南京师范大学

Hidden Charm and Hidden Bottom Pentaquark Molecular States

Jun-Tao Zhu
Nanjing Normal University

Collaborators : Jun He, Shu-Yi Kong, Lin-Qing Song and Yi Liu

Outline

- Review of relative experiments and theoretical works
- Theoretical frame
- Results and discussions
  1. P_c
  2. P_{cs}
  3. P_b
- Summary

Review of relative experiments

Phys. Rev. Lett. 115 072001 (2015)

Before 2015

Prediction before LHCb measurements

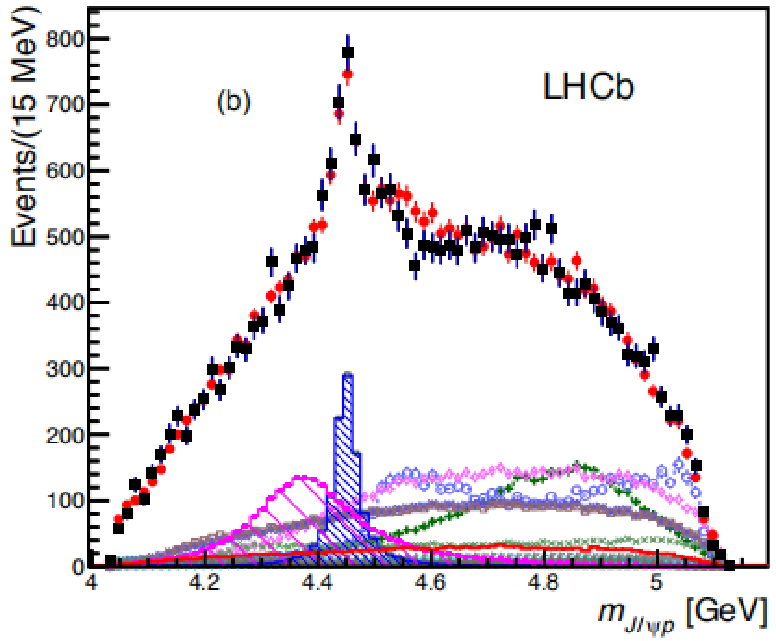
J.J.Wu, R.Molina, E.Oset and B.S.Zhou, Phys.Rev.Lett.105,232001;
J.J.Wu, T.-S.H. Lee, and B.S.Zou, Phys.Rev.C85,044002
Z.C.Yang, Z.F.Sun, J.He, X.Loiu and S.L.Zhu, Chin.Phys.C36,6
W.L.Wang, F.Huang, Z.Y.Zhang and B.S.Zou, Phys.Rev.D84,015203

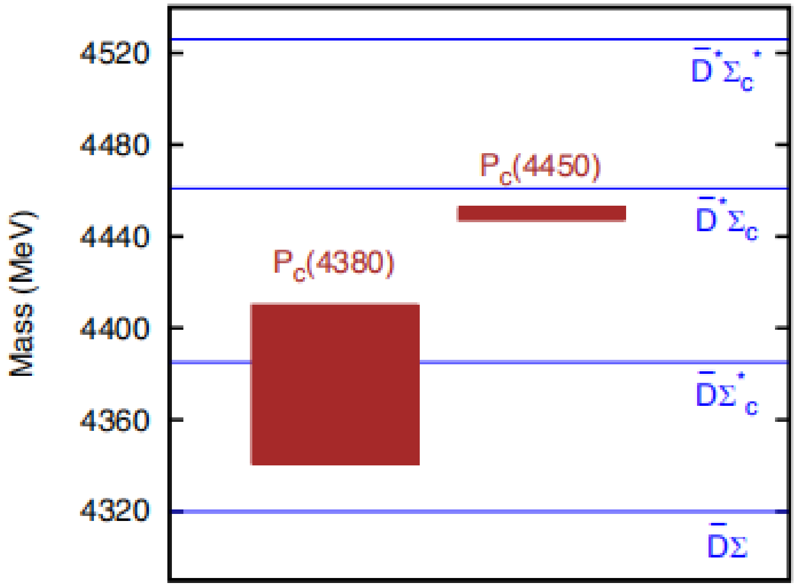
2015

$qqqc\bar{c}$

Resonance	Mass (MeV)	Width (MeV)
$P_c(4380)^+$	$4380 \pm 8 \pm 29$	$205 \pm 18 \pm 86$
$P_c(4450)^+$	$4449.8 \pm 1.7 \pm 2.5$	$39 \pm 5 \pm 19$

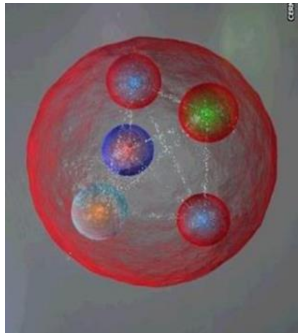
- $P_c(4450)$&$P_c(4380)$ are reported by LHCb.
- First discovery of hidden charm pentaquark.





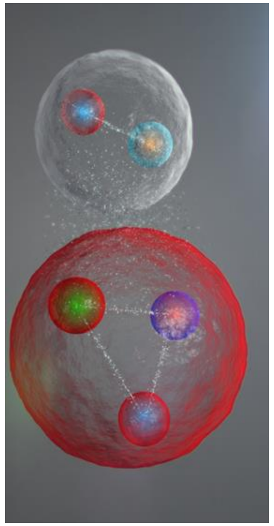
Review of theoretical works

Hidden charm pentaquarks(2015~2019)



Compact pentaquark

- R. F. Lebed, Phys. Lett. B 749 , 454-457 (2015)
- L. Maiani, A. D. Polosa and V. Riquer, Phys. Lett. B 749, 289-291 (2015)
- ……



Molecular states

- R. Chen, X. Liu, X. Q. Li and S. L. Zhu, Phys. Rev. Lett. 115, no. 13, 132002 (2015)
- H. X. Chen, W. Chen, X. Liu, T. G. Steele and S. L. Zhu, Phys. Rev. Lett. 115, no. 17, 172001 (2015)
- M. Karliner and J. L. Rosner, Phys. Rev. Lett. 115 no.12, 122001 (2015)
- L. Roca, J. Nieves and E. Oset, Phys. Rev. D 92, no. 9, 094003 (2015)
- T. J. Burns, Eur. Phys. J. A 51 no.11, 152(2015)
- J. He, Phys. Lett. B 753, 547 (2016)
- H. Huang and J. Ping, Phys. Rev. D 99, no.1, 014010 (2019)
- …………..

Anomalous triangle singularity

- X. H. Liu, Q. Wang and Q. Zhao, Phys. Lett. B 757, 231-236 (2016)

Review of relative experiments

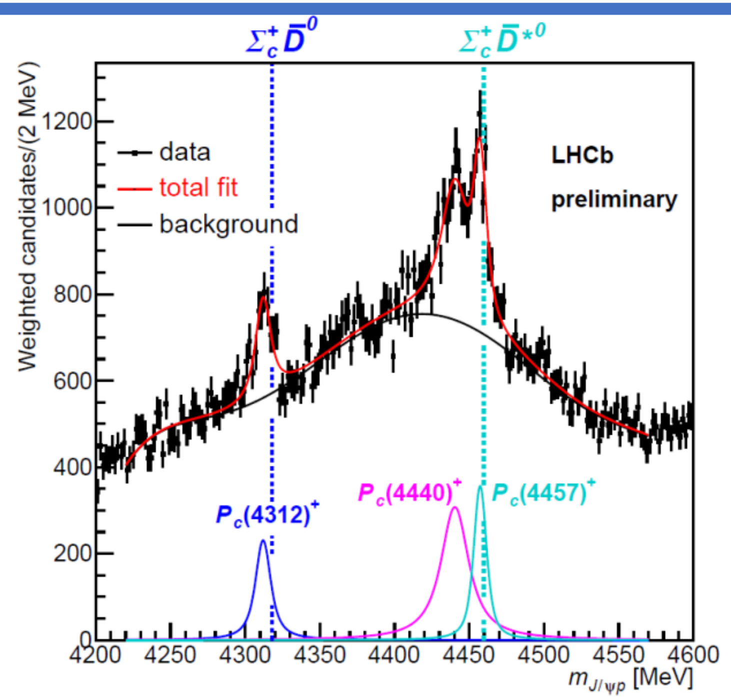
Phys. Rev. Lett. 122 no.22, 222001 (2019)

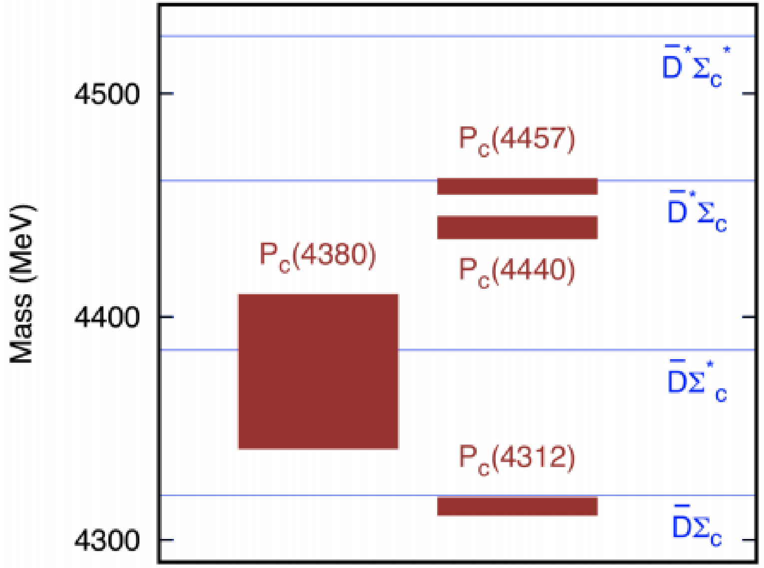
2019

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)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

- ➢ $P_c(4450) \longrightarrow P_c(4457) \& P_c(4440)$.
- ➢ New state $P_c(4312)$ is reported.

- ➢ The results favor molecular state interpretation.





Review of theoretical works

Hidden charm and bottom pentaquarks

QCD sum rule

- H. X. Chen, W. Chen and S. L. Zhu, Phys. Rev. D 100, no.5, 051501 (2019)

…….

Quark model

- H. Huang, J. He and J. Ping, [arXiv:1904.00221 [hep-ph]].

…….

Effective lagrangain approach

- C. J. Xiao, Y. Huang, Y. B. Dong, L. S. Geng and D. Y. Chen, Phys. Rev. D 100 no.1, 014022 (2019)
- Q. Wu and D. Y. Chen, Phys. Rev. D 100, no.11, 114002 (2019)

…….

Heavy-Quark Spin Symmetry

- M. Z. Liu, Y. W. Pan, F. Z. Peng, M. S´anchez S´anchez, L. S. Geng, A. Hosaka and M. Pavon Valderrama, Phys. Rev. Lett. 122, no.24, 242001 (2019)

…….

One boson exchange Model

- J. He Eur. Phys. J.C 79, no.5, 393 (2019)
- J. He and D. Y. Chen, Eur. Phys. J. C 79 no.11, 887 (2019)

……..

Hidden bottom

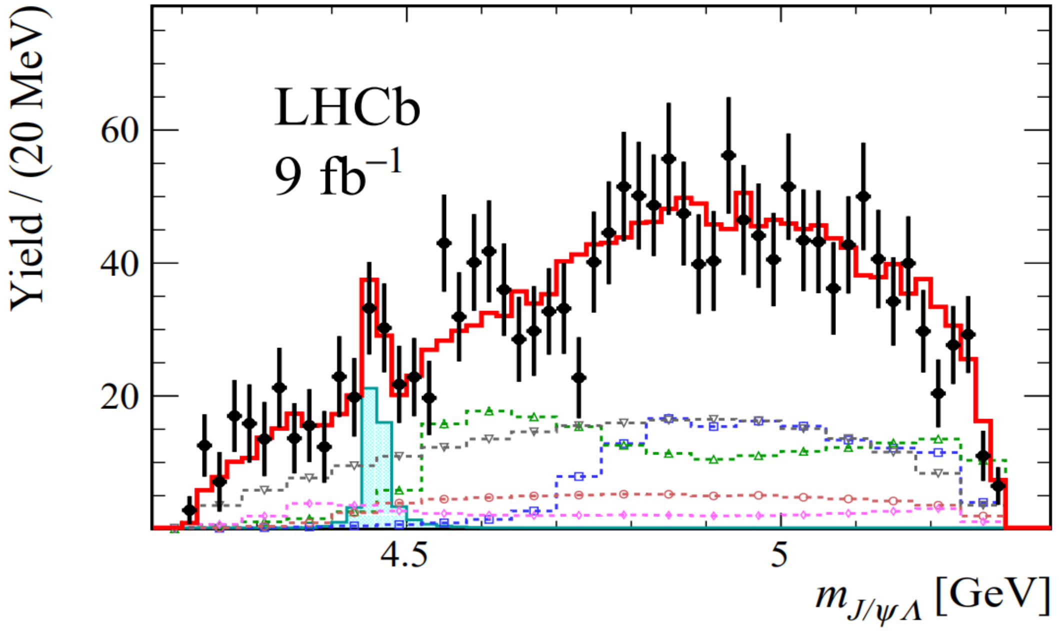
- J. Wu, Y. R. Liu, K. Chen, X. Liu and S. L. Zhu, Phys. Rev. D 95, no.3, 034002 (2017)
- Y. H. Lin, C. W. Shen and B. S. Zou, Nucl.Phys. A 980, 21-31 (2018)
- X. Y. Wang, J. He and X. Chen, Phys. Rev. D 101, no.3, 034032 (2020)
- H. Huang and J. Ping, Phys. Rev. D 99, no.1, 014010 (2019)
- G. Yang, J. Ping and J. Segovia, Phys. Rev. D 99, no.1, 014035 (2019)
- B. Wang, L. Meng and S. L. Zhu, JHEP 11, 108 (2019)
- J. T. Zhu, S. Y. Kong, Y. Liu and J. He, Eur. Phys.J. C 80, no.11, 1016 (2020)

