Analysis of the $B^+ \to K^+ J/\Psi\ \phi$ decay at low $J/\Psi\ \phi$ invariant masses and Ω_c states

En Wang, Ju Jun Xie, Li Sheng Geng and Eulogio Oset

Microscopic description of the dominant mechanism

Relashionship with the $B^+ \to K^+$ D*s D*sbar reaction

The X(4160) as a dynamically generated resonance, mostly D*s D*sbar

The unavoidable cusp in the $J/\Psi\ \phi$ distribution at the D*s D*sbar threshold

New fit to data al low $J/\Psi\ \phi$ invariant masses

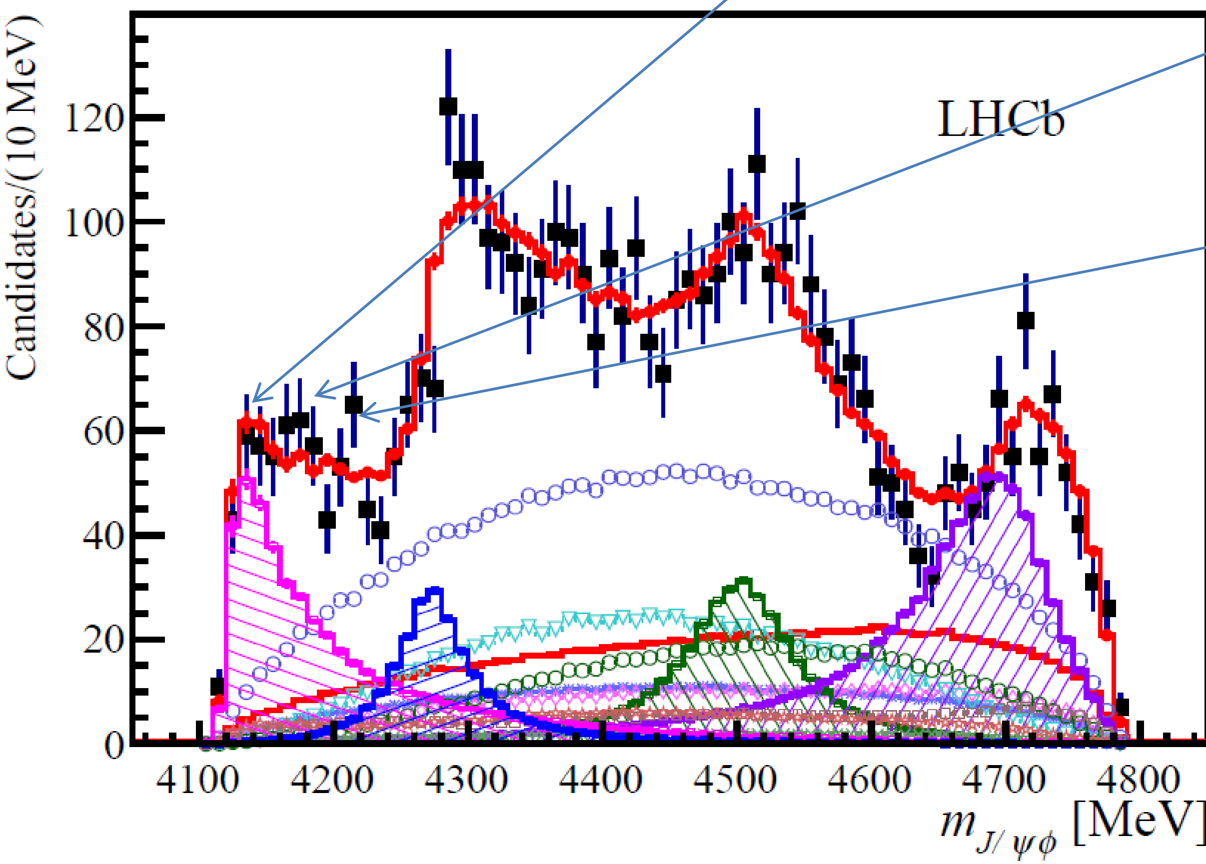
Amplitude analysis of $B^+ \to J/\psi \phi K^+$ decays

LHCb collaboration, PRD, PRL (2017)

Peak at 4135 MeV

Peak at 4160 MeV

Peak at the D*s D*sbar threshold



Why is there a peak at D*s D*sbar threshold in the J/Ψ ϕ mass distribution?

