Light mesons with a dressed quark-gluon vertex

Based on: M. N. Ferreira, Á. Miramontes, J. M. Morgado, J. Papavassiliou, Eur. Phys. J. C **86** (2026) 858 [arXiv: 2604.07221]

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Series of works with R. Alkofer, M. N. Ferreira, J. M. Morgado, J. Papavassiliou, J. M. Pawlowski

Eur. Phys. J. C **85** (2025) 1055 Eur. Phys. J. C **86** (2026) 325

Eur. Phys. J. C **86** (2026) 954 Phys. Lett. B **880** (2026) 140856

The SDE/BSE system and its kernel

Nonperturbative framework

- **SDE** —> dressed quark propagator:

$$S^{-1}(p) = i\not{p} + m + \Sigma(p),$$

$$\Sigma(p) = g^2 C_f \int_q \gamma^\nu S(q)\, \Gamma^\mu\, \Delta_{\mu\nu}(q-p),$$

with $S^{-1} = A(p)\not{p} + B(p)$, $\mathcal{M}(p) = B(p)/A(p)$.

- **Homogeneous BSE** —> eigenvalue problem:

$$\Gamma_M(p,P) = \int_k \mathcal{K}\, S(k_+)\, \Gamma_M\, S(k_-),$$

bound state at $\lambda(P^2) = 1$, i.e. $P^2 = -M^2$.

The same construction extends to baryons through the three-body Faddeev equation, and to multiquark states and glueballs.

[see the talks by Yao, Eichmann, Torres, Hoffer and Huber]

Rainbow-ladder (RL)

- A single *effective coupling* in a $\gamma^\mu \otimes \gamma^\mu$ exchange.[1]
- Very successful for ground-state pseudoscalars and vectors, for many space-like form factors and other observables.
- The interaction is reduced to a single tensor structure with an effective coupling, which is known to fall short for axial-vectors, radial excitations, time-like electromagnetic form factors.

[1] P. Maris and P. C. Tandy, Phys. Rev. C 61 (2000) 045202.

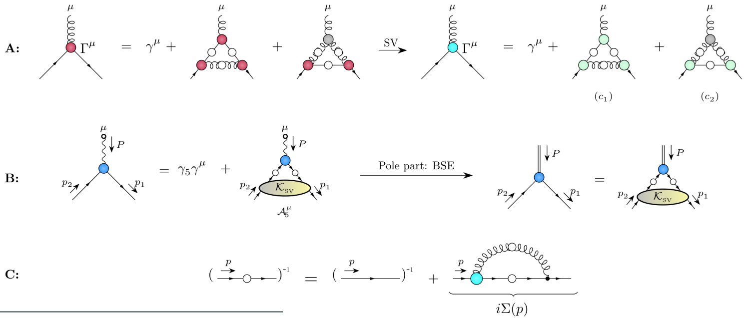
This work

- Instead of an effective coupling, the kernel $\mathcal{K}$ carries the *complete tensor structure* of the quark-gluon vertex Γ^μ, all eight form factors obtained from its own SDE, with the axial Ward-Takahashi identity kept exact.
- **Goal:** test on the light spectrum (u, d, s).

Inside the *vertex*-SDE diagrams, replace the full vertex by its classical part in the **symmetric** kinematics $q^2 = r^2 = p^2$:

$$\Gamma^{\mu}(q,r,-p) \longrightarrow V_{\mu}(q) = \gamma^{\mu}\, V(q), \qquad V(q) \equiv \lambda_1\big|_{q^2=r^2=p^2}.$$

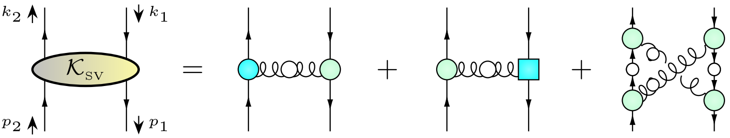
- $V(q)$ reproduces the full momentum dependence of the form factors very well.
- Yields a symmetry-preserving **triplet**: gap equation, vertex SDE, meson BSE.[1]



[1] M. N. Ferreira, A. S. Miramontes, J. M. Morgado, J. Papavassiliou, J. M. Pawlowski, Eur. Phys. J. C 86 (2026) 325.

