Impliations of the broad charm resonance measurement in B->Kll

Lyon and RZ 1406.0566v1(v2 to appear)

CP³ Origins
Cosmology & Particle Physics

CENTRE FOR THEORETICAL PHYSICS · Higgs

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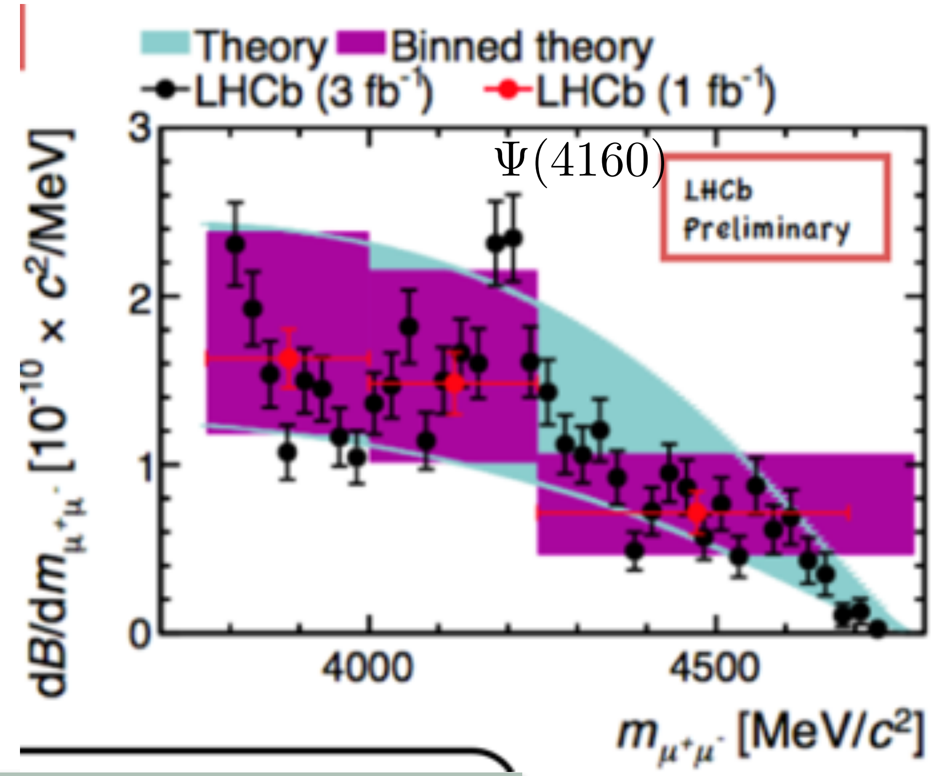
16 October 2014 — Implication of LHCb measurements (CERN)

Overview and main messages…

1) assessment

A. **factorisation** (failure)

B. **fits** probing **non-fac**. contributions



question: is it SM(QCD) or not?

2) implications and analysis

A. **right-handed currents** versus non-universal **polarisation**

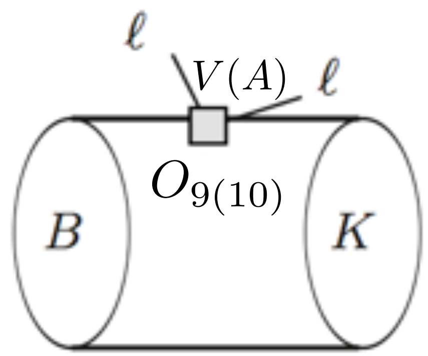
B. how surprising charm resonances
i) in view **$B \to J/\Psi K$** & ii) quark-hadron duality

C. **phase** of **J/Ψ unknown** (experiment)
impacts low q^2 e.g. Br($B \to Kll$) and P_5'

Basics of $B \to K^{(*)}ll$ for this talk

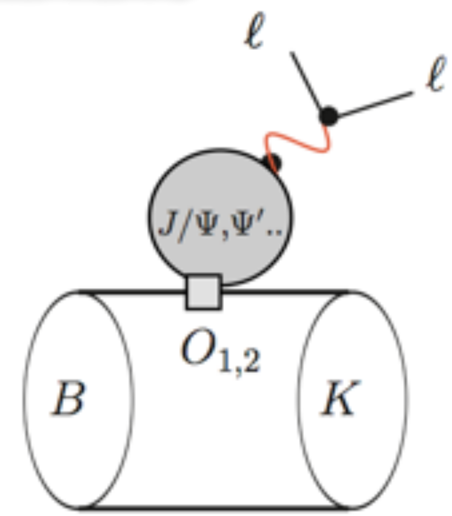
- main actors of this talk (same quantum numbers!)

short distance



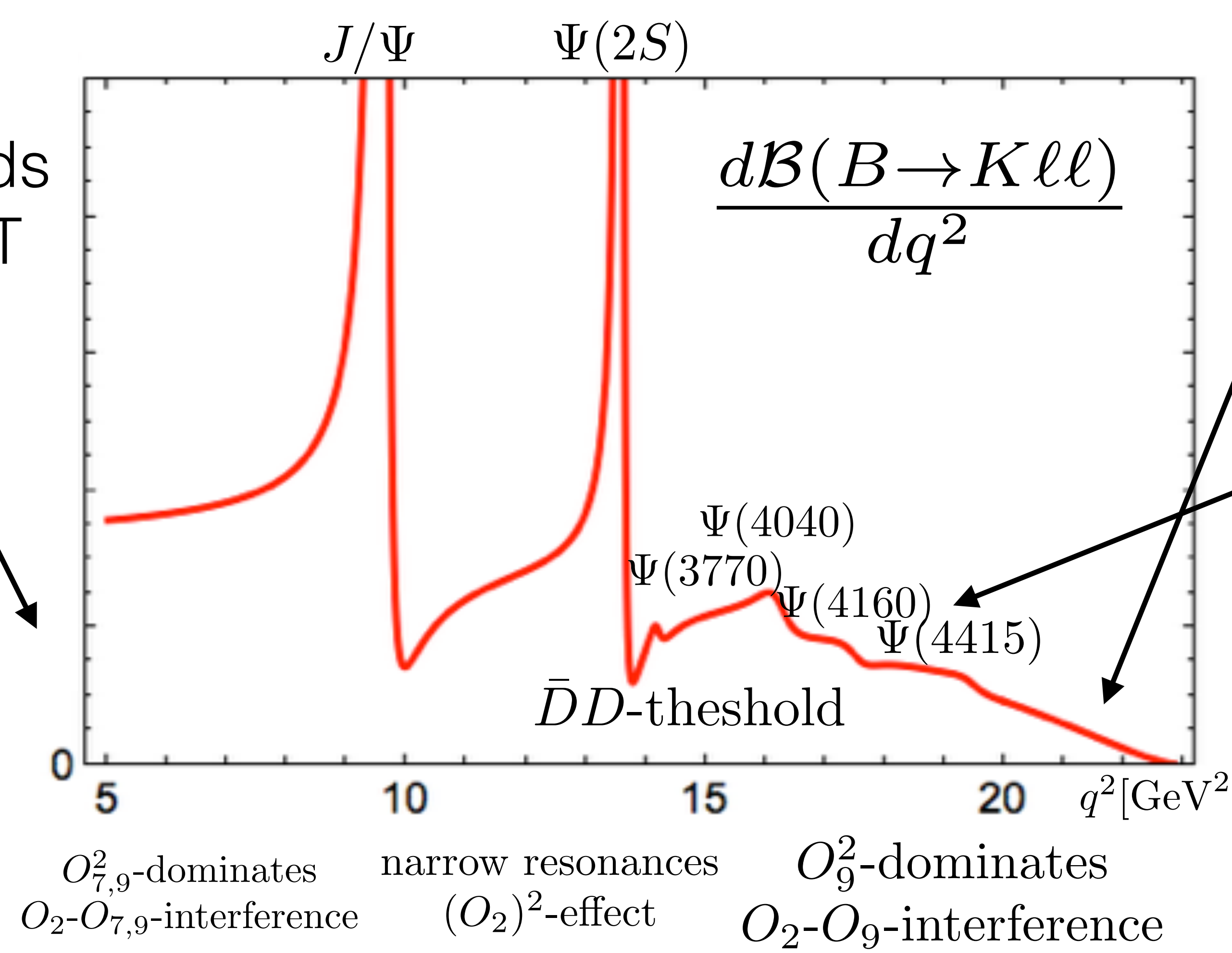
electroweak penguin (also O_7..)

