中國科學院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

For 2018 Workshop on Chirality, Vorticity and Magnetic Field in Heavy Ion Collisions

Phase Diagram of rotating matter

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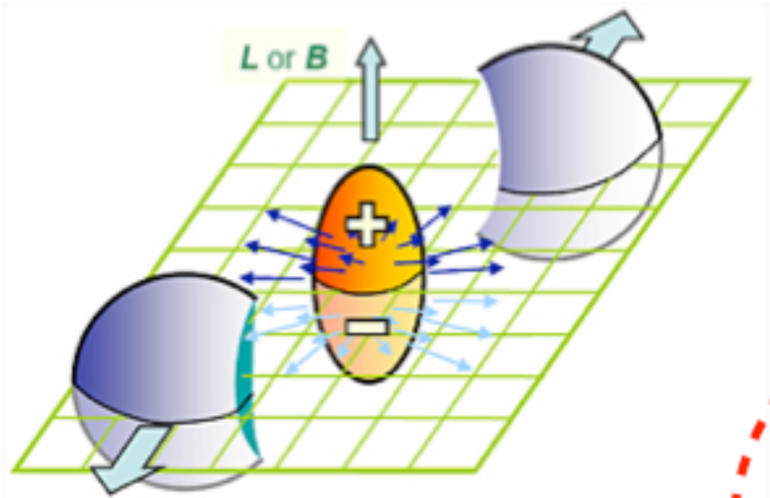
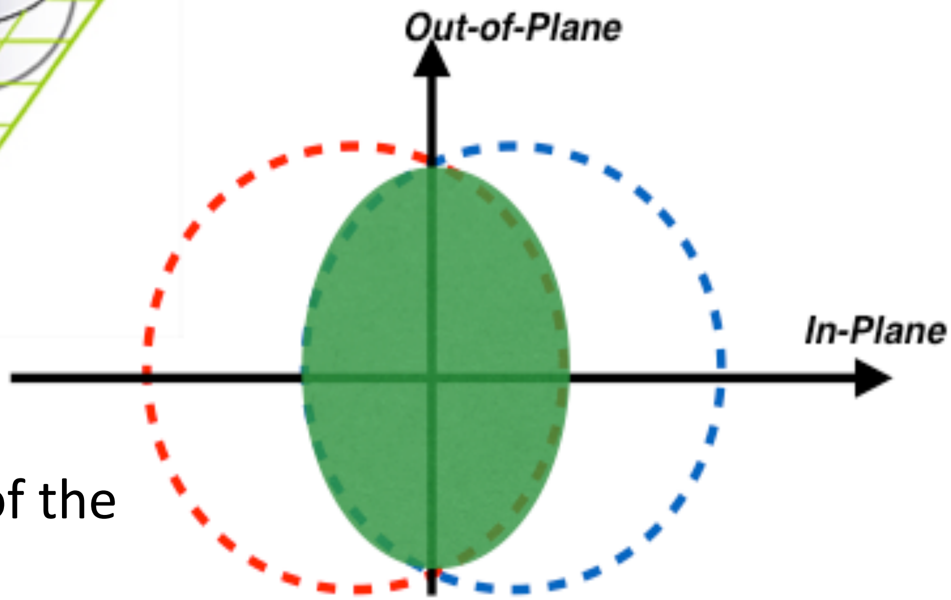
Collaborate with Prof. Mei Huang and Zhibin Li

