Exotic XYZ mesons in covariant quark model

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New Trends in HEP, 2016

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Contents

Exotics

- The elementary constituents in QCD are

quarks q, antiquarks $\bar{q}$, and gluons g.

- They are confined into color-singlet **hadrons**.
- The most stable hadrons predicted by the quark model:

conventional mesons $q\bar{q}$, baryons qqq and antibaryons $\bar{q}\bar{q}\bar{q}$.

- This simple picture is being challenged since 2003 with the discovery of almost two dozen charmonium- and bottomonium-like **XYZ** states that do not fit the naive quark-antiquark interpretation.
- Most of these states usually appear close to meson-meson thresholds and thus their dynamics can be strongly dictated by the nearby multiquark channels.

Exotics

- Basically, they were discovered by the Belle and BaBar experiments using e^+e^- collisions in the bottomonium region. The experiment BESIII can use e^+e^- collisions in the charmonium region to directly produce the $Y(4260)$ or $Y(4360)$.
- These energies allow to produce charged charmoniumlike states, the $Z_c(3900)$ and the $Z_c(4020)$.
- The $Z_c(3900)$ and the $Z_c(4020)$ are especially interesting because of their electric charge. Since a $c\bar{c}$ system is electrically neutral, these states must contain more quarks, and may be four-quark systems, or molecules composed of two two-quark systems.

talk by Makoto Takizawa (Belle) at SFHQ school, Dubna, 2016

Y

- $J^{PC} = 1^{--}$, neutral
- production $e^+e^- \to Y$
- Y has $c\bar{c}$ pair
- But Y is not simple charmonium
- Examples: Y(4005), Y(4260), Y(4360), Y(4660)

Z (Z_c and Z_b)

- Z_c has $c\bar{c}$ pair and a charge
- Thus minimal quark content of Z_c^+ is $c\bar{c}u\bar{d}$ (exotic state!)
- Usually the isospin of the Z is 1, neutral partner should exist.
- Z_b has $b\bar{b}$ pair and a charge
- Examples: $Z_b(10610), Z_b(10650)$, $Z_c(3900), Z_c(4200), Z_c(4430)$, etc.

X

- $X's$ are the non-$q\bar{q}$ mesons other than $Y's$ and $Z's$
- Most famous is $X(3872)$ observed in reaction $B^+ \to K^+$ $\pi^+\pi^- J/\psi$
- Examples: $X(3915), X(3940), X(4350)$

XYZ: short introduction

A. Hosaka et al. PTEP 2016, no. 6, 062C01 (2016) [arXiv:1603.09229 [hep-ph]]

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)
X(3872)	3871.69±0.17	<1.2	1^{++}	$B \to K(\pi^+\pi^- J/\psi)$
				$p\bar{p} \to (\pi^+\pi^- J/\psi) + \ldots$
				$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$
				$B \to K(\omega J/\psi)$
				$B \to K(D^{*0}\bar{D}^0)$
				$B \to K(\gamma J/\psi)$ and
				$B \to K(\gamma\psi(2S))$
$Z_c(3900)^+$	3888.7 ± 3.4	35±7	1^+	$e^+e^- \to (J/\psi\ \pi^+)\pi^-$
				$e^+e^- \to (D\bar{D}^*)^+\pi^-$
X(3915)	3915.6 ± 3.1	28±10	$0/2^{?+}$	$B \to K(\omega J/\psi)$
				$e^+e^- \to e^+e^-(\omega J/\psi)$
X(3940)	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^- \to J/\psi(DD^*)$
				$e^+e^- \to J/\psi\ (\ldots)$
Y(4008)	3891 ± 42	255±42	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$
$Z_c(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B \to K(\pi^+\chi_{c1}(1P))$
$X(4050)^+$	4054 ± 3	45	?	$e^+e^- \to (\pi^+\psi(2S))\pi^-$
Y(4140)	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B \to K(\phi J/\psi)$

