Anomalous tWb couplings

Interplay of top and bottom physics

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1010.2402, 1102.4347, 1109.2357

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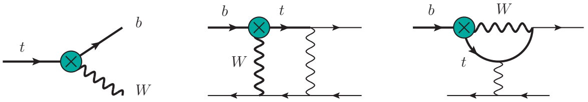

Motivation

- Top quark physics being explored with ever increasing precision!
- More than 99% of the time they decay through $t \to bW$ channel.
- This means that we can directly probe the tWb structure.
- Can we expect to find considerable deviations from SM structure?
  - Do not forget: virtual top quarks in B physics!
  - We can establish indirect bounds from well known observables!

TOP physics (direct bounds) $\Longleftrightarrow$ **BOTTOM physics (indirect bounds)**

Outline of the talk

- Formulation of the effective theory.

Bottom physics

- Effects in $B - \bar{B}$ mixing.
- Effects on rare B meson decays.
- Obtaining combined indirect constraints on anomalous couplings.
- Predictions for some observables.

Top physics

- Helicity fractions at NLO in QCD.
- Obtaining direct constraints.
- Comparison of direct and indirect constraints.

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- Effects in $B - \bar{B}$ mixing.
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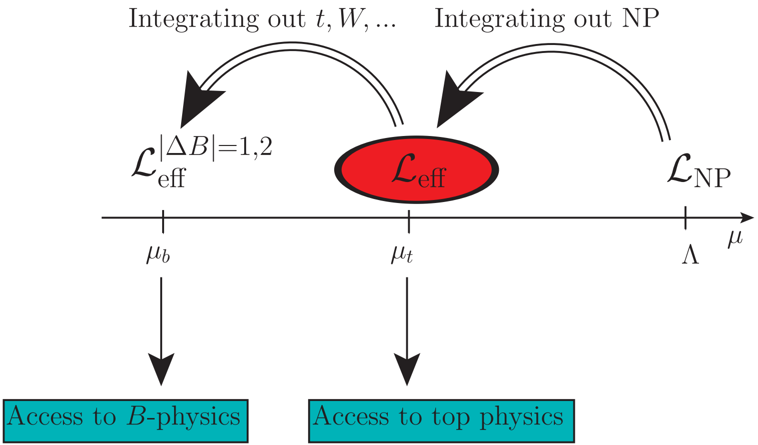
- Predictions for some observables.
- Projections for Super-Belle.

Top physics

- Helicity fractions at NLO in QCD.
- Obtaining direct constraints.
- Comparison of direct and indirect constraints.
- Projections for future LHC.

Formulating an effective theory

The strategy



Formulating an effective theory

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

Gauge structure

- Dim. 6 operators $\mathcal{Q}_i$
- Invariant under SM gauge group, built out of SM fields
  W. Buchmuller, D. Wyler
  1986
- Involving charged quark currents with W

$$\begin{aligned}
\left[\bar{u}\gamma^\mu d\right](\tilde{\phi}^\dagger \mathrm{i}D_\mu \phi) \\
\left[\bar{Q}\gamma^\mu \tau^a Q\right](\phi^\dagger \tau^a \mathrm{i}D_\mu \phi) \\
\left[\bar{Q}\sigma^{\mu\nu}\tau^a u\right]\tilde{\phi}W^a_{\mu\nu} \\
\left[\bar{Q}\sigma^{\mu\nu}\tau^a d\right]\phi W^a_{\mu\nu}
\end{aligned}$$

Formulating an effective theory

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$$[\bar{u}\gamma^\mu d](\tilde{\phi}^\dagger \mathrm{i} D_\mu \phi)$$
$$[\bar{Q}\gamma^\mu \tau^a Q](\phi^\dagger \tau^a \mathrm{i} D_\mu \phi)$$
$$[\bar{Q}\sigma^{\mu\nu}\tau^a u]\tilde{\phi} W^a_{\mu\nu}$$
$$[\bar{Q}\sigma^{\mu\nu}\tau^a d]\phi W^a_{\mu\nu}$$

Flavor structure

- MFV hypothesis

$$\bar{u} Y_u^\dagger A_{ud} Y_d d\,,\, \bar{Q} A_{QQ} Q\,,$$
$$\bar{Q} A_{Qu} Y_u u\,,\, \bar{Q} A_{Qd} Y_d d$$

- $A_{xy} = p[Y_u Y_u^\dagger, Y_d Y_d^\dagger]$
- Choose the basis

$$\begin{aligned} \langle Y_d \rangle &= \text{diag}(0,0,m_b/v)\,, \\ \langle Y_u \rangle &= V^\dagger \text{diag}(0,0,m_t/v) \\ Q_i &\equiv (V^*_{ki} u_{Li}, d_{Li}) \end{aligned}$$

Structure set, we can write down the operators.

Formulating an effective theory

- Plugging in different A_{xy} we establish the operator basis consisting of 7 distinct operators.

Lowest order in Y_d

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

Same operator basis used in $b \to s\gamma$ decays
B. Grzadkowski, M. Misiak
0802.1413

Higher order in Y_d

A. L. Kagan, G. Perez, T. Volansky, J. Zupan
0903.1794

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

$$Q_3 = (V^*_{kb}u_{Lk}, b_L), \qquad \bar{Q}'_3 = \bar{Q}_i V^*_{ti} = (\bar{t}_L, V_{ti}d_{iL})$$

Formulating an effective theory

- Plugging in different A_{xy} we establish the operator basis consisting of 7 distinct operators.

