Rare Decays from Flavor to QCD and Back

1) $B \to K^* \mu^+ \mu^-$ @ Low Recoil

2) SU(3)-ing 2-body decays of charm and CPX

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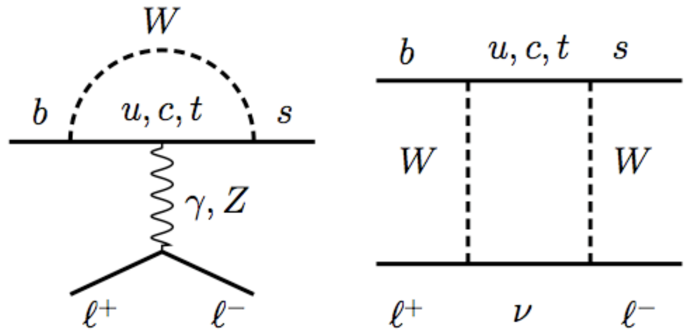
based on works with Christoph Bobeth, Danny van Dyk, Christian Hambrock, Martin Jung, Stefan Schacht, Roman Zwicky

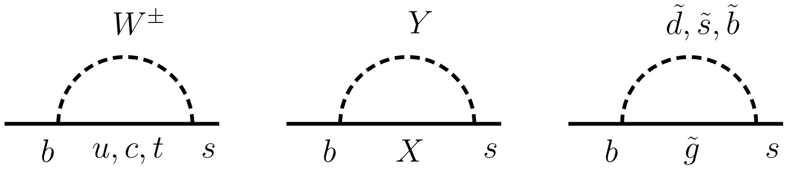
1)

Exclusive semileptonic FCNC $b \to s\mu^+\mu^-$ decays

$\Delta F = 1$ FCNC; sensitive to flavor in and beyond the SM.

$Br_{\rm SM} \sim 10^{-6} - 10^{-7}$





observed (at SM level):

$B \to K^{(*)}\mu^+\mu^-$ BaBar, Belle, CDF 6.8 fb^{-1} and LHCb 1 fb^{-1} LHCb-CONF-2012-008

$B_s \to \Phi\mu^+\mu^-$ CDF 2011 1101.1028 [hep-ex] LHCb 2012 LHCb-CONF-2012-008

$\Lambda_b \to \Lambda\mu^+\mu^-$ CDF 2011 1107.3753 [hep-ex]

distributions measured. precision physics started.

Different theory in both regions – binned data needed.

- Small dilepton mass $q^2 \leftrightarrow$ large hadronic recoil $E_{K^*} \gg \Lambda$
  QCD Factorization BBNS, Beneke, Feldmann, Seidel'01,04

- Large $q^2 \sim \mathcal{O}(m_b^2) \leftrightarrow$ low hadronic recoil $E_{K^*} \sim \Lambda$
  Operator product expansion in $1/m_b$ Grinstein,Pirjol '04, Beylich, Buchalla,Feldmann'11

THIS TALK:

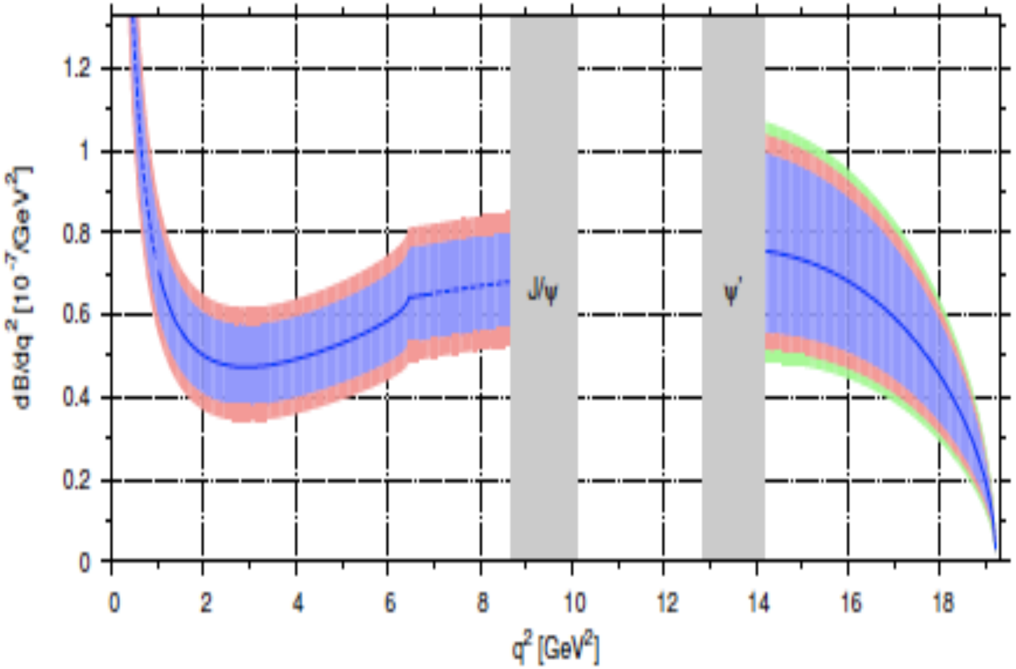
- Low recoil $B \to K^{(*)}\mu^+\mu^-$ predictions, pheno & implications

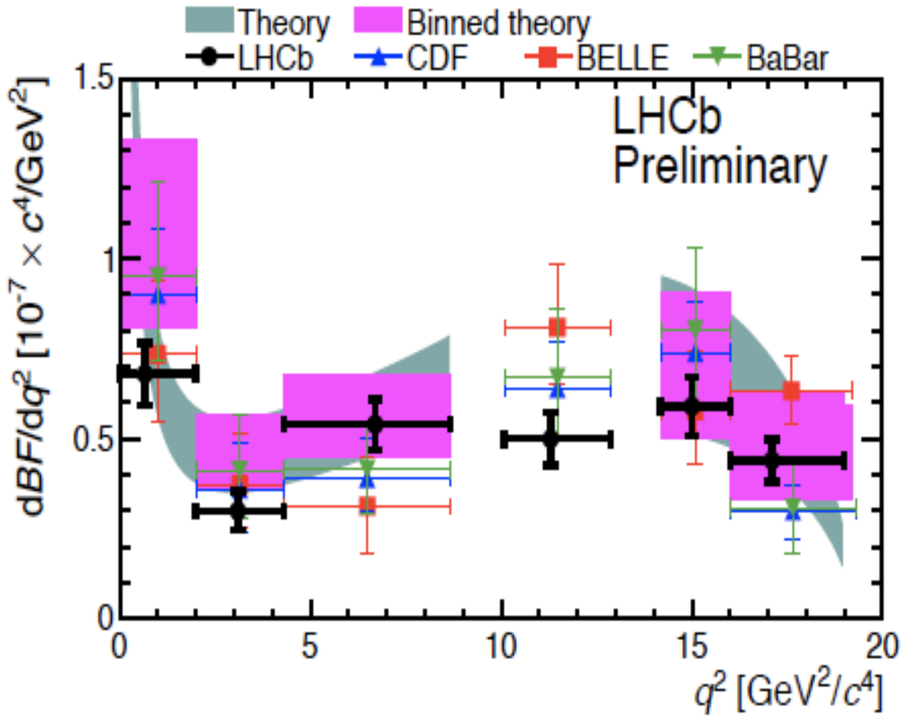
  Bobeth,GH, vanDyk, Wacker '10,11,12

- Extractions of hadronic form factor ratios at low recoil from data

  GH, Hambrock '12, and in preparation together with Schacht, Zwicky

Situation: Dilepton Mass Spectrum in $B \to K^* \mu^+ \mu^-$





left-hand Fig. from 1006.5013 [hep-ph] Blue band: form factor uncertainties, red: $1/m_b$ right-hand Fig. from LHCb-CONF-2012-008

Biggest source of theory uncertainty: the $B \to K^*$ form factors.

