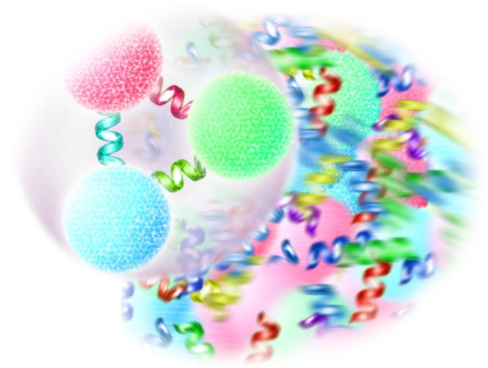
Hadron Phenomenology from First-Principle QCD Studies



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

Phys.Rev. D93 (2016) no.9, 096010 D. Binosi, L. Chang, J.P., S.X. Qin, and C. D. Roberts

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University of Valencia-CSIC

Workshop on

Bound states in strongly coupled systems

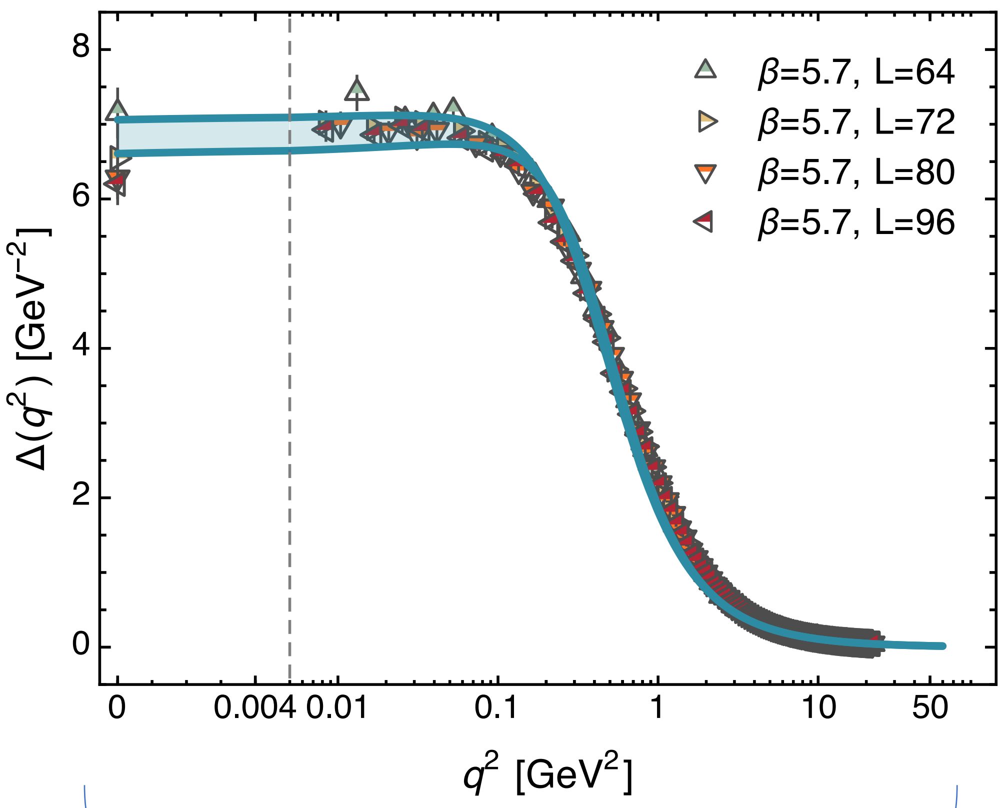
Mar, 12 2018 to Mar, 16 2018

The Galileo Galilei Institute For Theoretical Physics

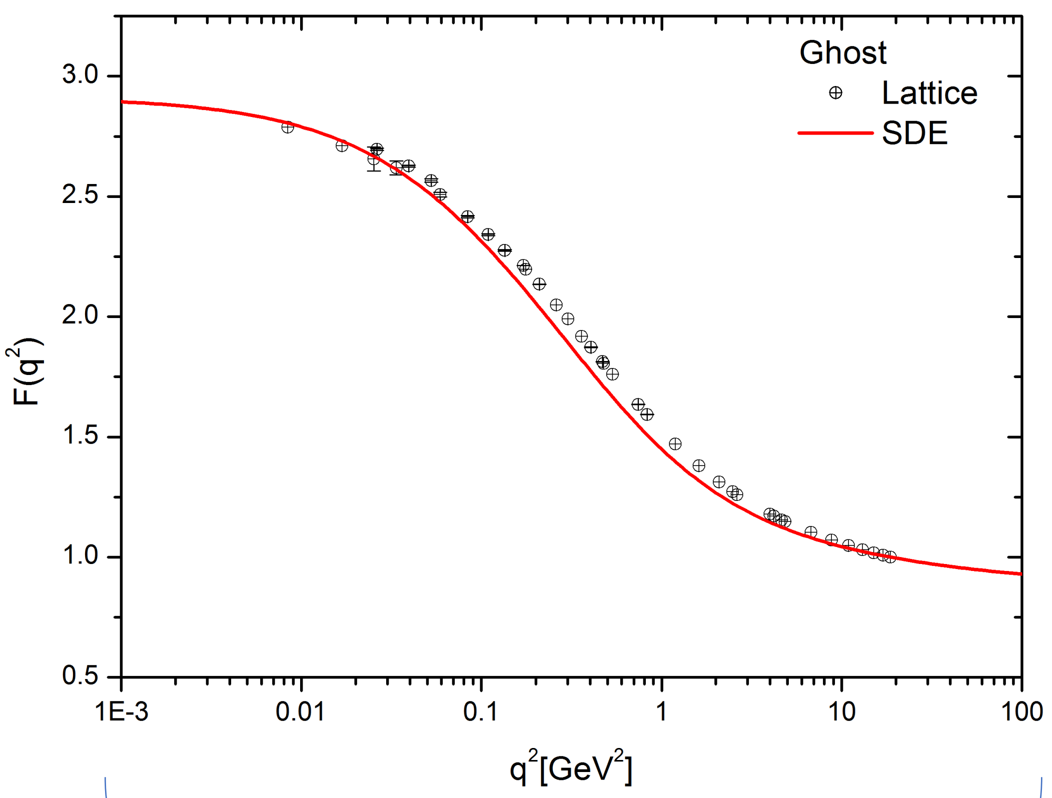
Centro Nazionale di Studi Avanzati dell'Istituto Nazionale di Fisica Nucleare