LHCb analysis

Contri-bution	sign. or Ref.	Fit results M_0 [MeV]	Γ_0 [MeV]	FF %	f_L	$f_\perp$
$X(4140)$	8.4σ	$4146.5 \pm 4.5\,^{+4.6}_{-2.8}$	$83 \pm 21\,^{+21}_{-14}$	$13.0 \pm 3.2\,^{+4.8}_{-2.0}$		
ave.	Table 1	4147.1 ± 2.4	15.7 ± 6.3			

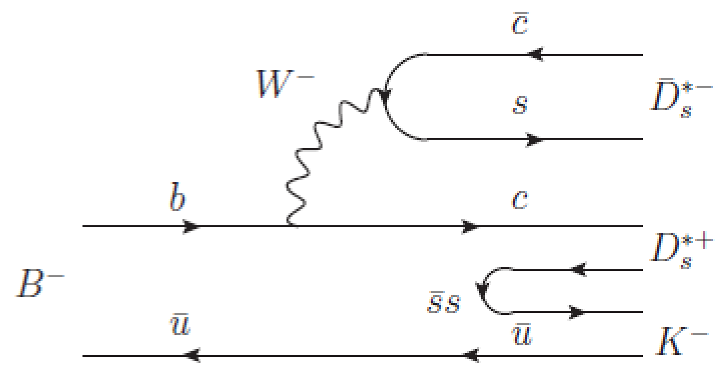
Table 1: Summary of experiments on the X(4140)

Year	Experiment luminosity	$B \to J/\psi\,\phi K$ yield	$X(4140)$ peak Mass [MeV]	Width [MeV]	Sign.	Fraction %
2008	CDF 2.7 fb^{-1} [1]	58 ± 10	$4143.0 \pm 2.9 \pm 1.2$	$11.7\,^{+8.3}_{-5.0} \pm 3.7$	3.8σ	
2009	*Belle* [22]	*325 ± 21*	*4143.0 fixed*	*11.7 fixed*	1.9σ	
2011	*CDF 6.0 fb*$^{-1}$ [29]	*115 ± 12*	$4143.4\,^{+2.9}_{-3.0} \pm 0.6$	$15.3\,^{+10.4}_{-6.1} \pm 2.5$	5.0σ	$14.9 \pm 3.9 \pm 2.4$
2011	LHCb 0.37 fb^{-1} [21]	346 ± 20	4143.4 fixed	15.3 fixed	1.4σ	< 7 @ 90%CL
2013	CMS 5.2 fb^{-1} [25]	2480 ± 160	$4148.0 \pm 2.4 \pm 6.3$	$28\,^{+15}_{-11} \pm 19$	5.0σ	10 ± 3 (stat.)
2013	D0 10.4 fb^{-1} [26]	215 ± 37	$4159.0 \pm 4.3 \pm 6.6$	$19.9 \pm 12.6\,^{+1.0}_{-8.0}$	3.0σ	$21 \pm 8 \pm 4$
2014	BaBar [24]	189 ± 14	4143.4 fixed	15.3 fixed	1.6σ	< 13.3 @ 90%CL
2015	D0 10.4 fb^{-1} [27]	$p\bar{p} \to J/\psi\,\phi\ldots$	$4152.5 \pm 1.7\,^{+6.2}_{-5.4}$	$16.3 \pm 5.6 \pm 11.4$	4.7σ (5.7σ)	
Average			4147.1 ± 2.4	15.7 ± 6.3		

Analysis of the $B^+ \to J/\psi\phi K^+$ data at low $J/\psi\phi$ invariant masses and the $X(4140)$ and $X(4160)$ resonances

