University of Chinese Academy of Sciences

QCD phase transitions in HICs

黄梅

中国科学院大学

第二十届全国中高能核物理大会暨第十四届全国中高能核物理专题研讨会

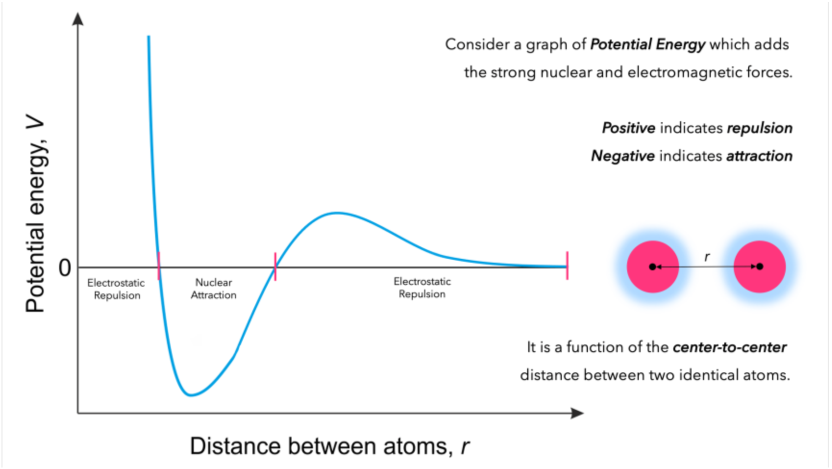
上海， 2025年4月25-28

1, Status of CEP from theory;

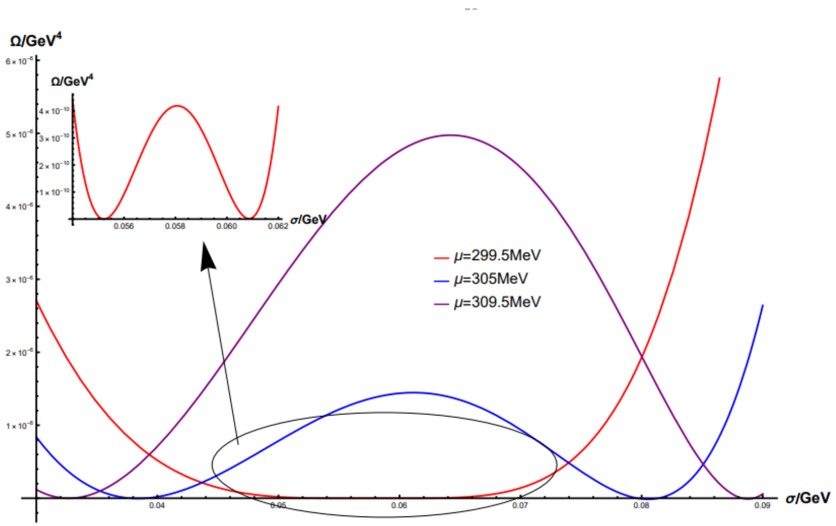
2, QCD phase transitions under rotation

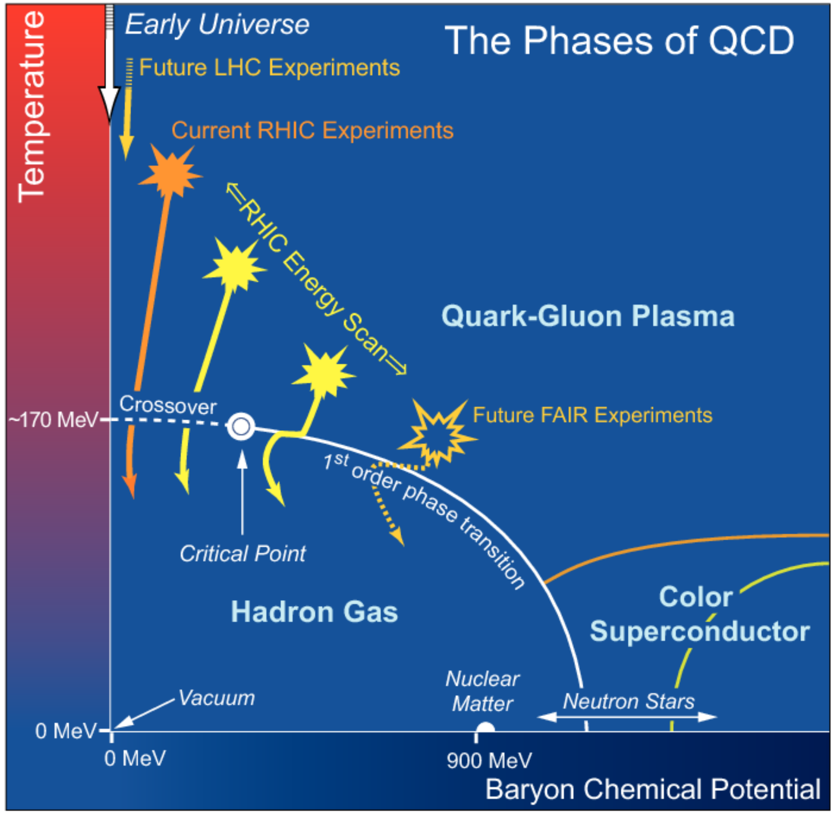
Existence of CEP at high baryon chemical potential

potential barrier is needed for 1st-order phase transition



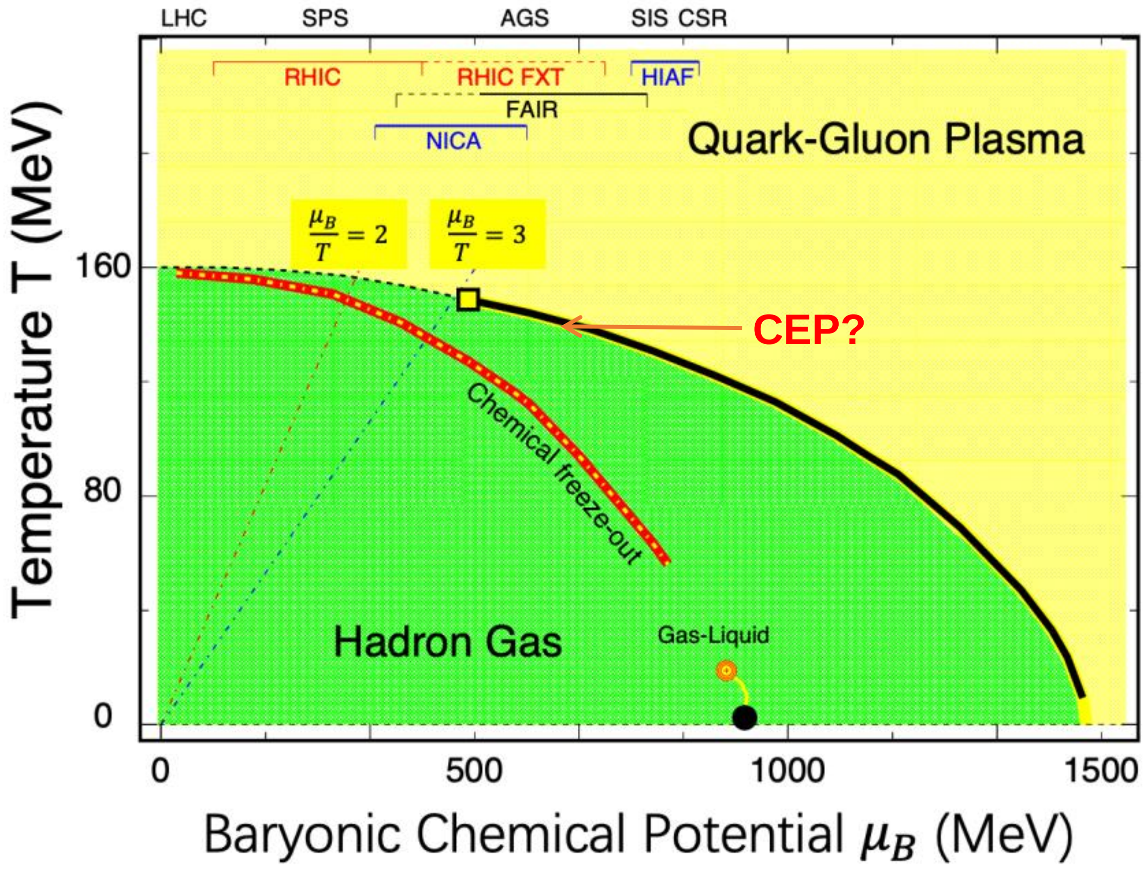
mu_B plays the role of repulsive vector interaction, potential barrier develops when mu_B increases, indicating a 1st-order phase transition.

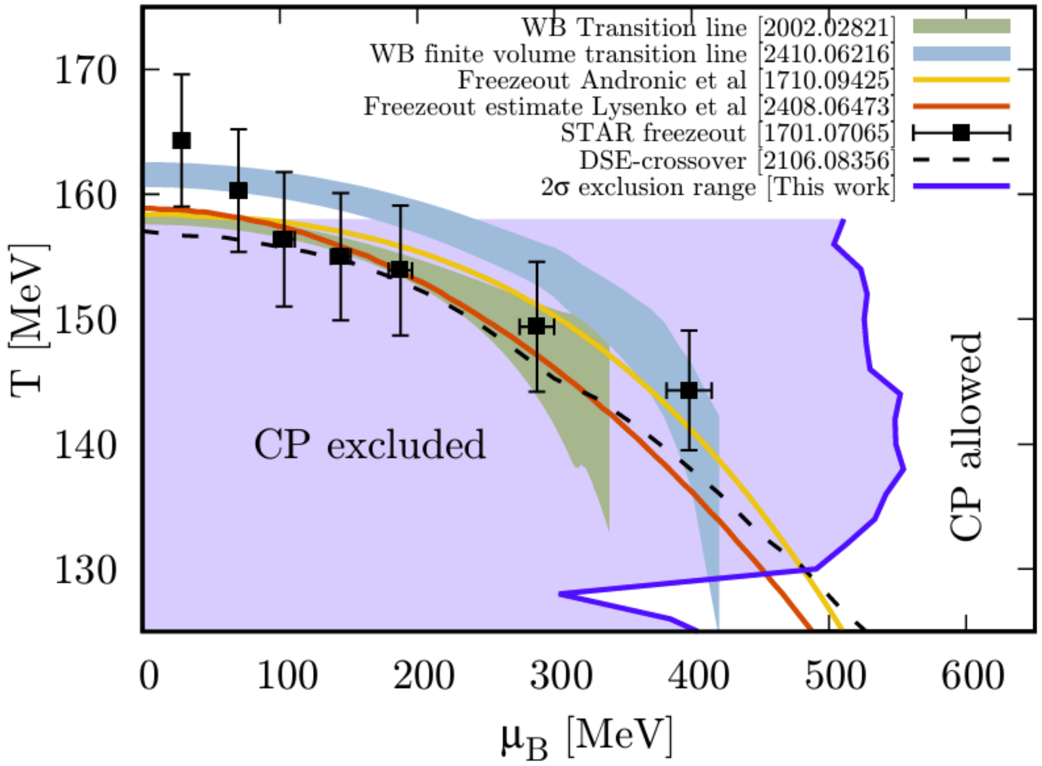




STAR results on CEP,
徐庆华，罗晓峰 大会报告

Latest lattice constraints on CEP





Lattice QCD constraints on the critical point,
Szabolcs Bors´anyi,1 Zolt´an Fodor, et.al., …arXiv: 2502.10267

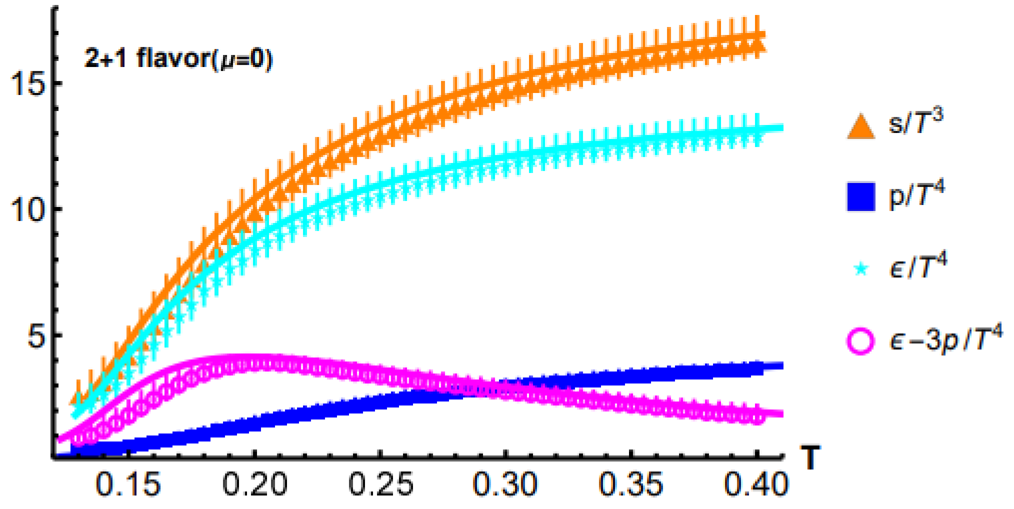
Equilibrium state

Theoretical predictions for the location of CEP

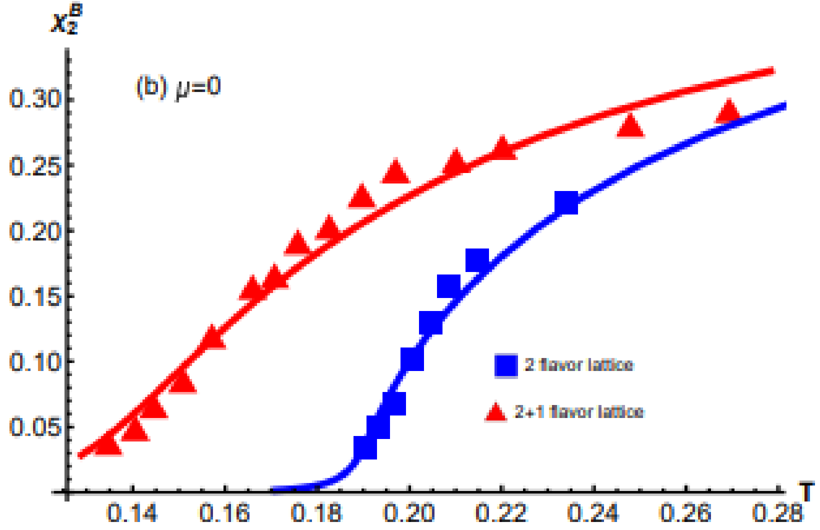
Nonperturbative theoretical calculations (rPNJL model, DSE-fRG,fRG,holographic QCD):

Strategy of model calculations:

1, Fit model paraters with Lattice QCD EOS and baryon number susceptibility at zero chemical potential;
2,Predictions at finite baryon number chemical potential.



