Yang-Mills and QCD correlation functions from the Curci-Ferrari model at two-loop order

Nahuel Barrios
Advisors: Marcela Peláez and Urko Reinosa

Rencontres de Physique des Particules - April 8, 2021

[N. Barrios, M. Peláez, U. Reinosa, and N. Wschebor. PRD (2020)]
[N. Barrios, J. Gracey, M. Peláez and U.Reinosa - arXiv]

Outline

1. The Curci-Ferrari model in Landau gauge
2. Two-loop ghost-antighost-gluon vertex in YM theory
3. Two-loop propagators in QCD
4. Conclusions and outlook

Motivation

Goal: Computation of correlation functions in YM and QCD in Landau gauge in euclidean space.

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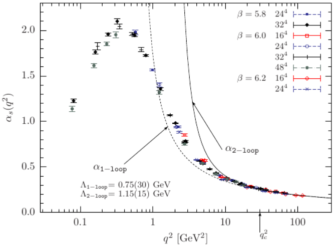
    UV: asymptotic freedom $\Longrightarrow$ perturbation theory.



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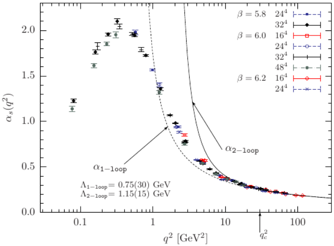

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IR: Landau pole!

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   - Schwinger-Dyson equations
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2. Modify FP action (Gribov copies).
   - Gribov-Zwanziger formalism
   - Curci-Ferrari model

Curci-Ferrari model in Landau gauge (quenched approximation)

$$L = \frac{1}{4}(F^a_{\mu\nu})^2 + \partial_\mu \bar{c}^a (D_\mu c)^a + i h^a \partial_\mu A^a_\mu + \frac{m^2}{2}(A^a_\mu)^2$$

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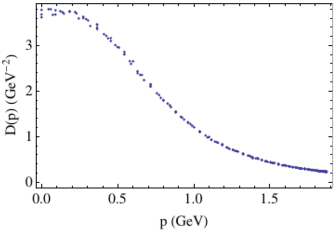

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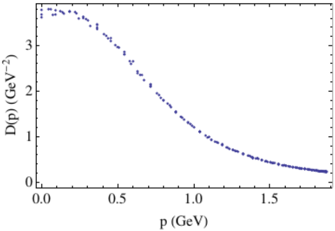

[A. Cucchieri, A. Maas and T. Mendes (2008)]

- In the UV limit we recover standard FP action
- CF has the same symmetries than FP, except BRST
- Renormalizable

Testing the model

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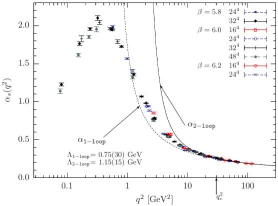

Expansion parameter $\sim N\dfrac{\alpha}{4\pi} < 1$

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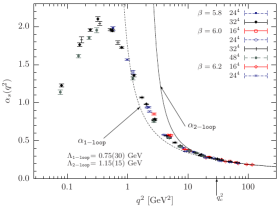

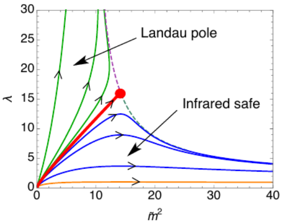

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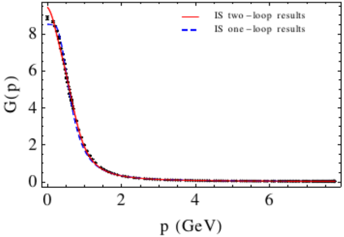
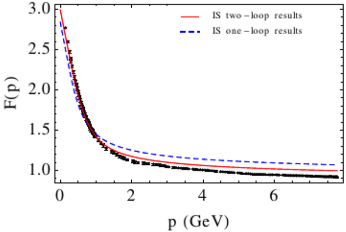
Infrared safe scheme

