Model Independent Constraints on New Physics in Rare B Decays

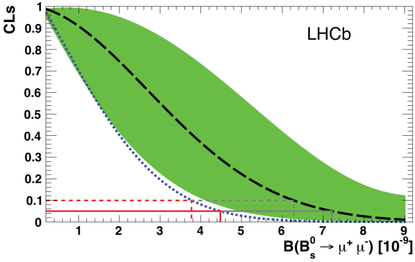
Wolfgang Altmannshofer

Fermilab

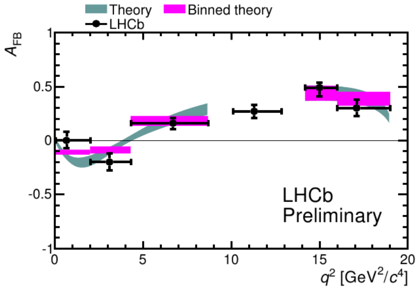
Phenomenology 2012 Symposium
University of Pittsburgh
May 7, 2012

based on:
WA, Paradisi, Straub 1111.1257
+ update 1205.xxxx

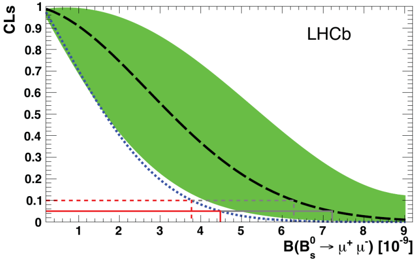
Motivation



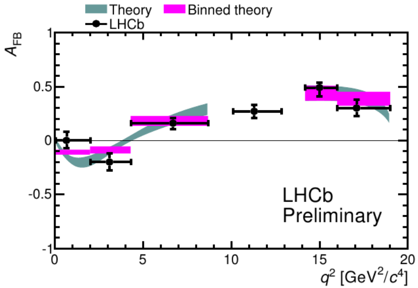
Recent LHCb data
on rare B decays shows
remarkable agreement with the
Standard Model predictions



Motivation



Recent LHCb data
on rare B decays shows
remarkable agreement with the
Standard Model predictions



How much room is left for
New Physics contributions
in rare B decays?

Rare B Decays as Probes of New Physics

$b \to s$ FCNC transitions are loop- and CKM-suppressed in the SM
$\to$ high sensitivity to New Physics

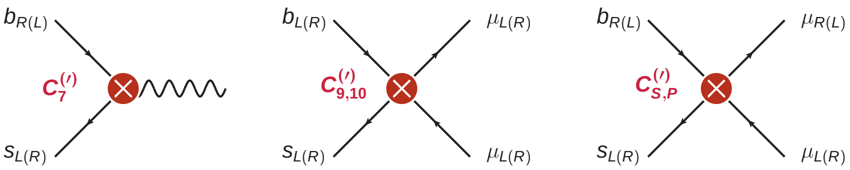
(incomplete) list of interesting observables in $b \to s$ decays:

decay	interesting observables	current exp. data
$B \to X_s \gamma$	BR	BaBar, Belle
$B \to K^* \gamma$	BR, S	BaBar, Belle
$B \to X_s \ell^+ \ell^-$	BR, A_{FB}	BaBar, Belle
$B \to K \mu^+ \mu^-$	BR, F_H	BaBar, Belle, CDF
$B \to K^* \mu^+ \mu^-$	BR, F_L, A_{FB}, S_3, A_7, A_8, A_9, ...	BaBar, Belle, CDF, LHCb
$B_s \to \mu^+ \mu^-$	BR	CDF, LHCb, CMS, Atlas

Effective Hamiltonian

$$\mathcal{H}_{\text{eff}}^{b\to s} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i \left(C_i \mathcal{O}_i + C_i' \mathcal{O}_i' \right)$$

