A new decay mode of higer charmonium states

EPJC78,605(2018)

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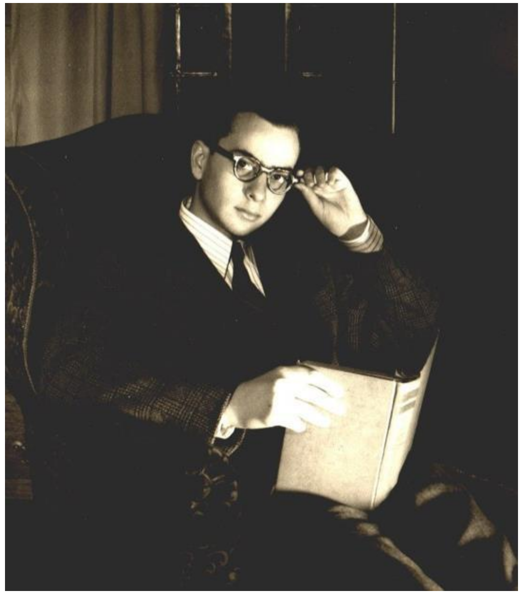
Outline

- 强子谱
- $^3p_0$ 模型
  - 粲偶数激发态1^{--}
    - 两重子末态衰变过程
    - 三体末态衰变过程
  - 底偶数激发态5S/6S
    - 三体末态衰变过程
- 小结与展望

几乎可以用一简单图像描述!

