The hidden-charm and hidden-bottom pentaquark resonances in scattering process

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第十八届全国中高能核物理大会
6.21 – 6.25, 2019,湖南师范大学

Outline

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V. Summary

I. Introduction

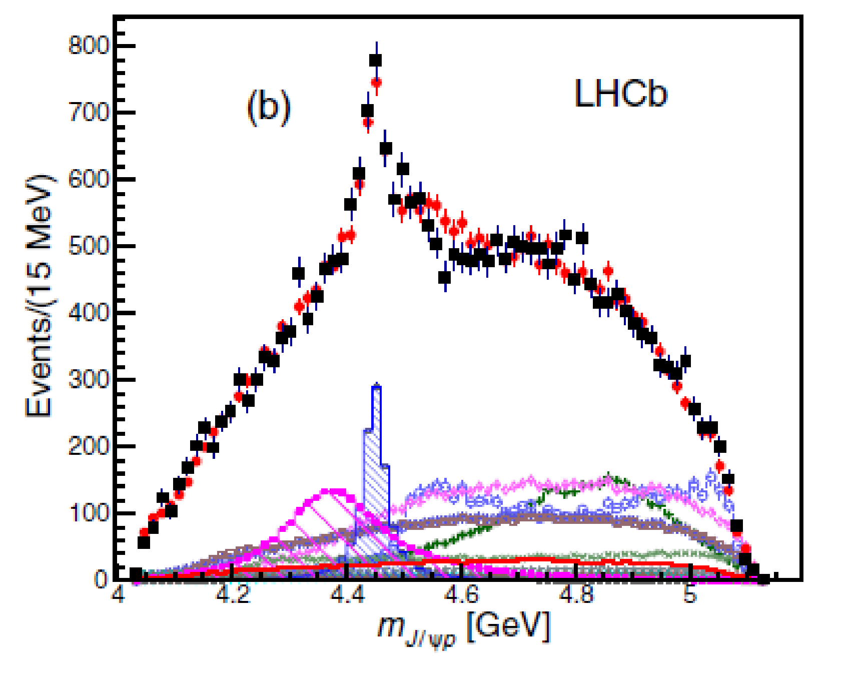
➢ **Experimental results**

LHCb Collaboration, PRL 115, 072001 (2015)

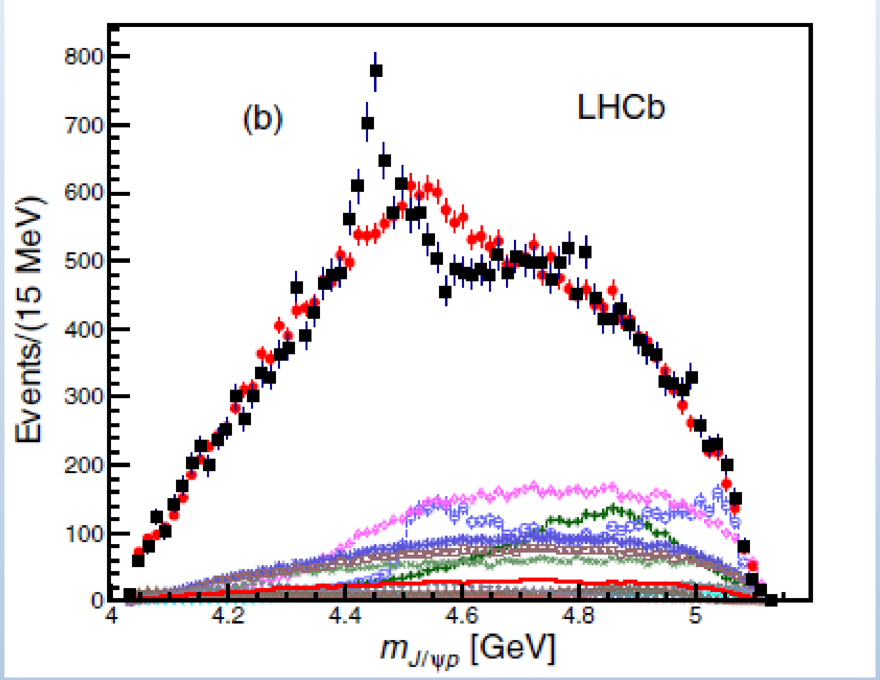
- The two P_c^+ states are found to have **masses and widths** of

$$M_{P_c\,(4380)} = 4380 \pm 8 \pm 29\ \text{MeV}$$
$$\Gamma_{P_c\,(4380)} = 205 \pm 18 \pm 86\text{MeV}$$
$$M_{P_c\,(4450)} = 4449.8 \pm 1.7 \pm 2.5\ \text{MeV}$$
$$\Gamma_{P_c\,(4450)} = 39 \pm 5 \pm 19\ \text{MeV}$$

- The best fit solution has **spin-parity J^P values**of $(3/2^-, 5/2^+)$.
- Acceptable solutions are also found for additional cases with opposite parity, either $(3/2^+, 5/2^-)$ or $(5/2^+, 3/2^-)$.



(b) $m_{J/\psi p}$ for the reduced Λ^* model with two P_c^+ states



(b) $m_{J/\psi p}$ for the extended Λ^* model fit without P_c^+ states.

LHCb Collaboration, arXiv:1904.03947

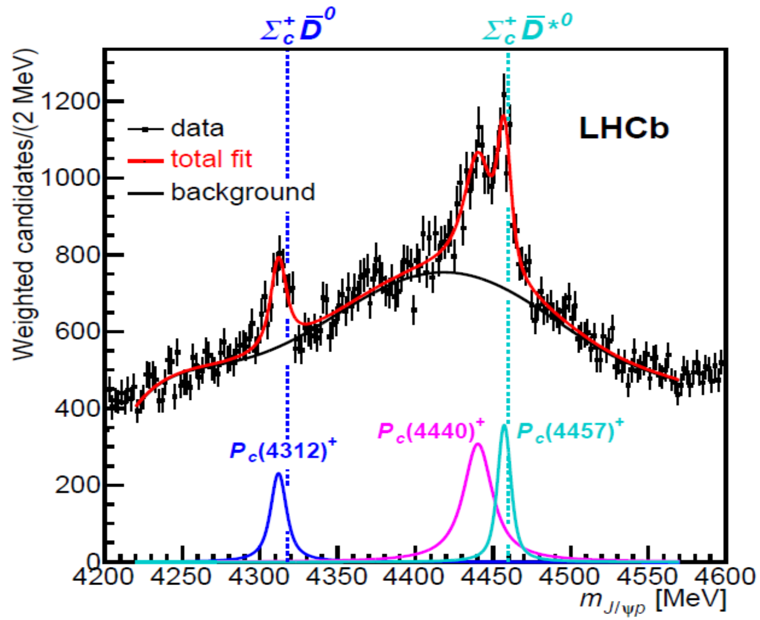


Figure 6: Fit to the $\cos\theta_{P_c}$-weighted $m_{J/\psi p}$ distribution with three BW amplitudes and a sixth-order polynomial background. This fit is used to determine the central values of the masses and widths of the P_c^+ states. The mass thresholds for the $\Sigma_c^+\bar{D}^0$ and $\Sigma_c^+\bar{D}^{*0}$ final states are superimposed.

