$b \to s\gamma$ with Horizontal Gauge Bosons

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Emmanuel Stamou

estamou@ph.tum.de

In collaboration with:

Andrzej Jerzy Buras and Luca Merlo

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The news and goals of this talk

◦ constrain BSM models with neutral gauge bosons

◦ Z' models
◦ gauge flavour models
◦ ...

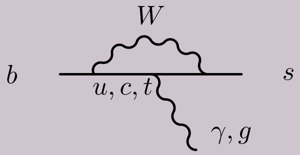
◦ present constraints from $b \to s\gamma$

◦ effects on the high NP scale
◦ effects from QCD mixing

What is new?

◦ potentially dangerous LR contribution from exotic fermions
◦ QCD mixing with neutral current-current operators

$b \to s\gamma$ a lesson from the SM



- FCNC process, loop-induced

- BR$(\bar{B} \to X_s\gamma)^{\text{exp}} = (3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$
- BR$(\bar{B} \to X_s\gamma)^{\text{SM}} = (3.15 \pm 0.23) \times 10^{-4}$

- Low-energy observable, determined at $\mu_b \approx m_b$

$$C_{7\gamma}(\mu_b) = \ 0.70 \ \ C_{7\gamma}(M_W) \ + \ 0.09 \ \ C_{8G}(M_W) \ - \ \mathbf{0.16} \ \ C_2(M_W)$$

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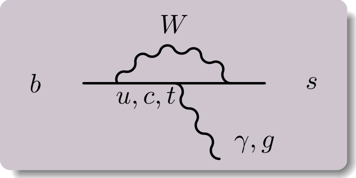

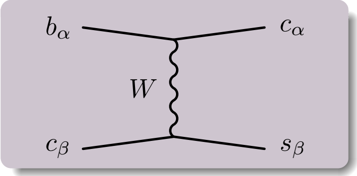

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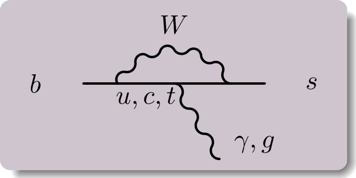
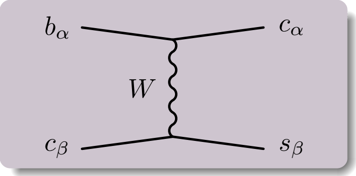
initial conditions

$b \to s\gamma$ a lesson from the SM





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QCD

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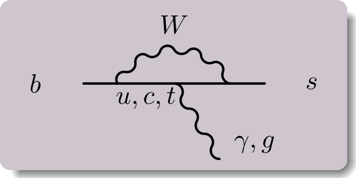

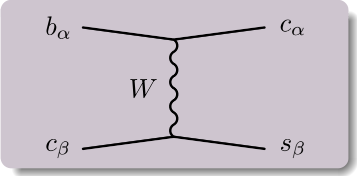

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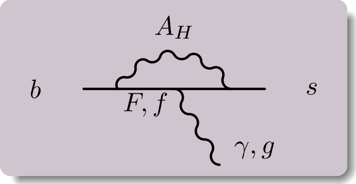
What happens when we extend the gauge symmetry?

(Grinstein et al. '09; Feldmann '10; Guadagnoli et al. '11)

NP in Wilson coefficients



- matching scale μ_{NP} : 200 GeV, 1 TeV, 10 TeV, . . .
- f : contribution from light quarks

broken GIM

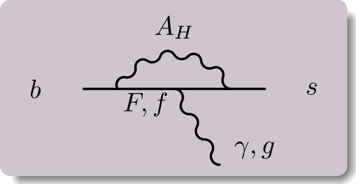
- F : contribution from exotic quarks

cancel anomalies

- F, f : LL, **LR** contribution

RR, RL contribution suppressed by m_s/m_b

NP in Wilson coefficients



Wilson coefficients at $\mu_{\rm NP}$

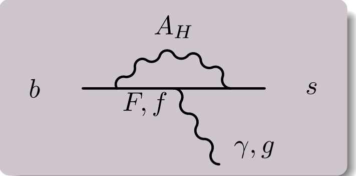
generic couplings

$$\Delta^{LL} C_{7\gamma}^{\rm heavy}(\mu_H) = -\frac{1}{6}\frac{g_H^2}{g_2^2}\frac{C_L^{sF*}C_L^{bF}}{V_{ts}^* V_{tb}}\frac{M_W^2}{M_{A_H}^2}\left(C_{8G}^{SM}(x)+\frac{1}{3}\right)$$

