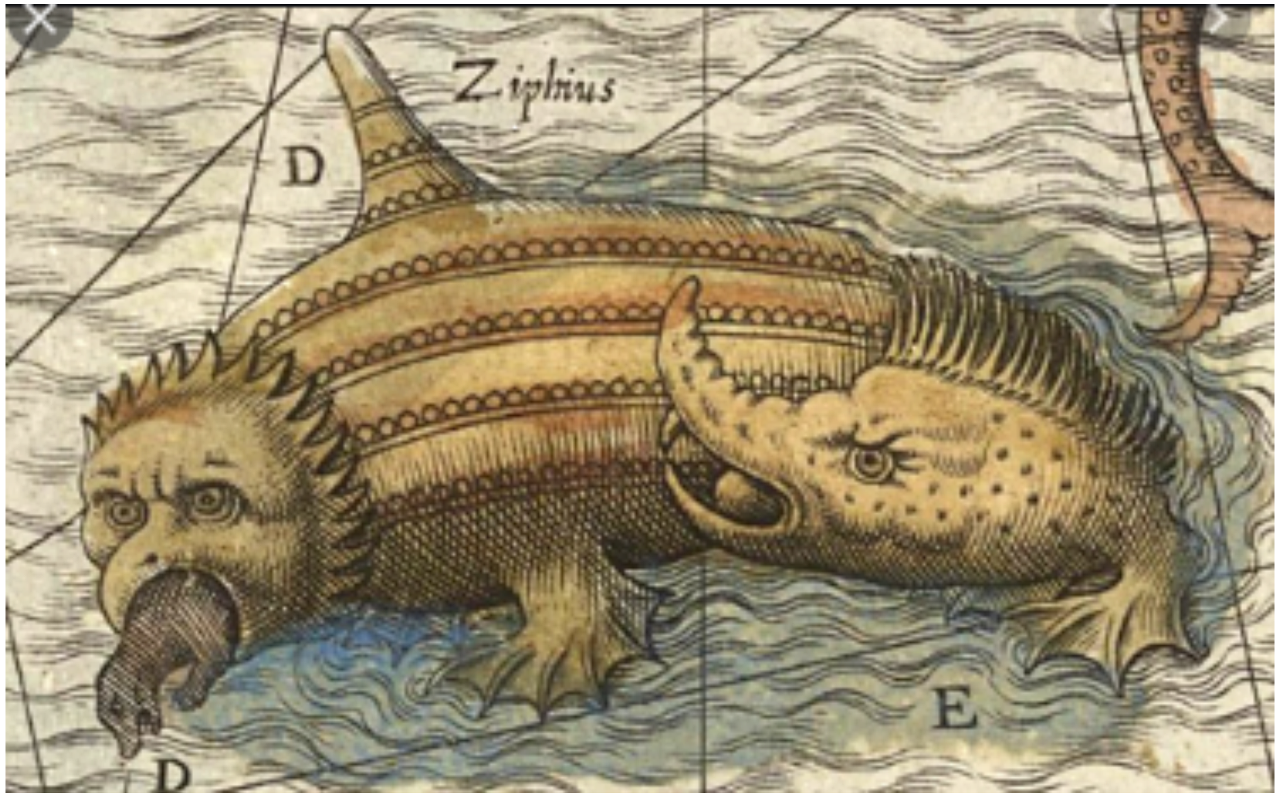
[248/146]

July, 2021

Interpreting the Pentaquark States

Eric Swanson

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



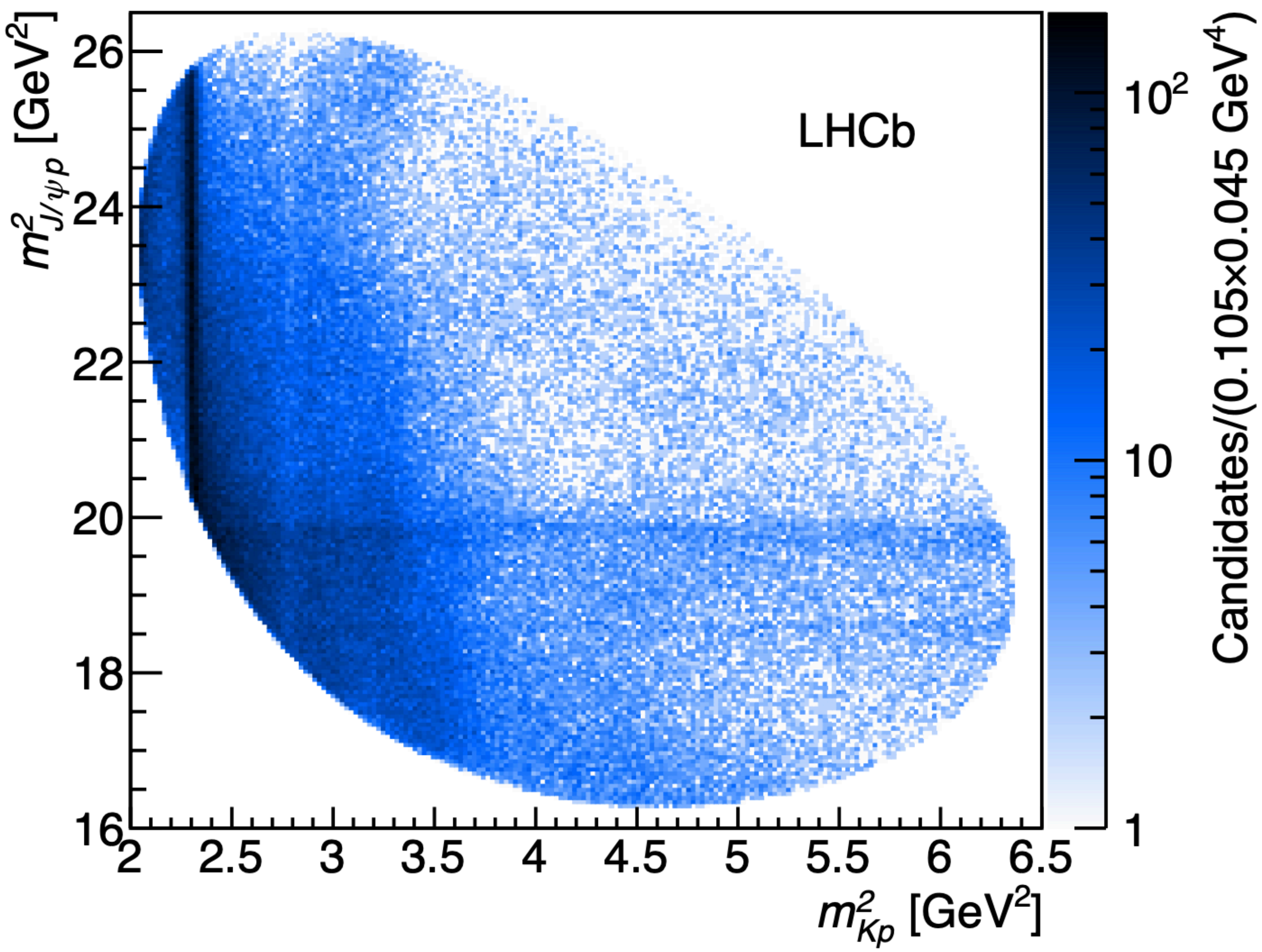
T.J. Burns and E.S. Swanson; writing now

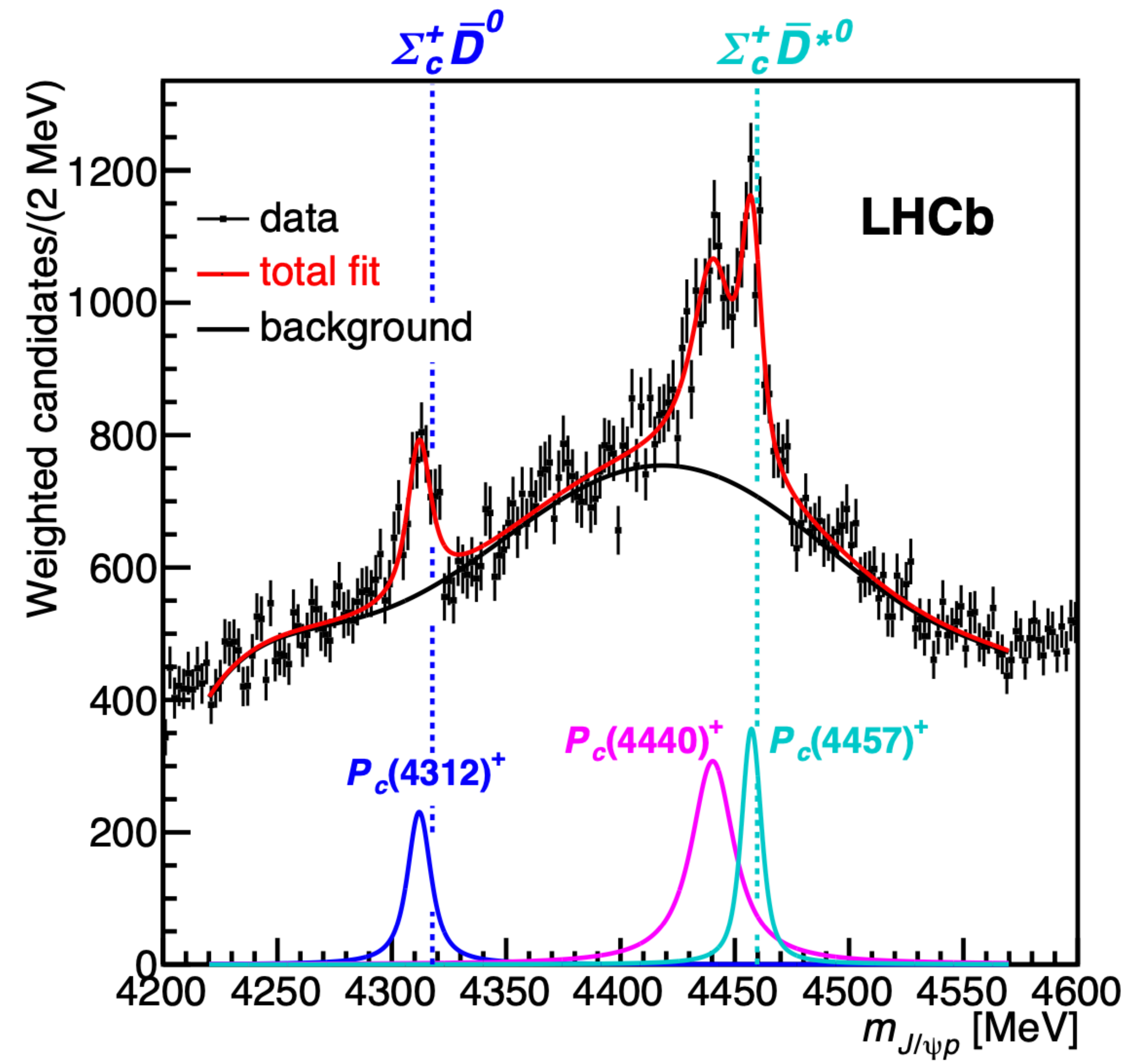
"Kinematic Singularity and Resonance Interpretations of the X(2900)"
T.J. Burns and E.S. Swanson; arXiv:2008.12838

