PERTURBATIVE STUDY OF YANG-MILLS FIELD UNDER (IMAGINARY) ROTATION

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OUTLINE

- Introduction
- 1-loop with background field:

  A0-condensate

  colormagnetic condensate
- 2-loop

  Feynman rule
- Summary

CURRENT STAGE

- Model studies
  (P)NJL, QM, Bag model, Holographic…
- Rotation + other backgrounds (magnetic field, chemical potential, etc)
- Lattice

  V. V. Braguta, A. Y. Kotov, D. D. Kuznedelev, and A. A. Roenko, Phys. Rev. D 103, 094515 (2021)
  J.-C. Yang and X.-G. Huang, arXiv:2307.05755 [hep-lat].
- Rotational effect on quark has been widely studied
- We don't know much about how rotation affects gluon sector

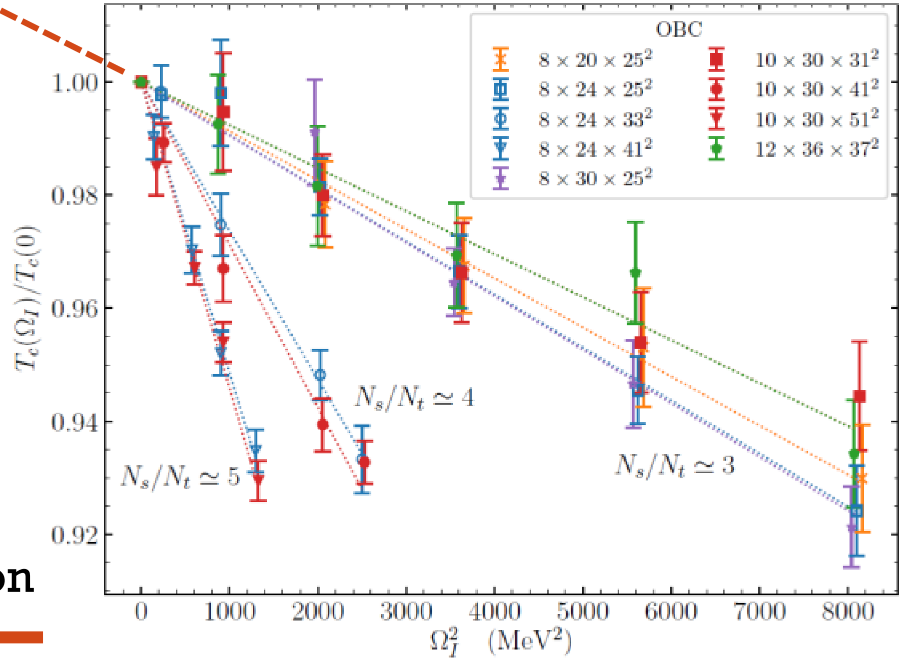
  S. Chen, K. Fukushima, and Y. Shimada, Phys. Rev. Lett. 129, 242002 (2022)
  M. N. Chernodub, Phys. Rev. D 103, 054027 (2021), Phys. Rev. D 107, 114502 (2023)
  Y-Q Zhao, S He, D Hou, L Li, and Z Li, JHEP04(2023)115

DISCREPANCY

- Lattice result with imaginary rotation

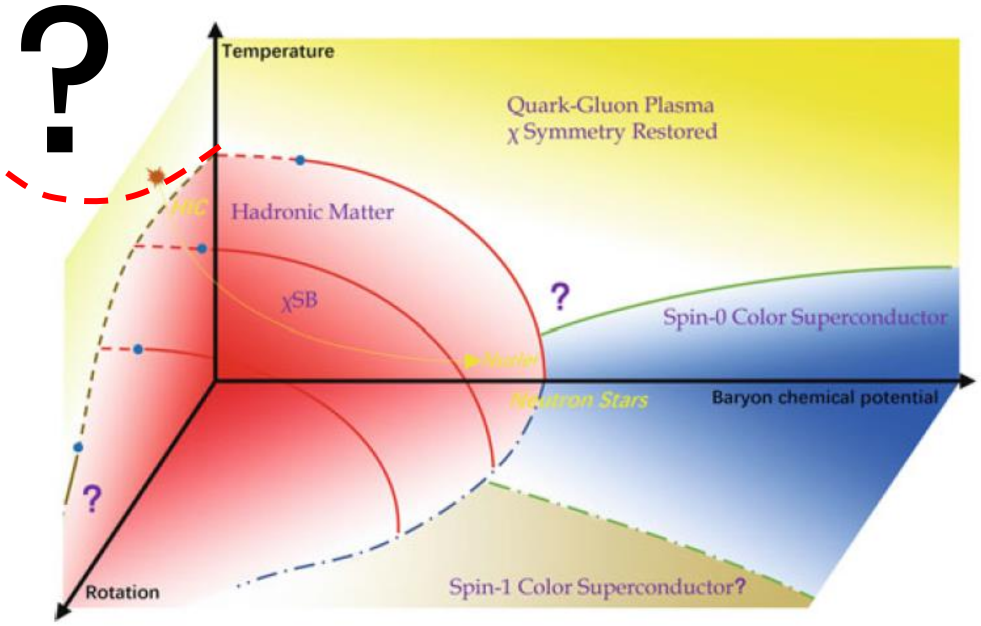
analytical continuation

$\Omega_I^2 \leftrightarrow -\Omega^2$



Real rotation

Braguta V V, Kotov A Y, Kuznedelev D D, et al. arXiv:2110.12302, 2021.



Tc decreases with increasing Ω_I → Tc increases with increasing real rotation

WHAT'S WRONG?

- Gauge sector contribution?
- Analytical continuation is not applicable?
- Something missed on lattice?
- Or something else?