XYZ: short introduction

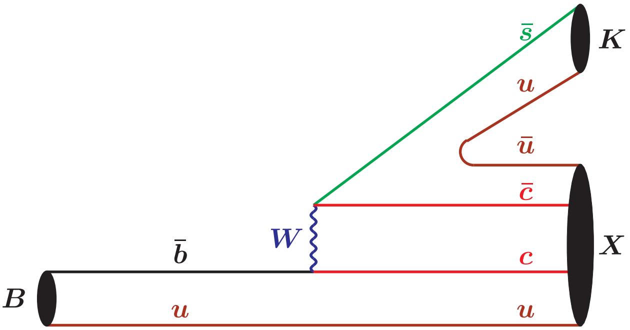
State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)
X(4160)	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^- \to J/\psi(D\bar{D}^*)$
$Z_c(4200)^+$	4196^{+35}_{-32}	370^{+99}_{-149}	?	$B \to K(\pi^+ J/\psi)$
$Z_c(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B \to K(\pi^+\chi_{c1}(1P))$
Y(4260)	4263 ± 5	108 ± 14	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^- J/\psi)$
				$e^+e^- \to (\pi^+\pi^- J/\psi)$
				$e^+e^- \to (\pi^0\pi^0 J/\psi)$
X(4350)	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$?^{?+}$	$e^+e^- \to e^+e^-(\phi J/\psi)$
Y(4360)	4361 ± 13	74 ± 18	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^-\psi(2S))$
$Z_c(4430)^+$	4485^{+36}_{-25}	200^{+49}_{-58}	1^+	$B \to K(\pi^+\psi(2S))$
				$B \to K(\pi^+ J/\psi)$
X(4630)	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^- \to \gamma(\Lambda_c^+\Lambda_c^-)$
Y(4660)	4664 ± 12	48 ± 15	1^{--}	$e^+e^- \to \gamma(\pi^+\pi^-\psi(2S))$
$Z_b(10610)^+$	10607.2 ± 2.0	18.4 ± 2.4	1^+	$e^+e^- \to (b\bar{b}\,\pi^+)\pi^-$
$Z_b(10610)^0$	$10609 \pm 4 \pm 4$	N.A.	1^{+-}	$e^+e^- \to (\Upsilon(2,3S)\pi^0)\pi^0$
$Z_b(10650)^+$	10652.2 ± 1.5	11.5 ± 2.2	1^+	$e^+e^- \to (b\bar{b}\,\pi^+)\pi^-$
$Y_b(10888)$	10888.4 ± 3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^- \to (\pi^+\pi^-\Upsilon(nS))$

X(3872)

A narrow charmonium-like state X(3872) was observed in the decay:

$$B^+ \rightarrow K^+ \underbrace{\pi^+\pi^- J/\psi}_{X}$$

S. K. Choi *et al.* [Belle Collaboration] Phys. Rev. Lett. 91, 262001 (2003)



X(3872)

- X-mass is close to $D^0 - D^{*\,0}$ mass threshold:

$$M_X = 3872.0 \pm 0.6\,(\mathrm{stat}) \pm 0.5\,(\mathrm{syst})\,\mathrm{MeV}$$

$$M_{D^0} + M_{D^{*\,0}} = 3871.81 \pm 0.25\,\mathrm{MeV}$$

- Its width $\Gamma_X \leq 2.3$ MeV at 90% CL.

