$B_s \to \mu^+ \mu^-$ and New Physics

from an EFT perspective

Diego Guadagnoli
LAPTh Annecy

Based on:
- Buras, Girrbach, DG, Isidori, EPJC 13
- DG, Isidori, PLB 13

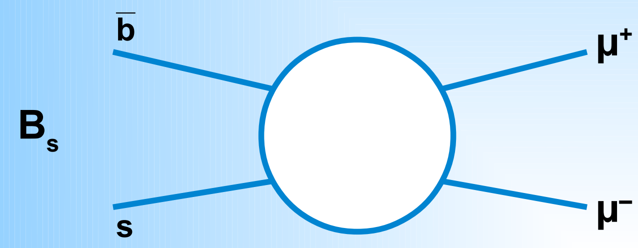
Outline

☑ **$B_s \to \mu\mu$ as a probe of extended Higgs sectors**

☑ **$B_s \to \mu\mu$ as an EW precision test**

With minimal assumptions, possible to correlate $B_s \to \mu\mu$ to *Z*-peak observables from LEP

☑ $B_s \to \mu\mu$ basics



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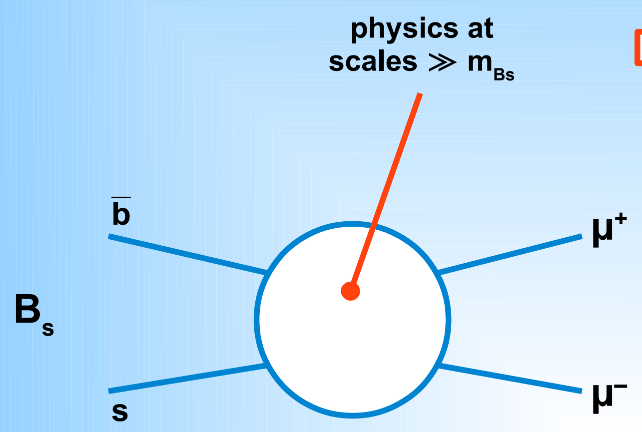

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"short-distance"
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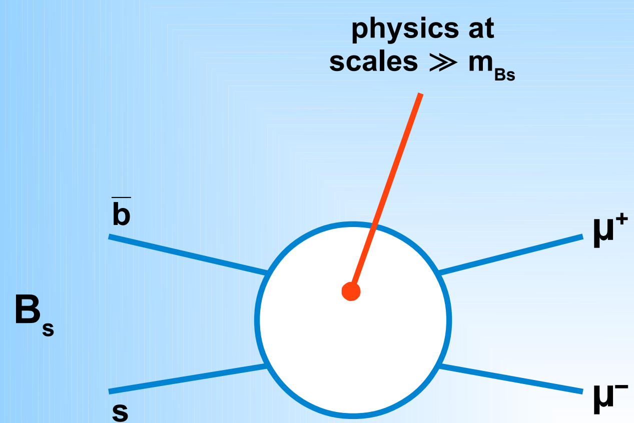

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within the SM: $Y\left(M_t^2/M_W^2\right)$

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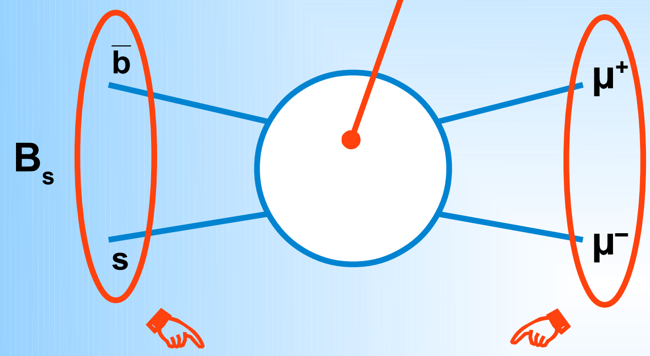

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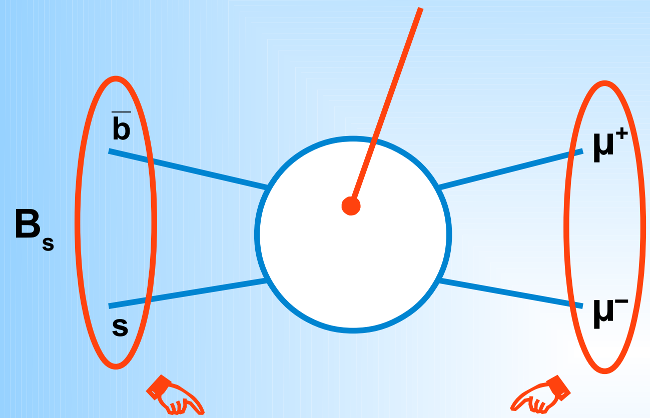

