Searching for New Physics with Flavor-Violating Observables

Wolfgang Altmannshofer

Fermilab

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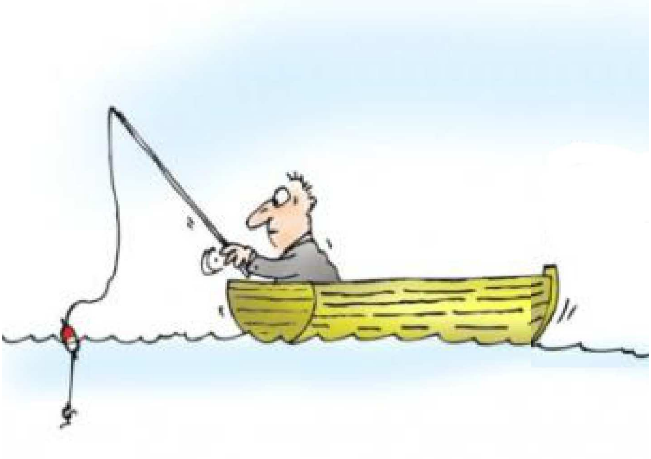
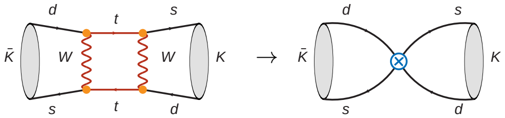


Example: CP Violation in Kaon mixing

- SM Amplitude is loop suppressed and CKM suppressed



$$\propto \frac{g^4}{16\pi^2}\frac{1}{M_W^2}(V_{td}V_{ts}^*)^2\ (\bar{s}_L\gamma_\mu d_L)^2$$

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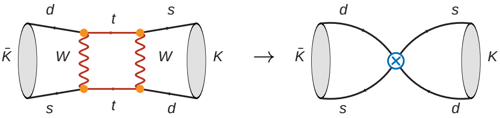
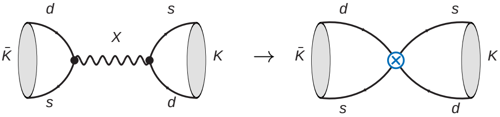


$$\propto \frac{g^4}{16\pi^2}\frac{1}{M_W^2}(V_{td}V_{ts}^*)^2\ (\bar{s}_L\gamma_\mu d_L)^2$$

- Generic NP amplitude is not necessarily suppressed



$$\propto \frac{1}{M_X^2}(\bar{s}\Gamma_1 d)(\bar{s}\Gamma_2 d)$$

- CP Violation in Kaon Mixing can probe extremely high scales

$$\Lambda_{\rm NP} = M_X \sim M_W \frac{4\pi}{g^2}\frac{1}{|V_{td}V_{ts}^*|} \sim 10^4\,TeV$$

Operator	Bounds on Λ in TeV ($c_{ij}=1$)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L \gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	Δm_K; ϵ_K
$(\bar{s}_R\, d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	Δm_K; ϵ_K
$(\bar{c}_L \gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{c}_R\, u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{b}_L \gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_R\, d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	Δm_{B_d}; $S_{\psi K_S}$
$(\bar{b}_L \gamma^\mu s_L)^2$	1.1×10^2		7.6×10^{-5}		Δm_{B_s}
$(\bar{b}_R\, s_L)(\bar{b}_L s_R)$	3.7×10^2		1.3×10^{-5}		Δm_{B_s}

Isidori, Nir, Perez '10

- Consider $\Delta F = 2$ dimension 6 operators $(c_{ij}/\Lambda^2) O_{ij}$
- a generic flavor structure $c_{ij} = O(1)$ requires a very high NP scale Λ
- NP at the natural TeV scale needs a highly non-generic flavor structure
- But: still lots of room for NP in many $\Delta F = 1$ processes
  and to some extent also in the B_s mixing phase

Some Promising Flavor Observables

Charm

- CP Violation in $D^0 - \bar{D}^0$ mixing (LHCb, SuperB, Belle II)
- direct CP Violation in SCS D decays (LHCb, SuperB, Belle II)
- ...

Kaons

- $K^+ \to \pi^+ \nu\bar{\nu}$ (NA62, ORKA)
- $K_L \to \pi^0 \nu\bar{\nu}$ (K0TO, Project X)
- ...

B Mesons

- CPV in B_s mixing (LHCb)
- $B_{s,d} \to \mu^+\mu^-$ (LHCb, CMS)
- $B \to X_s \ell^+\ell^-$ (SuperB, Belle II)
- $B \to K^{(*)}\ell^+\ell^-$ (LHCb, SuperB, Belle II)
- $B \to K^{(*)}\nu\bar{\nu}$ (SuperB, Belle II)
- $B \to K^*\gamma$ (LHCb, SuperB, Belle II)
- $B \to \tau\nu$ (SuperB, Belle II)
- ...

$+ \quad \cdots$

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1) $B \to \tau\nu$ (SuperB, Belle II)

- ...

