Revision of $K^- \, ^3He \to \Lambda \, pn$ and the $K^- pp$ bound state. Recent Ω_c and Pentaquark states

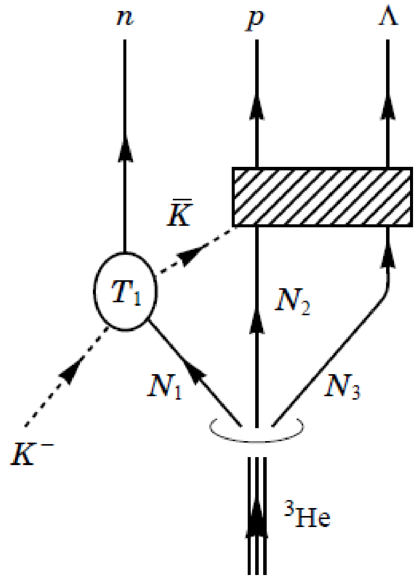
E. Oset, T. Sekihara, A. Ramos, V. R. Debastiani, F. M. Dias, W. H. Liang, C.W. Xiao, J. Nieves
IFIC, Universidad de Valencia

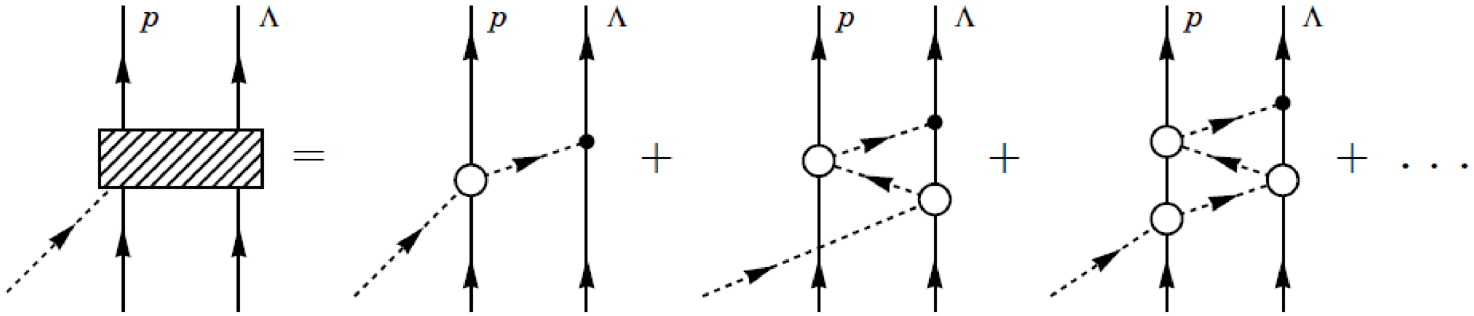
The $K^- \, ^3He \to \Lambda \, p \, n$ reaction and the $K^- pp$ bound state revisited

Ω_c states

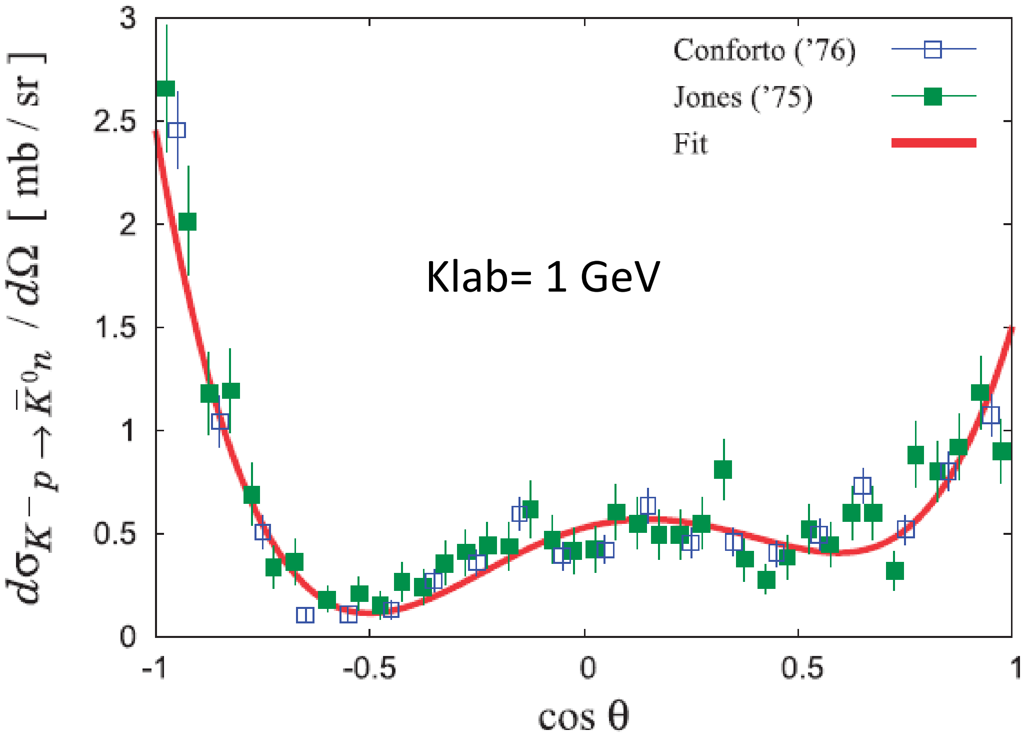
New pentaquarks in the $\Lambda_b \to J/\psi p K^-$ reaction

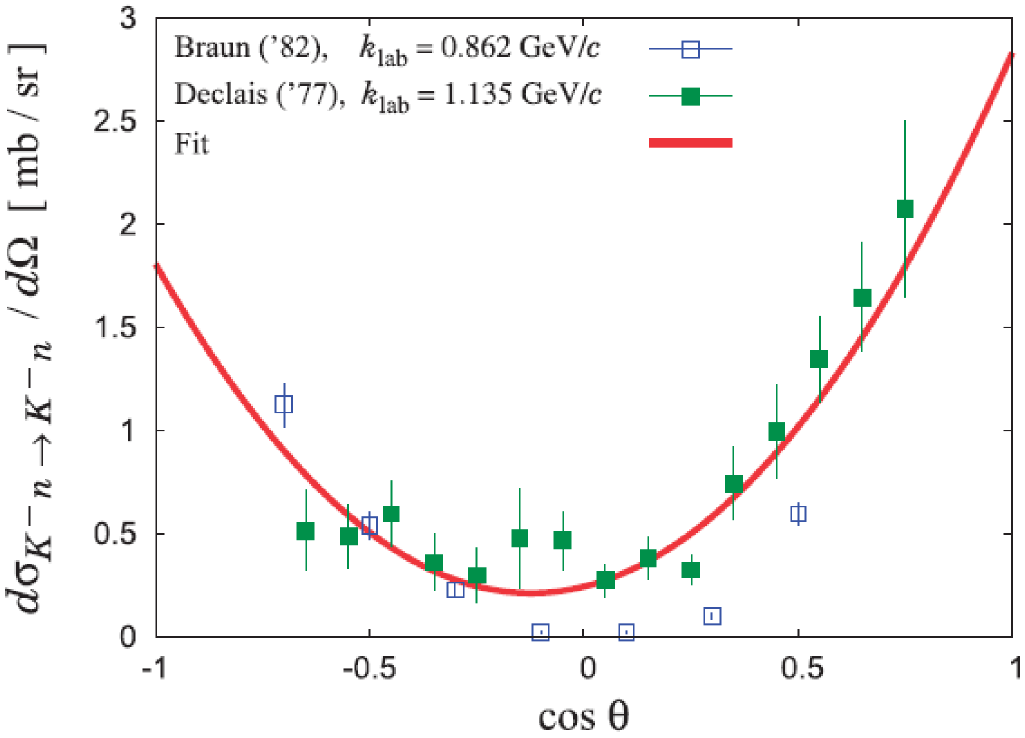
T. Sekihara, E. Oset, A. Ramos   PTEP (2016)



