Charm Production Theory

Random Musings

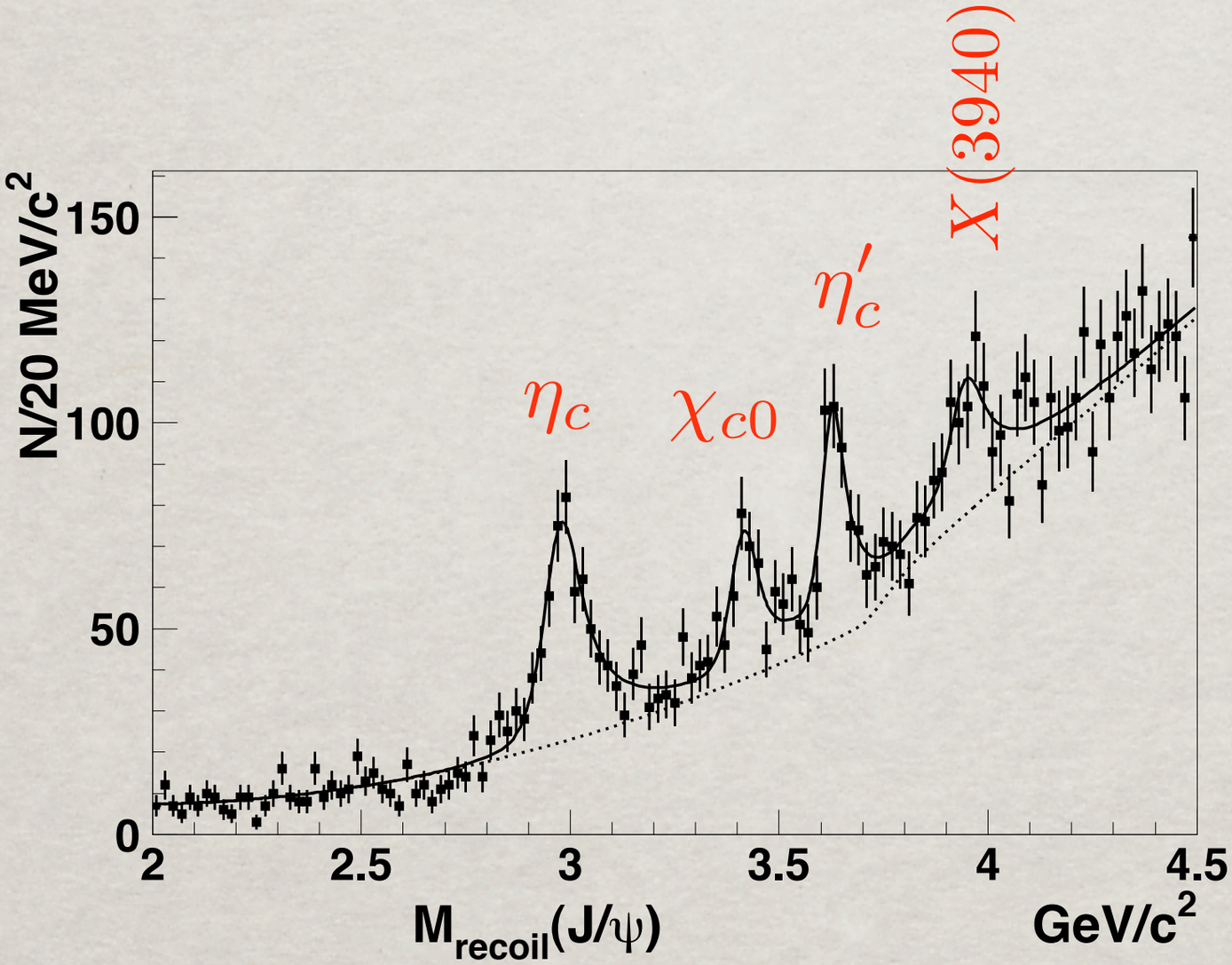
- $e^+e^- \to J/\psi X$, decay models, & NRQCD
- $B \to \psi K$ & factorisation

