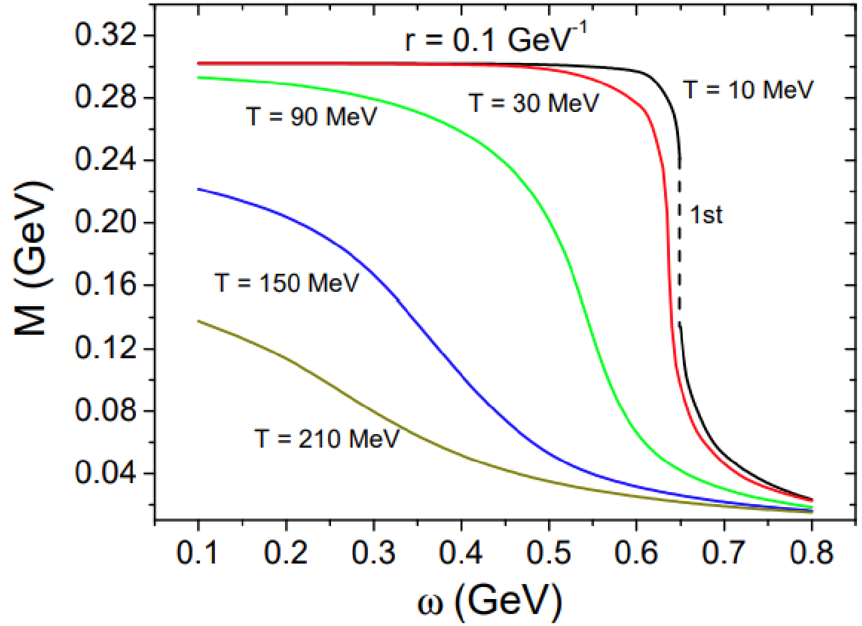
Phase transition



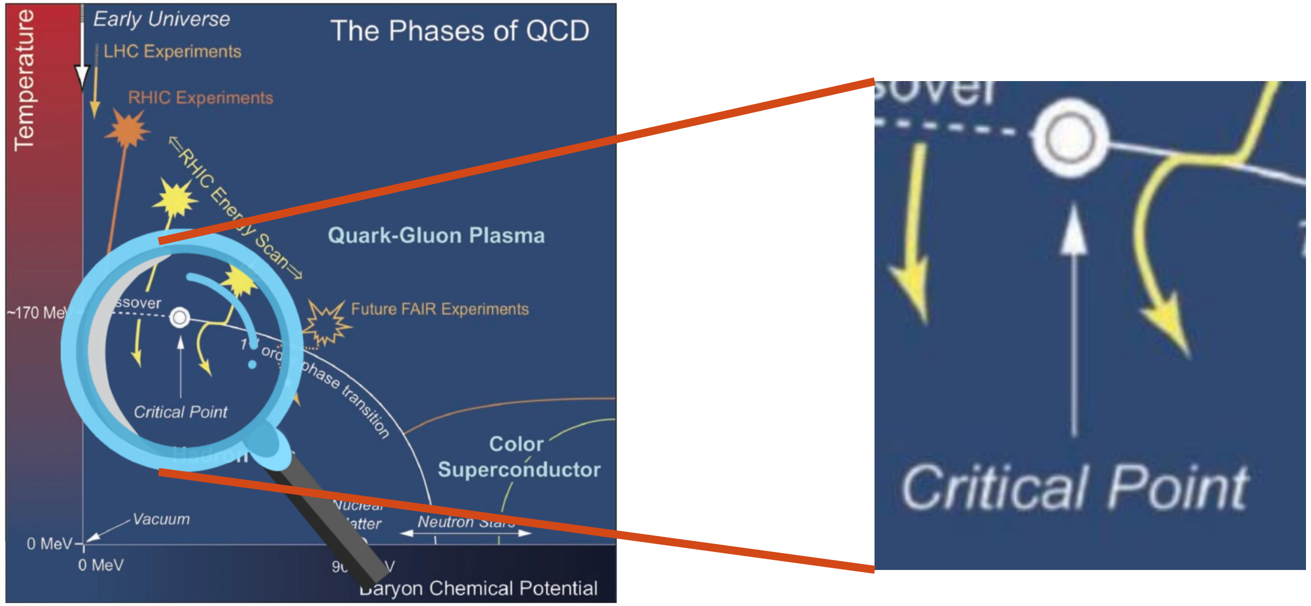
Q: Are these two aspects related?

