五夸克态结构及产生机制的理论进展

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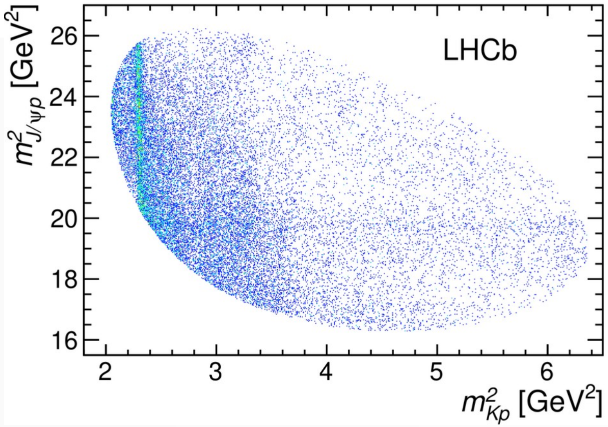
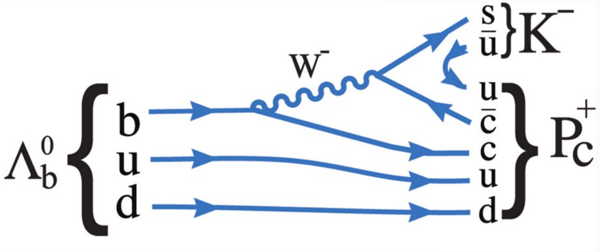
Interpretation of the LHCb Pc states as Hadronic Molecules and Hints of a Narrow Pc(4380)
Revisting the nature of the Pc states
In preparation

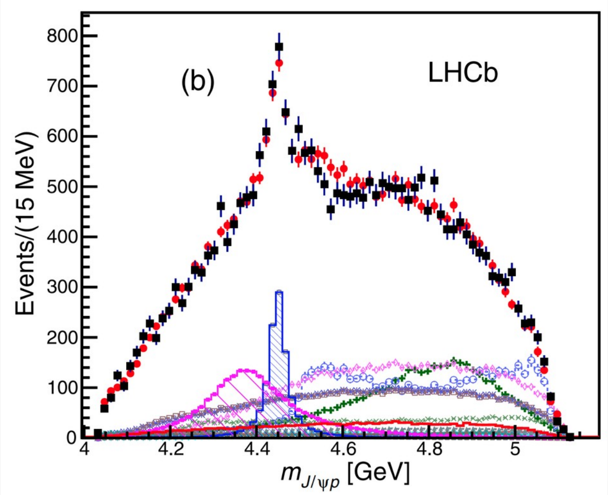
Charmonium-pentaquark states (I)

Observation of exotic structures (P_c) in $\Lambda_b^0 \to J/\psi p K^-$

LHCb, PRL 115, 072001 (2015)







$P_c(4380)^+$: $M = 4380 \pm 8 \pm 29$ MeV

$\Gamma = 205 \pm 18 \pm 86$ MeV

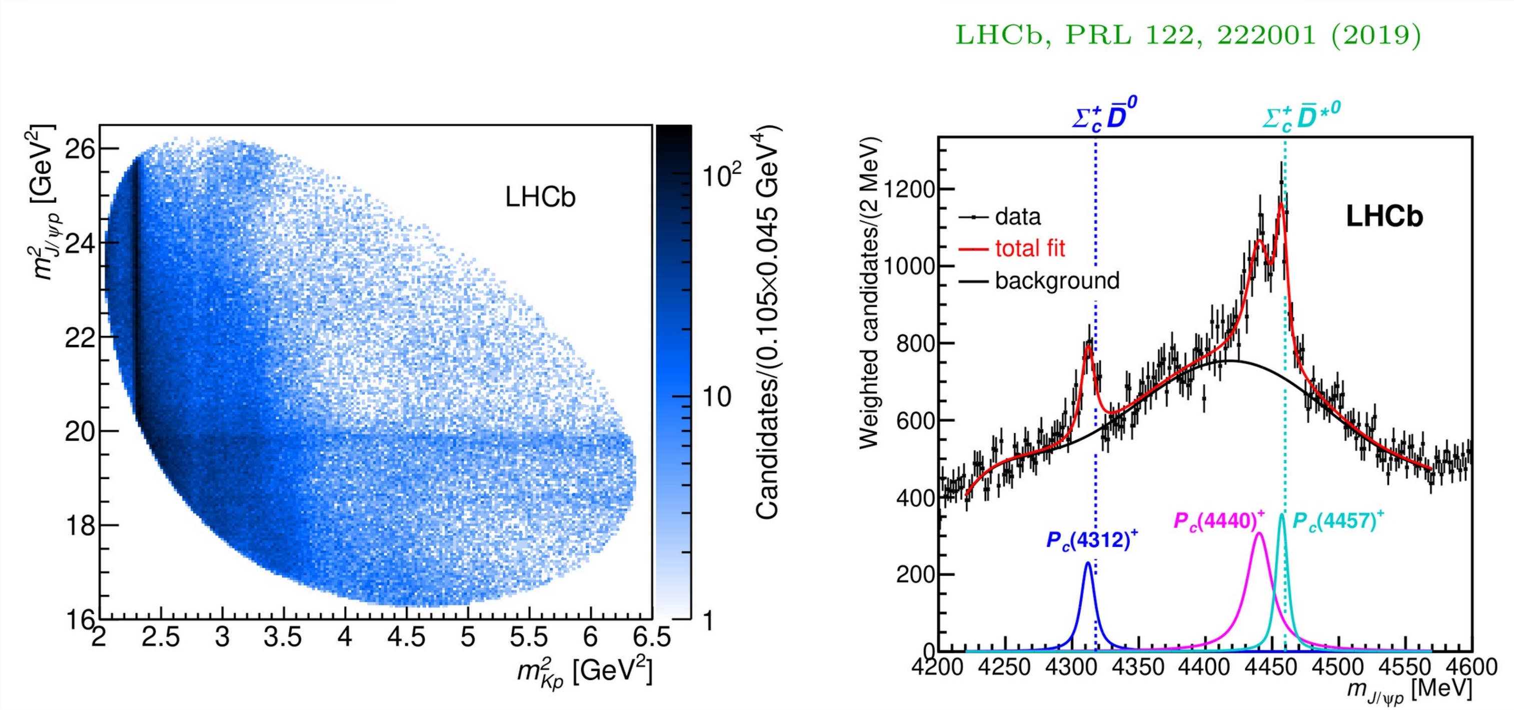
$P_c(4450)^+$: $M = 4449.8 \pm 1.7 \pm 2.5$ MeV

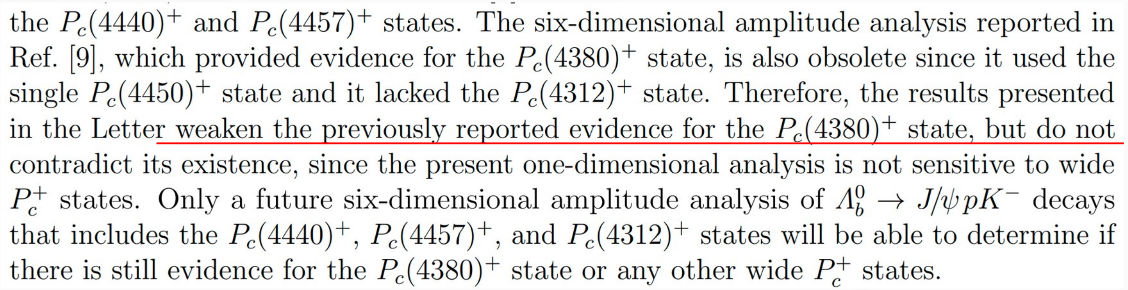
$\Gamma = 39 \pm 5 \pm 19$ MeV

Preferred Parity: Opposite

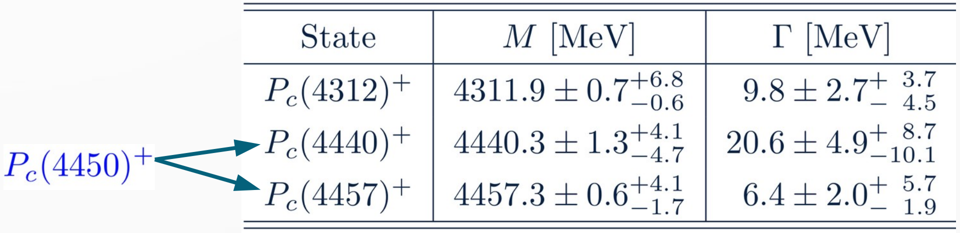
Charmonium-pentaquark states (II)

LHCb, PRL 122, 222001 (2019)





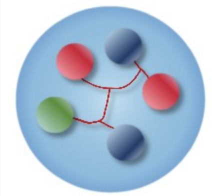
the $P_c(4440)^+$ and $P_c(4457)^+$ states. The six-dimensional amplitude analysis reported in Ref. [9], which provided evidence for the $P_c(4380)^+$ state, is also obsolete since it used the single $P_c(4450)^+$ state and it lacked the $P_c(4312)^+$ state. Therefore, the results presented in the Letter weaken the previously reported evidence for the $P_c(4380)^+$ state, but do not contradict its existence, since the present one-dimensional analysis is not sensitive to wide P_c^+ states. Only a future six-dimensional amplitude analysis of $\Lambda_b^0 \to J/\psi p K^-$ decays that includes the $P_c(4440)^+$, $P_c(4457)^+$, and $P_c(4312)^+$ states will be able to determine if there is still evidence for the $P_c(4380)^+$ state or any other wide P_c^+ states.