Long distance



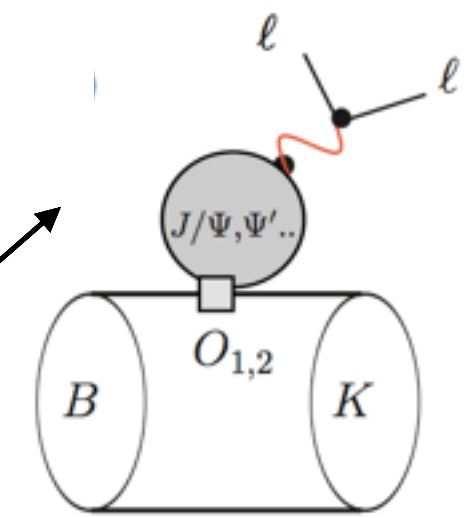
4-quark operators (also $O_{3..6}$)

K **fast**:
- **light-cone** methods
LCSR, QCDF/SCET



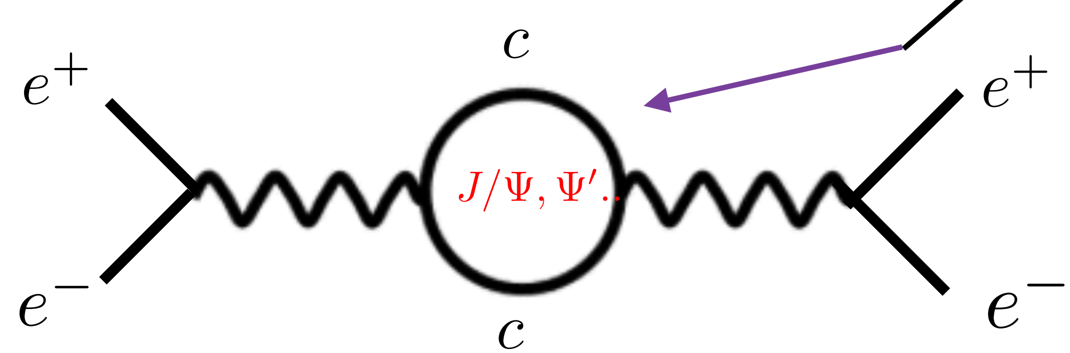
K **slow**:
- high-q^2 **"OPE"**
-**endpoint relations**

diagnostic shape for charm

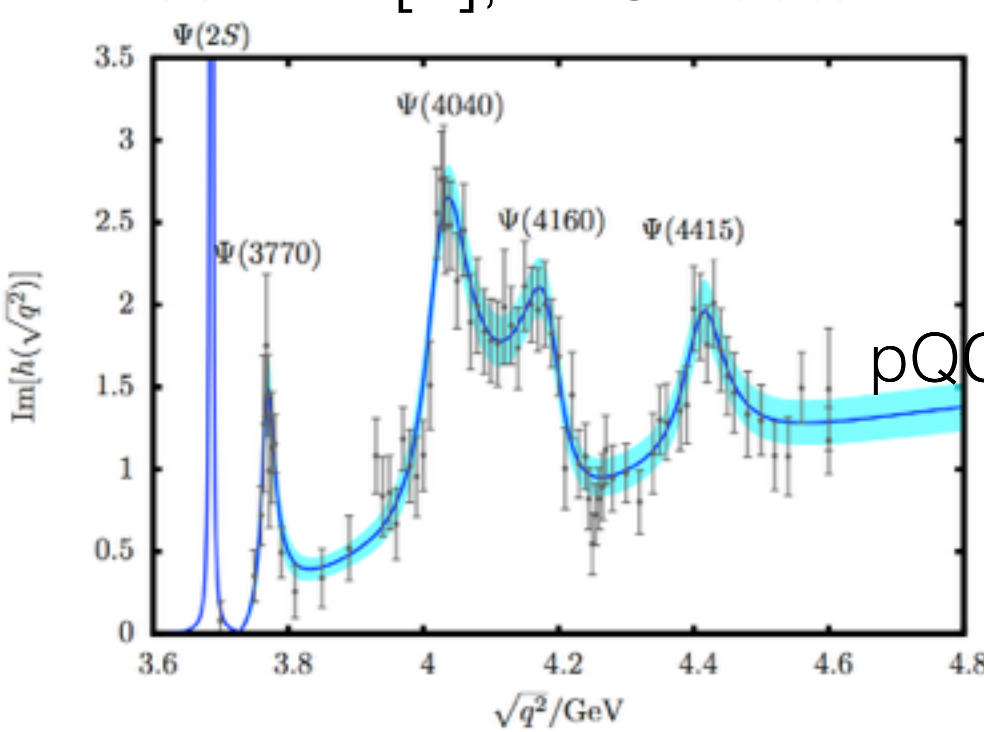


A. does factorisation describe B→Kll data?

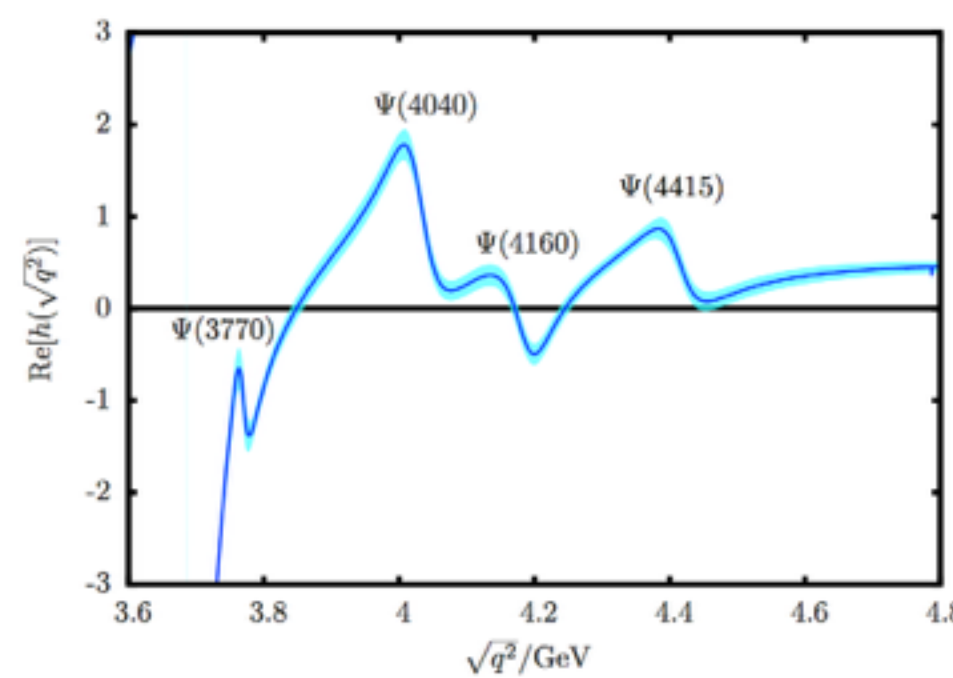
- vac. pol. $h(q^2)$ from e^+e^-→hadons as for (g-2)



