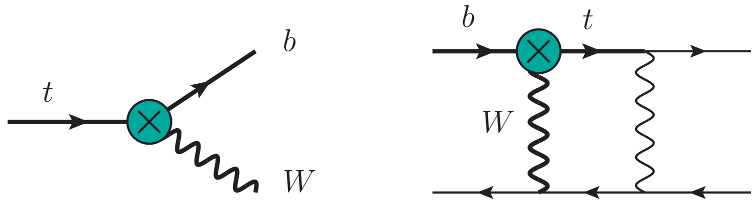
Anomalous tWb couplings

Interplay of top and bottom physics



Jure Drobnak

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9. 6. 2011, Perugia, Italy

PLHC 2011

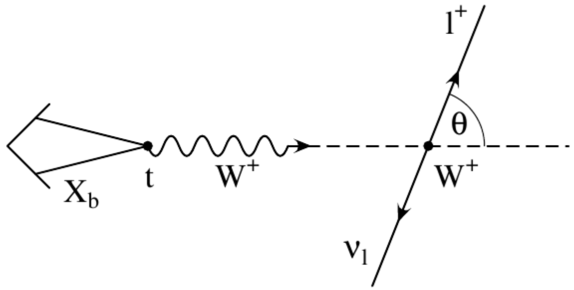
Outline of the talk

- Anomalous tWb couplings and top quark decays.
  - Effects on helicity fractions of W boson.
  - Analysis at NLO in QCD.
  - Direct constraints.
- Anomalous tWb couplings and $B_{d,s} - \bar{B}_{d,s}$ mixing.
  - Effects on the the mixing amplitude M_{12}.
  - Can these effects comply with the favored non-SM M_{12} values from recent fits?
  - If so, what kind of helicity fractions do they predict? $\leftarrow$ interplay
- Conclusions.

Helicity fractions of W boson in $t \to bW$

- We can split the decay width $\Gamma(t \to Wb)$ with respect to the polarization of the W boson.

$$\Gamma_{t \to bW} \quad = \quad \Gamma_L + \Gamma_- + \Gamma_+ \, , \qquad \mathcal{F}_i = \Gamma_i / \Gamma \, .$$



- Helicity fractions $\mathcal{F}_i$ are accessible through angular distribution of final state leptons **M. Fischer et al.** hep-ph/0011075 .

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

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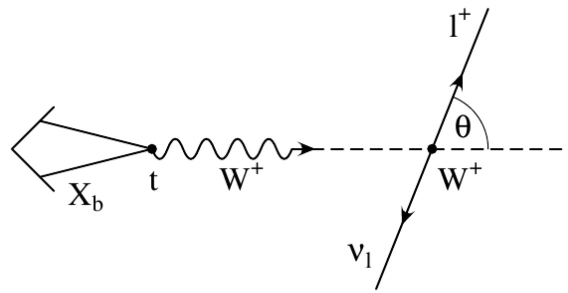

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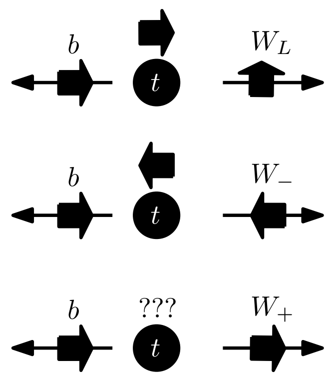
Theory side

- The "transverse plus" component is highly suppressed!
- Non-zero $\mathcal{F}_+$ in SM comes from QCD and EW corrections, $m_b \neq 0$.

$$\mathcal{F}_L^{\mathrm{SM}} = 0.687(5) \qquad \mathcal{F}_+^{\mathrm{SM}} = 0.0017(1)$$

A. Czarnecki et al. 1005.2625 **H. S. Do et al.** hep-ph/0209185 **M. Fischer et al.** hep-ph/0101322



- Measured $\mathcal{F}_+ > 0.2\%$ would indicate new physics effect!

