Lessons from Flavor Physics

Gino Isidori
[*University of Zürich*]

- Introduction
- SUSY & Flavor [*The Usual Suspects*]
- The $B \rightarrow K^{(*)} ll$ anomalies [*Charming Penguins strike back*]
- Flavor physics with the BEH boson [*Contact*]
- On the observed pattern of quark & lepton masses [*The Matrix*]
- Conclusions

Introduction

Despite its remarkable phenomenological success, the SM suffers of a series of theoretical & cosmological problems:

- Fine-tuning/UV sensitivity of the Higgs-mass term ["*hierarchy problem*"]
- Unexplained hierarchical structure of the Yukawa couplings ["*flavor puzzle*"]
- No explanation for the quantization of the U(1) charges [*hint of unification*?]
- No natural inclusion of neutrino masses [*hint of new heavy mass scale*?]
- Non coherent inclusion of gravity at the quantum level

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- No good candidates to explain dark matter, inflaton, and dark-energy

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i.e. the limit of a more fundamental theory, with new degrees of freedom

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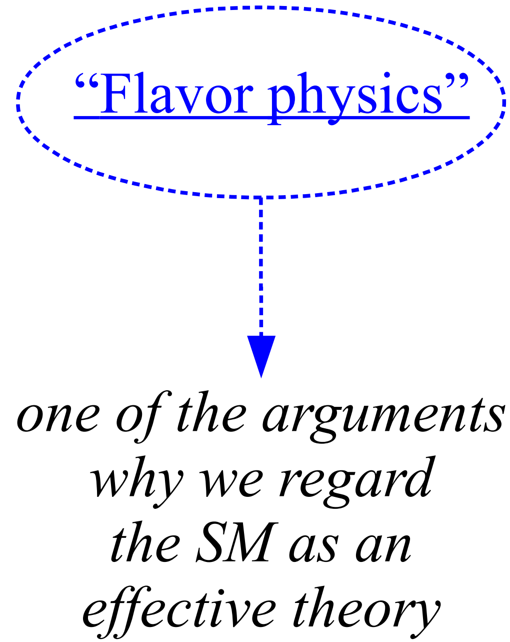

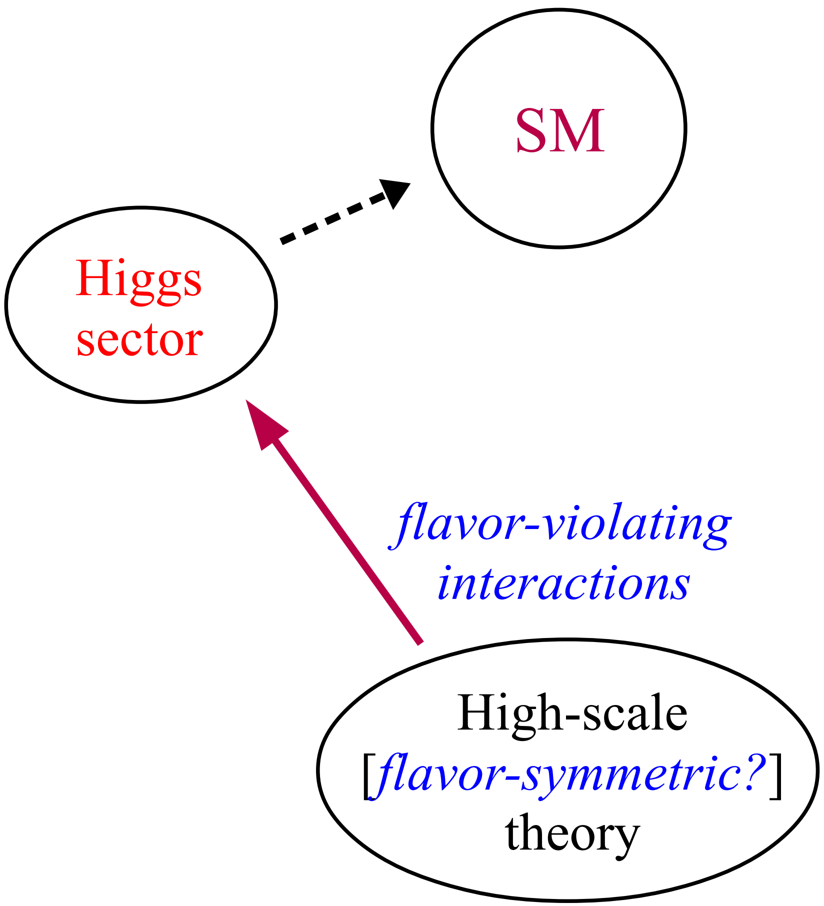

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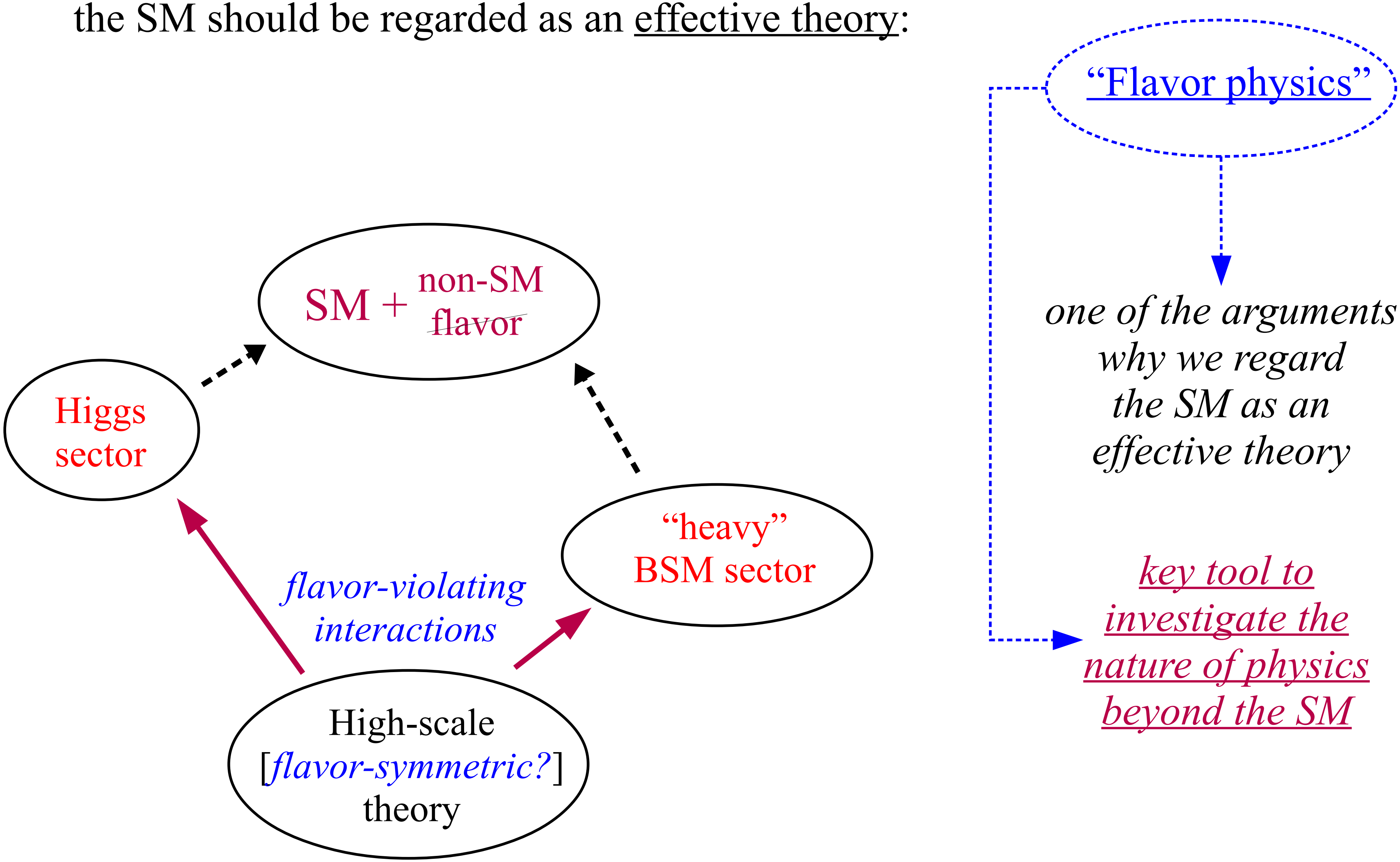

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$$V_{eff} = - \mu^2 \phi^+\phi + \lambda (\phi^+\phi)^2 + Y^{ij} \psi_L{}^i \psi_R{}^j \phi + \frac{g^{ij}}{\Lambda} L_L{}^i L_L{}^{Tj} \phi \phi^T + \ldots$$

The discovery of the Higgs boson completes the picture of the "*light degree of freedom*" in this effective theory

flavor-structure of the model

effective neutrino mass term

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Precision Higgs physics & flavor physics are two complementary tools to investigate (indirectly) the nature of physics beyond the SM

No Higgs... → *No flavor...*

The two key open questions in flavor physics:

- *What determines the observed pattern of masses and mixing angles of quarks and leptons?*

- *Which are the sources of flavor symmetry breaking accessible at low energies?*

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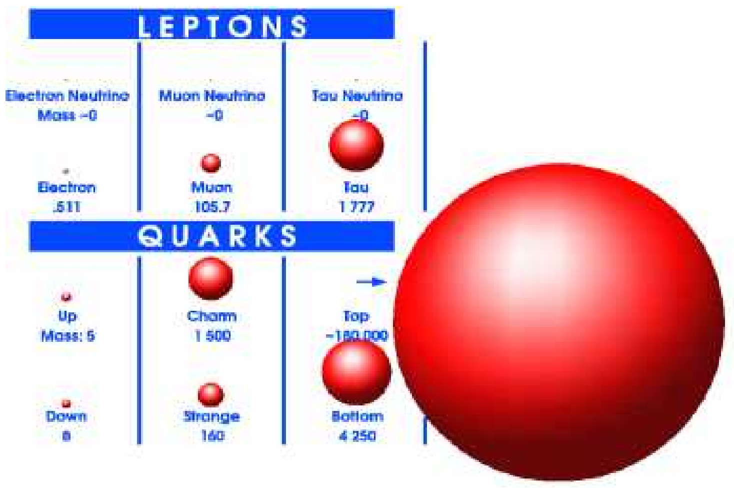
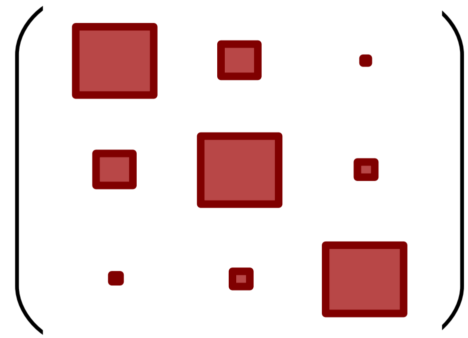


$V_{CKM} \sim$ 

Several plausible options on the market, with no outstanding case.

Easy to reproduce the observed mass matrices in terms of a reduced number of free parameters, while it is difficult to avoid problems with FCNCs

Hard to make progress without knowing the ultraviolet completion of the SM.

The two key open questions in flavor physics:

- *What determines the observed pattern of masses and mixing angles of quarks and leptons?*

- *Which are the sources of flavor symmetry breaking accessible at low energies?* [Is there anything else beside SM Yukawa couplings & neutrino mass matrix?]

Answering the second question is more "easy":

- It can be formulated independently of the UV completion of the theory.
- It is mainly a question of precision (both on the theory and on the experimental side).

↓

We learned a lot about the possible sources of flavor symmetry breaking from a series of high-precision measurements of <u>flavor-changing processes</u> performed in the recent past

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  [Is there anything else beside SM Yukawa couplings & neutrino mass matrix?]

$$\mathscr{L}_{\rm eff} = \mathscr{L}_{\rm gauge}(A_a, \psi_i) + \mathscr{L}_{\rm Higgs}(\phi, A_a, \psi_i) + \sum_{d\geq 5} \frac{c_n}{\Lambda^{d-4}} O_n^{(d)}(\phi, A_a, \psi_i)$$

$U(3)^5$ global flavor symmetry:

3 identical replica of the basic fermion family $[\psi = Q_L, u_R, d_R, L_L, e_R]$

Flavor-degeneracy broken by the <u>Yukawa interaction</u>

$$Y^{ij}\, \psi_L^i\, \psi_R^j\, \phi$$

Neutrino mass term + ...

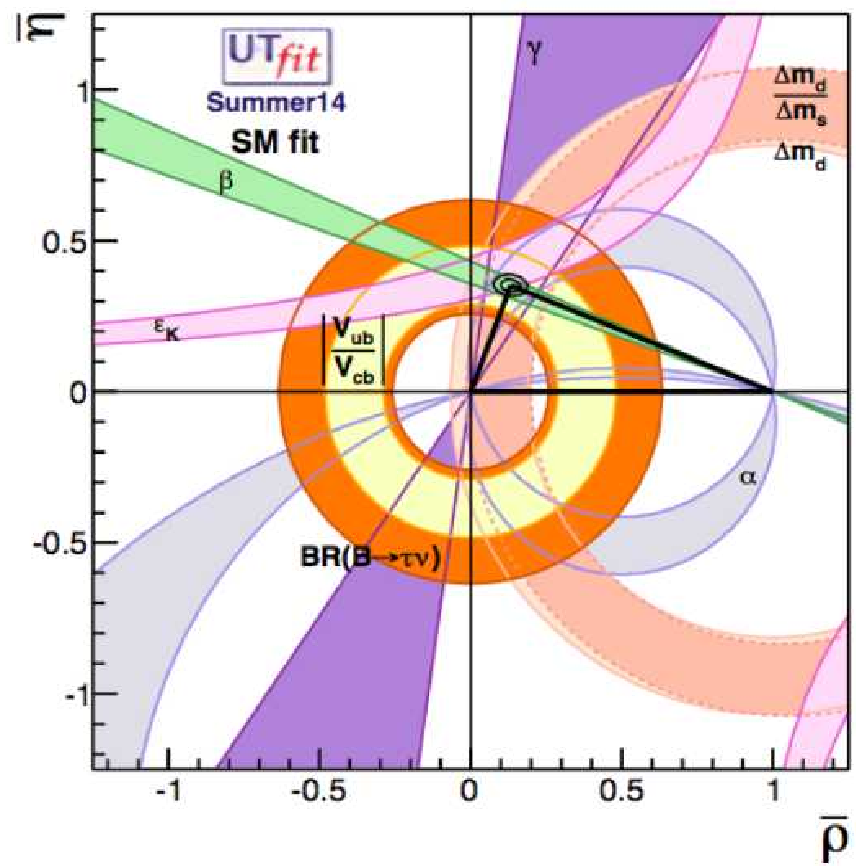
$$\frac{g^{ij}}{\Lambda} L_L^i L_L^{Tj}\, \phi\, \phi^T$$

Which are the sources of flavor symmetry breaking accessible at low energies?

