B->Vll QCD Aspects

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11-13 May b->sll in 2015 (Workshop-Edinburgh)

structure

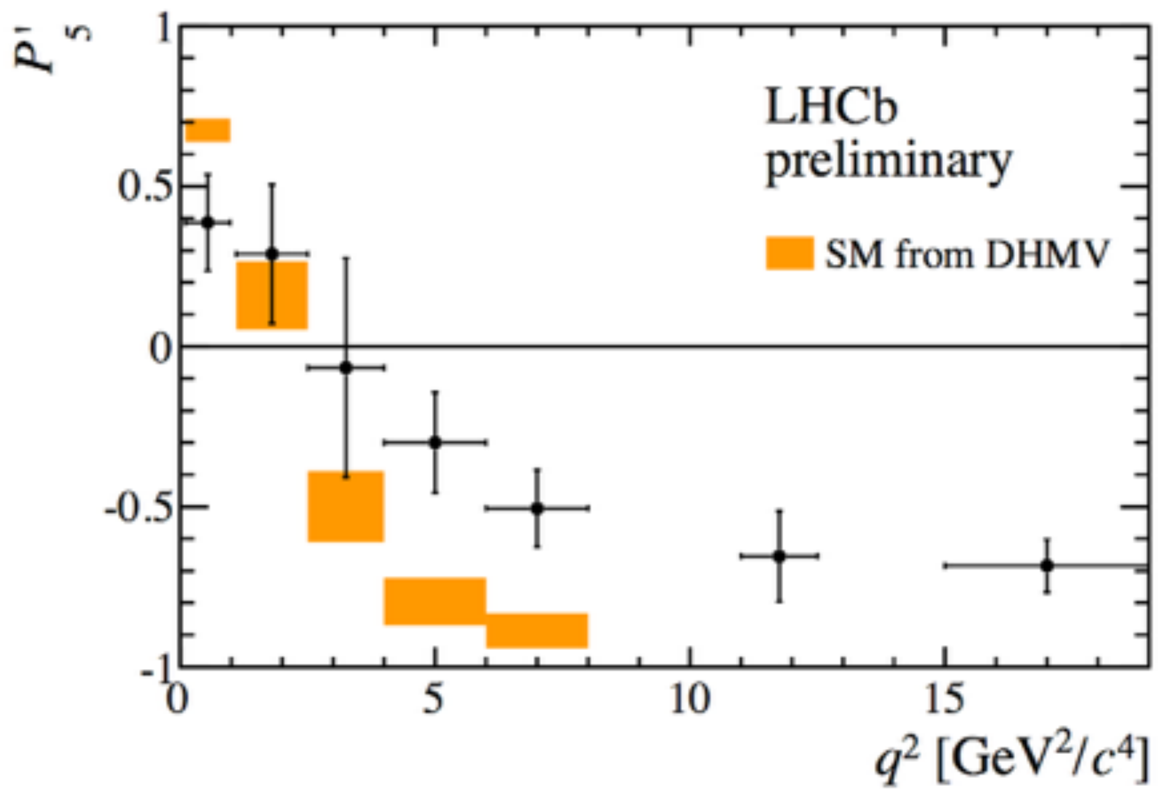
I. motivation

II. short and long distance — overview

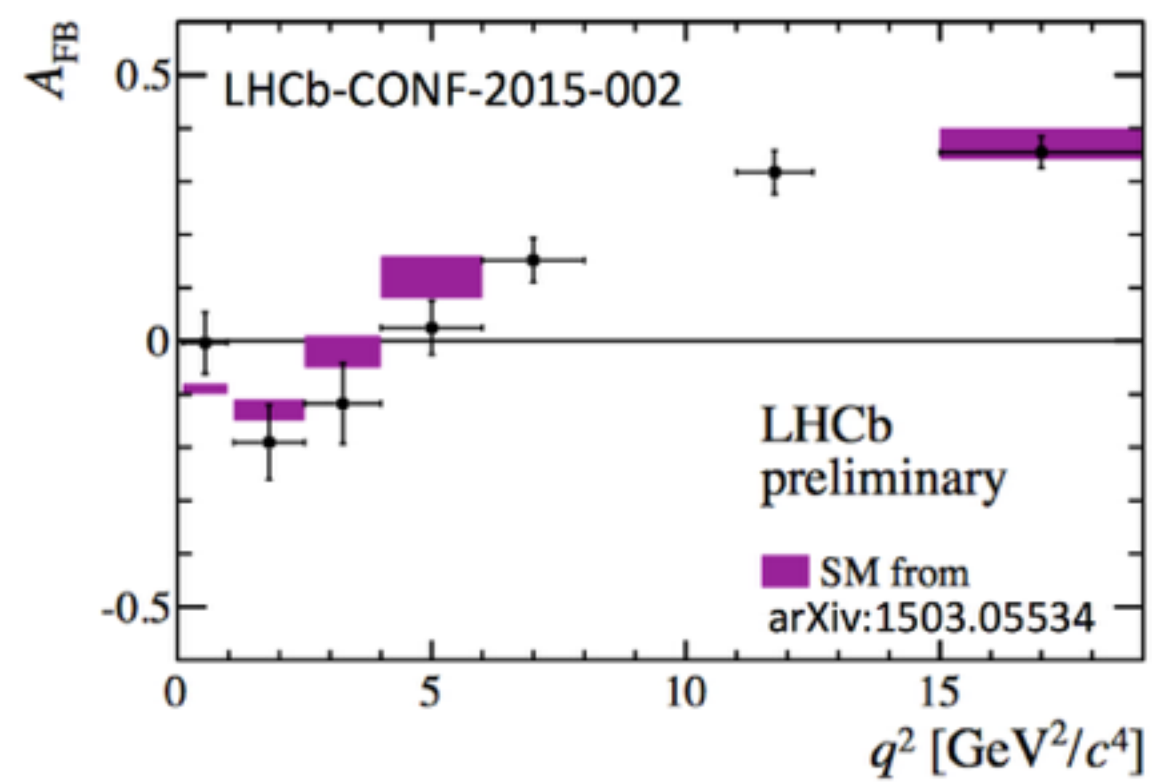
- ***II.a long distance***
- ***II.b short distance — form factors***
- ***II.c a note vector mesons (decay constants et al)***

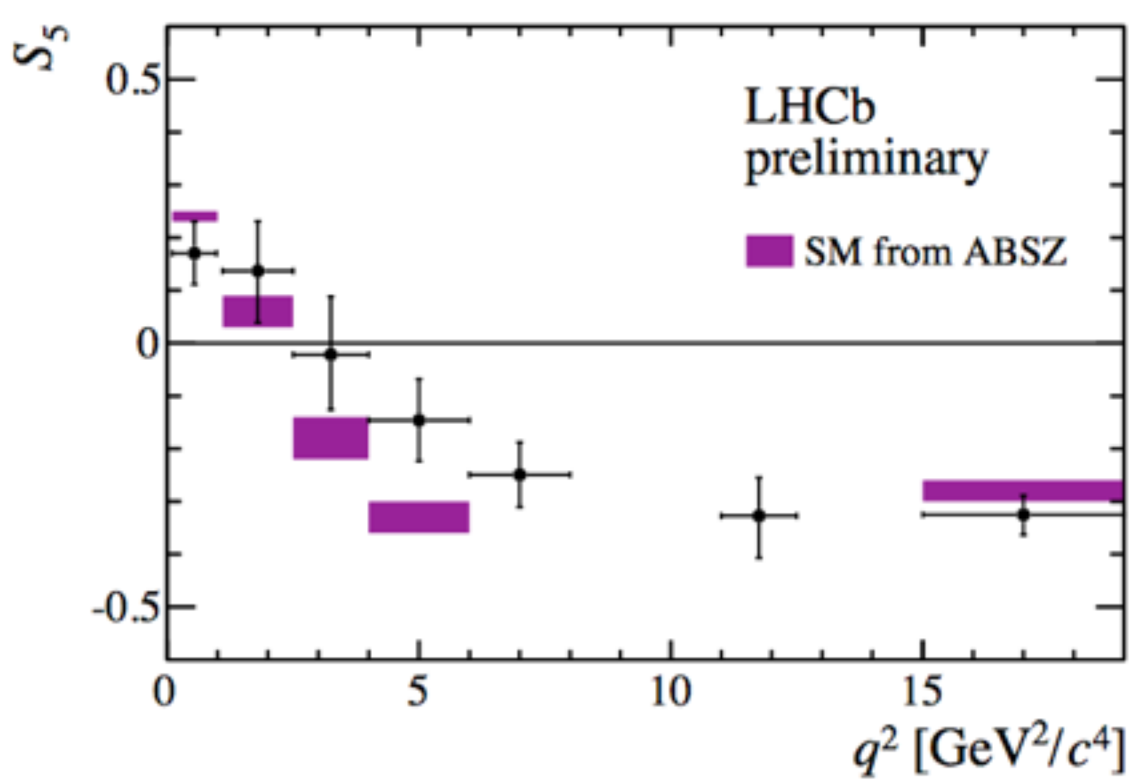
III summary

Of current importance … anomalies B->K*ll et al



$$A_{FB} = \frac{\Gamma(\cos\theta_{B\ell^+} > 0) - \Gamma(\cos\theta_{B\ell^+} < 0)}{\Gamma(\cos\theta_{B\ell^+} > 0) + \Gamma(\cos\theta_{B\ell^+} < 0)}$$





driven by zero of helicity amplitudes

$$H_{\perp}^{L,R} = [(\mathcal{C}_9 + \mathcal{C}_{9'}) \mp (\mathcal{C}_{10} + \mathcal{C}_{10'})] \frac{V}{M_B + M_{K^*}} + \frac{2m_b}{q^2} (\mathcal{C}_7 + \mathcal{C}_{7'}) T_1$$

$$+\mathrm{long} - \mathrm{distance}$$

closer look

Lyon and RZ 1406.0566

a) pronounced towards J/Ψ

b) photon penguin only — C_{10} (no long-distance) not necessary

c) high q^2 charm very pronounced (tomorrow)

altogether suggests (at least a large part) in P_5' et al is due to charm

- ***closer look***

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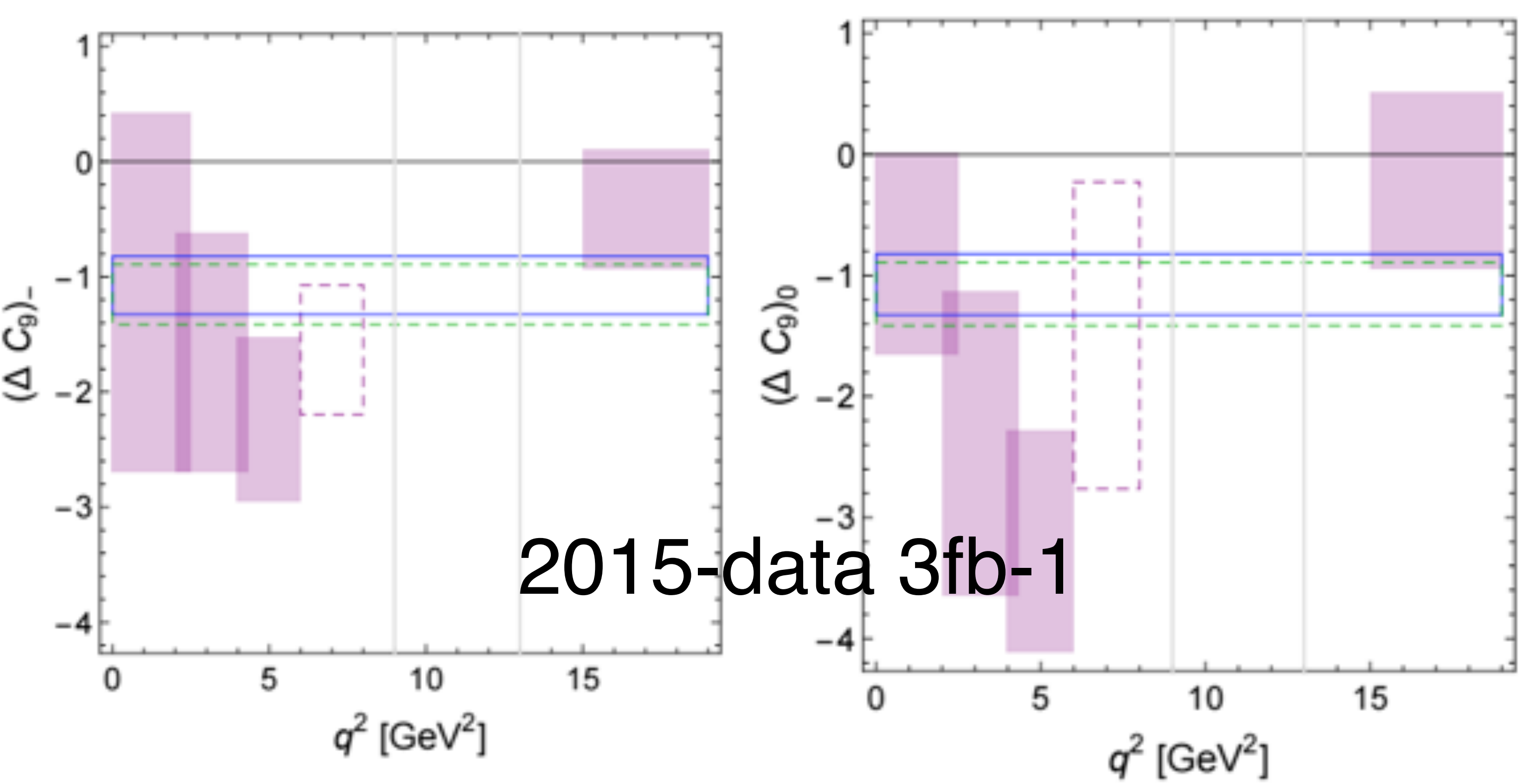
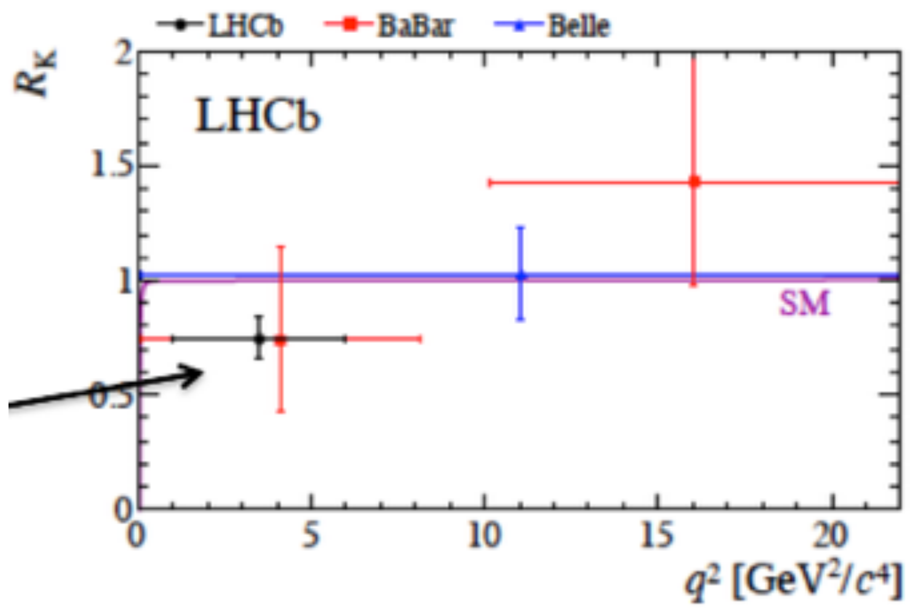
- ***Moriond 2015 data ….***

Straub's talk Moriond'15



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

- then **R$_K$-anomaly** (2.6σ) came along and there **charm** should play **no role** and this points towards true short-distance new physics



LHCb, PRL 113 (2014) 151601
Belle, PRL 103 (2009) 171801
Babar, PRD 86 (2012) 032012

$$R_K = \mathfrak{B}(B^+ \to K^+\mu^+\mu^-) / \mathfrak{B}(B^+ \to K^+e^+e^-)$$

- what are the size of QED corrections? QED corrections expected smaller than central-value effect (some talks tomorrow)

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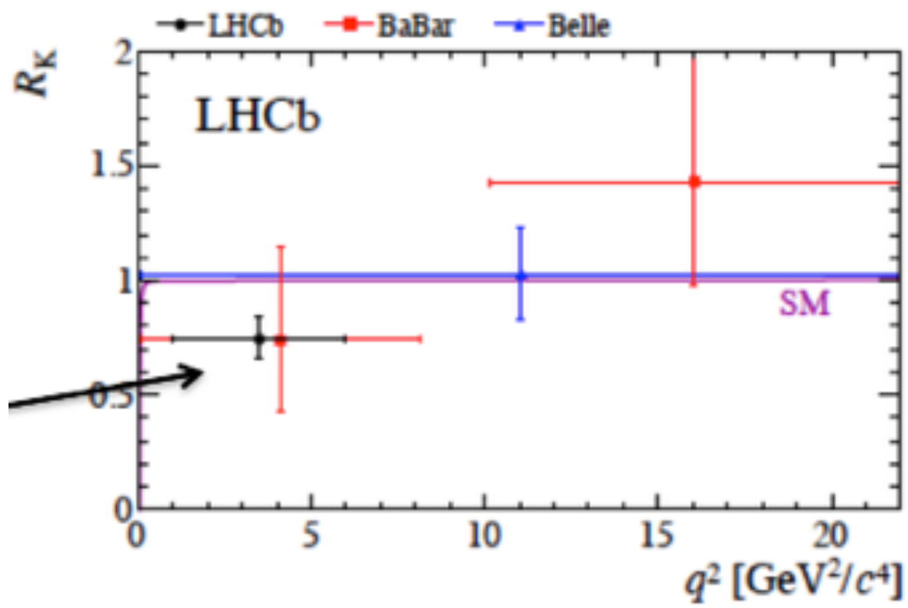