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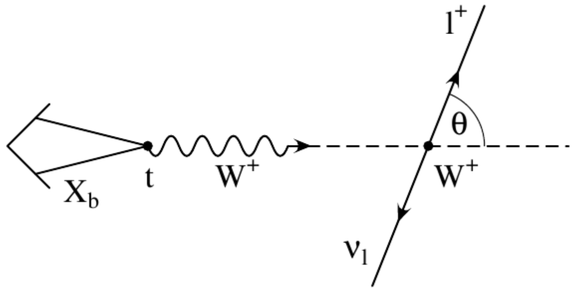

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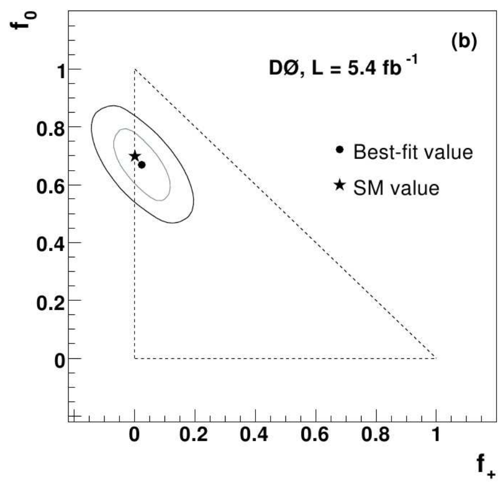
Experiment side

- Most recent measurements from Tevatron

$\mathcal{F}_L = 0.88(13) \qquad \mathcal{F}_+ = -0.15(9)$ **CDF** 1003.0224

$\mathcal{F}_L = 0.67(10) \qquad \mathcal{F}_+ = 0.023(53)$ **D0** 1011.6549

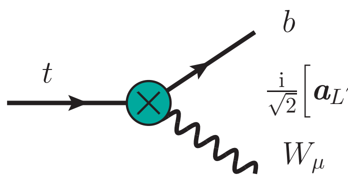


- Projected sensitivity for LHC ($L = 10\text{fb}^{-1}$)

$\sigma(\mathcal{F}_+) = \pm 0.002 \qquad \sigma(\mathcal{F}_L) = \pm 0.02$ **J. A. Aguilar-Saavedra et al.** 0705.3041

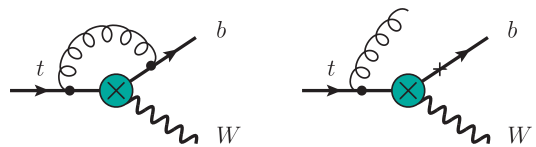
NP in tWb: effects on $\mathcal{F}_i$

- Most general parameterization of tWb vertex. **J. A. Aguilar-Saavedra** 0811.3842



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

- Helicity surpression in $\mathcal{F}_+$ present also in anomalous contributions.
- This mandates analysis at NLO in QCD.
  J. Drobnak, J. F. Kamenik, S. Fajfer 1010.2402



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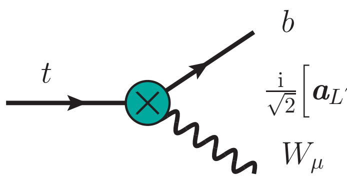

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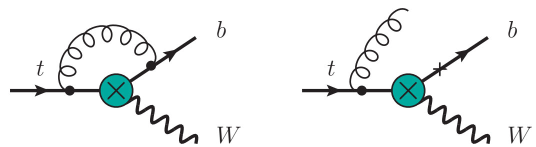

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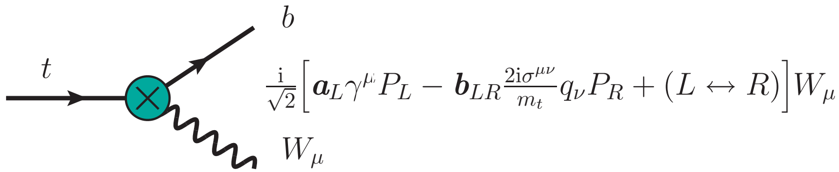