Arcetri, Firenze

Large-volume lattice simulations



Gluon propagator



Ghost dressing function

$$D(q^2) = \frac{F(q^2)}{q^2}$$

A. Cucchieri and T. Mendes, PoS LAT2007, 297 (2007), 0710.0412

P. O. Bowman et al., Phys. Rev. D76, 094505 (2007).

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

O. Oliveira and P. Silva, PoS LAT2009, 226 (2009).

Numerous studies within various theoretical frameworks

A. C. Aguilar, D. Binosi, and J. Papavassiliou, Phys. Rev. D78, 025010 (2008).

P. Boucaud et al., JHEP 06, 099 (2008), 0803.2161

D. Dudal, J. A. Gracey, S. P. Sorella, N. Vandersickel, and H. Verschelde, Phys. Rev. D78, 065047 (2008).

C. S. Fischer, A. Maas, and J. M. Pawlowski, Annals Phys. 324, 2408 (2009).

J. Serreau and M. Tissier, Phys. Lett. B712, 97 (2012).

J. Meyers and E.S. Swanson, Phys. Rev. D 90, no. 4, 045037 (2014).

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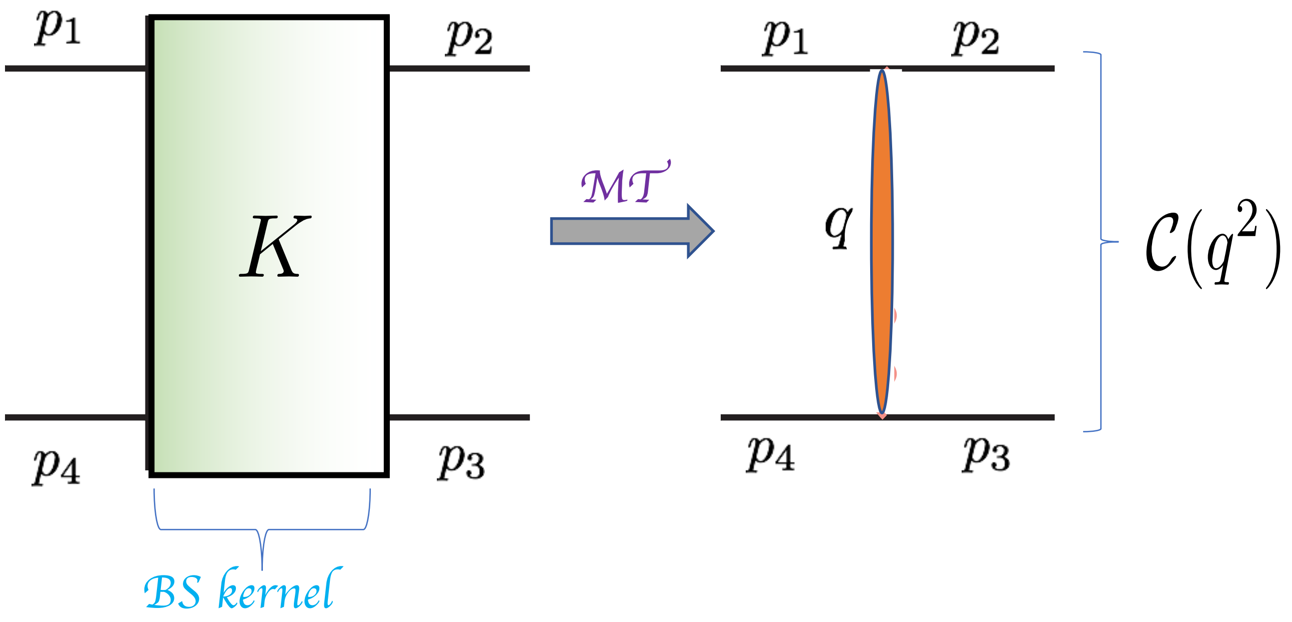
Many more ...

It is timely to use these building blocks in hadron phenomenology

"First-principle" derivation of the Maris-Tandy interaction

P. Maris and P.C. Tandy, Phys. Rev. C 60, 055214 (1999).

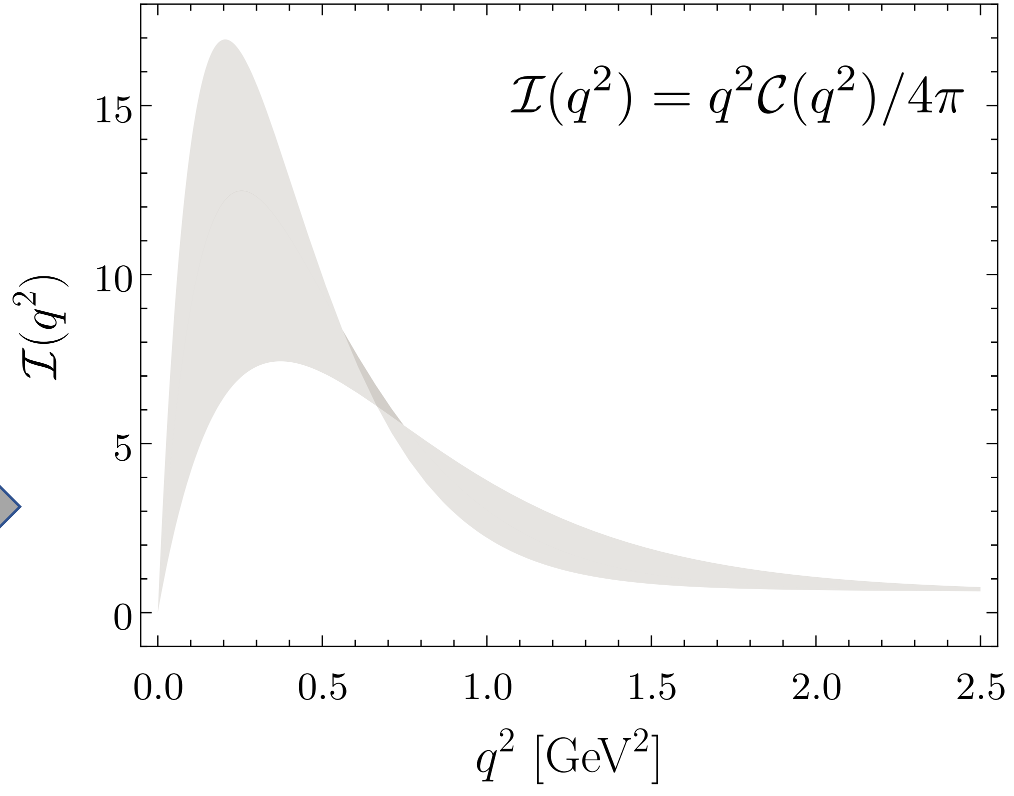
Maris-Tandy interaction



Phenomenological Ansatz

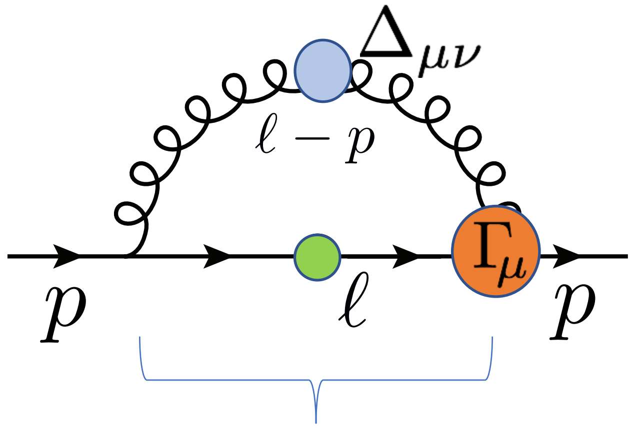
$$\mathcal{C}(q^2) = \underbrace{\frac{8\pi^2}{\omega^4} D e^{-q^2/\omega^2}}_{\text{IR}} + \underbrace{\frac{f(q^2)}{\ln[\tau + (1 + q^2/\Lambda_{QCD}^2)^2]}}_{\text{UV}}$$

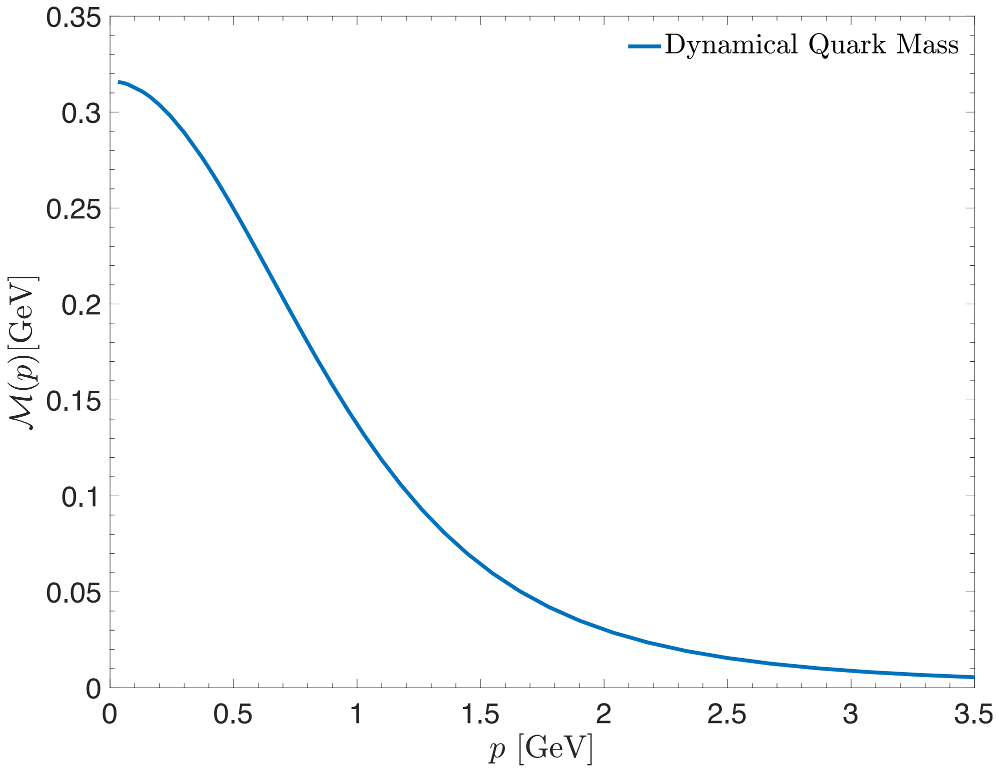
$$D\omega = (0.87)^3\ \mathrm{GeV}^3$$



Quark gap equation : dynamical equation for the quark propagator $S(\not{p})$

$$S^{-1}(\not{p}) = \not{p} + m_0 + \underbrace{i\Sigma(\not{p})}_{\textit{self-energy}}$$