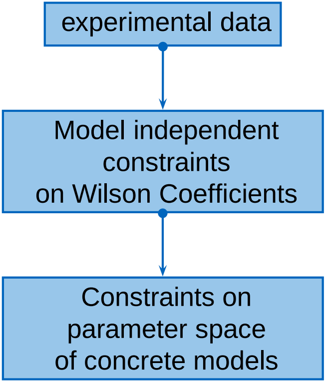
magnetic dipole operators — semileptonic operators — scalar operators



	C_7, C_7'	C_9, C_9'	C_{10}, C_{10}'	C_S, C_S', C_P, C_P'
$B \to (X_s, K^*)\,\gamma$	★			
$B \to (X_s, K, K^*)\,\ell^+\ell^-$	★	★	★	
$B_s \to \mu^+\mu^-$			★	★

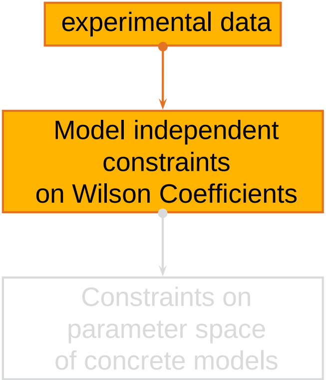
neglecting tensor operators

Constraining New Physics



see also Descotes-Genon, Ghosh, Matias, Ramon ’11, Bobeth, Hiller, van Dyk, Wacker ’11

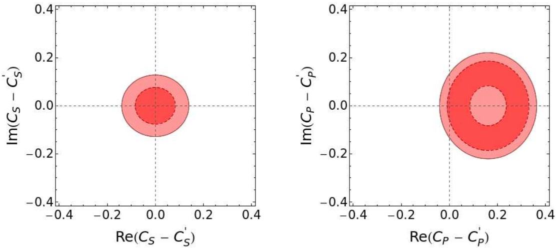
Constraining New Physics



- naive theorist's combination of experimental results
- assume experimental and theory uncertainties to be gaussian
- construct χ^2 function:

$$\chi^2 = \sum \frac{(O_{\text{exp}} - O_{\text{th}})^2}{\sigma_{\text{exp}}^2 + \sigma_{\text{th}}^2}$$

see also Descotes-Genon, Ghosh, Matias, Ramon '11, Bobeth, Hiller, van Dyk, Wacker '11 consider one complex Wilson coefficient at a time

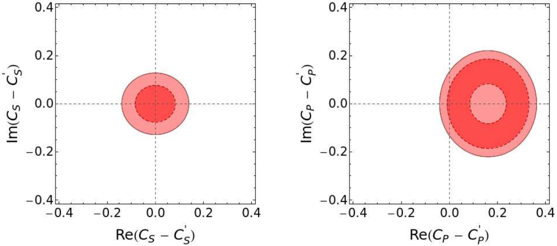


$$BR(B_s \to \mu^+\mu^-) \propto m_\mu^2 \left(\left| (C_{10}^{\rm SM} + C_{10}^{\rm NP} - C'_{10}) + \frac{m_{B_s}}{2m_\mu}(C_P - C'_P) \right|^2 + \left| \frac{m_{B_s}}{2m_\mu}(C_S - C'_S) \right|^2 \right)$$

Constraints on Scalar Currents

preliminary

consider one complex Wilson coefficient at a time



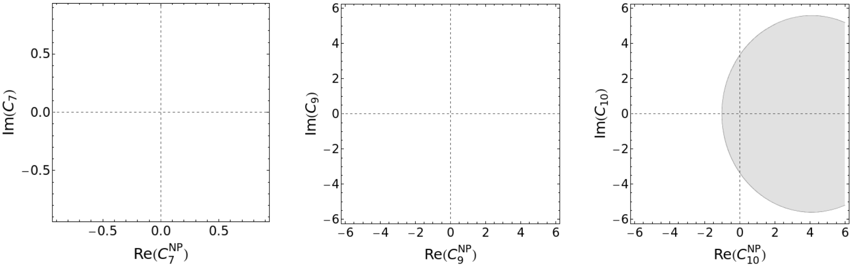
$$BR(B_s \to \mu^+\mu^-) \propto m_\mu^2 \left(\left| (C_{10}^{\rm SM} + C_{10}^{\rm NP} - C_{10}') + \frac{m_{B_s}}{2m_\mu}(C_P - C_P') \right|^2 + \left| \frac{m_{B_s}}{2m_\mu}(C_S - C_S') \right|^2 \right)$$