NAÏVE ESTIMATIONS

Y. Jiang and J. Liao, Phys. Rev. Lett. 117, 192302 (2016),



- Spin polarization $\sim\Omega$
- Spin alignment $\sim\Omega^2$
- Chiral condensate does not change much at small Ω
- Not that large effect
- But….



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Spin fluctuation? Just like baryon number?

QUALITATIVE STUDY: NJL MODEL

- Some assumptions and techniques are needed
  - We focus on the physic near the center (r=0)
  - Introducing rotation and chemical potential only act on quark or antiquark

$$V^0_{eff}(\Omega_q,\Omega_{\bar{q}},\mu_q,\mu_{\bar{q}}) = \frac{(m-m_0)^2}{4G} - N_c N_f \int_0^{\Lambda} \frac{\mathrm{d}^3 p}{(2\pi)^2} 2\varepsilon_p$$
$$+ N_c N_f \int_0^{\infty} \frac{\mathrm{d}^3 p}{(2\pi)^2} [T\ln(1+\mathrm{e}^{-(\varepsilon_p-\mu-\Omega_q/2-\mu_q)/T}) + T\ln(1+\mathrm{e}^{-(\varepsilon_p-\mu+\Omega_q/2-\mu_q)/T})$$
$$+ T\ln(1+\mathrm{e}^{-(\varepsilon_p+\mu-\Omega_{\bar{q}}/2-\mu_{\bar{q}})/T}) + T\ln(1+\mathrm{e}^{-(\varepsilon_p+\mu+\Omega_{\bar{q}}/2-\mu_{\bar{q}})/T})].$$

  - Then by taking derivative, we can get cumulants of spin and particle number
  - We define the spin correlation of quark-antiquark as

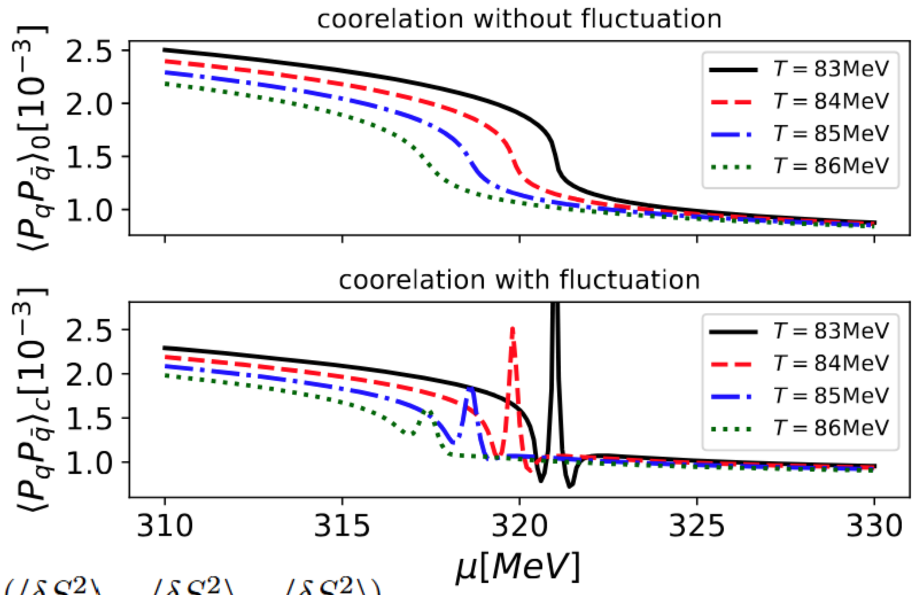
$$\langle P_q P_{\bar{q}} \rangle_c = \frac{4(\langle \delta S^2 \rangle - \langle \delta S_q^2 \rangle - \langle \delta S_{\bar{q}}^2 \rangle)}{\langle \delta N^2 \rangle - \langle \delta N_q^2 \rangle - \langle \delta N_{\bar{q}}^2 \rangle}.$$

