中国科学院大学
University of Chinese Academy of Sciences

Rotating SU(2) gluon matter and deconfinement transition

author:Yin Jiang

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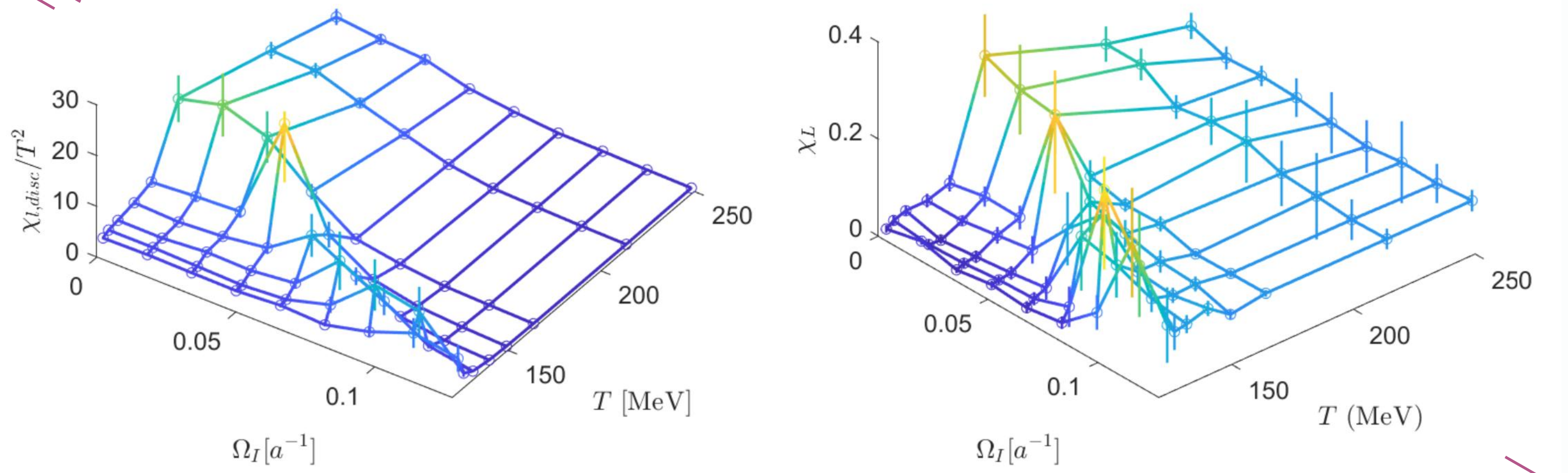
Introduction

