Top polarization at LHC and New Physics

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16/03/2011, Moriond EW

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Outline

- Interplay of NP CPV in $B_{s,d}$ systems and W polarization in $t \to b W$ decays
    - Parametrizing NP in $t\ b\ W$ interactions
    - Direct vs. indirect sensitivity to anomalous $t\ b\ W$ couplings

New physics in t→bW?

- The branching ratio is sensitive to the values of V_{tx} CKM elements

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

$$\mathcal{B}^{SM} \simeq \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{ts}|^2 + |V_{td}|^2}$$

J. Alwall et al.
hep-ph/0607115

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- Helicity fractions of the final state *W* provide additional information on the structure of the *tbW* coupling

$$\Gamma_{t\to Wb} = \frac{m_t}{16\pi} \frac{g^2}{2} \sum_i \Gamma^i \qquad \begin{array}{rcl} \mathcal{F}_L & \equiv & \Gamma^L/\Gamma \\ \mathcal{F}_\pm & \equiv & \Gamma^\pm/\Gamma \end{array} \qquad \sum_i \mathcal{F}_i = 1$$

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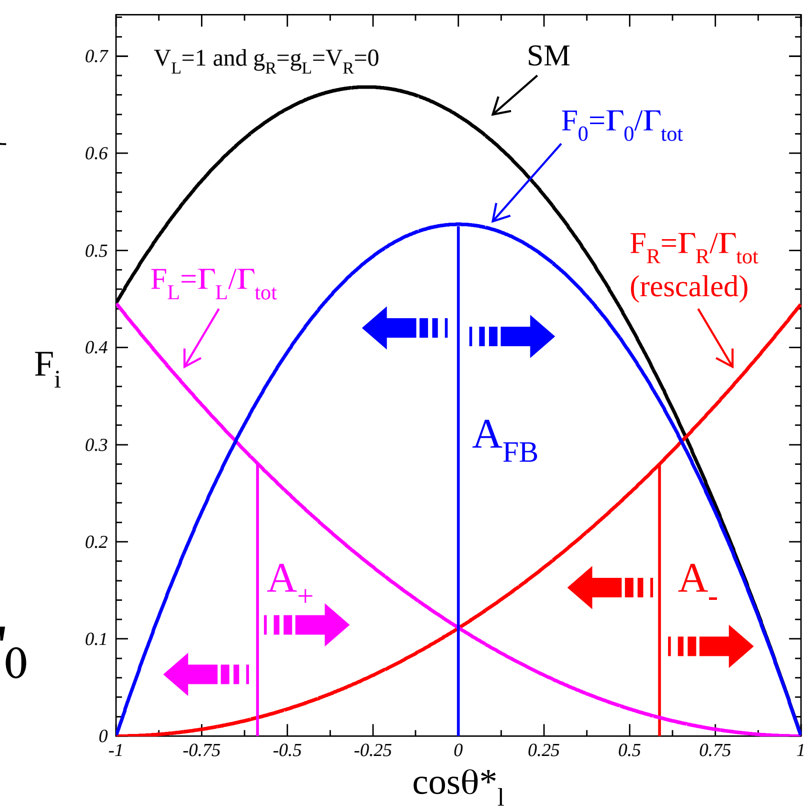
- Can be determined using angular distribution of charged leptons in *W* decay

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*_\ell} = \frac{3}{8}(1+\cos\theta^*_\ell)^2 F_R + \frac{3}{8}(1-\cos\theta^*_\ell)^2 F_L + \frac{3}{4}\sin^2\theta^*_\ell F_0$$

N. de Castro, CERN-THESIS-2008-083



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- Recently measured at the Tevatron

$$\begin{aligned} \mathcal{F}_L &= 0.88(13) \\ \mathcal{F}_+ &= -0.15(9) \end{aligned}$$

CDF [1003.0224]

$$\begin{aligned} \mathcal{F}_L &= 0.67(10) \\ \mathcal{F}_+ &= 0.023(53) \end{aligned}$$

D0 [1011.6549]

- Expected precision at the LHC better than 1%

J. A. Aguilar-Saavedra et al. [0705.3041]
N. de Castro, CERN-THESIS-2008-083

New physics in t→bW?