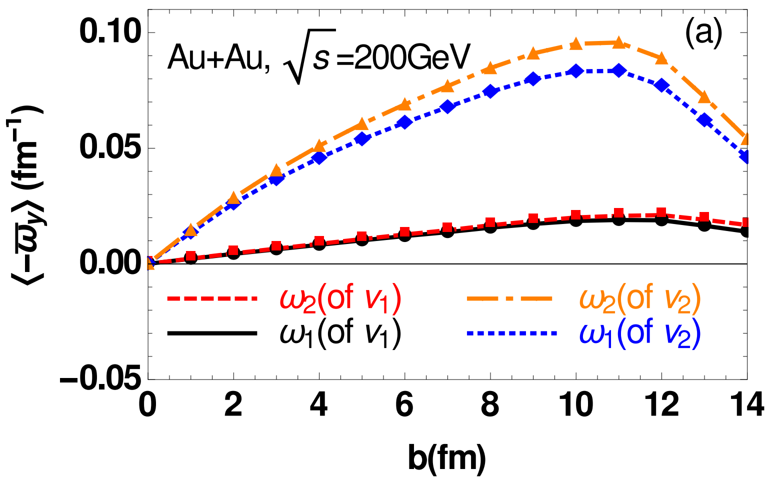
Rotation in Heavy Ion Collision

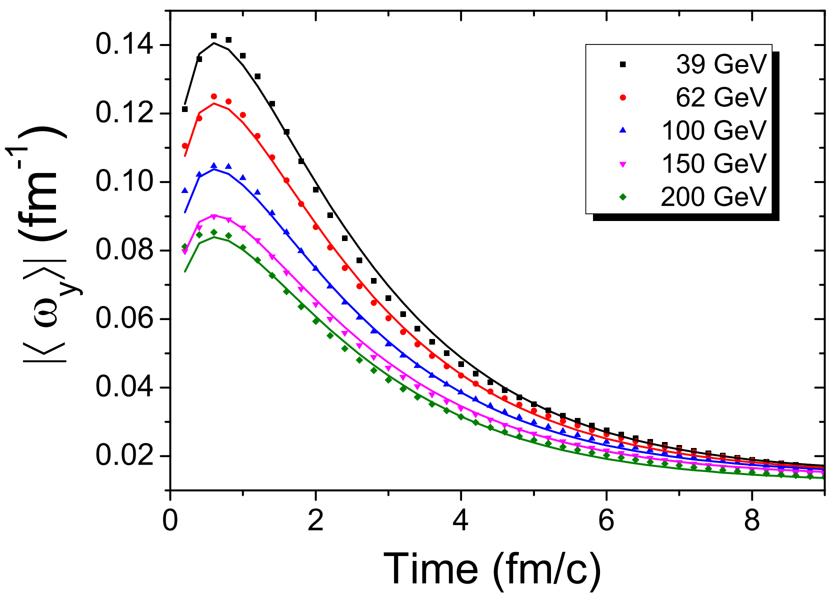




In off-central collision, most of the angular momentum is carried away by the spectators, but there still a nonzero angular momentum in the range of $10^3\hbar - 10^5\hbar$ remains.

Rotation in Heavy Ion Collision





Wei-Tian Deng et al. PRC(2016)

Yin Jiang et al. PRC(2016)

NJL Model

$$\mathcal{L} = \bar{\psi}[i\bar{\gamma}^{\mu}(\partial_{\mu} + \Gamma_{\mu}) - m]\psi + G_S[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2] - G_V[(\bar{\psi}\gamma_{\mu}\psi)^2 + (\bar{\psi}\gamma_{\mu}\gamma_5\psi)^2]$$

$$\Gamma_{\mu} = \frac{1}{4} \times \frac{1}{2}[\gamma^a, \gamma^b]\,\Gamma_{ab\mu} \qquad \Gamma_{ab\mu} = \eta_{ac}(e^c{}_{\sigma}G^{\sigma}{}_{\mu\nu}e_b{}^{\nu} - e_b{}^{\nu}\partial_{\mu}e^c{}_{\nu})$$

$$e^a{}_{\mu} = \delta^a{}_{\mu} + \delta^a{}_i\delta^0{}_{\mu}\,v_i \qquad e_a{}^{\mu} = \delta_a{}^{\mu} - \delta_a{}^0\delta_i{}^{\mu}\,v_i$$

Follow Yin Jiang and Jinfeng Liao, PRL(2017)

$$\Omega = \int d^3\mathbf{r}\left\{\frac{(M-m)^2}{4G_S} - \frac{(\mu-\tilde{\mu})^2}{4G_V} - \frac{TN_cN_f}{16\pi^2}\sum_n \int dk_t^2 \int dk_z[J_n(k_tr)^2 + J_{n+1}(k_tr)^2]\left[\ln(1+e^{(E_k-(n+\frac{1}{2})\omega-\tilde{\mu})/T})\right.\right.$$
$$\left.\left.+ \ln(1+e^{-(E_k-(n+\frac{1}{2})\omega-\tilde{\mu})/T}) + \ln(1+e^{-(E_k+(n+\frac{1}{2})\omega+\tilde{\mu})/T}) + \ln(1+e^{(E_k+(n+\frac{1}{2})\omega+\tilde{\mu})/T})\right]\right\},$$

