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

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

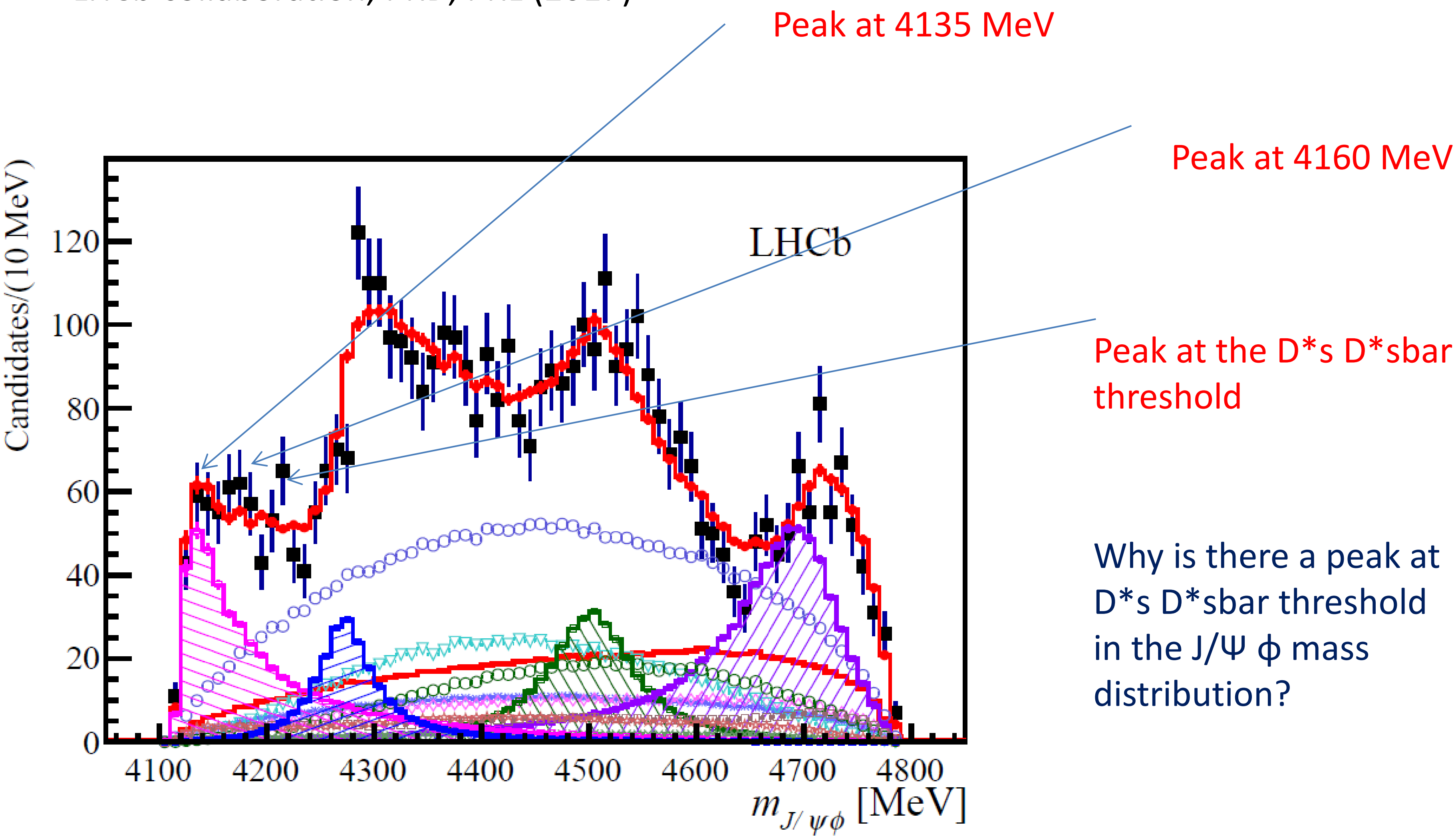
The X(4160) as a dynamically generated resonance, mostly D*s D*sbar