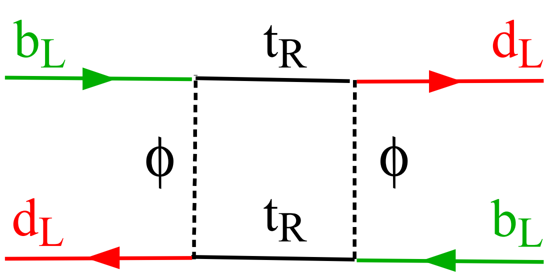
In the quark sector all measurements show a remarkable overall success of the CKM picture

This success is quite "embarrassing" if we assume there is some New Physics around the TeV scale...

$$M(B_d\text{-}\bar{B}_d) \sim \frac{y_t^4\,(V_{tb}^{*}V_{td})^2}{16\pi^2 m_t^2} + \frac{c_{NP}}{\Lambda_{NP}^{2}}$$



tiny SM contribution (Yukawa interaction)



possible large NP contribution (if Λ_{NP} ~ TeV and c_{NP} ~1), excluded by present data

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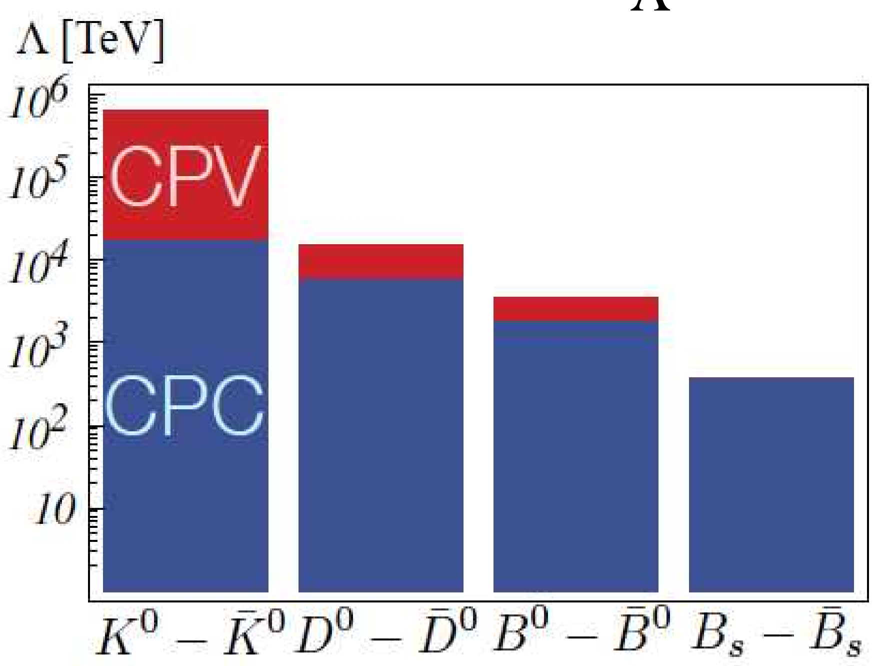

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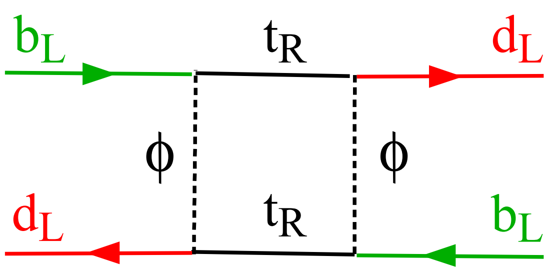


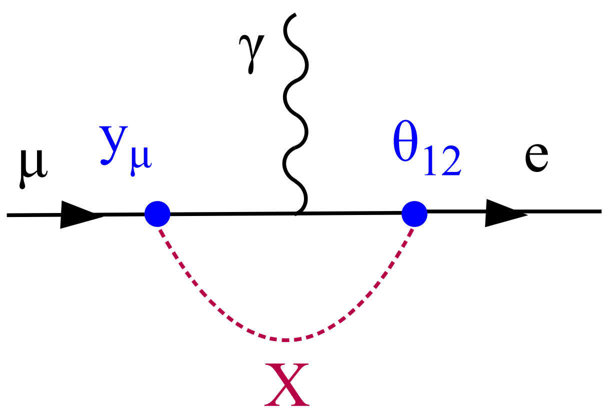
possible large NP contribution (if $\Lambda_{NP} \sim$ TeV and $c_{NP} \sim 1$), excluded by present data

Which are the sources of flavor symmetry breaking accessible at low energies?

Similar (even more stringent) bounds on the scale of NP come also from the lepton sector.

But such bounds should not be over-emphasized...

E.g.:



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MEG '13

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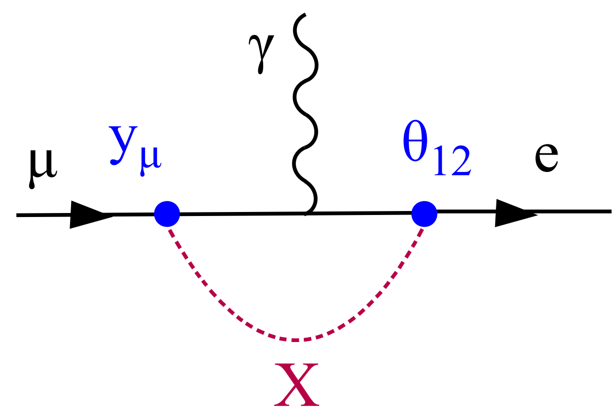

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MEG '13

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$M_X \gtrsim 200$ TeV

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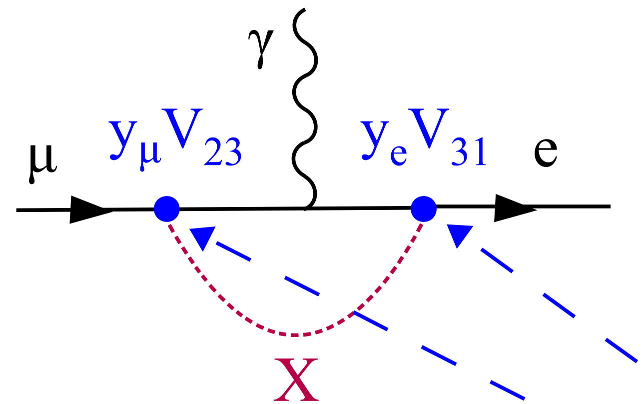

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MEG '13

$M_X \gtrsim 10$ GeV

Either NP is <u>very heavy</u>... or it has a non-trivial flavor-breaking pattern...

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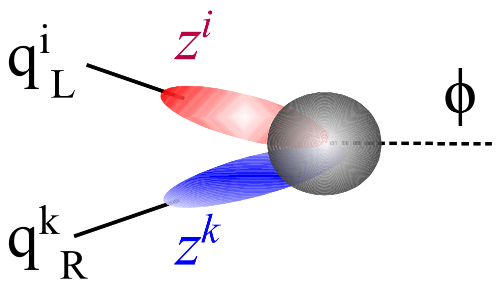
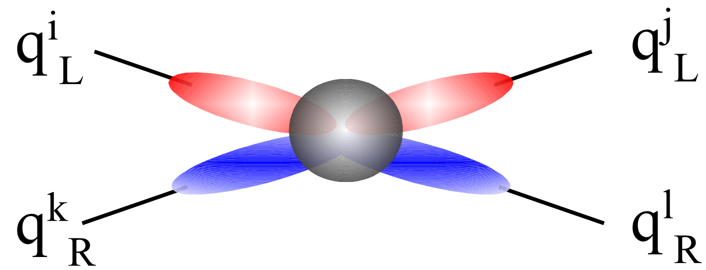
More generally, we have explored only a small fraction of a large (multi-dim.) parameter space. The bounds on the scale of NP are still relatively weak in realistic models linking flavor mixing beyond the SM to the observed mass hierarchies.
E.g.:

Partial Compositeness:





"Elementary-composite mixing" as unique source of fermion mass hierarchies

$$Y_D^{ij} \approx z_Q^{\,i} z_D^{\,j} \qquad\qquad Y_U^{ij} \approx z_Q^{\,i} z_U^{\,j}$$

$$z_Q^{\,3} \gg z_Q^{\,2} \gg z_Q^{\,1}$$
$$z_D^{\,3} \gg z_D^{\,2} \gg z_D^{\,1}$$
$$z_U^{\,3} \gg z_U^{\,2} \gg z_U^{\,1}$$

→ Natural suppression of flavor-violating processes involving the light generations

(*link with the smallness of light masses*)

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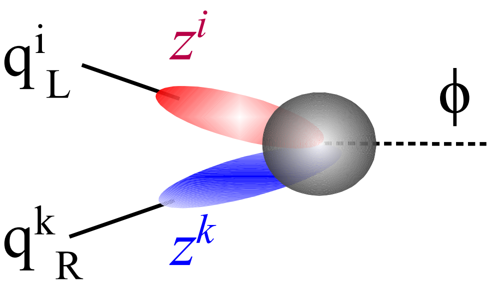

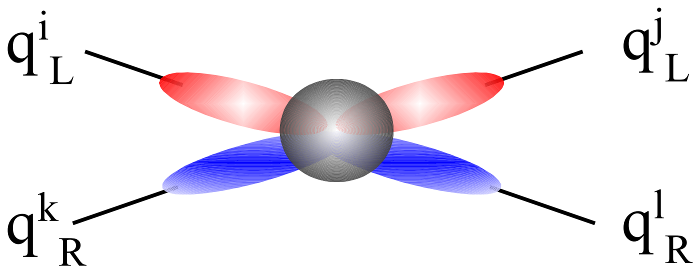

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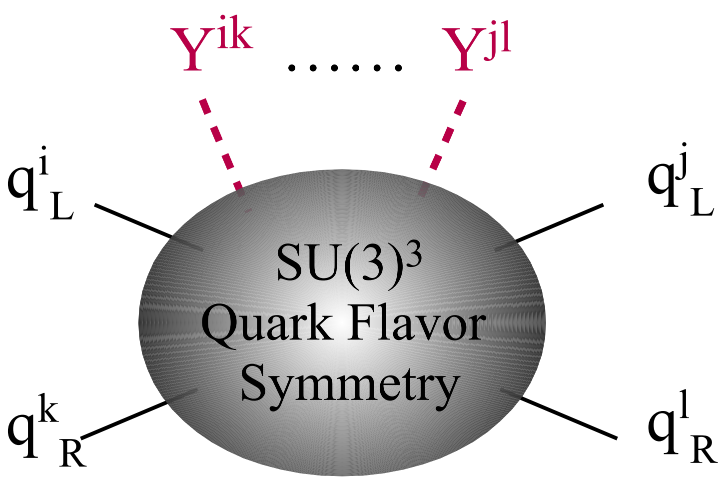
Minimal Flavor Violation



Yukawa couplings as unique sources of flavor symmetry breaking

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Mass scale of New Physics (*new colored & flavored particles*)

	< 1 TeV	few TeV	> few TeV
Direct New Physics searches @ high pT:	NP within direct reach @ 8 TeV	NP within reach @ 14 TeV	NP beyond direct searches @ LHC
Flavor Structure / *NP effects in Quark Flavor Physics*:			
Anarchic	huge [> O(1)]	sizable [O(1)]	sizable/small [< O(1)]
Small misalignment (*e.g. partial compositeness*)	sizable [O(1)]	small [O(10%)]	small/tiny [O(1-10%)]
Aligned to SM (*MFV*)	small [O(10%)]	tiny [O(1%)]	not visible [< 1%]

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SUSY & Flavor

$|V_{ub}|$ & CKMfits

$\Delta m_{B_{s,d}}$

$B_{s,d} \to \mu\mu$

ε_K, $\phi_{s,d}$

$B \to X_s\gamma$

"Split-family" SUSY

Despite the absence of signals, SUSY remains our best candidate for a UV completion of the SM not far from the TeV scale:

- Weakly coupled theory + light Higgs (*125 is well the SUSY region...*) + dark-matter & unification
- Some tuning in m_h is unavoidable: *do we really care if the fine-tuning is ~1% ?*

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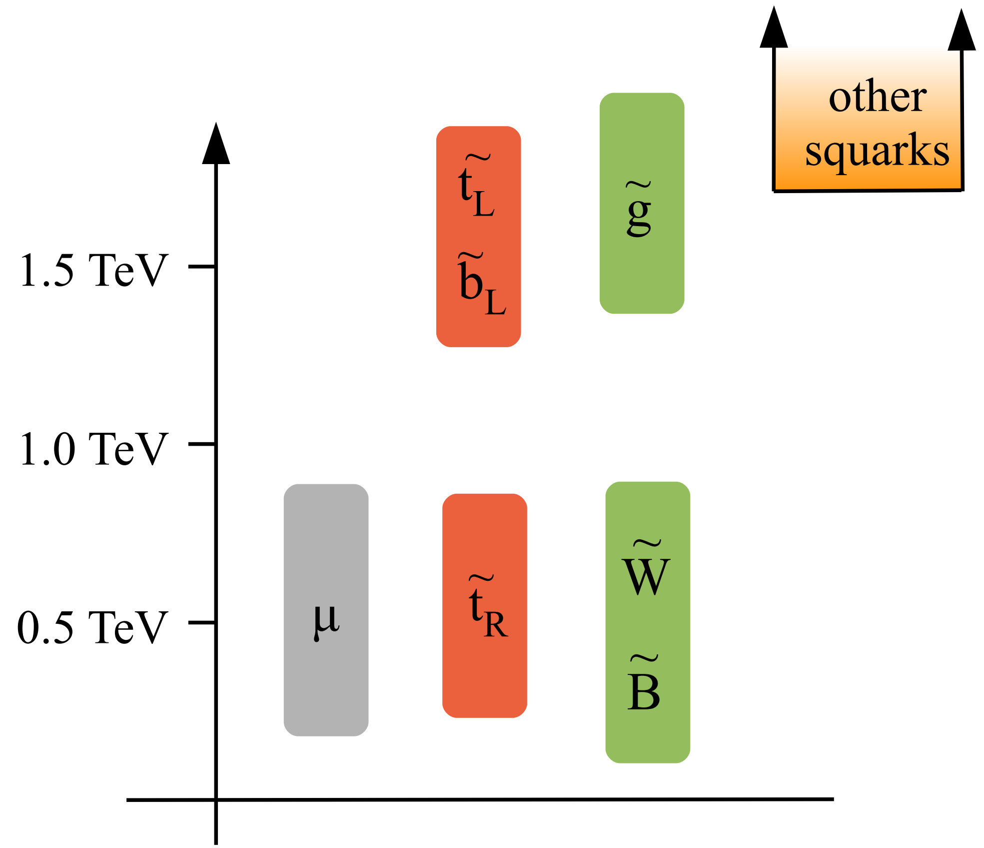
Most of the low-scale SUSY virtues are maintained if we assume a flavor non-trivial spectrum →

