ROMA, APR. 7 2010

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SNS of Pisa
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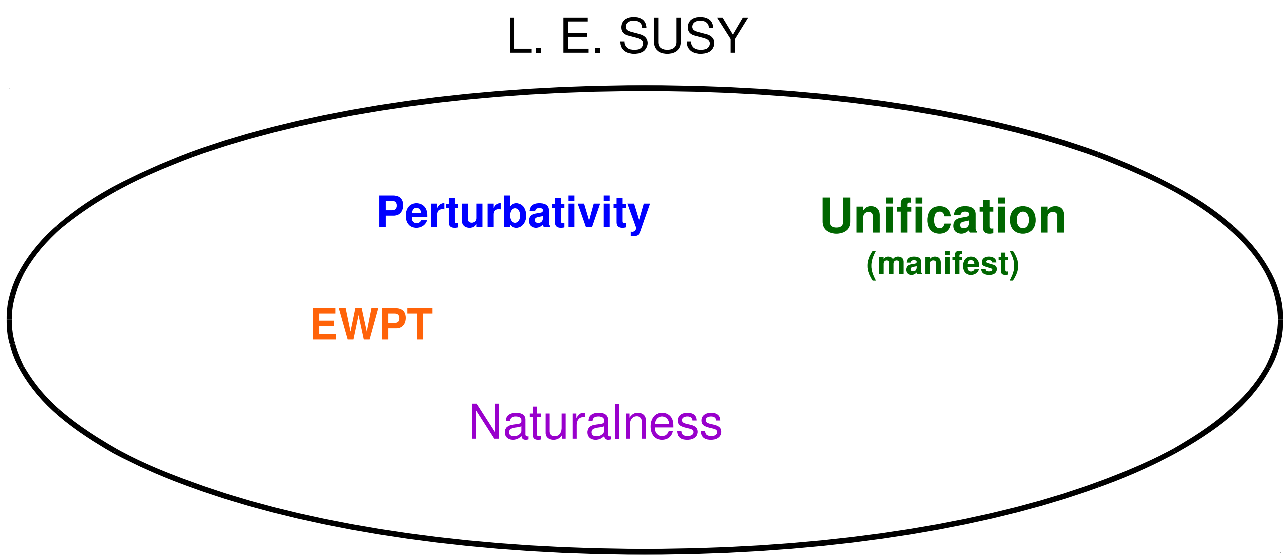
(part of a project in collaboration with:
R. Barbieri, **E. Bertuzzo**, **M. Farina**,
D. Pappadopulo)

SCUOLA NORMALE SUPERIORE PISA

Increasing the Higgs mass bound of the MSSM

1/5) Motivations

- Test of Low Energy Suspersymmetry: <u>crucial</u> at the LHC



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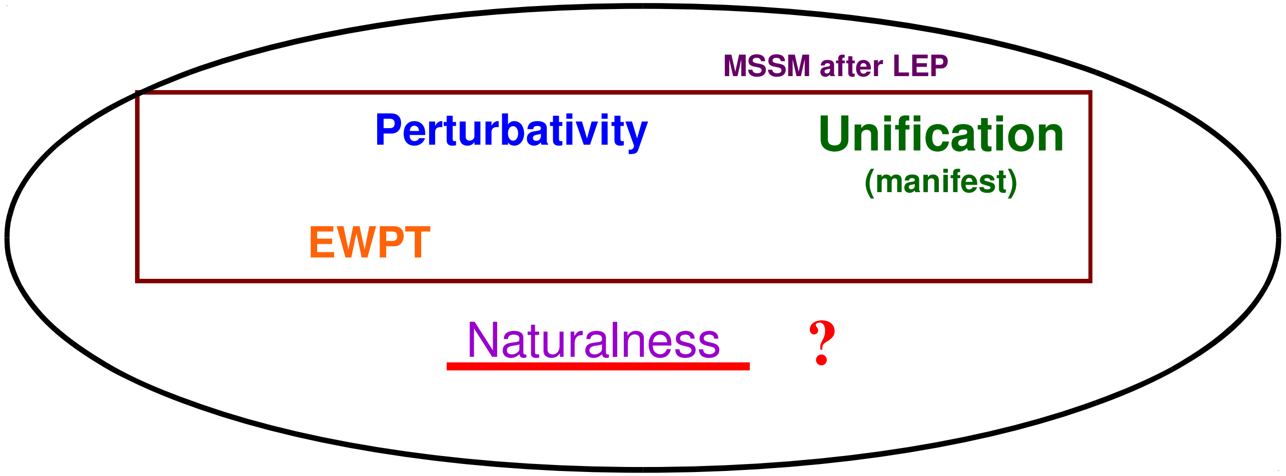
- Status of the MSSM:

L. E. SUSY $(m_h > 114.4\ \mathrm{GeV})$



$$m_h \lesssim 120\ \mathrm{GeV}$$

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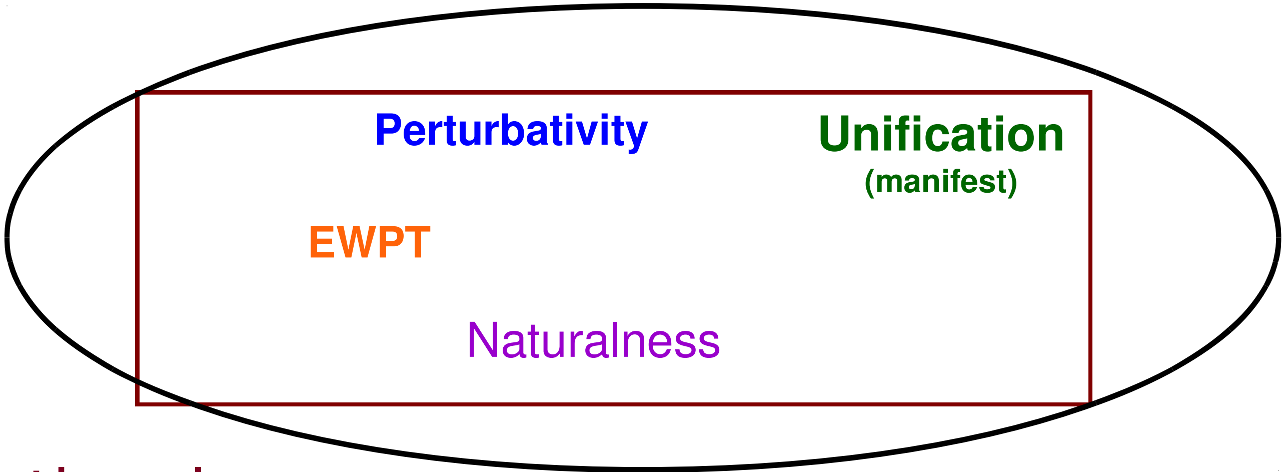