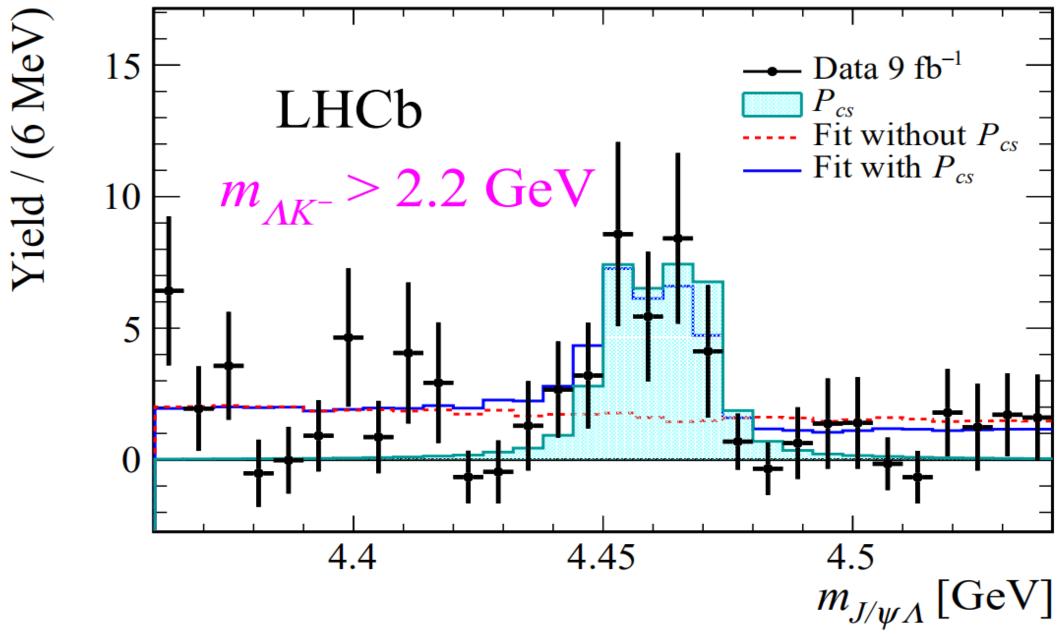
$P_{cs}(4459)$ $qqsc\bar{c}$

$\Xi_b^- \to J/\psi K^- \Lambda$

Implications workshop 2020 10.29

LHCb: arXiv:2101.12441v1 [hep-ph] 29 Jan 2021





2020

- Mass: $4458.8 \pm 2.9^{+4.7}_{-1.1}$ MeV , Width: $17.3 \pm 6.5^{+8.0}_{-5.7}$ MeV

$\mathbf{3.1\sigma - 4.1\sigma}$

- About 19MeV under the $\Xi_c \bar{D}^*$ threshold

Review of theoretical works

Strange hidden charm pentaquarks

- **Before 2015 :**
  - J. J. Wu, R. Molina, E. Oset and B. S. Zou, Phys. Rev. Lett. 105, 232001 (2010)

- **After 2015 :**
  - V. V. Anisovich, M. A. Matveev, J. Nyiri, A. V. Sarantsev and A. N. Semenova, Int. J. Mod. Phys. A 30, no.32, 1550190 (2015)
  - Z. G. Wang, Eur. Phys. J. C 76, no.3, 142 (2016)
  - A. Feijoo, V. K. Magas, Eur. Phys. J. C 76, no.8, 446 (2016)
  - J. X. Lu, E. Wang, J. J. Xie Phys. Rev. D 93, 094009 (2016)
  - H. X. Chen, L. S. Geng, W. H. Liang, E. Oset, E. Wang and J. J. Xie, Phys. Rev. C 93, no.6, 065203 (2016)
  - R. Chen, J. He and X. Liu, Chin. Phys. C 41, no.10, 103105 (2017) ……..

- **2019-2020 :**
  - C. W. Xiao, J. Nieves and E. Oset, Phys. Lett. B 799, 135051 (2019)
  - Q. Zhang, B. R. He and J. L. Ping, [arXiv:2006.01042 [hep-ph]].
  - B. Wang, L. Meng and S. L. Zhu, Phys. Rev. D 101, no.3, 034018 (2020) ……..

- **After 2020.10 :**
  - H. X. Chen, W. Chen, X. Liu and X. H. Liu, [arXiv:2011.01079 [hep-ph]].
  - F. Z. Peng, M. J. Yan, M. S´anchez and M. P. Valderrama, [arXiv:2011.01915 [hep-ph]].
  - Z. G. Wang, [arXiv:2011.05102 [hep-ph]].
  - R. Chen, [arXiv:2011.07214 [hep-ph]].

Relative research of our group

P_c

1. J. He, " **$\bar{D}\Sigma_c^*$ and $\bar{D}^*\Sigma_c$interactions and the LHCb hidden-charmed pentaquarks,"** Phys. Lett. B 753, 547 (2016)
2. J. He "**Study of Pc(4457), Pc(4440), and Pc(4312) in a quasipotential Bethe-Salpeter equation approach,**" Eur. Phys. J.C 79, no.5, 393 (2019)
3. J. He and D. Y. Chen, "**Molecular states from $\Sigma_c^{(*)}\bar{D}^{(*)}-\Lambda_c\bar{D}^{(*)}$interaction,**" Eur. Phys. J. C 79 no.11, 887 (2019)

P_{cs}

1. R. Chen, J. He and X. Liu, **Possible strange hidden-charm pentaquarks from $\Sigma_c^{(*)}\bar{D}_s^{(*)}$ *and* $\Xi_c^{(\prime,*)}\bar{D}^{(*)}$ interactions**, Chin. Phys. C 41, no.10, 103105 (2017)
2. Jun-Tao Zhu, Lin-Qing Song, Jun He, **Pcs(4459) and other possible molecular states from $\Xi_c^{(*)}\bar{D}^{(*)}$ and $\Xi_c'\bar{D}^{(*)}$ interactions.** Phys. Rev. D 103 (2021) 7, 074007

P_b

1. J. T. Zhu, S. Y. Kong, Y. Liu and J. He, "**Hidden-bottom molecular states from $\Sigma_b^{(*)}B^{(*)}-\Lambda_b B^{(*)}$ interaction,**" Eur. Phys. J. C 80, no.11, 1016 (2020)
2. X.Y. Wang, J. He, X. Chen, **Systematic study of the production of hidden-bottom pentaquarks via γp and $\pi^- p$ scatterings**. Phys. Rev. D 101(3), 034032 (2020).

Theoretical frame

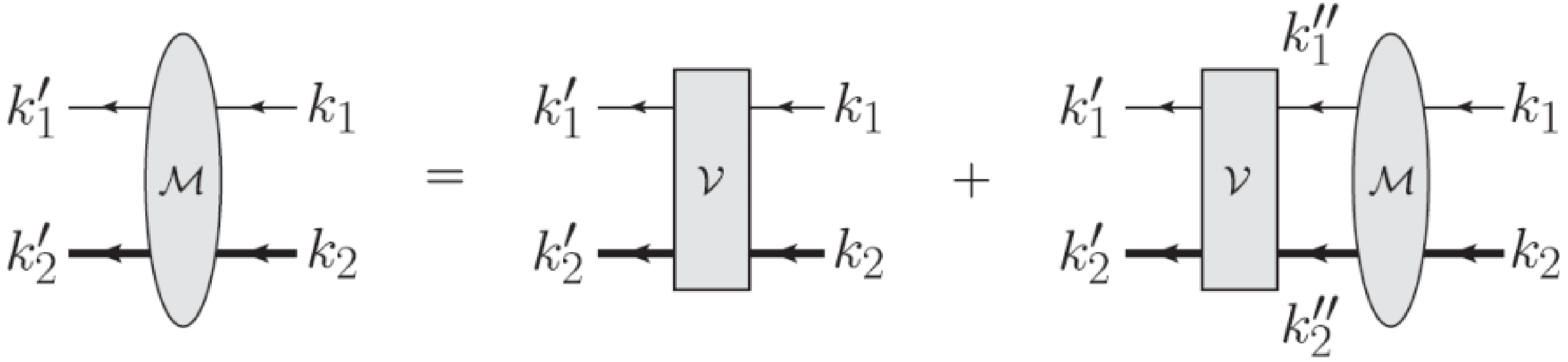
Theoretical frame

Method — **Quasipotential Bethe-Salpeter Equation**

Model — **One boson exchange model(OBE)**

Theoretical frame

Quasipotential approximation



$$\mathcal{M}(k_1'k_2',k_1k_2;P) = \mathcal{V}(k_1'k_2',k_1k_2;P) + \int \frac{d^4k_2''}{(2\pi)^4}\mathcal{V}(k_1'k_2',k_1''k_2'';P)G(k_1''k_2'';P)\mathcal{M}(k_1''k_2'',k_1k_2;P),$$

$$G_0(k'') = \frac{\delta^+(k_h''^2-m_h^2)}{k''^2_l-m_l^2}\ ,\ E_h = \sqrt{m^2+\vec{k}_h''^2}$$

The 4-dimensional BSE → **Quasipotential approximation** → **The 3-dimensional equation**

$$i\mathcal{M}(k',k) = i\mathcal{V}(k',k) + \int \frac{dk''}{(2\pi)^3} i\mathcal{V}(k',k'')G_0(k'')i\mathcal{M}(k'',k),$$

Theoretical frame

Partial wave decomposition

$$iM(k',k) = iV(k',k) + \int \frac{dk''}{(2\pi)^3} iV(k',k'')G_0(k'')iM(k'',k),$$

The 3-dimensional equation → **Partial wave decomposition** → **The 1-dimensional equation**

$$\mathcal{V}_{\lambda'\lambda}(\boldsymbol{k}',\boldsymbol{k}) = \sum_{J\lambda_R} \frac{2J+1}{4\pi} D^{J*}_{\lambda_R,\lambda'}(\phi',\theta',-\phi')\mathcal{V}^J_{\lambda'\lambda,\lambda_R}(\mathrm{k}',\mathrm{k})D^J_{\lambda_R,\lambda}(\phi,\theta,-\phi)$$

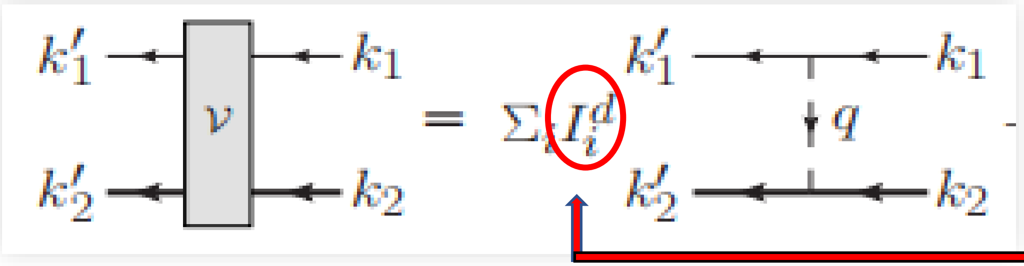
$$\rightarrow \quad \mathcal{V}^J_{\lambda'\lambda,\lambda_R}(\mathrm{k}',\mathrm{k}) = \frac{2J+1}{4\pi}\int d\Omega' d\Omega D^{J*}_{\lambda_R,\lambda'}(\phi',\theta',-\phi')\mathcal{V}_{\lambda'\lambda}(\boldsymbol{k}',\boldsymbol{k})D^J_{\lambda_R,\lambda}(\phi,\theta,-\phi)$$

$$\rightarrow \quad \mathcal{V}^J_{\lambda'\lambda}(\mathrm{k}',\mathrm{k}) = 2\pi\int d\cos\theta_{k,k'} d^J_{\lambda,\lambda'}(\theta_{k',k})\mathcal{V}_{\lambda'\lambda}(\boldsymbol{k}',\boldsymbol{k})$$

$$i\mathcal{M}_{\lambda',\lambda}(\mathrm{k}',\mathrm{k}) = i\mathcal{V}_{\lambda'\lambda}(\mathrm{k}',\mathrm{k}) + \int \frac{\mathrm{k}''^2 d\mathrm{k}''}{(2\pi)^3} i\mathcal{V}_{\lambda'\lambda''}(\mathrm{k}',\mathrm{k}'')G_0(\boldsymbol{k}'')i\mathcal{M}_{\lambda''\lambda}(\mathrm{k}'',\mathrm{k})$$

Theoretical frame

One boson exchange model(OBE)



Isospin factor

For example

	π	η	ρ	ω	σ
$\bar{D}^{(*)}\Sigma_c^{(*)} \to \bar{D}^{(*)}\Sigma_c^{(*)}$	$-1[\frac{1}{2}]$	$\frac{1}{6}[\frac{1}{6}]$	$-1[\frac{1}{2}]$	$\frac{1}{2}[\frac{1}{2}]$	1
$\bar{D}^{(*)}\Lambda_c \to \bar{D}^{(*)}\Lambda_c$	0	0	0	1	2
$\bar{D}^{(*)}\Lambda_c \to \bar{D}^{(*)}\Sigma_c^{(*)}$	$\frac{\sqrt{6}}{2}$	0	$\frac{\sqrt{6}}{2}$	0	0

