# Supersymmetric Scenarios
# & Perspectives for Higgs Physics

1 - Introduction

motivations vs direct limits, LEP 'H'

2 - Supersymmetric Dark Matter

limits on sparticle masses (↑, ↓)

3 - Muon Anomalous Magnetic Moment

indication for susy? $\mu \to e\gamma$?

4 - Post-LEP Benchmark Scenarios

what can you see where?

5 - Where do we go from here?

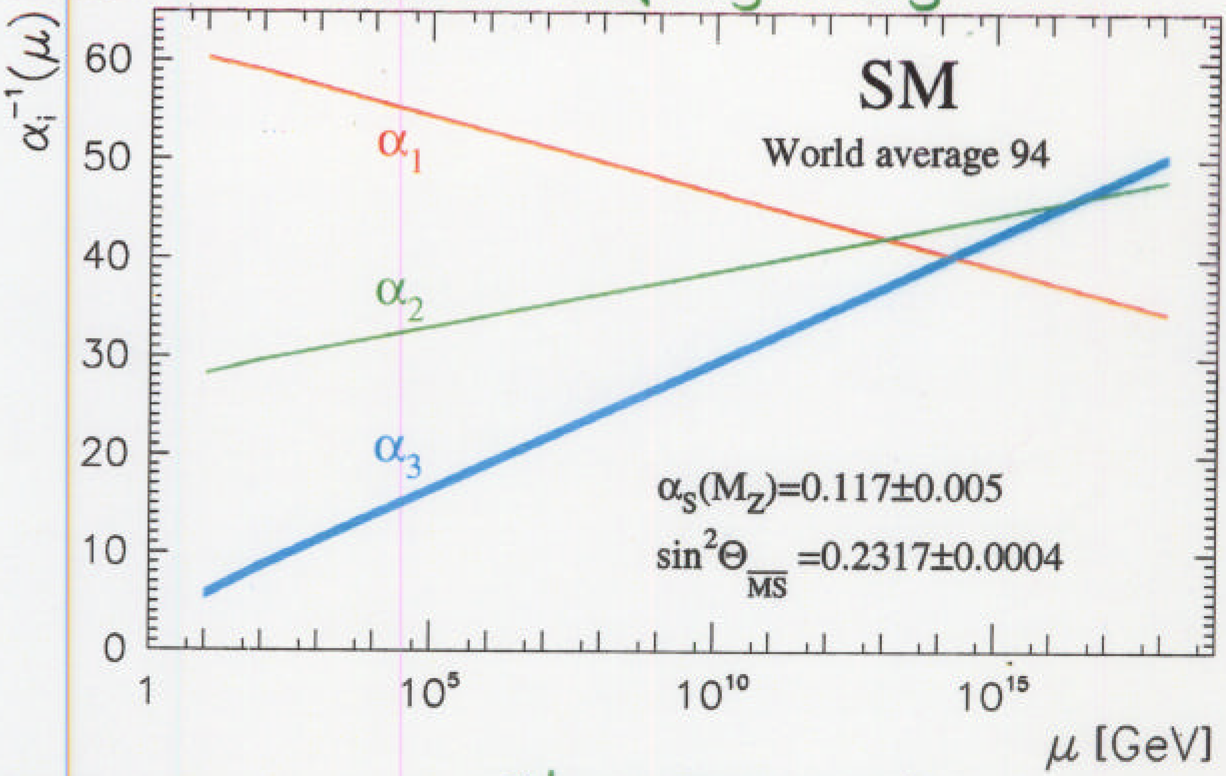
Tevatron, LHC, LC

6 - CLIC

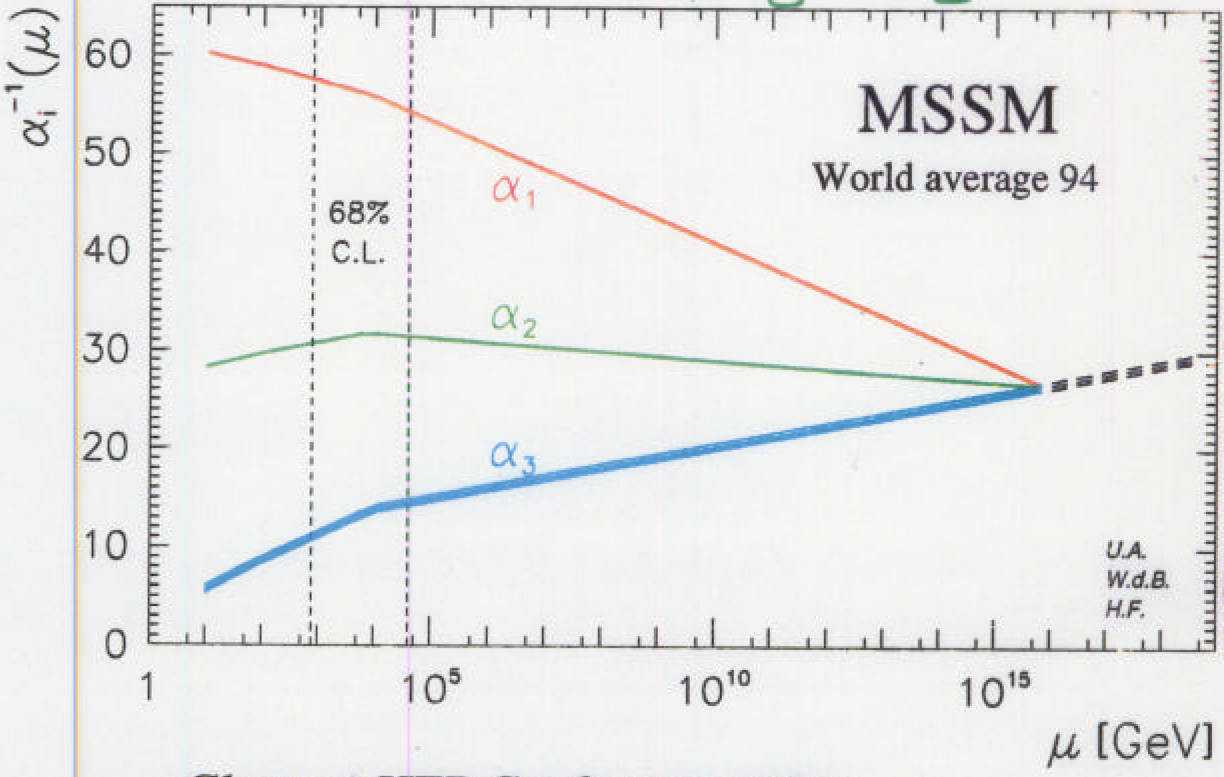
the ultimate smachine?

# Unification?

without supersymmetry



with supersymmetry



1990

(J.E.
+Kelley
+Nanopo

(Langack
+Luo

(Amald
de Boe
Fürsten

1991

Glasgow HEP Conference 1994 :

$M_S=10^{3.7\pm0.8\pm0.4}$ GeV $M_U=10^{15.9\pm0.2\pm0.1}$ GeV

# Supersymmetric Higgs Bosons

Two Higgs doublets: $H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$, $H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix}$

⇒ 8 degrees of freedom

3 eaten by $W^\pm, Z^0$ ⇒ $m_{W^\pm}, m_Z$

⇒ 5 physical Higgs bosons:

$\swarrow$ $\searrow$

3 neutral 2 charged

$h, H, A$ $H^\pm$

@ tree level: $V = \frac{g^2+g'^2}{8}\left(|H_1|^2 - |H_2|^2\right)^2 + \cdots$

two parameters: $(m_A, \tan\beta)$

⇒ all masses and couplings

in particular:

lightest Higgs: $m_h < m_Z$

But

## Radiative Corrections

$$\delta m_h^2 \propto \frac{m_t^4}{m_W^2}\ln\left(m_{\tilde{t}}^2/m_t^2\right)$$

⇒ $m_h \lesssim 130$ GeV

(Okada et

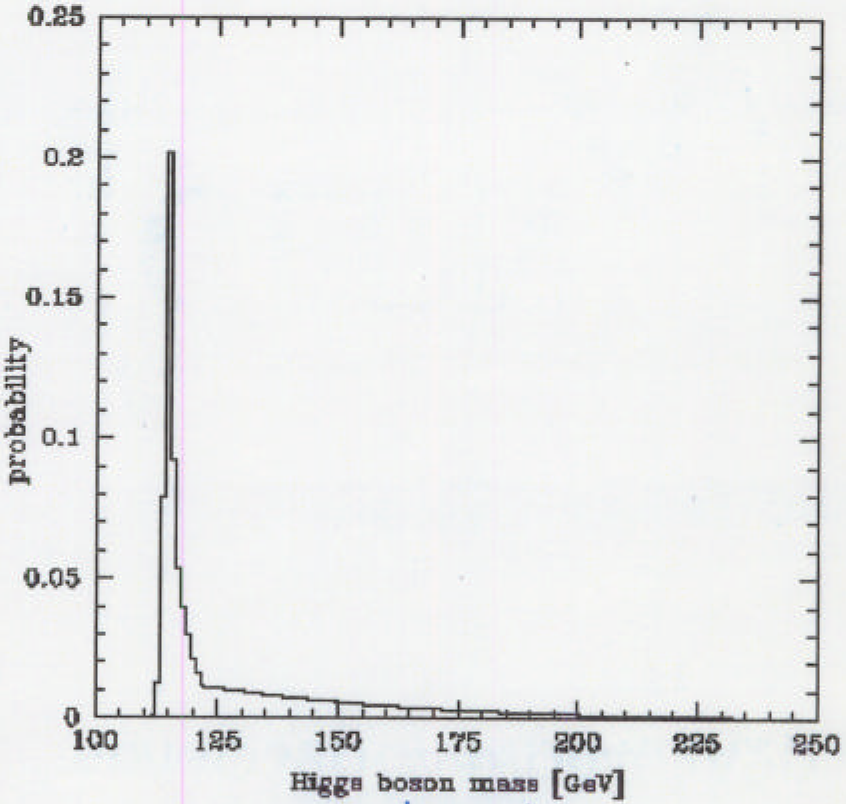
(J.E.+Ridolfi+Zwi

(Haber+Hempflin

# Probability Distribution for Higgs Mass

combining precision measurements

⊕ direct limits



Standard Model

(Erler:
hep-ph/0010153

# Experimental Constraints

(Spring 01

from LEP, Tevatron

- Charginos and neutralinos

$m_{\chi^\pm} \gtrsim 103$ GeV ; $m_\chi + m_{\chi'}$

↖ weaker if small mass difference

- Sleptons $m_{\tilde{l}} \gtrsim 100$ GeV

- Higgs bosons

$m_H > 113.5$ GeV (Standard Mod

similar for MSSM: $\tan\beta \lesssim 5$, CMSSN

weaker for $\tan\beta \gtrsim 8$ if not CM

- Squarks and gluinos

↖ particularly stops: role via

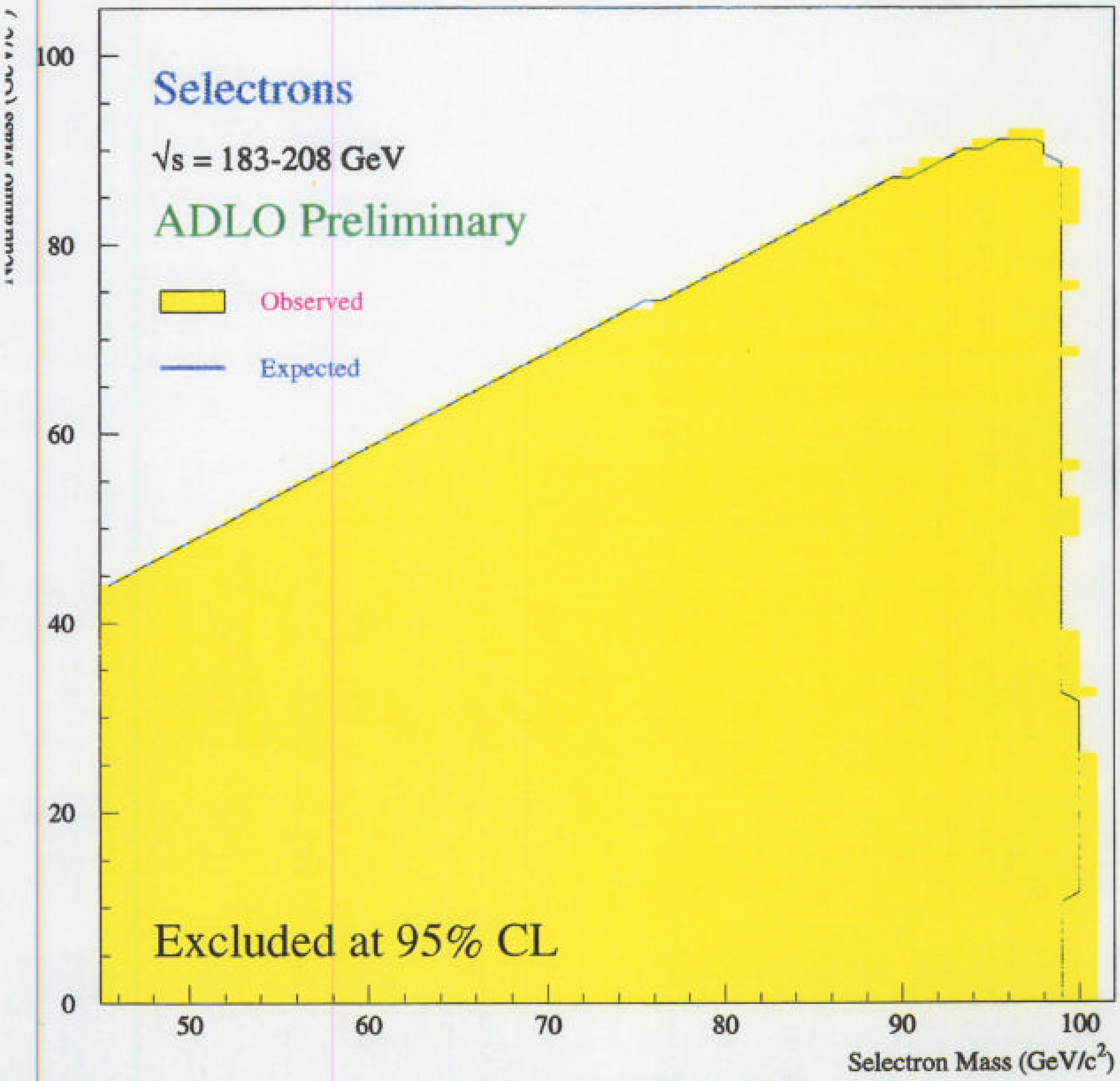
$$\delta m_h^2 \sim \frac{m_t^4}{m_W^2} \ln\left(m_{\tilde{t}}^2 / m_t^2\right)$$

Can be analyzed $\left\{\begin{array}{l} \text{assuming universal } m_0 \\ \text{relaxing} \end{array}\right.$

↗ also for Higgs

# LEP Constraint on Sleptons

$m_{\tilde{e}} \gtrsim 100$ GeV

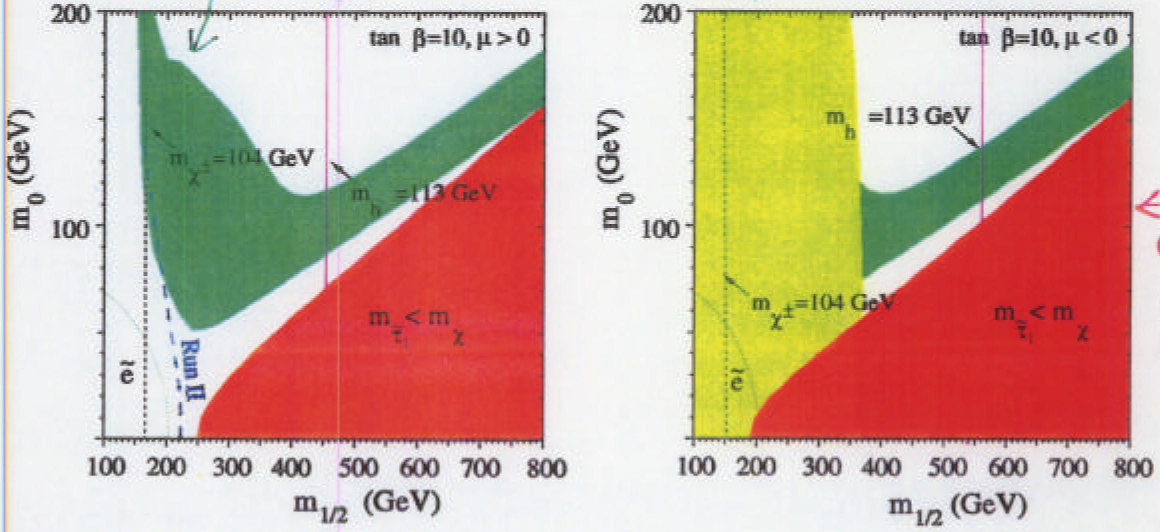


# Constraints on CMSSM Parameter Space

cosmological relic density

b→sγ

Higgs mass constraint



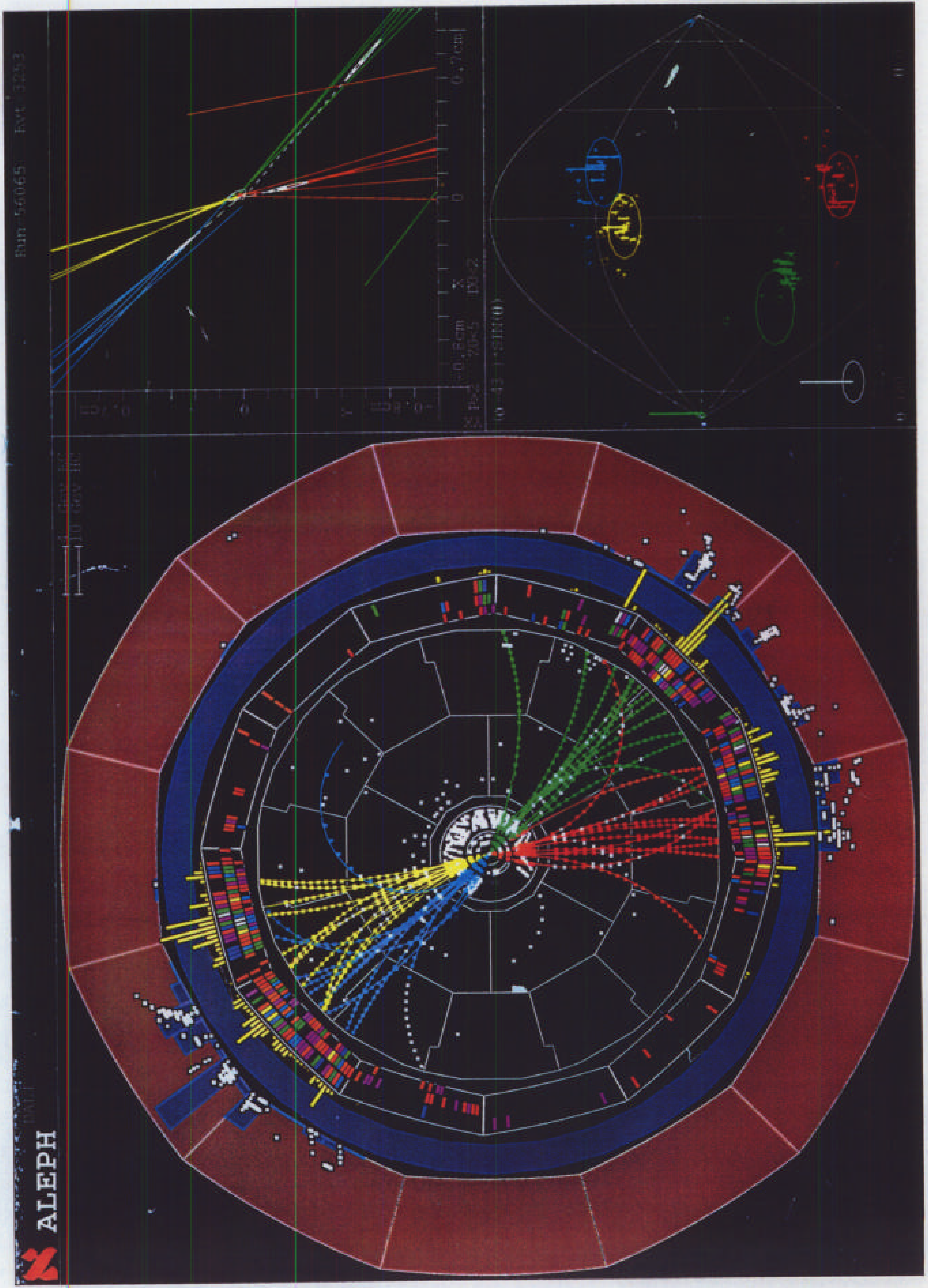
charged dark matter ($\chi$)

