Discriminating among models for $X(2900)$ states

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Prologue:

$P_c(4312)$, $P_c(4440)$, $P_c(4457)$ and $P^{\Lambda}_{\psi s}(4338)$

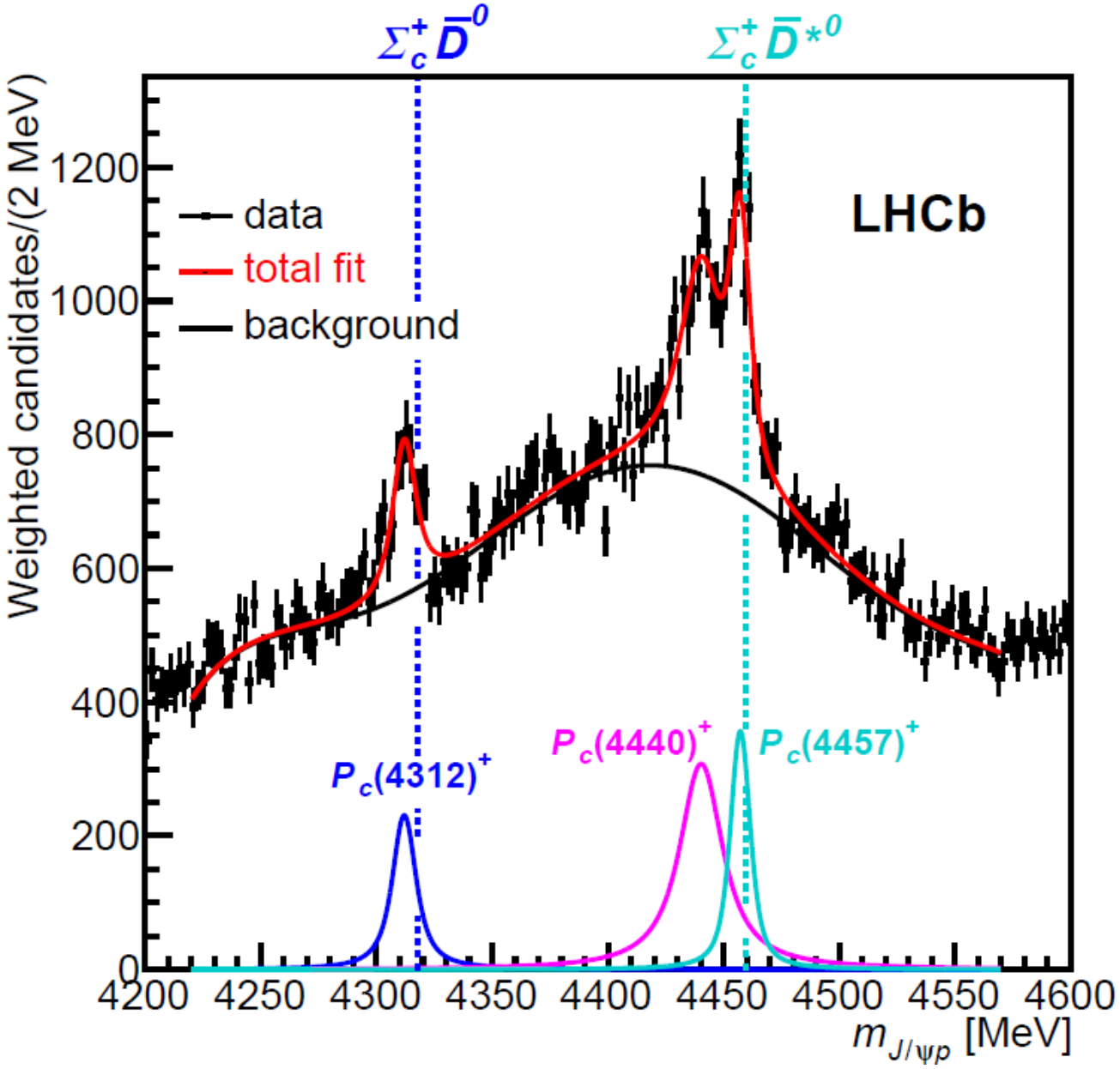
[T.B. & E.Swanson, 1908.03528 (PRD)]

[T.B. & E.Swanson, 2112.11527 (EPJA)]

[T.B. & E.Swanson, 2207.00511 (PRD)]

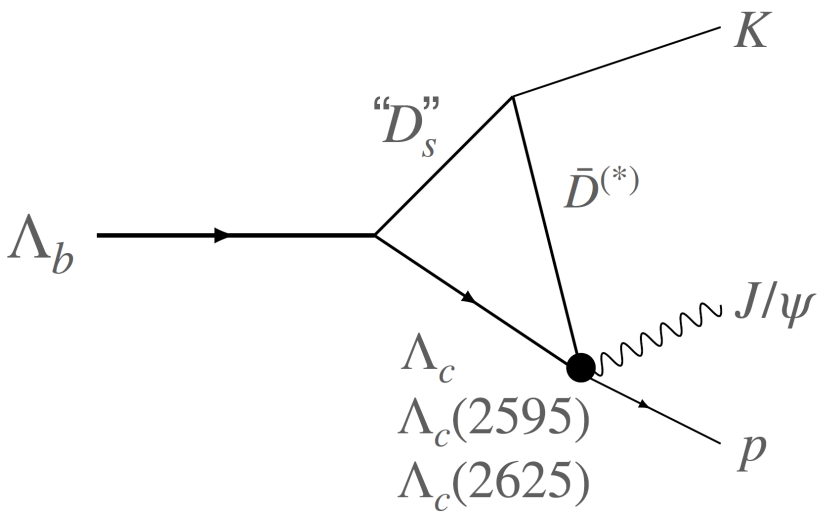
[T.B. & E.Swanson, 2208.05106 (PLB)]

$\Lambda_b \to J/\psi\, p\, K^-$: states decaying to $J/\psi p$ ($uudc\bar{c}$)

