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

from an EFT perspective

Diego Guadagnoli

LAPTh Annecy

Based on:
- Buras, Girrbach, DG, Isidori, EPJC 13
- DG, Isidori, 1302.3909

Outline

☑ **Th ↔ Exp Issues**

One-slide summary about what theory calculates vs. what exp measures

☑ **Impact on new physics** within an effective-theory approach

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

Theory (SM) ready to match expected experimental accuracy

- *SM prediction:*

$$BR[B_s \to \mu^+\mu^-]_{\mathrm{SM}} = (3.23 \pm 0.27) \cdot 10^{-9}$$

Statistical error

- dominated by f_{Bs} error (7%) followed by CKM error (4%)
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  - **Incomplete knowledge of NLO EW corrections:**

    - *Implied syst. error comparable to f_{Bs} error*
    - *Impact on above central value arguably small (~ O(1%)) in appropriate scheme*
    - *Final answer only from full calculation*

    See talk by M. Gorbahn

$B_s \rightarrow \mu\mu$ and new physics

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.)

SM operator

$$\boxed{O_A \equiv \left(\bar{b}\gamma_L^\alpha s\right)\left(\bar{\mu}\gamma_\alpha\gamma_5\mu\right)} \qquad O'_A \equiv \left(\bar{b}\gamma_R^\alpha s\right)\left(\bar{\mu}\gamma_\alpha\gamma_5\mu\right)$$

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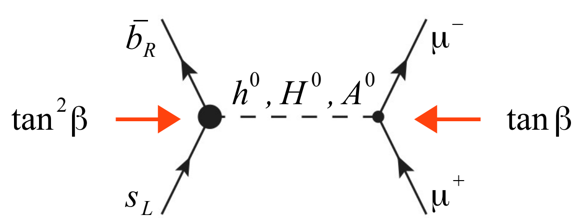
One famous example:
the MSSM with large tanß



Effectively tree-level diagrams:
Enhancement going as:

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

D. Guadagnoli, Portoroz 2013

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

DG, Isidori, 1302.3909

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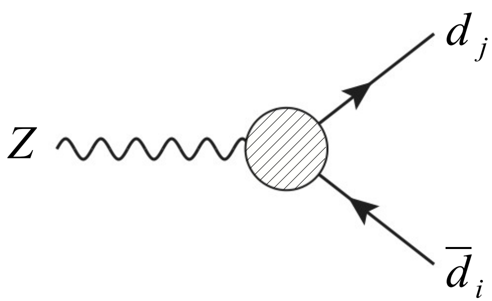

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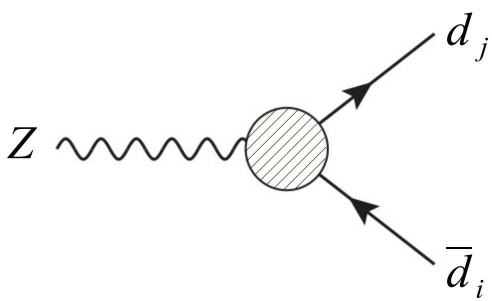
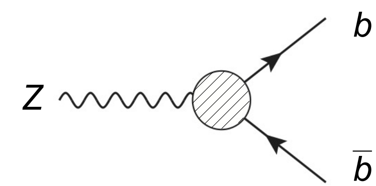


Flavor-diag: *i = j (= 3)*

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



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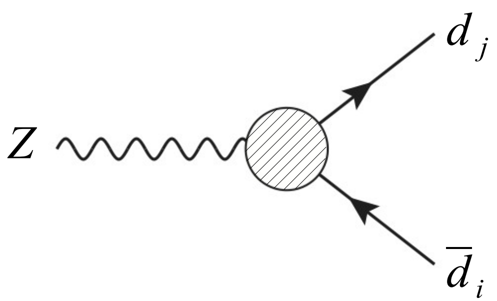

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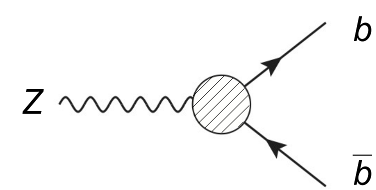

