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$K_1(1270)$-K_1 (1400) mixing in QCD sum rule

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第十七届粒子物理、核物理和宇宙学交叉学科前沿问题研讨会

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目 录

1. Introduction

1. The flavor SU(3) symmetry plays an important role in the conventional quark model, which classifies hadrons into various of irreducible representations.

2. Although the assumption of perfect flavor SU(3) symmetry succeeds in most of phenomenological analysis on hadron decays and spectrums, its breaking effect still cannot be neglected.

3. One of the physical effect due to the flavor SU(3) breaking is the hadron mixing.

1. Introduction

There are two sources of the flavor SU(3) breaking.

1. The electric charge difference among the u, d, s quarks, which involves the QED effect. the QED effect is expected to be tiny!

2. The mass difference between u, d and s quarks, which only provides QCD contribution to hardon mixing.

$$\mathcal{L}_0 = \sum_q \bar{\psi}_q (i \not{D} - m_u)\psi_q + e \sum_q e_s \bar{\psi}_q \not{A} \psi_q + e e_c \bar{\psi}_c \not{A} \psi_c,$$

$$\Delta\mathcal{L} = \underbrace{\boxed{\bar{\psi}_s (m_u - m_s)\psi_s}}_{\text{QCD}} + \underbrace{\boxed{e(e_u - e_s)\bar{\psi}_u \not{A} \psi_u}}_{\text{QED}}.$$

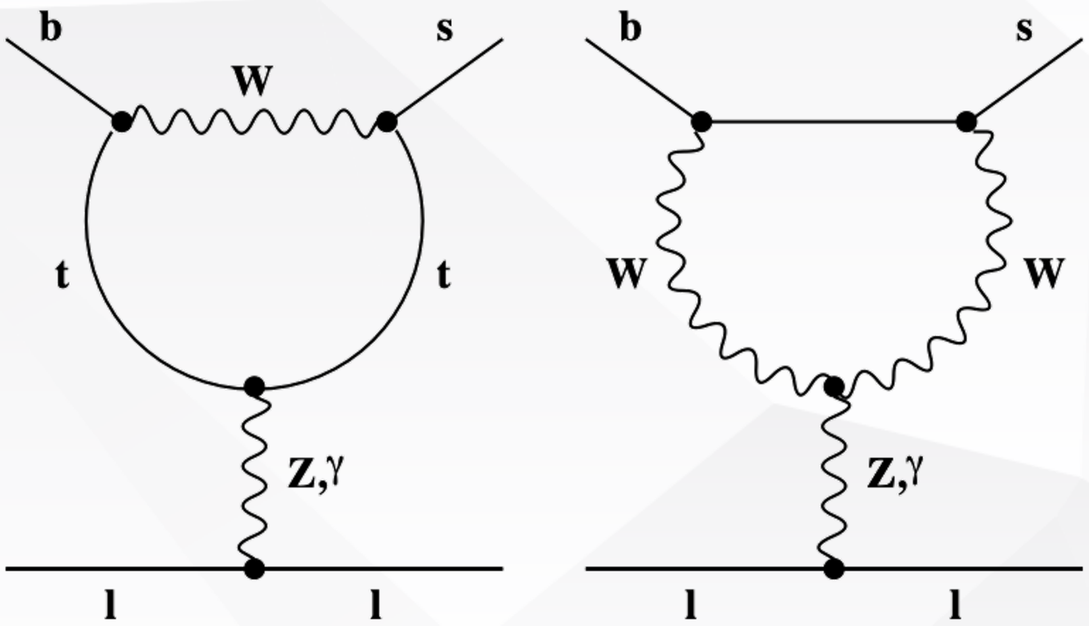
Flavor SU(3) breaking:

$$\underbrace{\begin{pmatrix} |K_1(1270)\rangle \\ |K_1(1400)\rangle \end{pmatrix}}_{\text{Physical states}} = \underbrace{\begin{pmatrix} \cos\theta_{K_1} & \sin\theta_{K_1} \\ -\sin\theta_{K_1} & \cos\theta_{K_1} \end{pmatrix}}_{\text{Mixing matrix}} \underbrace{\begin{pmatrix} |K_{1B}\rangle \\ |K_{1A}\rangle \end{pmatrix}}_{\text{Flavor states}} \begin{matrix} {}^1P_1 \; 1^{+-} \\ {}^3P_1 \; 1^{++} \end{matrix}$$

Mixing angle is very important!

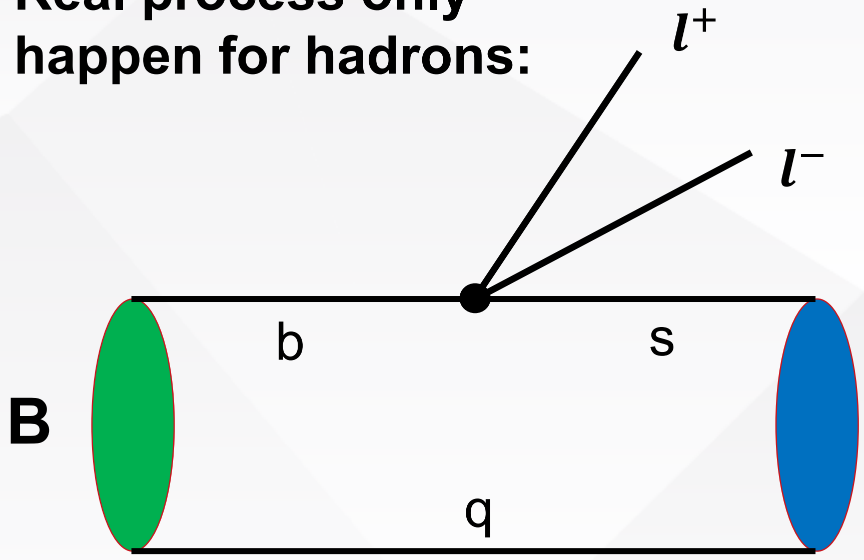
FCNC process:

FCNC decays: $B \to K\, l^+ l^-$



An indirect method of measuring θ_{K1} in D meson decays was proposed by P. F. Guo, D. Wang, F. S. Yu in Ref. [Nuclear Physics Review, 36, 125 (2019)].

Real process only happen for hadrons:



Mixing in axial vector kaons

$K,\ K^*,\ K_1 \cdots$

$0^-,\ 1^-,\ 1^+$

Sensitive to new physics !

1. Introduction

(1). Using early experimental information on masses and the partial rates of $K_1(1270)$ and $K_1(1400)$. *Phys.Rev.D* 47 (1993) 1252-1255

(2). Phenomenologically analyzing on the τ weak decays: $\tau \to K_1(1270)\nu_\tau$ and $\tau \to K_1(1400)\nu_\tau$,
Phys.Rev.D 67 (2003) 094007, Phys.Rev.D 79 (2009) 034014

(3). Analyzing the $f_1(1285) - f_1(1420)$ mixing angle and its correlation to θ_{K_1},
Z.Phys.C 76 (1997) 469-474

(4). Analyzing both the mixing angle of $f_1(1285) - f_1(1420)$ and $h_1(1175) - h_1(1380)$, PoS Hadron2013 (2013) 090

(5). Non-relativistic constituent quark model, Phys.Rev.D 56 (1997) R1368-R1372

(6). Extract θ_{K_1} from $B \to J/\psi\, K_1(1270)$ and $B \to J/\psi\, K_1(1400)$ in PQCD,
Eur.Phys.J.C 78 (2018) 3, 219

(7). QCD sum rules with two-point correlation function,
J.Phys.Conf.Ser. 348 (2012) 012012

K_1(1270)-K_1(1400) mixing angle in literatures

Refs.	$\lvert\theta_{K_1}\rvert$
(1)	33° or 57°
(2)	37° or 58°
(3)	$\left(31.7^{+2.8}_{-2.5}\right)^\circ$ or $\left(56.3^{+3.9}_{-4.1}\right)^\circ$
(4)	$28^\circ < \lvert\theta_{K_1}\rvert < 30^\circ$
(5)	$34^\circ < \lvert\theta_{K_1}\rvert < 55^\circ$
(6)	33° and 58°
(7)	$39^\circ \pm 4^\circ$

