The $Y(2175)$ State in the QCD Sum Rule

Hua-Xing Chen[1,2], Xiang Liu[2], Atsushi Hosaka[1] and Shi-Lin Zhu[2]
[1] *Research Center for Nuclear Physics (RCNP), Osaka University, Ibaraki, Osaka 567-0047, Japan*
[2] *Department of Physics, Peking University, Beijing 100871, China*

Recently Babar Collaboration observed a resonance $Y(2175)$ near the threshold in the process $e^+e^- \to \phi f_0(980)$ via initial-state radiation [1]. It has the quantum numbers $J^{PC} = 1^{--}$. The Breit-Wigner mass is $M = 2.175 \pm 0.010 \pm 0.015$ GeV, and width is $\Gamma = 0.058 \pm 0.016 \pm 0.020$ GeV. It has been also confirmed by BES collaboration in the process $J/\psi \to \eta\phi f_0(980)$. A fit with a Breit-Wigner function gives the peak mass and width of $M = 2.186 \pm 0.010 \pm 0.006$ GeV and $\Gamma = 0.065 \pm 0.023 \pm 0.017$ GeV [2].

In this work, we study the mass of the state $Y(2175)$ with the quantum numbers $J^{PC} = 1^{--}$ in the QCD sum rule. We have constructed both the diquark-antidiquark currents $(ss)(\bar{s}\bar{s})$ and the meson-meson currents $(\bar{s}s)(\bar{s}s)$, expecting that both ϕ and $f_0(980)$ have a large fraction of $\bar{s}s$. We find that there are two independent currents $\eta_{1,2}$ for both cases and verify the relations between them [4]. Then using the two $(ss)(\bar{s}\bar{s})$ currents, we calculate the OPE up to dimension twelve, which contains the $\langle\bar{s}s\rangle^4$ condensates. The convergence of the OPE turns our to be very good. We find that the OPE's of the two currents are similar, and therefore, the obtained results are also similar. By using both the SVZ sum rule and the finite energy sum rule, we find reasonably good stability (Borel window). For SVZ sum rule, the stability is obtained in the region $5 < s_0 < 7$ GeV^2 and $2 < M_B^2 < 4$ GeV^2. For finite energy sum rule, the stability is in the region $4.5 < s_0 < 5.5$ GeV^2. The resulting mass is about $2.2 \sim 2.4$ GeV. Considering the uncertainty in the sum rule, the state $Y(2175)$ can be accommodated in the QCD sum rule formalism although the central value of the mass is about 100 MeV higher than the experimental value. Taking the current $\eta_{1\mu}$ as an example, the mass is shown as functions of the Borel mass M_B and the threshold value s_0 in Fig. 1 [4].

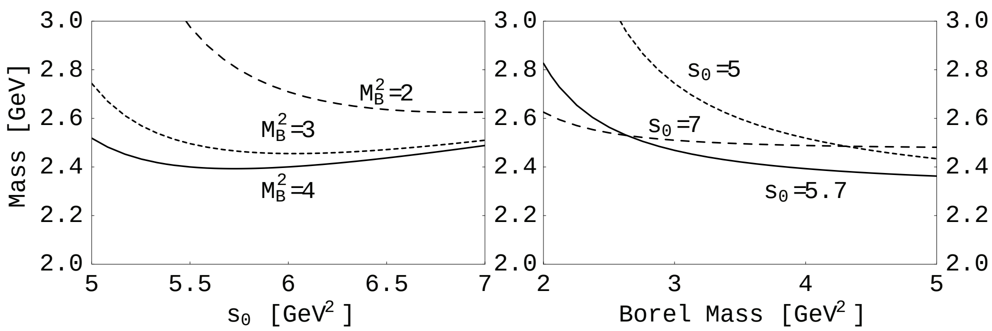

Figure 1: The mass of $Y(2175)$ as a function of M_B (Left) and s_0 (Right) in units of GeV for the current $\eta_{1\mu}$.

We have investigated the coupling of the currents to the lower lying states including $\phi(1020)$ and found that the relevant spectral density becomes negative, implying that the present four-quark currents can not describe those states properly. This fact indicates that the four-quark interpolating currents couple rather weakly to $\phi(1020)$, which is a pure $s\bar{s}$ state. It is an interesting observation that some type of four-quark interpolating currents may couple weakly to the conventional $q\bar{q}$ ground states. If future work confirms this point, we may have a novel framework to study the excited $q\bar{q}$ mesons using the four-quark interpolating currents, which is not feasible for the traditional $q\bar{q}$ interpolating currents.

Although the present analysis worked reasonably well, we can not completely exclude other possibilities for the nature of $Y(2175)$; it could be a threshold effect, a hybrid state $s\bar{s}G$, a tetraquark, an excited $s\bar{s}$ state or a mixture of all the above possibilities. Because of its non-exotic quantum number, it is not easy to establish its underlying structure. Clearly more experimental and theoretical investigations are required.

References

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