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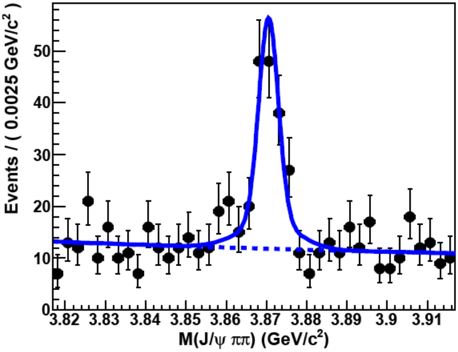
- The state was confirmed in B-decays by BaBar experiment

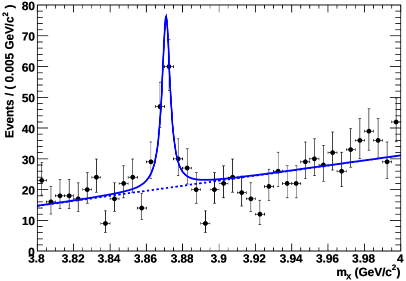
B. Aubert *et al.* Phys. Rev. Lett. 93, 041801 (2004)

and in $p\bar{p}$ production by Tevatron experiments CDF and DØ.

D. E. Acosta *et al.* [CDF Collaboration] Phys. Rev. Lett. 93, 072001 (2004);
V. M. Abazov *et al.* [D0 Collaboration] Phys. Rev. Lett. 93, 162002 (2004)

X(3872)





Belle **BABAR**

Fit to the $M(J/\psi\pi^+\pi^-)$ for the decay $B^+ \to K^+X$.

X(3872)

- **LHCb reported determination of the X(3872) meson quantum numbers**

R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. 110, 222001 (2013)

$$J^{PC} = 1^{++}$$

- **Belle reported evidence for the decay $X \to \pi^+\pi^-\pi^0 J/\psi$ dominated by the sub-threshold decay $X \to \omega J/\psi$.**

K. Abe *et al.*, [Belle Collaboration], arXiv:hep-ex/0505037,hep-ex/0505038

- **It was found that the branching ratio of this mode is almost the same as of $X \to \pi^+\pi^- J/\psi$**

$$\frac{\mathcal{B}(X \to J/\psi\pi^+\pi^-\pi^0)}{\mathcal{B}(X \to J/\psi\pi^+\pi^-)} = 1.0 \pm 0.4\,(\mathrm{stat}) \pm 0.3\,(\mathrm{syst}).$$

- **It implies strong isospin violation**

X(3872)

- The two-pion decay via intermediate ρ-meson is very difficult to explain by using an interpretation of the X(3872) as simple $c\bar{c}$ charmonium state with isospin 0.

- The possible candidate from $\bar{c}c$-spectroscopy:

$$\chi_{c_1}(2^3P_1) - \text{state with } J^{PC} = 1^{++}$$

  BUT the value of its mass varies from 3925 up to 3953 MeV. Also the decay width calculated in variuos models is too large.

- The X(3872) IS NOT the pure $\bar{c}c$-state

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- The X(3872) IS NOT the pure $\bar{c}c$-state

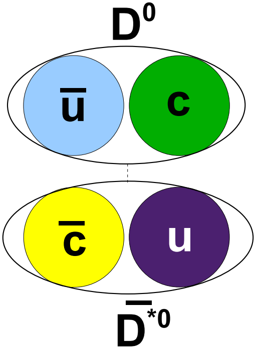
- a molecule bound state $D^0\bar{D}^{*0}$ with small binding energy

- a tetraquark state composed from a diquark and antidiquark

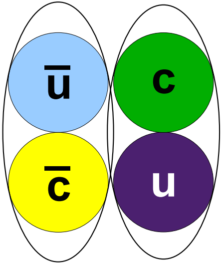
- threshold cusps

- hybrids and glueballs

X(3872)



D^0-$\bar{D}^{*0}$ "molecule"



diquark - antidiquark

M. Nielsen, F. S. Navarra and S. H. Lee, arXiv:0911.1958 [hep-ph]

X(3872)

- An intepretation of the X(3872) as a tetraquark was suggested in

L. Maiani, F. Piccinini, A. D. Polosa and V. Riquer, Phys. Rev. D 71, 014028 (2005)

$$X_q \Longrightarrow [cq]_{S=1}[\bar{c}\bar{q}]_{S=0} + [cq]_{S=0}[\bar{c}\bar{q}]_{S=1}, \qquad (q = u, d)$$

