Exotic mesons as diquark-antidiquark states

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Introduction

- Experimental data
- Diquarks
- Diquark - antiDiquark systematization
- Quarks recombination
- One pole and two poles decay amplitudes.
- Comparison with experimental data

Exotic states. Candidates

State	$m(MeV)$	$\Gamma(MeV)$	J^{PC}	$Process(mode)$
$Y(4140)$	4145.8 ± 2.6	18 ± 8	$?^{?+}$	$B^+ \to K^+(\phi J/\psi)$
$Y(4274)$	4293.8 ± 20	35 ± 16	$?^{?+}$	$B^+ \to K^+(\phi J/\psi)$
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0/2^{++}$	$\gamma\gamma \to (\phi J/\psi)$

- The data allow suggest a structure for exotic states
- and give an estimation of admixtures of the diquark - antiqiquark and the meson-meson components

[1] PDG, J. Beringer et al., Phys. Rev. D**86**, 010001 (2012)
[2] Belle Collab.: C.P. Shen et al., Phys.Rev.Lett. **104**, 112004; arXiv:0912.2383
[3] CDF-Collab.: T. Aaltonen et al., Phys.Rev.Lett. **102**, 242002; arXiv:0903.2229

Diquark

- The notion of the diquark was introduced by Gell-Mann [1]
- Effective composite particles with constituent quarks in the S-wave

$$\begin{aligned} \text{scalar},\ J^P &= 0^+ \quad : \quad (cs)_{0^+} \equiv S_{(cs)}\,, \\ \text{axial}-\text{vector},\ J^P &= 1^+ \quad : \quad (cs)_{1^+} \equiv A_{(cs)}\,. \end{aligned}$$

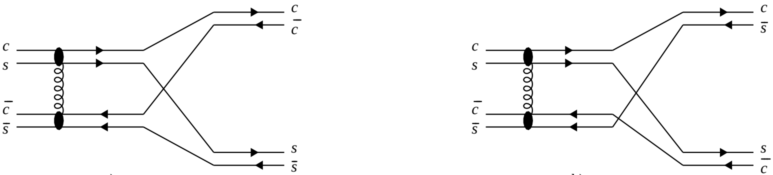
- Diquarks and quarks have the similar color structure

$$D_\mu^{(cs)} = \varepsilon_{\mu\alpha\beta}\, c_\alpha s_\beta$$

[1] M. Gell-Mann, Phys. Lett. **8**, 214 (1964).

Diquark - antiDiquark system. Recombination of quarks

- Recombination of quarks is responsible for dominant mode of the decay



a) b)

$$\Psi_{(cs)} \cdot \Psi_{(\bar{c}\bar{s})} = c_\alpha s_\beta \, \varepsilon_{\alpha\beta\gamma} \, \varepsilon_{\alpha'\beta'\gamma} \, \bar{c}_{\alpha'} \bar{s}_{\beta'} = \Psi_{(c\bar{c})}\Psi_{(s\bar{s})} - \Psi_{(c\bar{s})}\Psi_{(s\bar{c})}$$

- The formed diquark-antidiquark composite states should reveal themselves in decays coursed by the recombination processes

Diquark - antiDiquark system. Classification and Mass formula

The lowest states are S-wave composite diquark - antidiquark system

J^{PC}	First pole	Second pole
0^{++}	$S_{(Qs)} \cdot S_{(\bar{Q}\bar{s})}$	$A_{(Qs)} \cdot A_{(\bar{Q}\bar{s})}$
1^{++}	$\frac{1}{\sqrt{2}}\left[A_{(Qs)} \cdot S_{(\bar{Q}\bar{s})} + S_{(Qs)} \cdot A_{(\bar{Q}\bar{s})}\right]$	$---$
1^{+-}	$\frac{1}{\sqrt{2}}\left[A_{(Qs)} \cdot S_{(\bar{Q}\bar{s})} - S_{(Qs)} \cdot A_{(\bar{Q}\bar{s})}\right]$	$A_{(Qs)} \cdot A_{(\bar{Q}\bar{s})}$
2^{++}	$A_{(Qs)} \cdot A_{(\bar{Q}\bar{s})}$	$---$

Model consideration for pure diquark-antidiquark states similar that for quark-antiquark systems

$$m^{(J^{PC})} = m_D + m_{\bar{D}} + J(J+1)\Delta$$

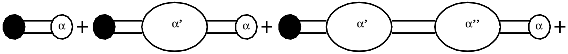
Diquark - antiDiquark system. Recombination channels

J^{PC}	Recombination Channels
0^{++}	$\frac{1}{4}\psi\phi,\ \frac{3}{4}\eta_c\eta,\ \frac{1}{4}D_s^{*+}D_s^{*-},\ \frac{3}{4}D_s^+D_s^-$
0^{++}	$\frac{3}{4}\psi\phi,\ \frac{1}{4}\eta_c\eta,\ \frac{3}{4}D_s^{*+}D_s^{*-},\ \frac{1}{4}D_s^+D_s^-$
1^{++}	$\psi\phi$
1^{+-}	$\frac{1}{2}\eta_c\phi,\ \frac{1}{2}\psi\eta,\ \frac{1}{2}D_s^{*+}D_s^-,\ \frac{1}{2}D_s^+D_s^{*-}$
1^{+-}	$\frac{1}{3}\eta_c\phi,\ \frac{1}{3}\psi\eta,\ \frac{2}{3}D_s^{*+}D_s^{*-},\ \frac{1}{3}D_s^{*+}D_s^-,\ \frac{1}{3}D_s^{*+}D_s^{*-}$
2^{++}	$\psi\phi,\ D_s^{*+}D_s^{*-}$

