Dynamical picture for the exotic XYZ states

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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 was changed since 2003 with the discovery of almost two dozen charmonium- and bottomonium-like XYZ states that do not fit the naive quark-antiquark interpretation.**

XYZ: short introduction

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)

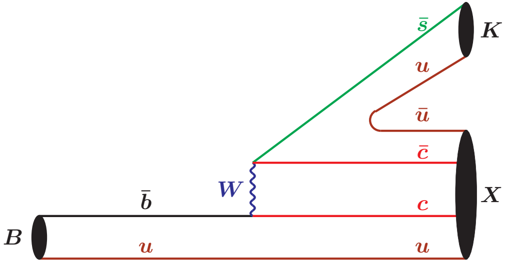
- Z_c has $c\bar{c}$ pair and a charge
- Thus minimal quark content of Z_c^+ is $c\bar{c}u\bar{d}$ (exotic state!)
- Usually the isospin of the Z is 1, neutral partner should exist.
- Z_b has $b\bar{b}$ pair and a charge
- Examples: $Z_b(10610)$, $Z_b(10650)$, $Z_c(3900)$, $Z_c(4200)$, $Z_c(4430)$, etc.

XYZ: short introduction

X

- **X′s are the non-$q\bar{q}$ mesons other than Y′s and Z′s**
- **Most famous is X(3872) observed by Belle in reaction**

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



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 $\Gamma_X \lesssim 2.3$ MeV at 90% CL.
- Quantum numbers $J^{PC} = 1^{++}$.
- Strong isospin violation

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

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)

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

- The physical states are the mixing of X_u and X_d

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

- 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.

Dynamical picture for multiquark states: covariant confined quark model

- **Main assumption: hadrons interact via quark exchange only**
- **Interaction Lagrangian**

$$\mathcal{L}_{int} = g_H \cdot H(x) \cdot J_H(x)$$

- **Quark currents**

$$J_M(x) = \int dx_1 \int dx_2 \, F_M(x; x_1, x_2) \cdot \bar{q}_1^a(x_1) \, \Gamma_M \, q_2^a(x_2) \qquad \text{Meson}$$

$$J_B(x) = \int dx_1 \int dx_2 \int dx_3 \, F_B(x; x_1, x_2, x_3) \qquad \text{Baryon}$$
$$\times \, \Gamma_1 \, q_1^{a_1}(x_1) \left(q_2^{a_2}(x_2) C \, \Gamma_2 \, q_3^{a_3}(x_3) \right) \cdot \varepsilon^{a_1 a_2 a_3}$$

$$J_T^{\mu}(x) = \int dx_1 \ldots \int dx_4 \, F_T(x; x_1, \ldots, x_4) \qquad \text{Tetraquark}$$
$$\times \left(q_1^{a_1}(x_1) \, C\Gamma_1 \, q_2^{a_2}(x_2) \right) \cdot \left(\bar{q}_3^{a_3}(x_3) \, \Gamma_2 C \, \bar{q}_4^{a_4}(x_4) \right) \cdot \varepsilon^{a_1 a_2 c} \varepsilon^{a_3 a_4 c}$$

The vertex functions and quark propagators

- The vertex functions

$$F_H(x, x_1, \ldots, x_n) = \delta^{(4)}\Big(x - \sum_{i=1}^{n} w_i x_i\Big)\, \Phi_H\Big(\sum_{i<j}(x_i - x_j)^2\Big)$$

where $w_i = m_i / \sum_i m_i$.

- We choose a Gaussian form for the function Φ_H with the only dimensional parameter Λ_H characterizing the size of the hadron.

- The quark propagators

$$S_q(x_1 - x_2) = \int \frac{d^4k}{(2\pi)^4 i} \frac{e^{-ik(x_1 - x_2)}}{m_q - \not k}$$

- The matrix elements of the physical processes are described by the Feynman diagrams which are the convolution of vertex functions and quark propagators.

