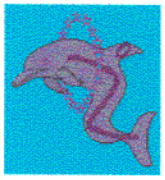
LEP searches for Higgs bosons in models beyond the Standard Model

Pierre Lutz
Delphi Saclay


- MSSM
- Charged and doubly-charged Higgs
- Invisible Higgs

- All limits are at 95% CL.
- LEP community still very active

Two Higgs Doublet Models

- Addition of doublets keeps $\rho = 1$
- 2HDM is the simplest of the extensions of the SM, with 2 complex scalar field doublets Φ_1 and Φ_2.
- the real parts mix with an angle α and give 2 neutral scalars (h and H).
- the (remaining) imaginary part is the pseudo-scalar A.
- In total, there are 5 physical scalar Higgs states (h, H, A, $H^{\pm}$) and 6 parameters (4 masses, $\tan\beta = v_2/v_1$ and α).
- The 2 decay channels hZ and hA are complementary, as are HZ and HA

$$\sigma_{hZ} = \sigma_{HZ}^{SM} \sin^2(\alpha - \beta) \qquad \sigma_{hA} = \sigma_{HZ}^{SM} \lambda \cos^2(\alpha - \beta)$$

- Type I 2HDM : one doublet couples to fermions, the other to bosons.
- Type II 2HDM : one doublet couples to "up" fermions, the other to "down" fermions. MSSM is a particular case of a Type II 2HDM, with 2 parameters at tree level.

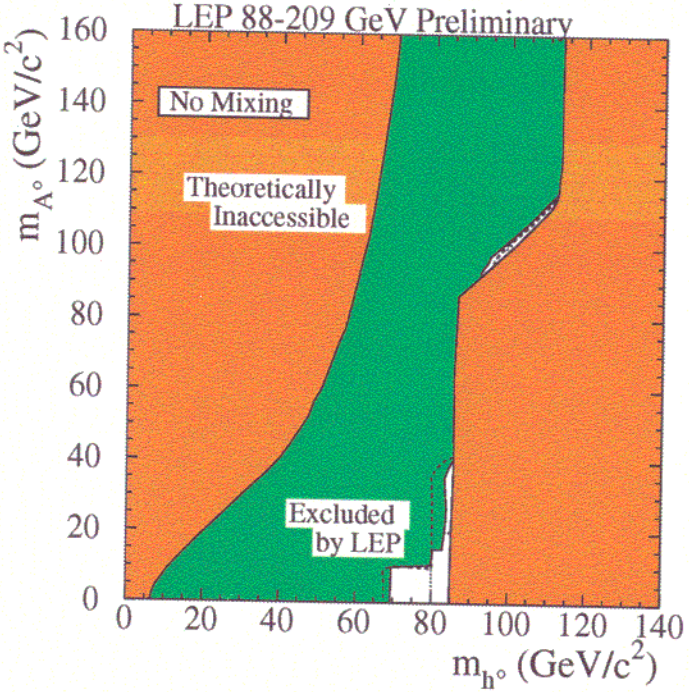
MSSM Benchmarks scans

Following *Carena et al.* hep-ph/9912223 (for the time being)

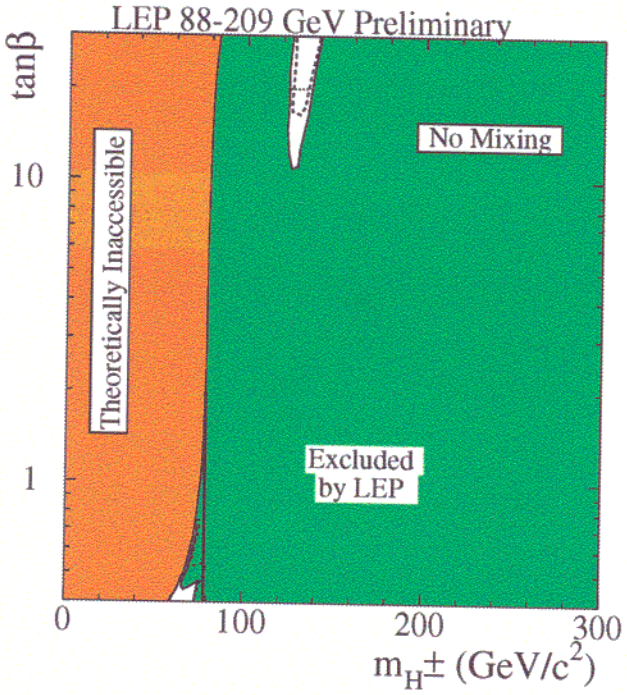
no mixing / max. m_h / large μ scenario		
m_{top}	= 174.3 GeV	top mass
M_{SUSY}	= 1 / 0.4 TeV	sfermion mass at EW scale
μ	= -200 / 1000 GeV	Higgs mixing parameter
M_2	= 200 / 400 GeV	gaugino mass at EW scale
$m_{\tilde{g}}$	= 0.8 / 0.2 TeV	gluino mass
$A_b = A_t$		trilinear Higgs-stop coupling
$X = A - \mu \cot \beta$	= 0 / 2 / -0.3 TeV	stop mixing parameter