The Bethe-Salpeter kernel $\mathcal{K}_{\text{sv}}$

The full quark-gluon vertex upgrades (a) and generates two further structures:



(a) dressed RL $\quad (b)$ quantum $\quad (c)$ crossed

- **(a) dressed RL**: one-gluon exchange, now with the full vertex in place of the bare γ^μ.
- **(b) quantum**: the same exchange, but carrying the vertex's loop-generated part, i.e. its tensor structure *beyond* γ^μ.
- **(c) crossed** : a two-gluon exchange containing only $V(q)$; **essential** to keep the axial WTI exact.[2]

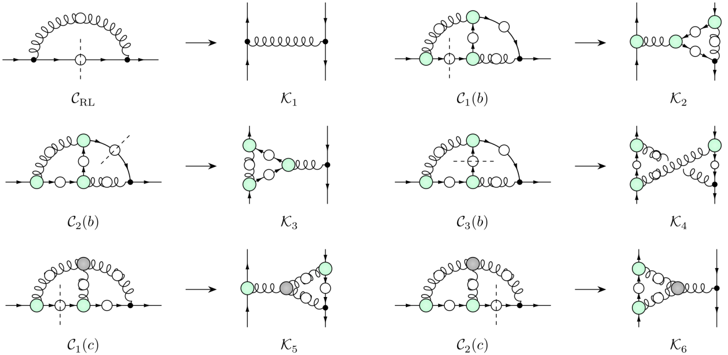
[2] M. N. Ferreira, A. S. Miramontes, J. M. Morgado, J. Papavassiliou, J. M. Pawlowski, Eur. Phys. J. C 86 (2026) 325.

The "cutting" procedure

- Classic criterion for symmetry-preserving kernels [3]:

$$\mathcal{K}(p,k,P) = -\frac{\delta\Sigma(p)}{\delta S(k)}.$$

- Operationally: "cut" each internal quark line in the self-energy $\Sigma(p)$.
- Cutting the SV self-energy reproduces *all six* diagrams of $\mathcal{K}_{\text{sv}}$.



[3] H. Munczek, Phys. Rev. D52, 4736 (1995).

WTIs with current masses

Contracting the vertex SDEs with P_μ still yields the *exact* axial and vector identities, from the same kernel $\mathcal{K}_{\rm sv}$:

Axial-vector vertex

$$-P_\mu \Gamma_5^\mu = S_f^{-1}(p_1)\gamma_5 + \gamma_5 S_{f'}^{-1}(p_2) + \underbrace{(m_f + m_{f'})\,\Gamma_5}_{\text{massive quarks}}$$

Vector vertex

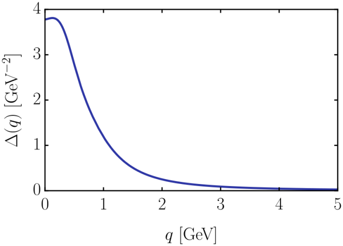
$$P_\mu \Gamma_V^\mu = S_f^{-1}(p_1) - S_{f'}^{-1}(p_2) + \underbrace{(m_f - m_{f'})\,\Gamma}_{\text{zero if } m_f = m_{f'}}$$

- The axial identity encodes chiral symmetry, and guarantees the pion as a Goldstone boson in the chiral limit.
- The vector identity encodes current conservation, which fixes the normalization of electromagnetic form factors.