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

LHCb Discovery

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

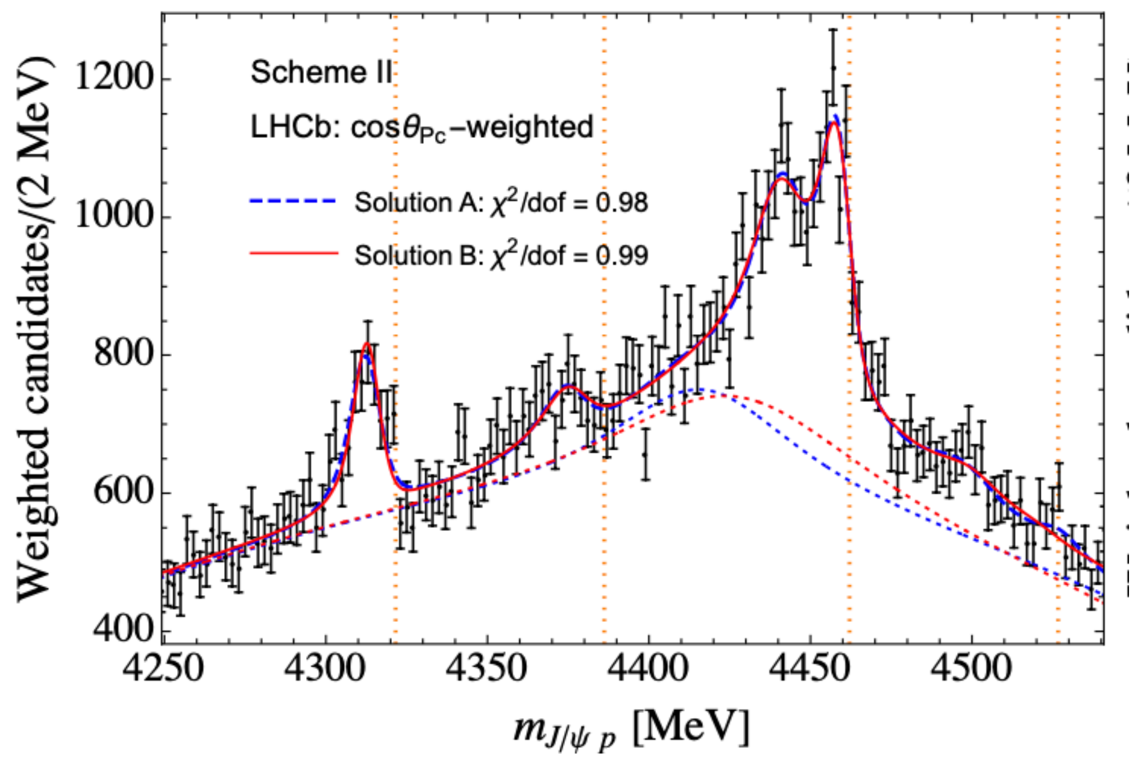




A Recent Molecular Model

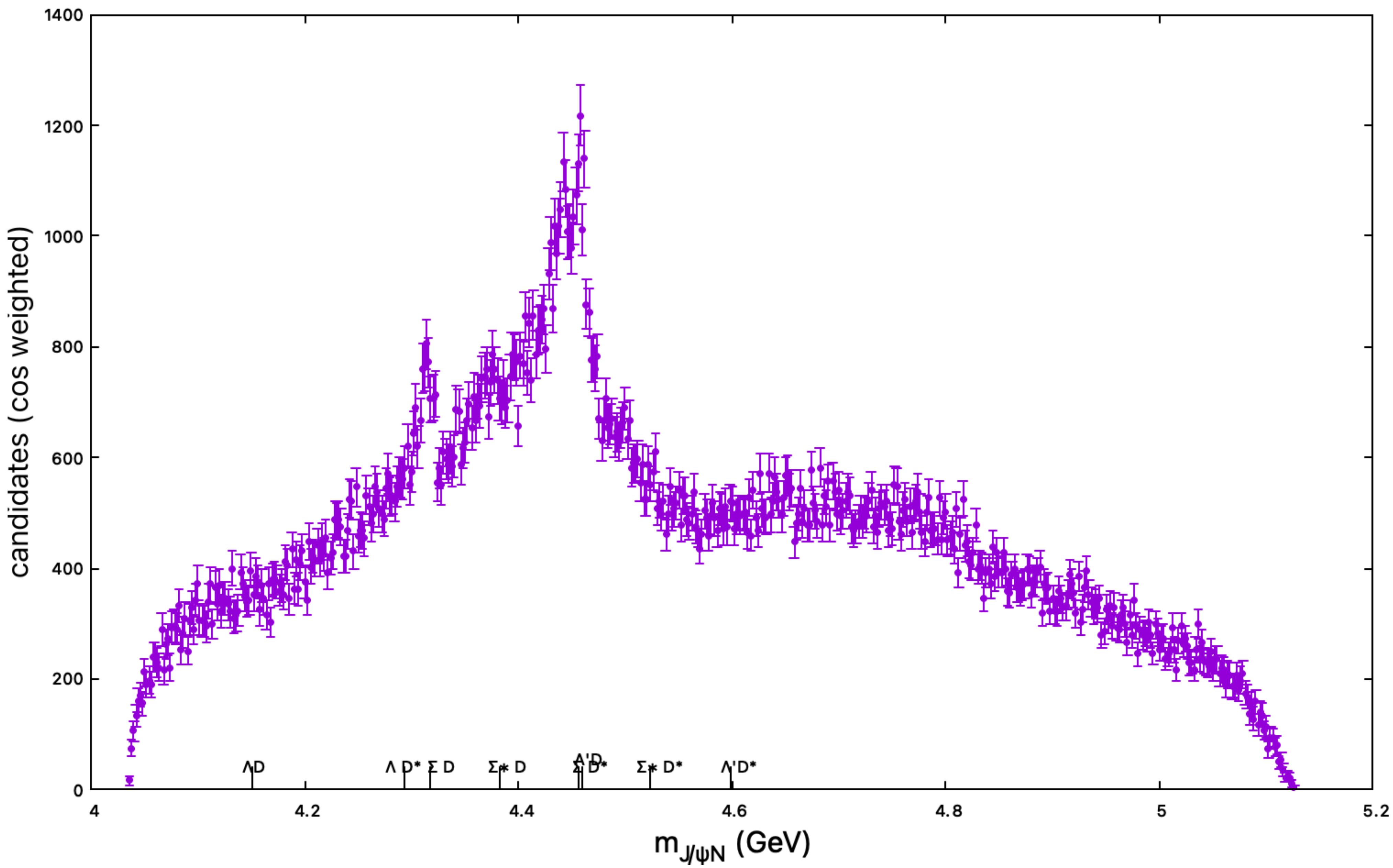
Du *et al.*, arXiv:2102.07159

			solution	A		solution	B	
	DC ([MeV])	RS	J^P	Pole [MeV]	$g_{\rm DC}$	J^P	Pole [MeV]	$g_{\rm DC}$
$P_c(4312)$	$\Sigma_c\bar{D}$ (4321.6)	I	$\frac{1}{2}^-$	$4314(1)-4(1)i$	$2.6(1)+0.4(2)i$	$\frac{1}{2}^-$	$4312(2)-4(2)i$	$2.9(1)+0.4(2)i$
$P_c(4380)$	$\Sigma_c^*\bar{D}$ (4386.2)	II	$\frac{3}{2}^-$	$4377(1)-7(1)i$	$2.8(1)+0.1(1)i$	$\frac{3}{2}^-$	$4375(2)-6(1)i$	$3.0(1)+0.1(1)i$
$P_c(4440)$	$\Sigma_c\bar{D}^*$ (4462.1)	III	$\frac{1}{2}^-$	$4440(1)-9(2)i$	$3.7(2)+0.6(1)i$	$\frac{3}{2}^-$	$4441(3)-5(2)i$	$3.6(1)+0.3(1)i$
$P_c(4457)$	$\Sigma_c\bar{D}^*$ (4462.1)	III	$\frac{3}{2}^-$	$4458(2)-3(1)i$	$2.1(2)+0.3(1)i$	$\frac{1}{2}^-$	$4462(4)-5(3)i$	$2.0(2)+1.2(3)i$
P_c	$\Sigma_c^*\bar{D}^*$ (4526.7)	IV	$\frac{1}{2}^-$	$4498(2)-9(3)i$	$4.0(1)+0.4(2)i$	$\frac{1}{2}^-$	$4526(3)-9(2)i$	$1.5(2)+1.1(4)i$
P_c	$\Sigma_c^*\bar{D}^*$ (4526.7)	IV	$\frac{3}{2}^-$	$4510(2)-14(3)i$	$3.3(2)+0.6(2)i$	$\frac{3}{2}^-$	$4521(2)-12(3)i$	$2.5(2)+0.9(2)i$
P_c	$\Sigma_c^*\bar{D}^*$ (4526.7)	IV	$\frac{5}{2}^-$	$4525(2)-9(3)i$	$1.9(2)+0.6(7)i$	$\frac{5}{2}^-$	$4501(3)-6(4)i$	$3.9(2)+0.1(2)i$

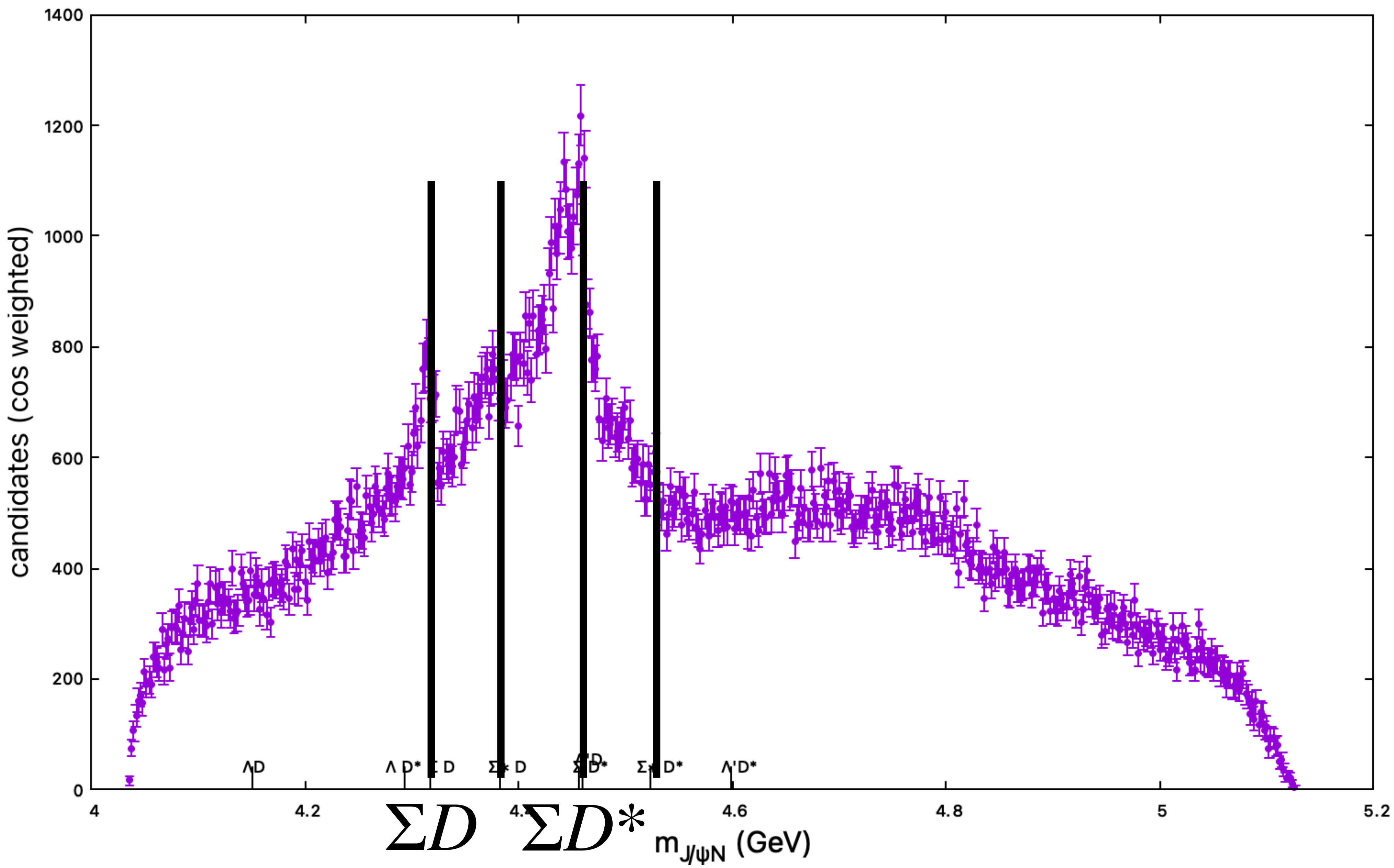


We will revisit this shortly.