- F_+ especially interesting probe - helicity suppressed in the SM
  - zero at LO in QCD and for vanishing b-quark mass
  - m_b dependence, α_s, $\alpha_s m_b$, α_s^2 and EW corrections known

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

H.S. Do et al., hep-ph/0209185
M. Fischer et al., hep-ph/0011075, hep-ph/0101322
A. Czarnecki et al., 1005.2625

- Measurement of F_+ larger than 0.2% would be indication of new physics
  - What kind of new physics?

t-b-W interaction beyond the SM

- Analyze using EFT: $$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2}\sum_i C_i \mathcal{Q}_i + {\rm h.c.} + \mathcal{O}(1/\Lambda^3)$$
  - Operators invariant under SM gauge group, free of tree-level FCNCs

B. Grzadkowski and M. Misiak, 0802.1413

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

...

$$\bar{Q}_3' = \bar{Q}_i V_{ti}^*$$

  - EWSB induces misalignment between components of Q_3
  - Isolation to only single flavor transition generally not stable
  - Can be controlled within the MFV approach

J. Drobnak, S. Fajfer & J.F.K., 1102.4347

    - Restricted set of 7 dominant charged current operators beyond SM

t-b-W interaction beyond the SM

- Analyze using EFT: $\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda^2}\sum_i C_i \mathcal{Q}_i + \text{h.c.} + \mathcal{O}(1/\Lambda^3)$
  - Operators invariant under SM gauge group, free of tree-level FCNCs

(a)

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

...

$$\bar{Q}'_3 = \bar{Q}_i V^*_{ti}$$

(b)

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

} present in models with large bottom Yukawa

t-b-W interaction beyond the SM

- In $t \to bW$ all operator contributions reduce to 4 chirality structures

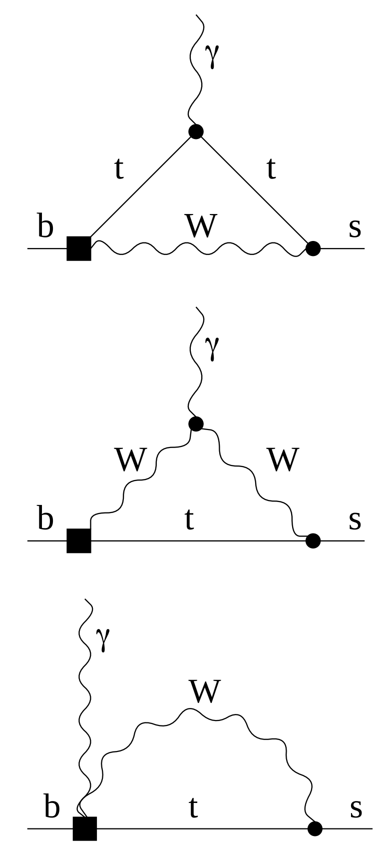
$$\mathcal{O}_L = \frac{g}{\sqrt{2}} W_\mu \left[\bar{b}_L \gamma^\mu t_L\right], \qquad \mathcal{O}_{LR} = \frac{g}{\sqrt{2}} W_{\mu\nu} \left[\bar{b}_L \sigma^{\mu\nu} t_R\right].$$

+ helicity flipped operators

$$\left(\begin{aligned} a_L &= \frac{v^2}{\Lambda^2} C_L = a_L^{\rm SM} + \delta a_L = V_{tb} + \delta a_L\,, \\ a_R &= \frac{v^2}{\Lambda^2} C_R\,, \qquad b_{LR,RL} = \frac{v m_t}{\Lambda^2} C_{LR,RL}\,, \end{aligned} \right)$$

- Same operators enter FCNC mediated B decays at one-loop

B. Grzadkowski and M. Misiak, 0802.1413



  - b→sγ especially sensitive since known to 7% in SM

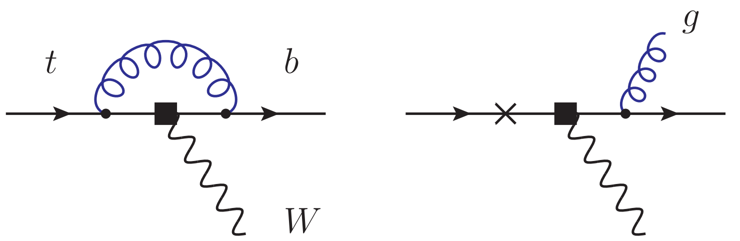
  - (Real) anomalous *t-b-W* interactions of class (a) analyzed at single insertion [Similar bounds also for real contributions of class (b)]

