SUSY Higgs and interpretation of LHC results

U. Ellwanger, LPT Orsay

Recall: SUSY $\longrightarrow$ at least 2 Higgs doublets H_u, H_d (+ Singlets ?)

All CP-even Higgs bosons H_i "share" their reduced couplings ξ_i (normalized w.r.t. the SM-like coupling) to electroweak gauge bosons:

$$\sum_i \xi_i^2 = 1$$

The couplings to b-quarks, t-quarks ($\longrightarrow$ gluon-gluon) can be enhanced or reduced, depending on $\tan\beta$ and the Higgs mixing angles

At present: (mild) excesses of events at ATLAS/CMS
for $M_H \sim 140 - 145$ GeV

What if these excesses are confirmed?

MSSM:

In the MSSM (minimal Higgs sector with two Higgs doublets) the mass M_h of the Standard Model-like Higgs Boson is bounded from above by

$$\left(M_h^{upper}\right)^2 \simeq M_Z^2 \cos^2 2\beta + \frac{m_t^4}{4\pi^2 v^2}\left(\ln\left(\frac{M_{stop}^2}{m_t^2}\right) + \frac{A_t^2}{M_{stop}^2}\left(1 - \frac{A_t^2}{12 M_{stop}^2}\right)\right) + ...$$

$$\longrightarrow M_h \lesssim 135 \text{ GeV if } M_{stop} \lesssim 3 \text{ TeV}$$

The second "heavy" CP-even Higgs boson H can have a mass in the 140-150 GeV range (with $M_h \sim 115$ GeV, $\tan\beta \sim 8 - 10$), but then its BR into WW/ZZ is small, $< 10^{-2}/10^{-3}$

(Question: could this be enhanced in the case of CP-violation?)

$\longrightarrow$ Split Susy, extra vector-like matter, extra U(1)', NMSSM (λ-Susy),...

Split SUSY:

Supersymmetry does not solve the Hierarchy Problem, but

— a light gaugino (bino) provides a dark matter candidate
— sparticles lead to gauge coupling unification
$\longrightarrow$ scalar sparticles like stops can be heavy

$$\longrightarrow M_H \gtrsim 140 \text{ GeV if } M_{stop} \gtrsim 10^6 \text{ GeV}$$

(D. Alves, E. Izaguirre, Jay G. Wacker, 1108.3390)

Extra Vector-like Matter

— Add extra SU(5) multiplets, keeping perturbative unification at the GUT scale: e.g. one $10 + \overline{10}$ and a superpotential $W = ... + H_u\, 10\, 10 + M_{10} 10\, \overline{10}$

— Assume that the extra scalars and fermions are sufficiently massive in order to comply with negative direct searches and electroweak precision observables ($\gtrsim 300 - 400$ GeV)

$\longrightarrow$ Rad. corrs. to M_H of the same type as top-stop loops:

$$\longrightarrow M_H \gtrsim 140 \text{ GeV if } M_{scalar} \gtrsim 5 M_{fermion}$$

(M. Asano, T. Moroi, R. Sato, T. Yanagida, 1108.2402,
M. Endo, K. Hamaguchi, S. Iwamoto, N. Yokozaki, 1108.3071,
J. Evans, M. Ibe, T. Yanagida, 1108.3437)

Extra U(1)'

— If the Higgs doublets carry U(1)' charges:
Extra quartic Higgs couplings from U(1)'-D-terms,
extra SM-singlets (see the NMSSM below)

$\longrightarrow$ Larger SM-like Higgs mass possible

— Models must comply with lower bounds on $M_{Z'} \gtrsim 2$ TeV,
absence of U(1)' anomalies $\longrightarrow$ enlarged field content

Scenarios with $M_H \gtrsim 140$ GeV are possible

(E. Ma, 1108.4029)

NMSSM

Solution of the μ-problem of the MSSM by an additional gauge singlet superfield S (the simplest Susy extension of the SM with a scale invariant superpotential):

$$W_{MSSM} = ... + \mu H_u H_d \quad \longrightarrow \quad W_{NMSSM} = ... + \lambda S H_u H_d + \tfrac{\kappa}{3} S^3 \ (+...)$$

$\longrightarrow$ 3 CP-even Higgs bosons, mixtures of H_u, H_d and S

$\longrightarrow$ Upper bound on the lightest CP-even state, valid also for the general NMSSM with additional Susy mass/tadpole terms:

$$\left(M_H^{upper}\right)^2 \simeq \left(M_{H,MSSM}^{upper}\right)^2 + \lambda^2 M_Z^2 \sin^2 2\beta + ...$$

(The second tree-level term decreases as $\tan^{-2}\beta$)
Assume $\lambda \lesssim 0.75$ ($\lambda(M_{GUT}) < \infty$), $M_{stop} \lesssim 1$ TeV, $m_{top} \sim 173$ GeV, incl. full electroweak 1-loop and h_t/α_s-2-loop corrections (Degrassi, Slavich):

$$M_H^{upper} \simeq 138 \ GeV$$

Moreover: $M_H = M_H^{upper}$ only if $H - S-$mixing terms vanish!