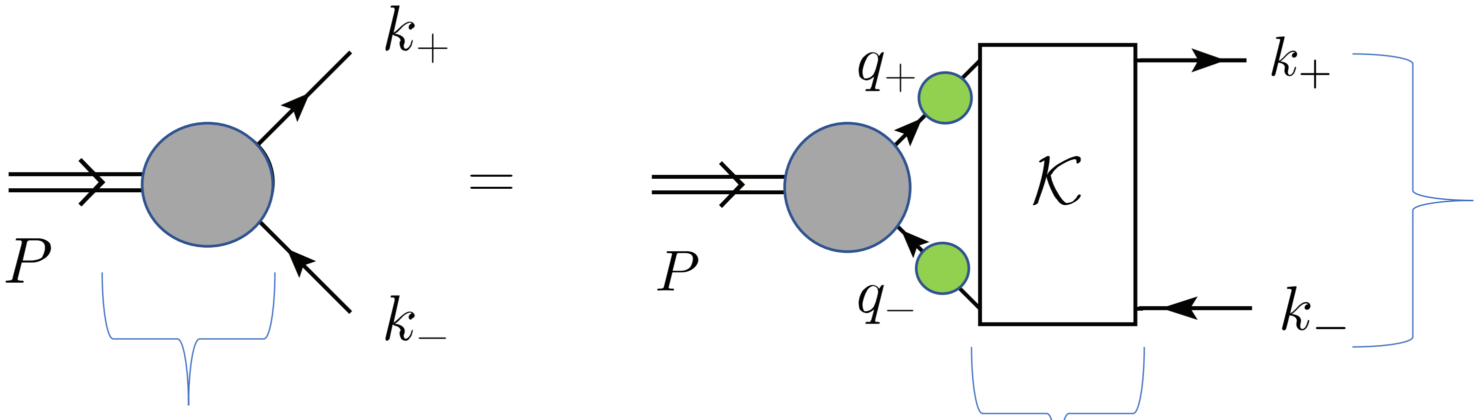
$\Sigma(\not{p}) =$ 



Fully dressed vertex left or right, but not both

Not manifestly left-right symmetric

Bethe-Salpeter equations for mesons



Manifestly left-right symmetric

BS amplitude

BS Kernel

Meson masses: $P^2 = -M^2$

P. Maris and C. D. Roberts, Int. J. Mod. Phys. E 12, 297 (2003)

G. Eichmann, arXiv:0909.0703

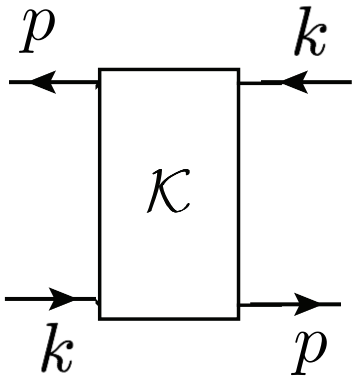
I.C. Cloet and C. D. Roberts, Prog. Part. Nucl. Phys. 77, 1 (2014)

BS kernel from quark self-energy

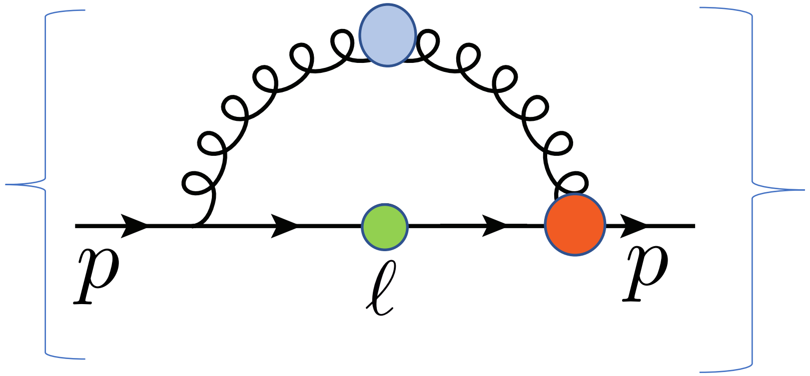
W. Heupel, T. Goecke and C.S. Fischer, Eur. Phys. J. A 50, 85 (2014)

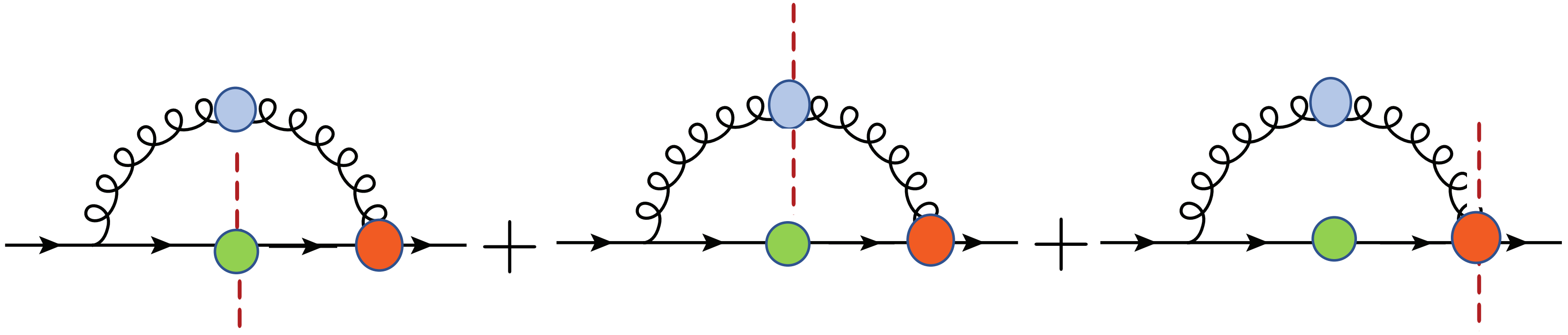
R. Williams, C.S. Fischer and W. Heupel, Phys. Rev. D 93, no. 3, 034026 (2016)

Formal relation : $\mathcal{K}(p,k;P) = -\dfrac{\partial \Sigma(p)}{\partial S(k)}$