2. mixing from SU(3) breaking

$$\mathcal{L}_{\rm QCD} = \mathcal{L}_0 + \Delta\mathcal{L}$$

SU(3) conserving term: The same mass for u, d, s:

$$\mathcal{L}_0 \;=\; \sum_q \bar{q}(i\not{D} - m_u)q$$

SU(3) breaking terms: The different mass for u, d, s:

$$\Delta\mathcal{L} \;=\; \bar{s}(m_u - m_s)s$$

$$\Delta H = \int d^3x \Delta\mathcal{H}(x) = -\int d^3x \Delta\mathcal{L}(x)$$

the mass eigenstates of the full Hamiltonian H:

$$H|K_1(1270)\rangle = m_{1270}|K_1(1270)\rangle,$$
$$H|K_1(1400)\rangle = m_{1400}|K_1(1270)\rangle.$$

the mass eigenstates of the SU(3) conserved Hamiltonian H0:

$$H_0|K_{1B}\rangle = m_{1B}|K_{1B}\rangle,$$
$$H_0|K_{1A}\rangle = m_{1A}|K_{1A}\rangle\rangle.$$

Full Hamiltonian: $H = H_0 + \Delta H$

2. mixing from SU(3) breaking

This method was firstly proposed in the study of $\Xi_c - \Xi_c'$ mixing :

H. Liu, W. Wang, Q. Zhang, the $\Xi_c - \Xi_c'$ mixing from lattice QCD, Phys.Lett.B 841 (2023) 137941.

H. Liu, W. Wang, Q. Zhang, Improved method to determine the $\Xi_c - \Xi_c'$ mixing, PRD 109(2024)036037.

and a further study including the QED effect:

Z. Deng, Y. Shi, W. Wang and J. Zeng, QED contributions to the $\Xi_c - \Xi_c'$ mixing, PRD109(2024)036014.

the QED effect is expected to be tiny!

2. mixing from SU(3) breaking

Transformation between doublets:

$$|K_P\rangle = (|K_1(1270)\rangle, |K_1(1400)\rangle)^T \qquad |K_F\rangle = (|K_{1B}\rangle, |K_{1A}\rangle)^T$$

$$|K_P\rangle = \begin{pmatrix} \cos\theta_{K_1} & \sin\theta_{K_1} \\ -\sin\theta_{K_1} & \cos\theta_{K_1} \end{pmatrix} |K_F\rangle = U|K_F\rangle$$

$$\begin{pmatrix} \langle K_{1B}(\lambda')|H|K_{1B}(\lambda)\rangle & \langle K_{1B}(\lambda')|H|K_{1A}(\lambda)\rangle \\ \langle K_{1A}(\lambda')|H|K_{1B}(\lambda)\rangle & \langle K_{1A}(\lambda')|H|K_{1A}(\lambda)\rangle \end{pmatrix}$$

$$= 2(2\pi)^3\delta^{(3)}(\vec{0})\delta_{\lambda\lambda'}$$

$$\times \begin{pmatrix} m_{1270}^2\ c_k^2 + m_{1400}^2\ s_k^2 & \boxed{(m_{1270}^2 - m_{1400}^2)\ c_k s_k} \\ (m_{1270}^2 - m_{1400}^2)\ c_k s_k & m_{1270}^2\ s_k^2 + m_{1400}^2\ c_k^2 \end{pmatrix}$$

$$\boxed{\begin{aligned}&\langle K_{1B}(\lambda')|H|K_{1A}(\lambda)\rangle \\ &= (2\pi)^3\delta^{(3)}(\vec{0})\langle K_{1B}(\lambda')|\Delta\mathcal{H}(0)|K_{1A}(\lambda)\rangle\end{aligned}}$$

$$s_k = \sin\theta_{K_1}$$
$$c_k = \cos\theta_{K_1}$$

2. mixing from SU(3) breaking

$$\sin 2\theta_{K_1} = \frac{m_s - m_u}{m_{1270}^2 - m_{1400}^2}\langle K_{1B}|\bar{s}s(0)|K_{1A}\rangle$$

Same 3-momentum!

$$\langle K_{1B}(p_2)|\bar{s}s(0)|K_{1A}(p_1)\rangle$$

$$= \epsilon_\mu^*(p_2)\left[F_1 g^{\mu\nu} + \frac{F_2}{M^2}\epsilon^{\mu\nu\alpha\beta}p_{1\alpha}p_{2\beta} + \frac{F_3}{M^2}p_1^\mu p_2^\nu\right]\epsilon_\nu(p_1)$$ **Only F_1 is necessary!**

$$\sin 2\theta_{K_1} = \frac{m_s - m_u}{m_{1400}^2 - m_{1270}^2}F_1(0)$$

3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR

$$\Pi_{\mu\nu\rho}(p_1,p_2) = i^2 \int d^4x d^4y\; e^{ip_2\cdot x} e^{-ip_1\cdot y} \langle 0|T\{J^{1B}_{\mu\nu}(x)\bar{s}s(0)J^{1A\dagger}_{\rho}(y)\}|0\rangle$$

$$J^{1B}_{\mu\nu} = \bar{q}\sigma_{\mu\nu}s, \quad J^{1A}_{\rho} = \bar{q}\gamma_\rho\gamma_5 s.$$

$$\begin{aligned}
\langle 0|J^{1B}_{\mu\nu}(0)|K_{1B}(p,\lambda)\rangle &= i f^{\perp}_{K_{1B}}\epsilon_{\mu\nu\alpha\beta}\epsilon^{\alpha}(p,\lambda)p^{\beta}, \\
\langle 0|J^{1A}_{\rho}(0)|K_{1A}(p,\lambda)\rangle &= -i f_{K_{1A}} m_{1A}\epsilon_{\rho}(p,\lambda), \\
\langle 0|J^{1A}_{\rho}(0)|K(p)\rangle &= i f_K p_\rho,
\end{aligned}$$

Hadron Level:
insert complete sets

$$\boxed{\sum_{\lambda_2}\int \frac{d^3k_2}{(2\pi)^3}\frac{1}{2E_{k_2}}|K_{1B}(k_2,\lambda_2)\rangle\langle K_{1B}(k_2,\lambda_2)|}$$

$$\boxed{\sum_{\lambda_1}\int \frac{d^3k_1}{(2\pi)^3}\frac{1}{2E_{k_1}}|K_{1A}(k_1,\lambda_1)\rangle\langle K_{1A}(k_1,\lambda_1)| + \int \frac{d^3k}{(2\pi)^3}\frac{1}{2E_k}|K(k,s=0)\rangle\langle K(k,s=0)|}$$

Quark-hadron duality

Quark-gluon Level:
OPE calculation

$$\boxed{\int \mathrm{d}^4 z e^{\mathrm{i}q\cdot z} T[O_a(z)O_b(0)] = \sum_k C_{abk}(q)O_k(0)}$$

3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR

Hadron Level:

$$
\begin{aligned}
&\Pi^{H}_{\mu\nu\rho}(p_1,p_2)\\
&= -m_A f_A f_B^{\perp}\epsilon_{\mu\nu\alpha\beta}p_2^{\beta}\left(-g^{\alpha\kappa}+\frac{p_2^{\alpha}p_2^{\kappa}}{m_B^2}\right)\frac{1}{p_2^2-m_{1B}^2}\left[F_1 g_{\kappa\tau}+\frac{F_2}{M^2}\epsilon_{\kappa\tau\rho\sigma}p_1^{\rho}p_2^{\sigma}+\frac{F_3}{M^2}p_{1\kappa}p_{2\tau}\right]\left(-g_{\rho}^{\tau}+\frac{p_1^{\tau}p_{1\rho}}{m_{1A}^2}\right)\frac{1}{p_1^2-m_{1A}^2}\\
&\quad + f_K f_{1B}^{\perp}\epsilon_{\mu\nu\alpha\beta}p_2^{\beta}p_{1\rho}\frac{1}{p_2^2-m_{1B}^2}\left(-g^{\alpha\kappa}+\frac{p_2^{\alpha}p_2^{\kappa}}{m_{1B}^2}\right)p_{1\kappa}\frac{G(q^2)}{m_K}\frac{1}{p_1^2-m_K^2}\\
&\quad \boxed{+\int_{s_1^{\rm th}}^{\infty}ds_1\int_{s_2^{\rm th}}^{\infty}ds_2\frac{\rho^{\rm conti}_{\mu\nu\rho}(s_1,s_2,q^2)}{(s_1-p_1^2)(s_2-p_2^2)}+\int_{s_1^{\rm th}}^{\infty}ds_1\frac{\rho^{\rm conti}_{1,\mu\nu\rho}(s_1,p_2,q^2)}{s_1-p_1^2}+\int_{s_2^{\rm th}}^{\infty}ds_2\frac{\rho^{\rm conti}_{2,\mu\nu\rho}(p_1,s_2,q^2)}{s_2-p_2^2}.}
\end{aligned}
$$

$$\langle K_{1B}(p_2)|\bar{s}s(0)|K(p_1)\rangle = \epsilon^{*}_{\mu}(p_2)p_1^{\mu}\frac{G(q^2)}{m_K}$$

