A hidden-charm $S = -1$ pentaquark from the decay $\Lambda_b \to J/\psi\, \eta\Lambda$ and $\Lambda_b \to J/\psi\, \phi\Lambda$

Hadron spectroscopy phenomenology workshop.

CERN, 7th November 2017.

Universitat de Barcelona

Albert Feijoo Aliau

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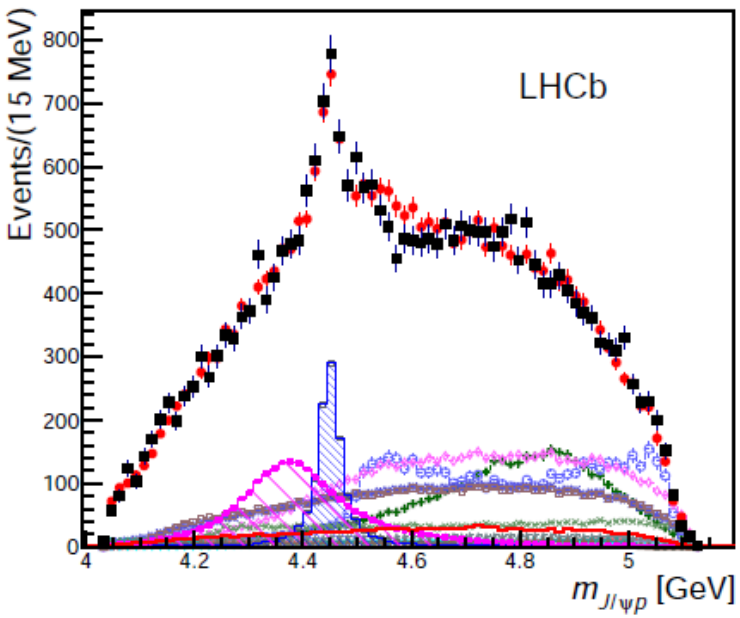
Motivation: Experimental background

2 **pentaquark** states were observed by the **LHCb Collaboration** in the invariant mass distribution ***J/ψp*** mass spectrum of the $\Lambda_b \longrightarrow J/\psi K^{-} p$ process:

	M (MeV)	Γ (MeV)
$P_c(4380)$	$4380 \pm 8 \pm 29$	$205 \pm 18 \pm 86$
$P_c(4450)$	$4449.8 \pm 1.7 \pm 2.5$	$39 \pm 5 \pm 19$

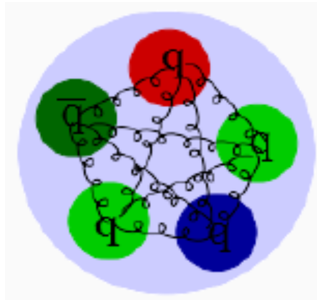
LHCb Collaboration, Phys. Rev. Lett. 115, 072001 (2015)



Motivation: Theoretical background

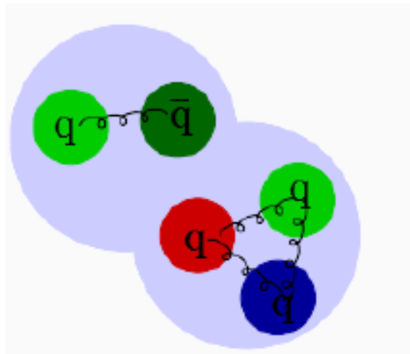
Prior to the experimental measurement, similar states had already been predicted by means of:

- **quark model approaches**



Wang, Huang, Zhang, Zou, PRC 84, 015203 (2011)
Yuan, Wei, He, Xu, Zou, EPJA 48, 61 (2012)

- **molecular picture**



Wu, Molina, Oset, Zou, PRL 105, 232001 (2010); PRC 84, 015202 (2011)
Yang, Sun, He, Liu, Zhu, Chin. Phys. C 36, 6 (2012)
Xiao, Nieves, Oset, PRD 88, 056012 (2013)
Karliner, Rosner, PRL 115, 122001 (2015)

Motivation: Theoretical background

- **molecular picture**

Wu, Molina, Oset, Zou, PRL 105, 232001 (2010); PRC 84, 015202 (2011)

(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	
$(0,-1)$		$\bar{D}_s^*\Lambda_c^+$	$\bar{D}^*\Xi_c$	$\bar{D}^*\Xi'_c$	$J/\psi\Lambda$
	$4368-2.8i$	$1.27-0.04i$	$3.16-0.02i$	$-0.10+0.13i$	$0.47+0.04i$
		1.27	3.16	0.16	0.47
	$4547-6.4i$	$0.01+0.004i$	$0.05-0.02i$	$2.61-0.13i$	$-0.61-0.06i$
		0.01	0.05	2.61	0.61

TABLE IX: Pole position (z_R) and coupling constants (g_a) to various channels for the states from $PB \to PB$ including the $J/\psi N$ and $J/\psi\Lambda$ channels.

(I,S)	z_R	Real axis		Γ_i
		M	Γ	
$(1/2,0)$				$J/\psi N$
	$4415-9.5i$	4412	47.3	19.2
$(0,-1)$				$J/\psi\Lambda$
	$4368-2.8i$	4368	28.0	5.4
	$4547-6.4i$	4544	36.6	13.8

TABLE X: Pole position (z_R), mass (M), total width (Γ, including the contribution from the light meson and baryon channel) and the decay widths for the $J/\psi N$ and $J/\psi\Lambda$ channels (Γ_i). The unit are in MeV

$S=-1$ charmonium states were predicted decaying into $J/\psi\Lambda$ and strongly coupling to $\bar{D}^*\Xi_C, \bar{D}^*\Xi'_C$ around 4.4 GeV

The existence of a hidden charm pentaquark in the I$=0, S=-1$ sector is likely

Motivation: Suggested reactions to observe a possible hidden-charm $S = -1$ pentaquark

$\Xi_b^- \to J/\psi\, K^- \Lambda$ Chen, Geng, Liang, Oset, Wang, Xie, PRC 93, 065203 (2016)

Statistics of the production of Ξ_b^- is much poorer than that of Λ_b.

$R_{\Xi_b^-}/R_{\Lambda_b} = \big(4.19 \pm 0.29(stat) \pm 0.15(syst)\big) \cdot 10^{-2}$ LHCb Collaboration, Phys. Lett. B 772, (2017)

$\Lambda_b \to J/\psi\, K^0 \Lambda$ Lu, Wang, Xie, Geng, Oset, PRD 93, 094009 (2016)

$\Lambda_b \to J/\psi\, \eta \Lambda$ Feijoo, Magas, Ramos, Oset, Eur. Phys. J. C76, no.8, 446 (2016)

$\Lambda_b \to J/\psi\, \phi \Lambda$ Tena, Magas, Ramos – work in progress

Motivation: Suggested reactions to observe a possible hidden-charm $S = -1$ pentaquark

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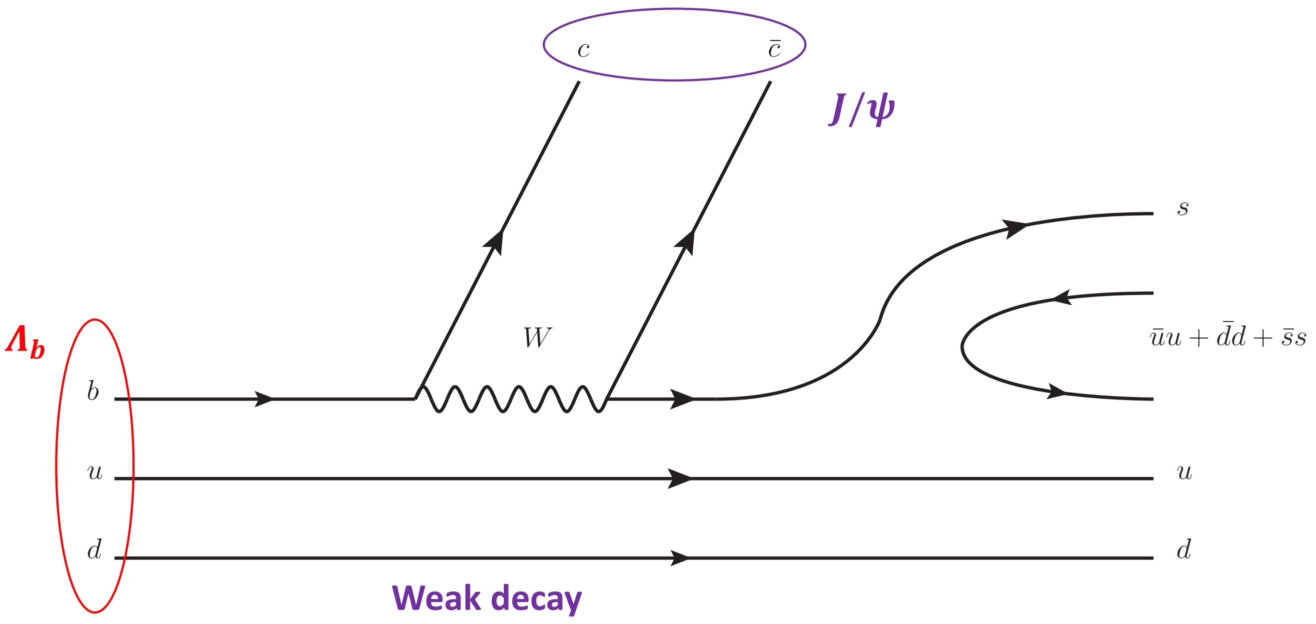
Production mechanism of a meson-baryon pair from the Λ_b weak decay

