Role of $Y(4630)$ in the $p\bar{p} \to \Lambda_c\bar{\Lambda}_c$ reaction near threshold

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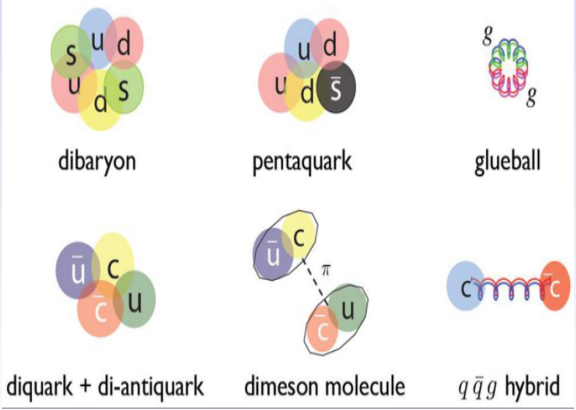
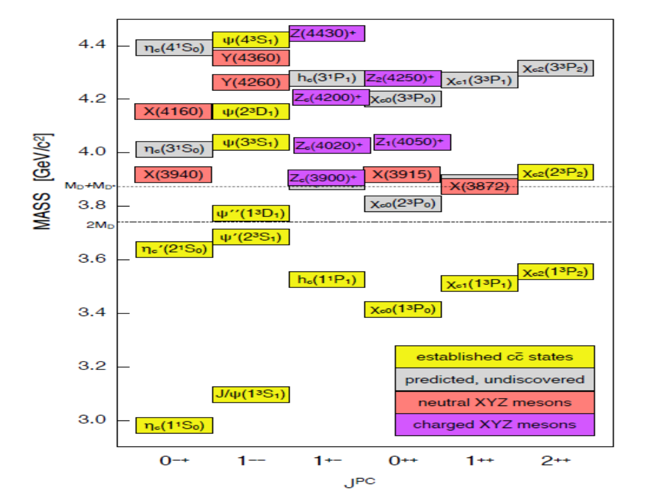
Outline

Exotic states

Besides conventional mesons and baryons, QCD do not forbid other hadrons, which are named as exotic states.



XYZ states



XYZ states below 4.5 GeV.

S. Olsen, PoS Bormio 050 (2015).

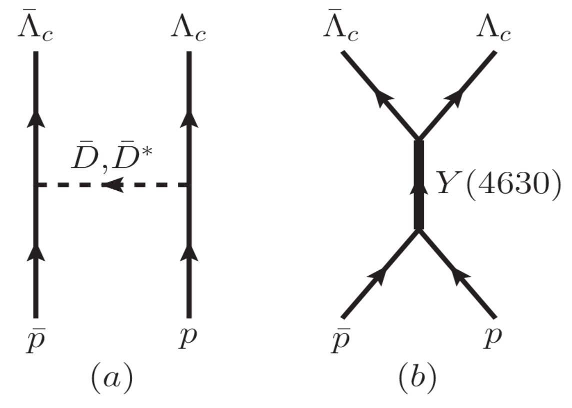
$Y(4630)$ and $Y(4660)$

1. A new charmonium-like $Y(4630)$, $J^{PC} = 1^{--}$, was firstly reported by the Belle collaboration in the exclusive $e^+e^- \to \Lambda_c\bar{\Lambda}_c$ process.
   $M = 4634^{+8+5}_{-7-8}$ MeV,$\Gamma = 92^{+40+10}_{-24-21}$ MeV
2. Above the $\Lambda_c\bar{\Lambda}_c$ threshold, another 1^{--} resonance $Y(4660)$ was observed in the process $e^+e^- \to \gamma_{\mathrm{ISR}}\pi^+\pi^-\psi(2S)$ by the Belle collaboration and BaBar Collaboration.
   $M = 4664 \pm 11 \pm 5$ MeV, $\Gamma = 48 \pm 15 \pm 3$ MeV

G. Pakhlova *et al.*[Belle Collaboration],Phys. Rev. Lett. **101**,172001 (2008)
X. L. Wang *et al.* [Belle Collaboration],Phys. Rev. Lett. **99**, 142002 (2007)
J. P. Lees *et al.* [BaBar Collaboration],Phys. Rev. D **89**, 111103 (2014)

Charmed baryon production reaction

We investigate the charmed baryon production reaction $p\bar{p} \to \Lambda_c \bar{\Lambda}_c$ in the effective Lagrangian approach.



Feynman diagrams for $p\bar{p} \to \Lambda_c \bar{\Lambda}_c$ reaction.