Heavy quark limit and chiral symmetry

Chen et al. PRD47(1993)1030; Yan et al.PRD46(1992)1148;
Wise, PRD45(1992)2188; Casalbuoni et al. Phys. Rept. 281(1997)145

Lagarangains

Meson

$$\mathcal{L}_{HH\mathbb{P}} = ig_1\langle \bar{H}_a^{\bar{Q}}\gamma_\mu \mathcal{A}_{ba}^\mu \gamma_5 H_b^{\bar{Q}}\rangle,$$

$$\mathcal{L}_{HH\mathbb{V}} = -i\beta\langle \bar{H}_a^{\bar{Q}} v_\mu (\mathcal{V}_{ab}^\mu - \rho_{ab}^\mu) H_b^{\bar{Q}}\rangle + i\lambda\langle \bar{H}_b^{\bar{Q}}\sigma_{\mu\nu}F^{\mu\nu}(\rho)\bar{H}_a^{\bar{Q}}\rangle,$$

$$\mathcal{L}_{HH\sigma} = g_s\langle \bar{H}_a^{\bar{Q}}\sigma \bar{H}_a^{\bar{Q}}\rangle,$$

Baryon

$$\mathcal{L}_S = -\frac{3}{2}g_1(v_\kappa)\epsilon^{\mu\nu\lambda\kappa}\mathrm{tr}[\bar{S}_\mu \mathcal{A}_\nu S_\lambda] + i\beta_S\,\mathrm{tr}[\bar{S}_\mu v_\alpha(\mathcal{V}^\alpha - \rho^\alpha)S^\mu] + \lambda_S\,\mathrm{tr}[\bar{S}_\mu F^{\mu\nu}S_\nu] + \ell_S\,\mathrm{tr}[\bar{S}_\mu \sigma S^\mu],$$

$$\mathcal{L}_{B_{\bar{3}}} = i\beta_B\mathrm{tr}[\bar{B}_{\bar{3}}v_\mu(\mathcal{V}^\mu - \rho^\mu)B_{\bar{3}}] + \ell_B\mathrm{tr}[\bar{B}_{\bar{3}}\sigma B_{\bar{3}}],$$

$$\mathcal{L}_{int} = ig_4\mathrm{tr}[\bar{S}^\mu \mathcal{A}_\mu B_{\bar{3}}] + i\lambda_I\epsilon^{\mu\nu\lambda\kappa}v_\mu\mathrm{tr}[\bar{S}_\nu F_{\lambda\kappa}B_{\bar{3}}] + h.c.,$$

Parameters

TABLE I: The coupling constants adopted in the calculation, which are cited from the literature [18, 57–59]. The λ and $\lambda_{S,I}$ are in the units of GeV^{-1}. Others are in the units of 1.

β	g	g_V	λ	g_s			
0.9	0.59	5.9	0.56	0.76			
β_S	ℓ_S	g_1	λ_S	β_B	ℓ_B	g_4	λ_I
-1.74	6.2	-0.94	-3.31	$-\beta_S/2$	$-\ell_S/2$	$3g_1/(2\sqrt{2})$	$-\lambda_S/\sqrt{8}$

Theoretical frame

One-boson-exchange model (OBE)

Potential

$$\mathcal{V}_{\mathbb{P},\sigma} = f_I \Gamma_1 \Gamma_2 P_{\mathbb{P},\sigma} f(q^2), \qquad \mathcal{V}_{\mathbb{V}} = f_I \Gamma_{1\mu} \Gamma_{2\nu} P_{\mathbb{V}}^{\mu\nu} f(q^2),$$

Propagators

$$P_{\mathbb{P},\sigma} = \frac{i}{q^2 - m_{\mathbb{P},\sigma}^2}, \qquad P_{\mathbb{V}}^{\mu\nu} = i\frac{-g^{\mu\nu} + q^\mu q^\nu / m_{\mathbb{V}}^2}{q^2 - m_{\mathbb{V}}^2},$$

Form factors

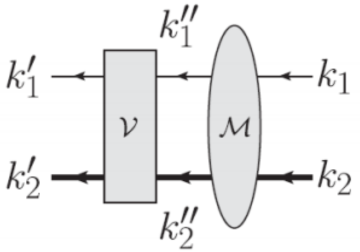
$$f_0(q^2) = 1.$$

$$f_1(q^2) = \frac{\Lambda_e^2 - m_e^2}{\Lambda_e^2 - q^2},$$

$$f_2(q^2) = \frac{\Lambda_e^4}{(m_e^2 - q^2)^2 + \Lambda^4},$$

$$f_3(q^2) = e^{-(m_e^2 - q^2)^2/\Lambda_e^2},$$

$$f_4(q^2) = \frac{\Lambda_e^4 + (q_t^2 - m_e^2)^2/4}{[q^2 - (q_t^2 + m_e^2)/2]^2 + \Lambda_e^4},$$



$$G_0(\mathrm{p}'') \to G_0(\mathrm{p}'') \left[e^{-(p_l''^2 - m_l^2)^2/\Lambda_r^4} \right]^2$$

$$\Lambda_e = \Lambda_r = m_e + \alpha\, 0.22\ GeV$$

Theoretical frame

Transformation to matrix euqation

Transformed as a matrix equation by Gauss discretization

$$iM_{ik} = iV_{ik} + \sum_{j=0}^{N} iV_{ij} G_j iM_{jk} \Rightarrow M = V + VGM$$

$$G_j = \begin{cases} -\frac{i\bar{q}}{32\pi^2 W} + \sum_j \left[\frac{w(q_j)}{(2\pi)^3} \frac{\bar{q}^2}{2W(q_j^2 - \bar{q}^2)}\right] & \text{for } j = 0, \text{ if } Re(W) > m_1 + m_2, \\ \frac{w(q_j)}{(2\pi)^3} \frac{q_j^2}{2E(q_j)[(W - E(q_j))^2 - \omega^2(q_j)]} & \text{for } j \neq 0 \end{cases}$$

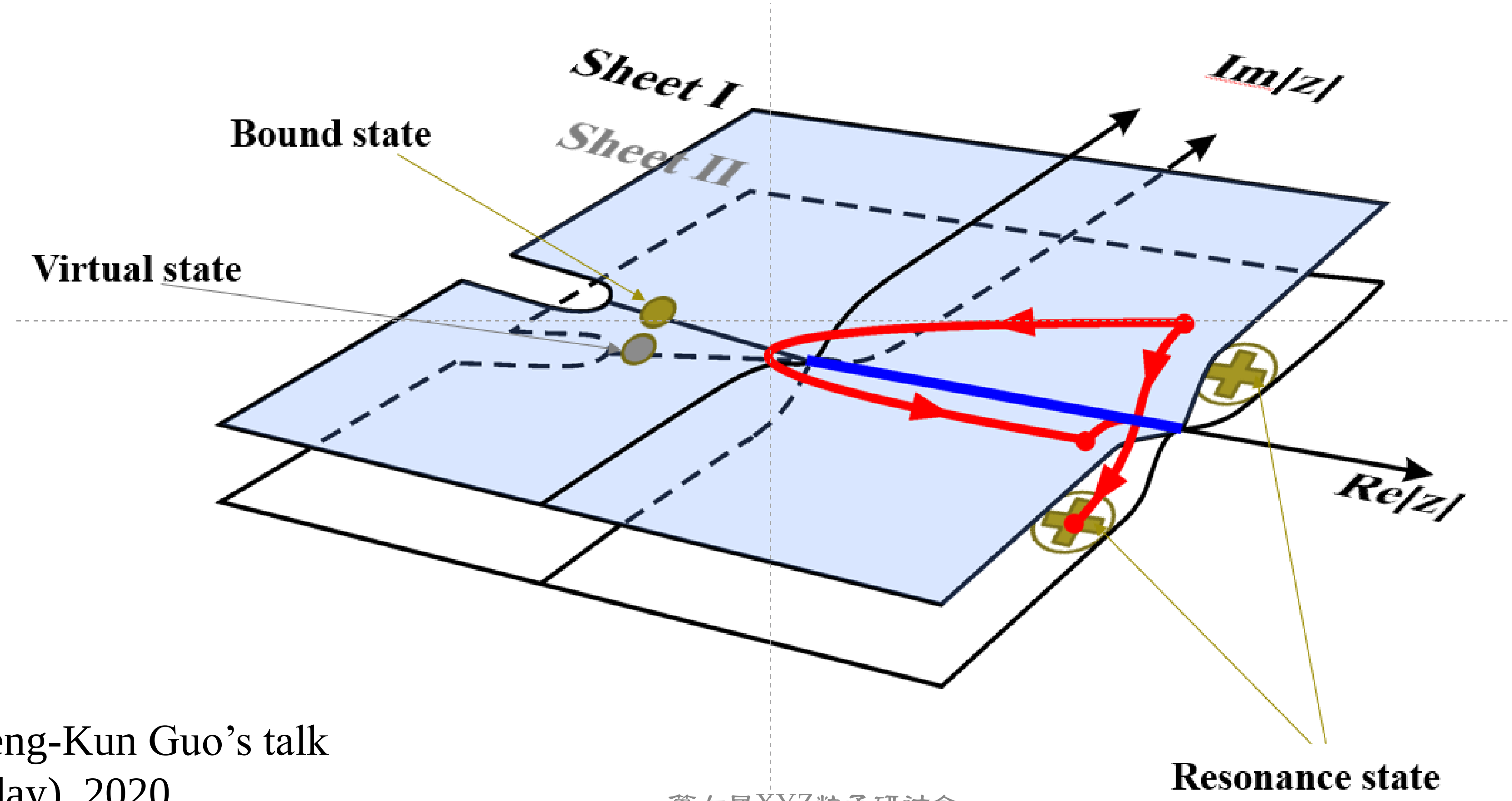
with $\bar{q} = \frac{1}{2W}\sqrt{[W^2 - (m_1 + m_2)^2][W^2 - (m_1 - m_2)^2]}$.

Search for the pole

$$M = (1 - VG)^{-1} V \quad \Rightarrow \quad |1 - VG| = 0$$

Theoretical frame

$$z = \mathrm{Re}z + i\mathrm{Im}z \quad \begin{cases} Re(Z) = \text{mass} \\ 2\ Im(Z) = \text{width} \end{cases}$$



Borrowed form Feng-Kun Guo’s talk
in Oct. 13th (Tuesday), 2020

Results and discussions

$$P_c$$

Eur. Phys. J. C 79 no.11, 887 (2019)

Threshold & Quantum Number

$$\Sigma_c^{(*)}\bar{D}^{(*)} - \Lambda_c\bar{D}^{(*)}$$

1. $\Sigma_c^*\bar{D}^*(4526.7)$ $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-\right) \quad \frac{3}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-\right)$
2. $\Sigma_c\bar{D}^*(4462.2)$ $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-\right) \quad \frac{3}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-\right)$
3. $\Sigma_c^*\bar{D}\,(4385.3)$ $\quad I(J^P) = \frac{1}{2}\left(\frac{3}{2}^-\right) \quad \frac{3}{2}\left(\frac{3}{2}^-\right)$
4. $\Sigma_c\bar{D}\,(4320.8)$ $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-\right) \quad \frac{3}{2}\left(\frac{1}{2}^-\right)$
5. $\Lambda_c\bar{D}^*\,(4295.1)$ $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-\right)$
6. $\Lambda_c\bar{D}\,(4153.7)$ $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-\right)$

Exchanged meson

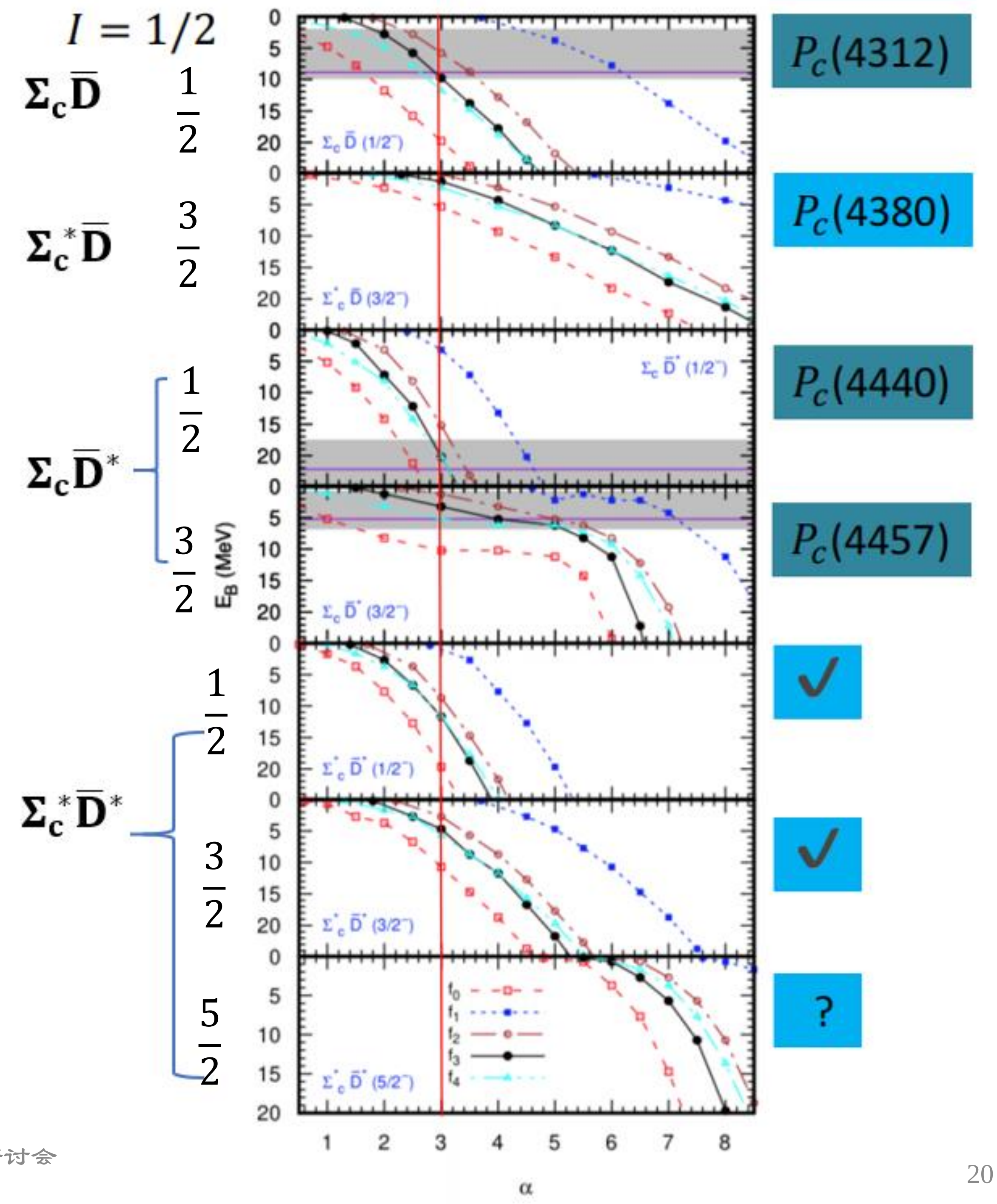
Table 2 The flavor factors for certain meson exchanges of certain interaction. The values in bracket are for the case of $I = 3/2$ if the values are different from these of $I = 1/2$.

