

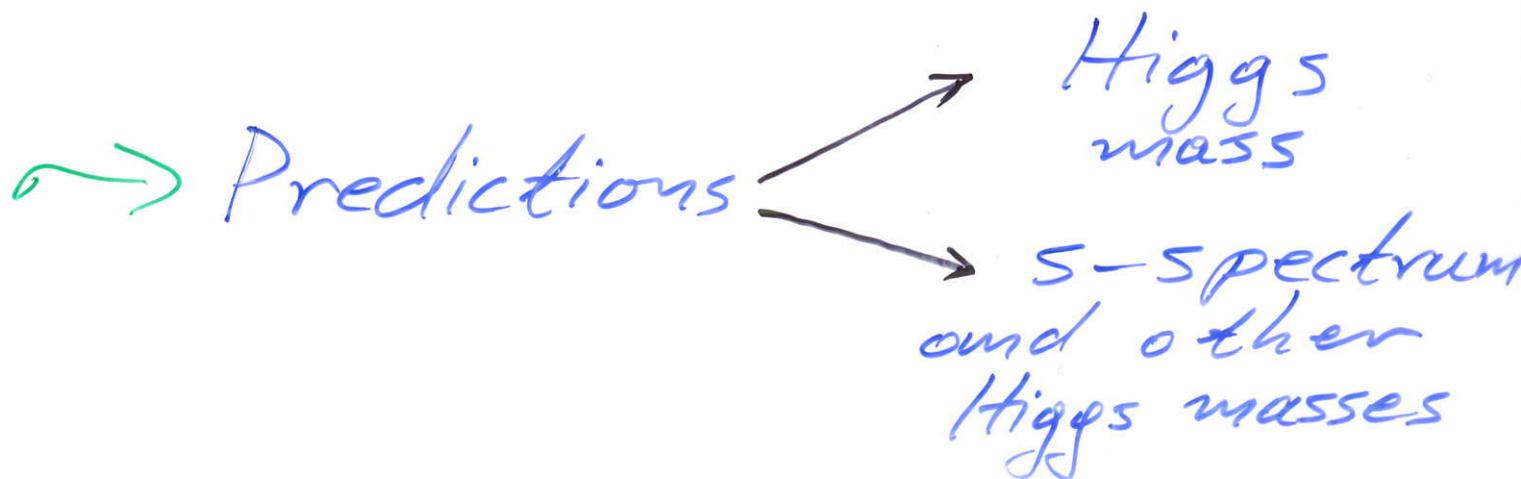
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Developments and further Challenges in Unified Theories

Quantum Reduction of Couplings in QFT

Applications

- Finite Unified Theories
- MSSM



After the discovery of the Higgs boson at the LHC, the Standard Model has been very successfully completed
→ low energy accessible part of a (more) fundamental Theory of Elementary Particle Physics.

However it contains

- ad hoc Higgs sector
- ad hoc Yukawa couplings
- ⇒ free parameters (> 20)

Renormalization programme
⇒ free parameters

Traditional way of reducing
the number of parameters

SYMMETRY

Celebrated example : GUTs

e.g. minimal $SU(5)$

testable
 $\sin^2 \theta_W$
successful
 m_T/m_b

However more SYMMETRY

(e.g. $SO(10)$, $E(6)$, $E(7)$, $E(8)$)

does not lead necessarily to
more predictions of the SM
parameters.

Extreme case : Superstring Ths

On the other hand

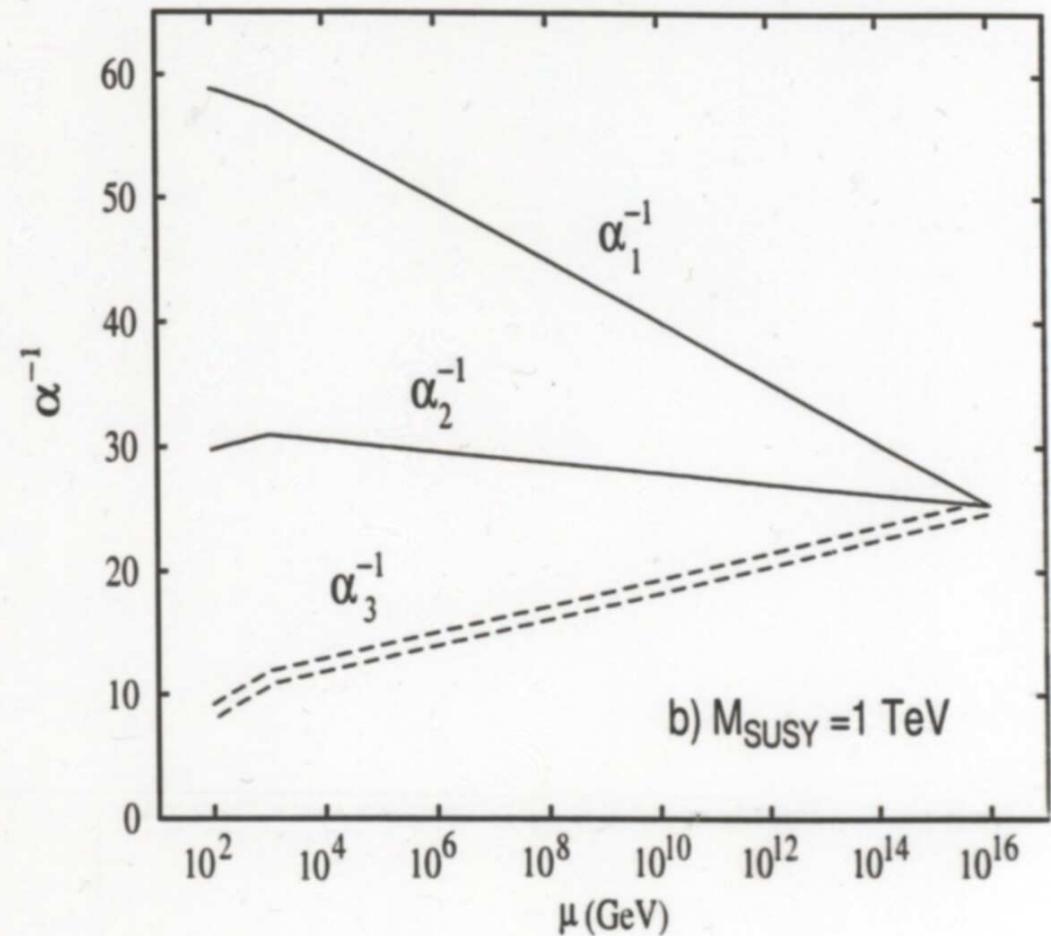
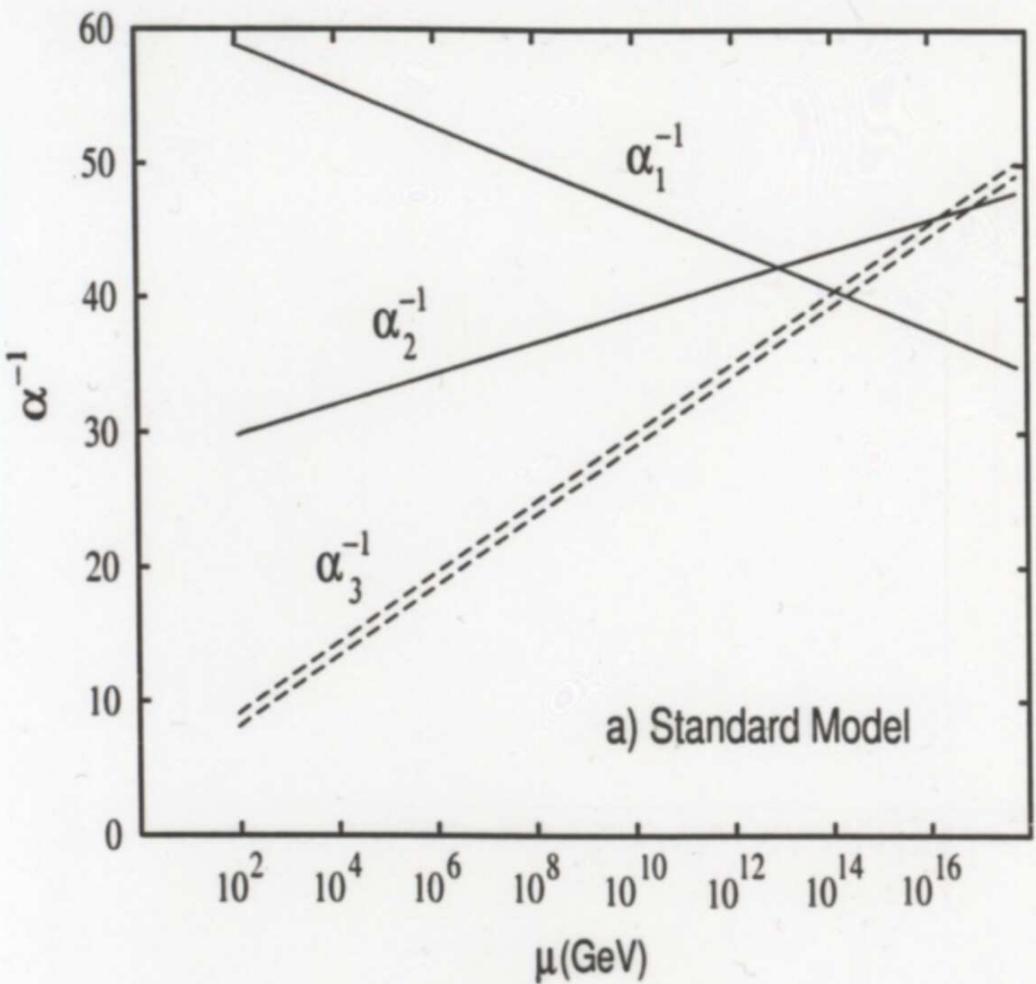
LEP data $\rightarrow N=1 \text{ SU}(5)$

~~$N=1 \text{ SU}(5)$~~ $\rightarrow \text{MSSM}$

MSSM best candidate for
Physics Beyond SM

But with $> 100!$ free parameters mostly in its SSB sector.

- Cures problem of quadratic divergencies of the SM (hierarchy problem)
- Restricts the Higgs sector leading to approximate prediction of the Higgs mass



Consider the SM with 2 Higgs doublets

$$\begin{aligned}
 V = & -\frac{1}{2} m_1^2 (H_1^+ H_1) - \frac{1}{2} m_2^2 (H_2^+ H_2) - \frac{1}{2} m_3^2 (H_1^+ H_2 + h.c.) \\
 & + \frac{1}{2} \lambda_1 (H_1^+ H_1) + \frac{1}{2} \lambda_2 (H_2^+ H_2)^2 \\
 & + \lambda_3 (H_1^+ H_1)(H_2^+ H_2) + \lambda_4 (H_1^+ H_2)(H_2^+ H_1) \\
 & + \left\{ \frac{1}{2} \lambda_5 (H_1 H_2)^2 + [\lambda_6 (H_1^+ H_1) + \lambda_7 (H_2^+ H_2)] (H_1^+ H_2) + h.c. \right\}
 \end{aligned}$$

Supersymmetry imposes tree level relations among couplings,

$$\lambda_1 = \lambda_2 = \frac{1}{4} (g^2 + g'^2)$$

$$\lambda_3 = \frac{1}{4} (g^2 - g'^2), \quad \lambda_4 = -\frac{1}{4} g^2$$

$$\lambda_5 = \lambda_6 = \lambda_7 = 0$$

With $v_1 = \langle \text{Re } H_1^\circ \rangle$, $v_2 = \langle \text{Re } H_2^\circ \rangle$

$$\text{and } v_1^2 + v_2^2 = (246 \text{ GeV})^2, \quad \frac{v_2}{v_1} = \tan \theta$$

$$\Rightarrow h^\circ, H^\circ, H^\pm, A^\circ$$

At tree level

$$M_{h^0, H^0}^2 = \frac{1}{2} \left\{ M_A^2 + M_Z^2 \mp \left[(M_A^2 + M_Z^2)^2 - 4 M_A^2 M_Z^2 \cos^2 2\theta \right]^{1/2} \right\}$$

$$M_{H^\pm}^2 = M_W^2 + M_A^2$$

$$\begin{cases} M_{h^0} < M_Z |\cos 2\theta| \\ M_{H^0} > M_Z \\ M_{H^\pm} > M_W \end{cases}$$

Radiative corrections

$$M_{h^0}^2 \simeq M_Z^2 \cos^2 2\theta + \frac{3 g^2 m_t^4}{16 \pi^2 M_W^2} \log \frac{\tilde{m}_{t_1}^2 \tilde{m}_{t_2}^2}{m_t^4}$$

- Finite Unified Theories
(from Quantum Reduction
of Couplings)
- Higher Dimensional Unified Theories
and Coset Space Dimensional
Reduction (Classical Reduction
of Couplings)
- Fuzzy Extra Dimensions
and Renormalizable Unified Theories

Quantum

Reduction of Couplings

Consider a GUT with

g - gauge coupling

g_i - other couplings (Yukawa, self-couplings)

Any relation among the couplings

$$\Phi(g, g_i, \dots) = \text{const}$$

which is RGI should satisfy

$$\frac{d}{dt} \Phi = 0, \quad \ell = \text{lyc}$$

$$\frac{d}{dt} \Phi = \frac{\partial \Phi}{\partial g} \frac{dg}{dt} + \sum_i \frac{\partial \Phi}{\partial g_i} \frac{dg_i}{dt} = 0$$

which is equivalent to

$$\frac{dg}{\ell_g} = \frac{dg_1}{\ell_1} = \frac{dg_2}{\ell_2} = \dots$$

characteristic
system

$$\Rightarrow \frac{dg}{d\bar{g}} \frac{d\bar{g}_i}{d\bar{g}} = \bar{g}_i \quad \begin{array}{l} \text{Reduction} \\ \text{eqs} \\ \text{Oehme} \\ \text{Zimmermann} \end{array}$$

Demand power series solution to the RE

$$\bar{g}_i = \sum_{n=0}^{\infty} p_i^{(n+1)} g^{2n+1}$$

Remarkably, uniqueness of these solutions can be decided already at 1-loop!

Assume

$$\bar{g}_i = \frac{1}{16\pi^2} \left[\sum_{j,k,l} \bar{g}_i^{(1)jkl} g_j g_k g_l + \sum_{i \neq j} \bar{g}_i^{(1)i} g_i g_j \right] +$$

$$g = \frac{1}{16\pi^2} \bar{g}_i^{(1)} g^3 + \dots$$

Assume $p_i^{(n)}$, $n \leq r$ have been uniquely determined

To obtain $p_i^{(r+1)}$, insert g_i in REs and collect terms of $O(g^{2r+1})$

$$\rightsquigarrow \sum_{\ell \neq g} M(r)_i^\ell p_e^{(r+1)} = \text{lower order quantities}$$

Known by assumption

where

$$M(r)_i^\ell = 3 \sum_{j, k \neq g} b_i^{(1)jk\ell} p_j^{(1)} p_k^{(1)} + b_i^{(1)\ell} - (2r+1) b_g^{(1)\ell} p_i^{(1)}$$

$$0 = \sum_{j, k, \ell \neq g} b_i^{(1)jk\ell} p_j^{(1)} p_k^{(1)} p_\ell^{(1)} + \sum_{\ell \neq g} b_i^{(1)\ell} p_\ell^{(1)} - b_g^{(1)} p_i^{(1)}$$

\Rightarrow for a given set of $p_i^{(1)}$, the

$p_i^{(n)}$ for all $n > 1$ can be uniquely determined if

$$\det M(n)_i^\ell \neq 0$$

for all n

Consider an $SU(N)$ (non-susy) theory with

$\phi^i(n), \hat{\phi}_i(\bar{n})$ - complex scalars

$\psi^i(n), \hat{\psi}_i(\bar{n})$ - Weyl spinors

$\gamma^\alpha (\alpha = 1, \dots, N^2 - 1)$ - "

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^\alpha F^{\alpha\mu\nu} + i\sqrt{2} [g_Y \bar{\psi}_j \gamma^\alpha T^\alpha \phi - g_Y \bar{\psi}_j \gamma^\alpha T^\alpha \hat{\phi}] + h.c. - V(\phi, \hat{\phi}),$$

$$\begin{aligned} V(\phi, \hat{\phi}) = & \frac{1}{4} J_1 (\phi^i \phi_i^*)^2 + \frac{1}{4} J_2 (\hat{\phi}_i \hat{\phi}_i^*)^2 \\ & + J_3 (\phi^i \phi_i^*) (\hat{\phi}_j \hat{\phi}_j^*) \\ & + J_4 (\phi^i \phi_j^*) (\hat{\phi}_i \hat{\phi}_j^*) \end{aligned}$$

Searching for power series solution of the R.E.s we find

$$g_Y = \bar{g}_Y = g; J_1 = J_2 = \frac{N-1}{N} g^2; J_3 = \frac{1}{2N} g^2; J_4 = -\frac{1}{2} g^2$$

i.e. SUSY

$N=1$ gauge theories

Consider a chiral, anomaly free, $N=1$ globally supersymmetric gauge th. based on a group G with gauge coupling g .