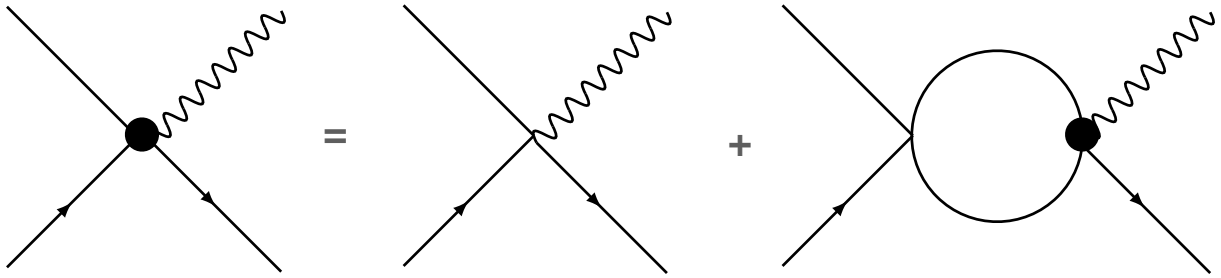


Note there are **two** states near the $\Sigma_c \bar{D}^*$ threshold

Model

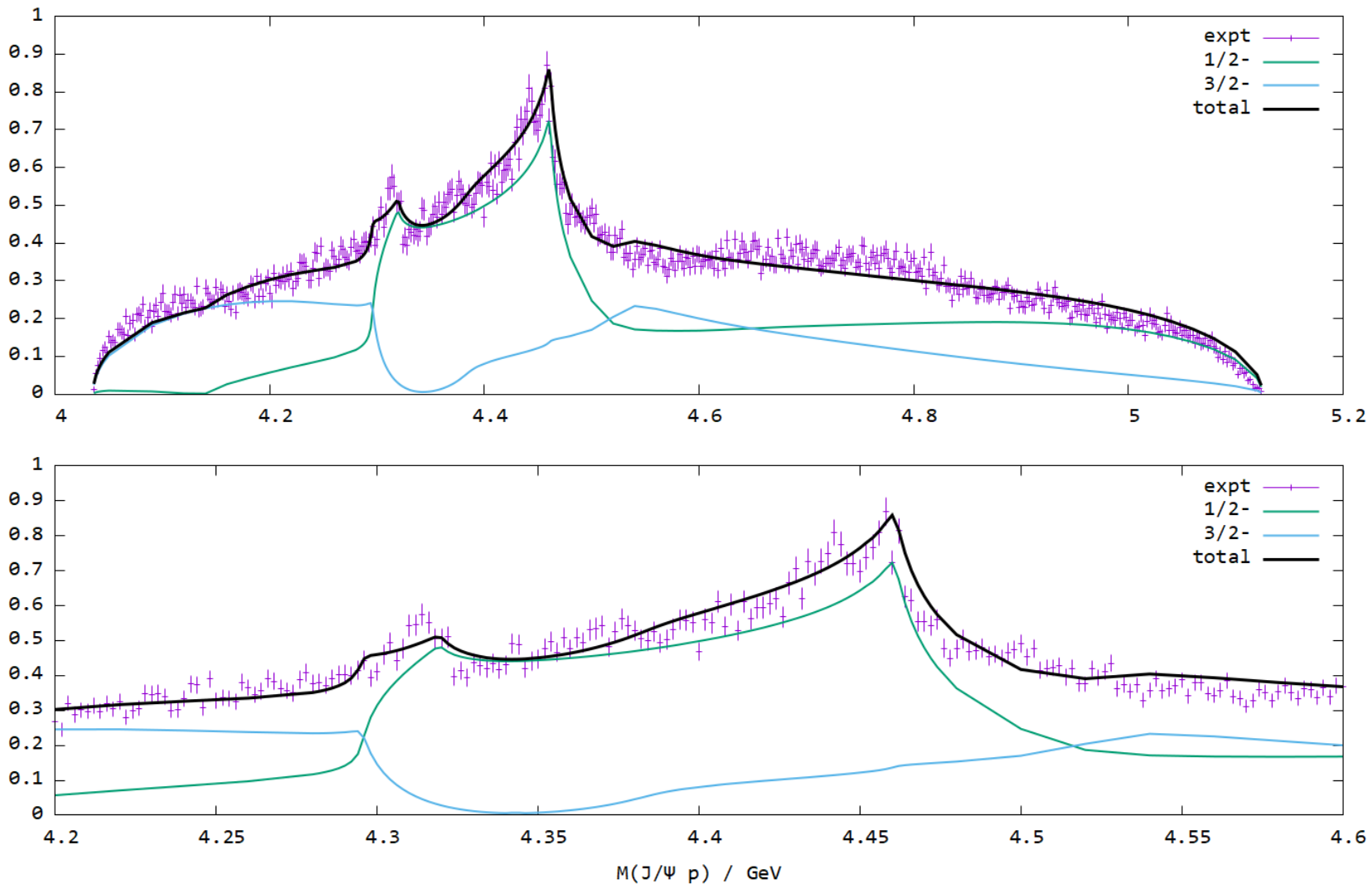


The "blob" is non-perturbative FSIs constrained by HQS

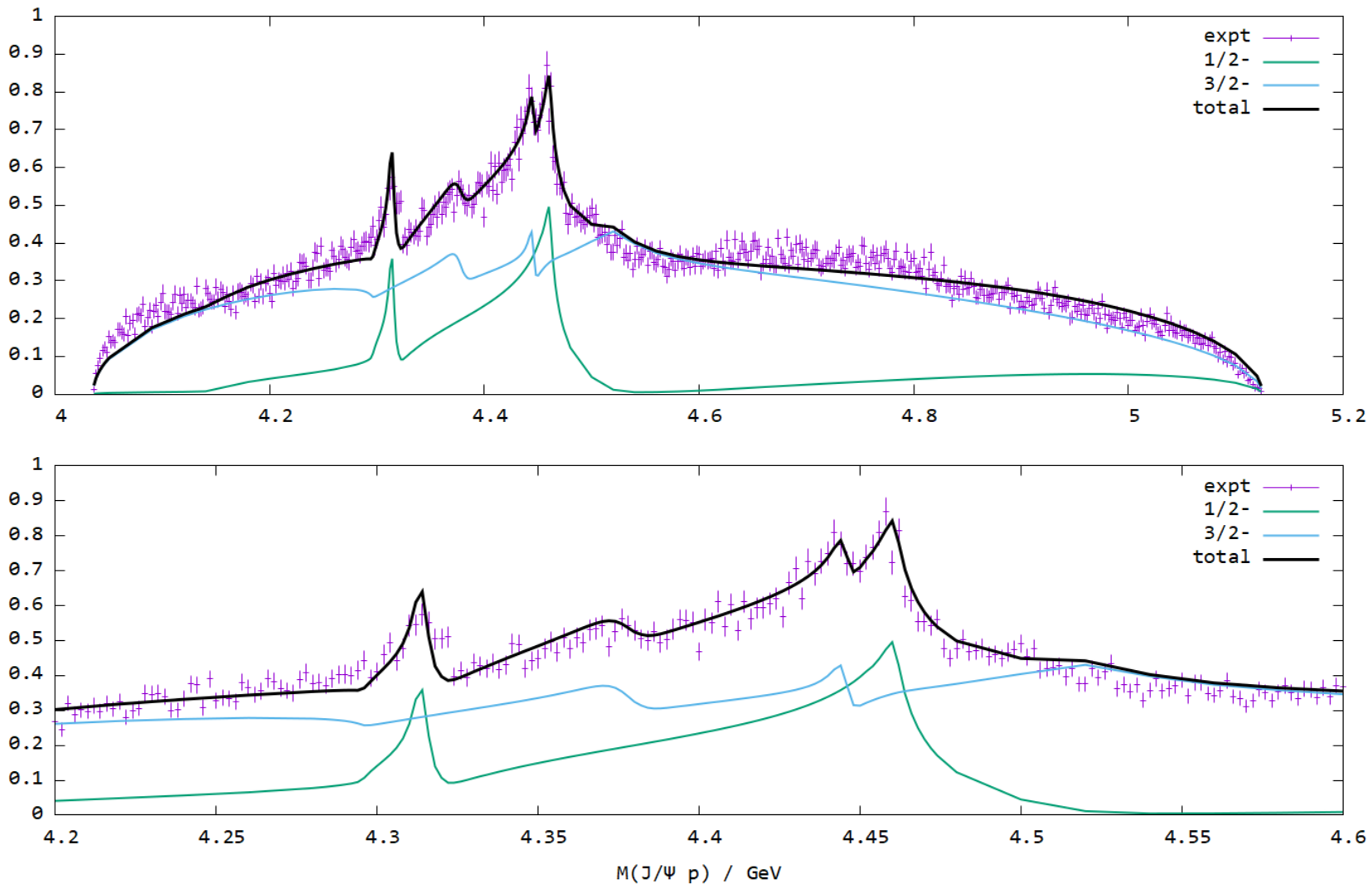


[Related work: Du, Baru, **Guo**, Hanhart, Meißner, Oller, Wang 1910.11846 (PRL), 2102.07159 (JHEP)]

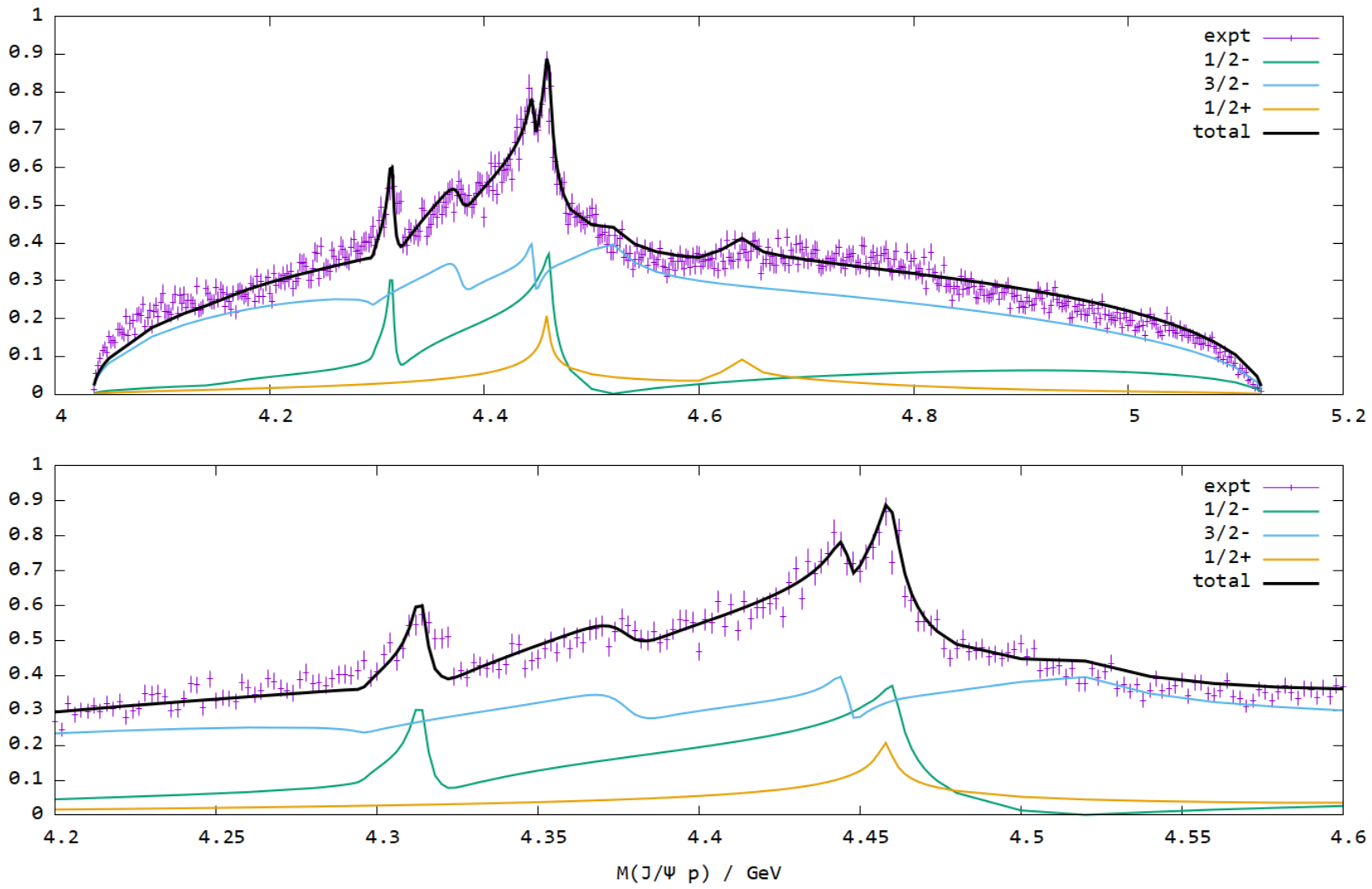
Case 1: $P_c(4457)$ as a $\Sigma_c \bar{D}^*$ cusp



