Analysis of the b1 meson decay in local tensor bilinear representation

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Preliminary: field-current identity

- Charged vector meson (ρ) Lagrangian

$$\mathcal{L} = -\frac{1}{4}f_{\mu\nu}^2 - \frac{1}{2}m_0\rho^2 + \mathcal{L}_m(\psi, D_\nu\psi, f_{\mu\nu}) - \frac{1}{4}F_{\mu\nu}^2$$

$$f_{\mu\nu}^a = \partial_\mu\rho_\nu^a - \partial_\nu\rho_\mu^a + g_0 f^{abc}\rho_\mu^b\rho_\nu^c$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

Equations of motion

$$\partial^\mu F_{\mu\nu} = -\frac{\delta\mathcal{L}}{\delta\hat{\rho}_\mu^0}\frac{\delta\hat{\rho}_\mu^0}{\delta A_\nu} = -\frac{e_0}{g_0}\frac{\delta\mathcal{L}}{\delta\hat{\rho}_\nu^0} = \boxed{-e_0\left(\frac{m_0^2}{g_0}\right)\rho_\nu^0,}$$

$$\partial^\mu\hat{f}_{\mu\nu}^a = g_0 J_\nu^{\rho,a} + m_0^2\hat{\rho}_\nu^a,$$

$$\hat{\rho}_\mu^0 \equiv \rho_\mu^3 + (e_0/g_0)A_\mu, \quad \hat{\rho}_\mu^\pm \equiv \rho_\mu^\pm$$

ρ can be coupled with U(1) gauge

by field redefinition $\phi_\mu^a \equiv (m_0^2/g_0)\hat{\rho}_\mu^a = (1/g_0)\partial^\nu\hat{f}_{\nu\mu}^a - J_\mu^{\rho,a}$

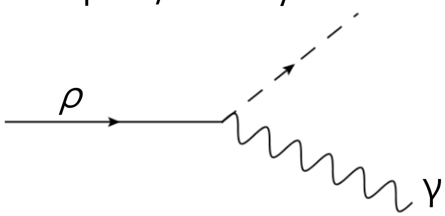
$$[\phi_i^a(r,t), \phi_j^b(r',t)] = 0,$$
$$[\phi_0^a(r,t), \phi_0^b(r',t)] = if^{abc}\delta^3(r-r')\phi_0^c(r,t),$$
$$[\phi_0^a(r,t), \phi_j^b(r',t)] = if^{abc}\delta^3(r-r')\phi_j^c(r,t) + i\left(m_0^2/g_0^2\right)\delta^{ab}\partial_{r_j}\delta^3(r-r'),$$

ρ field itself is conserved current
→ can be regarded as external source of E.M. field → photon leg can be replaced by ρ state

Vector meson dominance

- External photon can be replaced by vector meson

Example: $\rho \rightarrow \pi\ \gamma$



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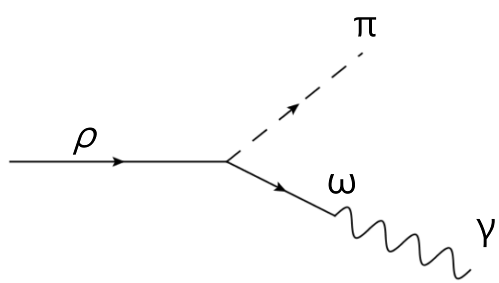
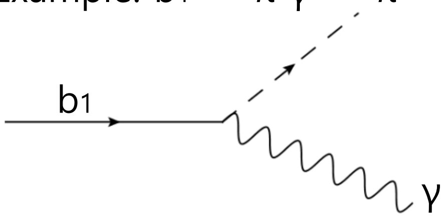


Effective Lagrangian in VMD hypothesis explains well

- **Exceptional phenomenon**

Example: $b_1 \rightarrow \pi\ \gamma$



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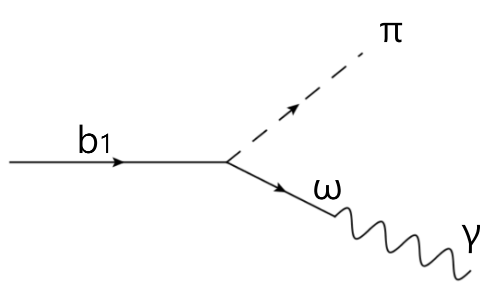


$\Gamma(b_1 \rightarrow \pi\Upsilon)$ = 230 KeV (experiment) $\Gamma(b_1 \rightarrow \pi\Upsilon)$ = 30~160 KeV (VMD scenario)

For b_1 decay, VMD hypothesis does not work well

b_1 in $(\frac{1}{2},\frac{1}{2}) \oplus (\frac{1}{2},\frac{1}{2})$ representation

