LANZHOU UNIVERSITY

第二届强子物理与重味物理理论与实验联合研讨会

Study of the multi-quark states with coupled channel approach

Chu-Wen Xiao（肖楮文）

Central South University（中南大学）

Collaborators: Juan Nieves, Eulogio Oset, Bing-Song Zou

Li-Sheng Geng, Jia-Jun Wu, Jun-Xu Lu

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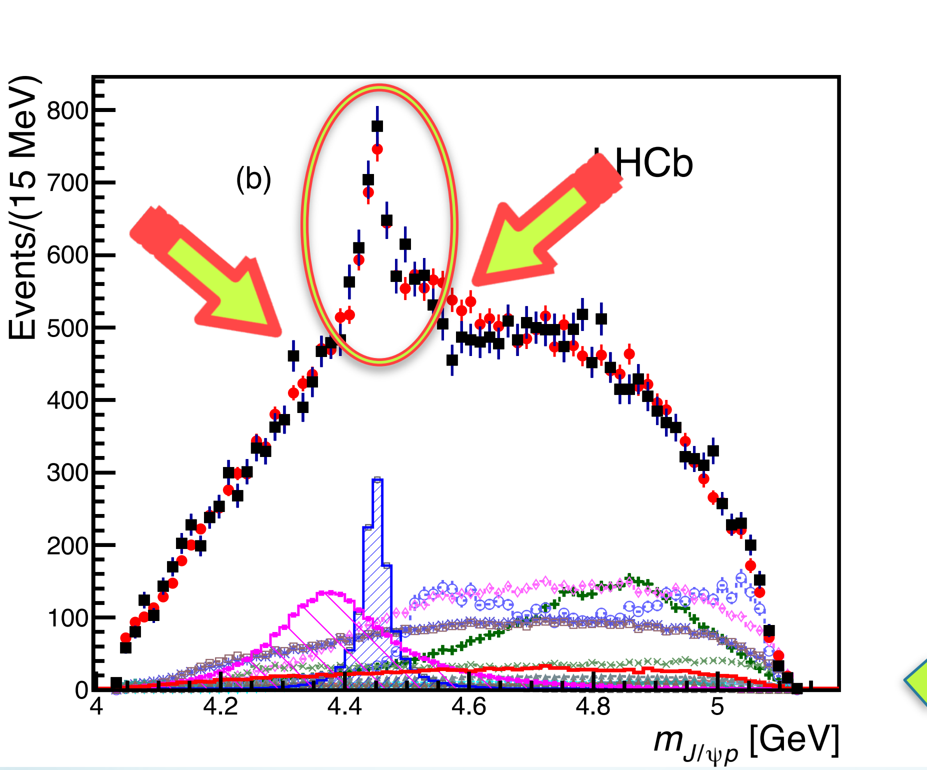
Outline

1. Background
2. Formalism
3. Results
4. Summary

§1. Background

First findings for the Pc states

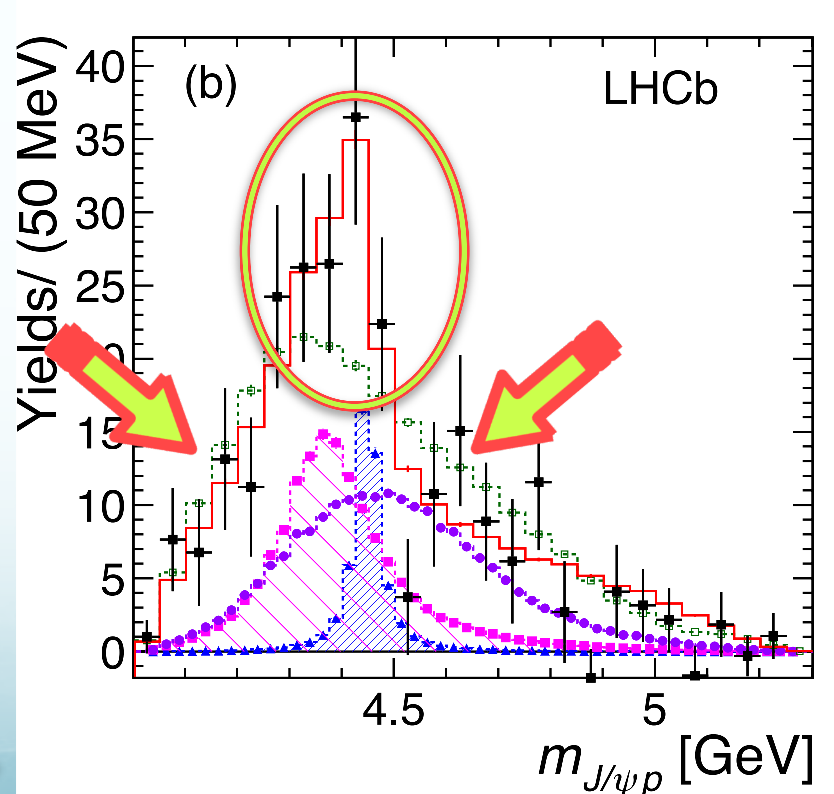


$P_c(4380)^+, \Gamma = 205$

$P_c(4450)^+, \Gamma = 39$

J^P ?

R. Aaij et al. (LHCb Collaboration), Phys. Rev. Lett. 115, 072001 (2015)



R. Aaij et al. (LHCb Collaboration), Phys. Rev. Lett. 117, 082003 (2016)

Updated results for the Pc states

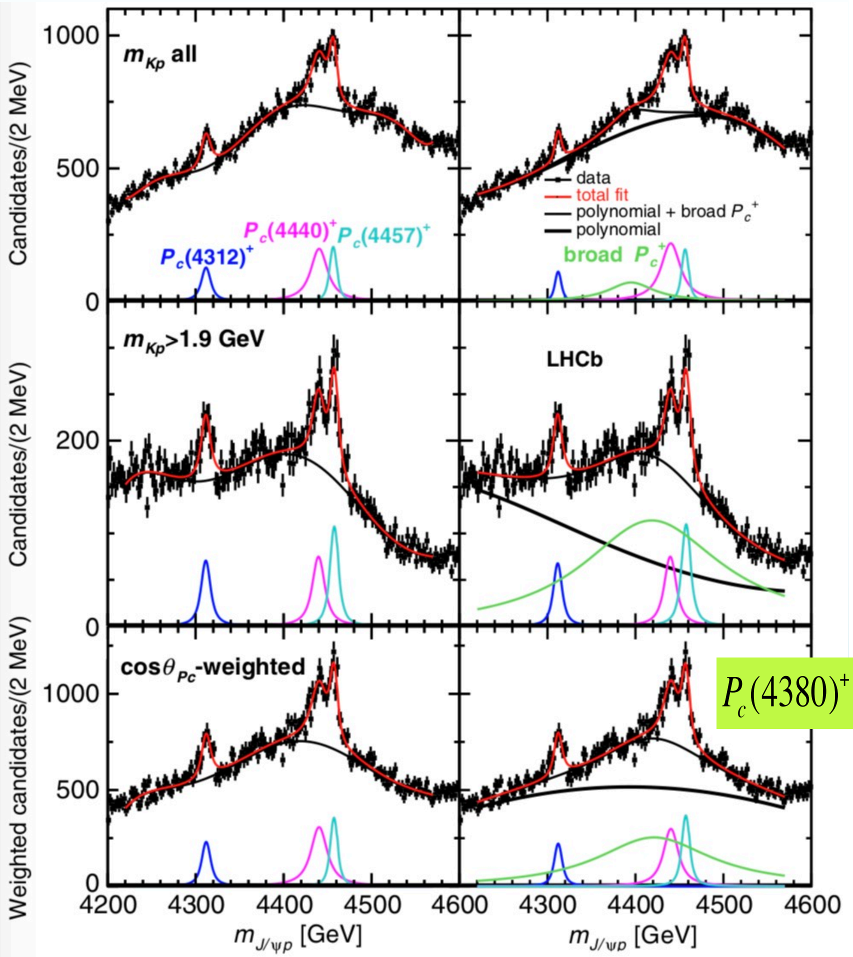
PHYSICAL REVIEW LETTERS **122**, 222001 (2019)

