The challenge of low scale flavor

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Sissa & INFN Trieste

R. de Adelhart Toorop, FB, L.Merlo,A.Paris JHEP 1103:035,040,2011
R. de Adelhart Toorop, FB, S.Morisi 1104.5676

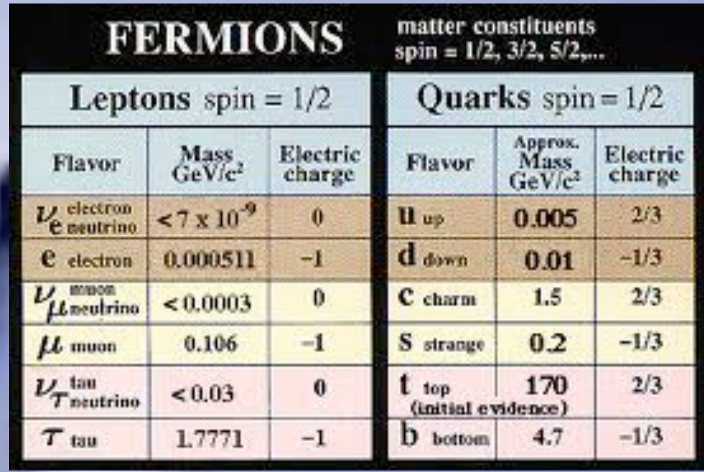
Flasy2011, Valencia, 11/07/2011


Flavor Puzzle

Flavor Puzzle

FERMIONS matter constituents spin = 1/2, 3/2, 5/2,...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c²	Electric charge	Flavor	Approx. Mass GeV/c²	Electric charge
ν_e electron neutrino	$< 7 \times 10^{-9}$	0	u up	0.005	2/3
e electron	0.000511	–1	d down	0.01	–1/3
ν_μ muon neutrino	< 0.0003	0	c charm	1.5	2/3
μ muon	0.106	–1	s strange	0.2	–1/3
ν_τ tau neutrino	< 0.03	0	t top (initial evidence)	170	2/3
τ tau	1.7771	–1	b bottom	4.7	–1/3



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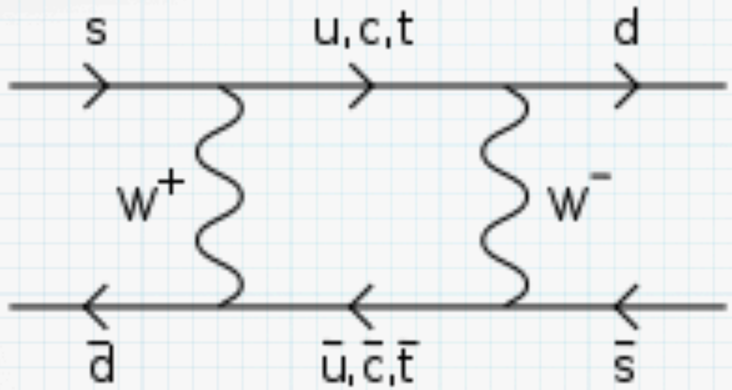
Flavor Puzzle

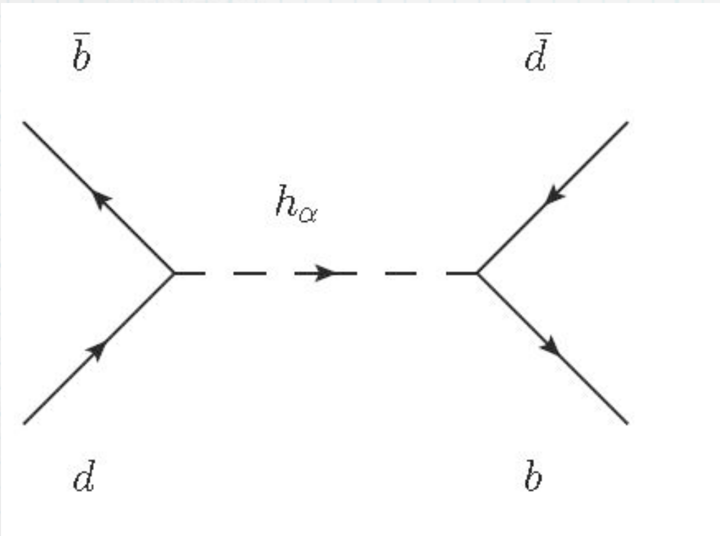
which symmetry ? (if any...)

which scale ?

SM contributions to FCNC



$$\frac{G_F^2}{16\pi^2}(V_{di}^\dagger V_{is})^2 m_i^2$$



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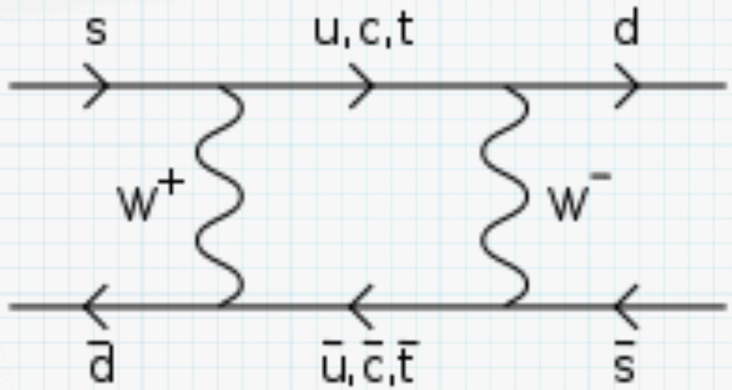

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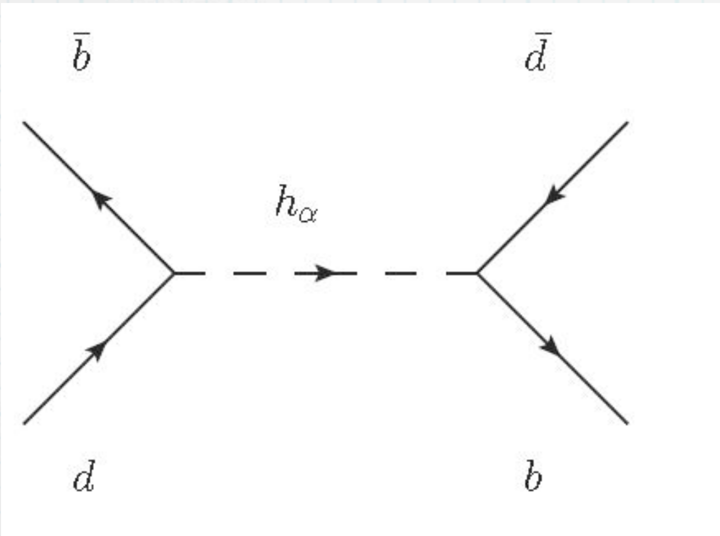
fix a flavor scale lower bound



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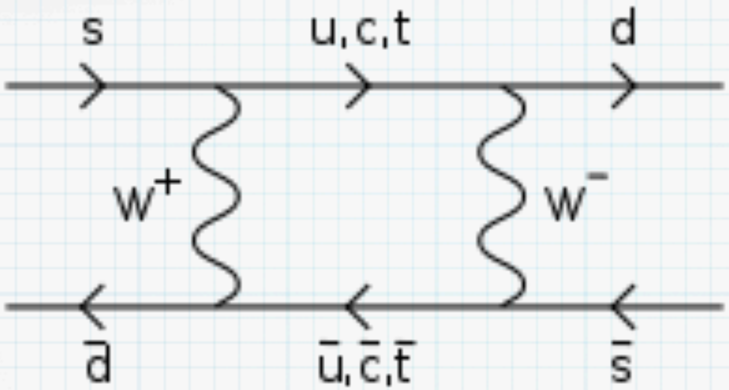

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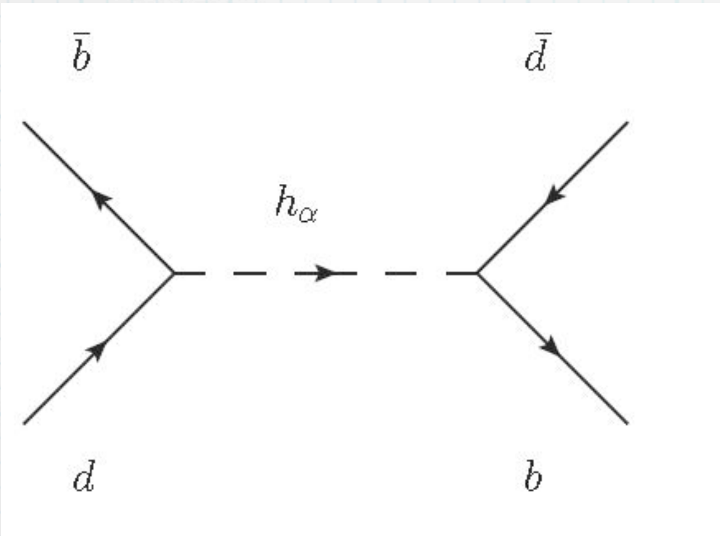
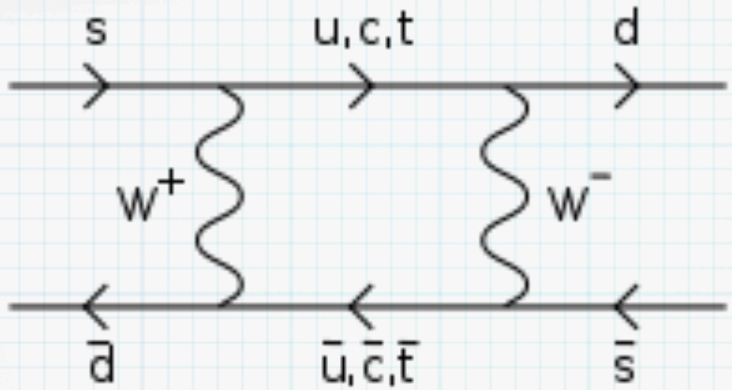


$$\frac{1}{\Lambda_F^2} \sim \frac{G_F}{16\pi^2}$$

Yukawa couplings

$$\Lambda_F \geq 1\,\text{TeV}$$

SM contributions to FCNC



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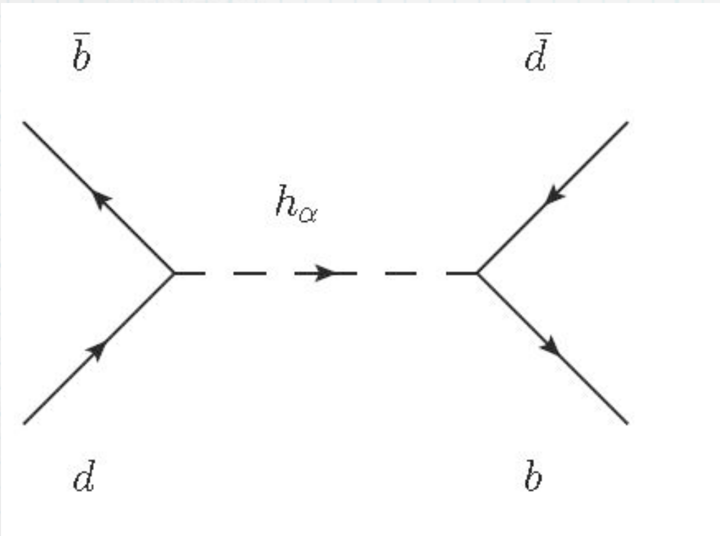