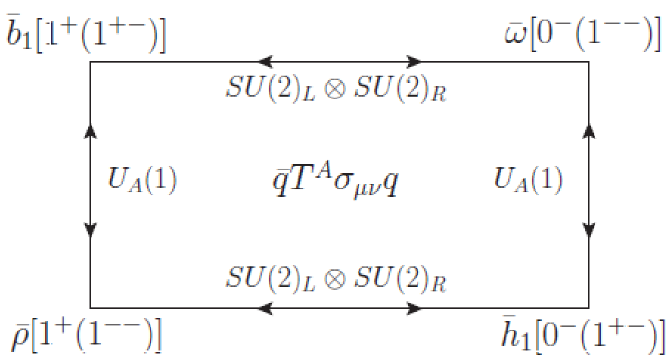
- Interpolating current in local tensor representation

$$\bar{b}_1: \ [I^G J^{PC} = 1^+(1^{+-})] \to \frac{1}{2}\epsilon_{ijk} \langle 0 \mid \bar{q} T^a \sigma_{ij} q \mid \bar{b}_1(p,\lambda)\rangle = i f^T_{b_1^a}(-\bar{\epsilon}_k^{(\lambda)} p_0)$$

The other vector mesons in tensor bilinear

$$\bar{\omega}: \ [I^G J^{PC} = 0^-(1^{--})] \to \langle 0 \mid \bar{q} T^0 \sigma_{0k} q \mid \bar{\omega}(p,\lambda)\rangle = i f^T_{\omega}(-\bar{\epsilon}_k^{(\lambda)} p_0),$$
$$\bar{\rho}: \ [I^G J^{PC} = 1^+(1^{--})] \to \langle 0 \mid \bar{q} T^a \sigma_{0k} q \mid \bar{\rho}(p,\lambda)\rangle = i f^T_{\rho^a}(-\bar{\epsilon}_k^{(\lambda)} p_0),$$
$$\bar{h}_1: \ [I^G J^{PC} = 0^-(1^{+-})] \to \frac{1}{2}\epsilon_{ijk} \langle 0 \mid \bar{q} T^0 \sigma_{ij} q \mid \bar{h}_1(p,\lambda)\rangle = i f^T_{h_1}(-\bar{\epsilon}_k^{(\lambda)} p_0),$$

If $U_A(1)$ and $SU(2)_L$ x $SU(2)_R$ symmetries exist, all the vector mesons are in $U(2)_L$ x $U(2)_R$



$SU(2)_L \otimes SU(2)_R$

$$[Q_5^a, J_k^{b_1,b}(x)] = -i\delta^{ab} J_k^{\omega}(x), \ [Q_5^a, J_k^{\omega}(x)] = i J_k^{b_1,a}(x),$$

$U_A(1)$

$$[Q_5^0, J_k^{\omega}(x)] = -i J_k^{h_1}(x), \ [Q_5^a, J_k^{\rho,b}(x)] = i\delta^{ab} J_k^{h_1}(x),$$

Soft pion breaking

- Field transformation and leaking charge

$$\psi_A(\vec{x},t) \to \psi_A(\vec{x},t) - i\Lambda_i[Q^i(t), \psi_A(\vec{x},t)]$$
$$= \psi_A(\vec{x},t) - i\Lambda_i M^i_{AB}\psi_B(x,t),$$

$$\mathcal{L} \to \mathcal{L} - (\partial^\alpha \Lambda_i) J^i_\alpha(\vec{x},t) - \Lambda_i(\partial^\alpha J^i_\alpha(\vec{x},t))$$

If the symmetry is broken, the divergence corresponds to leaking charge flow

$$\partial^\alpha J^i_\alpha(\vec{x},t) = i[Q^i(t), u(\vec{x},t)] = -i[Q^i(t), \mathcal{H}(\vec{x},t)]$$

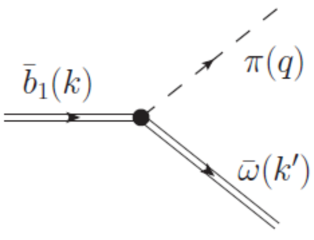
$$\frac{dQ^i(t)}{dt} = \int d^3x \partial^\alpha J^i_\alpha(\vec{x},t) = -i[Q^i(t), \int d^3x \mathcal{H}(\vec{x},t)]$$

- Pion corresponds to leaking chiral charge flow

$$\pi^a(x) \simeq -(1/m_\pi^2 f_\pi)\partial^\alpha J^a_{5\alpha}(x)$$

→ in soft limit, b1 decay into ω corresponds to chiral symmetry breaking

$$\langle \pi^a(q)\omega(k') \mid i\tilde{J}^a_{\mu\bar{\mu}}(k) \mid 0\rangle \simeq f^T_{b_1}\sum_\lambda \langle \pi^a(q)\omega(k') \mid \bar{b}^a_1(k,\lambda)\rangle \left(\bar{\epsilon}^{(\lambda)^*}_\mu k_{\bar{\mu}} - \bar{\epsilon}^{(\lambda)^*}_{\bar{\mu}} k_\mu\right) + \ldots$$
$$= \frac{i}{f_\pi}\int d^3x e^{-iq\cdot x} \langle \omega(k') \mid [J^a_{50}(x), i\tilde{J}^a_{\mu\bar{\mu}}(k)] \mid 0\rangle + \ldots$$

