AFTER THE FIRST LHC PHASE

TWO MAIN MESSAGES

ARE THEY REALLY SHOCKING?

A HIGGS LIKE PARTICLE DISCOVERED (A PARTICLE THAT LOOKS VERY MUCH LIKE THE ELEMENTARY HIGGS BOSON OF THE SM)

FUNDAMENTAL DISCOVERY BUT…SOME OF US KNEW IT ALREADY 20 YEARES AGO

NO SIGNAL OF NEW PHYSICS

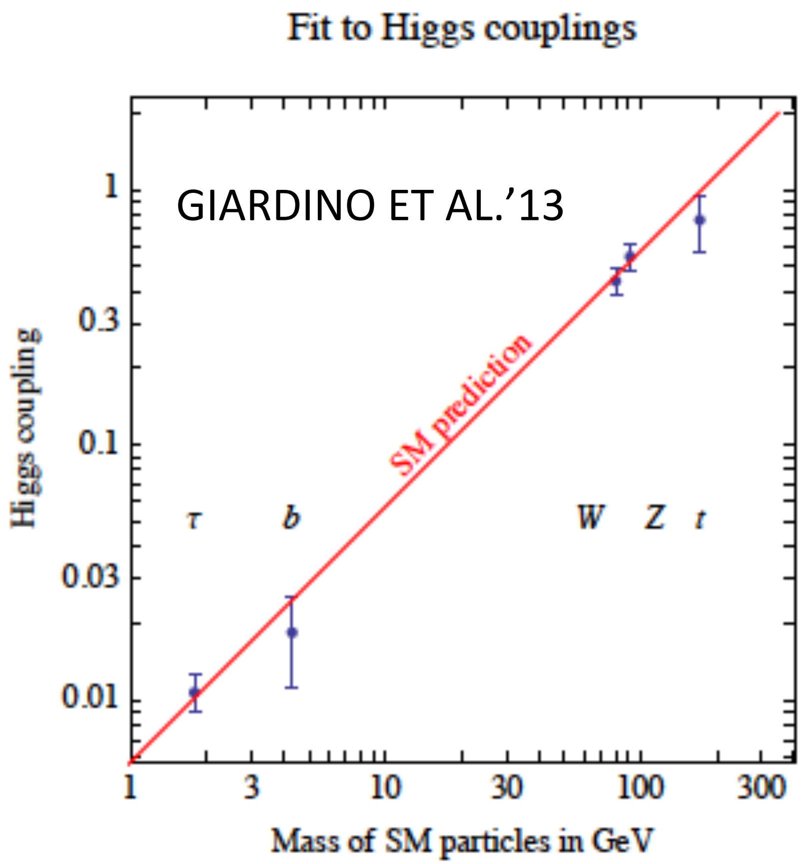
BUT… PRECISION LEP DATA, PRECISION FLAVOUR DATA, GAUGE COUPLING INIF. WERE POINTING IN THAT DIRECTION

ONCE WE KNOW IT FOR SURE,

WHAT DOES IT MEAN FOR PARTICLE PHYSICS?

IMPACT OF THE HIGGS DISCOVERY

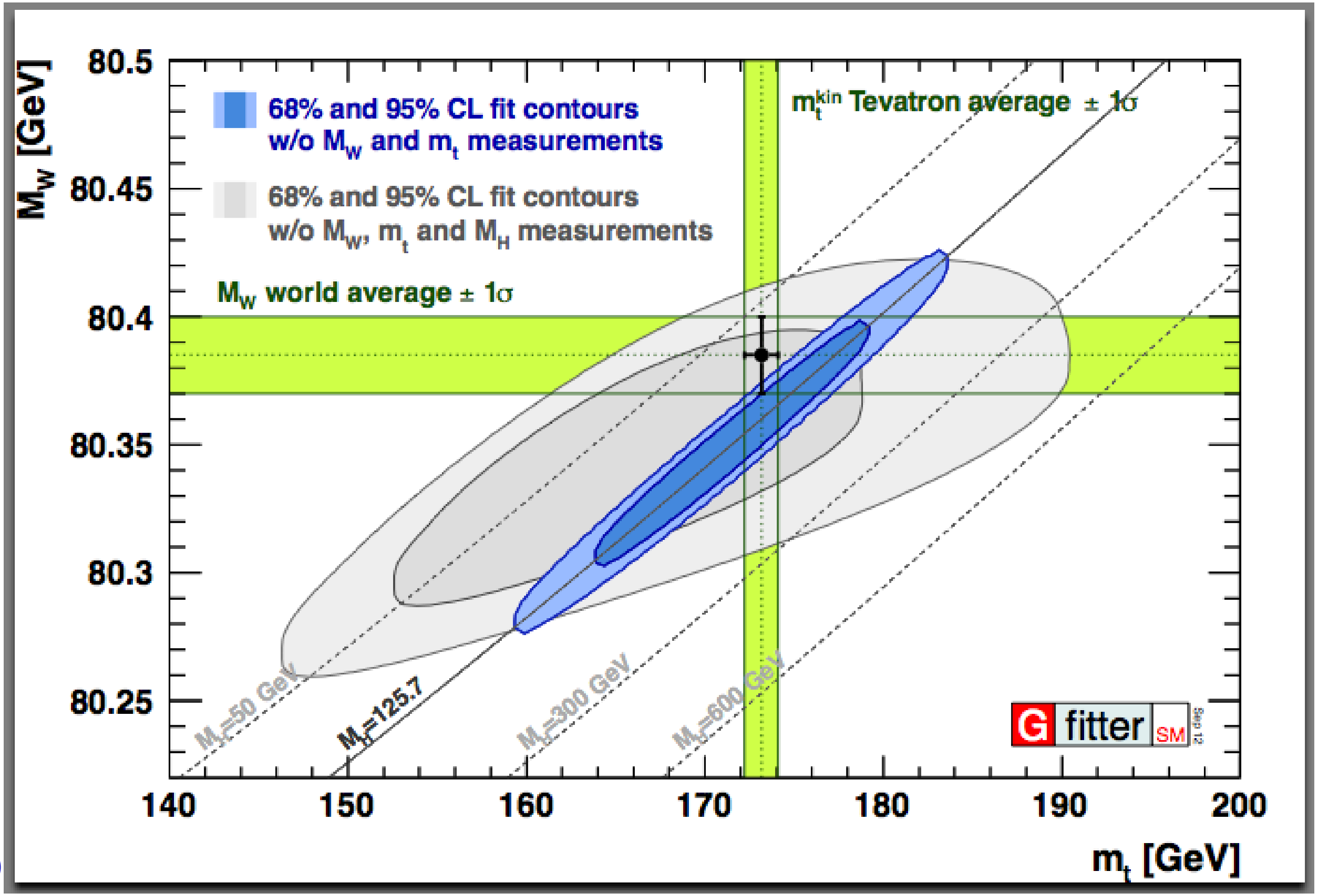
ITS COUPLINGS ARE WITHIN ~20% CONSISTENT WITH THE SM COUPLINGS