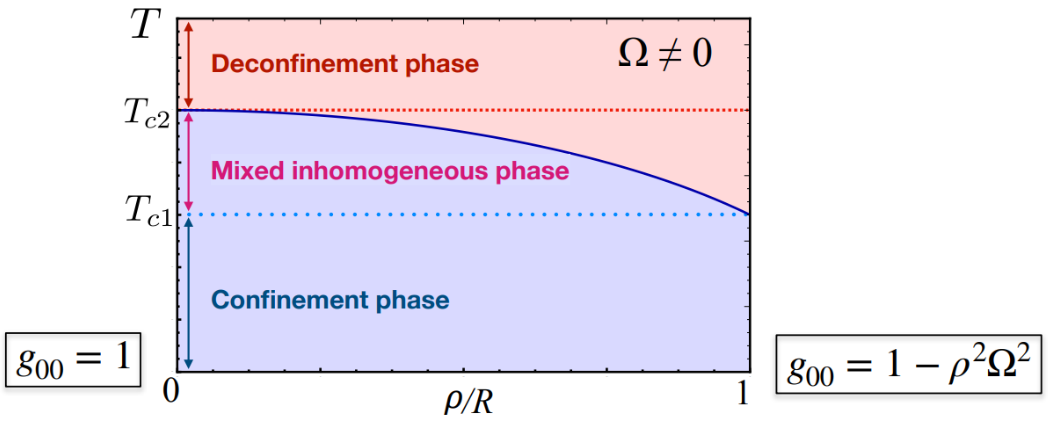
DIFFICULTIES OF REAL ROTATION

Chernodub PRD (2021), (2022)

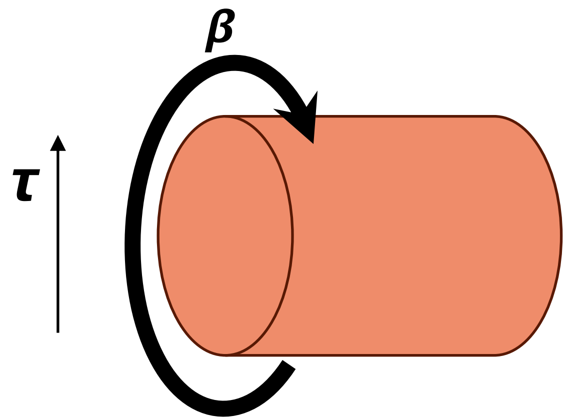
- Boundary condition to preserve causality
- Inhomogeneity
- Sign problem
- Subtlety of a Euclidean field theory

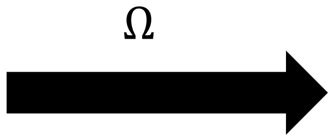
But anyway it works

Dmitri V. Fursaev, hep-th/0107089



$$T(\boldsymbol{x})\sqrt{g_{00}(\boldsymbol{x})} = T_0$$





In Complex Spacetime?

Winding number ⟶ Matsubara frequency

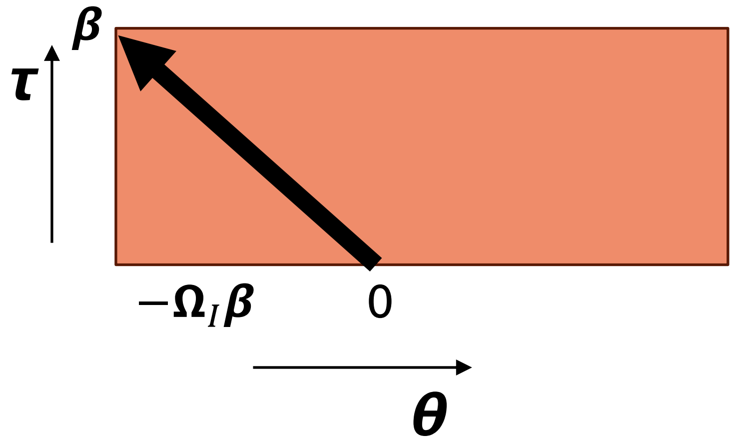
MAYBE RELATED COMMENT

- E. Witten, A Note On Complex Spacetime Metrics, 2111.06514 [hep-th]

This is a little subtle. The thermodynamics of a Schwarzschild black hole is related to a standard thermal ensemble $\mathrm{Tr}\exp(-\beta H)$. The thermodynamics of a rotating (Kerr) black hole is related to a more general ensemble $\mathrm{Tr}\exp(-\beta(H-\Omega J)$ where J is a conserved angular momentum and Ω is called the angular velocity. However, in asymptotically flat spacetime, this ensemble is unstable because a particle far from the black hole can have a negative value of $H-\Omega J$. Hence the quantum corrections to this ensemble are not well-defined, and it turns out that this is reflected in the fact that the quasi-Euclidean metric is not allowable.

IMAGINARY ROTATION

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



- Boundary condition for space is not necessary
- No sign problem
- Well defined Euclidean field theory
- twisted boundary condition

$$(\tau,\,\theta,\,r,\,z) \sim (\tau+\beta,\,\theta-\tilde{\Omega}_{\rm I},\,r,\,z)\,,$$

- Analytical continuation back to real rotation

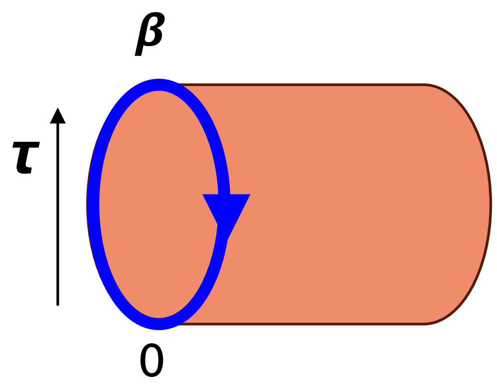
G.W. Gibbons and S.W. Hawking, Phys. Rev. D15 (1977) 2752.

- First things first, directly comparation to lattice results

POLYAKOV LOOP

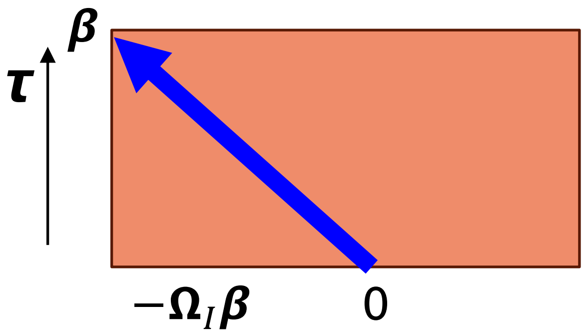
$$\Phi(\boldsymbol{x}) = \frac{1}{N}\mathrm{tr}\,\mathcal{P}\exp\left[\int_0^\beta dx_4 A_4(\boldsymbol{x}, x_f)\right],$$

- In flat spacetime



- Dependence on the boundary condition of imaginary time direction?

- In (imaginary) rotating frame, which one?