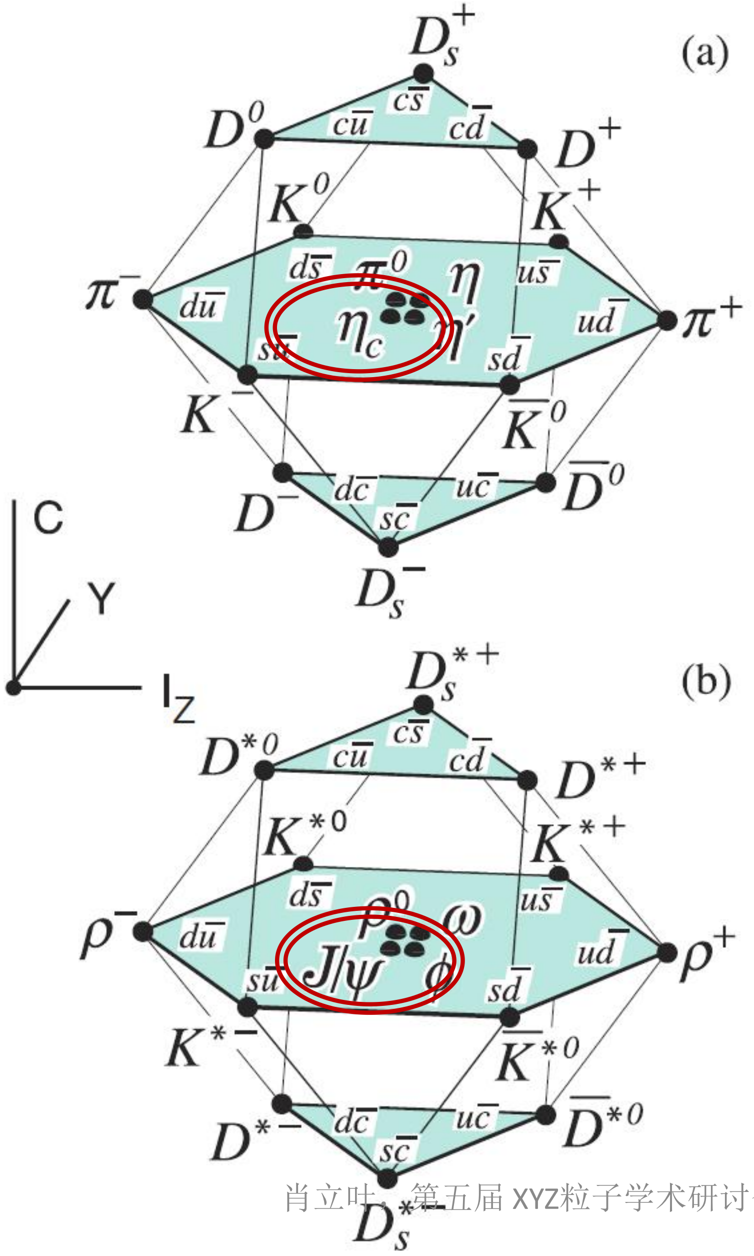


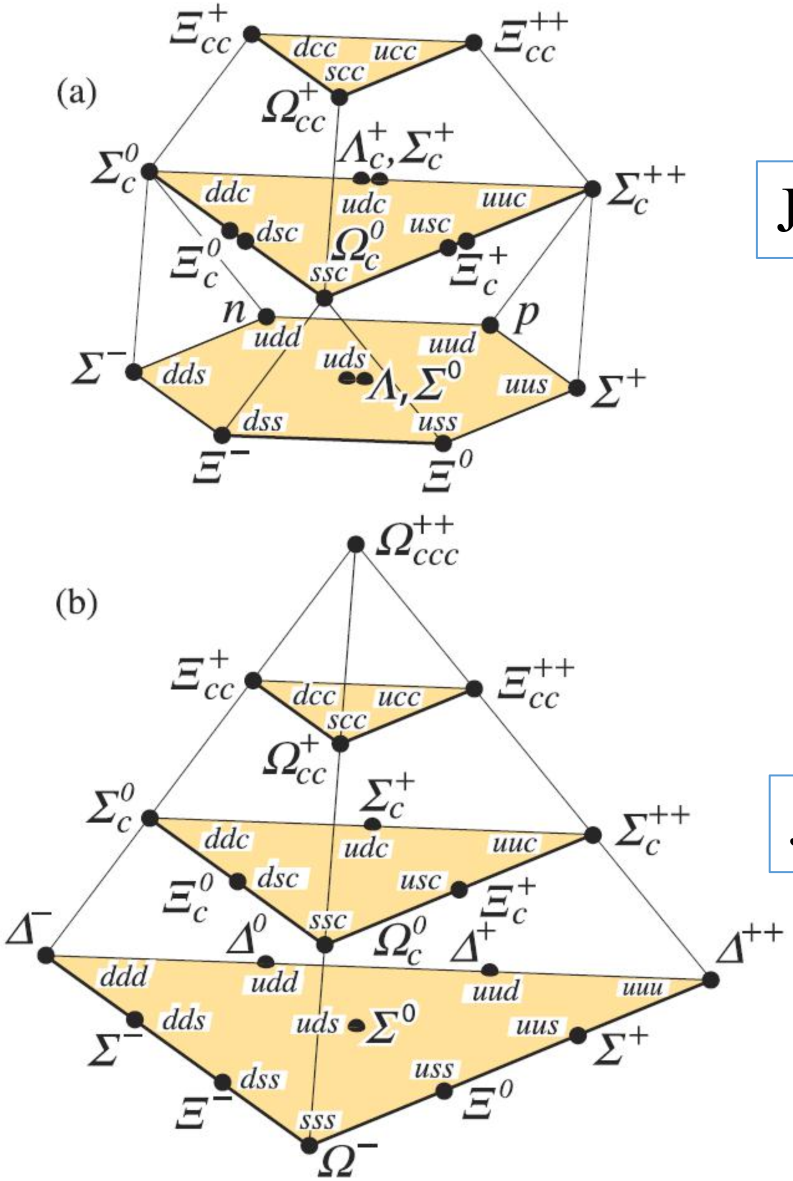
M. Gell-Mann

夸克模型

J=0

J=1

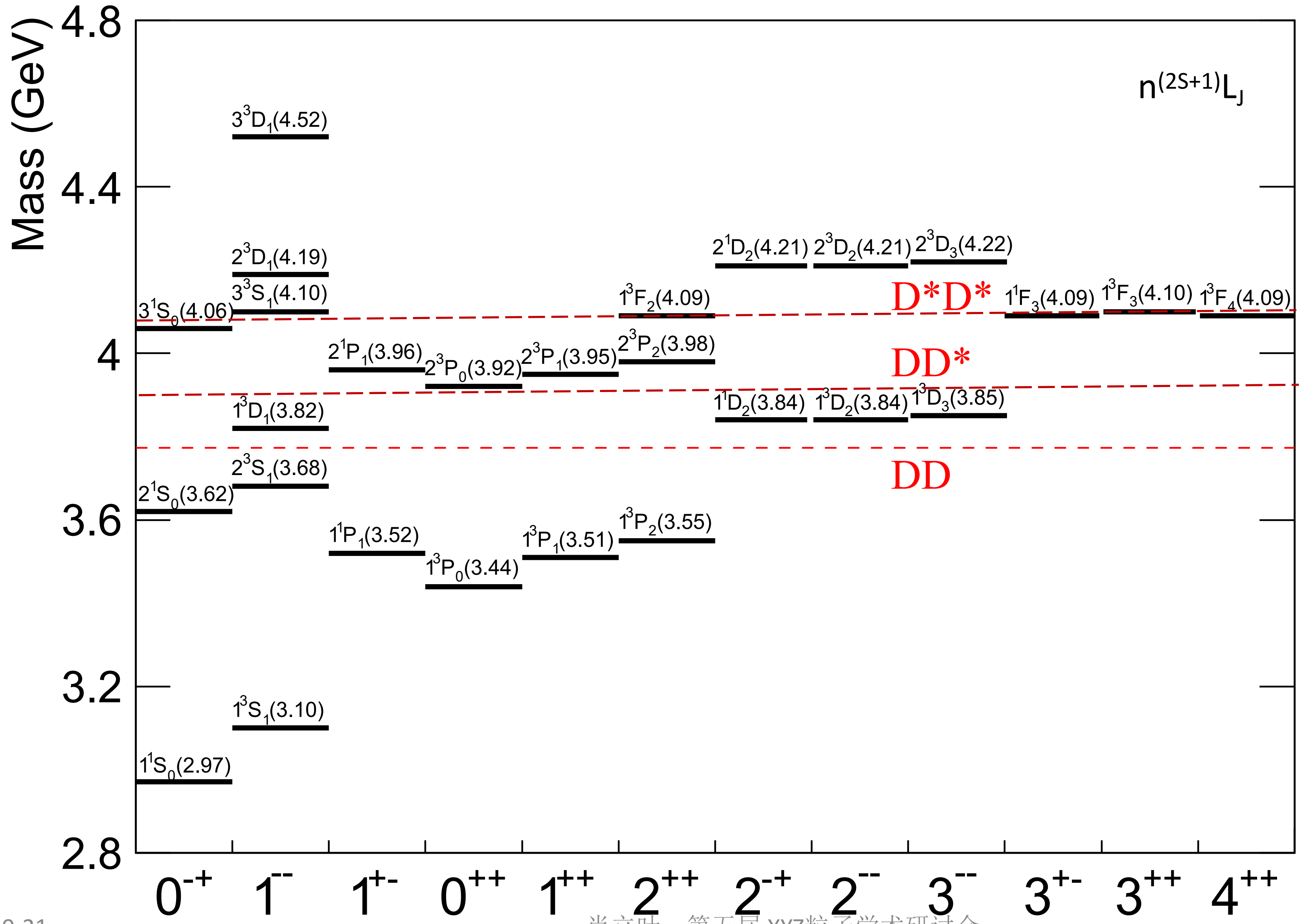




J=1/2

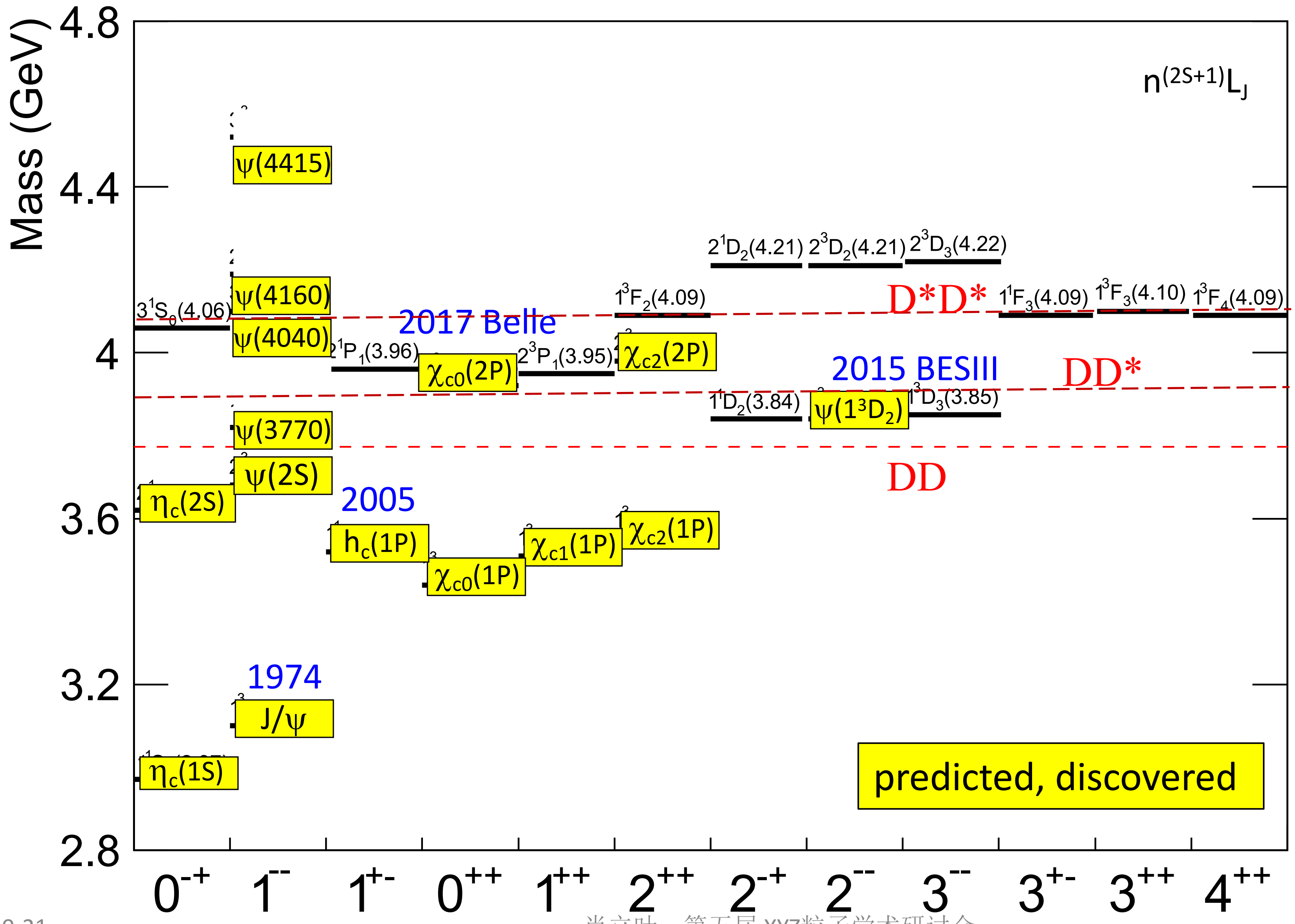
J=3/2

粲偶数质量谱



Godfrey & Isgur, PRD32, 189 (1985)

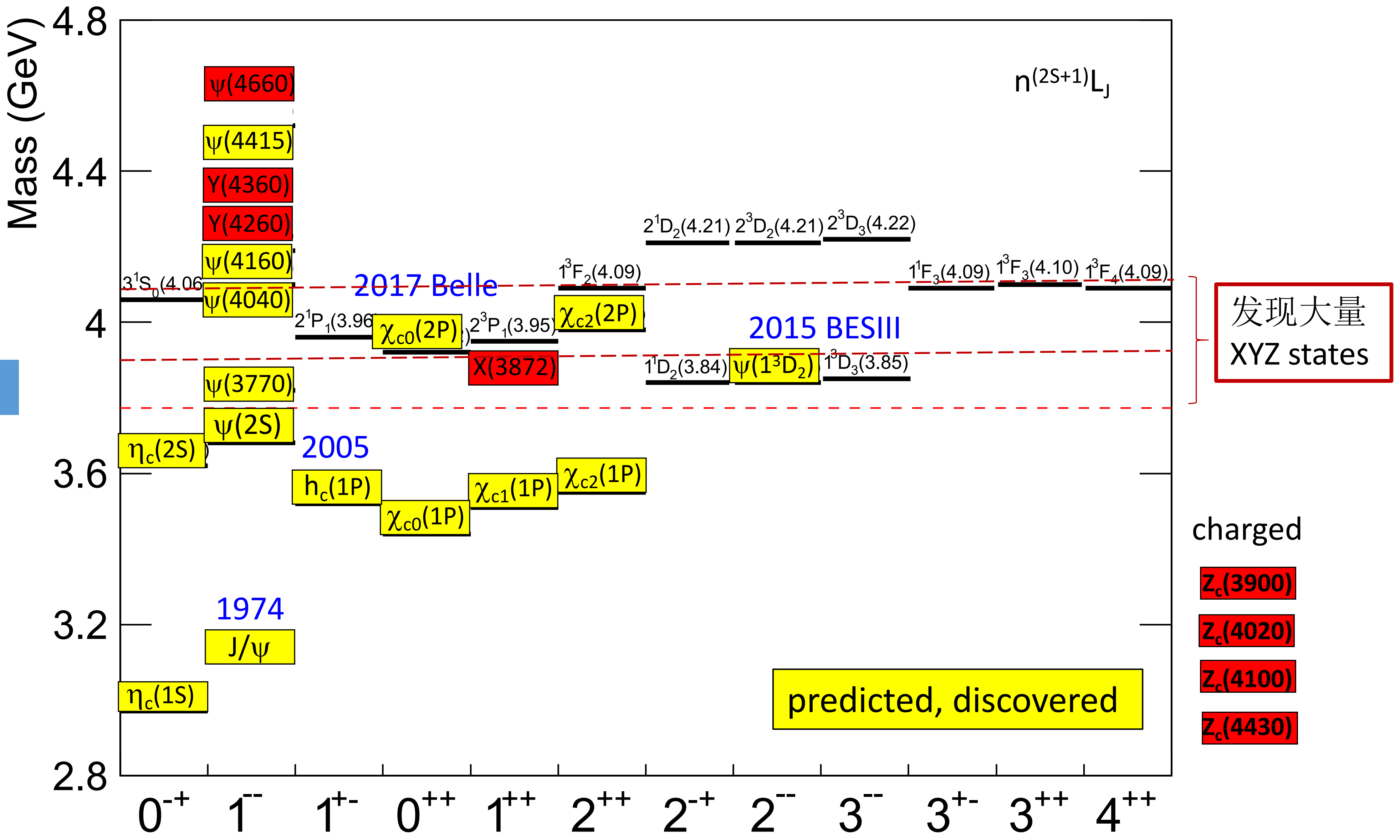
粲偶数质量谱



Godfrey & Isgur, PRD32, 189 (1985)

（类）粲偶数质量谱

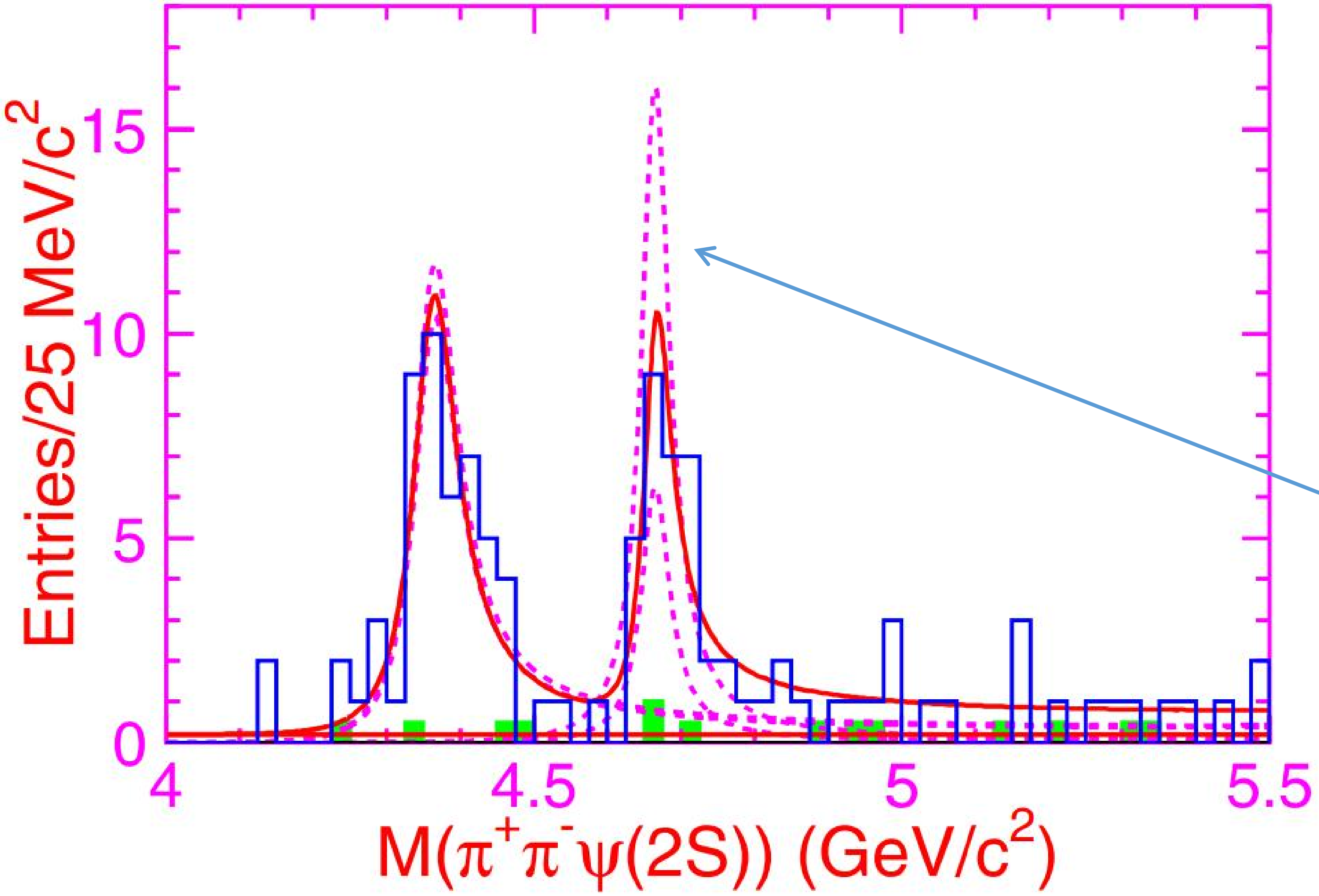
Belle
BaBar
CMS
CDF and D0
CLEO-c
BESIII
LHCb