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- $B_s \to \phi$ vs $B \to K^*$ tension in branching fraction (later)

tensions (anomalies): call for closer look of QCD evaluation

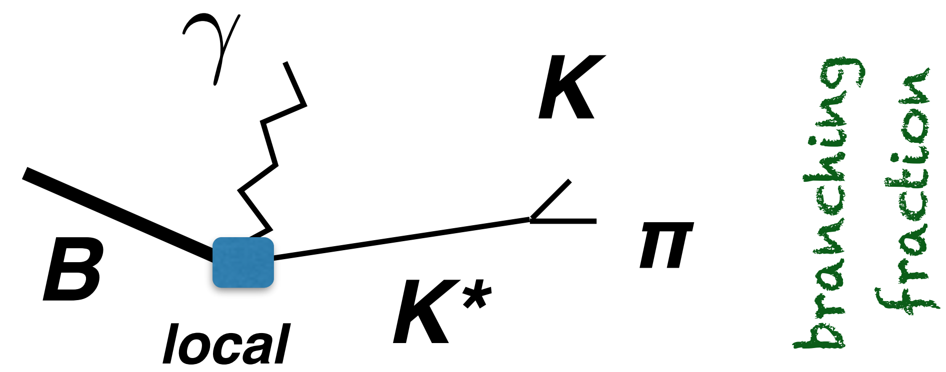
topic of this talk: what are these

- short-distance (SD) contributions — form factor

- long-distance (LD) contributions

topologies

SD-penguin



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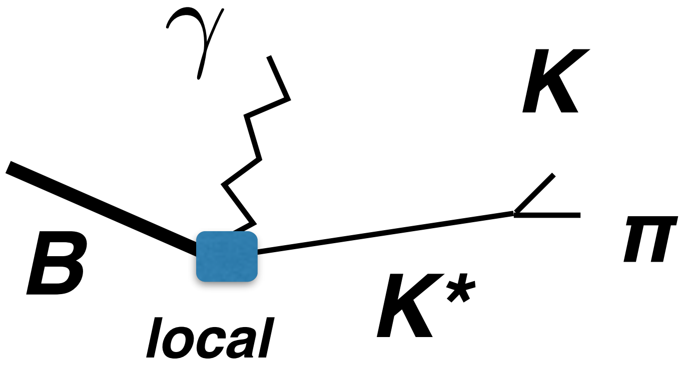
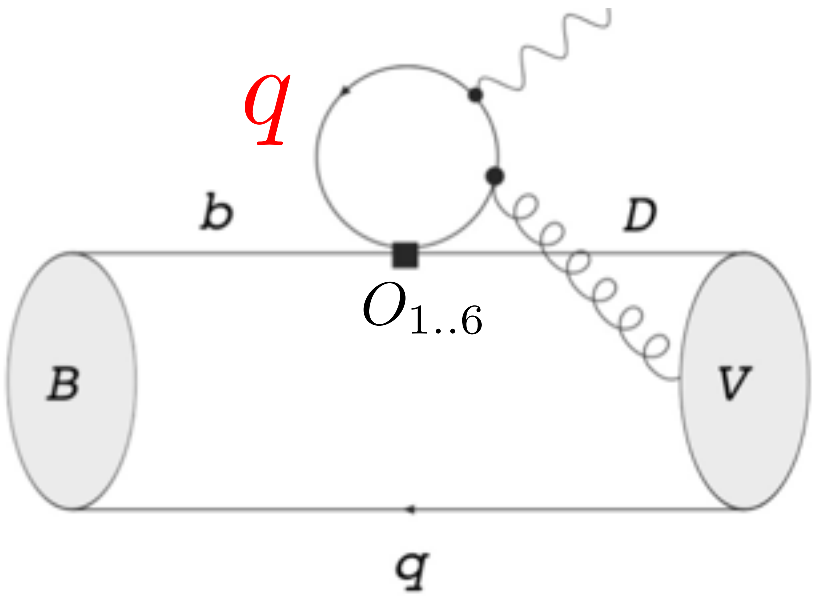


branching
fraction

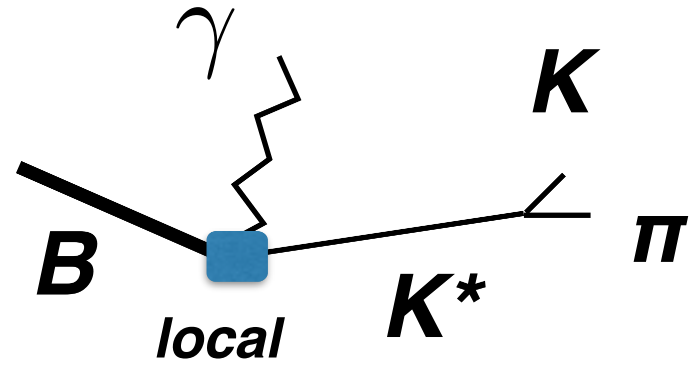


quark-loop

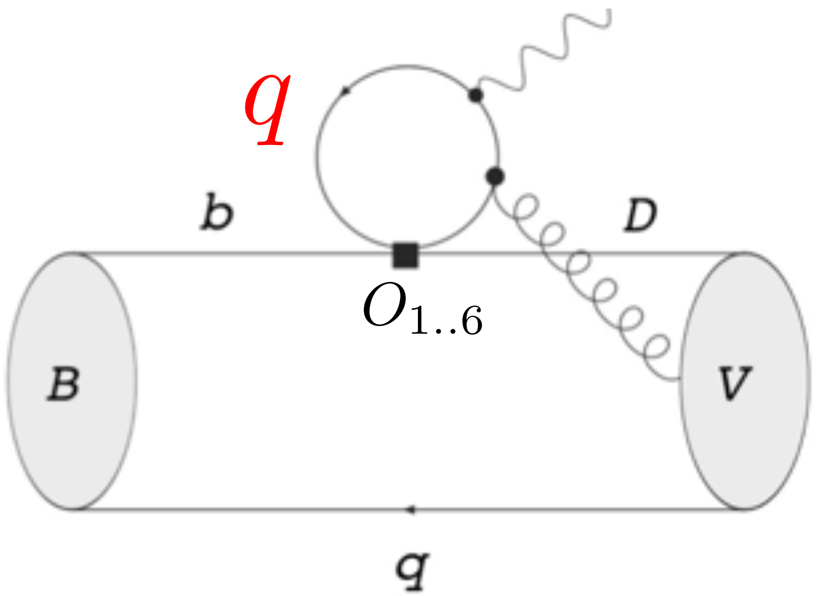
background
right-handed currents

topologies

SD-penguin



branching fraction



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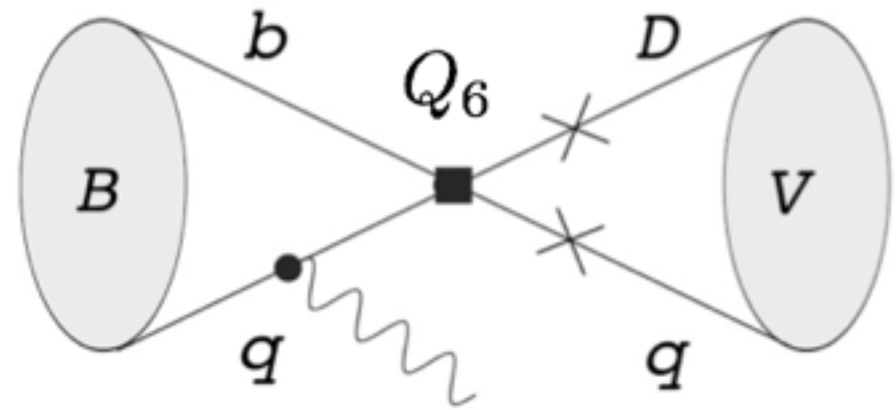
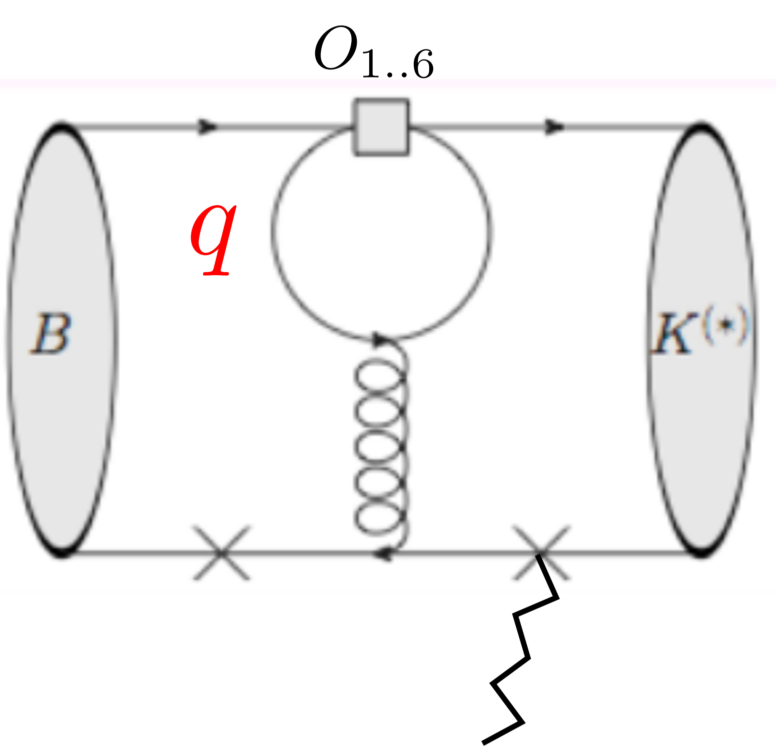


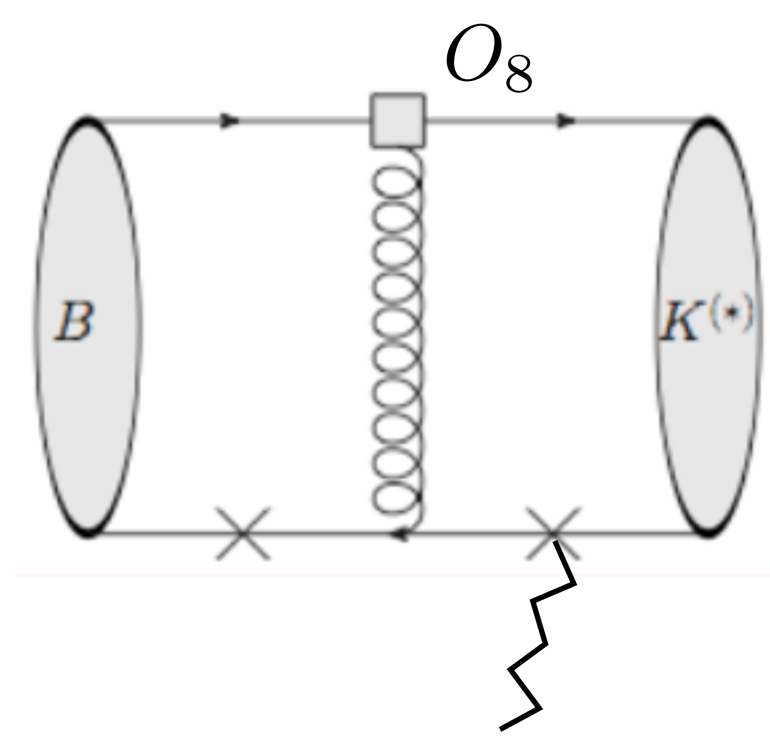
weak annihilation

CKM-enhanced b→d

isospin asymmetry

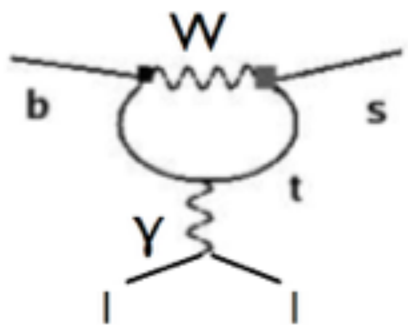


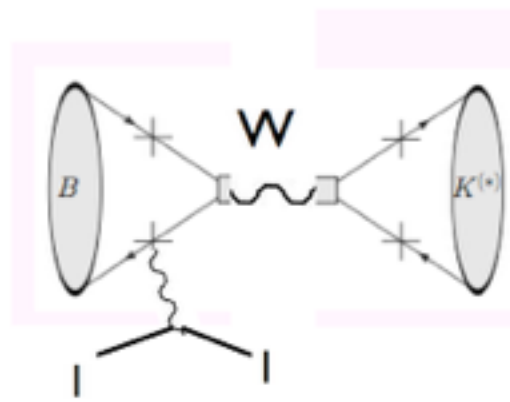
quark-loop scattering



chromo-penguin

another look





Wilson coefficient (UV-physics SM & BSM?)

operator (IR-physics)

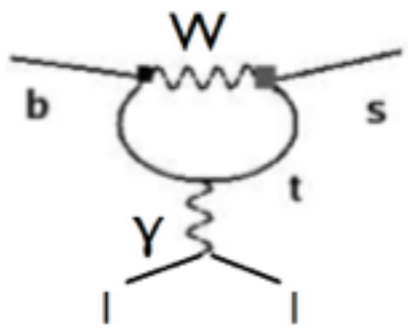
$$H_{\text{eff}} = \sum_i C^i(\mu_F) O^i(\mu_F)$$

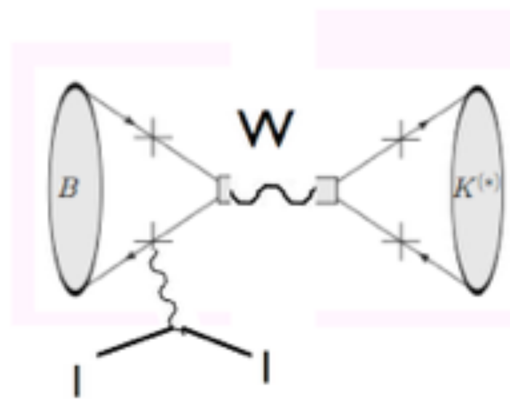
$$\mathcal{A} = \langle Vll|H_{\text{eff}}|B\rangle = \sum_i C_i(m_b)\langle Vll|O_i(m_b)|B\rangle$$

