Model-Independent Constraints on New Physics:
Minimal Flavour Violation (MFV)

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- *Outline*

❶ Model-Independent Analysis

➲ Flavour Problem and MFV

❷ Present Constraints on MFV (*at large tan*β)

➲ $\Delta F=2$ FCNC observables: ΔM_s, ...

➲ $\Delta F=1$ FCNC observables: $B \to X_s \gamma$, ...

➲ $\Delta F=1$ Charged Current processes: $B \to D \tau \nu$, ...

Interplay of Collider and Flavour Physics, March 15^{th}-17^{th}, CERN

Model-independent Analysis: Flavour Problem

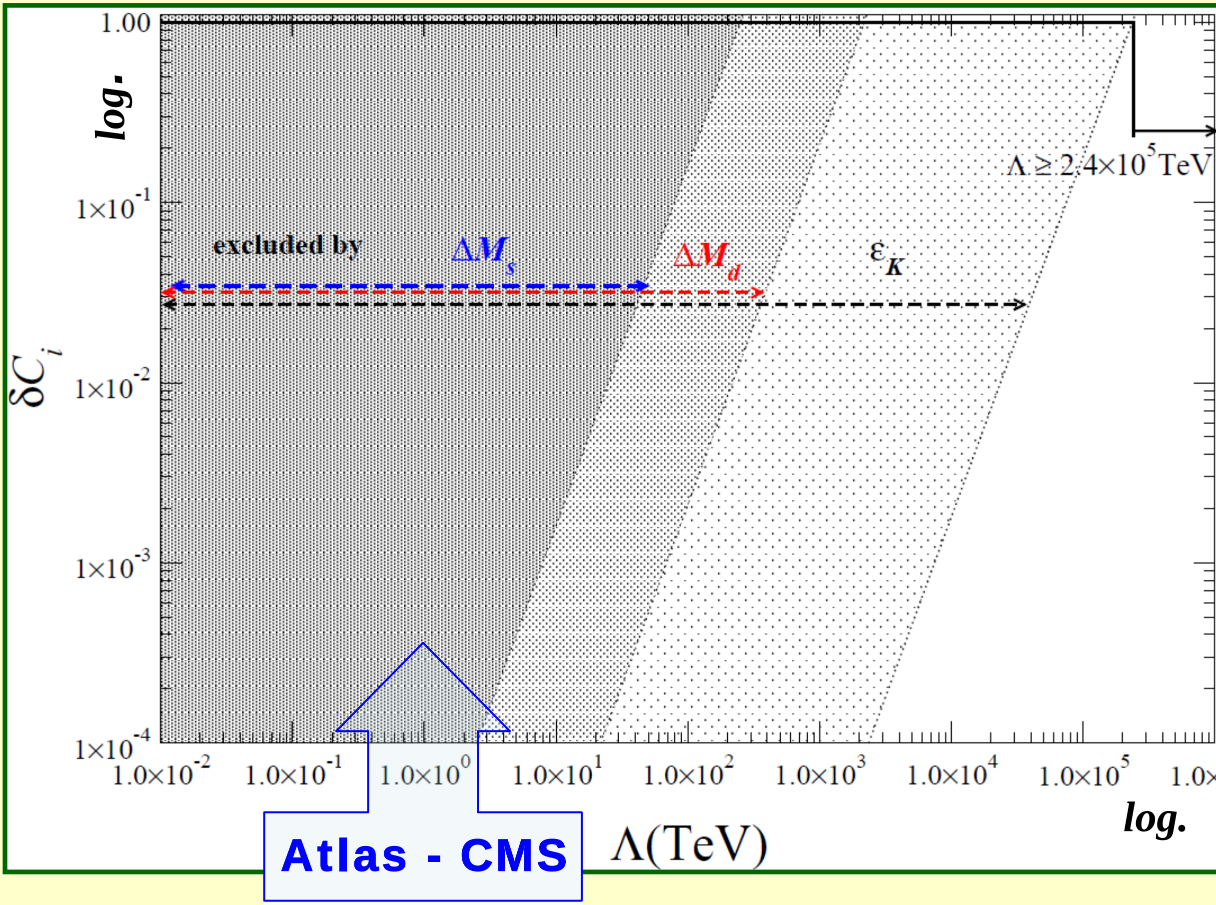
$$\mathcal{L}_{\text{eff}}(\mu \le M_Z) = \mathcal{L}_{\text{SM}}(H, A_i, \psi_i) + \frac{\delta C_i}{\Lambda^2}\mathcal{O}_i^{(6)}$$

BSM *contributions*

➲ *for example,*
for $\Delta F=2$ mixing:

$$\mathcal{O}_4^{(6)} = \bar{s}_R d_L \bar{s}_L d_R$$

$$\mathcal{O}_{SM}^{(6)} = \bar{s}_L \gamma^\mu d_L \bar{s}_L \gamma^\mu d_L \ldots$$



Bounds for generic flavour couplings

➲ $\delta C_i = 1$

s→d: $\Lambda \ge 2.4 \times 10^5$ **TeV** ε_K

b→d: $\Lambda \ge 2.2 \times 10^3$ TeV ΔM_d

b→s: $\Lambda \ge 2.5 \times 10^2$ TeV ΔM_s

values from UTfit 0707.0636

Model-independent Analysis: Flavour Problem

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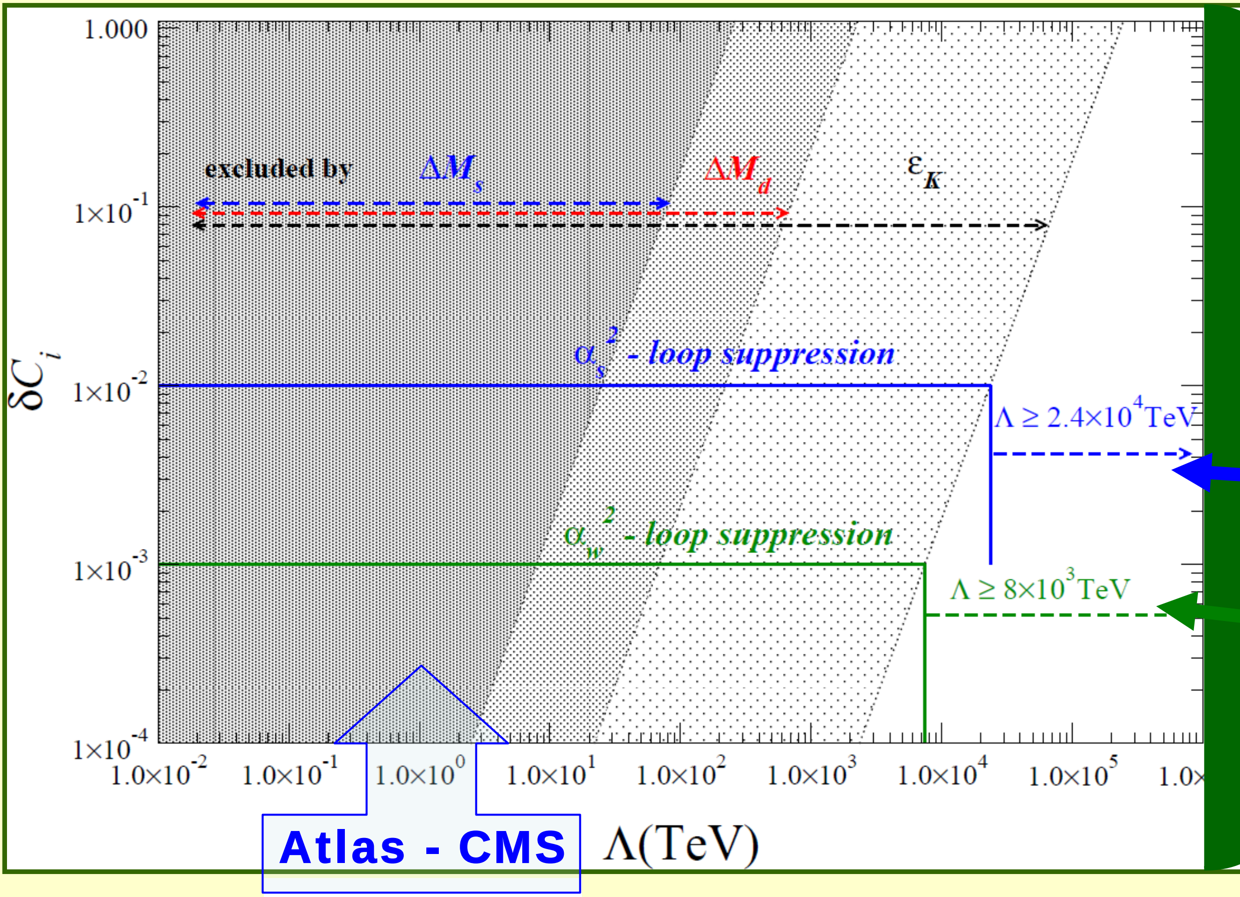