Disc ~ Im[h]; BESII-data'PLB08 → Re[h] **dispersion relation**

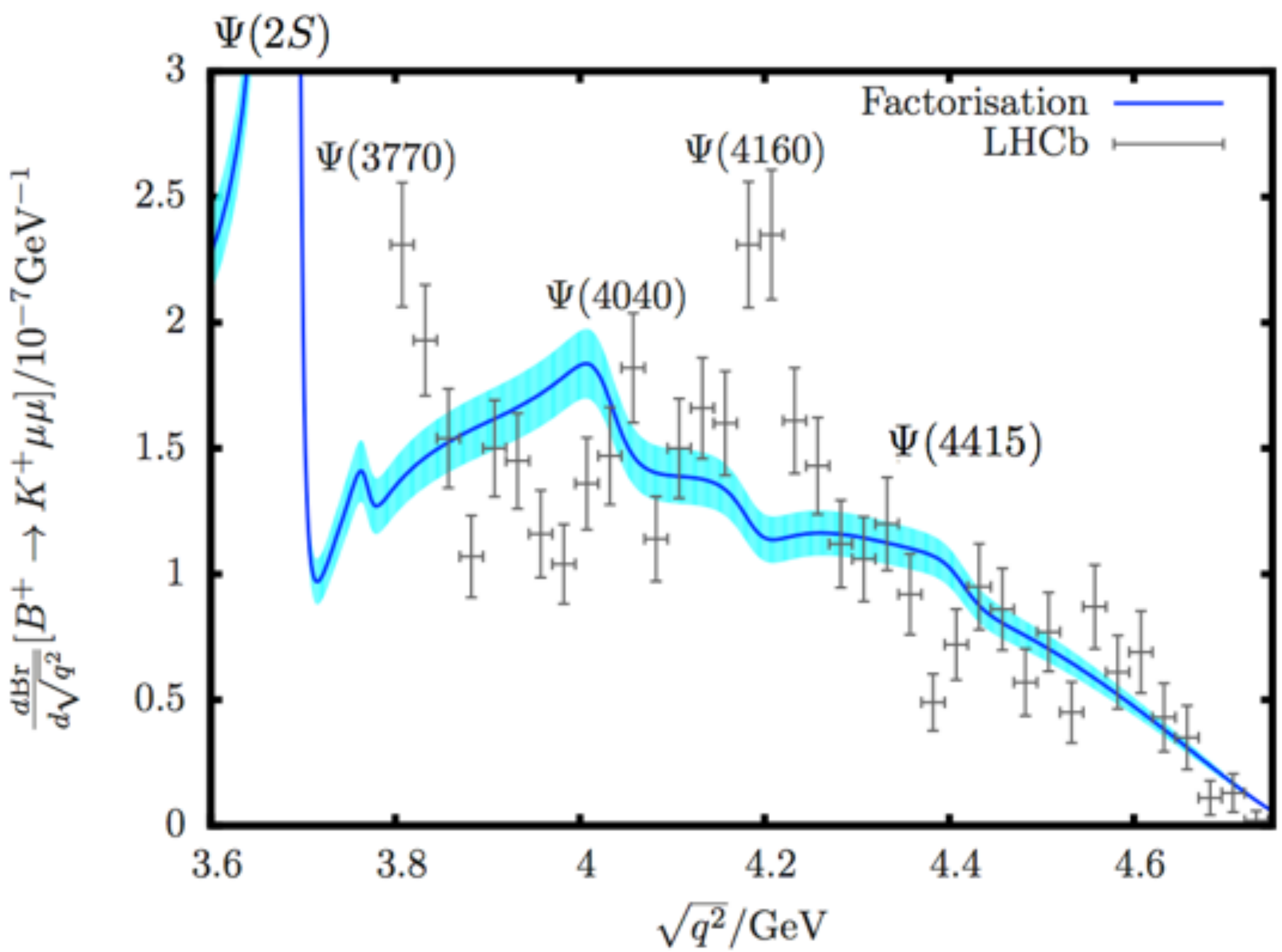


pQCD "ok"



our **χ^2/dof = 1.015**

Factorisation (BESII-data) applied to B→Kll at high q²



clear failure of factorisation

clarifying status of factorisation of importance since:

- factorisation used estimate of “duality violations”
- perturbative factorisation used in most high-q^2 OPE predictions

B. probing non-factorisable effects

- think resonances described Breit-Wigner

N.B. 1) location of pole & 2) residue are **physical**!

$$\mathcal{A}(B \to K\ell\ell)|_{q^2 \simeq m_\Psi^2} = \frac{\mathcal{A}(B \to \Psi K)\mathcal{A}^*(\Psi \to \ell\ell)}{q^2 - m_\Psi^2 + i m_\Psi \Gamma_\Psi} + ..$$

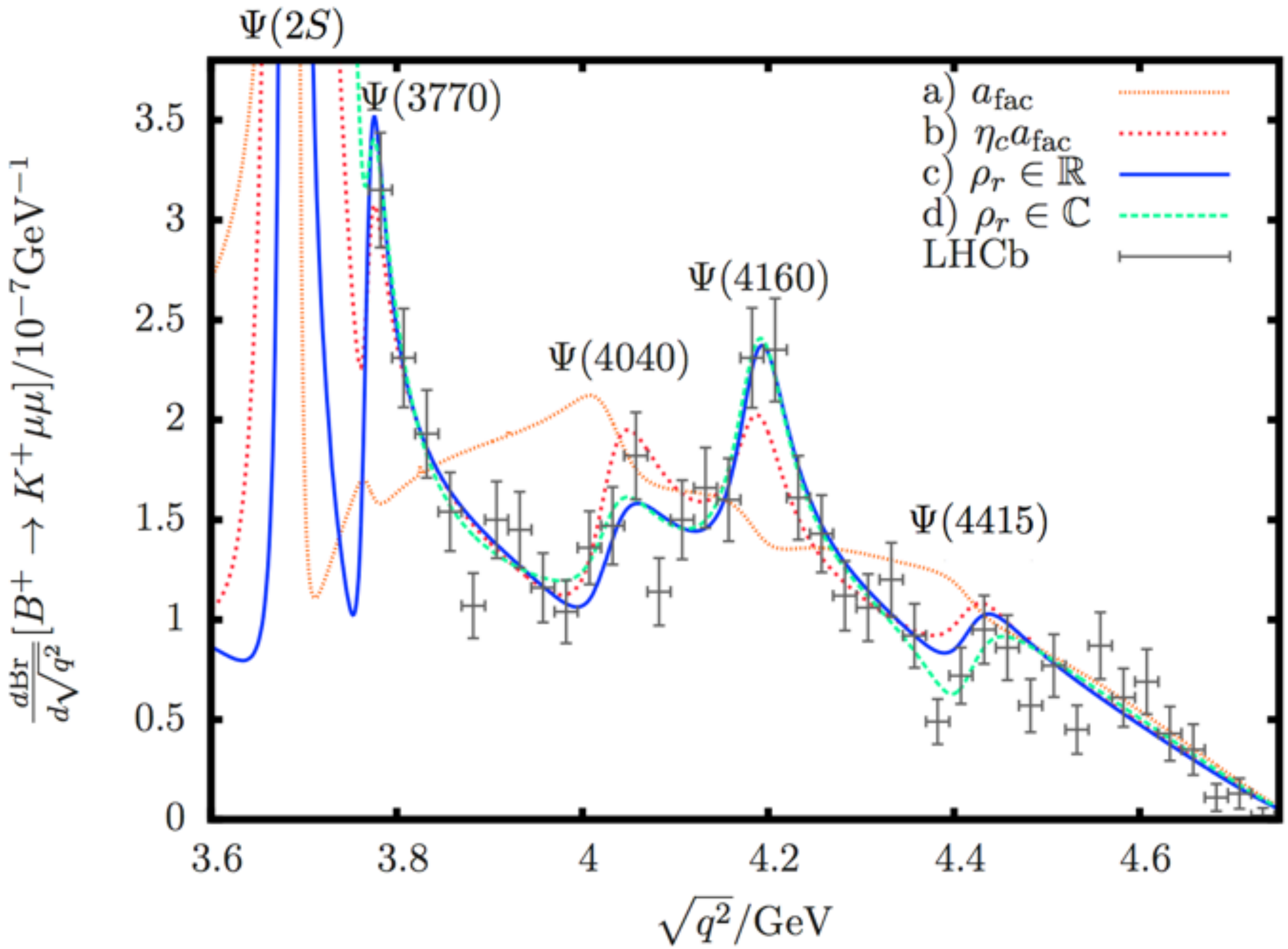
- idea: correct for Ψ-production (residue physical)

