News of B->V form factors from LCSR

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Particle Phenomenology From the Early Universe to High Energy Colliders

structure

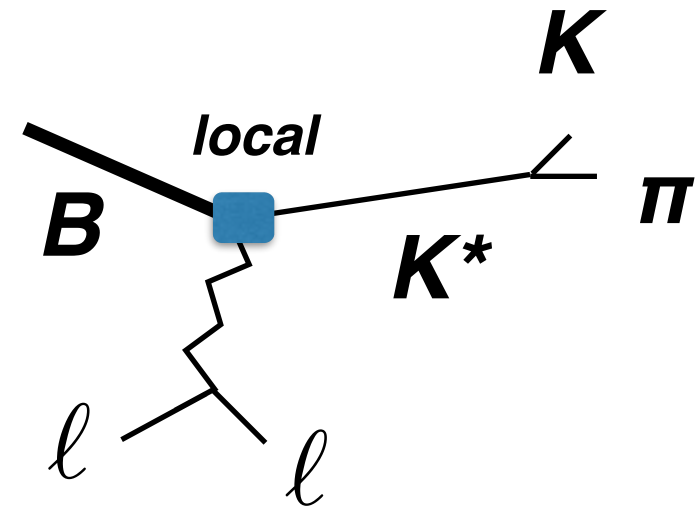
I. form factors

- error correlations
- use of equation of motion
- background effects

II. phenomenological discussion

- $B_s \to \phi$ vs $B \to K^*$ tension
- $|V_{ub}|$ from $B \to (\rho,\omega) l \nu$
- short comment charm resonances in $B \to K^{(*)} ll$

Definition of form factors



- *tensor & vector form factors*

$$\langle K^*(p,\eta)|\bar{s} i q_\nu \sigma^{\mu\nu}(1\pm\gamma_5)b|\bar{B}(p_B)\rangle = P_1^\mu T_1(q^2) \pm P_2^\mu T_2(q^2) \pm P_3^\mu T_3(q^2)$$

$$\langle K^*(p,\eta)|\bar{s}\gamma^\mu(1\mp\gamma_5)b|\bar{B}(p_B)\rangle = P_1^\mu \mathcal{V}_1(q^2) \pm P_2^\mu \mathcal{V}_2(q^2) \pm P_3^\mu \mathcal{V}_3(q^2) \pm P_P^\mu \mathcal{V}_P(q^2)$$

- *4 directions:*

$$P_P^\mu = i(\eta^*\cdot q)q^\mu\ , \qquad P_1^\mu = 2\epsilon^\mu{}_{\alpha\beta\gamma}\eta^{*\alpha}p^\beta q^\gamma\ ,$$

$$P_2^\mu = i\{(m_B^2 - m_{K^*}^2)\eta^{*\mu} - (\eta^*\cdot q)(p+p_B)^\mu\}\ , \qquad P_3^\mu = i(\eta^*\cdot q)\{q^\mu - \frac{q^2}{m_B^2 - m_{K^*}^2}(p+p_B)^\mu\}$$

- *in terms of traditional notation:*

$$\mathcal{V}_P(q^2) = \frac{-2m_{K^*}}{q^2}A_0(q^2)\ , \quad \mathcal{V}_1(q^2) = \frac{-V(q^2)}{m_B+m_{K^*}}\ , \quad \mathcal{V}_2(q^2) = \frac{-A_1(q^2)}{m_B-m_{K^*}}\ ,$$

$$\mathcal{V}_3(q^2) = \left(\frac{m_B+m_{K^*}}{q^2}A_1(q^2) - \frac{m_B-m_{K^*}}{q^2}A_2(q^2)\right) \equiv \frac{2m_{K^*}}{q^2}A_3(q^2)\ .$$

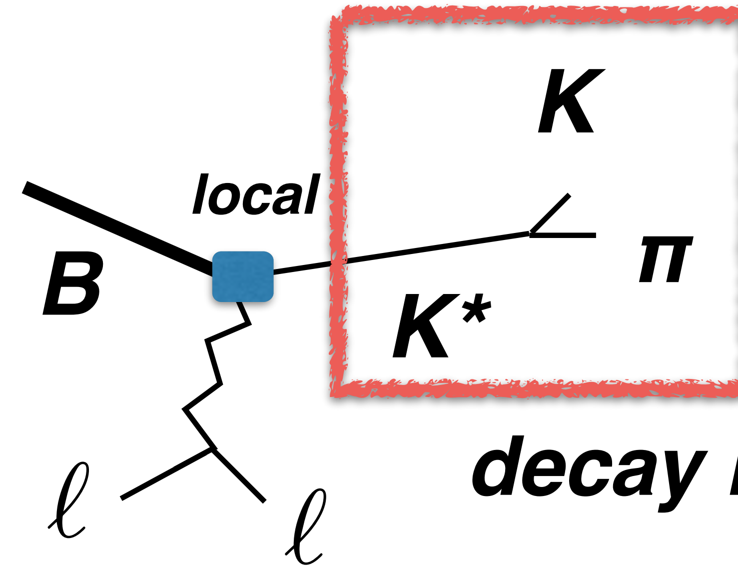
algebraically:

$$T_1(0) = T_2(0)$$

regularity:

$$A_0(0) = A_3(0)$$

Form factors & LCSR use appropriate correlation function Γ



decay K I.C*

- ***sum rule on one line:***

$$\frac{V(q^2)}{p_B^2 - m_B^2} + \int_{\text{threshold}} \frac{ds}{\pi} \frac{\text{Im}\Gamma^V(s,q^2)}{(s - p_B^2 - i0)} = \Gamma^V(p_B^2, q^2)|_{\text{LCOPE}}$$

exact equation

want	***estimate***	***compute***
$\langle K^*\|V_\mu\|B\rangle$	$\langle K^*\|V_\mu\|B\pi\pi\rangle + .$	twist & α_s-epxansion

$$V[\{m_b, \alpha_s, f^{\|}, f^{\perp}, ..\}|\{s_0, M_{\text{Borel}}\}](q^2)$$

input ⇒ correlation between form factors I.A

sum rule parameters some help equation of motion I.B

I.A results & error correlations

computation based on Ball & RZ'04 + O(ms)-tree + updated hadronic input

Bharucha, Straub, RZ 1503.05534

Error correlation of form factors

- idea: use input-uncertainty matrix to generate pseudo-data O(100pts) for all 7 form factors

  ⇒ fit-ansatz with $(\alpha_0, \alpha_1, ..)$-parameters
  provide full correlation-matrix “easy-to-implement”