Opportunity: Angular Analysis $B \to K^*(\to K\pi)\mu^+\mu^-$

$$d\Gamma^4 \sim J dq^2 d\cos\Theta_l d\cos\Theta_{K^*} d\Phi$$ Krüger, Sehgal,Sinha, Sinha hep-ph/9907386

$$\begin{aligned} J(q^2,\theta_l,\theta_{K^*},\phi) = {} & J_1^s \sin^2\theta_{K^*} + J_1^c \cos^2\theta_{K^*} + (J_2^s \sin^2\theta_{K^*} + J_2^c \cos^2\theta_{K^*}) \cos 2\theta_l \\ & + J_3 \sin^2\theta_{K^*} \sin^2\theta_l \cos 2\phi + J_4 \sin 2\theta_{K^*} \sin 2\theta_l \cos\phi + J_5 \sin 2\theta_{K^*} \sin\theta_l \cos\phi \\ & + J_6 \sin^2\theta_{K^*} \cos\theta_l + J_7 \sin 2\theta_{K^*} \sin\theta_l \sin\phi \\ & + J_8 \sin 2\theta_{K^*} \sin 2\theta_l \sin\phi + J_9 \sin^2\theta_{K^*} \sin^2\theta_l \sin 2\phi, \end{aligned} \tag{2.3}$$

Θ_l: angle between l^- and $\bar{B}$ in dilepton-CMS

Θ_{K^*}: angle between K and $\bar{B}$ in K^*-CMS

Φ: angle between normals of the $K\pi$ and l^+l^- planes

complex structure, plenty of observables, not all need full $\mathrm{d}^4\Gamma$.

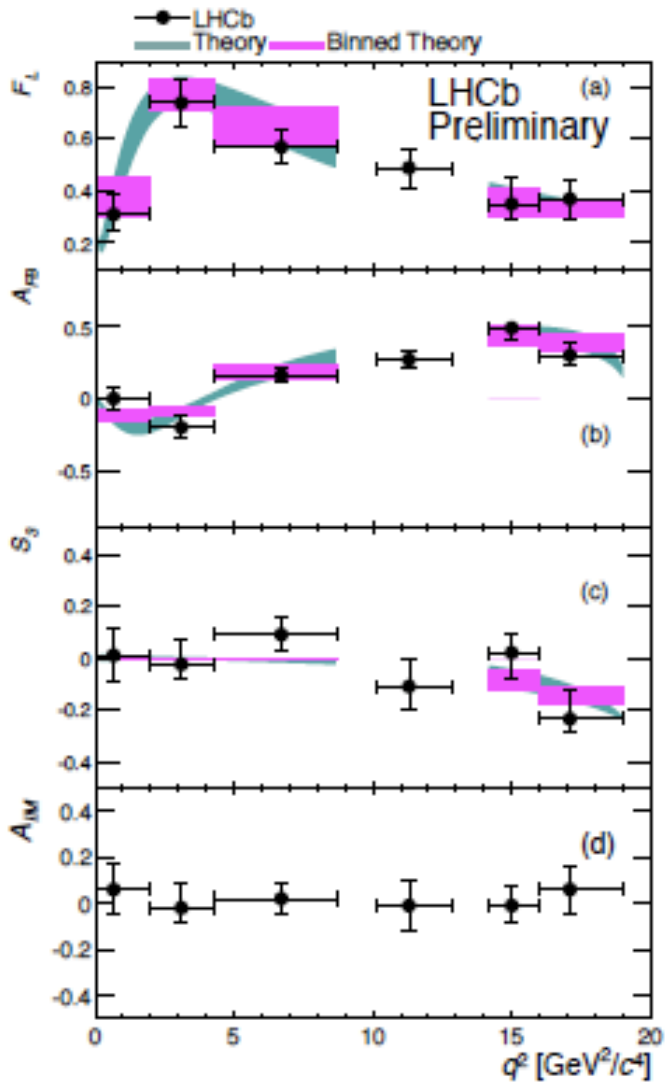
$\Gamma \sim J_1 - J_2/3$, $A_{\mathrm{FB}} \sim J_6$, $A_T^{(2)} \sim J_3$ Krüger, Matias hep-ph/0502060

With full $\Delta B = 1$ dimension six operators: Bobeth et al, 1212.2321 [hep-ph]

Angular distributions 2012 from LHCb with 1 fb^{-1}

$B^0 \to K^{*0}\mu^+\mu^-$ Angular Analysis Results

- 4D fit to 3 angles and mass
- Larger data sample enables measurements of S_3 and A_{IM}
- Error bars include systematic uncertainties
- Data points at average q^2 of signal candidates in data
- These are the most precise measurements to-date [preliminary]
- The results are consistent with the SM prediction [1]



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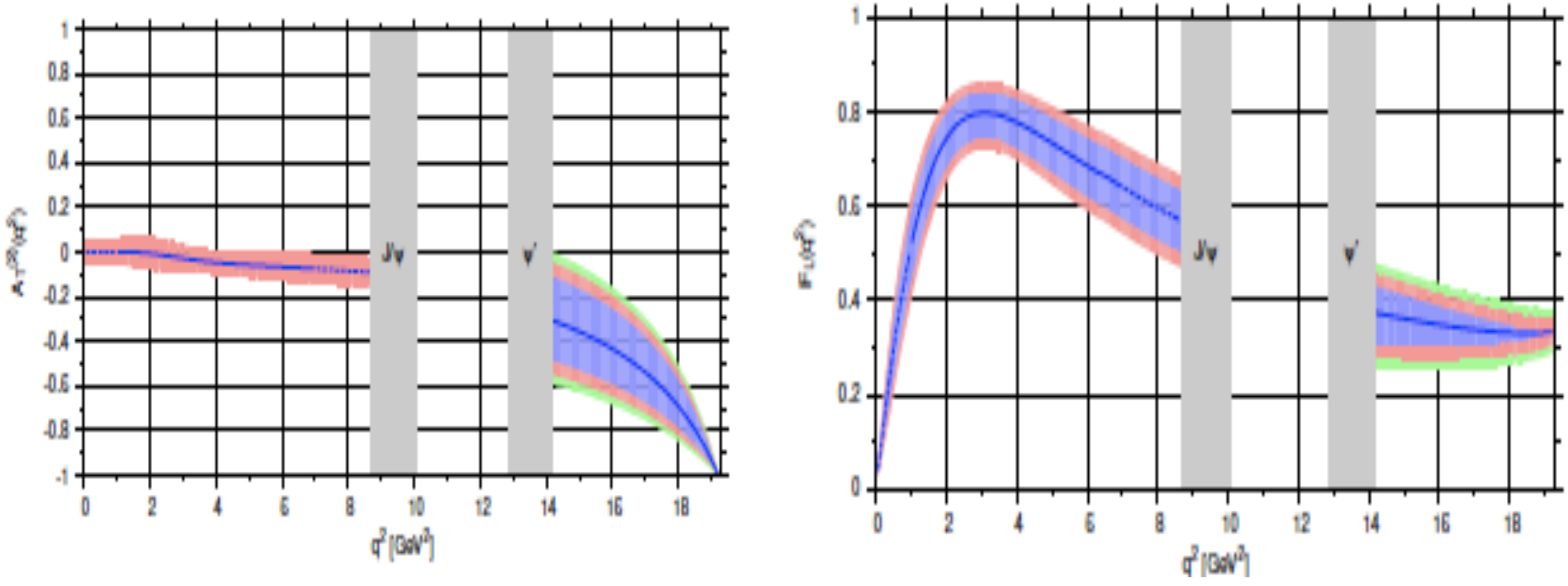
A_T^2 and F_L in $B \to K^* \mu^+ \mu^-$



Figs. from 1006.5013 [hep-ph] Blue band: form factor uncertainties, red: $1/m_b$ $A_T^{(2)} = 2S_3/(1-F_L)$

F_L: fraction of longitudinally polarized K^*

$A_T^{(2)}$: transverse Asymmetry; Null test of SM at low q^2

Both probe form factor ratios at low recoil! pollution from BSM right-handed currents can be controlled by e.g. $A_T^{(2)}$@large recoil; currently $\lesssim 30$ % Bobeth et al '12

A_T^2 and F_L in $B \to K^* \mu^+ \mu^-$ data 2012

	BaBar	CDF		LHCb	
q^2 [GeV^2]	F_L	F_L	$A_T^{(2)}$	F_L	$A_T^{(2)}$
$[14.18, 16]$	$0.43^{+0.13}_{-0.16}$	$0.40^{+0.12}_{-0.12}$	$0.11^{+0.65}_{-0.65}$	$0.35^{+0.10}_{-0.06}$	$0.06^{+0.24}_{-0.29}$
$[16, 19.xx]$	$0.55^{+0.15}_{-0.17}$	$0.19^{+0.14}_{-0.13}$	$-0.57^{+0.60}_{-0.57}$	$0.37^{+0.07}_{-0.08}$	$-0.75^{+0.35}_{-0.20}$