Eric Swanson

$$e^+e^- \longrightarrow \psi X$$

$e^+e^- \to J/\psi$ stuff

@ KEK



$X \to DD^*$

$X \not\to \omega J/\psi$

$\Gamma = 87 \pm 22 \pm 26$

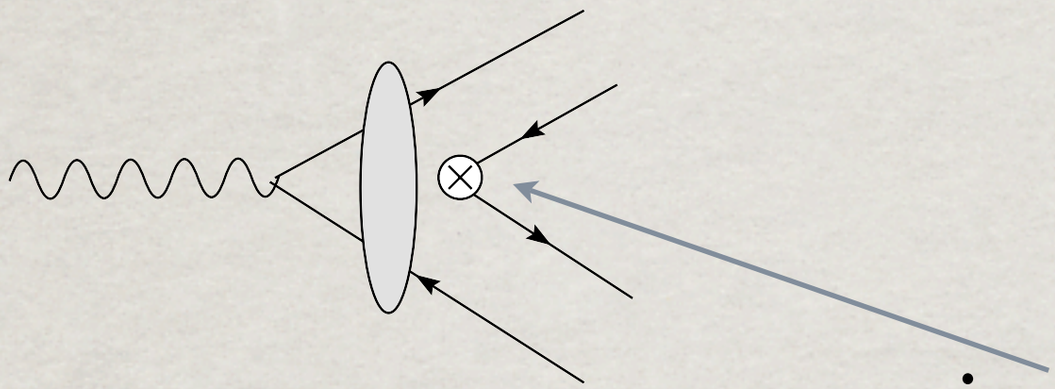
$\Gamma = 39 \pm 26$

P. Pakhlov, hep-ex/041204

K. Trabelsi, H05

$$\sqrt{s} = 3.1$$

Burns, Close, Thomas



spin-space factorisation

$$\psi(n) \to J/\psi\chi_2 = \sqrt{\frac{3}{20}} f_D(^3D_1) + \frac{1}{2} f_D(^5D_1) - \sqrt{\frac{28}{5}} f_D(^7D_1)$$

$$\psi(n) \to J/\psi\chi_1 = -2 f_S(^3S_1) - \frac{1}{2} f_D(^3D_1) + \sqrt{\frac{3}{4}} f_D(^5D_1)$$

$$\psi(n) \to J/\psi\chi_0 = -\sqrt{3} f_S(^3S_1)$$

$$\psi(n) \to J/\psi\eta = -\sqrt{2} f_P$$

$$\psi(n) \to J/\psi h_c = -\frac{1}{\sqrt{2}} f_D(^3D_1) + \sqrt{\frac{3}{2}} f_D(^5D_1)$$

$$\psi \to \omega f_0(980) = 0.14 \pm 0.05 \qquad \psi \to \omega f_1(1420) = 0.7 \pm 0.2$$

$$\psi \to \omega f_2 = 4.3 \pm 0.6 \qquad \psi \to \omega f_0(1710) = 0.36 \pm 0.06$$

NRQCD

$$\sigma(\psi) = \sum_n \sigma_n(\Lambda)\langle \mathcal{O}_n^{\psi}(\Lambda)\rangle$$

short distance

long distance
process independent
organise in powers of v

$$\mathcal{O}_1(^1S_0) = \psi^\dagger\chi\chi^\dagger\psi$$

$$\mathcal{O}_1(^3S_1) = \psi^\dagger\vec{\sigma}\chi\cdot\chi^\dagger\vec{\sigma}\psi$$

$$\mathcal{O}_8(^1S_0) = \psi^\dagger T^a\chi\chi^\dagger T^a\psi$$

$$\mathcal{O}_8(^3S_1) = \psi^\dagger T^a\vec{\sigma}\chi\cdot\chi^\dagger T^a\vec{\sigma}\psi$$

NRQCD

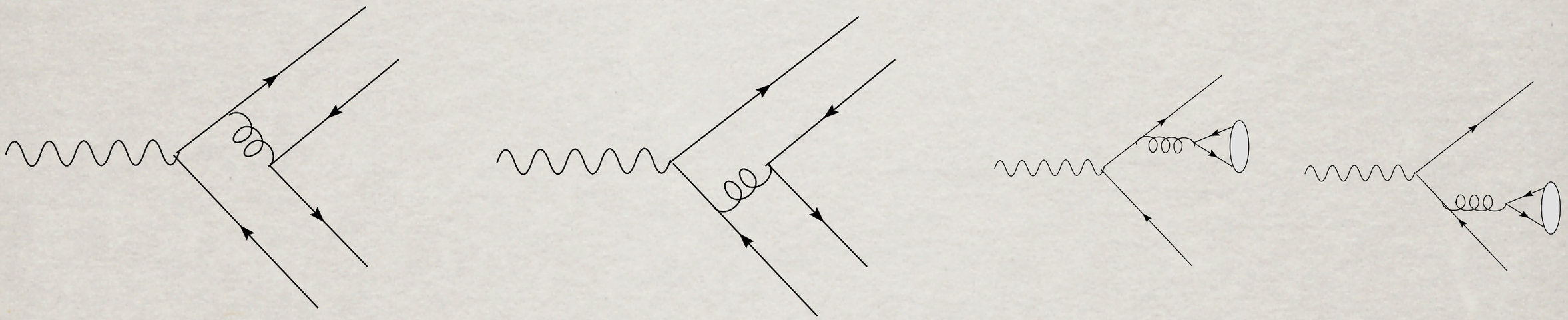
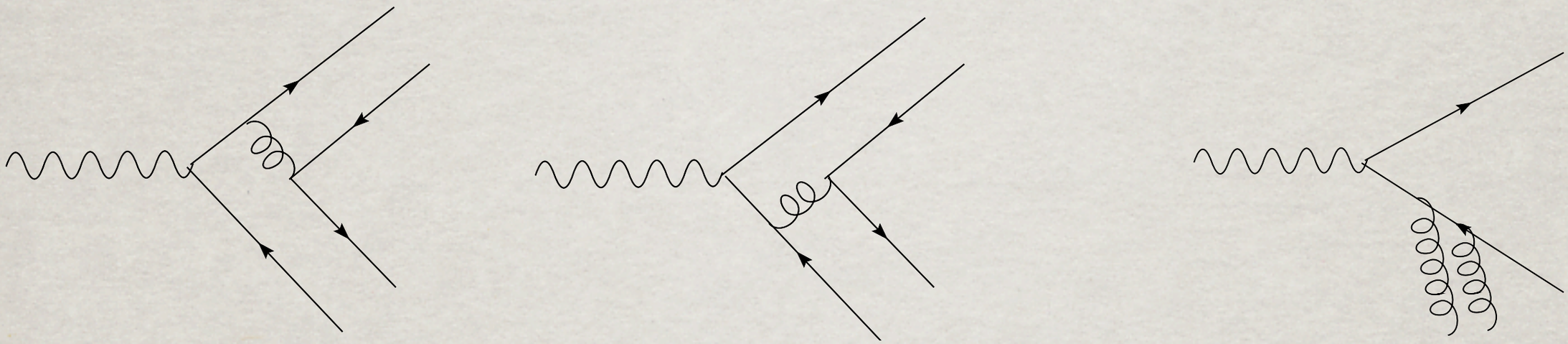