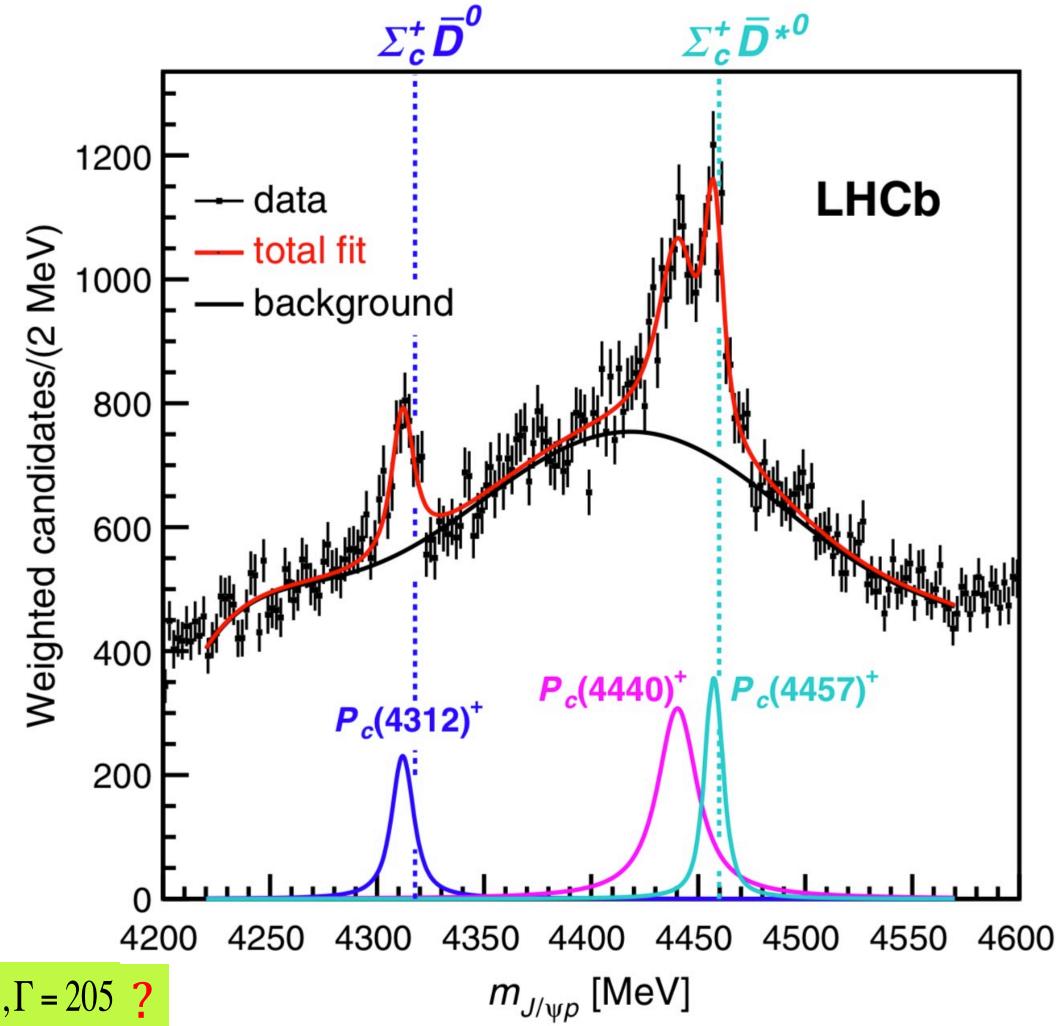
Featured in Physics

Observation of a Narrow Pentaquark State, $P_c(4312)^+$, and of the Two-Peak Structure of the $P_c(4450)^+$

R. Aaij *et al.*

(LHCb Collaboration)





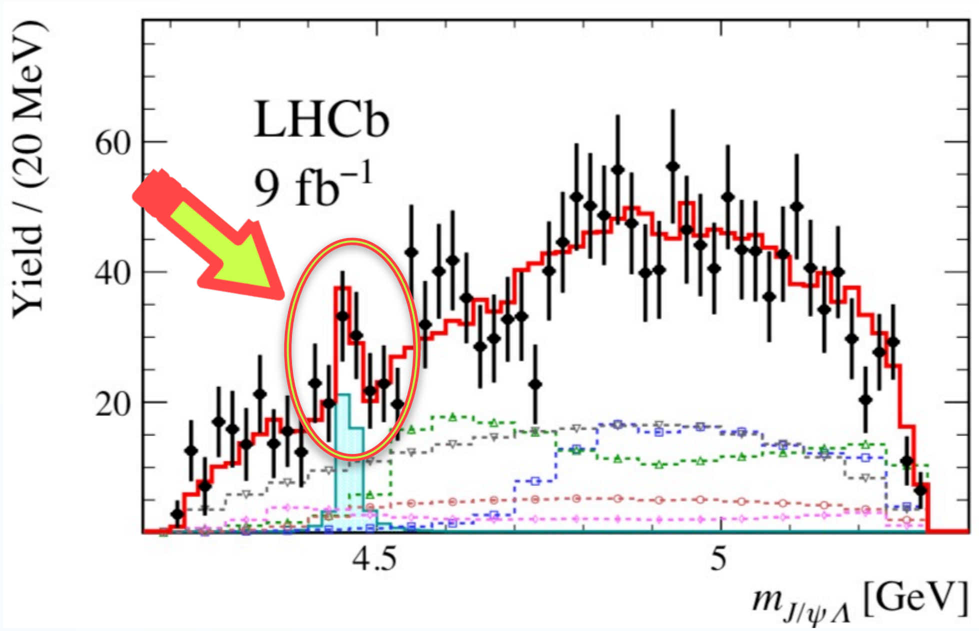
$P_c(4380)^+, \Gamma = 205$?

$$M_{P_{c1}} = 4311.9 \pm 0.7^{+6.8}_{-0.6}, \quad \Gamma_{P_{c1}} = 9.8 \pm 2.7^{+3.7}_{-4.5},$$

$$M_{P_{c2}} = 4440.3 \pm 1.3^{+4.1}_{-4.7}, \quad \Gamma_{P_{c2}} = 20.6 \pm 4.9^{+8.7}_{-10.1},$$

$$M_{P_{c3}} = 4457.3 \pm 0.6^{+4.1}_{-1.7}, \quad \Gamma_{P_{c3}} = 6.4 \pm 2.0^{+5.7}_{-1.9}.$$

New findings for the Pcs state

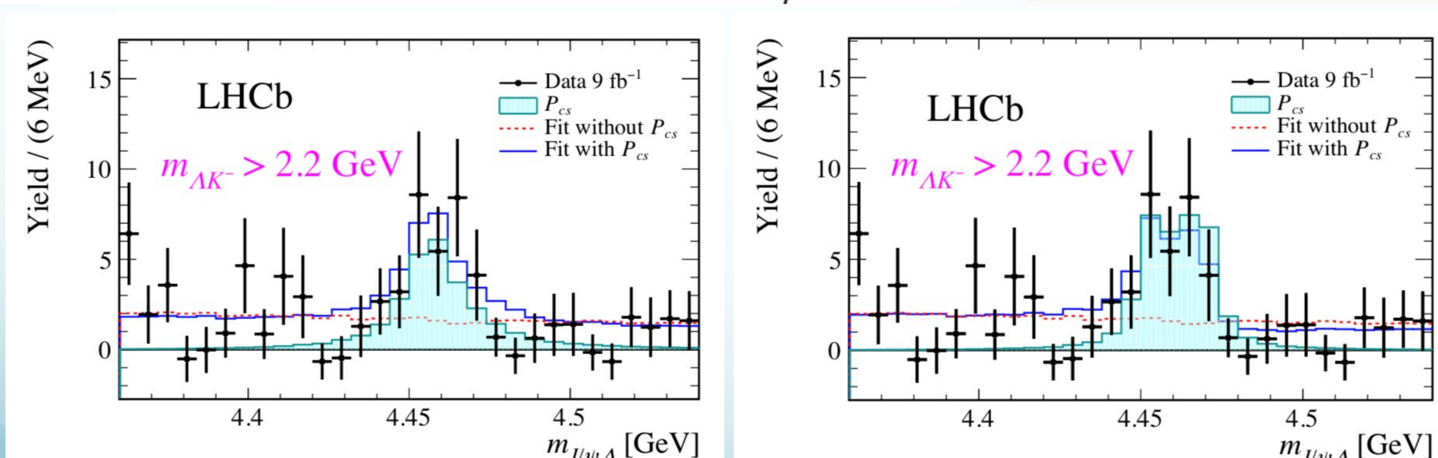


R. Aaij et al. (LHCb Collaboration), arXiv:2012.10380

State	M_0 [MeV]	Γ_0 [MeV]
$P_{cs}(4459)^0$	$4458.8 \pm 2.9\,^{+4.7}_{-1.1}$	$17.3 \pm 6.5\,^{+8.0}_{-5.7}$

J^P ?

mass difference of about 6 MeV



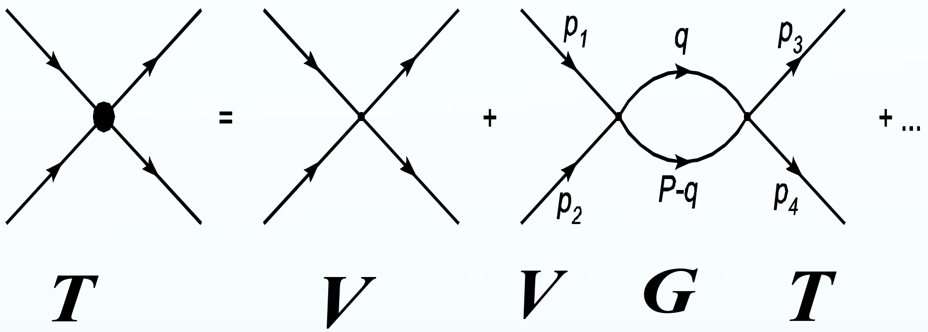
B. Wang, L. Meng and S. L. Zhu, **Phys. Rev. D 101** (2020) 034018.