- ***we use:***

$$F_i(q^2) = \frac{1}{1 - q^2/m^2_{R,i}} \sum_k \alpha^i_k \left[z(q^2) - z(0)\right]^k ,$$

z-expansion around single pole

k=0..2

LCSR: 0< q² <14GeV²

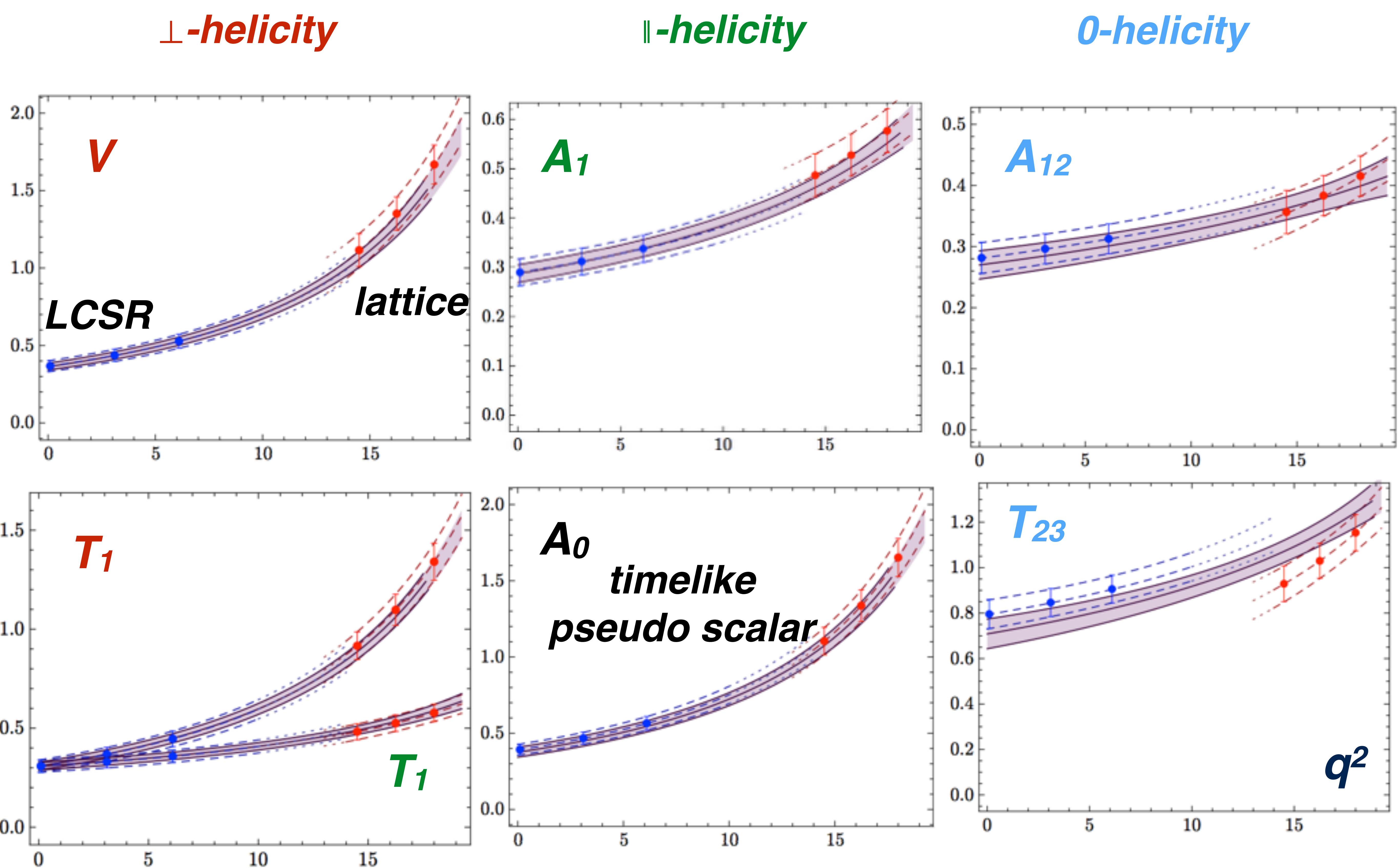
k=0..2

“entire range” combined with lattice

from Horgan,Liu, Meinel, Wingate’13

note: lattice with correlated errors as well

Combined LCSR & lattice plots



I.B the use of the equation of motion (EOM)

Grinstein Pirjol'04 study correction to Isgur-Wise relation

Hambrock, Hiller, Schacht, RZ '13 first application LCSR

Bharucha, Straub, RZ '15 more systematic exploitation

- ***constrains vector-to-tensor form factor for fixed helicity***
- ***importance for B->K*ll since zero of helicity amplitude largely determined by form factors***

$$H_\perp^{B\to V\ell\ell} \sim ..C_7^{\rm eff} T_1(q^2) + ..C_9^{\rm eff} V(q^2) + \text{long distance}$$

In particular $P_5' \sim \mathrm{Re}[H_0 H_\perp]$ for instance

EOM in QFT ⇔ relations between correlation functions

- ***the following equation valid on <K*|...|B>:***

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

- ***leads to 4 equation of motion***

$$T_1(q^2) + (m_b + m_s)\mathcal{V}_1(q^2) + \mathcal{D}_1(q^2) = 0\,,$$
$$T_2(q^2) + (m_b - m_s)\mathcal{V}_2(q^2) + \mathcal{D}_2(q^2) = 0\,,$$
$$T_3(q^2) + (m_b - m_s)\mathcal{V}_3(q^2) + \mathcal{D}_3(q^2) = 0\,,$$
$$(m_b - m_s)\mathcal{V}_P(q^2) + \left(\mathcal{D}_P(q^2) - \frac{q^2}{m_b + m_s}\mathcal{V}_P(q^2)\right) = 0\,.$$

where D_i's are form factors of derivative operator:

$$\langle K^*(p,\eta)|\bar{s}(2i\overleftarrow{D})^\mu(1\pm\gamma_5)b|\bar{B}(p_B)\rangle = P_1^\mu\,\mathcal{D}_1(q^2) \pm P_2^\mu\,\mathcal{D}_2(q^2) \pm P_3^\mu\,\mathcal{D}_3(q^2) \pm P_P^\mu\mathcal{D}_P(q^2)$$

Use of EOM

$$T_1(q^2) + (m_b + m_s)\mathcal{V}_1(q^2) + \mathcal{D}_1(q^2) = 0$$

- **Any form factor** determination has to **obey EOM** ⇒ **consistency check**
  - LCSR checked EOM at tree-level including O(m_s)-corrections works upon use of EOM of vector meson distribution amplitudes
  - lattice (future computations)

- Recall $F_i = F_i\{m_b, \alpha_s, f^{\|}, f^{\perp}, ..\}|\{s_0, M_{\rm Borel}\}](q^2)$

  One way to obey EOM set: $s_0[T_1] = s_0[V_1] = s_0[D_1]$

  - eliminates the major source of uncertainty T_1/V-ratio [rest O(1%)]
  - of course this has to be questioned …..