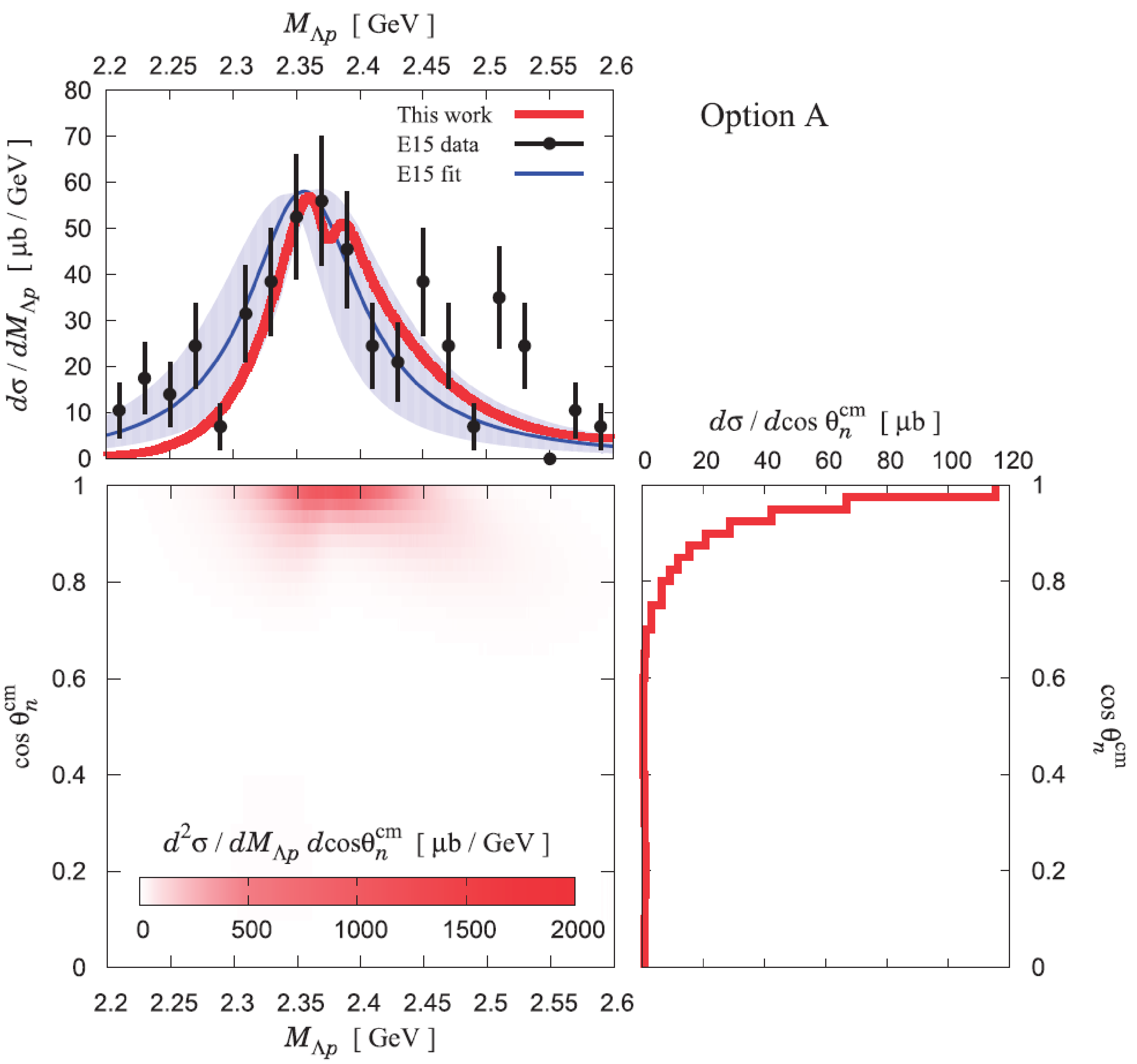


Kaon rescattering from the chiral unitary approach

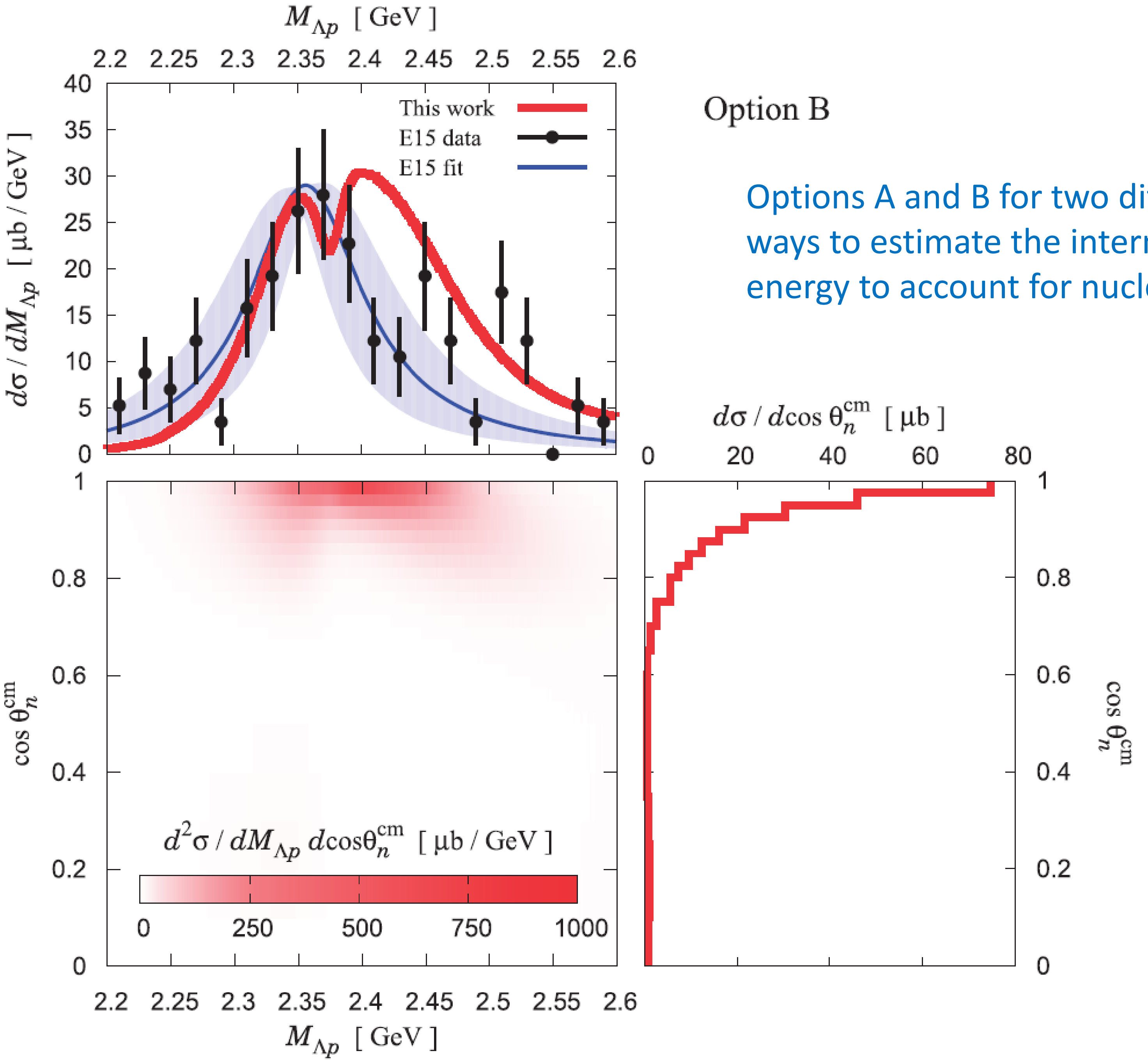




Input for T_1 from experiment



Y. Sada et al. [J-PARC E15 Collaboration], Prog. Theor. Exp. Phys. **2016**, 051D01 (2016)



Option B

Options A and B for two different ways to estimate the intermediate K energy to account for nucleon binding

Novelty: In the previous work T_1 was parametrized as a real amplitude taken at k_{lab}= 1 GeV, neglecting Fermi motion of the nucleons. Now Fermi motion is considered and we take a more complete amplitude

$$T_1(w_1, \boldsymbol{p}_{\rm out}, \boldsymbol{p}_{\rm in}) = g(w_1, p_{\rm out}, p_{\rm in}, x) - ih(w_1, p_{\rm out}, p_{\rm in}, x)\frac{(\boldsymbol{p}_{\rm out} \times \boldsymbol{p}_{\rm in}) \cdot \boldsymbol{\sigma}}{p_{\rm out}p_{\rm in}}$$

$$g(w, p_{\rm out}, p_{\rm in}, x) = \sum_{L=0}^{\infty} [(L+1)T_{L+}(w, p_{\rm out}, p_{\rm in}) + LT_{L-}(w, p_{\rm out}, p_{\rm in})] P_L(x),$$

$$h(w, p_{\rm out}, p_{\rm in}, x) = \sum_{L=1}^{\infty} [T_{L+}(w, p_{\rm out}, p_{\rm in}) - T_{L-}(w, p_{\rm out}, p_{\rm in})] P'_L(x),$$

T_L is taken up to L=4 from

[11] H. Kamano, S. X. Nakamura, T.-S. H. Lee and T. Sato, Phys. Rev. C **90**, 065204 (2014).