From now on consider only C_{10} and C_{10}' effects in $B_s \to \mu^+\mu^-$

Constraints on Left-Handed Currents

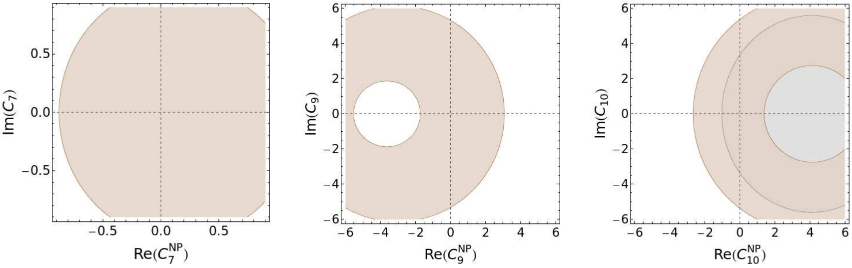
preliminary

consider one complex Wilson coefficient at a time (C_7, C_9, C_{10})



- $BR(B_s \to \mu^+\mu^-)$

consider one complex Wilson coefficient at a time (C_7, C_9, C_{10})

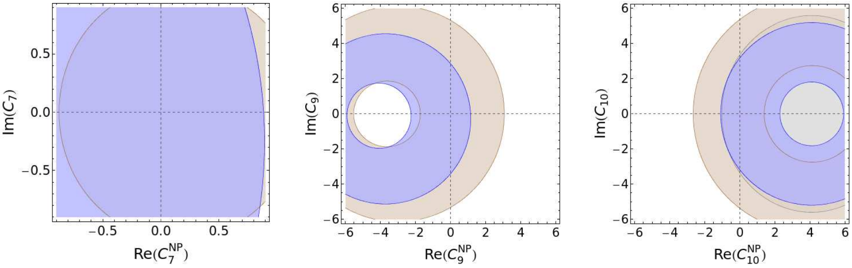


- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$
  (both low and high q^2 region)

Constraints on Left-Handed Currents

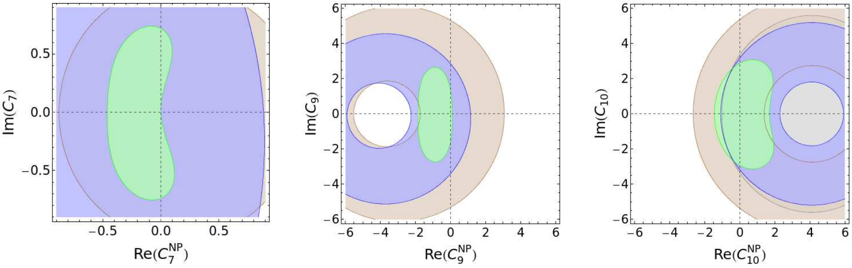
preliminary

consider one complex Wilson coefficient at a time (C_7, C_9, C_{10})



- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$
  (both low and high q^2 region)
- $BR(B \to K\mu^+\mu^-)$
  (both low and high q^2 region)

consider one complex Wilson coefficient at a time (C_7, C_9, C_{10})