Determine Tc at mu=0

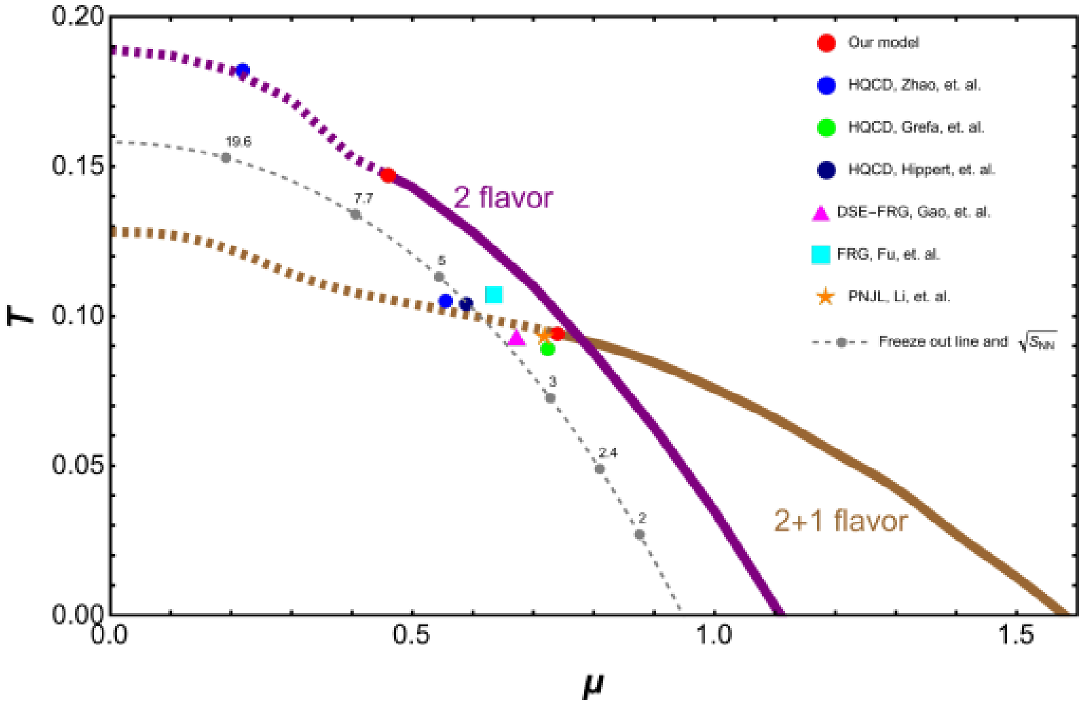


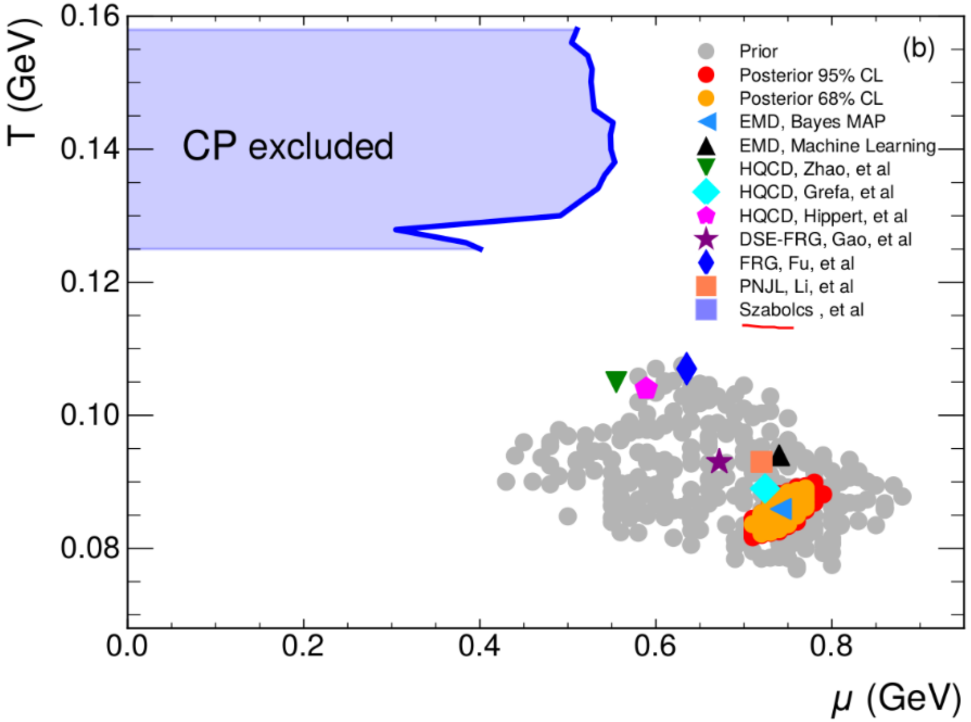
Determine mu dependent Tc

ML+hQCD:Xun Chen（陈勋）, MH, Phys.Rev.D 109 (2024) 5, L051902, e-Print:2401.06417

Equilibrium state

Locations of CEP from rPNJL model, holographic QCD models, DSE-fRG,fRG **converge** at around (Tc~90MeV, mu_B^c~700 MeV)





ML+hQCD:Xun Chen（陈勋）, MH, Phys.Rev.D 109 (2024) 5, L051902, e-Print:2401.06417 [hep-ph];e-Print: 2405.06179 [hep-ph]

J. Grefa, J. Noronha, J. Noronha-Hostler, I. Portillo, C. Ratti, and R. Rougemont, Phys. Rev. D 104, 034002 (2021), arXiv:2102.12042 [nucl-th]; ;
M. Hippert, J. Grefa, T. A. Manning, J. Noronha, J. Noronha-Hostler, I. Portillo Vazquez, C. Ratti, R. Rougemont, and M. Trujillo (2023) arXiv:2309.00579 [nucl-th], Y.-Q. Zhao, S. He, D. Hou（侯德富）, L. Li, and Z. Li, JHEP 04, 115 (2023), arXiv:2212.14662 [hep-ph]

rPNJL:Zhibin Li（李志镔）, Kun Xu（许坤）, Xinyang Wang（王昕杨） and MH, arXiv:1801.09215

DSE-fRG: *F. Gao（高飞）and J. M. Pawlowski, Phys. Rev. D 102, 034027 (2020), arXiv:2002.07500 [hep-ph].*

fRG:W.-j. Fu（付伟杰）, J. M. Pawlowski, and F. Rennecke, Phys. Rev. D 101, 054032 (2020), arXiv:1909.02991 [hep-ph].

Bayesian+hQCD: Liqiang Zhu, Xun Chen, Kai Zhou, Hanzhong Zhang（张汉中）, M.H., e-Print: 2501.17763　周凯 大会报告　朱力强 poster

Net proton number fluctuations near critical point

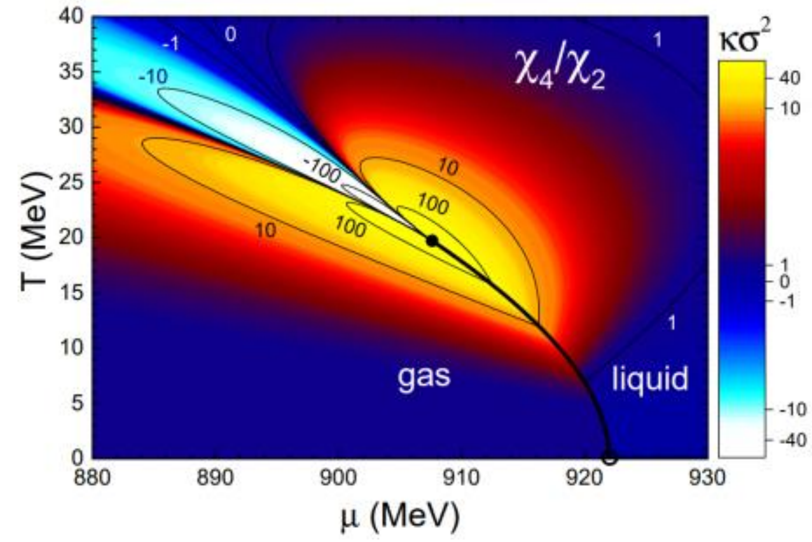
$$K_N = \ln(e^{tN}) = \sum_{n=1}^{\infty} k_n \frac{t^n}{n!}$$

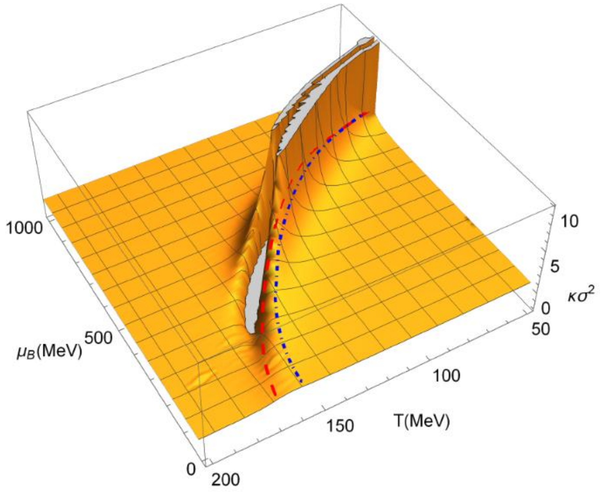
$$\ln Z^{gce}(T,V,\mu) = \ln[\sum_N e^{\mu N/T} Z^{ce}(T,V,N)]$$

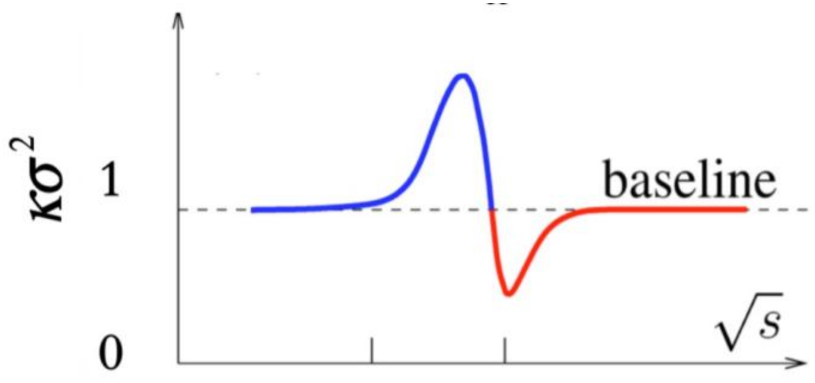
$$k_n \propto \frac{\partial^n (\ln Z^{gce})}{\partial \mu^n}$$

$$C_1 = \langle N \rangle = M$$
$$C_2 = \langle (\Delta N)^2 \rangle = \sigma^2$$
$$C_3 = \langle (\Delta N)^3 \rangle = S\sigma^3$$
$$C_4 = \langle (\Delta N)^4 \rangle - 3C_2^2 = \kappa\sigma^4$$

$$\frac{\sigma^2}{M} = \frac{C_2}{C_1}, S\sigma = \frac{C_3}{C_2}, \kappa\sigma^2 = \frac{C_4}{C_2}$$





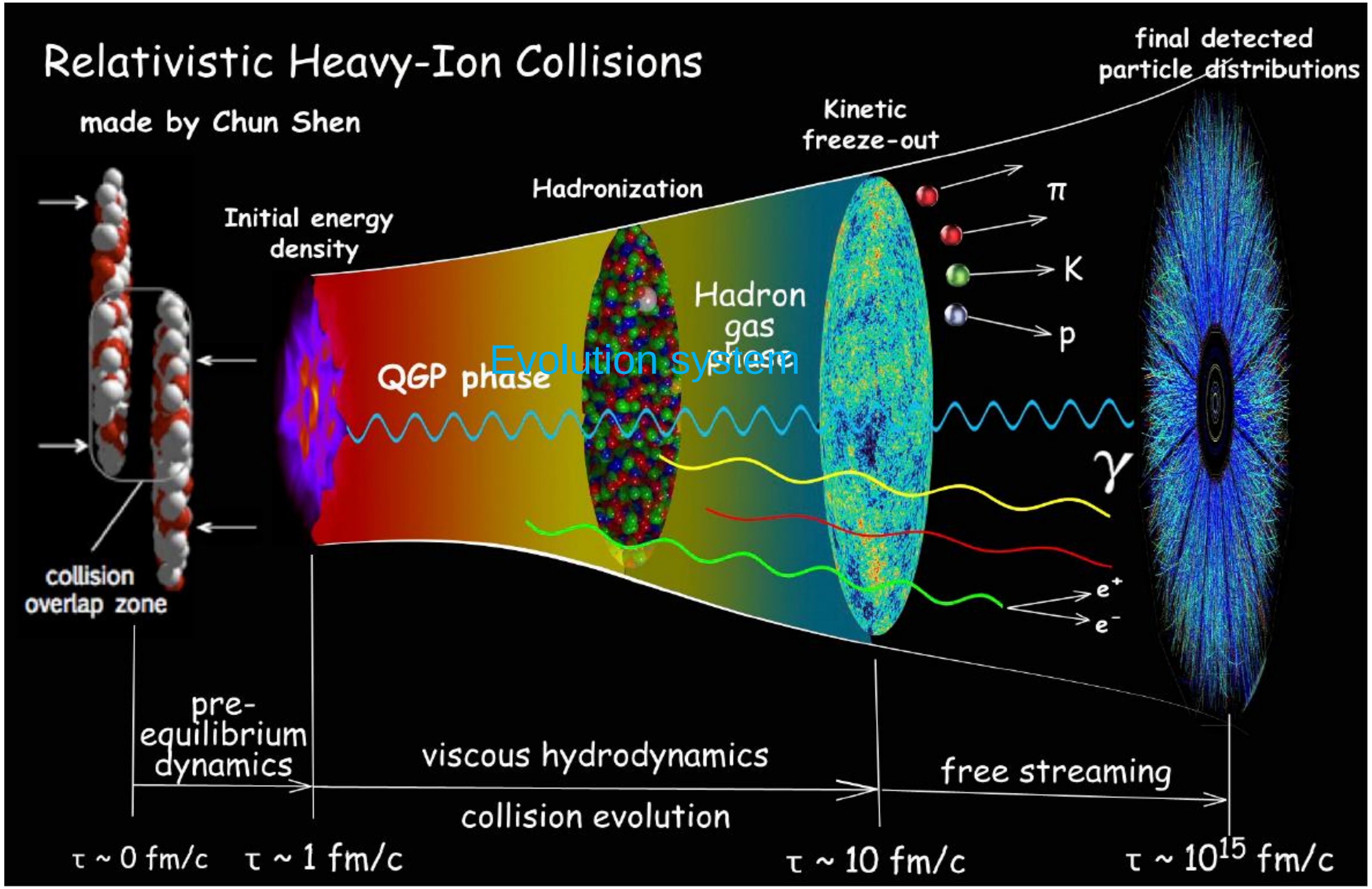


M.A.Stephanov,PRL107,052301(2011)

VV, Anchishkin, Gorenstein, Poberezhnyuk, PRC 92, 054901 (2015)

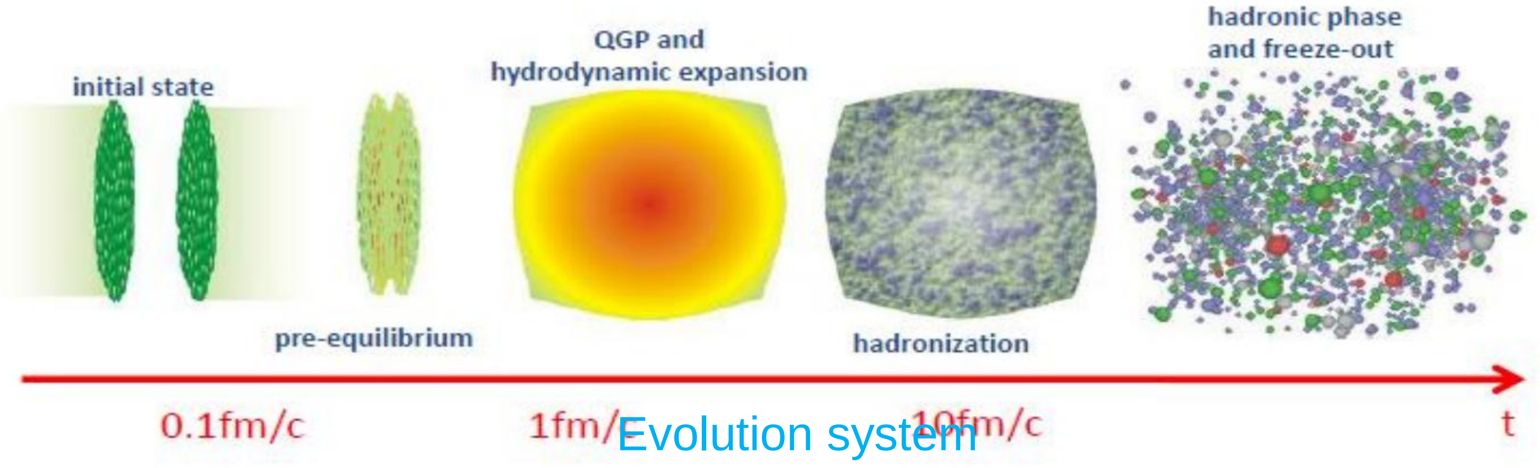
Relativistic Heavy-Ion Collisions

Relativistic heavy-ion collisions → hot QCD matter and its phase transition



Evolution system

Hybrid Model



Evolution system

Initial Conditions
SMASH

Hydro
CLVisc

Fist Sampler +
hadron cascade

arXiv:e-Print: 2404.02397 [hep-ph]