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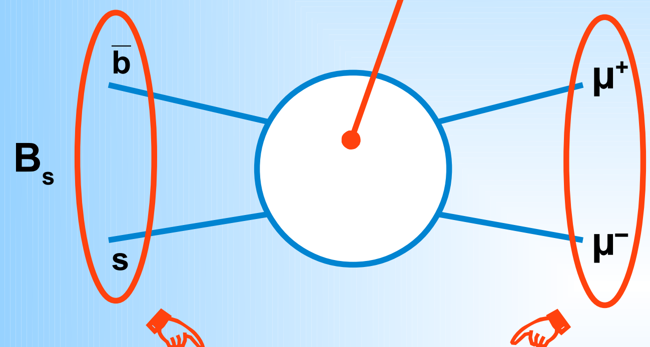

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evaluating this operator between external B_s and $\mu\mu$ states ⇨ $\dfrac{m_\mu^2}{M_W^2} \sim 10^{-6}$

very rare (and very clean) decay

D. Guadagnoli, Rencontres de Blois 2013

BR[$B_s \to \mu^+\mu^-$] beyond the SM

Model-independent approach: effective operators

Beyond the SM,
a total of 6 operators can contribute:

(One may write also two tensor operators,
but their matrix elements vanish for this process.)

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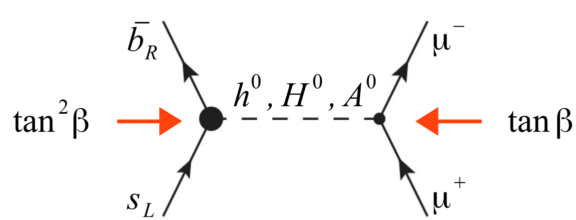
One famous example:
the MSSM with large tanß



Effectively tree-level diagrams:
Enhancement going as:

$$BR[B_s \to \mu^+\mu^-] \propto A_t^2 \frac{\tan^6\beta}{M_A^4}$$

BR[$B_s \to \mu\mu$] as an EW precision test

DG, Isidori, PLB 13

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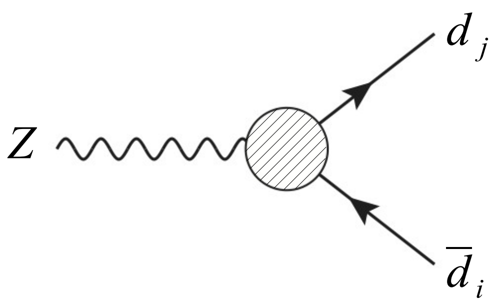

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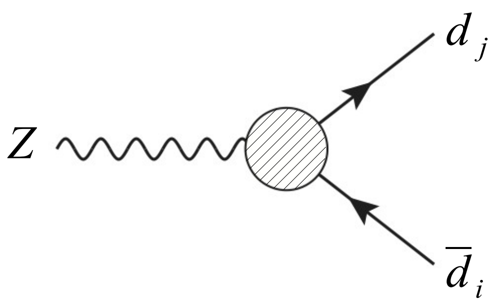

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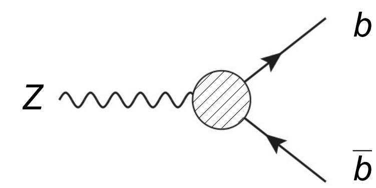
Affects LEP-measured
$Z \to b\,\bar{b}$ observables: R_b, A_b, A^b_{FB}



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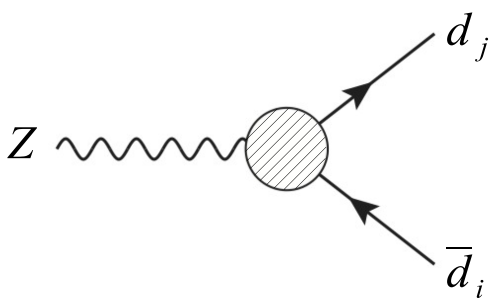