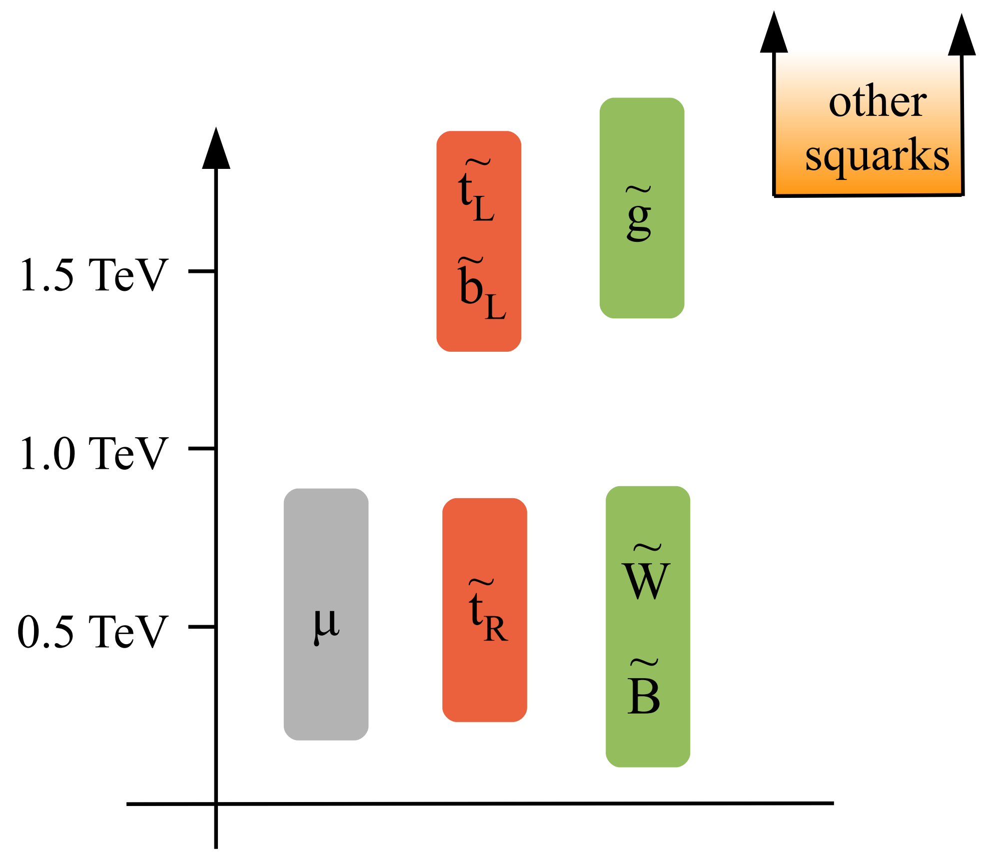
Dimopulos, Giudice, '95
Cohen, Kaplan, Nelson '96
+ many others...



- 3^{rd} gen. squarks + Higgsinos key ingredients in the m_h tuning
- splitting the 3^{rd} family can easily be motivated in flavor models

The Usual Suspects

- LHC experiments have started to directly explore this scenario & possible variations (e.g: *mini-spilt*...).
- In this context, flavor physics plays a key role [*non-trivial flavor structure*] → BSM effects mediated by 3rd gen. squarks & leptons:



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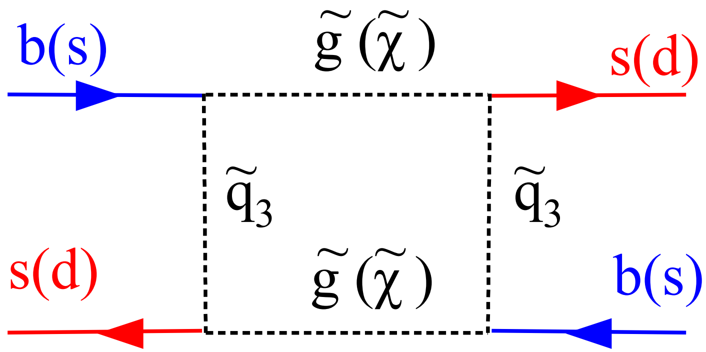
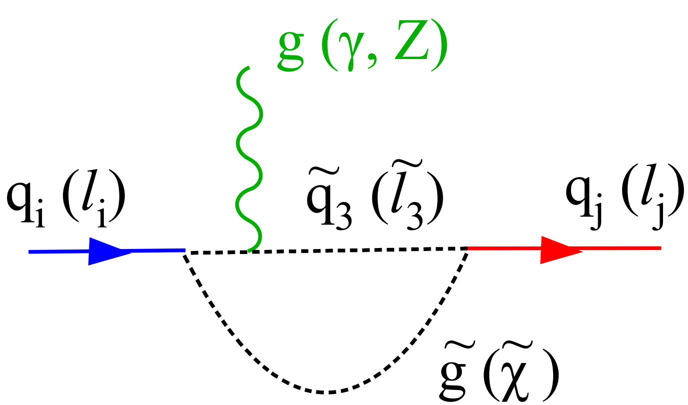


Possible "visible" [~ 5-20%] effects in

- CPV in K mixing (ε_K)
- CPV in $B_{s,d}$ mixing ($\phi_{s,d}$)



Possible "visible" [~ 5-20%] effects in

- Rare B decays ($B_s \to \mu\mu$, $B_s \to X_s\gamma$)
- LFV ($\mu \to e\gamma$) & EDMs

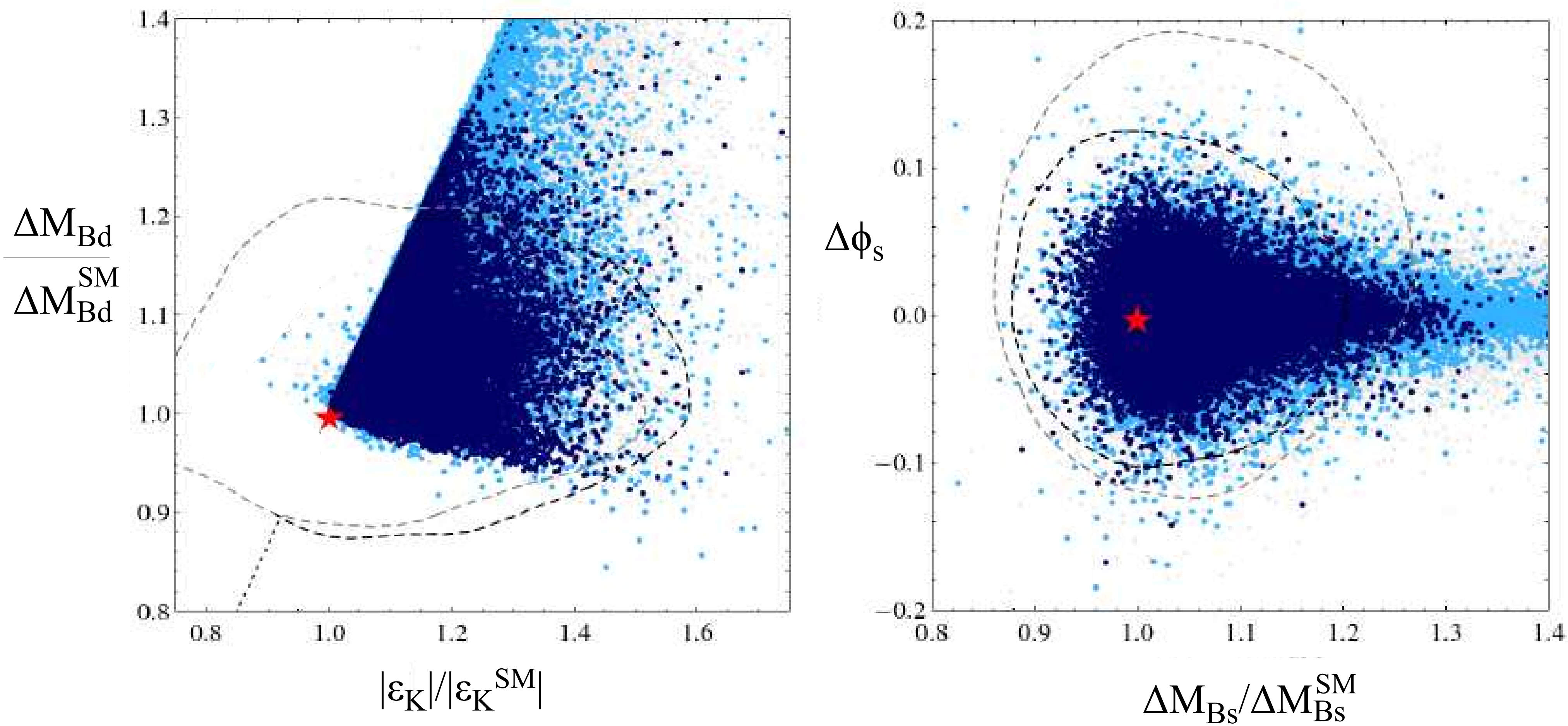
Barbieri *et al.* '12-'14; Delgado *et al.* '13
Althmanshofer, Harnik, Zupan, '13
Katz, Reece, Sajjad '14 + ...

Example I: *Meson mixing in "Natural SUSY" with U(2)^3 flavor symm.*

Barbieri *et al.*, '11

Points allowed by present CMS/ATLAS data:

Barbieri, Buttazzo, Sala, Straub, '14



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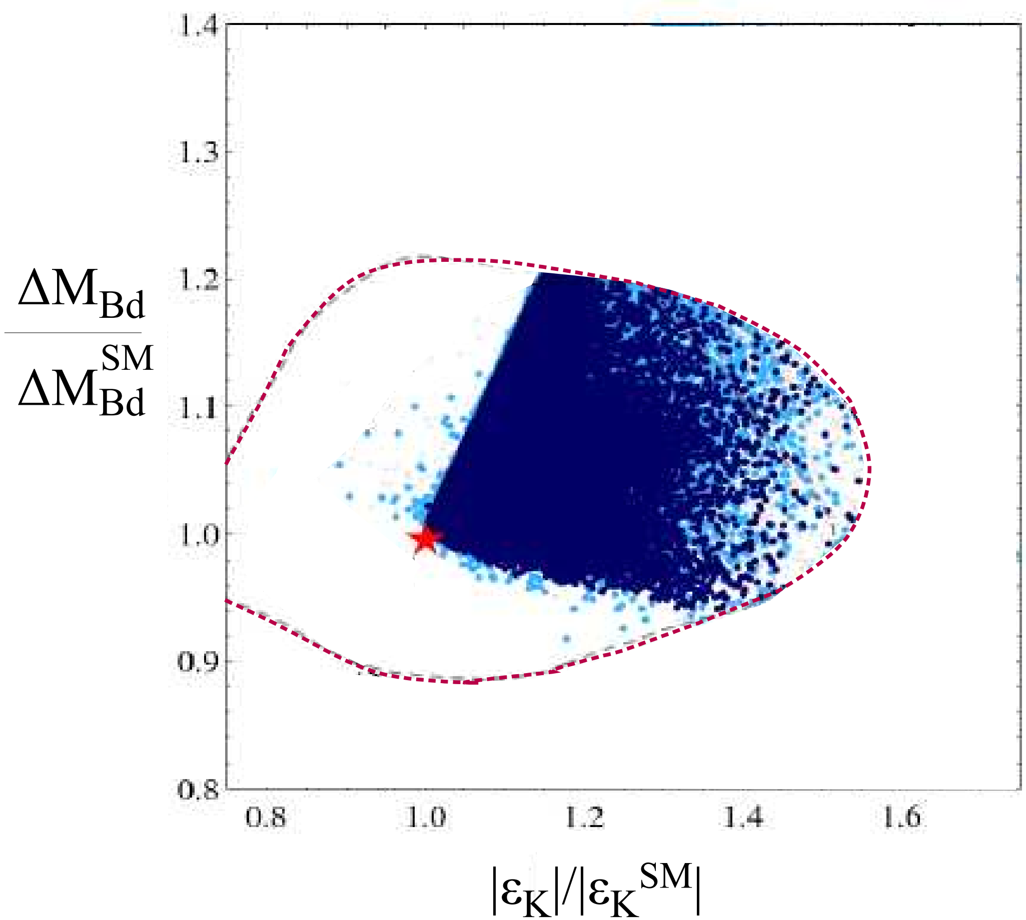