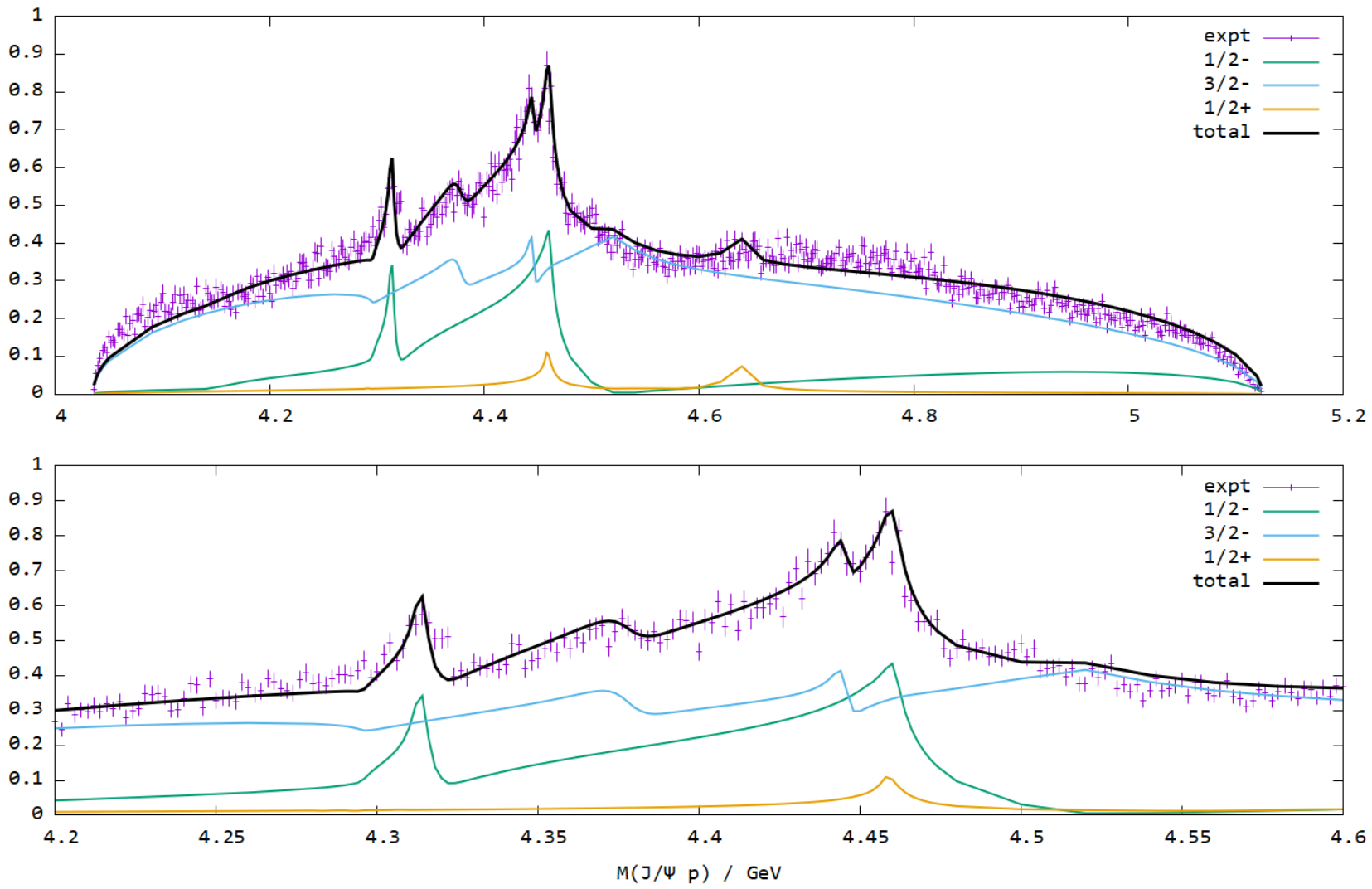
Case 2: $P_c(4312)$, "$P_c(4380)$" and $P_c(4440)$ bind



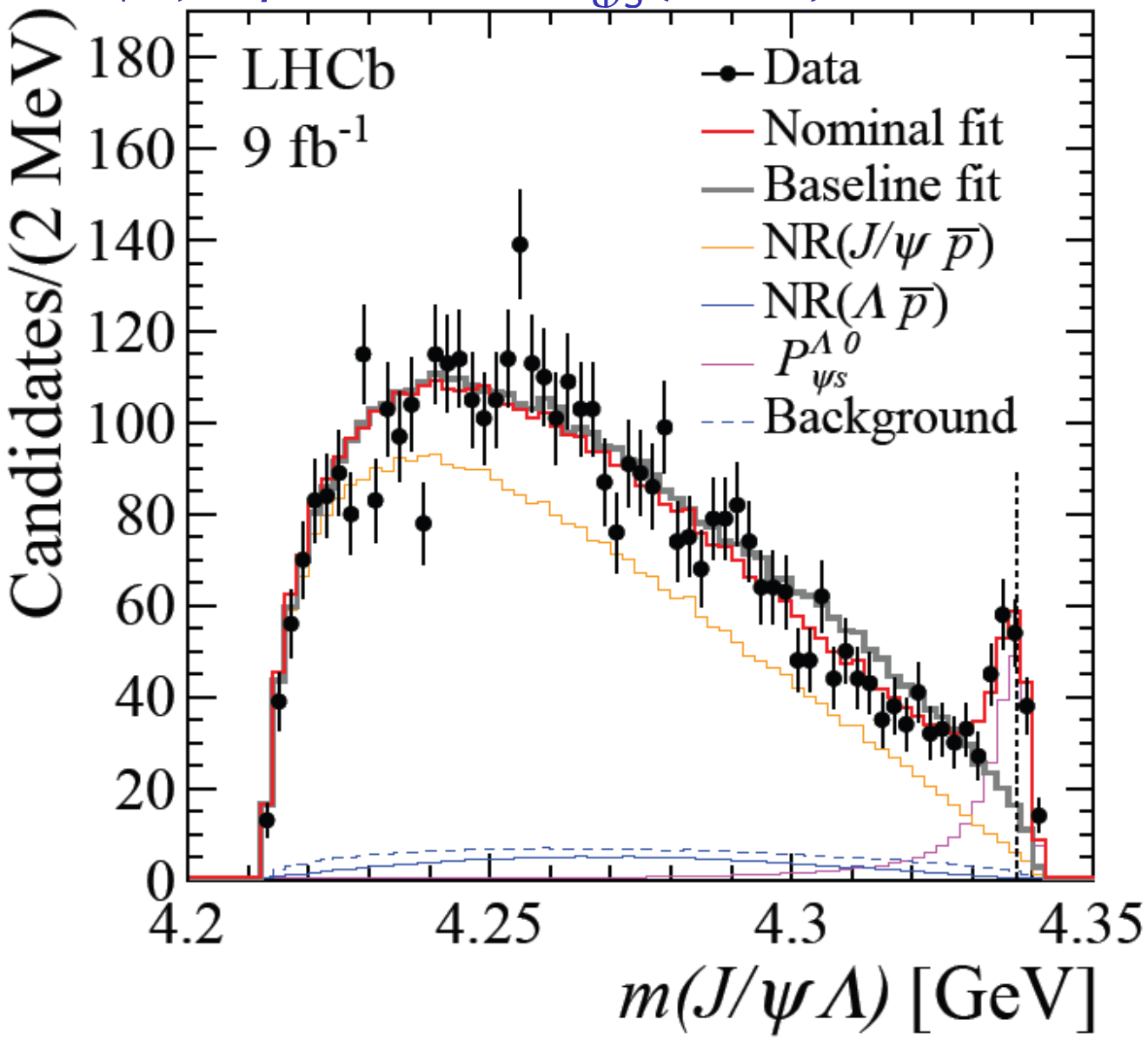
Case 4: $P_c(4457)$ as a $\Lambda_c(2595)\bar{D}$ triangle singularity



