QCD effects and search for new physics in t-> b W

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Outline

- Anomalous tWb coupling in collider physics
  - effects on helicity fractions;
  - NLO QCD corrections;
  - experimental results and constraints on anomalous couplings.

- anomalous tWb coupling in B physics
  - $b \to s\gamma$, $B_{d,s} - \bar{B}_{d,s}$ mixing and anomalous coupling;
  - interplay of SM and anomalous contribution in helicity amplitudes;

Summary and outlook;

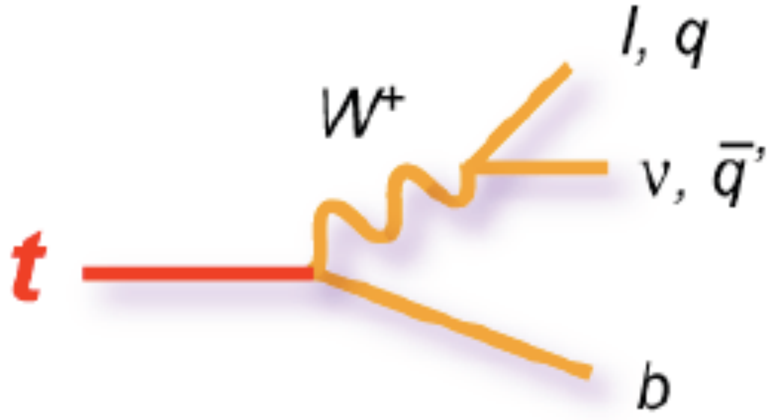
Dominant decay modes: $t \to Wq$

Important CKM matrix elements

$$V_{td}, \quad V_{ts}, \quad V_{tb}$$

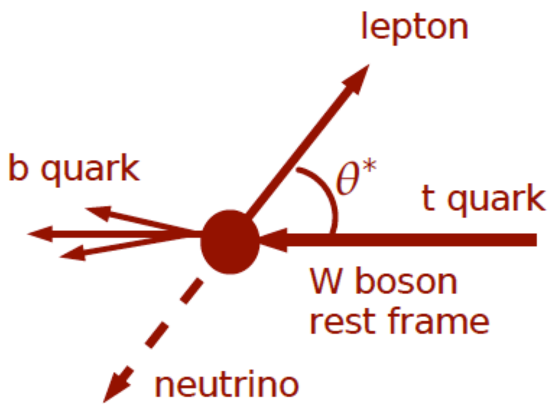
$$\Gamma(t \to bW)^{\rm SM} \simeq \frac{\alpha |V_{tb}|^2}{16 s_W^2} \frac{m_t^3}{m_W^2}$$

$$\frac{B(t \to Wb)}{B(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$



$$\Gamma(t \to W^+ q) \approx 1.5 \text{ GeV} > \Lambda_{QCD} \sim 200 \text{ MeV}$$

t -> b W in SM

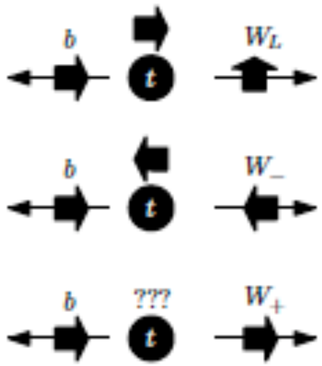


$$\mathcal{F}_i = \Gamma_i / \Gamma$$

helicity amplitudes of W

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell^*} = \frac{3}{8}(1+\cos\theta_\ell^*)^2\mathcal{F}_+ + \frac{3}{8}(1-\cos\theta_\ell^*)^2\mathcal{F}_- + \frac{3}{4}\sin^2\theta_\ell^*\mathcal{F}_L$$

$$\sum_i \mathcal{F}_i = 1$$



in SM nonzero value of $\mathcal{F}_+$ comes from QCD and EW corrections ($m_b \neq 0$).

Experimental results by CDF and D0

$$\mathcal{F}_L^{\rm CDF} = 0.88(13)$$
$$\mathcal{F}_+^{\rm CDF} = -0.15(9)$$

$$\mathcal{F}_L^{\rm D\O} = 0.669(102)$$
$$\mathcal{F}_+^{\rm D\O} = 0.023(53)$$

SM expectation

$$\mathcal{F}_L^{\rm SM} = 0.687(5)\,,$$
$$\mathcal{F}_+^{\rm SM} = 0.0017(1)\,.$$

A.Czarnecki et al.,1005.225;
H.S. Do et al., hep-ph/0209185;
M. Fisher et al., hep-ph/0101322

Measured $\mathcal{F}_+ > 0.2\%$ would indicated NP effects!