Figure 1: *The $m_{1/2}, m_0$ plane for the CMSSM with $\tan\beta = 10$, $A = -m_{1/2}$, and (a) $\mu > 0$, (b) $\mu < 0$, showing the region preferred by the cosmological relic density constraint $0.1 \le \Omega_\chi h^2 \le 0.3$ (medium, green shading), the excluded region where $m_{\tilde{\tau}} < m_\chi$ (dark, brown shading), and the region disallowed by our $b \to s\gamma$ analysis (light shading) [23]. Also shown as a near-vertical line is the contour $m_h = 113$ GeV for $m_t = 175$ GeV. For comparison, we also exhibit the reaches of LEP 2 searches for charginos $\chi^\pm$ and selectrons $\tilde{e}$, as well as the estimated reach of the Fermilab Tevatron collider for sparticle production [25].*

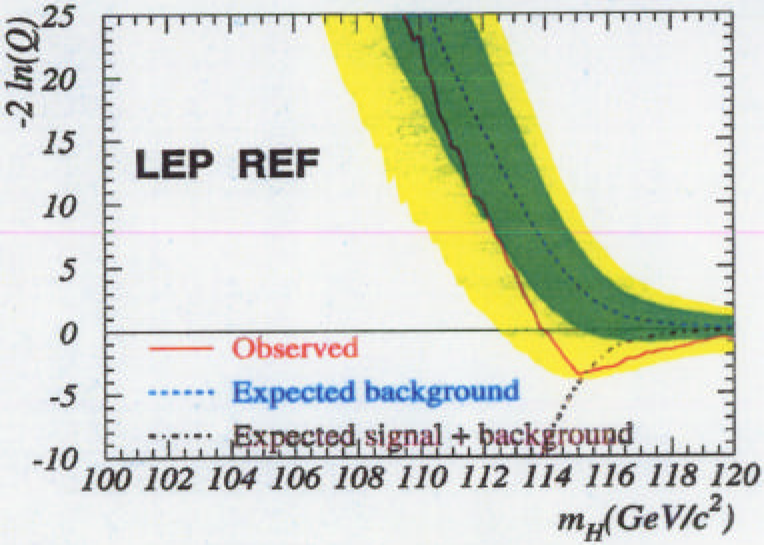
(EGNO
Ganis
Nanopoulos
Olive

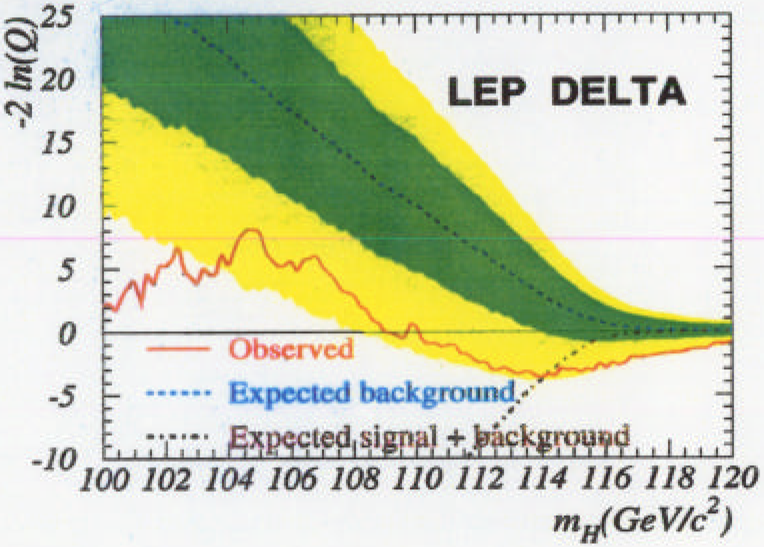
Made on 29-Aug-2000 20:36:27 by konstant with DALI_F1.
Filename: DC056065_003253_000829_2035.PS

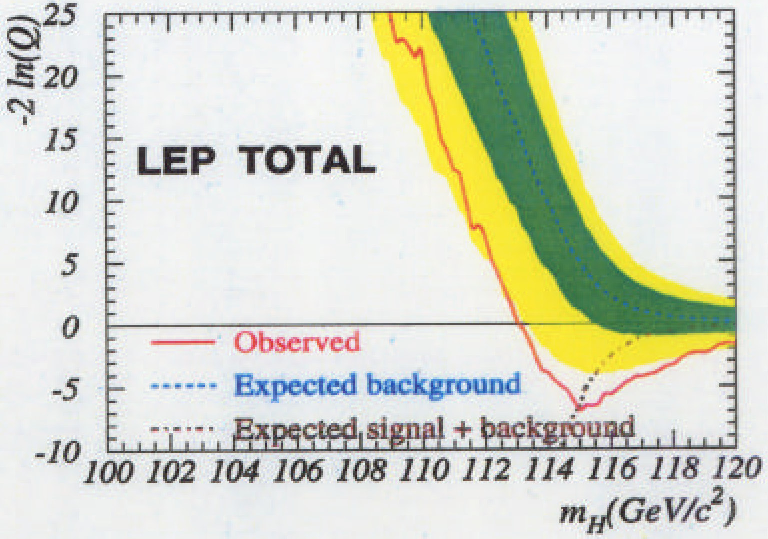
4



# $-2\ln(Q)$ ... REF, DELTA, TOTAL







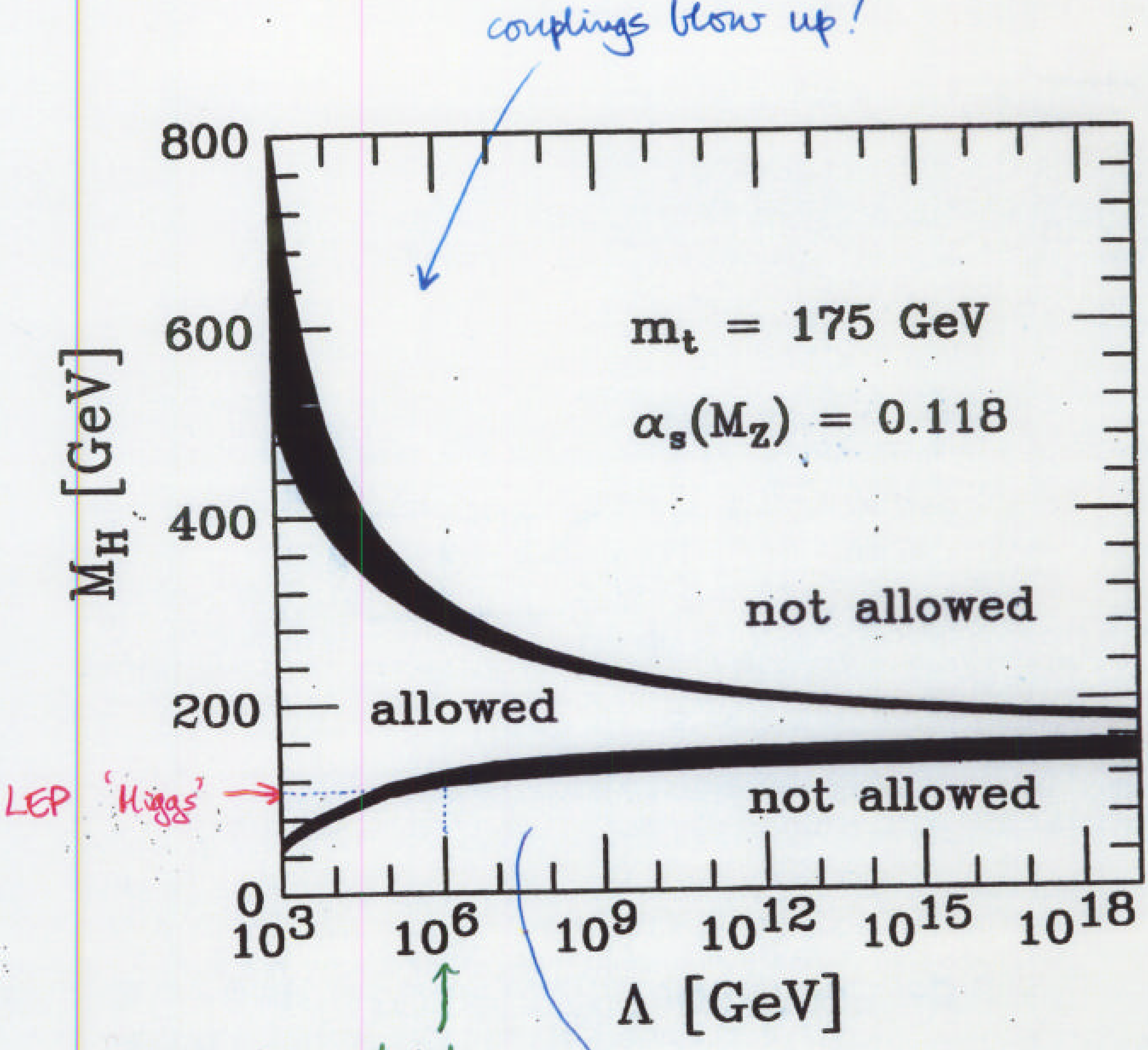
⇐

**Minimum @$m_H \approx 115$ GeV**

**Agreement with SM Higgs cross-sect. for**

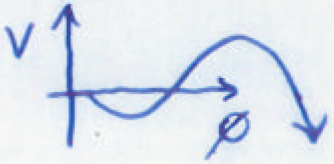
$m_H = 115.0^{+1.3}_{-0.9}$ **GeV**

# Limitations of the Standard Model



scale by which new physics must appear!

potential unstable!



(Hambye + Riesselmann

(Altarelli + Isidori

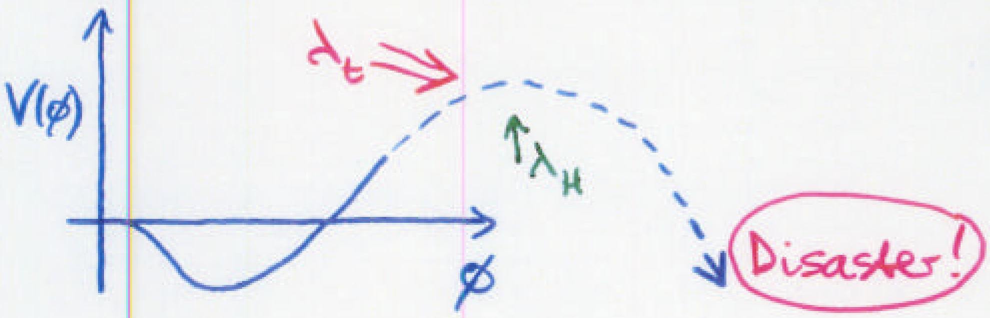
# What if $m_H = 115$ GeV?

(J.E. + Ganis + Nanopoulo
+ Olive : hep-ph/00093

## Standard Model

It must break down @ $E \lesssim 10^6$ GeV

because the effective potential becomes unstal



$\lambda_t$ beats $\lambda_H$

$m_H^2 \sim \lambda_H \langle 0|H|0$

need new physics @ $E < 10^6$ GeV

bosonic!

## Technicolour

predicts composite 'Higgs' scalar weighing

$m_H \sim 1 \text{ TeV}^{\dagger}$

and also 'light' pseudoscalars weighing

$m_P \lesssim 100$ GeV

but small coupling to $Z^{\dagger}$

we need a weakly-coupled theory

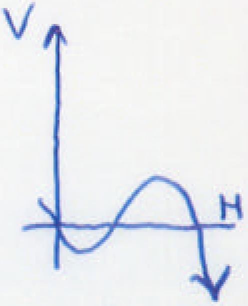
## Topcolour

predicts $m_H \gtrsim 300 \text{ GeV}^{\dagger}$

# It Quacks like Supersymmetry

To avoid vacuum collapse (Charybdi

must introduce new bosons



$\lambda_{22} |H|^2 |\phi|^2$

$\nwarrow$ $N_I$ isomultiplets $I$

RGE solutions very sensitive to $\lambda_{22}$

danger of non-perturbative blow-up (Scylla

$\swarrow$

can only be avoided by coupling to fermions, ...

to survive up to $m_p \sim 10^{19}$ GeV

couplings must be finely tuned

$\nearrow$

automatic within supersymmetry

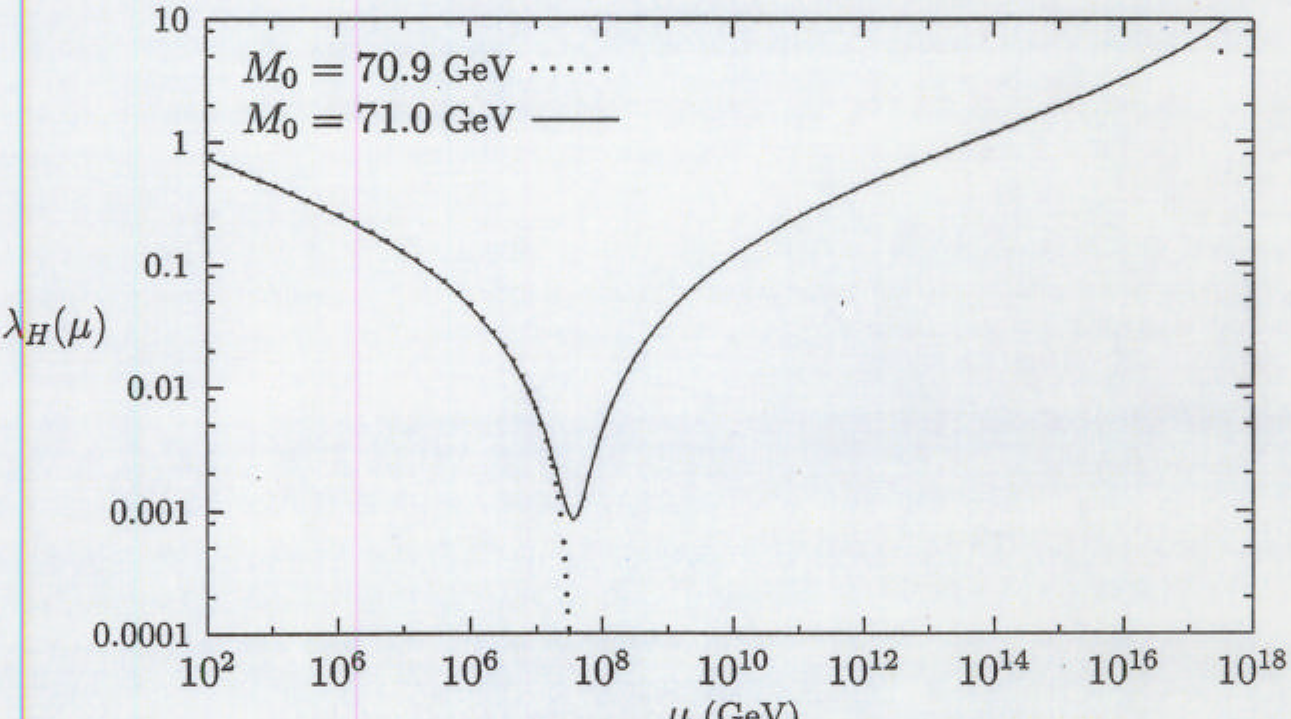
(J.E. + D. Ross:
hep-ph/0012067

# New physics must be fine-tuned

to steer between

potential collapse

blow-up of couplings.

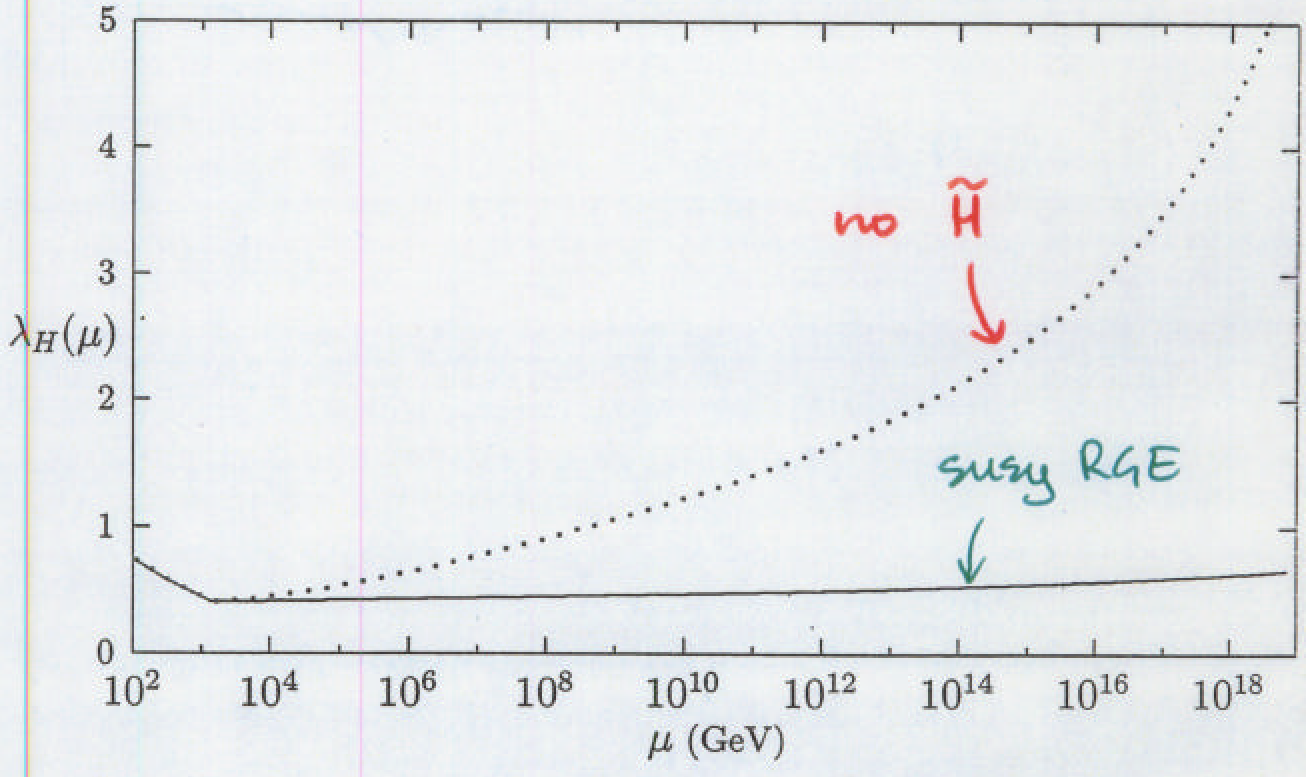


(J.E. + D.Ross -
hep-ph/0012067

# Fine-tuning quacks like supersymmetry

need relation: $\lambda_H \leftrightarrow \lambda_t, g$

natural in susy with $\tilde{t}, \tilde{H}$



(J.E. + D. Ross -
hep-ph/0012067

# Higgs mass sensitive to spartide masses

assume universal scalar $m_0$, gaugino $m_{1/2}$ (CMSSM)

$m_H$ ~ independent of $m_0$

depends on $m_{1/2}$

sensitive to $m_t$ $\Delta m_H \sim \Delta m_t$

also to higher-order QCD treatment: $\Delta m_H \sim 3$ GeV

and $\Delta m_H \sim 1$ GeV from higher-order e'weak

Calculate for $m_t = 170, 175, 180$ GeV

look for $m_{1/2}^{min}$ : $m_h \geq 113$ GeV ?