Benefits of $B \to K^*$ at low recoil

At low hadronic recoil transversity amplitudes $A_i^{L,R}$, $i = \perp, ||, 0$ related:

$$A_i^{L,R} \propto C^{L,R} \cdot f_i$$

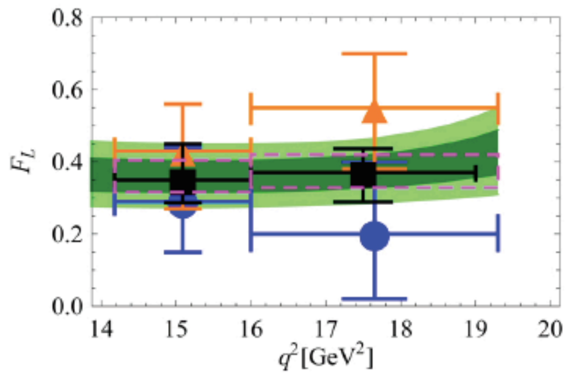
$C^{L,R}$: universal short-dist.-physics; $C^{L,R} = (C_9^{\text{eff}} \mp C_{10}) + \kappa \frac{2\hat{m}_b}{\hat{s}} C_7^{\text{eff}}$

$1/m_b$- corrections parametrically suppressed $\sim \alpha_s/m_b, C_7/C_9 1/m_b$

f_i: form factors

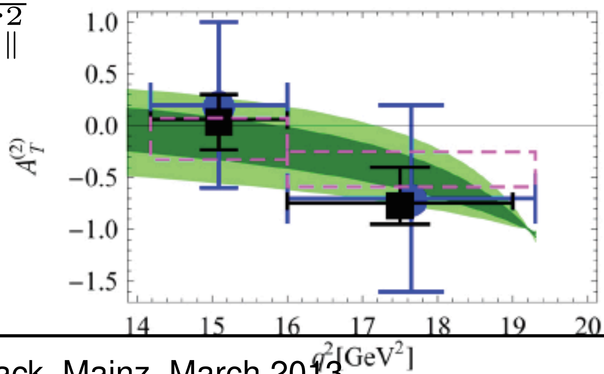
$C^{L,R}$ drops

out in ratios:



$$F_L = \frac{|A_0^L|^2 + |A_0^R|^2}{\sum_{X=L,R}(|A_0^X|^2 + |A_\perp^X|^2 + |A_\parallel^X|^2)} = \frac{f_0^2}{f_0^2 + f_\perp^2 + f_\parallel^2}$$

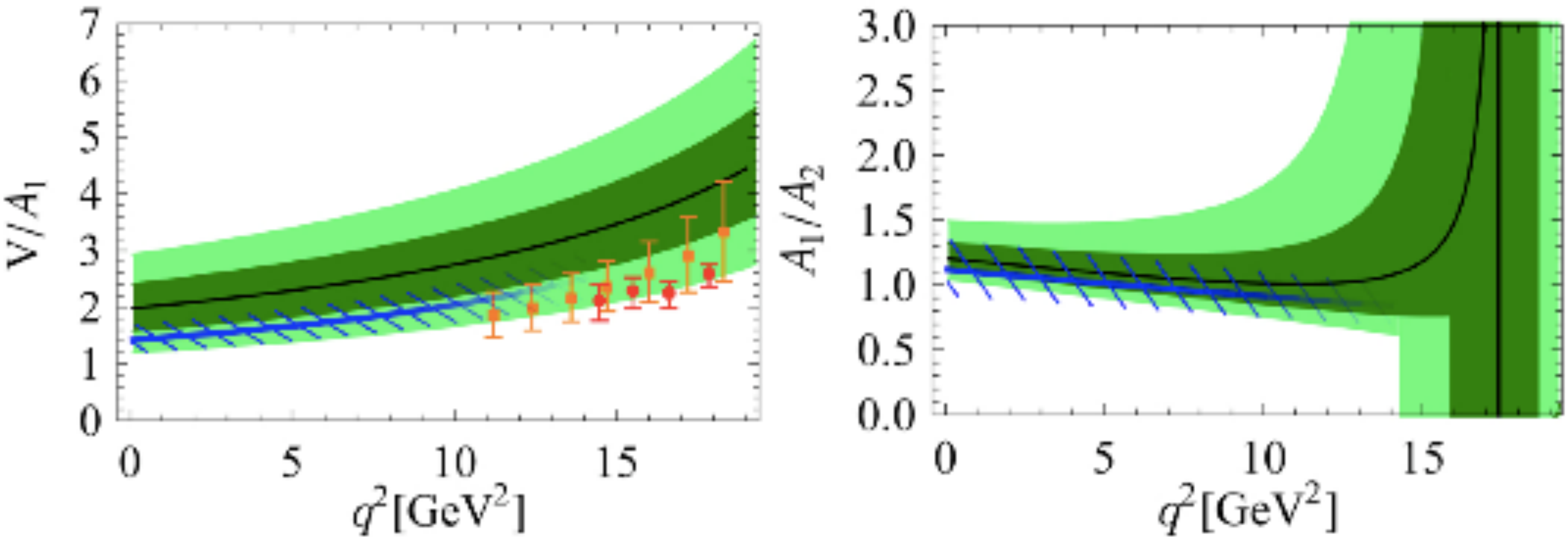
$$A_T^{(2)} = \frac{|A_\perp^L|^2 + |A_\perp^R|^2 - |A_\parallel^L|^2 - |A_\parallel^R|^2}{|A_\perp^L|^2 + |A_\perp^R|^2 + |A_\parallel^L|^2 + |A_\parallel^R|^2} = \frac{f_\perp^2 - f_\parallel^2}{f_\perp^2 + f_\parallel^2}$$



Extracting $B \to K^*$ form factors from data

Using series expansion $\hat{f}_i(t) = \frac{(\sqrt{-z(t,0)})^m (\sqrt{z(t,t_-)})^l}{B(t)\,\varphi_f(t)} \sum_k \alpha_{i,k}\, z^k(t)$

best-fit results: $\alpha_\parallel/\alpha_\perp = 0.43^{+0.11}_{-0.08},\ \alpha_0/\alpha_\perp = 0.15^{+0.03}_{-0.02}$



Yellow, red points; lattice QCD; blue bands: QCD sum rules Ball, Zwicky '05: green bands: $1, 2\sigma$ fit 1204.4444 [hep-ph]

Consistency between data (loreco-OPE), LCSR (small q^2) and lattice (large q^2)!

1. Its great to have (even more) data.

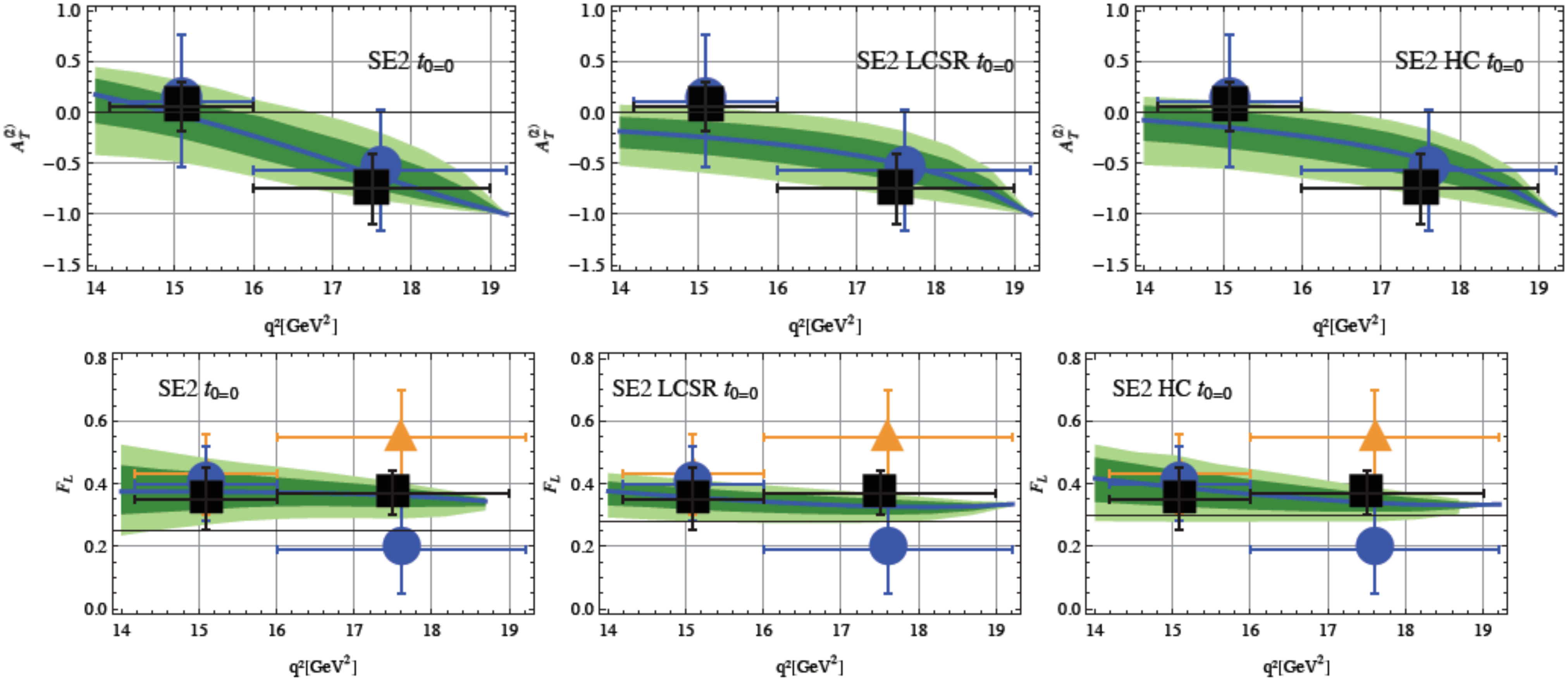
2. With (even one) more bins the sensitivity in the fits to the q^2-shape increases.

