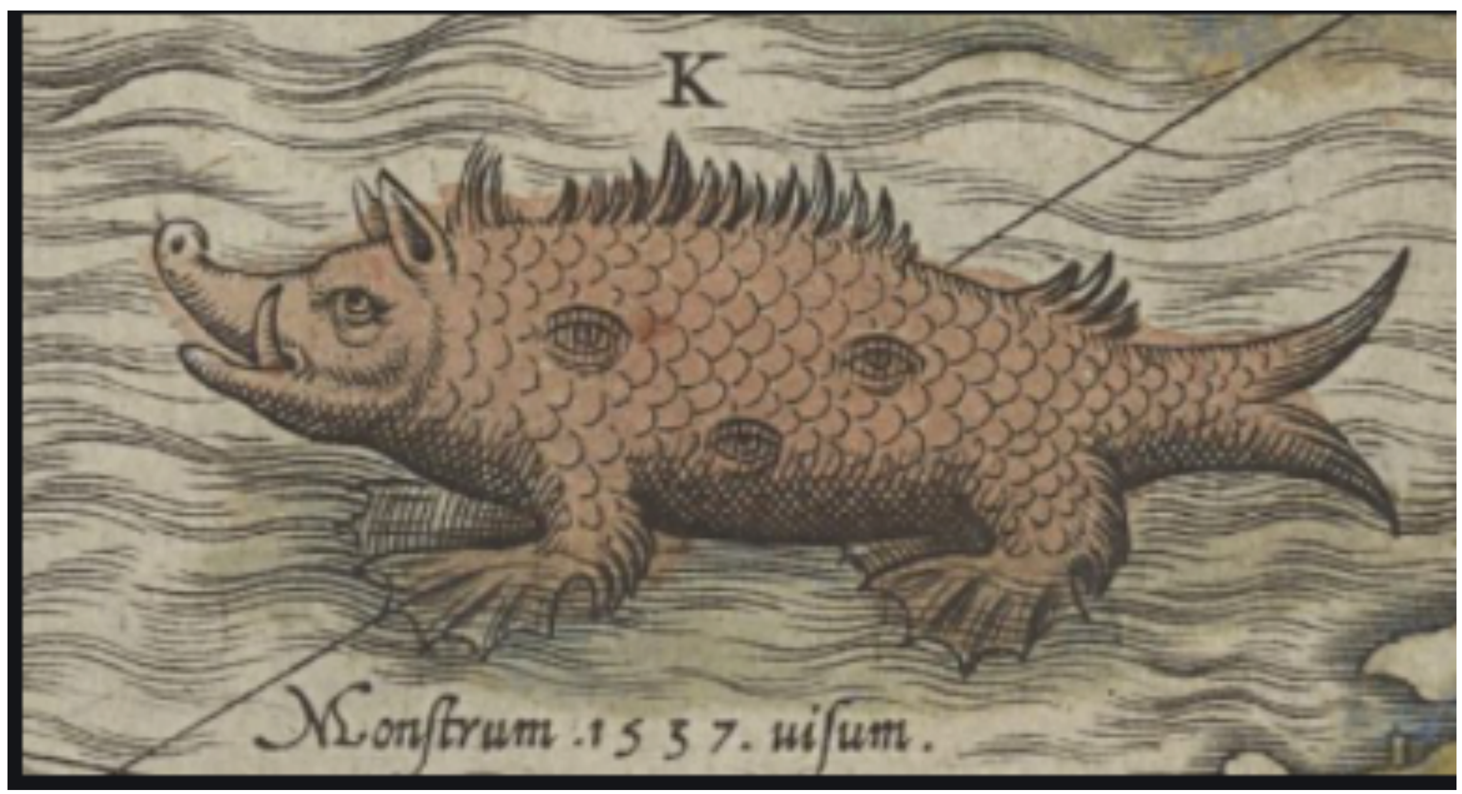
Multiquark Phenomenology

Eric Swanson

X(2866,0+)
X(2901,1+)

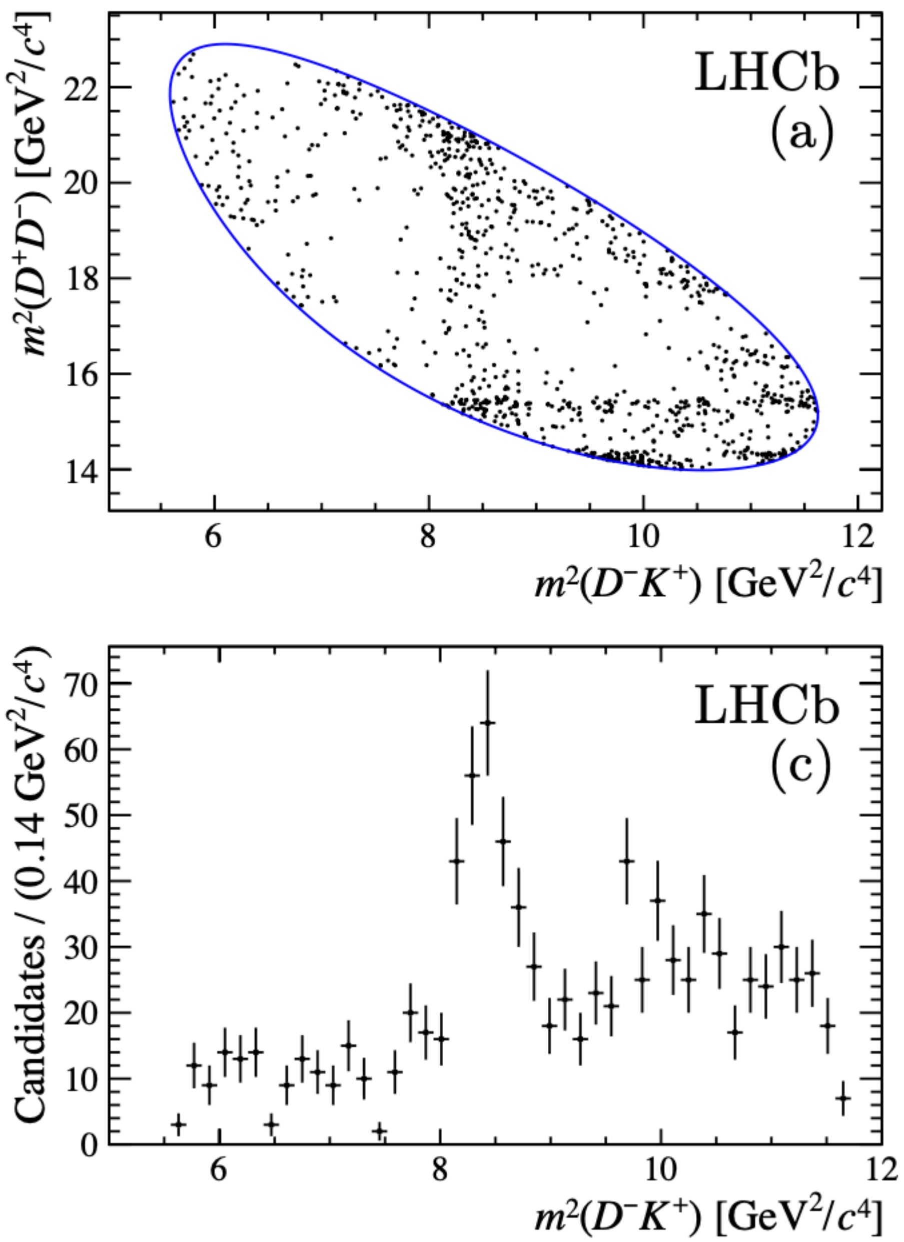


“Kinematic Singularity and Resonance Interpretations of the X(2900)”
T.J. Burns and E.S. Swanson; arXiv:2008.12838

“Discriminating Among Interpretations for the X(2900) States”
T.J. Burns and E.S. Swanson; arXiv:2009.05352

LHCb Discovery

$B^+ \to D^+ D^- K^+$



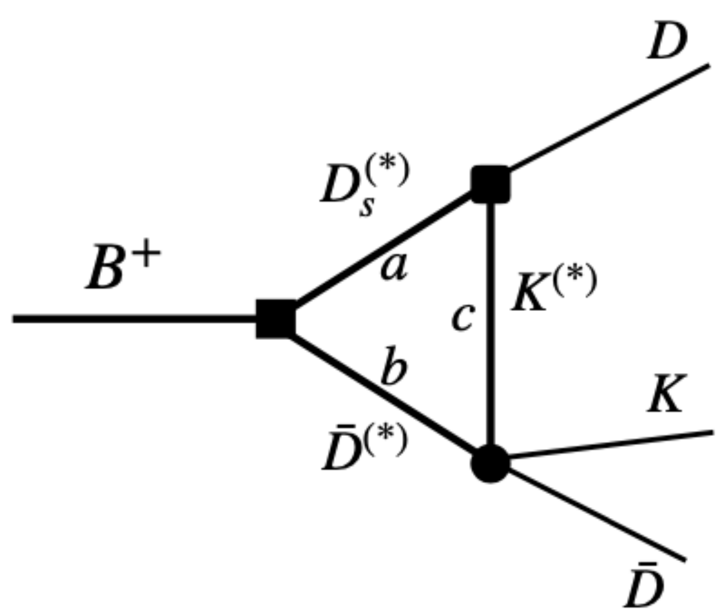
X_0 $\quad M = 2.866 \pm 0.007 \pm 0.002$ GeV, $\Gamma = 57 \pm 12 \pm 4$ MeV,

X_1 $\quad M = 2.904 \pm 0.005 \pm 0.001$ GeV, $\Gamma = 110 \pm 11 \pm 4$ MeV.

manifestly exotic channel $ud\bar{s}\bar{c}$

arXiv:2009.00026v2

Decay Model

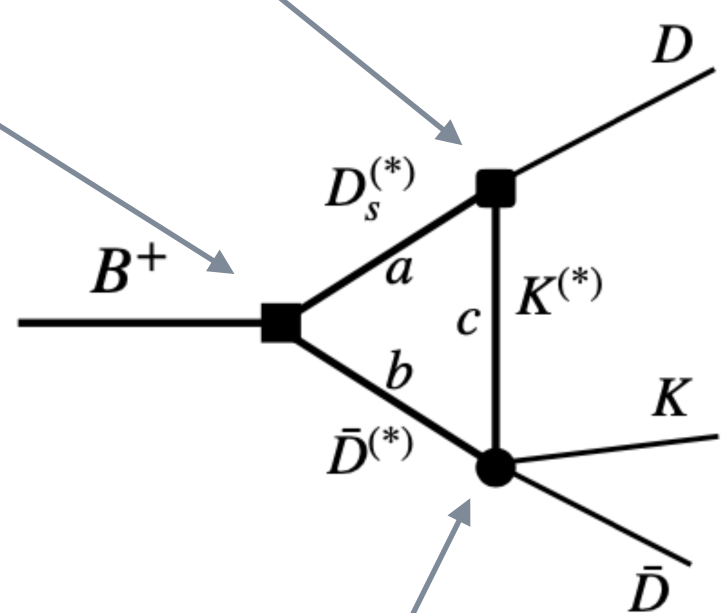


Decay Model

strong (3P0) vertex $\sim \frac{p}{\beta}\exp(-\frac{p^2}{12\beta^2})$

EW vertex

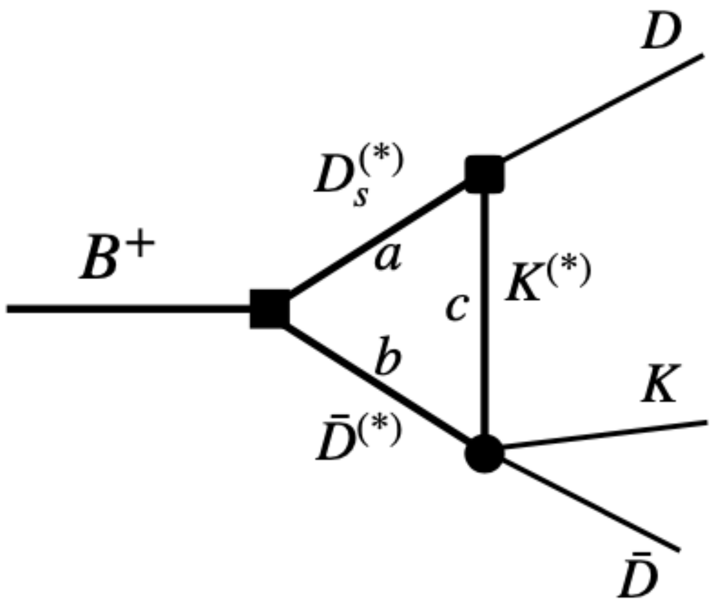
$$\xi \sim \left(\frac{2}{1+w}\right)^2$$



