$X(3915)$ as a tensor $D^*\bar{D}^*$ molecule

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$X(3915)$: Where are we now?

Experimental background (Belle & BaBar)

- $X(3915)$ in $B \to KX \to K(\omega J/\psi)$ and $\gamma\gamma \to X \to \omega J/\psi$
- $X(3940)$ (believed to be 2^{++}) in $\gamma\gamma \to X \to D\bar{D}$

Quantum numbers and possible identification of $X(3915)$

- Belle: 0^{++} or 2^{++} ($\chi_{c0}(2P)$ or $\chi_{c2}(2P)$ charmonium?)
- BaBar: 2^{++} ruled out by angular analysis in $\omega J/\psi$ ($\chi_{c0}(2P)$?)

Identification $X(3915) = \chi_{c0}(2P)$ raises questions

- Where is $X(3915) \to D\bar{D}$ mode?
- If $X^*(3860) = \chi_{c0}(2P)$ (Belle'2017) what is $X(3915)$?
- ...

The problem of the $X(3915)$ quantum numbers

- Alekseev'58;Krammer&Krasemann'78;Li,Close,&Barnes'91:

  In two-photon decays of 2^{++} positronium and quarkonium helicity-0 amplitude gives a small relativistic correction

- BaBar'2012:

  Under the assumption of helicity-2 dominance, angular distributions in the $\omega J/\psi$ final state are better described with $J = 0$ than with $J = 2$

- Zhou,Xiao&Zhou'2015:

  Helicity-2 dominance is not proved for exotic states $\Longrightarrow X(3915)/X(3940)$ might be helicity-0/2 realisations of an exotic 2^{++} tensor

- Baru,Hanhart,A.N'2017 (present talk):

  Can $X(3915)$ be explained as a tensor molecule?

Helicity decomposition of $\gamma\gamma \to X_2$ amplitude

Helicity-0 amplitude:

$$\mathcal{S}_1^{\rho\sigma} \propto g^{\rho\sigma}(\partial_\alpha F^{(1)}_{\mu\nu})(\partial^\alpha F^{(2)\mu\nu}) \Longrightarrow \varepsilon^{(1)}_\mu \varepsilon^{(2)}_\nu e_1^{\mu\nu\rho\sigma}$$

$$\mathcal{S}_2^{\rho\sigma} \propto (\partial^\rho F^{(1)}_{\mu\nu})(\partial^\sigma F^{(2)\mu\nu}) + (\partial^\sigma F^{(1)}_{\mu\nu})(\partial^\rho F^{(2)\mu\nu}) - \frac{1}{2} g^{\rho\sigma}(\partial_\alpha F^{(1)}_{\mu\nu})(\partial^\alpha F^{(2)\mu\nu}) \Longrightarrow \varepsilon^{(1)}_\mu \varepsilon^{(2)}_\nu e_2^{\mu\nu\rho\sigma}$$

$$\mathcal{S}_3^{\rho\sigma} \propto (\partial^\rho \partial^\sigma F^{(1)}_{\mu\nu}) F^{(2)\mu\nu} + F^{(1)}_{\mu\nu}(\partial^\rho \partial^\sigma F^{(2)\mu\nu}) \Longrightarrow \varepsilon^{(1)}_\mu \varepsilon^{(2)}_\nu e_3^{\mu\nu\rho\sigma}$$

Helicity-2 amplitude:

$$\mathcal{S}_4^{\rho\sigma} \propto F^{(1)\rho}_{\beta} F^{(2)\beta\sigma} + F^{(1)\sigma}_{\beta} F^{(2)\beta\rho} - \frac{1}{2} g^{\rho\sigma} F^{(1)}_{\mu\nu} F^{(2)\mu\nu} \Longrightarrow \varepsilon^{(1)}_\mu \varepsilon^{(2)}_\nu e_4^{\mu\nu\rho\sigma}$$

Helicity decompositions of the amplitude:

$$M(\gamma\gamma \to X_2) = e^2 \varepsilon^{(1)}_\mu \varepsilon^{(2)}_\nu \varepsilon_{\rho\sigma} \sum_{n=1}^{4} C_n e_n^{\mu\nu\rho\sigma}$$

Notice! Due to properties of the X_2 polarisation tensor $\varepsilon_{\rho\sigma}$

- helicity-0 amplitude is entirely defined by $C_2\sqrt{2} - C_3$
- helicity-2 amplitude is defined by C_4

Angular distribution for $\gamma\gamma \to X_2 \to$ final state

For the reaction $\gamma\gamma \to X_2 \to$ final state

$$\frac{d\sigma}{d\cos\theta} = \sigma_0 \left[f_0(\cos\theta) + R\, f_2(\cos\theta)\right]$$

$$\sigma = \sigma_0(1 + R)$$

- f_0 and f_2 — process-specific normalised to unity distributions
- σ_0 — contribution of the helicity-0 amplitude
- the ratio R is