	π	η	ρ	ω	σ
$\bar{D}^{(*)}\Sigma_c^{(*)} \to \bar{D}^{(*)}\Sigma_c^{(*)}$	$-1[\frac{1}{2}]$	$\frac{1}{6}[\frac{1}{6}]$	$-1[\frac{1}{2}]$	$\frac{1}{2}[\frac{1}{2}]$	1
$\bar{D}^{(*)}\Lambda_c \to \bar{D}^{(*)}\Lambda_c$	0	0	0	1	2
$\bar{D}^{(*)}\Lambda_c \to \bar{D}^{(*)}\Sigma_c^{(*)}$	$\frac{\sqrt{6}}{2}$	0	$\frac{\sqrt{6}}{2}$	0	0

Pc Single-channel calculation

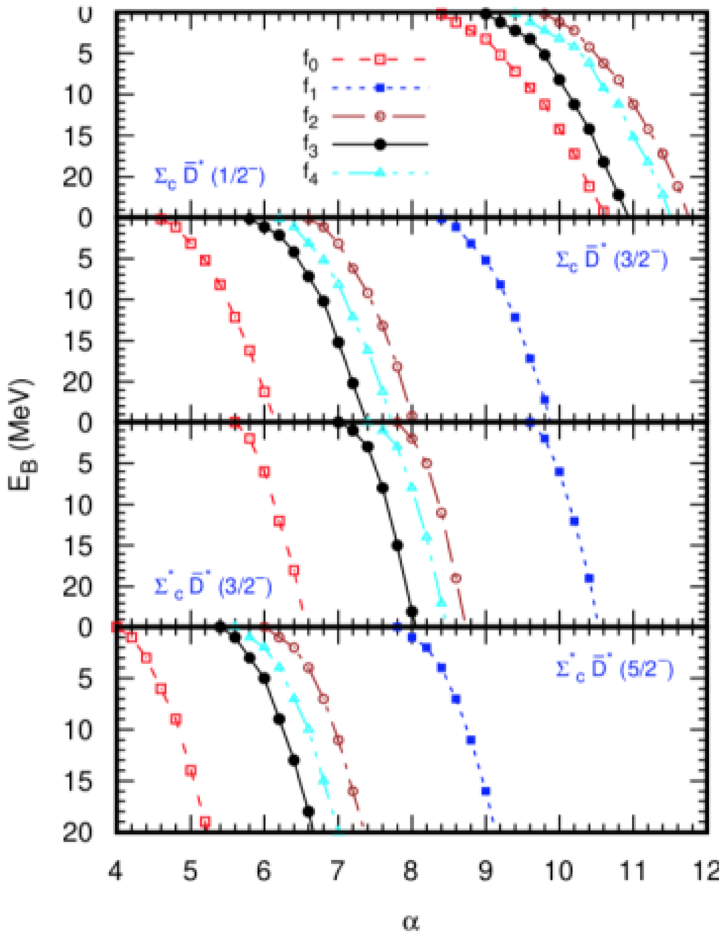
Discussion

- The curves reflect the binding energy with variation of parameter α .
- Five different curves correspond to five different form factors.
- We choose the $f_3(q^2) = e^{-(m_e^2-q^2)^2/\Lambda_e^2}$ **(black curve)**.
- The $\mathbf{\Sigma_c^{(*)}\bar{D}^{(*)}}$ system with **I=1/2** produce six molecular states in single-channel calculation.
- $\mathbf{\Sigma_c^*\bar{D}^*\,\frac{1}{2}(\frac{5}{2}^-)}$ and **four interactions with $I=\frac{3}{2}$** are attractive while too large α is required.
- $\mathbf{\Lambda_c\bar{D}^*}$and $\mathbf{\Lambda_c\bar{D}}$ can not be bound.



Pc Single-channel calculation

$I = 3/2$



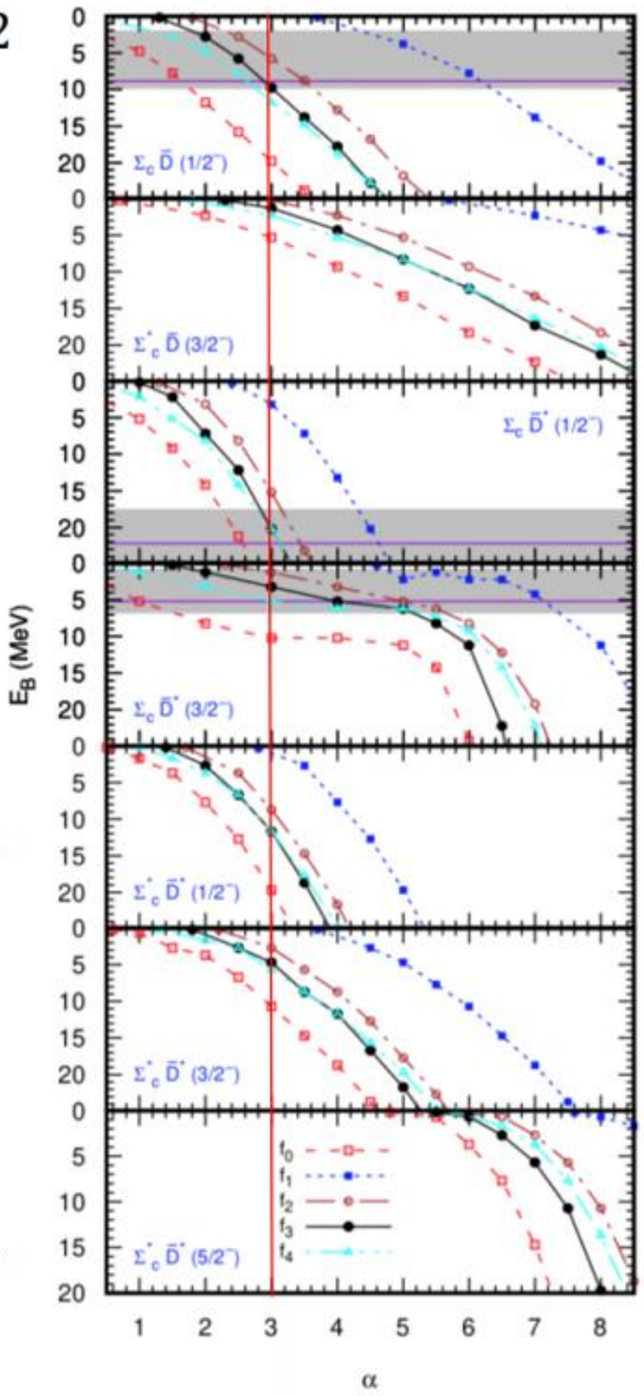
$I = 1/2$

$\Sigma_c \bar{D}$ — $P_c(4312)$

$\Sigma_c^* \bar{D}$ — $P_c(4380)$

$\Sigma_c \bar{D}^*$ — $P_c(4440)$, $P_c(4457)$

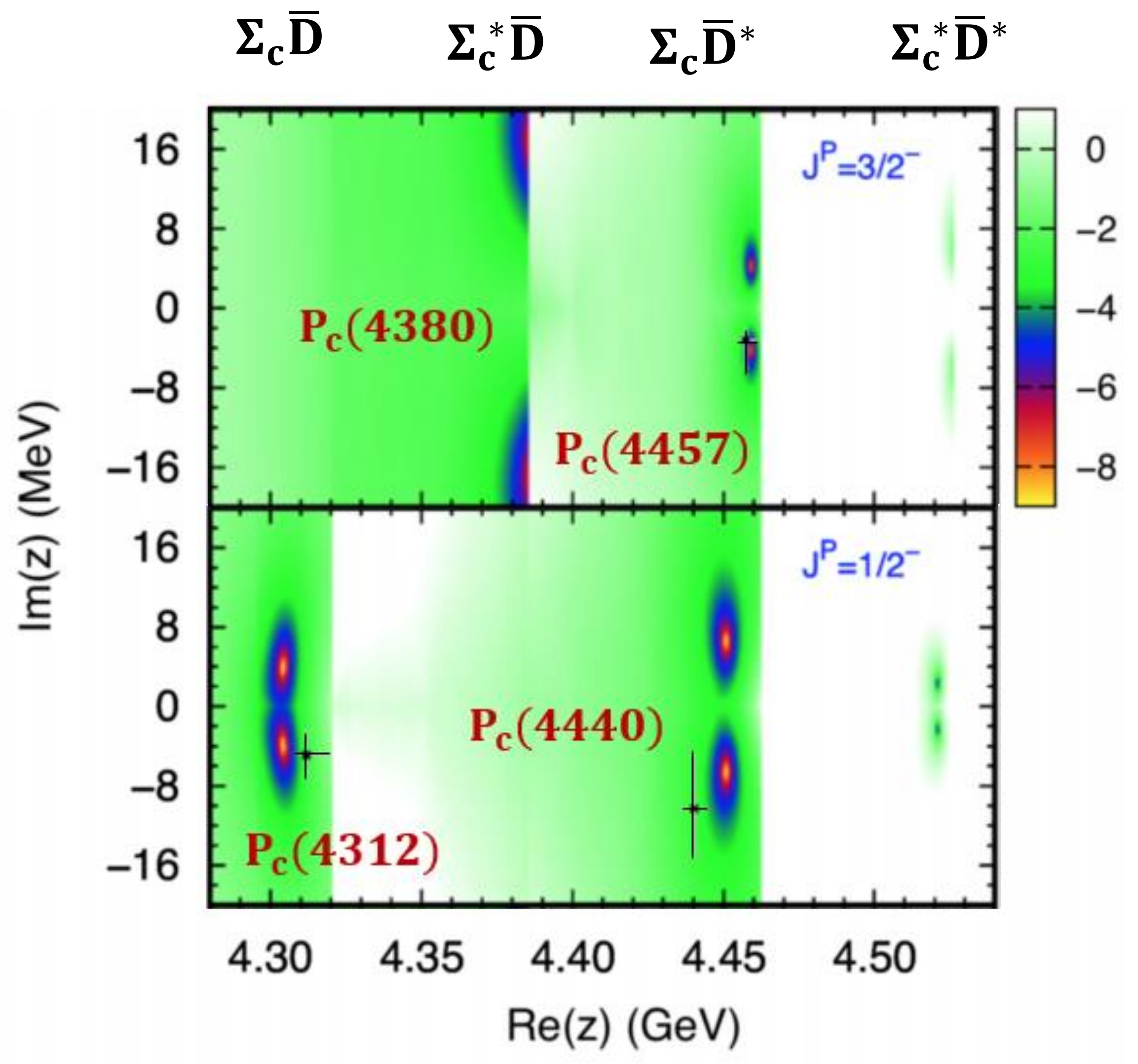
$\Sigma_c^* \bar{D}^*$ — ✓, ✓, ?



P_c Coupled-channel calculation

Discussion

- The color box reflect the value of $lg(|1 - VG|)$.
- The **black point** represent to the experimental values of Pc states .
- At $\alpha = 2.5$, six molecular states can be produced from $\Sigma_c^{(*)}\bar{D}^{(*)} - \Lambda_c\bar{D}^*$ interaction.
- The $\Sigma_c\bar{D}\left(\frac{1}{2}\right)$, $\Sigma_c\bar{D}^*(\frac{1}{2},\frac{3}{2})$ correspond to three narrow Pc states observed at LHCb.



Pc

Discussion

- $\Lambda_c\bar{D}^*$ is the main decay channel of the lower five states.
- $\Sigma_c\bar{D}^*, \Sigma_c^*\bar{D}$, *and* $\Lambda_c\bar{D}$ have considerable contributions to the $\Sigma_c^*\bar{D}^*$ $\frac{3}{2}^-$ state.
- The $\Sigma_c\bar{D}$ channel is found important to $\Sigma_c^*\bar{D}^*$ $\frac{1}{2}^-$ state.

