Supersymmetry, Baryon Number Violation and a Hidden Higgs

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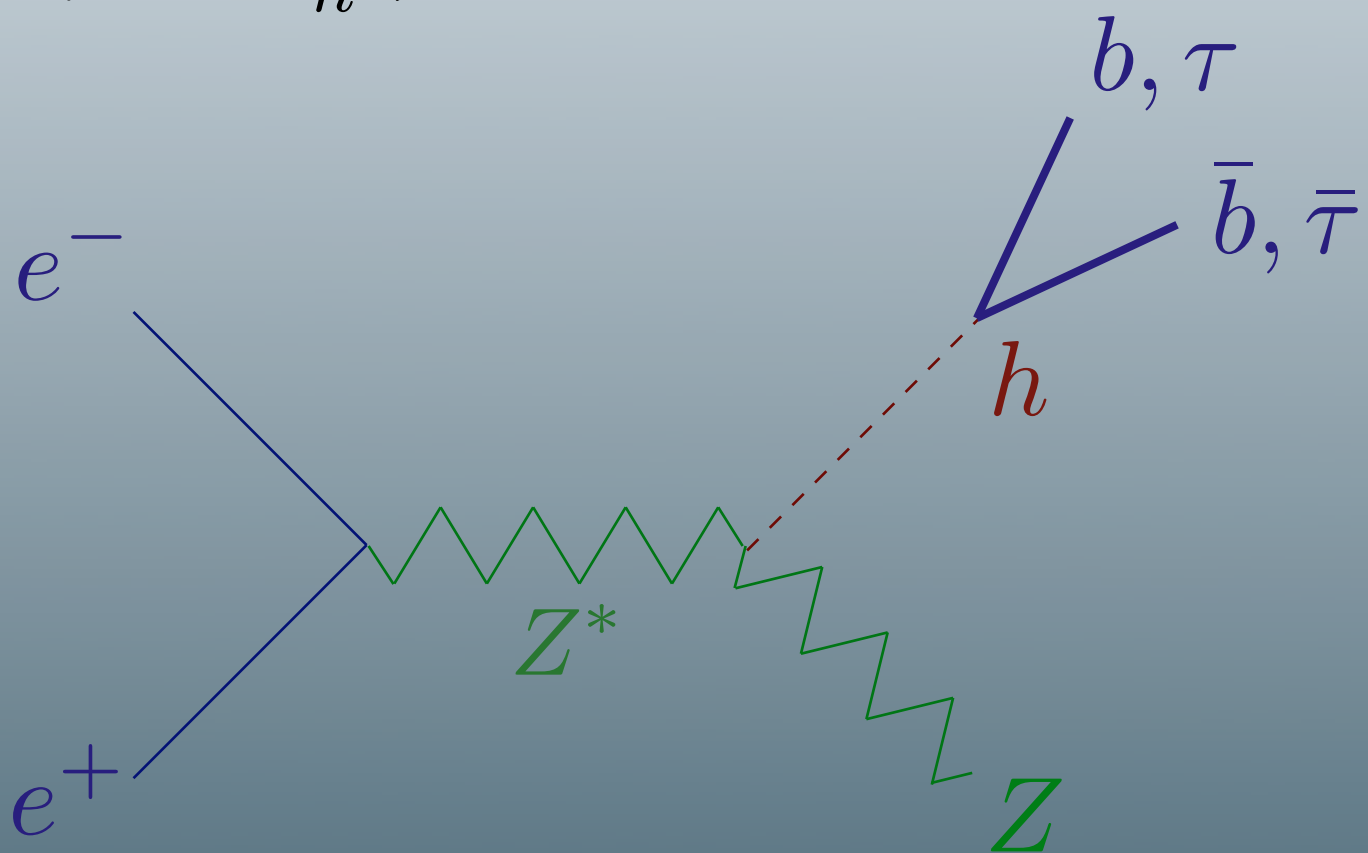
Summary

- LEP looked for a SM Higgs and didn't find it.
- Supersymmetry and Electroweak precision measurements prefer a Higgs lighter than the current bound.
- Non-standard decays of the Higgs severely weakens current bounds and opens up SUSY parameter space.
- New LEP(!) analyses are warranted. Higgs searches at the Tevatron and the LHC in these channels are a challenge...

Higgs: Direct Search

Dominant bound from LEP II

SM: $m_h > 114.4\,\mathrm{GeV}$



Decay modes of the Higgs

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$$\mathcal{H} = \lambda h f \bar{f} + \ldots \qquad h = v + \delta h$$

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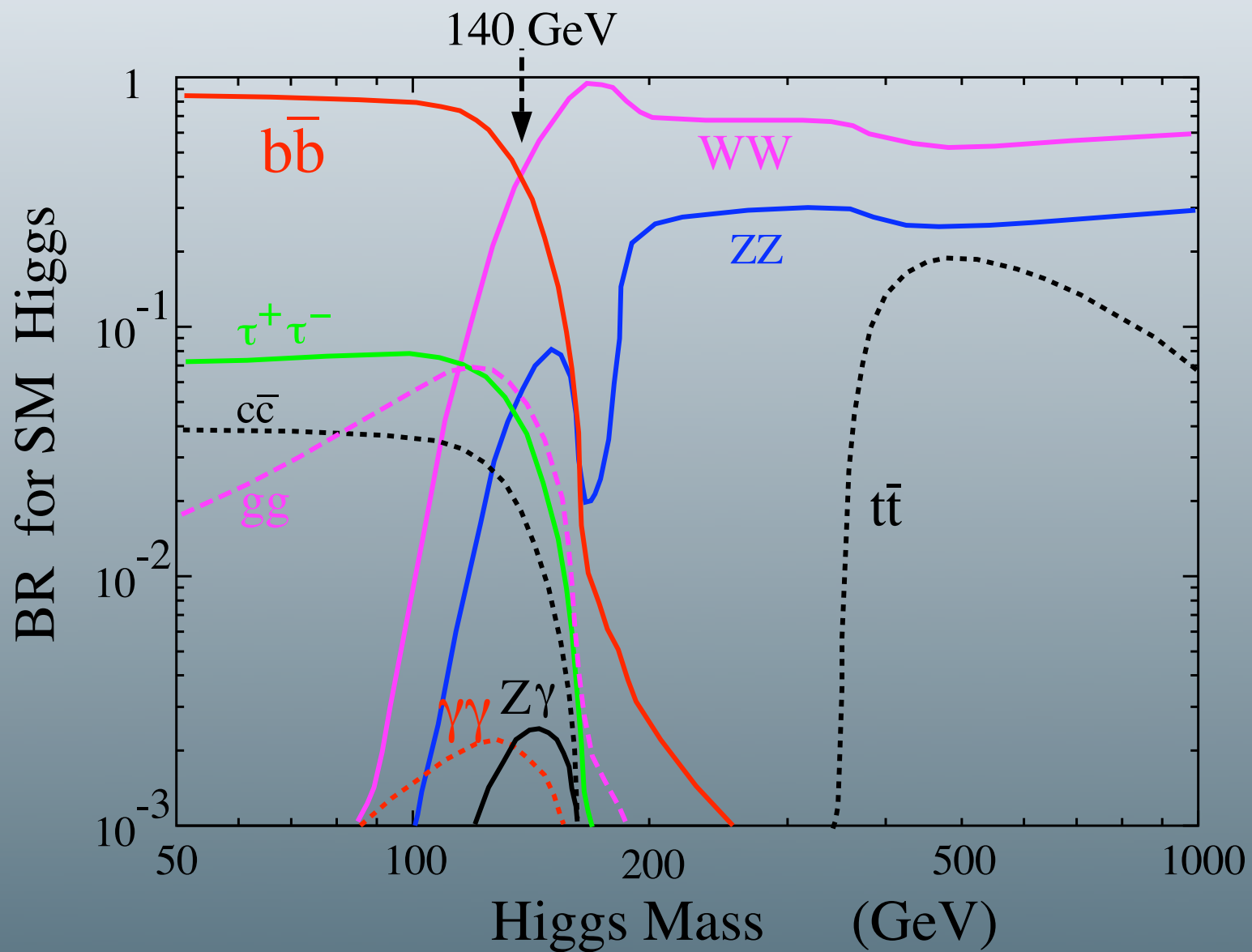
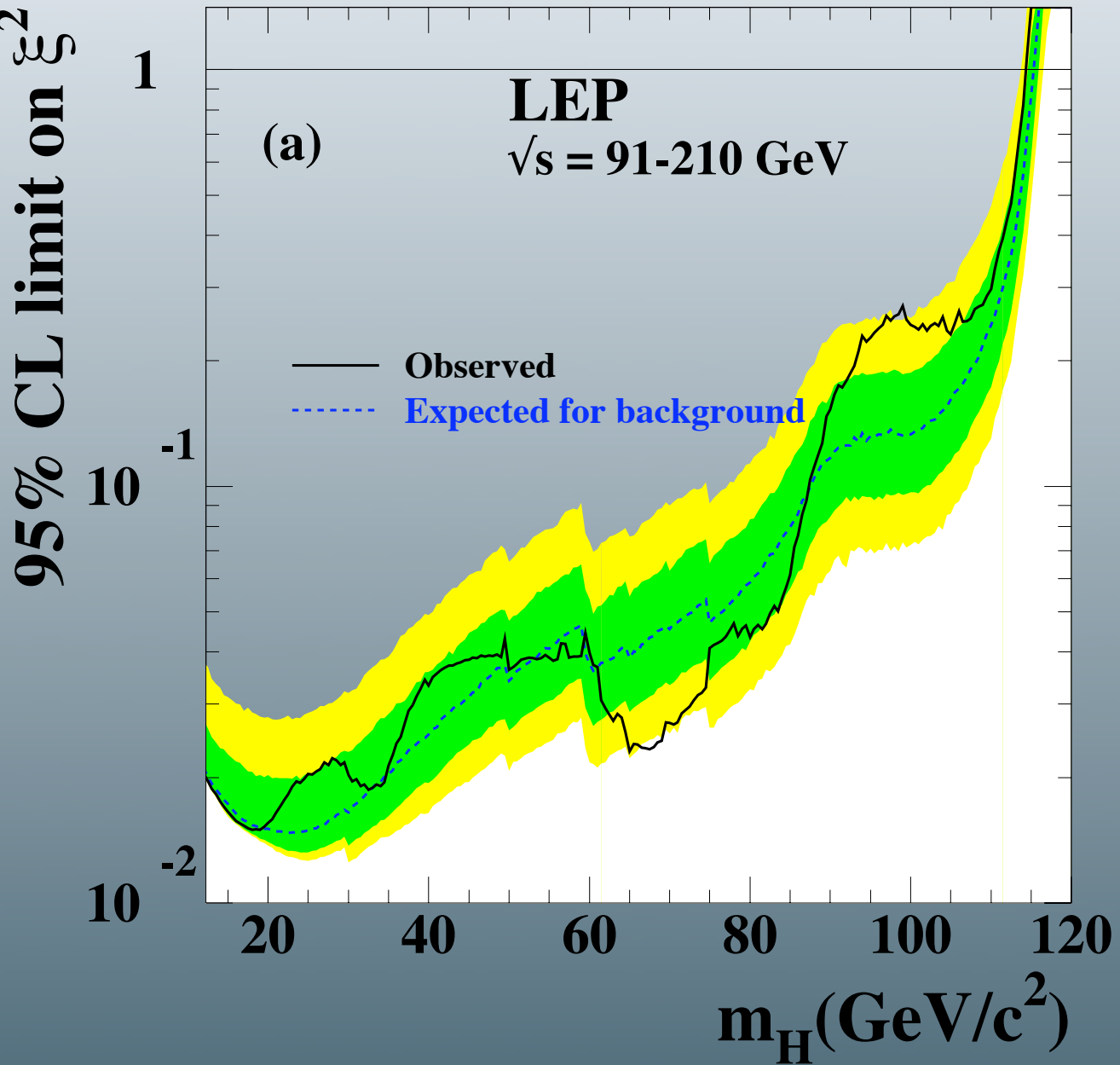
$$\Gamma_{h \to f\bar{f}} \propto \lambda^2 m_h, \quad 2m_f \ll m_h$$