Collaborators: Yifan Shen *（沈一凡）*, Wei Chen *（陈蔚）*, Kun Xu *（许坤）*, Xiangyu Wu *（吴翔宇）*

Evolution system

Hydrodynamics (CLVisc)

Conservation laws of energy-monmentum and net baryon current：

$$\nabla_\mu T^{\mu\nu} = 0 \quad \text{with} \quad T^{\mu\nu} = eU^\mu U^\nu - P\Delta^{\mu\nu} + \pi^{\mu\nu}$$

$$\nabla_\mu J^\mu = 0 \quad \text{with} \quad J^\mu = nU^\mu + V^\mu$$

Evolution system

Input:
1. Initial conditions
2. EoS from rPNJL model
(carry CEP information)

$$\Delta^{\mu\nu}_{\alpha\beta} D\pi^{\alpha\beta} = -\frac{1}{\tau_\pi}(\pi^{\mu\nu} - \eta_v \sigma^{\mu\nu}) - \frac{4}{3}\pi^{\mu\nu}\theta - \frac{5}{7}\pi^{\alpha<\mu}\sigma^{\nu>}_{\alpha} + \frac{9}{70}\frac{4}{e+p}\pi^{<\mu}_{\alpha}\pi^{\nu>\alpha}$$

$$\Delta^{\mu\nu} DV_\nu = -\frac{1}{\tau_V}\left(V^\mu - \kappa_B \nabla^\mu \frac{\mu_B}{T}\right) - V^\mu\theta - \frac{3}{10}V_\nu\sigma^{\mu\nu}$$

L.Pang （庞龙刚）et al, Phys.Rev. C86 (2012) 024911
L.Pang et al, Phys. Rev. C 97, 064918 (2018)
X.Wu et al, Phys. Rev. C 105, 034909 (2022)

1, EoS with CEP： Polyakov-loop-Nambu-Jona-Lasinio(PNJL) Model

Thermal Potential of PNJL Model:

Zhibin Li, Kun Xu, Xinyang Wang, Mei Huang. Eur.Phys.J.C 79 (2019) 3, 245

(μ_{Bc} = 720MeV, T_c= 93MeV)

$$
\begin{aligned}
\Omega_{\mathrm{PNJL}} = {} & U(\Phi,\bar{\Phi},T) + \\
& g_s \sum_f \sigma_f^2 - \frac{g_D}{2}\sigma_u\sigma_d\sigma_s + 3\frac{g_1}{2}\Big(\sum_f \sigma_f^2\Big)^2 + 3g_2\sum_f \sigma_f^4 - 6\sum_f \int_{-\Lambda}^{\Lambda} \frac{d^3p}{(2\pi)^3} E_f \\
& - 2T\sum_f \int_{-\infty}^{\infty} \frac{d^3p}{(2\pi)^3} \times \Big\{ \ln\Big[1 + 3\Phi e^{-\frac{E_f-\mu_f}{T}} + 3\bar{\Phi} e^{-2\frac{E_f-\mu_f}{T}} + e^{-3\frac{E_f-\mu_f}{T}}\Big] + \\
& \ln\Big[1 + 3\bar{\Phi} e^{-\frac{E_f+\mu_f}{T}} + 3\Phi e^{-2\frac{E_f+\mu_f}{T}} + e^{-3\frac{E_f+\mu_f}{T}}\Big]\Big\}
\end{aligned}
$$

2, EOS without CEP：numerical equation of state (NEOS) with multiple charges: net baryon (B), strangeness (S) and electric charge (Q)(NEOS-BQS) based on the lattice QCD EoS from the HotQCD collaboration

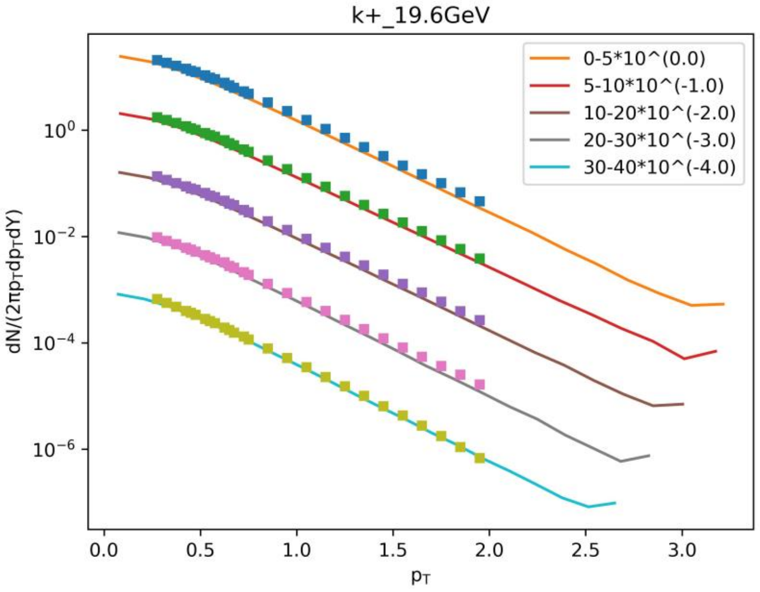
Parameters Table

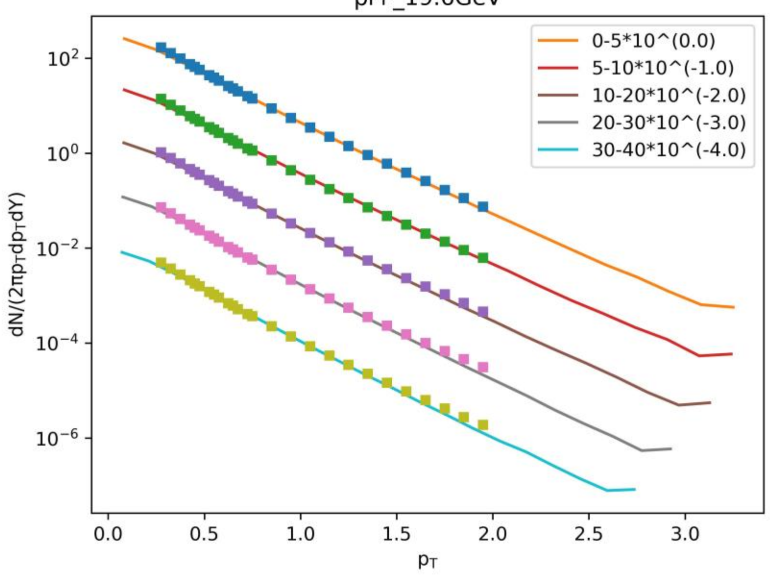
$\sqrt{s_{NN}}$ [GeV]	τ_0 [fm/c]	$R_\perp$ [fm]	R_η [fm]	C_{η_v}
7.7	3.2	1.4	0.5	0.2
14.5	1.68	1.4	0.5	0.2
19.6	1.22	1.4	0.5	0.15
27	1.0	1.2	0.5	0.12
39	0.9	1.0	0.7	0.08
62.4	0.7	1.0	0.7	0.08

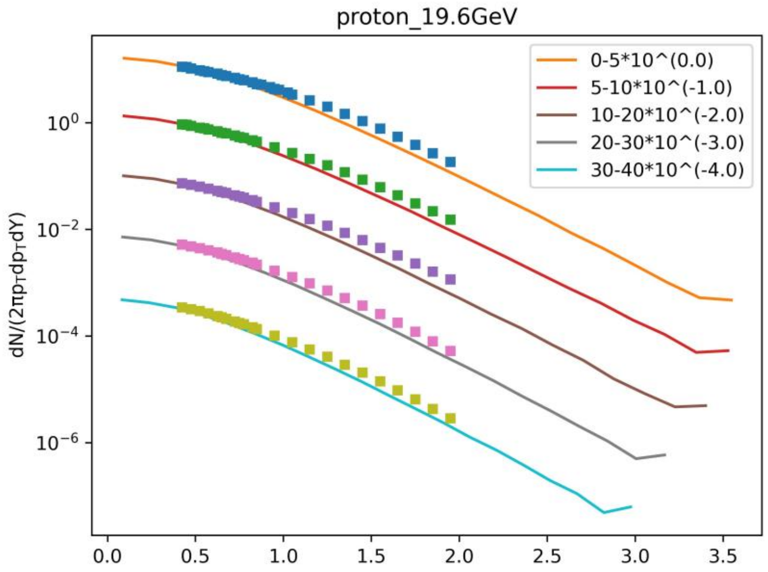
Evolution system

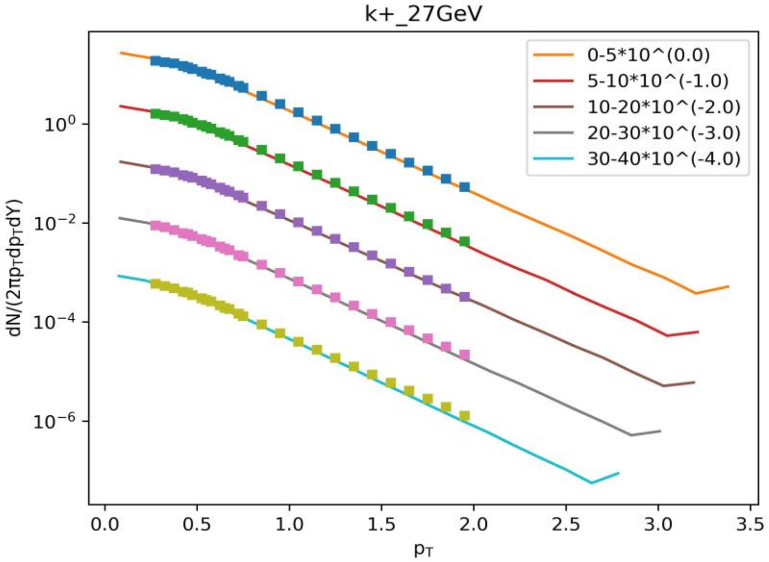
Identified particle spectra

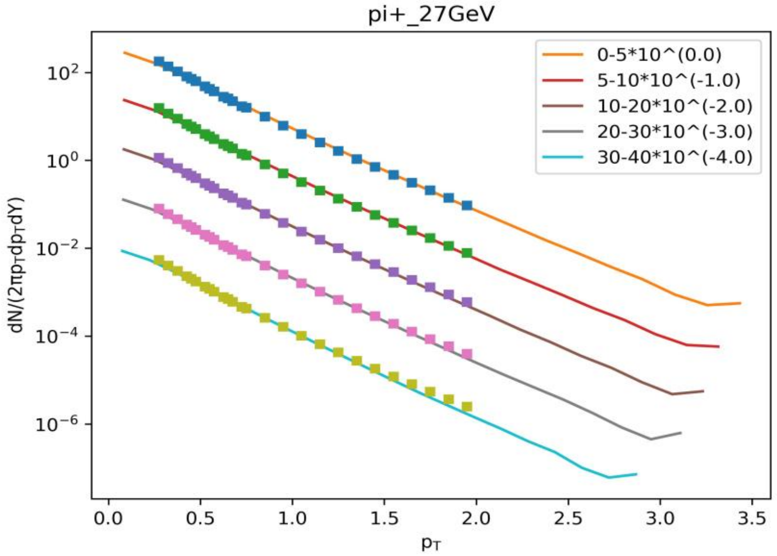
lines from simulation, points from STAR data,
and in agreement with experimental datas