Table 1: Summary of P_c^+ properties. The central values are based on the fit displayed in Fig. 6.

State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

➢ Theoretical studies

1) Molecular states:

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2) Soliton model

N.N. Scoccolaa, D.O. Riska, Mannque Rho, **Phys.Rev. D92 (2015) no.5, 051501**

3) Sum rules study

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Z.-G. Wang, **Eur.Phys.J. C76 (2016) no.2, 70** .

Hua-Xing Chen , Wei Chen, Shi-Lin Zhu, arXiv: 1903.11001 **[hep-ph]**

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L. Maiani, A.D. Polosa, and V. Riquer, **Phys.Lett. B749 (2015) 289-291**

R.L. Lebed, **Phys.Lett. B749 (2015) 454-457**

G.-N. Li, X.-G. He, M. He, **JHEP 1512 (2015) 128**

5) Anomalous triangle singularity

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J. J. Wu, T.-S. H. Lee and B. S. Zou, Phys. Rev. C **85**, 044002 (2012) [arXiv:1202.1036 [nucl-th]].

Z. C. Yang, Z. F. Sun, J. He, X. Liu and S. L. Zhu, Chin. Phys. C **36**, 6 (2012) [arXiv:1105.2901 [hep-ph]].

J. J. Wu, R. Molina, E. Oset and B. S. Zou, Phys. Rev. C **84**, 015202 (2011)

Dynamically generated N^* and Λ^* resonances in the hidden charm sector around 4.3 GeV

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(Received 11 November 2010; revised manuscript received 24 May 2011; published 6 July 2011)

The interactions of $\bar{D}\Sigma_c$-$\bar{D}\Lambda_c$, $\bar{D}^*\Sigma_c$-$\bar{D}^*\Lambda_c$, and related strangeness channels, are studied within the framework of the coupled-channel unitary approach with the local hidden gauge formalism. A series of meson-baryon dynamically generated relatively narrow N^* and Λ^* resonances are predicted around 4.3 GeV in the hidden charm sector. We make estimates of production cross sections of these predicted resonances in $\bar{p}p$ collisions for the experiment of antiproton annihilation at Darmstadt (PANDA) at the forthcoming GSI Facility for Antiproton and Ion Research (FAIR) facility.

Z. C. Yang, Z. F. Sun, J. He, X. Liu and S. L. Zhu, Chin. Phys. C **36**, 6 (2012) [arXiv:1105.2901 [hep-ph]].

The possible hidden-charm molecular baryons composed of anti-charmed meson and charmed baryon*

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Abstract With the one-boson-exchange model we have studied the possible existence of the very loosely bound hidden-charm molecular baryons composed of anti-charmed meson and charmed baryon. Our numerical results indicate that there exist $\Sigma_c\bar{D}^*$ states with $I(J^P)=\frac{1}{2}(\frac{1}{2}^-),\frac{1}{2}(\frac{3}{2}^-),\frac{3}{2}(\frac{1}{2}^-),\frac{3}{2}(\frac{3}{2}^-)$ and $\Sigma_c\bar{D}$ state with $\frac{3}{2}(\frac{1}{2}^-)$. But the $\Lambda_c\bar{D}$ and $\Lambda_c\bar{D}^*$ molecular states do not exist.

II. Quark model and calculation method

- **Quark model**

  Quark delocalization color screening model (QDCSM)

- QDCSM was developed by Nanjing-Los Alamos collaboration in1990s aimed to multi-quark study. (PRL 69, 2901, 1992)
- Two new ingredients (based on quark cluster model configuration):

  quark delocalization (orbital excitation)

  color screening (color structure)
- Apply to baryon-baryon interaction and dibaryons

  NN, N Λ, NΩ, …
  deuteron
  d*

  } success !

$$H=\sum_{i=1}^{5}\left(m_i+\frac{p_i^2}{2m_i}\right)-T_c+\sum_{i<j}[V^G(r_{ij})+V^\chi(r_{ij})+V^C(r_{ij})],$$

$$V^G(r_{ij})=\frac{1}{4}\alpha_s\lambda_i\cdot\lambda_j\left[\frac{1}{r_{ij}}-\frac{\pi}{2}\left(\frac{1}{m_i^2}+\frac{1}{m_j^2}+\frac{4\sigma_i\cdot\sigma_j}{3m_im_j}\right)\delta(r_{ij})-\frac{3}{4m_im_jr_{ij}^3}S_{ij}\right],$$

$$V^\chi(r_{ij})=\frac{1}{3}\alpha_{ch}\frac{\Lambda^2}{\Lambda^2-m_\chi^2}m_\chi\left\{\left[Y(m_\chi r_{ij})-\frac{\Lambda^3}{m_\chi^3}Y(\Lambda r_{ij})\right]\sigma_i\cdot\sigma_j+\left[H(m_\chi r_{ij})-\frac{\Lambda^3}{m_\chi^3}H(\Lambda r_{ij})\right]S_{ij}\right\}\mathbf{F}_i\cdot\mathbf{F}_j,\qquad \chi=\pi,K,\eta,$$

$$V^C(r_{ij})=-a_c\lambda_i\cdot\lambda_j[f(r_{ij})+V_0],$$

$$f(r_{ij})=\begin{cases} r_{ij}^2 & \text{if } \ i,j\text{occur in the same baryon orbit,} \\ \frac{1-e^{-\mu_{ij}r_{ij}^2}}{\mu_{ij}} & \text{if } \ i,j\text{occur in different baryon orbits,}\end{cases}$$

$$S_{ij}=\frac{(\sigma_i\cdot\mathbf{r}_{ij})(\sigma_j\cdot\mathbf{r}_{ij})}{r_{ij}^2}-\frac{1}{3}\sigma_i\cdot\sigma_j, \qquad (1)$$

➢ Calculation method

(1) Resonating group method (RGM)

In RGM, the multi-quark wave function is approximated by the cluster wave function,

$$\psi(\xi_1,\xi_2,\boldsymbol{R}) = \mathcal{A}[\phi(\xi_1)\phi(\xi_2)\chi(\boldsymbol{R})]$$

The internal motions of clusters are frozen and the relative motion wave function satisfies the following RGM equation

$$\int H(R'',R')\chi(R')dR' = E\int N(R'',R')\chi(R')dR'$$

$$\left\{\begin{array}{c} H(R'',R') \\ N(R'',R') \end{array}\right\} = \left\langle A[\phi_1\phi_2\delta(R-R'')]\middle|\left\{\begin{array}{c} H \\ 1 \end{array}\right\}\middle|A[\phi_1\phi_2\delta(R-R')]\right\rangle$$