Conventional extensions: $m_h \lesssim 150\ \mathrm{GeV}$

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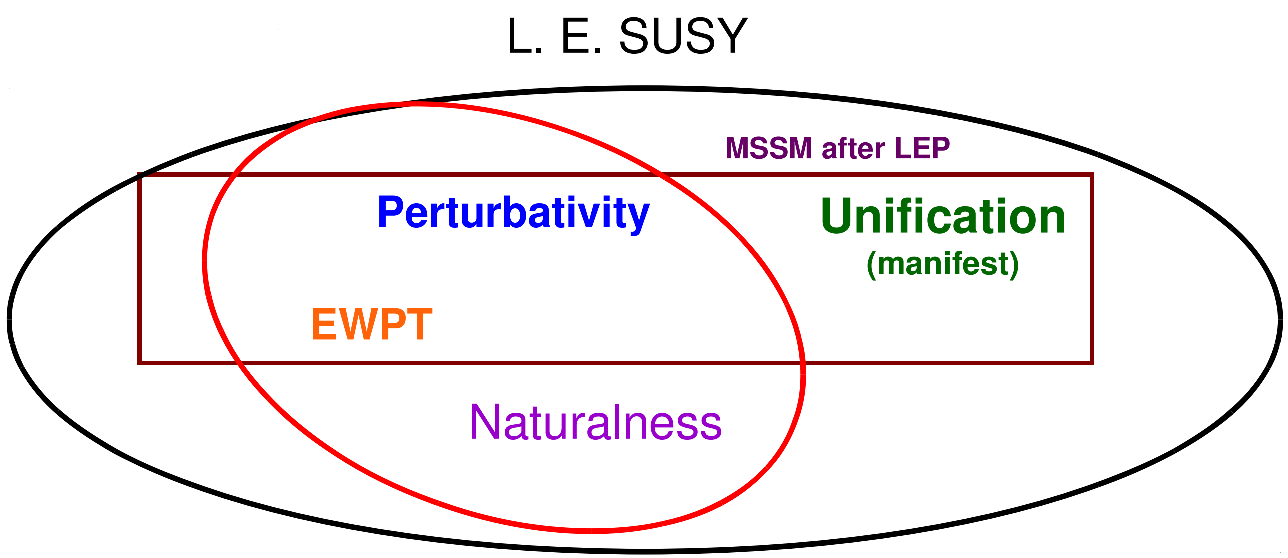

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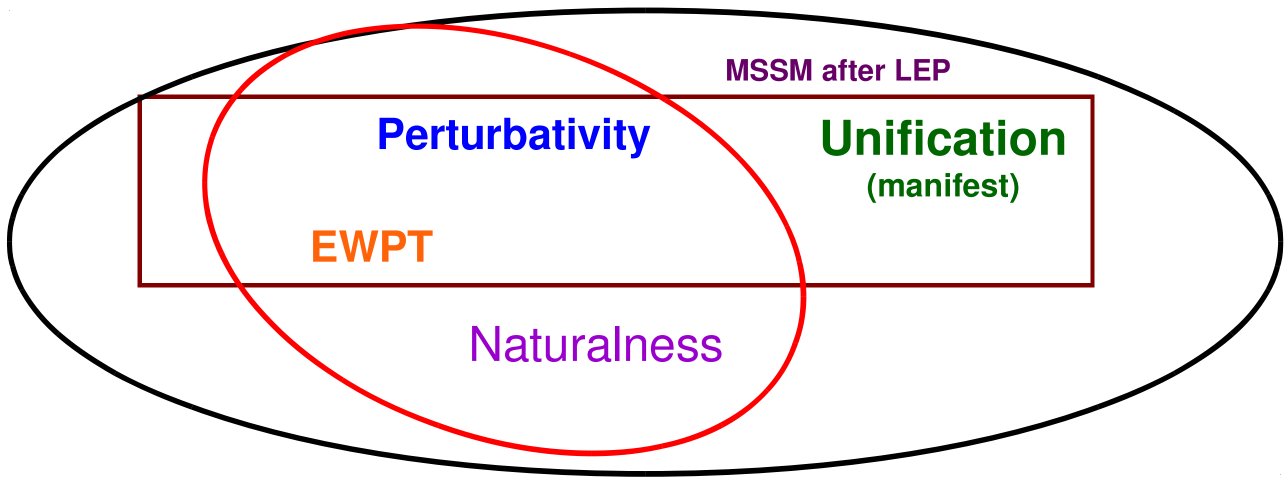

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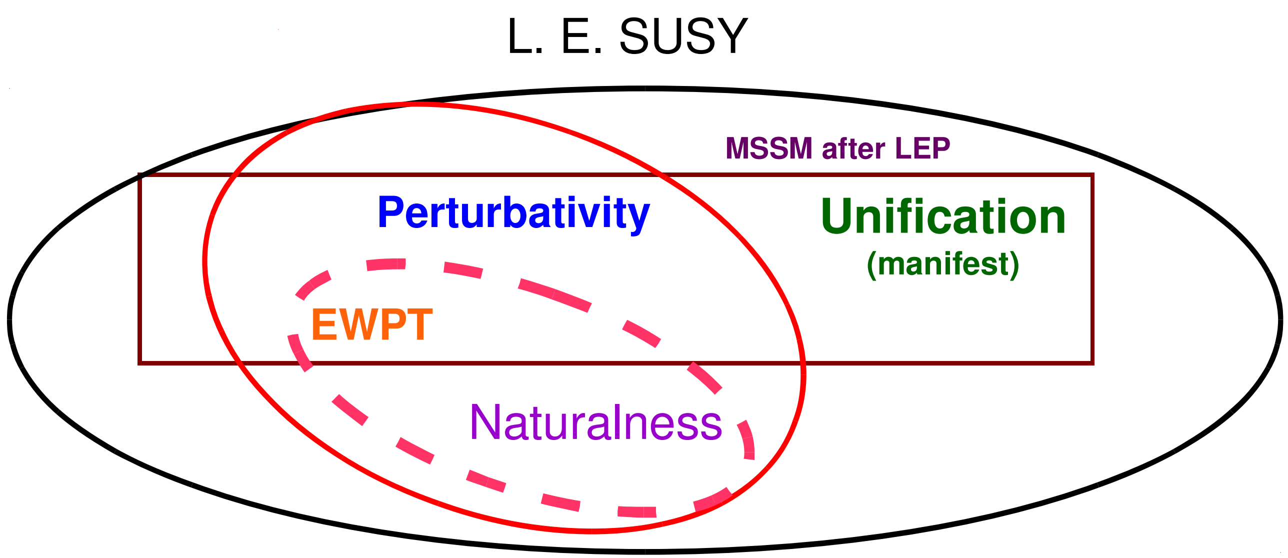

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2/5) Models

(lightest Higgs mass
↔ quartic coupling)

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lightest Higgs mass
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- MSSM: $$m_h \leq m_Z |\cos 2\beta|$$
- Gauge ext U(1): $$m_h^2 \leq \left(m_Z^2 + \frac{g_x^2 v^2}{2(1+\frac{M_X^2}{2M_\phi^2})}\right)\cos^2 2\beta$$

  P. Batra, A. Delgado, E. Kaplan, T. M. P. Tait, (2004)
- Gauge ext SU(2): $$m_h^2 \leq m_Z^2 \frac{g'^2 + \eta g^2}{g'^2 + g^2} \cos^2 2\beta \qquad \eta = \frac{1 + \frac{g_I^2 M_\Sigma^2}{g^2 M_X^2}}{1 + \frac{M_\Sigma^2}{M_X^2}}$$

  P. Batra, A. Delgado, E. Kaplan, T. M. P. Tait, (2004)
  A. Maloney, A. Pierce, J. G. Wacker (2006)
- λSUSY: $$m_h^2 \leq m_Z^2\left(\cos^2 2\beta + \frac{2\lambda^2}{g^2 + g'^2}\sin^2 2\beta\right)$$