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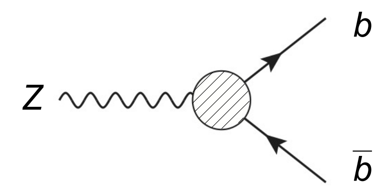
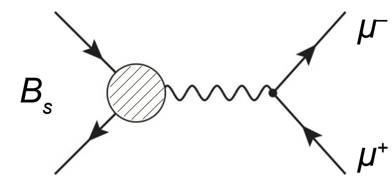


Flavor-off-diag: *$i \neq j$*

Affects Z-penguin-driven FCNCs,
in particular $B_s \to \mu\mu$



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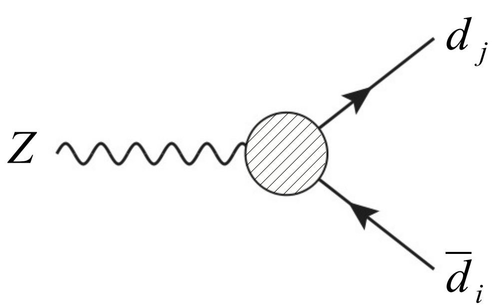

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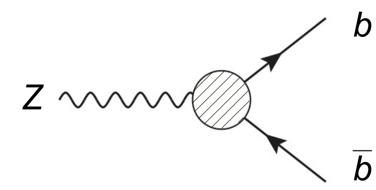

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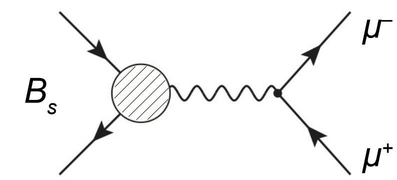

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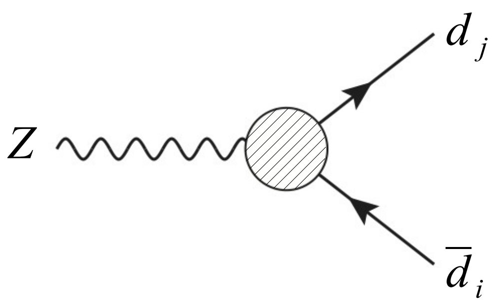

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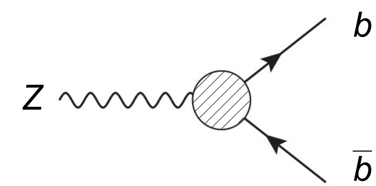

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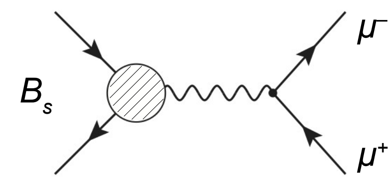

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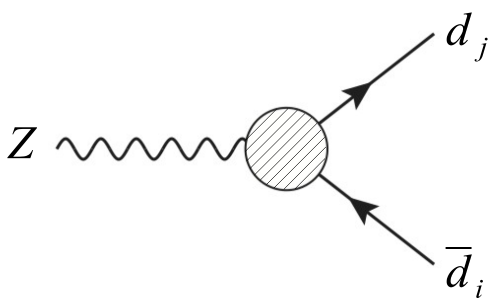

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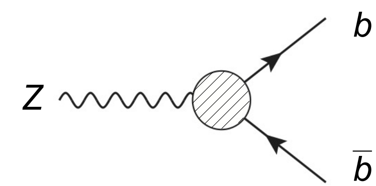

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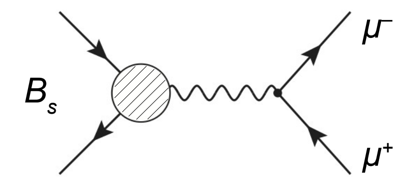

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Comments

- ☑ Three such structures compatible with the SM gauge group
- ☑ Other operators yield negligible effects in either *Z*-peak obs or in $B_s \to \mu\mu$
  - 4-fermion ops. negligible in Zbb
  - ops. involving field-strength tensors negligible in $B_s \to \mu\mu$

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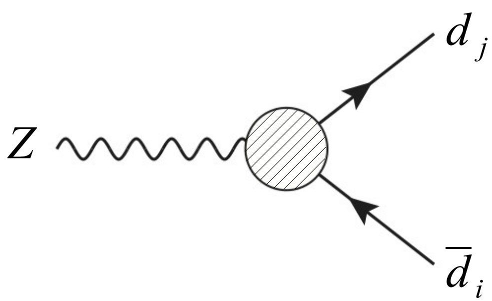