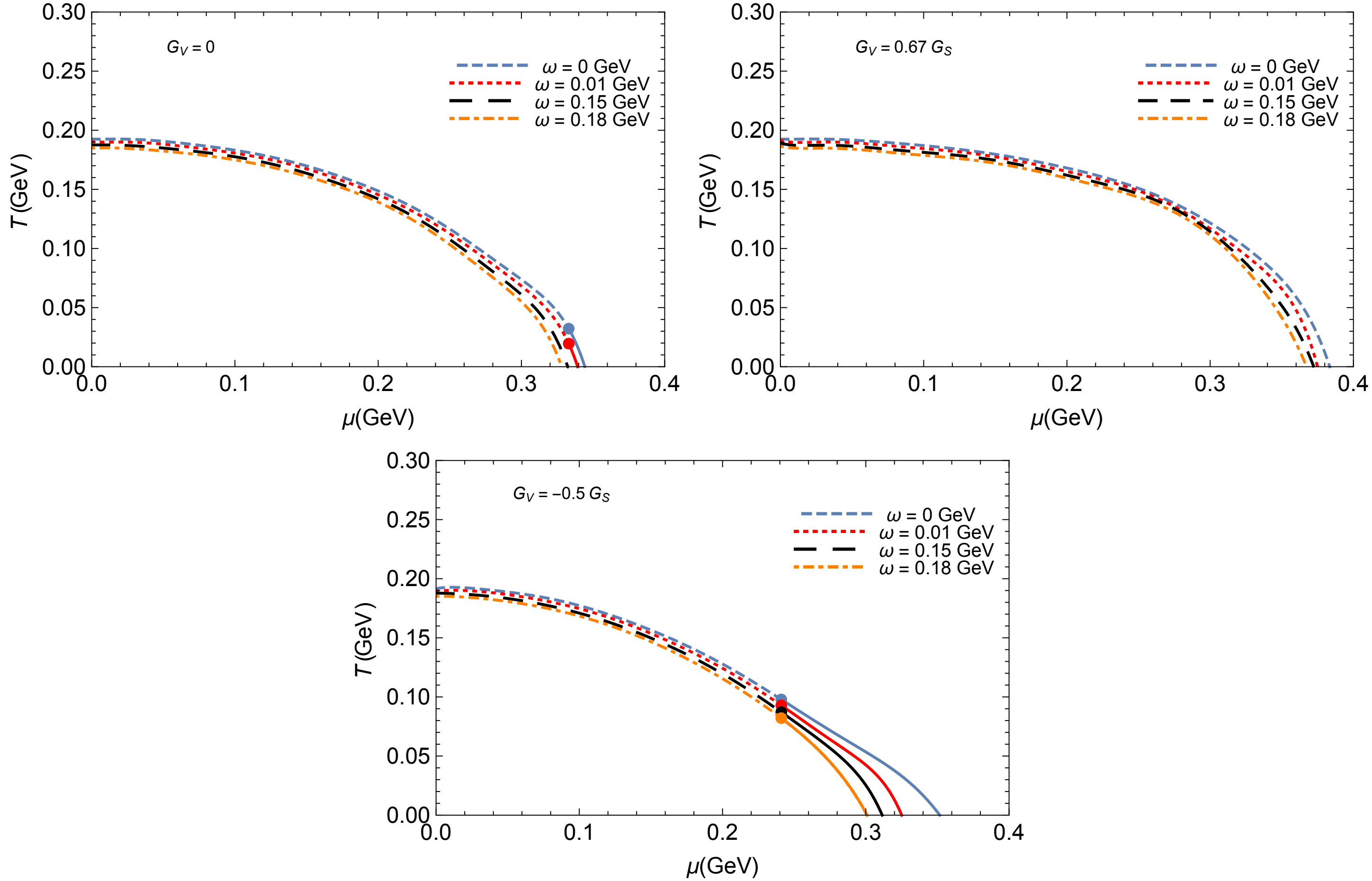
$E_k = \sqrt{k_z^2 + k_t^2 + M^2}$, $\mathbf{r}$ is the location from the center of rotation

$$\tilde{\mu} = \mu - 2G_V\left\langle\psi^{\dagger}\psi\right\rangle \qquad M = m - 2G_S\left\langle\bar{\psi}\psi\right\rangle$$