$P_c(4450)^+$

State	M [MeV]	Γ [MeV]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$

Proposals [after 2019]



Compact Pentaquark

Chromomagnetic model, JB Cheng and YR Liu, PRD100, 054002 (2019)

$P_c(4312),\ P_c(4440),\ P_c(4457)\text{:}\ J^P = 3/2^-,\ 1/2^-,\ 3/2^-$

$P_c(4380)^+$, $P_c(4440)^+$ and $P_c(4457)^+$ is $\frac{3}{2}^-$ R. Deng, PRD105, 116021 (2022)

Compact diquark model, Ali et al., JHEP10, 256 (2019)

$3/2^-$	4240 ± 29
$3/2^+$	4440 ± 35
$5/2^+$	4457 ± 35

R. Zhu et al., PLB797, 134869(2019)
Giron et al., JHEP05, 061 (2019)
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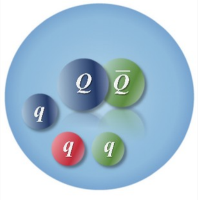
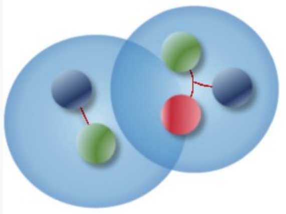


Hadron-Charmonium

Compact $(\bar{Q}Q)$ surrounded by light quarks

Eides et al., Mod. Phys. Lett. A 35, 2050151 (2020)

$J^P = 1/2^+,\ 1/2^-,\ 3/2^-$



Hadronic Molecule

Extended object

H.X. Chen et al., PRD100, 051501 (2019)
R. Chen et al., PRD100, 011502 (2019)
F.K. Guo et al., PRD99, 091501 (2019)
M.Z. Liu et al., PRL122, 242001 (2019)
Z.H. Guo et al., PLB793, 144 (2019)
L. Meng et al., PRD100, 014031(2019)
J.J. Wu et al., PRC100, 035026 (2019)
J.-Z. Wu et al., CPL41,091201(2024)
……

Kinematic effect

Kuang et al., EPJC80,433 (2020)
Nakamura, PRD103, L111503(2021)
Burns et al., PRD106,054029(2022)
……

Heavy Quark Spin Symmetry (HQSS)

- For a heavy-quark Q (charm, bottom) with $m_Q \gg \Lambda_{\rm QCD}$

☞ chromomag. interaction $\propto \dfrac{\sigma \cdot \mathbf{B}}{m_Q} \rightarrow 0$: independent of heavy-quark spin

- For a hadron containing a heavy-quark Q: $J = s_Q + j_\ell$

S-wave baryon-meson system
(ground states)

$s_Q = \frac{1}{2} \otimes \frac{1}{2} = 0 \oplus 1$

$j_\ell = \underline{\frac{1}{2} \oplus \frac{3}{2}}$ →

LO Contact Interaction: Only 2 LECs

	Molecule	J^P	M (MeV)		Molecule	J^P	M (MeV)
A	$\bar{D}\Sigma_c$	$\frac{1}{2}^-$	$4311.8 - 4313.0$	B	$\bar{D}\Sigma_c$	$\frac{1}{2}^-$	$4306.3 - 4307.7$
A	$\bar{D}\Sigma_c^*$	$\frac{3}{2}^-$	$4376.1 - 4377.0$	B	$\bar{D}\Sigma_c^*$	$\frac{3}{2}^-$	$4370.5 - 4371.7$
A	$\bar{D}^*\Sigma_c$	$\frac{1}{2}^-$	4440.3^*	B	$\bar{D}^*\Sigma_c$	$\frac{1}{2}^-$	4457.3^*
A	$\bar{D}^*\Sigma_c$	$\frac{3}{2}^-$	4457.3^*	B	$\bar{D}^*\Sigma_c$	$\frac{3}{2}^-$	4440.3^*
A	$\bar{D}^*\Sigma_c^*$	$\frac{1}{2}^-$	$4500.2 - 4501.0$	B	$\bar{D}^*\Sigma_c^*$	$\frac{1}{2}^-$	$4523.2 - 4523.6$
A	$\bar{D}^*\Sigma_c^*$	$\frac{3}{2}^-$	$4510.6 - 4510.8$	B	$\bar{D}^*\Sigma_c^*$	$\frac{3}{2}^-$	$4516.5 - 4516.6$
A	$\bar{D}^*\Sigma_c^*$	$\frac{5}{2}^-$	$4523.3 - 4523.6$	B	$\bar{D}^*\Sigma_c^*$	$\frac{5}{2}^-$	$4500.2 - 4501.0$

7 Pc states!

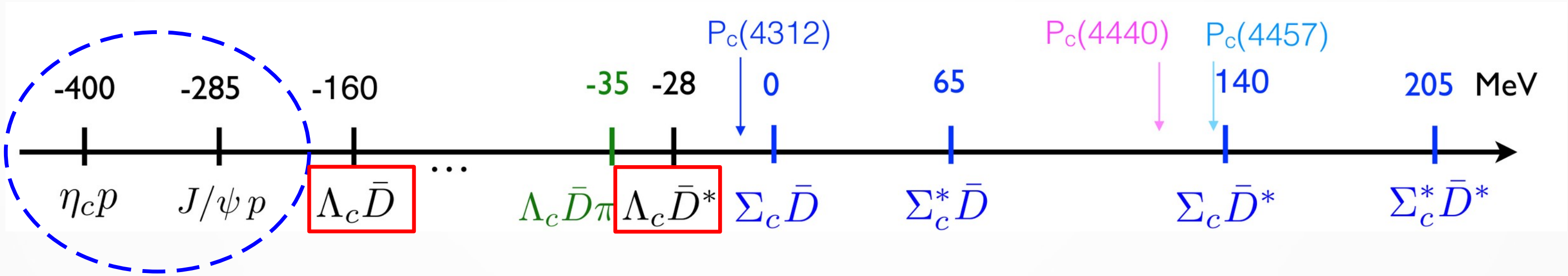
Xiao et al., PRD88, 56012 (2013)

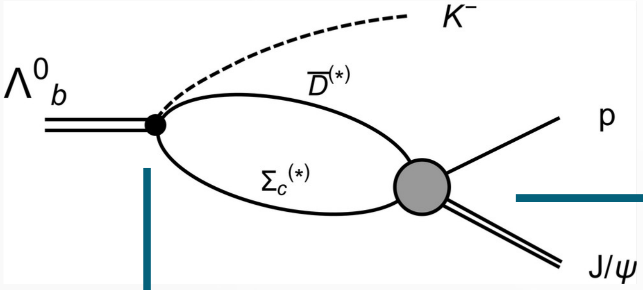
Liu et al., PRL122,242001 (2019)

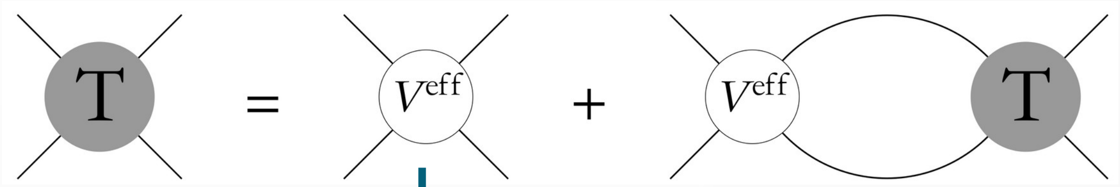
Molecular Interpretation [EFT]

MLD et al., PRL124,072001(2020)
MLD et al., JHEP08,157 (2021)

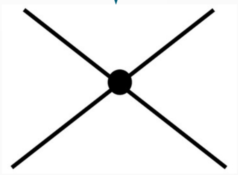
- A coupled-channel analysis of the LHCb spectra using an EFT approach







7 LECs for contact Production



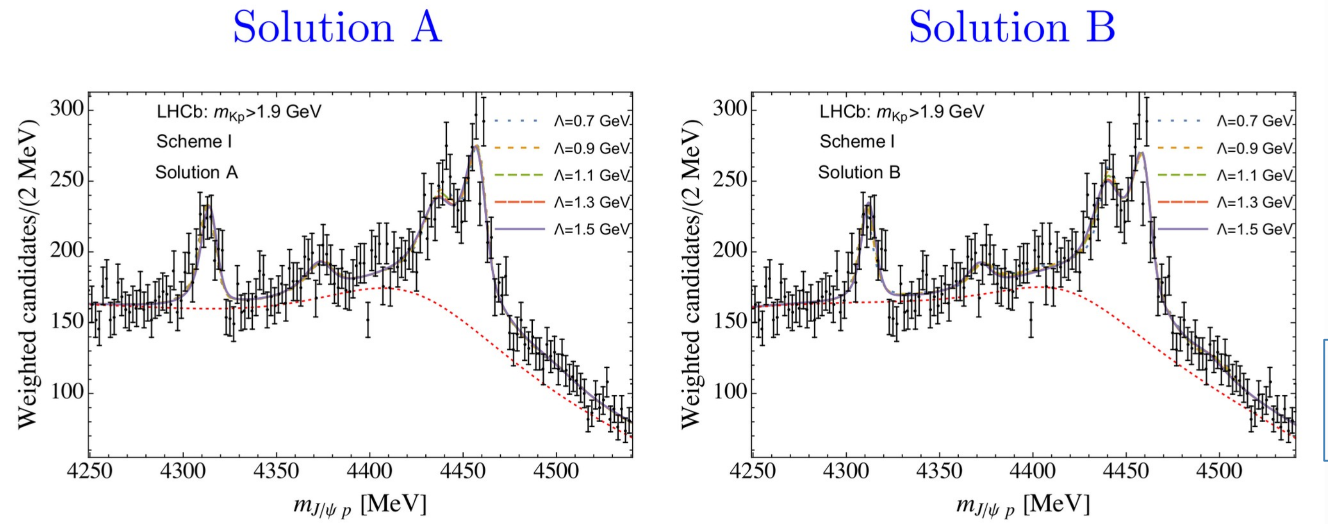
$\bar{D}^{(*)}\Sigma_c^{(*)} \to \bar{D}^{(*)}\Sigma_c^{(*)}$ 2 LECs

