Strong (light) Higgs dynamics with MFV

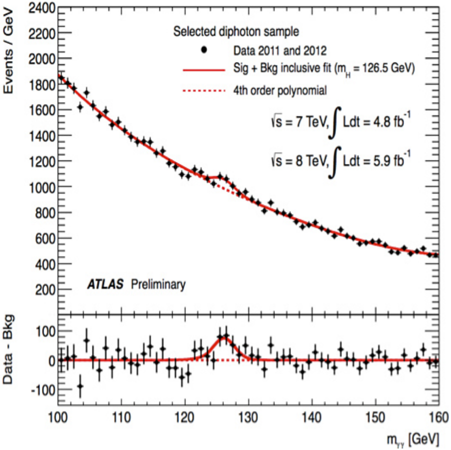
Juan Yepes

WHAT IS ν?-GGI Workshop-2012, Florence

Alonso, Gavela, Merlo, Rigolin & JY, JHEP 1206 (2012) 076,hep-ph/**1201.1511**

July 10, 2012

ATLAS

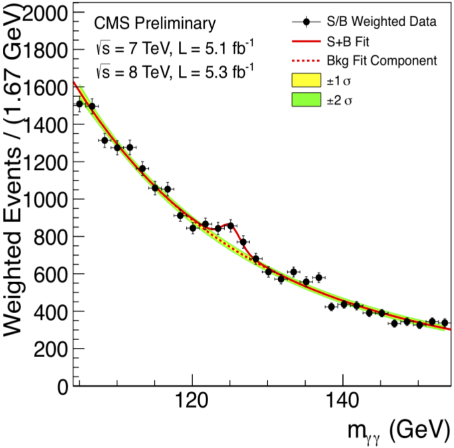


$123 < m_H(\text{GeV}) < 130$

Not excluded
$123 < m_H(\text{GeV}) < 130$ @ 95% C.L.

Excess $\sim$ 126.5 GeV @ 5σ

CMS



$122.5 < m_H(\text{GeV}) < 127$

Excluded
$110 < m_H(\text{GeV}) < 122.5$
and $127 < m_H(\text{GeV}) < 600$
with 95% C.L.

Excess $\sim$ 125 GeV @ 4.1σ
4.9σ from
$\gamma\gamma + WW + ZZ + \text{bb} + \tau\tau$

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Global

$$SU(2)_L \times SU(2)_R \rightarrow \mathbf{U} \sim (2,2)$$

Local

$$SU(2)_L \times U(1)_Y \rightarrow L(x)\,\mathbf{U}(x)\,R^\dagger(x),$$

$$L(x) = e^{i\vec{\epsilon}_L(x)\cdot\vec{\tau}/2}, \quad R(x) = e^{i\epsilon_Y(x)\tau_3/2}$$

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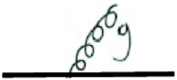
Covariant derivative

$$\mathcal{D}_\mu \mathbf{U} \equiv \partial_\mu \mathbf{U} + \frac{ig}{2}\tau_i W_\mu^i \mathbf{U} - \frac{ig'}{2}\mathbf{U}\tau_3 B_\mu .$$

What changes if the Higgs has strong interacting dynamics?

As in strongly interacting QCD $\alpha_s \sim 1 \Rightarrow$ unsuppressed multiple gluon emission



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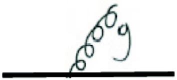
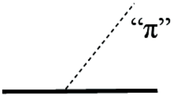


Strongly interacting Higgs $\lambda \sim 1 \Rightarrow$ unsuppressed longitudinal $W - Z$ components emission



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Building blocks: $\mathbf{U},\ \mathcal{D}_\mu \mathbf{U},\ \mathbf{T} = \mathbf{U}\tau_3\mathbf{U}^\dagger,\ \mathbf{V}_\mu = (\mathcal{D}_\mu \mathbf{U})\mathbf{U}^\dagger$

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Tower of operators contain, e.g.,

$$\frac{v^2}{4}\mathrm{Tr}[\mathbf{V}^\mu \mathbf{V}_\mu] \ldots$$

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Giudice, Grojean, Pomarol & Rattazzi '07

$$\Rightarrow \quad a_i \mathcal{O}_i \left[\rho + a \frac{h}{f} + b \frac{h^2}{f^2} + ... \right], \quad \rho = \frac{v}{f}$$

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We focus on the 1st term for $v \approx f$.
Now go to FLAVOR $\Rightarrow$

MINIMAL FLAVOR VIOLATION (MFV)

Ansatz: Yukawa couplings are the unique sources for flavor effects at low energy in SM and beyond. Chivukula & Georgi '87.

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$\overset{\text{recovering } \mathcal{G}_f}{\Longrightarrow}$ $\quad Y_U \sim (3, \overline{3}, 1) \qquad \& \qquad Y_D \sim (3, 1, \overline{3})$

$$\mathcal{L} = \mathcal{L}_{SM} + a_i \, \frac{\mathcal{O}_i^{d=6}}{\Lambda_f^2} + \ldots$$

$$O^{d=6} \sim c_{\alpha\beta} \, \bar{\psi}_\alpha \gamma^\mu \psi_\beta \left(\Phi^\dagger \mathcal{D}_\mu \Phi\right), \; c_{\alpha\beta} \, c_{\gamma\delta} \, \bar{\psi}_\alpha \psi_\beta \bar{\psi}_\gamma \psi_\delta$$

$c \sim YY^\dagger$, D'Ambrosio, Giudice, Isidori & Strumia '02

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Minimally flavour violating dimension six operator	main observables	Λ_f [TeV] $-$	$+$	
$\mathcal{O}_0 = \frac{1}{2}(\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L)^2$	ϵ_K, Δm_{B_d}	6.4	5.0	
$\mathcal{O}_{F1} = H^\dagger \left(\bar{D}_R \lambda_d \lambda_{FC} \sigma_{\mu\nu} Q_L\right) F_{\mu\nu}$	$B \to X_s \gamma$	9.3	12.4	
$\mathcal{O}_{G1} = H^\dagger \left(\bar{D}_R \lambda_d \lambda_{FC} \sigma_{\mu\nu} T^a Q_L\right) G^a_{\mu\nu}$	$B \to X_s \gamma$	2.6	3.5	
$\mathcal{O}_{\ell 1} = (\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L)(\bar{L}_L \gamma_\mu L_L)$	$B \to (X)\ell\bar{\ell}$, $K \to \pi\nu\bar{\nu}, (\pi)\ell\bar{\ell}$	3.1	2.7	*
$\mathcal{O}_{\ell 2} = (\bar{Q}_L \lambda_{FC} \gamma_\mu \tau^a Q_L)(\bar{L}_L \gamma_\mu \tau^a L_L)$	$B \to (X)\ell\bar{\ell}$, $K \to \pi\nu\bar{\nu}, (\pi)\ell\bar{\ell}$	3.4	3.0	*
$\mathcal{O}_{H1} = (\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L)(H^\dagger i D_\mu H)$	$B \to (X)\ell\bar{\ell}$, $K \to \pi\nu\bar{\nu}, (\pi)\ell\bar{\ell}$	1.6	1.6	*
$\mathcal{O}_{q5} = (\bar{Q}_L \lambda_{FC} \gamma_\mu Q_L)(\bar{D}_R \gamma_\mu D_R)$	$B \to K\pi$, $\epsilon'/\epsilon, \ldots$	~ 1		

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$$\Rightarrow \quad \Lambda_f \sim \text{TeV}$$

STRONG HIGGS DYNAMICS + MINIMAL FLAVOR VIOLATION

Non-linear expansion @ $d_\chi = 4$

$$\mathcal{O}_1 \sim \bar{\psi}_\alpha \gamma^\mu \left\{ \mathbf{U}\tau_3\mathbf{U}^\dagger, (\mathcal{D}_\mu \mathbf{U})\mathbf{U}^\dagger \right\} \psi_\beta, \qquad \mathcal{O}_2 \sim \bar{\psi}_\alpha \gamma^\mu (\mathcal{D}_\mu \mathbf{U})\mathbf{U}^\dagger \psi_\beta$$

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Linear expansion

$$\begin{aligned}
\mathcal{O}_{H1} &\sim i\left(\bar{\psi}_\alpha \gamma^\mu \psi_\beta\right)\left(\Phi^\dagger (D_\mu \Phi) - (D_\mu \Phi)^\dagger \Phi\right), \\
\mathcal{O}_{H2} &\sim i\left(\bar{\psi}_\alpha \gamma^\mu \tau^i \psi_\beta\right)\left(\Phi^\dagger \tau_i (D_\mu \Phi) - (D_\mu \Phi)^\dagger \tau_i \Phi\right), \\
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\mathcal{O}_{H4} &\sim i\epsilon^{ijk}\left(\bar{\psi}_\alpha \gamma^\mu \tau_i \psi_\beta\right)\left(\Phi^\dagger \tau_j \Phi\right)\left(\Phi^\dagger \tau_k (D_\mu \Phi) - (D_\mu \Phi)^\dagger \tau_k \Phi\right).
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$\mathcal{O}_4$ is a CP-ODD op.! $\rightarrow$ Natural $\not{CP}$ @ LO!!