En Wang, Ju Jun Xie, Li Sheng Geng and Eulogio Oset, arxiv 1710.0206

$$\begin{Bmatrix} u \\ d \end{Bmatrix} \begin{Bmatrix} c \\ s \end{Bmatrix} \begin{Bmatrix} t \\ b \end{Bmatrix}$$

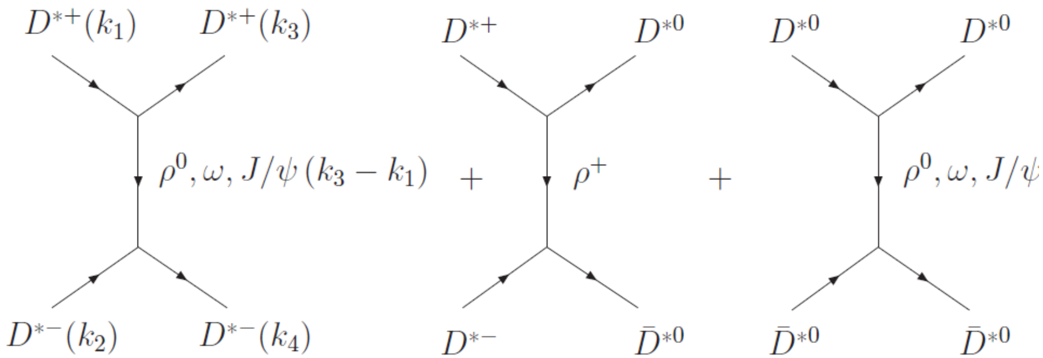


Cabibbo favoured process, and external emision, color favored

How can this be related to J/Ψ ϕ ?
D*s D*sbar is vector-vector with c cbar s sbar, can be related to J/Ψ ϕ (which also has c cbar s sbar)
One should study the vector-vector interaction with charm in coupled channels and see what happens.

The $Y(3940)$, $Z(3930)$ and the $X(4160)$ as dynamically generated resonances from the vector-vector interaction

R. Molina, E. Oset
PRD 2009



Local hidden gauge approach Bando et al. , used to get the potential V

Coupled channels

$\mathbf{D^*\bar{D}^*}(4017)$, $\mathbf{D_s^*\bar{D}_s^*}(4225)$, $\mathbf{K^*\bar{K}^*}(1783)$, $\rho\rho(1551)$, $\omega\omega(1565)$

$\phi\phi(2039)$, $\mathbf{J/\psi J/\psi}(6194)$, $\omega\mathbf{J/\psi}(3880)$, $\phi\mathbf{J/\psi}(4116)$, $\omega\phi(1802)$

$$T = (\hat{1} - VG)^{-1} V$$

$$G_i = i \int \frac{d^4q}{(2\pi)^4} \frac{1}{q^2 - m_1^2 + i\epsilon} \frac{1}{(P-q)^2 - m_2^2 + i\epsilon}$$

$I^G[J^{PC}]$	Theory		Experiment			
	Mass [MeV]	Width [MeV]	Name	Mass [MeV]	Width [MeV]	J^{PC}
$0^+[0^{++}]$	3943	17	$Y(3940)$	3943 ± 17 $3914.3^{+4.1}_{-3.8}$	87 ± 34 33^{+12}_{-8}	J^{P+}
$0^-[1^{+-}]$	3945	0	"$Y_p(3945)$"			
$0^+[2^{++}]$	3922	55	$Z(3930)$	3929 ± 5	29 ± 10	2^{++}
$0^+[2^{++}]$	4157	102	$X(4160)$	4156 ± 29	139^{+113}_{-65}	J^{P+}
$1^-[2^{++}]$	3912	120	"$Y_p(3912)$"			