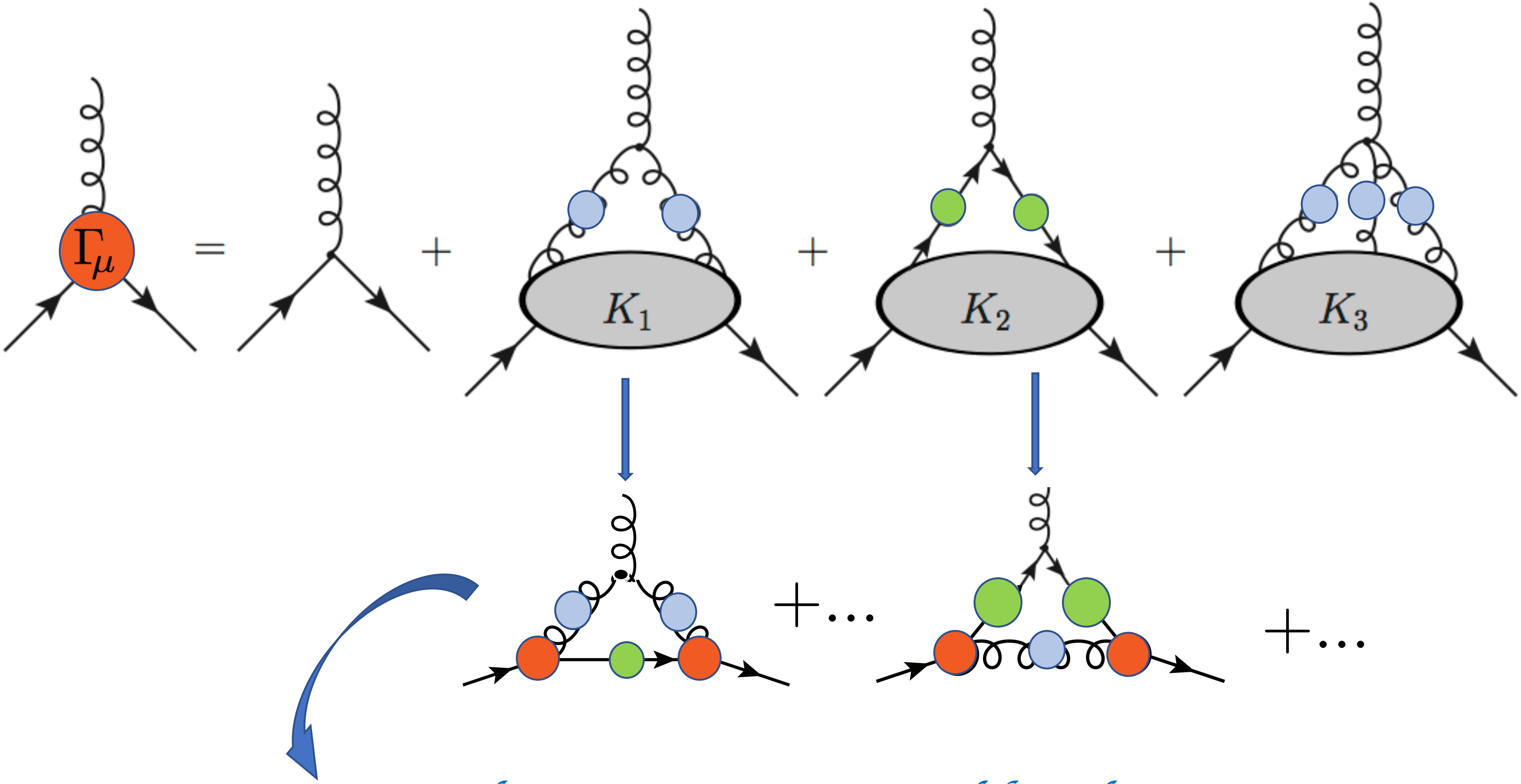


$= \dfrac{\partial}{\partial S(k)}$





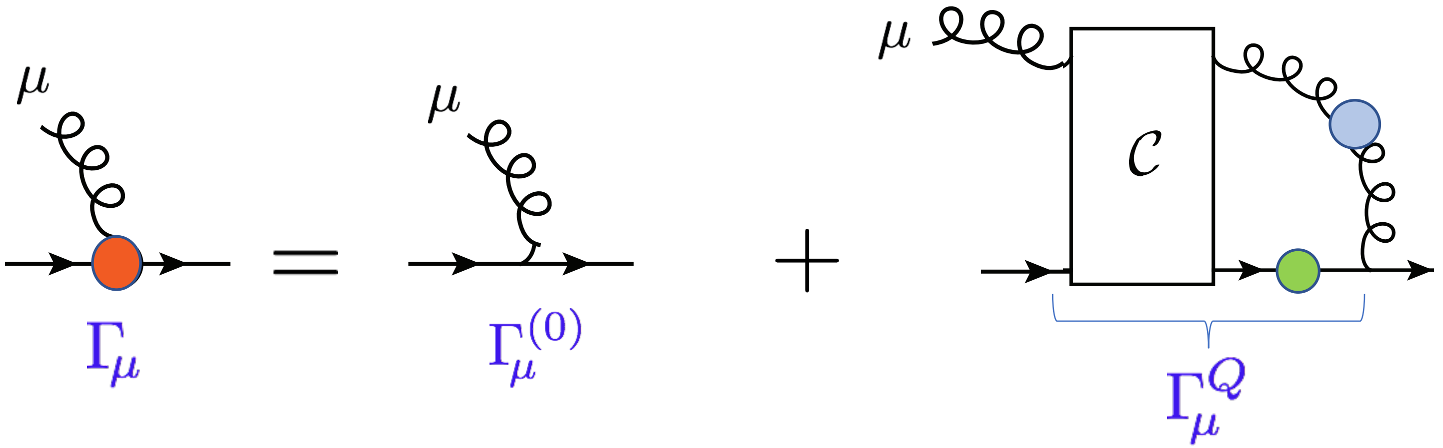
Vertex SDE seen from the point of view of the gluon



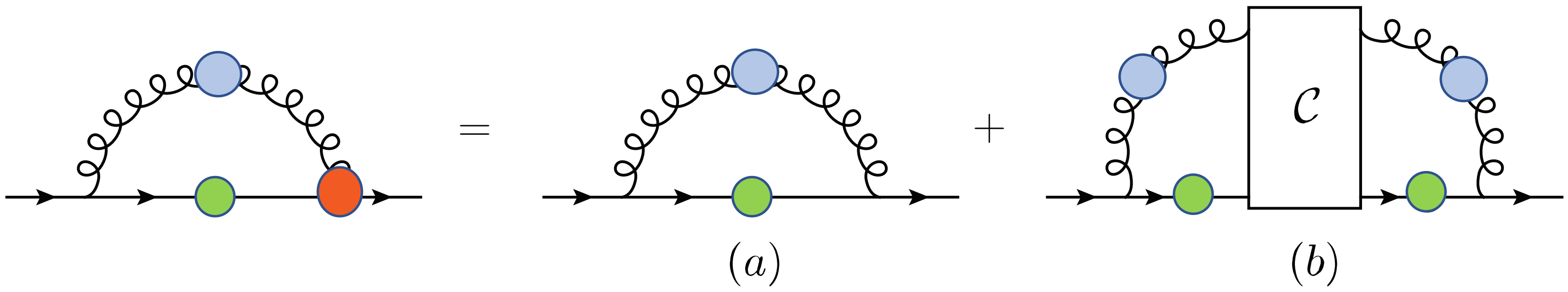
Resulting gap equation "very" left-right asymmetric

Vertex SDE seen from the point of view of the quark

Phys.Rev. D93 (2016) no.9, 096010, D. Binosi, L. Chang, J.P., S.X. Qin, and C. D. Roberts