$m_{1/2} \gtrsim 240$ GeV $m_\chi \gtrsim 95$ GeV

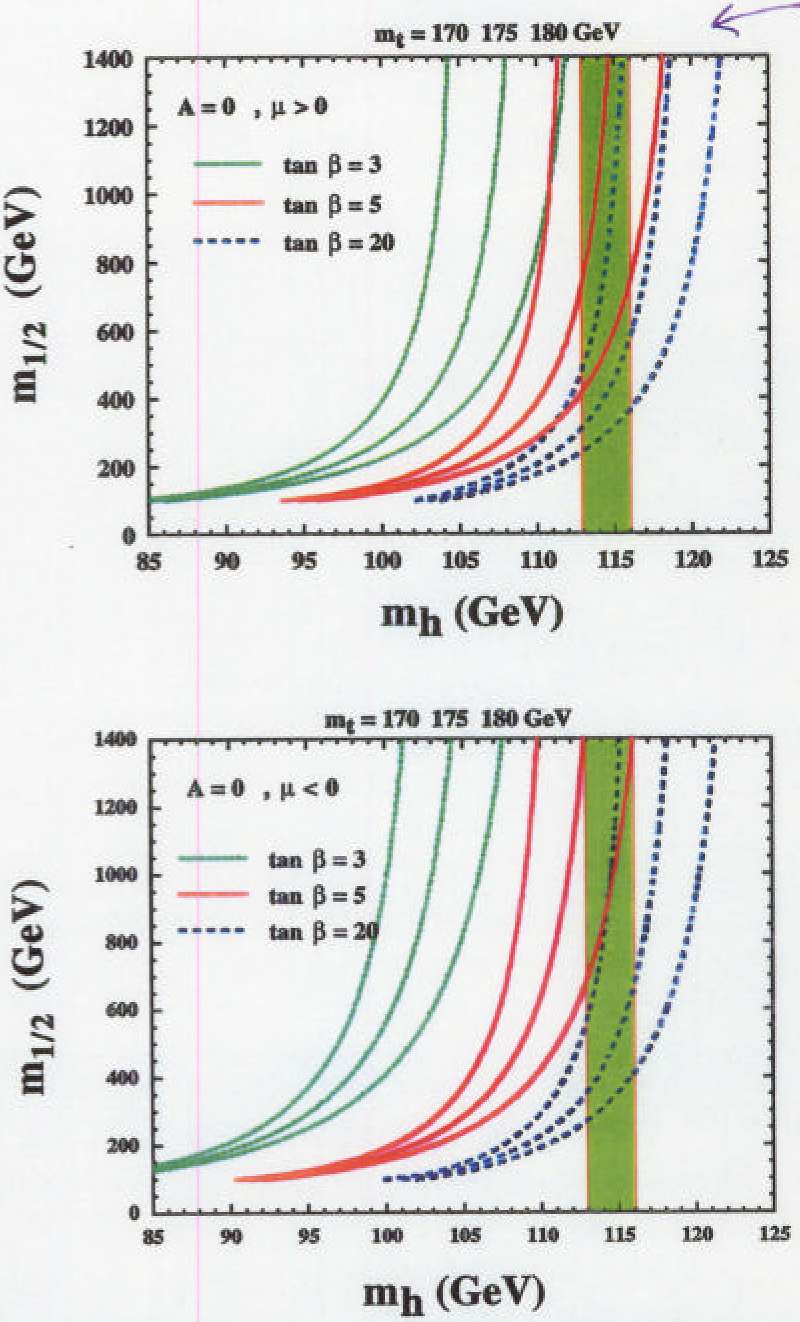
lightest supersymmetric particle

$m_{1/2}^{max}$ : $m_h \leq 116$ GeV ?

for $m_t = 170$ GeV, only limit from cosmology

$m_{1/2} \lessapprox 1400$ GeV $m_\chi \lessapprox 600$ GeV

(J.E.+Ganis+Nanopoulos
+Olive: hep-ph/00093



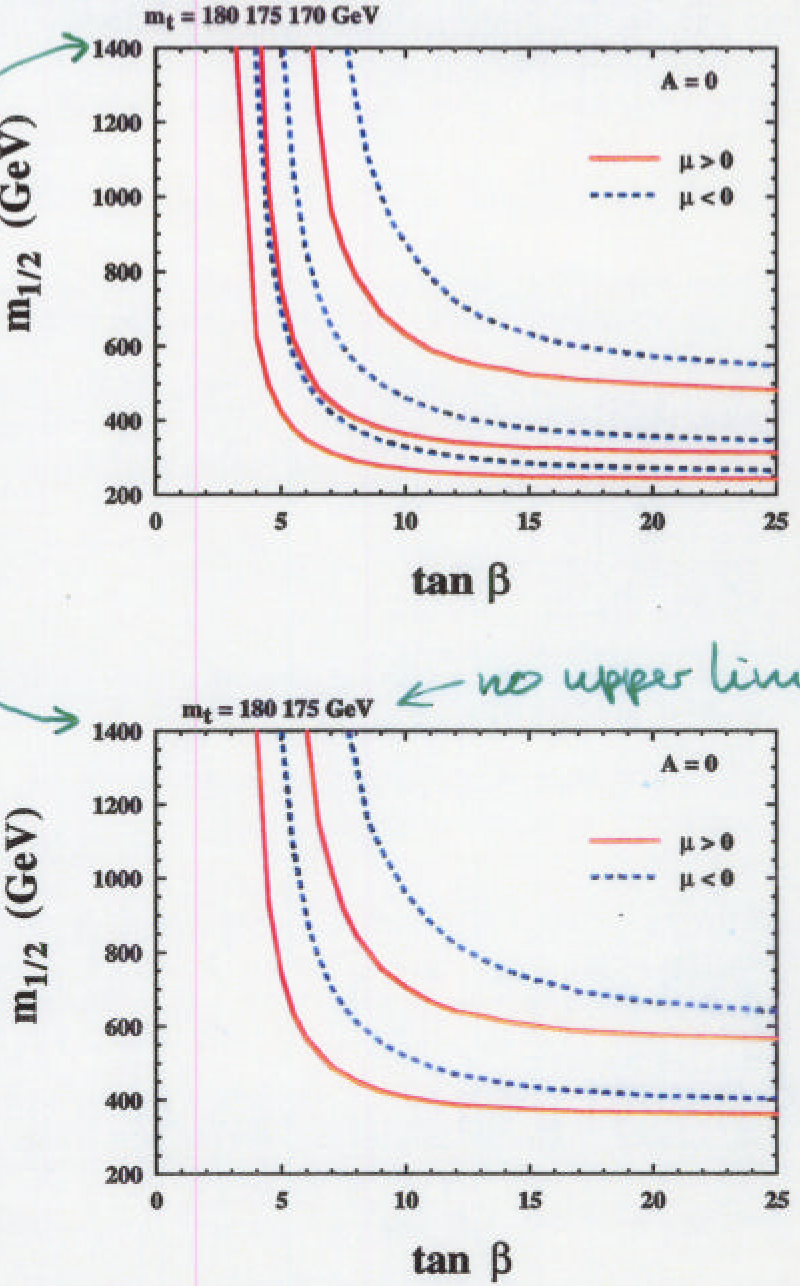
very dependent on $m_t$

Figure 2: *The sensitivity of $m_h$ to $m_{1/2}$ in the CMSSM for (a) $\mu > 0$ and (b) $\mu < 0$. The no-scale value $A = 0$ is assumed for definiteness. The dotted (green), solid (red) and dashed (blue) lines are for $\tan\beta = 3, 5$ and 20, each for $m_t = 170, 175$ and 180 GeV (from left to right). The lines are relatively unchanged as one varies $\tan\beta \gtrsim 10$, where they are also insensitive to the sign of $\mu$. The shaded vertical strip corresponds to* 113 GeV $\leq m_h \leq$ 116 GeV.

Sensitivity to $m_{1/2}$

(EGNO

upper limit from dark matter



Lower Limits

$m_h \geq 113$ Ge

⇓

$m_{\chi_2} \geq 240$ Ge

$\boxed{m_{\tilde{q},\tilde{g}} \gtrsim 600 \text{GeV}}$

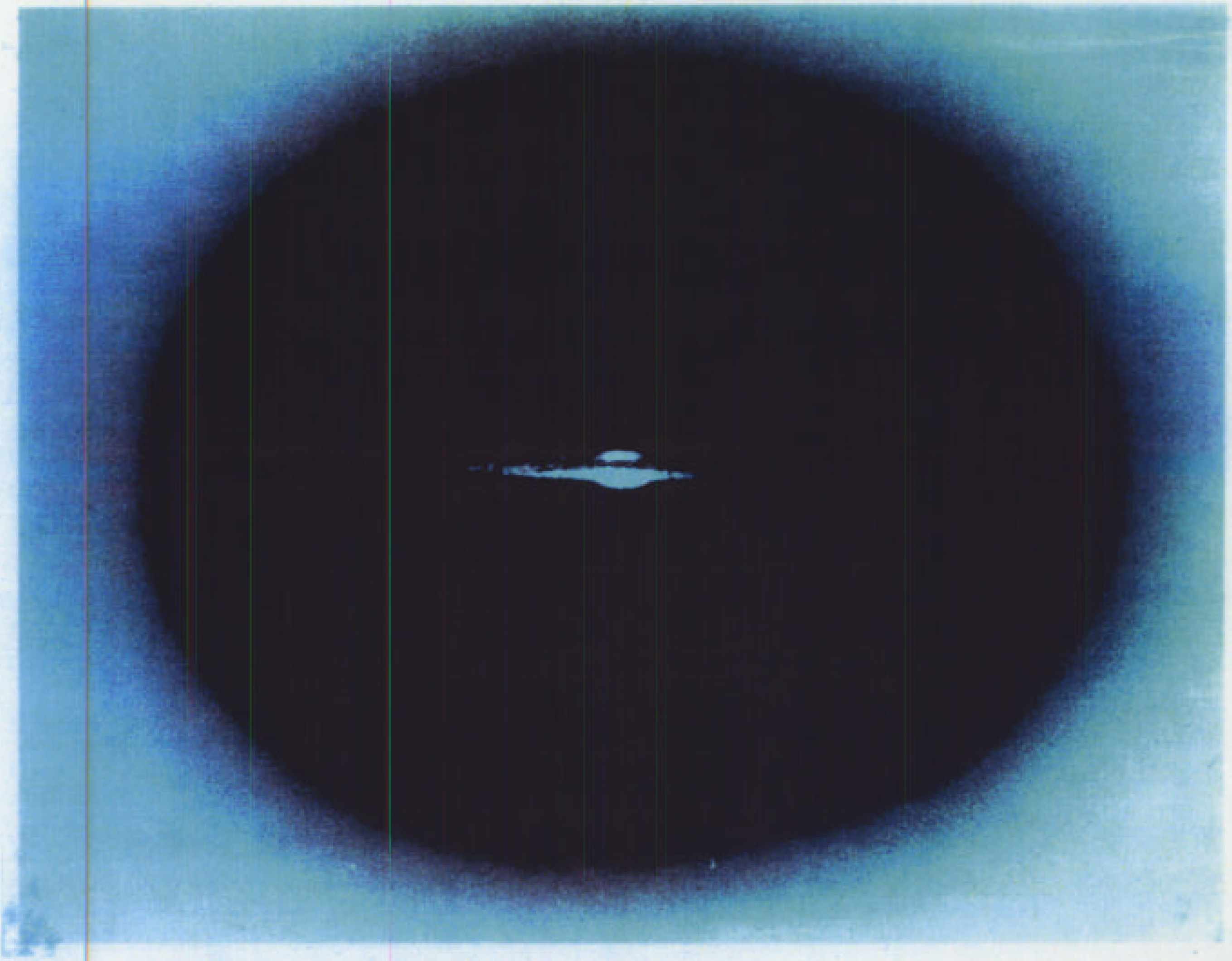
← no upper limit for $m_t = 170$G

Upper Limits

$m_h \leq 116$ GeV

Figure 4: *(a) The lower limit on $m_{1/2}$ required to obtain $m_h \geq 113$ GeV for $\mu > 0$ (solid, red lines) and $\mu < 0$ (dashed, blue lines), and $m_t = 170, 175$ and $180$ GeV, and (b) the upper limit on $m_{1/2}$ required to obtain $m_h \leq 116$ GeV for both signs of $\mu$ and $m_t = 175$ and $180$ GeV: if $m_t = 170$ GeV, $m_{1/2}$ may be as large as the cosmological upper limit $\sim 1400$ GeV. The corresponding values of the lightest neutralino mass $m_\chi \simeq 0.4 \times m_{1/2}$.*

(EGNO



$0.1 < \Omega h^2 < 0.3$

my favourite candidate for Cold Dark Matter

## 2-Lightest Supersymmetric Particle ?

- Expected to be stable in most models

⇒ present in Universe as cosmological relic

- Because of multiplicatively-conserved quantum number:

(Fayet

$$R \text{ parity} = \begin{cases} +1 & \text{for all particles} \\ -1 & \text{for all sparticles} \end{cases}$$

- Conservation related to those of baryon, lepton numbers:

$$R = (-1)^{3B+L+2S} \leftarrow \text{spin}$$

- Violation possible via spontaneous/explicit L >

$$\underset{\uparrow}{\langle 0|\tilde{\nu}|0\rangle \neq 0} \; ? \qquad \underset{\uparrow}{HL} \; \text{coupling}$$

constraints from laboratory, cosmology

3 important consequences of R conservation:

1) Sparticles always produced in pairs

e.g. $pp \to \tilde{q}\tilde{g}X$, $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^-$

2) Heavier sparticles decay into lighter ones

e.g. $\tilde{q} \to q\tilde{g}$, $\tilde{\mu} \to \mu\tilde{\gamma}$

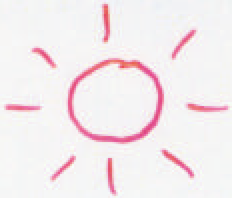
3) Lightest sparticle stable

no legal decay mode!

# Nature of Lightest Supersymmetric Particle

cannot have { electromagnetic charge
strong interactions

If it did, it would dissipate energy, condense int



be detectable as anomalous heavy isotopes

BUT upper limits ≪ expected abundance:

$$\frac{n_{heavy}}{n_{normal}} \lesssim 10^{-15} \rightarrow 10^{-30}$$

⇒ relic does not bind to ordinary nuclei

⇒ no strong or electromagnetic interactions

## Supersymmetric candidates

| | | | | |
|---|---|---|---|---|
| Spin: | 0 | $\frac{1}{2}$ | 1 | $\frac{3}{2}$ |
| | sneutrino | neutralino | — | gravitin |
| | excluded by LEP,<br>dark matter searches | $\tilde{\gamma}/\tilde{H}/\tilde{Z}$<br>↓ | | $\tilde{G}$<br>generally<br>heavier th |

## - Co-Annihilation Effects on Bino Density

(S.E.+Falk+Olive

annihilation between LSP , NLSP

lightest    next-to-lightest

potentially important if $\Delta m \sim \underset{\text{freeze-out temperature}}{T_f} \sim O(\frac{1}{20}) m$

because of small relative Boltzmann suppression:

$$e^{-\Delta m / T_f} = O(1)$$

in practice: important for $\Delta m / m \sim 0{\cdot}1$

co-annihilation much studied for Higgsinos:

$$m_{\chi^\pm} \sim m_\chi$$

found to be important also for Binos

NLSP is $\tilde{\tau}_R$ , also $\tilde{e}_R , \tilde{\mu}_R$ significant N$^n$LSP

Calculation of relic density:

$$\frac{dn}{dt} = -3Hn - \langle \sigma_{eff} v_{rel} \rangle (n^2 - n_{eq}^2)$$

$$n \equiv \sum_i n_i \quad , \quad \sigma_{eff} = \sum_{ij} \sigma_{ij} r_i r_j \quad , \quad r_i \equiv n_i^{eq} / n^{eq}$$

$$\sigma_{eff} = \sigma_{\chi\chi} r_\chi r_\chi + 4 \sigma_{\chi\tau} r_\chi r_\tau + 8 \sigma_{\chi e} r_\chi r_e + 2 (\sigma_{\tau\tau} + \sigma_{\tau\tau^*}) r_\tau r_\tau$$
$$+ 8 (\sigma_{\tau e} + \sigma_{\tau e^*}) r_\tau r_e + 4 (\sigma_{ee} + \sigma_{ee^*}) r_e r_e + 4 (\sigma_{e\mu} + \sigma_{e\mu^*}) r_e r_\mu$$

# Co-Annihilation Effect on Upper Bound on $m_\chi$

"tail" survives CCB for $\tan\beta \gtrsim 3$

$m_\chi \lesssim 600$ GeV

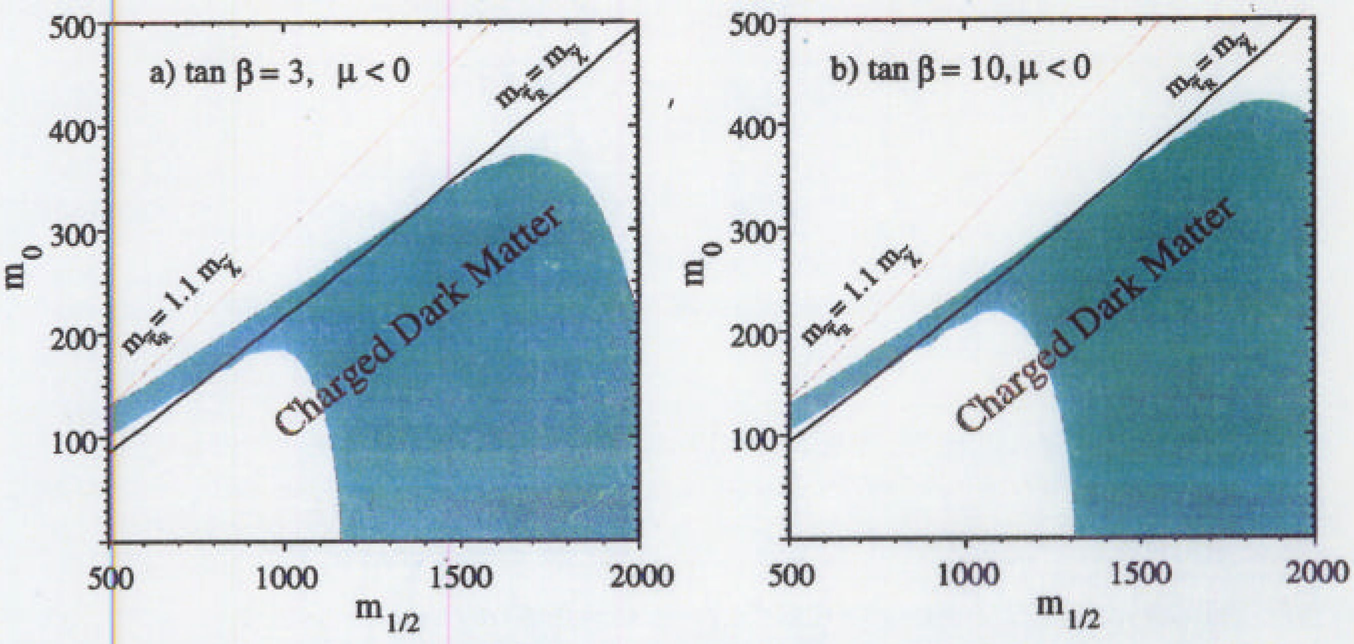


Figure 2: Same as Fig. 1(a,c), extended to larger values of $\mu$.

(J.E. + Falk + Olive + Sredni

# Parameter Space @ Large $\tan\beta$

Several improvements in relic abundance calculatio

Improved treatment of coannihilation

(J.E.+Falk+Ga
+Olive+Srednick
hep-ph/010209

extra diagrams
extra final states
$m_\tau$ effects
$\tilde\tau_1 - \tilde\tau_2$ mixing

relaxed upper limit on $m_{1/2}$ ($m_\chi$)

| | | | |
|---|---|---|---|
| $\tan\beta$ = | 30 | 35 | 50 |
| $m_{1/2} \rightarrow$ | 1700 | 1900 | 2200 |

$\Downarrow$

$m_\chi \simeq 900$ GeV

Accurate treatment of $\chi\chi \rightarrow A, H$ ← heavier MSS Higgse

rapid s-channel annihilation when $m_\chi \sim m_A/2$
'funnel' where $\Omega_\chi h^2$ suppressed ←
allowed bands on either side ←

sensitive to $m_t, m_b, A, ..$

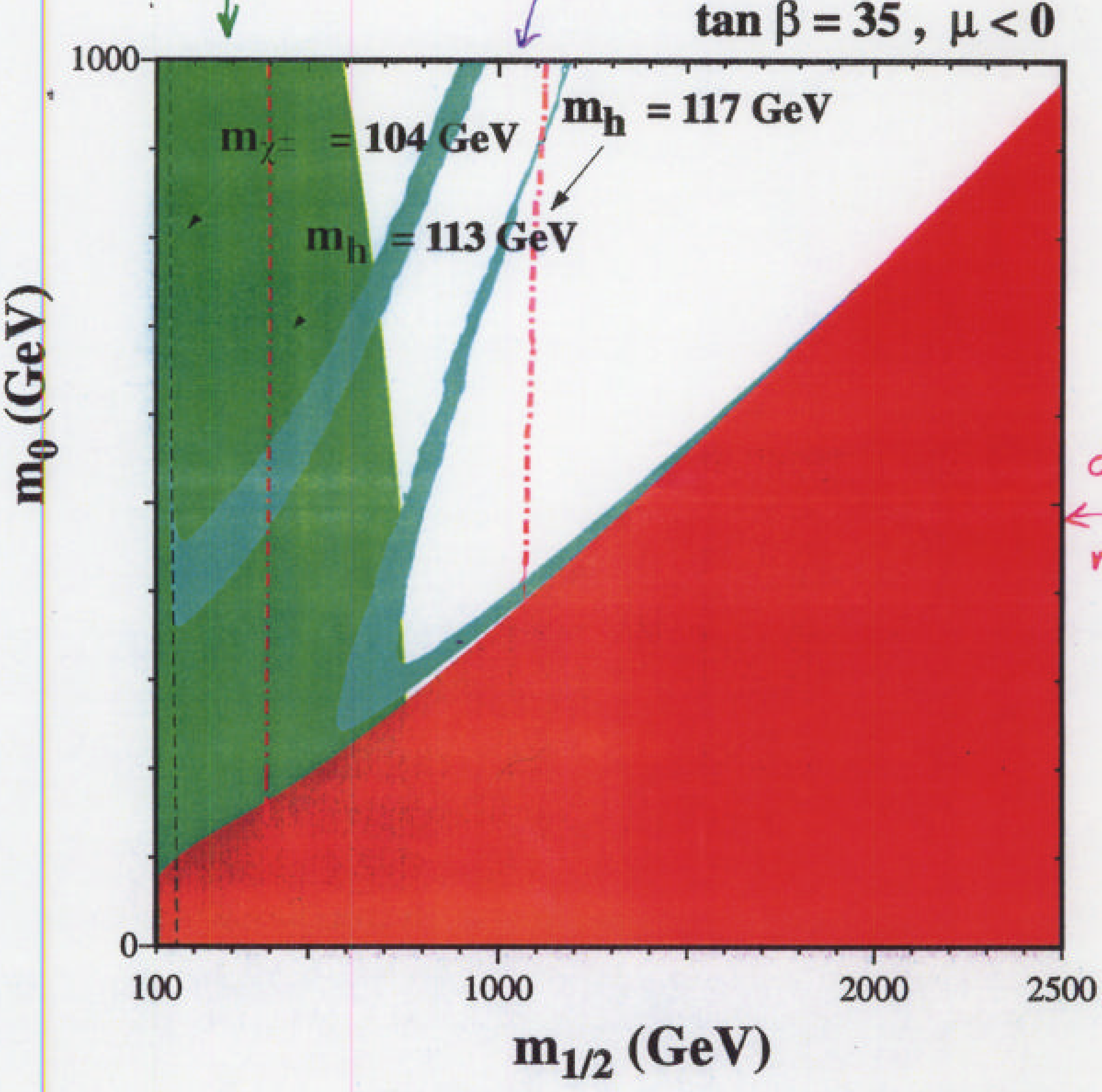
extend to large $m_0, m_{1/2}$

supersymmetry discovery no longer guaranteed @ LHC?

