UNIVERSIDAD DE MURCIA

Hidden charm pentaquarks in $\Lambda_b \to J/\Psi\ K^- p$

Luis Roca

University of Murcia (Spain)

Index:

- ✓ The LHCb pentaquarks, $P_c(4450)^+$, $P_c(4380)^+$
- ✓ The role of the $\Lambda(1405)$ in $\Lambda_b \to J/\psi \bar{K} N$
- ✓ $P_c(4450)^+$ as a $J^P=3/2^-$ $\bar{D}^*\Sigma_c - \bar{D}^*\Sigma_c^*$ molecule

L.R., J.Nieves, E.Oset, PRD 92, 094003 (2015)

- ✓ Inclusion of more Λ's and poor evidence for $P_c(4380)^+$

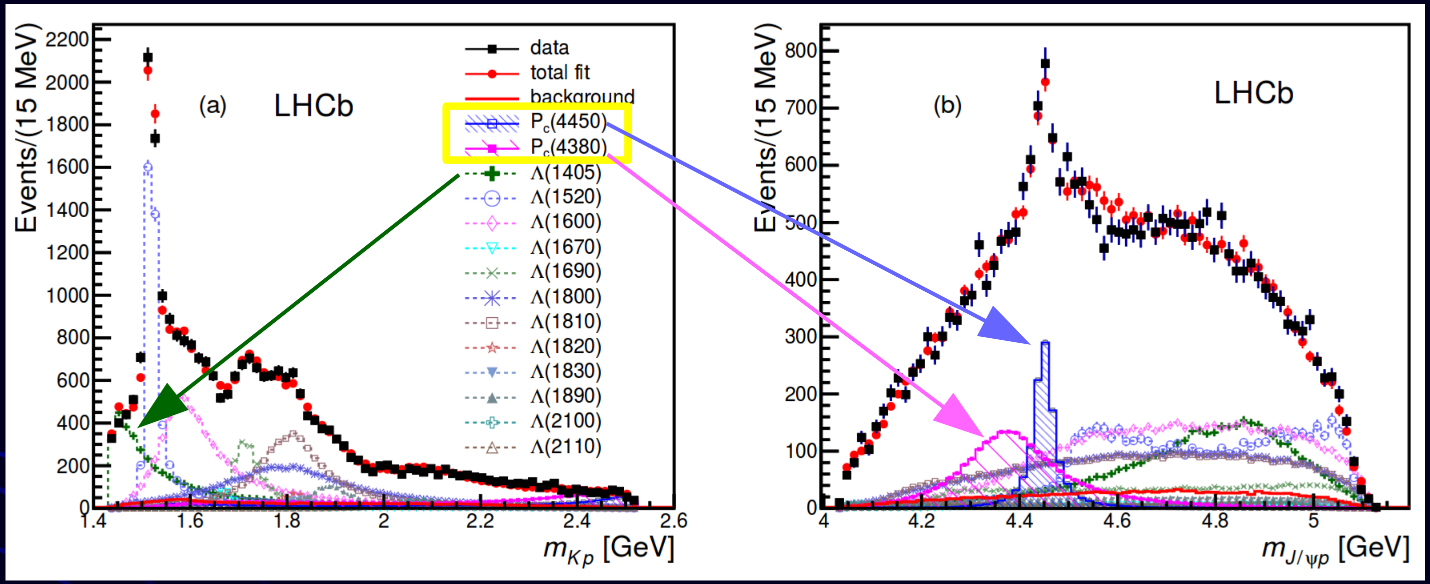
L.R., E.Oset, EPJ C, 76:591 (2016)

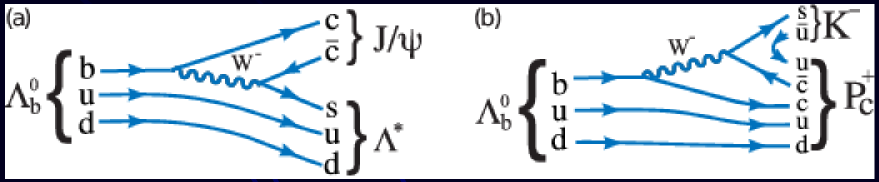
HADRON 2017, Salamanca, September 28, 2017

The LHCb pentaquarks, $P_c(4450)^+$, $P_c(4380)^+$

The $\Lambda_b \rightarrow J/\psi K^- p$ reaction was used to report the existence of two pentaquarks by the LHCb collaboration at CERN