$+ \quad \cdots$

$B \to \tau\nu$ and $\sin 2\beta$

HFAG combination of data from BaBar and Belle

$$BR(B^+ \to \tau^+\nu)_{\rm exp} = (1.64 \pm 0.34) \times 10^{-4}$$

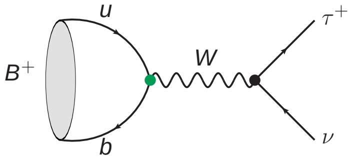
SM prediction depends strongly on $|V_{ub}|$:

1. Use direct determination of $|V_{ub}|$ from semileptonic B decays

$$|V_{ub}| = (3.89 \pm 0.44) \times 10^{-3} \quad \text{(PDG)}$$

$$BR(B^+ \to \tau^+\nu)_{\rm SM} = (1.04 \pm 0.25) \times 10^{-4}$$

Helicity suppressed tree level decay



$$BR(B^+ \to \tau^+\nu)_{\rm SM} \propto f_{B^+}^2 |V_{ub}|^2$$

Experimental Status and SM Prediction

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2. Take $|V_{ub}|$ from a CKM fit

   Determination by $\Delta M_d / \Delta M_s$ and $S_{\psi K_S}$ gives

$$|V_{ub}| = (3.43 \pm 0.16) \times 10^{-3}$$

$$BR(B^+ \to \tau^+\nu)_{\rm SM} = (0.80 \pm 0.11) \times 10^{-4}$$

$\to \sim 3\sigma$ discrepancy!

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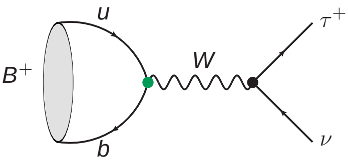

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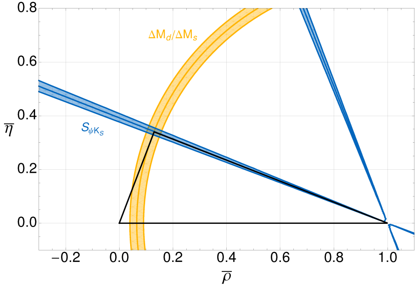

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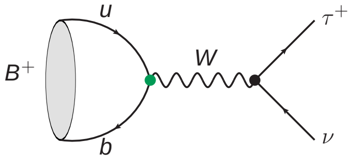

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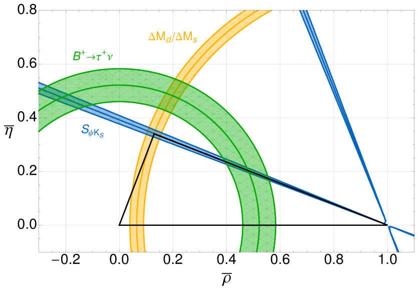
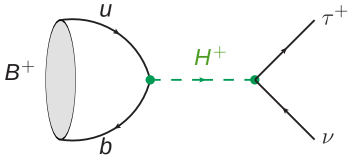
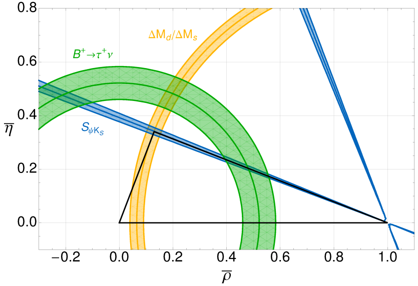


1. Charged Higgs contributions to $B^+ \to \tau^+ \nu$

charged Higgs can lift the helicity sup.



$$R_{B\tau\nu} = \frac{BR(B^+ \to \tau^+\nu)}{BR(B^+ \to \tau^+\nu)_{\rm SM}}$$



1. Charged Higgs contributions to $B^+ \to \tau^+\nu$

   $\sim$ +100% New Physics effect to match the central values

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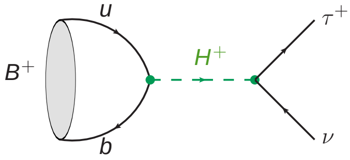

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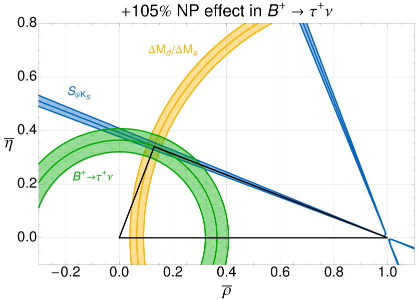

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   $\sim$ +100% New Physics effect to match the central values

$\rightarrow$ Discrepancy grows in a 2HDM of type II

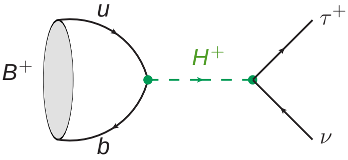
$$R^{\rm II}_{B\tau\nu} = \left(1 - \frac{m^2_{B^+}}{m^2_{H^+}} t^2_\beta\right)^2$$

$\rightarrow$ Discrepancy can be explained in a 2HDM with Minimal Flavor Violation

$$R^{\rm MFV}_{B\tau\nu} = \left|1 - \frac{m^2_{B^+}}{m^2_{H^+}} \frac{(t_\beta - \epsilon_b)(t_\beta - \epsilon_\tau)}{(1+\epsilon_b t_\beta)(1+\epsilon_\tau t_\beta)}\right|^2$$

(see e.g. Blankenburg, Isidori '11)

charged Higgs can lift the helicity sup.



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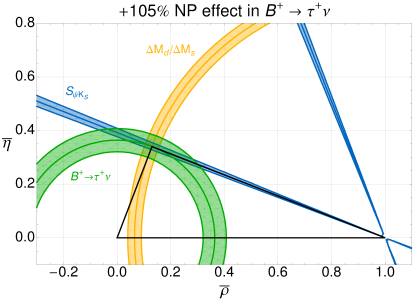

Possible New Physics Interpretations

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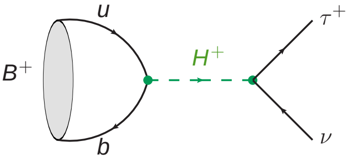
(see e.g. Blankenburg, Isidori '11)

2. New Physics in B_d mixing?

$$S_{\psi K_S} = \sin(2\beta + \phi_d^{\rm NP})$$

large nagative NP phase in the B_d mixing amplitude $\phi_d^{\rm NP} \simeq -20^\circ$ changes $\sin 2\beta$ by the right amount

charged Higgs can lift the helicity sup.