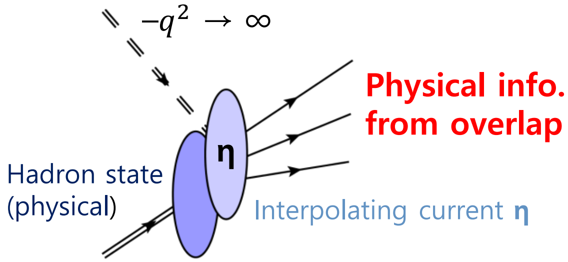


$$\tilde{J}^a_{\mu\bar{\mu}}(k) \equiv -\tfrac{1}{2}\epsilon_{\mu\bar{\mu}\alpha\bar{\alpha}}(k^2 - \bar{m}^2)\int d^4x e^{ikx}\bar{q}(x)T^a\sigma^{\alpha\bar{\alpha}}q(x)$$

$$[Q^a_5, J^{b_1,b}_k(x)] = -i\delta^{ab}J^\omega_k(x), \;\; [Q^a_5, J^\omega_k(x)] = iJ^{b_1,a}_k(x),$$

Interpolating current

- To obtain physical information



a. Quasi-particle state will be extracted from the overlap
b. We need to construct proper interpolating current which can be strongly overlapped with object hadron state
c. Our object: **ω and b1 meson in tensor representation**

- Projection operator

Covariant interpolation

$$\omega[0^-(1^{--})] \to \langle 0 \left| \bar{q} T^0 \sigma_{\mu\nu} q \right| \omega(p,\lambda) \rangle = i f_\omega^T \left(\epsilon_\mu^{(\lambda)} p_\nu - \epsilon_\nu^{(\lambda)} p_\mu \right)$$

$$b_1[1^+(1^{+-})] \to -\frac{1}{2}\epsilon_{\mu\nu\alpha\beta} \langle 0 \left| \bar{q} T^a \sigma^{\alpha\beta} q \right| b_1(p,\lambda) \rangle = i f_{b_1^a}^T \left(\epsilon_\mu^{(\lambda)} p_\nu - \epsilon_\nu^{(\lambda)} p_\mu \right)$$

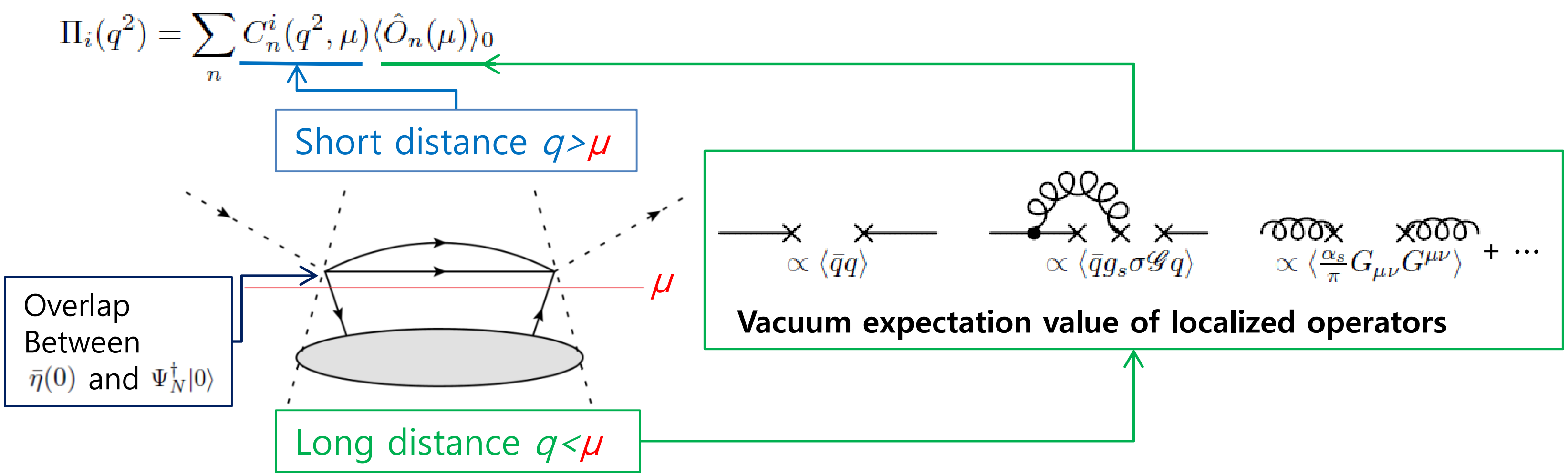
Projection of parity eigenmodes

$$\sum_\lambda \langle (1^{--})_{\mu\bar{\mu}}(p,\lambda) | (1^{--})_{\nu\bar{\nu}}(p,\lambda) \rangle \simeq p^2 {f_-^T}^2 P^{(-)}_{\mu\bar{\mu},\nu\bar{\nu}}, \qquad P^{(-)}_{\mu\bar{\mu};\nu\bar{\nu}} = g_{\mu\nu}\frac{p_{\bar{\mu}} p_{\bar{\nu}}}{p^2} + g_{\bar{\mu}\bar{\nu}}\frac{p_\mu p_\nu}{p^2} - g_{\bar{\mu}\nu}\frac{p_\mu p_{\bar{\nu}}}{p^2} - g_{\mu\bar{\nu}}\frac{p_{\bar{\mu}} p_\nu}{p^2},$$