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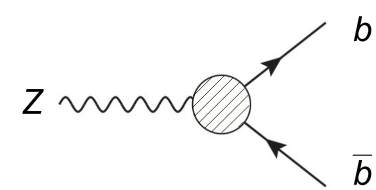

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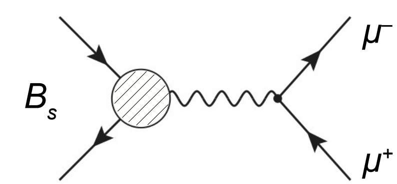

- Shifts in Zdd couplings can be implemented as contributions from effective operators (→ minimal model dep.)

The only operators relevant to the problem are of the form:

$$\text{Operators} \sim \left(\bar{d}_i\ \gamma^\mu\ X^{ij}\ d_j\right)\underbrace{\left(H^\dagger D_\mu H\right)}_{\sim\ v^2\ Z_\mu}$$

flavor structure $\to X^{ij}$

Comments

- Three such structures compatible with the SM gauge group
- Other operators yield negligible effects in either Z-peak obs or in $B_s \to \mu\mu$
  - 4-fermion ops. negligible in Zbb
  - ops. involving field-strength tensors negligible in $B_s \to \mu\mu$

Model (in)dependence of the BR[$B_s \to \mu\mu$] vs. $Z \to bb$ correlation

Recall:

from an Effective Theory point of view, <u>correlated shifts</u> on $B_s \to \mu\mu$ and $Z \to bb$ observables can only be generated by operators of the kind:

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Within frameworks as general (and motivated) as:

- Minimal Flavor Violation

See: D'Ambrosio *et al.*, NPB 02

or

- Partial Compositeness

See:
Davidson, Isidori, Uhlig, PLB 08;
Keren-Zur *et al.*, NPB 13

the X^{ij} can be fixed up to O(1) factors
(that btw weigh equally between Zbb and $B_s \to \mu\mu$)

Fixing the couplings. Case 1: MFV

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$$\delta g_L^{32} = \frac{V_{tb}^* V_{ts}}{|V_{tb}|^2} \delta g_L$$

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D. Guadagnoli, Rencontres de Blois 2013

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Fixing the couplings. Case 2: Partial Compositeness

See e.g.:
Davidson, Isidori, Uhlig, PLB 08

Basic observation #1. Within the dim-4 part of the Lagrangian, two are the possible sources of flavor violation:

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and/or

2. **As less well known:** Hierarchical kinetic terms for fermions

Restricting to dim-4 interactions, the two sources are interchangeable (→ only a matter of field-basis choice)

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$$Y_{u,d} = O(1) \xrightarrow{\text{canonical kin. terms}} \left(Y_{u,d}\right)_{ij} \propto z_Q^{(i)}\, z_{u,d}^{(j)}$$

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See e.g.:
Keren-Zur *et al.*, NPB 13

Basic observation #2.

The *very same* $Y_{u,d}$ pattern as above arises in scenarios of Partial Compositeness.

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Main point

- From the second picture it is evident that the relevant low-energy d.o.f. are not f_i , but rather $\epsilon_i f_i$
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Example

Flavor structure of the RH operator $O_{1R}^{32} \equiv i \left(\bar{b}_R \gamma^\mu s_R \right) H^\dagger D_\mu H$