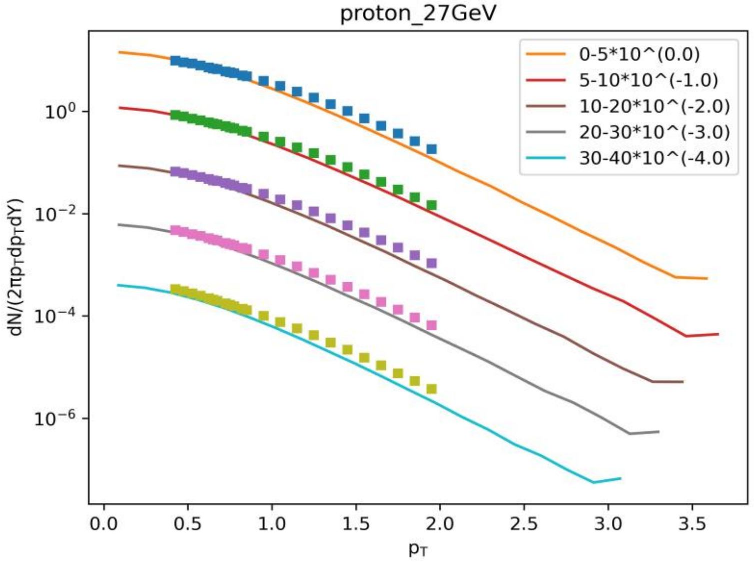




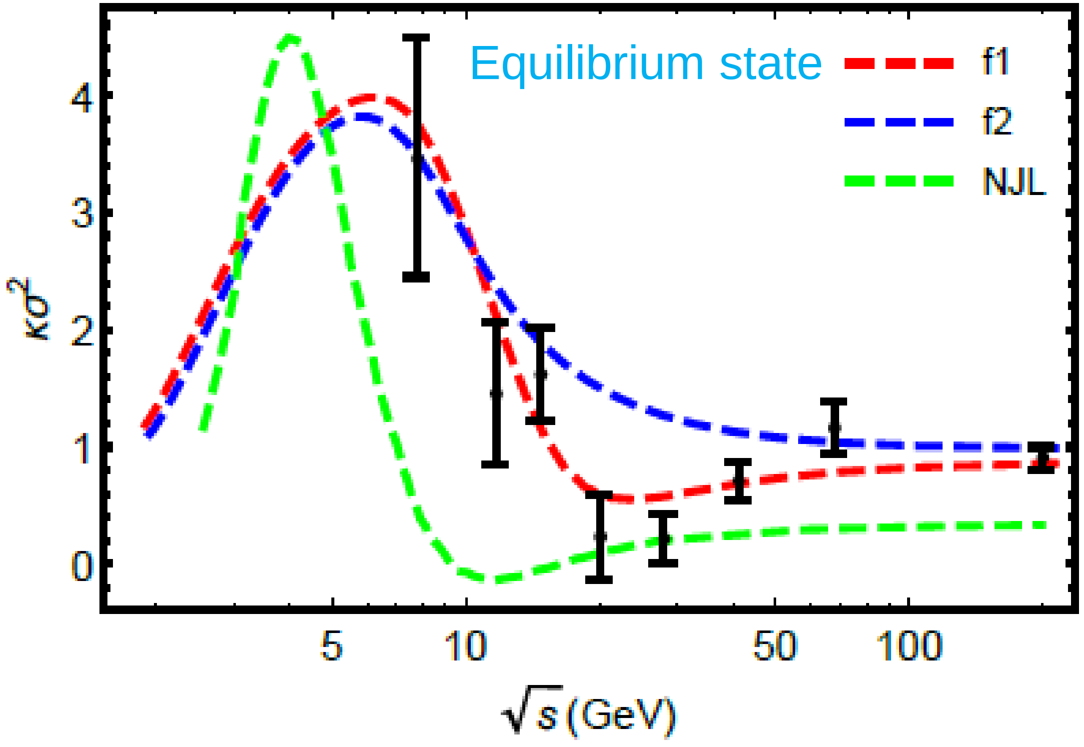




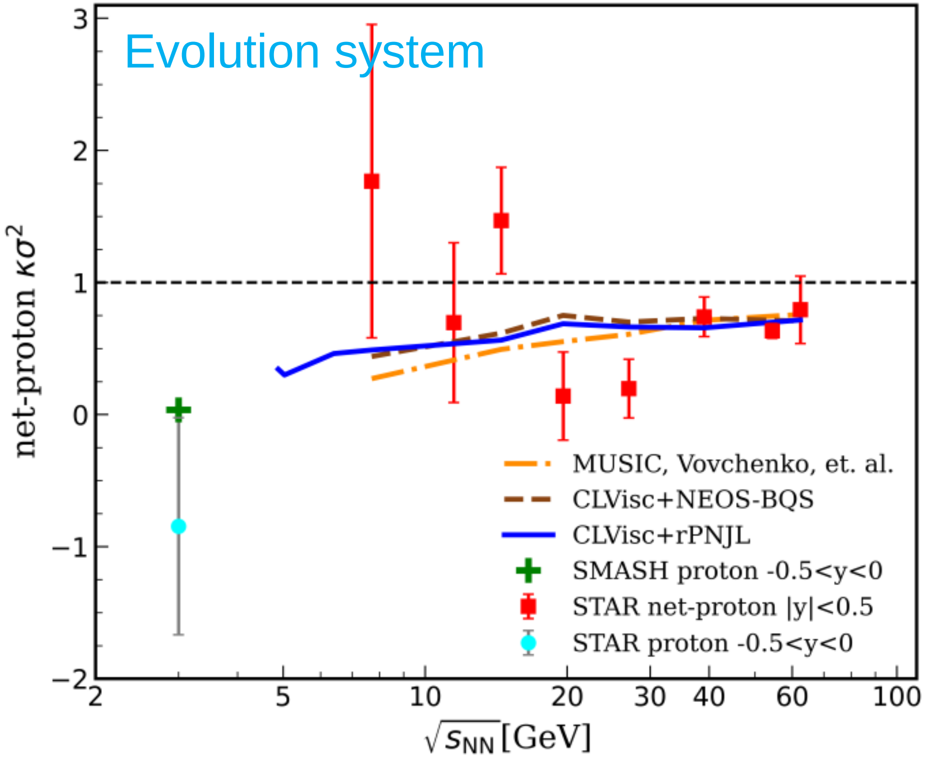




Bad news: Above 7.7 GeV, no peak structure and EOS independent



Zhibin Li, Kun Xu, Xinyang Wang and Mei Huang,
arXiv:1801.09215， EPJC 2019



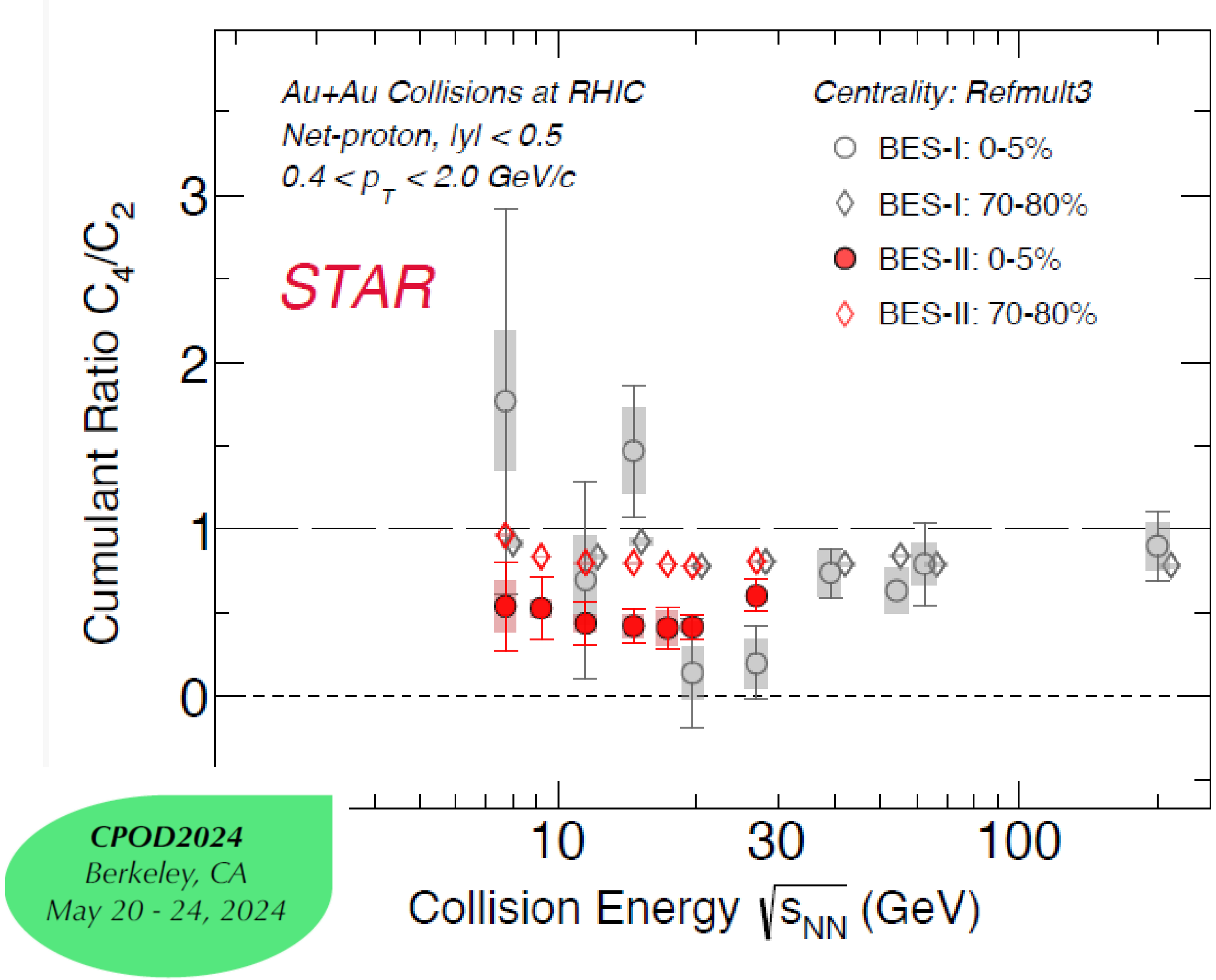
Yifan Shen, Wei Chen, Xiangyu Wu, Kun Xu, MH,
arXiv:e-Print: 2404.02397 [hep-ph]
沈一凡 poster

MUSIC: different hydrodynamics model

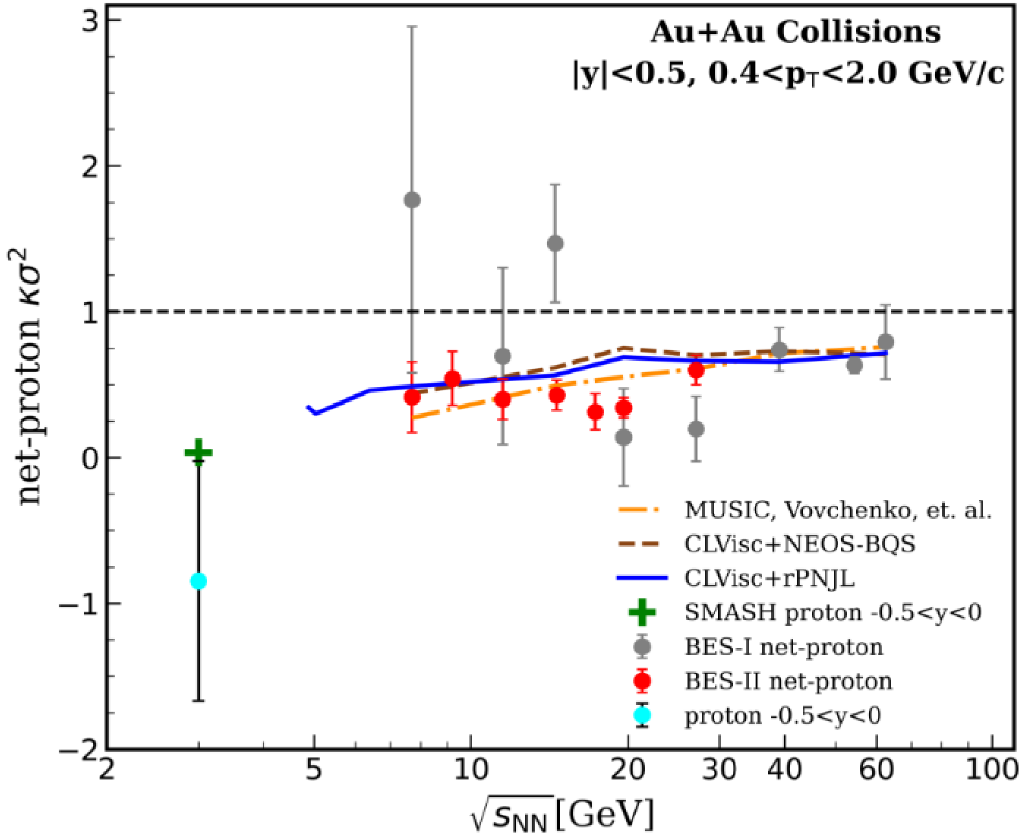
V. Vovchenko, V. Koch, and C. Shen, Phys. Rev.C 105, 014904 (2022)

Evolution system

Good news: Above 7.7 GeV, in agreement with latest Exp. results!



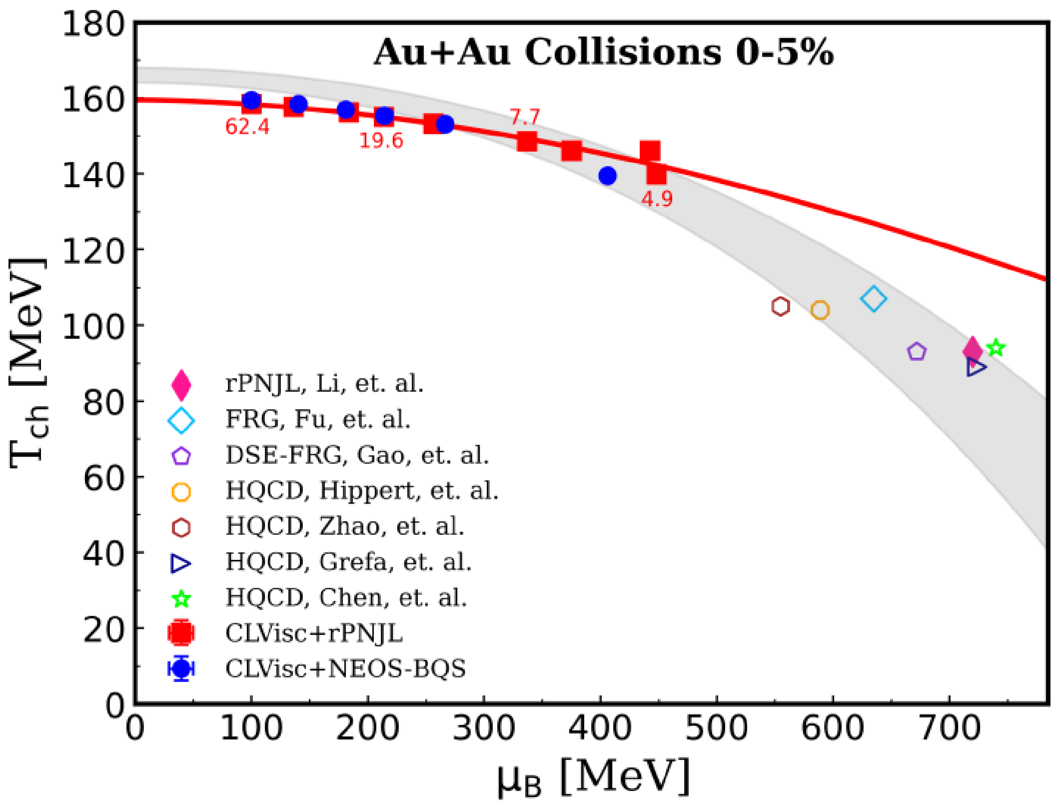
Ashish Pandav for STAR Collaboration
Lawrence Berkeley National Laboratory
May 21, 2024

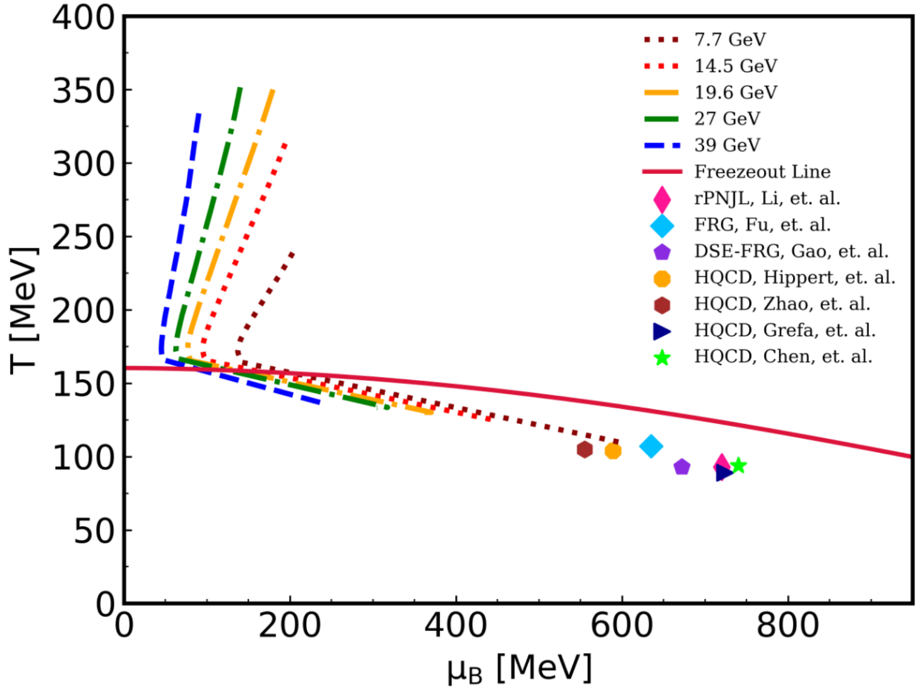


Yifan Shen, Wei Chen, Xiangyu Wu, Kun Xu, MH,
arXiv:e-Print: 2404.02397 [hep-ph]
沈一凡 poster

Signature washed out by hadronization?

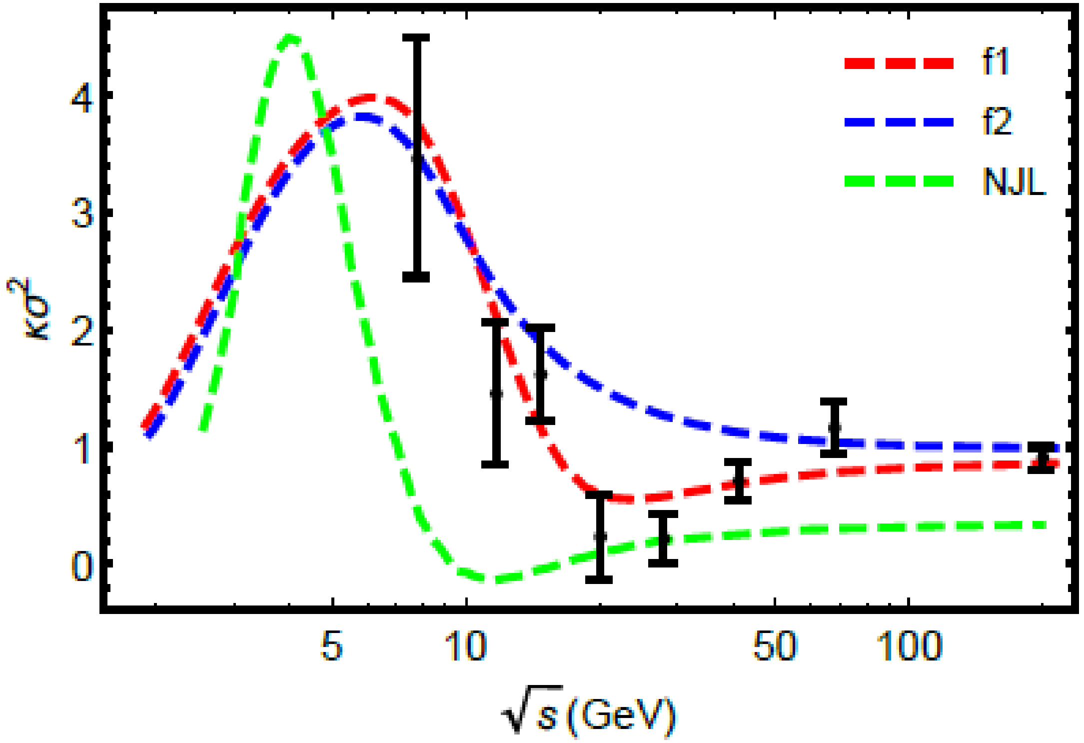
CEP is far away from evolution trajectory?

