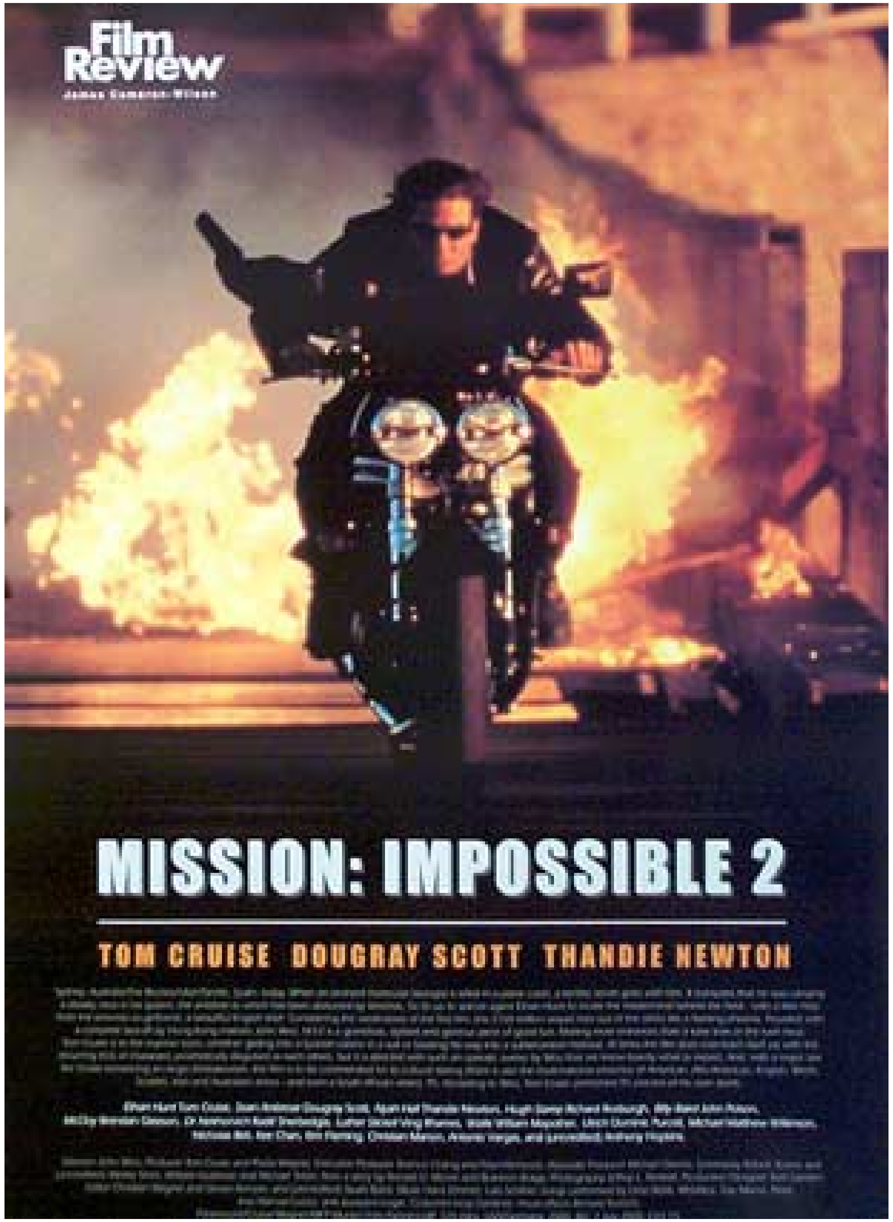
EWSB beyond the Standard Model: Supersymmetry?



Third Lecture Outline:

1. Why we do believe in S.M.?

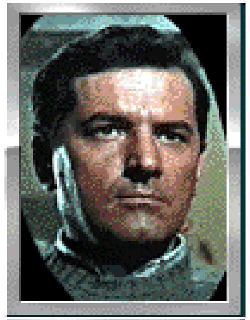
2. Why we do not believe in S.M.?

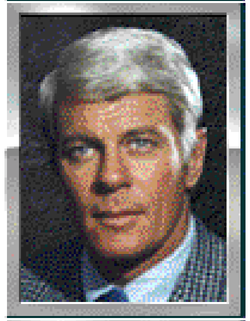
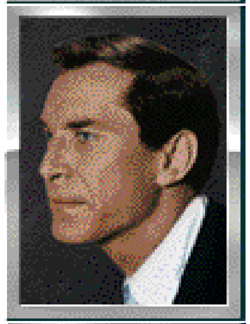
3. Why we believe in Supersymmetry?

4. Phenomenology
   Particle content, models, parameters,
   Higgs sector, ...

5. Some searches at LEP
   Higgs bosons, charginos, neutralinos, sleptons...

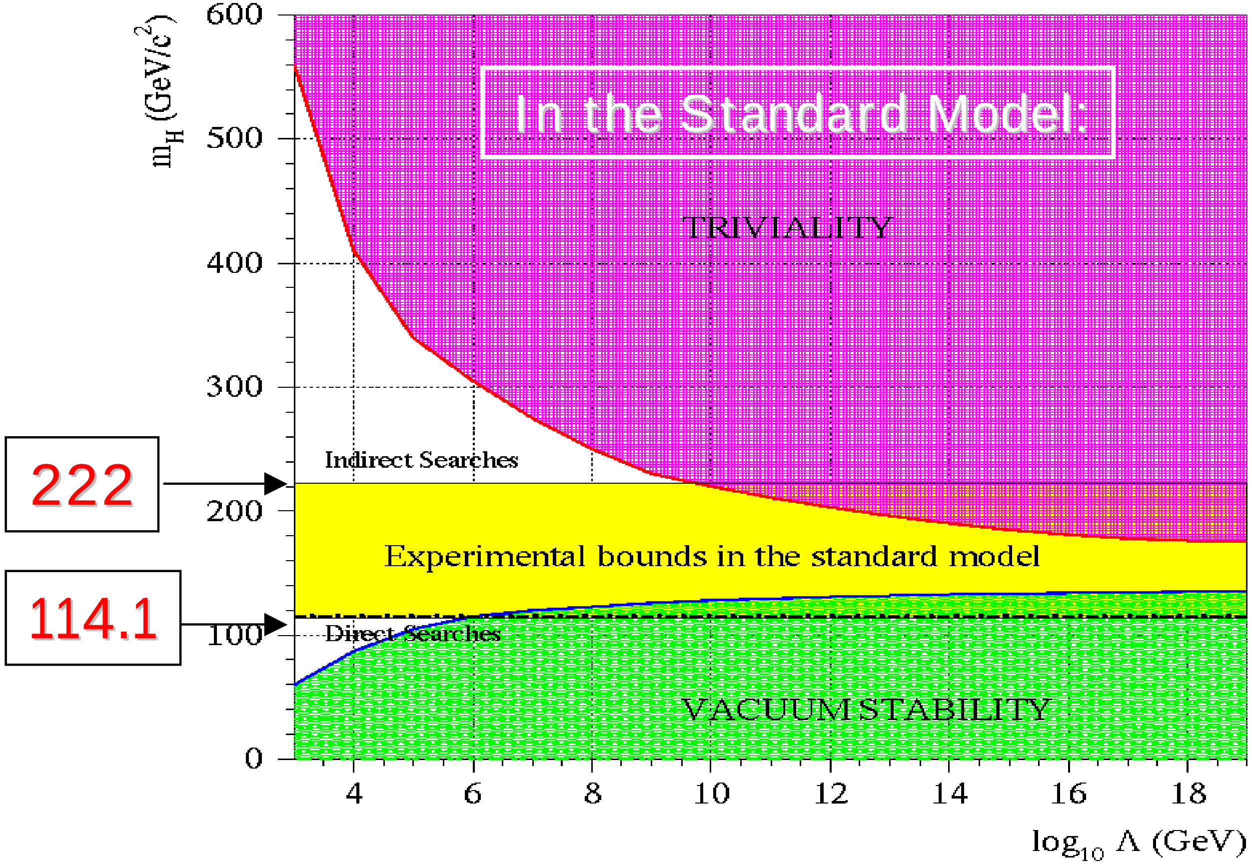
6. LSP mass limit, mSUGRA constraints

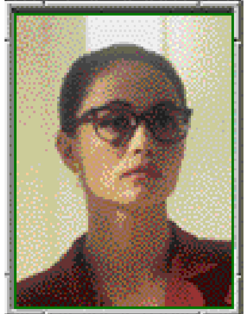


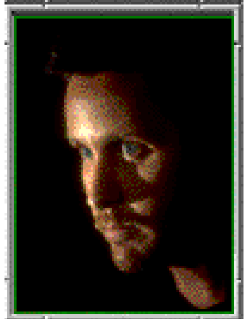




EWSB beyond the SM

Supersymmetry?



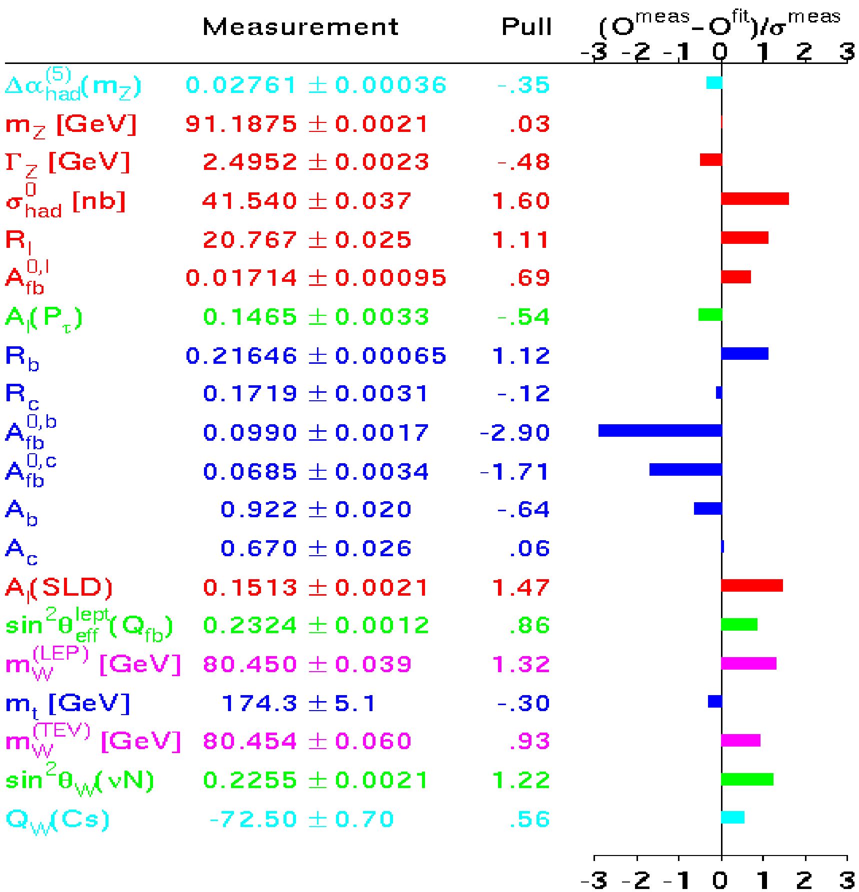



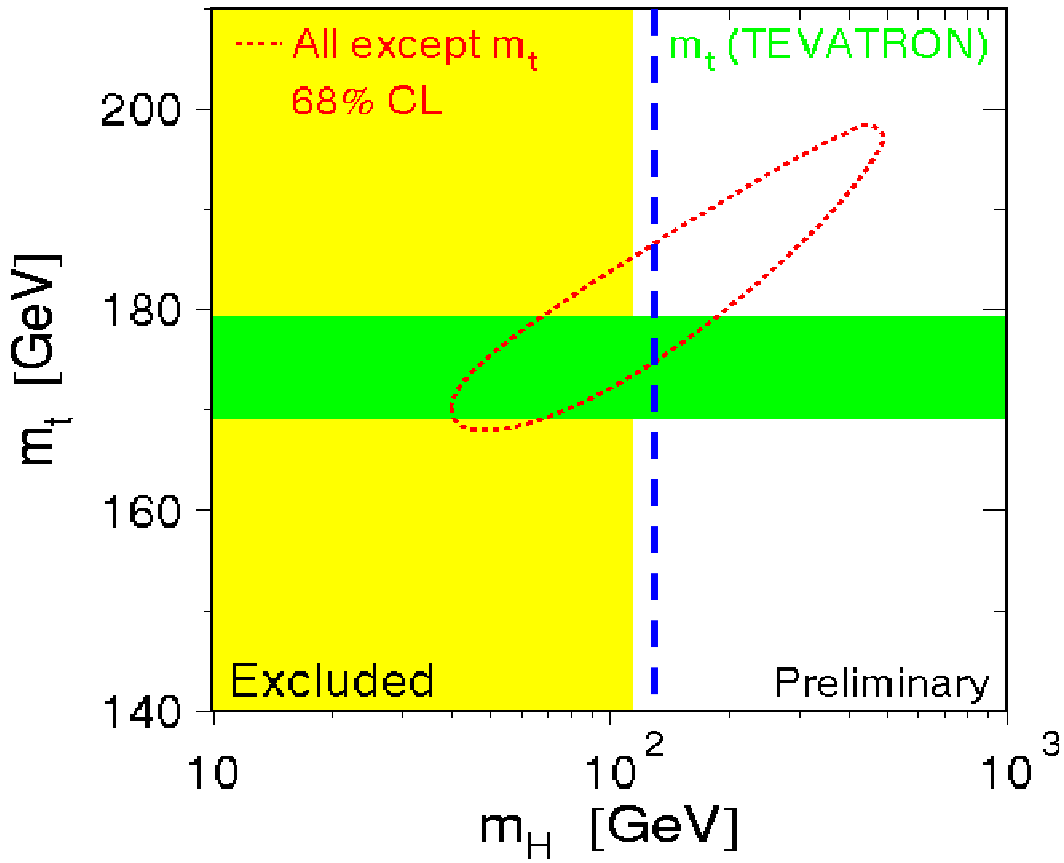
Given the successes of the standard model predictions,
why would we need to go beyond
and invent **a new symmetry** between

Bosons and Fermions ?

Why we do believe in the Standard Model

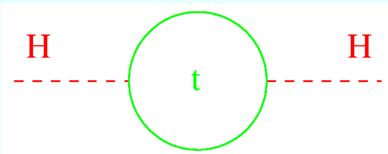
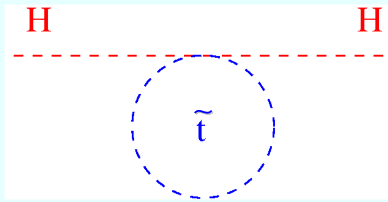
- Standard Model Internal Consistency tested at the 0.1% level
- No compelling evidence for any deviation beyond the expected statistical scatter
- EWSB Predictions of the Standard Model in agreement with direct measurements. The presence of a (rather light) Higgs boson seems to be required.





Why we do not believe in the Standard Model

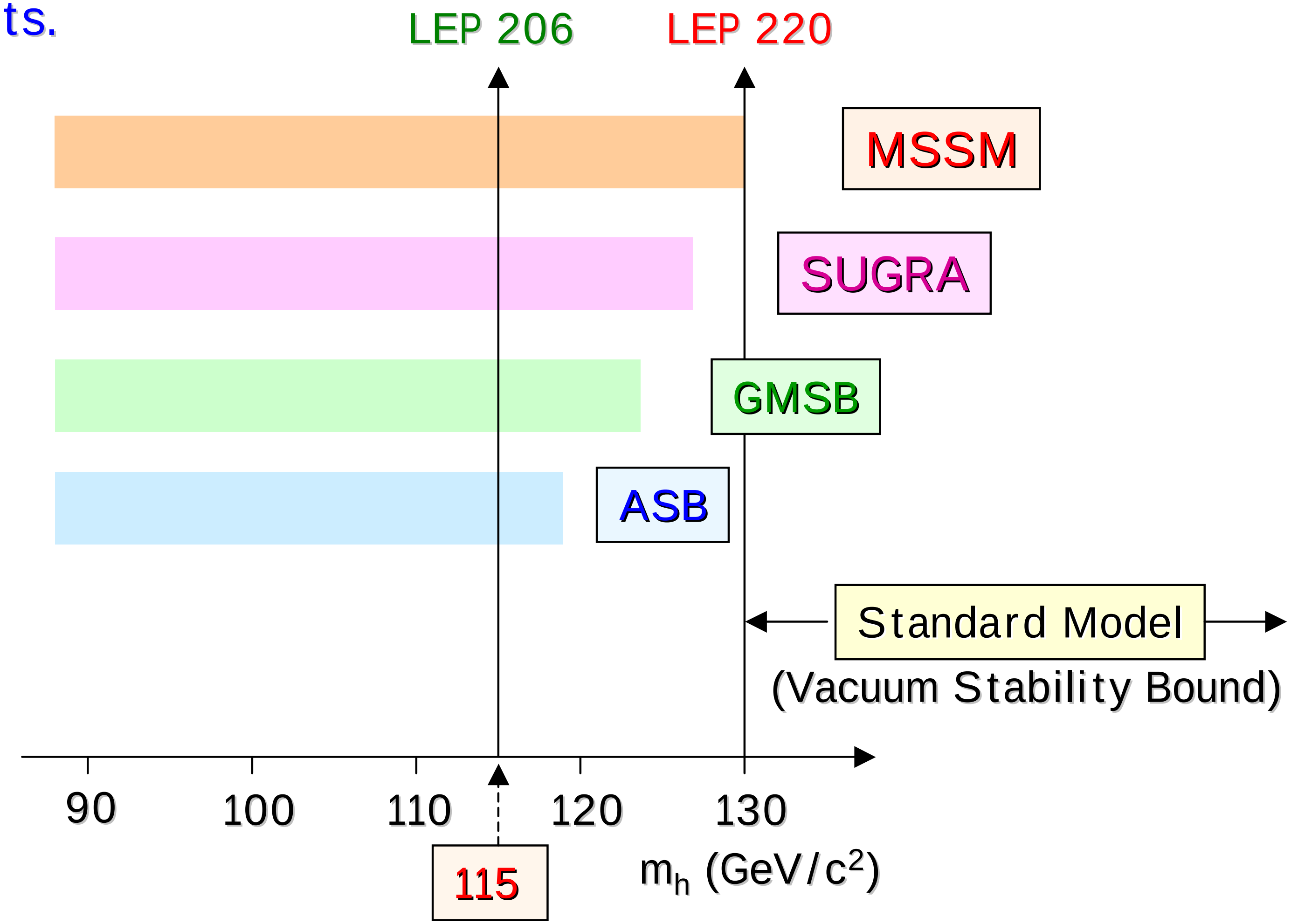
A few conceptual problems related to EWSB, i.e., to the Higgs sector:

Problems in the Standard Model	Solved in Supersymmetry?
UGLY Ad-hoc piece added to the model; Only scalar particle in the spectrum. Hierarchy problem: 250 GeV « 10^{19} GeV	**NATURAL** Scalars natural partners of fermions; Higgs bosons (h, H, A, $H^{\pm}$) natural partners of charginos and neutralinos. Hierarchy problem ?
UNSTABLE Corrections to the Higgs boson mass not only infinite, but large in addition. (Naturalness problem) $\delta m_H^2 \approx \Lambda^2 >> m_H^2$ 	**STABILIZED** Fermion and boson contributions to m_H cancel in exact supersymmetry: (Naturalness recovered) $\delta m_H^2 \approx o(\alpha/\pi) \times (m_B^2 - m_F^2)$ 
INACCEPTABLE? $\Delta V = -\lambda v^4$: contribution to the cosmological constant 52 orders of magnitude too large.	**POSSIBLY ACCEPTABLE?** Fermion and boson contributions to vacuum energy cancel in exact supersymmetry...

Needs gravity quantization (i.e., a coupling of Quantum Field Theory and General Relativity), apparently only possible in Supersymmetry...