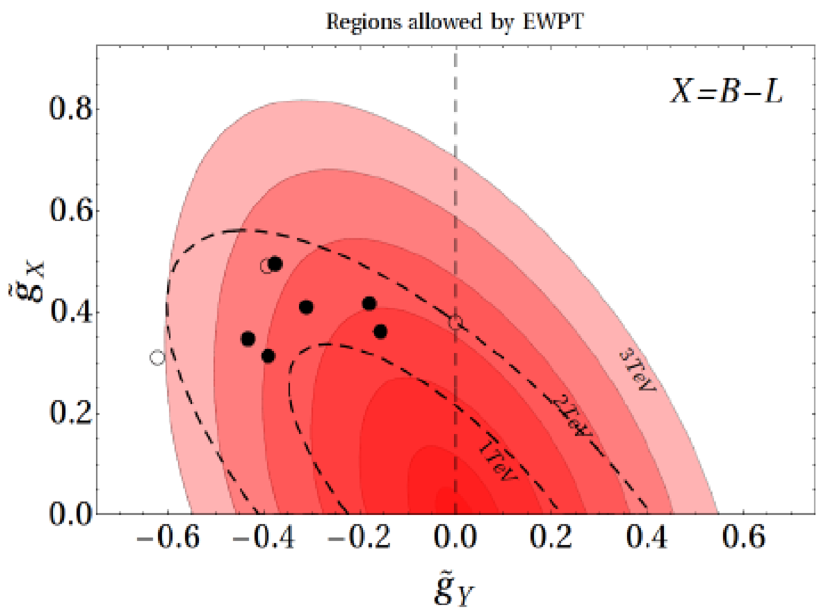
  R. Barbieri, L. J. Hall, Y. Nomura, V. S. Rychkov (2007)

3/5) Electroweak Precision Tests

- Gauge ext U(1): $M_X \gtrsim 5\ \text{TeV}$

☺

$(m_h = 2m_Z)$

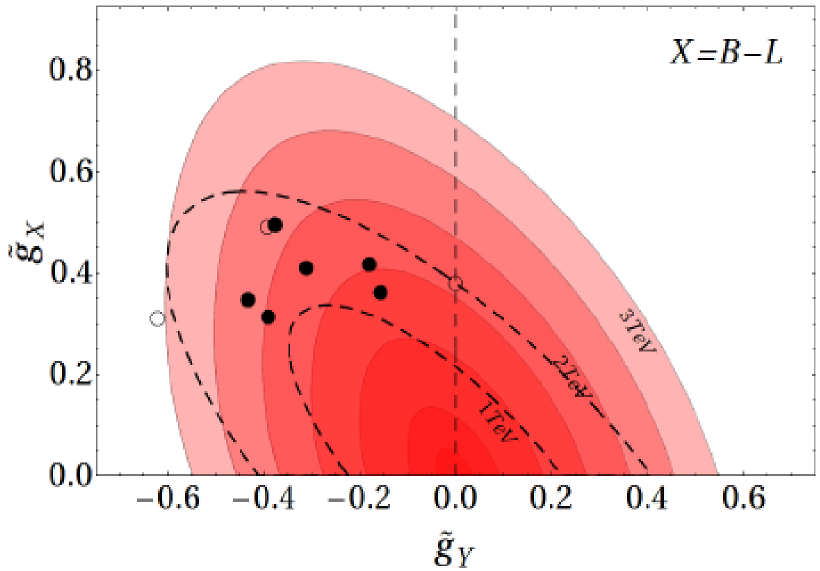


E. Salvioni, A. Strumia, G. Villadoro, F. Zwirner (2010)

3/5) Electroweak Precision Tests

- Gauge ext U(1): $M_X \gtrsim 5\ \text{TeV}$
  $(m_h = 2m_Z)$
- Gauge ext SU(2): $\dfrac{M_X}{5\ \text{TeV}} \gtrsim \dfrac{g_X}{g_Z}$
  (estimate)

Regions allowed by EWPT



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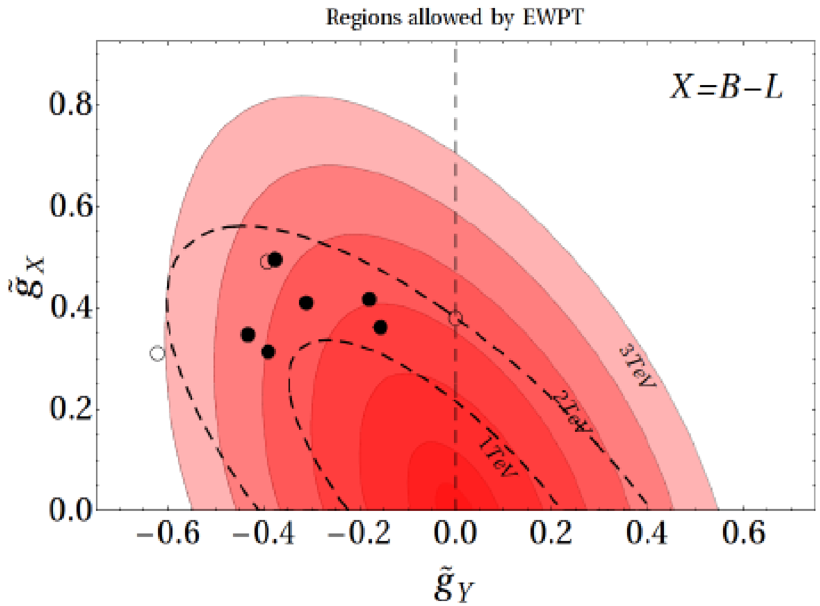

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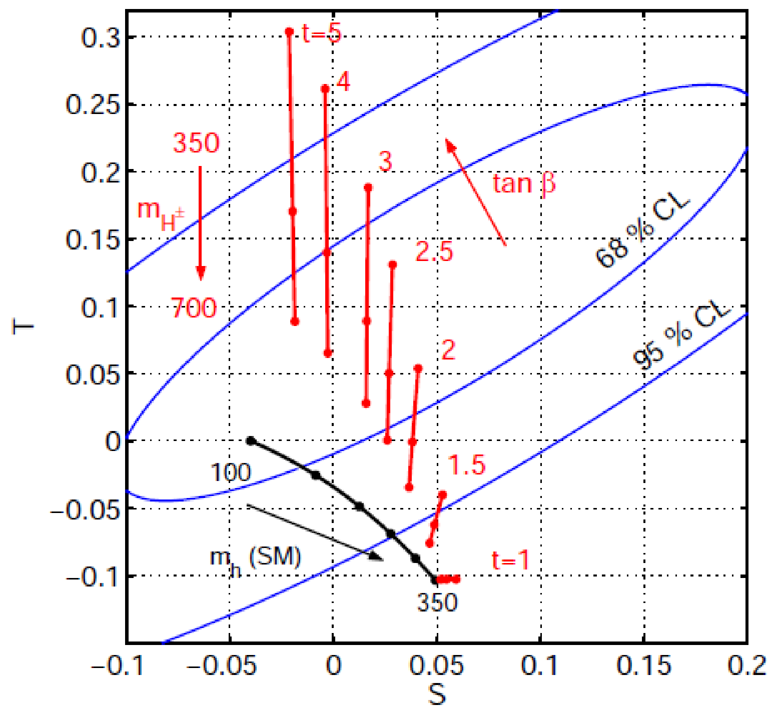
- λSUSY:



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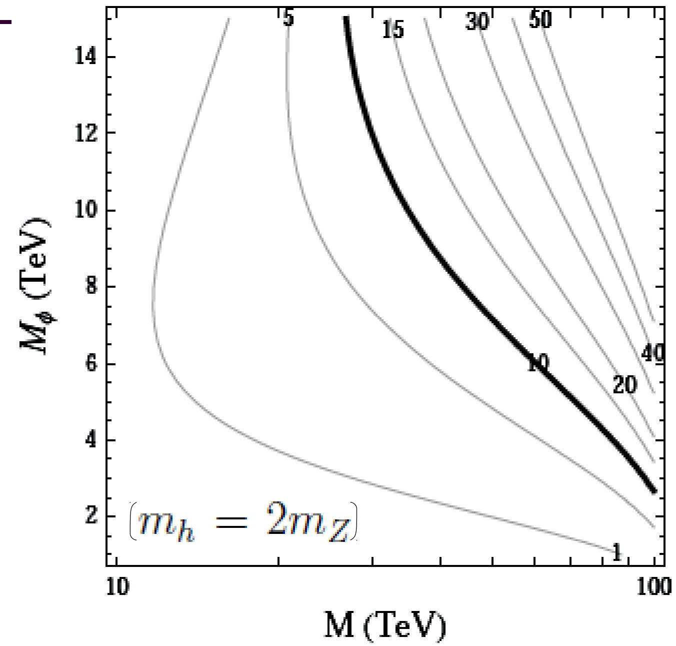
4/5) Naturalness bounds: tree + loop

- Gauge ext U(1):

$$M_X \leq 0.40\, M_\phi$$

+



4/5) Naturalness bounds: tree + loop

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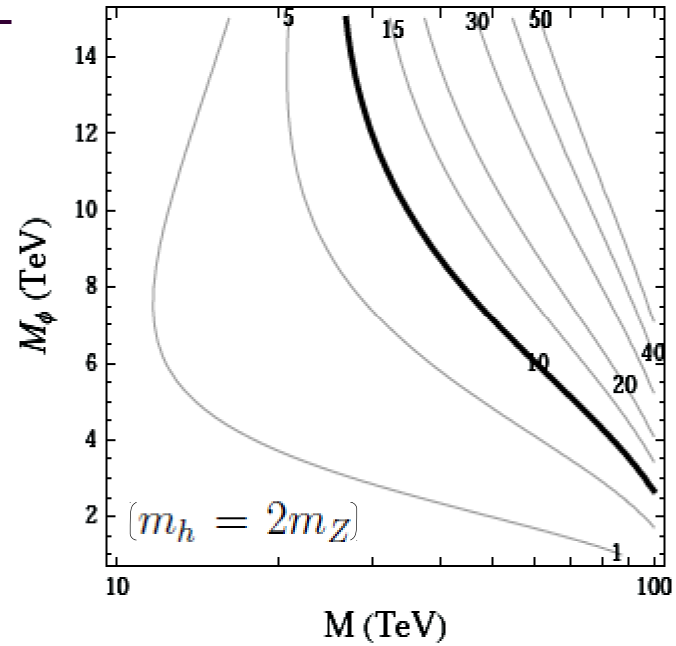
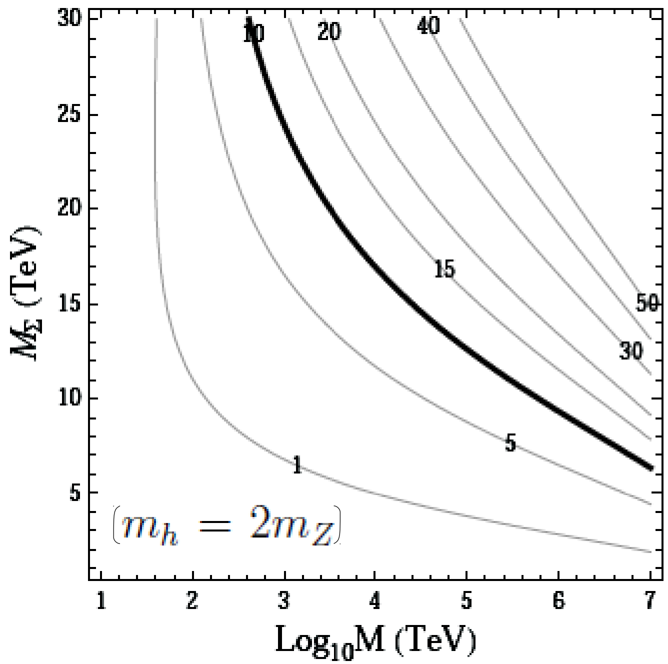


- Gauge ext SU(2):



+ $M_X \leq 0.22 M_\Sigma$

4/5) Naturalness bounds: tree + loop

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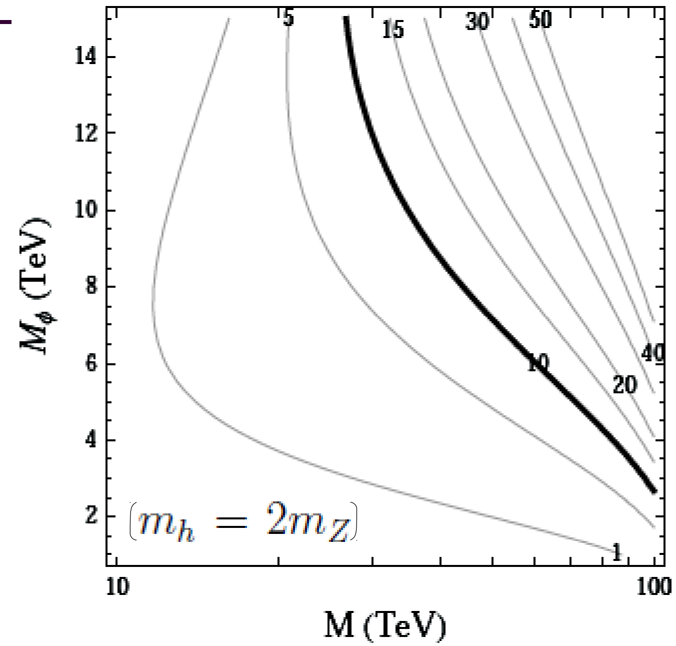

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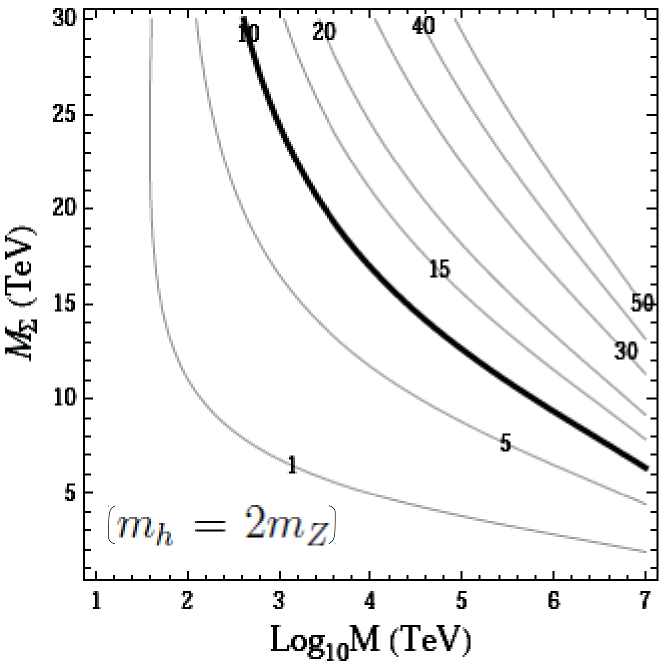