lattice result

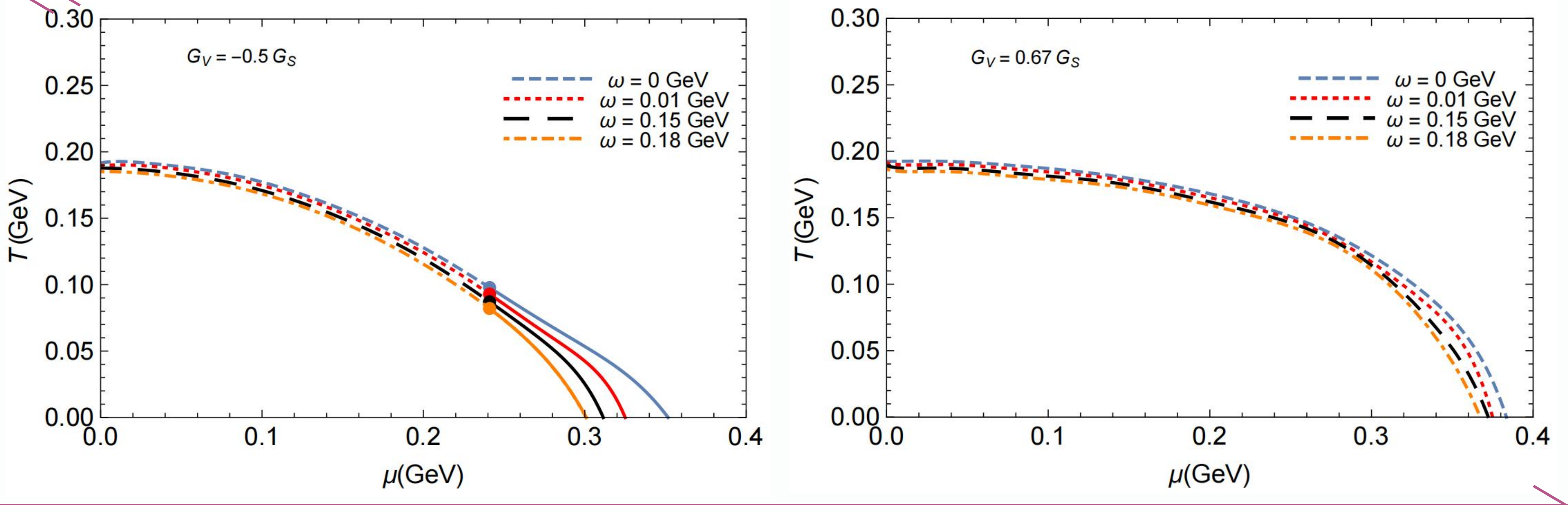


Non-central HIC shows fast rotation and could also affect the chiral symmetry.

LQCD calculations indicate that Ω for chiral and confinement deconfinement phase transitions almost coincide with each other and they both decrease with decreasing temperature, exhibiting the (imaginary) rotational suppression of the critical temperatures.

Introduction

NJL with other models' result



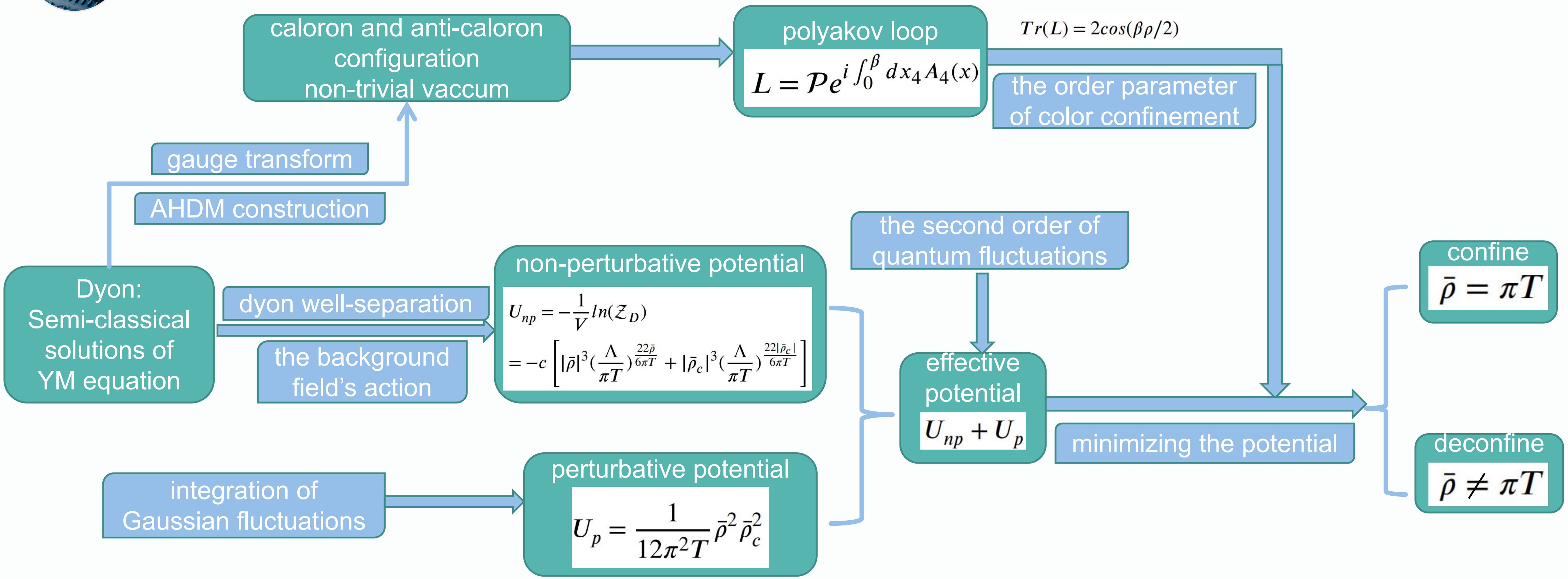
In most of these studies, quarks, which serve as the visible spin-carriers of the final state hadrons, have attracted notable interest. Gluons, which carry double spins and thus suffer double polarization effects, are neglected because of technical problems in most cases.