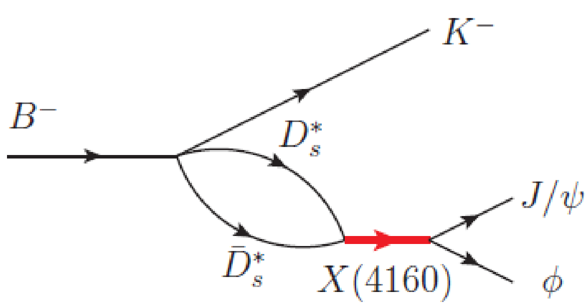
$$\sqrt{s}_{pole} = 4169 + i66,\ I^G[J^{PC}] = 0^+[2^{++}]$$

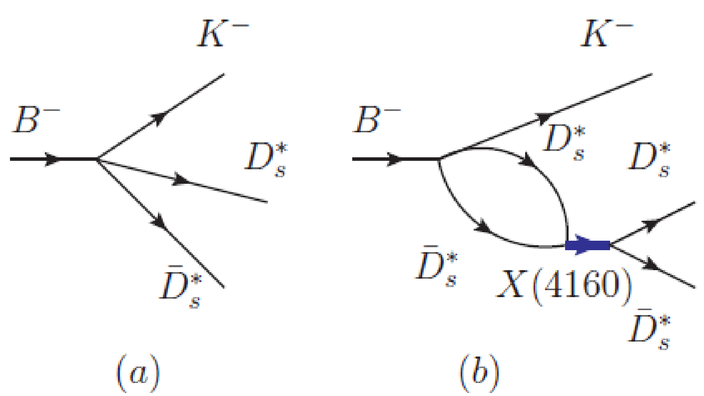
Couplings to channels

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

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

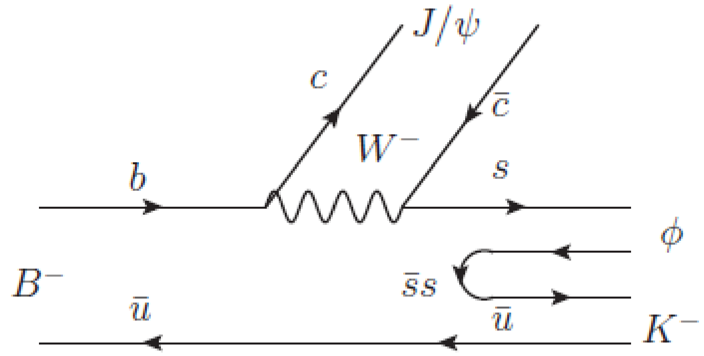
J/Ψ ϕ is obtained from the primary process via final state interaction



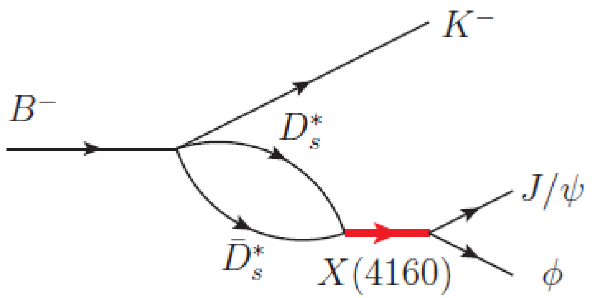


These two processes are related and the K⁻ J/Ψϕ production will have a cusp from the D*s D*sbar channel unavoidably

Alternative mechanism
Internal emission
Penalized by color factor



Resonant contribution
Substitute D*s D*sbar
by J/Ψ ϕ
Penalized by $g_{J/\psi\phi}/g_{D_s^*\bar{D}_s^*}$ factor



Double penalty: not competitive

We need d-waves in the K$^-$ to compensate for spin 2 of X(4160)

$$t^{\text{tree}}_{B^-\to K^- D_s^* \bar{D}_s^*} = A\left(\vec{\epsilon}\cdot\vec{k}\,\vec{\epsilon}\,'\cdot\vec{k} - \frac{1}{3}\vec{k}^2\vec{\epsilon}\cdot\vec{\epsilon}\,'\right)$$

$$\sum_{\text{pol}} |t^{\text{tree}}_{B^-\to K^- D_s^* \bar{D}_s^*}|^2 = \frac{2}{3}|\vec{k}|^4$$

