Two-loop ghost-gluon vertex in the Curci-Ferrari model

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Rencontres de Physique des Particules

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Outline

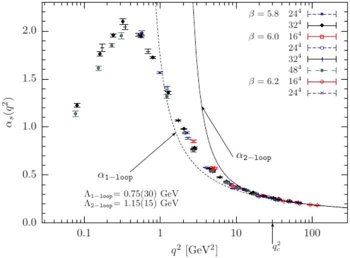
1. Motivation
2. The Curci-Ferrari model in Landau gauge
3. Two-loop ghost gluon vertex
4. Results
5. Conclusions and outlook

Motivation

Faddeev-Popov (FP) lagrangian - quenched approximation:

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

$$F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + gf^{abc} A^b_\mu A^c_\nu$$



- UV: asymptotic freedom $\Longrightarrow$ perturbation theory (PT)

[Sternbeck, Schiller, Bogolubsky (2006)]

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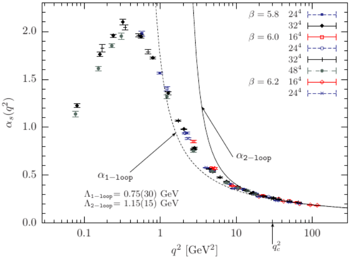

[Sternbeck, Schiller, Bogolubsky (2006)]

- UV: asymptotic freedom $\Longrightarrow$ perturbation theory (PT)
- IR: Landau pole $\Longrightarrow$ FP+~~PT~~
- Different approaches
  - Lattice simulations
  - Schwinger-Dyson equations
  - Functional renormalization group
  - Gribov-Zwanziger formalism ...

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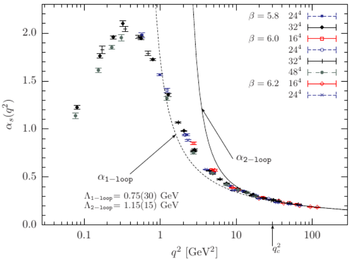

- expansion parameter: $\dfrac{\alpha}{4\pi}$
- Gribov copies

[Sternbeck, Schiller, Bogolubsky (2006)]

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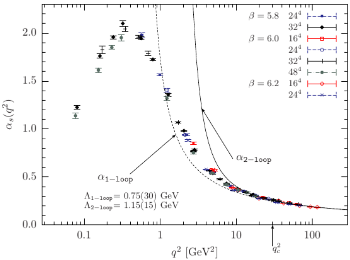
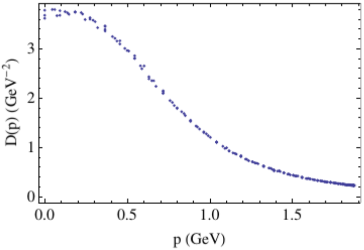


- expansion parameter: $\frac{\alpha}{4\pi}$
- Gribov copies
- Claim: Landau pole $\Longrightarrow$ ~~FP~~+PT

[Sternbeck, Schiller, Bogolubsky (2006)]

Curci-Ferrari (CF) model in Landau gauge (quenched approximation)

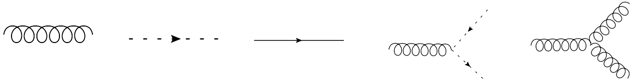
$$L = \frac{1}{4}(F^a_{\mu\nu})^2 + \partial_\mu \bar{c}^a (D_\mu c)^a + i h^a \partial_\mu A^a_\mu + \frac{m^2}{2}(A^a_\mu)^2$$



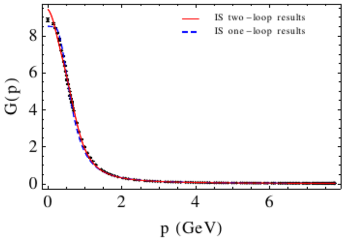
[Cucchieri, Maas, Mendes (2008)]

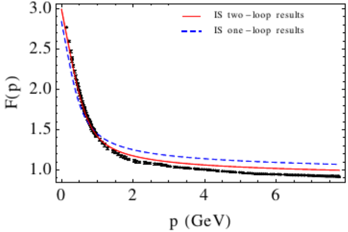
- Model 'phenomenologically' motivated: $D^{ab}_{\mu\nu}(p) = \delta^{ab} P^{\perp}_{\mu\nu}(p) \frac{1}{p^2 + m^2}$
- In the UV limit we recover standard FP action
- CF has the same symmetries than FP, except BRST

Testing the model: computing quantities with PT



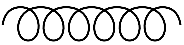
- gluonic sector $\Longrightarrow$ very good agreement with lattice data
- quark sector $\Longrightarrow$ not so well (coupling up to 3 times bigger)

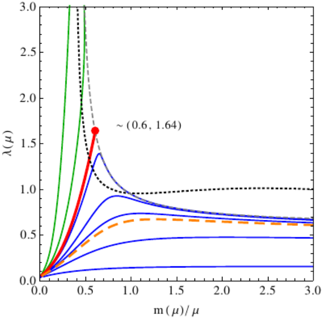




[Gracey, Peláez, Reinosa, Tissier (2019)]

Up to 2 loops...