- … yet: $T_1(q^2) + (m_b + m_s)\mathcal{V}_1(q^2) + \mathcal{D}_1(q^2) = 0$

  0.294 -0.272 -0.022

  $s_0^{T_1} \simeq 35\,\text{GeV}^2$ $s_0^{V} = s_0^{T_1} \pm 1\,\text{GeV}^2$ $s_0^{\mathcal{D}_1} = s_0^{T_1}\left({}^{+15}_{-6.5}\right)\,\text{GeV}^2$

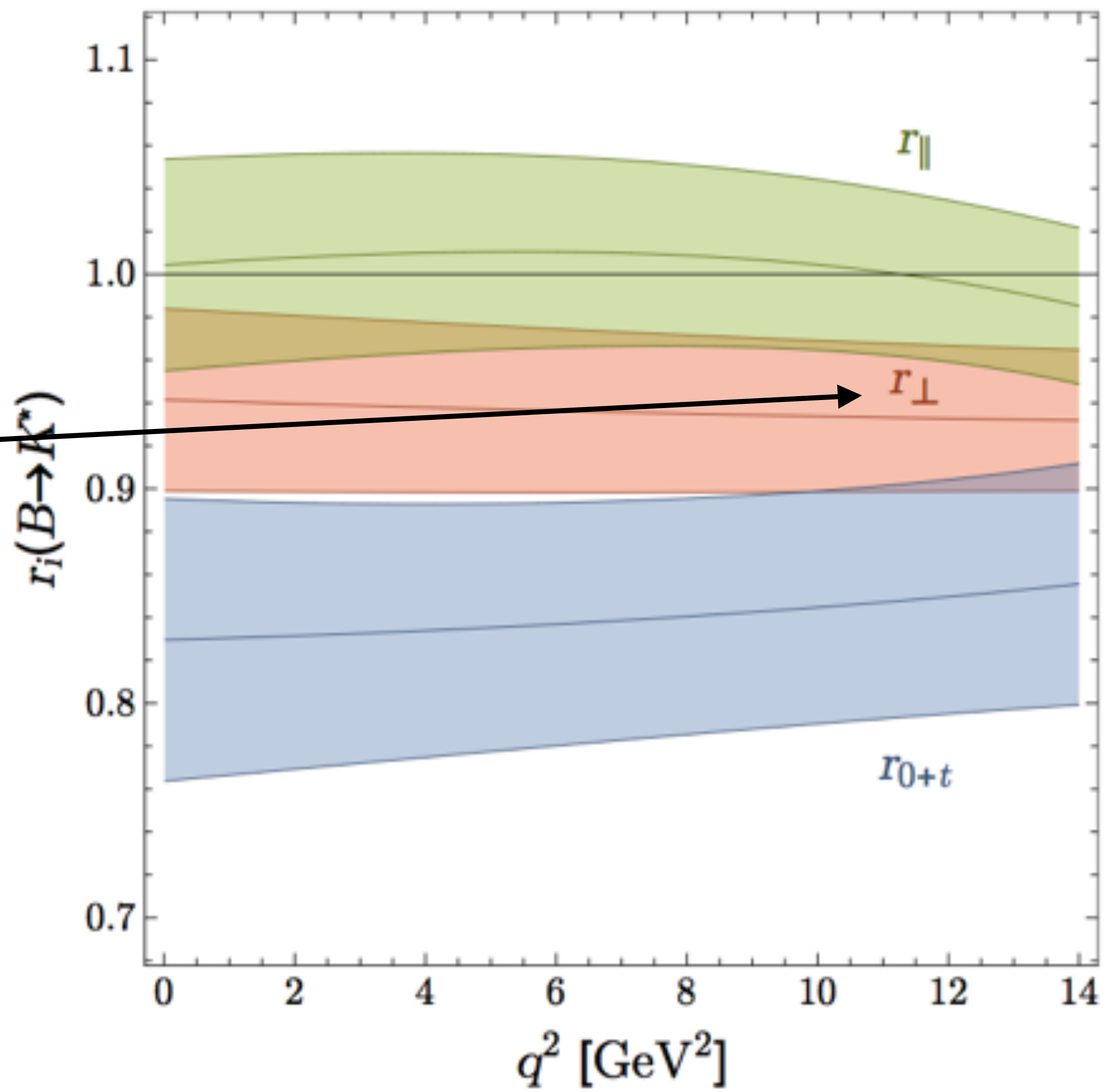
$^{+55}_{-63}\%$-shift in $\mathcal{D}_1$

- *Hence **if** D_1 is considered form factor then* $|s_0^{T_1} - s_0^V| < 1\,\mathrm{GeV}^2$

checked that **twist** and α_s -expansion is controlled
(⇒ more than a numerical accident)

- Vector-tensor form factor ratios determined up to 4-6%

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



note added

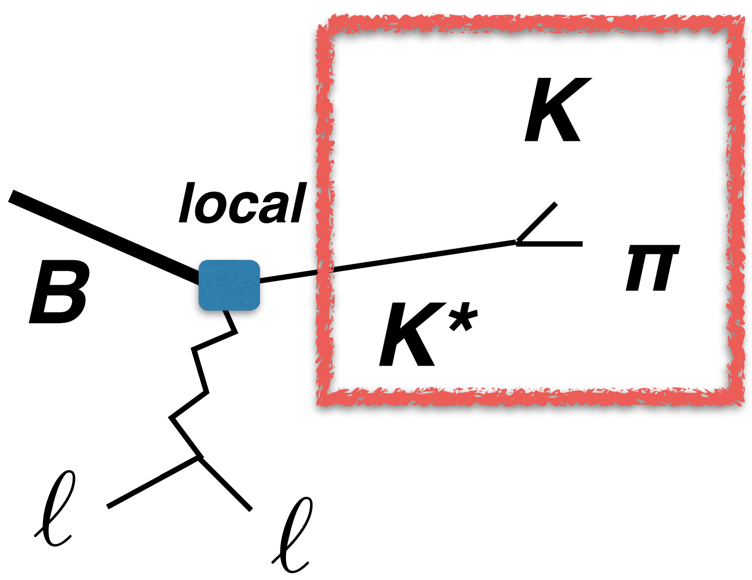
- similar to large energy Charles et al ‘98 limit and SCET investigations Beneke Feldmann ’00, Bauer et al’01 ……

similarity: both use equation of motion

difference: LCSR EOM in QCD — SCET EOM effective theory $1/m_b$

- $\Rightarrow$ ratios equal up to $1/m_b$ to “SCET-ratios” in Beneke Feldmann ’00

I.C background effects (decaying vector meson)



background effects

question background is present in theory
and experiment (important consistent treatment)

- $B \to \rho(\to \pi\pi) l\nu$ = signal … $\pi\pi$ in P-wave
  1) subtract S-wave experiment (no extra error for theory)
  2) what about resonant versus non-resonant $\pi\pi$ in P-wave?

