Podolsky Propagator as a low-Energy QCD interaction

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Talk outline

- Generalized QED
- Podolsky Propagator.
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- SDE and the low-energy QCD effective interaction
- Solutions to the SDE on the real axis and in the complex plane.
- The Bethe-Salpeter equation for pseudoscalar mesons.
- The pseudoscalar spectra and decay constants.
- Conclusions.

Generalized QED Lagrangian

$$\mathcal{L} = \bar{\psi}\left(i\hat{\partial} - m + e\hat{A}\right)\psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$

$$+ \frac{1}{2m_P^2}\partial^\mu F_{\mu\beta}\partial_\alpha F^{\alpha\beta} - \frac{1}{2\xi}\left[\left(1 + m_P^{-2}\partial^2\right)\partial^\mu A_\mu\right]^2$$

$$+ \delta_{Z_2}\bar{\psi}i\hat{\partial}\psi - \delta_{Z_0}\bar{\psi}m\psi + \delta_{Z_1}e\bar{\psi}\hat{A}\psi - \delta_{Z_3}\frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$

Podolsky Propagator.

$$G_{\mu\nu} = -i\Delta(q^2)P_{\mu\nu}(q),$$

$$P_{\mu\nu}(q) = \Delta_{\mu\nu}(q) - \left[g_{\mu\nu} + (1-\xi)\frac{q_\mu q_\nu}{q^2 - m_P^2}\right]\frac{1}{q^2 - m_P^2} + (1-2\xi)\frac{q_\mu q_\nu}{q^2(q^2 - m_P^2)} + \frac{q_\mu q_\nu}{(q^2 - m_P^2)^2},$$

$$\Delta_{\mu\nu}(q) = \left[g_{\mu\nu} - (1-\xi)\frac{q_\mu q_\nu}{q^2}\right]\frac{1}{q^2}$$

SDE and the low-energy QCD effective interaction

$$S_f^{-1}(p) = Z_2 \gamma \cdot p - Z_4 m_f(\mu) - Z_1 g^2 \int^\Lambda \frac{d^4k}{(2\pi)^4} G^{\mu\nu}(q) \frac{\lambda^a}{2} \gamma_\mu S_f(k) \frac{\lambda^a}{2} \Gamma_\nu(k,p),$$

$$S_f(p) = \frac{\mathcal{F}_f(p)}{\gamma \cdot p - \mathcal{M}_f(p)}$$

SDE and the low-energy QCD effective interaction

$$\frac{\mathcal{M}_f(p_E)}{\mathcal{F}_f(p_E)} = Z_4 m(\mu) + 3C_F \int \frac{d^4k_E}{(2\pi)^4} \frac{\mathcal{M}_f(k_E)\mathcal{F}_f(k_E)}{k_E^2 + \mathcal{M}_f^2(k_E)} \frac{\mathcal{G}(q_E^2)}{q_E^2},$$

$$\mathcal{G}(q_E^2) = 4\pi\alpha_{\text{eff}} \frac{m_P^2}{q_E^2 + m_P^2},$$

$$\mathcal{F}_f(p^2)\big|_{p^2=\mu^2} = 1, \quad S_f^{-1}(p)\big|_{p^2=\mu^2} = \gamma \cdot p - m_f(\mu),$$

SDE and the low-energy QCD effective interaction

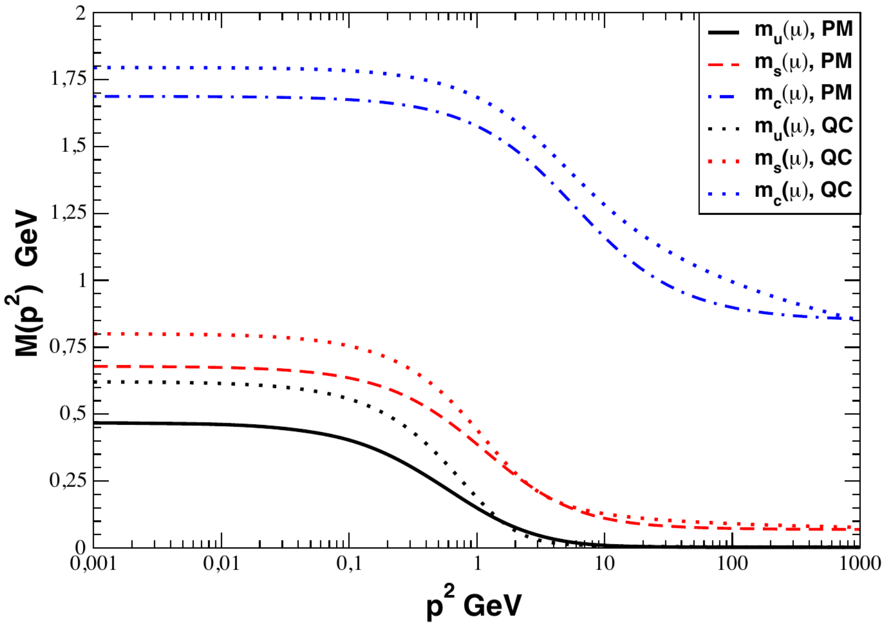
$$\frac{1}{\mathcal{F}_f(p_E)} = Z_2 + \frac{C_F}{p_E^2}\int \frac{d^4k_E}{(2\pi)^4}\frac{\mathcal{F}_f(k_E)}{k_E^2+\mathcal{M}_f^2(k_E)}\left[3p_E\cdot k_E + \frac{2[(p_E\cdot k_E)^2 - p_E^2 k_E^2]}{q_E^2}\right]\frac{\mathcal{G}(q_E^2)}{q_E^2}.$$

