On the $B_s \to \mu^+ \mu^-$ Decay

– measurement, SM prediction and impact on (selected) new physics –

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Based on:

- **Buras, Girrbach, DG, Isidori, EPJC 13**
- **DG, Isidori, 1302.3909**

Outline

☑ **Basic facts about $B_s \to \mu\mu$:** Why so small within the SM, why interesting beyond the SM

☑ **$B_s \to \mu\mu$ SM formula:** structure, prediction, uncertainties

☑ **Th ↔ Exp Issues:**
Establishing a contact between what theory calculates, and what exp measures

- Focus on final-state undetected radiation

☑ **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

Basic facts about

$B_s \rightarrow \mu\mu$

The $B_s \to \mu\mu$ decay within the SM: structure

See: Buchalla, Buras '93; Misiak, Urban '99

$BR[B_s \to \mu\mu]$ has the following structure

$$BR[B_s \to \mu^+ \mu^-] \simeq \frac{1}{\Gamma_s} \times \left(\frac{G_F^2 \alpha_{\mathrm{e.m.}}^2}{16 \pi^3 s_W^4} \right) \cdot \left| V_{tb}^* V_{ts} \right|^2 \cdot f_{B_s}^2 \, m_{B_s} \cdot m_\mu^2 \cdot Y^2 (m_t^2 / M_W^2)$$

couplings: gauge and CKM

hadronic matrix elem'

crucial: chiral suppression

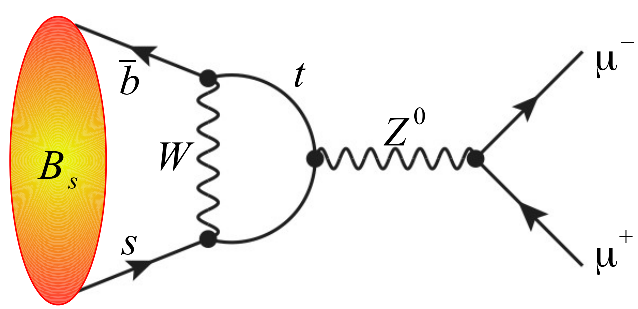
short-distance function (aka Wilson coefficient)

Some Comments

couplings and Y-function:

Example of diagram

The Z^0-penguin (contribution: ~ 80%)



- The relevant CKM structure is $V^*_{tb} V_{ts}$
- top-mass dependence from the loop

$B_s \to \mu\mu$ structure: continued

$$BR[B_s \to \mu^+ \mu^-] \simeq \frac{1}{\Gamma_s} \times \left(\frac{G_F^2 \alpha_{\rm e.m.}^2}{16 \pi^3 s_W^4} \right) \cdot |V_{tb}^* V_{ts}|^2 \cdot f_{B_s}^2 \, m_{B_s} \cdot m_\mu^2 \cdot Y^2 (m_t^2 / M_W^2)$$

hadronic matrix element

Recall: the final state is purely leptonic

The only non-null matrix elem' is:

$$\langle 0 | \bar{b} \gamma^\alpha \gamma_5 s | B_s(p) \rangle = -i f_{B_s} p^\alpha$$

- f_{Bs} is among the simplest quantities for lattice QCD
- high-precision calculations possible, and in part already reality

chiral suppression

What about p^α in the above matrix element?

- It contracts with the lepton current, yielding: $\bar{\mu} \, p^\alpha (c_V \gamma_\alpha + c_A \gamma_\alpha \gamma_5) \mu$
- Since p = p(μ^+) + p(μ^-), using the μμ-pair e.o.m. one gets: $2 m_\mu c_A \bar{\mu} \gamma_5 \mu$

Chiral suppression
m_μ^2 dependence
in the branching ratio

Within the SM, only one operator contributing:

$$O_A \equiv (\bar{b} \gamma_L^\alpha s)(\bar{\mu} \gamma_\alpha \gamma_5 \mu)$$

$B_s \to \mu\mu$ structure: continued

$$BR[B_s \to \mu^+\mu^-] \simeq \frac{1}{\Gamma_s} \times \left(\frac{G_F^2 \alpha_{e.m.}^2}{16\pi^3 s_W^4}\right) \cdot \left|V_{tb}^* V_{ts}\right|^2 \cdot f_{B_s}^2 m_{B_s} \cdot m_\mu^2 \cdot Y^2(m_t^2/M_W^2)$$