Superpotential

$$W = \frac{1}{2} m_{ij} \phi^i \phi^j + \frac{1}{6} C_{ijk} \phi^i \phi^j \phi^k$$

m_{ij} , C_{ijk} - gauge invariant tensors
 ϕ^i - matter fields transforming as an ir. rep. R_i of G .

Renormalization constants associated with W

$$\phi^{oi} = (Z_j^i)^{1/2} \phi^i, m_{ij}^o = Z_{ij}^{i'j'} m_{i'j'}, C_{ijk}^o = Z_{ijk}^{ijk} C_{i'j'k'}$$

$N=1$ non-renormalization theorem ensures absence of mass and cubic-int-term infinities

$$Z_{i''j''k''}^{ijk} Z_{i''}^{1/2 i'} Z_{j''}^{1/2 j'} Z_{k''}^{1/2 k'} = \delta_{(i''}^i \delta_{j''}^j \delta_{k''}^k$$

$$Z_{i''j''}^{ij} Z_{i''}^{1/2 i'} Z_{j''}^{1/2 j'} = \delta_{(i''}^i \delta_{j''}^j$$

(\mapsto the background field method)

$$Z_g Z_V^{1/2} = 1$$

\mapsto Only surviving infinities are $Z_{ij}^i (Z_V)$
i.e. one infinity for each field.

The 1-loop β -function of the gauge coupling is

$$\beta_g^{(1)} = \frac{dg}{dt} = \frac{g^3}{16\pi^2} \left[\sum_i l(R_i) - 3C_2(G) \right]$$

$l(R_i)$ - Dynkin index of R_i

$C_2(G)$ - quadratic Casimir of the adjoint rep.

β -functions of C_{ijk} , by virtue of the non-renormalization thm, are related with the anomalous dim. matrix γ_{ij}^k of ϕ^i

$$\beta_{ijk}^{(1)} = \frac{dC_{ijk}}{dt} = C_{ije} \gamma_k^e + C_{ike} \gamma_j^e + C_{jke} \gamma_i^e$$

$$\gamma_i^{(1)j} = z^{-\frac{1}{2}}{}_i^k \frac{d}{dt} z^{\frac{1}{2}}{}_k^j$$

$$= \frac{1}{32\pi^2} [C^{ske} C_{ike} - 2g^2 C_2(R_i) \delta_i^s]$$

$C_2(R_i)$ - quadratic Casimir of R_i

$$C^{ijk} = C^{*ijk}$$

$$f_g^{(2)} = \frac{1}{(16\pi^2)^2} 2g^5 \left[\sum_i \ell(R_i) - 3C_2(G) \right]$$

$$- \frac{1}{(16\pi^2)^2} \frac{g^3}{r} C_2(R_i) \left[C^{ijk\ell} (C_{ijk\ell} - 2g^2 C_2(R_i) \delta_{ij}^k) \right]$$

$$r : \text{tr} \delta^{ab}$$

Parkes, West, Jones
 Mezincescu, Yau
 Machacek, Vaughan

$$\gamma^{(2)i}_j = \frac{1}{(16\pi^2)^2} 2g^4 C_2(R_i) \left[\sum_i \ell(R_i) - 3C_2(G) \right]$$

$$- \frac{1}{(16\pi^2)^2} \frac{1}{2} \left[C^{ik\ell} (C_{jikm} + 2g^2 (R^a)_m^i (R^a)_j^\ell) \right]$$

$$\cdot \left[C^{mpq} (C_{elpq} - 2\delta_e^m g^2 C_2(R_i)) \right]$$

$$f_g^{NSVZ} = \frac{g^3}{16\pi^2} \left[\frac{\sum_i \ell(R_i) (1 - 2\gamma_i) - 3C_2(G)}{1 - g^2 C_2(G)/8\pi^2} \right]$$

Norikov - Shifman - Vainshtein - Zakharov

MSSM

Traces
2

$$W = Y_e Q H_2 e^c + Y_b Q H_1 b^c$$

$$+ Y_\tau L H_1 \tau^c + \mu H_1 H_2$$

The REs for the top, bottom and tau couplings,

$$\frac{d d_{e,b,\tau}}{d \alpha_3} = \frac{6 e_{e,b,\tau}}{6_3}$$

assuming perturbative expansion of the Yukawas in favour of α_3

$$d_e = c_1 \alpha_3 + c_2 \alpha_3^2 + \dots$$

$$d_b = p_1 \alpha_3 + p_2 \alpha_3^2 + \dots$$

$$d_\tau = o_1 \alpha_3 + o_2 \alpha_3^2 + \dots$$

(which being RGI hold at MGUT where $\alpha_3 = \alpha_2 = \alpha_1$)

have solutions with

$$c_1 \approx 0.892, c_2 \approx \frac{1}{4\pi} 2.42$$

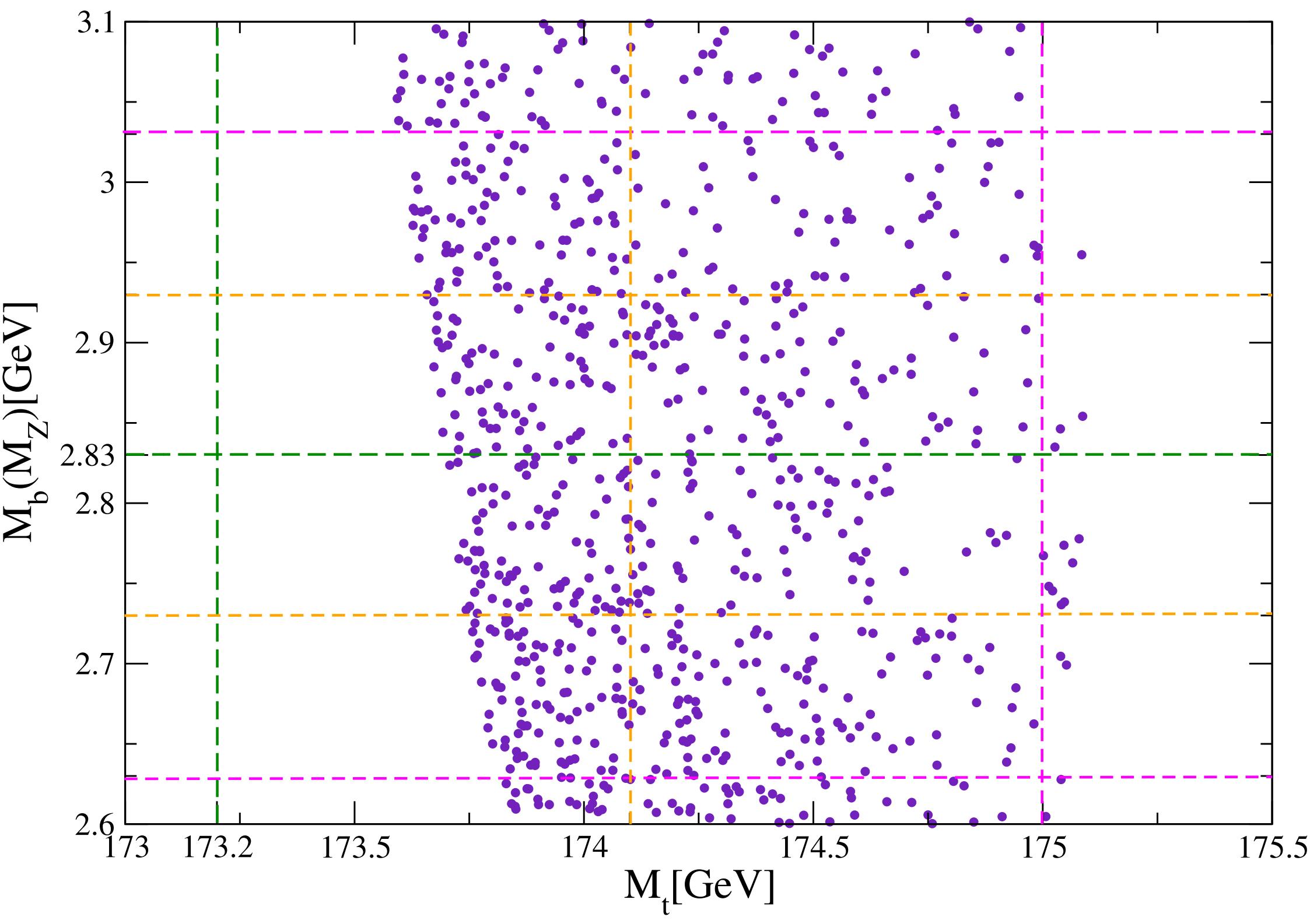
$$p_1 \approx 0.849, p_2 \approx \frac{1}{4\pi} 2.54$$

$$\theta_1 \approx -0.187, \theta_2 \approx -\frac{1}{4\pi} 1.46$$

Therefore $\alpha_t, \alpha_b, \alpha_s$ can be reduced, while α_r cannot and is left as a free parameter.

New observations

The $\alpha_t, \alpha_b, \alpha_s$ are not only reduced but they predict correctly the experimental values!



Finite Unification

Old days...

... divergences are "hidden under the carpet" (Dirac, Lects on Q.F.T., '84)

Recent years ...

... divergences reflect existence of a higher scale where new degrees of freedom are excited.

Not just artifacts of pert. th.

However the presence of quadratic divergences means that physics at one scale are very sensitive to unknown physics at higher scales.

⇒ SUSY theories which are free of quadratic divergences in spite of any experimental evidence...

⇒ Natural to expect that beyond unification scale the theory should be completely finite.

- $N=4 \Rightarrow$ finite to all orders in pert.
- $N=2 \Rightarrow$ only 1-loop contributions to β -function. Possible to arrange the spectrum so that theory is finite.

Multiplicities for massless irreducible reps with maximal helicity 1

$\frac{N}{\text{Spin}}$	1	1	2	2	4
1	-	1	-	1	1
$\frac{1}{2}$	1	1	2	2	4
0	2	-	4	2	6

$$N=2 : \mathcal{B}(g) = \frac{2g^3}{(4\pi)^2} \left(\sum_i T(Q_i) - C_2(G) \right)$$

e.g. $SU(N)$ with $2N$ fundamental
reps $\rightarrow \mathcal{B}(g) = 0$

$SU(5)$: $p(5 + \bar{5})$; $q(10 + \bar{10})$; $r(15 + \bar{15})$
with $p + 3q + 7r = 10$

$SO(10)$: $p(10 + \bar{10})$; $q(16 + \bar{16})$
with $p + 2q = 8$

E_6 : $4(27 + \bar{27})$

Finite Unified Theories

$N=1$

- 1-loop finiteness conditions

$$B_g^{(1)} = 0$$

$\gamma^{(1)i}{}_j = 0$ - anomalous dimensions
of all chiral superfields

- Exists complete classification
of all chiral $N=1$ models with
 $B_g^{(1)} = 0$
Hamidi - Patera - Schwarz
Jiang - Zhou

- 1-loop finiteness Parkes - West
Jones
- \rightarrow 2-loop finiteness Mezincescu

.... Exist simple criteria
that guarantee all
loop finiteness
(vanishing of all-loop
beta functions)