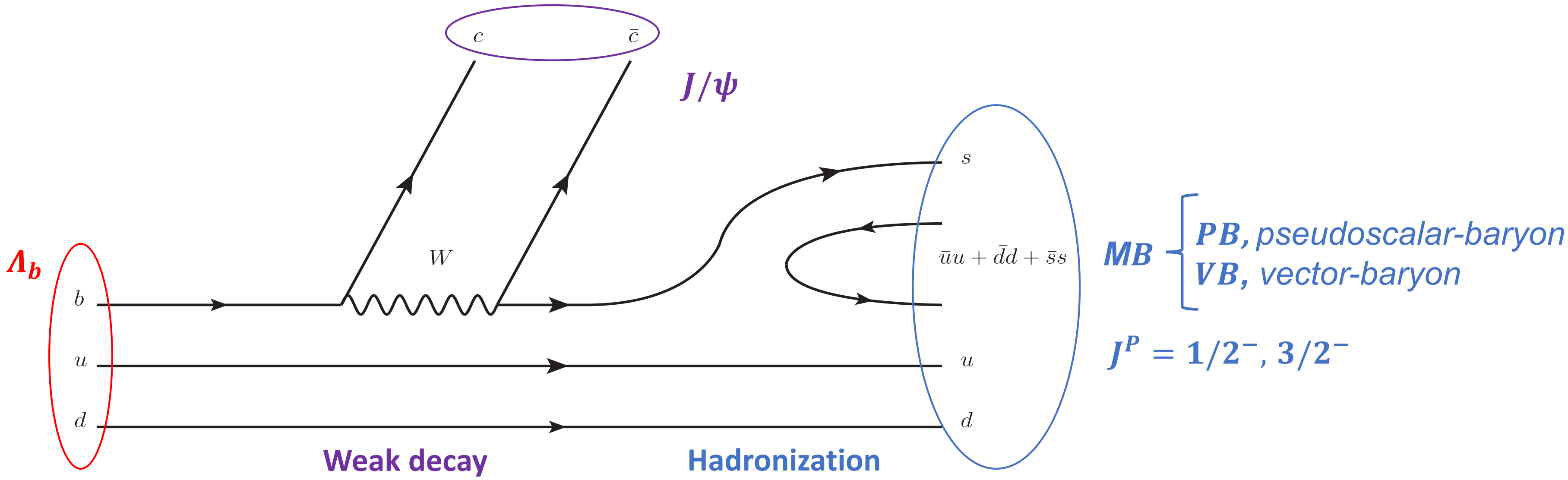
$\Lambda_b \to J/\psi\, MB$ Roca, Mai, Oset and Meissner, Eur. Phys. J. C 75, no. 5, 218 (2015)



$$|\Lambda_b\rangle = \frac{1}{\sqrt{2}}|b(ud - du)\rangle \longrightarrow \frac{1}{\sqrt{2}}|s(ud - du)\rangle$$

Cabibbo favored weak transition

Production mechanism of a meson-baryon pair from the Λ_b weak decay

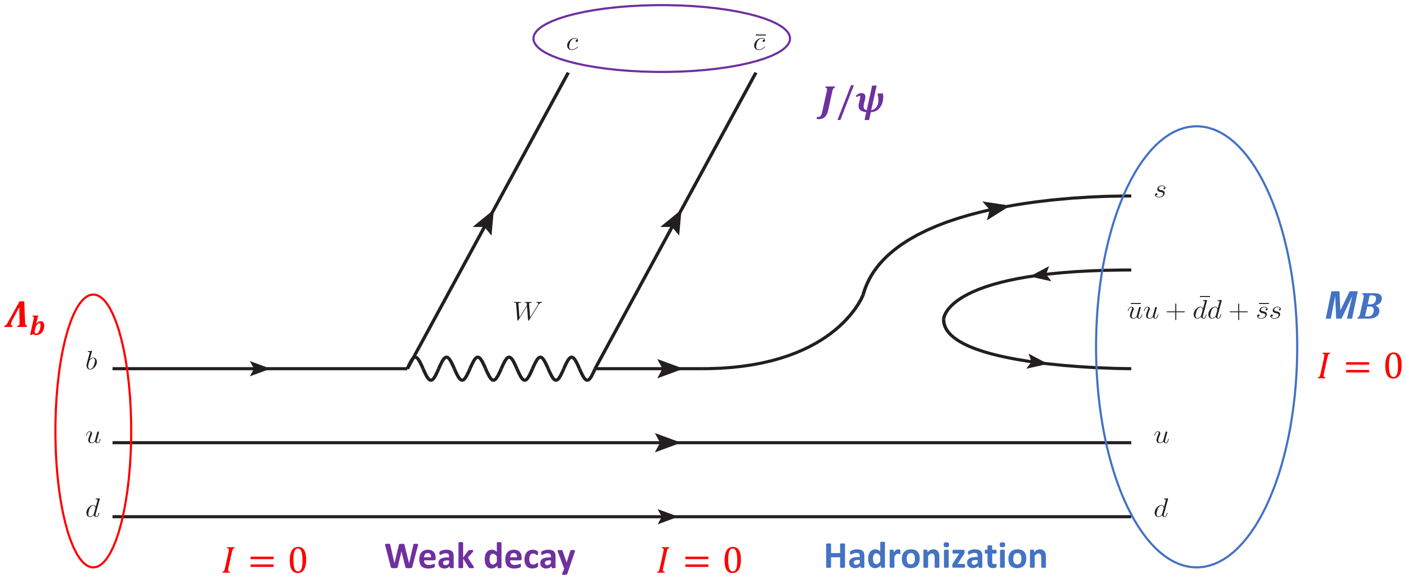


$$\frac{1}{\sqrt{2}}|s(ud-du)\rangle \longrightarrow \frac{1}{\sqrt{2}}\left|s\left(\bar{u}u+\bar{d}d+\bar{s}s\right)(ud-du)\right\rangle = \begin{cases} |K^-p\rangle + |\bar{K}^0 n\rangle + \frac{\sqrt{2}}{3}|\eta\Lambda\rangle & (\boldsymbol{PB}) \\ |K^{*-}p\rangle + |\bar{K}^{*0} n\rangle - \frac{\sqrt{2}}{3}|\phi\Lambda\rangle & (\boldsymbol{VB}) \end{cases}$$

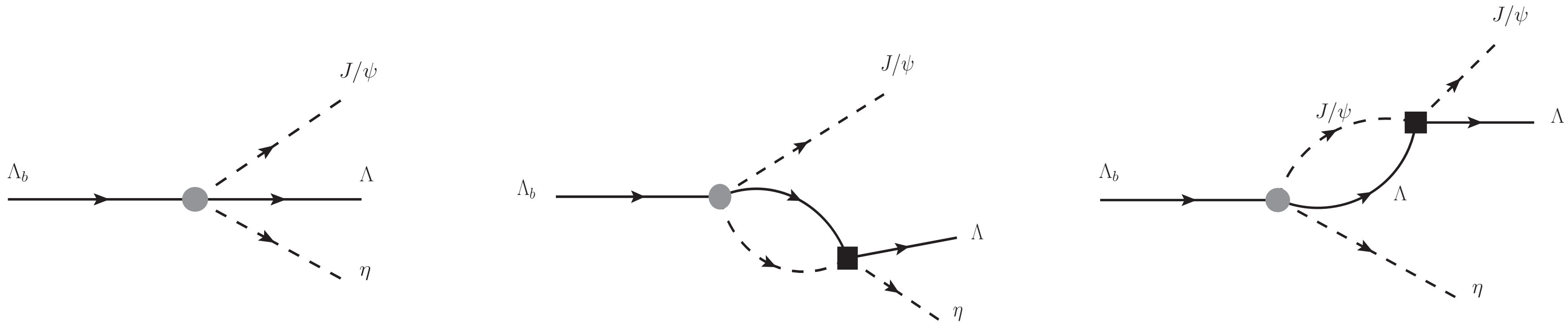
Production mechanism of a meson-baryon pair from the Λ_b weak decay