$$\sum_\lambda \langle (1^{+-})_{\mu\bar{\mu}}(p,\lambda) | (1^{+-})_{\nu\bar{\nu}}(p,\lambda) \rangle \simeq p^2 {f_+^T}^2 P^{(+)}_{\mu\bar{\mu},\nu\bar{\nu}}, \qquad P^{(+)}_{\mu\bar{\mu};\nu\bar{\nu}} = P^{(-)}_{\mu\bar{\mu},\nu\bar{\nu}} + (g_{\mu\bar{\nu}} g_{\bar{\mu}\nu} - g_{\mu\nu} g_{\bar{\mu}\bar{\nu}}),$$

QCD SR - operator product expansion

- Operator product expansion (Example: 2-quark condensate diagram)

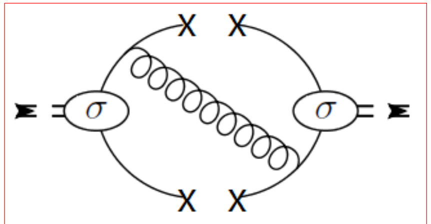


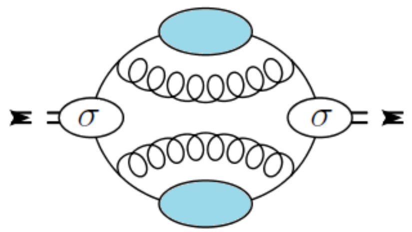
- Separation scale is mesonic scale (≤ 0.5 GeV)
  - **Wilson coefficient** contains perturbative contribution above separation scale – short-ranged partonic propagation in hadron
  - **Condensate** contains non-perturbative contribution below separation scale – long ranged correlation in low energy part of hadron
  - Quark confinement inside hadron is low energy QCD phenomenon
  - Genuine properties of hadron are reflected in **the condensates**

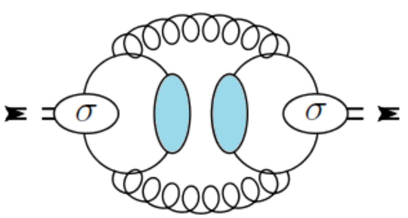
Four-quark condensates

- Four-quark pieces determine spectral structure of invariant

$$\mathcal{W}_M^{\text{subt.}}\left[\Pi_{\mp}^{\text{ope}}(k^2)\right] = \frac{1}{16\pi^2}\left[\left(1+\frac{7\alpha_s}{9\pi}\right)(M^2)^2 E_1(s_0) + \frac{\alpha_s}{3\pi}L(s_0)\right] - \frac{4\pi\alpha_s}{9M^2}\left\langle \bar{q}T^0\tau^{\bar{a}}\gamma_\eta q\bar{q}T^0\tau^{\bar{a}}\gamma^\eta q\right\rangle$$
$$\mp\frac{16\pi\alpha_s}{M^2}\left(\left\langle \bar{q}T^A\tau^{\bar{a}}q\bar{q}T^A\tau^{\bar{a}}q\right\rangle + \left\langle \bar{q}T^A\tau^{\bar{a}}\gamma_5 q\bar{q}T^A\tau^{\bar{a}}\gamma_5 q\right\rangle\right) + \frac{1}{48}\left\langle\frac{\alpha_s}{\pi}G^2\right\rangle$$







Usual vacuum saturation hypothesis gives same factorization

$$\left\langle \bar{q}T^A\tau^{\bar{a}}q\bar{q}T^A\tau^{\bar{a}}q\right\rangle \to -\frac{a_A}{18}\left\langle \bar{q}T^0 q\right\rangle^2$$
$$\left\langle \bar{q}T^A\tau^{\bar{a}}\gamma_5 q\bar{q}T^A\tau^{\bar{a}}\gamma_5 q\right\rangle \to -\frac{b_A}{18}\left\langle \bar{q}T^0 q\right\rangle^2$$

In Bank-Casher formula, only Dirac zero-mode contributes

$$\langle\bar{q}q\rangle = -\int d^4x \left\langle \sum_\lambda \frac{\psi_\lambda(x)^\dagger\psi_\lambda(x)}{V}\frac{1}{m-i\lambda}\right\rangle = -\pi\langle \mathrm{Tr}[J_{\lambda=0}(0,0)]\rangle$$

