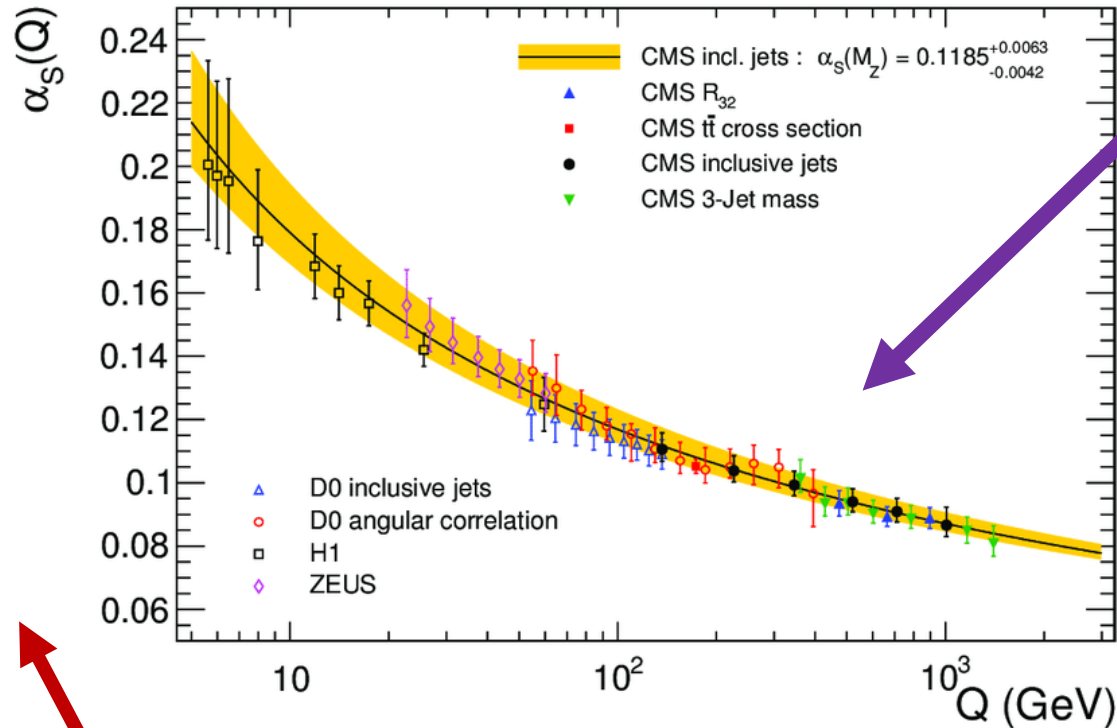


A perturbative window on the infrared regime of QCD

Julien Serreau

AstroParticule et Cosmologie,
Université de Paris

The ultraviolet Dr. Jeckyll and the infrared Mr. Hyde



Infrared physics

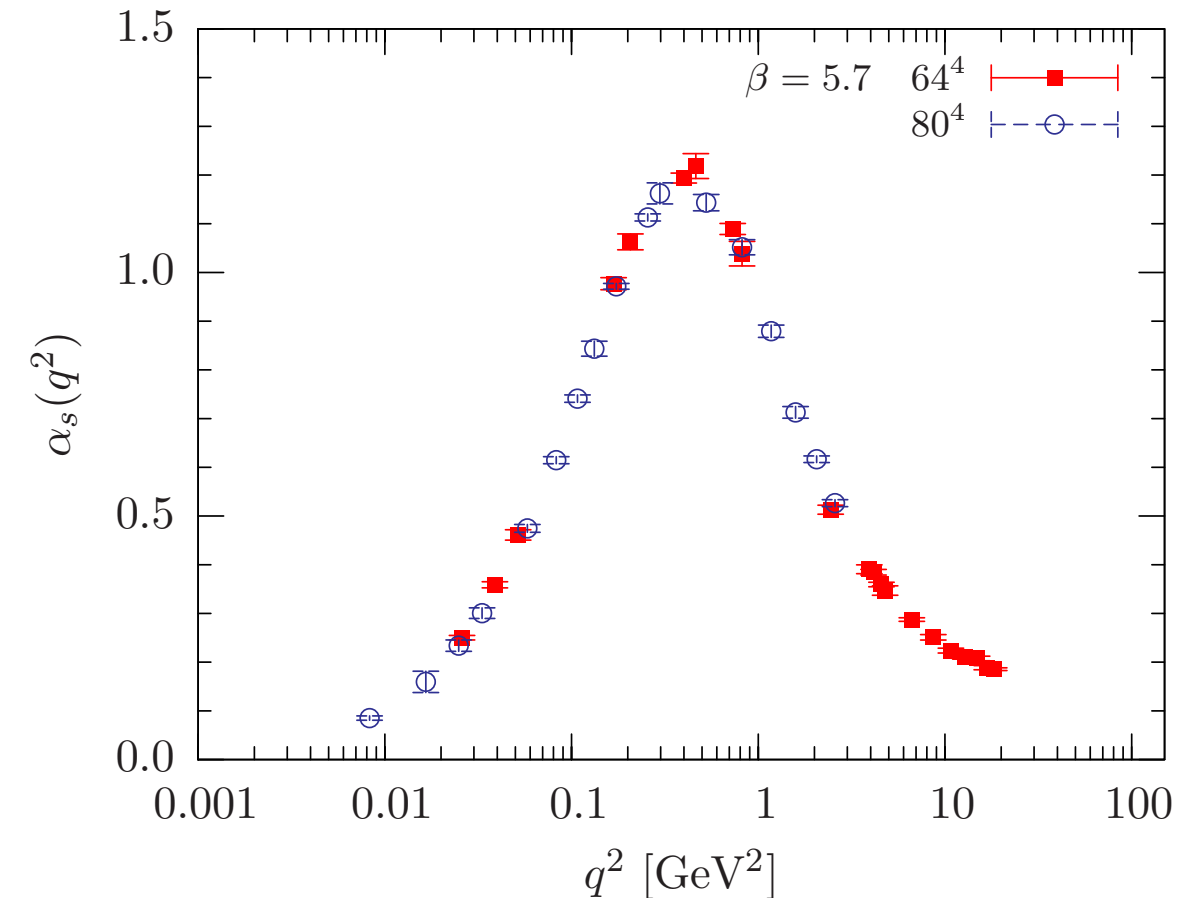
- Confinement
- Chiral symmetry breaking
- ...

Asymptotic freedom: the theory is weakly coupled in the UV