Dynamical hypothesis on δC_i:

➲ $\delta C_i \propto \alpha_S^2$
$\Lambda \ge 2.4 \times 10^4$ **TeV**

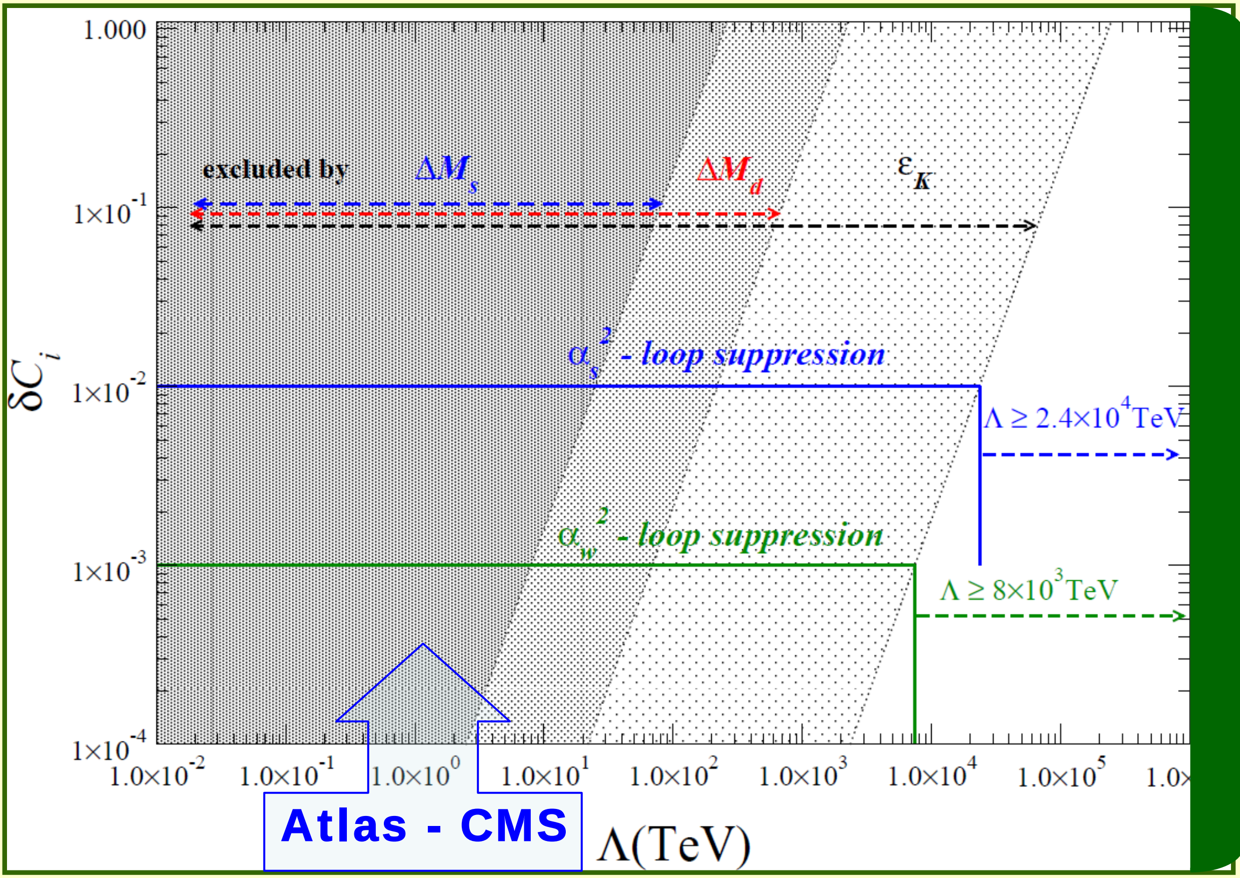
➲ $\delta C_i \propto \alpha_W^2$
$\Lambda \ge 8 \times 10^3$ **TeV**

UTfit 0707.0636

does not help

Model-independent Analysis: Flavour Problem

$$\mathcal{L}_{\rm eff}(\mu \le M_Z) = \mathcal{L}_{\rm SM}(H, A_i, \psi_i) + \frac{\delta C_i}{\Lambda^2}\mathcal{O}_i^{(6)}$$



$\delta C_i = 0$?
too strong restriction!

- at low energy, the minimal amount of flavour violation has been measured

$$Y_D = \hat{m}_D, Y_U = V^{+}_{CKM}\hat{m}_U$$

- RGE potentially $\delta C_i \neq 0$

$$\text{"} g^{FV}_{NP} = g^{FV}_{CKM} \times \log\left(\frac{M_Z}{M_?}\right)\text{"}$$

MFV: δC_i small by symmetry!
accommodates both flavour problem and RGE logs

Minimal Flavour Violation hypothesis:

[$\Lambda \sim O(1\text{TeV})$ + δC_i natural small by additional symmetries]

⬇

The breaking of the flavour symmetry occurs at very high scales and is mediated at low energy only by terms proportional to SM Yukawa couplings preserving the $U(3)^5$ SM Flavour group.

EFT: D'Ambrosio, Giudice, Isidori & Strumia '02

⟶ $\delta C_i \propto (y_t^2 V_{tk}^* V_{tj})^2$ (for FCNC with ext. d-type quark)

- Possibility of building a low-energy EFT: model-independent studies

Recently,

MFV in non-linear r.: Kagan, Perez, Zupan, Volansk '09; CPV: Mercolli & Smith, '09

Perez → this afternoon; Smith → Wed. morning

RGE logs: Paradisi, Ratz, Schieren, Simonetto '08; Colangelo, Nikolidakis, Smith '08;

earlier: Buras, Gambino, Gorbahn, Jager, L. Silvestrini '00
Chivukula & Georgi '86, J.L. Hall & L. Randall '90

Model-independent Analysis: $\Delta F=2$ constraints in MFV

EFT: D'Ambrosio, Giudice, Isidori & Strumia '02

$$\mathcal{L}^{MFV}_{eff} = \sum_i \frac{\delta C_i}{\Lambda^2} \mathcal{O}^{(6)}_i$$

$\mathcal{O}$ basis invariant under $SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R}$

$\mathcal{O}$'s written in terms of $Y_U = 3_{Q_L} \times 3_{U_R}, Y_D = 3_{Q_L} \times 3_{D_R}$

- **Due to the large top Y**, $Y_U Y_U^+ \propto y_t^2 \sim O(1)$

1) $\mathcal{O}^{(6)}_{SM} = \bar{Q}_L Y_U Y_U^+ \gamma^\mu Q_L \cdot \bar{Q}_L Y_U Y_U^+ \gamma^\mu Q_L$

$(V^*_{ts} V_{td})^2 \times \bar{s}_L \gamma^\mu d_L \bar{s}_L \gamma^\mu d_L \rightarrow \varepsilon_K$

$(V^*_{tb} V_{td})^2 \times \bar{b}_L \gamma^\mu d_L \bar{b}_L \gamma^\mu d_L \rightarrow \Delta M_d$

$(V^*_{ts} V_{tb})^2 \times \bar{b}_L \gamma^\mu s_L \bar{b}_L \gamma^\mu s_L \rightarrow \Delta M_s$

1 Higgs doublet, SM basis complete -> CMFV

Buras, Gambino, Gorbahn, Jager, L. Silvestrini '00

- **Adding Higgs doublets**, $Y_D \propto m_b / m_t \frac{\langle H_U \rangle}{\langle H_D \rangle} \sim O(1)$ (tanβ enhancement of down-type YDs)

2) $\left(\bar{Q}_L Y_D Y_D^+ Y_U Y_U^+ \gamma^\mu Q_L\right)^2$

$(V^*_{td} V_{tb})^2\ y_b^2 \times \bar{b}_L \gamma^\mu d_L \bar{b}_L \gamma^\mu d_L \rightarrow \Delta M_d$

$(V^*_{ts} V_{tb})^2\ y_b^2 \times \bar{b}_L \gamma^\mu s_L \bar{b}_L \gamma^\mu s_L \rightarrow \Delta M_s$

3) $\bar{D}_R Y_D^+ Y_U Y_U^+ Q_L \cdot \bar{Q}_L Y_U Y_U^+ Y_D D_R$

$(V^*_{ts} V_{tb})^2\ y_b y_s \times \bar{b}_R s_L \bar{b}_L s_R \rightarrow \Delta M_s$

A few extra $\mathcal{O}^{(6)}$s in a clear pattern between s->d & b->d, b->s transitions

Model-independent Analysis: ΔF=2 constraints in MFV

UTfit 0707.0636

- ***Due to the large top Y***, $Y_U Y_U^+ \propto y_t^2 \sim O(1)$

1) $\mathcal{O}_{SM}^{(6)} = \overline{Q}_L Y_U Y_U^+ \gamma^\mu Q_L \cdot \overline{Q}_L Y_U Y_U^+ \gamma^\mu Q_L$

$\Lambda \geq$ 5.5 TeV ← ε_K, ΔM_d, ΔM_s

$\Lambda \geq$ 0.5 TeV *loop*-suppr.