3. If you (lattice, sum rules,..) calculate form factors, please provide also ratios (with uncertainties).

4. Data-extracted form factor ratios constitute benchmarks for lattice form factor estimations at low recoil.

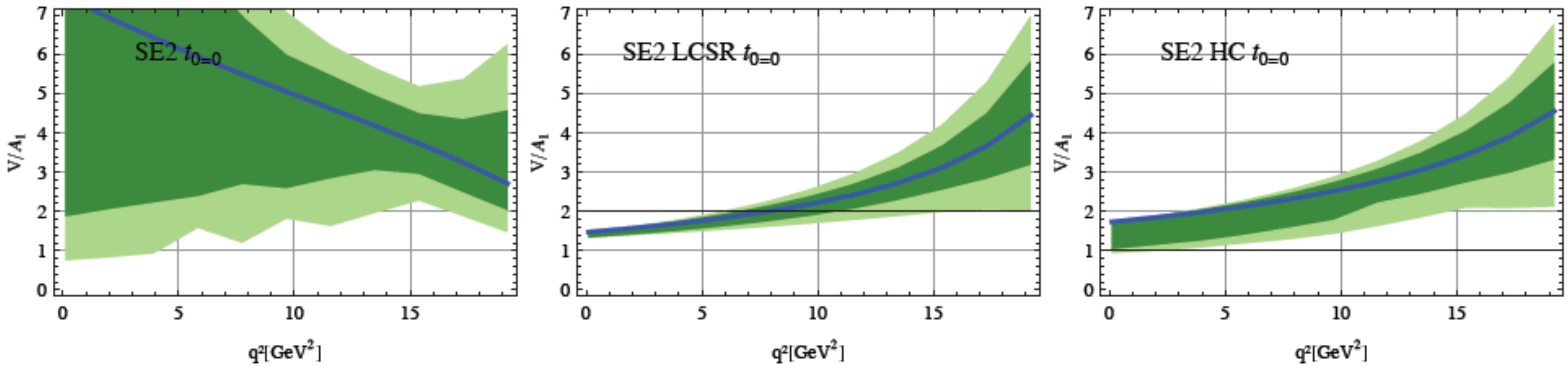
Advances in ... Extracting $B \to K^*$ form factors

Higher order Series Expansion; use theory input from low q^2: LCSR (sum rules) or $V(0)/A_1(0) = (m_B + m_{K^*})^2/(2m_B E_{K^*}) + \mathcal{O}(1/m_b) = 1.33 \pm 0.4$ (HC)



Fit ok with (mid: LCSR, right: HC) or without (left) low q^2-input.

Advances in ... Extracting $B \to K^*$ form factors



Predictivity at low q^2 is obtained from low q^2 input. (Required at higher order) Preliminary – Hambrock,GH,Schacht,Zwicky '13 in preparation

Data-extracted form factor ratios constitute benchmark for lattice form factor estimations at low recoil.

Exploiting $B \to K^* l^+ l^-$ at low recoil further

OPE in $1/Q$, $Q = \{m_b, \sqrt{q^2}\}$ by Grinstein, Pirjol '04 with heavy quark FF relations $T_{1,2,3} \leftrightarrow V, A_{1,2}$ leads to simply transversity structure with universal short-distance C and form factor coefficients f_i

$$A_i^{L,R} \propto C^{L,R} \cdot f_i$$

up to corrections of order $\alpha_s \Lambda / m_b$ and $(C_7/C_9)\Lambda/m_b$ (few percent).

Allows to design new observables which are Bobeth, GH,vanDyk 1006.5013, and '11,'12

– independent of form factors ($H_T^{(2,3,4,5)}$)

– independent of short-distance coefficients and test the form factors

– independent of either ones and test the theoretical low recoil framework $H_T^{(1)}$, $H_T^{(2)}/H_T^{(3)}$, $H_T^{(4)}/H_T^{(5)}$

Exploiting $B \to K^* l^+ l^-$ at low recoil further

$$H_T^{(1)} = \frac{\mathrm{Re}(A_0^L A_\parallel^{L*} + A_0^{R*} A_\parallel^R)}{\sqrt{\left(|A_0^L|^2 + |A_0^R|^2\right)\left(|A_\parallel^L|^2 + |A_\parallel^R|^2\right)}} = \frac{\sqrt{2} J_4}{\sqrt{-J_2^c\,(2J_2^s - J_3)}},$$

$$H_T^{(2)} = \frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^{R*} A_\perp^R)}{\sqrt{\left(|A_0^L|^2 + |A_0^R|^2\right)\left(|A_\perp^L|^2 + |A_\perp^R|^2\right)}} = \frac{\beta_l J_5}{\sqrt{-2J_2^c\,(2J_2^s + J_3)}},$$

$$H_T^{(3)} = \frac{\mathrm{Re}(A_\parallel^L A_\perp^{L*} - A_\parallel^{R*} A_\perp^R)}{\sqrt{\left(|A_\parallel^L|^2 + |A_\parallel^R|^2\right)\left(|A_\perp^L|^2 + |A_\perp^R|^2\right)}} = \frac{\beta_l J_6}{2\sqrt{(2J_2^s)^2 - J_3^2}}.$$

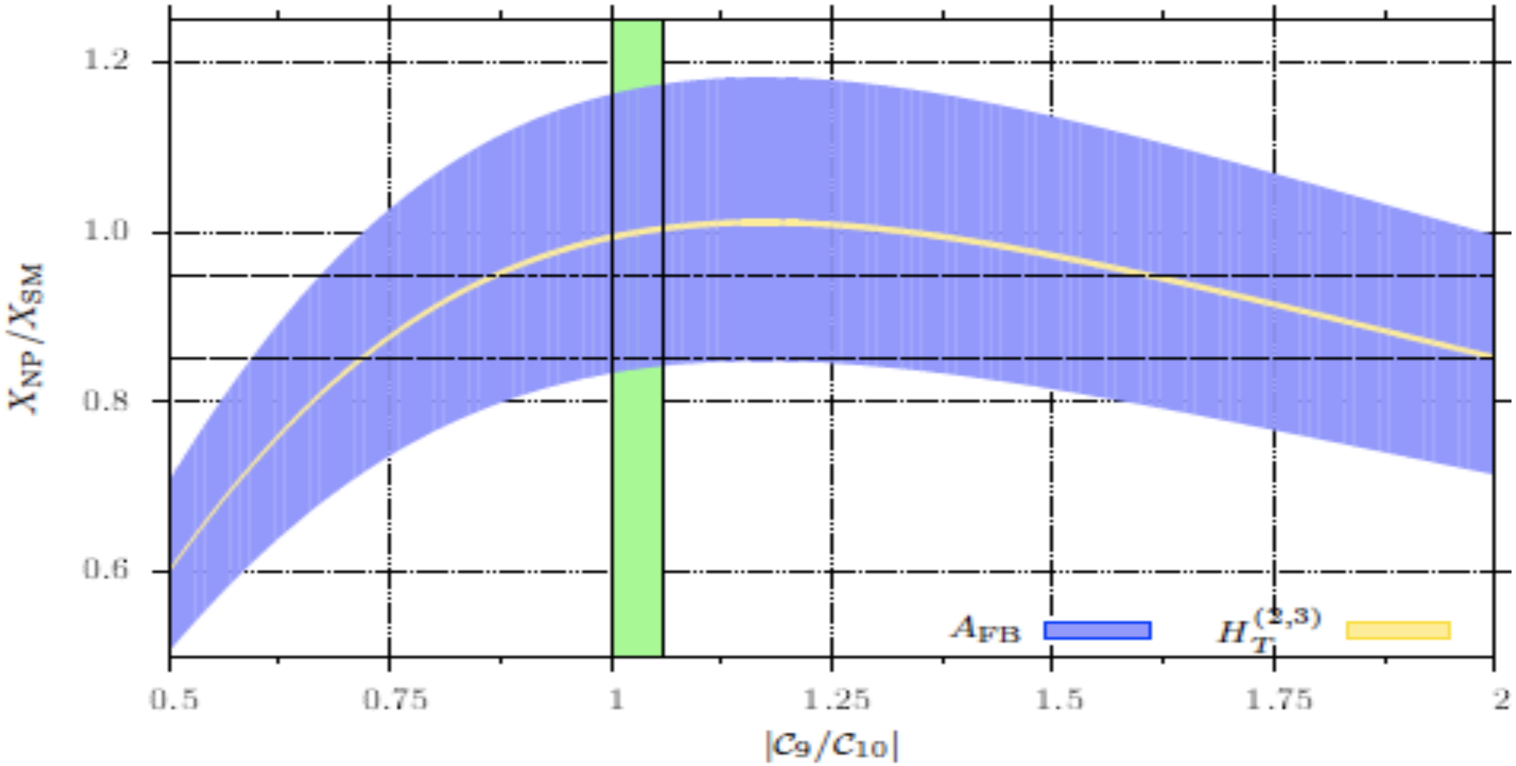
Low recoil Heavy-quark-OPE: $H_T^{(1)} = 1,$ $H_T^{(2)}/H_T^{(3)} = 1.$