$\Big|_{\text{2 loops}}$,  $\Big|_{\text{2 loops}} \implies m(p)$ and $g(p)$



[Gracey, Peláez, Reinosa, Tissier (2019)]

- Infrared safe:

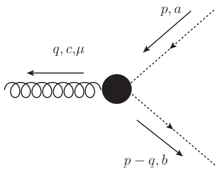
$$G^{-1}(p=\mu) = m^2 + \mu^2, \; F(p=\mu) = 1,$$
$$Z_g \sqrt{Z_A} Z_c = 1 \text{ and } Z_{m^2} Z_A Z_c = 1$$

- Vanishing momentum scheme:

$$G^{-1}(p=\mu) = m^2 + \mu^2, \; F(p=\mu) = 1,$$
$$Z_g \sqrt{Z_A} Z_c = 1 \text{ and } G(p=0) = \frac{1}{m^2}$$

In my thesis we would like to extend some of the calculations to two loops for two main reasons:

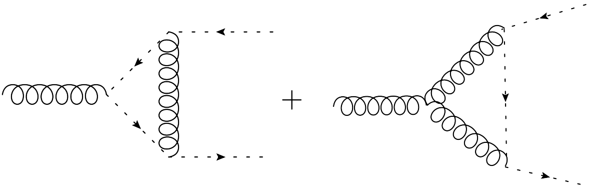
- To which extent PT converges
- Does it converge to Yang-Mills results?



We began with $\langle 0|A^a_\mu c^b \bar{c}^c|0\rangle$ to 2 loops and q=0

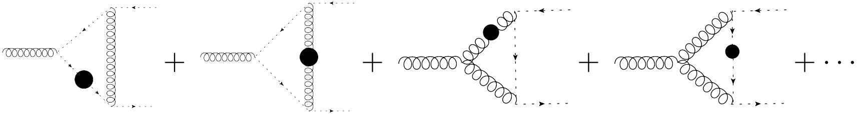
We had to compute 22 different diagrams:

1 loop diagrams

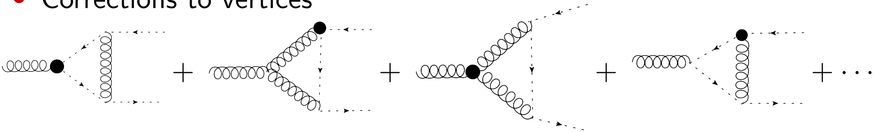


2 loops diagrams

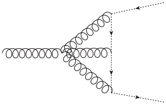
- Corrections to propagators



- Corrections to vertices



- Two-loop genuine



- Non-planar diagrams vanished thanks to the color factors

- Feynman rules + some computation

$$\int \frac{d^d q}{(2\pi)^d} \int \frac{d^d l}{(2\pi)^d} \frac{(p\cdot q)^{n_1}(p\cdot l)^{n_2}(q\cdot l)^{n_3}}{((p-q)^2+x)^{\nu_1}((p-l)^2+y)^{\nu_2}((q-l)^2+u)^{\nu_3}(q^2+v)^{\nu_4}(l^2+z)^{\nu_5}}$$

$$\downarrow$$

$$\int \frac{d^d q}{(2\pi)^d} \int \frac{d^d l}{(2\pi)^d} \frac{1}{((p-q)^2+x)^{\alpha_1}((p-l)^2+y)^{\alpha_2}((q-l)^2+u)^{\alpha_3}(q^2+v)^{\alpha_4}(l^2+z)^{\alpha_5}}$$

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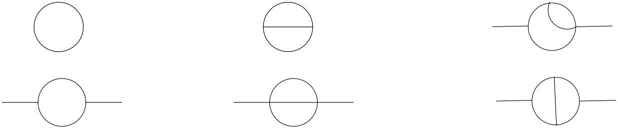
- Integration-by-parts identities (Laporta's algorithm) - FIRE implementation



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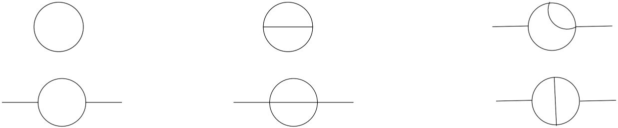
- Integration-by-parts identities (Laporta's algorithm) - FIRE implementation



- Computation of master integrals
  - dimensional regularization
  - computation of the finite parts - TSIL - and so on...