$$\langle pLM;\alpha|V|p'L'M';\alpha'\rangle = \lambda_{\alpha\alpha'}Y_{LM}(\hat{p})F_L(p)\cdot Y^*_{L'M'}(\hat{p}')F_{L'}(p').$$

$$F_L(x) = \frac{x^L}{1+x^2},\ x = p/\beta$$

Decay Model

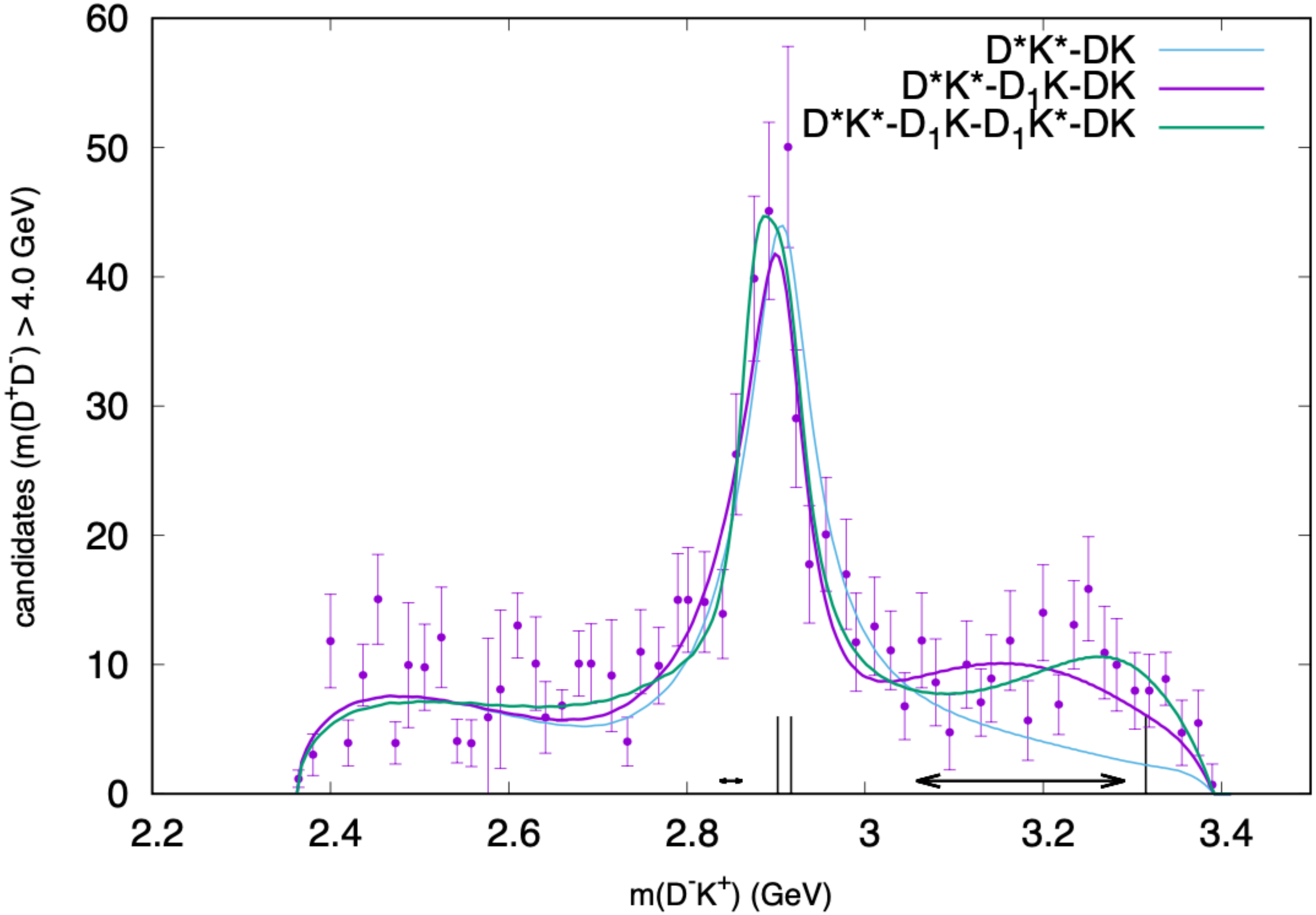


$$\mathcal{A} = \frac{g_{\mathrm{bg}}}{m_B^2} + \sum_{a\alpha(bc)} g_{a\alpha} \triangle_{a\alpha}(s_{DK}) \cdot t_{\alpha:DK}(s_{DK}) \cdot Y^*_{L_f M_f}(\widehat{k_{KD}}) F_{L_f}(k_{KD}).$$

$\lambda(1^-)$	$\bar{D}^* K^*\|_P$	$\bar{D}_1 K\|_S$	$\bar{D}_1 K^*\|_S$	$\bar{D} K\|_P$
$\bar{D}^* K^*\|_P$	C_3	C_2	C_2	C_3
$\bar{D}_1 K\|_S$		0	C_1	0
$\bar{D}_1 K^*\|_S$			C_1	0
$\bar{D} K\|_P$				0

case	C_1	C_2	C_3
weak	-3	3	2
moderate	-30	17	7
strong	-60	17	7

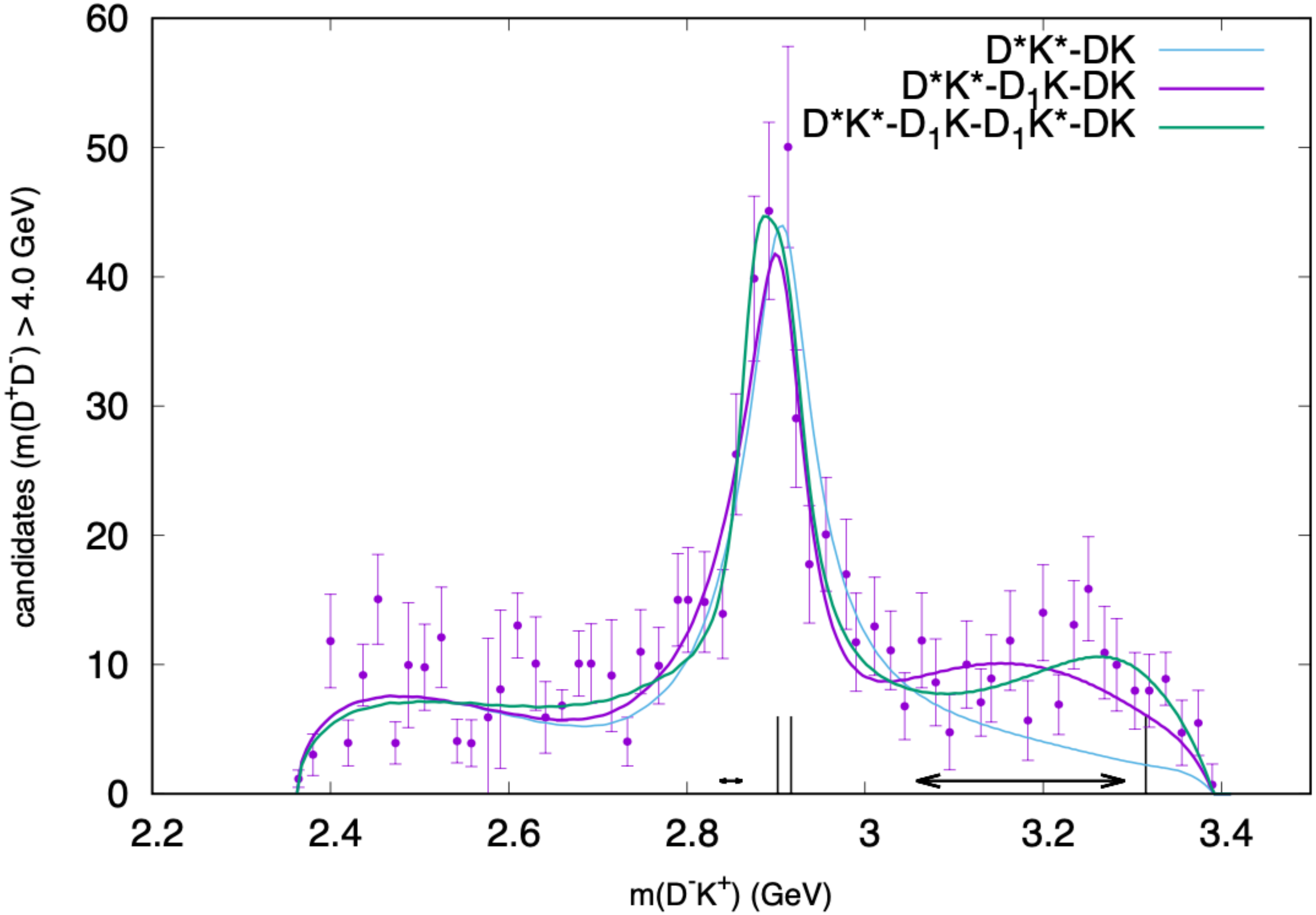
Results



thresholds: $\bar{D}^* K^*$, $\bar{D}_1 K$ $\bar{D}_1 K^*$

(strong case)