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

t→bW beyond the SM at NLO in QCD

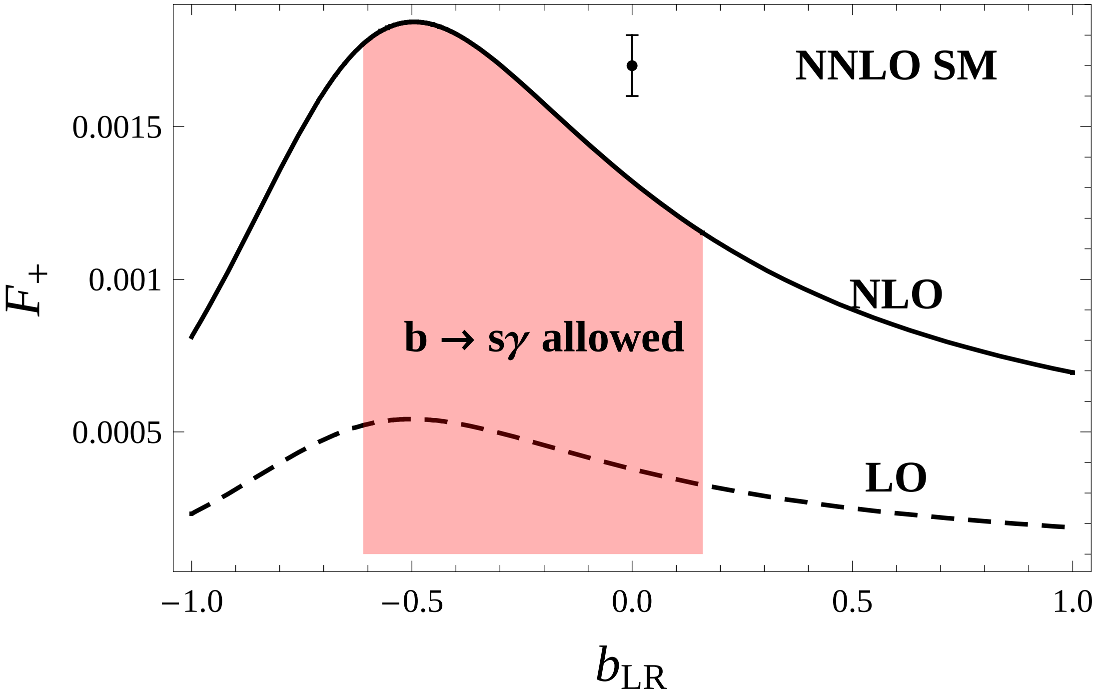
J. Drobnak, S. Fajfer & J.F.K., 1010.2402

- O_{LR} contributions to F_+ exhibit same helicity suppression as SM
  - mandates analysis at NLO in QCD



  - Taking into account indirect bounds on a_i, b_i from $b\to s\gamma$ estimate maximum enhancement possible

	SM (δa_L)	a_R	b_{RL}
$\mathcal{F}_+^{\rm NLO}/\mathcal{F}_+^{\rm LO}$	3.49	3.40	3.38
$\mathcal{F}_+^{\rm NLO}/10^{-3}$	1.32	1.34	1.34



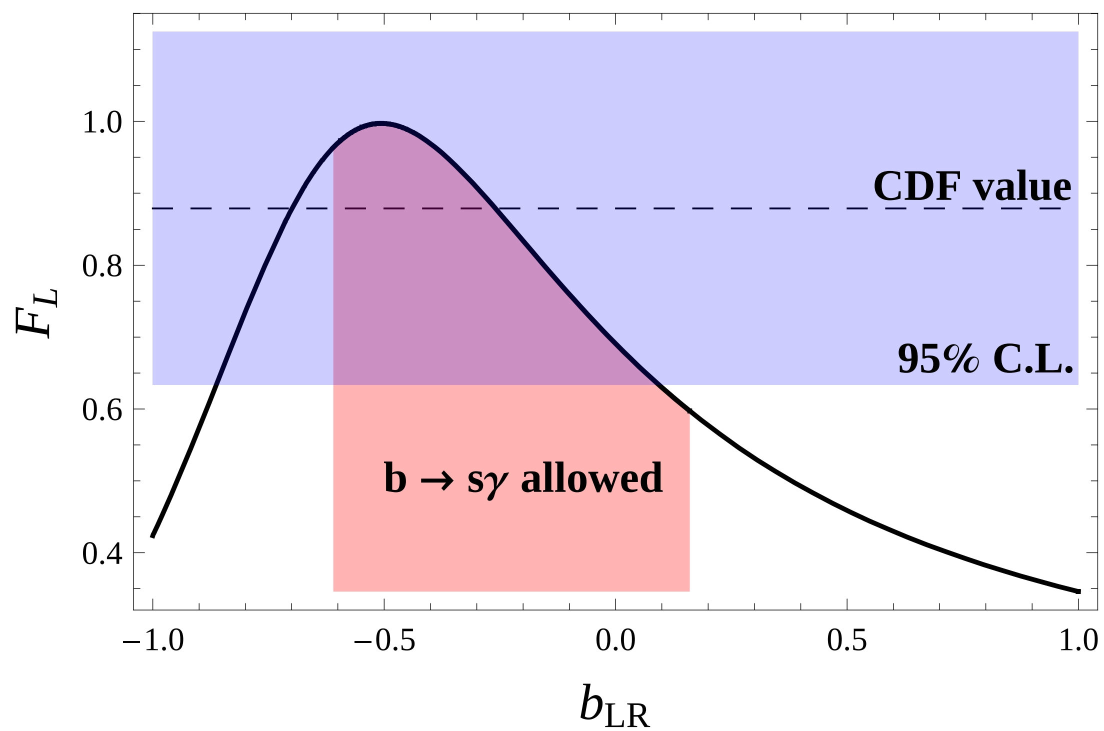
- Even in presence of such NP, F_+ cannot not significantly deviate from SM*

