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Study the structure of $X(3872)$ from its lineshape

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arxiv:2401.03373，arxiv:2401.00411

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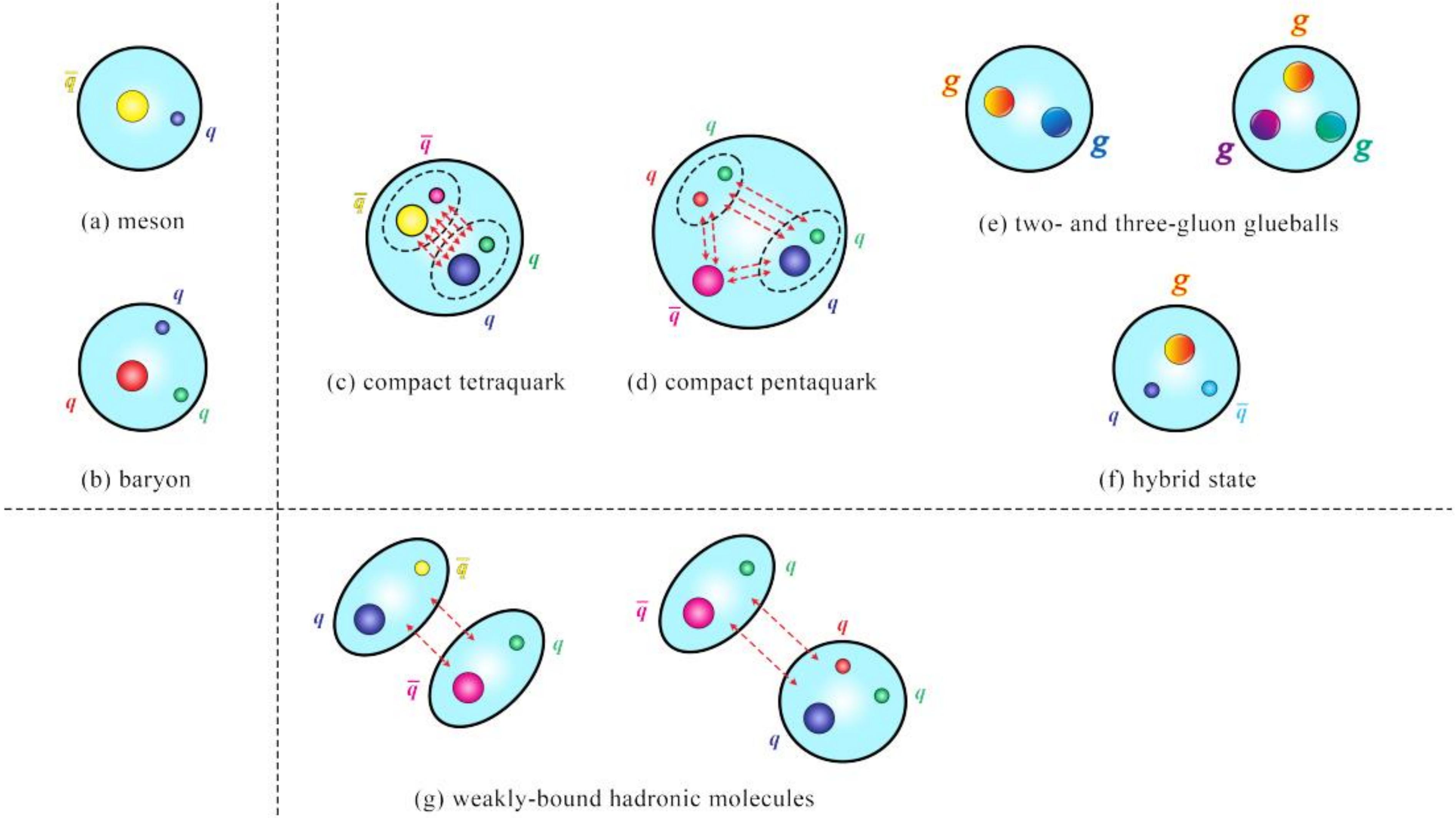
Outline

- Introduction
- The propagator in EFT incorporating Weinberg's compositeness theorem
- Study on $X(3872)$ using the propagator
- Summary


(a) meson
(b) baryon
(c) compact tetraquark
(d) compact pentaquark
(e) two- and three-gluon glueballs
(f) hybrid state
(g) weakly-bound hadronic molecules

Weinberg’s compositeness theorem

$$a = [2(1-Z)/(2-Z)]/\sqrt{2\mu B} + \mathcal{O}(m_\pi^{-1})$$

$$r = -[Z/(1-Z)]/\sqrt{2\mu B} + \mathcal{O}(m_\pi^{-1})$$

The a is scattering length, r is effective range. The Z is the wave function renormalization constant Z, presenting the probability of finding a compact component in the state, the hadron structure information encoded in Z .