A Look at the Data (LHCb cos weighted)



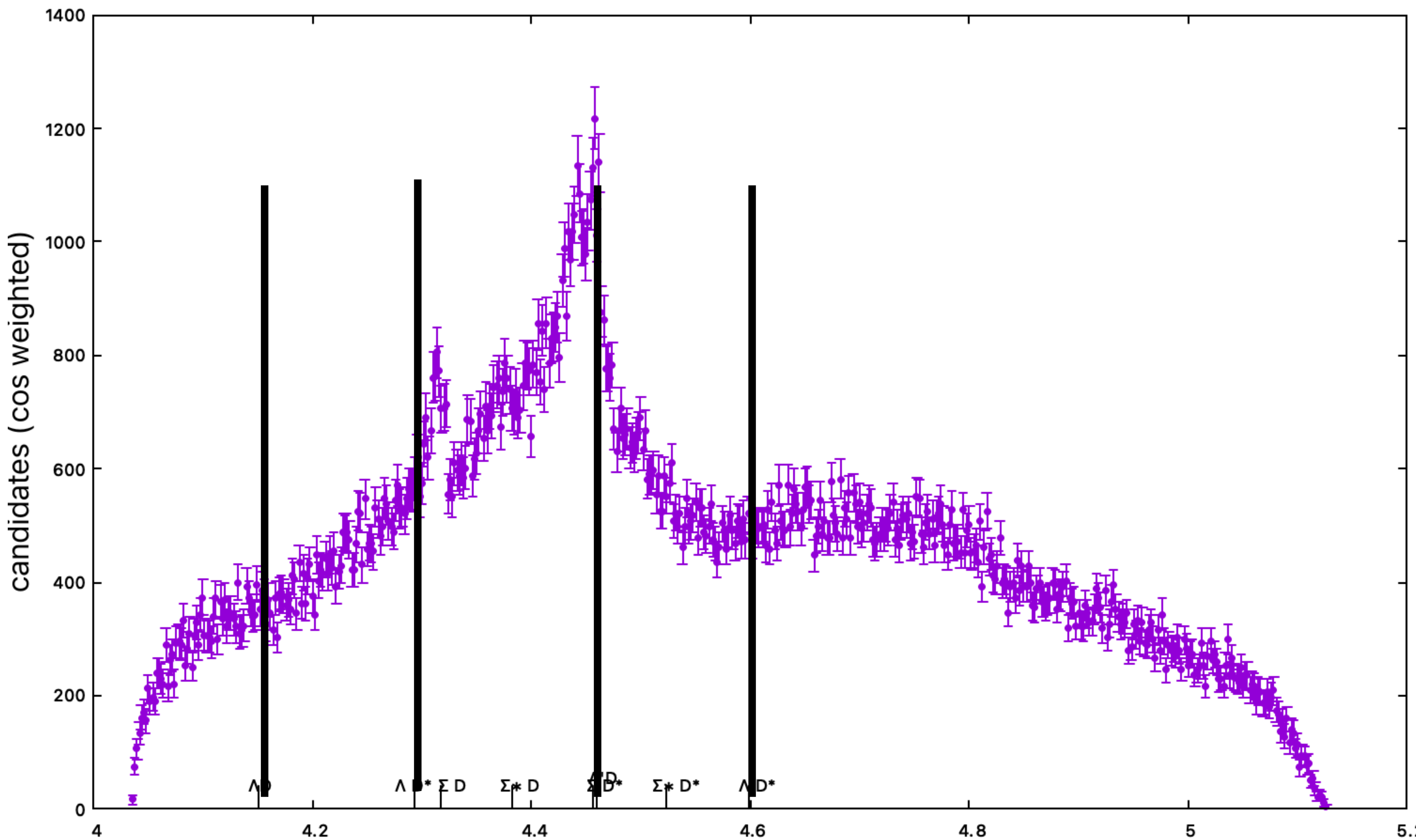
A Look at the Data (LHCb cos weighted)



$\Sigma D \quad \Sigma D^*$

$\Sigma^* D \quad \Sigma^* D^*$

A Look at the Data (LHCb cos weighted)



$\Lambda D \quad \Lambda D^* \quad \Lambda' D \quad \Lambda' D^*$

A Look at the Data (JLab)

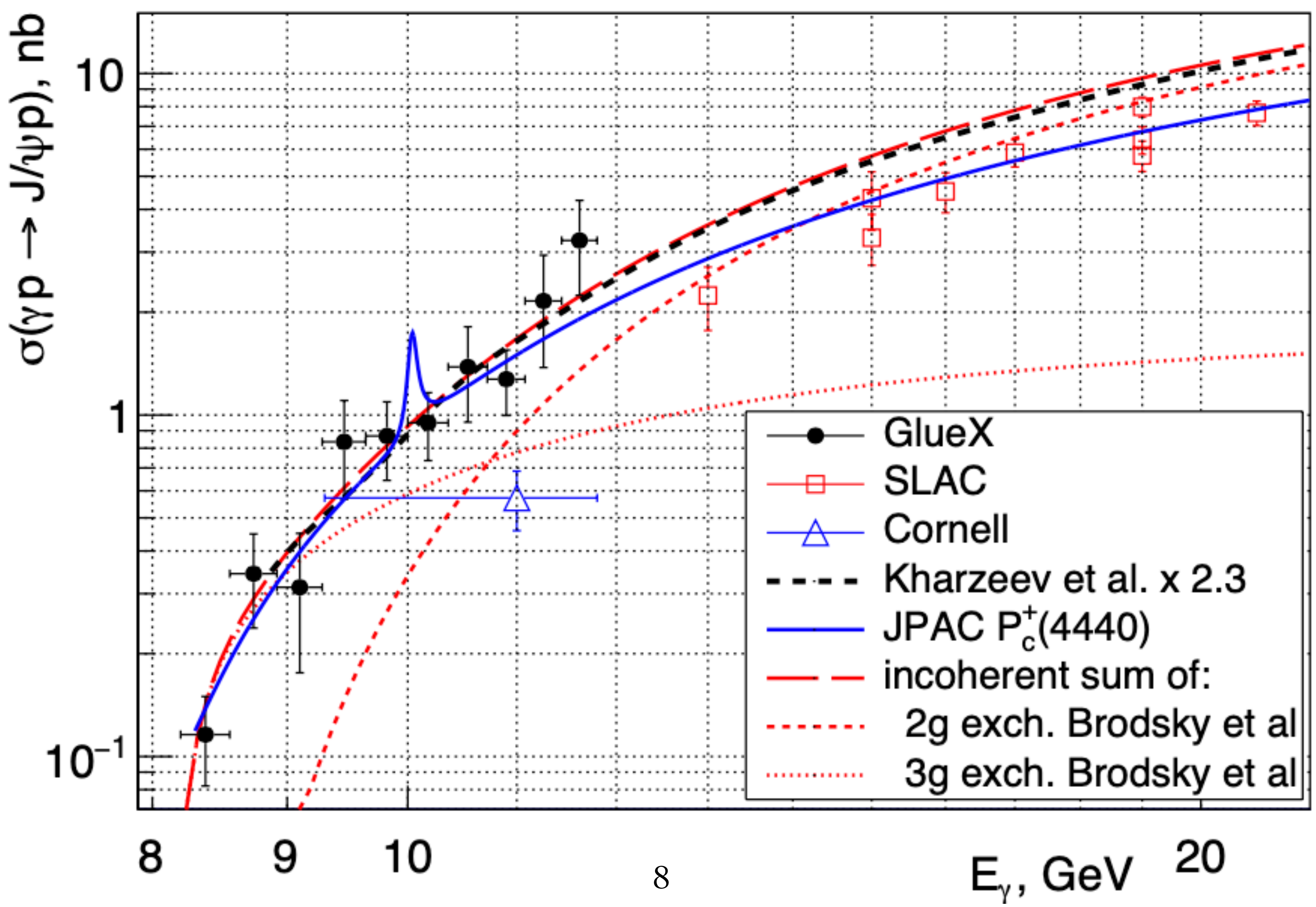
Hiller Blin et al. arXiv:1606.08912

Ali et al, arXiv:1905.10811

$$Bf(Pc(4312) \to J/\psi p) < 4.6\,\%\ (90\,\%\ C.L.)$$

$$Bf(Pc(4440) \to J/\psi p) < 2.3\,\%\ (90\,\%\ C.L.)$$

$$Bf(Pc(4457) \to J/\psi p) < 3.8\,\%\ (90\,\%\ C.L.)$$



A Look at the Data (JLab $J\psi$-007)