Comparison of direct and indirect bounds

- Indirect $b \to s\gamma$ constraints on most operators much better than present or projected precision of direct F_i measurements at Tevatron or LHC

- Exception: O_{LR}

  - CDF measurement of F_L puts competitive bounds on b_{LR} compared to indirect $b \to s\gamma$ bound



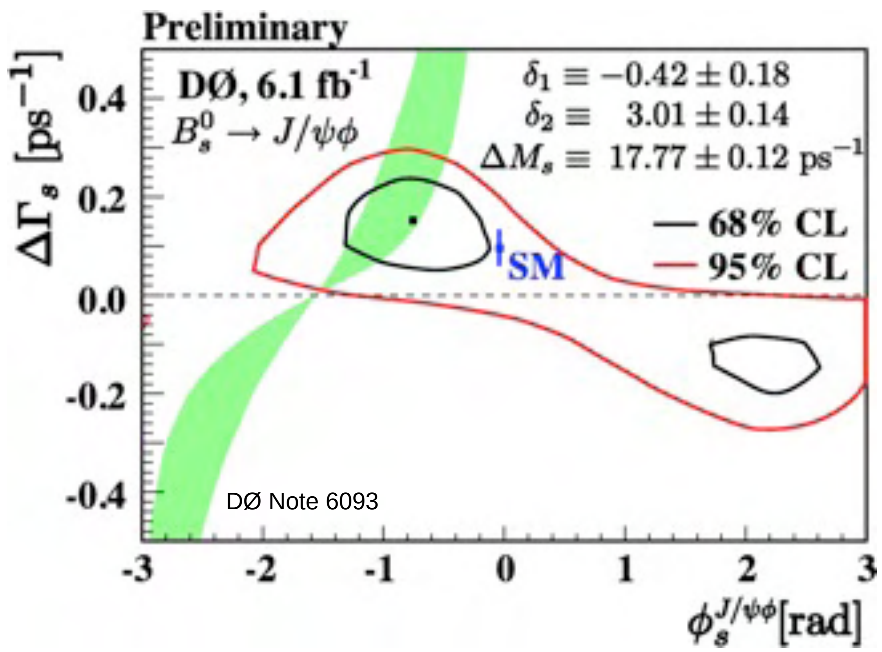
$$b_{LR} < 0.09\,, \quad 95\%\ \text{C.L.}\,.$$

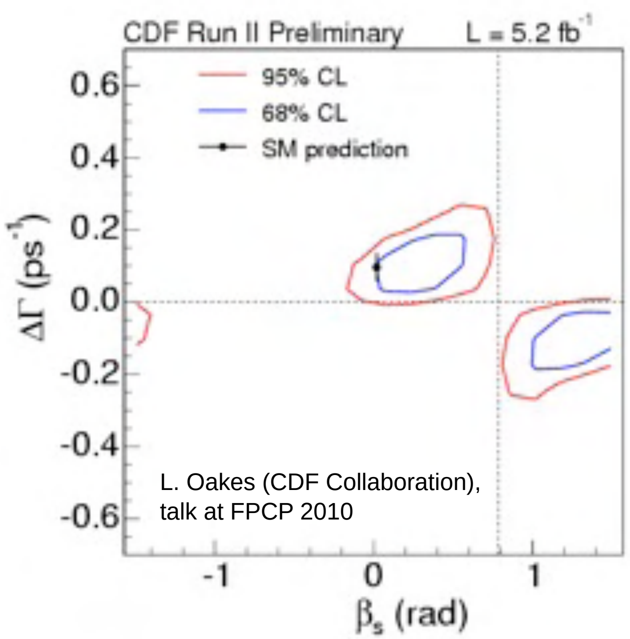
Recent developments in the B sector

- During the last three years increasing experimental hints of sizable CPV in B_s sector