Table 1: Cross Sections (fb) for $e^+e^- \to J/\psi H$ at $\sqrt{s} = 10.6$ GeV.

H	η_c	χ_{c0}	η_c'
BaBar	$17.6 \pm 2.8 \pm 2.1$	$10.3 \pm 2.5 \pm 1.8$	$16.4 \pm 3.7 \pm 3.0$
Belle	$25.6 \pm 2.8 \pm 3.4$	$6.4 \pm 1.7 \pm 1.0$	$16.5 \pm 3.0 \pm 2.4$
BL	2.31 ± 1.09	2.28 ± 1.03	0.96 ± 0.45
LHC	5.5	6.9	3.7
BC	~ 33		
BLL	26.7		26.6

Problem resolved at NLO? [Zhang, Gao, Chao, PRL96,092001 (06)?]

NRQCD



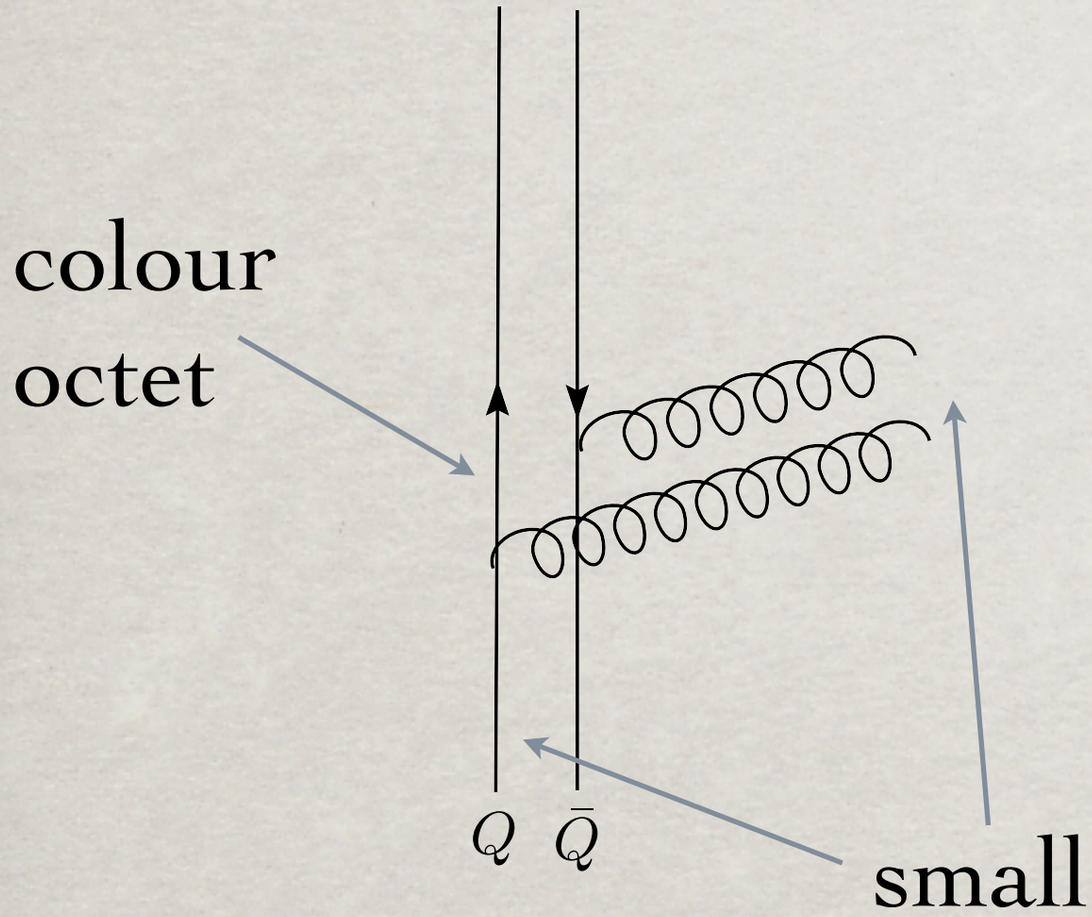
$$R = \frac{\sigma(e^+e^- \to J/\psi X_{c\bar{c}})}{\sigma(e^+e^- \to J/\psi X)} = 0.82 \pm 0.15 \pm 0.14$$