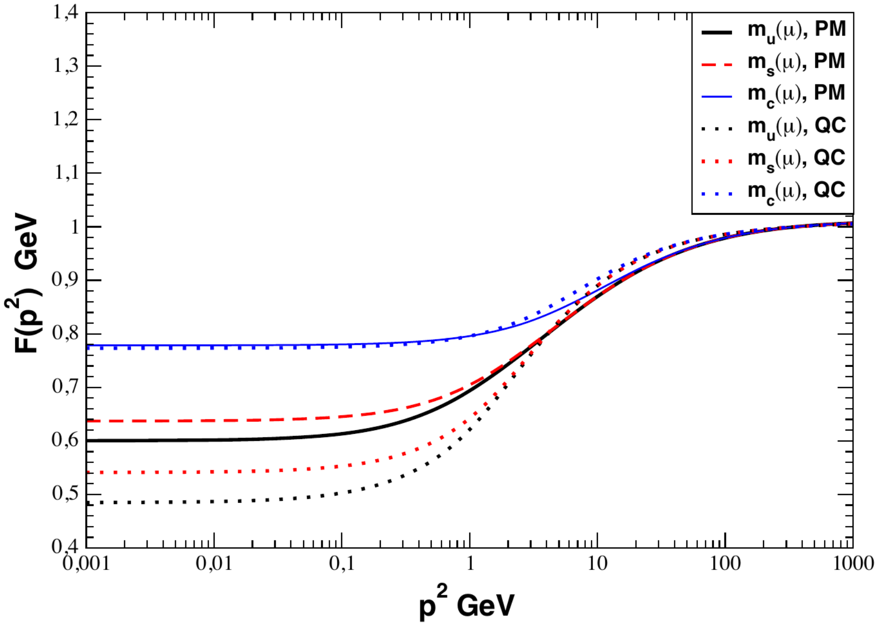
The Podolsky propagator in the Landau Gauge.

$$\Delta(q^2) = 1$$

$$D_{\mu\nu}(q) := \frac{m_P^2}{q_E^2 + m_P^2}\left(g_{\mu\nu} - \frac{q_{E\mu}q_{E\nu}}{q_E^2}\right)\frac{1}{q_E^2} = \frac{m_P^2}{q_E^2 + m_P^2}\Delta_{\mu\nu}^{\xi=0}(q_E^2).$$

- In the Landau gauge with \Delta(q^2)= 1 the Podolsky propagator is equivalent multiplying by a factor m^2_{P}/q^2 the massive gluon propagator introduced by Tissier-Wschebor (2010). The latter is motivated by the soft breaking of Becchi-Rouet-Stora-Tyutin (BRST) symmetry and described by a gluon-mass term in the Lagrangian corresponding to a particular case of the Curci-Ferrari model.


M(p²) GeV
p² GeV
2
1,75
1,5
1,25
1
0,75
0,5
0,25
0
0,001
0,01
0,1
1
10
100
1000
m_u(μ), PM
m_s(μ), PM
m_c(μ), PM
m_u(μ), QC
m_s(μ), QC
m_c(μ), QC