UTFit 0803.0659

- Hints of large (mixing-induced) CP Violation in $B_s \to J/\psi\, \phi$ decays





$$\beta_s = \frac{1}{2}\mathrm{Arg}\lambda_{f_{CP}}$$
$$\Delta\Gamma_s = \Gamma_L - \Gamma_H$$

- Evidence for an anomalous like-sign dimuon charge asymmetry (*b*-inclusive)

DØ, 1005.2757

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

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

Recent developments in the B sector

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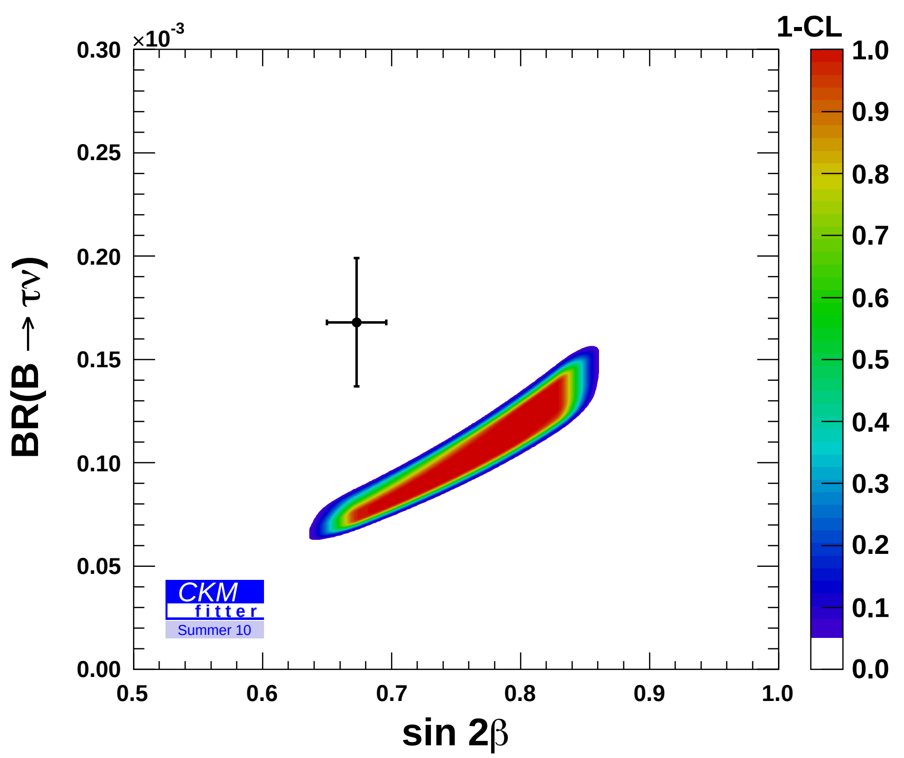
  - Hints of large (mixing-induced) CP Violation in $B_s \to J/\psi\ \phi$ decays
  - Evidence for an anomalous like-sign dimuon charge asymmetry (b-inclusive)
- At the same time, tensions developed within the CKM UT fit in the B_d sector

CKMFitter
0810.3139

Lunghi & Soni
0803.4340

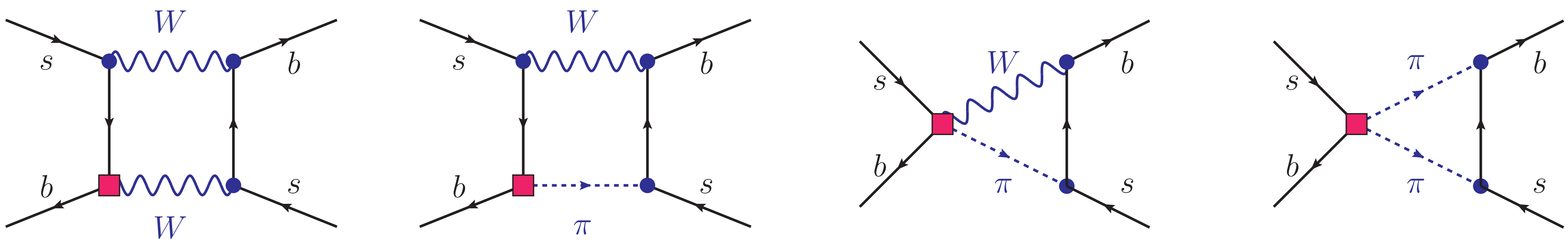
  - Leptonic B decay
  - CPV in B_d mixing
  - B_d mass difference



