Emergence of a gluon mass

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Perceiving the Emergence of Hadron Mass through

AMBER@CERN

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Perceiving the Emergence of Hadron Mass through AMBER@CERN (II)

Emergence : *low-level rules producing high-level phenomena with enormous apparent complexity*

Start from the QCD Lagrangian :

$$\mathcal{L}_{QCD} = -\frac{1}{4}G^{\mu\nu}_a G^a_{\mu\nu} + \frac{1}{2\xi}(\partial^\mu A^a_\mu)^2 + \partial^\mu \bar{c}^a \partial_\mu c^a + g f^{abc}(\partial^\mu \bar{c}^a) A^b_\mu c^c$$

+ Quarks

SDE, lattice, BSE …

and obtain

Dynamical generation of a fundamental mass scale in pure Yang-Mills (gluon mass)

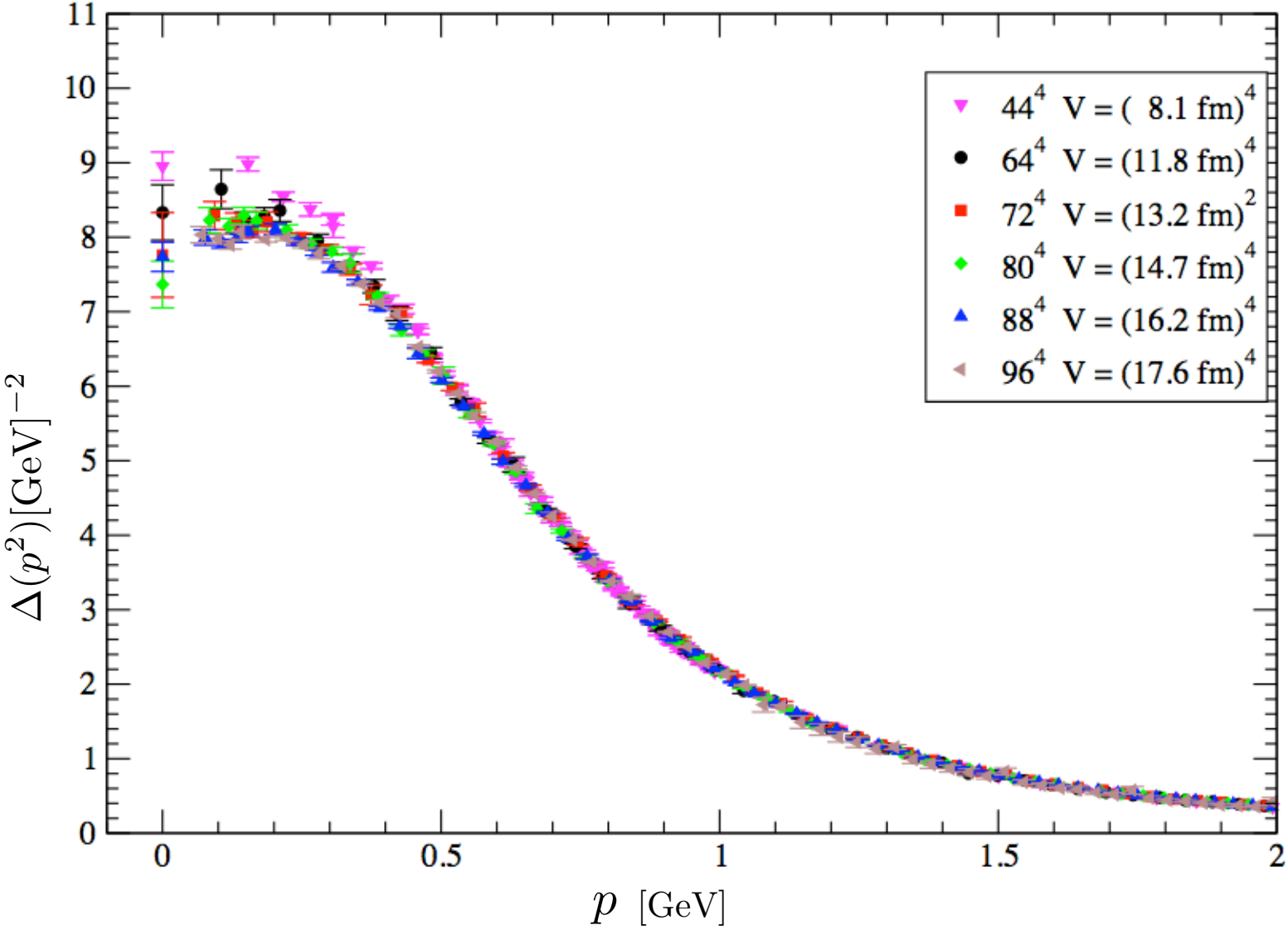
Quark constituent masses and chiral symmetry breaking

