Discussion Session @ MIAPP, 26 October 2016

Rare B Decays: Standard Model vs. New Physics

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Status of $b \to s\mu^+\mu^-$ anomalies

Current tensions in $b \to s\mu^+\mu^-$ transitions

Mode	Observable	Bin	Pull
$B^0 \to K^*\mu^+\mu^-$	P_5'	4–6	$-\mathbf{2.6\sigma}$
$B_s \to \phi\mu^+\mu^-$	BR	1–6	$-\mathbf{3.3\sigma}$
$B^+ \to K^+\mu^+\mu^-$	BR	1–6	$-\mathbf{2.0\sigma}$
$B^+ \to K^+\mu^+\mu^-$	BR	15–22	$-\mathbf{2.6\sigma}$

Suspects: New physics? Form factors? Charm loop?

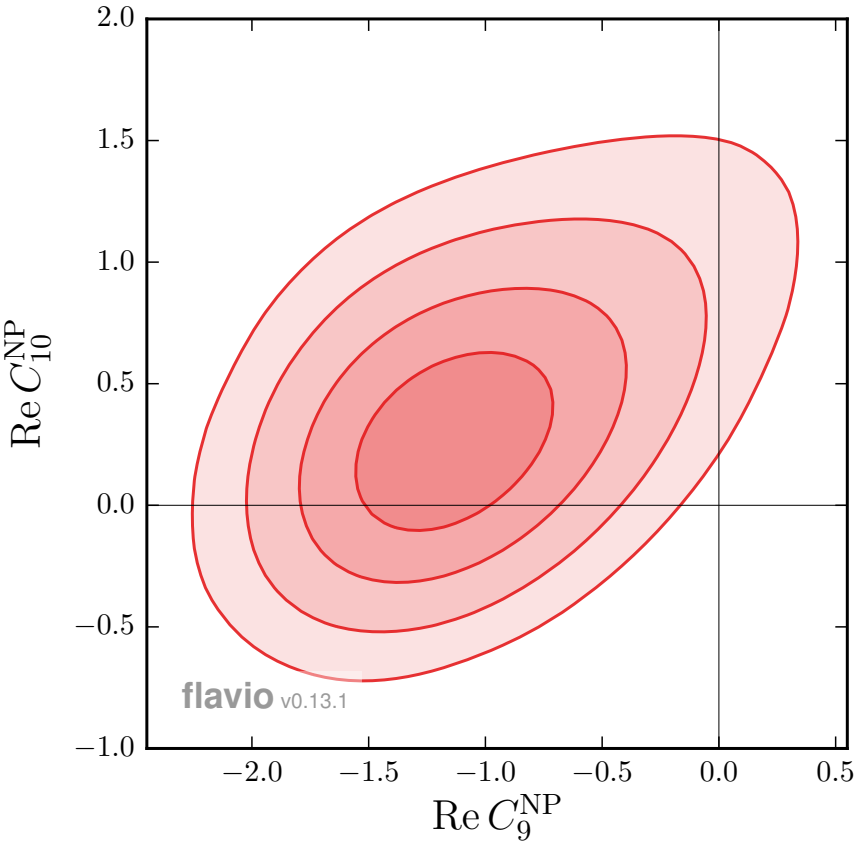
(flavio v0.13.1 using combined LCSR+LQCD FFs for $B \to V$ FFs Bharucha et al. 1503.05534 and FNAL/MILC $B \to K$ FFs Bailey 1509.06235; hadronic unc. estimated as in Altmannshofer and Straub 1411.3161)

New physics: effective field theory

Global constraints on C_9 & C_{10}

- including 3 fb^{-1} LHCb measurements
- Updated $B \to V$ FFs from v2 of Bharucha et al. 1503.05534
- Best fit point: **4.5σ pull** from SM

What does it mean?



see also Altmannshofer and Straub 1411.3161, Descotes-Genon et al. 1510.04239, Hurth et al. 1603.00865