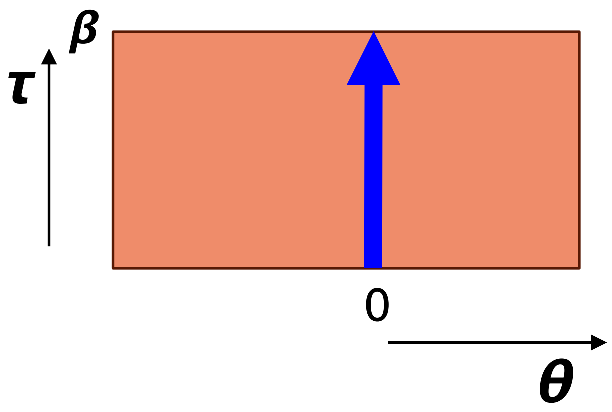


Killing vector

$n^\mu = (1, 0, -\Omega_I, 0)$

$n^2 = 1$

or



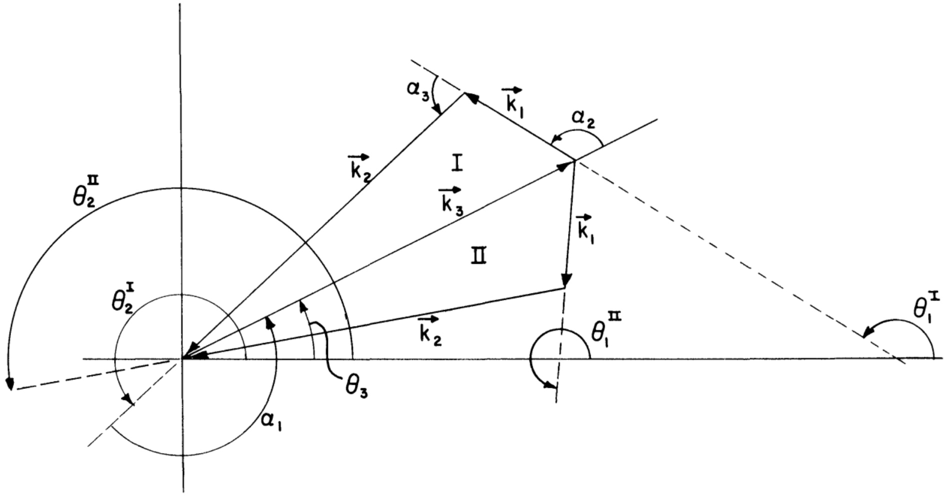
Killing vector

$n^\mu = (1, 0, 0, 0)$

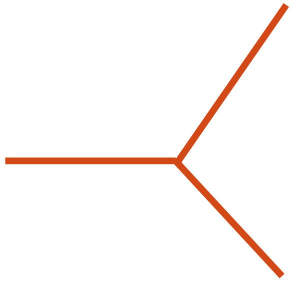
$n^2 = -1 - \Omega_I^2 r^2$

REMAINING DIFFICULTIES

- All fields feel rotation
- The interaction vertex is hard to deal with



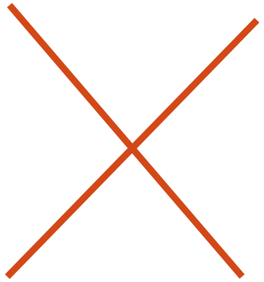
Jackson, SIAM J. MATH. ANAL. Vol. 3, No. 3, August 1972



$$\int_0^\infty J_{n_1}(k_1\rho)J_{n_2}(k_2\rho)J_{n_3}(k_3\rho)\rho\, d\rho$$

$$= \frac{\Delta}{6\pi A}[\cos(n_1\alpha_2 - n_2\alpha_1) + \cos(n_2\alpha_3 - n_3\alpha_2) + \cos(n_3\alpha_1 - n_1\alpha_3)],$$

where $n_1 + n_2 + n_3 = 0.$



$$\int r\mathrm{d}r J_{l_1}(p_{1t}r)J_{l_2}(p_{2t}r)J_{l_3}(p_{3t}r)J_{l_4}(p_{4t}r)\delta(l_1+l_2+l_3+l_4) \;=?$$

Fine at 2-loop level

FAILED ATTEMPTS 

- Kaluza-Klein method   Dmitri V. Fursaev, hep-th/0107089
  treat the curved background as an Abelian gauge vector field
  But too hard for me…

- Heat kernel expansion (Schwinger-DeWitt technique)

  Feynman Propagator in Curved Space-Time: A Momentum Space Representation,
  T.S. Bunch and L. Parker, Phys.Rev.D 20 (1979), 2499-2510

  Riemann normal coordinates

$$g_{\mu\nu} = \eta_{\mu\nu} - \frac{1}{3}R_{\mu\alpha\nu\beta}y^\alpha y^\beta - \frac{1}{6}R_{\mu\alpha\nu\beta;\gamma}y^\alpha y^\beta y^\gamma + \left(-\frac{1}{20}R_{\mu\alpha\nu\beta;\gamma\delta} + \frac{2}{45}R_{\alpha\mu\beta\lambda}R^\lambda{}_{\gamma\nu\delta}\right)y^\alpha y^\beta y^\gamma y^\delta + \cdots,$$

  We don't have curvature…

- Stay in coordinate space? $S_F(x,x') = (i\gamma^\mu\nabla_\mu - m)G(x,x')$ $G = \frac{-i}{16\pi}\int_0^\infty \frac{ds}{s^2} e^{-i[\sigma^2/s + sm^2 - is\epsilon] + i\frac{\Omega\Sigma_3}{2}\Delta t}$

NJL gap Eq. →

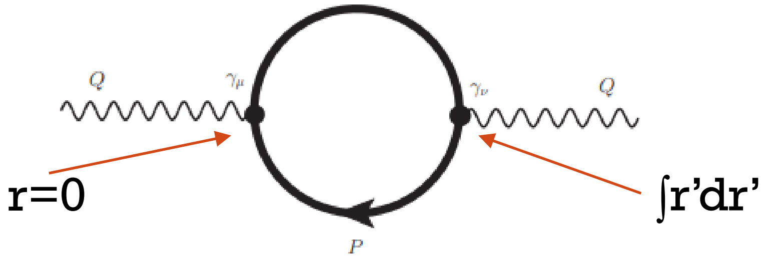
$$\frac{m}{g} = \frac{m}{4\pi}\sum_n \int_{1/\Lambda_{UV}^2}^\infty \frac{ds}{s^2} e^{\frac{-(n\beta)^2 - 2r^2 + 2r^2\cosh(\Omega n\beta)}{s} - sm^2}\cosh\left(\frac{\Omega}{2}n\beta\right)(-1)^n$$

Is this really useful?