Anomalous t-b-W interactions and B oscillations

J. Drobnak, S. Fajfer & J.F.K., 1102.4347

- Effective operators coupling *t-b-W* enter $B\bar{B}$ mixing observables at one-loop



  - Result in universal contributions to B_d and B_s oscillations

Ligeti et al. 1006.0432

Lenz et al. 1008.1593

    - have been analyzed in general, found consistent with present data

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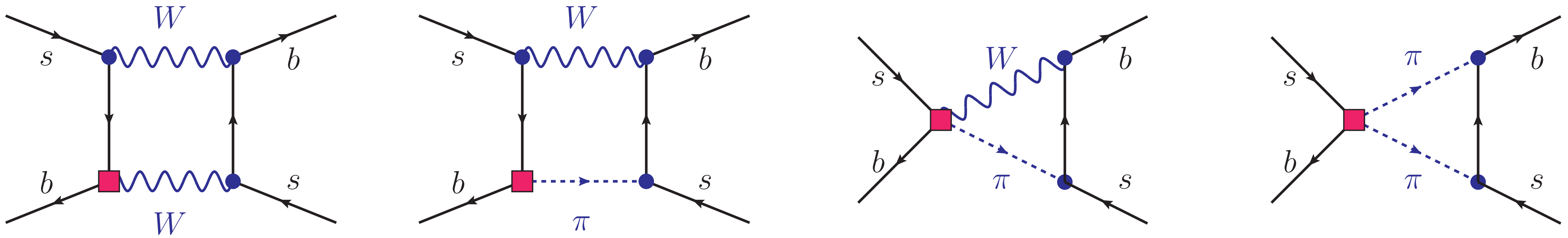
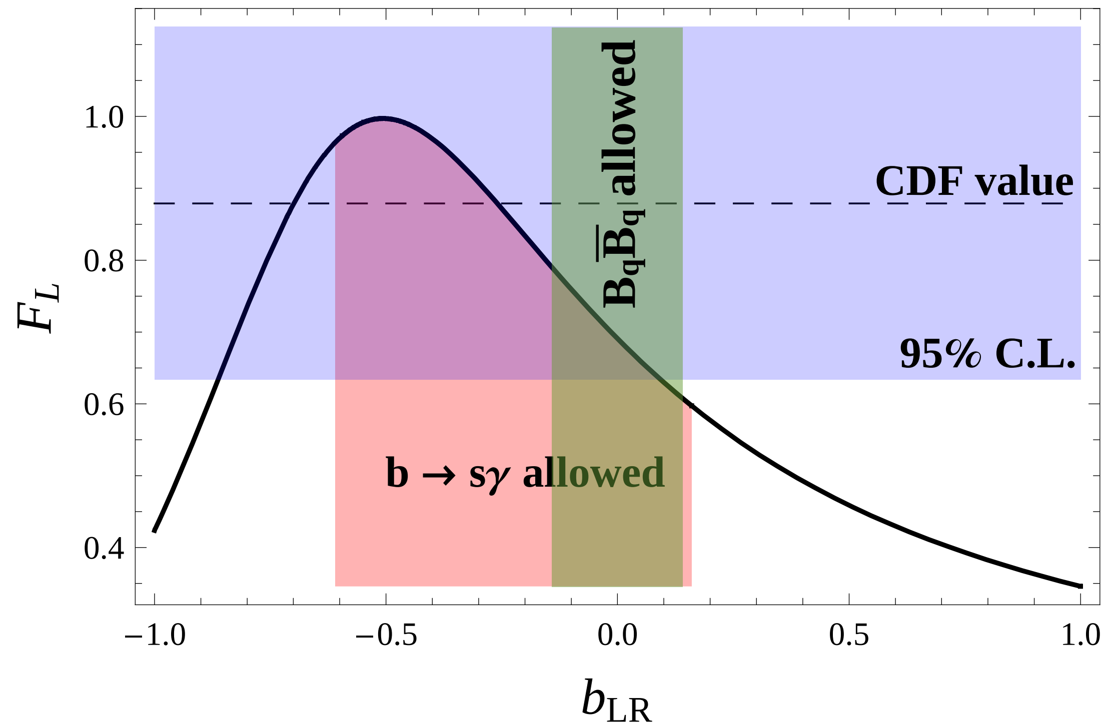