Decay modes of the Higgs

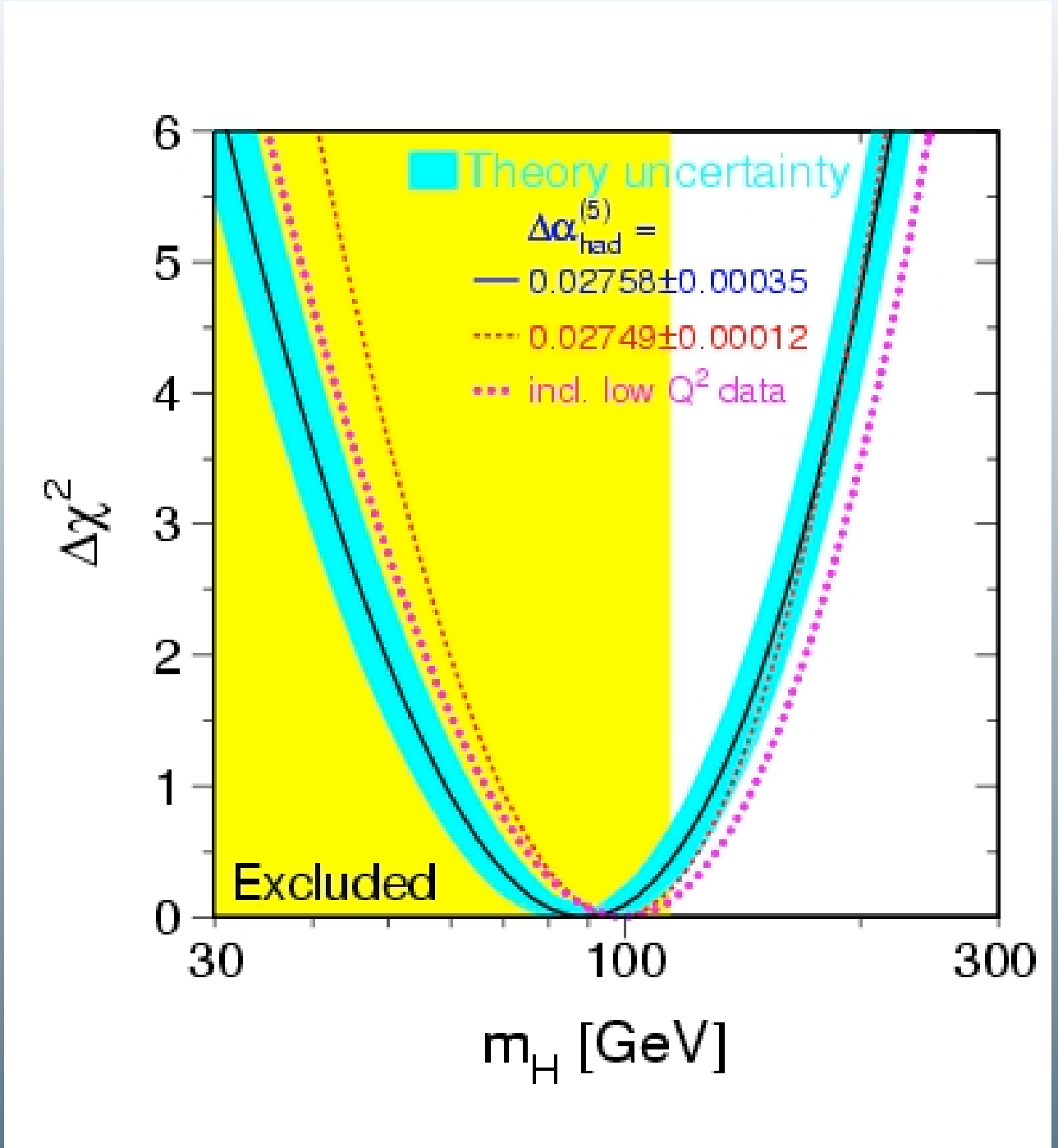


SM Higgs


95% CL limit on ξ^2
1
10^{-1}
10^{-2}
(a)
LEP
$\sqrt{s}$ = 91-210 GeV
Observed
Expected for background
20
40
60
80
100
120
$m_H(GeV/c^2)$

A light Higgs is preferred by data

Central value at 92 GeV.



The Higgs Mass

MSSM $\rightarrow m_{higgs} <$ 130ish GeV

??????????

With 100 new parameters!

The Higgs Mass

Reminder - in the Standard Model:

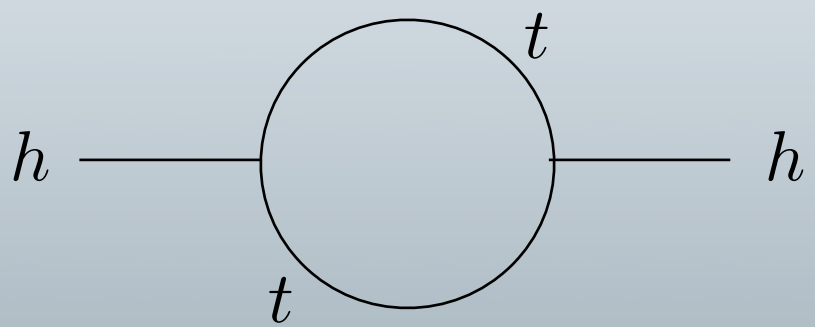
$$V \sim -\frac{1}{2}m^2h^2 + \frac{1}{4}\lambda h^4$$

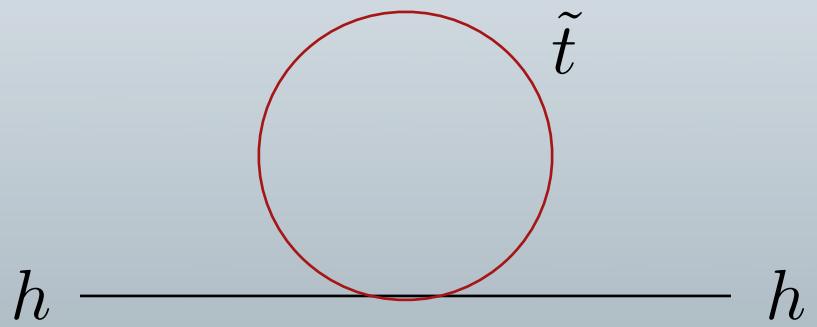
$$\frac{\partial V}{\partial h} = 0 \rightarrow \langle h \rangle \equiv v = \sqrt{m^2/\lambda}$$

$$m^2_{phys} \sim \lambda v^2$$

We know the relationship, not the mass

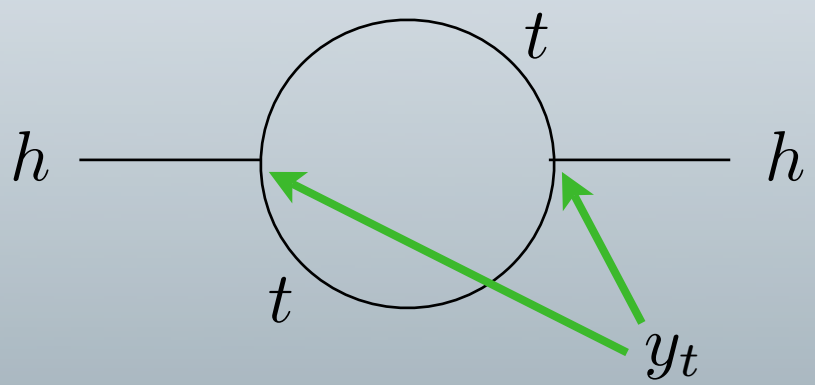
Top - Stop cancelation

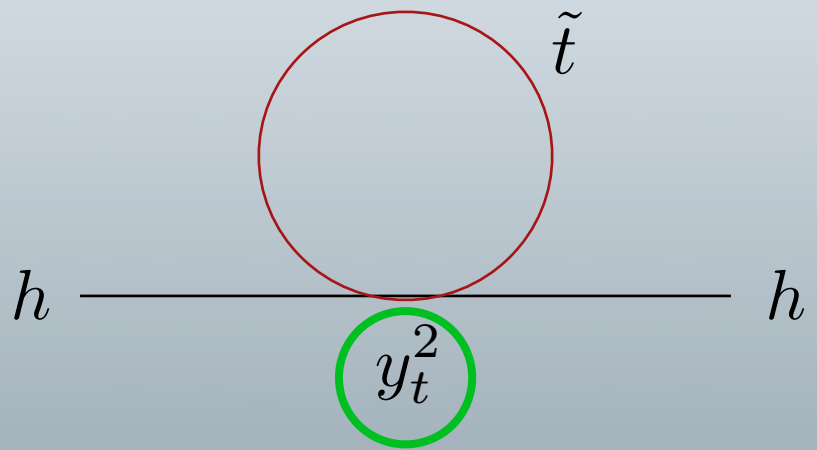




Exact supersymmetry - cancelation exact (up to w.f. ren.)

Top - Stop cancelation





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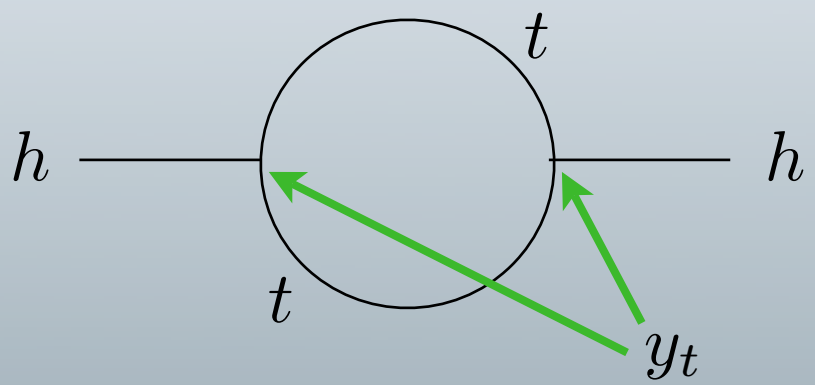
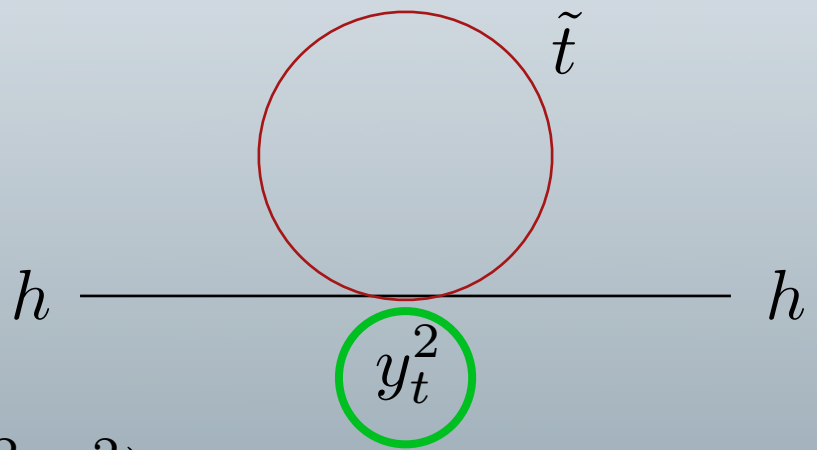
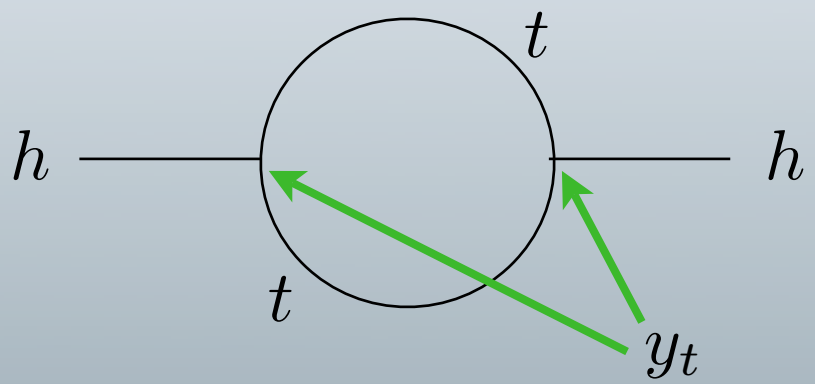
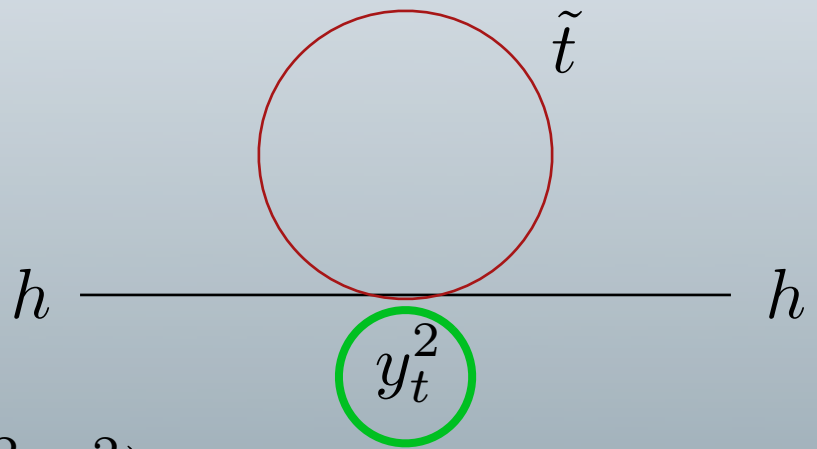