Yukawa couplings

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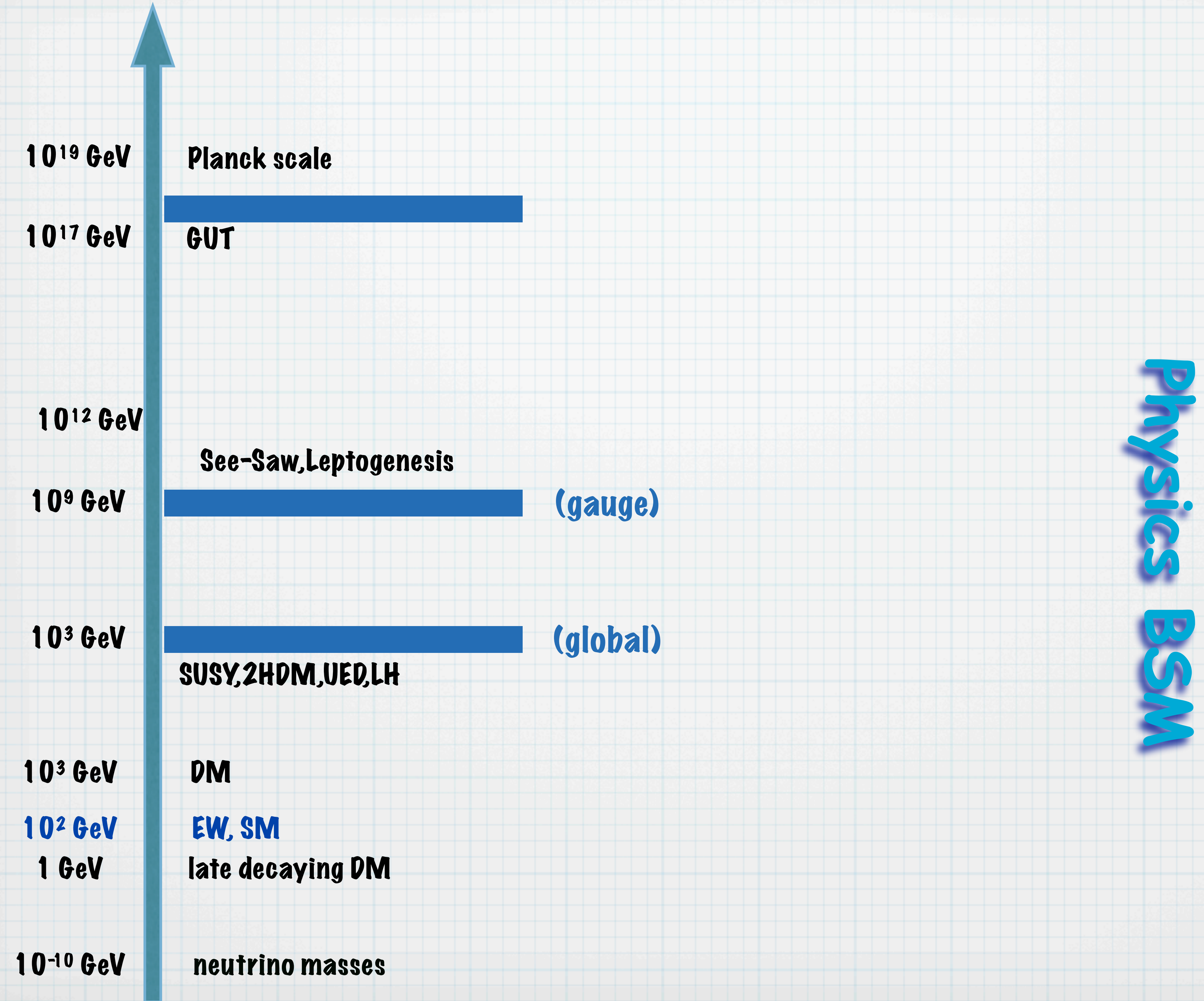
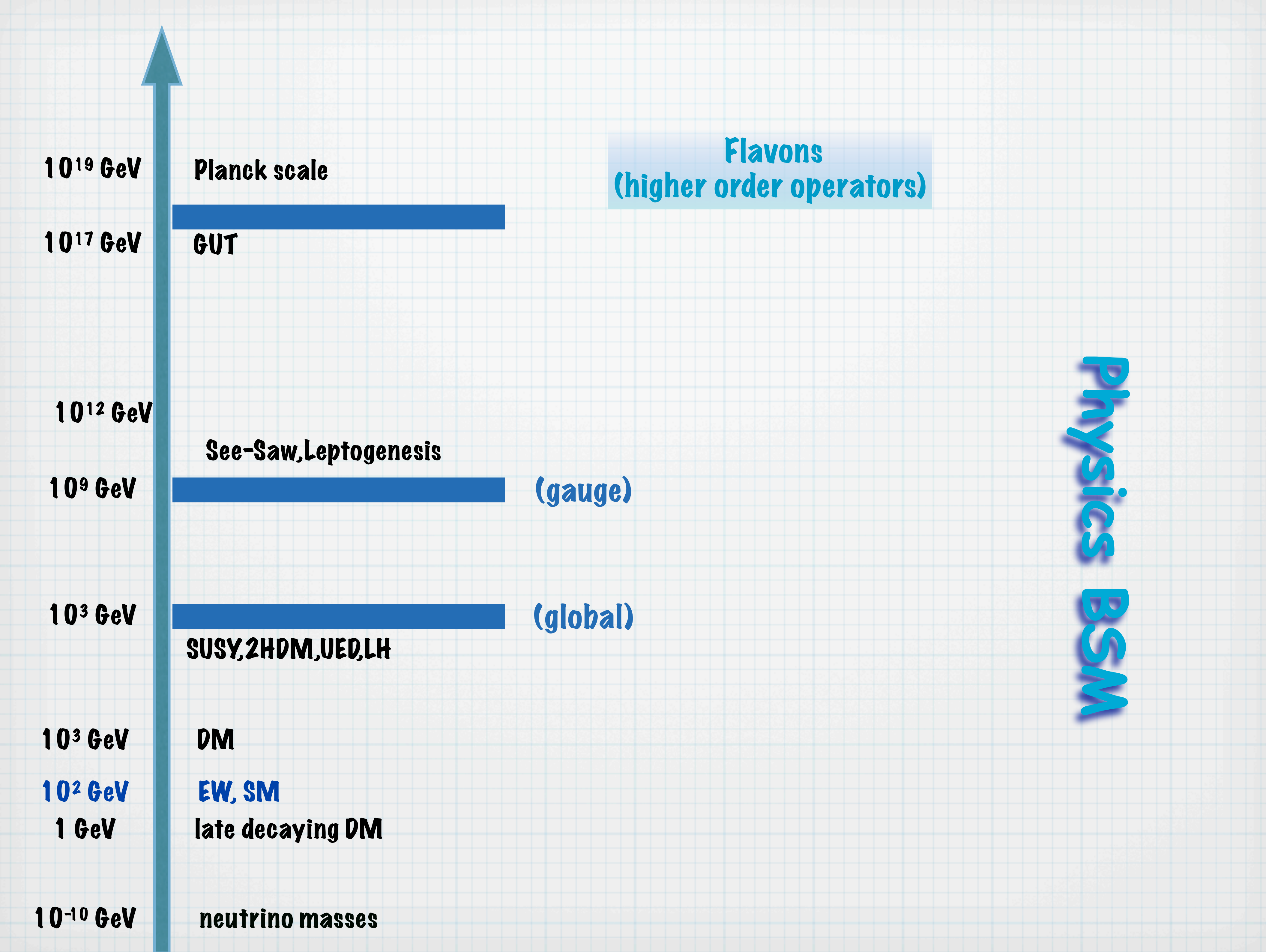
gauge couplings

$$\frac{g_F^2}{\Lambda_F^2} \sim \frac{G_F^2}{16\pi^2}(V^\dagger_{di}V_{is})^2 m_i^2$$

$$\Lambda_F \geq 10^6\,\mathrm{TeV}$$



10^{19} GeV
Planck scale
10^{17} GeV
GUT
10^{12} GeV
See-Saw,Leptogenesis
10^{9} GeV
(gauge)
10^{3} GeV
(global)
SUSY,2HDM,UED,LH
10^{3} GeV
DM
10^{2} GeV
EW, SM
1 GeV
late decaying DM
10^{-10} GeV
neutrino masses
Physics BSM


Flavons
(higher order operators)
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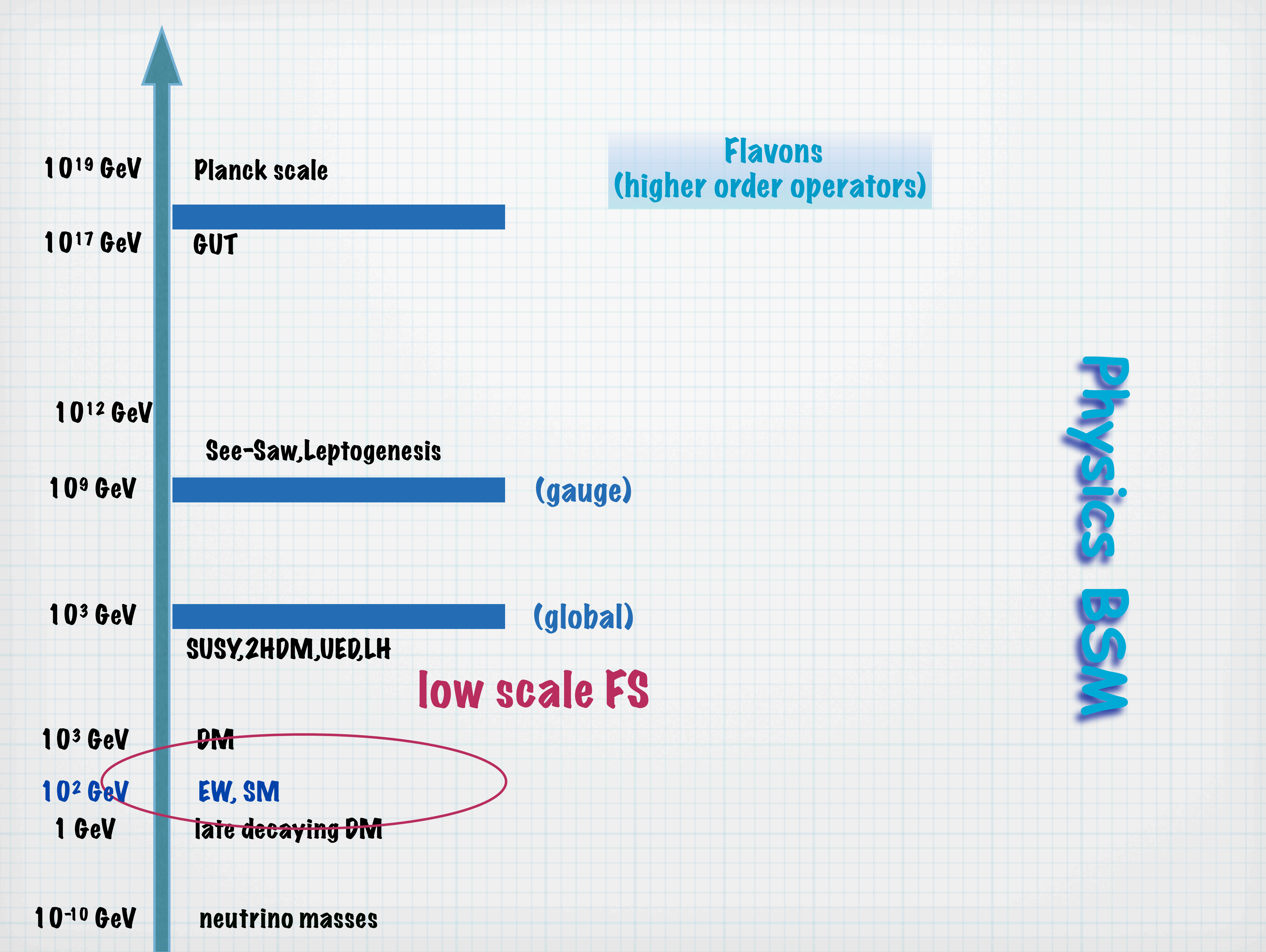

10¹⁹ GeV
Planck scale
Flavons
(higher order operators)
10¹⁷ GeV
GUT
10¹² GeV
See-Saw,Leptogenesis
10⁹ GeV
(gauge)
10³ GeV
(global)
SUSY,2HDM,UED,LH
low scale FS
Physics BSM
10³ GeV
DM
10² GeV
EW, SM
1 GeV
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10⁻¹⁰ GeV
neutrino masses

high scale Flavor Symmetry

A_4

charged leptons Z_3

neutrinos Z_2

$$y_e \frac{1}{\Lambda_F} L_i E^c_j \Phi_{T_k} H^d$$

$$U_\omega \sim \frac{1}{\sqrt{3}} \begin{pmatrix} 1 & 1 & 1 \\ 1 & \omega & \omega^2 \\ 1 & \omega^2 & \omega \end{pmatrix}$$

$$y_\nu \frac{1}{\Lambda_F} \frac{1}{\Lambda_M} L_i L_j \Phi_{S_k} H^u H^u$$

$$V_\nu = \begin{pmatrix} 0 & 1 & 0 \\ \frac{1}{\sqrt{2}} & 0 & -\frac{i}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & 0 & \frac{i}{\sqrt{2}} \end{pmatrix}$$

$$U_{lep} = U^\dagger_\omega V_\nu = U_{TBM}$$

high scale Flavor Symmetry

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Adhikary; Altarelli; Babu; B.; Brahmachari; Chen; Choubey; Ciafaloni; Csaki; Delaunay; Feruglio; Frampton; Frigerio; Ghosal; Grimus; Grojean; Grossmann; Hagedorn; He; Hirsh; Ghosal; Grimus; Grojean; Grossmann; Hagedorn; He; Hirsch; Honda; Joshipura; Kaneko; Keum; King; Kuhbock; Lavoura; Lin;
Ma; Malinsky; Matsuzaki; LM; Mitra; Morisi; Parida; Picariello; Rajasekaran; Romao; Skadhauge; Tanimoto; Torrente-Lujan; Urbano; Valle; Villanova del Moral; Volkas; Zee; ...

high scale Flavor Symmetry

problems!