Two-point functions - SU(3) YM

- Two- and three- point correlation functions

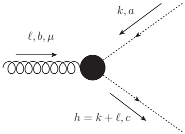




[Lattice data from: A.G. Duarte, O. Oliveira and P. J. Silva (2018)]
[Tissier, Wschebor (2011)]
[Gracey, Peláez, Reinosa, Tissier (2019)]

- From these fits we can extract $\lambda(\mu)$ and $m(\mu)$ and make predictions:
  - at non-zero temperature
  - we will focus on zero temperature in this talk

YM ghost-antighost-gluon vertex - vanishing gluon momentum



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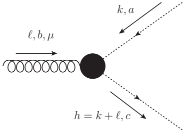
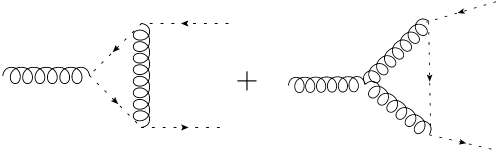
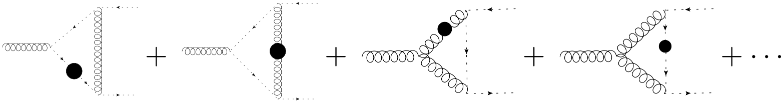


1-loop diagrams:

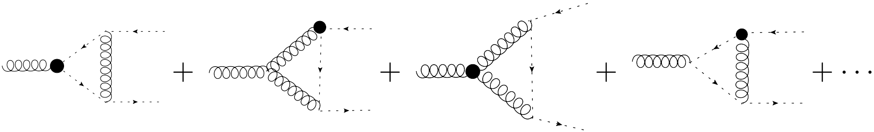


2-loop diagrams:

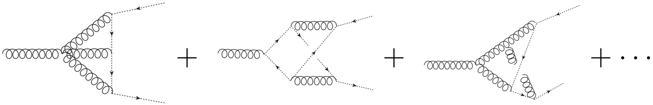
- Corrections to propagators



- Corrections to vertices

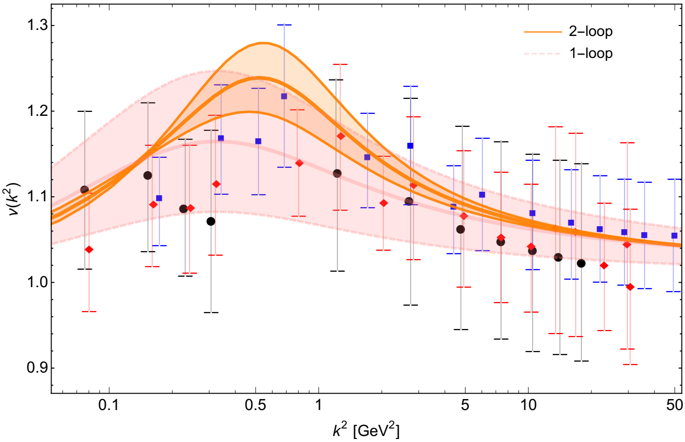


- Two-loop genuine



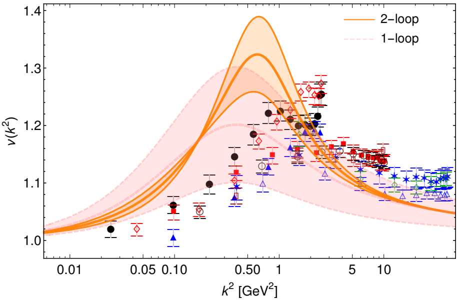
Non-planar diagrams (vanished thanks to Jacobi identity)

SU(3) YM prediction - ghost-gluon vertex - vanishing gluon momentum



[Lattice data from Sternbeck *et al.* (2006)]

SU(2) YM - ghost-gluon vertex - vanishing gluon momentum



Prediction

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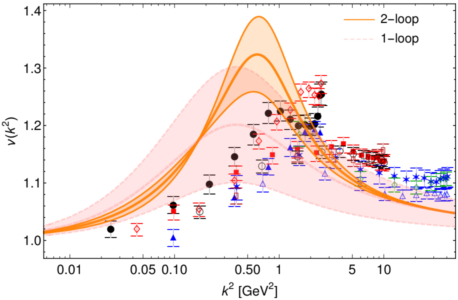