Amplitude

non-perturbative fcts of q²

another look





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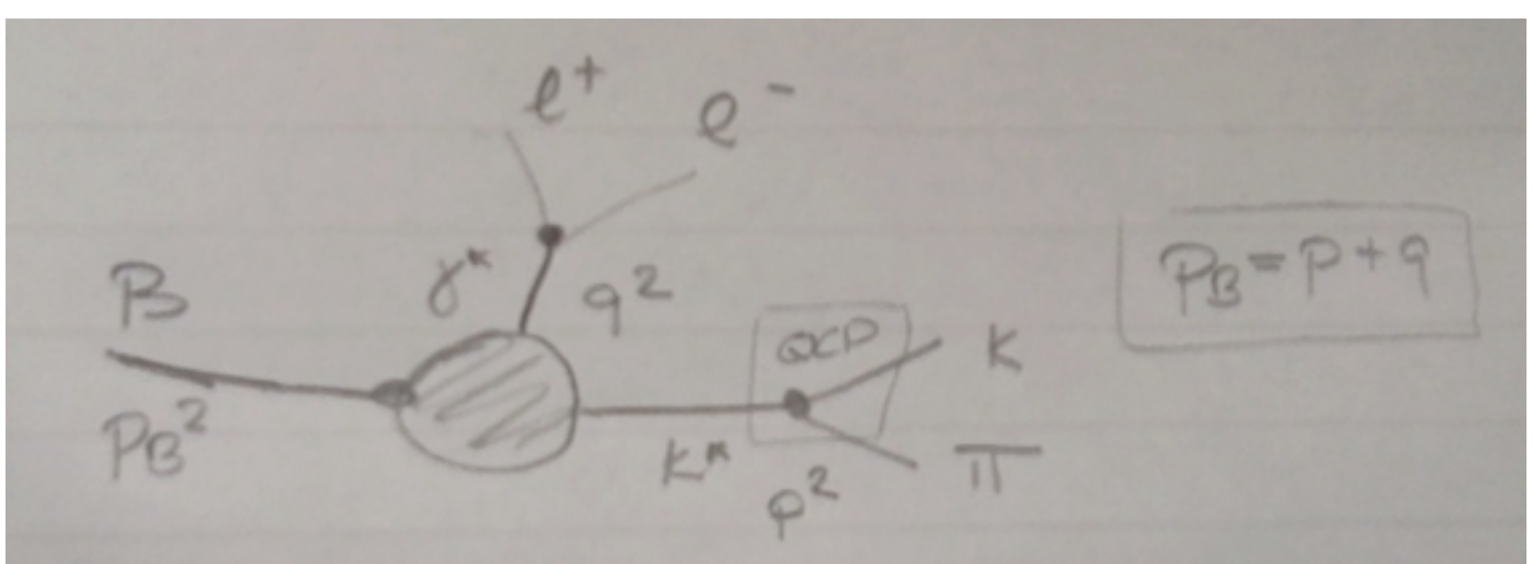
Amplitude

non-perturbative fcts of q^2

- Old principle of **analyticity**, unitarity etc:
  any amplitude determined by its singularities
  e.g. poles (intermediate single particles)
  branch cuts (intermediate multi-particles)

e.g. optical theorem

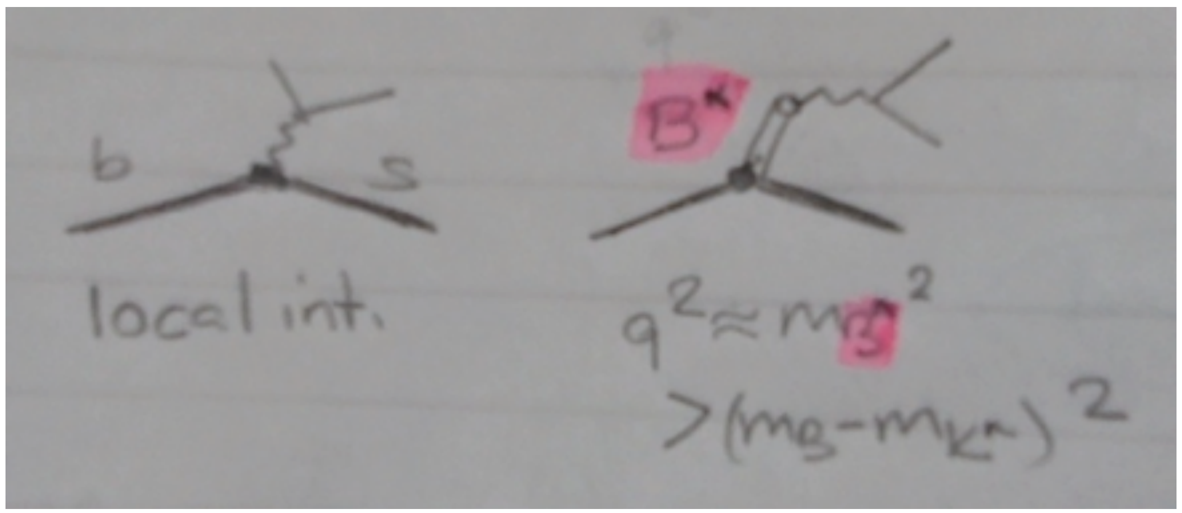


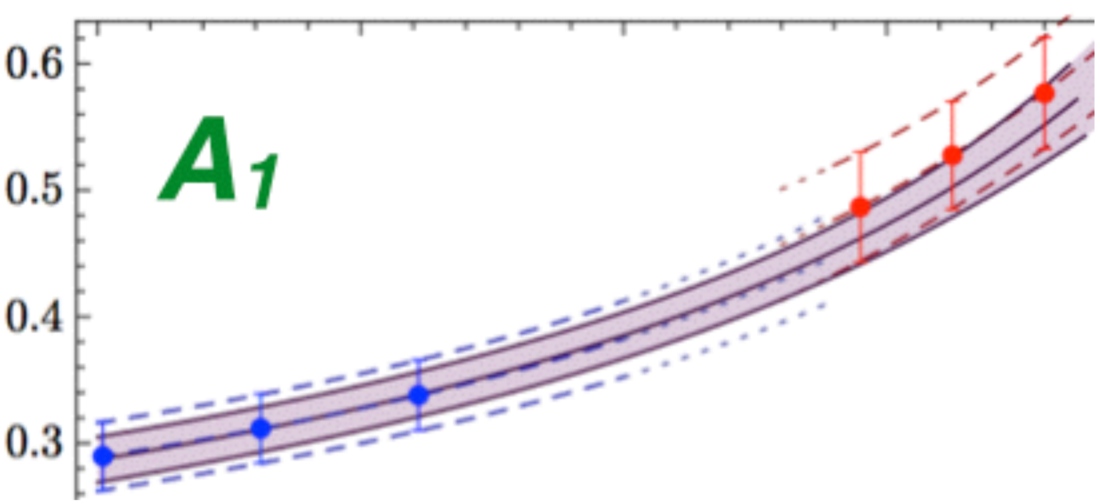
- two large momenta
  - $p_B^2 = m_B^2$ fixed
  - $4m_l^2 < q^2 < (m_B - m_{K^*})^2$

  trace them ….

short vs long distance

SD = form factor local int.





shape q^2 dictated by m_{B^*}-pole
(outside physical region)

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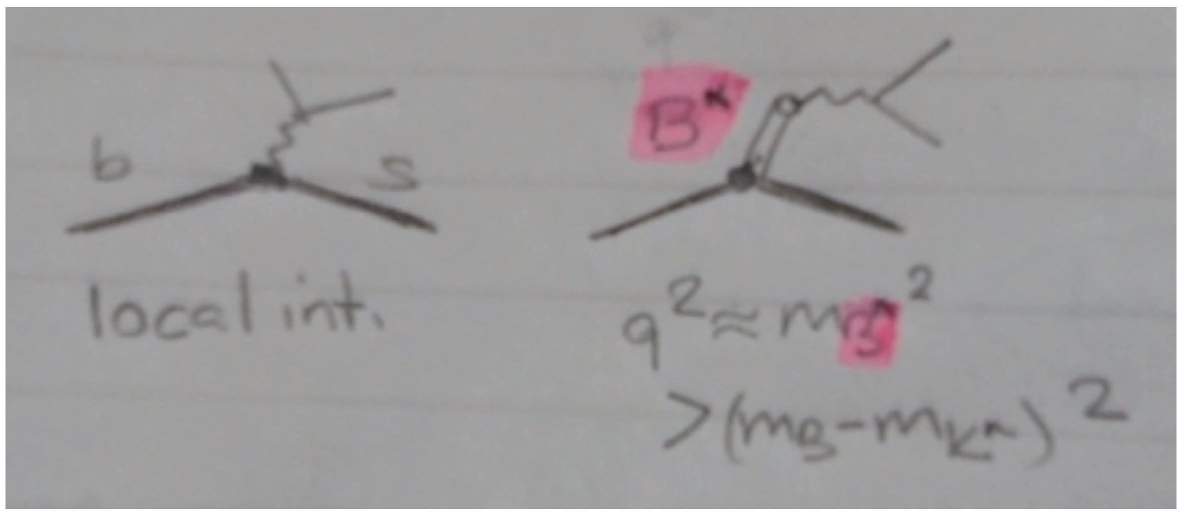
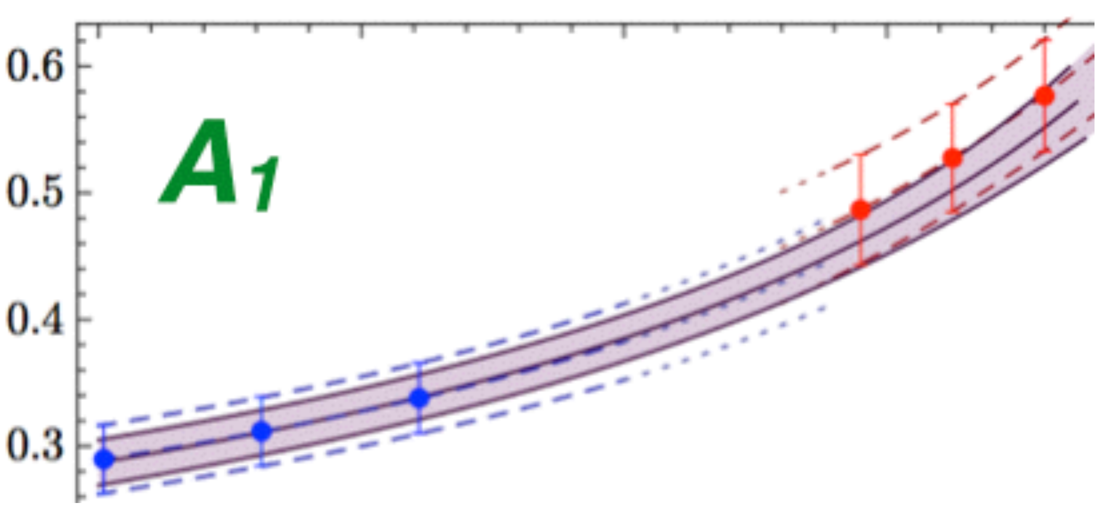
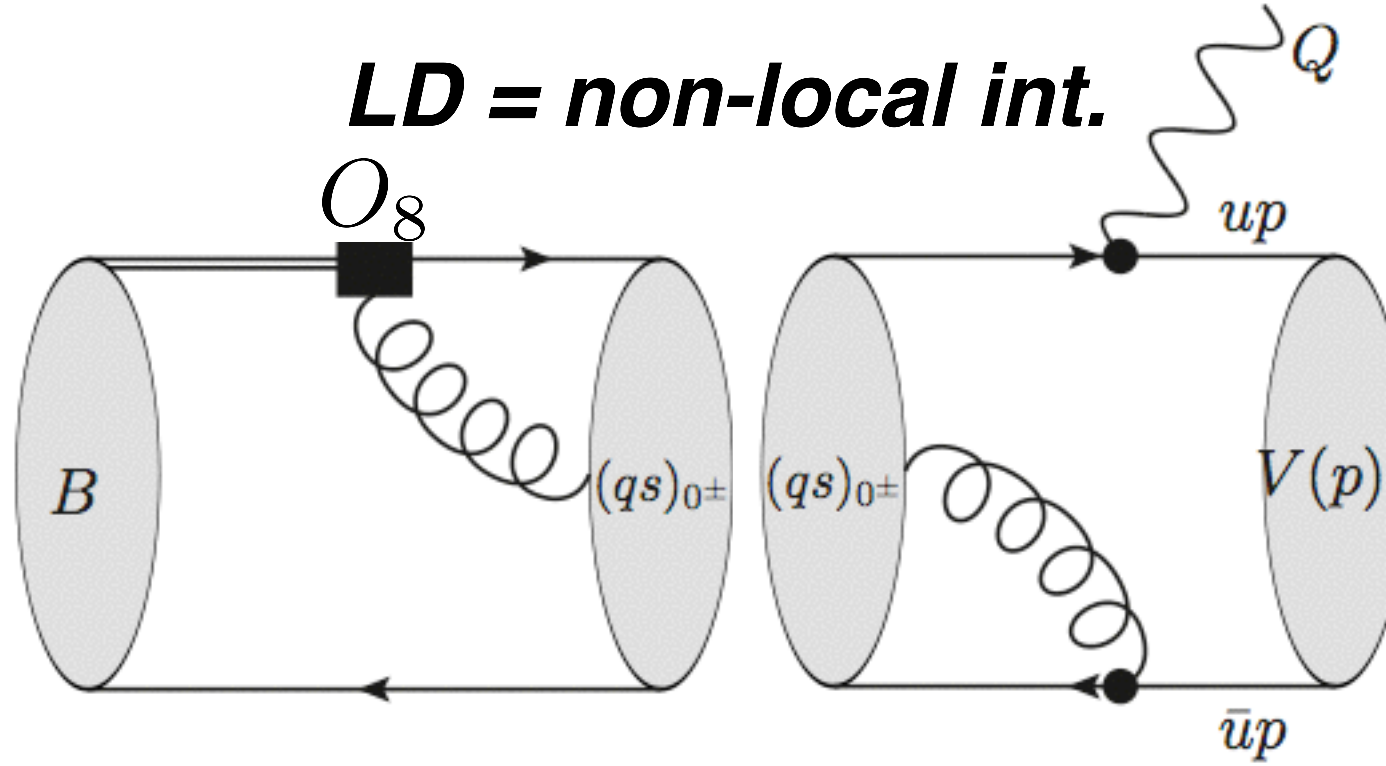




shape q^2 dictated by m_{B^*}-pole (outside physical region)

LD = non-local int.



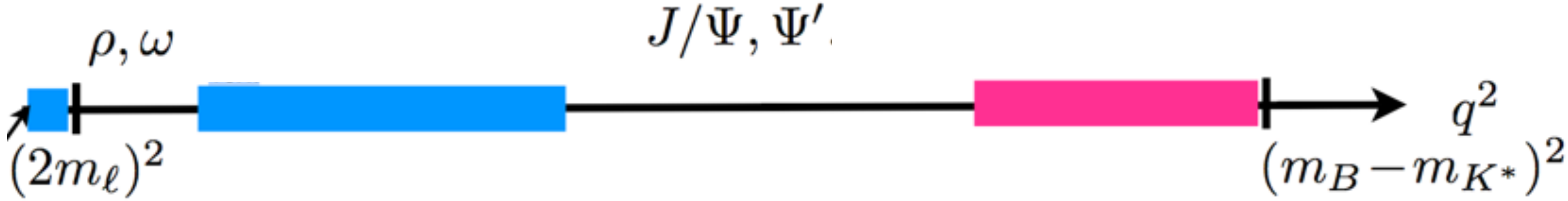
cut $p_B^2 = m_B^2$ fixed — interpretation:

Multihadron state $(\bar{s}q)_{0^\pm}$ q-number

result: strong phases

status: believed to be without problem
many states (broad) s.t.
partonic QCD is trustworthy

long distance and q²-singularities



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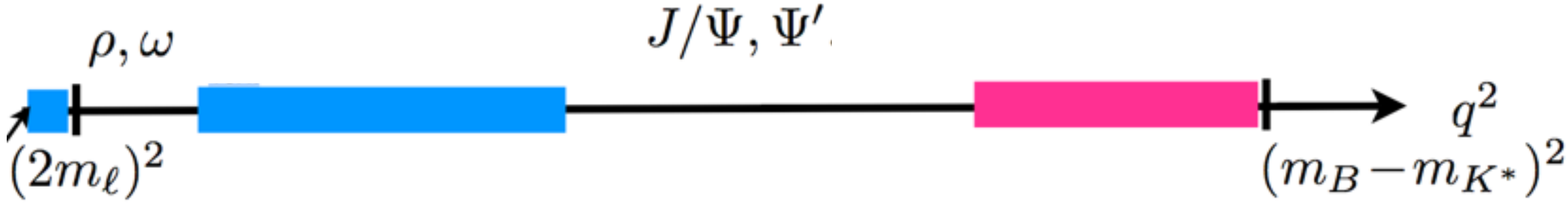
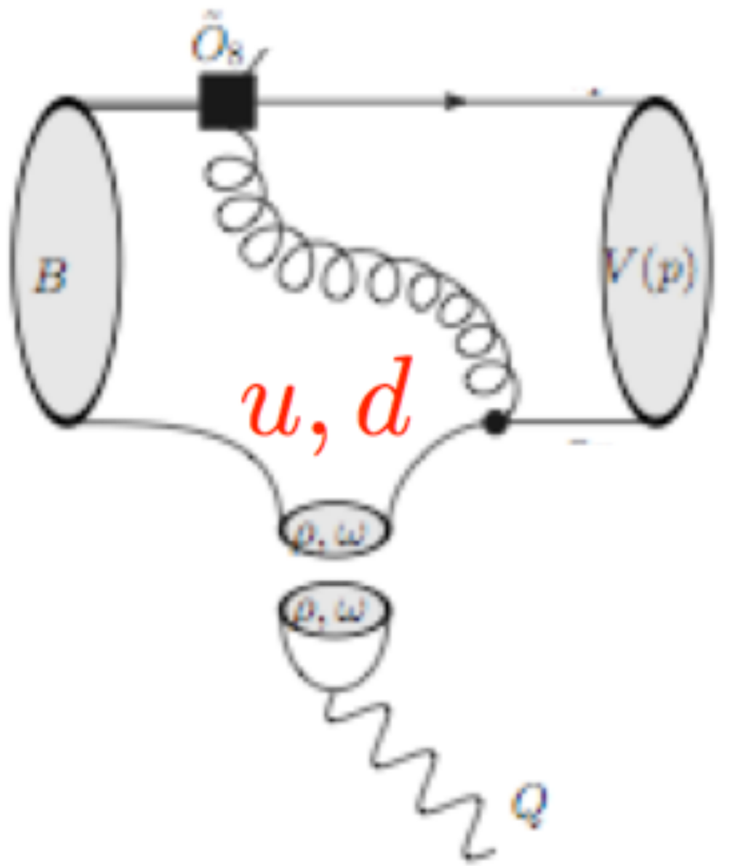