Broken SUSY $\quad \delta m_h^2 = f(m_t^2, m_{\tilde{t}}^2, y_t^2)$

Top - Stop cancelation





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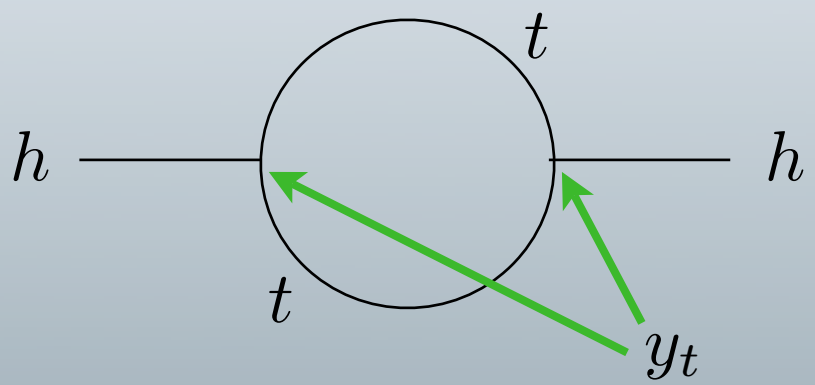
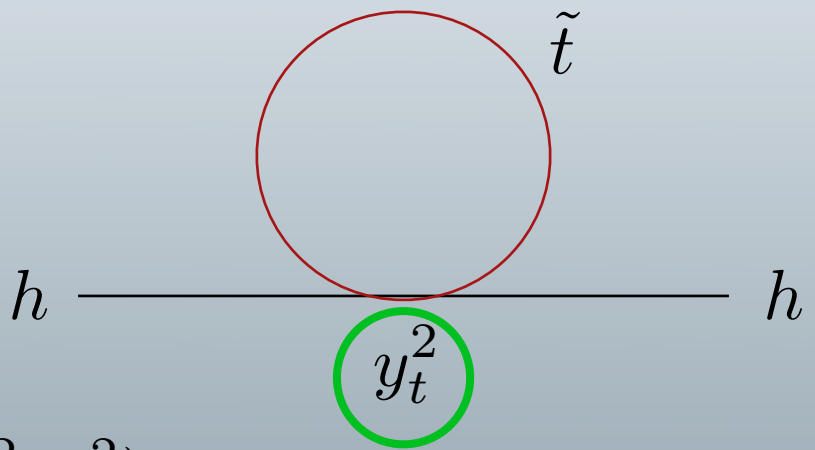
$$m_{\tilde{t}}^2 \neq m_t^2 \quad \rightarrow \quad \delta m_h^2 \propto (m_{\tilde{t}}^2 - m_t^2) \ln \Lambda$$ Soft breaking

Top - Stop cancelation





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$$y_{\tilde{t}}^2 \neq y_t^2 \quad \rightarrow \quad \delta m_h^2 \propto (y_{\tilde{t}}^2 - y_t^2) \Lambda^2 \qquad \text{Hard breaking}$$

The Supersymmetric Higgs Mass

The quartic coupling is dimensionless - thus supersymmetric to a good degree

$$\lambda = \frac{g^2}{2}\left[\frac{1}{2}|H_1|^2 - \frac{1}{2}|H_2|^2\right]^2$$

Predicted quartic!

$$m_h = M_Z|\cos 2\beta| \qquad \text{with} \qquad \tan\beta = \langle H_2\rangle/\langle H_1\rangle$$

What now?

Corrections to the Higgs mass

$$\lambda v^2 = m^2_{phys} = 2\mu^2 + m^2_{soft}$$

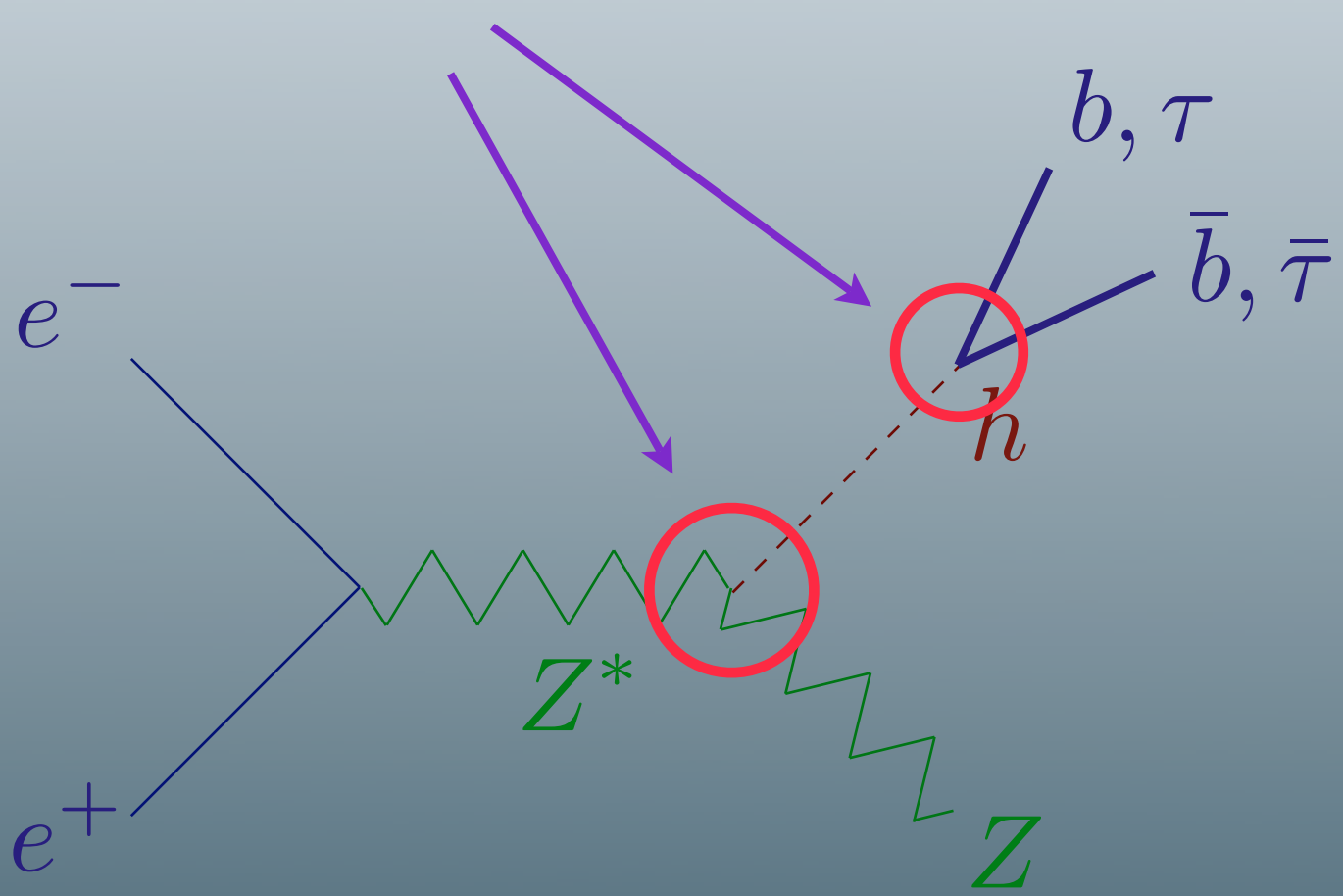
$\delta(m_h^2)_{phys} \propto y_t^2 m_t^2 \ln(m_{\tilde{t}}/m_t)$ grows as a log

$\delta(m_h^2)_{soft} \propto y_t^2 m_{\tilde{t}}^2 \ln(\Lambda/m_{\tilde{t}})$ grows as a power

Typically need stop masses near 1 TeV or large A terms

Alternative phenomenology of the Higgs

New couplings for the Higgs:



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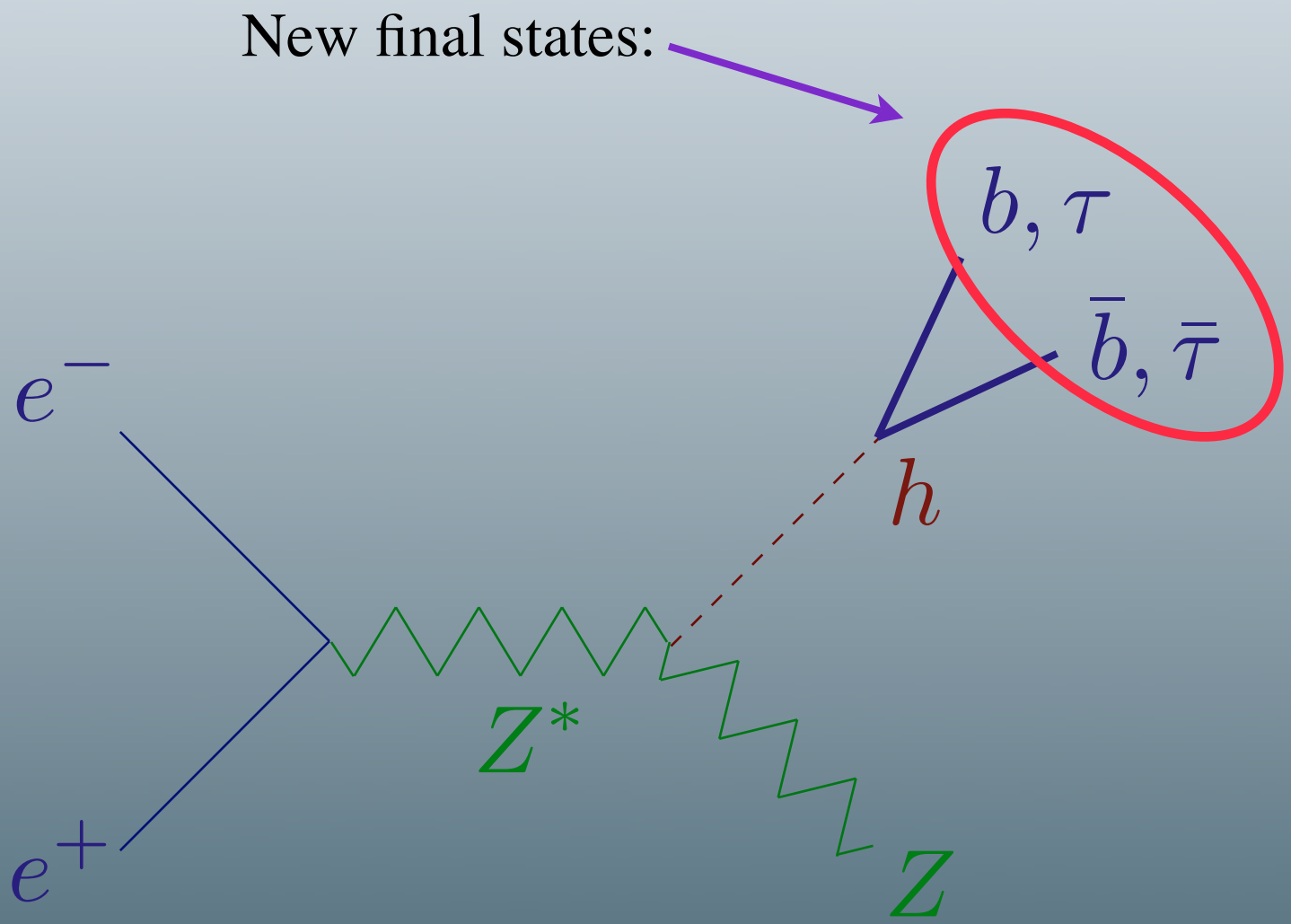
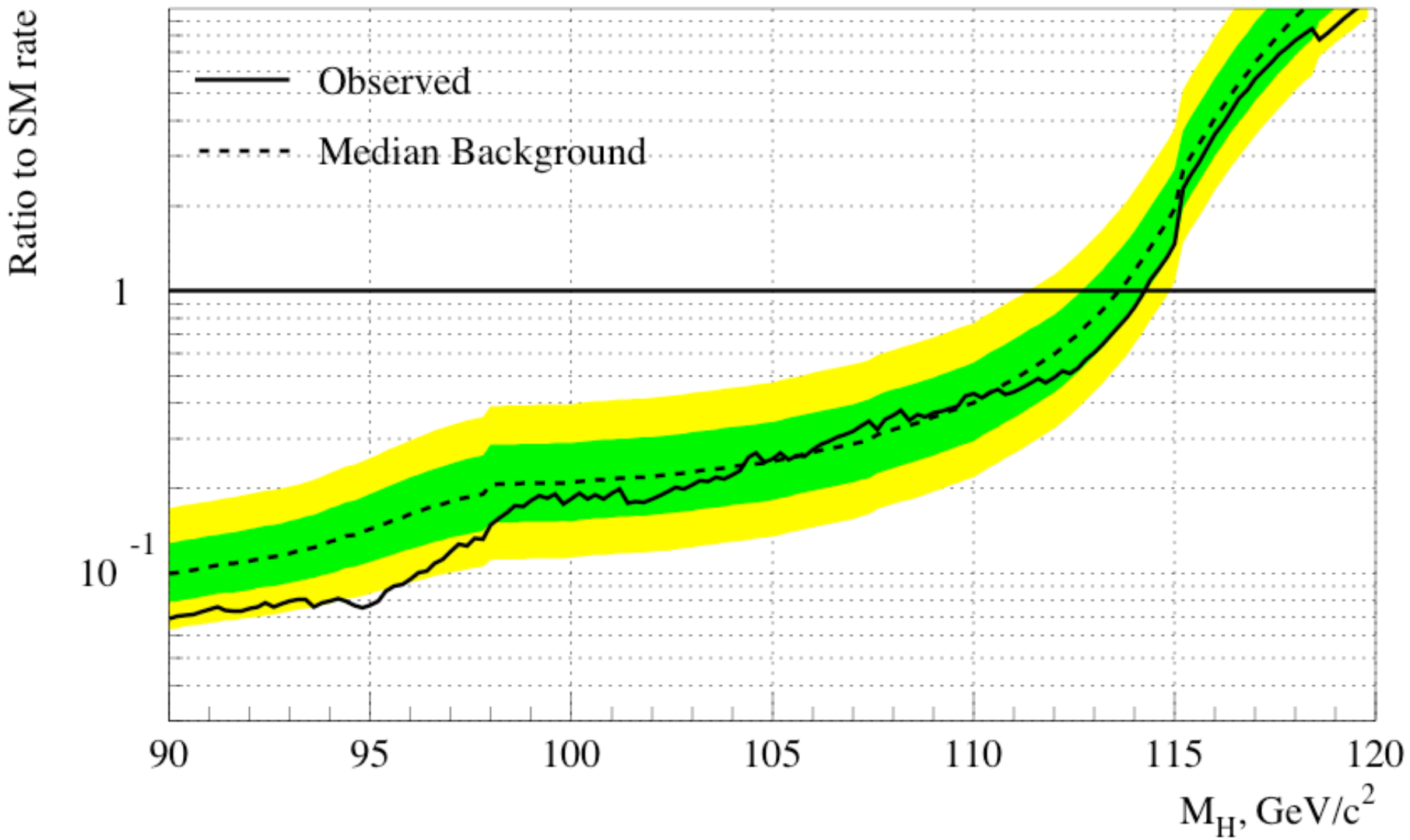
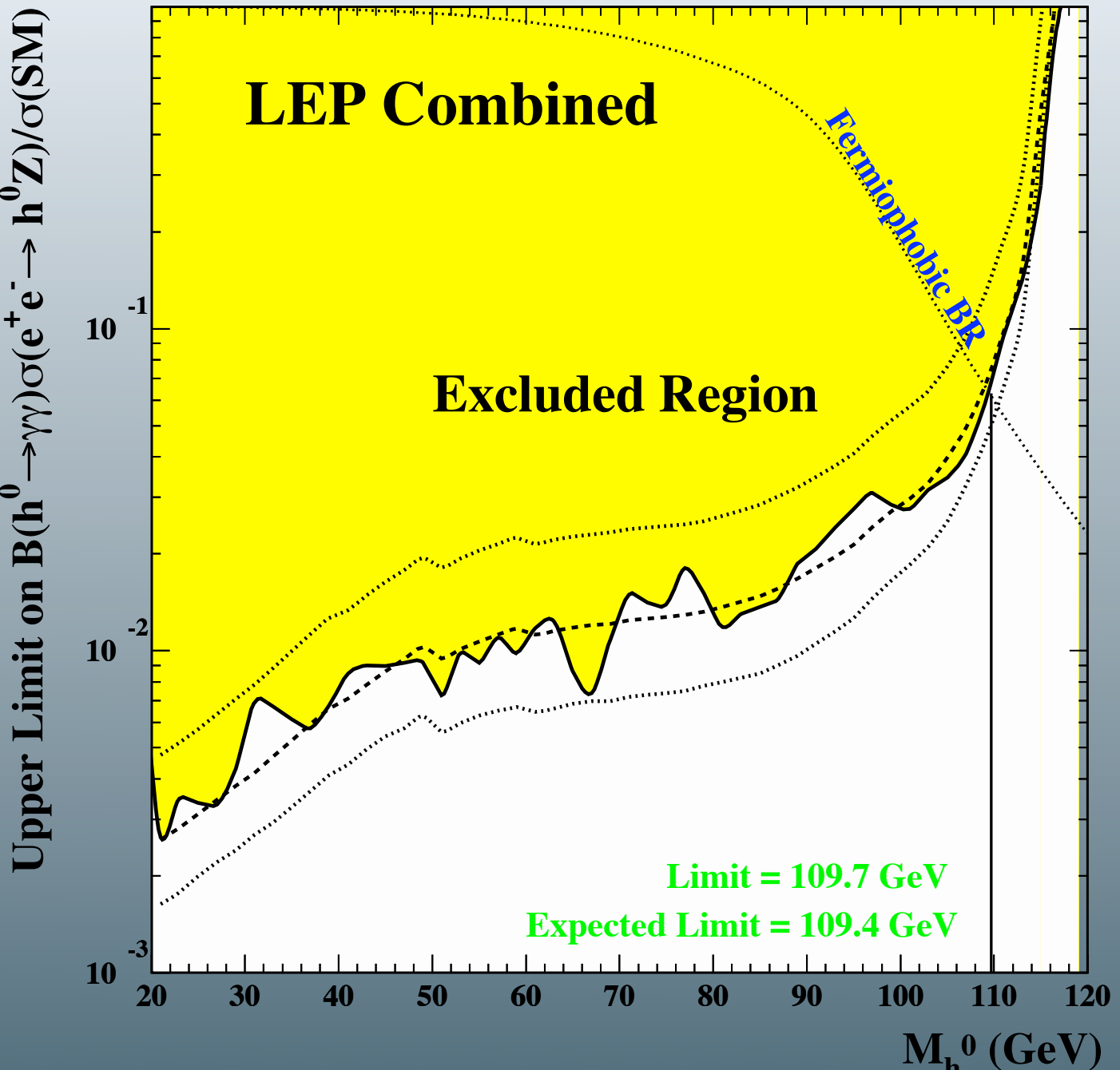


Invisible Higgs



LEP Combined - '01

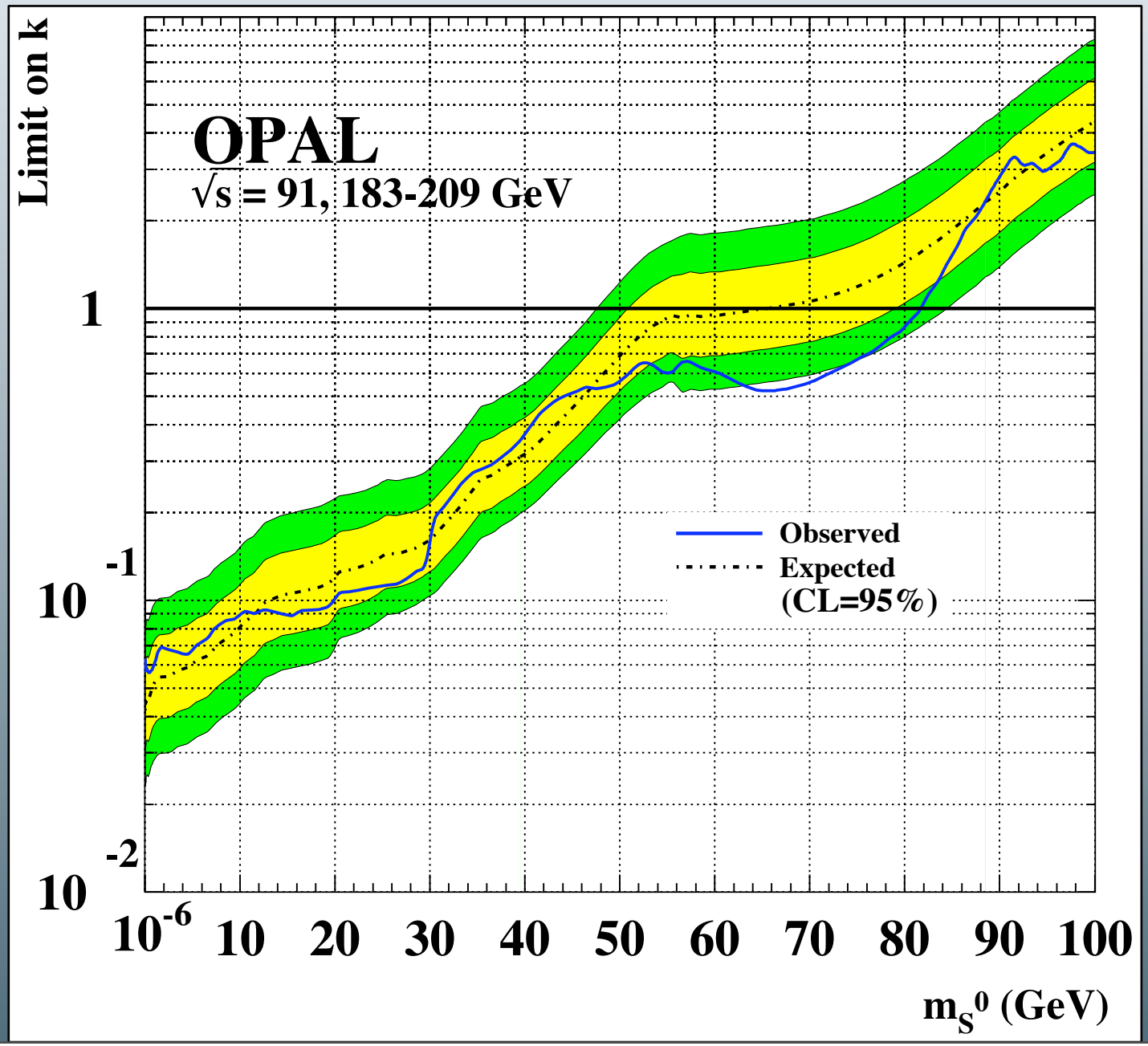
Fermiophobic



Only Searches so far...