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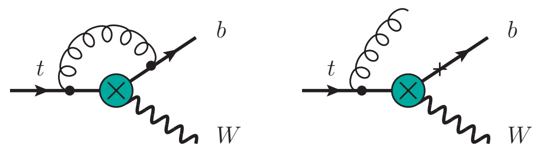

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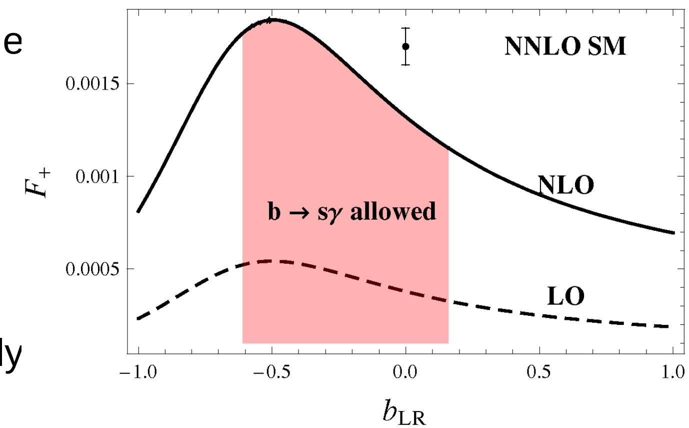
  Highest allowed effects on $\mathcal{F}_+$ given in the table and in the graph.

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

  Presence of anomalous tWb can not significantly change $\mathcal{F}_+$!



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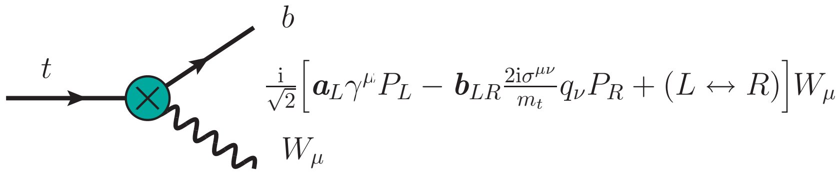

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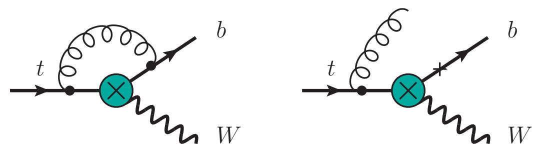

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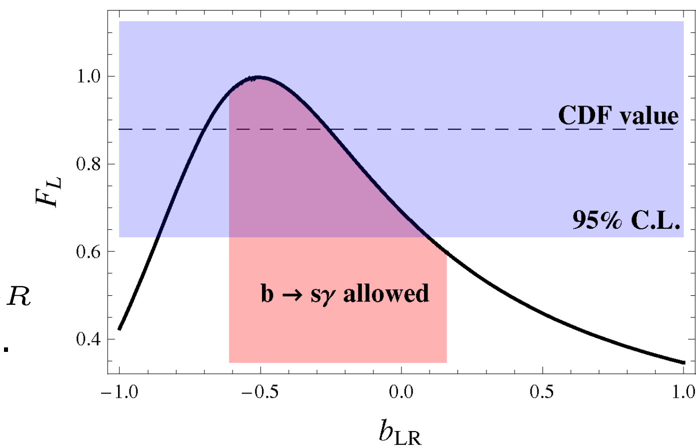
$$b_{LR} < 0.09\,,\ 95\%\ \text{C.L. from } \mathcal{F}_L$$
$$b_{LR} < 0.16\,,\ 95\%\ \text{C.L. from } b\to s\gamma$$

CDF measurement of $\mathcal{F}_L$ puts a bound on b_{LR} that is *competitive* with indirect $b\to s\gamma$ constraints.



$B_{d,s} - \bar{B}_{d,s}$ *mixing*

- Tevatron experiments quantifying B_s sector.