- The ***b***-quark and $\boldsymbol{\Lambda_b}$ have ***I=0***, therefore ***ud*** quark pair has ***I=0***
- We assume that ***u*** and ***d*** quarks act as ***spectators***
- After the weak decay the combination of ***ud*** with ***s*** can only form ***Λ (I=0)*** states

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



$\Lambda_b \to J/\psi\, \eta\Lambda$ decay: Transition amplitude



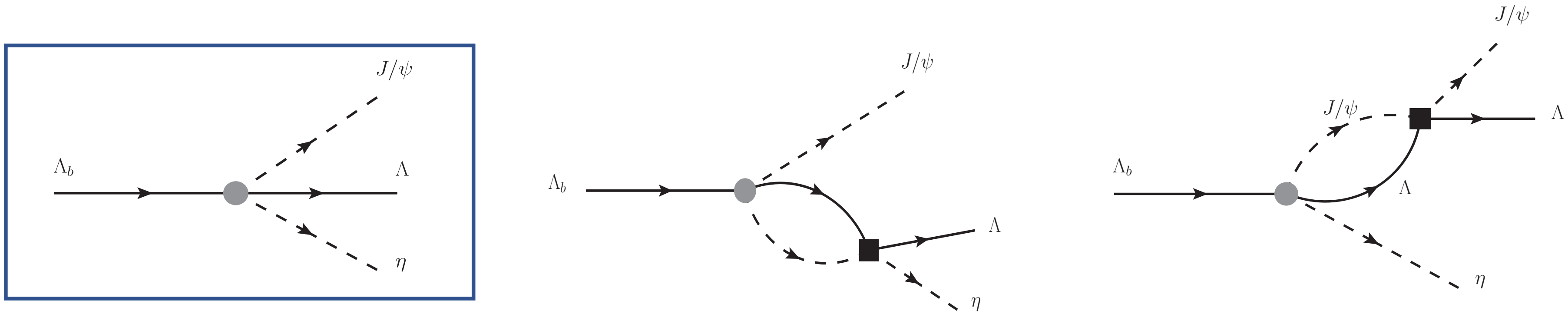
$$\mathcal{M}(M_{\eta\Lambda}, M_{J/\psi\Lambda}) = V_p \left[h_{\eta\Lambda} + \sum_i h_i G_i(M_{\eta\Lambda}) t_{i,\eta\Lambda}(M_{\eta\Lambda}) + h_{\eta\Lambda} G_{J/\psi\Lambda}(M_{J/\psi\Lambda}) t_{J/\psi\Lambda, J/\psi\Lambda}(M_{J/\psi\Lambda}) \right]$$

- The $\boldsymbol{V_P}$ factor absorbs the CKM matrix elements and the kinematic prefactors

Unknown overall factor → Arbitrary units
Taken as a constant value

Feijoo, Magas, Ramos, Oset: Phys.Rev. D92 (2015) no.7, 076015,
Erratum: Phys.Rev. D95 (2017) no.3, 039905

$\Lambda_b \to J/\psi\, \eta\Lambda$ decay: Transition amplitude

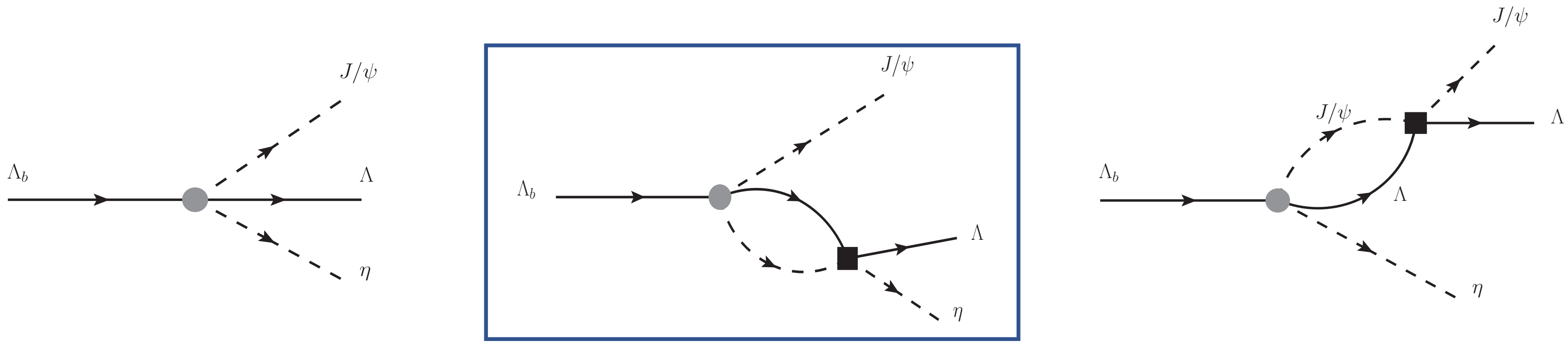


$$\mathcal{M}(M_{\eta\Lambda}, M_{J/\psi\Lambda}) = V_p \left[\boxed{h_{\eta\Lambda}} + \sum_i h_i G_i(M_{\eta\Lambda}) t_{i,\eta\Lambda}(M_{\eta\Lambda}) + h_{\eta\Lambda} G_{J/\psi\Lambda}(M_{J/\psi\Lambda}) t_{J/\psi\Lambda, J/\psi\Lambda}(M_{J/\psi\Lambda}) \right]$$

- $\boldsymbol{h_i}$ weights of the final meson-baryon states in the flavor wave function

$$h_{\pi^0\Sigma^0} = h_{\pi^+\Sigma^-} = h_{\pi^-\Sigma^+} = h_{K^+\Xi^-} = h_{K^0\Xi^0} = 0\,,$$
$$h_{K^-p} = h_{\bar{K}^0 n} = 1\,,\;\; h_{\eta\Lambda} = -\frac{\sqrt{2}}{3}$$

$\Lambda_b \to J/\psi\, \eta\Lambda$ decay: Transition amplitude



$$\mathcal{M}(M_{\eta\Lambda}, M_{J/\psi\Lambda}) = V_p \left[h_{\eta\Lambda} + \boxed{\sum_i h_i G_i(M_{\eta\Lambda}) t_{i,\eta\Lambda}(M_{\eta\Lambda})} + h_{\eta\Lambda} G_{J/\psi\Lambda}(M_{J/\psi\Lambda}) t_{J/\psi\Lambda,J/\psi\Lambda}(M_{J/\psi\Lambda}) \right]$$

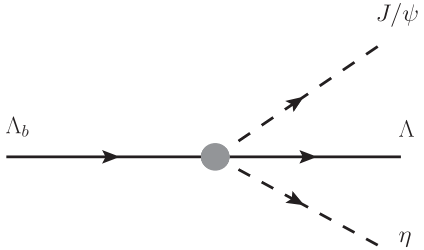
- Meson-Baryon loop function $\boldsymbol{G_i}$ ($i = K^- p,\ \bar{K}^0 n,\ \eta\Lambda$)

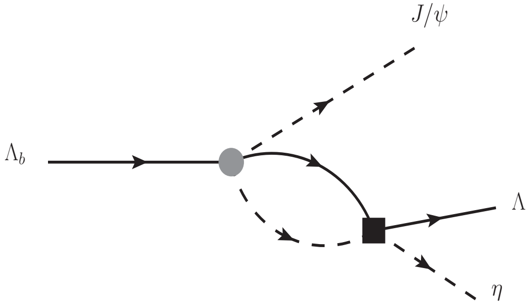
$$G_l = \frac{2M_l}{(4\pi)^2} \left\{ a_l(\mu) + \ln\frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s} \ln\frac{m_l^2}{M_l^2} + \frac{q_{\rm cm}}{\sqrt{s}} \ln\left[\frac{(s + 2\sqrt{s} q_{\rm cm})^2 - (M_l^2 - m_l^2)^2}{(s - 2\sqrt{s} q_{\rm cm})^2 - (M_l^2 - m_l^2)^2} \right] \right\}.$$