$h \to$ invisible	$m_h < 114\,\mathrm{GeV}$
$h \to jj$	$m_h < 113\,\mathrm{GeV}$
$h \to VV$	$m_h < 109.7\,\mathrm{GeV}$
$h \to \gamma\gamma$	$m_h < 117\,\mathrm{GeV}$
$h \to 2\phi \to 4b$	$m_h < 110\,\mathrm{GeV}$
$h \to X$ (leptonic Z)	$m_h < 82\,\mathrm{GeV}$

Non-standard Higgs Decays



Non-standard Higgs Decays

Most problematic decay:

$$h \longrightarrow \mathrm{N}\, jets$$

At the LHC, one would still look for SM decays to $\gamma\gamma,\ VV^*,$ with $S/\sqrt{B} \sim 8, 5 - 20$ (SM values) reduced.

E. Berger, C.-W. Chiang, J. Jiang, T. Tait, C. Wagner - '02

Alternative phenomenology of the Higgs

NMSSM (generalized):

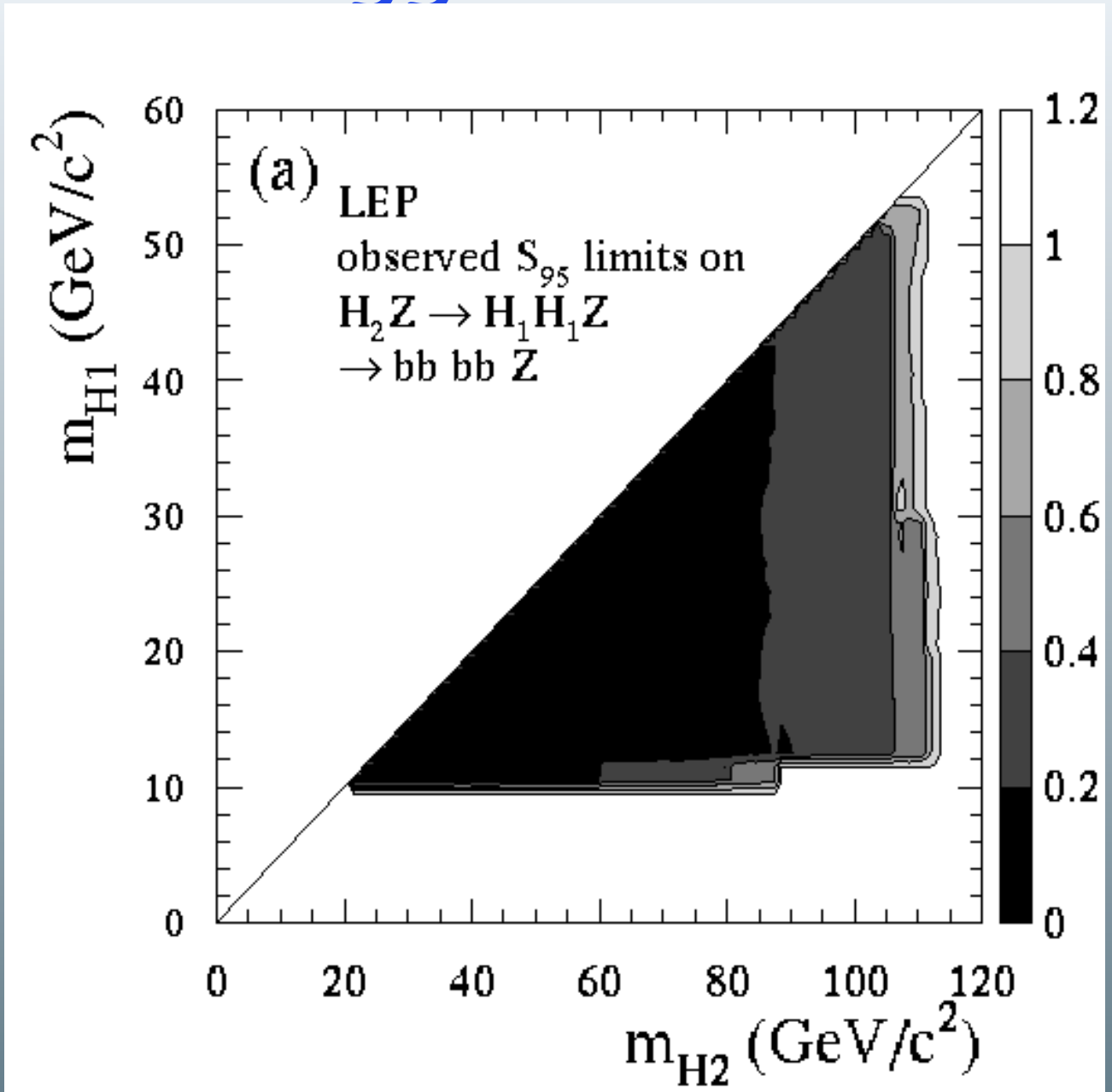
Add a singlet superfield to the spectrum - helps add to the Higgs mass and adds the possibility of

$$h \to aa \to XX$$
$$h \to ss \to XX$$
$$h \to ss \to 4a \to 4X$$

where the X is 2b's, 2 taus or 2 unflavored jets.

B. Dobrescu and K. Matchev - '00
R. Dermisek and J. Gunion - '04
S. Chang, P. Fox, N. Weiner - '05

Higgs to 4b's



But NOT 4 taus!

A Supersymmetric Standard Model

$$= H_2 Q U^c + H_1 Q D^c + H_1 L E^c + \mu H_1 H_2$$

$$= L Q D^c + U^c D^c D^c + L L E^c + \mu L H_2$$

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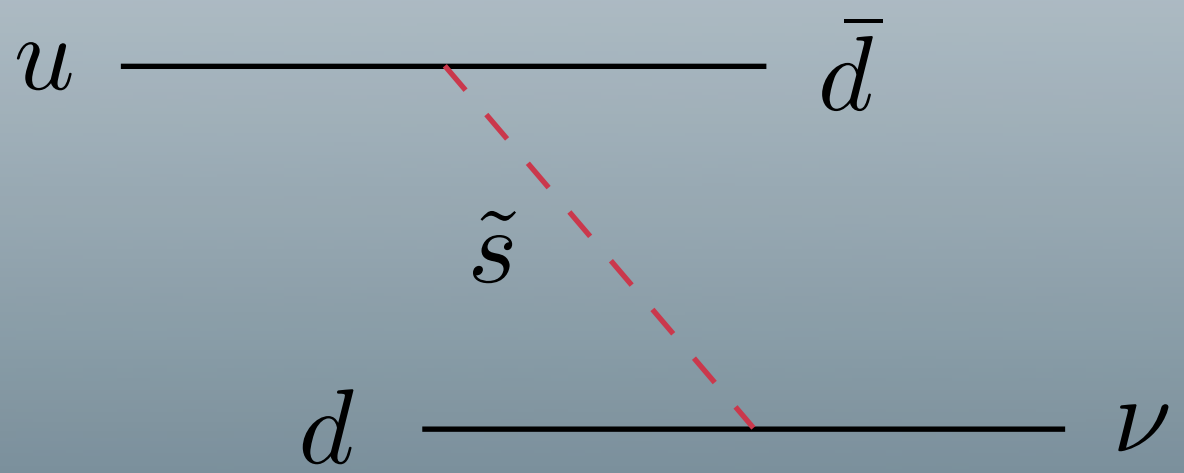

$$p \longrightarrow \pi^+ \nu$$

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Introduce a parity

$$Q \rightarrow -Q$$
$$H \rightarrow +H$$

Equivalent to:

$$\phi_{SM} \rightarrow +\phi_{SM}$$
$$\tilde{\phi}_{SP} \rightarrow -\tilde{\phi}_{SP}$$

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R Parity

A Supersymmetric Standard Model

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A Supersymmetric Standard Model

$$= H_2 Q U^c + H_1 Q D^c + H_1 L E^c + \mu H_1 H_2$$

$$= L Q D^c + U^c D^c D^c + L L E^c + \mu L H_2$$

Could have “Baryon Parity”.

A Supersymmetric Standard Model

$$= H_2 Q U^c + H_1 Q D^c + H_1 L E^c + \mu H_1 H_2$$

$$= \cancel{L Q D^c} + U^c D^c D^c \cancel{+ L L E^c} + \mu L H_2$$

or "Lepton Parity"

$$p \not\to X$$

X must have an odd number of fermions, thus its lepton number $L = 2n + 1$. No lepton parity violation, no decay.