based on dynamical coupled channels with SU(3) phenomenological Lagrangians

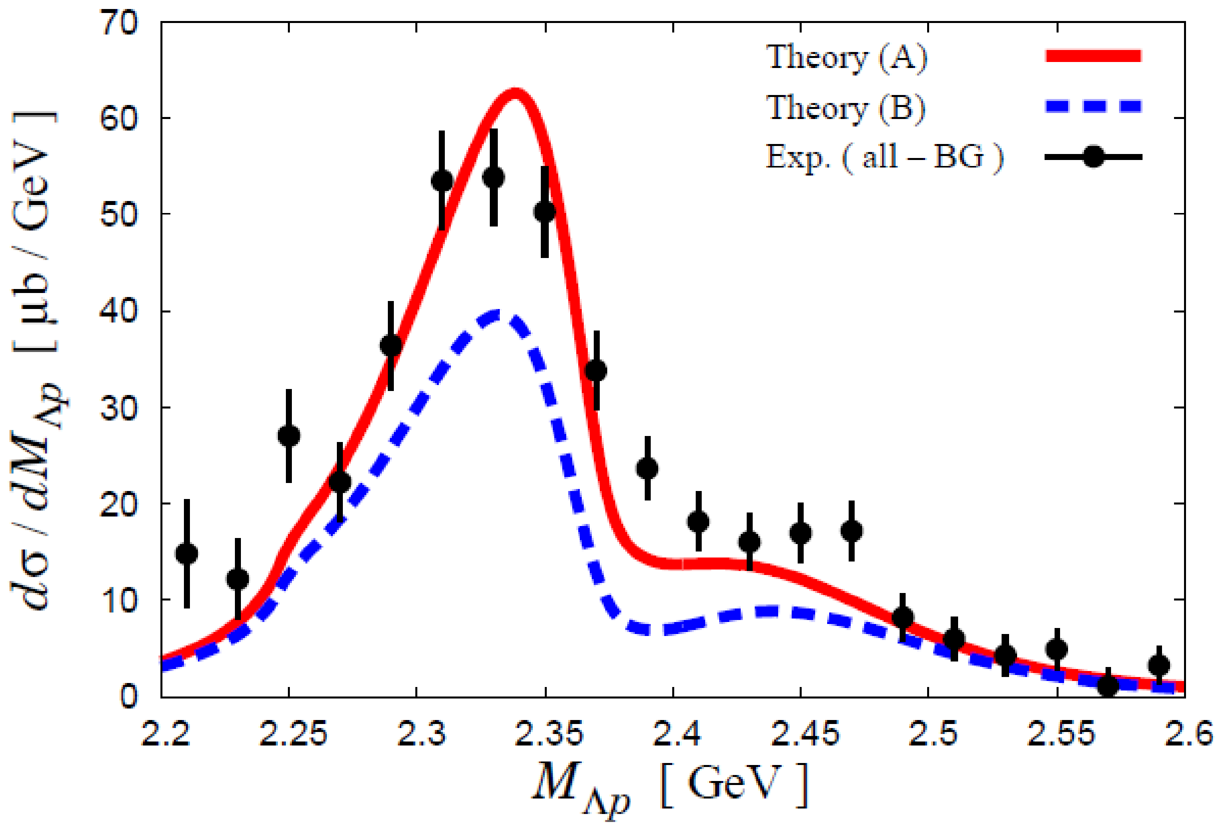


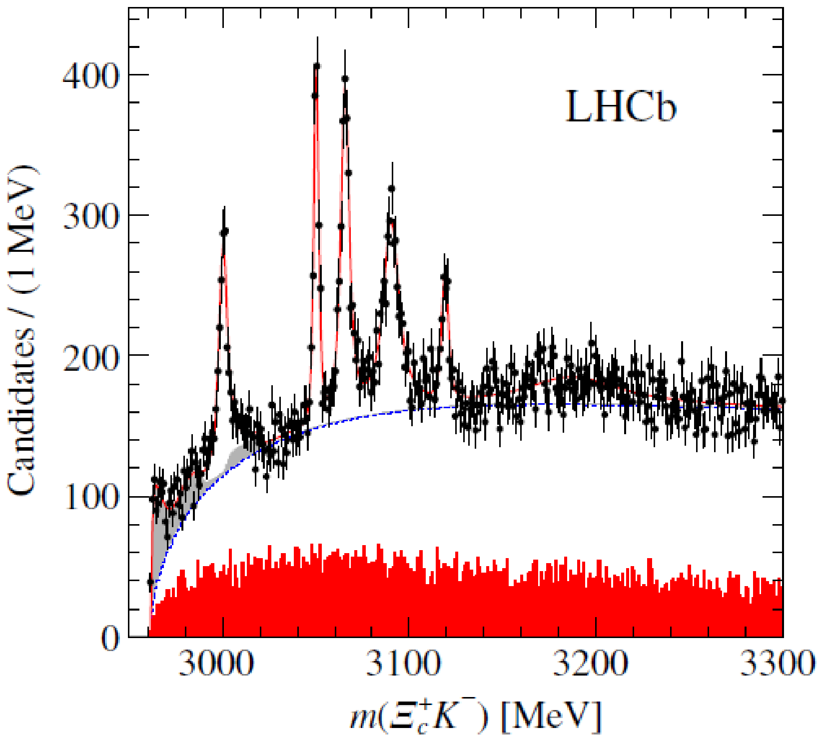
Fig. 3. Comparison between theoretical and experimental results of the Λp invariant mass spectrum $d\sigma/dM_{\Lambda p}$ for the $K^{-3}\text{He} \rightarrow \Lambda pn$ reaction in the momentum transfer window $350\ \text{MeV}/c < q_{\Lambda p} < 650\ \text{MeV}/c$. For the experimental data we subtract the background contribution in the experimental analysis [9].

[9] S. Ajimura *et al.* [J-PARC E15 Collaboration], Phys. Lett. B **789**, 620 (2019).

The low energy amplitudes of the kaons are the same, based on the chiral unitary approach, which lead to a $K^{-}pp$ bound state of about 20 Mev and width of about 80 MeV.

Molecular Ω_c states generated from coupled meson-baryon channels

V. R. Debastiani,[1,*] J. M. Dias,[1,2,†] W. H. Liang,[3,‡] and E. Oset[1,§] PRD (2018)



The Ξ_c K^- mass spectrum is studied with a sample of pp collision data by LHCb , PRL 017

Five clean narrow peaks are obtained

$\Omega_c(3000)^0$, $\Omega_c(3050)^0$, $\Omega_c(3066)^0$, $\Omega_c(3090)^0$, and $\Omega_c(3119)^0$

Resonance	Mass (MeV)	Γ (MeV)
$\Omega_c(3000)^0$	$3000.4 \pm 0.2 \pm 0.1^{+0.3}_{-0.5}$	$4.5 \pm 0.6 \pm 0.3$
$\Omega_c(3050)^0$	$3050.2 \pm 0.1 \pm 0.1^{+0.3}_{-0.5}$	$0.8 \pm 0.2 \pm 0.1$
		<1.2 MeV, 95% C.L.
$\Omega_c(3066)^0$	$3065.6 \pm 0.1 \pm 0.3^{+0.3}_{-0.5}$	$3.5 \pm 0.4 \pm 0.2$
$\Omega_c(3090)^0$	$3090.2 \pm 0.3 \pm 0.5^{+0.3}_{-0.5}$	$8.7 \pm 1.0 \pm 0.8$
$\Omega_c(3119)^0$	$3119.1 \pm 0.3 \pm 0.9^{+0.3}_{-0.5}$	$1.1 \pm 0.8 \pm 0.4$
		<2.6 MeV, 95% C.L.

Chiral Lagrangian

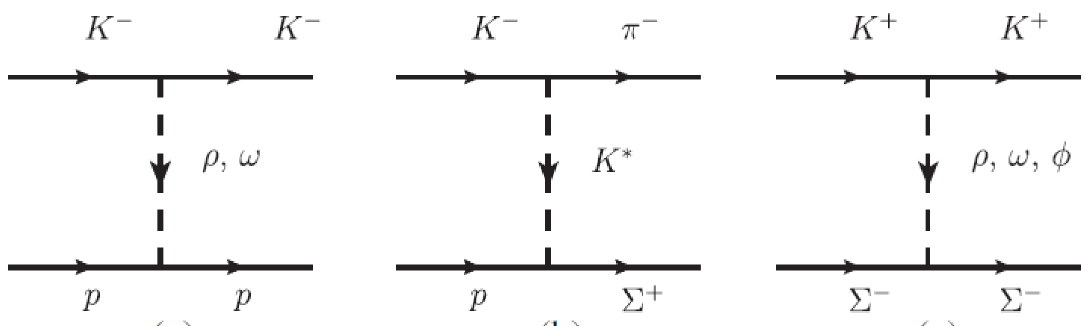
