Which supersymmetry, if any, at the Large Hadron Collider?

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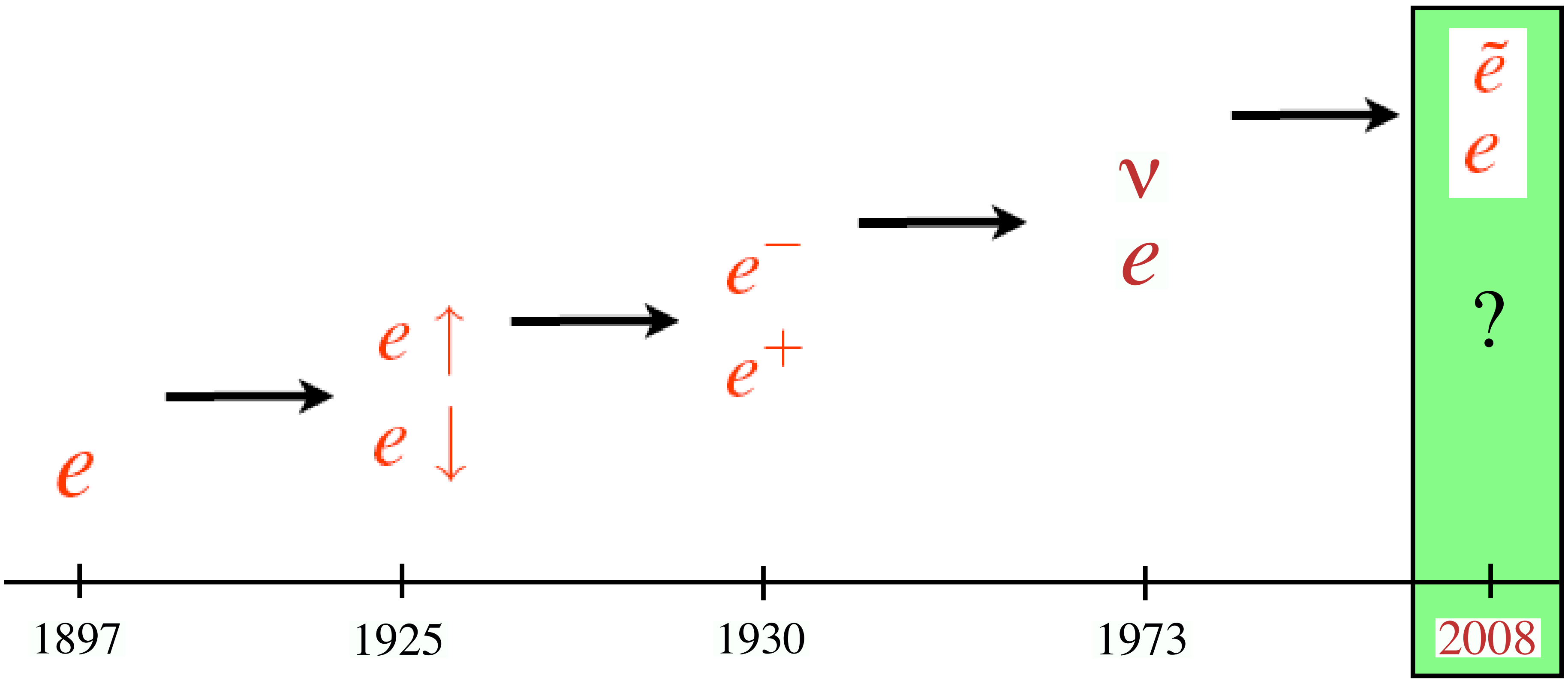
Pisa, March 19-21, 2007

The key to the economy of equations

the role of space-time and internal symmetries



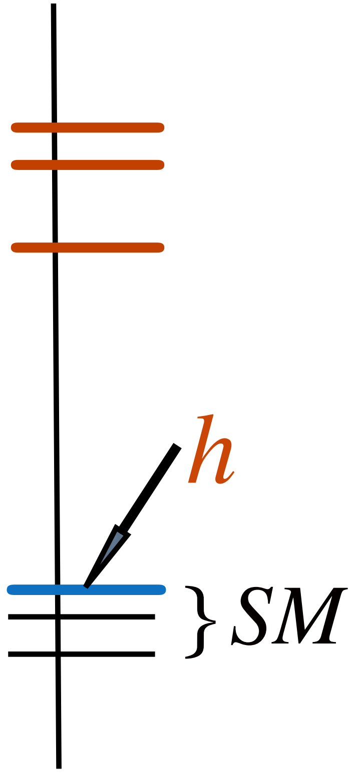
Supersymmetry as the most interesting theoretical candidate

Not unique, however and furthermore Why at the Fermi scale?