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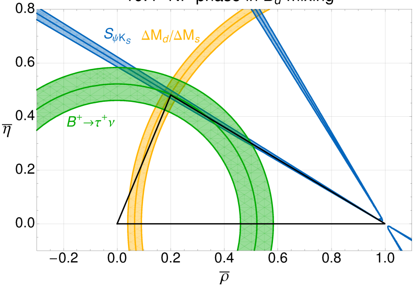
-19.4° NP phase in B_d mixing



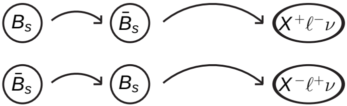
CP Violation in B_s Mixing

CPV Observables in B_s Mixing

CP violation in $b \to s$ transitions is predicted to be very small in the SM

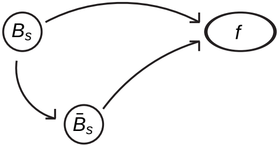
$$\beta_s \sim \text{Arg}(V_{ts}) \simeq 1^\circ \ , \ \phi_s^{\text{SM}} \sim 0.2^\circ \quad \to \quad \text{excellent probe of NP}$$

- semileptonic asymmetry



$$a_{\text{SL}}^s = \frac{\Gamma(\bar{B}_s \to X\ell^+\nu) - \Gamma(B_s \to X\ell^-\nu)}{\Gamma(\bar{B}_s \to X\ell^+\nu) + \Gamma(B_s \to X\ell^-\nu)} = \left|\frac{\Gamma_{12}^s}{M_{12}^s}\right| \sin(\phi_s^{\text{SM}} + \phi_s^{\text{NP}})$$

- time dependent CP asymmetry in decays to CP eigenstates $B_s \to f$ (e.g. $B_s \to \psi f_0$)



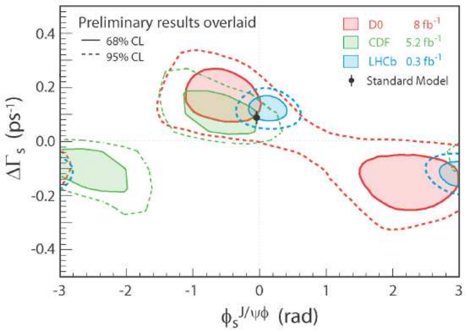
$$S_f \sin(\Delta M_s t) = \frac{\Gamma(\bar{B}_s(t) \to f) - \Gamma(B_s(t) \to f)}{\Gamma(\bar{B}_s(t) \to f) + \Gamma(B_s(t) \to f)}$$

$$S_f = \sin(2|\beta_s| - \phi_s^{\text{NP}})$$

Experimental Status

PRD 85, 032006 (2012), arXiv:1112.1726, arXiv:1112.3183
(see talks by Emilie Maurice and Hideki Miyake)

Phys.Rev. D84 (2011) 052007



- in the past CDF and D0 had a slight preference for a large negative B_s mixing phase in $B_s \to \psi\phi$
- LHCb finds a SM like B_s mixing phase

combination of the mixing phase determined from $B_s \to \psi\phi$ and $B_s \to \psi f_0$

$$\phi_s^{\rm LHCb} = 0.03 \pm 0.16 \pm 0.07$$

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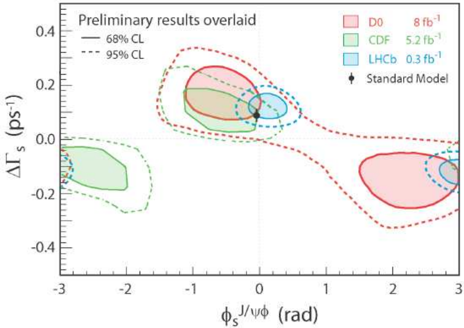

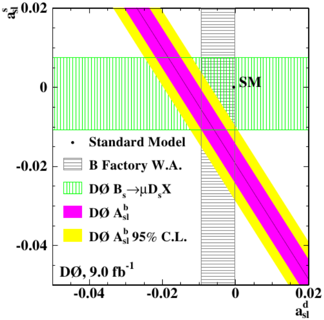

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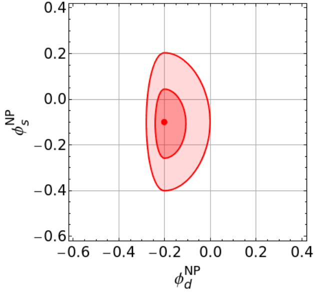
$$\phi_s^{\text{LHCb}} = 0.03 \pm 0.16 \pm 0.07$$

- like sign dimuon charge asymmetry measured by D0

$$A_{SL}^b = 0.59\, a_{SL}^d + 0.41\, a_{SL}^s = (-78.7 \pm 19.6)10^{-4}$$

- 3.9σ discrepancy with SM prediction
- large NP phase in B_s mixing?