- perturbation theory (Faddeev-Popov)
- « predicts » its own failure (Landau pole) at low energies

Nonperturbative phenomena...

A perturbative coupling in the Landau gauge



Lattice calculation of the strong coupling in the Taylor scheme in the SU(3) Yang-Mills theory
[Bogolubsky et al., *Phys. Lett. B* 676 (2009) 69]

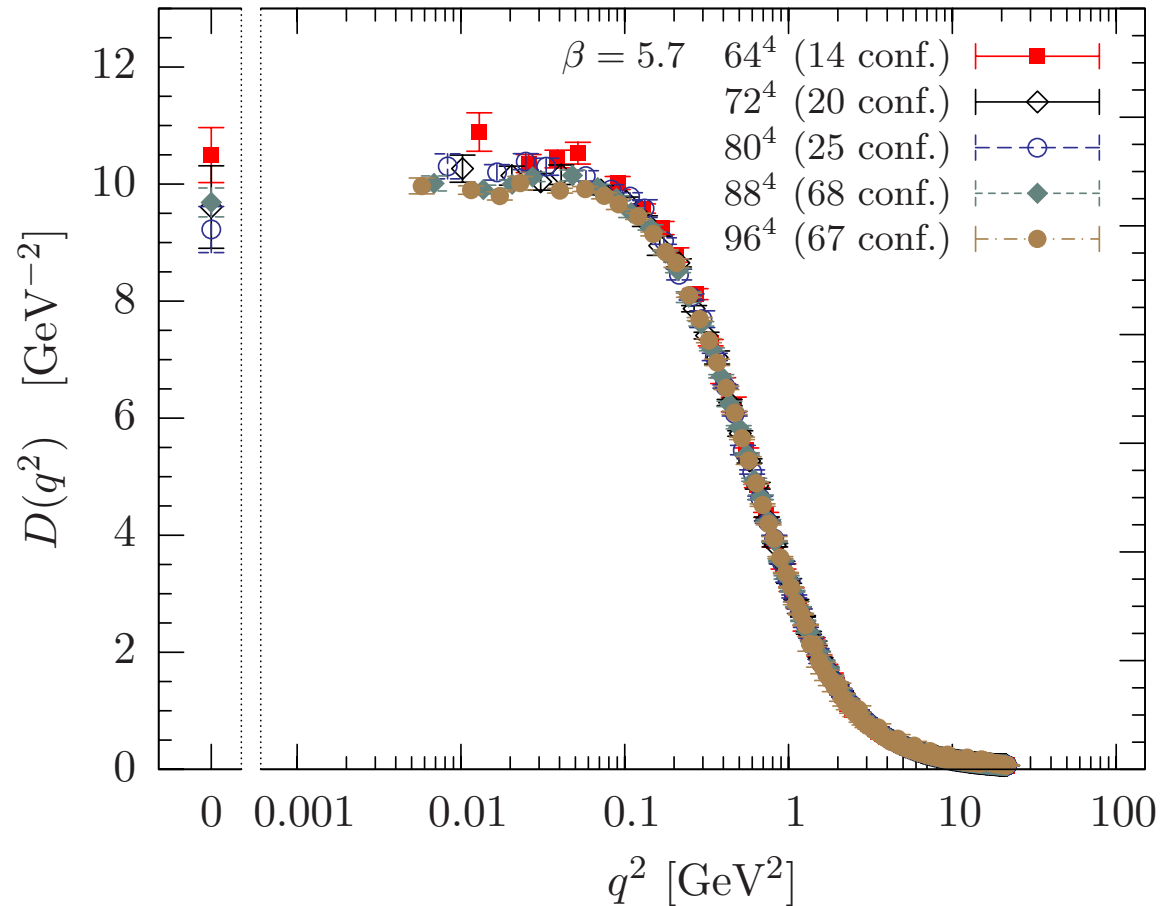
● The Landau pole is spurious !