As gauge correction, colored pieces can make non-zero contribution

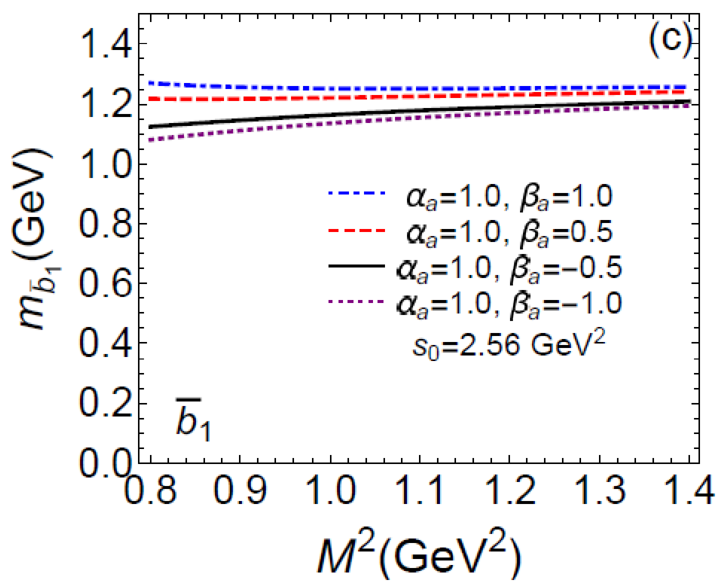
In vacuum, all the topological configuration can contribute

[a_0=0.8, b_0=0.4] has been used for the isoscalar mode
[a_a=1.0, b_a=0.5] has been used for the isovector mode

Borel sum rules for $[1^{+}(1^{+-})]$ state

- One-particle pole ansatz for the ground state

$$\mathcal{W}_M^{\text{subt.}}[\Pi^{\mp}_{\bar{q}T^A\sigma q}(k^2)] = \frac{1}{\pi}\int_0^{s_0} ds e^{-s/M^2} \mathrm{Im}\left[-\frac{f_{\mp}^{T\,2}}{s-m_{\mp}^2+i\epsilon}\right] = f_{\mp}^{T\,2} e^{-m_{\mp}^2/M^2}$$
$$= \frac{1}{16\pi^2}\left[\left(1+\frac{7\alpha_s}{9\pi}\right)(M^2)^2 E_1(s_0) + \frac{\alpha_s}{3\pi}L(s_0)\right] - \frac{4\pi\alpha_s}{9M^2}\langle \bar{q}T^0\tau^{\bar{a}}\gamma_\eta q\bar{q}T^0\tau^{\bar{a}}\gamma^\eta q\rangle$$
$$\mp \frac{16\pi\alpha_s}{M^2}\left(\langle \bar{q}T^A\tau^{\bar{a}}q\bar{q}T^A\tau^{\bar{a}}q\rangle + \langle \bar{q}T^A\tau^{\bar{a}}\gamma_5 q\bar{q}T^A\tau^{\bar{a}}\gamma_5 q\rangle\right) + \frac{1}{48}\left\langle \frac{\alpha_s}{\pi}G^2\right\rangle$$



$$m_{\mp}^2 = (M^2)^2\left(\frac{\partial}{\partial M^2}\mathcal{W}_M^{\text{subt.}}[\Pi^{(\mp)}_{\bar{q}T^A\sigma q}(k^2)]\right)\Big/\mathcal{W}_M^{\text{subt.}}[\Pi^{(\mp)}_{\bar{q}\sigma q}(k^2)]$$

Mass number converges near ~1.2 GeV
→ provides stable plateau in Borel window

Pole residue sum rules
→ provides stable plateau in Borel window

For this moment, one can regard $\overline{b_1}$ as physical b_1(1235) state

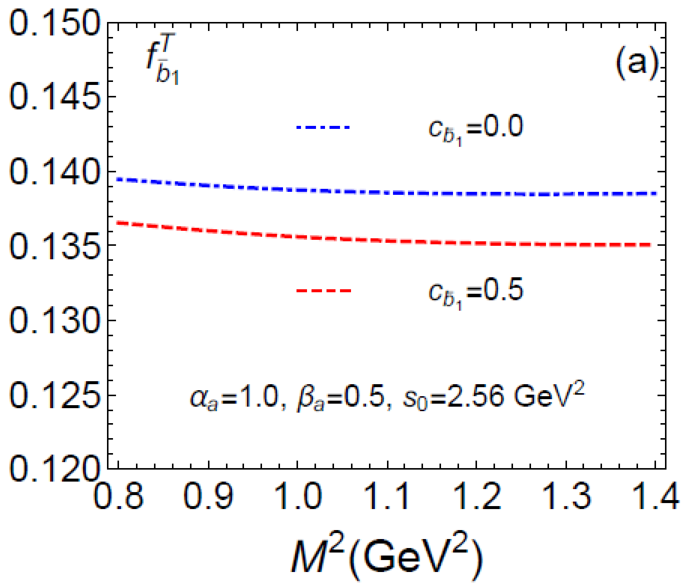
Borel sum rules for $[1^+(1^{+-})]$ state