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$$\delta\mathcal{L}_{d_\chi=4} = -\frac{g}{\sqrt{2}}\left[W^{\mu+}\bar{U}_L\gamma_\mu(a_W + i\,a_{CP})\left(\mathbf{y}_U^2 V + V\mathbf{y}_D^2\right)D_L + h.c.\right] +$$
$$-\frac{g}{2c_W}Z^\mu\left[a_Z^u\bar{U}_L\gamma_\mu\left(\mathbf{y}_U^2 + V\mathbf{y}_D^2 V^\dagger\right)U_L + a_Z^d\bar{D}_L\gamma_\mu\left(\mathbf{y}_D^2 + V^\dagger\mathbf{y}_U^2 V\right)D_L\right]$$

$$a_Z^u \equiv a_1 + a_2 + a_3\,, \qquad a_Z^d \equiv a_1 - a_2 - a_3\,,$$
$$a_W \equiv a_2 - a_3\,, \qquad a_{CP} \equiv -a_4\,.$$

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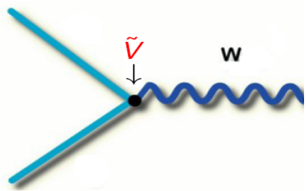
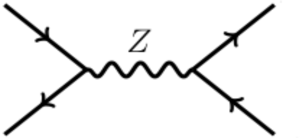


$$\tilde{V}_{ij} = V_{ij}\left[1 + (a_W + i a_{CP})(y_{u_i}^2 + y_{d_j}^2)\right]$$

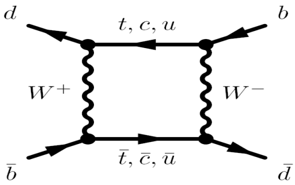
$\Rightarrow$ Impacts on $\Delta F = 1$ & $\Delta F = 2$ observables...

$\Delta F = 1$



Wilson coefficient modification $\Rightarrow \mathcal{Q}_{\bar{\nu}\nu}, \mathcal{Q}_{9V}, \mathcal{Q}_7 \ldots$

$\Delta F = 2$



Modifications on $\Rightarrow M_{12}^K, \varepsilon_K, M_{12}^{d,s}, A_{sl}^b$

$\Delta F = 1$ observables

$$\frac{G_F \alpha}{2\sqrt{2}\pi s_W^2} V_{ti}^* V_{tj} \sum_n C_n \mathcal{Q}_n + \text{h.c.}\,,,$$

$\Delta F = 1$ observables

$\frac{G_F \alpha}{2\sqrt{2}\pi s_W^2} V_{ti}^* V_{tj} \sum_n C_n \mathcal{Q}_n + \text{h.c.}\,,,$ C_n

$\Delta F = 1$ observables

$$\frac{G_F \alpha}{2\sqrt{2}\pi s_W^2} V_{ti}^* V_{tj} \sum_n C_n \mathcal{Q}_n + \text{h.c.}\,,, \qquad\qquad C_n = C_n^{SM}$$

$\Delta F = 1$ observables

$$\frac{G_F \alpha}{2\sqrt{2}\pi s_W^2} V_{ti}^* V_{tj} \sum_n C_n \mathcal{Q}_n + \text{h.c.}\,,, \qquad C_n = C_n^{SM} + C_n^{NP}$$

$\Delta F = 1$ observables

$$\frac{G_F \alpha}{2\sqrt{2}\pi s_W^2} V_{ti}^* V_{tj} \sum_n C_n \mathcal{Q}_n + \text{h.c.}\,,, \qquad\qquad C_n = C_n^{SM} + C_n^{NP}$$

FCNC operators basis

$$\begin{aligned}
\mathcal{Q}_{\bar\nu\nu} &= \bar d_i \gamma_\mu (1-\gamma_5) d_j\, \bar\nu \gamma^\mu (1-\gamma_5)\nu\,, & \mathcal{Q}_7 &= e_q\, \bar d_i \gamma_\mu (1-\gamma_5) d_j\, \bar q \gamma^\mu (1+\gamma_5) q\,,\\
\mathcal{Q}_{9V} &= \bar d_i \gamma_\mu (1-\gamma_5) d_j\, \bar\ell \gamma^\mu \ell\,, & \mathcal{Q}_9 &= e_q\, \bar d_i \gamma_\mu (1-\gamma_5) d_j\, \bar q \gamma^\mu (1-\gamma_5) q\,,\\
\mathcal{Q}_{10A} &= \bar d_i \gamma_\mu (1-\gamma_5) d_j\, \bar\ell \gamma^\mu \gamma_5 \ell\,, & \mathcal{Q}_{7\gamma} &= \tfrac{m_i}{g^2} \bar d_i (1-\gamma_5) \sigma_{\mu\nu} d_j\, (e\, F^{\mu\nu})\,,\\
& & \mathcal{Q}_{8G} &= \tfrac{m_i}{g^2} \bar d_i (1-\gamma_5) \sigma_{\mu\nu} T^a d_j\, (g_s\, G_a^{\mu\nu})\,.
\end{aligned}$$

Wilson coefficient modifications

$$C_n^{NP} \begin{cases} \sim y_t^2\, a_Z^d, & n = \bar\nu\nu, 9V, \ldots, 9 \\[2em] 0, & n = 7\gamma, 8G \end{cases}$$

$\Delta F = 1$ observables

Operator	Observable	Bound (@ 95% C.L.)
$\mathcal{O}_{9V}$	$B \to X_s l^+ l^-$	$-0.811 < a_Z^d < 0.232$
$\mathcal{O}_{10A}$	$B \to X_s l^+ l^-$,$B \to \mu^+\mu^-$	$-0.050 < a_Z^d < 0.009$
$\mathcal{O}_{\bar{\nu}\nu}$	$K^+ \to \pi^+ \bar{\nu}\nu$	$-0.044 < a_Z^d < 0.133$

$\Delta F = 2$ observables

$\Delta F = 2$-effective hamiltonian

$$\mathcal{H}_{\rm eff}^{\Delta F=2} = \frac{G_F^2\, M_W^2}{4\pi^2}\, C(\mu)\, Q, \qquad Q = (\bar{d}_i^\alpha\, \gamma_\mu\, P_L\, d_j^\alpha)(\bar{d}_i^\beta\, \gamma^\mu\, P_L\, d_j^\beta)$$

$\Delta F = 2$ observables

$\Delta F = 2$-effective hamiltonian

$$\mathcal{H}_{\text{eff}}^{\Delta F=2} = \frac{G_F^2\, M_W^2}{4\pi^2}\, C(\mu)\, Q, \qquad Q = (\bar{d}_i^{\alpha}\, \gamma_\mu\, P_L\, d_j^{\alpha})(\bar{d}_i^{\beta}\, \gamma^\mu\, P_L\, d_j^{\beta})$$

Mixing amplitudes:

$$M_{12}^K = \frac{\langle \bar{K}^0 | \mathcal{H}_{\text{eff}}^{\Delta S=2} | K^0 \rangle^*}{2\, m_K}\,, \qquad M_{12}^q = \frac{\langle \bar{B}_q^0 | \mathcal{H}_{\text{eff}}^{\Delta B=2} | B_q^0 \rangle^*}{2\, m_{B_q}} \quad q = d, s,$$

$\Delta F = 2$ observables

$\Delta F = 2$-effective hamiltonian

$$\mathcal{H}_{\text{eff}}^{\Delta F=2} = \frac{G_F^2\, M_W^2}{4\pi^2}\, C(\mu)\, Q, \qquad Q = (\bar{d}_i^{\alpha}\, \gamma_\mu\, P_L\, d_j^{\alpha})(\bar{d}_i^{\beta}\, \gamma^\mu\, P_L\, d_j^{\beta})$$

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Either K or B-system,

$$M_{12}$$

$\Delta F = 2$ observables

$\Delta F = 2$-effective hamiltonian

$$\mathcal{H}_{\rm eff}^{\Delta F=2} = \frac{G_F^2\, M_W^2}{4\pi^2}\, C(\mu)\, Q, \qquad Q = (\bar{d}_i^\alpha\, \gamma_\mu\, P_L\, d_j^\alpha)(\bar{d}_i^\beta\, \gamma^\mu\, P_L\, d_j^\beta)$$