A closer look

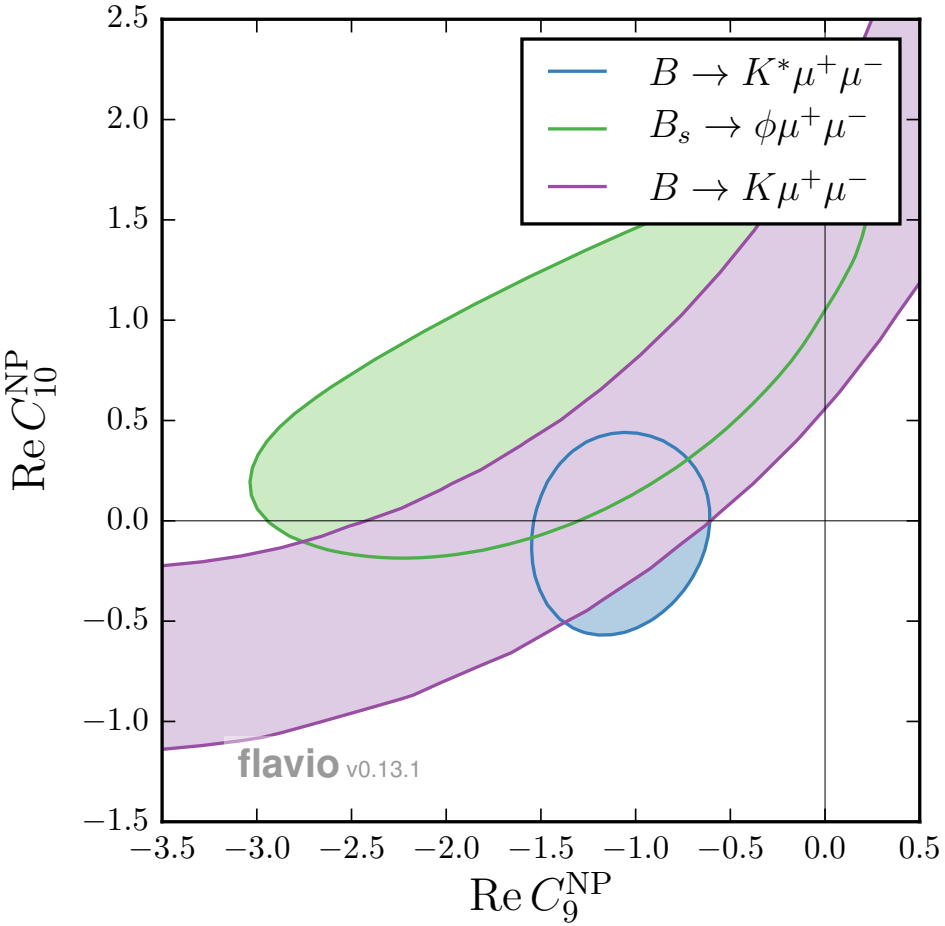
Pulls for individual modes:

- $B \to K^* \mu^+ \mu^-$: **2.7σ**
  - famous P_5' anomaly
- $B_s \to \varphi \mu^+ \mu^-$: **3.4σ**
  - BR @ low & high q^2

    cf. Bharucha et al. 1503.05534,

    Ronald R. Horgan et al. 1310.3887
- $B \to K \mu^+ \mu^-$: **2.6σ**
  - BR @ low $q^2 \to R_K$!
  - First pointed out in:

    Khodjamirian et al. 1211.0234



Key question

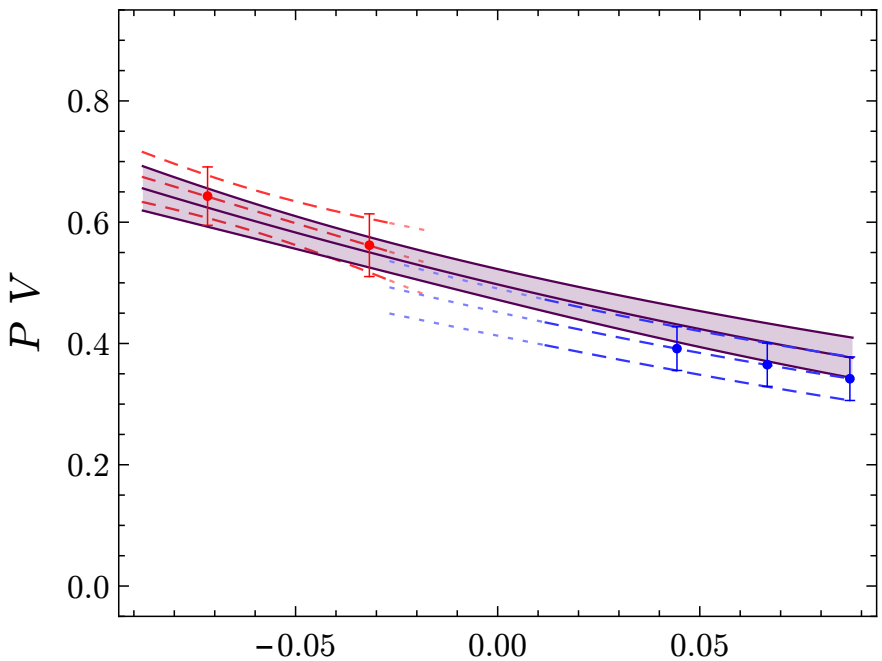
Given new physics can account for the tensions, are we sure there is no SM effect that can explain them?

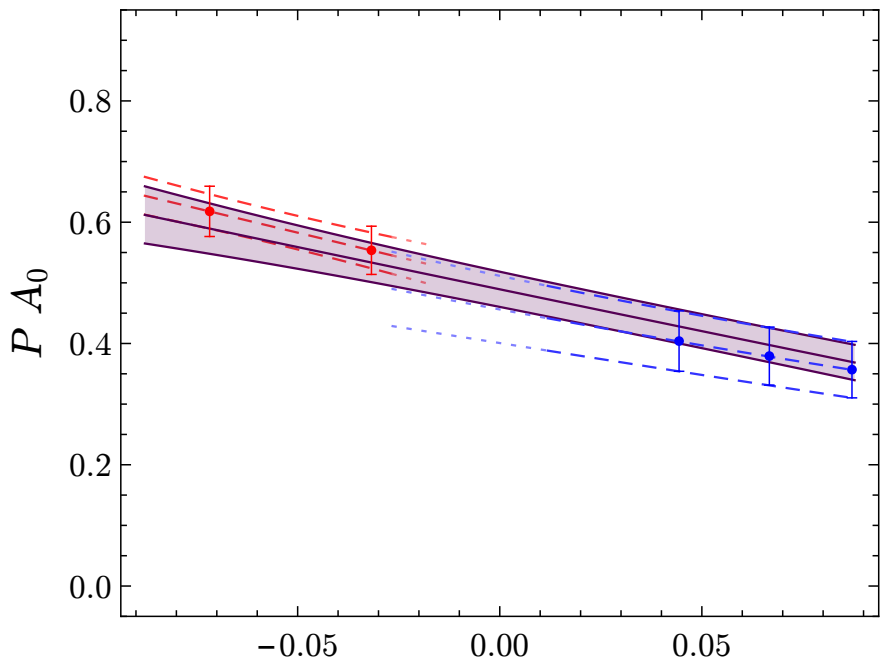
$\equiv$ Do we have our theory uncertainties under control?