part 1

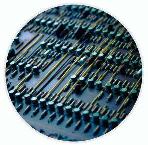
The color confinement and the deconfinement transition in SU(2)

Static pure SU(2) gluon system

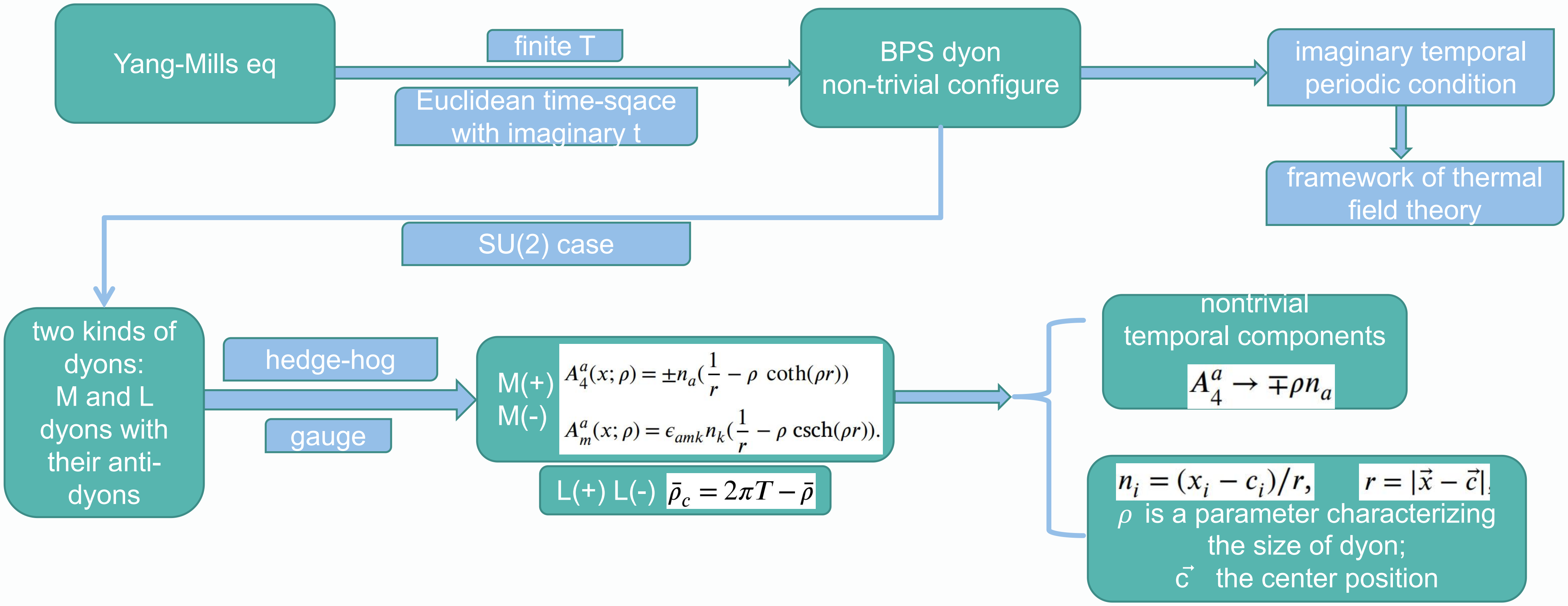
deconfinement transition.