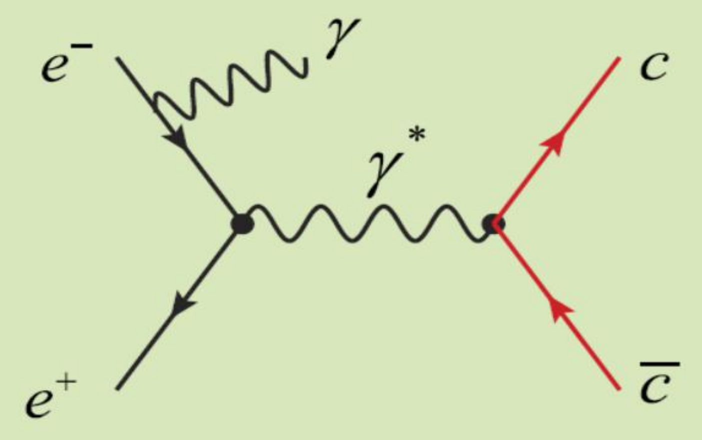


Godfrey & Isgur, PRD32, 189 (1985)

Y(4660)：首次被Belle观测到

PRL99 142002(2007)
673/fb data





$$M(Y(4660)) = 4664 \pm 11 \pm 5 MeV$$

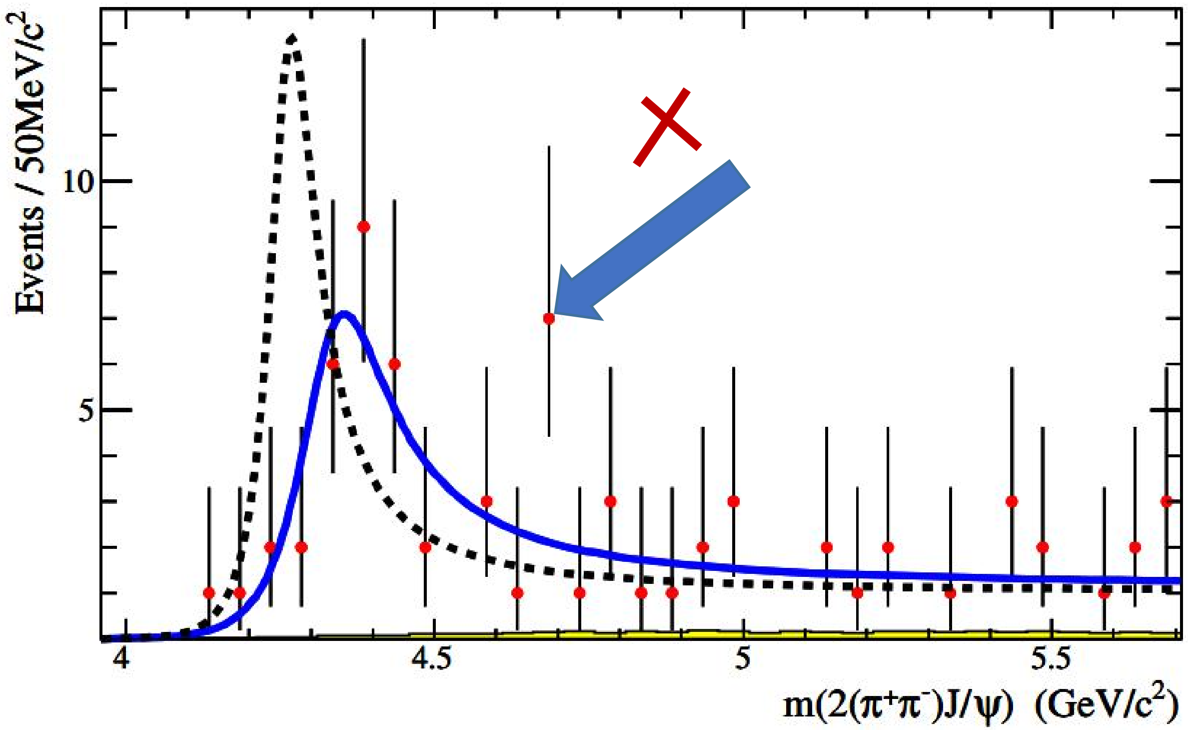
$$\Gamma_{tot}(Y(4660)) = 48 \pm 15 \pm 3 MeV$$

5.8σ

Y(4660)：没有被BaBar证实

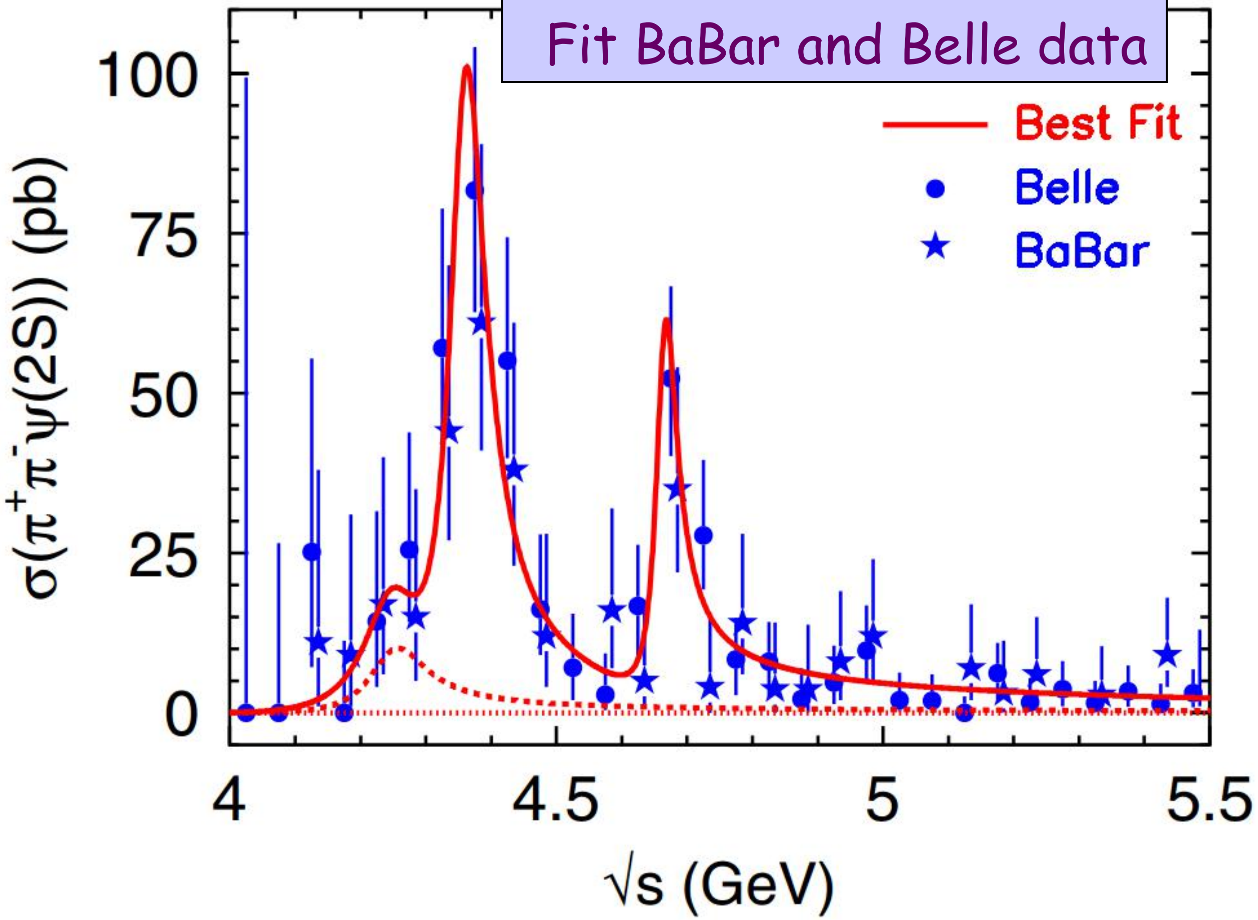
PRL98 212001(2007)

298/fb data



PRD78 014032(2008)