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)



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	$4146.5\pm4.5\,^{+4.6}_{-2.8}$	$83\pm21\,^{+21}_{-14}$	$13.0\pm3.2\,^{+4.8}_{-2.0}$		
ave.	Table 1	4147.1 ± 2.4	15.7 ± 6.3			

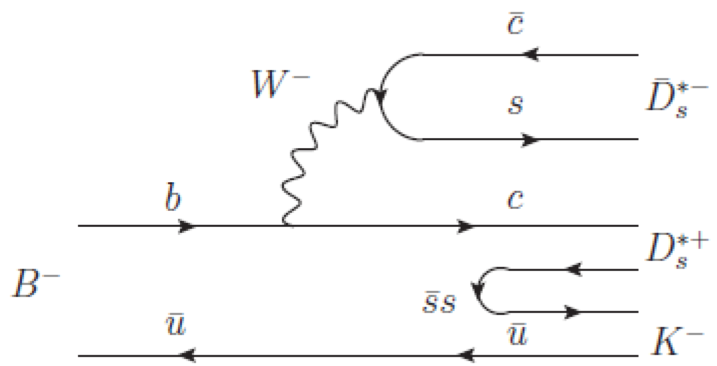
Table 1: Summary of experiments on the X(4140)

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	$4143.0\pm2.9\pm1.2$	$11.7\,^{+8.3}_{-5.0}\pm3.7$	3.8σ	
2009	*Belle* [22]	*325 ± 21*	*4143.0 fixed*	*11.7 fixed*	*1.9σ*	
2011	*CDF 6.0 fb^{-1}* [29]	*115 ± 12*	*$4143.4\,^{+2.9}_{-3.0}\pm0.6$*	*$15.3\,^{+10.4}_{-6.1}\pm2.5$*	*5.0σ*	*$14.9\pm3.9\pm2.4$*
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	$4148.0\pm2.4\pm6.3$	$28\,^{+15}_{-11}\pm19$	5.0σ	10 ± 3 (stat.)
2013	D0 10.4 fb^{-1} [26]	215 ± 37	$4159.0\pm4.3\pm6.6$	$19.9\pm12.6\,^{+1.0}_{-8.0}$	3.0σ	$21\pm8\pm4$
2014	BaBar [24]	189 ± 14	4143.4 fixed	15.3 fixed	1.6σ	<13.3 @ 90%CL
2015	D0 10.4 fb^{-1} [27]	$p\bar{p} \to J/\psi\,\phi \ldots$	$4152.5\pm1.7\,^{+6.2}_{-5.4}$	$16.3\pm5.6\pm11.4$	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

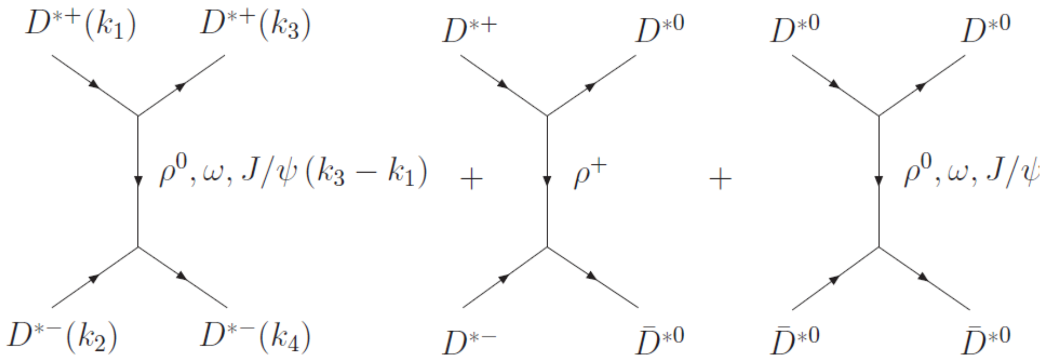
How can this be related to J/Ψ ϕ ?