Mixing amplitudes:

$$M_{12}^K = \frac{\langle \bar{K}^0 | \mathcal{H}_{\rm eff}^{\Delta S=2} | K^0 \rangle^*}{2\, m_K}\,, \qquad M_{12}^q = \frac{\langle \bar{B}_q^0 | \mathcal{H}_{\rm eff}^{\Delta B=2} | B_q^0 \rangle^*}{2\, m_{B_q}} \quad q = d, s,$$

Either K or B-system,

$$M_{12} = (M_{12})_{SM}$$

$\Delta F = 2$ observables

$\Delta F = 2$-effective hamiltonian

$$\mathcal{H}_{\text{eff}}^{\Delta F=2} = \frac{G_F^2\, M_W^2}{4\pi^2}\, C(\mu)\, Q, \qquad Q = (\bar{d}_i^{\alpha}\, \gamma_\mu\, P_L\, d_j^{\alpha})(\bar{d}_i^{\beta}\, \gamma^\mu\, P_L\, d_j^{\beta})$$

Mixing amplitudes:

$$M_{12}^K = \frac{\langle \bar{K}^0 | \mathcal{H}_{\text{eff}}^{\Delta S=2} | K^0 \rangle^*}{2\, m_K}\,, \qquad M_{12}^q = \frac{\langle \bar{B}_q^0 | \mathcal{H}_{\text{eff}}^{\Delta B=2} | B_q^0 \rangle^*}{2\, m_{B_q}} \quad q = d, s,$$

Either K or B-system,

$$M_{12} = (M_{12})_{SM} + (M_{12})_{NP}$$

$\Delta F = 2$ observables

Neutral kaon oscillation

$$\Delta M_K = 2\left[\mathrm{Re}(M_{12}^K)_{SM} + \mathrm{Re}(M_{12}^K)_{NP}\right],$$

$$\varepsilon_K = \frac{\kappa_\epsilon\, e^{i\,\varphi_\epsilon}}{\sqrt{2}\,(\Delta M_K)_{\text{exp}}}\left[\mathrm{Im}\left(M_{12}^K\right)_{SM} + \mathrm{Im}\left(M_{12}^K\right)_{NP}\right]$$

$\Delta F = 2$ observables

Neutral kaon oscillation

$$\Delta M_K = 2\left[\mathrm{Re}(M_{12}^K)_{SM} + \mathrm{Re}(M_{12}^K)_{NP}\right],$$

$$\varepsilon_K = \frac{\kappa_\epsilon\, e^{i\,\varphi_\epsilon}}{\sqrt{2}\,(\Delta M_K)_{\mathrm{exp}}}\left[\mathrm{Im}\left(M_{12}^K\right)_{SM} + \mathrm{Im}\left(M_{12}^K\right)_{NP}\right]$$

Neglecting all contributions proportional to $y_{u,d,s}$ and y_c^n with $n > 2$:

$$(M_{12}^K)_{NP} \sim \eta_2\,\lambda_t^2\,\mathcal{O}\left(y_t^2\,a_W,\; y_t^4\,a_{CP}^2,\; y_t^4\,(a_Z^d)^2\right) + \eta_1\,\lambda_c^2\,\mathcal{O}\left(y_c^2\,a_W\right) + 2\,\eta_3\,\lambda_t\,\lambda_c\,\mathcal{O}\left(y_t^2\,a_W,\; y_t^4\,a_{CP}^2\right)$$

$\Delta F = 2$ observables

Neutral meson oscillation

Mixing amplitude

$$M_{12}^q = (M_{12}^q)_{\rm SM}\, \mathcal{C}_{B_q}\, e^{2\,i\,\varphi_{B_q}}$$

$B_{d,s}$-mass differences

$$\Delta M_q = 2\,|M_{12}^q| \equiv (\Delta M_q)_{\rm SM}\, \mathcal{C}_{B_q}$$

$$\mathcal{C}_{B_d} = \mathcal{C}_{B_s} = \left|1 + \mathcal{O}\left(y_t^2\, a_W,\; y_t^4\,(a_Z^d)^2\right) + \,i\,\mathcal{O}\left(y_t^2 y_b^2\, a_W\, a_{CP}\right)\right|$$

$$\varphi_{B_d} = \varphi_{B_s} \sim \mathcal{O}\left(y_t^2 y_b^2\, a_W, a_{CP}\right)$$

$\Delta F = 2$ observables

Neutral meson oscillation

Mixing-induced CP asymmetries $S_{\psi K_S}$ & $S_{\psi\phi}$ for $B_d^0 \to \psi\, K_S$ & $B_s^0 \to \psi\, \phi$

$$S_{\psi K_S} = \sin(2\,\beta + 2\,\varphi_{B_d})\,, \qquad S_{\psi\phi} = \sin(2\,\beta_s - 2\,\varphi_{B_s})\,,$$

UT-angles β & β_s

$$\beta \equiv \arg\left(-\frac{V_{cb}^*\, V_{cd}}{V_{tb}^*\, V_{td}}\right)\,, \qquad \beta_s \equiv \arg\left(-\frac{V_{tb}^*\, V_{ts}}{V_{cb}^*\, V_{cs}}\right)\,,$$

$R_{BR/\Delta M}$

$$R_{BR/\Delta M} \sim \frac{\left|1 + (a_W + i\, a_{CP})\; y_b^2\right|^2}{\mathcal{C}_{B_d}}$$

$\Delta F = 2$ observables

B-semileptonic CP-Asymmetry

$$A_{sl}^{b} = (0.594 \pm 0.022)\, a_{sl}^{d} + (0.406 \pm 0.022)\, a_{sl}^{s} \,,$$

NP contributions

$$\Gamma_{12}^{q} = (\Gamma_{12}^{q})_{\mathrm{SM}}\, \tilde{\mathcal{C}}_{B_q} \qquad \text{with} \qquad \tilde{\mathcal{C}}_{B_q} = 1 + 2\, a_W\, y_b^2 \,,$$

$$a_{sl}^{q} = \left| \frac{\left(\Gamma_{12}^{q}\right)_{SM}}{\left(M_{12}^{q}\right)_{SM}} \right| \frac{\tilde{\mathcal{C}}_{B_q}}{\mathcal{C}_{B_q}} \sin\left(\phi_q + 2\varphi_{B_q}\right) \,,$$

$\Longrightarrow$

ε_K vs. $R_{BR/\Delta M}$

$a's$ from $a_i\mathcal{O}_i$

$$R_{BR/\Delta M} = \frac{BR(B^+ \to \tau^+\nu)}{\Delta M_{B_d}}$$

$$a_{CP} = \pm 0.1 \quad \to \quad \delta\varepsilon_K \approx 1.1\%\,, \qquad \delta R \approx -1.4\%\,,$$
$$a_W = 0.1(-0.1) \quad \to \quad \delta\varepsilon_K \approx +26\%(-19\%)\,, \qquad \delta R \approx -25\%(+30\%)\,,$$
$$a_Z^d = \pm 0.1 \quad \to \quad \delta\varepsilon_K \approx 124\%\,, \qquad \delta R \approx -62\%\,.$$

ε_K vs. $R_{BR/\Delta M}$

$a's$ from $a_i\mathcal{O}_i$

$$R_{BR/\Delta M} = \frac{BR(B^+ \to \tau^+\nu)}{\Delta M_{B_d}}$$

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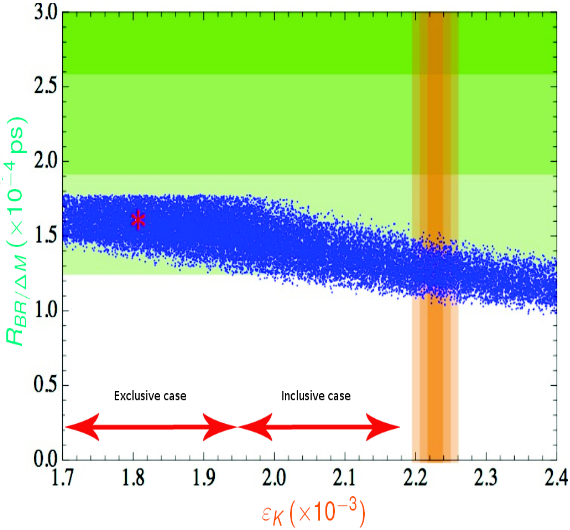
$$a_Z^d = \pm 0.1 \quad \to \quad \delta\varepsilon_K \approx 124\%\,, \quad \delta R \approx -62\%\,.$$

$$\varepsilon_K\uparrow(\approx\ \varepsilon_K^{\rm exp}\ \&\ S_{\psi K_S} \approx S_{\psi K_S}^{\rm exp})\ \&\ R_{BR/\Delta M}\downarrow$$