Scrutinizing theory uncertainties: form factors

$B \to K^*$ form factors

Complementarity and agreement between LCSR & LQCD form factors Bharucha et al. 1503.05534, R. R. Horgan et al. 1501.00367





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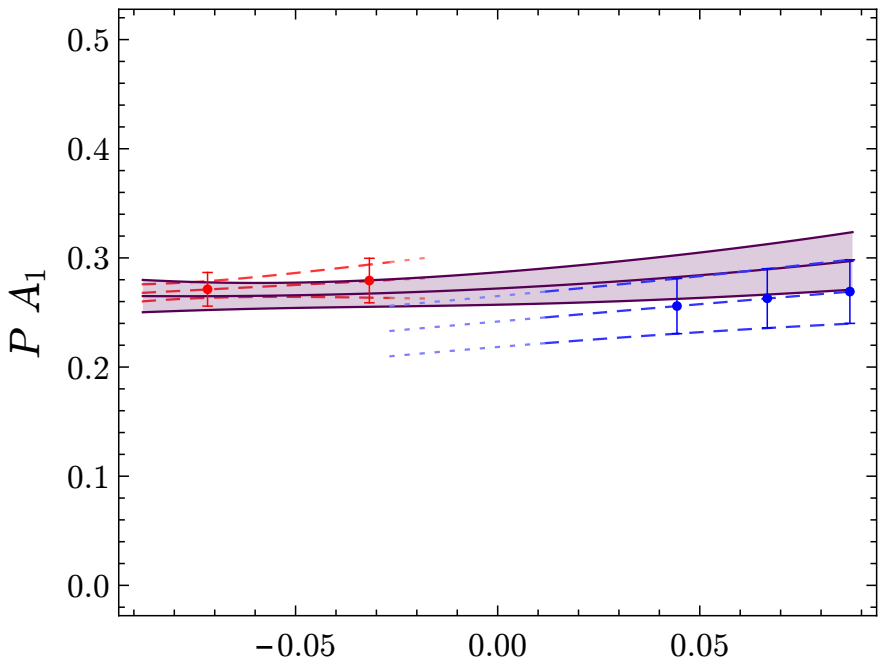