The data cannot confirm or refute the two-peak hypothesis.

§2. Formalism

- Coupled Channel Unitary Approach (CCUA)：solving Bethe-Salpeter (BS) equations, which take on-shell approximation to loops.

$$T = V + VGT, T = [1 - VG]^{-1} V$$



where V matrix (potentials) can be evaluated from the interaction Lagrangians.

J. A. Oller and E. Oset, Nucl. Phys. A 620 (1997) 438
E. Oset and A. Ramos, Nucl. Phys. A 635 (1998) 99
J. A. Oller and U. G. Meißner, Phys. Lett. B 500 (2001) 263

G is a diagonal matrix with the loop functions of each channels:

$$G_{ll}(s) = i \int \frac{d^4q}{(2\pi)^4} \frac{1}{(P-q)^2 - m_{l1}^2 + i\varepsilon} \frac{1}{q^2 - m_{l2}^2 + i\varepsilon}$$

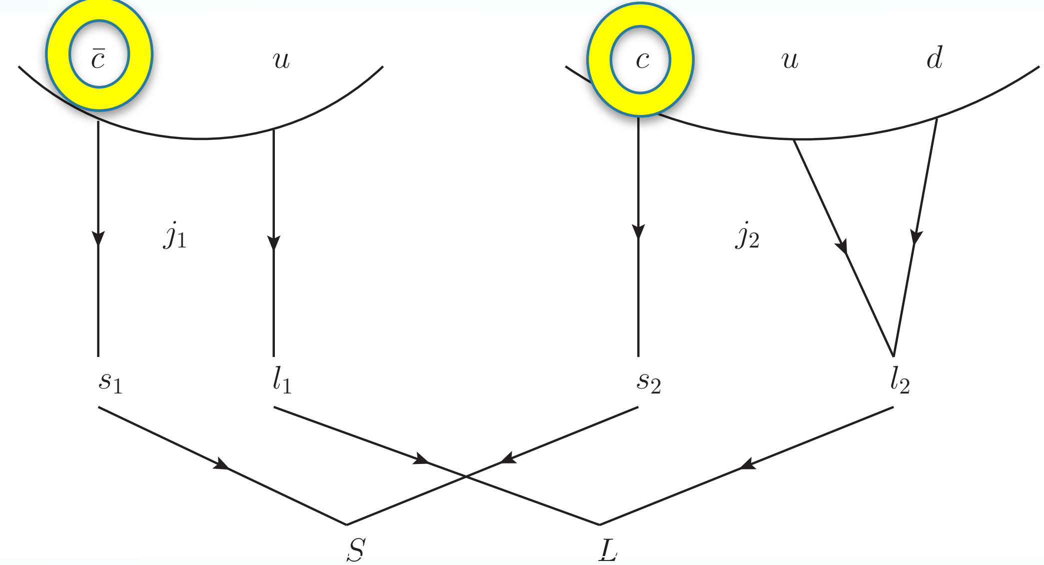
The coupled channel scattering amplitudes **T matrix satisfy the unitary** :

$$\mathrm{Im}\, T_{ij} = T_{in}\, \sigma_{nn}\, T_{nj}^*$$

$$\sigma_{nn} \equiv \mathrm{Im}\, G_{nn} = -\frac{q_{cm}}{8\pi\sqrt{s}} \theta(s - (m_1 + m_2)^2))$$

To search the poles of the resonances, we should extrapolate the scattering amplitudes to the second Riemann sheets:

$$G_{ll}^{II}(s) = G_{ll}^{I}(s) + i\, \frac{q_{cm}}{4\pi\sqrt{s}}$$



Considering the heavy quark spin symmetry

$\bar{D} \rightarrow \bar{D}^*$ $\Sigma_c \rightarrow \Sigma_c^*$

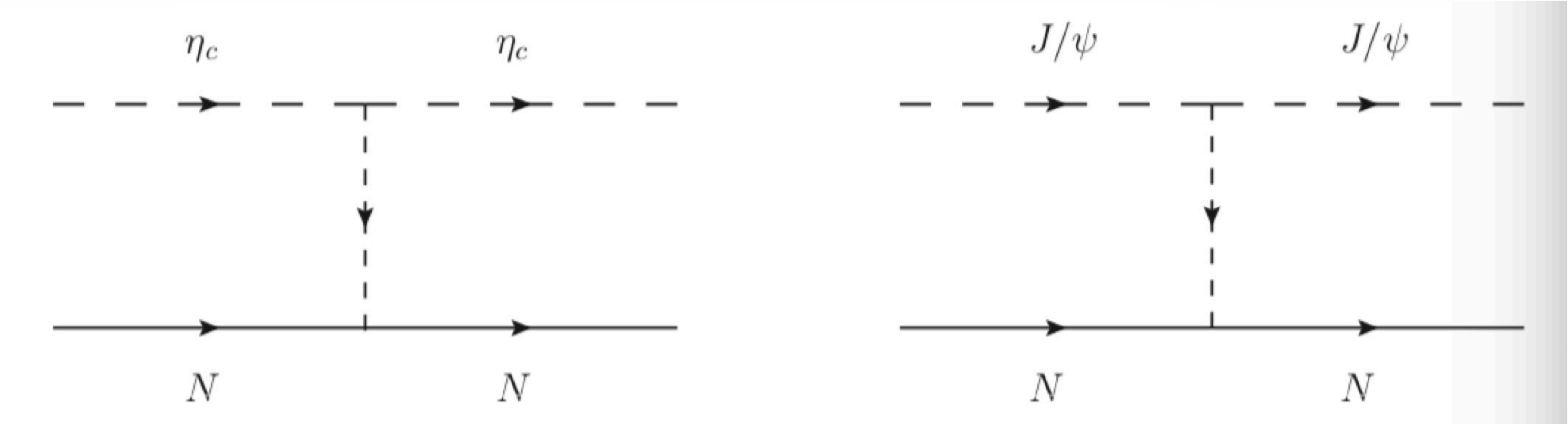
LECs

$J = 1/2, I = 1/2$

$$
\begin{array}{ccccccc}
\eta_c N & J_\Psi N & \bar{D}\Lambda_c & \bar{D}\Sigma_c & \bar{D}^*\Lambda_c & \bar{D}^*\Sigma_c & \bar{D}^*\Sigma_c^*
\end{array}
$$

$$
\begin{pmatrix}
\mu_1 & 0 & \frac{\mu_{12}}{2} & \frac{\mu_{13}}{2} & \frac{\sqrt{3}\mu_{12}}{2} & -\frac{\mu_{13}}{2\sqrt{3}} & \sqrt{\frac{2}{3}}\mu_{13} \\
0 & \mu_1 & \frac{\sqrt{3}\mu_{12}}{2} & -\frac{\mu_{13}}{2\sqrt{3}} & -\frac{\mu_{12}}{2} & \frac{5\mu_{13}}{6} & \frac{\sqrt{2}\mu_{13}}{3} \\
\frac{\mu_{12}}{2} & \frac{\sqrt{3}\mu_{12}}{2} & \mu_2 & 0 & 0 & \frac{\mu_{23}}{\sqrt{3}} & \sqrt{\frac{2}{3}}\mu_{23} \\
\frac{\mu_{13}}{2} & -\frac{\mu_{13}}{2\sqrt{3}} & 0 & \frac{1}{3}(2\lambda_2+\mu_3) & \frac{\mu_{23}}{\sqrt{3}} & \frac{2(\lambda_2-\mu_3)}{3\sqrt{3}} & \frac{1}{3}\sqrt{\frac{2}{3}}(\mu_3-\lambda_2) \\
\frac{\sqrt{3}\mu_{12}}{2} & -\frac{\mu_{12}}{2} & 0 & \frac{\mu_{23}}{\sqrt{3}} & \mu_2 & -\frac{2\mu_{23}}{3} & \frac{\sqrt{2}\mu_{23}}{3} \\
-\frac{\mu_{13}}{2\sqrt{3}} & \frac{5\mu_{13}}{6} & \frac{\mu_{23}}{\sqrt{3}} & \frac{2(\lambda_2-\mu_3)}{3\sqrt{3}} & -\frac{2\mu_{23}}{3} & \frac{1}{9}(2\lambda_2+7\mu_3) & \frac{1}{9}\sqrt{2}(\mu_3-\lambda_2) \\
\sqrt{\frac{2}{3}}\mu_{13} & \frac{\sqrt{2}\mu_{13}}{3} & \sqrt{\frac{2}{3}}\mu_{23} & \frac{1}{3}\sqrt{\frac{2}{3}}(\mu_3-\lambda_2) & \frac{\sqrt{2}\mu_{23}}{3} & \frac{1}{9}\sqrt{2}(\mu_3-\lambda_2) & \frac{1}{9}(\lambda_2+8\mu_3)
\end{pmatrix}_{I=1/2}
$$