- hard to disentangle in theory (in practice) and experiment
  main point: argue it might not be necessary

treat $\tau \to (\pi\pi)_{P\text{-}w}\, l\nu$ same way in extraction of f_ρ as in $B \to \rho(\to \pi\pi) l\nu$

ρ vs ππ-distribution amplitude

skip no time

- using 2-pion DA (def e.g. Polyakov'98) to describe B(→ππ)lν requires determination of the 2-pion DA

- for 0th Gegenbauer moment of vector 2-pion DA = pion form factor

$$F_i^{B\to\pi\pi}(q^2) = \begin{cases} \rho-\mathrm{DA}: & \frac{\langle\pi\pi|\rho\rangle}{m_{\pi\pi}^2-m_\rho^2+im_\rho\Gamma_\rho}\underbrace{\langle\rho|V_\mu|0\rangle}_{\sim f_\rho^{\parallel}} f_B^\mu(q^2)+.. \\ \pi\pi-\mathrm{DA}: & \underbrace{\langle\pi\pi|V_\mu|0\rangle}_{\sim F^{\pi\to\pi}(m_{\pi\pi}^2)} f_B^\mu(q^2)+.. \end{cases} \to \frac{f_\rho^{\parallel} m_\rho g_{\rho\pi\pi}}{m_{\pi\pi}^2-m_\rho^2-im_\rho\Gamma_\rho}$$

repeats other moments and current

- yet higher moments or tensor 2-pion DA no experimental info available

- ρ-DA uncertainties in (other) parameters take care of background effects in error budget

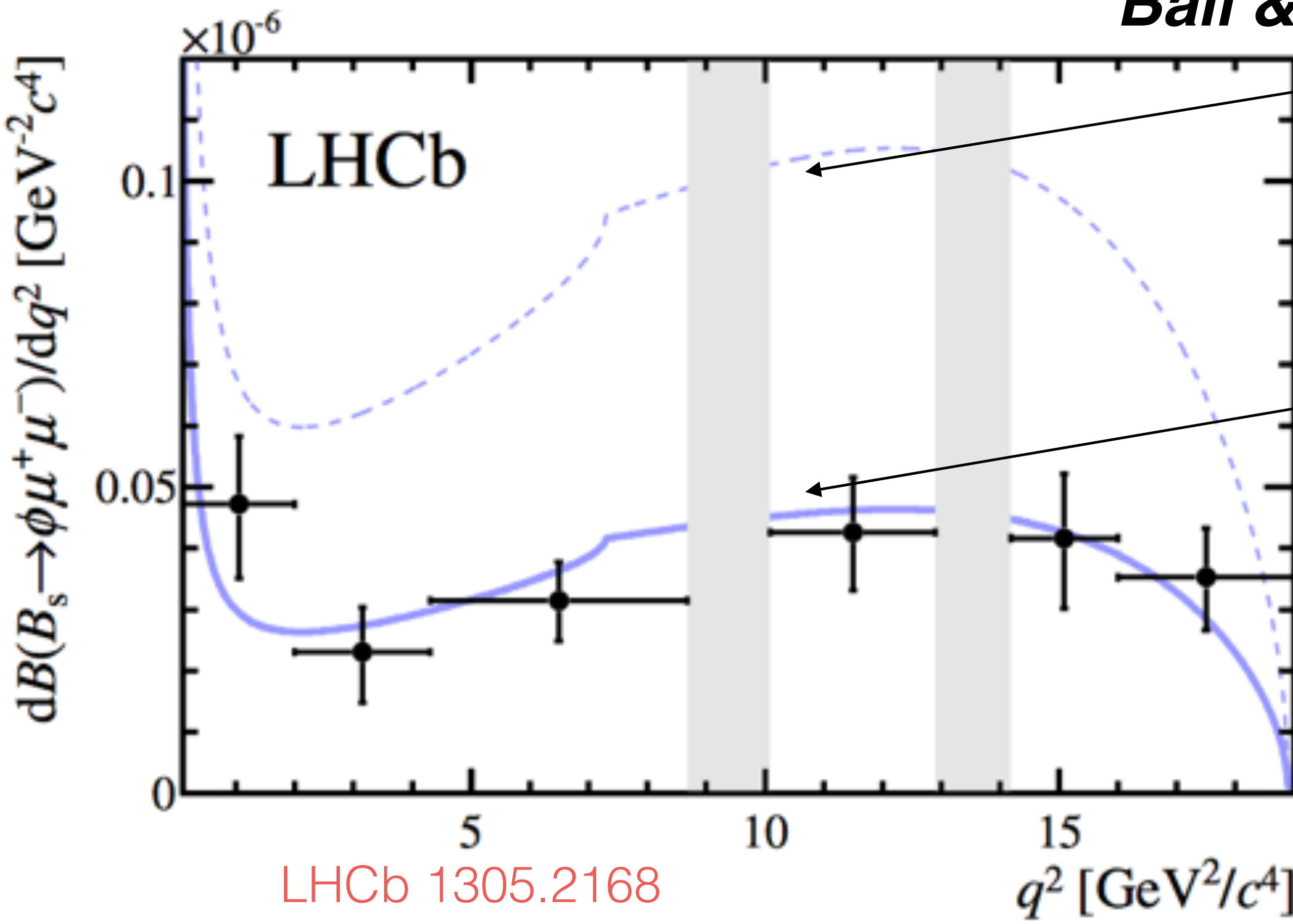
around ρ-meson peak do not see pragmatic advantage in near future of using 2-pion DA

II. phenomenological discussion

II.A $B_s \to \phi$ vs $B \to K^*$ tension

II.B $|V_{ub}|$ from $B \to (\rho,\omega) l\nu$

LHCb used
Ball & RZ'04 form factors



scaled to fit
by LHCb

LHCb 1305.2168

- new predictions picture same: “we’re off by factor of 2”
  shape ok — is there a **problem** with **form factor normalisation?**
  look at ratio $B_s \to \phi / B \to K^*$ where normalisation effects cancel …