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Affects Z-penguin-driven FCNCs,
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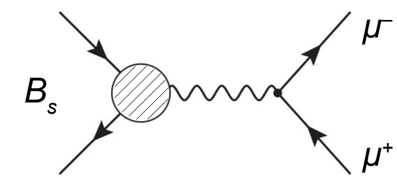

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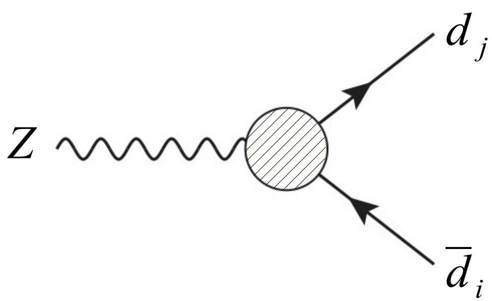

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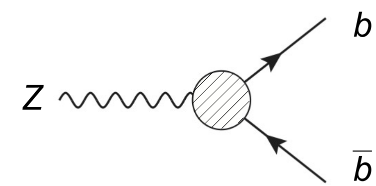

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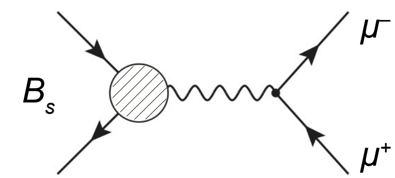

- At the Lagrangian leven, these coupling modifications may be parameterized as follows

$$L^{Zdd}_{\rm eff} = \frac{g}{c_W} Z_\mu \, \bar{d}^i \, \gamma^\mu \left[\left(g^{ij}_L + \delta g^{ij}_L \right) P_L + \left(g^{ij}_R + \delta g^{ij}_R \right) P_R \right] d^j$$

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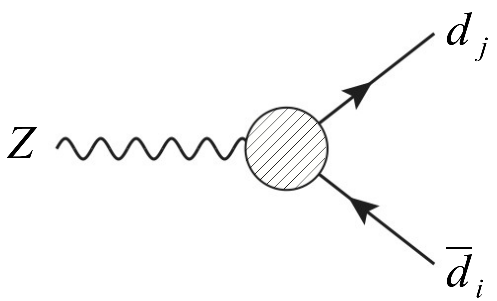

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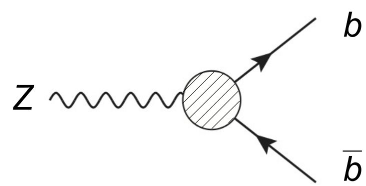

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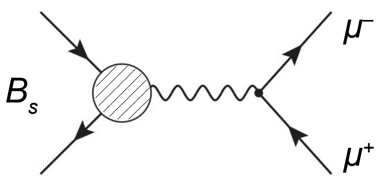

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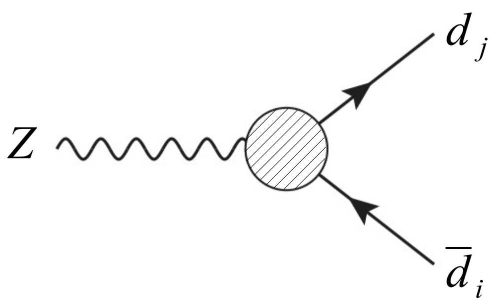

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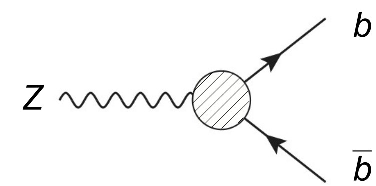

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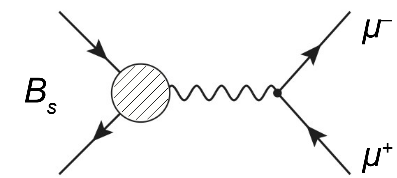