ONE STRATEGY

- Focus on local quantities at the center

M. Wei, et al,
Chin.Phys.C 46 (2022) 2, 024102



- Assumption: $\theta + \Omega t = 0$

A. Ayala et al., Phys. Rev. D 103, no.7, 076021 (2021), [erratum: Phys. Rev. D 104, no.3, 039901 (2021)],

$$S(p) = \frac{(p_0 + \Omega/2 - p_z + ip_\perp)(\gamma_0 + \gamma_3) + m(1 + \gamma_5)}{(p_0 + \Omega/2)^2 - \bar{p}^2 - m^2 + i\varepsilon}\mathcal{O}^+ + \frac{(p_0 - \Omega/2 + p_z - ip_\perp)(\gamma_0 - \gamma_3) + m(1 + \gamma_5)}{(p_o - \Omega/2)^2 - \bar{p}^2 - m^2 + i\varepsilon}\mathcal{O}^-.$$

} equivalent

- Momentum space representation
- Account for contribution from spin
- No r-dependent part (orbit contribution) → Maybe important when Ω is large

WHAT ELSE?

- I'm not smart enough to solve this exactly, so

WHAT ELSE?

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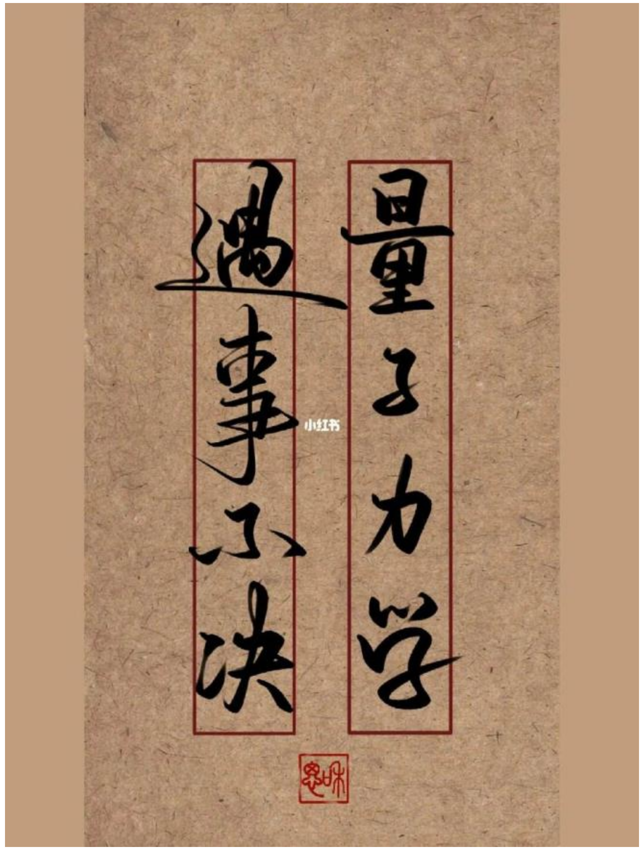
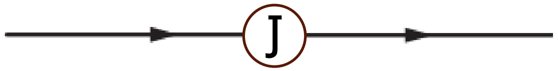


Just do perturbation

PERTURBATIVE EXPANSION OF Ω

Feynman Rule



$$\Omega\gamma^0(-ix\partial_y + iy\partial_x + \frac{i}{2}\gamma^1\gamma^2)$$

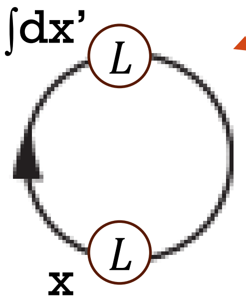
L S

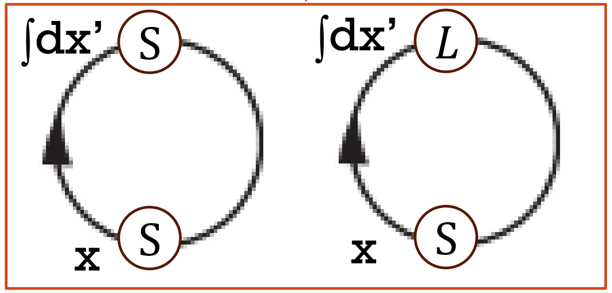
- Exercise 1: Fermion 1-loop effective action

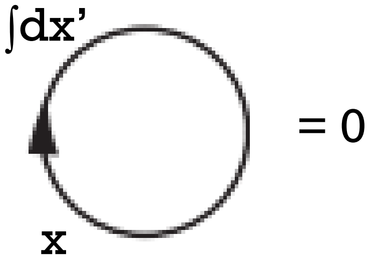
$$\ln Z = \int \mathrm{d}^3x \int \frac{p_\perp \mathrm{d}p_\perp \mathrm{d}p_z}{(2\pi)^2} \sum_l \{\beta\varepsilon + \ln[1+\mathrm{e}^{-\beta(\varepsilon-\Omega j)}] + \ln[1+\mathrm{e}^{-\beta(\varepsilon+\Omega j)}]\}[J_l(p_\perp r)^2 + J_{l+1}(p_\perp r)^2]$$

$$= \int \mathrm{d}^3x \int \frac{p_\perp \mathrm{d}p_\perp \mathrm{d}p_z}{(2\pi)^2} \sum_l \{\beta\varepsilon + 2\ln[1+\mathrm{e}^{-\beta\varepsilon}] + \frac{\mathrm{e}^{\beta\varepsilon}}{(1+\mathrm{e}^{\beta\varepsilon})^2}\beta^2\Omega^2 j^2 + O(\Omega^4)\}[J_l(p_\perp r)^2 + J_{l+1}(p_\perp r)^2]$$

$$\ln Z_2 = 2\int \mathrm{d}^3x \int \text{đ}^3p \frac{\mathrm{e}^{\beta\varepsilon}}{(1+\mathrm{e}^{\beta\varepsilon})^2}\beta^2\Omega^2(\frac{1}{2}r^2p_\perp^2 + \frac{1}{4})$$