$$\mathcal{L}_{VVV} = ig\,\langle [V_\nu, \partial_\mu V_\nu] V^\mu \rangle,$$
$$\mathcal{L}_{PPV} = -ig\,\langle [P, \partial_\mu P] V^\mu \rangle,$$
$$\mathcal{L}_{BBV} = g\left(\langle \bar{B}\gamma_\mu [V^\mu, B]\rangle + \langle \bar{B}\gamma_\mu B\rangle \langle V^\mu \rangle\right)$$

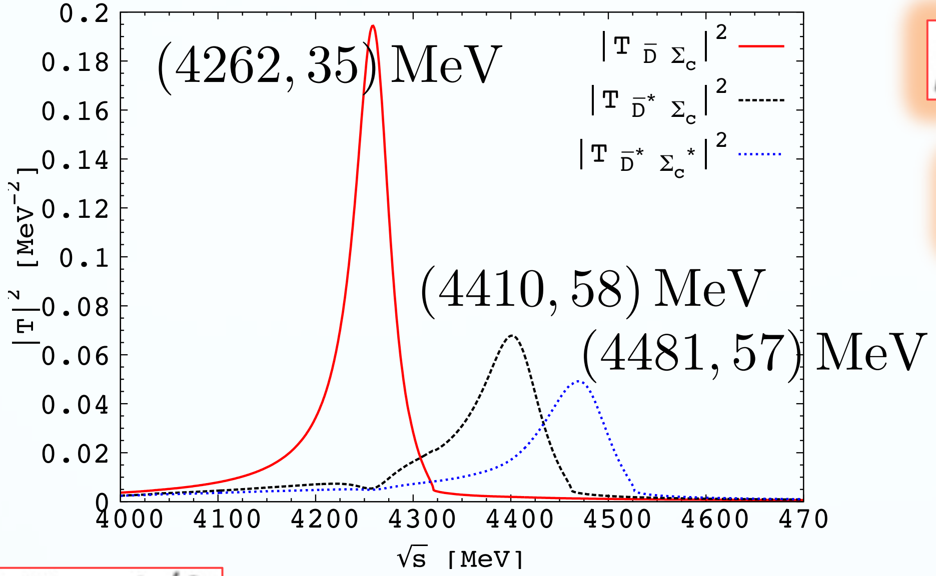


$J = 1/2, I = 1/2$

$$\mu_2 = \frac{1}{4f^2}(k^0 + k'^0), \qquad \mu_3 = -\frac{1}{4f^2}(k^0 + k'^0),$$
$$\mu_{12} = -\sqrt{6}\frac{m_\rho^2}{p_{D^*}^2 - m_{D^*}^2}\frac{1}{4f^2}(k^0 + k'^0), \qquad \mu_1 = 0,$$
$$\mu_{23} = 0, \qquad \lambda_2 = \mu_3, \qquad \mu_{13} = -\mu_{12}.$$

§3. Results

$J = 1/2, I = 1/2$

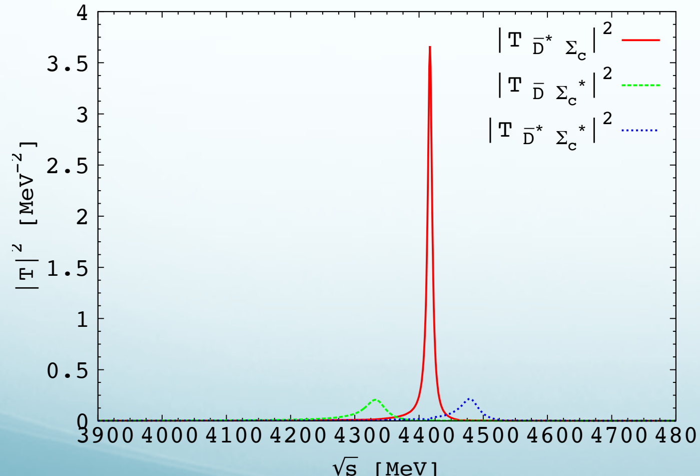


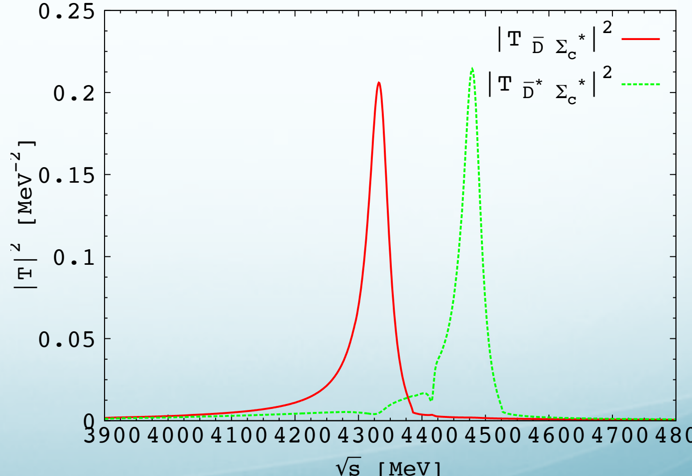
$\mu = 1000$ MeV

$a(\mu) = -2.3$

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

$J = 3/2, I = 1/2$





CWX, J. Nieves and E. Oset, Phys. Rev. D 88, 056012 (2013)

$P_c(4312)^+$ $a(\mu = 1\,\mathrm{GeV}) = -2.09$

$4306.38 + i7.62$	$\eta_c N$	$J/\psi N$	$\bar{D}\Lambda_c$	$\bar{D}\Sigma_c$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}^*\Sigma_c^*$
g_i	$0.67 + i0.01$	$0.46 - i0.03$	$0.01 - i0.01$	$2.07 - i0.28$	$0.03 + i0.25$	$0.06 - i0.31$	$0.04 - i0.15$
$\lvert g_i \rvert$	0.67	0.46	0.01	2.09	0.25	0.31	0.16

$P_c(4440)^+$

$4452.96 + i11.72$	$\eta_c N$	$J/\psi N$	$\bar{D}\Lambda_c$	$\bar{D}\Sigma_c$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}^*\Sigma_c^*$
g_i	$0.24 + i0.03$	$0.88 - 0.11$	$0.09 - i0.06$	$0.12 - i0.02$	$0.11 - i0.09$	$1.97 - i0.52$	$0.02 + i0.19$
$\lvert g_i \rvert$	0.25	0.89	0.11	0.13	0.14	2.03	0.19

$4520.45 + i11.12$	$\eta_c N$	$J/\psi N$	$\bar{D}\Lambda_c$	$\bar{D}\Sigma_c$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}^*\Sigma_c^*$
g_i	$0.72 - i0.10$	$0.45 - i0.04$	$0.11 - i0.06$	$0.06 - i0.02$	$0.06 - i0.05$	$0.07 - i0.02$	$1.84 - i0.56$
$\lvert g_i \rvert$	0.73	0.45	0.13	0.06	0.08	0.08	1.92

$4261.87 + i17.84$
g_i
$\lvert g_i \rvert$
$4410.13 + i29.44$
g_i
$\lvert g_i \rvert$
$4481.35 + i28.91$
g_i
$\lvert g_i \rvert$

$a(\mu) = -2.3$

$4374.33 + i6.87$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
$P_c(4457)^+$	$0.73 - i0.06$	$0.11 - i0.13$	$0.02 - i0.19$	$1.91 - i0.31$	$0.03 - i0.30$
$\lvert g_i \rvert$	0.73	0.18	0.19	1.94	0.30
$4452.48 + i1.49$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
g_i	$0.30 - i0.01$	$0.05 - i0.04$	$1.82 - i0.08$	$0.08 - i0.02$	$0.01 - i0.19$
$\lvert g_i \rvert$	0.30	0.07	1.82	0.08	0.19
$4519.01 + i6.86$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
g_i	$0.66 - i0.01$	$0.11 - i0.07$	$0.10 - i0.3$	$0.13 - i0.02$	$1.79 - i0.36$
$\lvert g_i \rvert$	0.66	0.13	0.10	0.13	1.82

$4334.45 + i19.41$
g_i
$\lvert g_i \rvert$
$4417.04 + i4.11$
g_i
$\lvert g_i \rvert$
$4481.04 + i17.38$
g_i
$\lvert g_i \rvert$

The former exercises have shown that the changes produced by using different couplings obtained in other approaches to QCD, with a certain amount of SU(4) or HQSS breaking, induce changes of the order of 20–30 MeV in bindings estimated in our approach to be of the order of 50 MeV. These uncertainties are in line with other systematic uncertainties that we must also admit from our partial ignorance in the regularization scale of the loops. Yet, with all these uncertainties, the binding of the states remains a solid conclusion, as does the order of magnitude of the binding energies; the maximum one can hope without further experimental information to constrain the input in our theory.