Bound state formation: mesons, hadrons, glueballs, hybrids, exotics …

Signals of Confinement

Large volume lattice simulations

The gluon propagator saturates in the deep infrared



I. Bogolubsky, E. Ilgenfritz, M. Muller-Preussker, and A. Sternbeck, Phys. Lett. B676, 69 (2009).

Emergent mass in the gauge sector

J. M. Cornwall, Phys. Rev. D26, 1453 (1982)

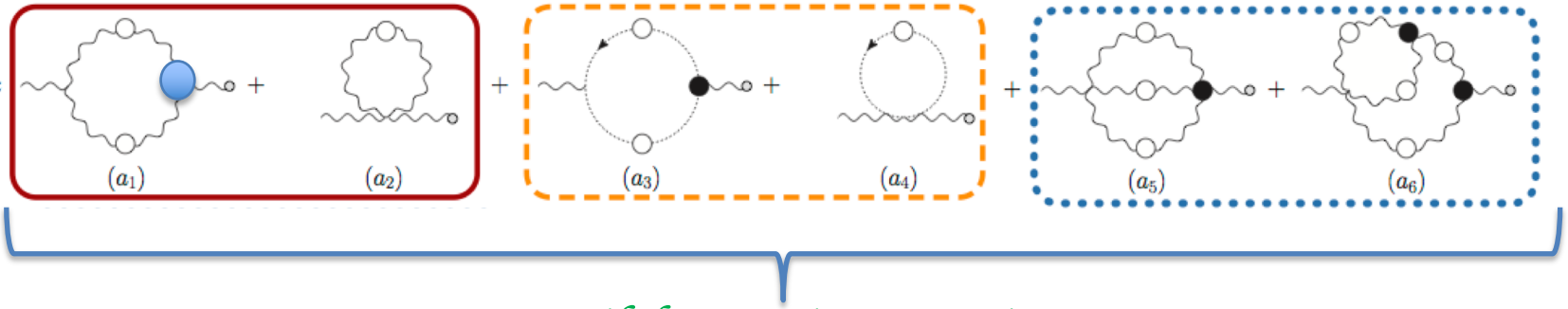
A.C. Aguilar, D. Binosi, J.P. (various works)

- Saturation of $\Delta(0)$ $\longleftrightarrow$ unequivocal signal of gluon mass generation
- A dynamical and nonperturbative mechanism is needed to accomplish this
- A mass term $m^2 A^2$ in the YM Lagrangian is forbidden by gauge invariance
- No quadratic divergences are allowed !
- All symmetries must be explicitly preserved.
  In particular, no violation of the STIs !

Schwinger-Dyson eqs. in the PT-BFM scheme

Pinch Technique

Background Field Method

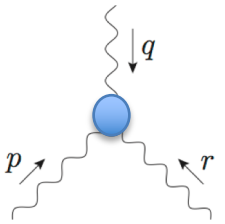
$\widetilde{\Pi}_{\mu\nu}(q) =$ 

Beautiful truncation properties !