$\bar{D}^{(*)}\Sigma_c^{(*)}(S) \to J/\Psi p(S),\ J/\Psi p(D)$

2 LECs

“Contact” Fits to the LHCb data

MLD et al., PRL124,072001(2020)
MLD et al., JHEP08,157 (2021)

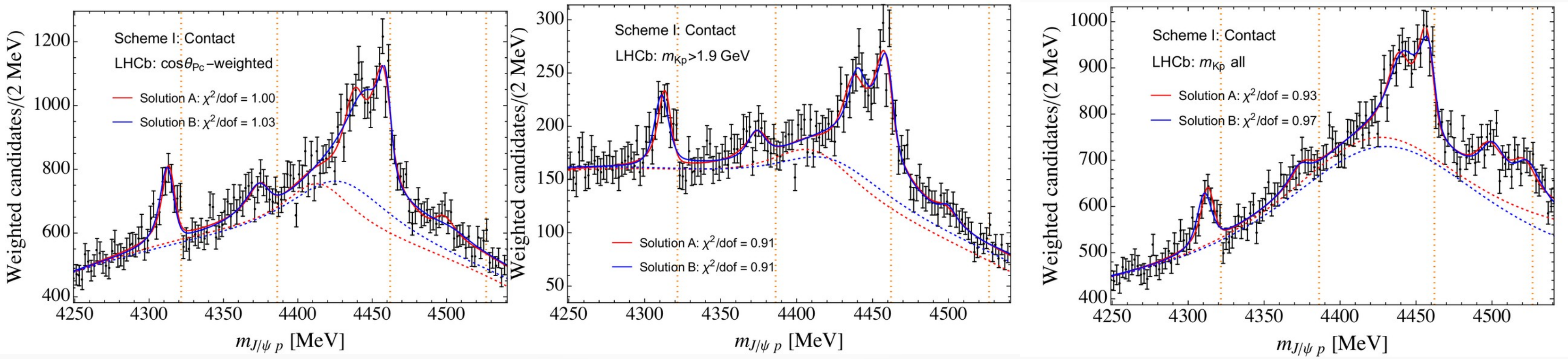


- ☞ $\Lambda > \Lambda_{\rm soft} \sim \sqrt{2\mu\delta} \sim 0.7$ GeV
- ☞ Cutoff-independent for both solution A and B

$\Sigma_c\bar{D}^*$	$P_c(4440)$	$P_c(4457)$
Fit A	$\frac{1}{2}^-$	$\frac{3}{2}^-$
Fit B	$\frac{3}{2}^-$	$\frac{1}{2}^-$

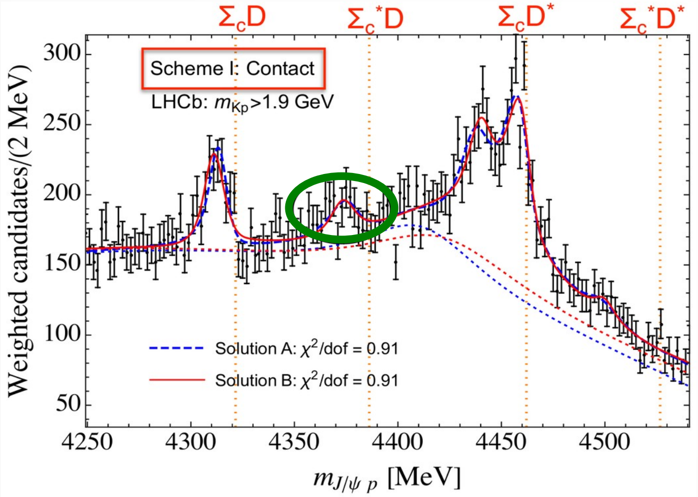
If $\Sigma_c^{(*)}\bar{D}^{(*)} \to \Lambda_c\bar{D}^{(*)}$ is included, one more LEC

☞ No need for $\Lambda_c\bar{D}^{(*)}$ overdetermined



Line shape and Pc Poles: Contact

MLD et al., PRL124,072001(2020)
MLD et al., JHEP08,157 (2021)



- $P_c(4312)$, $P_c(4440)$, $P_c(4457)$ are well understood as $\Sigma_c D$, $\Sigma_c D^*$ and $\Sigma_c D^*$ quasi-bound states, respectively
- A narrow Pc(4380) state predicted as a $\Sigma_c{}^*D$ $3/2^-$ molecule is seen in data

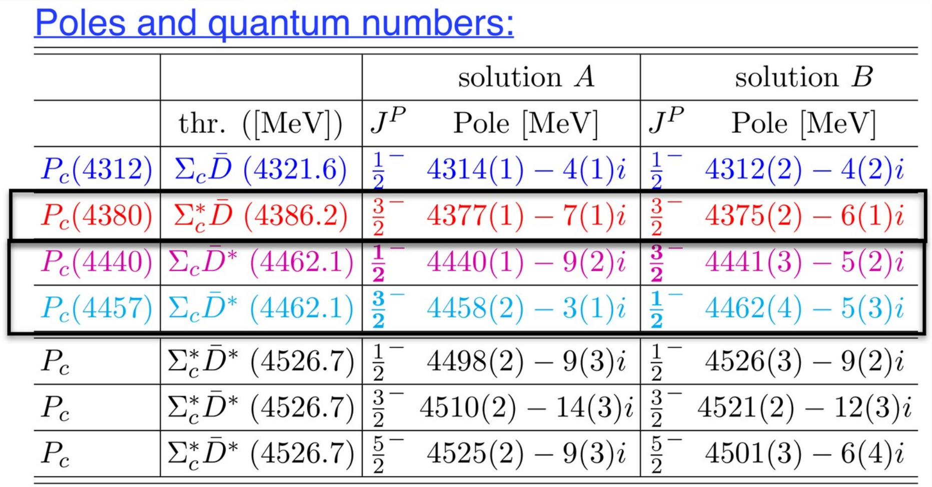
NOT the broad Pc(4380)

reported by LHCb in 2015

- $\Sigma_c{}^*D^*$ states are not seen yet, their production rate is suppressed ?

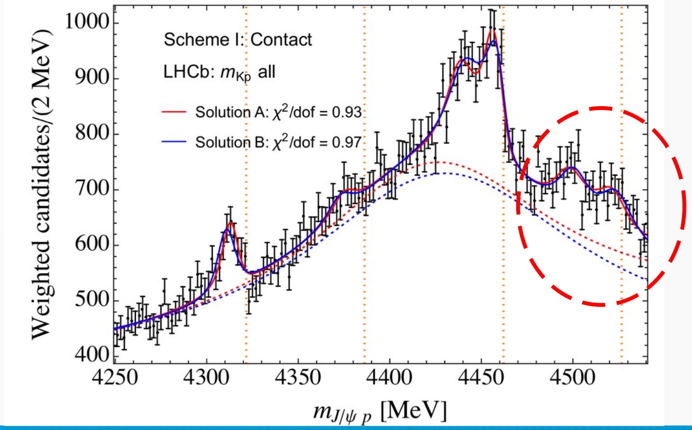
↪ prompt production in the *pp* collision in the LHC

P. Ling et al., EPJC81,819 (2021)



Poles and quantum numbers:

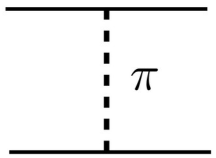
		solution A		solution B	
	thr. ([MeV])	J^P	Pole [MeV]	J^P	Pole [MeV]
$P_c(4312)$	$\Sigma_c\bar{D}$ (4321.6)	$\frac{1}{2}^-$	$4314(1)-4(1)i$	$\frac{1}{2}^-$	$4312(2)-4(2)i$
$P_c(4380)$	$\Sigma_c^*\bar{D}$ (4386.2)	$\frac{3}{2}^-$	$4377(1)-7(1)i$	$\frac{3}{2}^-$	$4375(2)-6(1)i$
$P_c(4440)$	$\Sigma_c\bar{D}^*$ (4462.1)	$\frac{1}{2}^-$	$4440(1)-9(2)i$	$\frac{3}{2}^-$	$4441(3)-5(2)i$
$P_c(4457)$	$\Sigma_c\bar{D}^*$ (4462.1)	$\frac{3}{2}^-$	$4458(2)-3(1)i$	$\frac{1}{2}^-$	$4462(4)-5(3)i$
P_c	$\Sigma_c^*\bar{D}^*$ (4526.7)	$\frac{1}{2}^-$	$4498(2)-9(3)i$	$\frac{1}{2}^-$	$4526(3)-9(2)i$
P_c	$\Sigma_c^*\bar{D}^*$ (4526.7)	$\frac{3}{2}^-$	$4510(2)-14(3)i$	$\frac{3}{2}^-$	$4521(2)-12(3)i$
P_c	$\Sigma_c^*\bar{D}^*$ (4526.7)	$\frac{5}{2}^-$	$4525(2)-9(3)i$	$\frac{5}{2}^-$	$4501(3)-6(4)i$



Including OPE

MLD et al., PRL124,072001(2020)
MLD et al., JHEP08,157 (2021)