Extract them from the $B \to K^*(\to K\pi)\mu^+\mu^-$ angular distribution.

Further Benefits of $B \to K^* l^+ l^-$ at low recoil: BSM

Reach in low recoil-integrated observables vs Wilson coefficients

C_9/C_{10}



green: SM; blue: A_{FB} (f_i-dependent) gold: $H_T^{(2)}$ (f_i-free)

Fig from 1212.2321

Further Benefits of $B \to K^* l^+ l^-$ at low recoil: BSM-CP

Reach in low recoil-integrated CP-asymmetries vs Wilson coefficients C'_{10}

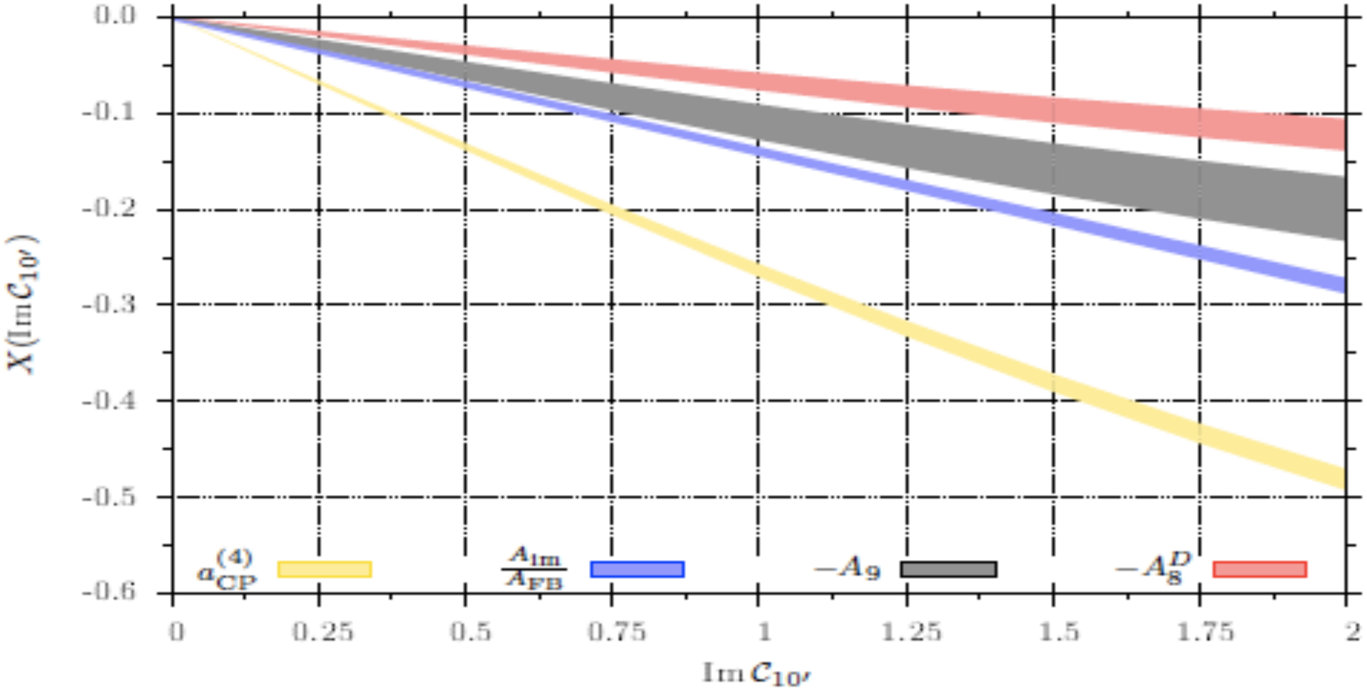


Fig from 1212.2321

gold: CP-asymmetry of $H_T^{(4)}$; blue $A_{im}/A_{FB} = J_9/J_{2s} \sim H_T^{(5)}/H_T^{(3)}$: both f_i-free; other two $A_{8,9}$ not

2)

$$\Delta A_{\rm CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$$

$\Delta A^{wa}_{\rm CP} = -0.00678 \pm 0.00147$ (pre-Moriond QCD 2013)

$\Delta A^{\rm SM}_{\rm CP} \sim \lambda^4 \times P/T \simeq 10^{-3} \times P/T$; $P/T \sim$ "$0.x$";
"$\Delta A^{\rm SM}_{\rm CP}$ is below permille " (traditional)

Are the data consistent with the SM? (large number of th papers)

Many Modes Measured

TABLE II. The observables and the data for indirect CP violation used in this work; see Appendix A for removal of effects from charm and kaon mixing.

Observable	Measurement	References
	SCS CP asymmetries	
$\Delta a_{CP}^{\rm dir}(K^+K^-, \pi^+\pi^-)$	-0.00678 ± 0.00147	[1–4,28,29]
$\Sigma a_{CP}^{\rm dir}(K^+K^-, \pi^+\pi^-)$	$+0.0014 \pm 0.0039$	[a][1–3,28,30]
$A_{CP}(D^0 \to K_S K_S)$	-0.23 ± 0.19	[31]
$A_{CP}(D^0 \to \pi^0\pi^0)$	$+0.001 \pm 0.048$	[31]
$A_{CP}(D^+ \to \pi^0\pi^+)$	$+0.029 \pm 0.029$	[32]
$A_{CP}(D^+ \to K_S K^+)$	-0.0011 ± 0.0025	[32–35]
$A_{CP}(D_s \to K_S \pi^+)$	$+0.031 \pm 0.015$	[a][32,33,36]
$A_{CP}(D_s \to K^+\pi^0)$	$+0.266 \pm 0.228$	[32]
	Indirect CP violation	
$a_{CP}^{\rm ind}$	$(-0.027 \pm 0.163) \times 10^{-2}$	[4]
$\delta_L = 2{\rm Re}(\varepsilon)/(1+\lvert\varepsilon\rvert^2)$	$(3.32 \pm 0.06) \times 10^{-3}$	[37]
	$K^+\pi^-$ strong phase difference	
$\delta_{K\pi}$	$21.4^\circ \pm 10.4^\circ$	[b][4]
	SCS branching ratios	
$\mathcal{B}(D^0 \to K^+K^-)$	$(3.96 \pm 0.08) \times 10^{-3}$	[37]
$\mathcal{B}(D^0 \to \pi^+\pi^-)$	$(1.401 \pm 0.027) \times 10^{-3}$	[37]
$\mathcal{B}(D^0 \to K_S K_S)$	$(0.17 \pm 0.04) \times 10^{-3}$	[37]
$\mathcal{B}(D^0 \to \pi^0\pi^0)$	$(0.80 \pm 0.05) \times 10^{-3}$	[37]
$\mathcal{B}(D^+ \to \pi^0\pi^+)$	$(1.19 \pm 0.06) \times 10^{-3}$	[37]
$\mathcal{B}(D^+ \to K_S K^+)$	$(2.83 \pm 0.16) \times 10^{-3}$	[37]
$\mathcal{B}(D_s \to K_S \pi^+)$	$(1.21 \pm 0.08) \times 10^{-3}$	[37]
$\mathcal{B}(D_s \to K^+\pi^0)$	$(0.62 \pm 0.21) \times 10^{-3}$	[37]
	CF[c] branching ratios	
$\mathcal{B}(D^0 \to K^-\pi^+)$	$(3.88 \pm 0.05) \times 10^{-2}$	[37]
$\mathcal{B}(D^0 \to K_S \pi^0)$	$(1.19 \pm 0.04) \times 10^{-2}$	[37]
$\mathcal{B}(D^0 \to K_L \pi^0)$	$(1.00 \pm 0.07) \times 10^{-2}$	[37]
$\mathcal{B}(D^+ \to K_S \pi^+)$	$(1.47 \pm 0.07) \times 10^{-2}$	[37]
$\mathcal{B}(D^+ \to K_L \pi^+)$	$(1.46 \pm 0.05) \times 10^{-2}$	[37]
$\mathcal{B}(D_s \to K_S K^+)$	$(1.45 \pm 0.05) \times 10^{-2}$	[a][37,38]
	DCS branching ratios	
$\mathcal{B}(D^0 \to K^+\pi^-)$	$(1.47 \pm 0.07) \times 10^{-4}$	[37]
$\mathcal{B}(D^+ \to K^+\pi^0)$	$(1.83 \pm 0.26) \times 10^{-4}$	[37]