Results

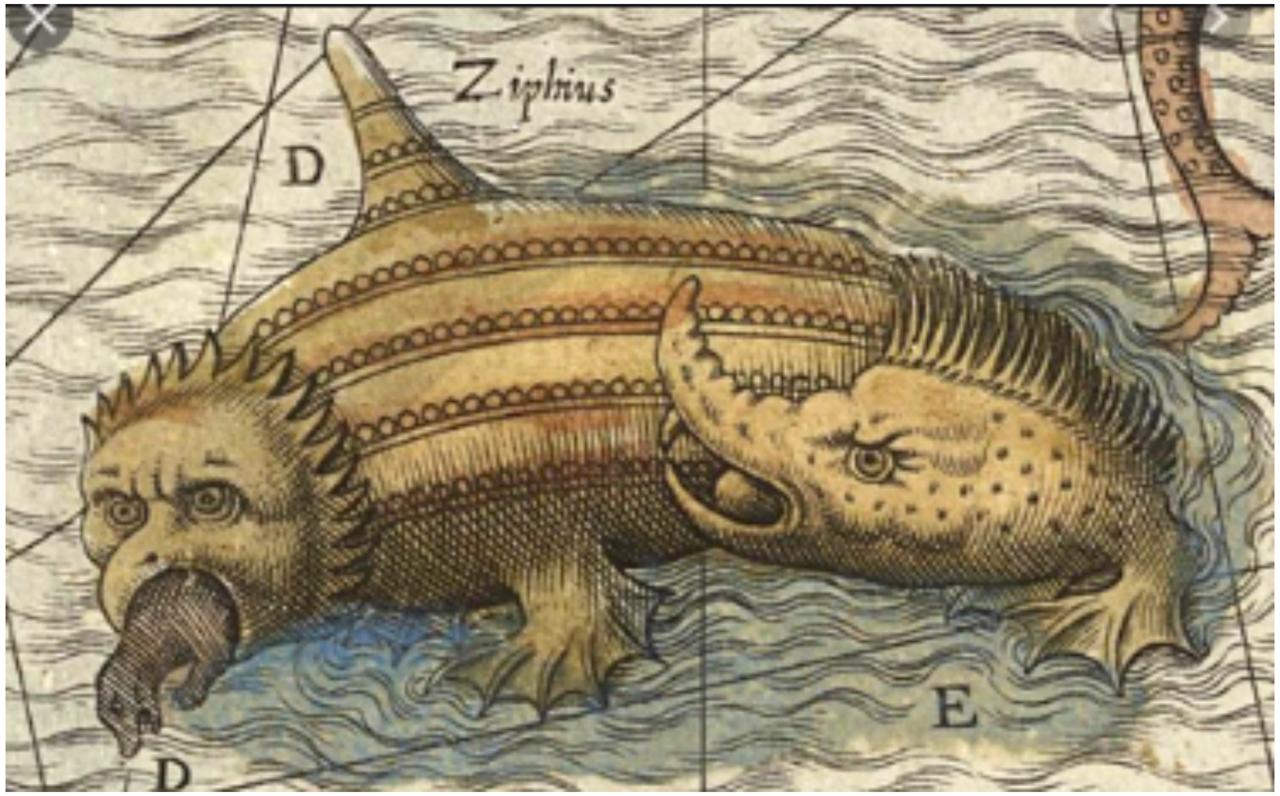


thresholds: $\bar{D}^*K^*$, $\bar{D}_1K$ $\bar{D}_1K^*$

resonances: 2849 - i 23 MeV 3173 - i 236 MeV

$\bar{D}^*K^* - \bar{D}_1K$ $\bar{D}_1K^*$

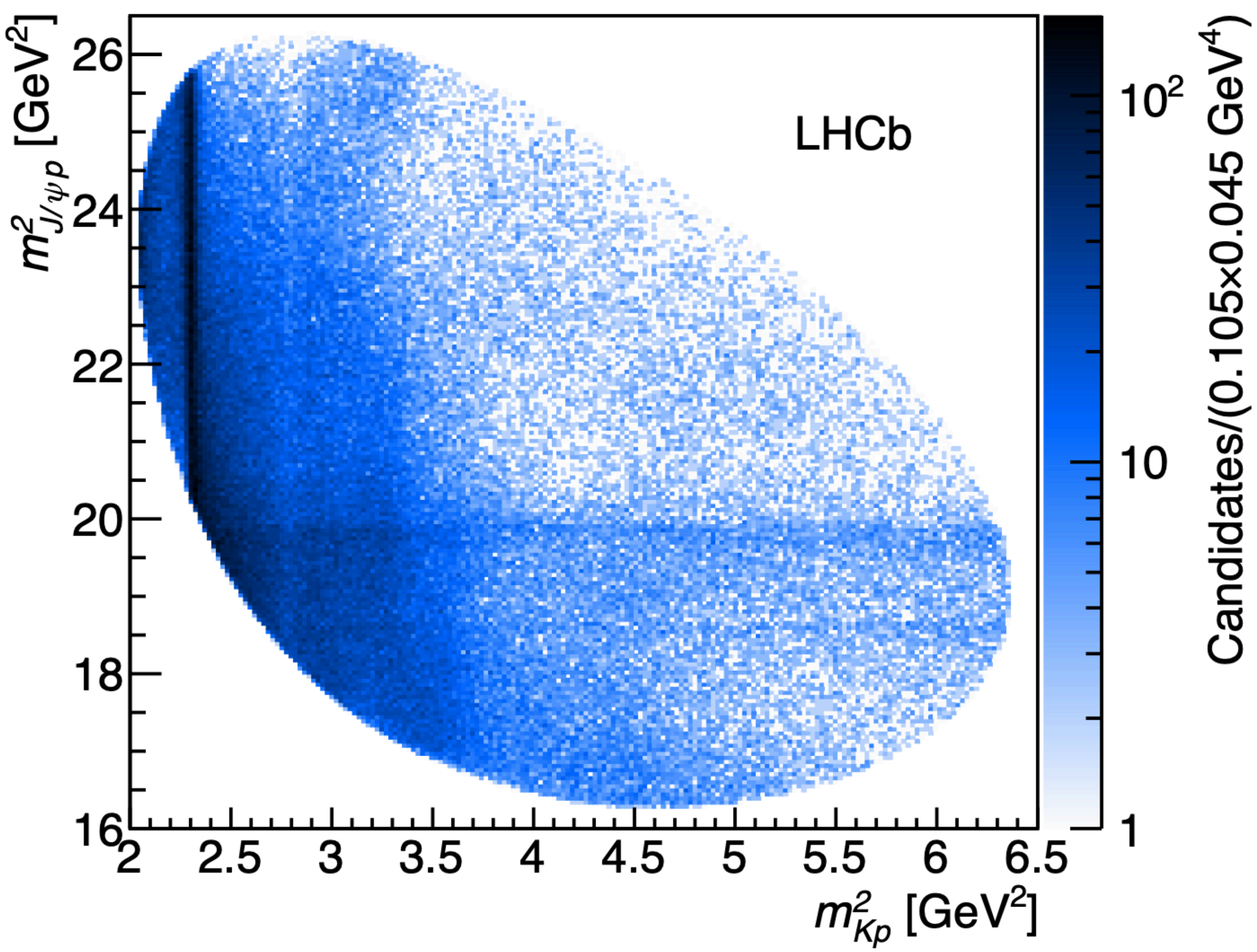
Pc(4457)
Pc(4440)
Pc(4312)