$$\begin{aligned} \mathcal{A}(B \to \Psi K)|_{\rm fac} &\sim f_+^{B\to K}(q^2)\mathcal{A}(\Psi \to \ell\ell) \\ &\to f_+^{B\to K}(q^2)\underbrace{\eta_\Psi}_{1+\text{non}-\text{fac}}\mathcal{A}(\Psi \to \ell\ell) \sim \mathcal{A}(B \to \Psi K) \end{aligned}$$

- fits $\boldsymbol{\eta_\Psi}$: b) global (scaled)fac; c) real-variable; d) complex-variable

only option d) sensible a priori

results ....



Fit	η_B	η_c	$\rho_{\Psi(2S)}$	$\rho_{\Psi(3370)}$	$\rho_{\Psi(4040)}$	$\rho_{\Psi(4160)}$	$\rho_{\Psi(4415)}$	χ^2/d.o.f.	d.o.f.	pts	p-value
$a)$	0.98	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$	3.59	99	117	$\simeq 10^{-30}$
$b)$	1.08	-2.55	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$	1.334	98	117	1.5%
$c)$	0.81	$\equiv 1$	-1.3	-7.2	-1.9	-4.6	-3.0	1.169	94	117	12%
$d)$	1.06	$\equiv 1$	3.8-5.1i	-0.1-2.3i	-0.5-1.2i	-3.0-3.1i	-4.5+2.3i	1.124	89	117	20%
			$6.4e^{-i53.3^\circ}$	$2.0e^{-i92^\circ}$	$1.3e^{-i111^\circ}$	$4.3e^{-i135^\circ}$	$5.1e^{i153^\circ}$				

2) Implications and contemplation

real question is whether this is SM(QCD) or not

right-handed currents (RHC) vs non-universal polarisation in $B \to K^* ll$

- issue imminent from structure of **helicity amplitudes**

$$H_0^V \sim (C_9 - C_9') \, \hat{H}_0{}^V(q^2) + .. \, , \quad H_{\|}^V \sim (C_9 - C_9') \hat{H}_{\|}^V(q^2) + .. \, , \quad H_{\perp}^V \sim \sqrt{\lambda_{K^*}} (C_9 + C_9') \, \hat{H}_{\perp}^V(q^2) + .. \, ,$$

RHC $C_9' \neq 0$ intertwined polarisation effects $0, \|, \perp$

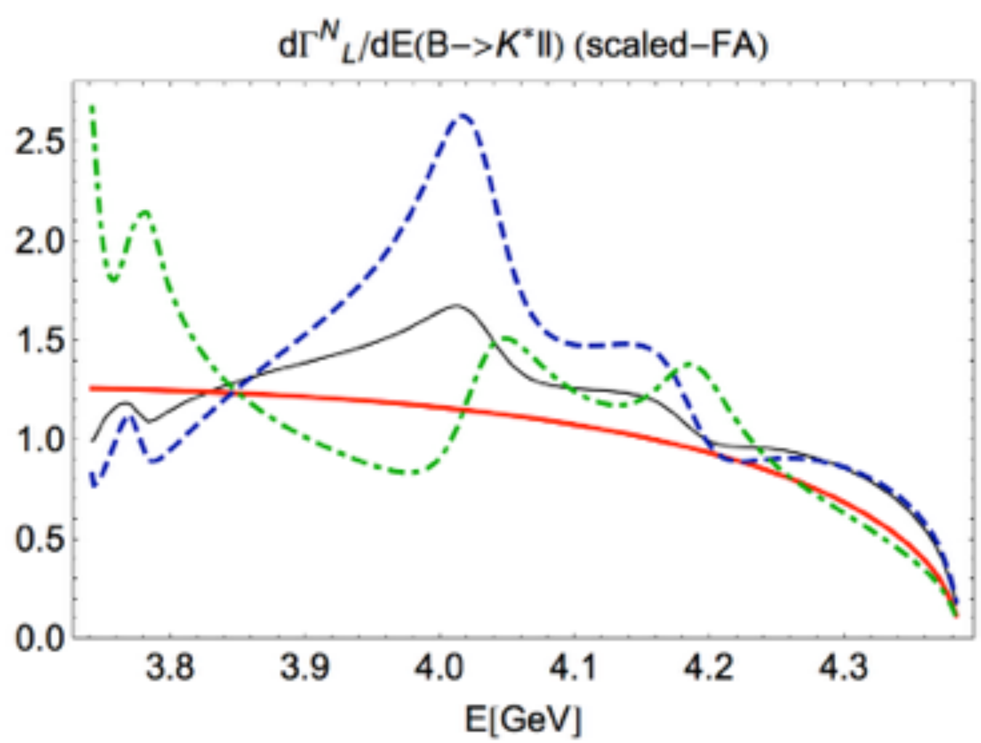
- question: do fac and non-fac depend differently on polarisation?