$\Rightarrow$ SHD + MFV able to soften $\varepsilon_K - S_{\psi K_S}$ anomaly, but not the SM tension for $BR(B^+ \to \tau^+\nu)$

ε_K vs. $R_{BR/\Delta M}$ from $\mathcal{O}_4$



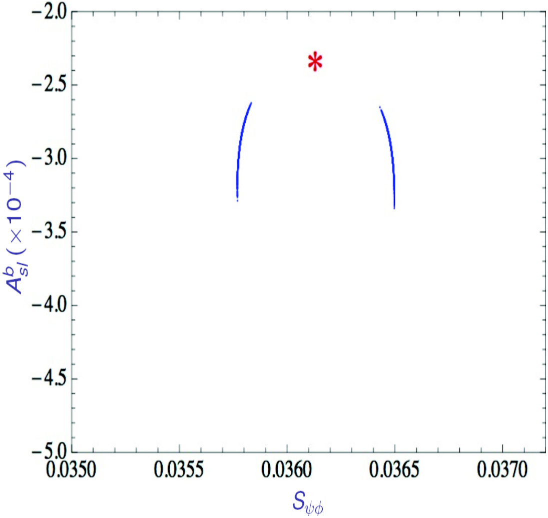
●: correlation $\varepsilon_K - R_{BR/\Delta M}$

$*$: SM values

Green & Orange: $1, 2, 3\sigma$ exp. values

$a_{CP} \in [-1, 1]$

$S_{\psi\phi}$ vs. A^b_{sl} from $\mathcal{O}_4$



●: correlation $S_{\psi\phi} - A^b_{sl}$

∗: SM values

Large values for a_{CP}

STRONG HIGGS DYNAMICS

$+$

MINIMAL FLAVOR VIOLATION

$\Downarrow$

- Different MFV phenomenology for the perturbative Higgs and the strong interacting regime, e.g., $\mathcal{O}_4$
- Natural $\not{CP}\,(\mathcal{O}_4)$ @ LO!!
- $\varepsilon_K - S_{\psi K_S}$ anomaly softened, still SM tension for $BR(B^+ \to \tau^+\nu)$
- Small $\delta S_{\psi\phi}$ & δA^b_{sl} experimentally allowed

$d_\chi = 4$ ops. have effects also on $b \to s\gamma$...

Going to $d_\chi = 5$...

$\bar{Q}_L \mathcal{O}_i \mathbf{U} Q_R$

$$\mathcal{O}_1 = \mathbf{V}_\mu \mathbf{V}^\mu, \qquad \mathcal{O}_4 = \mathbf{V}_\mu \, \mathbf{T} \, \mathbf{V}^\mu \, \mathbf{T}$$
$$\mathcal{O}_2 = \mathbf{V}_\mu \mathbf{V}^\mu \, \mathbf{T}, \qquad \mathcal{O}_5 = \mathbf{T} \, \mathbf{V}_\mu \, \mathbf{T} \, \mathbf{V}^\mu$$
$$\mathcal{O}_3 = \mathbf{V}_\mu \, \mathbf{T} \, \mathbf{V}^\mu, \qquad \mathcal{O}_6 = \mathbf{T} \, \mathbf{V}_\mu \, \mathbf{T} \, \mathbf{V}^\mu \, \mathbf{T}$$

$\bar{Q}_L \sigma^{\mu\nu} \mathcal{O}_i U Q_R$

$$\mathcal{O}_7 = [\mathbf{V}_\mu, \mathbf{V}_\nu], \qquad \mathcal{O}_9 = [\mathbf{V}_\mu \, \mathbf{T}, \mathbf{V}_\nu \, \mathbf{T}]$$
$$\mathcal{O}_8 = [\mathbf{V}_\mu, \mathbf{V}_\nu] \, \mathbf{T}, \qquad \mathcal{O}_{10} = [\mathbf{V}_\mu \, \mathbf{T}, \mathbf{V}_\nu \, \mathbf{T}] \, \mathbf{T}$$

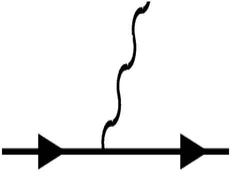
Dipole-type

$$\mathcal{O}_{11} = B_{\mu\nu}, \qquad \mathcal{O}_{13} = W_{\mu\nu}, \qquad \mathcal{O}_{15} = \mathbf{T} \, W_{\mu\nu}$$
$$\mathcal{O}_{12} = B_{\mu\nu} \, \mathbf{T}, \qquad \mathcal{O}_{14} = W_{\mu\nu} \, \mathbf{T}, \qquad \mathcal{O}_{16} = \mathbf{T} \, W_{\mu\nu} \mathbf{T}$$

$\Rightarrow$ Impact on $\Delta F = 1$ observable...dipole-type operator

$$\frac{a'}{\Lambda_{NP}^2} H^\dagger \bar{D}_R Y_d \lambda_{FC} \sigma_{\mu\nu} Q_L \ F^{\mu\nu},$$

$b \to s\gamma$



From $d_\chi = 5$

$$\frac{a_{7\gamma}}{f} = \frac{v}{2\sqrt{2}} \frac{a'}{\Lambda_{NP}^2} \leq \frac{10^{-4} - 10^{-3}}{\text{TeV}}$$

$$\Lambda_{NP} \sim 10\text{TeV}$$

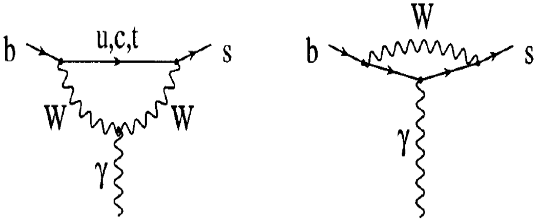
$$\alpha_{7\gamma} = c_W \ a_{B_{\mu\nu}} + s_W \ a_{W^3_{\mu\nu}}$$

$\Rightarrow$ Impact on $\Delta F = 1$ observable...dipole-type operator

$b \to s\gamma$

From $d_\chi = 4$

$a_w, a_{CP}, a_Z^d \sim \mathcal{O}(1)$



Thanks!

Tools

$$\mathcal{D}_\mu \mathbf{U} \equiv \partial_\mu \mathbf{U} + \frac{i\,g}{2}\tau_i\, W^i_\mu\, \mathbf{U} - \frac{i\,g'}{2}\mathbf{U}\,\tau_3\, B_\mu$$

$$\mathbf{T} = \mathbf{U}\tau_3\mathbf{U}^\dagger\,, \qquad \mathbf{T} \to L\,\mathbf{T}L^\dagger\,,$$

$$\mathbf{V}_\mu = (\mathcal{D}_\mu\mathbf{U})\mathbf{U}^\dagger\,, \qquad \mathbf{V}_\mu \to L\,\mathbf{V}_\mu L^\dagger\,.$$

Lagrangian for interaction between the gauge fields and the scalar sector:

$$\mathcal{L} = -\frac{1}{4}W^i_{\mu\nu}W_i^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{v^2}{4}\mathrm{Tr}[\mathbf{V}_\mu\mathbf{V}^\mu] + \delta\mathcal{L}\,,$$

$$\delta\mathcal{L}_{d_\chi=2} = a_{WZ}\,\frac{v^2}{4}\,\mathrm{Tr}[\mathbf{T}\,\mathbf{V}_\mu]\,\mathrm{Tr}[\mathbf{T}\,\mathbf{V}^\mu]\,,$$

Non-linear Yukawa interactions:

$$\mathscr{L}_Y = \frac{v}{\sqrt{2}}\,\overline{Q}_L\,\mathcal{Y}\,\mathbf{U}\,Q_R + \mathrm{h.c.}\,, \qquad Q_R = (u_R, d_R)$$

Tools

$$\mathcal{Y} \equiv \begin{pmatrix} Y_U & 0 \\ 0 & Y_D \end{pmatrix} = \begin{pmatrix} V^\dagger \mathbf{y}_U & 0 \\ 0 & \mathbf{y}_D \end{pmatrix}$$

Spurion field $\sim (8,1,1)$ for new FCNC effects

$$\lambda_F \equiv Y_U Y_U^\dagger + Y_D Y_D^\dagger = V^\dagger \mathbf{y}_U^2 V + \mathbf{y}_D^2$$

$d_\chi = 4$ ops.

$$\mathcal{O}_1 = \frac{i}{2} \bar{Q}_L \lambda_F \gamma^\mu \left\{ \mathbf{T}, \mathbf{V}_\mu \right\} Q_L \,, \qquad \mathcal{O}_2 = i \bar{Q}_L \lambda_F \gamma^\mu \mathbf{V}_\mu Q_L \,,$$

$$\mathcal{O}_3 = i \bar{Q}_L \lambda_F \gamma^\mu \mathbf{T} \mathbf{V}_\mu \mathbf{T} Q_L \,, \qquad \mathcal{O}_4 = \frac{1}{2} \bar{Q}_L \lambda_F \gamma^\mu \left[\mathbf{T}, \mathbf{V}_\mu \right] Q_L \,.$$