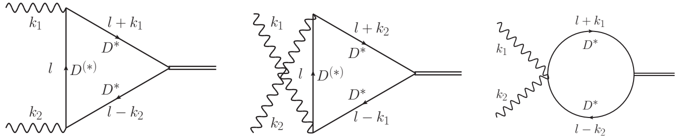
$$R = \frac{\sigma_2}{\sigma_0} \equiv \frac{2|A_{\pm 2}|^2}{|A_0|^2}$$

- helicity amplitudes are $A_0 = C_2\sqrt{2} - C_3$ and $A_{\pm 2} = \sqrt{\frac{3}{2}}C_4$

Note: for a genuine $\bar{c}c$ charmonium $R \gg 1$

The molecular model

- Assumption: $X(3915)$ is a tensor $D^*\bar{D}^*$ molecule
- X_2 is produced in $\gamma\gamma$ fusion via $D^{(*)}$-meson loops

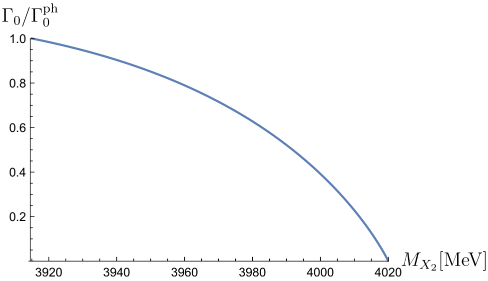


with electric and magnetic vertices $D^{(*)} \to D^{(*)}\gamma$

- Problem: Loops diverge $\Longrightarrow$ infinite coefficients $C_1..C_4$
- But! The combination $C_2\sqrt{2} - C_3$ is finite!
- Therefore, one observable is sufficient to fix the model!

Two-photon width of the tensor $D^*\bar{D}^*$ molecule

For $M_{X_2} \to M(D^*\bar{D}^*)$ strong cancellations between different contributions to the helicity-0 amplitude take place



Conclusion: Near threshold

$$\Gamma_0 \to 0 \quad \Longrightarrow \quad R \gg 1$$

that implies helicity-2 dominance

Calculation for the realistic X_2 mass

Problem: Coupling $g^2_{X_2 D^* D^*} \propto \sqrt{E_B[X(3915)]}$, however

$$E_B[X(3915)] = 2m_{D^*} - M(X(3915)) \sim 100 \text{ MeV}$$

$\Longrightarrow$ finite-range corrections are out of control ($\sqrt{m_{D^*} E_B}/\beta \simeq 1$)!

Solution: Assume X_2 to be spin partner of $X(3872) = D\bar{D}^*$
$\Longrightarrow$ heavy quark symmetry relates $g_{X_2 D^* D^*}$ and g_{XDD^*} with

$$E_B = M(D^0 D^{*0}) - M(X(3872)) = 0.01 \pm 0.20 \text{ MeV}$$

Then: The helicity-0 contribution to the $X_2 \to \gamma\gamma$ width is

$$\Gamma_0(X_2 \to \gamma\gamma) \approx 0.033\sqrt{E_B} \text{ keV} \lesssim 0.015 \text{ keV}$$

Corrections are controlled by the parameter $\Lambda_{\text{QCD}}/m_c \simeq 1/5$

Two-photon width of the tensor X_2: The ratio R

Theoretical value

$$\Gamma_{\rm th}(X_2 \to \gamma\gamma) \lesssim 0.015(1+R)\ \text{keV}$$

Experimental value ($\mathcal{B}(\chi_{c2} \to D\bar{D}) \approx 1$)

$$\Gamma_{\rm exp}(X_2 \to \gamma\gamma) \approx \Gamma(\chi_{c2} \to \gamma\gamma)\mathcal{B}(\chi_{c2} \to D\bar{D})$$
$$= (0.18 \pm 0.05 \pm 0.03)\ \text{keV}$$

To reconcile $\Gamma_{\rm th}(X_2 \to \gamma\gamma)$ with $\Gamma_{\rm exp}(X_2 \to \gamma\gamma)$ one needs

$$R \gtrsim 11 \gg 1$$

Conclusion

- Data currently available do not support sizeable contribution of helicity-0 amplitude in two-photon transitions through the tensor $D^*\bar{D}^*$ molecule
- Thus, exotic $X(3915)$ cannot be explained as a
  - tensor $D^*\bar{D}^*$ molecule (no other tensor S-wave candidates) which is
  - a spin partner of the $X(3872)$ (Occam's razor)
- Therefore, either tensor $X(3915)$ has a different exotic nature or it has to be identified as a scalar (ordinary or exotic)