Sylvester Joosten, GHP21 J/ψ-007

4% scale uncertainty on cross section limit

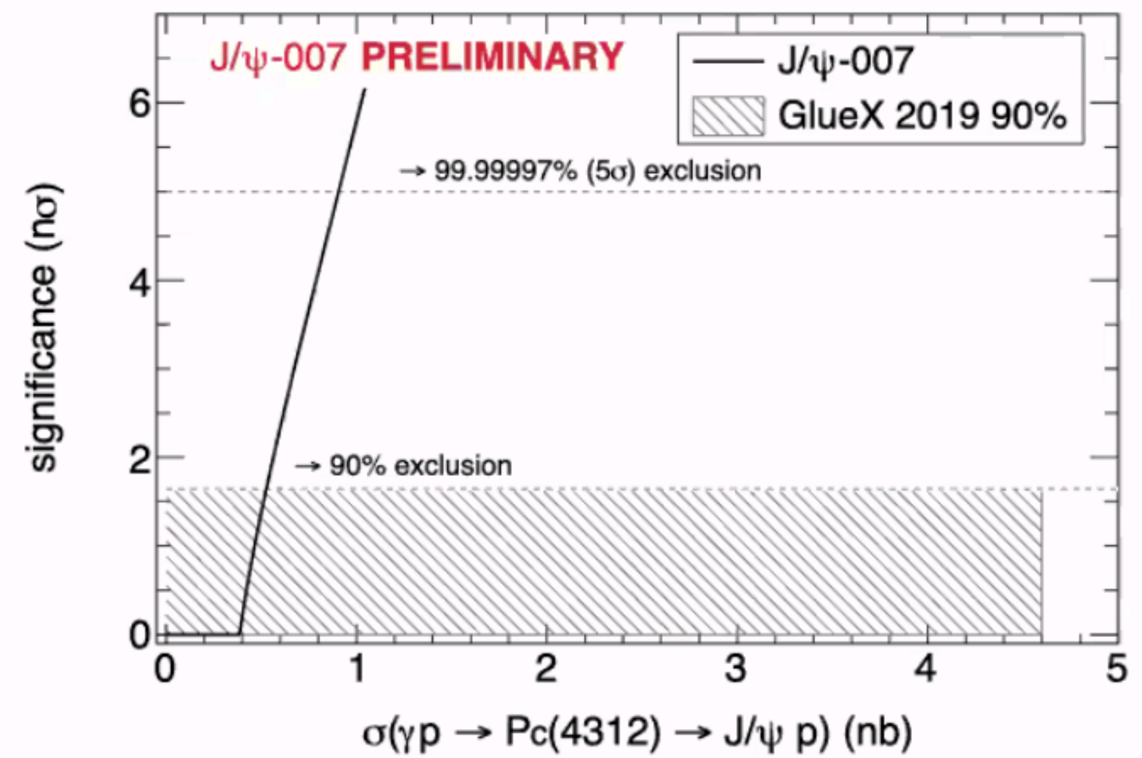
RESULTS AND IMPLICATIONS

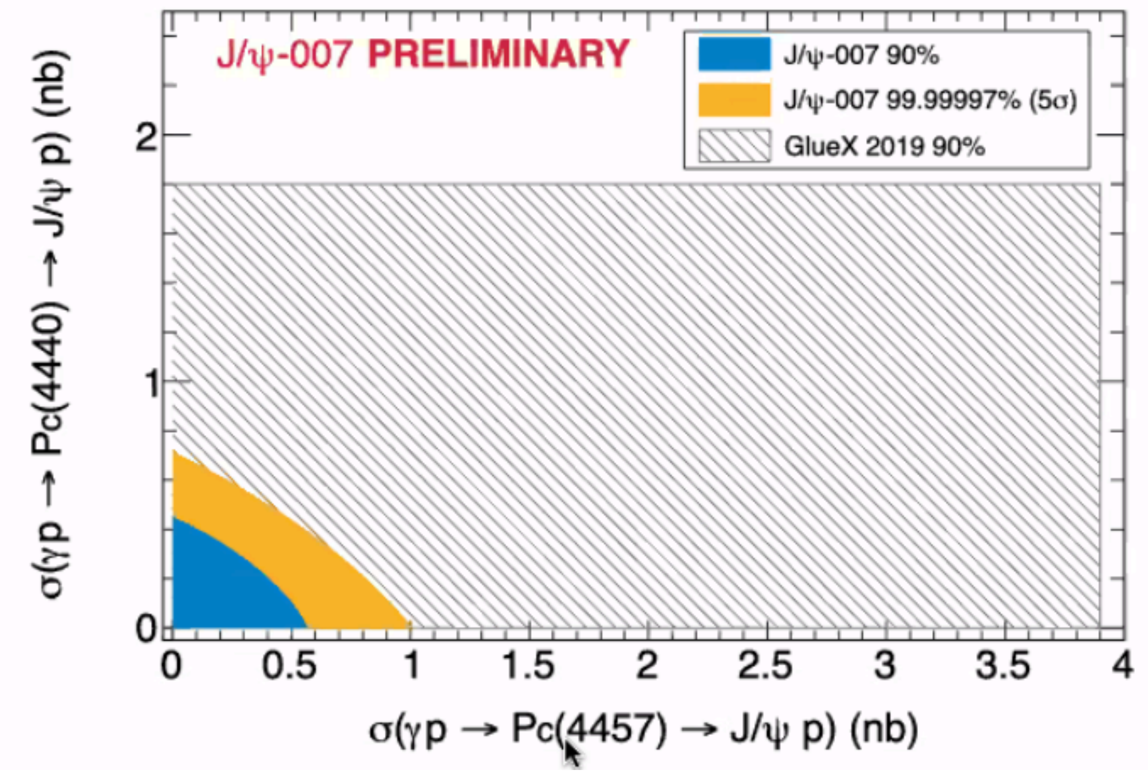
Cross-section at the resonance peak for model-independent upper limits

Upper limit for P_c cross section almost order of magnitude below GlueX limit.

Results are inconsistent with reasonable assumptions for true 5-quark states.

Door is still open for molecular states, but will be very hard to measure in photoproduction due to small overlap with both γp initial state and J/ψp final state





A Look at the Data (ΛD modes)

Amplitude analysis of $\Lambda_b^0 \to \Lambda_c^+ \overline{D}^0 K^-$ decays and pentaquark searches in the $\Lambda_c^+ \overline{D}^0$ system at the LHCb experiment

Alessio Piucci

Heidelberg University, Germany

First observation of the decay $\Lambda_b^0 \to \Lambda_c^+ \bar{D}^{(*)0} K^-$ in preparation of a pentaquark search in the $\Lambda_c^+ \bar{D}^{(*)0}$ system at the LHCb experiment

Marian Stahl (Heidelberg U.)
Jul 11, 2018

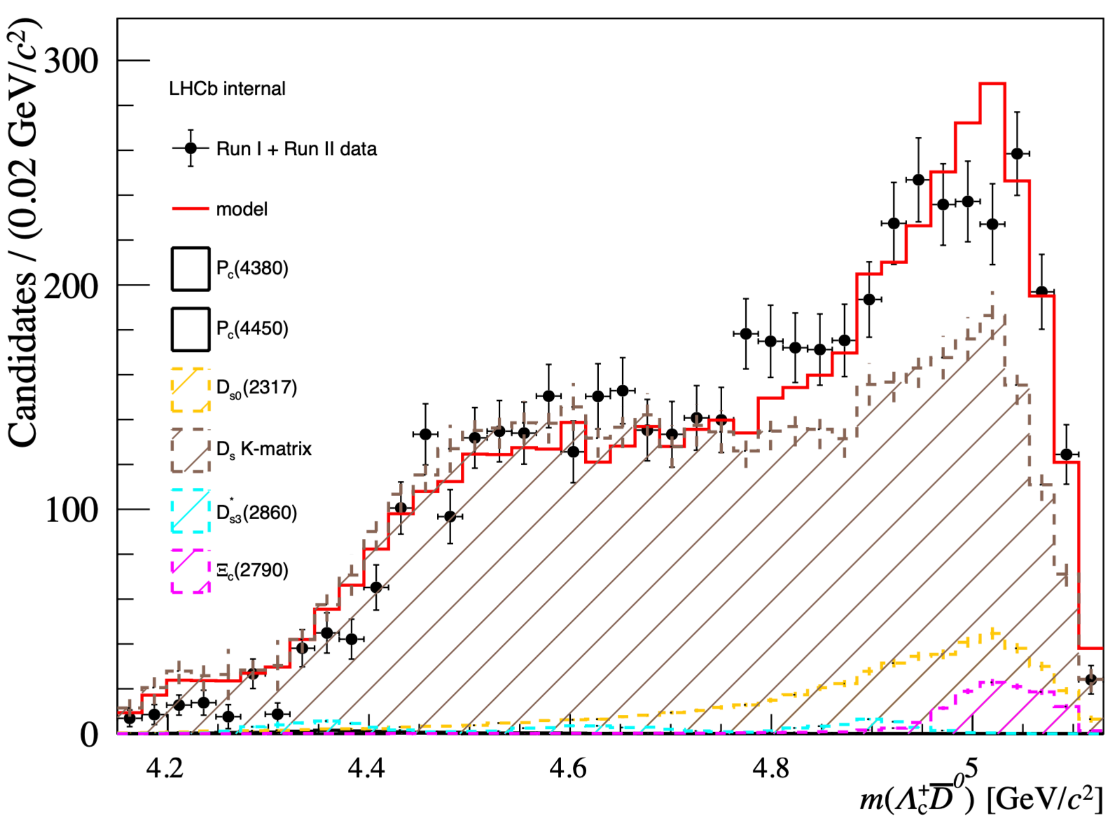
139 pages
Supervisors: Stephanie Hansmann-Menzemer (Heidelberg U.), Klaus Reygers (Heidelberg U.)
Thesis: PhD U. Heidelberg (main) (defense: Jul 11, 2018)
DOI: 10.11588/heidok.00025126
Report number: CERN-THESIS-2018-176
Experiments: CERN-LHC-LHCb
View in: CERN Document Server

http://cds.cern.ch/record/2640677

https://cds.cern.ch/record/2712057/files/10.11588_heidok.00027350.pdf

A Look at the Data (ΛD modes)

Piucci reports Pc fit fraction upper limits in $\Lambda_b \to \Lambda_c DK$



$P_c(4312)^+$ fit fraction < 0.004 (95%CL)

$P_c(4440)^+, J^P = \frac{1}{2}^-$ fit fraction < 0.006 (95%CL)

$P_c(4440)^+, J^P = \frac{3}{2}^-$ fit fraction < 0.0045 (95%CL)

$P_c(4457)^+, J^P = \frac{1}{2}^-$ fit fraction < 0.0045 (95%CL)

$P_c(4457)^+, J^P = \frac{3}{2}^-$ fit fraction < 0.008 (95%CL)

A Look at the Data (ΛD modes)

Combine with measurements of

$$\mathcal{R} \equiv \mathcal{B}(\Lambda_b^0 \to P_c^+ K^-)\mathcal{B}(P_c^+ \to J/\psi\, p)/\mathcal{B}(\Lambda_b^0 \to J/\psi\, pK^-)$$

and branching fractions

$$Bf(\Lambda_b \to J/\psi pK) = 3.2(5) \cdot 10^{-4}$$

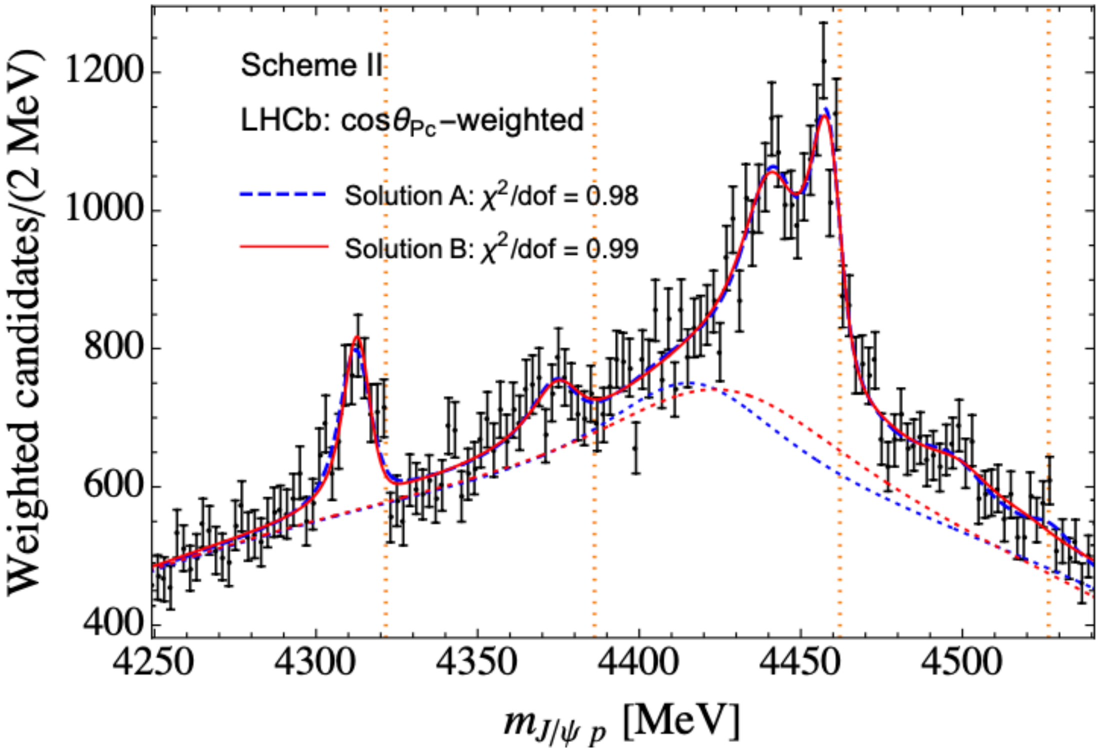
$$Bf(\Lambda_b \to D\Lambda_c K) = 1.5 \cdot 10^{-3}$$

to obtain upper limits

$$Bf(P_c \to \Lambda_c D) \lesssim \begin{cases} 6.3, & (4312) \\ 2.5, & (4440; 1/2^-) \\ 1.9, & (4440; 3/2^-) \\ 4.0, & (4457; 1/2^-) \\ 7.1, & (4457; 3/2^-) \end{cases} \cdot Bf(P_c \to J/\psi p)$$

A Recent Molecular Model (ii)

Du *et al.*, arXiv:2102.07159



(i) 3 extraneous resonances?

(ii) artificial production

(iii) restricted fit range/LD?

(iv) 4440 ΛD branching fraction?