Effective Low-Energy Lagrangian

$$\begin{aligned} \delta\mathcal{L}_{d_\chi=4} = & -\frac{g}{\sqrt{2}} \left[W^{\mu+} \bar{U}_L \gamma_\mu (a_W + i a_{CP}) \left(\mathbf{y}_U^2 V + V \mathbf{y}_D^2 \right) D_L + h.c. \right] + \\ & -\frac{g}{2 c_W} Z^\mu \left[a_Z^u \bar{U}_L \gamma_\mu \left(\mathbf{y}_U^2 + V \mathbf{y}_D^2 V^\dagger \right) U_L + a_Z^d \bar{D}_L \gamma_\mu \left(\mathbf{y}_D^2 + V^\dagger \mathbf{y}_U^2 V \right) D_L \right] \end{aligned}$$

$$a_Z^u \equiv a_1 + a_2 + a_3 \,, \qquad a_Z^d \equiv a_1 - a_2 - a_3 \,,$$
$$a_W \equiv a_2 - a_3 \,, \qquad a_{CP} \equiv -a_4 \,.$$

Non Unitarity and CP Violation

$$\tilde{V}_{ij} = V_{ij}\left[1 + (a_W + i a_{CP})(y^2_{u_i} + y^2_{d_j})\right]$$

$$\sum_k \tilde{V}^*_{ik}\tilde{V}_{jk} \simeq \delta_{ij} + \left[2\, a_W\, y_t^2 + (a_W^2 + a_{CP}^2)\, y_t^4\right]\, \delta_{it}\delta_{jt}$$

$$\sum_k \tilde{V}^*_{ki}\tilde{V}_{kj} \simeq \delta_{ij} + \left[2\, a_W\, y_t^2 + (a_W^2 + a_{CP}^2)\, y_t^4\right]\, V^*_{ti}\, V_{tj}$$

$$\arg\left(-\frac{\tilde{V}^*_{ik}\tilde{V}_{il}}{\tilde{V}^*_{jk}\tilde{V}_{jl}}\right) = \arg\left(-\frac{V^*_{ik}V_{il}}{V^*_{jk}V_{jl}}\right) + a_{CP}\,[2\, a_W\, \left(y^2_{u_j} - y^2_{u_i}\right)\left(y^2_{d_l} - y^2_{d_k}\right) + \\ - \left(3\, a_W^2 - a_{CP}^2\right)\left(y^2_{u_j} - y^2_{u_i}\right)\left(y^2_{d_l} - y^2_{d_k}\right)\left(y^2_{u_i} + y^2_{u_j} + y^2_{d_k} + y^2_{d_l}\right)] + O(a^4)\,,$$

$$\arg\left(-\frac{\tilde{V}^*_{tb}\tilde{V}_{td}}{\tilde{V}^*_{ub}\tilde{V}_{ud}}\right) \simeq \alpha + 2\, y_b^2\, y_t^2\, a_W\, a_{CP}\,,$$

$$\arg\left(-\frac{\tilde{V}^*_{cb}\tilde{V}_{cd}}{\tilde{V}^*_{tb}\tilde{V}_{td}}\right) \simeq \beta - 2\, y_b^2\, y_t^2\, a_W\, a_{CP}\,,$$

$$\arg\left(-\frac{\tilde{V}^*_{ub}\tilde{V}_{ud}}{\tilde{V}^*_{cb}\tilde{V}_{cd}}\right) \simeq \gamma - 2\, y_c^2\, y_b^2\, a_W\, a_{CP} \simeq \gamma\,.$$

$\Delta F = 1$ observables

FCNC-effective lagrangian

$$\frac{G_F \alpha}{2\sqrt{2}\pi s_W^2} V_{ti}^* V_{tj} \sum_n C_n \mathcal{Q}_n + \text{h.c.} ,$$

Wilson coefficient C_n:

$$C_n = C_n^{SM} + C_n^{NP}$$

FCNC operators basis

$$\begin{aligned}
\mathcal{Q}_{\bar\nu\nu} &= \bar d_i \gamma_\mu (1-\gamma_5) d_j \; \bar\nu \gamma^\mu (1-\gamma_5)\nu , \\
\mathcal{Q}_{9V} &= \bar d_i \gamma_\mu (1-\gamma_5) d_j \; \bar\ell \gamma^\mu \ell , \\
\mathcal{Q}_{10A} &= \bar d_i \gamma_\mu (1-\gamma_5) d_j \; \bar\ell \gamma^\mu \gamma_5 \ell ,
\end{aligned}$$

$$\begin{aligned}
\mathcal{Q}_7 &= e_q \; \bar d_i \gamma_\mu (1-\gamma_5) d_j \; \bar q \gamma^\mu (1+\gamma_5) q , \\
\mathcal{Q}_9 &= e_q \; \bar d_i \gamma_\mu (1-\gamma_5) d_j \; \bar q \gamma^\mu (1-\gamma_5) q , \\
\mathcal{Q}_{7\gamma} &= \frac{m_i}{g^2} \bar d_i (1-\gamma_5) \sigma_{\mu\nu} d_j \, (e F^{\mu\nu}) , \\
\mathcal{Q}_{8G} &= \frac{m_i}{g^2} \bar d_i (1-\gamma_5) \sigma_{\mu\nu} T^a d_j \, (g_s G_a^{\mu\nu}) .
\end{aligned}$$

Leading NP contributions non-linear MFV operators:

$$\begin{aligned}
C_{\nu\bar\nu}^{NP} &= -\kappa \, y_t^2 \, a_Z^d , \\
C_{9V}^{NP} &= \kappa \, (1 - 4 s_W^2) \, y_t^2 \, a_Z^d , \\
C_{10A}^{NP} &= -\kappa \, y_t^2 \, a_Z^d ,
\end{aligned}$$

$$\begin{aligned}
C_7^{NP} &= +2\kappa \, s_W^2 \, y_t^2 \, a_Z^d , \\
C_9^{NP} &= -2\kappa \, c_W^2 \, y_t^2 \, a_Z^d , \\
C_{7\gamma}^{NP} &= C_{8G}^{NP} = 0 .
\end{aligned}$$

$B^+ \to \tau^+ \nu$

$B^+ \to \tau^+ \nu$-tree-level charged current process.

$$BR(B^+ \to \tau^+ \nu) = \frac{G_F^2 \, m_{B^+} \, m_\tau^2}{8\pi} \left(1 - \frac{m_\tau^2}{m_{B^+}^2}\right)^2 F_{B^+}^2 \, |V_{ub}|^2 \, \left|1 + (a_W + i \, a_{CP}) \, y_b^2\right|^2 \, \tau_{B^+} ,$$

F_{B^+} is B decay constant.

$\Delta F = 2$ observables

$\Delta F = 2$-effective hamiltonian

$$\mathcal{H}_{\text{eff}}^{\Delta F=2} = \frac{G_F^2\, M_W^2}{4\pi^2}\, C(\mu)\, Q$$

Q neutral meson mixing operator:

$$Q = (\bar{d}_i^\alpha\, \gamma_\mu\, P_L\, d_j^\alpha)(\bar{d}_i^\beta\, \gamma^\mu\, P_L\, d_j^\beta)$$

Mixing amplitudes M_{12}^i ($i = K, d, s$):

$$M_{12}^K = \frac{\langle \bar{K}^0 | \mathcal{H}_{\text{eff}}^{\Delta S=2} | K^0 \rangle^*}{2\, m_K}\,, \qquad M_{12}^q = \frac{\langle \bar{B}_q^0 | \mathcal{H}_{\text{eff}}^{\Delta B=2} | B_q^0 \rangle^*}{2\, m_{B_q}}\,,$$

with $q = d,\, s$. For the K system, $M_{12}^K = (M_{12}^K)_{SM} + (M_{12}^K)_{NP}$. Neglecting all contributions proportional to $y_{u,d,s}$ and y_c^n with $n > 2$:

$$(M_{12}^K)_{SM} = R_K \left[\eta_2\, \lambda_t^2\, S_0(x_t) + \eta_1\, \lambda_c^2\, S_0(x_c) + 2\, \eta_3\, \lambda_t\, \lambda_c\, S_0(x_c,\, x_t) \right]^*\,,$$

$$(M_{12}^K)_{NP} = R_K \left[\eta_2\, \lambda_t^2 \left(y_t^2\, (2\, a_W + y_t^2\, a_{CP}^2)\, G(x_t) + \frac{(4\, \pi\, y_t^2\, a_Z^d)^2}{g^2} \right) + 2\eta_1\, \lambda_c^2\, a_W\, y_c^2\, G(x_c) + \right.$$
$$\left. + 2\, \eta_3\, \lambda_t\, \lambda_c \left(y_t^2\, (2\, a_W + a_{CP}^2\, y_t^2)\, H(x_t, x_c) + 2\, a_W\, y_c^2\, H(x_c, x_t) \right) \right]^*$$

$$R_K \equiv \frac{G_F^2\, M_W^2}{12\, \pi^2}\, F_K^2\, m_K\, \hat{B}_K$$

$\Delta F = 2$ observables

Neutral kaon oscillation

$$\Delta M_K = 2\left[\mathrm{Re}(M_{12}^K)_{SM} + \mathrm{Re}(M_{12}^K)_{NP}\right],$$

$$\varepsilon_K = \frac{\kappa_\epsilon\, e^{i\,\varphi_\epsilon}}{\sqrt{2}\,(\Delta M_K)_{\mathrm{exp}}}\left[\mathrm{Im}\left(M_{12}^K\right)_{SM} + \mathrm{Im}\left(M_{12}^K\right)_{NP}\right]$$