- One-particle pole ansatz for the ground state

$$\mathcal{W}_M^{\text{subt.}}[\Pi^{\mp}_{\bar{q}T^A\sigma q}(k^2)] = \frac{1}{\pi}\int_0^{s_0} ds e^{-s/M^2}\,\text{Im}\left[-\frac{f_{\mp}^{T\,2}}{s-m_{\mp}^2+i\epsilon}\right] = f_{\mp}^{T\,2} e^{-m_{\mp}^2/M^2}$$

$$= \frac{1}{16\pi^2}\left[\left(1+\frac{7\alpha_s}{9\pi}\right)(M^2)^2 E_1(s_0) + \frac{\alpha_s}{3\pi}L(s_0)\right] - \frac{4\pi\alpha_s}{9M^2}\langle \bar{q}T^0\tau^{\bar{a}}\gamma_\eta q\bar{q}T^0\tau^{\bar{a}}\gamma^\eta q\rangle$$

$$\mp \frac{16\pi\alpha_s}{M^2}\left(\langle \bar{q}T^A\tau^{\bar{a}}q\bar{q}T^A\tau^{\bar{a}}q\rangle + \langle \bar{q}T^A\tau^{\bar{a}}\gamma_5 q\bar{q}T^A\tau^{\bar{a}}\gamma_5 q\rangle\right) + \frac{1}{48}\left\langle\frac{\alpha_s}{\pi}G^2\right\rangle$$



$$m_{\mp}^2 = (M^2)^2\left(\frac{\partial}{\partial M^2}\mathcal{W}_M^{\text{subt.}}[\Pi^{(\mp)}_{\bar{q}T^A\sigma q}(k^2)]\right)\Big/\mathcal{W}_M^{\text{subt.}}[\Pi^{(\mp)}_{\bar{q}\sigma q}(k^2)]$$

Mass number converges near ~1.2 GeV
→ provides stable plateau in Borel window

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For this moment, one can regard $\bar{b}_1$ as physical b_1(1235) state

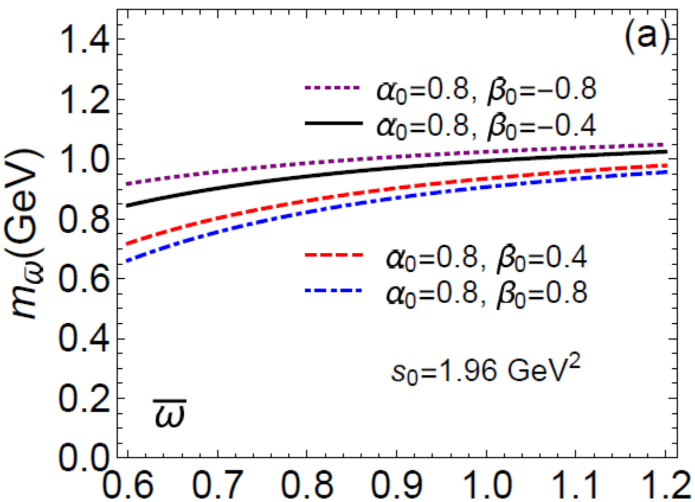
Borel sum rules for $[0^-(1^{--})]$ state

- One-particle pole ansatz for the ground state

$$\mathcal{W}_M^{\text{subt.}}[\Pi^{\mp}_{\bar{q}T^A\sigma q}(k^2)] = \frac{1}{\pi}\int_0^{s_0} ds e^{-s/M^2}\,\text{Im}\left[-\frac{f_{\mp}^{T\,2}}{s-m_{\mp}^2+i\epsilon}\right] = f_{\mp}^{T\,2} e^{-m_{\mp}^2/M^2}$$

$$= \frac{1}{16\pi^2}\left[\left(1+\frac{7\alpha_s}{9\pi}\right)(M^2)^2 E_1(s_0) + \frac{\alpha_s}{3\pi}L(s_0)\right] - \frac{4\pi\alpha_s}{9M^2}\langle \bar{q}T^0\tau^{\bar{a}}\gamma_\eta q\bar{q}T^0\tau^{\bar{a}}\gamma^\eta q\rangle$$

$$\mp \frac{16\pi\alpha_s}{M^2}\left(\langle \bar{q}T^A\tau^{\bar{a}}q\bar{q}T^A\tau^{\bar{a}}q\rangle + \langle \bar{q}T^A\tau^{\bar{a}}\gamma_5 q\bar{q}T^A\tau^{\bar{a}}\gamma_5 q\rangle\right) + \frac{1}{48}\left\langle \frac{\alpha_s}{\pi}G^2\right\rangle$$



$$m_{\mp}^2 = (M^2)^2\left(\frac{\partial}{\partial M^2}\mathcal{W}_M^{\text{subt.}}[\Pi^{(\mp)}_{\bar{q}T^A\sigma q}(k^2)]\right)\Big/\mathcal{W}_M^{\text{subt.}}[\Pi^{(\mp)}_{\bar{q}\sigma q}(k^2)]$$

Mass number ranges from 900 MeV ~ 1000 MeV
→ higher scale than mass of ω(782)
→ unstable Borel behavior
→ there is no ω resonance in mass number 1 GeV

π-ρ hybrid state can be suggested via anomalous interaction vertex

$$J^{\bar{\omega}}_{\mu\bar{\mu}}(x) \equiv \epsilon_{\mu\bar{\mu}\alpha\bar{\alpha}}\text{Tr}\left[\partial^\alpha\pi(x)\rho^{\bar{\alpha}}(x)\right]$$