(v) extreme background model:

$$f_{\mathrm{bgd}}(E) = b_0 + b_1 E^2 + b_2 E^4 + \frac{g_r^2}{(m-E)^2 + \Gamma^2/4},$$

			solution		A	solution		B
	DC ([MeV])	RS	J^P	Pole [MeV]	g_{DC}	J^P	Pole [MeV]	g_{DC}
$P_c(4312)$	$\Sigma_c\bar{D}$ (4321.6)	I	$\frac{1}{2}^-$	$4314(1)-4(1)i$	$2.6(1)+0.4(2)i$	$\frac{1}{2}^-$	$4312(2)-4(2)i$	$2.9(1)+0.4(2)i$
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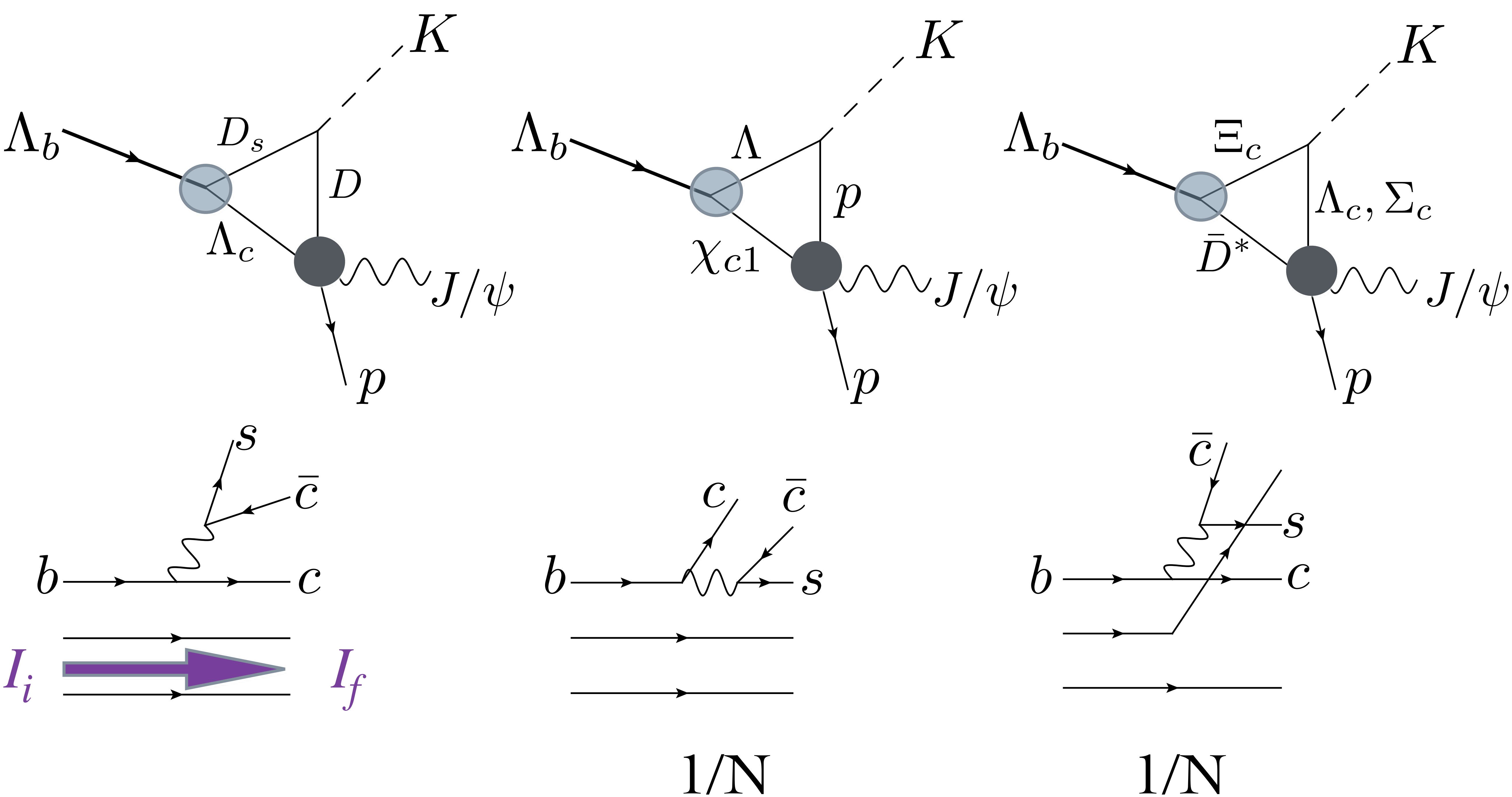
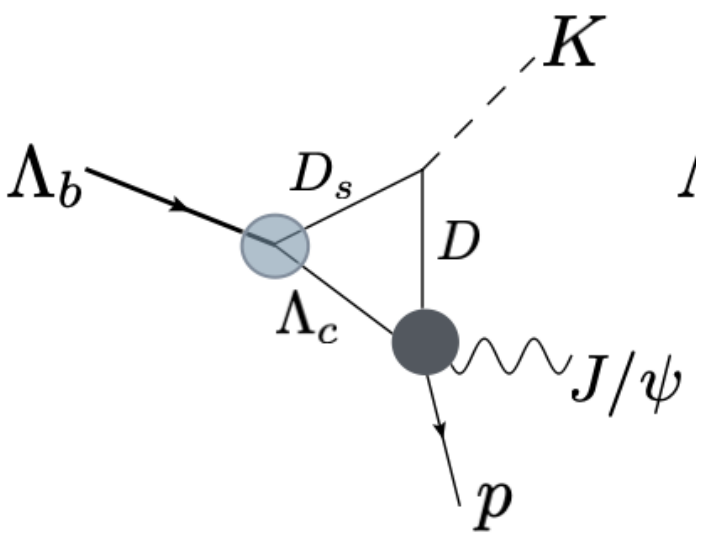
?

A Production/ Rescattering Model for Pentaquarks

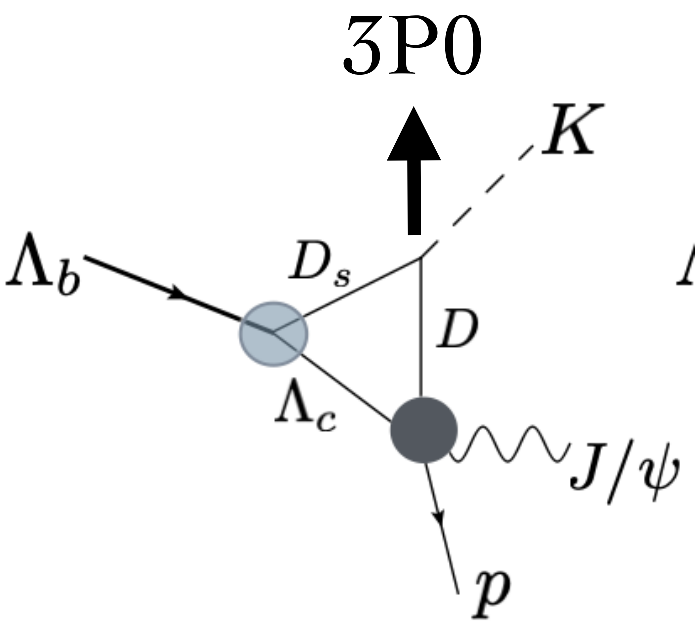
T.J. Burns and E.S. Swanson; writing now



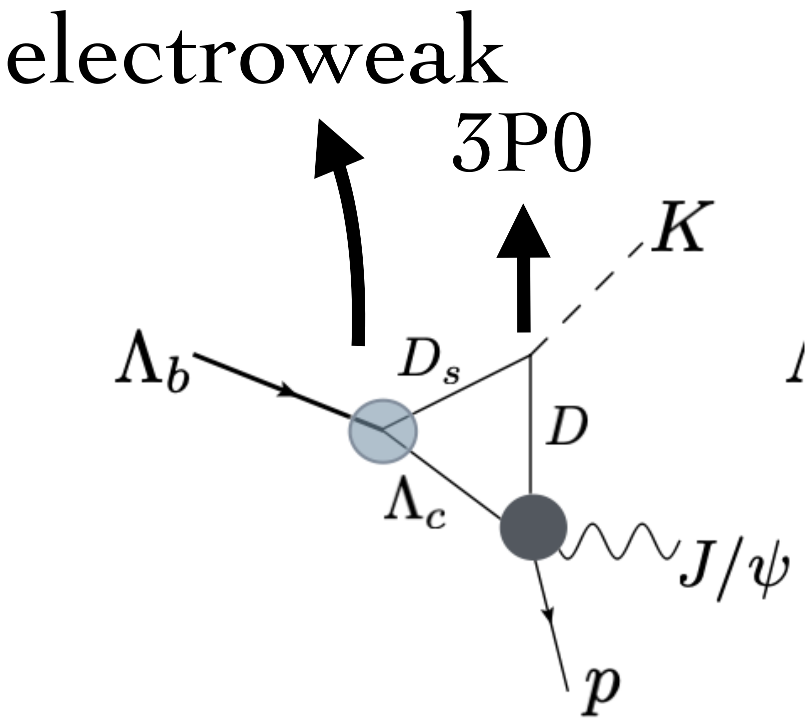
A Production/ Rescattering Model for Pentaquarks



A Production/ Rescattering Model for Pentaquarks



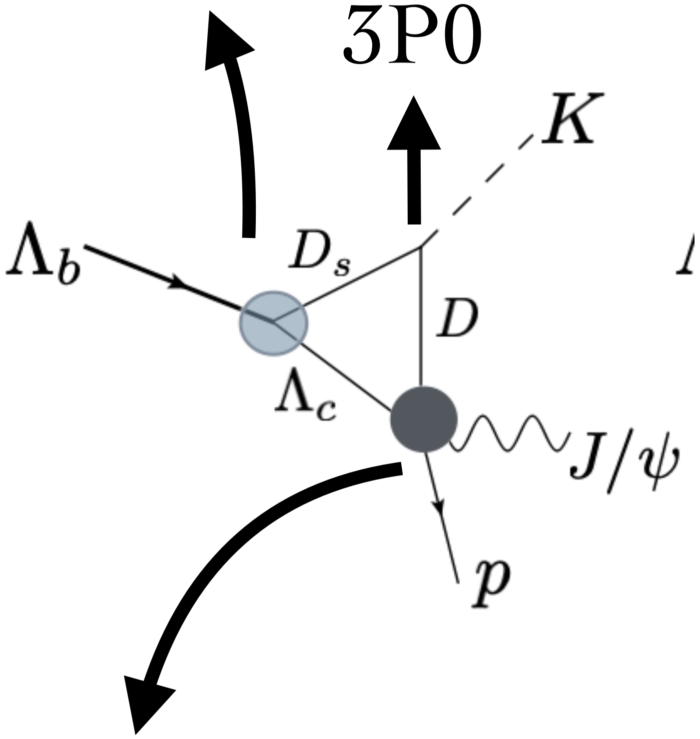
A Production/ Rescattering Model for Pentaquarks