$B_s \to \phi$ vs $B \to K^*$ tension

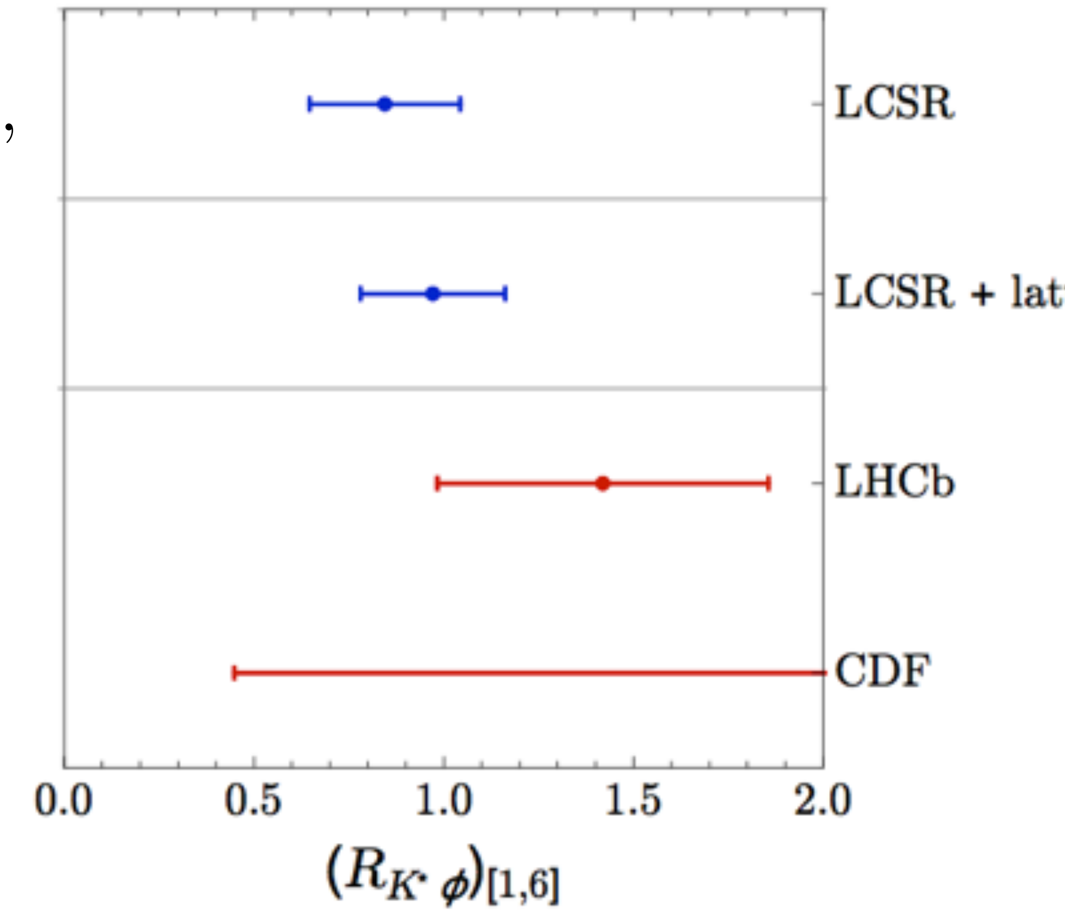
- at $q^2=0$ to photons

$$R^{(\gamma)}_{K^*\phi} \equiv \frac{\mathrm{BR}(B^0 \to K^{*0}\gamma)}{\mathrm{BR}(B_s \to \phi\gamma)}$$

Lyon, RZ '13	LHCb '12 1202.6267
$0.78(18)$	$1.23(32)$

- statistically not significant but persists at higher q^2

$$R_{K^*\phi}[q_1, q_2] \equiv \frac{d\mathrm{BR}(B^0 \to K^{*0}\ell^+\ell^-)/dq^2|_{[q_1,q_2]}}{d\mathrm{BR}(B_s \to \phi\ell^+\ell^-)/dq^2|_{[q_1,q_2]}},$$



origin of differences?

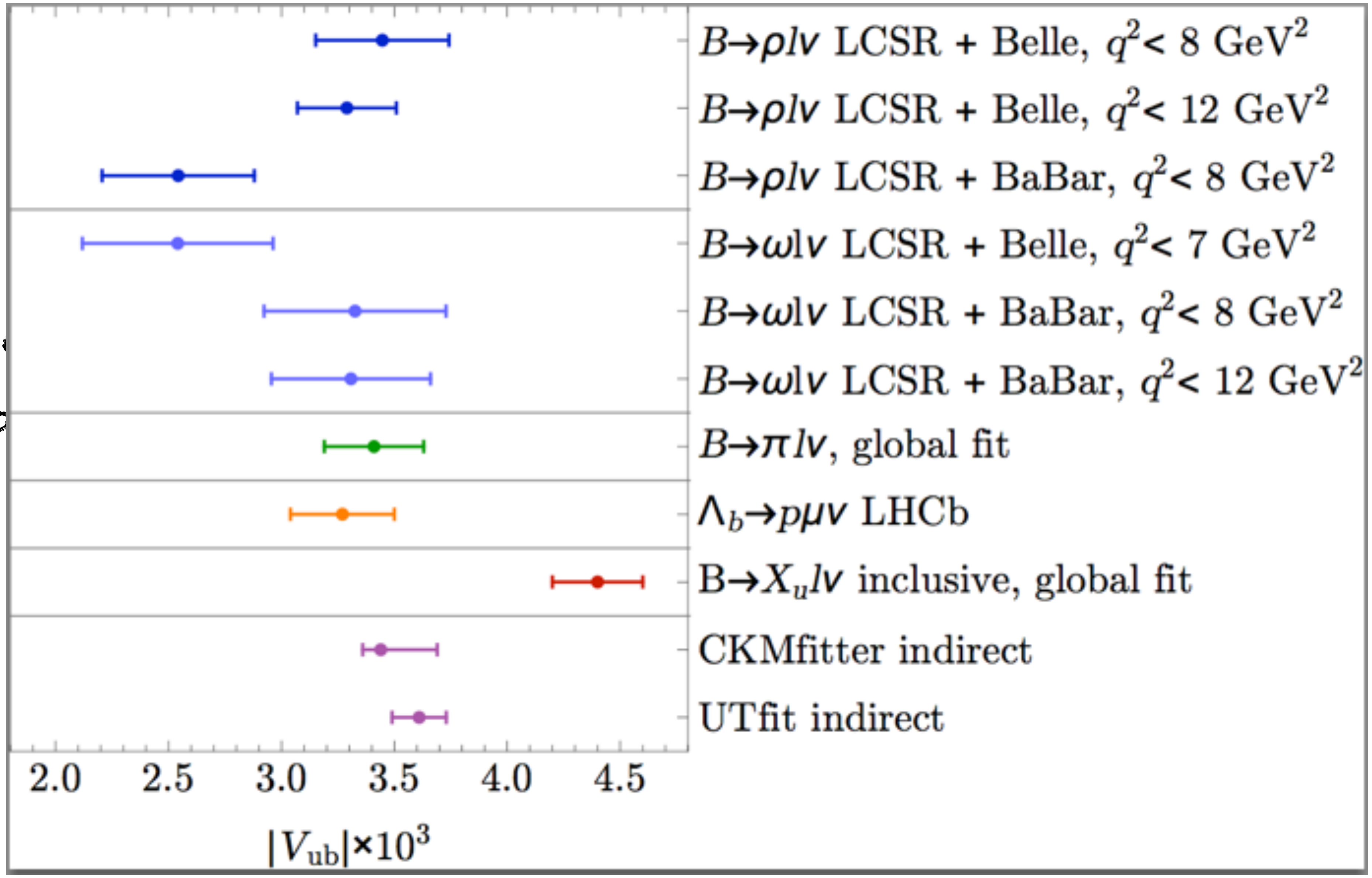
- lifetimes (effect small)
- weak annihilation taken from Lyon, RZ '13
- form factors determined mainly determined by decay constants …

calls for test of form factors?