F(p²) GeV
p² GeV
1,4
1,3
1,2
1,1
1
0,9
0,8
0,7
0,6
0,5
0,4
0,001
0,01
0,1
1
10
100
1000
m_u(μ), PM
m_s(μ), PM
m_c(μ), PM
m_u(μ), QC
m_s(μ), QC
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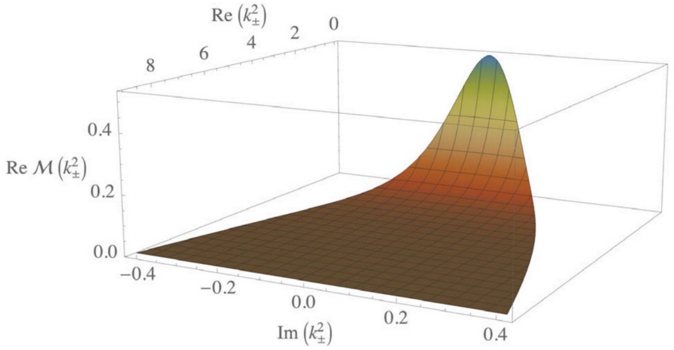
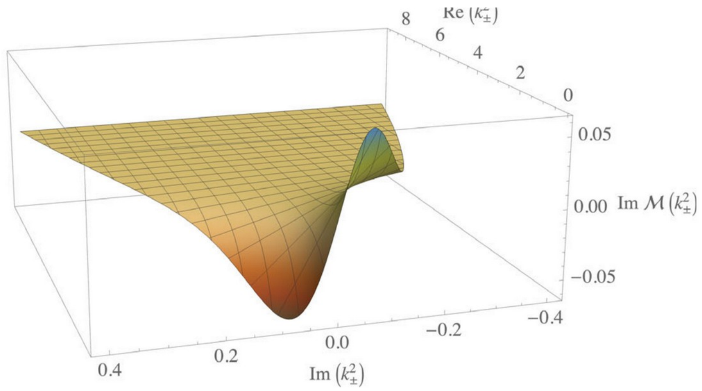


Re $(k_\pm^2)$
8
6
4
2
0
0.4
Re $\mathcal{M}(k_\pm^2)$
0.2
0.0
−0.4
−0.2
0.0
0.2
0.4
Im $(k_\pm^2)$



8
6
4
2
0
0.05
0.00
Im $\mathcal{M}(k_\pm^2)$
−0.05
0.4
0.2
0.0
−0.2
−0.4
Im $(k_\pm^2)$

$$\Gamma_{mn}^{fg}(p,P) = \int^{\Lambda} \frac{d^4 k_E}{(2\pi)^4} \mathcal{K}_{mn}^{kl}(p,k,P) [S_f(k_+) \Gamma^{fg}(k,P) S_g(k_-)]_{lk},$$

$$\mathcal{K}_{mn}^{kl}(p,k,P) = -4\pi\alpha_{\rm eff} \left(\frac{\lambda^a}{2}\gamma_\mu\right)_{kn} P_{\mu\nu}(q) \left(\frac{\lambda^a}{2}\gamma_\nu\right)_{ml},$$

$$\Gamma(p,P) = \gamma_5 [i\mathbb{I}_D E(p,P) + \gamma \cdot P F(p,P) + \gamma \cdot p\, p \cdot P G(p,P) + \sigma_{\mu\nu} p_\mu P_\nu H(p,P)],$$

	Podolsky model	Q.-C. model	Reference
M_π	0.138	0.138	0.139 [103]
f_π	0.133	0.139	0.130 [103]
f_π^{GMOR}	0.117		
M_K	0.494	0.493	0.493 [103]
f_K	0.164	0.164	0.156 [103]
f_K^{GMOR}	0.162	0.162	
$M_{\eta_c(1S)}$	2.985	3.065	2.984 [103]
$f_{\eta_c(1S)}$	0.454	0.389	0.395 [104]
$f_{\eta_c(1S)}^{\mathrm{GMOR}}$	0.451	0.380	
M_D	2.100	2.115	1.870 [103]
f_D	0.263	0.204	0.212 [105]
M_{D_s}	2.130	2.130	1.968 [103]
f_{D_s}	0.304	0.249	0.250 [105]

Conclusions

- We solve for the first time the DSE with the Podolsky propagator in rainbow truncation and find a mass gap for a typical hadronic scale of the Podolsky mass. Based on this observation, we propose a novel interaction model within the rainbow-ladder truncation of the DSE and BSE kernels, based on the Podolsky propagator which preserves gauge invariance in perturbative GQED.

Conclusions

- Employing these complex solutions for the quark propagators in the BSE, we fix the quark masses and interaction parameters with the masses of the π, K, ηc and find weak decay constants that agree very well with experimental reference values or results from lattice-QCD simulations. The D mesons are also obtained within this framework, where their masses are somewhat overestimated and the mass difference between the D and Ds is too small, a consequence of the too simplistic truncation for heavy-light systems.