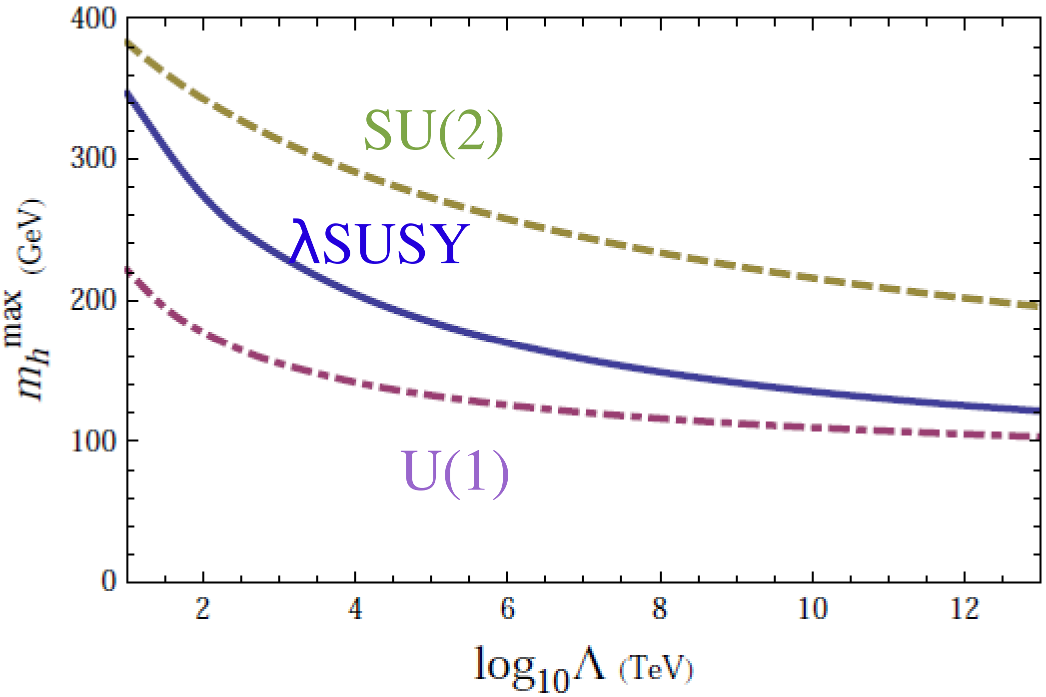
+ $M_X \leq 0.22 M_\Sigma$

- λSUSY: $m_s \lesssim 1$ TeV

  but OK

5/5) Conclusions

From a bottom-up point of wiew, the goal can be achieved.

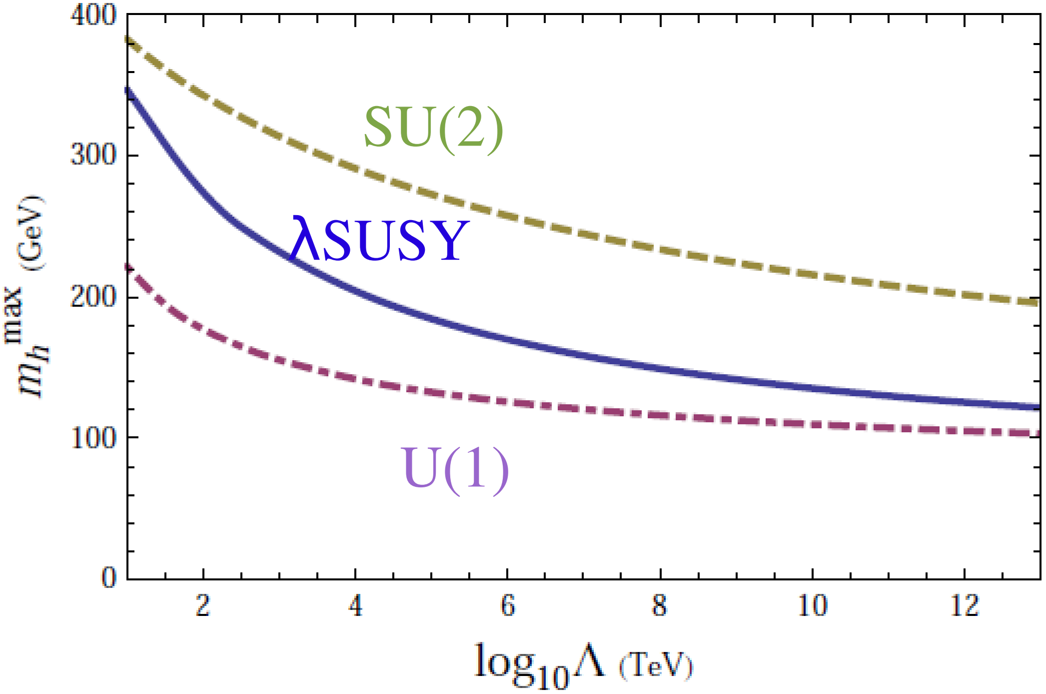


5/5) Conclusions

From a bottom-up point of view, the goal can be achieved.

Price to pay:

1) low Λ
2) low M
3) diff. soft scales
4) need ΔT:



	$m_h^{max}\,/\,m_Z$	Price to pay
$U(1)$	2	(1),(2),(3)
$SU(2)$	2	(3)
$SU(2)$	3	(2),(3)
$SU(2)$	4	(1),(2),(3),(4)
λSUSY	2	—
λSUSY	3	(1)

Backup Slides

B1) Motivations in detail

I) Is SUSY excluded if Higgs boson heavy?

-LEP2: m_h >114 GeV

-Increasing it radiatively:

m_h <115-120 GeV otherwise finetuning!

[for example: S.P.Martin hep-ph/0910.2732]

→ We look for tree level contribution to m_h

II) (If possible) ameliorate flavour problem

Naturalness: $m_z^2 \approx -2\,\mu_u^2$ → $\left|\delta m_{H_u}^2\right| = \Delta \frac{m_Z^2}{2}$

but if: $m_z^2 + .. \approx -2\,\mu_u^2$ then $\left|\delta m_{H_u}^2\right| = \Delta \frac{m_Z^2 + ..}{2}$

Heavier Higgs **allows** ⇒ Heavier 1° and 2° gen. sferm.

B2) Flavour problem: hierarchy

Simplified discussion

- Flavour probl.
  (How to suppress corrections from squark mass matrices and trilinears) → -Alignement / -Degeneracy / -Hierarchy

- Only hierarchy: not enough

$$m_{\tilde{q}_{1,2}} \gtrsim 35\ TeV \quad (\text{from } \Delta S = 2)$$
$$m_{\tilde{q}_{1,2}} \gtrsim 800\ TeV \quad (\text{from } \epsilon_K)$$

- If:

$$\delta^{LL} >> \delta^{RR}, \delta^{LR} \ (\text{or } \delta^{RR} >> \delta^{LL}, \delta^{LR})$$
$$\delta_{12}^{LL} \approx \lambda, \quad \frac{|m_1^2 - m_2^2|}{(m_1^2 + m_2^2)/2} \approx \lambda$$
$$\sin\phi_{CP} \approx 0.3$$
$$\delta_{i3} \approx \frac{m_{\tilde{q}_3}^2}{m_{\tilde{q}_{1,2}}^2}$$