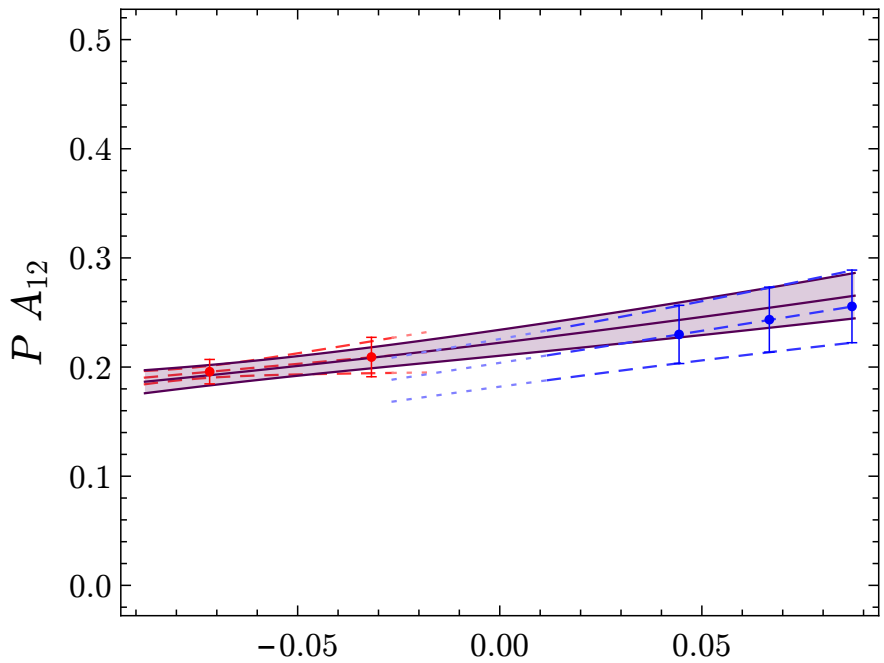

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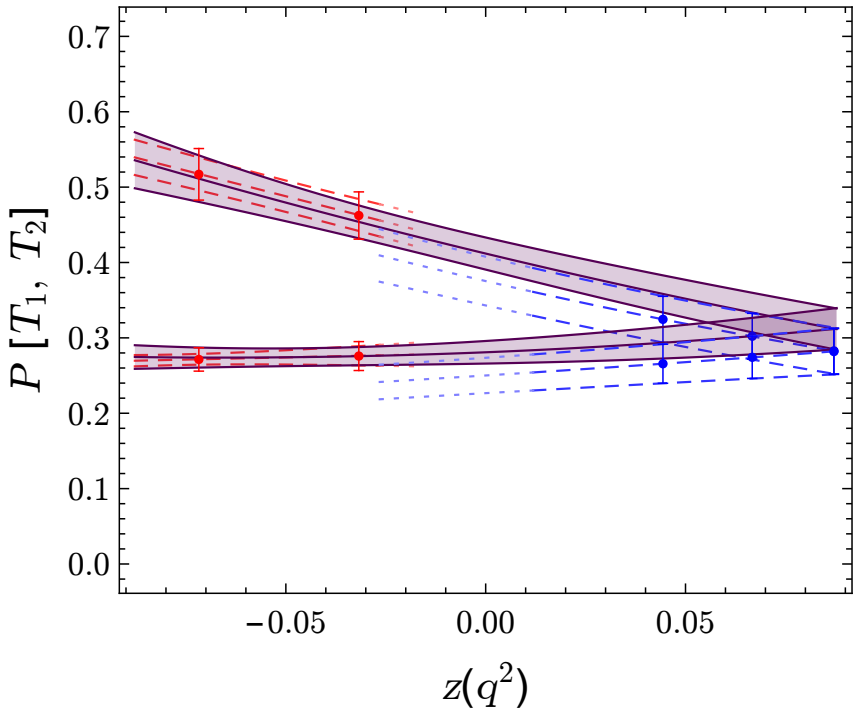
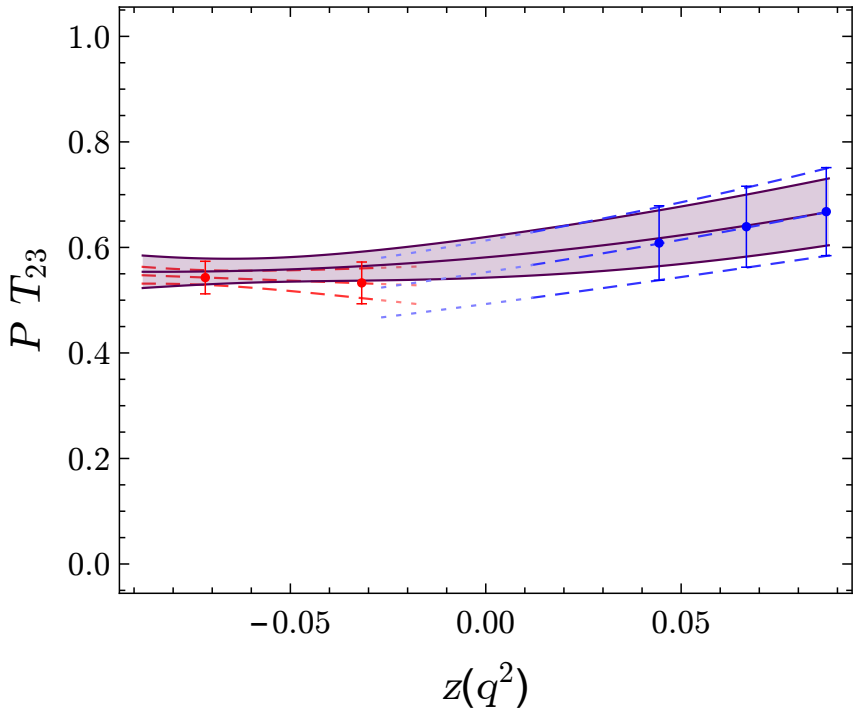




Discussion points

- Can we trust LCSR FFs to 10% (and their ratios to 5%)?
- Issue of K^* instability in LQCD and LCSR?
- LCSR with K^* LCDAs vs. B LCDAs

Scrutinizing theory uncertainties: non-factorisable effects

Non-factorisable effects: “charm loop”

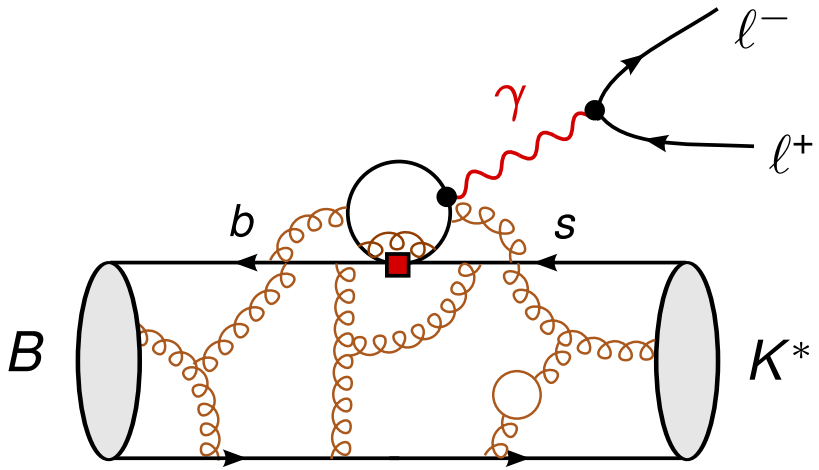
- Culprit: matrix element of $O_{1,2}$

$$\langle \bar{K}^* | T\{j^\mu_{\text{em}}(x) C_{1,2} O_{1,2}(0)\} | \bar{B} \rangle$$