Bounds on R-parity violation

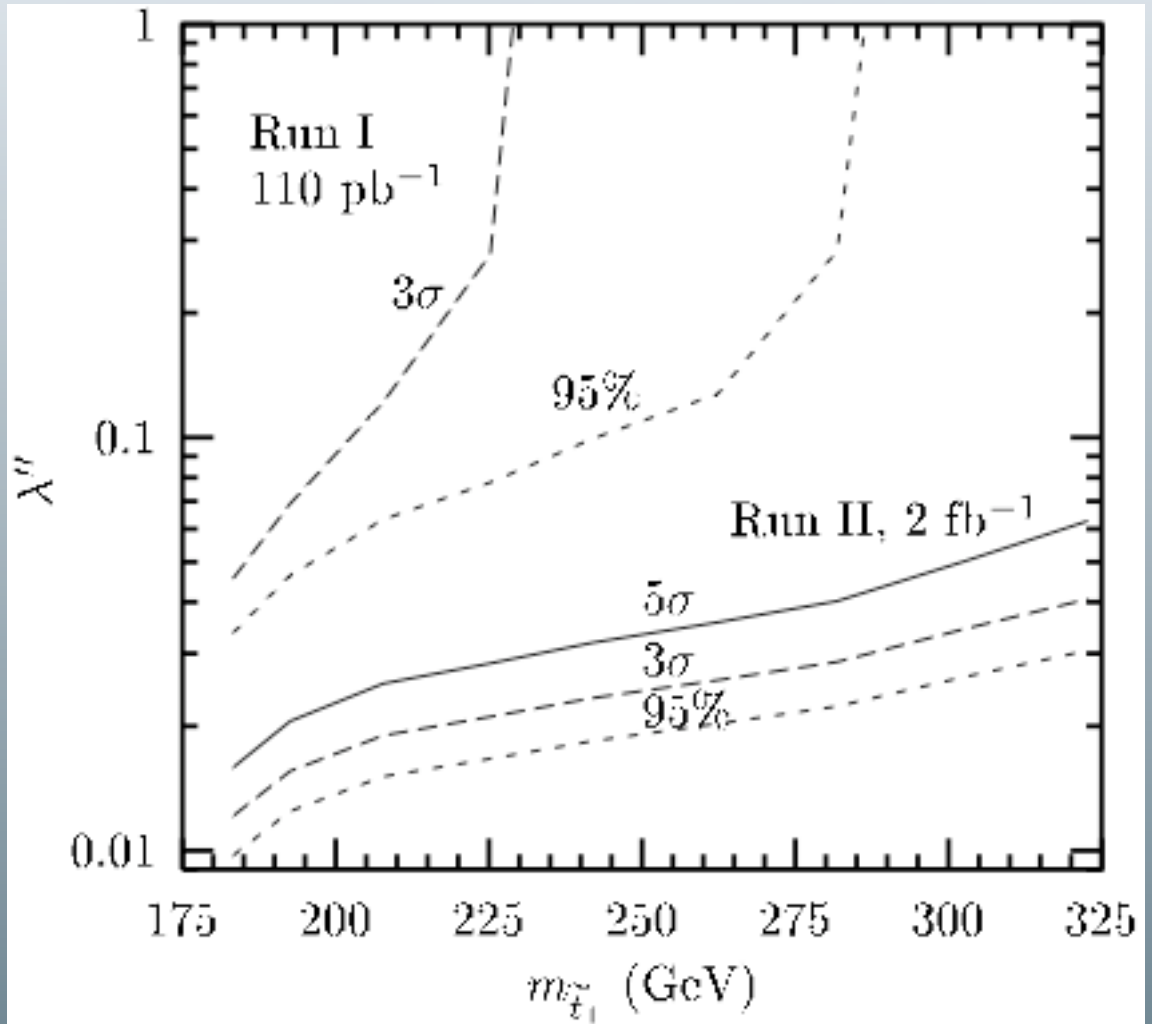
$$\lambda''_{ijk} U^c_i D^c_j D^c_k$$

$$\lambda''_{uds}, \lambda''_{udb} < 10^{-4}$$

$$\lambda''_{usb}, \lambda''_{cds}, \lambda''_{cdb}, \lambda''_{csb} < 1$$

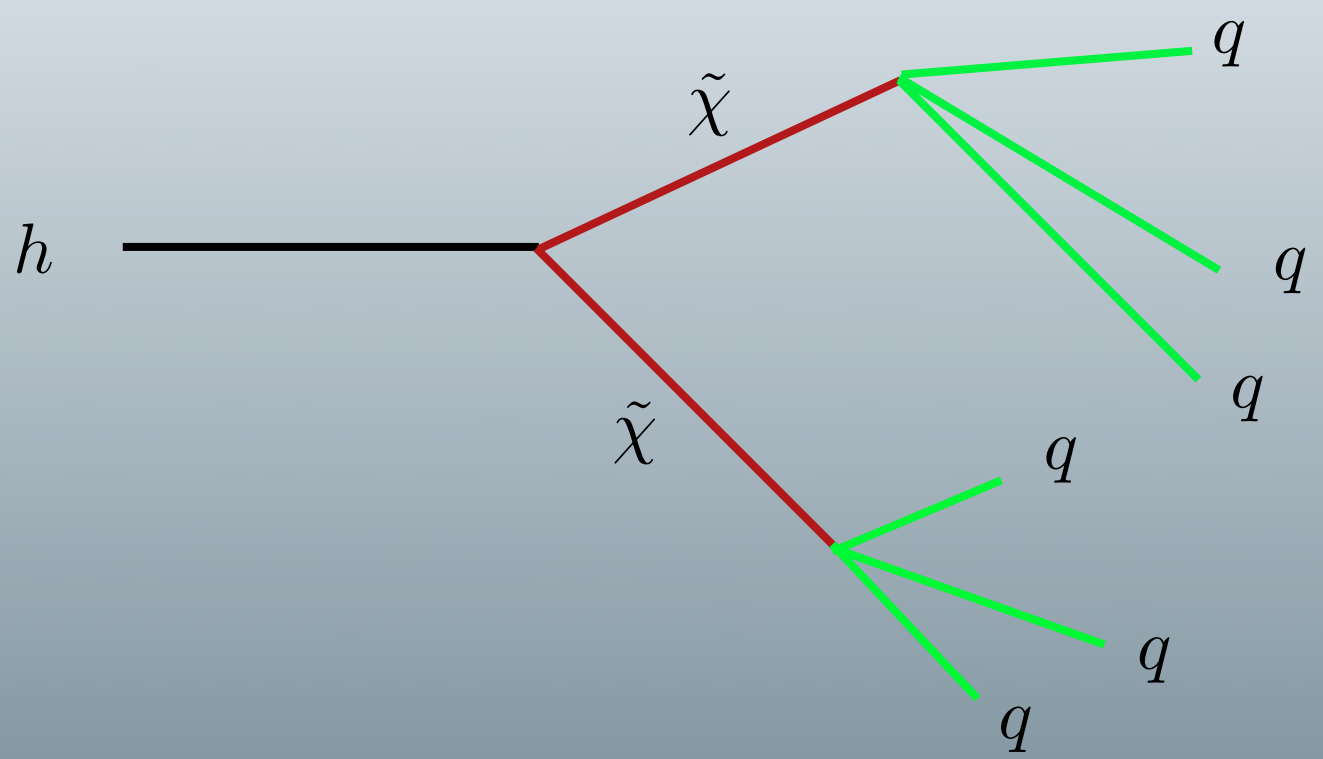
$$(\lambda''_{ijk} \lambda''_{i'j'k'}) < 10^{-2} \sim 10^{-4}$$

Single Stop Production



E. Berger, B. Harris, Z. Sullivan - '99

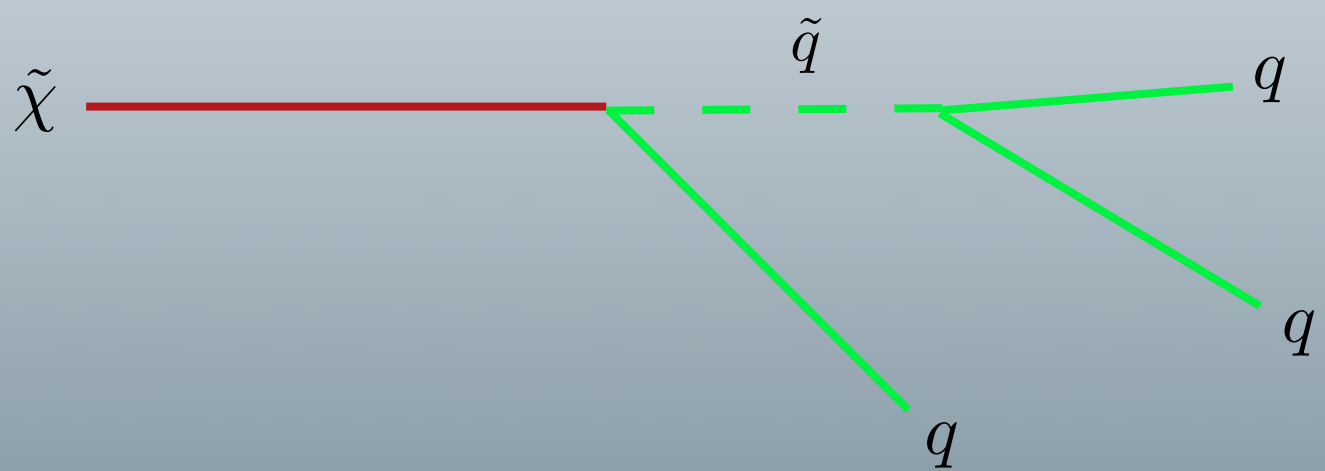
Higgs decays with B-violation



higgs -> 6 jets!