Masses' & couplings' dependence of the BR = "usual" FCNC-related suppression $\times \dfrac{m_\mu^2}{M_W^2}$

Additional "chiral" suppression: relative 10^{-6} factor

Chiral suppression && purely leptonic nature of the decay

⇓

Extremely rare && very clean decay at the same time

⇒ One of the best available probes of physics at and (well) above the LHC reach

[Buras, Girrbach, DG, Isidori, EPJC 13]

SM prediction

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

Let's look at the error in more detail

BR[$B_s \to \mu\mu$]: parametric dependence

- The main sources of error within the BR formula are:

$$BR[B_s \to \mu^+\mu^-] \simeq \frac{1}{\Gamma_s} \times \left(\frac{G_F^2 \alpha_{\rm e.m.}^2}{16\pi^3 s_W^4} \right) \cdot \left| V_{tb}^* V_{ts} \right|^2 \cdot f_{B_s}^2 m_{B_s} \cdot m_\mu^2 \cdot Y^2 (m_t^2 / M_W^2)$$

Thus, one can write the following phenomenological expression for the BR

top "pole" mass here

$$BR[B_s \to \mu^+\mu^-] = 3.23 \cdot 10^{-9} \cdot \left(\frac{\tau_{B_s}}{1.466\,\text{ps}} \right) \cdot \left(\frac{\text{Re}(V_{tb}^* V_{ts})}{4.05 \cdot 10^{-2}} \right)^2 \cdot \left(\frac{f_{B_s}}{227\,\text{MeV}} \right)^2 \cdot \left(\frac{M_t}{173.2\,\text{GeV}} \right)^{3.07}$$

- Thence one can easily work out the main error components as follows

	pdgLive	CKMfitter or UTfit	LQCD average (central value from C. Davies)	Tevatron average on 5.8/fb: 1107.5255
Input	$\tau_{B_s} = 1.466(31)\,\text{ps}$	$\text{Re}(V_{tb}^* V_{ts}) = 4.05(8) \cdot 10^{-2}$	$f_{B_s} = 227(8)\,\text{MeV}$	$M_t = 173.2(0.9)\,\text{GeV}$
Contribution to BR relative error	2%	4%	7%	1.6%

Total relative error expected for BR[$B_s \to \mu\mu$]: **about 8.5%**

Systematic error from EW corrections

- At present, EW corrections to the decay are not known completely, but only in the "large-m_t" approximation. This is the main source of uncertainty in the short-distance part of the calculation.

- This uncertainty corresponds to an ambiguity in the choice of the EW parameters (including m_t).

For example:

$s_W^2[\overline{\mathrm{MS}}\ \text{scheme}] \simeq 0.231$ vs. $s_W^2[\text{on-shell scheme}] \simeq 0.223$ → 7% variation in the BR ! (equivalent to the f_{Bs} error)

→ The question arises
"Is there a scheme where these corrections are minimized?"

Observation

Buras, Girrbach, DG, Isidori, EPJC 13

- For the process $K \to \pi \nu\nu$, NLO EW corrections have been computed [Brod *et al.*, PRD 11]
- There is one particular scheme, such that NLO EW effects are well below 1%
- It is true that $K \to \pi \nu\nu$ involves a different loop function than $B_s \to \mu\mu$. But for large m_t the dominant diagrams are the same in the two cases

→ *Adopt that very scheme for the $BR[B_s \to \mu\mu]$ estimate*

What theory calculates

vs.

what exp measures

Issue 1. On the initial state of the $B_s \to \mu\mu$ decay

Pointed out in De Bruyn *et al.*, *PRL 12 & PRD 12*

☑ $B_s \to \mu\mu$ arises from the following sequence:

$b\bar{b}$ production ⇒ the b hadronizes into a $\bar{B}_s$ or the $\bar{b}$ hadronizes into a B_s at t = 0 ⇒ the $\bar{B}_s$ (t) or the B_s (t) evolves with time and decays into μμ

In practice, at the exp level:

- there is no flavor tagging: exp measures the sum of $B_s(t) \to \mu\mu$ and $\bar{B}_s(t) \to \mu\mu$
- the decay time info is (for the moment) not used either ⇒ What one is effectively measuring is: $\int dt \{\Gamma(B_s(t) \to \mu\mu) + \Gamma(\bar{B}_s(t) \to \mu\mu)\}$