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new-physics enters here

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DG, Isidori, 1302.3909

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

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DG, Isidori, 1302.3909

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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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$$\overline{Q}_L Z_Q^{-2} \gamma^\mu D_\mu Q_L$$

with $Z_Q = \mathrm{diag}(z_Q^{(1)}, z_Q^{(2)}, z_Q^{(3)})$

and $z_Q^{(1)} \ll z_Q^{(2)} \ll z_Q^{(3)}$

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

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At a cutoff scale Λ, the SM fermions f_i couple linearly to operators O_i of a confining sector:

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- The two pictures are completely equivalent – at least within our context
- 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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BR[$B_s \to \mu\mu$] as an EWPT: results

DG, Isidori, 1302.3909

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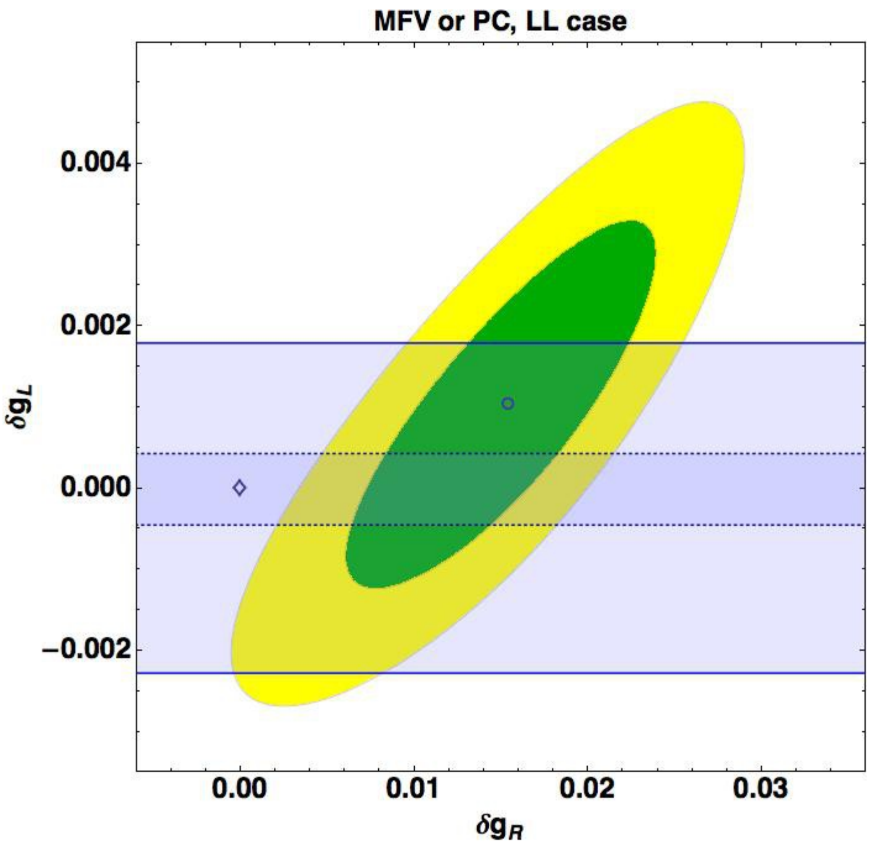