To remove the irrelevant form factors we operate the following projection on the correlation function

$$\epsilon^{\mu\rho\alpha\beta}p_1^{\nu}\Pi_{\mu\nu\rho}(p_1,p_2) = \tilde{\Pi}(p_1,p_2)(p_1^{\beta}p_2^{\alpha}-p_1^{\alpha}p_2^{\beta})$$

$$\tilde{\Pi}^{H}(p_1,p_2) = \frac{2m_{1A}f_{1A}f_{1B}^{\perp}F_1(q^2)}{(p_1^2-m_{1A}^2)(p_2^2-m_{1B}^2)}+\boxed{\cdots}$$

3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR

$$\mathcal{B}_{T_1,T_2}\{\tilde{\Pi}^H\}(q^2) = \mathcal{B}_{T_1,T_2}\{\tilde{\Pi}^{\rm QCD}\}(q^2),$$

OPE calculation

$$\underbrace{2m_{1A}f_{1A}f_{1B}^{\perp}\, e^{-\frac{m_{1A}^2}{T_1^2}} e^{-\frac{m_{1B}^2}{T_2^2}} F_1(q^2)}_{\text{Hadron Level}} = \underbrace{\frac{1}{\pi^2}\int_{s_1^{\rm min}}^{s_1^{\rm th}} ds_1 \int_{s_2^{\rm min}}^{s_2^{\rm th}} ds_2\, e^{-\frac{s_1}{T_1^2}} e^{-\frac{s_2}{T_2^2}} \boxed{{\rm Im}^2\tilde{\Pi}^{\rm QCD}(s_1,s_2,q^2)}}_{\text{Quark-gluon Level}}$$

Form factor

Hadron Level ⟷ Quark-gluon Level

Quark-hadron duality

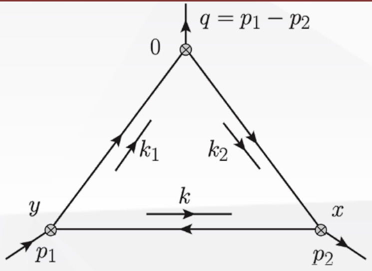
$$s_1^{\rm min} = s_2^{\rm min} = (m_s + m_q)^2$$

$s_{1,2}^{th}$: the threshold of first excited state

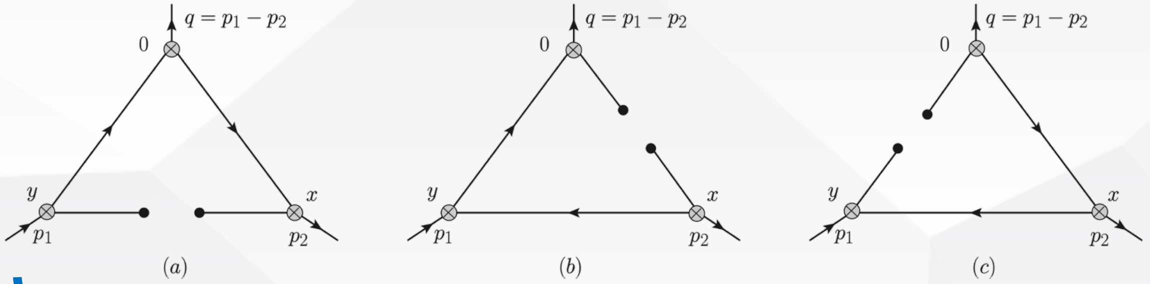
$$s_1^{\rm th} = m_{1A}^2 + \tau_{\rm th}(m_{K(1460)}^2 - m_{1A}^2)$$

$$s_2^{\rm th} = m_{1B}^2 + \tau_{\rm th}(m_{K(1650)}^2 - m_{1B}^2)$$

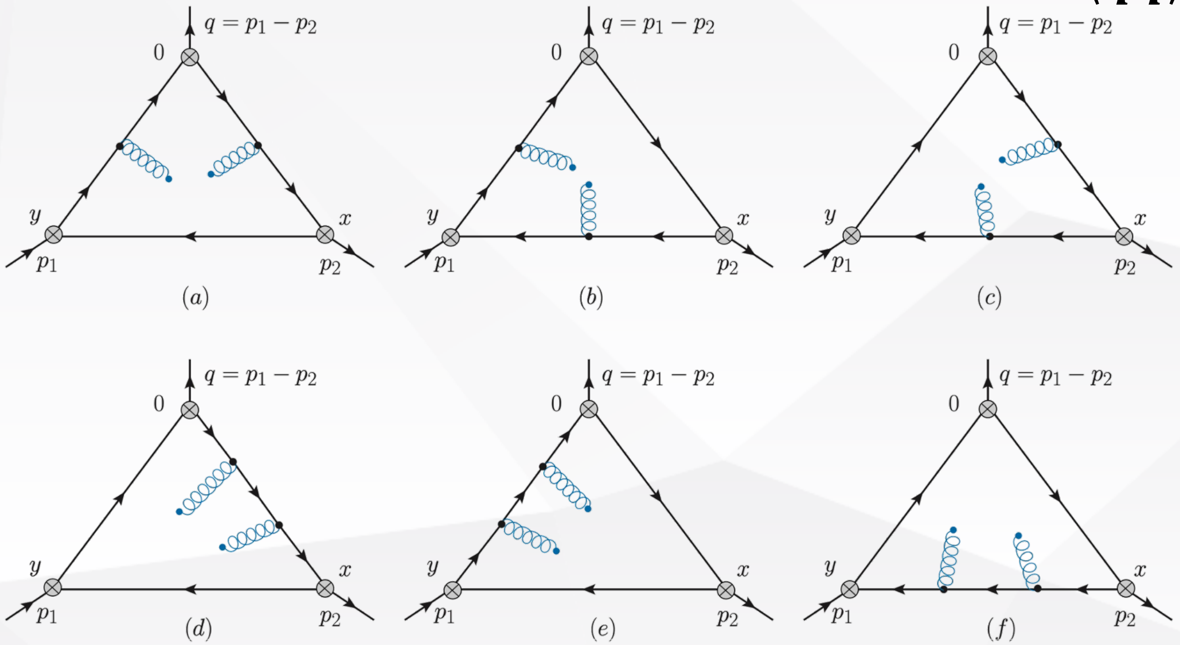
3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR



dim-0



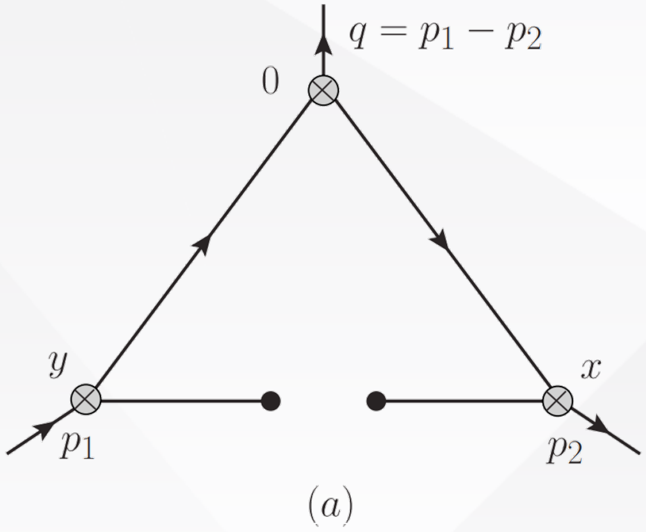
dim-3: $\langle \bar{q}q \rangle$



dim-4: $\langle G^a_{\mu\nu} G^{a\mu\nu} \rangle$

Vanish

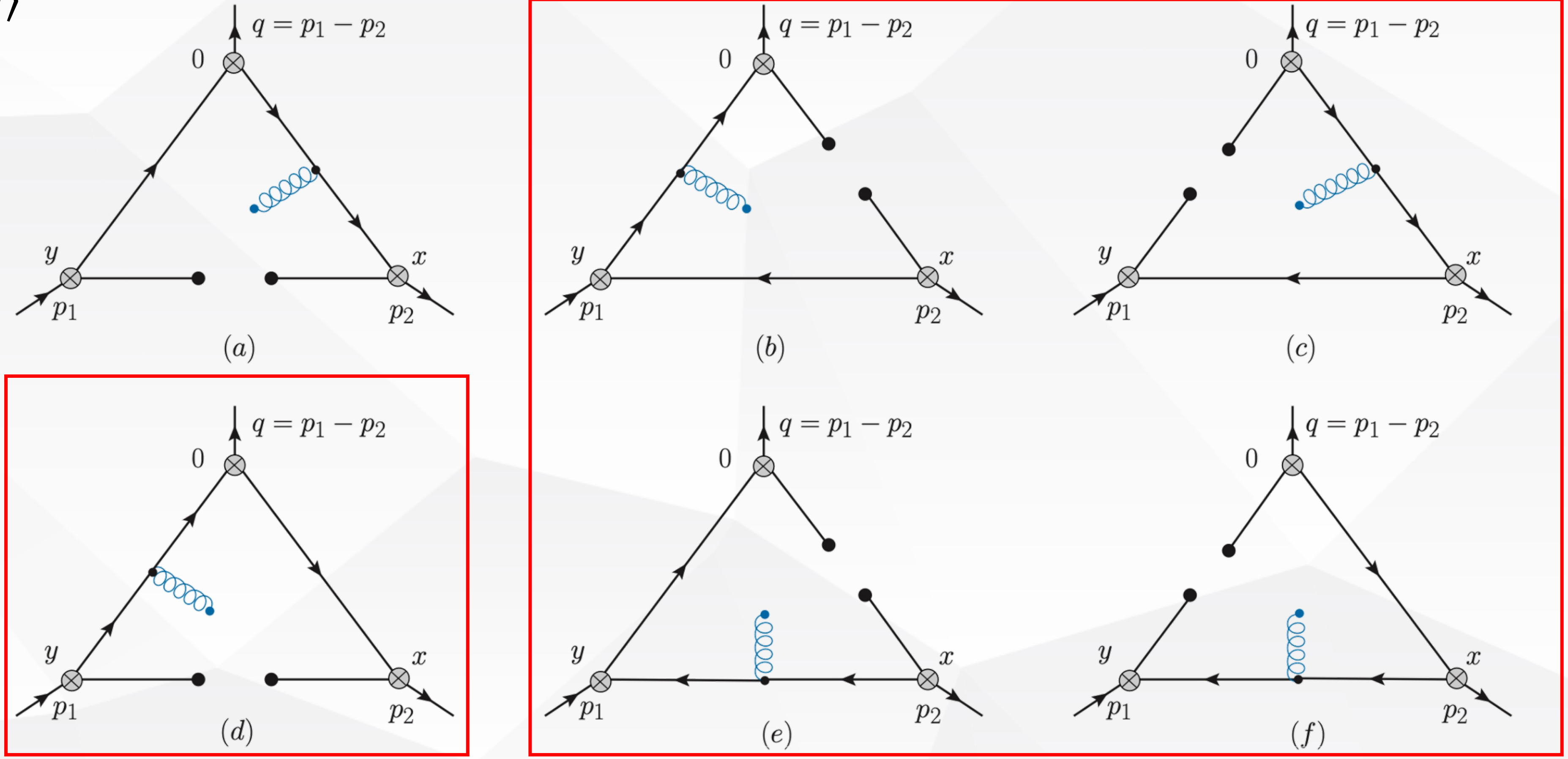
(d), (e) are suppressed by m_s^2; (f) is suppressed by m^2.



$$\left\langle 0 \left| \bar{q}^i_a(x) q^j_b(y) \right| 0 \right\rangle = \delta^{ji} \left[\langle \bar{q}q \rangle \frac{1}{12} \delta_{ba} + \langle \bar{q}Gq \rangle \frac{1}{192} (x-y)^2 \delta_{ba} \right]$$

dim-3 **dim-5**

dim-5: $\langle \bar{q} g_s \sigma_{\mu\nu} G^{\mu\nu} q \rangle$



(d) vanishes under the projection

$$\epsilon^{\mu\rho\alpha\beta} p_1^\nu \Pi_{\mu\nu\rho}(p_1, p_2) = \tilde{\Pi}(p_1, p_2)(p_1^\beta p_2^\alpha - p_1^\alpha p_2^\beta)$$

The diagrams (b), (c), (e) and (f) vanishes under double Borel transformation.

3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR

$$\Pi^{\text{pert}}_{\mu\nu\rho}(p_1,p_2,q^2) = \frac{iN_c}{(2\pi)^4}\int d^4k_1 d^4k_2 d^4k\ \delta^4(p_2-k_2-k)\delta^4(p_1-k_1-k) \times \frac{\mathrm{tr}[\not k\sigma_{\mu\nu}(\not k_2+m_s)(\not k_1+m_s)\gamma_\rho\gamma_5]}{k^2(k_2^2-m_s^2)(k_1^2-m_s^2)}.$$

dim-0

$$\Pi^{\bar q q}_{\mu\nu\rho}(p_1,p_2,q^2) = i^2\int d^4x d^4y\ e^{ip_2\cdot x}e^{-ip_1\cdot y} \times [\sigma_{\mu\nu}D_s^{(0)}(x,0)D_s^{(0)}(0,y)\gamma_\rho\gamma_5]\langle 0|\bar q_a^i(x)q_b^i(y)|0\rangle$$

dim-3 + dim-5

$$\Pi^{GG(a)}_{\mu\nu\rho}(p_1,p_2,q^2) = \int d^4x d^4y\ e^{ip_2\cdot x}e^{-ip_1\cdot y}\int \frac{d^4k_1}{(2\pi)^4}\frac{d^4k_2}{(2\pi)^4}\frac{d^4k}{(2\pi)^4}\ e^{ik_1\cdot y}e^{-ik_2\cdot x}e^{-ik\cdot(y-x)}\left(-\frac{i}{4}\right)^2 \times \mathrm{tr}\left[\frac{-i\not k}{k^2}\sigma_{\mu\nu}\frac{\sigma^{\alpha\beta}(\not k_2+m_s)+(\not k_2+m_s)\sigma^{\alpha\beta}}{(k_2^2-m_s^2)^2}\frac{\sigma^{\kappa\tau}(\not k_1+m_s)+(\not k_1+m_s)\sigma^{\kappa\tau}}{(k_2^2-m_s^2)^2}\gamma_\rho\gamma_5\right] \times \mathrm{tr}[t^At^B]g_s^2\langle 0|G^A_{\alpha\beta}(0)G^B_{\kappa\tau}(0)|0\rangle.$$