Why we do believe in Supersymmetry: Experimental Hints (I)

- A light Higgs boson is favoured by precision measurements.
- A 115 GeV/c^2 Higgs boson is hinted at by direct searches.
- Just in the range predicted by SUSY
- Too light for the SM without New Physics below 10^6 GeV...



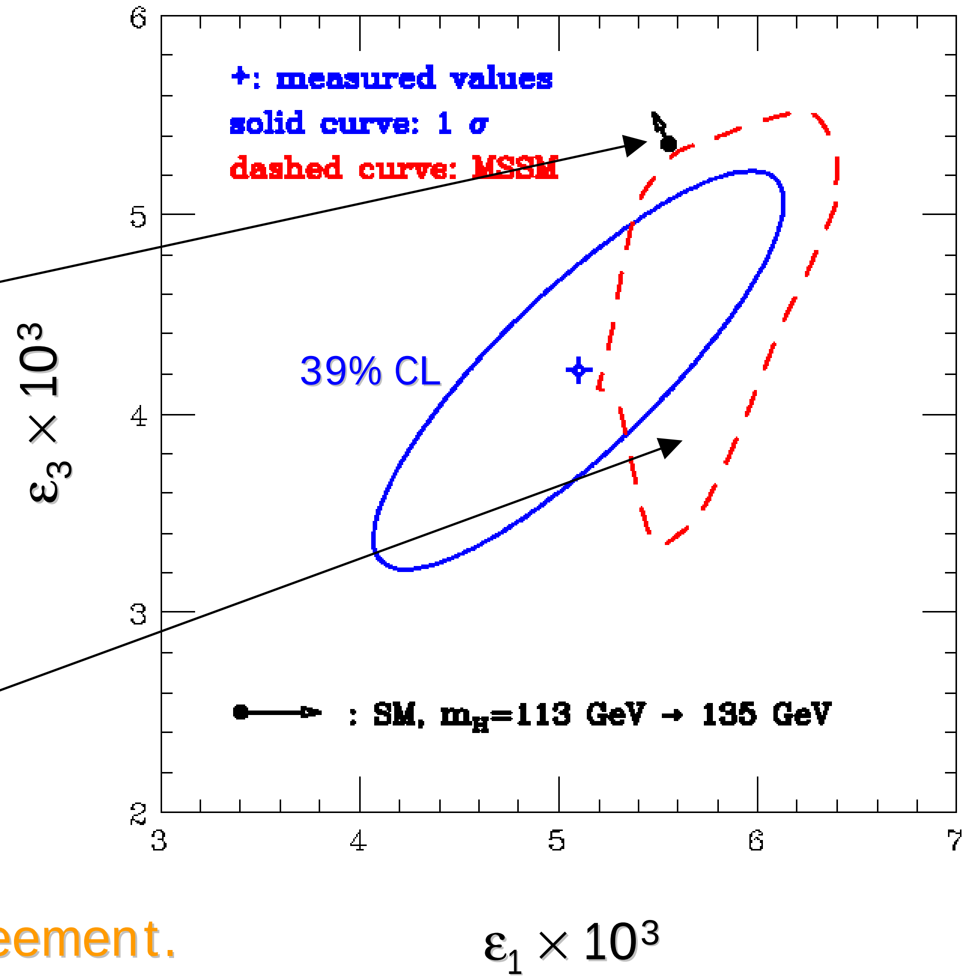
Why we do believe in Supersymmetry: Experimental Hints (II)

- New Physics at a scale below 10^6 GeV would modify the predictions for the EW precision measurements, with radiative corrections parameterized according to ε_1, ε_2, ε_3 (or S,T,U)

- In the Standard Model, for instance

$$\varepsilon_1 = \Delta\rho \approx \frac{\alpha}{\pi}\frac{m_{\rm top}^2}{m_Z^2} - \frac{\alpha}{4\pi}\log\frac{m_H^2}{m_Z^2}$$

$$\varepsilon_3 \approx +\frac{\alpha}{12\pi}\log\frac{m_H^2}{m_Z^2}$$



- Supersymmetry does not change much these predictions (better agreement with measured values ?)

- Model building with any other New Physics has not yet allowed such an agreement.

Why we do believe in Supersymmetry: Experimental Hints (I I I)

- Grand-Unified Theories (GUT), favoured, e.g., by non zero ν masses, predict the 3 coupling constants (QED, Weak, QCD) to unify at GUT scale.

- This unification does not happen in the Standard Model (+GUT), but does in Supersymmetry with a 1 TeV scale.

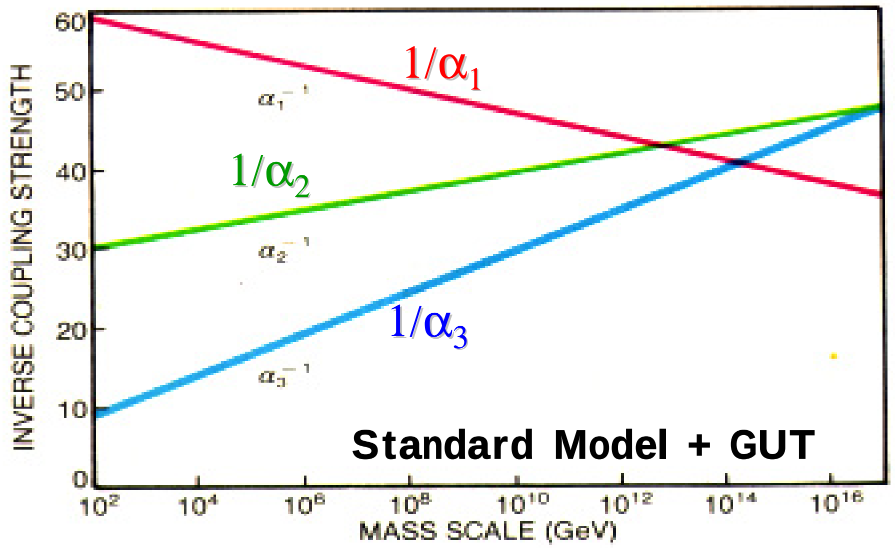
- Starting from the measured values of $\alpha_{QED}(m_Z)$ and $\sin^2\theta_W$, one finds:

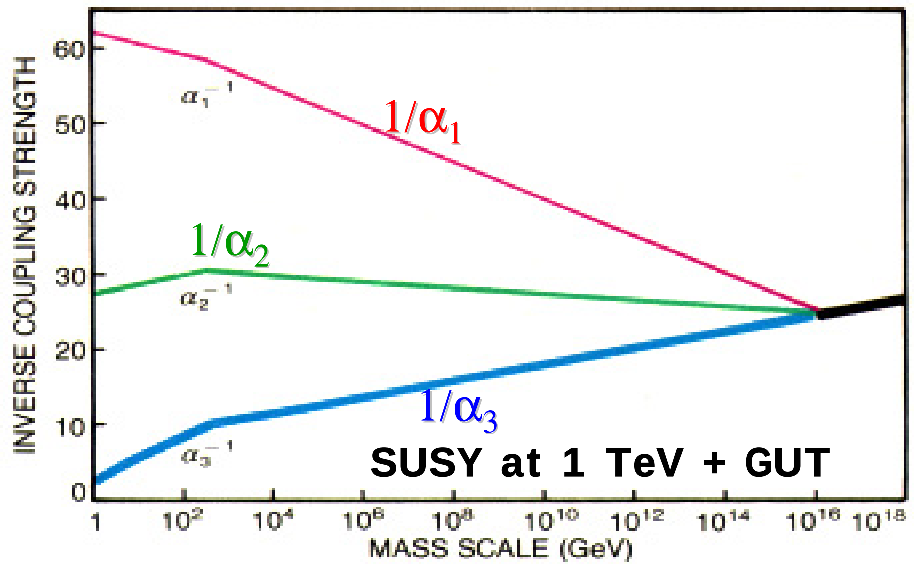
$$\alpha_S(m_Z) = 0.073 \pm 0.002 \text{ (Standard GUT)}$$

$$\alpha_S(m_Z) = 0.129 \pm 0.010 \text{ (SUSY GUT)}$$

- To be compared to the experimental value (mostly constrained by LEP):

$$\alpha_S(m_Z) = 0.118 \pm 0.003$$





Why we do believe in Supersymmetry: Experimental Hints (IV)

- Large scale structures in the Universe require the presence of cold dark matter (LSP, the Lightest Supersymmetric Particle ?)

- Half of the particles have already been discovered…

… BUT

- Supersymmetry can't be exact (e.g., $m_e \neq m_e$), thus needs to be broken.

- Supersymmetry is therefore a economy of principles. It is neither an economy of particles nor an economy of parameters.
  Not the end of the story !

Extremely rich phenomenology

Phenomenology: Minimal Particle Content

❑ Gauge / Gaugino Sector

Standard Bosons	Supersymmetric Partners
$W^{\pm}$ (3) $H^{\pm}$ (1)	Charginos (2×2) $\chi_1^{\pm}$ $\chi_2^{\pm}$
γ (2) Z (3) h (1) H (1) A (1)	Neutralinos (4×2) χ_1^0 χ_2^0 χ_3^0 χ_4^0
g_i (8×2)	Gluinos $\tilde{g}_i$ (8×2)

[Two Higgs doublets] [All fermions]

And also ...

Graviton G	Gravitino $\tilde{G}$

❑ Particle / Sparticle Sector

Standard Particles	Supersymmetric Partners
Leptons (2) ℓ	Sleptons (2×1) $\tilde{\ell}_{R,L}$
Neutrinos ν_ℓ	Sneutrinos $\tilde{\nu}_\ell$
Quarks q	Squarks $\tilde{q}_{R,L}$

[All scalars]

Phenomenology: R-Parity conservation

$$R_P = (-1)^{3B+L+2S}$$

Baryonic Number; Leptonic number; Spin

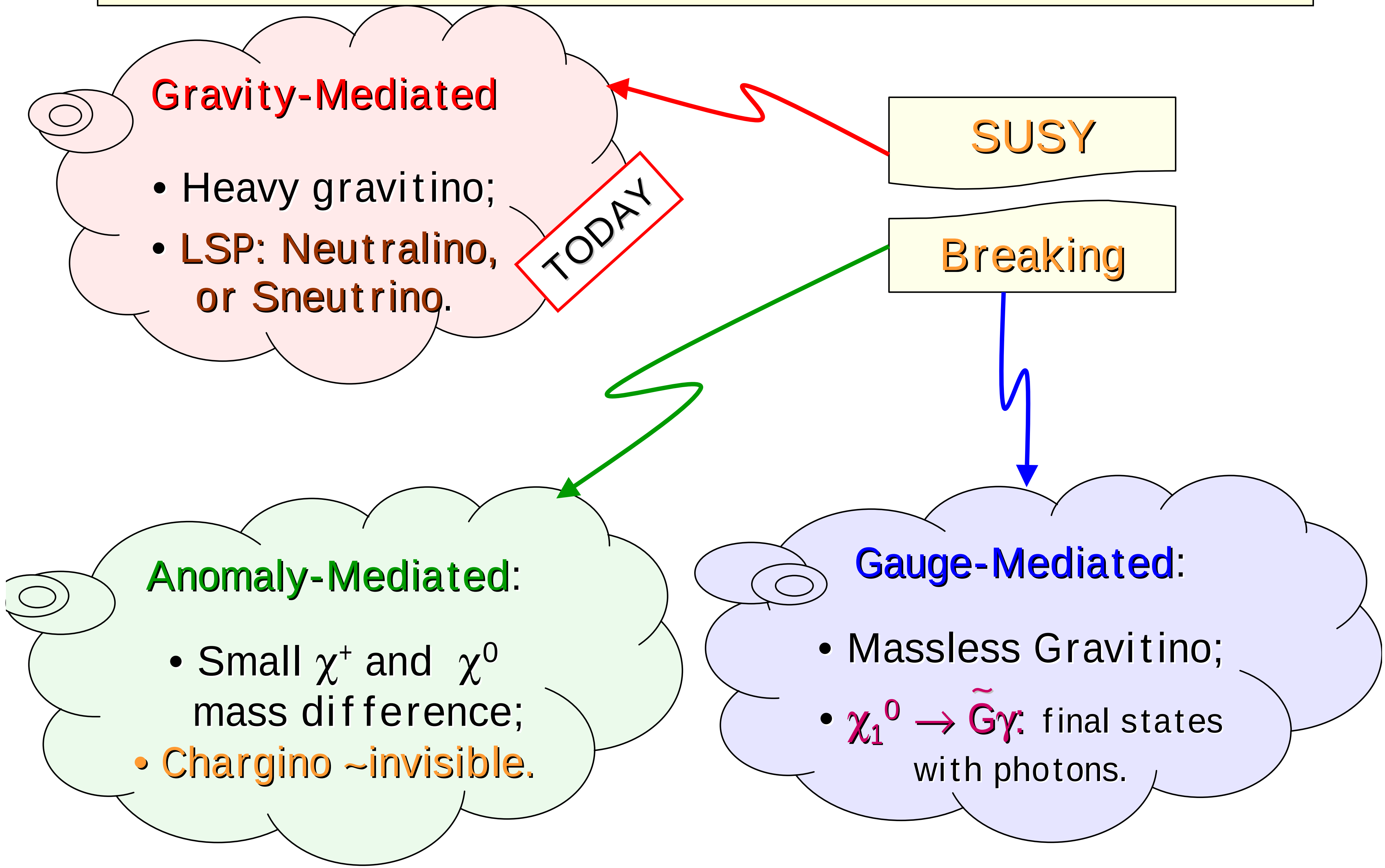
→ +1 for Standard Particles

→ -1 for Supersymmetric Partners

TODAY

R_P Conserved	R_P Violated
• SUSY particles are pair-produced • The LSP is stable (→ neutral,colourless → good dark-matter candidate) • All SUSY particles decay into the LSP	• The LSP decay into standard particles (no candidate for dark matter) • And so do all other SUSY particles
Experimental	**Signature**
• The LSP (neutral, colourless) interacts only weakly with matter: it is invisible. → MISSING ENERGY	• SUSY particles decay into quarks, leptons, neutrinos. → Multi-jet, multi-leptons final states, missing energy or not.

Phenomenology: Supersymmetry Breaking



Phenomenology: Models, Parameters (I)

The Minimal Supersymmetric extension of the Standard Model (MSSM):

TODAY

- m_A : pseudoscalar Higgs boson mass
- $\tan\beta$: ratio of vacuum expectation values of the two Higgs doublets
- μ : Higgs mixing parameter
- M_1, M_2, M_3 : Gaugino ~~SUSY~~ mass terms (give masses to χ^0, $\chi^\pm$, $\tilde{g}$)
- $m_{\tilde{\ell}_R}, m_{\tilde{\ell}_L}, m_{\tilde{\nu}_L}, m_{\tilde{q}_R}, m_{\tilde{q}_L}$: "Sfermion" ~~SUSY~~ mass terms
- A_t, A_b, A_τ, …: stop/sbottom/stau/… mixing parameters

➢ ≥ 100 parameters
➢ Not too predictive

Phenomenology: Models, Parameters (II)

TODAY

The constrained MSSM (C-MSSM):

Constrain the gauginos and sfermions mass parameters with GUT universality relations:

❑ Unify M_1, M_2, M_3 to a universal gaugino mass $m_{1/2}$ at the GUT scale

$$M_3 : M_2 : M_1 : m_{1/2} = \alpha_3 : \alpha_2 : \alpha_1 : \alpha_{GUT}$$

$$M_1 \approx 0.5 m_{1/2};\ M_2 \approx 0.8 m_{1/2};\ M_3 \approx 3.5 m_{1/2}.$$

$M_1 \to \chi^0$, $M_2 \to \chi^{\pm}$, $M_3 \to \tilde{g}$ (at the EW scale)

❑ Unify all sfermion mass parameters to a universal scalar mass m_0

$$m^2_{\tilde{\ell}_R} = m_0^2 + 0.15 m^2_{1/2} + \cdots$$

$$m^2_{\tilde{\ell}_L, \tilde{\nu}} = m_0^2 + 0.5\, m^2_{1/2} + \cdots$$

$$m^2_{\tilde{q}_{R,L}} = m_0^2 + 6\, m^2_{1/2} + \cdots$$

- Scalar and gaugino masses related
- Third family sfermion masses may have large mixing corrections ($\propto m^2_{top}$, m^2_b, m^2_τ)

$$\text{Stop}: m(\tilde{t}_1),\ m(\tilde{t}_2),\ A_t$$

$$\text{Sbottom}: m(\tilde{b}_1),\ m(\tilde{b}_2),\ A_b$$

$$\text{Stau}: m(\tilde{\tau}_1),\ m(\tilde{\tau}_2),\ A_\tau$$

Phenomenology: Models, Parameters (III)

Minimal SuperGravity (mSUGRA): TODAY

- Unify Higgs and scalar sector at the GUT scale

$$\Rightarrow \mathrm{m}_{\mathrm{A}} \text{ fixed by } (m_0, \tan\beta, \ldots)$$

- Unify all trilinear couplings at the GUT scale

$$\Rightarrow \text{all } A_i \text{'s unified to } A_0$$

- Break radiatively the ElectroWeak Symmetry

$$\Rightarrow |\mu| \text{ fixed by } (\mathrm{m}_0, \mathrm{m}_{1/2}, \tan\beta, \ldots)$$

- Only FIVE parameters left

$$m_0,\ m_{1/2},\ \tan\beta,\ A_0,\ \mathrm{sign}(\mu)$$

➤ Very predictive
➤ Realized in Nature?