RGM equation

$$\int L(R'', R')\chi(R')dR' = 0$$

where

$$L(R'', R') = H(R'', R') - EN(R'', R')$$

$$= [-\frac{\nabla_{R'}^2}{2\mu} + V_{rel}^D(R') - E_{rel}]\delta(R'' - R') + H^{EX}(R'', R') - EN^{EX}(R'', R').$$

(2) Kohn-Hulthen-Kato(KHK) variational method

$$\chi(R) = u(R)/R$$

Scattering wave function $u_L(R)$

$$u_t(R) = \sum_{i=0}^{n} c_i u_i(R)$$

$$\begin{cases} u_L(0) = 0 \\ u_L(R) = (h_L^{(-)}(k,R) + S_L h_L^{(+)}(k,R))R, \quad R > R_C \end{cases}$$

$$S_L = |S_L| e^{2i\delta_L}.$$

The scattering phase shift: δ_L

III. Bound state calculation

Eur. Phys. J. C. 76, 624 (2016)

➢ Hidden-charm pentaquarks

Table 3 The channels involved in the calculation

$S=\frac{1}{2}$	$N\eta_c$	NJ/ψ	$\Lambda_c D$	$\Lambda_c D^*$	$\Sigma_c D$
	$\Sigma_c D^*$	$\Sigma_c^* D^*$			
$S=\frac{3}{2}$	NJ/ψ	$\Lambda_c D^*$	$\Sigma_c D^*$	$\Sigma_c^* D$	$\Sigma_c^* D^*$
$S=\frac{5}{2}$	$\Sigma_c^* D^*$				

- The hidden charm pentaquark with I=1/2

$J^P=\frac{1}{2}^-$				$J^P=\frac{3}{2}^-$				
μ_{cc}	0.01	0.001	0.0001	μ_{cc}	0.01	0.001	0.0001	
$N\eta_c$	ub	ub	ub	NJ/ψ	ub	ub	ub	
NJ/ψ	ub	ub	ub	$\Lambda_c D^*$	ub	ub	ub	
$\Lambda_c D$	ub	ub	ub	$\Sigma_c D^*$	-16/4446	-11/4451	-10/4452	≠ Pc(4450)
$\Lambda_c D^*$	ub	ub	ub	$\Sigma_c^* D$	-17/4367	-14/4370	-12/4372	→ Pc(4380)
$\Sigma_c D$	−19/4300	−15/4304	−13/4306	$\Sigma_c^* D^*$	−17/4510	−15/4512	−13/4514	
$\Sigma_c D^*$	−21/4441	−19/4443	−18/4444	$J^P=\frac{5}{2}^-$				
$\Sigma_c^* D^*$	−24/4503	−23/4504	−21/4506	$\Sigma_c^* D^*$	−15/4512	−10/4517	−10/4517	

μ_{cc}	0.01			0.001			0.0001		
M_{cc}	4296	4437	4500	4300	4439	4501	4302	4440	4503
$\Sigma_c D$	95.5	2.9	4.8	96.0	2.5	4.5	96.7	2.1	4.2
$\Sigma_c D^*$	3.6	95.1	0.8	3.2	95.3	1.0	2.7	95.7	1.1
$\Sigma_c^* D^*$	0.9	2.0	94.4	0.8	2.2	94.5	0.6	2.2	94.7

Table 5 The masses (in MeV) of the hidden-charm molecular pentaquarks of $J^P = \frac{1}{2}^-$ with three closed channels coupling and the percentages of each channel in the eigen-states

$J^P = \frac{1}{2}^-$				$J^P = \frac{3}{2}^-$				$J^P = \frac{5}{2}^-$			
μ_{cc}	0.01	0.001	0.0001	μ_{cc}	0.01	0.001	0.0001	μ_{cc}	0.01	0.001	0.0001
M_{cc}	3881	3883	3884	M_{cc}	3997	3998	3998	M_{cc}	4512	4517	4517
$N\eta_c$	41.7	49.7	35.2	NJ/ψ	80.8	71.0	62.1	$\Sigma_c^* D^*$	100.0	100.0	100.0
NJ/ψ	23.1	24.4	29.3	$\Lambda_c D^*$	8.7	11.9	15.9				
$\Lambda_c D$	14.6	11.7	14.5	$\Sigma_c D^*$	1.2	1.9	2.6				
$\Lambda_c D^*$	0.9	0.4	2.0	$\Sigma_c^* D$	3.5	5.8	7.3				
$\Sigma_c D$	0.1	4.8	6.0	$\Sigma_c^* D^*$	5.8	9.4	12.1				
$\Sigma_c D^*$	4.5	6.4	12.4								
$\Sigma_c^* D^*$	15.1	2.6	0.6								

Table 6 The masses (in MeV) of the hidden-charm molecular pentaquarks with all channels coupling and the percentages of each channel in the eigen-states

μ_{cc}	0.01			0.001			0.0001		
M_{cc}	4362	4445	4551	4365	4450	4553	4368	4451	4554
$\Sigma_c D^*$	3.8	96.2	1.4	1.6	98.0	1.0	1.2	98.5	0.8
$\Sigma_c^* D$	91.0	2.8	4.0	94.1	1.0	3.7	95.5	0.7	3.0
$\Sigma_c^* D^*$	5.2	1.0	94.6	4.3	1.0	95.3	3.3	0.8	96.2

Table 7 The masses (in MeV) of the hidden-charm molecular pentaquarks of $J^P = \frac{3}{2}^-$ with three closed channels coupling and the percentages of each channel in the eigen-states

Hidden-bottom pentaquarks

Table 8 The binding energies (in MeV) of the hidden-bottom molecular pentaquarks of $I=\frac{1}{2}$

$J^P=\frac{1}{2}^-$		$J^P=\frac{3}{2}^-$		$J^P=\frac{5}{2}^-$	
$N\eta_b$	ub	$N\Upsilon(1s)$	ub	$\Sigma_b^*B^*$	−14
$N\Upsilon(1s)$	ub	Λ_bB^*	ub		
Λ_bB	ub	Σ_bB^*	−14		
Λ_bB^*	ub	Σ_b^*B	−15		
Σ_bB	−15	$\Sigma_b^*B^*$	−16		
Σ_bB^*	−21				
$\Sigma_b^*B^*$	−24				

Table 9 The masses (in MeV) of the hidden-bottom molecular pentaquarks with three closed channels coupling and the percentages of each channel in the eigen-states

M_{cc}	11,070	11,112	11,132
$J^P=\frac{1}{2}^-$			
Σ_bB	76.8	12.4	8.1
Σ_bB^*	21.7	67.7	10.2
$\Sigma_b^*B^*$	1.5	19.9	81.7
M_{cc}	11,091	11,121	11,138
$J^P=\frac{3}{2}^-$			
Σ_bB^*	5.1	86.5	9.5
Σ_b^*B	78.4	7.8	8.7
$\Sigma_b^*B^*$	16.5	5.7	81.8

Table 10 The masses (in MeV) of the hidden-bottom molecular pentaquarks of $I=\frac{1}{2}$ and the percentages of each channel in the eigen-states