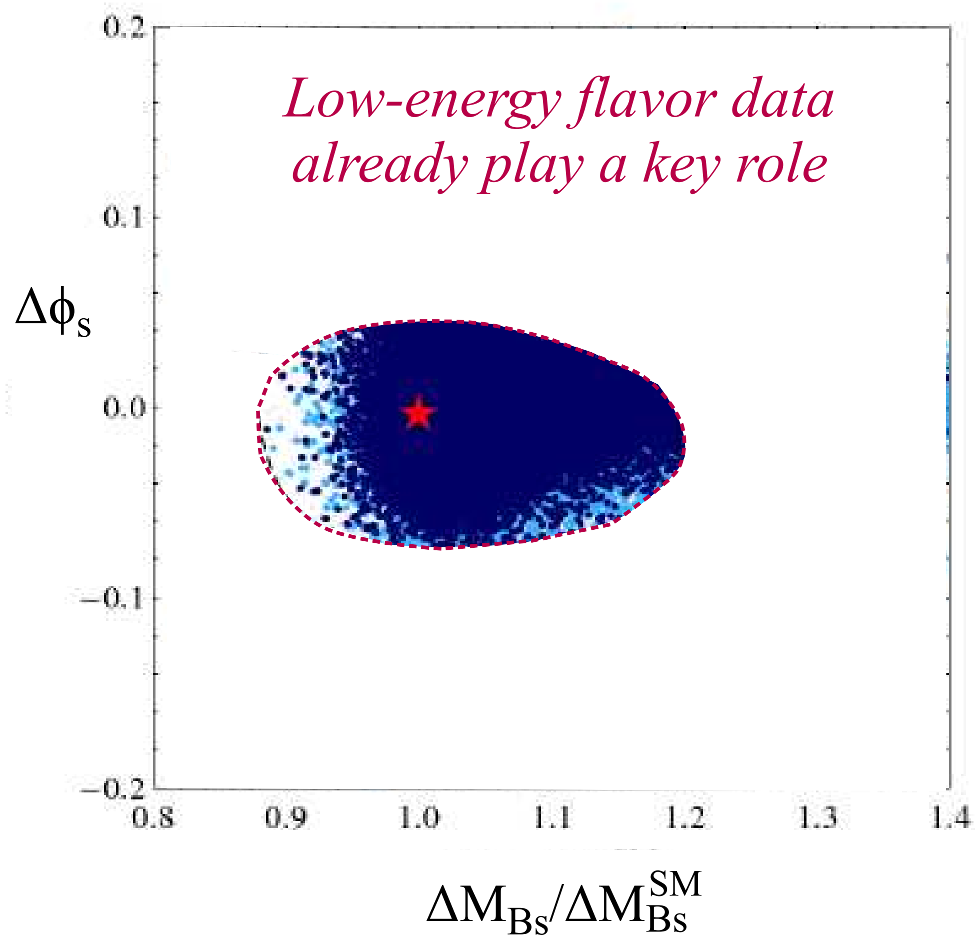

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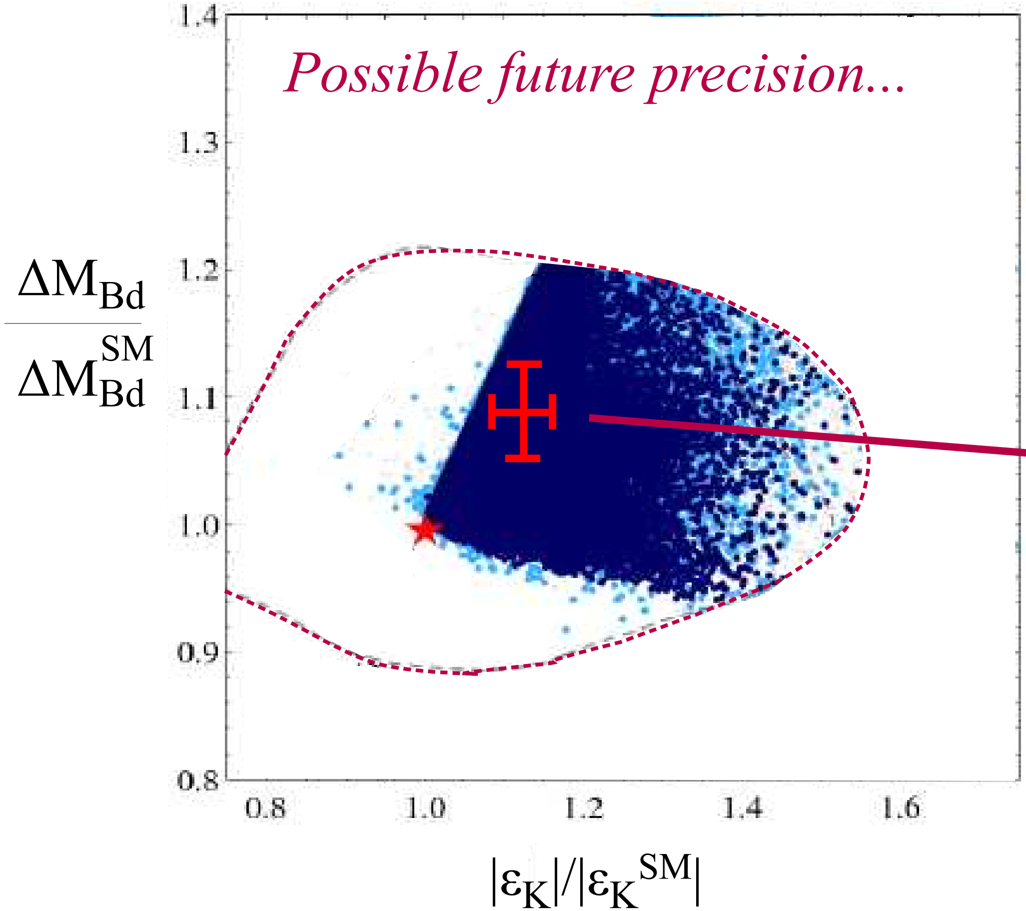
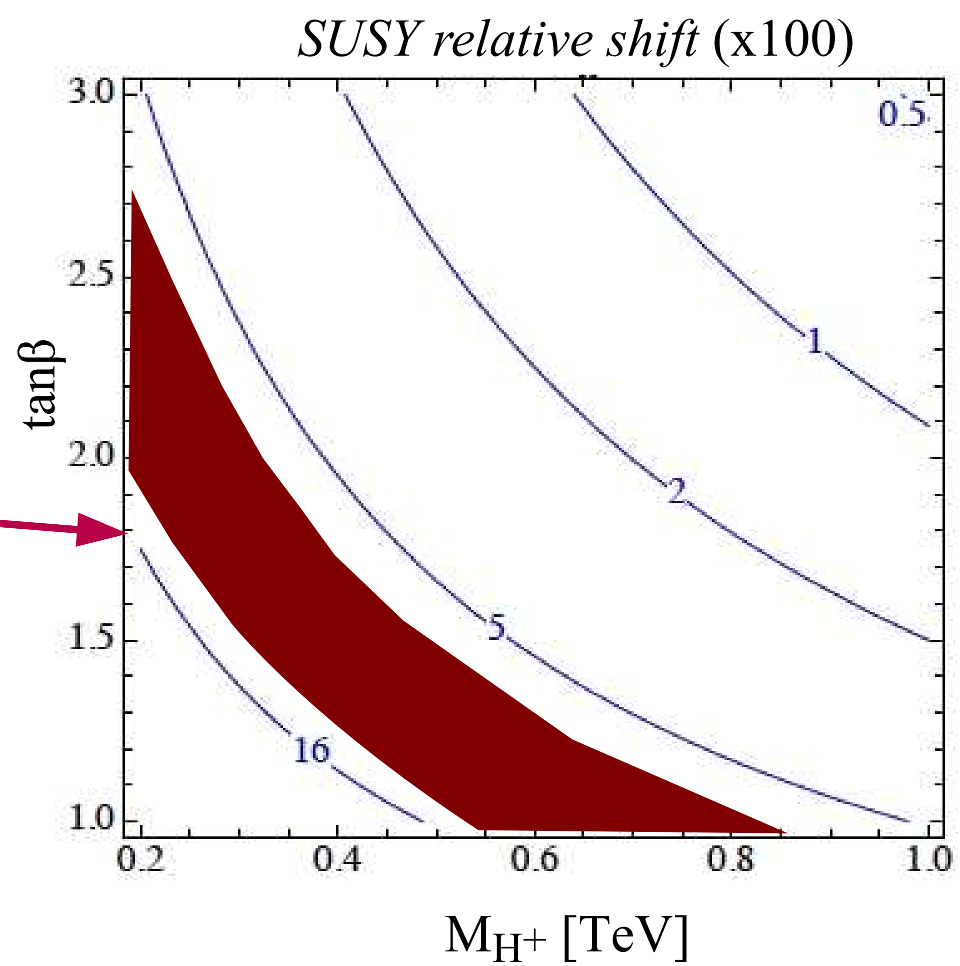


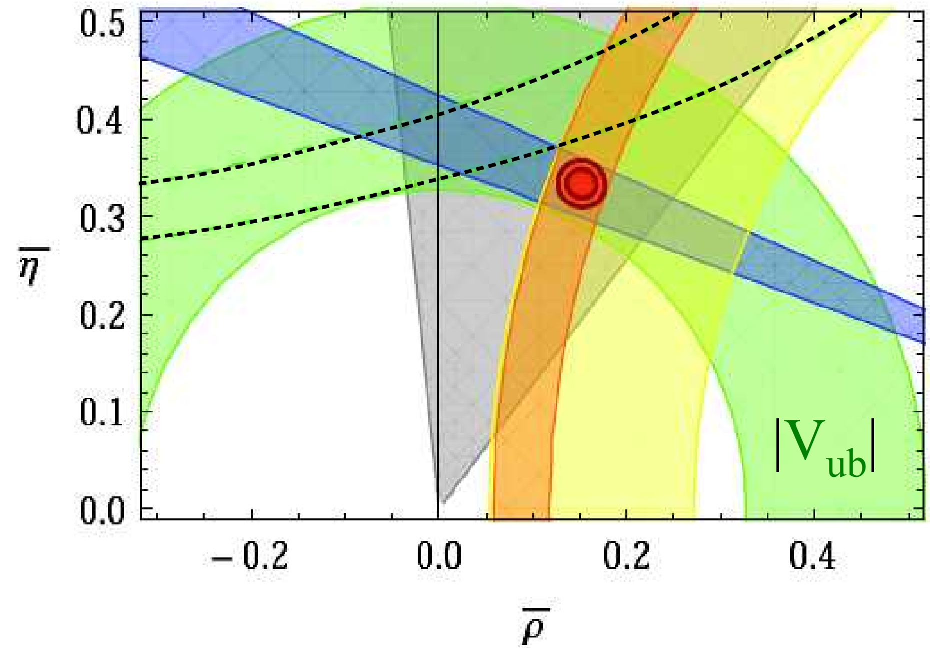


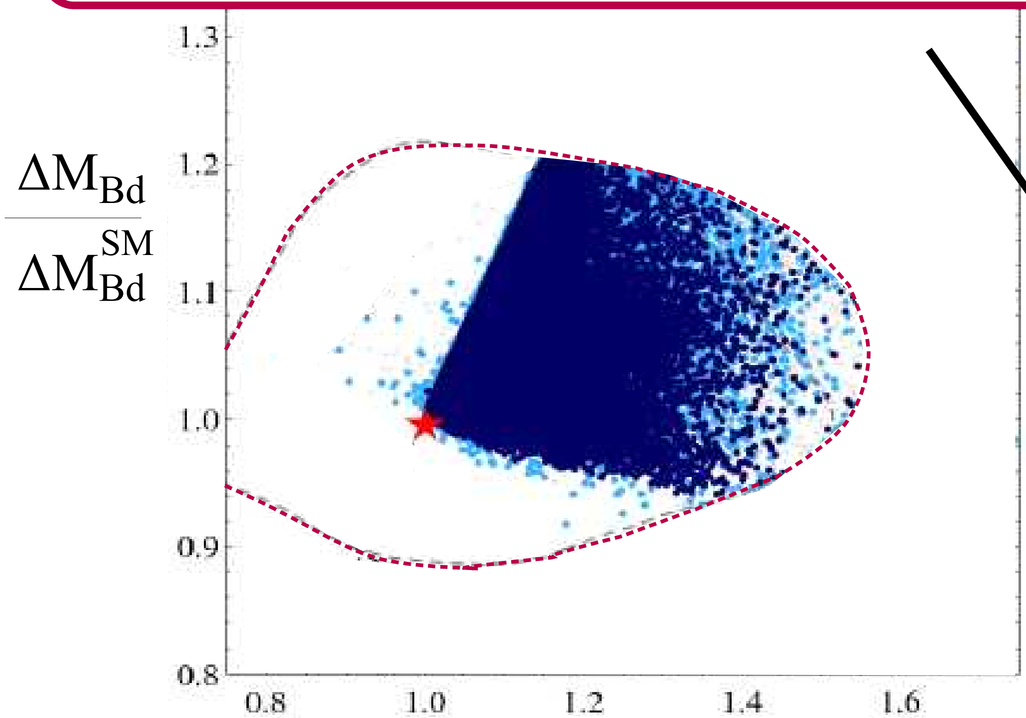
Example I: *Meson mixing in "Natural SUSY" with* $U(2)^3$ *flavor symm.*

N.B.: There is a (weak) evidence of a (positive) non-standard contribution to ε_K

In order to clarify the picture we need a more clean determination of $|V_{ub}|$ & γ

SM fit, no ε_K





$|\varepsilon_K|/|\varepsilon_K^{SM}|$

Complementary role of

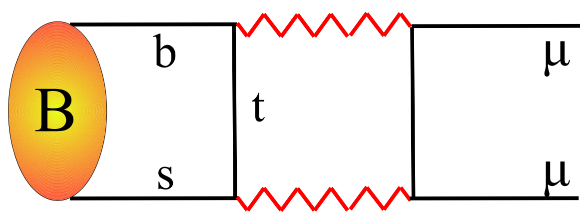
- Belle-II [$\rightarrow |V_{ub}|$ from $B \rightarrow \pi l \nu$ and $B \rightarrow \tau\nu$]
- and LHCb [$\rightarrow \gamma$]

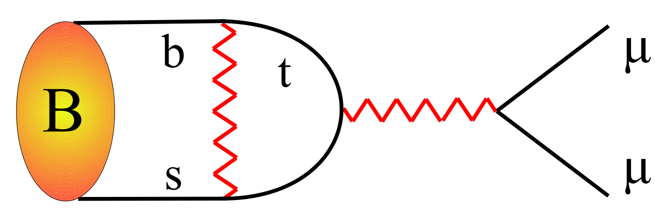
Example II: $B_{s,d} \to \mu\mu$ & SUSY

These modes are a unique source of information about flavor physics beyond the SM:

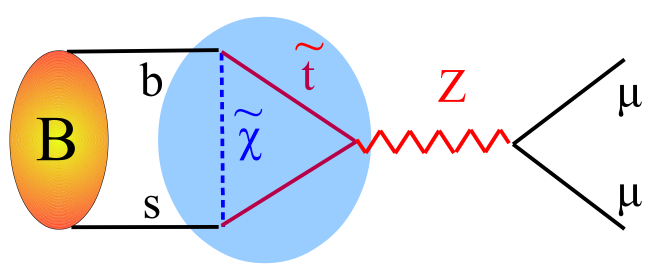
- theoretically very clean (virtually no long-distance contributions)
- particularly sensitive to FCNC *scalar currents* and FCNC *Z penguins*

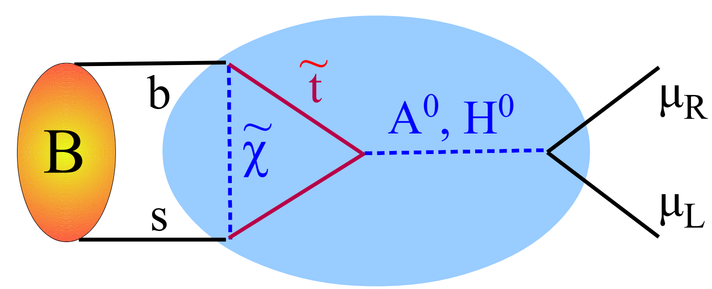
Leading SM diagrams (unitary gauge):





Possible non-SM contributions:





Relevant for BR = O(SM)

Possible large enhancement (e.g. SUSY @ large tanβ)

Example II: $B_{s,d} \to \mu\mu$ & SUSY

Recent developments both on the theory and on the experimental side:

$$\overline{BR}_{s,SM} = (3.65 \pm 0.23)\times 10^{-9}$$

(time-integrated average)

$$\overline{BR}_s^{(exp)} = (2.9 \pm 0.7)\times 10^{-9}$$

Bobeth, Gorbahn, Hermann, Misiak, Stamou, Steinhauser '13
\+
progress from Lattice QCD

LHCb + CMS '13

$$BR_{d,SM} = (1.06 \pm 0.09)\times 10^{-10}$$

$$BR_d^{(exp)} = (3.6 \pm 1.5)\times 10^{-10}$$

An overall th. error below 5% is definitely within the reach in the next few years

At this stage there is perfect compatibility, but we are only at the beginning...