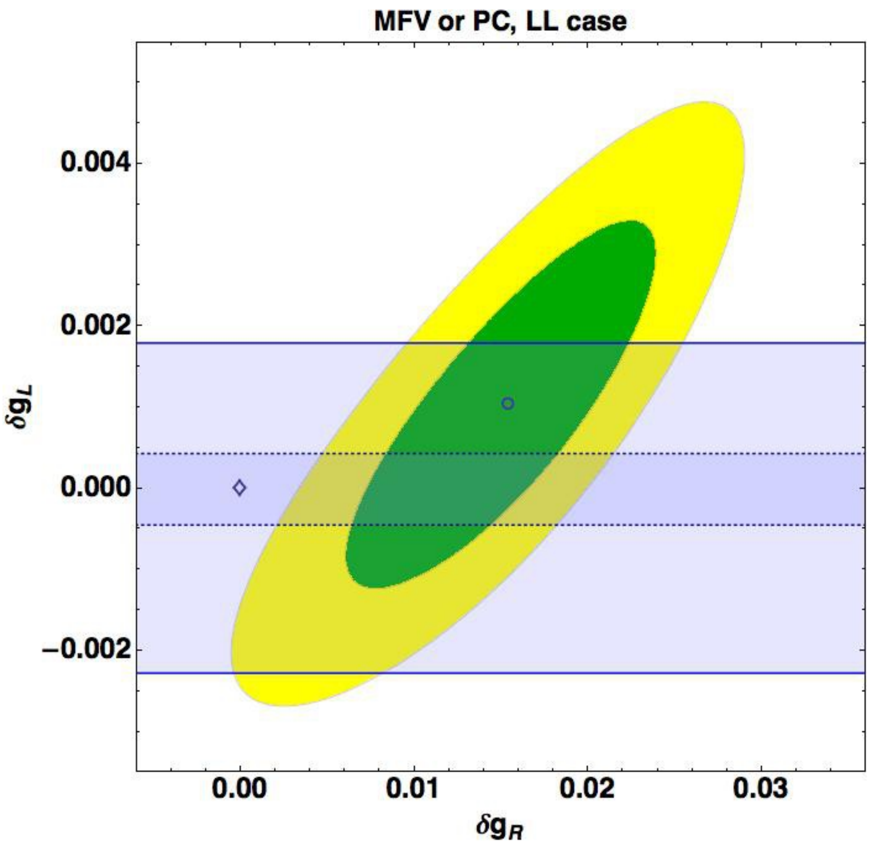
Wilson coeff.

$$\propto z_d^{(3)} z_d^{(2)} = \frac{z_Q^{(3)} z_d^{(3)} \, z_Q^{(2)} z_d^{(2)}}{z_Q^{(3)} z_Q^{(2)}} \propto \frac{m_b \, m_s}{|V_{tb}||V_{ts}|} \Rightarrow \delta g_R^{32} = \frac{m_b m_s}{|V_{tb}||V_{ts}|} \frac{|V_{tb}|^2}{m_b^2} \, \delta g_R$$

BR[$B_s \to \mu\mu$] as an EWPT: results

DG, Isidori, PLB 13

- One can then compare the limits on $\delta g_{L,R}$ obtained from *Z*-peak obs with those obtained from $B_s \to \mu\mu$



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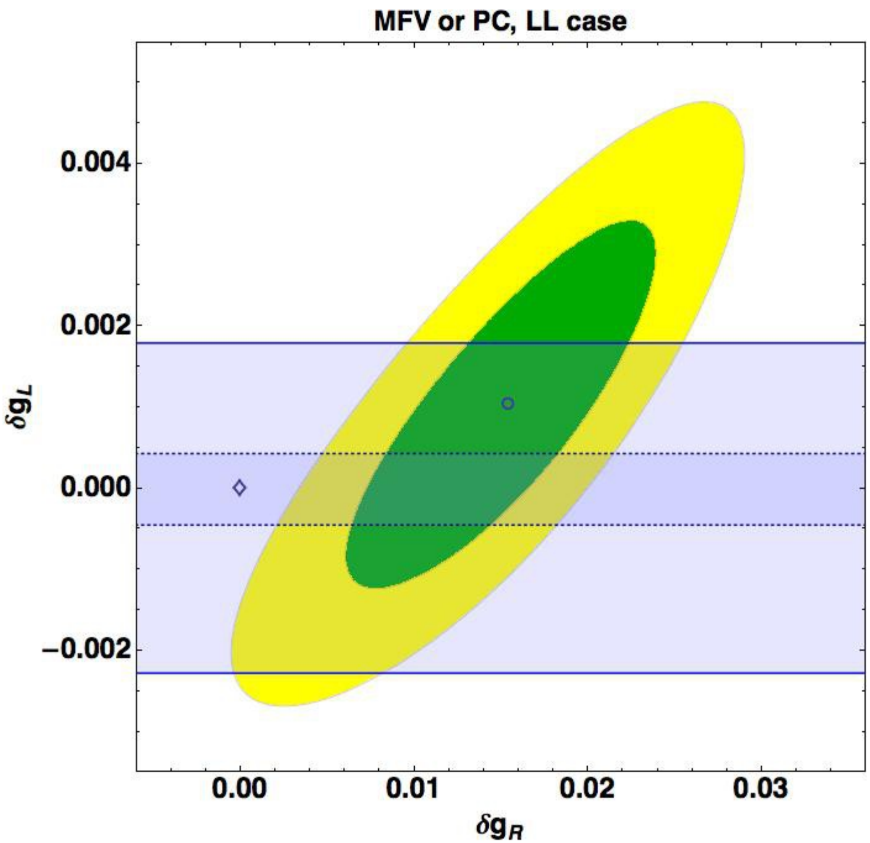