Combining data from

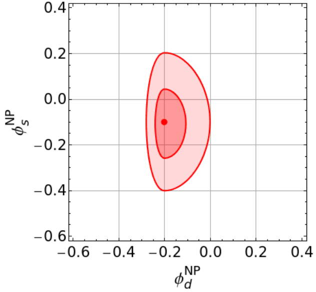
- time dependent CP asymmetry in $B_d \to \psi K_S$ from the B factories
- time dependent CP asymmetry in $B_s \to \psi\phi$ from CDF and D0
- time dependent CP asymmetries in $B_s \to \psi\phi$ and $B_s \to \psi f_0$ from LHCb

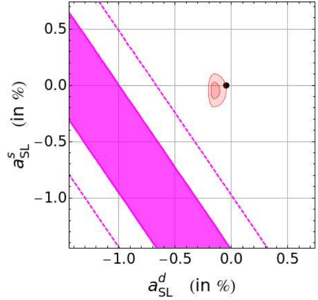
$\to$ still some room for a NP phase in B_s mixing

$\to$ preference towards a non-zero negative NP phase in B_d mixing (from tensions in the UT fit)

Naive Combination

(WA, Carena '11)





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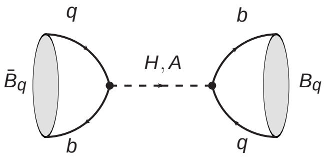
Large like-sign dimuon charge asymmetry cannot be explained

assumptions:

1. no significant NP contributions to the tree level decays $B_d \to \psi K_S$, $B_s \to \psi\phi$
2. no significant NP contributions to the absorptive parts of the mixing amplitudes $\Gamma_{12}^{d,s}$

Implication for Models with MFV

2 Higgs doublet models with Minimal Flavor Violation can contribute to B meson mixing at tree level
(Buras, Carlucci, Gori, Isidori ’10; Buras, Isidori, Paradisi ’10)



1) contributions proportional to Y_b^2

$\rightarrow$ universal shifts in the B_q mixing phases: $\phi_s^{\text{NP}} = \phi_d^{\text{NP}}$

- strongy suppressed if quartic couplings in the Higgs potential have “MSSM-like” structure
- are generically dominant for more general Higgs potentials

2) contributions proportional to $Y_b Y_s$ and $Y_b Y_d$

$\rightarrow$ negligible small for B_d mixing: $\phi_d^{\text{NP}} \ll \phi_s^{\text{NP}}$

$\rightarrow$ LHCb data on B_s mixing phase excludes non-standard phase in B_d mixing

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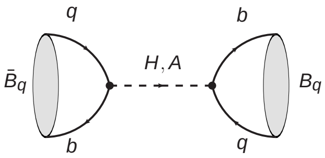

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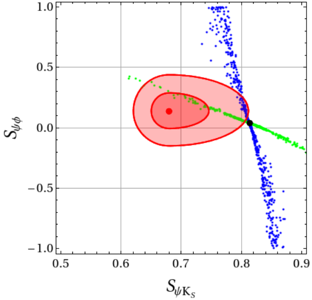


Ex: MSSM with MFV + dim 5 ops.
(WA, Carena '11)

a) in the Kähler-potential
(can lead to sizable tree level flavor changing Higgs couplings $\propto 1/M$)

b) and in the Superpotential
(modify the MSSM Higgs potential)

$B_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$

Experimental Status and SM Prediction

- CDF observes an excess of $B_s \to \mu^+\mu^-$ candidates (talk by Hideki Miyake)

$$BR(B_s \to \mu^+\mu^-)_{\text{CDF}} = (1.3^{+0.9}_{-0.7}) \times 10^{-8}$$

- CMS and LHCb set upper limits. Strongest bound currently from CMS (CERN seminar yesterday)

$$BR(B_s \to \mu^+\mu^-)_{\text{CMS}} < 7.7 \times 10^{-9} \text{ @ 95\% C.L.}$$

Main uncertainty in the SM prediction comes from the B_s decay constant f_{B_s}

1. eliminate f_{B_s} by normalizing to ΔM_s (assumes ΔM_s NP free) (Buras '03)

$$BR(B_s \to \mu^+\mu^-)_{\text{SM}} = (3.2 \pm 0.2) \times 10^{-9}$$

2. there has been remarkable progress on the lattice

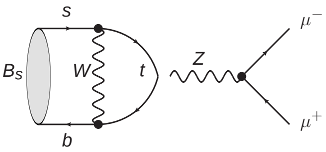
$$f_{B_s} = (225 \pm 4)\text{MeV} \quad \text{(HPQCD collaboration '11)}$$

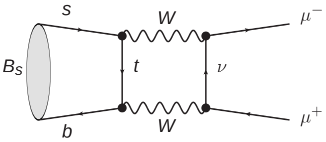
$$\to \quad BR(B_s \to \mu^+\mu^-)_{\text{SM}} = (3.0 \pm 0.2) \times 10^{-9}$$

$$f_{B_s} = (242.0 \pm 9.5)\text{MeV} \quad \text{(Fermilab lattice + MILC collaboration '11)}$$

$$\to \quad BR(B_s \to \mu^+\mu^-)_{\text{SM}} = (3.5 \pm 0.3) \times 10^{-9}$$

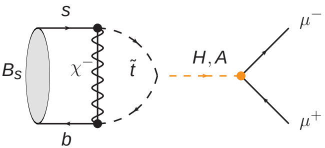
- strongly helicity suppressed in the SM
- induced by Z penguins and boxes





- most prominent example of NP effects: Higgs penguins in the MSSM
- lift the helicity suppression
- for large $\tan\beta$ huge enhancement possible (orders of magnitude) even in models with MFV

  (Choudhury, Gaur '98; Babu, Kolda '99)
- many other NP effects are possible: modified Z penguins, flavor changing Z', ...