- Isospin breaking: the state X_u breaks isospin symmetry maximally:

$$X_u = \frac{1}{\sqrt{2}}\Big\{\underbrace{\frac{X_u + X_d}{\sqrt{2}}}_{I=0} + \underbrace{\frac{X_u - X_d}{\sqrt{2}}}_{I=1}\Big\}.$$

- The physical states are the mixing of X_u and X_d

$$\begin{aligned} X_l \equiv X_{low} &= X_u \cos\theta + X_d \sin\theta, \\ X_h \equiv X_{high} &= -X_u \sin\theta + X_d \cos\theta. \end{aligned}$$

- The mixing angle θ is supposed to be found from the known ratio of the two-pion (via ρ) and three-pion (via ω) decay widths.

X(3872)-meson as a tetraquark state: Lagrangian

S. Dubnicka, A. Z. Dubnickova, M. A. Ivanov and J. G. Körner, Phys. Rev. D 81, 114007 (2010)

- An effective interaction Lagrangian

$$\mathcal{L}_{\rm int} = g_X \, X_{q\,\mu}(x) \cdot J^{\mu}_{X_q}(x), \qquad (q = u, d).$$

- The nonlocal version of the four-quark interpolating current

$$J^{\mu}_{X_q}(x) = \int dx_1 \ldots \int dx_4 \, \delta(x - \sum_{i=1}^{4} w_i x_i) \, \Phi_X\Big(\sum_{i<j}(x_i - x_j)^2\Big) \, J^{\mu}_{4q}(x_1, \ldots, x_4)$$

$$J^{\mu}_{4q} = \frac{1}{\sqrt{2}} \varepsilon_{abc} [q_a(x_4) C \gamma^5 c_b(x_1)] \, \varepsilon_{dec} [\bar{q}_d(x_3) \gamma^{\mu} C \bar{c}_e(x_2)] + (\gamma^5 \leftrightarrow \gamma^{\mu}),$$

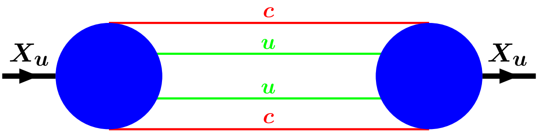
$$w_1 = w_2 = \frac{m_c}{2(m_q + m_c)} \equiv \frac{w_c}{2}, \qquad w_3 = w_4 = \frac{m_q}{2(m_q + m_c)} \equiv \frac{w_q}{2}.$$

Compositeness condition

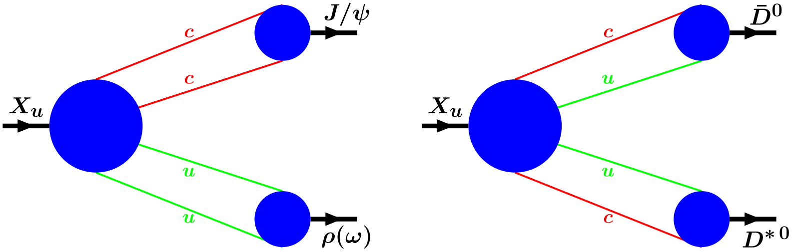
The coupling constant g_X is determined from the compositeness condition

$$Z_X = 1 - \Pi'_X(M_X^2) = 0$$

where $\Pi_X(p^2)$ is the scalar part of the vector-meson mass operator.



Strong off-shell decays



Since the X(3872) lies nearly the respective thresholds in both cases,

$$\begin{aligned} m_X - (m_{J/\psi} + m_\rho) &= -0.90 \pm 0.41\,\mathrm{MeV}, \\ m_X - (m_{D^0} + m_{D^{*\,0}}) &= -0.30 \pm 0.34\,\mathrm{MeV} \end{aligned}$$

the intermediate $\rho(\omega)$ and D^* mesons should be taken off-shell.

