Investigation on the Ω(2012) from QCD sum rules

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arXiv: 2405.06958

QCD 24
2024/07/09

Contents

- Background
- P-wave Ω baryon currents
- QCD sum rule analyses
- Numerical analyses
- Summary and outlook

New baryon candidates

- Significant progress has been achieved in baryon spectroscopy, with an increasing number of new baryon candidates

➢ Heavy baryons

$\Xi_c(2923)$ $\Lambda_b(5912)$

$\Xi_c(2939)$ $\Lambda_b(5920)$

$\Xi_c(2965)$ $\Xi_b(6087)$

$\Xi_b(6100)$

……

➢ Light baryons

$\Xi(1620)$

$\Xi(1690)$

$\Xi(1820)$

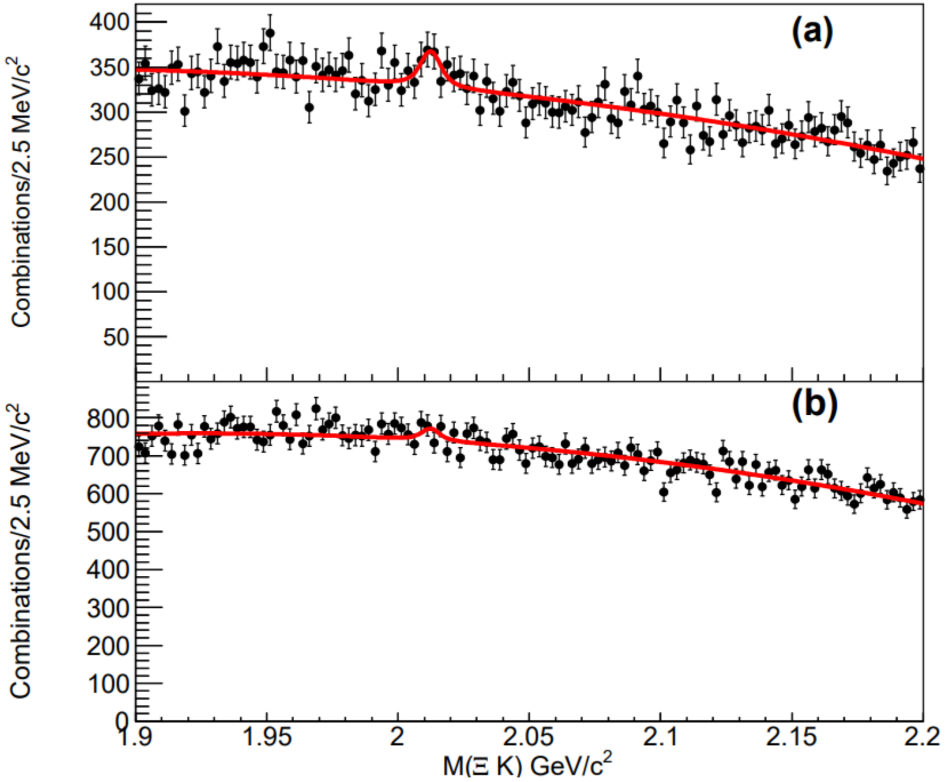
$\Omega(2012)$

……

Discovery of the $\Omega(2012)$

- In 2018, the excited Ω baryon, $\Omega(2012)$, was discovered for the first time by the Belle experiment in $\Xi^0 K^-$ and $\Xi^- K_s^0$ invariant mass distribution in $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ decays

Belle Collaboration, Phys. Rev. Lett. 121 (5) (2018) 052003



$$M = 2012.5 \pm 0.7 \pm 0.5 \text{ MeV},$$
$$\Gamma = 6.4^{+2.5}_{-2.0} \text{ MeV}.$$

Ω^-	$3/2^+$	****
$\Omega(2012)^-$	$?^-$	***
$\Omega(2250)^-$		***
$\Omega(2380)^-$		**
$\Omega(2470)^-$		**

Interpretation of the $\Omega(2012)$

- In 2021, the experimental evidence has been further strengthened by $\Omega_c \to \pi^+\Omega(2012) \to \pi^+ (\bar{K}\Xi)^-$ decay

Belle Collaboration, Phys. Rev. D 104 (5) (2021) 052005

- The mass of $\Omega(2012)$ is about 340 MeV higher than the ground state $\Omega(1672)$ and is just 16.6 MeV below the K^- and $\Xi^*(1530)$ mass threshold

340 MeV → the first P-wave excitation of the ground Ω baryon

16.6 MeV → a hadronic molecular

P-wave excitation of Ω baryon state

- The conventional quark model may naively explain the $\Omega(2012)$ to be the first P-wave excitation of the ground Ω baryon

before
- K. T. Chao, N. Isgur and G. Karl, Phys. Rev. D 23, 155 (1981)
- S. Capstick, N. Isgur, Phys. Rev. D 34 (1986) 9, 2809-2835

after
- L. Y. Xiao and X. H. Zhong, Phys. Rev. D 98, 034004 (2018)
- Z.Y. Wang, L.C. Gui, Q.F. Lu, L.Y. Xiao, X.-H. Zhong, Phys. Rev. D98 (11) (2018) 114023
- A. J. Arifi, D. Suenaga, A. Hosaka, Y. Oh, Phys. Rev. D 105 (9) (2022) 094006

……

- One important feature of this quark model picture is that there should be spin-orbit partners of both $J^P = 1/2^-$ and $J^P = 3/2^-$

P-wave excitation of Ω baryon state

- The spin $3/2^-$ state may decay to $\bar{K}\Xi$ via D-wave, or more likely decay to $\bar{K}\Xi(1530)$ via S-wave, but such a decay will be suppressed due to a small phase space factor
  (small decay width)

- The spin $1/2^-$ state will be easier to decay to $\bar{K}\Xi$ via S-wave with no phase space suppression, or decay to $\bar{K}\Xi(1530)$ via D-wave
  (large decay width)