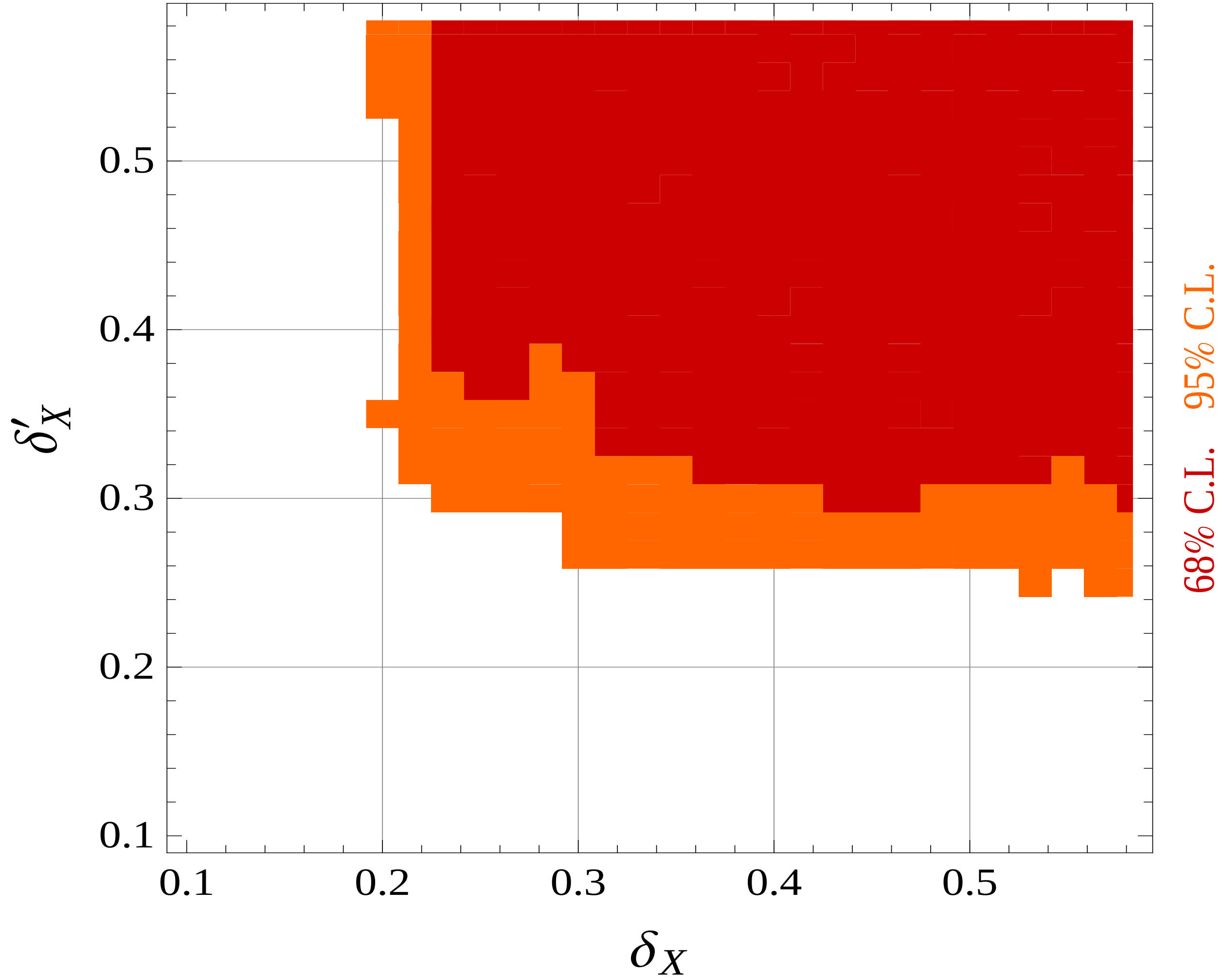
[a]The measurement quoted corresponds to our average. Systematic and statistical uncertainties are added in quadrature.
[b]Our symmetrization of uncertainties.
[c]Modes into $K_{S,L}$ assigned to CF decays.