Not the least property of the Standard Model

There are infinitely many theories at short distances, that give the same physics of the Standard Model,

as long as the Higgs boson is in their low-energy spectrum



We only know of approximate symmetries that can explain this

The proposed relevant symmetries

⇒ Supersymmetry

$(\phi, \psi) \Rightarrow \cancel{m^2\phi^2}$ if ψ massless $\qquad h = \phi$

⇒ Global symmetry

$h \longrightarrow h + \alpha \;\Rightarrow\; \cancel{m^2 h^2}$

⇒ Gauge symmetry in higher dim.s

$A_\mu \longrightarrow A_\mu + d_\mu \alpha \;\Rightarrow\; \cancel{m^2 A_\mu^2} \qquad h = A_5$

In all explicit examples, new phenomena required at a scale $\Lambda_{NP} \approx (3 \div 5) m_h$

⇒ What are these new phenomena?

⇒ Why haven't we seen any indirect signal of them yet?

top-down:

as at the beginning of the eighties

The quantum numbers of the SM fermions (charge quantization!) fit remarkably well in GUT schemes

$\Rightarrow$ unification

+ the supersymmetric desert

$\Rightarrow$ *Experimental successes*

(not enough to make unification a fact)

gauge unification (quantitative)

neutrino masses (semi-quantitative)

$\Rightarrow$ *Further tests*

(both difficult and crucial)

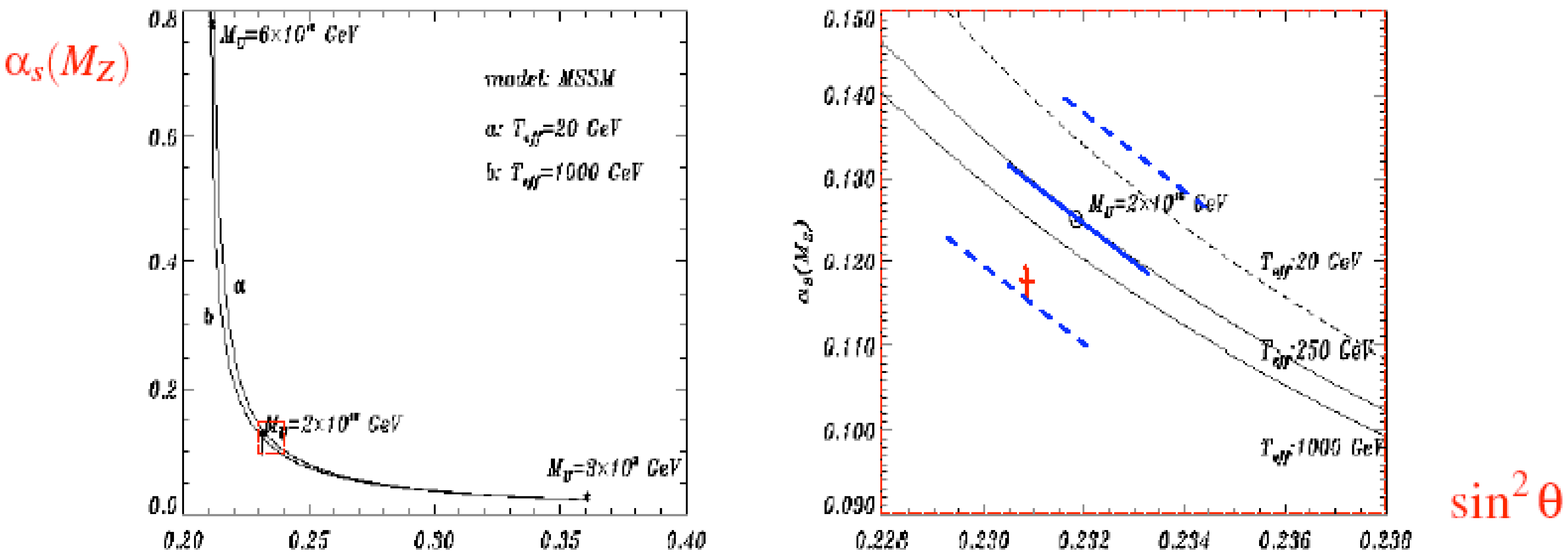
proton decay

neutrino-less double-beta decay

lepton flavour violation

(only 3 light neutrinos)