Lowest order in Y_d

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

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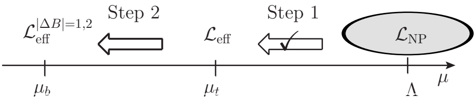
$$\begin{aligned}\mathcal{Q}'_{LL} &= [\bar{Q}_3\tau^a\gamma^\mu Q_3]\big(\phi_d^\dagger\tau^a \mathrm{i}D_\mu\phi_d\big)\\ &- [\bar{Q}_3\gamma^\mu Q_3]\big(\phi_d^\dagger \mathrm{i}D_\mu\phi_d\big)\\ \mathcal{Q}''_{LL} &= \Big\{[\bar{Q}'_3\tau^a\gamma^\mu Q_3]\big(\phi_d^\dagger\tau^a \mathrm{i}D_\mu\phi_d\big)\\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

$$Q_3 = (V^*_{kb}u_{Lk}, b_L), \qquad \bar{Q}'_3 = \bar{Q}_i V^*_{ti} = (\bar{t}_L, V_{ti}d_{iL})$$

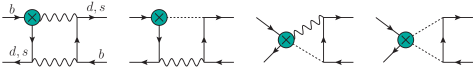
- Richer structure than a mere change in tWb. More plausible!
- $\mathcal{Q}_{LL}, \mathcal{Q}_{LRt}$ also modify tWd, tWs couplings, $\mathcal{Q}'_{LL}, \mathcal{Q}_{LRb}$ also modify uWb, cWb couplings!

Bottom physics

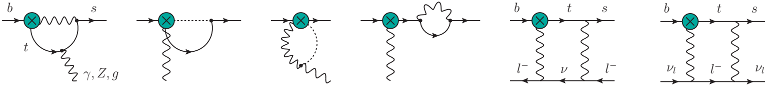


- Step 2: integrating out $t, W, \ldots$.
- Matching to low energy Lagrangian up to $\mathcal{O}(1/\Lambda^2)$.

$|\Delta B| = 2$ for $B_{d,s} - \bar{B}_{d,s}$ mixing



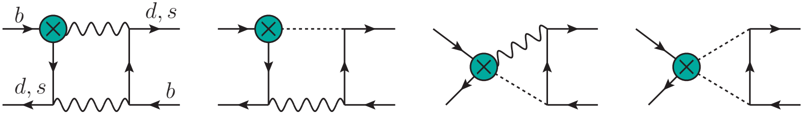
$|\Delta B| = 1$ for $B \to X_s \gamma, g, l^+ l^-, \nu\bar{\nu}$ decays



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

- Our operators effect the mixing amplitudes $M_{12}^{(d,s)} = M_{12}^{(d,s)\mathrm{SM}}\,\Delta$.
- Same impact on B_d and B_s systems.

$$\mathcal{L}_{\mathrm{eff}}^{|\Delta B|=2} = -\frac{G_F^2 m_W^2}{4\pi^2}\left(V_{tb}V_{td,s}^*\right)^2 C_1(\mu)\mathcal{O}_1^{d,s}\,, \qquad \mathcal{O}_1^d = [\bar{d}_L^\alpha \gamma^\mu b_L^\alpha][\bar{d}_L^\beta \gamma_\mu b_L^\beta]\,,$$



- Some computational details
  - One operator insertion,
  - General R_ξ gauge for W (pseudo-Goldstone bosons),
  - Massless limit for u, c quarks, CKM unitarity,
  - Neglect external momenta,
  - $\overline{\mathrm{MS}}$ for UV div. (last diagram - log div.)

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

Result of matching

$$\begin{aligned}\Delta C_1 &= \left(\mathrm{Re}[\kappa_{LL}] + \kappa''_{LL}/2\right) S_0^{LL}(x_t,\mu) \\ &+ \left(\mathrm{Re}[\kappa_{LRt}] + \kappa'_{LRt}/2\right) S_0^{LRt}(x_t) \\ &+ 2\kappa'_{LL}\, S_0^{\mathrm{SM}}(x_t)\end{aligned}$$

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

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

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

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Couple of things to note:

1) Within our assumptions operators $\mathcal{Q}_{RR}$ and $\mathcal{Q}_{LRb}$ do not contribute.

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

Result of matching

$$\begin{aligned}\Delta C_1 &= \left(\mathrm{Re}[\kappa_{LL}] + \kappa''_{LL}/2\right)\, S_0^{LL}(x_t,\mu) \\ &+ \left(\mathrm{Re}[\kappa_{LRt}] + \kappa'_{LRt}/2\right)\, S_0^{LRt}(x_t) \\ &+ 2\kappa'_{LL}\, S_0^{\mathrm{SM}}(x_t)\end{aligned}$$

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

Couple of things to note:

2) Only *real parts* of κ_{LL} and κ_{LRt} enter ΔC_1.

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

Result of matching

$$\Delta C_1 = \left(\mathrm{Re}[\kappa_{LL}] + \kappa''_{LL}/2\right) S_0^{LL}(x_t,\mu) + \left(\mathrm{Re}[\kappa_{LRt}] + \kappa'_{LRt}/2\right) S_0^{LRt}(x_t) + 2\kappa'_{LL}\, S_0^{\mathrm{SM}}(x_t)$$

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

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

Couple of things to note:

3) $S_0^{LL}(x_t,\mu) = x_t \log\frac{m_W^2}{\mu^2} + \cdots$ needs a counterterm $\mathcal{Q} = [\bar{Q}\gamma^\mu A_{QQ} Q][\bar{Q}\gamma_\mu A'_{QQ} Q]$

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

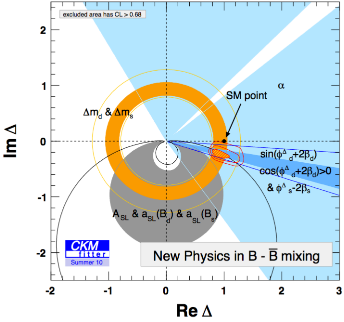
- Analyzing one operator at a time.

$$\Delta = 1 + \frac{\Delta C_1}{C_1^{\rm SM}} \approx 1 - 2.57\,{\rm Re}[\kappa_{LL}] - 1.54\,{\rm Re}[\kappa_{LRt}] + 2.00\,\kappa'_{LL} - 1.29\,\kappa''_{LL} - 0.77\,\kappa'_{LRt}$$

- Turning to observables: global analysis by now out of date

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

$\phi_s = 0.03 \pm 0.16 \pm 0.07$ **LHCb** Conf. Note: 2011-056



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  $\phi_s = 0.03 \pm 0.16 \pm 0.07$ **LHCb** Conf. Note: 2011-056
- **Considering all κ_i to be real**, we can still derive the 95% C.L. bounds on real parts of κ_i.

$$-0.09 < \kappa_{LL} < 0.08$$
$$-0.11 < \kappa'_{LL} < 0.11$$
$$-0.18 < \kappa''_{LL} < 0.18$$
$$-0.14 < \kappa_{LRt} < 0.13$$
$$-0.29 < \kappa'_{LRt} < 0.29$$

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

- Analyzing one operator at a time.