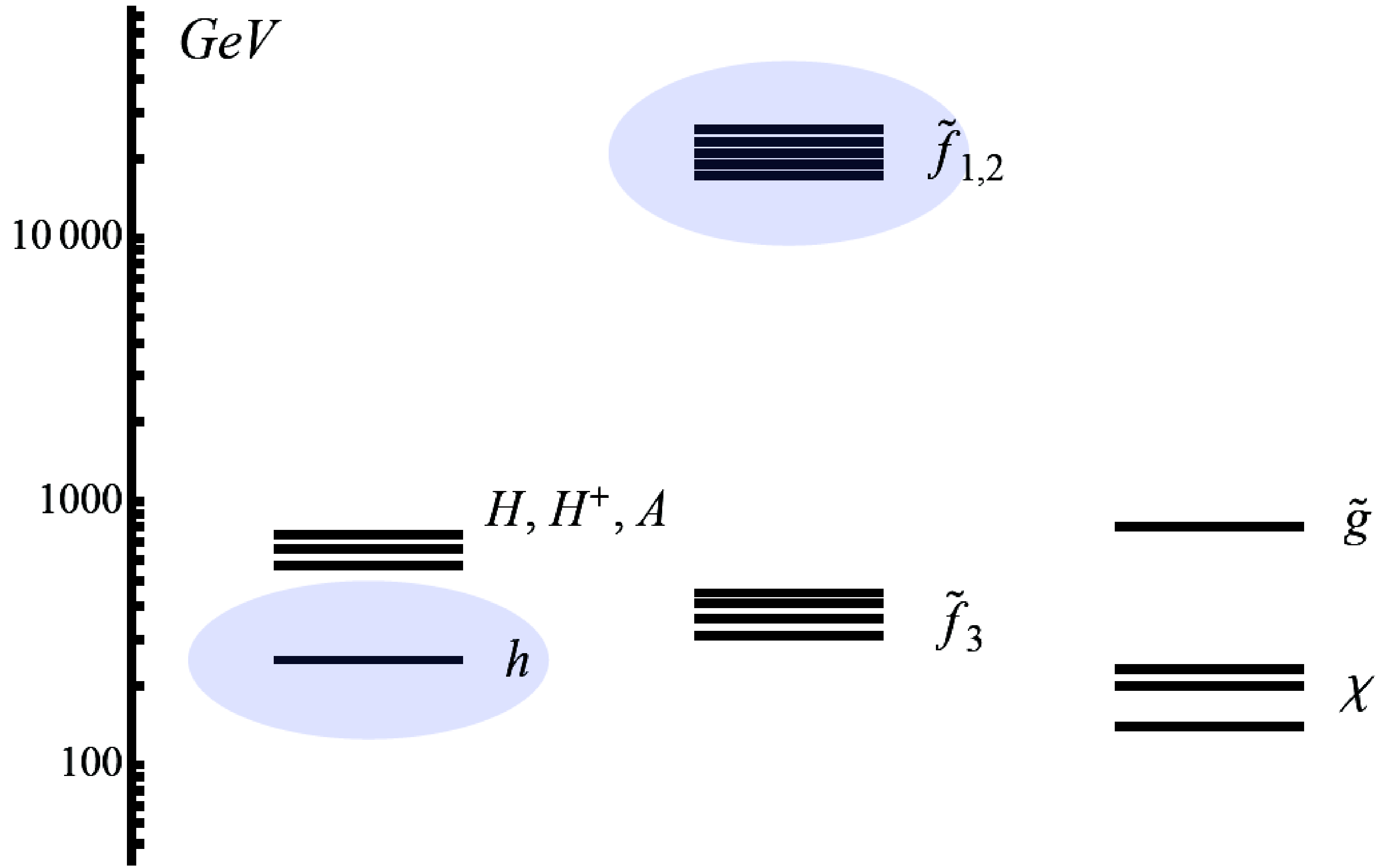
→ Then one can defend:

$$m_{\tilde{q}_{1,2}} \gtrsim 15\ TeV$$

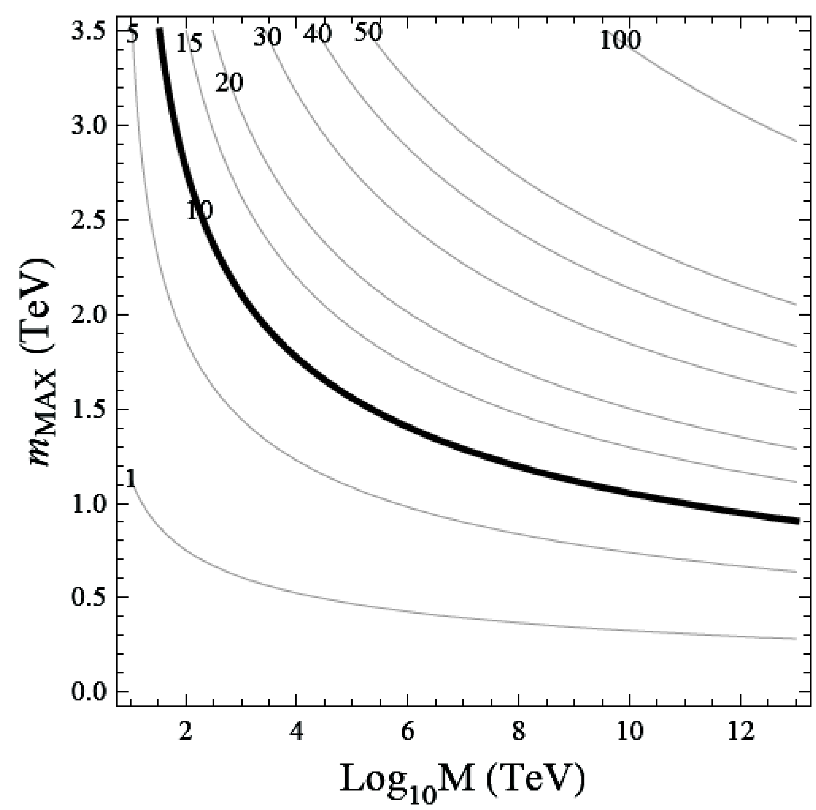
Statement based on the analisys:
G. F. Giudice, M. Nardecchia, A. Romanino, *Hierarchical soft terms and flavour physics*, Nucl Phys B **813** (2009) 156-173.

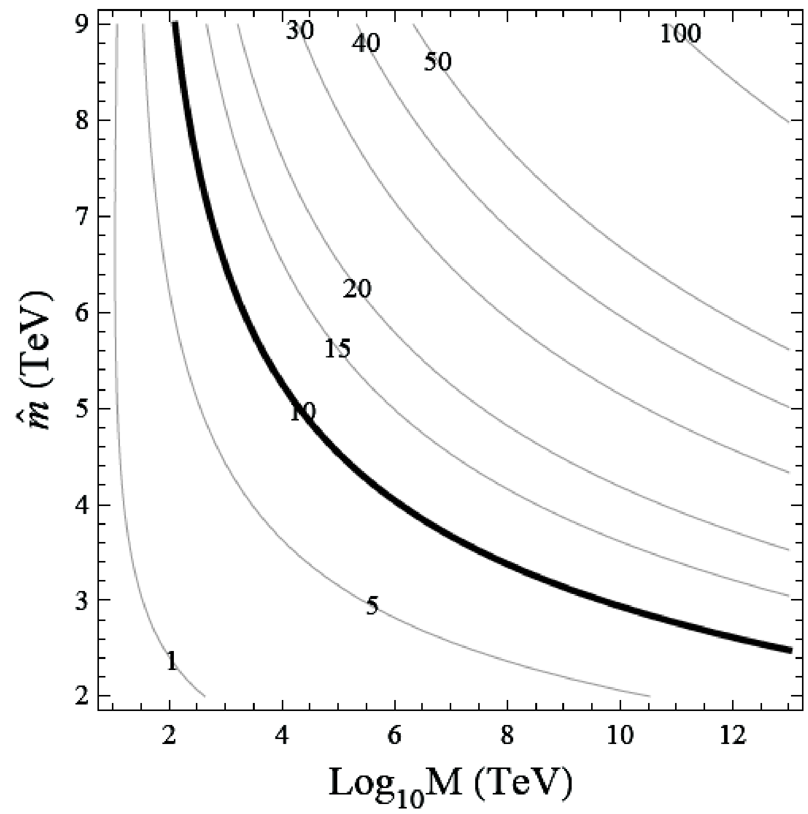
B3) "A Non Standard Supersymmetric Spectrum"