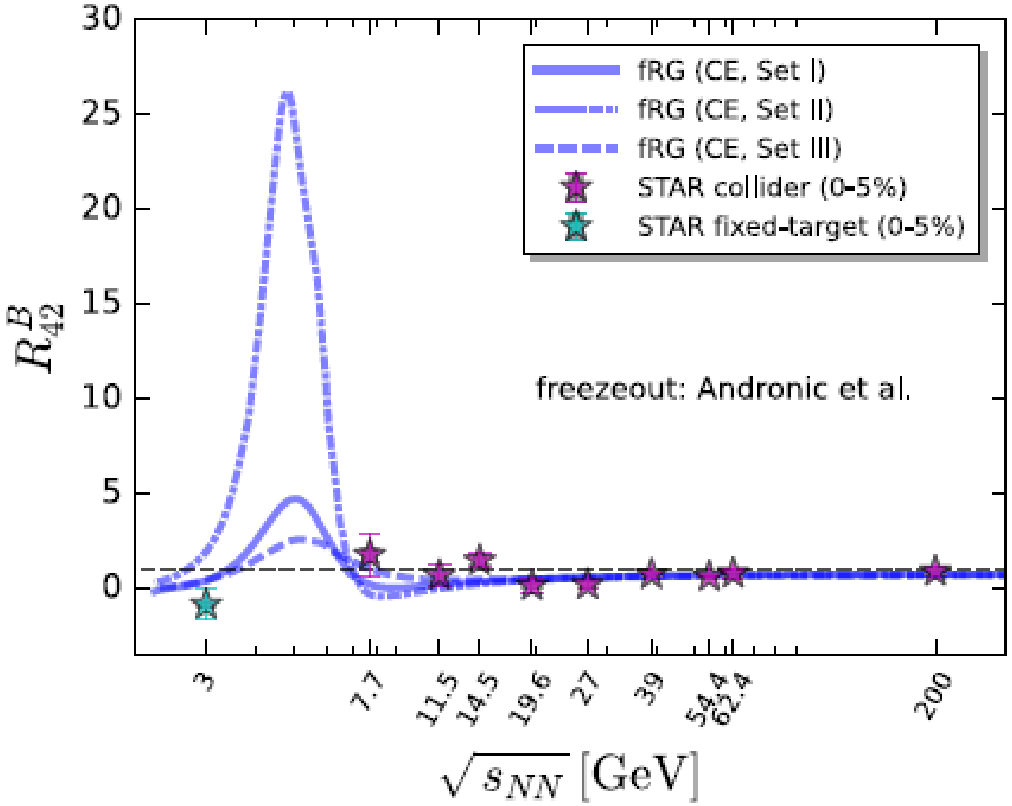




isentropic evolution line

Waiting for results around 5GeV (NICA,FAIR,HIAF) !



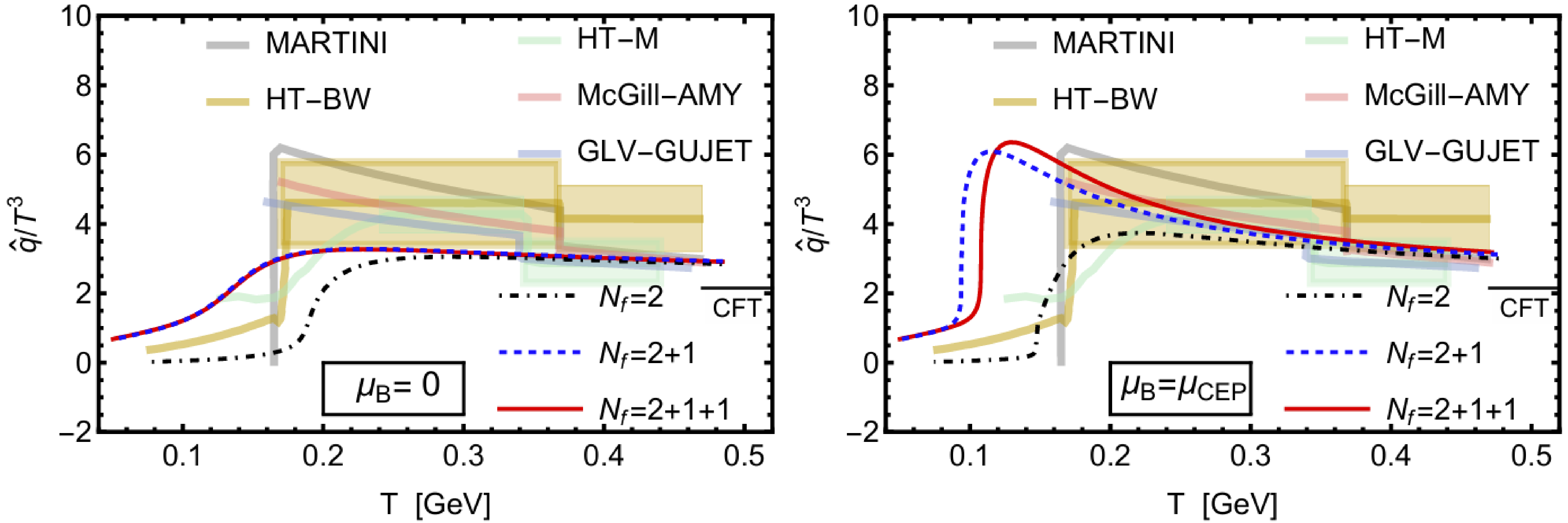


rPNJL: Zhibin Li（李志镔）, Kun Xu（许坤）, Xinyang Wang and MH, arXiv:1801.09215, EPJC 2019

fRG: Weijie Fu（付伟杰）, Luo, Pawlowski, Rennecke, Yin, arXiv: 2308.15508

CEP is there, we might need to find other signals free of hadronization, e.g., jet quenching?

Dilepton, photon production?



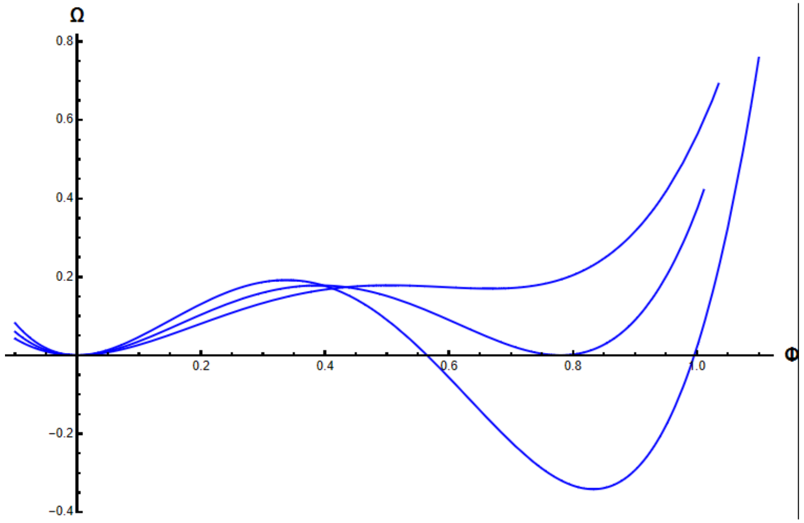
Is there any signals from jet quenching at 5 GeV ?

Zhibin Li, Danning Li, M.H., e-Print: 2504.04147 [hep-ph]

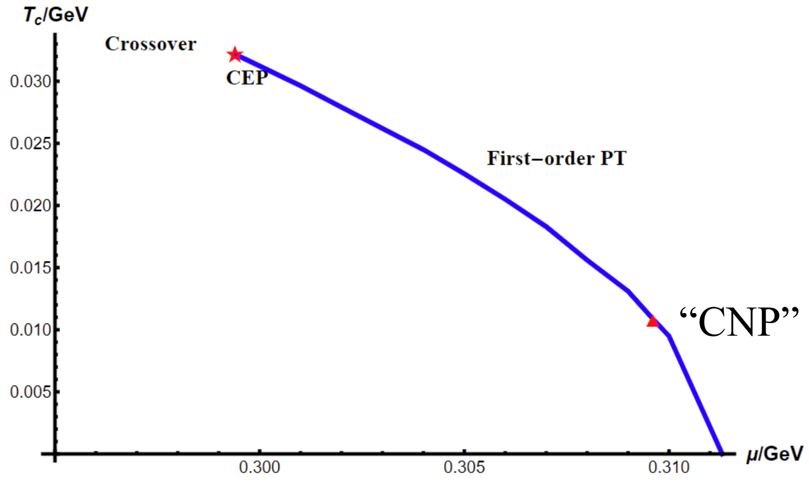
李志镔 分会报告

Dynamical 1st-order phase transition: false vacuum decay rate

Jingdong Shao（邵惊冬）, Hong Mao（毛鸿）, MH,
arXiv: 2410.06780, 2410.00874

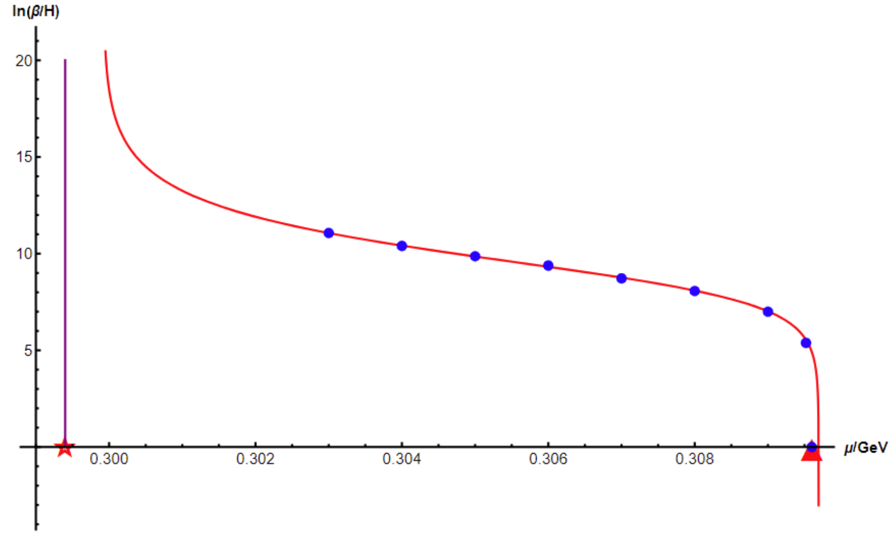


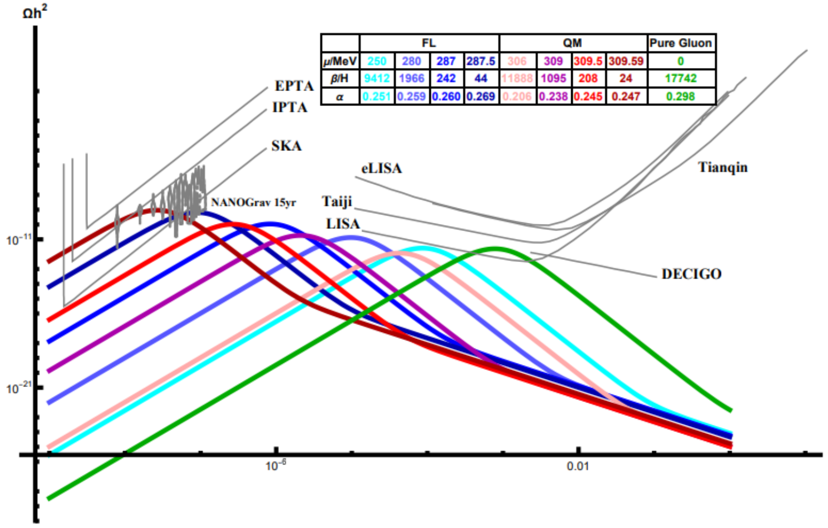
“CNP”



临界成核点
Long-lived false vacuum

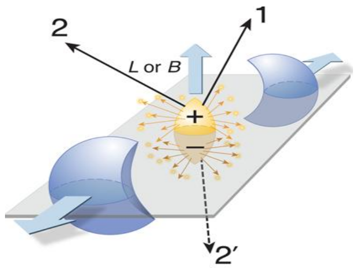
高密核物质- >蓄核能池？



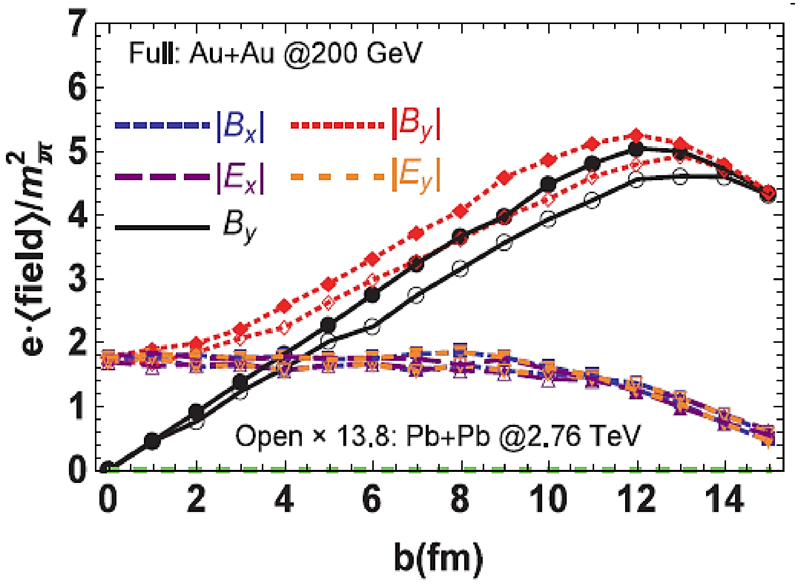


	FL				QM				Pure Gluon
μ/MeV	250	280	287	287.5	306	309	309.5	309.59	0
β/H	9412	1966	242	44	11888	1095	208	24	17742
α	0.251	0.259	0.260	0.269	0.206	0.238	0.245	0.247	0.298

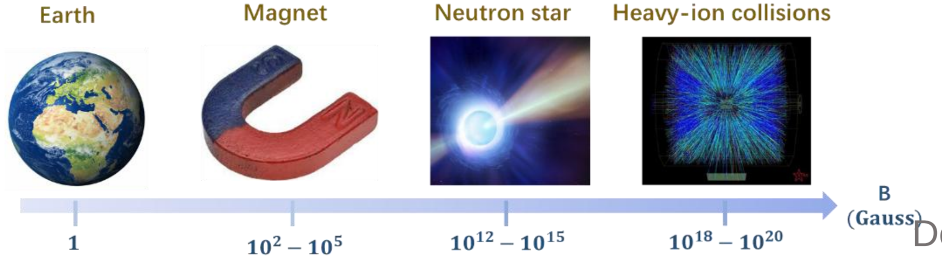
MAGNETIC FIELDS

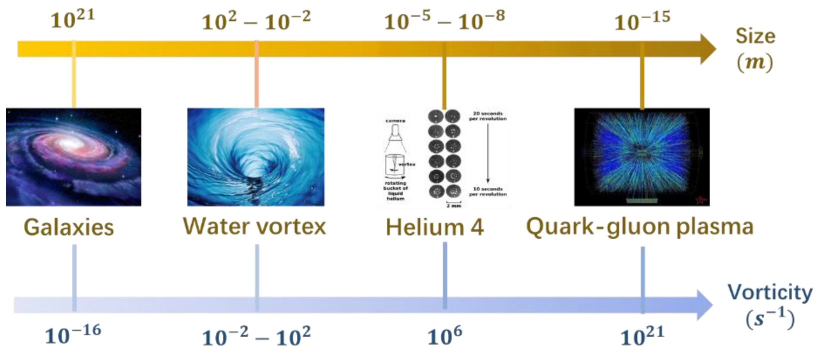


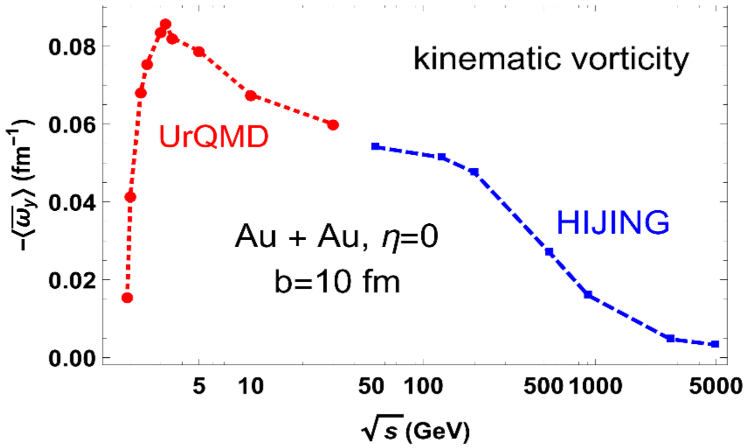
ROTATION



HIJING (Deng-XGHuang PRC2012)