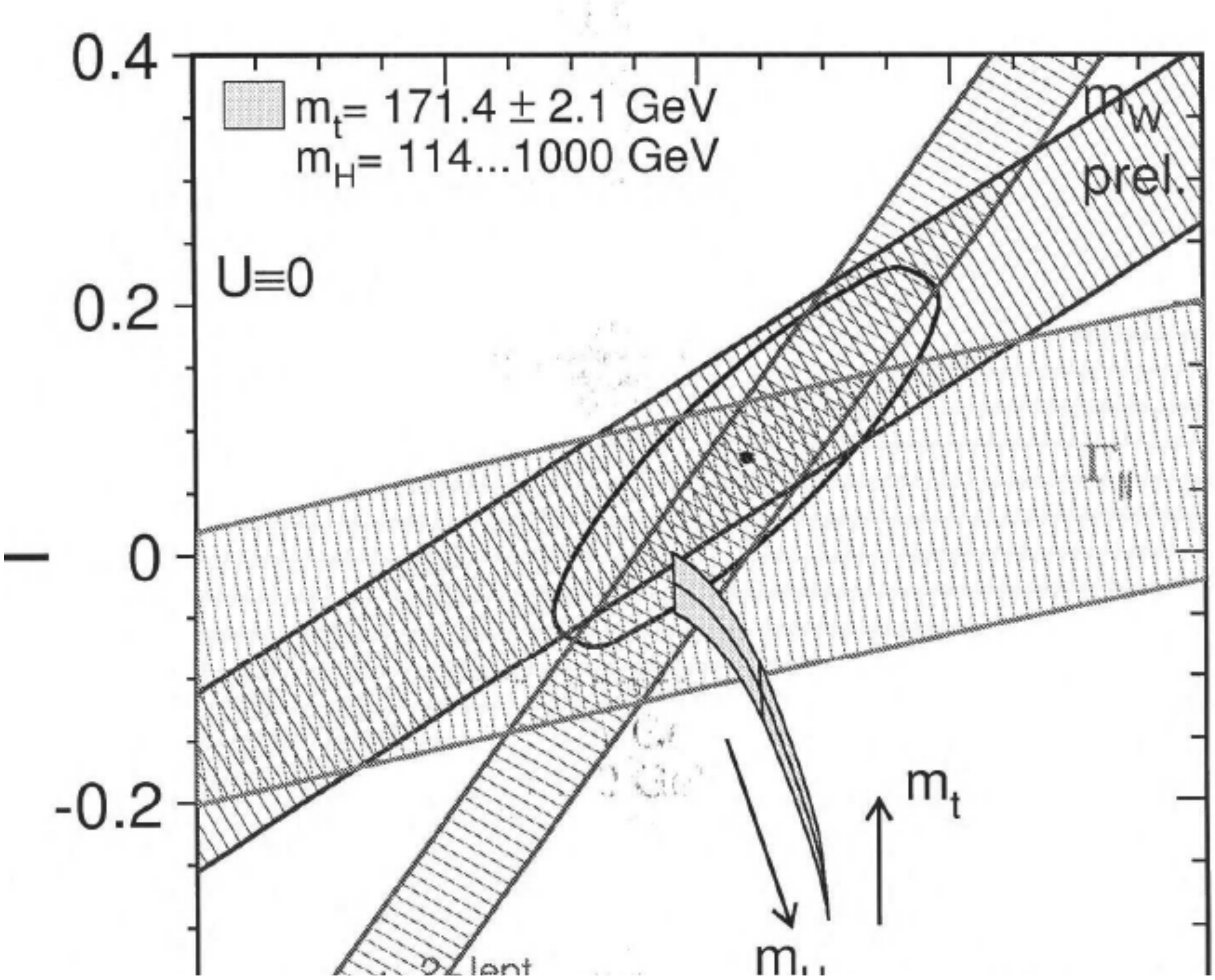
Mh=125 GeV

ITS COUPLINGS ARE WITHIN ~20% CONSISTENT WITH THE SM COUPLINGS➔

➔ CONSISTENCY WITH THE EW PRECISION DATA (FITS IN THE SM); NO CONSPIRACY BETWEEN HEAVY HIGGS AND NEW PHYSICS EFFECTS



68% and 95% CL fit contours
w/o M_W and m_t measurements
68% and 95% CL fit contours
w/o M_W, m_t and M_H measurements
m_t^{kin} Tevatron average ± 1σ
M_W world average ± 1σ
M_H=50 GeV
M_H=125.7
M_H=300 GeV
M_H=600 GeV
G fitter SM
Sep 12
M_W [GeV]
m_t [GeV]
80.5
80.45
80.4
80.35
80.3
80.25
140
150
160
170
180
190
200



0.4
0.2
0
-0.2
T
m_t= 171.4 ± 2.1 GeV
m_H= 114...1000 GeV
U≡0
m_W
prel.
Γ_{ll}
m_t
m_H

➔ THE SM WITH THE SIMPLEST VERSION OF THE HIGGS MECHANISM IS AT LEAST A GOOD EFFECTIVE THEORY

MOREOVER, REMARKABLY

HIGGS SELF-COUPLING

$$\lambda|H|^4 \qquad v = 246GeV \qquad \to \lambda = 0.12$$

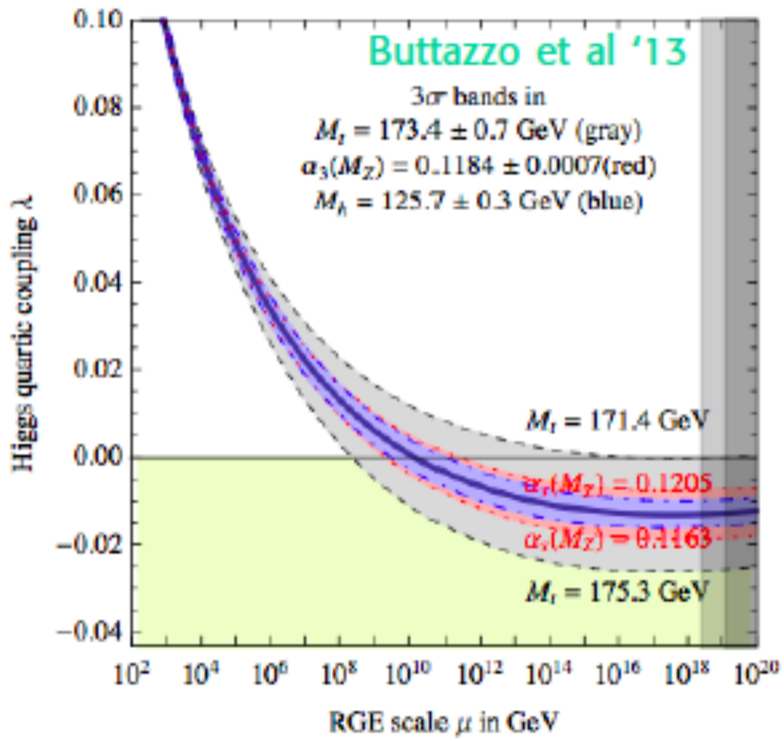
WELL WITHIN PERTURBATIVE REGIME!

A TRIUMPH OF THINKING SIMPLE

VACUUM STABILITY IN SM

$$V = \frac{\lambda(\mu)}{4} h^4$$

$$\lambda_0 = \frac{m_h^2}{4v^2}$$



IN THE ABSENCE OF NEW PHYSICS, FOR $m_h = 125GeV$ THE UNIVERSE BECOMES

METASTABLE AT $\Lambda \approx 10^{10-12} GeV$

BUT WITH SUFFICIENTLY LONG LIFE TIME!

VARIOUS SPECULATIONS ON THE MEANING OF THAT RESULT (ANTHROPIC PRINCIPLE, MULTIVERSE…)

BUT THERE IS SOME PHYSICS BSM (RIGHT-HANDED NEUTRINOS, DARK MATTER..) AND IT MAY CHANGE THE RUNNING OF THE COUPLING

IN ANY CASE,

DONT RUSH TO TOO QUICK CONCLUSIONS ABOUT THE VALIDITY OF THE SM TO VERY HIGH ENERGIES BECAUSE:

HIGGS COUPLINGS VERSUS NEW SCALES!!

$$M = 1 TeV$$ → less than (3- 5) % deviations from the SM couplings

A GUESS BASED THE ABSENCE OF NEW PARTICLES SO FAR:

WITH MORE DATA, THE PROPERTIES OF THE HIGGS WILL GET CLOSER TO THE SM PREDICTIONS;

VERY CHALLANGING: DEVIATIONS MAY BE OF THE ORDER OF THE PRESENT UNCERTAINITIES IN THE SM PREDICTIONS

MSSM AS AN ILLUSTRATION

$$g_{hVV} = \sin(\beta - \alpha)$$

$$g_{htt} = \frac{\cos\alpha}{\sin\beta} \qquad g_{hbb} = -\frac{\sin\alpha}{\cos\beta}$$

DECOUPLING LIMIT: $\alpha = \beta - \pi/2$

------→ SM COUPLINGS

$$\delta g \approx O(\frac{m_Z^2}{m_A^2})$$

COMPOSITE HIGGS MODELS

$$g_{VVh} = g_{VVh}^{SM}\sqrt{(1 - \frac{v^2}{f^2})}$$

NO MATTER HOW CHALLANGING IT MAY BE
TO SEE BSM PHYSICS THAT WAY,

PRECISION HIGGS (AND TOP) PHYSICS
LOOKS NOW LIKE A MUST!

(ILC?)

WHAT ABOUT OTHER „TOOLS" IN SEARCHING FOR BSM PHYSICS?

- DIRECT SEARCHES FOR NEW PARTICLES:

MORE SCALARS IN THE HIGGS SECTOR (2HDM, MSSM, NMSSM…),
EVEN LIGHTER THAN THE „HIGGS" BUT „WEAKLY COUPLED" ?
SUPERPARTNERS? HEAVY FERMIONS? SPIN 1 RESONANCES?

- FLAVOUR PHYSICS

- DARK MATTER SEARCHES

STRATEGICLY, THOSE „TOOLS" MAY TURN OUT MORE FRUITFUL THAN PRECISION HIGGS PHYSICS BUT SHOULD NOT REPLACE IT.

WHAT IS THE IMPACT OF THE FIRST LHC PHASE ON THOSE „TOOLS"?

GIVEN THAT APPARENT FINAL SUCCESS OF THE SM AND THE ABSENCE OF ANY EVIDENCE FOR NEW PARTICLES (SO FAR)—

HAS THE CASE FOR BSM PHYSICS CHANGED?

HAVE WE LOST OUR GUIDING PRINCIPLE BASED ON
THE (UN)NATURALNESS OF THE SM HIGGS POTENTIAL ?

THE MOTIVATION REMAINS INTACT: IT IS
THE QUESTION ABOUT THE ORIGIN OF THE FERMI CONSTANT

CAN THE W MASS BE SENSIBLY CALCULATED IN A DEEPER THEORY?
CAN WE „DERIVE" EWSB?

NATURALNESS – a vague concept

SM IS A RENORMALISABLE THEORY.

Thus if one ignores the hierarchy problem it is completely finite and predictive
If you do not care about fine tuning you are not punished!!

(GUIDO ALTARELLI)

ONLY WHEN YOU CARE TO PREDICT M_W , YOU FACE THE QUESTION!

ANY SHORT DISTANCE PHYSICS THAT COUPLES TO THE HIGGS (RH NEUTRINO, GUT PARTICLES..) WOULD INTRODUCE QUADRATIC SENSITIVITY OF M_W TO THOSE SCALES

UNLESS… WE DO SOMETHING ABOUT THAT

SO, CAN WE CALCULATE THE FERMI CONSTANT OR IT IS A FREE PARAMETER OF THE THEORY AND WE MUST TAKE IT FROM EXPERIMENT ?