CWX, J. Nieves and E. Oset, Phys. Rev. D 88, 056012 (2013)

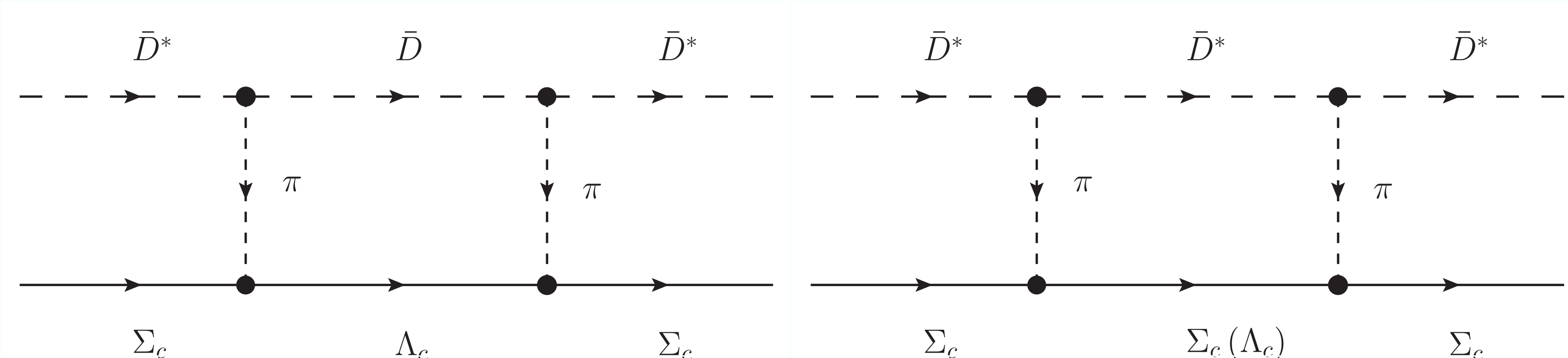
states [MeV]	Widths [MeV]	Main channel	J^P	Experimental state
4306.4	15.2	$\bar{D}\Sigma_c$	$1/2^-$	$P_c(4312)$
4452.9	23.4	$\bar{D}^*\Sigma_c$	$1/2^-$	$P_c(4440)$
4452.5	3.0	$\bar{D}^*\Sigma_c$	$3/2^-$	$P_c(4457)$

M. Z. Liu, Y. W. Pan, F. Z. Peng, M. S. Sanchez, L. S. Geng, A. Hosaka, and M. P. Valderrama, Phys. Rev. Lett. 122 (2019) 242001

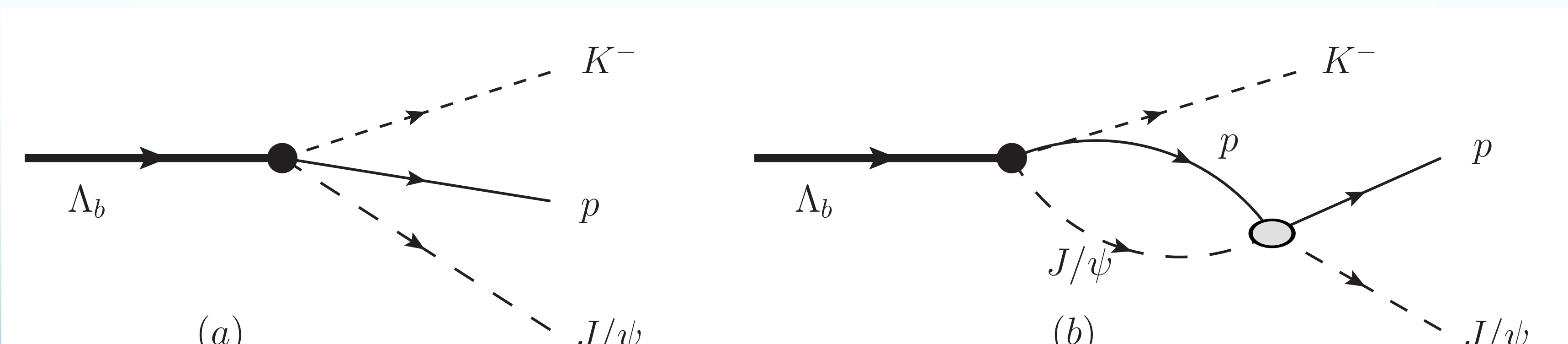
$$M_{P_{c1}} = 4311.9 \pm 0.7^{+6.8}_{-0.6}, \quad \Gamma_{P_{c1}} = 9.8 \pm 2.7^{+3.7}_{-4.5},$$
$$M_{P_{c2}} = 4440.3 \pm 1.3^{+4.1}_{-4.7}, \quad \Gamma_{P_{c2}} = 20.6 \pm 4.9^{+8.7}_{-10.1},$$
$$M_{P_{c3}} = 4457.3 \pm 0.6^{+4.1}_{-1.7}, \quad \Gamma_{P_{c3}} = 6.4 \pm 2.0^{+5.7}_{-1.9}.$$

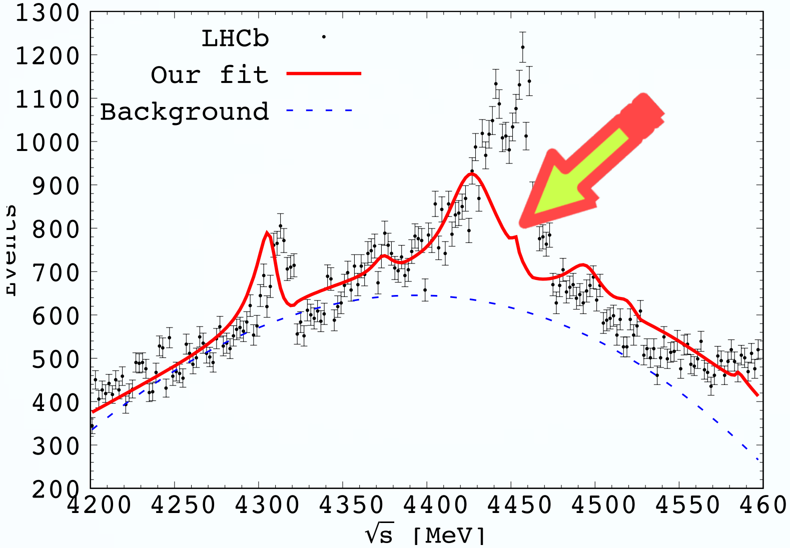
CWX, J. Nieves and E. Oset, Phys. Rev. D100 (2019) 014021

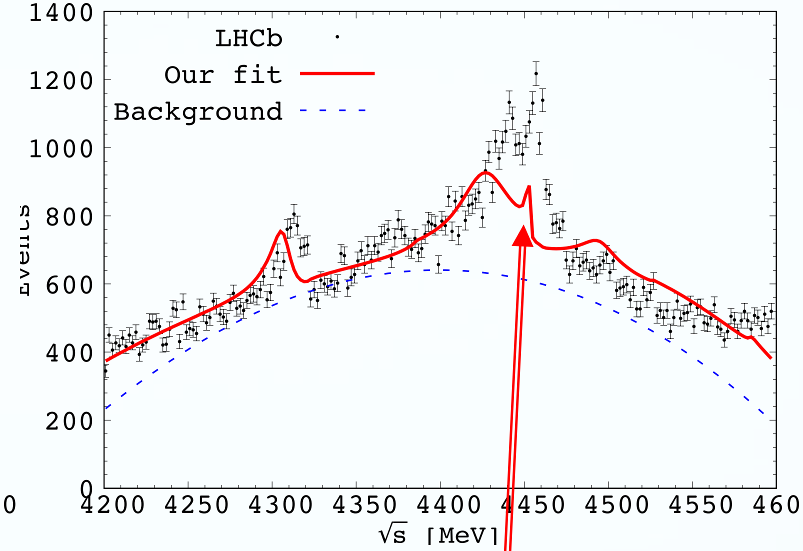
Next, we try to make a further investigation......