  Some indications of NP

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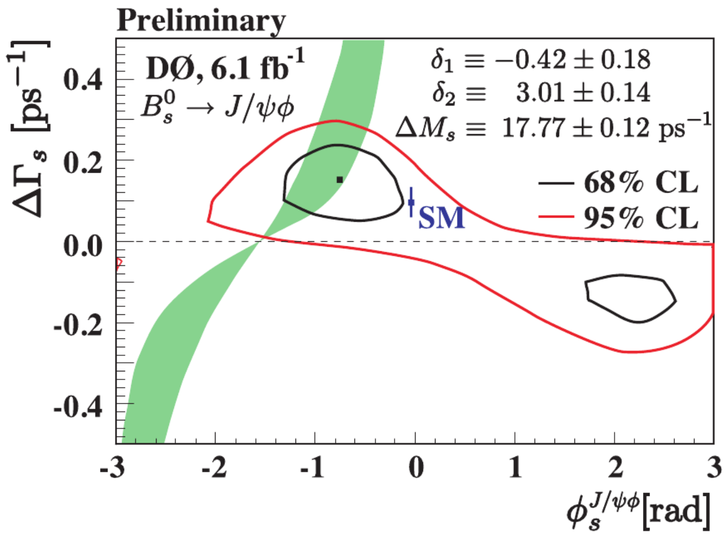
D0
Note 6093-CONF

CDF
Public Note 10206



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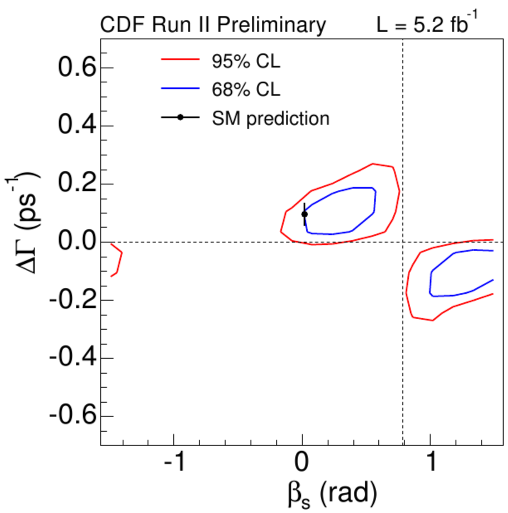

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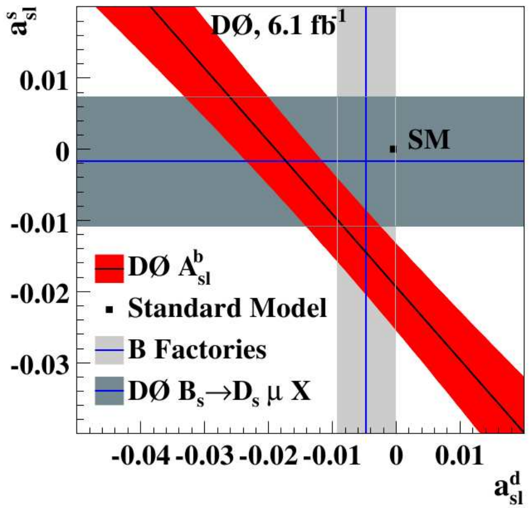
  D0 Note 6093-CONF   **CDF** Public Note 10206

- Dimuon charge asymmetry. **D0** 1007.0395



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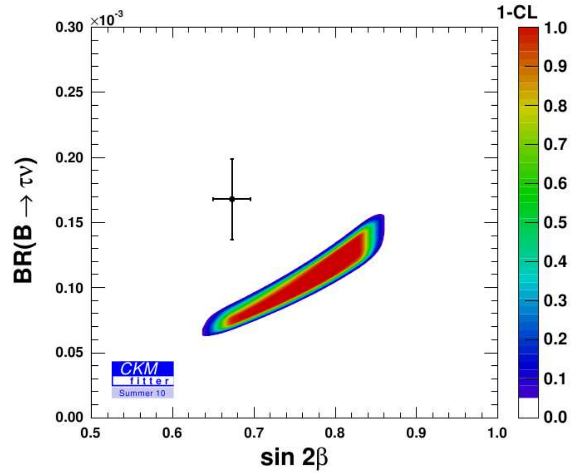