A_4

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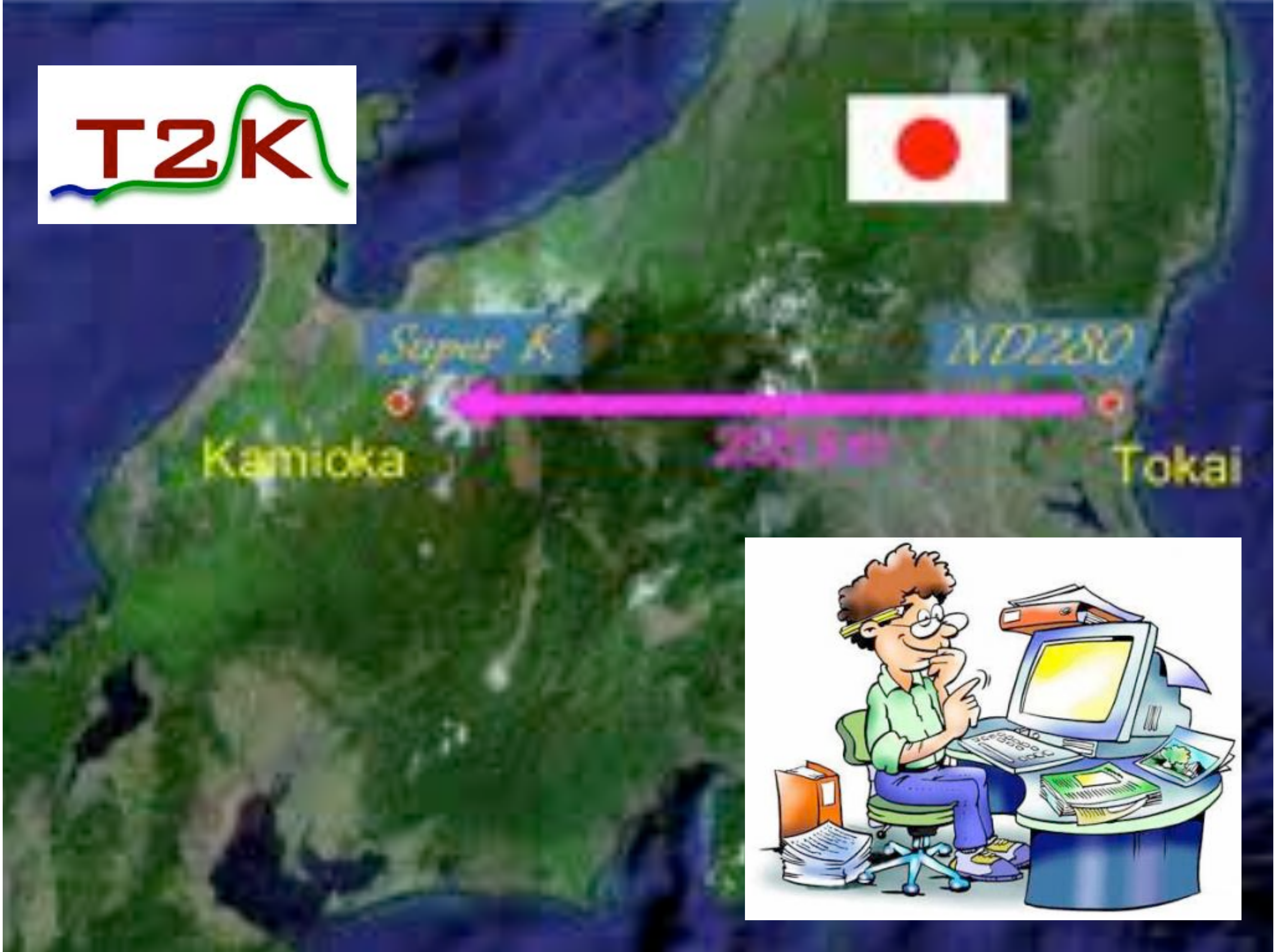
moreover ....


T2K
Super K
ND280
Kamioka
Tokai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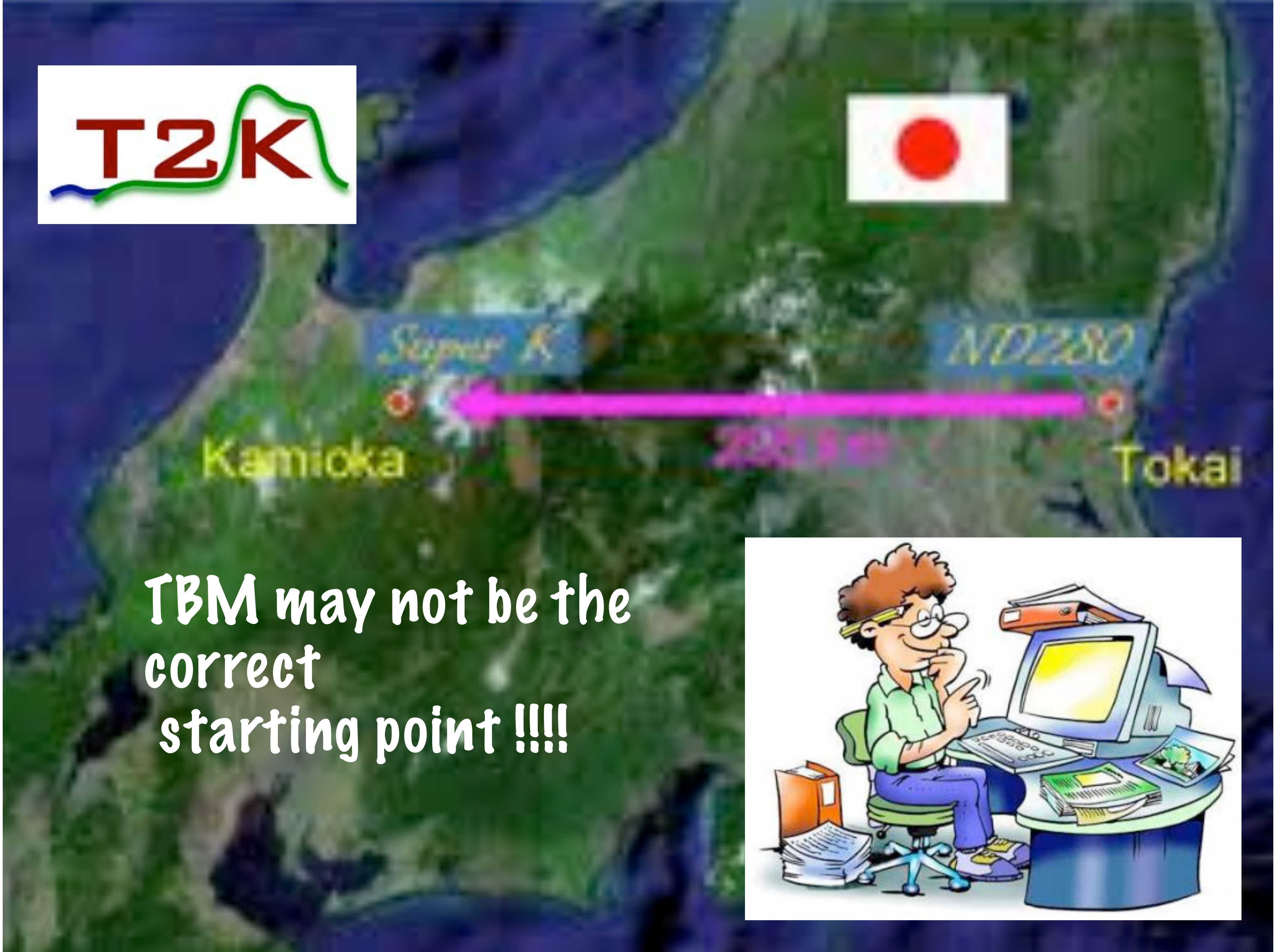

TBM may not be the correct
starting point !!!!

low scale Flavor Symmetry

breaking in one direction

SM higgs charged under the flavor symmetry,
h is also an A4 (DFS) triplet

$$\Phi \sim (\phi_1, \phi_2, \phi_3)$$

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EW- Flavor unification

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EW- Flavor unification

- more minimal (less new degrees of freedom)
- more interesting (possible signatures)
- no exact TBM
- phenomenologically more constrained
- may have useful different applications (DDM)

in literature....

$$\langle \Phi \rangle \sim (vr, ve^{-i\omega}, ve^{i\omega})$$

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$$\langle \Phi \rangle \sim (vr, ve^{-i\omega}, ve^{i\omega})$$

BUT..

ALLOWED?

Lavoura-Kuhbock model
(0711.0670[hep-ph])

quarks

$$M_n = D \begin{pmatrix} y_1 v_1 & y_2 v_1 & y_3 v_1 \\ y_1 v_2 & \omega y_2 v_2 & \omega^2 y_3 v_2 \\ y_1 v_3 & \omega^2 y_2 v_3 & \omega y_3 v_3 \end{pmatrix}, \quad M_p = D^* \begin{pmatrix} y_4 v_1 & y_5 v_1 & y_6 v_1 \\ y_4 v_2 & \omega y_5 v_2 & \omega^2 y_6 v_2 \\ y_4 v_3 & \omega^2 y_5 v_3 & \omega y_6 v_3 \end{pmatrix}$$

Morisi-Peinado model
0910.4389[hep-ph]

leptons

$$M_l = \begin{pmatrix} 0 & ae^{i\alpha} & be^{-i\alpha} \\ be^{i\alpha} & 0 & ar \\ ae^{-i\alpha} & br & 0 \end{pmatrix}, \qquad M_\nu = \begin{pmatrix} xr^2 & \kappa re^{-i\alpha} & \kappa re^{i\alpha} \\ \kappa re^{-i\alpha} & zr^2 & \kappa \\ \kappa re^{i\alpha} & \kappa & yr^2 \end{pmatrix}.$$

Discrete DM model
Hirsh et al. Phys.Rev.D82,
[hep-ph] 1104.5676

leptons & quarks

$$M_d = \begin{pmatrix} m_d & 0 & 0 \\ 0 & m_s & 0 \\ 0 & 0 & m_b \end{pmatrix} + \frac{v_H v_\eta^2}{\Lambda^2} \begin{pmatrix} f_{dd} & f_{ds} & f_{db} \\ f_{sd} & f_{ss} & f_{sb} \\ f_{bd} & f_{bs} & f_{bb} \end{pmatrix}$$

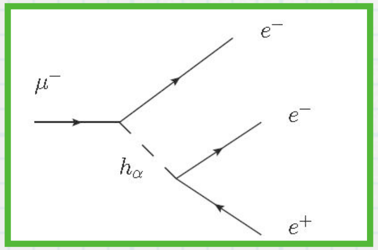
Constraints on the higgs-flavons...

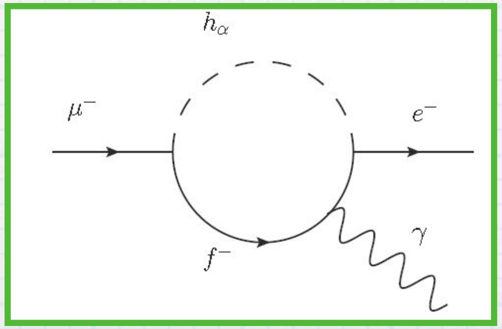
model independent — **higgs-guage bosons**

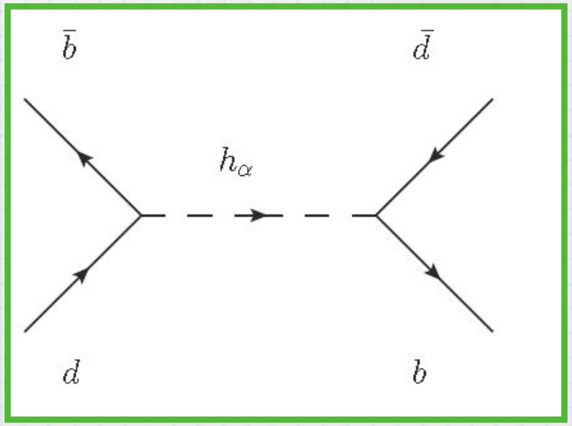
- unitarity
- Z,W decays
- h-> 2 W decay
- STU

model dependent — **higgs-fermions**

- Rare decays
- Meson oscillations







the scalar potential

$$
\begin{aligned}
V[\Phi_a] &= \mu^2(\Phi_1^\dagger\Phi_1 + \Phi_2^\dagger\Phi_2 + \Phi_3^\dagger\Phi_3) + \lambda_1(\Phi_1^\dagger\Phi_1 + \Phi_2^\dagger\Phi_2 + \Phi_3^\dagger\Phi_3)L^2 \\
&+ \lambda_3(\Phi_1^\dagger\Phi_1\Phi_2^\dagger\Phi_2 + \Phi_1^\dagger\Phi_1\Phi_3^\dagger\Phi_3 + \Phi_2^\dagger\Phi_2\Phi_3^\dagger\Phi_3) \\
&+ \lambda_4(\Phi_1^\dagger\Phi_2\Phi_2^\dagger\Phi_1 + \Phi_1^\dagger\Phi_3\Phi_3^\dagger\Phi_1 + \Phi_2^\dagger\Phi_3\Phi_3^\dagger\Phi_2) \\
&+ \frac{\lambda_5}{2}\left[e^{i\epsilon}[(\Phi_1^\dagger\Phi_2)^2 + (\Phi_2^\dagger\Phi_3)^2 + (\Phi_3^\dagger\Phi_1)^2] + e^{-i\epsilon}[(\Phi_2^\dagger\Phi_1)^2 + (\Phi_3^\dagger\Phi_2)^2 + (\Phi_1^\dagger\Phi_3)^2]\right],
\end{aligned}
$$

parameters
more
constrained
(fl sym)

minima classification

$$
\Phi_a = \frac{1}{\sqrt{2}}\begin{pmatrix}\Phi_a^{1R} + i\Phi_a^{1I} \\ \Phi_a^{0R} + i\Phi_a^{0I}\end{pmatrix} \to \frac{1}{\sqrt{2}}\begin{pmatrix}\mathrm{Re}\ \phi_a^1 + i\,\mathrm{Im}\ \phi_a^1 \\ v_a e^{i\omega_a} + \mathrm{Re}\ \phi_a^0 + i\ \mathrm{Im}\ \phi_a^0\end{pmatrix}
$$