# CMSSM Parameter Space @ Large tanβ

b→sγ

rapid annihilation via A pole



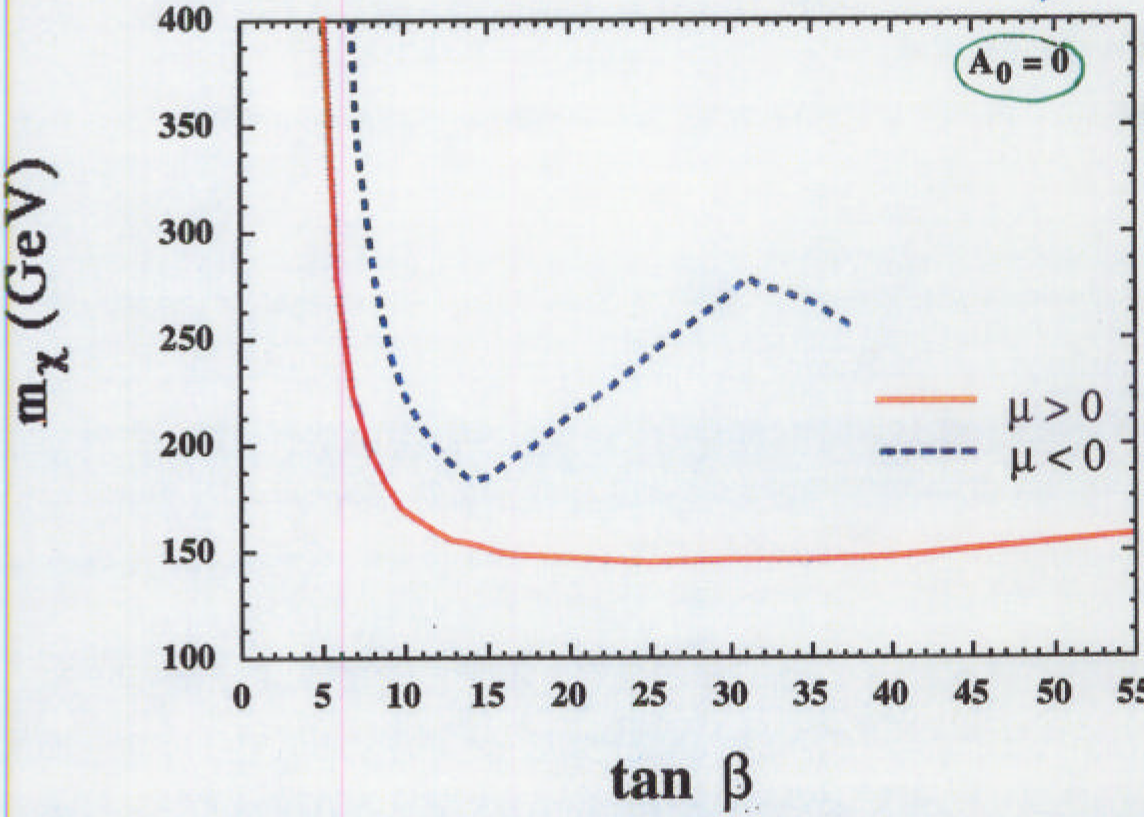
charged dark matter

(J.E.+Falk+Ganis+Olive+Srednicki: hep-ph/0102098

# Lower Limit on Cosmological Relic Mass

from LEP et al.

depends on these



$m_t = 175$

$m_b = 425$

(J.E. + Falk + Ganis + Olive + Srednick

hep-ph/0102098

# How Finely Tuned is Supersymmetric Dark Matt

often said that $0.1 \le \Omega_\chi h^2 \le 0.3$ is 'natural'

can this be quantified?

(J.E.+K.Olive: hep-ph/01050

our proposal: $\Delta_i^\Omega = \frac{\partial \ln \Omega}{\partial \ln a_i}$ ← CMSSM parameter

$$\Delta^\Omega = \sqrt{\sum_i (\Delta_i^\Omega)^2}$$

Results:

$\Delta^\Omega \lesssim 10$ in 'generic' domains for $\tan\beta = 1$

even $\lesssim 3$

increases in coannihilation region: $\Delta^\Omega \lesssim 20$

at large $\tan\beta = 50$ : $\Delta^\Omega \gtrsim 30$

in rapid pole-annihilation region: $\Delta^\Omega \sim 20$

in 'focus-point' region: $\Delta^\Omega \sim 500$

Corollary question:

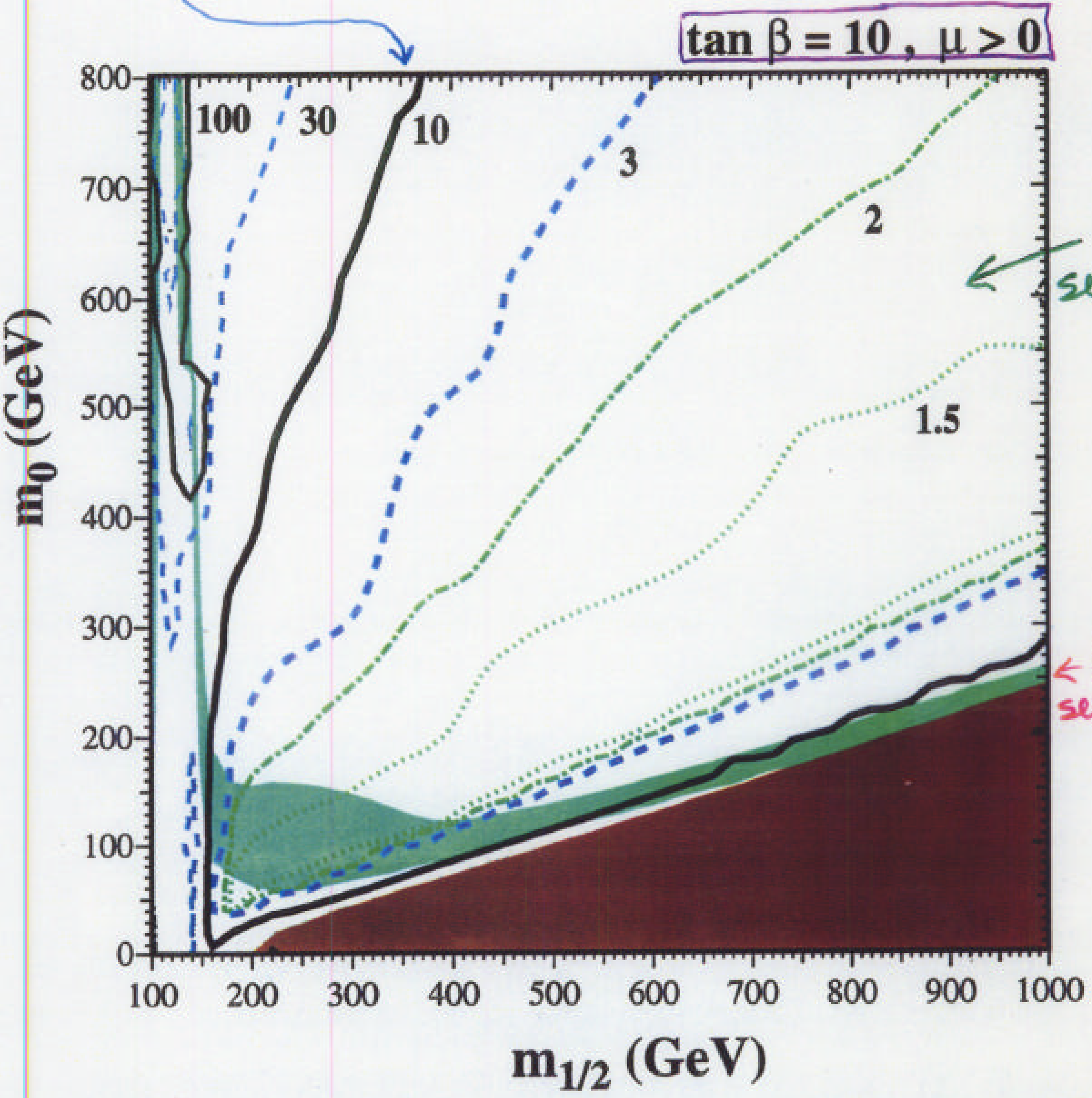
how accurately can one calculate $\Omega_\chi h^2$ using LHC data? (+LC?)

< 10% in 'generic' domai

Relic - Density

# Fine-Tuning Contours in the CMSSM

$$\Delta^{\Omega} \equiv \sqrt{\sum_i \frac{\partial \ln \Omega_\chi h^2}{\partial \ln a_i}^2}$$



low sensitivi

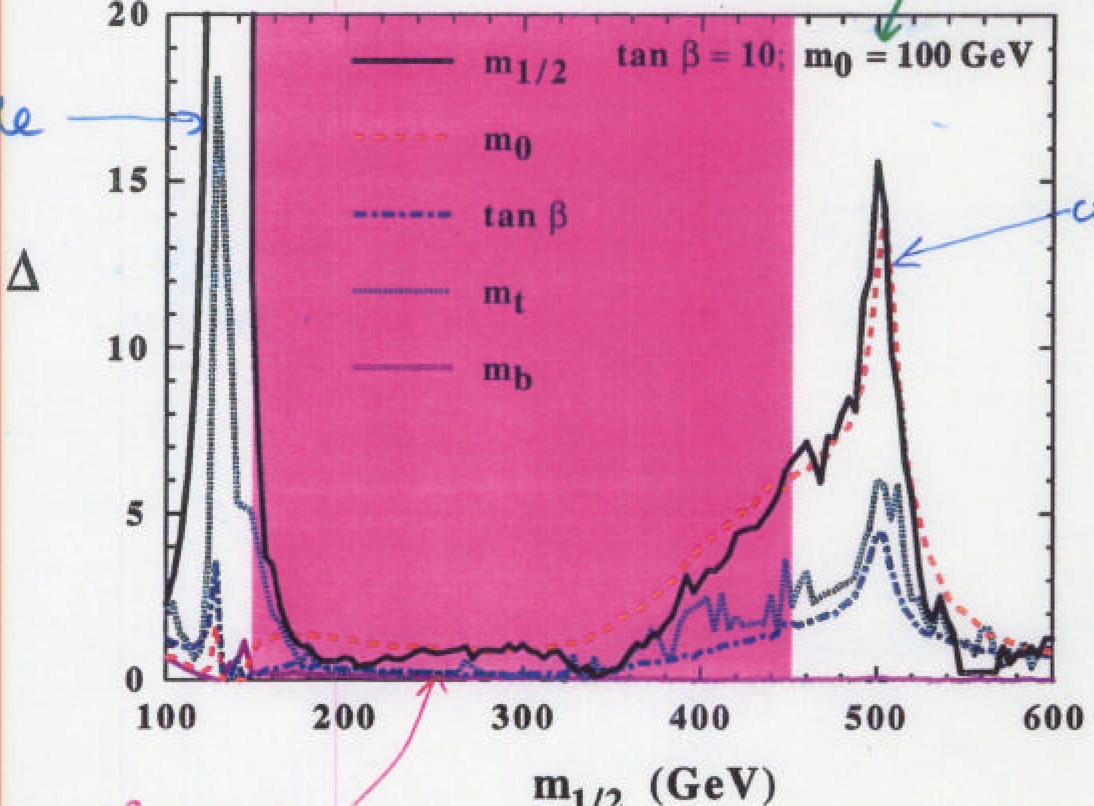
highe sensitivi

(J.E. + K.Olive: hep-ph/0105004

# Sensitivity of Relic Density

to different input parameters $\Delta_i^{\Omega}$

along slice in $(m_{1/2}, m_0)$ plane @ fixed



h pole

coannihilati

$0.1 \leq \Omega_\chi h^2 \lesssim 0.3$

(J.E. + K. Olive:
hep-ph/0105004

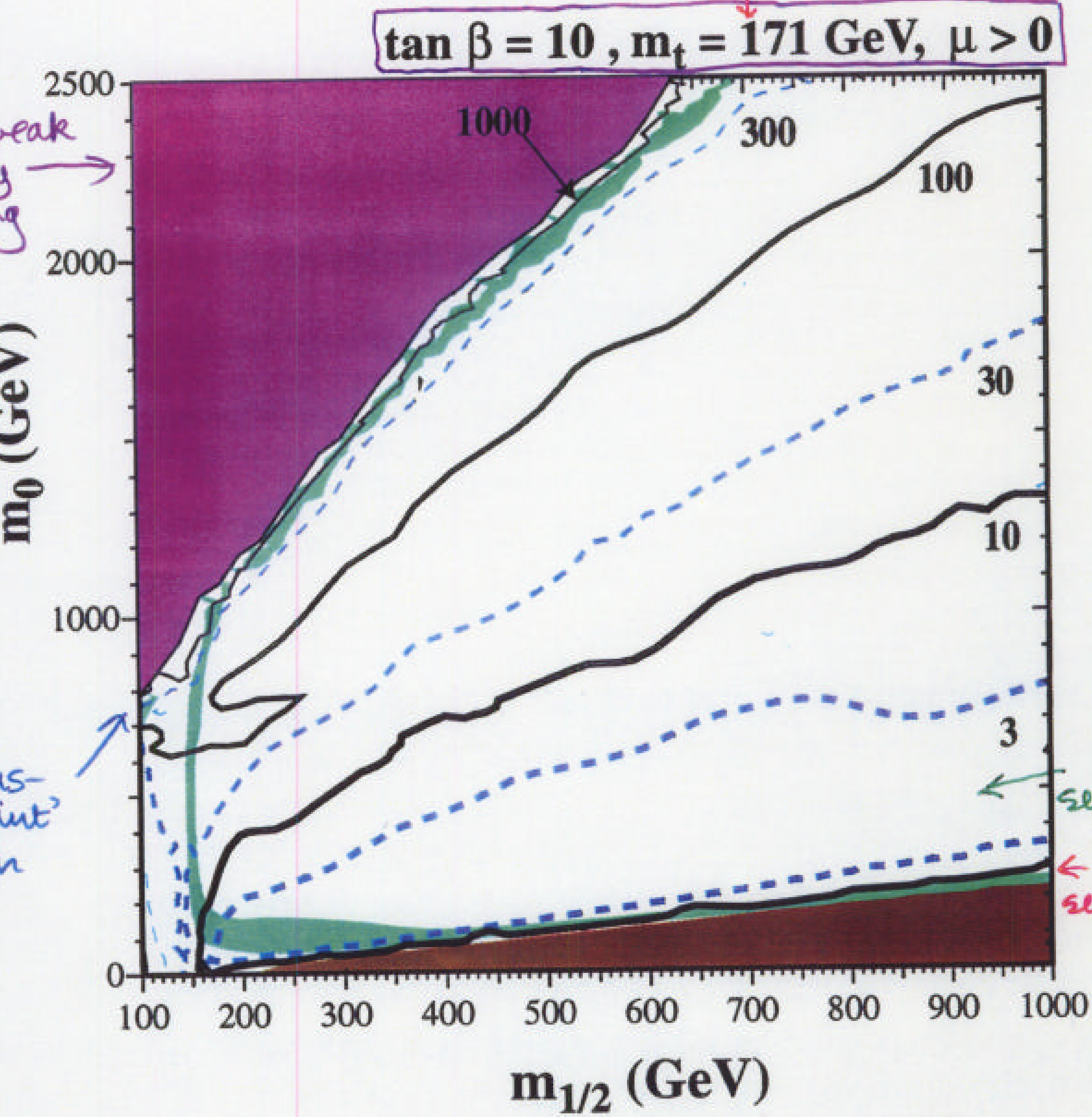
Relic-Density

# Fine-Tuning Contours in the CMSSM

$$\Delta^{\Omega} \equiv \sqrt{\sum_i \frac{\partial \ln \Omega_\chi h^2}{\partial \ln a_i}^2}$$

very sensitive in focus-point region

no electroweak symmetry breaking



'focus-point' region

low sensiti

high sensiti

(J.E. + K.Olive: hep-ph/0105004

# 3 - Muon Anomalous Magnetic Moment

BNL measures 2·6σ deviation from Standard Model:

$$a_\mu^{exp} - a_\mu^{th} = 42 \pm \underset{\nearrow}{16}$$ (E821

largest theoretical error from QCD

≪ experimental error : ±7

would require new physics @ TeV scale

naturally explained by supersymmetry

if $\mu > 0$

tanβ not small

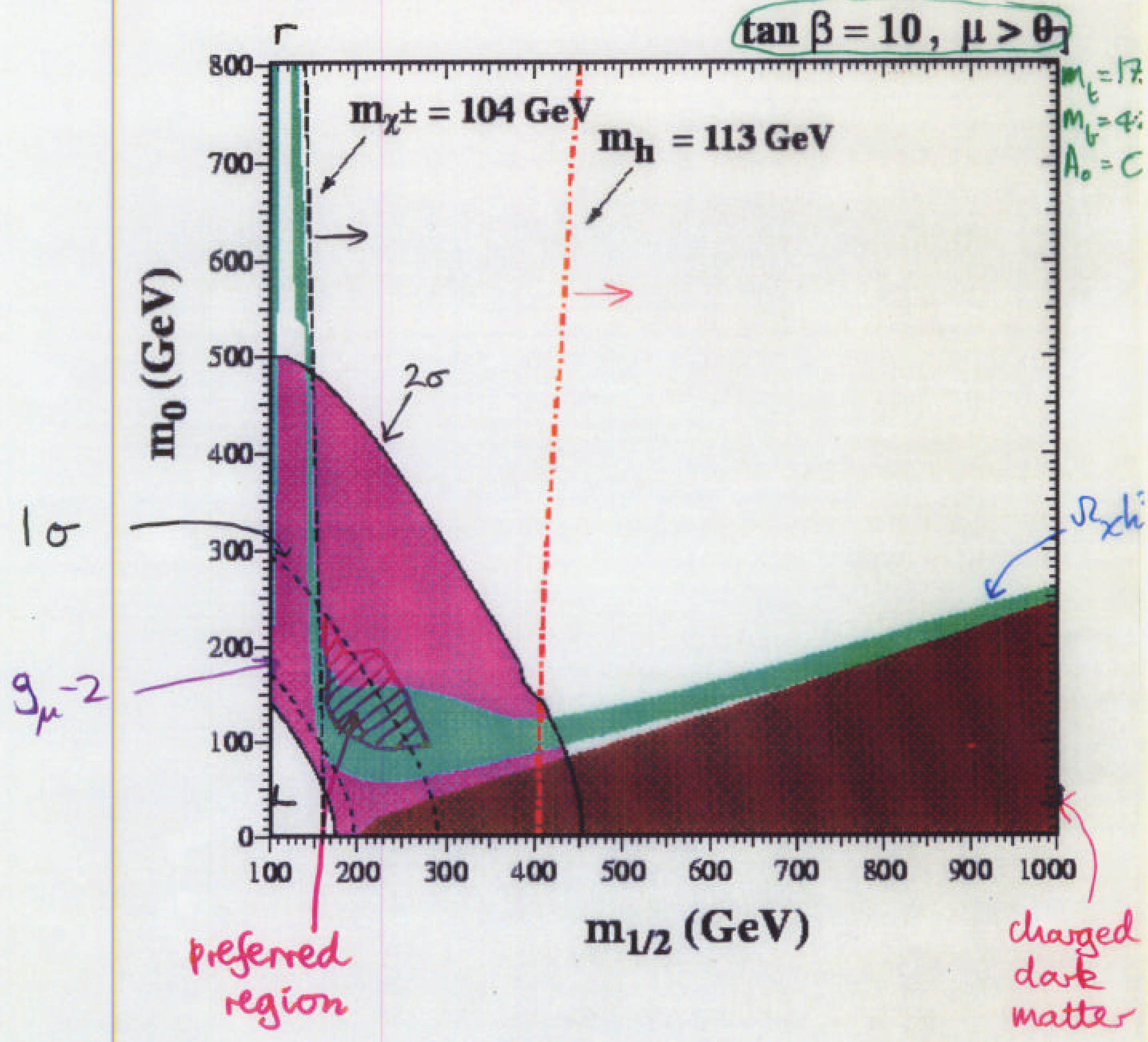
↳ $\gtrsim 10$

Overall consistency: $a_\mu$, cosmology, $m_H$, $b \to s\gamma$

$m_\chi \simeq 150$ to 350 GeV

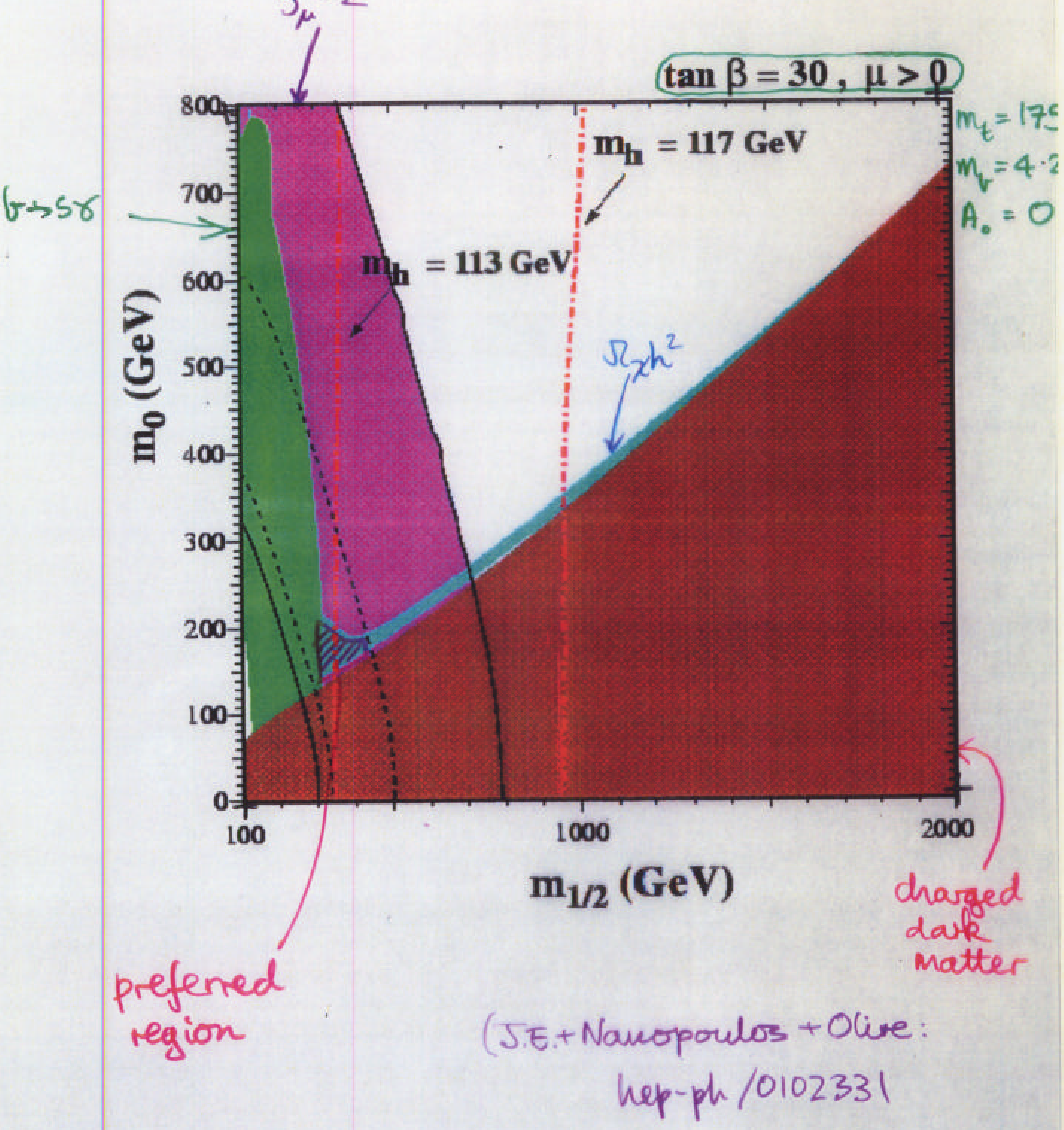
expect to see supersymmetry @ LHC

# Impact of Muon Magnetic Moment



(J.E. + Nanopoulos + Olive:
hep-ph/0102331

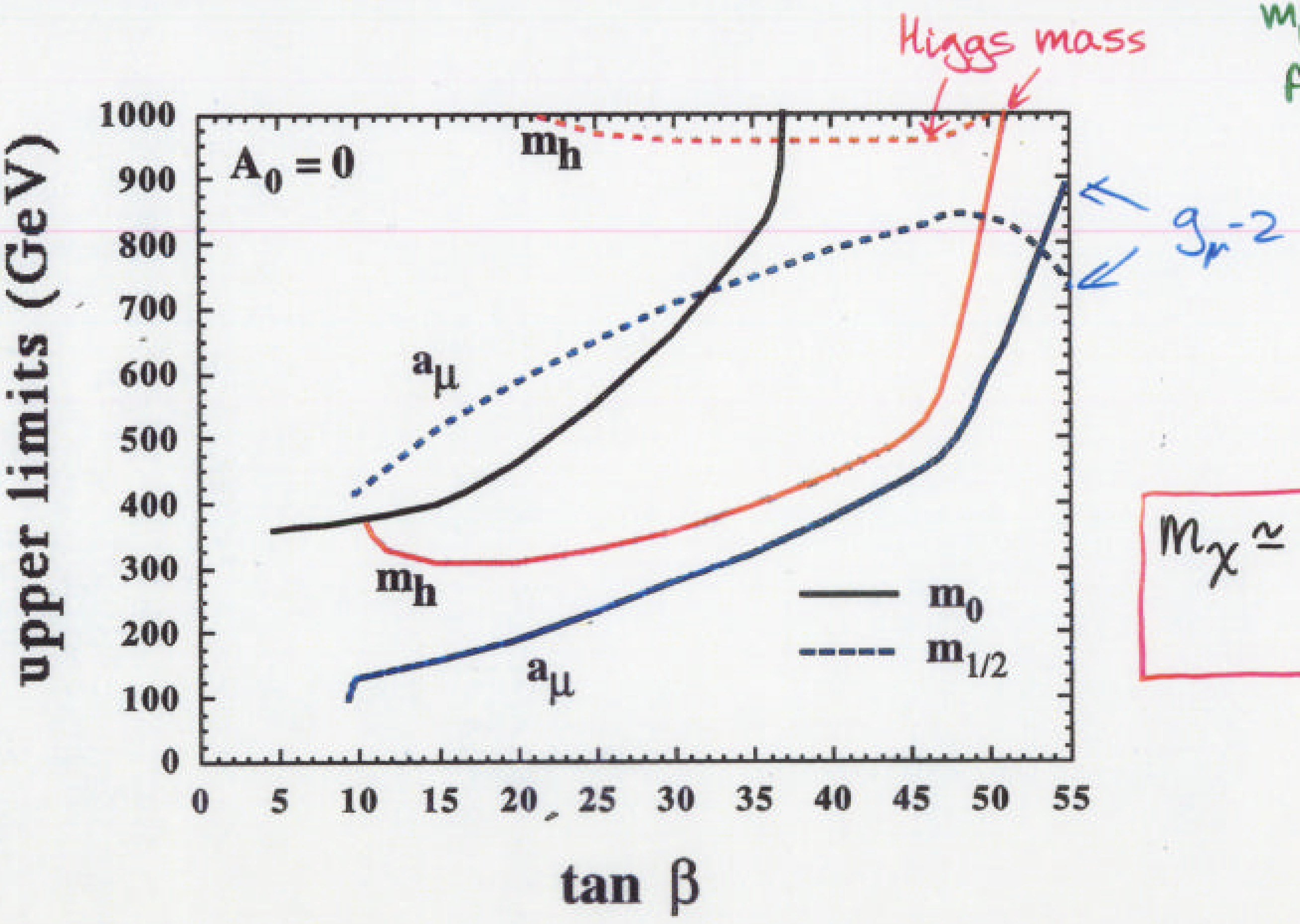
# Impact of Muon Magnetic Moment



(J.E. + Nanopoulos + Olive: hep-ph/0102331

# Upper limits on CMSSM Mass Parameters

for $m_t = 175$ GeV,
$m_b = 4.25$ GeV,
$A_0 = 0$



$m_\chi \simeq 150$ to $350$ GeV

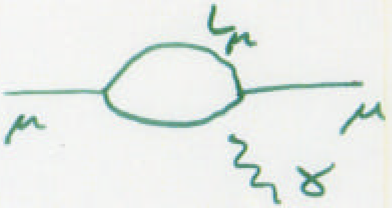
(J.E. + Nanopoulos + Olive:
hep-ph/0102331

## $\mu\to e\gamma$

## Encouragement from $g_\mu-2$

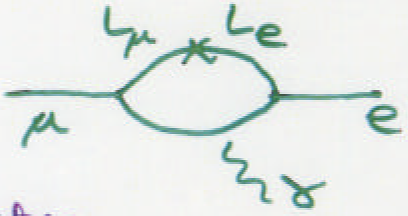
non-trivial vertex @ scale ≲ 1 Te

made by particles carrying $L_\mu$



$\nu$ oscillations ⇒ $\Delta L_\mu \neq 0$

⇒ expect analogous vertex



concrete example: supersymmetry

(J.E.+Nanopoulos+Oli

⇒ measurement of $(g_\mu-2)$ fixes sparticle mass scale ⇒ fix $\Gamma(\mu\to e\gamma)$ within given flavour texture

$g_\mu-2$ within $\frac{1}{2}\sigma$

⇒ $B(\mu\to e\gamma)$ within $\frac{1}{2}$ order of magnitud

(Carvalho+J.E.+Gomez+Lol

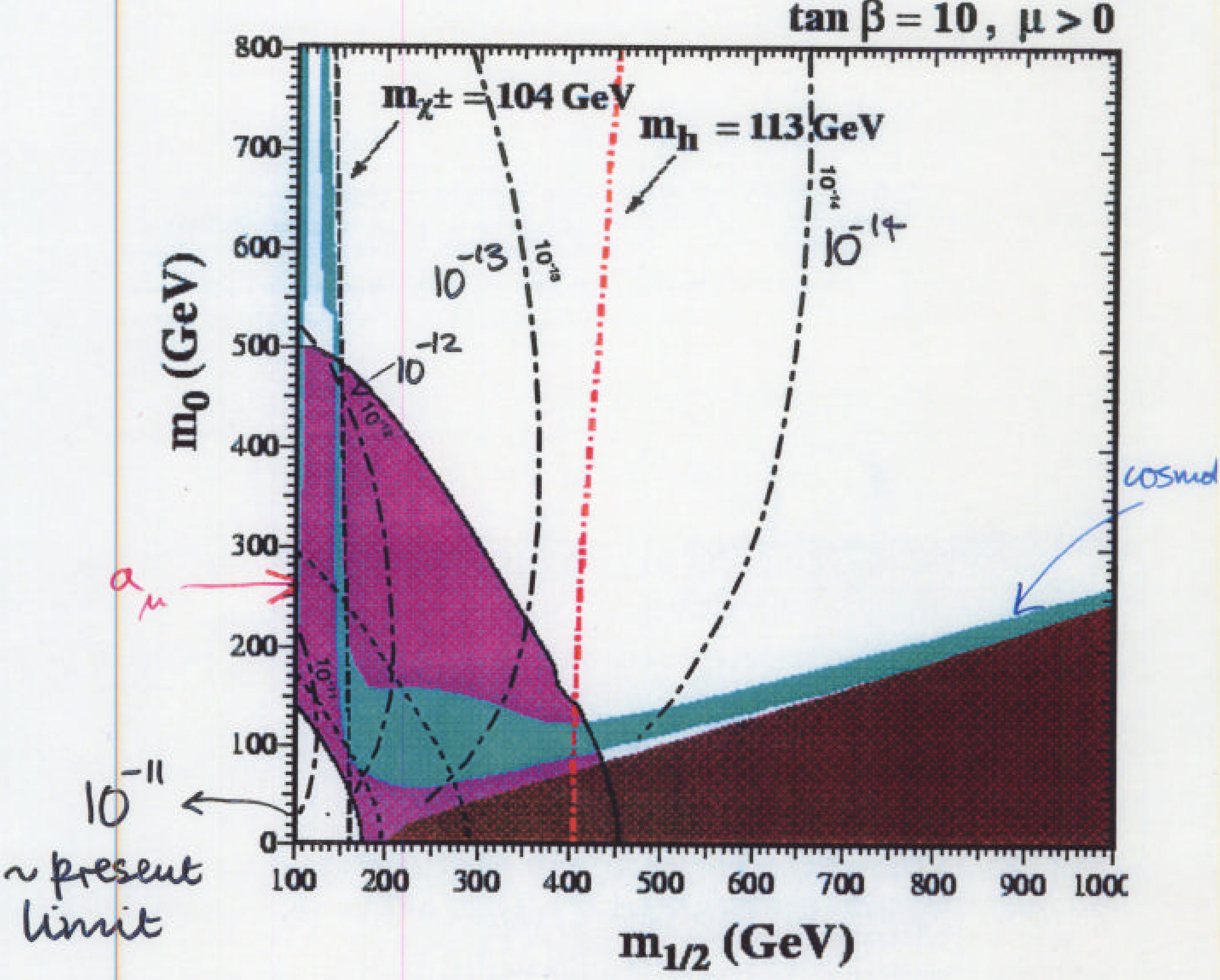
## $\mu\to 3e$, $\mu\to e$ conversion on nuclei

more opportunities to search for $\Delta L_\mu \neq 0$

theory, experimental problems different

# $\mu \to e\gamma$ in view of $a_\mu$, Super-Kamiokande

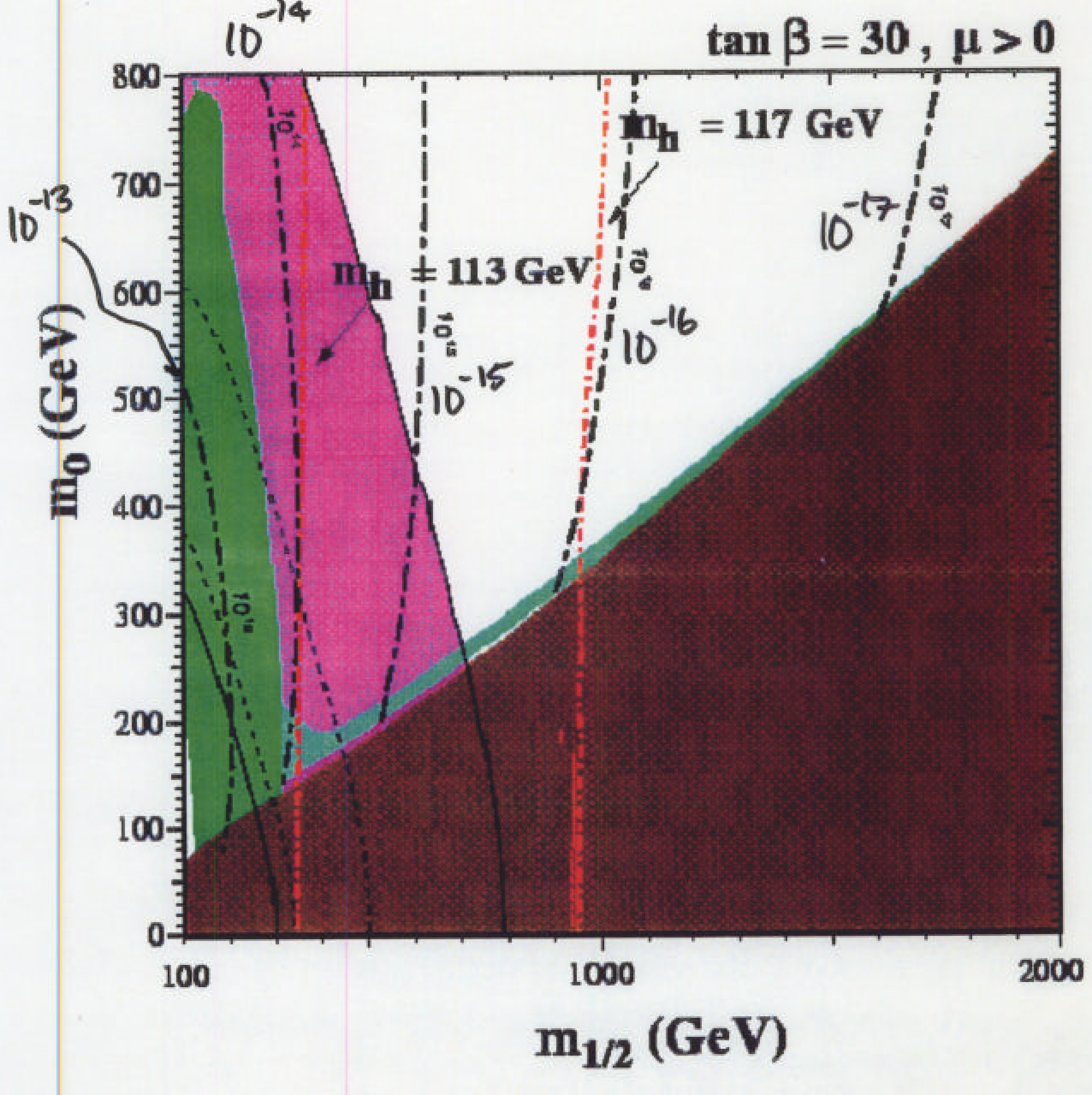
in Abelian flavour texture model



(Carvalho + J.E. + Gomez + Lola: hep-ph/0103256

# $\mu Ti \to e Ti$ in view of $a_\mu$, $\nu$ oscillations

in Abelian texture model



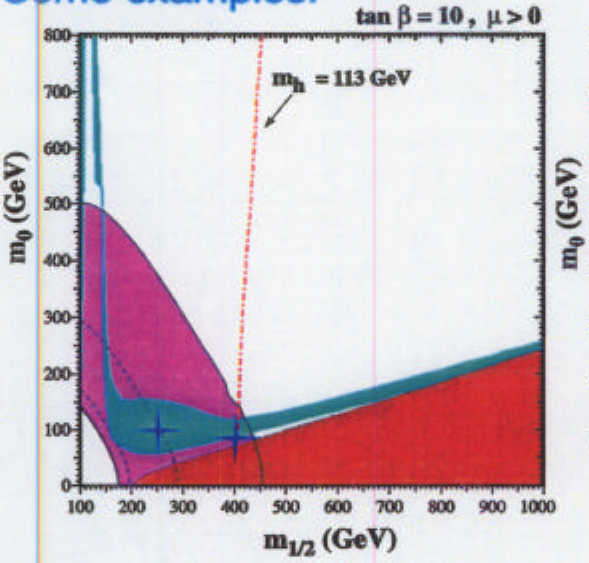
(Carvalho + J.E. + Gomez + Lola:
hep-ph/0103256

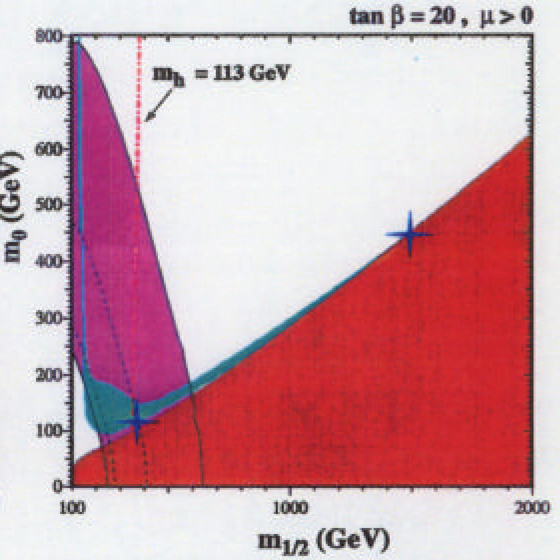
# Parameter choice for benchmark points

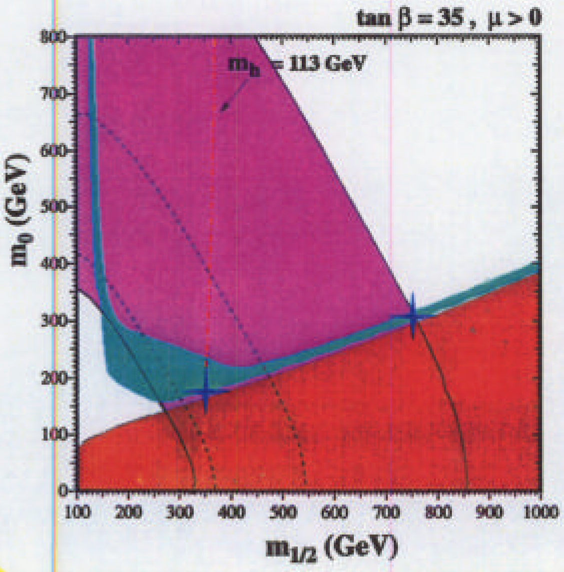
Based on following criteria:

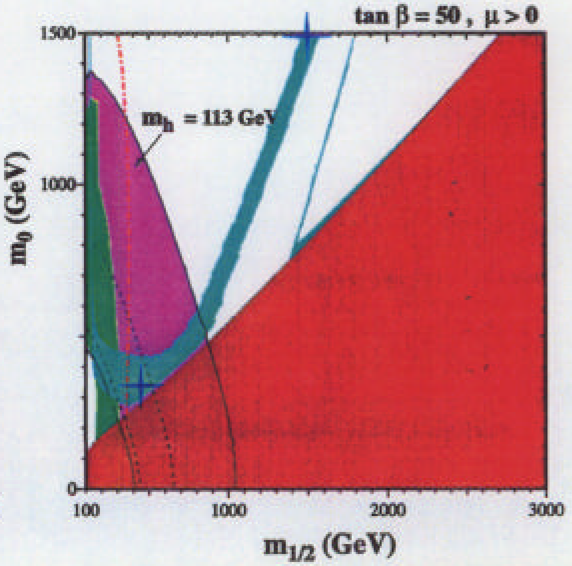
- tan$\beta \geq 5$
- mostly $\mu > 0$ (muon g-2); mostly $m_h \geq 113$ GeV (LEP)
- choose somewhat "extreme" points in the prefered region
- in some cases points are not included because they lead to a spectroscopy too similar to one already included
- the chosen points are not an unbiased statistical sampling of the MSUGRA possibilities

Some examples:

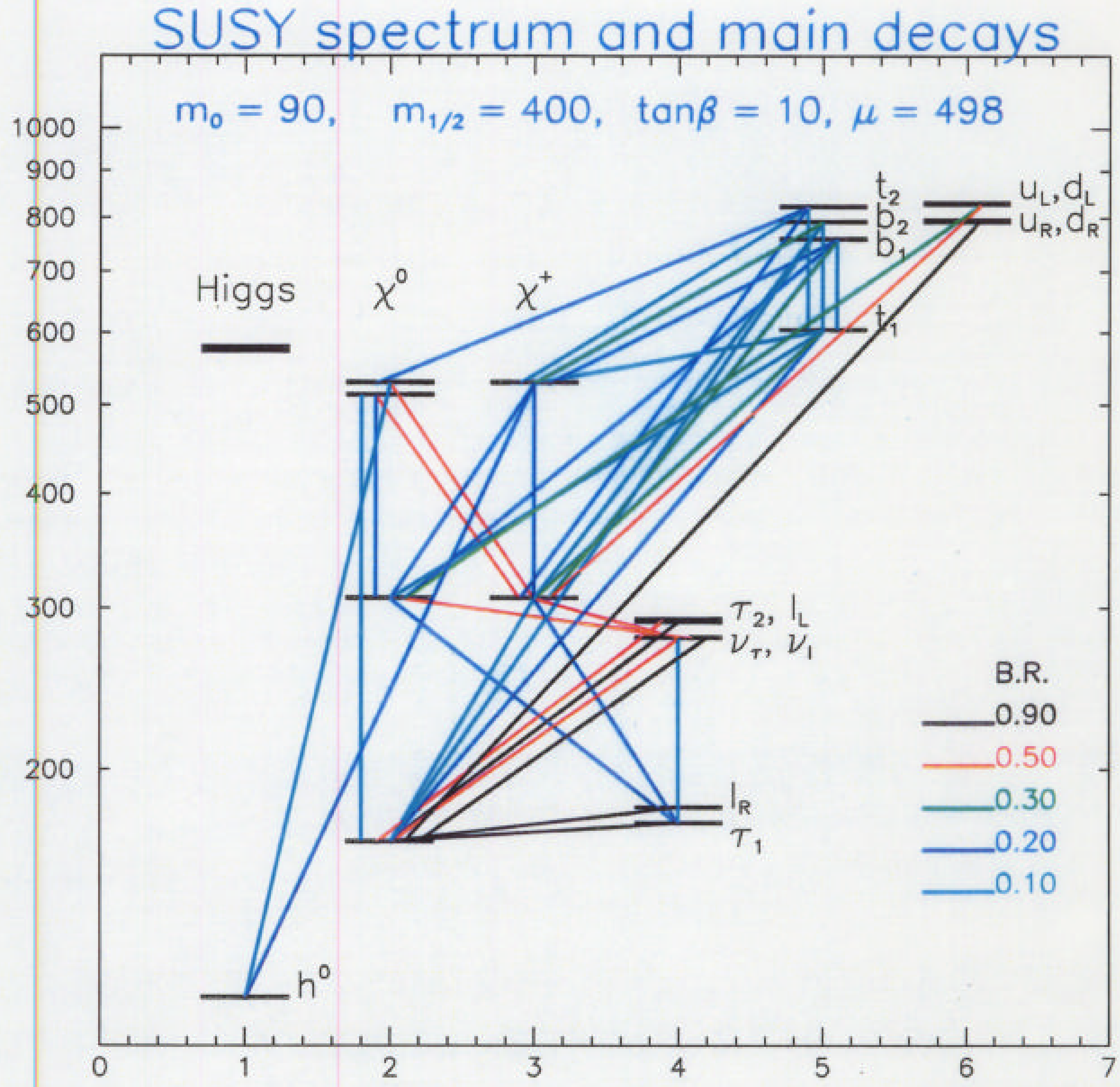








# Mass spectrum for benchmark C



See everything at CLIC

# 5 - Where do we go from here?

## Prospects for Higgs Discovery

Tevatron will have chance if $m_H = 115\,\mathrm{GeV}$

if heavier?

not before 2007?

LHC will discover it @ any mass

will observe 2 or 3 decay modes

measure mass to ~ 1%

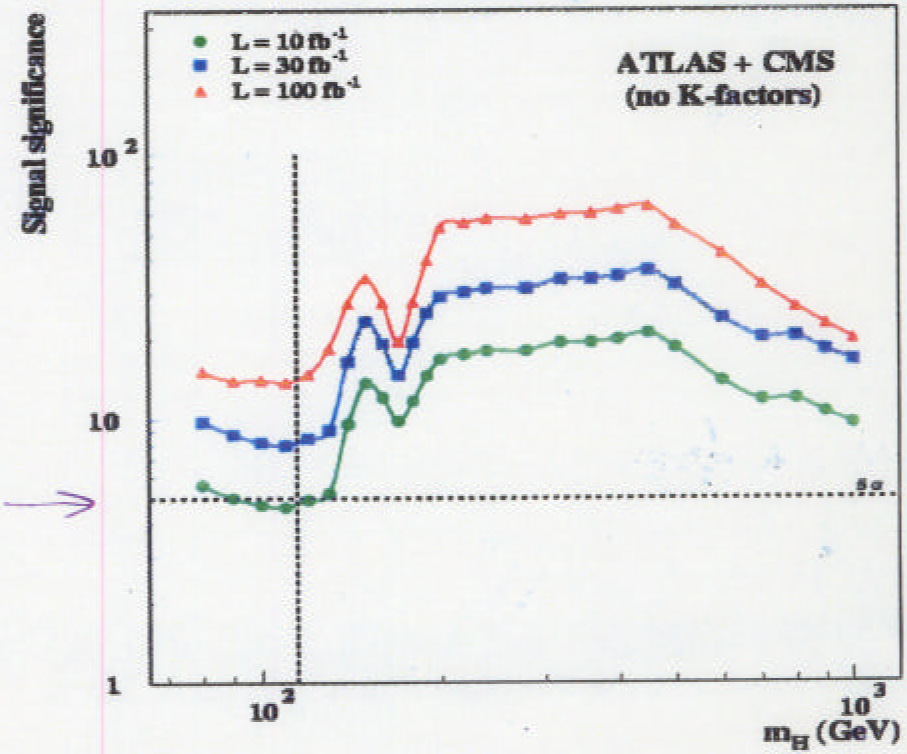
cover MSSM parameter space

↘ several times?

new analysis including LEP, universality, cosmology

measure MSSM parameters?

# Detectability of Higgs @ LHC



'discovery' →

expect ~ 1fb$^{-1}$ in first year

~ 10fb$^{-1}$ second

# CMSSM Higgs Production @ Hadron Colliders

$h_{CMSSM}$ vs $H_{SM}$

is there any suppression (enhancement)?

NO if you impose LEP ( J.E.+Heinemeye
+Olive+Weiglei

$b \to s\gamma$

$g_\mu - 2$

$\Omega_\chi h^2$

$$\sigma(gg \to h)B(h \to \gamma\gamma) \gtrsim 0.85 \times SM$$

$$\sigma(W/Z/\bar{t}t+h)B(h \to \bar{b}b) \gtrsim 1.00 \times SM$$

larger suppressions possible if abandon one or more constraints

$\sigma(gg \to h) B(h \to \gamma\gamma)$

CMSSM/SM

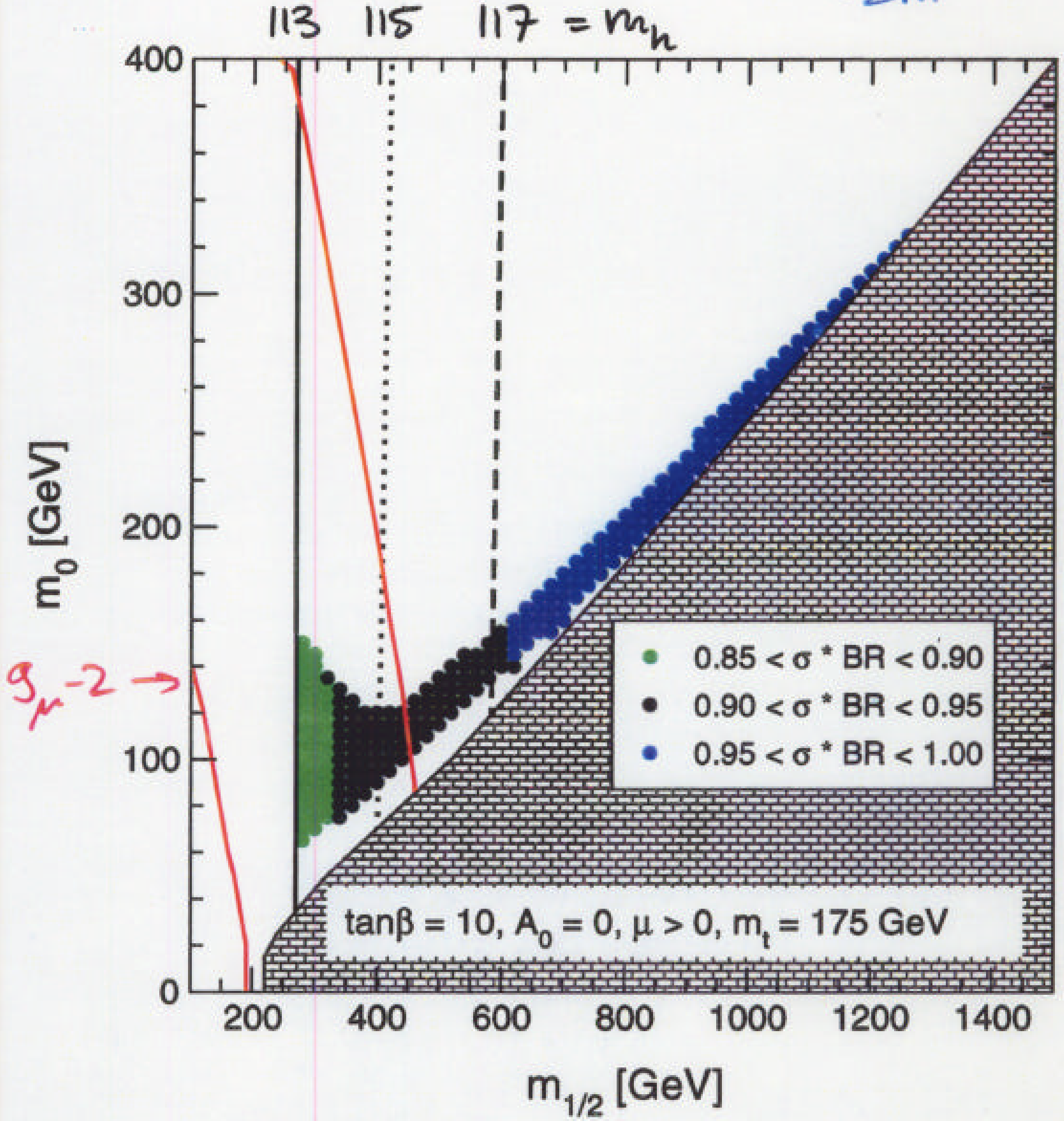


Figure 1: $\sigma(gg \to h) \times B(h \to \gamma\gamma)$, *normalized to the SM value with the same Higgs mass, plotted in the* $(m_{1/2}, m_0)$ *plane for* $\mu > 0$ *and* $\tan\beta = 10$.

(J.E + Heinemeyer
+ Olive + Weiglein

$\sigma(gg \to h) B(h \to \gamma\gamma)$

CMSSM/SM

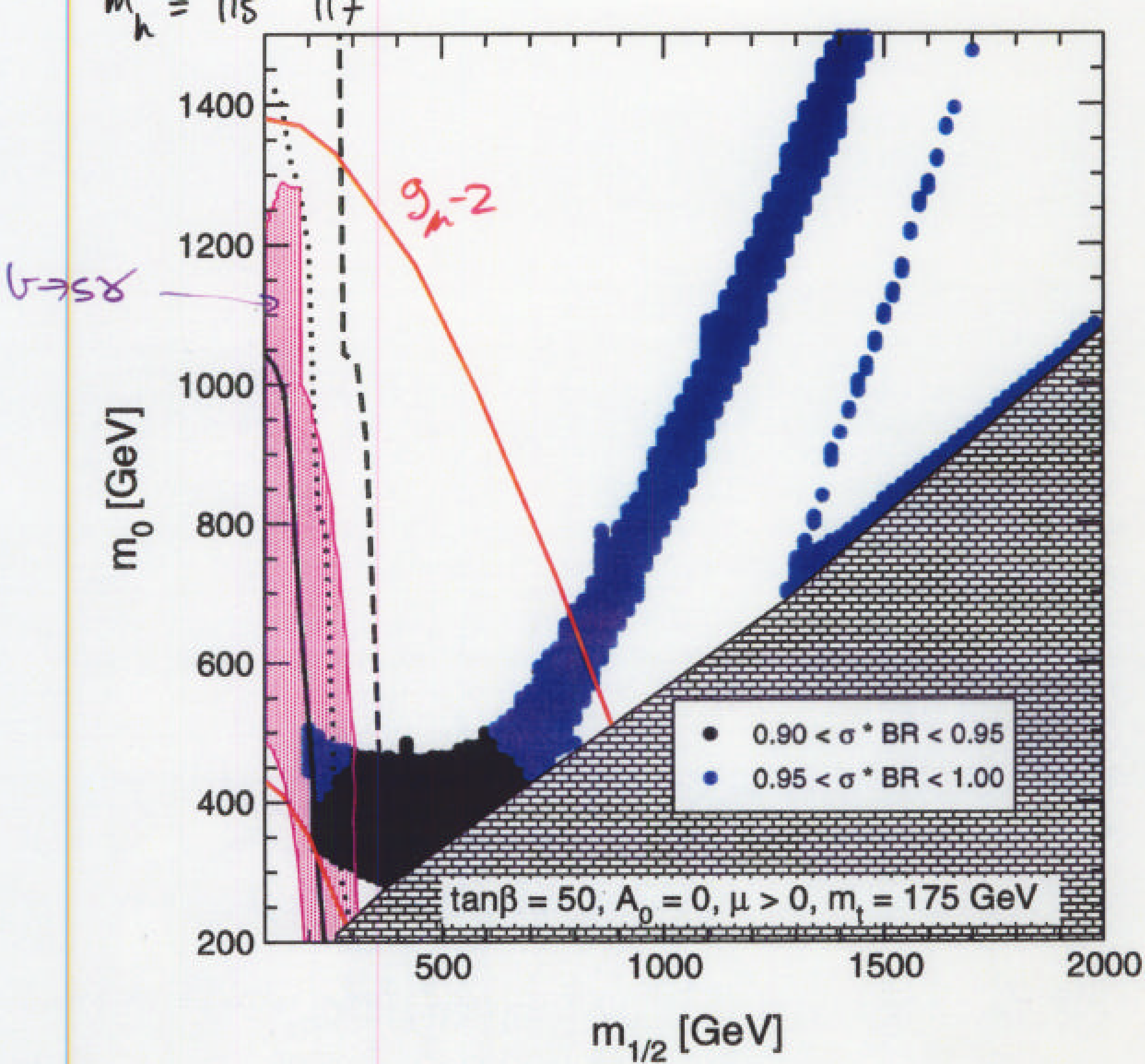


Figure 2: *$\sigma(gg \to h) \times \mathcal{B}(h \to \gamma\gamma)$, normalized to the SM value with the same Higgs mass, plotted in the $(m_{1/2}, m_0)$ plane for $\mu > 0$ and $\tan\beta = 50$.*

( J.E. + Heinemeyer
+ Olive + Weiglein

$\sigma(gg \to h) B(h \to \gamma\gamma)$

CMSSM/SM

$m_h = 113, 115, 117$

$b \to s\gamma$

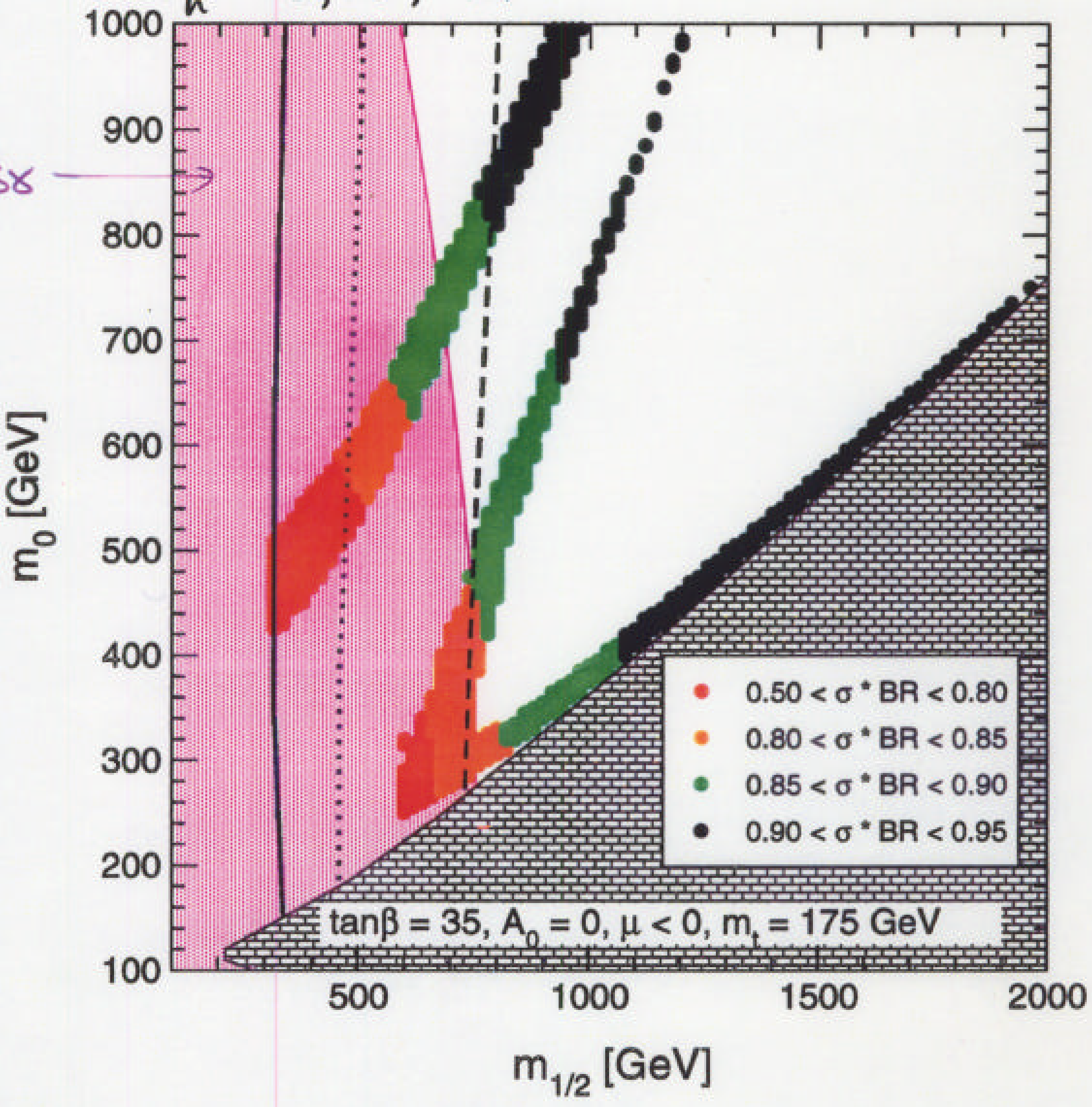


Figure 3: $\sigma(gg \to h) \times \mathcal{B}(h \to \gamma\gamma)$, *normalized to the SM value with the same Higgs mass, plotted in the* $(m_{1/2}, m_0)$ *plane for* $\mu < 0$ *and* $\tan\beta = 35$.