Fit BaBar and Belle data

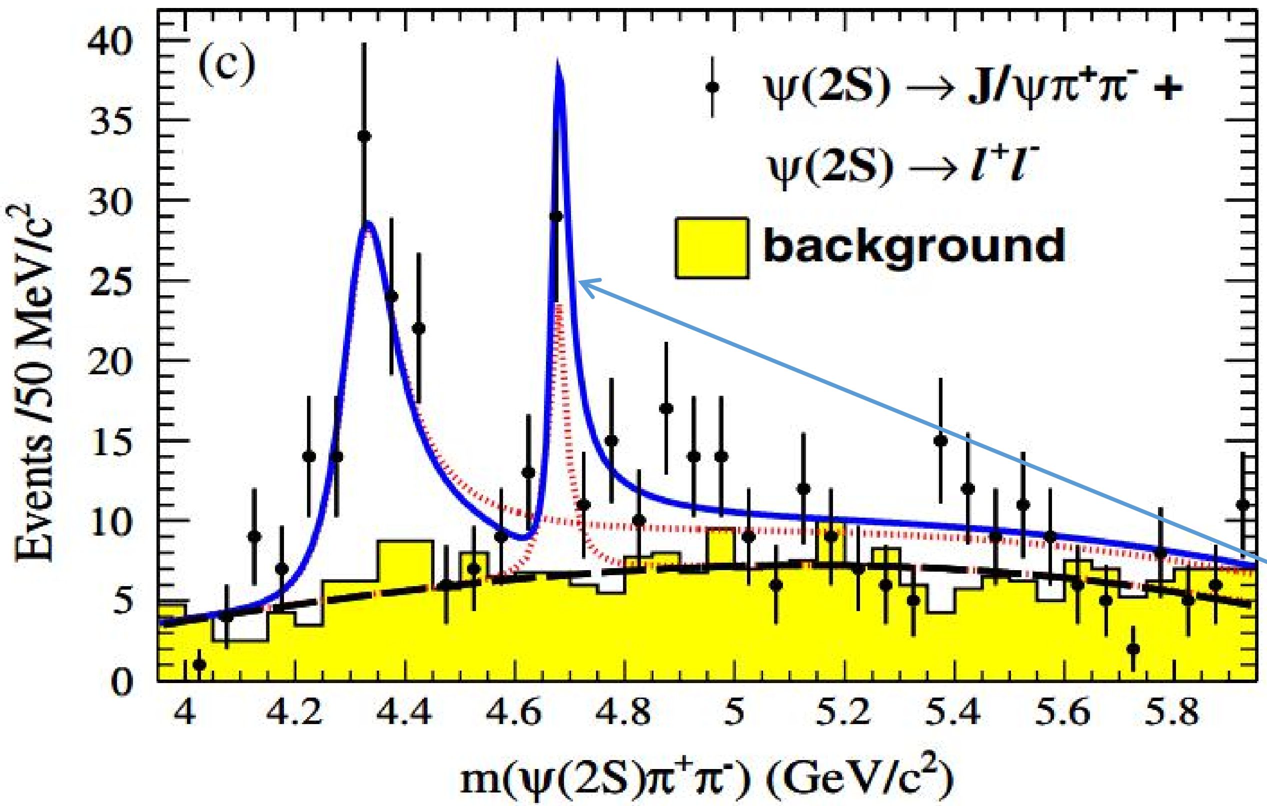


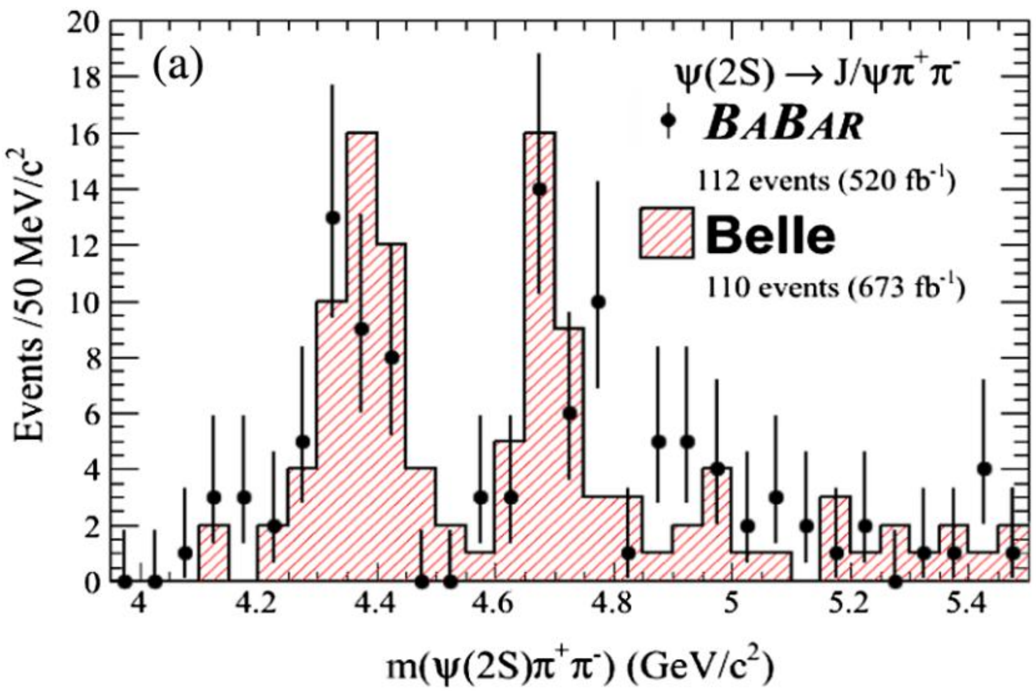
$$M(Y(4660)) = 4661^{+9}_{-8} \pm 6MeV$$

$$\Gamma(Y(4660)) = 42^{+17}_{-12} \pm 6MeV$$

Y(4660)：在2012年被BaBar证实

PRD89 111103(2014)
520/fb data



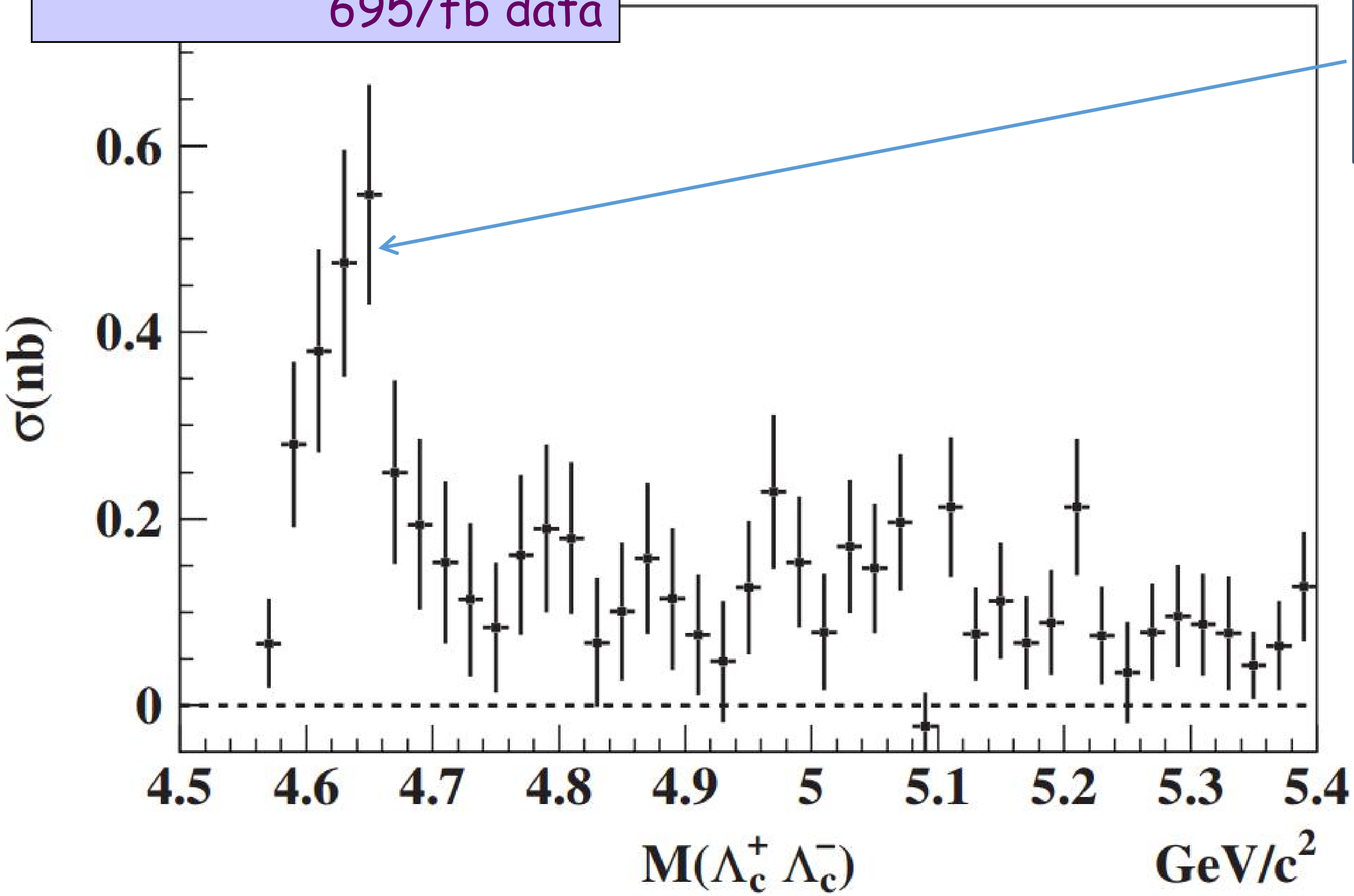


$$M(Y(4660)) = 4669 \pm 21 \pm 3 MeV$$
$$\Gamma_{tot}(Y(4660)) = 104 \pm 48 \pm 10 MeV$$

5.7σ

Y(4630)：首次被Belle观测到

PRL101 172001(2008)
695/fb data



$$M(Y(4630)) = 4634^{+8}_{-7}(stat)^{+5}_{-8}(syst)MeV$$

$$\Gamma_{tot}(Y(4630)) = 92^{+40}_{-24}(stat)^{+10}_{-21}(syst)MeV$$

8.2σ

consistent with Y(4660)

Y(4660) 和 Y(4630): 理论上存在很多解释

Y(4660)

- As charmonium state:
  - $\psi(6S)$
  - $\psi(5D)$
  - $\psi(5S)$
  - $\psi(4D)$
  - $\psi(4S)$
  - $\psi(3D)$
- As exotic state:
  - $\psi' f_0(980)$ bound state
  - tetraquark state
  - hadro-charmonium state

Y(4630)

- As exotic state:
  - $\Lambda_c \bar{\Lambda}_c$ bound state
  - tetraquark state

Y(4660) and Y(4630)

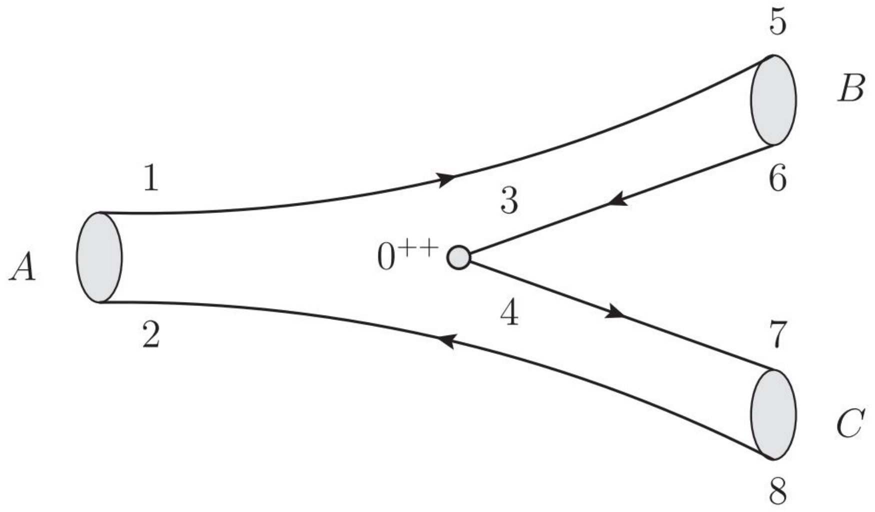
- As charmonium state:
  - tetraquark state
  - $\psi' f_0(980)$ bound state

Phys. Rept. 639, 1-121 (2016)

$Y(4660) \to \Lambda_c \bar{\Lambda}_c$

$^3P_0$ 模型：

$$A(\text{初态介子}) \rightarrow B(\text{末态介子}) + C(\text{末态介子})$$



0^{++} → $l=1$, $S=1$ → $^{2S+1}L_J = {}^3P_0$

$$\boxed{H_{q\bar{q}} = \gamma \sum_f 2m_f \int d^3x \bar{\psi}_f \psi_f}$$

nonrelativistic limit

$$T = -3\gamma \sum_m \langle 1m;1-m|00\rangle \int d^3p_3 d^3p_4 \delta^3(p_3+p_4) \times \omega_0^{34} \varphi_0^{34} \chi_{1,-m}^{34} \mathrm{Y}_1^m\left(\frac{p_3-p_4}{2}\right) a_{3i}^+ b_{4j}^+$$

$$\omega_0^{34} = \frac{R_4\bar{R}_3 + G_4\bar{G}_3 + B_4\bar{B}_3}{\sqrt{3}}$$

$$\varphi_0^{34} = \frac{u_4\bar{u}_3 + d_4\bar{d}_3 + s_4\bar{s}_3}{\sqrt{3}}$$

$$\mathrm{Y}_1^m(\vec{p}) = |\vec{p}| y_1^m(\theta,\varphi)$$

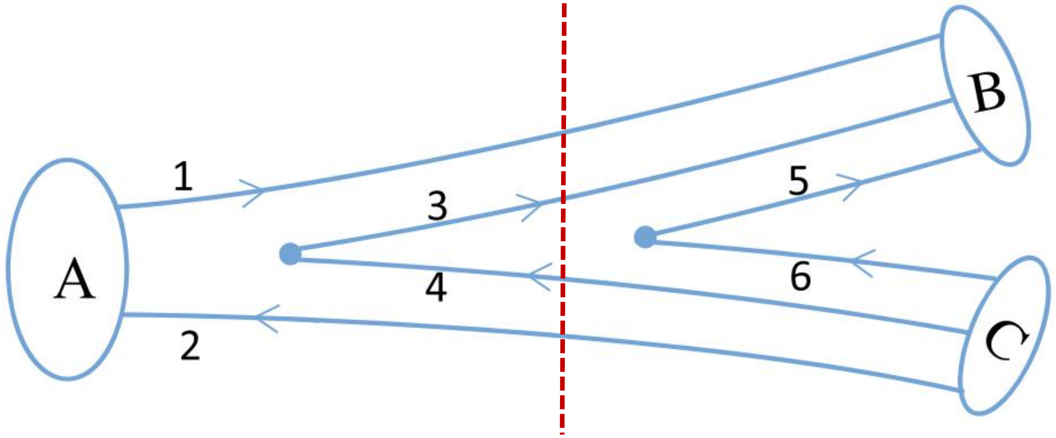
L. Micu, Nucl. Phys. B10,521(1969).