Phenomenology: The Higgs Sector (I)

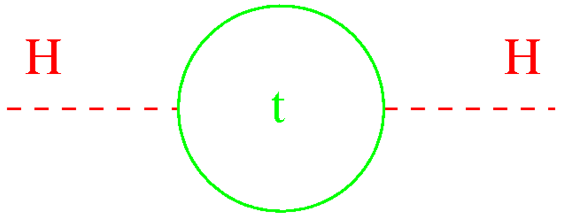
In the Standard Model

• One Higgs doublet
v.e.v. v

• One physical state
H

• One parameter
m_H

• Radiative corrections to m_h
quadratically divergent



In the M.S.S.M

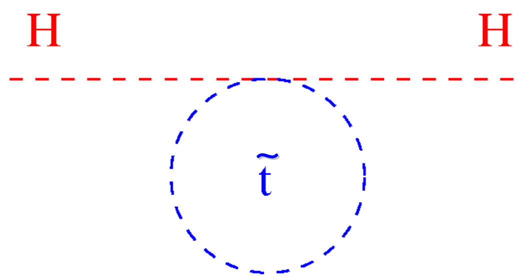
• Two Higgs doublets
v.e.v.'s v_1 and v_2

• Five physical states

h, H,	A,	H^+, H^-
CP-even (α)	CP-odd	Charged

• Two parameters (at tree-level)
m_h, $\tan\beta = v_2/v_1$

• Radiative corrections to m_h, m_H
stabilized and finite

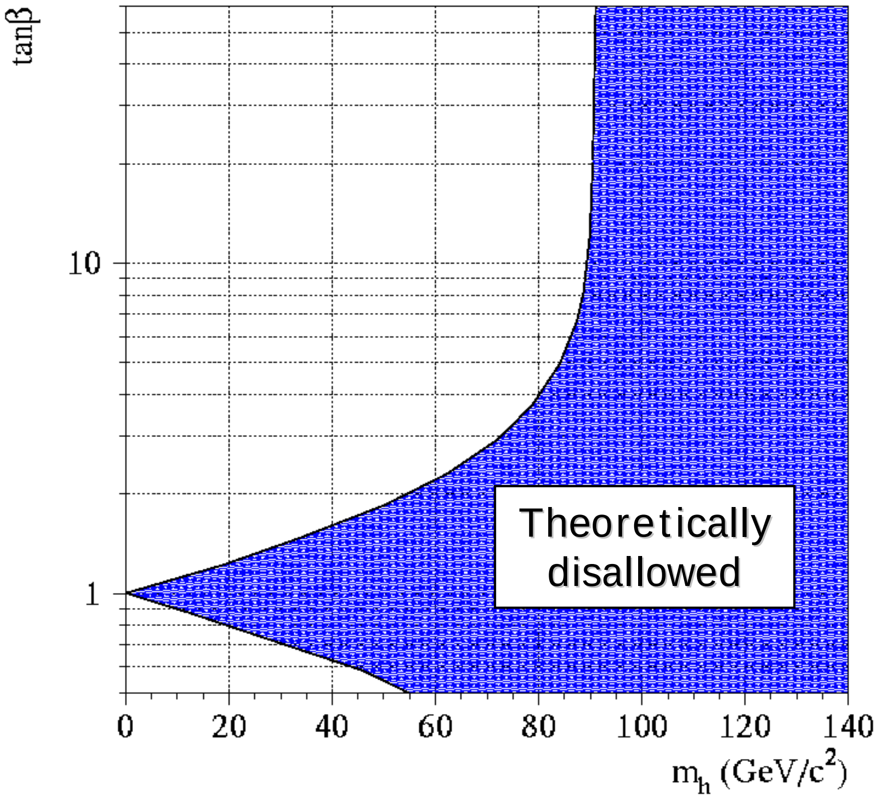


Depend on $m_{top},\ m_{\tilde{t}_1},\ m_{\tilde{t}_2},\ A_t,\ \mu,\ \tan\beta,\ \ldots$

Phenomenology: The Higgs Sector (II)

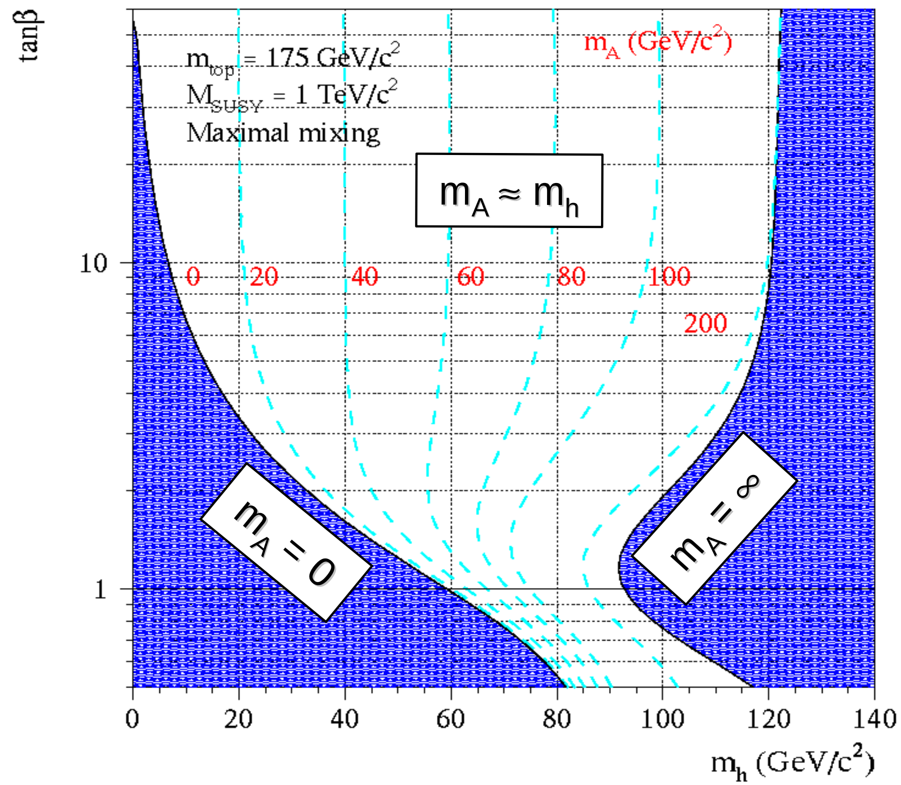
In exact Supersymmetry

$$m_{\mathrm{h}} \leq m_{Z} |\cos 2\beta|$$



In broken Supersymmetry

$$\Delta m_{\mathrm{h}}^{2} = \frac{3g^{2}}{8\pi^{2}\sin^{2}\beta}\frac{m_{\mathrm{top}}^{4}}{m_{\mathrm{W}}^{2}}\log\left(\frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_{\mathrm{top}}^{2}}\right) + \cdots$$



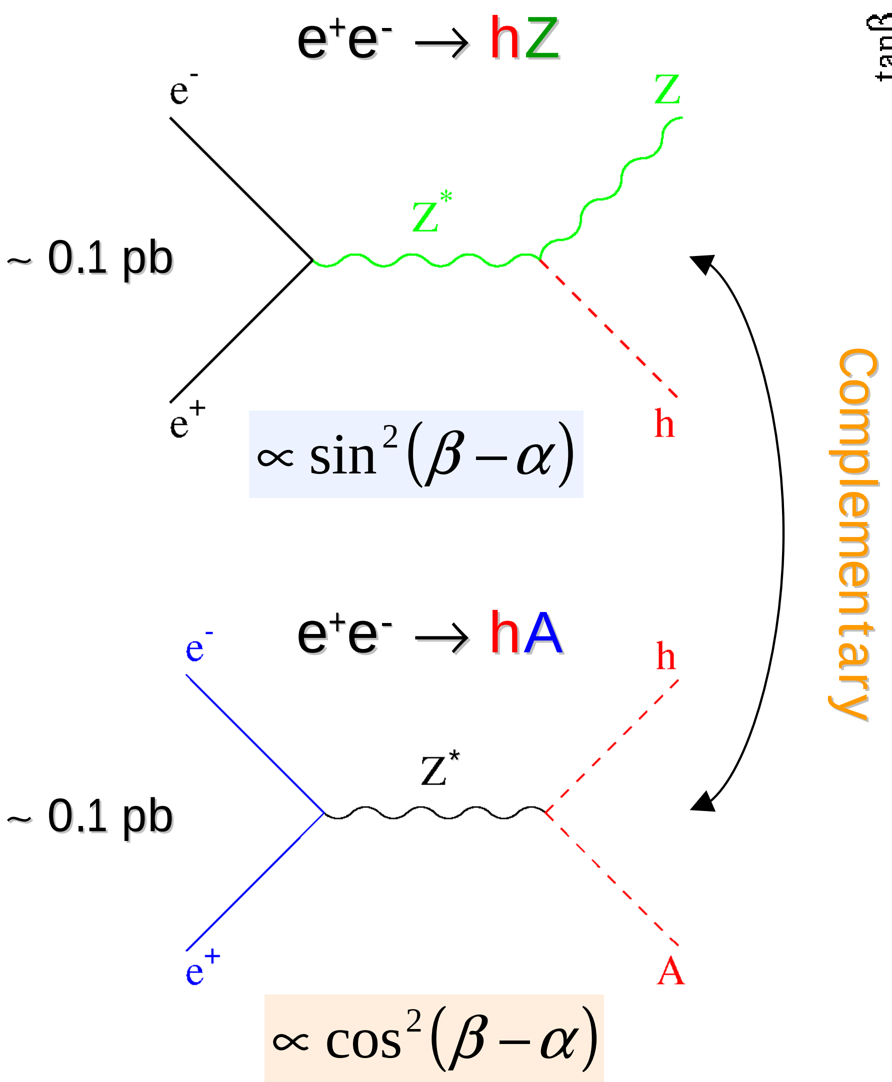
$$m_{\mathrm{h}} \leq 130\,\mathrm{GeV}/c^{2},\; m_{\mathrm{H}} \geq 130\,\mathrm{GeV}/c^{2}$$

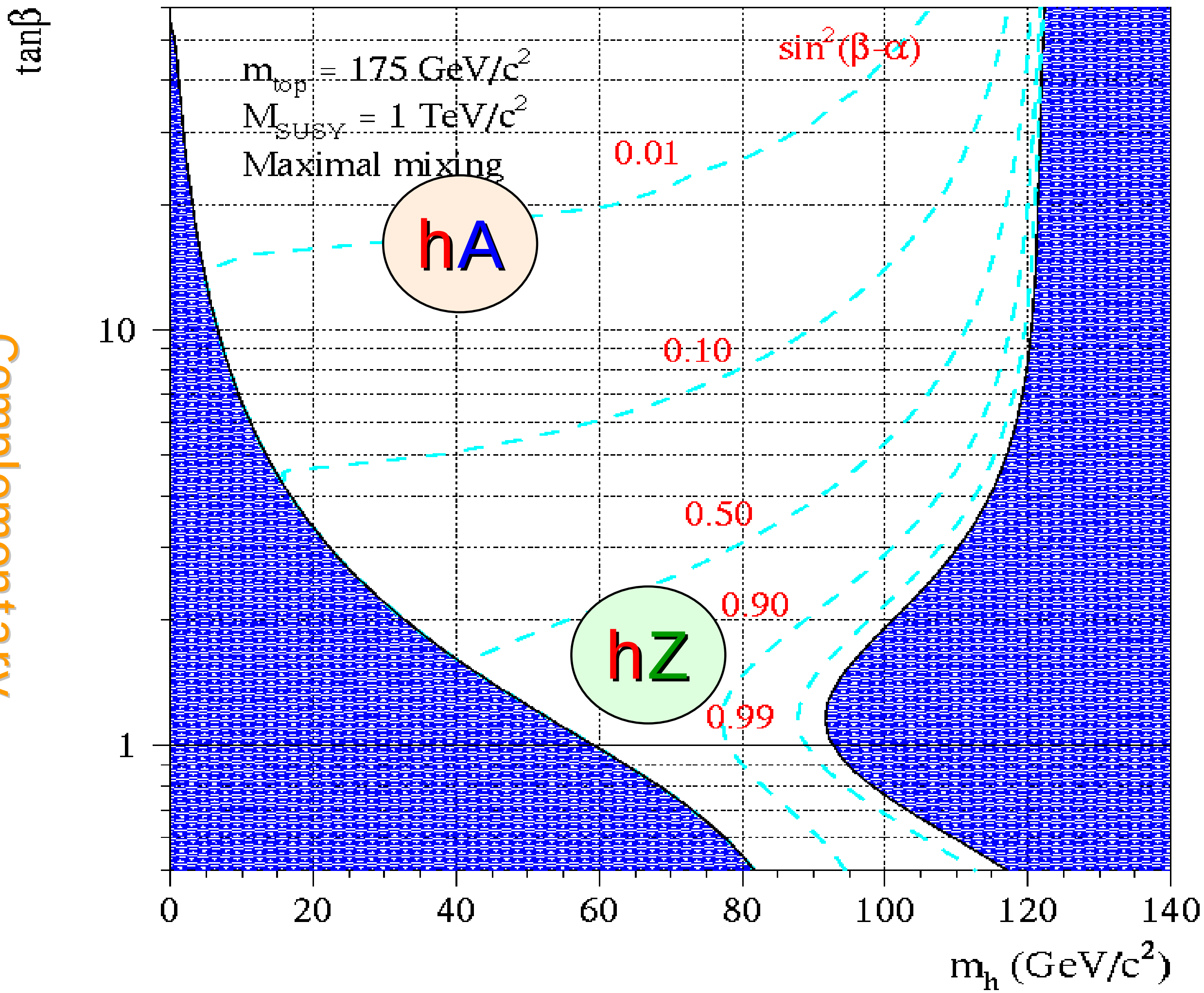
Phenomenology: The Higgs Sector (III)

- H too heavy to be produced at LEP;
- Therefore, look for h and A

- In the MSSM: $m^2_{H^\pm} = m^2_W + m^2_A + \delta^2_{rad.}$ (small)

  Charged Higgs bosons too heavy for LEP2, too.



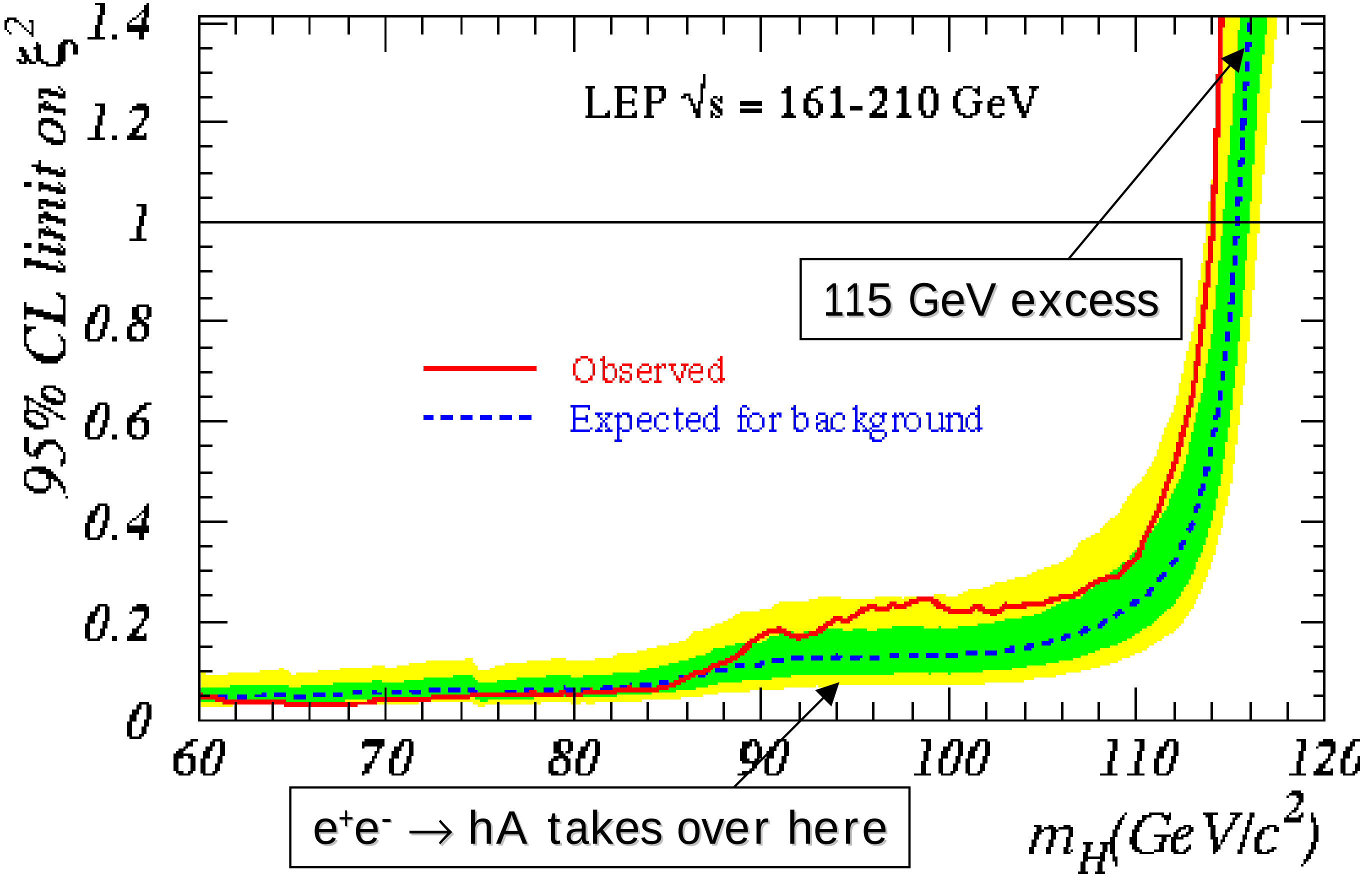


$\Rightarrow$ **Look for both processes !**

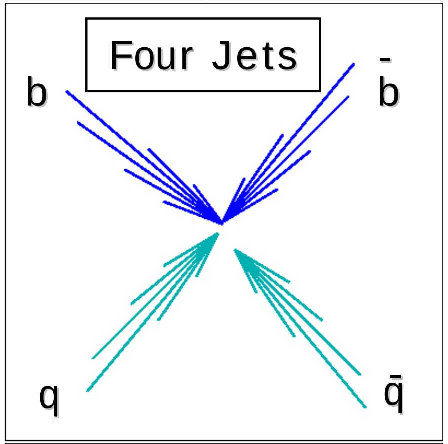
Searches at LEP: $e^+e^- \rightarrow hZ$ (I)

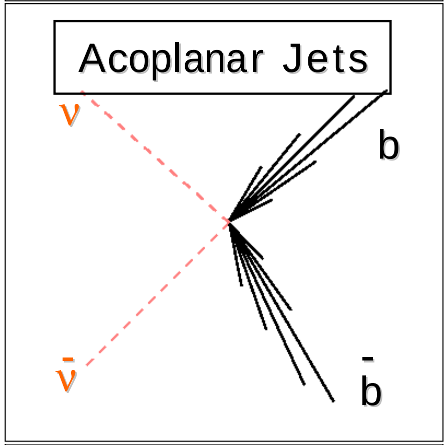
- Standard Model-like decays (mostly $b\bar{b}$ and $\tau^+\tau^-$)

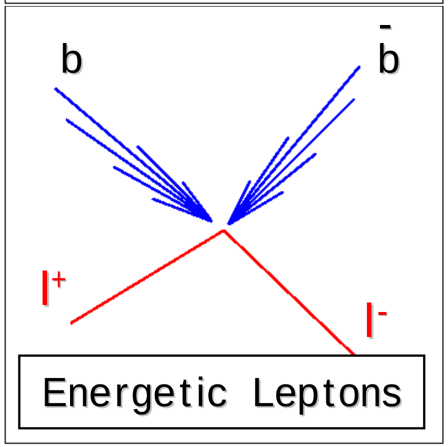
⇒ Limit in the $[m_h, \sin^2(\beta-\alpha)]$ plane:



Usual topologies:



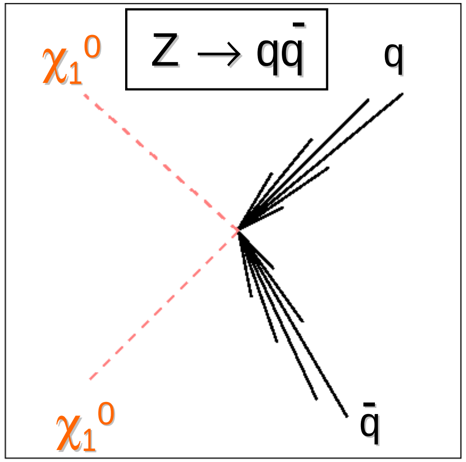




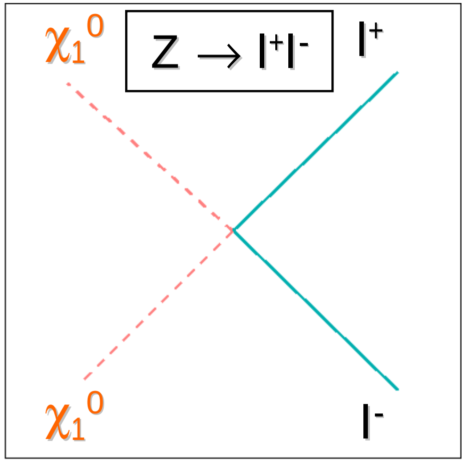
- SUSY-specific decays?