Quark diagrams

- Let us consider a general ℓ-loop Feynman diagram with n local propagators and m Gaussian vertices.
- Use the Schwinger representation of the propagator:

$$\frac{m + \not{k}}{m^2 - k^2} = (m + \not{k}) \int_0^\infty d\alpha \; \exp[-\alpha(m^2 - k^2)]$$

- The general expression for the diagram

$$\Pi(p_1, \ldots, p_m) = \int_0^\infty d^n\alpha \int [d^4k]^\ell \; \mathrm{Num} \; \exp[-\sum_{i=1}^{n} \alpha_i m_i^2 + \sum_j \tilde{\alpha}_j (K_j + P_j)^2)]$$

where K_i is the linear combination of the loop momenta and P_i is the linear combination of the external momenta. Num stands for the numerator product of propagators.

Go to integration over a simplex

- **Generally speaking, the diagram contains the branch points and thresholds corresponding to quark production.**
- **After doing the loop integrations one obtains**

$$\Pi = \int_0^\infty d^n\alpha \, F(\alpha_1, \ldots, \alpha_n) \,,$$

where F stands for the whole structure of a given diagram.

- **The set of Schwinger parameters α_i can be turned into a simplex by introducing an additional t–integration via the identity**

$$1 = \int_0^\infty dt \, \delta(t - \sum_{i=1}^n \alpha_i)$$

leading to

$$\Pi = \int_0^\infty dt t^{n-1} \int_0^1 d^n\alpha \, \delta\Big(1 - \sum_{i=1}^n \alpha_i\Big) \, F(t\alpha_1, \ldots, t\alpha_n) \,.$$

Infrared confinement

- We cut the upper integration over "t" at $1/\lambda^2$ and obtain

$$\Pi^c = \int\limits_0^{1/\lambda^2} dt t^{n-1} \int\limits_0^1 d^n\alpha \, \delta\Big(1 - \sum_{i=1}^n \alpha_i\Big) \, F(t\alpha_1, \ldots, t\alpha_n)$$

- By introducing the infrared cut-off one has removed all possible thresholds in the quark loop diagram.

- We take the cut-off parameter λ to be the same in all physical processes.

Infrared confinement

- We consider the case of a scalar one–loop two–point function:

$$\Pi_2(p^2) = \int \frac{d^4 k_E}{\pi^2} \frac{e^{-s\, k_E^2}}{[m^2 + (k_E + \frac{1}{2} p_E)^2][m^2 + (k_E - \frac{1}{2} p_E)^2]}$$

where the numerator factor $e^{-s\, k_E^2}$ comes from the product of nonlocal vertex form factors of Gaussian form. k_E, p_E are Euclidean momenta ($p_E^2 = -\, p^2$).

- Doing the loop integration one obtains

$$\Pi_2(p^2) = \int\limits_0^\infty dt \frac{t}{(s+t)^2} \int\limits_0^1 d\alpha \, \exp\left\{ -t\,[m^2 - \alpha(1-\alpha)p^2] + \frac{st}{s+t}\left(\alpha - \frac{1}{2}\right)^2 p^2 \right\}$$

A branch point at $p^2 = 4m^2$

Infrared confinement

- **By introducing a cut-off in the t–integration one obtains**

$$\Pi_2^c(p^2) = \int_0^{1/\lambda^2} dt \frac{t}{(s+t)^2} \int_0^1 d\alpha \, \exp\left\{ -t\,[m^2 - \alpha(1-\alpha)p^2] + \frac{st}{s+t}\left(\alpha - \frac{1}{2}\right)^2 p^2 \right\}$$

where the one–loop two–point function $\Pi_2^c(p^2)$ no longer has a branch point at $p^2 = 4m^2$.

