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Background Effective Action with Nonlinear Massive Gauge Fixing

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Motivation

Gauge Theories: Fundamental QFTs for the description of particles.

- By construction entail invariance under local gauge transformations affected by the symmetry group $\mathcal{G}$.
- Non-Abelian gauge theories, e.g. Yang-Mills, QCD,...

Inclusion of dynamically generated mass regulator parameters in pure Yang-Mills theory.

- Supported by lattice simulations for $\mathcal{G} = SU(2)$ & $SU(3)$.
- Regulate the IR divergences of the theory.
- Pheno models with such mass deformations, e.g. Curci-Ferrari, provide quite accurate results.

Goals

- Study of Euclidean quantum pure Yang-Mills theory

$$\mathcal{L} = \frac{1}{4} F^a_{\mu\nu} F^a_{\mu\nu}, \tag{1}$$

by including gluon & ghost mass regulator parameters in a symmetry respecting manner.

- Investigate the effect of these mass regulator parameters in the behavior of our model on the level of the one-loop effective action.

Setting up the Model

- Background field method $A^a_\mu = \bar{A}^a_\mu + a^a_\mu$.
  - Manifest background gauge invariance.
- Choose a **Fourier weight** during gauge fixing [1]

$$S_{\text{gf}} = \int v^a \mathcal{F}^a[\bar{A}, a], \tag{2}$$

with v^a: external (Nakanishi-Lautrup) scalar field,
and $\mathcal{F}^a[\bar{A}, a]$: gauge fixing condition.

- Insert mass regulators as part of the nonlinear gauge fixing condition

$$\mathcal{F}^a[a, \bar{A}] = \frac{v^a}{2|v|^2} a^b_\mu \left[\bar{m}^2 \delta^{bc}_{\mu\nu} - \frac{1}{\xi} \left(\bar{D}_\mu \bar{D}_\nu \right)^{bc} \right] a^c_\nu + \left(1 + \frac{\bar{m}^2_{\text{gh}}}{-\bar{D}^2} \right) \left(\bar{D}_\mu a_\mu \right)^a . \tag{3}$$

- Model preserves **background gauge** and **BRST** invariance.

One-Loop Effective Action

- Effective action at one-loop around small fluctuations

$$\Gamma_{1\text{L}} = \frac{1}{4} F^a_{\mu\nu} F^a_{\mu\nu} - \ln\left(\Delta_{\text{FP}}\right) + \frac{1}{2} \ln\left(\det M\right). \tag{4}$$

- For the **ghost sector**

$$\Delta_{\text{FP}}[0, A] = \det\left(D^2 - \bar{m}^2_{\text{gh}}\right). \tag{5}$$

- For the **gluon sector**

$$M^{ab}_{\mu\nu}[A; \xi] = \bar{m}^2 \delta^{ab}_{\mu\nu} - 2\bar{g} f^{abc} F^c_{\mu\nu} - \left(D^2\right)^{ab} \delta_{\mu\nu}. \tag{6}$$

- v-independent effective action to one-loop order.
- Insertion of mass regulator parameters through their respective sectors.

Result: Running Coupling

Dim. Reg in $\overline{\text{MS}}$ scheme

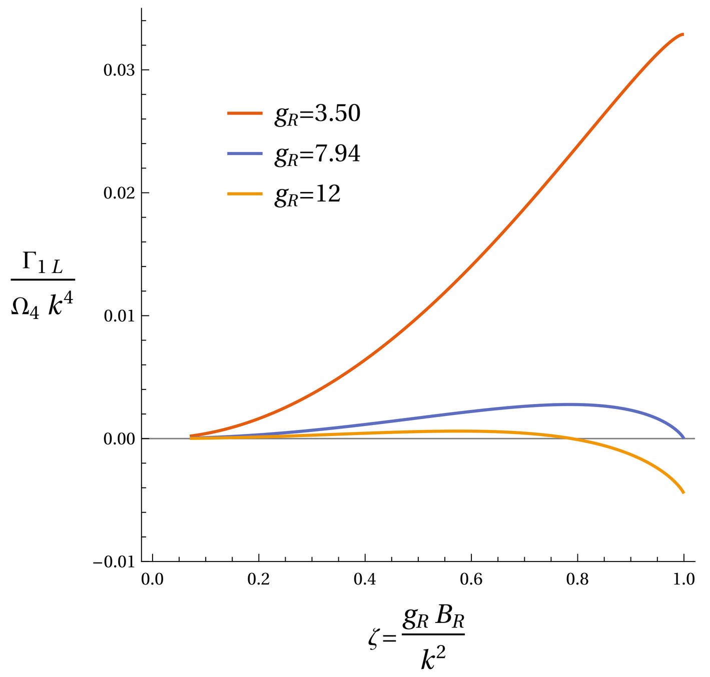
$$\beta_{g^2} = -\frac{22 N_c}{3} \frac{g^4}{(4\pi)^2} \tag{7}$$

Sharp UV proper-time cutoff Λ

$$\beta_{g^2} = -\frac{22 N_c}{3} \frac{g^4}{(4\pi)^2} e^{-\frac{k^2}{\Lambda^2}}. \tag{8}$$

- Results agree with each other for $\Lambda \to \infty$.
- Agreement with universal YM one-loop beta function.
- Choice of common mass scale $\bar{m}^2 = \bar{m}^2_{\text{gh}} = k^2$,
  - k^2 surpasses the UV scale $\Rightarrow$ Decoupling of modes in (8)