- the max. m_h scenario was designed to yield the maximal value of the higgs mass ($\sim$ 130 GeV)
- the large μ scenario is designed to produce suppressed Higgs decays to $b\bar{b}$. With the flavor independent searches, this scenario is now excluded.

LEP 2001 combination. In this scenario, max. $m_h \sim 118$ GeV.

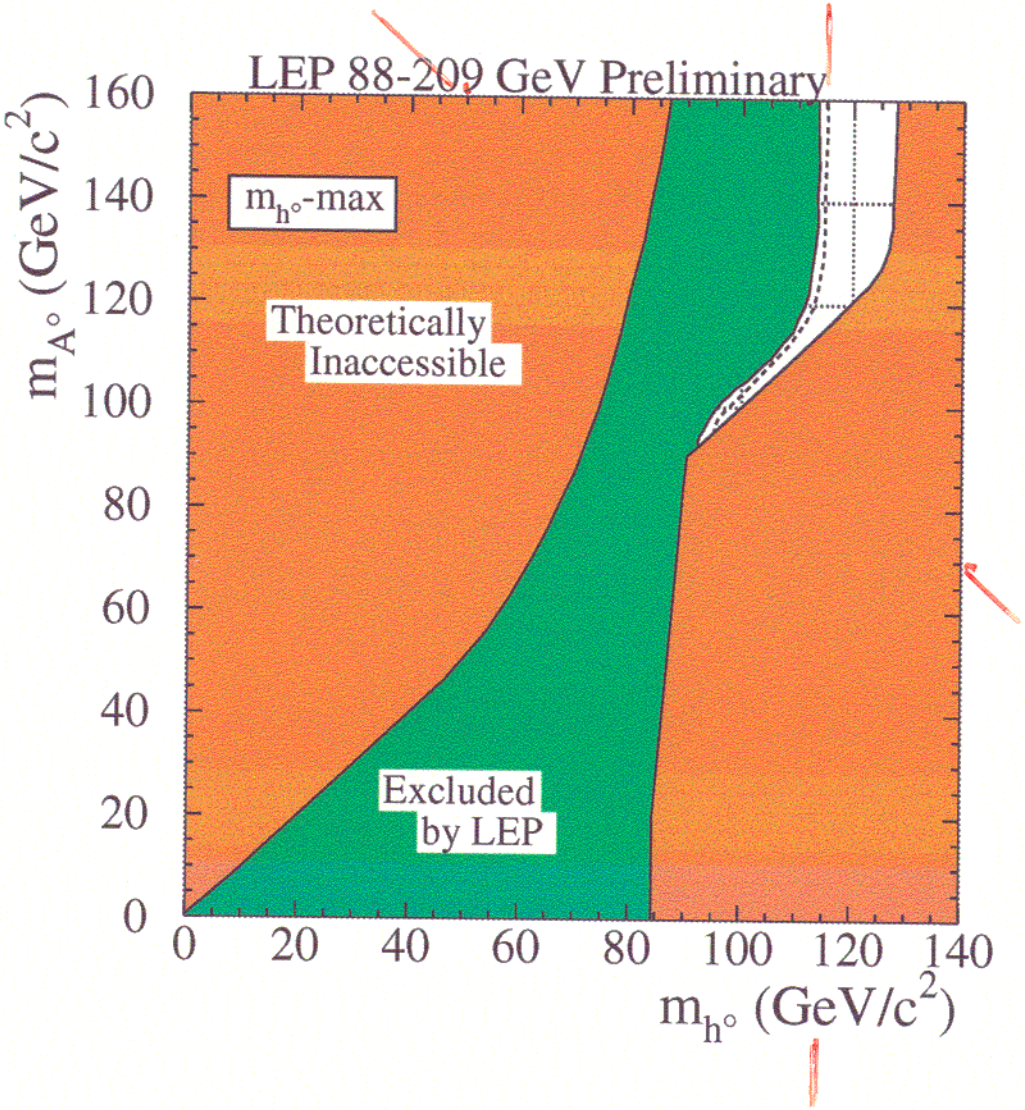


The region $m_h \sim m_A$ is beyond the hA kin. reach. This would have probably been covered with a mild upgrade of LEP energy.