- **The confinement scenario also allows to include all possible both two-quark and multi-quark resonance states in our calculations.**

Model parameters

The values of quark masses m_{q_i}, the infrared cutoff parameter λ and the size parameters Λ_{H_i} have been defined by the fit to the well-known physical observables.

m_u	m_s	m_c	m_b	λ	
0.241	0.428	1.672	5.046	0.181	GeV

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

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

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

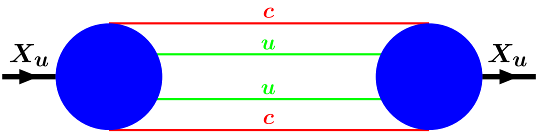
$$w_1 = w_2 = \frac{m_c}{2(m_q + m_c)} \equiv \frac{w_c}{2}, \qquad w_3 = w_4 = \frac{m_q}{2(m_q + m_c)} \equiv \frac{w_q}{2}.$$

Compositeness condition

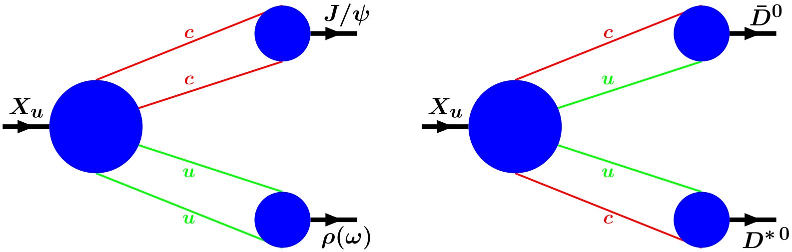
The coupling constant g_X is determined from the compositeness condition

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

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,

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

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

The narrow width approximation

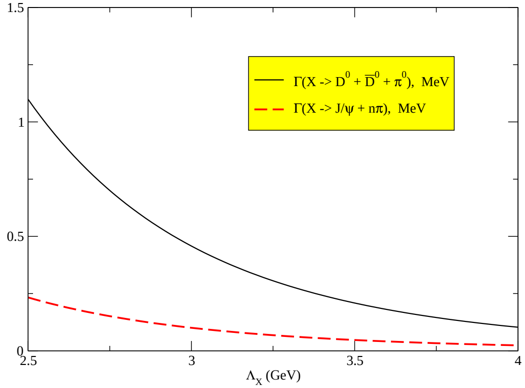
$$\frac{d\Gamma(X \to J/\psi + n\pi)}{dq^2} = \frac{1}{8\, m_X^2\, \pi} \cdot \frac{1}{3} |M(X \to J/\psi + v^0)|^2$$
$$\times \frac{\Gamma_{v^0}\, m_{v^0}}{\pi} \frac{p^*(q^2)}{(m_{v^0}^2 - q^2)^2 + \Gamma_{v^0}^2\, m_{v^0}^2} \mathrm{Br}(v^0 \to n\pi),$$

$$\frac{d\Gamma(X_u \to \bar{D}^0 D^0 \pi^0)}{dq^2} = \frac{1}{2\, m_X^2\, \pi} \cdot \frac{1}{3} |M(X_u \to \bar{D}^0 D^{*\,0})|^2$$
$$\times \frac{\Gamma_{D^{*\,0}}\, m_{D^{*\,0}}}{\pi} \frac{p^*(q^2)\, \mathcal{B}(D^{*\,0} \to D^0 \pi^0)}{(m_{D^{*\,0}}^2 - q^2)^2 + \Gamma_{D^{*\,0}}^2\, m_{D^{*\,0}}^2},$$