with present $B_s \to \mu\mu$ exp error

$$|\delta g_L|^{\text{MFV or PC}} < 2.3\times10^{-3}$$

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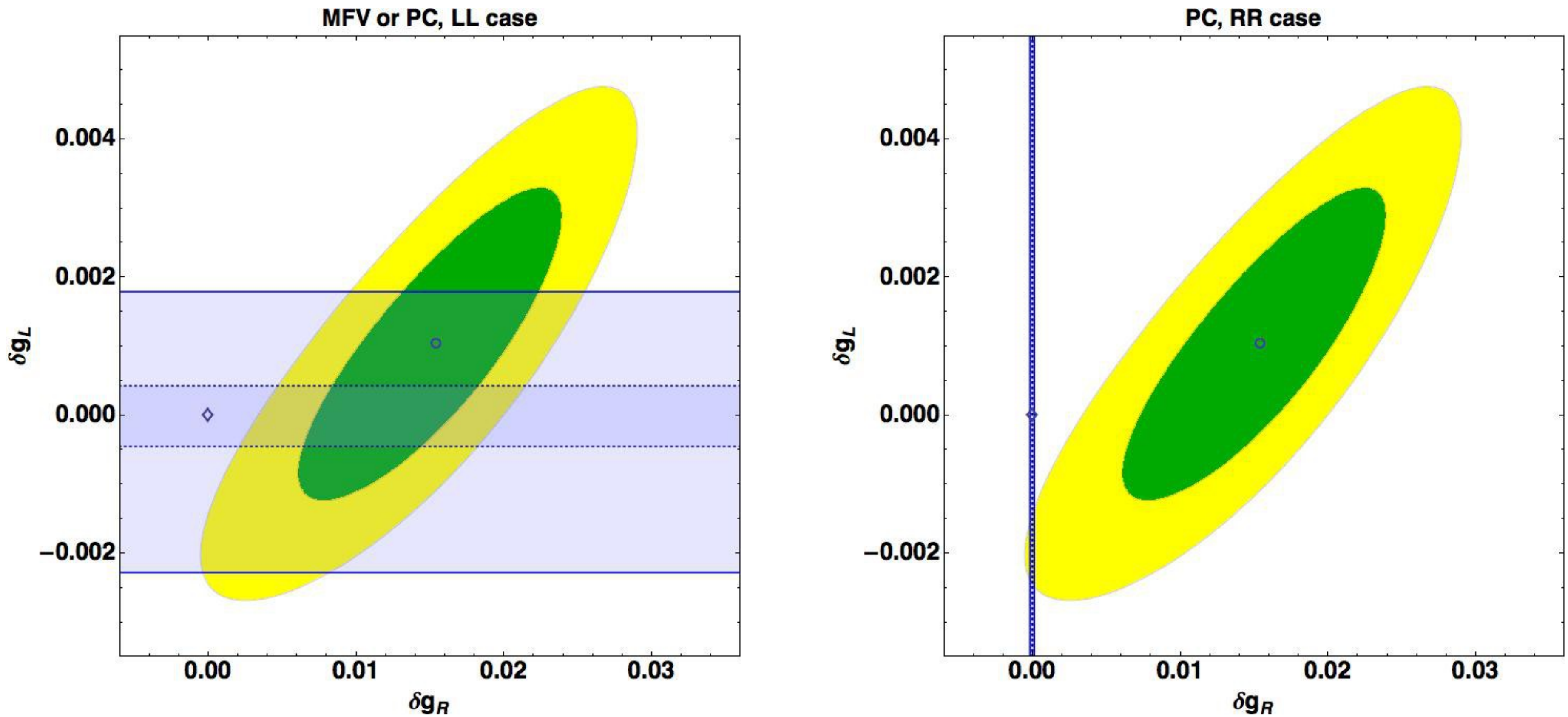