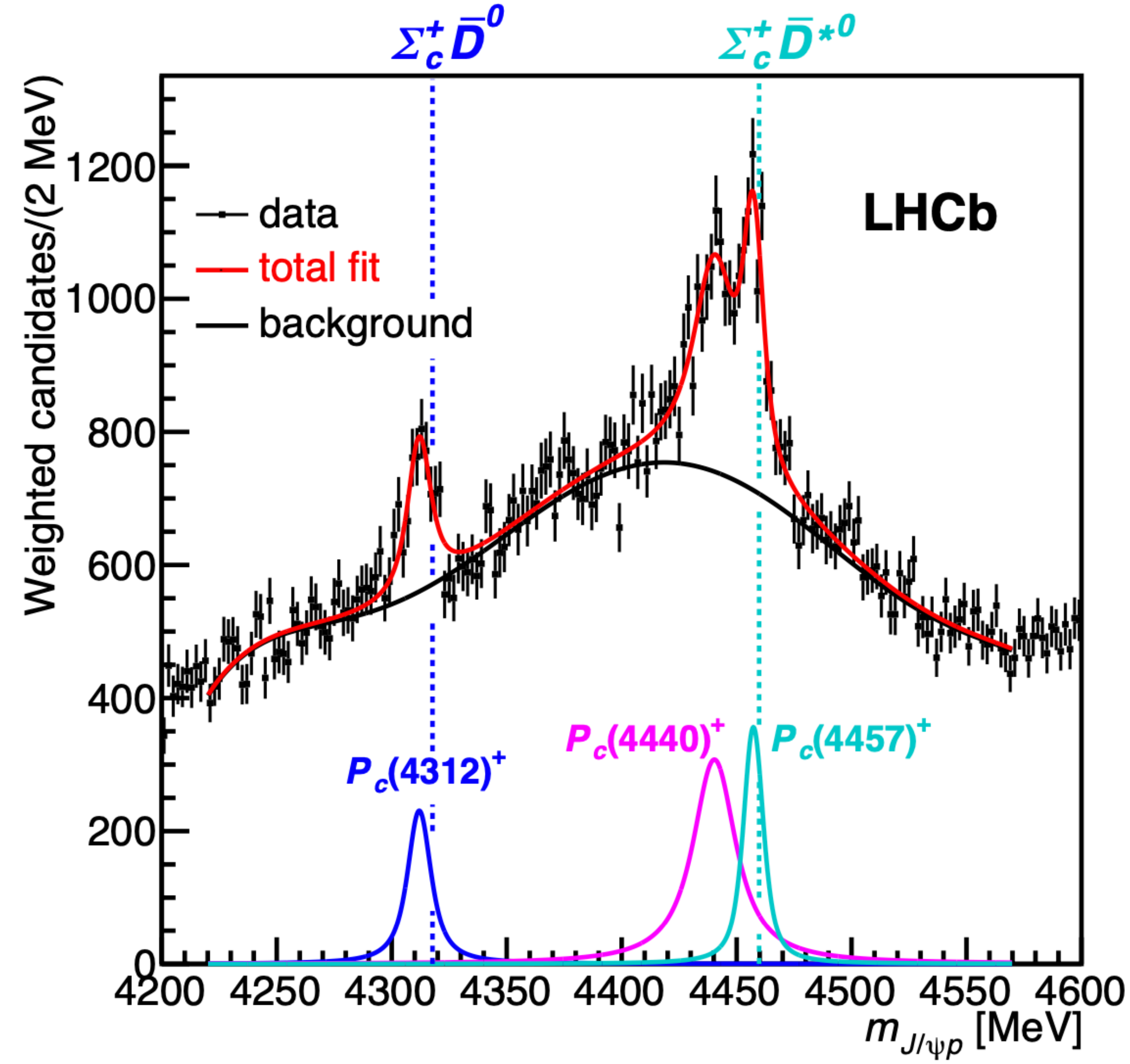


T.J. Burns and E.S. Swanson; writing now

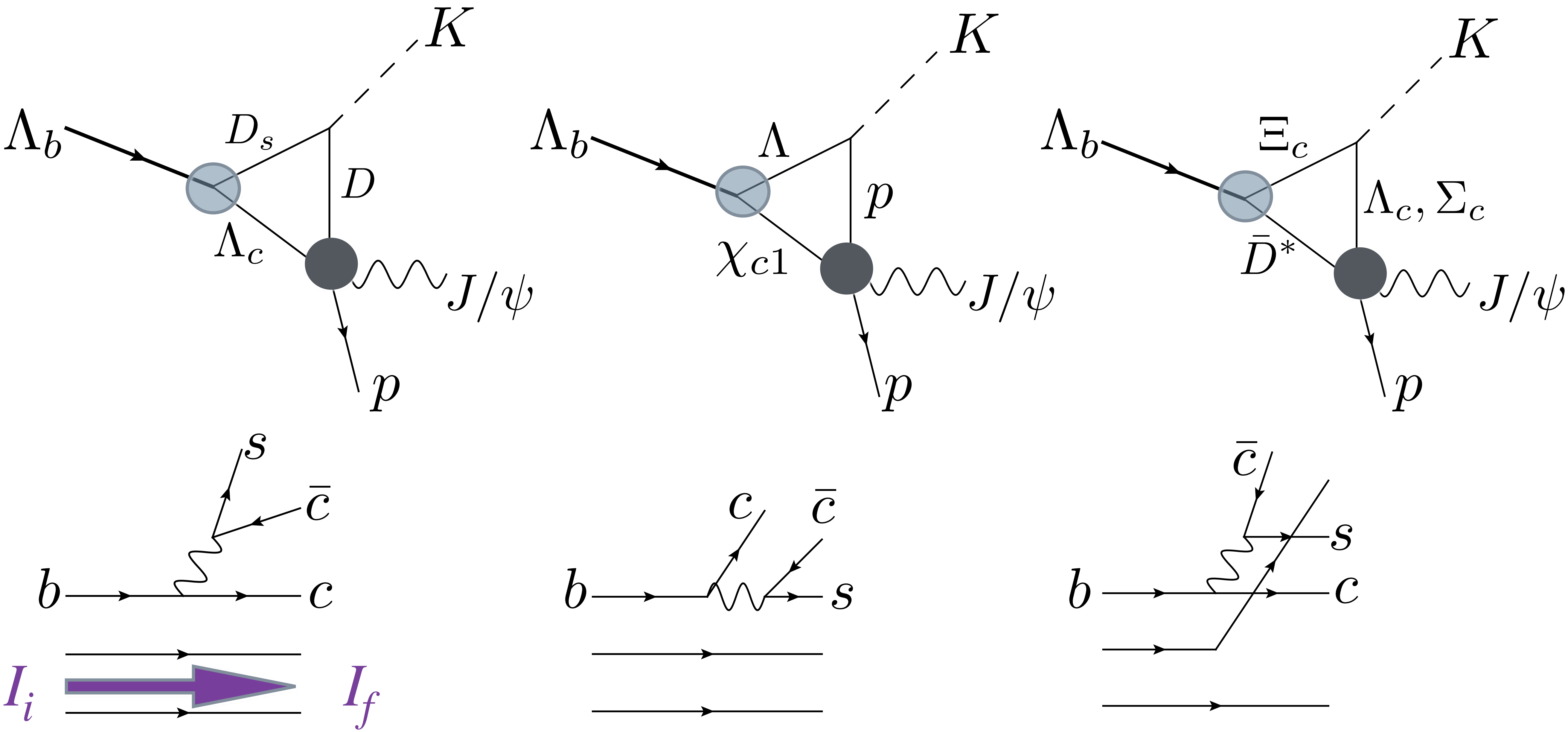
LHCb Discovery

$$\Lambda_b^0 \to J/\psi p K^-$$





Decay Model



1/N 1/N

Decay Model

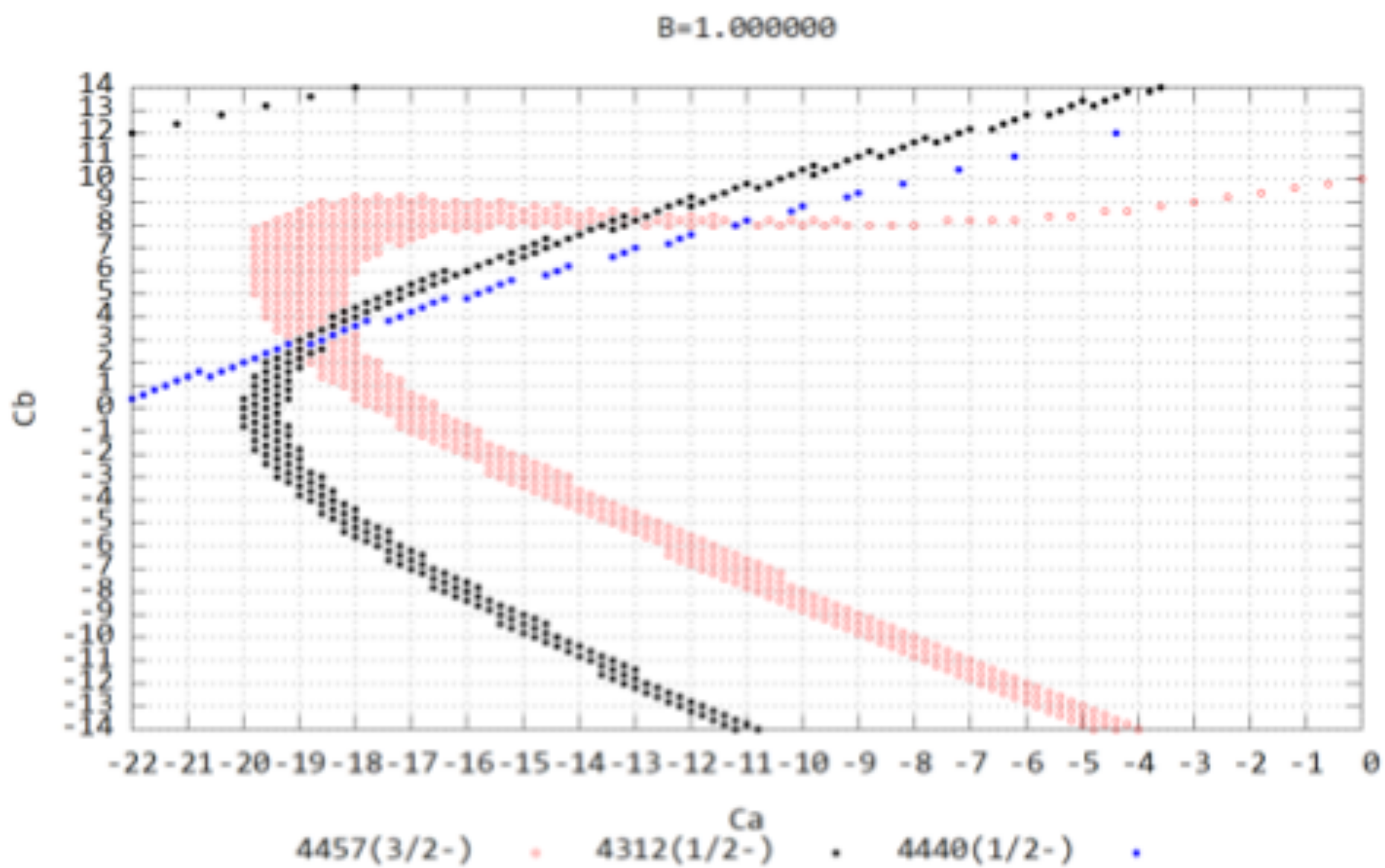
$1/2^-$	$D_s^*\Lambda_c D$	$D_s^*\Lambda_c D^*$	$\Sigma_c D$	$\Sigma_c D^*$	$\Sigma_c^* D^*$	$J/\psi N$
$D_s^*\Lambda_c D$	A	0	0	$\sqrt{3}B$	$\sqrt{6}B$	$\frac{\sqrt{3}}{2}D$
$D_s^*\Lambda_c D^*$		A	$\sqrt{3}B$	$-2B$	$\sqrt{2}B$	$-\frac{D}{2}$
$\Sigma_c D$			C_a	$\frac{2}{\sqrt{3}}C_b$	$-\sqrt{2/3}C_b$	$-\frac{1}{2\sqrt{3}}E$
$\Sigma_c D^*$				$C_a - \frac{4}{3}C_b$	$-\frac{\sqrt{2}}{3}C_b$	$\frac{5}{6}E$
$\Sigma_c^* D^*$					$C_a - \frac{5}{3}C_b$	$\frac{\sqrt{2}}{3}E$
$J/\psi N$						0

$3/2^-$	$D_s^*\Lambda_c D^*$	$\Sigma_c^* D$	$\Sigma_c D^*$	$\Sigma_c^* D^*$	$J/\psi N$
$D_s^*\Lambda_c D^*$	A	$-\sqrt{3}B$	B	$\sqrt{5}B$	D
$\Sigma_c^* D$		C_a	$\frac{C_b}{\sqrt{3}}$	$\sqrt{\frac{5}{3}}C_b$	$-\frac{E}{\sqrt{3}}$
$\Sigma_c D^*$			$C_a + \frac{2}{3}C_b$	$-\frac{\sqrt{5}}{3}C_b$	$\frac{E}{3}$
$\Sigma_c^* D^*$				$C_a - \frac{2}{3}C_b$	$\frac{\sqrt{5}}{3}E$
$J/\psi N$					0

$1/2^+$	$D_s^*\Lambda_c' D$	$D_s^*\Lambda_c' D^*$	$\Sigma_c D(P)$	$\Sigma_c D^*(P)$	$J/\psi N(P)$
$D_s^*\Lambda_c' D$	f_a	$2f_b/\sqrt{3}$	–	–	G
$D_s^*\Lambda_c' D^*$		$f_a - \frac{4}{3}f_b$	–	–	H
$\Sigma_c D$			–	–	
$\Sigma_c D^*$				–	
$J/\psi N$					0