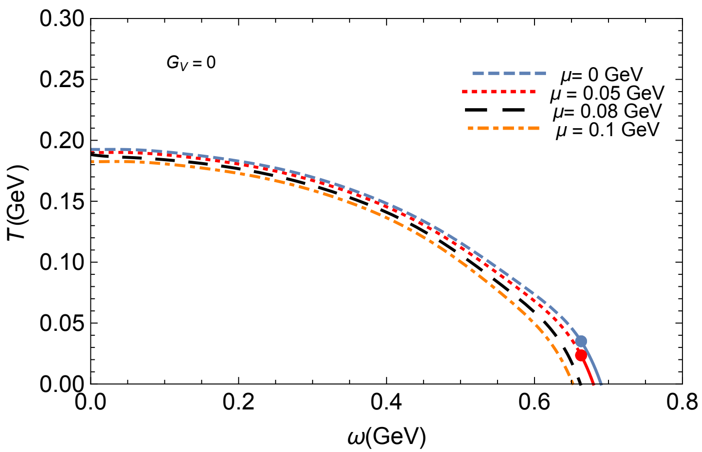
- Gap equations $\dfrac{\partial\Omega}{\partial M} = 0, \quad \dfrac{\partial\Omega}{\partial\tilde{\mu}} = 0.$

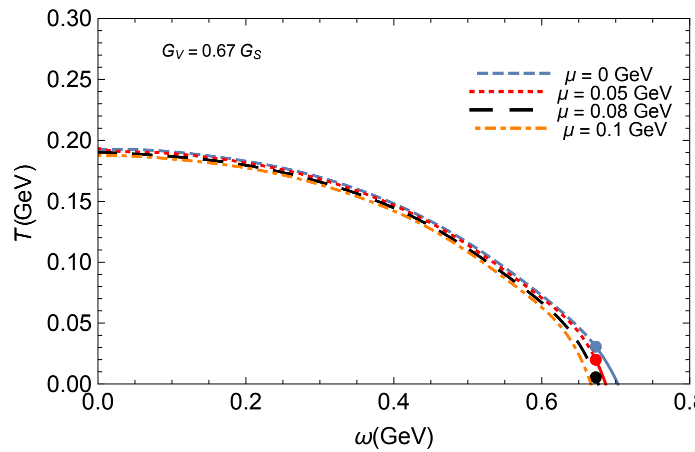
X.W, Z.L and Mei Huang Arxiv: 1803.xxxx

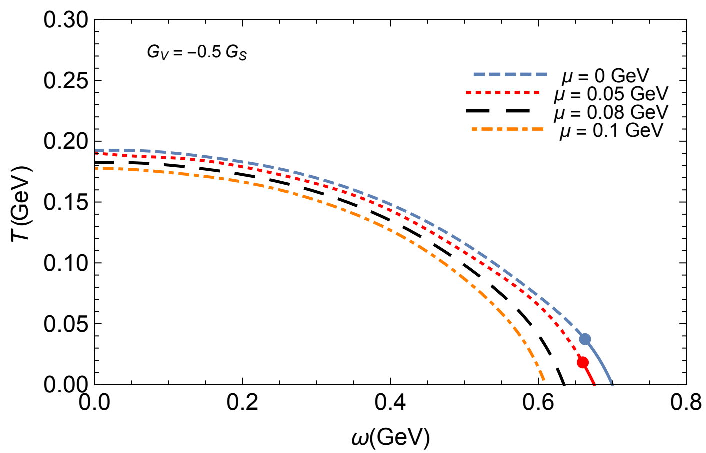
Phase diagram on T-μ plane with different ω