The exp-measured BR can be defined as follows:

$$BR(B_s \to \mu\mu)_{\text{exp}} \equiv \int_0^\infty dt \frac{1}{2} \{\Gamma(B_s(t) \to \mu\mu) + \Gamma(\bar{B}_s(t) \to \mu\mu)\}$$

See:
Dunietz, Fleischer, Nierste
hep-ph/0012219, PRD

BR_{exp} vs. BR_{th}

See:
De Bruyn *et al.*
PRL 12

What exp measures

$$BR_{\mathbf{exp}} \equiv \int_0^\infty dt\, \frac{1}{2}\{\Gamma(B_s(t)\to\mu\mu)+\Gamma(\bar{B}_s(t)\to\mu\mu)\}$$

Expressing $B_s(t)$ and $\bar{B}_s(t)$ in terms of the mass eigenstates, this sum can be rewritten as

$$= \int_0^\infty dt\, \frac{1}{2}\{R_H e^{-\Gamma_H t} + R_L e^{-\Gamma_L t}\}$$

whence, integrating over t, one gets:

$$BR_{\mathbf{exp}} \equiv \tau_s \left(\frac{R_H+R_L}{2}\right) \frac{1}{1-\Delta\Gamma_s/2\Gamma_s}$$

Note
Γ_s is the average between the $B_{s,H}$ and $B_{s,L}$ widths

What theory calculates

The theoretical BR discussed at the beginning is equivalent to:

$$BR_{\mathbf{th}} \equiv \frac{\tau_s}{2}\{\Gamma(B_s(t)\to\mu\mu)+\Gamma(\bar{B}_s(t)\to\mu\mu)\}\big|_{t=0}$$

Expressing $B_s(t)$ and $\bar{B}_s(t)$ as before, one gets:

$$BR_{\mathbf{th}} \equiv \tau_s \left(\frac{R_H+R_L}{2}\right)$$

The relation between BR_{exp} and BR_{th} is therefore

$$BR_{\mathbf{exp}} \equiv BR_{\mathbf{th}} \frac{1}{1-\Delta\Gamma_s/2\Gamma_s}$$

$$= BR_{\mathbf{th}} \frac{1}{1-0.072}$$

See:
- LHCb-CONF-2012-002
- latest HFAG average: 1207.1158

BR[$B_s \to \mu\mu$]: SM vs. exp

- The quantity to be compared with exp is therefore

$$BR[B_s \to \mu^+\mu^-]_{\text{SM pred.}} = \frac{(3.23 \pm 0.27)\cdot 10^{-9}}{1-0.072} = (3.48 \pm 0.29)\cdot 10^{-9}$$

- LHCb finds:

Selected for a Viewpoint in *Physics*

PRL **110,** 021801 (2013) PHYSICAL REVIEW LETTERS week ending 11 JANUARY 2013

First Evidence for the Decay $B_s^0 \to \mu^+\mu^-$

R. Aaij *et al.**
(LHCb Collaboration)

(Received 12 November 2012; published 7 January 2013)

A search for the rare decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ is performed with data collected in 2011 and 2012 with the LHCb experiment at the Large Hadron Collider. The data samples comprise 1.1 fb^{-1} of proton-proton collisions at $\sqrt{s} = 8$ TeV and 1.0 fb^{-1} at $\sqrt{s} = 7$ TeV. We observe an excess of $B_s^0 \to \mu^+\mu^-$ candidates with respect to the background expectation. The probability that the background could produce such an excess or larger is 5.3×10^{-4} corresponding to a signal significance of 3.5 standard deviations. A maximum-likelihood fit gives a branching fraction of $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$, where the statistical uncertainty is 95% of the total uncertainty. This result is in agreement with the standard model expectation. The observed number of $B^0 \to \mu^+\mu^-$ candidates is consistent with the background expectation, giving an upper limit of $\mathcal{B}(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10}$ at 95% confidence level.

Issue 2. Definition of the final state: 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:

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

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

- Why should this correction be significant?

Main physics argument

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

real emitted soft photons + **virtual soft photons**

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

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.