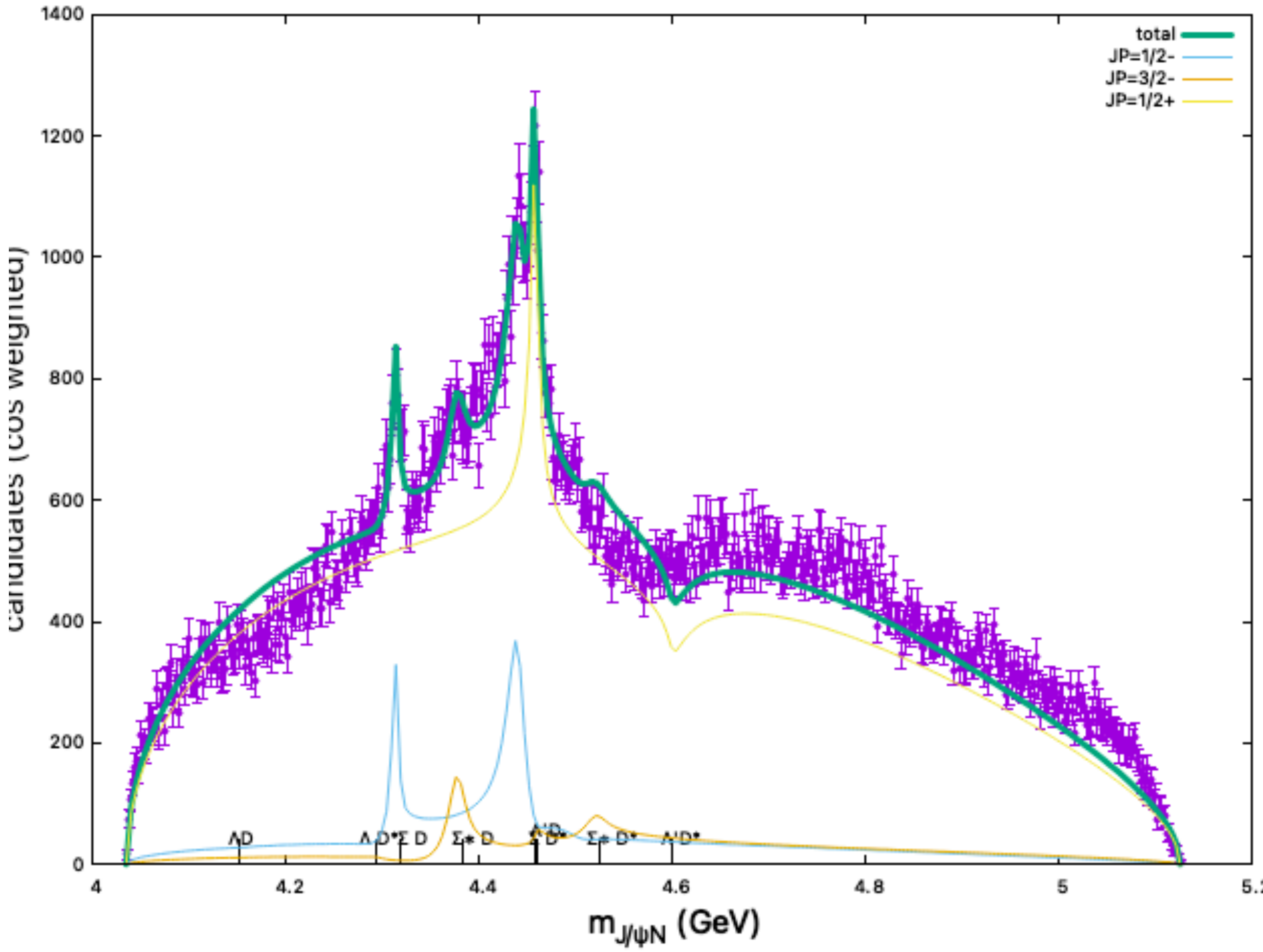
Decay Model

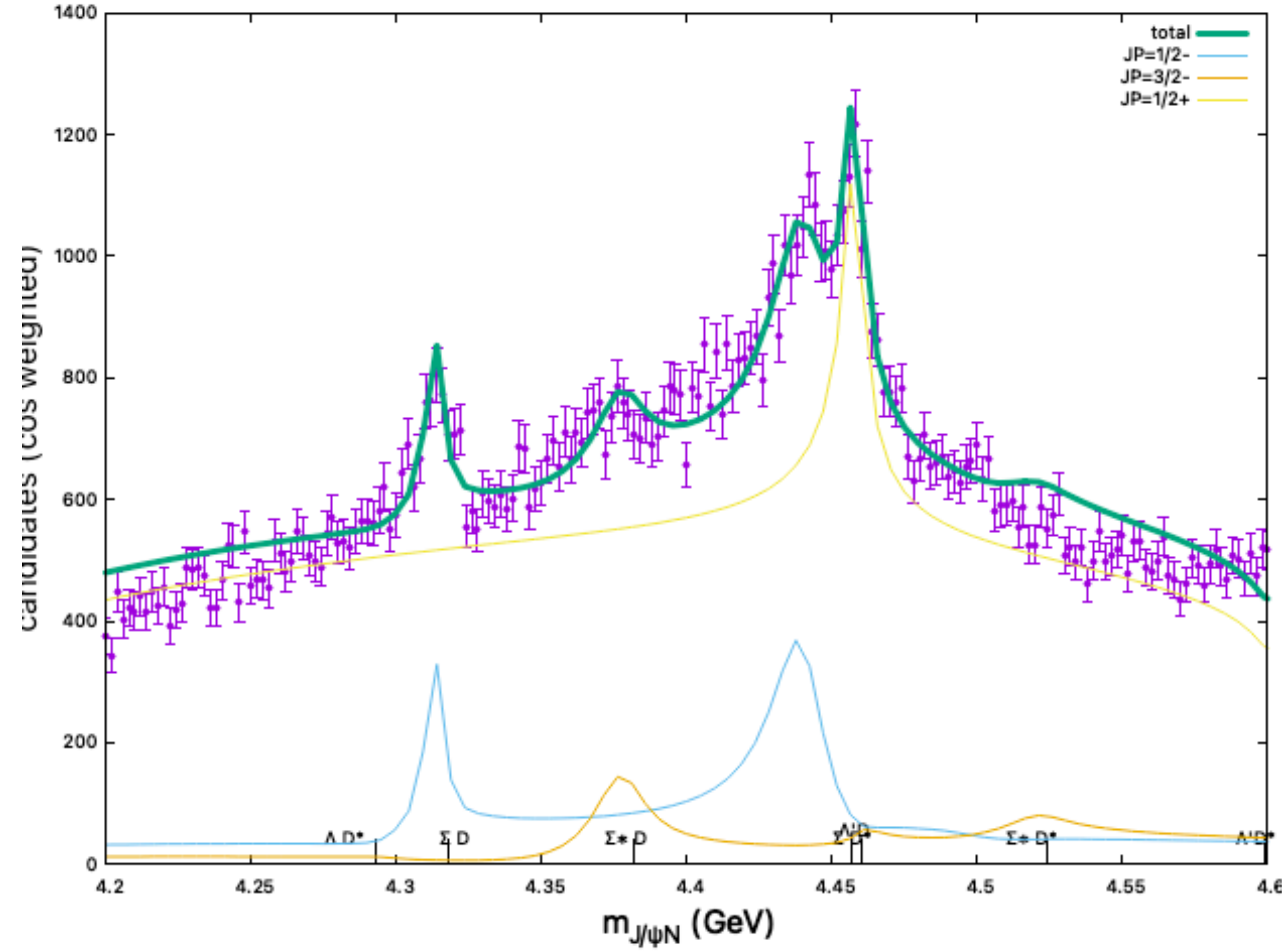
	SD	S*D	SD*		S*D*			L'D
	1/2-	3/2-	1/2-	3/2-	1/2-	3/2-	5/2-	1/2+
	Ca	Ca	Ca-4/3Cb	Ca+2/3Cb	Ca-5/3Cb	Ca-2/3Cb	Ca+Cb	
Case 1	4312	4380	4440	4457	(x)	x		
Case 2	4312	4380	4457	4440		x	x	
Case 3	4312	4380		4440			x	4457
Case 4	4312	4380	4440		(x)	x		4457



Results

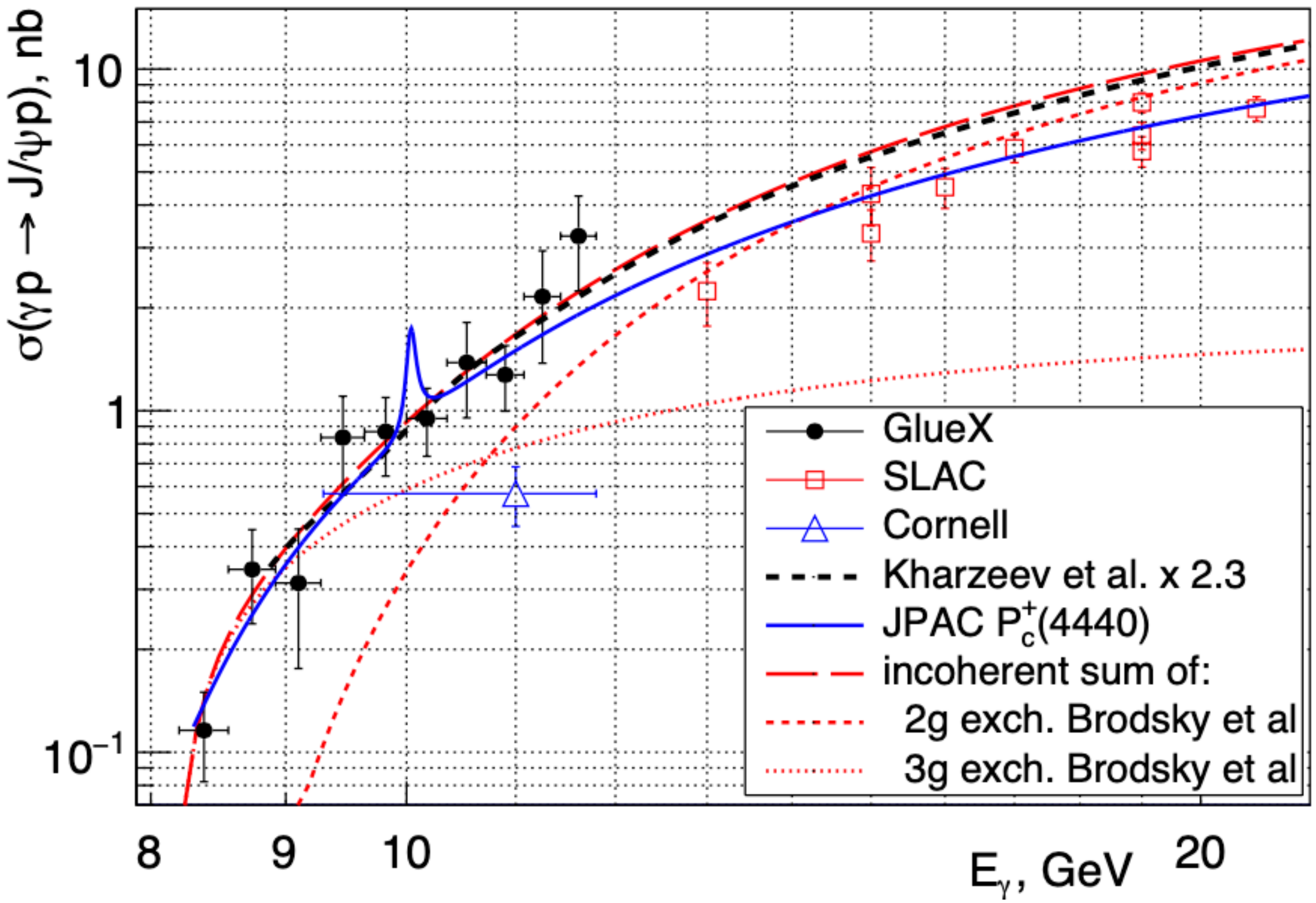
case 4 (others do not do well)