- ***Adding Higgs doublets***, $Y_D \propto m_b / m_t \frac{\langle H_U \rangle}{\langle H_D \rangle} \sim O(1)$ ***(tanβ enhancement of down-type YDs)***

2) $\left(\overline{Q}_L Y_D Y_D^+ Y_U Y_U^+ \gamma^\mu Q_L\right)^2$

$\Lambda \geq$ 5.1 TeV ← ΔM_d, ΔM_s

3) $\overline{D}_R Y_D^+ Y_U Y_U^+ Q_L \cdot \overline{Q}_L Y_U Y_U^+ Y_D D_R$

$M_H \geq 5.\ \tan\beta/50$ TeV ← ΔM_s

Model-independent Analysis: $\Delta F=2$ constraints in MFV

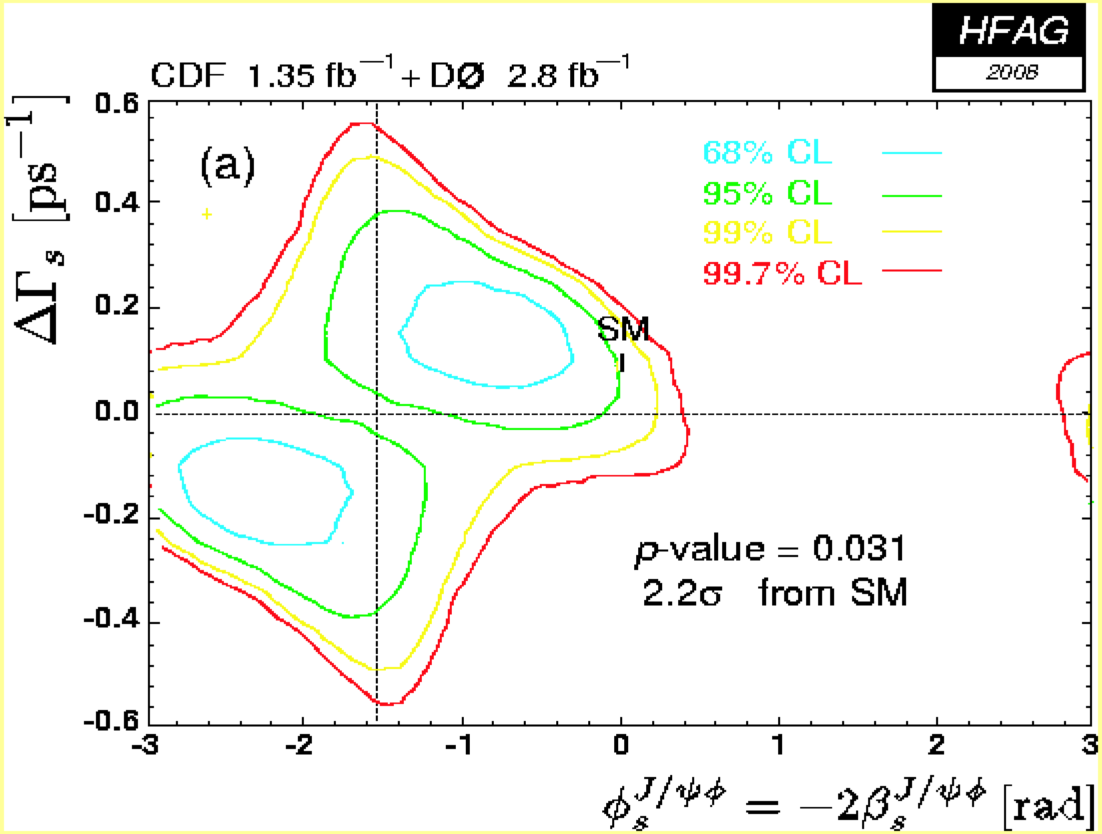
- CPV signals in the B_s sector:

$\beta_s^{MFV} \approx \beta_s^{SM}$

$B_s \to \psi\phi$

t-dependent CP asymmetries

LHCb ***Tevatron***



Key observable to kill MFV
2.2σ deviation!

$\phi_s = -2\beta_s$

UTfit 0803.0659

Model-independent Analysis: ΔF=1 FCNC constraints in MFV

$$\mathcal{L}_{\rm eff}^{\rm MFV} = \sum_i \frac{\delta C_i}{\Lambda^2} \mathcal{O}_i^{(6)}$$

$(\lambda_{FC})_{ij} = (Y_U Y_U^\dagger)_{ij}$

- $\Delta F=1$ Higgs field:

$\mathcal{O}_{H1} = i\left(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L\right) H_U^\dagger D_\mu H_U$, $\mathcal{O}_{H2} = i\left(\bar{Q}_L \lambda_{FC} \tau^a \gamma_\mu Q_L\right) H_U^\dagger \tau^a D_\mu H_U$,

- $\Delta F=1$ gauge field:

$\mathcal{O}_{G1} = H_D\left(\bar{Q}_L \lambda_{FC} \lambda_d \sigma_{\mu\nu} T^a D_R\right)\left(g_s G^a_{\mu\nu}\right)$, $\mathcal{O}_{G2} = \left(\bar{Q}_L \lambda_{FC} \gamma_\mu T^a Q_L\right)\left(g_s D_\mu G^a_{\mu\nu}\right)$

$\mathcal{O}_{F1} = H_D\left(\bar{Q}_L \lambda_{FC} \lambda_d \sigma_{\mu\nu} D_R\right)\left(e F_{\mu\nu}\right)$, $\mathcal{O}_{F2} = \left(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L\right)\left(e D_\mu F_{\mu\nu}\right)$,

- $\Delta F=1$ semileptonic field:

$\mathcal{O}_{\ell 1} = \left(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L\right)\left(\bar{L}_L \gamma_\mu L_L\right)$, $\mathcal{O}_{\ell 2} = \left(\bar{Q}_L \lambda_{FC} \gamma_\mu \tau^a Q_L\right)\left(\bar{L}_L \gamma_\mu \tau^a L_L\right)$

$\mathcal{O}_{\ell 3} = \left(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L\right)\left(\bar{E}_R \gamma_\mu E_R\right)$,

- $\Delta F=1$ scalar density: 2 Higgs doublets

$\mathcal{O}_{S1} = \left(\bar{Q}_L \lambda_{FC} \lambda_d D_R\right)\left(\bar{E}_R \lambda_\ell L_L\right)$

after ewsb

$$Q_7 = \frac{e}{g^2} m_j \, \bar{d}_i \sigma_{\mu\nu} (1+\gamma_5) d_j \, F_{\mu\nu} \, ,$$

$$Q_8 = \frac{g_s}{g^2} m_j \, \bar{d}_i \sigma_{\mu\nu} T^a (1+\gamma_5) d_j \, G^a_{\mu\nu}$$

$$Q_9 = \bar{d}_i \gamma_\mu (1-\gamma_5) d_j \sum_\ell \bar{\ell} \gamma_\mu \ell$$

$$Q_{10} = \bar{d}_i \gamma_\mu (1-\gamma_5) d_j \sum_\ell \bar{\ell} \gamma_\mu \gamma_5 \ell$$

$$Q_{\nu\bar{\nu}} = \bar{d}_i \gamma_\mu (1-\gamma_5) d_j \sum_\nu \bar{\nu} \gamma_\mu (1-\gamma_5) \nu$$

$$Q_S^\ell = \bar{d}_i (1+\gamma_5) d_j \, \bar{\ell} (1-\gamma_5) \ell$$

~ many ΔF=1 operators

$H_U \to H_D$ and/or $\lambda_{FC} \to Y_D Y_D^\dagger \lambda_{FC}$

6 ΔF=1 independent combinations after ewsb:

(as much as available ΔF=1 ''clean'' observables)

Model-independent Analysis: ΔF=1 FCNC constraints in MFV

$Br(B_d \to X_s \gamma)_{E_\gamma > 1.6 \text{ GeV}}$

th (7%): $(3.13 \pm 0.23) \times 10^{-4}$ *NNLO: Misiak et al '06*

exp (7%): $(3.52 \pm 0.24) \times 10^{-4}$ *HFAG*

b→s

s→d

$Br(B_d \to X_s l^+ l^-)$: 3 bins (out of r.)