  - Result in universal contributions to B_d and B_s oscillations

  - Class (a)
    - b_{RL}, a_{RR} severely constrained by $b \to s\gamma$, made irrelevant in $B\bar{B}$
    - δa_{LL} and b_{LR} contributions at LO are real relative to SM phase, cannot explain CPV anomalies
      - best lower bound on b_{LR}



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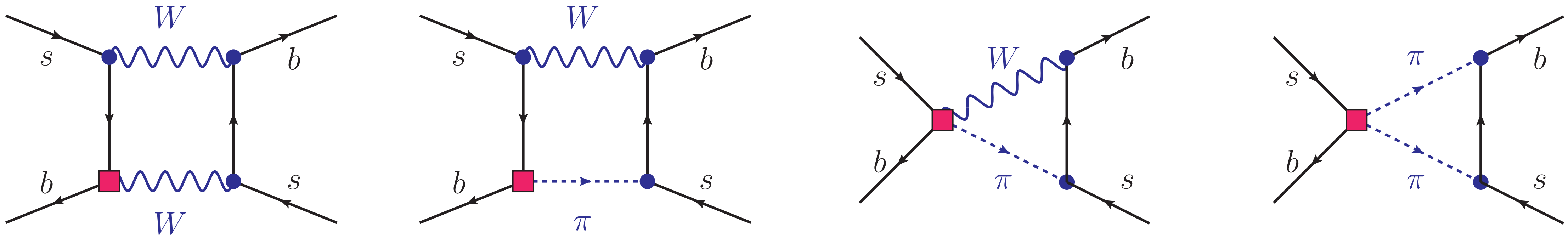

- Result in universal contributions to B_d and B_s oscillations

- Class (b) $\left(\kappa_{LL}^{\prime(\prime\prime)} = \frac{C_{LL}^{\prime(\prime\prime)}}{\Lambda^2\sqrt{2}G_F}, \qquad \kappa_{LRt}^{\prime} = \frac{C_{LRt}^{\prime}}{\Lambda^2 G_F} \right)$

  - not overly constrained by $b \to s\gamma$

  - contributions to $B\bar{B}$ at LO can be complex
    can accommodate CPV anomalies

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

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J. Drobnak, S. Fajfer & J.F.K., 1102.4347