$A(B_s \to \mu^+\mu^-) \propto \tan^3\beta / M_A^2$

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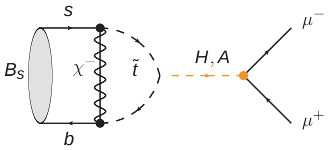


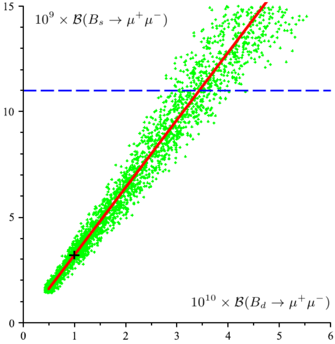
$A(B_s \to \mu^+\mu^-) \propto \tan^3\beta / M_A^2$

"Golden" MFV Relation

(Buras '03; Hurth, Isidori, Kamenik, Mescia '08)

$$\frac{BR(B_s \to \mu^+\mu^-)}{BR(B_d \to \mu^+\mu^-)} \simeq \frac{f_{B_s}^2}{f_{B_d}^2}\frac{\tau_{B_s}}{\tau_{B_d}}\frac{|V_{ts}|^2}{|V_{td}|^2} \simeq 35$$

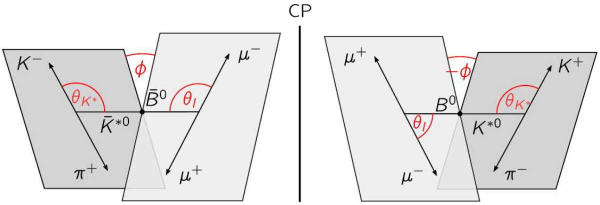
Relation holds in the SM and in all models where flavor violation is determined by the CKM matrix.



(Isidori, Straub '12)

Angular Observables in
$B \to K^* \mu^+ \mu^-$

A Goldmine for New Physics Searches



The 4 body decay
$B^0 \to K^*(\to K^+\pi^-)\mu^+\mu^-$
and its conjugate mode
$\bar{B}^0 \to \bar{K}^*(\to K^-\pi^+)\mu^+\mu^-$
are described by 4-fold differential decay distributions

$$\frac{d\bar{\Gamma}}{dq^2\, d\cos\theta_{K^*}\, d\theta_\ell\, d\phi} \quad , \quad \frac{d\Gamma}{dq^2\, d\cos\theta_{K^*}\, d\theta_\ell\, d\phi}$$

- a plethora of observables can be extracted from the angular distributions
  (Lunghi, Matias ’06; Egede et al ’08,’10; Bobeth et al ’08,’10,’11; Alok et al ’10,’11; WA, Ball, Bharucha, Buras, Straub, Wick ’08; Matias, Mescia, Ramon, Virto ’12; ...)
- allow detailed insight in the structure of possible NP contributions

$$C_7 m_b(\bar{s}_L(\sigma F)b_R) \quad , \quad C_9(\bar{s}_L\gamma_\mu b_L)(\bar{\mu}\gamma^\mu\mu) \quad , \quad C_{10}(\bar{s}_L\gamma_\mu b_L)(\bar{\mu}\gamma^\mu\gamma_5\mu)$$
$$C_7' m_b(\bar{s}_R(\sigma F)b_L) \quad , \quad C_9'(\bar{s}_R\gamma_\mu b_R)(\bar{\mu}\gamma^\mu\mu) \quad , \quad C_{10}'(\bar{s}_R\gamma_\mu b_R)(\bar{\mu}\gamma^\mu\gamma_5\mu)$$

- possible issue: large theoretical uncertainties due to formfactors

$\rightarrow$ normalizing the anglular distributions to the differential decay width cancels form factor uncertainties to a large extent

$\Leftrightarrow$ uncertainty in the overall normalization, but shape of the distribution is robust

Accessing Observables from the Angular Distribution

- One dimensional angular distributions give access to the well known observables
  F_L, the K^* longitudinal polarization fraction, and
  A_{FB}, the forward-backward asymmetry
- Also the transversal asymmetry $S_3 = \frac{1}{2}A_T^{(2)}(1-F_L)$ and the CP asymmetry A_9 can be obtained from a 1-dim angular analysis

$$\frac{d(\Gamma+\bar{\Gamma})}{dq^2 d\cos\theta_{K^*}} \propto 2F_L \cos^2\theta_{K^*} + (1-F_L)\sin^2\theta_{K^*}$$

$$\frac{d(\Gamma-\bar{\Gamma})}{dq^2 d\cos\theta_\ell} \propto A_{FB}\cos\theta_\ell + \frac{3}{4}F_L\sin^2\theta_\ell + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell)$$

$$\frac{d(\Gamma+\bar{\Gamma})}{dq^2 d\phi} \propto 1 + S_3\cos 2\phi + A_9 \sin 2\phi$$

- The CP asymmetries A_7 and A_8 require a 2 or 3 dimensional angular analysis

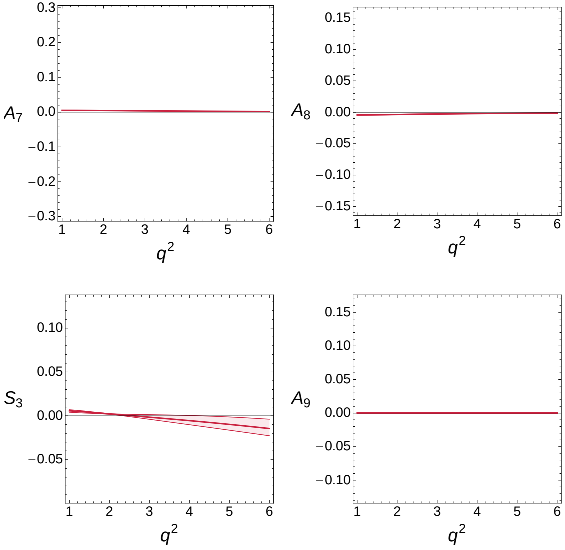
$$\left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_{K^*} \, \frac{d(\Gamma-\bar{\Gamma})}{dq^2 d\phi d\cos\theta_{K^*}} \propto S_5\cos\phi + A_7\sin\phi$$

$$\left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_\ell \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_{K^*} \, \frac{d(\Gamma+\bar{\Gamma})}{dq^2 d\phi d\cos\theta_{K^*} d\cos\theta_\ell} \propto S_4\cos\phi + A_8\sin\phi$$