dim-4

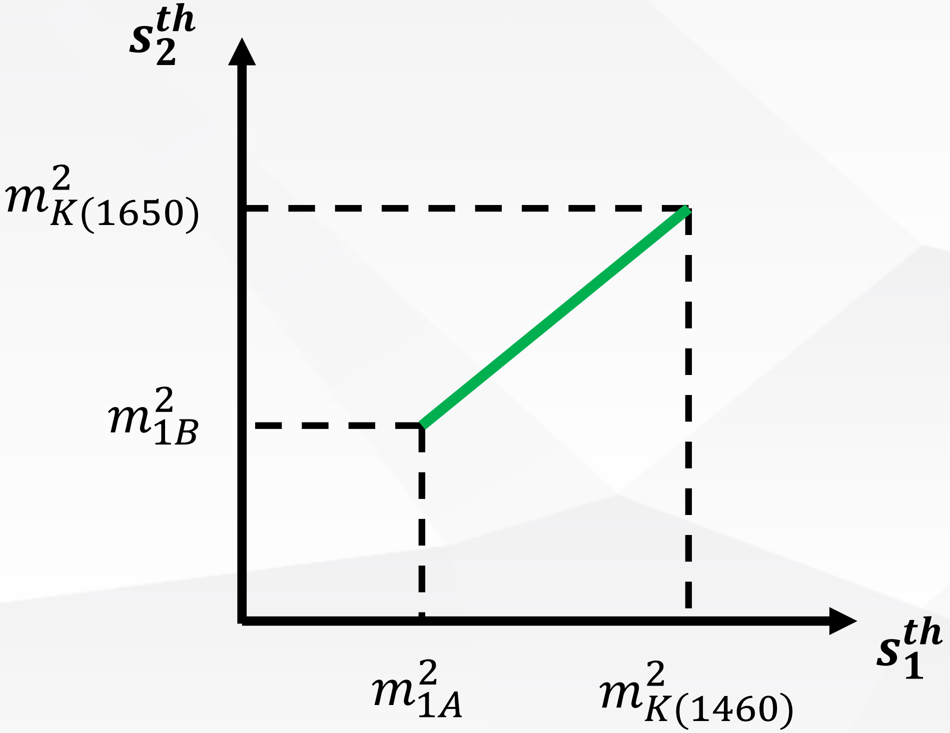
$$\Pi^{GG(b)}_{\mu\nu\rho}(p_1,p_2,q^2) = \int d^4x d^4y\ e^{ip_2\cdot x}e^{-ip_1\cdot y}\int \frac{d^4k_1}{(2\pi)^4}\frac{d^4k_2}{(2\pi)^4}\ e^{ik_1\cdot y}e^{-ik_2\cdot x}\left(-\frac{i}{32\pi^2}\right)\left(-\frac{i}{4}\right)\mathrm{tr}[t^At^B] \times \mathrm{tr}\left[\frac{(\not y-\not x)\sigma^{\kappa\tau}+\sigma^{\kappa\tau}(\not y-\not x)}{(y-x)^2}\sigma_{\mu\nu}\frac{i(\not k_2+m_s)}{k_2^2-m_s^2}\frac{\sigma^{\alpha\beta}(\not k_1+m_s)+(\not k_1+m_s)\sigma^{\alpha\beta}}{(k_1^2-m_s^2)^2}\gamma_\rho\gamma_5\right] \times g_s^2\langle 0|G^A_{\alpha\beta}(0)G^B_{\kappa\tau}(0)|0\rangle.$$

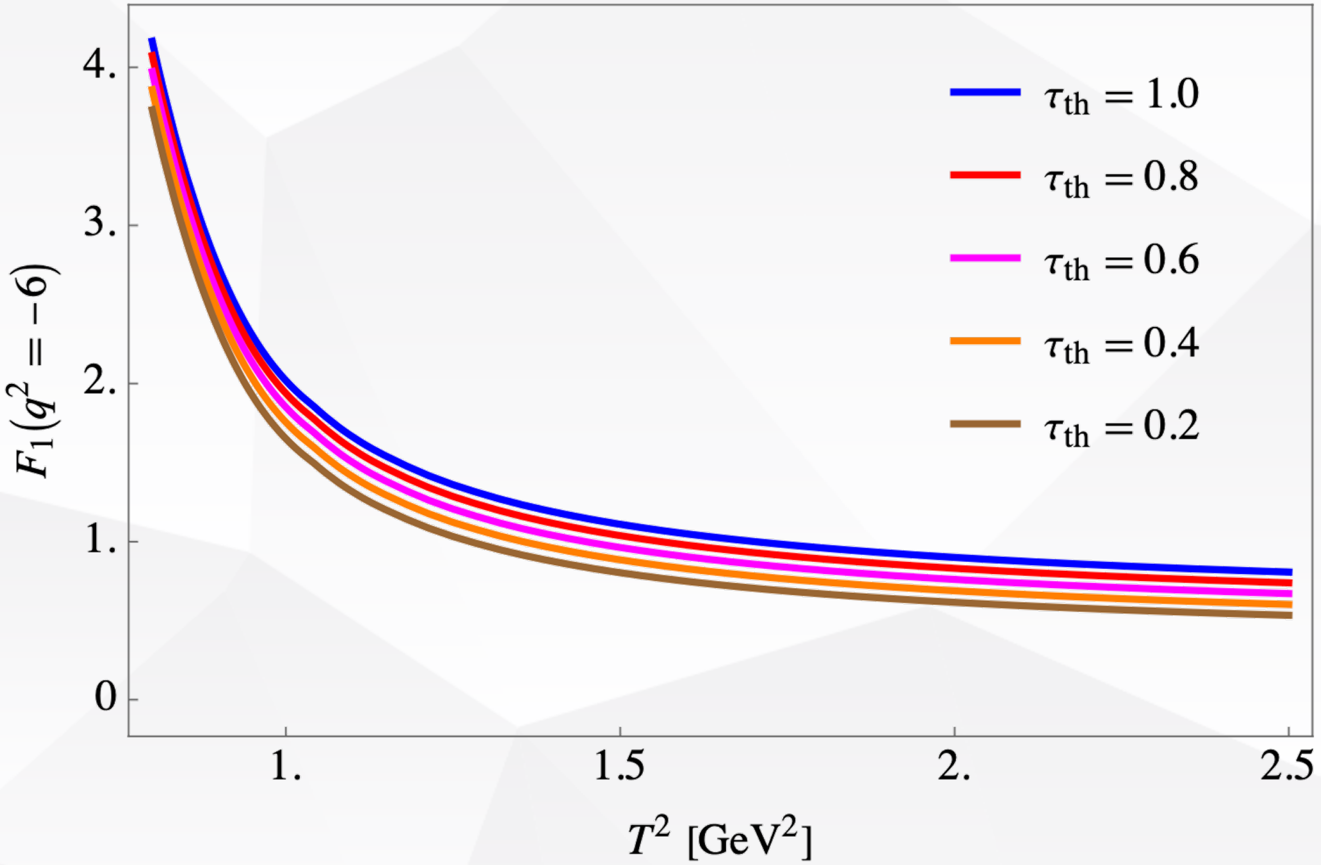
$$\Pi^{\bar q G q(2)}_{\mu\nu\rho}(p_1,p_2,q^2) = i^2\int d^4x d^4y\ e^{ip_2\cdot x}e^{-ip_1\cdot y}\int \frac{d^4k_1}{(2\pi)^4}\frac{d^4k_2}{(2\pi)^4}\ e^{ik_1\cdot y}e^{-ik_2\cdot x} \times \left[\sigma_{\mu\nu}\left(\frac{-i}{4}\right)\frac{\sigma^{\alpha\beta}(\not k_2+m_s)+(\not k_2+m_s)\sigma^{\alpha\beta}}{(k_2^2-m_s^2)^2}\frac{i(\not k_1+m_s)}{k_1^2-m_s^2}\gamma_\rho\gamma_5\right]_{ab} \times t^A_{ij}\langle 0|\bar q_a^i(x)g_sG^A_{\alpha\beta}(0)q_b^i(y)|0\rangle.$$