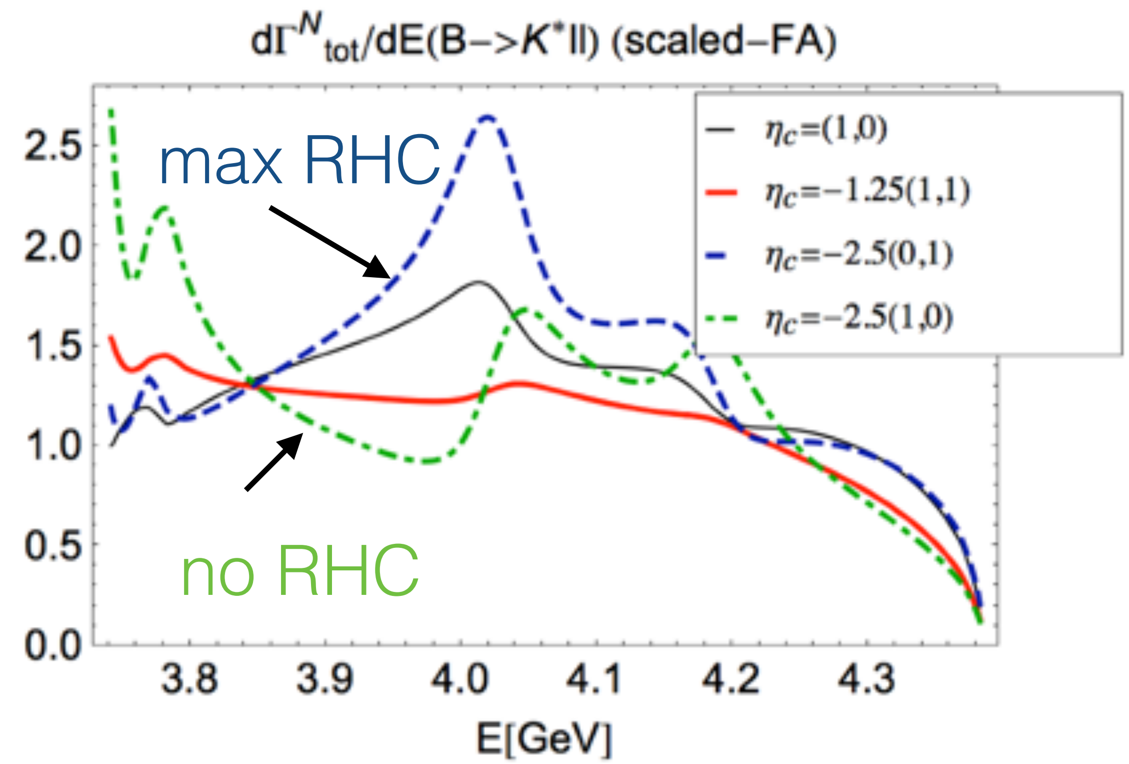
$$\frac{|H_0^V|}{|H_{\|}^V|} \stackrel{?}{\simeq} \frac{|f_0^V|}{|f_{\|}^0|} \quad \text{for some } q^2, \; f \text{ form factor}$$

S-state: J/Ψ ok, Ψ(2S) okish,
P-state: χ_{c1} broken
D-state: Ψ(3370),Ψ(4160) ? —- experimentally accessible

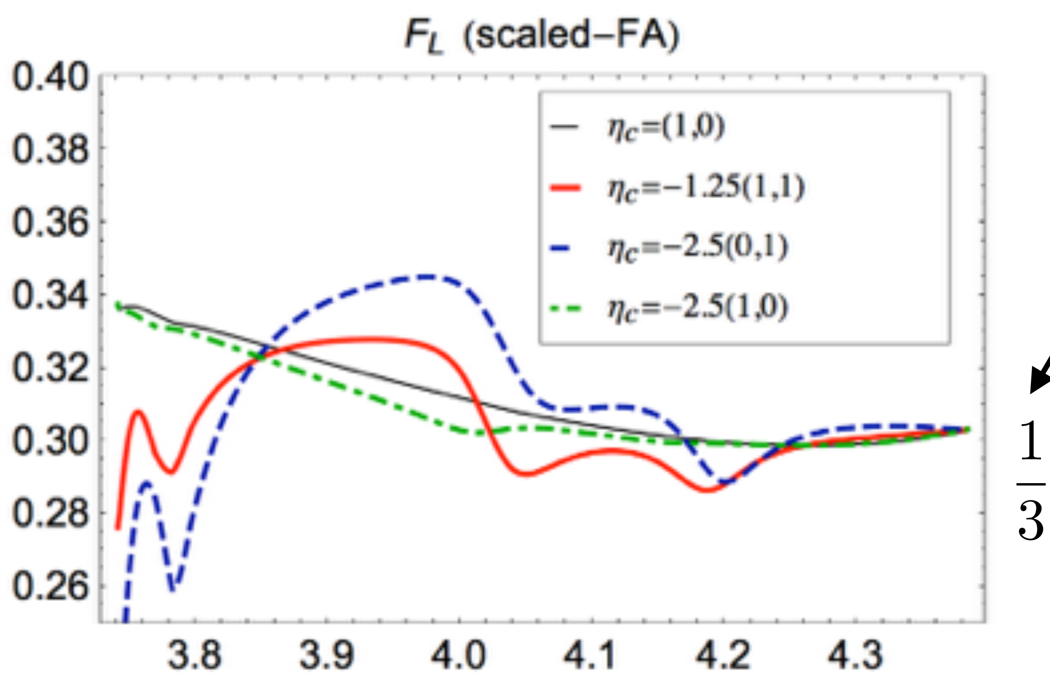
what is the pattern?

- **if polarisation universal** then $Br_X(B \to K^* ll)$ X=L,tot good observable to test for right-handed currents*





- **if polarisation universal** and **no RHC** then resonance effect minimal in class of observables Hiller and RZ'13



e.g. **black** and **green** curve nearly **identical** even though green curve has 2.5 as much resonances!
N.B. endpoint all curves asymptotes 1/3

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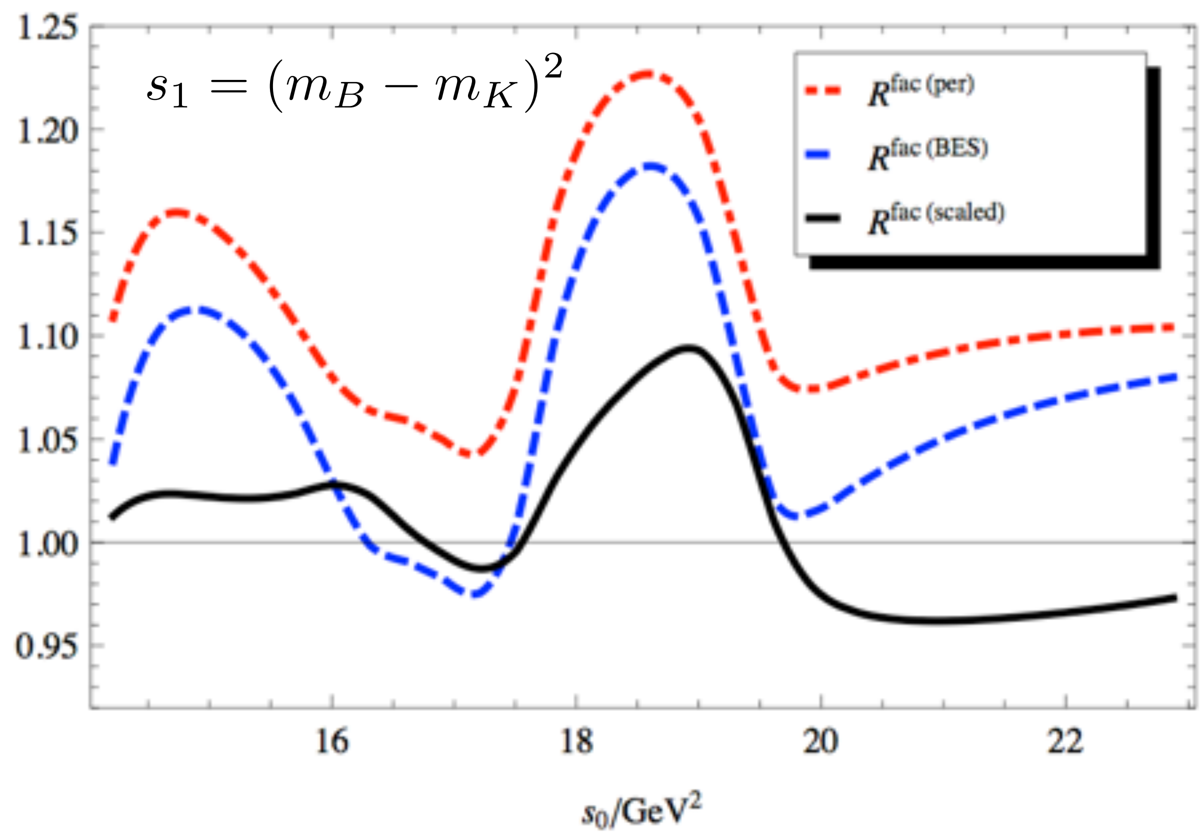
* *assumes effect same magnitude in $B \to K^* ll$ (could be bit smaller or larger in reality)*