● $\lambda = \frac{\alpha_S N_c}{4\pi} \lesssim 0.3$

➔ A perturbative description should be possible

➔ Incompatible with the Faddeev-Popov approach

A gluon (screening) mass in the Landau gauge

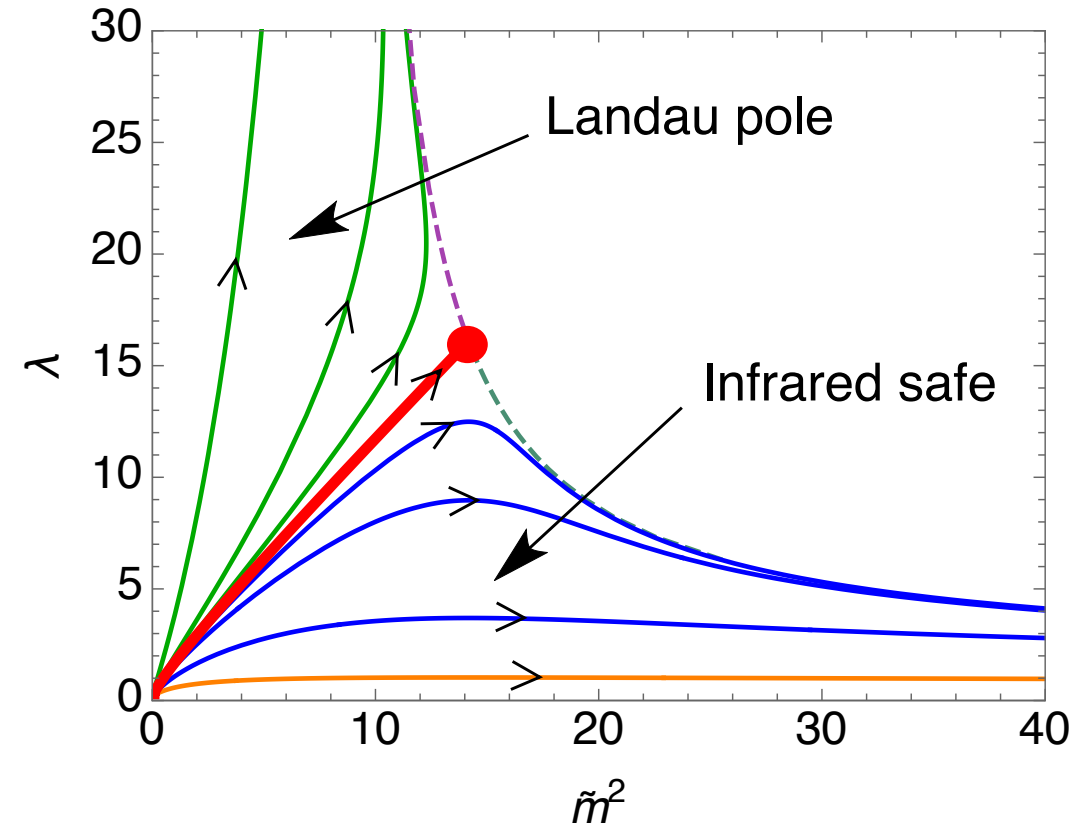


Lattice calculation of the Euclidean gluon propagator in the SU(3) Yang-Mills theory [Bogolubsky et al., *Phys. Lett. B* 676 (2009) 69].