Example II: $B_{s,d} \to \mu\mu$ & SUSY

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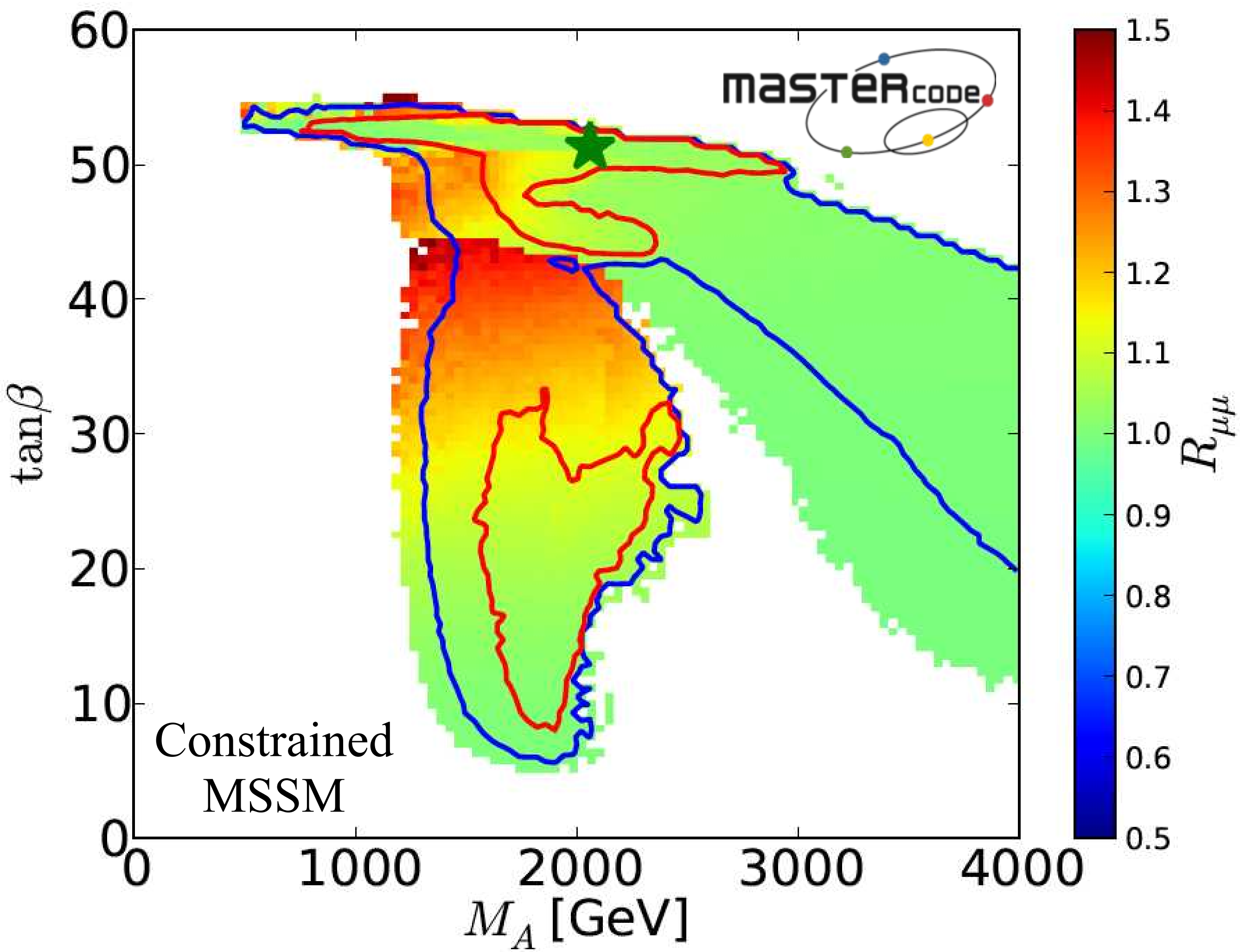

The possible large effects occurring in the MSSM at large tanβ are ruled out...

...but more precision on this mode can still provide very valuable infos

Buchmueller *et al.* [Mastercode]
Mahmoudi *et al.* [SuperIso]
Roszkowski *et al.* '12
Haisch & Mahmoudi '12
Althmanshofer *et al.* '13
…

Example II: $B_{s,d} \to \mu\mu$ & SUSY

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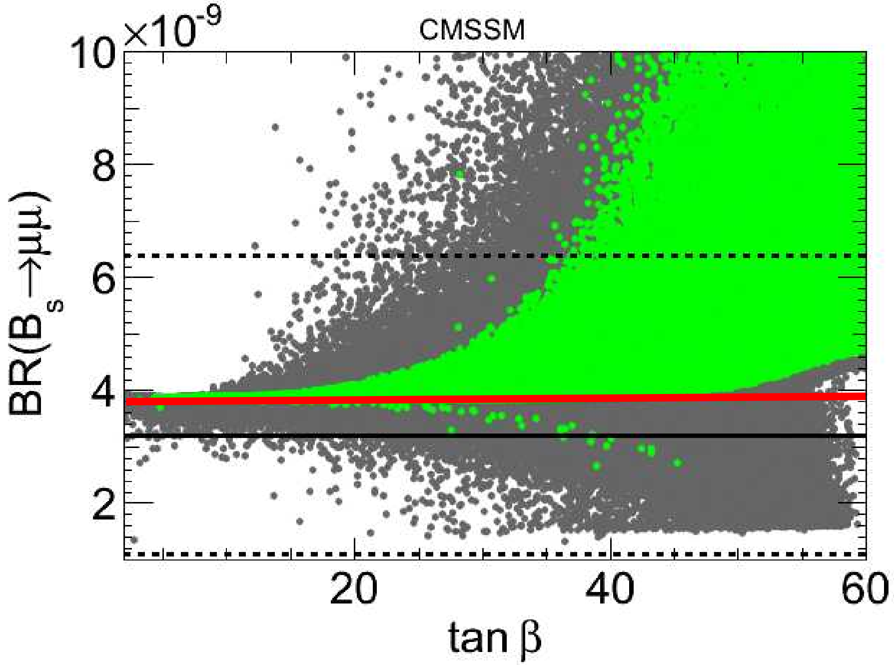
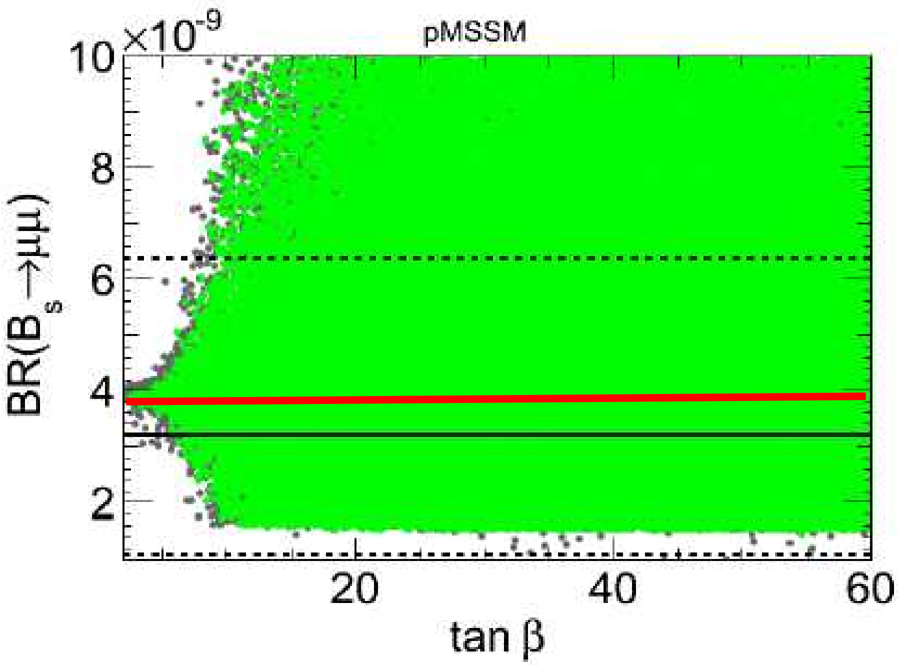


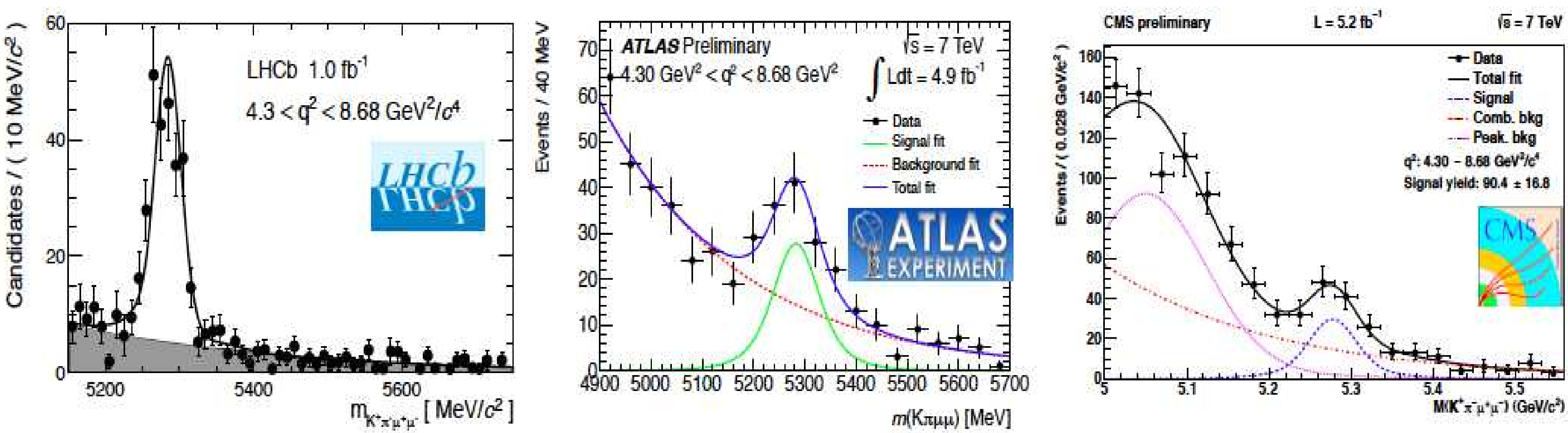


Arbey *et al.* '12

The B → $K^{(*)}$ *ll* anomalies

The B → K$^{(*)}$ *ll* anomalies

B → K*μμ signals from the 3 LHC experiments:



General considerations:

Similarly to $B_{s,d} \rightarrow ll$, also $B \rightarrow K^{(*)} ll$ are FCNC amplitudes and, as such, are useful probes of flavor dynamics beyond the SM

- No SM tree-level contribution
- Strong suppression within the SM because of CKM hierarchy

Key point to be addressed: th. control of QCD effects, larger and potentially more dangerous than in $B_{s,d} \rightarrow ll$.

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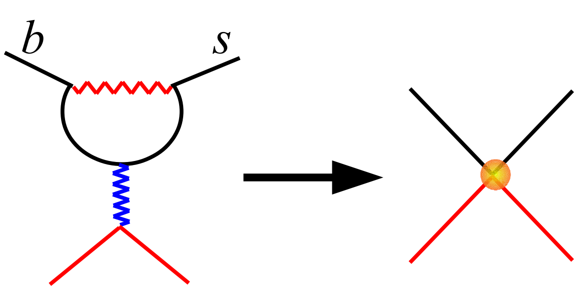
Three-step procedure to deal with the various scales of the problem:

1st step: Construction of a local eff. Hamiltonian at the electroweak scale



$$H_{\rm eff} = \Sigma_i\, C_i(M_W)\, Q_i$$

- Heavy NP encoded in the $C_i(M_W)$
- No difference among the various $b \to s\, ll$ decays

2nd step: Evolution of H_{eff} down to low scales using RGE

FCNC operators (E.W. penguins)

$$Q_9 = Q_f (b\,s)_{V-A} (l\,l)_V$$
$$Q_{10} = Q_f (b\,s)_{V-A} (l\,l)_A$$
$$\vdots$$

$$H_{eff} = \Sigma_i\, C_i(M_W)\, Q_i$$

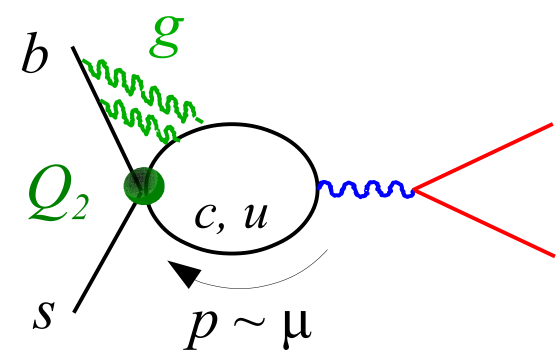
$$\downarrow$$

$$H_{eff} = \Sigma_i\, C_i(\mu \sim m_b)\, Q_i$$

Four-quark (tree-level) ops.:

$$Q_1 = (b\,s)_{V-A} (c\,c)_{V-A}$$
$$Q_2 = (b\,c)_{V-A} (c\,s)_{V-A}$$
$$\vdots$$

Mixing of the four-quark Q_i into the FCNC Q_i
["dilution" of the potentially interesting NP]:



Negligible for Q_{10} [$B_{s,d} \to ll$ & $B \to K^{(*)} ll$]

Large for "photon penguins" Q_9 [$B \to K^{(*)} ll$ only]