Projected sensitivity for LHC (L = 10 fb^{-1})

$$\sigma(\mathcal{F}_+) = \pm 0.002 \qquad \sigma(\mathcal{F}_L) = \pm 0.02$$

J.A. Aguilar-Saavedra et al. 0705.3041; (Gzandkowski and Misiak, 0802.1413)

New Physics searches in top quark physics

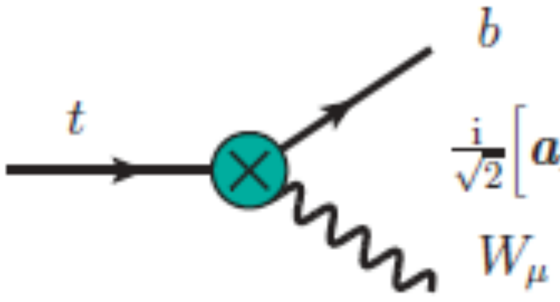
Why to look for NP in top ?

i) Due to its large mass, higher order corrections involving new particles are often more important than for lighter fermions;

ii) Its large mass has a special role in electroweak symmetry breaking.

Large sample of top quarks at LHC precise measurements of its couplings are already available to test SM and possible NP predictions.

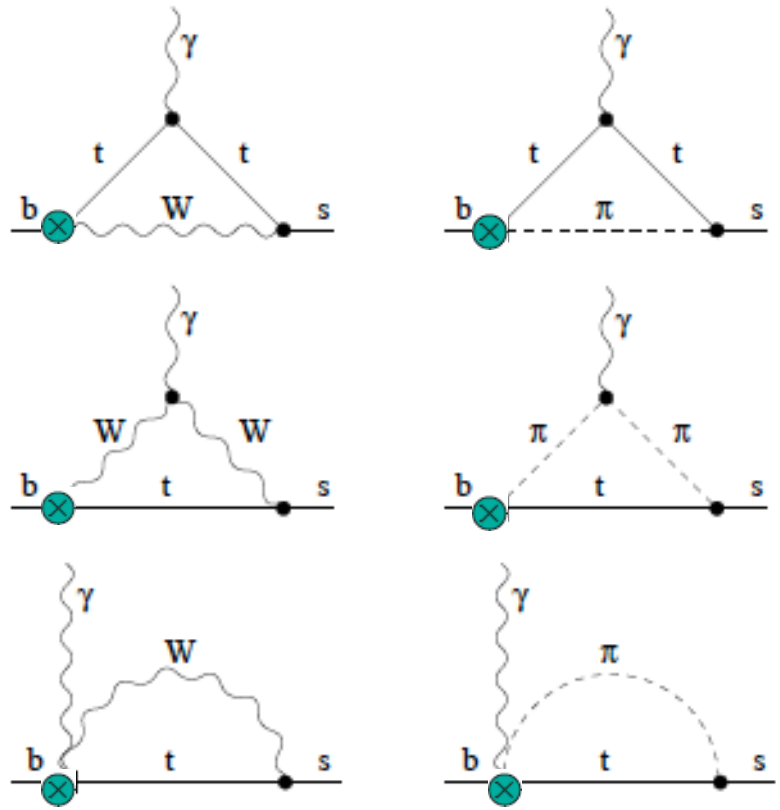
NP in tWb coupling



$$\frac{i}{\sqrt{2}}\left[\mathbf{a}_L\gamma^\mu P_L - \mathbf{b}_{LR}\frac{2i\sigma^{\mu\nu}}{m_t}q_\nu P_R + (L\leftrightarrow R)\right]W_\mu$$

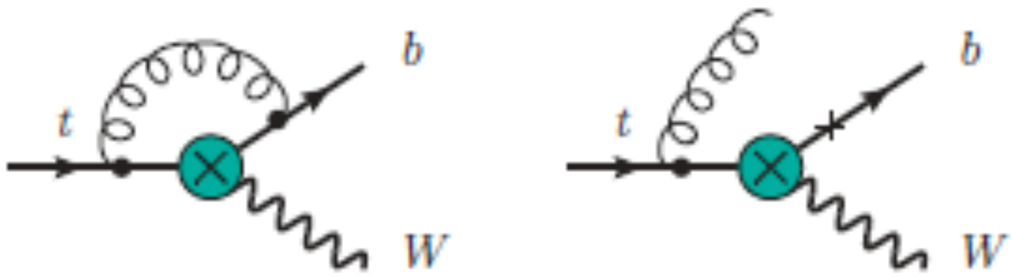
$$a_L = a_L^{SM} + \delta a_L = V_{tb} + \delta a_L$$

The same couplings appear in the FCNC process $b \to s\gamma$!