- The spin-parity of $\mathbf{\Omega(2012)}$ is likely to be $J^P = 3/2^-$

Molecule state

- A molecular picture of $\overline{K}\Xi(1530)$ has been proposed and extensively discussed in the one-boson-exchange model and the chiral unitary approach

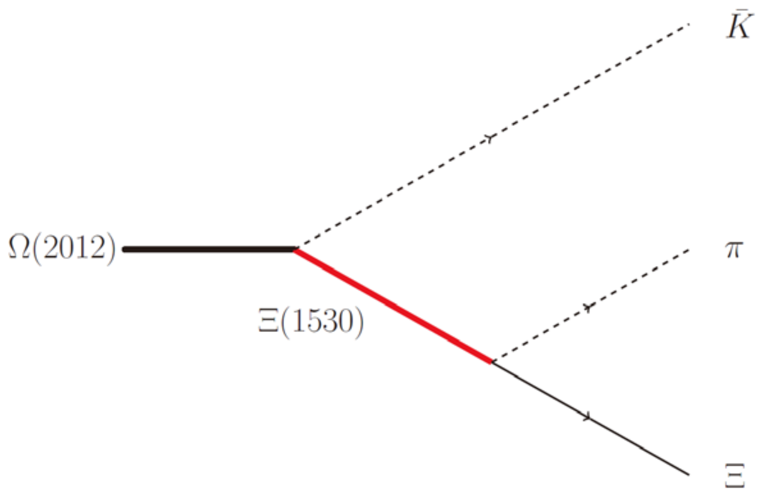
M. P. Valderrama, Phys. Rev. D 98, 054009 (2018)
Y. H. Lin and B. S. Zou, Phys. Rev. D 98,056013 (2018)
Y. Huang, M. Z. Liu, J. X. Lu, J. J. Xie and L. S. Geng, Phys. Rev. D 98,076012 (2018)
R. Pavao and E. Oset, Eur. Phys. J. C 78, 857 (2018)
T. Gutsche, V. E. Lyubovitskij, J. Phys. G 48 (2) (2020) 025001
X. Liu, H. Huang, J. Ping, D. Chen, Phys. Rev. C 103 (2) (2021) 025202.

……

- Unlike the quark model picture, the spin $1/2^-$ state is not easily generated in the molecular picture

Molecule state

- The molecular state may lead to a large contribution to the three-body decay of $\Omega(2012) \to \overline{K}\Xi(1530) \to \overline{K}\Xi\pi$



- In experiments, it was first reported that such a three-body decay was not observed in 2019, but in 2022 the measurement was revisited and the possibility of the three-body decay was discussed

Belle collaboration, arXiv: 2207.03090

$$\mathcal{R}^{\Xi\pi\bar{K}}_{\Xi\bar{K}} \equiv \frac{\mathcal{B}[\Omega(2012) \to \Xi(1530)\bar{K} \to \Xi\pi\bar{K}]}{\mathcal{B}[\Omega(2012) \to \Xi\bar{K}]} < 11.9\%$$

S. Jia, et al, Phys. Rev. D 100 (3) (2019) 032006

Mixing of two picture

- A hybrid picture of three-quark and molecular structures was proposed in a coupled-channel approach. It was found that both the three-quark core and $\bar{K}\Xi(1530)$ channel are essential for the description of $\boldsymbol{\Omega(2012)}$ resonance

Q.-F. Lu, H. Nagahiro, A. Hosaka, Phys.Rev. D 107 (1) (2023) 014025

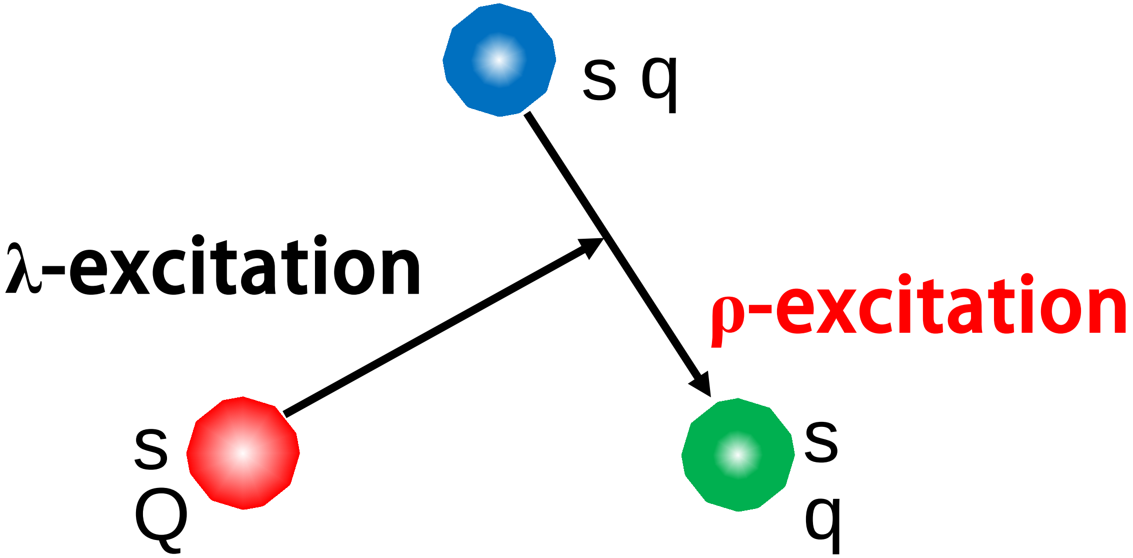
- It would be fair to say that the structure of $\boldsymbol{\Omega(2012)}$ is not yet well understood, and this has motivated us to study further properties of this state in another theoretical approach based on QCD sum rules

Contents

P-wave ss diquark

- We construct the P-wave Ω baryon currents with a covariant derivative, assuming that the parity of $\Omega(2012)$ is negative

- It is not easy to differentiate the ρ mode and λ mode orbital excitations. We find it much easier to construct the currents of the ρ mode, which contains the P-wave ss diquark field