α_r	CC	$\Sigma_c\bar{D}^*$		$\Sigma_c^*\bar{D}$		$\Sigma_c\bar{D}$		$\Lambda_c\bar{D}^*$		$\Lambda_c\bar{D}$		sum	
	pole	pole	Br	pole	Br	pole	Br	pole	Br	pole	Br	$\sum \mathrm{Im}_i$	$\frac{\mathrm{Im}_{CC}}{\sum \mathrm{Im}_i}$
$\Sigma_c^*\bar{D}^*(1/2^-)$													
1.5	$1.2+1.0i$	$1.8+0.1i$	17	$2.1+0.1i$	17	$1.2+0.3i$	50	$1.7+0.1i$	17	$1.9+0.0i$	0	0.6	167
2.0	$3.0+1.6i$	$3.7+0.2i$	18	$3.9+0.2i$	18	$2.9+0.5i$	45	$4.6+0.2i$	18	$3.7+0.0i$	0	1.1	145
2.5	$5.5+2.3i$	$6.1+0.3i$	19	$6.6+0.3i$	19	$5.3+0.7i$	44	$6.4+0.3i$	19	$6.4+0.0i$	0	1.6	144
3.0	$7.4+3.1i$	$8.8+0.4i$	18	$9.0+0.4i$	18	$7.1+1.0i$	45	$8.4+0.4i$	10	$9.2+0.0i$	0	2.2	141
$\Sigma_c^*\bar{D}^*(3/2^-)$													
2.0	$0.0+4.2i$	$0.3+0.7i$	28	$0.5+0.7i$	28	$1.2+0.0i$	0	$0.0+0.9i$	36	$1.1+0.2i$	8	2.5	168
2.5	$0.0+5.8i$	$1.0+1.2i$	32	$1.1+0.8i$	22	$2.3+0.0i$	0	$0.0+1.5i$	41	$2.3+0.2i$	5	3.7	158
3.0	$0.0+6.8i$	$1.7+1.7i$	37	$1.6+1.0i$	22	$3.4+0.0i$	0	$0.0+1.7i$	37	$3.4+0.2i$	4	4.6	148
3.5	$0.0+7.5i$	$2.2+2.1i$	41	$2.0+1.1i$	22	$4.2+0.1i$	2	$0.0+1.5i$	29	$4.4+0.3i$	6	5.1	147
$\Sigma_c\bar{D}^*(1/2^-)$													
1.0	$3.5+1.9i$	--	--	$3.0+0.0i$	0	$2.9+0.3i$	20	$3.3+1.2i$	80	$3.0+0.0i$	0	1.5	127
2.0	$8.2+4.8i$	--	--	$8.7+0.2i$	5	$8.0+0.5i$	12	$9.1+3.3i$	80	$8.7+0.1i$	2	4.1	117
3.0	$13.8+8.8i$	--	--	$15.2+0.9i$	11	$14.1+0.8i$	9	$15.5+6.3i$	74	$16.2+0.5i$	6	8.5	104
4.0	$17.7+14.7i$	--	--	$23.2+2.1i$	15	$19.0+1.5i$	11	$21.5+9.4i$	66	$22.1+1.2i$	9	14.2	104
$\Sigma_c\bar{D}^*(3/2^-)$													
1.0	$2.7+1.0i$	--	--	$1.8+0.3i$	19	$1.6+0.0i$	0	$1.4+1.0i$	63	$1.6+0.3i$	19	1.6	63
1.5	$3.5+2.3i$	--	--	$2.1+0.4i$	13	$2.0+0.0i$	0	$0.9+2.4i$	75	$1.7+0.4i$	13	3.2	72
2.0	$3.4+3.6i$	--	--	$2.1+0.4i$	9	$2.1+0.1i$	2	$0.0+3.5i$	78	$1.6+0.5i$	11	4.5	80
2.5	$2.8+4.2i$	--	--	$2.1+0.4i$	12	$2.0+0.1i$	3	$0.0+2.4i$	71	$1.4+0.5i$	15	3.4	81
3.0	$2.6+4.5i$	--	--	$2.0+0.4i$	13	$2.0+0.1i$	3	$0.0+2.0i$	65	$1.4+0.6i$	19	3.1	69
$\Sigma_c^*\bar{D}(3/2^-)$													
2.5	$0.0+19i$	--	--	--	--	$0.4+0i$	0	$0.0+16i$	100	$0.4+0i$	0	16	119
3.0	$0.0+24i$	--	--	--	--	$0.6+0i$	0	$0.0+19i$	100	$0.6+0i$	0	19	126
3.5	$0.0+28i$	--	--	--	--	$0.9+0i$	0	$0.0+22i$	100	$0.9+0i$	0	22	127
4.0	$0.0+30i$	--	--	--	--	$1.0+0i$	0	$0.0+25i$	100	$1.0+0i$	0	25	120
$\Sigma_c\bar{D}(1/2^-)$													
1.0	$3.7+2.0i$	--	--	--	--	--	--	$3.4+2.1i$	88	$2.1+0.3i$	13	2.4	83
1.5	$8.1+2.9i$	--	--	--	--	--	--	$6.1+3.0i$	88	$3.3+0.4i$	12	3.4	85
2.0	$11.4+4.0i$	--	--	--	--	--	--	$9.4+4.0i$	89	$4.6+0.5i$	11	4.5	89
2.5	$17.8+4.6i$	--	--	--	--	--	--	$13.6+4.9i$	87	$5.9+0.7i$	13	5.6	82
3.0	$23.6+4.8i$	--	--	--	--	--	--	$18.4+5.1i$	86	$7.1+0.8i$	14	5.9	81

Results and discussions

$$\boldsymbol{P_{cs}}$$

P_{cs}

Threshold & Quantum Number

$\Xi_c^{(\prime,*)}\bar{D}^{(*)} - \Xi_c \bar{D}^{(*)}$

1.	$\Xi_c^*\bar{D}^*(4654.6)$	$I(J^P) = 0\left(\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-\right)$	$1\left(\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-\right)$
2.	$\Xi_c'\bar{D}^*(4587.4)$	$I(J^P) = 0\left(\frac{1}{2}^-, \frac{3}{2}^-\right)$	$1\left(\frac{1}{2}^-, \frac{3}{2}^-\right)$
3.	$\Xi_c^*\bar{D}\ (4513.2)$	$I(J^P) = 0\left(\frac{3}{2}^-\right)$	$1\left(\frac{3}{2}^-\right)$
4.	$\Xi_c\bar{D}^*(4478.0)$	$I(J^P) = 0\left(\frac{1}{2}^-, \frac{3}{2}^-\right)$	$1\left(\frac{1}{2}^-, \frac{3}{2}^-\right)$
5.	$\Xi_c'\bar{D}\ (4446.0)$	$I(J^P) = 0\left(\frac{1}{2}^-\right)$	$1\left(\frac{1}{2}^-\right)$
6.	$\Xi_c\bar{D}\ (4336.6)$	$I(J^P) = 0\left(\frac{1}{2}^-\right)$	$1\left(\frac{1}{2}^-\right)$

Exchanged meson

TABLE II: The flavor factors f_I for certain meson exchanges of certain interaction. The values in bracket are for the case of $I = 1$ if the values are different from these of $I = 0$

	π	η	ρ	ω	σ
$\bar{D}^{(*)}\Xi_c^{(\prime,*)} \to \bar{D}^{(*)}\Xi_c^{(\prime,*)}$	$-\frac{3}{4}[\frac{1}{4}]$	$-\frac{1}{12}$	$-\frac{3}{4}[\frac{1}{4}]$	$\frac{1}{4}$	1
$\bar{D}^{(*)}\Xi_c \to \bar{D}^{(*)}\Xi_c$	0	0	$-\frac{3}{2}[\frac{1}{2}]$	$\frac{1}{2}$	2
$\bar{D}^{(*)}\Xi_c \to \bar{D}^{(*)}\Xi_c^{(\prime,*)}$	$-\frac{3}{2\sqrt{2}}[\frac{1}{2\sqrt{2}}]$	$\frac{-1}{2\sqrt{2}}$	$-\frac{3}{2\sqrt{2}}[\frac{1}{2\sqrt{2}}]$	$\frac{1}{2\sqrt{2}}$	0

Pcs Single-channel results

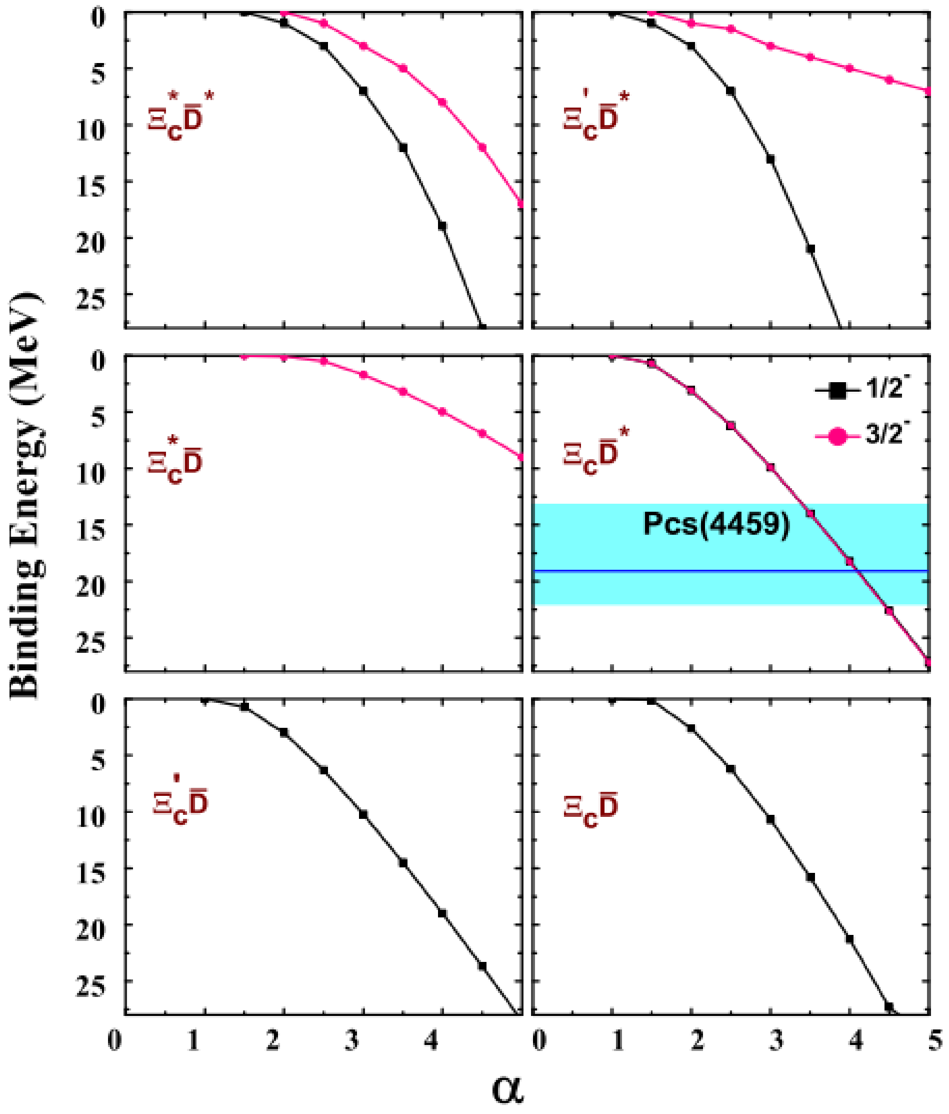
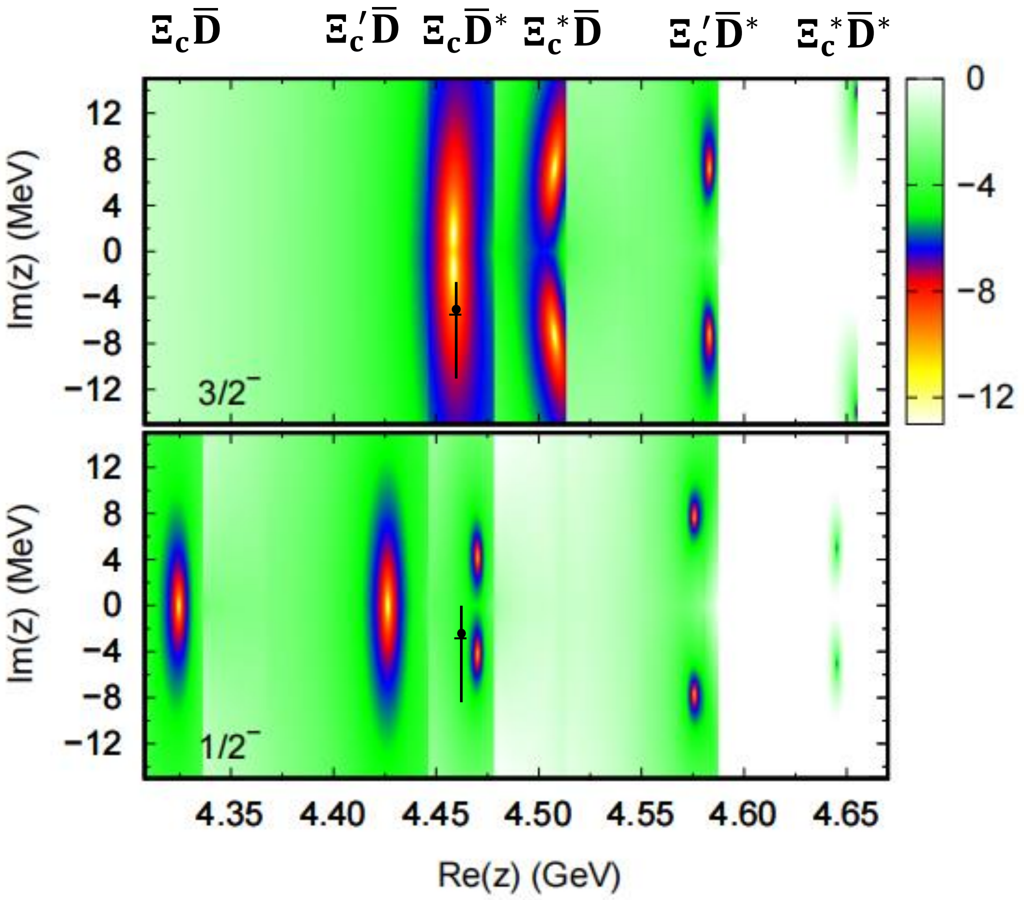


FIG. 1: The binding energies of the bound states from six single-channel interactions with the variation of parameter α. All states carry scalar isospin $I = 0$. The thresholds of the six channels are 4654.6, 4587.4, 4513.2, 4478.0, 4446.0, 4336.6 MeV for $\Xi_c^*\bar{D}^*$, $\Xi_c'\bar{D}^*$, $\Xi_c^*\bar{D}$, $\Xi_c\bar{D}^*$, $\Xi_c'\bar{D}$, and $\Xi_c\bar{D}$, respectively. The blue line and the band are the experimental mass and uncertainties of the $P_{cs}(4459)$.