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

Combining real and virtual corrections

Recap

Real-photon correction factor

$$= \left(E_{\text{cut}} / \lambda \right)^{\frac{\alpha_{em}}{\pi} \#}$$

- λ = IR cutoff
- E_{cut} = max total energy for the emitted soft photons

Virtual-photon correction factor

$$= \left(\lambda / \Lambda \right)^{\frac{\alpha_{em}}{\pi} \#}$$

- λ = IR cutoff
- Λ = $m_{B_s} / 2$ = max energy for each virtual photon

Total soft-photon correction factor

$$= \left(E_{\text{cut}} / \Lambda \right)^{\frac{\alpha_{em}}{\pi} \#}$$

Beware: this correction is already taken into account by LHCb

Exp vs. Theory Branching Ratio

The practical relation connecting the theoretical BR with the experimental (LHCb) one is as follows:

$$BR(B_s \to \mu\mu[+n\gamma])\Big|_{\sum E_{\gamma i} \le E_{\text{cut}}} = \left(\frac{E_{\text{cut}}}{m_{B_s}/2} \right)^{\frac{\alpha_{\text{e.m.}}}{\pi} \#} \cdot BR(B_s \to \mu\mu)_{\text{th}}$$

$$= 0.89 \cdot BR(B_s \to \mu\mu)_{\text{th}}$$

with a typical LHCb photon cut of E_{cut} = 60 MeV

$B_s \to \mu\mu$ 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

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

$$O_S \equiv (\bar{b}P_L s)(\bar{\mu}\mu) \qquad O'_S \equiv (\bar{b}P_R s)(\bar{\mu}\mu)$$

$$O_P \equiv (\bar{b}P_L s)(\bar{\mu}\gamma_5\mu) \qquad O'_P \equiv (\bar{b}P_R s)(\bar{\mu}\gamma_5\mu)$$

☑ The very "delicate" structure of the SM prediction
is easily spoiled beyond the SM.

Thanks to Gino Isidori
for making this point

- Via what kind of interactions?

Observation: the $B_s \to \mu\mu$ amplitude remains a well-defined object in the limit where gauge interactions go to zero.

$$A_{B_s\to\mu\mu} \propto G_F \cdot \alpha_{e.m.} \cdot Y(M_t^2/M_W^2) \quad \text{with} \quad Y\left(\frac{M_t^2}{M_W^2}\right) \sim \frac{M_t^2}{M_W^2} \quad \text{because of GIM}$$

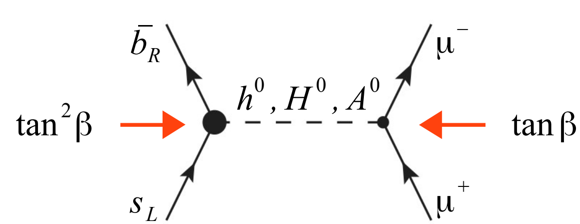
- Hence the relevant proportionality is:

$$A_{B_s\to\mu\mu} \propto \frac{1}{v^2} \cdot g^2 \cdot \frac{M_t^2}{M_W^2} \propto \frac{y_t^2}{v^2}$$

the g^2 dependence cancels out

So this process is a genuine probe
of Yukawa interactions
i.e. of the scalar-fermion sector

One famous example:
the MSSM with large tanß



Effectively tree-level diagrams:
Enhancement going as:

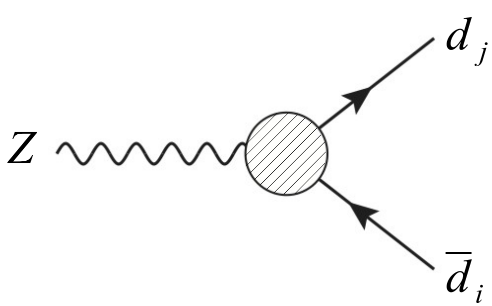
$$BR[B_s \to \mu^+\mu^-] \propto A_t^2 \frac{\tan^6\beta}{M_A^4}$$

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

DG, Isidori, 1302.3909

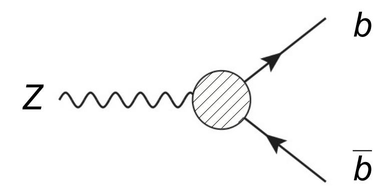
- $B_s \to \mu\mu$ is more than 'just' a probe of new scalars mediating FCNCs

Consider the Z-$\bar{d}_i$-d_j coupling:



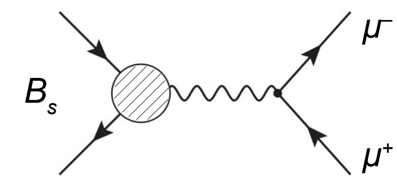
Flavor-diag: *i = j (= 3)*

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



Flavor-off-diag: *i ≠ j*

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



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

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

new-physics enters here

where:

SM couplings

$$g_L^{ii} = -\frac{1}{2} + \frac{1}{3} s_W^2 + \text{loops}$$

$$g_R^{ii} = \frac{1}{3} s_W^2 + \text{loops} \qquad g_{L,R}^{ij} = 0 + \text{loops}$$

Effective theory

DG, Isidori, 1302.3909

- 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 (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 $B_s \to \mu\mu$

- In this approach, there is a correlation between $Z \to b\,\bar{b}$ and $B_s \to \mu\mu$.

  This correlation is fixed, after specifying the X^{ij} couplings.

  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

- ☑ MFV is the statement that – even beyond the SM – the only structures that break the flavor symmetry are the SM Yukawa couplings

- ☑ How to use this statement to build allowed interactions?

  1. Assign to $Y_{u,d}$ fictitious transformation properties under the flavor group, to recover symmetry invariance

     Example: the SM up-quark Yukawa $\overline{Q}_L Y_u U_R$ ⇨ $(Y_u)_{ij}$ is such that:
     - i transforms as a **3** of $SU(3)_{Q_L}$
     - j transforms as a $\overline{\mathbf{3}}$ of $SU(3)_{U_R}$

  2. Use the $Y_{u,d}$ as building blocks for any other flavor coupling

     Example: operators with the bilinear $\overline{Q}^i_L \gamma^\mu X_{ij} Q^j_L$ ⇨ $X_{ij} = O(1) \times (Y_u Y_u^\dagger)_{ij}$

Example

For the left-handed coupling shifts it follows, e.g.

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

- δg_L^{32}: shift in the Zbs coupling: affects $B_s \to \mu\mu$
- $\frac{V^*_{tb} V_{ts}}{|V_{tb}|^2}$: flavor structure (fixed within the framework)
- δg_L: shift in $Z \to b\bar{b}$

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:

1. Yukawa interactions (as known)

and/or

2. hierarchical kinetic terms for fermions (in a non-canonical wave-function normalization)

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

About source 2

- Hierarchical kin. terms can arise in extra-dims as non-trivial profiles of fermion wave-functions in the extra-dims
- Hierarchies are then transmitted to the Yukawa interactions, once kin. terms are made canonical
- Before transmission, Yukawa interactions can therefore be patternless, i.e. be O(1) anarchic matrices

Example

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

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

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

&& $Y_{u,d} = O(1)$ → (canonical basis) $(Y_{u,d})_{ij} \propto z_Q^{(i)} z_{u,d}^{(j)}$

Fixing the couplings. Case 2: Partial Compositeness

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.

The defining property of (fermion) Partial Compositeness is as follows.

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

$$\text{interactions} = \epsilon_i \, f_i \, O_i$$

- the ϵ_i measure the degree of compositeness of f_i
- apart from an overall factor, *the ϵ_i can be identified with the z_i of the previous picture*

Main points

- 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 $\epsilon_i f_i$. Building our EFT with $\epsilon_i f_i$ the flavor structure is fixed – apart from O(1) factors