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- Three operators can contribute also new phases.

SM predictions **U. Nierste, A. Lenz** 1102.4274

$$\Delta m_s^{\rm SM} = 17.3 \pm 2.6\ {\rm ps}^{-1}$$
$$\phi_s^{\rm SM} = (3.8 \pm 1.0) \times 10^{-3}$$

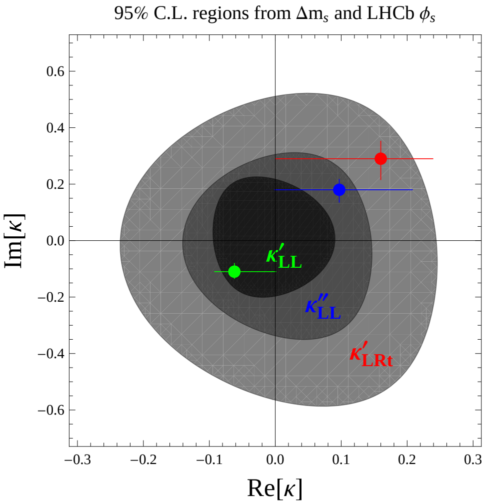
Exp. values **LHCb** Conf. Note: 2011-056 **CDF** hep-ex/0609040

$$\Delta m_s^{\rm exp} = 17.77 \pm 0.12\ {\rm ps}^{-1}$$
$$\phi_s^{\rm LHCb} = 0.03 \pm 0.17$$

$$\begin{aligned}\Delta m_s &= \Delta m_s^{\rm SM}\sqrt{{\rm Re}[\Delta]^2 + {\rm Im}[\Delta]^2} \\ \phi_s &= \phi_s^{\rm SM} + \arctan\frac{{\rm Im}[\Delta]}{{\rm Re}[\Delta]}\end{aligned}$$

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

- Very simple χ^2 analysis using Δm_s and ϕ_s



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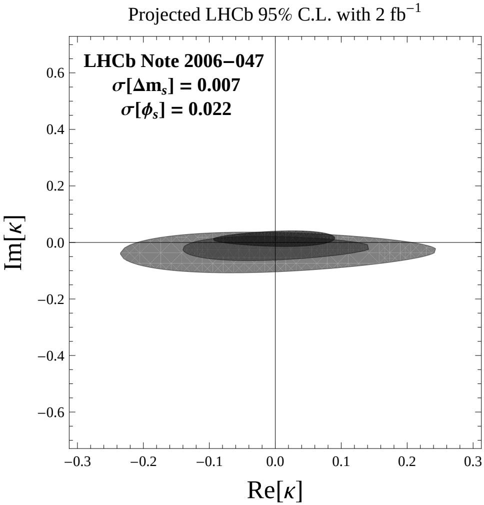

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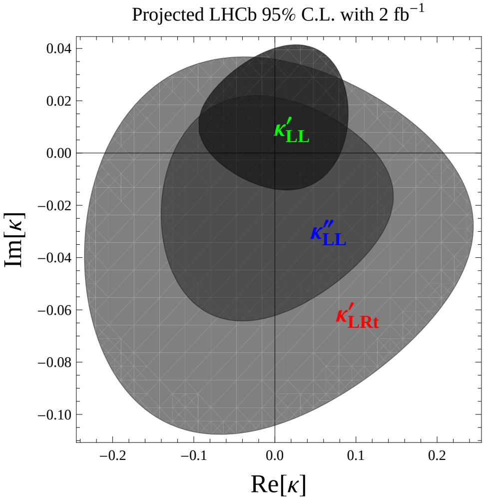


Effects in B decays

- Matching to the standard low energy effective Lagrangian.

$$\mathcal{L}_{\text{eff}}^{|\Delta B|=1} = \mathcal{L}_{\text{QCD}\times\text{QED}} + \frac{4G_F}{\sqrt{2}}\Big[\sum_{i=1}^{2} C_i (V_{ub}V_{us}^* \mathcal{O}_i^{(u)} + V_{cb}V_{cs}^* \mathcal{O}_i^{(c)})\Big]$$
$$+ \frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \Big[\sum_{i=3}^{10} C_i \mathcal{O}_i + C_{\nu\bar\nu}\mathcal{O}_{\nu\bar\nu}\Big],$$

Most relevant operators

$$\mathcal{O}_7 = \frac{e m_b}{(4\pi)^2}\big(s_L \sigma_{\mu\nu} b_R\big) F^{\mu\nu},$$

$$\mathcal{O}_9 = \frac{e^2}{(4\pi)^2}\big(s_L \gamma^\mu b_L\big)\big(\bar\ell \gamma_\mu \ell\big),$$

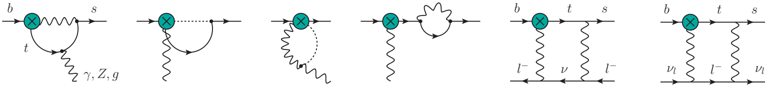
$$\mathcal{O}_8 = \frac{g_s m_b}{(4\pi)^2}\big(s_L \sigma_{\mu\nu} T^a b_R\big) G_a^{\mu\nu},$$

$$\mathcal{O}_{10} = \frac{e^2}{(4\pi)^2}\big(s_L \gamma^\mu b_L\big)\big(\bar\ell \gamma_\mu \gamma_5 \ell\big),$$

$$\mathcal{O}_{\nu\bar\nu} = \frac{e^2}{(4\pi)^2}\big(\bar s_L \gamma^\mu b_L\big)\big(\bar\nu \gamma_\mu (1-\gamma^5)\nu\big).$$

Effects in B decays

- Computation of 47 diagrams



- Similar computational setup as in $B - \bar{B}$ mixing case.