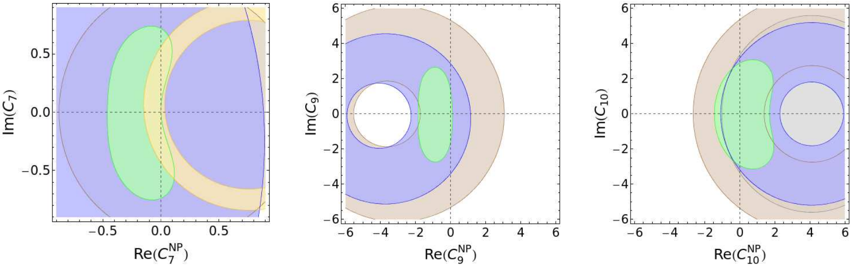


- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$
  (both low and high q^2 region)
- $BR(B \to K\mu^+\mu^-)$
  (both low and high q^2 region)
- $B \to K^*\mu^+\mu^-$
  (BR, A_{FB}, F_L, S_3 and A_9
  both low and high q^2 region)

Constraints on Left-Handed Currents

preliminary

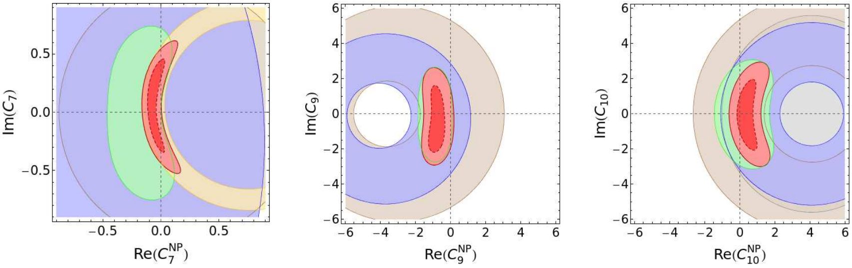
consider one complex Wilson coefficient at a time (C_7, C_9, C_{10})



- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$
  (both low and high q^2 region)
- $BR(B \to K \mu^+\mu^-)$
  (both low and high q^2 region)
- $B \to K^* \mu^+\mu^-$
  (BR, A_{FB}, F_L, S_3 and A_9
  both low and high q^2 region)
- $BR(B \to X_s \gamma)$

Constraints on Left-Handed Currents

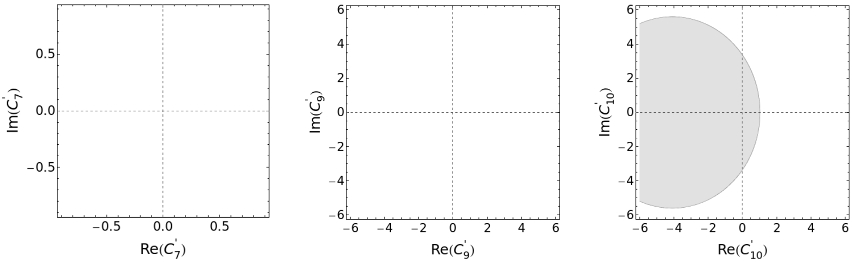
consider one complex Wilson coefficient at a time (C_7, C_9, C_{10})



- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$ (both low and high q^2 region)
- $BR(B \to K \mu^+\mu^-)$ (both low and high q^2 region)
- $B \to K^* \mu^+\mu^-$ (BR, A_{FB}, F_L, S_3 and A_9 both low and high q^2 region)
- $BR(B \to X_s \gamma)$

Data shows reasonable agreement with SM: $\chi^2_{SM}/N_{dof} = 24.6/23$

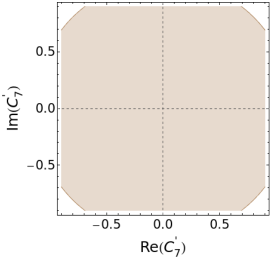
Imaginary parts are less constrained $\to$ need to measure CP asymmetries consider one complex Wilson coefficient at a time (C'_7, C'_9, C'_{10})