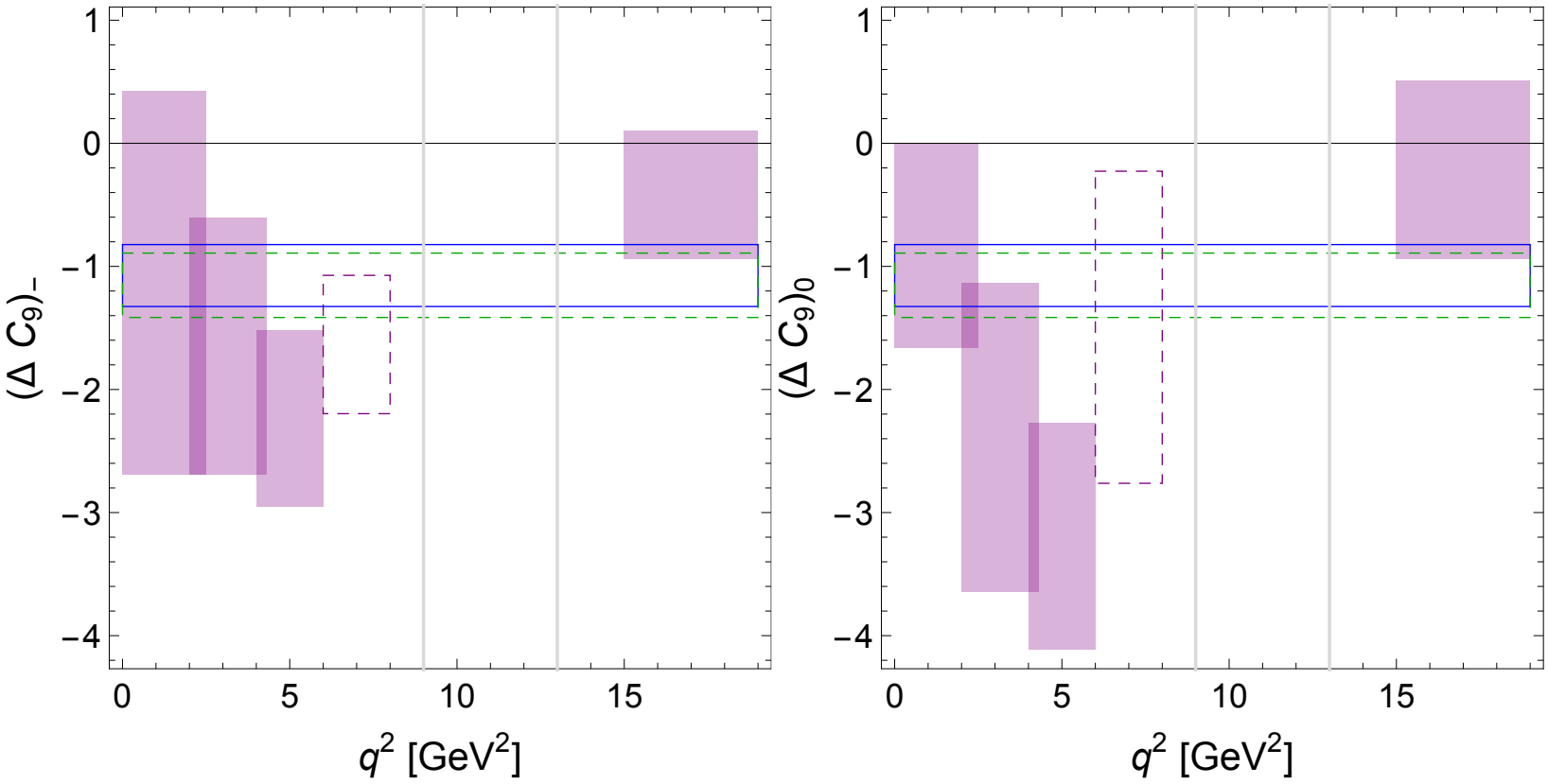
- Since $O_9 \propto \bar{\ell}\gamma^\mu \ell$, h_λ could mimic a new phyiscs effect in C_9
- Without loss of generality, can be parametrised as complex-valued (CP-even) helicity-dependent shift in C_9:

$$C_9^{\text{SM}} + \Delta C_9^{+,-,0}(q^2)$$

$$O_2 = (\bar{s}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu b_L)$$



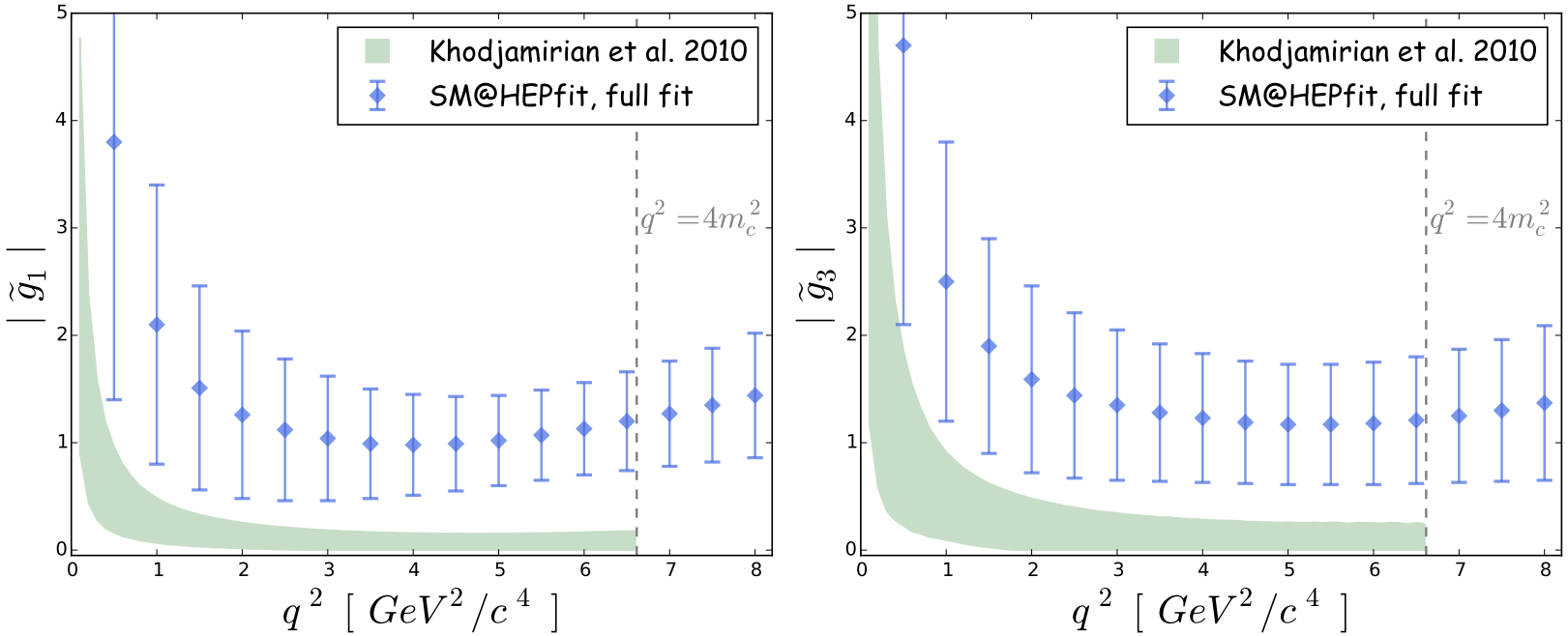
q^2 dependence of ΔC_9^λ



DS @ Moriond EW 2015; Altmannshofer and Straub 1503.06199

(1σ boxes)