At low energies $b \to s\gamma$ is very restrictive!

(Gzandkowski and Misiak, 0802.1413)



• anomalous contribution is helicity suppressed in $\mathcal{F}_+$;

• due to helicity suppression one should determine NLO in QCD (J. Drobnak, S.F., J. F. Kamenik 1010.2402)

Interesting: the constraints coming from $b \to s\gamma$ already allow that SM contribution in $\mathcal{F}_+$ is modified by 2%

QCD corrections to Γ^i : Bernreuter et al., hep-ph/0308296; Fischer et al., hep-ph/01013 22, A. Czarnecki et al, 1005.2625.

QCD corrections

QCD corrections are calculated to polarized decay rates Γ^i including all operators of NP.
Both UV and IR divergences appear!

$$\Gamma^{(L,+,-)} = |a_L|^2\Gamma_a^{(L,+,-)} + |b_{LR}|^2\Gamma_b^{(L,+,-)}$$

$$+ 2\mathrm{Re}\{a_L b_{LR}^*\}\Gamma_{ab}^{(L,+,-)} + \langle L\leftrightarrow R, +\leftrightarrow -\rangle$$

	L	$+$	$-$
$\Gamma_a^{i,\mathrm{NLO}}/\Gamma_a^{i,\mathrm{LO}}$	0.90	3.50	0.93
$\Gamma_b^{i,\mathrm{NLO}}/\Gamma_b^{i,\mathrm{LO}}$	0.96	4.71	0.91
$\Gamma_{ab}^{i,\mathrm{NLO}}/\Gamma_{ab}^{i,\mathrm{LO}}$	0.93	3.75	0.92

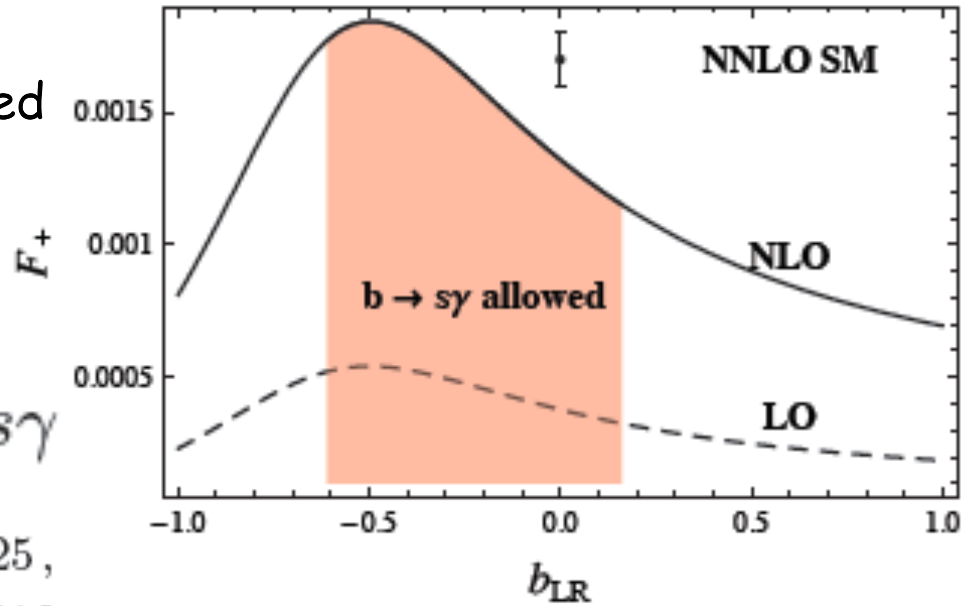
1. Effects on $\mathcal{F}_+$

assumptions: parameters real, considered one at the time;