	exp **(30%):**	***th*** (10-25%):
$[q^2 \in [0.04, 1.0] \text{ GeV}^2]$	$(0.6 \pm 0.5) \times 10^{-6}$	$(0.8 \pm 0.2) \times 10^{-6}$
$[q^2 \in [1.0, 6.0] \text{ GeV}^2]$	$(1.6 \pm 0.5) \times 10^{-6}$	$(1.6 \pm 0.1) \times 10^{-6}$
$[q^2 > 14.4 \text{ GeV}^2]$	$(4.4 \pm 1.3) \times 10^{-7}$	$(2.4 \pm 0.8) \times 10^{-7}$

Babar+Belle *NNLO: Bobeth et al. '01, Asatrian et al., '02*

$$Q_7 = \frac{e}{g^2} m_j \, \bar{d}_i \sigma_{\mu\nu} (1+\gamma_5) d_j \, F_{\mu\nu} \; ,$$

$$Q_8 = \frac{g_s}{g^2} m_j \, \bar{d}_i \sigma_{\mu\nu} T^a (1+\gamma_5) d_j \, G^a_{\mu\nu}$$

$$Q_9 = \bar{d}_i \gamma_\mu (1-\gamma_5) d_j \sum_\ell \bar{\ell} \gamma_\mu \ell$$

$$Q_{10} = \bar{d}_i \gamma_\mu (1-\gamma_5) d_j \sum_\ell \bar{\ell} \gamma_\mu \gamma_5 \ell$$

$$Q_{\nu\bar{\nu}} = \bar{d}_i \gamma_\mu (1-\gamma_5) d_j \sum_\nu \bar{\nu} \gamma_\mu (1-\gamma_5) \nu$$

$$Q^\ell_S = \bar{d}_i (1+\gamma_5) d_j \, \bar{\ell} (1-\gamma_5) \ell$$

$Br(B_s \to \mu^+ \mu^-)$:

th (20%): $(4.1 \pm 0.8) \times 10^{-9}$

Exp: $< 5.8 \times 10^{-8}$ (95% CL) *CDF*

$A_{FB}(B_d \to K^* l^+ l^-)$: 2 bins

	exp **(large):**	*Babar+Belle '09*
$[q^2 < 6.25 \text{ GeV}^2]$	$0.24^{+0.19}_{-0.24}$	-0.01 ± 0.02
$[q^2 > 10.24 \text{ GeV}^2]$	$0.76^{+0.53}_{-0.34}$	0.20 ± 0.08 [[illegible]

6 ΔF=1 independent combinations after ewsb:
(can now be constrained by ΔF=1 observables)

$Br(K^+ \to \pi^+ \nu\nu)$:

BNL $(14.7^{+13.0}_{-8.9}) \times 10^{-11}$ ***th*** (10%):

Model-independent Analysis: ΔF=1 FCNC constraints in MFV

Hurth, Isidori, Kamenik, F.M '08

δC_i ★	95% probability bound	Observables
δC_7	$[-0.14, 0.06] \cup [1.42, 1.62]$	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
δC_9	$[-2.8, 0.8]$	$B \to X_s\ell^+\ell^-$
δC_{10}	$[-0.4, 2.3]$	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$
$\delta C_S^\mu/m_b$	$[-0.09, 0.09]/(4.2\text{GeV})$	$B_s \to \mu^+\mu^-$
$\delta C_{\nu\bar{\nu}}$	$[-6.1, 2.0]$	$K^+ \to \pi^+\nu\bar{\nu}$

★ Mind: CKM couplings factorized out

available range for δCi in MFV =>predictions

$$Q_7 = \frac{e}{g^2} m_j\, \bar{d}_i \sigma_{\mu\nu} (1+\gamma_5)\, d_j\, F_{\mu\nu}\ ,$$

$$Q_8 = \frac{g_s}{g^2} m_j\, \bar{d}_i \sigma_{\mu\nu} T^a (1+\gamma_5)\, d_j\, G^a_{\mu\nu}$$

$$Q_9 = \bar{d}_i \gamma_\mu (1-\gamma_5)\, d_j \sum_\ell\ \bar{\ell}\gamma_\mu \ell$$

$$Q_{10} = \bar{d}_i \gamma_\mu (1-\gamma_5)\, d_j \sum_\ell\ \bar{\ell}\gamma_\mu \gamma_5 \ell$$

$$Q_{\nu\bar{\nu}} = \bar{d}_i \gamma_\mu (1-\gamma_5)\, d_j \sum_\nu\ \bar{\nu}\gamma_\mu (1-\gamma_5)\, \nu$$

$$Q_S^\ell = \bar{d}_i (1+\gamma_5)\, d_j\ \bar{\ell}(1-\gamma_5)\,\ell$$

O(1TeV) scale as much as ΔF=2 constraints

Operator	Λ_i@95%	Observables
$H_D^\dagger (\bar{D}_R \lambda_d \lambda_{FC} \sigma_{\mu\nu} Q_L)(eF_{\mu\nu})$	6.1	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
$H_D^\dagger (\bar{D}_R \lambda_d \lambda_{FC} \sigma_{\mu\nu} T^a Q_L)(g_s G^a_{\mu\nu})$	3.4	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
$(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L)(eD_\mu F_{\mu\nu})$	1.5	$B \to X_s\ell^+\ell^-$
$i(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L) H_U^\dagger D_\mu H_U$	1.1[a]	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$
$i(\bar{Q}_L \lambda_{FC} \tau^a \gamma_\mu Q_L) H_U^\dagger \tau^a D_\mu H_U$	1.1[a]	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$
$(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L)(\bar{L}_L \gamma_\mu L_L)$	1.7	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$
$(\bar{Q}_L \lambda_{FC} \gamma_\mu \tau^a Q_L)(\bar{L}_L \gamma_\mu \tau^a L_L)$	1.7	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$
$(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L)(\bar{E}_R \gamma_\mu E_R)$	2.7	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$

for CMFV: Bobeth, Bona, Buras, Ewerth, Pierini, Silvestrini Weiler '05

Model-independent Analysis: ΔF=1 FCNC constraints in MFV

Hurth, Isidori, Kamenik, F.M '08

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δC_{10}	$[-0.4, 2.3]$	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$
$\delta C_S^{\mu}/m_b$	$[-0.09, 0.09]/(4.2\mathrm{GeV})$	$B_s \to \mu^+\mu^-$
$\delta C_{\nu\bar{\nu}}$	$[-6.1, 2.0]$	$K^+ \to \pi^+\nu\bar{\nu}$

available range for δCi in MFV =>predictions

1)Predictions in MFV: way to test and falsify MFV

Observable	Experiment	MFV bound	SM prediction
$R^{(\mu/e)}(B \to K\ell^+\ell^-) - 1$	0.17 ± 0.28	$[-0.004, 0.14]$	$O(10^{-4})$ [64]
$R^{(\mu/e)}(B \to K^*\ell^+\ell^-) - 1$	$0.37^{+0.53}_{-0.40} \pm 0.09$	$[-0.002, 0.01]$	$\lesssim 10^{-2}$
$\mathcal{B}(B_d \to \mu^+\mu^-)$	$< 1.8 \times 10^{-8}$ ★	$< 1.2 \times 10^{-9}$	$1.3(3) \times 10^{-10}$
$\mathcal{B}(B \to X_s\tau^+\tau^-)$	– ★	$< 5 \times 10^{-7}$	$1.6(5) \times 10^{-7}$
$\mathcal{B}(B \to K\nu\bar{\nu})$	★	$< 0.4 \times 10^{-4}$	$(0.5 \pm 0.1) \times 10^{-5}$
$\mathcal{B}(B \to K^*\nu\bar{\nu})$	★	$< 9.4 \times 10^{-5}$	$(0.68 \pm 0.10) \times 10^{-5}$
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})$	★	$< 2.9 \times 10^{-10}$	$2.9(5) \times 10^{-11}$