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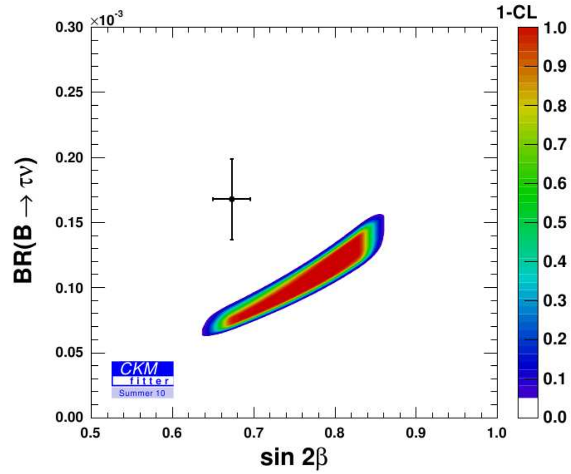

- Could NP be hiding in $B_{d,s} - \bar{B}_{d,s}$ mixing?

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

- Analyzed and found consistency with present data with $\Delta_{d,s} = 1$ disfavored!

  Z. Ligeti, M. Papucci, G. Perez, J. Zupan 1006.0432 **A. Lenz, U. Nierste and CKMfitter group** 1008.1593

NP in tWb: $B_{d,s} - \bar{B}_{d,s}$ mixing

- Anomalous tWb can cause $\Delta_{d,s} \neq 1$!
- Effective vertex notation sufficient for setting direct constraints from $t \to Wb$ decays.
- For indirect constraints we take a step further: effective theory, described by the Lagrangian

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

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- Restrictions:
  - Dim. 6 operators, invariant under SM gauge group, involving charged quark currents with W.
  - Minimal Flavor Violation.
  - Rid tree level FCNCs in down sector and flavor universal interactions affecting G_F.

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Lowest order in down Yukawa

$$\begin{aligned}
\mathcal{Q}_{RR} &= V_{tb}[\bar{t}_R\gamma^\mu b_R]\big(\phi_u^\dagger \mathrm{i} D_\mu \phi_d\big)\,,\\
\mathcal{Q}_{LL} &= [\bar{Q}_3'\tau^a\gamma^\mu Q_3']\big(\phi_d^\dagger\tau^a \mathrm{i} D_\mu \phi_d\big)\\
&- [\bar{Q}_3'\gamma^\mu Q_3']\big(\phi_d^\dagger \mathrm{i} D_\mu \phi_d\big),\\
\mathcal{Q}_{LRt} &= [\bar{Q}_3'\sigma^{\mu\nu}\tau^a t_R]\phi_u W^a_{\mu\nu}\,,\\
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\end{aligned}$$

Same operator bases used in $b \to s\gamma$ decays

B. Grzadkowski, M. Misiak

0802.1413

Higher order in down Yukawa

A. L. Kagan, G. Perez, T. Volansky, J. Zupan

0903.1794

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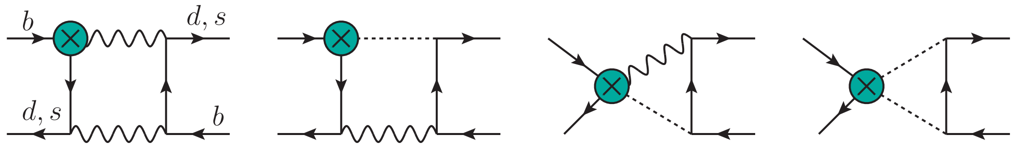
- $\mathcal{Q}'_{LL}$ and $\mathcal{Q}_{LRb}$ modify also uWb and cWb couplings