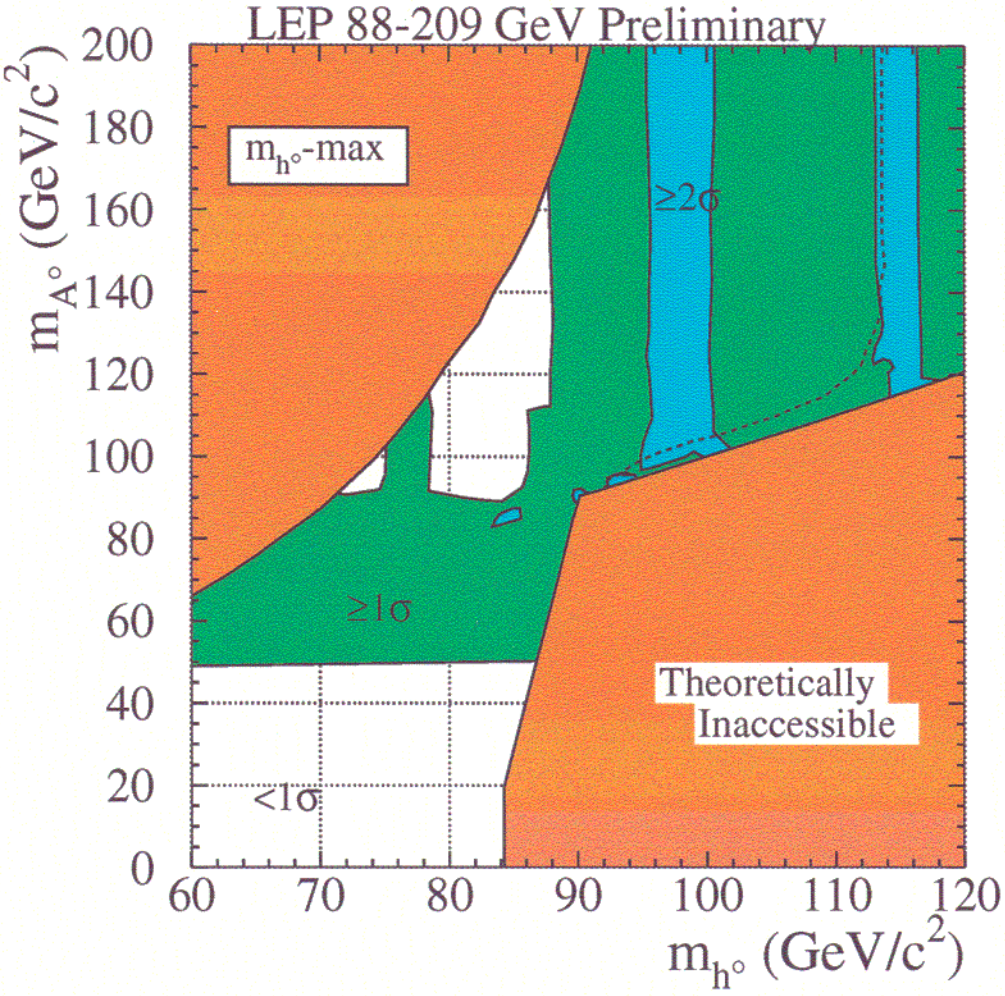
The ($\tan\beta \sim 0.4$; $m_{H^+} \sim 74$ GeV) region will probably be covered in the next LEP combination, thanks to dedicated $H^+ \rightarrow$ WA analyses and flavor ind. searches.

m_h-max scenario



- LEP 2001 combination
- Without radiative corrections, MSSM would have been widely excluded.
- The hZ and hA kinematic walls are visible.
- $m_h > 91.0$ (expected 94.6) GeV
- $m_A > 91.9$ (expected 95.0) GeV
- Why Δ(exp.-obs.) so big ?

m_h-max scenario



- the lightblue areas show an excess over the SM prediction.
- bands come from the hZ search (at ~97 and 115 GeV).
- islands along the diagonal from the hA one.
- statistically not surprising.
- but some are speculating ...