- **$\Xi_c\bar{D}^*(\frac{1}{2}^-)$ and $\Xi_c\bar{D}^*(\frac{3}{2}^-)$ bound states are very close**
- **Pcs(4459) can be reproduced at $\alpha = 3.5 - 4.5$**
- **Coupled-channel effect should be added**

Pcs Coupled-channel calculation



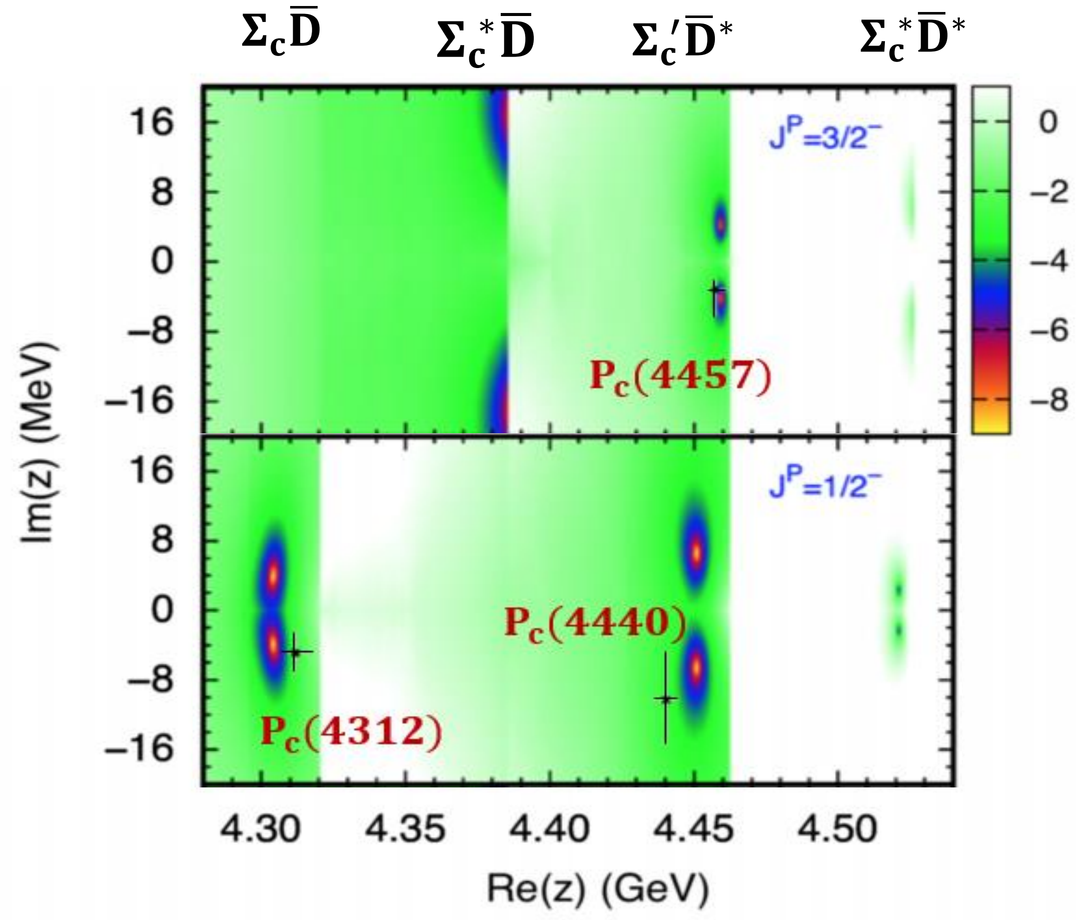
α	$\Xi_c^*\bar{D}^*\frac{1}{2}$	$\Xi_c^*\bar{D}^*\frac{3}{2}$	$\Xi_c'\bar{D}^*\frac{1}{2}$	$\Xi_c'\bar{D}^*\frac{3}{2}$
2.0	$1.5+0.4i$	$0.2+0.4i$	$5.2+1.9i$	$1.3+2.1i$
2.5	$3.7+1.4i$	$2.0+4.4i$	$6.9+4.6i$	$1.9+5.0i$
3.0	$7.4+3.3i$	N	$8.2+6.8i$	$2.6+6.9i$
3.5	$11.4+6.6i$	N	$4.9+8.7i$	$5.6+7.3i$
α	--	$\Xi_c^*\bar{D}\frac{3}{2}$	$\Xi_c\bar{D}^*\frac{1}{2}$	$\Xi_c\bar{D}^*\frac{3}{2}$
2.0	--	$0.1+2.1i$	$2.2+0.9i$	$4.6+0.7i$
2.5	--	$2.8+4.3i$	$4.5+2.2i$	$10.5+1.1i$
3.0	--	$6.3+7.0i$	**7.9+4.0i**	**19.7+1.6i**
3.5	--	$18.4+9.3i$	$13.3+6.4i$	$33.3+0.7i$
α	$\Xi_c'\bar{D}\frac{1}{2}$	--	$\Xi_c\bar{D}\frac{1}{2}$	--
2.0	$4.9+0.0i$	--	0.2	--
2.5	$10.8+0.0i$	--	3.9	--
3.0	$19.4+0.0i$	--	8.5	--
3.5	$30.9+0.0i$	--	14.0	--

- $\alpha = 3.0$
- Pcs(4459) is the candidate of the $\Xi_c\bar{D}^*\ 0(\frac{3}{2}^-)$ state

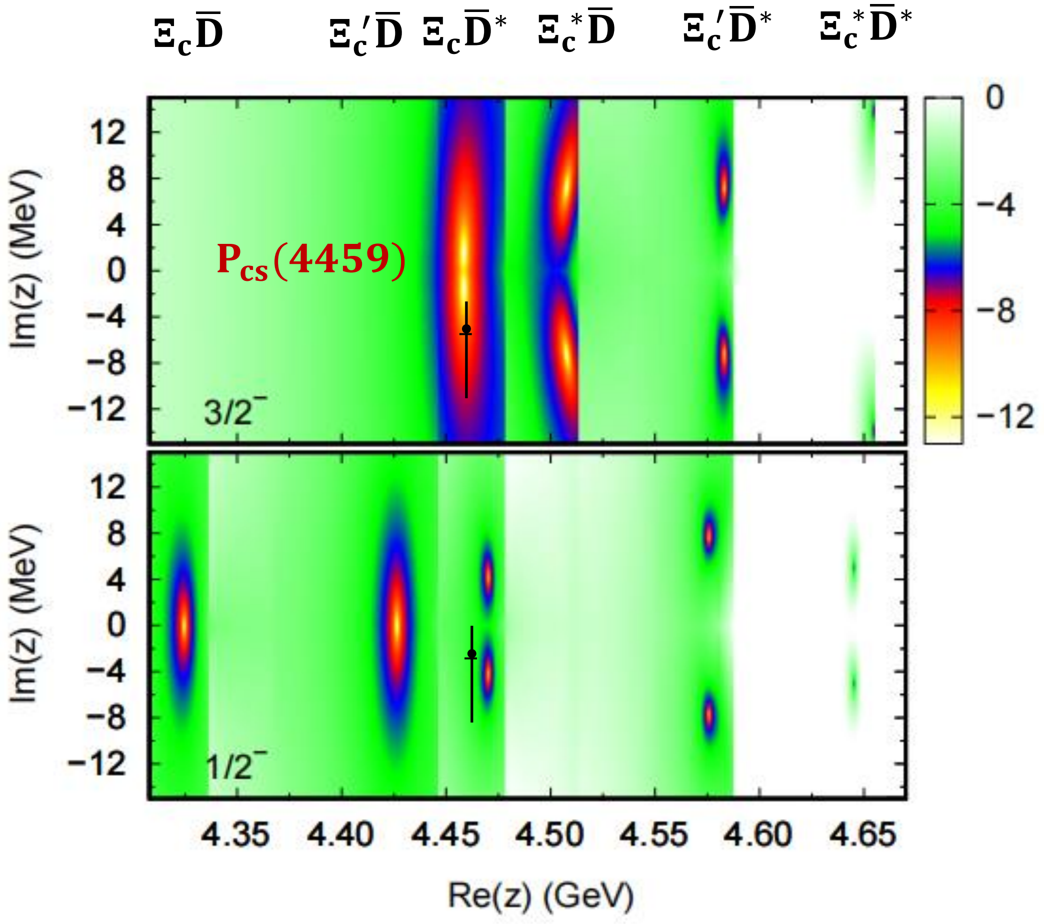
- The small mass gap about 10 MeV requires high precision measurement to distinguish these two states in experiment.

Compare with Pc

P_c α =2.5



P_{cs} $\alpha = 3.0$



Pcs

Two-channel calculation

α	$\Xi_c'\bar{D}^*$	$\Xi_c^*\bar{D}$	$\Xi_c\bar{D}^*$	$\Xi_c'\bar{D}$	$\Xi_c\bar{D}$
$\Xi_c^*\bar{D}^*(1/2^-)$ $M_{th}=4654.6$MeV					
2.0	$1.7+0.1i$	$1.8+0.1i$	$1.8+0.0i$	$1.7+0.2i$	$1.8+0.0i$
2.5	$4.8+0.2i$	$4.9+0.2i$	$4.6+0.1i$	$4.2+0.5i$	$4.5+0.0i$
3.0	$9.0+0.4i$	$9.2+0.5i$	$8.3+0.2i$	$7.4+1.4i$	$7.6+0.1i$
3.5	$14.0+0.6i$	$14.5+0.8i$	$12.9+0.3i$	$11.3+2.8i$	$11.3+0.2i$
$\Xi_c^*\bar{D}^*(3/2^-)$ $M_{th}=4654.6$MeV					
2.0	$0.2+0.1i$	$0.4+0.0i$	$0.1+0.2i$	$0.4+0.0i$	$0.4+0.0i$
2.5	$1.2+0.7i$	$1.5+0.3i$	$0.1+0.3i$	$2.0+0.1i$	$1.9+0.0i$
3.0	$2.7+1.4i$	$2.7+0.8i$	$0.1+2.5i$	$4.2+0.1i$	$4.1+0.0i$
3.5	$4.3+2.3i$	$3.7+1.7i$	$0.1+3.1i$	$6.9+0.1i$	$6.7+0.0i$
$\Xi_c'\bar{D}^*(1/2^-)$ $M_{th}=4587.4$MeV					
2.0	−−	$5.8+0.1i$	$4.7+1.5i$	$5.7+0.1i$	$5.7+0.0i$
2.5	−−	$10.9+0.4i$	$8.1+3.8i$	$10.4+0.2i$	$10.1+0.2i$
3.0	−−	$17.3+0.9i$	$12.1+6.9i$	$15.6+0.6i$	$14.9+0.7i$
3.5	−−	$24.7+2.0i$	$16.3+12.2i$	$20.8+1.3i$	$19.8+1.6i$
$\Xi_c'\bar{D}^*(3/2^-)$ $M_{th}=4587.4$MeV					
2.0	−−	$1.6+0.0i$	$0.7+2.1i$	$1.8+0.0i$	$1.3+0.3i$
2.5	−−	$3.2+0.1i$	$1.3+5.9i$	$3.6+0.0i$	$1.8+1.4i$
3.0	−−	$4.9+0.4i$	−−	$5.4+0.1i$	−−
3.5	−−	$6.2+0.6i$	−−	$7.1+0.1i$	−−

α	$\Xi_c'\bar{D}^*$	$\Xi_c^*\bar{D}$	$\Xi_c\bar{D}^*$	$\Xi_c'\bar{D}$	$\Xi_c\bar{D}$
$\Xi_c^*\bar{D}(3/2^-)$ $M_{th}=4513.2$MeV					
2.0	−−	−−	$0.1+1.9i$	$0.1+0.0i$	$0.1+0.0i$
2.5	−−	−−	$0.7+3.7i$	$0.5+0.0i$	$0.5+0.0i$
3.0	−−	−−	$3.9+5.2i$	$1.7+0.0i$	$1.7+0.0i$
3.5	−−	−−	$11.2+6.1i$	$3.3+0.0i$	$3.2+0.0i$
$\Xi_c\bar{D}^*(1/2^-)$ $M_{th}=4478.0$MeV					
2.0	−−	−−	−−	$2.1+0.7i$	$3.1+0.0i$
2.5	−−	−−	−−	$4.1+1.6i$	$6.2+0.0i$
3.0	−−	−−	−−	$6.3+2.7i$	$9.9+0.0i$
3.5	−−	−−	−−	$8.6+3.8i$	$14.0+0.0i$
$\Xi_c\bar{D}^*(3/2^-)$ $M_{th}=4478.0$MeV					
2.0	−−	−−	−−	$3.9+0.6i$	$3.1+0.0i$
2.5	−−	−−	−−	$8.2+0.9i$	$6.2+0.0i$
3.0	−−	−−	−−	$13.7+1.1i$	$9.9+0.0i$
3.5	−−	−−	−−	$20.5+1.2i$	$14.0+0.0i$
$\Xi_c'\bar{D}(1/2^-)$ $M_{th}=4446.0$MeV					
2.0	−−	−−	−−	−−	$3.0+0.0i$
2.5	−−	−−	−−	−−	$6.3+0.0i$
3.0	−−	−−	−−	−−	$10.2+0.0i$
3.5	−−	−−	−−	−−	$14.5+0.0i$