Anomalous tWb couplings and M_{12}

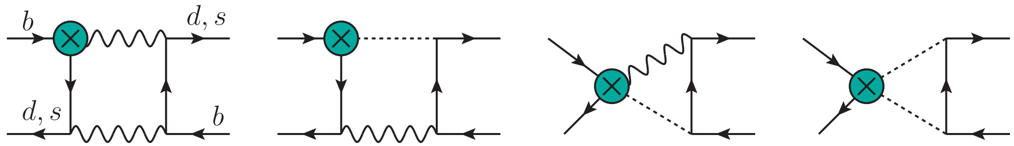


- The set of our seven dim-six operators contribute to $\Delta_{d,s}$ J. Drobnak, J. F. Kamenik, S. Fajfer 1102.4347

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

- Analyze one operator at the time, use fitted values of $\Delta_{d,s}$ from A. Lenz, U. Nierste and CKMfitter group 1008.1593 .

Anomalous tWb couplings and M_{12}



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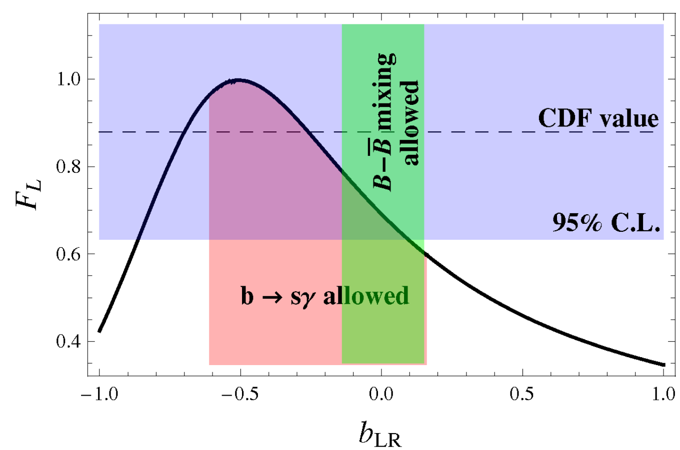
$$- 0.77\,\kappa'_{LRt} + \{4.48_d, 4.46_s\}\kappa^2_{RR} + \{4.15_d, 4.13_s\}\kappa^2_{LRb}\,,$$

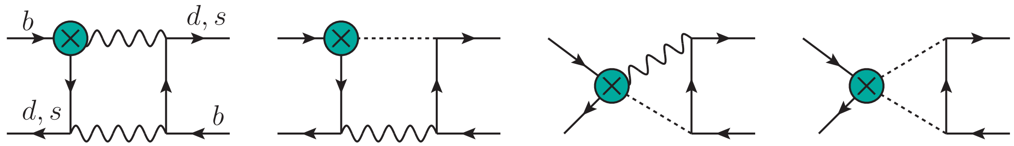
- Analyze one operator at the time, use fitted values of $\Delta_{d,s}$ from A. Lenz, U. Nierste and CKMfitter group 1008.1593 .

1) $\kappa_{LL} = \frac{C_{LL}}{\Lambda^2\sqrt{2}G_F}$ and $\kappa_{LRt} = \frac{C_{LRt}}{\Lambda^2 G_F}$ can not contribute new CPV phases.
New bounds obtained

$$-0.082 < \kappa_{LL} < 0.078\,, \quad \text{at 95\% C.L.}\,,$$
$$-0.14 < \kappa_{LRt} < 0.13\,, \quad \text{at 95\% C.L.}\,.$$



Anomalous tWb couplings and M_{12}



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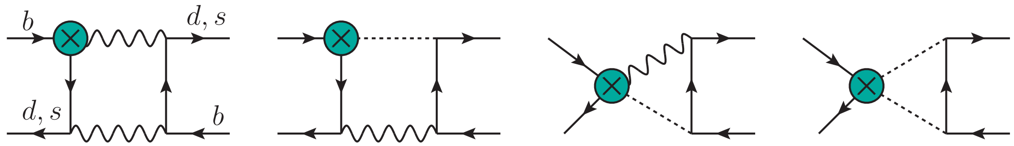
2) $\kappa_{RR} = \frac{C_{RR}}{\Lambda^2 2\sqrt{2}G_F}$ and $\kappa_{LRb} = \frac{C_{LRb}}{\Lambda^2 G_F}$ severely constrained by $b \to s\gamma$. Contribute to mixing only upon two insertions. No considerable effect on $\Delta_{d,s}$.