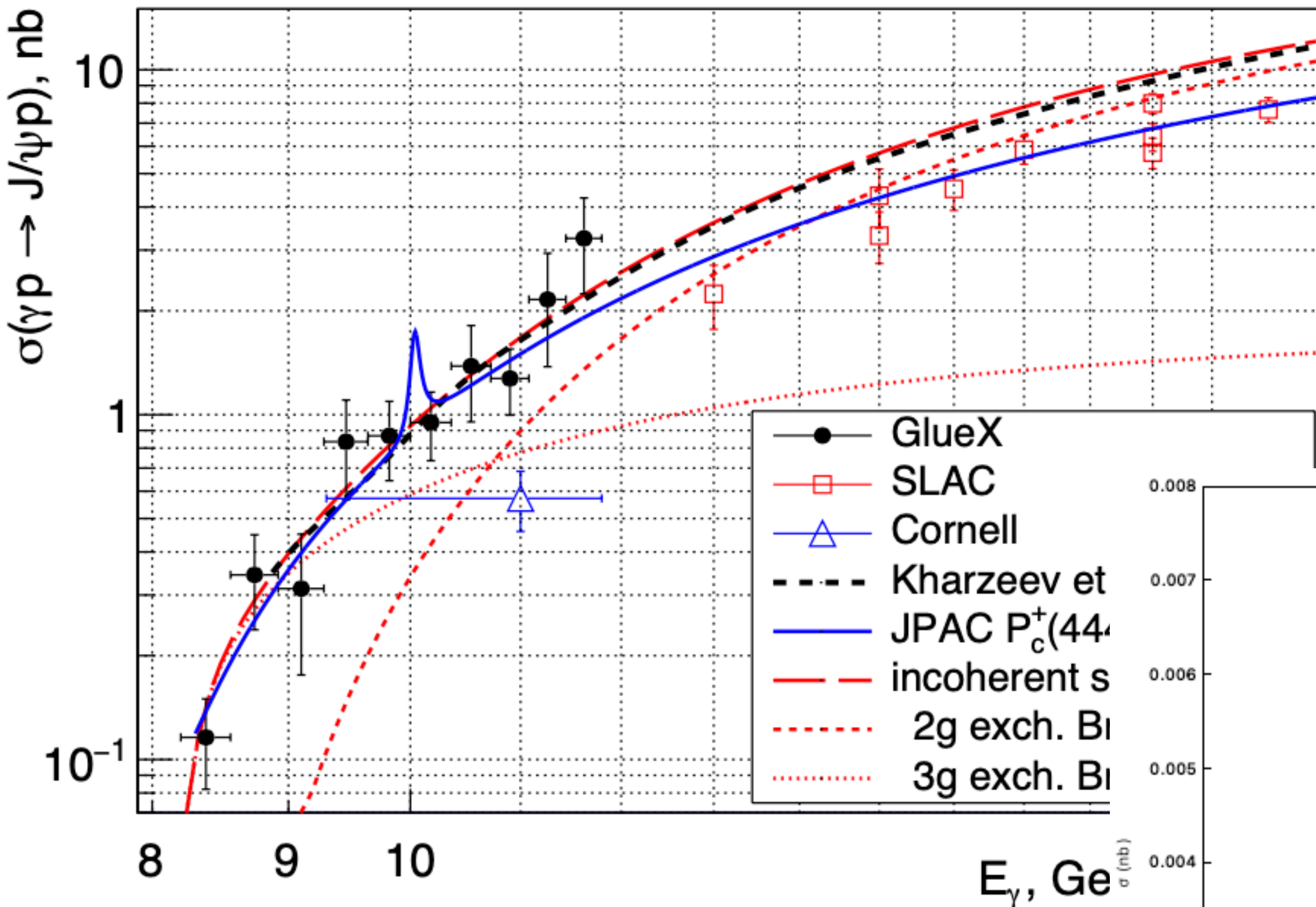
Results

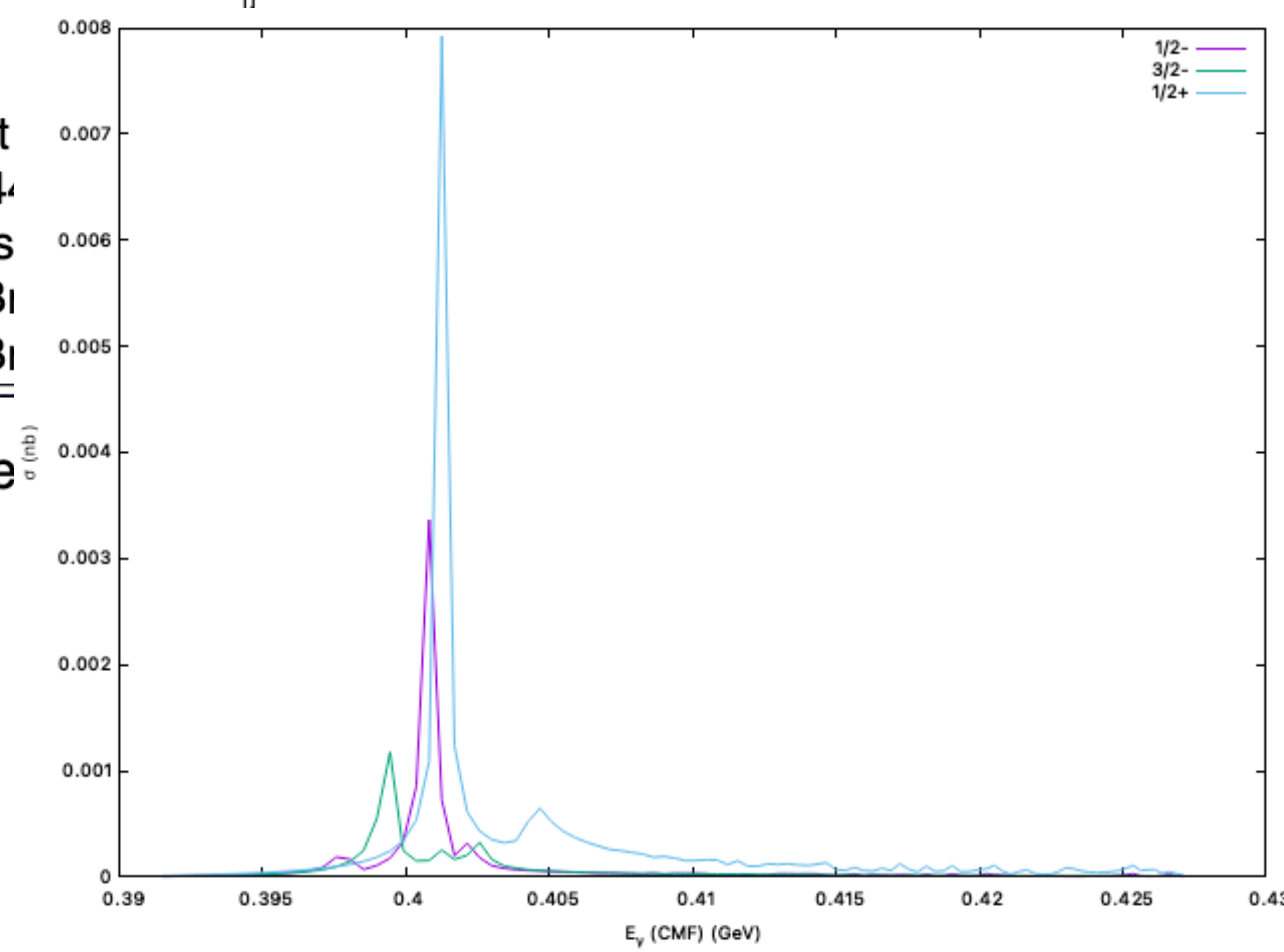
JLab non-observation



Results

JLab non-observation





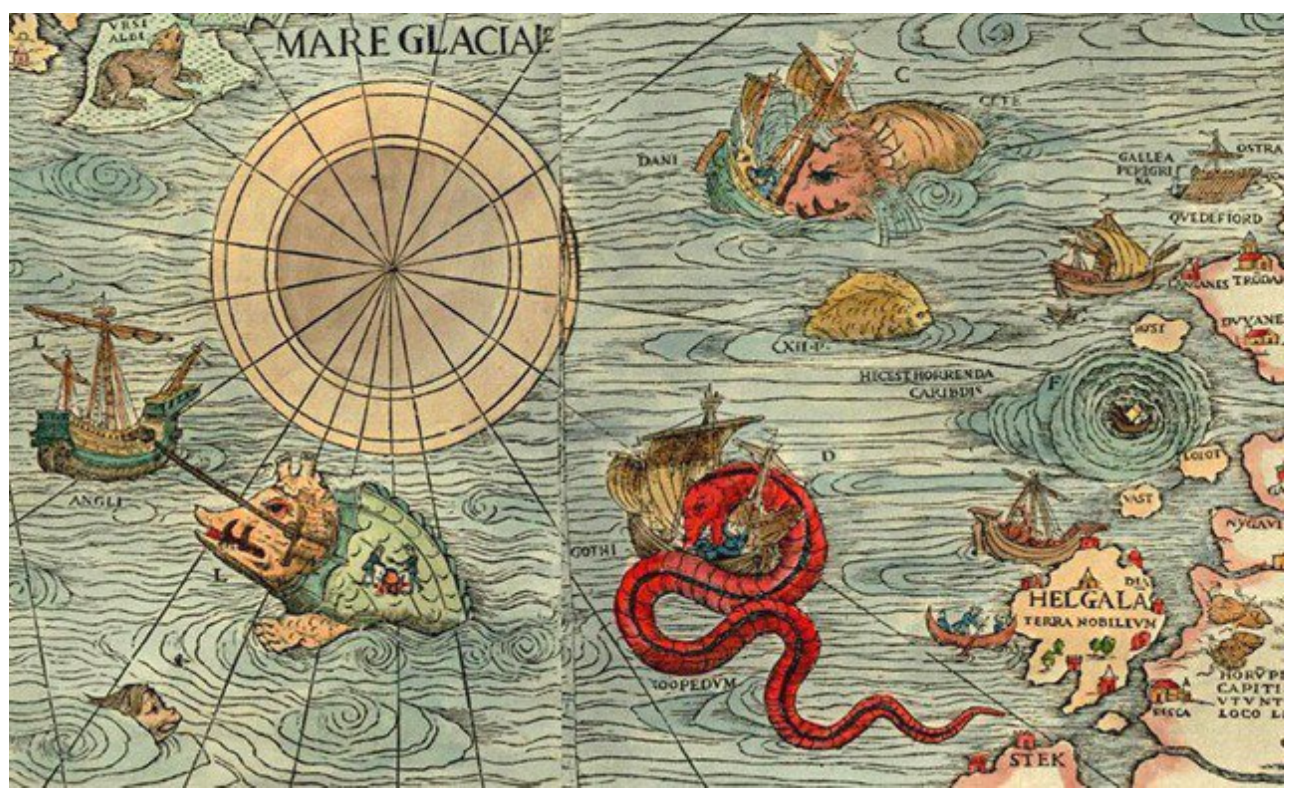
JLab bound is evaded by the production triangle!

X(4150;2-) X(4140;1+) Zcs(4000;1+)

X(4630,1-) X(4274,1+) Zcs(4220,1+)

X(4500,0+) X(4685,1+)

X(4700,0+)