dim-5

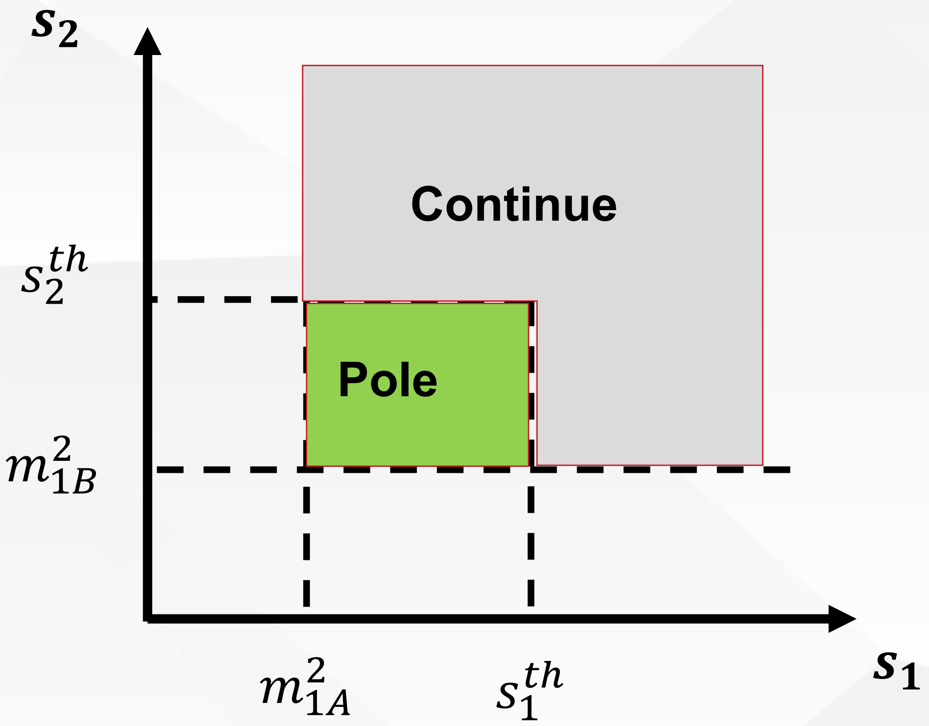
Threshold:

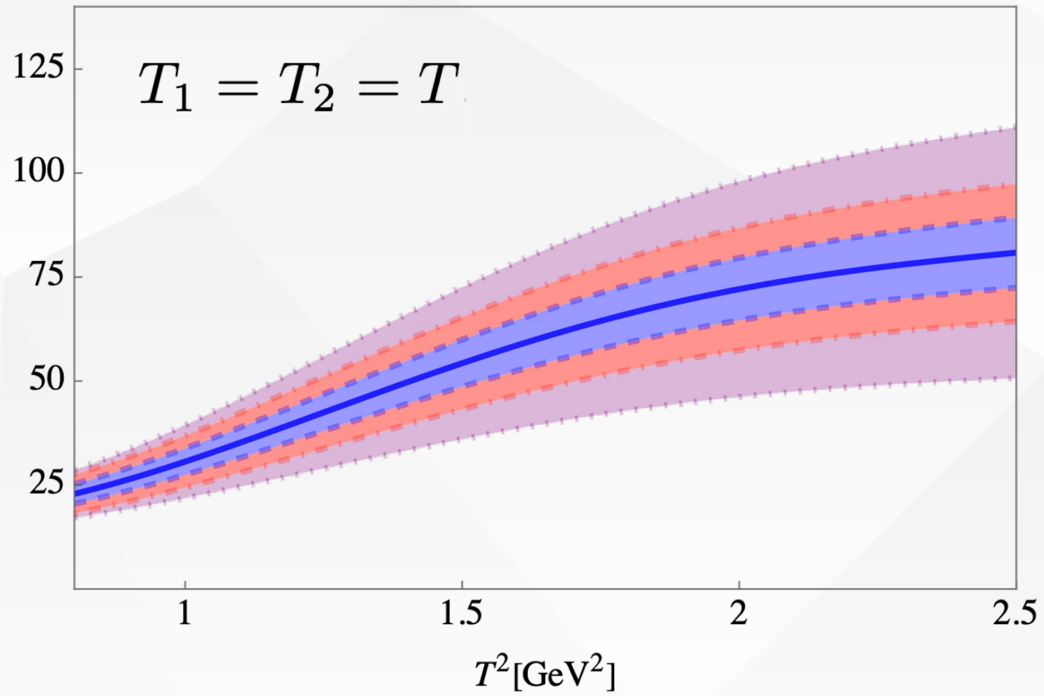
$$s_1^{\mathrm{th}} = m_{1A}^2 + \tau_{\mathrm{th}}(m_{K(1460)}^2 - m_{1A}^2)$$
$$s_2^{\mathrm{th}} = m_{1B}^2 + \tau_{\mathrm{th}}(m_{K(1650)}^2 - m_{1B}^2)$$





3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR





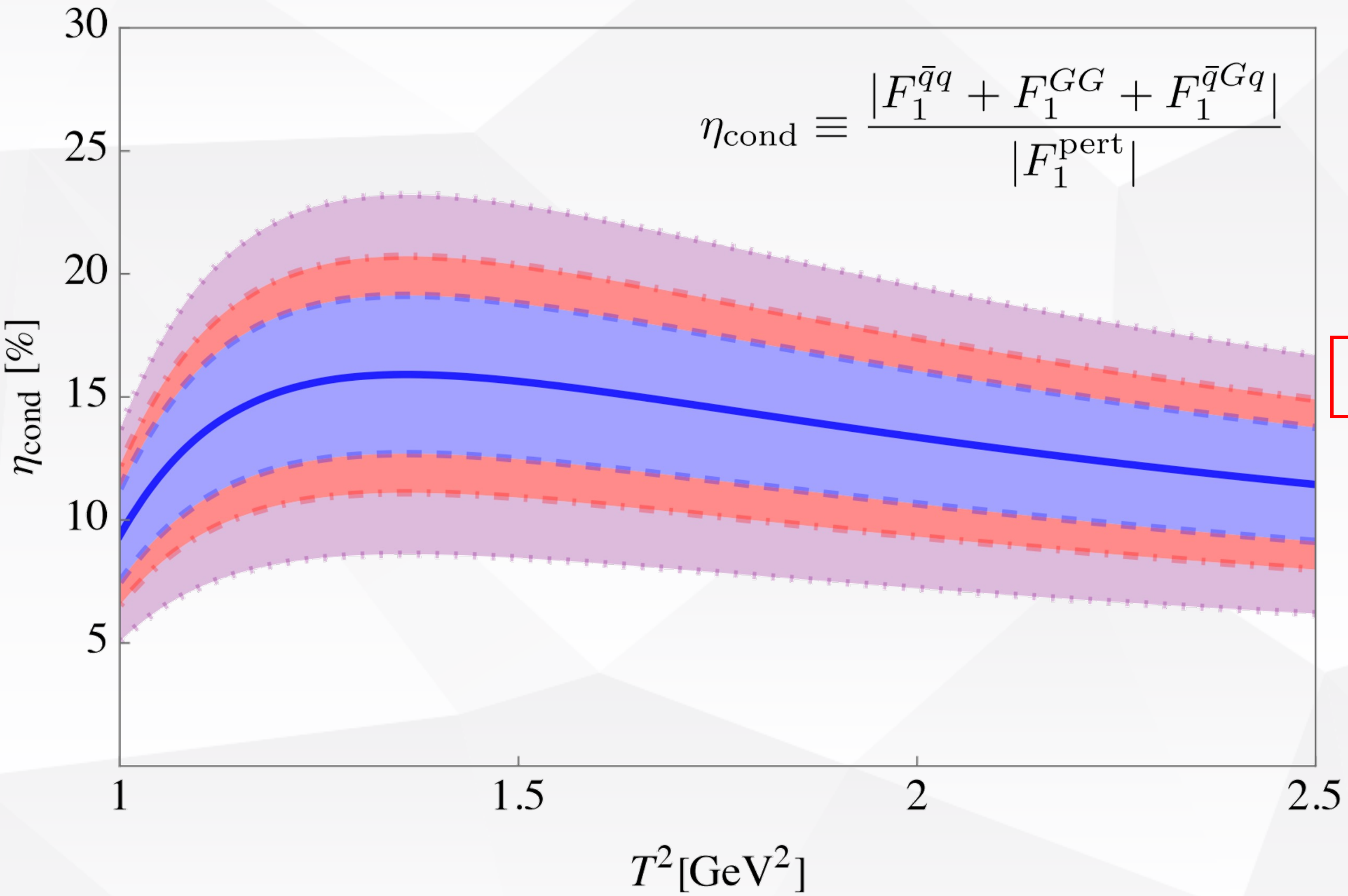
$$\xi_{\rm conti} \equiv \frac{\int_{s_1^{\rm th}}^{\infty} ds_1 \int_{s_2^{\rm th}}^{\infty} ds_2\, e^{-\frac{s_1}{T_1^2}} e^{-\frac{s_2}{T_2^2}} \,{\rm Im}^2\tilde{\Pi}^{\rm QCD}(s_1, s_2, q^2)}{\int_0^{\infty} ds_1 \int_0^{\infty} ds_2\, e^{-\frac{s_1}{T_1^2}} e^{-\frac{s_2}{T_2^2}} \,{\rm Im}^2\tilde{\Pi}^{\rm QCD}(s_1, s_2, q^2)} \lesssim 0.5,$$

$$\frac{\text{Continue}}{\text{Continue+Pole}} < 50\%$$

$$\boxed{1.16\ \mathrm{GeV}^2 < T_{\rm upper}^2 < 2.39\ \mathrm{GeV}^2}$$

The continuous spectrum contribution must be smaller than the pole contribution!