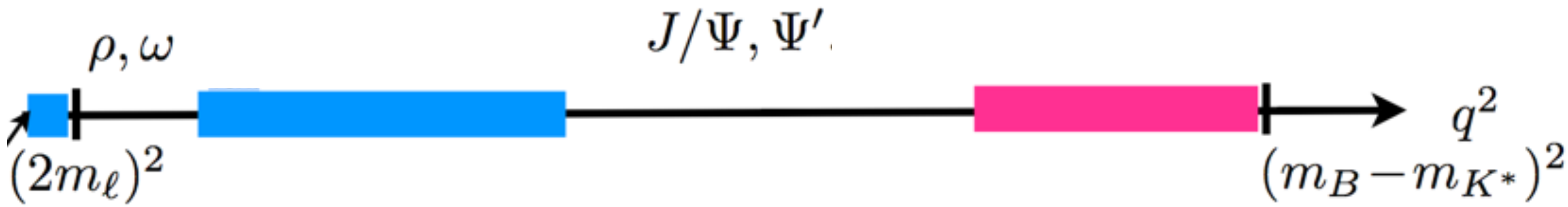
- radiation from light-quark



taken care of by photon DA

characteristic $1/q^2$ fall-off

long distance and q^2-singularities



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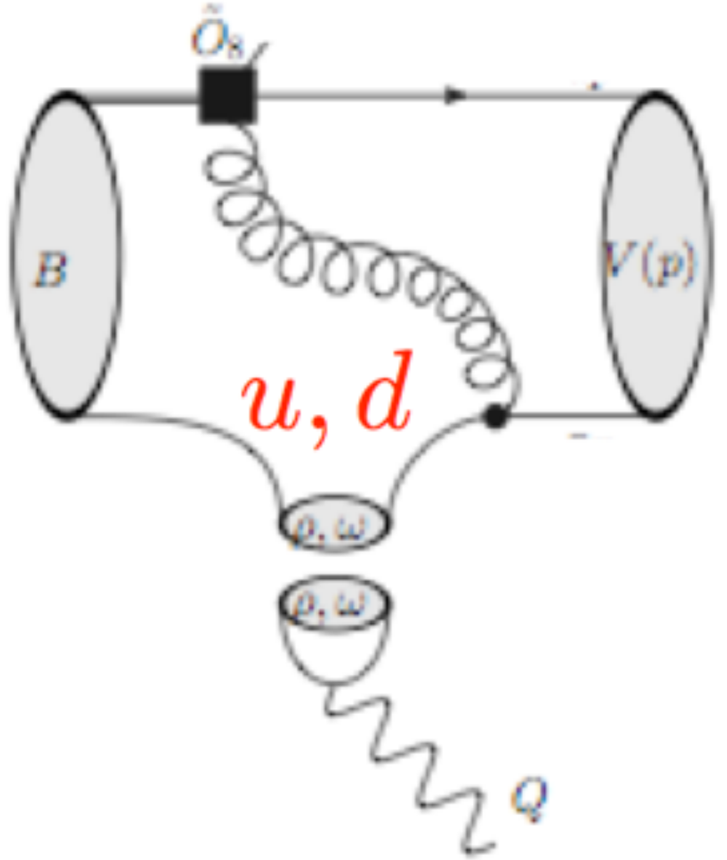

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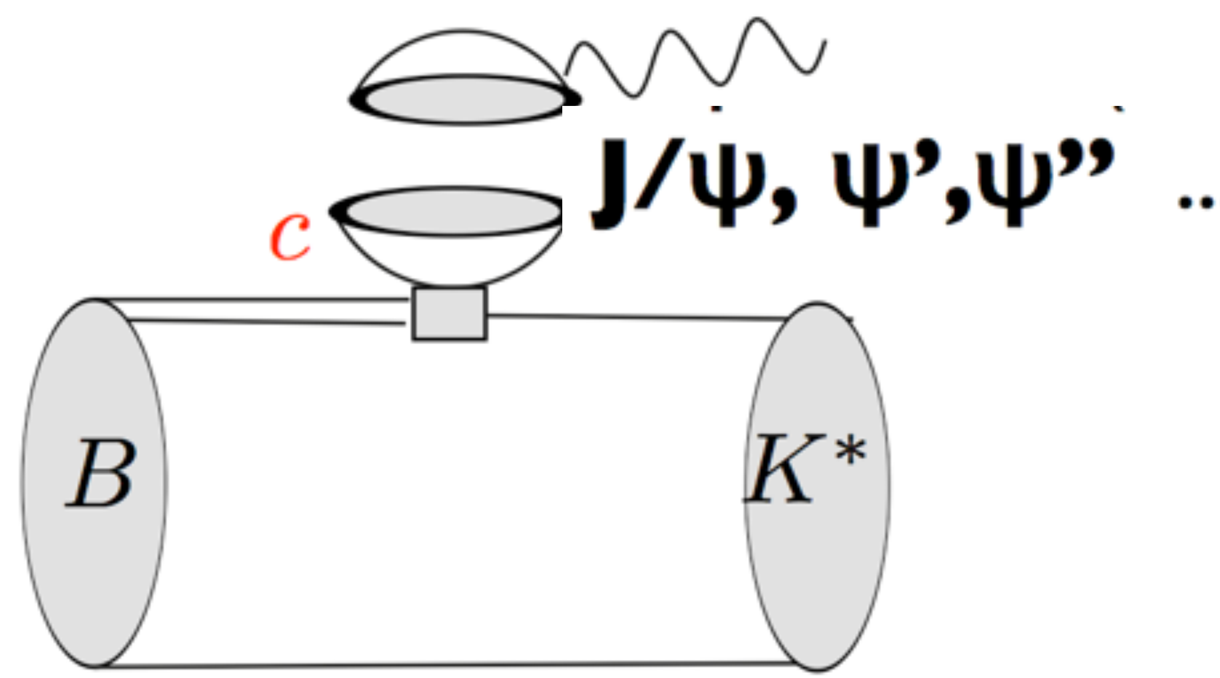
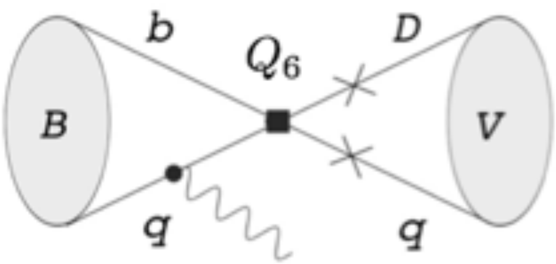
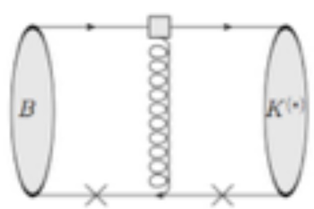
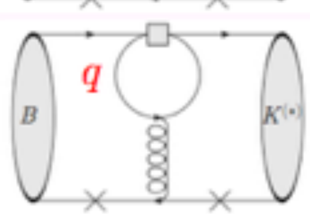
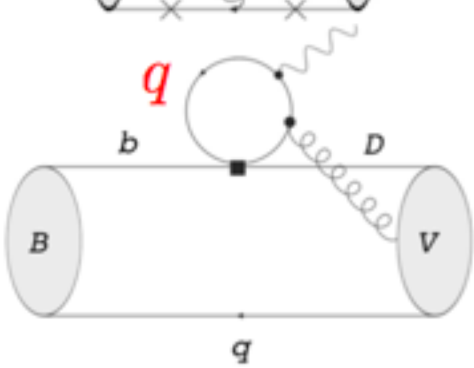
characteristic $1/q^2$ fall-off

- radiation from charm quark



required closer look and
theory and experiment working
together (tomorrow)

long-distance brief overview status

	QCDF	LCSR
comments:	1) depends B-meson DA 2) at 1/m endpoint divergences	1) depend on spurious momentum and analytic continuation thereof 2) includes photon DA
	1/m accidental?	photon DA sizeable Khodjamirian et al'95 Ali Braun'95 Lyon, RZ'13
	the 1/m divergent	Dimou, Lyon, RZ'12
	idem	not done (some work)
	non-factorisable	various bits done Ball, Jones, RZ'06, Khodjamirian et al'10, ..later

Bosch, Buchalla'01

Beneke, Feldman, Seidel'01

generally:
to disentangle short from long-distance effects need fine q^2-binning

II.b form factors - short distance

- general: low-q^2 meson fast light-cone methods LCSR
  high-q^2 meson slow lattice (effective theory b)

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pseudo scalar B->K,π
3 (main) form factors

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  Bouchard et al'13
  LCSR: twist-3 $O(a_s)$
  Ball RZ'04 , Khodjamirian et al'08,10?

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7 (main) form factors

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  Horgan et al'13
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  Ball RZ'04 , Bharucha, Straub, RZ'15
  LCSR: B-meson DA, tree-level
  Mannel, Offen, Khodjamirian 06

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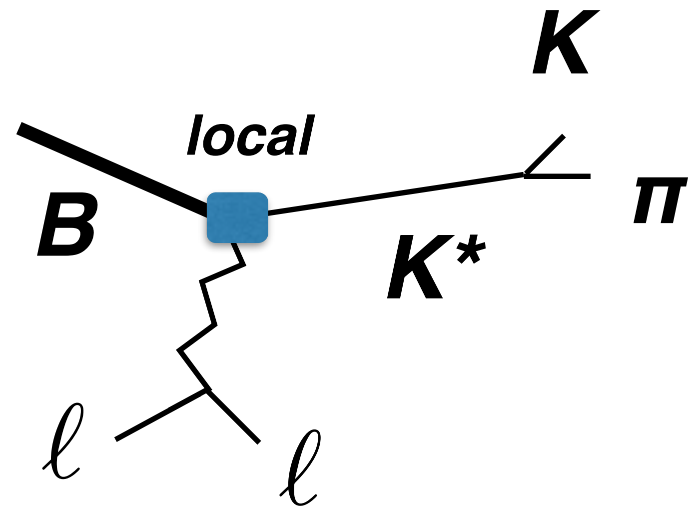
report progress on recent update vector form factors

Definition of form factors



- *tensor* & *vector* *form factors*

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

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

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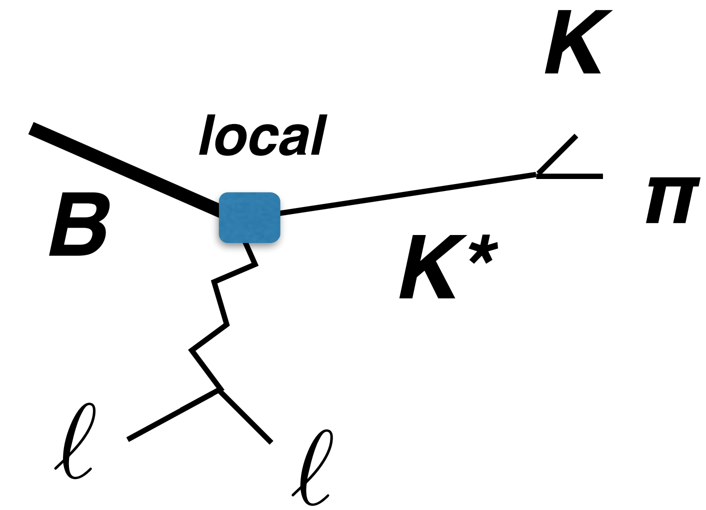

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- ***4 directions:***

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

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

- ***in terms of traditional notation:***

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

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

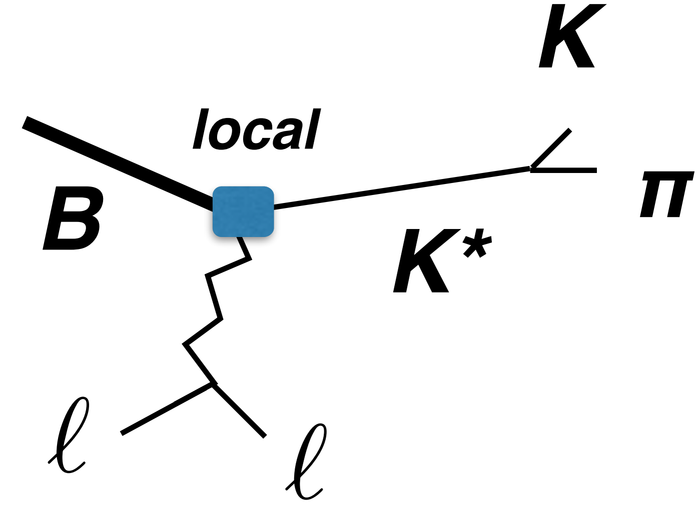
algebraically:

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

regularity:

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

Form factors & LCSR use appropriate correlation function Γ



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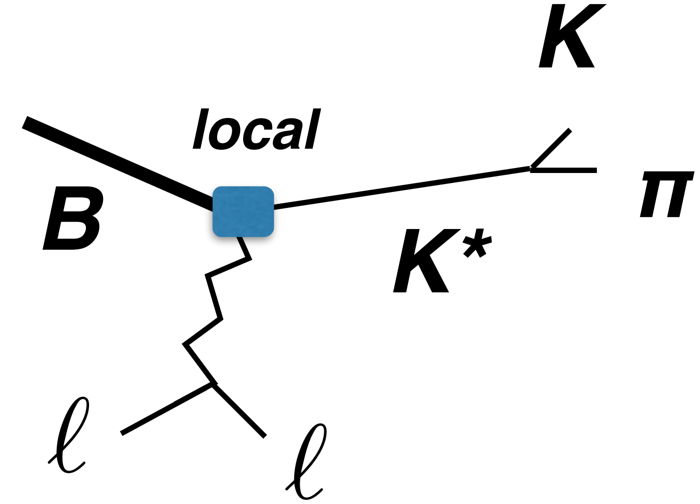

- ***sum rule on one line:***

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

exact equation

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

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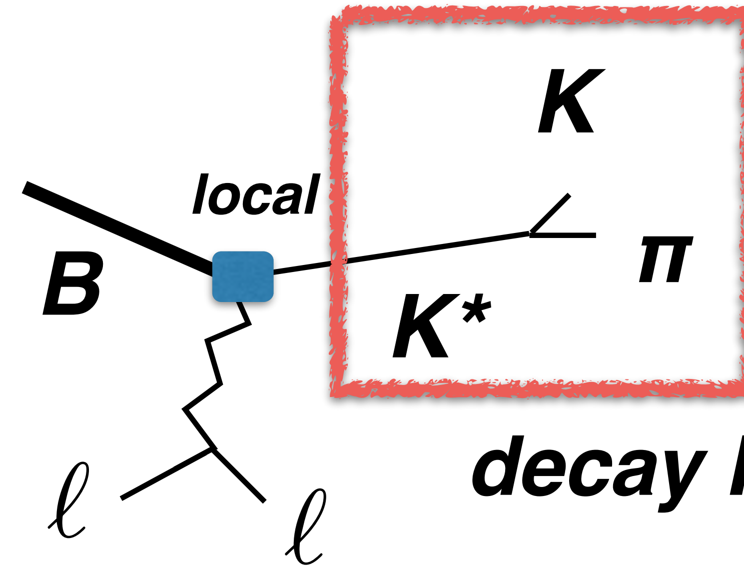

decay K* I.C

- *sum rule on one line:*

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

input ⇒ correlation between form factors I.A

sum rule parameters some help equation of motion I.B

II.b.1 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"