Neutral meson oscillation

$$M_{12}^q = (M_{12}^q)_{\mathrm{SM}}\,\mathcal{C}_{B_q}\, e^{2\,i\,\varphi_{B_q}},$$

NP effects from $\mathcal{C}_{B_{d,s}}$ and $\varphi_{B_{d,s}}$

$$M_{12}^q = R_{B_q}\left[\lambda_t^2\, S_0(x_t)\right]^*, \qquad \text{with} \qquad R_{B_q} \equiv \frac{G_F^2\, M_W^2}{12\,\pi^2} F_{B_q}^2\, m_{B_q}\, \hat{B}_{B_q}\, \eta_B,$$

$B_{d,s}$-mass differences

$$\Delta M_q = 2\,|M_{12}^q| \equiv (\Delta M_q)_{\mathrm{SM}}\,\mathcal{C}_{B_q},$$

$$\mathcal{C}_{B_d} = \mathcal{C}_{B_s} = \left|1 + 2\,a_W\left(y_t^2\,\frac{G(x_t)}{S_0(x_t)} + y_b^2\right) + \frac{(4\,\pi\, y_t^2\, a_Z^d)^2}{g^2\, S_0(x_t)} + 2\,i\,a_W\, a_{CP}\, y_t^2\, y_b^2\,\frac{G(x_t)}{S_0(x_t)}\right|.$$

$\Delta F = 2$ observables

Neutral meson oscillation

Mixing-induced CP asymmetries $S_{\psi K_S}$ & $S_{\psi\phi}$ for $B_d^0 \to \psi\, K_S$ & $B_s^0 \to \psi\, \phi$

$$S_{\psi K_S} = \sin(2\,\beta + 2\,\varphi_{B_d})\,, \qquad S_{\psi\phi} = \sin(2\,\beta_s - 2\,\varphi_{B_s})\,,$$

UT-angles β & β_s

$$\beta \equiv \arg\left(-\frac{V_{cb}^*\, V_{cd}}{V_{tb}^*\, V_{td}}\right)\,, \qquad \beta_s \equiv \arg\left(-\frac{V_{tb}^*\, V_{ts}}{V_{cb}^*\, V_{cs}}\right)\,,$$

New phases

$$\varphi_{B_d} = \varphi_{B_s} = 2\, a_W\, a_{CP}\, y_t^2\, y_b^2\, \frac{G(x_t)}{S_0(x_t)}\,.$$

$R_{BR/\Delta M}$

$$R_{BR/\Delta M} = \frac{3\,\pi\,\tau_{B+}}{4\,\eta_B\,\hat{B}_{B_d}\,S_0(x_t)}\,\frac{m_\tau^2}{M_W^2}\,\frac{|V_{ub}|^2}{\left|V_{tb}^*\,V_{td}\right|^2}\left(1-\frac{m_\tau^2}{m_{B_d}^2}\right)^2\frac{\left|1+(a_W+i\,a_{CP})\,y_b^2\right|^2}{\mathcal{C}_{B_d}}$$

$\Delta F = 2$ observables

B-semileptonic CP-Asymmetry

$$A^b_{sl} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} \,,$$

N_b^{++} & N_b^{--} number of events containing two μ^+ or μ^-. In $p\bar{p}$ colliders, such events can only arise through $B_d^0 - \bar{B}_d^0$ or $B_s^0 - \bar{B}_s^0$ mixings.

$$A^b_{sl} = (0.594 \pm 0.022)\, a^d_{sl} + (0.406 \pm 0.022)\, a^s_{sl} \,,$$

$$a^d_{sl} \equiv \left| \frac{\left(\Gamma^d_{12}\right)_{SM}}{\left(M^d_{12}\right)_{SM}} \right| \sin\phi_d = (5.4 \pm 1.0) \times 10^{-3} \sin\phi_d \,,$$

$$a^s_{sl} \equiv \left| \frac{(\Gamma^s_{12})_{SM}}{(M^s_{12})_{SM}} \right| \sin\phi_s = (5.0 \pm 1.1) \times 10^{-3} \sin\phi_s \,,$$

$$\phi_d \equiv \arg\left(- \left(M^d_{12}\right)_{SM} / \left(\Gamma^d_{12}\right)_{SM} \right) = -4.3^\circ \pm 1.4^\circ \,,$$

$$\phi_s \equiv \arg\left(- (M^s_{12})_{SM} / (\Gamma^s_{12})_{SM} \right) = 0.22^\circ \pm 0.06^\circ \,.$$

NP contributions

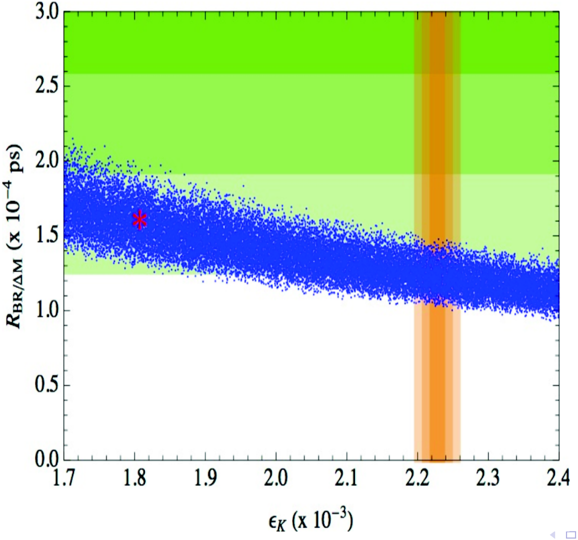
$$\Gamma^q_{12} = (\Gamma^q_{12})_{\rm SM}\, \tilde{C}_{B_q} \qquad \text{with} \qquad \tilde{C}_{B_q} = 1 + 2\, a_W\, y_b^2 \,,$$

$$a^q_{sl} = \left| \frac{(\Gamma^q_{12})_{SM}}{(M^q_{12})_{SM}} \right| \frac{\tilde{C}_{B_q}}{C_{B_q}} \sin\left(\phi_q + 2\varphi_{B_q}\right) \,,$$

Impact on the observables of specific parameter values

Parameter	$\delta\varepsilon_K$	$\delta R_{BR/\Delta M}$	δA^b_{sl}
$a_{CP} = 0.1(-0.1)$	$\approx 1.1\%$	$\approx -1.4\%$	$\approx 1.1\%(-1.6\%)$
$a_W = 0.1(-0.1)$	$\approx +26\%(-19\%)$	$\approx -25\%(+30\%)$	$\approx +33\%(-23\%)$
$a^d_Z = \pm 0.1$	$\approx 124\%$	$\approx -62\%$	$\approx 160\%$