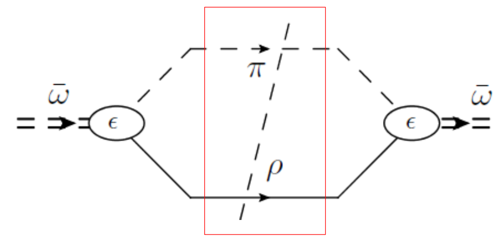
$$\mathcal{L}^{\epsilon 1}_{\omega\pi\rho} = \frac{g_{\omega\pi\rho}}{2}\epsilon^{\mu\bar{\mu}\alpha\bar{\alpha}}\omega_{\mu\bar{\mu}}\partial_\alpha\pi^a\rho^a_{\bar{\alpha}}$$

Borel sum rules for $[0^-(1^{--})]$ state

- Spectral sum rules for hybrid state

Imaginary part is changed as

$$\mathrm{Im}[\Pi^{(-)}_{\bar{q}T^0\sigma q}(k^2)] = \pi f_-^{T\,2}\delta(k^2 - m_-^2) \Rightarrow \boxed{c^2_{\bar{\omega}\pi\rho}\mathrm{Im}[\Pi^{\bar{\omega}}_{(-)}(k^2)]}$$



Phenomenological correlator

$$\Pi^{\bar{\omega}}_{\mu\bar{\mu};\nu\bar{\nu}}(k) = -i\int d^4x e^{ikx}\left\langle \mathcal{T}\left[\epsilon_{\mu\bar{\mu}\alpha\bar{\alpha}}\mathrm{Tr}\left[\partial^\alpha\pi(x)\rho^{\bar{\alpha}}(x)\right]\epsilon_{\nu\bar{\nu}\beta\bar{\beta}}\mathrm{Tr}\left[\partial^\beta\pi(0)\rho^{\bar{\beta}}(0)\right]\right]\right\rangle$$

