Unraveling $K(1690)$ as a pseudoscalar $ud\bar{d}\bar{s}$ tetraquark state

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A crypto-exotic $J^P = 0^-$ state

- Three resonance structures in P-wave ρK channel around (1.4,1.7,1.9)GeV.

PRD, 79:114029, 2009 PRD, 32:189–231, 1985. PRD, 108(1):014034, 2023. EPJC, 77(12):861, 2017. EPJA, 59(3):40, 2023.

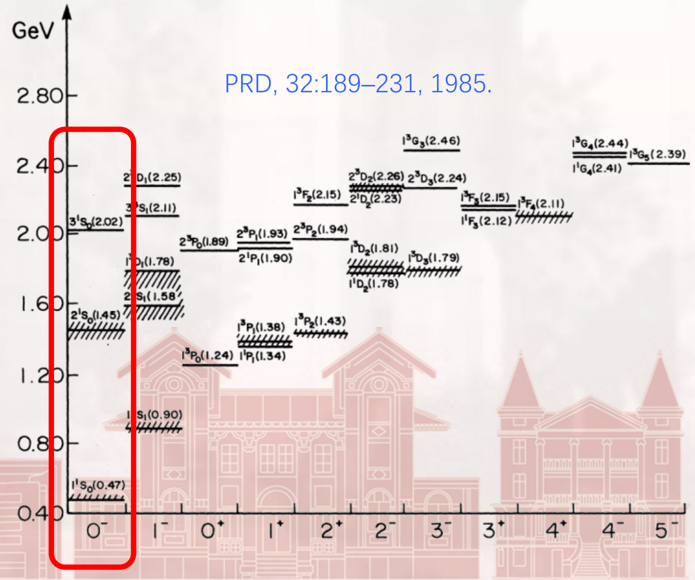
- QM predicts only two excited K meson below 2.5GeV
- Lightest--$K(1430)$ Heaviest--$K(1830)$
- Middle one -- $K(1690)$??? A candidate for exotic strange meson

Tetraquark or hybrid meson ?

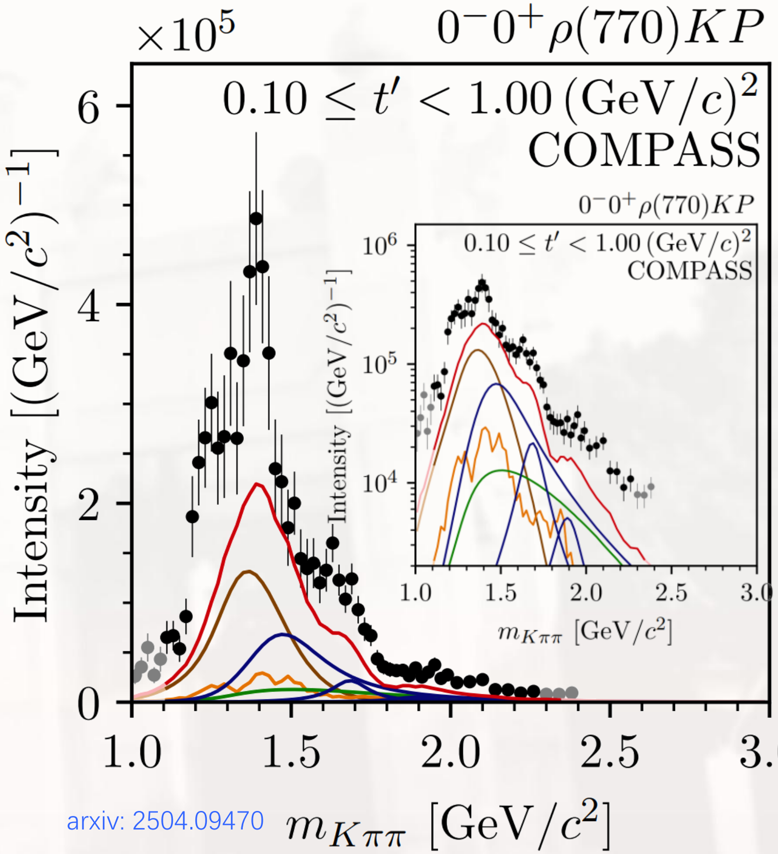
arxiv: 2504.09470

		$K(1690)/K(1630)$	$K(1830)$
COMPASS	m_0 [MeV/c^2]	$1687 \pm 10^{+\ 2}_{-67}$	$1893 \pm 17^{+13}_{-39}$
	Γ_0 [MeV/c^2]	$\boxed{140 \pm 20^{+50}_{-50}}$	$160 \pm 40^{+60}_{-80}$
PDG	m_0 [MeV/c^2]	$1629 \pm\ 7$	$1874 \pm 43^{+\ 59}_{-115}$
	Γ_0 [MeV/c^2]	$\boxed{16^{+19}_{-16}}$	$168 \pm 90^{+208}_{-104}$

$J^P = ?^?$ of $K(1630)$



PRD, 32:189–231, 1985.