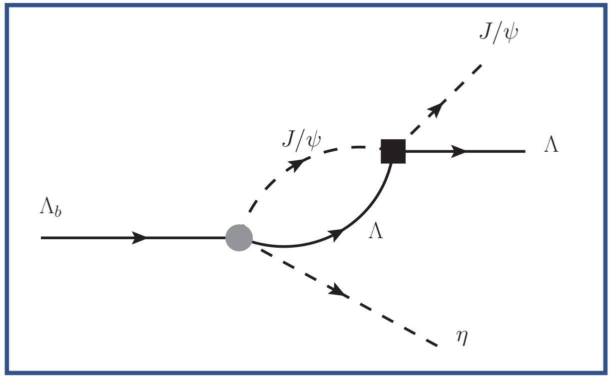
- Scattering amplitude $\boldsymbol{t_{i,\eta\Lambda}}$ from:

Feijoo, Magas, Ramos:
Phys. Rev. C 92, 015206 (2015)
Nucl. Phys. A 954, 58 (2016)
EPJ Web Conf. 137 05003 (2017)

$\Lambda_b \to J/\psi\,\eta\Lambda$ decay: Transition amplitude







$$\mathcal{M}(M_{\eta\Lambda}, M_{J/\psi\Lambda}) = V_p \left[h_{\eta\Lambda} + \sum_i h_i G_i(M_{\eta\Lambda}) t_{i,\eta\Lambda}(M_{\eta\Lambda}) + \boxed{h_{\eta\Lambda} G_{J/\psi\Lambda}(M_{J/\psi\Lambda}) t_{J/\psi\Lambda,J/\psi\Lambda}(M_{J/\psi\Lambda})} \right]$$

- Scattering amplitude $\boldsymbol{t}_{J/\psi\Lambda}$ from:

$$t_{J/\psi\Lambda,J/\psi\Lambda} = \frac{g^2_{J/\psi\Lambda}}{M_{J/\psi\Lambda} - M_R + \mathrm{i}\,\frac{\Gamma_R}{2}}$$

$$g_{J/\psi\Lambda} = -0.61 - 0.06\mathrm{i}$$

$$M_R = 4550 \text{ MeV},\ \Gamma_R = 4550 \text{ MeV}$$

- J/ψ -Λ loop function $\boldsymbol{G}_{J/\psi\,\Lambda}$

$$a_{J/\psi\Lambda} = -2.3$$

Wu, Molina, Oset, Zou:PRL 105, 232001 (2010);
PRC 84, 015202 (2011)

$\Lambda_b \to J/\psi\, \eta\Lambda$ decay: double differential cross-section and Dalitz plot

$$\frac{d^2\Gamma}{dM_{\eta\Lambda}dM_{J/\psi\Lambda}} = \frac{1}{(2\pi)^3}\frac{4M_{\Lambda_b}M_{\Lambda}}{32M_{\Lambda_b}^3}\overline{\sum}|\mathcal{M}(M_{\eta\Lambda}, M_{J/\psi\Lambda})|^2 2M_{\eta\Lambda}2M_{J/\psi\Lambda}$$

Integration limits fixing the invariant mass $M_{\eta\Lambda}$ (Dalitz plot)

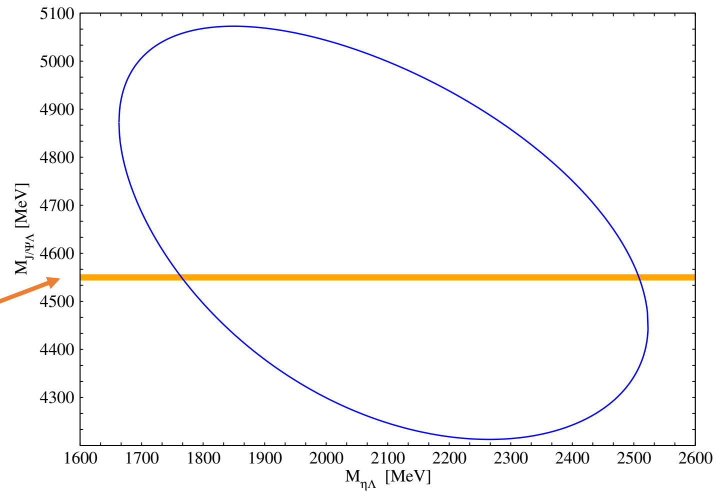
$$\left(M^2_{J/\psi\Lambda}\right)_{\max} = \left(E^*_\Lambda + E^*_{J/\psi}\right)^2 - \left(\sqrt{E^{*\,2}_\Lambda - M^2_\Lambda} - \sqrt{E^{*\,\,2}_{J/\psi} - m^2_{J/\psi}}\right)^2$$

$$\left(M^2_{J/\psi\Lambda}\right)_{\min} = \left(E^*_\Lambda + E^*_{J/\psi}\right)^2 - \left(\sqrt{E^{*\,2}_\Lambda - M^2_\Lambda} + \sqrt{E^{*\,\,2}_{J/\psi} - m^2_{J/\psi}}\right)^2$$

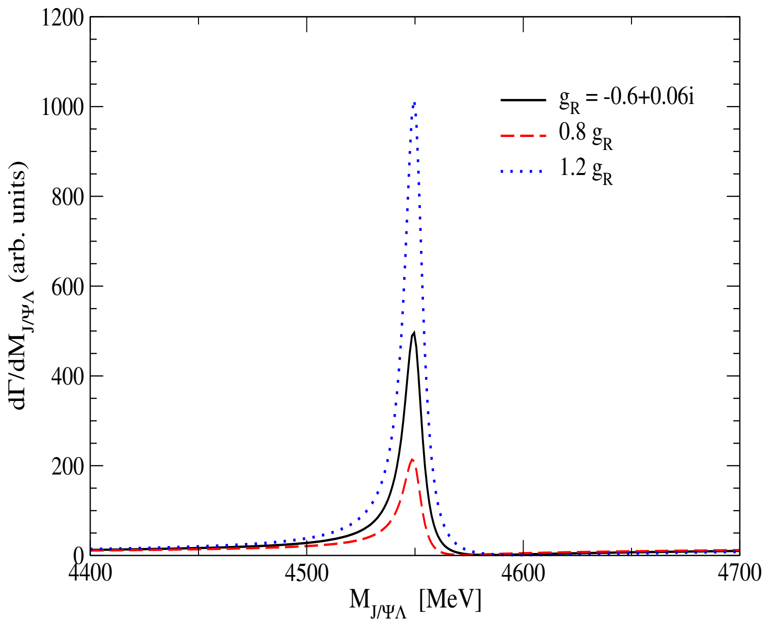
$$E^*_\Lambda = \frac{M^2_{\eta\Lambda} - m^2_\eta + M^2_\Lambda}{2M_{\eta\Lambda}}$$

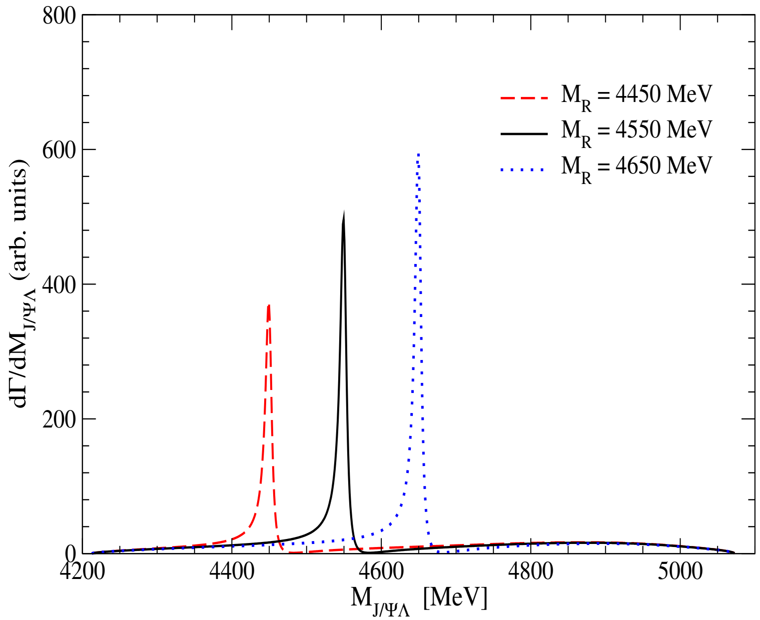
$$E^*_{J/\psi} = \frac{M^2_{\Lambda_b} - M^2_{\eta\Lambda} - m^2_{J/\psi}}{2M_{\eta\Lambda}}$$

Strange pentaquark can be observed!