Sensitivity to New Physics

- The transversal asymmetry $S_3 \propto A_T^{(2)}$ is sensitive to CP conserving RH currents
- The CP asymmetry A_9 is sensitive to CP violating RH currents
- The CP asymmetries A_7 and A_8 are sensitive to CP violating LH currents

- SM predictions of $A_{7,8,9}$ and S_3 are strongly suppressed



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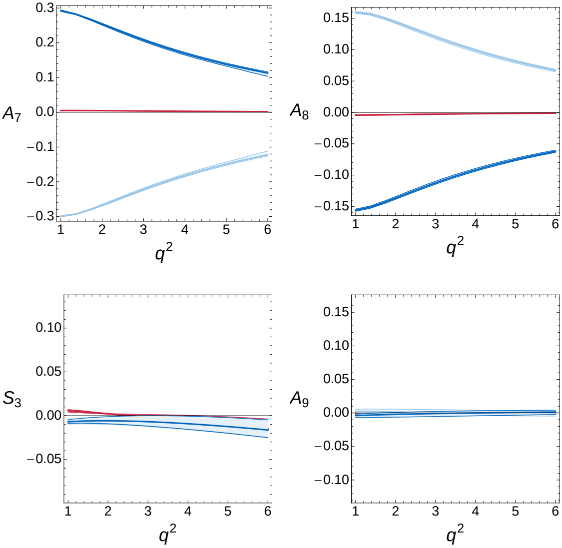
- New Physics Examples

1. Complex NP contribution to the left-handed magnetic operator $\bar{s}_L(\sigma F)b_R$



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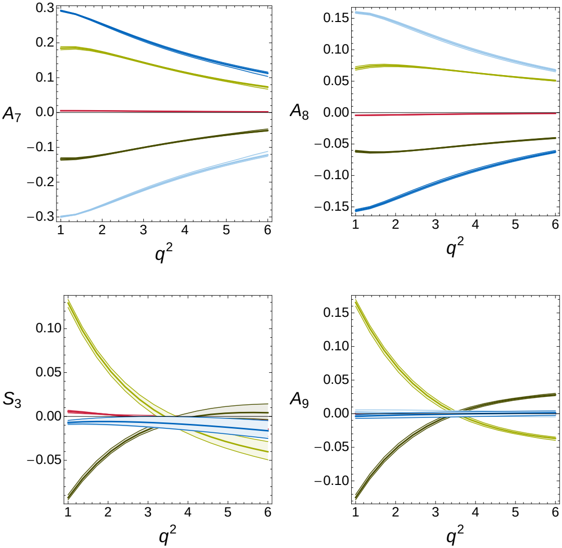
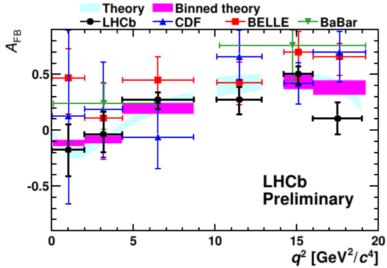
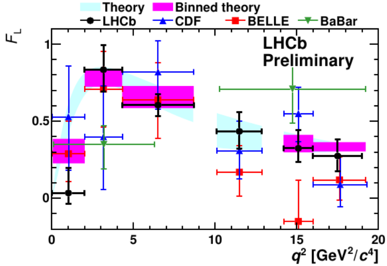
1. Complex NP contribution to the left-handed magnetic operator $\bar{s}_L(\sigma F)b_R$
2. Complex NP contribution to the right-handed magnetic operator $\bar{s}_R(\sigma F)b_L$



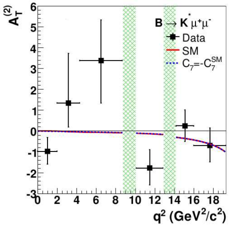
Experimental Status

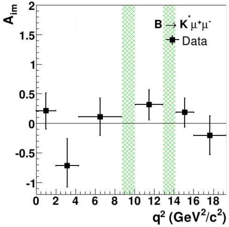




arXiv:1112.3515 [hep-ex]

- BaBar, Belle, CDF and LHCb have results for A_{FB} and F_L
- hint for a non-standard A_{FB} at low q^2 by Belle is not confirmed by LHCb
- CDF presented first results on $A_T^{(2)} \propto S_3$ and $A_{im} = A_9$



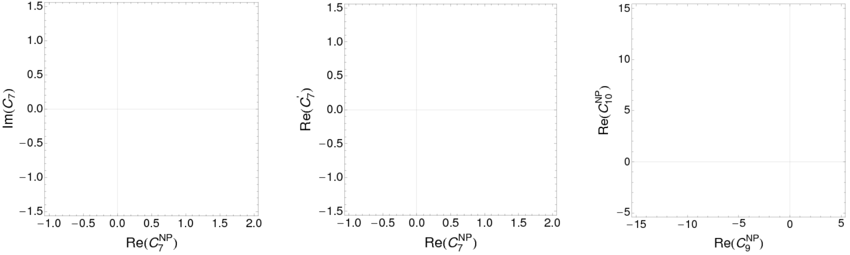


arXiv:1108.0695 [hep-ex]