CP conserving

- (v,v,v)
- (v,0,0)
- (v_1, v_2, v_3)

CP breaking

- (v exp[i a] ,v,0)
- (v exp[i a] ,v exp[-i a], r v)

the scalar potential

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parameters more constrained (fl sym)

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up to indeces permutation

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- (v exp[i a] ,v,0)
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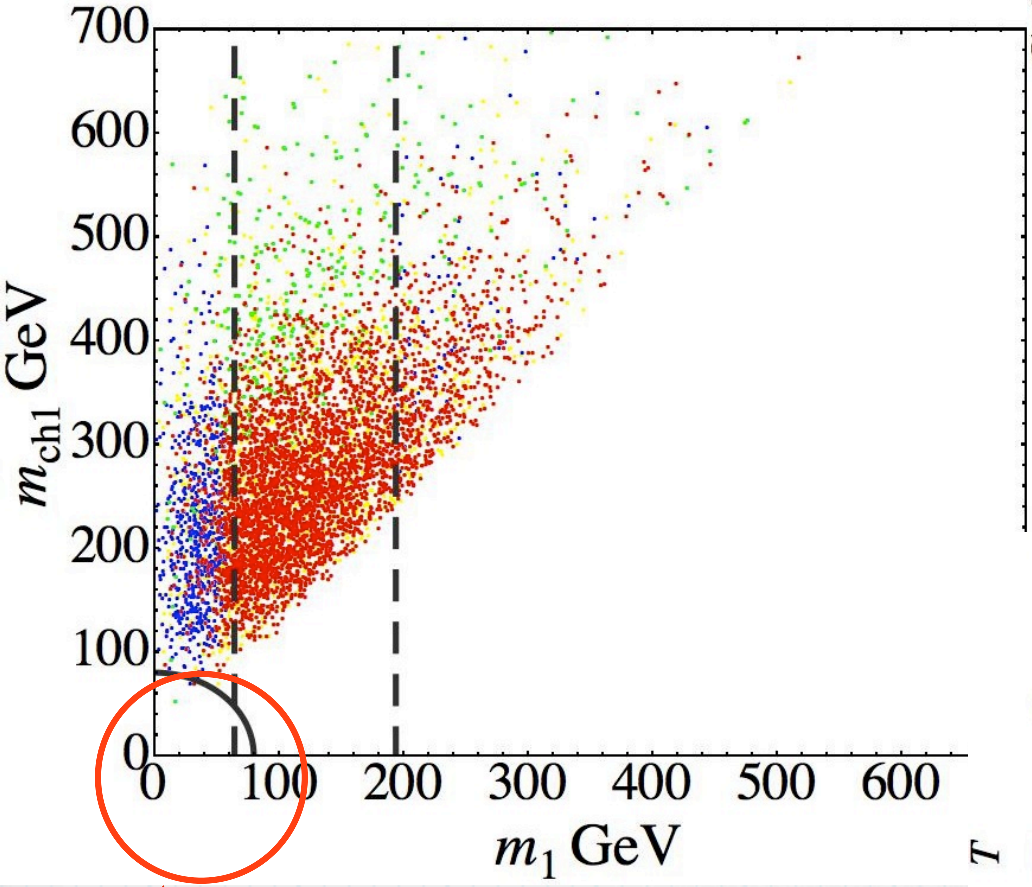
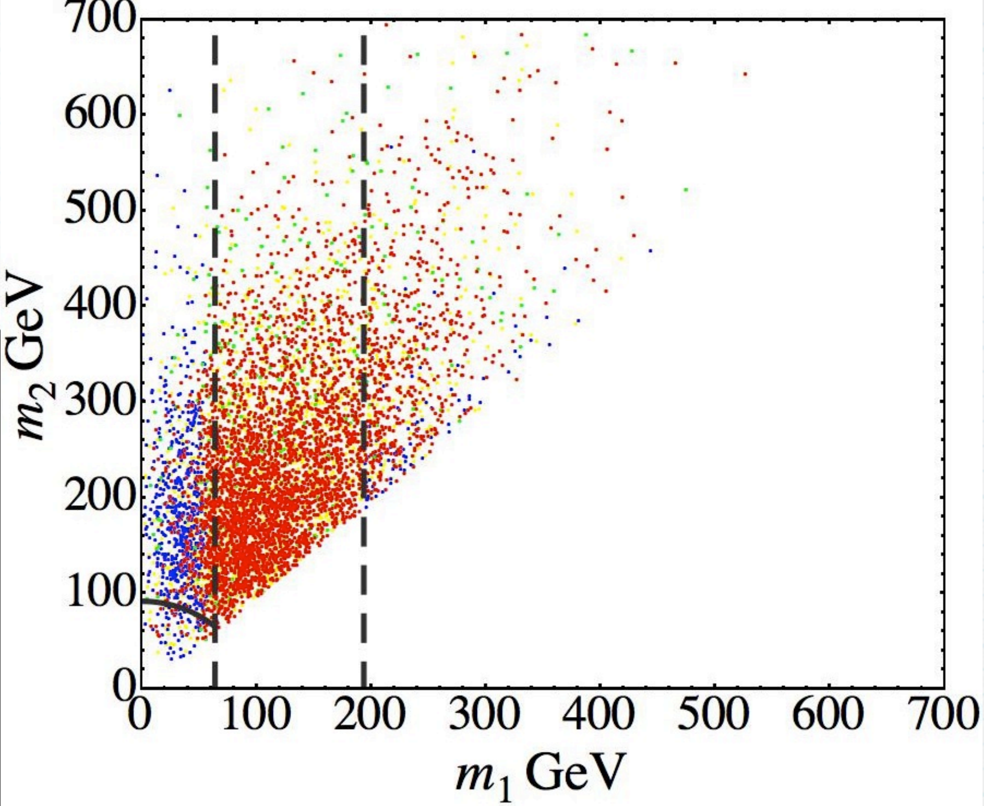
model independent approach

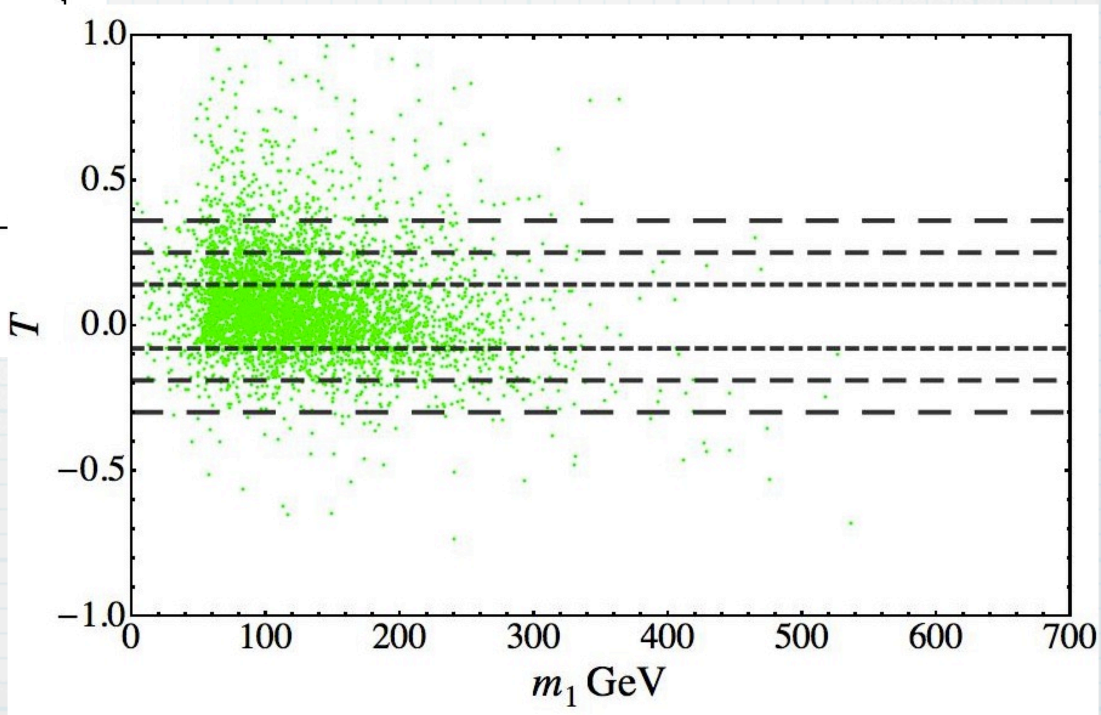
all the ingredients...

CP conserving (v,v,v)