Searches at LEP: $e^+e^- \to hZ$ (II)

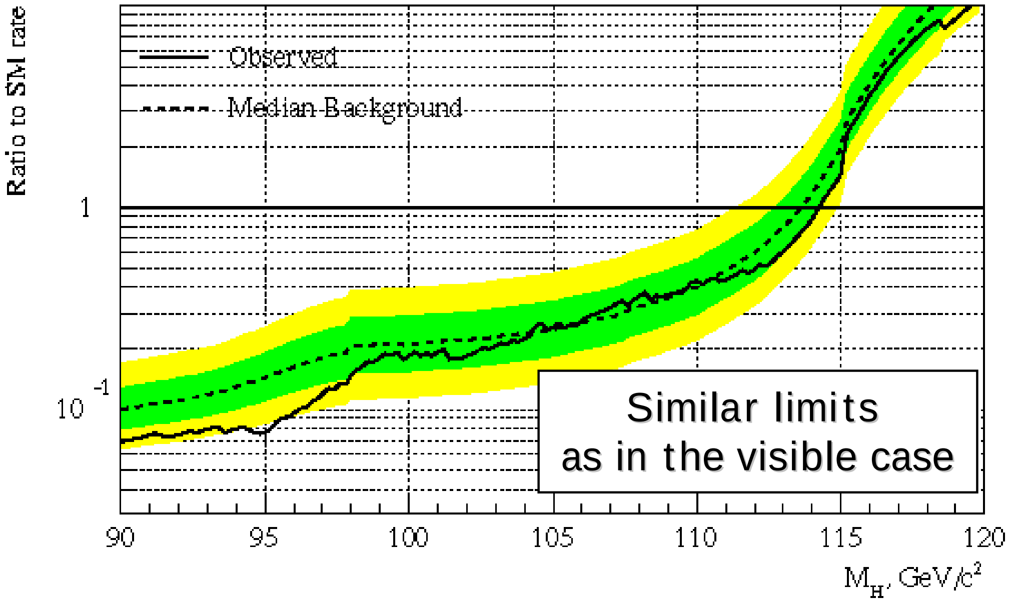
- Invisible decays: $h \to \chi_1^0 \chi_1^0$



Acoplanar Jets
($H\nu\nu$)



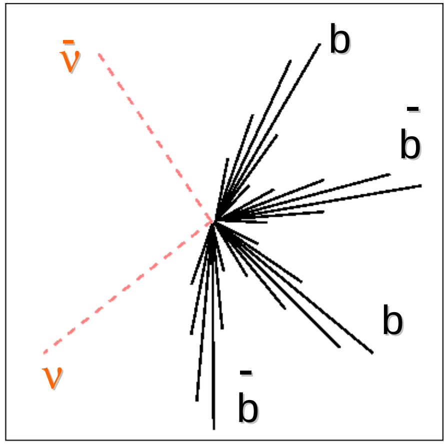
Acoplanar Leptons
(W^+W^-)



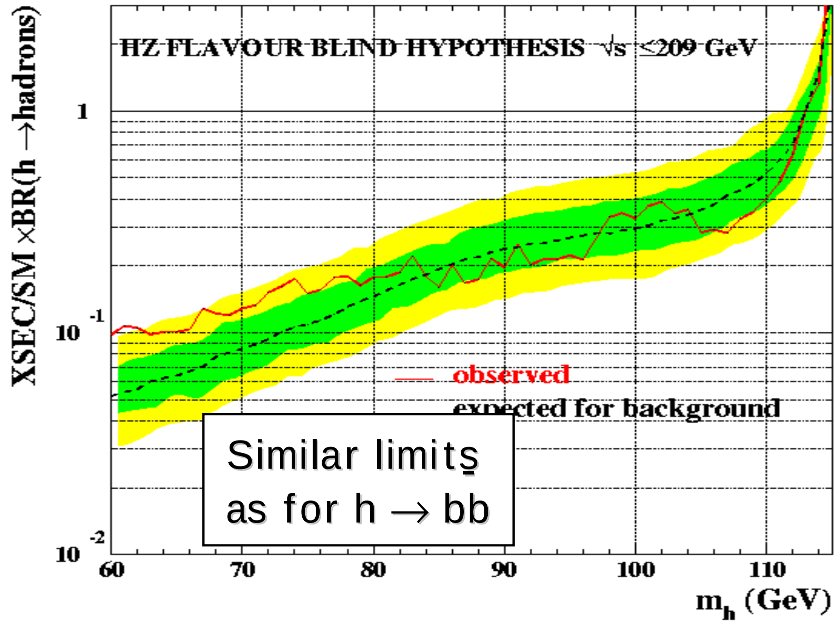
- Decays into Higgses: $h \to AA$ with, e.g., $A \to b\bar{b}$:

Efficiency at least as large as for the Standard-Model-decay $h \to b\bar{b}$

$Z \to \nu\bar{\nu}$

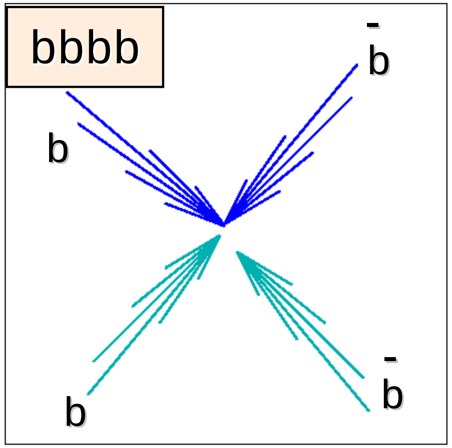


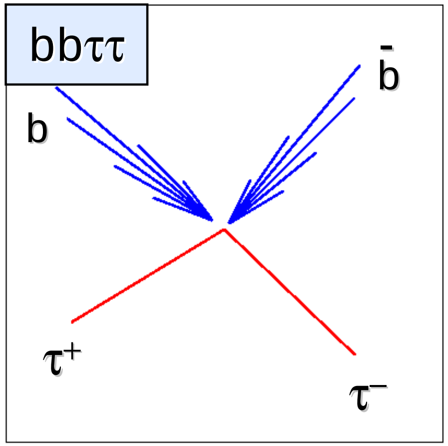
- Flavour-Blind Search: $h \to b\bar{b}$, $c\bar{c}$, gg



Searches at LEP: $e^+e^- \to hA$

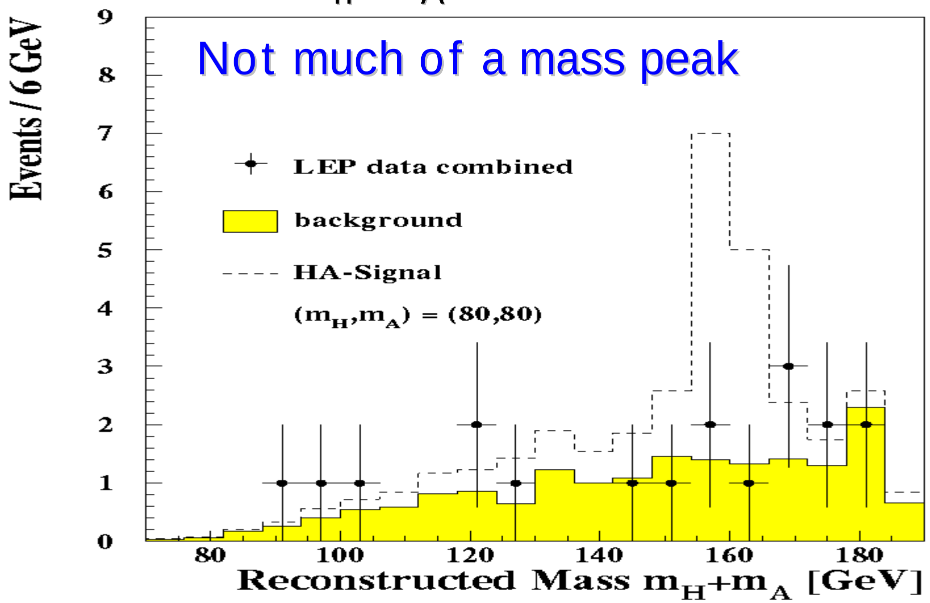
Topologies: h, A $\to b\bar{b}$, $\tau^+\tau^-$



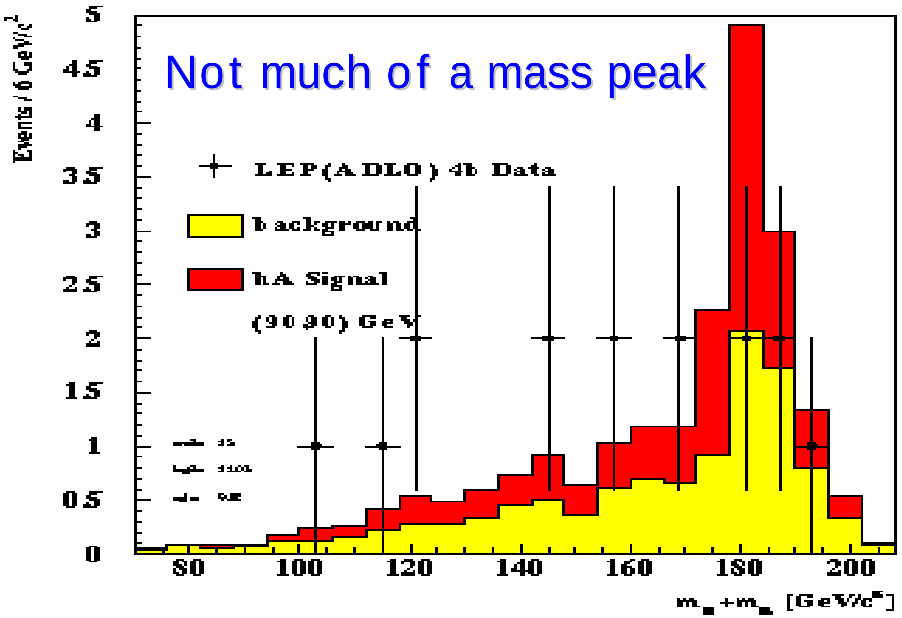


- Fit jet energies with the energy and momentum constraint, as for the W^+W^- events;
- Determine the h and A masses as for the W^+W^- events.

m_h+m_A, $\sqrt{s}$ = 189 GeV

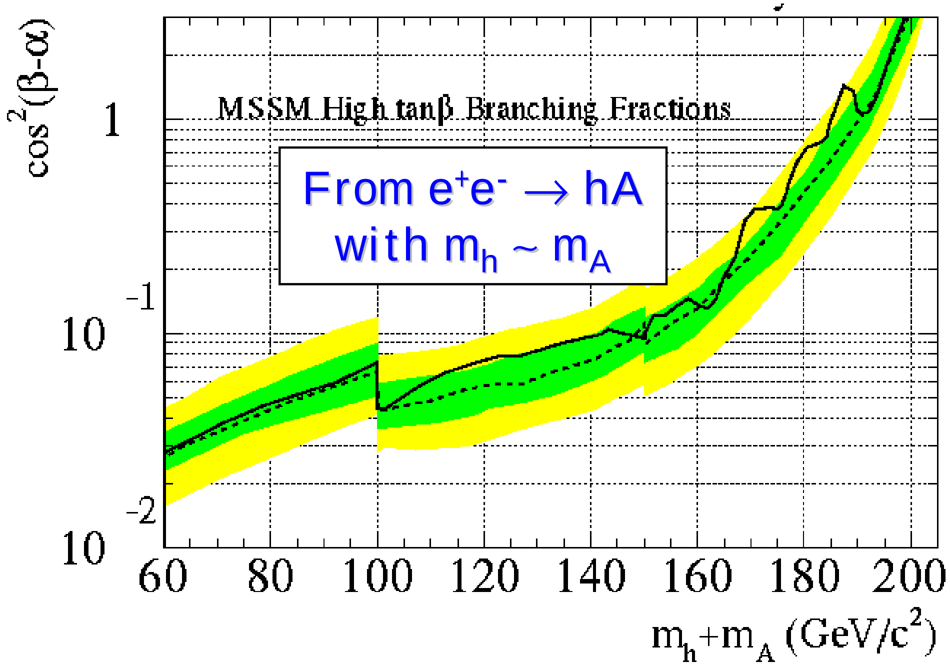


m_h+m_A, $\sqrt{s}$ = 200-210 GeV



Searches at LEP: Limits from $e^+e^- \to hZ, hA$

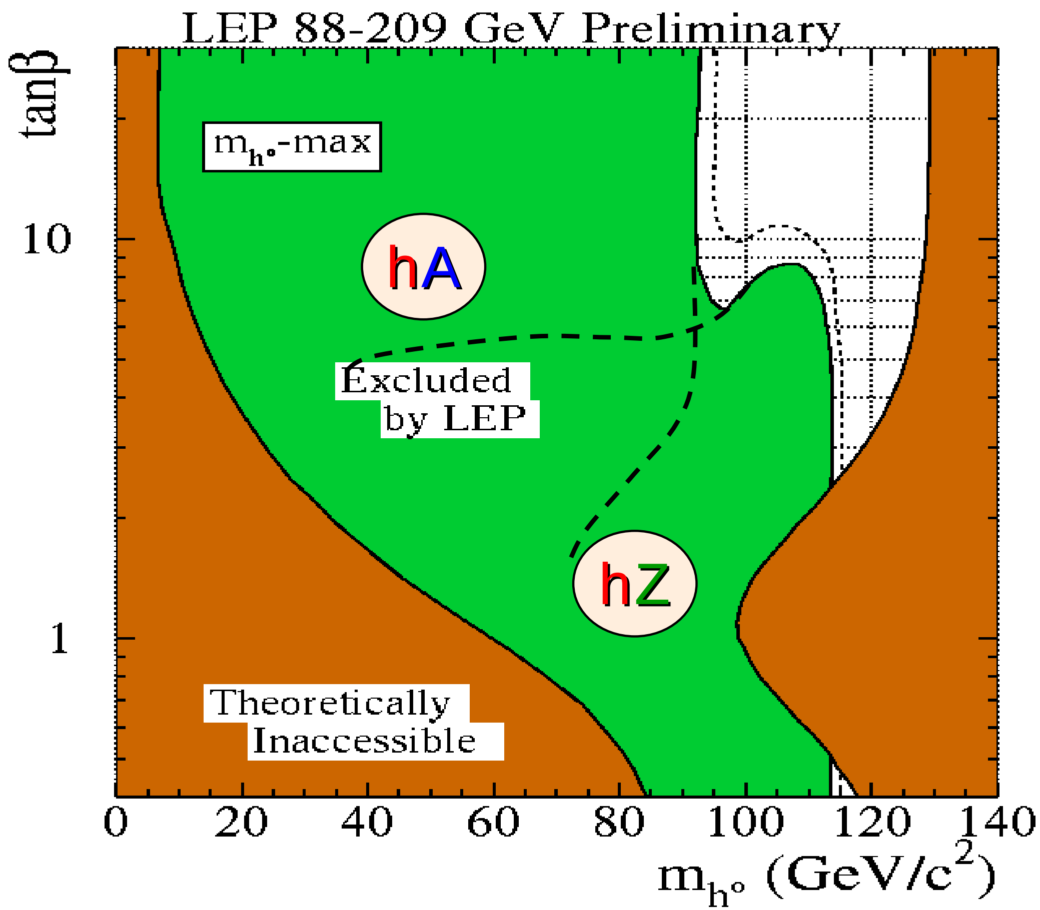
⇒ Limit in the $[m_h, \cos^2(\beta-\alpha)]$ plane:



Combining hZ and hA results
$\cos^2(\beta-\alpha) + \sin^2(\beta-\alpha) = 1$ (!)

⇒ Limit in the $[m_h, \tan\beta]$ plane:

$m_h, m_A > 91\text{-}92$ GeV/c^2
at 95% C.L., any tanβ.

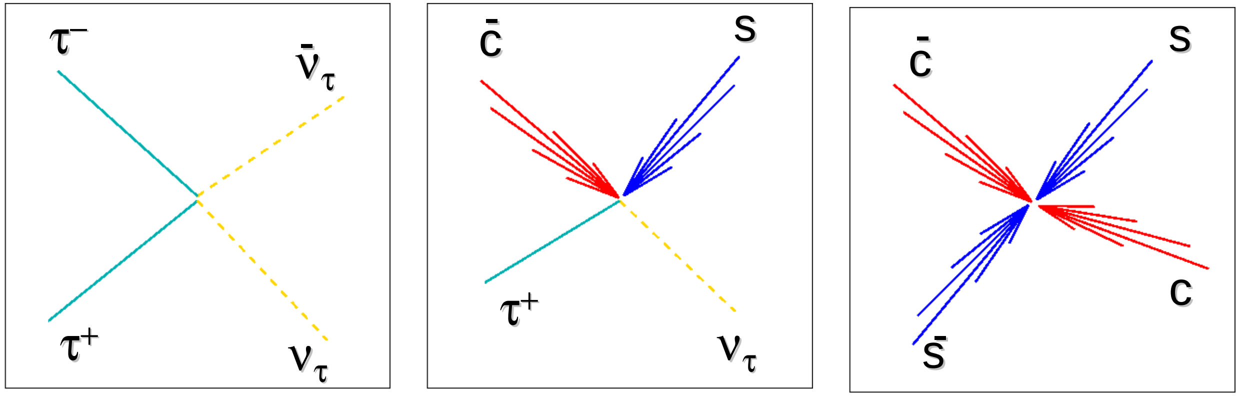


$0.5 < \tan\beta < 2.4$ excluded at 95% C.L.

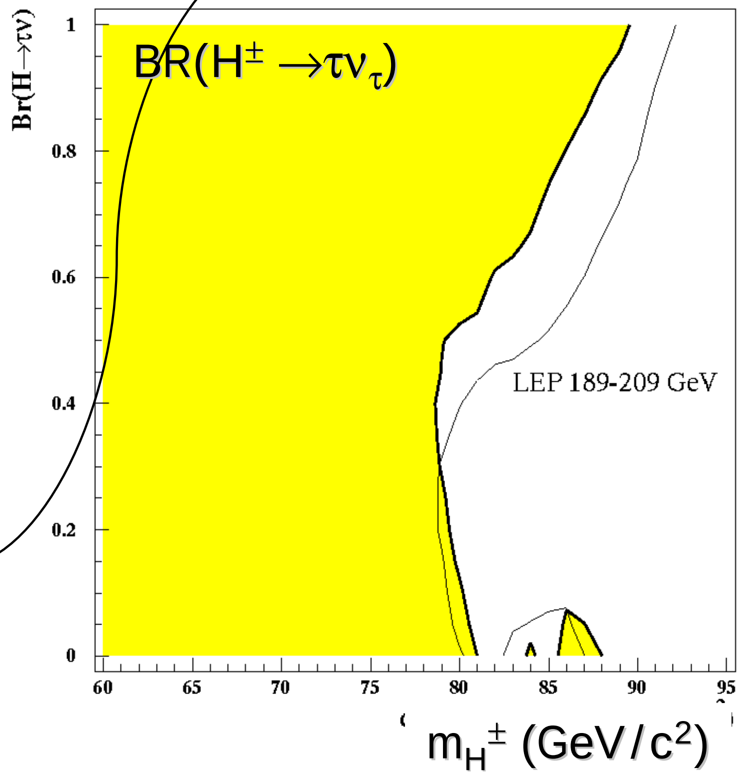
Note: LEP 220 would have covered
the whole MSSM parameter space...
i.e., found/excluded Supersymmetry

Searches at LEP: $e^+e^- \to H^+H^-$

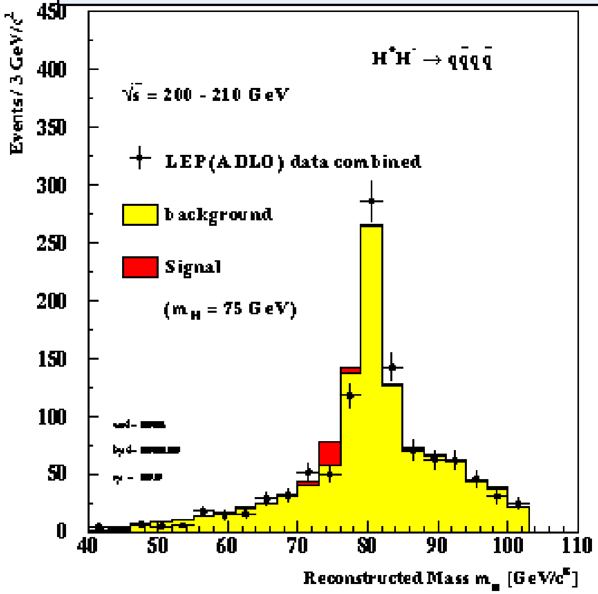
Topologies: $H^+ \to \tau^+\nu_\tau,\ c\bar{s}$ (like W^+W^- events)

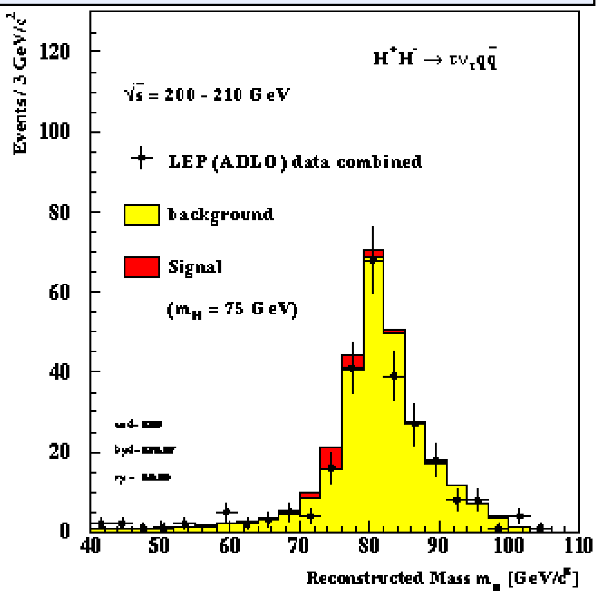


LIMITS ...