$$\langle \delta S_q^2 \rangle = -\frac{V}{T}\frac{\partial^2 V_{eff}(\Omega_q,\Omega_{\bar{q}})}{\partial(\frac{\Omega_q}{T})^2}\Big|_{\Omega_q=\Omega_{\bar{q}}=\Omega},$$
$$\langle \delta S_{\bar{q}}^2 \rangle = -\frac{V}{T}\frac{\partial^2 V_{eff}(\Omega_q,\Omega_{\bar{q}})}{\partial(\frac{\Omega_{\bar{q}}}{T})^2}\Big|_{\Omega_q=\Omega_{\bar{q}}=\Omega},$$
$$\langle \delta N_q^2 \rangle = -\frac{V}{T}\frac{\partial^2 V_{eff}}{\partial(\frac{\mu_q}{T})^2}\Big|_{\mu_q=\mu_{\bar{q}}=0},$$
$$\langle \delta N_{\bar{q}}^2 \rangle = -\frac{V}{T}\frac{\partial^2 V_{eff}}{\partial(\frac{\mu_{\bar{q}}}{T})^2}\Big|_{\mu_q=\mu_{\bar{q}}=0}.$$

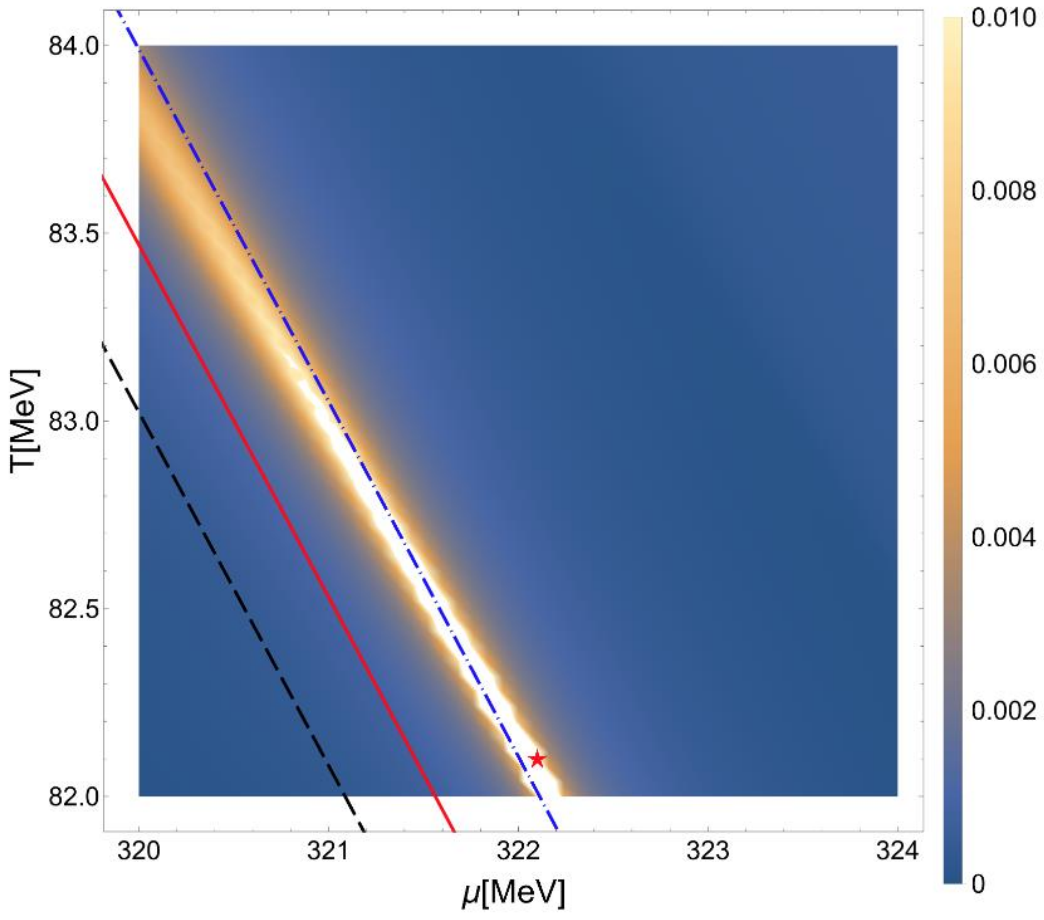
SPIN CORRELATION ENHANCED BY CEP!