BELLE-CONF-0331

$$R_{NRQCD} \approx 0.1$$

Peskin's OPE

Peskin, NPB156, 365 (79)



$$L_{eff} = -\sum_{N=1} C_E^{(N)ij} a_0^3 \epsilon_B^{2-2N} \cdot E^i D_0^{2N-2} E^j$$

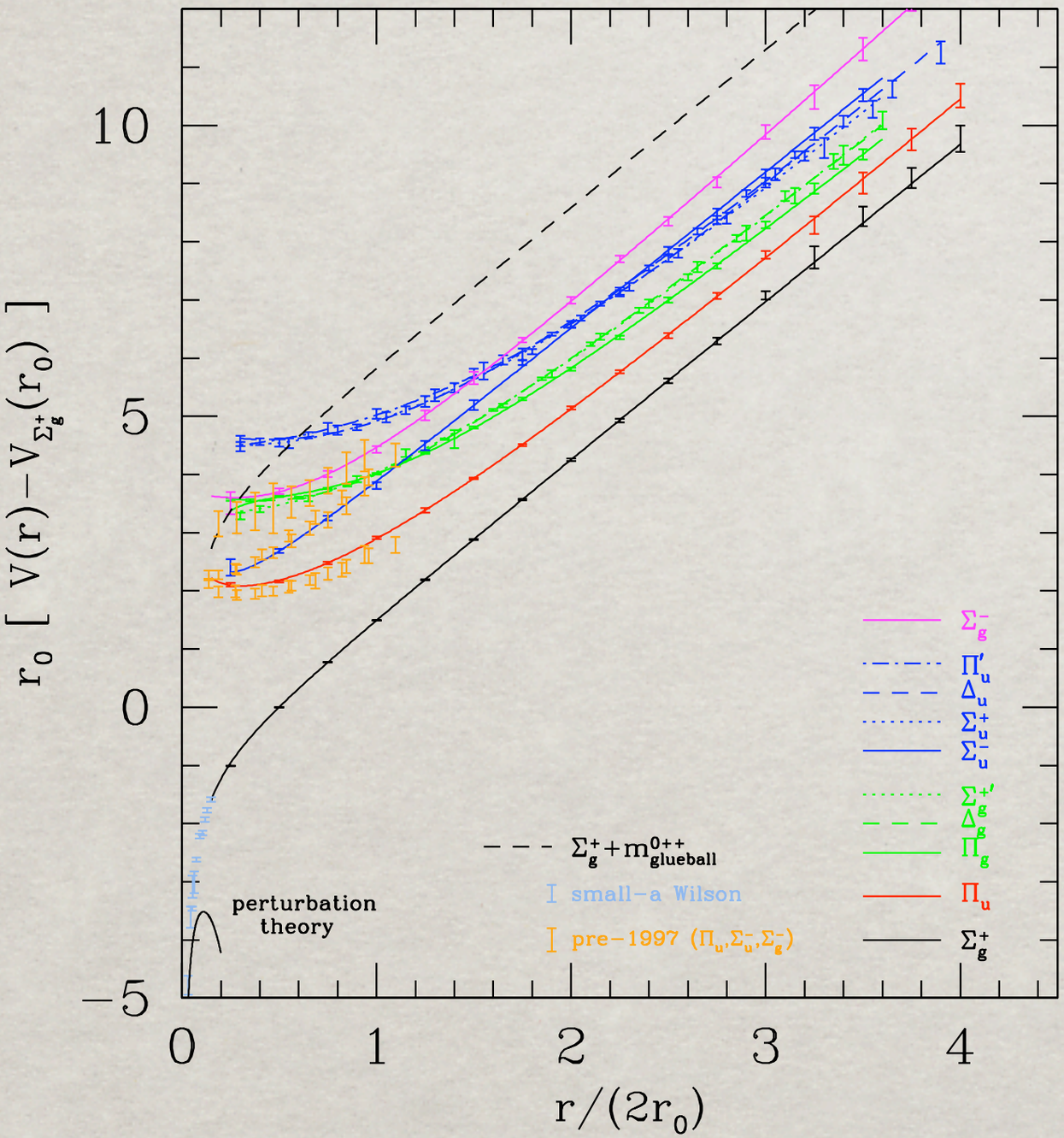
$$C_E^{(N)ij} = 2\pi\alpha_s \frac{\epsilon_B^{2N-2}}{N_c a_0^3} \langle\phi| r^i \frac{1}{(H_A - M_\phi)^{2N-1}} r^j |\phi\rangle$$