T.J. Burns and E.S. Swanson; in progress

LHCb Discovery

$B^+ \to J/\psi\phi K^+$

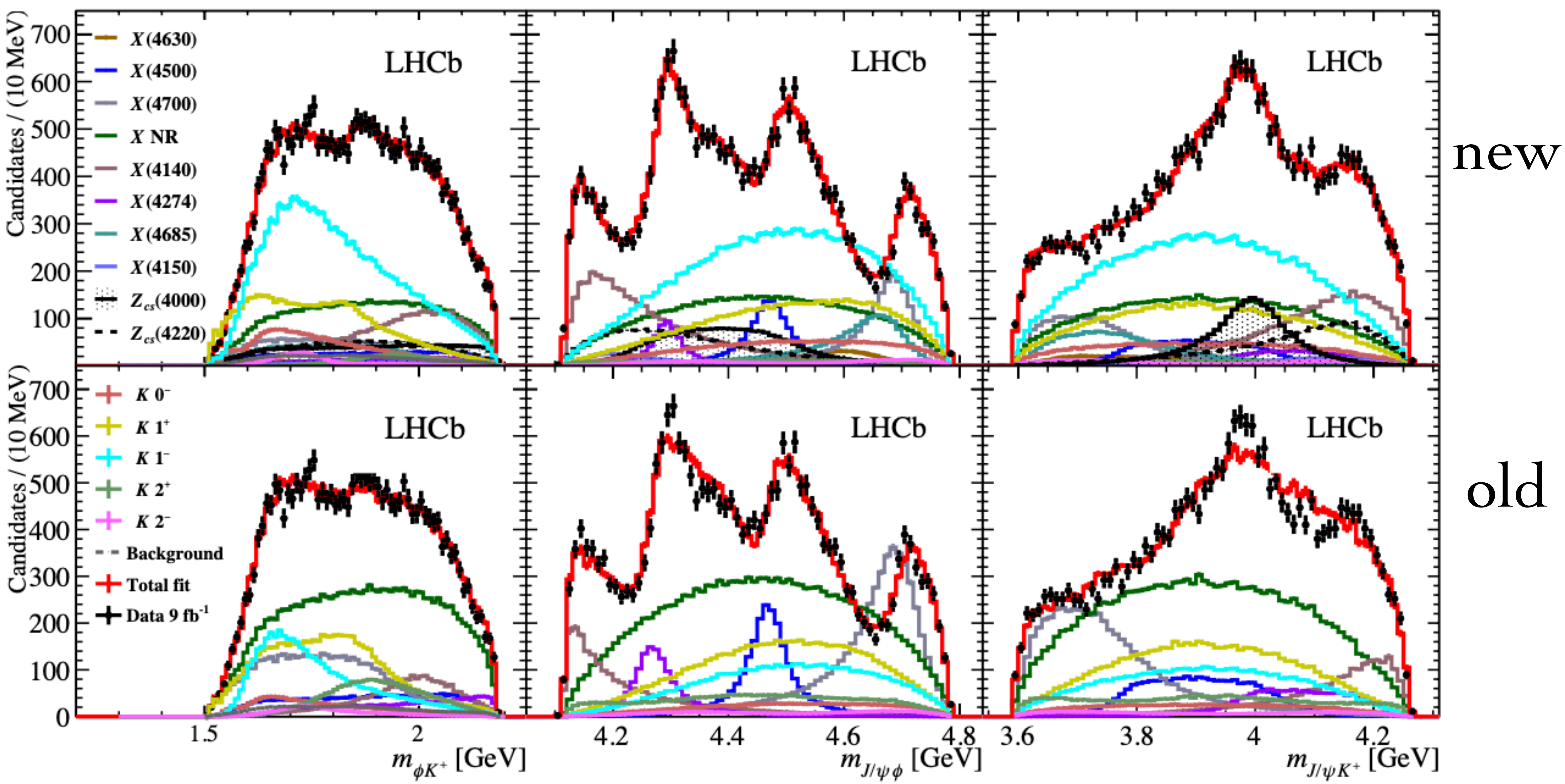
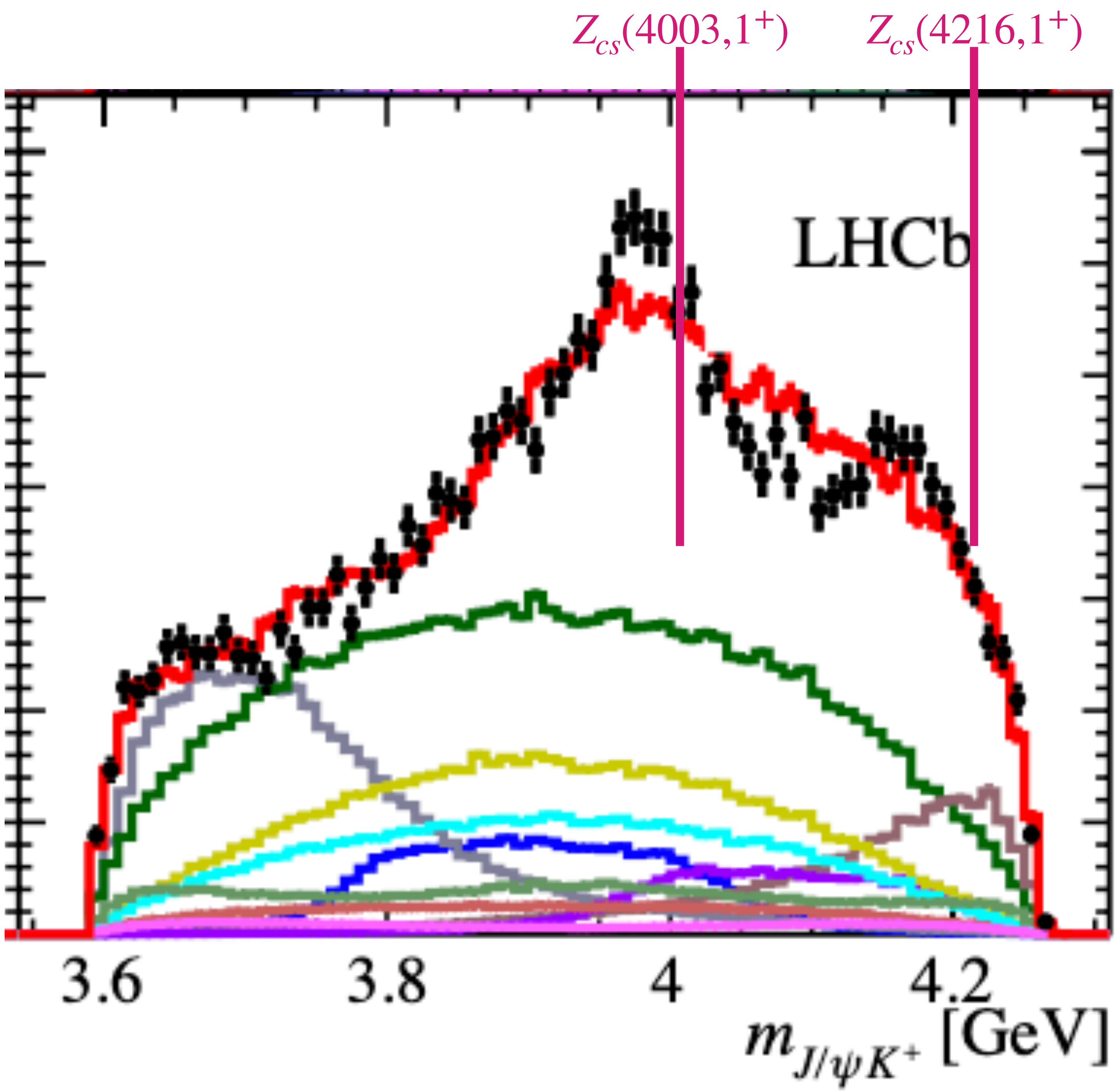
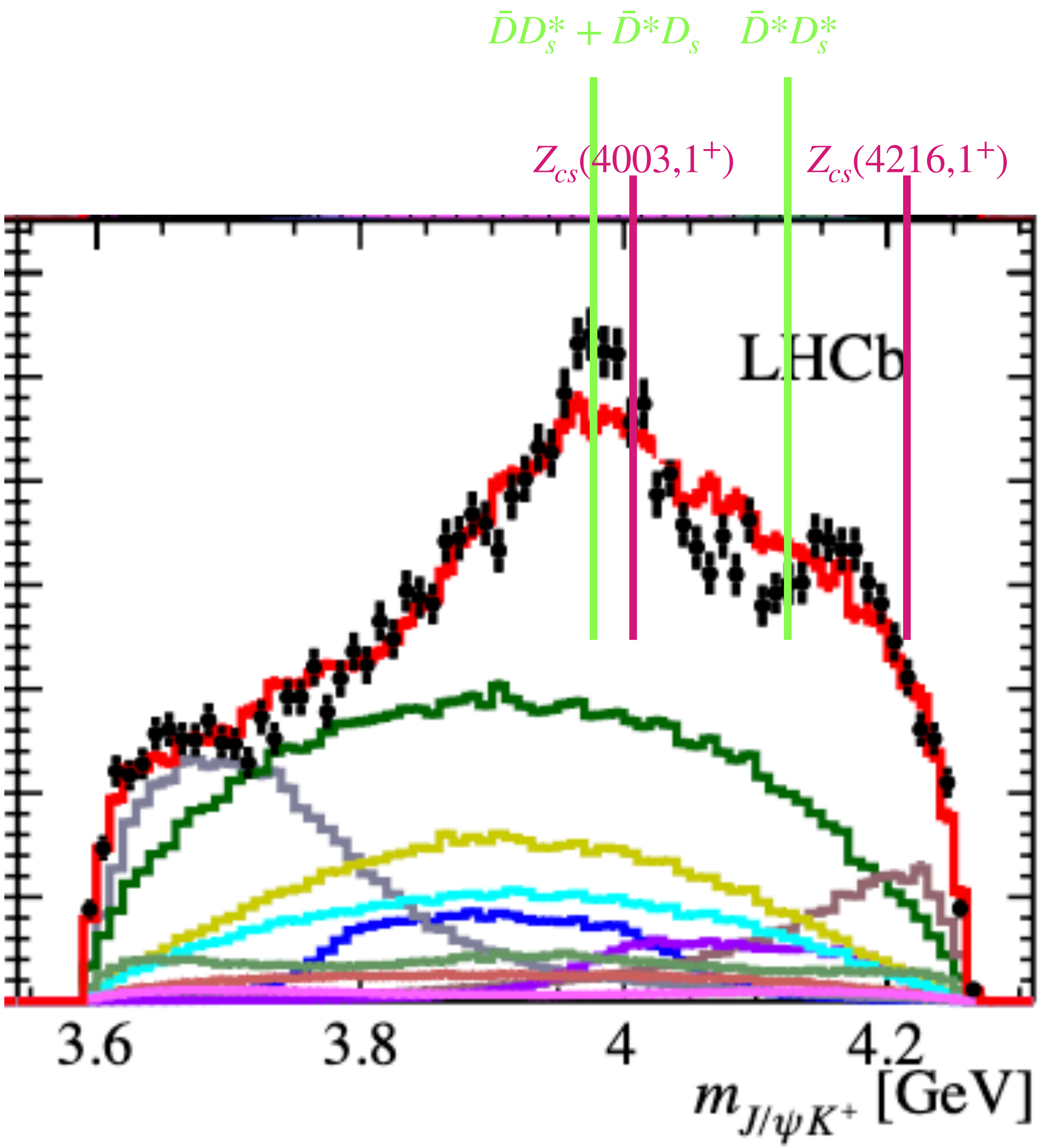


Figure 3: Distributions of ϕK^+ (left), $J/\psi\phi$ (middle) and $J/\psi K^+$ (right) invariant masses for the $B^+ \to J/\psi\phi K^+$ candidates (black data points) compared with the fit results (red solid lines) of the default model (top row) and the Run 1 model (bottom row).