Symmetries manifest: all sorts of "alarms" go off if one tries "forbidden" things

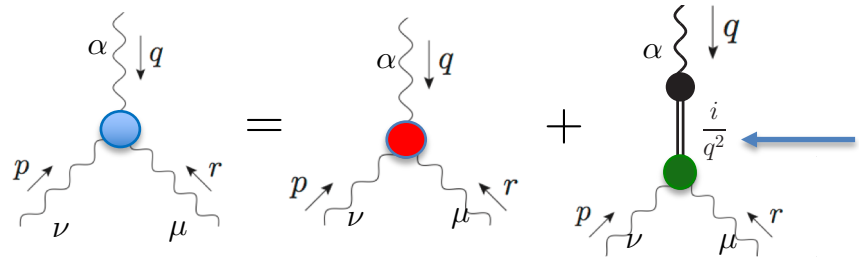
Crucial dynamical ingredient:

Existence of "massive" solution requires the presence of massless poles inside the three-gluon vertex



$I\!\Gamma_{\alpha\mu\nu}(q,r,p)$

Schwinger mechanism in Yang-Mills theories



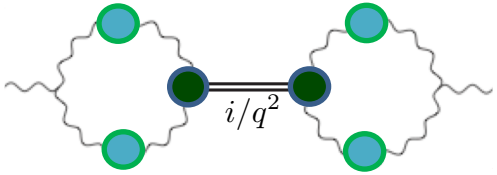
$\mathbb{\Gamma}_{\alpha\mu\nu}(q,r,p)$ $\quad \Gamma^{\mathbf{np}}_{\alpha\mu\nu}(q,r,p)$ $\quad \Gamma^{\mathbf{P}}_{\alpha\mu\nu}(q,r,p)$

Dynamically generated massless & colored excitations

A.C.Aguilar, D. Ibanez, V. Mathieu, and J. P., Phys. Rev. D 85, 014018 (2012)

$\Gamma^{\mathbf{P}}_{\alpha\mu\nu}(q,r,p)$

Triggers the "Schwinger mechanism"



J.S. Schwinger , Phys. Rev.125, 397 (1962); Phys.Rev.128, 2425 (1962)

Makes possible $\Delta^{-1}(0) \neq 0$

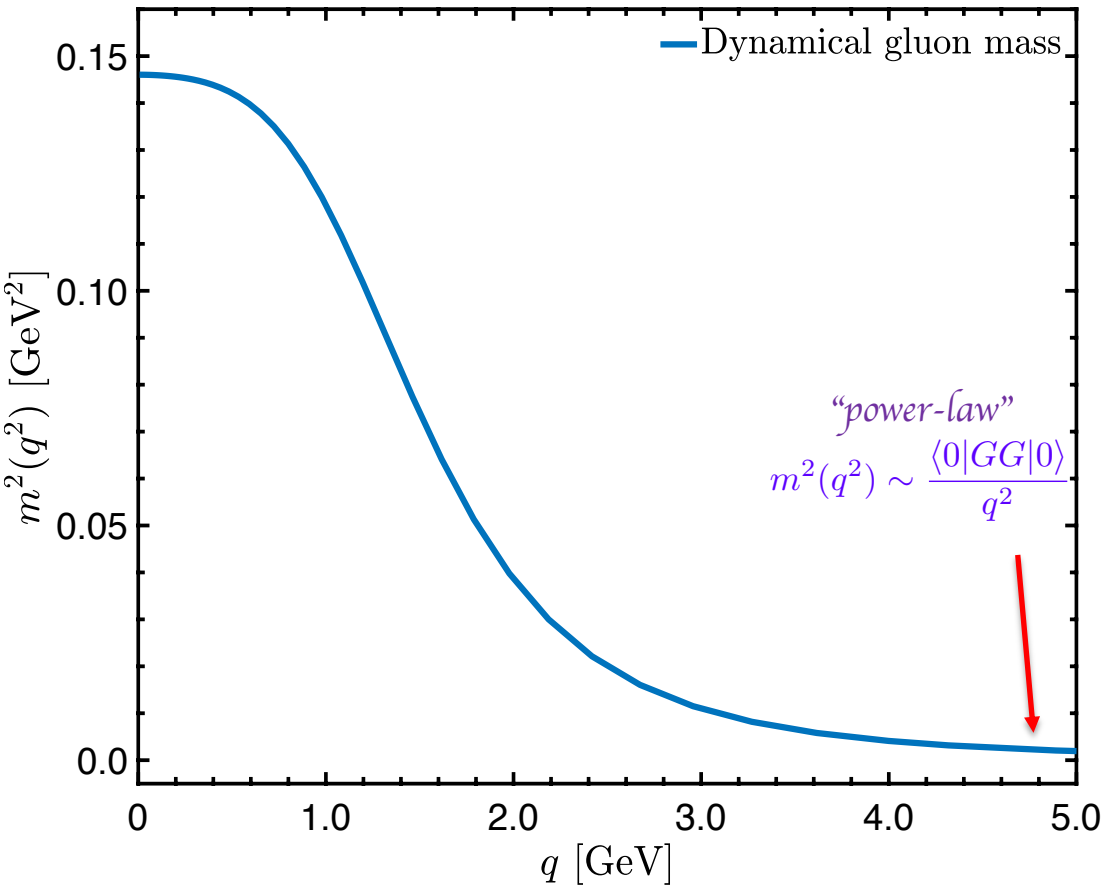
$$P_{\alpha\alpha'}(q)P_{\mu\mu'}(r)P_{\nu\nu'}(p)\,\Gamma^{\mathbf{P}}_{\alpha\mu\nu}(q,r,p) = 0$$