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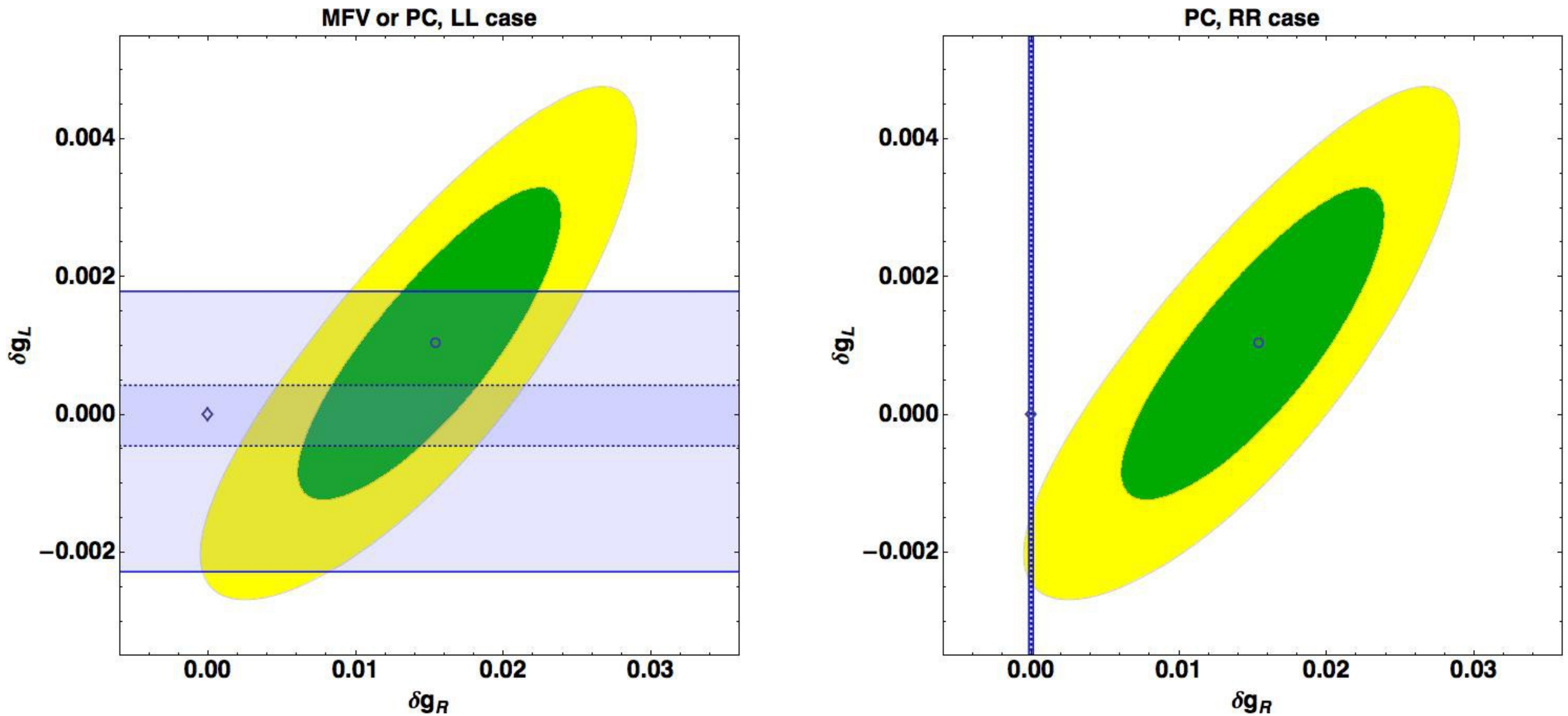

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Conclusions

- *To the extent that no deviations wrt the SM prediction are observed, $B_s \to \mu\mu$ is a (formidable) null test of new physics*

- *Example 1: $B_s \to \mu\mu$ as a Yukawa-driven decay*
  - *Exquisite probe of modifications in scalar-fermion couplings, even with scalars above threshold for direct production*

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- *Example 2: $B_s \to \mu\mu$ as a Z-penguin-driven process*
  - *able to test even tiny deviations in Z-down-quark couplings*
  - *E.g., within generic partial compositeness:*

    $O(10^{-5})$ deviations in couplings to RH down-quarks: way more stringent than EWPO