A Production/ Rescattering Model for Pentaquarks

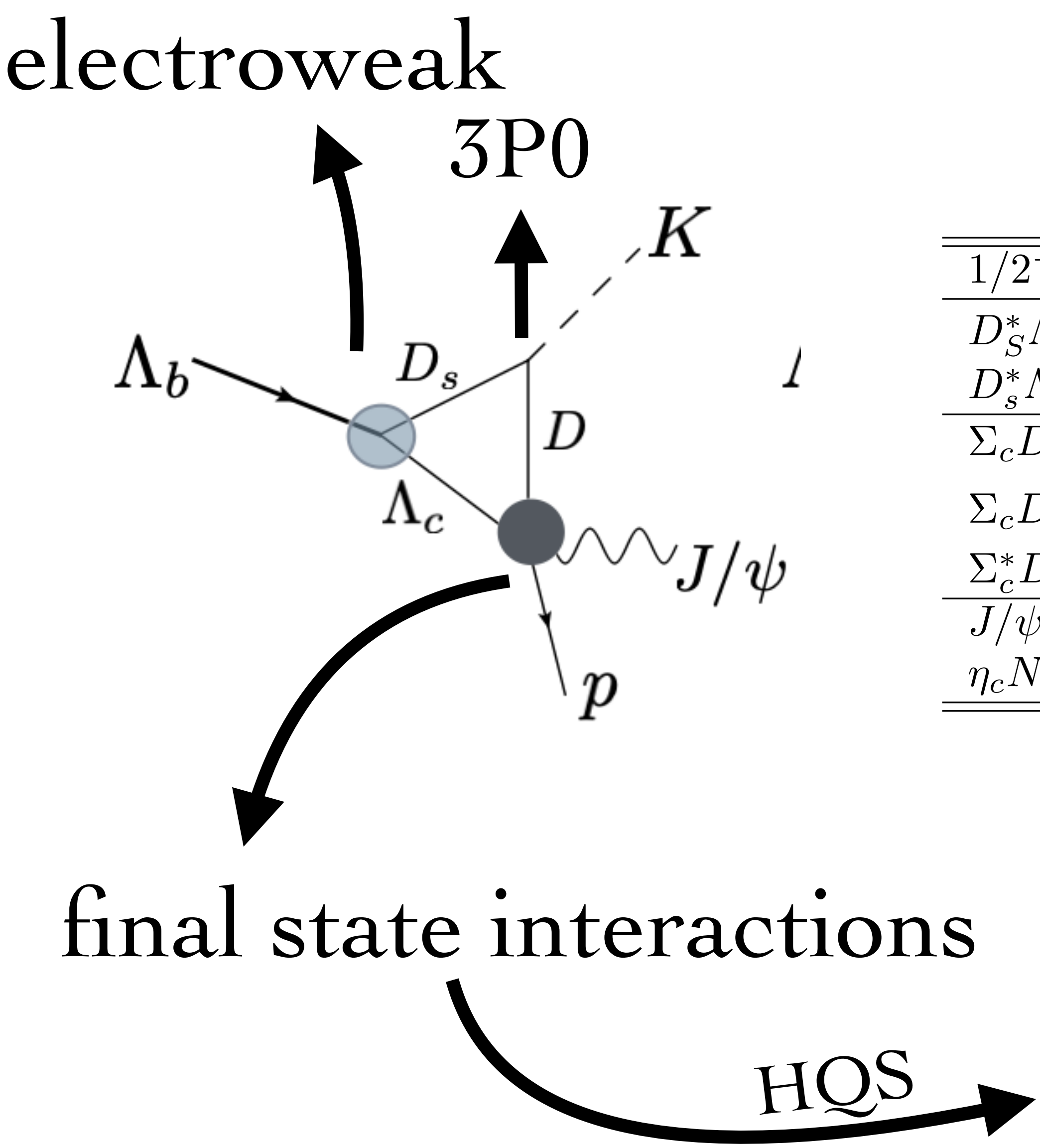
electroweak

3P0



final state interactions

A Production/ Rescattering Model for Pentaquarks



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

$1/2^+$	$D_s^*\Lambda_c' D$	$D_s^*\Lambda_c' D^*$	$\Sigma_c D(P)$	$\Sigma_c D^*(P)$	$J/\psi N(2P)$	$J/\psi N(4P)$	$\eta_c N$
$D_s^*\Lambda_c' D$	f_a	$2f_b/\sqrt{3}$	0	0	$g_a/6\sqrt{3} - 4g_b/3\sqrt{3}$	$(g_a+g_b)\sqrt{2}/3\sqrt{3}$	$g_a/2$
$D_s^*\Lambda_c' D^*$		$f_a - \frac{4}{3}f_b$	0	0	$-5g_a/18 - 4g_b/9$	$-10\sqrt{2}g_a/18 + \sqrt{2}g_b/9$	$-g_a/2\sqrt{3}$
$\Sigma_c D$			0	0	0	0	0
$\Sigma_c D^*$				0	0	0	0
$J/\psi N(2P)$					0	0	0
$J/\psi N(4P)$						0	0
$\eta_c N$							0

A Production/ Rescattering Model for Pentaquarks

(i) employs the preferred production mechanism

(ii) $\eta_c N$ predictions possible

(iii) other decay mode predictions possible

(iv) fitting the full energy range constrains the model

(v) $J/\psi N$ branching fractions are controlled by D & E

(vi) 4412 ($1/2^-$) : $\Lambda_c D$ has zero coupling

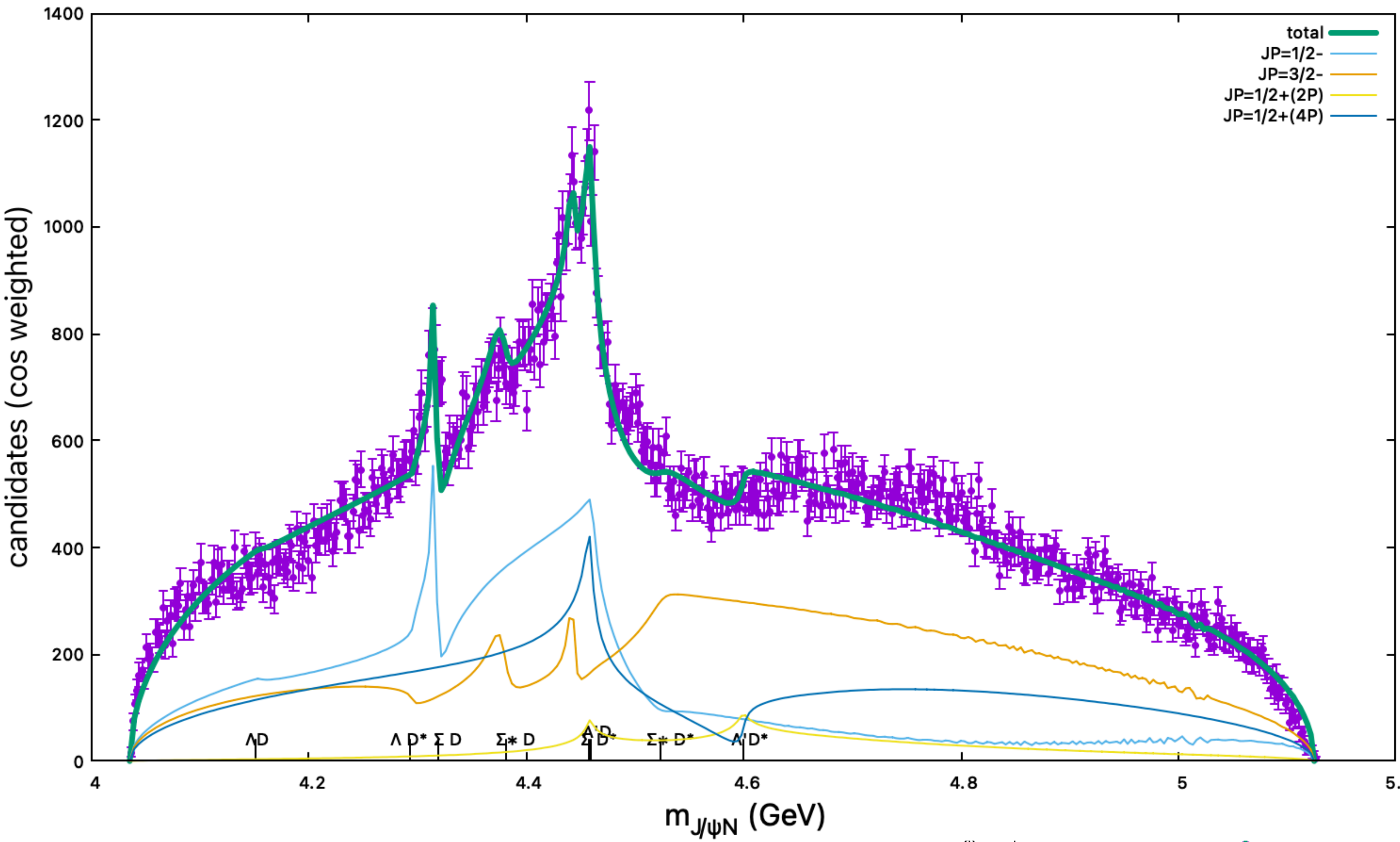
(vii) 4440 ($3/2^-$) : $\Lambda_c D$ has D-wave coupling

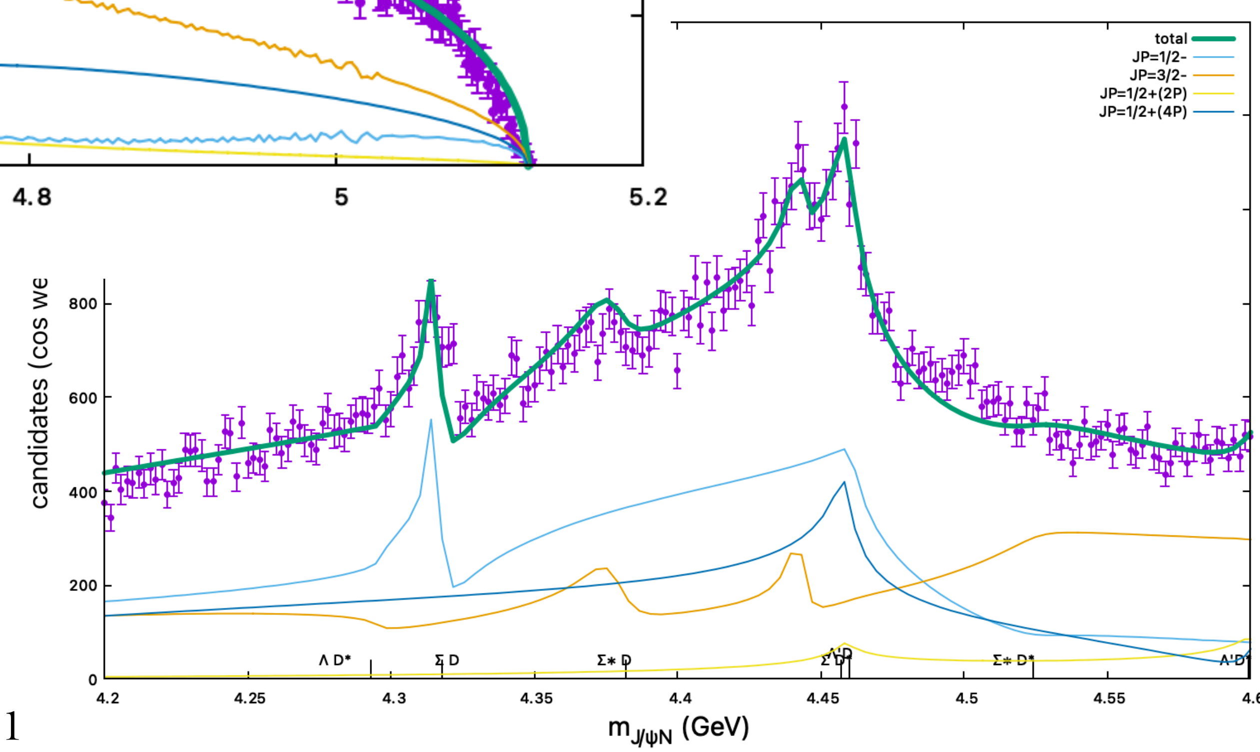
(viii) 4457 ($1/2^\pm$) : cusp(s) explanation

(ix) $1/2^-$ and $3/2^-$ $\Sigma_c^* D^*$ resonances are eliminated by -Cb

(x) shoulder and 4450 hump is due to $1/2^-$ $\Sigma_c D - \Sigma_c D^*$ interactions + threshold cusp

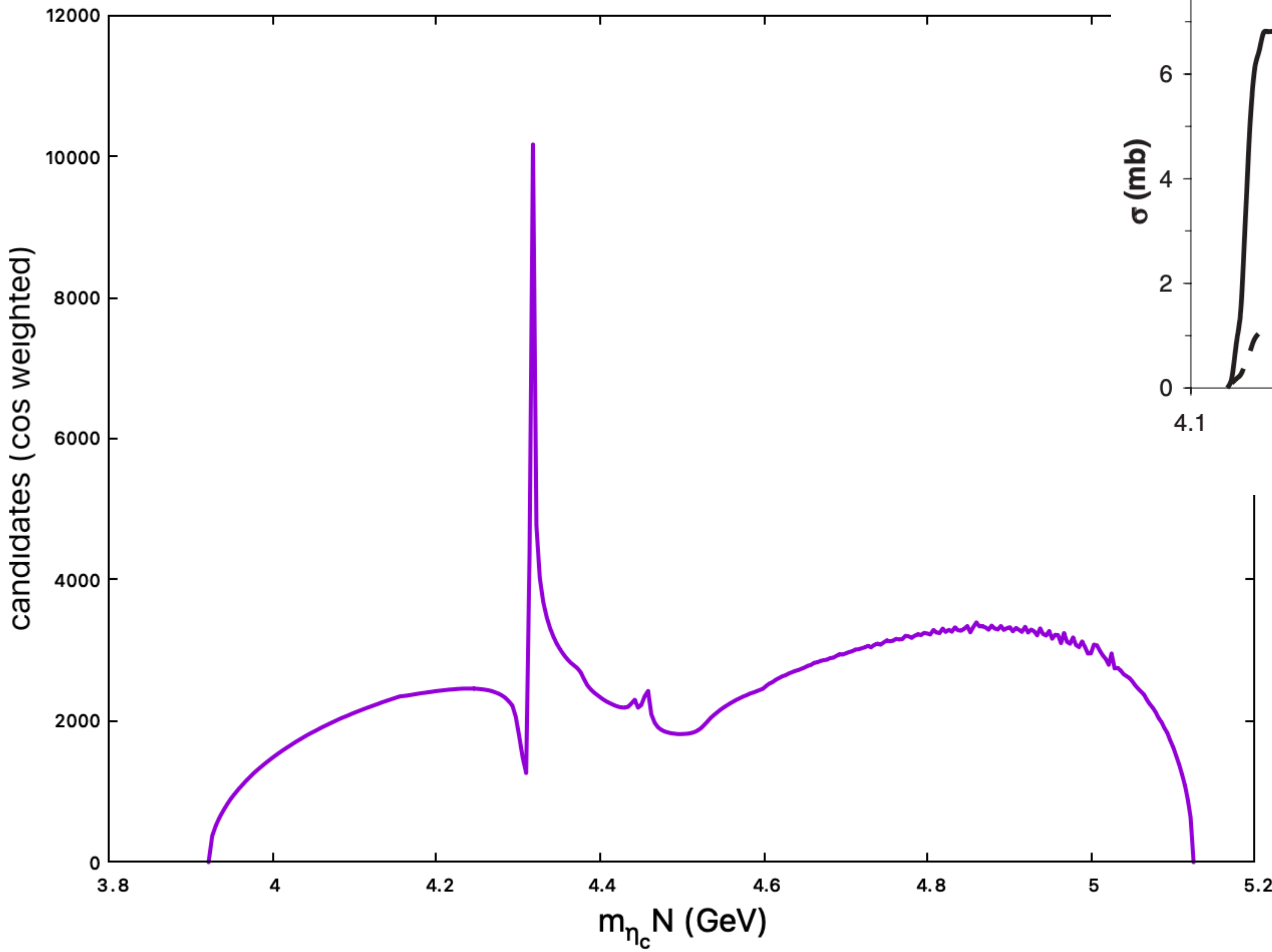
A Production/ Rescattering Model for Pentaquarks