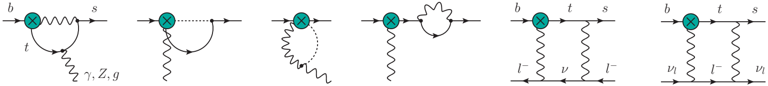
$$A[b \to s\gamma] = \underbrace{\bullet}_{C_9} \left[\bar{s}_L q^2 \gamma^\alpha - q^\alpha \not{q} b_L\right] + \underbrace{\bullet}_{C_7} \left[\bar{s}_L m_b \sigma^{\alpha\beta} q_\beta b_R\right]$$

$$\otimes \; \frac{1}{q^2}\left[\bar{l}\gamma_\alpha l\right]$$

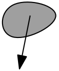
$$A[b \to sg] = \underbrace{\bullet}_{C_8} \left[\bar{s}_L m_b \sigma^{\alpha\beta} q_\beta T_a b_R\right]$$

Effects in B decays

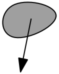
- Computation of 47 diagrams



- Similar computational setup as in $B - \bar{B}$ mixing case.

$A[b \to sZ] =$  $[\bar{s}_L \gamma^\alpha b_L] \;\Rightarrow\; \otimes \frac{1}{m_Z^2}\left[\bar{l}(g_V \gamma_\alpha + g_A \gamma_\alpha \gamma^5) l\right]$

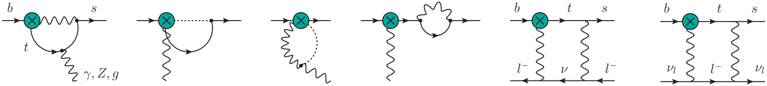
$C_9,\ C_{10}$

$A[b \to s l^+ l^-]_{\text{box}} =$  $\left[\bar{s}_L \gamma^\alpha b_L\right]\left[\bar{l}(\gamma_\alpha - \gamma_\alpha \gamma^5) l\right]$

$C_9,\ C_{10}$

Effects in B decays

- Computation of 47 diagrams



- Similar computational setup as in $B - \bar{B}$ mixing case.
- We obtain the change of low-energy Wilson coefficients

$$C_i = C_i^{\rm SM} + \underbrace{\sum_j f_j^{(i)}(x_t,\mu)\ \kappa_j + \tilde{f}_j^{(i)}(x_t,\mu)\ \kappa_j^*}_{\delta C_i}$$

$$i = 1, \ldots, 10, \nu\bar{\nu}\,, \qquad j = LL, RR, LRt, \ldots$$

- This matching gives us access to many observables.

Bounds from radiative B decays

- First apply the results to two well measured observables, using semi-numerical formulae from Sebastien Descotes-Genon et al. 1104.3342

$B \to X_s\gamma$, $E_\gamma > 1.6$ GeV

$$\mathcal{B}^{\text{exp.}} = (3.55 \pm 0.26) \times 10^{-4}$$
$$\mathcal{B}^{\text{the.}} = (3.15 \pm 0.23 - 8.52\,\delta C_7 - 2.55\,\delta C_8) \times 10^{-4}$$

$B \to X_s\mu^+\mu^-$, low q^2

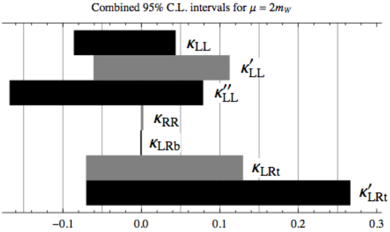
$$\mathcal{B}^{\text{exp.}} = (1.60 \pm 0.5) \times 10^{-6}$$
$$\mathcal{B}^{\text{the.}} = (15.86 \pm 1.10 - 0.30\,\delta C_7 - 0.09\,\delta C_8 + 2.68\,\delta C_9 - 4.83\,\delta C_{10}) \times 10^{-7}$$

- Note: δC_i stands for $\mathrm{Re}[\delta C_i]$

Bounds on real parts of κ_i

- We consider one operator $\mathcal{Q}_i$ to contribute at a time to obtain 95% C.L. intervals for real parts of κ_i.

	$B-\bar{B}$	$B\to X_s\gamma$	$B\to X_s\mu^+\mu^-$	combined	
κ_{LL}	0.08 −0.09	0.03 −0.12	0.48 −0.49	0.04 −0.09	(0.03 −0.10)
κ'_{LL}	0.11 −0.11	0.17 −0.04	0.31 −0.30	0.11 −0.06	(0.10 −0.06)
κ''_{LL}	0.18 −0.18	0.06 −0.22	1.02 −1.04	0.08 −0.17	(0.05 −0.15)
κ_{RR}		0.003 −0.0006	0.68 * −0.66	0.003 −0.0006	(0.002 −0.0006)
κ_{LRb}		0.0003 −0.001	0.34 * −0.35	0.0003 −0.001	(0.003 −0.01)
κ_{LRt}	0.13 −0.14	0.51 −0.13	0.38 −0.37	0.13 −0.07	(0.12 −0.14)
κ'_{LRt}	0.29 −0.29	0.41 −0.11	0.75 −0.73	0.27 −0.07	(0.25 −0.06)



- For $B\to X_s\gamma$ bounds agree nicely with B. Grzadkowski, M. Misiak 0802.1413 .
- κ_{RR} and κ_{LRb} bounds sever. The two operators give helicity flip "for free" $\Rightarrow m_{t,W}/m_b$ enhancement

Bounds on real parts of κ_i

- We consider one operator $\mathcal{Q}_i$ to contribute at a time to obtain 95% C.L. intervals for real parts of κ_i.