Lucchesi-Piquet
Sibold

Ermushov
Kazakov
Tarasov

Leigh-Susskind

- All-loop finite $SU(5)$ \Rightarrow top quark mass ✓

Kapetanakis
Mondragon
Z
>92

~~~~~

~~Susy~~ sector

Jones  
Mezincescu  
Yao

- 1-loop finiteness cond  
(require in particular  
universal soft ~~susy~~  
scalar masses)

$$(m^2)_j^i = \frac{1}{3} MN^* \delta_j^i )$$

.. 1-loop finiteness

Jack  
Jones

→ 2-loop finiteness

### Reduction of couplings

• Extension of method in SSB sector

+ application in min susy  $SU(5)$  Kubo  
Mondragon<sub>2</sub>

.. 1-loop sum rule for soft scalar masses in non-finite susy ths. Kawamura  
Kobayashi  
Kubo

... 2-loop sum rule for soft scalar masses in finite ths. Kubo  
Mondragon<sub>2</sub>

\* All-loop RGI relations in finite and non-finite ths Yamada  
Hisano,  
Shifman  
Kazakov  
Jack, Jones,  
Pickering

\*\* All-loop sum rule for  
soft scalar masses in finite <sup>Kobayashi</sup>  
and non-finite ths <sup>Kubo</sup> <sup>Z</sup>

• • SU(5) FUTs <sup>Kobayashi</sup>  
<sup>Kubo</sup> <sup>Mondragon</sup>

• Prediction of s-spectrum in  
terms of few parameters starting  
from several hundreds GeV.

• The LSP is neutralino ✓ <sup>(see e.g.  
Kazakov  
et. al.  
Yoshioka)</sup>

• Radiative E-W breaking ✓ <sup>(see e.g.  
Brignole  
Ibanez, Munoz)</sup>

• No funny colour, charge ✓ <sup>(see e.g.  
Casas et.al)</sup>

\* Prediction of Higgs masses

Lightest  $\sim 118 - 129$  GeV

Similar results also for min susy SU(5)

Consider a chiral, anomaly free,  $N=1$  gauge theory with group  $G$ .  
 The superpotential is

$$W = \frac{1}{6} Y^{ijk} \bar{\Phi}_i \bar{\Phi}_j \bar{\Phi}_k + \frac{1}{2} \mu^{ij} \bar{\Phi}_i \bar{\Phi}_j$$

$Y^{ijk}$  } gauge invariant  
 $\mu^{ij}$  } Yukawa couplings

$\bar{\Phi}_i$  - matter superfields  
 in irreducible reps of  $G$

Necessary and sufficient conditions  
 for  $N=1$  1-loop finiteness

- Vanishing of  $6g^{(1)}$  implies

$$\sum_i l(R_i) = 3 C_2(G) \quad ||$$

$l(R_i)$  - Dynkin index of  $R_i$

$C_2(G)$  - Quadratic Casimir of  $G$  (adjoint)

$\Rightarrow$  Selection of the field content  
 (representations) of the theory

• • Vanishing of  $\gamma^{(1)i}_{ij}$  implies

$$Y^{i\kappa\ell} Y_{j\kappa\ell} = 2 \delta^i_j g^2 C_2(R_i) //$$

↑                                           ↑  
Yukawa                                      gauge

$C_2(R_i)$  - quadratic Casimir of  $R_i$

$$Y_{ijk} = (Y_{ijk})^*$$

⇒ Yukawa and gauge couplings  
are related.

Note •  $\mu^{ij}$  are not restricted

• Appearance of  $U(1)$  is incompatible  
with 1<sup>st</sup> cond.

... 2<sup>nd</sup> cond forbids the presence of  
singlets with nonvanishing couplings.

∴ ⇒ ~~Susy~~ by G-invariant  
soft terms

\* 1-loop finiteness condts necessary  
and sufficient to guarantee 2-loop finiteness

\* 1-loop finiteness condts ensure that  
 $\mathcal{G}_g^{(3)}$  in 3-loops vanishes but in general  
 $\gamma^{(3)}$  does not.

Grisaru - Milewski - Zanon  
Parke - West

What happens in higher loops?

So far 1-loop finiteness  
condts (on  $\gamma_s$ ) are telling us

$$Y^{ijk} = Y^{ijk}(g)$$

$$\mathcal{G}_Y^{(1)ijk} = 0$$

\* \* Necessary and sufficient condts  
for vanishing  $b_g$  and  $b_{ijk}$  to all  
orders

$$1. \quad b_g^{(1)} = 0$$

$$2. \quad g^{(1)i} = 0$$

$$3. \quad b_Y^{ijk} = b_g \frac{d Y^{ijk}}{d g}$$

Lucchesi  
Piquet  
Sibold

admit power series solutions which  
in lowest order is a solution of  
condt 2.

- 3'. There exist solutions to  $g^{(1)i} = 0$   
of the form
- $$Y^{ijk} = \rho^{ijk} g, \quad \rho^{ijk} - \text{complex}$$
3. →
4. These solutions are isolated  
and non-degenerate considered  
as solutions of  $b_Y^{(1)ijk} = 0$

Recall

R-invariance, axial anomaly

In massless  $N=1$  this

$U(1)$  chiral transformation  $\mathcal{R}$ :

$$A_\mu \rightarrow A_\mu , \gamma \rightarrow e^{-i\alpha} \gamma ,$$

$$\phi \rightarrow e^{-i\frac{2}{3}\alpha} \phi , \psi \rightarrow e^{i\frac{1}{3}\alpha} \psi , \dots$$

$$\psi_D = \begin{pmatrix} \psi \\ \chi \end{pmatrix} \rightarrow e^{i\alpha \gamma_5} \psi_D$$

Noether current  $J_R^\mu = \bar{\chi}_D \gamma^\mu \gamma^5 \chi_D + \dots$

$$\leadsto \partial_\mu J_R^\mu = r (\epsilon^{\mu\nu\rho\sigma} F_{\mu\nu} F_{\rho\sigma} + \dots)$$

$$r = B_g^{(1)} !$$

Only 1-loop contributions  
due to non-renormalization thm.

Adler, Bardeen, Jackiw, Pi, Shei, Zee