MSSM updates

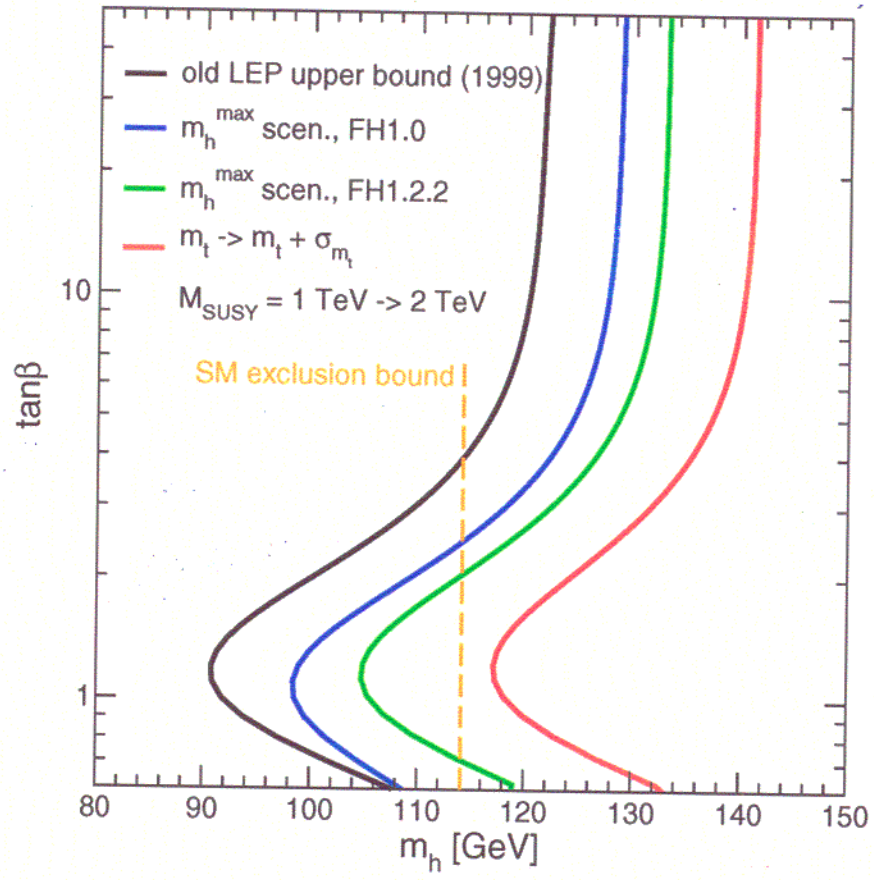
ALEPH, DELPHI and L3 updated their MSSM analyses for this conf.

limits in max. m_h scenario			
	m_h	m_A	$\tan\beta$ excl.
ALEPH (new, final)	89.8 (91.3)	90.1 (91.6)	0.7 - 2.3
DELPHI(new, final)	89.1 (89.4)	90.0 (90.2)	0.54 - 2.36
L3 (new, prelim.)	86.0 (88.4)	86.5 (88.6)	0.55 - 2.2
OPAL (still 2001)	79.3 (85.1)	80.6 (86.9)	0.9 - 1.7
LEP 2001	91.0 (94.6)	91.9 (95.0)	0.5 - 2.4

A LEP combination is expected for the coming months, with probably more (new) benchmarks, for many reasons, in particular :

New theoretical radiative corrections
A CP violating MSSM scenario

new radiative corrections computation



courtesy of G. Weiglein

- a new version (1.2.2) of FeynHiggs includes sub-leading non-log $\mathcal{O}(\alpha_t^2)$ terms thus shifting the max. m_h by ~ 4 GeV at high $\tan\beta$ (from blue to green lines).
- as soon as confirmed, the LEP Higgs Working Group will use it.