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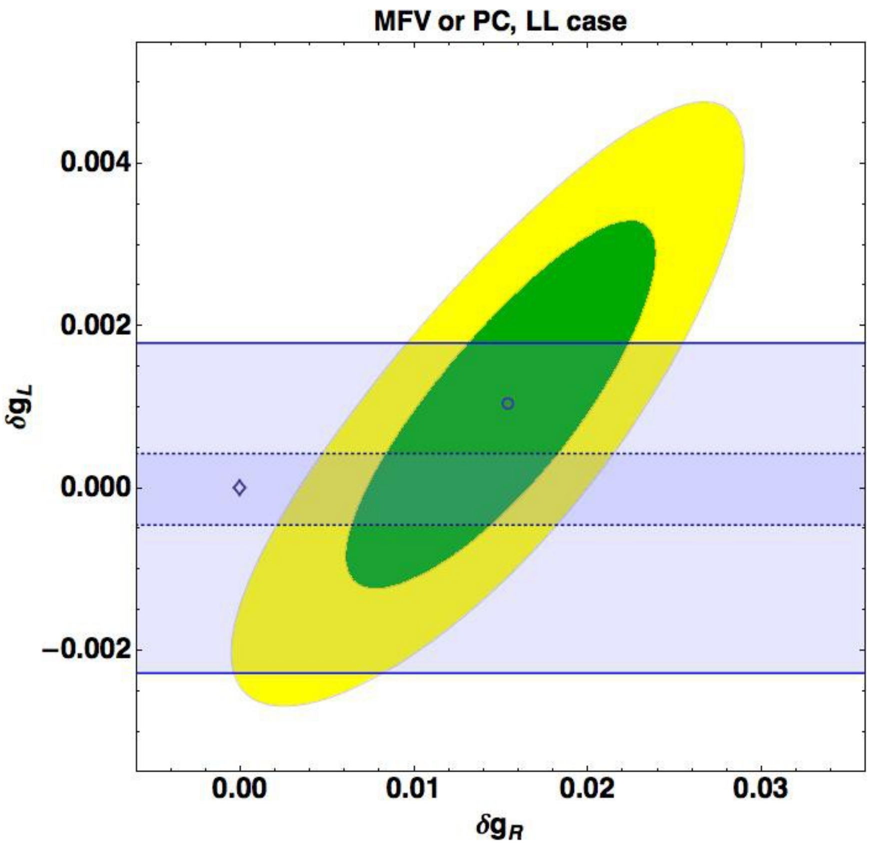

with present $B_s \to \mu\mu$ exp error

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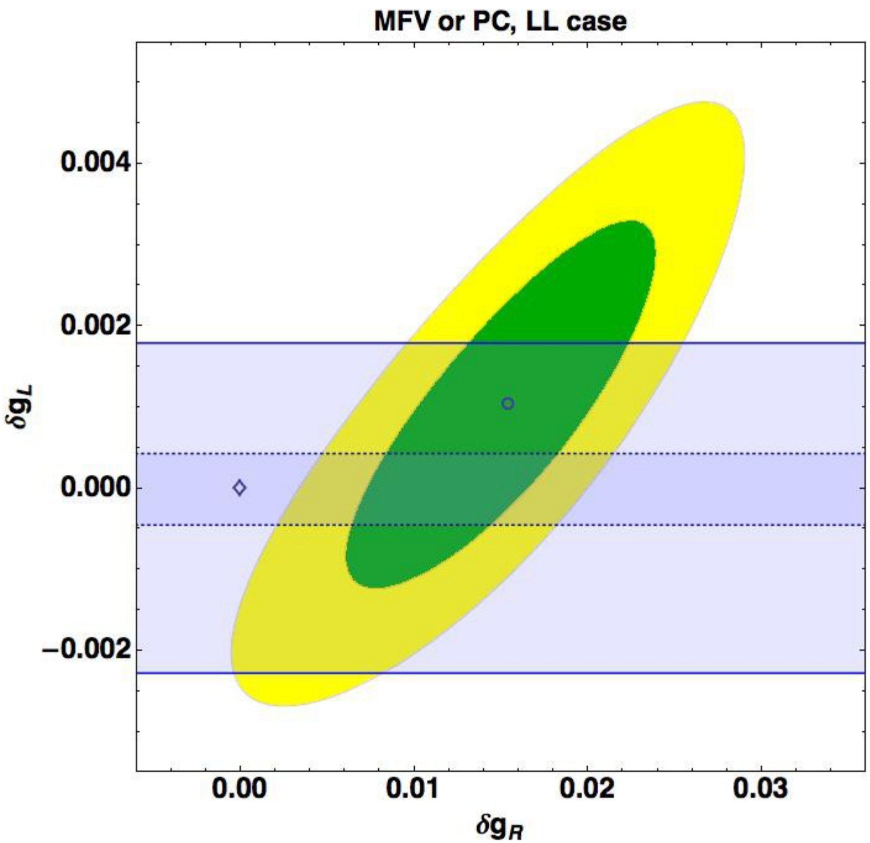