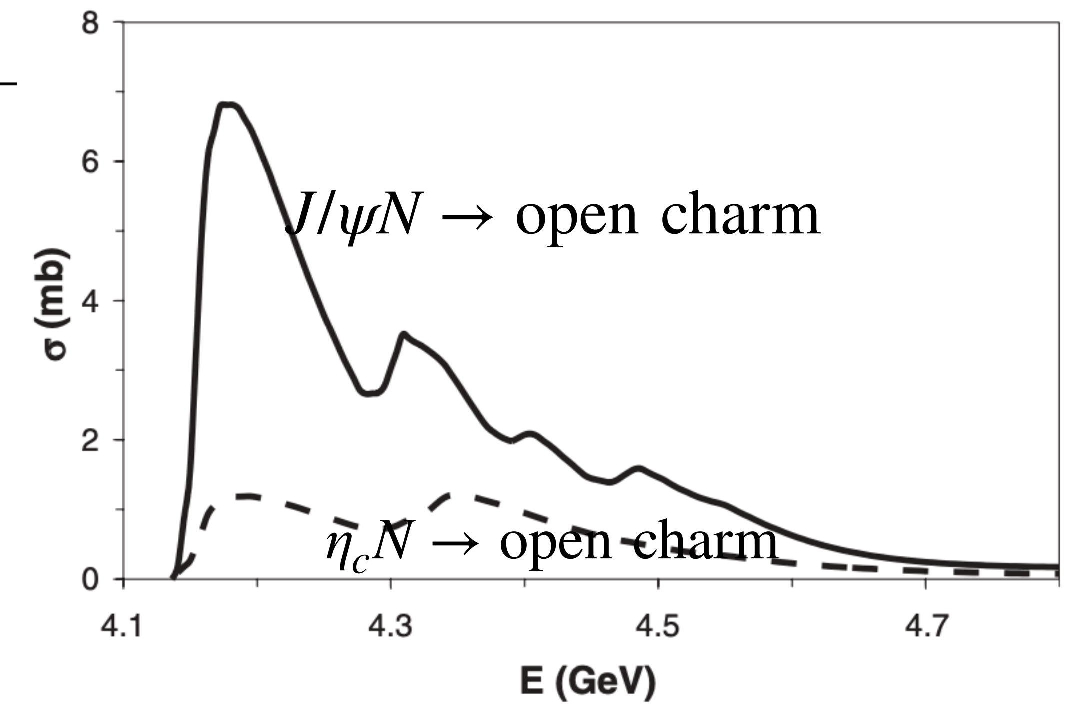




A Production/ Rescattering Model for Pentaquarks

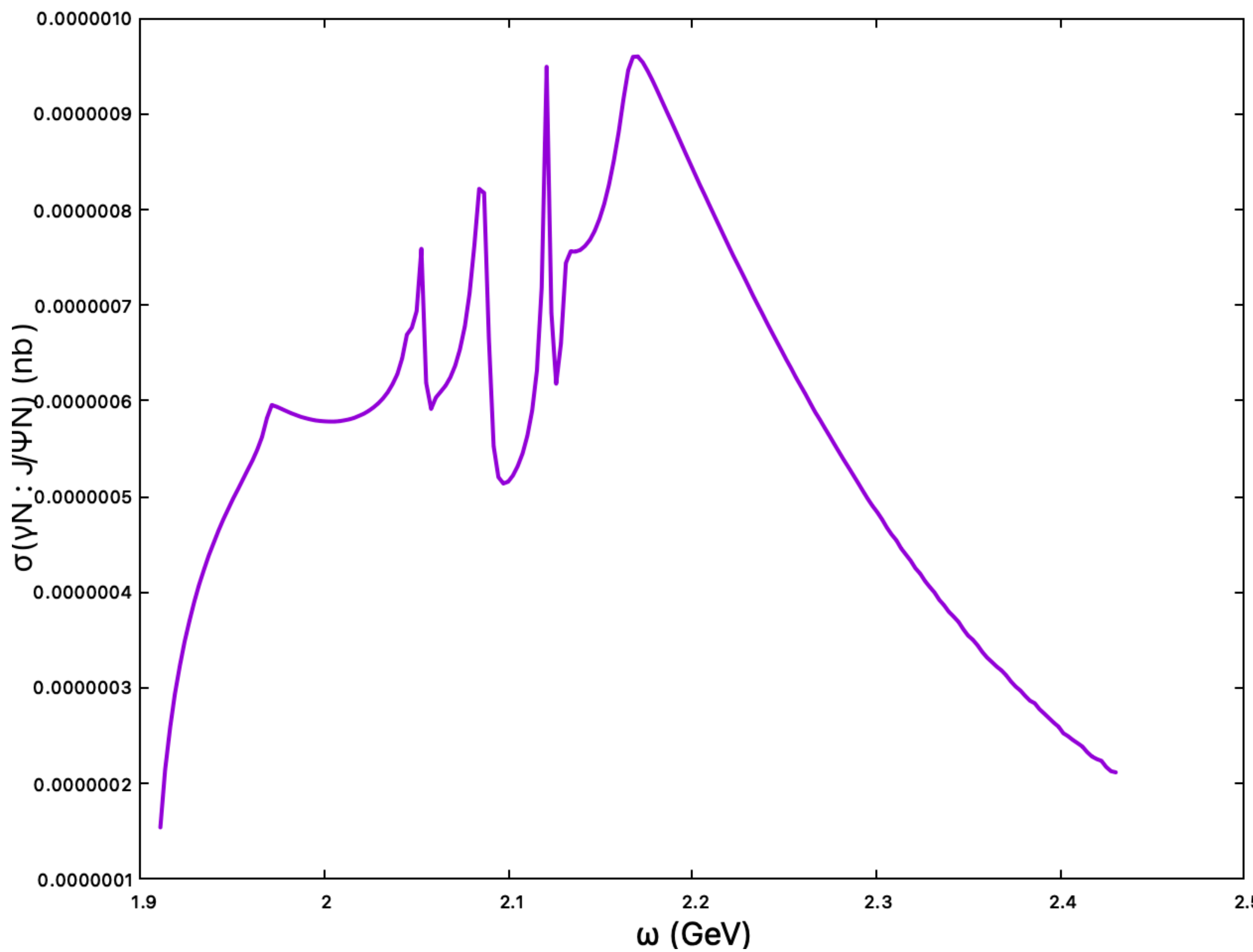
$$\Lambda_b \to \eta_c p K$$





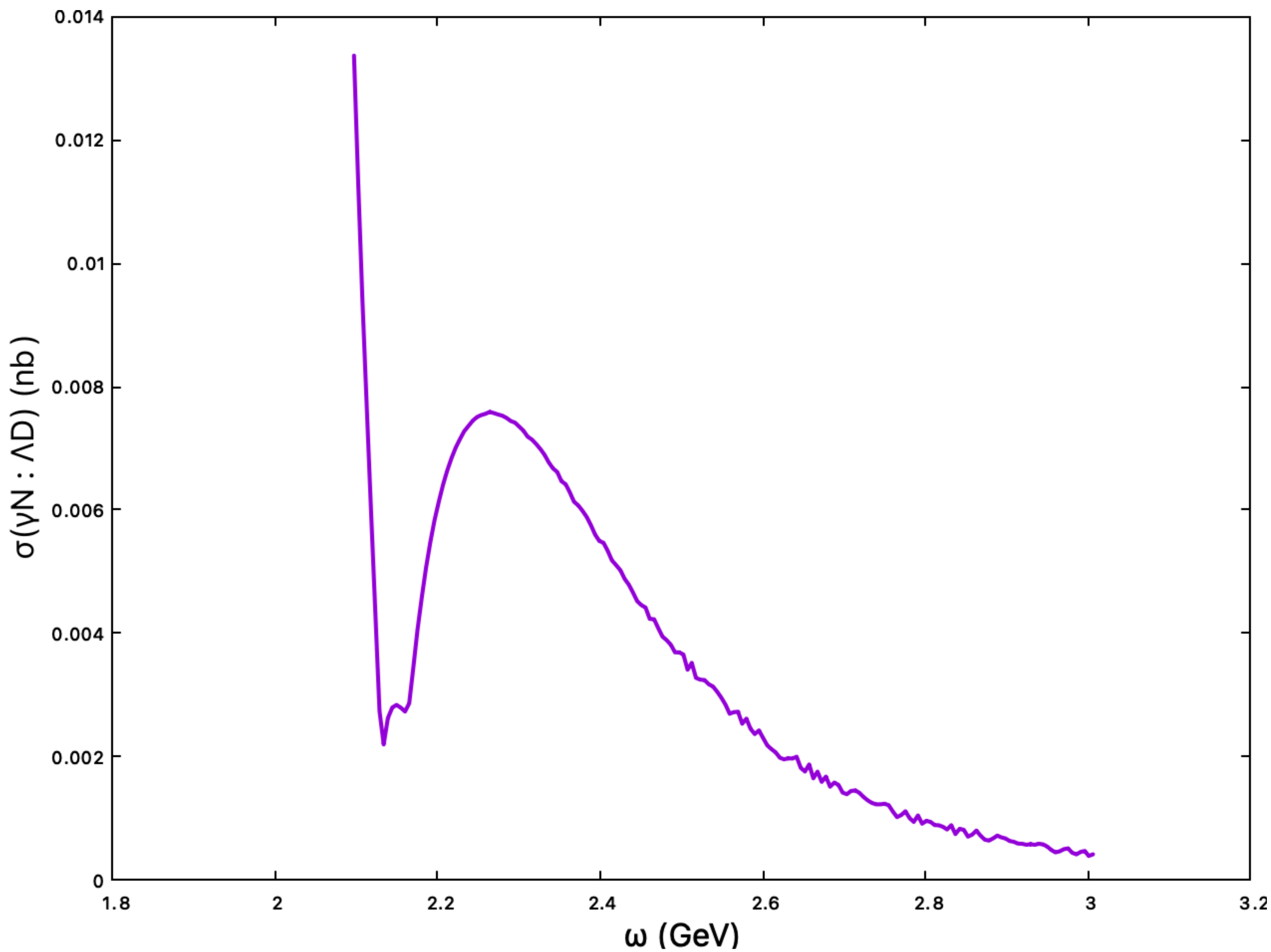
A Production/ Rescattering Model for Pentaquarks