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Three bule-resonance components

$K(1690)$ – pseudoscalar Tetraquark $uq\bar{q}\bar{s}$?

- QCD sum rules starts from correlation functions:

$$\Pi(q^2) = \mathrm{i}\int \mathrm{d}^d x\, \mathrm{e}^{\mathrm{i}qx}\langle 0|T[J(x)J^\dagger(0)|0\rangle$$

- There exist 10 $J^P = 0^-$ tetraquark currents

$$6_F\otimes\bar{6}_F(S)\ \begin{cases} S_6 = u_a^T C d_b(\bar{d}_a\gamma_5 C\bar{s}_b^T + \bar{d}_b\gamma_5 C\bar{s}_a^T) \\ V_6 = u_a^T C\gamma_5 d_b(\bar{d}_a C\bar{s}_b^T + \bar{d}_b C\bar{s}_a^T) \\ T_3 = u_a^T C\sigma_{\mu\nu} d_b(\bar{d}_a\sigma_{\mu\nu}\gamma_5 C\bar{s}_b^T - \bar{d}_b\sigma_{\mu\nu}\gamma_5 C\bar{s}_a^T) \end{cases}$$

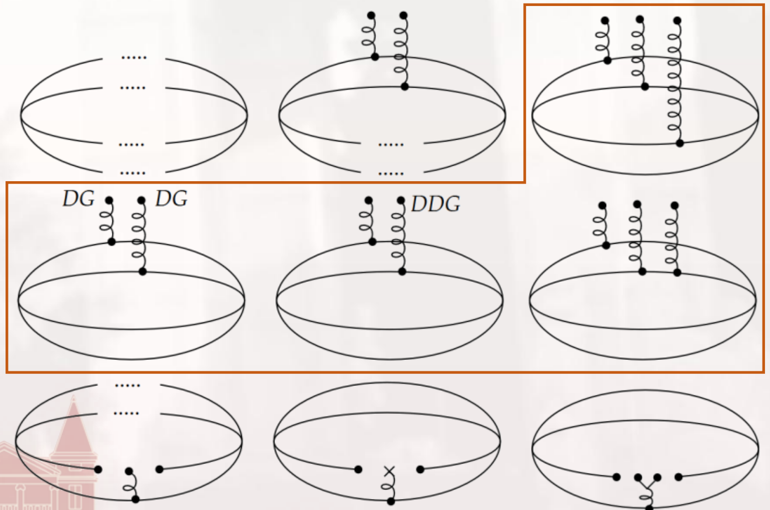
$$\bar{3}_F\otimes 3_F(A)\ \begin{cases} S_3 = u_a^T C d_b(\bar{d}_a\gamma_5 C\bar{s}_b^T - \bar{d}_b\gamma_5 C\bar{s}_a^T) \\ V_3 = u_a^T C\gamma_5 d_b(\bar{d}_a C\bar{s}_b^T - \bar{d}_b C\bar{s}_a^T) \\ T_6 = u_a^T C\sigma_{\mu\nu} d_b(\bar{d}_a\sigma_{\mu\nu}\gamma_5 C\bar{s}_b^T + \bar{d}_b\sigma_{\mu\nu}\gamma_5 C\bar{s}_a^T) \end{cases}$$

$$\bar{3}_F\otimes\bar{6}_F(M)\ \begin{cases} A_6 = u_a^T C\gamma_\mu d_b(\bar{d}_a\gamma_\mu\gamma_5 C\bar{s}_b^T + \bar{d}_b\gamma_\mu\gamma_5 C\bar{s}_a^T) \\ P_3 = u_a^T C\gamma_\mu\gamma_5 d_b(\bar{d}_a\gamma_\mu C\bar{s}_b^T - \bar{d}_b\gamma_\mu C\bar{s}_a^T) \end{cases}$$

$$6_F\otimes 3_F(M)\ \begin{cases} P_6 = u_a^T C\gamma_\mu\gamma_5 d_b(\bar{d}_a\gamma_\mu C\bar{s}_b^T + \bar{d}_b\gamma_\mu C\bar{s}_a^T) \\ A_3 = u_a^T C\gamma_\mu d_b(\bar{d}_a\gamma_\mu\gamma_5 C\bar{s}_b^T - \bar{d}_b\gamma_\mu\gamma_5 C\bar{s}_a^T) \end{cases}$$

- Up to dimension-8 nonperturbative condensates:

$\langle\bar{q}q\rangle, \langle g^2G^2\rangle, \langle\bar{q}q\rangle^2, \langle\bar{q}Gq\rangle, \langle g^3fG^3\rangle\ \langle\bar{q}GDq\rangle, \langle\bar{q}(DG)q\rangle$ ...