★ room for NP contributions

for B->K(*)νν, recently
Altmannshofer, Buras, Straub Wick '09

Model-independent Analysis: $\Delta F=1$ FCNC constraints in MFV

Hurth, Isidori, Kamenik, F.M '08

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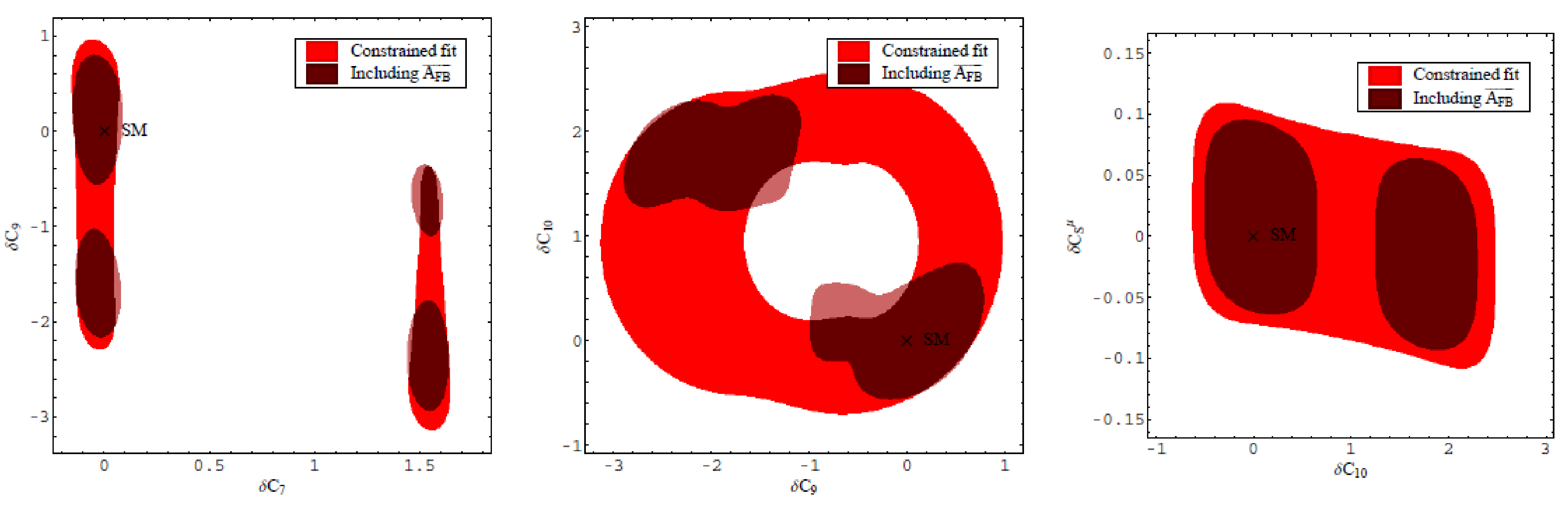
available range for δC_i in MFV => predictions



$A_{FB}(B_d \to K^* l^+ l^-)$, plays a special role: large exp err. but sensitive to independent δC_i

Model-independent Analysis: ΔF=1 FCNC constraints in MFV

Hurth, Isidori, Kamenik, F.M '08

δC_i	95% probability bound	Observables
δC_7	$[-0.14, 0.06] \cup [1.42, 1.62]$	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
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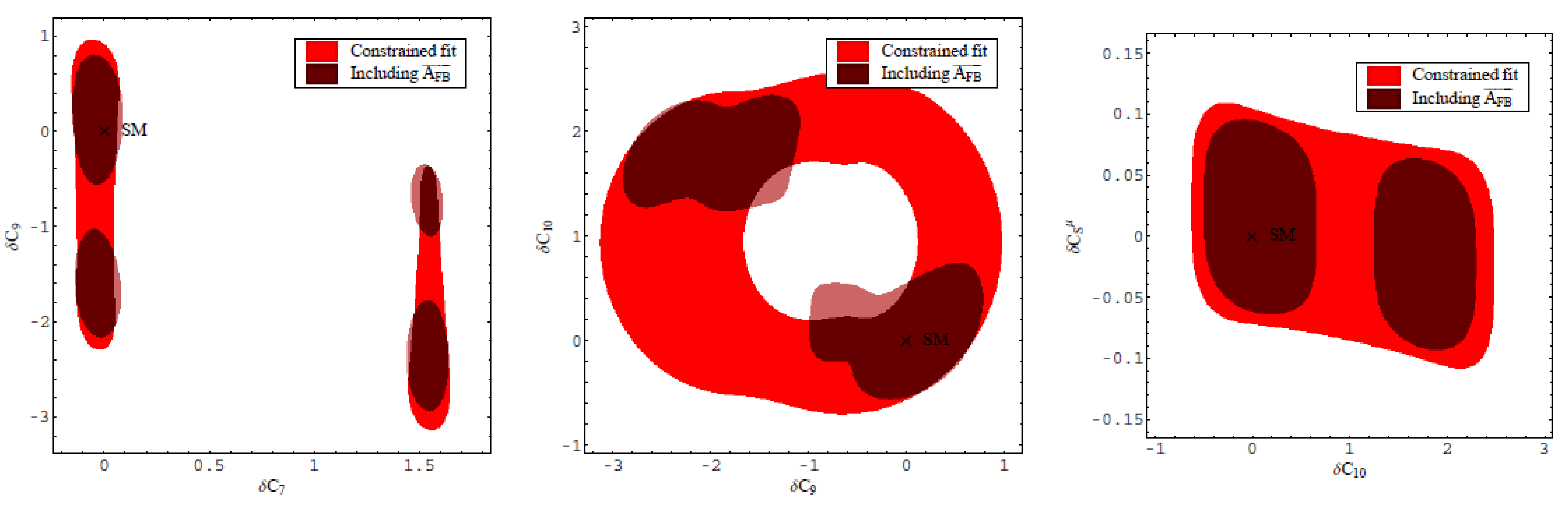
available range for δCi in MFV =>predictions



$B_d \to K^* l^+ l^-$: in future, full angular analysis gives access to other th. clean obs: LHCb, SFF

recent refs: Egede et al. '08, Altmannshofer et al. '08

Model-independent Analysis: ΔF=1 FCNC constraints in MFV

Hurth, Isidori, Kamenik, F.M '08

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$\delta C_{\nu\bar{\nu}}$	$[-6.1, 2.0]$	$K^+ \to \pi^+\nu\bar{\nu}$

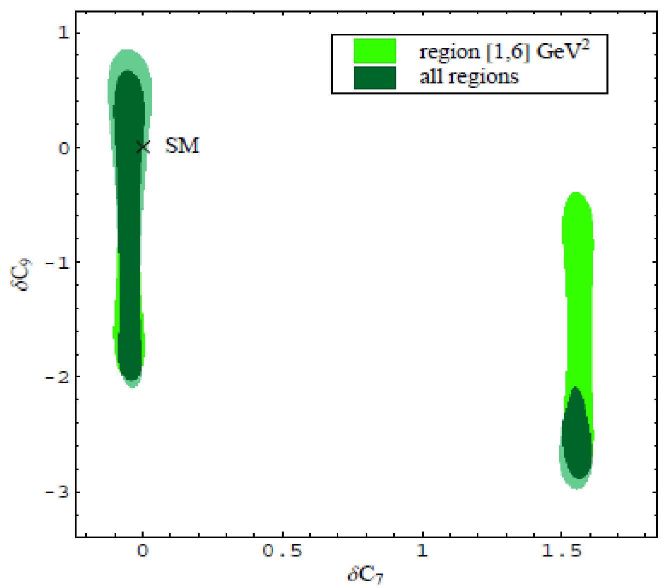
available range for δCi in MFV
=>predictions

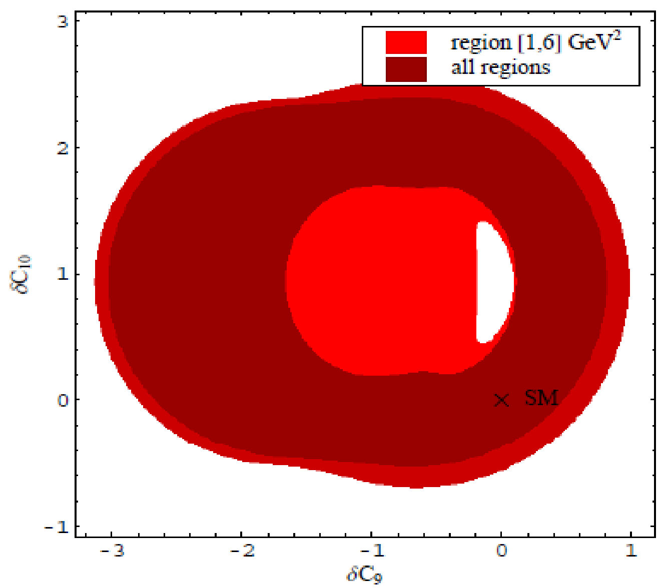
$B_d \to X_s l^+l^-$: *interesting information from low and high q^2 bin*