Decay d	$B_1^{3_1}$	$B_1^{3_2}$	$B_8^{3_1}$	$B_8^{3_2}$	$B_8^{6_1}$	$B_8^{6_2}$	$B_8^{15_1}$	$B_8^{15_2}$	$B_8^{15_3}$	$B_{27}^{15_1}$	$B_{27}^{15_2}$	$B_{27}^{15_3}$	$B_{27}^{24_1}$	$B_{27}^{24_2}$	B_{27}^{42}
SCS															
$D^0 \to K^+K^-$	$\frac{1}{4\sqrt{10}}$	$\frac{1}{8}$	$\frac{1}{10\sqrt{2}}$	$\frac{1}{4\sqrt{5}}$	$\frac{1}{10}$	$-\frac{1}{10\sqrt{2}}$	$-\frac{7}{10\sqrt{122}}$	$\frac{\sqrt{\frac{3}{122}}}{5}$	$-\frac{1}{20}$	$-\frac{31}{20\sqrt{122}}$	$-\frac{17}{20\sqrt{366}}$	$\frac{7}{40}$	$-\frac{1}{10\sqrt{6}}$	$\frac{1}{10\sqrt{2}}$	$-\frac{13}{20\sqrt{42}}$
$D^0 \to \pi^+\pi^-$	$\frac{1}{4\sqrt{10}}$	$\frac{1}{8}$	$\frac{1}{10\sqrt{2}}$	$\frac{1}{4\sqrt{5}}$	$-\frac{1}{10}$	$\frac{1}{10\sqrt{2}}$	$-\frac{11}{10\sqrt{122}}$	$-\frac{2\sqrt{\frac{2}{183}}}{5}$	$\frac{3}{20}$	$-\frac{23}{20\sqrt{122}}$	$\frac{11}{20\sqrt{366}}$	$-\frac{1}{40}$	$\frac{1}{10\sqrt{6}}$	$-\frac{1}{10\sqrt{2}}$	$\frac{\sqrt{\frac{7}{6}}}{20}$
$D^0 \to \bar{K}^0K^0$	$-\frac{1}{4\sqrt{10}}$	$-\frac{1}{8}$	$\frac{1}{5\sqrt{2}}$	$\frac{1}{2\sqrt{5}}$	0	0	$-\frac{9}{5\sqrt{122}}$	$-\frac{1}{5\sqrt{366}}$	$\frac{1}{10}$	$-\frac{9}{20\sqrt{122}}$	$-\frac{1}{20\sqrt{366}}$	$\frac{1}{40}$	$-\frac{1}{2\sqrt{6}}$	$-\frac{1}{2\sqrt{2}}$	$\frac{19}{20\sqrt{42}}$
$D^0 \to \pi^0\pi^0$	$-\frac{1}{8\sqrt{5}}$	$-\frac{1}{8\sqrt{2}}$	$-\frac{1}{20}$	$-\frac{1}{4\sqrt{10}}$	$\frac{1}{10\sqrt{2}}$	$-\frac{1}{20}$	$\frac{11}{20\sqrt{61}}$	$\frac{2}{5\sqrt{183}}$	$-\frac{3}{20\sqrt{2}}$	$-\frac{57}{40\sqrt{61}}$	$\frac{7}{20\sqrt{183}}$	$\frac{1}{40\sqrt{2}}$	$\frac{1}{5\sqrt{3}}$	$\frac{1}{20}$	$-\frac{1}{20\sqrt{21}}$
$D^+ \to \pi^0\pi^+$	0	0	0	0	0	0	0	0	0	$-\frac{2(1-\bar{\Delta})}{\sqrt{61}}$	$\frac{5(1-\bar{\Delta})}{8\sqrt{183}}$	0	$\frac{1-\bar{\Delta}}{4\sqrt{3}}$	0	$\frac{1-\bar{\Delta}}{8\sqrt{21}}$
$D^+ \to \bar{K}^0K^+$	0	0	$\frac{3}{10\sqrt{2}}$	$\frac{3}{4\sqrt{5}}$	$\frac{1}{10}$	$-\frac{1}{10\sqrt{2}}$	$\frac{7}{10\sqrt{122}}$	$-\frac{\sqrt{\frac{3}{122}}}{5}$	$\frac{1}{20}$	$-\frac{3\sqrt{\frac{2}{61}}}{5}$	$-\frac{23}{20\sqrt{366}}$	$\frac{1}{5}$	$-\frac{1}{10\sqrt{6}}$	$-\frac{\sqrt{2}}{5}$	$-\frac{19}{20\sqrt{42}}$
$D_s \to K^0\pi^+$	0	0	$\frac{3}{10\sqrt{2}}$	$\frac{3}{4\sqrt{5}}$	$-\frac{1}{10}$	$\frac{1}{10\sqrt{2}}$	$\frac{11}{10\sqrt{122}}$	$\frac{2\sqrt{\frac{2}{183}}}{5}$	$-\frac{3}{20}$	$-\frac{3}{5\sqrt{122}}$	$\frac{19}{20\sqrt{366}}$	$-\frac{1}{10}$	$-\frac{\sqrt{\frac{2}{3}}}{5}$	$-\frac{1}{10\sqrt{2}}$	$-\frac{19}{20\sqrt{42}}$
$D_s \to K^+\pi^0$	0	0	$-\frac{3}{20}$	$-\frac{3}{4\sqrt{10}}$	$\frac{1}{10\sqrt{2}}$	$-\frac{1}{20}$	$-\frac{11}{20\sqrt{61}}$	$-\frac{2}{5\sqrt{183}}$	$\frac{3}{20\sqrt{2}}$	$-\frac{17}{10\sqrt{61}}$	$\frac{\sqrt{\frac{3}{61}}}{20}$	$\frac{1}{10\sqrt{2}}$	$-\frac{\sqrt{3}}{10}$	$\frac{1}{20}$	$-\frac{\sqrt{\frac{3}{7}}}{20}$
CF															
$D^0 \to K^-\pi^+$	0	0	0	0	$\frac{1}{5}$	$\frac{1}{5\sqrt{2}}$	$-\frac{\sqrt{\frac{2}{61}}}{5}$	$-\frac{7}{5\sqrt{366}}$	$-\frac{1}{5}$	$\frac{\sqrt{\frac{2}{61}}}{5}$	$\frac{7}{5\sqrt{366}}$	$\frac{1}{5}$	$\frac{1}{20\sqrt{6}}$	$\frac{1}{20\sqrt{2}}$	$-\frac{1}{2\sqrt{42}}$
$D^0 \to \bar{K}^0\pi^0$	0	0	0	0	$-\frac{1}{5\sqrt{2}}$	$-\frac{1}{10}$	$\frac{1}{5\sqrt{61}}$	$\frac{7}{10\sqrt{183}}$	$\frac{1}{5\sqrt{2}}$	$\frac{3}{10\sqrt{61}}$	$\frac{7\sqrt{\frac{3}{61}}}{20}$	$\frac{3}{10\sqrt{2}}$	$-\frac{\sqrt{3}}{20}$	$-\frac{3}{20}$	0
$D^+ \to \bar{K}^0\pi^+$	0	0	0	0	0	0	0	0	0	$\frac{1}{\sqrt{122}}$	$\frac{7}{2\sqrt{366}}$	$\frac{1}{2}$	$-\frac{1}{4\sqrt{6}}$	$-\frac{1}{4\sqrt{2}}$	$-\frac{1}{2\sqrt{42}}$
$D_s \to \bar{K}^0K^+$	0	0	0	0	$-\frac{1}{5}$	$-\frac{1}{5\sqrt{2}}$	$-\frac{\sqrt{\frac{2}{61}}}{5}$	$-\frac{7}{5\sqrt{366}}$	$-\frac{1}{5}$	$\frac{\sqrt{\frac{2}{61}}}{5}$	$\frac{7}{5\sqrt{366}}$	$\frac{1}{5}$	$\frac{1}{5\sqrt{6}}$	$\frac{1}{5\sqrt{2}}$	$\frac{1}{\sqrt{42}}$
DCS															
$D^0 \to K^+\pi^-$	0	0	0	0	0	$-\frac{\sqrt{2}}{5}$	$\frac{2\sqrt{\frac{2}{61}}}{5}$	$\frac{7\sqrt{\frac{2}{183}}}{5}$	0	$-\frac{2\sqrt{\frac{2}{61}}}{5}$	$-\frac{7\sqrt{\frac{2}{183}}}{5}$	0	$-\frac{1}{4\sqrt{6}}$	$\frac{3}{20\sqrt{2}}$	$-\frac{1}{2\sqrt{42}}$
$D^0 \to K^0\pi^0$	0	0	0	0	0	$\frac{1}{5}$	$-\frac{2}{5\sqrt{61}}$	$-\frac{7}{5\sqrt{183}}$	0	$-\frac{3}{5\sqrt{61}}$	$-\frac{7\sqrt{\frac{3}{61}}}{10}$	0	$-\frac{\sqrt{3}}{8}$	$-\frac{3}{40}$	0
$D^+ \to K^0\pi^+$	0	0	0	0	0	$\frac{\sqrt{2}}{5}$	$\frac{2\sqrt{\frac{2}{61}}}{5}$	$\frac{7\sqrt{\frac{2}{183}}}{5}$	0	$-\frac{2\sqrt{\frac{2}{61}}}{5}$	$-\frac{7\sqrt{\frac{2}{183}}}{5}$	0	$-\frac{1}{4\sqrt{6}}$	$-\frac{3}{20\sqrt{2}}$	$-\frac{1}{2\sqrt{42}}$
$D^+ \to K^+\pi^0$	0	0	0	0	0	$-\frac{1}{5}$	$-\frac{2}{5\sqrt{61}}$	$-\frac{7}{5\sqrt{183}}$	0	$-\frac{3}{5\sqrt{61}}$	$-\frac{7\sqrt{\frac{3}{61}}}{10}$	0	$-\frac{\sqrt{3}}{8}$	$\frac{3}{40}$	0
$D_s \to K^0K^+$	0	0	0	0	0	0	0	0	0	$-\sqrt{\frac{2}{61}}$	$-\frac{7}{\sqrt{366}}$	0	$\frac{1}{2\sqrt{6}}$	0	$\frac{1}{\sqrt{42}}$

To linear $SU(3)$-Xing, 13 complex matrix elements.

Table from 1211.3734; Previous $SU(3)$ works: Quigg'80, Pirtskhalava,Uttayara

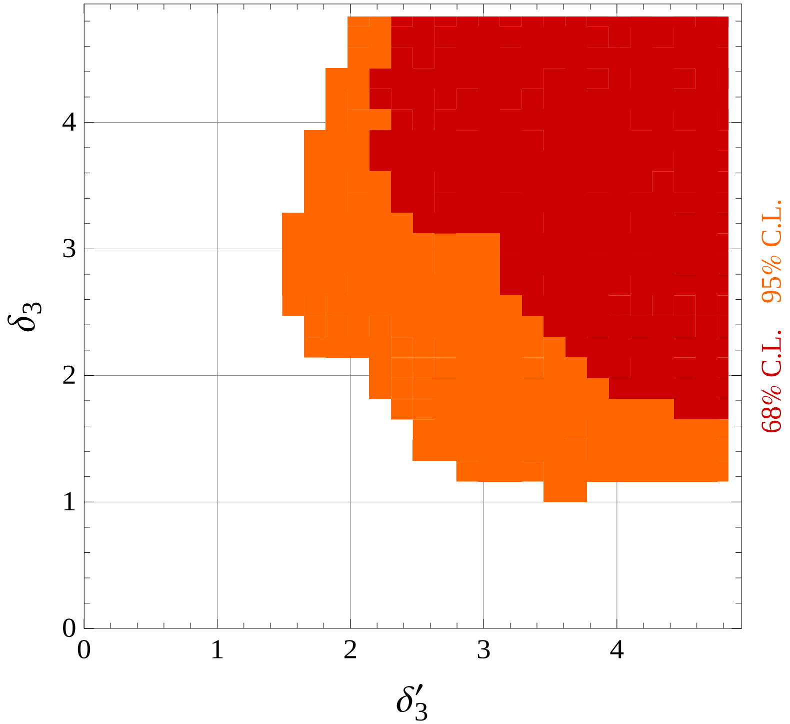
Does the SU(3)-expansion makes sense in Charm?