	SM (δa_L)	a_R	b_{RL}
$\mathcal{F}_+^{\mathrm{NLO}}/10^{-3}$	1.32	1.34	1.34

Constraints are better from $b \to s\gamma$ for

$$-0.13 \le \delta a_L \le 0.03\,, -0.0007 \le a_R \le 0.0025\,,$$
$$-0.61 \le b_{LR} \le 0.16\,, -0.0004 \le b_{RL} \le 0.0016\,.$$

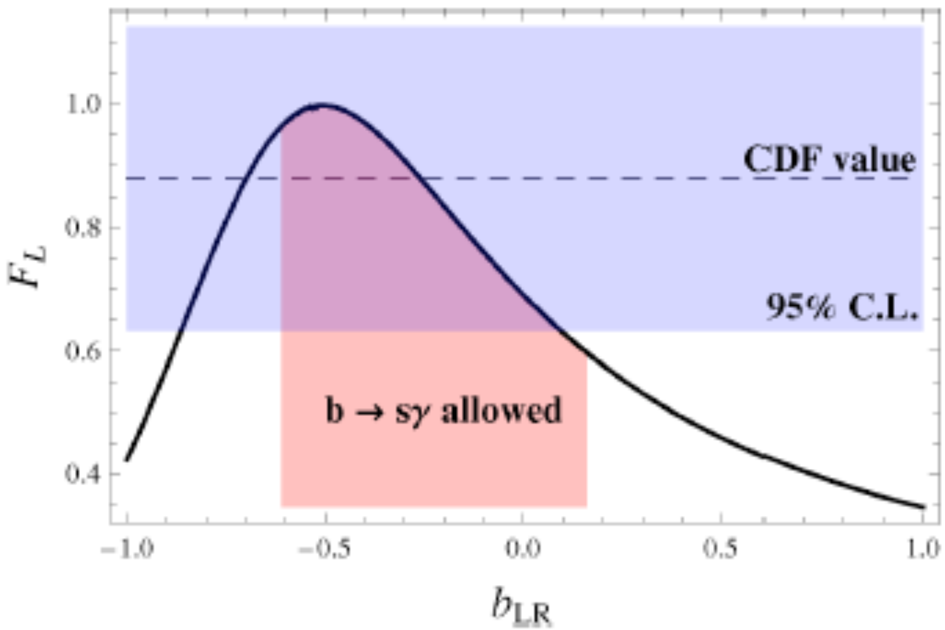


2. Effects on $\mathcal{F}_L$

$\mathcal{F}_L$ - decreased by QCD corrections, 1% in all cases.

bound on b_{LR} is weaker from $b \to s\gamma$

$$\boxed{b_{LR} \quad < \quad 0.09, \;\; 95\% \;\; C.L.(\mathcal{F}_L)}$$
$$b_{LR} \quad < \quad 0.16, \;\; 95\% \;\; C.L. \;\; (b \to s\gamma)$$

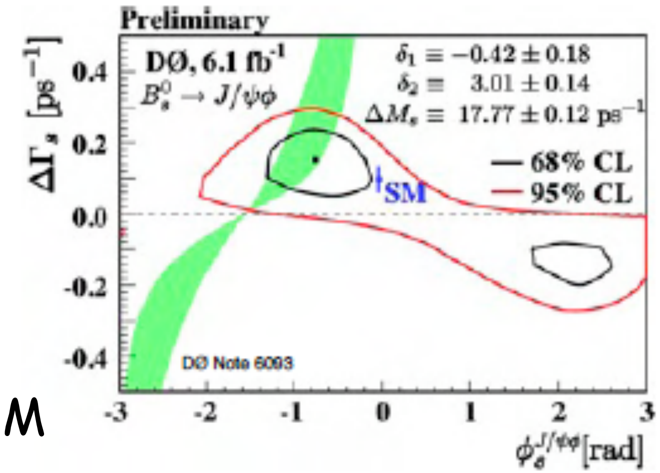


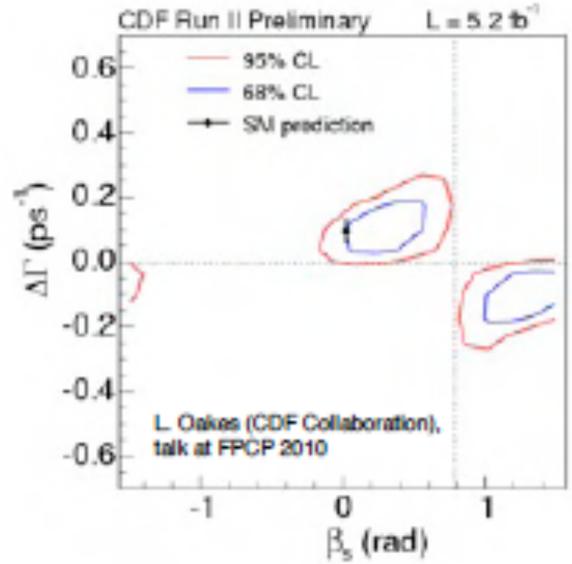
Constraints from B – $\bar{B}$ oscillations