The (only) evidence

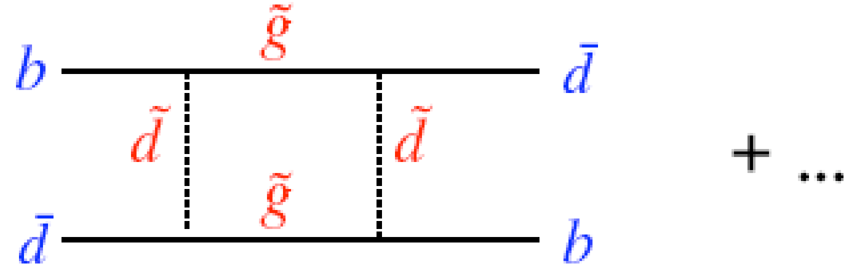


(Unification, however, not enough to require s-particles within reach of the LHC)

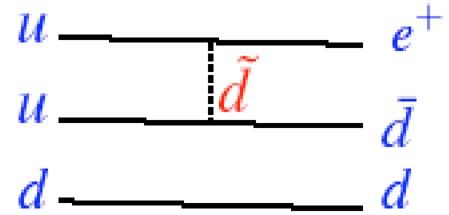
Questions for the standard Grand Picture

$\Longrightarrow$ Why no s-particles yet?

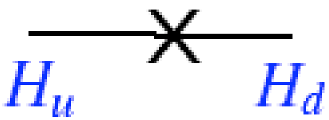
$\Longrightarrow$ Why no new flavour violation?



$\Longrightarrow$ Why B and L conserved?



$\Longrightarrow$ Why are there light Higgs bosons at all?



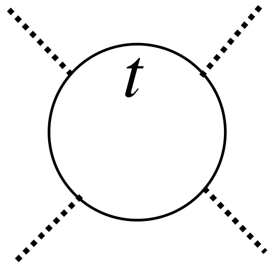
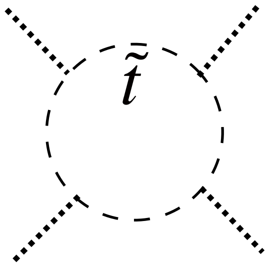
$\Longrightarrow$ Why not $m_h < m_Z$?

The Higgs boson(s) in Supersymmetry (MSSM)

$\Rightarrow$ *The Higgs quartic coupling is a gauge coupling*

$f = \cancel{H^3} \quad \Rightarrow \quad V \propto D^2 = g^2(h_1^2 - h_2^2)^2$

$\Rightarrow m_h(tree\ level) = M_Z \sin\beta$ *against* $m_h(LEP) > 114\ GeV$

$\Delta V(1\ loop) \approx$  $+$  $\approx \frac{6\lambda_t^4}{16\pi^2} \log \frac{m_{stop}^2}{m_t^2}$

$\Rightarrow \quad m_{stop} > 1\ TeV$

$M_Z^2 = (90GeV)^2 \left(\frac{< m_{\tilde{t}} >}{200GeV}\right)^2 \log \frac{\Lambda_{UV}}{< m_{\tilde{t}} >} \pm$ etc.

$log = 3 \div 30$

The reactions

1. Don't panic

(yes, but why at LHC?)

2. A problem of the Susy breaking mechanism?

(the difficulty looks pretty generic)

3. The LEP limit may be invalid: h may have decayed into final states harder to detect

(not easy to accommodate)