Example

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

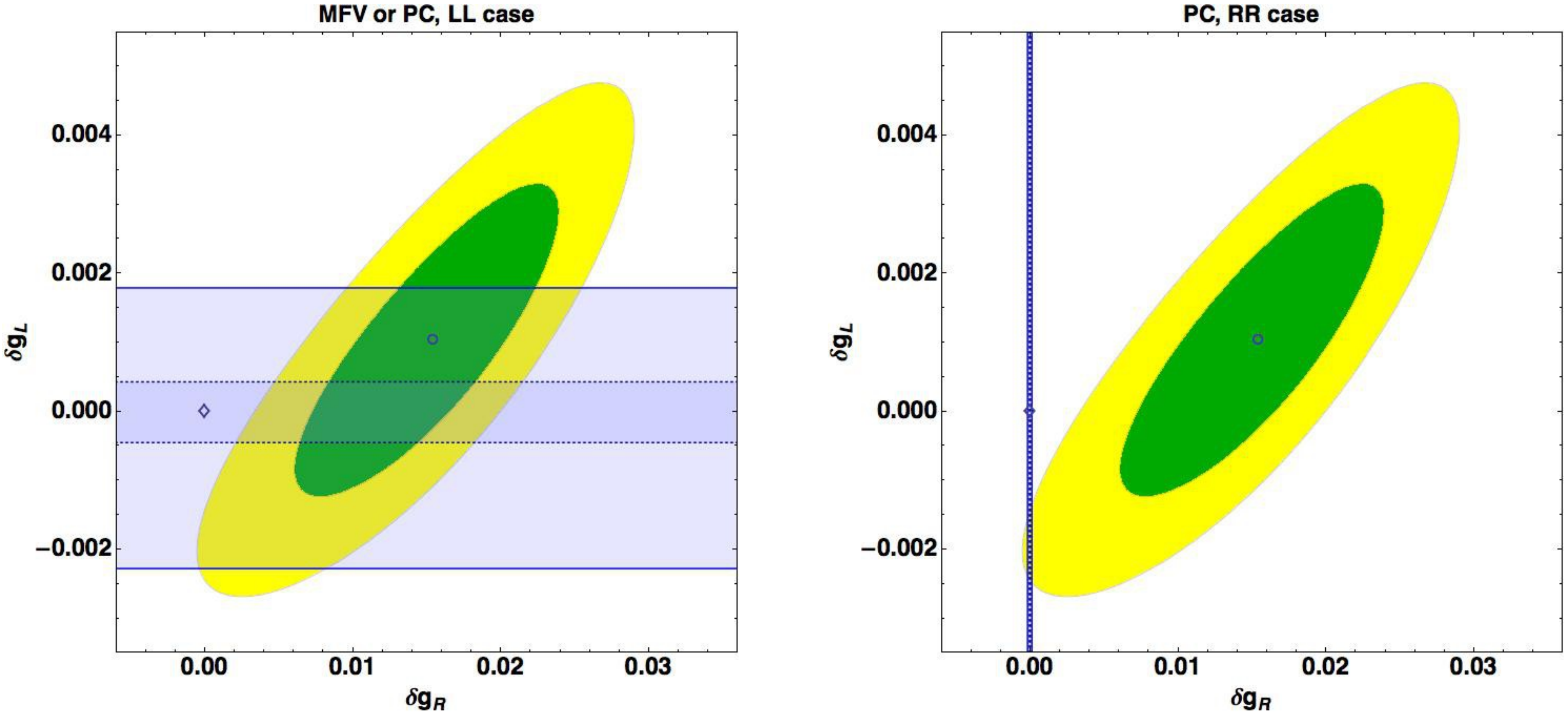
Wilson coeff.

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

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

DG, Isidori, 1302.3909

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



with present $B_s \to \mu\mu$ exp error	$\lvert\delta g_L\rvert^{\text{MFV or PC}} < 2.3\times10^{-3}$	$\lvert\delta g_R\rvert^{\text{PC}} < 1.6\times10^{-4}$
with ~ 10% $B_s \to \mu\mu$ error	$\lvert\delta g_L\rvert^{\text{MFV or PC}} < 4.6\times10^{-4}$	$\lvert\delta g_R\rvert^{\text{PC}} < 3.3\times10^{-5}$

Conclusions

The decay $B_s \to \mu\mu$ is one of the highlights of the LHCb program, and one major test of physics beyond the SM. Controlling the SM prediction is crucial for new-physics tests.

☑ **Theory (SM) ready to match expected experimental accuracy**

- *We get:*

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

- ***Statistical error:*** *dominated by f_{Bs} , followed by CKM error. Short-term improvements expected*

- ***Systematics:*** *various effects*
  - **Effect of $B_s - \overline{B}_s$ oscillations:** $BR_{\rm exp} \;=\; BR_{\rm th} \times 1.09$
  - **Effect of soft undetected photons in the final state:** $BR_{\rm exp} \;=\; BR_{\rm th} \times 0.89$ — Taken into account by LHCb ⇨ NO need to correct for it
  - **Incomplete knowledge of NLO EW corrections:** *Arguably negligible error in scheme we propose*

Conclusions

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

- *To the extent that no deviations wrt the SM prediction are observed, it is a (formidable) null test 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: way more stringent than EWPO