Weinberg S. Phys. Rev., 1963, 130: 776
Weinberg S. Phys. Rev. B, 1965, 137: 672

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Relations: $g^2 = \frac{2\pi\sqrt{2\mu B}}{\mu^2}(1-Z)$, $g_0^2 = g^2/Z$, $B_0 = \frac{2-Z}{Z}B$

The propagator for the S-wave near-threshold state is written as

$$\mathrm{G_X}(E) = \frac{iZ}{D_{EFT}(E)}, \qquad D_{EFT}(E) = E + B + \tilde{\Sigma}'(E) + i\,\Gamma/2,$$

$$\tilde{\Sigma}'(E) = -g^2[\frac{\mu}{2\pi}\sqrt{-2\mu E - i\epsilon} + \frac{\mu\sqrt{2\mu B}}{4\pi B}(E-B)].$$

For a two-body channel, denoted as DD, with a threshold M_{th} and a near-threshold state X with mass M and width Γ.

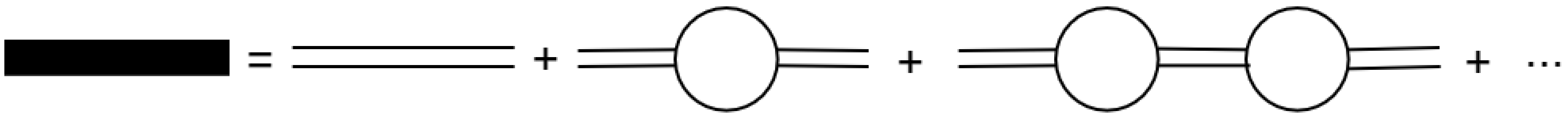


Figure. Full propagator for the near-threshold state.
The double line denotes the bare state.

The full propagator can be rewritten as

$$i\Delta = \frac{iZ}{2E + (2-Z)B - g^2\frac{\mu}{2\pi}\sqrt{-2\mu E - i\epsilon} + iZ\,\Gamma_0/2}$$

$$= \frac{iZ}{E + B - g^2\frac{\mu}{2\pi}\sqrt{-2\mu E - i\epsilon} - (1-Z)(E-B) + iZ\,\Gamma_0/2}$$

$$= \frac{iZ}{E + B - g^2\frac{\mu}{2\pi}\sqrt{-2\mu E - i\epsilon} - g^2\frac{\mu\sqrt{2\mu B}}{4\pi B}(E-B)] + iZ\,\Gamma_0/2}$$

We can find $\boldsymbol{\Gamma = Z\Gamma_0}$

For $X(3872)$, we may also consider the charged DD channel. The full propagator, which include the charged DD channel, can be written as

$$G_{X(3872)} = \frac{iZ}{E + B + \widetilde{\Sigma}'(E) + i\,\Gamma/2},$$

$$\widetilde{\Sigma}'(E) = -g^2 \left[\frac{\mu}{2\pi}\sqrt{-2\mu E - i\epsilon} + \frac{\mu\sqrt{2\mu B}}{4\pi B}(E - B)\right] -$$

$$g_c^2 \left[\frac{\mu_c}{2\pi}\sqrt{-2\mu_c(E-\delta) - i\epsilon} + \frac{\mu_c\sqrt{2\mu_c(B+\delta)}}{4\pi(B+\delta)}(E - B - 2\delta)\right].$$

- Breit-Wigner amplitude:

$$f(E) = \frac{1}{D_{BW}(E)}, D_{BW}(E) = E + B + i\,\Gamma/2$$

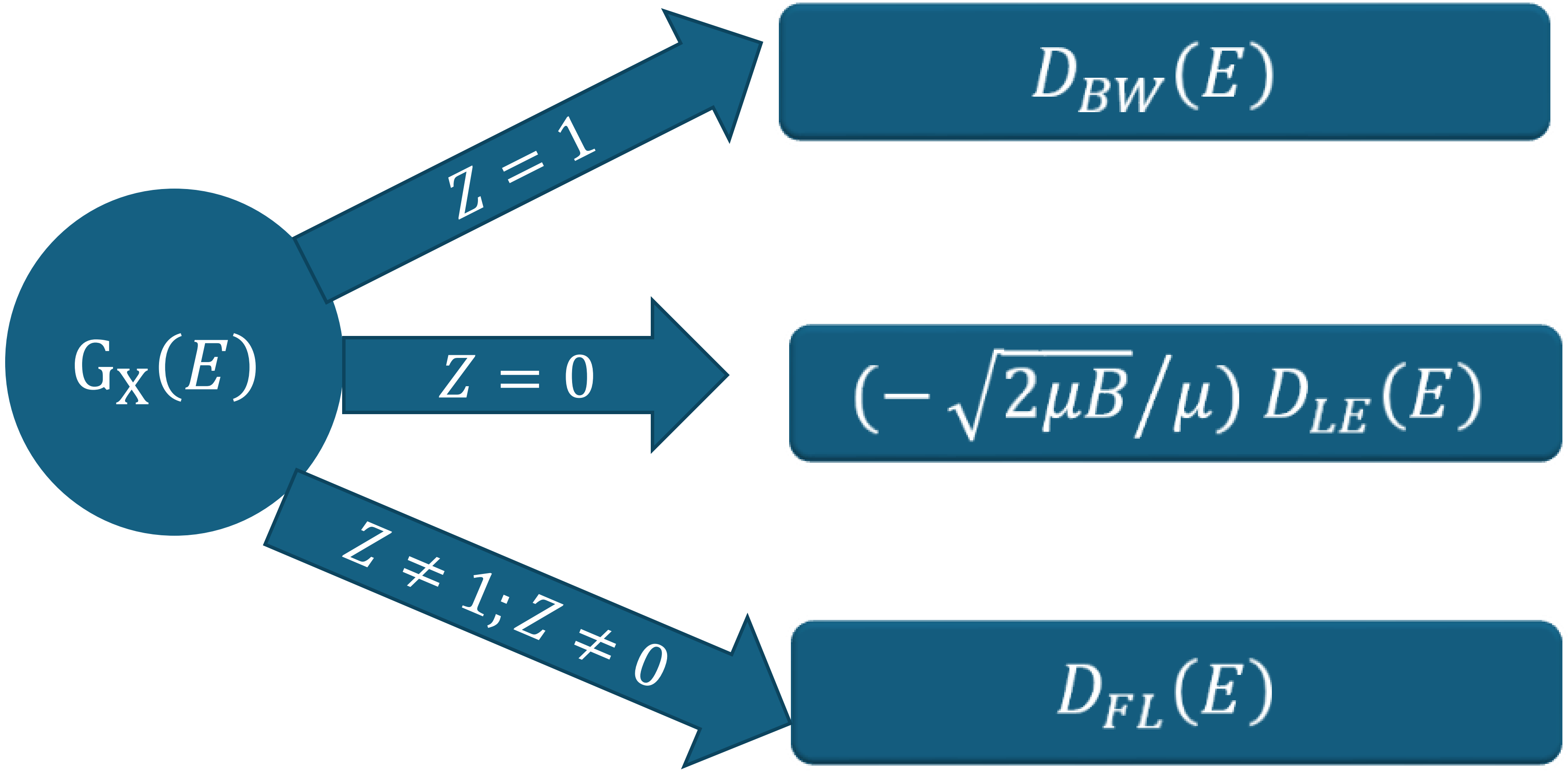
- Flatté amplitude:

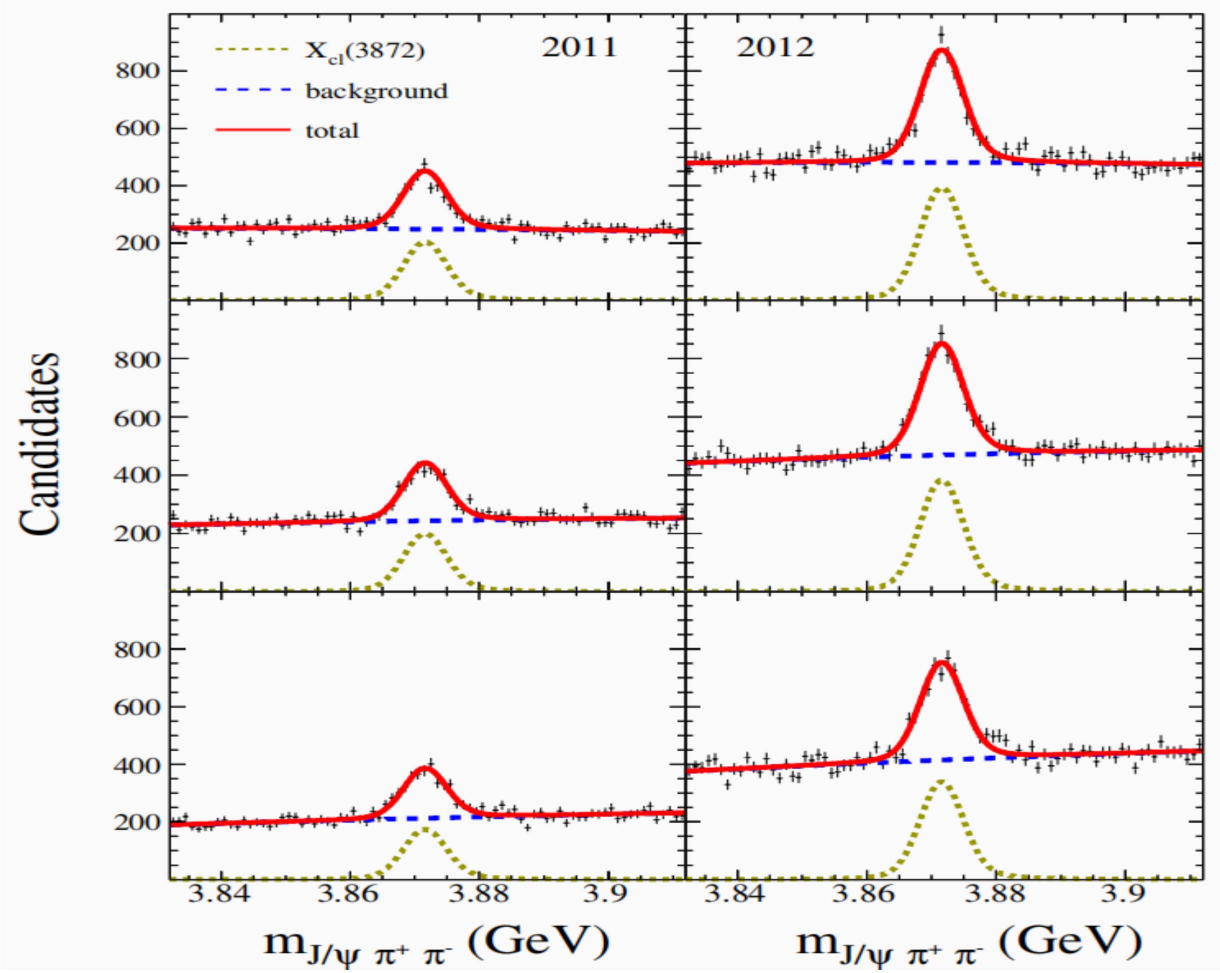
$$f(E) = \frac{1}{D_{FL}(E)}, D_{FL}(E) = E - E_f - \frac{1}{2} g_1 \sqrt{-2\mu E} + i\frac{1}{2}\Gamma_f$$

- Low-energy scattering amplitude:

$$f(E) = \frac{1}{D_{LE}(E)}, D_{LE}(E) = -1/a + \sqrt{-2\mu E - i\epsilon}$$

S. M. Flatte, Phys. Lett. B 63 (1976) 224–227.
E. Braaten and M. Lu, Phys. Rev. D 76 (2007) 094028.


$G_X(E)$
$Z = 1$
$Z = 0$
$Z \neq 1; Z \neq 0$
$D_{BW}(E)$
$(-\sqrt{2\mu B}/\mu)\, D_{LE}(E)$
$D_{FL}(E)$