$\boxed{\text{contact} + \text{OPE}}$



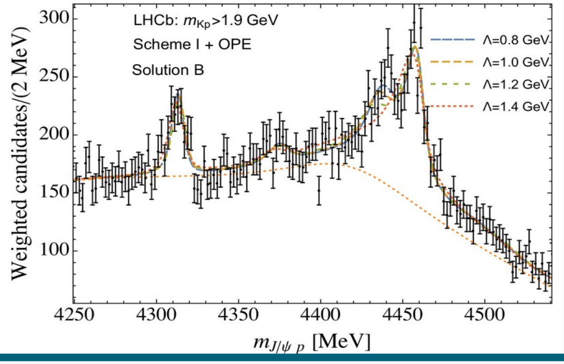
Long range: OPE

Determined by exp. data

☞ No solution A

☞ Solution B:
Cut-off dependent

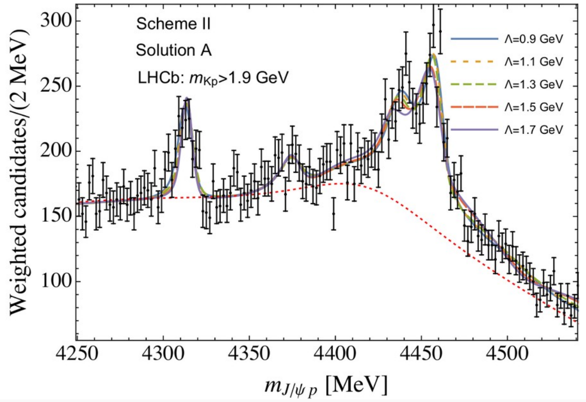
☞ $\Lambda_{\text{soft}} \sim 700$ MeV



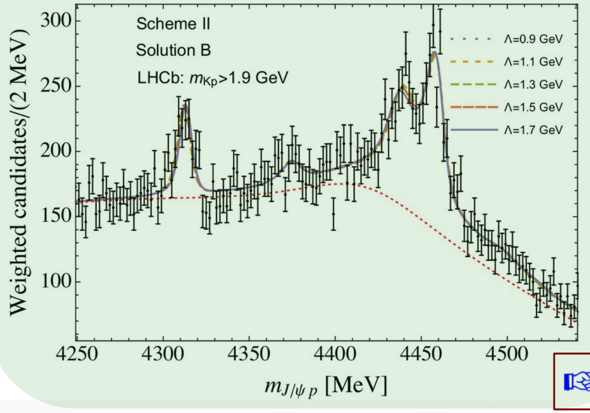
$\boxed{+\,\Lambda_c \bar{D}^{(*)}}$

$\boxed{\text{contact} + \text{OPE} + \text{S-D}}$

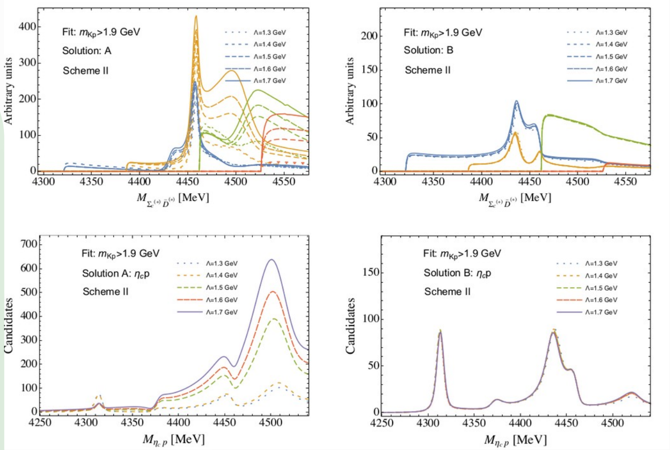
Solution A



Solution B



Solution A $\Lambda_{\text{soft}} \sim 0.7$ GeV Solution B



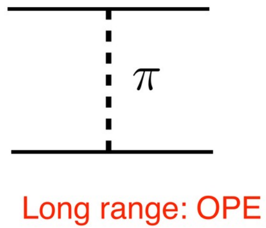
☞ Overdetermined. w/ $\Lambda_c \bar{D}^{(*)}$ $\Lambda_{\text{soft}} \sim 0.9$ GeV

☞ Cutoff-independent only for solution B

Including OPE

MLD et al., PRL124,072001(2020)
MLD et al., JHEP08,157 (2021)

contact + OPE



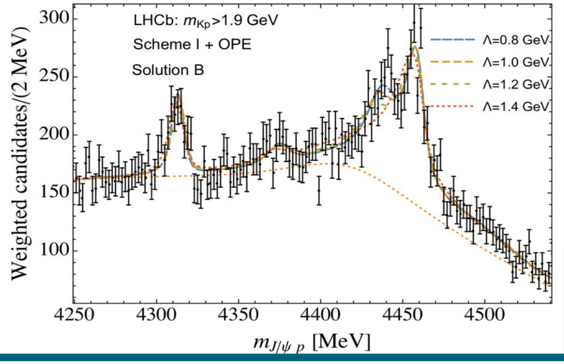
Long range: OPE

Determined by exp. data

☞ No solution A

☞ Solution B:
Cut-off dependent

☞ $\Lambda_{\rm soft} \sim 700$ MeV



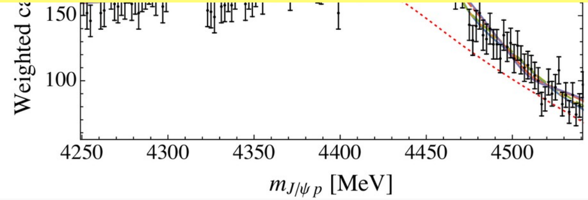
$+\ \Lambda_c \bar{D}^{(*)}$

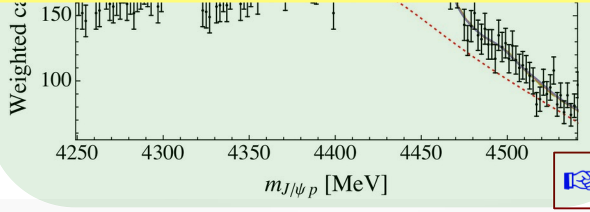
contact + OPE + S-D

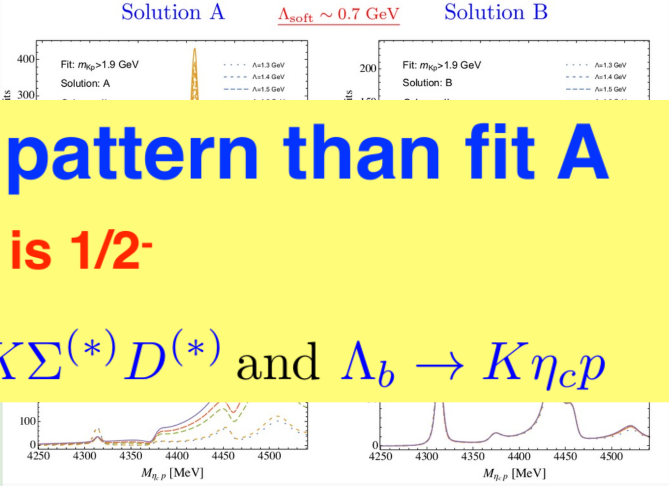
Fit B shows a much more natural pattern than fit A

⇒ P_c(4440) is $3/2^-$ and P_c(4457) is $1/2^-$

⇒ experimentally testable via $\Lambda_b \to K\Sigma^{(*)}D^{(*)}$ and $\Lambda_b \to K\eta_c p$







☞ Overdetermined. w/ $\Lambda_c \bar{D}^{(*)}$ $\Lambda_{\rm soft} \sim 0.9$ GeV

☞ Cutoff-independent only for solution B

Analysis based on Born–Oppenheimer effective field theory

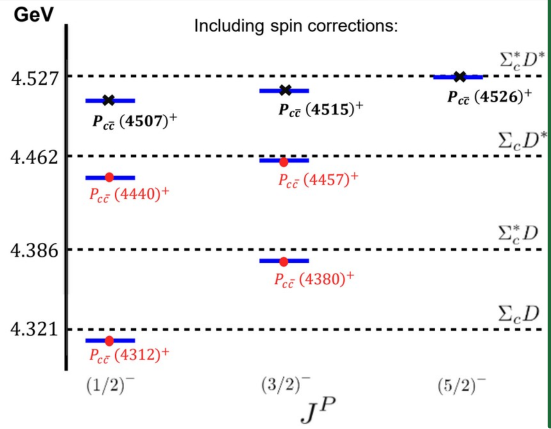
$$E_{(\Lambda)_\eta}(r) \equiv E_{\kappa,|\lambda|}(r) = \lim_{T\to\infty} \frac{i}{T}\log\left[\langle \text{vac}|\mathcal{O}_{\kappa,\lambda}(T/2,\,\boldsymbol{r},\,\boldsymbol{R})\,\mathcal{O}^\dagger_{\kappa,\lambda}(-T/2,\,\boldsymbol{r},\,\boldsymbol{R})|\text{vac}\rangle\right]$$

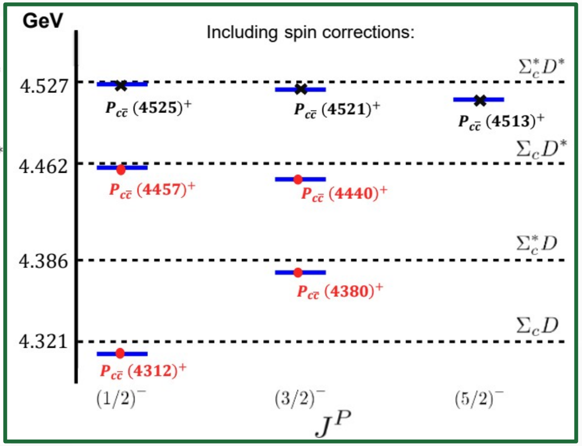
$$\mathcal{O}_{\kappa,\lambda}(t,\boldsymbol{r},\boldsymbol{R}) = \chi^\dagger(t,\boldsymbol{R}+\boldsymbol{r}/2)\,\phi(t;\boldsymbol{R}+\boldsymbol{r}/2,\boldsymbol{R})\,P^{\alpha\dagger}_{\kappa,\lambda}H^{\alpha,a}_{8,\kappa}(t,\boldsymbol{R})\,T^a\,\phi(t;\boldsymbol{R},\boldsymbol{R}-\boldsymbol{r}/2)\,\psi(t,\boldsymbol{R}-\boldsymbol{r}/2)$$