$[q^2 \in [0.04, 1.0]\ \text{GeV}^2]$

$[q^2 \in [1.0, 6.0]\ \text{GeV}^2]$

$[q^2 > 14.4\ \text{GeV}^2]$





Model-independent Analysis: ΔF=1 FCNC constraints in MFV

δC_i	95% probability bound	Observables
δC_7	$[-0.14, 0.06] \cup [1.42, 1.62]$	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
δC_9	$[-2.8, 0.8]$	$B \to X_s\ell^+\ell^-$
δC_{10}	$[-0.4, 2.3]$	$B \to X_s\ell^+\ell^-$, $B_s \to \mu^+\mu^-$
$\delta C_S^\mu/m_b$	$[-0.09, 0.09]/(4.2\mathrm{GeV})$	$B_s \to \mu^+\mu^-$
$\delta C_{\nu\bar\nu}$	$[-6.1, 2.0]$	$K^+ \to \pi^+\nu\bar\nu$

available range for δCi in MFV =>predictions

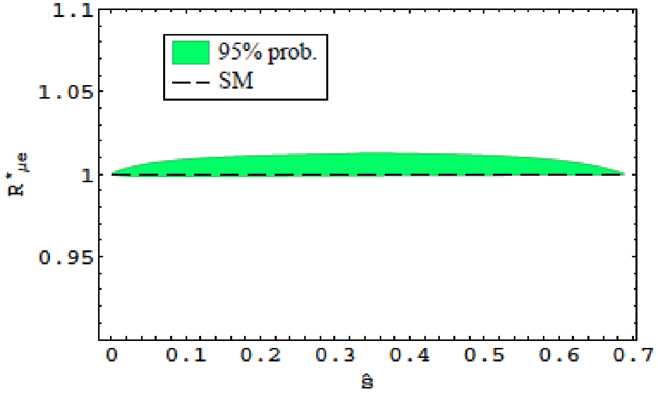
2)Predictions in MFV: way to test and falsify MFV

- Predictive relations between observables linked by CKM factors

$$\frac{\Gamma(B_s \to \ell^+\ell^-)}{\Gamma(B_d \to \ell^+\ell^-)} \approx \frac{f_{B_s} m_{B_s}}{f_{B_d} m_{B_d}} \left|\frac{V_{ts}}{V_{td}}\right|^2 .$$

valid at both small and large $\tan\beta$!

- $R_{K^*} \equiv \Gamma(B \to K^*\mu^+\mu^-)/\Gamma(B \to K^*e^+e^-)$ close to SM values even at large $\tan\beta$



Hurth,Isidori,Kamenik, F.M '08

Hiller & Kruger '03

Model-independent Analysis: $\Delta F=1$ FCNC constraints in MFV

δC_i	95% probability bound	Observables
δC_7	$[-0.14, 0.06] \cup [1.42, 1.62]$	$B \to X_s\gamma$, $B \to X_s\ell^+\ell^-$
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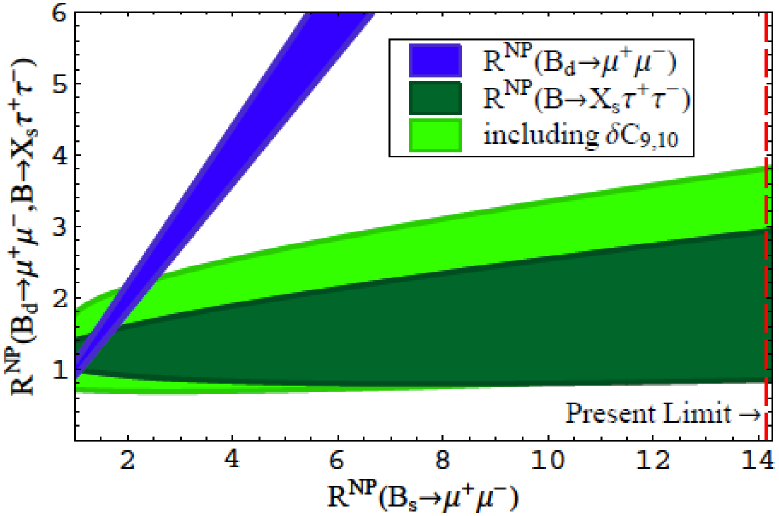
$\delta C_S^\mu/m_b$	$[-0.09, 0.09]/(4.2\mathrm{GeV})$	$B_s \to \mu^+\mu^-$
$\delta C_{\nu\bar{\nu}}$	$[-6.1, 2.0]$	$K^+ \to \pi^+\nu\bar{\nu}$

available range for δC_i in MFV =>predictions

3)Predictions in MFV: way to test and falsify MFV

- $B \to X_s\tau^+\tau^-$ - room for density operator contributions: m_τ/m_μ relative enhancement - (SM $\times 3$ contributions to Br still allowed)



tanβ enhancement at work

Hurth, Isidori, Kamenik, F.M '08

Model-independent Analysis: Flavour Changing Neutral Current constraints in MFV

- Bounds can be set on the complete set of MFV contributions at both small and large $\tan\beta$ → *extra operators*

- Bounds on NP contributions from $\Delta F=2$ obs very constraining

$$\Lambda \geq 5 \text{ TeV}$$

- in $\Delta F=1$ processes,
  - mainly $\delta C_{7\gamma}$ very constraining
  - not all ambiguities can be resolved

$$\Lambda \geq 6 \text{ TeV}$$

Tree level NP d.o.f: $\Lambda \geq 6$ TeV

Loop-suppressed NP d.o.f: $\Lambda \geq 0.6$ TeV

$\Delta F=1$ Charged Current Processes: H^+ bounds

$$\mathcal{L}_{eff}^{CC} = \frac{4G_F}{\sqrt{2}} V_{qb} \sum_{\substack{\ell=e,\mu,\tau \\ U=u,c}} \left(\overline{U}\gamma_L^{\mu} b \overline{\ell}_L \gamma_L^{\mu} \nu_L + C_{NP}^{\ell} \overline{U}_L b_R \overline{\ell}_R \nu_L \right)$$

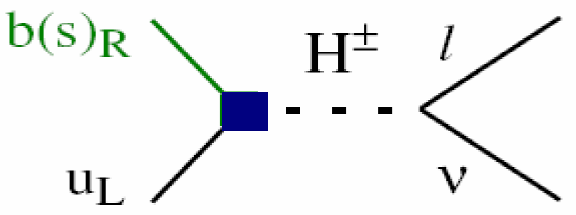
In MFV

$$C_{NP}^{\tau} = -\frac{m_b m_\tau}{M_{H^+}^2} \frac{\tan^2\beta}{1+\varepsilon_0 \tan\beta}$$

- *$\tan\beta$ enhancement of down-type Ys: competitive to $W^{\pm}_{||}$ tree-level exchange*
- *the sign of C_{NP}^{ℓ} fixed in MFV: destructive interference with SM*
- *$\varepsilon_0 \tan\beta$ resumes $U(1)_{PQ}$ breaking corrections*

=> 2HDM -> $\varepsilon_0 \sim 0.00$ and SUSY-> $\varepsilon_0 \sim 0.01 x f(M_{Susy})$

Tree-level H+ exchange



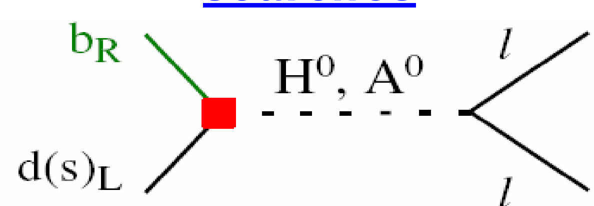
CC

$B^{\pm} \to \tau^{\pm} \nu$

$B^{\pm} \to D \tau^{\pm} \nu$

$(K^{\pm} \to \mu^{\pm} \nu)$

Complementary to H^0 searches



FCNC $B_{s,d} \to l^+ l^-$

$\Delta F=1$ Charged Current Processes: H^+ bounds

$$C^{\tau}_{NP} = -\frac{m_b m_\tau}{M^2_{H^+}} \frac{\tan^2\beta}{1+\varepsilon_0 \tan\beta} \quad \text{(MFV)}$$

$B^\pm \to \tau^\pm \nu$

$$Br(B\to\tau\nu) \propto |V_{ub}|^2 f_B^2 m_B m_\tau^2 \times \left(1+\frac{m_B^2}{m_B m_\tau} C^\tau_{NP}\right)^2$$

1. *helicity suppressed in the SM, m_τ*
2. *hadronic uncertainty in f_B:*
   ~20% accuracy from Lattice
   (use $\Delta m_d \propto f_B^2$ for Δm_d NP free, like in MFV-MSSM)

$Br=(1.41 \pm 0.43)\times 10^{-4}$ [Belle-Babar]