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

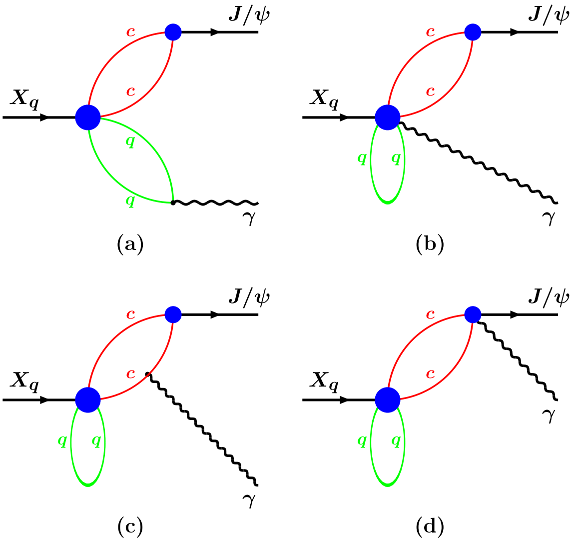


$$\frac{\Gamma(X \to D^0 \bar{D}^0 \pi^0)}{\Gamma(X \to J/\psi \pi^+ \pi^-)} = \begin{cases} 4.5 \pm 0.2 & \text{theor} \\ 10.5 \pm 4.7 & \text{expt} \end{cases}$$

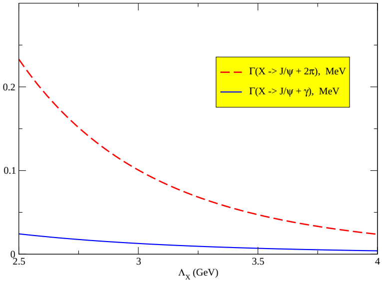
Radiative X-decay

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

Phys. Rev. D 84, 014006 (2011)



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

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

which fits very well the experimental data from the Belle Collaboration

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

$Z_c(3900)$: Data from BESIII and Belle

- **Discovery mode (mass and width measured)**

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

- **$D\bar{D}^*$ mode (mass and width measured)**

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

- **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,
Phys. Rev. D 94, no. 9, 094017 (2016)

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

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

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

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

- **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.**
- **Since this result contradict to the data, 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 $\Lambda_{Z_c} = 3.3 \pm 1.1$ GeV then**

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

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

$Z_c(3900)$: theoretical interpretation

Preliminary data from BESIII:

$$\mathbf{R(Z) = \frac{\mathcal{B}(Z_c(3900) \to \rho\eta_c)}{\mathcal{B}(Z_c(3900) \to \pi J/\psi)} = 2.1 \pm 0.8.}$$

Our result:

$$\mathbf{R(Z) = 1.8 \pm 0.4}$$

$Z_b(10610)$ and $Z_b'(10610)$: experiment

- **Observation of two charged bottomoniumlike resonances:**

Belle Coll. Phys. Rev. Lett. 108, 122001 (2012); Phys. Rev. D91, 072003 (2015)

$$\Upsilon(5S) \to \pi^+ \underbrace{\pi^- \Upsilon(nS)}_{Z_b^-} \quad \text{and} \quad \Upsilon(5S) \to \pi^+ \underbrace{\pi^- h_b(mP)}_{Z_b^-}$$

(n=1,2,3) (m=1,2)

- **Masses and widths:**

$$M_{Z_b} = (10607.2 \pm 2.0)\ \text{MeV}, \qquad \Gamma_{Z_b} = (18.4 \pm 2.4)\ \text{MeV},$$

$$M_{Z_b'} = (10652.2 \pm 1.5)\ \text{MeV}, \qquad \Gamma_{Z_b'} = (11.5 \pm 2.2)\ \text{MeV}.$$

- **Quantum numbers are $I^G(J^P) = 1^+(1^+)$.**

$Z_b(10610)$ and $Z_b'(10610)$: experiment

- **Observation in $\mathbf{B\bar{B}\pi}$ channels:**

Belle Coll. Phys. Rev. Lett. 116, no. 21, 212001 (2016)

$$e^+e^- \to \pi^+ \underbrace{(B\bar{B}^*)^-}_{Z_b^-} \quad \text{and} \quad e^+e^- \to \pi^+ \underbrace{(B^*\bar{B}^*)^-}_{Z_b'^-}$$