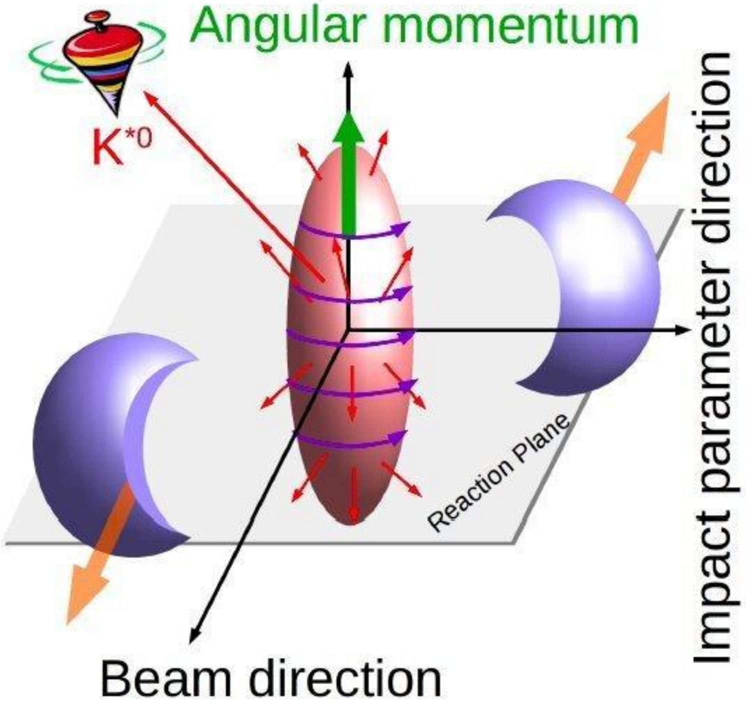


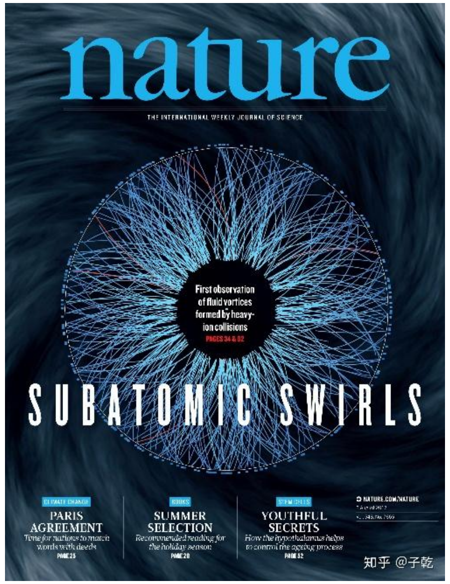


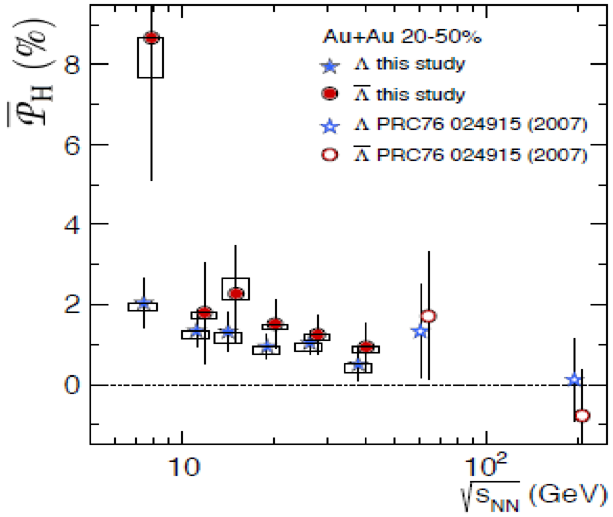
Deng-XGHuang PRC2016

Deng-XGHuang-GLMa-Zhang PRC2020

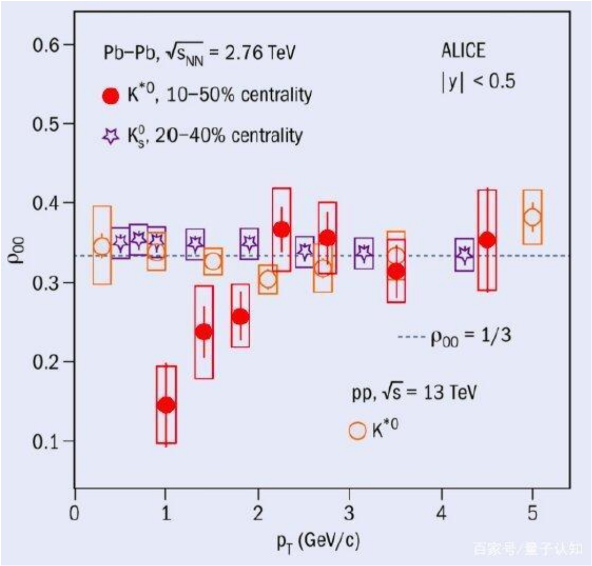
$O(10^4)-O(10^5)\hbar$







Nature 548 (2017) 62-65



Physical Review Letters (2020).
DOI: 10.1103/PhysRevLett.125.012301

Theoretical side:

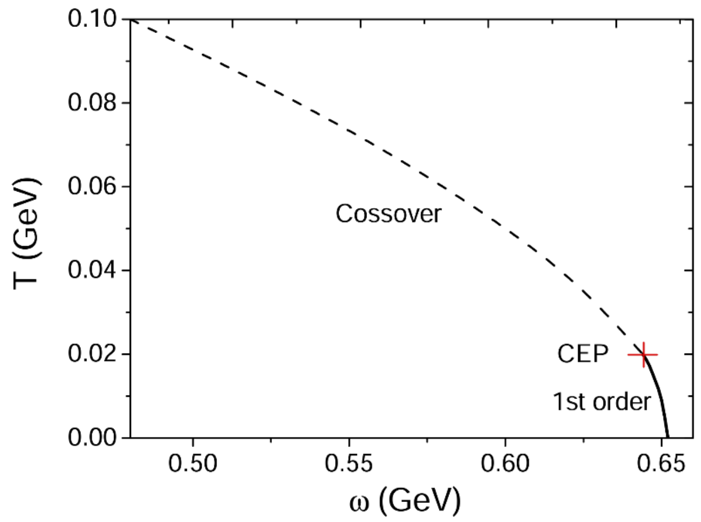
梁作堂，王新年，王群，
黄旭光，高建华，浦实，庄鹏飞，
侯德富，尹伊，宋慧超，陈诗乐，
姜寅，曹高清，盛欣力，陈浩磊，
许坤，魏明华，孙飞，陈亦点，
陈勋…

Chial dynamics under rotation from NJL model

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

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

$$\mathcal{L} = \bar{\psi}[i\gamma^{\mu}(\partial_{\mu} + \gamma^0 \omega \hat{J}_z) - M]\psi - \mu\psi^{\dagger}\psi - \frac{(M-m)^2}{4G_S}.$$



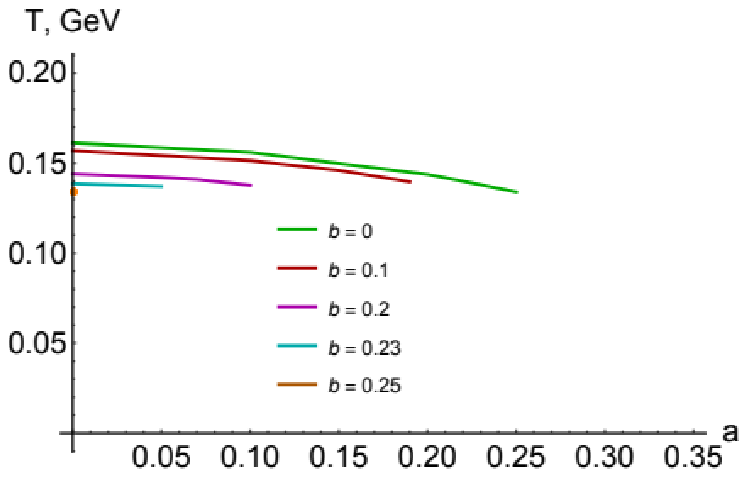
Angular velocity is similar to the chemical potential, critical temperature decreases with angular velocity.

Consistent with many other effective model results, many references should be here.

Yin Jiang（姜寅）, Jinfeng Liao, PRL2016

Holographic results: critical temperature decreases with angular velocity

Kerr-AdS black holes



A

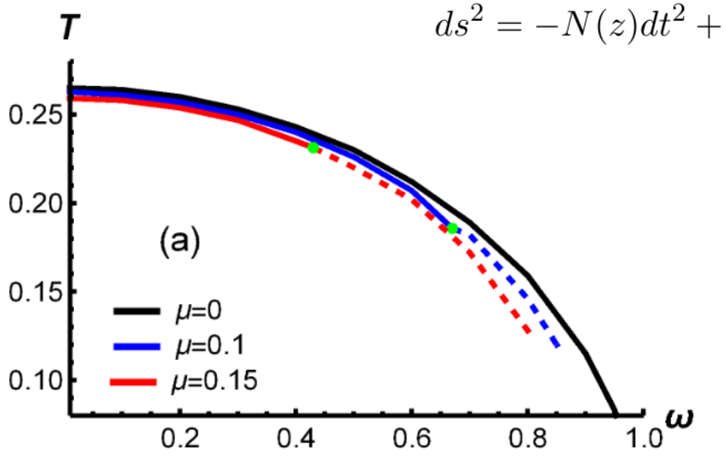
I.Y. Aref'eva, et al., e-Print: 2004.12984, JHEP (2021),
Confirmed by many results in this framework

local Lorentz boost

Pure gluon system

$$t \to \frac{1}{\sqrt{1-(\omega l)^2}}(t+\omega l^2\theta), \phi \to \frac{1}{\sqrt{1-(\omega l)^2}}(\theta+\omega t).$$

$$ds^2 = -N(z)dt^2 + \frac{H(z)dz^2}{G(z)} + R(z)(d\theta + P(z)dt)^2 + H(z)\sum_{i=1}^{2} dx_i^2,$$



$$N(z) = \frac{H(z)G(z)(1-\omega^2 l^2)}{1-G(z)\omega^2 l^2},$$
$$H(z) = \frac{L^2 e^{2A_e(z)}}{z^2},$$
$$R(z) = H(z)\gamma^2 l^2 - H(z)G(z)\gamma^2\omega^2 l^4,$$
$$P(z) = \frac{\omega - G(z)\omega}{1-G(z)\omega^2 l^2},$$
$$\gamma = \frac{1}{\sqrt{1-\omega^2 l^2}}.$$

Xun Chen, Lin Zhang, Danning Li,
Defu Hou, MH, arXiv: 2010.14478, JHEP (2021)
Confirmed by many results in this framework

Influence of relativistic rotation on the confinement/deconfinement transition in gluodynamics

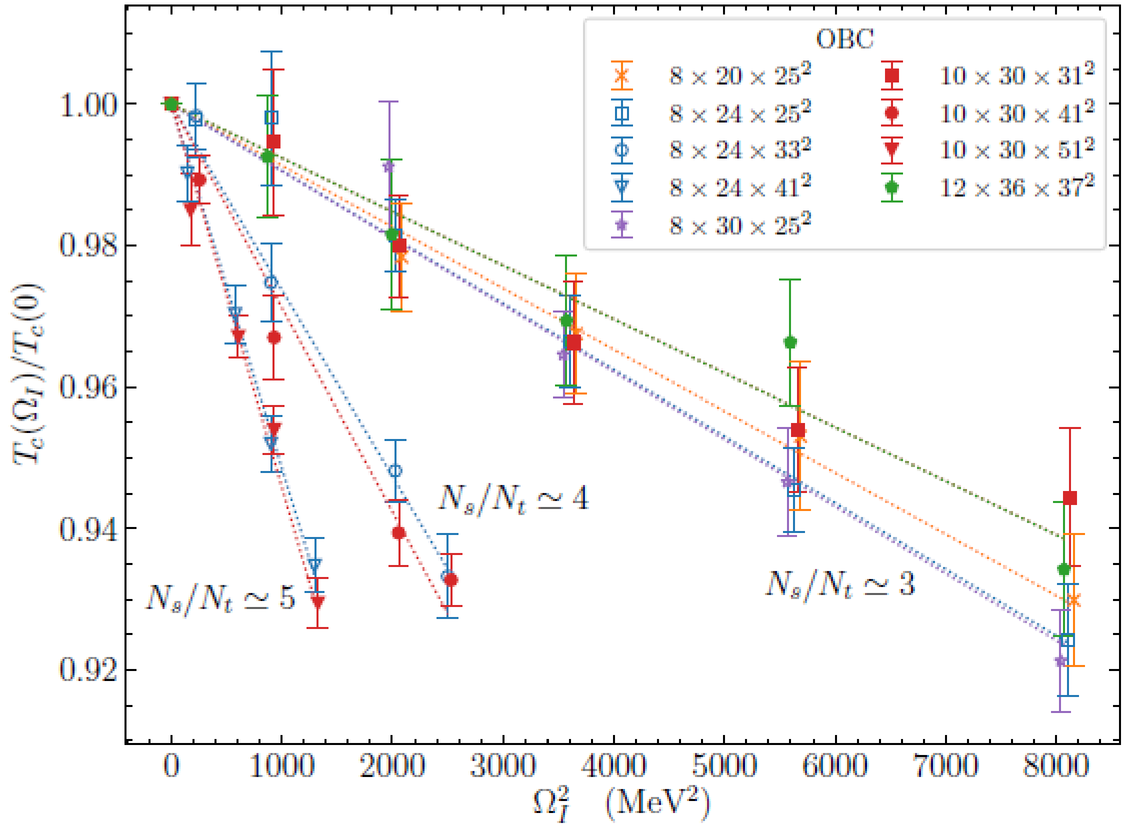
V. V. Braguta,[1,2,3,*] A. Yu. Kotov,[4,†] D. D. Kuznedelev,[3,‡] and A. A. Roenko[1,§]

Phys.Rev.D 103 (2021) 9, 094515,
e-Print: 2102.05084

$$g_{\mu\nu} = \begin{pmatrix} 1 - r^2\Omega^2 & \Omega y & -\Omega x & 0 \\ \Omega y & -1 & 0 & 0 \\ -\Omega x & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

imaginary angular velocity $\Omega_I = -i\Omega$

$$\frac{T_c(\Omega_I)}{T_c(0)} = 1 - C_2\Omega_I^2 \qquad \frac{T_c(\Omega)}{T_c(0)} = 1 + C_2\Omega^2$$



Critical temperature of deconfinement phase transition increases with rotation in lattice! Confirmed by other lattice studies!