2nd step: Evolution of H_{eff} down to low scales using RGE

FCNC operators (E.W. penguins)

$$Q_9 = Q_f (b s)_{V-A} (l l)_V$$
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Four-quark (tree-level) ops.:

$$Q_1 = (b s)_{V-A} (c c)_{V-A}$$
$$Q_2 = (b c)_{V-A} (c s)_{V-A}$$
$$\vdots$$

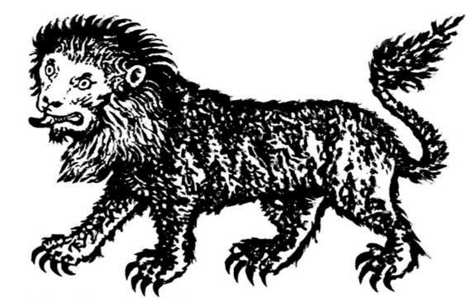
3rd step: Evaluation of the hadronic matrix elements

$$A(B \to f) = \Sigma_i\, C_i(\mu)\, \langle f |\, Q_i\, | B \rangle (\mu)$$

- sensitivity to long-distances (*cc* threshold...)
- distinction between
  inclusive (OPE + $1/m_{b,c}$ expansion)
  exclusive modes (hadronic form factors → Lattice or LCSR)

HIC SUNT LEONES

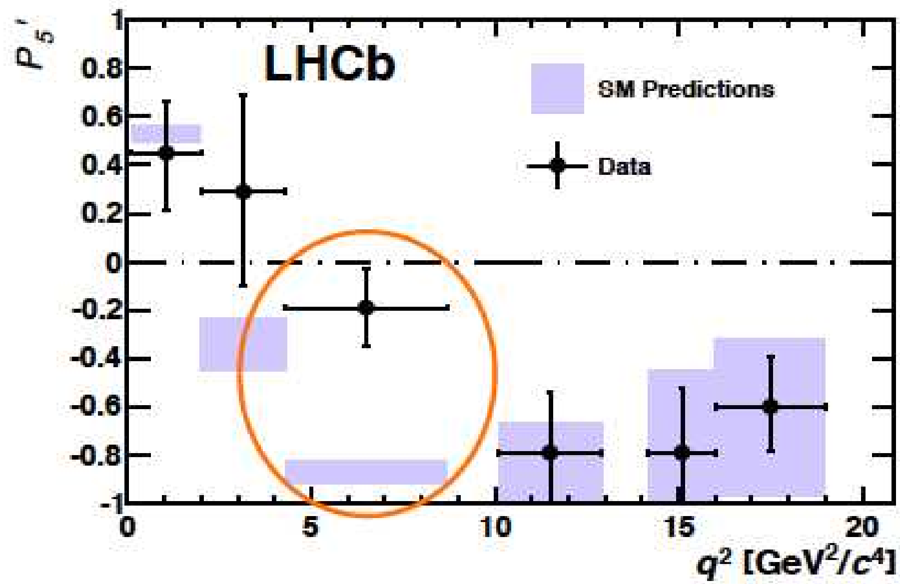
non-perturbative effects...



The anomalies:

I. The P_5' anomaly in $B \to K^{*0}\mu\mu$

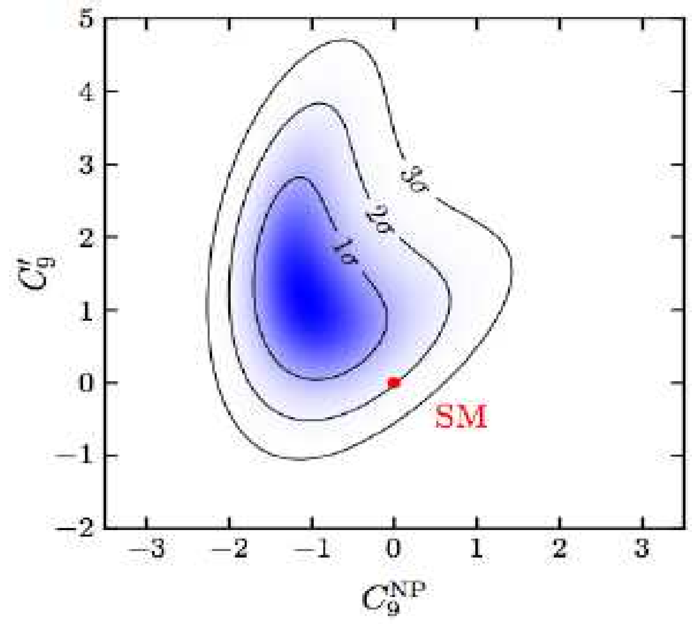
3.7σ local discrepancy
vs. SM [Descotes-Genon *et al.* '13]



II. Overall smallness of the four $BR(B \to H\mu\mu)$, $H = K^{*0}, K^{*+}, K^+, K^0$

Pro NP:

- Reduced tension with data in both cases with a unique fit of modified Wilson coefficients (mainly C_9)
- The corresponding effective NP scale is high (~10 TeV), not in contradiction with other data



Descotes-Genon, Matias, Virto '13
Altmannshofer & Straub '13
Beaujean, Bobeth, van Dyk '13
Horgan *et al.* '13

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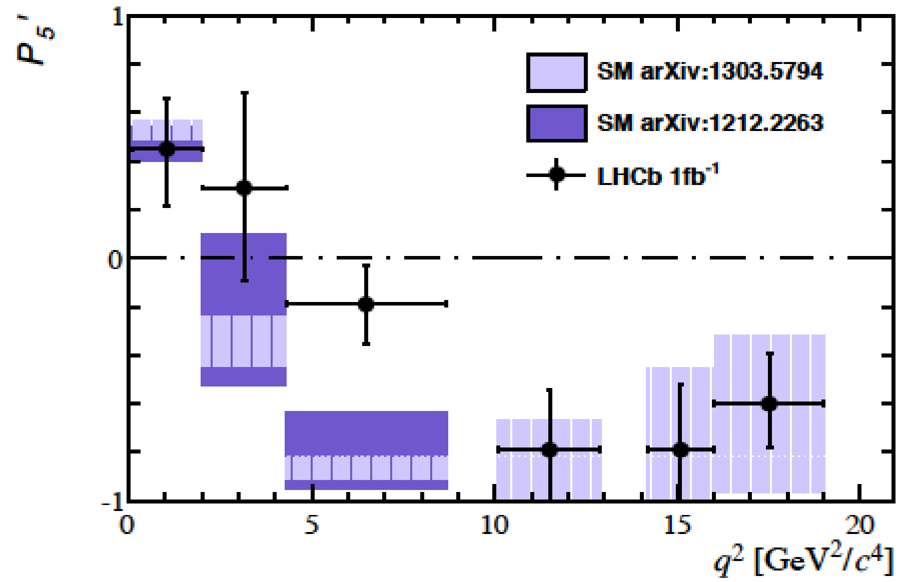

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- The corresponding effective NP scale is high (~10 TeV), not in contradiction with other data

Against NP:

- Main effect in P_5' not far from cc threshold
- Significance reduced with conservative estimates of non- perturbative corrections

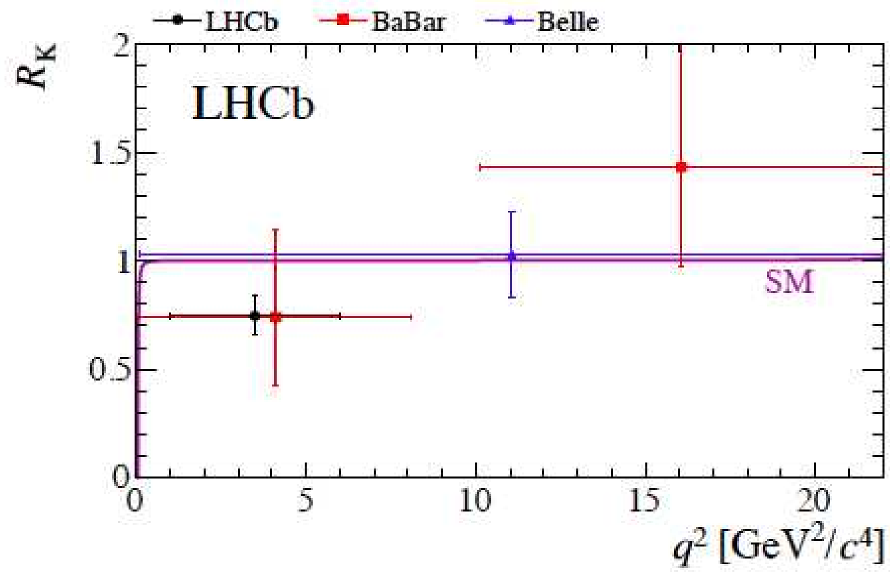
Jaeger *et al.* '12
Hambrock *et al.* '13
Hiller & Zwicky '13

The anomalies:

III. The lepton universality ratio
$d\Gamma(B^+ \to K^+\mu\mu)/d\Gamma(B^+ \to K^+ee)$

$$R_K = 0.745^{+0.090}_{-0.074}(\text{stat})^{+0.036}_{-0.036}(\text{syst})$$

2.6σ from SM



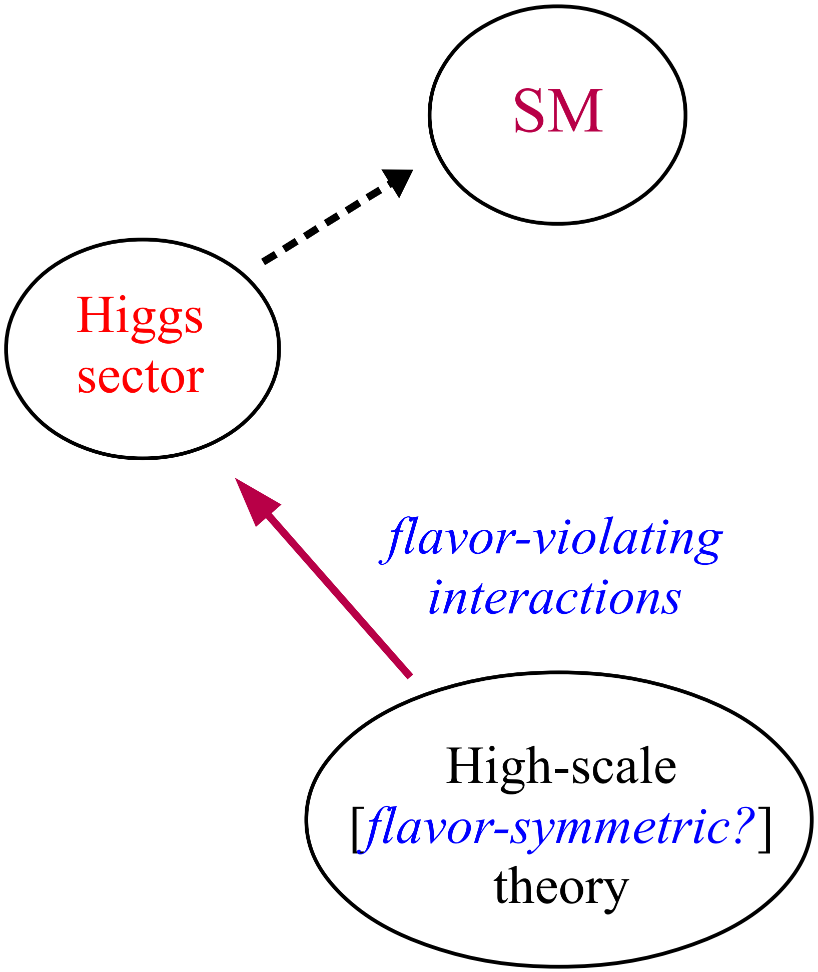
Key features:

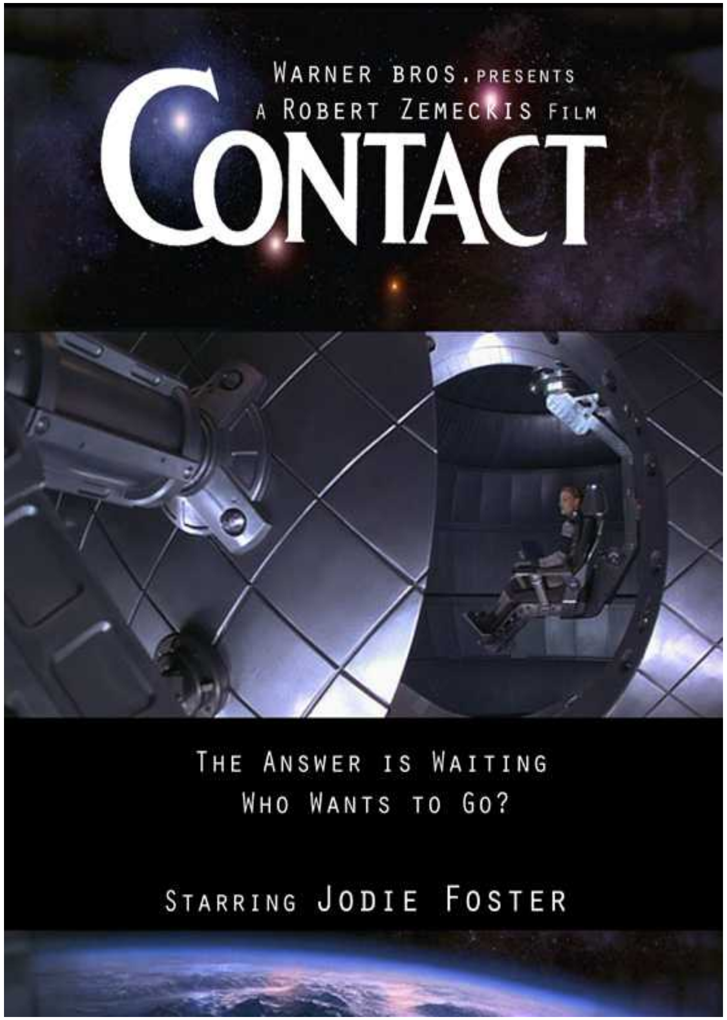
- Th. prediction very solid (*QCD cannot affect lepton universality...*)
- NP in $b \to see$? → *does not fit in a trivial way with any of the previous anomalies...*

Final considerations:

- *Intriguing BSM hints in $b \to sll$ transitions, but no clear evidence yet* (exp. fluctuations + theory errors may explain all the effects)
- *More data* (on both exclusive & inclusive modes) *can help to clarify the picture*

Flavor physics with the BEH boson





Flavor-violating Higgs decays

Higgs-mediated FCNCs are extremely suppressed in the SM, but can be very large in models with an extended Higgs sector.