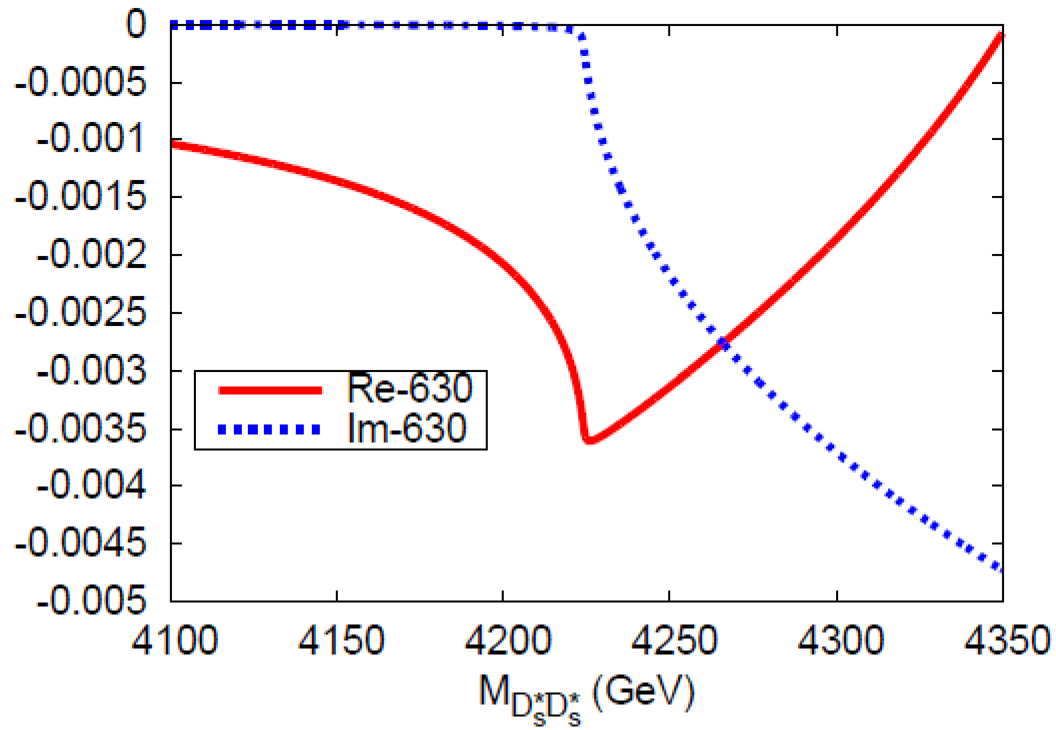
$$\frac{d\Gamma}{dM_{\text{inv}}(D_s^*\bar{D}_s^*)} = \frac{1}{(2\pi)^3}\frac{1}{4M_{B^-}^2}\frac{2}{3}|\vec{k}|^4|\vec{k}'|\,\tilde{p}_{D_s^*}|A|^2$$

for $D_s^*\bar{D}_s^*$ production including the $X(4160)$ resonance, we make the following replacement,

$$A \to A\left[1 + G_{D_s^*\bar{D}_s^*}(M_{\text{inv}}(D_s^*\bar{D}_s^*)) \times t_{D_s^*\bar{D}_s^*\to D_s^*\bar{D}_s^*}(M_{\text{inv}}(D_s^*\bar{D}_s^*))\right]$$

To obtain the mass distribution for $J/\psi\phi$

$$A \to A \times G_{D_s^*\bar{D}_s^*}(M_{\text{inv}}(J/\psi\phi)) \times t_{D_s^*\bar{D}_s^*\to J/\psi\phi}(M_{\text{inv}}(J/\psi\phi))$$