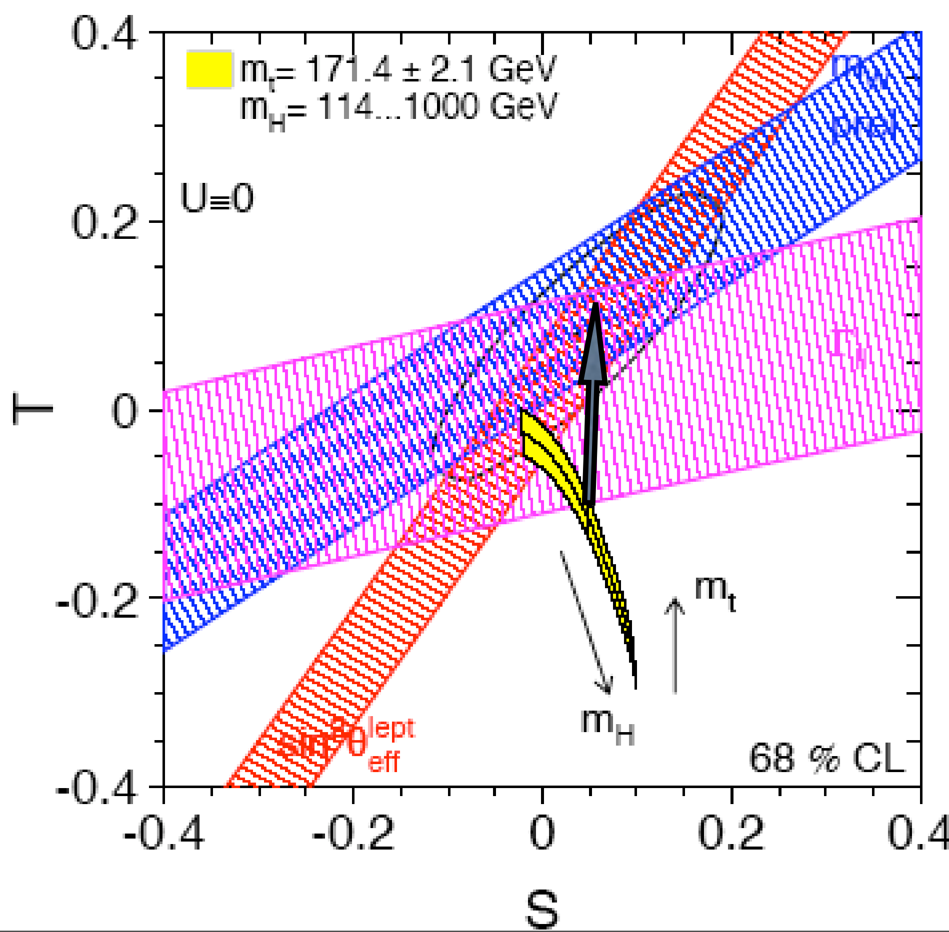
4. The Higgs boson may be significantly heavier than we thought

(have we been misled in interpreting the EWPT?)

The indirect determination of the Higgs mass

Rad Corr predict m_W and m_t well. Also m_h ?

predicted $\Longrightarrow$	$m_t = 177.6^{+12}_{-9}$	$m_W = 80.361(20)$	$m_h = 85^{+39}_{-28}$
measured $\Longrightarrow$	$m_t = 171.4 \pm 2.1$	$m_W = 80.392(29)$	?



A heavier Higgs would require a positive ΔT

LEPEWWG - Summer 2006

Our proposal

(B, Hall, Nomura, Rychkov)

Increase the Higgs quartic coupling by a largish λ in

$$f = \lambda S H_1 H_2$$

λ ≈ 1~2, so that perturbative (only) up to 10 ~ 20 TeV

This makes the Higgs boson heavier and, at the same time, induces a sizeable ΔT *from loops controlled by* λ^4

Parameters:

Scalar sector: h, H, A; $H^\pm$ *Fermions:* $\chi_1, \chi_2, \chi_3; \chi^\pm$

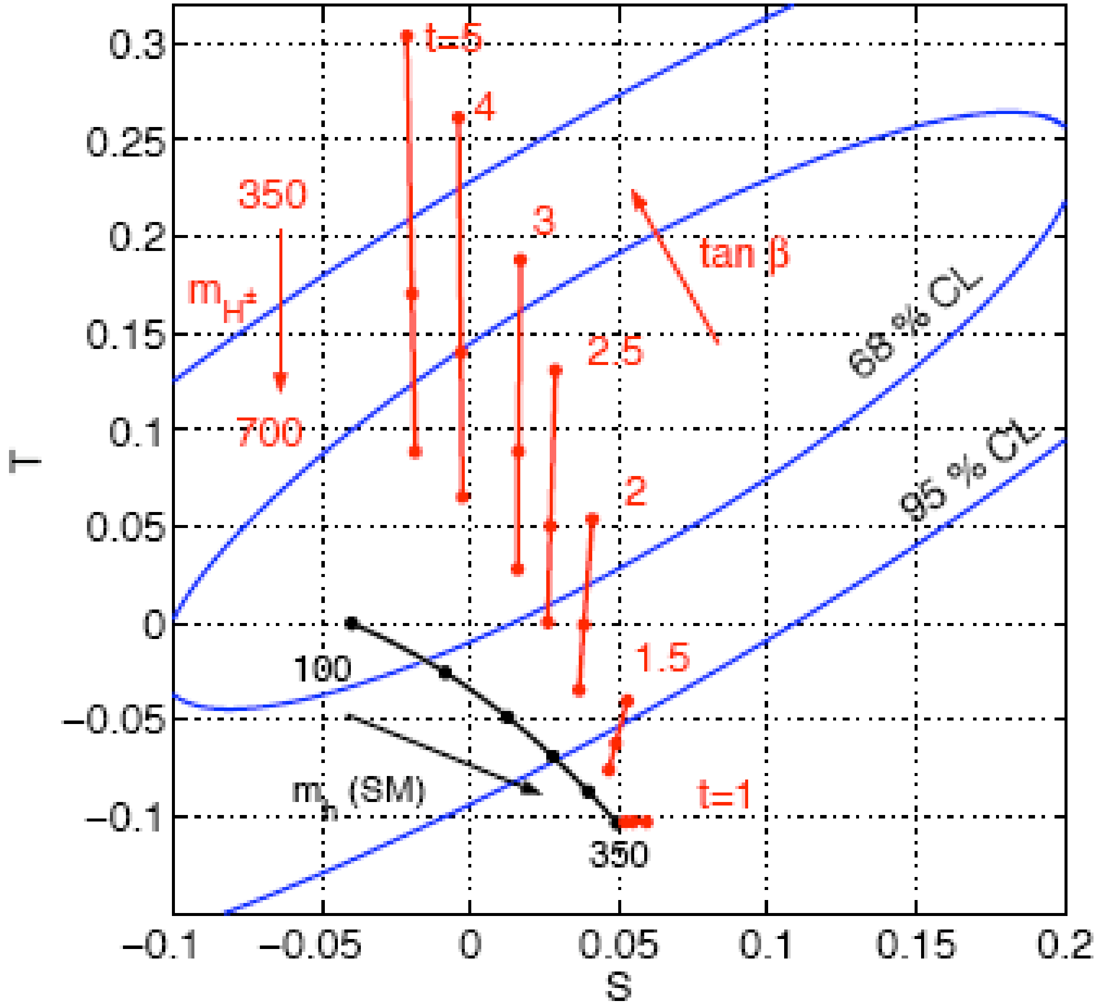
$\mu_1^2, \mu_2^2, \mu_3^2 \rightarrow \tan\beta, m_{H^+}, v$ μ, M