## Supercurrent

$$J = \left\{ J_R^{\mu}, Q_{\alpha}^{\mu}, T^{\mu}_{\nu} \right\}, \quad \begin{array}{l} \text{vector} \\ \text{super} \\ \text{multiplet} \end{array}$$

associated to R-invariance    associated to susy    associated to translation inv.

Ferrara + Zumino

(supercurrent is represented as vector superfield)

$$V_{\mu}(x, \theta, \bar{\theta}) = Q_{\mu}(x) - i \theta^{\alpha} Q_{\alpha\dot{\mu}}(x) + i \bar{\theta}_{\dot{\alpha}} \bar{Q}_{\mu}^{\dot{\alpha}}(x) - 2(\theta \sigma^{\nu} \bar{\theta}) T_{\mu\nu}(x) + \dots$$

- $J_R^{\mu} \neq \bar{J}_R^{\mu}$

- $J_R^{\mu} = \bar{J}_R^{\mu} + O(t)$

In addition

$$S = \left\{ b_g F^{\mu\nu} F_{\mu\nu} + \dots, b_g \epsilon^{\mu\nu\rho\sigma} F_{\mu\nu} F_{\rho\sigma} + \dots, b_g \bar{J}^{\beta} G_{\alpha\beta} F_{\mu\nu} + \dots, \dots \right\}$$

Clan K  
Piquet  
Sibold

Super trace anomaly of  $T^{\mu}_{\nu}$       anomaly of R-current

trace anomaly of susy current

There is a relation, whose structure is independent from the renormalization scheme, although individual coefficients (except the 1-loop values of b-functions) may be scheme dependent

$$r = \beta_g (1 + x_g) + \beta_{ijk} x^{ijk} - \delta_A r^A$$

radiative corrections

unrenormalized  
coefficients of anomalies  
associated to chiral inv.  
of superpotential

linear combinations  
of anomalous dims

Thm: If (i) no gauge anomaly

(ii)  $\beta''_g(g) = 0$  i.e. no R-current anomaly

(iii)  $\gamma^{(1)i} = 0$  implies also  $r^A = 0$

(iv) exist solutions to  $\gamma^{(1)} = 0$  of the form  $\beta_{ijk} = p_{ijk} g$ ,  $p_{ijk}$  - complex

(v) these solutions are isolated + non-degenerate

when considered as solutions of  $B_{ijk}^{(1)} = 0$

- Then each of all solutions can be uniquely extended to a formal power series in  $g$ , and the  $N=1$  YM models depend on the single coupling constant  $g$  with all  $\beta$ -functions vanishing to all orders.

Proof: Inserting  $B_{ijk} = \frac{\partial g}{\partial^3 t} f_{ijk}$  in the identity and taking into account the vanishing of  $r, r^A$   
 $\leadsto 0 = \frac{\partial g}{\partial^3 t} (1 + O(t))$

Its solution (as formal power series in  $t$ ) is:  $\frac{\partial g}{\partial^3 t} = 0$     //  
and  $B_{ijk} = 0$  too.    //

2-loop RGEs for SSB parameters

Martin-Vaughn-Yamada-Jack-Jones

1994

Consider  $N=1$  gauge thy with

$$W = \frac{1}{6} Y^{ijk} \bar{\Phi}_i \bar{\Phi}_j \bar{\Phi}_k + \frac{1}{2} \mu^{ij} \bar{\Phi}_i \bar{\Phi}_j$$

and SSB terms

$$\begin{aligned} -\mathcal{L}_{SSB} = & \frac{1}{6} h^{ijk} \phi_i \phi_j \phi_k + \frac{1}{2} b^{ij} \phi_i \phi_j \\ & + \frac{1}{2} (m^2)_j^i \phi^{*i} \phi_j + \frac{1}{2} M \lambda \lambda + h.c. \end{aligned}$$

• 1-loop finiteness conditions

$$h^{ijk} = -M Y^{ijk}$$

$$(m^2)_j^i = \frac{1}{3} M M^* \delta_j^i \quad \text{universality}$$

in addition to  $\delta g^{(1)} = \gamma^{(1)i} j_j = 0$

• 1-loop finiteness

$\rightarrow$  2-loop finiteness

Assuming

- $\ell_g^{(1)} = \gamma^{(1)i}{}_i = 0$
- the reduction eq

$$\ell_Y^{ijk} = \ell_g d\gamma^{ijk}/dg$$

admits power series solution

$$\gamma^{ijk} = g \sum_{n=0} P_{(n)}^{ijk} g^{2n}$$

- $(m^2)_j^i = m_j^2 \delta_j^i$

$$\Rightarrow (m_i^2 + m_j^2 + m_k^2)/MM^* = 1 + \frac{g^2}{16\pi^2} \Delta^{(2)}$$

for  $i, j, k$  with  $P_{(0)}^{ijk} \neq 0$

where  $\Delta^{(2)} = -2 \sum_\ell \left[ (m_\ell^2/MM^*) - \frac{1}{3} \right] \ell(\chi_\ell)$

- $\Delta^{(2)} = 0$  for  $N=4$  with 5Tr cond
- $\Delta^{(2)} = 0$  for the  $N=1, SU(5)$  FUTs!

# The $SU(5)$ finite model

Kapetanakis, Mondragon, Z

Kobayashi, Kubo, Mondragon, Z

## Content

|                                         | $H_\alpha$ | $\bar{H}_\alpha$               |                |
|-----------------------------------------|------------|--------------------------------|----------------|
| $3(\bar{5} + 10) + 4(5 + \bar{5}) + 24$ |            |                                | Jones-Raby     |
| ↑<br>fermion,<br>supermultiplets        |            | ↑<br>scalar<br>supermultiplets | Hamidi-Schwarz |
|                                         |            |                                | Guijosa et.al  |
|                                         |            |                                | Kazakov        |
|                                         |            |                                | Babu-Enkhba    |
|                                         |            |                                | Gogoladze      |