Real and Imaginary parts of the G function of Ds* Ds*bar

Note the singularity of Re G at the threshold

This must create a cusp like structure in J/Ψ ϕ production at threshold of D*s D*sbar

$$t_{D_s^* \bar{D}_s^* \to D_s^* \bar{D}_s^*} = \frac{g^2_{D_s^* \bar{D}_s^*}}{M^2_{\rm inv}(D_s^* \bar{D}_s^*) - M_X^2 + i M_X \Gamma_X}$$

$$t_{D_s^* \bar{D}_s^* \to J/\psi\phi} = \frac{g_{D_s^* \bar{D}_s^*} g_{J/\psi\phi}}{M^2_{\rm inv}(J/\psi\phi) - M_X^2 + i M_X \Gamma_X}$$

Γ_0 accounts for the width of the X(4160) to light VV channels

$$\Gamma_X = \Gamma_0 + \Gamma_{J/\psi\phi} + \Gamma_{D_s^* \bar{D}_s^*}$$

With this width we incorporate the Flatté effect

$$\Gamma_{J/\psi\phi} = \frac{|g_{J/\psi\phi}|^2}{8\pi M_X^2} \tilde{p}_\phi,$$

$$\Gamma_{D_s^* \bar{D}_s^*} = \frac{|g_{D_s^* \bar{D}_s^*}|^2}{8\pi M_X^2} \tilde{p}_{D_s^*} \Theta(M_{\rm inv}(D_s^* \bar{D}_s^*) - 2M_{D_s^*}).$$

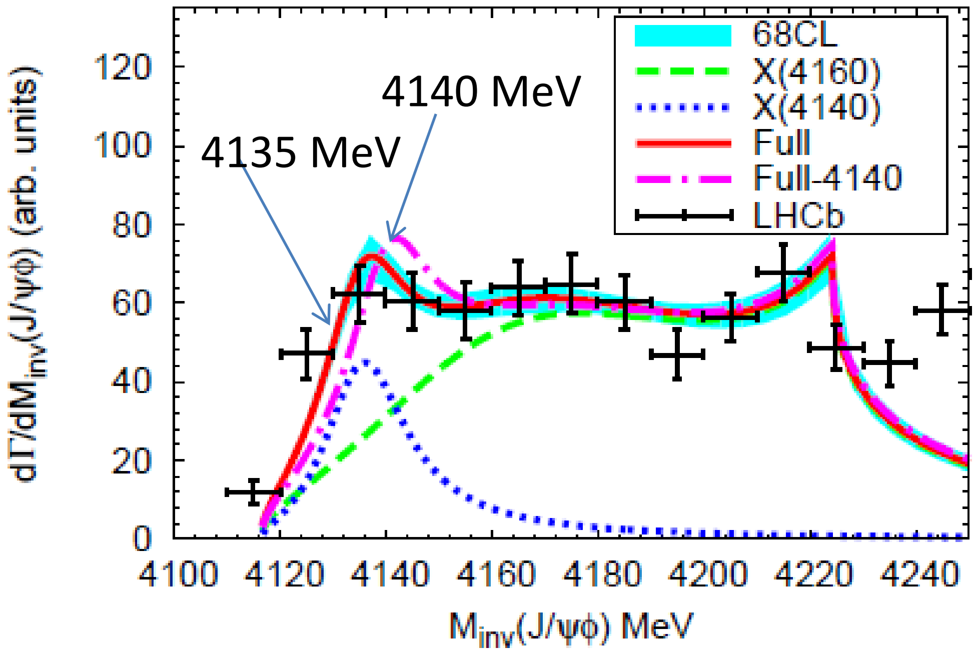
To account for the production of $J/\psi\phi$ via the 1^{++} $X(4140)$ resonance, we take the suitable operator with the kaon in P-wave $(\vec{\epsilon}_{J/\psi} \times \vec{\epsilon}_\phi) \cdot \vec{k}$.