$Q\bar{Q}$ color state	Light spin k^P	BO quantum # $D_{\infty h}$	l	J^P $\{s=0, s=1\}$
Octet	$(1/2)^+$	$(1/2)_g$	$1/2$	$\{1/2^-, (1/2, 3/2)^-\}$
8	$(3/2)^+$	$\{(1/2)'_g, (3/2)_g\}$	$3/2$	$\{3/2^-, (1/2, 3/2, 5/2)^-\}$

不束缚

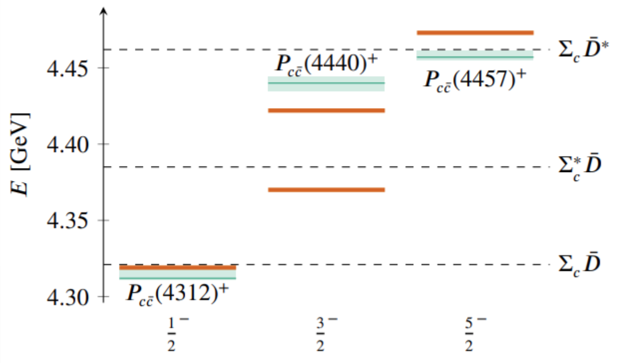
Brambilla et al., PRD112, 114037(2025)





衰变分析倾向于右边

Alasiri et al., PLB873, 140162(2026)



HQEFT

$P_c(4457)$ as a $J^P = 5/2^-$ $\Sigma_c^*\bar{D}^*$ (4526.7 MeV) bound state.

HQEFT analysis of BOEFT results

$$C_{\frac{1}{2}} \equiv \left\langle s_Q \otimes \frac{1}{2} \middle| \hat{\mathcal{H}}_I \middle| s_Q \otimes \frac{1}{2} \right\rangle, \quad C_{\frac{3}{2}} \equiv \left\langle s_Q \otimes \frac{3}{2} \middle| \hat{\mathcal{H}}_I \middle| s_Q \otimes \frac{3}{2} \right\rangle,$$

$$V_C^{\frac{1}{2}^-} = \left(\begin{array}{ccc} \frac{1}{3}C_{\frac{1}{2}} + \frac{2}{3}C_{\frac{3}{2}} & \frac{2}{3\sqrt{3}}C_{\frac{1}{2}} - \frac{2}{3\sqrt{3}}C_{\frac{3}{2}} & \frac{1}{3}\sqrt{\frac{2}{3}}C_{\frac{1}{2}} - \frac{1}{3}\sqrt{\frac{2}{3}}C_{\frac{3}{2}} \\ \frac{2}{3\sqrt{3}}C_{\frac{1}{2}} - \frac{2}{3\sqrt{3}}C_{\frac{3}{2}} & \frac{7}{9}C_{\frac{1}{2}} + \frac{2}{9}C_{\frac{3}{2}} & -\frac{\sqrt{2}}{9}C_{\frac{1}{2}} + \frac{\sqrt{2}}{9}C_{\frac{3}{2}} \\ \frac{1}{3}\sqrt{\frac{2}{3}}C_{\frac{1}{2}} - \frac{1}{3}\sqrt{\frac{2}{3}}C_{\frac{3}{2}} & -\frac{\sqrt{2}}{9}C_{\frac{1}{2}} + \frac{\sqrt{2}}{9}C_{\frac{3}{2}} & \frac{8}{9}C_{\frac{1}{2}} + \frac{1}{9}C_{\frac{3}{2}} \end{array}\right) \begin{array}{c} |\Sigma_c\bar{D}\rangle \\ |\Sigma_c\bar{D}^*\rangle \\ |\Sigma_c^*\bar{D}^*\rangle \end{array}$$

$$V_C^{\frac{3}{2}^-} = \left(\begin{array}{ccc} \frac{1}{9}C_{\frac{1}{2}} + \frac{8}{9}C_{\frac{3}{2}} & -\frac{1}{3\sqrt{3}}C_{\frac{1}{2}} + \frac{1}{3\sqrt{3}}C_{\frac{3}{2}} & -\frac{\sqrt{5}}{9}C_{\frac{1}{2}} + \frac{\sqrt{5}}{9}C_{\frac{3}{2}} \\ -\frac{1}{3\sqrt{3}}C_{\frac{1}{2}} + \frac{1}{3\sqrt{3}}C_{\frac{3}{2}} & \frac{1}{3}C_{\frac{1}{2}} + \frac{2}{3}C_{\frac{3}{2}} & +\frac{1}{3}\sqrt{\frac{5}{3}}C_{\frac{1}{2}} - \frac{1}{3}\sqrt{\frac{5}{3}}C_{\frac{3}{2}} \\ -\frac{\sqrt{5}}{9}C_{\frac{1}{2}} + \frac{\sqrt{5}}{9}C_{\frac{3}{2}} & \frac{1}{3}\sqrt{\frac{5}{3}}C_{\frac{1}{2}} - \frac{1}{3}\sqrt{\frac{5}{3}}C_{\frac{3}{2}} & \frac{5}{9}C_{\frac{1}{2}} + \frac{4}{9}C_{\frac{3}{2}} \end{array}\right) \begin{array}{c} |\Sigma_c\bar{D}^*\rangle \\ |\Sigma_c^*\bar{D}\rangle \\ |\Sigma_c^*\bar{D}^*\rangle \end{array}$$

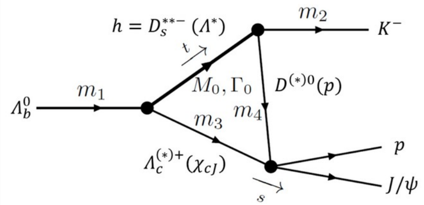
$$V_C^{\frac{5}{2}^-} = C_{\frac{3}{2}}. \qquad |\Sigma_c^*\bar{D}^*\rangle$$

$$\mathbb{V}_C^{\frac{1}{2}^-} = P_{1/2}.V_C^{\frac{1}{2}^-}.P_{1/2}^{-1} = \begin{pmatrix} C_{\frac{3}{2}} & 0 & 0 \\ 0 & C_{\frac{1}{2}} & 0 \\ 0 & 0 & C_{\frac{1}{2}} \end{pmatrix}$$

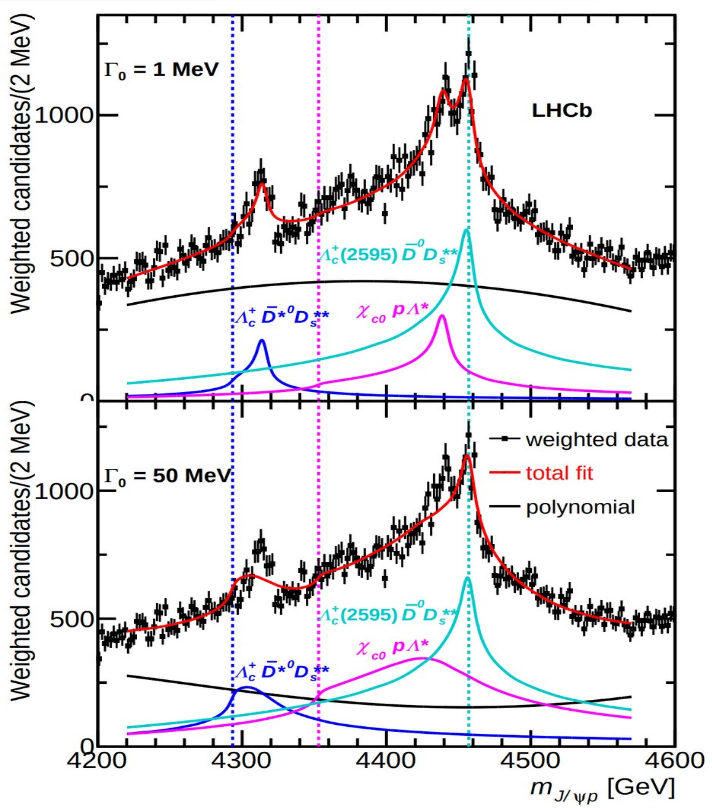
$$\mathbb{V}_C^{\frac{3}{2}^-} = P_{3/2}.V_C^{\frac{3}{2}^-}.P_{3/2}^{-1} = \begin{pmatrix} C_{\frac{3}{2}} & 0 & 0 \\ 0 & C_{\frac{3}{2}} & 0 \\ 0 & 0 & C_{\frac{1}{2}} \end{pmatrix}$$

$\boxed{C_{\frac{1}{2}} = 0}$ ⇒ 4 states!