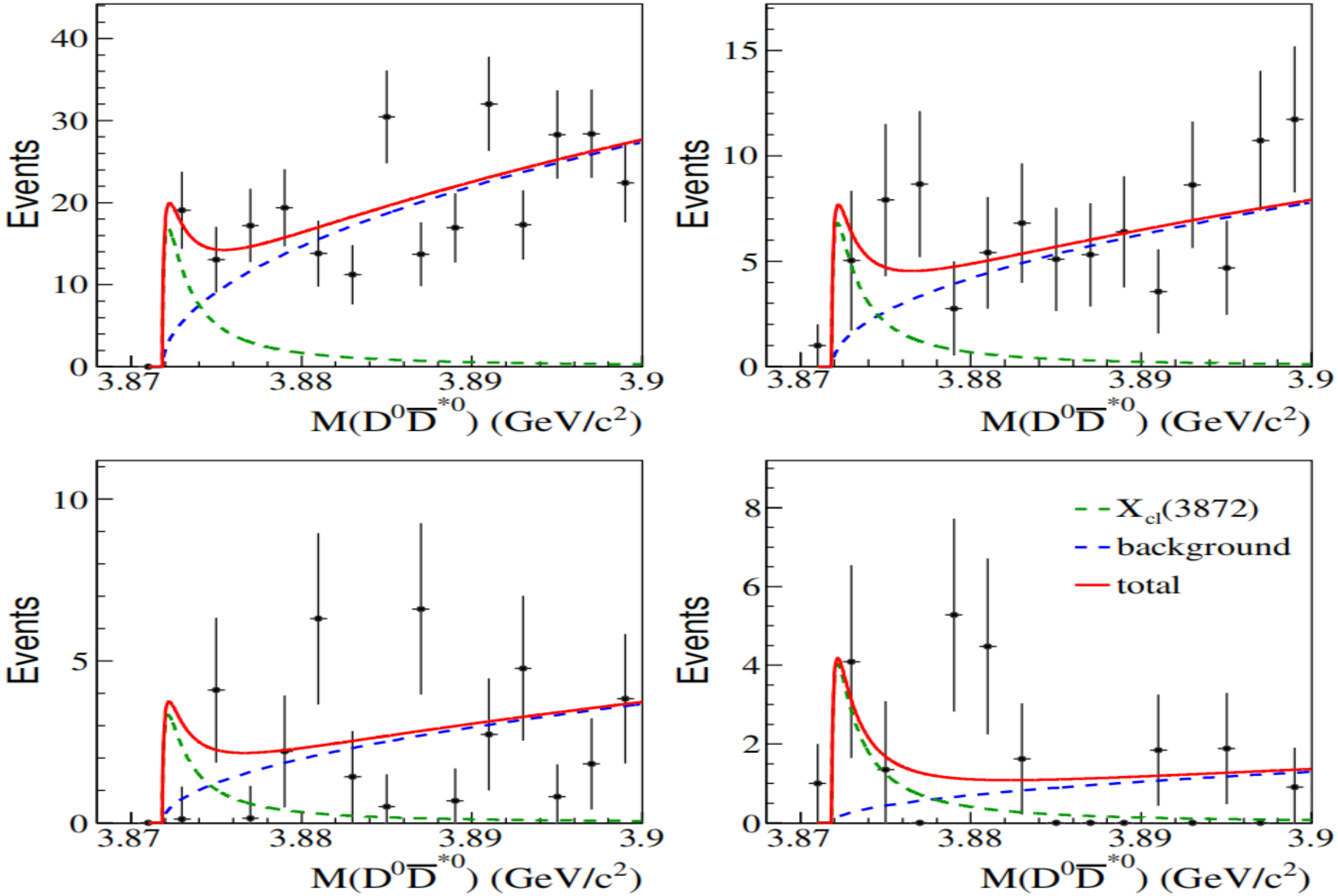


$P_{\pi^+\pi^-} \leq 12GeV$

$20GeV \leq P_{\pi^+\pi^-} \leq 12GeV$

$12GeV \leq P_{\pi^+\pi^-} \leq 50GeV$

The mass distributions of $X(3872)$ based on LHCb data. The points with error bars represent data. The red solid line shows the total fit result, blue dashed line shows the contribution of background.



$B^+ \to X(3872)K^+$

$B^0 \to X(3872)K^0$

The $M(D^0\bar{D}^{0*})$distributions based on Belle data, $\bar{D}^{0*} \to \bar{D}^0\gamma$(left) and $\bar{D}^{0*} \to \bar{D}^0\pi^0\gamma$ (right).

The parameters from fitting lineshape of $X(3872)$.

Fitting scheme	Z	Γ(MeV)	B(MeV)	χ^2/ndf
LHCb Fit	0.543 ± 0.123	4.65 ± 0.55	0.977 ± 0.091	0.800
Belle Fit	0.410 ± 0.047	3.2 ± 96.6	2.304 ± 0.729	0.982
Combined Fit	0.520 ± 0.109	4.513 ± 0.483	0.977 ± 0.075	0.973

H. Xu, N. Yu, and Z. Zhang, arxiv:2401.00411.
R. Aaij et al. (LHCb), Physical Review D 102, 092005 (2020).
H. Hirata et al. (Belle), Phys. Rev. D 107, 112011
A. Esposito, L. Maiani, A. Pilloni, et al., Phys. Rev. D 105, L031503 (2022).
M. Ablikim, et al. (BESIII Collaboration), Phys.Rev.Lett. 132 (2024) 15, 151903

Summary

- The propagator for near-threshold states in EFT incorporating Weinberg's compositeness theorem is general.
- The fitting result of Z for $X(3872)$ is non-vanishing based on LHCb and Belle data.
- We are analysing the Z for $X(3872)$ using the propagator considering the charged DD channel.

Thanks for your attention!