$$\mathcal{L}^B = \frac{1}{4f_\pi^2}\langle \bar{B} i\gamma^\mu [(\Phi\partial_\mu\Phi - \partial_\mu\Phi\Phi)B - B(\Phi\partial_\mu\Phi - \partial_\mu\Phi\Phi)]\rangle$$

Equivalent method:
Local hidden gauge approach

$$\mathcal{L}_{\mathrm{VPP}} = -ig\langle[\Phi, \partial_\mu\Phi]V^\mu\rangle, \qquad \mathcal{L}_{BBV} = g\left(\langle\bar{B}\gamma_\mu[V^\mu, B]\rangle + \langle\bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle\right)$$

$$\Phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix} \qquad B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}$$

$$V_\mu = \begin{pmatrix} \frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & \rho^+ & K^{*+} \\ \rho^- & -\frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu$$



(a) (b) (c)

$$\rho^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d}),$$
$$\omega = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}),$$
$$\phi = s\bar{s}.$$

approximation of taking $\gamma^\mu \to \gamma^0$

$$\langle p|g\rho^0|p\rangle \equiv \frac{1}{\sqrt{2}}\frac{1}{\sqrt{2}}\langle \phi_{\rm MS}\chi_{\rm MS} + \phi_{\rm MA}\chi_{\rm MA}|g\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})| \times \phi_{\rm MS}\chi_{\rm MS} + \phi_{\rm MA}\chi_{\rm MA}\rangle, \quad (10)$$

TABLE I. $J = 1/2$ states chosen and threshold mass in MeV.

States	$\Xi_c \bar{K}$	$\Xi'_c \bar{K}$	ΞD	$\Omega_c \eta$	ΞD^*	$\Xi_c \bar{K}^*$	$\Xi'_c \bar{K}^*$
Threshold	2965	3074	3185	3243	3327	3363	3472

TABLE II. $J = 3/2$ states chosen and threshold mass in MeV.

States	$\Xi^*_c \bar{K}$	$\Omega^*_c \eta$	ΞD^*	$\Xi_c \bar{K}^*$	$\Xi^* D$	$\Xi'_c \bar{K}^*$
Threshold	3142	3314	3327	3363	3401	3472

Back to Ω_c states

BARYON WAVE FUNCTIONS

Ξ_c^+: $\frac{1}{\sqrt{2}} c(us - su)$, and the spin wave function is the mixed antisymmetric, $\chi_{\rm MA}$, for the two light quarks.