Anomalous tWb couplings and M_{12}



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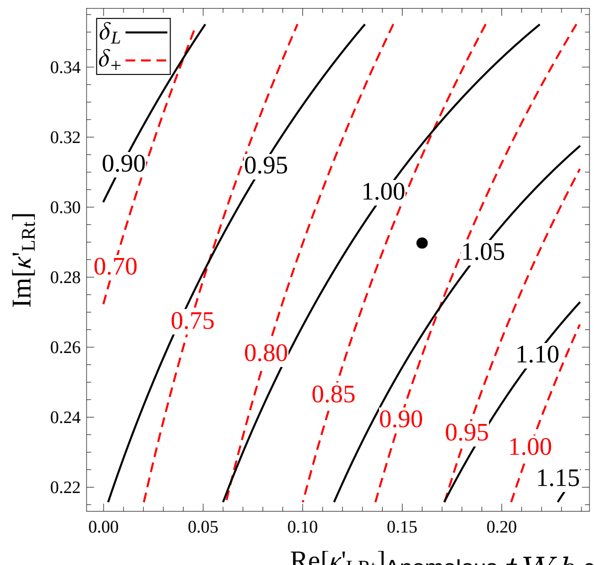
3) $\kappa'^{('')}_{LL} = \frac{C'^{('')}_{LL}}{\Lambda^2\sqrt{2}G_F}$ and $\kappa'_{LRt} = \frac{C'_{LRt}}{\Lambda^2 G_F}$ not overly constrained by $b \to s\gamma$.

	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 fitted values and 1σ intervals

- Up to 30% change in $\mathcal{F}_+$
- Up to 15% change in $\mathcal{F}_L$



Conclusions

- Helicity fractions can give information about tWb coupling
  - Possible measured $\mathcal{F}_+ \gg 0.1\%$ can not be explained by a simple effective vertex.
  - Latest measurements of $\mathcal{F}_L$ give direct bounds on anomalous dipole couplings competitive with indirect bounds from $b \to s\gamma$ (MFV).

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- Anomalous top coupling affect $B - \bar{B}$ mixing.
  - For MFV models with small bottom Yukawa effects, the bounds are competitive, in some cases improved, compared to bounds from $b \to s\gamma$.
  - MVF models with large bottom Yukawa effects could accommodate the latest global fits (complex Wilson coefficients).

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  - Possible measured $\mathcal{F}_+ \gg 0.1\%$ can not be explained by a simple effective vertex.
  - Latest measurements of $\mathcal{F}_L$ give direct bounds on anomalous dipole couplings competitive with indirect bounds from $b \to s\gamma$ (MFV).
- Anomalous top coupling affect $B - \bar{B}$ mixing.
  - For MFV models with small bottom Yukawa effects, the bounds are competitive, in some cases improved, compared to bounds from $b \to s\gamma$.
  - MVF models with large bottom Yukawa effects could accommodate the latest global fits (complex Wilson coefficients).
  - Favored non-zero dipole Wilson coefficient affects the helicity fractions!

Extra slides: MFV framework

- Lagrangian formally invariant under the SM flavor group $\mathcal{G}^{\rm SM} = U(3)_Q \times U(3)_u \times U(3)_d$
- Only $\mathcal{G}^{\rm SM}$ symmetry breaking spurionic fields in the theory are the up and down quark Yukawa matrices $Y_{u,d}$, formally transforming as $(3, \bar{3}, 1)$ and $(3, 1, \bar{3})$ respectively.
- Most general $\mathcal{G}^{\rm SM}$ invariant quark bilinear flavor structures

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

  where $\mathcal{A}_{xy}$ are arbitrary polynomials 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 $\langle Y_u \rangle = V^\dagger {\rm diag}(m_u, m_c, m_t)/v_u$