Charmed baryon production reaction

The relevant effective Lagrangians of the vertexes can be written as

$$\mathcal{L}_{\Lambda_c pD} = ig_{\Lambda_c pD}\bar{\Lambda}_c\gamma_5 pD$$

$$\mathcal{L}_{\Lambda_c pD^*} = g_{\Lambda_c pD^*}\bar{\Lambda}_c\gamma^\mu pD^*_\mu$$

$$\mathcal{L}_{Y\Lambda_c\bar{\Lambda}_c} = g_{Y\Lambda_c\bar{\Lambda}_c}Y_\mu\bar{\Lambda}_c\gamma^\mu\Lambda_c$$

$$\mathcal{L}_{Yp\bar{p}} = g_{Yp\bar{p}}Y_\mu\bar{p}\gamma^\mu p$$

X. D. Guo, D. Y. Chen, H.W. Ke, X. Liu, and X. Q. Li Phys. Rev. D 93, 054009 (2016).

Charmed baryon production reaction

According to the Feynman rules, the scattering amplitudes for the $p\bar{p} \to \Lambda_c\bar{\Lambda}_c$ reaction can be obtained straightforwardly with the above effective Lagrangians,

$$\begin{aligned}\mathcal{M}_D &= g^2_{\Lambda_c pD}\mathcal{F}^2(q^2_D, m^2_D)\bar{\upsilon}(p_1, s_1)\gamma_5\upsilon(p_3, s_3) \\ &\quad G_D\bar{u}(p_4, s_4)\gamma_5 u(p_2, s_2),\end{aligned}$$

$$\begin{aligned}\mathcal{M}_{D^*} &= -g^2_{\Lambda_c pD^*}\mathcal{F}^2(q^2_{D^*}, m^2_{D^*})\bar{\upsilon}(p_1, s_1)\gamma_\mu\upsilon(p_3, s_3) \\ &\quad G^{\mu\nu}_{D^*}\bar{u}(p_4, s_4)\gamma_\nu u(p_2, s_2),\end{aligned}$$

$$\begin{aligned}\mathcal{M}_Y &= -g_{Y\Lambda_c\bar{\Lambda}_c}g_{Yp\bar{p}}F_Y(q^2_Y, m^2_Y)\bar{\upsilon}(p_1, s_1)\gamma_\mu\upsilon(p_2, s_2) \\ &\quad G^{\mu\nu}_Y\bar{u}(p_4, s_4)\gamma_\nu u(p_3, s_3),\end{aligned}$$

The couplings constants

1. The $\Lambda_c\bar{\Lambda}_c$ is the dominant decay channel
2. The $p\bar{p}$ decay ratio being 1%

$$\Gamma(Y(4630) \to \Lambda_c\bar{\Lambda}_c) = \frac{g^2_{Y\Lambda_c\bar{\Lambda}_c}(m_Y^2 + 2m_{\Lambda_c}^2)|\vec{p}^{\,\rm cm}_{\Lambda_c}|}{6\pi m_Y^2},$$

$$\Gamma(Y(4630) \to p\bar{p}) = \frac{g^2_{Yp\bar{p}}(m_Y^2 + 2m_p^2)|\vec{p}^{\,\rm cm}_p|}{6\pi m_Y^2}$$

$$g_{Y\Lambda_c\bar{\Lambda}_c} = 1.78,\ \ g_{Yp\bar{p}} = 0.087$$

Form factors and cut-off parameters

The monopole form factor for the t-channel D and D^* interaction vertices

$$\mathcal{F}(q^2, m^2) = \frac{\Lambda^2 - m^2}{\Lambda^2 - q^2},$$

The cut-off parameter Λ can be parametrized as

$$\Lambda = m + \alpha\Lambda_{\mathrm{QCD}},\ \Lambda_{\mathrm{QCD}} = 220MeV$$

The form factor for s-channel $Y(4630)$ state

$$F_Y(q^2, m^2) = \frac{\Lambda_Y^4}{\Lambda_Y^4 + (q^2 - m_Y^2)^2},\ \Lambda_Y = 500MeV$$

The propagators

The D and D^* meson propagators

$$G_D = \frac{i}{q^2 - m_D^2},$$

$$G_{D^*}^{\mu\nu} = -i\frac{g^{\mu\nu} - q^\mu q^\nu / m_{D^*}^2}{q^2 - m_{D^*}^2}.$$

The propagator for $Y(4630)$ 1^{--} state can be written as,

$$G_Y = -i\frac{g^{\mu\nu} - q^\mu q^\nu / m_Y^2}{q^2 - m_Y^2 + i m_Y \Gamma_Y},$$

$\Gamma_Y = 92$ MeV is the total width of the $Y(4630)$ meson.