An effective mass term in the infrared?

A modified gauge-fixed Lagrangian: The Curci-Ferrari model

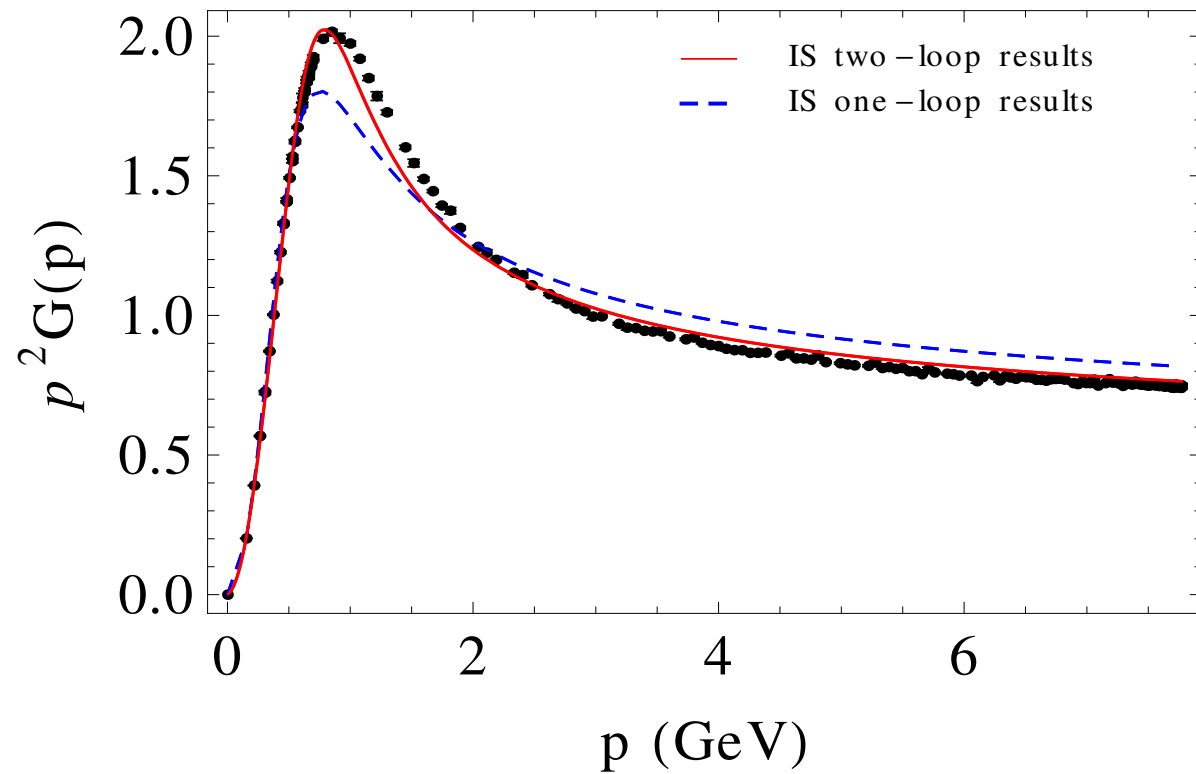
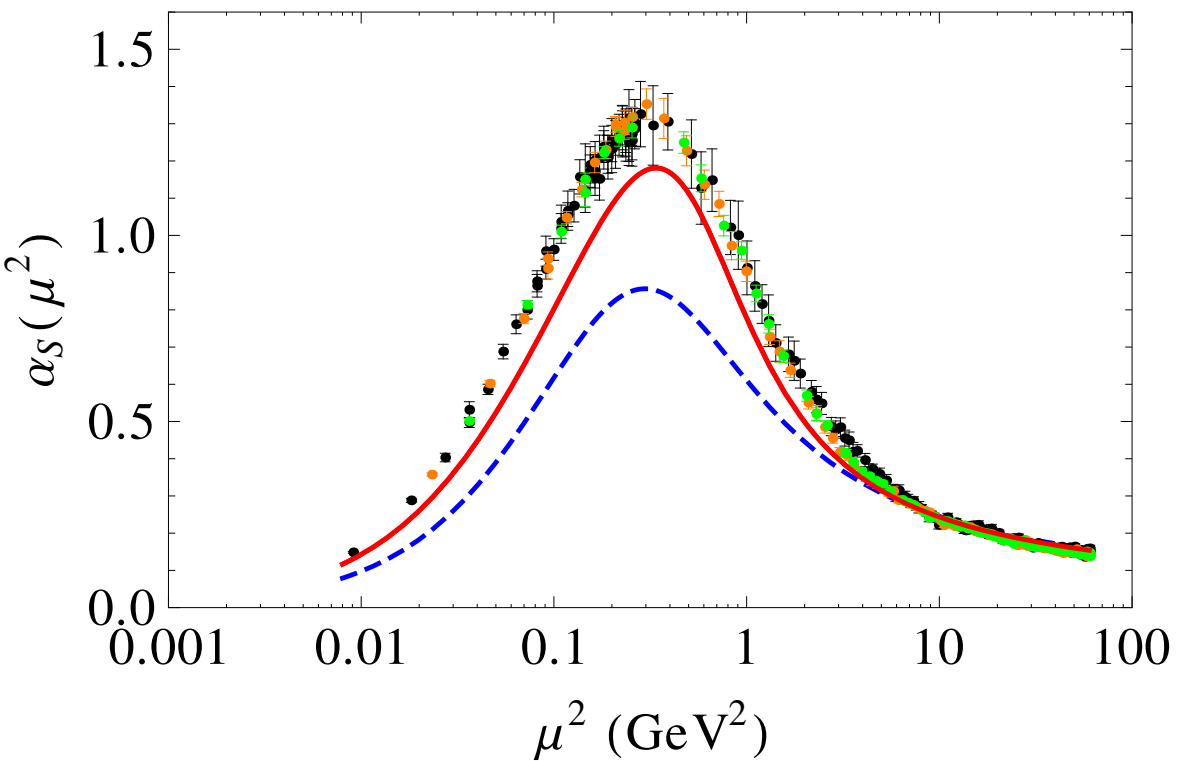
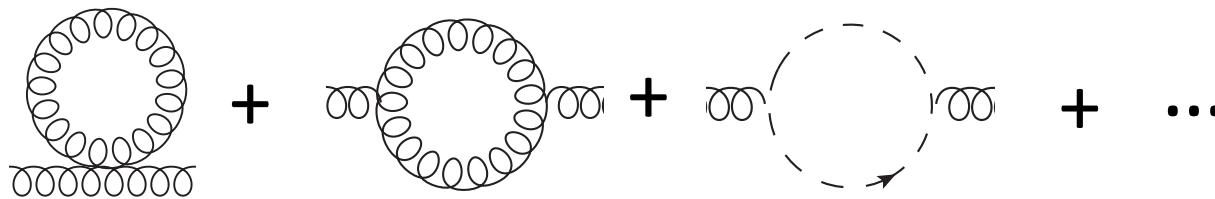
$$\mathcal{L} = \frac{1}{4}(F_{\mu\nu}^a)^2 + \partial_\mu \bar{c}^a (D_\mu c)^a + ih^a \partial_\mu A_\mu^a + \frac{m^2}{2}(A_\mu^a)^2$$