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

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

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

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

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

$I^G[J^{PC}]$	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	"$Y_p(3912)$"			

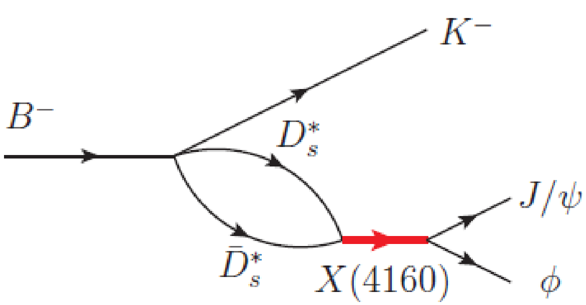
$$\sqrt{s}_{pole} = 4169 + i66,\ I^G[J^{PC}] = 0^+[2^{++}]$$

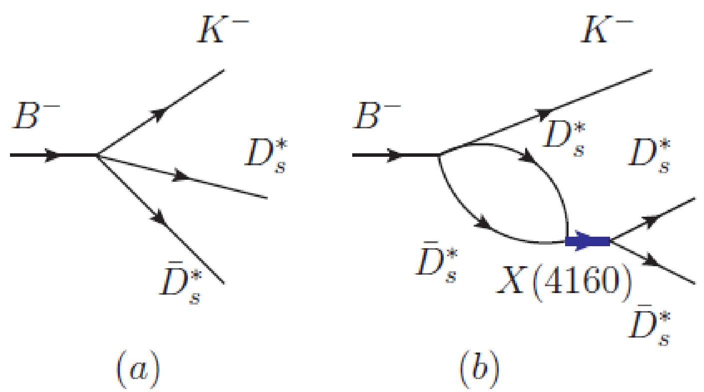
Couplings to channels

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

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

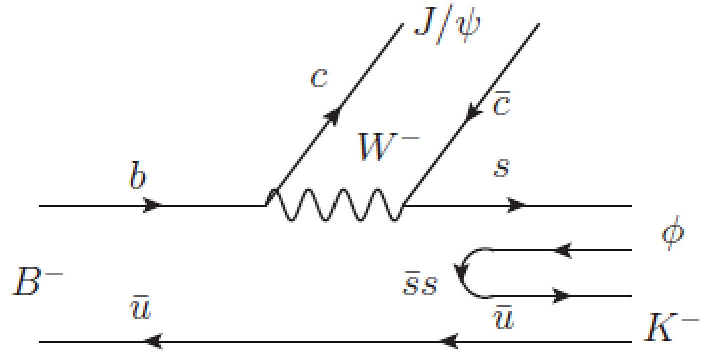
J/Ψ ϕ is obtained from the primary process via final state interaction

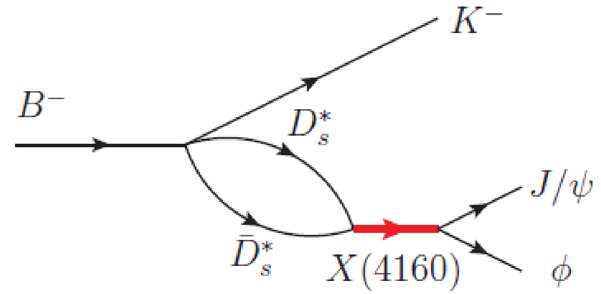




These two processes are related and the K⁻ J/Ψϕ production will have a cusp from the D*s D*sbar channel unavoidably