$$\Gamma_{R,\mu}\Big|_{\text{2 loops}} =$$

$$-ig_R f^{abc} p_\mu \left(\boxed{1 - Z_g^2 g_R^2 \Pi^{\text{1 loop}}(Z_m^2 m_R^2) - g^4 \Pi^{\text{2 loops}}(m^2)} \right)$$

$$\downarrow$$

$$G^{C\bar{C}A}(p,0)$$

$$\Gamma_{R,\mu}\Big|_{2\text{ loops}} =$$

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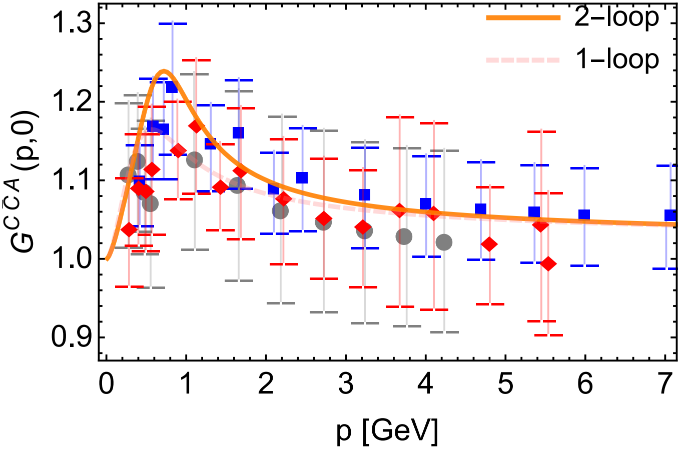
↓

$$G^{C\bar{C}A}(p,0)$$

SU(3) - Preliminary results



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

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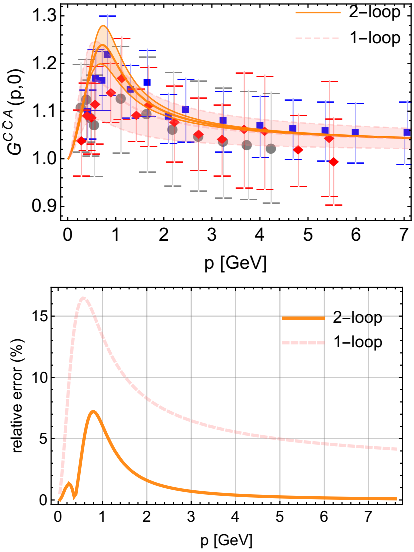
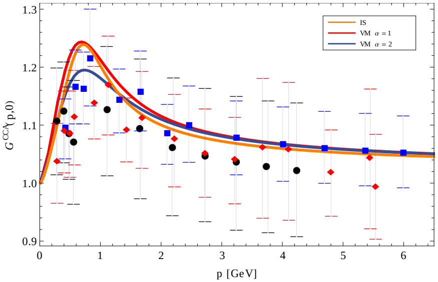


- The result is a pure prediction of the model
- Error bars of lattice do not allow us to say whether there has been an improvement respect to the one-loop result
- The expansion is consistent: the error diminishes as we go further in the series
- Checks: $m \to 0$ limit (Davydychev, Osland, Tarasov (1998)) and $p \to 0$ limit

Dependence on the renormalization scheme

Since we are performing a perturbative calculation we expect some dependency on the renormalization scheme

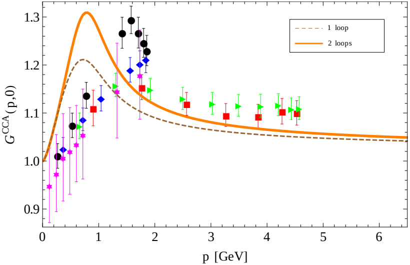
- Vanishing momentum scheme:
  - This scheme presents a Landau pole
  - To avoid this: instead of $\mu = p$, we evaluate at $\mu = \sqrt{p^2 + \alpha m_0^2}$

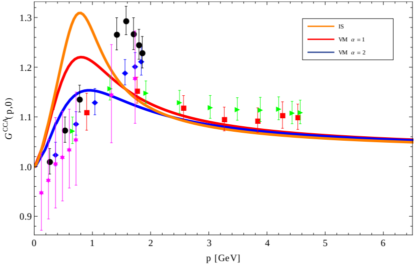


- The three schemes are in good agreement with each other

SU(2) - Preliminary results

- The coupling constant in SU(2) is roughly 30 % larger than SU(3)
- Perturbation theory becomes less powerful
- We observe a stronger dependence on the scheme





[Lattice data from Cucchieri, Maas, Mendes (2008)]

Conclusions and outlook

- We presented the preliminary results for the ghost gluon vertex (with vanishing momentum for the external gluon) in the CF model for SU(3) and SU(2)
- SU(3) shows a very good agreement with lattice data with different renormalization schemes
- SU(2) shows relatively good results only at a qualitative level
- This study is consistent with the idea of a convergent perturbative expansion, at least in the SU(3) case

Future:

- Slavnov-Taylor identity between three gluon vertex and ghost gluon vertex
- Inclusion of quarks

Thank you for your attention!