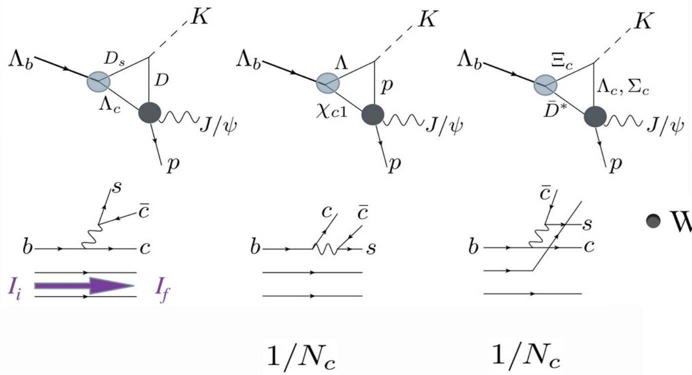
Triangle Diagrams

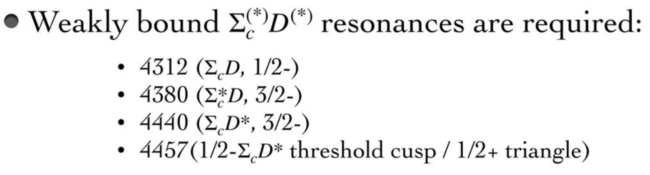


LHCb, PRL122, 222001 (2019)

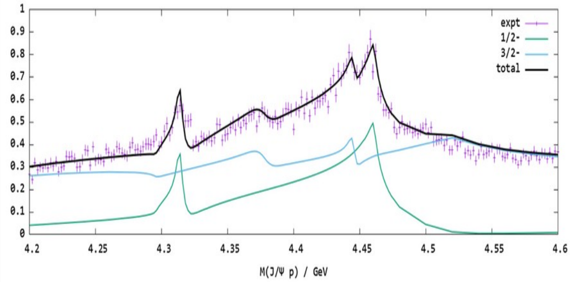


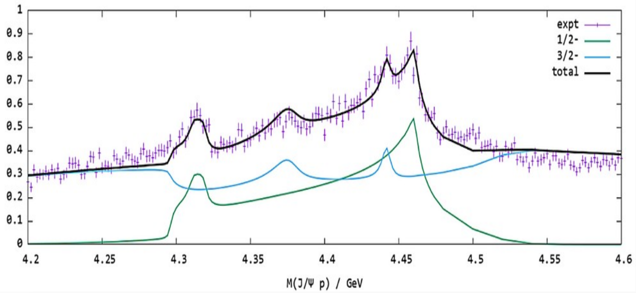
Burns et al., PRD106,054029 (2022)

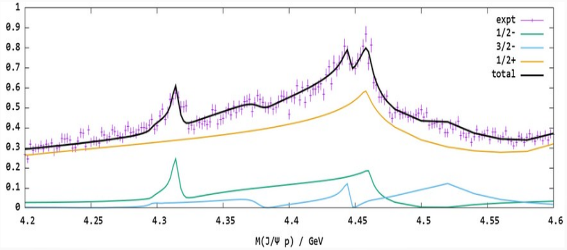


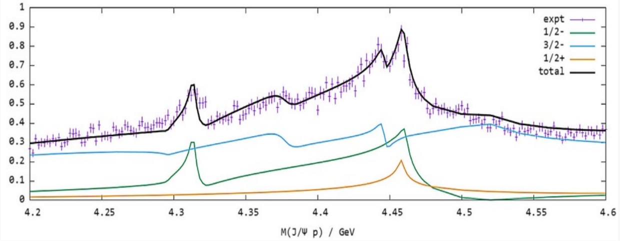


- Weakly bound $\Sigma_c^{(*)}D^{(*)}$ resonances are required:
  - 4312 ($\Sigma_c D$, 1/2-)
  - 4380 ($\Sigma_c^* D$, 3/2-)
  - 4440 ($\Sigma_c D^*$, 3/2-)
  - 4457(1/2-$\Sigma_c D^*$ threshold cusp / 1/2+ triangle)