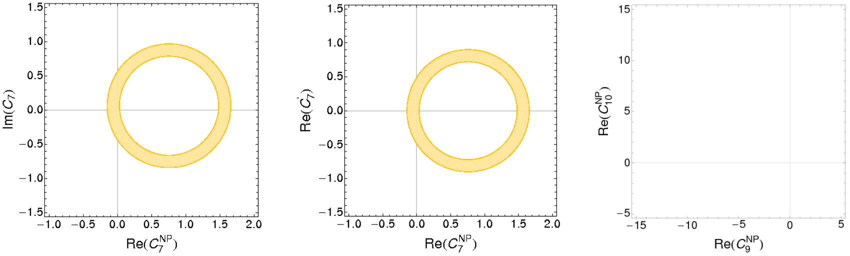
Constraints on New Physics

WA, Paradisi, Straub ’11

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



Data shows agreement with SM predictions and can be used to constrain New Physics contributions in a model independent way see also Descotes-Genon, Ghosh, Matias, Ramon '11, Bobeth, Hiller, van Dyk, Wacker '11



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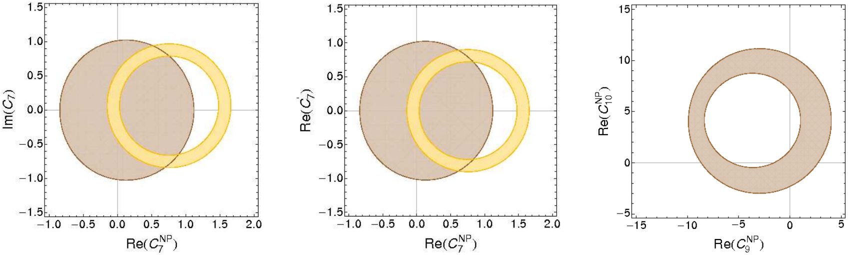

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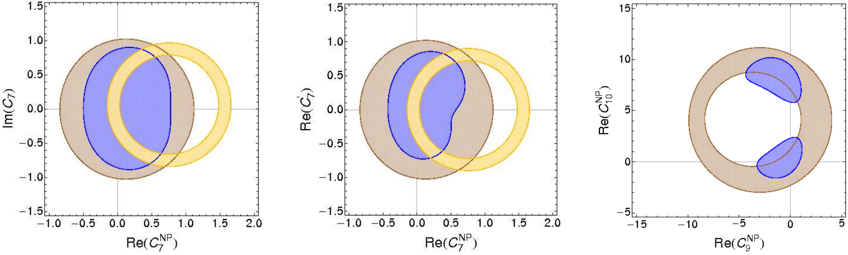

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  (BR, A_{FB} and F_L)

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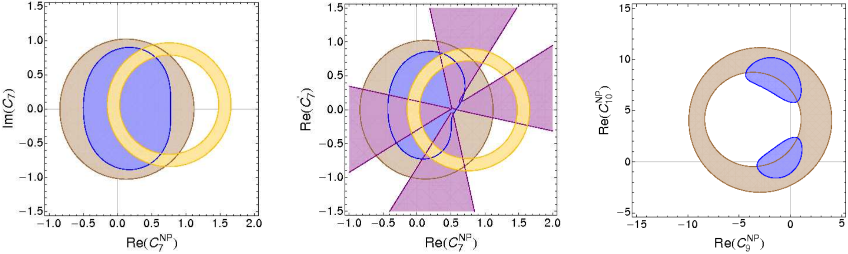

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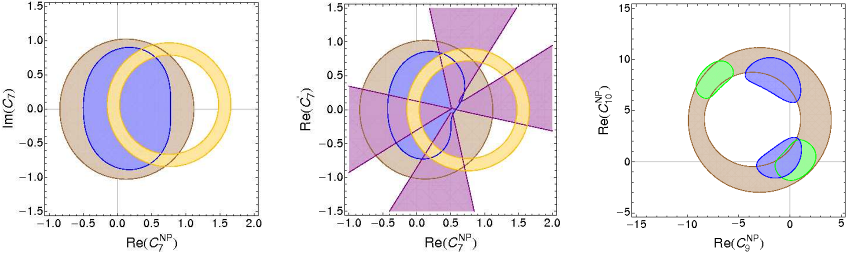

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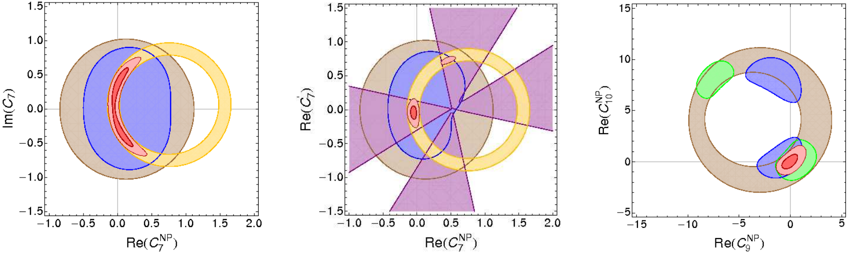

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Much more parameter space allowed, if more than 2 Wilson coefficients are considered simultaneously

Sc	BR($B_s \to \mu^+\mu^-$)	BR($B_s \to \tau^+\tau^-$)	$\lvert\langle A_7\rangle_{[1,6]}\rvert$	$\lvert\langle A_8\rangle_{[1,6]}\rvert$	$\lvert\langle A_9\rangle_{[1,6]}\rvert$	$\langle S_3\rangle_{[1,6]}$
1	$[1.0, 5.6] \times 10^{-9}$	$[2, 12] \times 10^{-7}$	0	0	0	0
2	$[1.0, 5.4] \times 10^{-9}$	$[2, 12] \times 10^{-7}$	$< 31\%$	$< 15\%$	0	0
3	$< 5.6 \times 10^{-9}$	$< 12 \times 10^{-7}$	$< 22\%$	$< 17\%$	$< 12\%$	$[-6\%, 15\%]$
4	$< 5.5 \times 10^{-9}$	$< 12 \times 10^{-7}$	$< 34\%$	$< 20\%$	$< 15\%$	$[-11\%, 18\%]$
5	$[1.4, 5.5] \times 10^{-9}$	$[3, 12] \times 10^{-7}$	$< 27\%$	$< 14\%$	0	0
6	$< 3.8 \times 10^{-9}$	$< 8 \times 10^{-7}$	$< 22\%$	$< 18\%$	$< 12\%$	$[-3\%, 18\%]$
7	$< 4.1 \times 10^{-9}$	$< 9 \times 10^{-7}$	$< 28\%$	$< 21\%$	$< 13\%$	$[-7\%, 19\%]$