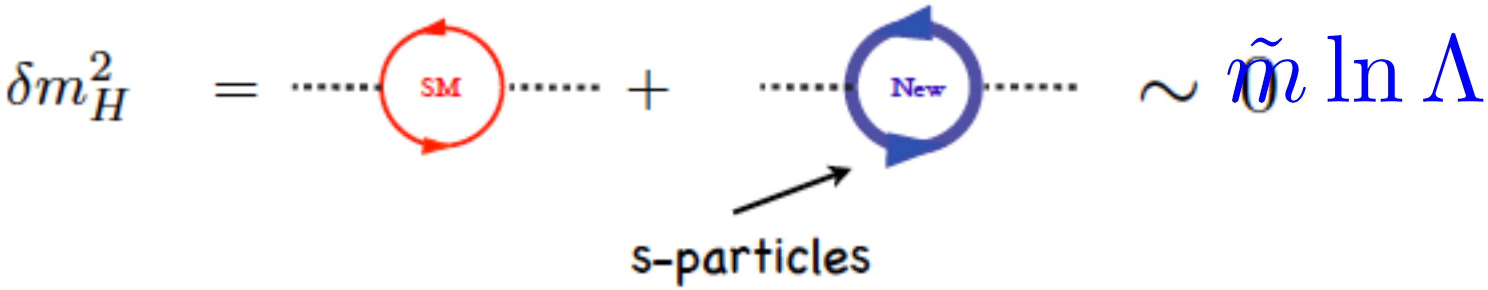
WITH THE ABOVE GUIDELINE, THERE ARE TWO MAIN DIRECTIONS:

SUPERSYMMETRY

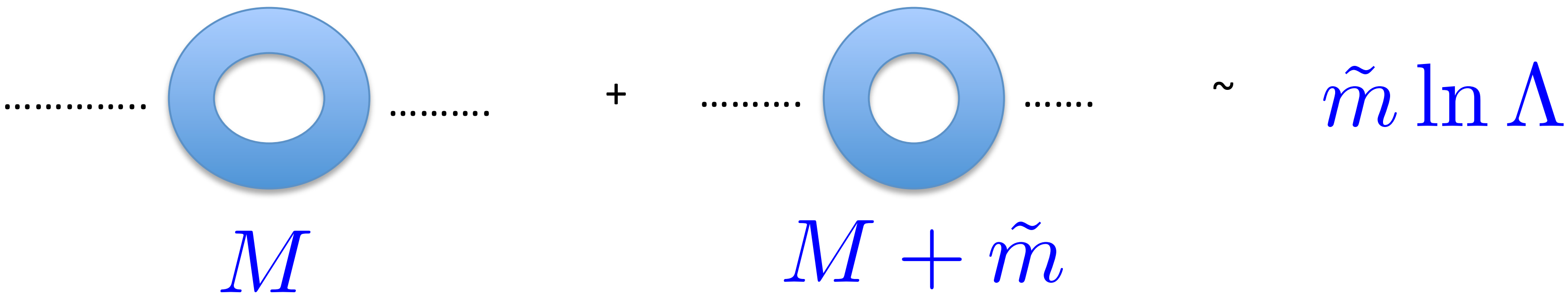
COMPOSITE HIGGS MODELS (HIGGS DOUBLET AS A NAMBU- GOLDSTONE BOSON OF A NEW STRONG SECTOR, LARGE EXTRA DIMENSIONS, DECONSTRUCTION…)

ALSO, CLASSICAL SCALE INVARIANCE AND
A REVIVAL OF THE COLEMAN-WEINBERG EWSB BY DIMENSIONAL TRANSMUTATION; IN ATTEMPTS OF PREDICTING THE FERMI CONSTANT IN SM+RH NEUTRINOS + DARK MATTER

Supersymmetry

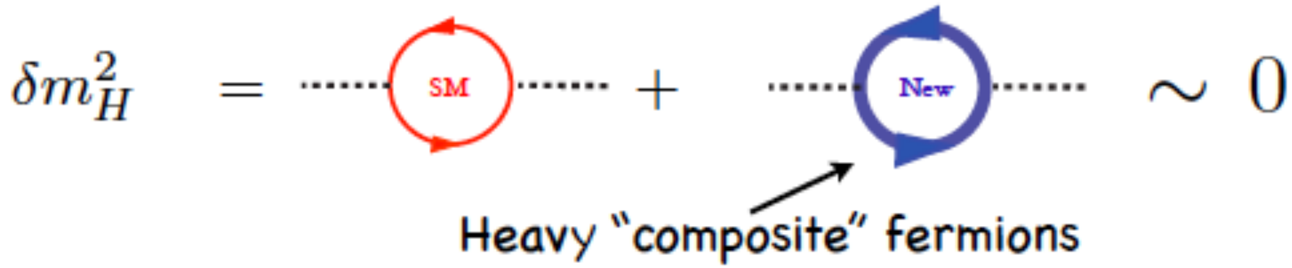


UNIQUE FEATURE:
ALSO CANCELLATION OF QUADRATIC SENSITIVITY TO MUCH HIGHER SCALES



The Higgs boson as a pseudoGolsdtone

(like the π in QCD)



SUPERSYMMETRY **COMPOSITE HIGGS**

BOTH:

- **LINK THE FERMI SCALE TO THE LARGE TOP QUARK YUKAWA COUPLING AND NEW MASS SCALES IN A PERTURBATIVE WAY**
- **CAN ACCOMMODATE 125 GeV MASS**

COMPOSITE MODELS ARE IN PRINCIPLE DOING WELL FOR THE HIGGS POTENTIAL AND 125 GeV, AS GOOD AS SUPERSYMMETRY

BUT,

A LOT OF ARBITRARINESS ,

NO EASY UV COMPLETIONS

RENORMALISABILITY of the SM – NO LONGER AN ISSUE?

ALL THAT CAN BE CONFRONTED WITH THE WELL KNOWN VIRTUES OF SUPERSYMMETRY

THE PROBLEM IS THAT BOTH LOOK A BIT FINE TUNED NOW

STILL, WE HAVE PLENTY OF MODELS THAT REDUCE FINE TUNING FROM 10^{14}

TO 10^2 OR 10^3. IS IT MUCH WORSE THAN 10?

NATURALNESS AT MORE FUNDAMENTAL LEVEL,
E.G. IN THE THEORY FOR SOFT TERMS?

NATURALNESS?- YES, BUT PERHAPS ONE SHOULD BE MORE OPEN MINDED.

THIS SEEMS TO BE THE LESSON FROM THE LHC. CERTAINLY A CHANGE OF PERSPECTIVE BUT THE PREVIOUS ONE WAS NOT BASED ON ANY STRONG ARGUMENTS.

MOREOVER, SIMPLICITY AND PERTURBATIVITY PUTS COMPOSITE MODELS A BIT IN DEFENSIVE??

BEING MORE RELAXED ON NATURALNESS,

CONSTRAINTS FROM 125 GeV HIGGS

COMPOSITE: GENERIC PREDICTION IS

1)A LIGHT (1 TeV) FERMION

2)NARROWER HIGGS BOSON AND WEAKER SIGNAL STRENGTH

$$R = \sigma \times BR/(\sigma \times BR)_{SM}$$

FOR ALL CHANNELS

This is because the Higgs couples non-linearly and the coupling to the SM particles is suppressed by

$$\xi = \sqrt{(1 - v^2/f^2)}$$

(for fermions more model dependent but also suppressed)

BUT THE LATTER EFFECTS MAY BE VERY TINY

LESSONS FROM $M_h \approx 125 GeV$ FOR SUSY

MSSM

- WE ARE BOTHERED BY ABOUT O(5 GeV) „TOO HIGH" MASS
- IN MSSM WITH Msusy=1 TeV, LARGE LEFT-RIGHT STOP „MIXING" NEEDED $|X_t|/M_{\mathrm{SUSY}} = \sqrt{6}$
- FOR $|X_t|/M_{\mathrm{SUSY}} = 1$ ONE NEEDS $M_{\mathrm{SUSY}} \approx 5 TeV$

NMSSM? CAN BE MORE „NATURAL"…

NMSSM AS A SOURCE OF O(5 GeV) CORRECTION?

$(\hat{s}, \ \hat{h})$ MIXING EFFECTS

ENHANCED FOR b-PHOBIC s

OR MSSM WITH STRUCTUREFUL (FLAVOURFUL?) SOFT TERMS AT UV

SEVERAL SOURCES OF SUPERSYMMETRY BREAKING

- **SINGLET AND NON-SINGLET F-TERMS (CHARGED UNDER SM AND/ OR FLAVOUR GAUGE GROUPS)**

- **GRAVITY + ANOMALY MEDIATION (COMPRESSED GAUGINO SPECTRUM-GAUGE COUPLING UNIFICATION,**

- **GEOMETRICAL SEQUESTERING OR D-TERM BREAKING --→ INVERTED HIERARCHY OF SFERMION MASSES?**

THAT BRINGS US TO FLAVOUR PHYSICS…..

FLAVOUR PHYSICS- SENSITIVE TO HIGH SCALES

	SM	PRESENT EXP BOUND	
$\mu \to e\gamma$	10^{-13}	10^{-54}	
$EDMS$ NEUTRON	10^{-26}	10^{-32}	
ELECTRON		?	
$K_L \to \pi^0 \nu\bar{\nu}$	10^{-8}	10^{-11}	ANDRZEJ BURAS' TABLE
$K^+ \to \pi^+ \nu\bar{\nu}$		3x SM	
$B_d \to \mu^+\mu^-$		5xSM	
$B_S \to K^* \nu\bar{\nu}$		2xSM	
$t \to c\gamma$			

LET'S BE AMBITIOUS AND TRY TO EXPLAIN THE FERMION MASS SPECTRUM

New sources of FCNC and CP violation are controlled by the proposed theory of fermion masses; FCNC problem is usually substantially ameliorated.