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

- ***we use:***

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

z-expansion around single pole

k=0..2

LCSR: $0 < q^2 < 14 GeV^2$

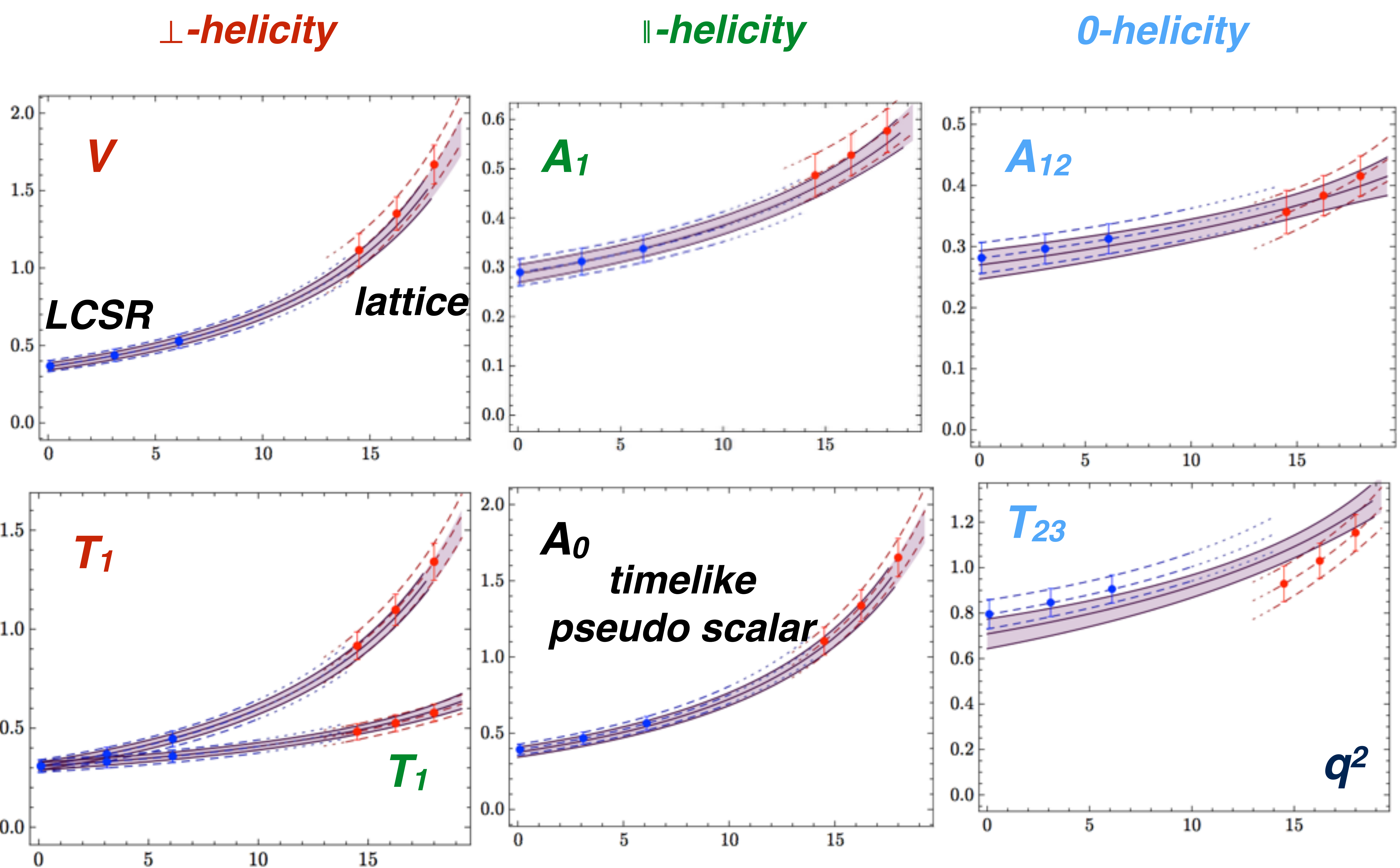
k=0..2

"entire range" combined with lattice

from Horgan,Liu, Meinel, Wingate'13

note: lattice with correlated errors as well

Combined LCSR & lattice plots



II.b.2 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 $P_5' \sim \text{Re}[H_0 H_\perp]$ for instance

EOM in QFT ⇔ relations between correlation functions

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

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

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- ***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)

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

  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%)]
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- … 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

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

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

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

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(⇒ more than a numerical accident)

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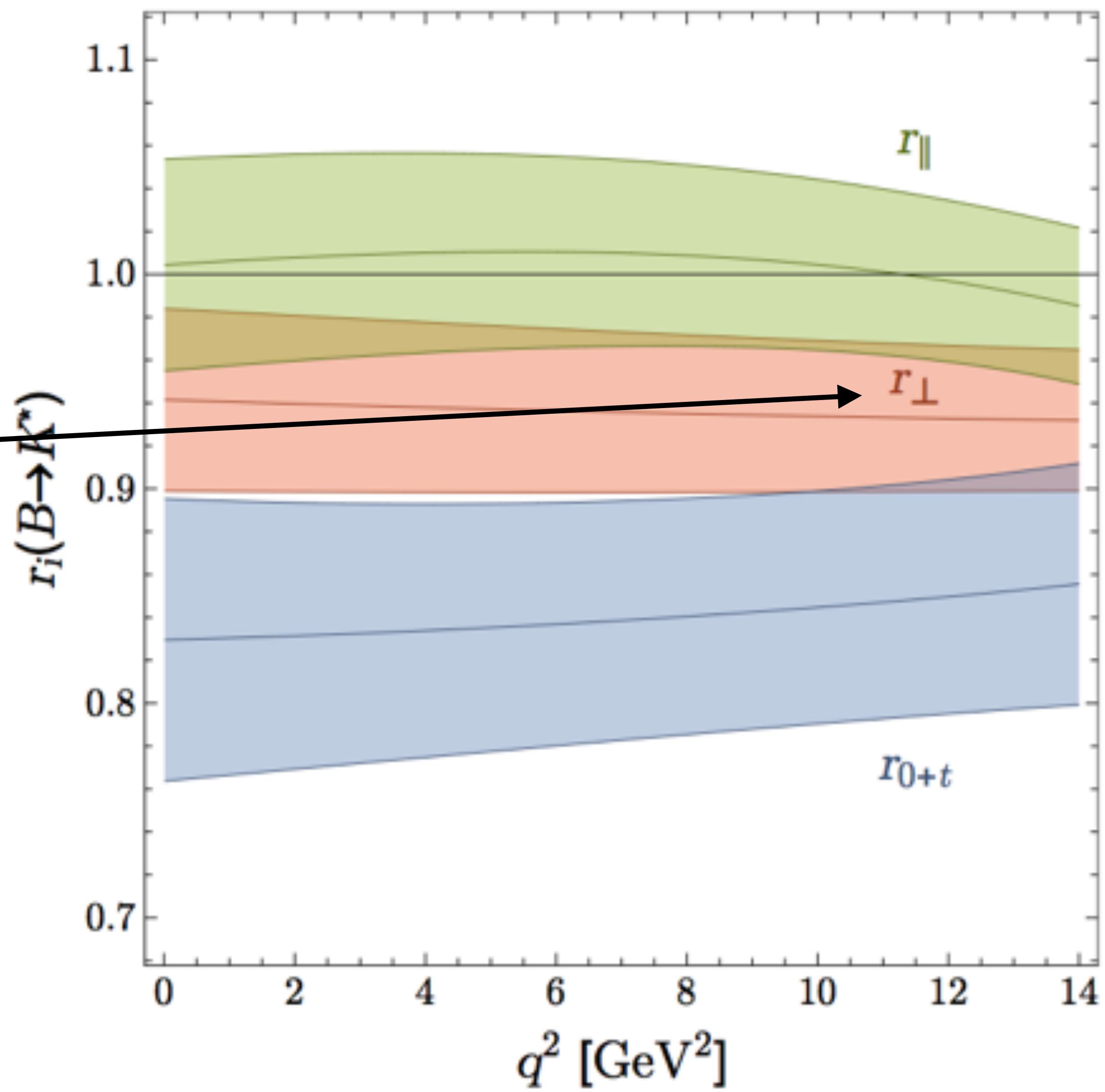
- Vector-tensor form factor ratios determined up to 4-6%

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



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 $1/m_b$

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

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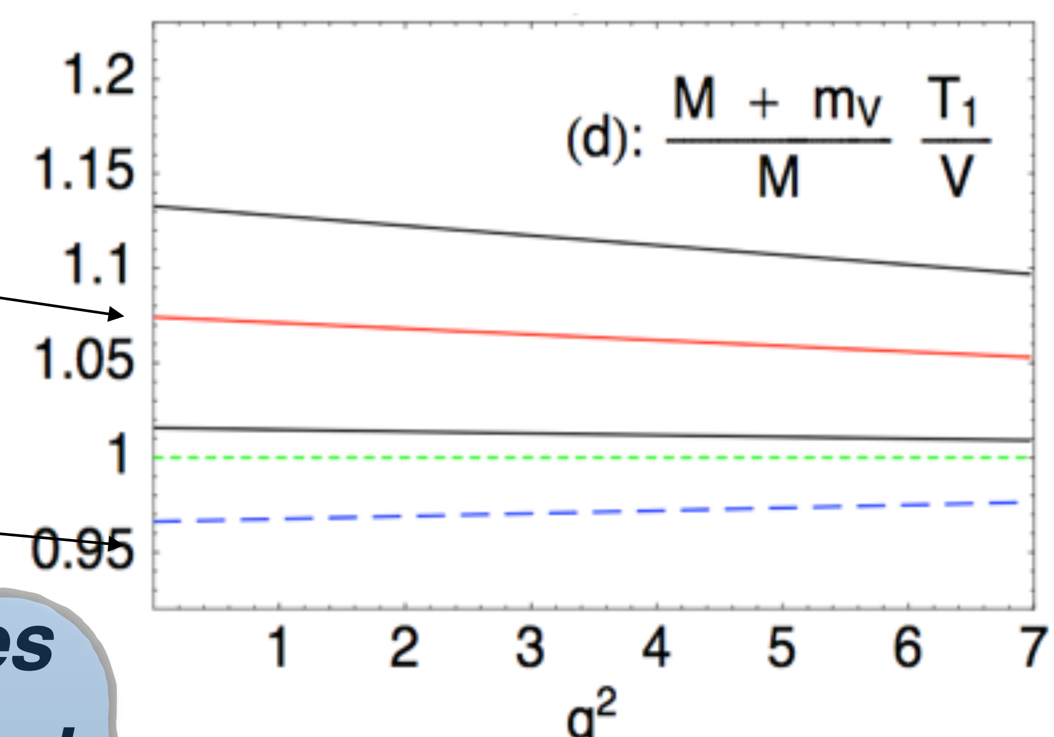
- numerical comparison LCSR vs heavy quark limes

heavy quark ratio (ratio endpt conv.)

old LSCR (new one similar)



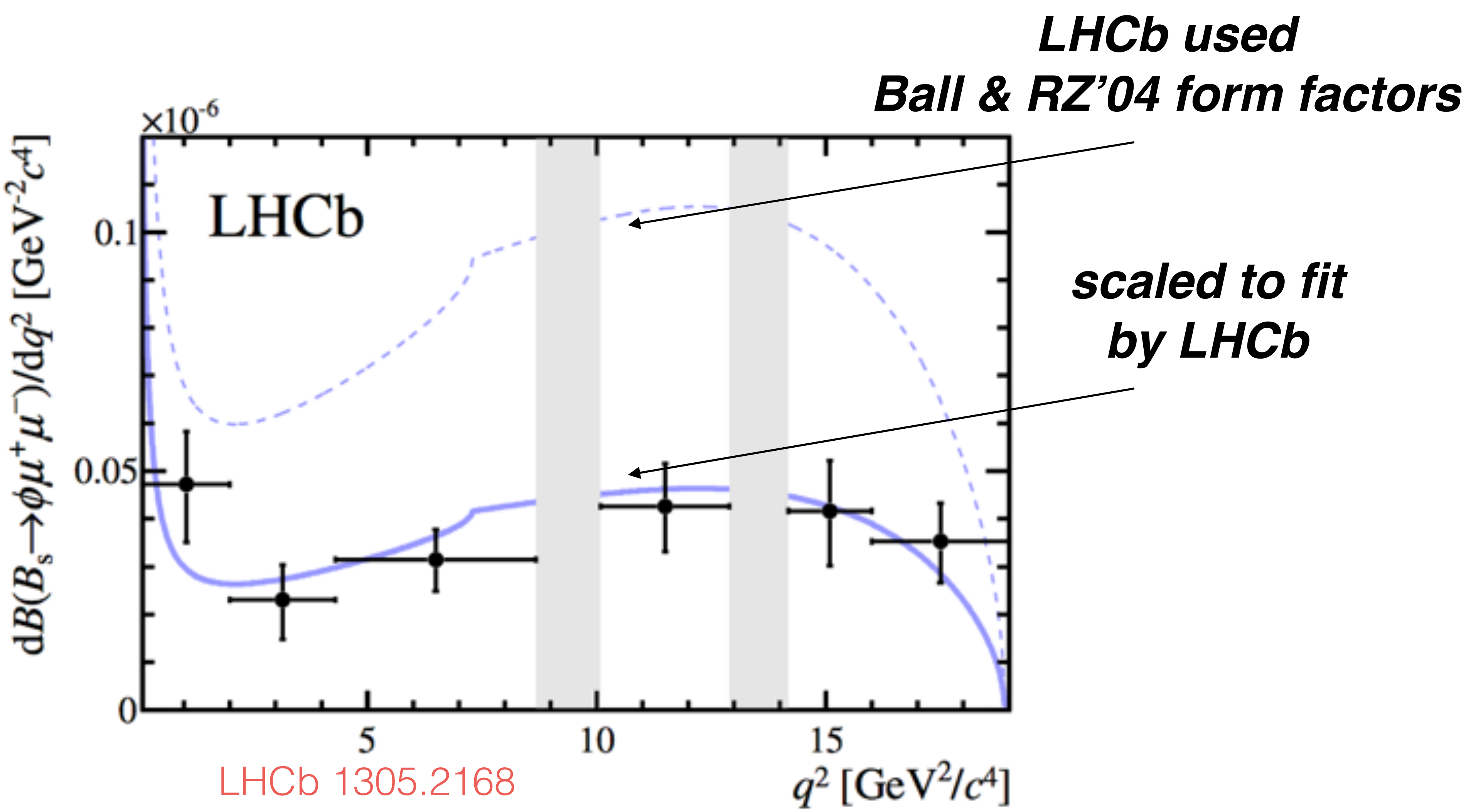
- from Beneke Feldmann '00

correction ca 10% heavy quark limes
LCSR ought to reproduce heavy quark value in heavy quark limes

phenomenological discussion

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

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



LHCb 1305.2168

phenomenological discussion

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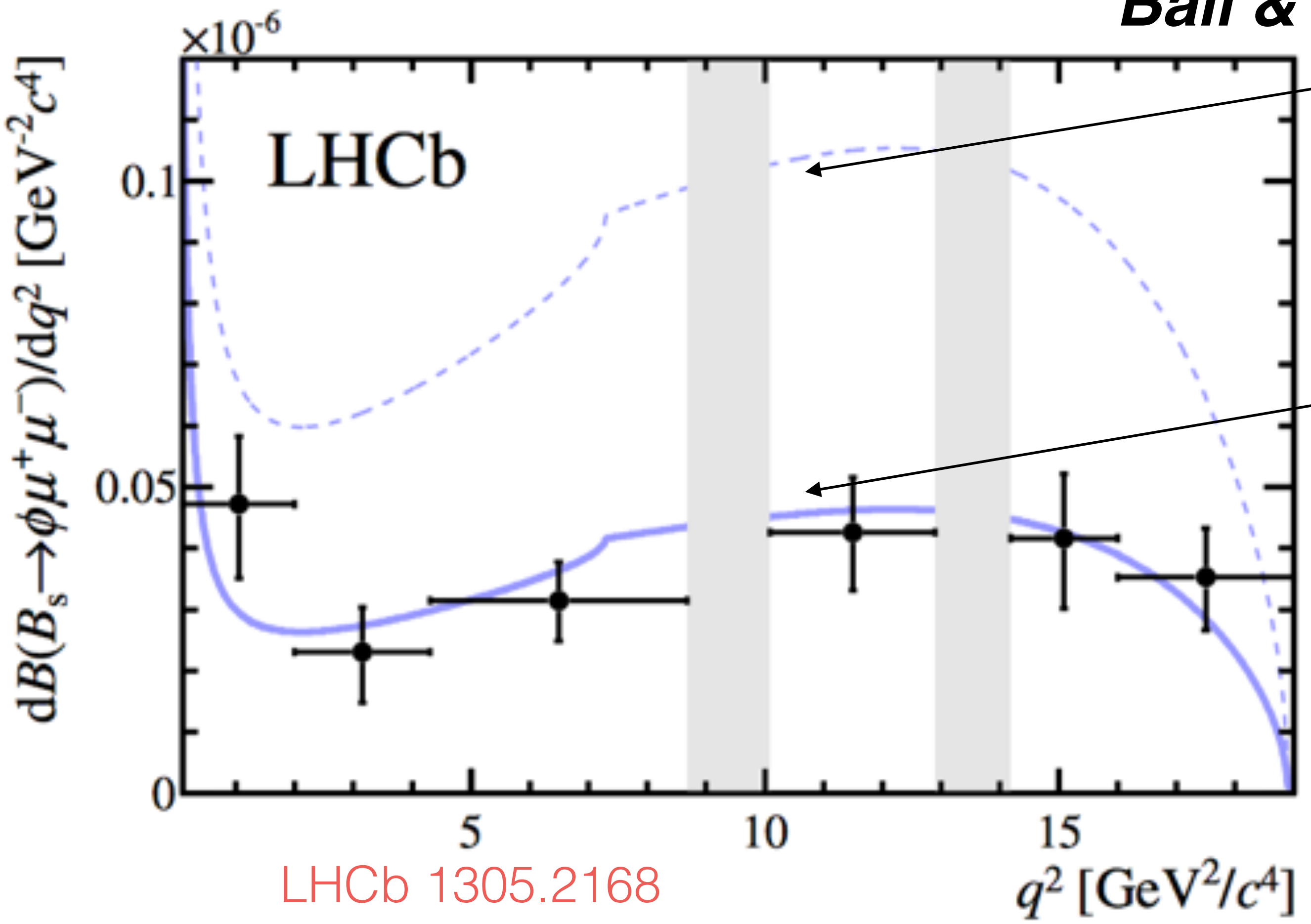
LHCb used Ball & RZ'04 form factors