$$\Rightarrow W = \sum_{i=1}^3 \left[ \frac{1}{2} g_i^u (10_i 10_i H_i + g_i^d 10_i \bar{5}_i \bar{H}_i) \right] \\ + g_{23}^u 10_2 10_3 H_4 + g_{23}^d 10_2 \bar{5}_3 \bar{H}_4 + g_{32}^d 10_3 \bar{5}_2 \bar{H}_4 \\ + \sum_{\alpha=1}^4 g_\alpha^+ H_\alpha 24 \bar{H}_\alpha + g^2 / 3 (24)^3$$

(with enhanced discrete symmetry  
after reduction of couplings)

We find

$$B_g^{(1)} = 0$$

$$B_{i\alpha}^{(1)} = \frac{1}{16\pi^2} \left[ -\frac{96}{5} g^2 + 3 \sum_{\beta=1}^4 (g_{i\beta}^u)^2 + 3 \sum_{j=1}^3 (g_{j\alpha}^u) \right. \\ \left. + \frac{24}{5} (g_\alpha^f)^2 + 4 \sum_{\beta=1}^4 (g_{i\beta}^d)^2 \right] g_{i\alpha}^u$$

$$B_{i\alpha}^{(d)} = \frac{1}{16\pi^2} \left[ -\frac{84}{5} g^2 + 3 \sum_{\beta=1}^4 (g_{i\beta}^u)^2 + \frac{24}{5} (g_\alpha^f)^2 \right. \\ \left. + 4 \sum_{j=1}^3 (g_{j\alpha}^d)^2 + 6 \sum_{\beta=1}^4 (g_{i\beta}^d)^2 \right] g_{i\alpha}^d$$

$$B_\alpha^{(1)} = \frac{1}{16\pi^2} \left[ -30 g^2 + \frac{63}{5} (g^f)^2 + 3 \sum_{\alpha=1}^4 (g_\alpha^f)^2 \right] g_\alpha^f$$

$$B_\alpha^{(f)} = \frac{1}{16\pi^2} \left[ -\frac{98}{5} g^2 + 3 \sum_{i=1}^3 (g_{i\alpha}^u)^2 \right. \\ \left. + 4 \sum_{i=1}^3 (g_{i\alpha}^d)^2 + \frac{48}{5} (g_\alpha^f)^2 \right. \\ \left. + \sum_{\beta=1}^4 (g_{\beta\alpha}^f)^2 + \frac{21}{5} (g^f)^2 \right] g_\alpha^f$$

Considering  $g$  as the primary coupling, we solve the Red. Eqs.

$$B_g = \beta_a \frac{dg}{d\beta_a}$$

requiring power series ansatz.

$$\Rightarrow (g_{ii}^u)^2 = \frac{8}{5} g^2 + \dots, (g_{ii}^d)^2 = \frac{6}{5} g^2 + \dots$$

$$(g^\lambda)^2 = \frac{15}{7} g^2 + \dots, (g_4^f)^2 = g^2, (g_\alpha^+)^2 = 0 + \dots (\alpha=1,2,3)$$

Higher order terms can be uniquely determined.

$\Rightarrow$  All 1-loop  $B$ -functions vanish

Moreover

All 1-loop anomalous dimensions of chiral fields vanish.

$$\gamma_{10i}^{(1)} = \frac{1}{16\pi^2} \left[ -\frac{36}{5} g^2 + 3 \sum_{b=1}^4 (g_{ib}^u)^2 + 2 \sum_{b=1}^4 (g_{ib}^d)^2 \right]$$

$$\gamma_{\bar{s}i}^{(1)} = \frac{1}{16\pi^2} \left[ -\frac{24}{5} g^2 + 4 \sum_{b=1}^4 (g_{ib}^d)^2 \right]$$

$$\gamma_{H_\alpha}^{(1)} = \frac{1}{16\pi^2} \left[ -\frac{24}{5} g^2 + 3 \sum_{i=1}^3 (g_{i\alpha}^u)^2 + \frac{24}{5} (g_\alpha^f)^2 \right]$$

$$\gamma_{\bar{H}_\alpha}^{(1)} = \frac{1}{16\pi^2} \left[ -\frac{24}{5} g^2 + 4 \sum_{i=1}^3 (g_{i\alpha}^d)^2 + \frac{24}{5} (g_\alpha^f)^2 \right]$$

$$\gamma_{24}^{(1)} = \frac{1}{16\pi^2} \left[ -\frac{10}{5} g^2 + \sum_{\alpha=1}^4 (g_\alpha^f)^2 + \frac{21}{5} (g_\lambda)^2 \right]$$

$\Rightarrow$  Necessary and sufficient conditions for finiteness to all orders are satisfied

- $SU(5)$  breaks down to the standard model due to  $\langle 24 \rangle$
- Use the freedom in mass parameters to obtain only a pair of Higgs fields light, acquiring v.e.v.
- Get rid of unwanted triplets rotating the Higgs sector (after a fine tuning)  
see Quiros et. al., Kazakov et. al  
YoshioKa
- Adding soft terms we can achieve SUSY breaking.

# 1) Gauge Couplings Unification

$$\sin^2 \theta_W, \alpha_{em} \rightarrow \alpha_3(M_Z)$$

Marciano + Serjanevic

Aniałdi et. al.

# 2) Bottom-Tau Yukawa Unif.

$SU(5)$ -type

$$\rightarrow m_t \sim 100 - 200 \text{ GeV}$$

Barger et. al.  
Carena et. al.

# \*3) Top-Bottom-Tau Yuk Unif.

$$h_t^2 = \frac{4}{3} h_{b,\tau}^2 \quad \text{in } SU(5) - \text{FUT}$$

Similar to  $SO(10)$

Ananthanarayanan et. al.

$$\rightarrow m_t \sim 160 - 200 \text{ GeV}$$

Barger et. al.  
Carena et. al.

# \*4) Gauge-Top-Bottom-Tau Unif.

$$\text{e.g. FUT-}SU(5): h_t^2 = \frac{8}{5} g_V^2; h_{b,\tau}^2 = \frac{6}{5} g_V^2$$

| $M_s$ [GeV] | $\alpha_{3(5f)}(M_Z)$ | $\tan \beta$ | $M_{\text{GUT}}$ [GeV] | $M_b$ [GeV] | $M_t$ [GeV] |
|-------------|-----------------------|--------------|------------------------|-------------|-------------|
| 300         | 0.123                 | 54.1         | $2.2 \times 10^{16}$   | 5.3         | 183         |
| 500         | 0.122                 | 54.2         | $1.9 \times 10^{16}$   | 5.3         | 183         |
| $10^3$      | 0.120                 | 54.3         | $1.5 \times 10^{16}$   | 5.2         | 184         |

### FUTA

| $M_s$ [GeV]       | $\alpha_{3(5f)}(M_Z)$ | $\tan \beta$ | $M_{\text{GUT}}$ [GeV] | $M_b$ [GeV] | $M_t$ [GeV] |
|-------------------|-----------------------|--------------|------------------------|-------------|-------------|
| 800               | 0.120                 | 48.2         | $1.5 \times 10^{16}$   | 5.4         | 174         |