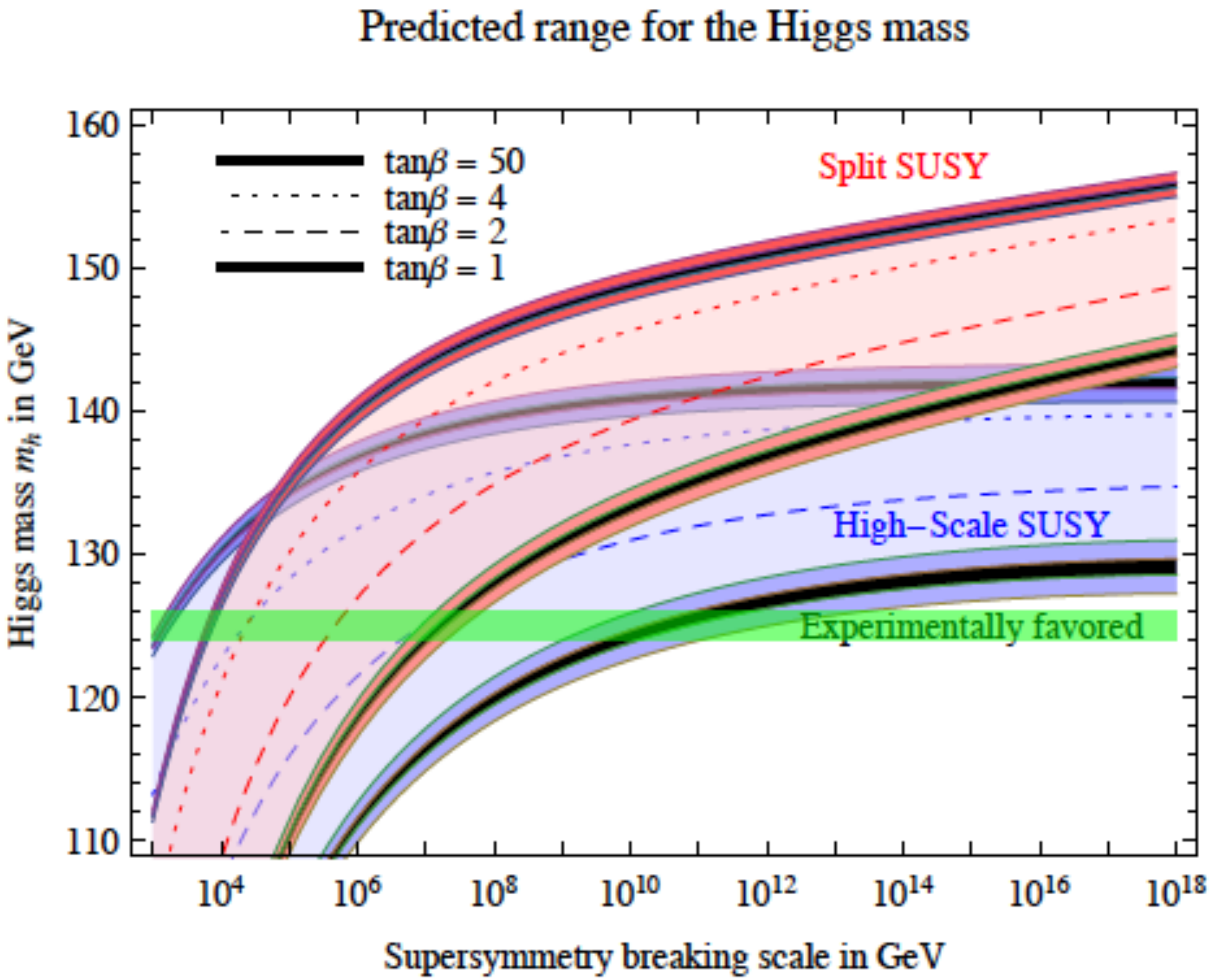
LINKING NATURALNESS IN SUPERSYMMETRY TO FLAVOUR PHYSICS?

„GOOD" FERMION MASS MODELS HINT TO INVERTED SFERMION MASS HIERARCHY, IF STOPS ARE TO REMAIN LIGHT

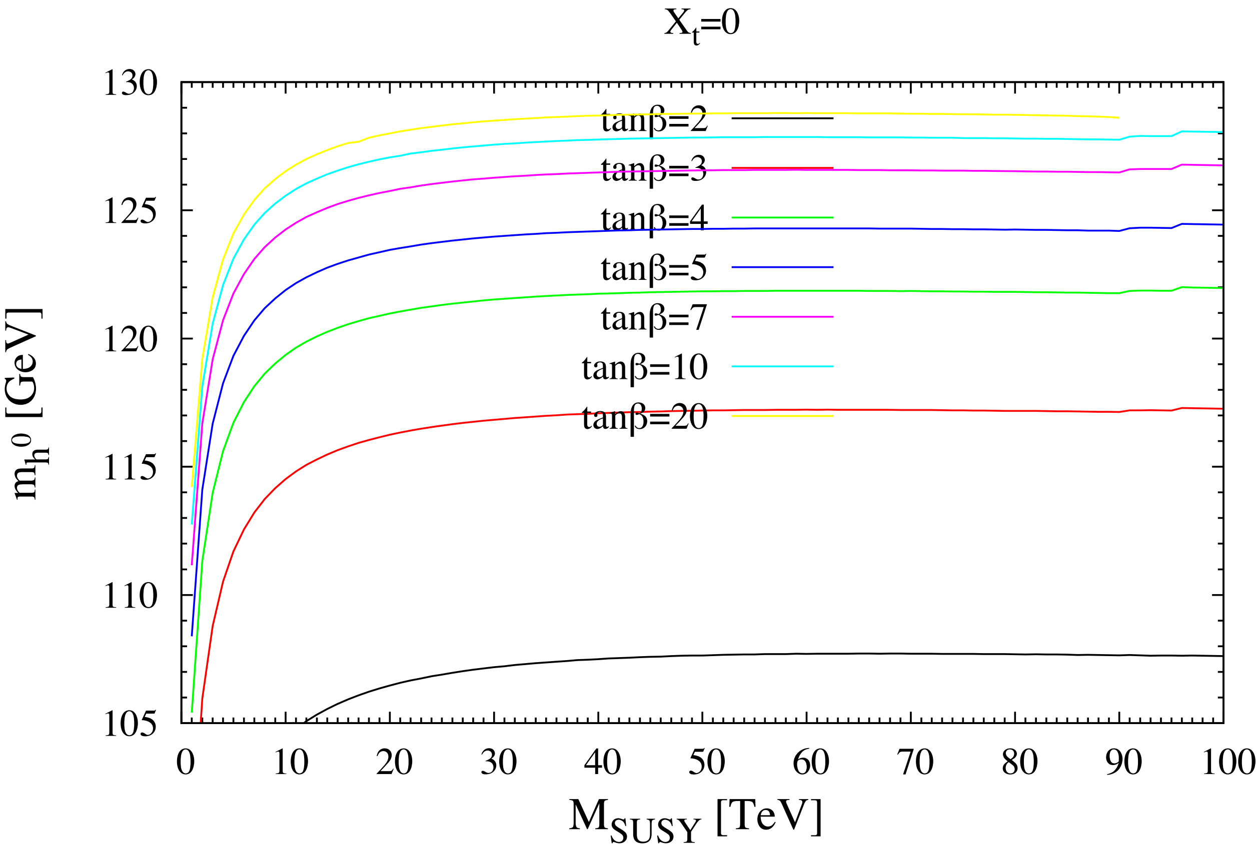
D-TERM MASS SPLITTING BETWEEN SFERMION FAMILIES AT HIGH SCALE

UPPER BOUNDS ON THE SUPERSYMMETRIC SPECTRUM

OVERSHOOTING THE HIGGS MASS!



Predicted range for the Higgs mass
tanβ = 50
tanβ = 4
tanβ = 2
tanβ = 1
Split SUSY
High−Scale SUSY
Experimentally favored
Higgs mass m_h in GeV
160
150
140
130
120
110
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
Supersymmetry breaking scale in GeV



X_t=0
130
125
120
115
110
105
0
10
20
30
40
50
60
70
80
90
100
m_h^0 [GeV]
M_SUSY [TeV]
tanβ=2
tanβ=3
tanβ=4
tanβ=5
tanβ=7
tanβ=10
tanβ=20

SUMMARY

NO REASON YET TO:

- GIVE UP THE QUESTION ABOUT THE ORIGIN OF THE FERMI SCALE AS A GUIDING PRINCIPLE FOR THE BSM PHYSICS*
- TO RUSH TO THE LANDSCAPE PICTURE FOR THE FERMI SCALE

THE EXPERIMENTAL EXPLORATION OF THE TeV SCALE IS STILL IN A VERY PRELIMINARY STAGE

MEANWHILE:
INCREASE PRECISION OF THE SM PREDICTIONS AND EXP RESULTS FOR THE h;
FILL IN EXPERIMENTAL LOOPHOLES LIKE E.G. A LIGHT SCALAR SEARCH

*) **SHOULD WE BECOME MORE OPEN MINDED WITH RESPECT TO THE QUANTIFICATION OF THE CONCEPT OF NATURALNESS AND IN SEARCHING FOR NON-MINIMAL MODELS**

FLAVOUR PUZZLE- MASSES, MIXING?

EVERYTHING ANTHROPIC?!

DARK MATTER?

DATA, DATA, DATA, PLEASE

SUSY?

COMPOSITE?