Ways out:

a) $\lambda > 0.75$ (λ-Susy): either

— additional matter/gauge interactions such that $\lambda(Q^2)$ does not increase (strongly) with Q^2, or

— accept $\lambda(Q'^2) \to \infty$, new strong interactions at $Q' < M_{GUT}$ ($S =$ composite field, fat Higgs...)

$\longrightarrow$ $M_H \sim 200$ GeV possible

b) Drop the (unneccessary) assumption that $H_{SM} \equiv H_1$:

IF $H_{SM} = H_2$ (H_1 mostly singlet, with a mass possibly below 114 GeV):

Typically $M_{H_{SM}} > M_H^{upper}$ due to $H - S-$mixing!

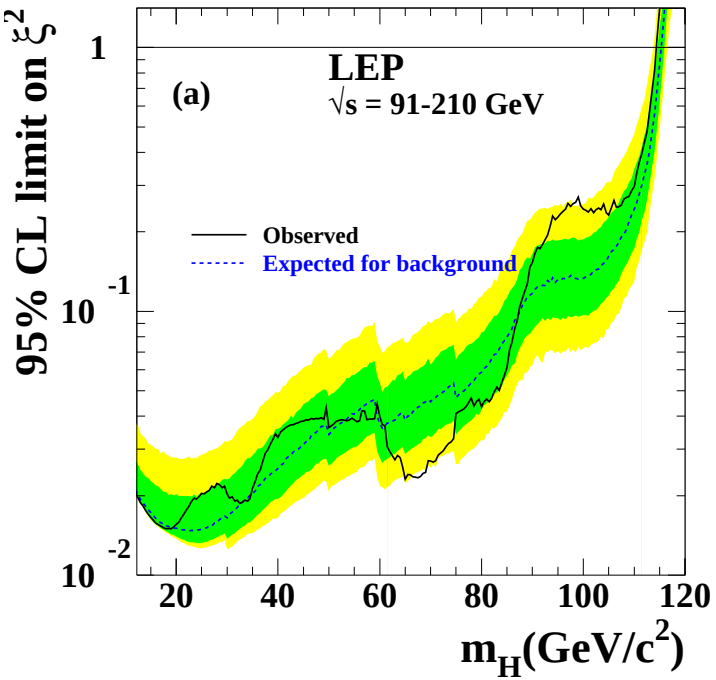
BUT: The reduced coupling to electroweak bauge bosons ξ_2 of H_2 becomes $\xi_2 < 1$ due to $H - S-$mixing; also: slightly reduced couplings (by 70-90%) to b-quarks, t-quarks/gluon-gluon (U.E., 1108.0157):

Examples ($\lambda \sim 0.7$, $\tan\beta \sim 2.7$):

M_{H_2}	140 GeV	145 GeV	150 GeV
ξ_2	0.92	0.86	0.73
M_{H_1}	91 GeV	97 GeV	115 GeV
ξ_1	0.40	0.51	0.68

Note: $\xi_1^2 + \xi_2^2 \simeq 1$,
M_{H_1} and ξ_1 are consistent
with LEP constraints,
which are particularly weak
for $M_{H_1} \sim 95$ GeV
(Dermisek, Gunion)

$\longrightarrow$ $M_{H_{SM}} \gtrsim 140$ GeV
is possible, but slightly
reduced signal rates!



Note:

— H_1 could be visible at the Tevatron (if CDF/D0 look for M_H as light as ~ 100 GeV)

— The H_1 production cross section$\times BR(H_1 \to \gamma\gamma)$ could be enhanced by a factor 6 w.r.t. the SM, if the H_d component of H_1 happens to be small (U.E., 1012.1201)
$\longrightarrow$ the reduced width for $H_1 \to b\bar{b}$ enhances the $BR(H_1 \to \gamma\gamma)$ by a factor up to 10

Moreover: possibly less E_T^{miss} in sparticle decay cascades in the NMSSM compared to the MSSM from additional bino $\to$ singlino transitions

$\to$ An attractive scenario within an attractive model, but:

Finally, after ~ 35 years of Susy extensions of the Standard Model, DATA will decide and NOT "naturalness arguments" of theorists (including mine...)