Best for indirect H^+ searches but only feasible at •SuperB

Isidori & Paradisi '06;
earlier: Hou '93;Akeroyd & Recksiegel '03

$B^\pm \to D\,\tau^\pm \nu$

$$\frac{d\Gamma(B\to D\tau\nu)}{dq^2} \propto |V_{cb}|^2 \rho_V(q^2) \times \left(1-\frac{m_\tau^2}{m_B^2}\left|1+\frac{t(w)}{(m_b-m_c)m_\tau}C^\tau_{NP}\right|^2 \rho_S(q^2)\right)$$

1. ρ_V : vector component (~0.5 Br)→ $W^\pm$
   =>from exp. $B\to De\nu$ spectrum & Lattice
2. ρ_S : scalar component (~0.5 Br)→ $W^\pm$, $H^\pm$
   => helicity suppressed m_τ

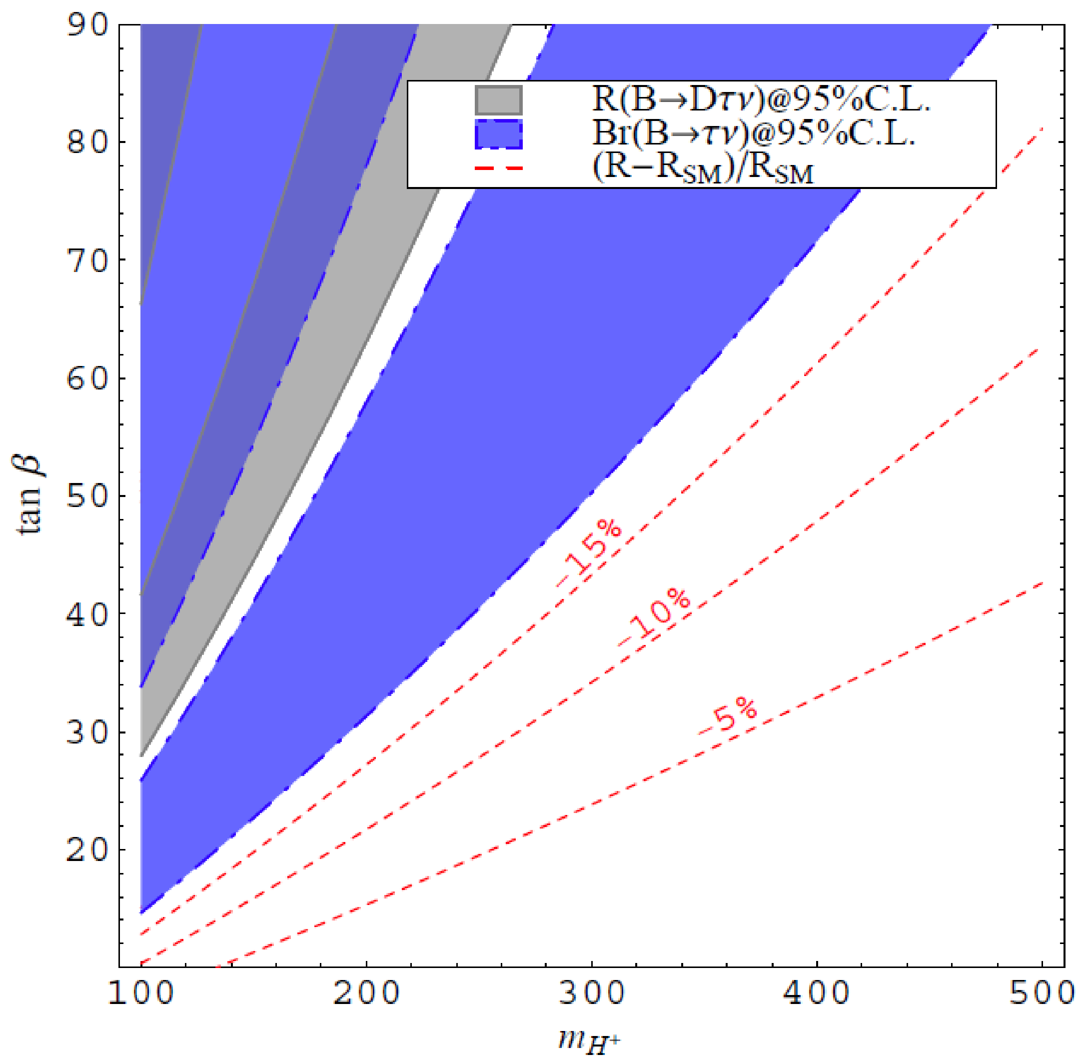
$Br=(0.86 \pm 0.30)\times 10^{-2}$ [Babar]

Only scalar component sensitivity to H^+ but opportunity for Lhcb

Kamenik & F.M '08:Nierste, Trine, Westhoff'08, Trine ICHEP08. earlier: Hou '93;Kiers&Soni '97

$\Delta F=1$ Charged Current Processes: H^+ bounds

$$C^{\tau}_{NP} = -\frac{m_b m_\tau}{M^2_{H^+}} \frac{\tan^2\beta}{1+\varepsilon_0 \tan\beta} \quad \text{(MFV)}$$



To reduce hadronic uncertainty it is useful to consider the ratio ***$R = Br(B\to D\tau\nu)/Br(B\to De\nu)$***

in the SM, uncertainty of $Br(B\to D\tau\nu)/Br(B\to De\nu) \sim 6\%$

H^+ bounds with *$R(B\to D\tau\nu)$:*
not as sensitive as $Br(B\to\tau\nu)$, but competitive thanks different exp. & theory prospects

Kamenik & F.M '08:
Nierste, Trine, Westhoff '08

updates on, Trine ICHEP'08

Conclusions:

The MFV allows us for a bottom -> up approach:

- *testable and model-independent predictions*

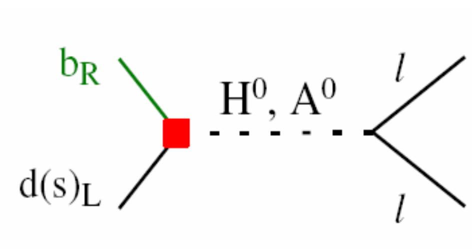
① $\beta_s^{MFV} \approx \beta_s^{SM}$

② $$\frac{\Gamma(B_s \to \ell^+\ell^-)}{\Gamma(B_d \to \ell^+\ell^-)} \approx \frac{f_{B_s} m_{B_s}}{f_{B_d} m_{B_d}} \left|\frac{V_{ts}}{V_{td}}\right|^2$$

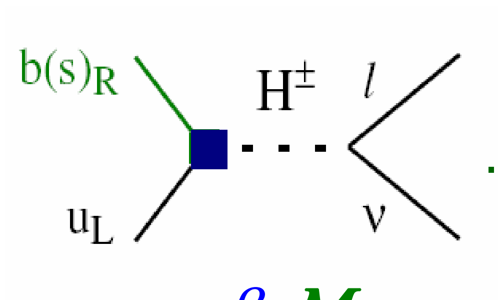
- *powerful tool to analyse future precise data on Flavour Physics*

- *with the flavour constraints embedded in MFV, the residual info directly points to Atlas-CMS searches (**masses and FC couplings**):*

interplay ⇒ $\Lambda \geq$ 6 TeV,



tanβ, M_A ,

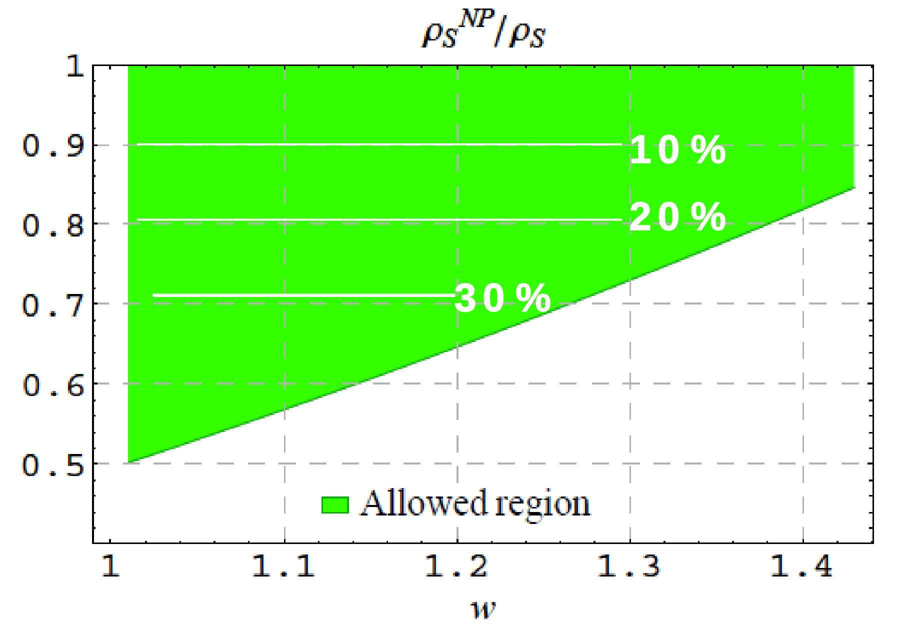


tanβ, M_{H^+} .