( J.E. + Heinemeyer
+ Olive + Weiglein

# Prospects for Supersymmetry Discovery

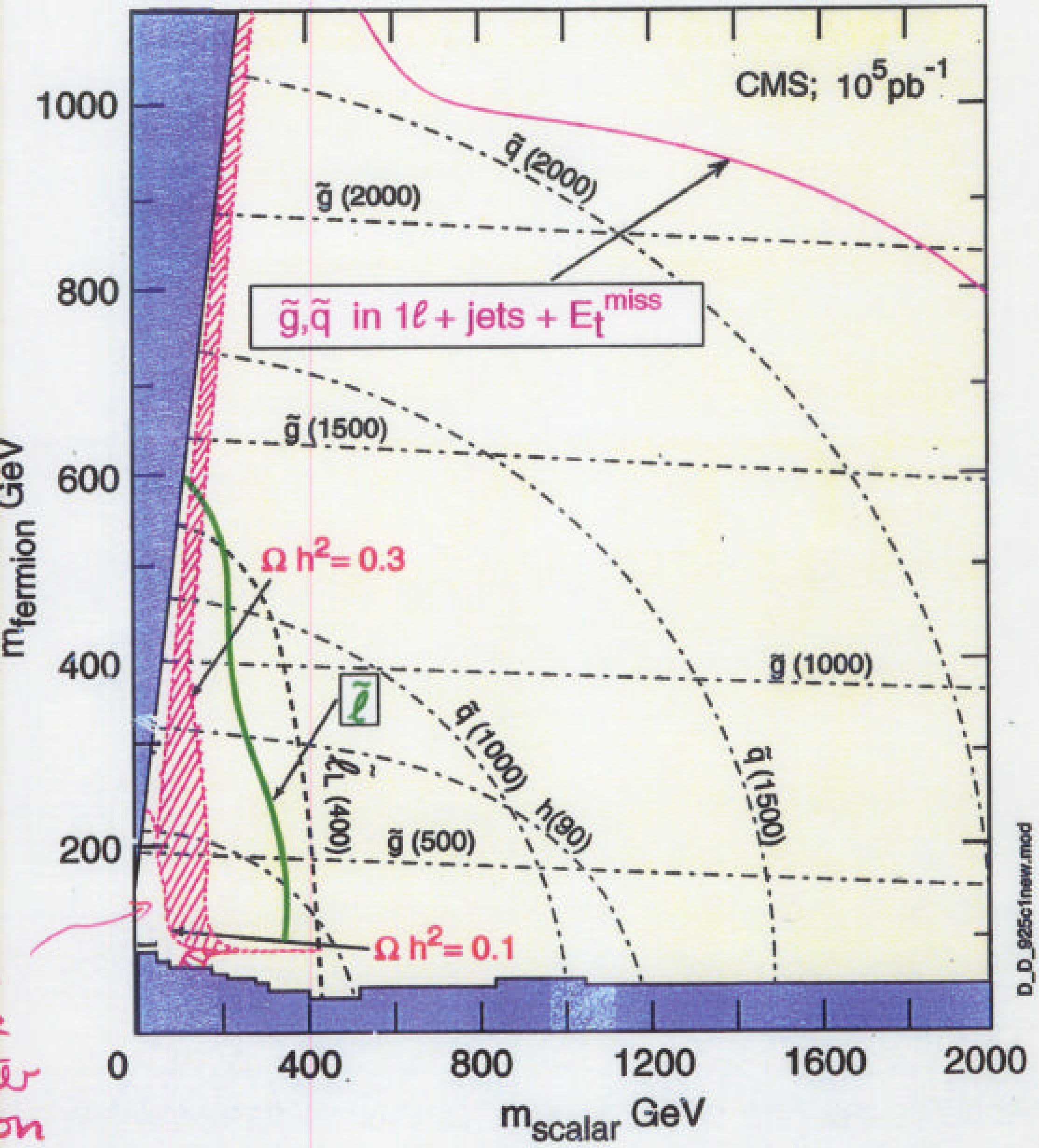
Tevatron
most of parameter space c LEP
disfavoured by Higgs 'limit'
little chance?

LHC
'guaranteed' discovery
can 'cover' cosmological region
rich opportunities in cascades
some sensitivity to sleptons, $\chi^{\pm}$, ..

# Expected reach in various channels

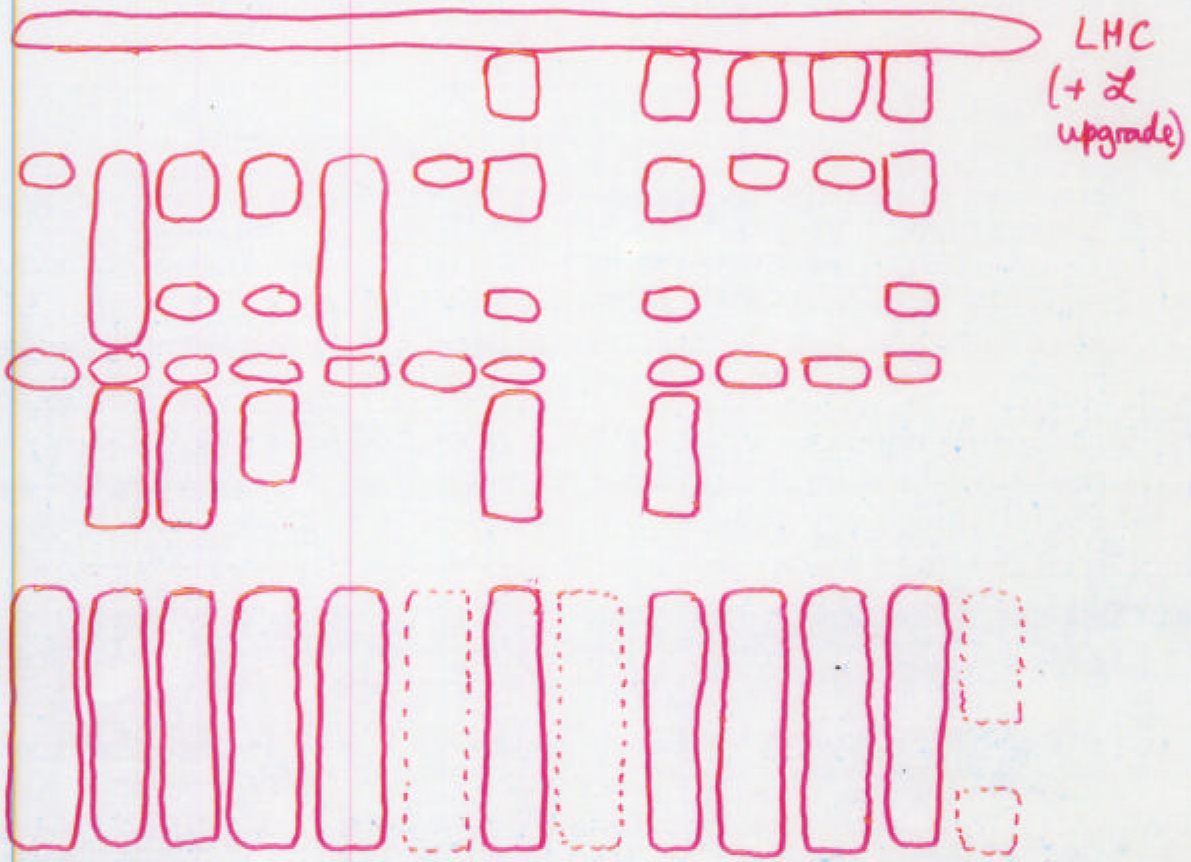
m SUGRA; tgβ = 2 (~ same up to tgβ ~ 5), $A_0 = 0$, $\mu < 0$

5 σ contours ($N_\sigma = N_{sig}/\sqrt{N_{sig}+N_{bkgd}}$) for $10^5 pb^{-1}$



cold dark matter region

(CMS


LHC
(+ ℒ upgrade)

# Post-LHC Physics Scenario

Higgs: discovered

$\Delta m/m \sim 10^{-2}$ to $10^{-3}$

one or two decays observed

MSSM: found several sparticles

not heavier higgses, charginos, sleptons

some precision measurements

# $e^+e^-$ Linear Collider Physics

- very clean experimental environment
- egalitarian production of new weakly-interacti particles
- polarization
- $e\gamma$, $\gamma\gamma$, $e^-e^-$ colliders "for free"
- complementary to LHC

what energy scale?

$2m_t$? $m_Z + m_H$? $2\tilde{m}$?

↑ ↑

estimated unknown

how/when to fix energy scale?

- flexibility essential

$m_Z, 2m_W \longleftarrow ?$ $\longrightarrow 2$ TeV

↑ ↑ ↑

$10^9$ polarized Z? $\delta m_W$ reach comparable to LHC

# Fixing the Sparticle Mass Scale with Cold Dark Matter

(J.E. + Ganis + Olive
hep-ph/991232

Cosmology ⇒ $\Omega_{CDM} h^2 \leq 0.3$

Supersymmetric dark matter density

$\Omega_\chi \uparrow$ as $m_\chi$, $m_0, m_{1/2} \uparrow$

⇒ region of $(m_0, m_{1/2})$ plane where

$\Omega_\chi h^2 \leq 0.3$ is bounded

stretched to large $m_{1/2}$ by $\nearrow \chi \tilde{\tau}$ coannihilatio
(J.E. + Falk + Olive (+ Sredni
1998

How much of dark matter region is covered by a LC with given $E_{CM}$?

~ 60 % if $E_{cm} = 0.5$ TeV

~ 90 % if $E_{cm} = 1$ TeV

all if $E_{cm} \gtrsim 1.25$ TeV

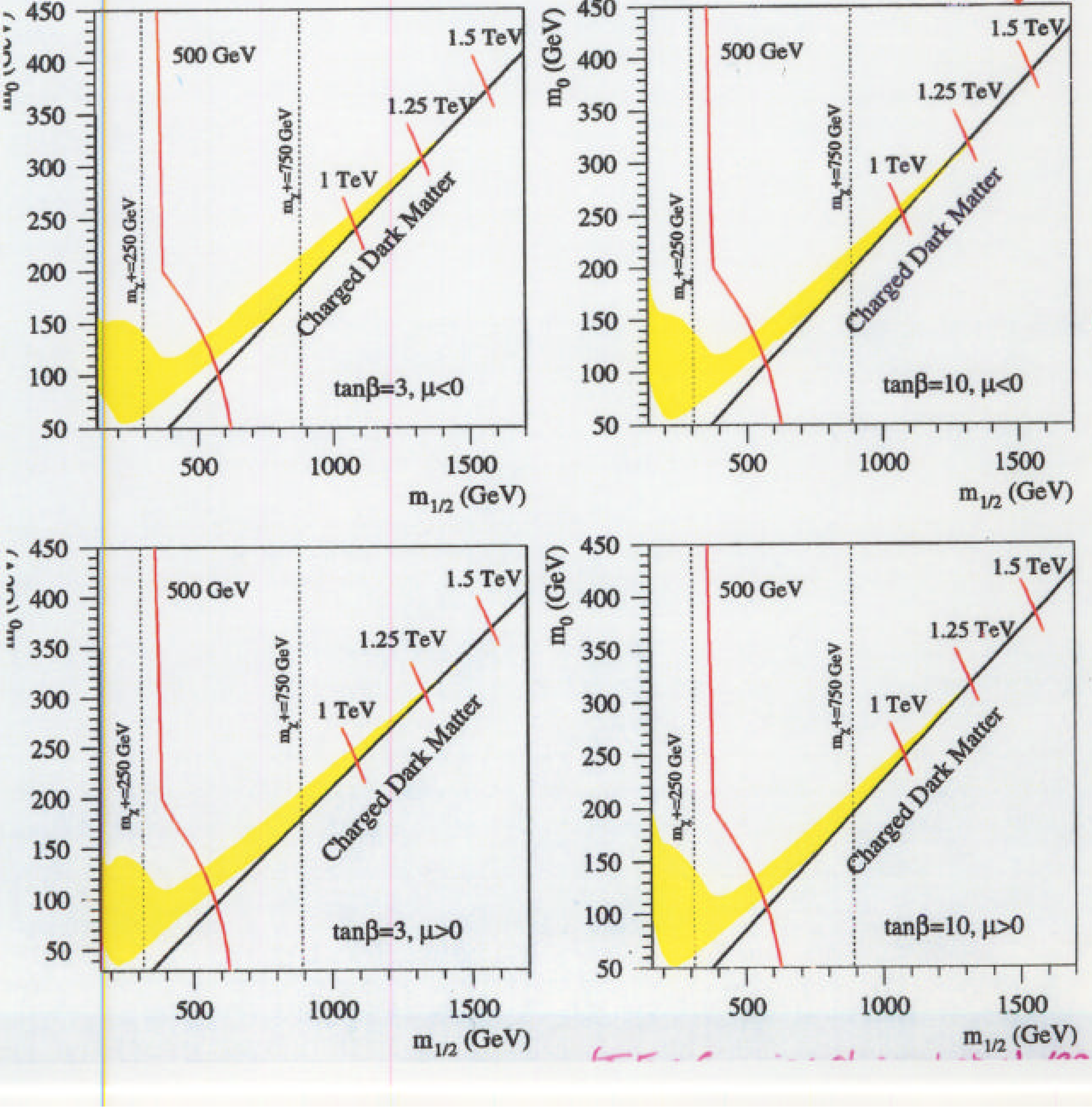
# Linear Collider coverage of Supersymmetric dark matter region

$\Omega h^2 \leq 0.3$

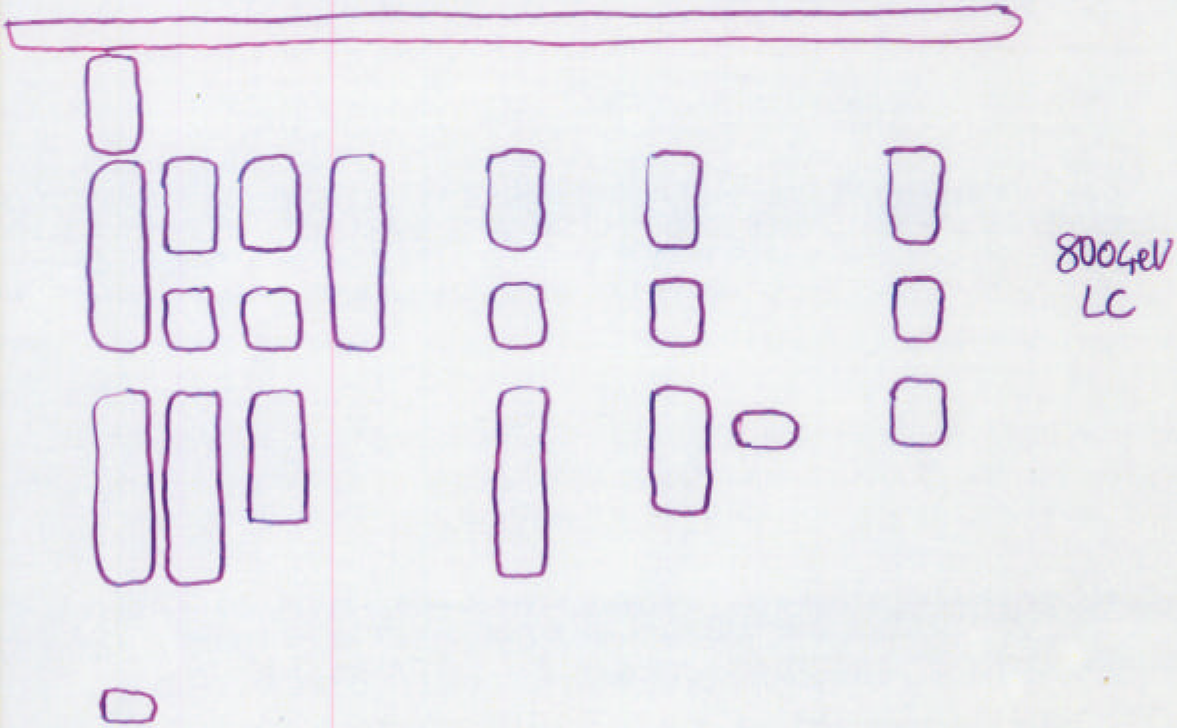
what $E_{cm}$ is needed?

reach with $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$

## Cross section limit $\sigma_{lim}$ = 1 fb



[illegible]


800GeV
LC

- We will need a LC
- Complementary to LHC

  exploration $\oplus$ precision

- Need widest possible energy range

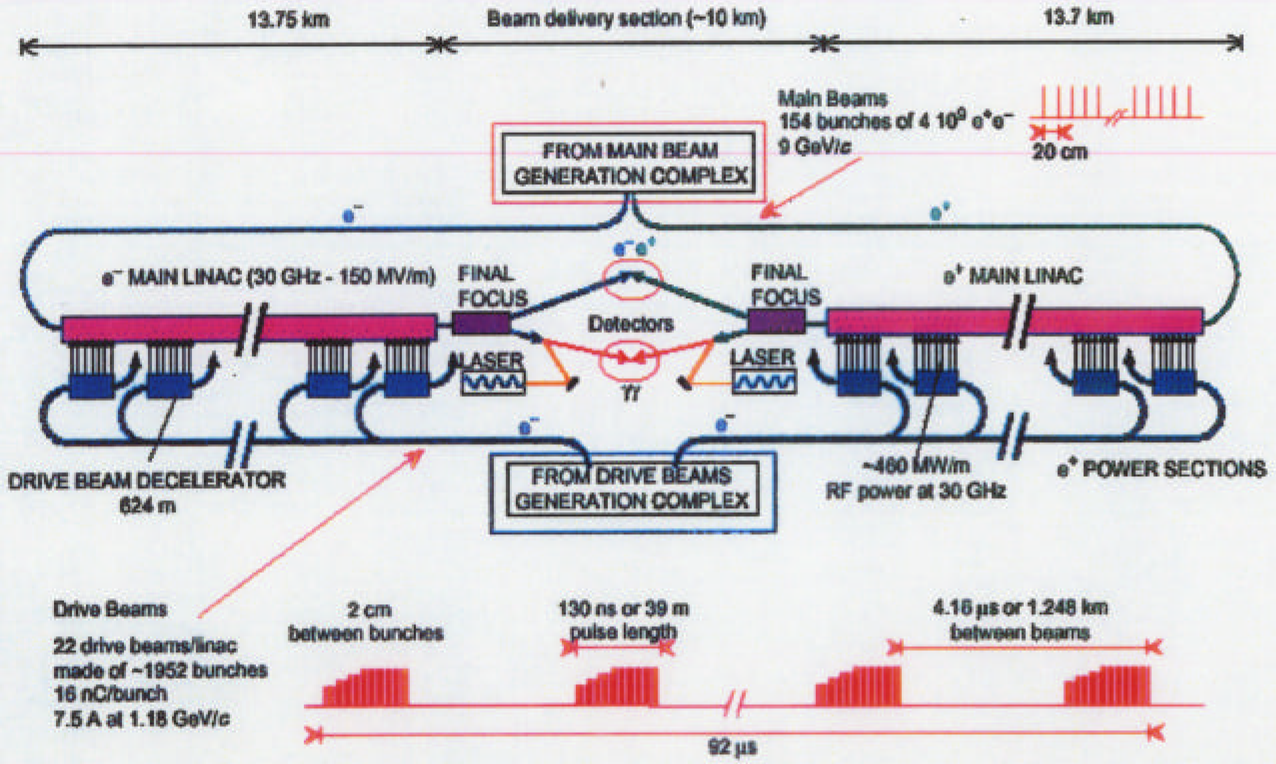
  initial $\oplus$ extensions $\oplus$ back to Z/W

- Should converge on single project

for rest of talk:

assume a LC in the ~ TeV Ecm
range will be built

# CLIC Layout



13.75 km

Beam delivery section (~10 km)

13.7 km

Main Beams
154 bunches of 4 $10^9$ $e^+e^-$
9 GeV/c

20 cm

FROM MAIN BEAM GENERATION COMPLEX

$e^-$ MAIN LINAC (30 GHz - 150 MV/m)