in the limit of decoupling the S scalar and gauginos

Back to the ElectroWeak Precision Tests

$\lambda = 2$

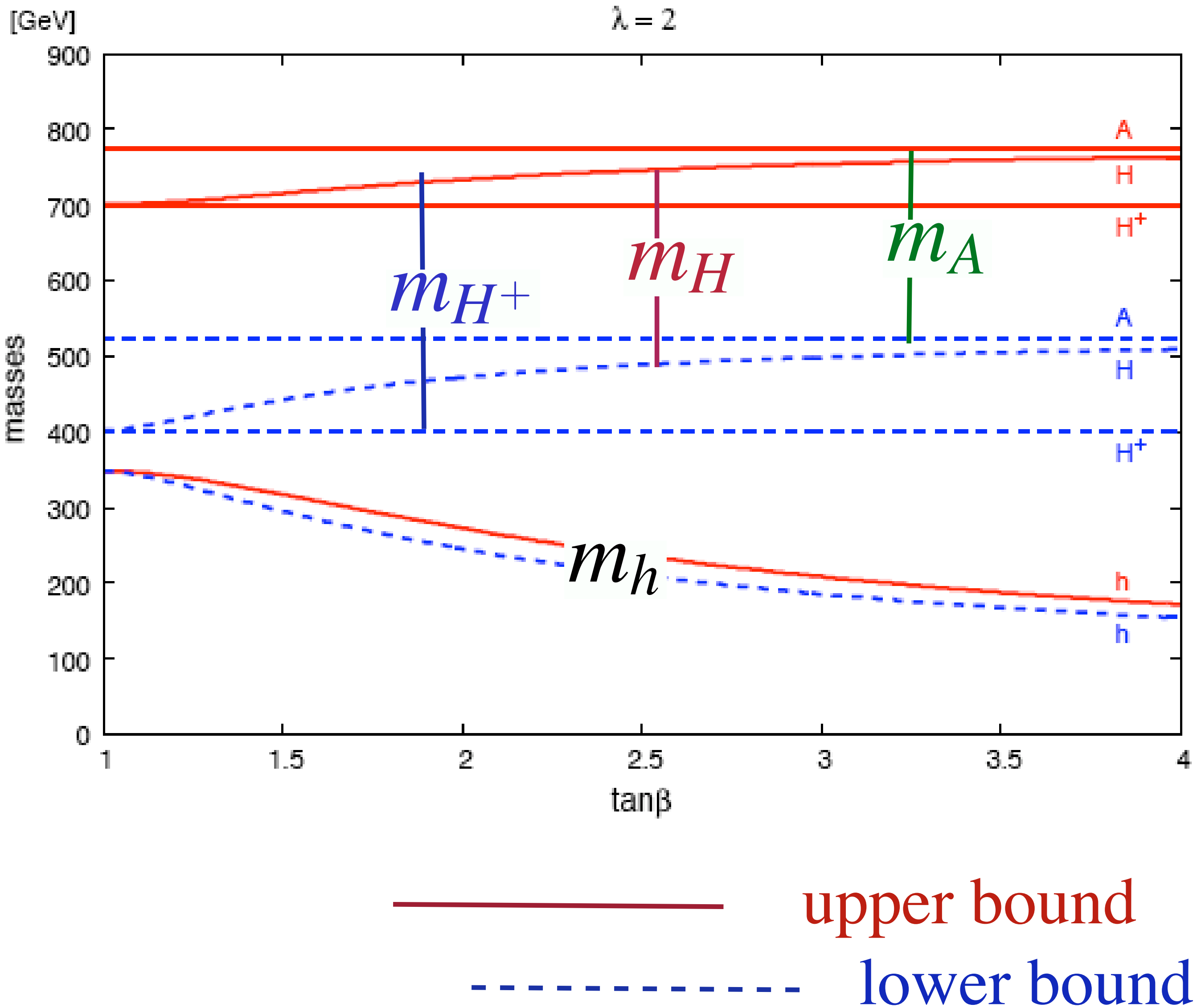
S and T from Higgs boson loops



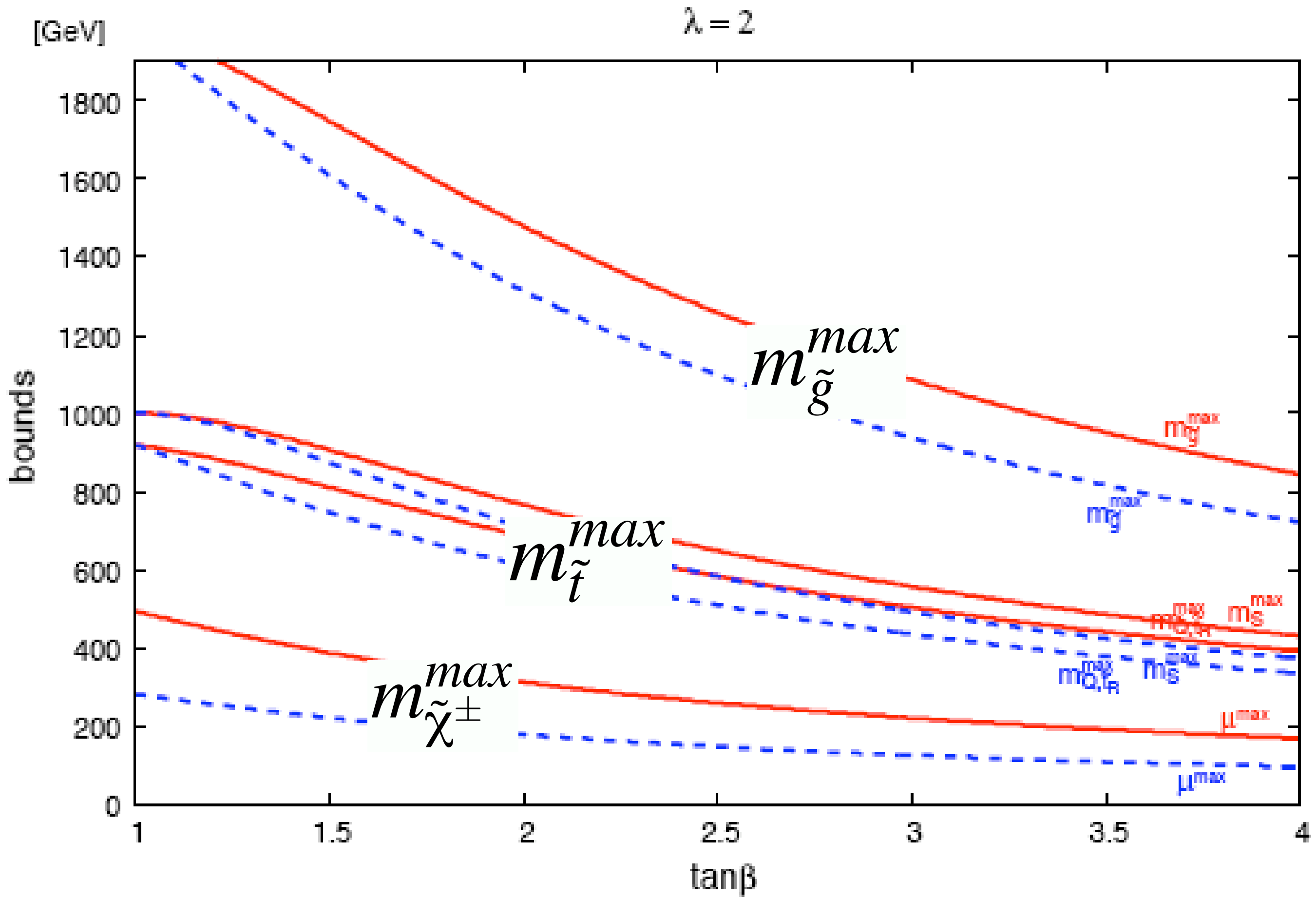
For $\tan\beta \leq 2.5$ and s-particles in their natural range, most of the parameter space inside the 1-2σ ellipse