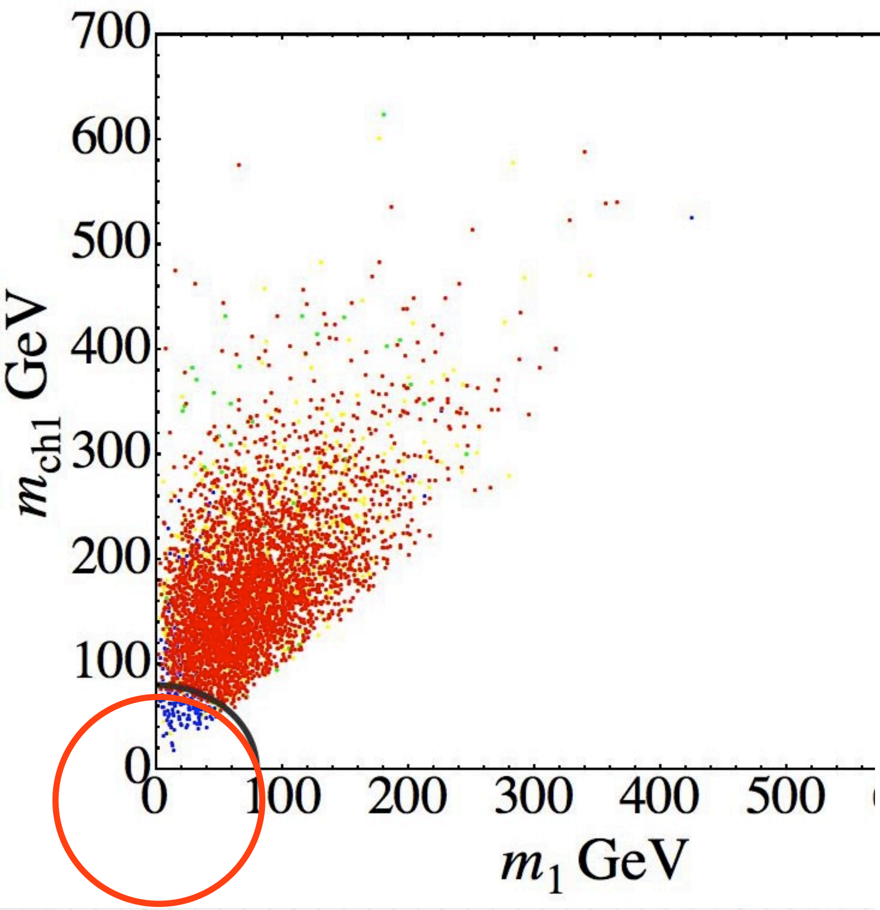


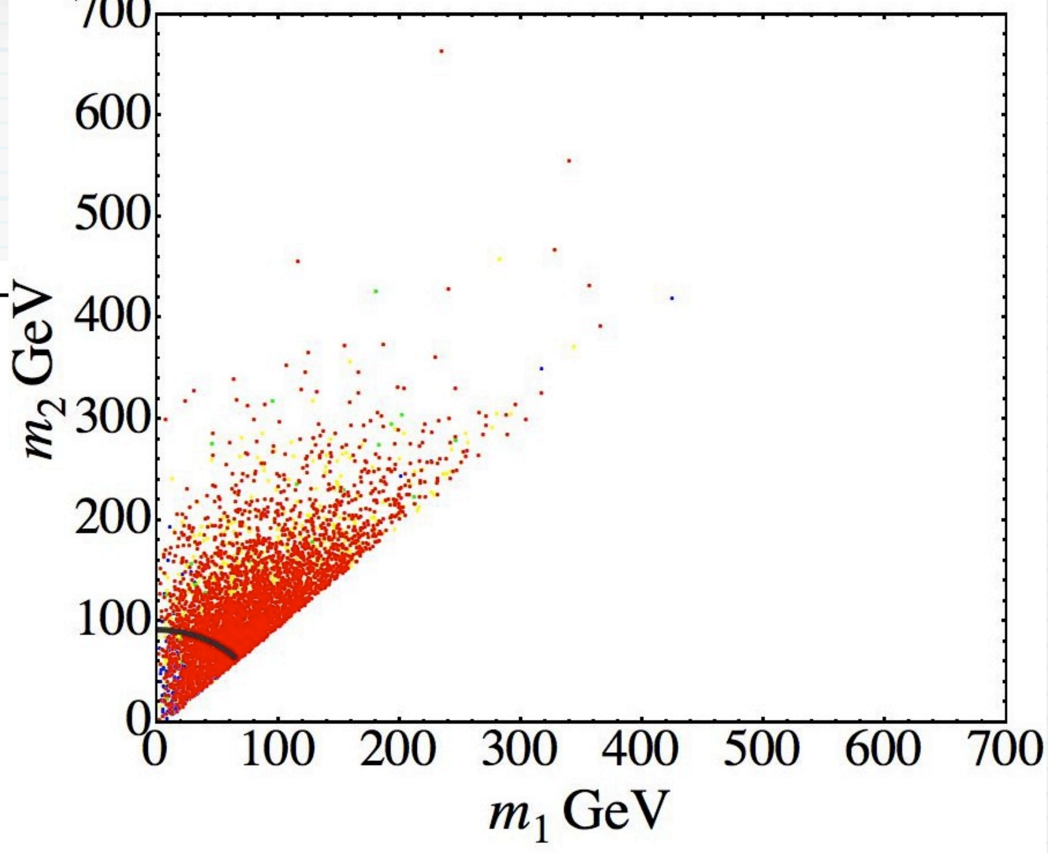
W decays

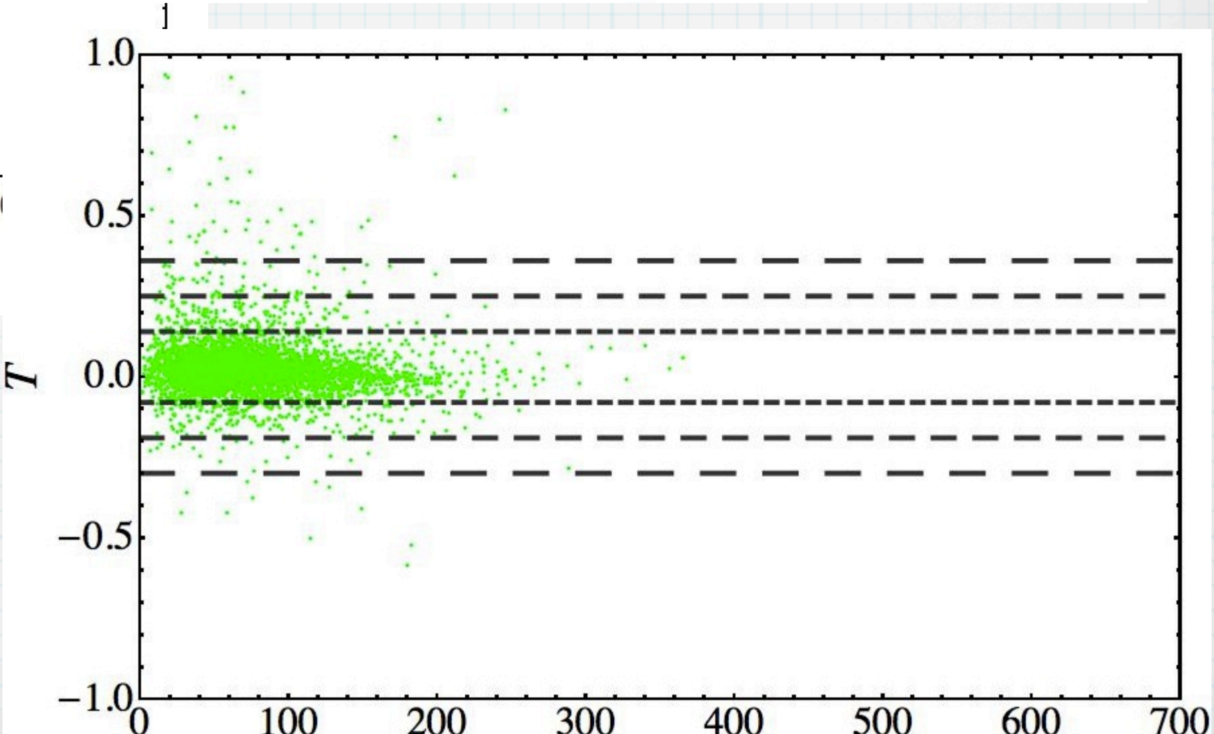




CP breaking (v e^(i a) ,v, 0)

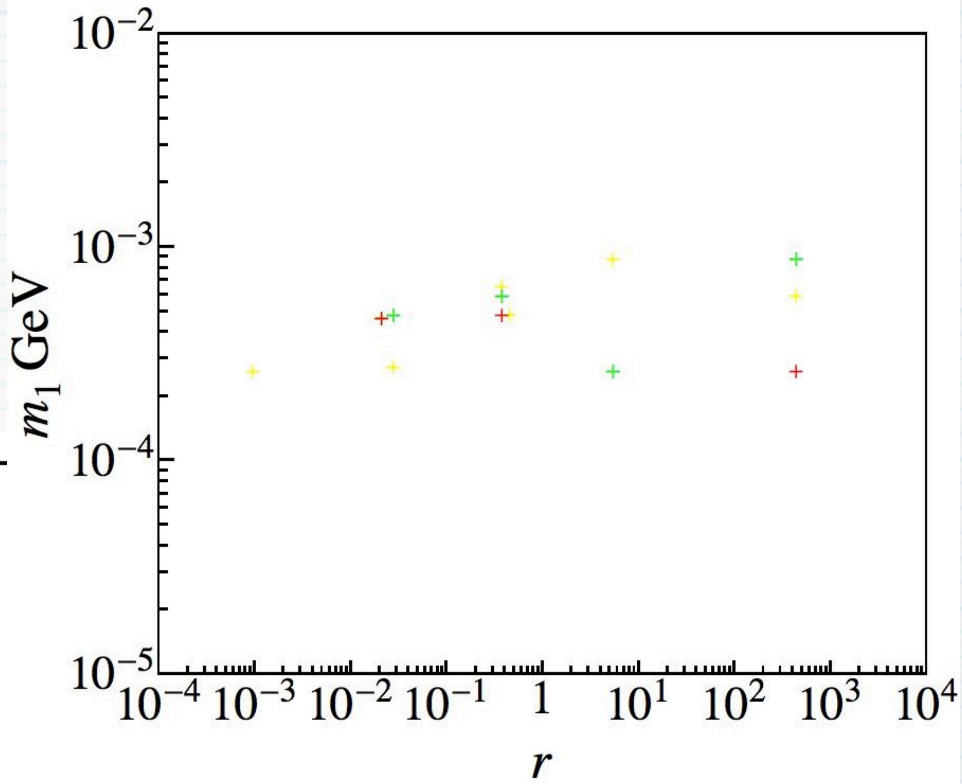


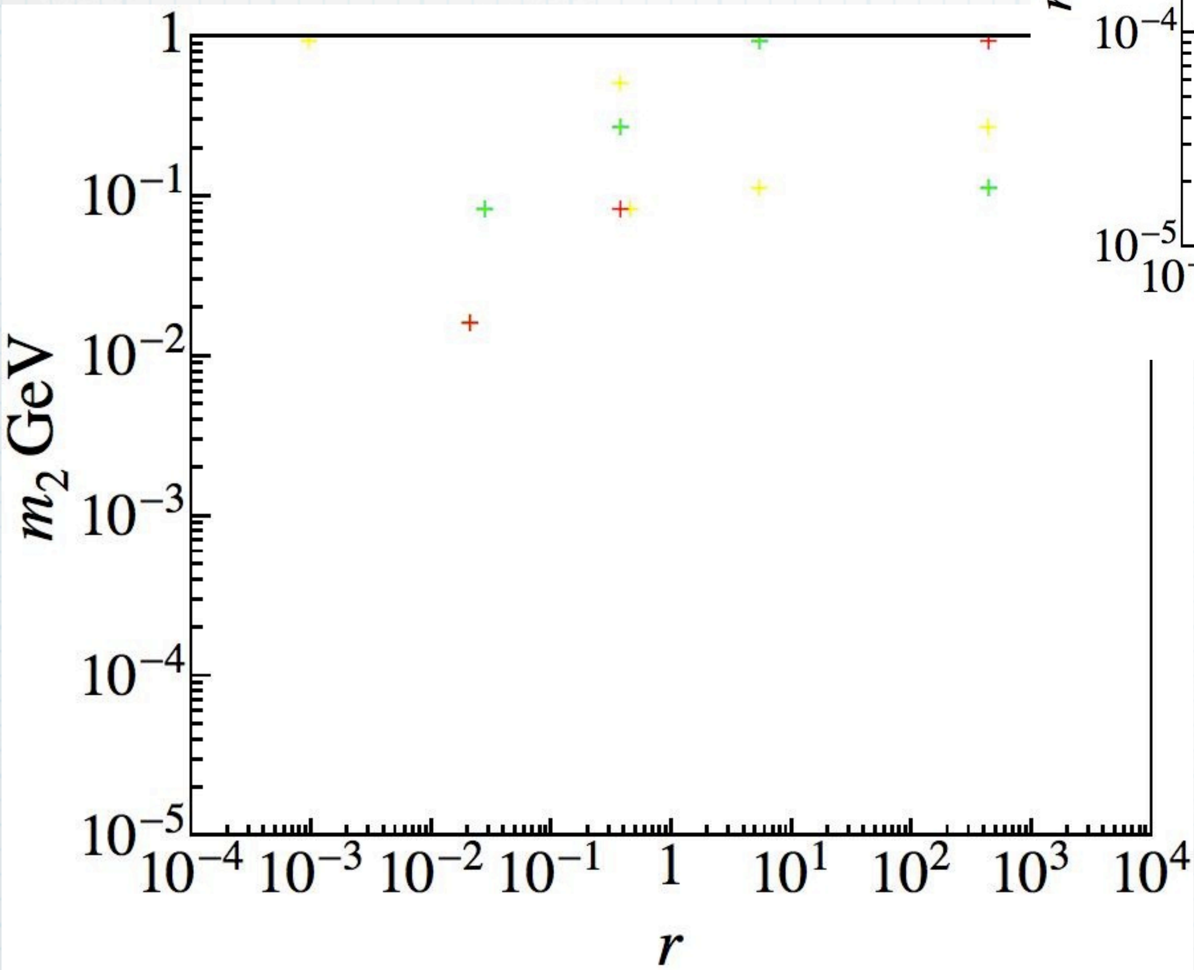




W decays

CP breaking (v e^(i a) ,v e^(-i a), r v)