SM+RH NEUTRINOS +DARK MATTER + COLEMAN-WEINBERG

END

NON-LINEAR PARAMETRIZATIONS OF GOLDSTONE BOSONS

$$\Sigma = f \begin{pmatrix} \frac{H^a}{H} \sin(\frac{H}{f}) \\ \cos(\frac{H}{f}) \end{pmatrix}$$

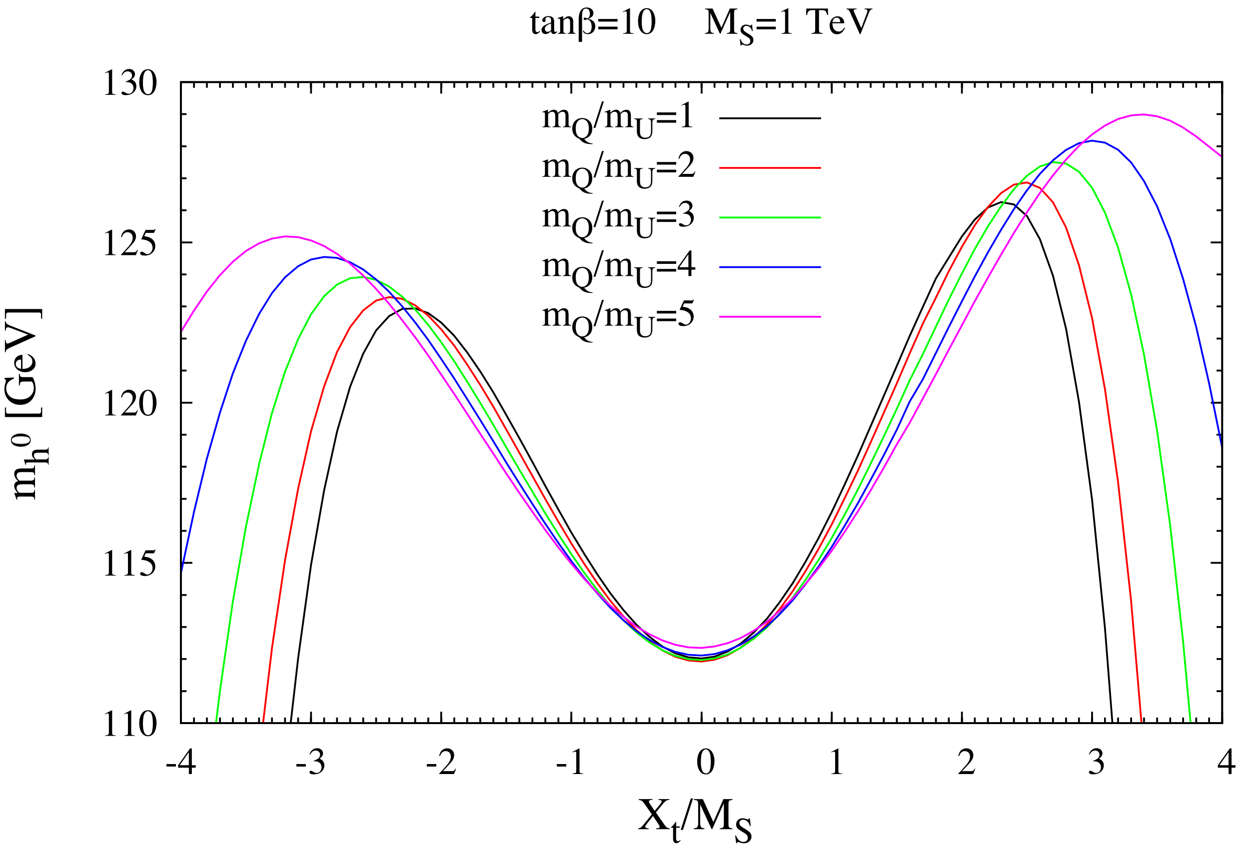
H^a 4 Goldstones

$$H^2 = H^a H^a$$

$$H^a = (\bar{v} + h) \begin{pmatrix} \frac{\pi^i}{\pi} \sin(\frac{\pi}{\bar{v}}) \\ \cos(\frac{\pi}{\bar{v}}) \end{pmatrix}$$

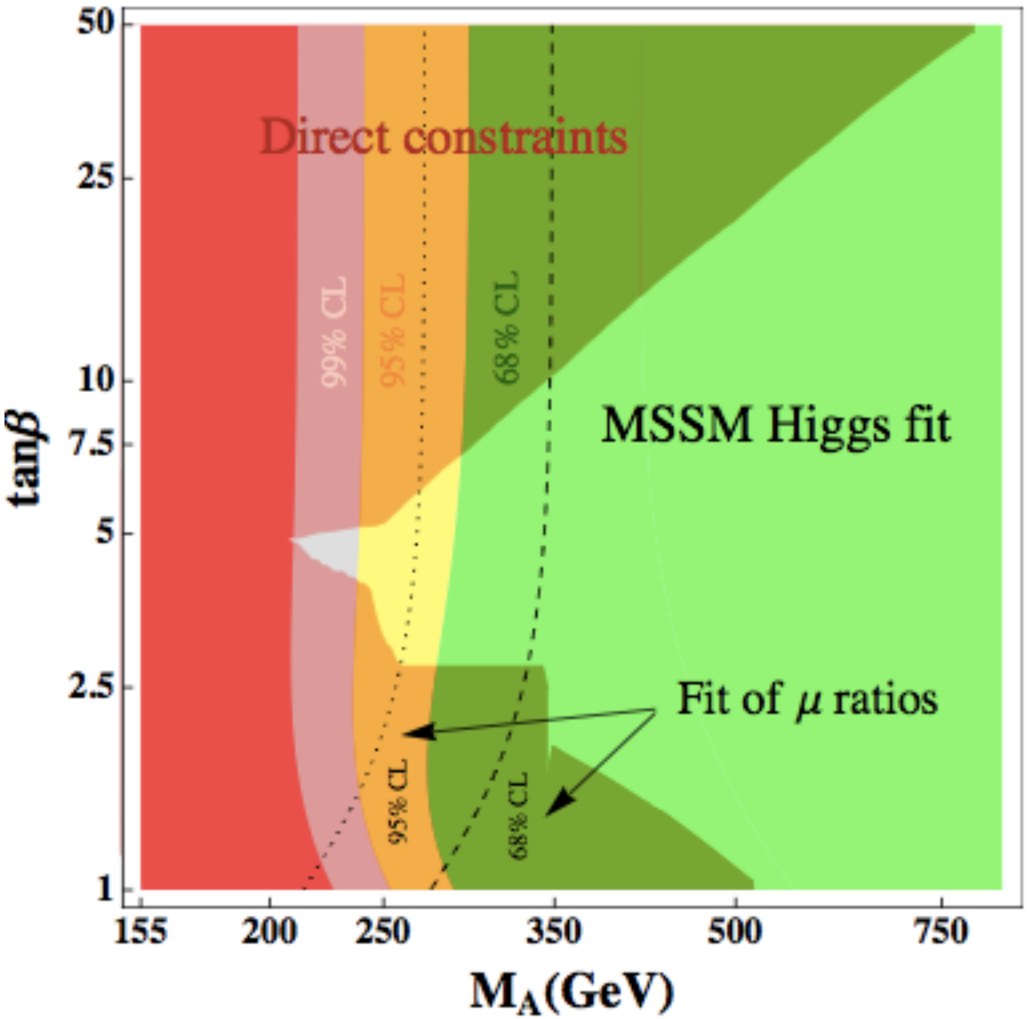
$$v = f \sin(\frac{\bar{v}}{f})$$

M. BADZIAK ET AL



$$X_t = A_t - \mu \tan \beta$$

$$M_s \approx \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$



DJOUADI,MAIANI, MOREAU, POLOSA, QUEVILLON, RIQUER

MSSM

$$m_h = M_Z^2 \cos^2(2\beta) + (\delta m_h^2)^{\rm rad}$$

$$(\delta m_h^2)^{\rm rad} \approx \frac{3g^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\left(\frac{M_{\rm SUSY}^2}{m_t^2}\right) + \frac{X_t^2}{M_{\rm SUSY}^2}\left(1 - \frac{X_t^2}{12 M_{\rm SUSY}^2}\right)\right]$$

$$M_{\rm SUSY} \equiv \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

$$X_t \equiv A_t - \mu / \tan\beta$$

Generic characteristics of the scalar sector in extensions of the SM with elementary (supersymmetry) or composite scalars:

More scalars;

none of the scalars couple to *WW* and to fermions exactly like the SM scalar (because of the mixing between them)

New particles:

their exchange can contribute to the production and decays of h

DEVIATIONS FROM THE SM PREDICTIONS FOR PRODUCTION CROSS SECTION AND BR OF THE LIGHTES SCALAR

Looks like good news but… how big effects can we expect?

$$\mathcal{O}(v^2/M^2) \qquad \mathcal{O}(1/M^2)$$

The absence of new physics appears as a paradox to us

Still the picture suggested by the last 20 years of data is simple and clear:

Take the SM, extended to include Majorana neutrinos, as the theory valid up to very high energy

Dark Matter? Axions
Baryogenesis? Thru leptogenesis
Coupling Unification? SO(10) with an intermediate scale

Possibly Nature has a way, hidden to us, to realize a deeper form of naturalness at a more fundamental level