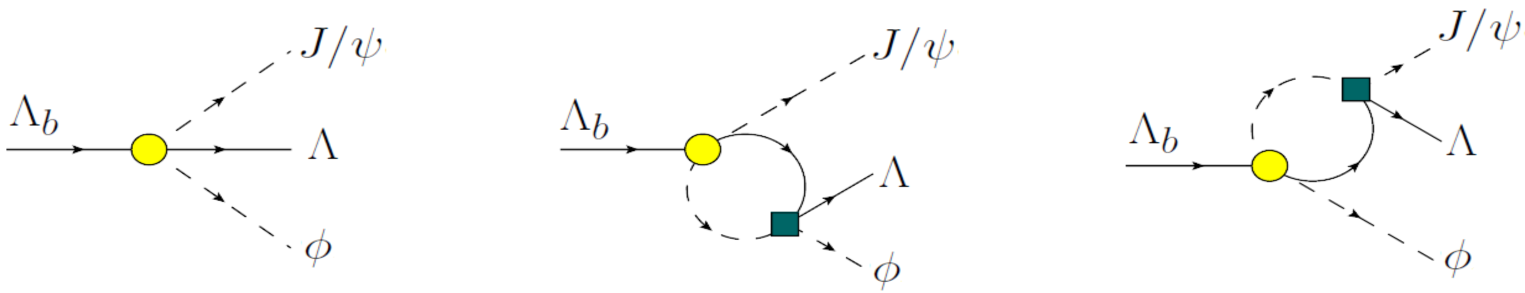
$\Lambda_b \to J/\psi\, \eta\Lambda$ decay: $J/\psi\ \Lambda$ mass distribution



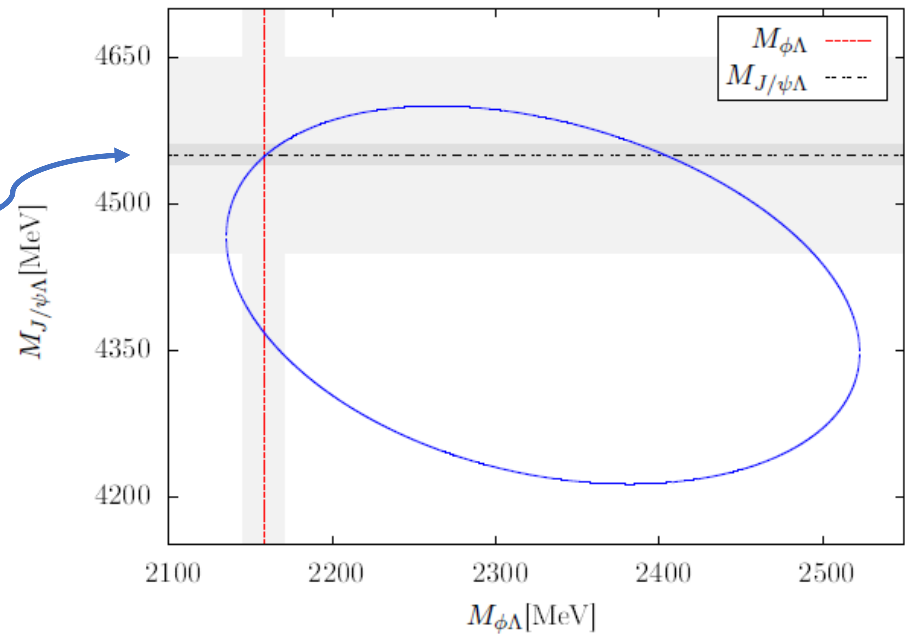


Clear signal of the strange pentaquark!!!

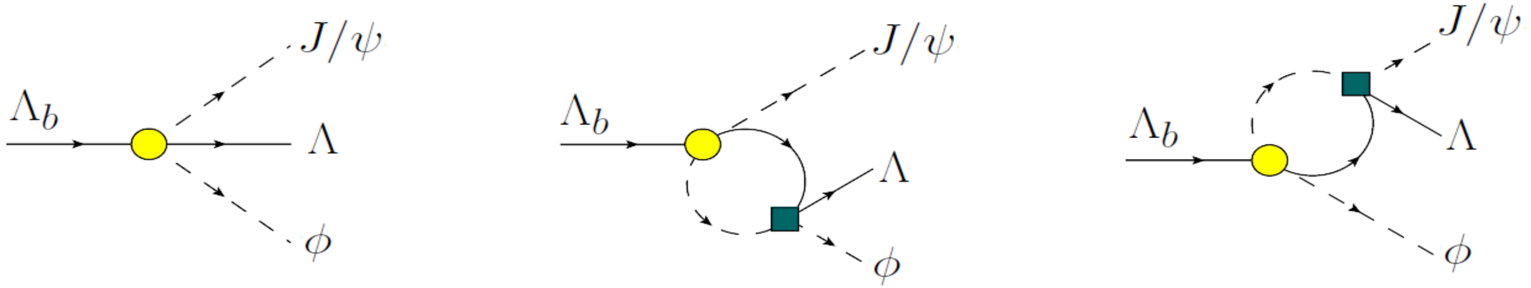
$\Lambda_b \to J/\psi\, \phi\Lambda$ *decay: Transition-amplitude contributions and Dalitz plots*



Strange pentaquark can be observed if $M_R \leq 4550$ MeV



$\Lambda_b \to J/\psi\ \phi\Lambda$ decay: Transition-amplitude contributions and Dalitz plots



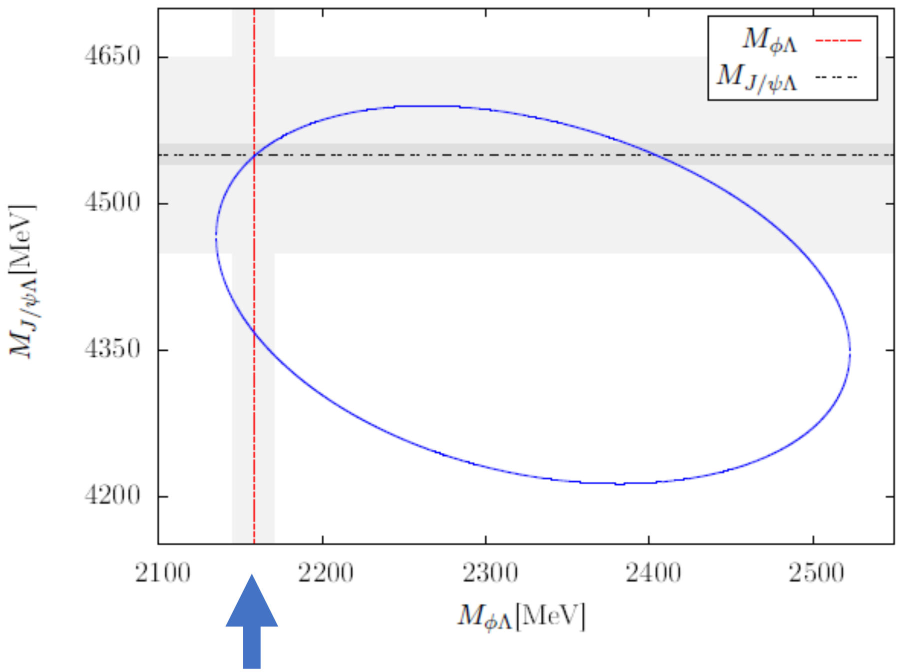
Dynamically generated resonances from the vector octet-baryon octet interaction

Oset, Ramos, Eur. Phys. J. A44, 445 (2010)

z_R	$1784 + i4$		$1906 + i70$		$2158 + i13$	
	g_i	$\|g_i\|$	g_i	$\|g_i\|$	g_i	$\|g_i\|$
$\bar{K}^* N(1833)$	$3.3 + i0.07$	3.3	$0.1 + i0.2$	0.3	$0.2 + i0.3$	0.3
$\omega\Lambda(1898)$	$1.4 + i0.03$	1.4	$0.4 + i0.2$	0.5	$-0.3 - i0.2$	0.4
$\rho\Sigma(1964)$	$-1.5 + i0.03$	1.5	$3.1 + i0.7$	3.2	$0.01 - i0.08$	0.08
$\phi\Lambda(2135)$	$-1.9 - i0.04$	1.9	$-0.6 - i0.3$	0.6	$0.5 + i0.3$	0.5
$K^*\Xi(2212)$	$0.1 + i0.003$	0.1	$0.3 + i0.1$	0.3	$3.2 - i0.1$	3.2

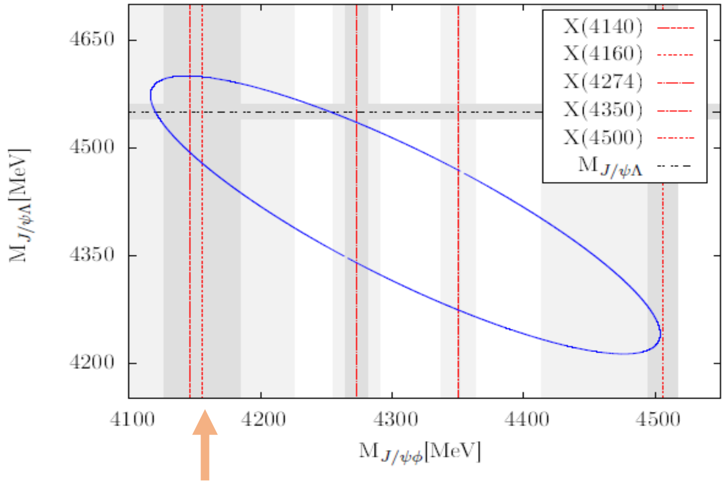
Table 2: Pole position and coupling constants to various channels of the resonances found in the $I = 0, S = -1$ sector.