Case 5: $P_c(4457)$ as a $1/2^+$ $\Lambda_c(2595)\bar{D}$ resonance

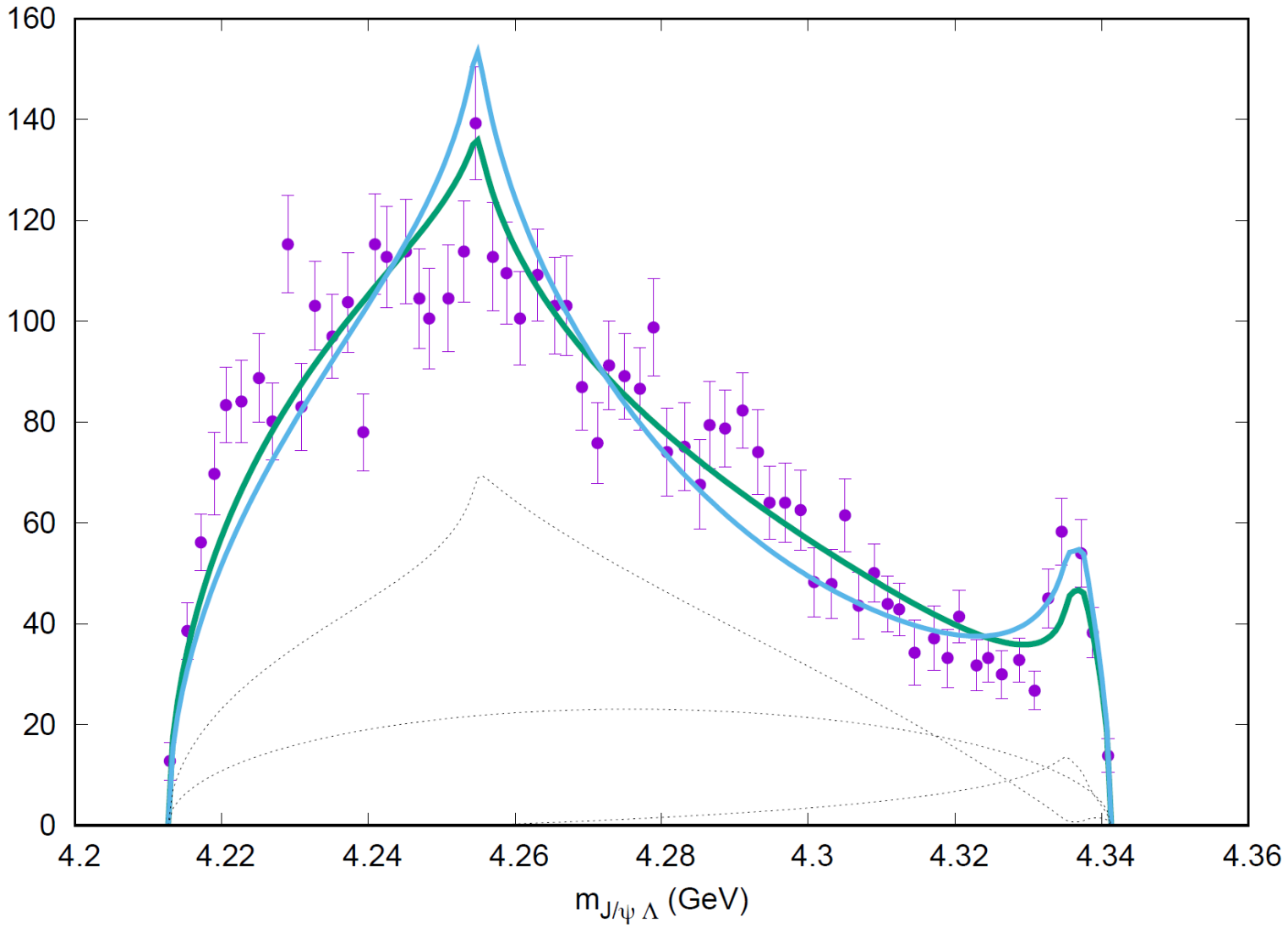


$B^- \to J/\psi \Lambda \bar{p}$ LHCb : $P^{\Lambda}_{\psi s}(4338)$



$\Xi_c \bar{D}$ molecule? Karliner/Rosner, Wang/Liu, **Ortega** et al.
But note it is not bound.

Similar (but simpler) model gives a decent fit



The peak at $\Lambda_c^+ D_s^-$ threshold is a cusp

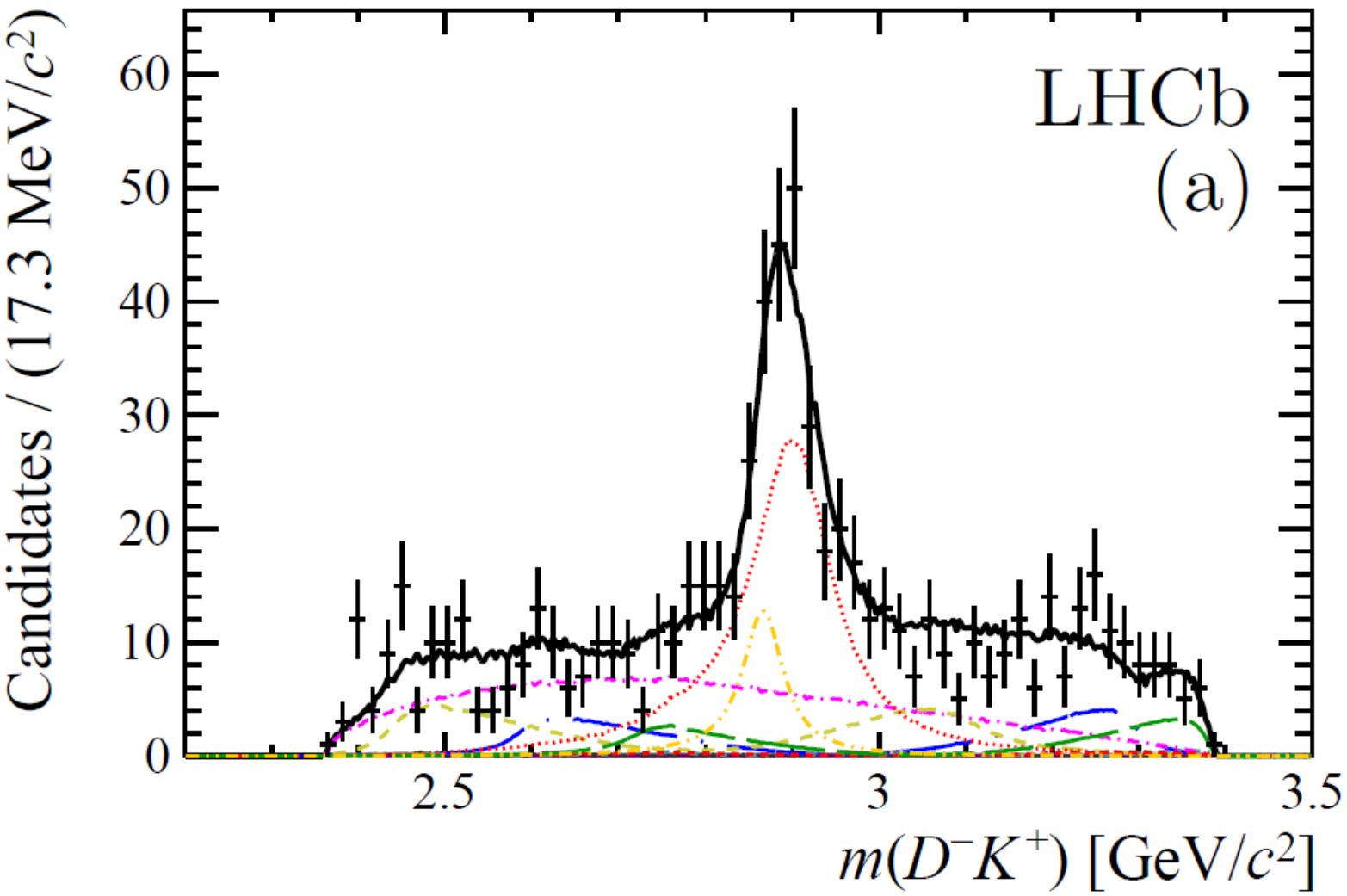
The $P_{\psi s}^{\Lambda}(4338)$ peak at $\Xi_c \bar{D}$ threshold is a triangle singularity