LHCb Coll. (CERN), Phys.Rev.Lett. 115 (2015) 7, 072001



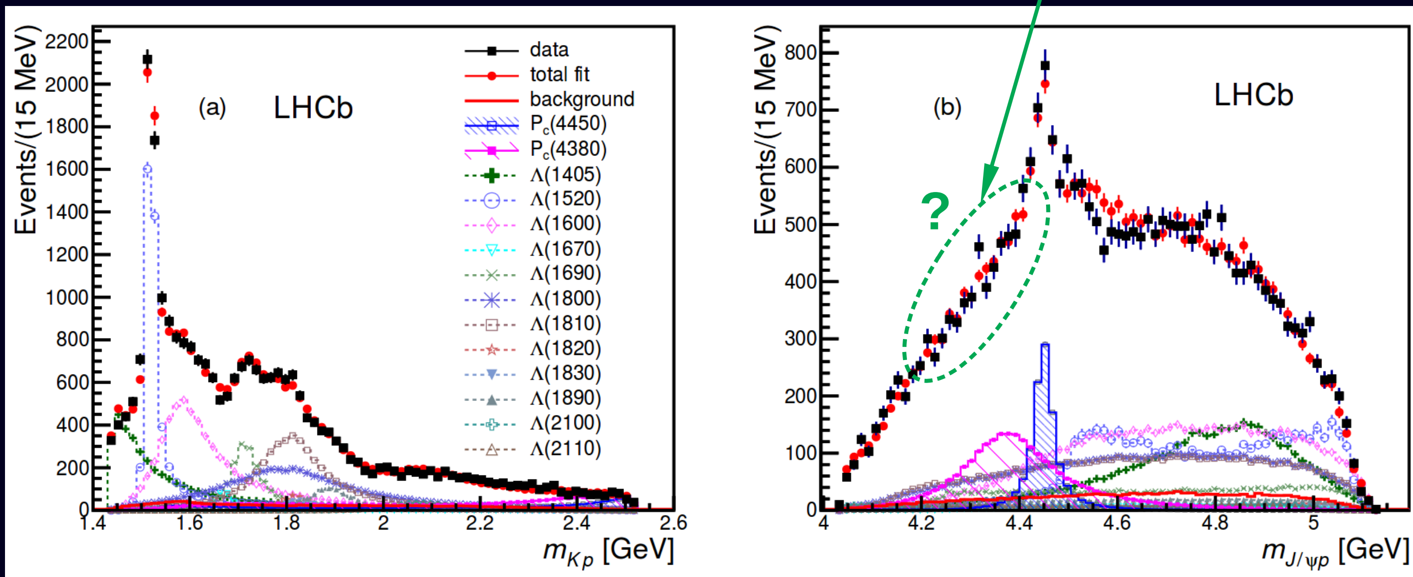


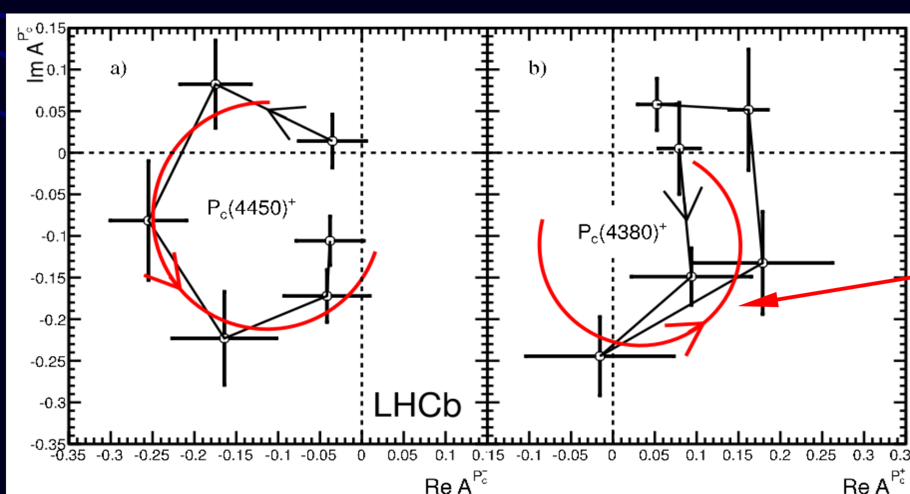
First claimed hidden-charm baryon

Best fit provides ($J^P(4380)$,$J^P(4450)$)=($3/2^-$,$5/2^+$), but also possible ($3/2^+$,$5/2^-$) and ($5/2^+$,$3/2^-$)

$P_c(4380)^+$ more controversial:

No “apparent bump” in the experimental spectra





Strange Argand plot behaviour

Breit-Wigner expectation

Only “exotic baryons” quoted in the **PDG**:

PDG particle data group 1957 2017 Particle Listings

HOME: | pdgLive | Summary Tables | Reviews, Tables, Plots | Particle Listings

2017 Review of Particle Physics

Please use this **CITATION**:
C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016) and 2017 update.

Cut-off date for this update was January 15, 2017.

Particle Listings

Search Listings

- **Gauge & Higgs Bosons** (gamma, g, W, Z, ...)
- **Leptons** (e, mu, tau, neutrinos, heavy leptons ...)
- **Quarks** (u, d, s, c, b, t, ...)
- **Mesons** (pi, K, D, B, psi, Upsilon, ...)
- **Baryons** (p, n, Lambda_b, Xi, ...)
  - N Baryons (S = 0, I = 1/2)
  - Delta Baryons (S = 0, I = 3/2)
  - Lambda Baryons (S = -1, I = 0)
  - Sigma Baryons (S = -1, I = 1)
  - XI Baryons (S = -2, I = 1/2)
  - Omega Baryons (S = -3, I = 0)
  - Charmed Baryons (C = +1)
  - Doubly-charmed Baryons (C = +2)
  - Bottom Baryons (B = -1)
  - Exotic Baryons
    - Pentaquarks (new)
    - P(c)(4380)+
    - P(c)(4450)+
  - Collapse Exotic Baryons table
  - Collapse Baryons table
- **Other Searches** (SUSY, Compositeness, ...)

All pages © 2017 Regents of the University of California

Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016) and 2017 update

$P_c(4380)^+$

Status: $*$

A resonance seen in $\Lambda_b^0 \to P_c^+ K^-$, then $P_c \to J/\psi p$, with a significance of 9 standard deviations. The $J/\psi p$ quark content is $u u d c \overline{c}$, a pentaquark. See also the $P_c(4450)^+$. In the best amplitude fit, the two states have opposite parity, one having $J = 3/2$, the other $J = 5/2$.

Extraction of the pentaquark signals requires some understanding of the dominant $K^- p$ background. AAIJ 15P used a model-dependent approach. AAIJ 16AG reanalyzed the data making minimal assumptions about the $K^- p$ background, and thus confirmed the strong significance of the pentaquark signals.

Citation: C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016) and 2017 update

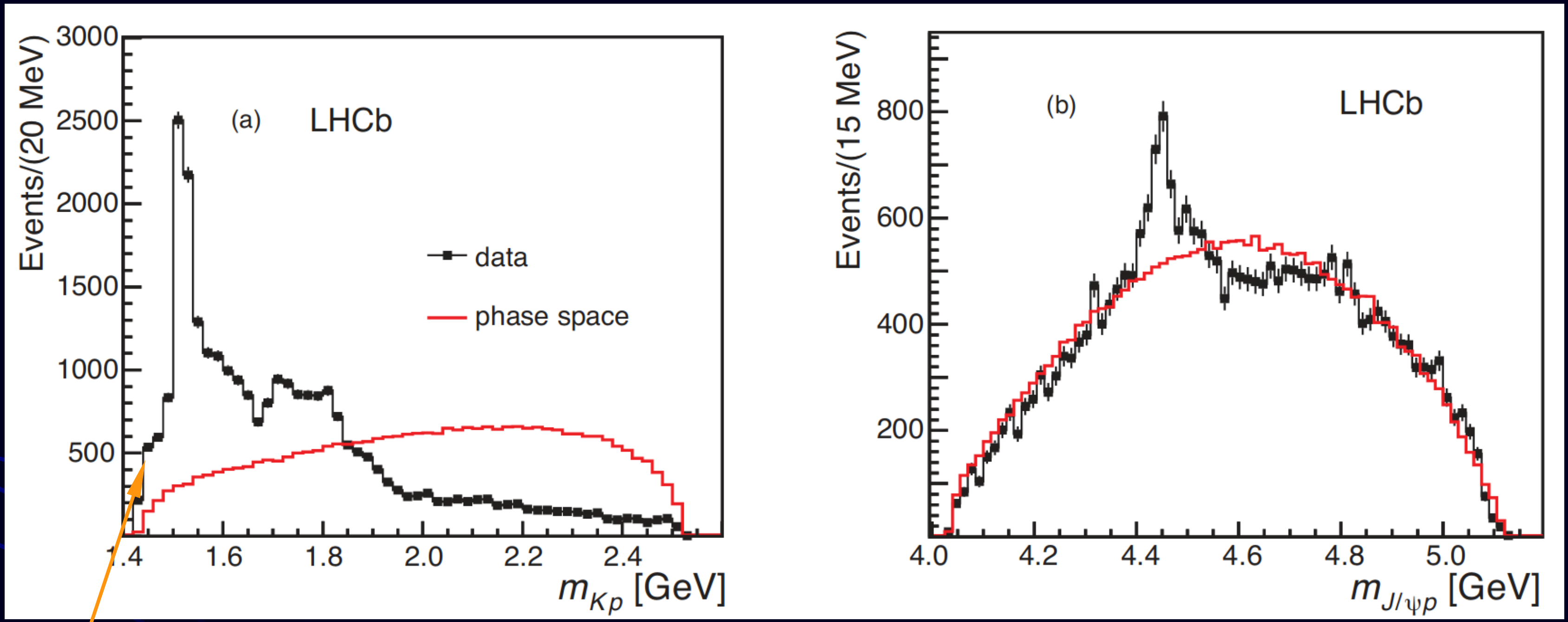
$P_c(4450)^+$

Status: $*$

A resonance seen in $\Lambda_b^0 \to P_c^+ K^-$, then $P_c \to J/\psi p$, with a significance of 12 standard deviations. The $J/\psi p$ quark content is $u u d c \overline{c}$, a pentaquark. See also the $P_c(4380)^+$. In the best amplitude fit, the two states have opposite parity, one having $J = 3/2$, the other $J = 5/2$.