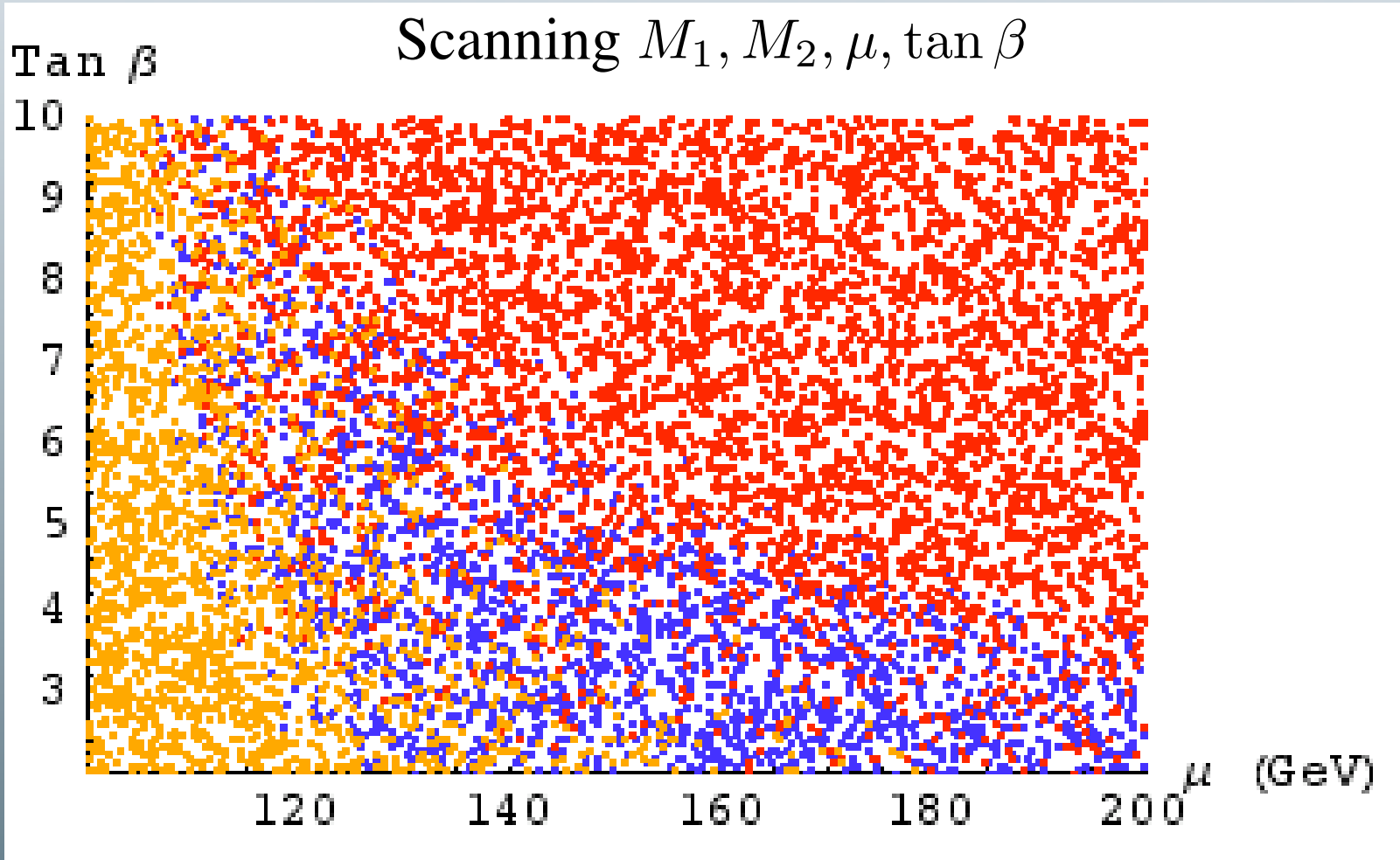
$m_h > 82\ \mathrm{GeV}$

Neutralino Decay



$\lambda'' \sim 0.1$ squark masses < 400 GeV for fast decays

H -> Neutralinos



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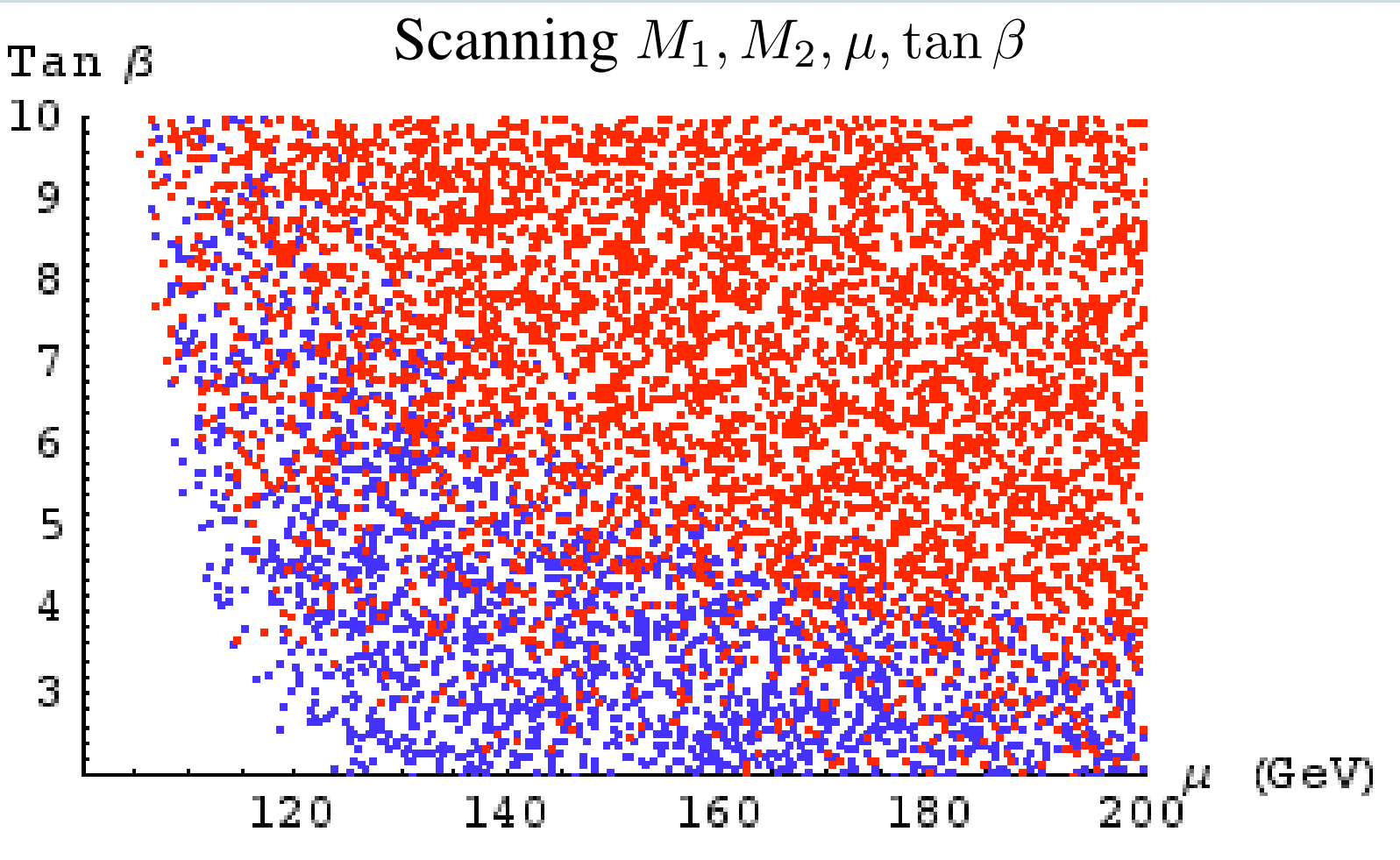
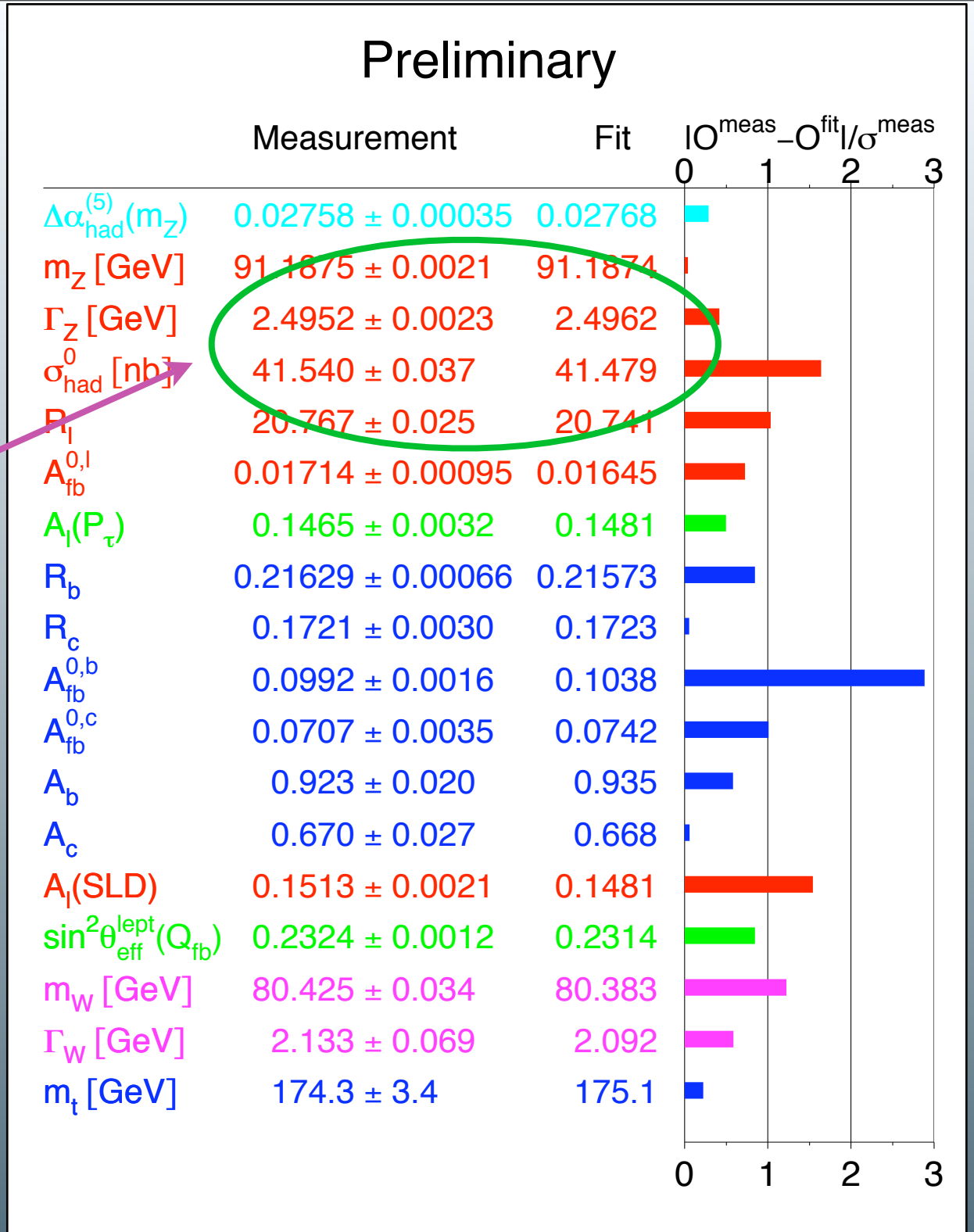


LEP I Constraints

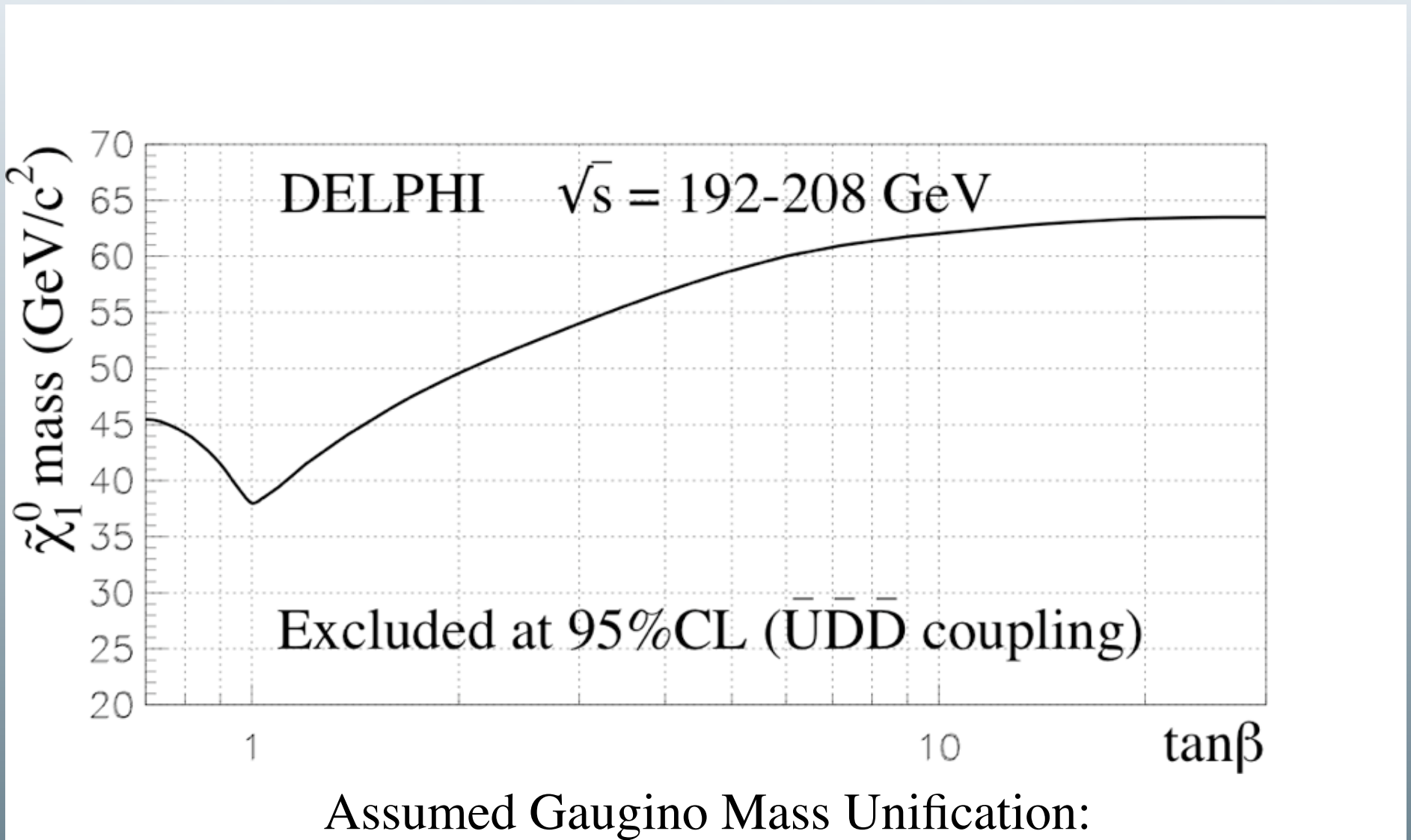
Z couples due to mixing of neutralinos. Typically add about 2 MeV to the width.

$$\Delta\chi^2 \sim 1$$

(Thanks Tim!)



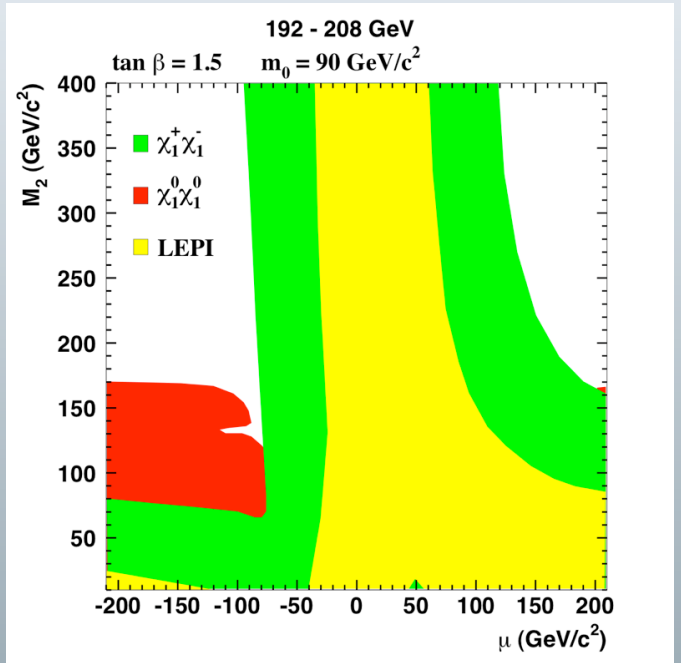
Search for RPV SUSY (Delphi)