The narrow width approximation

$$\frac{d\Gamma(X \to J/\psi + n\pi)}{dq^2} = \frac{1}{8\, m_X^2\, \pi} \cdot \frac{1}{3} |M(X \to J/\psi + v^0)|^2$$

$$\times \frac{\Gamma_{v^0}\, m_{v^0}}{\pi} \frac{p^*(q^2)}{(m_{v^0}^2 - q^2)^2 + \Gamma_{v^0}^2\, m_{v^0}^2} \mathrm{Br}(v^0 \to n\pi),$$

$$\frac{d\Gamma(X_u \to \bar{D}^0 D^0 \pi^0)}{dq^2} = \frac{1}{2\, m_X^2\, \pi} \cdot \frac{1}{3} |M(X_u \to \bar{D}^0 D^{*0})|^2$$

$$\times \frac{\Gamma_{D^{*0}}\, m_{D^{*0}}}{\pi} \frac{p^*(q^2)\, \mathcal{B}(D^{*0} \to D^0 \pi^0)}{(m_{D^{*0}}^2 - q^2)^2 + \Gamma_{D^{*0}}^2\, m_{D^{*0}}^2},$$

Strong decay widths

- Two new adjustable parameters: θ and Λ_X.
- The ratio

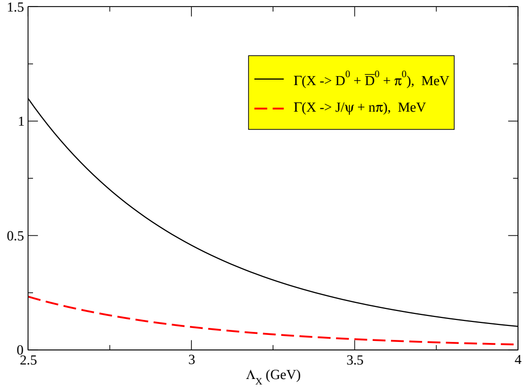
$$\frac{\Gamma(X_u \to J/\psi + 3\,\pi)}{\Gamma(X_u \to J/\psi + 2\,\pi)} \approx 0.25$$

  is very stable under variation of Λ_X.
- Using this result and the central value of the experimental data

$$\frac{\Gamma(X_{l,h} \to J/\psi + 3\,\pi)}{\Gamma(X_{l,h} \to J/\psi + 2\,\pi)} \approx 0.25 \cdot \left(\frac{1 \pm \tan\theta}{1 \mp \tan\theta}\right)^2 \approx 1$$

  gives $\theta \approx \pm 18.4^o$ for X_l ("+") and X_h ("−"), respectively.
- This is in agreement with the results obtained by both Maiani: $\theta \approx \pm 20^o$ and Nielsen: $\theta \approx \pm 23.5^o$.

Strong decay widths

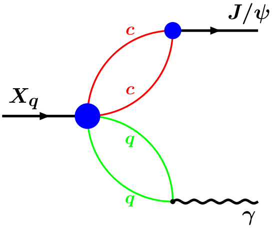


$$\frac{\Gamma(X \to D^0 \bar{D}^0 \pi^0)}{\Gamma(X \to J/\psi \pi^+ \pi^-)} = \begin{cases} 4.5 \pm 0.2 & \text{theor} \\ 10.5 \pm 4.7 & \text{expt} \end{cases}$$

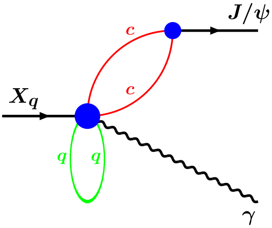
Radiative X-decay

S. Dubnicka, A. Z. Dubnickova, M. A. Ivanov, J. G. Koerner, P. Santorelli and G. G. Saidullaeva,

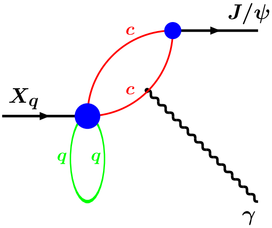
Phys. Rev. D 84, 014006 (2011)