- Comparison with the case w/o fluctuation

$$\langle P_q P_{\bar{q}} \rangle_0 = \frac{\int d^3p (f_q^\uparrow - f_q^\downarrow)(f_{\bar{q}}^\uparrow - f_{\bar{q}}^\downarrow)}{\int d^3p (f_q^\uparrow + f_q^\downarrow)(f_{\bar{q}}^\uparrow + f_{\bar{q}}^\downarrow)}.$$



$$\langle P_q P_{\bar{q}} \rangle_c = \frac{4(\langle \delta S^2 \rangle - \langle \delta S_q^2 \rangle - \langle \delta S_{\bar{q}}^2 \rangle)}{\langle \delta N^2 \rangle - \langle \delta N_q^2 \rangle - \langle \delta N_{\bar{q}}^2 \rangle}.$$

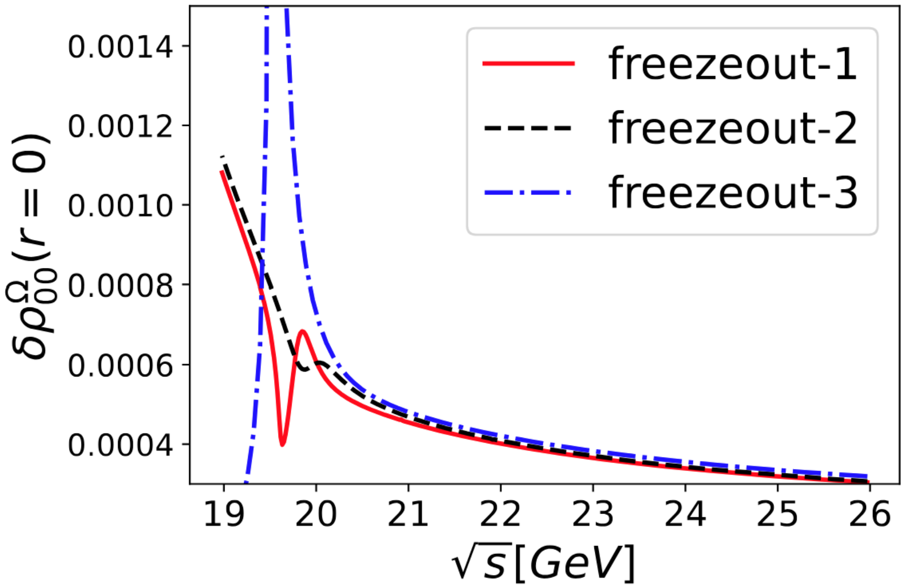


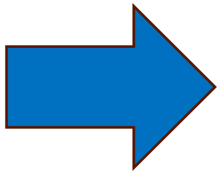
VECTOR MESON SPIN ALIGNMENT

- Along imaginary freezeout lines

$$\rho_{00} = \frac{1 - \langle P_q P_{\bar{q}} \rangle}{3 + \langle P_q P_{\bar{q}} \rangle} \approx \bar{\rho}_{00} - \delta\rho_{00}^{\Omega}.$$