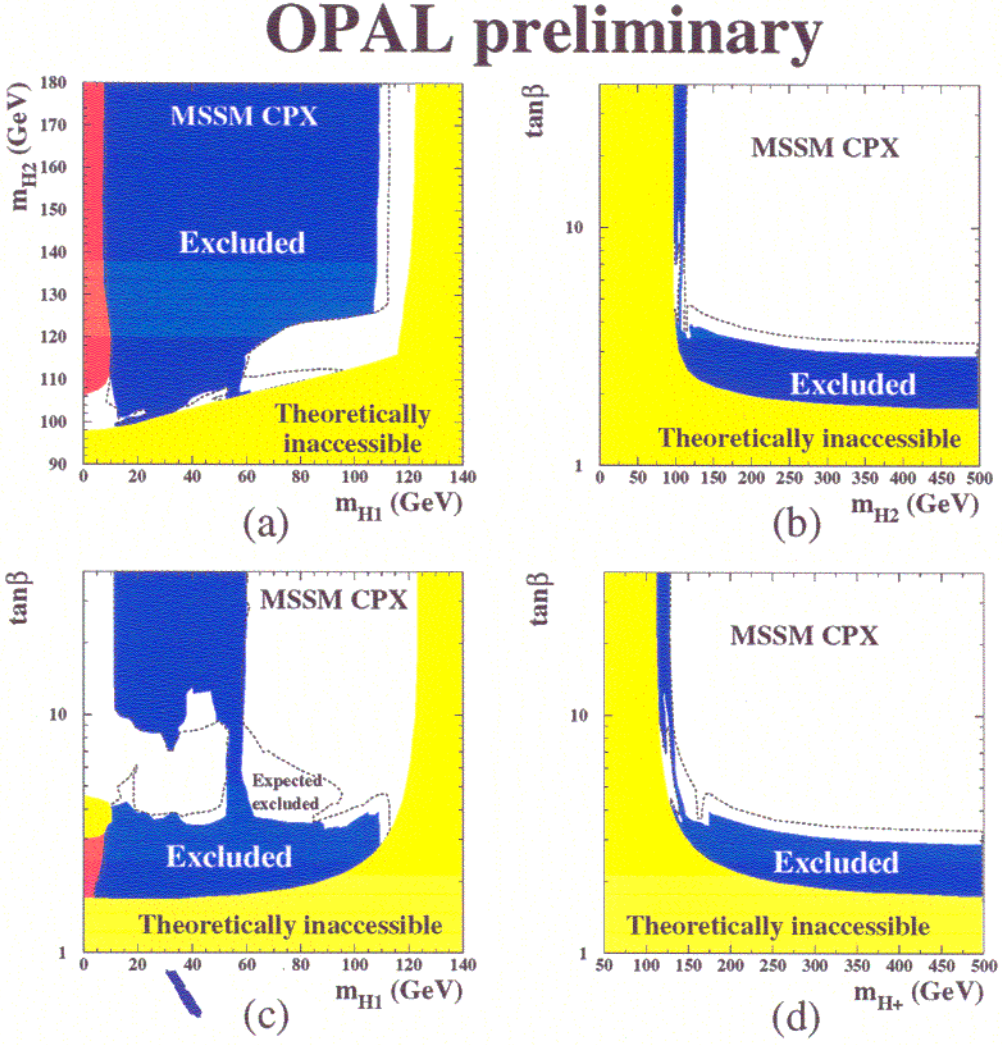
CP violating MSSM

- The SUSY breaking trilinear couplings have phases in general, inducing CP violation
- Higgs mass eigenstates H_1, H_2, H_3 are not the CP eigenstates
- Search channels are H_1Z, H_2Z and H_1H_2
- Lightest Higgs boson might have escaped detection at LEP2
- Still true $m_{H_1} < 130$ GeV, and decays into $b\bar{b}$ and $\tau\tau$
- New features
  - 2 Higgsstrahlung processes simultaneously
  - large mass difference for $\tan\beta > 10$, dedicated analyses required
  - $H_2 \rightarrow H_1H_1$ dominant if kinematically allowed

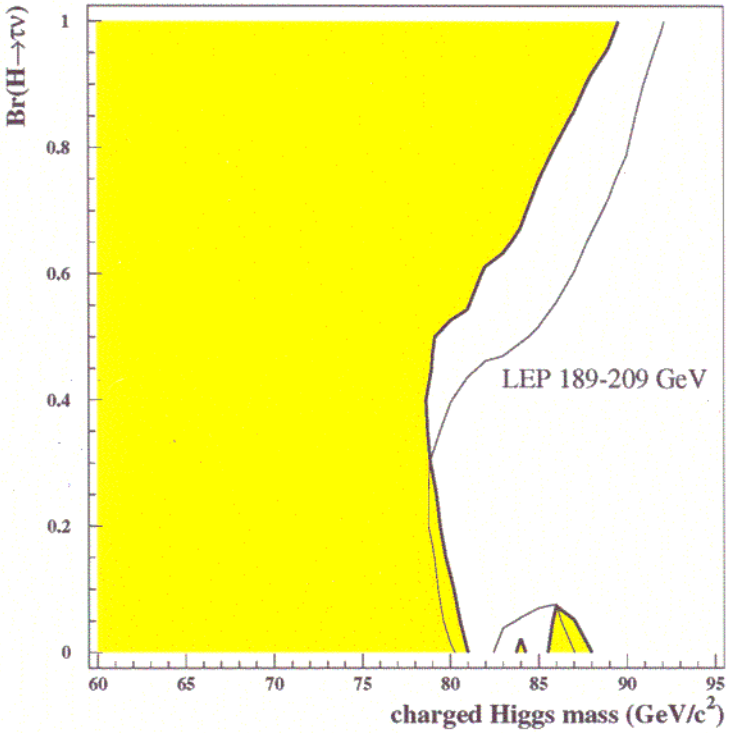
A benchmark has been designed (*Carena et al.* hep-ph/0009212)
(electron and neutron EDM constraints OK) (called CPX scenario)