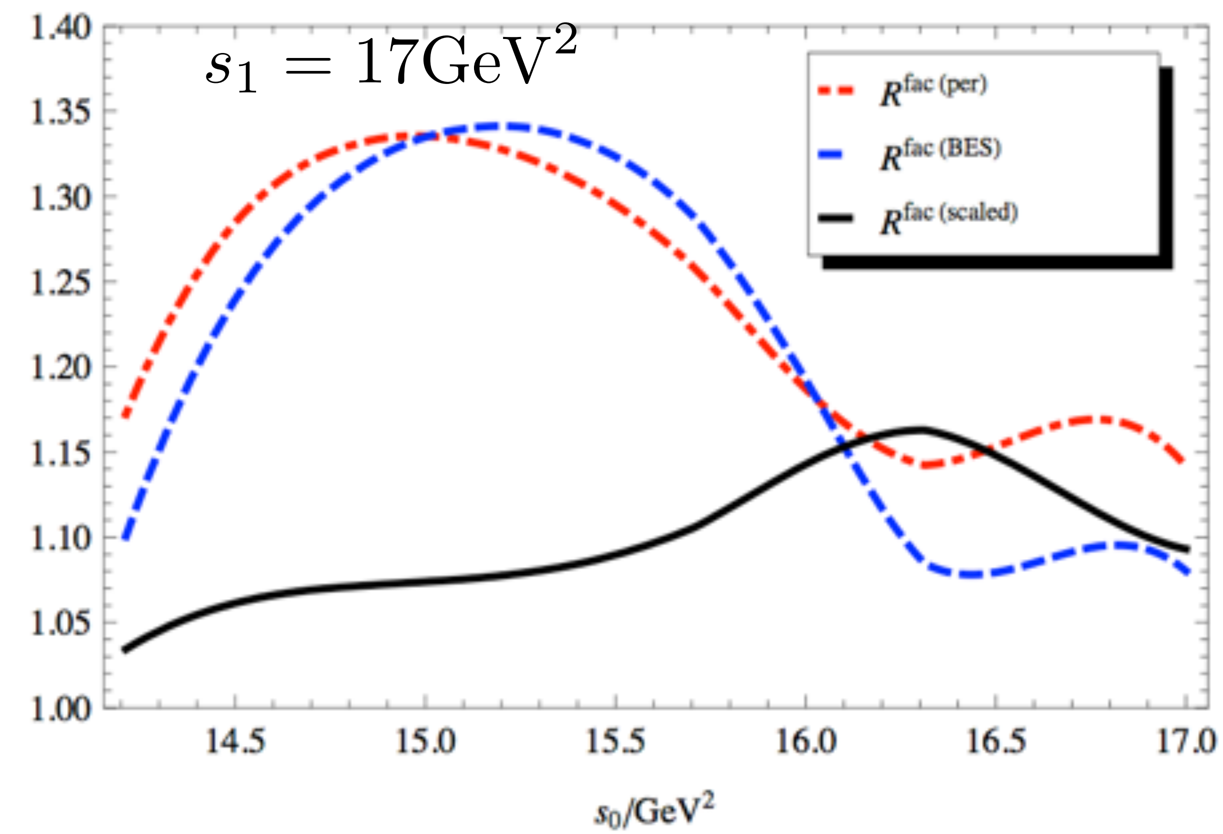
Br(B→Kll) high q^2: a priori and a posteriori

- ratio of Br(B→Kll) using
  i) factorisation perturbative (no resonances)
  ii) factorisation (BES-data)
  vs data as function lower bin bdry s_0

$$\frac{\mathrm{Br}(B^+ \to K^+ \ell\ell)^{i),ii)}_{[s_0,s_1]}}{\mathrm{Br}(B^+ \to K^+ \ell\ell)^{fit-d)}_{[s_0,s_1]}}$$

basically as good as data (by construction)



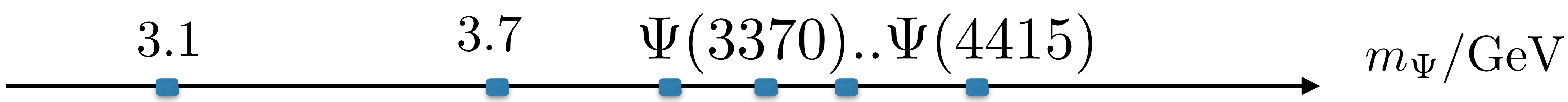


if assume that effect is **SM** ⇒

one has to give some thought to this issues when making predictions

Factorisation as a function of m_Ψ

- for a long time there has been information on B→J/ΨK and B→Ψ(2S)K quantify failure of factorisation by scale factor $\eta_\Psi = 1 + \text{non-fac}$



$$|\eta_{J/\Psi}| \simeq 1.4 \quad |\eta_{\Psi(2S)}| \simeq 1.8 \quad \eta_\Psi(\text{broad}) \simeq -2.5$$

1. whereas corr. to J/Ψ, Ψ(2S) could be 40%, 80% “only” , the **new** information is that on **average** there is **350%** correction for **broad Ψ(3770) - Ψ(4415)**

2. N.B magnitude 2.5 not a big surprise but that they i) **all have “same sign”** & ii) **sign negative** **challenges quark-hadron duality*** (nominal core 50%)

is it really SM(QCD)? or new bccs-operators?

3. N.B. phase of J/Ψ is unknown Ψ(2S) marginal knowledge from fit phase influences low q^2 observables in bin close to J/Ψ

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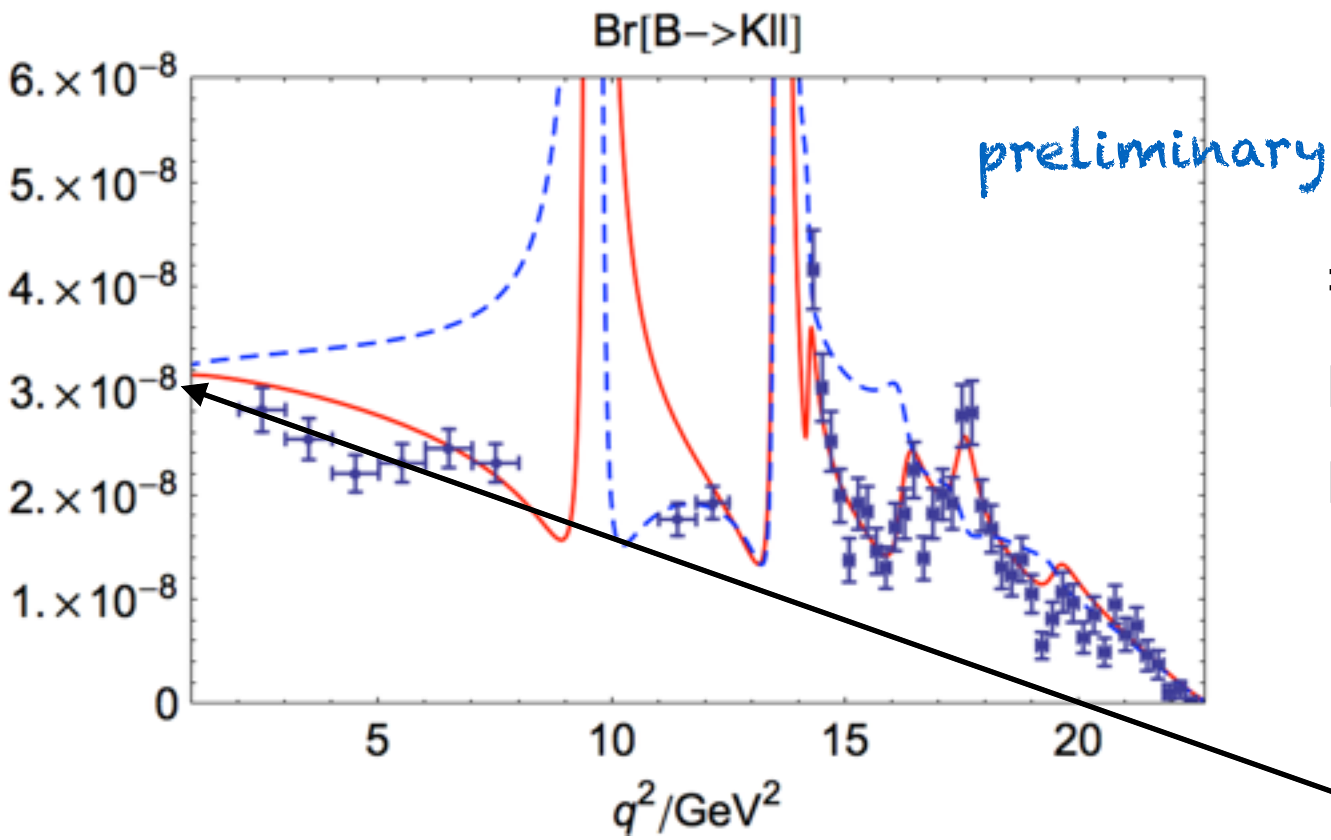
* *more in paper and in backup slides (no time for discussion here)*