$$H_A = \alpha_s \frac{1}{6r}$$

$$C_E(1S) = \frac{14\pi}{3(N_c^2 - 1)}$$

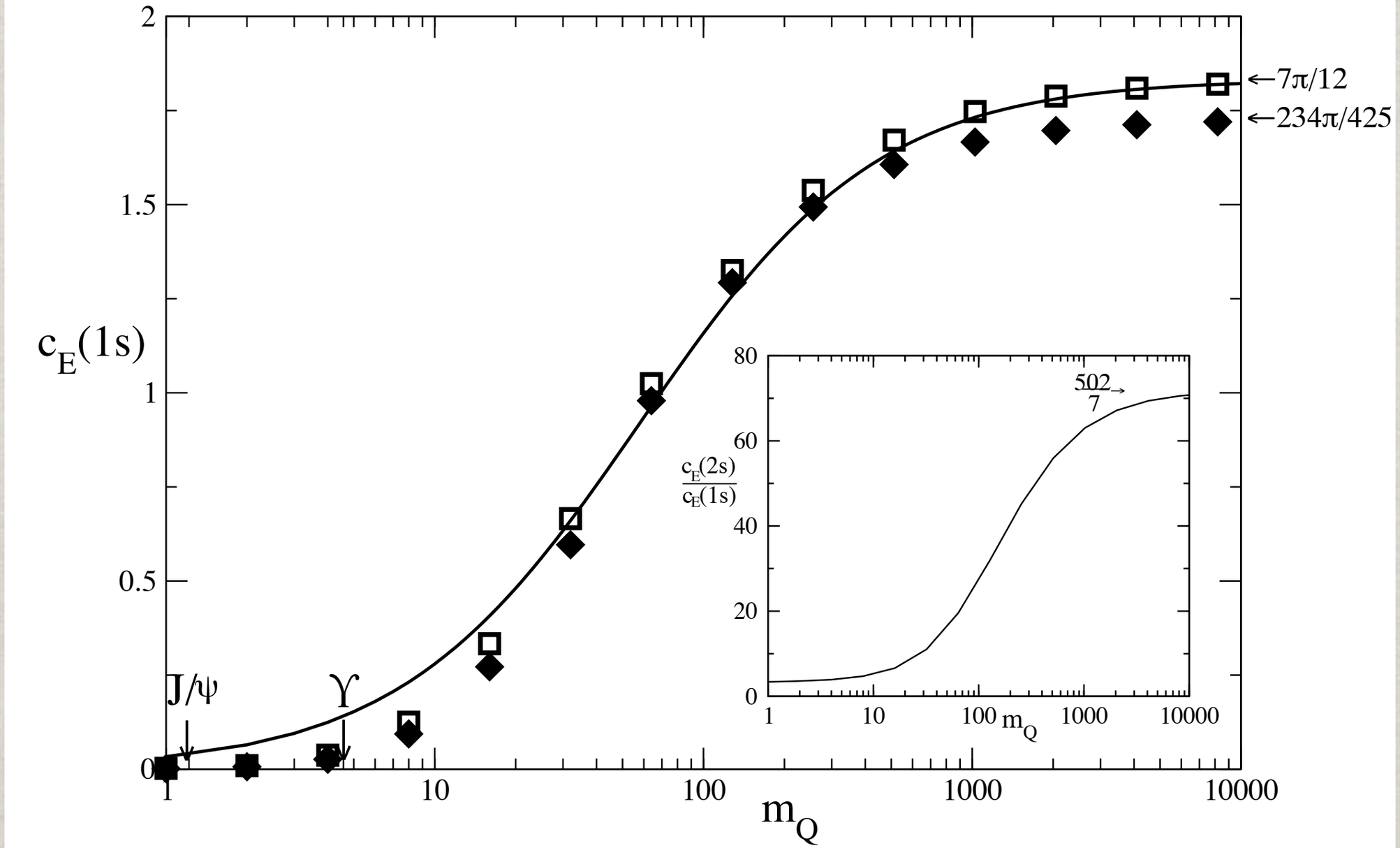
$$C_E(2S) = \frac{502}{7} C_E(1S)$$

Adiabatic hybrid surfaces



H_A *not* observed

universal behaviour *not* observed



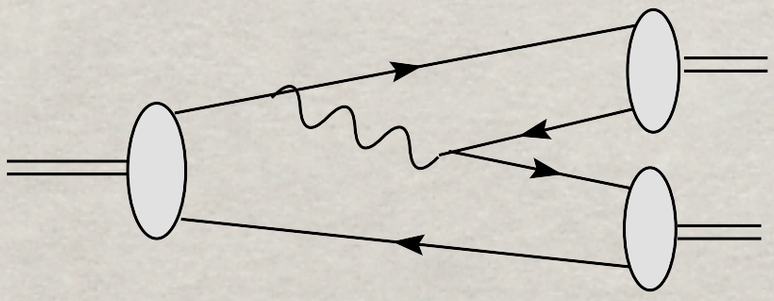
Lakhina & Swanson, PLB582, 172 (04)