1: real LH currents (C_i real, $C_i' = 0$)
2: complex LH currents (C_i complex, $C_i' = 0$)
3: complex RH currents ($C_i = 0$, C_i' complex)
4: generic NP (C_i and C_i' complex)

5: LH modified Z couplings + complex C_7
6: RH modified Z couplings + complex C_7'
7: generic modified Z couplings + complex C_7, C_7'

(ranges for $BR(B_s \to \ell^+\ell^-)$ assume absence of scalar contributions)

- in the presence of non-standard CP violation, $\langle A_7\rangle$ and $\langle A_8\rangle$ can be as large as $\pm 35\%$ and $\pm 20\%$
- in the presence of RH currents, $\langle A_9\rangle$ and $\langle S_3\rangle$ can be as large as $\pm 15\%$

Direct CP Violation in $D \to K^+K^-$ and $D \to \pi^+\pi^-$

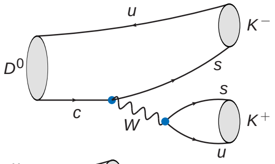
(see also talk by Jernej Kamenik)

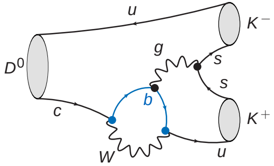
New Physics in Charm Decays?

Direct CPV in singly Cabibbo suppressed D^0 decays ($D \to K^+K^-$ and $D \to \pi^+\pi^-$) is strongly suppressed in the SM (interference of tree diagram with highly suppressed gluon penguin)

$$A_{\rm CP}^{\rm dir}(K^+K^-) \sim \frac{V_{ub}V_{cb}}{V_{us}V_{cs}} \frac{\alpha_s}{\pi} \sim 10^{-4}$$

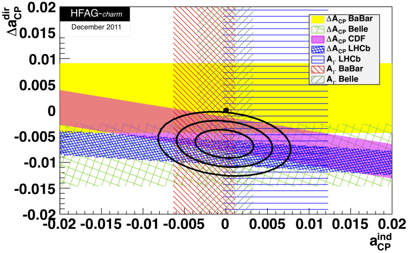
$\to$ considered excellent probe of NP (Grossman, Kagan, Nir '06)





LHCb evidence for charm CP violation (3.5σ)
(arXiv:1112.0938 [hep-ex], talk by Emilie Maurice)

$$\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$$



- ΔA_{CP} is to a good approx. the difference of the direct CP asymmetries in $D \to K^+K^-$ and $D \to \pi^+\pi^-$
- Precise SM prediction is difficult due to large uncertainties in hadronic matrix elements.
- Recent SM predictions (post-dictions?) give values

ΔA_{CP}	$\simeq$	-0.4%	Brod, Kagan, Zupan '11
ΔA_{CP}	$\simeq$	-0.25%	Cheng, Chiang '12

$\to$ SM explanation of the LHCb measurement cannot be fully excluded

Possible New Physics Interpretations

1) NP effects in loop induced flavor changing chromomagnetic operators

$$m_c \bar{c}_R (\sigma G) u_L$$

- can give chirally enhanced contributions to ΔA_{CP}
- are least constrained by other flavor data
  (Isidori, Kamenik, Ligeti, Perez ’11)
- can arise in SUSY models with non-standard sources of flavor violaton
  (Giudice, Isidori, Paradisi ’12)

2) Tree level induced 4 fermion operators

$$(\bar{c}\Gamma_1 u)(\bar{q}\Gamma_2 q)$$

- are typically strongly constrained by $D^0 - \bar{D}^0$ mixing
- Constraints become stronger for heavier NP particles!

→ Most tree level explanations (Z's, heavy gluons, diquarks, ...) do not work

Few can be made viable in corners of parameter space
(WA, Primulando, Yu, Yu ’12)

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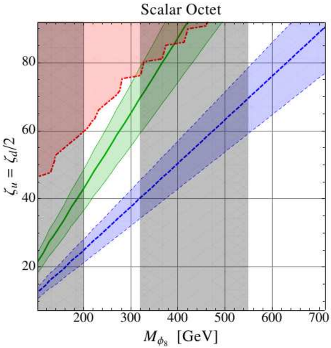

Example:

Scalar octet with small flavor changing $c_R \to u_L$ coupling

→ ϵ'/ϵ suppressed by 1st generation quark masses

→ Constraint from $D^0 - \bar{D}^0$ mixing can be avoided for small masses

→ strong constraints from colliders (4 jet final states)

Summary

Low energy flavor observables probe
New Physics at the TeV scale and beyond

- Previous hints of some non-standard effects (large B_s mixing phase at CDF and D0, no zero-crossing of A_{FB} in $B \to K^* \mu^+ \mu^-$ at Belle) have not been confirmed by LHCb
- There are still many observables where large New Physics effect can show up ($B_{s,d} \to \mu^+ \mu^-$, CP asymmetries in $B \to K^* \mu^+ \mu^-$, ...)
- LHCb (+CDF) evidence for charm CP violation might be a signal of New Physics

$\rightarrow$ Looking forward to upcoming results on flavor observables!

Buona Pesca!