State coupling to $\phi\Lambda$ with $M_R = 2158$ MeV and $\Gamma_R = 13$ MeV



$\Lambda_b \to J/\psi\ \phi\Lambda$ decay: Transition-amplitude contributions and Dalitz plots

$M_{J/\psi\phi}$			Observed at
$X(4140)$	4143.4 ± 1.9	15.5 ± 6.3	CMS
	$4146.5 \pm 4.5^{+4.5}_{-2.8}$	$83 \pm 21^{+21}_{-14}$	LHCb
	$4159.0 \pm 4.3 \pm 6.6$	$19.9 \pm 12.6^{+1.0}_{-8.0}$	D0
	$4143 \pm 2.9 \pm 1.2$	$11.7^{+8.3}_{-5.0} \pm 3.7$	Fermilab
$X(4160)$	4156 ± 29	139^{+113}_{-65}	Belle
	4169	132	[PRD80,2009]
$X(4274)$	4293 ± 20	35 ± 16	CMS, D0
	$4273.3 \pm 8.3^{+17.2}_{-3.6}$	$56.2 \pm 10.9^{+8.4}_{-11.1}$	LHCb
$X(4350)$	4350.6 ± 0.7	13 ± 4	Belle
$X(4500)$	4506 ± 11	92 ± 21	LHCb



Theoretical model

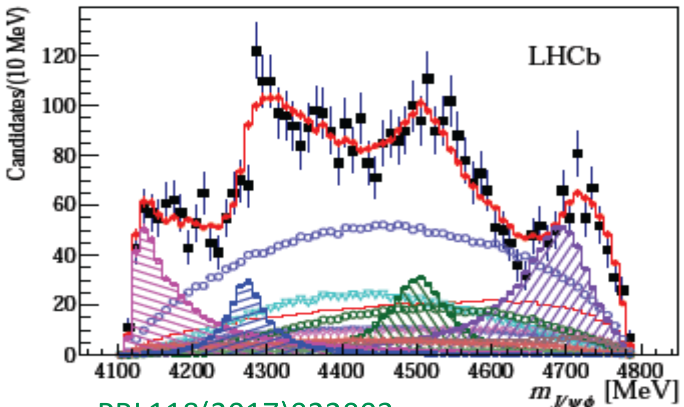
$\sqrt{s}_{pole} = 4169 + i66,\ I^G[J^{PC}] = 0^+[2^{++}]$

$D^*\bar{D}^*$	$D_s^*\bar{D}_s^*$	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$
$1225 - i490$	$18927 - i5524$	$-82 + i30$	$70 + i20$	$3 - i2441$

$\phi\phi$	$J/\psi J/\psi$	$\omega J/\psi$	$\phi J/\psi$	$\omega\phi$
$1257 + i2866$	$2681 + i940$	$-866 + i2752$	$-2617 - i5151$	$1012 + i1522$

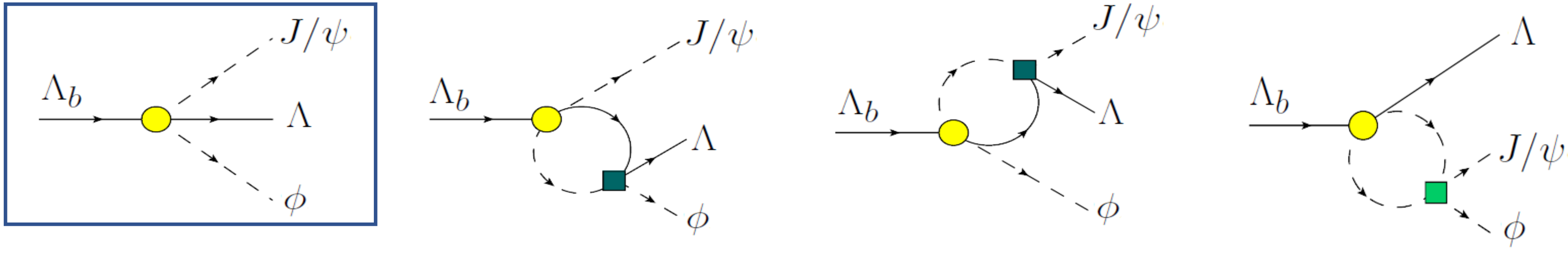
Table 5: Couplings g_i in units of MeV for $I = 0,\ J = 2$ (second pole).

Molina, Oset, Phys.Rev. D80 (2009) 114013



PRL118(2017)022003

$\Lambda_b \to J/\psi\ \phi\Lambda$ decay: Transition-amplitude contributions and Dalitz plots

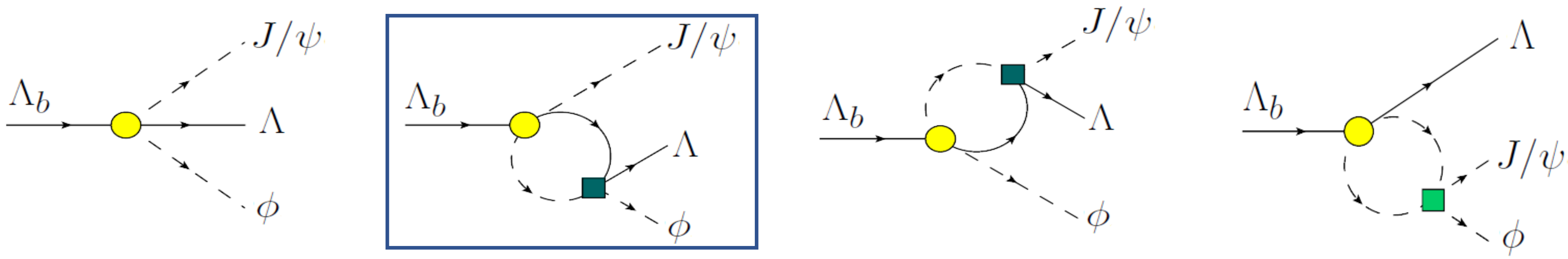


$$\mathcal{M}(M_{\phi\Lambda}, M_{J/\psi\Lambda}, M_{J/\psi\phi}) = V_p \Big[h_{\phi\Lambda} + \sum_i h_i G_i(M_{\phi\Lambda}) t_{i,\phi\Lambda}(M_{\phi\Lambda}) + h_{\phi\Lambda} G_{J/\psi\Lambda}(M_{J/\psi\Lambda}) t_{J/\psi\Lambda}(M_{J/\psi\Lambda})$$
$$+ h_{\phi\Lambda} G_{J/\psi\phi}(M_{J/\psi\phi}) t_{J/\psi\phi}(M_{J/\psi\phi}) \Big]$$

- $\boldsymbol{h_i}$ weights of the final meson-baryon states in the flavour wave function

$$h_{\bar{K}^{*0}n} = h_{K^{*-}p} = 1,\ h_{\phi\Lambda} = -\sqrt{\frac{2}{3}},$$
$$h_{\rho\Sigma} = h_{\omega\Lambda} = h_{K^{*}\Xi} = 0$$

$\Lambda_b \to J/\psi\, \phi\Lambda$ decay: Transition-amplitude contributions and Dalitz plots



$$\mathcal{M}(M_{\phi\Lambda}, M_{J/\psi\Lambda}, M_{J/\psi\phi}) = V_p\Big[h_{\phi\Lambda} + \sum_i h_i G_i(M_{\phi\Lambda}) t_{i,\phi\Lambda}(M_{\phi\Lambda}) + h_{\phi\Lambda} G_{J/\psi\Lambda}(M_{J/\psi\Lambda}) t_{J/\psi\Lambda}(M_{J/\psi\Lambda}) + h_{\phi\Lambda} G_{J/\psi\phi}(M_{J/\psi\phi}) t_{J/\psi\phi}(M_{J/\psi\phi})\Big]$$