Mass Distributions: No excess over exp. background.





$$m_{H^\pm} \geq 78.6\ \mathrm{GeV}/c^2$$
at 95% C.L.

Not too useful in the MSSM:

$$m^2_{H^\pm} = m^2_{W} + m^2_{A} + \delta^2_{\mathrm{rad.}}\ (\mathrm{small})$$

Searches at LEP: Charginos, Neutralinos (I)

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<tr><th>Production Processes</th><th>Decays</th><th>Final States</th></tr>
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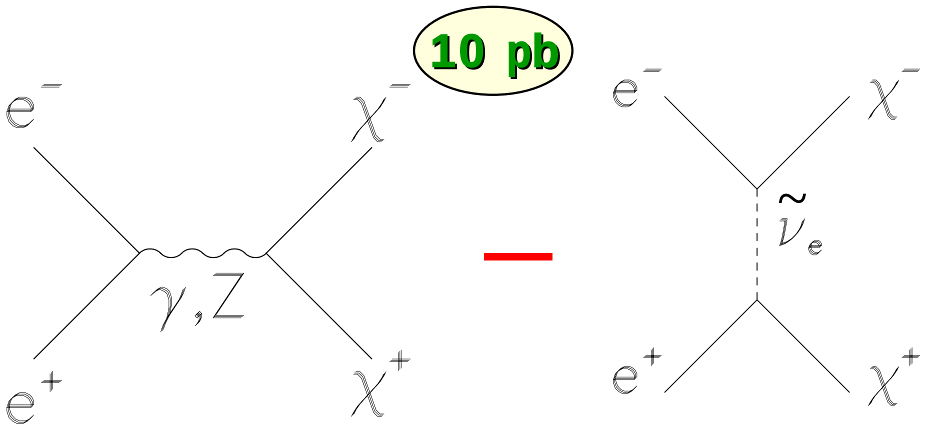
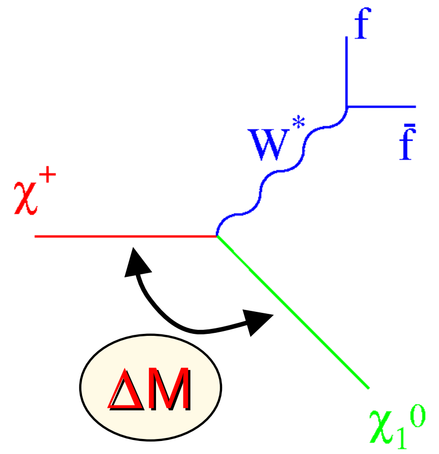
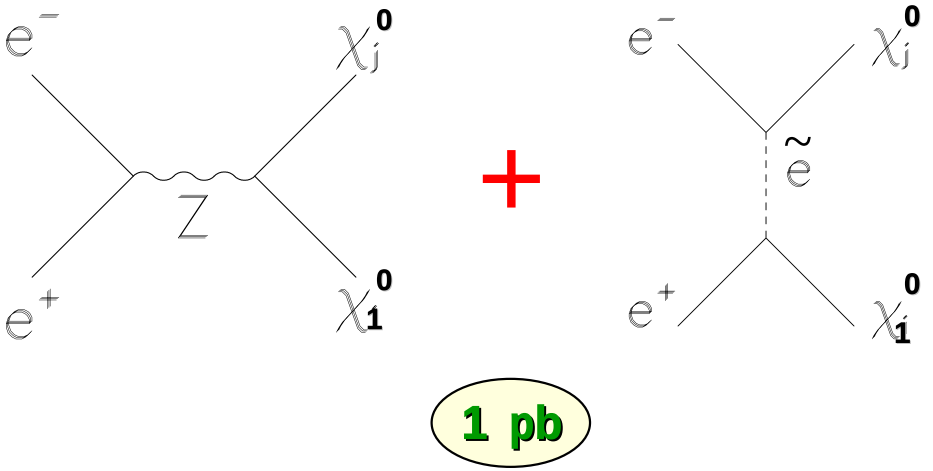


Destructive interference. Cross section may vanish for small sneutrino masses (m_0)
</td>
<td>


</td>
<td>
Four fermions
(quark or leptons)
with missing E

Visible energy
proportional to
ΔM
</td>
</tr>
<tr>
<td>


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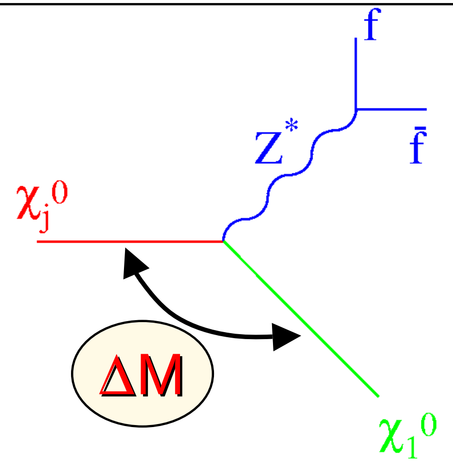
<td>


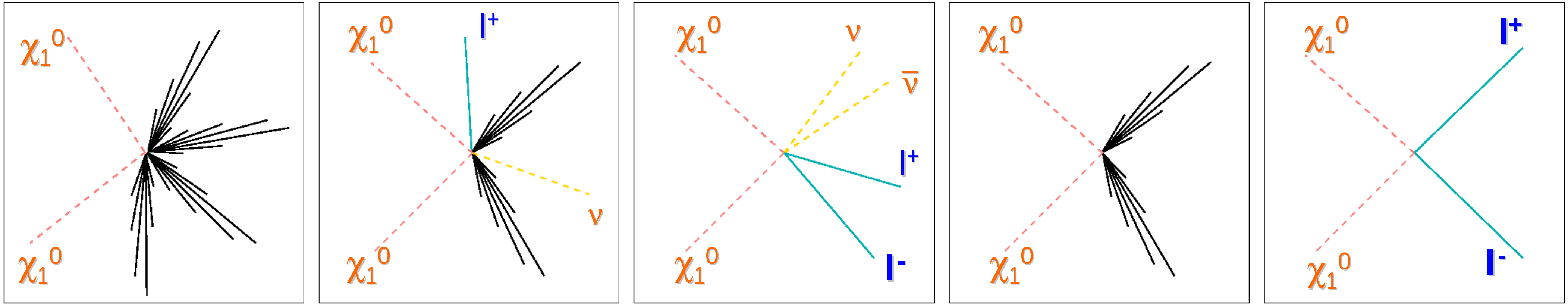
$\chi_2^0 \to \tilde{\nu}\bar{\nu} \to \chi_1^0 \nu\bar{\nu}$ (invisible) may become dominant for small m_0
</td>
<td>
Two fermions
(quark or leptons)
with missing E

Visible energy
proportional to
ΔM
</td>
</tr>
</table>

Searches at LEP: Charginos, Neutralinos (II)

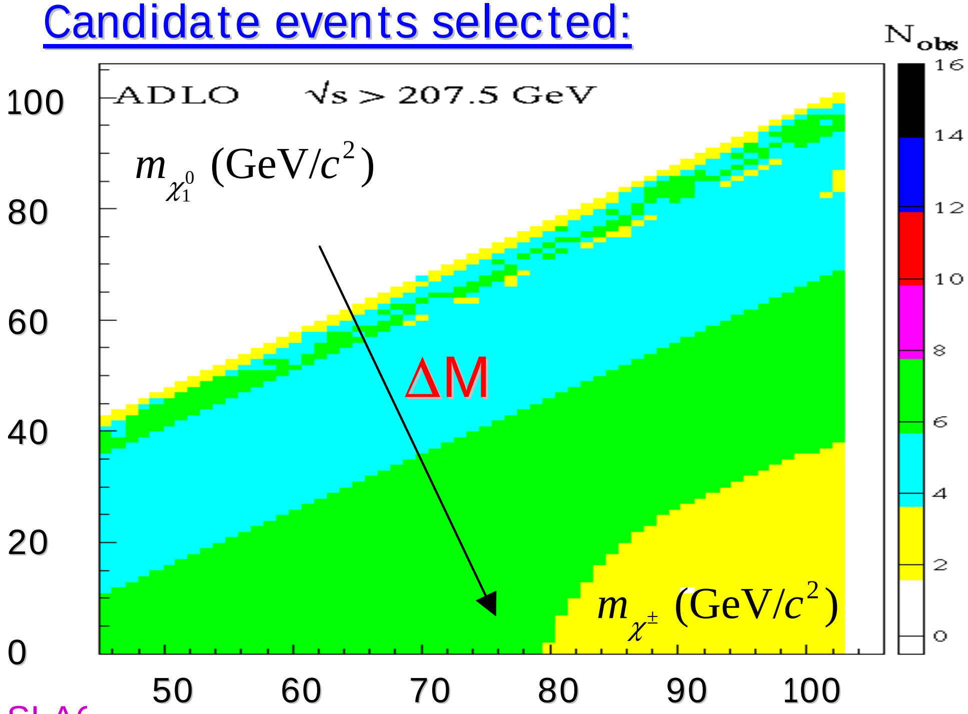
Final State Topologies:

WW → qqqq | WW → lνqq | WW → lν lν | Z → qq | Z → l⁺l⁻

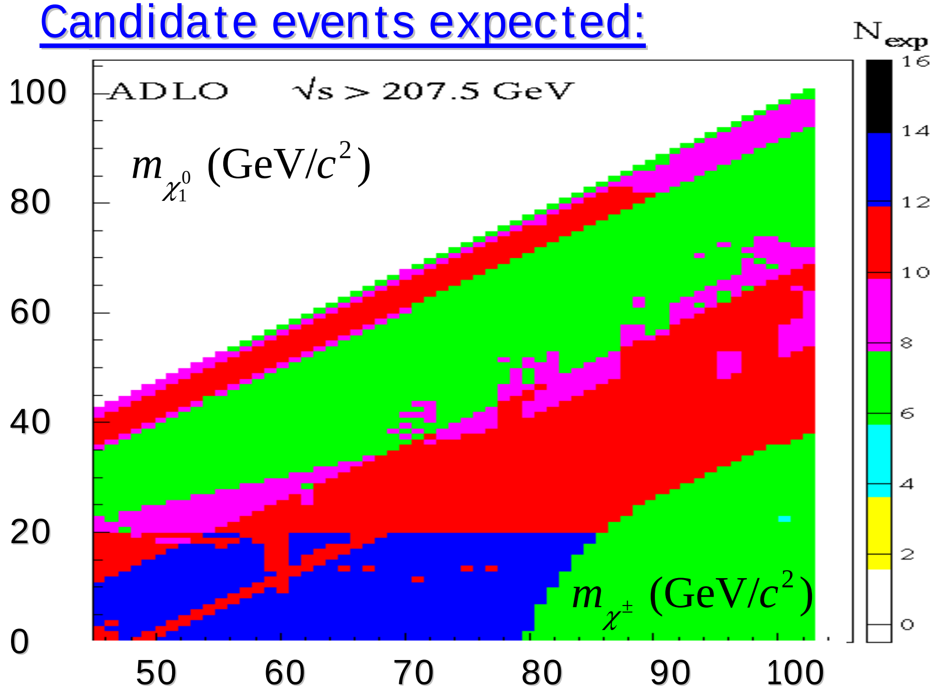


Hadrons + E miss | Mixed + E miss | Acoplanar leptons | Acoplanar jets | Acoplanar leptons

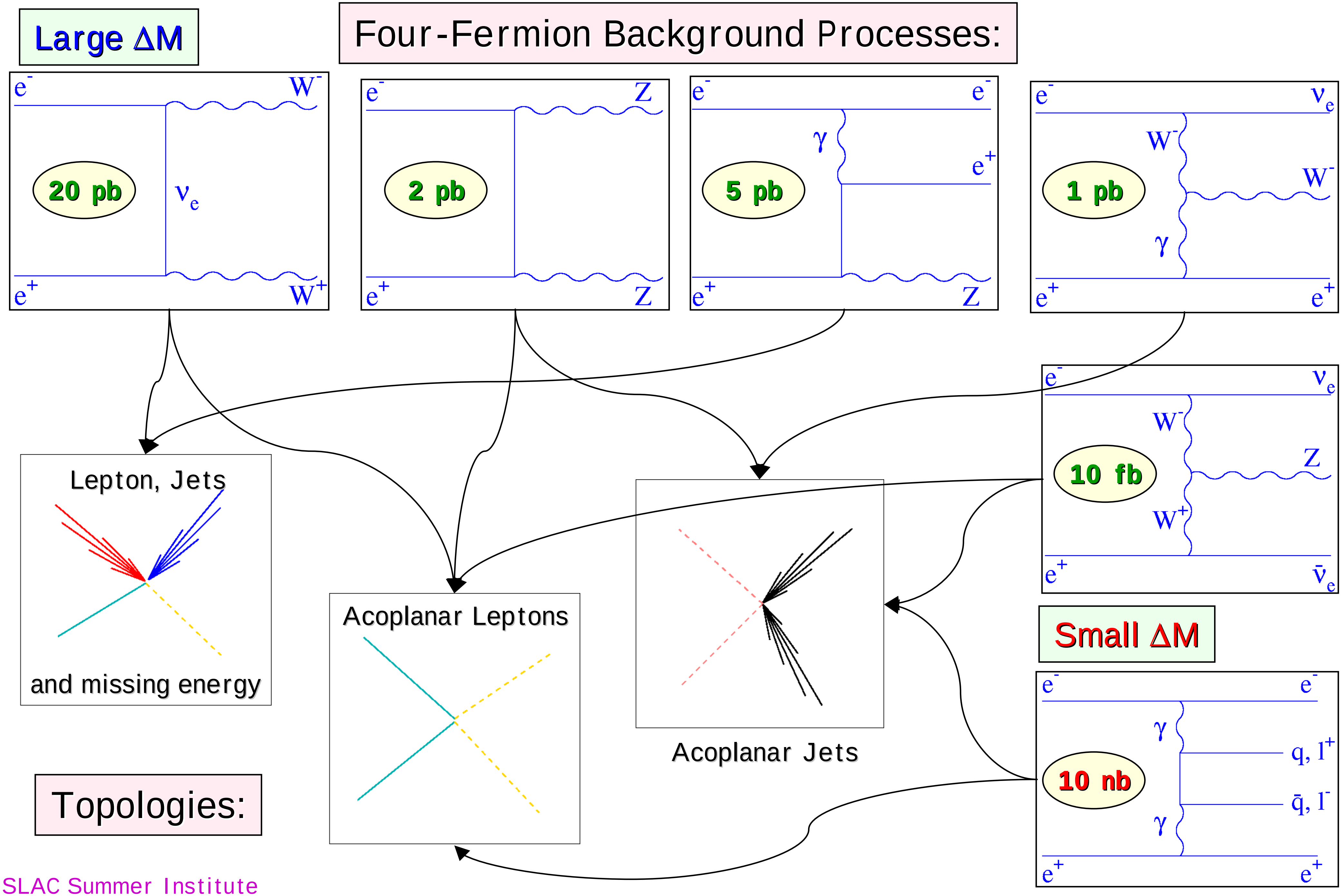
Candidate events selected:



Candidate events expected:



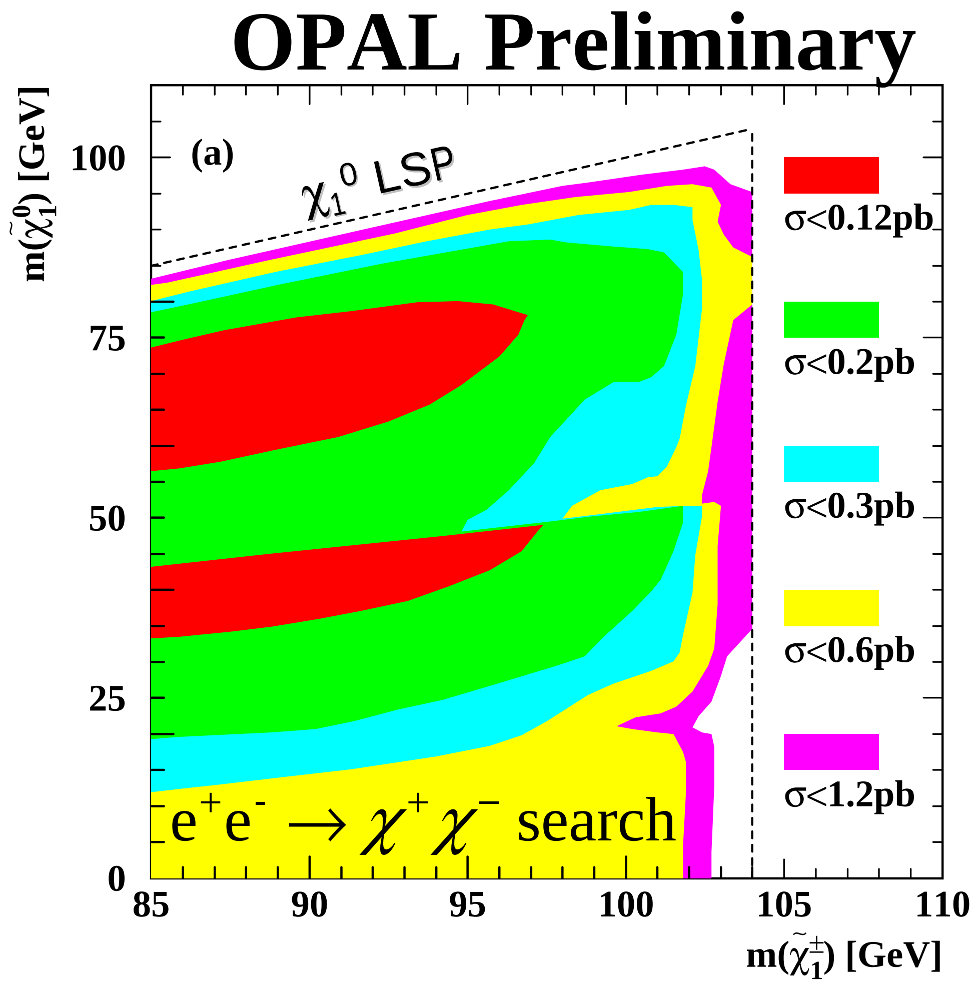
Searches at LEP: Charginos, Neutralinos (III)