| $10^3$            | 0.119                 | 48.2         | $1.4 \times 10^{16}$   | 5.4         | 174         |
| $1.2 \times 10^3$ | 0.118                 | 48.2         | $1.3 \times 10^{16}$   | 5.4         | 174         |

### FUTB

| $M_s$ [GeV] | $\alpha_{3(5f)}(M_Z)$ | $\tan \beta$ | $M_{\text{GUT}}$ [GeV] | $M_b$ [GeV] | $M_t$ [GeV] |
|-------------|-----------------------|--------------|------------------------|-------------|-------------|
| 300         | 0.123                 | 47.9         | $2.2 \times 10^{16}$   | 5.5         | 178         |
| 500         | 0.122                 | 47.8         | $1.8 \times 10^{16}$   | 5.4         | 178         |
| 1000        | 0.119                 | 47.7         | $1.5 \times 10^{16}$   | 5.4         | 178         |

### MIN SU(5)

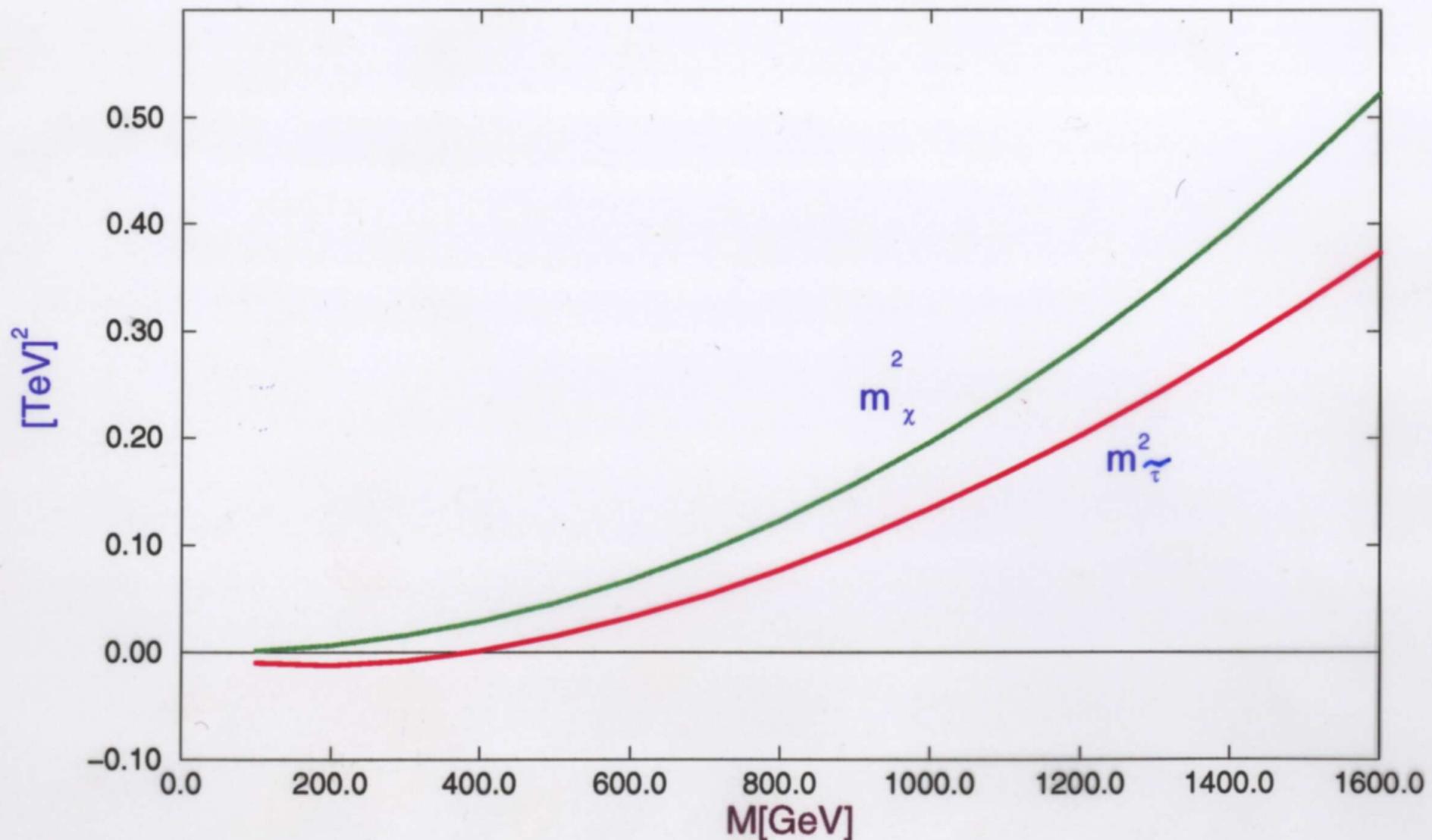
The predictions for the three models for different  $M_s$

With theoretical corrections and uncertainties<sup>8</sup>  
 $\sim 4\%$

$M_t = 173.8 \pm 5$  GeV;  $178.0 \pm 4.3$  GeV  
 CDF + D0

# Model A

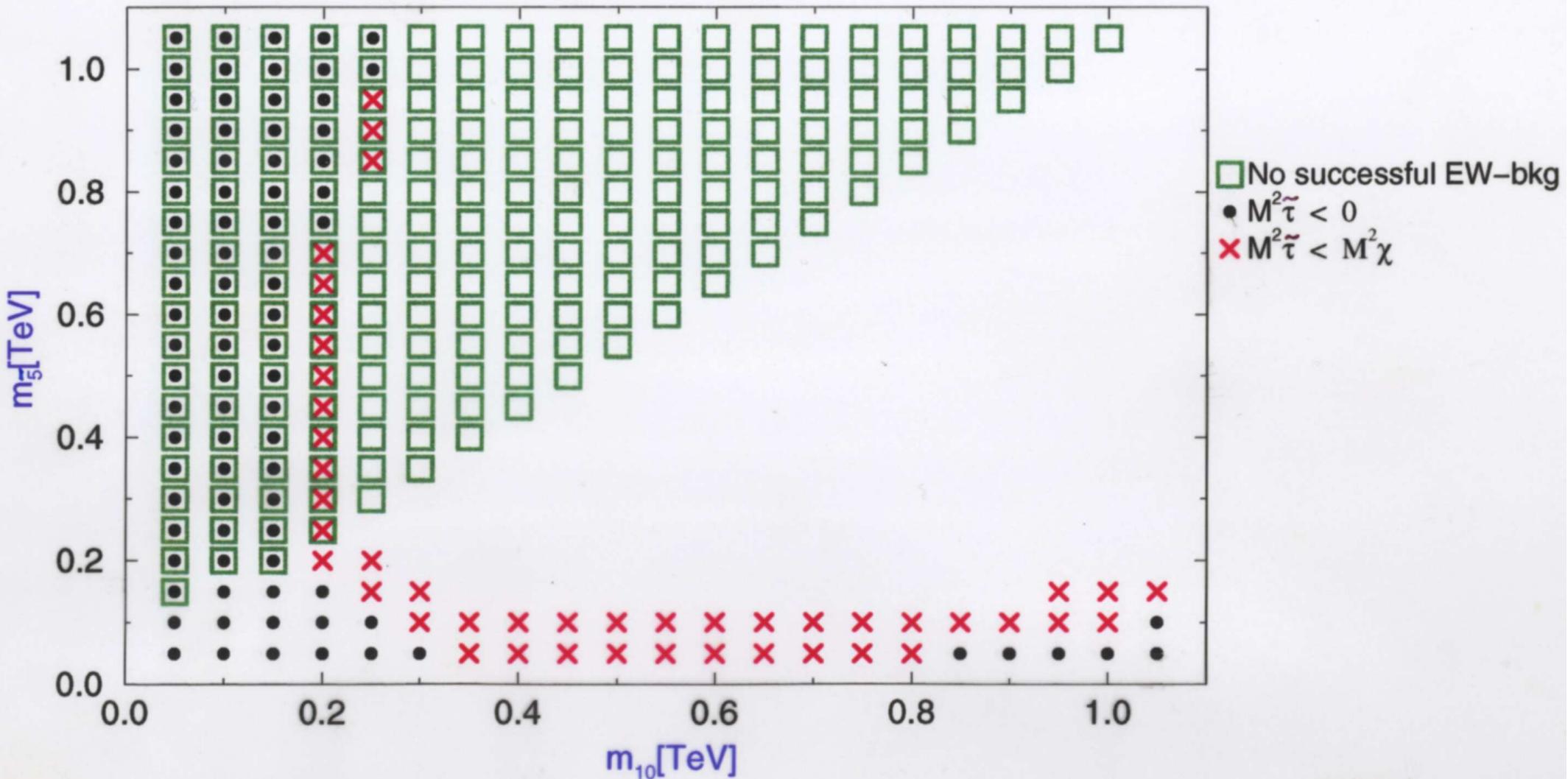
Similar behaviour holds for Model B too



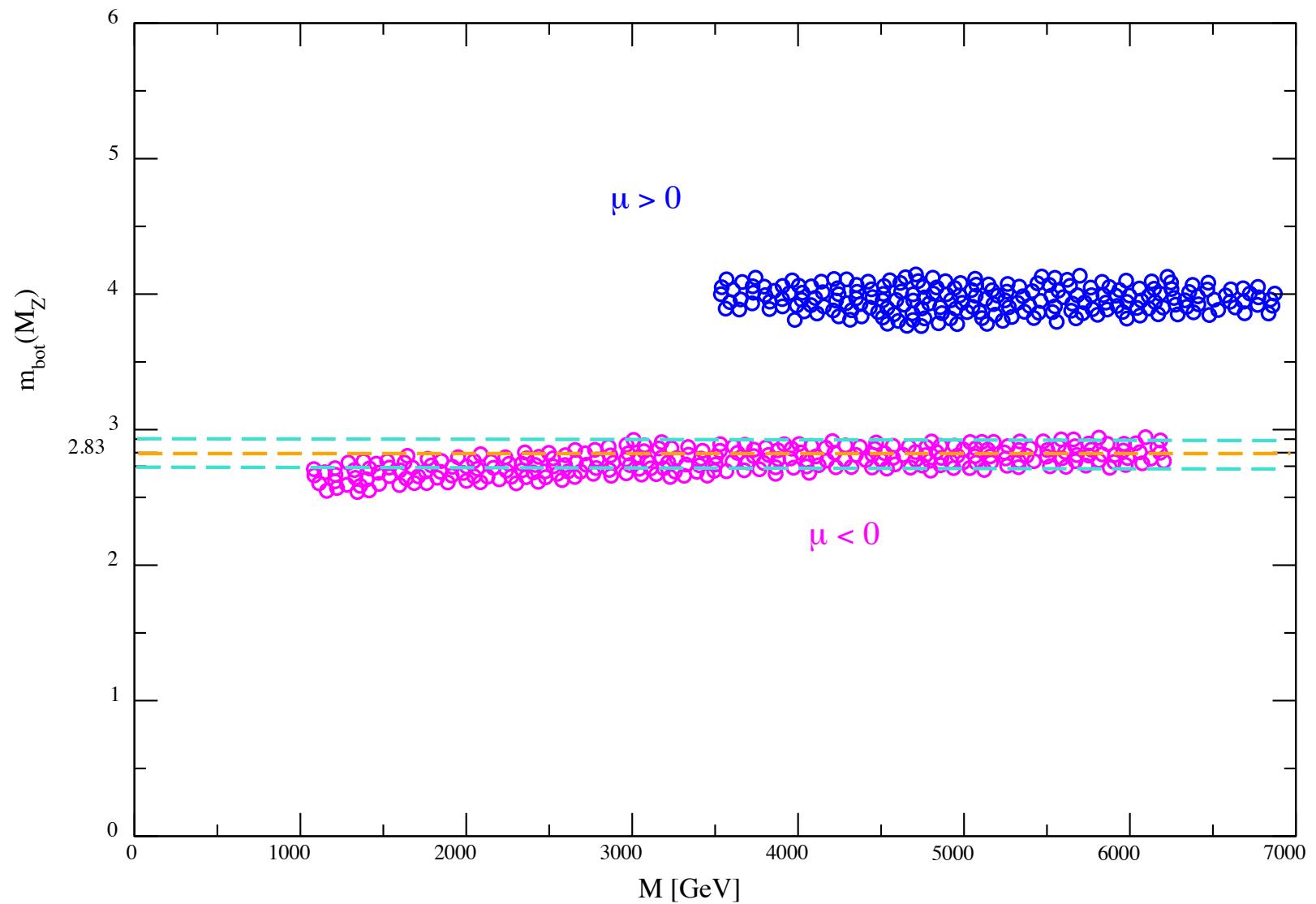
$m^2_{\tilde{\tau}}$  and  $m^2_\chi$  for the universal choice of soft scalar masses

# Model A

$M_{\text{susy}} = 0.3 \text{ TeV}$



The empty region yields a neutralino as LSP



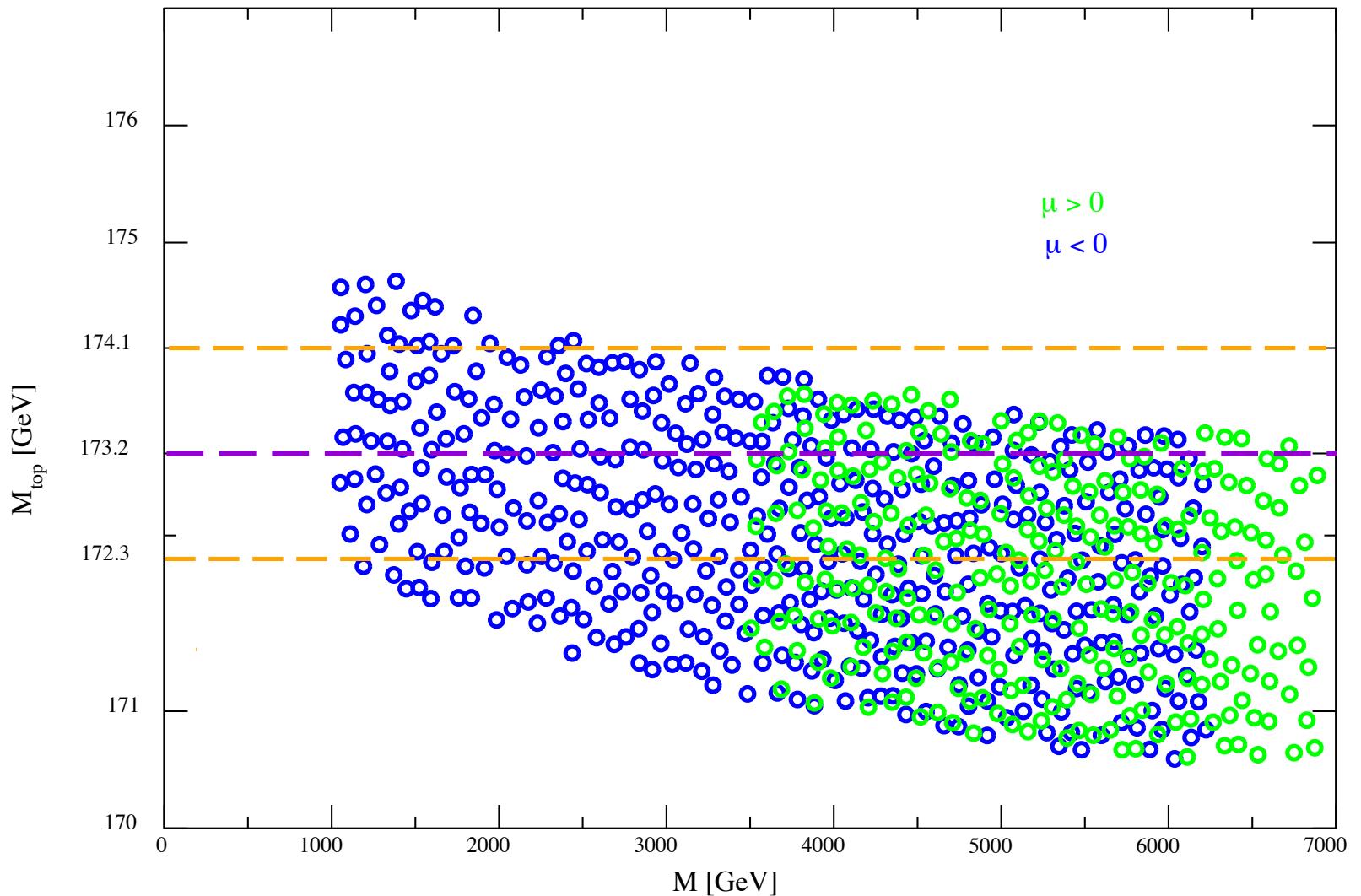
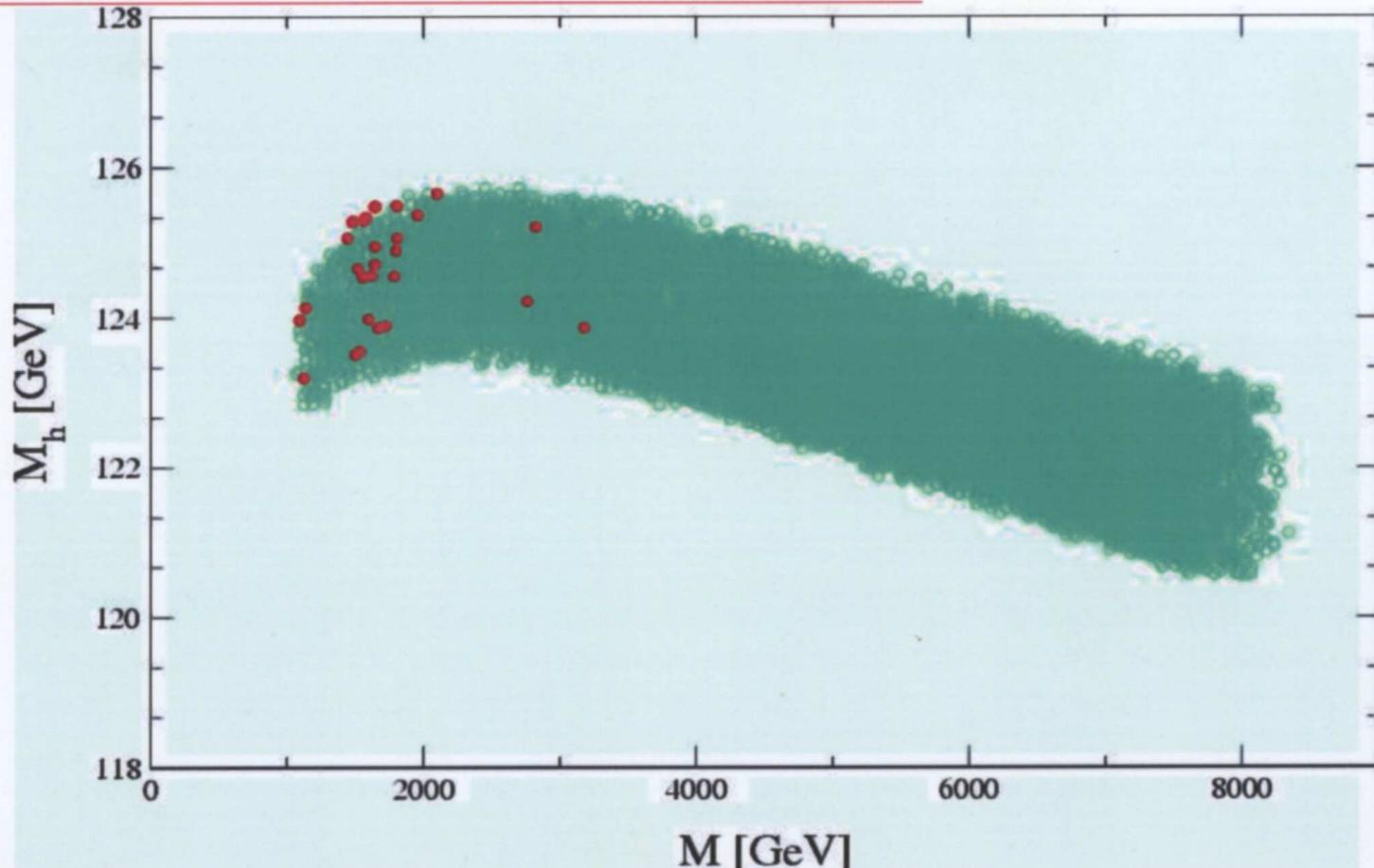


Figure 1: The bottom quark mass at the  $Z$  boson scale (upper) and top quark pole mass (lower plot) are shown as function of  $M$  for both models and both signs of  $\mu$ .

### 3D) Predictions for the light Higgs boson



green: consistent with  $B$  physics constraints

red: agreement with (loose) CDM bound

$$118 \text{ GeV} \leq M_h \leq 129 \text{ GeV} \quad (\text{incl. theor. unc.})$$

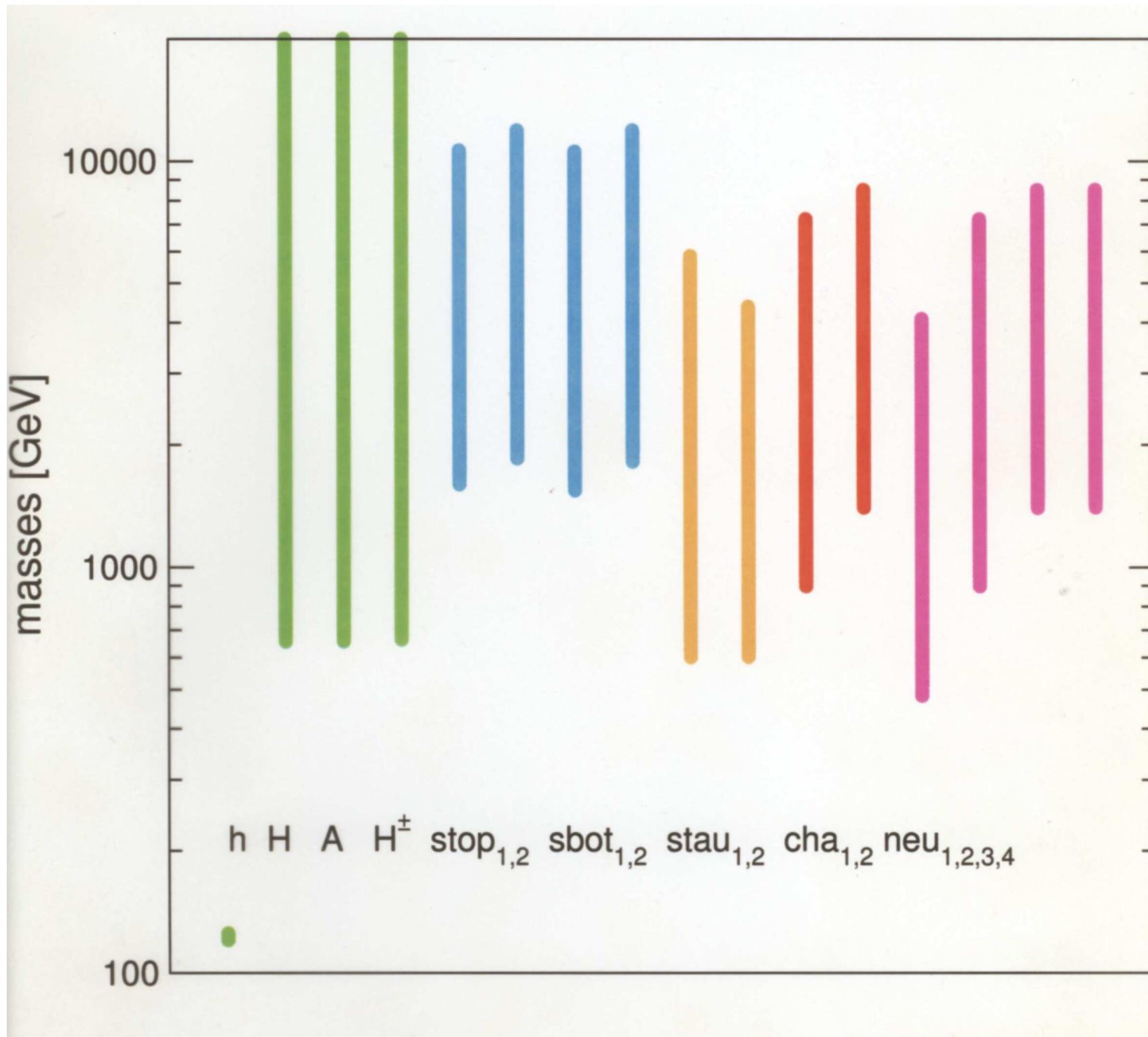
⇒ “easy” to find for LHC (but “only” SM-like . . .)

## Typical mass spectrum for FUTB- :

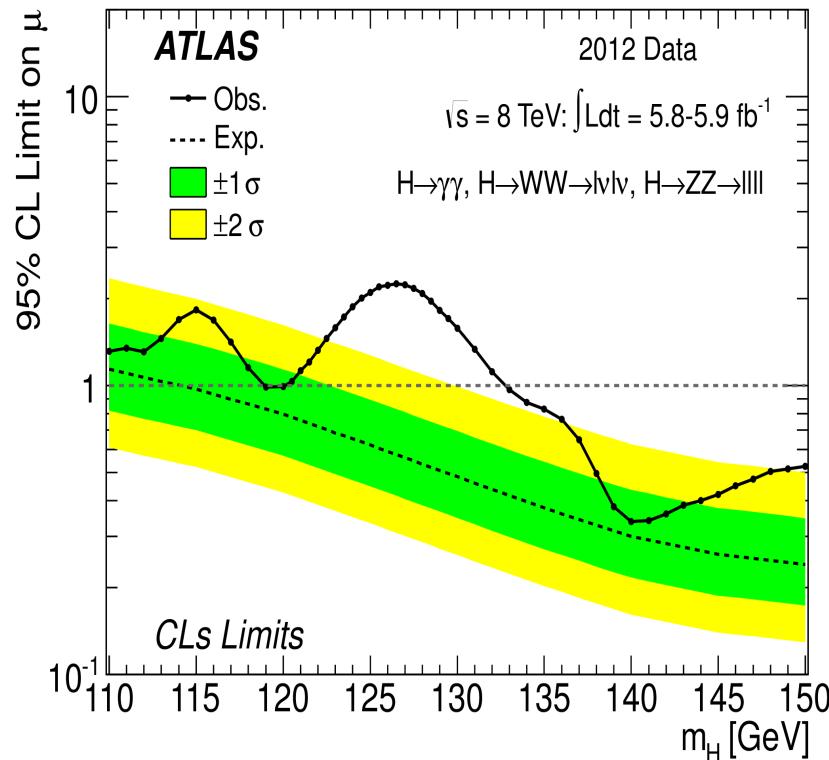
|                          |      |                       |       |
|--------------------------|------|-----------------------|-------|
| $m_t$                    | 172  | $\overline{m_b}(M_Z)$ | 2.7   |
| $\tan \beta =$           | 46   | $\alpha_s$            | 0.116 |
| $m_{\tilde{\chi}_1^0}$   | 796  | $m_{\tilde{\tau}_2}$  | 1268  |
| $m_{\tilde{\chi}_2^0}$   | 1462 | $m_{\tilde{\nu}_3}$   | 1575  |
| $m_{\tilde{\chi}_3^0}$   | 2048 | $\mu$                 | -2046 |
| $m_{\tilde{\chi}_4^0}$   | 2052 | $B$                   | 4722  |
| $m_{\tilde{\chi}_1^\pm}$ | 1462 | $M_A$                 | 870   |
| $m_{\tilde{\chi}_2^\pm}$ | 2052 | $M_{H^\pm}$           | 875   |
| $m_{\tilde{t}_1}$        | 2478 | $M_H$                 | 869   |
| $m_{\tilde{t}_2}$        | 2804 | $M_h$                 | 124   |
| $m_{\tilde{b}_1}$        | 2513 | $M_1$                 | 796   |
| $m_{\tilde{b}_2}$        | 2783 | $M_2$                 | 1467  |
| $m_{\tilde{\tau}_1}$     | 798  | $M_3$                 | 3655  |

|               |           |
|---------------|-----------|
| M1            | 580 GeV   |
| M2            | 1077 GeV  |
| Mgluino       | 2754 GeV  |
| Stop1         | 1876 GeV  |
| Stop2         | 2146 GeV  |
| Sbot1         | 1849 GeV  |
| Sbot2         | 2117 GeV  |
| Mstau1        | 635 GeV   |
| Mstau2        | 867 GeV   |
| Char1         | 1072 GeV  |
| Char2         | 1597 GeV  |
| Neu1          | 579 GeV   |
| Neu2          | 1072 GeV  |
| Neu3          | 1591 GeV  |
| Neu4          | 1596 GeV  |
| Mh            | 123.1 GeV |
| MH            | 679 GeV   |
| MA            | 680 GeV   |
| MH $^\pm$     | 685 GeV   |
| Mtop          | 172.2 GeV |
| Mbot( $M_Z$ ) | 2.71 GeV  |

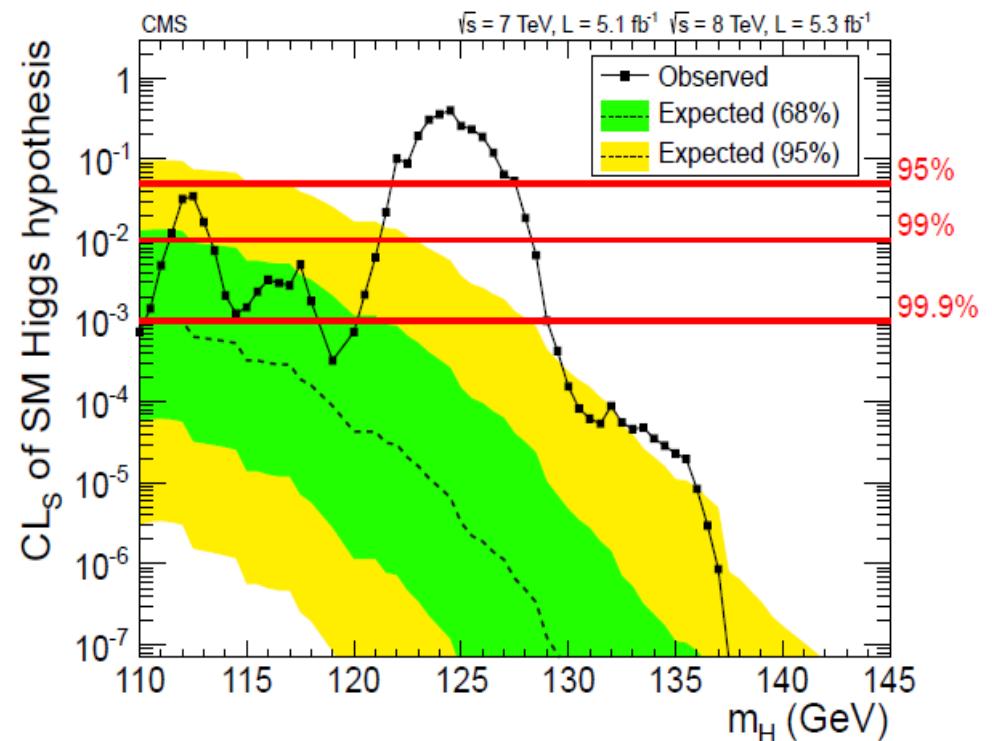
FUTB,  $\mu < 0$



It is where the SM predicts it should be



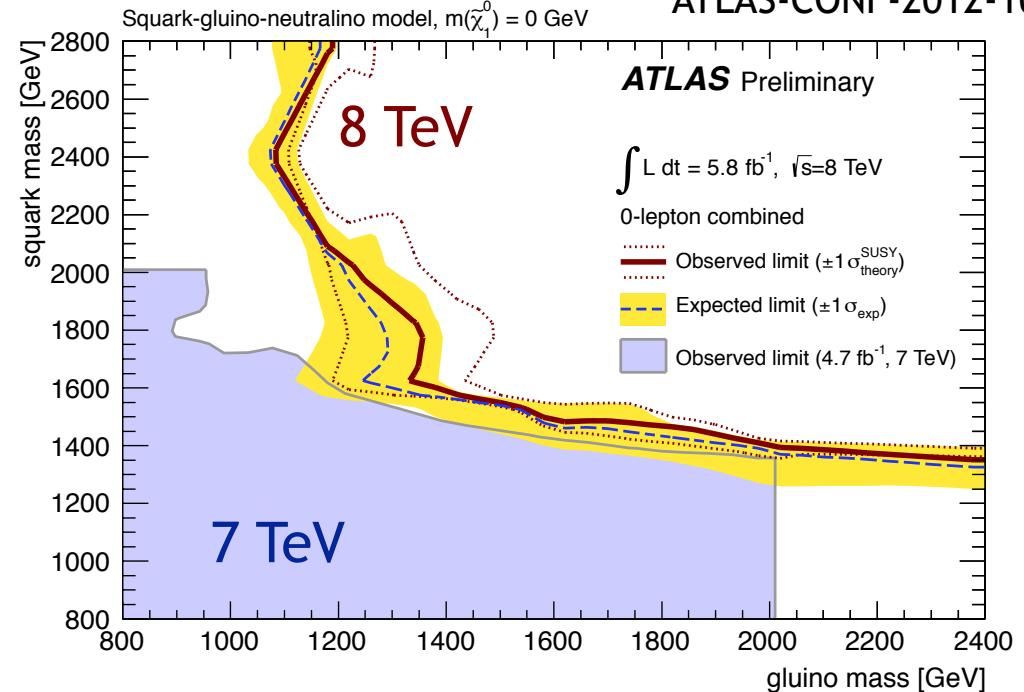
$$M_H = 126 \pm 0.4 \text{ (stat.)} \pm 0.4 \text{ (syst.)} \text{ GeV}$$



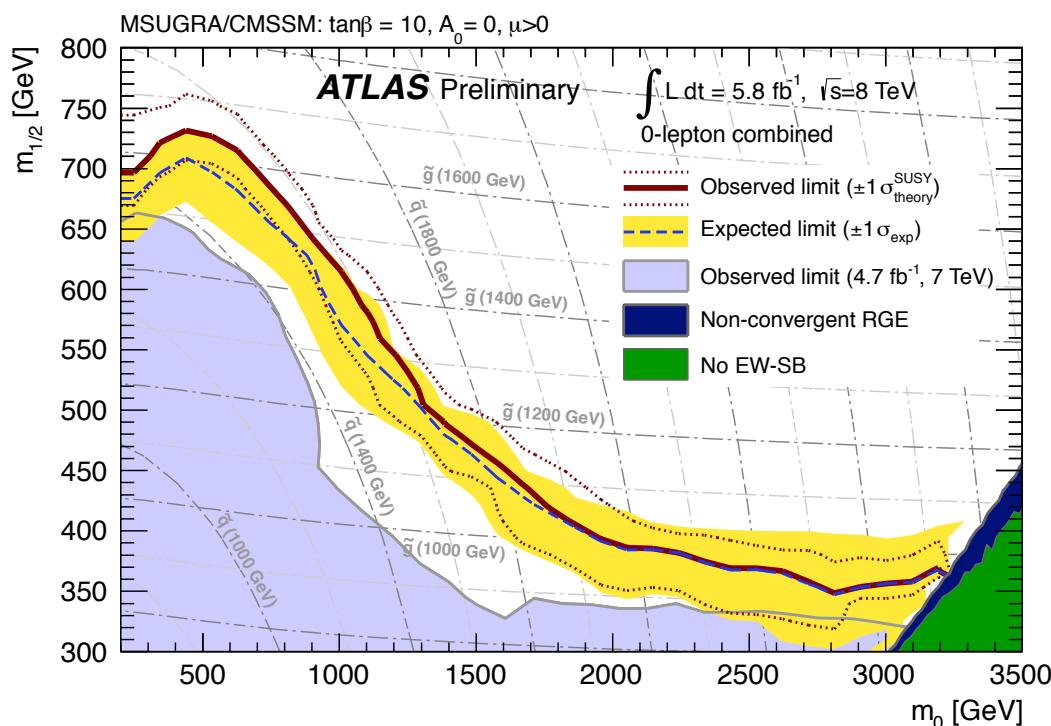
$$M_H = 125.3 \pm 0.4 \text{ (stat.)} \pm 0.5 \text{ (syst.)} \text{ GeV}$$

# Jets+MET results

- Exclusions in the squark-gluino mass plane for a simplified SUSY model



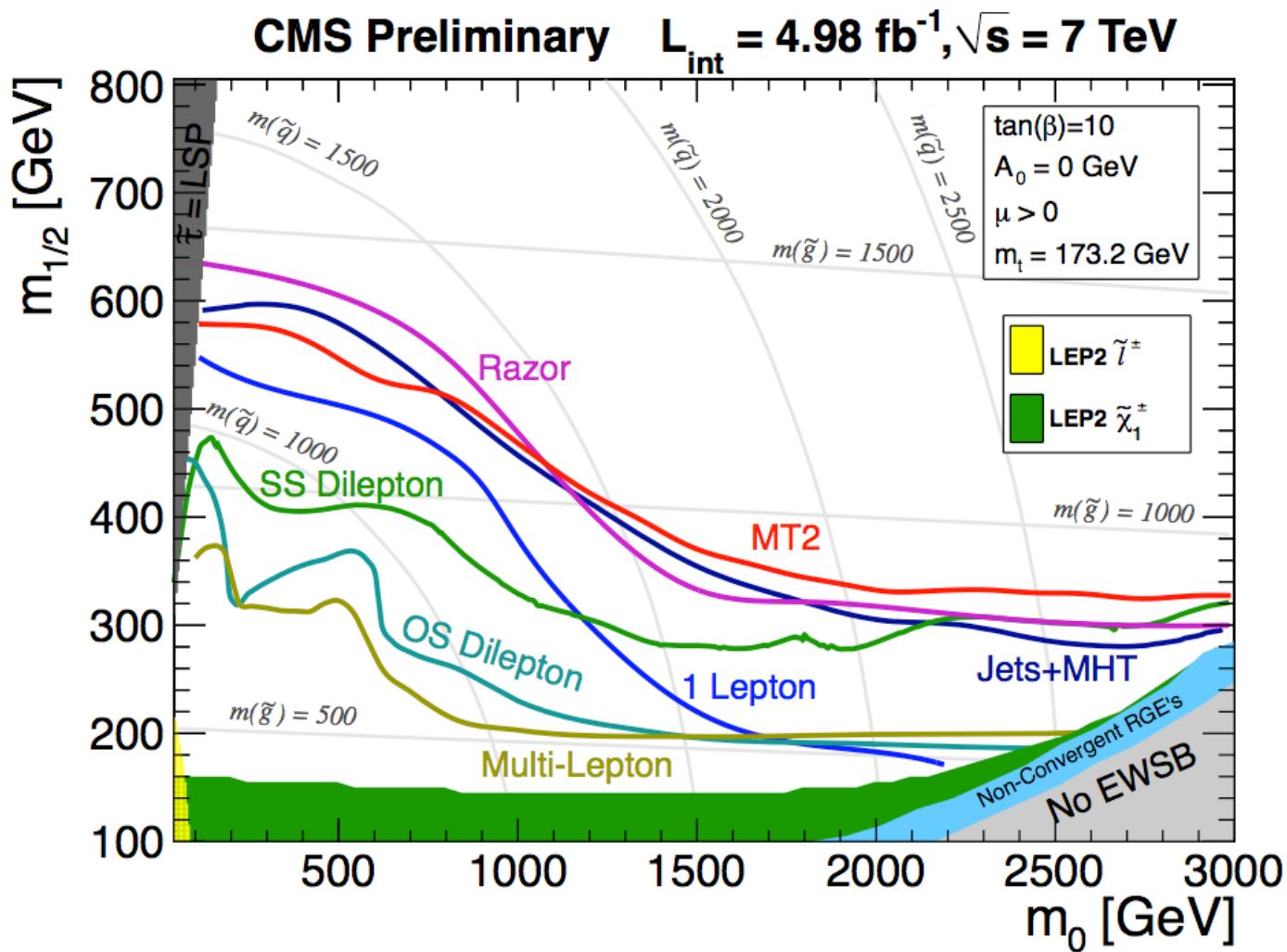
Limits stable up to ~200 GeV mass LSP



- CMSSM ( $m_{1/2}, m_0$ ) plane: equal mass squarks and gluinos excluded below 1500 GeV



# No SUSY (so far).

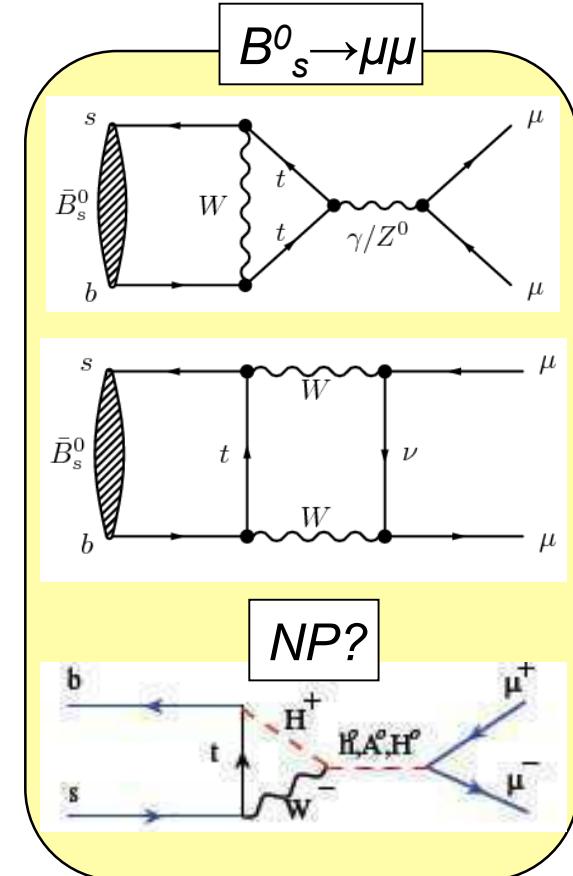