$X(2900)$ in B decays

[T.B. & Swanson 2008.12838 (PLB)]

[T.B. & E.Swanson, 2009.05352 (PRD)]

LHCb: $X(2900)$ states in $B^+ \to D^+X, X \to D^-K^+$



Experimental properties

Two $X(2900)$ states in $B^+ \to D^+ X, X \to D^- K^+$

Their minimal flavour content is $ud\bar{s}\bar{c}$

$X_0(2900)$	$2.866 \pm 0.007 \pm 0.002$ GeV	0^+
$X_1(2900)$	$2.904 \pm 0.005 \pm 0.001$ GeV	1^-
$\bar{D}^* K^*$	2.902 GeV	$0^+, 1^+, 2^+$ (in S-wave)
$\bar{D}_1(2420) K$	2.917 GeV	1^- (in S-wave)

Tetraquark

Tetraquark interpretations:

- [Karliner & Rosner, 2008.05993]
- [He, Wang & Zhu, 2008.07145]
- [Zhang, 2008.07295]

But

- No evidence for *bound* $ud\bar{s}\bar{c}$ in lattice [Hudspith et al 2006.14294], quark model [Zouzou et al 1986], QCD sum rules [Agaev et al 1907.04017]
- Mass inconsistent with variational quark model [Lu, Chen, Dong, 2008.07340]
- If $X(2900)$ are orbital/radial excitations, where are ground states?
- 1^- state awkward (P-wave)

Molecule

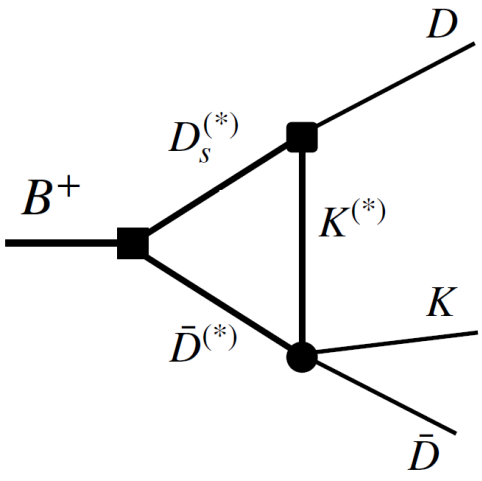
Many models for 0^+ $X_0(2900)$:

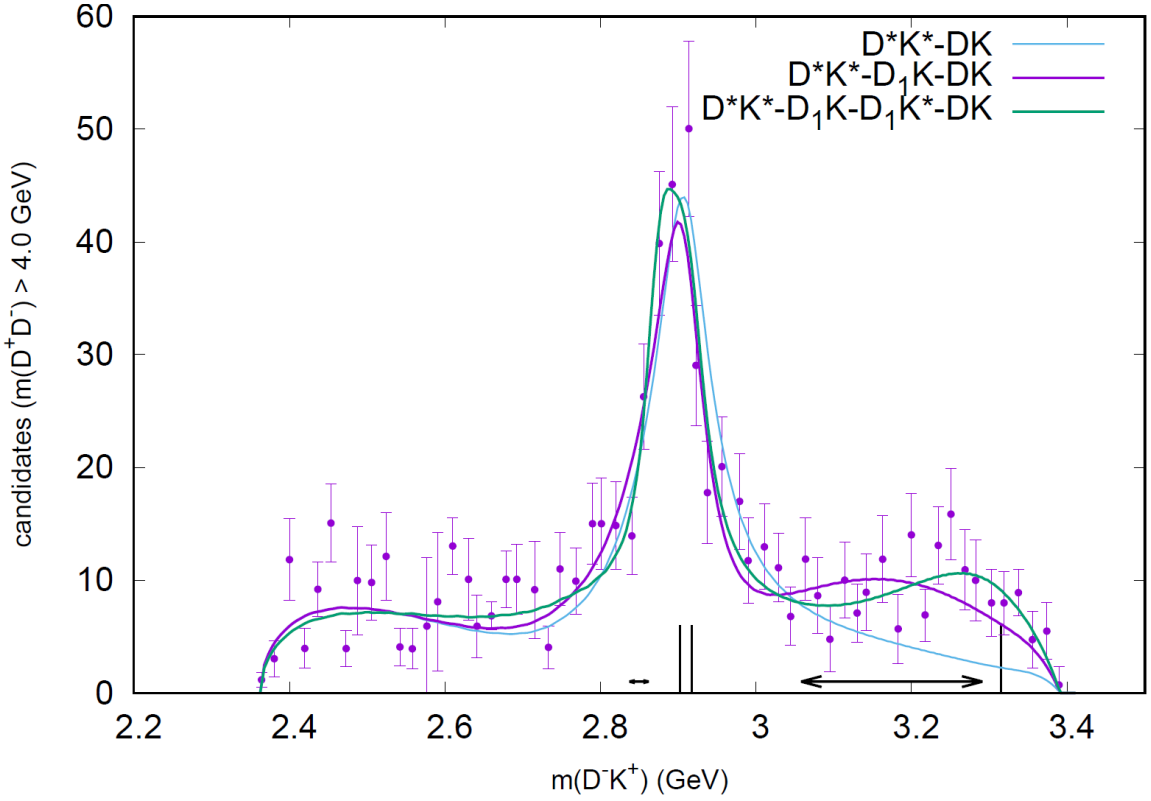
- isoscalar $\bar{D}^* K^*$ with vector hidden gauge [Molina et al 1005.0355, 2008.11171]
- isoscalar $\bar{D}^* K^*$ with effective Lagrangian [Liu et al 2008.07389]
- isovector $\bar{D}^* K^*$ with effective Lagrangian [He and Chen 2008.07782]
- isoscalar $\bar{D}^* K^*$ with heavy quark symmetry [Hu et al 2008.06894]
- isoscalar $\bar{D}^* K^*$ with molecular and diquark d.o.f. [Chen et al 2008.07516, Xue et al 2008.09516]

The 1^- $X_1(2900)$ is more difficult:

- virtual state from $\bar{D}_1(2420)K$ [He and Chen 2008.07782]

Triangle with FSIs [T.B. & Swanson 2008.12838]





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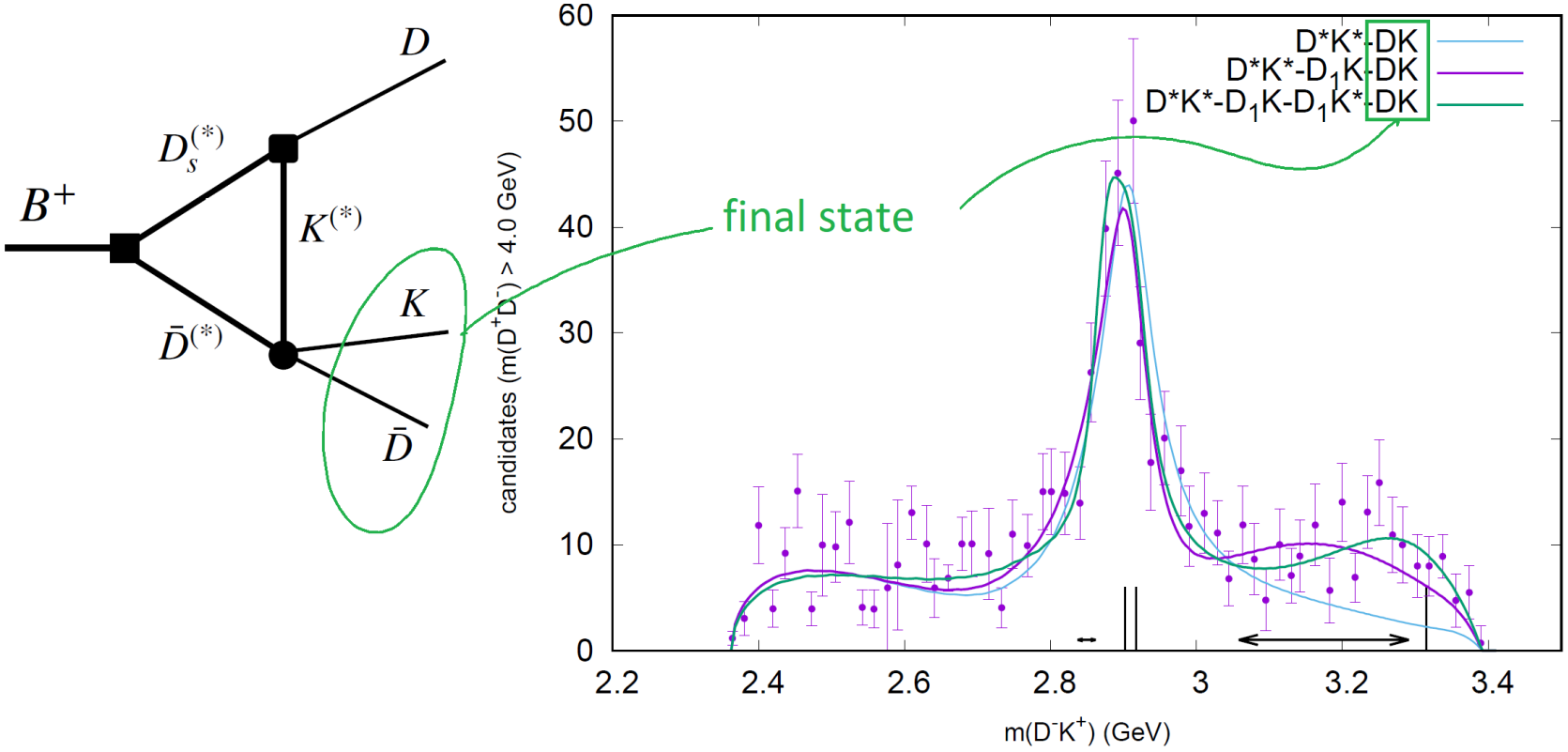