$\tan\beta = 1$ = an exact custodial symmetry point

Particle spectrum (the Higgs bosons)



Particle spectrum (naturalness bounds)



$\lambda = 2$

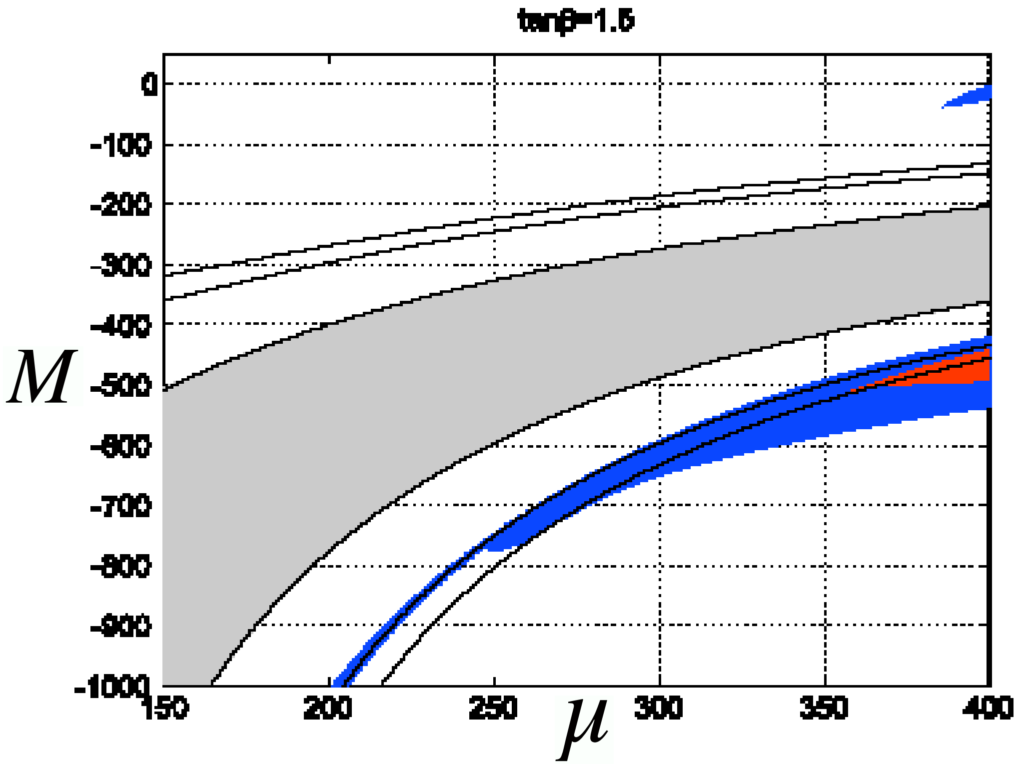
with up to 20% tuning $(m^{max} \propto \sqrt{\Delta/5})$

$\Lambda_{mess} = 100\ TeV$

Always a light neutralino in the spectrum $m_{\chi_1} < m_{\tilde{\chi}^{\pm}}$

No significant bound on s-fermions (other than stop)
and on SU(2)xU(1) gauginos

Higgsino Dark Matter



Blue: $\Omega\, h^2$=0.09-0.13

White: $\Omega\, h^2$<0.09

Red: $\Omega\, h^2$>0.13

Grey: $m_{LSP}<m_Z/2$

Black lines: $m_{LSP}=m_W,m_Z$

$LSP = \alpha\widetilde{S} + \beta\widetilde{H}_1 + \gamma\widetilde{H}_2$

MSSM: need coannihilations or $m_{\tilde{h}DM} \approx 1\ TeV$

$\lambda SUSY$: negligible coannihilations, Z-coupling suppressed $m_{\tilde{h}DM} \approx 100\ GeV$