ε_K vs. $R_{BR/\Delta M}$ from $\mathcal{O}_{1,2,3}$



●: correlation
$\varepsilon_K - R_{BR/\Delta M}$

∗: SM values

Green & Orange:
$1, 2, 3\sigma$ exp. values

$a_W \in [-1, 1]$,
$a_Z^d \in [-0.1, 0.1]$
and $a_{CP} = 0$

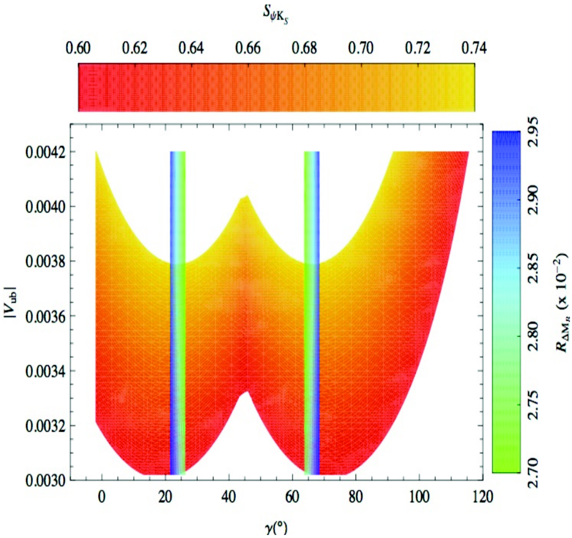
Phenomenological Analysis

Input parameters and the SM analysis

$G_F = 1.16637(1) \times 10^{-5}$ GeV^{-2}	[30]	$m_{B_d} = 5279.5(3)$ MeV	[30]
$M_W = 80.399(23)$ GeV	[30]	$m_{B_s} = 5366.3(6)$ MeV	[30]
$s^2_W \equiv \sin^2\theta_W = 0.23116(13)$	[30]	$F_{B_d} = 205(12)$ MeV	[32]
$\alpha(M_Z) = 1/127.9$	[30]	$F_{B_s} = 250(12)$ MeV	[32]
$\alpha_s(M_Z) = 0.1184(7)$	[30]	$\hat{B}_{B_d} = 1.26(11)$	[32]
$m_u(2\text{ GeV}) = 1.7 \div 3.1$ MeV	[30]	$\hat{B}_{B_s} = 1.33(6)$	[32]
$m_d(2\text{ GeV}) = 4.1 \div 5.7$ MeV	[30]	$F_{B_d}\sqrt{\hat{B}_{B_d}} = 233(14)$ MeV	[32]
$m_s(2\text{ GeV}) = 100^{+30}_{-20}$ MeV	[30]	$F_{B_s}\sqrt{\hat{B}_{B_s}} = 288(15)$ MeV	[32]
$m_c(m_c) = (1.279 \pm 0.013)$ GeV	[36]	$\xi = 1.237(32)$	[32]
$m_b(m_b) = 4.19^{+0.18}_{-0.06}$ GeV	[30]	$\eta_B = 0.55(1)$	[37, 38]
$M_t = 172.9 \pm 0.6 \pm 0.9$ GeV	[30]	$\Delta M_d = 0.507(4)\,\text{ps}^{-1}$	[30]
$m_K = 497.614(24)$ MeV	[30]	$\Delta M_s = 17.77(12)\,\text{ps}^{-1}$	[30]
$F_K = 156.0(11)$ MeV	[32]	$\sin(2\beta)_{b\to c\bar{c}s} = 0.673(23)$	[30]
$\hat{B}_K = 0.737(20)$	[32]	$\phi_s^{\psi\phi} = 0.55^{+0.38}_{-0.36}$	[39, 40]
$\kappa_\epsilon = 0.923(6)$	[41]	$\phi_s^{\psi\phi} = 0.03 \pm 0.16 \pm 0.07$	[42]
$\varphi_\epsilon = (43.51 \pm 0.05)^\circ$	[43]	$R_{\Delta M_B} = (2.85 \pm 0.03) \times 10^{-2}$	[30]
$\eta_1 = 1.87(76)$	[44]	$A^b_{sl} = (-0.787 \pm 0.172 \pm 0.093) \times 10^{-2}$	[34]
$\eta_2 = 0.5765(65)$	[37]	$\lvert V_{us}\rvert = 0.2252(9)$	[30]
$\eta_3 = 0.496(47)$	[45]	$\lvert V_{cb}\rvert = (40.6 \pm 1.3) \times 10^{-3}$	[30]
$\Delta M_K = 0.5292(9) \times 10^{-2}\,\text{ps}^{-1}$	[30]	$\lvert V_{ub}^{\text{incl.}}\rvert = (4.27 \pm 0.38) \times 10^{-3}$	[30]
$\lvert\epsilon_K\rvert = 2.228(11) \times 10^{-3}$	[30]	$\lvert V_{ub}^{\text{excl.}}\rvert = (3.38 \pm 0.36) \times 10^{-3}$	[30]
$\tau_{B^\pm} = (1641 \pm 8) \times 10^{-3}$ ps	[30]	$\lvert V_{ub}^{\text{comb.}}\rvert = (3.89 \pm 0.44) \times 10^{-3}$	[30]
$BR(B^+ \to \tau^+\nu) = (1.65 \pm 0.34) \times 10^{-4}$	[30]	$\gamma = (73^{+22}_{-25})^\circ$	[30]

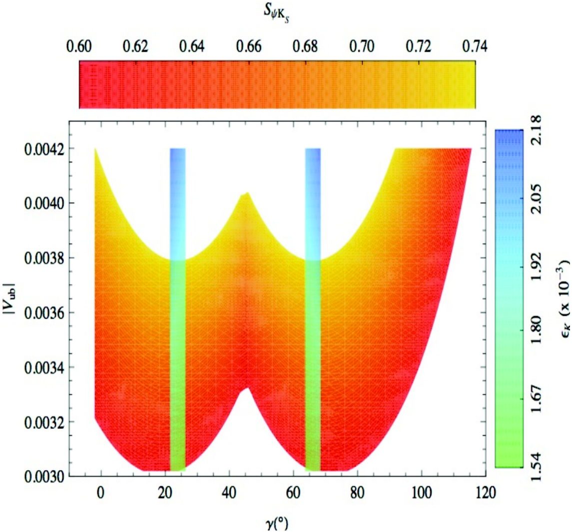
Phenomenological Analysis

$|V_{ub}| - \gamma$ parameter space



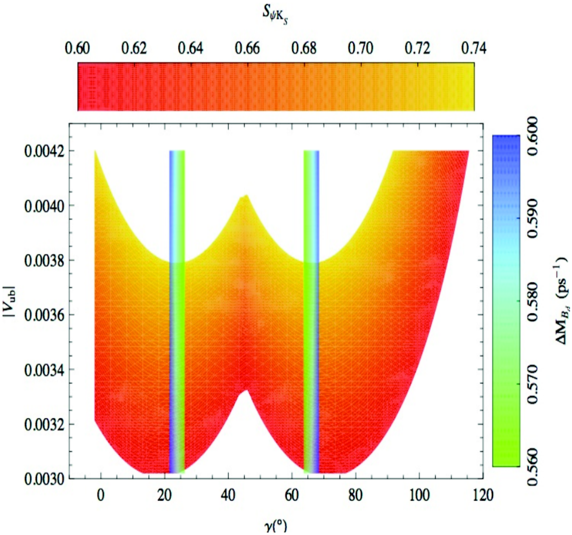
Phenomenological Analysis

ε_K



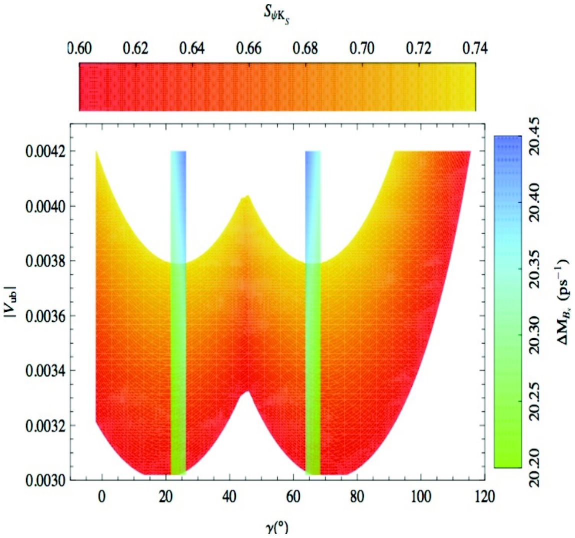
Phenomenological Analysis

ΔM_{B_d}



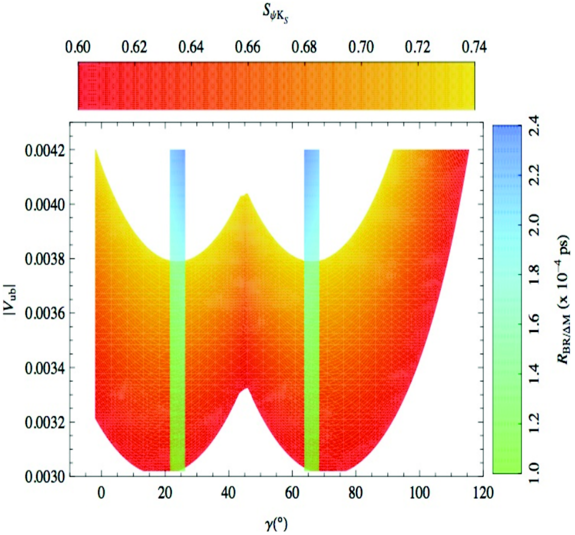
Phenomenological Analysis

ΔM_{B_s}



Phenomenological Analysis

$R_{BR/\Delta M}$



Phenomenological Analysis

In order to illustrate the features of the MFV scenario with a strong interacting Higgs sector, the numerical analysis of the following sections will be presented choosing as reference point, $(|V_{ub}|, \gamma) = (3.5\times10^{-3}, 66^\circ)$, corresponding to $S_{\psi K_S} \simeq 0.692$ and $R_{\Delta M_B} \simeq 2.83\times10^{-2}$. For this point