$J^P=\frac{1}{2}^-$		$J^P=\frac{3}{2}^-$		$J^P=\frac{5}{2}^-$	
M_{cc}	10,304	M_{cc}	10,382	M_{cc}	11,143
$N\eta_b$	33.8	$N\Upsilon(1s)$	34.6	$\Sigma_b^*B^*$	100.0
$N\Upsilon(1s)$	14.7	Λ_bB^*	32.6		
Λ_bB	24.2	Σ_bB^*	18.7		
Λ_bB^*	5.2	Σ_b^*B	13.7		
Σ_bB	2.1	$\Sigma_b^*B^*$	0.4		
Σ_bB^*	0.7				
$\Sigma_b^*B^*$	19.3				

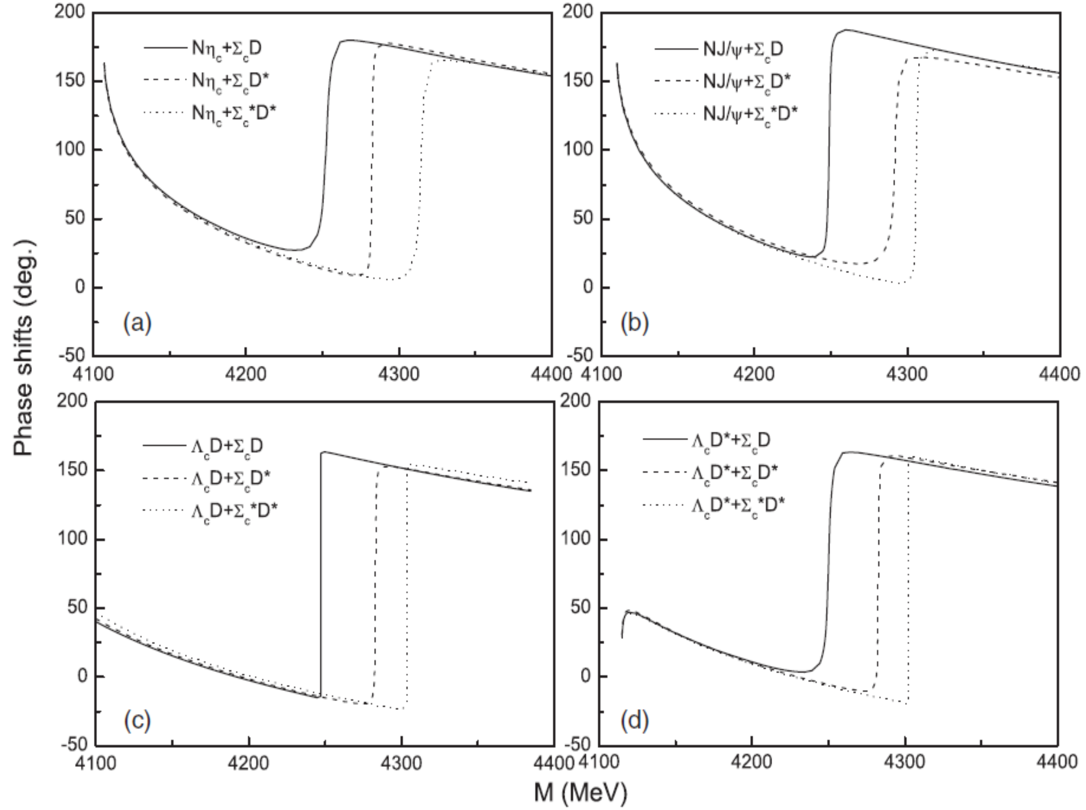
- The results are similar to the hidden-charm molecular pentaquark

IV. Resonance state and decay width

Phys. Rev. D. 99, 014010 (2019)

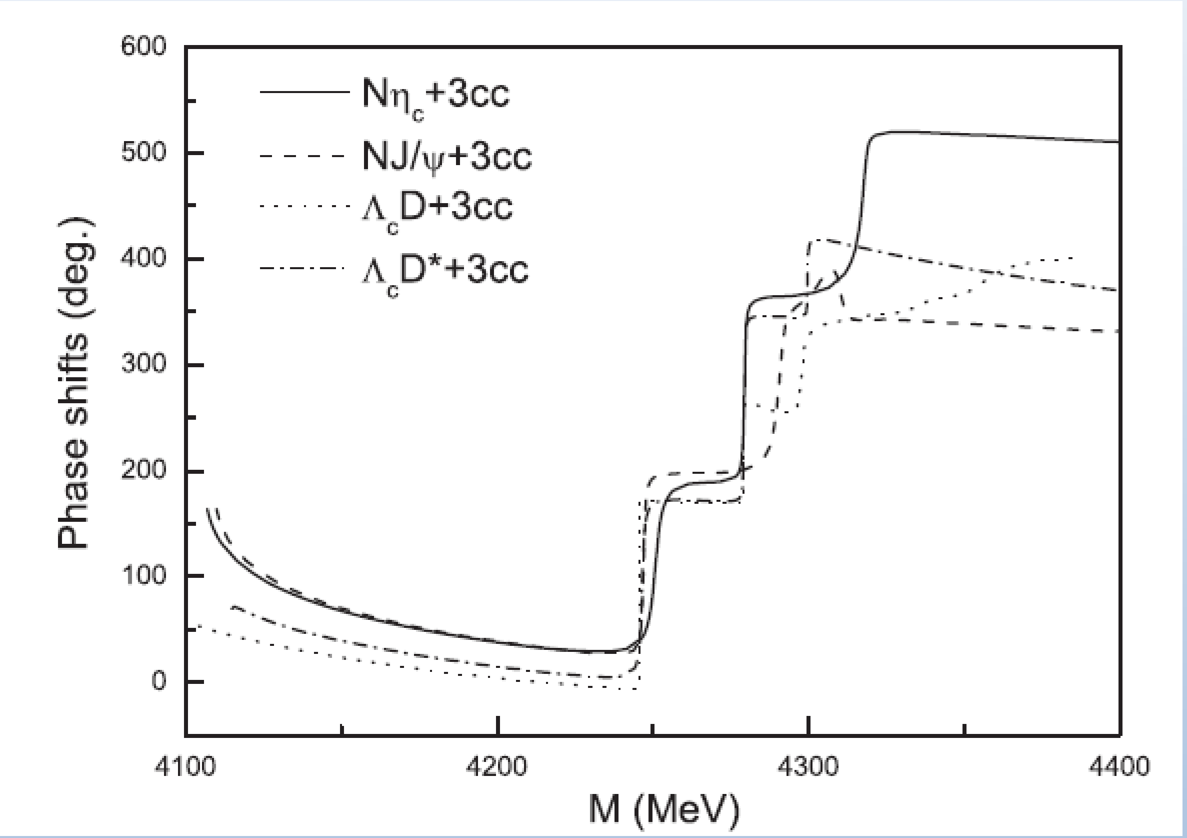
- **Hidden-charm pentaquarks**

The $N\eta_c$, NJ/ψ, $\Lambda_c D$, and $\Lambda_c D^*$ S-wave phase shifts with two-channel coupling for the $IJ^P = \frac{1}{2}\frac{1}{2}^-$ system.