the unknown J/Ψ phase

$$\eta_{J/\Psi} = |\eta_{J/\Psi}| e^{i\delta_{J/\Psi}} \simeq 1.4 e^{i\delta_{J/\Psi}}$$

- to match/fit slop of pQCD charm $\delta_{J/\psi} \simeq 0$ e.g. Khodjamirian et al'10 and others
- let's change phase to $\delta_{J/\psi} \simeq \pi$ and compare with Br(B→Kll)



$\Longrightarrow$ empirically $\delta_{J/\psi} \simeq \pi$
not absurd (even slightly favoured)
not as conclusive as high q^2

- $\delta_{J/\psi} \simeq \pi$ matched charm amplitude to SM at $q^2 = 0$
  well but then slope of charm amplitude has wrong sign!
  $\Longrightarrow$ more precise data binning

relation to $P_{5'}$

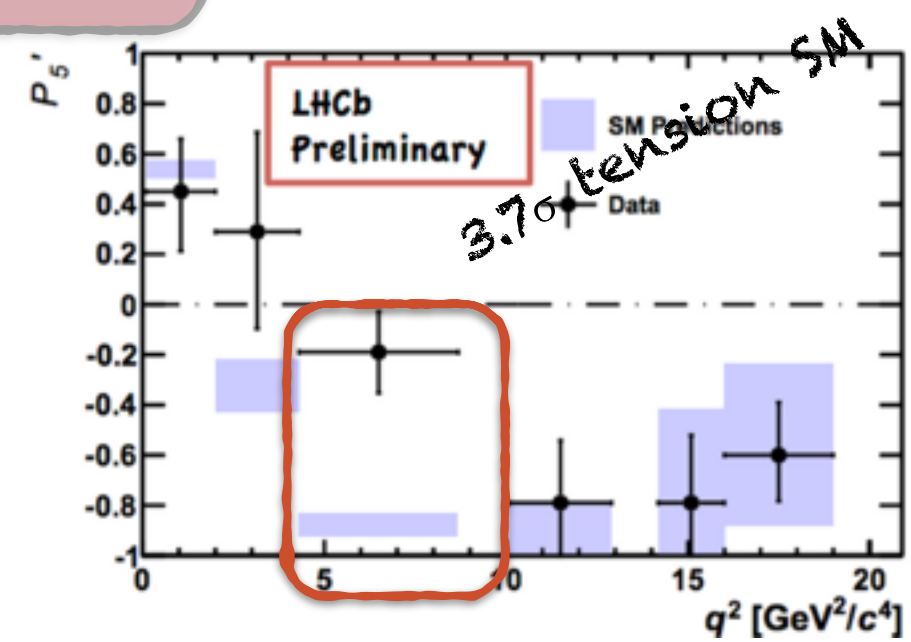
preliminary sketch

- change to $\delta_{J/\Psi} \simeq \pi$ will affect other observables and the decisive q^2-spectrum is the thing to look out for

- let's define "average shift" of C_9 as function of the bin

$$\Delta C_9|^K_{s_0,s_1} = a_{\rm fac} \int_{s_0}^{s_1} ds (h_c^{\delta_{J/\Psi}=\pi}(s) - h_c^{pQCD}(s))$$

$[s_0, s_1]/\mathrm{GeV}^2$	$[4.3, 8.68]$	$[2, 4.3]$	$[1, 6]$
$\Delta C_9\|^K_{s_0,s_1}$	-2	-0.5	-0.6



- $[4.3,8.68]$:$(\Delta C_9, \Delta C_9')=(-1.6,-1.4) \Rightarrow \Delta P_5' \simeq -0.4$

  recall that $\Delta C_9'$ not significant
  hence $\Delta C_9 \simeq -2$ can close to LHCb-value*

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* *effect larger in $B \to K^* ll$ as breaking of factorisation stronger $B \to J/\Psi K^*$ than in $B \to J/\Psi K$*

conclusions and summary

- **factorisation** approximation **fails** spectacularly (resonances same sign) $\Longrightarrow$ **pressure SM(QCD)** in view of quark-hadron duality (backup slides)

- can there be **new physics in bscc-operators?** (contrived) what are the constraints? $b \to s\gamma$, $\Delta\Gamma_s$, ..

- **If** polarisation universality is established (reasonable level) $\Rightarrow$ test for right-handed currents in bccs-operators in $Br_{L,tot}(B \to K^* ll)$

- How distinguish short-distance from long-distance* new physics? ***If** non form factor **q^2-dependence $\Rightarrow$ long-distance new physics****

- change in **$\delta_{J/\psi} \simeq \pi$** (empirically unknown) fits **shape** and magnitude of $Br(B \to Kll)$ low q^2 and also looks promising for P_5'

- whereas charm troubles short-distance new physics searches
  i) of course there is room for short-distance new physics in $C_9^{\rm eff}$
  ii) progress in form factor correlations (backup) should help in searches
  iii) charm resonances are lepton-universal $\Rightarrow$ no relation to R_K

thanks for you attention

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* *long distance new physics: $\delta H_{NP} = \delta C\, O$ which contributes to long-distance physics*

backup slides

comment on form factor correlations ….

Use of equation of motion for form factors

- Consider QCD e.o.m./Ward-identity (*study correction Isgur-Wise relations*)

Grinstein Pirjol'04

$$i\partial^\nu(\bar{s}i\sigma_{\mu\nu}(\gamma_5)b) = -(m_s \pm m_b)\bar{s}\gamma_\mu(\gamma_5)b + i\partial_\mu(\bar{s}(\gamma_5)b) - 2\bar{s}i\overleftarrow{D}_\mu(\gamma_5)b$$

- Evaluate on ⟨K*| …|B⟩ get 4 independent equations e.g.

$$T_1(q^2) - \frac{(m_b + m_s)}{m_B + m_{K^*}}V(q^2) + \mathcal{D}_1(q^2) = 0$$

- 1) any determination of form factors must satisfy e.o.m.