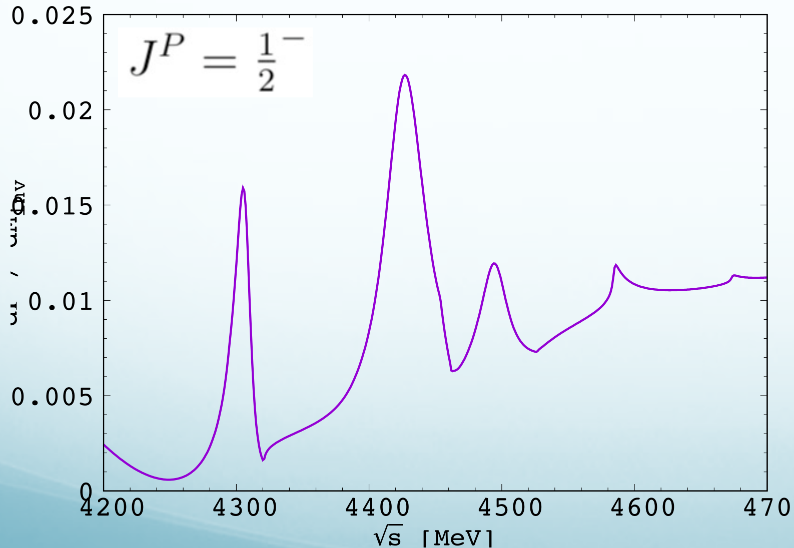
Consider $J/\psi p$ produced directly and final state interactions

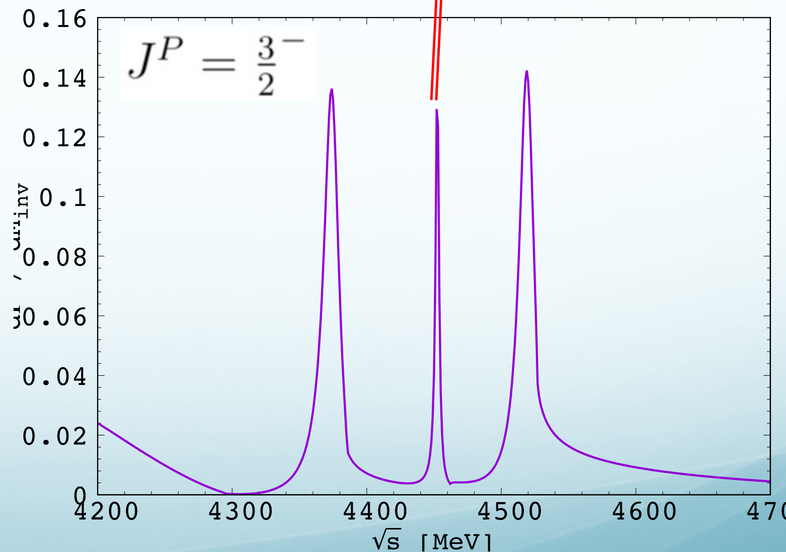




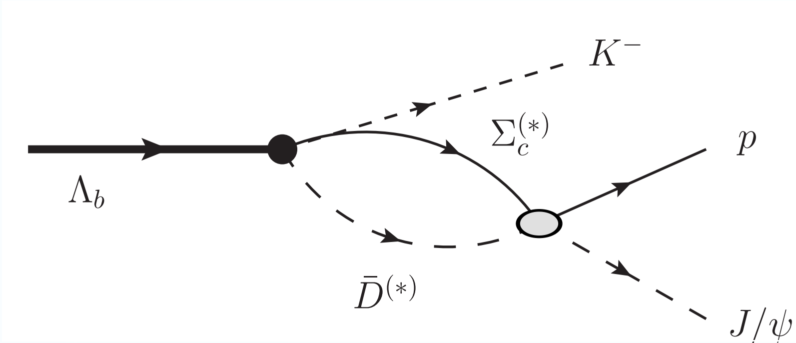


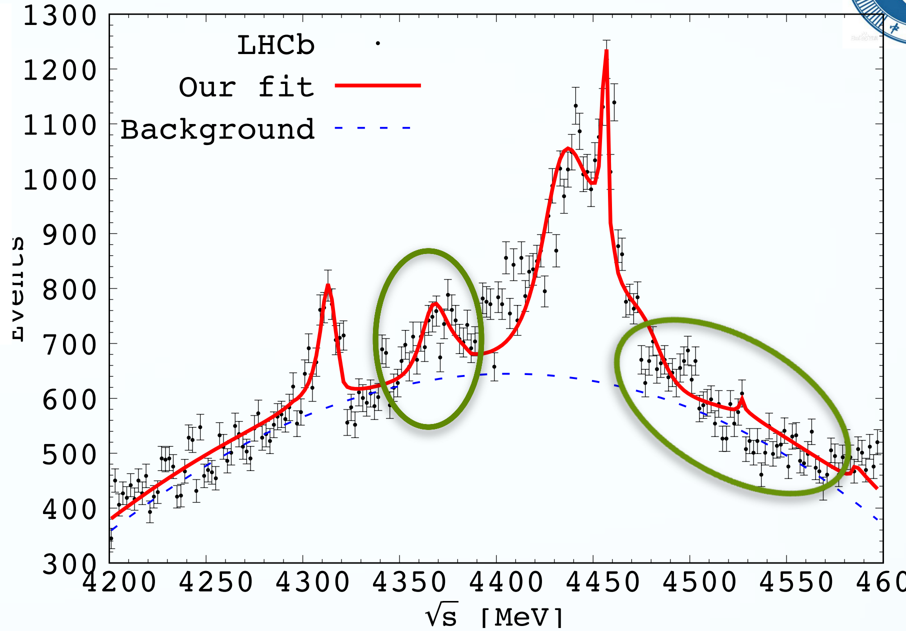
Indeed, this direct production is OZI suppressed!





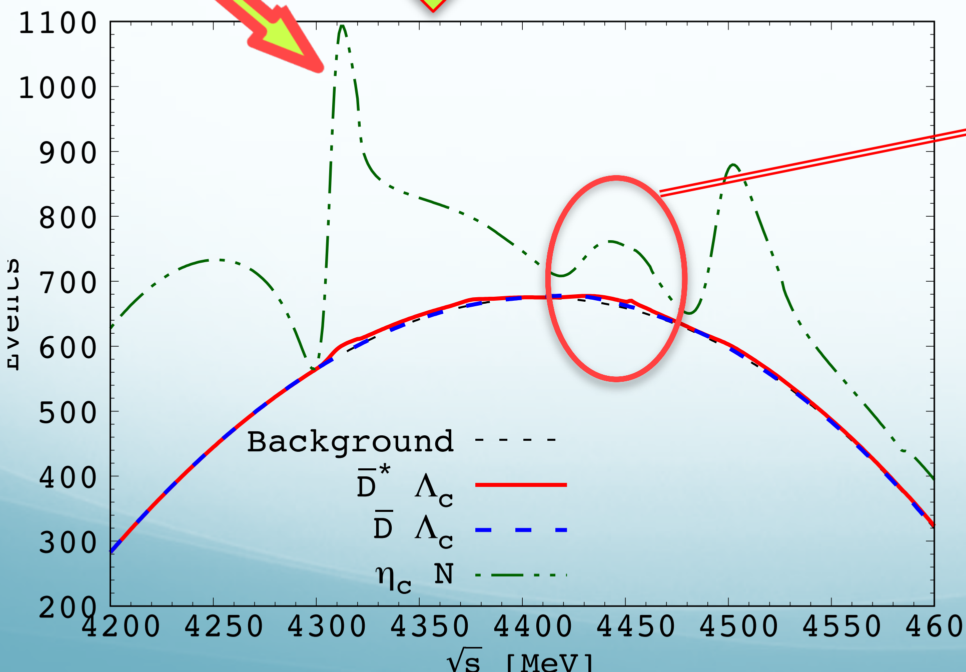
Consider $J/\psi p$ produced indirectly





$a(\mu = 1\,\mathrm{GeV}) = -2.09$

$P_c(4312)$



$J^P = \frac{1}{2}^-$

$P_c(4440)$ and $P_c(4457)$

CWX, J. X. Lu, J. J. Wu, and L. S. Geng, Phys. Rev. D102 (2020) 056018

$I = 1/2, J^P = 1/2^-$

(4306.0 + i7.0) MeV	$\eta_c N$	$J/\psi N$	$\bar{D}\Lambda_c$	$\bar{D}\Sigma_c$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}^*\Sigma_c^*$
$\|g_i\|$	0.59	0.41	0.01	1.99	0.10	0.02	0.03
Γ_i	9.7	3.9	0.0	…	0.1	…	…
Br	69.0%	27.6%	0.0%	…	0.9%	…	…
(4433.0 + i11.0) MeV	$\eta_c N$	$J/\psi N$	$\bar{D}\Lambda_c$	$\bar{D}\Sigma_c$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}^*\Sigma_c^*$
$\|g_i\|$	0.16	0.49	0.03	0.07	0.03	2.42	0.06
Γ_i	0.7	6.4	0.1	0.2	0.0	…	…
Br	3.4%	29.0%	0.3%	1.1%	0.2%	…	…
(4500.0 + i5.5) MeV	$\eta_c N$	$J/\psi N$	$\bar{D}\Lambda_c$	$\bar{D}\Sigma_c$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}^*\Sigma_c^*$
$\|g_i\|$	0.37	0.26	0.05	0.03	0.02	0.02	2.29
Γ_i	4.5	1.9	0.2	0.1	0.0	0.0	…
Br	41.2%	17.7%	1.5%	0.5%	0.3%	0.0%	…