Experimental indication of sizable CPV in B_s :

- mixing induced, significant CPV in $B_s \to J/\psi\, \Phi$ decays;
- evidence for anomalous like-sign dimuon charge asymmetry;

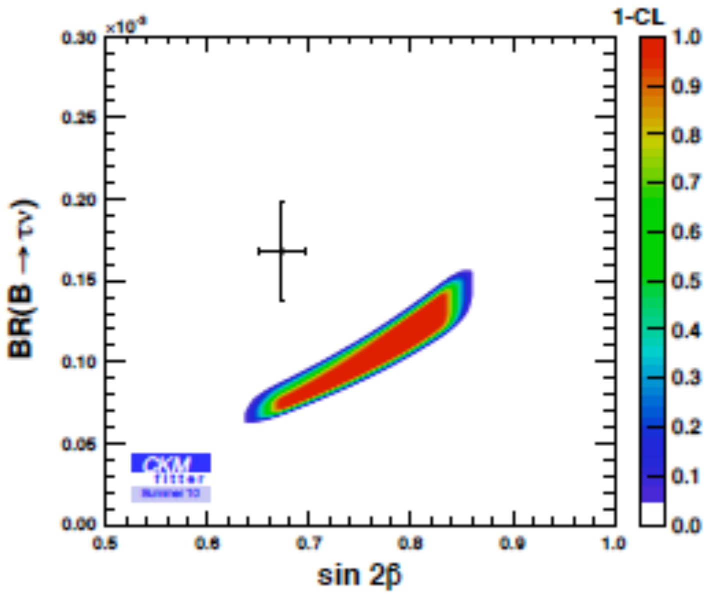
} 3.3 σ from SM





$$a^b_{\rm SL} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} \qquad b\bar{b} \to \mu^+\mu^+ X$$

$$a^b_{\rm SL} = (0.506 \pm 0.043)\, a^d_{\rm SL} + (0.494 \pm 0.043)\, a^s_{\rm SL}$$



Tensions present in the B_d sector

- decay into τ leptons;
- CPV in B_d system;
- B_d mass difference.

} 2.9 σ from SM

Effective Lagrangian describing New Physics

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2}\sum_i C_i Q_i + {\rm h.c.} + \mathcal{O}(1/\Lambda^3)$$

Our goal to accommodate observed CPV in B- system!

Electroweak symmetry breaking in SM induces misalignment of the up and down quark mass basis due to CKM;

NP effects isolated in tWd_j interaction require fine – tuning;

Minimal flavor violation (MFV) $\longrightarrow$ operators are flavor aligned with the up or the down Yukawa couplings

Notation

$$Q_3 = (V^*_{kb} u_{Lk}, b_L),\ Q'_3 = (t_L, V_{ti} d_{iL}),\ \sigma^{\mu\nu} = {\rm i}[\gamma^\mu, \gamma^\nu]/2$$

MFV analyses: following operator basis

$$
\begin{aligned}
Q_{LL} &= [\bar{Q}'_3\tau^a\gamma^\mu Q'_3](\phi_d^\dagger\tau^a \mathrm{i}D_\mu\phi_d) - [\bar{Q}'_3\gamma^\mu Q'_3](\phi_d^\dagger \mathrm{i}D_\mu\phi_d), \\
Q_{LRt} &= [\bar{Q}'_3\sigma^{\mu\nu}\tau^a t_R]\phi_u W^a_{\mu\nu}, \\
Q_{RR} &= V_{tb}[\bar{t}_R\gamma^\mu b_R](\phi_u^\dagger \mathrm{i}D_\mu\phi_d), \\
Q_{LRb} &= [\bar{Q}_3\sigma^{\mu\nu}\tau^a b_R]\phi_d W^a_{\mu\nu},
\end{aligned}
$$