Zcs Thresholds



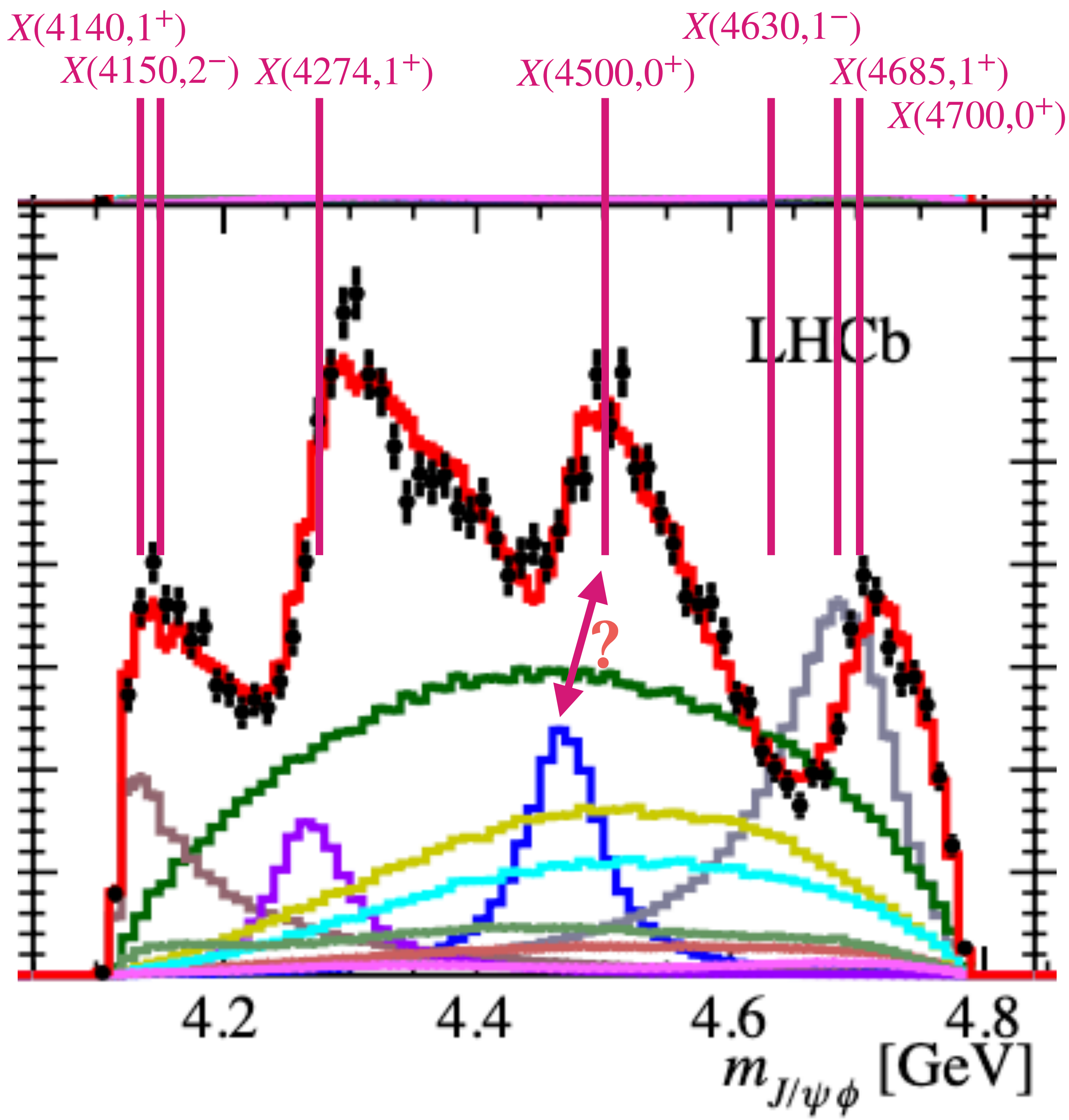
Zcs Thresholds



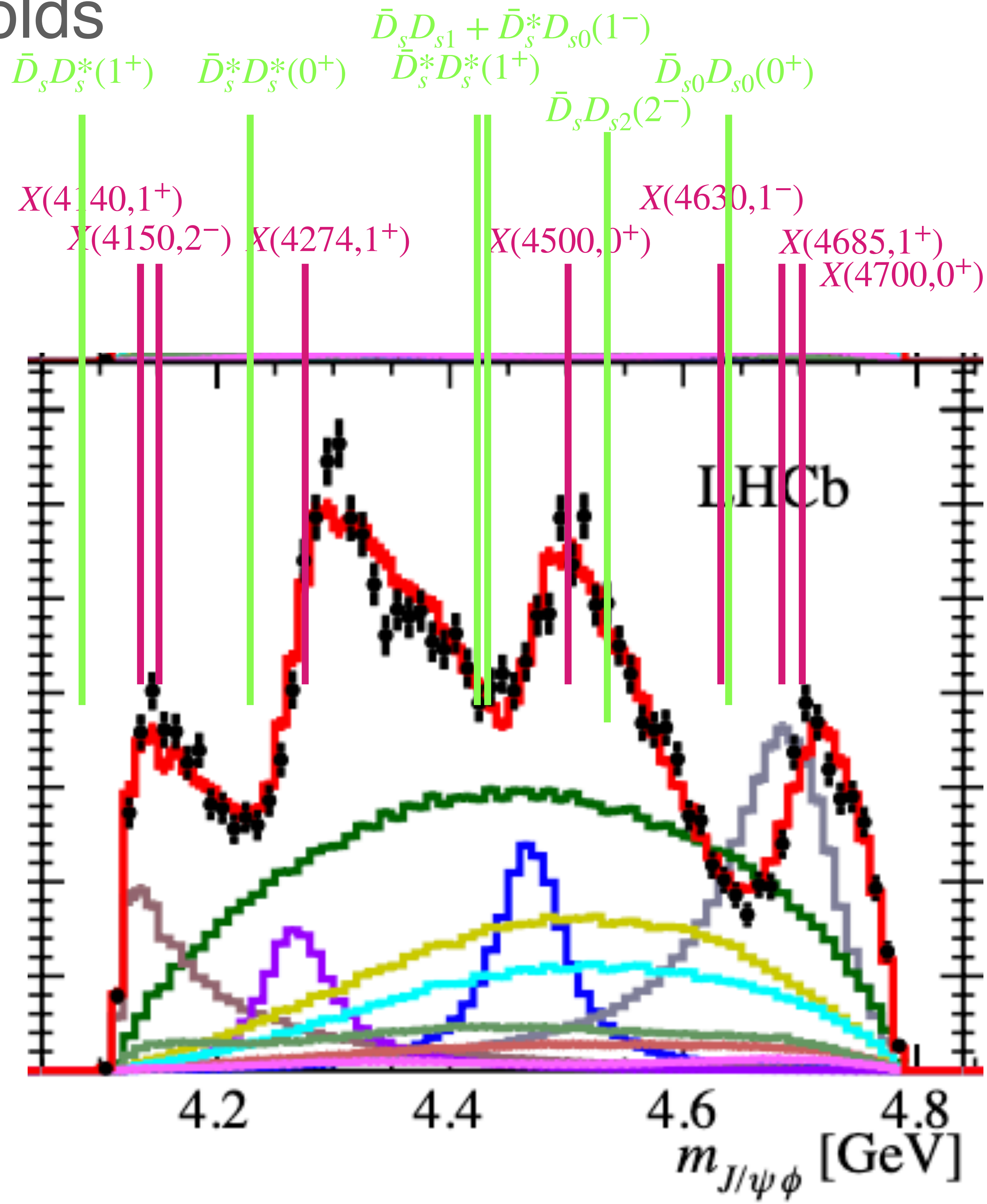
1+ psi-K S-waves:

DDs* 3981
D*Ds 3978
D*Ds* 4122
D0Ds1 4759
D1Ds0 4738
D1Ds1 4880
D1Ds1' 4956
D1Ds2 4990
D2Ds1 4920
D2Ds1' 4996
D2Ds2 5030

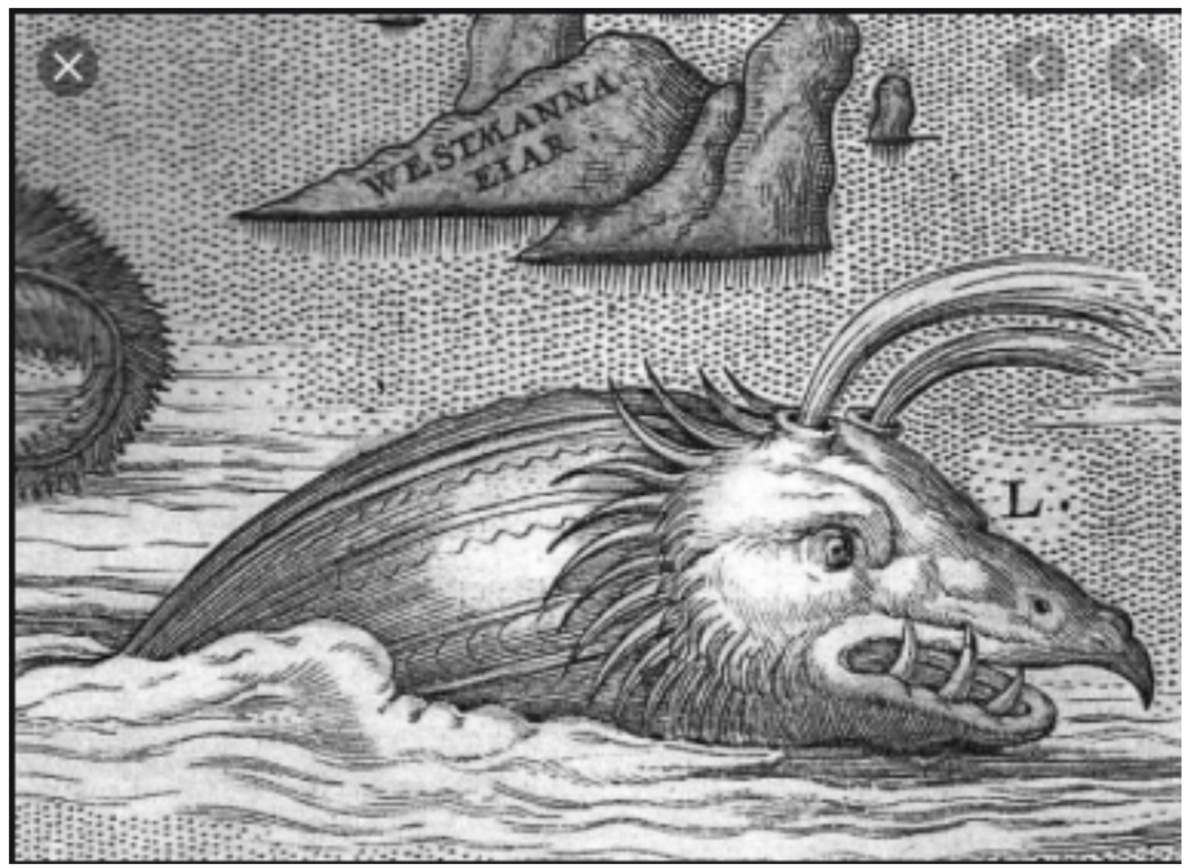
X Thresholds



X Thresholds



Conclusions & Observations



Conclusions and Observations

- "Triangles" do a good job of 'explaining' the X1, although a weakly bound $\bar{D}^*K^* - \bar{D}_1K$ resonance explanation is slightly preferred.

- "Triangles" explain 'kinks' at $\Lambda_c D$, $\Lambda_c' D^*$ and the 4457 peak ($\Lambda_c' D$); weakly bound $\Sigma_c D$ resonances are required for the 4312 ($\Sigma_c D$), 4380 ($\Sigma_c^* D$), & 4440 ($\Sigma_c^* D^*$) . Triangle-FSI cooperation evades JLab bounds.

- "Triangles" and weakly bound states appear to have little to do with the $J/\psi - \phi$ and $J/\psi - K$ states.

~thank you~

$J/\psi - \phi$ S-waves

0+:
DsDs 3936
Ds*Ds* 4224
Ds0Ds0 4634
Ds1Ds1 4918
Ds1Ds1’ 4994
Ds1’Ds1’ 5070
Ds2Ds2 5138

1-:
DsDs1 4427
DsDs1’ 4503
Ds*Ds0 4429
Ds*Ds1 4571
Ds*Ds1’ 4647
Ds*Ds2 4681

1+:
DsDs* 4080
Ds*Ds* 4424
Ds1Ds1 4918
Ds1Ds1’ 4994
Ds1’Ds1’ 5070
Ds1Ds2 5028
Ds1’Ds2 5104
Ds2Ds2 5138

2-:
DsDs2 4537
Ds1Ds* 4571
Ds1’Ds* 4647
Ds*Ds2 4681

$X(2^-)$			
$X(4150)$	4.8 (8.7)	$4146 \pm 18 \pm 33$	$135 \pm 28\,^{+\,59}_{-\,30}$
$X(1^-)$			
$X(4630)$	5.5 (5.7)	$4626 \pm 16\,^{+\,18}_{-\,110}$	$174 \pm 27\,^{+\,134}_{-\,73}$
All $X(0^+)$			
$X(4500)$	20 (20)	$4474 \pm 3 \pm 3$	$77 \pm 6\,^{+\,10}_{-\,8}$
$X(4700)$	17 (18)	$4694 \pm 4\,^{+\,16}_{-\,3}$	$87 \pm 8\,^{+\,16}_{-\,6}$
$\mathrm{NR}_{J/\psi\phi}$	4.8 (5.7)		
All $X(1^+)$			
$X(4140)$	13 (16)	$4118 \pm 11\,^{+\,19}_{-\,36}$	$162 \pm 21\,^{+\,24}_{-\,49}$
$X(4274)$	18 (18)	$4294 \pm 4\,^{+\,3}_{-\,6}$	$53 \pm 5 \pm 5$
$X(4685)$	15 (15)	$4684 \pm 7\,^{+\,13}_{-\,16}$	$126 \pm 15\,^{+\,37}_{-\,41}$
All $Z_{cs}(1^+)$			
$Z_{cs}(4000)$	15 (16)	$4003 \pm 6\,^{+\,4}_{-\,14}$	$131 \pm 15 \pm 26$
$Z_{cs}(4220)$	5.9 (8.4)	$4216 \pm 24\,^{+\,43}_{-\,30}$	$233 \pm 52\,^{+\,97}_{-\,73}$