- A simple extension of the **Faddeev-Popov Lagrangian**
- Preserves the UV properties of the theory (including renormalisability).
- The **Curci-Ferrari mass** screens the infrared divergences responsible for the (spurious) Landau pole of the Faddeev-Popov perturbation theory.

[Tissier, Wschebor, *Phys. Rev. D*84 (2011) 045018]

Perturbative results for Yang-Mills theories



Perturbative results in the Curci-Ferrari model against lattice data for the SU(3) theory in d=4 [Gracey et al., *Phys. Rev. D* 100 (2019) 034023]

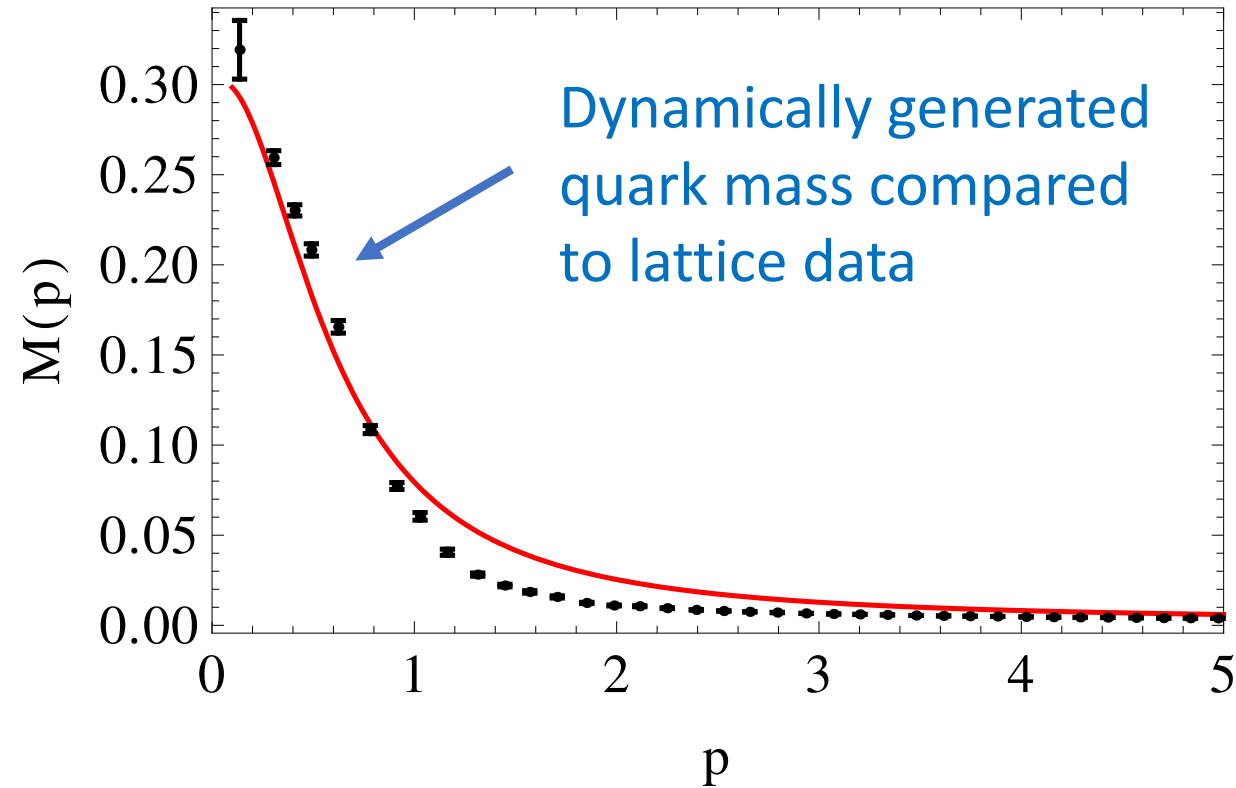
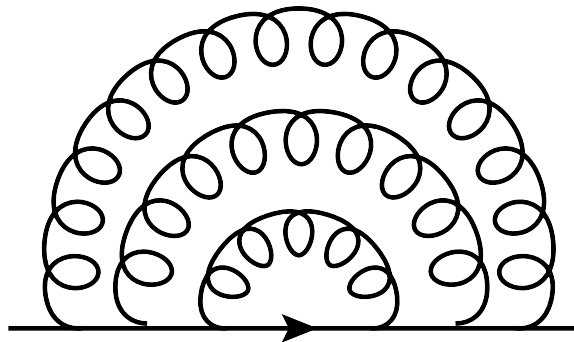
Dynamical quarks and spontaneous breaking of the chiral symmetry

Lattice results show that the quark sector is **strongly coupled** in the infrared