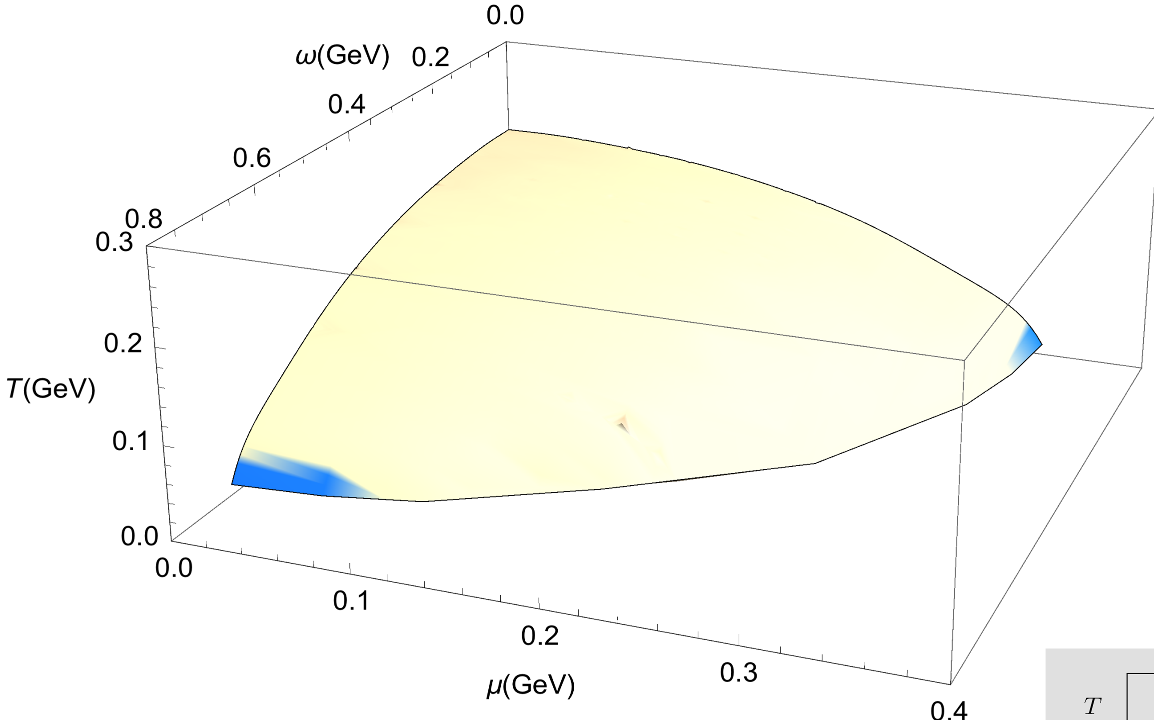
Phase diagram on T-ω plane with different μ



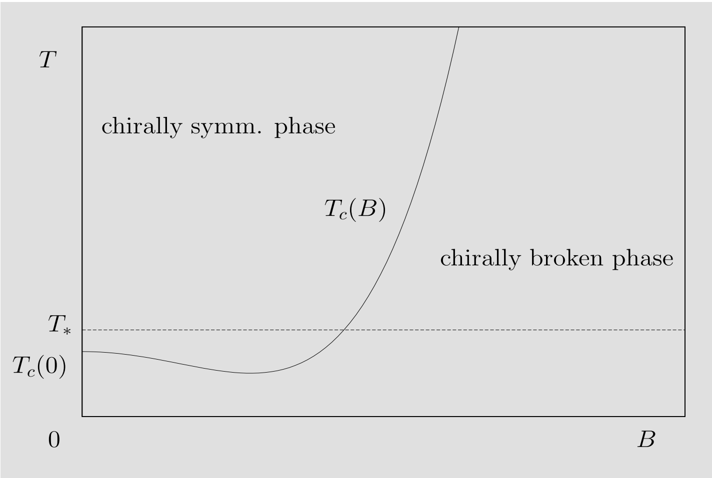




Phase Diagram in 3D (T-μ-ω)



Quiet different with in a magnetic field case.
E.-M. Ilgenfritz et al. PRD(2014)



Experiment measurement

- The peaked baryon number susceptibilities along the freeze-out line is solely determined by the CEP, this can be used as an evident signature for the existence of the CEP, the peak position is close to the location of the CEP in the QCD phase diagram.
- The cumulants of conserved quantities up to fourth order have been measured in BES-I program at RHIC.

STAR Collaboration, PRL(2010)
STAR Collaboration, PRL(2014)
X.Luo et al. Nucl. Sci. Tech(2017)

