A new look at the X compositeness from its lineshape

Based on: A. Carducci, G. Cianti, P. D'Annibali, D. Germani, A. D. Polosa (2026)

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The compositeness problem

The question: what is the $X(3872)$ made of?

- Mass sits right at threshold: $m(X) \simeq m(D^0) + m(D^{*0})$, $B \lesssim$ few hundred keV.
- Compact tetraquark: $[cq][\bar{c}\bar{q}]$, an *elementary* field at the EFT scale.
- Hadronic molecule: a $D\bar{D}^*$ shallow bound state, *dynamically generated* — its pole comes from resumming $D\bar{D}^*$ bubbles, no fundamental X field.

The claim of this work

The answer is already encoded in the lineshape, but only if the amplitude used to fit it is derived from the right effective Lagrangian. The parametrization currently used (Flatté) presupposes the existence of an elementary X.

Compositeness from the effective range

- Universal S-wave amplitude at low energy:

$$f = \frac{1}{-1/a + \frac{1}{2} r_0 k^2 - ik}$$

- Weinberg[1]: $r_0 > 0 \Rightarrow$ composite (bound state); $r_0 < 0 \Rightarrow$ non-zero field renormalization Z, i.e. elementary.
- LHCb lineshape fitted with the Flatté amplitude f_- gives $r_0^- = -5.34$ fm: large and negative.

The circularity

f_- treats X on the same footing as $D, \bar{D}^*$. Its r_0 is negative by construction — the fit tests the *self consistency* of the elementary hypothesis, not the molecular one.

[1] S. Weinberg, Phys. Rev. **137** (1965) B672

The auxiliary-field Lagrangian

An EFT with no elementary X

Kaplan[2]: a shallow bound state can be described by an auxiliary field Φ (no external legs, no loops) with a wrong sign kinetic term, $\sigma = -1$:

$$\mathcal{L}_{\text{eff}} = N^\dagger \left(i\partial_t + \frac{\nabla^2}{2M} \right) N + \sigma\, \Phi^\dagger \left(i\partial_t + \frac{\nabla^2}{4M} - \Delta \right) \Phi - \left[y\, \Phi^\dagger N N + \text{h.c.} \right] - \tfrac{1}{2} C\, (N^\dagger N)^2$$

- Φ is a bookkeeping device (Hubbard–Stratonovich): it just repackages the contact NN interaction.
- $n, p \to D, \bar{D}^*$ and $\Phi \to X$ generate a lineshape distinct from Flatté's.
- The sign $\sigma = -1$ is what makes $r_0 > 0$ come out.

[2] D. B. Kaplan, Nucl. Phys. B **494** (1997) 471 [nucl-th/9610052]

The coupling is not free: the Landau coupling

A loosely bound state couples to its constituents with a universal strength fixed by B and the reduced mass m:

$$g_B^2 = \frac{2\pi}{m}\sqrt{\frac{2B}{m}}$$

Consequence

For a genuinely molecular state the lineshape has no free coupling: y must come out of the same order of the Landau value. This is the discriminating constraint.

L. D. Landau, JETP **39** (1960); A. Esposito, A. Glioti, D. Germani, A. D. Polosa, Riv. Nuovo Cim. **48** (2025) 95

Validation: the deuteron

Benchmark: does it reproduce the deuteron?

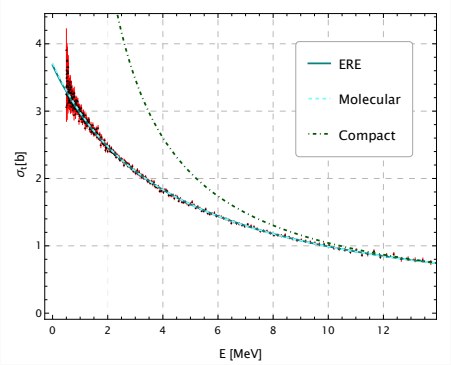
Consider an NN scattering and solve the Lippmann–Schwinger equation with $V_{\text{eff}}(p) = C + \dfrac{\sigma y^2}{E - \Delta}$:

$$\mathcal{A}_{\text{eff}} = -\frac{C(E-\Delta) + \sigma y^2}{E - \Delta + i\frac{Mp}{4\pi}(C(E-\Delta) + \sigma y^2)}, \tag{1}$$

$\sigma = -1 \Rightarrow$ Auxiliary field = molecular interpretation

$\sigma = 1 \Rightarrow$ real field = compact interpretation

Fitting real np scattering data



Triplet-channel np cross section, EXFOR data.