R. Barbieri, E. Bertuzzo, M. Farina, P.L., D. Pappadopulo, IN PREPARATION



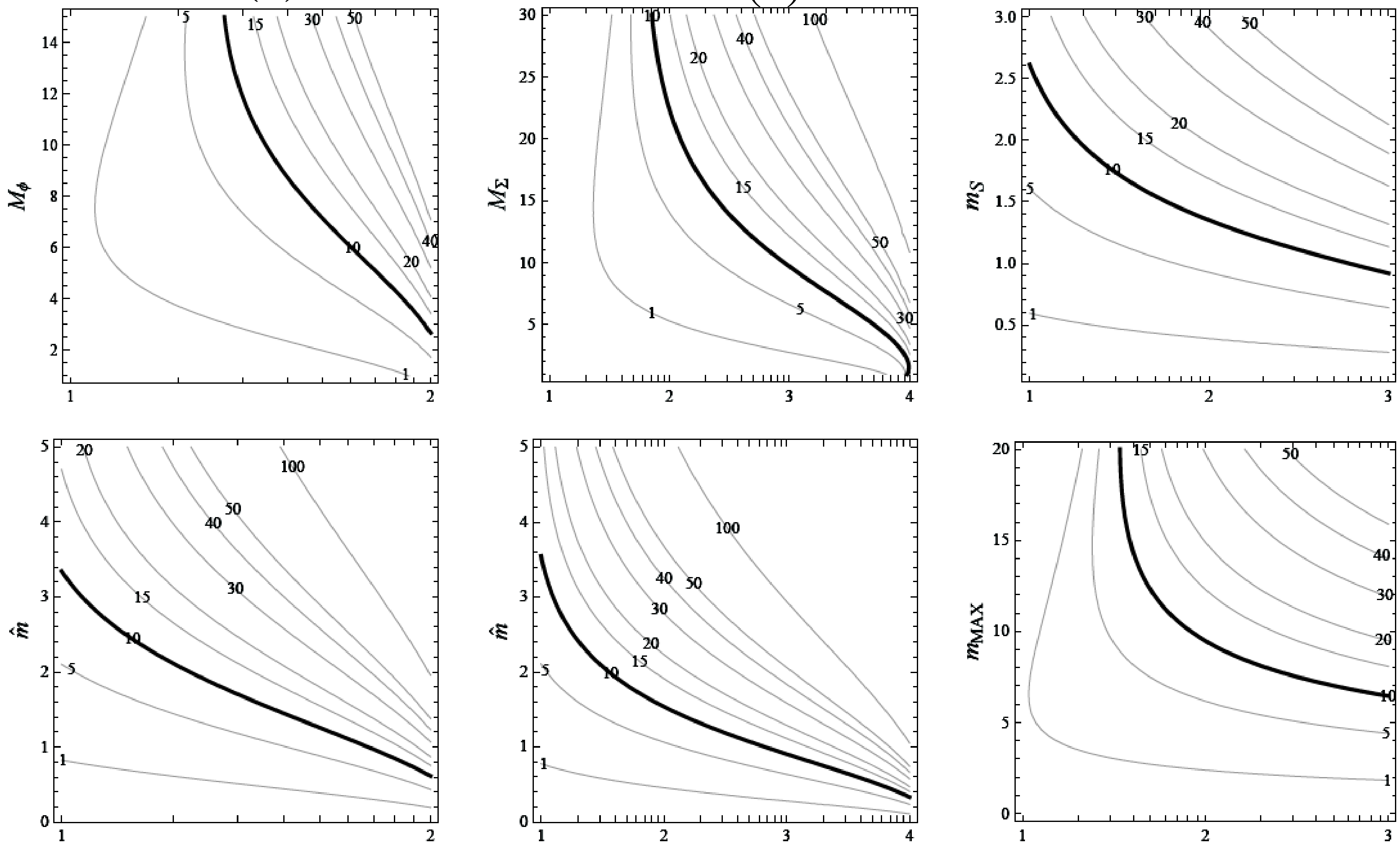
B4) Naturalness in MSSM (1°-2° gen)





B5) Naturalness in Extended Models

U(1) SU(2) λSUSY



P. Batra, A. Delgado, E. Kaplan, T. M. P. Tait, JHEP 02(2004)043, [arXiv:hep-ph/0309149].

B6) Gauge extension U(1)

- Idea: increase D-term: -New gauge group $U(1)_x$

  -Extra scalars s, ϕ, ϕ^c

	ϕ	ϕ^c	H_u	H_d	d	u	Q	e	n	L
Y	0	0	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{3}$	$-\frac{2}{3}$	$\frac{1}{6}$	1	0	$-\frac{1}{2}$
$X = \frac{L-B}{2} + X_\phi$	q	$-q$	0	0	$\frac{1}{6}$	$\frac{1}{6}$	$-\frac{1}{6}$	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$
$Y+X$	q	$-q$	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	0	$\frac{1}{2}$	$-\frac{1}{2}$	0