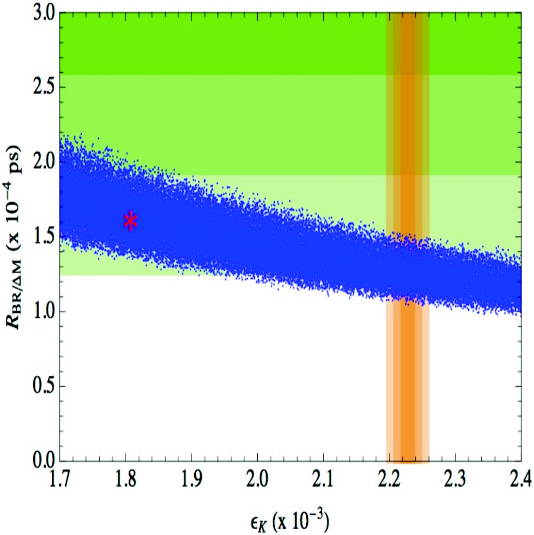
$$\varepsilon_K = 1.8\times10^{-3}\,, \qquad R_{BR/\Delta M} = 1.6\times10^{-4}\ \text{ps}\,.$$

$$S_{\psi\phi} = 0.036\,.$$

$$A^b_{sl} = -2.3\times10^{-4} \qquad \left(a^d_{sl} = -4.0\times10^{-4}\,, \qquad a^s_{sl} = 1.9\times10^{-5}\right)\,,$$

$$\begin{aligned} a_{CP} &= 0.1(-0.1) &\longrightarrow&\qquad \delta A^b_{sl} \approx 1.1\%(1.6\%)\\ a_W &= 0.1(-0.1) &\longrightarrow&\qquad \delta A^b_{sl} \approx 33\%(-23\%)\\ a^d_Z &= \pm0.1 &\longrightarrow&\qquad \delta A^b_{sl} \approx 160\%\,. \end{aligned}$$

ε_K vs. $R_{BR/\Delta M}$ from all $\mathcal{O}_i$



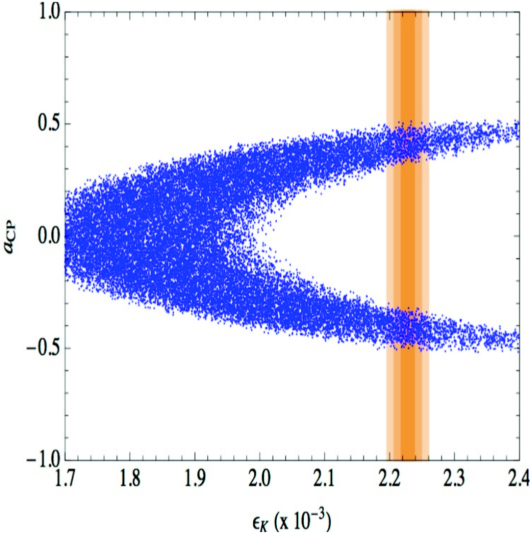
●: correlation $\varepsilon_K - R_{BR/\Delta M}$

∗: SM values

Green & Orange: $1, 2, 3\sigma$ exp. values

$a_W, a_{CP} \in [-1, 1]$,
$a_Z^d \in [-0.1, 0.1]$

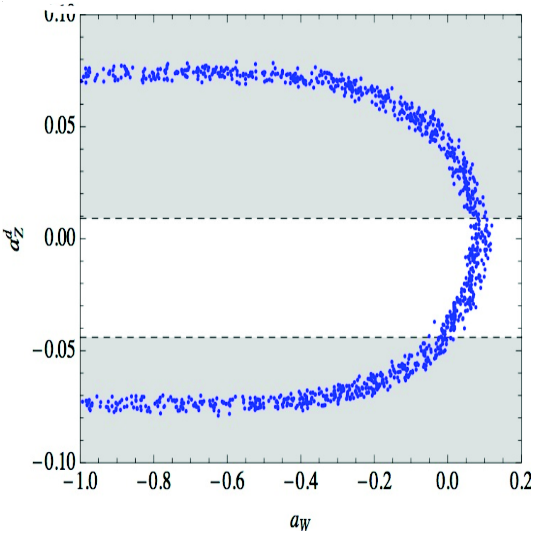
From $\mathcal{O}_4$



a_{CP} from $\mathcal{O}_4$

R inside its 3σ exp. value

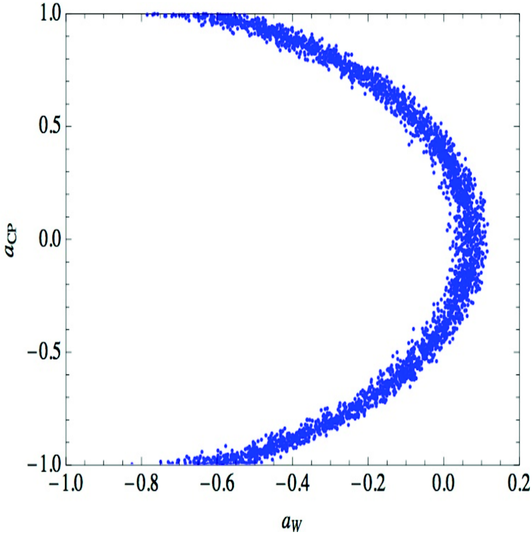
From $\mathcal{O}_{1,2,3}$



a_W-a_Z^d from $\mathcal{O}_{1,2,3}$

Obs inside its 3σ exp. value

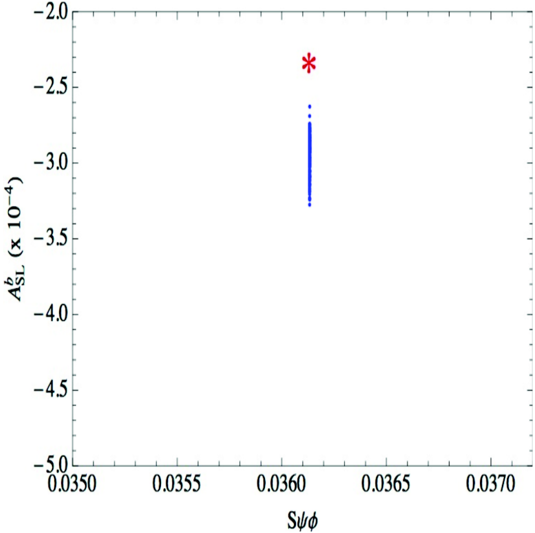
From all $\mathcal{O}_i$



$a_W - a_{CP}$ and
$a_Z^d \in [-0.044, 0.009]$
from $\mathcal{O}_i$

Obs inside its 3σ exp. value

$S_{\psi\phi}$ vs. A^b_{sl} from $\mathcal{O}_{1,2,3}$

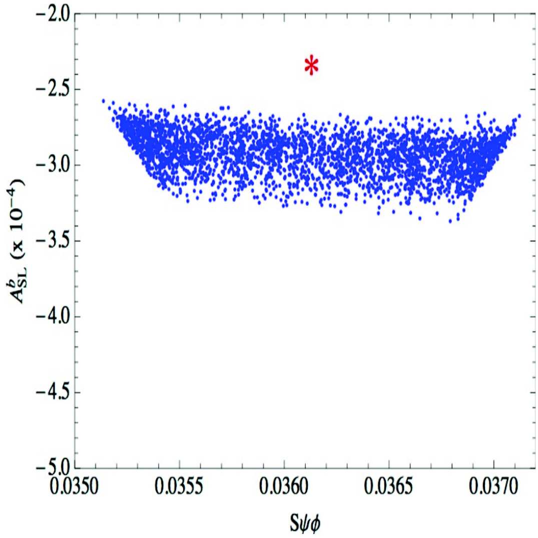


●: correlation $S_{\psi\phi} - A^b_{sl}$

∗: SM values

$a_W \in [-1, 1]$, $a_{CP} = 0$,
$a^d_Z \in [-0.044, 0.009]$

$S_{\psi\phi}$ vs. A^b_{sl} from all $\mathcal{O}_i$



●: correlation $S_{\psi\phi} - A^b_{sl}$

∗: SM values

$a_W, a_{CP} \in [-1, 1]$,
$a^d_Z \in [-0.044, 0.009]$