Extraction of the pentaquark signals requires some understanding of the dominant $K^- p$ background. AAIJ 15P used a model-dependent approach. AAIJ 16AG reanalyzed the data making minimal assumptions about the $K^- p$ background, and thus confirmed the strong significance of the pentaquark signals.

The $\Lambda(1405)$ in $\Lambda_b \to J/\psi\ \Lambda(1405)$



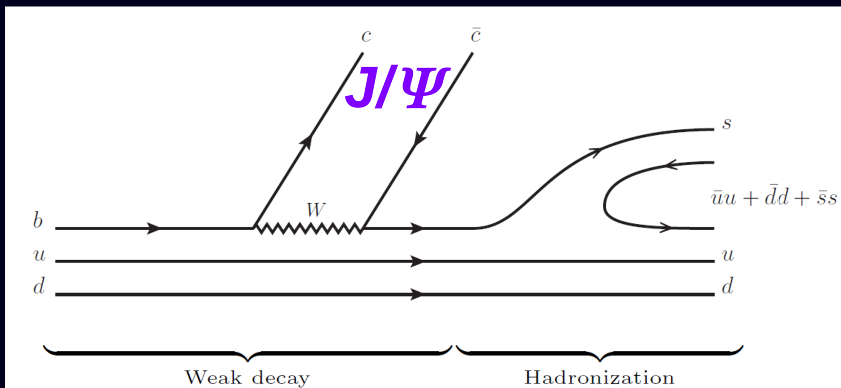
Large concentration of strength around threshold → $\Lambda(1405)$ relevant

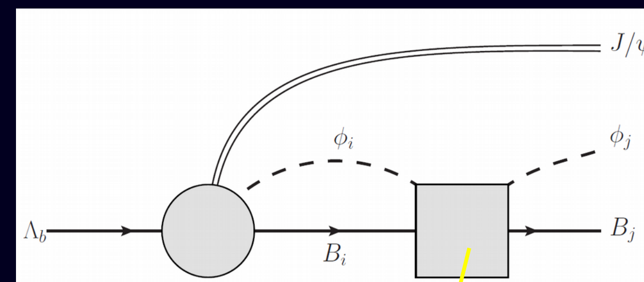
The $\Lambda(1405)$ in $\Lambda_b \to J/\psi\ \Lambda(1405)$

L.R., M.Mai, E.Oset and U.G.Meißner, Eur.Phys.J.C 75 (2015) 5, 218

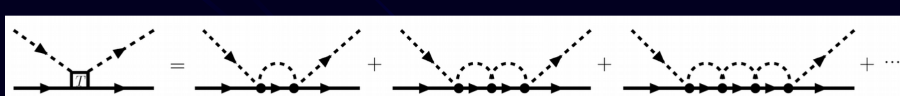
$\Lambda_b \to J/\psi\, \pi\Sigma$ $\Lambda_b \to J/\psi\, \bar{K}N$

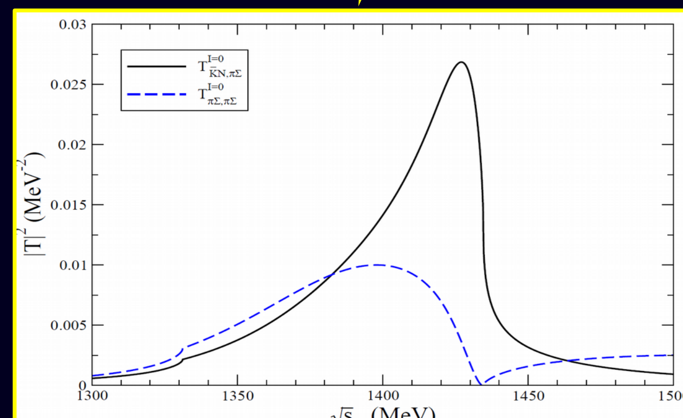
Λ_b





Meson-baryon amplitudes in coupled channels from chiral unitary approach

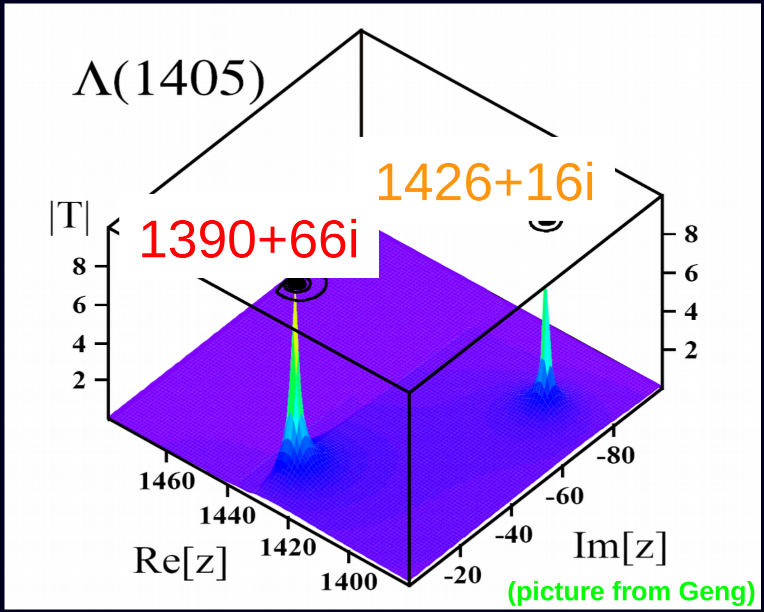




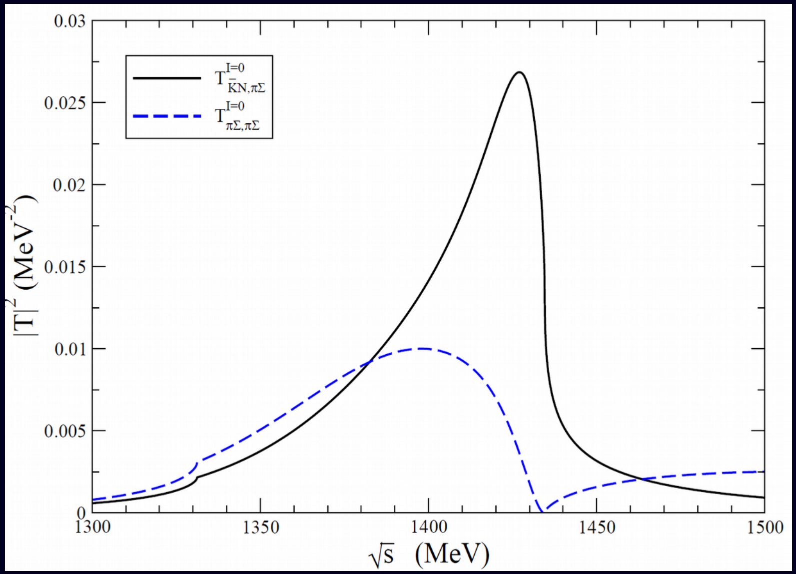
$T = [1 - VG]^{-1}V$

Oset,Ramos'98; Oller,Meissner'01; Jido et al'03, Hyodo et.al'03, Garcia-Recio et al.'03, ...