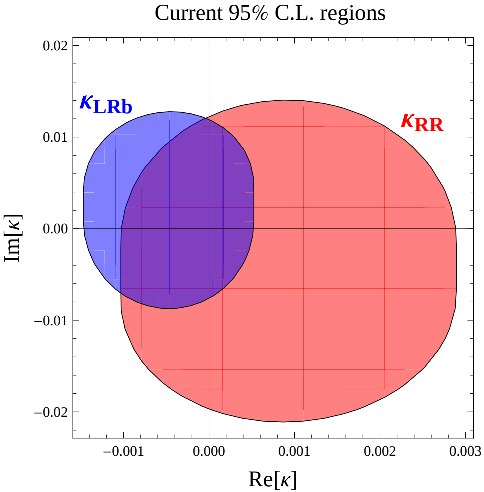
	$B-\bar{B}$	$B \to X_s\gamma$	$B \to X_s\mu^+\mu^-$	combined	
κ_{LL}	0.08 / -0.09	0.03 / -0.12	0.48 / -0.49	0.04 / -0.09 $\left(\begin{matrix}0.03\\-0.10\end{matrix}\right)$	$\Lambda > 0.82$ TeV
κ'_{LL}	0.11 / -0.11	0.17 / -0.04	0.31 / -0.30	0.11 / -0.06 $\left(\begin{matrix}0.10\\-0.06\end{matrix}\right)$	$\Lambda > 0.74$ TeV
κ''_{LL}	0.18 / -0.18	0.06 / -0.22	1.02 / -1.04	0.08 / -0.17 $\left(\begin{matrix}0.05\\-0.15\end{matrix}\right)$	$\Lambda > 0.60$ TeV
κ_{RR}		0.003 / -0.0006	0.68 * / -0.66	0.003 / -0.0006 $\left(\begin{matrix}0.002\\-0.0006\end{matrix}\right)$	$\Lambda > 3.18$ TeV
κ_{LRb}		0.0003 / -0.001	0.34 * / -0.35	0.0003 / -0.001 $\left(\begin{matrix}0.003\\-0.01\end{matrix}\right)$	$\Lambda > 9.26$ TeV
κ_{LRt}	0.13 / -0.14	0.51 / -0.13	0.38 / -0.37	0.13 / -0.07 $\left(\begin{matrix}0.12\\-0.14\end{matrix}\right)$	$\Lambda > 0.81$ TeV
κ'_{LRt}	0.29 / -0.29	0.41 / -0.11	0.75 / -0.73	0.27 / -0.07 $\left(\begin{matrix}0.25\\-0.06\end{matrix}\right)$	$\Lambda > 0.56$ TeV

- For $B \to X_s\gamma$ bounds agree nicely with B. Grzadkowski, M. Misiak 0802.1413 .
- κ_{RR} and κ_{LRb} bounds sever. The two operators give helicity flip "for free" $\Rightarrow m_{t,W}/m_b$ enhancement

Bounds on imaginary parts of κ_i

$$A_{X_s\gamma}^{\rm CP} = \frac{\Gamma(\bar{B}\to X_s\gamma) - \Gamma(B\to X_{\bar{s}}\gamma)}{\Gamma(\bar{B}\to X_s\gamma) + \Gamma(B\to X_{\bar{s}}\gamma)} = (-0.012 \pm 0.028)_{\rm exp.}$$

- Based on recent analysis of CP asymmetry in $B \to X_s\gamma$ in M. Benzke et al. 1012.3167 we attempt to constrain $\mathrm{Im}[\kappa_i]$ for operators that do not contribute new phases in $B - \bar{B}$.
- Constraints on $\mathrm{Im}[\kappa_{RR}]$ and $\mathrm{Im}[\kappa_{LRb}]$ turn out to be at pre-cent level.
- Other operators remain unconstrained.



Bounds on imaginary parts of κ_i

$$A^{\rm CP}_{X_s\gamma} = \frac{\Gamma(\bar{B} \to X_s\gamma) - \Gamma(B \to X_{\bar{s}}\gamma)}{\Gamma(\bar{B} \to X_s\gamma) + \Gamma(B \to X_{\bar{s}}\gamma)} = (-0.012 \pm 0.028)_{\rm exp.}$$

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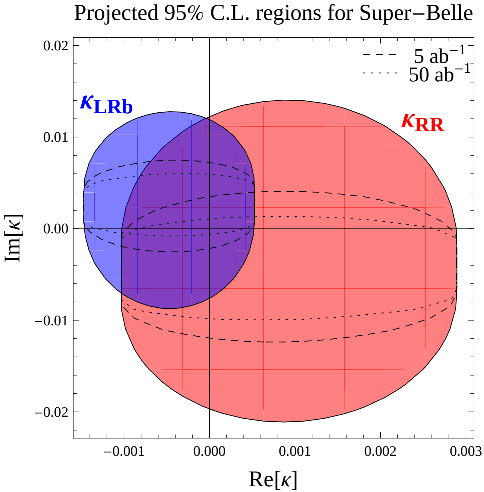
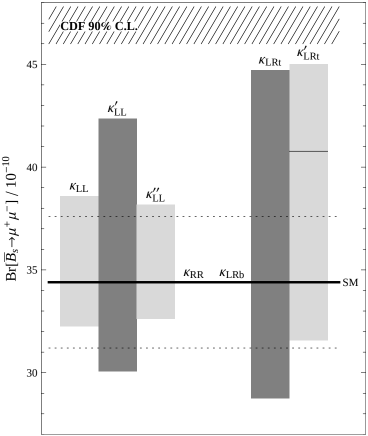


Predictions

- Having derived the bounds on κ_i, we can study to what extent these can still affect other rare B decay observables.