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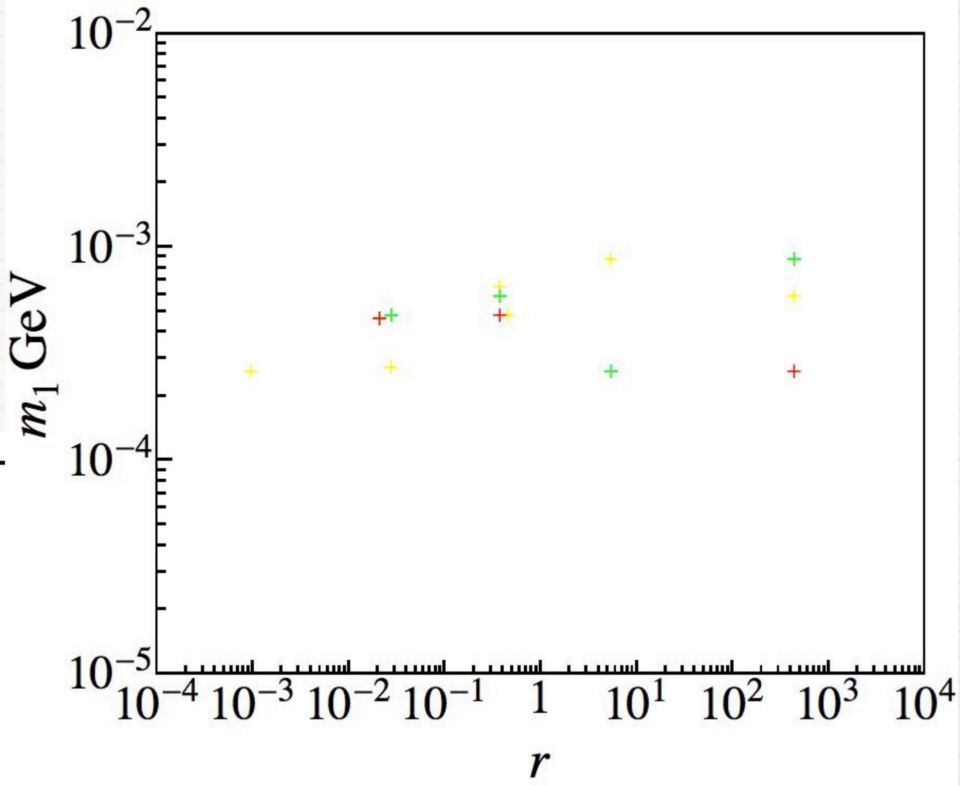
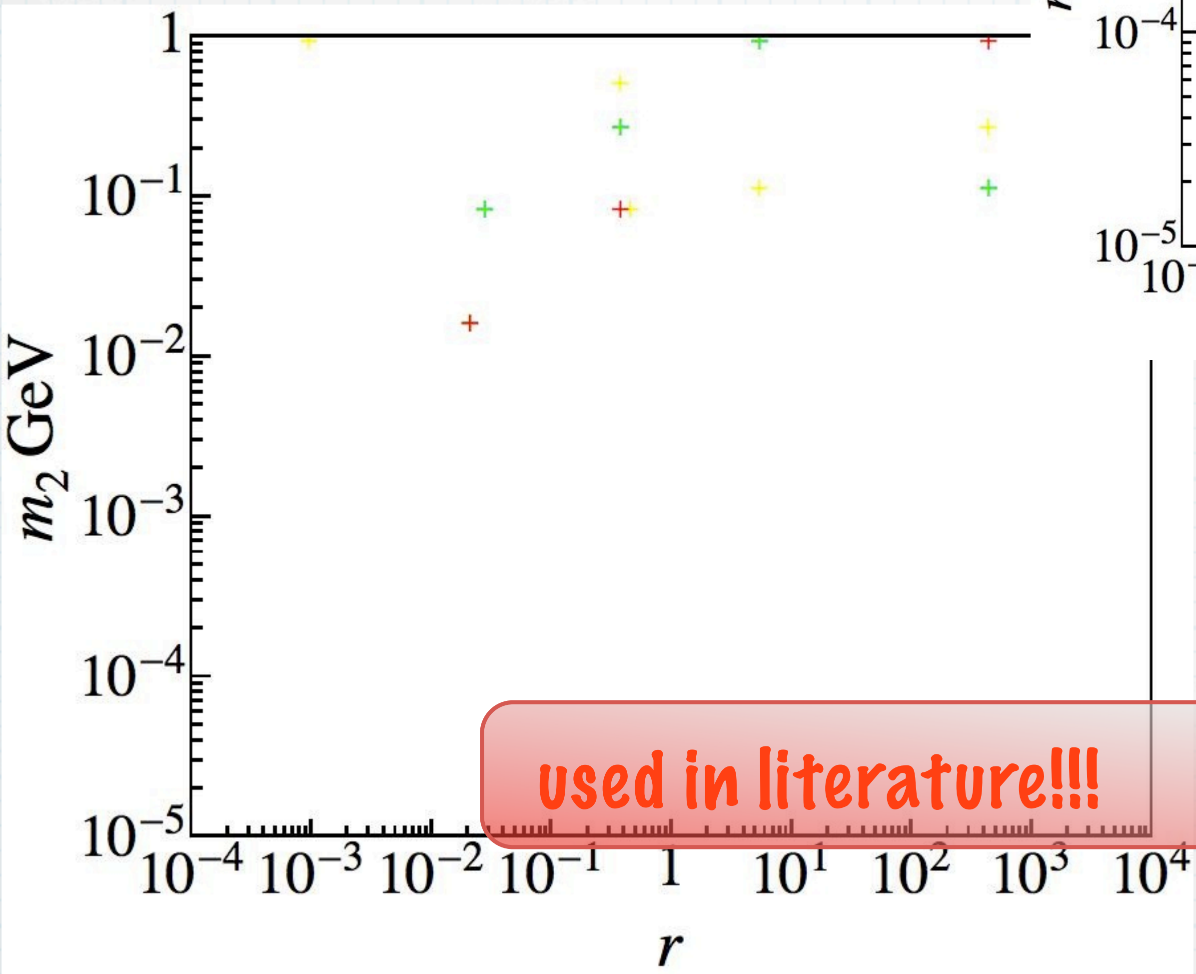
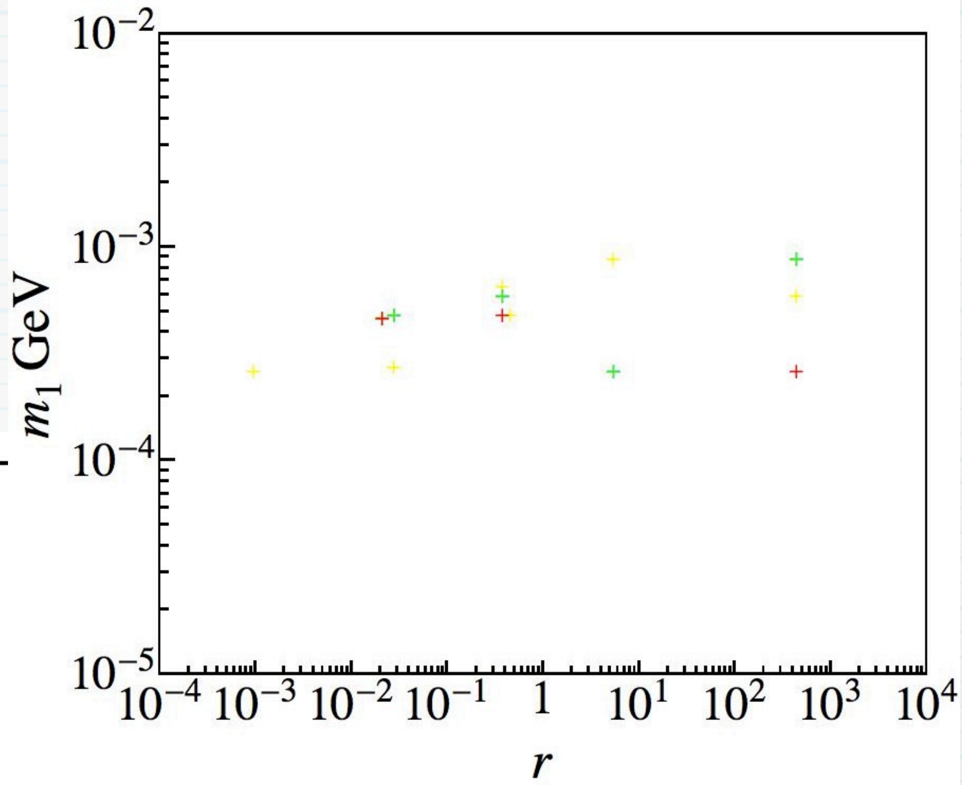
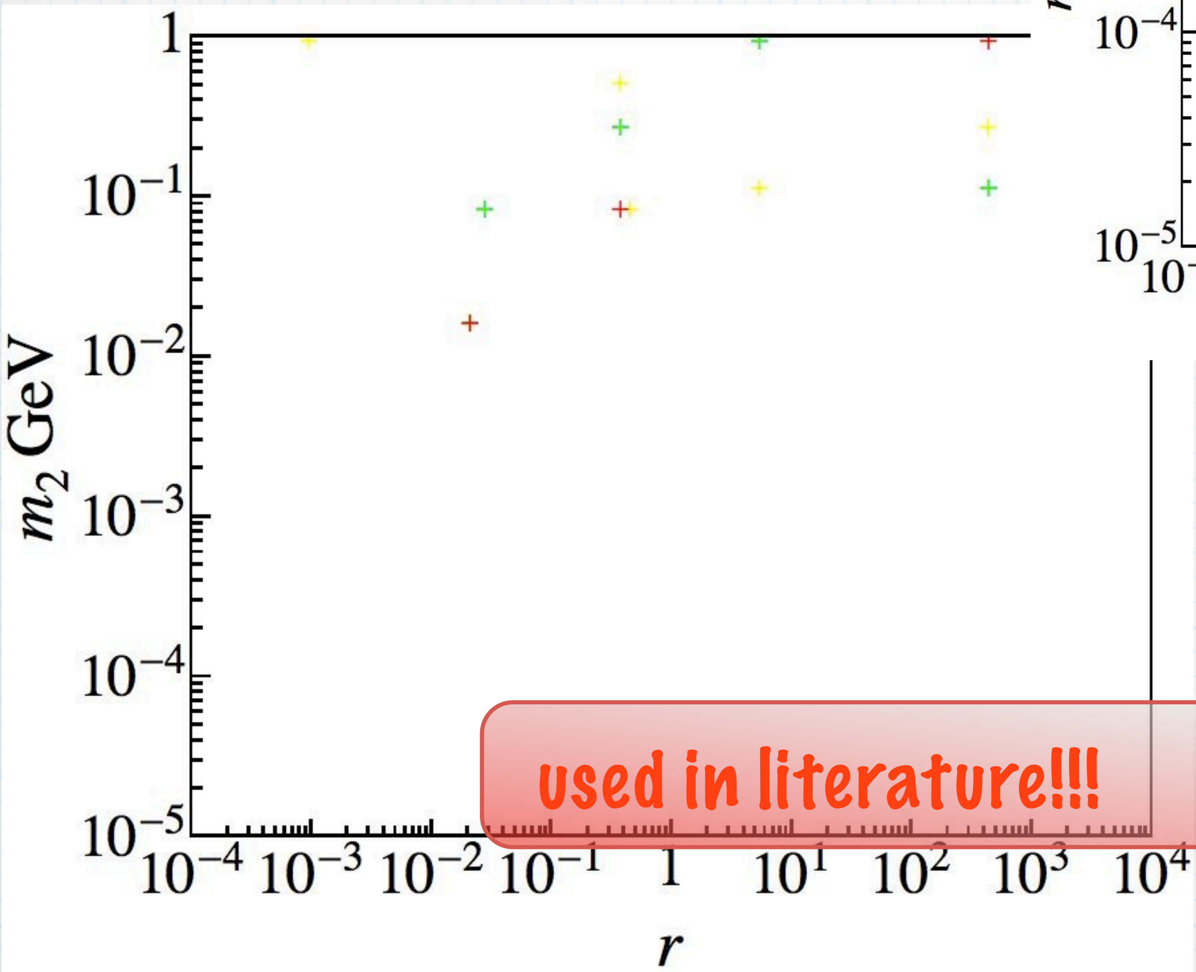




used in literature!!!