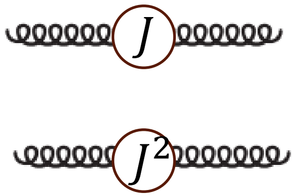






PERTURBATIVE EXPANSION OF Ω

Feynman Rule

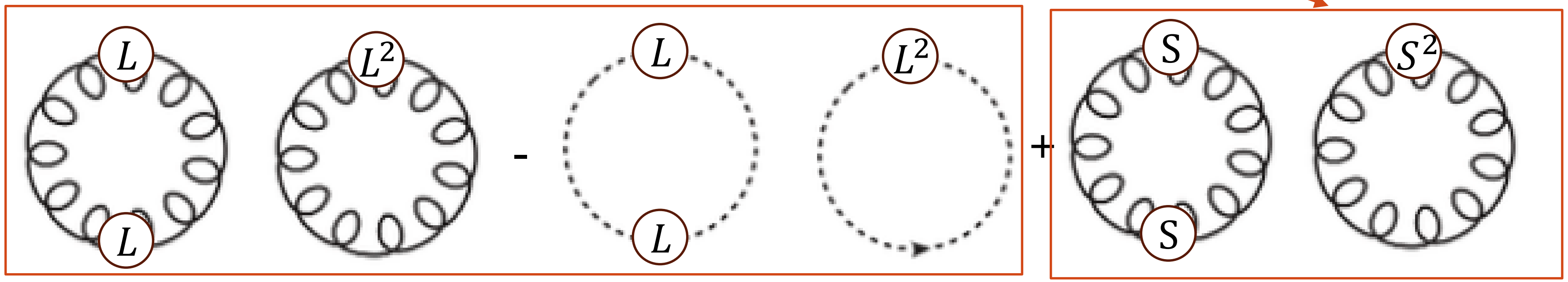


$2\Omega \hat{J}_z \partial_\tau$

$-\Omega^2 \hat{J}_z^2$

- Exercise 2: massless Gauge boson
  No S-L contribution, since Sz is off diagonal

$$\ln Z_2 = 2N_g \int d^3x \int đ^3p \frac{e^{\beta\varepsilon}}{(1-e^{\beta\varepsilon})^2}\beta^2\Omega^2(\frac{1}{2}r^2p_\perp^2+1)$$



- Despite tedious calculations, it seems no difficulties to go to higher loop

ADD SOME BACKGROUND FIELDS TO SU(2)

Because its simple

- Metric

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

- Background field formalism

$$\mathcal{A}^a_\mu = \bar{A}^a_\mu + A^a_\mu$$
$$\bar{A}^a_\mu = \delta^a_3 \bar{A}^3_\mu + \delta^a_8 \bar{A}^8_\mu$$

in tangent space, we choose $\bar{A}^3_{\hat{\mu}} = (\phi, \frac{1}{2}Hy, -\frac{1}{2}Hx, 0)$ for SU(2)

A0 condensate, related to Polyakov loop

chromo-magnetic condensate

Assumption: homogeneous condensate

- Lagrangian

$$\mathcal{L}_E = \frac{1}{4}\bar{F}^a_{\mu\nu}\bar{F}^{a\mu\nu} + \frac{1}{2}\bar{F}^a_{\mu\nu}F^{a\mu\nu} + \frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + \mathcal{L}_{gf} + \mathcal{L}_{gh}$$

$$\mathcal{L}_{gf} = \frac{1}{2}(\nabla^B_\mu A^{a\mu})^2$$ Feynman gauge

$$\mathcal{L}_{gh} = \bar{c}\nabla^B_\mu D^\mu c$$

Some lattice results

V.I. Demchik, N.V. Kolomoyets, and V.V. Skalozub. Spatial structure of the polyakov loop in external chromomagnetic field in lattice su(2) gluodynamics. *Visnyk Dnipropetrovskogo universytetu. Fizyka. Radioelectronika*, 21(2):13–17, 2013.

V. Demchik and V. Skalozub. Spontaneous creation of chromomagnetic field and A(0)-condensate at high temperature on a lattice. *J. Phys.*, A41:164051, 2008.

GAUGE FIELD GO TO TANGENT SPACE

- With the help of vierbein

$$A_{\hat{\mu}} = e_{\hat{\mu}}{}^{\mu} A_{\mu}$$

- Simple replacement in Lagrangian

$$\partial_\tau \to \partial_\tau - i\Omega_I \hat{J}_z$$

$$\hat{J}_z A_{\hat{\mu}} = (\hat{L}_z \delta^\nu_\mu + \hat{S}_{z\mu}{}^{\nu}) A_{\hat{\nu}}$$

$$\hat{J}_z c = \hat{L}_z c$$

$$\hat{S}_z = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & -i & 0 \\ 0 & i & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

- At one loop level, the Lagrangian can be diagonalized with

$$A^a_+ = \frac{1}{\sqrt{2}}(A^a_{\hat{x}} + A^a_{\hat{y}}), \quad A^a_- = \frac{1}{\sqrt{2}}(A^a_{\hat{x}} - A^a_{\hat{y}})$$

$$A^+_\pm = \frac{1}{\sqrt{2}}(A^1_\pm + A^2_\pm), \quad A^-_\pm = \frac{1}{\sqrt{2}}(A^1_\pm - A^2_\pm)$$

- 1-loop effective potential

$$V(r) = \frac{1}{2}H^2 + \frac{1}{S}\sum_n \sum_{l=-\lambda}^{N-\lambda} \sum_{\lambda\in\mathbb{N}} \sum_{\pm} \int \frac{\mathrm{d}k_z}{2\pi} \ln[(\omega_n - \Omega_I(l \mp 1) + g\phi)^2 + gH(2\lambda + 1 \pm 2) + k_z^2]\Phi_l^2(\lambda, \tfrac{1}{2}gHr^2)$$

A0 CONDENSATE

S. Chen, K. Fukushima, and Y. Shimada
Phys.Rev.Lett. 129 (2022) 24, 242002

- gH=0
- Weiss potential

$$V(\phi;\tilde{\Omega}_{\rm I})|_{\tilde{r}=0} = \frac{\pi^2 T^4}{3}\sum_{\boldsymbol{\alpha}}\sum_{s=\pm1} B_4\left(\left(\frac{\phi\cdot\boldsymbol{\alpha}+s\tilde{\Omega}_{\rm I}}{2\pi}\right)_{\rm mod\ 1}\right).$$