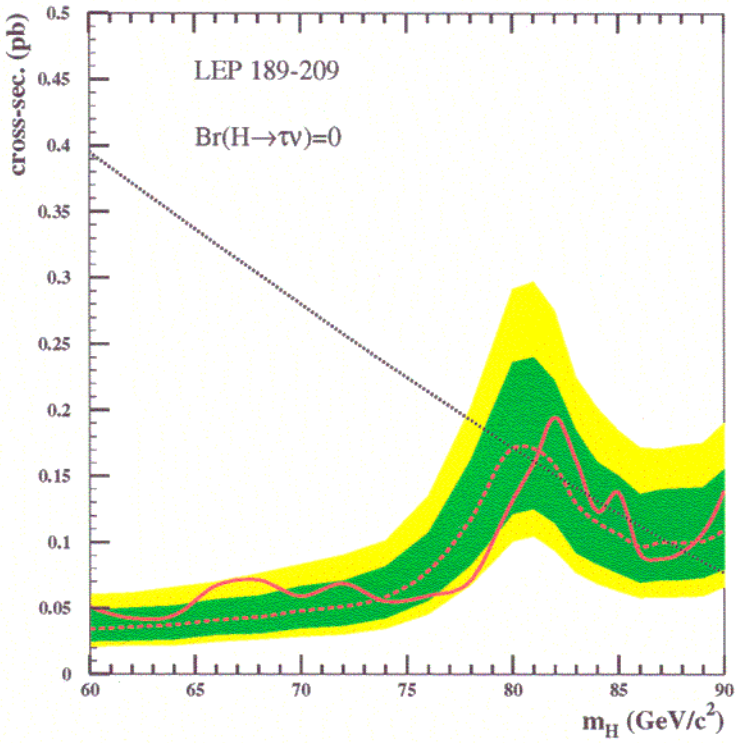
$\tan\beta$	m_{H^+}	μ	m_{SUSY}	m_2	$\lvert A_q\rvert = \lvert m_{\tilde{g}}\rvert$	$\arg(A_q)=\arg(m_{\tilde{g}})$
0.4 - 40	0 - 1 TeV	2 TeV	500 GeV	200 GeV	1 TeV	90°

- regions in red are excluded by Z width constraint or by decay mode ind. searches.
- very sensitive to top mass !



$\mathrm{BR}(\mathrm{H}^+ \to \tau^+\nu)+\mathrm{BR}(\mathrm{H}^+ \to c\bar{s}) = 1$ was the working assumption.

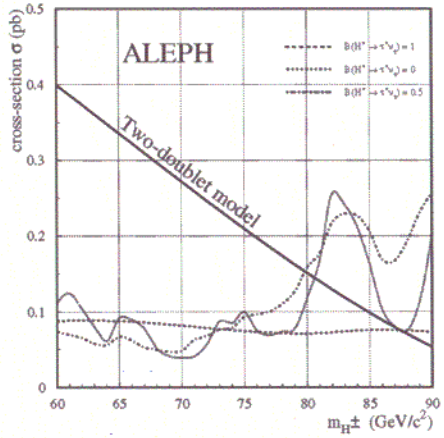


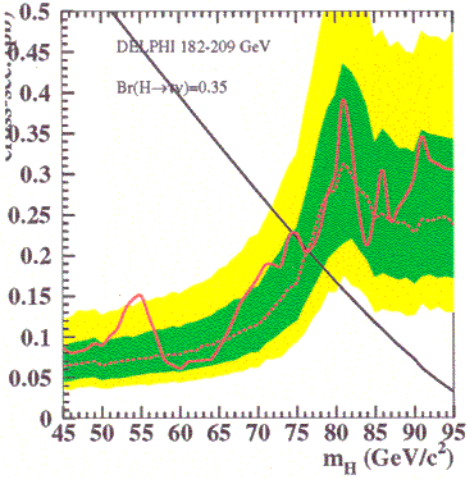


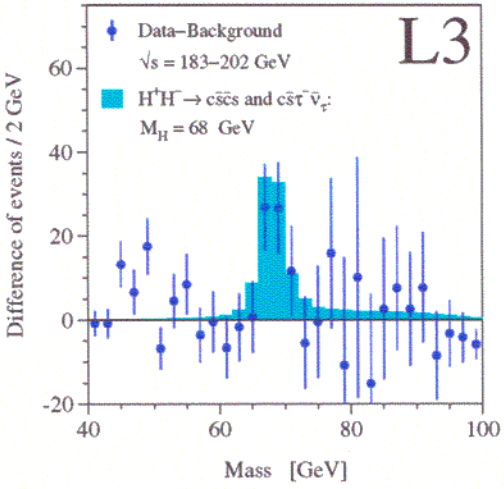
LEP combined limit (summer 2001) was $m_{H^+} > 78.6$ GeV for any BR
The loss of sensitivity near m_W is unavoidable.