Operators invariant on SM gauge group, no FCNC at tree level; P.J. Fox et al, 0704.1482 Q.H. Cao et al. 2007; Gzandkowski and Misiak, 0802.1413

$$
\begin{aligned}
Q'_{LL} &= [\bar{Q}_3\tau^a\gamma^\mu Q_3](\phi_d^\dagger\tau^a \mathrm{i}D_\mu\phi_d) - [\bar{Q}_3\gamma^\mu Q_3](\phi_d^\dagger \mathrm{i}D_\mu\phi_d), \\
Q''_{LL} &= [\bar{Q}'_3\tau^a\gamma^\mu Q_3](\phi_d^\dagger\tau^a \mathrm{i}D_\mu\phi_d) - [\bar{Q}'_3\gamma^\mu Q_3](\phi_d^\dagger \mathrm{i}D_\mu\phi_d), \\
Q'_{LRt} &= [\bar{Q}_3\sigma^{\mu\nu}\tau^a t_R]\phi_u W^a_{\mu\nu},
\end{aligned}
$$

present in models with large bottom- Yukawa effects A. Kagan et al. 0903.1794

Matching to low- energy effective Lagrangian

$$
\mathcal{L}_{\rm eff} = -\frac{G_F^2 m_W^2}{4\pi^2}(V_{tb}V^*_{td,s})^2\sum_{i=1}^{5} C_i(\mu) Q_i^{d,s}
$$

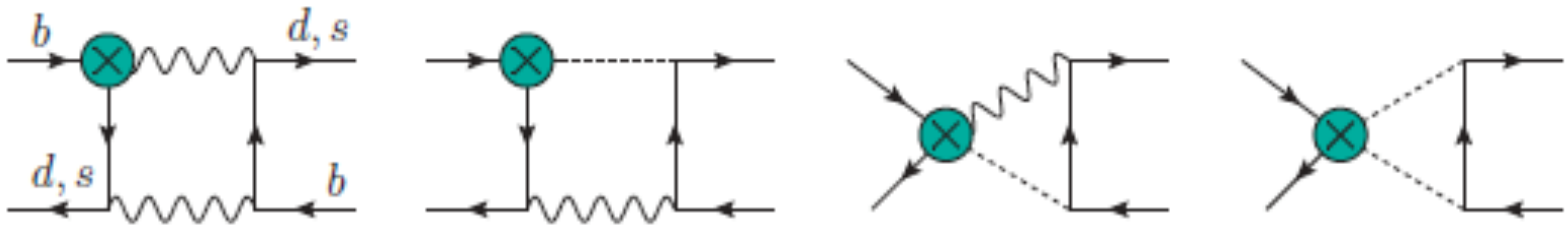
D. Bećirević et al., hep-ph/0112303

In numerical study $C_1(m_b) = 0.840\, C_1(m_t)$

A.J. Buras et al., hep-ph/0102316

Anomalous tbW coupling in B oscillations

ΔM_B



$$M_{12}^{(d,s)} = M_{12}^{(d,s)\mathrm{SM}}\,\Delta_{d,s}$$

Z. Ligeti et al., 1006.0432
A. Lenz et al. (CKMfitter group) 1008.1593

$\Delta_{d,s} \neq 1$ disfavoured!

$\Delta_{d,s} \neq 1$ can be explained by the presence of anomalous tWb couplings!

Set of dimension 6 operators contribute $\Delta_{d,s}$

$$\boxed{\begin{aligned}\Delta_{d,s} &= 1 - 2.57\,\mathrm{Re}\{\kappa_{LL}\} + 2.00\,\kappa'_{LL} - 1.29\,\kappa''_{LL} - 1.54\,\mathrm{Re}\{\kappa_{LRt}\} \\ &- 0.77\,\kappa'_{LRt} + \{4.48_d, 4.46_s\}\kappa^2_{RR} + \{4.15_d, 4.13_s\}\kappa^2_{LRb}\,,\end{aligned}}$$