Contribution from critical fluctuation



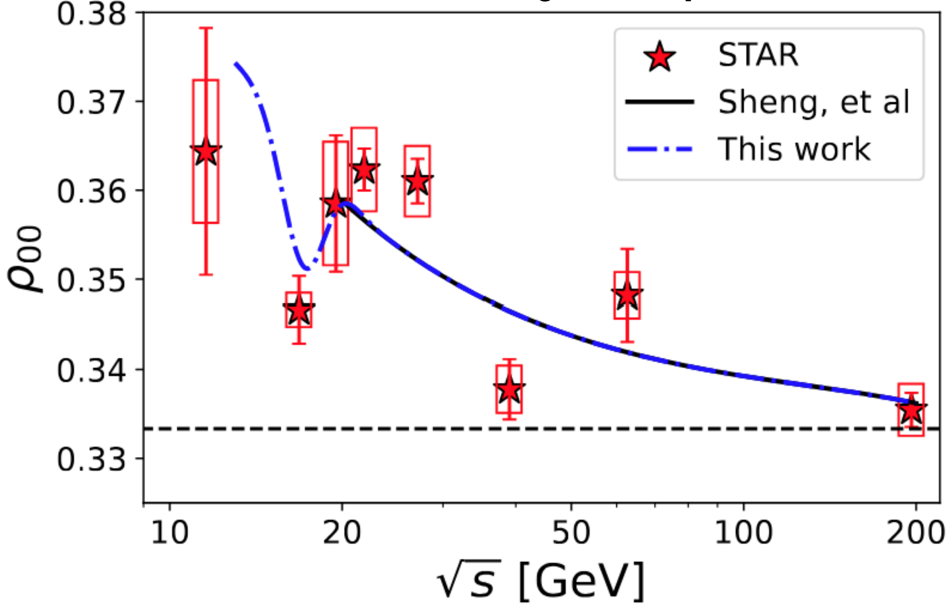


As additional contribution

A SCHEMATIC FIGURE

G. Wilks' talk@SQM2024

X.-L. Sheng, et al, Phys. Rev. Lett. 131, 042304 (2023)



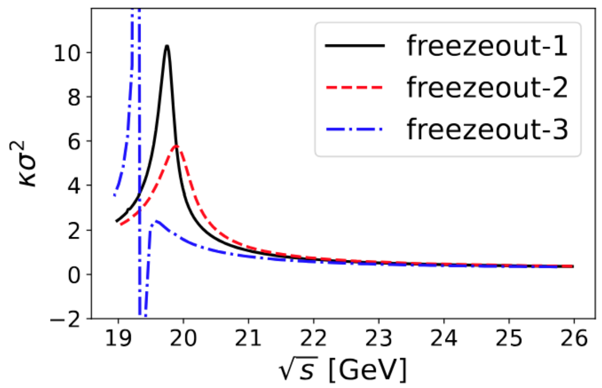
TAKE-HOME MESSAGES

- Quark spin also fluctuates near the CEP
- Critical fluctuation near CEP can lead to non-monotonic behavior of Spin alignment & Hyperon-anti-Hyperon correlation
- Spin alignment & Hyperon-anti-Hyperon correlation can serve as signatures for CEP

$$\frac{N_{H\bar{H}}^{\uparrow\uparrow} + N_{H\bar{H}}^{\downarrow\downarrow} - N_{H\bar{H}}^{\uparrow\downarrow} - N_{H\bar{H}}^{\downarrow\uparrow}}{N_{H\bar{H}}^{\uparrow\uparrow} + N_{H\bar{H}}^{\downarrow\downarrow} + N_{H\bar{H}}^{\uparrow\downarrow} + N_{H\bar{H}}^{\downarrow\uparrow}}$$

- Effect on higher order cumulants will be more significant

Quark spin kurtosis



THANKS !