R. D. Carlitz and M. Kislinger , Phys. Rev. D2,336(1970).

$^3P_0$ 模型：ψ(nS/nD)→$\Lambda_c\bar{\Lambda}_c$

A(初态介子)$\rightarrow B$(末态重子)$+C$(初态重子)

$$H_{q\bar{q}}=\gamma\sum_f 2m_f\int d^3x\bar{\psi}_f\psi_f$$



$$\delta^3(\mathbf{p}_A-\mathbf{p}_B-\mathbf{p}_C)M^{M_{J_A}M_{J_B}M_{J_B}}=\frac{\sum_k\langle BC|H_{q\bar{q}}|k\rangle\langle k|H_{q\bar{q}}|A\rangle}{E_k-E_A}.$$

hadron level: J^P=1^{--}

PRD89 114010(2014)

$D\bar{D}_1, D^*\bar{D}_1, D^*\bar{D}_0, D^*\bar{D}_2, J/\psi\, f_0(500)/f_0(600),$

$h_c(1P)\eta, h_c(1P)\pi, \chi_{c0}(1P)\omega(782), \chi_{c2}(1P)\omega(782)$

~ 4.0GeV

quark level: intermediate state - initial state = two quarks

$Ek-EA\approx 0.6GeV\approx 2m_q$ as a constant

$^3P_0$ 模型：$\psi(nS/nD)\to\Lambda_c\bar{\Lambda}_c$

$$\boxed{H_{q\bar{q}} = \gamma\sum_f 2m_f\int d^3x\bar{\psi}_f\psi_f}$$

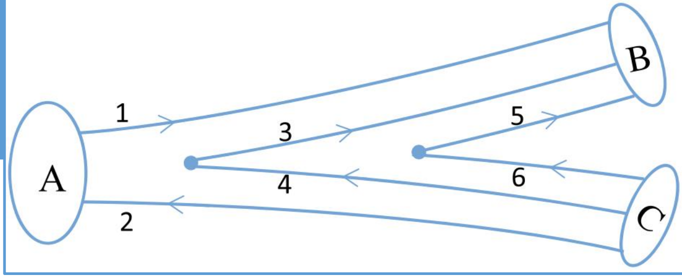
$$\begin{aligned}
T = {} & \frac{9\gamma^2}{4m_\mu}\sum_{m,m'}\langle 1m;1-m|00\rangle\langle 1m';1-m'|00\rangle \\
& \times\int d^3\mathbf{p}_3 d^3\mathbf{p}_4 d^3\mathbf{p}_5 d^3\mathbf{p}_6\,\delta^3(\mathbf{p}_3+\mathbf{p}_4)\delta^3(\mathbf{p}_5+\mathbf{p}_6) \\
& \times\varphi_0^{34}\omega_0^{34}\chi_{1,-m}^{34}\mathcal{Y}_1^m\left(\frac{\mathbf{p}_3-\mathbf{p}_4}{2}\right)a_{3i}^\dagger b_{4j}^\dagger \\
& \times\varphi_0^{56}\omega_0^{56}\chi_{1,-m'}^{56}\mathcal{Y}_1^{m'}\left(\frac{\mathbf{p}_5-\mathbf{p}_6}{2}\right)a_{5i}^\dagger b_{6j}^\dagger,
\end{aligned}$$

$$\boxed{\delta^3(\mathbf{p}_A-\mathbf{p}_B-\mathbf{p}_C)M^{M_{J_A}M_{J_B}M_{J_B}} = \frac{\sum_k\langle BC|H_{q\bar{q}}|k\rangle\langle k|H_{q\bar{q}}|A\rangle}{E_k-E_A}.}$$

$$\frac{\langle BC|H_{q\bar{q}}H_{q\bar{q}}|A\rangle}{2m_q} \xrightarrow{\text{nonrelativistic limit}}$$

$$\boxed{Ek - EA \approx 0.6GeV \approx 2m_q \qquad \text{as a constant}}$$

$^3P_0$ 模型：ψ(nS/nD)→$\Lambda_c\bar{\Lambda}_c$



C. Hayne and N. Isgur, Phys.Rev. D25,1944(1982).

- meson wave function

$$
\begin{aligned}
|A(N_A\,{}^{2S_A+1}L_A J_A M_{J_A})(\mathbf{p}_A)\rangle &= \sqrt{2E_A}\varphi_A^{12}\omega_A^{12} \\
&\times \sum_{M_{L_A},M_{S_A}} \langle L_A M_{L_A}; S_A M_{S_A} | J_A M_{J_A}\rangle \\
&\times \int d^3\mathbf{p}_1 d^3\mathbf{p}_2 \delta^3(\mathbf{p}_1+\mathbf{p}_2-\mathbf{p}_A) \\
&\times \Psi_{N_A L_A M_{L_A}(\mathbf{p}_1,\mathbf{p}_2)} \chi^{12}_{S_A M_{S_A}} |q_1(\mathbf{p}_1) q_2(\mathbf{p}_2)\rangle,
\end{aligned}
$$

SHO wave function

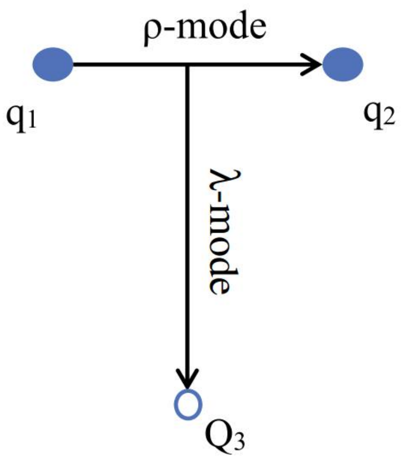
spatial wave function

$$
\psi^0_{lm}(\mathbf{p}) = (-i)^l \left[\frac{2^{l+2}}{\sqrt{\pi}(2l+1)!!}\right]^{\frac{1}{2}} \left(\frac{1}{\beta}\right)^{l+\frac{3}{2}} \times \exp\left(-\frac{\mathbf{p}_R^2}{2\beta^2}\right)\mathcal{Y}_l^m(\mathbf{p}),
$$

- baryon wave function

$$
\psi_{0,0} = 3^{\frac{3}{4}}\left(\frac{1}{\pi\alpha_\rho^2}\right)^{\frac{3}{4}}\left(\frac{1}{\pi\alpha_\lambda^2}\right)^{\frac{3}{4}} \exp\left(-\frac{\mathbf{p}_\rho^2}{2\alpha_\rho^2}-\frac{\mathbf{p}_\lambda^2}{2\alpha_\lambda^2}\right)
$$

$$
\begin{aligned}
|B(N_B\,{}^{2S_B+1}L_B J_B M_{J_B})(\mathbf{p}_B)\rangle &= \sqrt{2E_B}\varphi_B^{135}\omega_B^{135} \\
&\times \sum_{M_{L_B},M_{S_B}} \langle L_B M_{L_B}; S_B M_{S_B} | J_B M_{J_B}\rangle \\
&\times \int d^3\mathbf{p}_1 d^3\mathbf{p}_3 d^3\mathbf{p}_5 \delta^3(\mathbf{p}_1+\mathbf{p}_3+\mathbf{p}_5-\mathbf{p}_B) \\
&\times \Psi_{N_B L_B M_{L_B}(\mathbf{p}_1,\mathbf{p}_3,\mathbf{p}_5)} \chi^{135}_{S_B M_{S_B}} |q_1(\mathbf{p}_1) q_3(\mathbf{p}_3) q_5(\mathbf{p}_5)\rangle.
\end{aligned}
$$

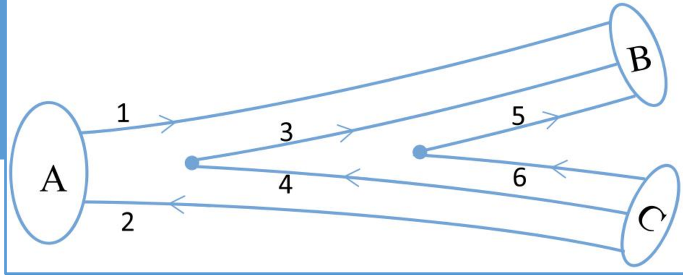


$$
\rho = \frac{\mathbf{r}_1-\mathbf{r}_2}{\sqrt{2}}
$$

$$
\lambda = \frac{\mathbf{r}_1+\mathbf{r}_2-2\mathbf{r}_3}{\sqrt{6}}
$$

$$
\alpha_\lambda = \left(\frac{3m_Q}{2m_q+m_Q}\right)^{1/4}\alpha_\rho
$$

${}^3P_0$ 模型：$\psi(nS/nD)\to\Lambda_c\bar{\Lambda}_c$



$$\Gamma[A\to BC]=\pi^2\frac{|\mathbf{p}|}{M_A^2}\frac{1}{2J_A+1}\times\sum_{M_{J_A},M_{J_B},M_{J_C}}|\mathcal{M}^{M_{J_A}M_{J_B}M_{J_C}}|^2$$

$$\mathcal{M}_{4S}=\frac{1}{3\sqrt{35}}\left(15\beta\frac{\partial}{\partial\beta}+6\beta^2\frac{\partial^2}{\partial\beta^2}+2\beta^3\frac{\partial^3}{\partial\beta^3}\right)\mathcal{M}_{1S},$$

$$\mathcal{M}_{5S}=\frac{1}{18\sqrt{70}}\left(63+72\beta\frac{\partial}{\partial\beta}+96\beta^2\frac{\partial^2}{\partial\beta^2}+24\beta^3\frac{\partial^3}{\partial\beta^3}+4\beta^4\frac{\partial^4}{\partial\beta^4}\right)\mathcal{M}_{1S},$$

$$\mathcal{M}_{6S}=\frac{1}{45\sqrt{77}}\left(\frac{675}{2}\beta\frac{\partial}{\partial\beta}+240\beta^2\frac{\partial^2}{\partial\beta^2}+120\beta^3\frac{\partial^3}{\partial\beta^3}+20\beta^4\frac{\partial^4}{\partial\beta^4}+2\beta^5\frac{\partial^5}{\partial\beta^5}\right)\mathcal{M}_{1S},$$

$$\mathcal{M}_{3D}=\frac{1}{3\sqrt{14}}\left(7+2\beta\frac{\partial}{\partial\beta}+2\beta^2\frac{\partial^2}{\partial\beta^2}\right)\mathcal{M}_{1D},$$

$$\mathcal{M}_{4D}=\frac{1}{3\sqrt{231}}\left(27\beta\frac{\partial}{\partial\beta}+6\beta^2\frac{\partial^2}{\partial\beta^2}+2\beta^3\frac{\partial^3}{\partial\beta^3}\right)\mathcal{M}_{1D},$$

$$\mathcal{M}_{5D}=\frac{1}{6\sqrt{6006}}\left(231+120\beta\frac{\partial}{\partial\beta}+144\beta^2\frac{\partial^2}{\partial\beta^2}+24\beta^3\frac{\partial^3}{\partial\beta^3}+4\beta^4\frac{\partial^4}{\partial\beta^4}\right)\mathcal{M}_{1D}.$$

理论结果:

TABLE I: The $\Lambda_c\bar{\Lambda}_c$ partial decay widths (MeV) of the vector charmonium with a mass of $M = 4643$ MeV. $\mathcal{B}$ represents the branching ratio of the $\Lambda_c\bar{\Lambda}_c$ pair.

$$M(Y(4660)) = 4643 \pm 9 MeV$$
$$\Gamma_{tot}(Y(4660)) = 72 \pm 11 MeV$$

State	$\psi(4^3S_1)$	$\mathcal{B}$	$\psi(5^3S_1)$	$\mathcal{B}$	$\psi(6^3S_1)$	$\mathcal{B}$
$\Gamma_{\Lambda_c\bar{\Lambda}_c}$	6.57	9%	2.44	3%	0.84	1%
State	$\psi(3^3D_1)$	$\mathcal{B}$	$\psi(4^3D_1)$	$\mathcal{B}$	$\psi(5^3D_1)$	$\mathcal{B}$
$\Gamma_{\Lambda_c\bar{\Lambda}_c}$	0.33	0.4%	0.19	0.3%	0.09	0.1%

$\Gamma(\psi(4S/5S/6S) \to \Lambda_c\bar{\Lambda}_c) \sim$ a few MeV

$\Gamma(\psi(3D/4D/5D) \to \Lambda_c\bar{\Lambda}_c) \sim$ less than one MeV

If the enhancement Y(4630) in the $\Lambda_c\bar{\Lambda}_c$ invariant-mass distribution is the same atructure as Y(4660), the Y(4660) resoannce is most likely to be a S-wave charmonium state.