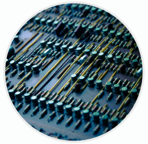
Static pure SU(2) gluon system



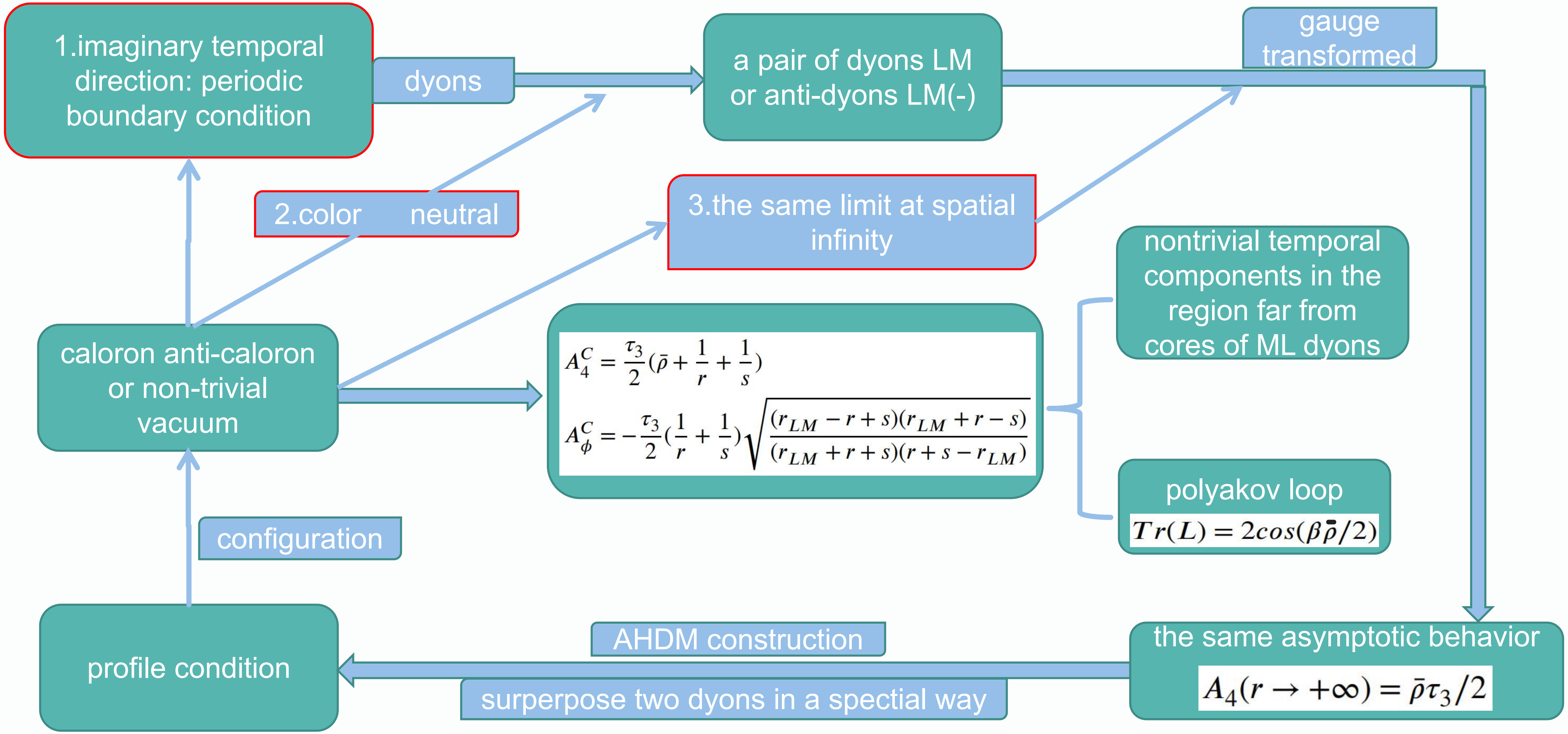
SU(2) BPS dyon.



Static pure SU(2) gluon system



non-trivial vaccum and polyakov loop.