- **It was found that the $\mathbf{B^{(*)}\bar{B}^*}$-decays dominate among the corresponding final states.**
- **Assuming that the $\mathbf{Z_b}$-decays are saturated by $\mathbf{\Upsilon(nS)\pi}$ $\mathbf{(n = 1, 2, 3)}$, $\mathbf{h_b(mP)\pi}$ $\mathbf{(m = 1, 2)}$ and $\mathbf{B^{(*)}\bar{B}^*}$ channels, the relative decay fractions were determined.**

$Z_b(10610)$ and $Z_b'(10610)$: theory

- Since the masses of the $Z_b^+(10610)$ and $Z_b'(10650)$ are very close to the respective $B^*\bar{B}$ (10604 MeV) and $B^*\bar{B}^*$ (10649 MeV) thresholds, it was suggested that they have molecular-type binding structures.

A.E. Bondar, A. Garmash, A.I. Milstein, R. Mizuk and M. B. Voloshin, Phys. Rev. D 84, 054010 (2011)

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

$$J^{\mu\nu}_{Z_b'^+} = \varepsilon^{\mu\nu\alpha\beta}(\bar{d}\gamma_{\alpha} b)(\bar{b}\gamma_{\beta} u)$$

- Such a choice guarantees that the Z_b-state can only decay to the $[\bar{B}^* B + c.c.]$ pair whereas the Z_b'-state can decay only to a $\bar{B}^* B^*$ pair. Decays into the BB-channels are forbidden.
- The nonlocal generalization of the above 4-quark currents is straightforward. Then we are able to calculate the matrix elements and the widths of all relevant two-body decays.

$Z_b(10610)$ and $Z_b'(10610)$: theory

The bottomonium states ${}^{2S+1}L_J$.

quantum number $I^G(J^{PC})$	name	quark current	mass (MeV)
$0^+(0^{-+})$ $(S=0, L=0)$	${}^1S_0 = \eta_b(1S)$	$\bar{b}\, i\gamma^5\, b$	9399.00 ± 2.30
$0^-(1^{--})$ $(S=1, L=0)$	${}^3S_1 = \Upsilon$	$\bar{b}\,\gamma^\mu\, b$	9460.30 ± 0.26
$0^+(0^{++})$ $(S=1, L=1)$	${}^3P_0 = \chi_{b0}$	$\bar{b}\, b$	9859.44 ± 0.52
$0^+(1^{++})$ $(S=1, L=1)$	${}^3P_1 = \chi_{b1}$	$\bar{b}\,\gamma^\mu\gamma^5\, b$	9892.72 ± 0.40
$0^-(1^{+-})$ $(S=0, L=1)$	${}^1P_1 = h_b(1P)$	$\bar{b}\,\overleftrightarrow{\partial}^\mu\,\gamma^5\, b$	9899.30 ± 0.80

- Due to G-parity conservation the following decays are forbidden:

  $$Z_b \to \Upsilon + \rho, \quad Z_b \to \eta_b + \pi, \quad Z_b \to \chi_{b1} + \pi, \quad Z_b \to h_b + \rho.$$

  The decay $Z_b \to \chi_{b1} + \rho$ is not allowed kinematically.

- There are therefore only the three allowed decays:

  $$Z_b^+ \to \Upsilon + \pi^+, \qquad Z_b^+ \to h_b + \pi^+, \qquad Z_b^+ \to \eta_b + \rho^+.$$