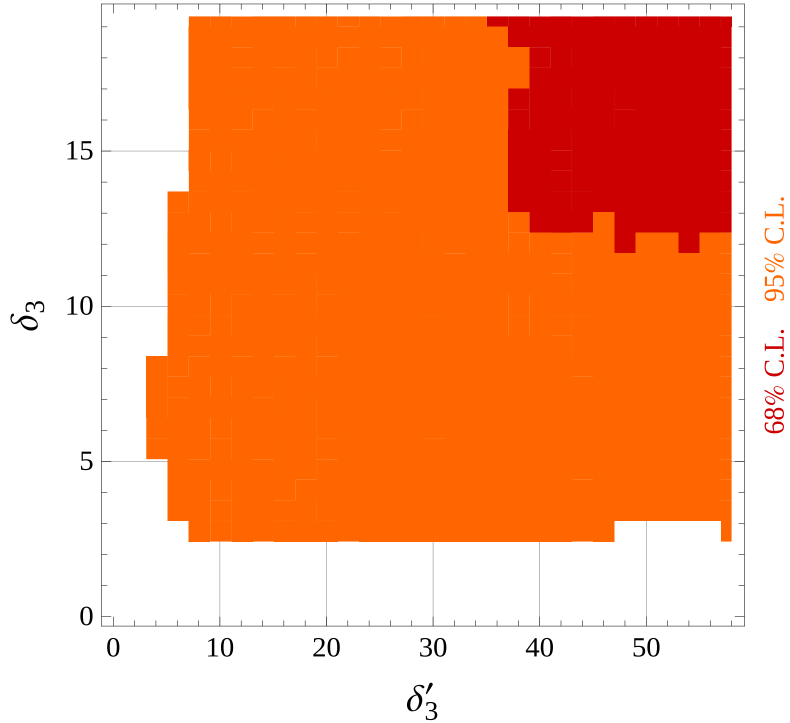


Fit works with SU(3)-Xing of order 30 %. Fig from 1211.3734

δ_X: max ratio matrix elements; δ'_X: max ratio decay amplitudes.

Penguin enhancement?

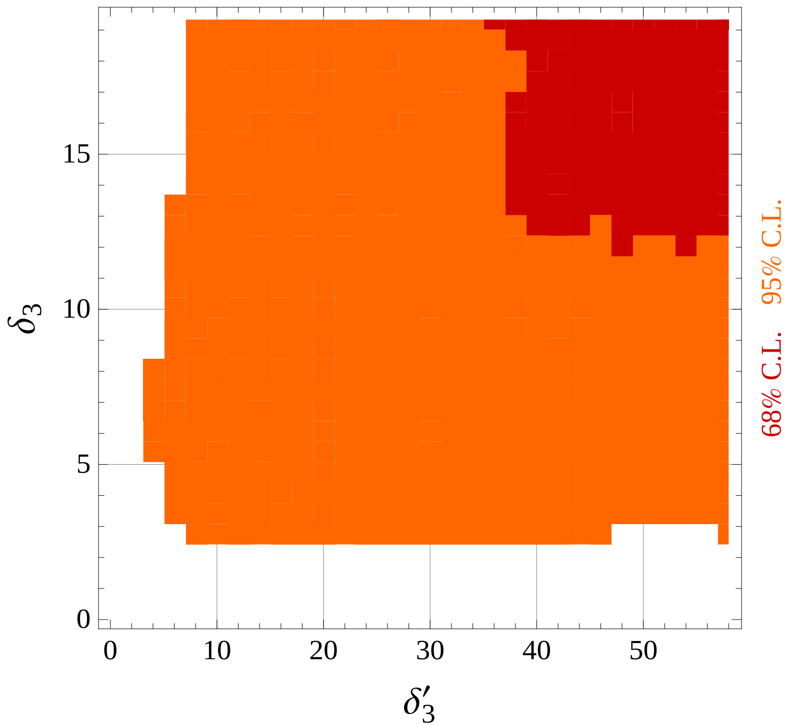


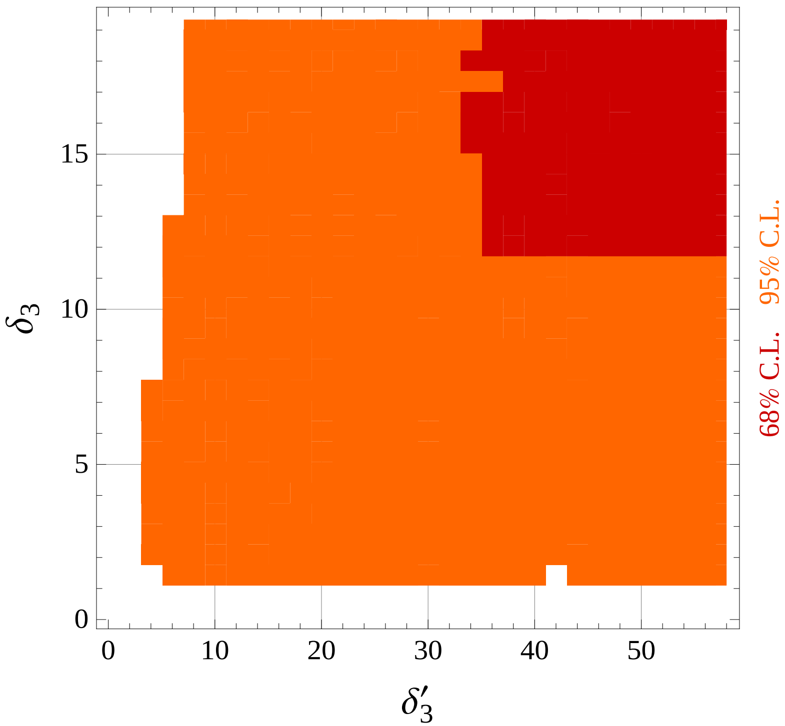


Left: without $A_{CP}(D^0 \to K_S K_S)$,$A_{CP}(D_s \to K_S \pi^+)$,$A_{CP}(D_s \to K^+ \pi^0)$

Right: All data – penguins even more enhanced . Figs from 1211.3734

Penguin enhancement?!





Left: All data from 1211.3734: $\Delta A_{\mathrm{CP}}^{wa} = -0.00678 \pm 0.00147$

Right: All data post Moriond QCD 2013: $\Delta A_{\mathrm{CP}}^{wa} = -0.0032 \pm 0.0012$

(LHCb update/new) (Fig. courtesy of M.Jung/S.Schacht).

The penguins still need to be enhanced.

(0. This is the most compehensive SU(3)-X-analysis without th bias; first full fit with 25 fit parameters.)

1. $SU(3)$-analysis predicts $A_{CP}(D^0 \to K_S K_S)$ enhanced w.r.t $A_{CP}(D^0 \to K^+K^-)$ by $\sim 1/\delta_X$.

2. Future data can reveal pattern among BSM models with CPX due to operators with diff SU(3) representations:

- $A_{CP}(D^+ \to \pi^+\pi^0)$ characterizes $\Delta I = 3/2$ in H_{eff}. 1204.3557 Grossman et al
- U-spin change in $K^+K^-/\pi^+\pi^-$ and $D_s \to K_s\pi^+/D^+ \to K_S K^+$.

4. Fits sharpen with better data ..... and/or dynamical input.

Stay Tuned

Summary

- It is fantastic to witness great advances in FCNC physics and respective tests of SM and BSM physics.
- I reported on recent th advances in rare $b \to s$ and $c \to u$ decays.
- Cross talk between flavor and QCD allows for a sharper interpretation of data.
- Verdict still out.

Please see original papers for complete reference list.