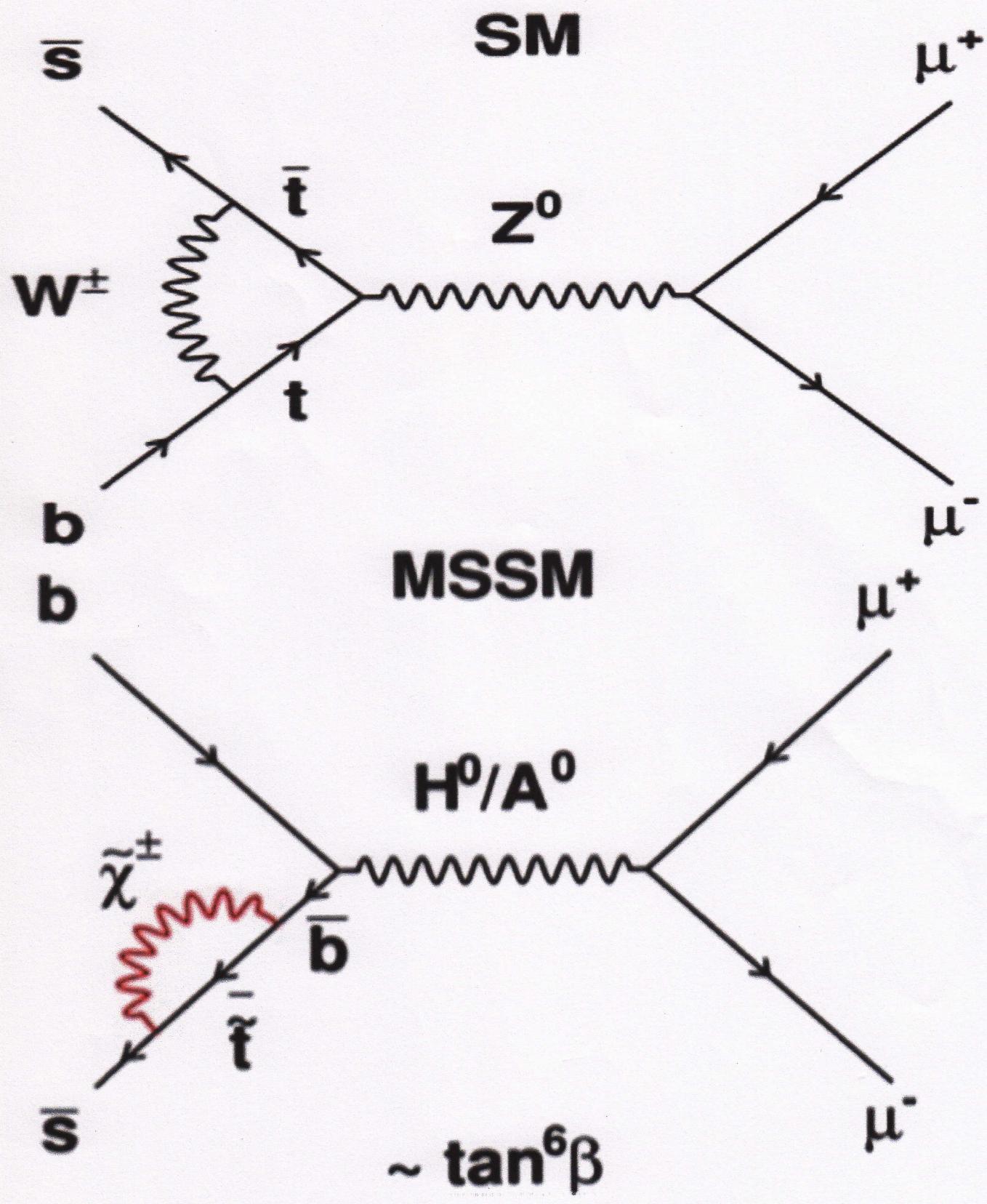
At least within constrained MSS models.

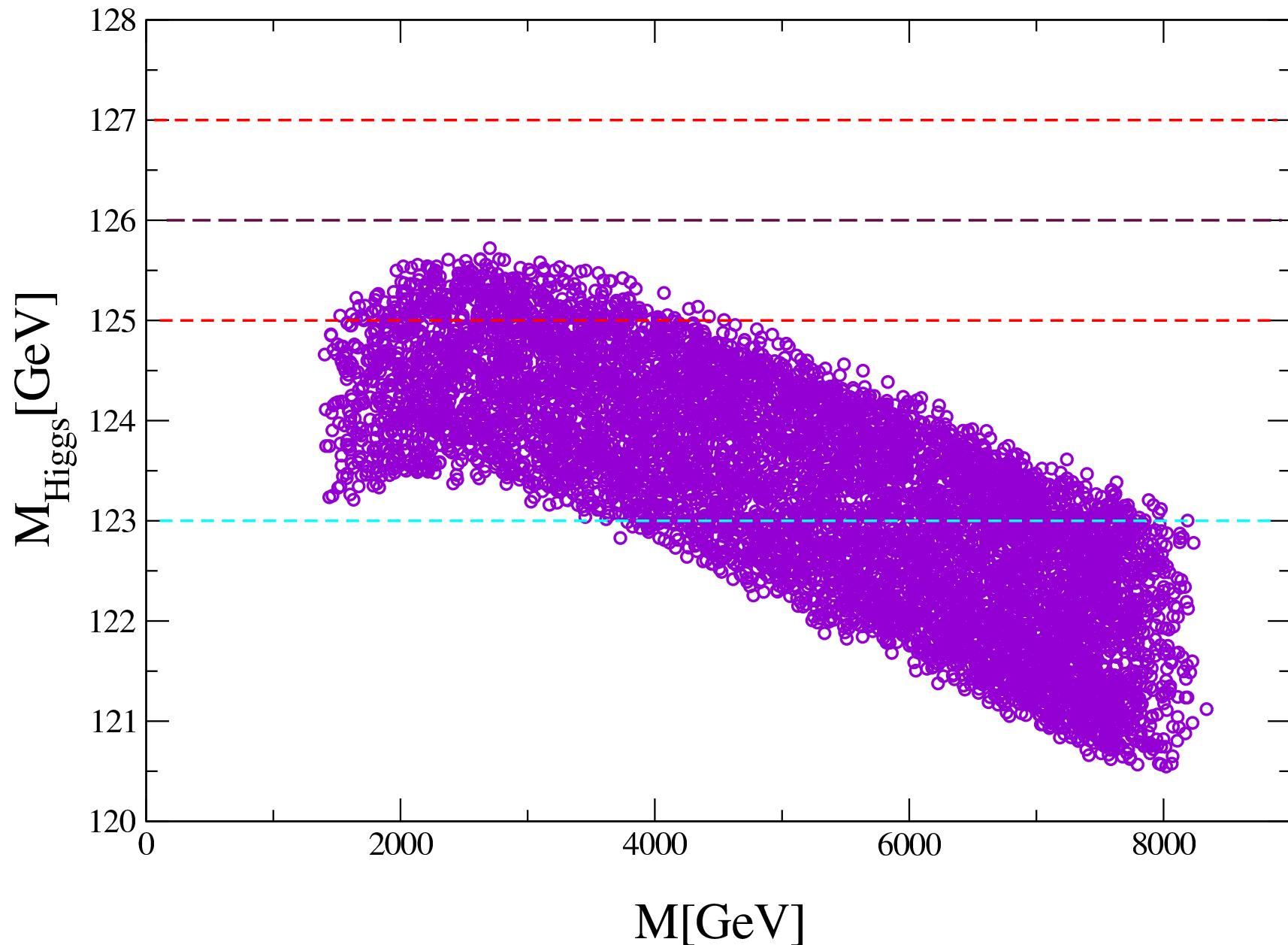
# Search for NP in $B_{s(d)} \rightarrow \mu^+ \mu^-$

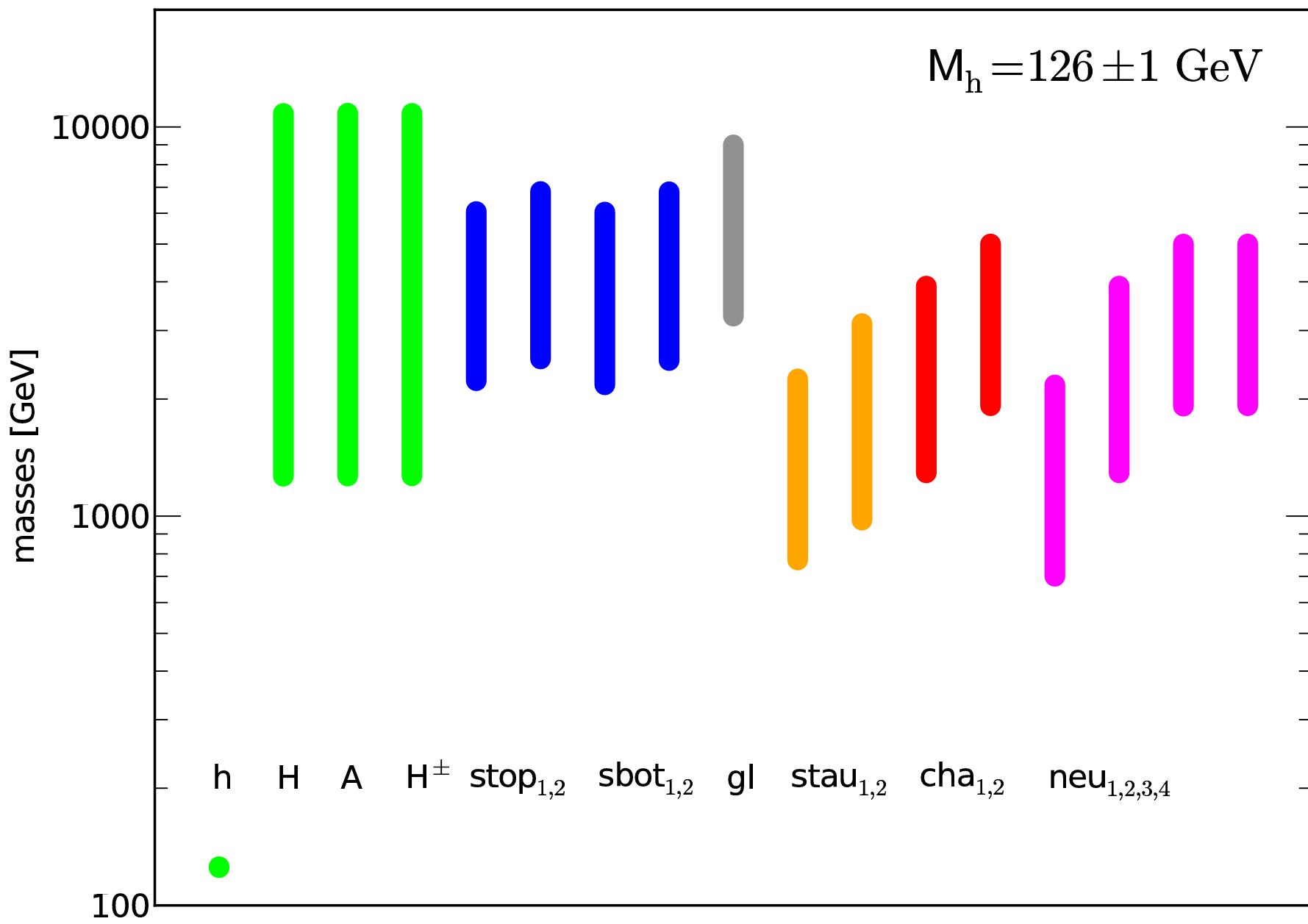
34

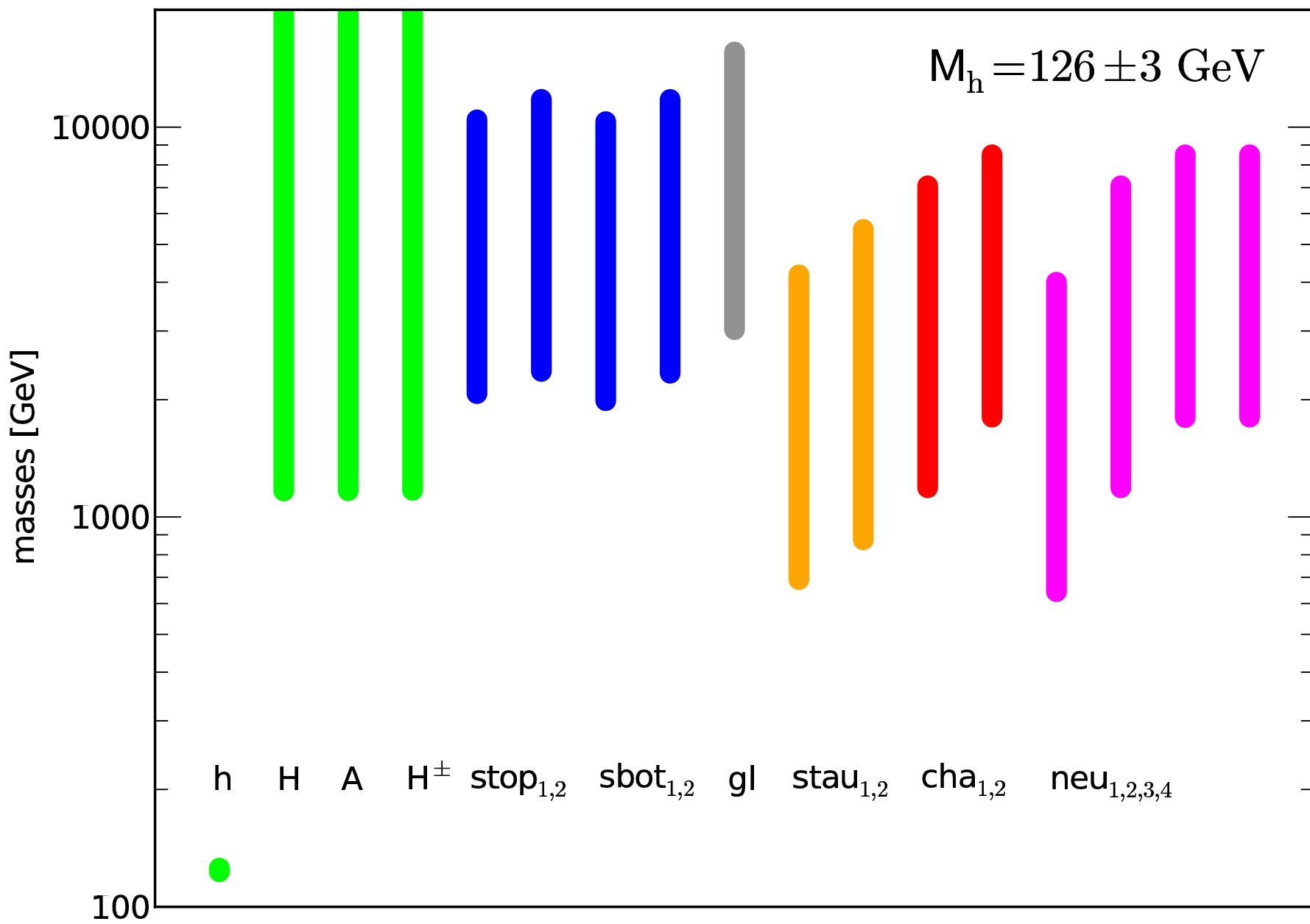
- Highly suppressed in SM - FCNC plus helicity  $(m_\mu/M_B)^2$  - and well predicted
  - ▣  $\text{BR}(B_s \rightarrow \mu^+ \mu^-) = 3.2 \pm 0.03 \ 10^{-9}$
  - ▣  $\text{BR}(B_d \rightarrow \mu^+ \mu^-) = 0.11 \pm 0.01 \ 10^{-9}$ 
    - A.J.Buras et al: arXiv: 1208.0934
- Sensitive to NP
  - ▣ Could be strongly enhanced in SUSY
  - ▣ In MSSM scales like  $\sim \tan^6 \beta \rightarrow$
- Limit or measurement of  $B_{s,d} \rightarrow \mu^+ \mu^-$  will strongly constraint parameter space











# MSSM

Mondragon  
Tracas, 2

- Based on the new observation that top, bottom Yukawa couplings and  $\alpha_s$  satisfy RGI relations, i.e. are successfully (theoretically and experimentally!) reduced
  - Assuming in addition a RGI relation among the trilinear couplings in the superpotential and in the corresponding ones in the soft supersymmetry breaking (scalar) sector
- Prediction of the Higgs masses and s-spectrum

All-loop relations among

SSB  $\beta$ -functions

Yamada  
Hisano-Shifman  
Kazakov  
Jack-Jones-Pickering

$$\beta_M = 20 \left( \frac{\partial g}{\partial g} \right)$$

$$\begin{aligned} \beta_h^{ijk} &= \gamma_e^i h^{lsk} + \gamma_e^j h^{ilk} + \gamma_e^k h^{isl} \\ &\quad - 2\gamma_e^i C^{lsk} - 2\gamma_e^j C^{ilk} - 2\gamma_e^k C^{isl} \end{aligned}$$

$$(\beta_{m^2})_j^i = \left[ \Delta + \times \frac{\partial}{\partial g} \right] \gamma_j^i$$

$$\text{where } O = \left( M g^2 \frac{\partial}{\partial g^2} - h^{lmn} \frac{\partial}{\partial C^{lmn}} \right)$$

$$\begin{aligned} \Delta &= 200^* + 2 |M|^2 g^2 \frac{\partial}{\partial g^2} \\ &\quad + \tilde{C}_{lmn} \frac{\partial}{\partial C^{lmn}} + \tilde{C}^{lmn} \frac{\partial}{\partial C^{lmn}} \end{aligned}$$

$$(\gamma_e)_j^i = O \gamma_j^i, \quad C_{lmn} = (C^{lmn})^*$$

$$\tilde{C}^{ijk} = (m^2)_e^i C^{ljk} + (m^2)_e^j C^{ilk} + (m^2)_e^k C^{ijl}$$

Assuming the existence of RG surfaces on which

a)  $C = C(\beta)$  or equivalently

$$\frac{d C^{ijk}}{d g} = \frac{\delta_C^{ijk}}{\delta g}$$

i.e. reduction of couplings

b)  $h^{ijk} = -M \frac{d C(\beta)}{d \ln g}$

$$M = \frac{g_3}{g} M_0$$

$$h^{ijk} = -M_0 \delta_C^{ijk} \quad \text{Sack-Jones}$$

$$b^{ij} = -M_0 \delta_\mu^{ij} \quad \text{Kobayashi-Kubo-Z}$$

$$m_i^2 + m_j^2 + m_k^2 = |M|^2 \frac{d \ln C^{ijk}}{d \ln g}$$

are RG to all-loops.

In supergravity framework,

$M_0 = m_{3/2}$  gravitino mass

## Sketch of proof

Assuming  $C \frac{\partial}{\partial C} = C^* \frac{\partial}{\partial C^*}$

for a RGI surface  $F(g, C^{ijc}, C^{ijc*})$

$$\rightarrow \frac{d}{dg} = \left( \frac{\partial}{\partial g} + 2 \frac{B_g}{B_g} \frac{\partial}{\partial C} \right)$$

Consider

$$O = \left( M g^2 \frac{\partial}{\partial g^2} - h \frac{\partial}{\partial C} \right)$$

$$(b) \rightarrow O = \frac{1}{2} M \frac{d}{d \ln g}$$

$$\text{and } \ell_M = M \frac{d}{d \ln g} \left( \frac{B_g}{g} \right)$$

$$\Rightarrow M = \frac{B_g}{g} M_0 \quad \text{Generalized Hisano - Sifman}$$

Similarly we obtain the rest relations

# Application of the RGI relations in MSSM

$$W = Y_t Q H_2 \ell^c + Y_b Q H_1 b^c + \mu H_1 H_2 + \dots$$

$$\mathcal{L}_{SSB} = \sum_{\phi} m_{\phi}^2 \phi^* \phi + \left[ m_3^2 H_1 H_2 + \sum_{i=1,2}^3 \frac{1}{2} M_i \lambda_i \lambda_i^* + h.c. \right] \\ + h_t \phi_Q H_2 \phi_{\ell^c} + h_b \phi_Q H_1 \phi_b^c + \dots + h.c.$$

In MSSM the assumption (a) is a fact! as we have seen, i.e.

$$dY_{t,b} / dg_3 = \beta Y_{t,b} / \beta g_3 \text{ hold.}$$

Then assuming (b), i.e. that

$$h_{t,b} = -M dY_{t,b} / dg$$

is RGI to all-loops, we obtain that

the following relations are

RGI to all-loops

$$M = \frac{b g_3}{g_3} M_U$$

$$h_{\epsilon,b} = -M_U g_3 \frac{d Y_{\epsilon,b}}{d g_3}$$

$$m_3 = -M_U g_3 \frac{d \mu}{d g_3}$$

$$m_i^2 + m_j^2 + m_k^2 = |M_U|^2 \frac{d Y_{\epsilon,b}}{d \ln g_3}$$

"<sub>1</sub> (at  
1-loop)

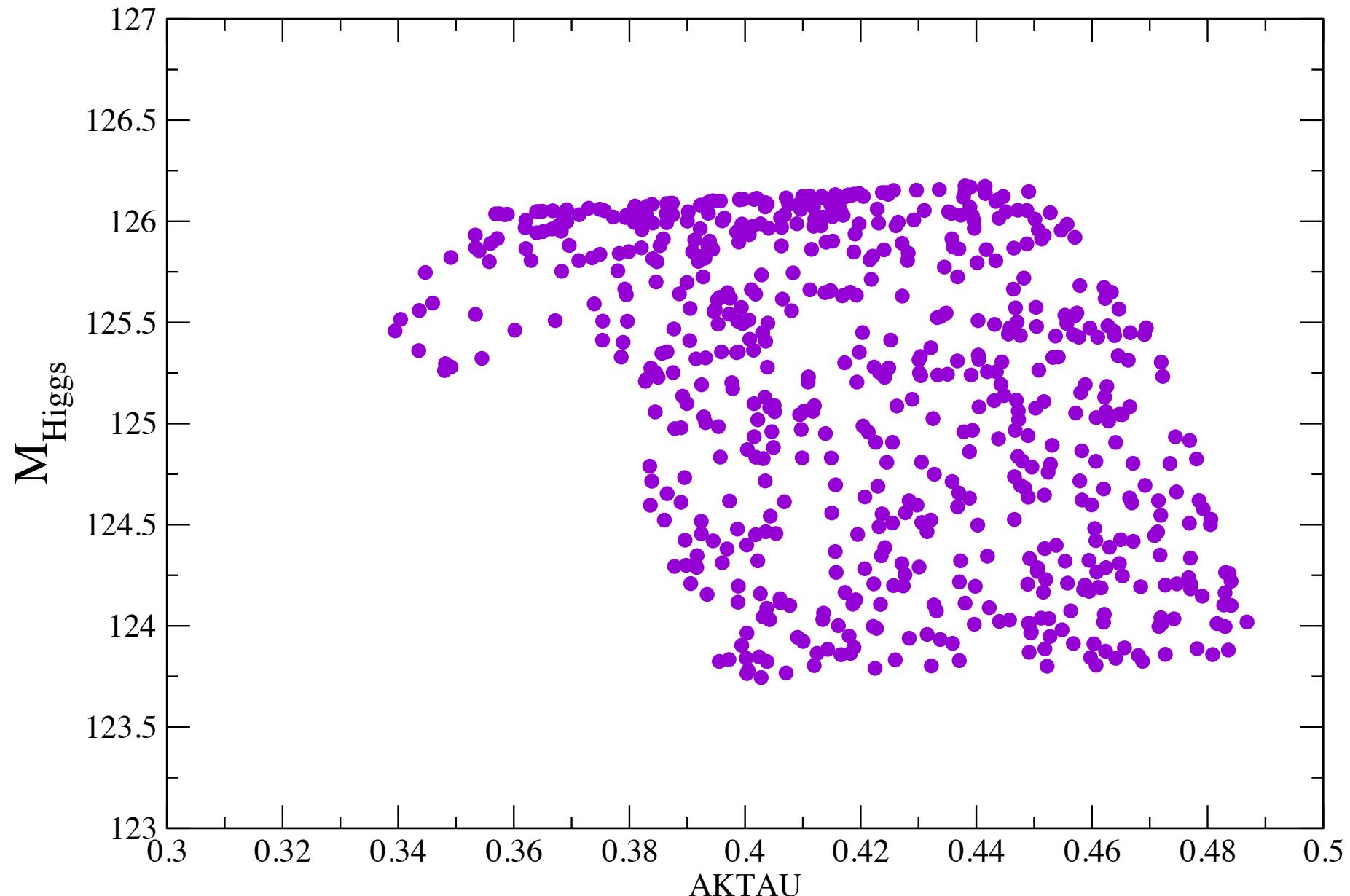
Since all gauge couplings meet at the unification scale  $M_U$ , we have the following boundary cond's

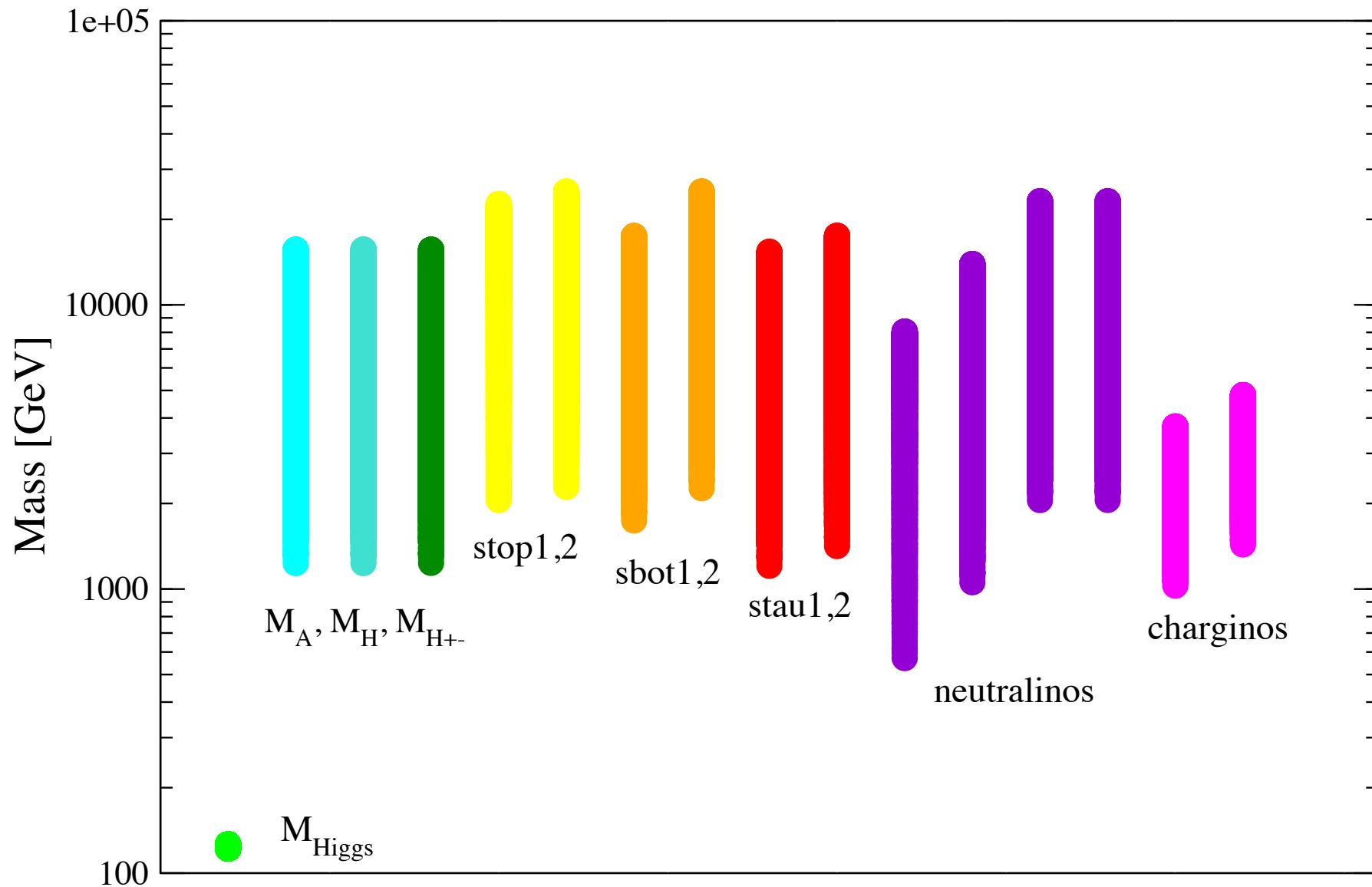
at  $M_U$

$$Y_{\epsilon,b} = c_{\epsilon,b} g_U, \quad h_{\epsilon,b} = M_U Y_{\epsilon,b}$$