- Three fits: ERE, molecular $|f_+|^2$, compact $|f_-|^2$.
- ERE: $a_t = 5.435(6)$ fm, $r_{0t} = 1.71(1)$ fm.
- Molecular: $y_+ = 0.0573(2)$ MeV$^{-1/2}$
  Compare with Landau coupling g_B: $y \sim \sqrt{2} g_B$
- Compact: no stable minimum ($y_- \sim 150$ MeV$^{-1/2}$).

J. M. Clement *et al.*, Nucl. Phys. A **183** (1972) 51; EXFOR, N. Otuka *et al.*, Nucl. Data Sheets **120** (2014) 272

Back to the $X(3872)$

Two lineshapes for the X

Both include the charged $D^+\bar{D}^{*-}$ threshold at $\delta \simeq 8.2$ MeV and an inelastic width Γ_r:

$$f_\mp = \frac{\mp \frac{m g_\mp^2}{2\pi}}{E - \Delta \pm i \frac{m g_\mp^2}{2\pi} \left[\sqrt{2mE} + i\sqrt{-2m(E-\delta)} \pm i\frac{\Gamma_r}{2} \right]},$$

f_- : Flatté, compact

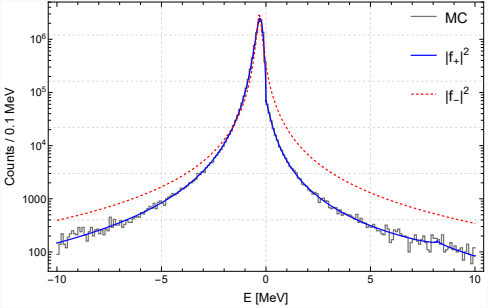
f_+ : auxiliary field, molecular

- For $k \to 0$ both collapse onto the ERE amplitude, but with different parameters:

$$r_0^\pm = \pm \frac{2\pi}{m^2 g_\pm^2} - \frac{1}{\sqrt{2m\delta}}, \tag{2}$$

  so $r_0^+ > r_0^{\min} = -1.58$ fm while $r_0^- < 0$ always.
- In f_- the coupling g_- is purely phenomenological; in f_+, it must be $g_+ \sim g_B$.

Can the two be told apart? Pseudo-data test



- 10^6 MC events generated from $|f_+|^2$ with $B = 200$ keV, $\Gamma_X = 480$ keV (Γ_X from the conservative bound set by $\mathcal{B}_X\Gamma_X = \Gamma(X \to DD\pi) \propto g_B^2$).
- Refit with both $|f_+|^2$ and $|f_-|^2$.
- The peak region is degenerate; the tails discriminate.

A molecular X therefore must be fit well by f_+ with y at the Landau value.

A. D. Polosa, Phys. Lett. B **746** (2015) 248 [arXiv:1505.03083]

Conclusions

Conclusions and proposal

- The Flatté amplitude used on LHCb data assumes an elementary X; the resulting $r_0^- < 0$ is an output of that assumption, not a test of it. Weinberg's criterion applied this way is circular.
- A truly molecular X requires the auxiliary field amplitude f_+ ($\sigma = -1$), with the coupling constrained by the Landau value g_B.
- Validated on the deuteron: this proposed molecular lineshape fits np data, while the compact one (Flatté) does not.

What we ask for

Refit the LHCb $X(3872)$ lineshape with f_+: the molecular hypothesis survives only if (i) the fit is good and (ii) $y \simeq g_B$. Never done on the available data.

Thank you!