$$M_{\rm inv}(D_s^* \bar{D}_s^*) \to M_{\rm inv}(J/\psi\phi),$$

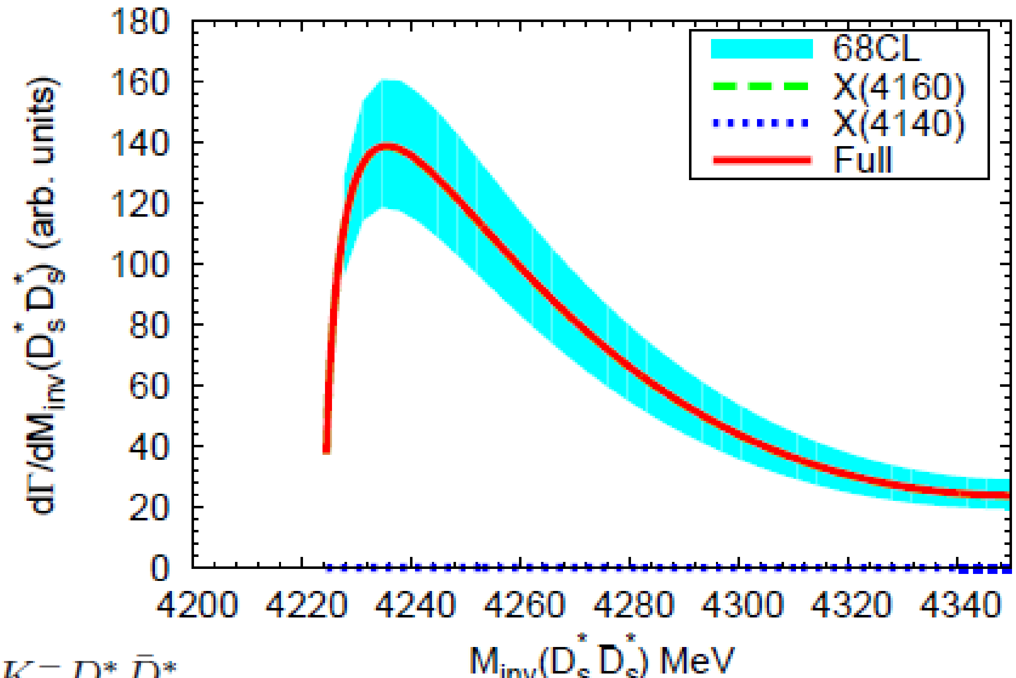
$$\frac{2}{3}|\vec{k}|^4 \to 2|\vec{k}|^2, \quad \tilde{p}_{D_s^*} \to \tilde{p}_\phi,$$

$$A \to \frac{B\, M^4_{X(4140)}}{M^2_{\rm inv}(J/\psi\phi) - M^2_{X(4140)} + i M_{X(4140)} \Gamma_{X(4140)}}$$

For this we take the standard PDG mass and width



Result fitting A and B parameters
Also Γ_0, compatible with Molina. Then
Γ_{tot}=90+-10 MeV, compatible with exp.



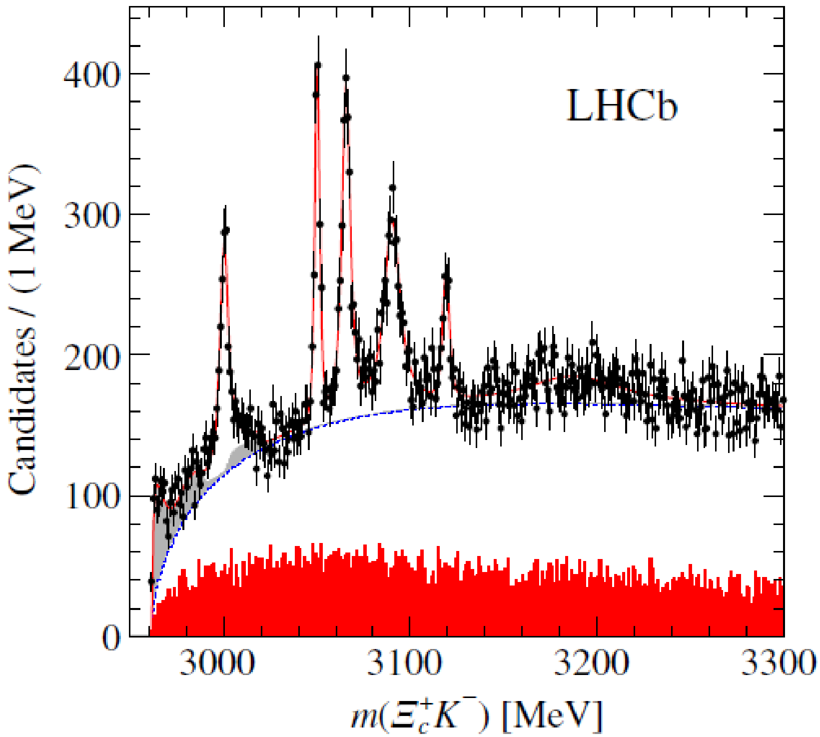
The relative strength of these two decays is a prediction