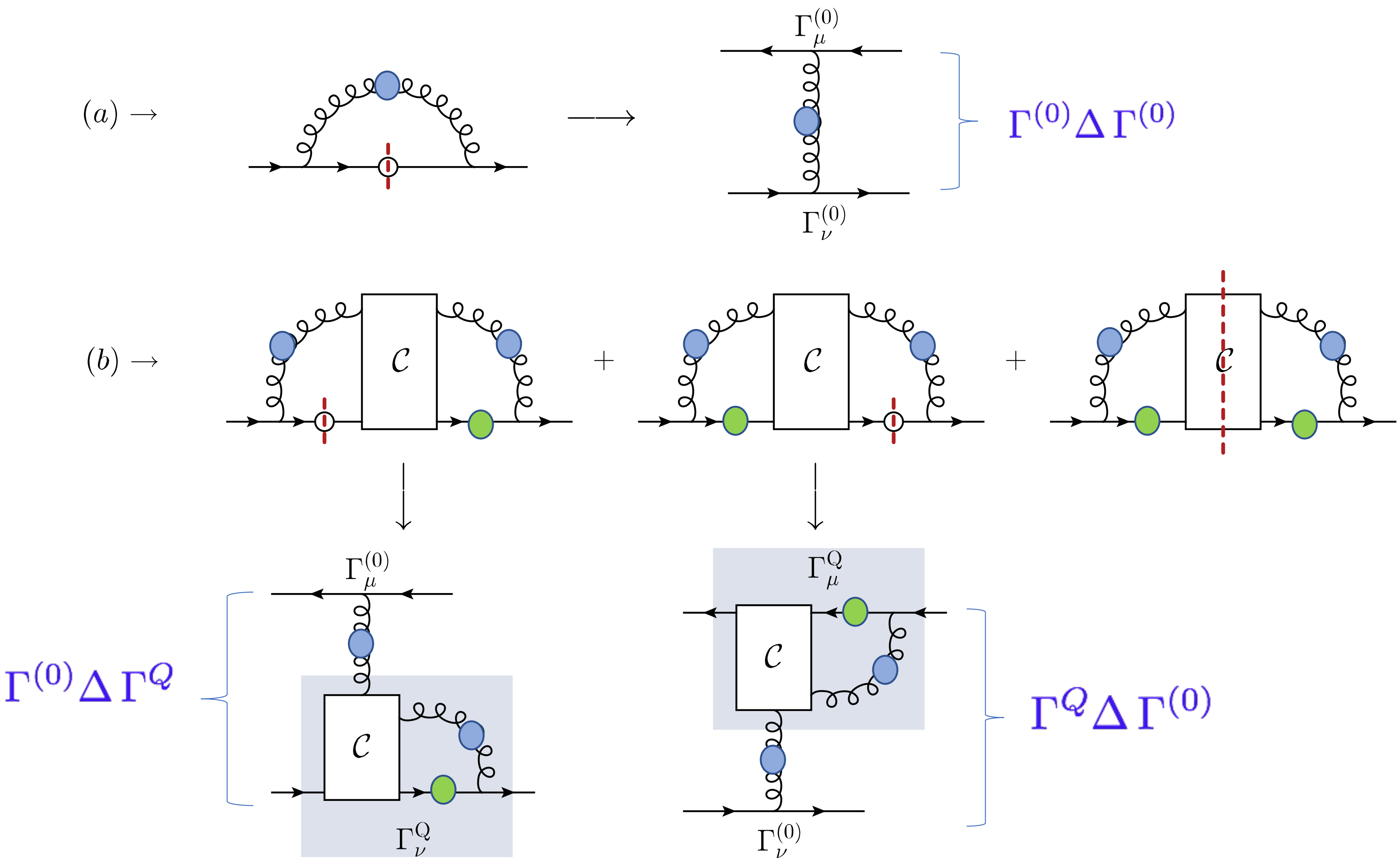


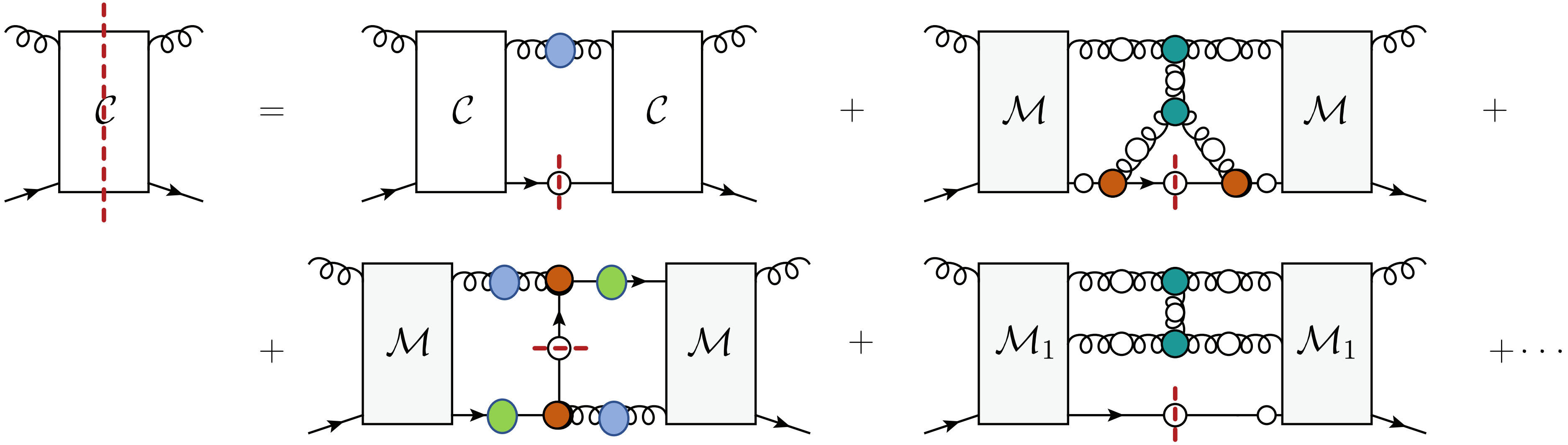
Insert into the gap equation



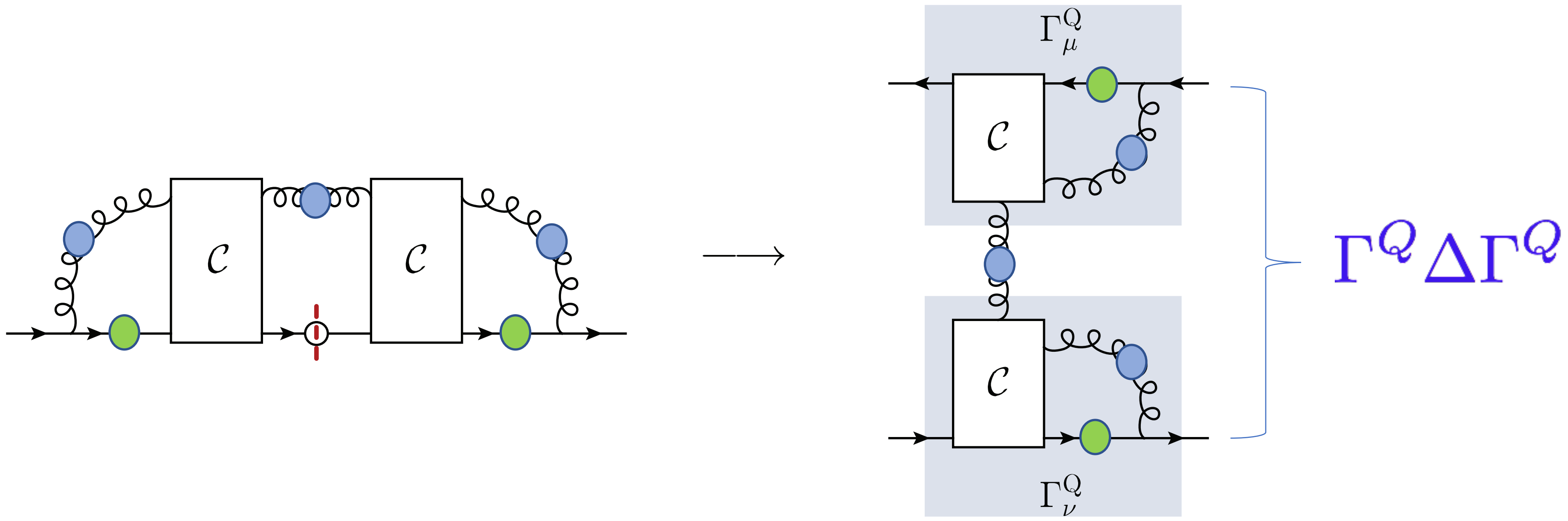
Manifestly left-right symmetric

To get the BS kernel, implement all possible cuts




$\mathcal{C}$ = $\mathcal{C}$ $\mathcal{C}$ + $\mathcal{M}$ $\mathcal{M}$ +
+ $\mathcal{M}$ $\mathcal{M}$ + $\mathcal{M}_1$ $\mathcal{M}_1$ + ⋯