$|V_{ub}|$ from $B \to (\rho,\omega) l\nu$

involves vector form factors

consistent with
other exclusiv
determinatio



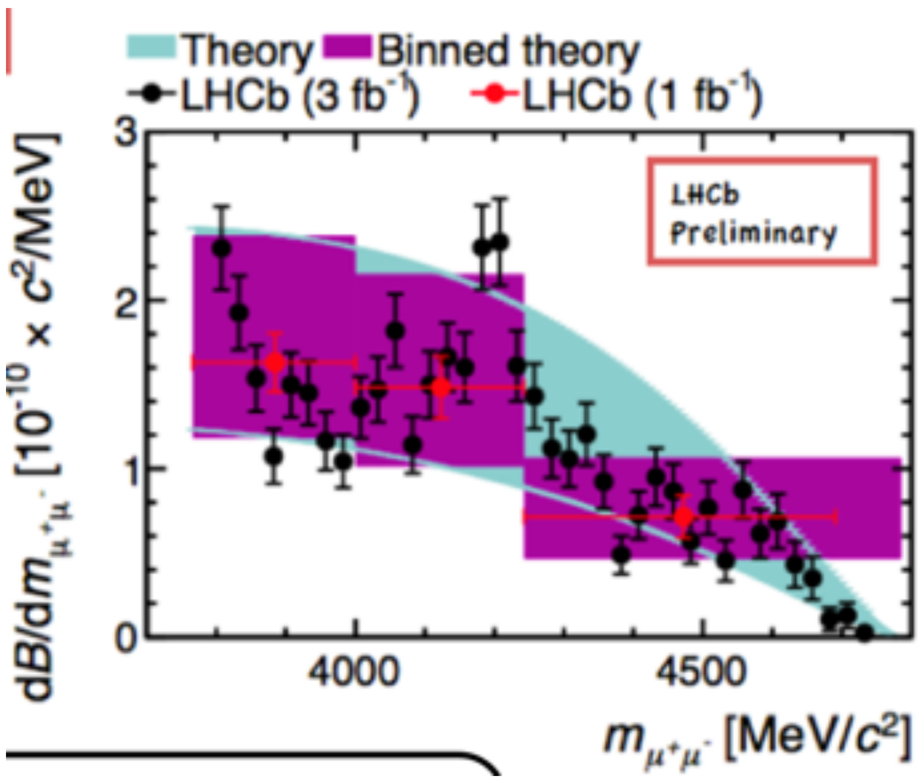
⇒ no sign of (serious) normalisation problems

as questioned by $B_s \to \phi\mu\mu$

note: B-factory $|V_{ub}|$-values (could raise) if S-wave subtracted using ang-analysis

II.C comment charm resonances in B→K (*)ll

$$\mathrm{BF}(B \to K\ell\ell)$$

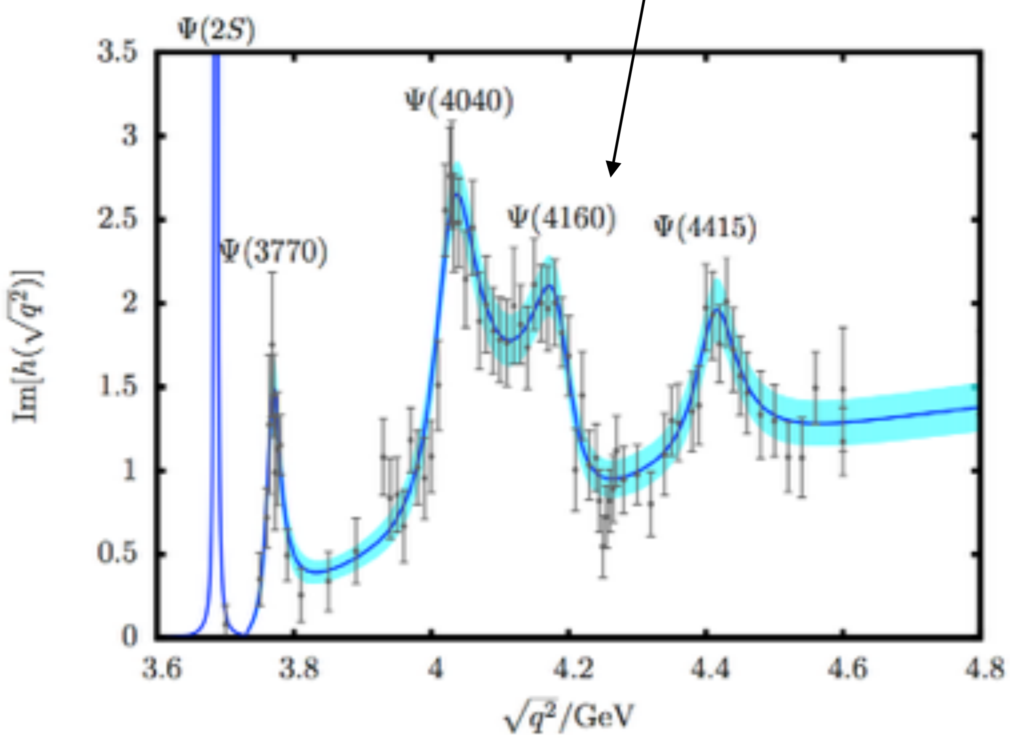


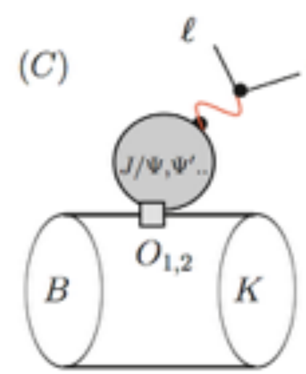
LHCb PRL 111 (2013)