$J^P = 3/2^-$

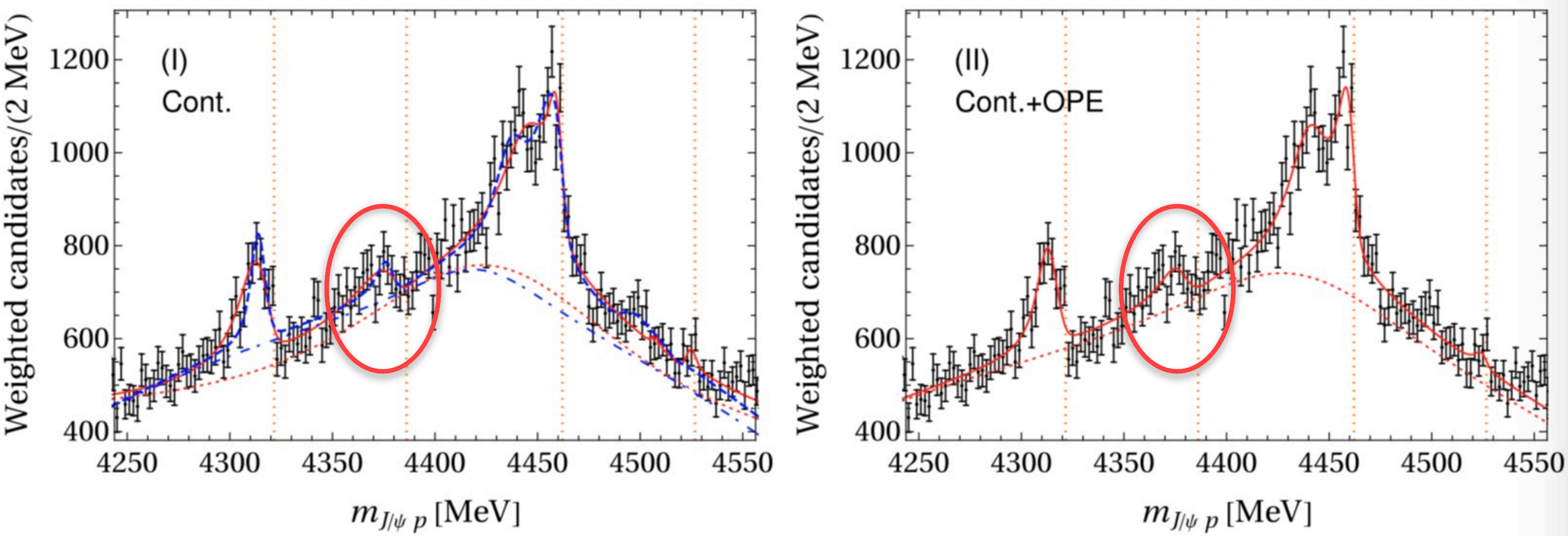
(4374.3 + i6.9) MeV	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
$\|g_i\|$	0.73	0.18	0.19	1.94	0.30
Γ_i	13.5	1.1	…	…	…
Br	98.4%	7.7%	…	…	…
(4452.5 + i1.5) MeV	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
$\|g_i\|$	0.30	0.07	1.82	0.08	0.19
Γ_i	2.6	0.2	…	0.2	…
Br	85.9	6.9	…	8.3	…
(4519.0 + i6.9) MeV	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
$\|g_i\|$	0.66	0.13	0.10	0.13	1.82
Γ_i	12.7	0.9	0.3	0.8	…
Br	92.4%	6.7%	2.5%	5.8%	…

PHYSICAL REVIEW LETTERS **124,** 072001 (2020)

Evidence that the LHCb P_c states are hadronic molecules and the existence of a narrow $P_c(4380)$

Meng-Lin Du,[1,*] Vadim Baru,[1,2,3,†] Feng-Kun Guo,[4,5,‡] Christoph Hanhart,[6,§]
Ulf-G. Meißner,[1,6,7,¶] José A. Oller,[8,**] and Qian Wang[9,10,††]

We also show that there is clear evidence for a narrow $\Sigma_c^* \bar{D}$ bound state in the data which we call $P_c(4380)$, different from the broad one reported by LHCb in 2015. With this state established, all



We make further study on the hidden charm strange sectors:

i) $J = 1/2,\ I = 0$

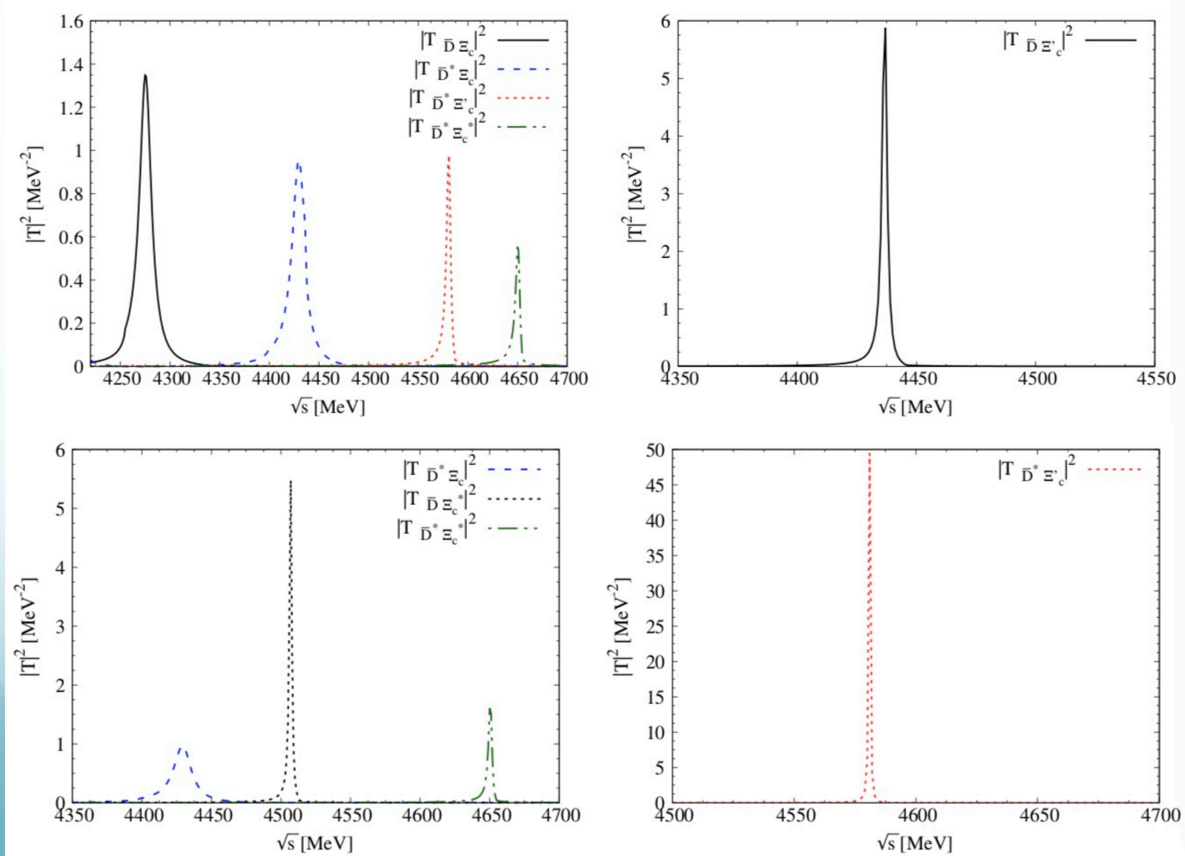
$\eta_c\Lambda,\ J/\psi\Lambda,\ \bar{D}\Xi_c,\ \bar{D}_s\Lambda_c,\ \bar{D}\Xi'_c,\ \bar{D}^*\Xi_c,\ \bar{D}^*_s\Lambda_c,\ \bar{D}^*\Xi'_c,\ \bar{D}^*\Xi^*_c.$

ii) $J = 3/2,\ I = 0$

$J/\psi\Lambda,\ \bar{D}^*\Xi_c,\ \bar{D}_s\Lambda_c,\ \bar{D}^*\Xi'_c,\ \bar{D}\Xi^*_c,\ \bar{D}^*\Xi^*_c.$

