14th International Conference on Hypernuclear and Strange Particle Physics - HYP2022

Contribution ID: **64** Type: **poster**

Analysis of coupled-channel potentials with quark and hadron degrees of freedom

Tuesday 28 June 2022 16:10 (1 minute)

As a recent topic of heavy flavor systems, exotic charmonia called X, Y, Z have been observed experimentally above the meson-meson threshold. Masses of X, Y, Z, however, are not reproduced by the Cornell potential only with the degrees of freedom of $\bar{c}c$. This indicates that the X, Y, Z states have coupled channel effects of $\bar{c}c$ and meson-meson states strongly.

Because of the color confinement of quarks, the $\bar{c}c$ potentials diverge at large distance. On the other hand, the meson-meson potentials vanish at large distance, because the interaction range is limited by the inverse pion mass. What then is the effect of the coupling to the two-hadron channels in the $\bar{c}c$ potentials and vice versa? It is expected that the coupling to the meson-meson channel affect $\bar{c}c$ potentials and the coupling of mesons with $\bar{c}c$ affect meson-meson potentials.

In this talk, we consider the channel couplings between the $\bar{c}c$ and meson-meson potentials, and investigate the properties of the effective potentials which are obtained by eliminating one of the channels.[1]
We show that these effective potentials $V_{\rm eff}(E)$ at energy E are written as follows

$$\langle boldsymbolr'_{\bar{D}D}|V_{\rm eff}^{\bar{D}D}(E)|boldsymbolr_{\bar{D}D}\rangle = V^{\bar{D}D}(boldsymbolr)\delta(boldsymbolr'-boldsymbolr)+\sum_n \frac{\langle boldsymbolr'_{\bar{D}D}|V^t|\phi_n\rangle\langle\phi_n|V^t|boldsymbolr_{\bar{D}D}\rangle}{E-E_n},$$

$$\langle boldsymbolr'_{\bar{c}c}|V_{\rm eff}^{\bar{c}c}(E)|boldsymbolr_{\bar{c}c}\rangle = V^{\bar{c}c}(boldsymbolr)\delta(boldsymbolr'-boldsymbolr)+\int d\,boldsymbolp \frac{\langle boldsymbolr'_{\bar{c}c}|V^t|boldsymbolp_{\rm full}\rangle\langle boldsymbolp_{\rm full}|V^t|boldsymbolr_{\bar{c}c}\rangle}{E-E_{boldsymbolp}+i0^+},$$

where $boldsymbolr$ and $boldsymbolr'$ are coordinates before and after interactions, V is potentials of internal interactions, V^t is the transition potential of channel couplings, $|\phi_n\rangle$ is the eigenstate of the $\bar{c}c$ Hamiltonian with energy E_n, and $|boldsymbolp^{\rm full}\rangle$ is the meson-meson eigenstate with energy $E_{boldsymbolp}$.

We discuss that the coupling to the eliminated channel induces the non-local and energy dependent effective potential, irrespective of the behavior of the transition potential. In addition, when the hadron channel having continuous scattering eigenstates is eliminated, the resulting $\bar{c}c$ potential contains an imaginary part. The physical property which stems from imaginary part, however, may be lost by the finite terms of the derivative expansion.

[1] H. Feshbach, Ann. Phys. 5, 357 (1958); ibid., 19, 287 (1962).

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Session Classification: 6; Poster session