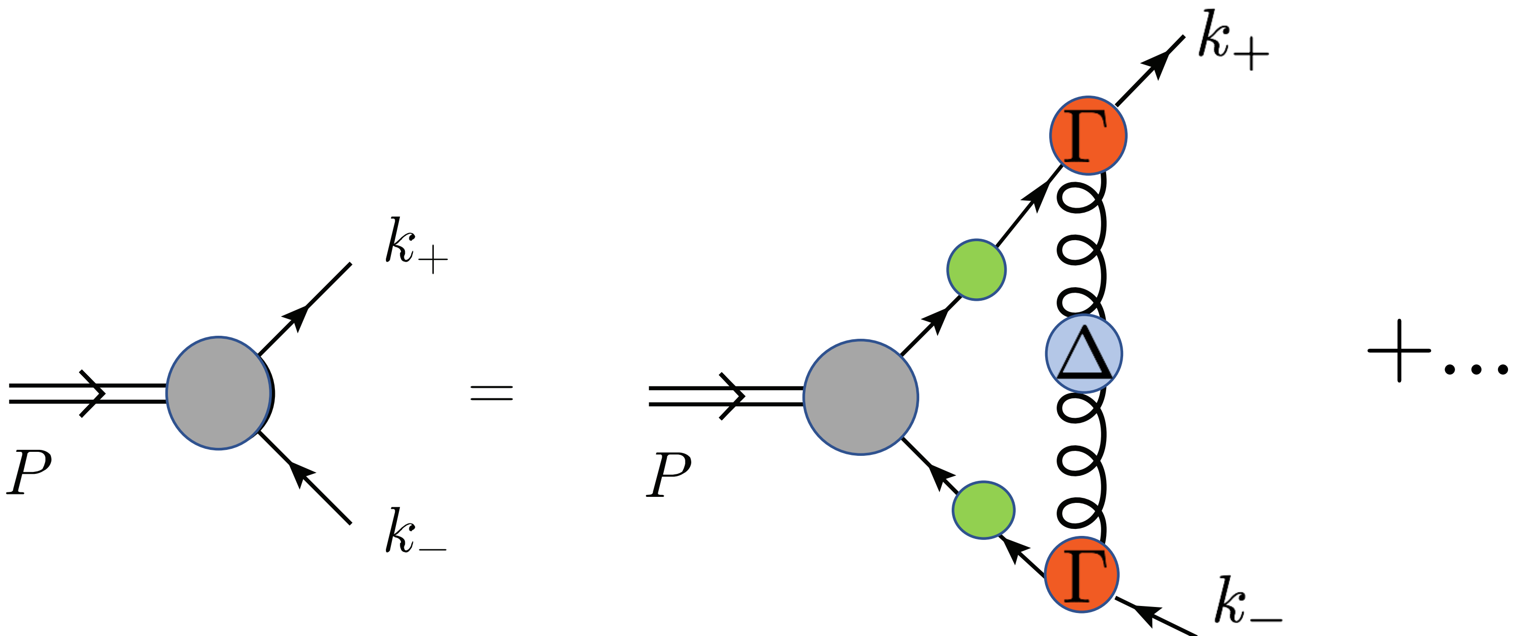
Crucial “cut”:


$\mathcal{C}$ $\mathcal{C}$ ⟶
Γ_μ^{Q}
$\mathcal{C}$
$\mathcal{C}$
Γ_ν^{Q}
$\Gamma^Q \Delta \Gamma^Q$

The BSE kernel obtained through "cutting":

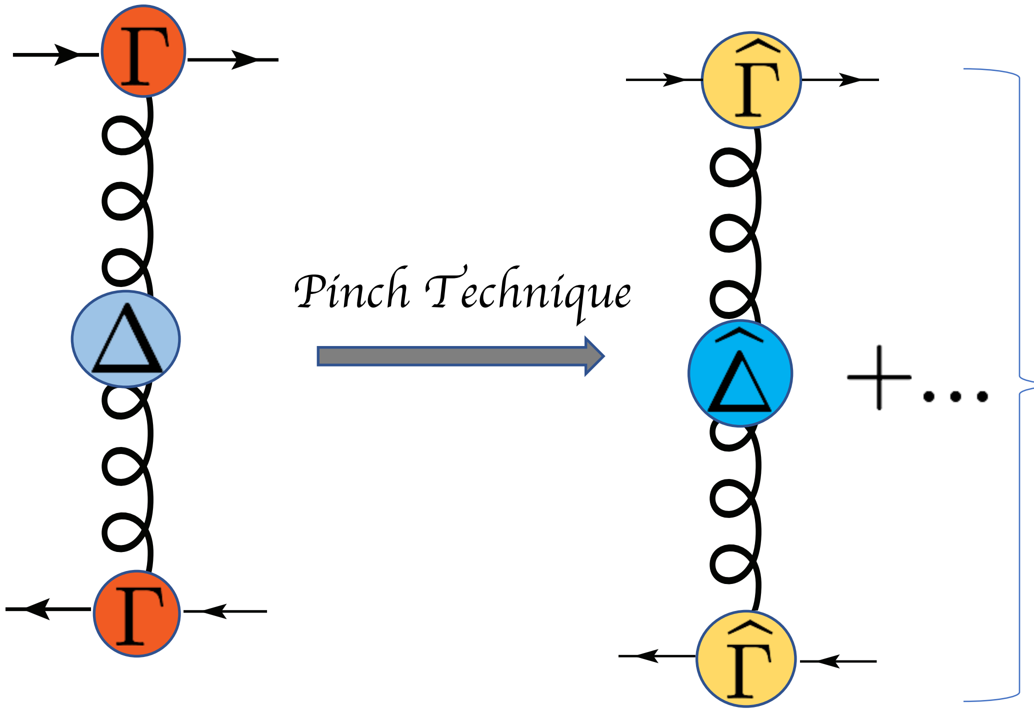
$$\mathcal{K}_{(a)+(b)} = \Gamma^{(0)}\Delta\,\Gamma^{(0)} + \Gamma^{(0)}\Delta\,\Gamma^{Q} + \Gamma^{Q}\Delta\,\Gamma^{(0)} + \Gamma^{Q}\Delta\,\Gamma^{Q} + \text{boxes}$$

Since $\Gamma_\mu = \Gamma_\mu^{(0)} + \Gamma_\mu^{Q}$ $\Longrightarrow$ $\mathcal{K}_{(a)+(b)} = \Gamma\Delta\Gamma + \text{boxes}$



PT-BFM framework

D.Binosi and J. P, Phys. Rept. 479, 1 (2009)



Effective "Abelianization"

$$\underbrace{q^{\mu}\widehat{\Gamma}_{\mu}(q,p_1,p_2) = S^{-1}(p_2) - S^{-1}(p_1)}_{\text{QED-like Ward-Takahashi identity}}$$

$$\Delta(q^2) = \underbrace{\widehat{\Delta}(q^2)}_{\substack{\text{Captures the renormalization-group logs}\\ \text{just as the photon vacuum polarization}}}[1 + \underbrace{G(q^2)}_{\text{Ghost-related function}}]^2$$

Captures the renormalization-group logs just as the photon vacuum polarization

$$Z_g = \widehat{Z}_A^{-1/2}$$

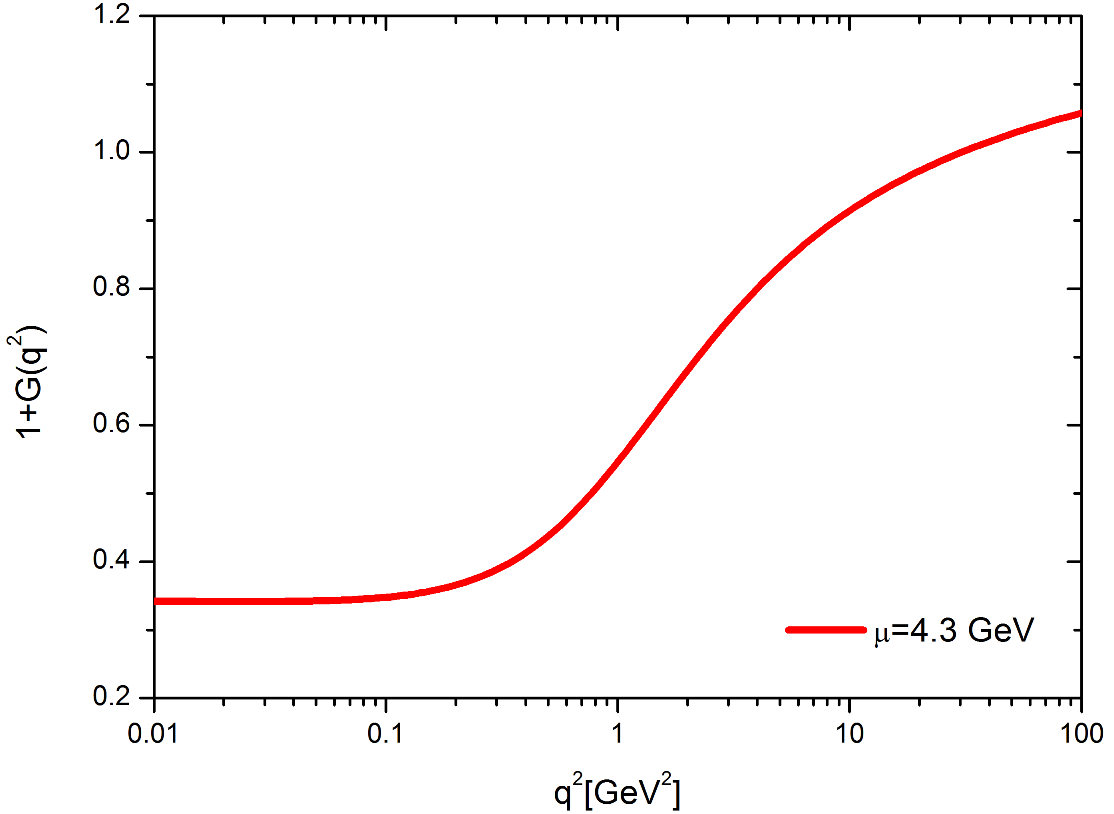
(as in QED !)