One pole decay amplitude

Amplitude is represented as an infinite sum of dispersion relation loop diagrams

$$A_{(X\to\alpha)} \; = \; g_X \, \frac{1}{m^2_{J^{PC}} - s - \sum\limits_{\alpha'} g_{\alpha'} \, C_{\alpha'} (\Re L_{\alpha'} + \Im L_{\alpha'}) \, g_{\alpha'}} \, g_\alpha \, .$$



- The loop $L_\alpha = \int\limits_{(M_a+M_b)^2}^{+\infty} \frac{ds'}{\pi} \frac{\rho_\alpha(s')}{s'-s-i0}$ has been calculated in technique of dispersion relation integrals
- Pole position $\quad s = m^2_{J^{PC}} - g^2_\alpha \sum\limits_\alpha C_\alpha \Re L_\alpha$
- $\Im L_\alpha \; = \; \rho_\alpha$

Two poles decay amplitude

The D-matrix technique allows us to control effects of the overlap and the mixing of resonances with two poles.

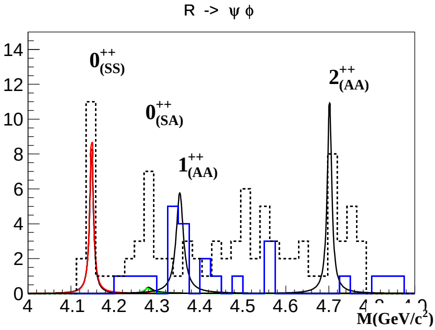
$$\begin{aligned} A^{(J^{PC})}_{(X\to\alpha)} &= g_{(X\to 1)}\frac{1}{\Delta}\Big[d_1(1-g^2 L_{22}d_2)+d_2 L_{21}d_1\Big]g_{(1\to\alpha)} \\ &+g_{(X\to 2)}\frac{1}{\Delta}\Big[d_2(1-L_{11}d_1)+d_1 L_{12}d_2\Big]g_{(2\to\alpha)} \end{aligned}$$

$$\Delta^{(1^{+-})} = (1-L_{11}d_1)(1-L_{22}d_2)-L_{12}d_2 L_{21}d_1$$

$$d_i = \frac{1}{m_i^2 - s}$$

$$L_{ij} = \sum_\alpha g_{i\to\alpha}\, C_\alpha\, L_\alpha\, g_{\alpha\to j}$$

Comparison with CDF and Belle data



$$M_{S_{(cs)}} = 2072\, MeV\,, \quad M_{A_{(cs)}} = 2137\, MeV \quad \Delta = 70\, MeV$$

$m_{0^{++}}(MeV)$	$m_{1^{++}}(MeV)$	$m_{1^{+-}}(MeV)$	$m_{2^{++}}(MeV)$
4143.4	**4350.6**	4350.6	4699.5
4274.4		4416.1	

Thank You

Summary and Outlook

- Schematic description of exotic meson with hidden charm using diquarks constituents have been done
- Quark - antidiquark construction works for low-lying mesons
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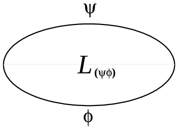
- Will be consider diquark antidquark systems with *b*-quark and light quarks.

$$
\begin{array}{rcl|rcl}
M_{\psi\phi}^{threshold} & = & 4003 MeV & M_{D_s^{*+} D_s^{*-}}^{threshold} & = & 4224 MeV \\
M_{\psi\eta}^{threshold} & = & 3531 MeV & M_{D_s^{*+} D_s^{-}}^{threshold} & = & 4080 MeV \\
M_{\eta_c\phi}^{threshold} & = & 4116 MeV & M_{D_s^{+} D_s^{*-}}^{threshold} & = & 4080 MeV \\
M_{\eta_c\eta}^{threshold} & = & 3644 MeV & M_{D_s^{+} D_s^{-}}^{threshold} & = & 3936 MeV
\end{array}
$$

Loop Diagrams



$$L_{\psi\phi} = \int\limits_{(M_\psi+M_\phi)^2}^{+\infty} \frac{ds'}{\pi}\frac{\rho_{\psi\phi}(s')}{s'-s-i0}$$

$$\int\limits_{(M_a+M_b)^2}^{\infty} \frac{ds'}{\pi}\cdot\frac{Z(s')}{s'-s-i0} \to \ell_0 + \int\limits_{(M_a+M_b)^2}^{\infty} \frac{ds'}{\pi}\frac{s-s_0}{(s'-s_0)(s'-s-i0)}\cdot Z(s')$$

$$L = \ell_0 + \frac{\lambda}{s} + \rho_{ab}(s)\left[\frac{1}{\pi}\ln\frac{\sqrt{s-(M_a-M_b)^2}-\sqrt{s-(M_a+M_b)^2}}{\sqrt{s-(M_a-M_b)^2}+\sqrt{s-(M_a+M_b)^2}} + i\right].$$

$$\lambda = \frac{\sqrt{(M_a+M_b)^2(M_a-M_b)^2}}{16\pi^2}\ln\frac{\sqrt{(M_a+M_b)^2}+\sqrt{(M_a-M_b)^2}}{\sqrt{(M_a+M_b)^2}-\sqrt{(M_a-M_b)^2}}\quad .$$

$$\rho_{ab}(s) = \frac{1}{16\pi s}\sqrt{[s-(M_a+M_b)^2][s-(M_a-M_b)^2]}\,.$$