Static pure SU(2) gluon system

partition function one loop and effective potential.

take into account all the configurations
integral over collective coordinates

$$\bar{A}(x;\{\xi_i\})$$

partition function

$$\mathcal{Z} = \int DA_\mu exp(-S[A])$$
$$= \int \Pi_i d\xi_i exp(-S[\bar{A}]) Det(-D^2)$$

the dyon well-separation assumption

$$\mathcal{Z}_D = \sum_{N_M, N_{\bar{M}}, N_L, N_{\bar{L}}} \frac{1}{N_M! N_{\bar{M}}! N_L! N_{\bar{L}}!}$$
$$\times \left[\int d^3 c_M |\bar{\rho}|^3 exp(-S[A_M])\right]^{N_M + N_{\bar{M}}}$$
$$\times \left[\int d^3 c_L |\bar{\rho}_c|^3 exp(-S[A_L])\right]^{N_L + N_{\bar{L}}}$$

the running coupling

$$\left(\frac{\Lambda}{\pi T}\right)^{22/3} = e^{-8\pi^2/g^2}$$

non-perturbative potential

$$U_{np} = -\frac{1}{V} ln(\mathcal{Z}_D)$$
$$= -c\left[|\bar{\rho}|^3 \left(\frac{\Lambda}{\pi T}\right)^{\frac{22\bar{\rho}}{6\pi T}} + |\bar{\rho}_c|^3 \left(\frac{\Lambda}{\pi T}\right)^{\frac{22|\bar{\rho}_c|}{6\pi T}}\right]$$

Yang-Mills action

$$S[A] = \int d^4x G^2/4g^2$$

$$S[A_{M/L}] = S[A_{\bar{M}/\bar{L}}]$$

Dyon	Action
M	ρ_M
$\bar{M}$	ρ_M
L	$2\pi T - \rho_L$
$\bar{L}$	$2\pi T - \rho_{\bar{L}}$

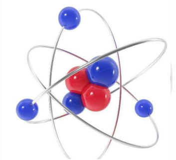
perturbative potential

$$U_p = \frac{1}{12\pi^2 T} \bar{\rho}^2 \bar{\rho}_c^2$$

part 2

The rotation impact on QCD

SU(2) gluon system in rotating frame



Semi-classical solutions of dyons.

Lagrangian

$$G^a_{0m} = \partial_0 A^a_m - \partial_m A^a_0 + f^{abc} A^b_0 A^c_m + A^a_n \partial_n v_m - v_n \partial_n A^a_m$$

$$G^a_{mn} = \partial_m A^a_n - \partial_n A^a_m + f^{abc} A^b_m A^c_n .$$

$G_{i0} = F_{i0} + v^j F_{ij}$

$A_0 + v^j A_j$

invariant under the ω dependent gauge transform

Y-Mills equation

$$\partial_i G^a_{4i} = \epsilon_{ade} G^e_{4i} A^d_i$$

$$\partial_i G^a_{ij} = v_i \partial_i G^a_{4j} + (\partial_j v_i) G^a_{4i} + \epsilon_{ade}(G^d_{4j} A^e_4 + G^e_{jn} A^d_n)$$

$\vec{\omega} \to i\vec{\omega}$ for a real velocity will make the Lagrangian density complex,

periodic boundary condition

twisted boundary condition

$$A^{D,rot} = (A^D_4(x;\rho_D) + \delta A_4,\ \vec{A}^D(x;\rho_D))$$

$$\delta A_4 = \mp \omega_a \frac{\tau^a}{2}$$ ✔

$$A^{\text{static}}_\mu(t, \varrho, \phi - \omega t, z)$$ ✘

$$G_{\mu\nu}[A^{D,rot}] = G_{\mu\nu}[A^D(\rho_D) + \delta A_4]$$
$$= G_{\mu\nu}[A^D(\rho_D); \omega = 0]$$
$$S[A^{rot}] = S[A^D(\rho_D) + \delta A_4]$$
$$= S[A^D(\rho_D); \omega = 0]$$

the field strength tensor or dyon action will not change

Clearly the asymptotic value of A_4 has been shifted by $\pm\omega$ for every kind of dyons

the standard imaginary-time formalism of thermal field theory

SU(2) gluon system in rotating frame

non-trivial vaccum and polyakov loop.