$$\underbrace{\widehat{d}(q^2) = \alpha_s \widehat{\Delta}(q^2) = \frac{\alpha_s \Delta(q^2)}{[1+G(q^2)]^2}}$$

Process-independent and *renormalization-group invariant* combination

Nonperturbative dynamical equation for $1+G(q^2)$

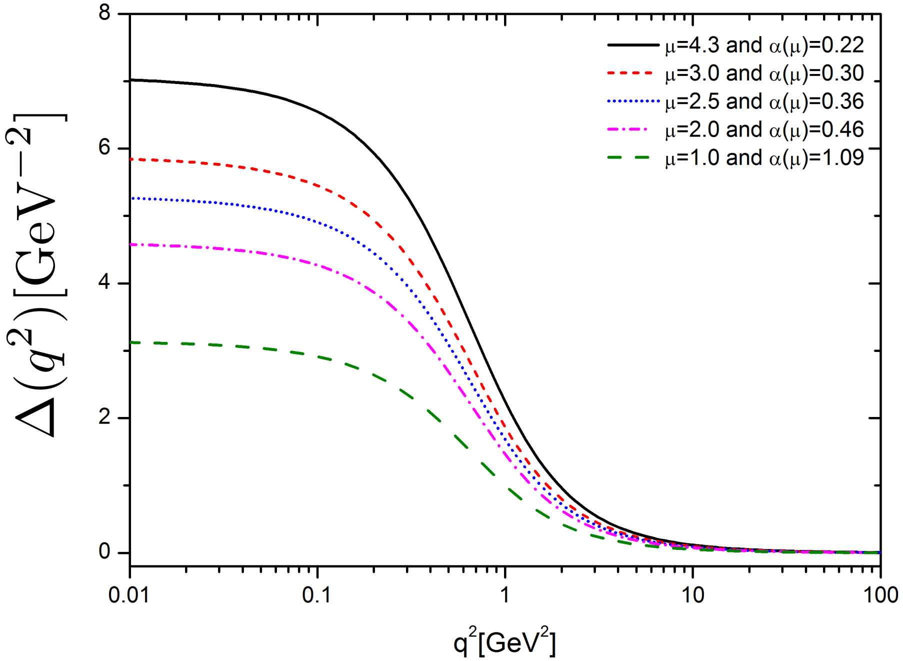
$$1+G(q^2) = 1 - \frac{C_A g^2}{3}\int_k \left[2 + \frac{(k\cdot q)^2}{k^2 q^2}\right]\Delta(k)\underbrace{D(k+q)}_{\text{Ghost propagator}}$$



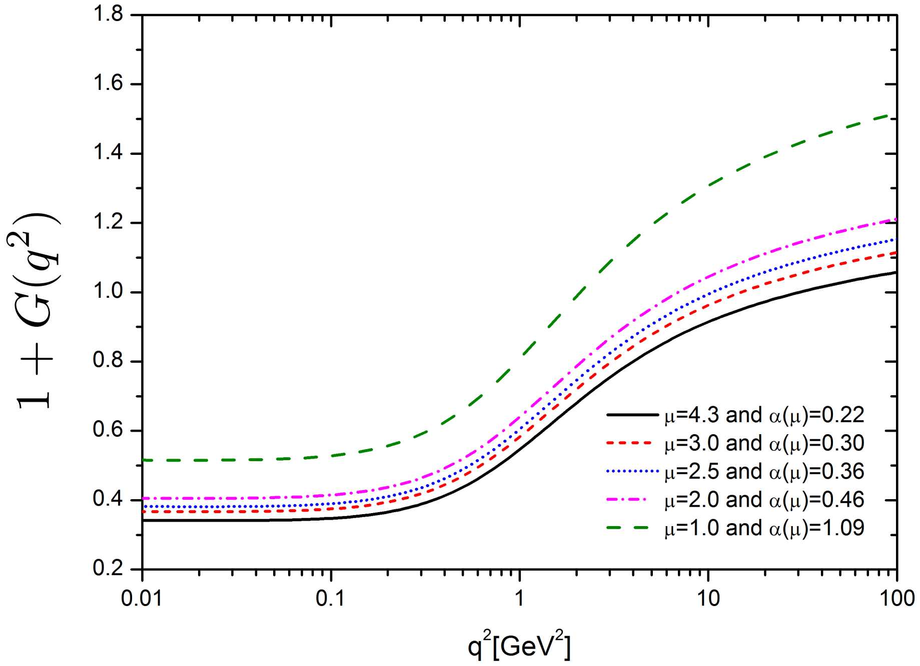
A.C.Aguilar, D. Binosi and J.P. , Phys. Rev. D 78, 025010 (2008)
A.C.Aguilar., D. Binosi, J.P. , and J. Rodríguez-Quintero, Phys. Rev. D80, 085018 (2009)

The μ-dependent ingredients

1



2

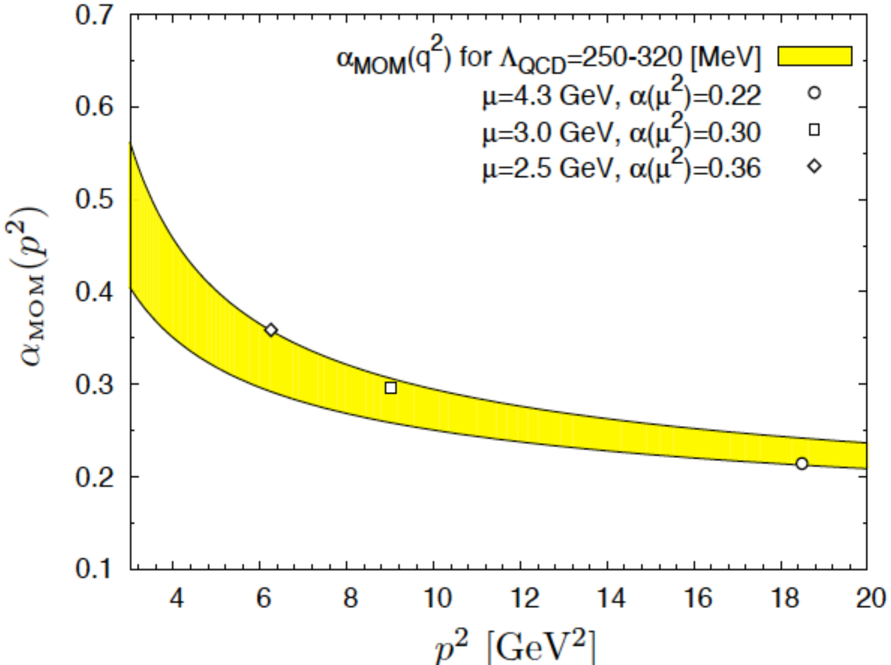


3 $\alpha_s(\mu) = g^2(\mu)/4\pi$

From self-consistency of ghost SDE with lattice data

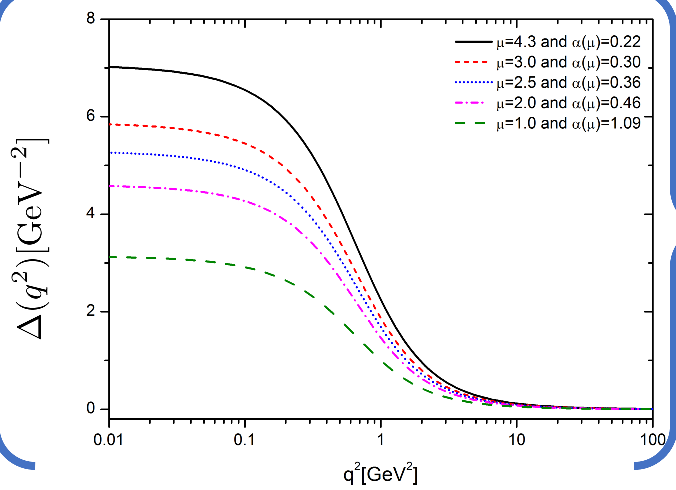
$$\alpha_s(\mu) = 0.22$$
$$\alpha_s(\mu) = 0.30$$
$$\alpha_s(\mu) = 0.36$$
$$\alpha_s(\mu) = 0.46$$
$$\alpha_s(\mu) = 1.09$$