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
$0.78(18)$	$1.23(32)$

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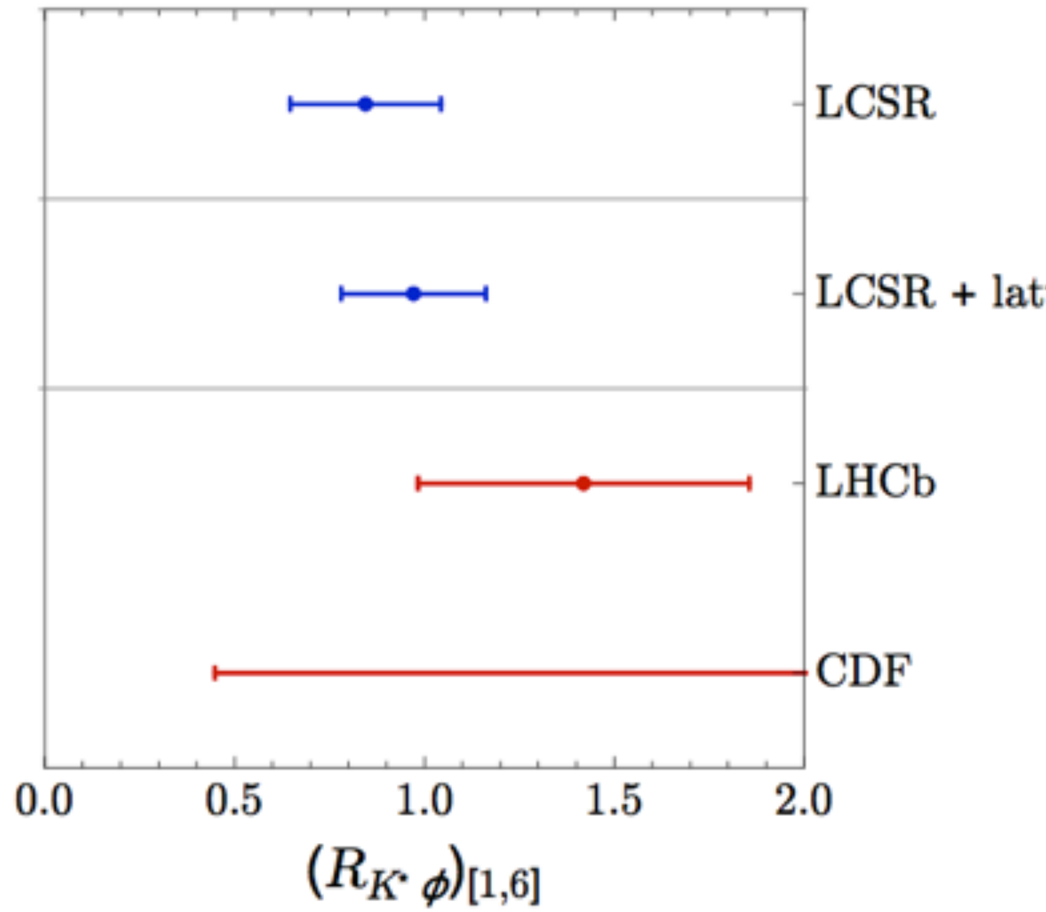

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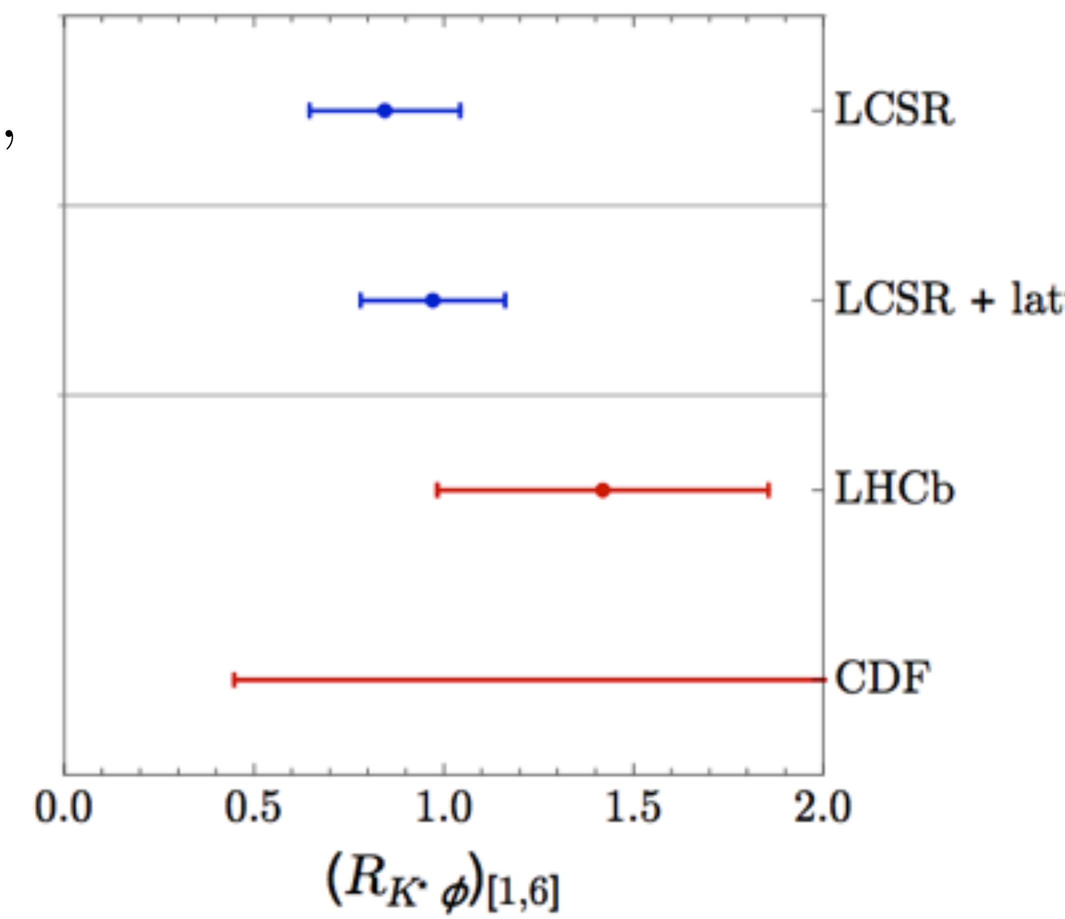


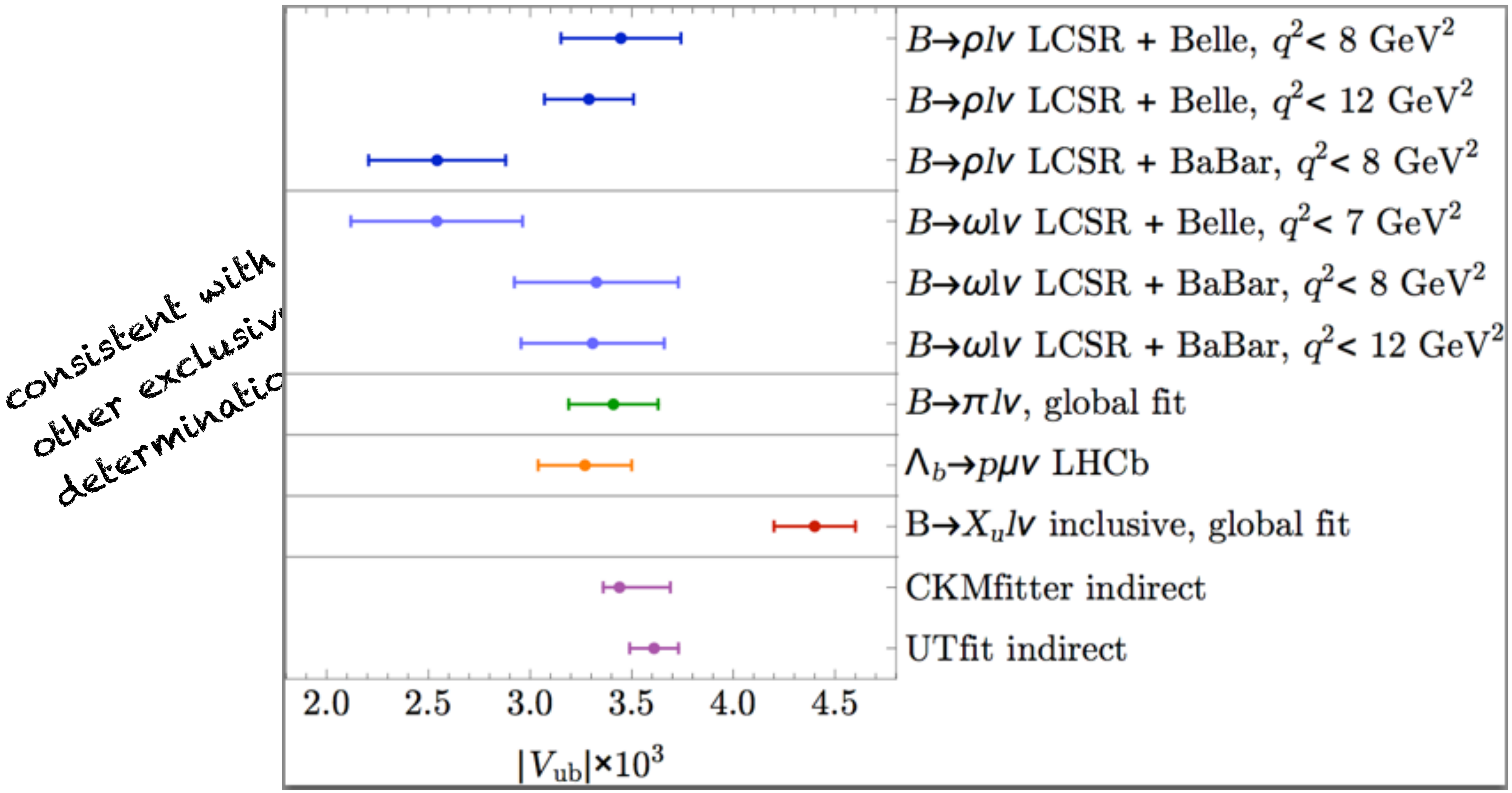
origin of differences?

- 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



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

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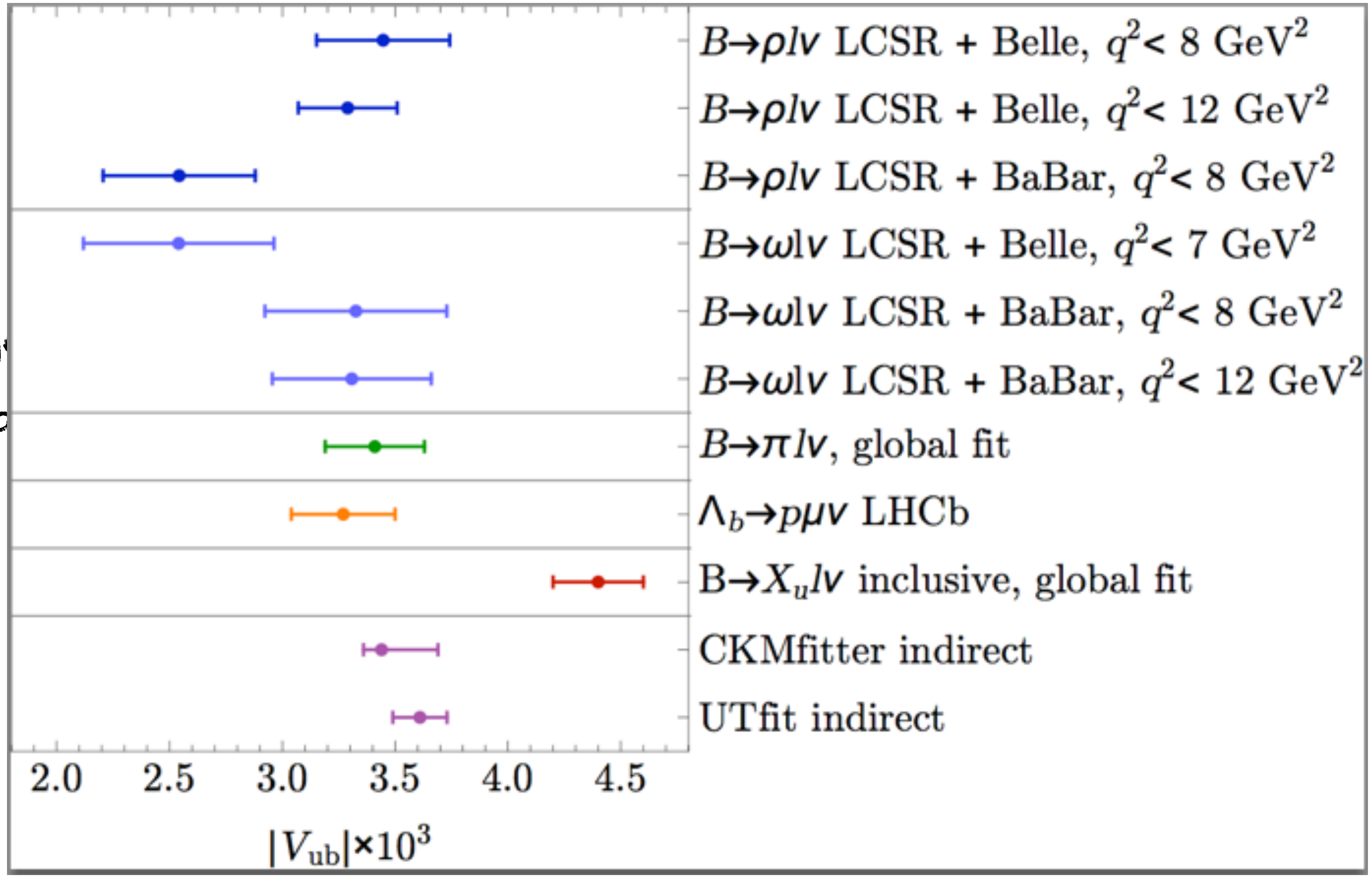
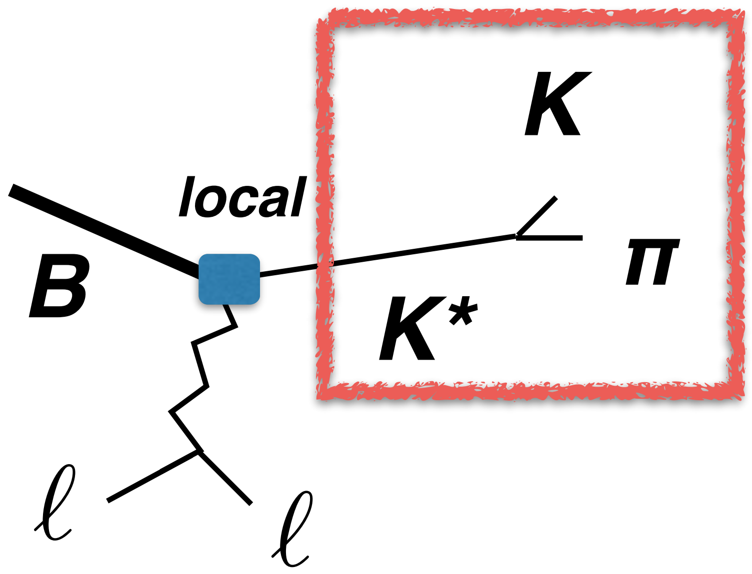


consistent with other exclusive determinatio

⇒ 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

I.C background effects (decaying vector meson)



II.c comment: vector meson - unstable particles

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  (S-wave etc ought to be subtract)

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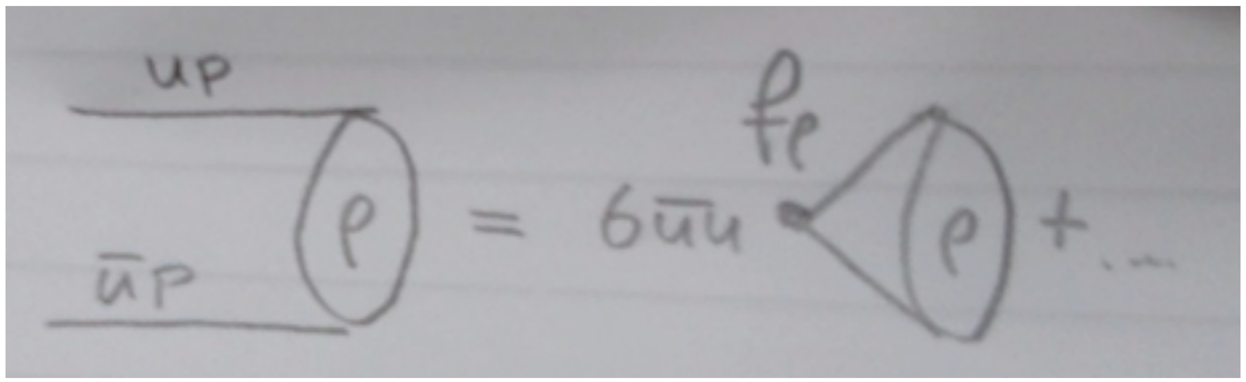
- **experiment**: project out P-wave — ansatz P-wave amplitude
  ρ and ρ',ρ'' maybe more background
  more data ansatz refined (LHCb is pushing standards)

how vector meson described in light-cone approach ?