理论结果:

TABLE II: The possible assignments of the $Y(4660)$ with the predicted masses (MeV) from various models.

State	QM [47]	QM [48]	QM [49]	SSE/EA[50]	NR/GI [51]	SP [10]	LP/SP [52]
$\psi(4^3S_1)$	4625	4450	4389	4398/4426	4406/4450	4273	4412/4281
$\psi(5^3S_1)$	$\cdots$	$\cdots$	4641	4642/4672	$\cdots$	4463	4711/4472
$\psi(6^3S_1)$	$\cdots$	$\cdots$	$\cdots$	4804/4828	$\cdots$	4608	$\cdots$
$\psi(3^3D_1)$	$\cdots$	4520	4426	4464/4477	$\cdots$	4317	4478/4336
$\psi(4^3D_1)$	$\cdots$	$\cdots$	4641	4690/4707	$\cdots$	$\cdots$	$\cdots$
$\psi(5^3D_1)$	$\cdots$	$\cdots$	$\cdots$	4840/4855	$\cdots$	$\cdots$	$\cdots$

10、 PRD79,094004 (2009).
47、 PRD72,094004 (2005).
48、 PRD21,203 (1980).
49、 PRD32,189 (1985).
50、 arXiv:0810.2875.
51、 Phys. Atom. Nucl.72,638 (2009).
52、 PRD72,054026 (2005).

理论结果:

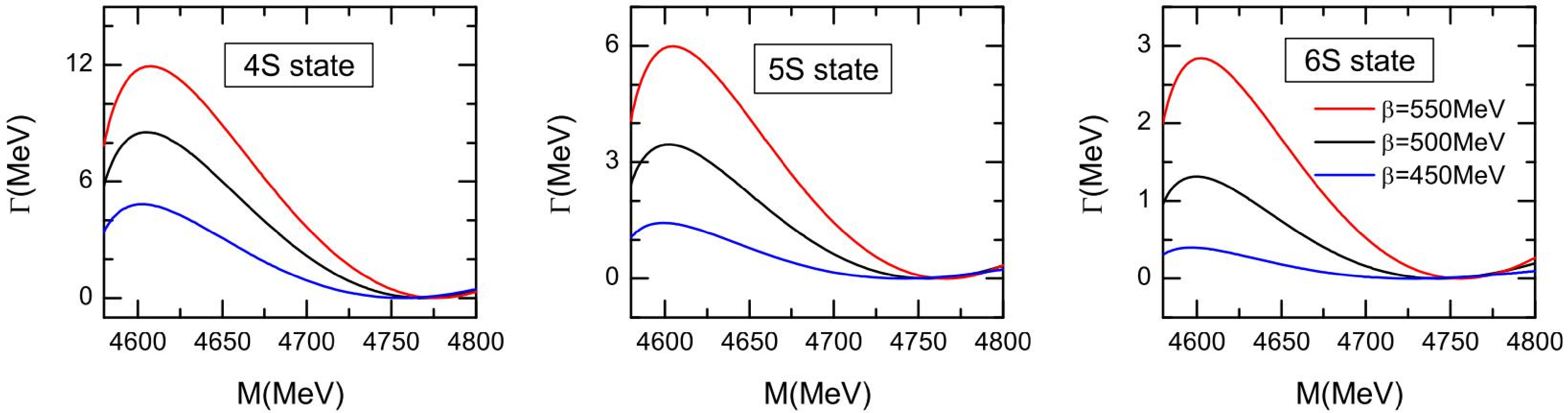
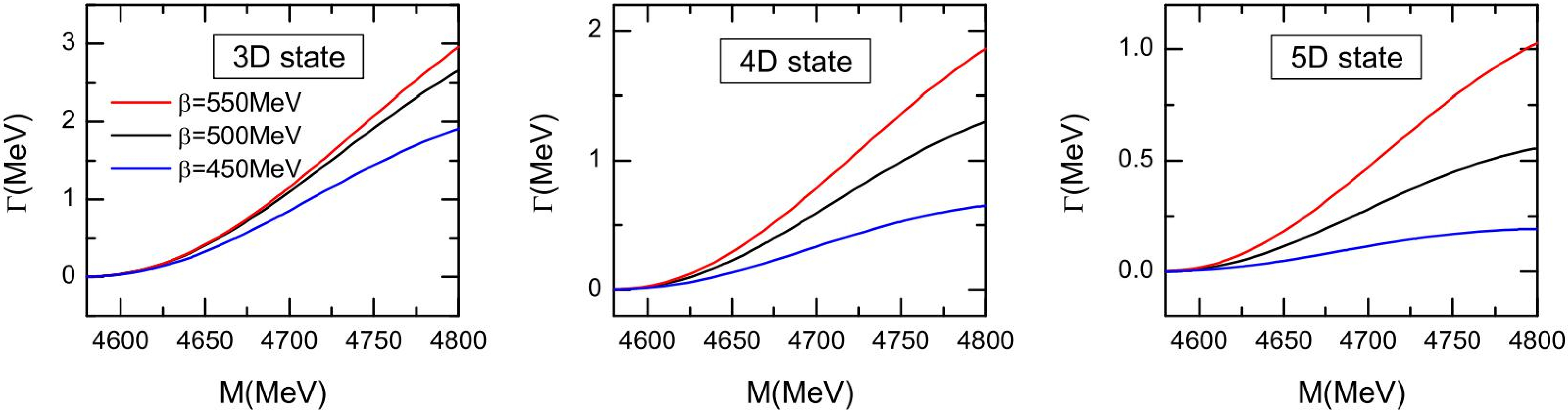


Fig. 3 The variation of the $\Lambda_c\overline{\Lambda}_c$ decay width with the mass of the S-wave vector charmonium. The blue, black, and red lines correspond to the predictions with different values of the harmonic oscillator strength $\beta = 450$, 500, and 550 MeV, respectively

理论结果:


3D state
β=550MeV
β=500MeV
β=450MeV
4D state
5D state
Γ(MeV)
M(MeV)
0
1
2
3
0.0
0.5
1.0
4600
4650
4700
4750
4800

小结:

- The $\Lambda_c\bar{\Lambda}_c$ partial decay width of the excited vector charmonium states around 4.6 GeV:

  ★ $\Gamma(\psi(4S/5S/6S)\to\Lambda_c\bar{\Lambda}_c)$ ∽ a few MeV

  ★ $\Gamma(\psi(3D/4D/5D)\to\Lambda_c\bar{\Lambda}_c)$ ∽ less than one MeV

- If the enhancement Y(4630) in the $\Lambda_c\bar{\Lambda}_c$ invariant-mass distribution is the same atructure as Y(4660), the Y(4660) resoannce is most likely to be a S-wave charmonium state.

- This OZI allowed mode provides a new tool to explore the higer charmonium, which can be produced abundantly at Belle-II.

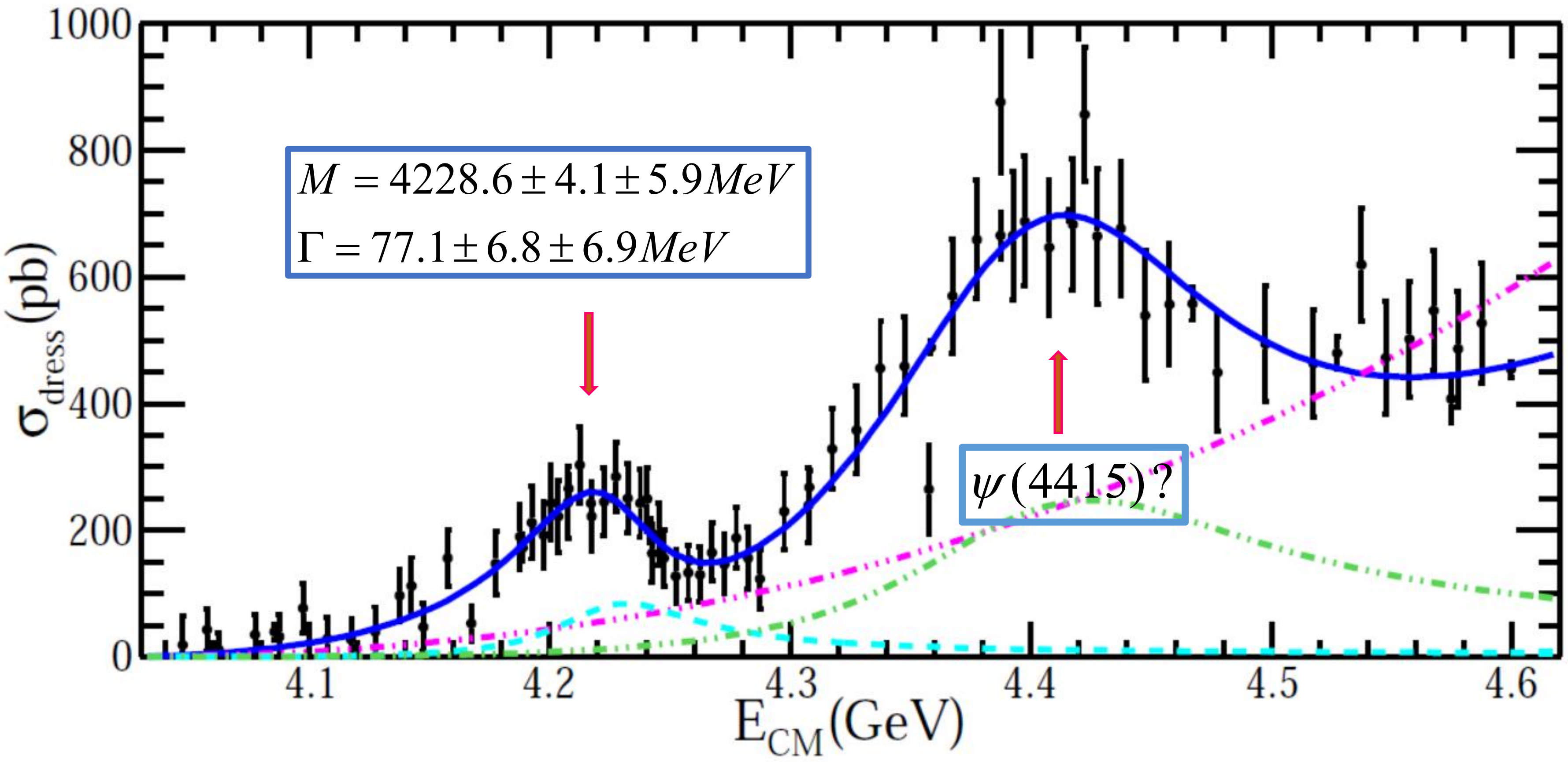
$\psi(nS/nD) \rightarrow D^{(*)}_{(s)} D^{(*)}_{(s)} \pi/K/\eta/\omega/\rho$