CP breaking (v e^(i a) ,v e^(-i a), r v)





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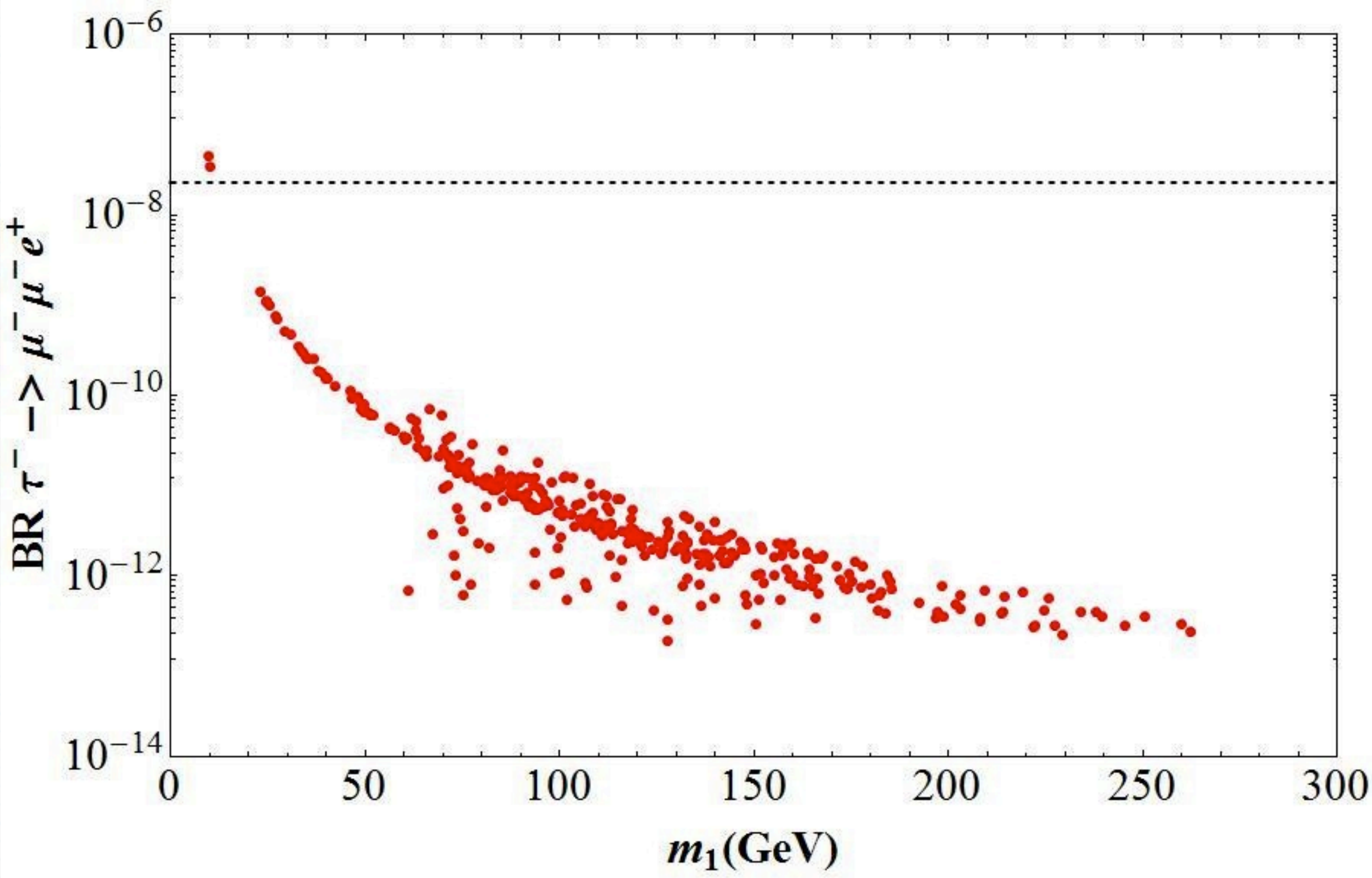
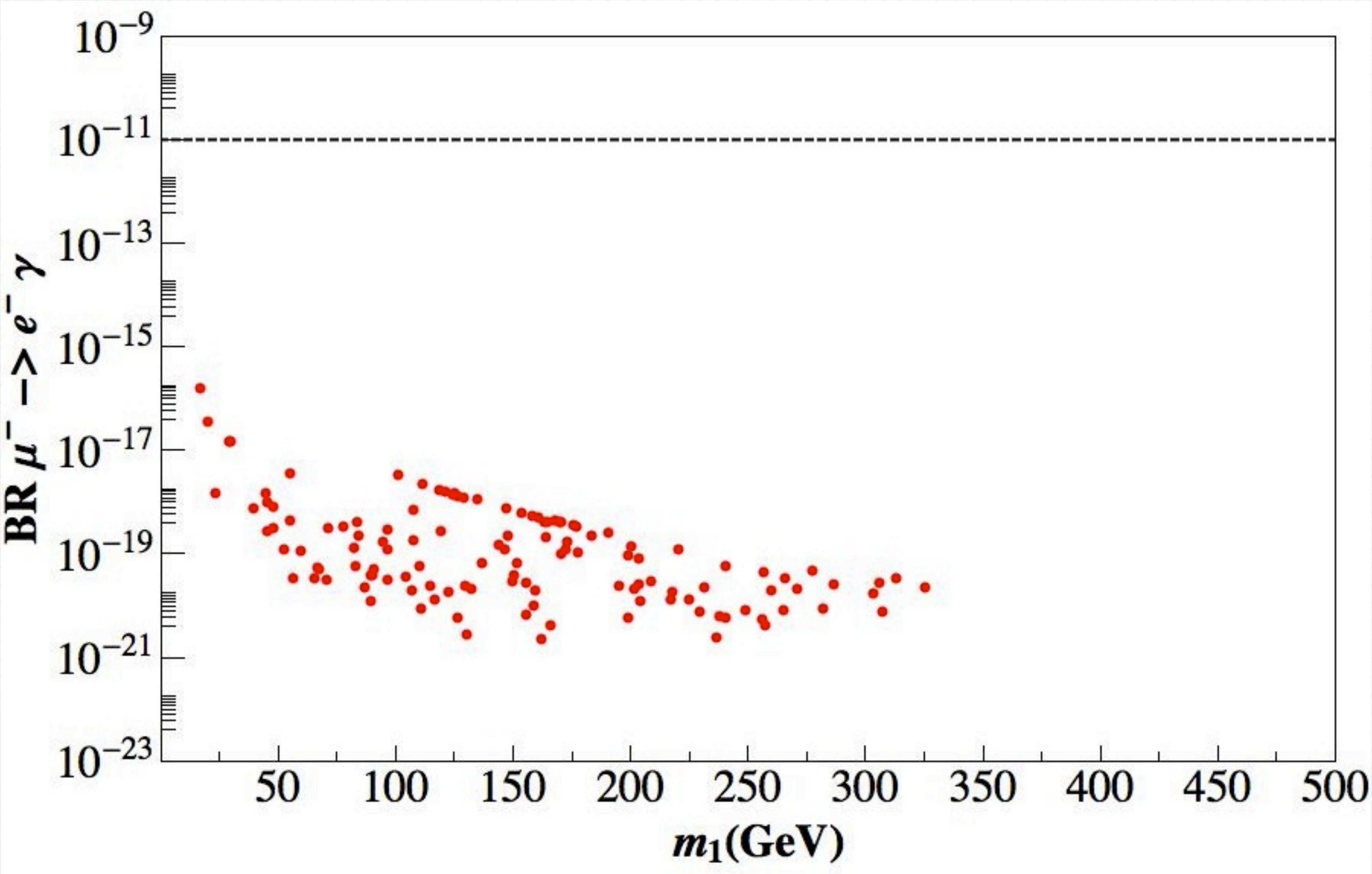
model may be saved by adding appropriate A4 soft terms