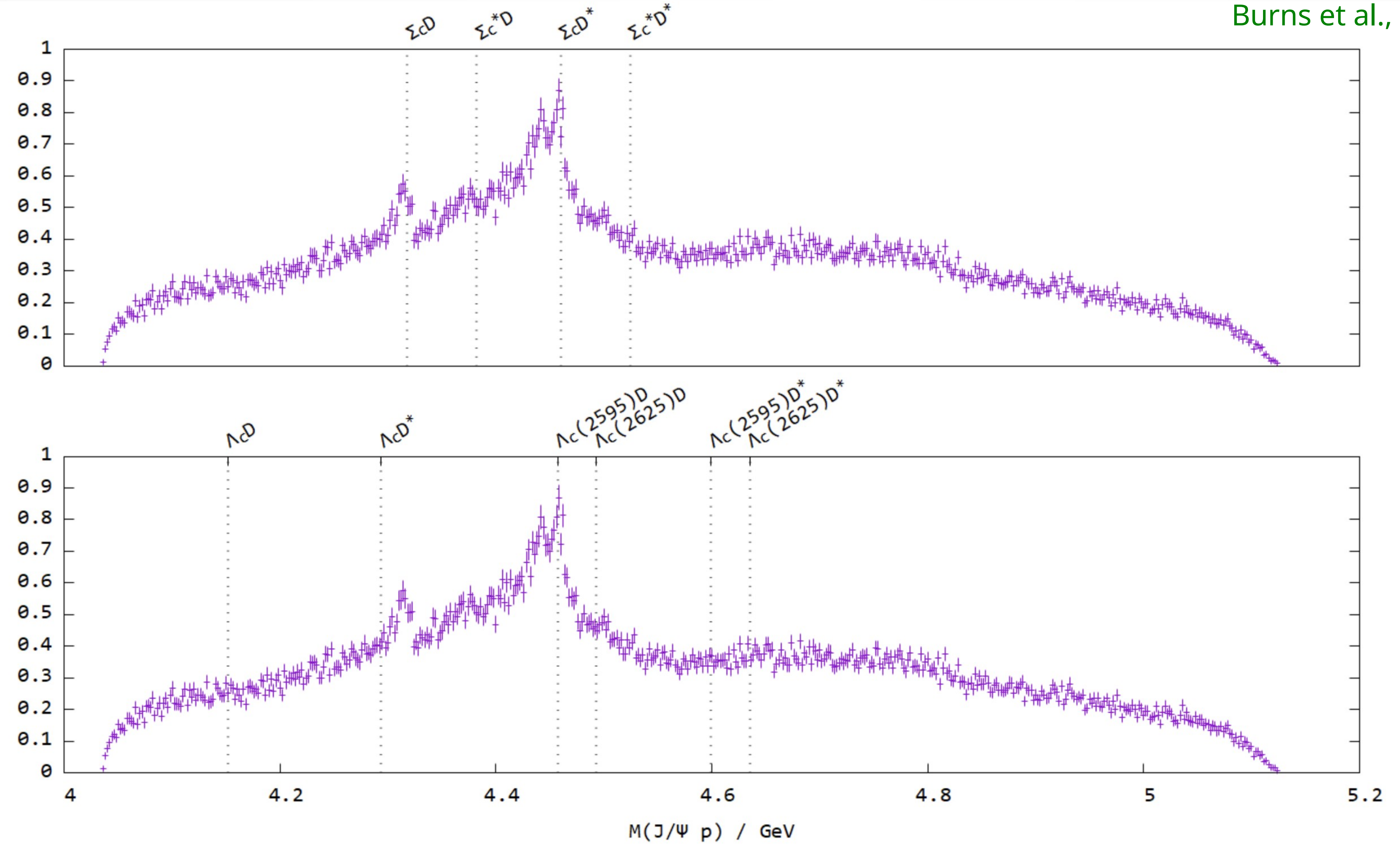




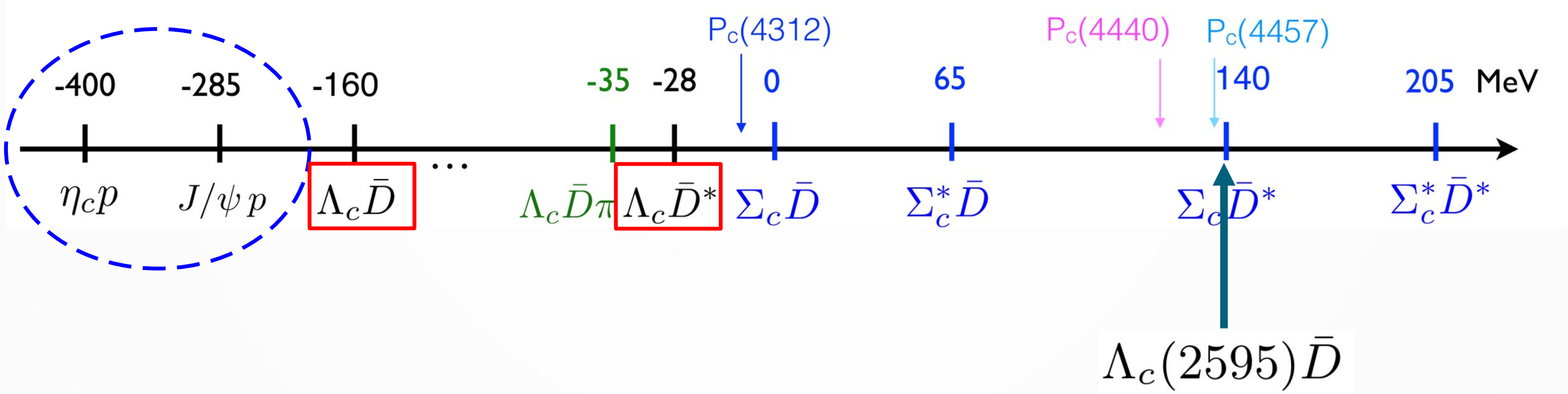


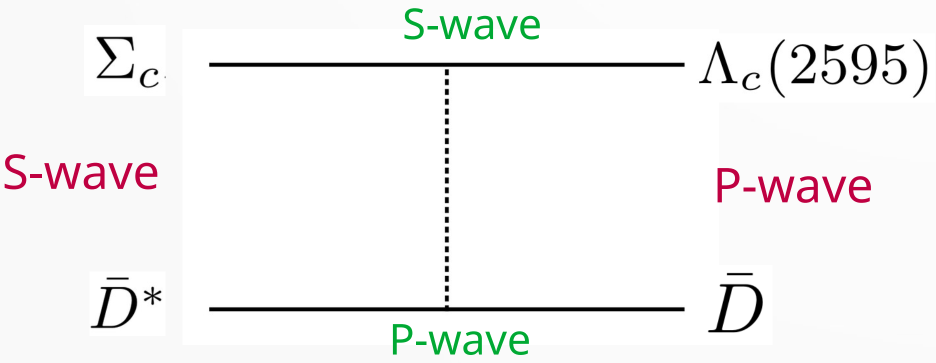
A look at the data

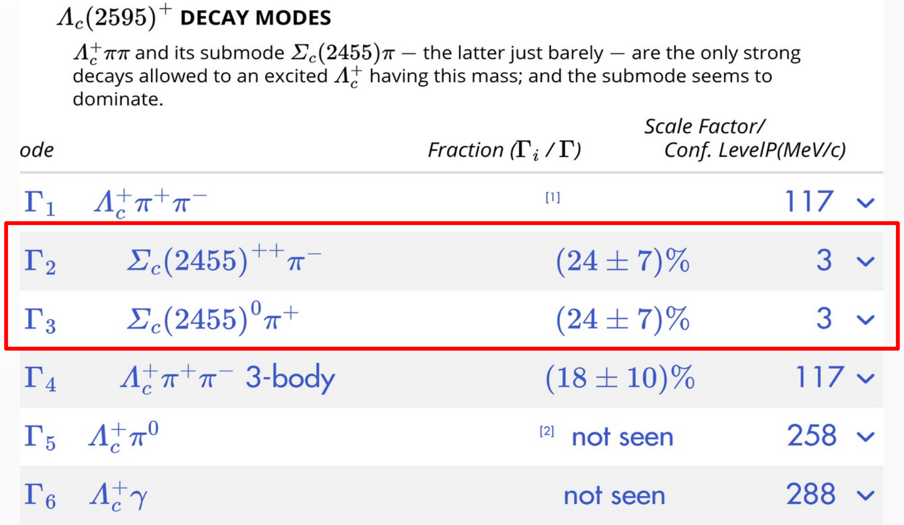
Burns et al., PRD106,054029 (2022)



Including Λc(2595)D







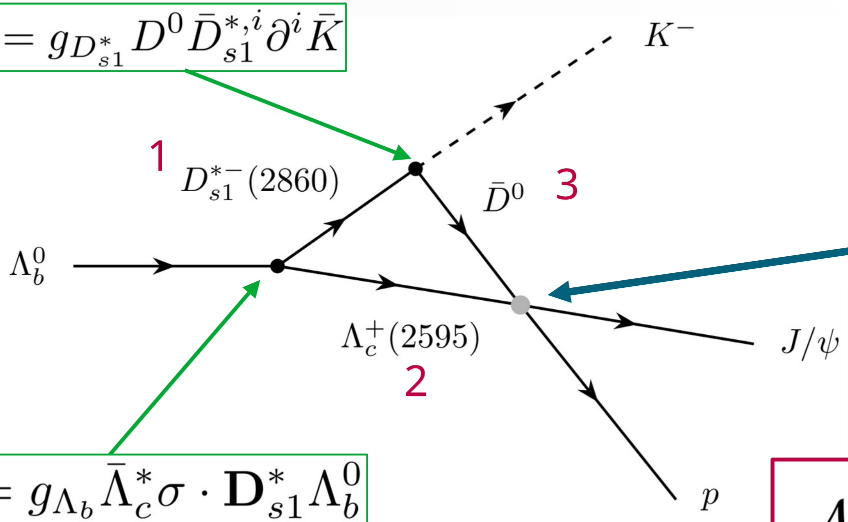
$\Lambda_c(2595)^+$ **DECAY MODES**

$\Lambda_c^+\pi\pi$ and its submode $\Sigma_c(2455)\pi$ — the latter just barely — are the only strong decays allowed to an excited Λ_c^+ having this mass; and the submode seems to dominate.

	ode	Fraction (Γ_i / Γ)	Scale Factor/ Conf. Level	P(MeV/c)
Γ_1	$\Lambda_c^+\pi^+\pi^-$	[1]		117
Γ_2	$\Sigma_c(2455)^{++}\pi^-$	$(24 \pm 7)\%$		3
Γ_3	$\Sigma_c(2455)^{0}\pi^+$	$(24 \pm 7)\%$		3
Γ_4	$\Lambda_c^+\pi^+\pi^-$ 3-body	$(18 \pm 10)\%$		117
Γ_5	$\Lambda_c^+\pi^0$	[2] not seen		258
Γ_6	$\Lambda_c^+\gamma$	not seen		288

Production of the LHCb Pc states

$$\mathcal{L}_{D_{s1}^*} = g_{D_{s1}^*} D^0 \bar{D}_{s1}^{*,i} \partial^i \bar{K}$$



$$\mathcal{L}_b = g_{\Lambda_b} \bar{\Lambda}_c^* \sigma \cdot \mathbf{D}_{s1}^* \Lambda_b^0$$

$$T^J(E) = \left[1 - V^J(E) \cdot G(E)\right]^{-1} \cdot V^J(E)$$

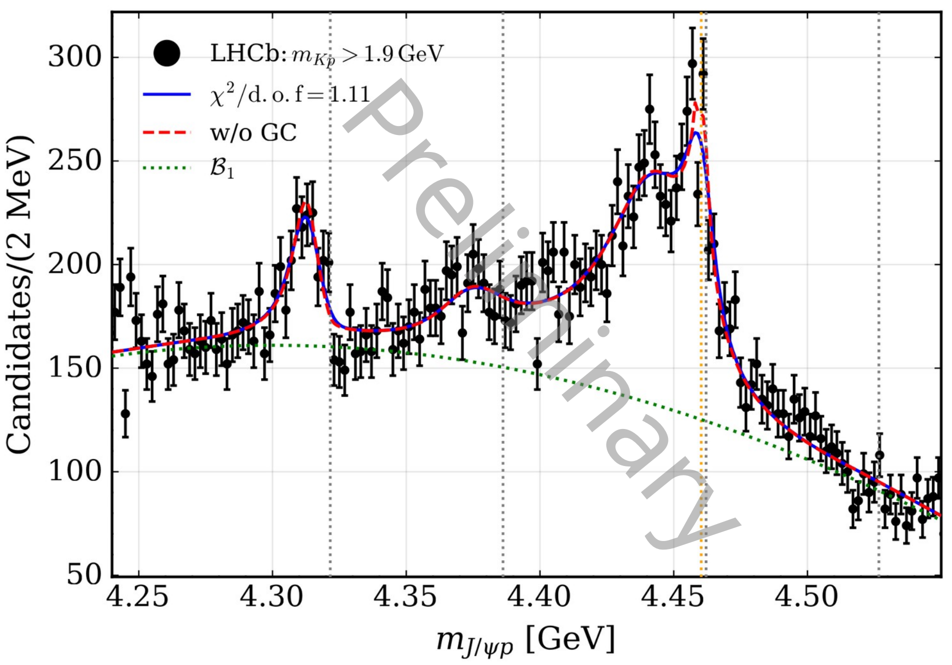
$$T_{4i}^J(E) = \sum_{\alpha=1}^{3} T_{4\alpha}^J(E) G_\alpha(E) \mathcal{V}_{\alpha i}^J$$

$$\boxed{\mathcal{A}^J(E) = g(I^{(1)}(p_K) - I(p_K)) p_K^2 T_{4i}^J(E)}$$

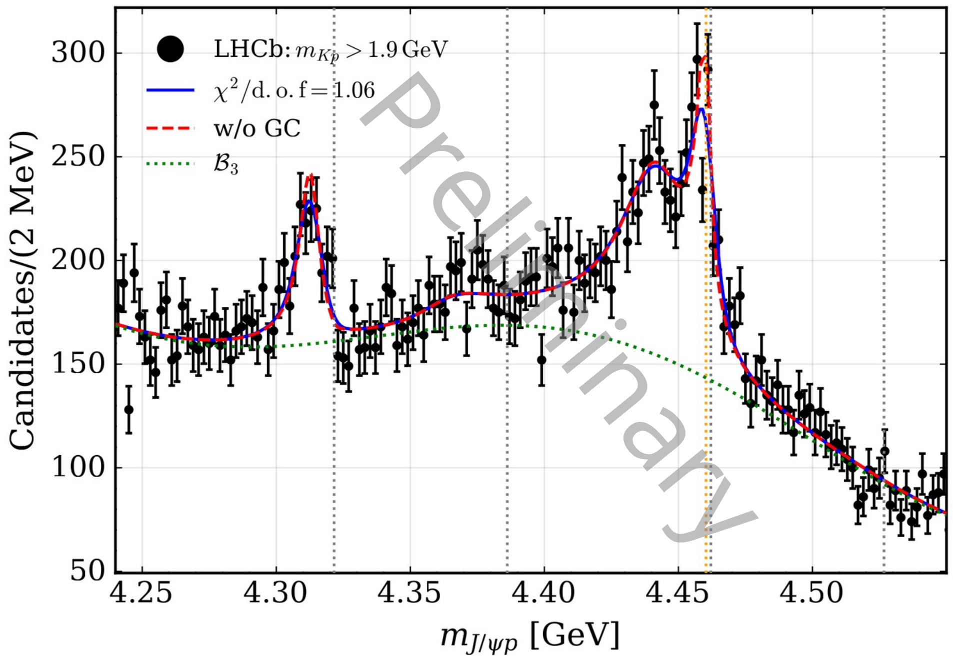
$$I(q) \equiv i \int \frac{\mathrm{d}^4 l}{(2\pi)^4} \frac{1}{(l^2 - m_1^2)\left((P-l)^2 - m_2^2\right)\left((l-q)^2 - m_3^2\right)},$$

$$q^i I^{(1)}(q) \equiv i \int \frac{\mathrm{d}^4 l}{(2\pi)^4} \frac{l^i}{(l^2 - m_1^2)\left((P-l)^2 - m_2^2\right)\left((l-q)^2 - m_3^2\right)}.$$