P-wave ss diquark

- For the P-wave ss diquark within a derivative, three types of diquarks remain non-vanishing:

$$\epsilon^{abc} s_a^T C\gamma_5 \overleftrightarrow{D}_\mu s_b \qquad \epsilon^{abc} s_a^T C \overleftrightarrow{D}_\mu s_b \qquad \epsilon^{abc} s_a^T C\gamma_\mu\gamma_5 \overleftrightarrow{D}_\mu s_b$$

- This diquark has a suitable internal P -wave structure. In fact, $s_a^T C\gamma_5 s_b$ has quantum number $J^P = 0^+$ which is S-wave, with total spin $S_{12} = 0$. After applying a derivative, $s_a^T C\gamma_5 \overleftrightarrow{D}_\mu s_b$ becomes a pure P -wave diquark

P-wave ss diquark

- For the P-wave ss diquark within a derivative, three types of diquarks remain non-vanishing:

$$\epsilon^{abc} s_a^T C\gamma_5 \overleftrightarrow{D}_\mu s_b \qquad \epsilon^{abc} s_a^T C \overleftrightarrow{D}_\mu s_b \qquad \epsilon^{abc} s_a^T C\gamma_\mu\gamma_5 \overleftrightarrow{D}_\mu s_b$$

- Phenomenologically, the P-wave ss diquark with the color representation $\overline{3}_c$ can only have the total spin $S_{12} = 0$. Thus it has antisymmetric color, symmetric flavor, antisymmetric orbital structure, and antisymmetric spin, so its total structure is antisymmetric, satisfying the Pauli principle

P-wave ss diquark

- For the P-wave ss diquark within a derivative, three types of diquarks remain non-vanishing:

$$\epsilon^{abc} s_a^T C\gamma_5 \overleftrightarrow{D}_\mu s_b \qquad \epsilon^{abc} s_a^T C \overleftrightarrow{D}_\mu s_b \qquad \epsilon^{abc} s_a^T C\gamma_\mu\gamma_5 \overleftrightarrow{D}_\mu s_b$$

- In contrast, the other two diquarks, before applying a derivative, $s_a^T C s_b$ and $s_a^T C\gamma_\mu\gamma_5 s_b$ themselves have already P -wave nature ($J^P = 0^-$ and $J^P = 1^-$). When a derivative is applied, they obtain complicated structure unlike the P-wave field

P-wave Ω baryon currents

- Combining the diquark with the third quark field of spin $1/2$, we can write the currents for the P-wave **Ω** baryon with the total angular momentum $J_{tol} = 1/2, 3/2$

$$
\begin{aligned}
J &= s_1 \otimes s_2 \otimes s_3 \otimes l_\rho \otimes l_\lambda \\
&\rightarrow [s_1 \otimes s_2 \otimes l_\rho] \otimes s_3 \\
&= s_{12} \otimes l_\rho \otimes s_3 \\
&= j_{12} \otimes s_3 \\
&= 1/2 \oplus 3/2 \, .
\end{aligned}
$$

$s_1/\ s_2/\ s_3=1/2$

$s_{12}=0,\ j_{12}=1$

$l_\rho=1$

- Their corresponding P-wave **Ω** baryon currents are

$$J = -2\epsilon^{abc} \left[(D^\mu s_a^T) C \gamma_5 s_b\right] \gamma_\mu s_c \, ,$$

$$J_\mu = -2\epsilon^{abc} \left[(D^\nu s_a^T) C \gamma_5 s_b\right] (g_{\mu\nu} - \frac{1}{4}\gamma_\mu \gamma_\nu) s_c$$

Contents

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QCD sum rule analyses

- The current matrix element $J_\mu = -2\epsilon^{abc}\left[(D^\nu s_a^T)C\gamma_5 s_b\right](g_{\mu\nu} - \frac{1}{4}\gamma_\mu\gamma_\nu)s_c$

$$\langle 0|J_\mu|\Omega; 3/2^-\rangle = f_- u_\mu(q)$$

$$\langle 0|J_\mu|\Omega; 3/2^+\rangle = f_+\gamma_5 u_\mu(q)$$

- We study the correlation function with the following Lorentz structure

$$\begin{aligned}\Pi_{\mu\nu}(q^2) &= i\int d^4x e^{iqx}\langle 0|\mathbf{T}[J_\mu(x)J_\nu^\dagger(0)]|0\rangle \\ &= (\frac{q_\mu q_\nu}{q^2} - g_{\mu\nu})\Pi(q^2) + \cdots .\end{aligned}$$

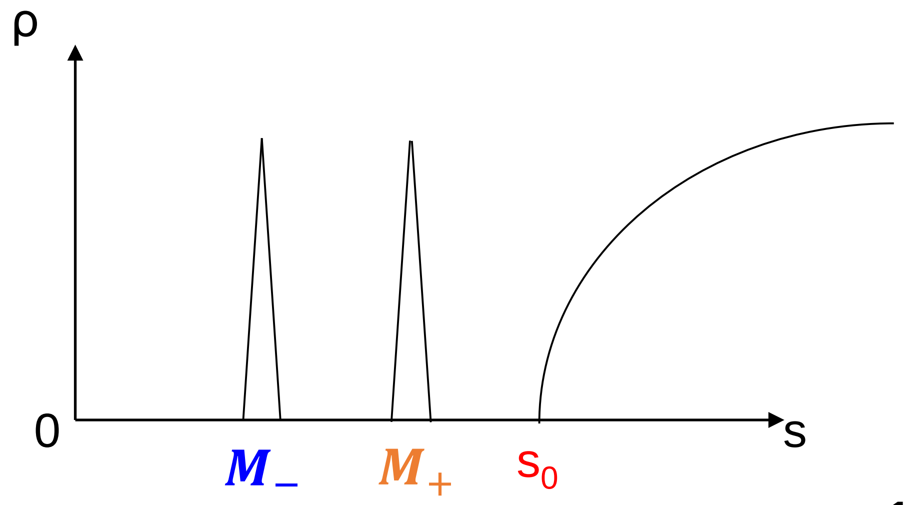
QCD sum rule analyses

- $\Pi(q^2)$ can be expressed as a dispersion relation

$$\Pi(q^2) = \int_{s_<}^{\infty} \frac{\rho(s)}{s - q^2 - i\varepsilon} ds \qquad \rho(s) \equiv \mathrm{Im}\Pi(s)/\pi, \quad s_< = 9m_s^2$$