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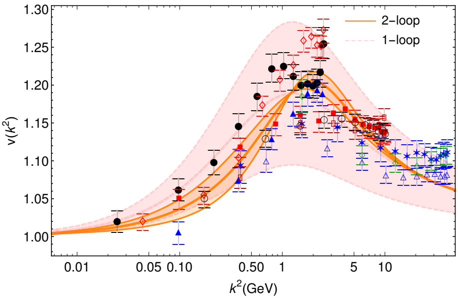
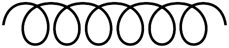


Fit

[Lattice data from A. Maas (2020)]

Two-loop QCD propagators from the CF model. Nf=2

$F(k)$



$D(k)$

$$S(k) = Z(k)\frac{i\not{k} + \mathbb{1}M(k)}{k^2 + M^2(k)}$$

37 2-loop diagrams, 6 1-loop diagrams in total.

[M. Peláez, M. Tissier and N. Wschebor (2014)]
[R. Williams, C. S. Fischer and W. Heupel (2015)]
[A. Cyrol, M. Mitter, J. Pawlowski and N. Strodthoff (2017)]
[A. C. Aguilar, J. C. Cardona, M. N. Ferreira and J. Papavassiliou (2018)]
[F. Gao, J. Papavassiliou and J. Pawlowski (2021)]

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- coupling is up to 3 times larger than in YM sector in the IR
- SBCS cannot be reproduced within a purely perturbative approach.

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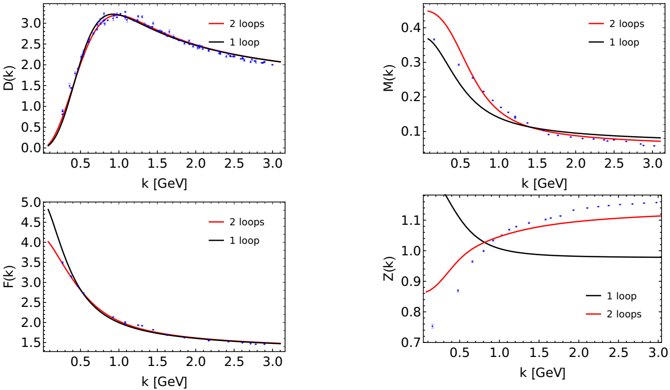
Two fits:

- Minimizing $\chi^2 \equiv \frac{1}{4}\left(\chi_F^2 + \chi_D^2 + \chi_Z^2 + \chi_M^2\right)$
- Minimizing $\tilde{\chi}^2 \equiv \frac{1}{3}\left(\chi_F^2 + \chi_D^2 + \chi_Z^2\right)$

Results M_π=426 MeV

Minimizing χ



[Lattice data from A. Sternbeck, K. Maltman, M. Muller-Preussker, L. von Smekal (2012) and O. Oliveira, P.J. Silva, J. I. Skullerud, A. Sternbeck (2019)]

Error table for χ

order	λ_0	m_0	M_0	$\chi_F(\%)$	$\chi_D(\%)$	$\chi_Z(\%)$	$\chi_M(\%)$
1-loop	0.39	430	140	3.3	5.3	19.3	16.1
2-loop	0.32	390	160	2.4	3.7	5.3	9.0

masses in MeV.

Error table for $\tilde{\chi}$

order	$\chi_F(\%)$	$\chi_D(\%)$	$\chi_Z(\%)$
1-loop	5.5	3.9	16.1
2-loop	2.5	3.7	3.0

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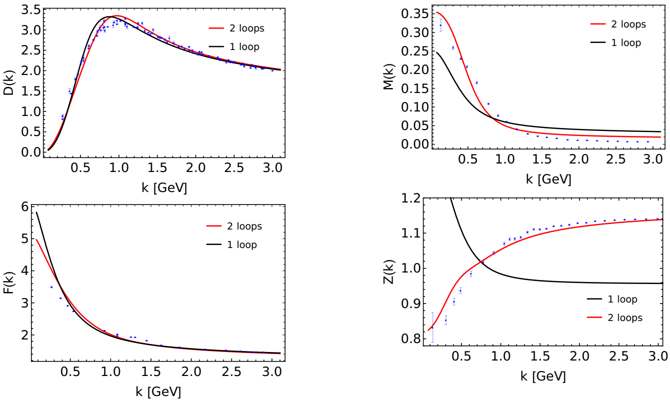