Production of the LHCb Pc states



$$\mathcal{B}_1(E) = b_0 + b_1 E^2 + b_2 E^4$$



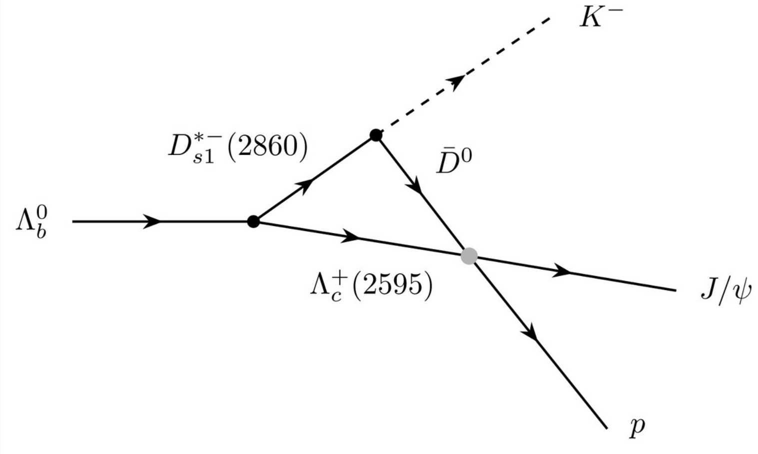
$$\mathcal{B}_3(E) = b_0 + b_1 E^2 + b_2 E^4 + \frac{b_3^2}{(E - b_4)^2 + b_5^2}.$$

Solution B! ⇒ **$P_c(4440)$ is $3/2^-$ and $P_c(4457)$ is $1/2^-$**

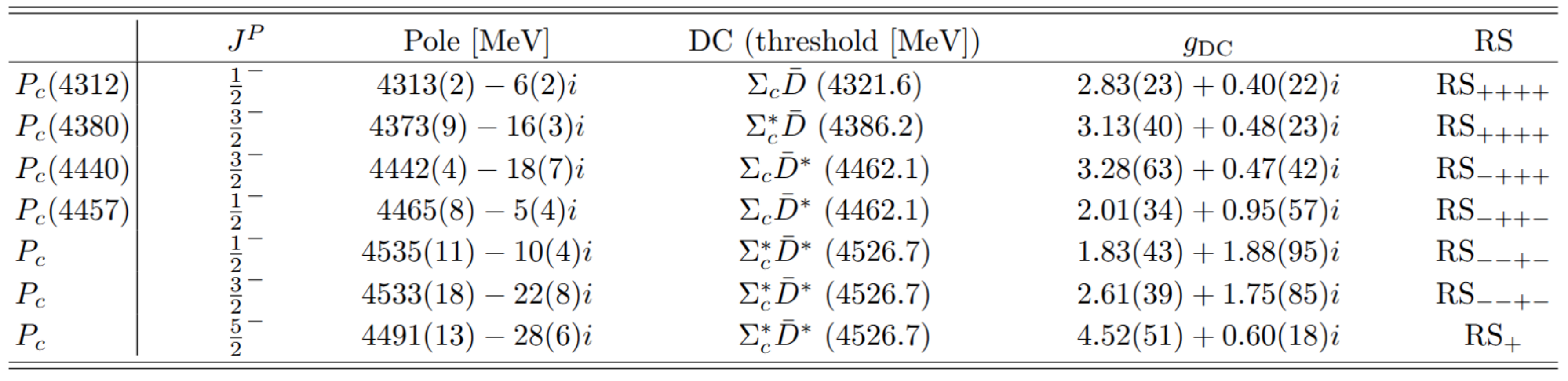
$\Lambda_c(2595)\bar{D}$ not significant!

consistent with Yalikun et al., PRD104,094039(2021)

Production of the LHCb Pc states



$$R = \frac{\Gamma(\Lambda_b^0 \to P_c^+ K^- \to J/\psi p K^-)}{\Lambda_b^0 \to D_{s1}^*(2860)\Lambda_c(2595)} \approx 5\%$$

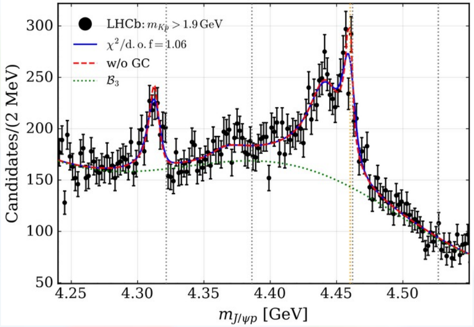


	J^P	Pole [MeV]	DC (threshold [MeV])	$g_{\rm DC}$	RS
$P_c(4312)$	$\frac{1}{2}^-$	$4313(2) - 6(2)i$	$\Sigma_c\bar{D}$ (4321.6)	$2.83(23) + 0.40(22)i$	RS_{++++}
$P_c(4380)$	$\frac{3}{2}^-$	$4373(9) - 16(3)i$	$\Sigma_c^*\bar{D}$ (4386.2)	$3.13(40) + 0.48(23)i$	RS_{++++}
$P_c(4440)$	$\frac{3}{2}^-$	$4442(4) - 18(7)i$	$\Sigma_c\bar{D}^*$ (4462.1)	$3.28(63) + 0.47(42)i$	RS_{-+++}
$P_c(4457)$	$\frac{1}{2}^-$	$4465(8) - 5(4)i$	$\Sigma_c\bar{D}^*$ (4462.1)	$2.01(34) + 0.95(57)i$	RS_{-++-}
P_c	$\frac{1}{2}^-$	$4535(11) - 10(4)i$	$\Sigma_c^*\bar{D}^*$ (4526.7)	$1.83(43) + 1.88(95)i$	RS_{--+-}
P_c	$\frac{3}{2}^-$	$4533(18) - 22(8)i$	$\Sigma_c^*\bar{D}^*$ (4526.7)	$2.61(39) + 1.75(85)i$	RS_{--+-}
P_c	$\frac{5}{2}^-$	$4491(13) - 28(6)i$	$\Sigma_c^*\bar{D}^*$ (4526.7)	$4.52(51) + 0.60(18)i$	RS_{+}

Conclusions and Propects

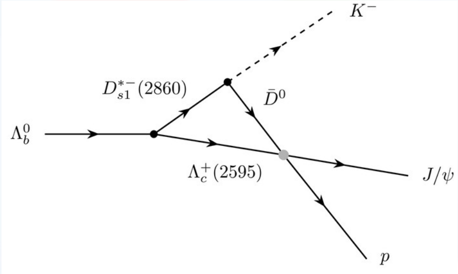
Conclusions

- Molecular interpretation of the Pc's and 7 Pc's are predicted from HQSS
- A narrow Pc(4380), different from the broad one reporeted by LHCb in 2015
- Production through the triangle diagram
- The missing Pc's from HQSS in LHCb is naturally explained
- Pc(4312): J=1/2, Pc(4457): J=1/2, Pc(4440): J=3/2



Propects

- The missing Pc's from HQSS, Pc's with strangeness
- Lattice simulations



$$R = \frac{\Gamma(\Lambda_b^0 \to P_c^+ K^- \to J/\psi p K^-)}{\Lambda_b^0 \to D_{s1}^*(2860)\Lambda_c(2595)} \approx 5\%$$

Thank you very much for your attention!

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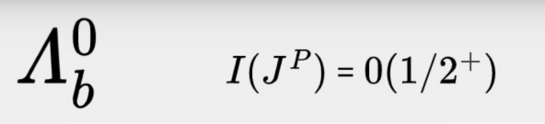
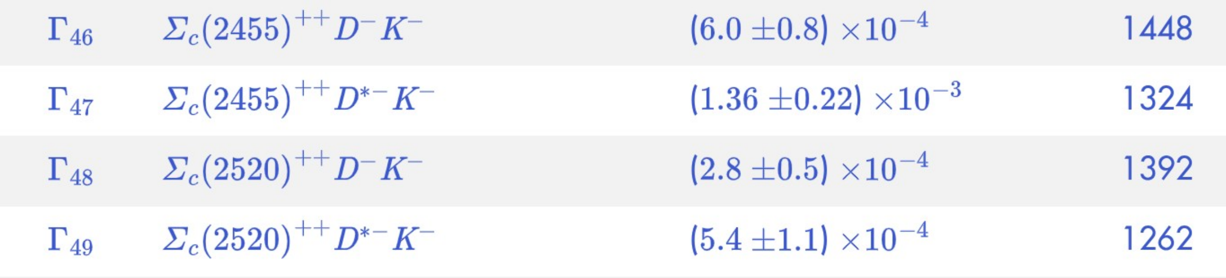
backup



Λ_b^0 $I(J^P) = 0(1/2^+)$



Γ_{46}	$\Sigma_c(2455)^{++} D^- K^-$	$(6.0 \pm 0.8) \times 10^{-4}$	1448
Γ_{47}	$\Sigma_c(2455)^{++} D^{*-} K^-$	$(1.36 \pm 0.22) \times 10^{-3}$	1324
Γ_{48}	$\Sigma_c(2520)^{++} D^- K^-$	$(2.8 \pm 0.5) \times 10^{-4}$	1392
Γ_{49}	$\Sigma_c(2520)^{++} D^{*-} K^-$	$(5.4 \pm 1.1) \times 10^{-4}$	1262

Γ_{36}	$\Lambda_c^+ D^-$	$(4.6 \pm 0.6) \times 10^{-4}$	1886
Γ_{37}	$\Lambda_c^+ D_s^-$	(1.10 ± 0.10) %	1833
Γ_{38}	$\Lambda_c^+ D_s^{*-}$	(1.83 ± 0.18) %	1748
Γ_{39}	$\Lambda_c^+ \overline{D}^0 K^-$	$(2.13 \pm 0.20) \times 10^{-3}$	1581
Γ_{40}	$\Lambda_c^+ \overline{D}^{*0} K^-$	$(6.6 \pm 0.7) \times 10^{-3}$	1471