$Z_b(10610)$ and $Z_b'(10610)$: numerical results

F. Goerke, T. Gutsche, M.A. Ivanov, J.G. Körner and V.E. Lyubovitskij, Phys. Rev. D 96, no. 5, 054028 (2017)

- **All adjustable parameters of our model have been fixed in our previous studies by a global fit to a multitude of experimental data.**
- **The only two new parameters are the size parameters of the two exotic $Z_b(Z_b')$ states. As a guide to adjust them we take the experimental values of the largest branching fractions presented by Belle:**

$$\mathcal{B}(Z_b^+ \to [B^+\bar{B}^{*\,0} + \bar{B}^0 B^{*\,+}]) = 85.6^{+1.5+1.5}_{-2.0-2.1}\,\%\,,$$

$$\mathcal{B}(Z_b'^+ \to \bar{B}^{*\,+} B^{*\,0}) = 73.7^{+3.4+2.7}_{-4.4-3.5}\,\%\,.$$

- **By using the central values of these branching rates and total decay widths we find the central values of our size parameters $\Lambda_{Z_b} = 3.45$ GeV and $\Lambda_{Z_b'} = 3.00$ GeV. Allowing them to vary in the interval**

$$\Lambda_{Z_b} = 3.45 \pm 0.05 \text{ GeV} \qquad \Lambda_{Z_b'} = 3.00 \pm 0.05 \text{ GeV}\,,$$

we obtain the values of various decay widths.

$Z_b(10610)$ and $Z_b'(10610)$: numerical results

Channel	Widths, MeV	
	$Z_b(10610)$	$Z_b'(10650)$
$\Upsilon(1S)\pi^+$	5.9 ± 0.4	$9.5^{+0.7}_{-0.6}$
$h_b(1P)\pi^+$	$(0.14 \pm 0.01) \cdot 10^{-1}$	$0.74^{+0.05}_{-0.04} \cdot 10^{-3}$
$\eta_b\rho^+$	4.4 ± 0.3	$7.5^{+0.6}_{-0.5}$
$B^+\bar{B}^{*0} + \bar{B}^0 B^{*+}$	$20.7^{+1.6}_{-1.5}$	—
$B^{*+}\bar{B}^{*0}$	—	$17.1^{+1.5}_{-1.4}$

Total widths, MeV

	Theory	Belle Expt.
$Z_b(10610)$	$30.9^{+2.3}_{-2.1}$	25 ± 7
$Z_b'(10650)$	$34.1^{+2.8}_{-2.5}$	23 ± 8

$Z_b(10610)$ and $Z'_b(10610)$: numerical results

- **The Belle observations indicate that the decays involving bottomonium states are significantly suppressed compared with the B-meson modes.**
- **In our calculation we find that the modes with $\Upsilon(1S)\pi^+$ and $\eta_b\rho^+$ are suppressed but not as much as in the data.**

$$\frac{\Gamma\left(Z_b \to \Upsilon(1S)\pi\right)}{\Gamma\left(Z_b \to B\bar{B}^* + c.c.\right)} \approx 0.29\,, \qquad \frac{\Gamma\left(Z_b \to \eta_b\rho\right)}{\Gamma\left(Z_b \to B\bar{B}^* + c.c.\right)} \approx 0.21\,,$$

$$\frac{\Gamma\left(Z'_b \to \Upsilon(1S)\pi\right)}{\Gamma\left(Z'_b \to B^*\bar{B}^*\right)} \approx 0.56\,, \qquad \frac{\Gamma\left(Z'_b \to \eta_b\rho\right)}{\Gamma\left(Z'_b \to B^*\bar{B}^*\right)} \approx 0.44\,.$$

- **The decays into the $h_b(1P)\pi^+$ mode are suppressed by the p-wave suppression factor.**

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.**

Summary

- **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 $\sim$ 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.**

Summary

- By using molecular-type four-quark currents for the recently observed resonances $Z_b(10610)$ and $Z_b(10650)$, we have calculated their two-body decay rates into a bottomonium state plus a light meson as well as into B-meson pairs.

- We have fixed the model size parameters by adjusting the theoretical values of the largest branching fractions of the modes with the B-mesons in the final states to their experimental values.

- We found that the modes with $\Upsilon(1S)\pi^+$ and$\eta_b\rho^+$ in the final states are suppressed but not as much as the Belle Collaboration reported.