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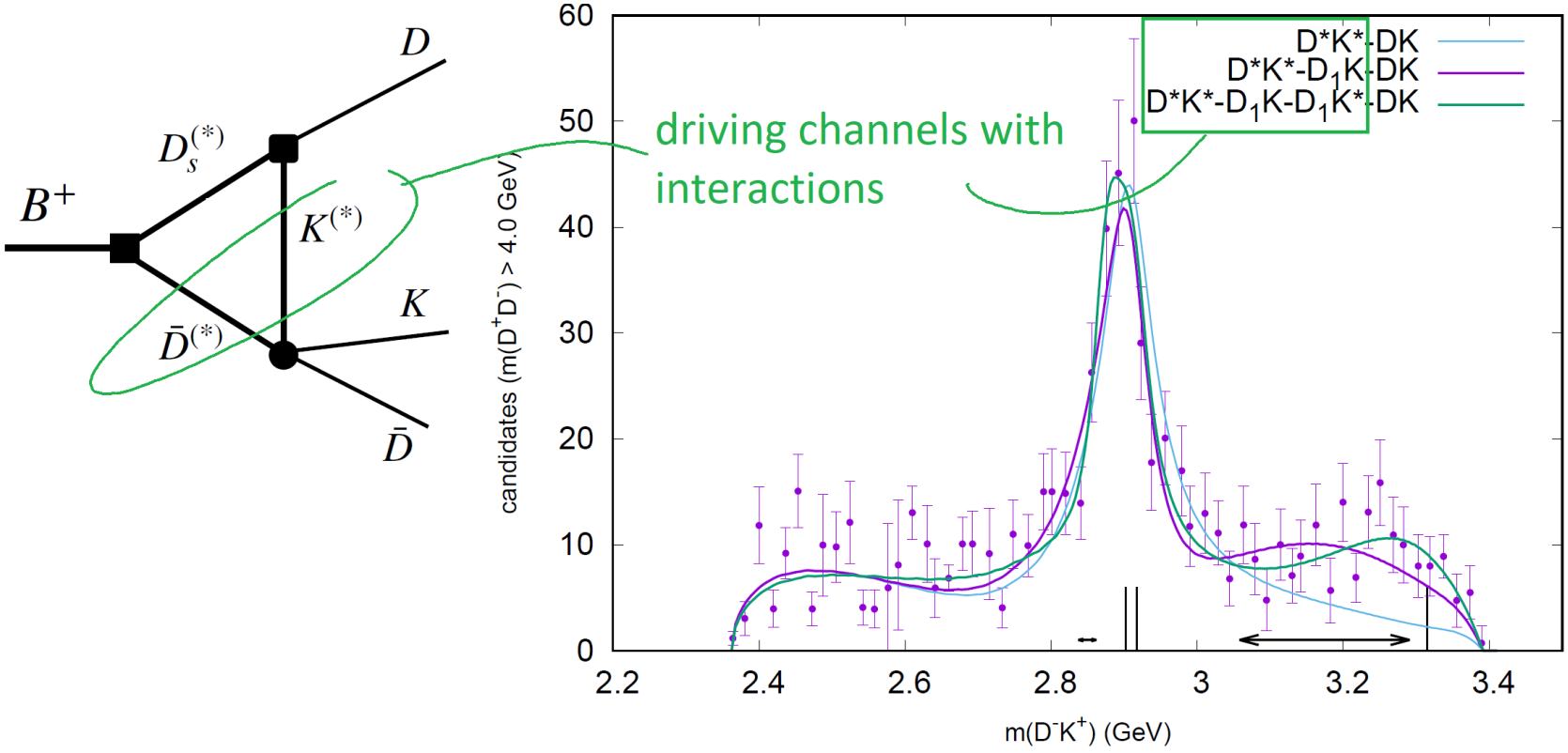

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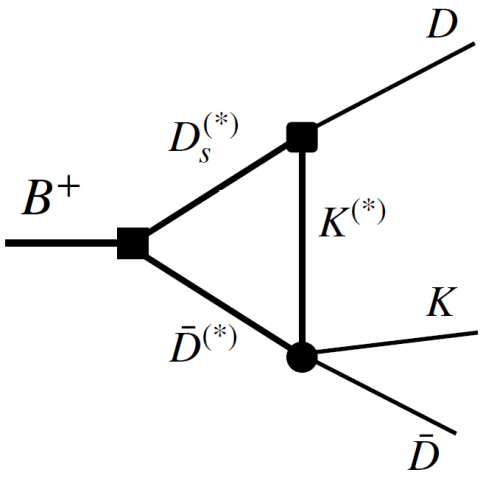
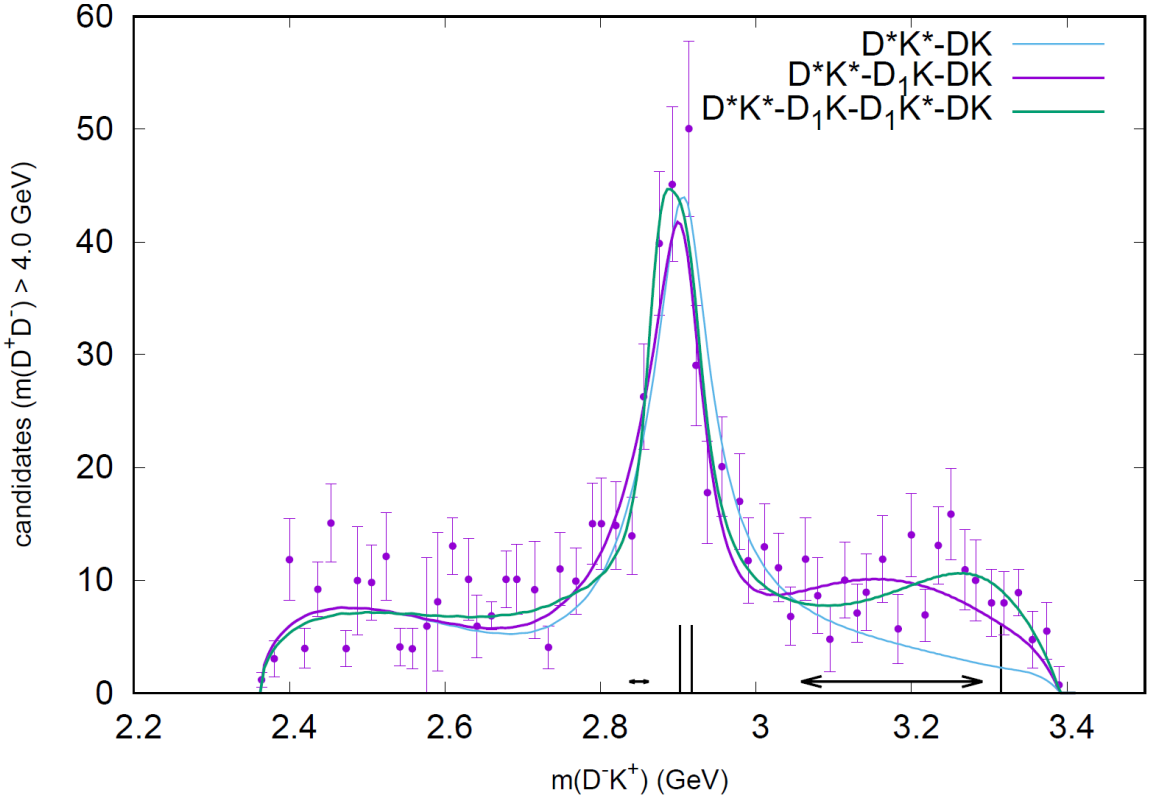
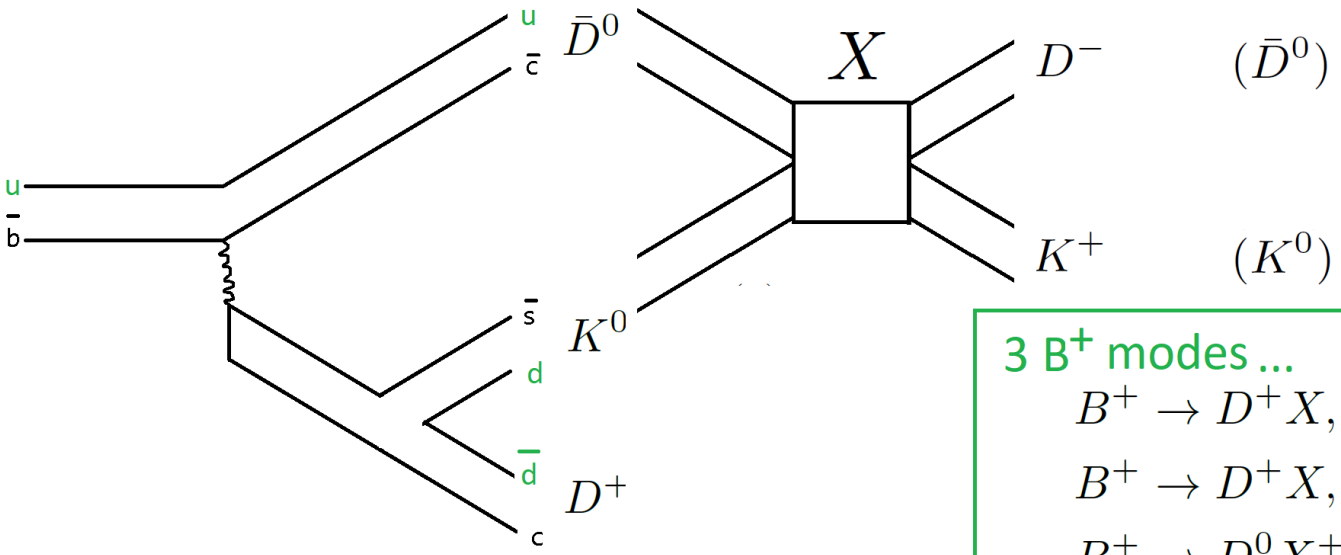