Extra slides: MFV framework

Linear MFV

- Simplest case of linear MFV where within $\langle \mathcal{A}_{xy} \rangle$ higher powers of $\langle Y_d Y_d^\dagger \rangle \simeq \mathrm{diag}(0, 0, m_b^2/v_d^2)$ can be neglected. Neglecting also contributions suppressed by first and second generation quark masses, the only relevant flavor contributions of the arbitrary $\mathcal{A}_{xy}$ structures

$$\bar{t}_R V_{tb} b_R \,, \qquad \bar{Q}_i Q_i \,, \qquad \bar{Q}_i V_{ti}^* V_{tj} Q_j \,,$$

$$\bar{Q}_i V_{ti}^* t_R \,, \qquad \bar{Q}_3 b_R \,, \qquad \bar{Q}_i V_{ti}^* V_{tb} b_R \,.$$

Extra slides: MFV framework

Non-Linear MFV

- Generalization to MFV scenarios where large bottom Yukawa effects can be important.
- Higher powers of $\langle Y_d Y_d^\dagger \rangle$ within $\mathcal{A}_{xy}$ effectively project to the third generation in the down sector yielding the following additional flavor structures

$$\bar{Q}_3 Q_3 \,, \qquad \bar{Q}_3 V_{tb}^* V_{tj} Q_j \,, \qquad \bar{Q}_3 V_{tb}^* t_R \,.$$

Basis independence

Example: $\bar{Q} A_{QQ} Q \to \bar{Q}_i \langle Y_u Y_u^\dagger \rangle_{ij} Q_j$

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- **Up-Yukawa diagonal**

$$\langle Y_u Y_u^\dagger \rangle_{ij} = \delta_{3i}\delta_{3j}\,\frac{m_t^2}{v^2}\,, \qquad Q_i = \begin{pmatrix} u_i \\ V_{ik}\,d_k \end{pmatrix}$$

$$\bar{Q}_i \langle Y_u Y_u^\dagger \rangle_{ij} Q_j = \frac{m_t^2}{v^2}\,\bar{Q}_3 Q_3 = \frac{m_t^2}{v^2}\,(\bar{t}, V_{3k}^*\bar{d}_k)\begin{pmatrix} t \\ V_{3k}\,d_k \end{pmatrix}$$

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- **Down-Yukawa diagonal**

$$\langle Y_u Y_u^\dagger \rangle_{ij} = V_{3i}^* V_{3j} \frac{m_t^2}{v^2} \,, \qquad Q_i = \begin{pmatrix} V_{ki}^* u_k \\ d_i \end{pmatrix}$$

$$\begin{aligned} \bar{Q}_i \langle Y_u Y_u^\dagger \rangle_{ij} Q_j &= \bar{Q}_i \frac{m_t^2}{v^2} V_{3i}^* V_{3j} Q_j = \frac{m_t^2}{v^2} (V_{mi} \bar{u}_m, \bar{d}_i) V_{3i}^* V_{3j} \begin{pmatrix} V_{nj}^* u_n \\ d_j \end{pmatrix} \\ &= \frac{m_t^2}{v^2} (\bar{t}, V_{3i}^* \bar{d}_i) \begin{pmatrix} t \\ V_{3j} d_j \end{pmatrix} \end{aligned}$$

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$$\bar{Q}_i \langle Y_u Y_u^\dagger \rangle_{ij} Q_j = \frac{m_t^2}{v^2} \bar{Q}_3 Q_3 = \frac{m_t^2}{v^2} (\bar{t}, V_{3k}^* \bar{d}_k) \begin{pmatrix} t \\ V_{3k} d_k \end{pmatrix}$$

- **Down-Yukawa diagonal**

$$\langle Y_u Y_u^\dagger \rangle_{ij} = V_{3i}^* V_{3j} \frac{m_t^2}{v^2} \,, \qquad Q_i = \begin{pmatrix} V_{ki}^* u_k \\ d_i \end{pmatrix}$$

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