Even assuming a single Higgs doublet, but allowing non-vanishing higher-dimensional operators → h-mediated FCNC are unavoidable:

Azatov, Toharia, Zhu '09
Agashe & Contino '09

$$Y^{ij}\, \psi_L^{\,i} \psi_R^{\,j}\, \phi + \varepsilon^{ij}\, \psi_L^{\,i} \psi_R^{\,j}\, \phi^3 + \ldots$$

↓

$$\underbrace{(vY^{ij} + v^3\, \varepsilon^{ij})}_{vY_{\rm eff}}\, \psi_L^{\,i} \psi_R^{\,j} + (Y^{ij} + 3v^2\, \varepsilon^{ij})\, \psi_L^{\,i} \psi_R^{\,j}\, h + \ldots \qquad \varepsilon^{ij} = \frac{c^{ij}}{\Lambda^2}$$

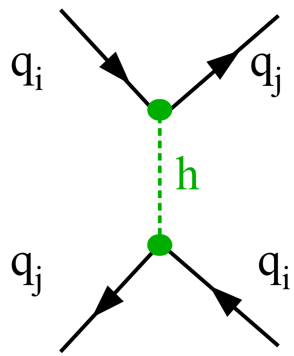
h FCNC couplings if $Y^{ij} \neq c\, \varepsilon^{ij}$

Interplay between:

- Indirect constraints [from h-mediated amplitudes @ low-energies]
- Direct FCNC h decays [enhanced sensitivity of h(125) → *suppressed width*]

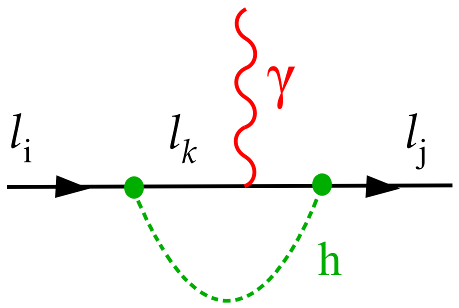
Flavor-violating Higgs decays

$$\mathcal{L}_{\rm eff} = \sum_{i,j=d,s,b\ (i\neq j)} c_{ij}\ \bar{d}^i_L d^j_R h + \sum_{i,j=u,c,t\ (i\neq j)} c_{ij}\ \bar{u}^i_L u^j_R h + \sum_{i,j=e,\mu,\tau\ (i\neq j)} c_{ij}\ \bar{\ell}^i_L \ell^j_R h + \text{H.c.}$$



Strongly bounded by ΔF=2 (except for terms involving the top)

Bounds less severe in the lepton sector, especially for the τμ and τe modes



↓

Indirect bounds imply $\text{BR}(h \to \tau\mu, \tau e) \lesssim 10\%$

Blankenburg, Ellis, G.I. '12
Harnik, Kopp, Zupan, '12
Davidson, Verdier, '12

Celis, Cirigliano, Passemar, '13
Kopp & Nardecchia '14

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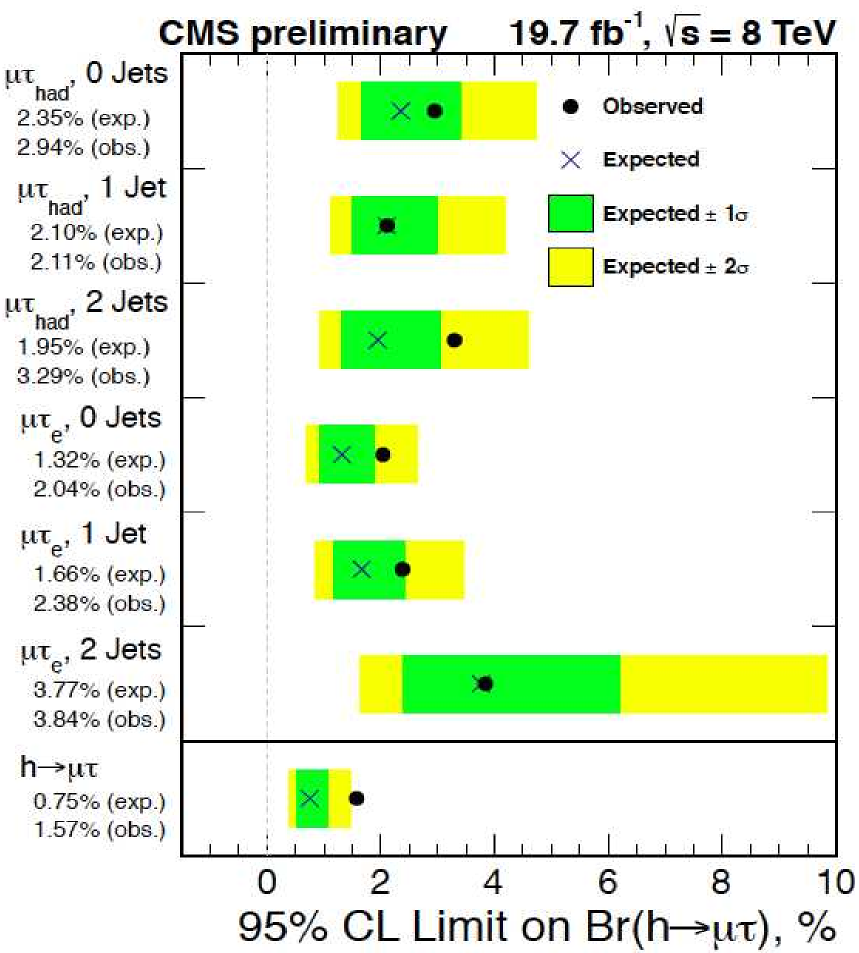

$$\text{BR}(h \to \tau\mu) = (0.89\,^{+\,0.40}_{-\,0.37})\%$$

CMS '14

Flavor-violating Higgs decays

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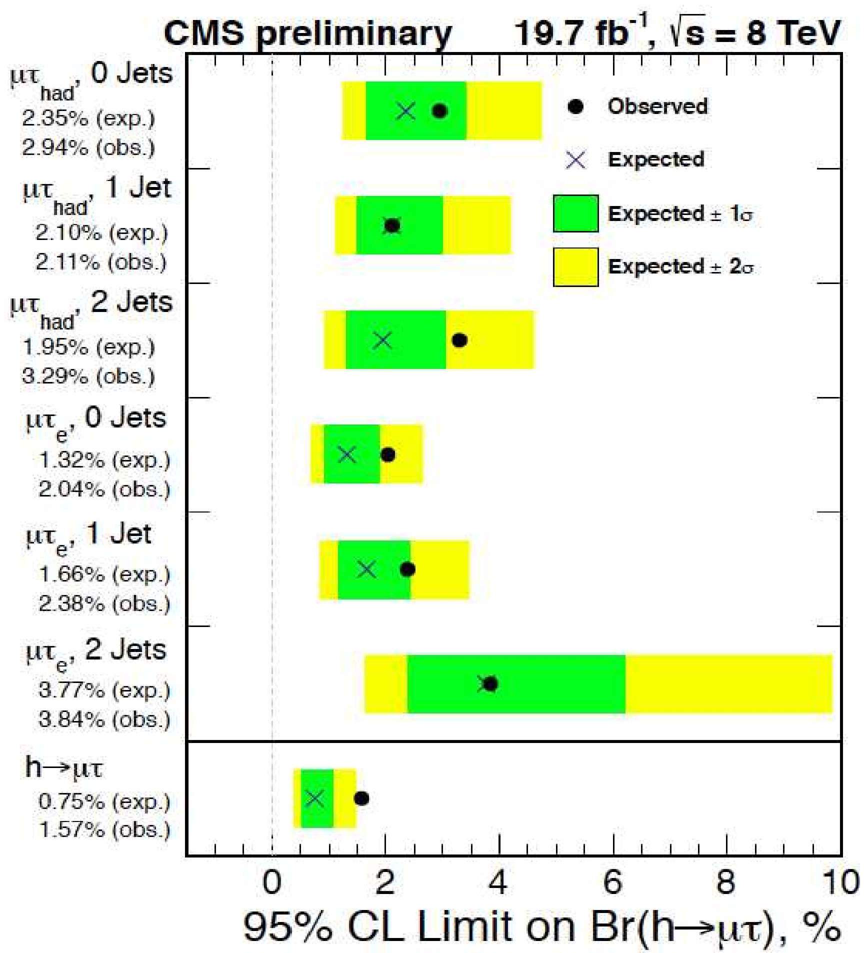

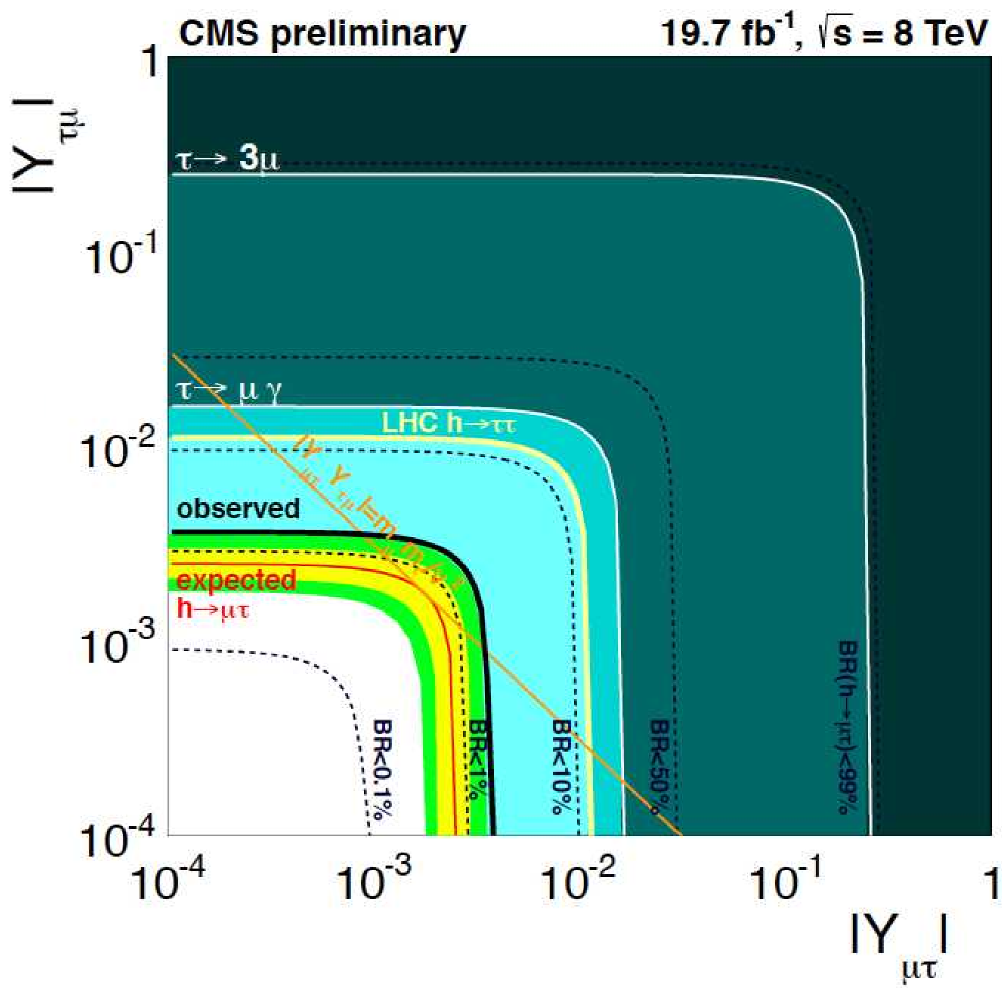

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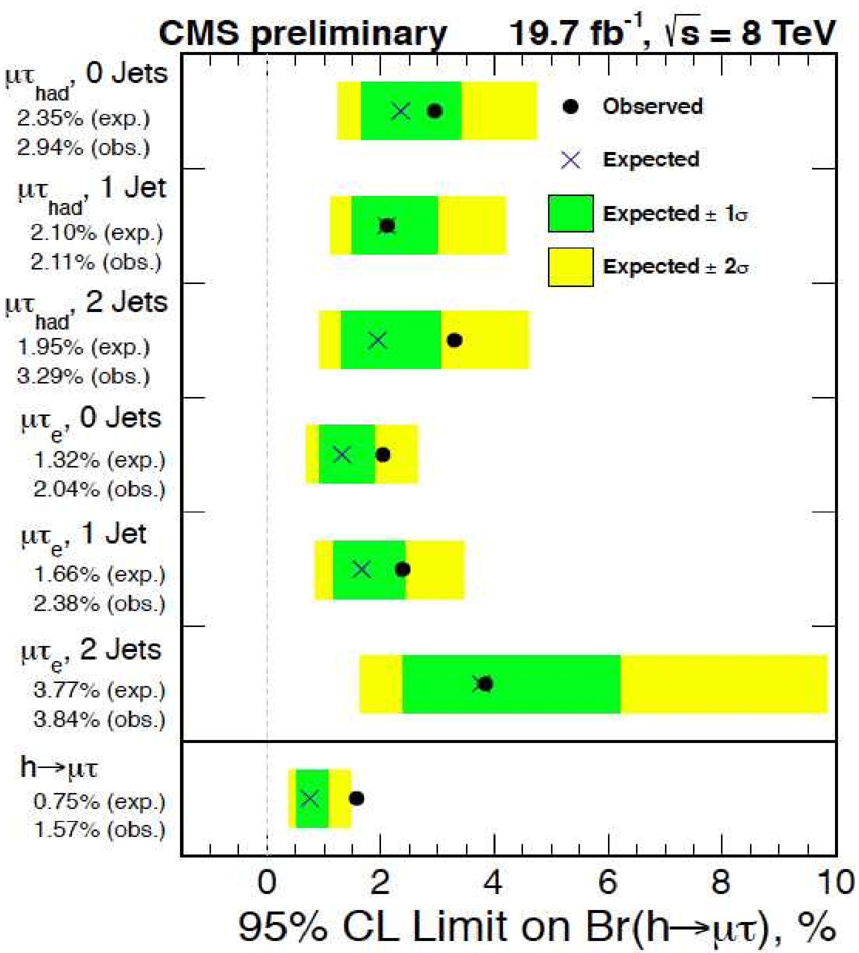