Ji-Chong Yang,Xu-Guang Huang e-Print: 2307.05755 [hep-lat]

$$\frac{T_c(\Omega)}{T_c(0)} = 1 + C_2\Omega^2$$

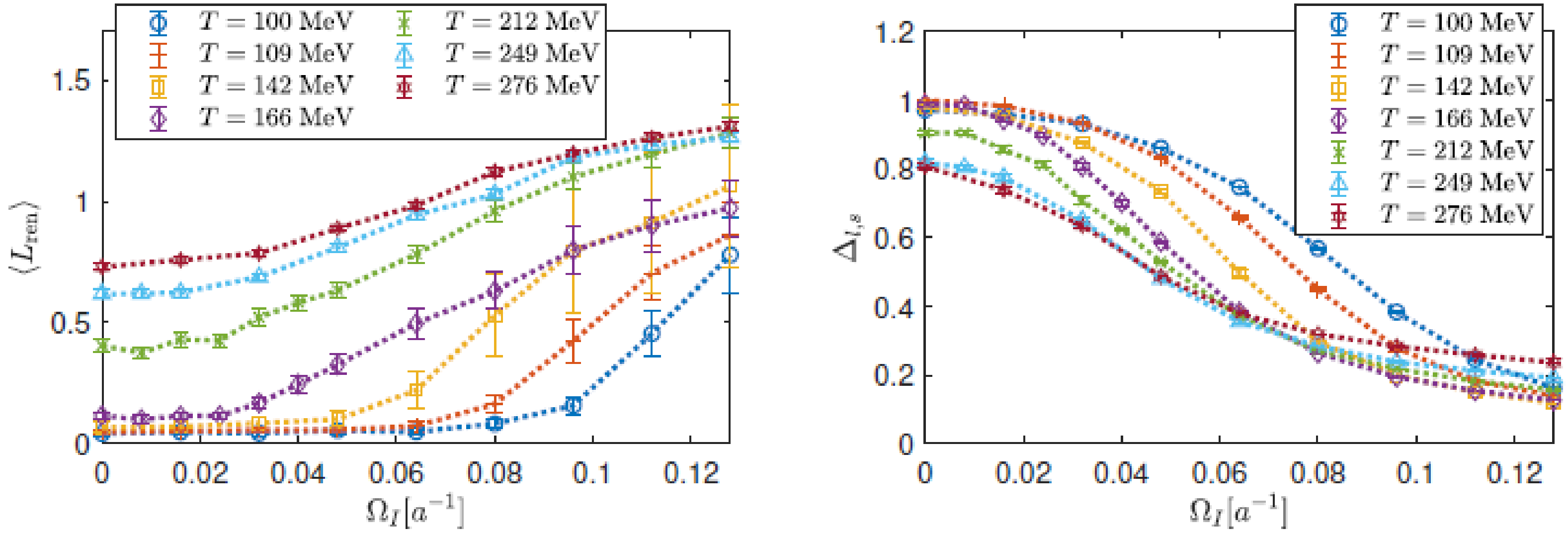


FIG. 4. The Polyakov loop and chiral condensate as functions of Ω_I.

Opposite results on the effect of rotation on the critical temperature of deconfinement phase transition in hQCD and lattice has attracted much attention ! What's missing?

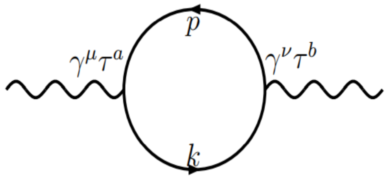
XXXII International (online) Workshop on High Energy Physics "Hot problems of Strong Interactions", Nov.9-13, 2020

Victor Ambrus, *Phys.Lett.B* 855 (2024), e-Print: 2502.09738,…
Maxim Chernodub, Phys.Rev.D 103 (2021), *Phys.Rev.D* 110 (2024),…
Kenji Fukushima, *Phys.Lett.B* 859 (2024),…
Matthias Kaminski *Phys.Rev.D* 108 (2023), …
Gaoqing Cao（曹高清）, e-Print: 2310.03310,…
Yin Jiang（姜寅）, Phys.Lett.B 862 (2025),…
……

Vector meson masses as functions of angular velocity

$$\Pi^{\mu\nu,ab}(q) = -i\int d^4\tilde{r}Tr_{sfc}[i\gamma^\mu\tau^a S(0;\tilde{r})i\gamma^\nu\tau^b S(\tilde{r};0)]e^{q\cdot\tilde{r}}$$

$-i\Pi^{\mu\nu,ab}(q) =$

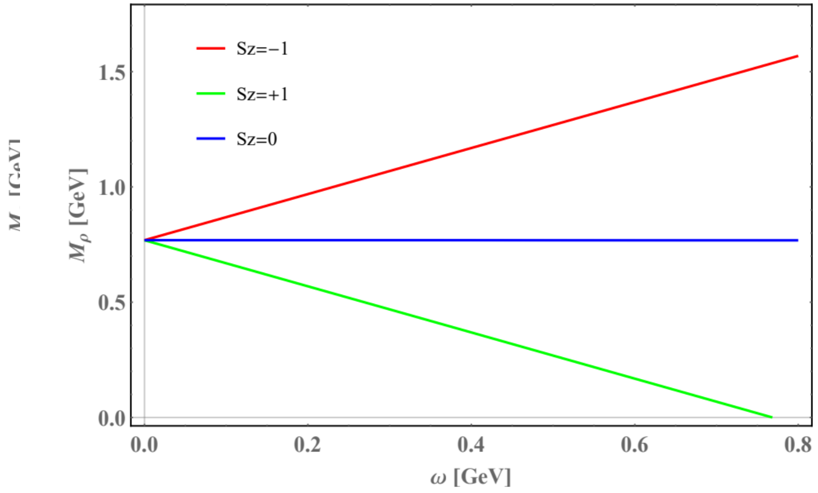


$$D_\rho^{\mu\nu}(q^2) = D_1(q^2)P_1^{\mu\nu} + D_2(q^2)P_2^{\mu\nu} + D_3(q^2)L^{\mu\nu} + D_4(q^2)u^\mu u^\nu$$

$$P_1^{\mu\nu} = -\epsilon_1^\mu\epsilon_1^\nu, (S_z = -1 \text{ for } \rho \text{ meson}$$
$$P_2^{\mu\nu} = -\epsilon_2^\mu\epsilon_2^\nu, (S_z = +1 \text{ for } \rho \text{ meson}$$
$$L^{\mu\nu} = -b^\mu b^\nu, (S_z = 0 \text{ for } \rho \text{ meson })$$

$$1 + 2G_V A_i^2 = 0$$

$$A_1^2 = -(\Pi_{11} - i\Pi_{12}), (S_z = -1 \text{ for } \rho \text{ mes}$$
$$A_2^2 = -\Pi_{11} - i\Pi_{12}, (S_z = +1 \text{ for } \rho \text{ meson })$$
$$A_3^2 = \Pi_{33}, (S_z = 0 \text{ for } \rho \text{ meson })$$



Minghua Wei（魏明华）, Ying Jiang, MH, 2011.10987

Zeeman splitting effect for different spin component! Mass of spin component +1 vector meson decreases with rotation. Rotation is charge blind, rho meson can be regarded as a gluon.

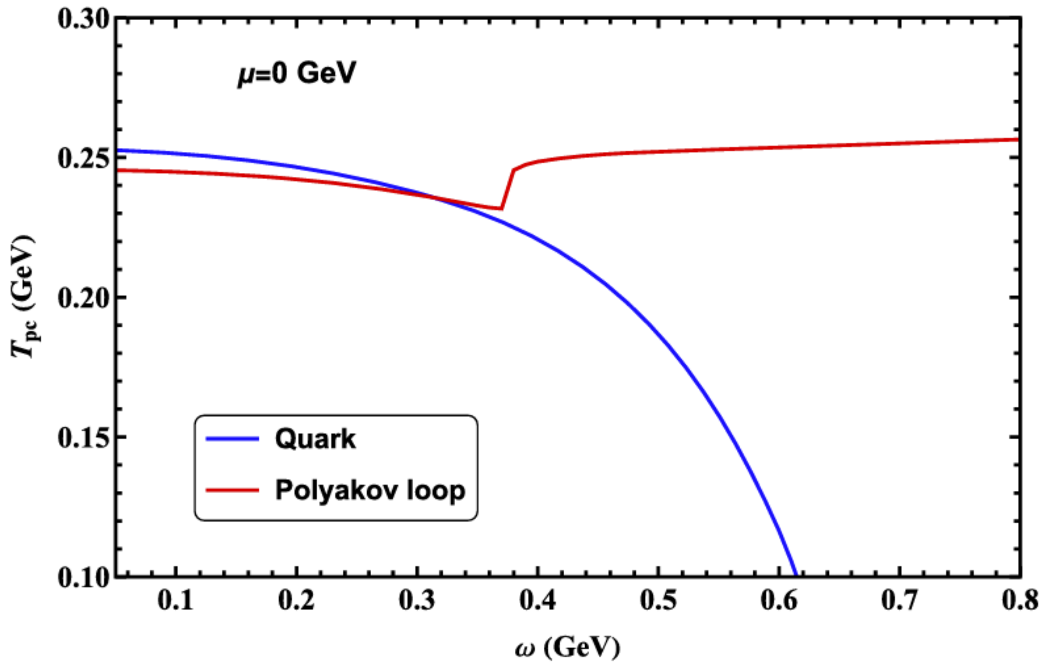
For massless gluon, will have BEC. (corresponding to Nielson-Olesson instability by Kenji?

Gluons are spin-1 particles, should be more sensitive to rotation than that of quarks!

Add gluodynamics under rotation in PNJL

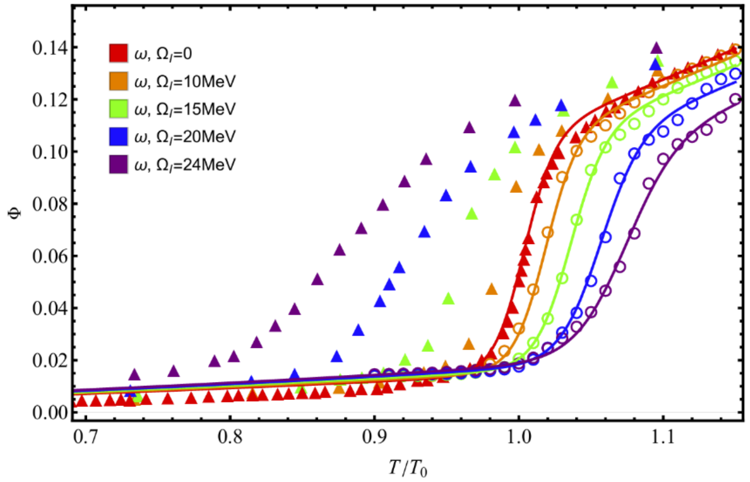
Fei Sun （孙飞）, Kun Xu, MH, e-Print: 2307.14402, PRD2023

$$\mathcal{L}_{\text{PNJL}} = \mathcal{L}_{\text{NJL}} + \bar{\psi}\gamma^{\mu}A_{\mu}\psi - \mathcal{U}(\Phi, \bar{\Phi}, T),$$



Splitting of chiral and deconfinement phase transitions induced by rotation!

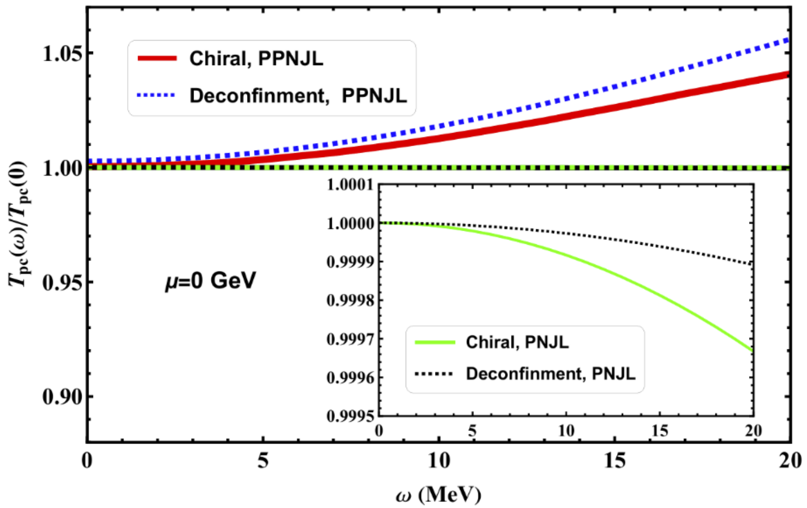
Polarized-Polyakov-loop Nambu–Jona-Lasinio model under rotation



$$\Phi\left(T,\omega\right)=\left(\frac{T}{T_0}\right)^2 f\left(T,\omega\right)$$

Fit Lattice data V. V. Braguta PRD2021

$$\frac{\mathcal{U}\left(\Phi,\bar{\Phi},T,\omega\right)}{T^4}=-Cf\left(T,\omega\right)\left(\frac{T}{T_0}\right)^2\Phi\bar{\Phi}-\frac{1}{3}\left(\Phi^3+\bar{\Phi}^3\right)+C^{-1}f^{-1}\left(T,\omega\right)\left(\frac{T}{T_0}\right)^{-2}\Phi^2\bar{\Phi}^2,$$



Both chiral and deconfinement PTs critical temperatures increase with rotation!

Lesson: Polarized gluons should be taken into account under rotation!

Fei Sun（孙飞）, Jingdong Shao, Rui Wen, Kun Xu, and MH,
e-Print: 2402.16595, PRD 2024

Holographic QCD Model Nf=2

$$\begin{aligned} S^s_{\rm tot} &= S^s_G + S^s_M, \\ S^s_G &= \frac{1}{16\pi G_5}\int d^5x\sqrt{-g^s}e^{-2\Phi}\left[R^s + 4\partial_M\Phi\partial^M\Phi - V^s(\Phi) - \frac{h(\Phi)}{4}e^{\frac{4\Phi}{3}}F_{MN}F^{MN}\right], \\ S^s_M &= -\int d^5x\sqrt{-g^s}e^{-\Phi}\mathrm{Tr}\left[\nabla_M X^\dagger\nabla^M X + V_X(|X|, F_{MN}F^{MN})\right], \end{aligned}$$

Anisotropic background under rotation,
cylindrical coordinate

$$ds^2 = \frac{L^2e^{2A_e(z)}}{z^2}\left[-f(z)dt^2 + \frac{dz^2}{f(z)} + e^{B(z)}dr^2 + r^2e^{B(z)}d\theta^2 + e^{-2B(z)}dx_3^2\right],$$

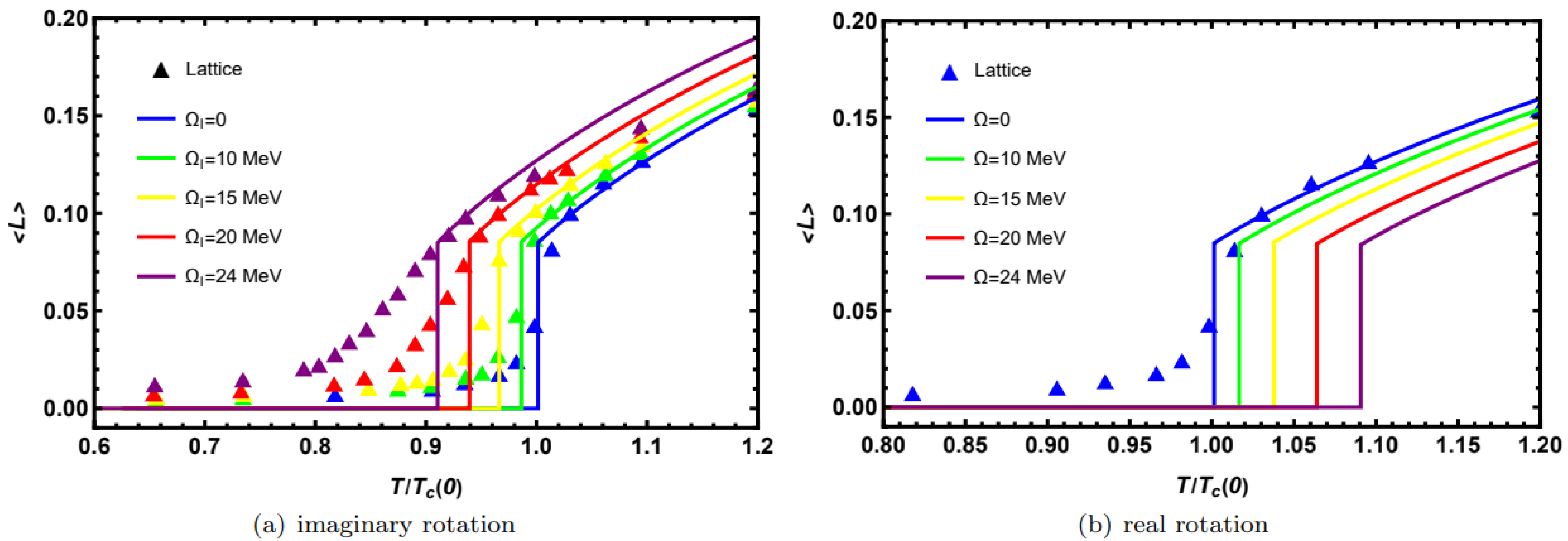
$$A_M = (A_t, 0, 0, A_\theta, 0), \qquad A_\theta = \Omega r^2, \qquad A_\theta \sim \Omega r^2 + \rho_\theta(r, z).$$