Prediction for

The $D_s^* \bar{D}_s^*$ mass distribution of the $B^- \to K^- D_s^* \bar{D}_s^*$

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 $\Xi_c K^-$ mass spectrum is studied with a sample of pp collision data by LHCb , PRL 017

Five clean narrow peaks are obtained

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

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.

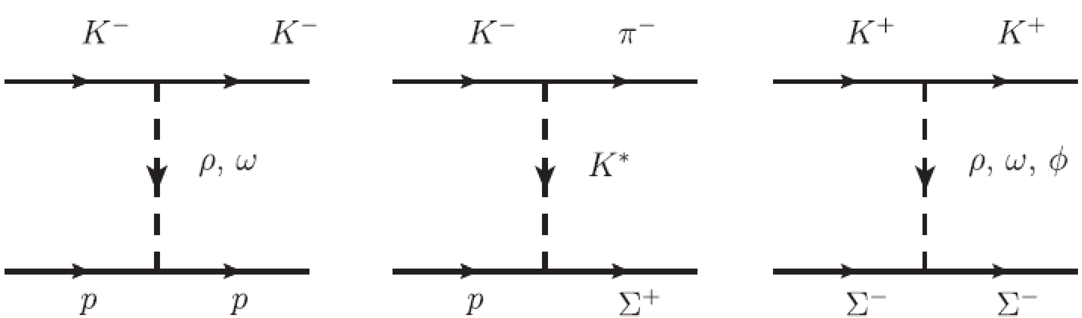
Chiral Lagrangian

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

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

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

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



(a) (b) (c)

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

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

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

$\Xi_c^{\prime 0}$: the same as $\Xi_c^{\prime}$, changing $(us + su) \rightarrow (ds + sd)$.

Ω_c^0: css, and the spin wave function χ_{MS} in the last two quarks, like that for $\Xi_c^{\prime}$.

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

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

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

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

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

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.

$3054.05 + i0.44$	$\Xi_c \bar{K}$	$\Xi_c' \bar{K}$	ΞD	$\Omega_c \eta$	ΞD^*	$\Xi_c \bar{K}^*$	$\Xi_c' \bar{K}^*$
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^*	$\Xi_c \bar{K}^*$	$\Xi_c' \bar{K}^*$
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.

3124.84	$\Xi_c^* \bar{K}$	$\Omega_c^* \eta$	ΞD^*	$\Xi_c \bar{K}^*$	$\Xi^* D$	$\Xi_c' \bar{K}^*$
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 ligh 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 .

Conclusions

We claim that there are three peaks in the $J/\Psi\phi$ distribution

--One corresponding to X(4140) with mass around 4135 MeV, and width around 15 MeV.

--Another one corresponding to X(4160)

--A third one corresponding to a cusp of the related D*s D*sbar channel

New fits to data by the LHCb collaboration accounting for the possible production of X(4160) coupling explicitly to both J/Ψ ϕ and D*s D*sbar would be advisable

The measurement of the B+ -> K+ D^*_s D^*_sbar close to the D^*_s D^*_sbar threshold would be enlightening

As to the Ω_c states, we obtain three states using an extention of the local hidden gauge approach, with coupled channels and unitarity, which can be associated to LHCb states, both in mass and width, with only one parameter, a regularizing cutoff, which comes out of natural size.