3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR

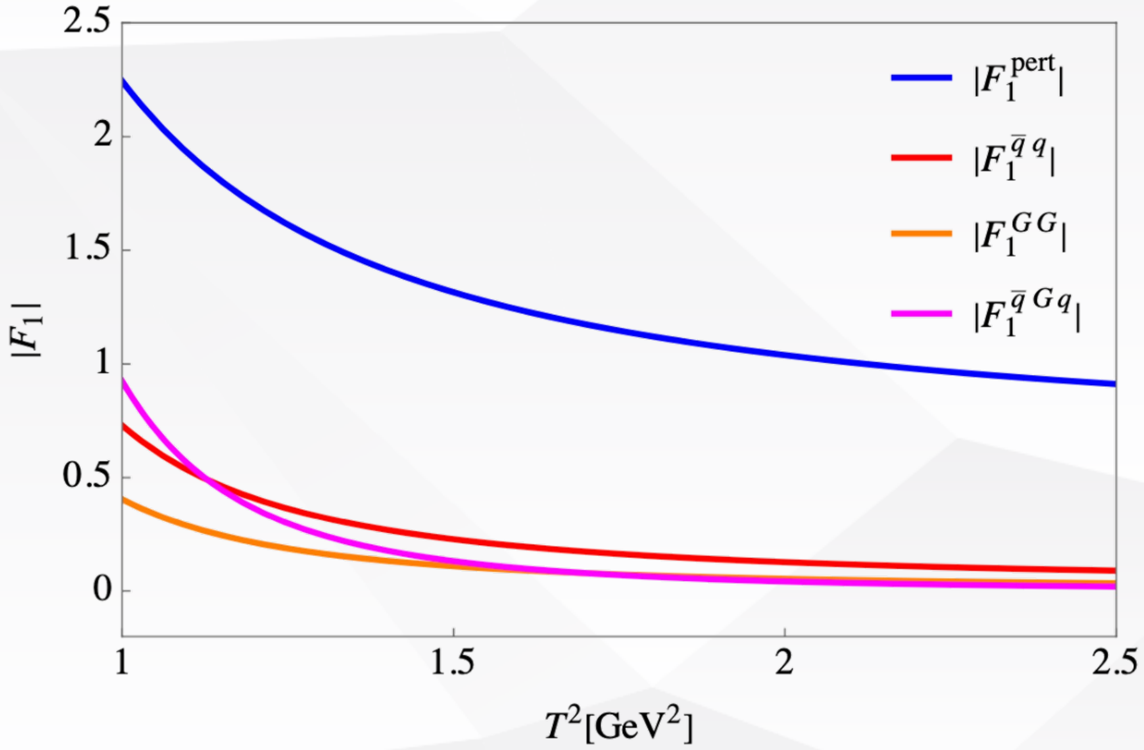


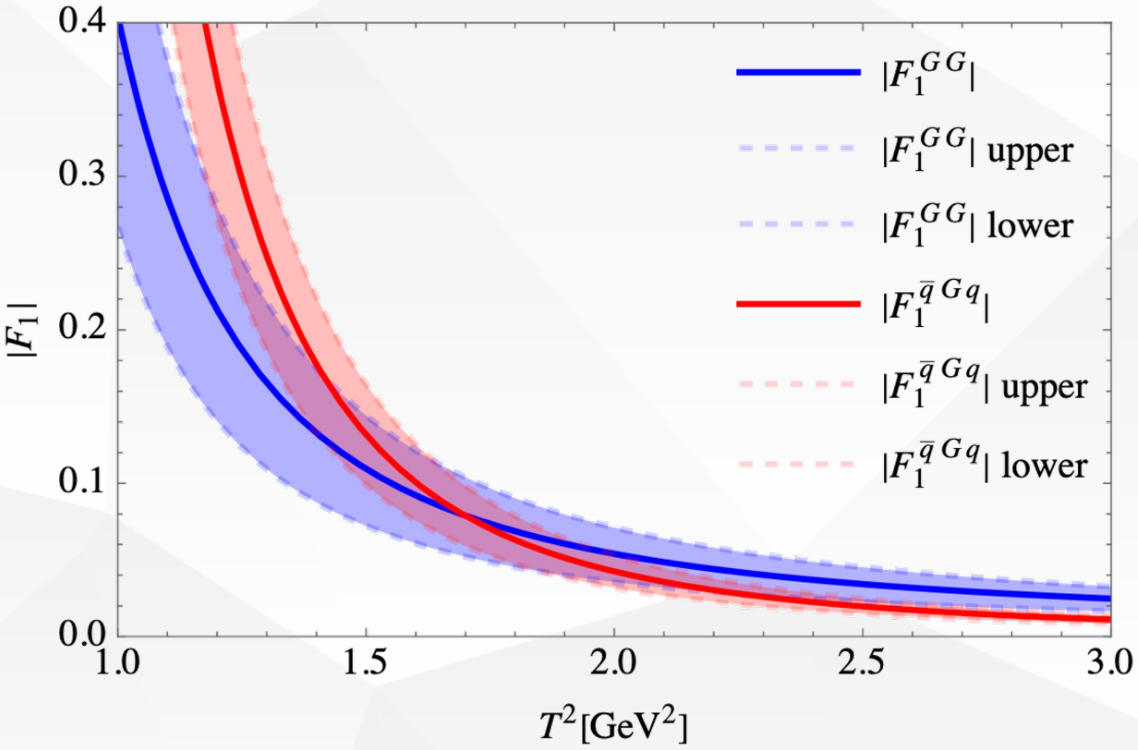
$1.16\ \mathrm{GeV}^2 < T^2_{\rm upper} < 2.39\ \mathrm{GeV}^2$

3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR

Demand:

$$|F_1^{\text{pert}}| > |F_1^{\bar{q}q}| > |F_1^{GG}| > |F_1^{\bar{q}Gq}|.$$





$$\boxed{1.17\ \text{GeV}^2 < T^2_{\text{lower}} < 2.64\ \text{GeV}^2}$$

The contribution from higher dimension less than lower dimension!