- At the hadron level, we obtain the spectral density by inserting the complete set of intermediate hadronic states

$$\begin{aligned}\rho^{\mathrm{phen}}(s) &\equiv \sum_n \delta(s - M_n^2)\langle 0|J_\mu|n\rangle\langle n|J_\nu^\dagger|0\rangle \\ &= f_-^2(\not{q} + M_-)\delta(s - M_-^2) \\ &\quad + f_+^2(\not{q} - M_+)\delta(s - M_+^2) \\ &\quad + \theta(s - s_0)\rho^{\mathrm{cont}}(s)\,,\end{aligned}$$



QCD sum rule analyses

- At the hadron level, the correlation function can be given as

$$\Pi^{\rm phen}(q^2) = f_-^2 \frac{\not{q} + M_-}{M_-^2 - q^2 - i\epsilon} + f_+^2 \frac{\not{q} - M_+}{M_+^2 - q^2 - i\epsilon}$$
$$= \Pi_1^{\rm phen}(q^2)\not{q} + \Pi_0^{\rm phen}(q^2)\,,$$

$$\rho_1^{\rm phen}(s) = f_-^2 \delta(s - M_-^2) + f_+^2 \delta(s - M_+^2)\,,$$
$$\rho_0^{\rm phen}(s) = f_-^2 M_- \delta(s - M_-^2) - f_+^2 M_+ \delta(s - M_+^2)$$

- Finally we can get the spectral densities for negative and positive parity states as

$$\rho_\mp^{\rm phen}(s) = \sqrt{s}\rho_1^{\rm phen}(s) \pm \rho_0^{\rm phen}(s)$$

QCD sum rule analyses

- At the quark-gluon level, we insert explicit forms of currents into the correlation function, contract out pairs of quark field which are quark propagator of QCD
- We get the master formula expressed in terms of quark propagator

$$\Pi_{\mu\nu}(q) = i\int d^4x e^{iq\cdot x}\langle 0|\mathcal{T}\{J_\mu(x){J^\dagger}_\nu(0)\}|0\rangle$$

$$\downarrow$$

$$\begin{aligned}\Pi^{\rm OPE}_{\mu\nu}(q) &= \epsilon_{abc}\epsilon_{a'b'c'}\int d^4x e^{iqx}\langle 0|\Big\{S_s^{ca'}(x)\gamma_\nu \widetilde{S}_s^{ab'}(x)\gamma_\mu S_s^{bc'}(x) - S_s^{ca'}(x)\gamma_\nu \widetilde{S}_s^{bb'}(x)\gamma_\mu S_s^{ac'}(x) \\ &- S_s^{cb'}(x)\gamma_\nu \widetilde{S}_s^{aa'}(x)\gamma_\mu S_s^{bc'}(x) + S_s^{cb'}(x)\gamma_\nu \widetilde{S}_s^{ba'}(x)\gamma_\mu S_s^{ac'}(x) - S_s^{cc'}(x)Tr\left[S_s^{ba'}(x)\gamma_\nu \widetilde{S}_s^{ab'}(x)\gamma_\mu\right] \\ &+ S_s^{cc'}(x)Tr\left[S_s^{bb'}(x)\gamma_\nu \widetilde{S}_s^{aa'}(x)\gamma_\mu\right]\Big\}|0\rangle,\end{aligned}$$

QCD sum rule analyses

- Insert propagator to master formula, we can get the correlation function in the form of the operator product expansion(OPE)