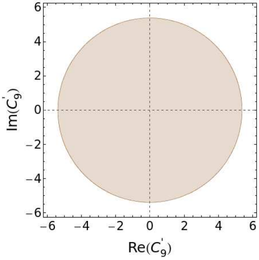


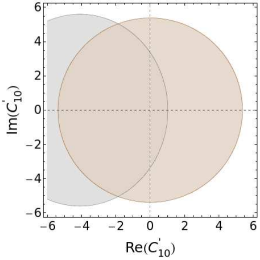
- $BR(B_s \to \mu^+\mu^-)$

Constraints on Right-Handed Currents *preliminary*

consider one complex Wilson coefficient at a time (C'_7, C'_9, C'_{10})



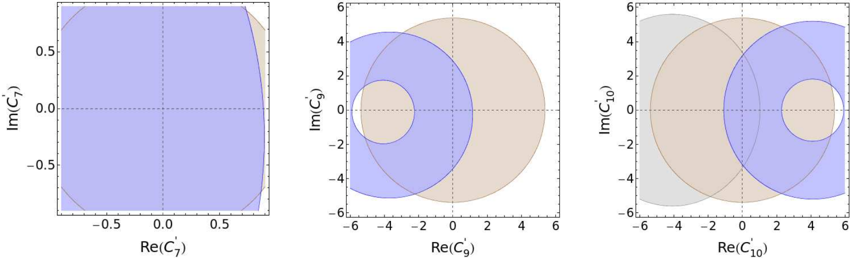




- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s\ell^+\ell^-)$
  (both low and high q^2 region)

Constraints on Right-Handed Currents *preliminary*

consider one complex Wilson coefficient at a time (C'_7, C'_9, C'_{10})

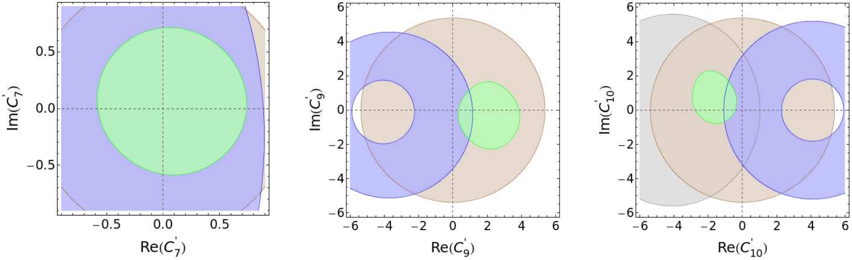


- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$
  (both low and high q^2 region)
- $BR(B \to K\mu^+\mu^-)$
  (both low and high q^2 region)

Constraints on Right-Handed Currents

preliminary

consider one complex Wilson coefficient at a time (C_7', C_9', C_{10}')

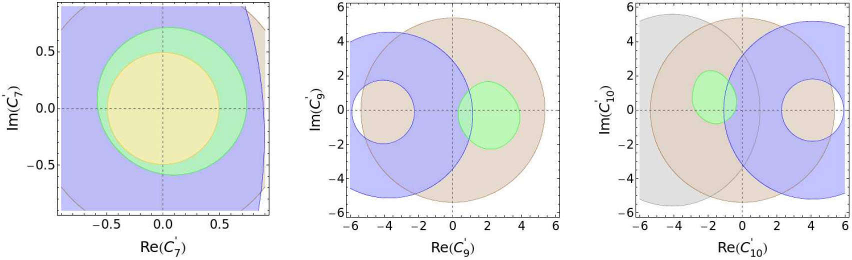


- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$
  (both low and high q^2 region)
- $BR(B \to K\mu^+\mu^-)$
  (both low and high q^2 region)
- $B \to K^*\mu^+\mu^-$
  (BR, A_{FB}, F_L, S_3 and A_9
  both low and high q^2 region)

Constraints on Right-Handed Currents

preliminary

consider one complex Wilson coefficient at a time (C_7', C_9', C_{10}')