- The phase shifts of the open channels clearly show three resonance states.

FIG. 2. The $N\eta_c$, NJ/ψ, $\Lambda_c D$, and $\Lambda_c D^*$ S-wave phase shifts with four-channel coupling for the $IJ^P = \frac{1}{2}\frac{1}{2}^-$ system.



- There are three resonance states in the $N\eta_c$ scattering phase shifts corresponding to $\Sigma_c D, \Sigma_c D^*, \Sigma_c^* D^*$
- In other scattering channels there are only two resonance states corresponding to $\Sigma_c D, \Sigma_c D^*$

TABLE II. The masses and decay widths (in MeV) of the $IJ^P = \frac{1}{2}\frac{1}{2}^-$ resonance states in the $N\eta_c$, NJ/ψ, $\Lambda_c D$, and $\Lambda_c D^*$ S-wave scattering process.

Pc(4312) Pc(4457)

	Two-channel coupling						Four-channel coupling					
	$\Sigma_c D$		$\Sigma_c D^*$		$\Sigma_c^* D^*$		$\Sigma_c D$		$\Sigma_c D^*$		$\Sigma_c^* D^*$	
	M'	Γ_i	M'	Γ_i	M'	Γ_i	M'	Γ_i	M'	Γ_i	M'	Γ_i
$N\eta_c$	4312.9	6.0	4451.7	1.1	4523.1	3.5	4311.3	4.5	4448.8	1.0	4525.8	4.0
NJ/ψ	4309.9	2.0	4461.6	4.0	4514.7	1.2	4307.9	1.2	4459.7	3.9	nr	⋯
$\Lambda_c D$	4308.4	0.003	4452.6	1.0	4512.6	0.004	4306.7	0.02	4461.6	1.0	nr	⋯
$\Lambda_c D^*$	4311.6	3.5	4452.5	1.0	4510.8	0.005	4307.7	1.4	4449.0	0.3	nr	⋯
Γ_{total}		11.5		7.1		4.7		7.1		6.2		4.0

Investigating the hidden-charm and hidden-bottom pentaquark resonances in scattering process

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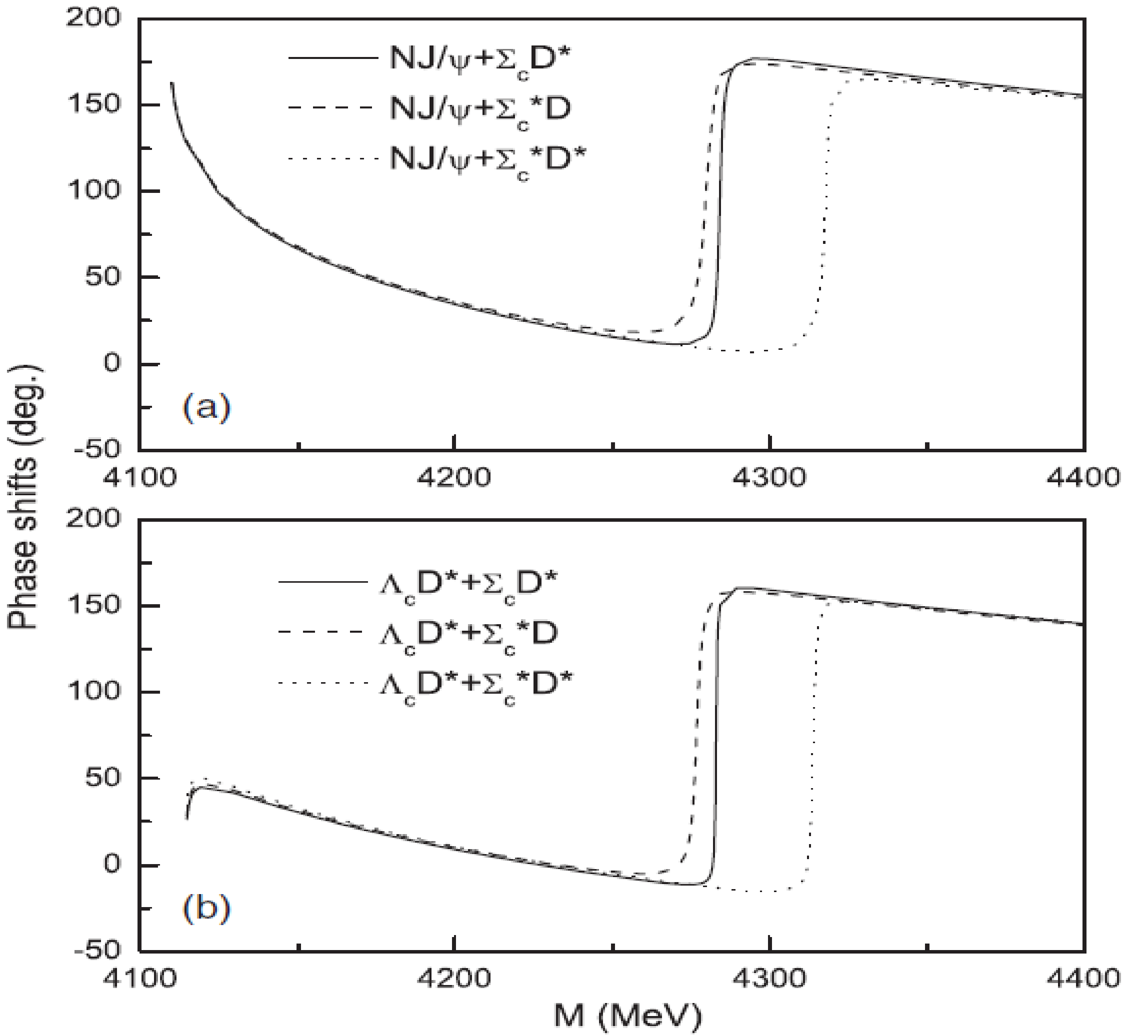
(Received 25 November 2018; published 9 January 2019)

FIG. 3. The NJ/ψ and $\Lambda_c D^*$ S-wave phase shifts with two-channel coupling for the $IJ^P = \frac{1}{2}\frac{3}{2}^-$ system.



- The phase shifts of the open channels clearly show three resonance states.

FIG. 4. The NJ/ψ and $\Lambda_c D^*$ S-wave phase shifts with four-channel coupling for the $IJ^P = \frac{1}{2}\frac{3}{2}^-$ system.