Dimension 10

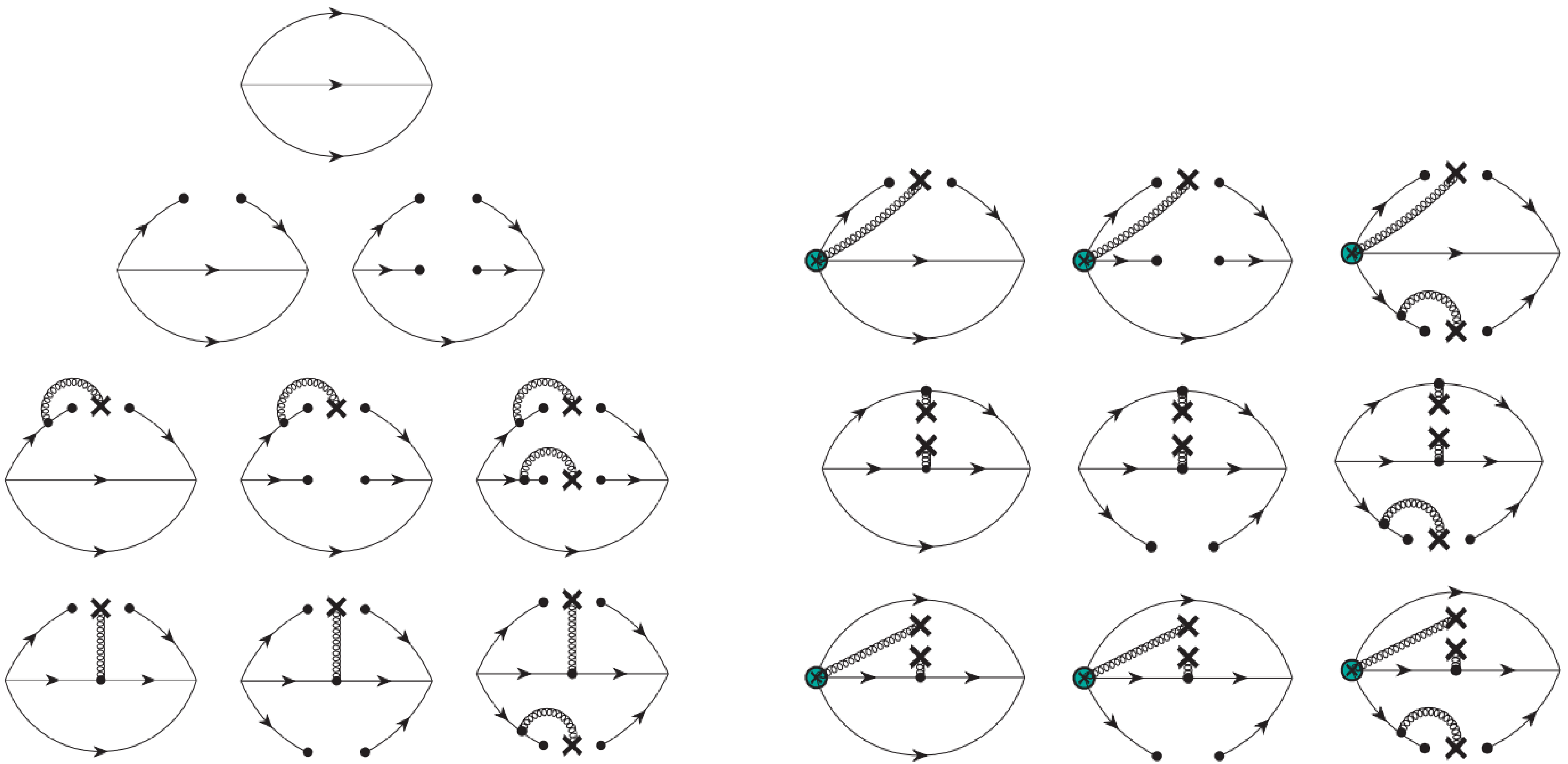
$$\rho_1^{\mathrm{OPE}}(s) = \frac{5s^3}{36864\pi^4} - \frac{167m_s^2 s^2}{40960\pi^4} - \Big(\frac{5\langle g_s^2GG\rangle}{49152\pi^4} - \frac{11m_s\langle\bar{s}s\rangle}{1024\pi^2}\Big)s + \Big(-\frac{263m_s\langle g_s\bar{s}\sigma Gs\rangle}{73728\pi^2} + \frac{155m_s^2\langle g_s^2GG\rangle}{196608\pi^4}\Big) - \Big(\frac{89\langle\bar{s}s\rangle\langle g_s\bar{s}\sigma Gs\rangle}{3072} - \frac{29m_s\langle g_s^2GG\rangle\langle\bar{s}s\rangle}{147456\pi^2} - \frac{m_s^2\langle\bar{s}s\rangle^2}{128}\Big)\delta(s) + \Big(-\frac{361\langle g_s\bar{s}\sigma Gs\rangle^2}{36864} - \frac{\langle g_s^2GG\rangle\langle\bar{s}s\rangle^2}{1152} + \frac{m_s\langle g_s^2GG\rangle\langle g_s\bar{s}\sigma Gs\rangle}{3072\pi^2} + \frac{7m_s^2\langle\bar{s}s\rangle\langle g_s\bar{s}\sigma Gs\rangle}{192}\Big)\delta'(s)\,,$$

Dimension 11

$$\rho_0^{\mathrm{OPE}}(s) = \frac{23m_s s^3}{32768\pi^4} - \frac{\langle\bar{s}s\rangle s^2}{96\pi^2} - \Big(\frac{317m_s\langle g_s^2GG\rangle}{589824\pi^4} - \frac{103m_s^2\langle\bar{s}s\rangle}{1536\pi^2} + \frac{37\langle g_s\bar{s}\sigma Gs\rangle}{3072\pi^2}\Big)s + \Big(\frac{441m_s^2\langle g_s\bar{s}\sigma Gs\rangle}{8192\pi^2} + \frac{25\langle\bar{s}s\rangle\langle g_s^2GG\rangle}{24576\pi^2}\Big) - \Big(\frac{13m_s^2\langle g_s^2GG\rangle\langle\bar{s}s\rangle}{4096\pi^2} - \frac{13\langle g_s^2GG\rangle\langle g_s\bar{s}\sigma Gs\rangle}{294912\pi^2} + \frac{5m_s\langle\bar{s}s\rangle\langle g_s\bar{s}\sigma Gs\rangle}{64}\Big)\delta(s) + \Big(-\frac{5m_s\langle g_s\bar{s}\sigma Gs\rangle^2}{2084} - \frac{3m_s\langle g_s^2GG\rangle\langle\bar{s}s\rangle^2}{1024} + \frac{9m_s^2\langle g_s^2GG\rangle\langle g_s\bar{s}\sigma Gs\rangle}{8192\pi^2}\Big)\delta'(s) \quad (1$$

QCD sum rule analyses

- Feynman diagrams in the present study



QCD sum rule analyses

- By equating the spectral densities at the hadron and quark-gluon levels, and by performing the Borel transformation, we derive the sum rule equation as

$$\begin{aligned}\Pi_{\mp}(s_0, M_B) &= 2M_{\mp} f_{\mp}^2 e^{-M_{\mp}^2/M_B^2} \\ &= \int_{s_<}^{s_0} (\sqrt{s}\rho_1^{\mathrm{OPE}}(s) \pm \rho_0^{\mathrm{OPE}}(s)) e^{-s/M_B^2} ds.\end{aligned}$$

- Π_- is the equation for the negative parity state, Π_+ is the equation for the positive parity state