● perturbative coupling in the pure gauge sector

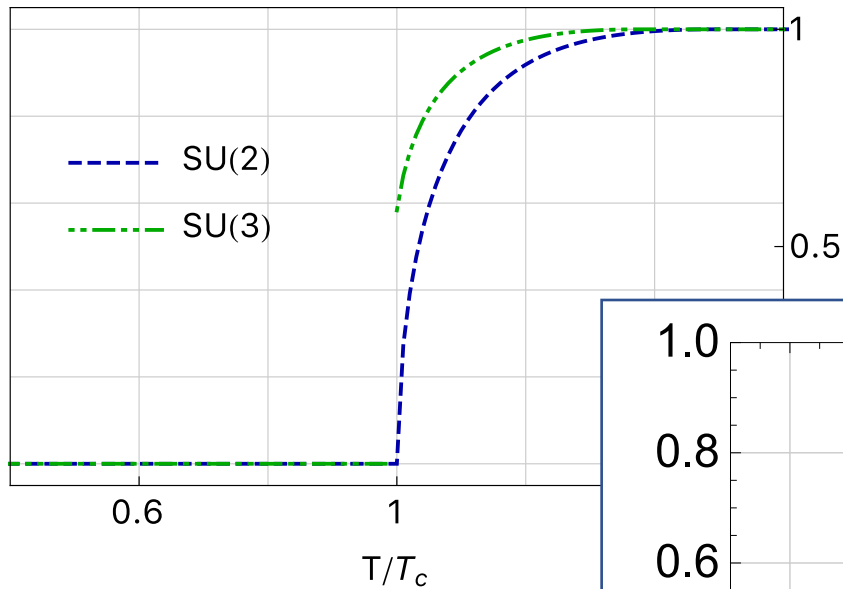
● expansion in $1/N_c$

➡ Controlled resummation of rainbow diagrams for the quark propagator



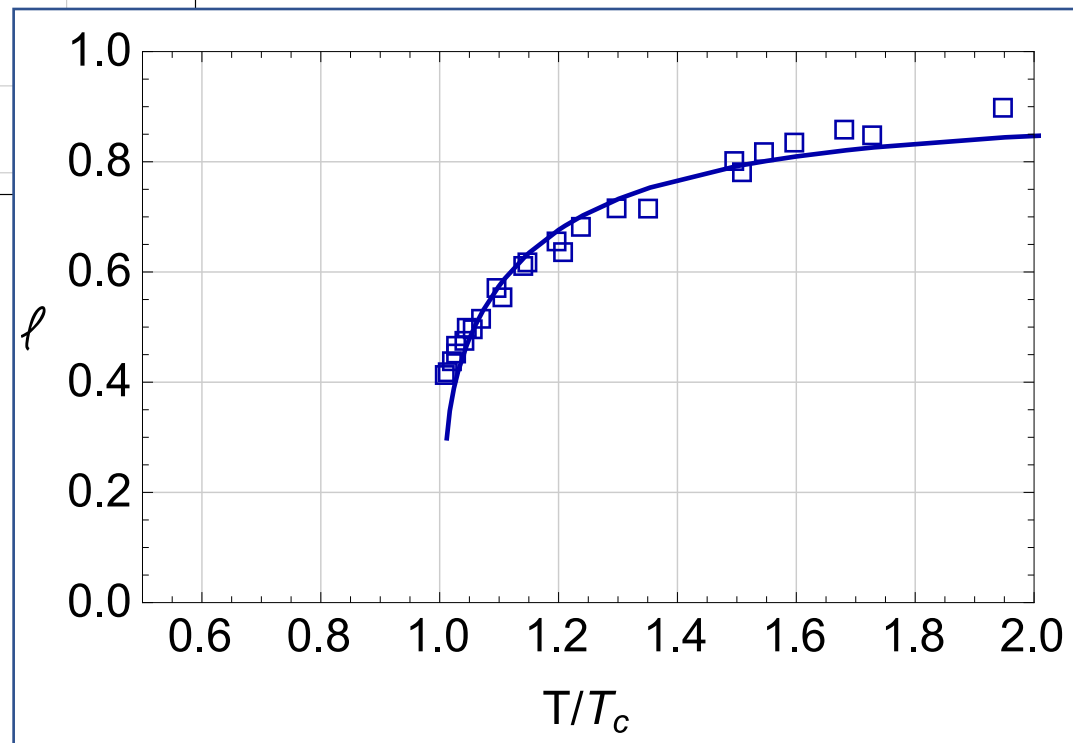
[Peláez et al., *Phys. Rev. D*, 103 (2021) 094035]