J. Drobnak, S.F., J.F. Kamenik, 1102.4347

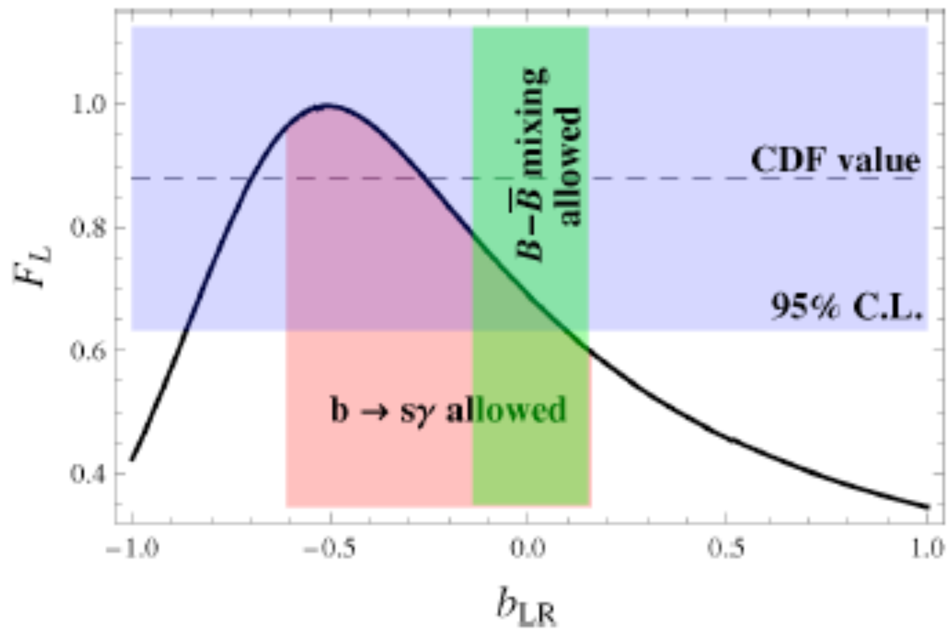
Using fitted values of $\Delta_{d,s}$ from CKM fitter group (1008.1593), we analyzed one operator at the time

a)
$$\left.\begin{aligned}\kappa_{LL} &= \frac{C_{LL}}{\Lambda^2\sqrt{2}G_F} \\ \kappa_{LRt} &= \frac{C_{LRt}}{\Lambda^2 G_F}\end{aligned}\right\}$$

do not give contribution to new CPV phase

new bounds are obtained
$$\left\{\begin{aligned} -0.082 < \kappa_{LL} < 0.078\,, &\quad \text{at 95\% C.L.}\,, \\ -0.14 < \kappa_{LRt} < 0.13\,, &\quad \text{at 95\% C.L.}\,. \end{aligned}\right.$$

combined B physics constraints + CDF value



b)

$$\kappa_{RR} = \frac{C_{RR}}{\Lambda^2 2\sqrt{2} G_F}$$

$$\kappa_{LRb} = \frac{C_{LRb}}{\Lambda^2 G_F}$$

- severely constrained by b -> s γ;
- do not contribute significantly to $\Delta_{d,s}$.

c)

$$\kappa_{LL}^{\prime(\prime\prime)} = \frac{C_{LL}^{\prime(\prime\prime)}}{\Lambda^2 \sqrt{2} G_F}$$

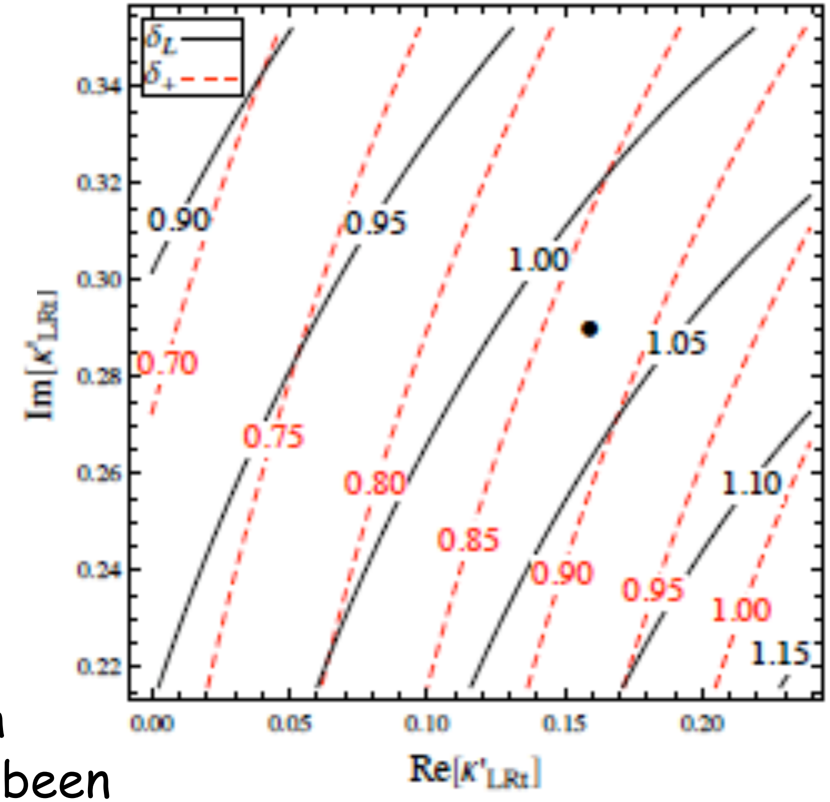
$$\kappa'_{LRt} = \frac{C'_{LRt}}{\Lambda^2 G_F}$$