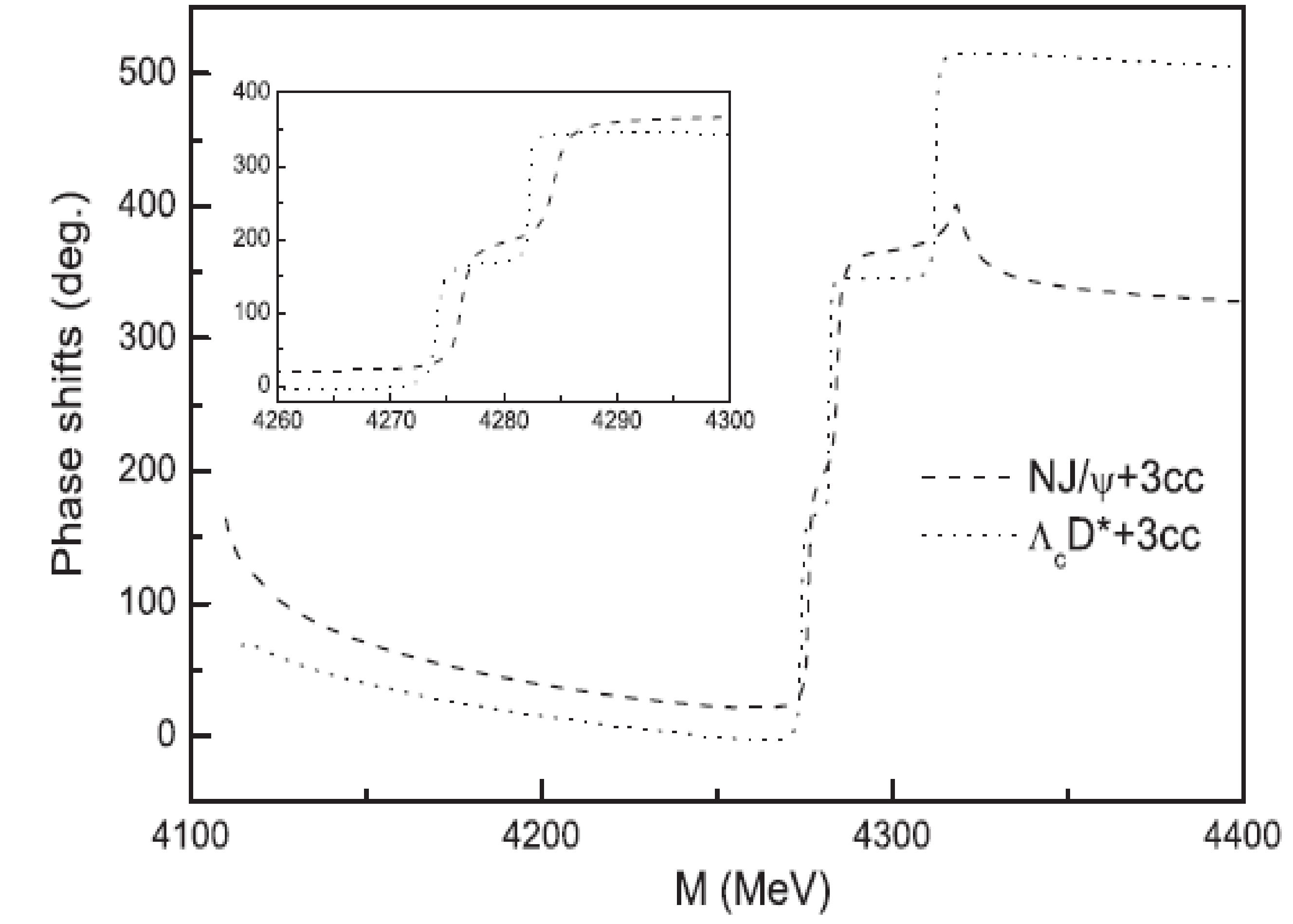


TABLE III. The masses and decay widths (in MeV) of the $IJ^P = \frac{1}{2}\frac{3}{2}^-$ resonance states in the NJ/ψ and $\Lambda_c D^*$ S-wave scattering process.

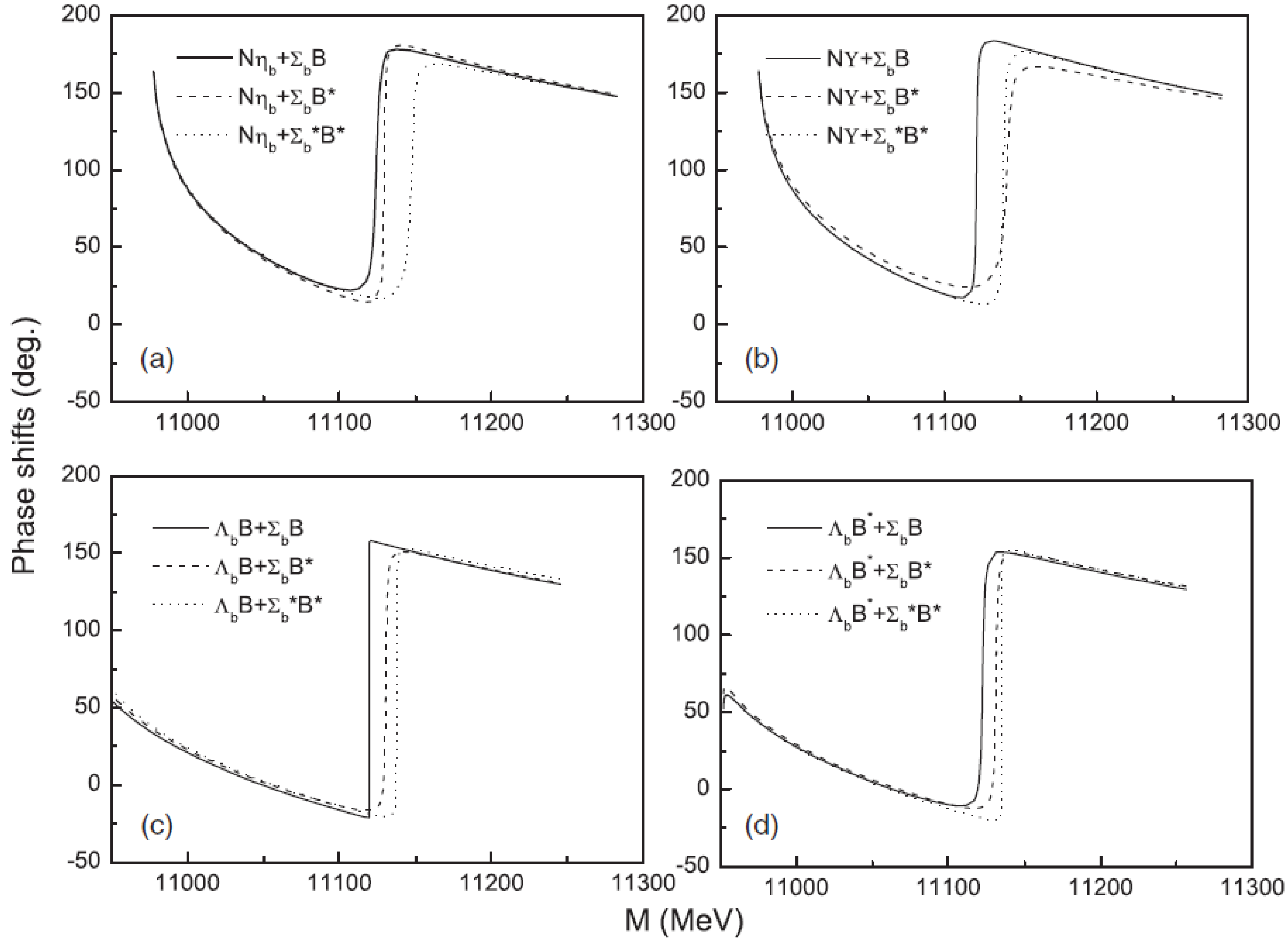
	Two-channel coupling					
	$\Sigma_c D^*$		$\Sigma_c^* D$		$\Sigma_c^* D^*$	
	M'	Γ_i	M'	Γ_i	M'	Γ_i
NJ/ψ	4453.8	1.7	4379.7	4.5	4526.4	2.5
$\Lambda_c D^*$	4452.7	0.8	4377.6	3.2	4522.7	1.8
Γ_{total}		2.5		7.7		4.3
	Four-channel coupling					
	$\Sigma_c D^*$		$\Sigma_c^* D$		$\Sigma_c^* D^*$	
	M'	Γ_i	M'	Γ_i	M'	Γ_i
NJ/ψ	4445.7	1.5	4376.4	1.5	nr	$\cdots$
$\Lambda_c D^*$	4444.0	0.3	4374.4	0.9	4523.0	1.0
Γ_{total}		1.8		2.4		1.0