$$\gamma N \to J/\psi N$$



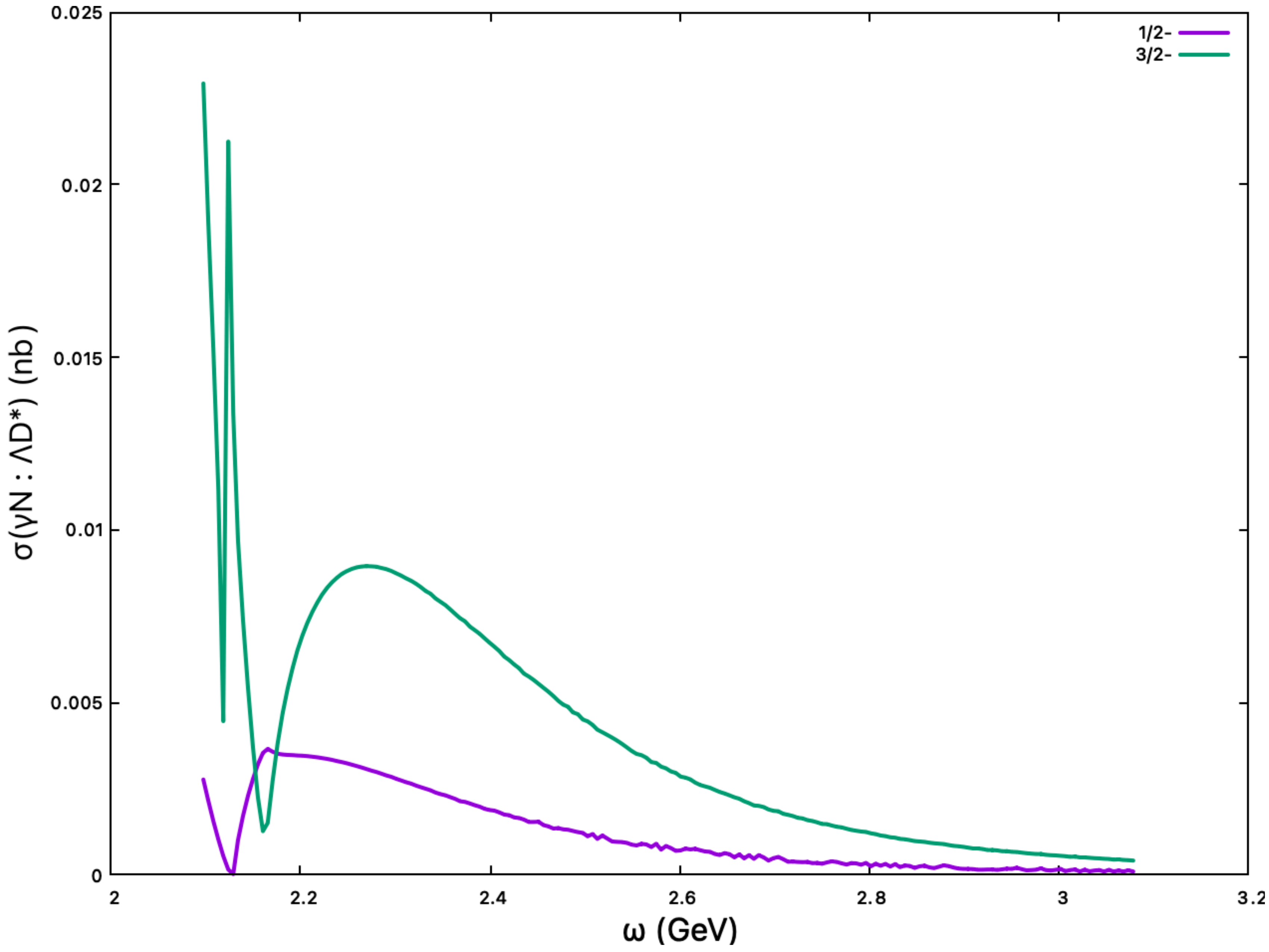
A Production/ Rescattering Model for Pentaquarks

$$\gamma N \to D\Lambda_c$$



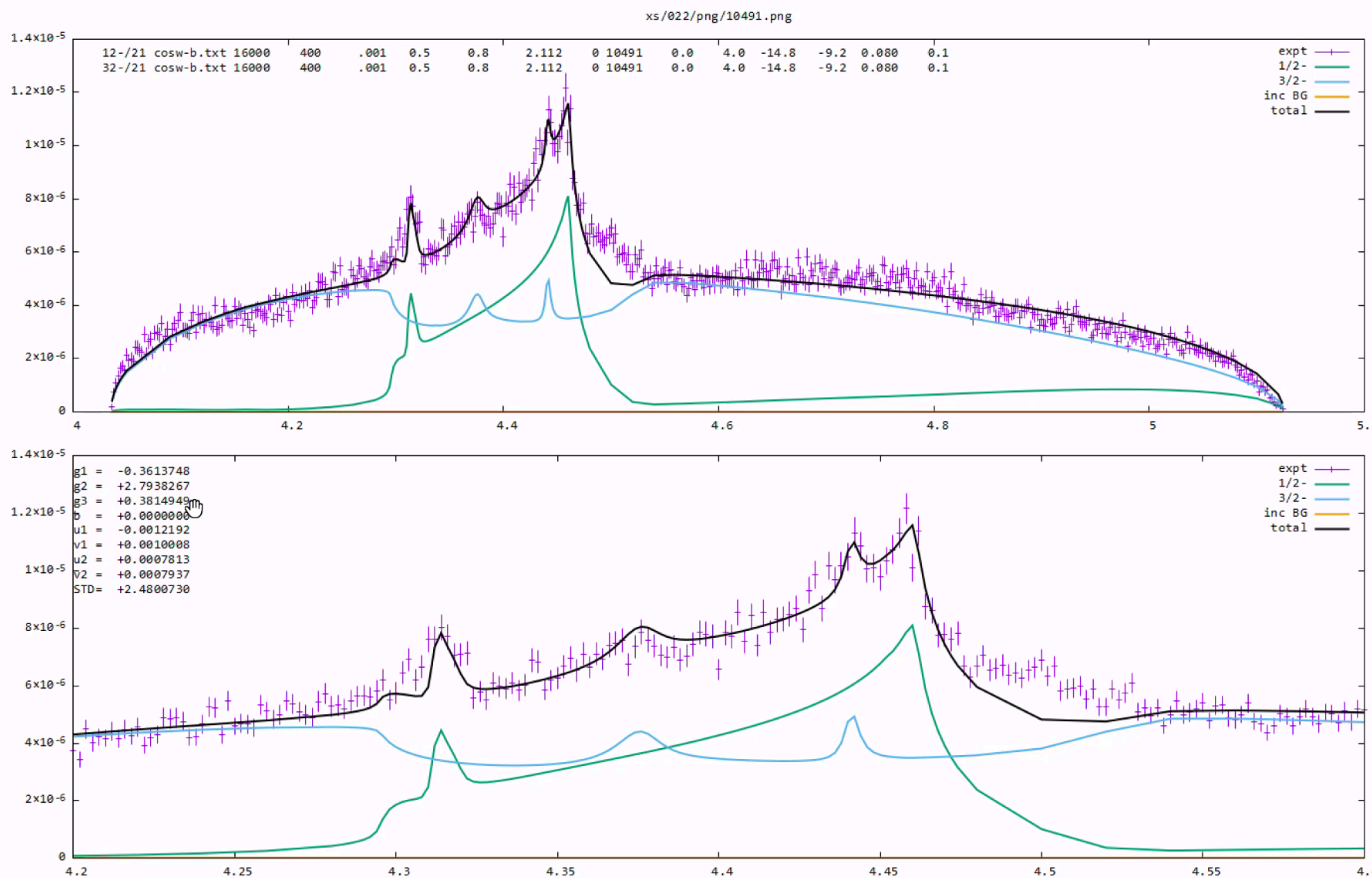
A Production/ Rescattering Model for Pentaquarks

$$\gamma N \to D^* \Lambda_c$$

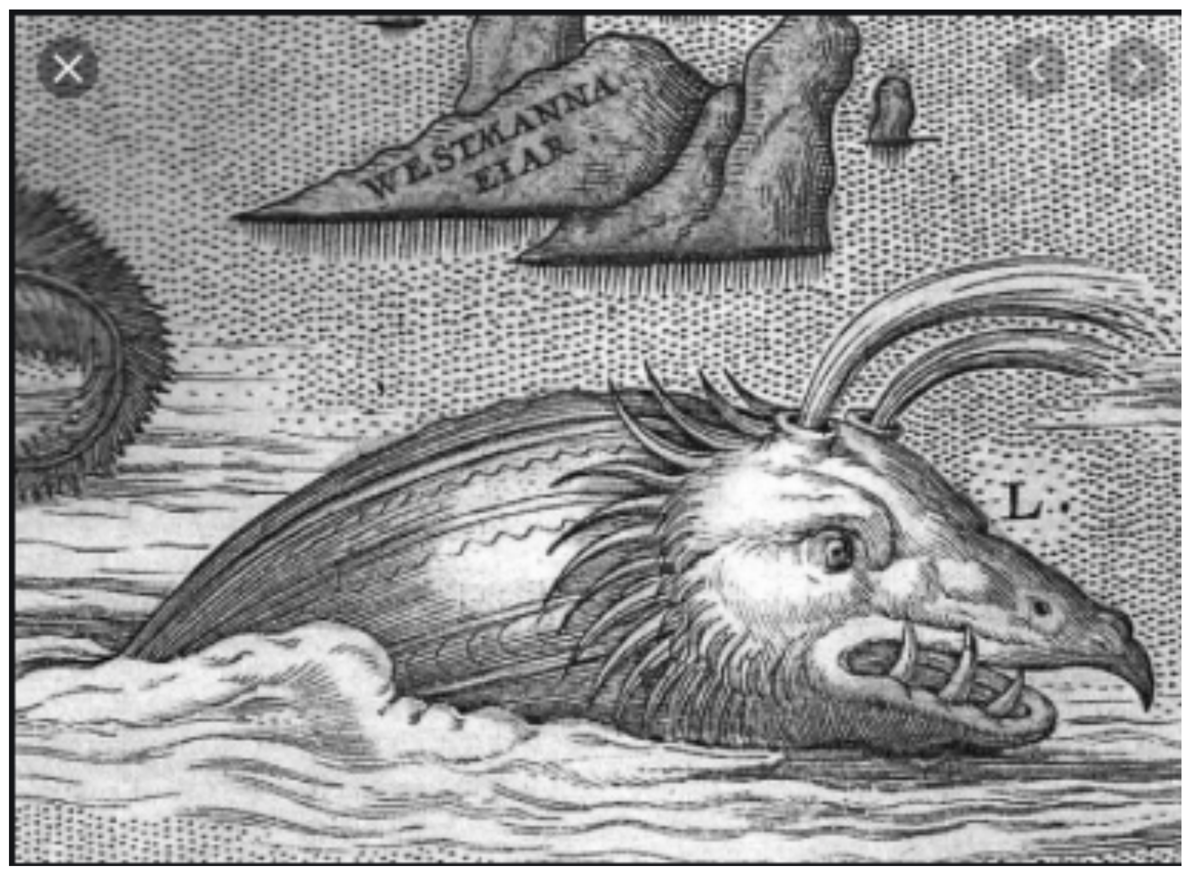


A Production/ Rescattering Model for Pentaquarks

fit with no 1/2+



Conclusions & Observations



- Data exclude many models.

- Good fits obtained by insufficiently constrained models should not be taken as evidence in favour of the model assumptions.

- "Triangles" explain 'kinks' at $\Lambda_c D$, $\Lambda_c' D^*$ and possibly the 4457 peak ($\Lambda_c' D$).

- Weakly bound $\Sigma_c^{(*)} D^{(*)}$ resonances are required:
    - 4312 ($\Sigma_c D$, 1/2-)
    - 4380 ($\Sigma_c^* D$, 3/2-)
    - 4440 ($\Sigma_c D^*$, 3/2-)
    - 4457(1/2-$\Sigma_c D^*$ threshold cusp / 1/2+ triangle)

~thank you~