Charmed baryon production reaction

The total amplitude for the process $p\bar{p} \to \Lambda_c \bar{\Lambda}_c$ are the coherent sum of $\mathcal{M}_D$, $\mathcal{M}_{D^*}$, and $\mathcal{M}_Y$,

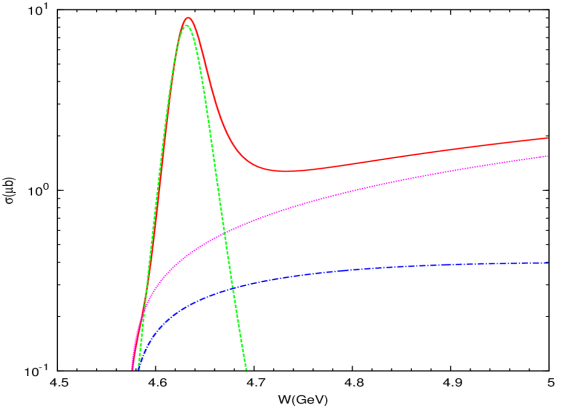
$$\mathcal{M} \;=\; \mathcal{M}_D + \mathcal{M}_{D^*} + \mathcal{M}_Y .$$

The differential cross section

$$\frac{\mathrm{d}\,\sigma}{\mathrm{d}\cos\theta} = \frac{1}{32\pi s} \frac{|\vec{p}_3^{\,\mathrm{c.m.}}|}{|\vec{p}_1^{\,\mathrm{c.m.}}|} \left(\frac{1}{4} \sum_{s_1, s_2, s_3, s_4} |\mathcal{M}|^2 \right)$$

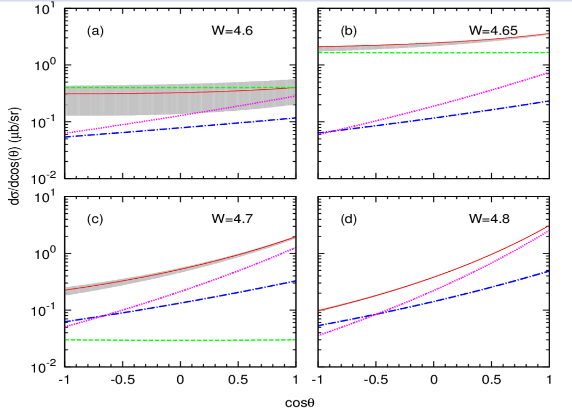
s is the invariant mass square of the $p\bar{p}$ system, θ denotes the angle of the outgoing baryon Λ_c relative to the beam direction in the c.m. frame.

Total cross section



Total cross sections for $p\bar{p} \to \Lambda_c \bar{\Lambda}_c$ reaction.

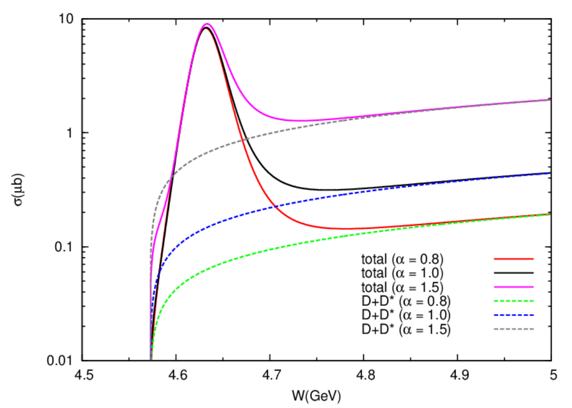
Differential cross sections



Differential cross sections for $p\bar{p} \to \Lambda_c\bar{\Lambda}_c$ reaction.

Discussions

The cut-off parameter for the D and D^* mesons exchanges $\Lambda = m + \alpha\Lambda_{\text{QCD}}$, with $\Lambda_{\text{QCD}} = 220$ MeV.



Total cross section of the $p\bar{p} \to \Lambda_c\bar{\Lambda}_c$ reaction varies with parameter α.

Summary

Within the effective Lagrangian approach, we have phenomenologically investigated the $p\bar{p} \to \Lambda_c\bar{\Lambda}_c$ reaction.

1. The t-channel D and D^* mesons exchanges and the s-channel $Y(4630)$ contribution.
2. Clear bump structures and minor background.
3. Search for charmonium-like state $Y(4630)$.
4. may be tested in the future by the $\bar{\text{P}}$ANDA facility.

Thank You!