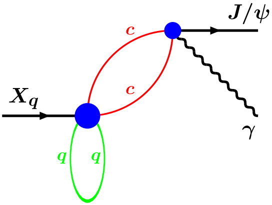
(a)



(b)



(c)



(d)

Radiative X-decay

The on-mass shell conditions

$$\varepsilon_X^\mu p_\mu = 0, \qquad \varepsilon_{J/\psi}^\nu q_{1\nu} = 0, \qquad \varepsilon_\gamma^\rho q_{2\rho} = 0$$

leave us five Lorentz structures:

$$\begin{aligned} T_{\mu\rho\nu}(q_1, q_2) &= \varepsilon_{q_2\mu\nu\rho}(q_1 \cdot q_2)\, W_1 + \varepsilon_{q_1 q_2 \nu\rho} q_{1\mu}\, W_2 + \varepsilon_{q_1 q_2 \mu\rho} q_{2\nu}\, W_3 \\ &+ \varepsilon_{q_1 q_2 \mu\nu} q_{1\rho}\, W_4 + \varepsilon_{q_1 \mu\nu\rho}(q_1 \cdot q_2)\, W_5 \,. \end{aligned}$$

Using the gauge invariance condition

$$q_2^\rho T_{\mu\rho\nu} = (q_1 \cdot q_2)\varepsilon_{q_1 q_2 \mu\nu}(W_4 + W_5) = 0$$

one has $W_4 = -W_5$ which reduces the set of independent covariants to four. However, there are two nontrivial relations among the four covariants which can be derived by noting that the tensor

$$T_{\mu[\nu_1\nu_2\nu_3\nu_4\nu_5]} = g_{\mu\nu_1}\varepsilon_{\nu_2\nu_3\nu_4\nu_5} + \mathrm{cycl.}(\nu_1\nu_2\nu_3\nu_4\nu_5)$$

vanishes in four dimensions since it is totally antisymmetric in the five indices $(\nu_1, \nu_2, \nu_3, \nu_4, \nu_5)$.

Radiative X-decay

The two conditions reduce the set of independent covariants to two. This is the appropriate number of independent covariants since the photon transition is described by two independent amplitudes as e.g. by the E1 and M2 transition amplitudes. One has

$$\Gamma(X \to \gamma\, J/\psi) = \frac{1}{12\pi}\,\frac{|\vec{q}_2|}{m_X^2}\left(|H_L|^2 + |H_T|^2\right) = \frac{1}{12\pi}\,\frac{|\vec{q}_2|}{m_X^2}\left(|A_{E1}|^2 + |A_{M2}|^2\right),$$

where the helicity amplitudes H_L and H_T are expressed in terms of the Lorentz amplitudes as

$$H_L = i\frac{m_X^2}{m_{J/\psi}}|\vec{q}_2|^2\left[W_1 + W_3 - \frac{m_{J/\psi}^2}{m_X|\vec{q}_2|}W_4\right],$$

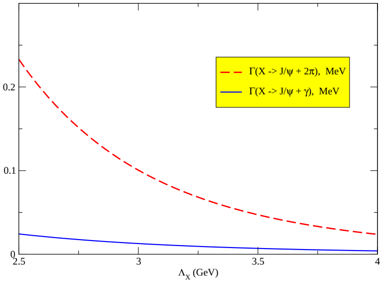
$$H_T = -im_X|\vec{q}_2|^2\left[W_1 + W_2 - \left(1 + \frac{m_{J/\psi}^2}{m_X|\vec{q}_2|}\right)W_4\right],$$