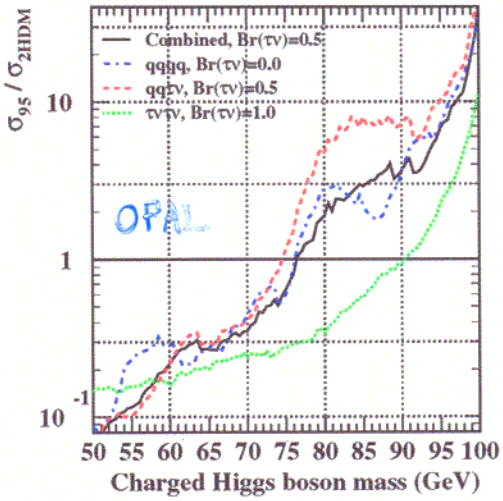
Charged Higgs boson

ALEPH, DELPHI and OPAL produced new results for this conf.
L3 is investigating an excess around 68 GeV, not seen by any other exp.

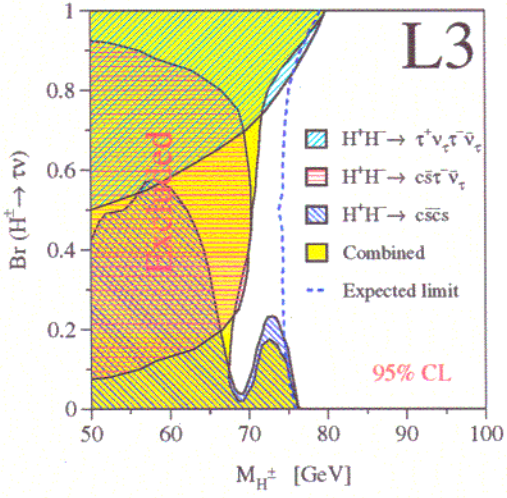






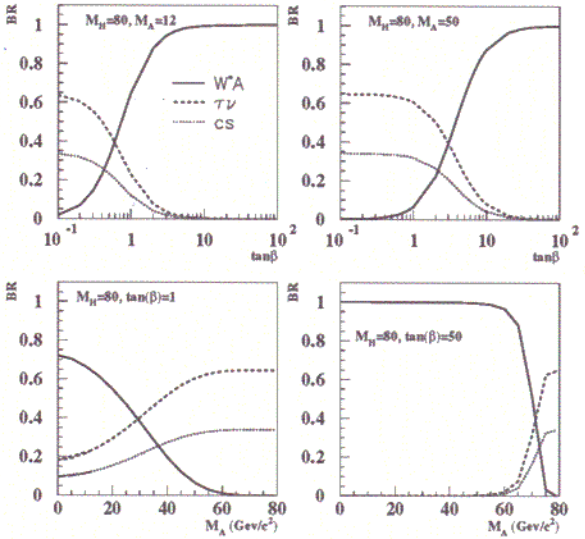


Mass limits are
ALEPH : 79.3 (exp. 77.1)
DELPHI : 74.3 (exp. 76.4)
OPAL : 75.5 (exp. 74.5)