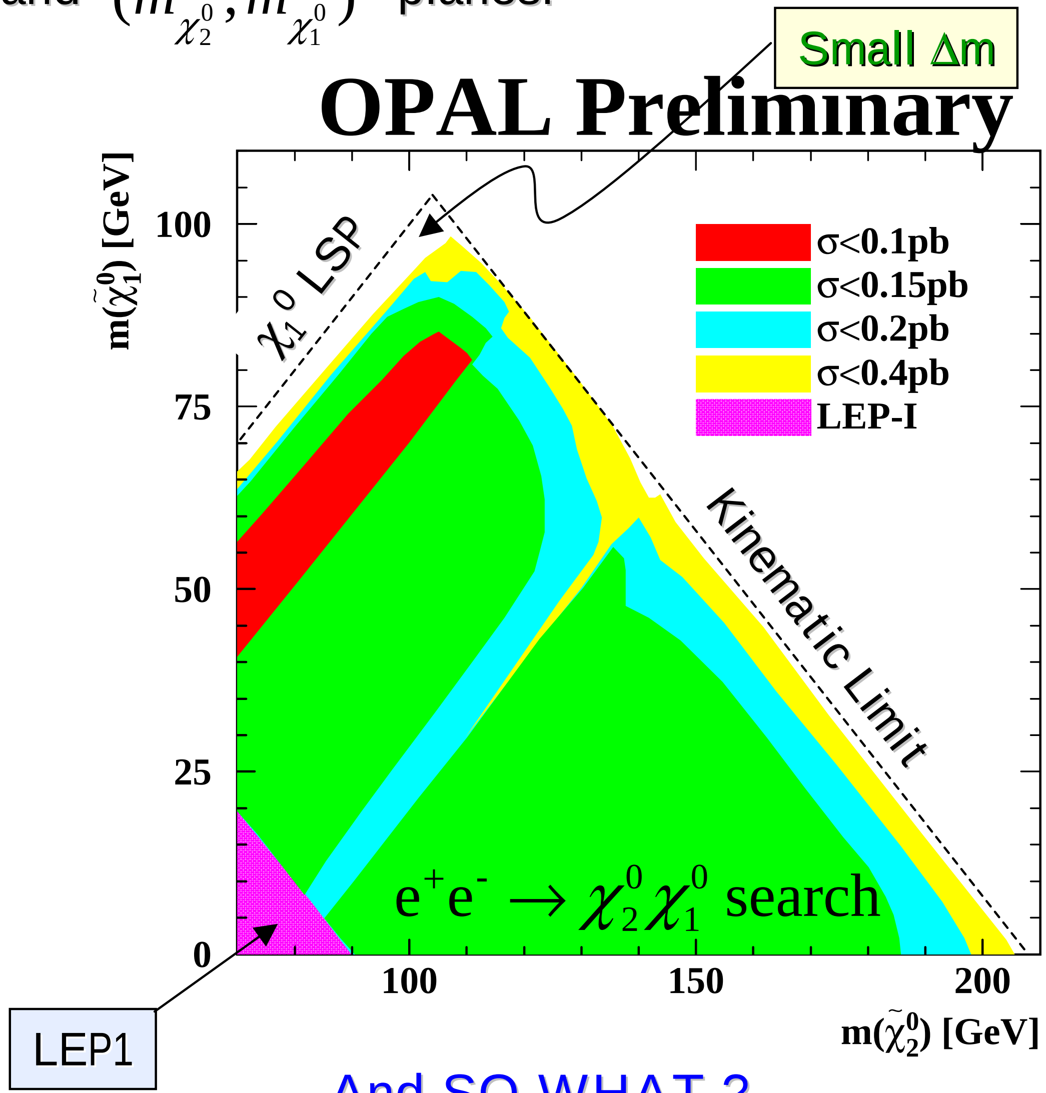


Searches at LEP: Charginos, Neutralinos (IV)

Presentation of the result

- **Model Independent:** 95% C.L. upper limit on the $\chi^+\chi^-$ and $\chi_2^0\chi_1^0$ cross sections in the $(m_{\chi^+}, m_{\chi_1^0})$ and $(m_{\chi_2^0}, m_{\chi_1^0})$ planes.





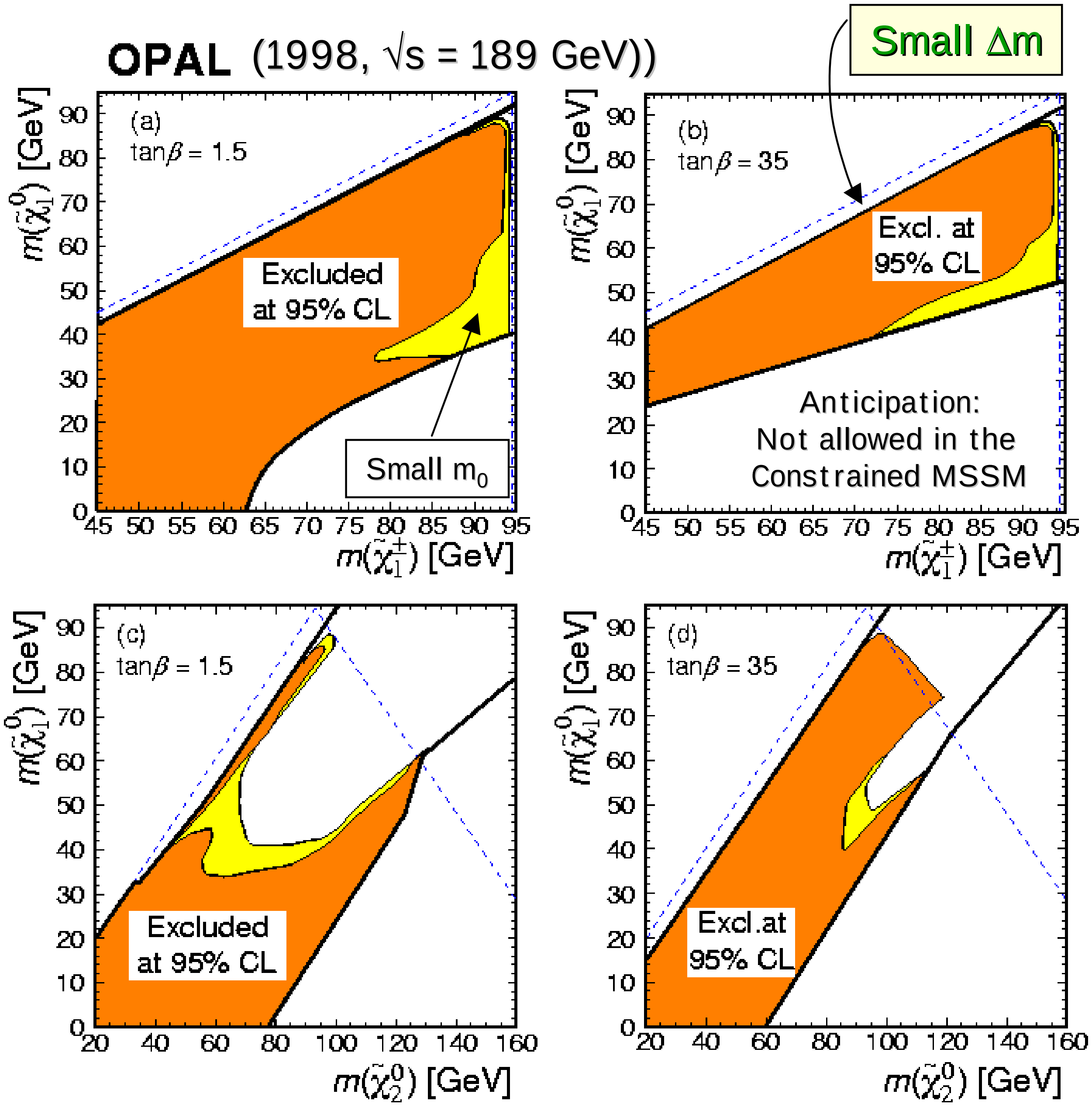
... And SO WHAT ?

Searches at LEP: Charginos, Neutralinos (V)

❑ In the MSSM:

The chargino and neutralino production cross section can be computed as a function of the χ^+ and χ^0 masses, under the assumption that masses of sfermions are large (→ negligible interference in the cross section).

95% C.L. excluded regions in the $(m_{\chi^+}, m_{\chi_1^0})$ and the $(m_{\chi_2^0}, m_{\chi_1^0})$ planes



Still not extremely exciting ...

Searches at LEP: Charginos, Neutralinos (VI)

- In the C-MSSM: The chargino and neutralino masses unify via $m_{1/2}$ (M_2) and can be expressed as a function of M_2, μ and $\tan\beta$.

The chargino and neutralino searches results can therefore be combined, and the result reported in the (M_2, μ) plane for different $\tan\beta$ values.

Limit on the LSP mass ($m_{1/2}$)

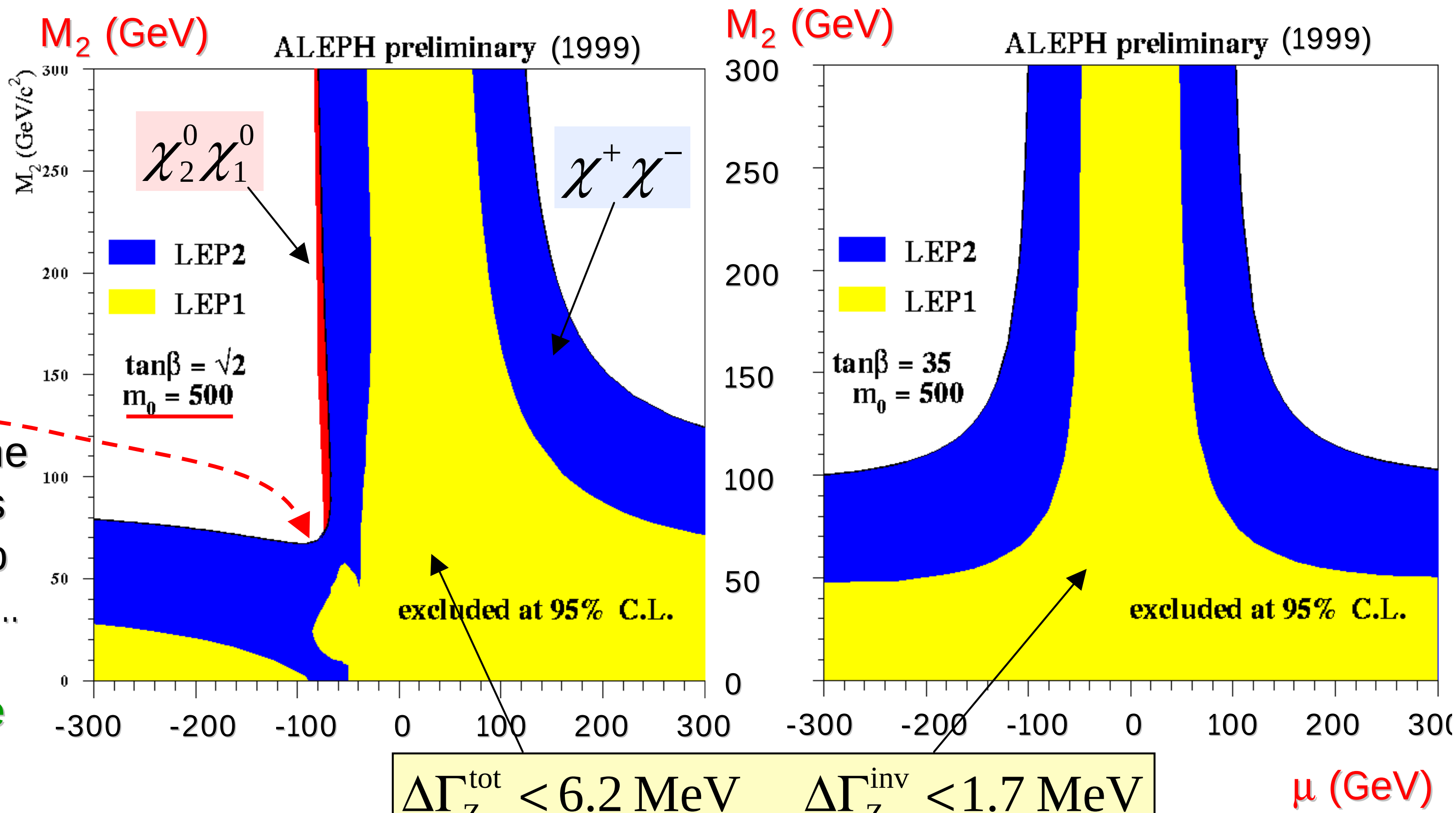
⇧

Limit on M_2

(increases with $\tan\beta$)

For smaller m_0, the excluded domains shrink, leaving no limit on M_2... but ...

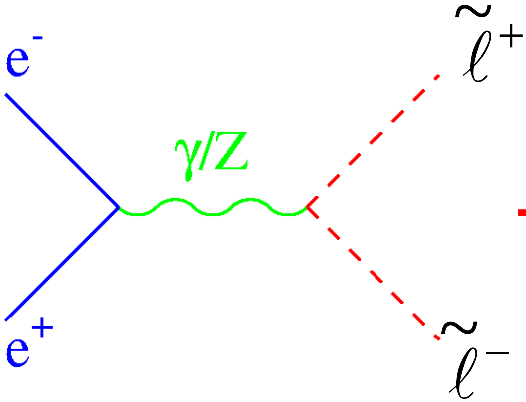
Sleptons become light...



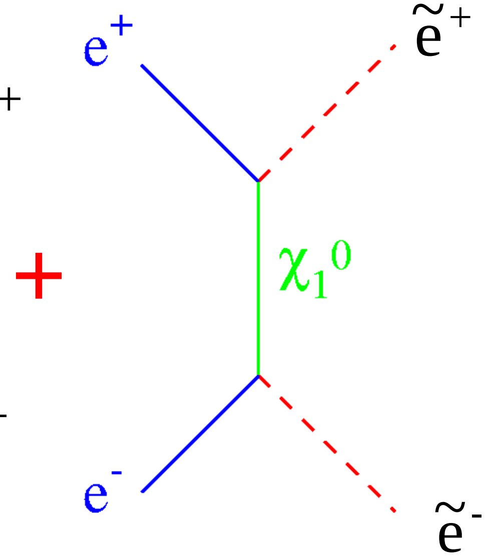
$$\Delta\Gamma_Z^{tot} < 6.2\ \mathrm{MeV} \qquad \Delta\Gamma_Z^{inv} < 1.7\ \mathrm{MeV}$$

Searches at LEP: Sleptons (I)

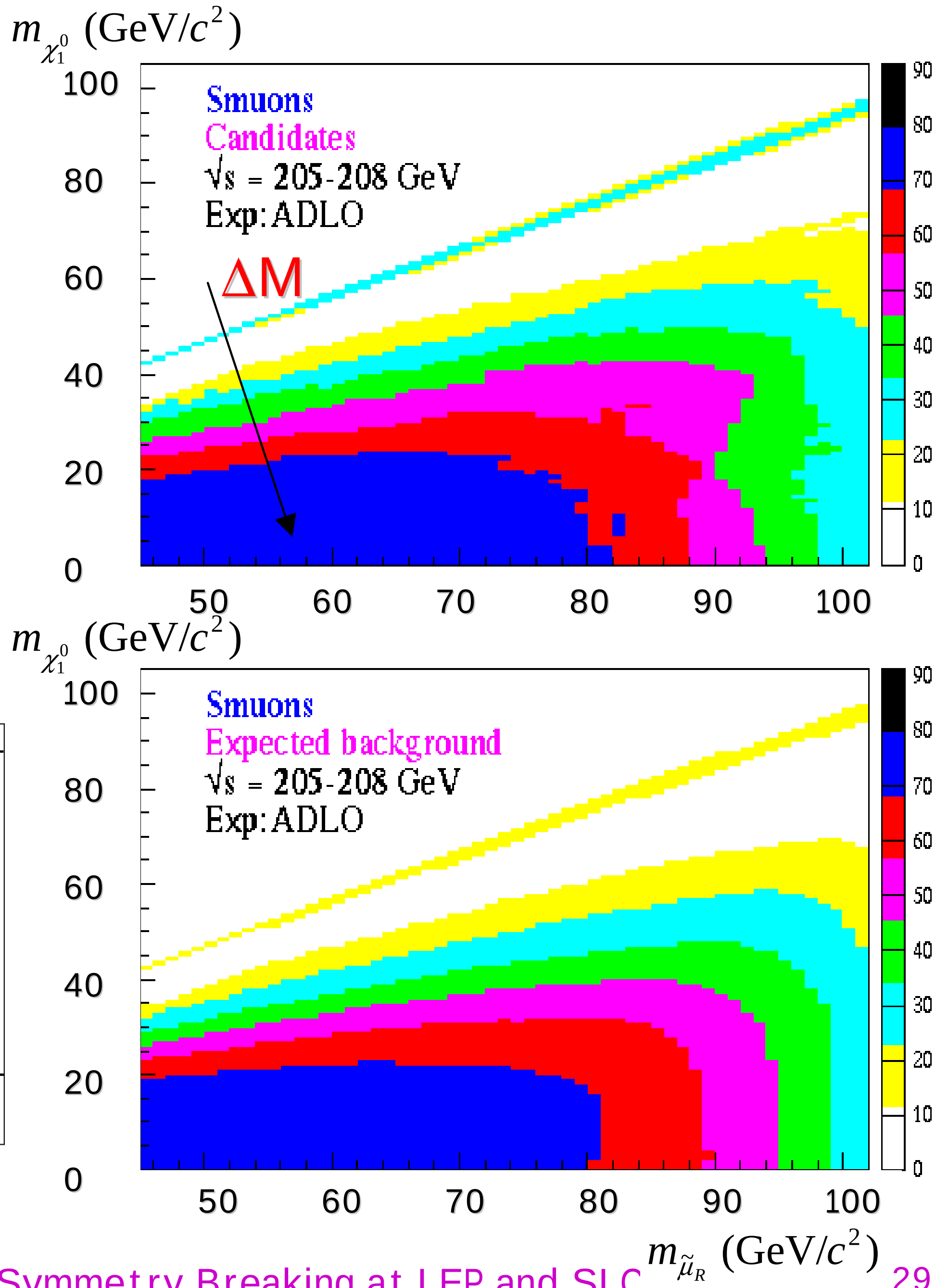
Production:



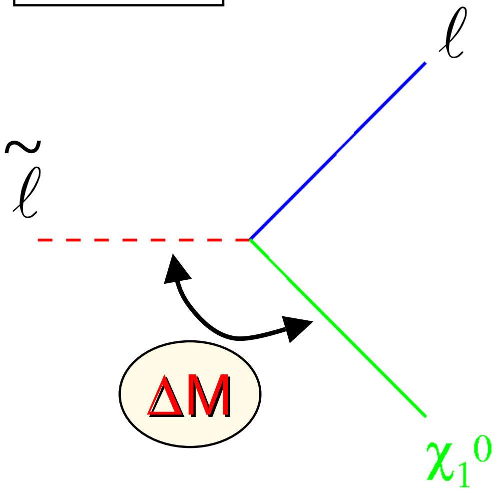
This graph depends only
on the slepton mass



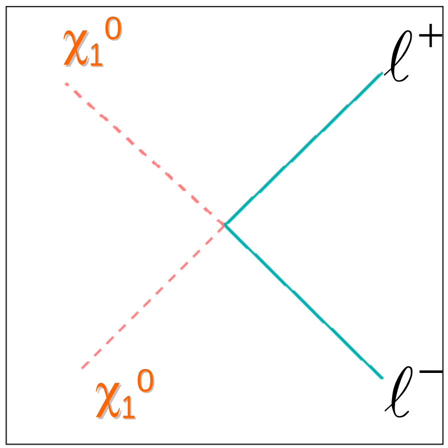
Results for smuons (2000)



Decay:



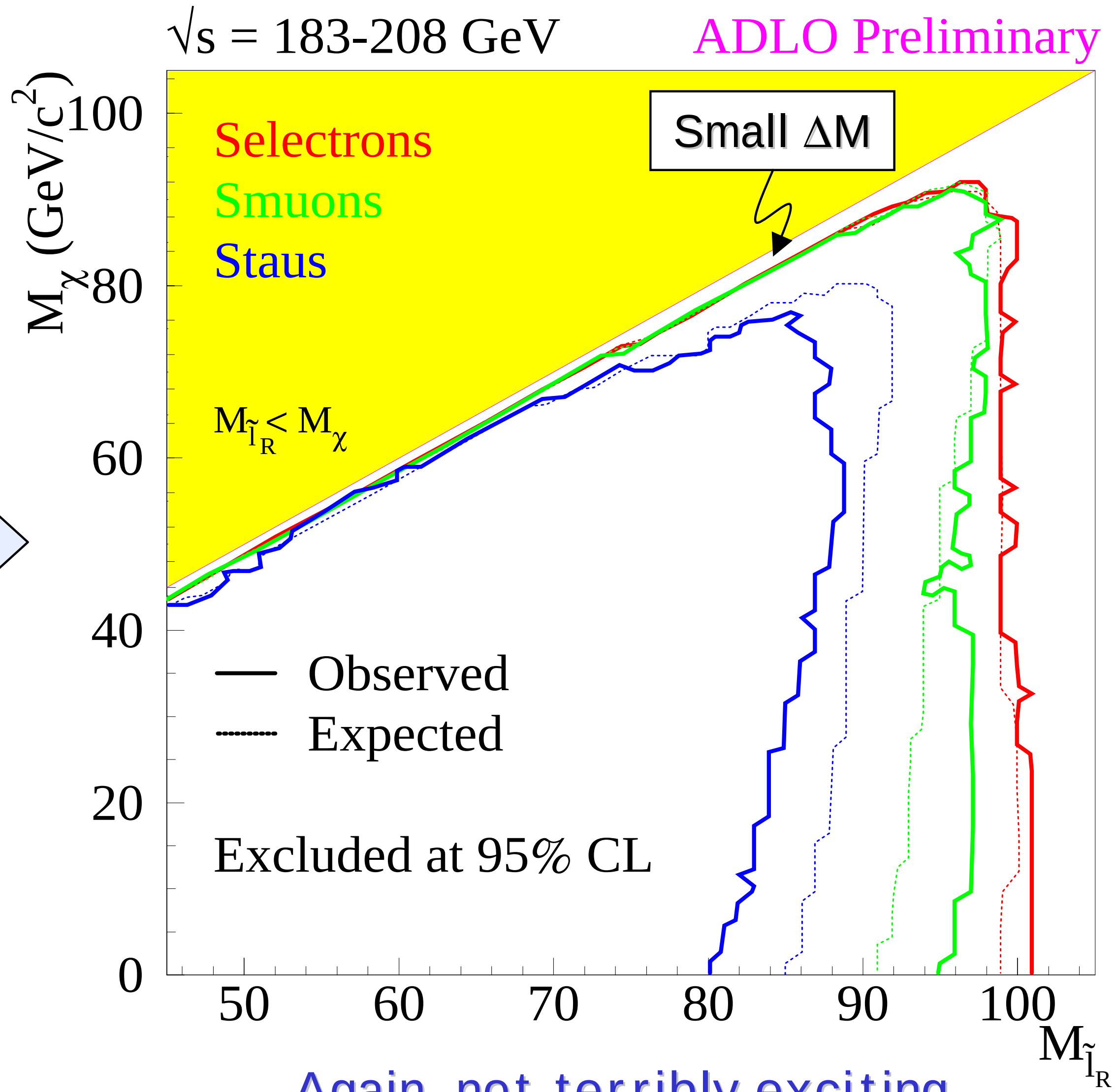
Topology:



Acoplanar Leptons

Searches at LEP: Sleptons (II)

Result expressed in terms of 95% C.L. excluded domains in the $(m_{\tilde{\ell}}, m_{\chi_1^0})$ plane



Limits for $\Delta M > 10$ GeV/c² :

$$m_{\tilde{e}_R} \geq 99\ \mathrm{GeV}/c^2$$

$$m_{\tilde{\mu}_R} \geq 95\ \mathrm{GeV}/c^2$$

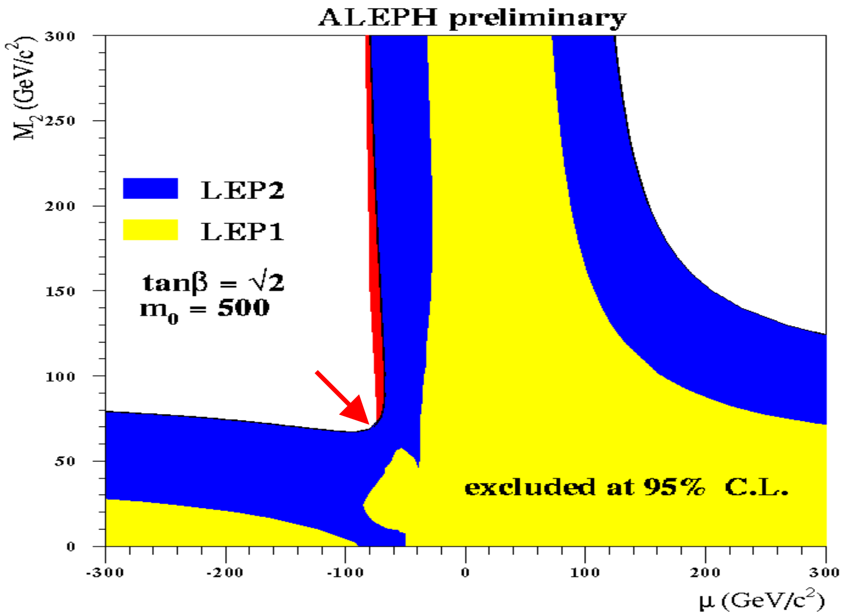
$$m_{\tilde{\tau}_R} \geq 80\ \mathrm{GeV}/c^2$$

at 95% C.L.

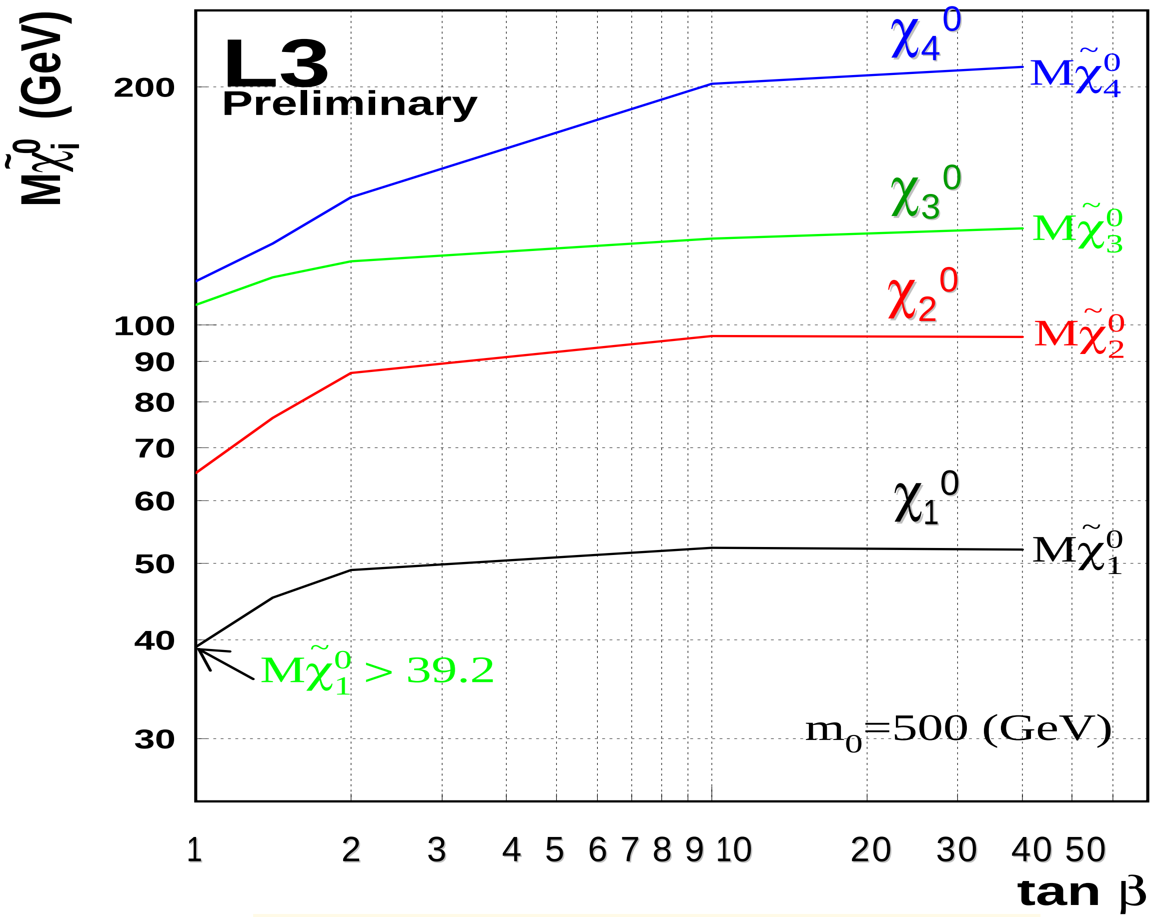
Again, not terribly exciting …
But it allows a LSP mass limit
to be set in the C-MSSM

Interpretation: LSP Mass Lower Limit (I)

- Large m_0 ($\geq$ 100 GeV/c^2)
  - $\Rightarrow$ Large chargino and neutralino cross section;
  - $\Rightarrow$ Limit on M_2 for each tanβ value



  - $\Rightarrow$ Constrain $m_{1/2}$ as a function of tanβ
  - $\Rightarrow$ Constrain $m(\chi_1^0)$ for each tanβ



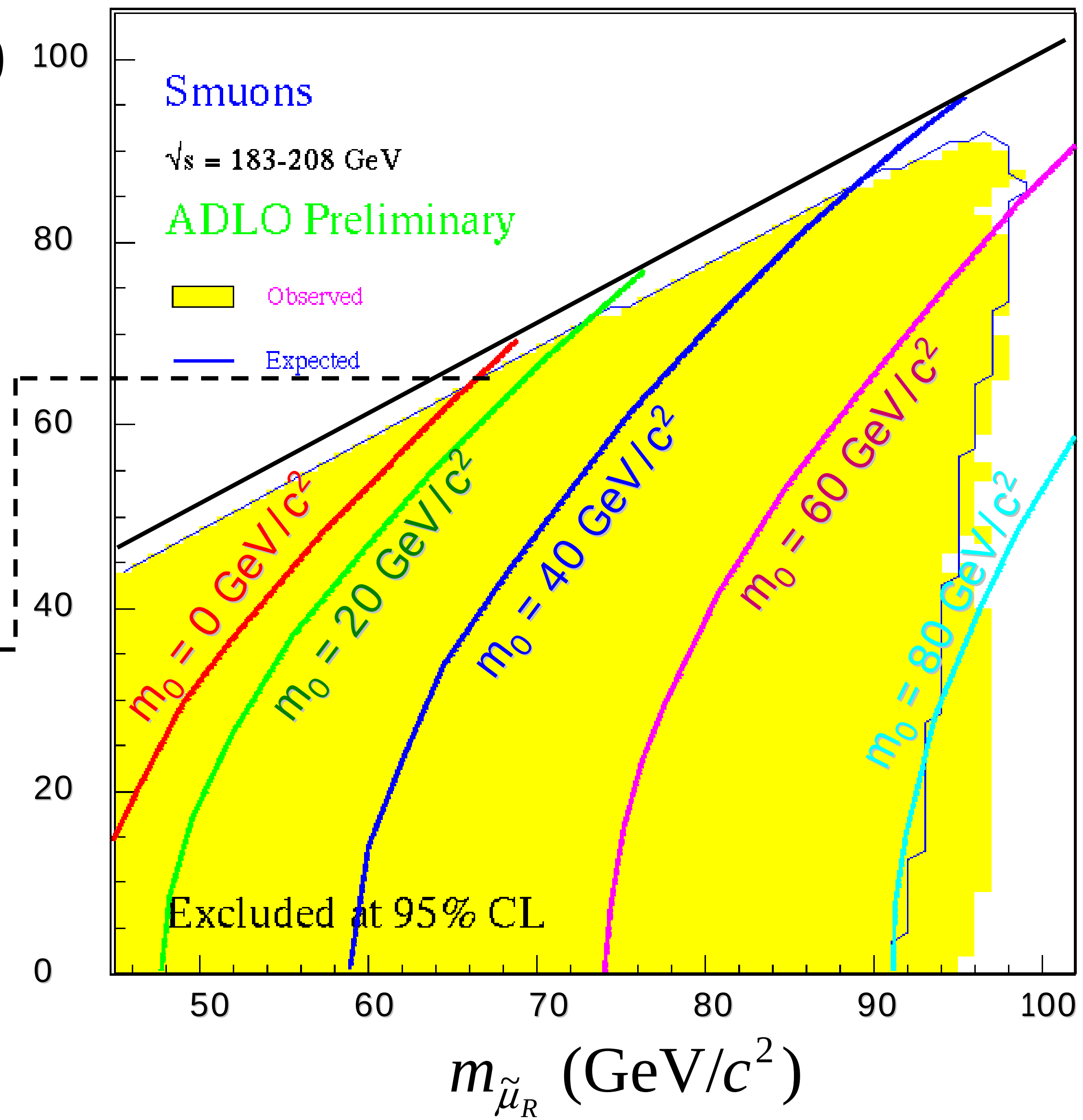
$$m(\chi_1^0) > 39.6\,\mathrm{GeV/c^2}\ \ \mathrm{ALEPH}$$
$$m(\chi_1^0) > 38.7\,\mathrm{GeV/c^2}\ \ \mathrm{DELPHI}$$
$$m(\chi_1^0) > 39.4\,\mathrm{GeV/c^2}\ \ \mathrm{L3}$$
$$m(\chi_1^0) > 38.0\,\mathrm{GeV/c^2}\ \ \mathrm{OPAL}$$

(Large m_0)

Interpretation: LSP Mass Lower Limit (II)

➢ Small m_0 ($\leq$ 60 GeV/c^2)

$$m^2_{\tilde{\ell}_R} = m_0^2 + 0.15 m_{1/2}^2 + m_Z^2 \sin^2\vartheta_W \left|\cos 2\beta\right|$$



⇒ A limit on the slepton mass can constrain $m_{1/2}$;

⇒ ... and therefore $m(\chi_1^0)$

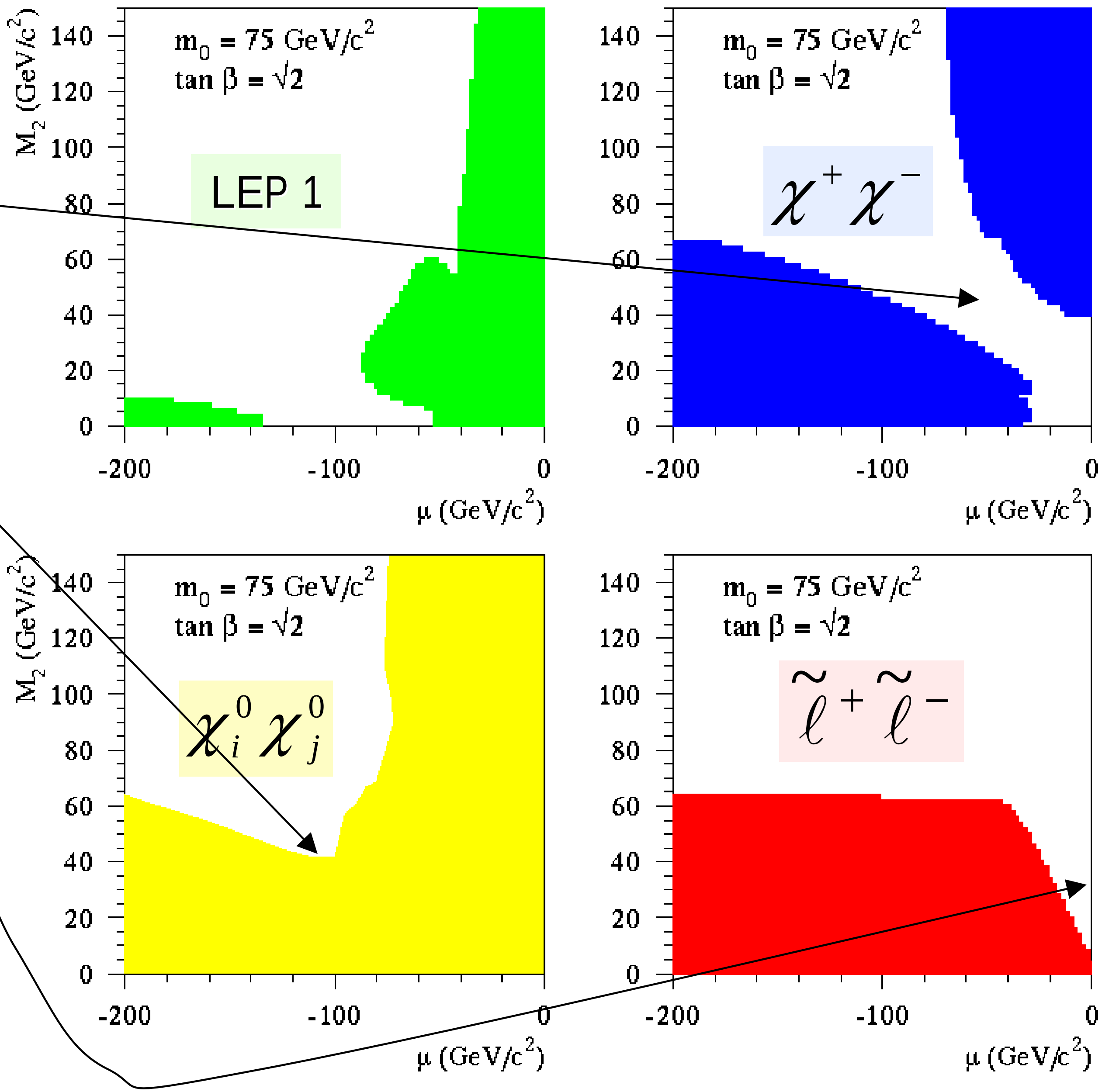
⇒ $m(\chi_1^0) > 65\,\mathrm{GeV}/c^2$ ALDO
(small m_0)

⇒ But the limit starts to vanish for m_0 in excess of 60 GeV/c^2.