  2) Correlation function lattice/LCSR are compatible e.o.m. up to irrelevant contact terms

Hambrock, Hiller, Schacht, Zwicky '13
Bharucha, Straub, Zwicky'14 (to appear)

$$T_1(q^2) - \frac{(m_b+m_s)}{m_B+m_{K^*}}V(q^2) + \mathcal{D}_1(q^2) = 0$$

- 1) denote $F(q^2)^{s_0^F, M_F^2}$, s_0^F threshold, M_F^2 Borel parameter
  then compatible with eom $s_0^{T_1} = s_0^V = s_0^{\mathcal{D}_1}$ and $M_{T_1}^2 = M_V^2 = M_{\mathcal{D}_1}^2$ *
  2) observe $T_1, V \gg D_1$ (5% maximal) over q^2-range $[0,15]\mathrm{GeV}^2$

- even associate 40% uncertainty to D_1 then ratio

$$r_\perp = \frac{(m_b+m_s)}{m_B+m_{K^*}}\frac{V(q^2)}{T_1(q^2)}$$ determined up to 2%

Crucial for $B \to K^* ll$ pheno as determines zero of helicity amplitude ….

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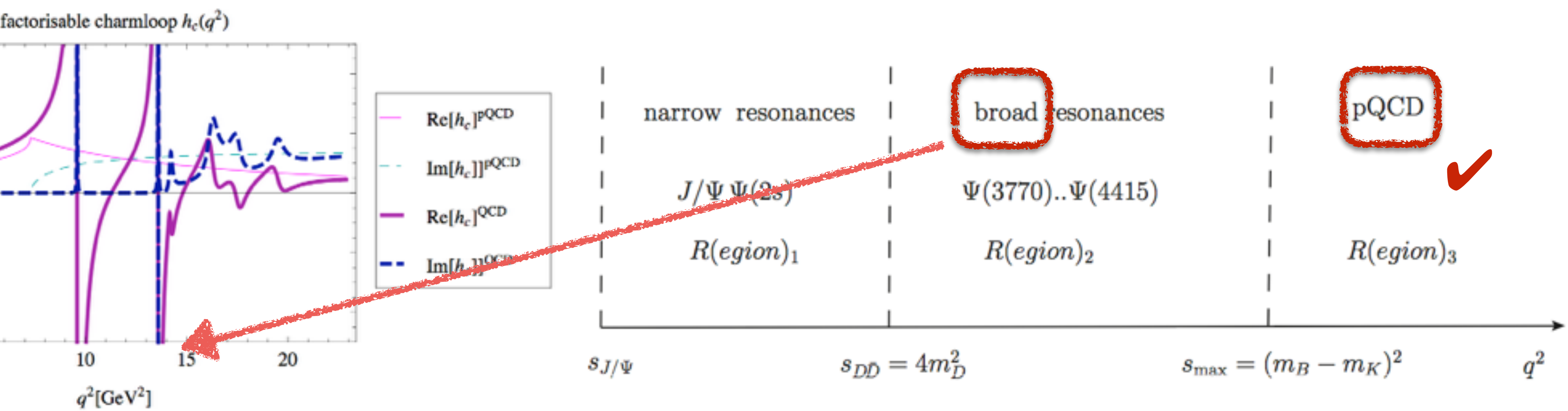
* *means that s_0 and M^2 of T_1 and V highly correlated*

Quark-hadron duality

- colloquially: "when smeared (integrated) over large enough interval quark and hadrons lead to quantitatively similar results"
- formal level only approach (known to me) via dispersion relations (DR) non-fac. correction obey same (verified) DR as factorisable part

$$H^{V,X}(s) = H^{V,X}(s_0) + \frac{(s-s_0)}{2\pi i}\int_{s_{J/\Psi}}^{\infty} \frac{dt}{t-s_0}\,\frac{\mathrm{Disc}[H^{V,X}](t)}{t-s-i0}\ , \qquad X \in \{\mathrm{fac}, \mathrm{cor}\}\ .$$

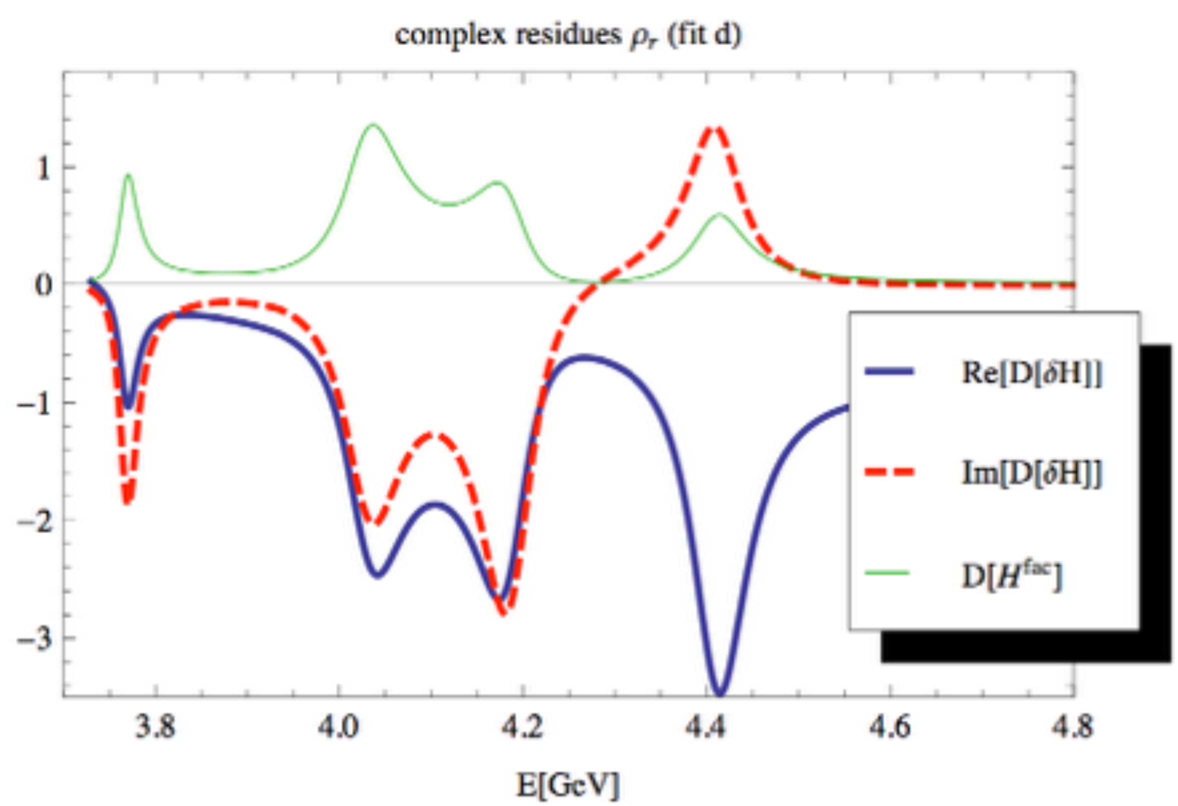


second conclusions of phase 2:

- factorisable part duality over open charm is ok less 10% error
- could expect same pattern for non-factorisable part

possible pitfall — (non)-positivity

- factorisable part is positive definite (related cross section)
  non-factorisable part isn't (that's what we tested for in fit d)



- fit d) effect of cancellations 20%
  instead of 350% its 280%
  ⇒ that's not it!

third **conclusions** of phase 2:

- in our analysis we have not come across any signs that QCD can explain this effect. Yet charm-physics has a reputation of being notoriously difficult.

- extending the duality interval over J/Ψ and $\Psi(2S)$ resonances is desirable in view of the results …. how to improve