" Longitudinally coupled "

Drops out from "lattice observables" and transversely projected Green's functions

Natural parametrization

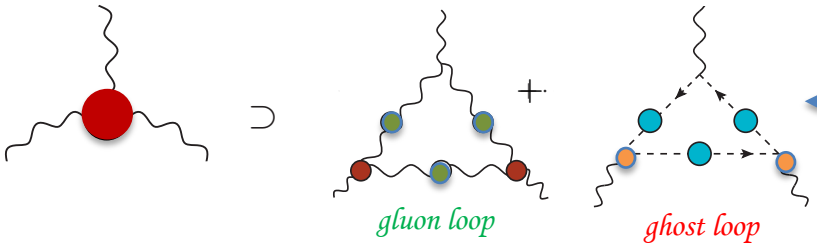
$$\Delta^{-1}(q) = \underbrace{q^2 J(q)}_{\text{kinetic term}} + \underbrace{m^2(q)}_{\text{running mass}}$$



$m(0) \sim 375\,\mathrm{MeV}$ (*Landau gauge*)

Infrared suppression of the three-gluon vertex: intriguing nonperturbative feature

A.C.Aguilar, D.Binosi, D.Ibañez, J.P., Phys. Rev. D 89, no. 8, 085008 (2014)



massless ghost propagators

log-divergences in the infrared

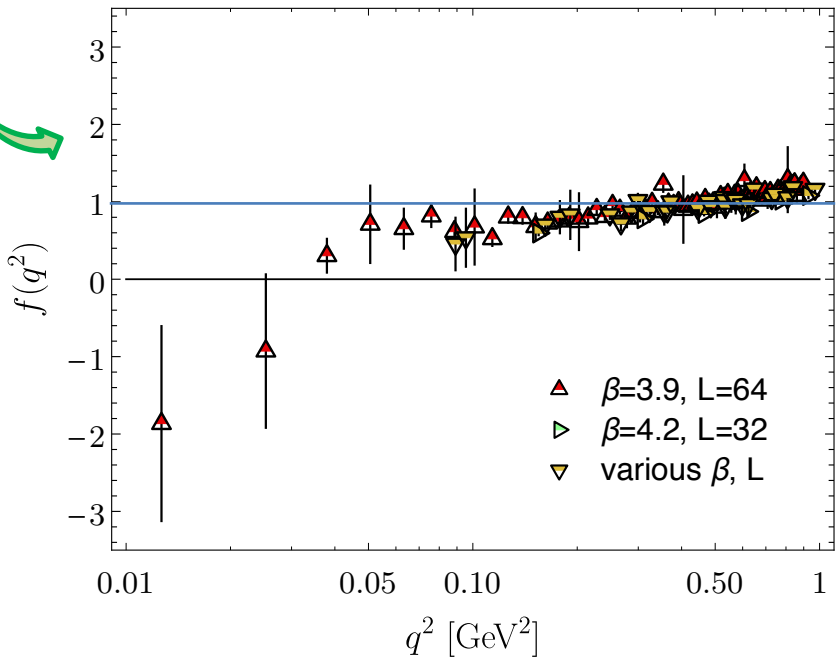
$$\Gamma^{\mathbf{np}}_{\alpha\mu\nu} = f(q,r,p)\,\Gamma^{(0)}_{\alpha\mu\nu}$$