B DECAYS AND RESCATTERING

RESCATTERING IN B DECAYS

$B \to \chi_{cJ} K^{(*)}$

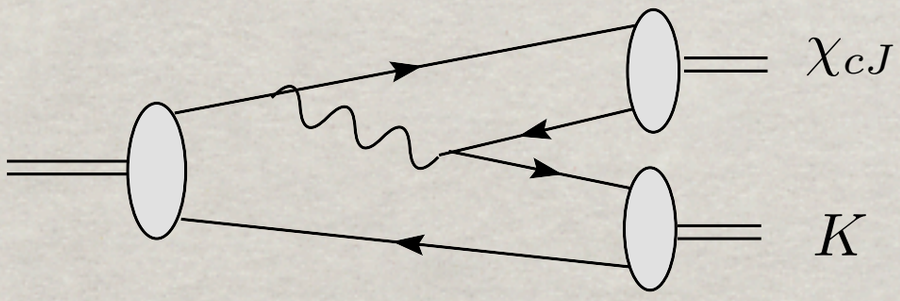
	factorisation
$Br(B \to \chi_{c0} K) = 1.4(2) \cdot 10^{-4}$	zero
$Br(B \to \chi_{c1} K) = 4.9(5) \cdot 10^{-4}$	non-zero
$Br(B \to \chi_{c2} K) < 2.9 \cdot 10^{-5}$	zero

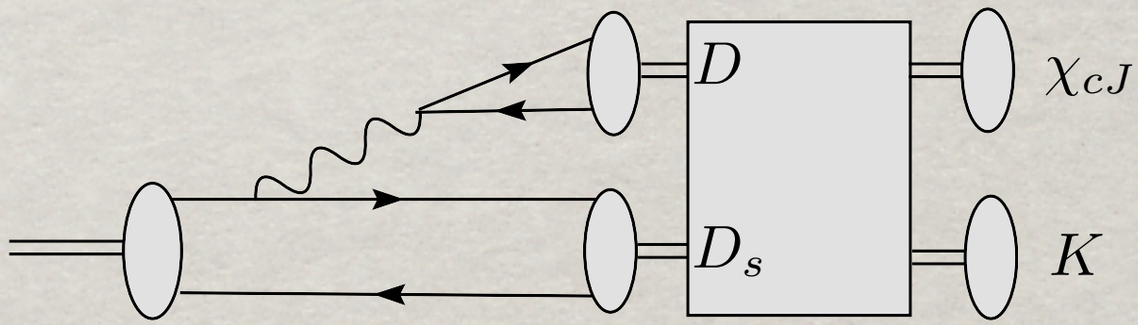


RESCATTERING IN B DECAYS

$B \to \chi_{cJ} K^{(*)}$

	factorisation	final state interaction
$Br(B \to \chi_{c0} K) = 1.4(2) \cdot 10^{-4}$	zero	S-wave
$Br(B \to \chi_{c1} K) = 4.9(5) \cdot 10^{-4}$	non-zero	P-wave
$Br(B \to \chi_{c2} K) < 2.9 \cdot 10^{-5}$	zero	D-wave