Polarized gluodynamics represented by a rotation-dependent dilation field

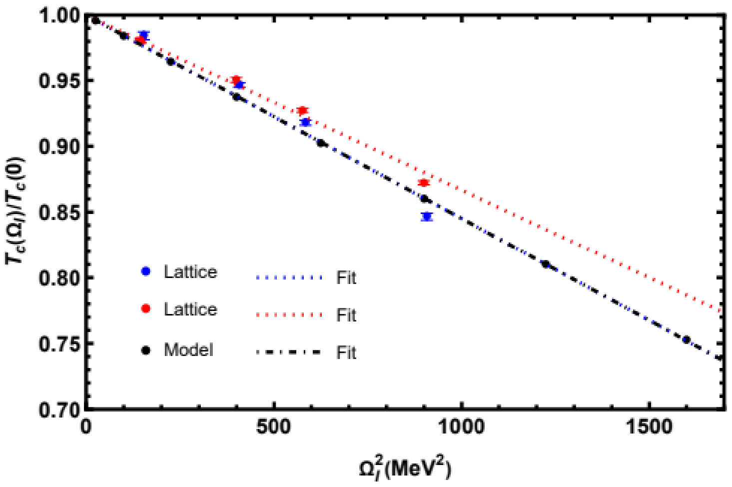
$$\Phi = (\mu_G + \mu_\Omega\Omega^2)^2 z^2 \tanh(\mu_{G^2}^4 z^2/(\mu_G + \mu_\Omega\Omega^2)^2).$$

Yidian Chen, X. Chen, D. Li and MH, arXiv:2405.06386, Phys.Rev.D 111 (2025)

陈亦点 分会报告



(a) imaginary rotation (b) real rotation



$$T_c(\Omega_I)/T_c(0) = 1 - C_2\Omega_I^2$$

The only parameter μ_Ω to be determined in the DHQCD model is based on the relationship between the phase transition temperature $T_c(\Omega_I)$ and the imaginary angular velocity predicted by lattice QCD.

Yidian Chen, X. Chen, D. Li and MH, arXiv:2405.06386, Phys.Rev.D 111 (2025)

Results

Yidian Chen, X. Chen, D. Li and MH, arXiv:2405.06386, Phys.Rev.D 111 (2025)
陈亦点分会报告

Critical temperature of deconfinement phase transition increases with rotation inagreement with lattice results!

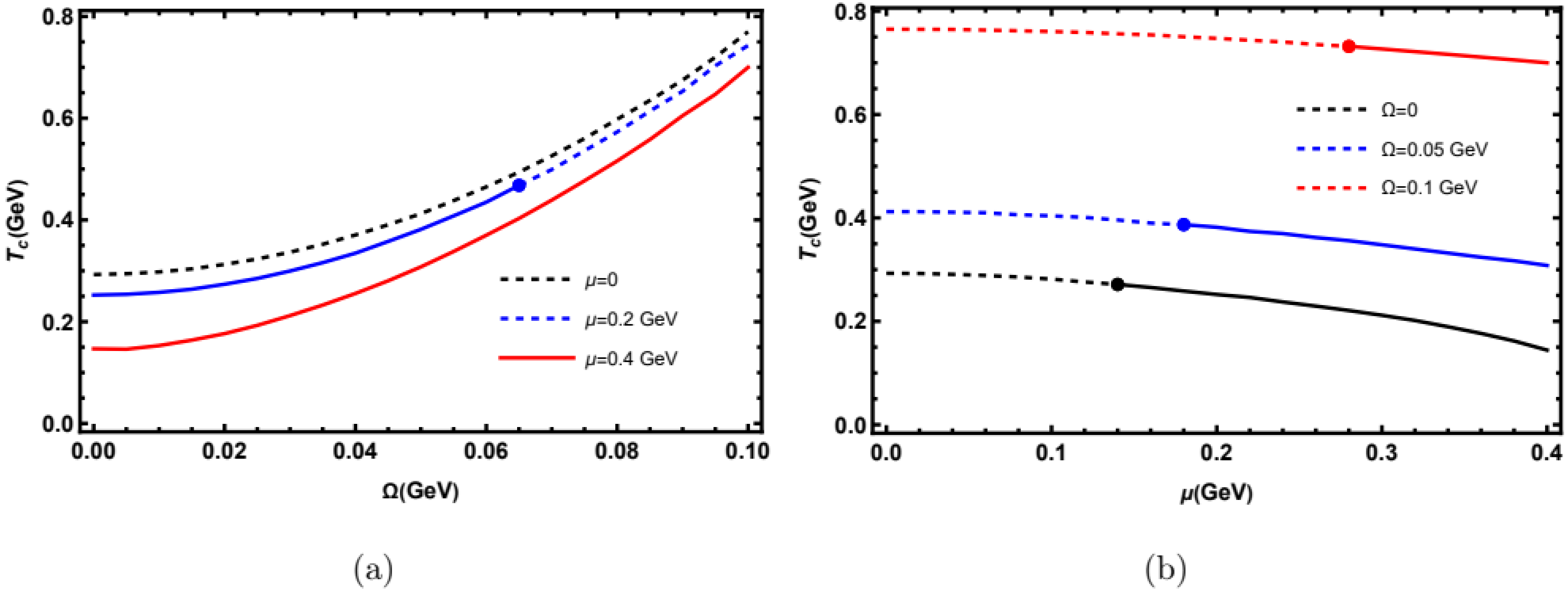


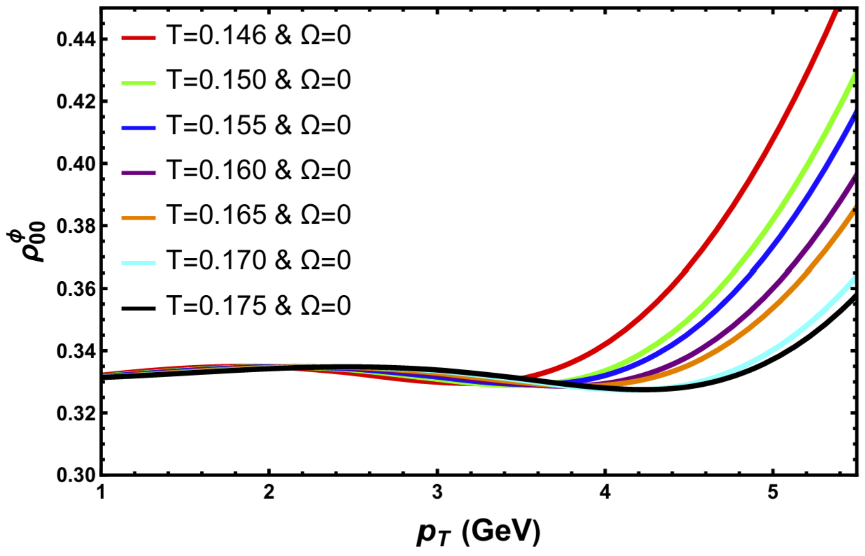
FIG. 7. The $T-\Omega$ and $T-\mu$ phase diagrams of chiral phase transition for 2-flavor system.

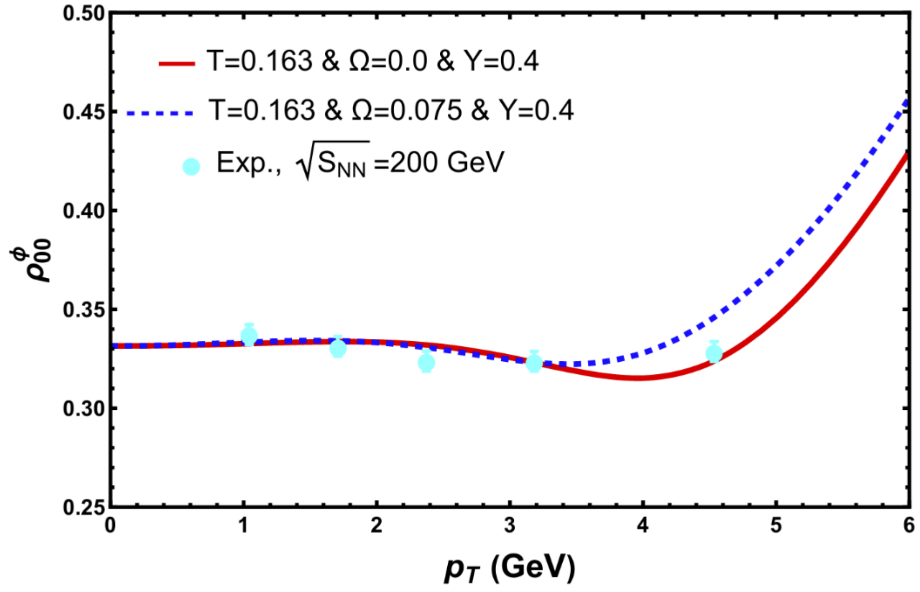
Spin alignment in Holographic QCD Model Nf=2+1+1

Hiwa A. Ahmed, Yidian Chen, and MH, arXiv:2501.13401, PRD2025

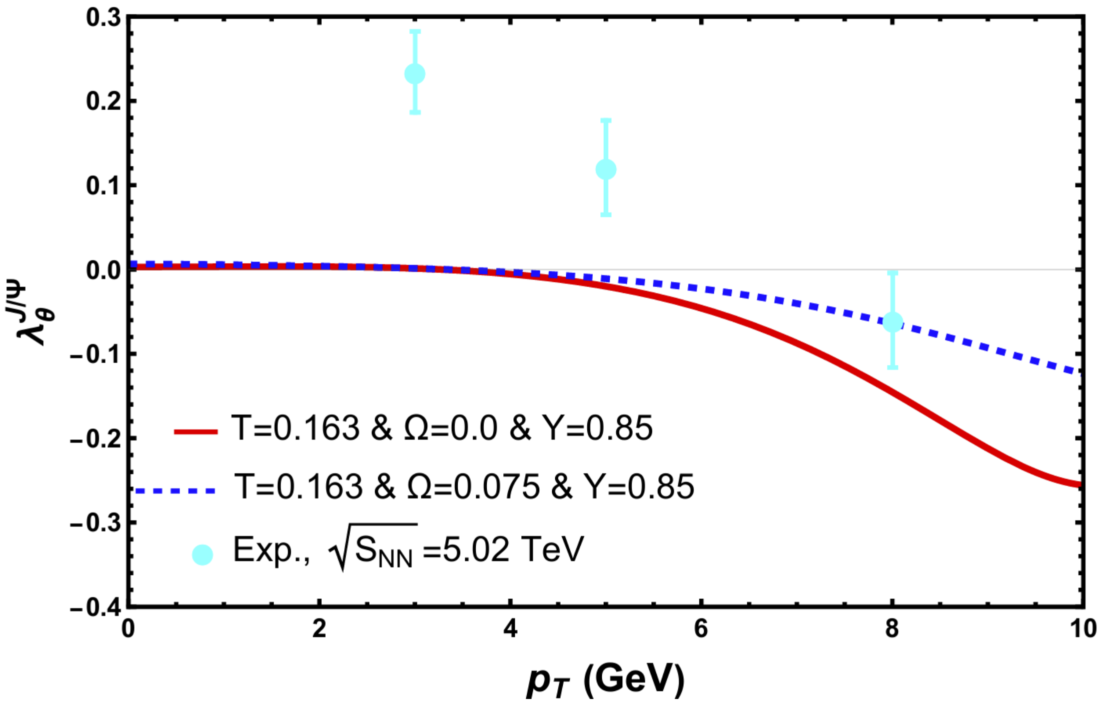
Hiwa A. Ahmed， Poster

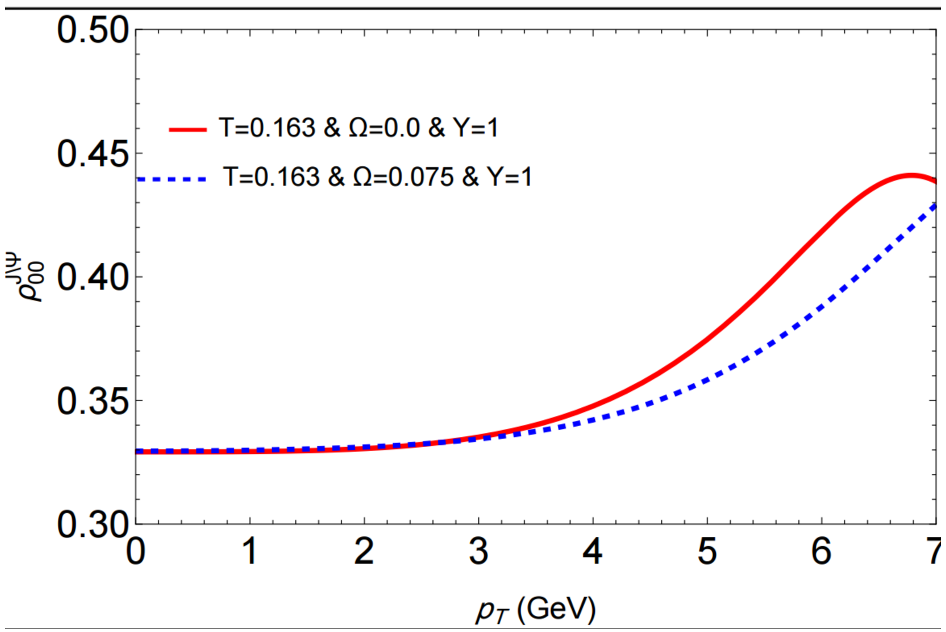
$$\varrho^{\mu\nu}(x,p) = \sum_{\lambda,\lambda'=0,\pm1} v^{\mu}(\lambda,p)v^{*\nu}(\lambda',p)\,\tilde{\varrho}_{\lambda\lambda'}(x,p),$$





For the ϕ meson, the averaged ρ00 over the full range of azimuthal angle shows weak temperature dependence at low transverse momentum (pT), but significant suppression at high pT, aligning with experimental observations





The J/Ψ meson, however, displays insensitivity to temperature and rotation up to pT = 5 GeV

Summary

1. From theory side, non-perturbative methods, including DSE, fRG, holographic QCD methods have made much progress in understanding QCD phase structure and QCD matter, hQCD with the help of machine learning steps into quantitative era.
2. Theoretical calculations from different methods give a convergent location of CEP on (T,mu_B) phase diagram. Considering hydro evolution of the realistic HIC collisions, no explicit signature of CEP is found above 7.7 GeV. Need to find other signals of CEP free of hadronization, e.g., jet quenching, photon/dilepton emission?
3. The puzzle on critical temperature of QCD PTs under rotation is understood by considering polarized gluon DOF! Spin alignment taking into account of gluon polarization under rotation is needed.

https://indico.ihep.ac.cn/event/24476/

Holographic applications: from Quantum Realms to the Big Bang

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感谢！
Many Thanks