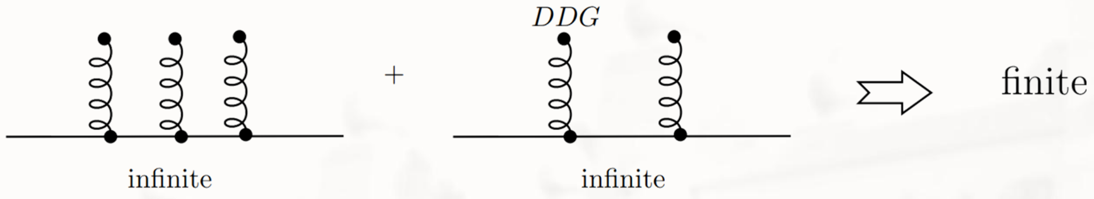
Containing IR divergence

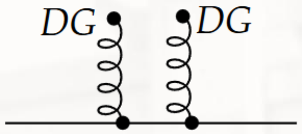
- The lowest lying resonance

$$M_X = \sqrt{\frac{L_1(s_0, M_B^2)}{L_0(s_0, M_B^2)}}\quad L_k(s_0, M_B^2) = \int_0^{s_0}\rho(s)s^k \mathrm{e}^{-s/M_B^2}\mathrm{d}s$$

IR safety of $\langle g^3 fG^3\rangle$ in QCD Sum Rules

- IR safety for the single quark propagator. (ignore $g^4\langle\bar{q}q\rangle^2$)

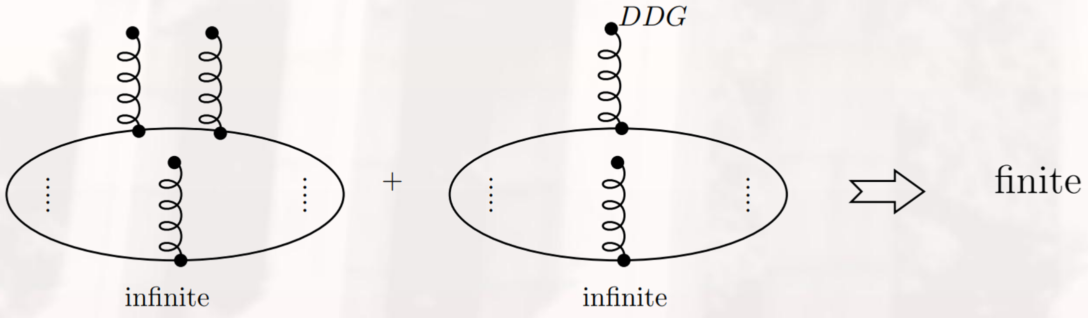


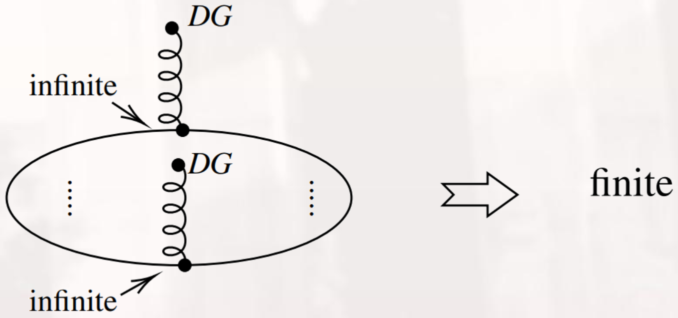


$$= \frac{-i\delta_{ij}\langle g^3 fG^3\rangle\Gamma\left(\frac{d}{2}-1\right)\not{x}}{1728d(d+2)\pi^{d/2}(-x^2)^{d/2-3}}$$

Must be calculated in d-dimensional !
Propagator and condensate.

- IR safety for the two different quark propagators.