HQSS

$a(\mu = 1\,\mathrm{GeV}) = -2.09$



- $J = 1/2,\ I = 0$

$a(\mu = 1\,\mathrm{GeV}) = -2.09$

Thres.	4099.58	4212.58	4366.61	4254.80	4445.34	4477.92	4398.66	4586.66	4654.48
	$\eta_c\Lambda$	$J/\psi\Lambda$	$\bar{D}\Xi_c$	$\bar{D}_s\Lambda_c$	$\bar{D}\Xi_c'$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}^*\Xi_c^*$
$4276.59 + i7.67$									
g_i	$0.17 - i0.03$	$0.29 - i0.07$	$\mathbf{2.93 + i0.08}$	$0.76 + i0.31$	$0.00 + i0.01$	$0.01 + i0.02$	$0.01 + i0.04$	$0.01 - i0.02$	$0.01 - i0.03$
$\|g_i\|$	0.17	0.30	**2.93**	0.82	0.01	0.02	0.05	0.02	0.03
$4429.84 + i7.92$									
g_i	$0.29 - i0.11$	$0.17 - i0.07$	$0.00 - i0.00$	$0.00 - i0.00$	$0.15 - i0.26$	$\mathbf{2.78 + i0.01}$	$0.66 + i0.32$	$0.01 + i0.05$	$0.01 + i0.03$
$\|g_i\|$	0.31	0.18	0.00	0.00	0.30	**2.78**	0.73	0.05	0.04
$4436.70 + i1.17$									
g_i	$0.24 + i0.03$	$0.14 + 0.01$	$0.00 - i0.00$	$0.00 - i0.00$	$\mathbf{1.72 - i0.04}$	$0.22 - i0.31$	$0.06 - i0.01$	$0.01 - i0.04$	$0.01 - i0.03$
$\|g_i\|$	0.24	0.14	0.00	0.00	**1.72**	0.38	0.07	0.04	0.03
$4580.96 + i2.44$									
g_i	$0.12 - i0.00$	$0.37 - i0.04$	$0.02 - i0.01$	$0.02 - i0.01$	$0.03 - i0.00$	$0.02 - i0.02$	$0.03 - i0.02$	$\mathbf{1.57 - i0.17}$	$0.00 + i0.02$
$\|g_i\|$	0.12	0.37	0.02	0.02	0.03	0.03	0.03	**1.58**	0.02
$4650.86 + i2.59$									
g_i	$0.32 - i0.05$	$0.19 - i0.03$	$0.02 - i0.01$	$0.03 - i0.02$	$0.02 - i0.00$	$0.01 - i0.01$	$0.02 - i0.01$	$0.01 - i0.00$	$\mathbf{1.41 - i0.23}$
$\|g_i\|$	0.32	0.19	0.03	0.04	0.02	0.02	0.02	0.02	**1.43**

- $J = 3/2,\ I = 0$

Thres.	4212.58	4477.92	4398.66	4586.66	4513.17	4654.48
	$J/\psi\Lambda$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}\Xi_c^*$	$\bar{D}^*\Xi_c^*$
$4429.52 + i7.67$						
g_i	$0.31 - i0.10$	$\mathbf{2.77 - i0.02}$	$0.67 + i0.32$	$0.00 + i0.0.02$	$0.00 - i0.06$	$0.00 + i0.0.04$
$\lvert g_i \rvert$	0.32	**2.77**	0.74	0.02	0.06	0.04
$4506.99 + i1.03$						
g_i	$0.27 - i0.02$	$0.02 - i0.03$	$0.02 - i0.02$	$0.00 - i0.03$	$\mathbf{1.56 - i0.07}$	$0.00 - i0.05$
$\lvert g_i \rvert$	0.27	0.03	0.03	0.03	**1.56**	0.05
$4580.96 + i0.34$						
g_i	$0.14 - i0.01$	$0.01 - i0.01$	$0.01 - i0.01$	$\mathbf{1.54 - i0.02}$	$0.02 - i0.00$	$0.00 - i0.04$
$\lvert g_i \rvert$	0.14	0.01	0.02	**1.54**	0.02	0.04
$4650.58 + i1.48$						
g_i	$0.29 - i0.02$	$0.02 - i0.01$	$0.03 - i0.02$	$0.03 - i0.01$	$0.03 - i0.00$	$\mathbf{1.40 - i0.13}$
$\lvert g_i \rvert$	0.29	0.03	0.03	0.03	0.03	**1.41**

CWX, J. Nieves and E. Oset, Phys. Lett. B 799 (2019) 135051.

- $J = 1/2,\ I = 0$

$a_\mu(\mu = 1\ \text{GeV}) = -1.94$

Chan.	$\eta_c\Lambda$	$J/\psi\Lambda$	$\bar{D}\Xi_c$	$\bar{D}_s\Lambda_c$	$\bar{D}\Xi_c'$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}^*\Xi_c^*$
Thres.	4099.58	4212.58	4366.61	4254.80	4445.34	4477.92	4398.66	4586.66	4654.48
$4310.53 + i8.23$									
$\|g_i\|$	0.15	0.27	**2.33**	0.69	0.00	0.04	0.09	0.01	0.02
Γ_i	0.57	1.18	–	13.86	–	–	–	–	–
Br.	3.47%	7.16%	–	84.21%	–	–	–	–	–
$4445.12 + i0.19$									
$\|g_i\|$	0.10	0.06	0.00	0.00	**0.72**	0.08	0.04	0.01	0.01
Γ_i	0.29	0.08	0.00	0.00	–	–	0.04	–	–
Br.	74.74%	21.22%	0.01%	0.01%	–	–	10.62%	–	–
$4459.07 + i6.89$	$P_{cs}(4459)$								
$\|g_i\|$	0.22	0.13	0.00	0.00	0.07	**2.16**	0.61	0.03	0.02
Γ_i	1.59	0.46	0.00	0.00	0.01	–	11.14	–	–
Br.	11.57%	3.31%	0.00%	0.00%	0.70%	–	80.86%	–	–
4586.66?									
$\|g_i\|$	–	–	–	–	–	–	–	–	–
4654.48?									
$\|g_i\|$	–	–	–	–	–	–	–	–	–

- $J = 3/2,\ I = 0$

Chan.	$J/\psi\Lambda$	$\bar{D}^*\Xi_c$	$\bar{D}_s^*\Lambda_c$	$\bar{D}^*\Xi_c'$	$\bar{D}\Xi_c^*$	$\bar{D}^*\Xi_c^*$
Thres.	4212.58	4477.92	4398.66	4586.66	4513.17	4654.48
$4459.02 + i6.83$		$P_{cs}(4459)$				
$\lvert g_i \rvert$	0.28	**2.16**	0.61	0.02	0.04	0.03
Γ_i	2.00	–	11.15	–	–	–
Br.	14.68%	–	81.64%	–	–	–
4586.66?						
$\lvert g_i \rvert$	–	–	–	–	–	–
4513.17?						
$\lvert g_i \rvert$	–	–	–	–	–	–
4654.48?						
$\lvert g_i \rvert$	–	–	–	–	–	–

CWX, J. J. Wu and B. S. Zou, Phys. Rev. D 103 (2021) 054016.

§4. Summary

- Our results of bound states ——molecular states

a $\bar{D}\Sigma_c$ state
Having $J = 1/2$.

$P_c(4312)^+$ $\bar{D}\Xi_c$ $\bar{D}\Xi'_c$

a $\bar{D}\Sigma_c^*$ state
With $J = 3/2$.

$P_c(4380)$? $P_{cs}(4459)$ $\bar{D}\Xi_c^*$

a $\bar{D}^*\Sigma_c$ state
Degenerate in $J = 1/2,\ 3/2$.

$P_c(4440)^+$ $P_c(4457)^+$ $\bar{D}^*\Xi_c$ $\bar{D}^*\Xi'_c$

a $\bar{D}^*\Sigma_c^*$ state
Degenerate in $J = 1/2,\ 3/2,\ 5/2$.

$\bar{D}^*\Xi_c^*$

$P_c(4380)^+, \Gamma = 205$?

Hope that our predictions can be found in the future experiments!

谢谢大家！

Thanks for your attention!