3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR

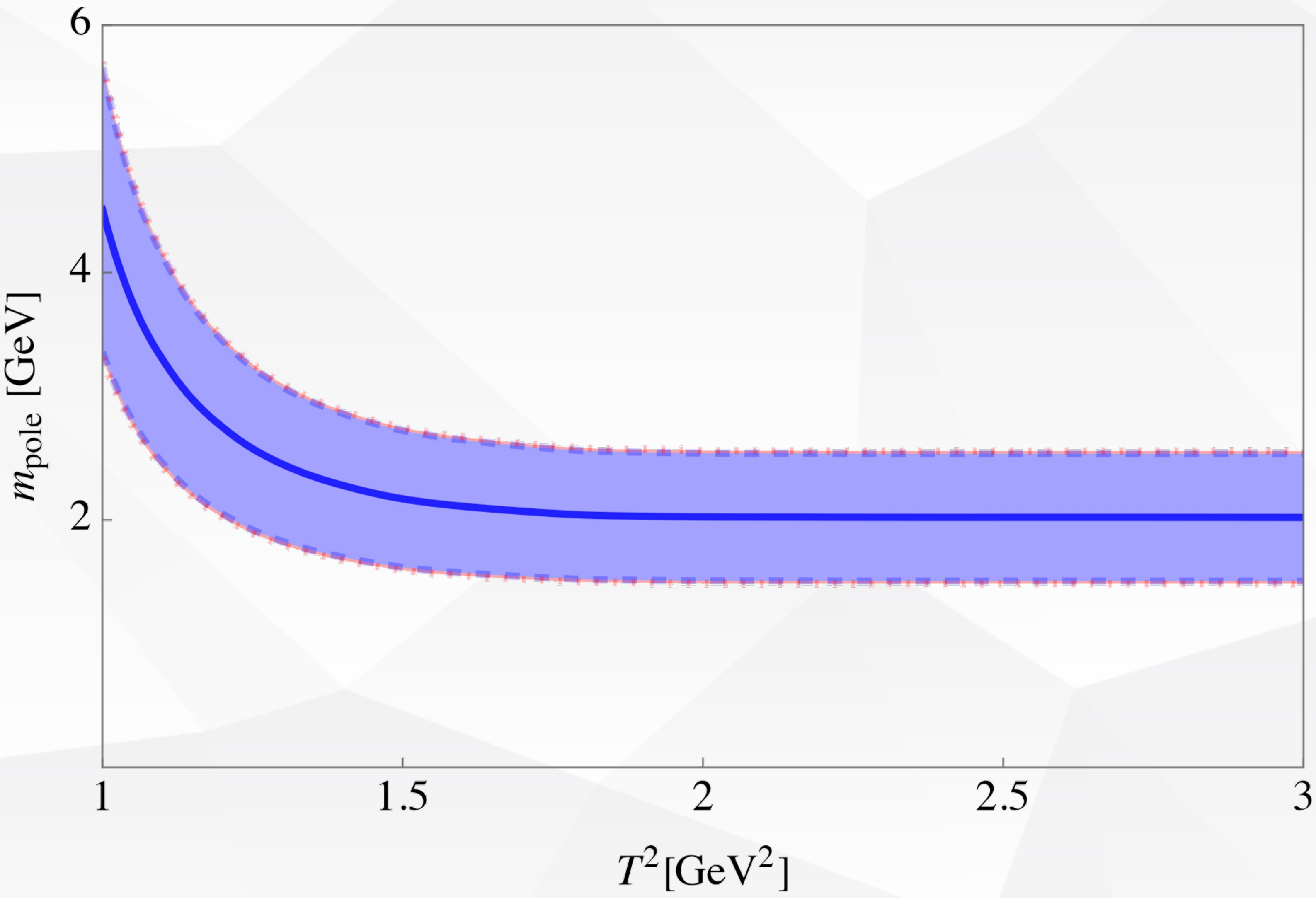
$$1.16\ \mathrm{GeV}^2 < T^2_{\mathrm{upper}} < 2.39\ \mathrm{GeV}^2$$
$$1.17\ \mathrm{GeV}^2 < T^2_{\mathrm{lower}} < 2.64\ \mathrm{GeV}^2$$

$$\Rightarrow \boxed{1.17\ \mathrm{GeV}^2 < T^2 < 2.39\ \mathrm{GeV}^2}$$

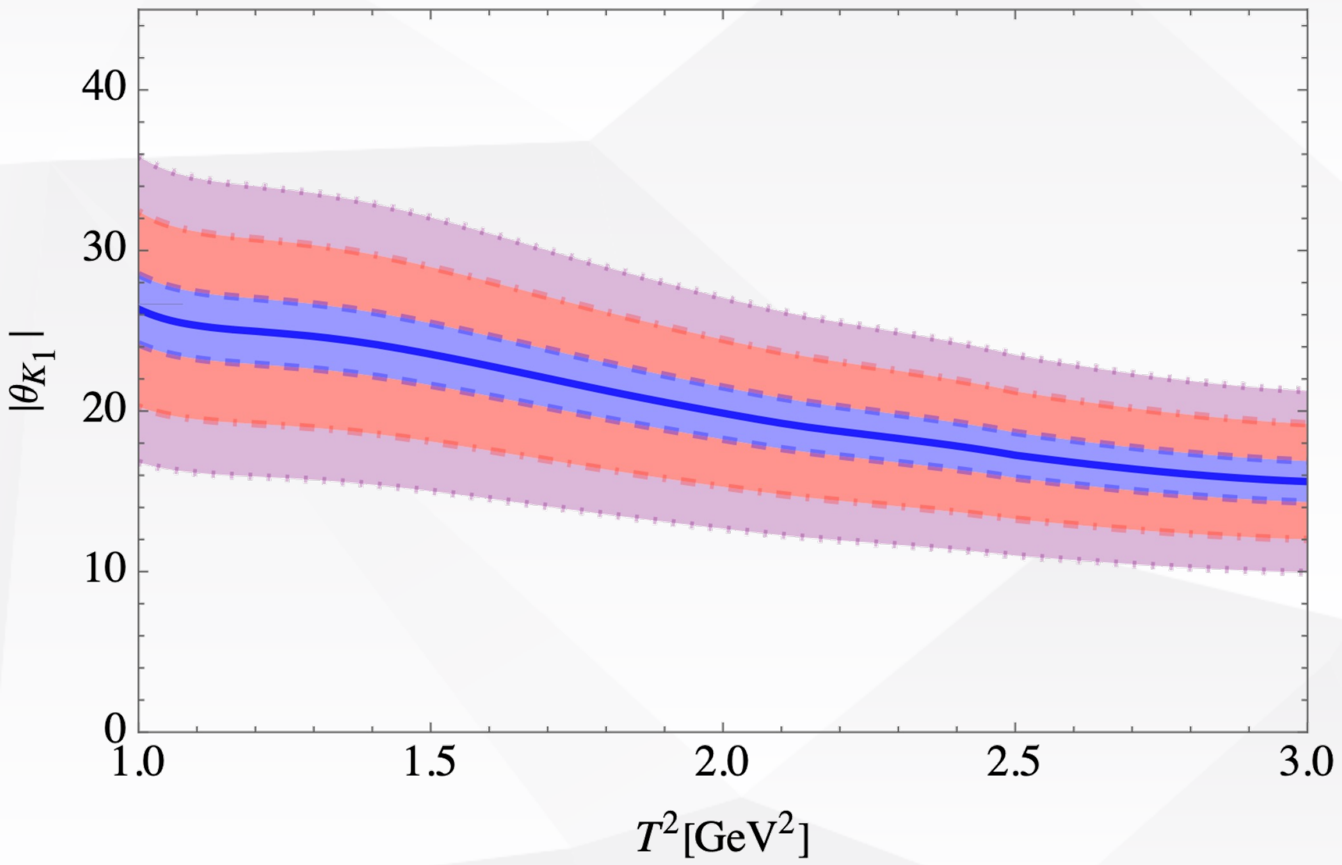
However, instead of the physical region, QCDSR calculation establish on the deep Euclidean region result: F1(q2 ≪ 0) is known.

$$F_1(q^2) = \frac{F_1(0)}{1 - q^2/m^2_{\mathrm{pole}}}$$

3. $K_1(1270)$- $K_1(1400)$ mixing in QCDSR



3. K_1(1270)- K_1(1400) mixing in QCDSR



Refs.	$\|\theta_{K_1}\|$
This Work	$21.4° \pm 9°$ or $68.6° \pm 9°$
(1)	$33°$ or $57°$
(2)	$37°$ or $58°$
(3)	$(31.7^{+2.8}_{-2.5})°$ or $(56.3^{+3.9}_{-4.1})°$
(4)	$28° < \|\theta_{K_1}\| < 30°$
(5)	$34° < \|\theta_{K_1}\| < 55°$
(6)	$33°$ and $58°$
(7)	$39° \pm 4°$

Consistent within the error

4. summary

- Divide the Hamiltonian into the SU(3) conserving and breaking terms.
- Relate $\sin\theta_{K_1}$ with kaon matrix element.
- QCD sum rules calculation for the kaon matrix element.
- Determine the appropriate Borel parameters.

Thank you!