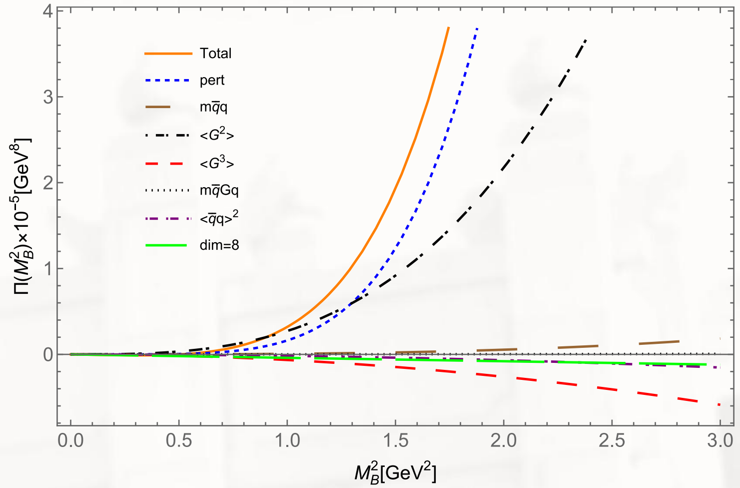


The LO of $\langle g^3 fG^3\rangle$ can be fully calculated.

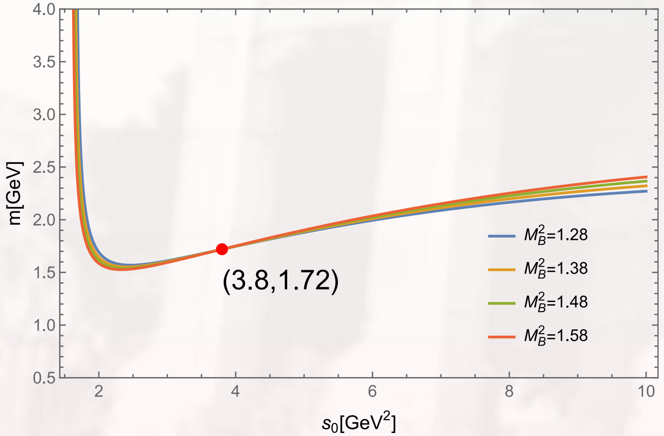
The impact of $\langle g^3 f G^3 \rangle$

- Take current P_3 as an example. Contribution

$$\Pi^{\text{pert}} > \Pi^{\langle G^2 \rangle} > \Pi^{\langle G^3 \rangle} > \Pi^{\langle \bar{q} q \rangle^2} > \cdots$$

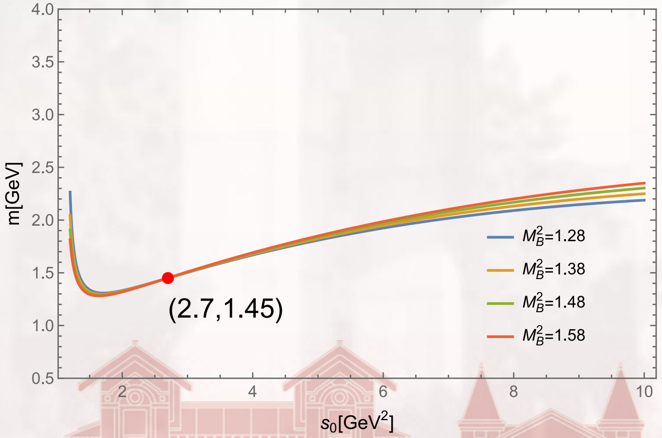


With $\langle g^3 f G^3 \rangle$



Differ by 20%!

Without $\langle g^3 f G^3 \rangle$



$\langle g^3 f G^3 \rangle$ provides significant Contribution in light tetraquark systems!

Results for $ud\bar{d}\bar{s}$

- Uncertainty is from s_0, condensates and m_s.

Currents	$s_0(\pm 0.2\,\text{GeV}^2)$	$M_B^2\,(\text{GeV}^2)$	m (GeV)	PC(%)
P_6	3.3	$1.14 \sim 1.35$	1.62 ± 0.10	> 15
P_3	3.8	$1.28 \sim 1.50$	1.72 ± 0.10	> 20
V_3	3.3	$1.42 \sim 1.62$	1.60 ± 0.16	> 10
A_3	2.8	$0.95 \sim 1.20$	1.48 ± 0.20	> 10
T_6	2.4	$0.75 \sim 1.10$	1.36 ± 0.05	> 15
T_3	4.7	$0.90 \sim 1.35$	1.92 ± 0.04	> 25

1.Masses of currents (P_6, P_3, V_3) are consistent with $K(1690)$, supporting the interpretation of is as a tetraquark state.

3.(A_3, T_6) and T_3 are close to $K(1460)$ and $K(1830)$

Thank you!