Compare with MOM results



The μ-independent combination

$\alpha_s(\mu) \times$



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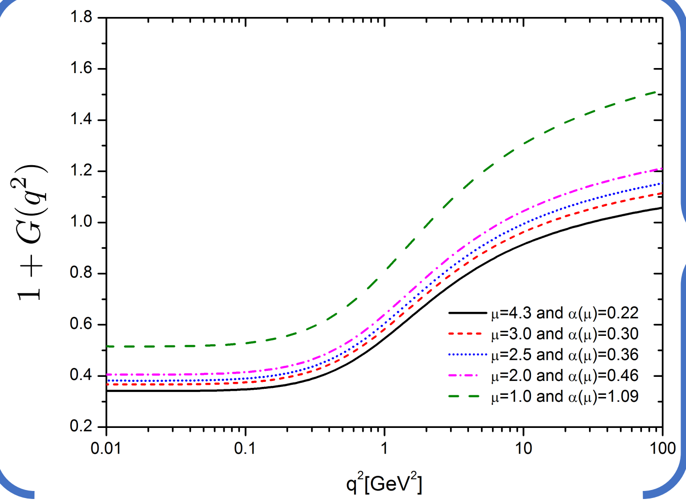
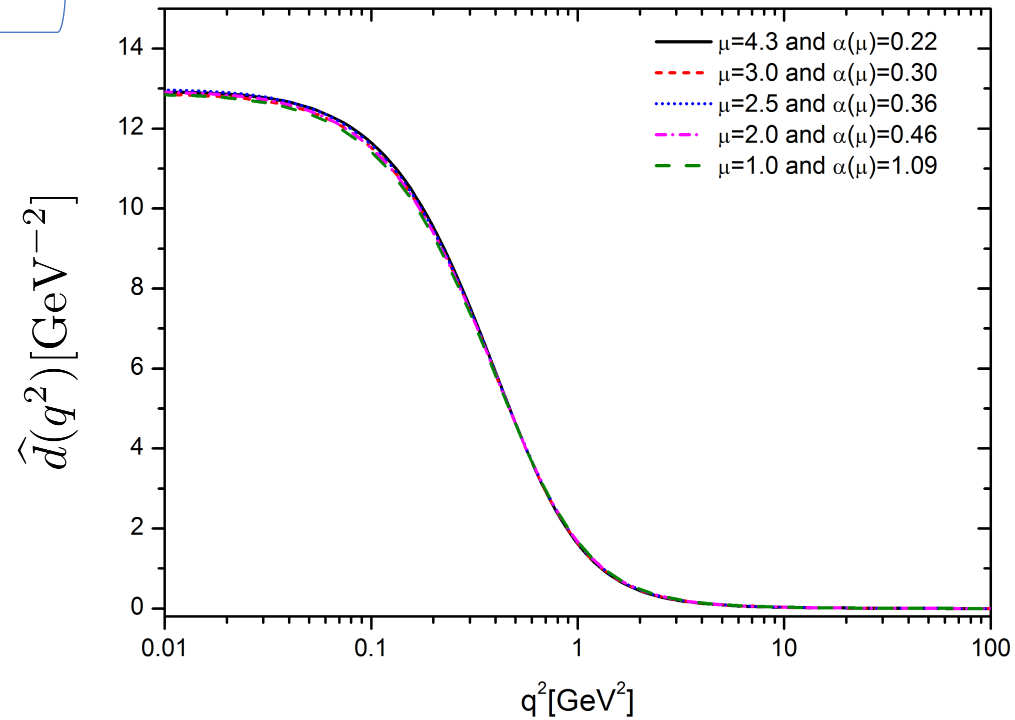


2



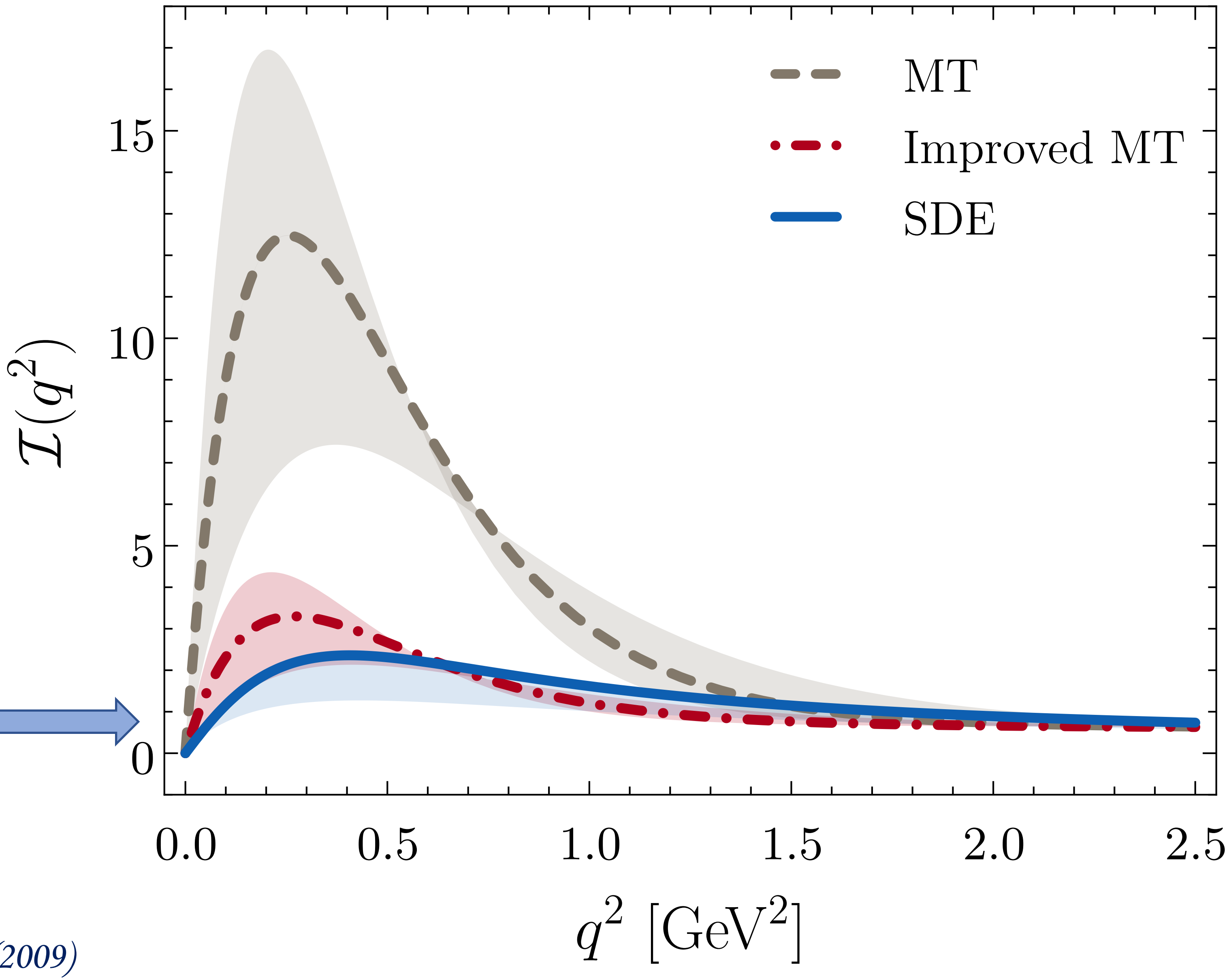
A.C. Aguilar, D. Binosi, J.P. , and J. Rodríguez-Quintero,
Phys. Rev. D80, 085018 (2009)

The μ –independent interaction strength

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

To make contact with the M-T interactions set

$$\mathcal{I}(q^2) = q^2\,\widehat{d}(q^2)$$



L. Chang and C.D. Roberts, Phys. Rev. Lett. 103, 081601 (2009)

Conclusions

First steps towards a "beyond rainbow-ladder" analysis

"First-principles" candidate for the Maris-Tandy interaction,
with definite quantum field theoretic origin and properties

Acts as a bridge between "bottom-up" and "top-down" approaches

Much more effort is required for reaching a "symmetry-preserving" truncation framework