$^3P_0$ 模型：ψ(nS/nD)→三体末态

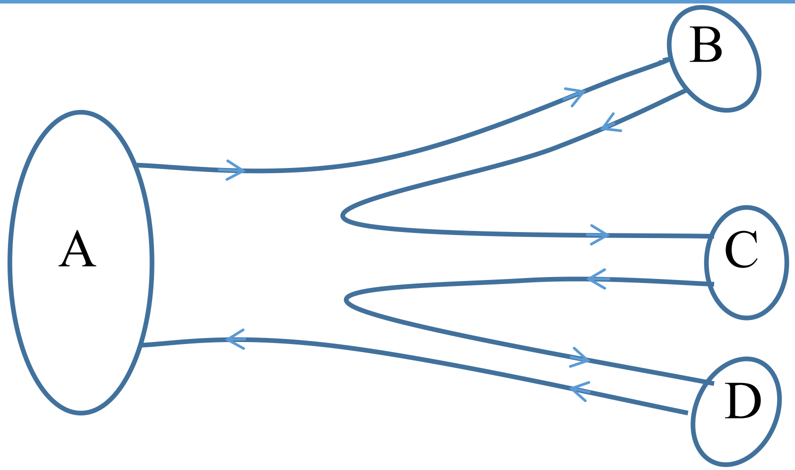
Evidence of a resonant structure in the $e^+e^- \to \pi^+ D^0 D^{*-}$ cross section between 4.05 and 4.60 GeV

(BESIII Collaboration)

arXiv:1808.02847



$^3P_0$ 模型：ψ(nS/nD)→三体末态



$D^{0(*)}$	$D^{+(*)}$	$D_s^{+(*)}$
$\pi^0(\omega,\eta,\rho)/\pi^+/K^+$	$\pi^-(\rho^-)/\pi^0(\omega,\eta,\rho)/\overline{K}^0$	$K^-/K^0/\eta$

$\overline{D}^{0(*)}/D^{-(*)}/D_S^{-(*)}$

$$
\begin{aligned}
T = &\frac{9\gamma^2}{4m_\mu}\sum_{m,m'}\langle 1m;1-m|00\rangle\langle 1m';1-m'|00\rangle \\
&\times\int d^3\mathbf{p}_3 d^3\mathbf{p}_4 d^3\mathbf{p}_5 d^3\mathbf{p}_6 \delta^3(\mathbf{p}_3+\mathbf{p}_4)\delta^3(\mathbf{p}_5+\mathbf{p}_6) \\
&\times\varphi_0^{34}\omega_0^{34}\chi_{1,-m}^{34}\mathcal{Y}_1^m\left(\frac{\mathbf{p}_3-\mathbf{p}_4}{2}\right)a_{3i}^\dagger b_{4j}^\dagger \\
&\times\varphi_0^{56}\omega_0^{56}\chi_{1,-m'}^{56}\mathcal{Y}_1^{m'}\left(\frac{\mathbf{p}_5-\mathbf{p}_6}{2}\right)a_{5i}^\dagger b_{6j}^\dagger,
\end{aligned}
$$

$$
\begin{aligned}
\Gamma = &\int_0^\infty \frac{\pi^3}{M_A}\frac{1}{2J_A+1} \\
&\times\left|\mathcal{M}^{M_{J_A}M_{J_B}M_{J_C}M_{J_D}}(E_B,E_C)\right|^2 \\
&\times\ \mathrm{d}E_B\mathrm{d}E_C
\end{aligned}
$$

$^3P_0$ 模型：ψ(nS/nD)→三体末态

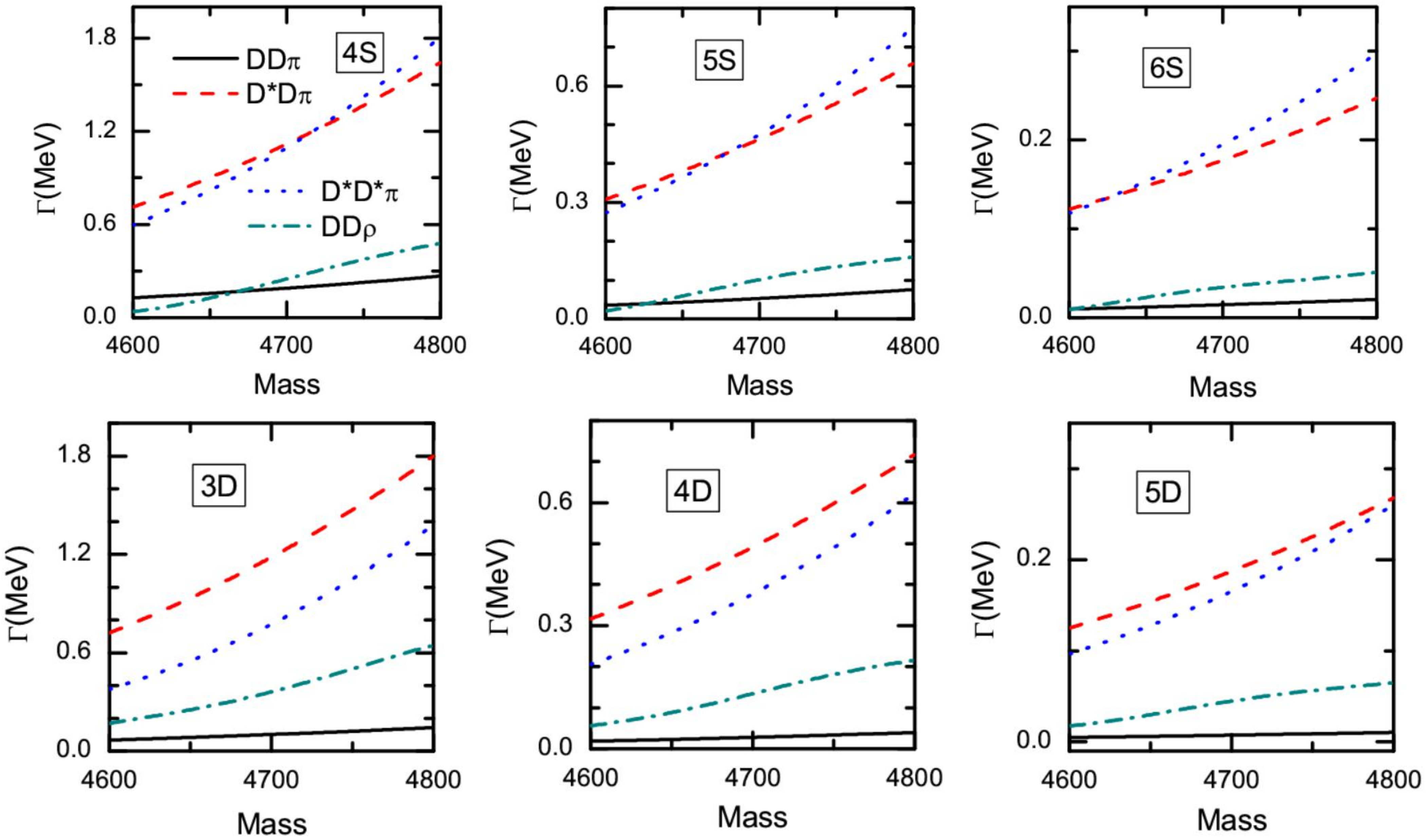
$M(Y(4660)) = 4643 \pm 9 MeV$

$\Gamma_{tot}(Y(4660)) = 72 \pm 11 MeV$

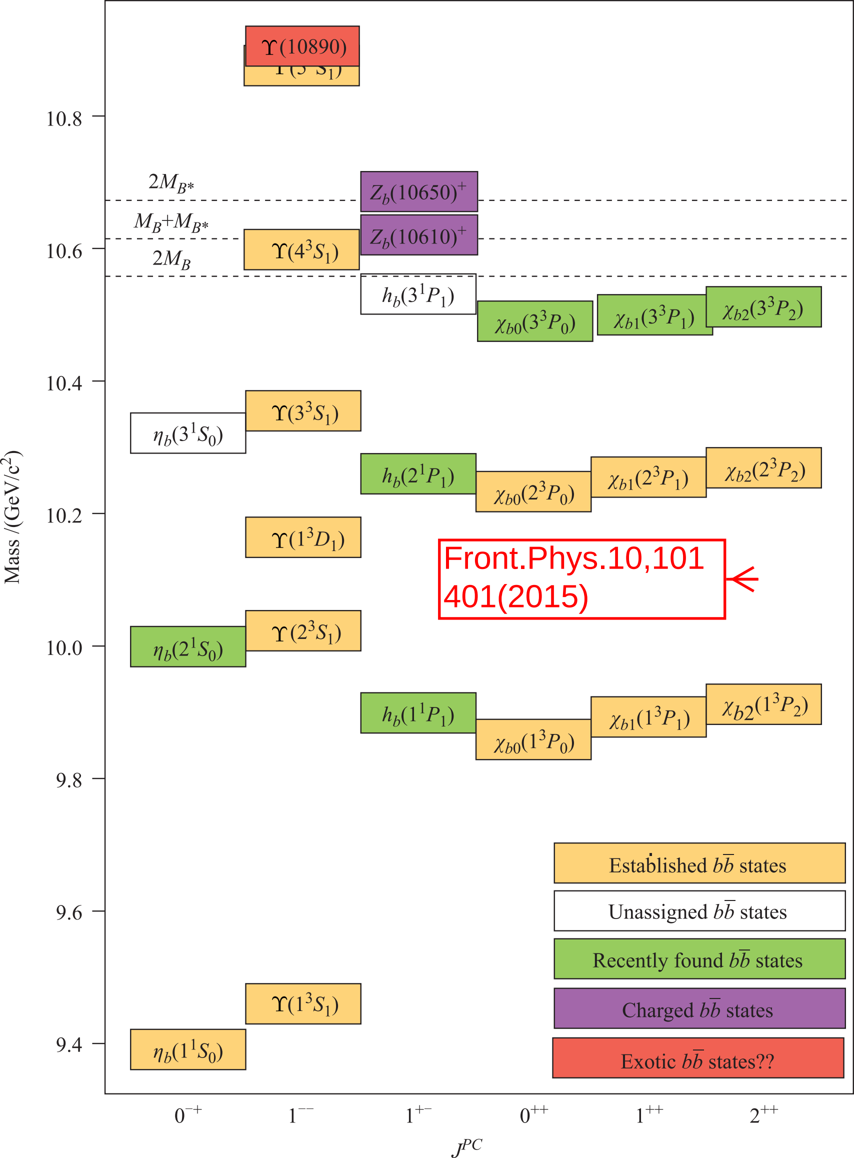
宽度单位MeV，质量M=4643MeV，γ=5.04

State	$\psi(4^3S_1)$	$\psi(5^3S_1)$	$\psi(6^3S_1)$
$\Gamma_{D\bar{D}\pi}$	0.15	0.04	0.01
$\Gamma_{D\bar{D}^*\pi+D^*\bar{D}\pi}$	0.87	0.37	0.14
$\Gamma_{D^*\bar{D}^*\pi}$	0.78	0.35	0.15
$\Gamma_{D\bar{D}\rho}$	0.11	0.05	0.02
State	$\psi(3^3D_1)$	$\psi(4^3D_1)$	$\psi(5^3D_1)$
$\Gamma_{D\bar{D}\pi}$	81.1 keV	22.0 keV	5.9 keV
$\Gamma_{D\bar{D}^*\pi+D^*\bar{D}\pi}$	0.90	0.39	0.15
$\Gamma_{D^*\bar{D}^*\pi}$	0.52	0.27	0.12
$\Gamma_{D\bar{D}\rho}$	0.24	0.08	0.03