- through light-cone DA — mainly f_ρ meson decay constant



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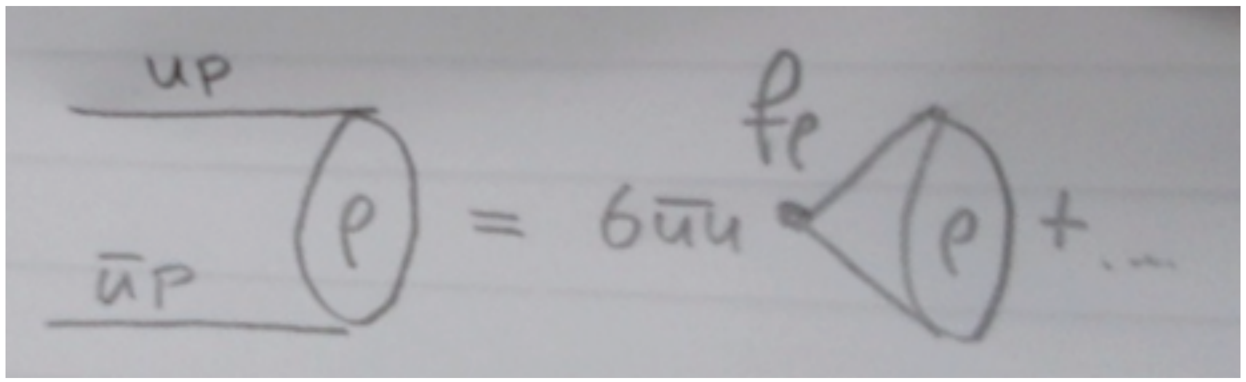

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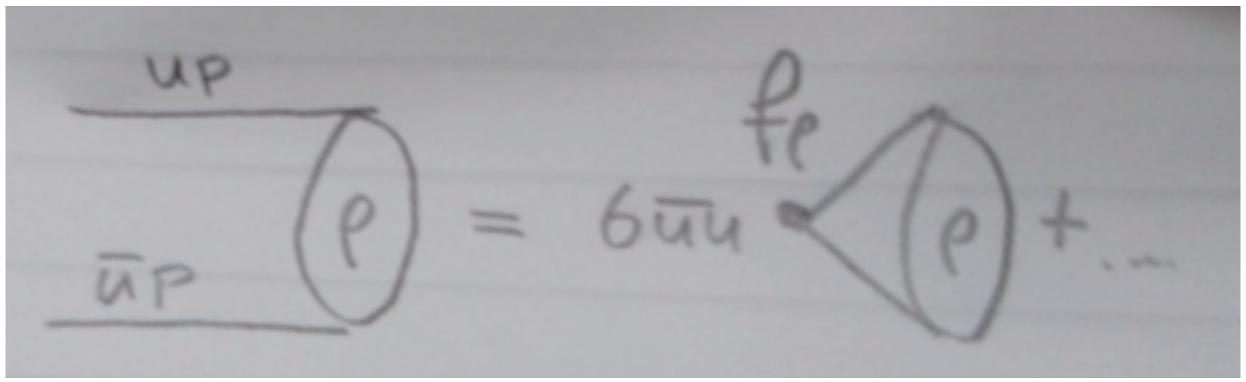

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- lot of these experiments a bit old not same standards as today
  -> important to do new measurements
  -> PDG effort to check old input on tau decays e+e—>ρ etc
  For example PDG'06 vs PDG'12 lowers f_{K^*} by 7% and therefore form factor by 7%!

treat vector meson the same way
in every experiment

conclusions and summary

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thanks for your attention

Backup

Why is it so small?

inclusive = sum of **exclusive** -
is K^* special?

- assuming m_q=0, one closed Dirac trace, leading twist-2, V-A

$$\mathcal{A}(B \to V(p)\gamma(q)^*) = \epsilon(q)_\mu \mathrm{tr}[\not{\eta}\not{p} I^\mu (1-\gamma_5)] \sim I_2$$

$$\text{Ansatz: } I^\mu = I_0^\mu + I_1 \not{p}\gamma^\mu + I_2 \not{q}\gamma^\mu + I_3^\mu \not{p}\not{q}$$

Dimou, Lyon, RZ'12
(appendix)

one structure survives (like large energy limit …)

$\Rightarrow$ **H_- = 0 + O(q^2,m_V^2,m_s)** — suppression systematic **leading twist 2**

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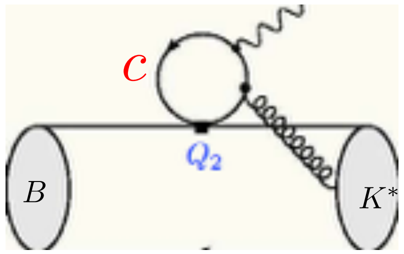
attempt to answer questions:

1.natural to use twist-3 to look for effects:



twist-3

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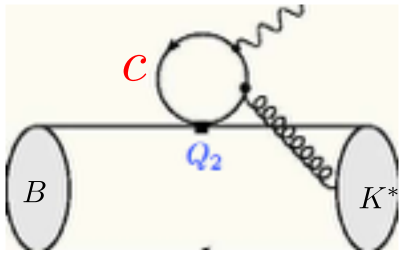
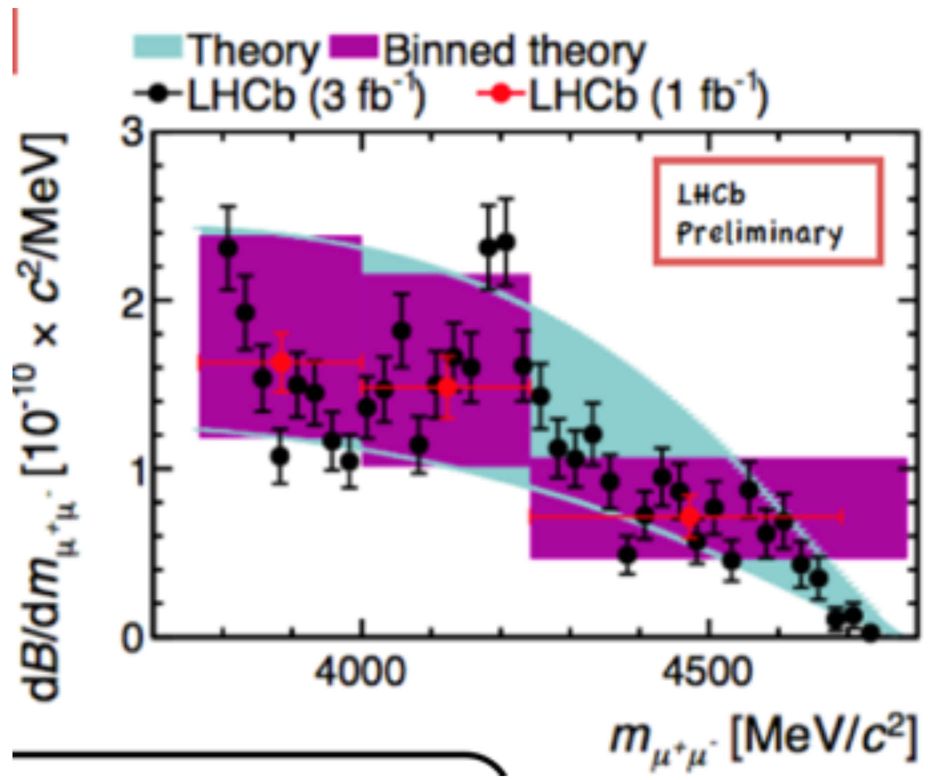
1. natural to use twist-3 to look for effects: 

twist-3

2. heavy use of light-cone dynamics - might well be different for higher resonances and might be a way to partially **reconcile** with **inclusive decay!**

II.C comment charm resonances in B→K $^{(*)}$ll

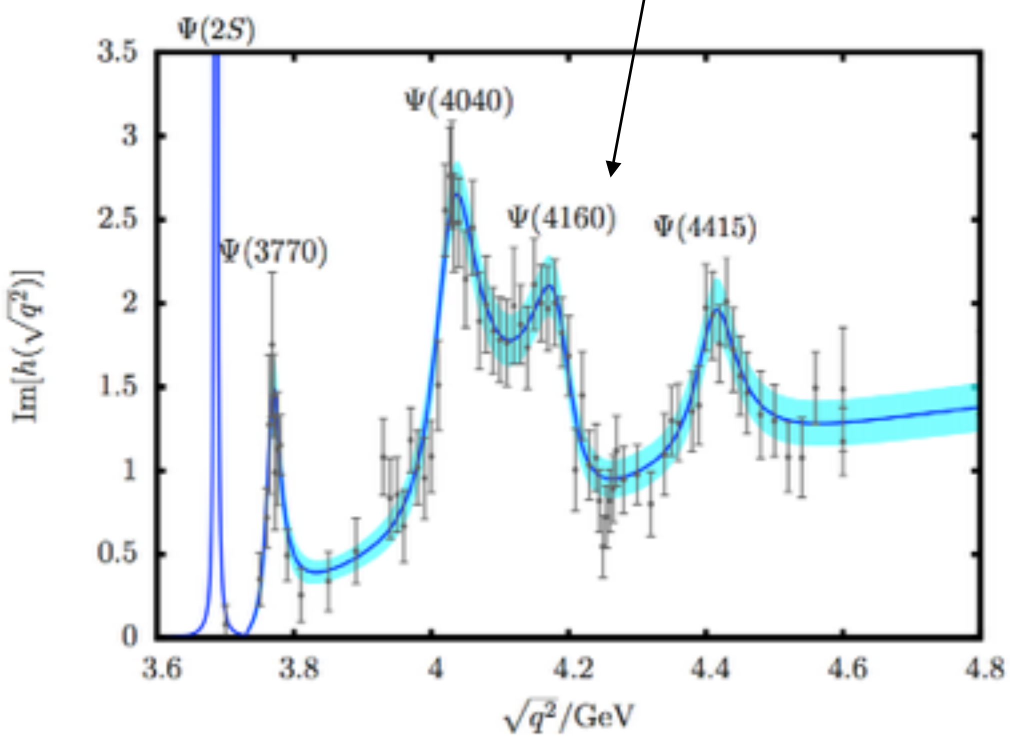
$$\mathrm{BF}(B \to K\ell\ell)$$

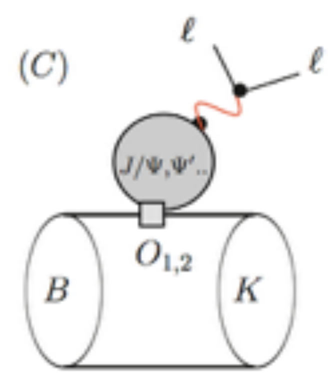


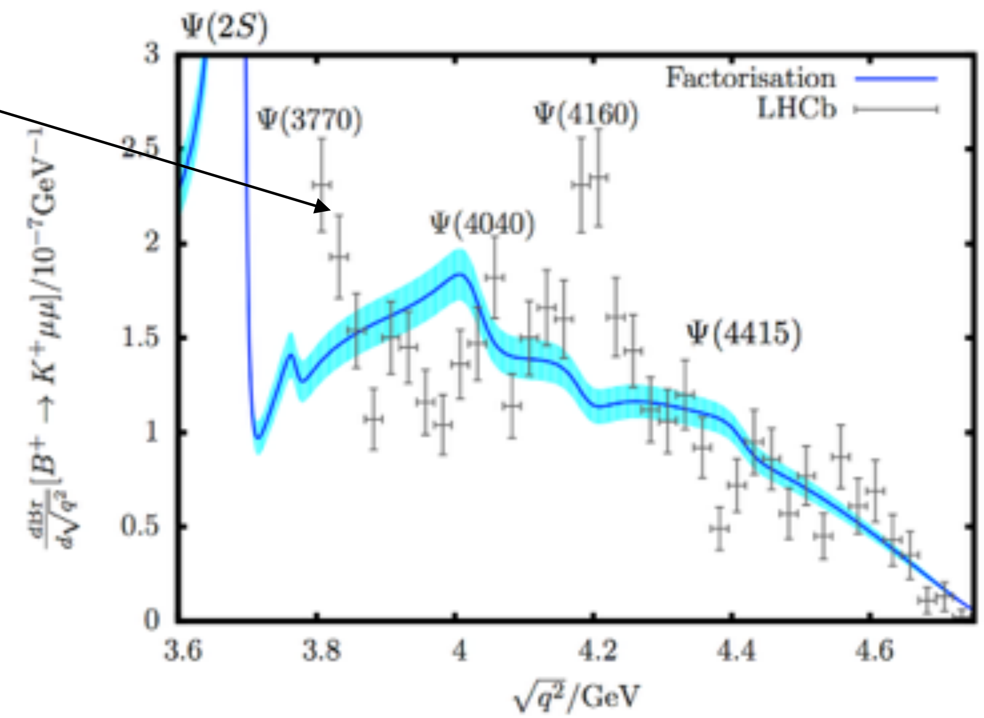
LHCb PRL 111 (2013)