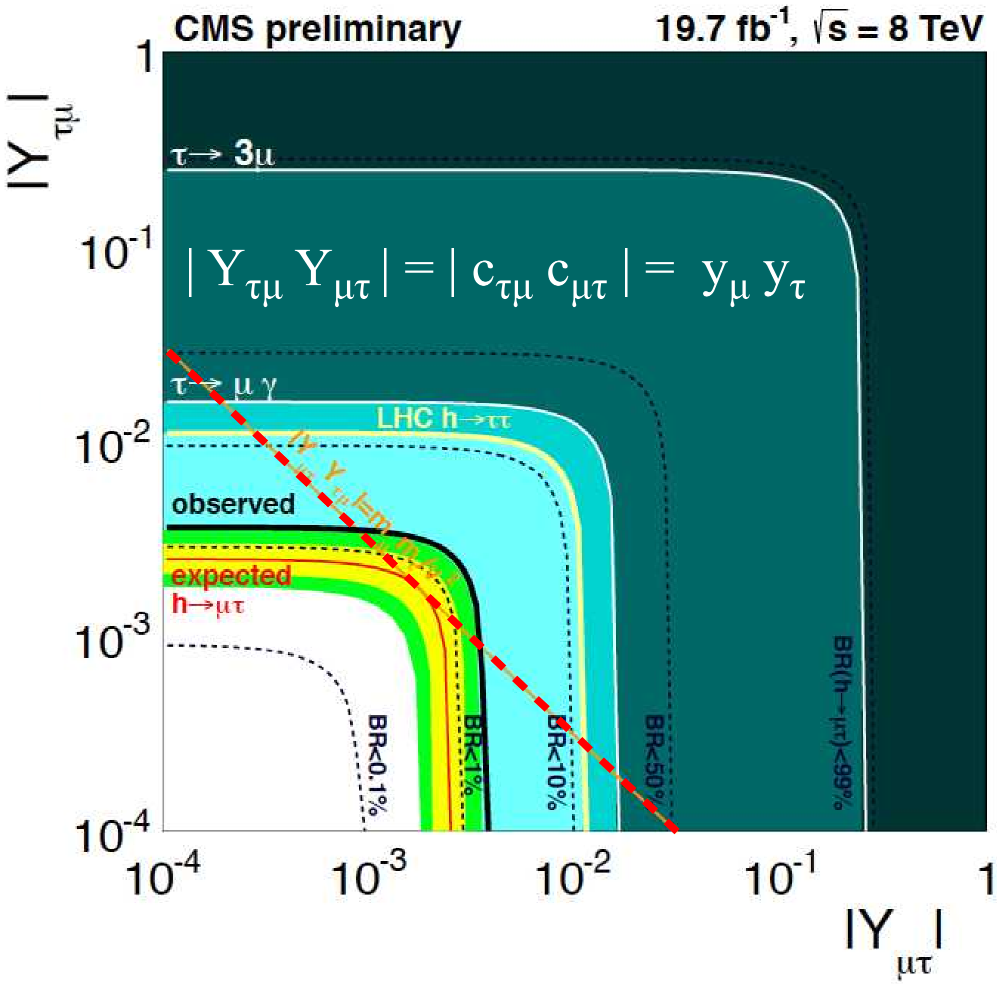

What determines the observed pattern of quark & lepton masses?

What determines the observed pattern of quark & lepton masses?

Two main roads:

Anarchy
+
Anthropic selection

- It works well for $m_{u,d}$
- Maybe good also for ν masses & mixing [*anarchy*]
- But what about CKM and the other masses?

The symmetric way

- Natural hint from the pattern of Yukawa couplings.
- Less evident, but not excluded, in the neutrino case
- "large" flavor symmetry + "small" breaking is the best way to explain the absence of NP signals so far in FCNCs

"Large" (non-Abelian) flavor groups + "small" breaking terms

$U(3)^3 = U(3)_Q \times U(3)_U \times U(3)_D$

- Largest flavor symmetry group compatible with the SM gauge symmetry
- MFV = minimal breaking of $U(3)^3$ by $(3,\underline{3})$ terms [*SM Yukawa couplings*]

Chivukula & Georgi, '89

D'Ambrosio, Giudice, G.I., Strumia, '02

main virtue

- Naturally small effects in FCNC observables (assuming TeV-scale NP)

main problems

- No explanation for *Y* hierarchies (masses and mixing angles) & large symmetry breaking due to y_t

$U(2)^3 = U(2)_Q \times U(2)_U \times U(2)_D$ flavor symmetry

acting on 1^{st} & 2^{nd} generations

Barbieri, G.I., Jones-Perez, Lodone, Straub, '11

- The exact symmetry limit is good starting point for the SM quark spectrum ($m_u=m_d=m_s=m_c=0$, $V_{CKM}=1$) → we only need small breakings terms

"Large" (non-Abelian) flavor groups + "small" breaking terms

I. A problem of both these approaches *-attributing a special role to the hierarchies of the Yukawa couplings-* is the problem of neutrino masses:

- Why neutrino mixing angles are not as small as in the quark sector?
- Why the mass hierarchies in the neutrino sector are not as large?

II. A second common drawback is that the ansatz for the symmetry breaking pattern is put in "by hand" (*non-dynamical spurion analysis*)

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Recent th. progress

Yukawas from V(Y)
U(3)^3 *invariant potentials*

Feldmann *et al.* '09
Alonso, Gavela, *et al.* '11-'13
Nardi '11; Espinosa, Fong, Nardi '12

Gauging of U(3)^3 & U(2)^3

Albrecht, Feldmann, Mannel, '09
Grinstein, Redi, Villadoro, '09
D'Agnolo & Straub, '11

- *The symmetric way* [*a possible option…*]

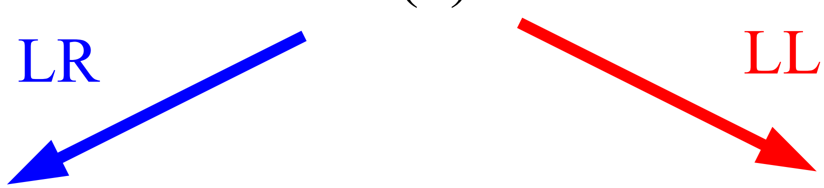
Let's assume the Yukawa couplings and the (Majorana) neutrino mass matrix are *dynamical fields* of the the MFV flavor group [= $U(3)^5$], and that their values are determined by a *minimization principle* (e.g. the potential minimum)

↓

The "natural solutions" [*i.e. solution requiring no tuning in the parameters of the potential*] are the configurations preserving maximally unbroken subgroups.

Michel & Radicati, '69
Cabibbo & Maiani, '69

$U(3)^5$



$Y \propto (0,0,1)$ [unbroken $U(2)_L \mathrm{x} U(2)_R$]

$|M_\nu| \propto (1,1,1)$ [unbroken $O(3)_L$]

Alonso, Gavela, G.I., Maiani, '13

Under this hypothesis, we are naturally led to a hierarchical spectrum for quarks & charged leptons and a degenerate spectrum for neutrinos

The symmetric way [*a possible option...*]

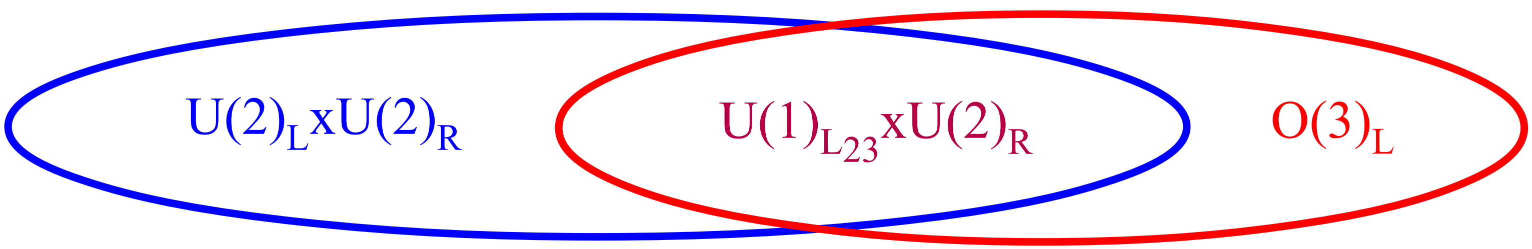
$U(3)_E \times U(3)_L$

Alonso, Gavela, G.I, Maiani, '13

LR → $Y \propto (0,0,1)$ [unbroken $U(2)_L x U(2)_R$]

LL → $M_\nu \propto \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$ (unbroken $O(3)_L$)

same $U(3)_L$ basis



A "natural orientation" of $O(3)_L$ vs. $U(2)_L$ preserving an unbroken U(1) symmetry implies a π/4 mixing angle in the PMNS matrix.

▶ *The symmetric way* [*a possible option...*]

$U(3)_E \times U(3)_L$

Alonso, Gavela, G.I, Maiani, '13

LR

LL

$Y \propto (0,0,1)$ [unbroken $U(2)_L x U(2)_R$]

$M_\nu \propto \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$ (unbroken $O(3)_L$)

same $U(3)_L$ basis

$\frac{m_\mu}{m_\tau} = O(\varepsilon)$

Sub-leading $U(2)_L$ breaking resolving 1-2 degeneracy

$|s_{13}| \sim O(\varepsilon), \quad |s_{12}| \sim O(1)$

$$\frac{m_\mu}{m_\tau} \sim 0.06 < \frac{\Delta m_{atm}^2}{m_\nu^2} = O(\varepsilon) < |s_{13}| \sim 0.2$$

$\langle m_\nu \rangle \approx 0.1 \text{ eV}$

▶ *The symmetric way* [*a possible option...*]

$$U(3)_E \times U(3)_L$$

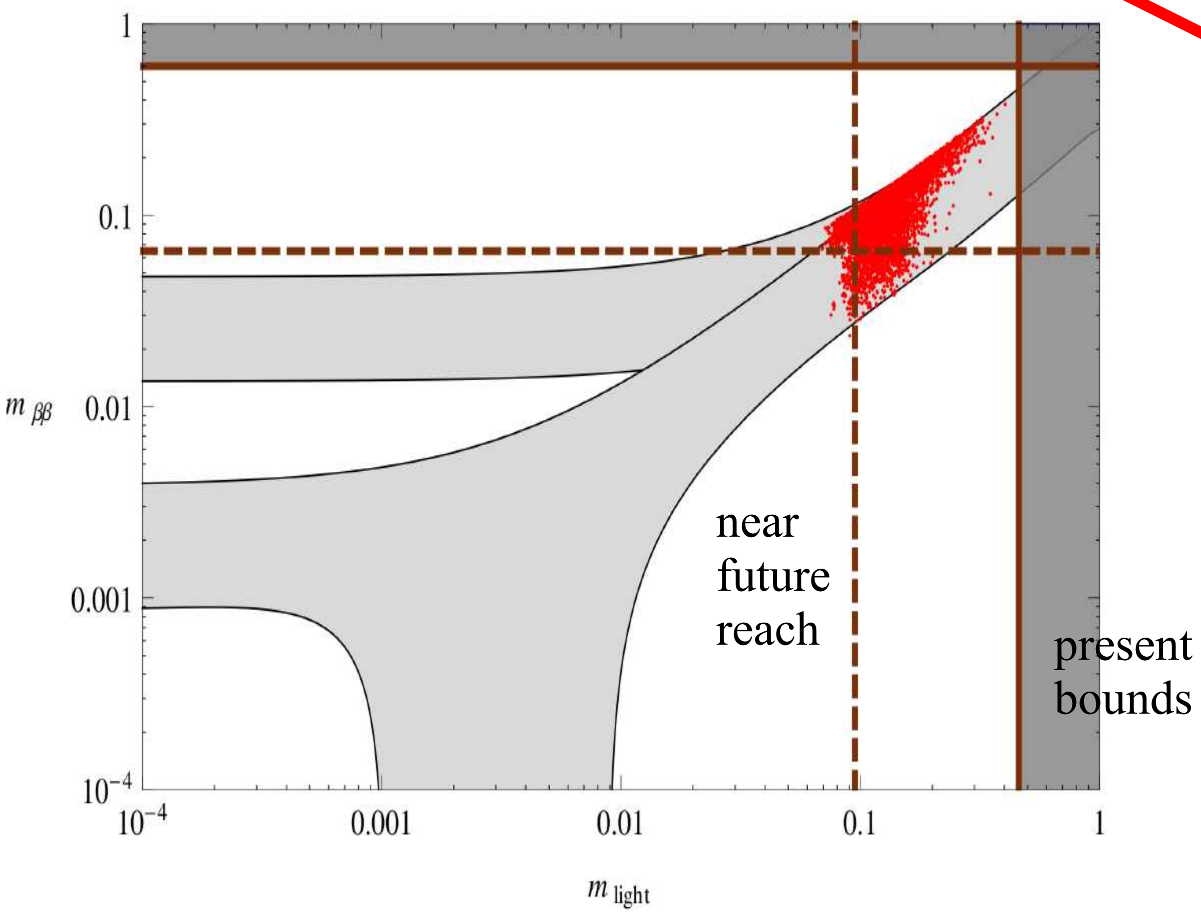
LL

$$M_\nu \propto \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix} \quad \left(\text{unbroken } O(3)_L \right)$$

+

$$\frac{\Delta m_{atm}^2}{m_\nu^2} = O(\varepsilon)$$

$$\langle m_\nu \rangle \approx 0.1 \text{ eV}$$



If all this is correct... 0ν2β decay experiments should be very close to observe a positive signal...

Conclusions

- Flavor-changing transitions represent a “unique window” on BSM physics. *There is still a lot to learn & explore, also in view of HL-LHC.*

- The “Usual Suspects” (ε_K, ϕ_s, $B \to \mu\mu$, ...) may hide NP signals @ 10% level in well-motivated models (e.g. “split-family SUSY”) → need combined th+exp precision at the few% level → essential to improve quality of CKM fits

- Intriguing NP hints (of “exotic” nature) in $B \to K^{(*)}ll$ decays, but picture far form being clear → more data can help to clarify the situation

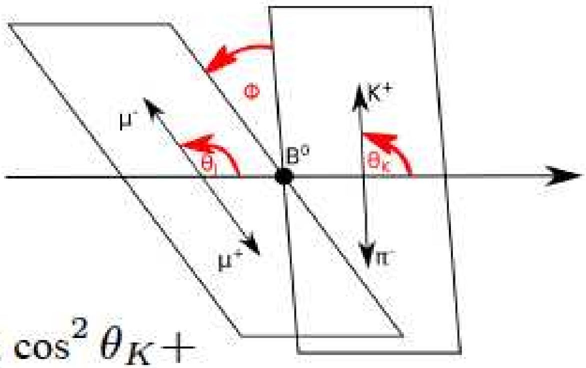
- Worth to improve searches of exotic flavor-violating effects, such as $H \to \tau\mu$ [*many additional interesting searches not covered in this talk...*]

- We should not give-up on models trying to “explain” masses & mixing from symmetry principles → *the overall scale of neutrino masses could be the key...*


Backup

What's P$_5$' ?

Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$



$$\frac{d^4(\Gamma+\bar{\Gamma})}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi\, dq^2} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi + S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

$$P'_{4,5} = \frac{S_{4,5}}{\sqrt{F_L(1-F_L)}}$$