Two poles in the complex plane



Amplitudes in the real axis:



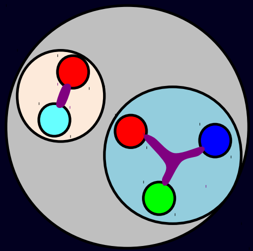
Couplings to different channels:

z_R $(I=0)$	$1390+66i$ g_i	$\lvert g_i\rvert$	$1426+16i$ g_i	$\lvert g_i\rvert$
$\pi\Sigma$	$-2.5-1.5i$	2.9	$0.42-1.4i$	1.5
$\bar{K}N$	$1.2+1.7i$	2.1	$-2.5+0.94i$	2.7
$\eta\Lambda$	$0.010+0.77i$	0.77	$-1.4+0.21i$	1.4
$K\Xi$	$-0.45-0.41i$	0.61	$0.11-0.33i$	0.35

Recall: no explicit resonances included!

(dynamically generated from chiral dynamics and unitarity)

Provide the actual shape of the amplituds. **Not Breit-Wigners!**



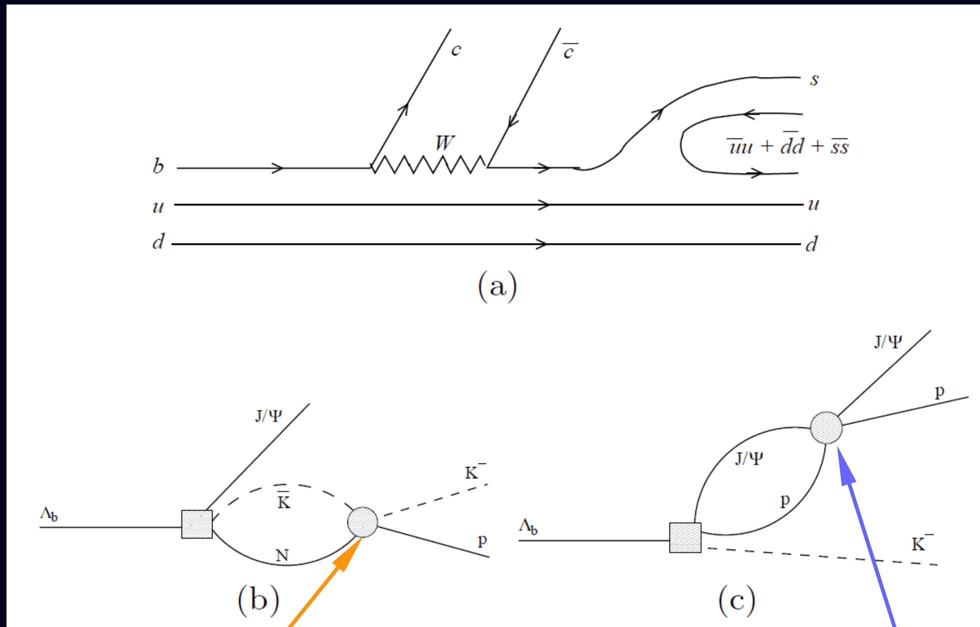
Lowest pole dominated by $\pi\Sigma$

Highest pole dominated by $\overline{K}N$

Resonance shape may be different for different reactions!

Our model:

L.R., J.Nieves, E.Oset, arXiv:1507.04249 [hep-ph].



UChPT as explained before: Λ(1405)

$J/\psi N,\ \bar{D}^*\Lambda_c,\ \bar{D}^*\Sigma_c,\ \bar{D}\Sigma_c^*$ and $\bar{D}^*\Sigma_c^*$ coupled channels

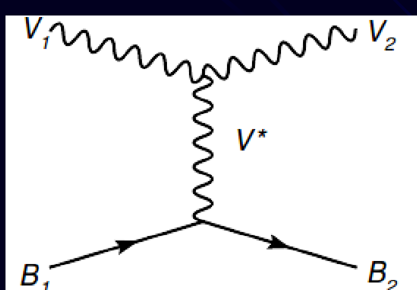
Xiao, Nieves, Oset, PRD88 (2013) 056012

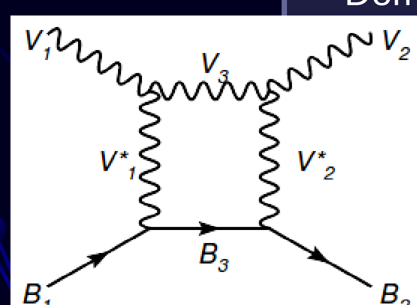
Wu, Molina,,Oset, Zou, PRC84 (2011) 015202

Poles at $4334 + 19i$ MeV, $4417 + 4i$ MeV and $4481 + 17i$ MeV

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

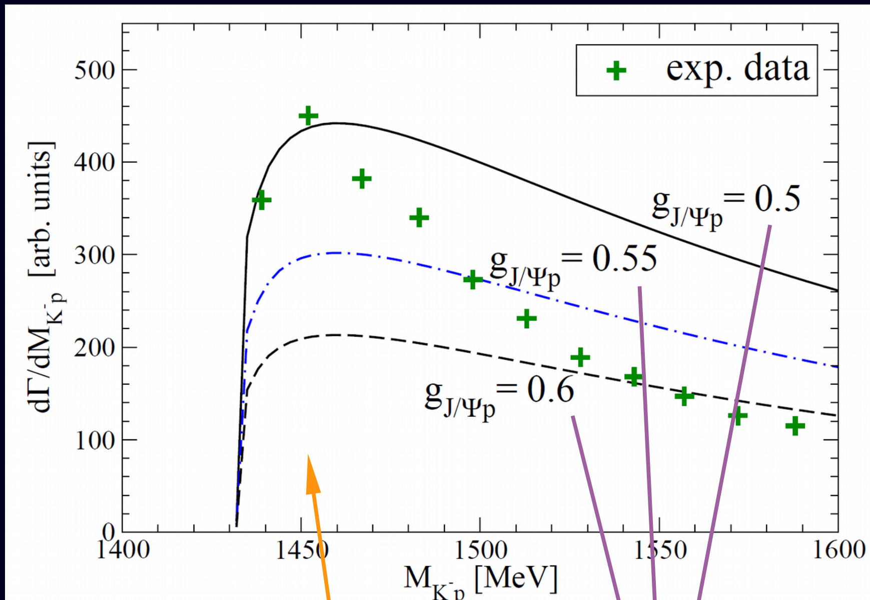
Dominant coupling to $\bar{D}^*\Sigma_c - \bar{D}^*\Sigma_c^*$

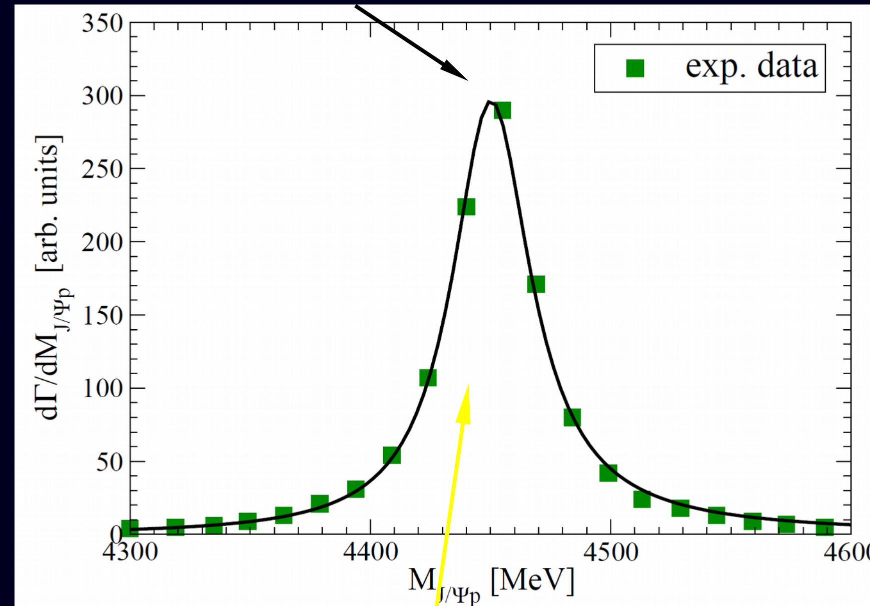




+ unitarization

(Strength fitted to experiment)