?

Pc(4440) Pc(4380)

➢ Hidden-bottom pentaquarks

The $N\eta_b$, $N\Upsilon$, $\Lambda_b B$, and $\Lambda_b B^*$ S-wave phase shifts with two-channel coupling for the $IJ^P = \frac{1}{2}\frac{1}{2}^-$ system.



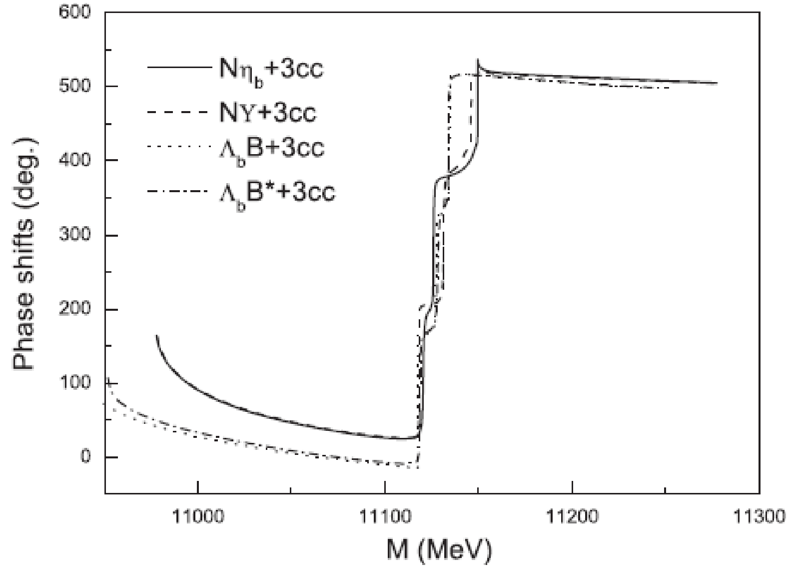


FIG. 6. The $N\eta_b$, $N\Upsilon$, $\Lambda_b B$ and $\Lambda_b B^*$ S-wave phase shifts with four-channel coupling for the $IJ^P = \frac{1}{2}\frac{1}{2}^-$ system.

TABLE IV. The masses and decay widths (in MeV) of the $IJ^P = \frac{1}{2}\frac{1}{2}^-$ resonance states in the $N\eta_b$, $N\Upsilon$, $\Lambda_b B$, and $\Lambda_b B^*$ S-wave scattering process.

	Two-channel coupling						Four-channel coupling					
	$\Sigma_b B$		$\Sigma_b B^*$		$\Sigma_b^* B^*$		$\Sigma_b B$		$\Sigma_b B^*$		$\Sigma_b^* B^*$	
	M'	Γ_i	M'	Γ_i	M'	Γ_i	M'	Γ_i	M'	Γ_i	M'	Γ_i
$N\eta_b$	11 083.3	4.0	11 123.9	1.4	11 154.5	4.7	11 079.8	1.2	11 120.6	0.4	11 156.9	2.0
$N\Upsilon$	11 080.4	1.4	11 135.4	6.6	11 146.2	2.0	11 077.5	0.1	11 125.8	0.8	11 153.5	3.0
$\Lambda_b B$	11 079.0	0.000 3	11 125.4	2.0	11 145.1	0.49	11 077.2	0.001	11 122.0	0.6	11 141.8	0.1
$\Lambda_b B^*$	11 082.2	2.6	11 126.2	2.3	11 142.7	0.22	11 078.3	0.3	11 123.0	1.2	11 141.5	0.4
Γ_{total}		7.0		12.3		7.4		1.6		3.0		5.5