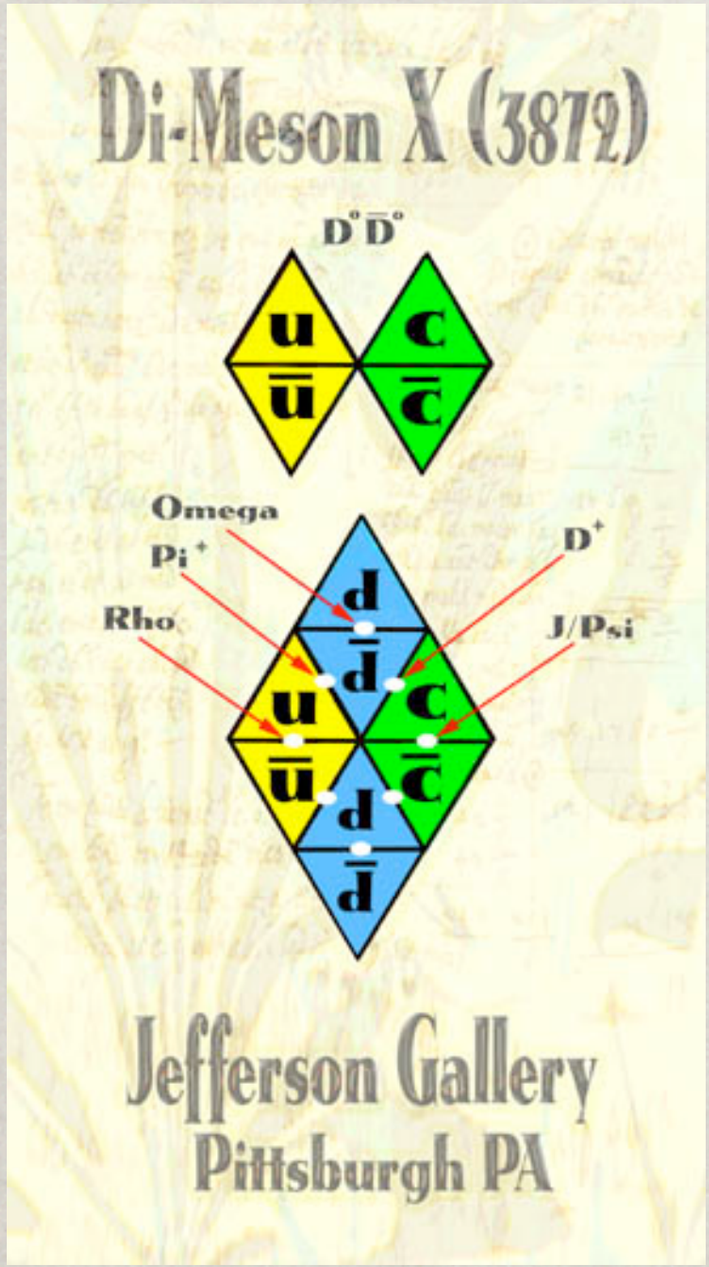
RESCATTERING IN B DECAYS

$B \to J/\psi K^{(*)}$

	$\frac{Br(B\to J/\psi K^*)}{Br(B\to J/\psi K)}$	$\frac{\Gamma_L(B\to J/\psi K^*)}{\Gamma(B\to J/\psi K^*)}$
expt	1.64 ± 0.34	$0.66 \pm 0.1^{+0.10}_{-0.08}$
		$0.80 \pm 0.08 \pm 0.05$
BSWi	4.23	0.57
BSWii	1.61	0.36
ISGW	1.71	0.06
QCDSR	7.60	0.36

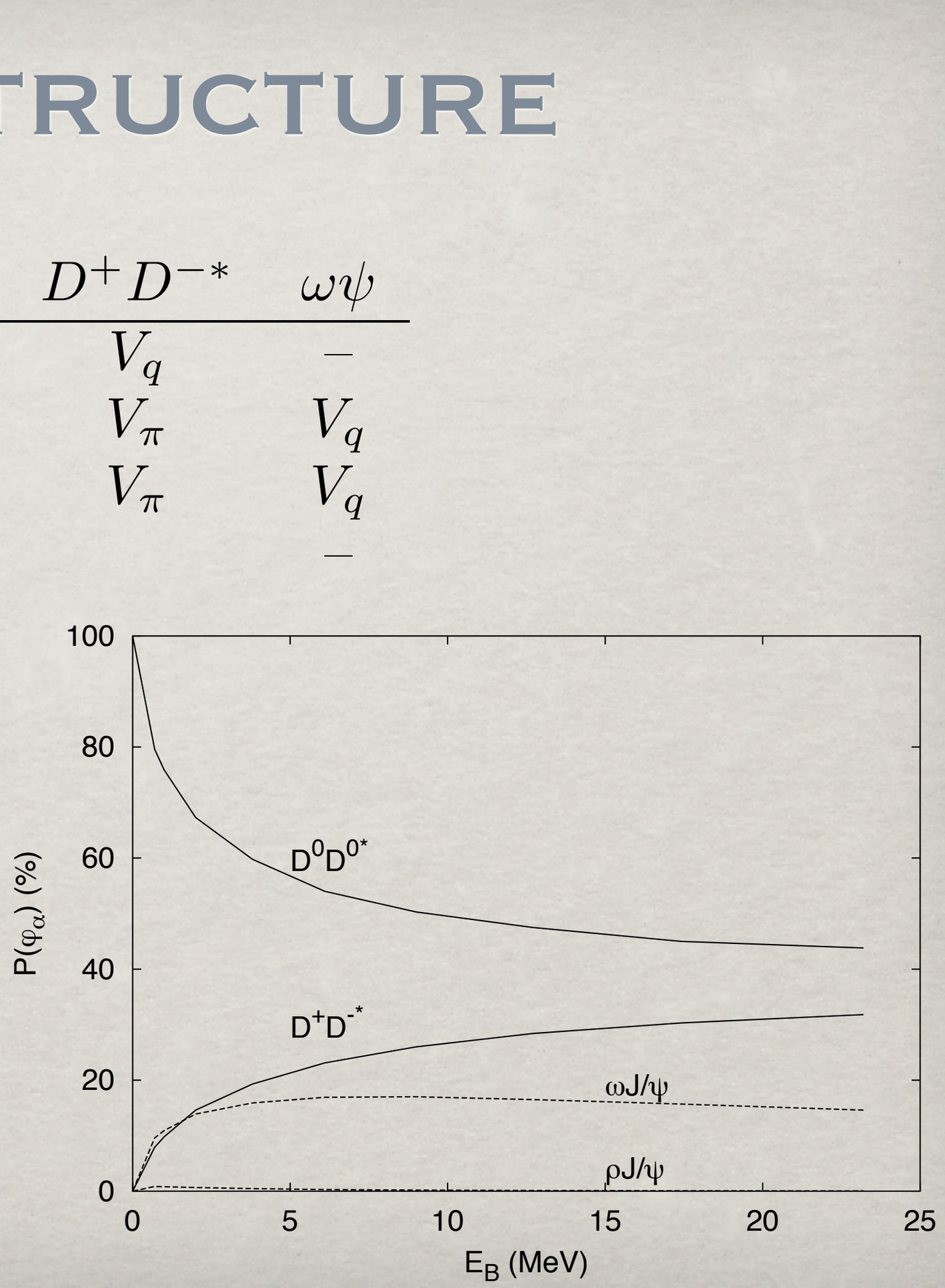
expt	$\lvert A_0\rvert^2$	$\lvert A_\perp\rvert^2$	$\delta_{\lvert\rvert}$	$\delta_\perp$
CLEO	$0.52 \pm 0.07 \pm 0.04$	$0.16 \pm 0.08 \pm 0.04$	$3.00 \pm 0.37 \pm 0.04$	$-0.11 \pm 0.046 \pm 0.03$
CDF	$0.59 \pm 0.06 \pm 0.01$	$0.23 \pm 0.19 \pm 0.04$	$2.2 \pm 0.5 \pm 0.1$	$-0.6 \pm 0.5 \pm 0.1$
BaBar	$0.556 \pm 0.009 \pm 0.010$	$0.233 \pm 0.010 \pm 0.005$	$2.93 \pm 0.08 \pm 0.04$	$2.91 \pm 0.05 \pm 0.03$
Belle	$0.574 \pm 0.012 \pm 0.009$	$0.195 \pm 0.012 \pm 0.008$	$-2.887 \pm 0.090 \pm 0.008$	$2.938 \pm 0.064 \pm 0.010$