QCD sum rule analyses

- The masses and coupling constants are obtained as

$$M_{\mp}^{2}(s_0, M_B) = \frac{\int_{s_<}^{s_0} (\sqrt{s}\rho_1^{\rm OPE}(s) \pm \rho_0^{\rm OPE}(s)) s e^{-s/M_B^2} ds}{\int_{s_<}^{s_0} (\sqrt{s}\rho_1^{\rm OPE}(s) \pm \rho_0^{\rm OPE}(s)) e^{-s/M_B^2} ds}$$

$$f_{\mp}^{2}(s_0, M_B) = \frac{\int_{s_<}^{s_0} (\sqrt{s}\rho_1^{\rm OPE}(s) \pm \rho_0^{\rm OPE}(s)) e^{-s/M_B^2} ds \times e^{M_{\mp}^2/M_B^2}}{2M_{\mp}}$$

Contents

Numerical analyses

- Take $J^p = 3/2^-$ state as an concrete example

- Mass formula

$$M_{\mp}^2(s_0, M_B) = \frac{\int_{s_<}^{s_0} (\sqrt{s}\rho_1^{\mathrm{OPE}}(s) \pm \rho_0^{\mathrm{OPE}}(s)) s e^{-s/M_B^2} ds}{\int_{s_<}^{s_0} (\sqrt{s}\rho_1^{\mathrm{OPE}}(s) \pm \rho_0^{\mathrm{OPE}}(s)) e^{-s/M_B^2} ds}$$

- Two parameters: s_0, M_B

- Criteria:
  1. The convergence of OPE
  2. The pole contribution
  3. The mass dependence on these two parameters

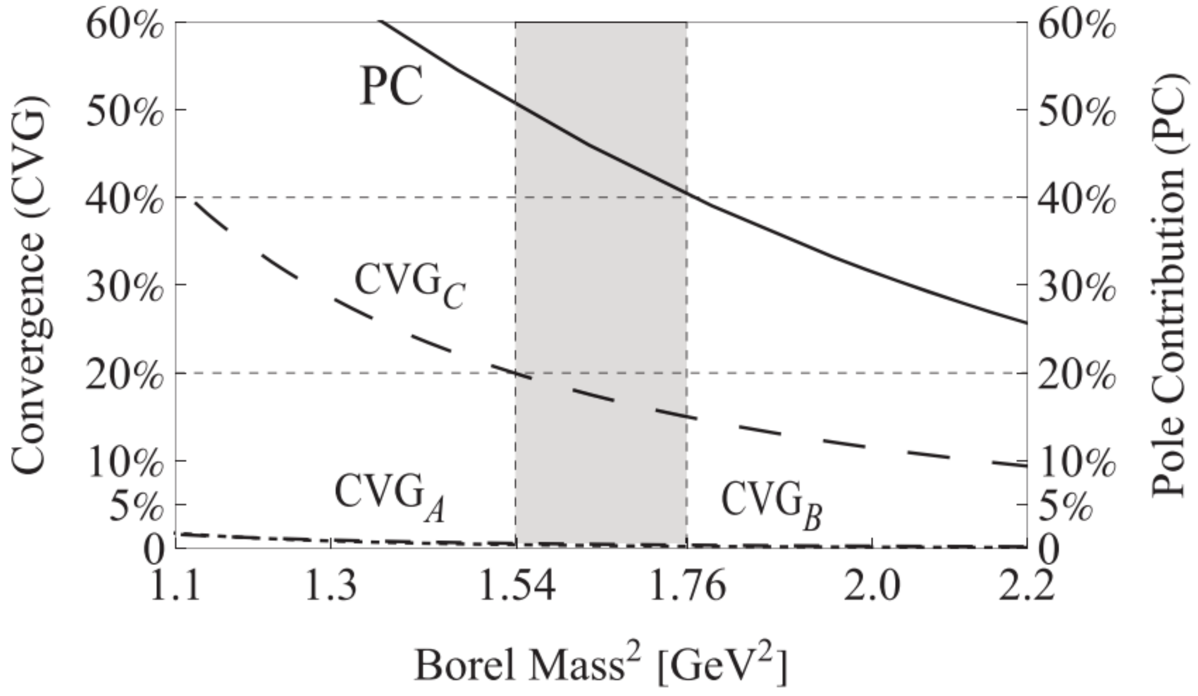
Numerical analyses

- The convergence of OPE

$$\mathrm{CVG}_A \equiv \left| \frac{\Pi_-^{D=11+10+9+8}(\infty, M_B^2)}{\Pi_-(\infty, M_B^2)} \right| \leq 5\% \,,$$

$$\mathrm{CVG}_B \equiv \left| \frac{\Pi_-^{D=7+6}(\infty, M_B^2)}{\Pi_-(\infty, M_B^2)} \right| \leq 10\% \,,$$

$$\mathrm{CVG}_C \equiv \left| \frac{\Pi_-^{D=5+4}(\infty, M_B^2)}{\Pi_-(\infty, M_B^2)} \right| \leq 20\% \,,$$



- The pole contribution

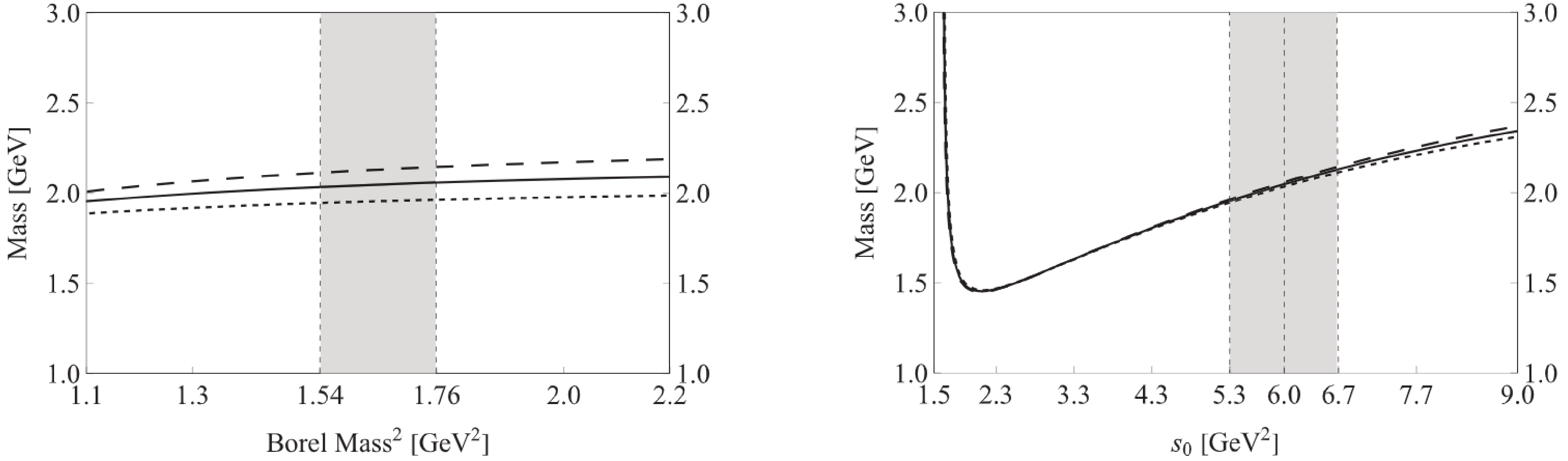
$$\mathrm{PC} \equiv \left| \frac{\Pi_-(s_0, M_B^2)}{\Pi_-(\infty, M_B^2)} \right| \geq 40\% \,.$$