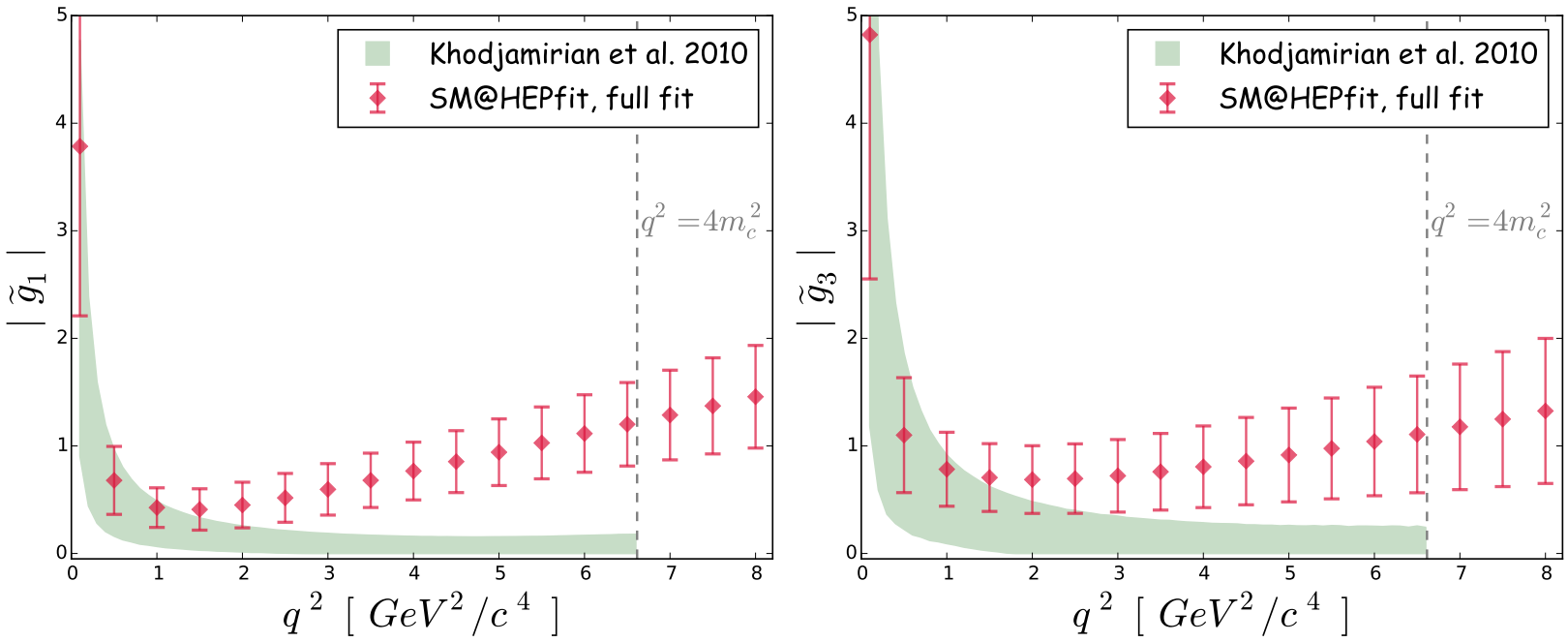
q^2 dependence of ΔC_9^λ



Ciuchini et al. 1512.07157

- Bayesian fit assuming a polynomial form for h_λ
- roughly: $\tilde{g}_1 \propto \Delta C_9^-$, $\tilde{g}_3 \propto \Delta C_9^0$

q^2 dependence of ΔC_9^λ



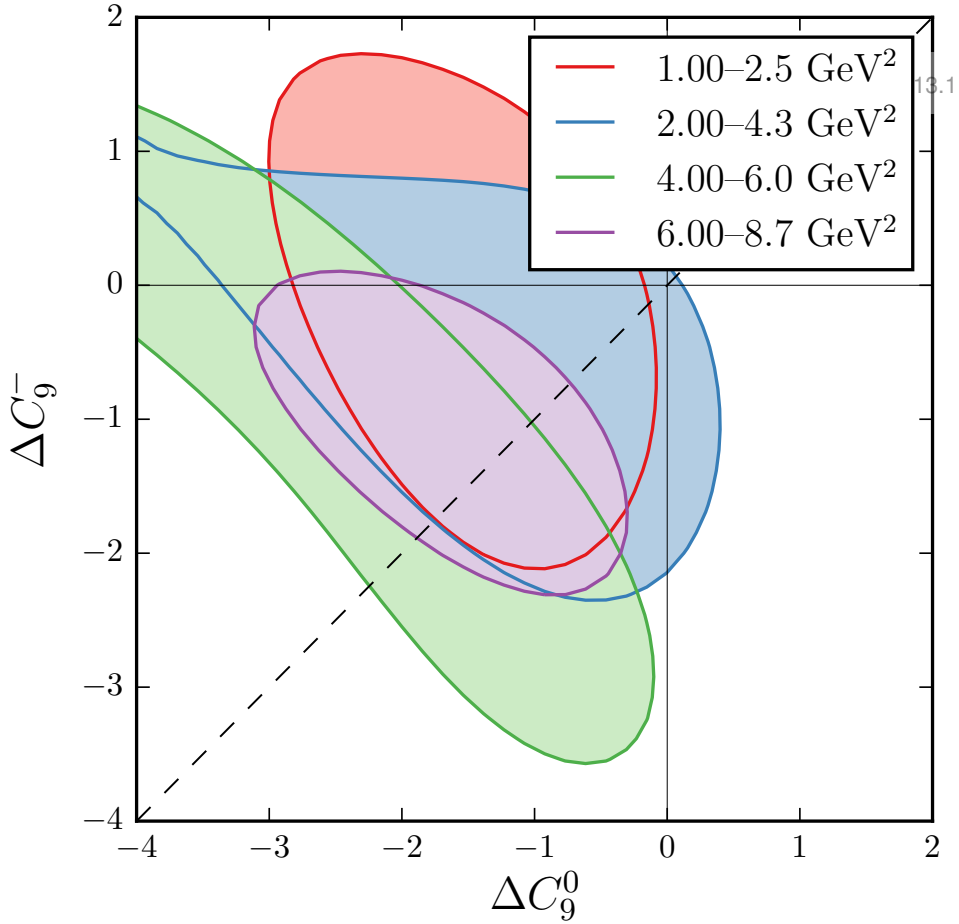
Ciuchini et al. 1512.07157

- Bayesian fit assuming a polynomial form for h_λ
- roughly: $\tilde{g}_1 \propto \Delta C_9^-$, $\tilde{g}_3 \propto \Delta C_9^0$
- **assuming** small ΔC_9^λ for small q^2 (expected for SM, but not NP!)

q^2 dependence of ΔC_9^λ

- Bin-by-bin fit of ΔC_9^0 vs. ΔC_9^-
- New physics: expect $\Delta C_9^0 = \Delta C_9^-$ equal for all bins

Current data **not precise enough** to exclude new physics hypothesis!