$P_c(4450)^+$

$\Lambda(1405)$

Range of couplings predicted by the model

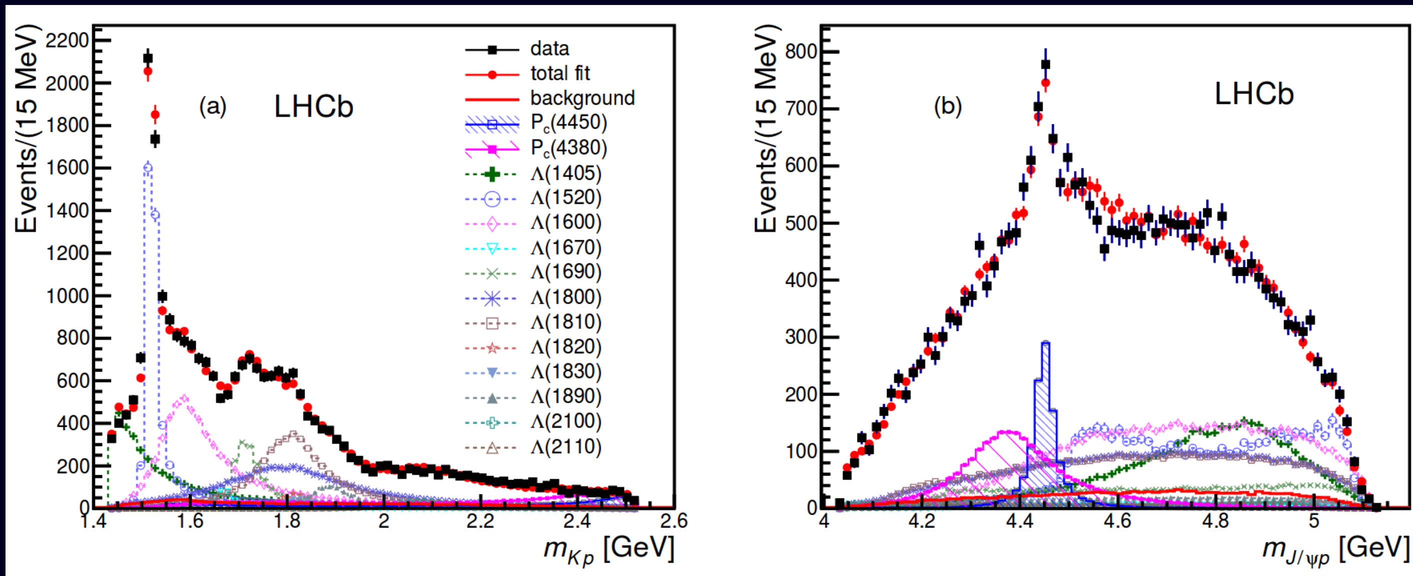
Relative strength between both panels is not trivial at all and is a genuine prediction from the theory

Results explained with $P_c(4450)^+$ being $J^P=3/2^-$ $\bar{D}^*\Sigma_c - \bar{D}^*\Sigma_c^*$ molecule

Experimental fit allows $J^P=5/2^+$, $5/2^-$, $3/2^-$

Analysis including more resonances

L.R., E.Oset, EPJ C, 76:591 (2016)



Many Λ resonances relevant to fit the overall invariant mass spectra

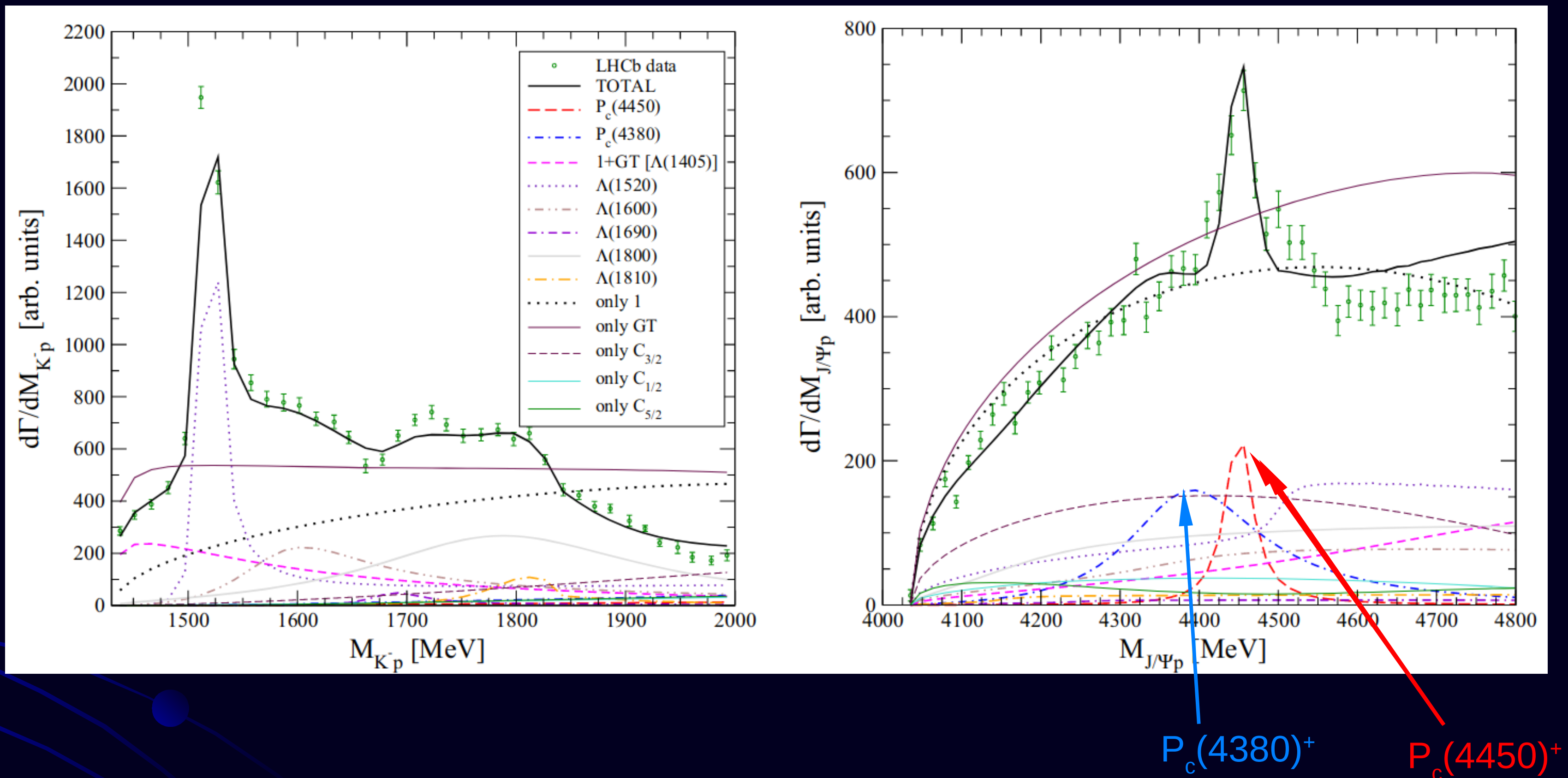
We include:

$J'^{P'}$	$\frac{1}{2}^-$	$\frac{1}{2}^+$	$\frac{1}{2}^+$	$\frac{3}{2}^-$
Λ	Λ(1405) Λ(1800)	Λ(1600) Λ(1810)	Λ(1600) Λ(1810)	Λ(1520) Λ(1690)

UChPT

Breit-Wigners with Flatté parametrization of the widths plus proper spin structure

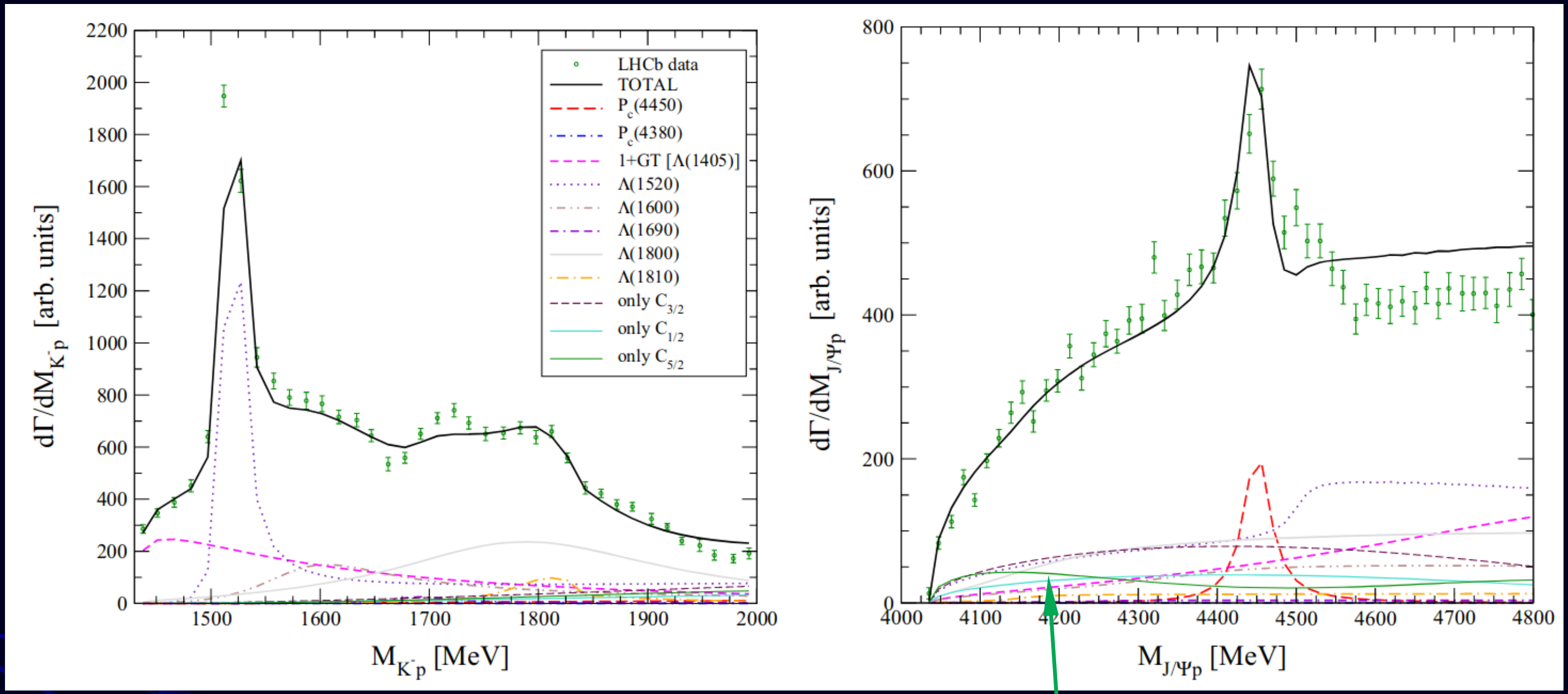
Results of our fit



Quality of the fit almost independent of J^P assignments for the P_C's

Fit without including the lowest mass pentaquak, $P_c(4380)^+$:

- Similar quality of the fit



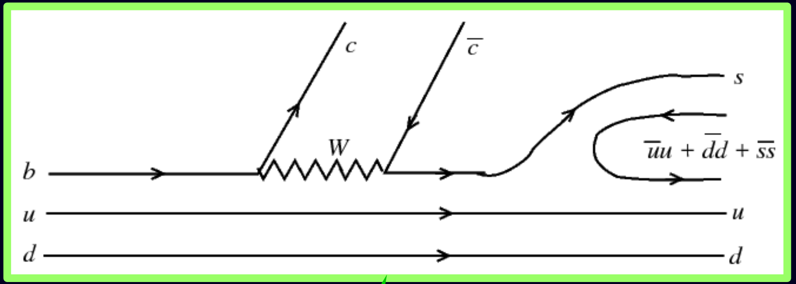
Effect of the $P_c(4380)^+$ can be accomodated by an increase in a contact term with $5/2^+$ quantum numbers

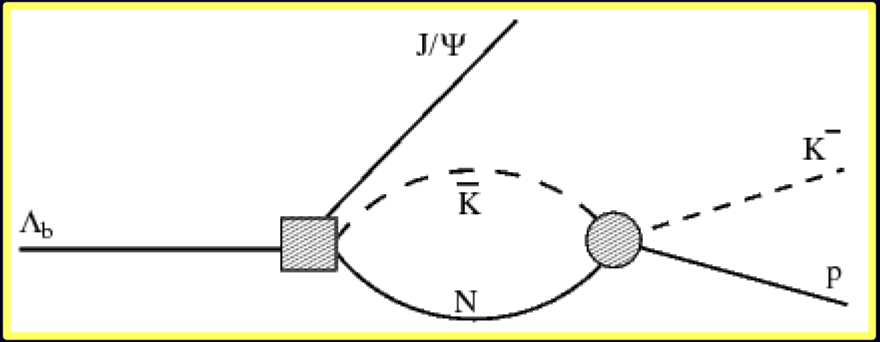
(original experimental LHCb fit only included up to spin 3/2 nonresonant components)

LHCb Coll. (CERN), Phys.Rev.Lett. 115 (2015) 7, 072001

A tricky issue regarding the $\Lambda(1405)$ and a contact term...