SPONTANEOUS CHIRAL SYMMETRY BREAKING IN STRONG INTERACTIONS

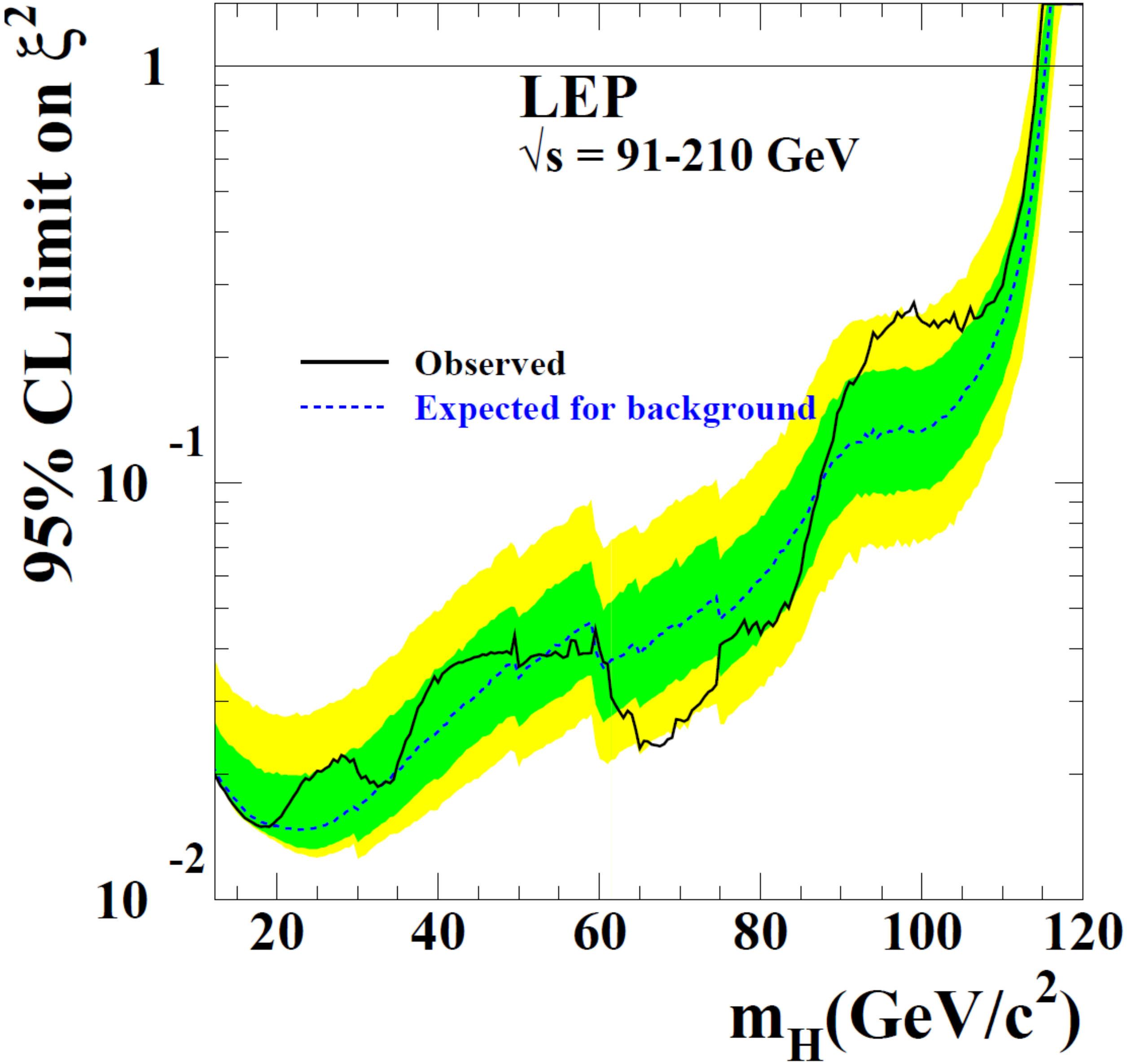
Sigma model description: fermions and elementary scalar

$$\Sigma = \begin{pmatrix} \sigma + i\pi^3 & -i\pi^1 + \pi^2 \\ \pi^2 + i\pi^1 & \sigma - i\pi^3 \end{pmatrix}, \qquad \Sigma \to g_L \Sigma g_R^\dagger$$

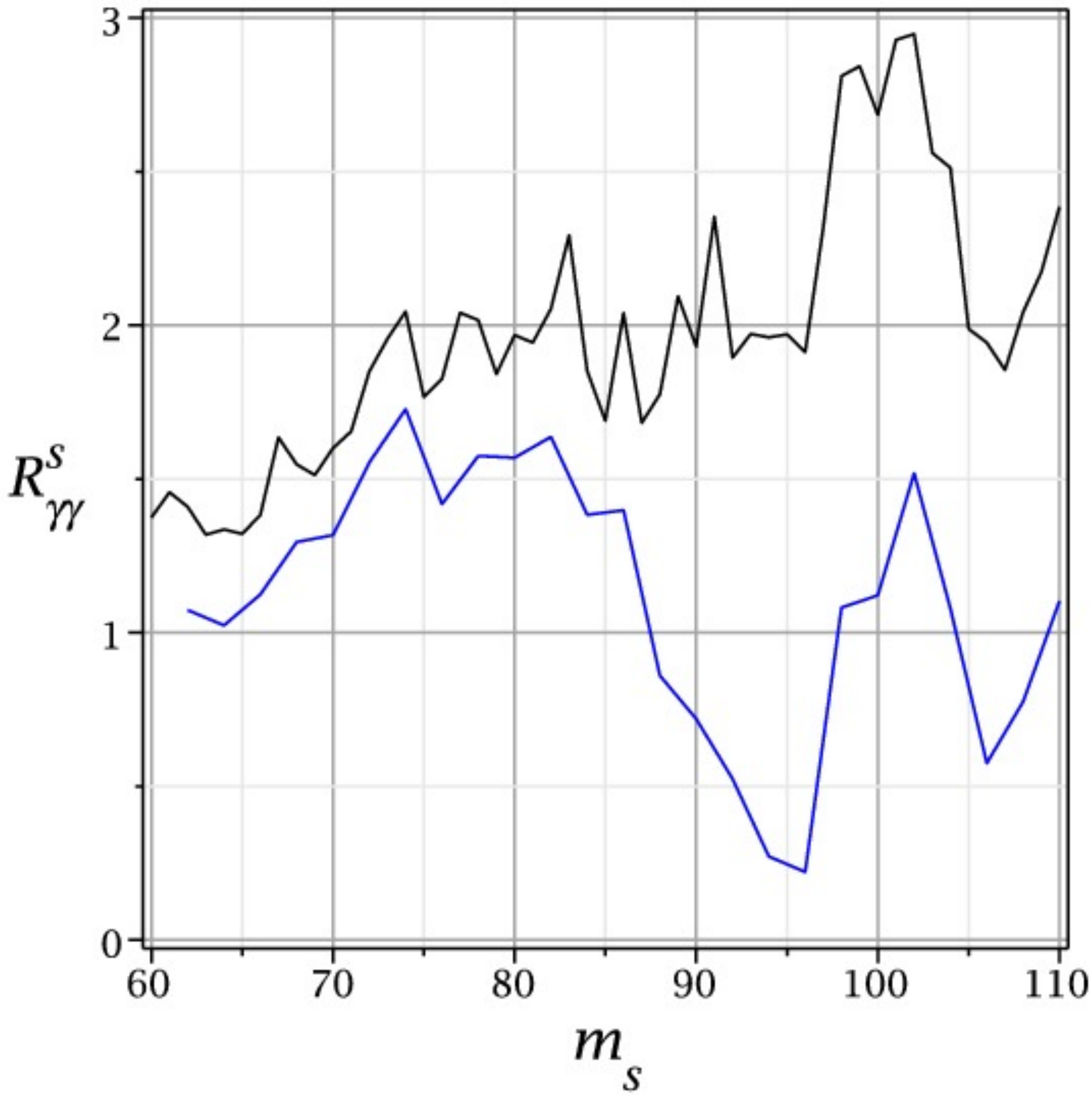
$$\mathcal{L} = i\bar{\Psi}\partial_\mu\gamma_\mu\Psi - g\bar{\Psi}_L\Sigma\Psi_R - g\bar{\Psi}_R\Sigma^+\Psi_L + \mathcal{L}(\Sigma)$$

Spontaneous symmetry breaking is described by an *ad hoc* ansatz for the potential for the scalar field, giving

$$< \sigma >= f_\pi$$



LEP
√s = 91-210 GeV
Observed
Expected for background
95% CL limit on ξ²
1
10⁻¹
10⁻²
20
40
60
80
100
120
m_H(GeV/c²)