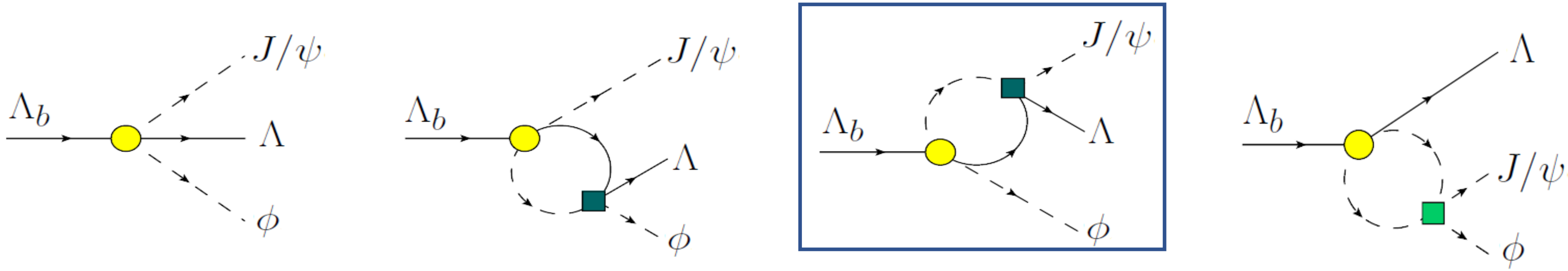
- Meson-Baryon loop function $\boldsymbol{G_i}$ $(i = K^{*-}p,\ \overline{K}^{*0}n,\ \phi\Lambda)$

$$G_l = \frac{2M_l}{(4\pi)^2}\left\{a_l(\mu) + \ln\frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s}\ln\frac{m_l^2}{M_l^2} + \frac{q_{\rm cm}}{\sqrt{s}}\ln\left[\frac{(s + 2\sqrt{s}q_{\rm cm})^2 - (M_l^2 - m_l^2)^2}{(s - 2\sqrt{s}q_{\rm cm})^2 - (M_l^2 - m_l^2)^2}\right]\right\}.$$

- Scattering amplitude $\boldsymbol{t_{i,\phi\Lambda}}$ from:

Oset, Ramos, Eur. Phys. J. A44, 445 (2010)

$\Lambda_b \to J/\psi\ \phi\Lambda$ decay: Transition-amplitude contributions and Dalitz plots



$$\mathcal{M}(M_{\phi\Lambda}, M_{J/\psi\Lambda}, M_{J/\psi\phi}) = V_p\Big[h_{\phi\Lambda} + \sum_i h_i G_i(M_{\phi\Lambda}) t_{i,\phi\Lambda}(M_{\phi\Lambda}) + \boxed{h_{\phi\Lambda} G_{J/\psi\Lambda}(M_{J/\psi\Lambda}) t_{J/\psi\Lambda}(M_{J/\psi\Lambda})}$$
$$+ h_{\phi\Lambda} G_{J/\psi\phi}(M_{J/\psi\phi}) t_{J/\psi\phi}(M_{J/\psi\phi})\Big]$$

- Scattering amplitude $\boldsymbol{t_{J/\psi\Lambda}}$ from:

$$t_{J/\psi\Lambda, J/\psi\Lambda} = \frac{g^2_{J/\psi\Lambda}}{M_{J/\psi\Lambda} - M_R + \mathrm{i}\,\frac{\Gamma_R}{2}}$$

$$g_{J/\psi\Lambda} = -0.61 - 0.06\mathrm{i}$$

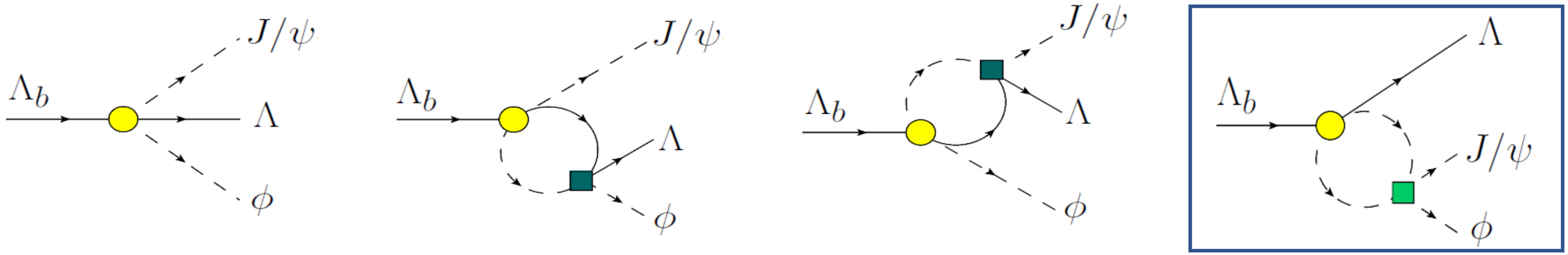
$$M_R = 4550\ \mathrm{MeV},\ \Gamma_R = 4550\ \mathrm{MeV}$$

- J/ψ -Λ loop function $\boldsymbol{G_{J/\psi\,\Lambda}}$

$$a_{J/\psi\Lambda} = -2.3$$

Wu, Molina, Oset, Zou:PRL 105, 232001 (2010); PRC 84, 015202 (2011)

$\Lambda_b \to J/\psi\ \phi\Lambda$ decay: Transition-amplitude contributions and Dalitz plots



$$\mathcal{M}(M_{\phi\Lambda}, M_{J/\psi\Lambda}, M_{J/\psi\phi}) = V_p\Big[h_{\phi\Lambda} + \sum_i h_i G_i(M_{\phi\Lambda}) t_{i,\phi\Lambda}(M_{\phi\Lambda}) + h_{\phi\Lambda} G_{J/\psi\Lambda}(M_{J/\psi\Lambda}) t_{J/\psi\Lambda}(M_{J/\psi\Lambda})$$

$$+ \boxed{h_{\phi\Lambda} G_{J/\psi\phi}(M_{J/\psi\phi}) t_{J/\psi\phi}(M_{J/\psi\phi})}\Big]$$

- Scattering amplitude $t_{J/\psi\phi}$ from:

$$t_{J/\psi\phi} = \frac{g^2_{J/\psi\phi}}{s - s_R}$$

$$g_{J/\psi\phi} = -2617 - 5151\mathrm{i}MeV$$

$$s_R = 4169 + 66\mathrm{i}MeV$$

$$\sqrt{s} = M_{J/\psi\phi}$$

- J/ψ-ϕ loop function $G_{J/\psi\phi}$

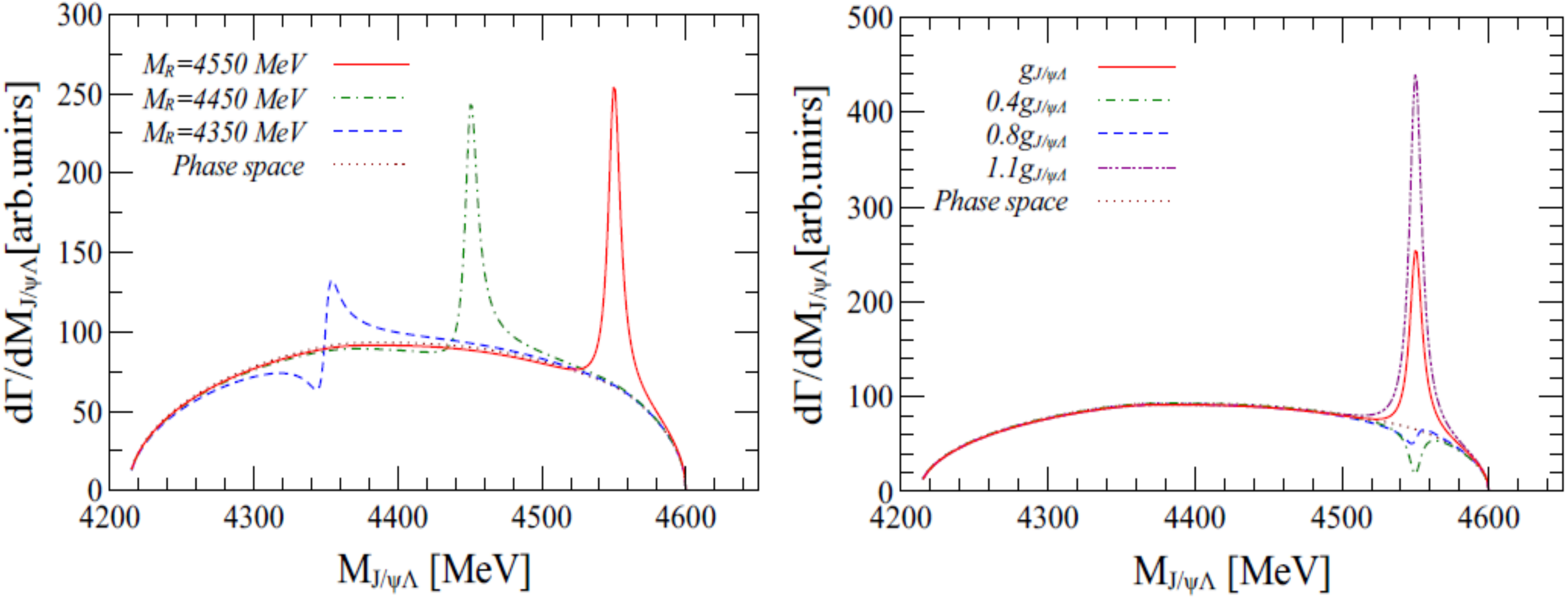
$$G_l(M_{J/\psi\phi}) = \frac{1}{(4\pi)^2}\Big\{a_l(\mu) + \ln\frac{m_1^2}{\mu^2} + \frac{m_2^2 - m_1^2 + s}{2s}\log\left(\frac{m_2^2}{m_1^2}\right) +$$