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

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







Lyon RZ 1406.0566

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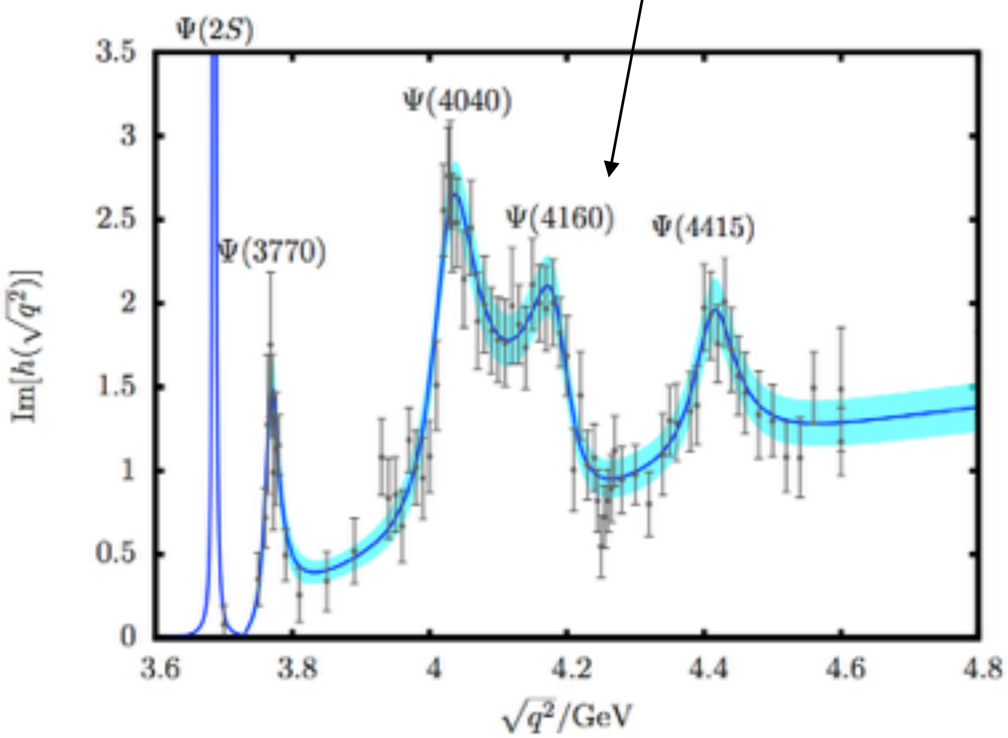
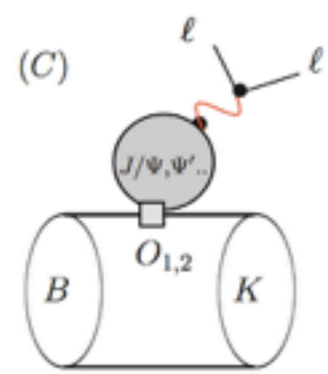
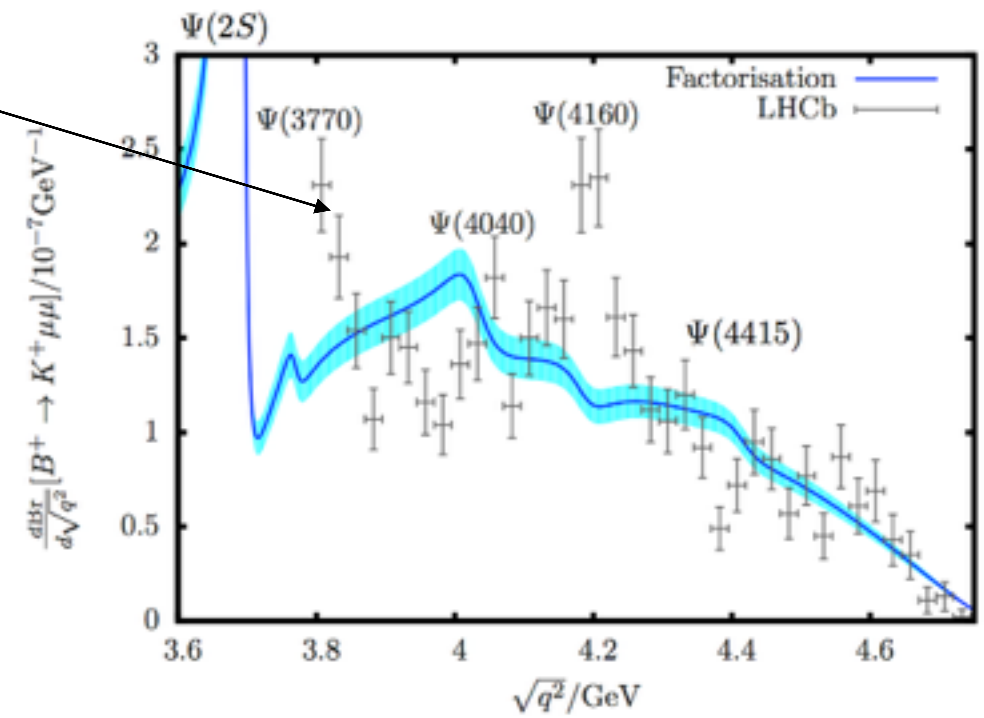
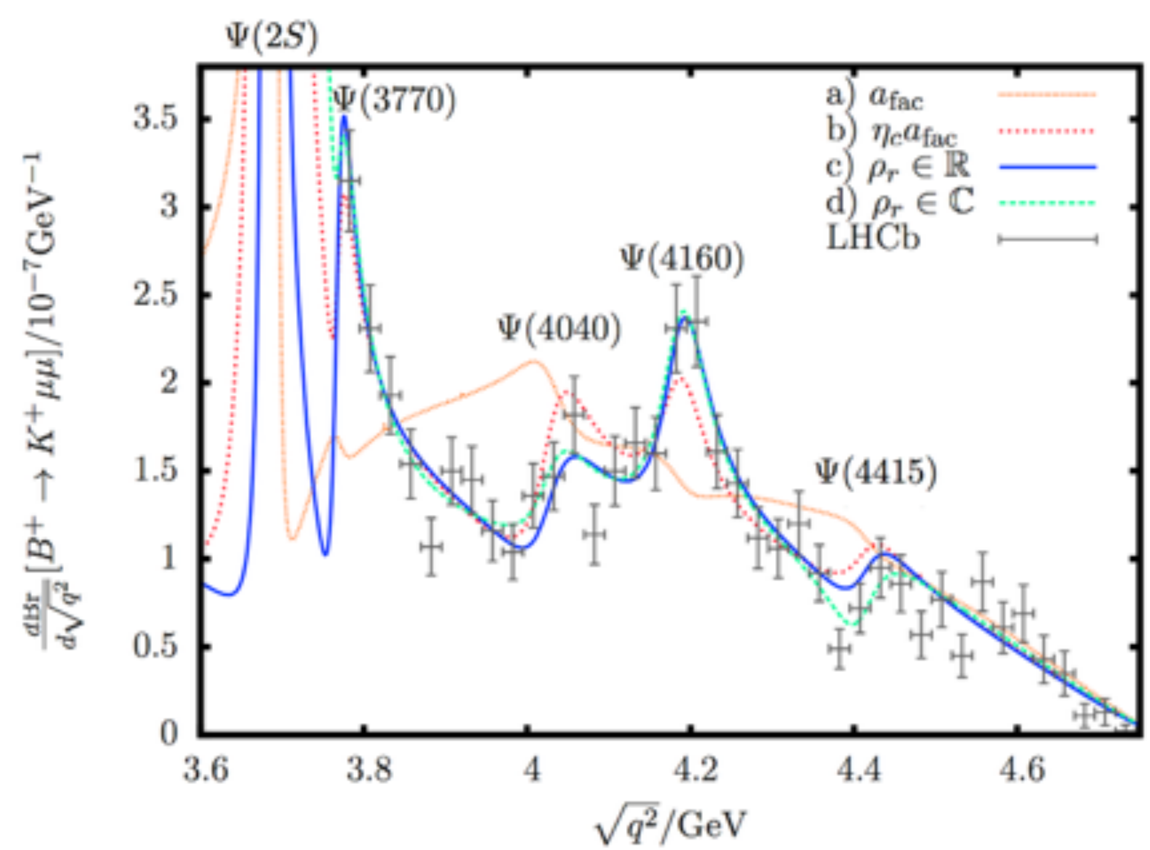


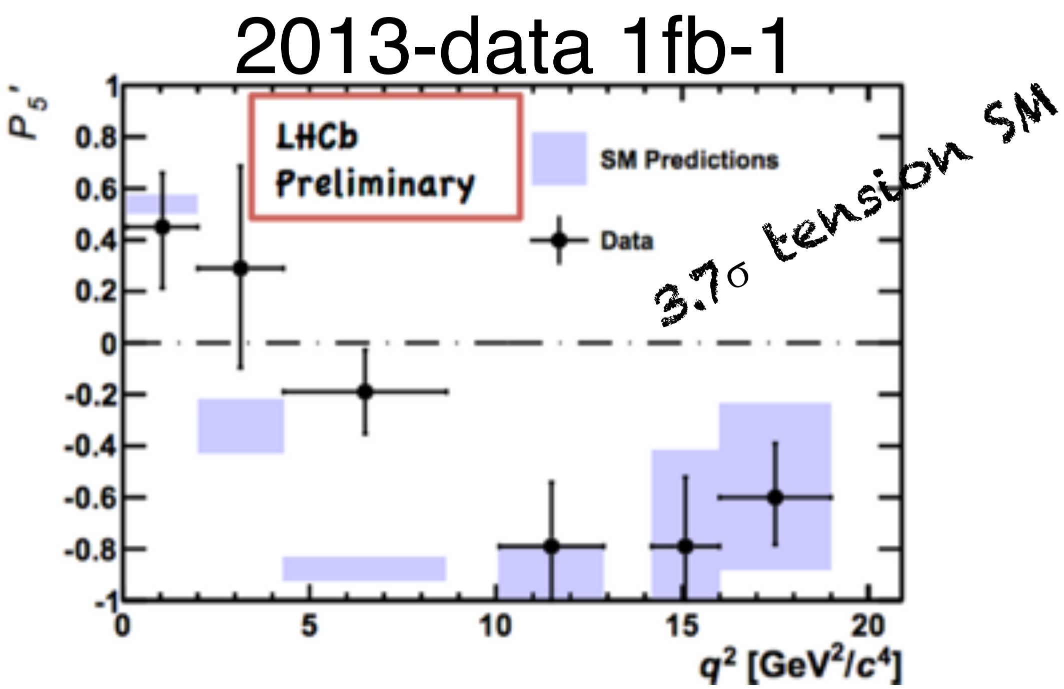


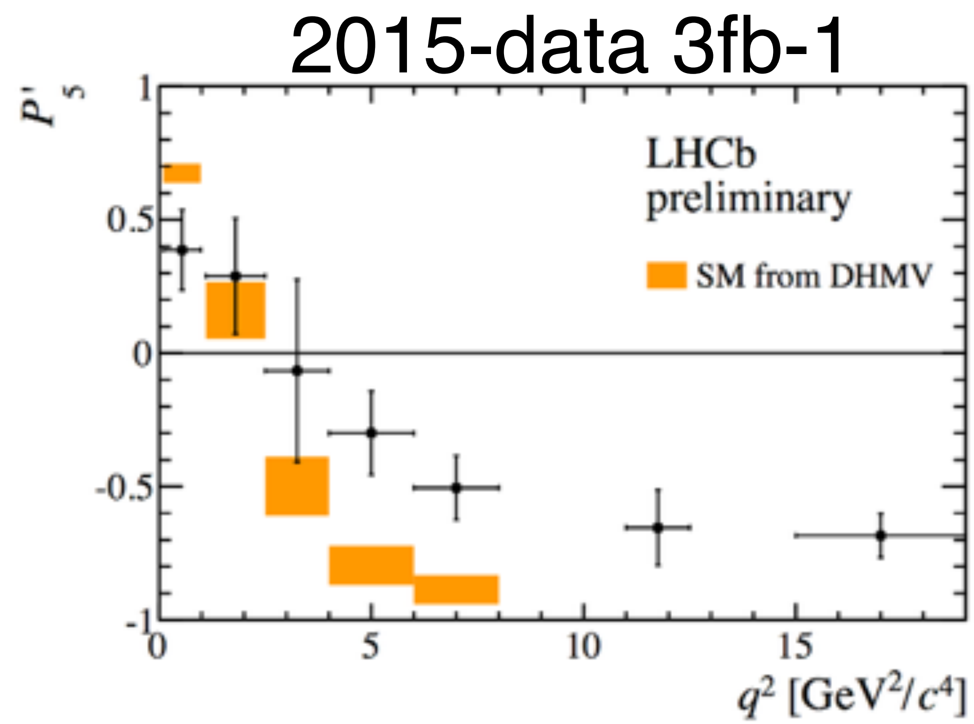


hight of resonances in naive fac. by factor ~(-2.5) fits the data well



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





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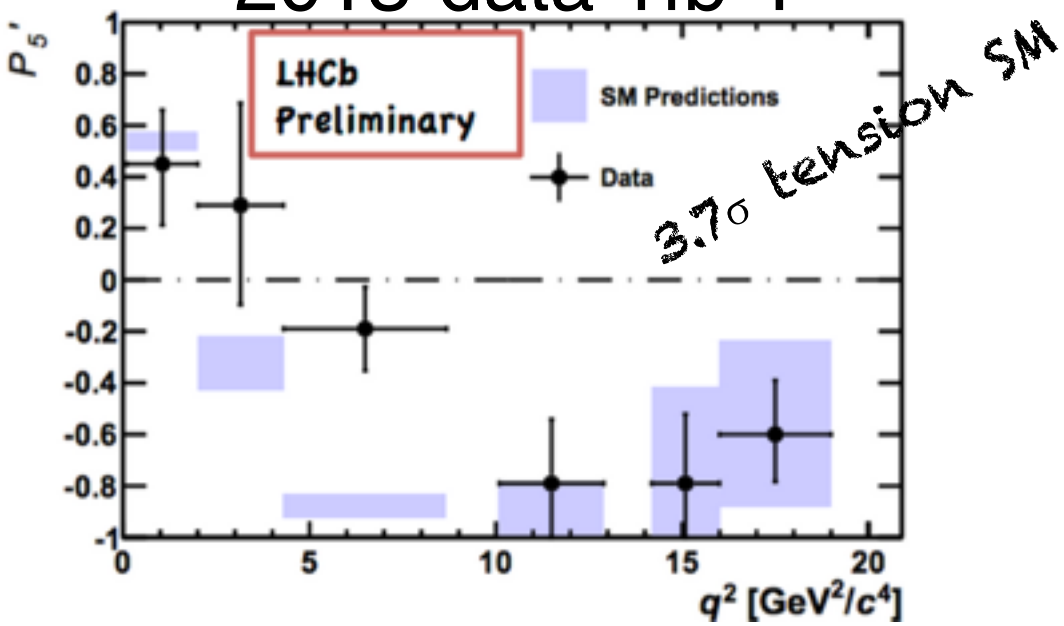
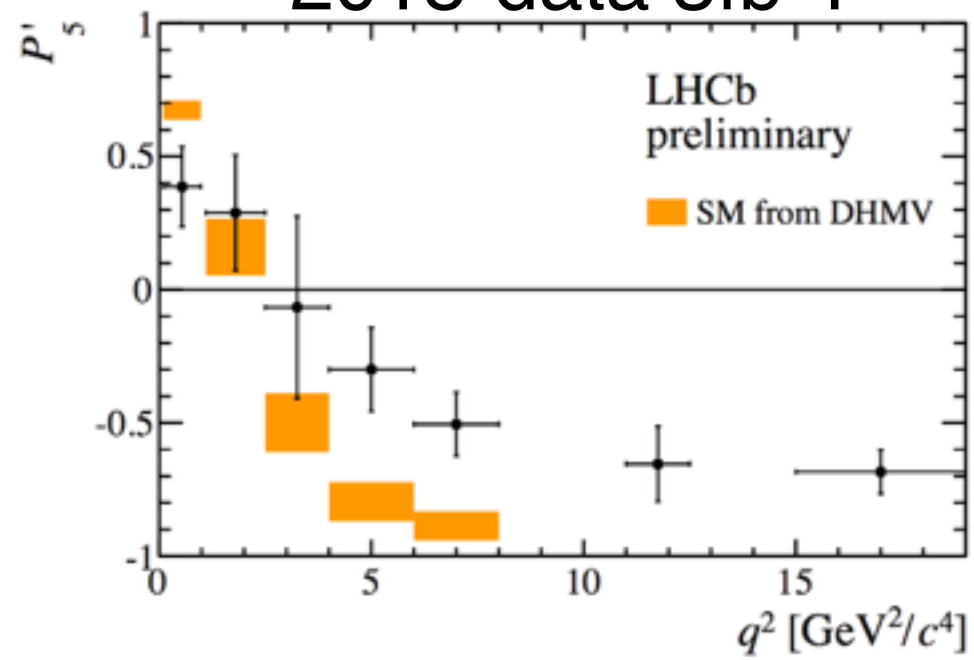
2013-data 1fb-1



2015-data 3fb-1



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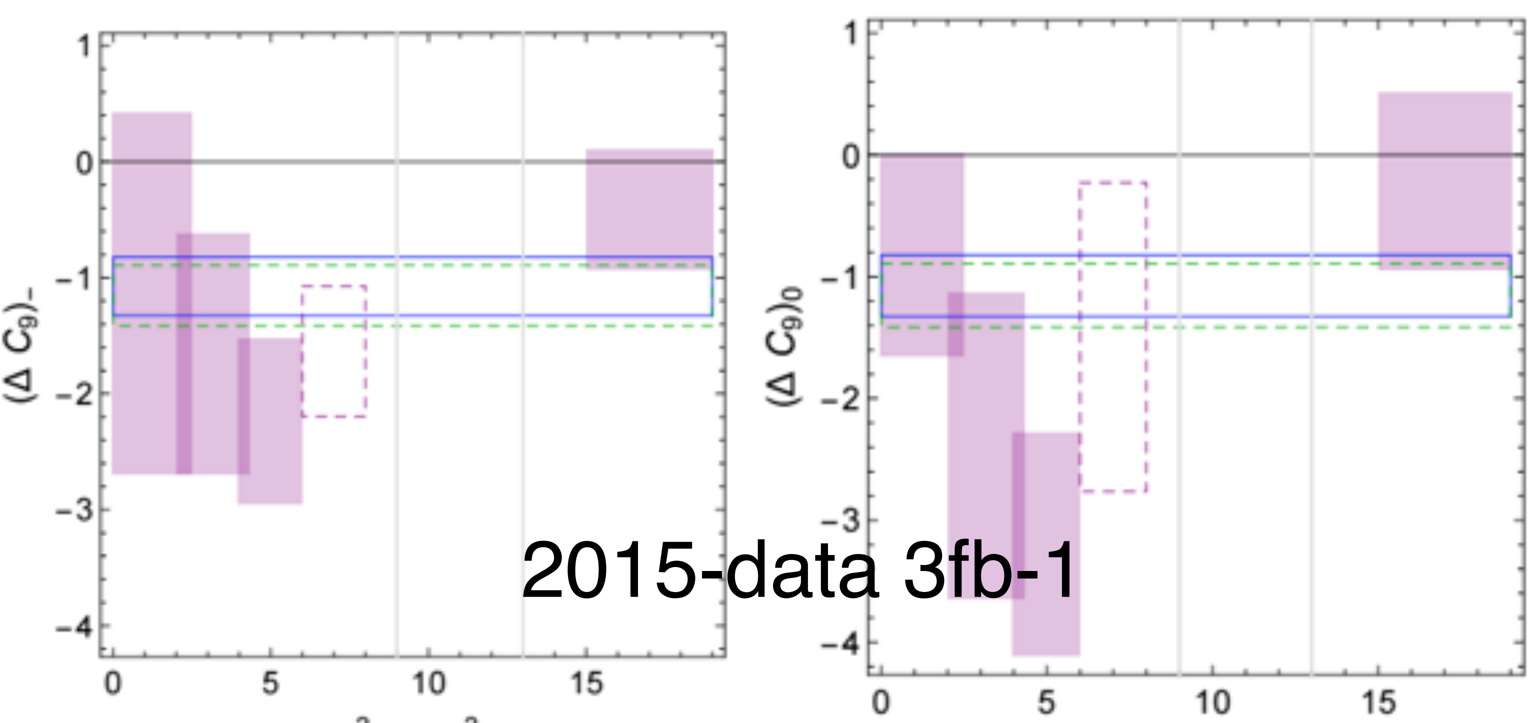
Straub's talk Moriond'15 (proceedings & Wolfgang's talk)



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

ρ vs ππ-distribution amplitude

skip no time

- using 2-pion DA (def e.g. Polyakov'98) to describe $B(\to\pi\pi)l\nu$ requires determination of the 2-pion DA

ρ vs ππ-distribution amplitude

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