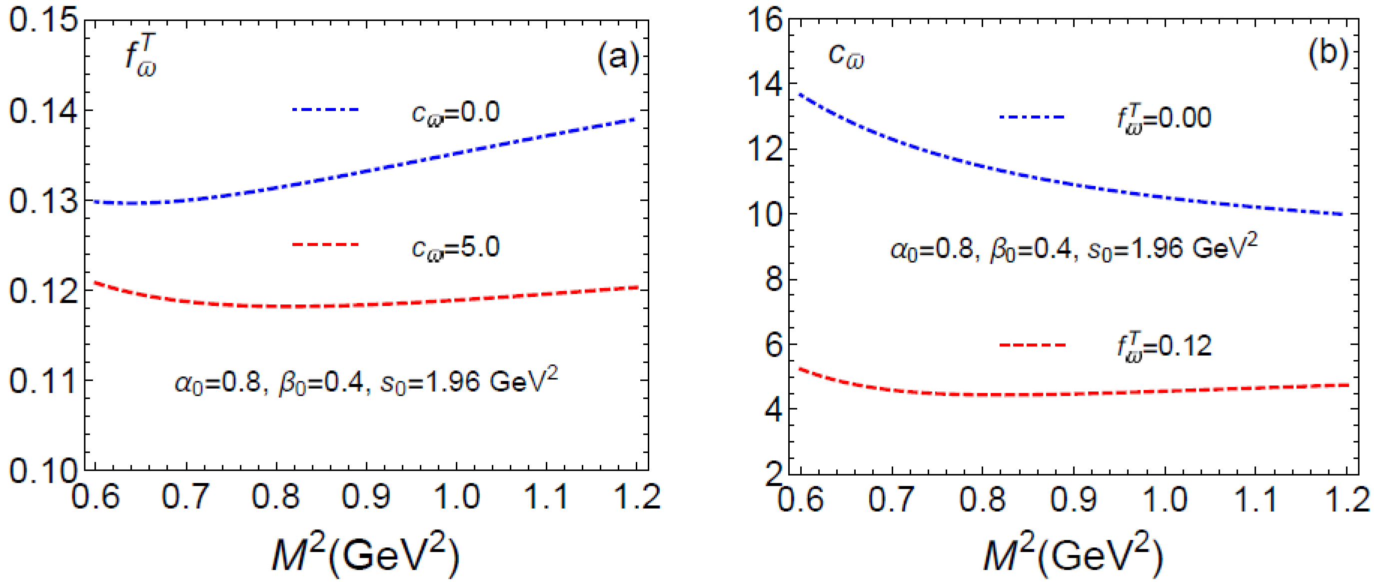
Weighted invariant for parity-odd mode

$$\begin{aligned}
\mathcal{W}^{\mathrm{subt.}}_M\left[\Pi^{\bar{\omega}}_-(k^2)\right] &= -\frac{3}{64\pi^2}\int_{m_\rho^2}^{s_0} ds\, e^{-s/M^2}\left(-\frac{s}{6} + \frac{m_\rho^2}{2} - \frac{1}{2}\frac{(m_\rho^2)^2}{s} + \frac{1}{6}\frac{(m_\rho^2)^3}{s^2}\right) \\
&= -\frac{3}{64\pi^2}\left\{\frac{M^2}{6}\left(s_0 e^{-s_0/M^2} - m_\rho^2 e^{-m_\rho^2/M^2}\right) + \frac{(M^2)^2}{6}\left(e^{-s_0/M^2} - e^{-m_\rho^2/M^2}\right)\right. \\
&\quad - \frac{m_\rho^2}{2}M^2\left(e^{-s_0/M^2} - e^{-m_\rho^2/M^2}\right) - \frac{(m_\rho^2)^2}{2}\left[\Gamma\left(0, m_\rho^2/M^2\right) - \Gamma\left(0, s_0/M^2\right)\right] \\
&\quad \left. - \frac{(m_\rho^2)^3}{6}\left[\frac{e^{-s_0/M^2}}{s_0} - \frac{e^{-m_\rho^2/M^2}}{m_\rho^2} + \frac{1}{M^2}\left\{\Gamma\left(0, m_\rho^2/M^2\right) - \Gamma\left(0, s_0/M^2\right)\right\}\right]\right\}
\end{aligned}$$

Borel sum rules for $[1^{+}(1^{+-})]$ state

- Spectral sum rules considering the hybrid coupling

$$|c_{\bar{\omega}\pi\rho}| = \left[\mathcal{W}_M^{\rm subt.}[\Pi^{\bar{q}T^0\sigma q}_{(-)}(k^2)]/\mathcal{W}_M^{\rm subt.}[\Pi^{\bar{\omega}}_{(-)}(k^2)]\right]^{\frac{1}{2}}$$



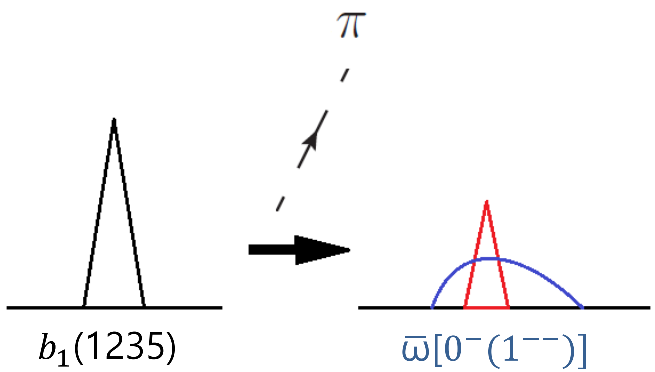
Both of the pole residue and the hybrid coupling becomes stable after the hybrid/pole correction

After pion breaking from $\boldsymbol{b_1}$**(1235),** $\bar{\omega}[0^{-}(1^{--})]$ state can couple π-ρ hybrid state

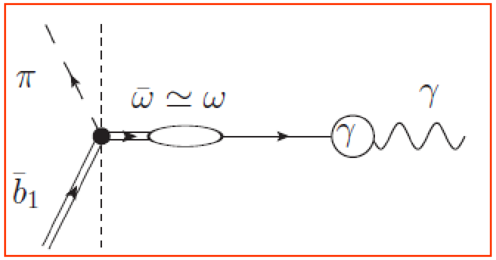
This intermediate hybrid state has loop structure → off-shell contribution can be important

$\Gamma(\mathbf{b_1} \to \bar{\omega}[0^-(1^{--})] \to \pi\text{-}\gamma)$

- Two possible final γ state

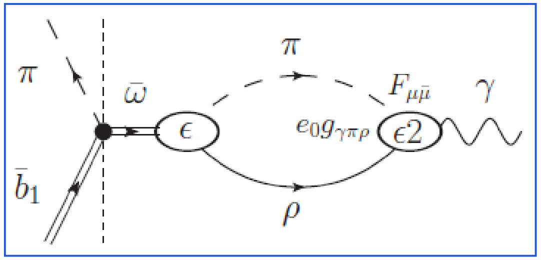


Final photon state via ω(782) (VMD channel)



If ϖ[0⁻(1⁻⁻)] state goes through ω(782) state, the radiative decay will follow VMD scenario

Final photon state from the π-ρ hybrid state



$$\mathcal{L}^{\epsilon 2}_{\gamma\pi\rho} = \frac{e_0 g_{\gamma\pi\rho}}{2m_\rho}\epsilon^{\mu\bar{\mu}\alpha\bar{\alpha}} F_{\mu\bar{\mu}}\partial_\alpha \pi^a \rho^a_{\bar{\alpha}} \simeq \frac{e_0 g_{\gamma\pi\rho}}{m_\rho} F_{\mu\bar{\mu}}\bar{\omega}^{\mu\bar{\mu}}$$

In the goldstone limit for pion, the most of loop phase space in is off-shell
→ direct channel would be important

Summary

- $\bar{\boldsymbol{b}}_{\mathbf{1}}$ can mixes with $\bar{\omega}$ in local tensor representation
- In chiral symmetry broken phase, $\bar{\omega}[0^{-}(1^{--})]$ state can be obtained from $\bar{\boldsymbol{b}}_{\mathbf{1}}$ after pion breaking
- The $\bar{\omega}[0^{-}(1^{--})]$ can couple with the intermediate hybrid state of π-ρ mesons
- Loop structure of the intermediate state allows direct photon coupling channel, which would be the additional source for radiative decay width