model dependent constraints

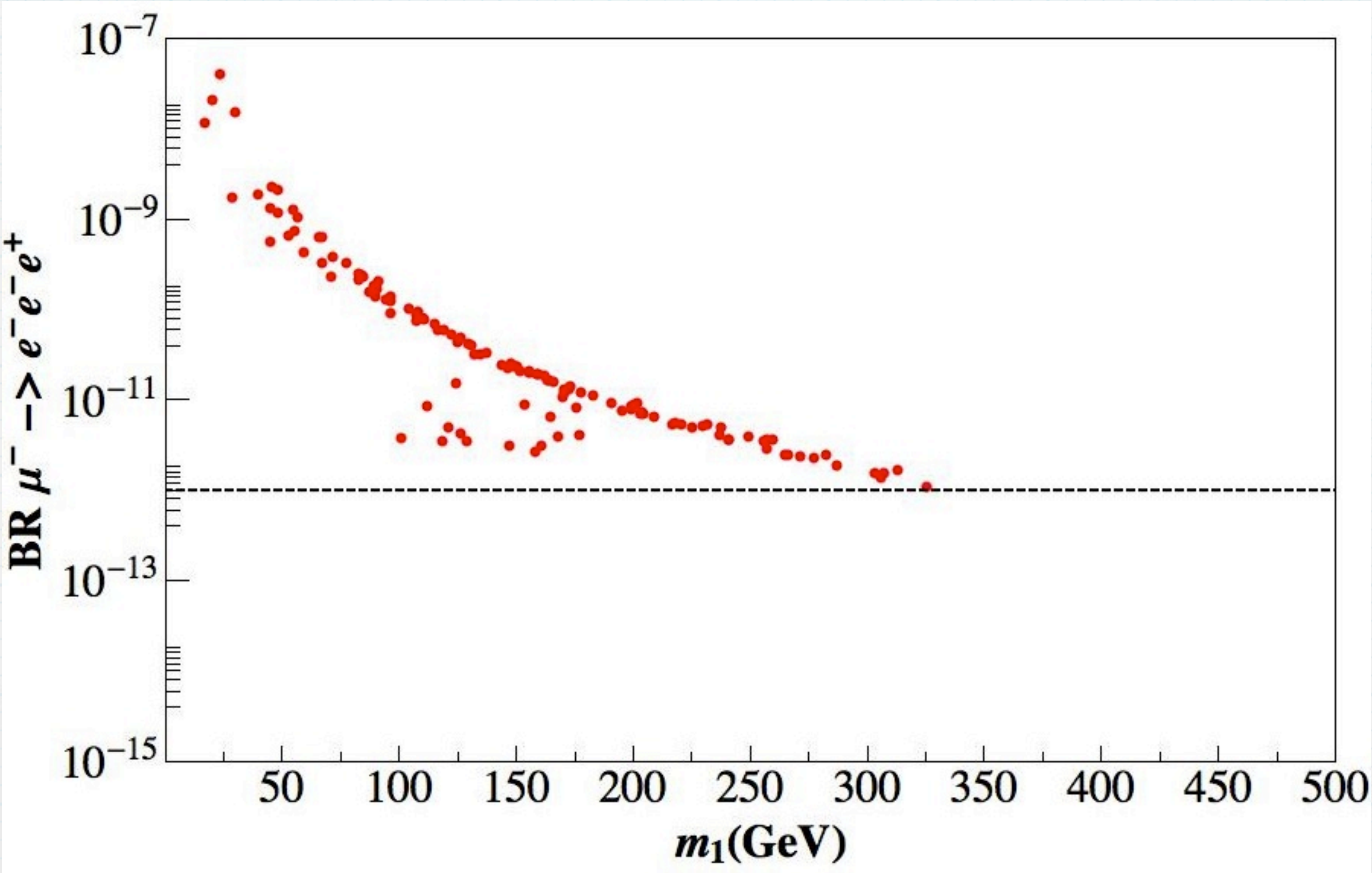
Ma-Rajasekaran



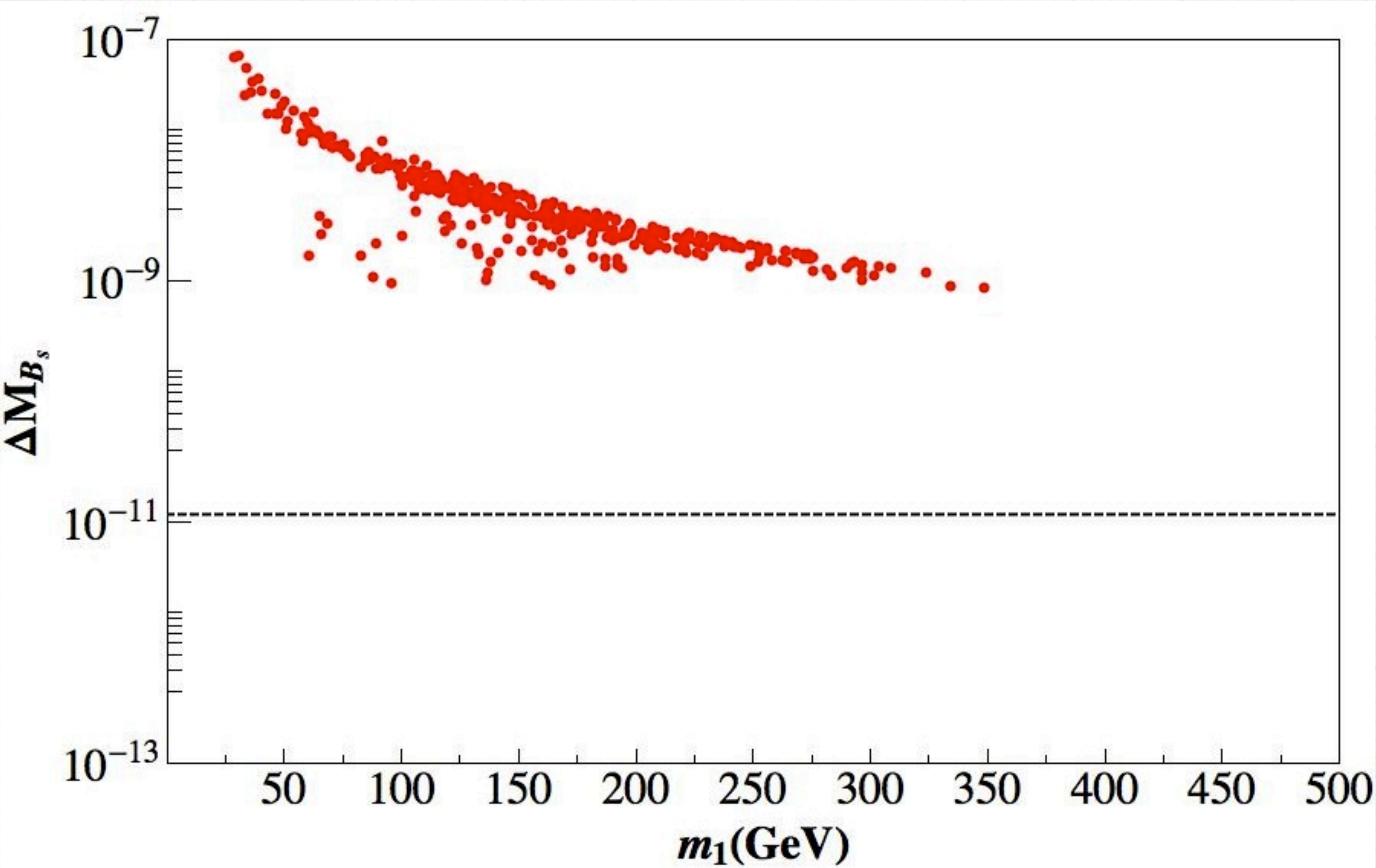
Morisi-Peinado



Morisi-Peinado



Lavoura-Kuhbock



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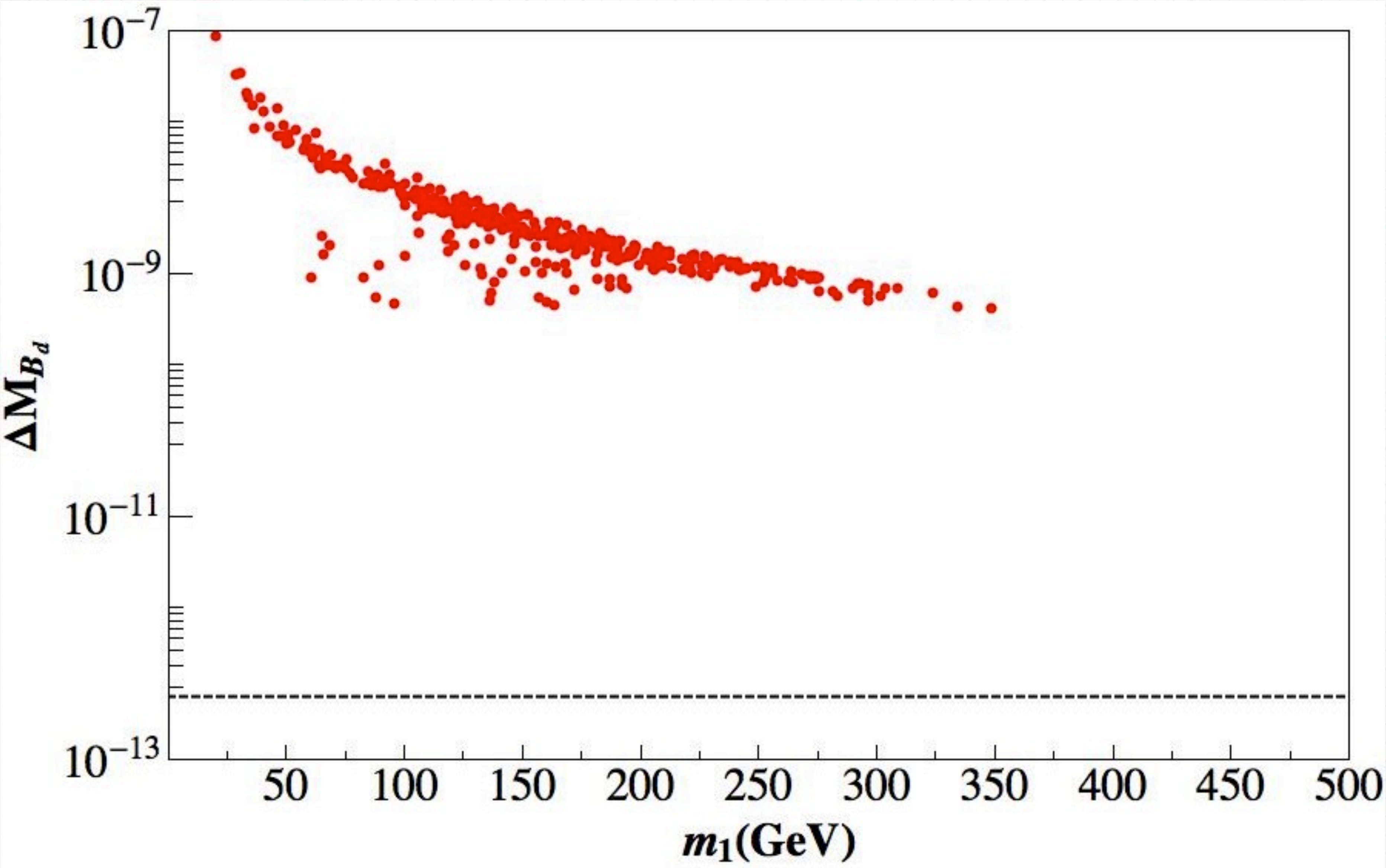
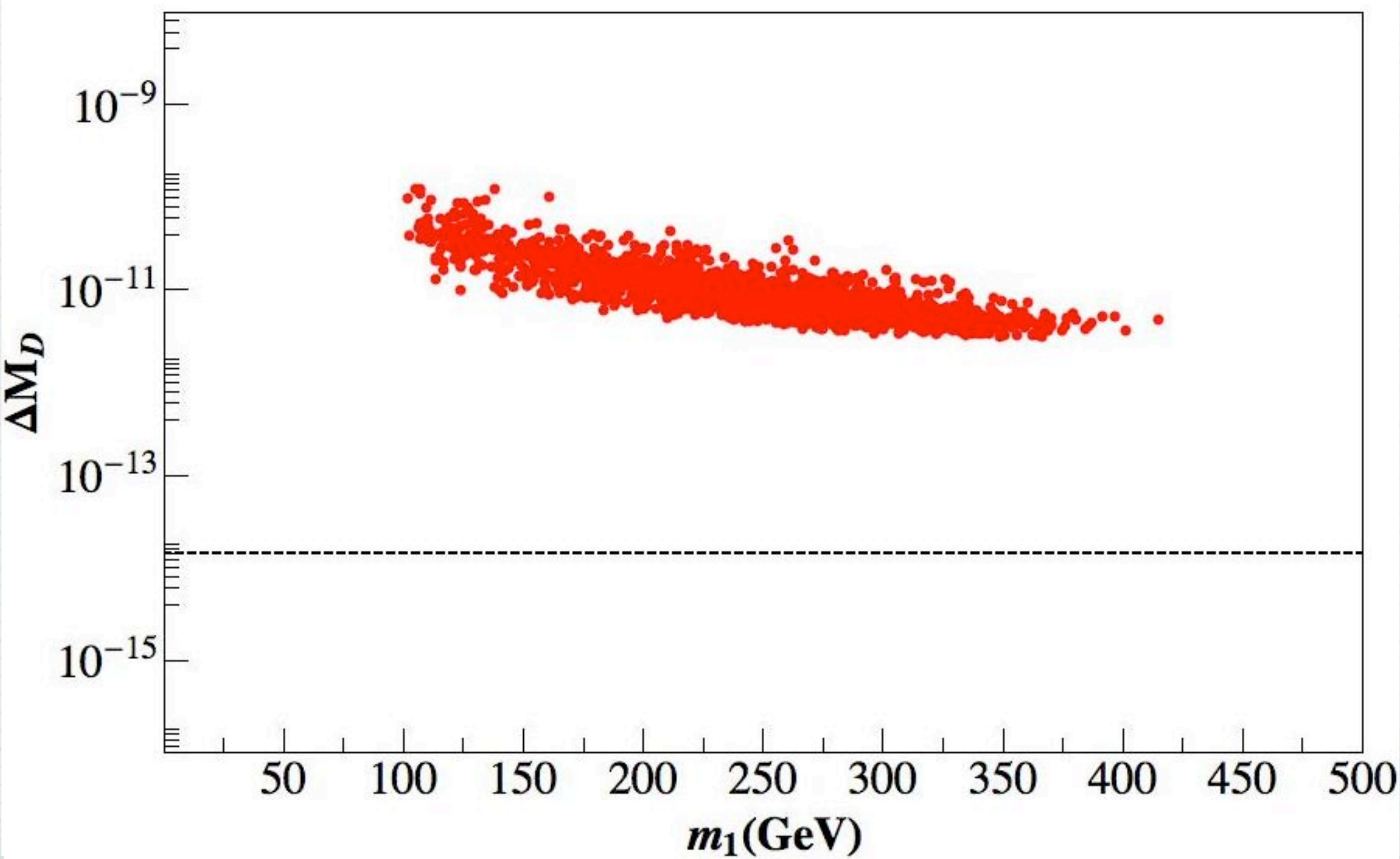
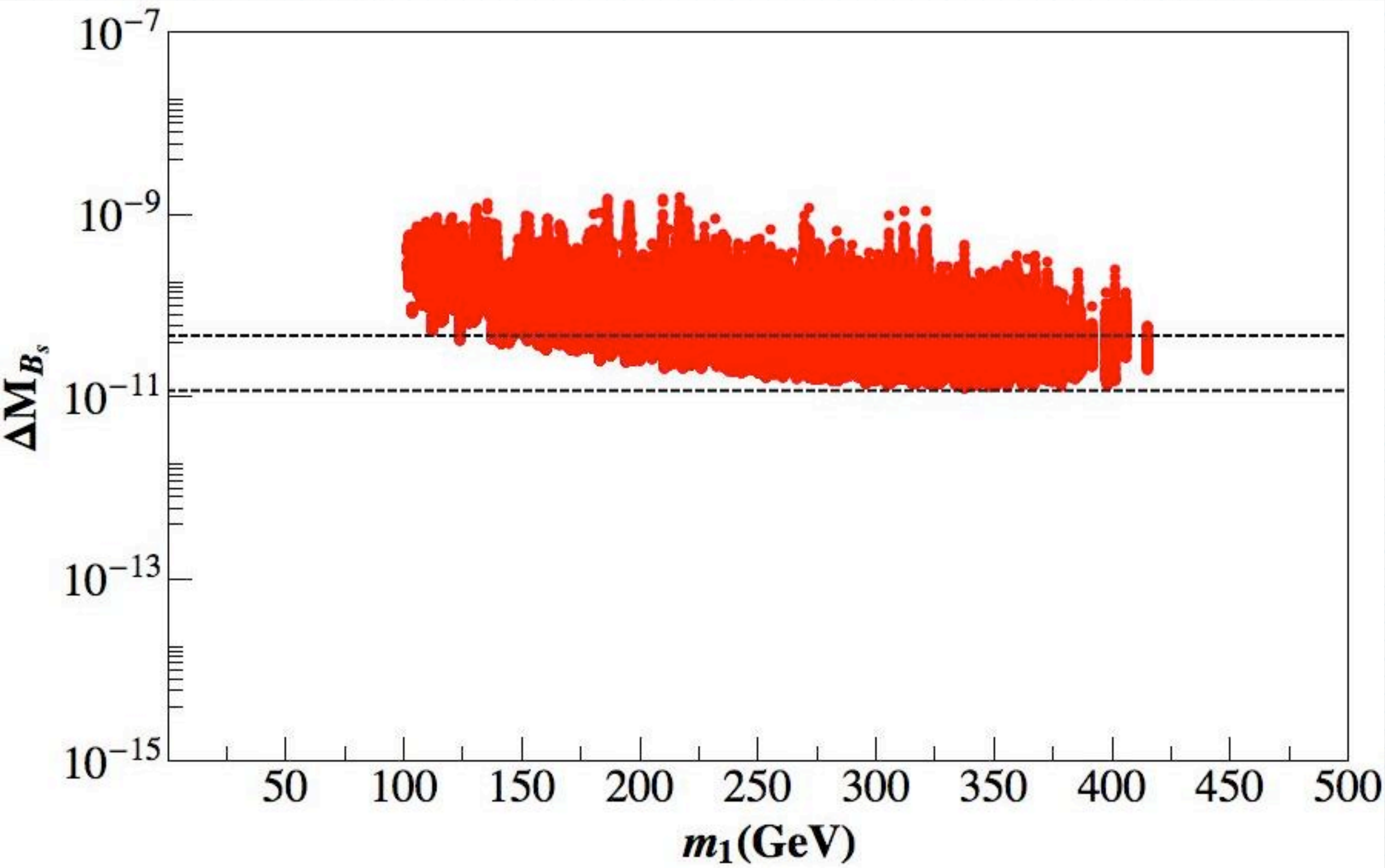


DDM extended to quarks R. de Adelhart Toorop, FB, S.Morisi 11045676



DDM extended to quarks R. de Adelhart Toorop, FB, S.Morisi 11045676



Conclusions

★ Charging the SM higgs under a discrete flavor symmetry (A4) is quite appealing

★ Models more phenomenological interesting, theta13 starts different from zero, but...

★More constrained!

★ Even with a model independent approach higgs-gauge bosons constraints may rule out configurations already used

★Bounds arising from the fermion sector are even stronger

★A lesson for model builders: good alignment for mass matrices maybe disfavored/ruled out by phenomenology

★ Not addressed in this talk: possible signatures at LHC, effects of CP violation arising by the vev alignments?

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Thanks!