Ξ_c^0: the same as Ξ_c^+, changing $(us - su) \to (ds - sd)$.

$\Xi_c'^+$: $\frac{1}{\sqrt{2}} c(us + su)$, and now the spin wave function for the three quarks is the mixed symmetric, $\chi_{\rm MS}$, in the last two quarks,

$\Xi_c'^0$: the same as Ξ'_c, changing $(us + su) \to (ds + sd)$.
Ω_c^0: css, and the spin wave function $\chi_{\rm MS}$ in the last two quarks, like that for Ξ'_c.

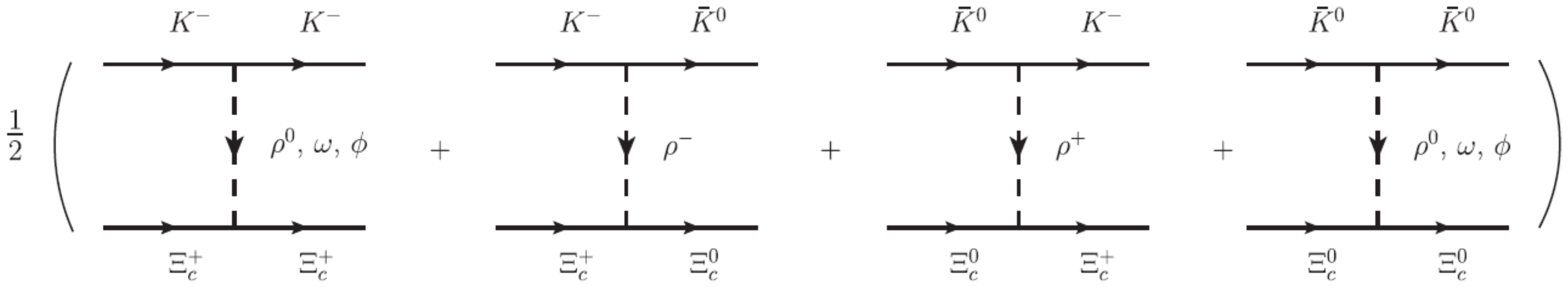


FIG. 3. Diagrams in the $\bar{K}\Xi_c \to \bar{K}\Xi_c$ transition.

Upper vertex

$$\mathcal{L}_{\rm VPP} = -ig\langle[\Phi, \partial_\mu \Phi]V^\mu\rangle$$

$$-it_{K^- \to K^-}\begin{pmatrix}\rho^0 \\ \omega \\ \phi\end{pmatrix} = gV_\mu(-ip^\mu - ip'^\mu)\begin{pmatrix}1/\sqrt{2} \\ 1/\sqrt{2} \\ -1\end{pmatrix},$$

$$-it_{K^- \to \bar{K}^0 \rho^-} = g\rho^{+\mu}(-ip^\mu - ip'^\mu),$$

$g = m_V/2\,f$,
$f = 93$ MeV

Lower vertex

$$\frac{1}{\sqrt{2}}\langle(us - su)|\begin{pmatrix} g\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d}) \\ g\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) \\ gs\bar{s}\end{pmatrix}|\frac{1}{\sqrt{2}}(us - su)\rangle$$

$$= \begin{pmatrix}\frac{1}{\sqrt{2}}g \\ \frac{1}{\sqrt{2}}g \\ g\end{pmatrix}.$$

No need to invoke SU(4)

With light vector exchange the heavy quarks
are spectators. Nothing depends upon them.
Heavy quark symmetry is automatically implemented

$$T = [1 - VG]^{-1} V, \qquad G_l^{II} = G_l^{I} + i\frac{2M_l q}{4\pi\sqrt{s}}, \qquad T_{ij} = \frac{g_i g_j}{\sqrt{s} - z_R}$$

Exp (MeV)
M Γ

TABLE VI. The coupling constants to various channels for the poles in the $J^P = 1/2^-$ sector, with $q_{\max} = 650$ MeV, and $g_i G_i^{II}$ in MeV.

Exp (MeV) M, Γ	$3054.05 + i0.44$	$\Xi_c \bar{K}$	$\Xi_c' \bar{K}$	ΞD	$\Omega_c \eta$	ΞD^*	$\Xi_c \bar{K}^*$	$\Xi_c' \bar{K}^*$
3050, 0.8	g_i	$-0.06 + i0.14$	$1.94 + i0.01$	$-2.14 + i0.26$	$1.98 + i0.01$	0	0	0
	$g_i G_i^{II}$	$-1.40 - i3.85$	$-34.41 - i0.30$	$9.33 - i1.10$	$-16.81 - i0.11$	0	0	0
	$3091.28 + i5.12$	$\Xi_c \bar{K}$	$\Xi_c' \bar{K}$	ΞD	$\Omega_c \eta$	ΞD^*	$\Xi_c \bar{K}^*$	$\Xi_c' \bar{K}^*$
3090, 8.7	g_i	$0.18 - i0.37$	$0.31 + i0.25$	$5.83 - i0.20$	$0.38 + i0.23$	0	0	0
	$g_i G_i^{II}$	$5.05 + i10.19$	$-9.97 - i3.67$	$-29.82 + i0.31$	$-3.59 - i2.23$	0	0	0

TABLE VIII. The coupling constants to various channels for the poles in the $J^P = 3/2^-$ sector, with $q_{\max} = 650$ MeV, and $g_i G_i^{II}$ in MeV.

Exp (MeV) M, Γ	3124.84	$\Xi_c^* \bar{K}$	$\Omega_c^* \eta$	ΞD^*	$\Xi_c \bar{K}^*$	$\Xi^* D$	$\Xi_c' \bar{K}^*$
3119, 1.1	g_i	1.95	1.98	0	0	-0.65	0
	$g_i G_i^{II}$	-35.65	-16.83	0	0	1.93	0
	$3290.31 + i0.03$	$\Xi_c^* \bar{K}$	$\Omega_c^* \eta$	ΞD^*	$\Xi_c \bar{K}^*$	$\Xi^* D$	$\Xi_c' \bar{K}^*$
	g_i	$0.01 + i0.02$	$0.31 + i0.01$	0	0	$6.22 - i0.04$	0
	$g_i G_i^{II}$	$-0.62 - i0.18$	$-5.25 - i0.18$	0	0	$-31.08 + i0.20$	0

We get three states in very good agreement with experiment, both mass and width

Related work:

[15] J. Hofmann and M. F. M. Lutz, Nucl. Phys. **A763**, 90 (2005).

[16] C. E. Jimenez-Tejero, A. Ramos, and I. Vidana, Phys. Rev. C **80**, 055206 (2009).

[17] O. Romanets, L. Tolos, C. Garcia-Recio, J. Nieves, L. L. Salcedo, and R. G. E. Timmermans, Phys. Rev. D **85**, 114032 (2012).

Revisions made after experiment to fit some parameter

[41] G. Montaña, A. Feijoo, and A. Ramos, Eur. Phys. J. A **54**, 64 (2018).