- Simple replacement

$$\phi\cdot\alpha \to \phi\cdot\alpha \pm \beta\Omega_I$$

- Still true at higher loop?
  Rotation contribution to 3-gluon interaction and gluon-ghost vertex differently

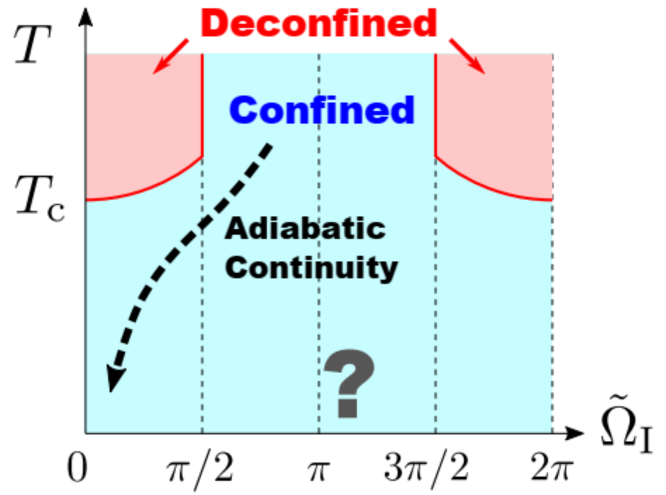
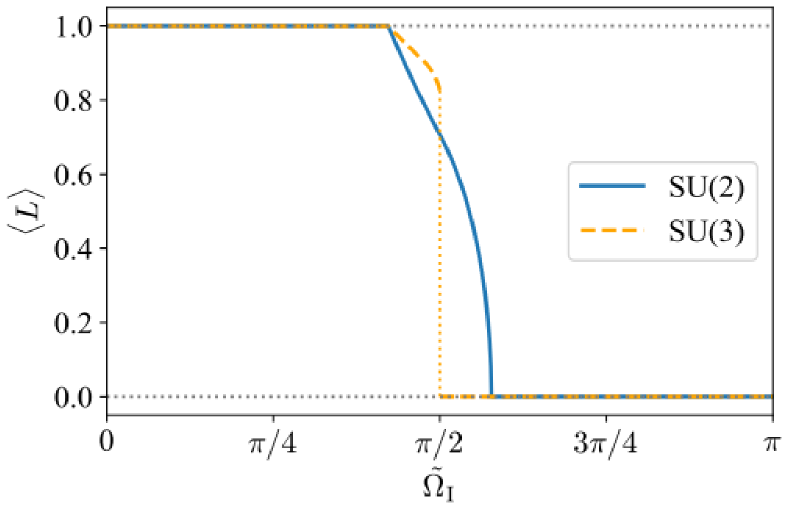


FIG. 4. Conjectured phase diagram on the $\tilde{\Omega}_{\rm I}$-T plane around the rotation axis, $\tilde{r}=0$, for the SU(3) case. Solid curves represent the phase transition.



CHROMO-MAGNETIC CONDENSATE

- At r=0

$$V(0) = \frac{1}{2}H^2 + \frac{gH}{2\pi\beta}\sum_{n}\sum_{\lambda\in\mathbb{N}}\sum_{s=\pm1}\int\frac{\mathrm{d}k_z}{2\pi}\ln[(\omega_n + s\Omega_I + g\phi)^2 + gH(2\lambda+1+2s) + k_z^2]$$

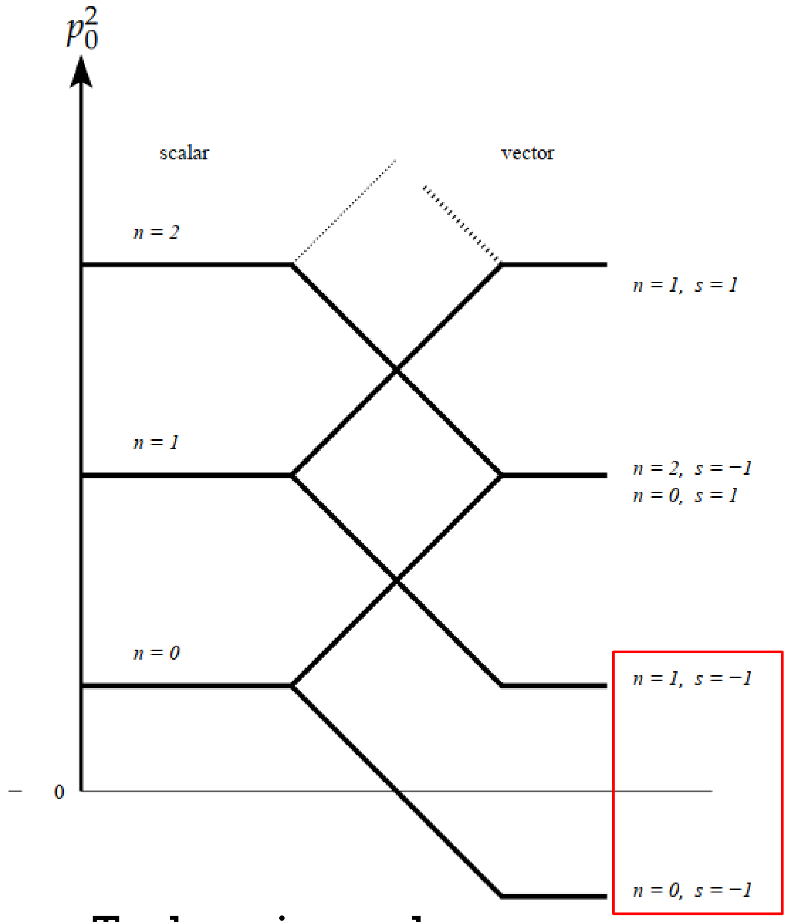
- Ω=0, T=0: Savvidy Vacuum

G.K. Savvidy, Phys. Lett. B, 71:133, 1977

- Nielsen-Olsen instability

N.K Nielsen and P. Olesen., Nucl. Phys. B, 144(2-3):376–396, 1978.