The confinement-deconfinement transition at nonzero temperature and density

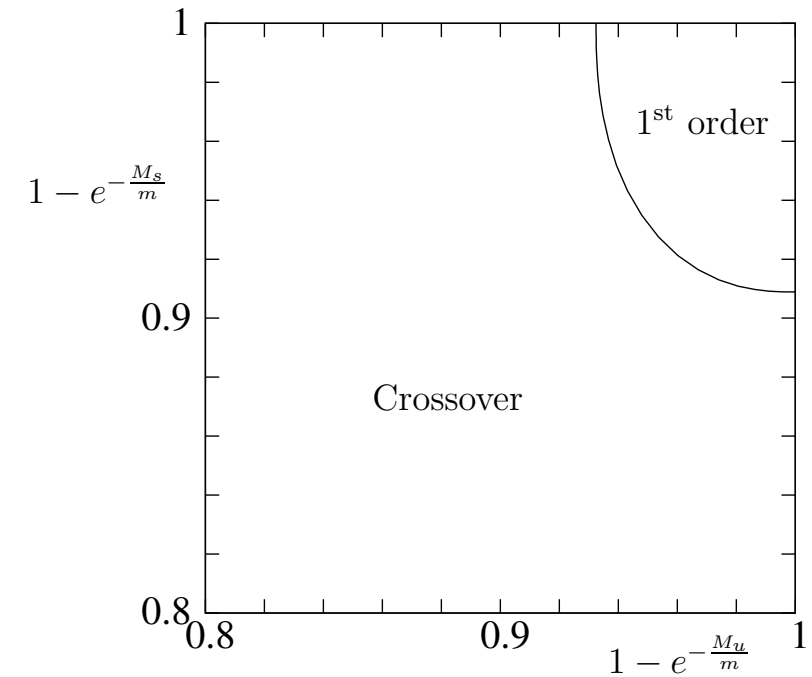


[Reinosa et al.,
Phys. Lett. B 742 (2015) 61]

- Confined phase at low temperature
- Phase transition at high temperature
- Quantitative agreement with lattice data



[Van Edmond et al., 2104.08974 [hep-ph]]



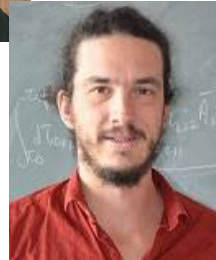
[Reinosa et al.,
Phys. Rev. D 92(2015) 025021]

The Montevideo-Paris-(Liverpool) collaboration

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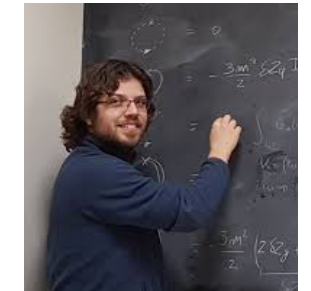
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Duifje Maria van Egmond
(postdoc)



Daniel Kroff
(former postdoc)

Scientific production (period 2010 – 2021)

- 25 publications (*Phys. Lett. B, Phys. Rev. D, SciPost*)
- ~ 75 contributions at national and international conferences

Scientific Events

International workshop *Infrared QCD*


APC, Nov. 2017


About 30 participants during 3 days

Funds from the FRIF and the CNRS PICS
irQCD



Infrared QCD Workshop
November 8-10, 2017
APC, Paris Diderot University
Paris - France

Invited speakers
Reinhard Alkofer - Graz University
David Dudal - Leuven University
Markus Huber - Graz University
Jean-Loïc Kneur - Montpellier University
Mario Mitter - Brookhaven National Laboratory
Orlando Oliveira - Coimbra University
Jan Pawłowski - Heidelberg University
Marcela Peláez - Montevideo University
Hugo Reinhardt - Tübingen University
Urko Reinosa - Ecole Polytechnique Palaiseau
José Rodríguez-Quintero - Huelva University
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Matthieu Tissier - Pierre & Marie Curie University



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Nicolás Wschebor

<https://indico.in2p3.fr/e/infraredqcd>



Grants

- LIA : Laboratoire International Associé *Institut Franco-Uruguayen de Physique* (directeur France : M. Tissier) (2019-2024)
- ECOS programs (2011-2014) (2018-2021)
- PICS *irQCD* (2017-2020)
- Program *InPhyNiTi* from CNRS (2015)
- PEPS from the CNRS program *Physique théorique et interfaces* (2014)
- Invited professorships from Université de Paris, École Polytechnique Palaiseau, Sorbonne Université, and from Universidad de la República

Prospects

- Origin of the Curci-Ferrari mass term in the Landau gauge in relation with the issue of Gribov copies
- Area law for the Wilson loop and confinement
- Calculation of hadronic observables and experimental measurement of the (Landau gauge) gluon mass (cf. quark masses)
- Controlled study of the QCD phase diagram in the (T, μ) plane and the critical endpoint