$$\Delta^{LR} C_{7\gamma}^{\rm heavy}(\mu_H) = -\frac{1}{6}\frac{g_H^2}{g_2^2}\frac{C_L^{sF*}C_R^{bF}}{V_{ts}^* V_{tb}}\frac{M_W^2}{M_{A_H}^2}\frac{m'_F}{m_b}C_{8G}^{LR}(x)$$

with $x = \frac{m_F'^2}{M_{A_H}^2}$, similarly for $\Delta^{LL} C_{7\gamma}^{\rm light}(\mu_H)$ and $\Delta^{LR} C_{7\gamma}^{\rm light}(\mu_H)$

NP in Wilson coefficients



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strong enhancement through m'_F/m_b, dominates

similar for top-contribution in LR models (Cho, Misiak '94; Bobeth, Misiak, Urban '00)

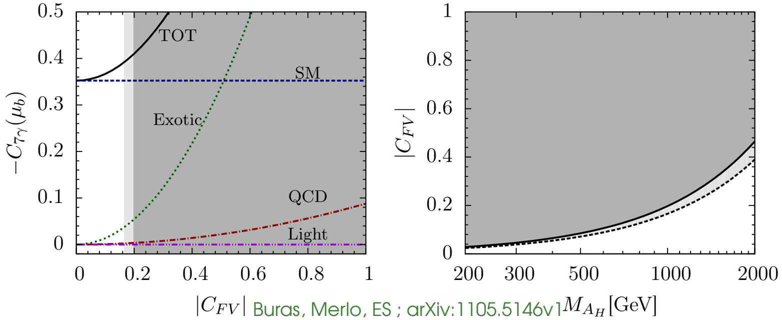
Constraints with general couplings

Exotic LR contribution dominates

1st constraint: sign SM-like: $\Delta C_{7\gamma}(\mu_{\text{NP}}) < 0$
2nd constraint: NP enhances BR at most $+1\sigma(+2\sigma)$ above exp.

Toy model

$\mu_{\text{NP}} = 1$ TeV $m'_F = 10$ TeV $|C_{FV}| = |C_{FC}|$



Buras, Merlo, ES ; arXiv:1105.5146v1

See-saw couplings

$$\mathcal{L}_{\text{see-saw}} = \begin{pmatrix} \bar{\psi}_L & \bar{\Psi}_L \end{pmatrix} \begin{pmatrix} 0 & M_2^D \\ M_1^D & \hat{M} \end{pmatrix} \begin{pmatrix} \psi_R \\ \Psi_R \end{pmatrix}$$

See-saw mechanism

- exotic fermions explain SM masses and mixings
- low NP scale
- protection against FCNCs

cf. talk by Prof. Mohapatra

$$C_{L,R}^{sF} \approx \sqrt{\frac{m_s}{m'_F}} \qquad C_{L,R}^{bF} \approx \sqrt{\frac{m_b}{m'_F}}$$

Suppression of exotic contribution, QCD effects important.

See-saw couplings

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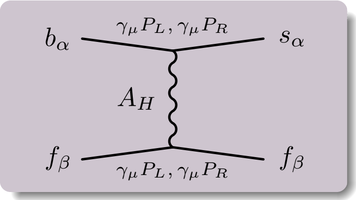
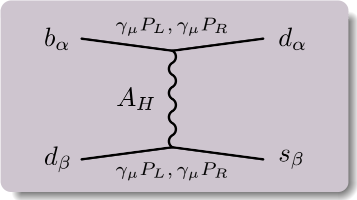
Neutral current-current operators



48 operators



8 operators

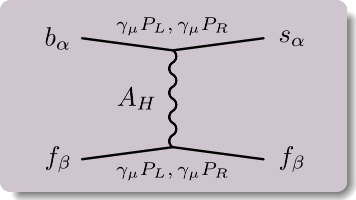
Mix into dipole operators contributing to $C_{7\gamma}(\mu_b)$.