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

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

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

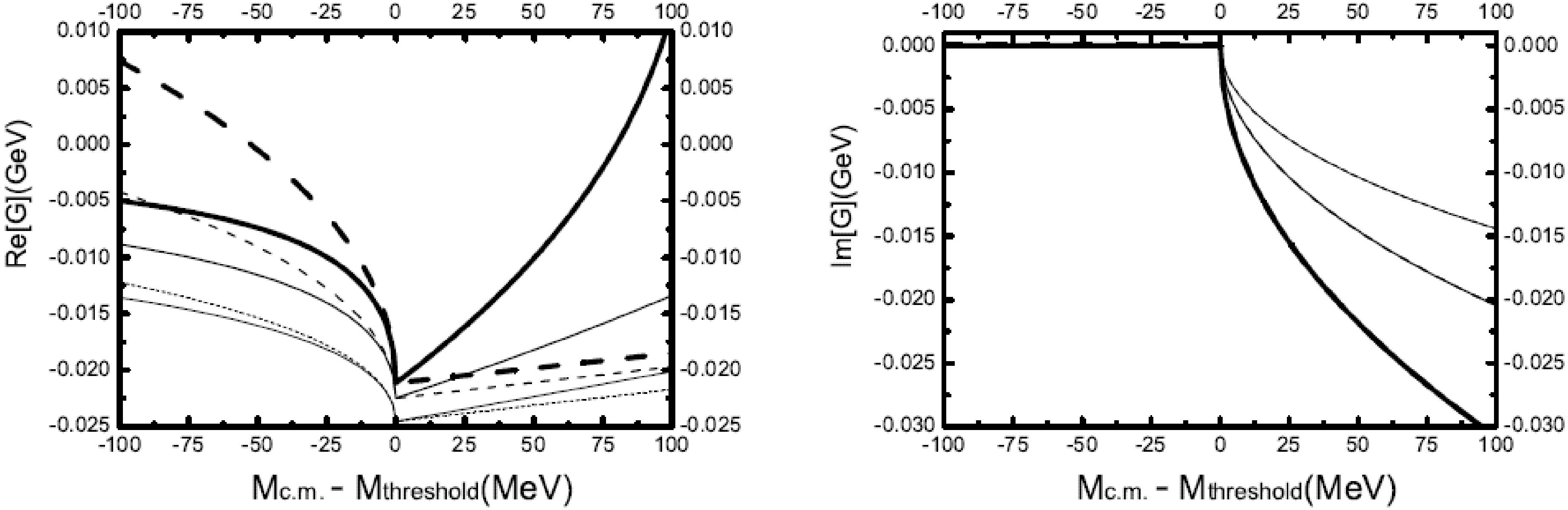
$$\frac{d\Gamma}{dM_{\rm inv}(D_s^*\bar{D}_s^*)} = \frac{1}{(2\pi)^3}\frac{1}{4M_{B^-}^2}\frac{2}{3}|\vec{k}|^4|\vec{k}'|\,\tilde{p}_{D_s^*}|A|^2$$