- When Ω=0, A0 condensate can help



Tachyonic mode when $\lambda = 0, \quad s = -1$

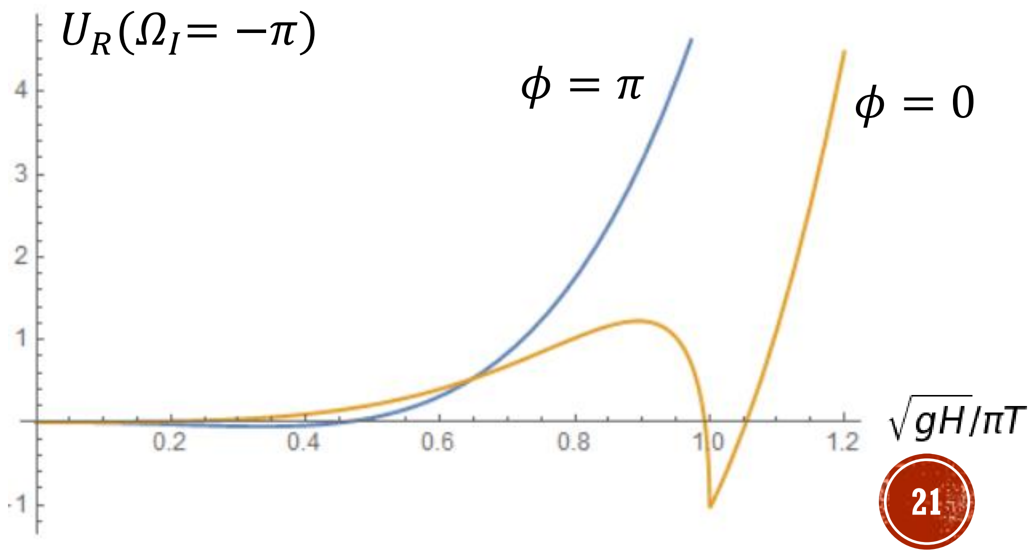
CHROMO-MAGNETIC CONDENSATE

- Effective potential

$$U_R = \frac{11 g^2 H^2}{48\pi^2}\ln(\frac{gH}{\mu_0^2}) - \frac{(gH)^{\frac{3}{2}}}{\pi^2\beta}\sum_{n=1}^{\infty}\frac{1}{n}[K_1(n\beta\sqrt{gH}) - \frac{\pi}{2}Y_1(n\beta\sqrt{gH}))]\cos n\beta(g\phi - \Omega_I)$$
$$- 2\frac{(gH)^{\frac{3}{2}}}{\pi^2\beta}\sum_{n=1}^{\infty}\sum_{\lambda=0}^{\infty}\frac{1}{n}\sqrt{2\lambda+3}K_1(n\beta\sqrt{gH(2\lambda+3)})\cos n\beta g\phi\cos n\beta\Omega_I$$
$$U_I = -\frac{(gH)^2}{8\pi} - \frac{(gH)^{\frac{3}{2}}}{2\pi^2\beta}\sum_{n=1}\frac{1}{n}J_1(n\beta\sqrt{gH})\cos n\beta(g\phi - \Omega_I)$$

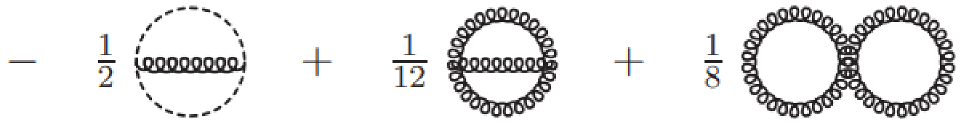
- No replacement $\phi\cdot\alpha \to \phi\cdot\alpha \pm \beta\Omega_I$
- Imaginary part can be cured at 2-loop

M. Bordag, V. Skalozub, Eur.Phys.J.C 82 (2022) 5, 390



GO TO HIGHER LOOP

- 2-loop correction



- gH=0, again to check $\phi \cdot \alpha \to \phi \cdot \alpha \pm \beta \Omega_I$
- So we need Feynman rule under rotation

FEYNMAN RULE FOR SU(2)

- Gluon propagator a, μ  b, ν

$$G^{ab}_{\mu\nu} = \frac{1}{2}\begin{pmatrix} G_{\mu\nu}(p_4+g\phi)+G_{\mu\nu}(p_4-g\phi) & -iG_{\mu\nu}(p_4+g\phi)+iG_{\mu\nu}(p_4-g\phi) & 0 \\ i(G_{\mu\nu}(p_4+g\phi)-iG_{\mu\nu}(p_4-g\phi)) & G_{\mu\nu}(p_4+g\phi)+G_{\mu\nu}(p_4-g\phi) & 0 \\ 0 & 0 & 2G_{\mu\nu}(p_4) \end{pmatrix} \xrightarrow{\;g\phi=0\;} \delta^{ab}G_{\mu\nu}$$

- where

$$G_{\mu\nu}(x,x') = \frac{\mathrm{e}^{ip_4\Delta\tau+ip_z\Delta z}}{(ip_4-i\Omega_I l)^2+\mathbf{p}^2}\begin{pmatrix} \phi_l\phi_l'^* & 0 & 0 & 0 \\ 0 & \frac{1}{2}(\phi_{l+1}\phi_{l+1}'^*+\phi_{l-1}\phi_{l-1}'^*) & \frac{i}{2}(\phi_{l+1}\phi_{l+1}'^*-\phi_{l-1}\phi_{l-1}'^*) & 0 \\ 0 & -\frac{i}{2}(\phi_{l+1}\phi_{l+1}'^*-\phi_{l-1}\phi_{l-1}'^*) & \frac{1}{2}(\phi_{l+1}\phi_{l+1}'^*+\phi_{l-1}\phi_{l-1}'^*) & 0 \\ 0 & 0 & 0 & \phi_l\phi_l'^* \end{pmatrix}$$

- Gauge dependence

$$G^{\xi}_{\mu\nu}(x,x') = G_{\mu\nu}(x,x') - (1-\xi)\partial_\mu\partial'_\nu \frac{\mathrm{e}^{ip_4\Delta\tau+ip_z\Delta z}\phi_l\phi_l'^*}{[(ip_4-i\Omega_I l)^2+\mathbf{p}^2]^2}$$

GLUON PROPAGATOR

Euclidean thermal Green functions of photons in generalized Euclidean Rindler spaces for any Feynman - like gauge
V. Moretti, Int.J.Mod.Phys.A 12 (1997), 3787-3798, hep-th/9607178