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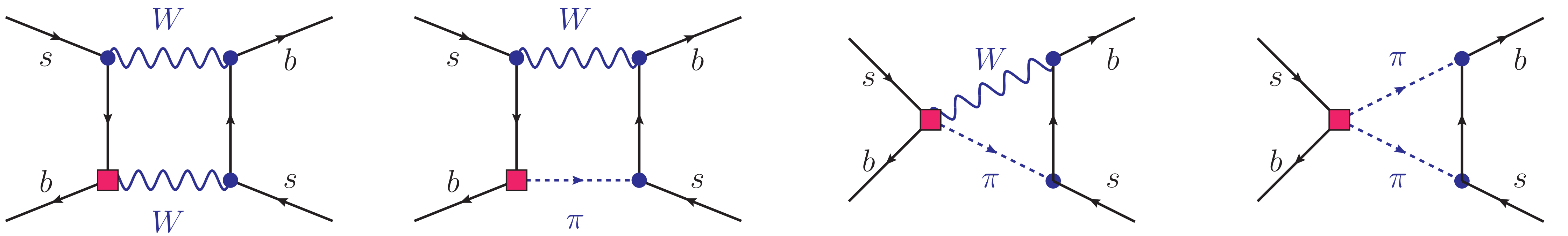
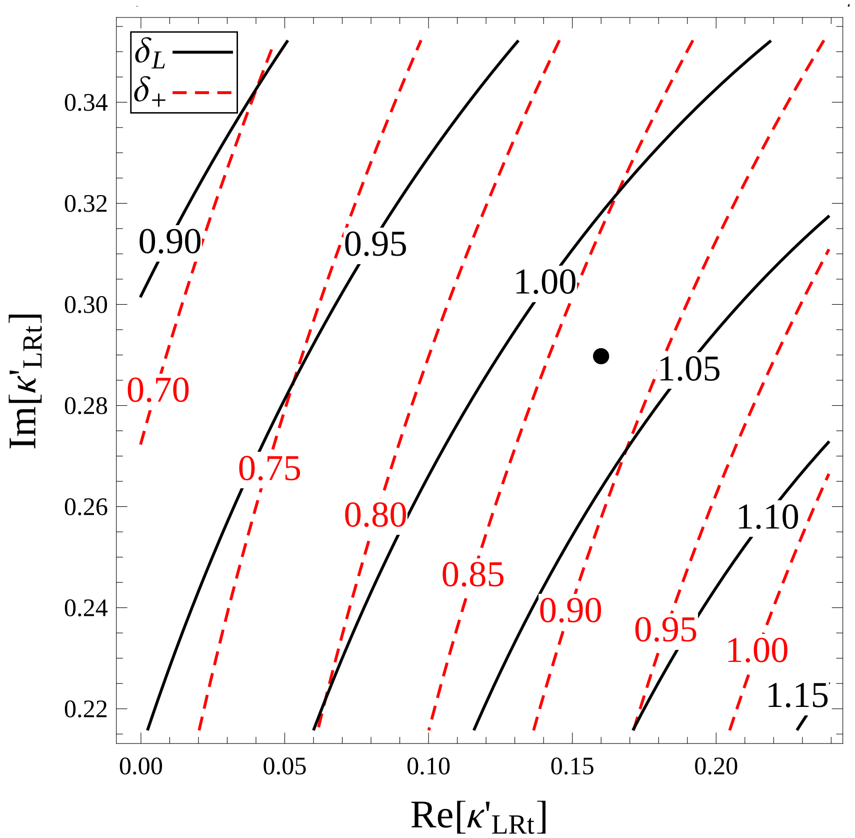


- Result in universal contributions to B_d and B_s oscillations

- Class (b) $\left(\kappa'^{(\prime\prime)}_{LL} = \frac{C'^{(\prime\prime)}_{LL}}{\Lambda^2 \sqrt{2} G_F}\,, \qquad \kappa'_{LRt} = \frac{C'_{LRt}}{\Lambda^2 G_F} \right)$
  - not overly constrained by $b \to s\gamma$
  - contributions to $B\bar{B}$ at LO can be complex
    can accommodate CPV anomalies
  - κ'_{LRt} will affect F_i measurements

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



Conclusions

- *W* helicity fractions in $t \to bW$ decay can probe the structure of *t*-*b*-*W* couplings
    - Indirect bounds from $b \to s\gamma$ disfavor significant deviations in F_+ for single contributions of dim-6 operators
    - Measurements of F_L already competitive in constraining effective *tbW* dipole interactions

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  - Can accommodate NP CPV hints in MFV models with large bottom Yukawa

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    - Competitive constrains on effective *t*-*b*-*W* couplings
    - Can accommodate NP CPV hints in MFV models with large bottom Yukawa
    - CPV dipole *tbW* operator contributions will affect *t*→*bW* decay characteristics
        - In decays of polarized top quarks, can define CPV helicity observables
        - Could be probed in single top production at the LHC

J. A. Aguilar–Saavedraa, J. Bernabéu
1005.5382

Backup

MFV NP in charged quark currents

- General chirality decomposition of operators

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

- Flavor decomposition with small bottom Yukawa:
  - A_{ij} in term of polynomials of $Y_uY_u^\dagger$:

$$\begin{array}{lll} \bar{t}_R V_{tb} b_R\,, & \bar{Q}_i Q_i\,, & \bar{Q}_i V_{ti}^* V_{tj} Q_j\,, \\ \bar{Q}_i V_{ti}^* t_R\,, & \bar{Q}_3 b_R\,, & \bar{Q}_i V_{ti}^* V_{tb} b_R\,, \end{array}$$

- Large bottom Yukawa effects
  - Allow for $Y_dY_d^\dagger$ insertions in A_{ij}: $\bar{Q}_3 Q_3\,, \quad \bar{Q}_3 V_{tb}^* V_{tj} Q_j\,, \quad \bar{Q}_3 V_{tb}^* t_R$
- Condition of new CPV: $\mathrm{Tr}[A_{ij}\, Y_uY_u^\dagger\, Y_dY_d^\dagger] \neq 0$ Blum et al., 0903.2118
  - In MFV need both Y_u and Y_d contributions in A_{ij}