Full Operator Basis

Q^{cc} , Q_P , Q_D , $\boldsymbol{Q^{nn}}$, Q'_P , Q'_D , $\boldsymbol{Q^{nn\prime}}$

$$\Delta C_{7\gamma}(\mu_b) = \kappa_7 \, \Delta C_{7\gamma}(\mu_H) + \kappa_8 \, \Delta C_{8G}(\mu_H) + \\ + \sum_{\substack{A=L,R \\ f=u,c,t,d,s,b}} \kappa^f_{LA} \, \Delta^{LA} C^f_2(\mu_H) + \sum_{A=L,R} \hat{\kappa}^d_{LA} \, \Delta^{LA} \hat{C}^d_2(\mu_H).$$

Neutral current-current operators



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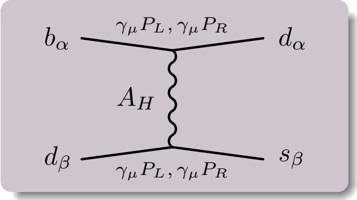

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Anomalous Dimensions

	Q^{cc}	Q_P	Q_D	$\boldsymbol{Q^{nn}}$	Q'_P	Q'_D	$\boldsymbol{Q^{nn\,\prime}}$
Q^{cc}	X_1	X_2	X_3	0			
Q_P	0	X_4	X_5	0			
Q_D	0	0	X_6	0			
$\boldsymbol{Q^{nn}}$	0	$\boldsymbol{Y_1}$	$\boldsymbol{Y_2}$	$\boldsymbol{Y_3}$			
Q'_P					X_4	X_5	0
Q'_D					0	X_6	0
$\boldsymbol{Q^{nn\,\prime}}$					$\boldsymbol{Y_1}$	$\boldsymbol{Y_2}$	$\boldsymbol{Y_3}$

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Constraints with see-saw couplings

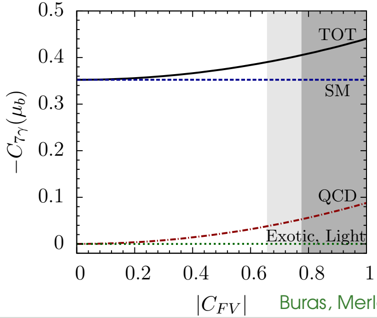
1st constraint: sign SM-like

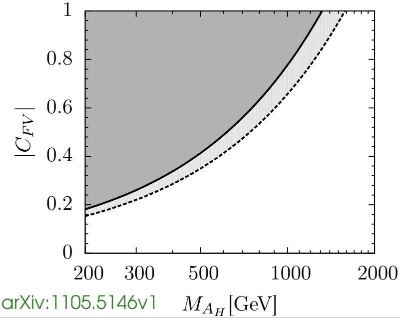
$$\Delta C_{7\gamma}(\mu_{\text{NP}}) < 0$$

2nd constraint: NP enhances BR at most $+1\sigma(+2\sigma)$ above exp.

$$-\Delta C_{7\gamma}(\mu_b) + 1.4\left(|\Delta C_{7\gamma}(\mu_b)|^2 + |\Delta C'_{7\gamma}(\mu_b)|^2\right) \lesssim 4.2(6.1) \times 10^{-2}$$

Toy model: $|C^b_{FV}| = |C_{FC}|$





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Conclusions

Summary

- heavy neutral gauge bosons change initial conditions
- heavy neutral gauge bosons generate new operators
- QCD RG mixes them into $C_{7\gamma}$
- new anomalous dimension matrix

Results

- $b \to s\gamma$ constrains Z' or gauge flavour models
- constraints depend on specific model
- QCD RG effects should not be underestimated

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Muito obrigado!

Backup: Magic numbers

μ_H	200 GeV	1 TeV	5 TeV	10 TeV
κ_7	0.525	0.459	0.409	0.391
κ_8	0.117	0.125	0.129	0.130
$\kappa_{LL}^{u,c}$	0.038	0.057	0.076	0.084
κ_{LL}^{t}	−0.002	−0.003	−0.002	−0.001
κ_{LL}^{d}	−0.040	−0.057	−0.072	−0.078
$\kappa_{LL}^{s,b}$	0.087	0.090	0.090	0.090
$\hat{\kappa}_{LL}^{d}$	0.127	0.147	0.162	0.168
$\kappa_{LR}^{u,c}$	0.084	0.127	0.172	0.191
κ_{LR}^{t}	0.004	0.012	0.023	0.028
κ_{LR}^{d}	−0.015	−0.025	−0.036	−0.041
$\kappa_{LR}^{s,b}$	−0.078	−0.092	−0.105	−0.111
$\hat{\kappa}_{LR}^{d}$	0.470	0.661	0.859	0.947