Dyon	Action	$A_4^3(\infty)$	$\Phi(\infty)$
M	ρ_M	$\rho_M - \omega$	$\rho_M - \omega n_3$
$\bar{M}$	ρ_M	$\rho_{\bar{M}} + \omega$	$\rho_{\bar{M}} + \omega n_3$
L	$2\pi T - \rho_L$	$\rho_L + \omega$	$\rho_L + \omega n_3$
$\bar{L}$	$2\pi T - \rho_{\bar{L}}$	$\rho_{\bar{L}} - \omega$	$\rho_{\bar{L}} - \omega n_3$

stringy gauge

$$A_4^{M/L,rot}(r \to +\infty) = \bar{\rho}\frac{\tau_3}{2} = (\rho_{M/L} \mp \omega)\frac{\tau_3}{2}.$$

$$\rho_{M,L} = \bar{\rho} \pm \omega.$$

$$A_4^{M/L,rot} = A_4^{M/L}(x; \bar{\rho} \pm \omega) \mp \omega\frac{\tau_3}{2}$$

$$A_i^{M/L,rot} = A_i^{M/L}(x; \bar{\rho} \pm \omega)$$

far-from-core region

$$r, s >> r_{LM}$$

dyons near rotation axis

$$s \simeq \sqrt{x_1^2 + x_2^2 + (x_3 - z_L)^2}$$

$$r \simeq \sqrt{x_1^2 + x_2^2 + (x_3 - z_M)^2}$$

$$(A_4^C + \delta A_4, A_i^C)$$

$$\delta A_4 = 0.$$

$$A^{C,rot} \simeq A^C(x; \bar{\rho})$$

action

$$S = -\frac{1}{4g^2}\int d^4x(-2G_{0i}^a G_{0i}^a + G_{mn}^a G_{mn}^a)$$

$$G_{i0} = F_{i0} + v^j F_{ij}$$

$$A_0 + v^j A_j$$

Polyakov loop

$$L = \mathcal{P}e^{i\int_0^\beta dx_4(A_4 + v_m A_m)} \equiv e^{i\Phi(x)}$$

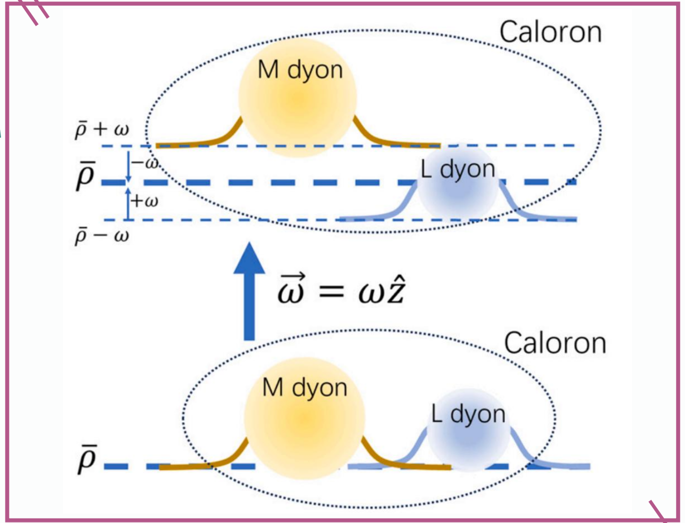
$$Tr(L) = 2cos(\beta\rho/2)$$

action is invariant under the ω dependent gauge transformation

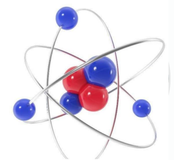
$$A_0 \to U A_0 U^\dagger + iU(\partial_0 + v^j\partial_j)U^\dagger,$$

$$A_i \to U A_i U^\dagger + iU\partial_i U^\dagger.$$

the ω -dependent Polyakov loop now transforms as the static case



SU(2) gluon system in rotating frame



effective potential.