3
2
1
0
$R^s_{\gamma\gamma}$
60
70
80
90
100
110
m_s

SM

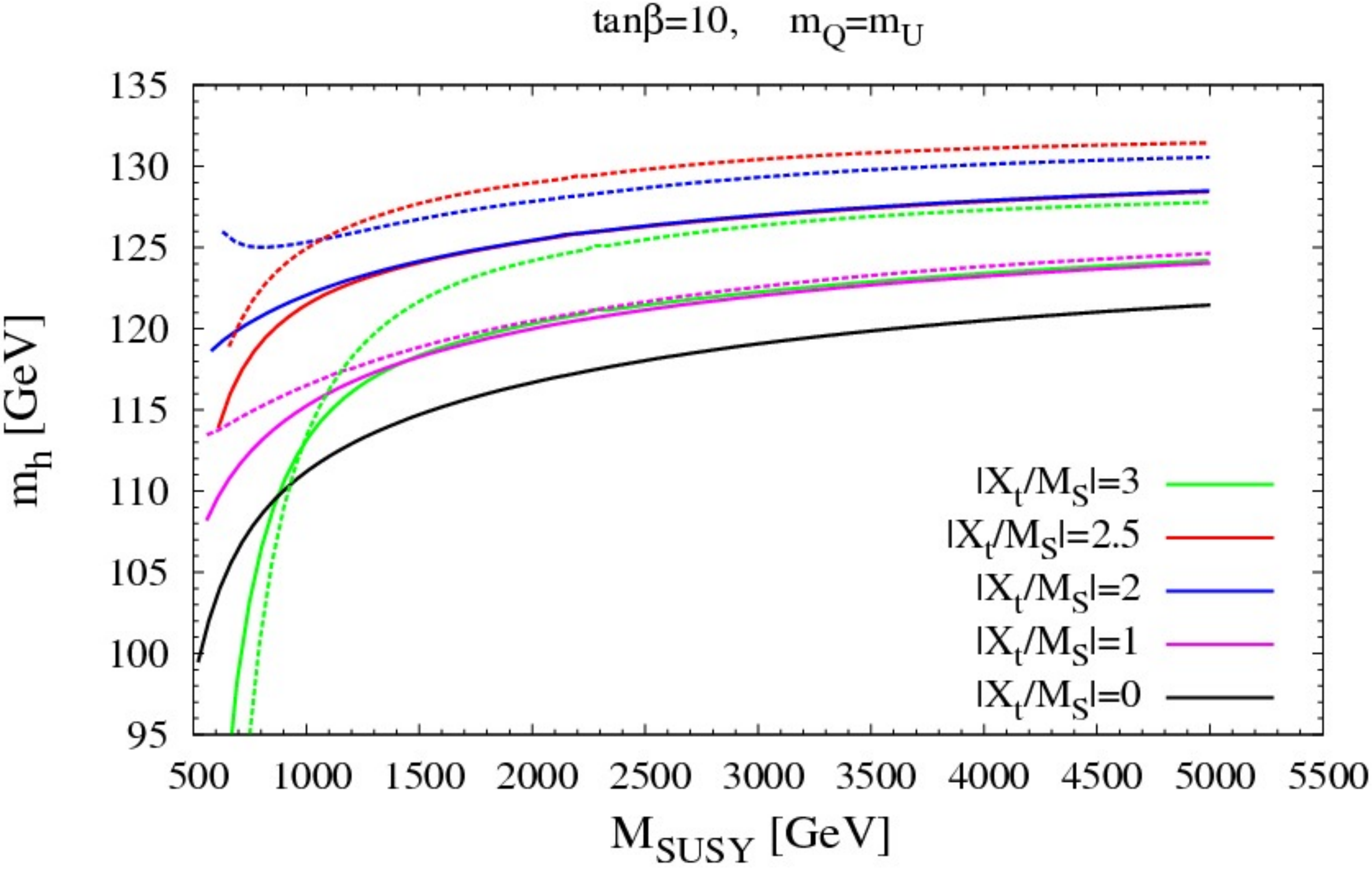
$$V = m_H^2 |H|^2 + \lambda |H|^4$$

$$v^2 = -\frac{m_H^2}{\lambda}, \qquad m_h^2 = -2m_H^2 = 2\lambda v^2$$

$$v = 246 GeV \qquad \rightarrow \lambda = 0.12$$

WELL WITHIN PERTURBATIVE REGIME

NO LANDAU POLE UP TO THE PLANCK SCALE



tanβ=10, $m_Q=m_U$
m_h [GeV]
M_{SUSY} [GeV]
$|X_t/M_S|=3$
$|X_t/M_S|=2.5$
$|X_t/M_S|=2$
$|X_t/M_S|=1$
$|X_t/M_S|=0$

$$m_h = \hat{M}_{hh} + \Delta_{\mathrm{mix}}$$

$$\Delta_{\mathrm{mix}} \approx \frac{g_s^2}{2}\left(m_h - \frac{m_s^2}{m_h}\right) + \mathcal{O}(g_s^4)$$

$$\begin{pmatrix} \hat{M}^2_{hh} & \hat{M}^2_{hs} \\ \hat{M}^2_{hs} & \hat{M}^2_{ss} \end{pmatrix},$$

DIAGONAL IN THE BASIS

$$s = g_s \hat{h} + \sqrt{1 - g_s^2}\,\hat{s}$$

$$h = \sqrt{1 - \bar{g}_s^2}\,\hat{h} - g_s^2\,\hat{s}$$

$$W_{\mathrm{NMSSM}} = \lambda S H_u H_d + f(S)\,.$$

$$\hat{M}^2 = \begin{pmatrix} \hat{M}^2_{hh} & \frac{1}{2}(M_Z^2 - \lambda^2 v^2)\sin 4\beta & \lambda v(2\mu - \Lambda \sin 2\beta) \\ & \hat{M}^2_{HH} & \lambda v \Lambda \cos 2\beta \\ & & \hat{M}^2_{ss} \end{pmatrix},$$

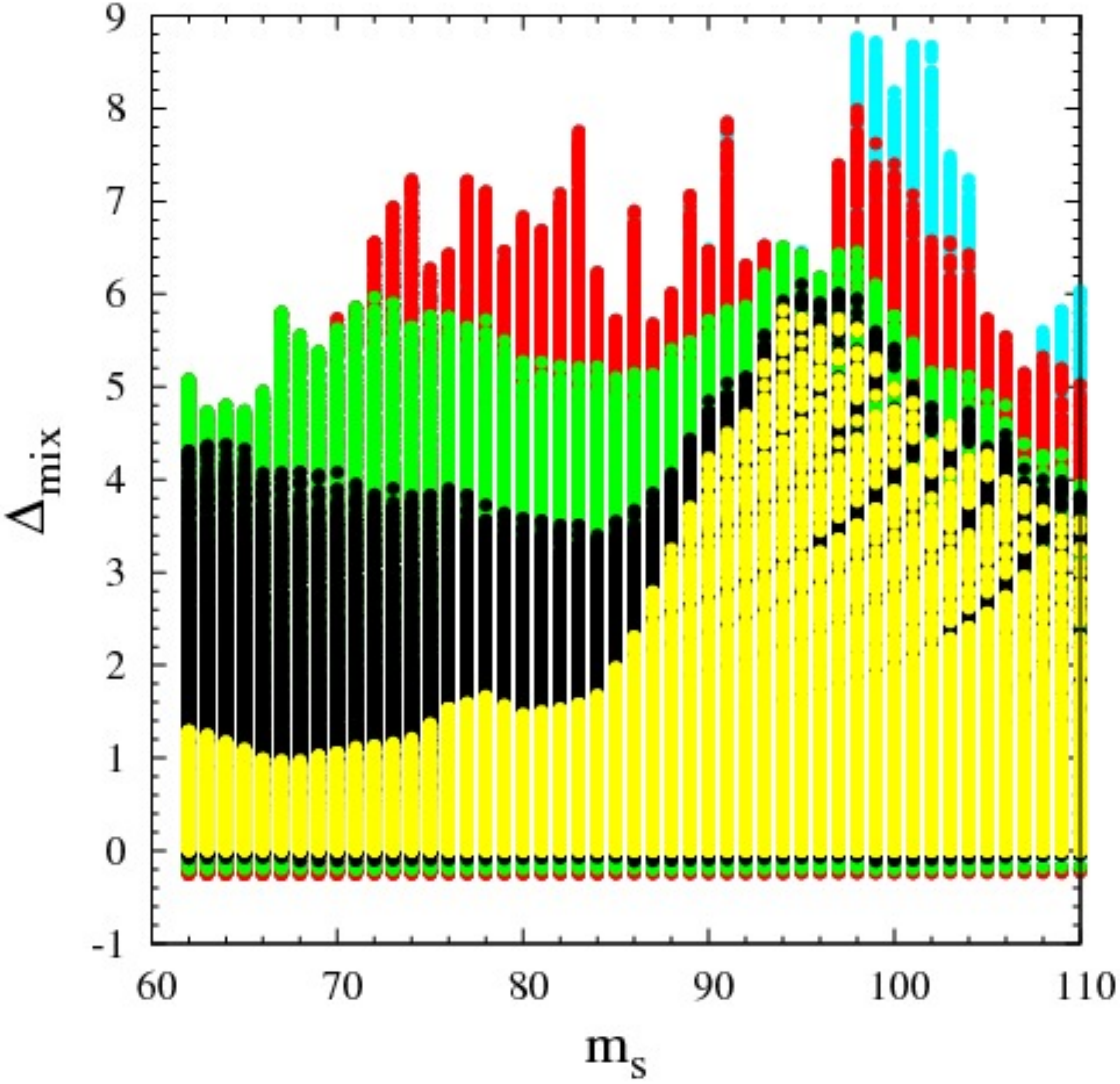
$$\hat{M}^2_{hh} = M_Z^2 \cos^2(2\beta) + (\delta m_h^2)^{\mathrm{rad}} + \lambda^2 v^2 \sin^2(2\beta)$$

EVADE LEP BOUNDS BASED ON THE IDENTIFICATION OF b QUARKS BY SUPPRESING THE bb and tau tau decay channels

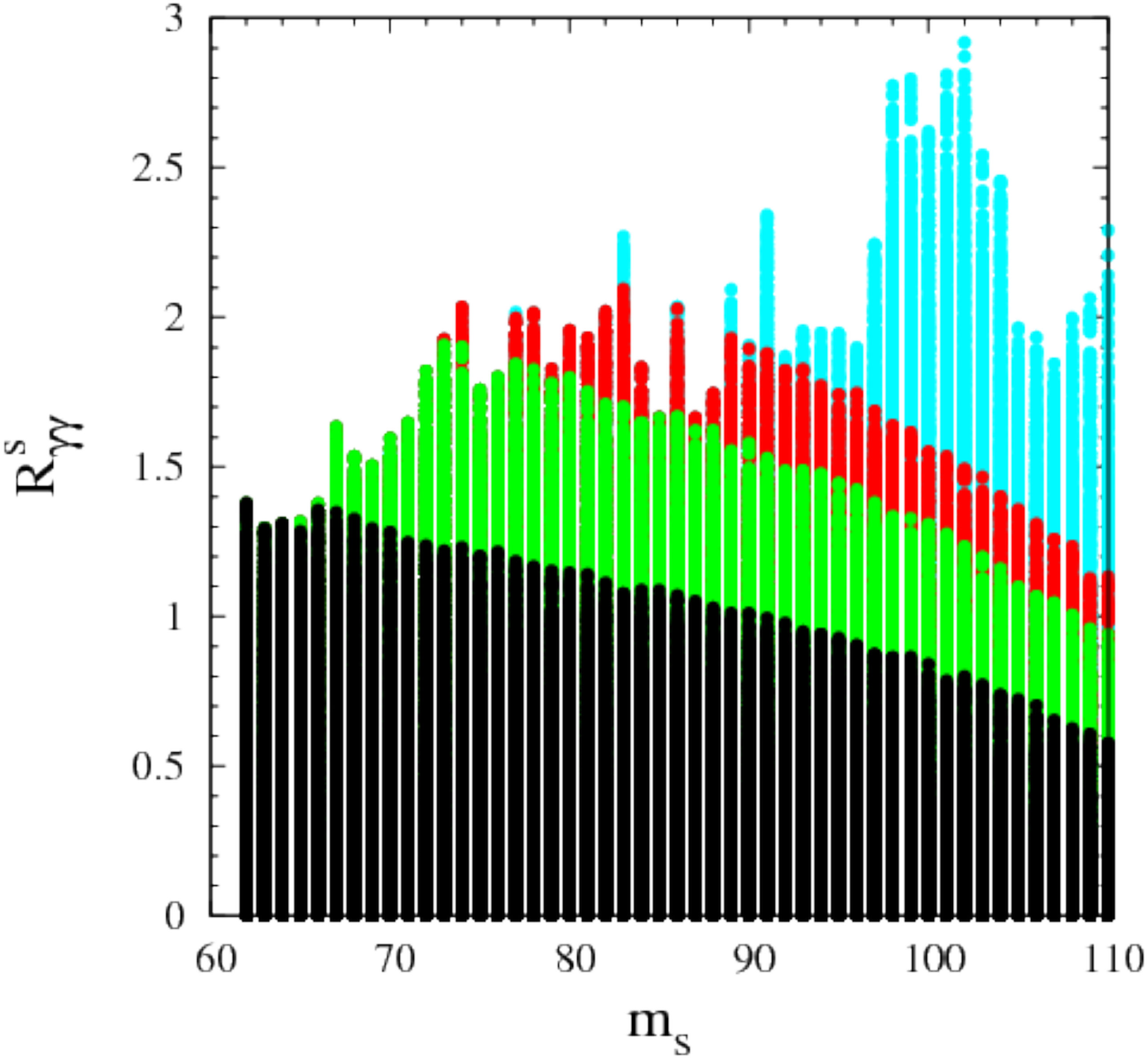
THE $\hat{h}$ COMPONENT IN s, GIVEN BY g_s^2 IS THEN BOUNDED BY THE LEP BOUNDS BASED ON THE IDENTIFICATION OF TWO HADRONIC JETS