Direct detection by Higgs exchange 1 order of magnitude below current limits

LHC phenomenology - Higgs spectrum

(a preliminary investigation)

1. h, H, A copiously produced in gluon-gluon fusion (σ~0.1-10 pb)

2. Both h and H likely maybe visible into h, H →ZZ→ 4e, 4μ

3. A likely visible into A → Zh → 4e, 4μ + jj

The measurements of the 3 h,H,A-masses could allow a determination of all λSUSY parameters in the Higgs sector

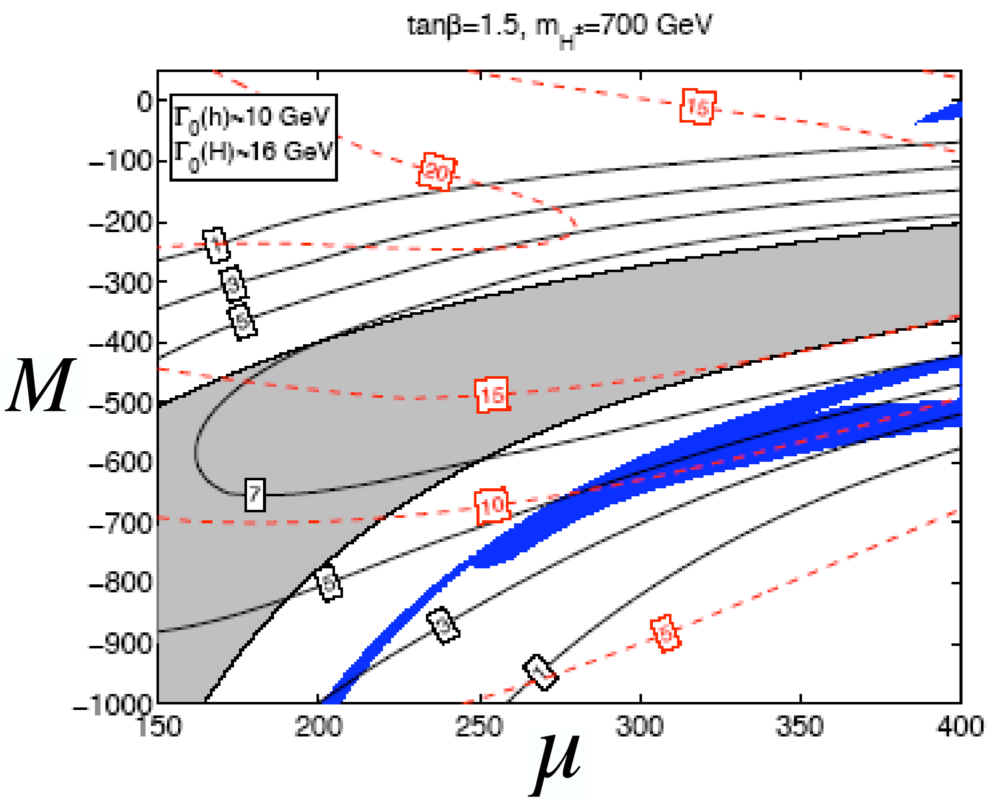
λ + $\mu_1^2(s), \mu_2^2(s), \mu_3^2(s)$ - (v-constraint)

LHC phenomenology - the Higgsino sector

2 param.s: M, μ

$h, H \to \chi\chi,\ \tilde{h}^+\tilde{h}^-$ significant due to large λ

M, μ measurable if Γ_h, Γ_H reconstructed from 4l final states



$$\Gamma_0(h) = \Gamma(h \to WW + ZZ)$$

$$\Gamma_0(H) = \Gamma(h \to WW + ZZ + t\bar{t} + hh)$$

Conclusions
even beyond supersymmetry

*⇒ LHC will explore **for the first time** the **relevant** energy range, well above the Fermi scale*

$$\Lambda_{QCD},\ G_F^{-1/2}$$

Physics in its normal way of operation

Useful to keep an open mind

The grand view: unification + supersymmetry + the desert

⋮

A minimalistic view: do we know where is the Higgs mass?

Allow me to recall the ambition of the task!