$$|\vec{q}_2| = \frac{m_X^2 - m_{J/\psi}^2}{2m_X}.$$

The E1 and M2 multipole amplitudes are obtained via

$$A_{E1/M2} = (H_L \mp H_T)/\sqrt{2}.$$

Radiative X-decay



If one takes $\Lambda_X \in (3,4)$ GeV with the central value $\Lambda_X = 3.5$ GeV then our prediction for the ratio of widths reads

$$\frac{\Gamma(X_l \to \gamma + J/\psi)}{\Gamma(X_l \to J/\psi + 2\pi)}\bigg|_{\rm theor} = 0.15 \pm 0.03$$

which fits very well the experimental data from the Belle Collaboration

$$\frac{\Gamma(X \to \gamma + J/\psi)}{\Gamma(X \to J/\psi\, 2\pi)} = \begin{cases} 0.14 \pm 0.05 & \textbf{Belle} \\ 0.22 \pm 0.06 & \textbf{BaBar} \end{cases}$$

$Z_c(3900)$

Data:

- Discovery mode

$$e^+e^- \to \pi^+ \underbrace{\pi^- J/\psi}_{Z_c^-} \qquad \text{BESIII, Belle}$$

- Mass and width (MeV)

$$M_{Z_c} = \begin{cases} 3899.0 \pm 3.6(\text{stat}) \pm 4.9(\text{syst}) & \text{BESIII} \\ 3894.5 \pm 6.6(\text{stat}) \pm 4.5(\text{syst}) & \text{Belle} \end{cases}$$

$$\Gamma_{Z_c} = \begin{cases} 46 \pm 10(\text{stat}) \pm 20(\text{syst}) & \text{BESIII} \\ 63 \pm 24(\text{stat}) \pm 26(\text{syst}) & \text{Belle} \end{cases}$$

$Z_c(3900)$

- $D\bar{D}^*$ mode

$$e^+e^- \to \pi^\pm \underbrace{(D\bar{D}^*)^\mp}_{Z_c^\mp} \qquad \text{BESIII}$$

- Mass and width (MeV)

$$\begin{aligned} M_{pole} &= 3883.9 \pm 1.5 \pm 4.2 \\ \Gamma_{pole} &= 24.8 \pm 3.3 \pm 11.0 \end{aligned}$$

- Angular distribution $\pi Z_c \Longrightarrow$ $J^P = 1^+$
- Enhancement of $D\bar{D}^*$ mode compare with $\pi J/\psi$

$$\frac{\Gamma(Z_c(3885) \to D\bar{D}^*)}{\Gamma(Z_c(3900) \to \pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$$

$Z_c(3900)$: theoretical interpretation

F. Goerke, T. Gutsche, M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij and P. Santorelli,
"Four-quark structure of Zc(3900), Z(4430) and Xb(5568) states," arXiv:1608.04656 [hep-ph].

- **Assume that Z_c is a four-quark state with a tetraquark-type current (similar to X(3872))**

$$J^\mu = \frac{i}{\sqrt{2}} \varepsilon_{abc}\varepsilon_{dec} \left[(u_a^T C\gamma_5 c_b)(\bar{d}_d \gamma^\mu C \bar{c}_e^T) - (u_a^T C\gamma^\mu c_b)(\bar{d}_d \gamma_5 C \bar{c}_e^T) \right]$$

- **Matrix element of the decay $1^+(p,\mu) \to 1^-(q_1,\nu) + 0^-(q_2)$**

$$M = (A\, g^{\mu\nu} + B\, q_1^\mu q_2^\nu)\, \varepsilon_\mu \varepsilon_\nu^*$$