Interpretation: LSP Mass Lower Limit (III)

- Moderate m_0 (60-80 GeV/c^2)

ALEPH (1997)



⇒ Chargino cross section may vanish (neg've interference) in a (M_2, μ) corridor

⇒ Neutralinos may become invisible:

$$\chi_2^0 \to \tilde{\nu}\bar{\nu} \to \chi_1^0 \nu\bar{\nu}$$

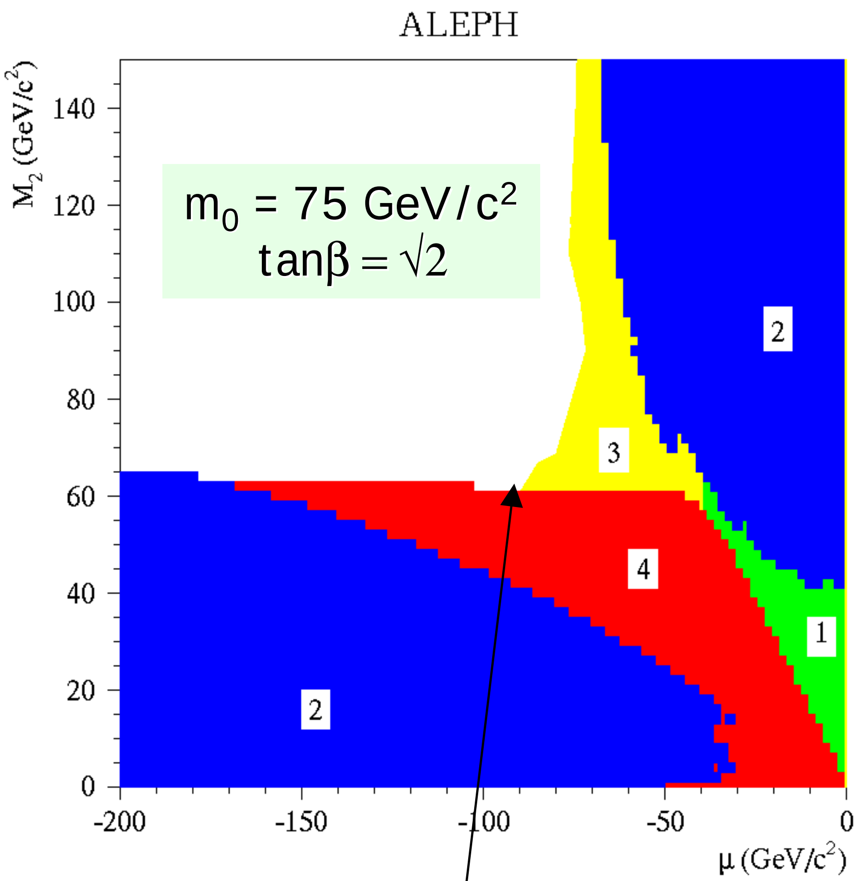
⇒ The limit from sleptons slowly vanishes due to limited centre-of mass energy;

⇒ Weaker constraint from each of the searches on the LSP mass

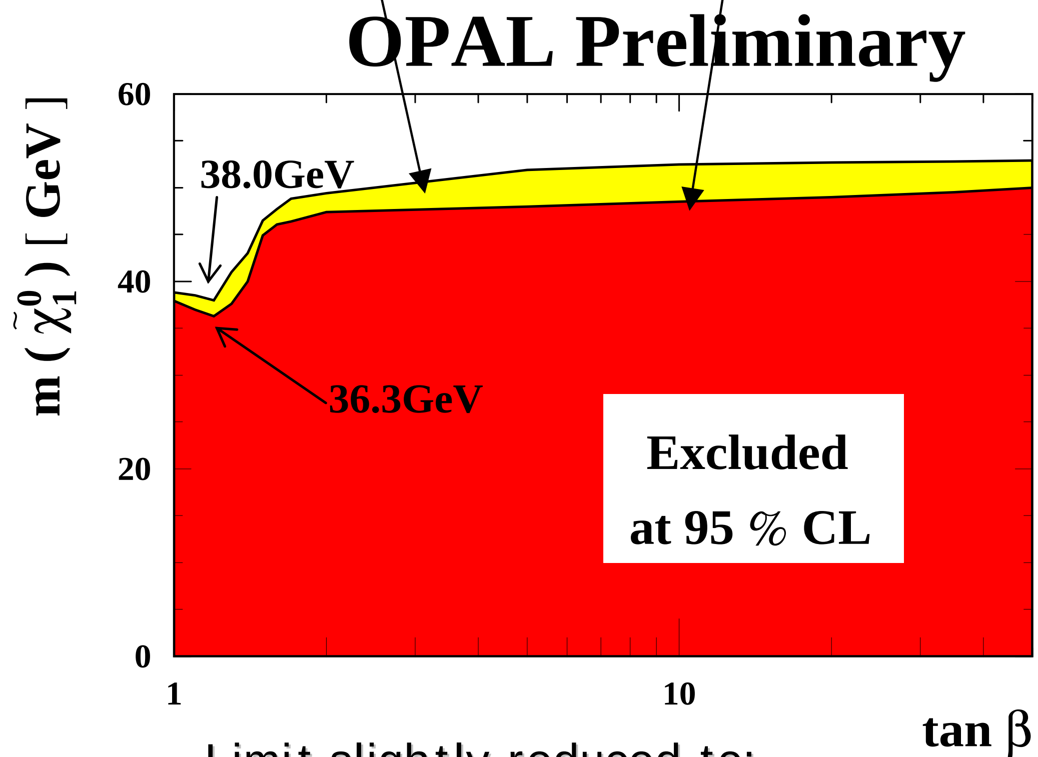
COMBINE THEM ALL !

Interpretation: LSP Mass Lower Limit (IV)

With all searches combined



Get an m_0-independent limit on $m_{1/2}$, i.e., on the LSP mass, for each value of $\tan\beta$.



Limit slightly reduced to:

$$m(\chi_1^0) > 36.3\,\mathrm{GeV/c^2}\ \mathrm{OPAL}$$
$$m(\chi_1^0) > 38.7\,\mathrm{GeV/c^2}\ \mathrm{DELPHI}$$

obtained for small $\tan\beta$ values

Interpretation: LSP Mass Lower Limit (VI)

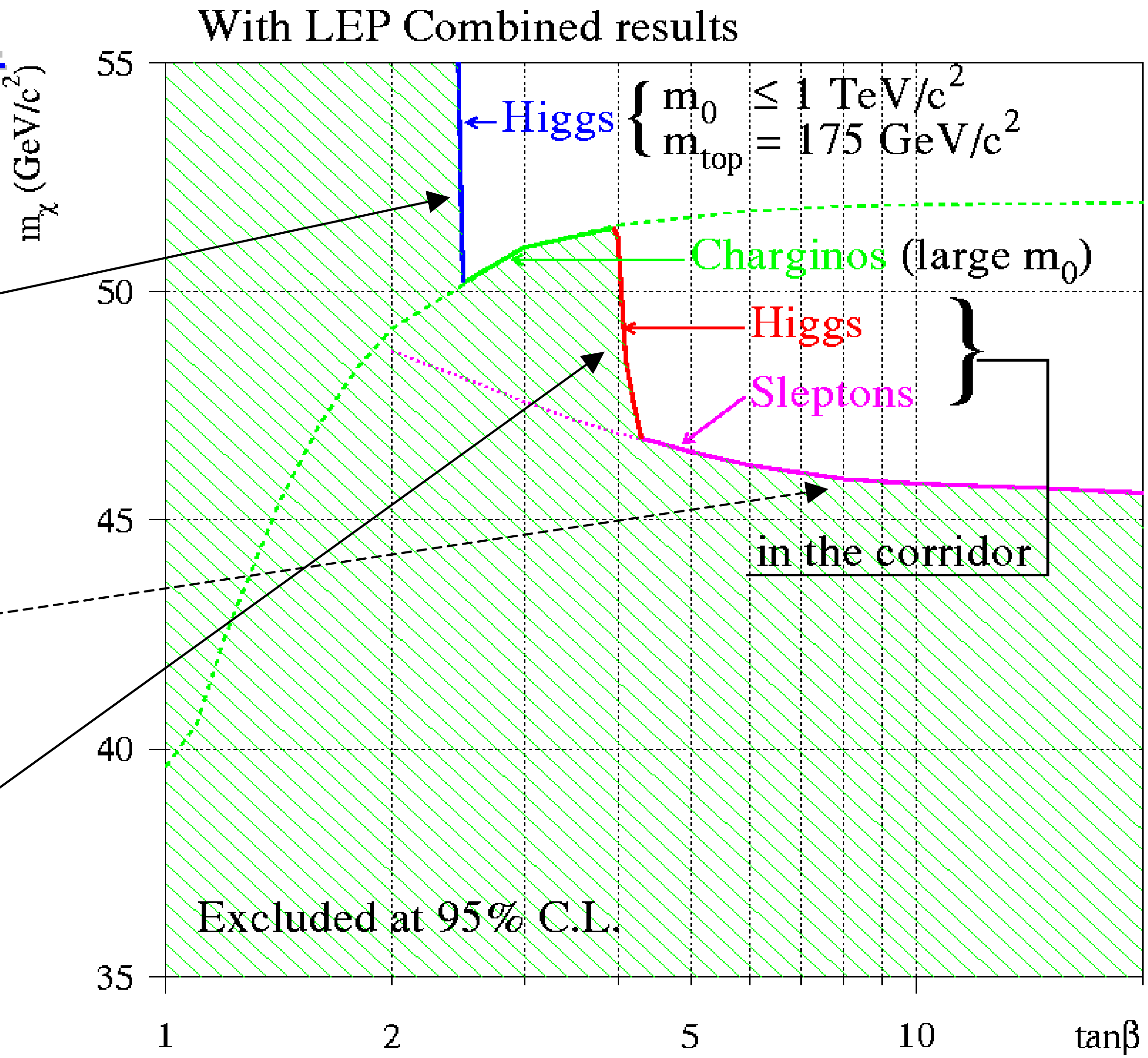
➤ Impact of the Higgs searches.

⇒ The small tanβ values (up to 2.4) are covered by the hZ searches for all m_0 values up to 1 TeV/c^2;

⇒ For large tanβ values, there is no absolute limit from Higgs searches. The LSP mass limit is set by slepton searches in the "corridor" (small m_0)

⇒ While tanβ decreases, Higgs searches start playing a role again in the corridor (small m_0 ⇔ smaller rad. corr. to m_h, thus excluded by searches)

⇒ Stronger overall limit on the LSP mass (in the C-MSSM).



$$m(\chi_1^0) > 46\,\mathrm{GeV}/c^2 \quad \mathrm{ALDO}$$

Interpretation: Constraints in mSUGRA (I)

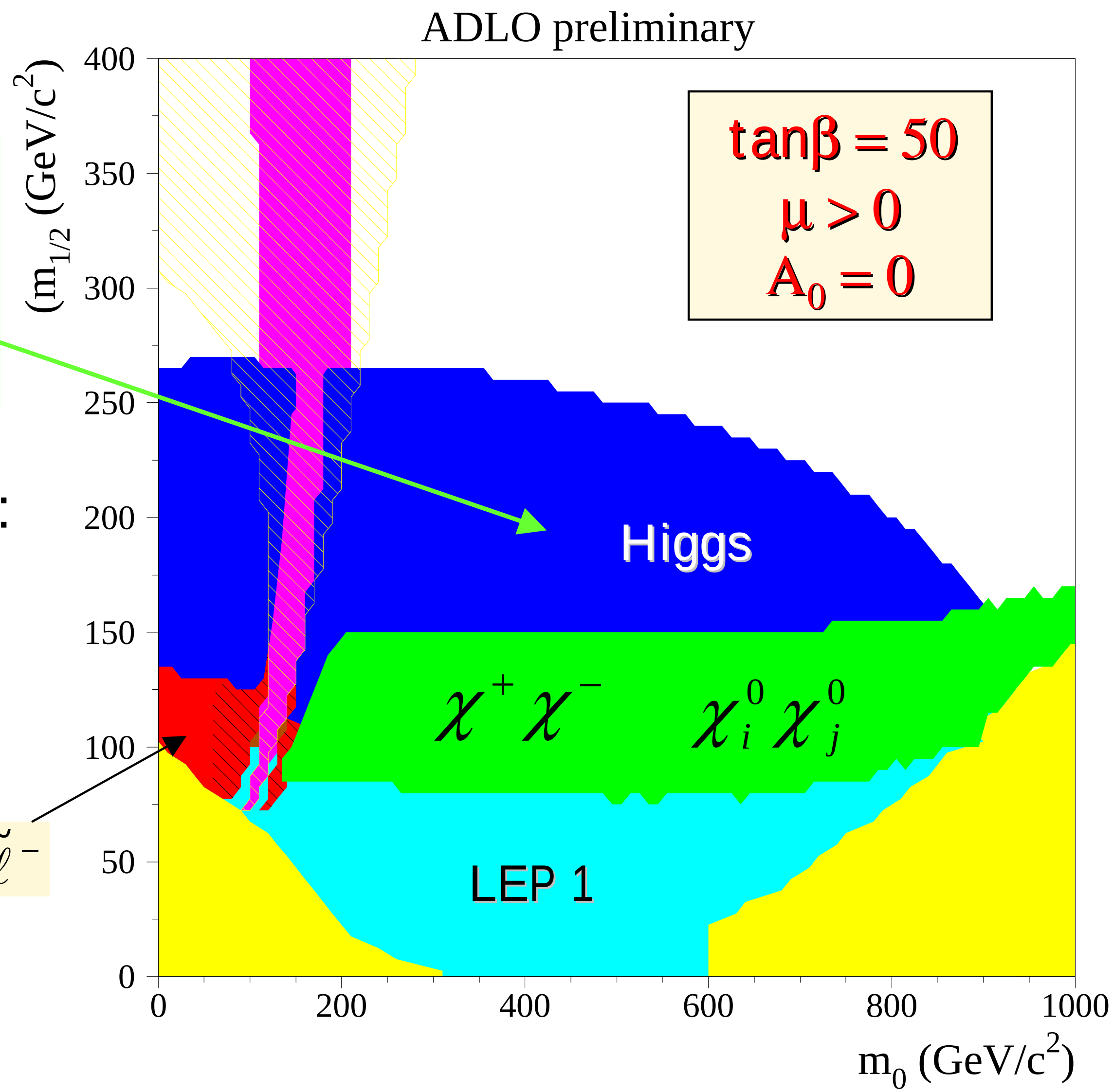
In mSUGRA, the Higgs boson mass itself (not only the radiative corrections to the Higgs boson mass) is fixed by m_0 and $m_{1/2}$.

For moderate m_0, $m_{1/2}$, the Higgs Boson mass remains accessible to LEP searches even at large values of tanβ.

Scan of the $\left(m_{1/2}, m_0\right)$ plane:

Regions excluded by:

1. *Theory*
2. *Z width (ΔΓ)*
3. *Charginos, Neutralinos*
4. *Sleptons*
5. *Higgs*
6. *Stable heavy charged*



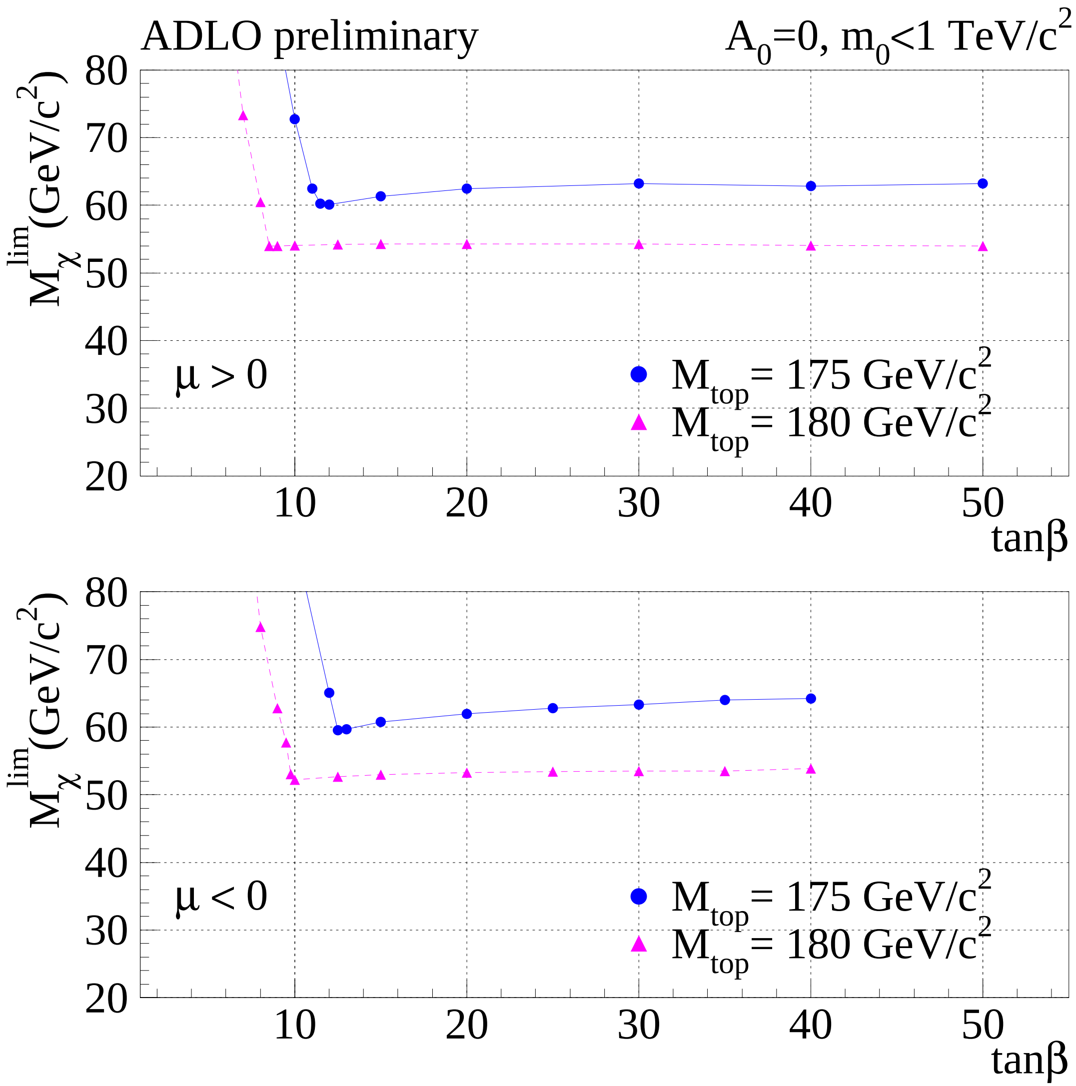
Interpretation: Constraints in mSUGRA (II)

Scan in the $m_{1/2}, m_0, \tan\beta, A_0$ space

Even tighter limit on the LSP mass when the mSUGRA constraints are enforced.

$$m(\chi_1^0) \geq 55 - 60 \text{ GeV/c}^2$$

at 95% C.L.



Conclusions of the 3rd Lecture

Twelve years of searches at LEP put severe constraints on Supersymmetry

- In mSUGRA: $m(\chi_1^0) \geq 55 - 60\ \mathrm{GeV/c}^2$ (with a lot of theoretical assumptions)
- In the C-MSSM (SUSY + GUT mass relations):

$$m(\chi_1^0) \geq 46\ \mathrm{GeV/c}^2,\ m(\chi^\pm) \geq 91\ \mathrm{GeV/c}^2$$

$$m(\tilde{e}) \geq 77\ \mathrm{GeV/c}^2,\ m(\tilde{\mu}) \geq 83\ \mathrm{GeV/c}^2,\ m(\tilde{\tau}) \geq 65\ \mathrm{GeV/c}^2$$

- In the MSSM:

$$m(\chi_1^0) \geq 40\ \mathrm{GeV/c}^2$$ for heavy sfermions and with gaugino mass unification

$$m(h) \geq 91\ \mathrm{GeV/c}^2 \qquad \tan\beta \geq 2.4$$

- But much weaker LSP limit in the MSSM with light sfermions
- No LSP limit without gaugino mass unification
- No LSP limit with other SUSY breaking mechanism (e.g., AMSB)

Overall Conclusion: The LEP/SLD Legacy

- LEP and SLD led to unprecedented precisions tests of the electroweak symmetry breaking mechanism, favouring a rather light Higgs boson (between 114 and 222 GeV/c^2 at 95% CL in the Standard Model).
- In this respect, the Standard Model has been very successful and was shown to be internally very consistent, up to a precision of 0.1%.
- Notwithstanding these successes, the Standard Model suffers from conceptual diseases, which can be cured in practice (with today's theoretical knowledge) by Supersymmetry only.
- Amazingly enough, several experimental hints of Supersymmetry were observed by LEP and SLD. (Mostly indirect, with maybe a light Higgs boson with mass 115.6±1.0 GeV/c^2, just in the range predicted by SUSY)
- However, Supersymmetry is already very constrained by LEP1 and LEP2 searches: $m_h > 91$ GeV/c^2, $\tan\beta > 2.4$. If GUT mass relations are assumed in the MSSM, the LSP mass exceeds 46 GeV/c^2 at 95% CL.
- Direct evidence for SUSY is expected to show up soon (Tevatron, LHC, NLC)