Baryon number susceptibilities

The cumulants of baryon number distributions are given by

$$C_n^B = VT^3\chi_n^B$$

Here, the baryon number susceptibilities

$$\chi_n^B = \frac{\partial^n(P/T^4)}{\partial(\mu_B/T)^n},$$

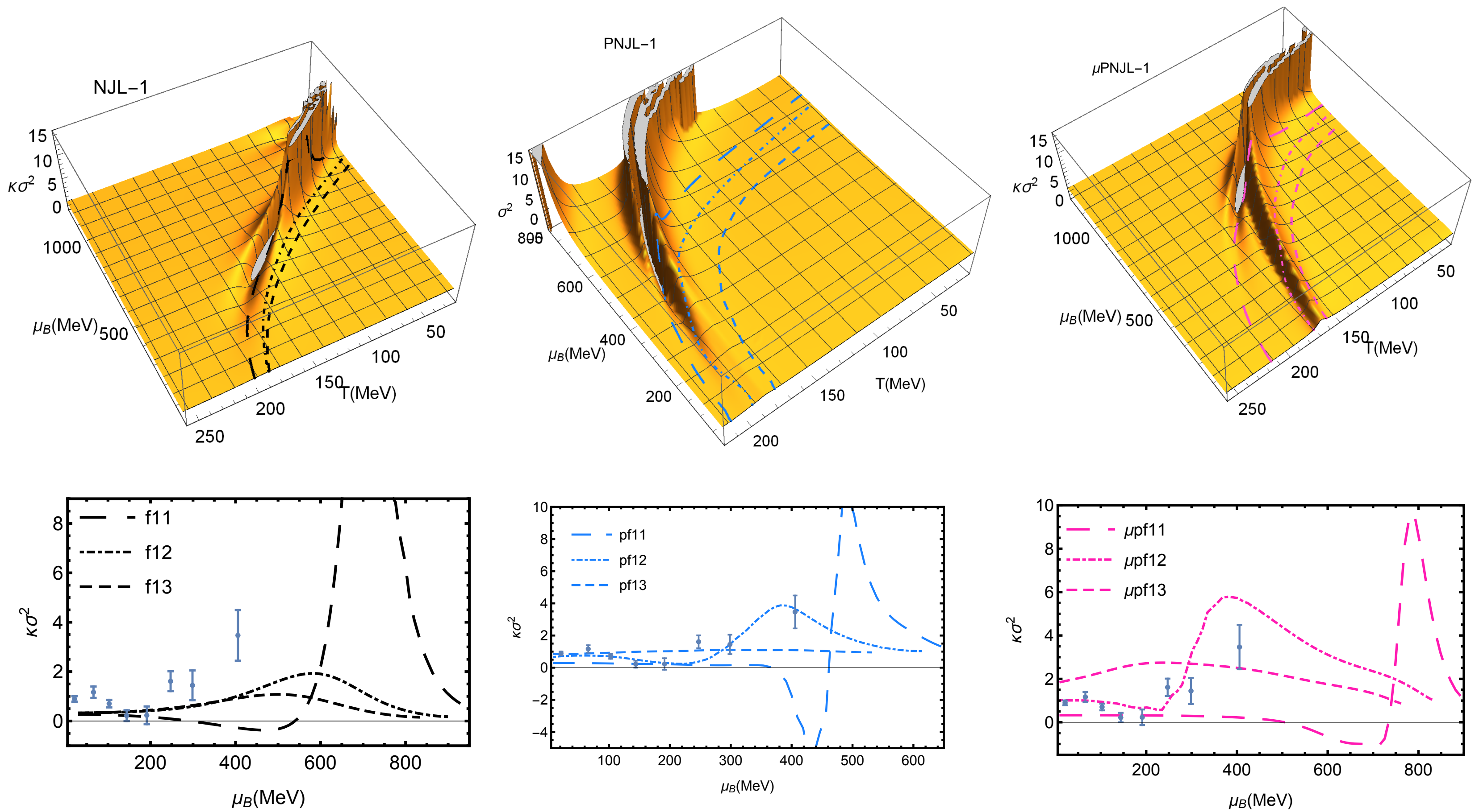
with the pressure P $= -\Omega$ which is just the minus grand potential. The variance and kurtosis are defined by

$$\sigma^2 = C_2^B, \qquad \kappa = \frac{C_4^B}{(\sigma^2)^2}.$$

The relations between observable quantities and theoretical calculations is

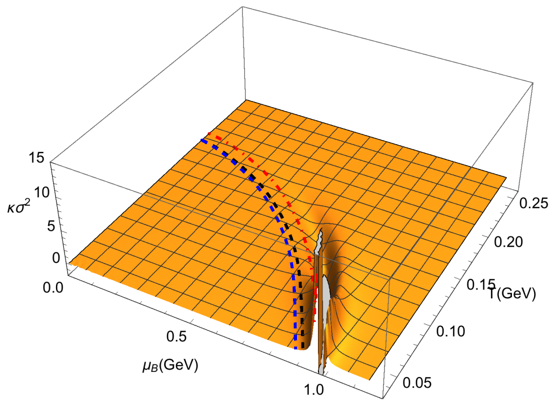
$$\kappa\sigma^2 = \frac{C_4^B}{C_2^B} = \frac{\kappa_4^B}{\kappa_2^B}$$