$$m_3 = -M_U \mu,$$

$$m_{H_2}^2 + m_{\phi_Q}^2 + m_{\phi_L}^2 = M_U^2, \quad m_{H_1}^2 + m_{\phi_Q}^2 + m_{\phi_R}^2 = M_U^2$$





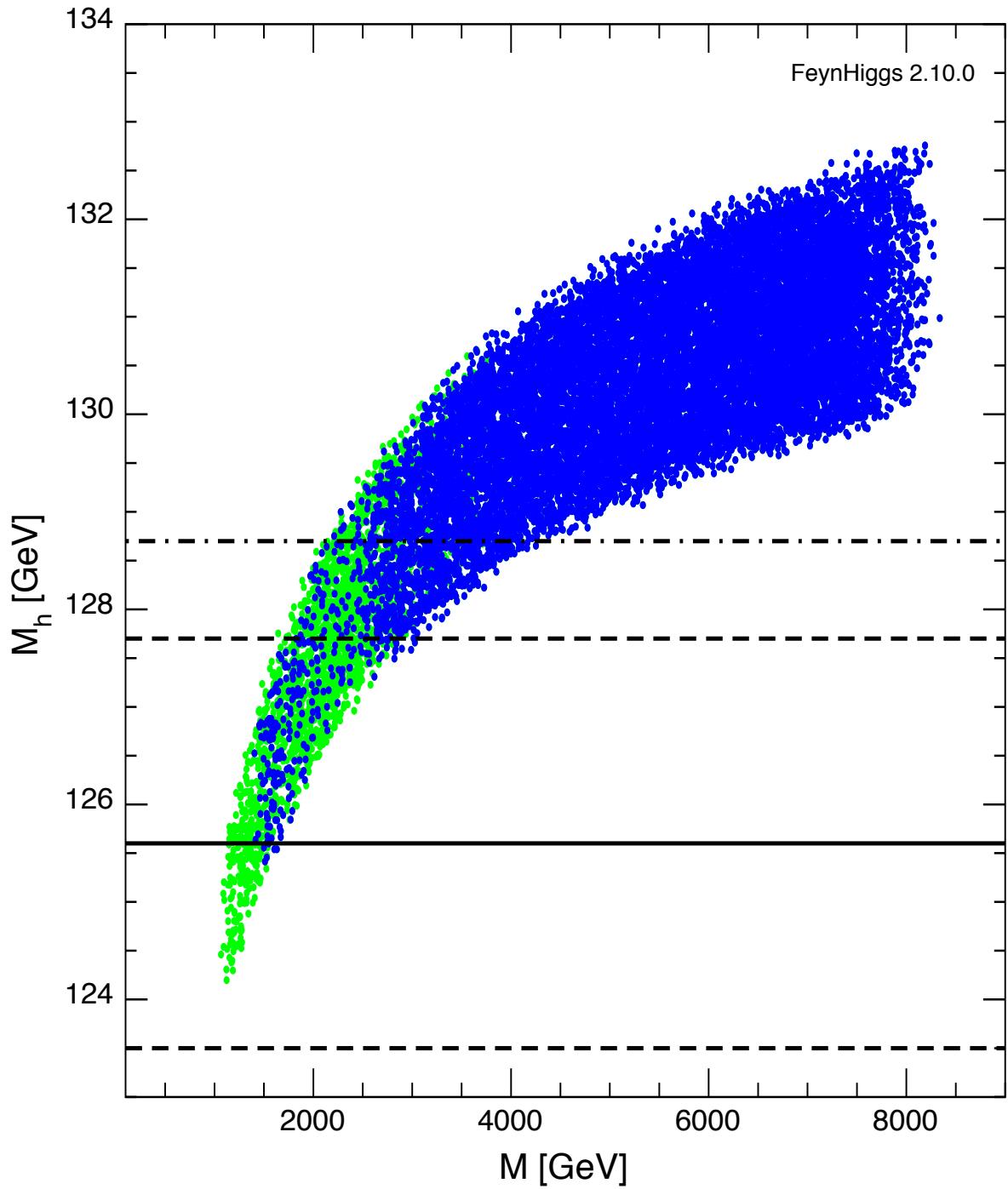


Figure 2: The lightest Higgs boson mass,  $M_h$ , as a function of  $M$  in the model  **$SU(5)$ -FUT** (with  $\mu < 0$ ) . The blue points fulfill the  $B$ -physics constraints (see text).

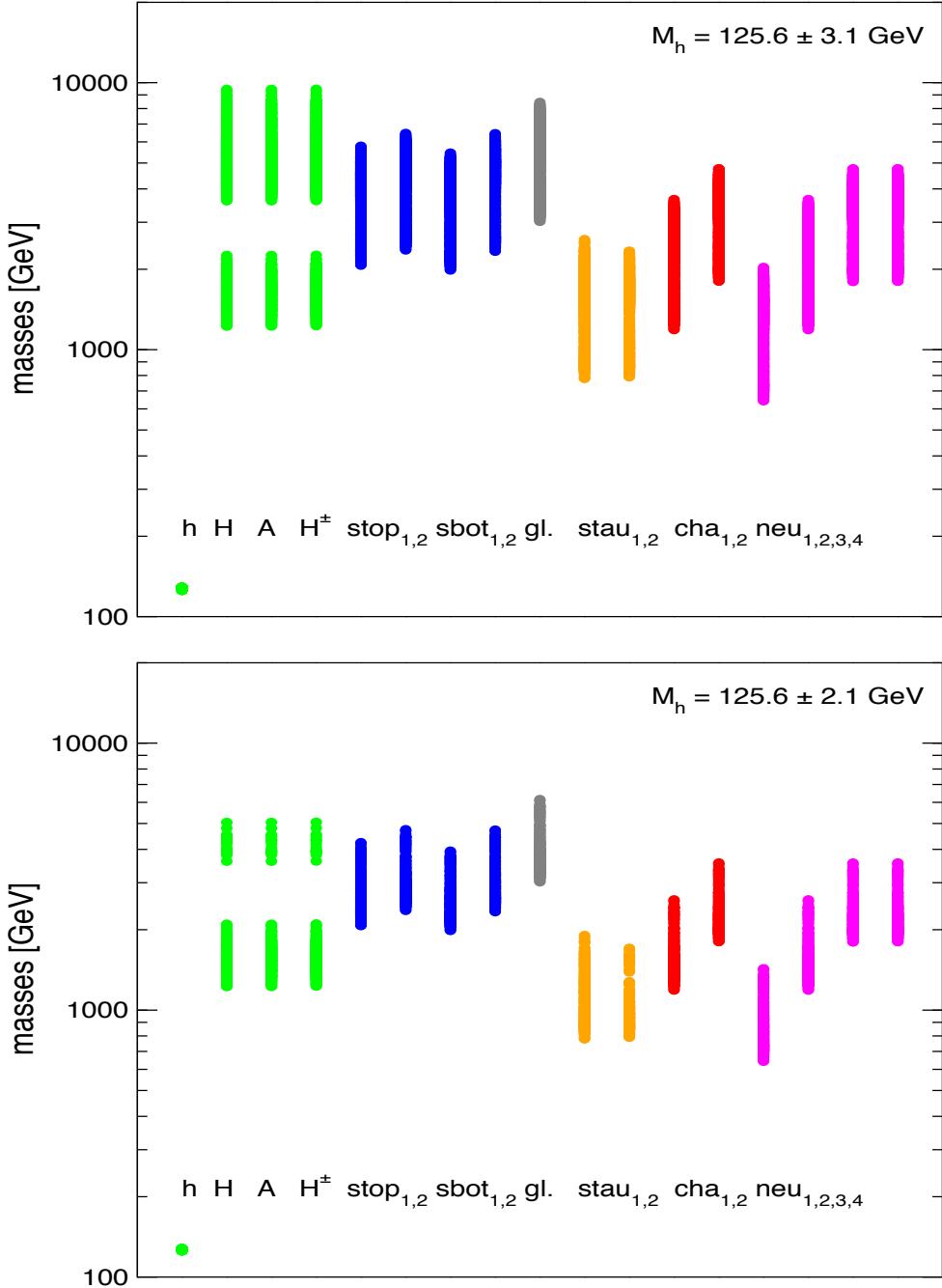


Figure 3: The upper (lower) plot shows the spectrum of  **$SU(5)$ -FUT** (with  $\mu < 0$ ) after imposing the constraint  $M_h = 125.6 \pm 3.1$  (2.1) GeV. The points shown are in agreement with the quark mass constraints and the  $B$ -physics observables. The light (green) points on the left are the various Higgs boson masses. The dark (blue) points following are the two scalar top and bottom masses, followed by the lighter (gray) gluino mass. Next come the lighter (beige) scalar tau masses. The darker (red) points to the right are the two chargino masses followed by the lighter shaded (pink) points indicating the neutralino masses.

|                          |       |                          |       |
|--------------------------|-------|--------------------------|-------|
| $m_b(M_Z)$               | 2.74  | $m_t$                    | 172.1 |
| $M_h$                    | 127.4 | $M_A$                    | 1514  |
| $M_H$                    | 1514  | $M_{H^\pm}$              | 1518  |
| $m_{\tilde{t}_1}$        | 2483  | $m_{\tilde{t}_2}$        | 2808  |
| $m_{\tilde{b}_1}$        | 2403  | $m_{\tilde{b}_2}$        | 2786  |
| $m_{\tilde{\tau}_1}$     | 892   | $m_{\tilde{\tau}_2}$     | 1089  |
| $m_{\tilde{\chi}_1^\pm}$ | 1453  | $m_{\tilde{\chi}_2^\pm}$ | 2127  |
| $m_{\tilde{\chi}_1^0}$   | 790   | $m_{\tilde{\chi}_2^0}$   | 1453  |
| $m_{\tilde{\chi}_3^0}$   | 2123  | $m_{\tilde{\chi}_4^0}$   | 2127  |
| $m_{\tilde{g}}$          | 3632  |                          |       |

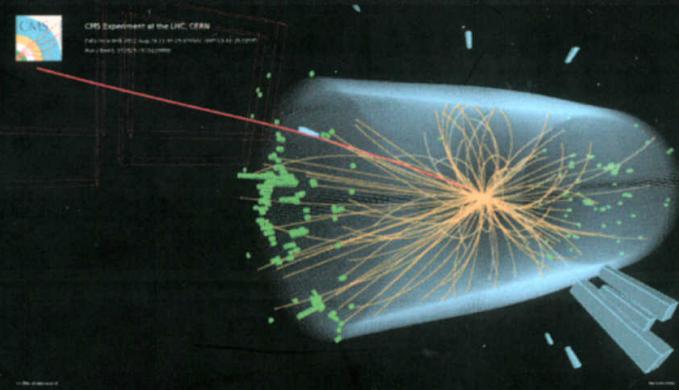
|                          |       |                          |       |
|--------------------------|-------|--------------------------|-------|
| $m_b(M_Z)$               | 2.82  | $m_t$                    | 172.5 |
| $M_h$                    | 128.6 | $M_A$                    | 4862  |
| $M_H$                    | 4861  | $M_{H^\pm}$              | 4867  |
| $m_{\tilde{t}_1}$        | 4167  | $m_{\tilde{t}_2}$        | 4666  |
| $m_{\tilde{b}_1}$        | 3913  | $m_{\tilde{b}_2}$        | 4650  |
| $m_{\tilde{\tau}_1}$     | 1593  | $m_{\tilde{\tau}_2}$     | 1756  |
| $m_{\tilde{\chi}_1^\pm}$ | 2547  | $m_{\tilde{\chi}_2^\pm}$ | 3515  |
| $m_{\tilde{\chi}_1^0}$   | 1405  | $m_{\tilde{\chi}_2^0}$   | 2547  |
| $m_{\tilde{\chi}_3^0}$   | 3512  | $m_{\tilde{\chi}_4^0}$   | 3515  |
| $m_{\tilde{g}}$          | 6066  |                          |       |

Table 1: A heavy (light) spectrum of a  **$SU(5)$ -FUT** (with  $\mu < 0$ ) parameter point is shown in the right (left) table. Both are compliant with the  $B$  physics constraints. All masses are in GeV.

# Reduction of couplings

## Higgs and top mass predictions Finite Theories

A guided tour through thirty years of research  
based on twenty-three articles



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In spite of their limitations, perturbative local field theories are still of prominent practical value.

It is remarkable that the intrinsic ambiguities connected with locality and causality – most of the time associated with ultraviolet infinities – can be summarized in terms of a formal group which acts in the space of the coupling constants or coupling functions attached to each type of local interaction.

It is therefore natural to look systematically for stable submanifolds. Some such have been known for a long time: e.g., spaces of renormalizable interactions and subspaces characterized by systems of Ward identities mostly related to symmetries.

A systematic search for such stable submanifolds has been initiated by W. Zimmermann in the early eighties.

Disappointing for some time, this program has attracted several other active researchers and recently produced physically interesting results.

It looks at the moment as the only theoretically founded algorithm potentially able to decrease the number of parameters within the physically favoured perturbative models.

A handwritten signature in blue ink, appearing to read "Alfonse".