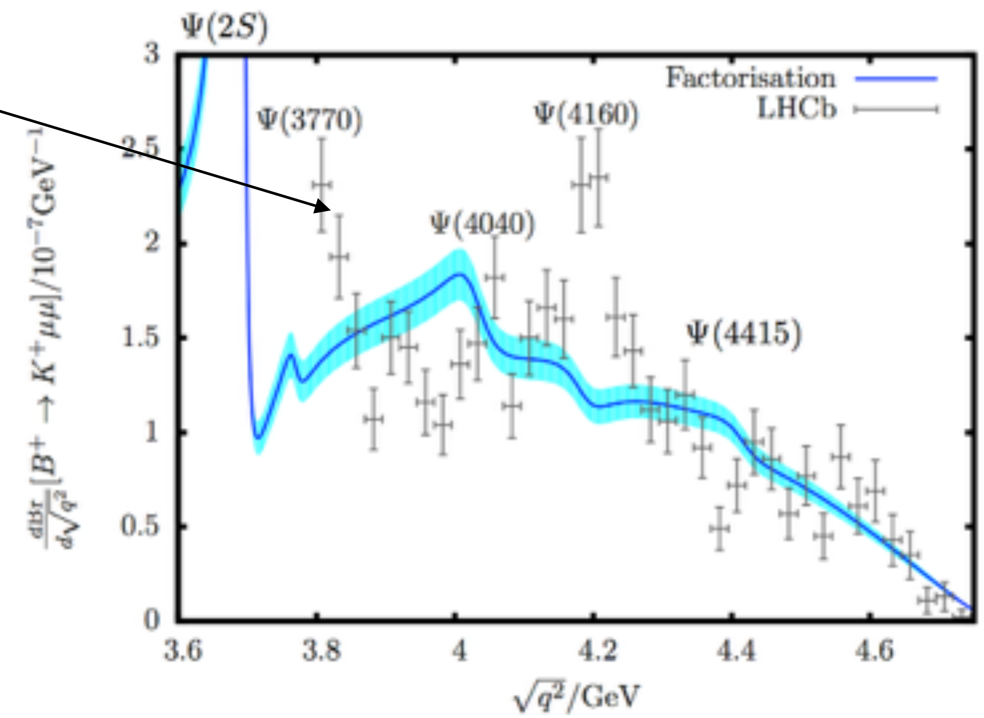
pronounced $J^{PC} = 1^{--}$ charm resonance structure

Lyon RZ 1406.0566

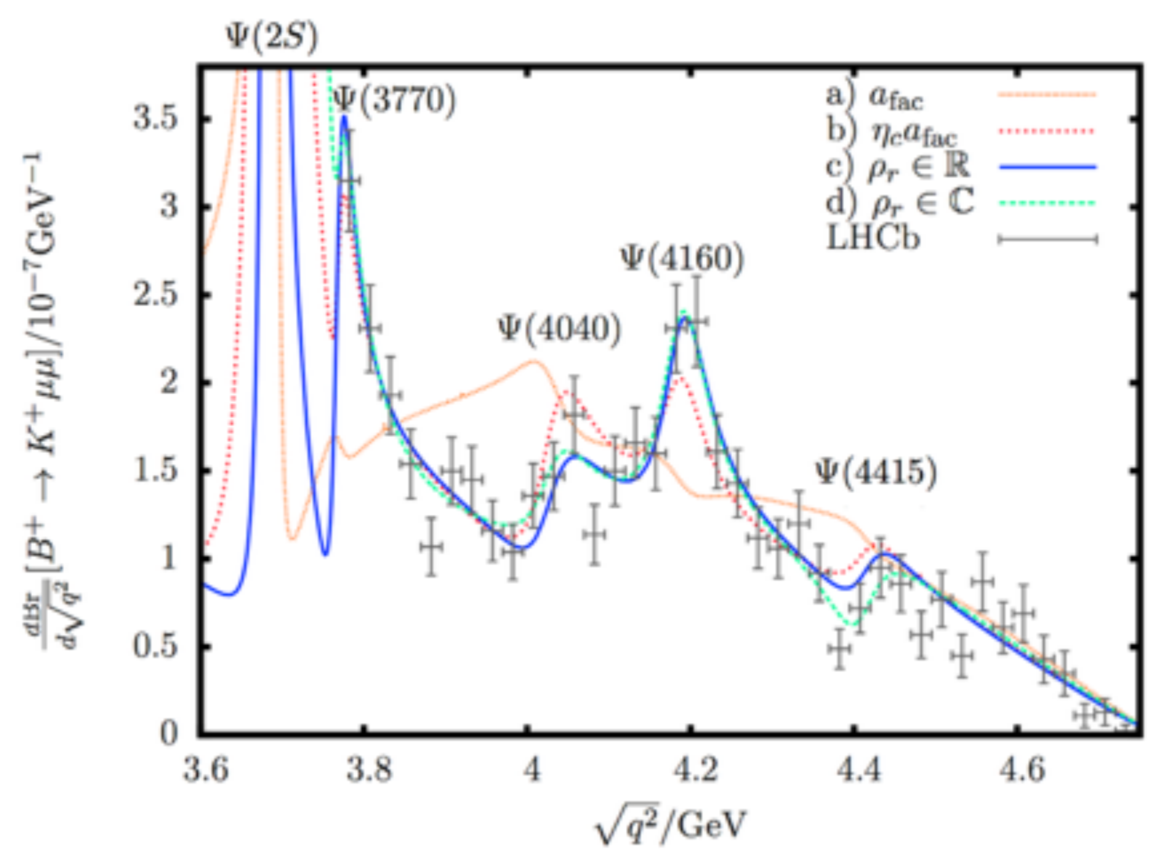
- Using a fit to BES-II data $e^+e^- \to$ hadrons able to check status of "naive" factorisation at high q^2 in $B \to Kll$