$$1.54\ \mathrm{GeV}^2 \leq M_B^2 \leq 1.76 \Leftrightarrow s_0 = 6.0\ \mathrm{GeV}^2$$

$$s_0^{\min} = 5.3\ \mathrm{GeV}^2$$

Numerical analyses

- The mass of $3/2^-$ state as a function of these two parameters



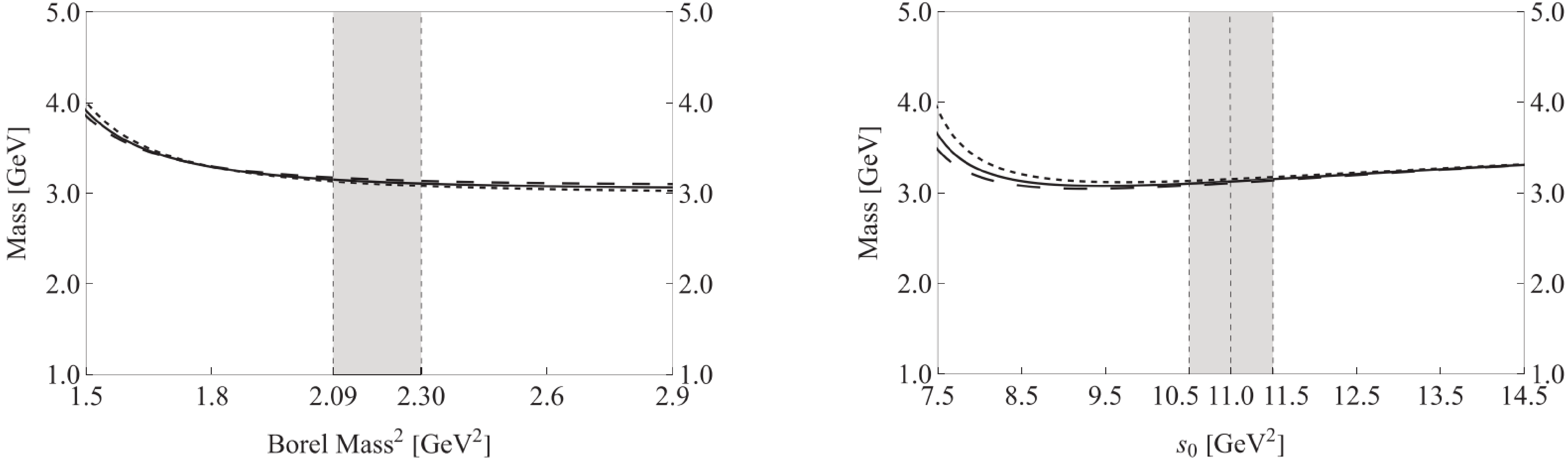
$$M_{3/2^-} = 2.05^{+0.09}_{-0.10}\ \text{GeV}\,,$$

$$f_{3/2^-} = 0.037^{+0.007}_{-0.007}\ \text{GeV}^3$$

$$s_0^{\min} = 5.3\ \text{GeV}^2$$

Numerical analyses

- The mass dependence on the two parameters for the $J^p = 3/2^+$ state



$$M_{3/2^+} = 3.13^{+0.27}_{-0.18}\ \text{GeV}\,,$$
$$f_{3/2^+} = 0.074^{+0.015}_{-0.009}\ \text{GeV}^3$$

Numerical analyses

- The masses and the couple constants for the $J^p = 3/2$ state using the current with a derivative

$$J_\mu = -2\epsilon^{abc}\left[(D^\nu s_a^T)C\gamma_5 s_b\right](g_{\mu\nu} - \frac{1}{4}\gamma_\mu\gamma_\nu)s_c$$

TABLE I: Masses and coupling constants extracted from the currents J in Eq. (5), J_μ in Eq. (6), and J'_μ in Eq.(30).