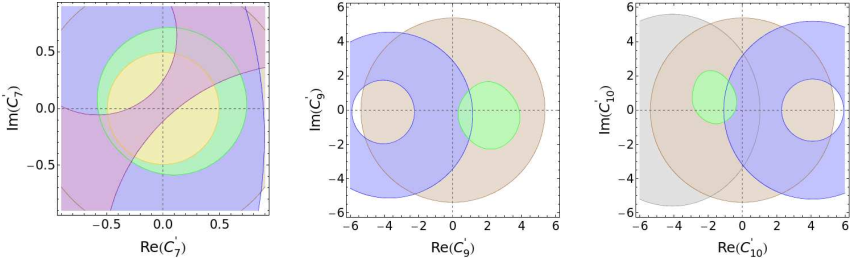


- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$ (both low and high q^2 region)
- $BR(B \to K\mu^+\mu^-)$ (both low and high q^2 region)
- $B \to K^*\mu^+\mu^-$ (BR, A_{FB}, F_L, S_3 and A_9 both low and high q^2 region)
- $BR(B \to X_s\gamma)$

Constraints on Right-Handed Currents

preliminary

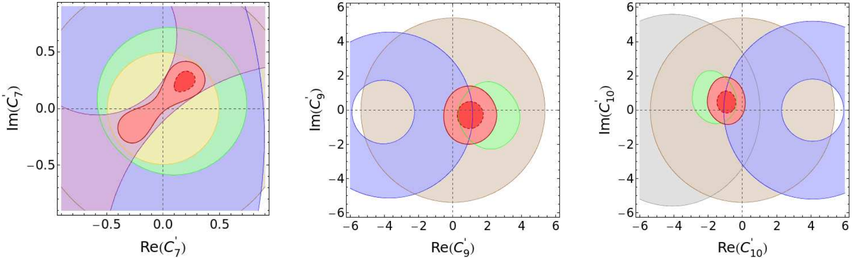
consider one complex Wilson coefficient at a time (C'_7, C'_9, C'_{10})



- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$ (both low and high q^2 region)
- $BR(B \to K\mu^+\mu^-)$ (both low and high q^2 region)
- $B \to K^*\mu^+\mu^-$ (BR, A_{FB}, F_L, S_3 and A_9 both low and high q^2 region)
- $BR(B \to X_s\gamma)$
- $B \to K^*\gamma$ (time dependent CP asymmetry)

Constraints on Right-Handed Currents

consider one complex Wilson coefficient at a time (C_7', C_9', C_{10}')



- $BR(B_s \to \mu^+\mu^-)$
- $BR(B \to X_s \ell^+\ell^-)$ (both low and high q^2 region)
- $BR(B \to K \mu^+\mu^-)$ (both low and high q^2 region)
- $B \to K^* \mu^+\mu^-$ (BR, A_{FB}, F_L, S_3 and A_9 both low and high q^2 region)
- $BR(B \to X_s \gamma)$
- $B \to K^* \gamma$ (time dependent CP asymmetry)

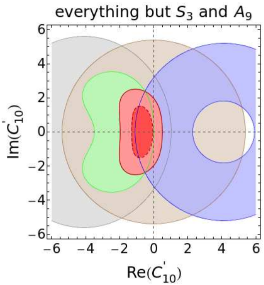
complementary information from the different exclusive decays

imaginary parts are as constrained as real parts

Impact of S_3 and A_9

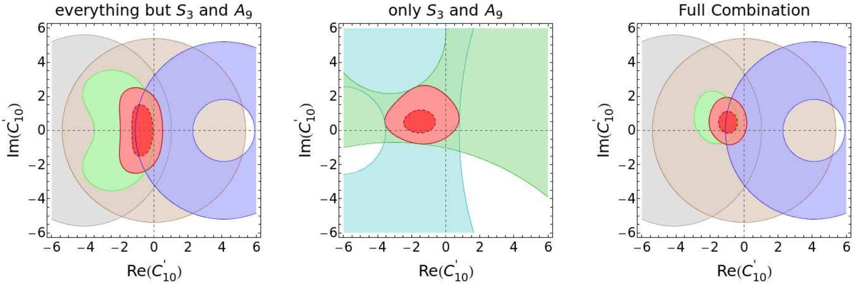
preliminary

- $B \to K^* \mu^+ \mu^-$ offers two observables that vanish in absence of right-handed currents: S_3 (aka $A_T^{(2)}$) and A_9
- S_3 probes CP conserving right-handed currents
- A_9 probes CP violating right-handed currents