X(3872) PRODUCTION

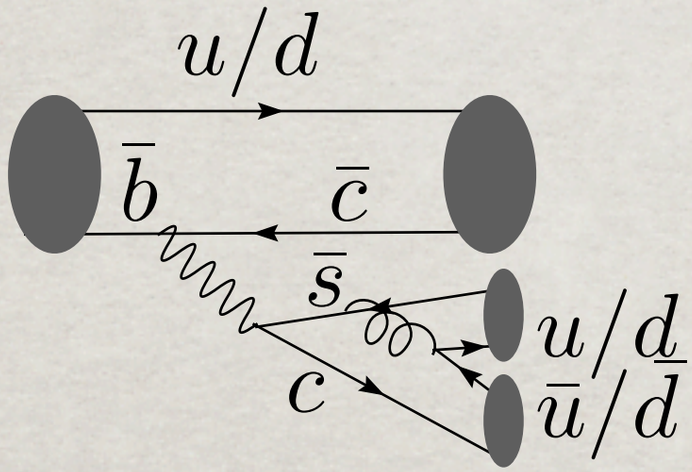


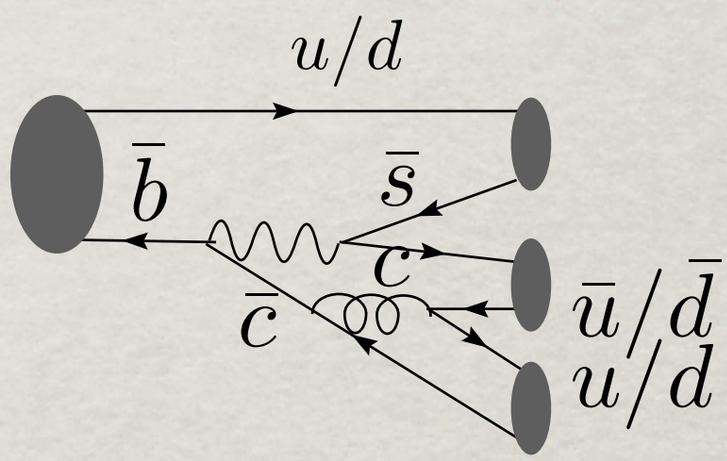
X(3872) STRUCTURE

V	$\rho\psi$	$D^0\bar{D}^{0*}$	D^+D^{-*}	$\omega\psi$
$\rho\psi$	–	V_q	V_q	–
$D^0\bar{D}^{0*}$		V_π	V_π	V_q
D^+D^{-*}			V_π	V_q
$\omega\psi$				–

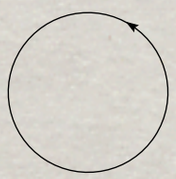


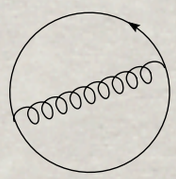
$$B^0 \to K^+ D^0 D^- \qquad B^0 \to K^0 D^0 \bar{D}^0$$
$$B^0 \to K^0 D^- D^+ \qquad B^0 \to K^0 D^+ D^-$$
$$B^+ \to K^+ D^0 \bar{D}^0 \qquad B^+ \to K^+ D^+ D^-$$
$$B^+ \to K^0 \bar{D}^0 D^+$$

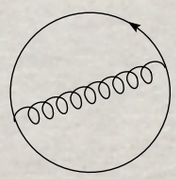




colour:







D. Bernard, Beijing, 6-05

$$\frac{Br(B^0 \to XK^0)}{Br(B^+ \to XK^+)} = 0.61(36)(6)$$

$$\frac{Br(B^0 \to K^0 X)}{Br(B^+ \to K^+ X)} = \frac{|4Z_{+-}^{1/2} + Z_{00}^{1/2}|^2}{|4Z_{00}^{1/2} + Z_{+-}^{1/2}|^2} \approx 0.06 - 0.29$$

Conclusions

- NRQCD supplants the colour singlet and colour evaporation models, but does it work for charm?
- there is ample evidence of non-factorisation in B decays
- B decays and e^+e^- are an excellent laboratory for exploring the dynamics of strong QCD

✣ ÆRIC MEC HEHT GEWYRCAN