Result: Study of Effective Action

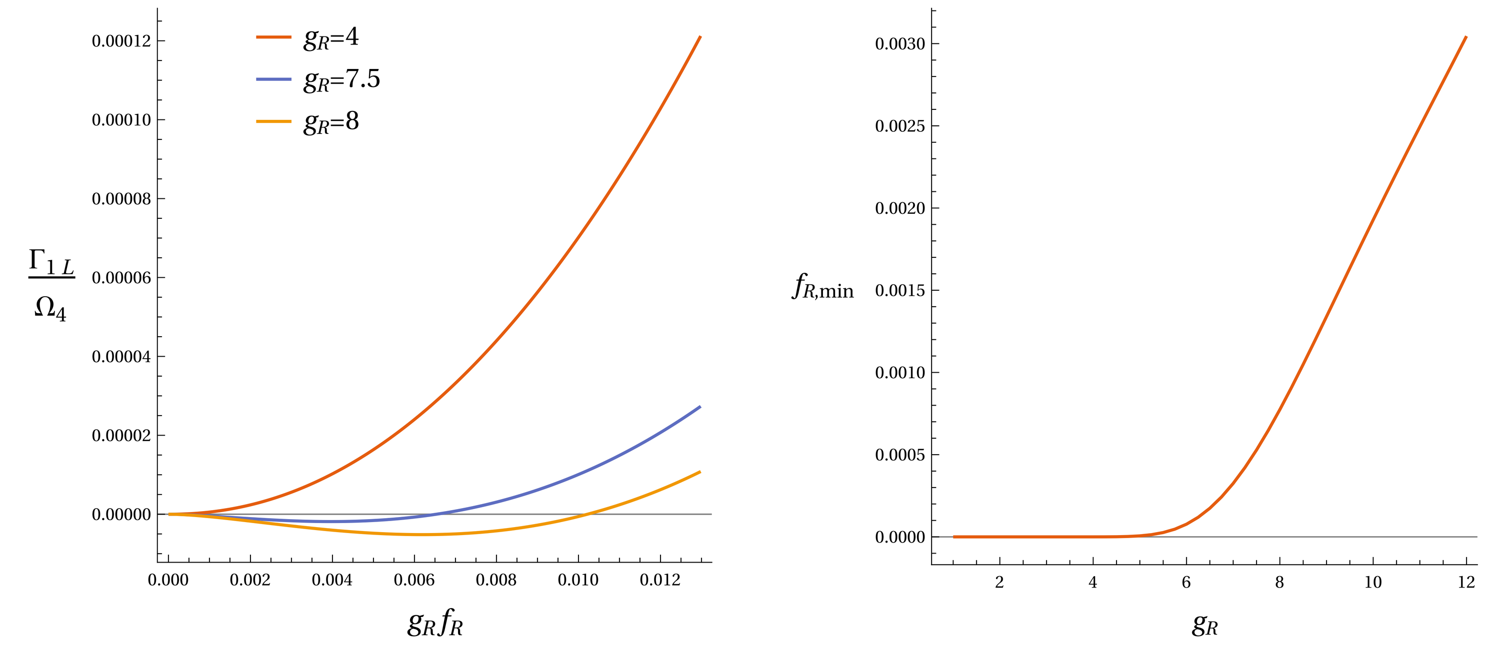


Effective action for **constant magnetic fields.**

- $\boldsymbol{k^2 \geq g_R B_R}$, finite gluonic contribution region
- $\boldsymbol{k^2 < g_R B_R}$, diverges due to unstable modes contribution.
- Origin of unstable modes $\Rightarrow$ gluon sector. [2]
- Systematic way of dealing with unstable modes within **domain of validity**!

Result: Study of the Effective Action

- For **self dual backgrounds**, study the effective action



- For **small couplings** the classical contribution dominates $\Rightarrow$ quadratic increase.
- Further increase of the coupling $\Rightarrow$ existence of **nontrivial minimum**.
- Zero modes spoil large field behavior $\left(\sim -f_R^2 \ln \frac{f_R^2}{\bar{m}^4}\right)$.
- Instability can be regulated by IR suppressing regulator.
- Qualitative agreement with FRG result. [3, 4]
- For $g_R \geq g_{\text{crit}} \simeq 5$, **continuous increase** of minimum by increasing the coupling, see right plot.
- Indication of **gluon condensate**!

Conclusions

- **Regulator mass parameters** can be inserted in pure Yang-Mills theory as part of the gauge fixing condition and provide an action that respects the symmetries of the theory.
- The one-loop effective action does not give rise to new divergences.
- Study of the form of the one-loop effective action indicates the existence of a **non-trivial minimum**!
- Disclaimer: Validity of perturbation theory and higher loop contribution.

References

[1] S. Asnafi, H. Gies and L. Zambelli; *Phys. Rev. D* (2019); **99**(8):085009.

[2] N. K. Nielsen and P. Olesen; *Nucl. Phys. B* (1978); **144**:376–396.

[3] A. Eichhorn, H. Gies and J. M. Pawlowski; *Phys. Rev. D* (2011); **83**:045014.

[4] J. Horak, F. Ihssen, J. Papavassiliou, J. M. Pawlowski, A. Weber and C. Wetterich (2022); 2201.09747.