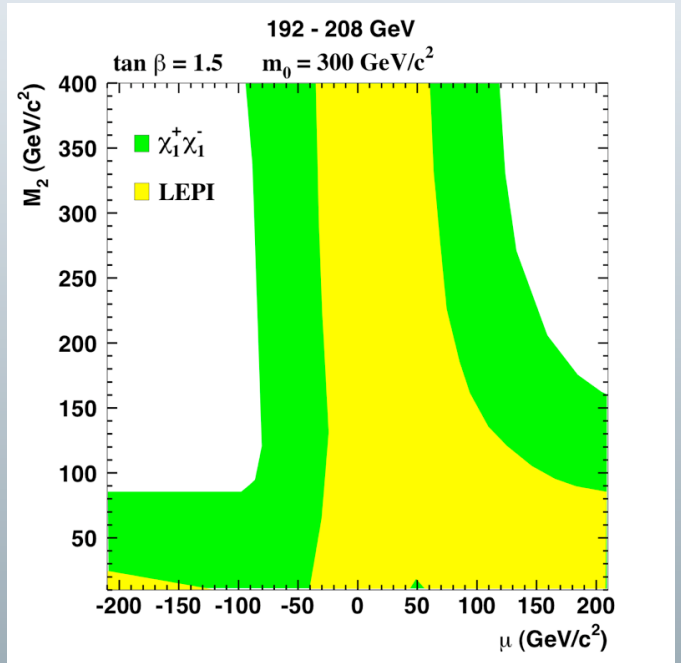


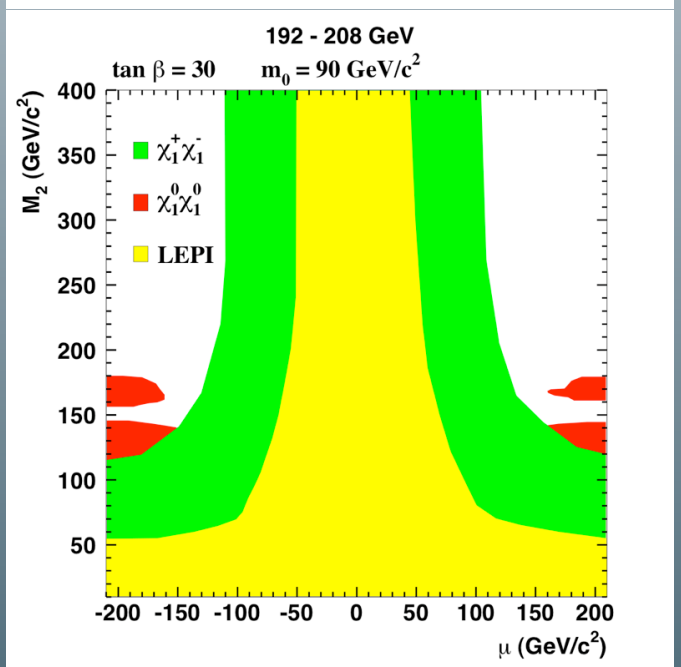
Assumed Gaugino Mass Unification:

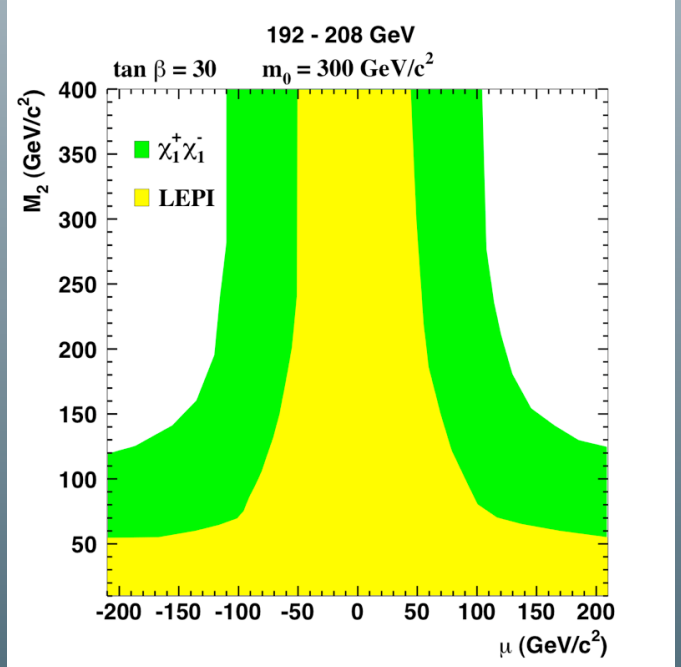
$$M_1 = \frac{5}{3} \tan\theta_W{}^2 M_2$$

Search for RPV SUSY (Delphi)

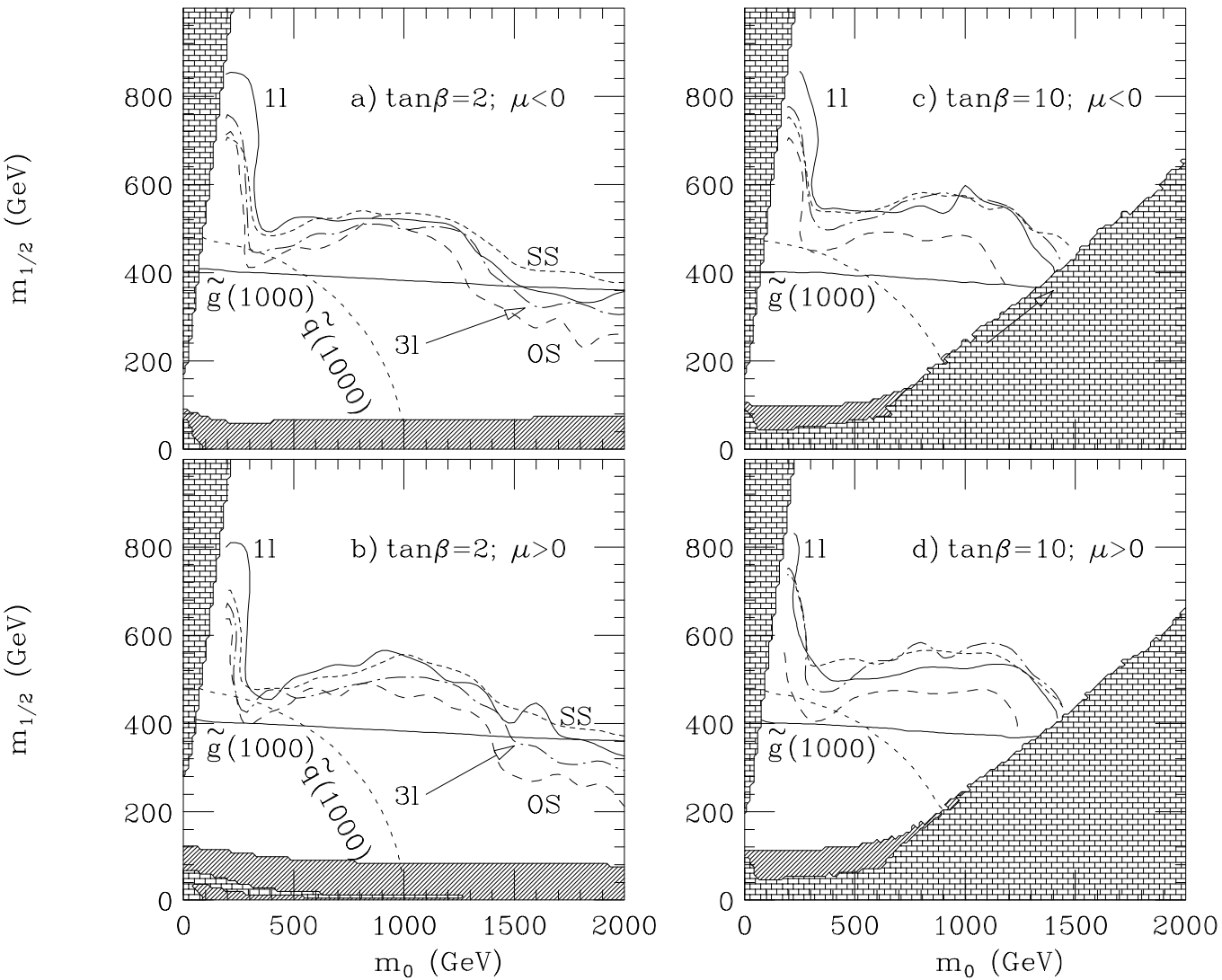




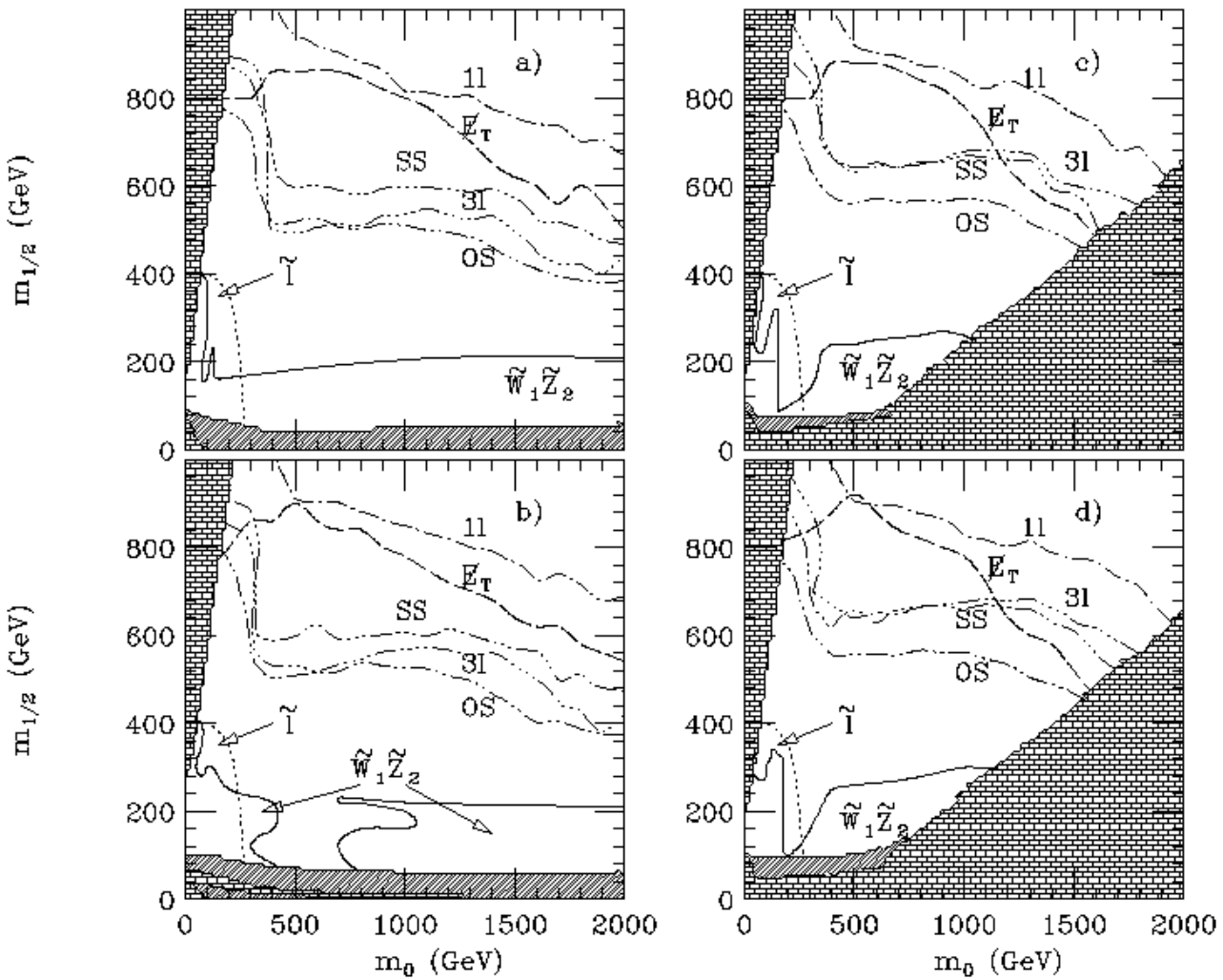




R-parity violating SUSY at the LHC



R-parity preserving SUSY at the LHC



Conclusions

A Higgs which decays to a multi-jet final state happens in some SUSY parameter space and allows $m_h \sim m_Z$

LEP analyses should continue!

There are Higgses that LEP can see and the LHC can't. Tevatron study should be done.