Results and discussions

$$P_b$$

P_b

Threshold & Quantum Number

$$B^{(*)}\Sigma_b^{(*)} - B^{(*)}\Lambda_b$$

1. $\Sigma_b^* B^*$ (11155) $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-\right) \quad \frac{3}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-\right)$
2. $\Sigma_b B^*$ (11135) $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-\right) \quad \frac{3}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-\right)$
3. $\Sigma_b^* B$ (11110) $\quad I(J^P) = \frac{1}{2}\left(\frac{3}{2}^-\right) \quad \frac{3}{2}\left(\frac{3}{2}^-\right)$
4. $\Sigma_b B$ (11090) $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-\right) \quad \frac{3}{2}\left(\frac{1}{2}^-\right)$
5. $\Lambda_b B^*$ (10944) $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-, \frac{3}{2}^-\right)$
6. $\Lambda_b B$ (10899) $\quad I(J^P) = \frac{1}{2}\left(\frac{1}{2}^-\right)$

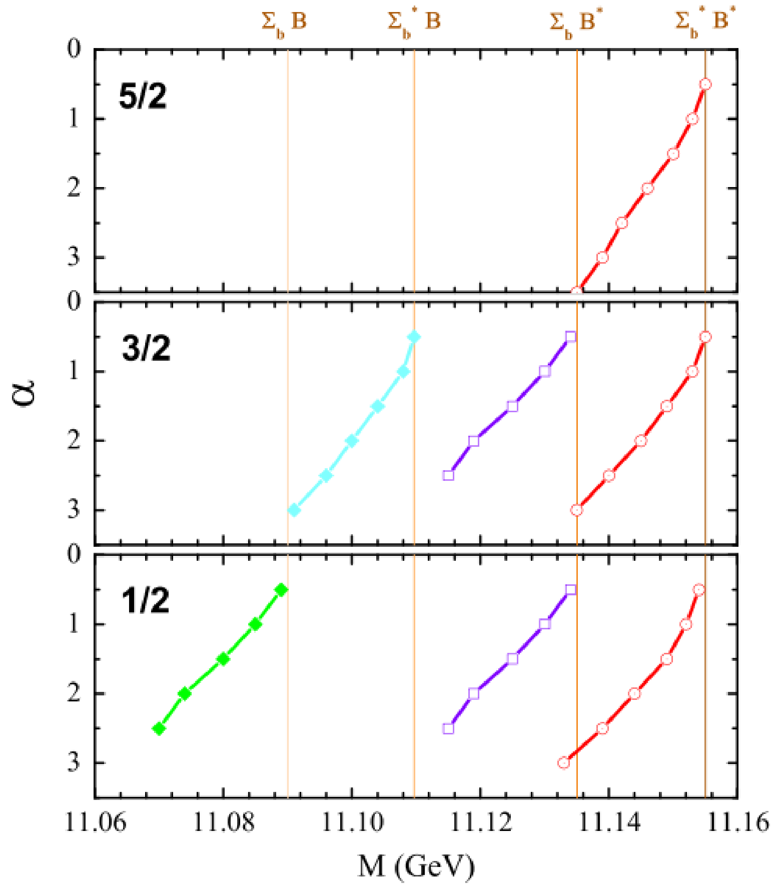
Exchanged meson

Table 2 The flavor factors f_I for certain meson exchanges of certain interaction. The values in bracket are for the case of $I = 3/2$ if the values are different from these of $I = 1/2$

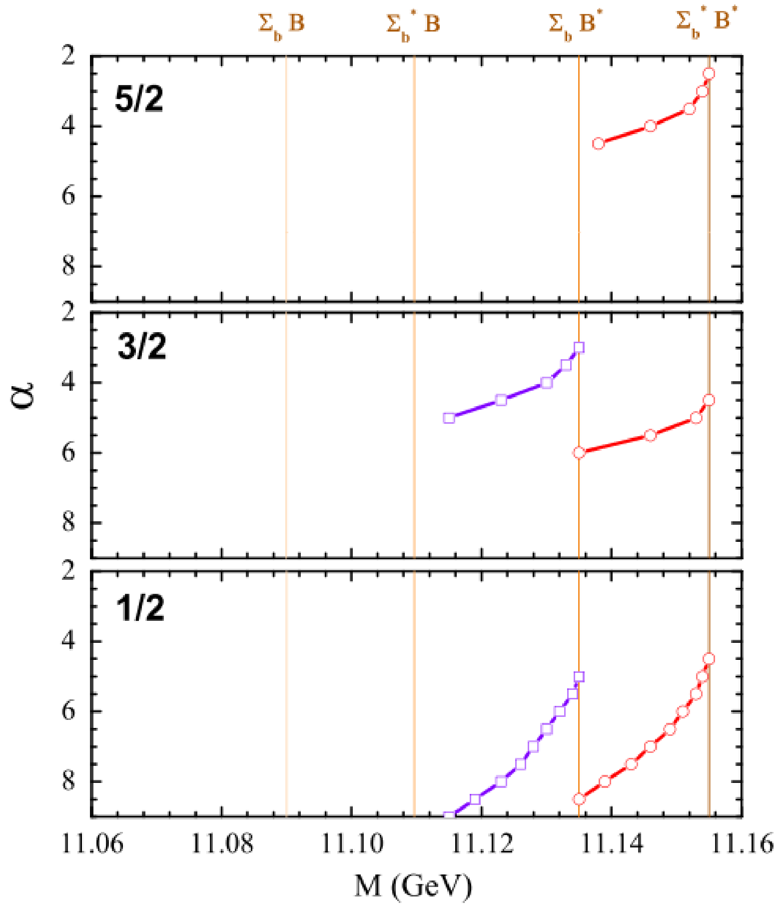
	π	η	ρ	ω	σ
$B^{(*)}\Sigma_b^{(*)} \to B^{(*)}\Sigma_b^{(*)}$	$-1[\frac{1}{2}]$	$\frac{1}{6}[\frac{1}{6}]$	$-1[\frac{1}{2}]$	$\frac{1}{2}[\frac{1}{2}]$	1
$B^{(*)}\Lambda_b \to B^{(*)}\Lambda_b$	0	0	0	1	2
$B^{(*)}\Lambda_b \to B^{(*)}\Sigma_b^{(*)}$	$\frac{\sqrt{6}}{2}$	0	$\frac{\sqrt{6}}{2}$	0	0

P_b Single-channel calculation

$I = 1/2$



$I = 3/2$

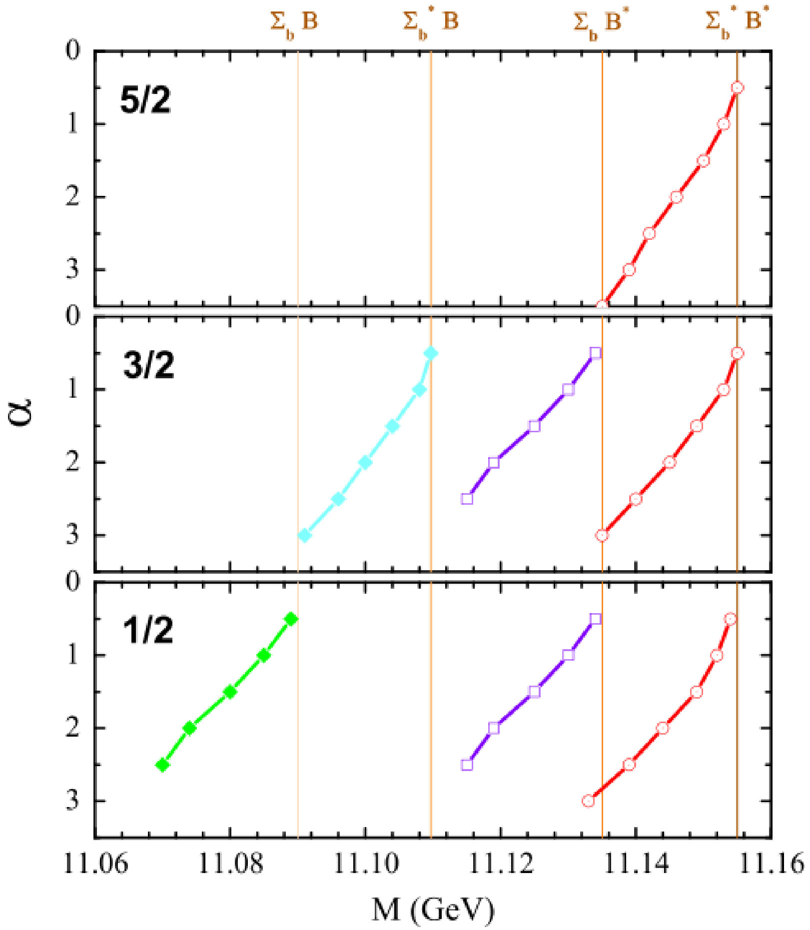


- All seven states with I=1/2 are bound near the threshold
- The tendencies for poles of the same channel are similar

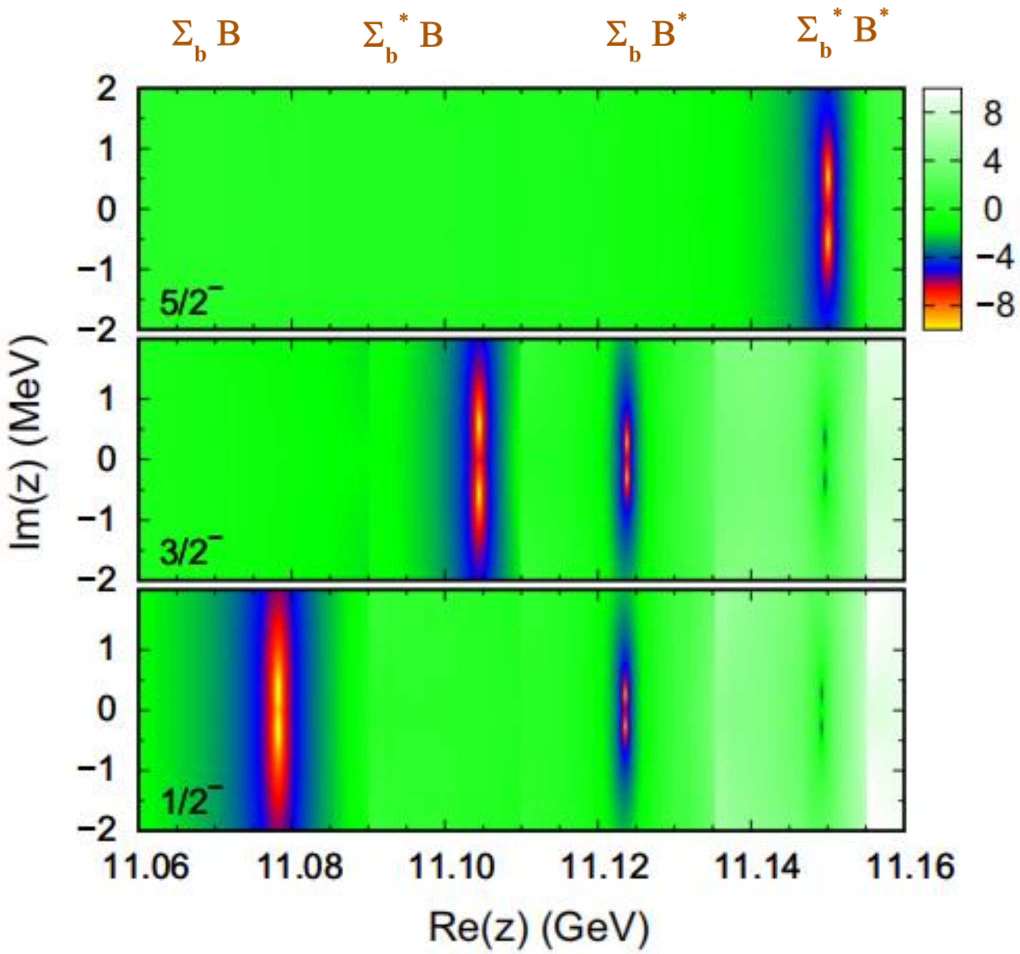
- Two lower states can not be bound even at $\alpha = 9.0$
- The rest five states might be bound, but large α is required