ΔF=1 Charged Current Processes: H^+ bounds

$$C_{NP}^{\tau} = -\frac{m_b m_\tau}{M_{H^+}^2}\frac{\tan^2\beta}{1+\varepsilon_0\tan\beta} \quad \text{(MFV)}$$

$$\rho_S^{NP}(w) = \left|1 + \frac{t(w)}{(m_b - m_c)m_\tau} C_{NP}^{\tau}\right|^2 \rho_S(w),$$



$B^{\pm} \to D\,\tau^{\pm}\,\nu$

$$\frac{d\Gamma(B\to D\tau\nu)}{dw} \propto |V_{cb}|^2 \rho_V(w) \times \left(1 - \frac{m_\tau^2}{m_B^2}\left|1 + \frac{t(w)}{(m_b - m_c)m_\tau} C_{NP}^{\tau}\right|^2 \rho_S(w)\right)$$

2. ρ_S : scalar component (~0.5 Br)→ $W^{\pm}$, $H^{\pm}$

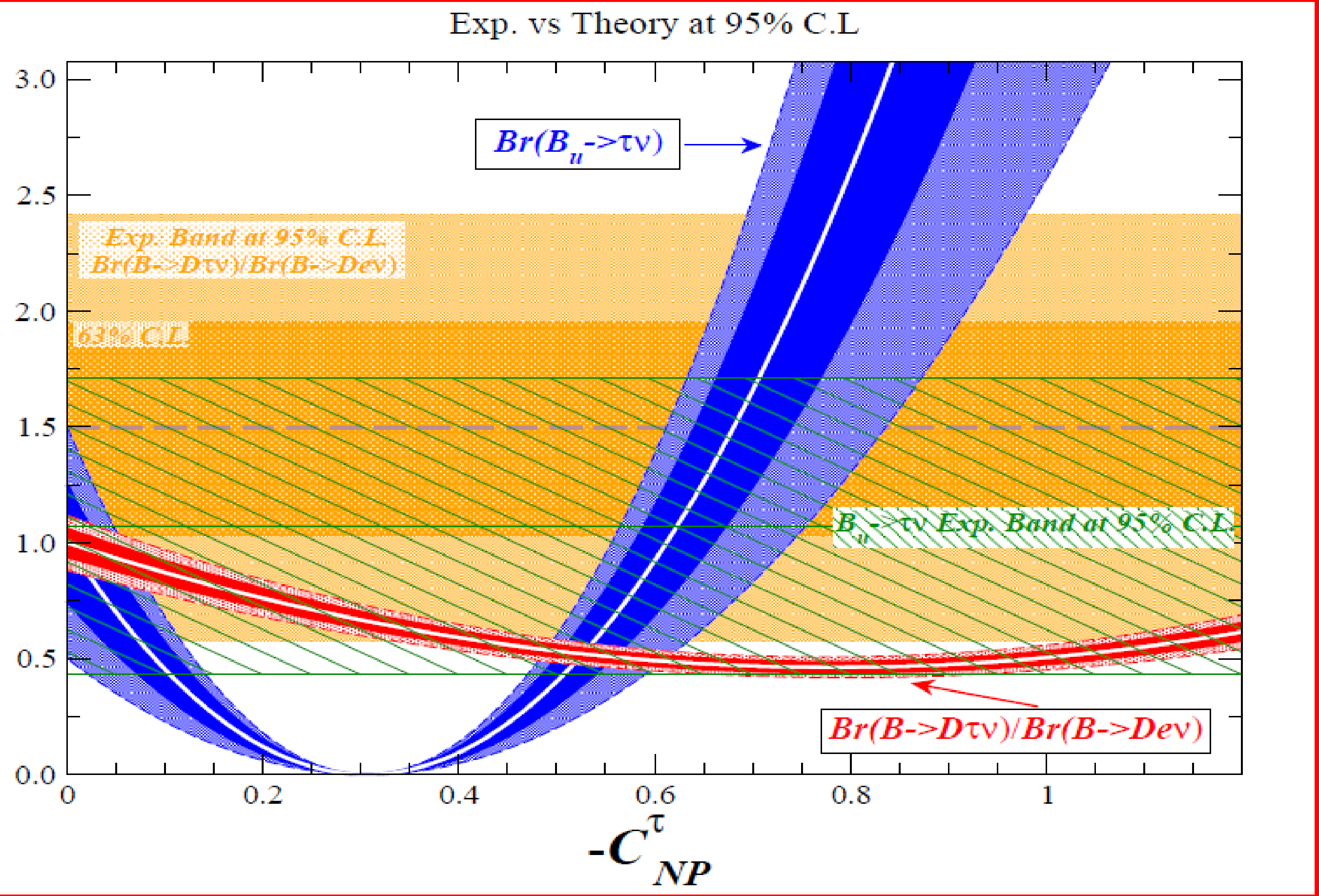
=> *elicity suppresses* m_τ

$\Delta F=1$ Charged Current Processes: H^+ bounds

$$C^{\tau}_{NP} = -\frac{m_b m_\tau}{M^2_{H^+}} \frac{\tan^2\beta}{1+\varepsilon_0 \tan\beta} \quad \text{(MFV)}$$

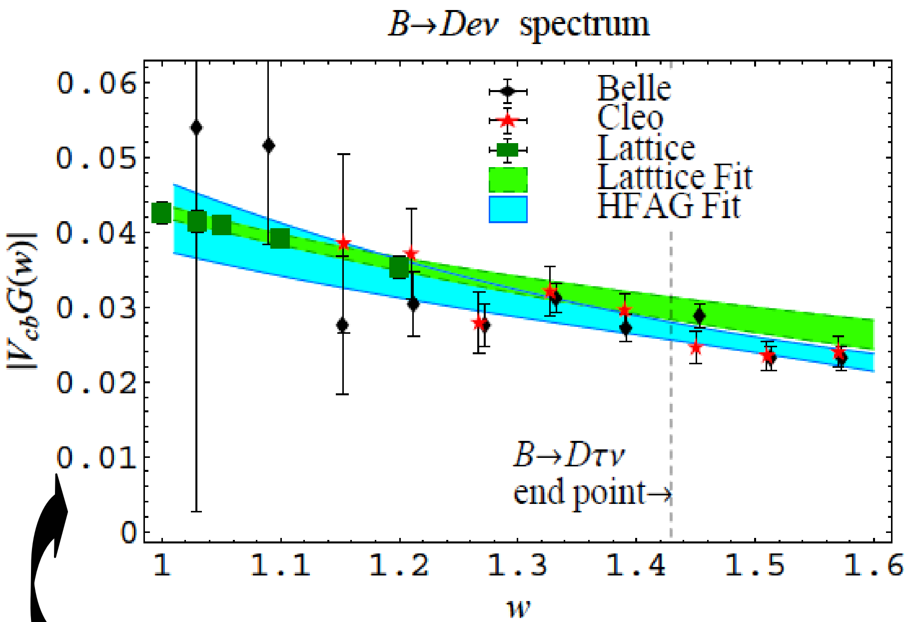
$B^{\pm} \to \tau^{\pm} \nu$

$B^{\pm} \to D\, \tau^{\pm} \nu$



ΔF=1 Charged Current Processes: H^+ bounds

HFAG'08:
De Divitiis, Petronzio and Tantalo '07'08



$B^\pm \to D\ \tau^\pm\ \nu$

$$\frac{d\Gamma(B\to D\tau\nu)}{dw} \propto |V_{cb}|^2\, \rho_V(w) \times \left(1-\frac{m_\tau^2}{m_B^2}\left|1+\frac{t(w)}{(m_b-m_c)m_\tau}C_{NP}^{\tau}\right|^2 \rho_S(w)\right)$$

1. ρ_V **:** vector component (~0.5 Br)→ $W^\pm$

ρ_V **:**

- under control by the exp. B→Deν spectrum &/or Lattice: ~5%
  -> can be improved by Belle!
- *partially cancels in the ratio* ***B→Dτν/B→Deν***

ρ_S **:** *from Lattice => ratio of ffs and symmetry at work*

Kamenik & F.M '08:Nierste, Trine, Westhoff '08