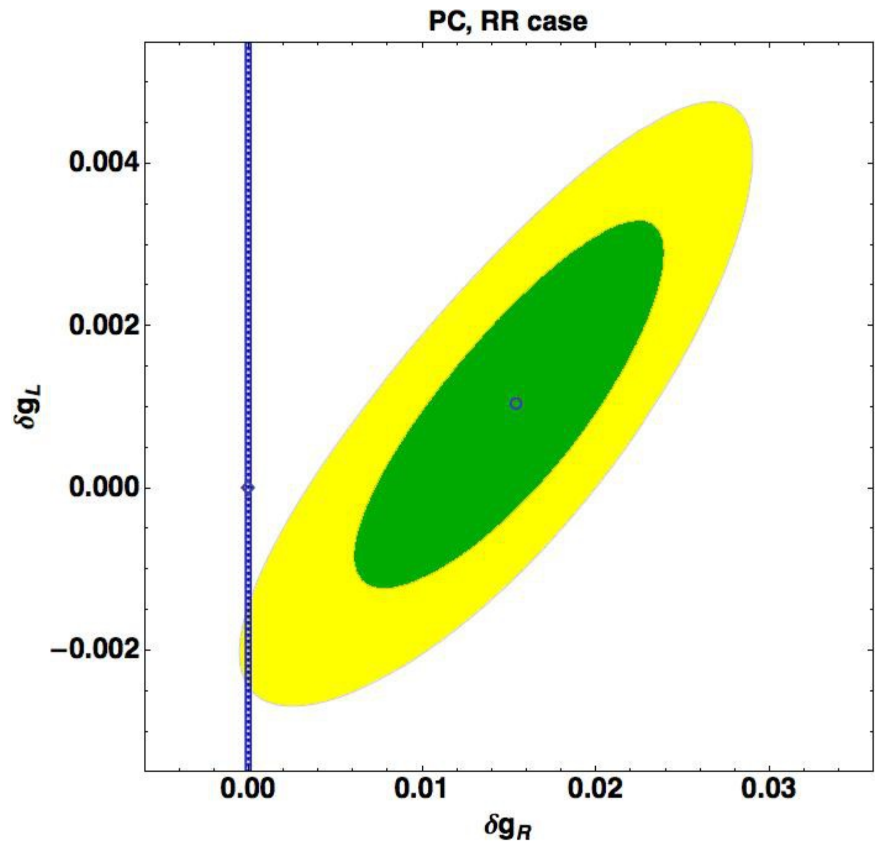

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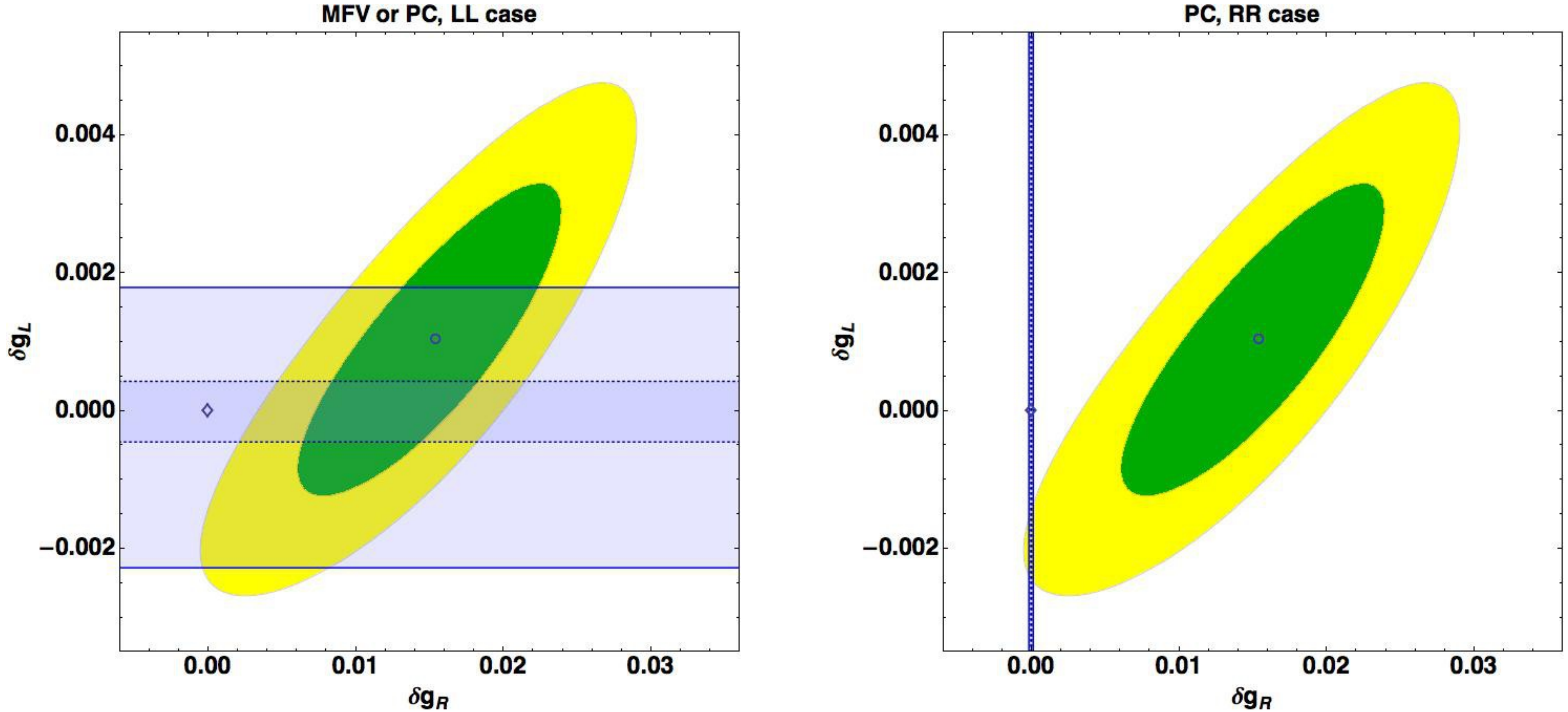

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Conclusions

☑ **$B_s \to \mu\mu$: SM vs. exp**

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☑ **$B_s \to \mu\mu$ and new physics**

- *To the extent that no deviations wrt the SM prediction are observed, it is a (formidable) <u>null test</u> of new physics*
- *One example of $B_s \to \mu\mu$ constraining power:*
  - *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: <u>way more stringent than EWPO</u>

Systematics from soft radiation

Ideally, the final state is a μμ-pair such that $m_{\mu\mu} \approx m_{Bs}$ In practice, this final state may come with a number of soft, undetected, photons, so that what one is actually measuring is:

$$BR(B_s \to \mu\mu) \;+\; BR(B_s \to \mu\mu + n\gamma)\big|_{n\neq 0}$$

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Main physics argument

- A proper treatment of soft photons must sum up the contribution from an <u>arbitrary number</u> of:

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cutoff 1 $= \sum_i E_{\gamma i} = \underbrace{E_{\rm cut}}$

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cutoff 2 $= \Lambda \leq \underbrace{\frac{m_{B_s}}{2}}$

kinematic limit of the energy that a virtual γ can have

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cutoff of exp origin:
minimum energy that one or more γ have to have to be detectable

cutoff 2 $= \Lambda \leq \underbrace{\frac{m_{B_s}}{2}}$

kinematic limit of the energy that a virtual γ can have

- Furthermore, the two contributions, separately, have each an IR cutoff.

Systematics from soft radiation

Ideally, the final state is a μμ-pair such that $m_{\mu\mu} \approx m_{B_s}$ In practice, this final state may come with a number of soft, undetected, photons, so that what one is actually measuring is:

$$BR(B_s \to \mu\mu) + BR(B_s \to \mu\mu + n\gamma)|_{n \neq 0}$$

[(dominant) sub-leading e.m. correction to the BR]

Why should this correction be significant?

Beware: this correction is already taken into account by LHCb

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Since the two cutoffs are (generally) vastly different, the correction may well be important – and in fact it is.

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taking E_{cut} = 60 MeV [LHCb]
correction = 0.89