$$\frac{q_{\rm cm}}{\sqrt{s}}\left[\log\left(\frac{s - m_2^2 + m_1^2 + 2p\sqrt{s}}{-s + m_2^2 - m_1^2 + 2p\sqrt{s}}\right) + \log\left(\frac{s + m_2^2 - m_1^2 + 2p\sqrt{s}}{-s - m_2^2 + m_1^2 + 2p\sqrt{s}}\right)\right]\Big\}$$

$$a_{J/\psi\,\phi} = -2$$

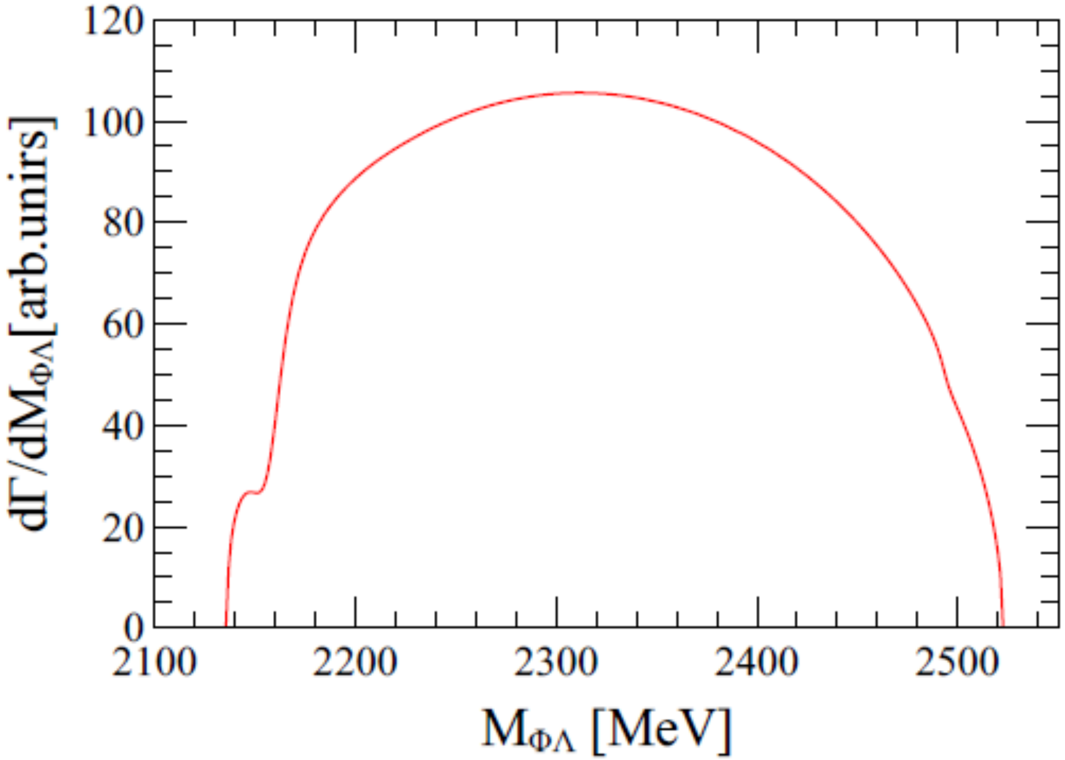
Molina, Oset, Phys.Rev. D80 (2009) 114013

$\Lambda_b \to J/\psi\ \phi\Lambda$ decay: $J/\psi\ \Lambda$ mass distribution



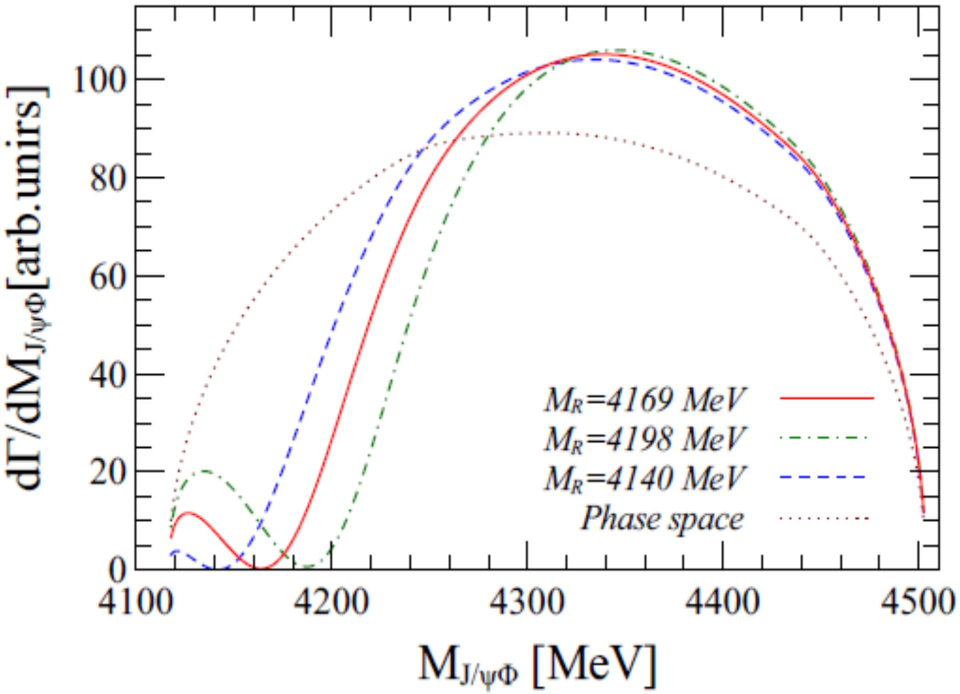
Strange pentaquark is clearly observable for masses
$4350 \leq M_R \leq 4550$ (MeV), in accordance with
Wu, Molina, Oset, Zou, PRL 105, 232001 (2010);
PRC 84, 015202 (2011)

$\Lambda_b \to J/\psi\ \phi\Lambda$ *decay: $\phi\Lambda$ mass distribution*



A small dip appears at $M_{\phi\Lambda} = 2158$ MeV as predicted in
Oset, Ramos, EPJ A44 (2010)

$\Lambda_b \to J/\psi\ \phi\Lambda$ decay: $J/\psi\ \phi$ mass distribution



Strong dip is seen in the position of X(4160)

$X(4160)$	4156 ± 29	139^{+113}_{-65}
	4169	132

Molina, Oset, Phys.Rev. D80 (2009) 114013

CONCLUSIONS

- Our studies have shown that the $\Lambda_b \to J/\psi\, \eta\Lambda$ *and* $\Lambda_b \to J/\psi\, \phi\Lambda$ reactions are very promising to discover a strange partner of the hidden charm Pentaquark around 4450 MeV

- $\Lambda_b \to J/\psi\, \phi\Lambda$ decay also allows the observation of other exotics:

  X(4160) peak within the considered uncertainty range (from $M_{J/\psi\phi}$ invariant mass)
  X(4140), X(4160), X(4274), X(4350), X(4500) can also be observed

  New strange resonances within the range from 2100 to 2500 MeV could be seen in the $\phi\Lambda$ invariant mass distribution, the $M_{\phi\Lambda} = 2158$ MeV resonance is unlikely to be observed experimentally with model parameters from Oset, Ramos, EPJ A44 (2010)

Work in progress…

Eulogio Oset (Review, Nucl.Phys. A954 (2016) 371-392):

”**We are just at the beginning of a new era** and it is most probable that more pentaquark states are likely to be observed in the near future. The interpretation of the experiments and studies to learn about the nature of the states is a task **that will require the combined efforts of both experimentalists and theoreticians**.”