P_b Coupled-channel calculation

$I = 1/2$



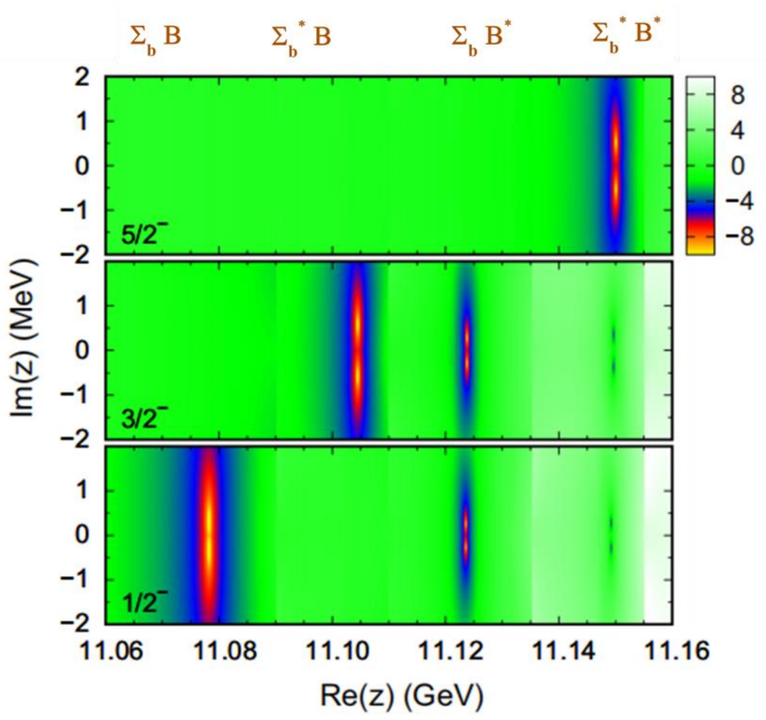
$\alpha = 1.5$



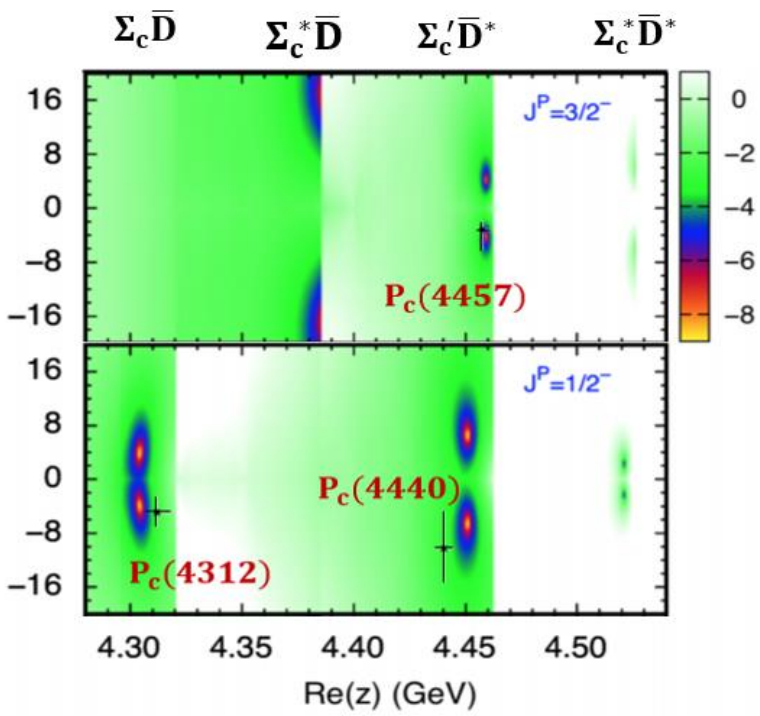
- The $\Sigma_b^* B^*$ $\left(\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-\right)$ states are nearly degenerate, but the state with $J^P = \frac{5}{2}^-$ will be more outstanding.
- The mass of two $\Sigma_b B^*$ states are extremely close too.
- The $\Sigma_b^* B$ $(\frac{1}{2}^-, \frac{3}{2}^-)$ states are also recommended to be searched for in experiments.

Compare with P_c and P_{cs}

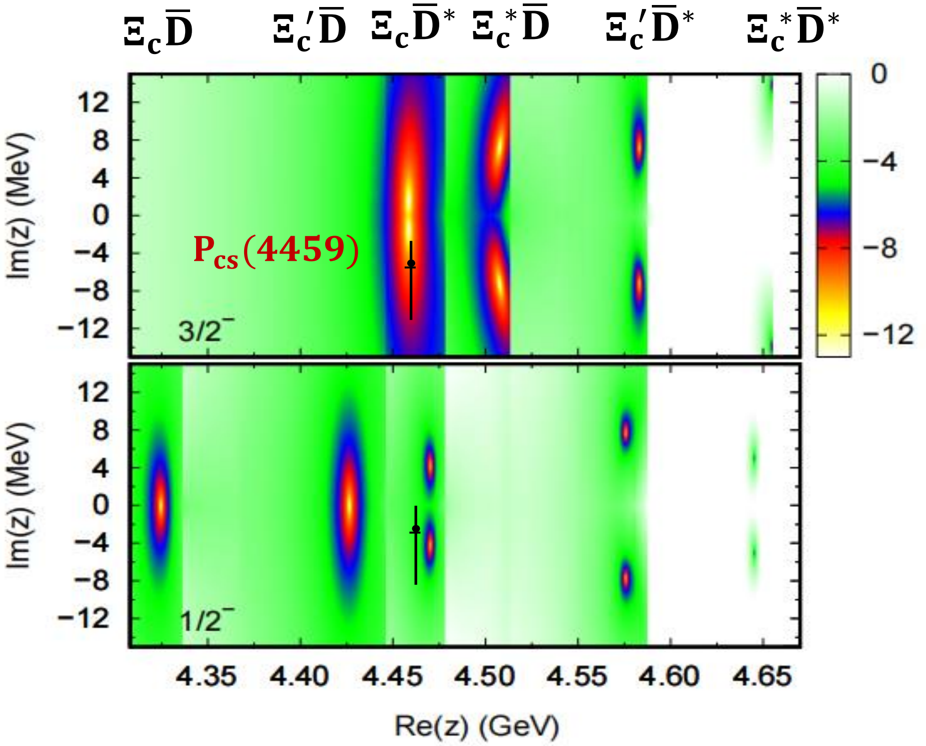
P_b $\alpha = 1.5$



P_c $\alpha = 2.5$



P_{cs} $\alpha = 3.0$



- The significant states may be easy to be found.

P_b Two-channel calculation

	α_r	CC	$\Sigma_b B^*$	$\Sigma_b^* B$	$\Sigma_b B$	$\Lambda_b B^*$	$\Lambda_b B$
$\Sigma_b^* B^*(1/2^-)$ $M_{th} = 11155$ MeV	0.6	$0.6 + 0.02i$	$0.6 + 0.01i$	$0.6 + 0.01i$	$0.6 + 0.01i$	$0.6 + 0.00i$	$0.6 + 0.00i$
	1.0	$2.4 + 0.09i$	$2.5 + 0.03i$	$2.5 + 0.03i$	$2.5 + 0.04i$	$2.5 + 0.02i$	$2.5 + 0.00i$
	1.5	$5.8 + 0.28i$	$6.1 + 0.07i$	$6.0 + 0.10i$	$6.0 + 0.16i$	$6.0 + 0.16i$	$6.1 + 0.00i$
	2.0	$9.6 + 0.40i$	$10.3 + 0.24i$	$10.4 + 0.25i$	$9.9 + 0.31i$	$10.3 + 0.63i$	$10.5 + 0.00i$
$\Sigma_b^* B^*(3/2^-)$ $M_{th} = 11155$MeV	0.6	$0.5 + 0.03i$	$0.5 + 0.02i$	$0.5 + 0.01i$	$0.5 + 0.00i$	$0.5 + 0.00i$	$0.5 + 0.00i$
	1.0	$2.2 + 0.10i$	$2.3 + 0.04i$	$2.3 + 0.03i$	$2.3 + 0.02i$	$2.3 + 0.01i$	$2.3 + 0.00i$
	1.5	$5.3 + 0.36i$	$5.5 + 0.07i$	$5.7 + 0.03i$	$5.6 + 0.08i$	$5.6 + 0.12i$	$5.6 + 0.03i$
	2.0	$8.6 + 1.38i$	$9.3 + 0.19i$	$9.8 + 0.09i$	$9.8 + 0.16i$	$9.4 + 0.48i$	$9.7 + 0.17i$
$\Sigma_b^* B^*(5/2^-)$ $M_{th} = 11155$ MeV	0.6	$0.4 + 0.04i$	$0.4 + 0.01i$	$0.4 + 0.01i$	$0.4 + 0.01i$	$0.4 + 0.00i$	$0.4 + 0.00i$
	1.0	$2.1 + 0.15i$	$2.4 + 0.01i$	$2.1 + 0.05i$	$2.0 + 0.01i$	$2.1 + 0.01i$	$2.1 + 0.00i$
	1.5	$4.9 + 0.52i$	$5.3 + 0.01i$	$5.1 + 0.02i$	$5.0 + 0.27i$	$4.9 + 0.25i$	$5.0 + 0.07i$
	2.0	$8.6 + 1.38i$	$9.3 + 0.19i$	$9.8 + 0.09i$	$9.8 + 0.16i$	$9.4 + 0.48i$	$9.7 + 0.17i$

- $\Lambda_b B^{(*)}$ will be the main decay channel of seven states.
- The width of seven states are very small, about 1MeV or smaller.

P_b

Two coupled channel calculation

	α_r	CC	$\Sigma_b B^*$	$\Sigma_b^* B$	$\Sigma_b B$	$\Lambda_b B^*$	$\Lambda_b B$
$\Sigma_b B^*(1/2^-)$ $M_{th} = 11135$ MeV	0.5	$1.4 + 0.01i$	−−	$1.2 + 0.00i$	$1.2 + 0.00i$	$1.2 + 0.00i$	$1.2 + 0.00i$
	1.0	$5.7 + 0.05i$	−−	$5.0 + 0.01i$	$5.0 + 0.02i$	$5.0 + 0.01i$	$5.0 + 0.00i$
	1.5	$11.4 + 0.26i$	−−	$10.0 + 0.05i$	$10.1 + 0.05i$	$10.0 + 0.07i$	$10.1 + 0.03i$
	2.0	$17.6 + 0.70i$	−−	$15.7 + 0.25i$	$16.1 + 0.09i$	$15.7 + 0.22i$	$15.9 + 0.03i$
$\Sigma_b B^*(3/2^-)$ $M_{th} = 11135$ MeV	0.5	$1.4 + 0.02i$	−−	$1.2 + 0.00i$	$1.2 + 0.00i$	$1.2 + 0.00i$	$1.2 + 0.00i$
	1.0	$5.7 + 0.17i$	−−	$5.1 + 0.01i$	$5.1 + 0.14i$	$5.1 + 0.02i$	$5.1 + 0.00i$
	1.5	$11.2 + 0.28i$	−−	$10.1 + 0.02i$	$10.3 + 0.22i$	$10.0 + 0.20i$	$10.1 + 0.05i$
	2.0	$17.2 + 0.45i$	−−	$15.7 + 0.03i$	$16.2 + 0.33i$	$15.0 + 0.81i$	$15.5 + 0.31i$
$\Sigma_b^* B(3/2^-)$ $M_{th} = 11110$ MeV	1.0	$2.4 + 0.08i$	−−	−−	$2.4 + 0.00i$	$2.4 + 0.07i$	$2.4 + 0.00i$
	1.5	$5.5 + 0.57i$	−−	−−	$5.7 + 0.00i$	$5.4 + 0.49i$	$5.7 + 0.00i$
	2.0	$8.4 + 2.05i$	−−	−−	$9.6 + 0.00i$	$8.8 + 1.56i$	$9.6 + 0.00i$
$\Sigma_b B(1/2^-)$ $M_{th} = 11090$ MeV	0.5	$1.6 + 0.00i$	−−	−−	−−	$1.4 + 0.00i$	$1.4 + 0.00i$
	1.0	$6.0 + 0.04i$	−−	−−	−−	$5.3 + 0.04i$	$5.3 + 0.00i$
	1.5	$11.8 + 0.33i$	−−	−−	−−	$10.2 + 0.25i$	$10.4 + 0.00i$
	2.0	$17.9 + 1.60i$	−−	−−	−−	$15.4 + 1.17i$	$16.1 + 0.00i$

Summary

P_c

- The three LHCb P_c states can be explained as $\Sigma_c\bar{D}\left(\frac{1}{2}\right)$, $\Sigma_c\bar{D}^*(\frac{1}{2},\frac{3}{2})$ **states** well.
- $\Lambda_c\bar{D}^*$ is an important decay channel of P_c states.

P_{cs}

- **$P_{cs}(4459)$ can be assigned as $\Xi_c\bar{D}^*(\frac{3}{2}^-)$ state, but two pole-structure can not be excluded.**
- The $\Xi_c\bar{D}\left(\frac{1}{2}^-\right)$, $\Xi_c'\bar{D}\left(\frac{1}{2}^-\right)$, $\Xi_c^*\bar{D}\left(\frac{3}{2}^-\right)$ **and** $\Xi_c'\bar{D}^*(\frac{1}{2}^-,\frac{3}{2}^-)$ are also suggested, and the $\Xi_c^*\bar{D}^*\left(\frac{1}{2}^-,\frac{3}{2}^-\right)$ seem too weak to be found.

P_b

- Five hidden bottom states $\Sigma_b^*B^*\left(\frac{5}{2}^-\right)$, $\Sigma_bB^*\left(\frac{1}{2}^-,\frac{3}{2}^-\right)$, $\Sigma_b^*B\left(\frac{3}{2}^-\right)$ and $\Sigma_bB\left(\frac{1}{2}^-\right)$ are suggested.
- Λ_bB^* is also an important decay channel for hidden bottom states .
- Such states can be searched for at COMPASS, J-PARC, especially the Electron Ion Collider (EicC) in China.

南京师范大学

THANK YOU