dyons

$$A_4^{M/L,rot} = A_4^{M/L}(x;\bar{\rho}\pm\omega) \mp \omega\frac{\tau_3}{2}$$

$$A_i^{M/L,rot} = A_i^{M/L}(x;\bar{\rho}\pm\omega)$$

$$S_{M,\bar{M}} = \frac{(\bar{\rho}\pm i\omega)}{2\pi T}\frac{8\pi^2}{g^2}$$

$$S_{L,\bar{L}} = \frac{(\bar{\rho}_c\pm i\omega)}{2\pi T}\frac{8\pi^2}{g^2}$$

$$\mathcal{Z}_D = \sum_{N_M,N_{\bar{M}},N_L,N_{\bar{L}}} \frac{1}{N_M!N_{\bar{M}}!N_L!N_{\bar{L}}!} \times\left[\int d^3c_M|\bar{\rho}|^3 exp(-S[A_M])\right]^{N_M+N_{\bar{M}}} \times\left[\int d^3c_L|\bar{\rho}_c|^3 exp(-S[A_L])\right]^{N_L+N_{\bar{L}}}$$

$$U_{np} = -\frac{1}{V}ln(\mathcal{Z}_D) = -c\left[|\bar{\rho}|^3(\frac{\Lambda}{\pi T})^{\frac{22\bar{\rho}}{6\pi T}} + |\bar{\rho}_c|^3(\frac{\Lambda}{\pi T})^{\frac{22|\bar{\rho}_c|}{6\pi T}}\right]$$

dyon well-separation

analytical continuation

✔ $sgn(\rho) \Leftrightarrow |\rho|$

✘ $|\rho| \Leftrightarrow |\rho\pm i\omega|$

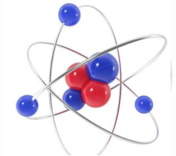
$\rho\tau_3/2 \Leftrightarrow sgn(\rho)\,\rho\tau_3/2$
global gauge transformation

action be complex with a real velocity. origin of the sign problem

$$\mathcal{Z}_{rot,D} = \sum_{N_M,N_{\bar{M}},N_L,N_{\bar{L}}} \frac{1}{N_M!N_{\bar{M}}!N_L!N_{\bar{L}}!} \times\left[\int d^3c_M\, sgn(\bar{\rho})(\bar{\rho}+i\omega)^3 exp(-S[\bar{A}_M])\right]^{N_M} \times\left[\int d^3c_{\bar{M}}\, sgn(\bar{\rho})(\bar{\rho}-i\omega)^3 exp(-S[\bar{A}_{\bar{M}}])\right]^{N_{\bar{M}}} \times\left[\int d^3c_L\, sgn(\bar{\rho}_c)(\bar{\rho}_c+i\omega)^3 exp(-S[\bar{A}_L])\right]^{N_L} \times\left[\int d^3c_{\bar{L}}\, sgn(\bar{\rho}_c)(\bar{\rho}_c-i\omega)^3 exp(-S[\bar{A}_{\bar{L}}])\right]^{N_{\bar{L}}}$$

$$U_{np}(T,\omega) = -\frac{1}{V}ln\mathcal{Z}_{rot,D} = -\frac{c}{2}[sgn(\bar{\rho})(\bar{\rho}+i\omega)^3(\frac{\Lambda}{\pi T})^{\frac{22sgn(\bar{\rho})(\bar{\rho}+i\omega)}{6\pi T}} + sgn(\bar{\rho}_c)(\bar{\rho}_c+i\omega)^3(\frac{\Lambda}{\pi T})^{\frac{22sgn(\bar{\rho}_c)(\bar{\rho}_c+i\omega)}{6\pi T}}] - \frac{c}{2}[sgn(\bar{\rho})(\bar{\rho}-i\omega)^3(\frac{\Lambda}{\pi T})^{\frac{22sgn(\bar{\rho})(\bar{\rho}-i\omega)}{6\pi T}} + sgn(\bar{\rho}_c)(\bar{\rho}_c-i\omega)^3(\frac{\Lambda}{\pi T})^{\frac{22sgn(\bar{\rho}_c)(\bar{\rho}_c-i\omega)}{6\pi T}}].$$