For the $\Lambda(1405)$ channel we have





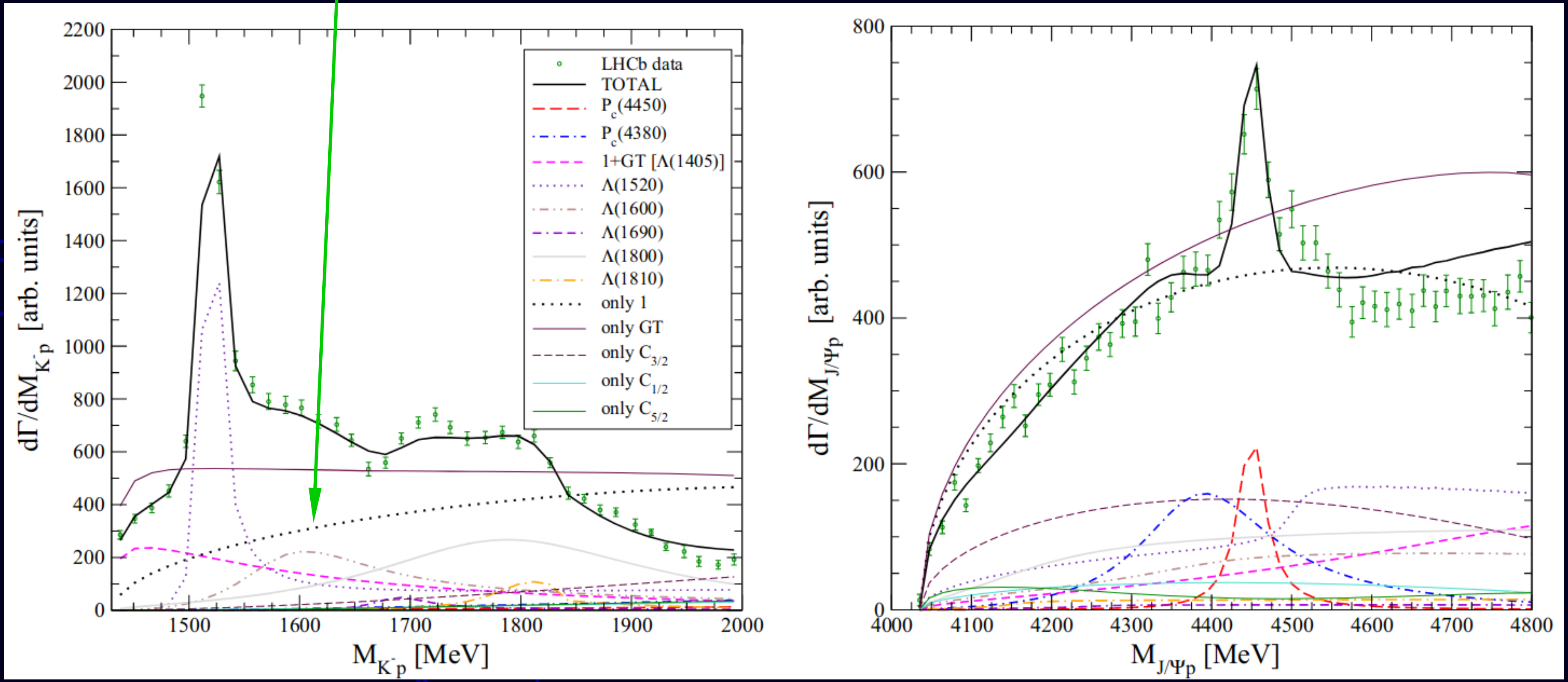
$$1 + G_{K^-p}(M_{K^-p})\, t^{I=0}_{\bar{K}N,\bar{K}N}(M_{K^-p})$$

Contact term negligible in exp. LHCb fit

However we get a very important contribution

Contradiction?

NO, (by chance)



$$1 + GT = V^{-1}T,$$

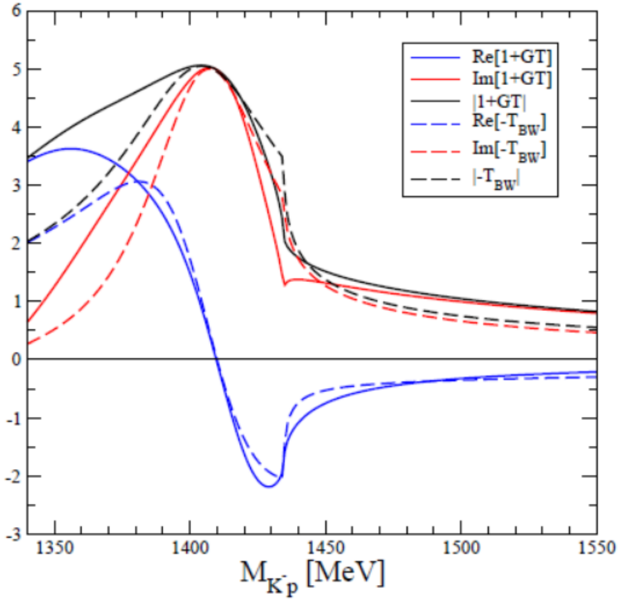
$$(1+GT)_{11} = (V^{-1}T)_{11} = \frac{T_{11}V_{22} - T_{12}V_{12}}{V_{11}V_{22} - V_{12}^2}$$

$$T_{11} \simeq \frac{g_1^A g_1^A}{\sqrt{s} - \sqrt{s_0^A}} + \frac{g_1^B g_1^B}{\sqrt{s} - \sqrt{s_0^B}}$$

$$T_{12} \simeq \frac{g_1^A g_2^A}{\sqrt{s} - \sqrt{s_0^A}} + \frac{g_1^B g_2^B}{\sqrt{s} - \sqrt{s_0^B}}$$

T_{11} and T_{12} are not proportional

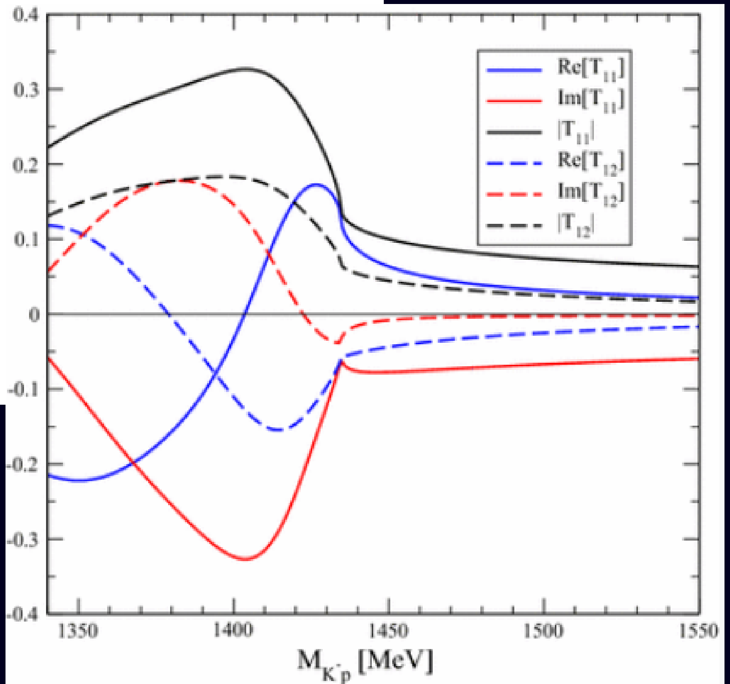
If V_{12} is small $(1+GT)_{11} \simeq \frac{T_{11}}{V_{11}} \propto -T_{11}$



11: Kbar N -> Kbar N

12: Kbar N -> πΣ

and recall the Λ(1405) has two poles.