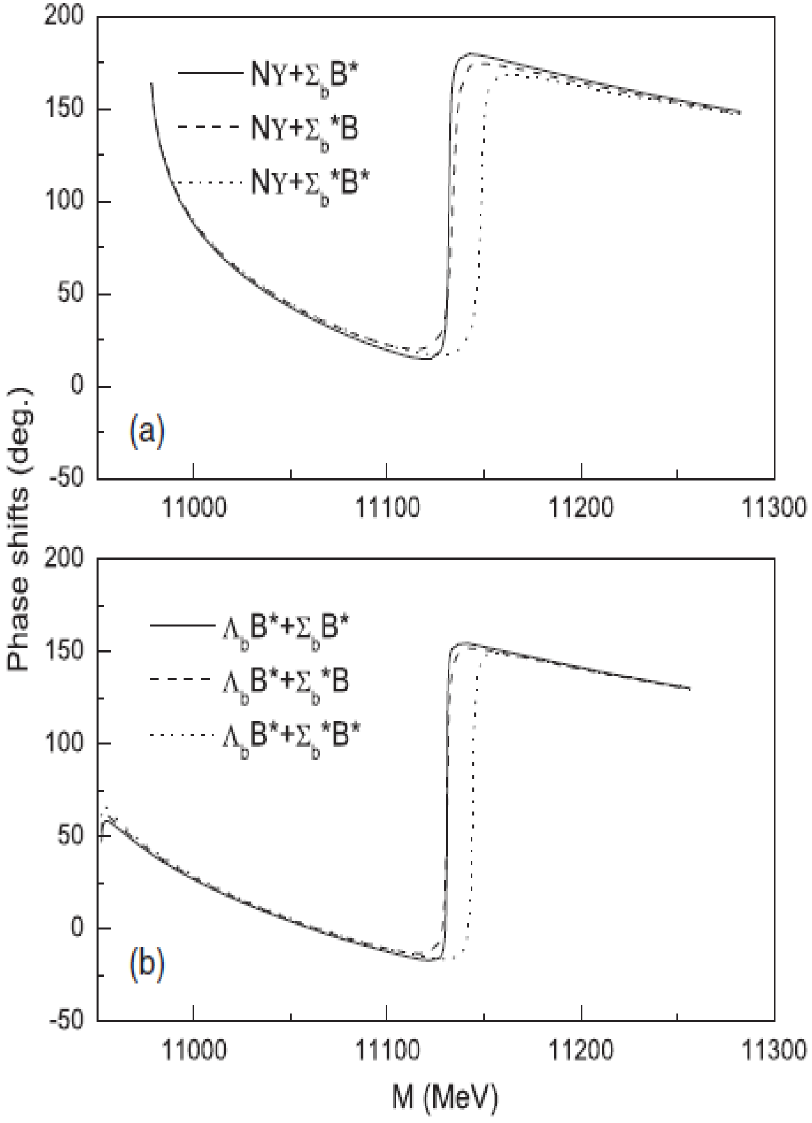


FIG. 7. The $N\Upsilon$ and $\Lambda_b B^*$ S-wave phase shifts with two-channel coupling for the $IJ^P = \frac{1}{2}\frac{3}{2}^-$ system.

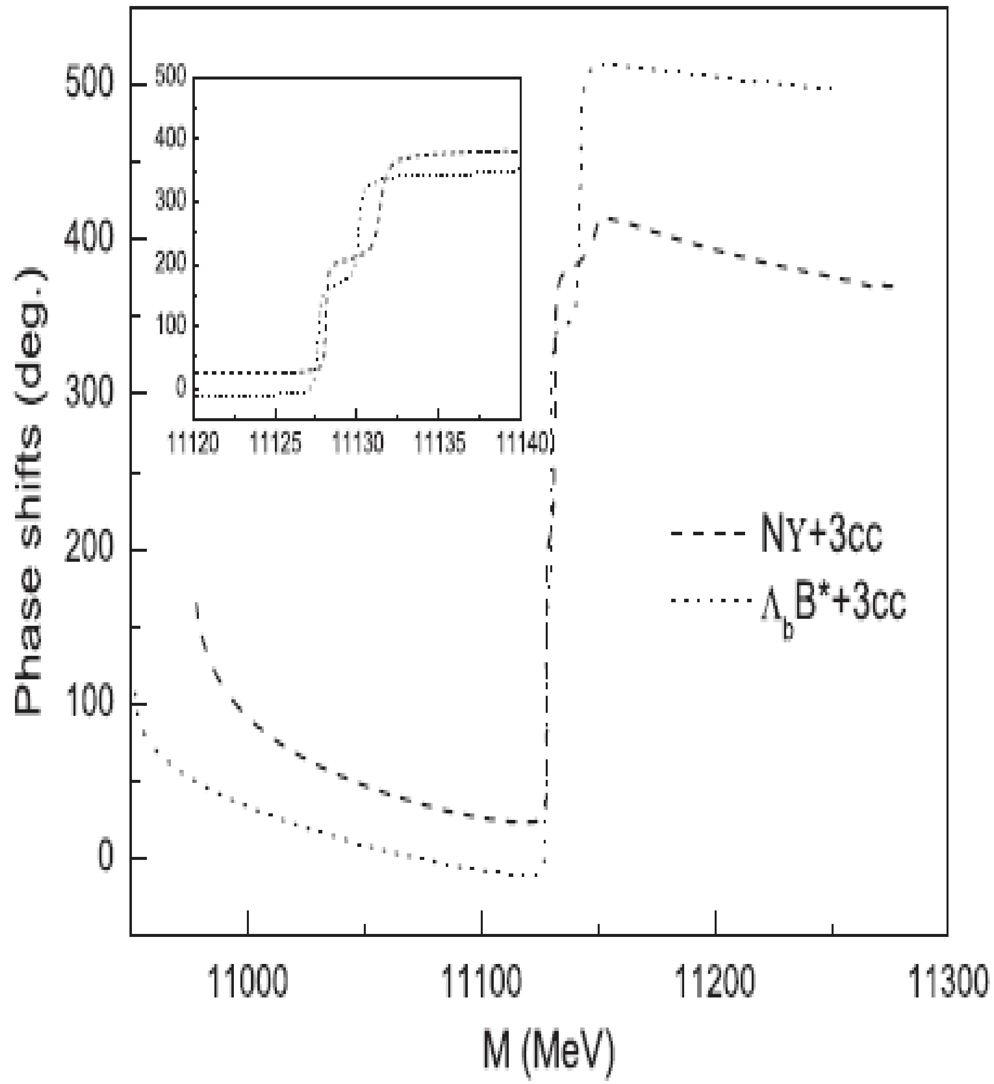


FIG. 8. The $N\Upsilon$ and $\Lambda_b B^*$ S-wave phase shifts with four-channel coupling for the $IJ^P = \frac{1}{2}\frac{3}{2}^-$ system.

TABLE V. The masses and decay widths (in MeV) of the $IJ^P = \frac{1}{2}\frac{3}{2}^-$ resonance states in the $N\Upsilon$ and $\Lambda_b B^*$ S-wave scattering process.

	Two-channel coupling					
	$\Sigma_b B^*$		$\Sigma_b^* B$		$\Sigma_b^* B^*$	
	M'	Γ_i	M'	Γ_i	M'	Γ_i
$N\Upsilon$	11 126.3	1.7	11 105.8	4.4	11 155.7	3.8
$\Lambda_b B^*$	11 125.5	0.9	11 103.5	2.6	11 152.0	2.7
Γ_{total}		2.6		7.0		6.5
	Four-channel coupling					
	$\Sigma_b B^*$		$\Sigma_b^* B$		$\Sigma_b^* B^*$	
	M'	Γ_i	M'	Γ_i	M'	Γ_i
$N\Upsilon$	11 122.7	0.2	11 103.6	0.8	nr	⋯
$\Lambda_b B^*$	11 122.2	0.2	11 102.4	0.3	11 150.0	1.8
Γ_{total}		0.4		1.1		1.8

V. Summary

- For $J^P = 1/2^-$, it is possible to form bound states: Nηc and there exists some resonance states: ΣcD, ΣcD*, Σc*D*.
- For $J^P = 3/2^-$, there exists quasi-bound states: NJ/ψ; and some resonance states: Σc*D, ΣcD*, Σc*D.
- For $J^P = 5/2^-$, there exists quasi-bound states: Σc*D*.
- Pc(4380): Σc*D, $J^P = 3/2^-$

  Pc(4312): ΣcD, $J^P = 1/2^-$

  Pc(4440): ΣcD*, $J^P = 1/2^- or\ 3/2^-$

  Pc(4457): ΣcD*, $J^P = 1/2^- or\ 3/2^-$
- For the hidden-bottom system, the results are similar. Both the resonance states with $IJ^P = 1/2 \quad 1/2^-$ and $IJ^P = 1/2 \quad 3/2^-$ are found from corresponding scattering process. The masses of these states are all above 11 GeV while their widths are only a few MeV.

Thank you!