- 90% C.L. branching ratio interval
  T. Aaltonen
  1107.2304

$$4.6 \times 10^{-9} < \mathcal{B}[\bar{B}_s \to \mu^+\mu^-] < 3.9 \times 10^{-8}$$

Predictions

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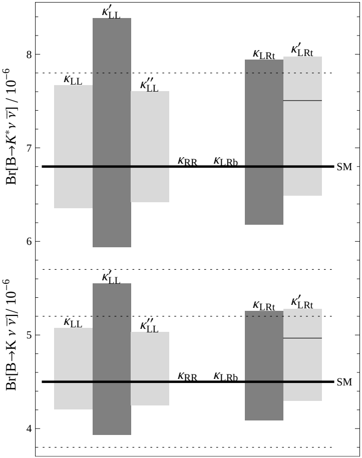
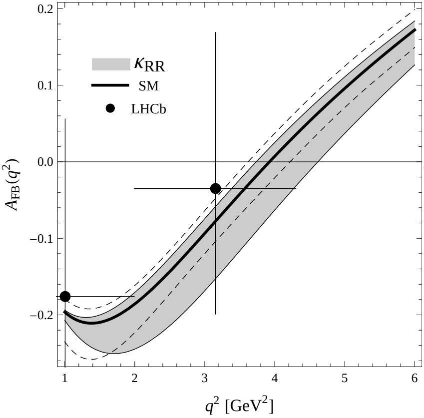


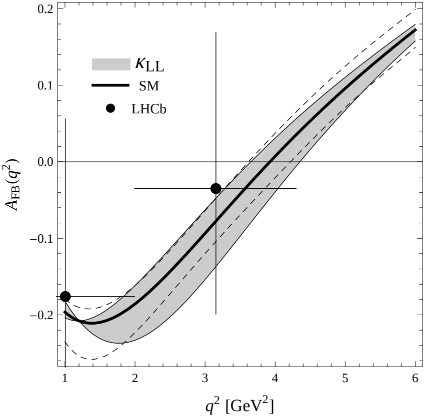
- Branching ratios for $B \to K^{(*)}\nu\bar{\nu}$
  W. Altmannshofer
  0902.0160
- To be measured at Super-B factories.

Predictions

- Having derived the bounds on κ_i, we can study to what extent these can still affect other rare B decay observables.

- $A_{\rm FB}(q^2)$ in the $\bar{B}_d \to \bar{K}^* \ell^+ \ell^-$ **Sebastien Descotes-Genon et al.** 1104.3342





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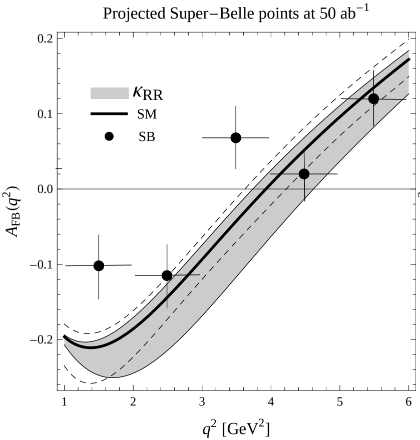
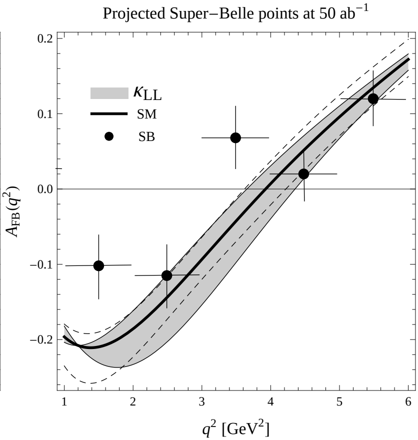


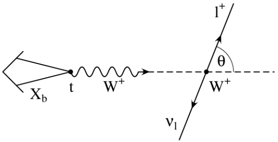


Top physics

W helicity fractions is $t \to bW$

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

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



- Helicity fractions are accessible through angular distribution of final state leptons **M. Fischer et al.** hep-ph/0011075 .

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

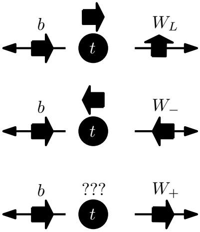
Theory side

- The $\mathcal{F}_+$ 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 $\mathcal{F}_+ > 0.2\%$ NP effect!



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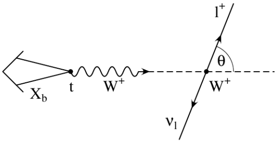

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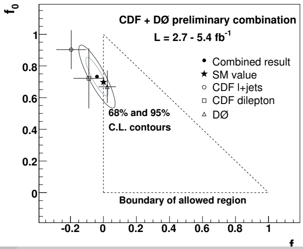
Experimental side

- ◇ Most recent combined measurements from Tevatron

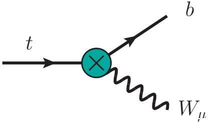
$$\mathcal{F}_L = 0.732 \pm 0.081 \qquad \mathcal{F}_+ = -0.039 \pm 0.045$$

- ◇ Projected sensitivity for LHC ($L = 10\mathrm{fb}^{-1}$)
  J. A. Aguilar-Saavedra et al. 0705.3041

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



$\mathcal{F}_i$ at NLO in QCD

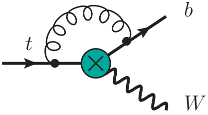


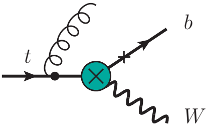
$$\underbrace{\mathrm{i}\frac{g}{\sqrt{2}}V_{tb}^*\gamma^\mu P_L}_{\mathrm{SM}} + \frac{\mathrm{i}g}{\sqrt{2}}\Big[\boldsymbol{a}_L\gamma^\mu P_L - \boldsymbol{b}_{LR}\frac{2\mathrm{i}\sigma^{\mu\nu}}{m_t}q_\nu P_R + (L \leftrightarrow R)\Big]$$

- All our 7 operators contribute

$$\mathcal{Q}_{LL}^{(\prime,\prime\prime)} \to a_L\,, \quad \mathcal{Q}_{LRt}^{(\prime)} \to b_{LR}\,,$$
$$\mathcal{Q}_{RR} \to a_R\,, \quad \mathcal{Q}_{LRb} \to b_{RL}\,.$$

- We analyze NLO QCD corrections.