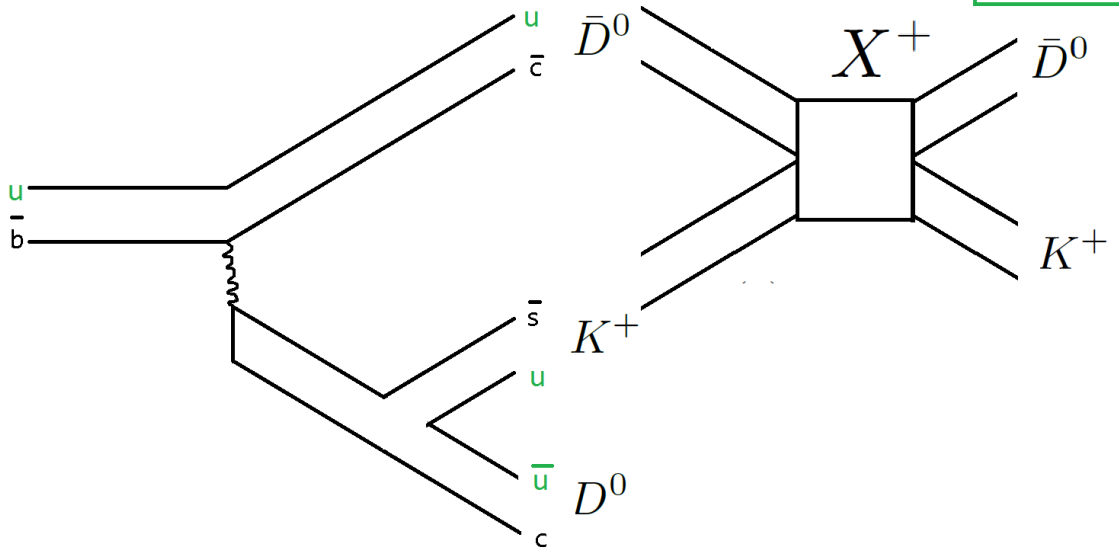
This is an example fit.
Given parametric freedom, can't really distinguish triangle scenario (weak FSIs) from resonance scenario (strong FSIs)

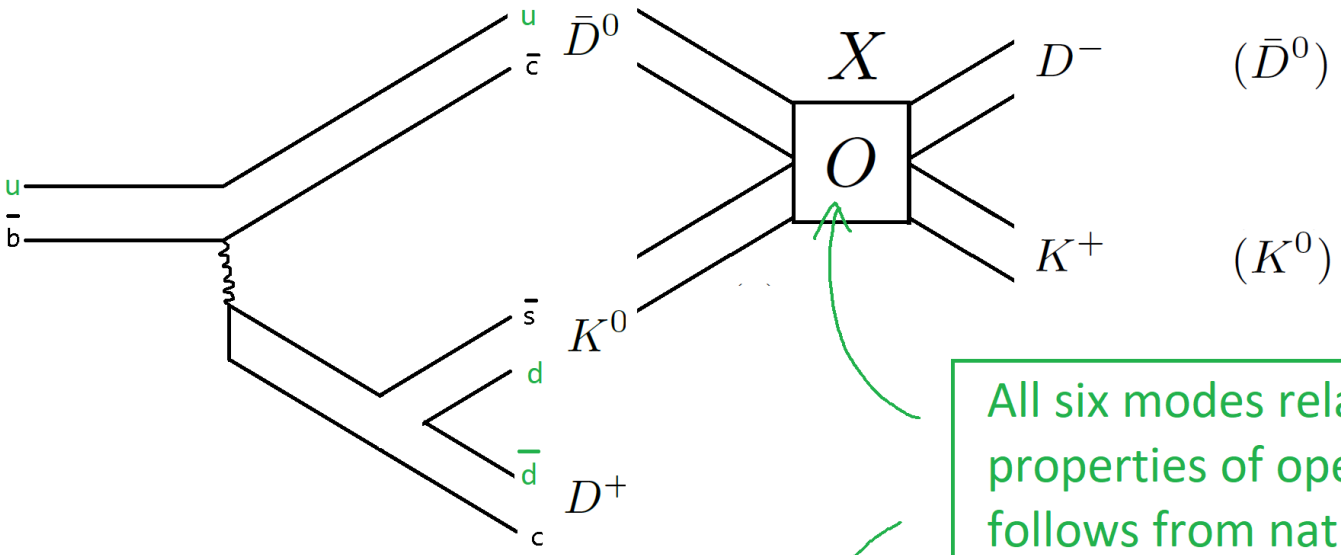


3 B^+ modes ...

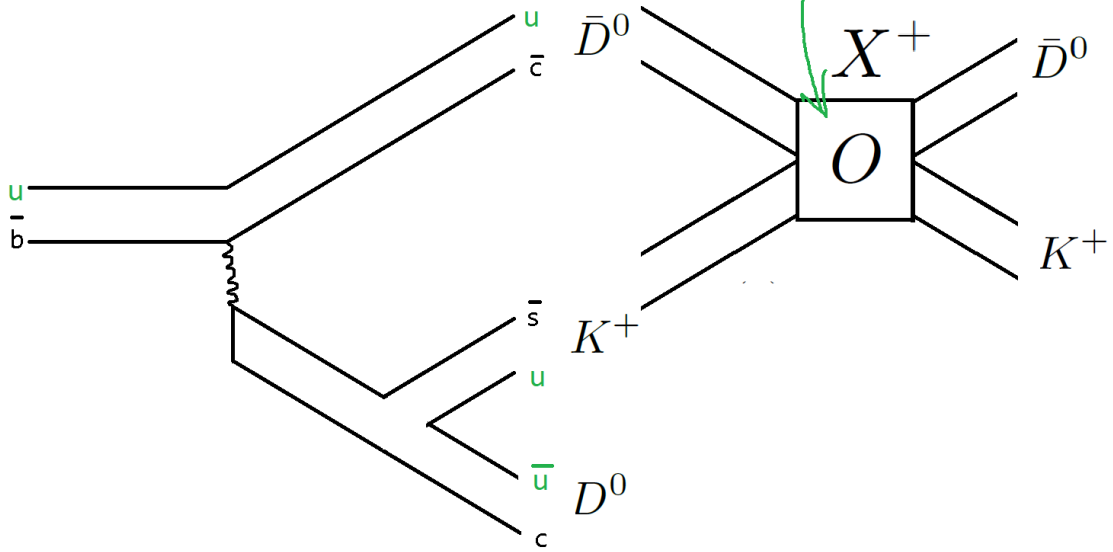
$$B^+ \to D^+ X,\ X \to D^- K^+,$$
$$B^+ \to D^+ X,\ X \to \bar{D}^0 K^0,$$
$$B^+ \to D^0 X^+,\ X^+ \to \bar{D}^0 K^+.$$

... and another 3 for B^0





All six modes related by isospin properties of operator *O*, which follows from nature of *X*.