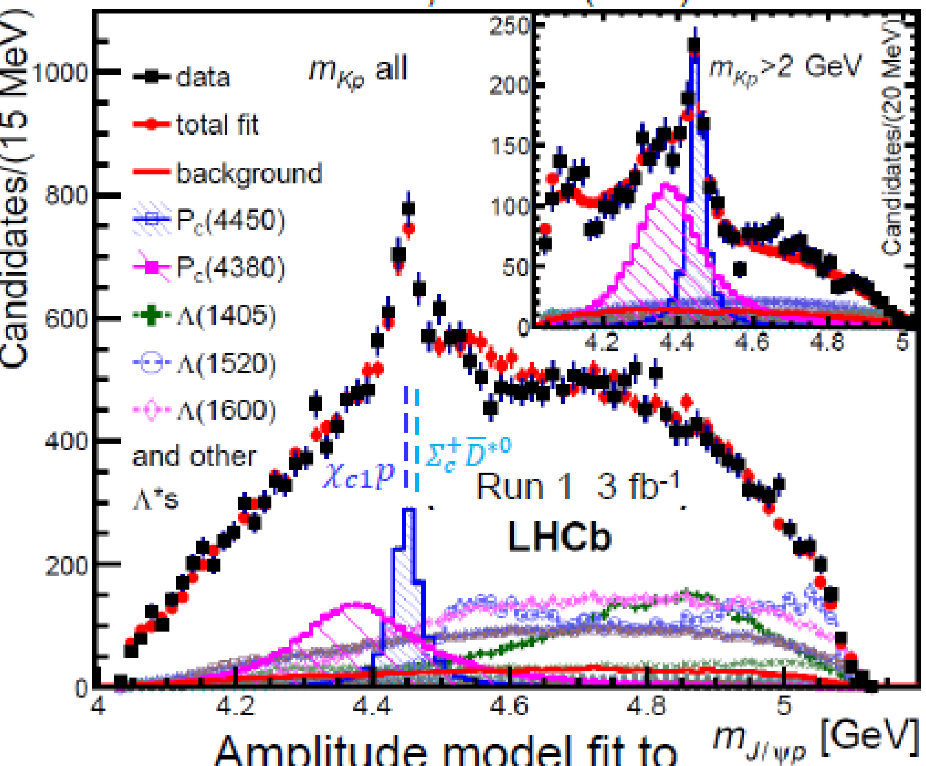
Uses SU(4) : matrix elements exchanging light vectors are equal. Results similar to ours, but only two states, since they study $1/2^-$ states only

J.~Nieves, R.~Pavao and L.~Tolos, Omega _c excited states within a SU(6)}_ HQSS model, Eur. Phys. J. C 78 114 (2018)

Better results than in [17] but the widths and the positions not so good as in the works of Montaña and present work .

Run 1 evidence for $P_c^+ \to J/\psi p$ pentaquarks in $\Lambda_b \to J/\psi p K^-$

PRL 115, 072001 (2015)



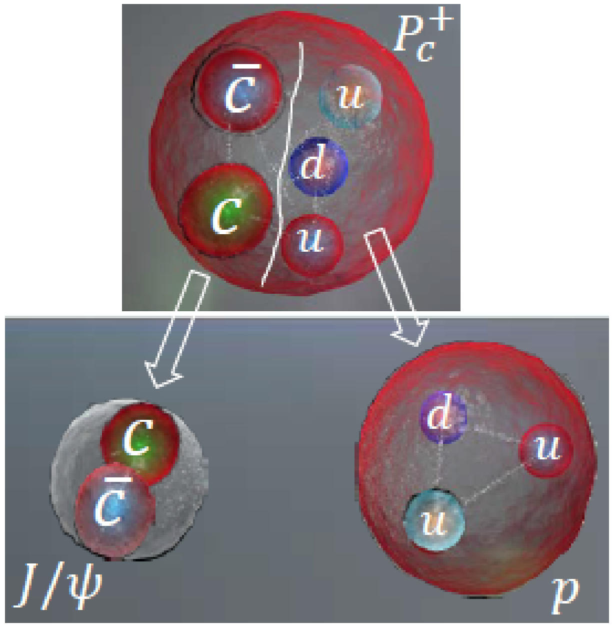
Amplitude model fit to masses and decay angles

$P_c(4450)^+$	$M =$	$4450 \pm 2 \pm 3$ MeV
	$\Gamma =$	$39 \pm 5 \pm 19$ MeV
	$F.F. =$	$4.1 \pm 0.5 \pm 1.1$ %
$P_c(4380)^+$	$M =$	$4380 \pm 8 \pm 29$ MeV
	$\Gamma =$	$205 \pm 18 \pm 86$ MeV
	$F.F. =$	$8.4 \pm 0.7 \pm 4.2$ %

27k $\Lambda_b \to J/\psi p K^-$ signal events
5.4% background

Tightly-bound pentaquark

$M_{P_c^+} = M_{J/\psi} + M_p + \sim 400\text{MeV}$

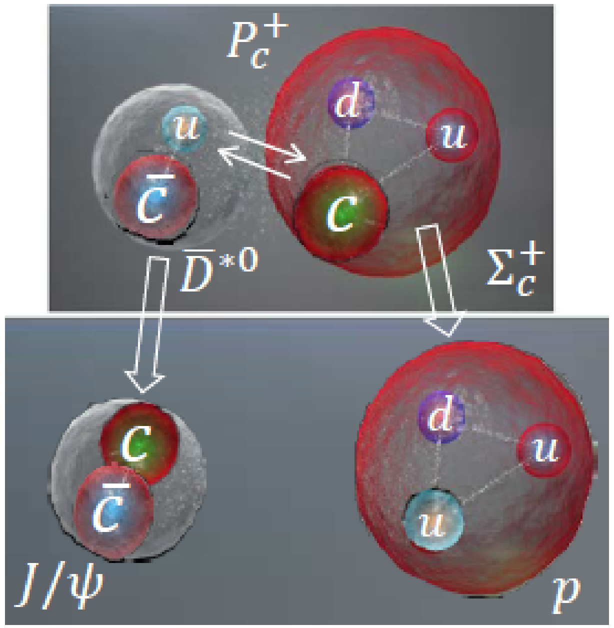


- Decay by fall-apart:
  - **Wide states?**
  - What slows it down to make $P_c(4450)^+$ narrow? L between **diquarks**?
  - $P_c(4380)^+$ S=1,L=0 broad, $P_c(4450)^+$ S=0,L=1 narrow
- Spectrum (**confining potential**)
  - Many states expected (n,L,S)

L. Maiani, A. D. Polosa, V. Riquer, PL B749 (2015) 289
R. F. Lebed, PL, B749 (2015) 454
V.V. Anisovich, M.A. Matveev, J. Nyiri, A.V. Sarantsev PL,. B749 (2015) 454
and others

Loosely-bound pentaquark

$M_{P_c^+} = M_{\bar{D}^{*0}} + M_{\Sigma_c^+} - \sim\text{few MeV}$
Fast fall-apart prevented