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

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

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

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



The real part (left) and imaginary part (right) of two G functions

From J J Wu and B S Zou , PLB 2012

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

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

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

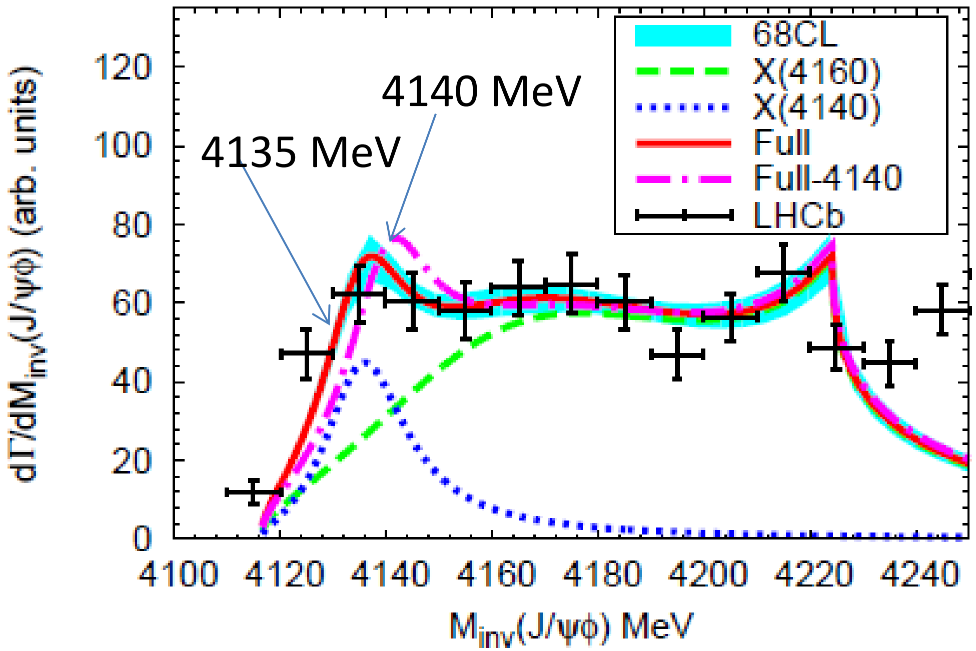
To account for the production of $J/\psi\phi$ via the 1^{++} $X(4140)$ resonance, we take the suitable operator with the kaon in P-wave $(\vec{\epsilon}_{J/\psi} \times \vec{\epsilon}_\phi) \cdot \vec{k}$.

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

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

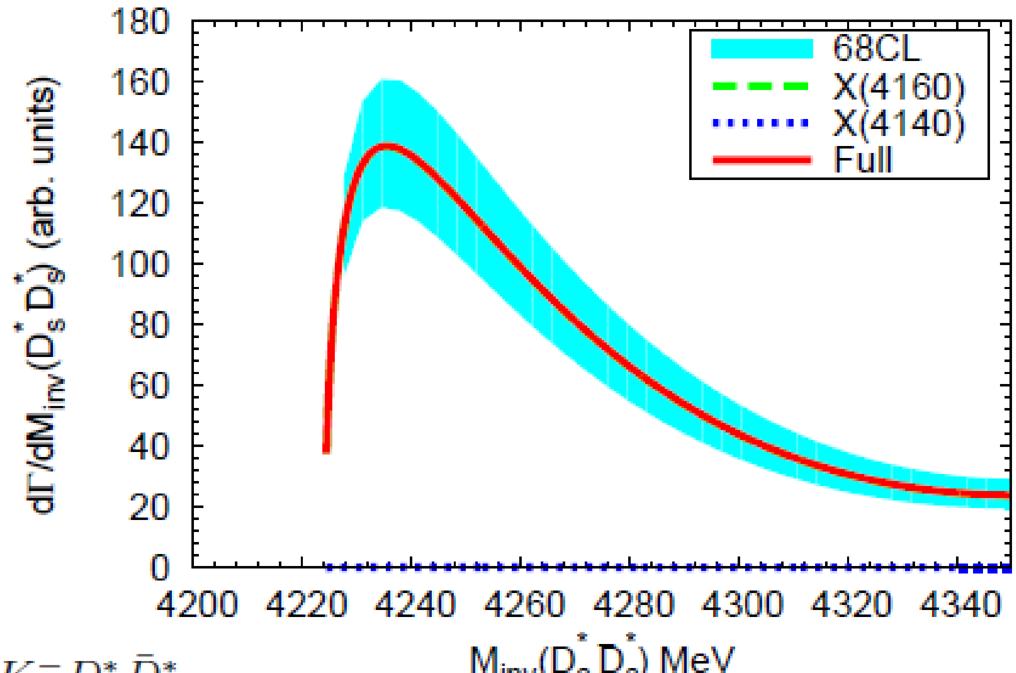
$$A \to \frac{B\, M^4_{X(4140)}}{M^2_{\rm inv}(J/\psi\phi) - M^2_{X(4140)} + i M_{X(4140)} \Gamma_{X(4140)}}$$

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 $B^- \to K^- D_s^* \bar{D}_s^*$

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 $J/\Psi\ \phi$ 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