- Eigenvalue equation

$$\nabla_\mu \nabla^\mu A_\nu - (1 - \frac{1}{\xi})(\nabla_\nu \nabla^\mu A_\mu) = \lambda A_\nu$$

- For Feynman gauge

$$A_\mu^{(1)} = (1,0,0,0)\phi_l \qquad j = l$$
$$A_\mu^{(2)} = (0,1,i,0)\phi_l \qquad j = l-1$$
with
$$A_\mu^{(3)} = (0,1,-i,0)\phi_l \qquad j = l+1$$
$$A_\mu^{(4)} = (0,0,0,1)\phi_l \qquad j = l$$

- For arbitrary ξ, use

$$A_\mu^\xi = (\partial_\tau, \partial_x, \partial_y, \partial_z)\phi_l$$

- Propagator end at the center can be expanded as plane wave

$$\int p_t \mathrm{d}p_t \phi_l(0)\phi_l'^*(r) = \int p_t \mathrm{d}p_t J_0(p)$$
$$= \int p_t \mathrm{d}p_t \mathrm{d}p_\theta \mathrm{e}^{ip_t \cos\theta_p} = \int \mathrm{d}p_x \mathrm{d}p_y \mathrm{e}^{ip_x x + ip_y y}$$

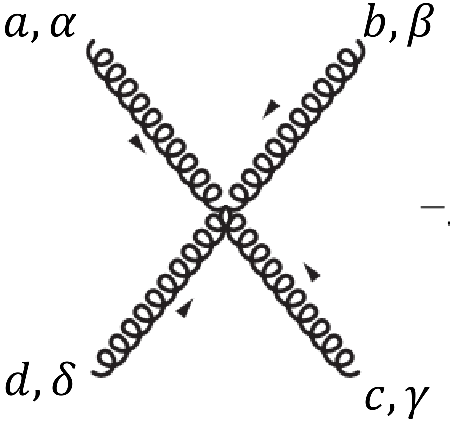
$$G_{\mu\nu} = -\eta^{\parallel}_{\mu\nu} G(ip_4) - \eta^{\perp}_{\mu\nu}[G(ip_4 + i\Omega_I) + G(ip_4 - i\Omega_I)] + S_{z\mu\nu}[G(ip_4 + i\Omega_I) - G(ip_4 - i\Omega_I)]$$

FEYNMAN RULE FOR SU(2)

- Ghost propagator

$$G^{ab} = \frac{1}{2}\begin{pmatrix} G(p_4+g\phi)+G(p_4-g\phi) & -iG(p_4+g\phi)+iG(p_4-g\phi) & 0 \\ i(G(p_4+g\phi)-iG(p_4-g\phi)) & G(p_4+g\phi)+G(p_4-g\phi) & 0 \\ 0 & 0 & 2G(p_4) \end{pmatrix} \xrightarrow{\quad g\phi=0 \quad} \delta^{ab}G$$

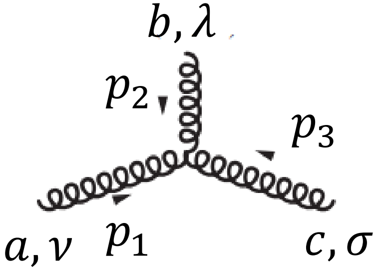
- Four-gluon interaction



$$-g^2[f^{eab}f^{ecd}(\eta^{\alpha\gamma}\eta^{\beta\delta}-\eta^{\alpha\delta}\eta^{\beta\gamma})+f^{eac}f^{edb}(\eta^{\alpha\delta}\eta^{\beta\gamma}-\eta^{\alpha\beta}\eta^{\gamma\delta})+f^{ead}f^{ebc}(\eta^{\alpha\beta}\eta^{\gamma\delta}-\eta^{\alpha\gamma}\eta^{\beta\delta})]$$

FEYNMAN RULE FOR SU(2)

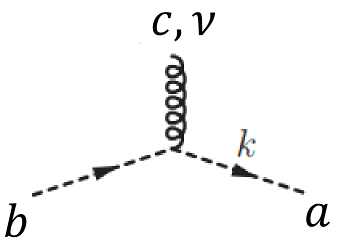
- Three-gluon interaction



$$-g[(iP_1^{ia\langle\lambda})^{\sigma\rangle\nu} f^{ibc} - (iP_2^{ib\langle\nu})^{\sigma\rangle\lambda} f^{aic} + (iP_3^{ic\langle\nu})^{\lambda\rangle\sigma} f^{abi}$$

where $(iP^{ia\lambda})^{\sigma\nu} = ip^{\lambda}\eta^{\sigma\nu}\delta^{ia} - \eta^{\lambda 4} i\Omega_I \hat{J}_z^{\sigma\nu}\delta^{ia} - \eta^{\lambda 4}\eta^{\sigma\nu} g\phi f^{i3a}$

- Gluon-ghost interaction



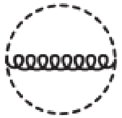
$$-g(iP_{\nu}^{aa'})f^{a'bc}$$

Orbit contribution only

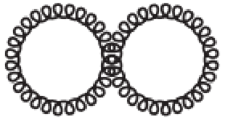
2-LOOP CORRECTION AT THE CENTER

Rotation only result

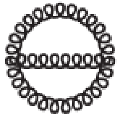
- Tedious but possible

$-\quad \frac{1}{2}$ 

$$\frac{3}{2}g^2\int_k\int_q[2(k_3p_3+k_4p_4)G(ik_4)+(k_1p_1+k_2p_2)(G(ik_4+i\Omega_I)+G(ik_4-i\Omega_I))]G(ip_4)G(-ik_4+ip_4)$$

$\frac{1}{8}$ 

$$-\frac{3}{4}g^2\int_k\int_q\{4G(ik_4)G(ip_4)+4G[ik_4)(G(ip_4+i\Omega_I)+G(ip_4-i\Omega_I)]+4[G(ik_4+i\Omega_I)$$
$$+G(ik_4-i\Omega_I)]G(ip_4)+[G(ik_4+i\Omega_I)+G(ik_4-i\Omega_I)][G(ip_4+i\Omega_I)+G(ip_4-i\Omega_I)]\}$$

$\frac{1}{12}$ 

Too long to be shown

Still ongoing…

SUMMARY

- As less assumption as possible
- At least we can do some calculation of QCD under (imaginary) rotation
- Some other quantities to compare with lattice
- zzz

THANKS !