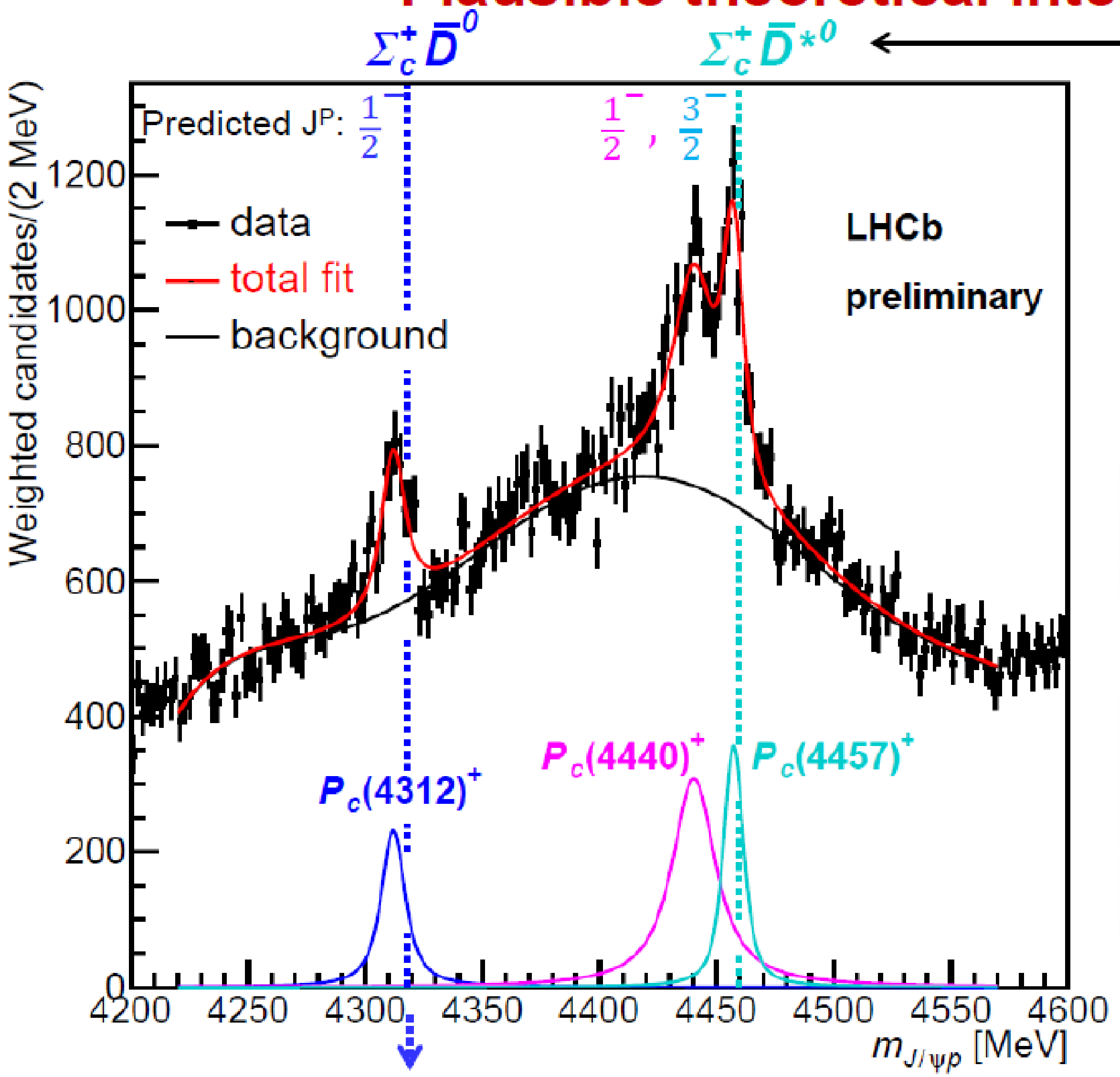


- Decay by heavy quarks changing confinement partners, then fall-apart:
  - **All states narrow**
- Spectrum (**shallow potential well**)
  - n=0,L=0 between hadron
  - Very few states expected (S)
  - Weak binding: masses a few MeV below the related baryon-meson thresholds
- Only $\Sigma_c^+\bar{D}^{(*)0}$ expected to bind:
  - $P_c(4450)^+ = \Sigma_c^+\bar{D}^{*0}$ molecule?
- Peaking at $\Lambda_c^+\bar{D}^{(*)0}$, $\chi_{cJ}p$ thresholds possible from triangle diagram processes:
  - $P_c(4450)^+ = \chi_{c1}p$ threshold?

Wu,Molina,Oset,Zou, PRL105 (2010) 232001
Wang,Huang,Zhang,Zou, PR C84 (2011) 015203
Karliner,Rosner, PRL 115 (2015) 122001
and others

Guo,Meissner,Wang,Yang, PRD92 (2015) 071502

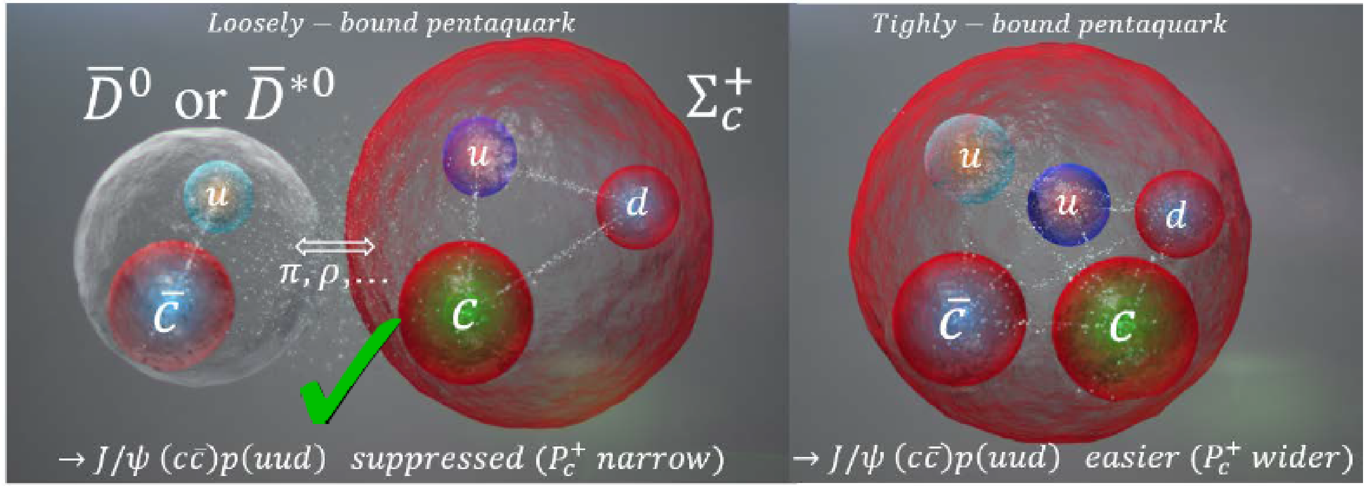
Plausible theoretical interpretation



The **only** thresholds below which molecular bound states are expected in this mass range

LHCb-PAPER-2019-014 in preparation

The near-threshold masses and the narrow widths of $P_c(4312)^+$, $P_c(4440)^+$ and $P_c(4457)^+$ favor "molecular" pentaquarks with meson-baryon substructure!