Plot based on discussion with C. Bobeth

Dispersion relation

- Charm contribution obeys a dispersion relation

  Khodjamirian et al. 1006.4945

Schematically:

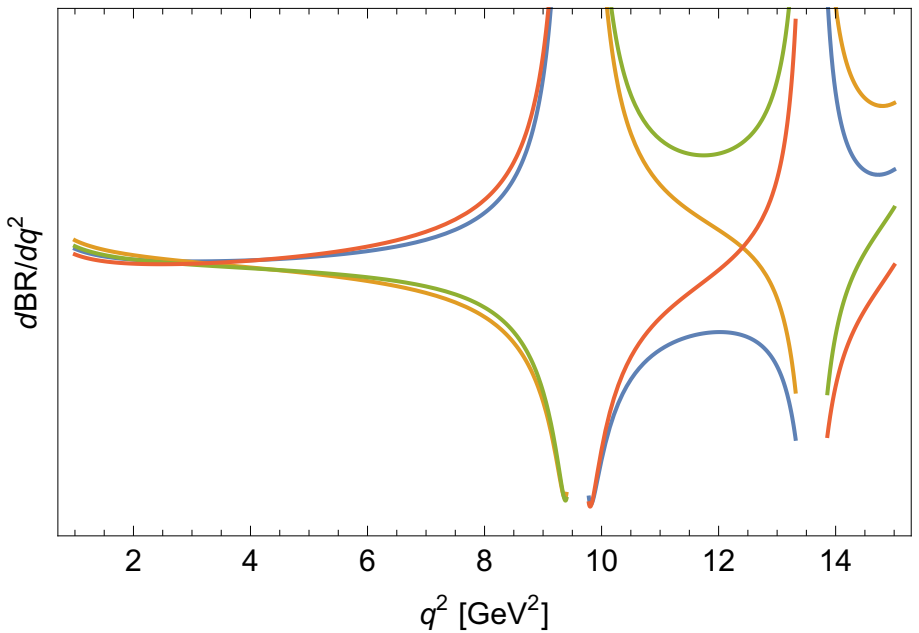
$$h_-(q^2) = h_-(0) + q^2 h'_-(0) + q^4 \left[\underbrace{\mathrm{BW}_{J/\psi} + \mathrm{BW}_{\psi(2S)}}_{\substack{\text{Measured from } B \to \psi K^* \\ \text{up to overall phase}}} + \underbrace{h_-^{\text{higher}}(q^2)}_{\substack{\text{small impact} \\ \text{below } m^2_{J/\psi}(?)}} \right]$$

etc.

Charmonium interference

The q^2 dependence of the differential rate between the J/ψ and $\psi(2S)$ resonances can be used to infer the sign of the interference

Khodjamirian et al. 1006.4945, Lyon and Zwicky 1406.0566

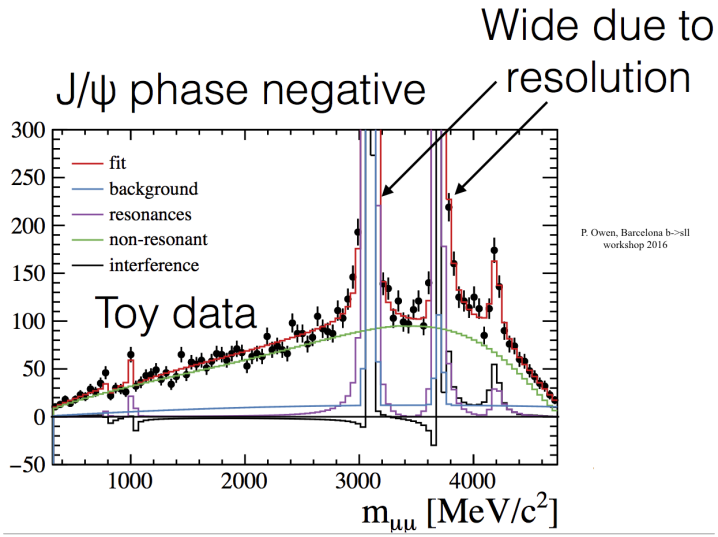


* this is only a cartoon – not actual numerics

Meanwhile at LHCb

Measuring phase differences

- Measure relative phase between narrow resonances and penguin amplitudes
  $\rightarrow$ Model resonances as relativistic BWs multiplied by relative scale and phase Lyon et al. [1406.0566], Hiller et al. [1606.00775]
  $\rightarrow$ Use this model to replace $Y(q^2)$ in $C_9^{eff} = Y(q^2) + C_9$
  $\rightarrow$ $B \rightarrow K$ form factors constrained to LCSR+Lattice predictions
  $\rightarrow$ Fit for phases and C_9 and C_{10}



- Fit dimuon spectrum in $B^+ \rightarrow K^+\mu^+\mu^-$
  $\rightarrow$ Expect precision of phase $\sim$ 0.1 rad (ambiguities over sign of phase)[Owen Barcelona workshop 2016]
- In final stages of review

Discussion points

- Exploiting the dispersion relation (and $B \to \psi K^*$ data), can we put an upper (lower) bound on the charm loop effect in the critical 4–6 GeV^2 region?
- Any other way to get a handle on the size (and sign) of the effect?

Outlook

- Which measurements at Belle-II could help reducing theory uncertainties?
- Which measurements at Belle-II could help probing a possible NP effect?
- Which cleaner observables will be accessible at Belle-II?
  - inclusive $B \to X_s \ell^+ \ell^-$
  - ...