- Potential for scalars: $V = V_{MSSM} + V_{H\phi} + V_\phi$

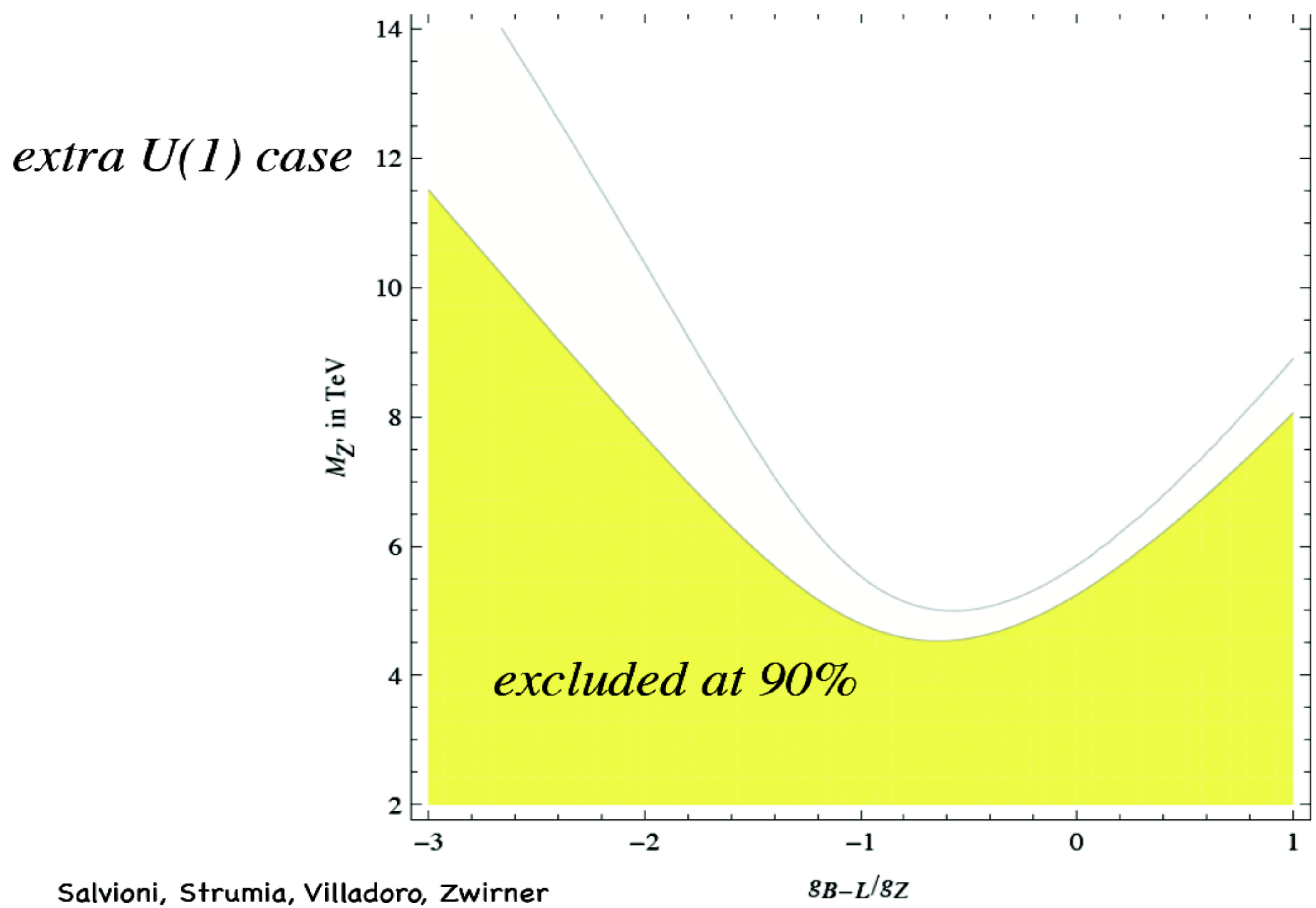
new D-term

$$V_{H\phi} = \frac{1}{2} g_x^2 \left(\frac{1}{2}|H_u|^2 - \frac{1}{2}|H_d|^2 + q|\phi|^2 - q|\phi^c|^2 + .. \right)^2$$

$$V_\phi = \lambda^2 |\phi|^2 |\phi^c|^2 - B(\phi\phi^c + h.c.) + M^2_{(\phi)}|\phi|^2 + M^2_{(\phi^c)}|\phi^c|^2$$

(- Superpotential $W = \lambda\, s\, (\phi\phi^c - w^2)$ + soft terms)

B7) EWPT in U(1) case



Salvioni, Strumia, Villadoro, Zwirner

P. Batra, A. Delgado, E. Kaplan, T. M. P. Tait, JHEP 02(2004)043, [arXiv:hep-ph/0309149].

B8) Gauge extension SU(2)

- Gauge group: $SU(2)_I \times SU(2)_{II} \times U(1)_Y$
- Fields: Σ $(2,2)$, s (singlet), MSSM fields charged under $SU(2)_I$
- Potential of scalar sector: $V = V_{H\Sigma} + V_{\Sigma}$

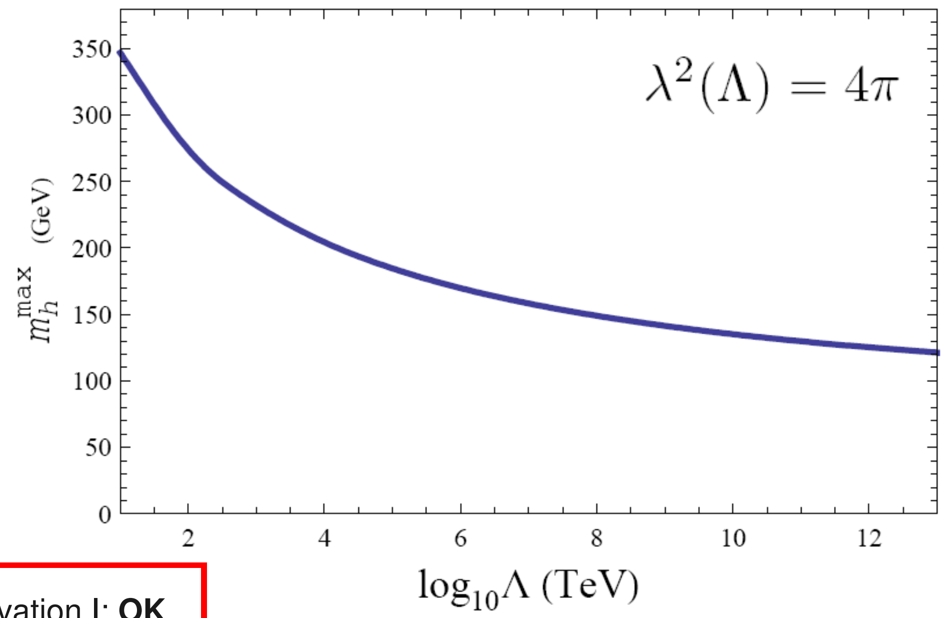
$$\begin{aligned} V_{H\Sigma} &= \mu_u^2|H_u|^2 + \mu_d^2|H_d|^2 + \mu_3^2(H_u H_d + h.c.) \\ &+\frac{1}{2}g'^2\left(\frac{1}{2}|H_u|^2 - \frac{1}{2}|H_d|^2 + ..\right)^2 + \frac{1}{2}g_{II}^2\sum_a \left(\mathrm{Tr}\left[\Sigma T^a \Sigma^+\right]\right)^2 \\ &+\frac{1}{2}g_I^2\sum_a \left(\mathrm{Tr}\left[\Sigma^+ T^a \Sigma\right] + H_u^+ T^a H_u + H_d^+ T^a H_d + ..\right)^2 \end{aligned}$$

Model thoroughly studied in: R. Barbieri, L. J. Hall, Y. Nomura, V. S. Rychkov, [arXiv:hep-ph/0607332].

B9) λSUSY

- Model: add to superpotential: $\lambda S H_u H_d$
  (just one singlet) which takes a vev.
- Minimization of potential → $m_h \leq \lambda v \sin\beta$
- Naturalness constraints on $\hat{m}$ → unchanged! (no additional interactions)
- Running:

$$\frac{d\lambda}{dt} = \frac{\lambda}{16\pi^2}\left(4\lambda^2 + 3y_t^2 - 3g_2^2 - \frac{3}{5}g_1^2\right)$$



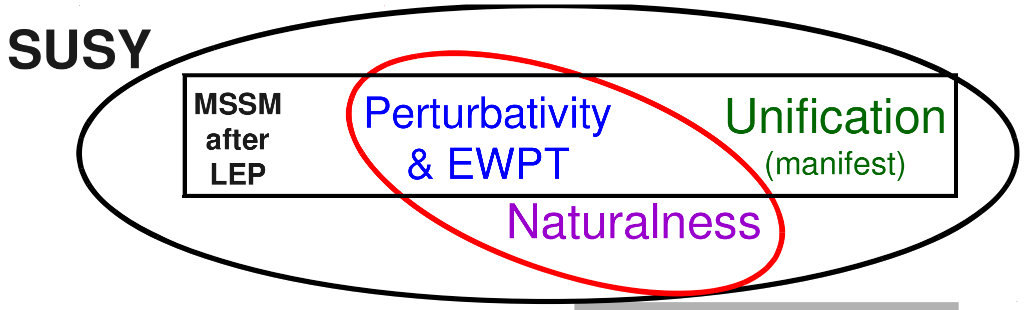
-Large m_h with Λ not so small

-Possible to ameliorate Flavour, for ex. if $m_h = 2m_Z$ and $M \lesssim 100$ TeV

Motivation I: **OK**

Motivation II: **OK!**

B10) Conclusions in words



- There exist extensions of the MSSM in which m_h can be raised at up to 200-300 GeV.
- This often requires low Λ and/or low M.
- <u>Gauge extensions</u>: naturalness and EWPT force low M. The abelian model has low Λ. Sferm. of 1° and 2° gener. are lighter than 2 TeV.
  No improvement in non universal model.
- <u>λSUSY</u>: Λ low (depends on m_h), M unconstrained. Sferm. of 1°-2° gen. can be heavier → flavor problem ameliorated if hierarchy and low M.
- Phenomenology: larger m_h, hierarchical scenarios (MMSSM-like)