However, we need to measure J^Ps to confirm molecular hypothesis, find isospin partners, …

Can diquark substructure separated by a potential barrier [Maiani, Polosa, Riquer, PL,B778, 247 (2018)] produce width suppression?
Are masses near thresholds just by coincidence?
This hypothesis is not ruled out

Existence of $\Sigma_c^+ \bar{D}^0$ molecule would imply importance of ρ-exchange

$P_c(4312)^+$, $P_c(4440)^+$ not near triangle diagram thresholds, $P_c(4457)^+$ is (see backup slides).

Heavy quark spin symmetric molecular states from $\bar{D}^{(*)}\Sigma_c^{(*)}$ and other coupled channels in the light of the recent LHCb pentaquarks

C. W. Xiao,[1] J. Nieves,[2] and E. Oset[2,3] PRD (2019)

$I = 1/2$, $\eta_c N$, $J/\psi N$, $\bar{D}\Lambda_c$, $\bar{D}\Sigma_c$, $\bar{D}^*\Lambda_c$, $\bar{D}^*\Sigma_c$, $\bar{D}^*\Sigma_c^*$ for spin parity $J^P = 1/2^-$

$J/\psi N$, $\bar{D}^*\Lambda_c$, $\bar{D}^*\Sigma_c$, $\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c^*$ for $J^P = 3/2^-$

$$T = [1 - V\,G]^{-1}\,V$$

HQSS tells that the interaction cannot depend on the spin of the heavy quarks. Then one rewrites the physical states in terms of a basis of states where the spin of the light quarks and the heavy ones are separated.
This produces symmetries in the matrix elements of the interaction.

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

$$
\begin{array}{ccccccc}
\eta_c N & J/\psi N & \bar{D}\Lambda_c & \bar{D}\Sigma_c & \bar{D}^*\Lambda_c & \bar{D}^*\Sigma_c & \bar{D}^*\Sigma_c^*
\end{array}
$$

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

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

$$
\begin{array}{ccccc}
J/\psi N & \bar{D}^*\Lambda_c & \bar{D}^*\Sigma_c & \bar{D}\Sigma_c^* & \bar{D}^*\Sigma_c^*
\end{array}
$$

$$
\left(\begin{array}{ccccc}
\mu_1 & \mu_{12} & \frac{\mu_{13}}{3} & -\frac{\mu_{13}}{\sqrt{3}} & \frac{\sqrt{5}\mu_{13}}{3} \\
\mu_{12} & \mu_2 & \frac{\mu_{23}}{3} & -\frac{\mu_{23}}{\sqrt{3}} & \frac{\sqrt{5}\mu_{23}}{3} \\
\frac{\mu_{13}}{3} & \frac{\mu_{23}}{3} & \frac{1}{9}(8\lambda_2+\mu_3) & \frac{\lambda_2-\mu_3}{3\sqrt{3}} & \frac{1}{9}\sqrt{5}(\mu_3-\lambda_2) \\
-\frac{\mu_{13}}{\sqrt{3}} & -\frac{\mu_{23}}{\sqrt{3}} & \frac{\lambda_2-\mu_3}{3\sqrt{3}} & \frac{1}{3}(2\lambda_2+\mu_3) & \frac{1}{3}\sqrt{\frac{5}{3}}(\lambda_2-\mu_3) \\
\frac{\sqrt{5}\mu_{13}}{3} & \frac{\sqrt{5}\mu_{23}}{3} & \frac{1}{9}\sqrt{5}(\mu_3-\lambda_2) & \frac{1}{3}\sqrt{\frac{5}{3}}(\lambda_2-\mu_3) & \frac{1}{9}(4\lambda_2+5\mu_3)
\end{array}\right)_{I=1/2}
$$

- $J=5/2,\ I=1/2$

$$
\bar{D}^*\Sigma_c^*:\ (\lambda_2)_{I=1/2}
$$

The different terms are evaluated using an extensión of the local hidden gauge approach, with the exchange of vector mesons.

$$\mu_1 = 0, \quad \mu_{23} = 0, \quad \lambda_2 = \mu_3, \quad \mu_{13} = -\mu_{12},$$

$$\mu_2 = \frac{1}{4f^2}(k^0 + k'^0), \quad \mu_3 = -\frac{1}{4f^2}(k^0 + k'^0),$$

$$\mu_{12} = -\sqrt{6}\,\frac{m_\rho^2}{p_{D*}^2 - m_{D*}^2}\,\frac{1}{4f^2}\,(k^0 + k'^0),$$

$f = f_\pi = 93$ MeV, k^0, k'^0 are the energies of the external mesons

The only free parameter is the subtraction constant in the regularization of the meson baryon loops. We take it such that the average mass of our states agrees with experiment.

TABLE I. Dimensionless coupling constants of the $(I = 1/2, J^P = 1/2^-)$ poles found in this work to the different channels.

$(4306.38 + i7.62)$ 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	$0.67 + i0.01$	$0.46 - i0.03$	$0.01 - i0.01$	$\mathbf{2.07 - i0.28}$	$0.03 + i0.25$	$0.06 - i0.31$	$0.04 - i0.15$
$\lvert g_i \rvert$	0.67	0.46	0.01	2.09	0.25	0.31	0.16
$(4452.96 + i11.72)$ 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	$0.24 + i0.03$	$0.88 - 0.11$	$0.09 - i0.06$	$0.12 - i0.02$	$0.11 - i0.09$	$\mathbf{1.97 - i0.52}$	$0.02 + i0.19$
$\lvert g_i \rvert$	0.25	0.89	0.11	0.13	0.14	2.03	0.19
$(4520.45 + i11.12)$ 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	$0.72 - i0.10$	$0.45 - i0.04$	$0.11 - i0.06$	$0.06 - i0.02$	$0.06 - i0.05$	$0.07 - i0.02$	$\mathbf{1.84 - i0.56}$
$\lvert g_i \rvert$	0.73	0.45	0.13	0.06	0.08	0.08	1.92

????

TABLE II. Same as Table I for $J^P = 3/2^-$.

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

TABLE III. Identification of some of the $I = 1/2$ resonances found in this work with experimental states.

Mass [MeV]	Width [MeV]	Main channel	J^P	Experimental state
4306.4	15.2	$\bar{D}\Sigma_c$	$1/2^-$	$P_c(4312)$
4453.0	23.4	$\bar{D}^*\Sigma_c$	$1/2^-$	$P_c(4440)$
4452.5	3.0	$\bar{D}^*\Sigma_c$	$3/2^-$	$P_c(4457)$

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Similar conclusions based on single channels.

Conclusions

Improvements on the $K^- \, {}^3He \to \Lambda \, pn$, adjusting to the experimental cuts, lead to a very good agreement with experiment. Results compatible with small binding of the $K^- pp$ system

Extension of chiral unitary theory to the heavy sector, using the exchange of vectors in the hidden gauge approach, together with unitarity in coupled channels leads to neat predictions for molecular states

Recent results for Ω_c states and the new pentaquarks states of hidden charm, are giving support to these molecular pictures.