Current	state	s_0^{min} [GeV^2]	Working Regions		Pole [%]	Mass [GeV]	Couple constant [GeV^3]
			M_B^2 [GeV^2]	s_0 [GeV^2]			
J	$\|\Omega; 1/2^+\rangle$	9.7	1.91-2.40	11.0	40-55	$3.05^{+0.21}_{-0.15}$	$0.168^{+0.045}_{-0.040}$
	$\|\Omega; 1/2^-\rangle$	5.5	1.58-1.73	6.0	40-47	$2.07^{+0.07}_{-0.07}$	$0.079^{+0.011}_{-0.011}$
J_μ	$\|\Omega; 3/2^+\rangle$	10.5	2.09-2.30	11.0	40-46	$3.13^{+0.27}_{-0.18}$	$0.074^{+0.015}_{-0.009}$
	$\|\Omega; 3/2^-\rangle$	5.3	1.54-1.76	6.0	40-51	$2.05^{+0.09}_{-0.10}$	$0.037^{+0.007}_{-0.007}$
J'_μ	$\|\Omega'; 3/2^+\rangle$	3.3	1.48-1.77	4.0	40-52	$1.59^{+0.10}_{-0.12}$	$0.033^{+0.006}_{-0.006}$
	$\|\Omega'; 3/2^-\rangle$	11.5	3.30-3.93	13.0	40-51	$3.15^{+0.16}_{-0.17}$	$0.092^{+0.018}_{-0.018}$

Numerical analyses

- The masses and the couple constants for the $J^p = 1/2$ state using the current with a derivative

$$J = -2\epsilon^{abc}\left[(D^\mu s_a^T)C\gamma_5 s_b\right]\gamma_\mu s_c$$

TABLE I: Masses and coupling constants extracted from the currents J in Eq. (5), J_μ in Eq. (6), and J'_μ in Eq.(30).

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J'_μ	$\|\Omega';3/2^+\rangle$	3.3	1.48-1.77	4.0	40-52	$1.59^{+0.10}_{-0.12}$	$0.033^{+0.006}_{-0.006}$
	$\|\Omega';3/2^-\rangle$	11.5	3.30-3.93	13.0	40-51	$3.15^{+0.16}_{-0.17}$	$0.092^{+0.018}_{-0.018}$

Numerical analyses

- The masses and the couple constants for the $J^p = 3/2$ state using the current without a derivative

$$J'_\mu = -\sqrt{3}\epsilon^{abc} s_a^T C\gamma_\mu s_b s_c$$

TABLE I: Masses and coupling constants extracted from the currents J in Eq. (5), J_μ in Eq. (6), and J'_μ in Eq.(30).

Current	state	$s_0^{\min}$ [GeV^2]	Working Regions M_B^2 [GeV^2]	Working Regions s_0 [GeV^2]	Pole [%]	Mass [GeV]	Couple constant [GeV^3]
J	$\|\Omega; 1/2^+\rangle$	9.7	1.91-2.40	11.0	40-55	$3.05^{+0.21}_{-0.15}$	$0.168^{+0.045}_{-0.040}$
	$\|\Omega; 1/2^-\rangle$	5.5	1.58-1.73	6.0	40-47	$2.07^{+0.07}_{-0.07}$	$0.079^{+0.011}_{-0.011}$
J_μ	$\|\Omega; 3/2^+\rangle$	10.5	2.09-2.30	11.0	40-46	$3.13^{+0.27}_{-0.18}$	$0.074^{+0.015}_{-0.009}$
	$\|\Omega; 3/2^-\rangle$	5.3	1.54-1.76	6.0	40-51	$2.05^{+0.09}_{-0.10}$	$0.037^{+0.007}_{-0.007}$
J'_μ	$\|\Omega'; 3/2^+\rangle$	3.3	1.48-1.77	4.0	40-52	$1.59^{+0.10}_{-0.12}$	$0.033^{+0.006}_{-0.006}$
	$\|\Omega'; 3/2^-\rangle$	11.5	3.30-3.93	13.0	40-51	$3.15^{+0.16}_{-0.17}$	$0.092^{+0.018}_{-0.018}$

Contents

- Background
- P-wave Ω baryon currents
- QCD sum rule analyses
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Summary and outlook

- We have constructed the P-wave Ω baryon currents with a derivative of spin 1/2 and 3/2 by performing the spin projections
- We have analyzed the parity projected QCD sum rules to separate the positive parity state and negative parity state
- Our QCD sum rule results predict both $1/2^-$ and $3/2^-$ states in the mass region of $\Omega(2012)$. Considering the narrow width, the $\Omega(2012)$ is likely to be a P -wave excited Ω baryon with spin $3/2^-$. The $1/2^-$ state is expected to have a wider width, which could be tested by future experiments.
- We will study its decay properties to further determine its spin

Summary and outlook

- Until now, only the mass and width of the $\boldsymbol{\Omega(2012)}$ resonance were measured, more experimental information is needed
- Furthermore, both on theoretical and experimental sides, the studies on the radiative decay of $\boldsymbol{\Omega(2012)}$ are also important, and they will be helpful to further understand the nature of the $\boldsymbol{\Omega(2012)}$ state

Thanks for your attention !

Backup slides

Backup

$$\mathcal{R}_{\Xi\bar{K}}^{\Xi\pi\bar{K}} = 0.97$$

Belle collaboration, arXiv: 2207.03090

Backup

Propagator of the strange quark

$$
\begin{aligned}
& iS_s^{ab}(x-y) \qquad (28)\\
= \;& \langle 0|\mathbf{T}[s^a(x)\bar{s}^b(y)]|0\rangle \\
= \;& \frac{i\delta^{ab}}{2\pi^2(x-y)^4}(\hat{x}-\hat{y}) - \frac{\delta^{ab}}{12}\langle\bar{s}s\rangle \\
& + \frac{i}{32\pi^2(x-y)^2}\frac{\lambda^n_{ab}}{2}g_s G^n_{\mu\nu}\left(\sigma^{\mu\nu}(\hat{x}-\hat{y}) + (\hat{x}-\hat{y})\sigma^{\mu\nu}\right) \\
& - \frac{1}{4\pi^2(x-y)^4}\frac{\lambda^n_{ab}}{2}g_s G^n_{\mu\nu}x^\mu y^\nu(\hat{x}-\hat{y}) \\
& + \frac{\delta^{ab}(x-y)^2}{192}\langle g_s\bar{s}\sigma G s\rangle - \frac{m_s\delta^{ab}}{4\pi^2(x-y)^2} \\
& + \frac{i\delta^{ab}}{48}m_s\langle\bar{s}s\rangle(\hat{x}-\hat{y}) + \frac{i\delta^{ab}}{8\pi^2(x-y)^2}m_s^2(\hat{x}-\hat{y})\,.
\end{aligned}
$$