symmetric point: $q^2 = p^2 = r^2$

$$f(q^2) = a\left[1 + b\ln\frac{q^2+m^2}{\mu^2} + c\ln\frac{q^2}{\mu^2}\right]$$

"protected" "unprotected"

$$f(0) \to -\infty$$



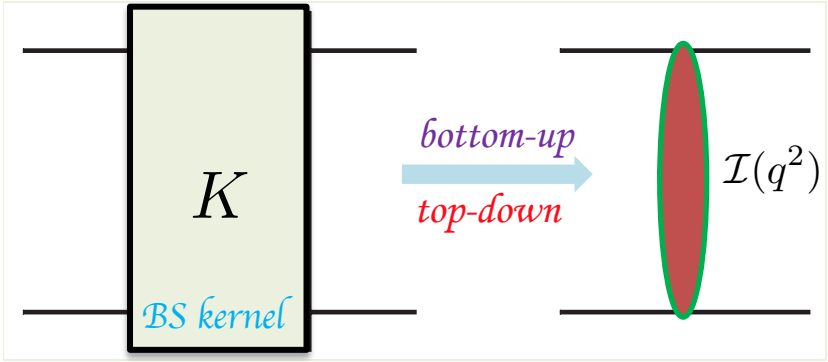
- Dramatic confirmation that all pieces fit together and are tightly interlocked !
- Phenomenological implication for bound state formation (glueballs, hybrids, EIC physics, etc)

E.~V.~Souza et al, Eur. Phys. J. A 56, no.1, 25 (2020)
S.S.Xu et al, Eur. Phys. J. A 55, no.7, 113 (2019)

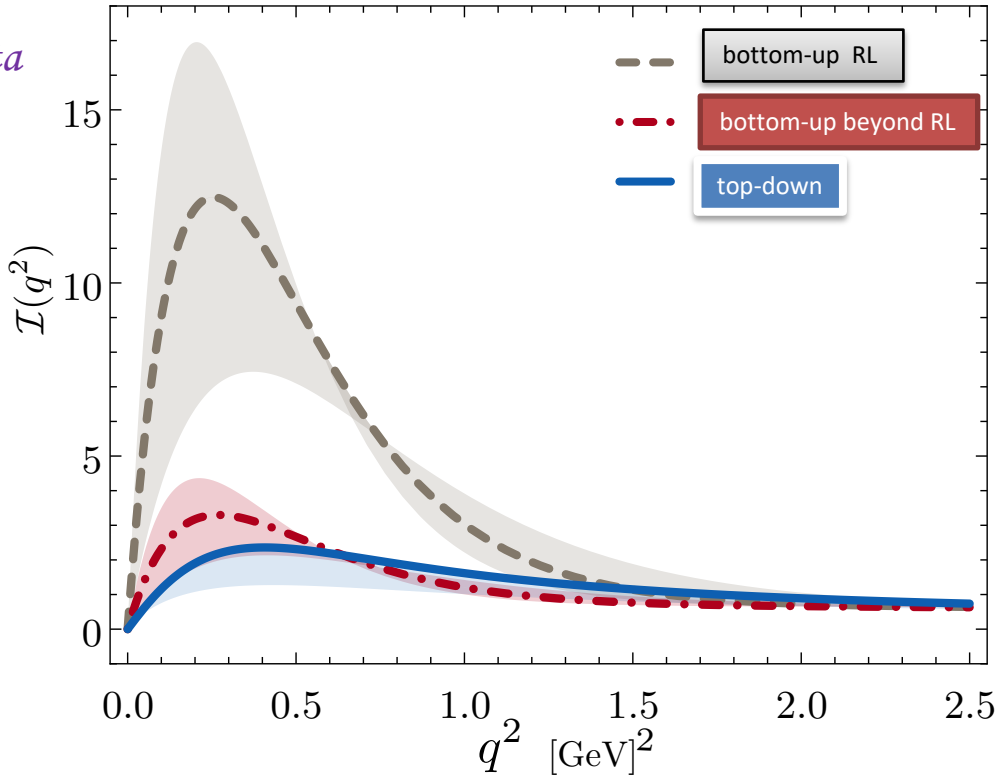
A.Athenodorou et al, Phys. Lett. B761, 444 (2016)
A.G.Duarte, O.Oliveira, and P.J.Silva, Phys. Rev. D 94 (2016) no.7, 074502
A.C.Aguilar et al, Eur. Phys. J. C 80, no.2, 154 (2020)