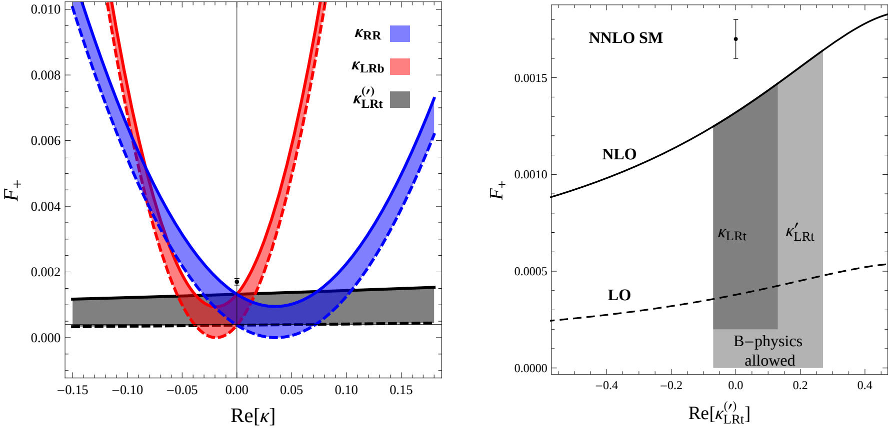




$\mathcal{F}_i$ at NLO in QCD

$\mathcal{F}_+$ helicity fraction

- As in SM, also here QCD corrections contribute significantly.
- Experimental errors to big for constraints.
- Anomalous couplings cannot increase $\mathcal{F}_+$ to 1% level (**B physics!**)

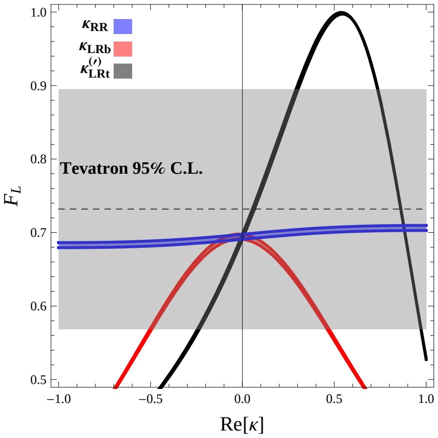


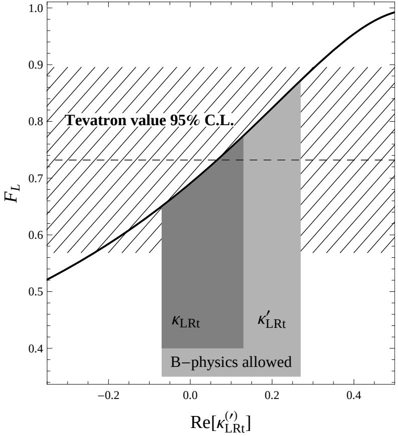
$\mathcal{F}_i$ at NLO in QCD

$\mathcal{F}_L$ helicity fraction

- Exp. values of $\mathcal{F}_L$ give direct bounds (for $\kappa^{(\prime)}_{LRt}$ competitive)

$$-0.49 < \kappa_{LRb} < 0.46\,, \qquad -0.23 < \kappa^{(\prime)}_{LRt} < 0.30$$





$\mathcal{F}_i$ at NLO in QCD

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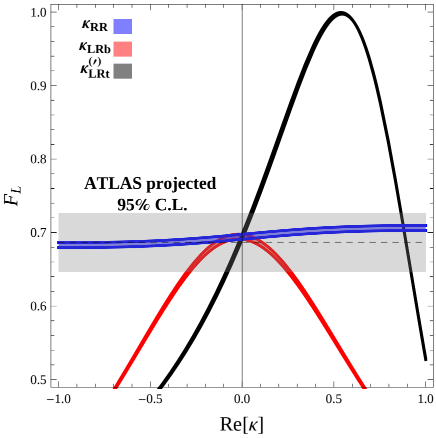
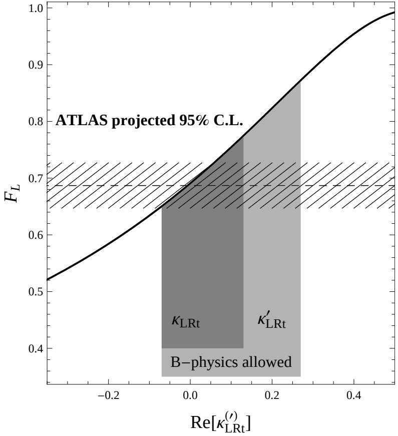
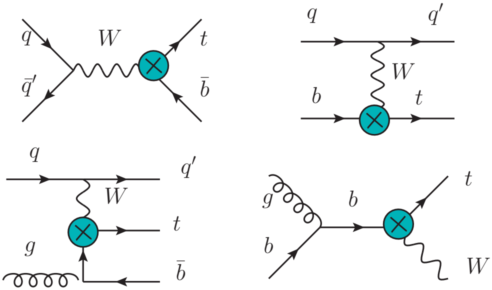




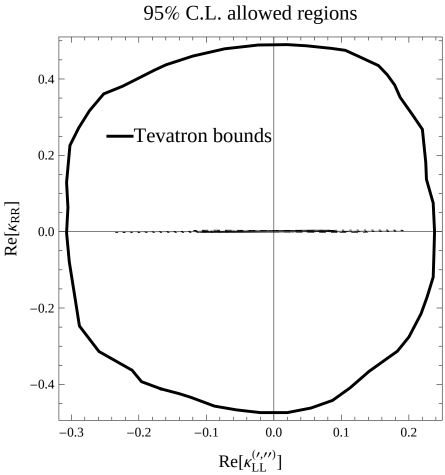
Comparison of direct and indirect bounds

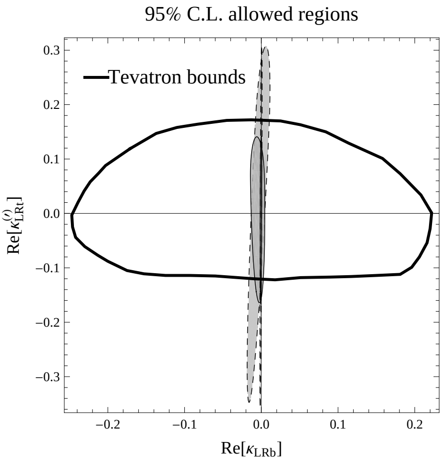
- Anomalous tWb couplings also affect single top production!