Gluon propagator (Landau gauge)

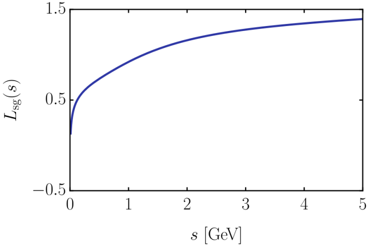
$$\Delta_{\mu\nu}(q) = P_{\mu\nu}(q)\,\Delta(q)$$

Lattice data,[1] renormalized at 2 GeV.



Three-gluon vertex

Planar degeneracy $\Rightarrow$ a single form factor suffices.[2]

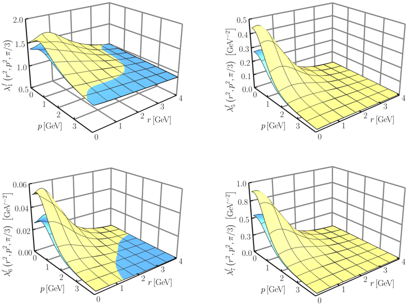


[1] A. Ayala, A. Bashir, D. Binosi, M. Cristoforetti, J. Rodríguez-Quintero, Phys. Rev. D 86 (2012) 074512.

[2] A. C. Aguilar, F. De Soto, M. N. Ferreira, J. Papavassiliou, J. Rodríguez-Quintero, S. Zafeiropoulos, Eur. Phys. J. C 80 (2020) 154.

The quark-gluon vertex and the quark propagator

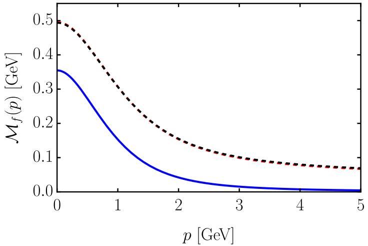
- Chirally symmetric ($\lambda_{1,5,6,7}$) and chiral-symmetry-breaking ($\lambda_{2,3,4,8}$); substituting $V_{u,s}(q)$ gives all eight, with full kinematics.
- Beyond the classical form factor λ_1, this includes the anomalous chromomagnetic moment (λ_4) and the spin-momentum curvature (λ_7).
- **All** participate actively in the binding.



chirally symmetric $\lambda_{1,5,6,7}$ (u yellow, s blue).

Dressed propagator: constituent mass

- Feeding the vertex into the gap equation yields the constituent mass $\mathcal{M}_f(p) = B_f(p)/A_f(p)$.
- In the soft-gluon limit, solved in the complex plane, the propagator develops two real poles [see Morgado's talk].[4]
- Here, with full kinematics in the spacelike region, the reconstructed propagator shows the same pole structure.



[4] R. Alkofer, M. N. Ferreira, A. S. Miramontes, J. M. Morgado, J. Papavassiliou, Phys. Lett. B 880 (2026) 140856.

From the SDEs to the meson spectrum

Where we stand

- The quark-gluon vertex with its eight form factors, the dressed quark propagators for u and s, and the two external inputs. Everything the BSE needs is in place.
- In principle, one could now solve the BSE directly at the bound-state momentum.

The obstacle

- The bound state sits at timelike $P^2 = -M^2$, where the quark momenta $k_\pm = k \pm P/2$ become complex.
- The propagator and the vertex would then be needed in a region of the complex plane whose analytic structure is currently under investigation, and this region grows with the mass of the state.

Strategy

- Solve the BSE only in the spacelike region, where everything is real and well behaved, and *extrapolate* the eigenvalue $\lambda(P^2)$ to the on-shell point $\lambda(P^2) = 1$ using the Schlessinger Point Method, well tested in this context.[5]
- A resampling procedure yields the mass and its uncertainty.

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[5] L. Schlessinger, Phys. Rev. 167 (1968) 1411. D. Binosi, R.-A. Tripolt, Phys. Lett. B 801 (2020) 135171.