- **Decay width**

$$\Gamma = \frac{|q_1|}{24\pi p^2} \left\{ \left(3 + \frac{|q_1|^2}{q_1^2}\right) A^2 + \frac{|q_1|^2}{q_1^2}(p^2 + q_1^2 - q_2^2)\, AB + \frac{|q_1|^4}{q_1^2} p^2\, B^2 \right\}$$

where the final state three-momentum in Z_c rest frame is given by

$$|q_1| = \lambda^{1/2}(p^2, q_1^2, q_2^2)/2\sqrt{p^2}$$

$Z_c(3900)$: theoretical interpretation

- We found that $A \equiv 0$ analytically in the case of the $D\bar{D}^*$ final state.
- This results in a significant suppression of the decay widths due to the D–wave suppression factor of $|q_1|^5$.
- In the calculation we have only one free parameter Λ_{Z_c}.
- If the parameter Λ_{Z_c} is varied in the region $\Lambda_{Z_c} = 3.3 \pm 1.1$ GeV then the decay widths vary as

$$\begin{aligned}
\Gamma(Z_c^+ \to J/\psi + \pi^+) &= (4.3^{+0.7}_{-0.6})\,\text{MeV}\,,\\
\Gamma(Z_c^+ \to \eta_c + \rho^+) &= (8.0^{+1.2}_{-1.0})\,\text{MeV}\,,\\
\Gamma(Z_c^+ \to \bar{D}^0 + D^{*\,+}) &\propto 10^{-9}\,\text{MeV}\,,\\
\Gamma(Z_c^+ \to \bar{D}^{*\,0} + D^+) &\propto 10^{-9}\,\text{MeV}\,.
\end{aligned}$$

- Since the experimental data show that the $Z_c(3900)$ has a much more stronger coupling to DD^* than $J/\psi\pi$, one has to conclude that the tetraquark-type current for $Z_c(3900)$ is in discord with experiment.

$Z_c(3900)$: theoretical interpretation

- **Assume that Z_c is a four-quark state with a molecular-type current**

$$J^\mu = \frac{1}{\sqrt{2}}\left[(\bar{d}\gamma_5 c)(\bar{c}\gamma^\mu u) + (\bar{d}\gamma^\mu c)(\bar{c}\gamma_5 u)\right]$$

- **Now the form factor A in the expansion of the amplitude is not equal to zero.**

- **If the Λ_{Z_c} is varied in the limits as above then the decay widths vary as**

$$\begin{aligned}
\Gamma(Z_c^+ \to J/\psi + \pi^+) &= (1.8 \pm 0.3)\,\text{MeV}\,, \\
\Gamma(Z_c^+ \to \eta_c + \rho^+) &= (3.2^{+0.5}_{-0.4})\,\text{MeV}\,, \\
\Gamma(Z_c^+ \to \bar{D}^0 + D^{*+}) &= (10.0^{+1.7}_{-1.4})\,\text{MeV}\,, \\
\Gamma(Z_c^+ \to \bar{D}^{*0} + D^+) &= (9.0^{+1.6}_{-1.3})\,\text{MeV}\,.
\end{aligned}$$

- **Thus a molecular-type current for the Z_c is in accordance with the experimental observation.**

Summary

- We have studied the properties of the X(3872) as a tetraquark.
- We have calculated the strong decays $X \to J/\psi + \rho(\to 2\pi)$, $X \to J/\psi + \omega(\to 3\pi)$, $X \to D + \bar{D}^*(\to D\pi)$ and electromagnetic decay $X \to \gamma + J/\psi$.
- The comparison with available experimental data allows one to conclude that the X(3872) can be a tetraquark state.
- We have critically checked two possible four-quark configurations for $Z_c(3900)$: tetraquark and molecular.
- We have calculated the partial widths of the decays $Z_c^+(3900) \to J/\psi\pi^+$, $\eta_c\rho^+$ and $\bar{D}^0 D^{*+}$, $\bar{D}^{*0} D^+$.
- It turned out the decays $Z_c(3900) \to \bar{D}D^*$ are significantly suppressed on the case of a tetraquark configuration.
- Alternatively, in the case of a molecular configuration the partial widths of those decays are close to ~ 15 MeV and exceeded the partial widths for the decays $Z_c(3900) \to J/\psi\pi$, $\eta_c\rho$ by a factor of 6-7 in accordance with BESIII-experiment.