Bridging a gap between continuum QCD and abinitio predictions of hadron observables

D. Binosi, L. Chang, J.P. and C.D. Roberts, Phys. Lett. B742, 183 (2015)



- *bottom-up scheme: infer interaction by fitting data within a well-defined truncation of the matter sector SDEs that are relevant to bound state properties.*
- *top down approach: ab initio computation of the interaction via direct analysis of the gauge sector gap equations*
- *Significant step toward parameter-free predictions of hadron properties*



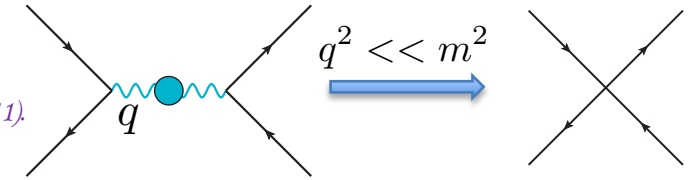
Conclusions

- The gluon self-interactions generate a dynamical mass scale in the gauge sector of QCD

- Important theoretical and phenomenological implications

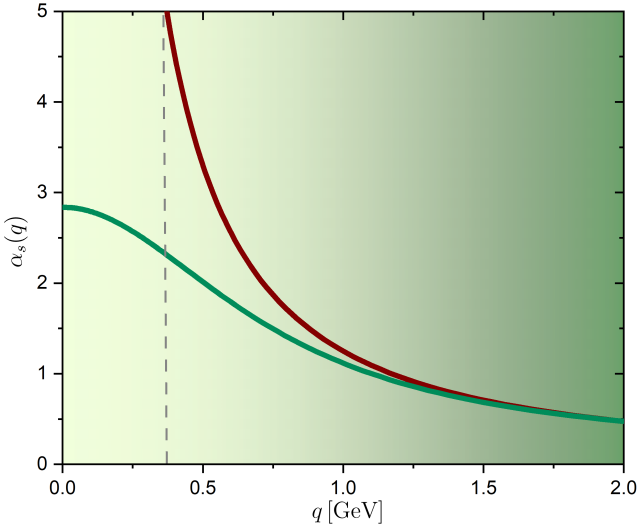
- "Contact interactions" from first principles

  S.-X. Qin, L. Chang, Y.-X. Liu, C. D. Roberts and D. J. Wilson, Phys. Rev. C 84, 042202 (2011).



- Tames the Landau pole; allows for the QCD generalization of the process-independent Gell-Mann – Low effective charge

D.Binosi, C.Mezrag, J.P., C.D.Roberts, and J.Rodriguez-Quintero, Phys. Rev. D 96, no.5, 054026 (2017)



- The dynamical generation of a running gluon mass may alone be sufficient to remove the Gribov ambiguity.

F.Gao, S.X.Qin, C.D.Roberts, and J.Rodriguez-Quintero, Phys. Rev. D 97, no.3, 034010 (2018)