Impact of S_3 and A_9

- $B \to K^* \mu^+ \mu^-$ offers two observables that vanish in absence of right-handed currents: S_3 (aka $A_T^{(2)}$) and A_9
- S_3 probes CP conserving right-handed currents
- A_9 probes CP violating right-handed currents



- measurements by LHCb (and CDF) already lead to non-trivial constraints

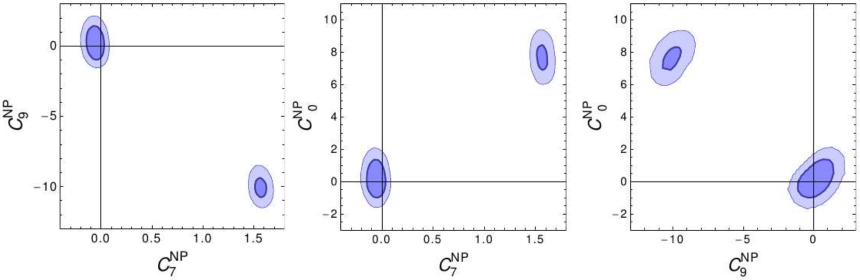
Implications for the NP Scale

preliminary

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{eff}}^{\text{SM}} + \sum_i \left(\frac{c_i}{\Lambda_{\text{NP}}^2} \mathcal{O}_i + \frac{c_i'}{\Lambda_{\text{NP}}^2} \mathcal{O}_i' \right)$$

Operator		Λ_{NP} (TeV) for $\lvert c_i^{(\prime)} \rvert = 1$			
		$+$	$-$	$+i$	$-i$
$\mathcal{O}_7 =$	$(\bar{s}\sigma_{\mu\nu}P_R b)F^{\mu\nu}$	69	275	43	39
$\mathcal{O}_7' =$	$(\bar{s}\sigma_{\mu\nu}P_L b)F^{\mu\nu}$	46	71	83	48
$\mathcal{O}_9 =$	$(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)$	28	73	21	23
$\mathcal{O}_9' =$	$(\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)$	48	22	24	28
$\mathcal{O}_{10} =$	$(\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$	45	32	23	23
$\mathcal{O}_{10}' =$	$(\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$	25	82	36	25
$\mathcal{O}_S - \mathcal{O}_S' =$	$\frac{m_b}{m_{B_s}}(\bar{s}\gamma_5 b)(\bar{\ell}\ell)$	93	93	98	98
$\mathcal{O}_P - \mathcal{O}_P' =$	$\frac{m_b}{m_{B_s}}(\bar{s}\gamma_5 b)(\bar{\ell}\gamma_5 \ell)$	173	58	93	93

consider 3 real left-handed Wilson coefficients simultaneously
marginalize over the third one

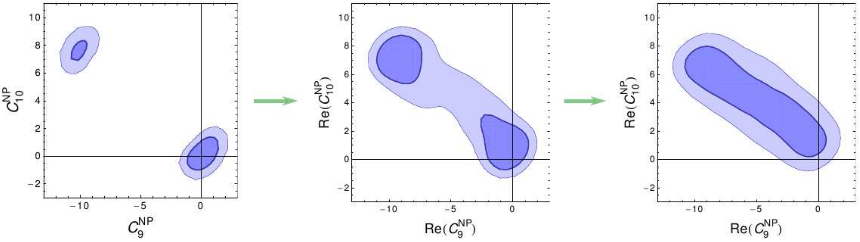


Flipped sign solutions:

- $C_{7,9,10} = -C_{7,9,10}^{SM}$: cannot be excluded by low energy data
- $C_7 = -C_7^{SM}$: excluded by $B \to X_s \ell^+ \ell^-$ (Gambino, Haisch, Misiak '04) and (now) also by LHCb measurement of $A_{FB}(B \to K^* \mu^+ \mu^-)$
- $C_{9,10} = -C_{9,10}^{SM}$: excluded by LHCb measurement of $A_{FB}(B \to K^* \mu^+ \mu^-)$

Generalizations II

consider also phases and right-handed currents



only left-handed currents	only left-handed currents	left- and right-handed currents
only CKM CP violation	generic CP violation	generic CP violation

- More data needed to break degeneracies
- Observables that are directly sensitive to right-handed currents and/or CP violation

Predictions for Observables

preliminary

95% C.L. predictions for observables to be measured/improved

C_i	C_i'	$\text{BR}(B_s \to \mu^+\mu^-)$	$\lvert\langle A_7\rangle_{[1,6]}\rvert$	$\lvert\langle A_8\rangle_{[1,6]}\rvert$	$\lvert\langle A_9\rangle_{[1,6]}\rvert$	$\langle S_3\rangle_{[1,6]}$
R	0	$[1.7, 4.8] \times 10^{-9}$	0	0	0	0
C	0	$[1.1, 4.4] \times 10^{-9}$	$< 25\%$	$< 14\%$	0	0
0	C	$[0.9, 4.5] \times 10^{-9}$	$< 23\%$	$< 16\%$	$< 8\%$	$[-4\%, 8\%]$
R	R	$< 4.6 \times 10^{-9}$	0	0	0	$[-7\%, 14\%]$
C	C	$< 4.3 \times 10^{-9}$	$< 34\%$	$< 21\%$	$< 13\%$	$[-7\%, 13\%]$

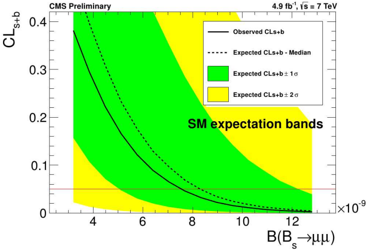
Still room for New Physics!

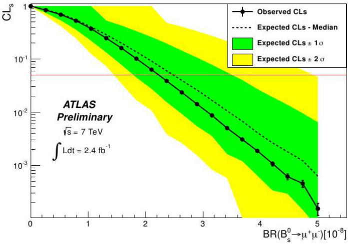
Summary

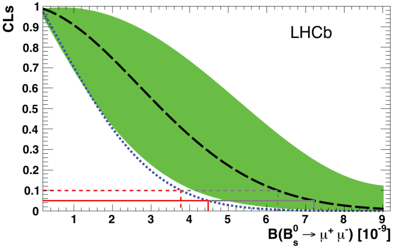
- Recent experimental results on $B \to K^{(*)}\mu^+\mu^-$ and $B_s \to \mu^+\mu^-$ show good agreement with the Standard Model predictions
- Strong constraints on New Physics: $\Lambda_{\rm NP} \gtrsim 20 - 200$ TeV for O(1) $b \to s$ couplings at tree level
- The different exclusive decays give complementary information on right-handed currents: Looking forward to LHCb results on $B \to K\mu^+\mu^-$
- Looking forward to improved measurements of observables directly sensitive to right-handed currents and CP violation: S_3, $A_{7,8,9}$, ...

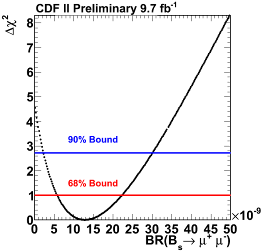
Back Up

Our Naive $B_s \to \mu^+\mu^-$ Combination









$$\text{BR}(B_s \to \mu^+\mu^-)_{\text{exp}} = (2.4 \pm 1.6) \times 10^{-9}$$

Large Isospin Breaking?