$$\xi_{jj}^2 \equiv C_{sZZ}^2 \times \frac{\mathrm{BR}(s \to jj)}{\mathrm{BR}(s \to jj)_{SM}}$$

$$C_{sZZ} = g_s$$



9
8
7
6
5
4
3
2
1
0
-1
60
70
80
90
100
110
Δ_{mix}
m_s



BLACK, GREEN, RED → WITHIN $1, 2, 3\sigma$ OF THE h SIGNAL STRENGTH

$\gamma\gamma$ SIGNAL OF b-PHOBIC S

ONE HAS TO SIMULTANEOUSLY
CONSIDER h PROPERTIES FROM THE LHC SINCE THEY ARE CORRELATED;

ALSO CORRELATED ARE THE H PROPERTIES

b-PHOBIC LIGHT SCALAR AS AN EFFECT OF THE 3x3 MIXING

BADZIAK, OLECHOWSKI, SP archiv 1304.5437 (JHEP)

BARBIERI, BUTTAZZO, KANNIKE, SALA, TESI archiv 1307.4937

$$X = g_X \hat{h} + \beta_X \hat{H} + \gamma_X \hat{s}$$

(OBVIOUSLY, ONLY THREE INDEPENDENT)

$$X = h, H, s$$

$$C_{Sdd} = g_s + \beta_s \tan\beta \qquad C_{hdd} = g_h + \beta_h \tan\beta$$

$$C_{suu} \approx g_s \qquad C_{huu} = \sqrt{1 - g_s^2}$$

$$C_{sVV} = g_s \qquad C_{hVV} = \sqrt{1 - g_s^2}$$

b-PHOBIC LIGHT SCALAR IS A REALISTIC POSSIBILITY IN NMSSM

3 CP-even Higgs fields

H_u H_d S

CONVENIENT BASIS

$$\hat{h} = H_u \sin\beta + H_d \cos\beta$$

$$\hat{H} = -H_u \cos\beta + H_d \sin\beta$$

$$\hat{s} = S$$

$\hat{h}$ HAS THE SAME COUPLINGS AS THE SM HIGGS

MASS EIGENSTATES h H s

b-PHOBIC LIGHT SCALAR IS A REALISTIC POSSIBILITY IN NMSSM

A NUMBER OF WELL IDENTIFIED PARAMETER REGIONS, FOR INSTANCE

SMALL $\tan\beta$ AND $\lambda \approx O(1)$

(MOST OFTEN CONSIDERED)

$\tan\beta > O(5)$ AND $\lambda \approx O(0.1)$

$$W_{\rm NMSSM} = \lambda S H_u H_d + f(S)\,.$$

NMSSM: 3 CP-even scalars h H s

LET'S FOCUS ON THE CASE

$$m_s < m_h < m_H$$

LEP BOUNDS ON SIGNAL STRENGTH

$$\xi^2_{b\bar{b}} \equiv C^2_{sZZ} \times \frac{\mathrm{BR}(s \to b\bar{b})}{\mathrm{BR}(h^{\mathrm{SM}} \to b\bar{b})}$$

b-PHOBIC s ? **ESCAPED DETECTION SO FAR?**

NATURALNESS OF THE HIGGS POTENTIAL

SM

$$V = (m_H^2 + \delta m_H^2)|H|^2 + (\lambda + \delta\lambda)|H|^4$$

$$v^2 = -\frac{m_H^2 + \delta m_H^2}{2(\lambda + \delta\lambda)}$$

$$M_h^2 = 4(\lambda + \delta\lambda)v^2 = -2(m_H^2 + \delta m_H^2)$$

$$F.T. = \frac{|\delta m_H^2|}{M_h^2/2}$$

SUPERSYMMETRY

(FERMION-BOSON SYMMETRY)

COMPOSITE

FERMION SYMMETRY IN THE STRONG SECTOR

TREE LEVEL

$$V = m^2|H|^2 + (g^2\cos 2\beta + \dots)|H|^4$$

$$V = 0$$

CRUCIAL ROLE PLAYED BY RADIATIVE CORRECTIONS

$$V = (m_H^2 + \delta m_H^2)|H|^2 + (\lambda + \delta\lambda)|H|^4 + \dots$$

WITH $m_H^2 = \lambda = 0$ FOR COMPOSITE

RADIATIVE CORRECTIONS

SUPERSYMMETRY: SOFTLY BROKEN BY PARTICLE-SPARTICLE MASS SPLITTING; TOP AND STOP COUPLE TO THE HIGGS WITH YUKAWA COUPLING

COMPOSITE:

TAKE EFFECTIVE SO(5)/SO(4) AS AN EXAMPLE; SCALAR Σ AND FERMION $\Psi^T = (\psi, T)$ 5-PLETS

SO(5) INVARIANT TERMS $$m_0 \bar{\Psi}\Psi + \frac{1}{m}(\bar{\Psi}\Sigma)(\Sigma^\dagger \Psi)$$

AFTER SPONTANEOUS BREAKING

THE LIGHTER, E.G $m_\psi = g_\psi f$

THE HEAVIER $m_T = g_T f$

f -SCALE OF SPONTANEOUS BREAKING

COMPOSITE (cont..): SO(5) EXPLICITLY BROKEN BY THE MIXING OF THE SM FERMIONS WITH Ψ

$$y f(\bar{q}\psi + \ldots.)$$

SINCE THE HIGGS DOUBLET (GOLDSTONE) COUPLES TO SO(5) FERMIONS

$$Y H \bar{\psi} T \quad \text{WITH} \quad Y = f/m \quad ,$$

AFTER DIAGONALISATION OF THE MASS MATRIX ONE GETS

$$y_t = Y \frac{y^2 f^2}{m_\psi^2} = Y \frac{y^2}{g_\psi^2} \approx \frac{y^2}{g_\psi}$$

AND SOME ADDITIONAL CONTRIBUTIONS TO THE VECTOR-LIKE FERMION MASSES

RADIATIVE CORRECTIONS

SUPERSYMMETRY

$$\delta m_H^2 = -\frac{3}{8\pi^2} y_t^2 \; m_Q^2 \; ln\Lambda$$

COMPOSITE HIGGS

(EFFECTIVE DESCRIPTION)

$$\delta m_H^2 = -\frac{3}{8\pi^2} C_{rep} y_t g_\psi \; m_T^2 \; (ln)$$

QUADRATIC DEPENDENCE EITHER ON THE STOP MASS OR ON THE HEAVIEST FERMION IN THE COMPOSITE SO(5) MULTIPLET (RESTORING SO(5) INVARIANCE)

$$v^2 = \frac{-(m_H^2 + \delta m_H^2)}{(\lambda + \delta\lambda)}$$

$$m_h^2 = 2(\lambda + \delta\lambda) v^2$$

$$\delta\lambda = \frac{3}{16\pi^2} y_t^4 ln(m_Q^2/m_t^2)$$

$$\delta\lambda = C'_{rep} \frac{3}{16\pi^2} y_t^2 g_\psi^2 ln(10)$$

SUPERSYMMETRY- THE HEAVIER THE HIGGS THE MORE FT IN THE VEV BECAUSE y_t IN $\delta\lambda$ TOO SMALL (MSSM), LARGE LOG NEEDED

COMPOSITE: EASY TO GET 125 WITH THE FREE PARAMETER g_ψ;

PUTTING NUMBERS IN SIMPLE MODELS: 125 IMPLIES $m_\psi = g_\psi f$ IN THE RANGE OF 1 TeV!

(THE LIGHTEST FERMION IN THE SO(5) MULTIPLET)

CONCLUSIONS ON THE HIGGS POTENTIAL:
SUPERSYMMETRY- THE HEAVIER THE HIGGS THE MORE FT IN THE VEV;

y_t IN $\delta\lambda$ TOO SMALL, LARGE LOG NEEDED

COMPOSITE: EASY TO GET 125 WITH THE FREE PARAMETER g_ψ;

PUTTING NUMBERS IN SIMPLE MODELS: 125 IMPLIES $m_\psi = g_\psi f$

IN THE RANGE OF 1 TeV!

IT DOES NOT AUTOMATICALLY
IMPLY LARGE FT:

$$v^2 = (C/C')(g_T^2/y_t g_\psi) f^2$$

IN FACT, FOR SPLIT MULTIPLETS, THE HEAVIER THE HIGGS THE LESS FT IN VEV