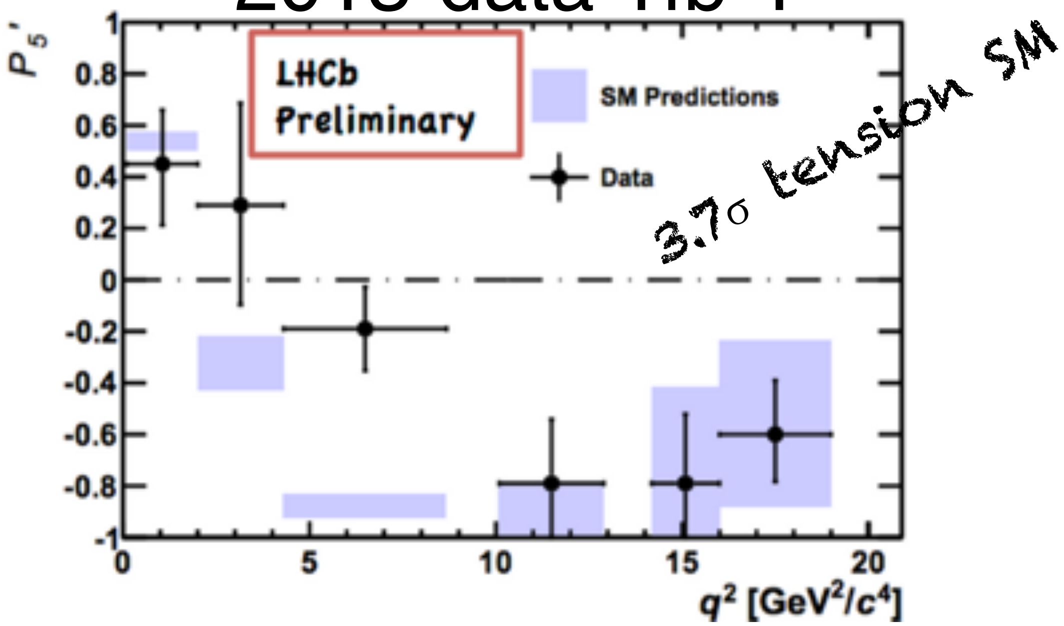


hight of resonances in naive fac. by factor ~(-2.5) fits the data well

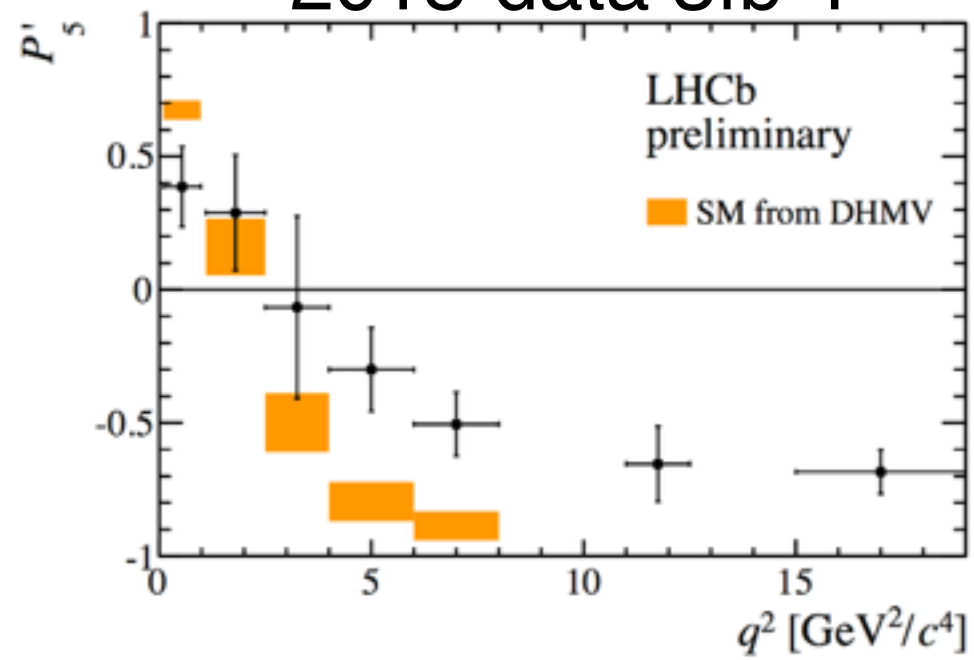


- Led us to speculate P_5'-anomaly in $B \to K^{(*)}ll$ might be related to charm (since charm pronounced)

2013-data 1fb-1

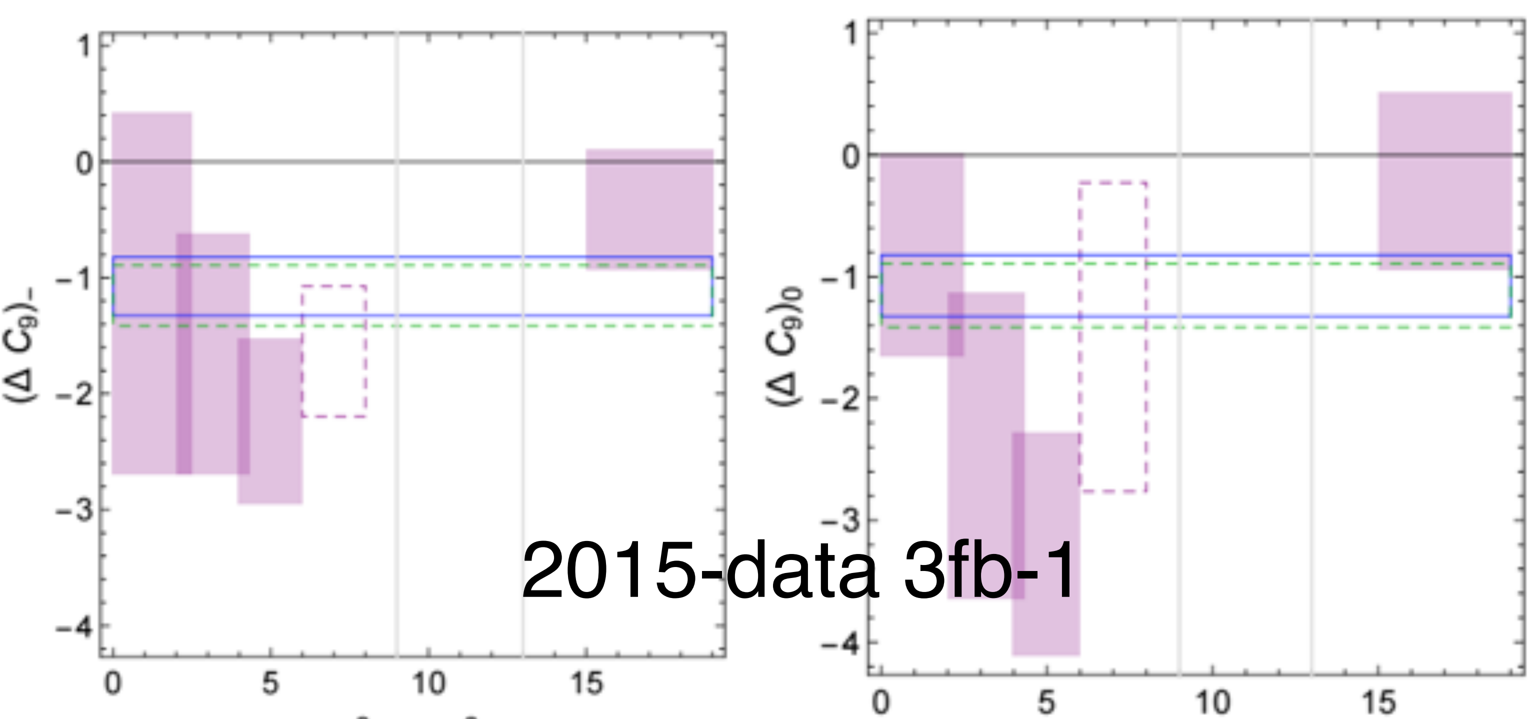


2015-data 3fb-1



- 1) pronounced to J/Ψ 2) accommodated by photon penguin C_{10} not nec.

Straub's talk Moriond'15 (proceedings & Wolfgang's talk)



2015-data 3fb-1

- effect same sign as in naive fac. in "-" versus "0" helicity
- my comment: that's what $B \to J/\Psi K^*$ experimental angular analysis predicts for J/Ψ,Ψ(2S)-contributions

conclusions and summary

- wether global $\Delta C_9^{\text{short-distance}} \simeq -1$ remains is tricky question — needs more data

- then **R_K-anomaly** (2.6σ) came along and there **charm** should play **no role** and this points towards true short-distance new physics
  talks by Crivellin, Hiller, Altmannshofer, Nardecchia, Vicente

- **equation of motion** & **correlated errors** for form factors help to predict angular observables like P_5' with higher precision

thanks for your attention