FINAL FOCUS

Detectors

$e^-e^+$

$\gamma\gamma$

LASER

$e^+$ MAIN LINAC

DRIVE BEAM DECELERATOR
624 m

FROM DRIVE BEAMS GENERATION COMPLEX

~480 MW/m
RF power at 30 GHz

$e^+$ POWER SECTIONS

Drive Beams

22 drive beams/linac
made of ~1952 bunches
16 nC/bunch
7.5 A at 1.18 GeV/c

2 cm
between bunches

130 ns or 39 m
pulse length

4.16 µs or 1.248 km
between beams

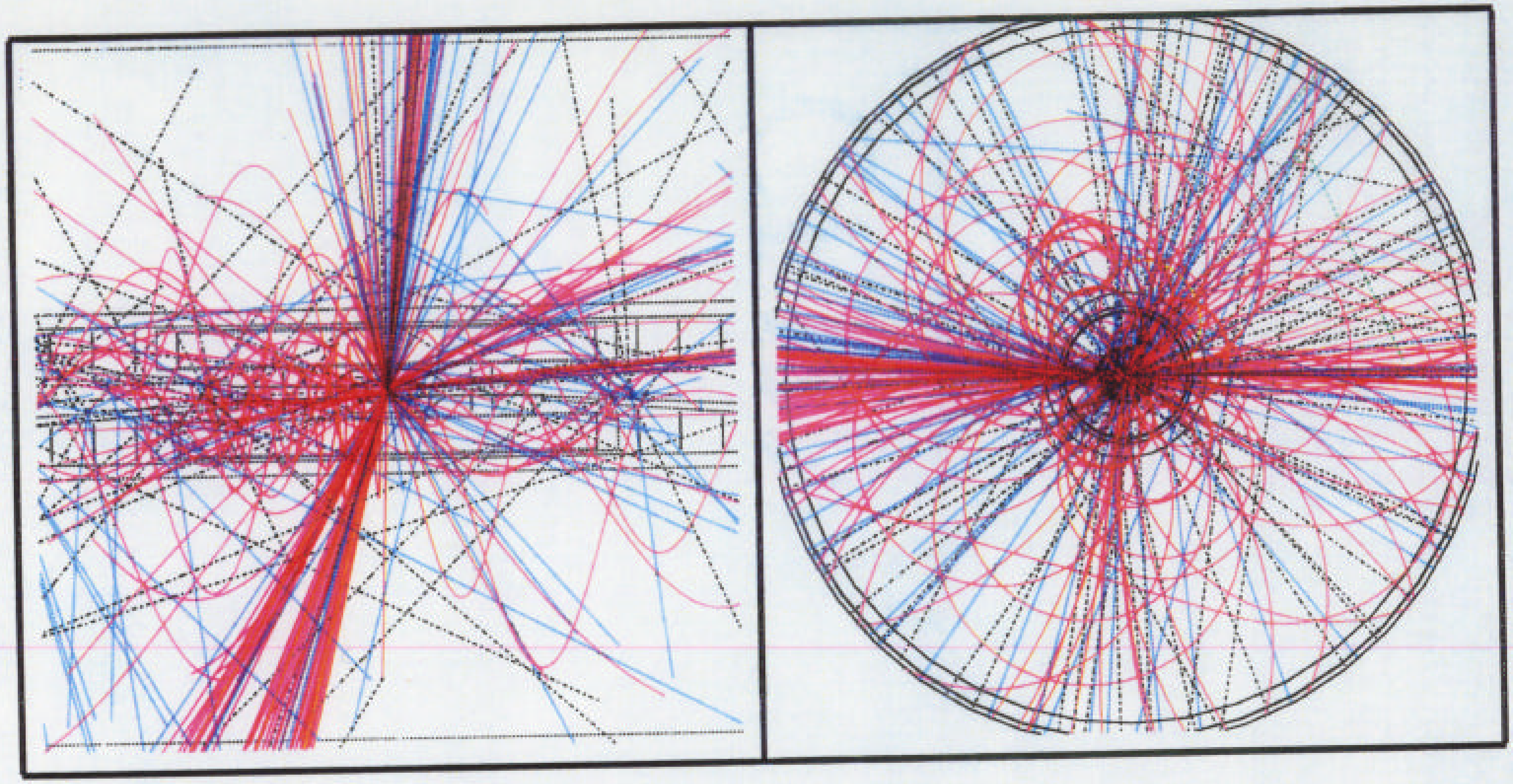
92 µs

SPC 20.9.99 K. Hübner

# CLIC Parameters

| Beam param. at I.P. $E_{CM}$ = | 0.5 TeV | 1 TeV | 3 TeV | 5 TeV |
|---|---|---|---|---|
| Luminosity ($10^{34}$cm$^{-1}$s$^{-1}$) | 0.5 | 1.1 | 10.6 | 14.9 |
| Mean energy loss (%) | 3.6 | 9.2 | 32 | 40 |
| Photons /electrons | 0.8 | 1.1 | 2.2 | 2.6 |
| Rep. Rate (Hz) | 200 | 150 | 75 | 50 |
| $10^9$ $e^{\pm}$ / bunch | 4 | 4 | 4 | 4 |
| Bunches / pulse | 150 | 150 | 150 | 150 |
| Bunch spacing (cm) | 20 | 20 | 20 | 20 |
| H/V $\varepsilon_n$ ($10^{-8}$ rad.m) | 188/10 | 148/7 | 60/1 | 58/1 |
| Beam size (H/V) (nm) | 196/4.5 | 123/2.7 | 40/0.6 | 27/0.45 |
| Bunch length (µm) | 50 | 50 | 30 | 25 |
| Accel.gradient (MV/m) | 100 | 100 | 150 | 200 |
| Two linac length (km) | 7 | 14 | 27.5 | 35 |
| Power / section (MW) | 116 | 116 | 231 | 386 |
| RF to beam effic. (%) | 35.5 | 35.5 | 26.6 | 19.4 |
| AC to beam effic. (%) | 14.2 | 14.2 | 10.6 | 7.8 |
| AC power (MW) | 68 | 102 | 206 | 310 |

# $e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}\,\bar{t}b$ for $\sqrt{s} = 3$ TeV, $M(H^\pm) = 900$ GeV, $B = 4$ T

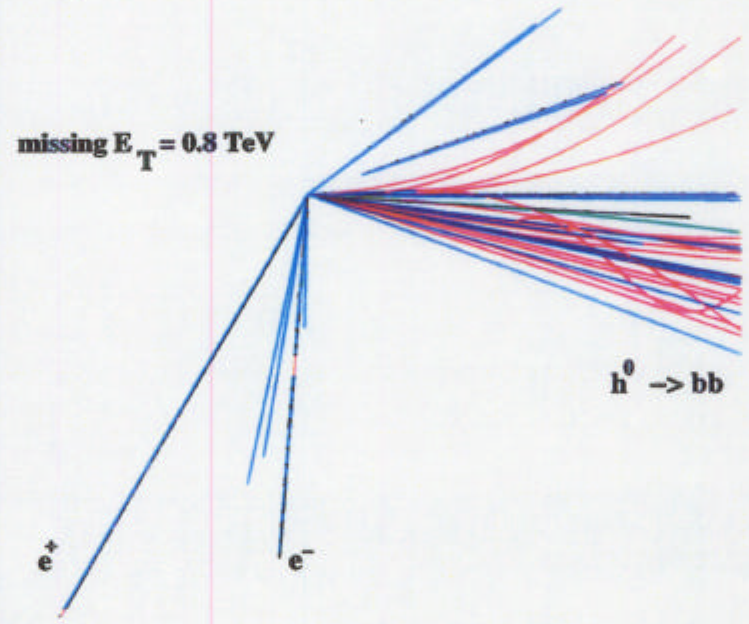


# SUSY

## Completing the Sparticle Spectrum at a multi-TeV Collider

**CLIC 3 TeV**

$e^+e^- \to e_L e_R$



$m_{\tilde{e}} = 1050$ GeV $\qquad m_{h^0} = 115$ GeV

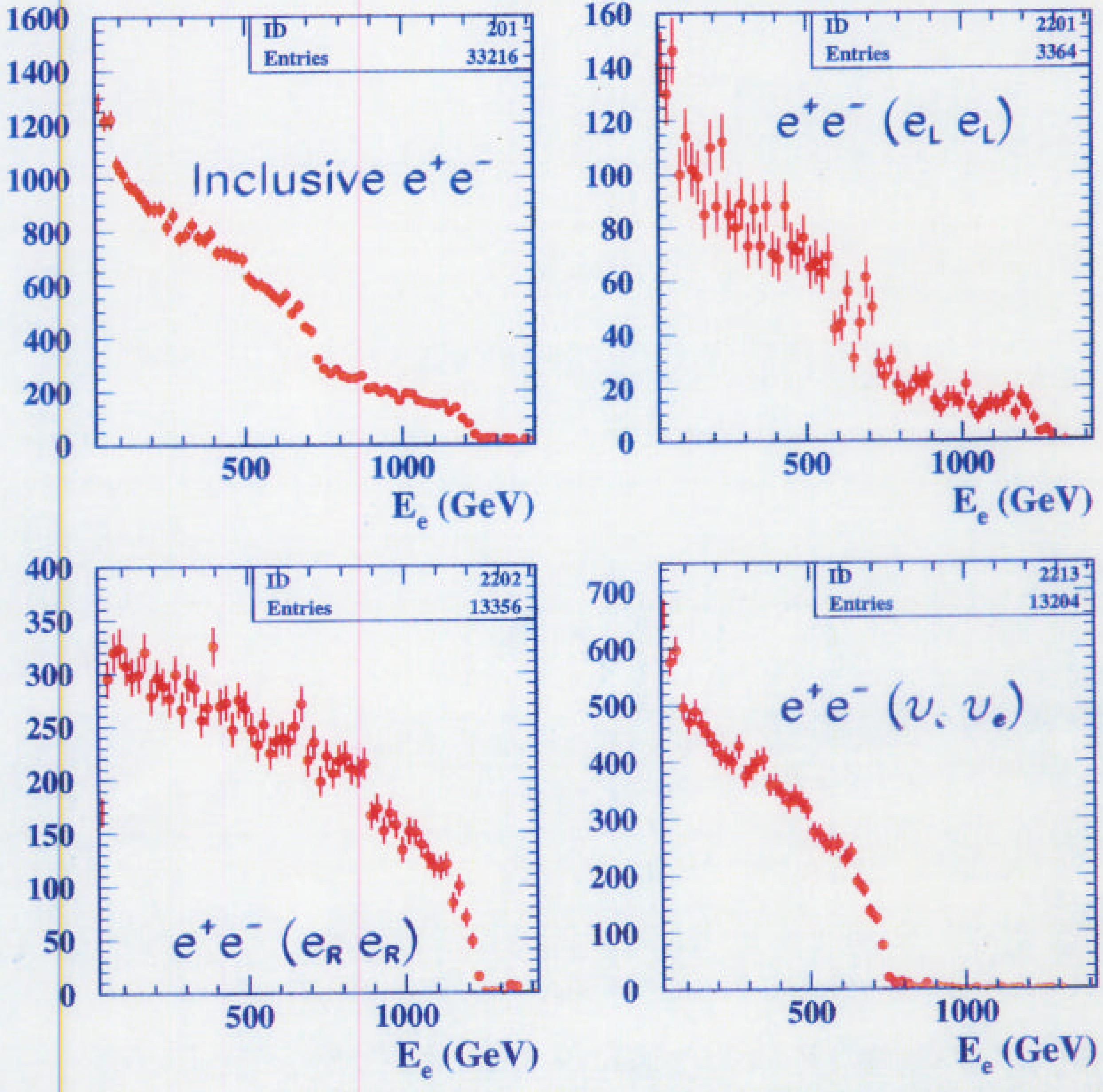
$\tilde{e_L} \to e\tilde{\chi}_2^0 \qquad \tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h \qquad h \to b\bar{b}$

$\tilde{e_R} \to e\tilde{\chi}_1^0$

# Sample CLIC Physics Study

is this an issue?

## CLIC beamstrahlung ($10^{35}$)



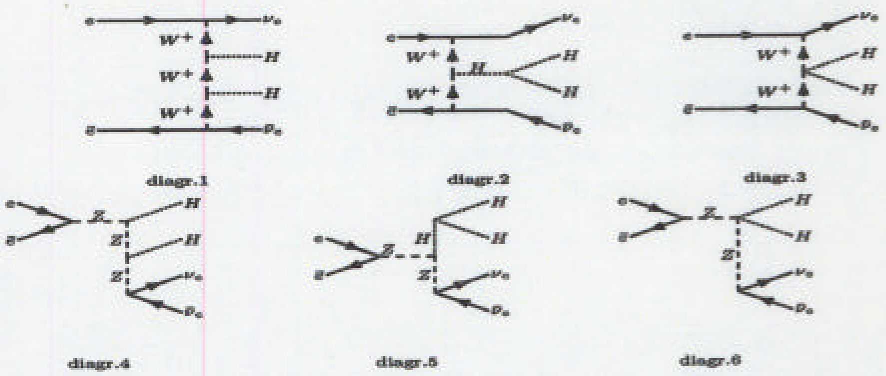
# Light Higgs

## Study of Triple Higgs Coupling at CLIC

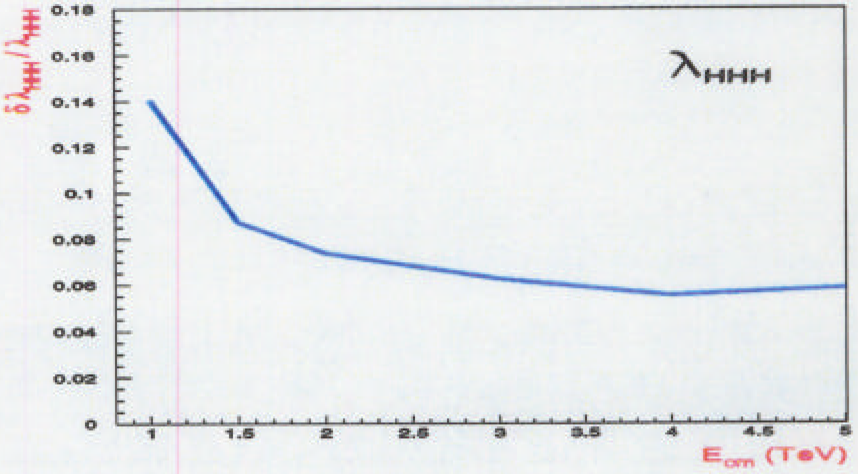
M. Battaglia

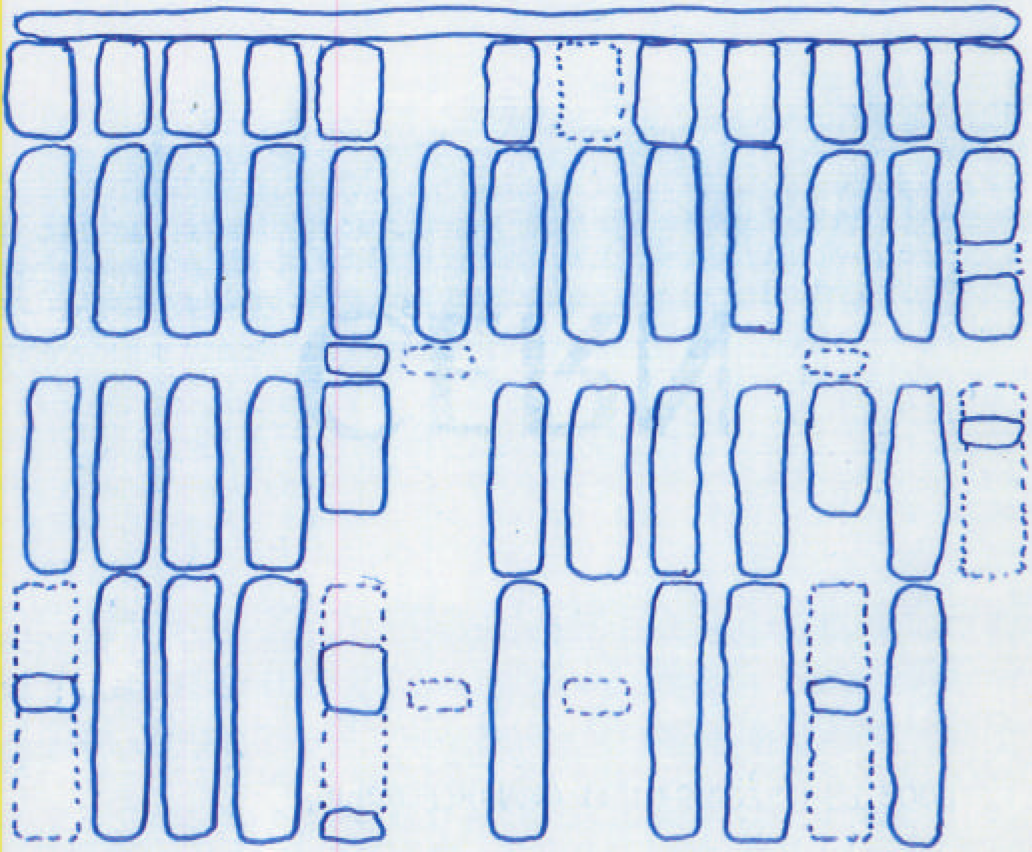
✦ Extract $\lambda_{HHH}$ from $\sigma(e^+e^- \rightarrow \nu\nu HH)$ for $M_H = 120$ GeV/$c^2$ ($\sim 20 - 25\%$ atTESLA)

✦ $\sigma(e^+e^- \rightarrow \nu\nu HH) \simeq \sigma(e^+e^- \rightarrow \nu\nu ZZ \rightarrow b\bar{b})$



Precision on $\lambda_{HHH}$ (5000 fb$^{-1}$)

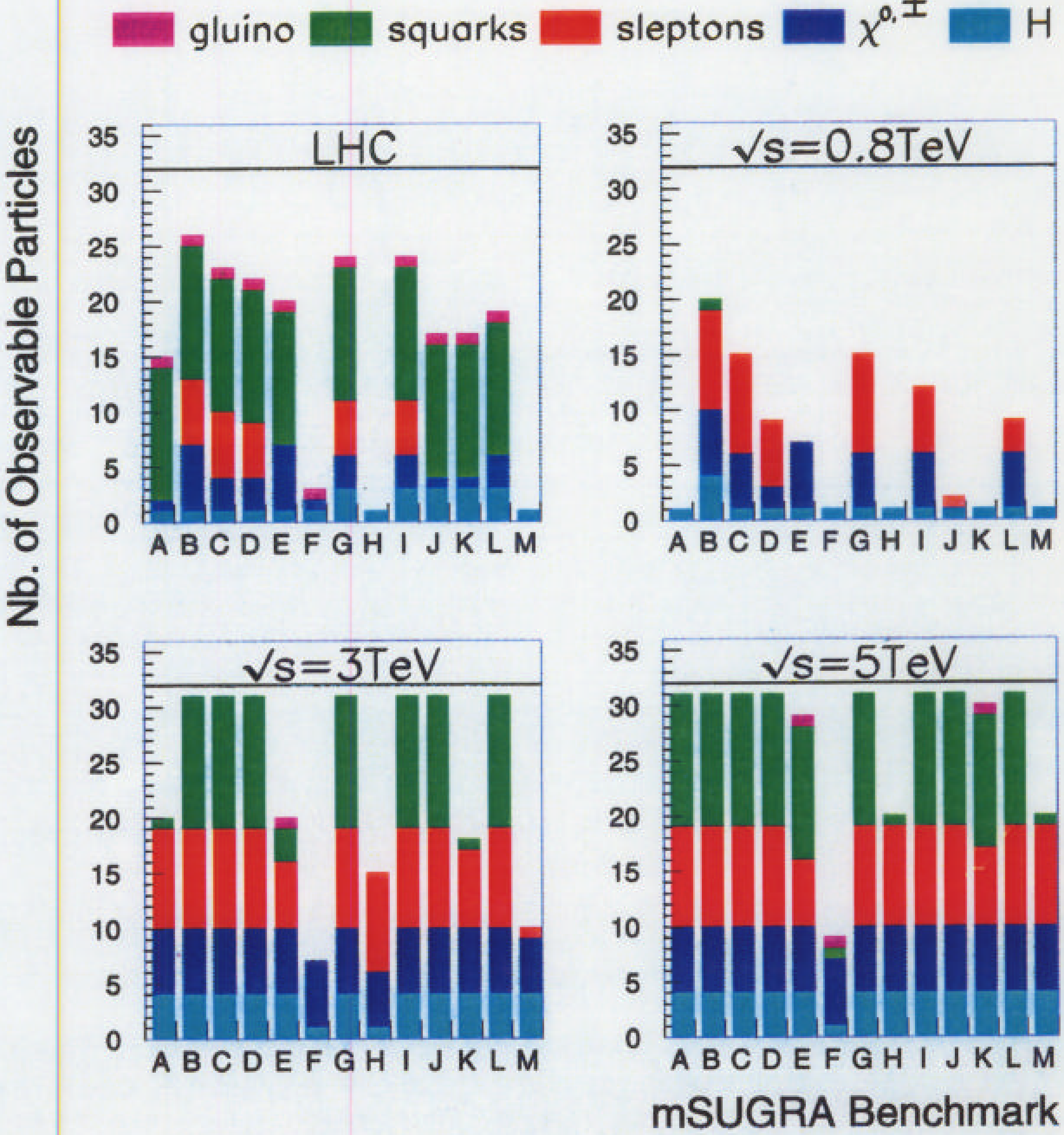




CLIC
3TeV
(5TeV)

# Visible Sparticles @ Different Colliders

in benchmark scenarios



## Conclusions

- The (lightest) Higgs is probably light
- It quacks like supersymmetry
- Cannot (yet) fix the spaticle threshold
- Some information may arrive < LHC

  $g_\mu - 2$, Tevatron, ...
- The LHC will set the scale

  do we want to wait?
- The LHC will not tell the whole story

  we will need a LC: energy?
- CLIC would (probably) complete sspectrum

  how is supersymmetry broken?

  ↓

  VLHC?