	$\pi\ (0^{-+})$	$\rho\ (1^{--})$	$a_1\ (1^{++})$	$b_1\ (1^{+-})$	$\pi(1300)$	$\rho(1450)$
This work	0.139(1)	0.763(5)	1.12(7)	1.14(6)	1.24(7)	1.32(11)
RL	0.139	0.732	0.894	0.822	1.12(2)	0.986
Exp. (PDG)	0.139(1)	0.775(1)	1.23(4)	1.230(3)	1.30(10)	1.46(3)

- Light current quark mass used to fix the pion.
- $a_1\,/\,b_1$ **near-degeneracy** is reproduced, consistent with PDG.
- Radial excitations $\pi(1300), \rho(1450)$ markedly improved.[6]

[6] RL values from Hagel, Fischer, Huber and Yigzaw. Eur.Phys.J.A 62 (2026) 7, 129

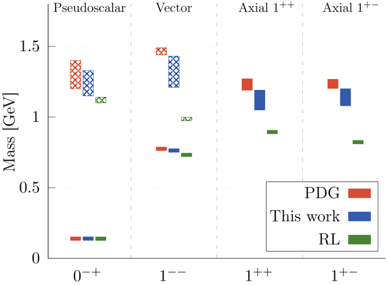
Results II: the strange $u\bar{s}$ sector

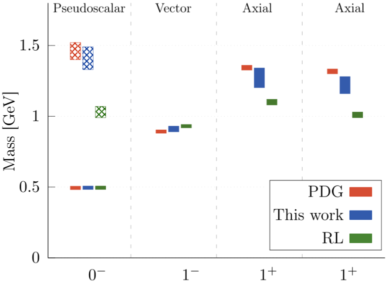
	K	K^*	K_{1A}	K_{1B}	$K(1460)$
This work	0.495(1)	0.91(2)	1.27(7)	1.20(6)	1.41(8)
RL	0.495	0.930	1.10(2)	1.01(2)	1.03(4)
Exp. (PDG)	0.494(1)	0.892(1)	1.343(17)	1.317(17)	1.46(6)

- The strange current mass fixes K.
- Our solutions are the *unmixed* states for K_{1A}, K_{1B} ; PDG entries are un-mixed with $\theta = (40 \pm 5)^\circ$ for comparison.[7]

[7] Z.-S. Liu, X.-L. Chen, D.-K. Lian, N. Li, W. Chen, Phys. Rev. D 111 (2025) 014014.

Spectrum overview





- Systematic improvement across different J^{PC} channels, obtained with a single kernel. Data compared to RL [8].

[8] RL values from Hagel, Fischer, Huber and Yigzaw. Eur.Phys.J.A 62 (2026) 7, 129

Conclusions and outlook

Conclusions

- Good agreement with the PDG. A clear, systematic improvement over traditional approaches.
- The full tensor structure of the quark-gluon vertex supplies the needed interaction strength, with the symmetry-preserving kernel keeping it consistent.

Outlook

- Main limitation: the SPM extrapolation range $\Longrightarrow$ light states only.
- Extend the quark-gluon vertex into the complex plane $\longrightarrow$ [See Jose Morgado Talk]
- Add Minkowski-space data points to shorten the extrapolation. (*in progress*)

Part of an organized effort

This work is part of an ongoing programme:

A comprehensive approach to the physics of mesons

A. S. Miramontes, J. M. Morgado, J. Papavassiliou, J. M. Pawlowski — Eur. Phys. J. C **85** (2025) 1055

Pion physics with dressed quark-gluon vertices

M. N. Ferreira, A. S. Miramontes, J. M. Morgado, J. Papavassiliou, J. M. Pawlowski — Eur. Phys. J. C **86** (2026) 325

Quark-gluon vertex in the complex plane

M. N. Ferreira, A. S. Miramontes, J. M. Morgado, J. Papavassiliou — Eur. Phys. J. C **86** (2026) 954

Real poles with opposite-sign residues in the non-perturbative quark propagator

R. Alkofer, M. N. Ferreira, A. S. Miramontes, J. M. Morgado, J. Papavassiliou — Phys. Lett. B **880** (2026) 140856

Light mesons in the symmetric-vertex approximation

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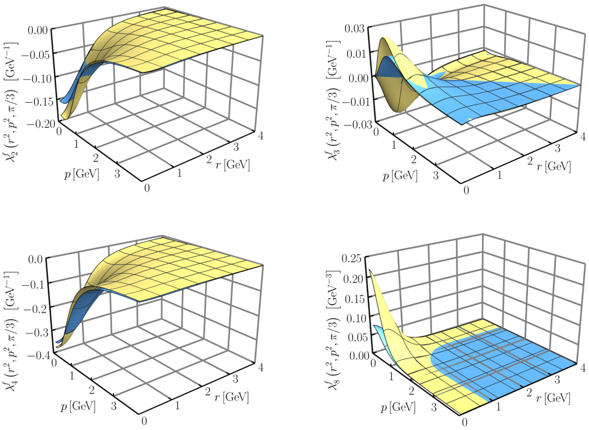
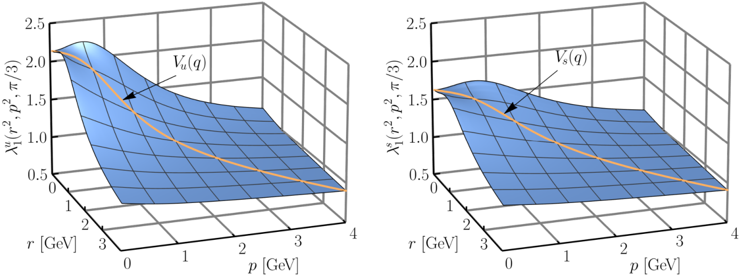
Backup - chiral-symmetry-breaking form factors

The chiral-symmetry-breaking form factors $\lambda^f_{2,3,4,8}$ of the quark-gluon vertex within the SV approximation ($f = u$ yellow, $f = s$ blue).



The functions $V_u(q)$ and $V_s(q)$

- Solve the gap equation + vertex SDE *once per flavour* (ud and s).
- Read off the symmetric slice $V_f(q) = \lambda_1^f(q^2, q^2, \pi/3)$.



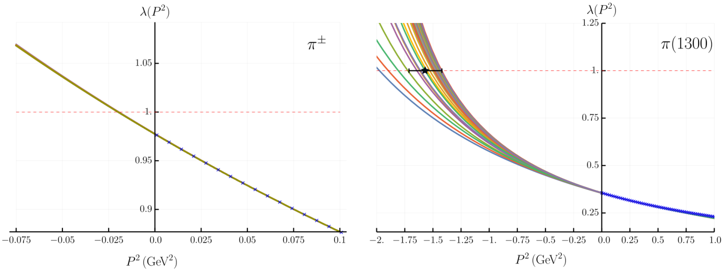
λ_1^u and λ_1^s; the diagonal slice ($r^2 = p^2$) is identified with $V_{u,s}(q)$.

From Euclidean data to masses

- Solving the BSE at a total momentum P gives the eigenvalue $\lambda(P^2)$; a bound state of mass M sits at $\lambda(P^2) = 1$, i.e. $P^2 = -M^2$.
- That on-shell point is timelike ($P^2 < 0$), where the propagator and vertex would be needed at complex momenta with poorly-known poles and cuts.

Strategy: the Schlessinger Point Method (SPM)

Solve only in the spacelike region ($P^2 > 0$, where $\lambda < 1$) and *extrapolate* $\lambda(P^2)$ to $\lambda(P^2) = 1$. A resampling procedure yields the mass and its uncertainty.[9]



[9] L. Schlessinger, Phys. Rev. 167 (1968) 1411. D. Binosi, R.-A. Tripolt, Phys. Lett. B 801 (2020) 135171.