not overly constrained by b -> s γ;

	Re	Im
κ'_{LL}	$-0.062^{+0.063}_{-0.030}$	$-0.110^{+0.029}_{-0.024}$
κ''_{LL}	$0.097^{+0.048}_{-0.098}$	$0.180^{+0.037}_{-0.044}$
κ'_{LRt}	$0.160^{+0.079}_{-0.160}$	$0.290^{+0.062}_{-0.074}$

Central value and 1 σ interval

$\delta_L \equiv \mathcal{F}_L/\mathcal{F}_L^{\rm SM} \quad \delta_+ \equiv \mathcal{F}_+/\mathcal{F}_+^{\rm SM}$



- contributions to B – B̄ at LO can be complex and can accommodate CPV anomalies;

- the bound on κ_{LL} is similar in both cases, while the bound on $\kappa'_{L,Rt}$ has been considerably improved in the case of B system oscillations;

- $\kappa'_{L,Rt}$ will affect $\mathcal{F}_i$ measurements;

up to 30% change in $\mathcal{F}_+$ and up to 15% in $\mathcal{F}_L$

Are there any model of NP leading to anomalous tbW couplings?

W. Bernreuther et al, 0812.1643:

- 2HD model
- MSSM

magnitudes of $a_L, \quad b_{LR}$ by <1%

- TC2
- Little Higgs Model

top quark plays special role

In TC2 model a_L can be reduced significantly, implying reduction of top width by ~ 10%

Summary and outlook

1. Helicity amplitude corresponding transverse polarization of W boson can reach maximum value of 2 per-mille in the presence of a non SM effective operators;

2. QCD correction increases contribution the new operator, since it lifts suppression of the leading order result;

3. Indirect constraints coming from $B \to X_s \gamma$ already severely constrain NP contribution;

4. We set new bound on b_{LR} lowering previous bound coming from $B \to X_s \gamma$

5. Anomalous top couplings might affect $B - \bar{B}$ mixing (competitive constraints to tbW ;

6. MFV models with large bottom Yukawa coupling could accommodate the latest global fits – complex Wilson coefficients;

7. Helicity amplitudes could be probed in single top production at LHC.

Additional slide

SM flavor group $\mathcal{G}^{\rm SM} = U(3)_Q \times U(3)_u \times U(3)_d$

Spurion fields transform as: $(3,\bar{3},1)$ and $(3,1,\bar{3})$

Most general quark flavor bilinears $\bar{u} Y_u^\dagger \mathcal{A}_{ud} Y_d d\,, \quad \bar{Q} \mathcal{A}_{QQ} Q\,, \quad \bar{Q} \mathcal{A}_{Qu} Y_u u\,, \quad \bar{Q} \mathcal{A}_{Qd} Y_d d\,,$

Large bottom Yukawa effects:
Insertion of $Y_d Y_d^\dagger$ $\bar{Q}_3 Q_3\,, \qquad \bar{Q}_3 V_{tb}^* V_{tj} Q_j$

$\mathcal{A}_{xy}$ polinomials of $Y_u Y_u^\dagger$ and/or $Y_d Y_d^\dagger$

$\langle Y_d \rangle = {\rm diag}(m_d, m_s, m_b)/v_d$ and $\langle Y_u \rangle = V^\dagger {\rm diag}(m_u, m_c, m_t)/v_u$

$\mathrm{Tr}[A_{ij}\, Y_u Y_u^\dagger\, Y_d Y_d^\dagger] \neq 0$ Blum et al., 0903.2118 condition for CPV