Results for $X_1(2900)$ and its charged partners

(For $X_0(2900)$ scale by 5.6 / 30.6)

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

Results for $X_1(2900)$ and its charged partners

(For $X_0(2900)$ scale by 5.6 / 30.6)

neutral X modes

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
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Results for $X_1(2900)$ and its charged partners

(For $X_0(2900)$ scale by 5.6 / 30.6)

charged X modes

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triangle diagram with quark-exchange (QE), one-pion exchange (OPE) or effective field theory (EFT) interactions

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
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Resonance, either molecular or tetraquark

Mixed isospin case relevant for molecule

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

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$$f(B \to DX, X \to \bar{D}K) = \frac{\boxed{\mathcal{B}(B \to DX, X \to \bar{D}K)}}{\mathcal{B}(B \to D\bar{D}K)}$$

relations among matrix elements and small correction (B lifetime)

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
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$$f(B \to DX, X \to \bar{D}K) = \frac{\boxed{\mathcal{B}(B \to DX, X \to \bar{D}K)}}{\mathcal{B}(B \to D\bar{D}K)}$$

matrix elements equal in pairs

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\boxed{\mathcal{B}(B \to DDK)}}$$

enhancement if 3-body small

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\boxed{\mathcal{B}(B \to D\bar{D}K)}$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

fractional uncertainty

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

existing channel is largest

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

neutral mode is comparable

general prediction, same for all models

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

remaining predictions discriminate among models

uncertainties are large but predictions still discriminate

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

same production mode

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
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Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
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Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

same production mode

different final state

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

selection rule

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
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Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

same production mode

different final state

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

discriminates, despite large uncertainties

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
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Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

same production mode

different final state

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

constraint on contact terms

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
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Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

same production mode

different final state

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

constraint on isospin mixing angle

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
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Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

same production mode

different final state

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
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Triangle, QE	30.6	23.2	0	0	4.6	8.3
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Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

similar patterns for neutral X in neutral B decays

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

triangle selection rule opposite

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
$\mathcal{B}(B \to D\bar{D}K)$	2.2 ± 0.7	2.7 ± 1.1	15.5 ± 2.1	10.7 ± 1.1	14.5 ± 3.3	7.5 ± 1.7
$f(B \to DX, X \to \bar{D}K)$						
Triangle, QE	30.6	23.2	0	0	4.6	8.3
Triangle, OPE	30.6	23.2	1.1	1.5	1.2	2.1
Triangle, EFT	30.6	23.2	$1.1\left(1-\frac{C_0}{C_1}\right)^2$	$1.5\left(1-\frac{C_0}{C_1}\right)^2$	$1.2\left(1+\frac{C_0}{C_1}\right)^2$	$2.1\left(1+\frac{C_0}{C_1}\right)^2$
Resonance, $I=0$	30.6	23.2	4.3	5.8	0	0
Resonance, $I=1$	30.6	23.2	4.3	5.8	18.6	33.4
Resonance, I mixed	30.6	23.2	$4.3\tan^2\left(\theta+\frac{\pi}{4}\right)$	$5.8\tan^2\left(\theta-\frac{\pi}{4}\right)$		
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

similar patterns for neutral X in neutral B decays

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

charged partners
discriminate among models

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
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charged partners
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	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
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absent only in I=0 resonance scenario

$$f(B \to DX, X \to \bar{D}K) = \frac{\mathcal{B}(B \to DX, X \to \bar{D}K)}{\mathcal{B}(B \to D\bar{D}K)}$$

charged partners discriminate among models

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to \bar{D}^0K^0$	$B^+ \to D^+X$, $X \to \bar{D}^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to \bar{D}^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
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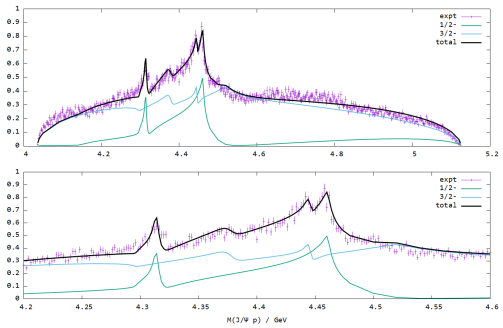
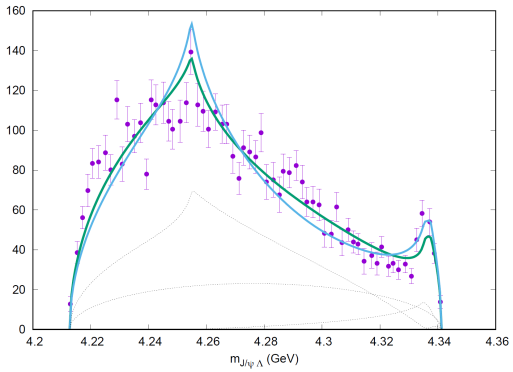
$\Delta f/f$	0.1	0.53	0.36	0.35	0.41	0.41

enormous fit fractions in I=1 resonance scenario

Conclusions

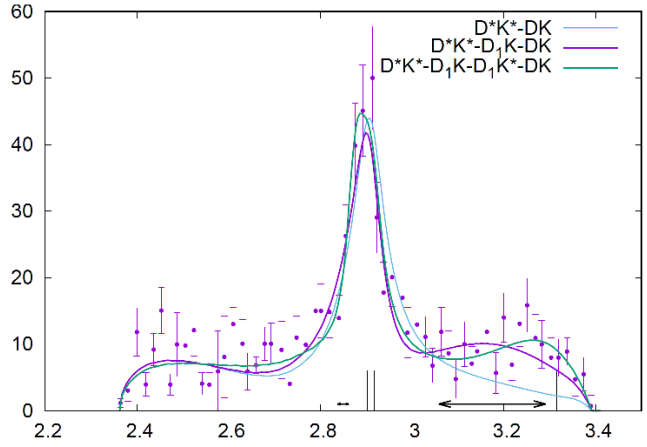


- P_c states in $\Lambda_b \to J/\psi p\ K^-$ are well-described by a model with colour-favoured production and heavy-quark symmetry

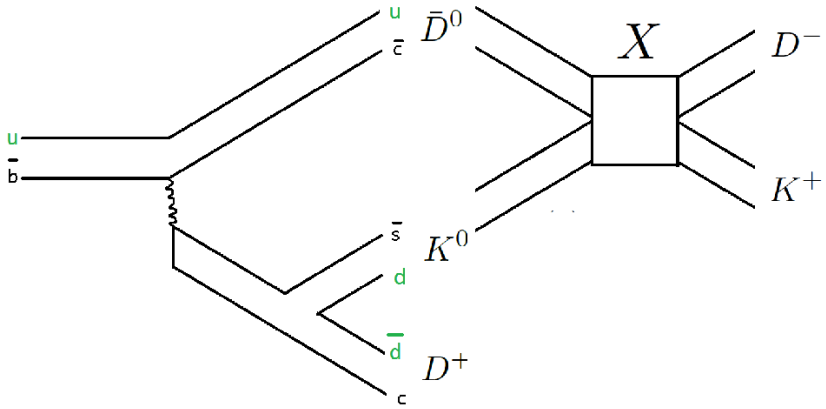


- $P^{\Lambda}_{\psi s}(4338)$ in $B^- \to J/\psi \Lambda \bar{p}$ is described by a similar model, where it is due to the triangle singularity.

Conclusions



Triangle and resonance scenarios fit experimental data in amplitude model



Assuming
- dominance of colour-favoured transitions, and
- isospin

we get relations among fit fractions

	$B^+ \to D^+X$, $X \to D^-K^+$	$B^0 \to D^0X$, $X \to D^0K^0$	$B^+ \to D^+X$, $X \to D^0K^0$	$B^0 \to D^0X$, $X \to D^-K^+$	$B^+ \to D^0X^+$, $X^+ \to D^0K^+$	$B^0 \to D^+X^-$, $X^- \to D^-K^0$
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absent only in I=0 resonance scenario

Six possible modes
- some new modes have very large fit fraction
- pattern can discriminate among models