Summary

- $P_c(4450)^+$, $P_c(4380)^+$ are the only exotic baryons quoted by the PDG (1-star status)

- Only seen in one experiment and one reaction: $\Lambda_b \rightarrow J/\psi K^- p$ by LHCb coll. at CERN

- The important role of $\Lambda(1405)$ in $\Lambda_b \rightarrow J/\psi \bar{K} N$ allows us to check the possible nature of the $P_c(4450)^+$ as a $J^P=3/2^-$ molecule. Results non-trivially compatible with this picture

- Further improvement: Inclusion of more Λ resonances and fit to overall spectra:
  - - Good fits but similar for differenrt J^P (not conclusive)
  - - $P_c(4380)^+$ not essential in the fit

effect can be mimicked by a non-resonant 5/2 contribution

BACK SLIDES

Predictions for hidden charm Baryon states

J J Wu, R Molina, E. O, B S Zou, PRL (2010)

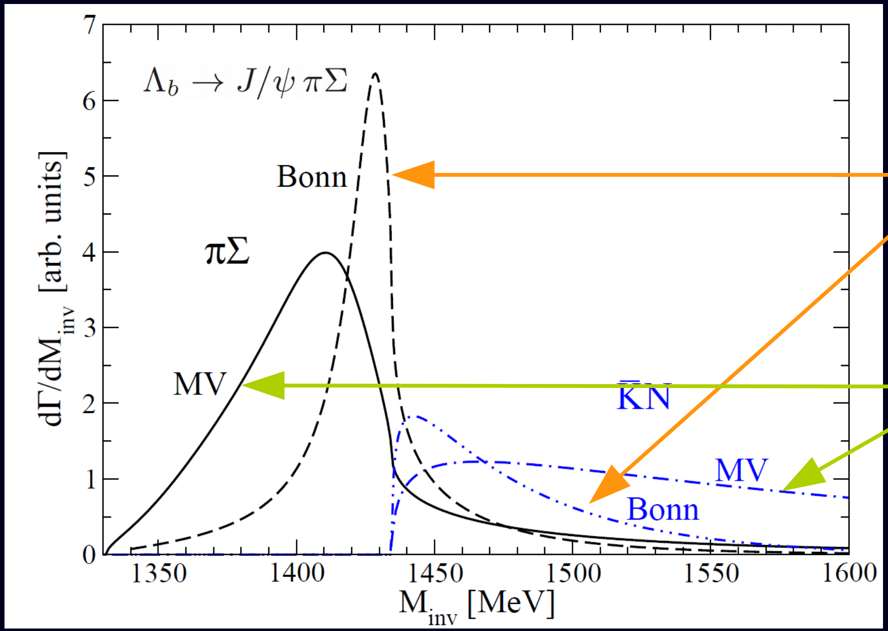
(I,S)	z_R	g_a		
$(1/2,0)$		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	$J/\psi N$
	$4415-9.5i$	$2.83-0.19i$	$-0.07+0.05i$	$-0.85+0.02i$
		2.83	0.08	0.85

In s-wave: $3/2^-$

C W Xiao, J Nieves, E. O, PRD 2013 : D*bar Σ_c* channel included

$4417.04+i4.11$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
g_i	$0.53-i0.07$	$0.08-i0.07$	$2.81-i0.07$	$0.12-i0.10$	$0.11-i0.51$
$\|g_i\|$	0.53	0.11	2.81	0.16	0.52
$4481.04+i17.38$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
g_i	$1.05+i0.10$	$0.18-i0.09$	$0.12-i0.10$	$0.22-i0.05$	$2.84-i0.34$
$\|g_i\|$	1.05	0.20	0.16	0.22	2.86

Reflects the highest mass Λ(1405) pole



Two different UChPT models:

- ✓ Higher order meson-baryon Lagrangians fitted to photoproduction and meson-baryon cross sections

  Bruns, Mai, Meißner, Phys.Lett. B697 (2011) 254

- ✓ Lowest order chiral Lagrangian with modified kernel

  (Our model explained above)

  L.R., E.Oset, Phys.Rev.C 88 (2013) 055206

$$\sum |T|^2 = 3|a|^2 + |b|^2 \frac{3}{2}\vec{k}^2 + |c|^2 3\vec{k}^2 + |e|^2 \frac{2}{3}\vec{k}^4 + |f|^2 \frac{2}{3}\vec{k}^2 \left[(\vec{p}\cdot\vec{k})^2 + \frac{1}{3}\vec{k}^2\vec{p}^{\,2}\right] - \frac{4}{3}\vec{k}^2\vec{p}\cdot\vec{k}\left[\mathrm{Re}(bf^*) - 2\,\mathrm{Re}(cf^*)\right],$$

$$a = \alpha_1\left(1 + G_{K^-p}(M_{K^-p})\, t^{I=0}_{\bar{K}N,\bar{K}N}(M_{K^-p})\right) + \delta_{J^P_B,\frac{1}{2}^-}\alpha_2\, G_{J/\psi p}\frac{g^2_{J/\psi\, p}}{M_{J/\psi\, p} - m_{P_c(4450)} + i\frac{\Gamma_{P_c(4450)}}{2}} + \delta_{J^P_A,\frac{1}{2}^-}\alpha_3\, G_{J/\psi p}\frac{g^2_{J/\psi\, p}}{M_{J/\psi\, p} - m_{P_c(4380)} + i\frac{\Gamma_{P_c(4380)}}{2}} + \alpha_4\frac{1}{M_{K^-p} - m_{\Lambda(1800)} + i\frac{\Gamma_{\Lambda(1800)}}{2}},$$

$$b = \frac{4}{3}\alpha_5\frac{1}{M_{K^-p} - m_{\Lambda(1600)} + i\frac{\Gamma_{\Lambda(1600)}}{2}} + \frac{4}{3}\alpha_6\frac{1}{M_{K^-p} - m_{\Lambda(1810)} + i\frac{\Gamma_{\Lambda(1810)}}{2}} + C_{3/2}\left[1 + \delta_{J^P_B,\frac{3}{2}^-}\alpha_2\, G_{J/\psi p}\frac{g^2_{J/\psi\, p}}{M_{J/\psi\, p} - m_{P_c(4450)} + i\frac{\Gamma_{P_c(4450)}}{2}} + \delta_{J^P_A,\frac{3}{2}^-}\alpha_3\, G_{J/\psi p}\frac{g^2_{J/\psi\, p}}{M_{J/\psi\, p} - m_{P_c(4380)} + i\frac{\Gamma_{P_c(4380)}}{2}}\right]$$

$$c = -\frac{1}{3}\alpha_5\frac{1}{M_{K^-p} - m_{\Lambda(1600)} + i\frac{\Gamma_{\Lambda(1600)}}{2}} - \frac{1}{3}\alpha_6\frac{1}{M_{K^-p} - m_{\Lambda(1810)} + i\frac{\Gamma_{\Lambda(1810)}}{2}} + C_{1/2}\left[1 + \delta_{J^P_B,\frac{1}{2}^-}\alpha_2\, G_{J/\psi p}\frac{g^2_{J/\psi\, p}}{M_{J/\psi\, p} - m_{P_c(4450)} + i\frac{\Gamma_{P_c(4450)}}{2}} + \delta_{J^P_A,\frac{1}{2}^-}\alpha_3\, G_{J/\psi p}\frac{g^2_{J/\psi\, p}}{M_{J/\psi\, p} - m_{P_c(4380)} + i\frac{\Gamma_{P_c(4380)}}{2}}\right]$$

$$e = \alpha_7\frac{1}{M_{K^-p} - m_{\Lambda(1520)} + i\frac{\Gamma_{\Lambda(1520)}}{2}} + \alpha_8\frac{1}{M_{K^-p} - m_{\Lambda(1690)} + i\frac{\Gamma_{\Lambda(1690)}}{2}},$$

$$f = C_{5/2}\left[1 + \delta_{J^P_B,\frac{5}{2}^+}\alpha_9\frac{1}{M_{J/\psi\, p} - m_{P_c(4450)} + i\frac{\Gamma_{P_c(4450)}}{2}} + \delta_{J^P_A,\frac{5}{2}^+}\alpha_{10}\frac{1}{M_{J/\psi\, p} - m_{P_c(4380)} + i\frac{\Gamma_{P_c(4380)}}{2}}\right].$$