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1-loop	0.41	400	60	6.3	6.1	20.6	27.3
2-loop	0.36	360	50	5.6	5.1	1.9	12.7

Error table for $\tilde{\chi}$

order	$\chi_F(\%)$	$\chi_D(\%)$	$\chi_Z(\%)$
1-loop	4.9	4.0	14.3
2-loop	2.4	3.3	1.3

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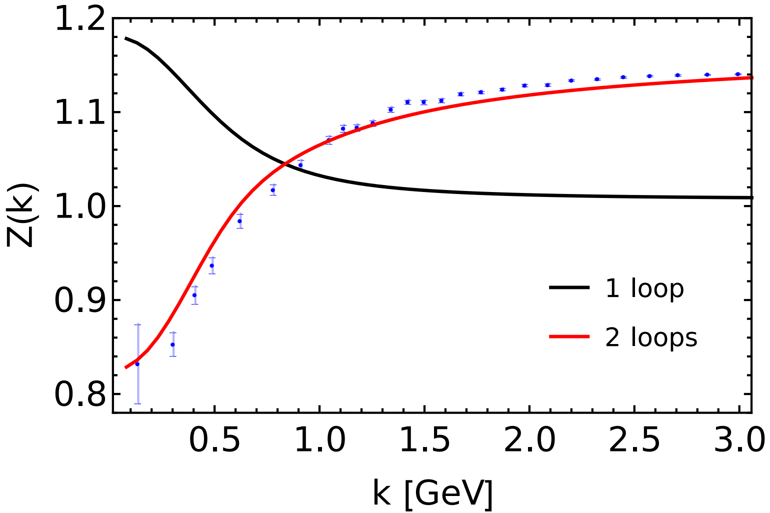
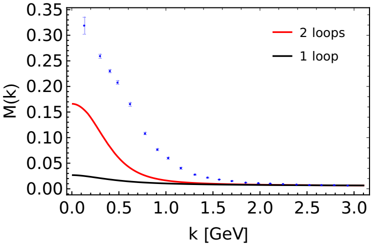
Error comparison

M_π	$\chi_{2-loop}(\%)$	$\tilde{\chi}_{2-loop}(\%)$
150	7.5	2.5
426	5.6	3.1

Results Z - M_π=150 MeV - $\tilde{\chi}$



How much mass can we generate by fixing the quark mass in the UV?



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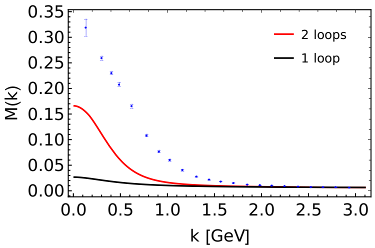

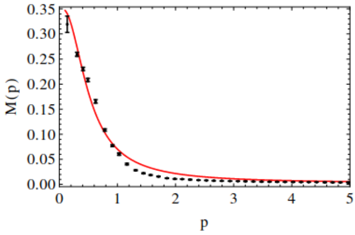

- The constituent quark mass is only reproduced to 10 % accuracy at one-loop and 50 % at two-loop.
- SBCS can be captured in the CF model via the RI expansion: expansion in powers of gauge coupling and $\frac{1}{N}$ [M. Peláez, U. Reinosa, J. Serrau, M. Tissier, N. Wschebor (2017), (2021)]

Conclusions and outlook

- Ghost-antighost-gluon is very well reproduced in SU(3) YM theory via the CF model at two-loop order.
- For SU(2) the results are not as good as SU(3), although they represent an improvement with respect to the one-loop evaluation.
- QCD F(k) and D(k) are well captured by a perturbative expansion within the CF model.
- Once two-loop contributions are included Z(k) is reproduced within a perturbative approach in the CF model with excellent agreement.
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