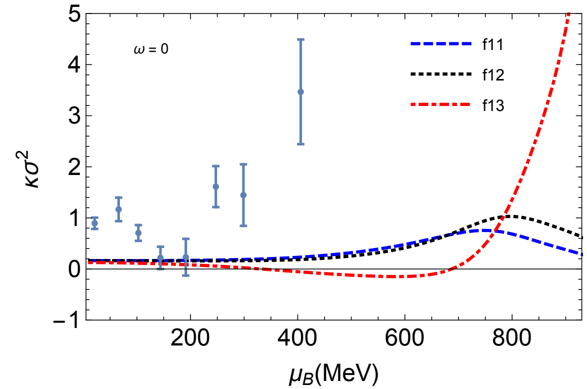
Kurtosis of net number fluctuations in different NJL-Based models without rotation

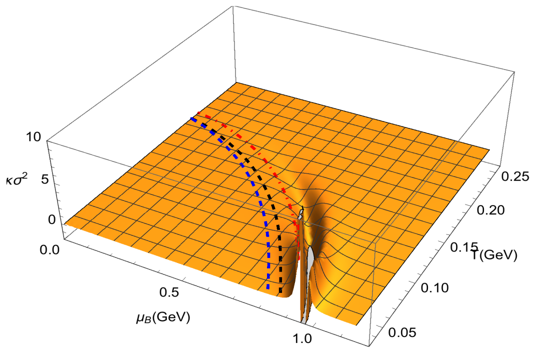


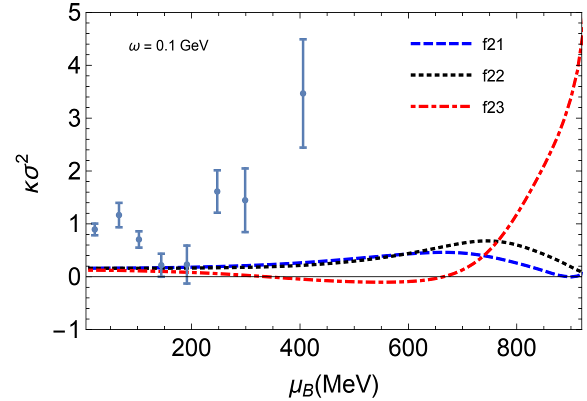
Z.L, X.W and Mei Huang arXiv:1801.09215

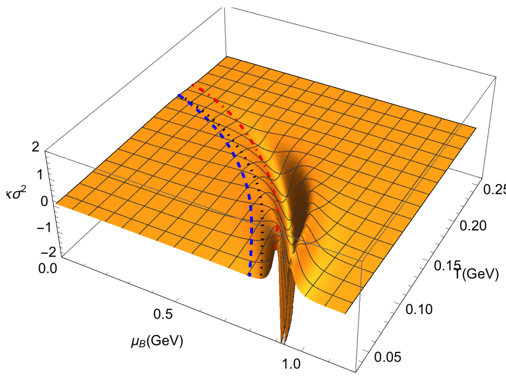
With rotation(preliminary result)

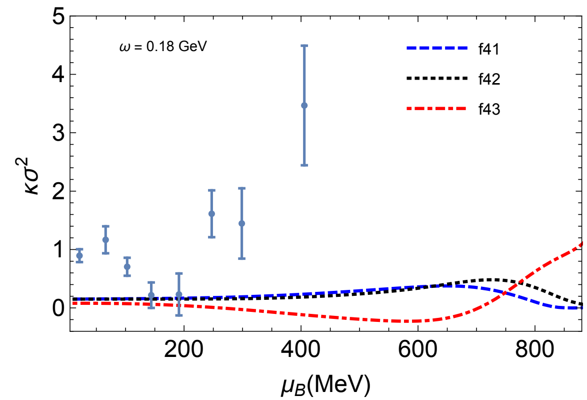












Summary

- Angular velocity plays a similar role as vector channel. It almost gives an addition part of dynamical quark chemical potential.
- The phase transition on ω-T plane is similar as the phase transition on μ-T plane.
- In our model, we assume the angular momentum is much smaller than the inverse of system transverse size which means we did not include the boundary effect. Also the gluodynamics contribution is not included here and it still a puzzle how to include this as what we did in non- rotation system.

Thank you !