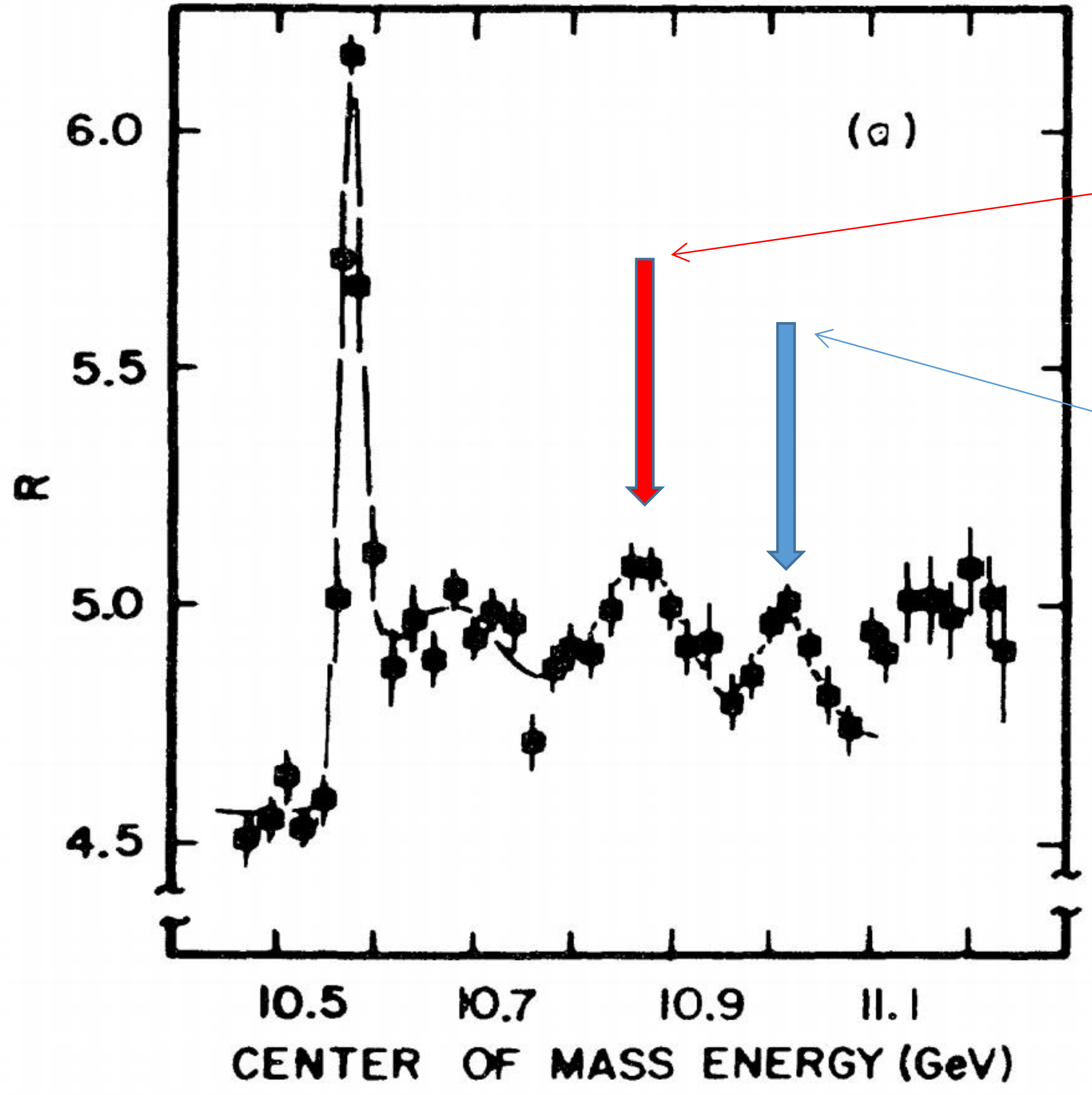
$^3P_0$ 模型：ψ(nS/nD)→三体末态



$\Upsilon(5S/6S) \rightarrow B^{(*)}B^{(*)}\pi$


Υ(10890)
10.8
$2M_{B*}$
$Z_b(10650)^+$
M_B+M_{B*}
$Z_b(10610)^+$
10.6
$\Upsilon(4^3S_1)$
$2M_B$
$h_b(3^1P_1)$
$\chi_{b0}(3^3P_0)$
$\chi_{b1}(3^3P_1)$
$\chi_{b2}(3^3P_2)$
10.4
$\Upsilon(3^3S_1)$
$\eta_b(3^1S_0)$
$h_b(2^1P_1)$
$\chi_{b0}(2^3P_0)$
$\chi_{b1}(2^3P_1)$
$\chi_{b2}(2^3P_2)$
10.2
$\Upsilon(1^3D_1)$
Front.Phys.10,101
401(2015)
10.0
$\Upsilon(2^3S_1)$
$\eta_b(2^1S_0)$
$h_b(1^1P_1)$
$\chi_{b0}(1^3P_0)$
$\chi_{b1}(1^3P_1)$
$\chi_{b2}(1^3P_2)$
9.8
Mass /(GeV/c^2)
Established $b\bar{b}$ states
9.6
Unassigned $b\bar{b}$ states
Recently found $b\bar{b}$ states
Charged $b\bar{b}$ states
$\Upsilon(1^3S_1)$
9.4
$\eta_b(1^1S_0)$
Exotic $b\bar{b}$ states??
0^{-+}
1^{--}
1^{+-}
0^{++}
1^{++}
2^{++}
J^{PC}

Υ(5S/6S): 在1984年首先被CLEO观测到



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$$M_{5S} = 10868 \pm 6 \pm 5 MeV$$
$$\Gamma_{5S} = 112 \pm 17 \pm 23 MeV$$

$$M_{6S} = 11019 \pm 5 \pm 7 MeV$$
$$\Gamma_{6S} = 61 \pm 13 \pm 22 MeV$$

BABAR
BELLE

Υ(5S) 实验数据

$$M(10860) = 10889.0^{+3.2}_{-2.6}\,MeV$$

$$\Gamma(10860) = 52^{+6}_{-7}\,MeV$$

Υ(10860) DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$B\overline{B}X$	$(76.2\ ^{+2.7}_{-4.0})\ \%$	
Γ_2	$B\overline{B}$	$(5.5 \pm 1.0)\ \%$	
Γ_3	$B\overline{B}^* +$ c.c.	$(13.7 \pm 1.6)\ \%$	
Γ_4	$B^*\overline{B}^*$	$(38.1 \pm 3.4)\ \%$	
Γ_5	$B\overline{B}^{(*)}\pi$	$< 19.7\ \%$	90%
Γ_6	$B\overline{B}\pi$	$(0.0 \pm 1.2)\ \%$	
Γ_7	$B^*\overline{B}\pi + B\overline{B}^*\pi$	$(7.3 \pm 2.3)\ \%$	
Γ_8	$B^*\overline{B}^*\pi$	$(1.0 \pm 1.4)\ \%$	
Γ_9	$B\overline{B}\pi\pi$	$< 8.9\ \%$	90%
Γ_{10}	$B_s^{(*)}\overline{B}_s^{(*)}$	$(20.1 \pm 3.1)\ \%$	
Γ_{11}	$B_s\overline{B}_s$	$(5 \pm 5) \times 10^{-3}$	
Γ_{12}	$B_s\overline{B}_s^* +$ c.c.	$(1.35 \pm 0.32)\ \%$	
Γ_{13}	$B_s^*\overline{B}_s^*$	$(17.6 \pm 2.7)\ \%$	

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$\Upsilon(6S)$ 实验数据

$$M(11020) = 10992.9^{+10.0}_{-3.1}\ MeV$$

$$\Gamma(11020) = 49^{+9}_{-15}\ MeV$$

$\Upsilon(11020)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$e^+ e^-$	$(2.7^{+1.0}_{-0.8}) \times 10^{-6}$

$\Upsilon(11020)$ PARTIAL WIDTHS

$\Gamma(e^+ e^-)$ **Γ_1**

VALUE (keV)	*DOCUMENT ID*		*TECN*	*COMMENT*
0.130±0.030 OUR AVERAGE				
0.095±0.03 ±0.035	BESSON	85	CLEO	$e^+ e^- \rightarrow$ hadrons
0.156±0.040	LOVELOCK	85	CUSB	$e^+ e^- \rightarrow$ hadrons

$^3P_0$ 模型：Υ(5S/6S)→三体末态

PRD92 054034(2015) $\gamma=0.6*\sqrt{96\pi}$

Table 1: The $B^{(*)}\bar{B}^{(*)}\pi$ partial decay width (MeV) of the vector bottomonium ($\gamma = 10.42$).

Initial State	Final State	$\Gamma_{\beta=550\text{ MeV}}$	$\Gamma_{\beta=600\text{ MeV}}$	$\Gamma_{\beta=650\text{ MeV}}$	$\Gamma_{\text{exp.}}$
$\Upsilon\left(5^3S_1\right)$	$B\bar{B}\pi$	0.05	0.09	0.13	0.0 ± 0.6
10889.9	$B\bar{B}^*\pi + B^*\bar{B}\pi$	0.60	0.54	0.42	3.7 ± 1.7
	$B^*\bar{B}^*\pi$	0.37	0.32	0.25	0.5 ± 0.8
$\Upsilon\left(6^3S_1\right)$	$B\bar{B}\pi$	0.08	0.15	0.25	
10992.9	$B\bar{B}^*\pi + B^*\bar{B}\pi$	1.12	1.42	1.53	
	$B^*\bar{B}^*\pi$	0.95	1.21	1.34	

总结：

粲偶数激发态：

- The $\Lambda_c\bar{\Lambda}_c$ partial decay width of the excited vector charmonium states around 4.6 GeV:
  - ★ $\Gamma(\psi(4S/5S/6S) \to \Lambda_c\bar{\Lambda}_c)$ ∽ a few MeV
  - ★ $\Gamma(\psi(3D/4D/5D) \to \Lambda_c\bar{\Lambda}_c)$ ∽ less than one MeV
- 4S/5S/6S/3D/4D/5D 衰变到三体末态 各个道宽度 ∽ 零点几个MeV

底偶数激发态：

- 5S/6S 衰变到三体末态 各个道宽度∽ 零点几个MeV

Thanks