- Combining helicity fractions and single top production 95% C.L. constrains on regions are obtained **J. A. AguilarSaavedra, N. F. Castro, A. Onofre** 1105.0117

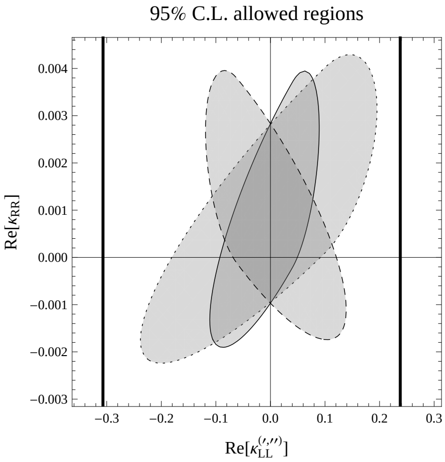
Comparison of direct and indirect bounds

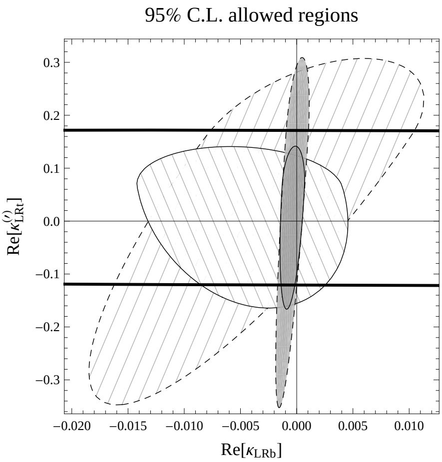




- In κ_{RR} and κ_{LRb} directions indirect constraints much stronger!
- In κ_{LL} and κ_{LRt} directions constraints comparable!

Comparison of direct and indirect bounds





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Conclusions

- We have formulated an effective theory with MFV giving rise to anomalous tWb interactions to examine the effects in B and top physics.
- We have we set indirect bounds on real parts of anomalous couplings κ_i from $B-\bar{B}$ mixing, $B \to X_s\gamma$ and $B \to X_s\mu^+\mu^-$.
- MFV models with large bottom Yukawa effects can contribute new mixing phases!
- Using ϕ_s, Δm_s and the direct CP asymmetry in $b \to s\gamma$ we were able to constrain imaginary parts of κ'_{LL}, κ''_{LL}, κ'_{LRt}, κ_{RR} and κ_{LRb}.
- Direct bounds from Tevatron are competitive with indirect bounds for $\kappa^{(\prime)}_{LRt}$ and $\kappa^{(\prime,\prime\prime)}_{LL}$.
- Super-B factories and further results from LHC will improve the bounds significantly.

Backup Slides

MFV

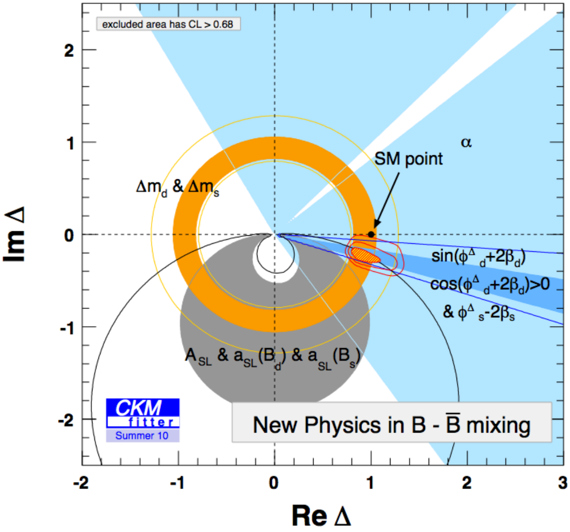
- A necessary condition for new flavor violating structures $\mathcal{Y}_x$ to introduce new sources of CP violation in quark transitions is that K. Blum, Y. Grossman, Y. Nir et al. 0903.2118

$$\mathrm{Tr}\Big(\mathcal{Y}_x[\langle Y_u Y_u^\dagger\rangle, \langle Y_d Y_d^\dagger\rangle]\Big) \neq 0\,.$$

- In MFV models (where $\mathcal{Y}_x$ is built out of Y_u and Y_d) this condition can only be met if $\mathcal{Y}_x$ contains products of both Y_u and Y_d which is the case with all our operators except Q_{LL} and Q_{LRt}.

Projected sensitivities

- ATLAS with $10\ \mathrm{fb}^{-1}$
  - $\mathcal{F}_L$ helicity fraction: $\sigma[\mathcal{F}_L] = 0.02$
- LHCb with $2\ \mathrm{fb}^{-1}$
  - ϕ_s from $b \to c\bar{c}s$: $\sigma[\phi_s] = 0.022$
  - Δm_s from $B_s \to D_s\pi$: $\sigma[\Delta m_s] = 0.007$
- Super-Belle with $5\ \mathrm{ab}^{-}1$
  - $A^{\mathrm{CP}}_{X_s\gamma}$: $\sigma[A^{\mathrm{CP}}_{X_s}] = 0.01$



excluded area has CL > 0.68
2
1
0
-1
-2
-2
-1
0
1
2
3
Im Δ
Re Δ
α
SM point
Δm_d & Δm_s
sin(φ^Δ_d+2β_d)
cos(φ^Δ_d+2β_d)>0
& φ^Δ_s-2β_s
A_SL & a_SL(B_d) & a_SL(B_s)
CKM fitter
Summer 10
New Physics in B - B̄ mixing

Back