SU(2) gluon system in rotating frame



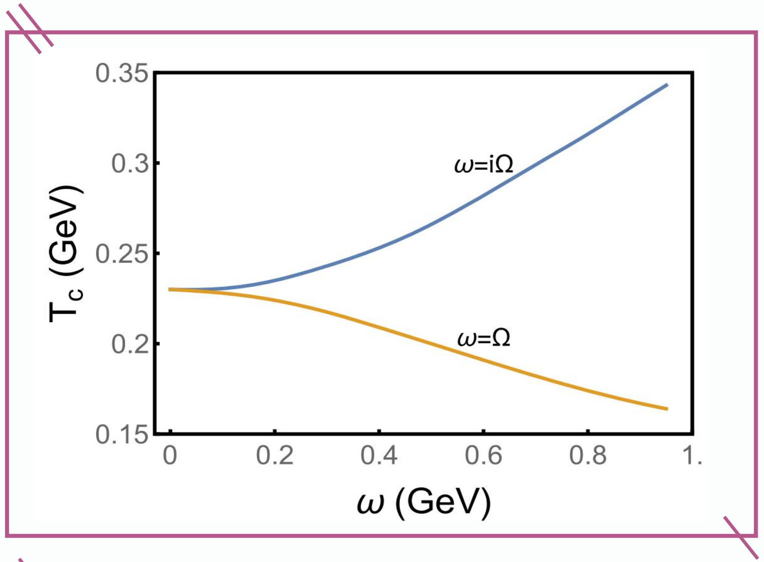
result.

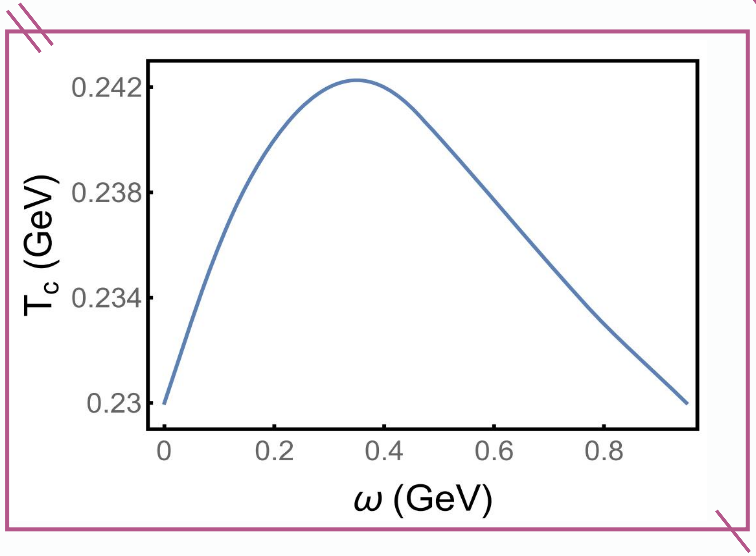
$$U_p(T,\omega) = -\sum_{\substack{s,m=1 \\ n=-\infty}}^{+\infty} \frac{e^{\frac{sn\omega}{T}}\cosh(\frac{s\omega}{T})}{\pi^2 s R^3}\frac{4\xi_n^{(m)}\cos(s\frac{\bar{\rho}}{T})}{J_{n+1}(\xi_n^{(m)})^2} \times J_n(\xi_n^{(m)}\frac{r}{R})^2 K_1(s\frac{\xi_n^{(m)}}{TR}).$$

magnify the non-perturbative part

$$g(\omega) = (1 + 0.1|\omega|/\Lambda)g$$

$$(\frac{\Lambda}{\pi T})^{22/3} = e^{-8\pi^2/g^2}$$





Results indicate that only a stronger coupling constant can help to confine color charges. While both the non-trivial vacuum and quantum fluctuations contribute to an increased likelihood of deconfinement as rotation speed rises. The competition between these two opposing trends can ultimately results in a non-monotonic relationship between the critical temperature and angular velocity.

谢谢