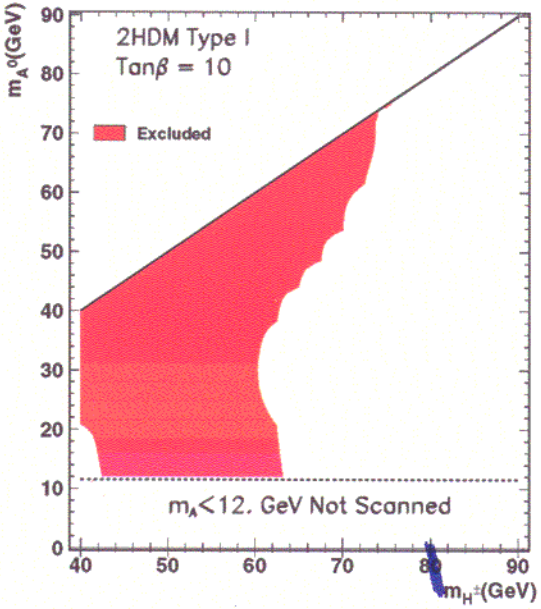


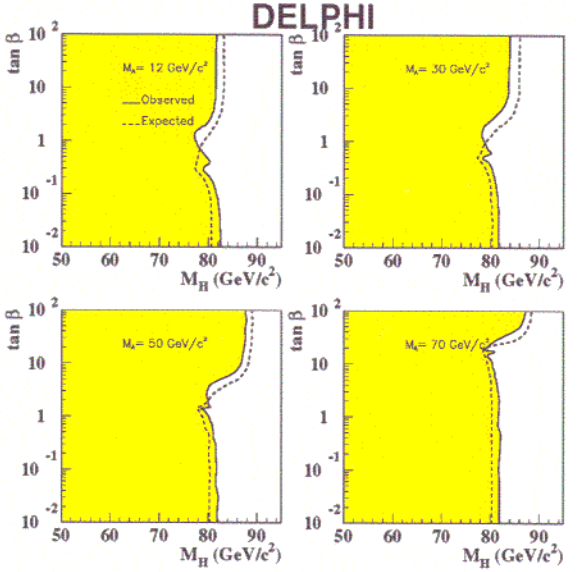
Charged Higgs boson : bosonic decays

In 2HDM type II, BR($H^+ \rightarrow AW^{*+}$) becomes important at low $\tan\beta$.
In 2HDM type I, this decay mode is dominant for $\tan\beta > 1$.
OPAL and DELPHI search for the possible final states of that channel, assuming the A to decay into $b\bar{b}$, and thus $m_A > 12$ GeV.



OPAL

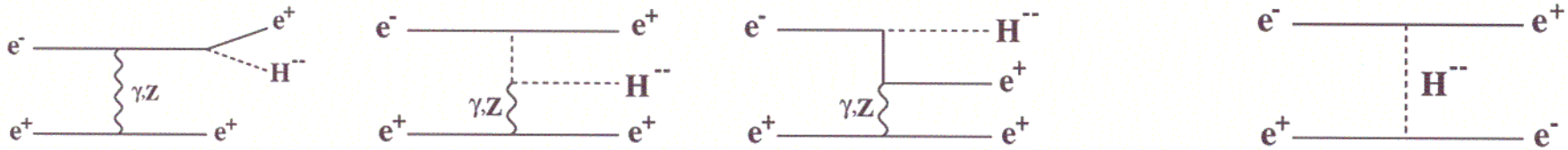




$m_{H^+} > 76.7$ (exp. 77.9) GeV
for any $\tan\beta$ and m_A

Doubly Charged Higgs boson

- $H^{\pm\pm}$ exist in LR symmetric models
- at tree level, $H^{\pm\pm}$ couples only to charged leptons (and bosons)
- thus, both pair-production and single-production are possible at LEP

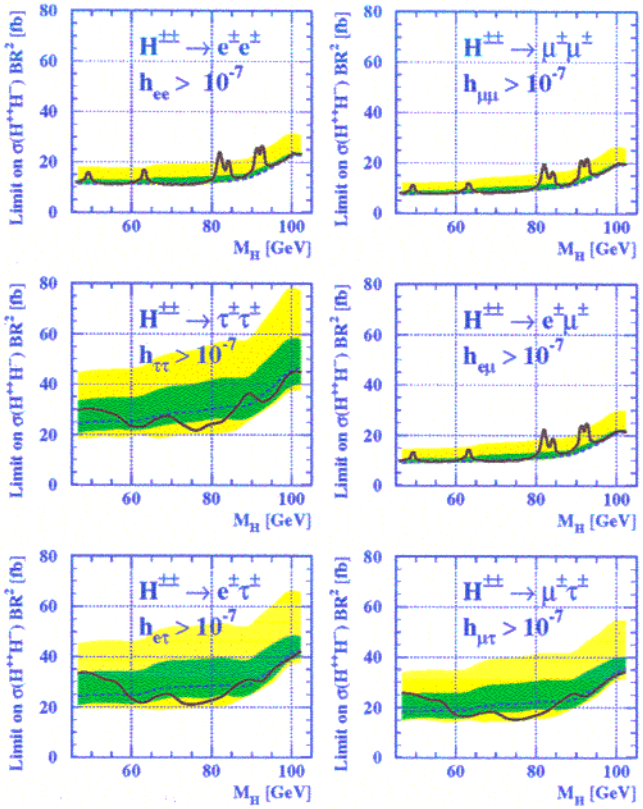


- indirect constraints (Bhabha, FCNC, μ decay), thus $\tau\tau$ decay interesting.
- if $h_{\tau\tau} > 10^{-7}$, decay at interaction point.
- OPAL searched for all possible decays assuming decay at IP
  DELPHI only for $\tau\tau$ decays but for all lifetimes
- OPAL (new) looked also for single-production and constraints from Bhabha scattering.

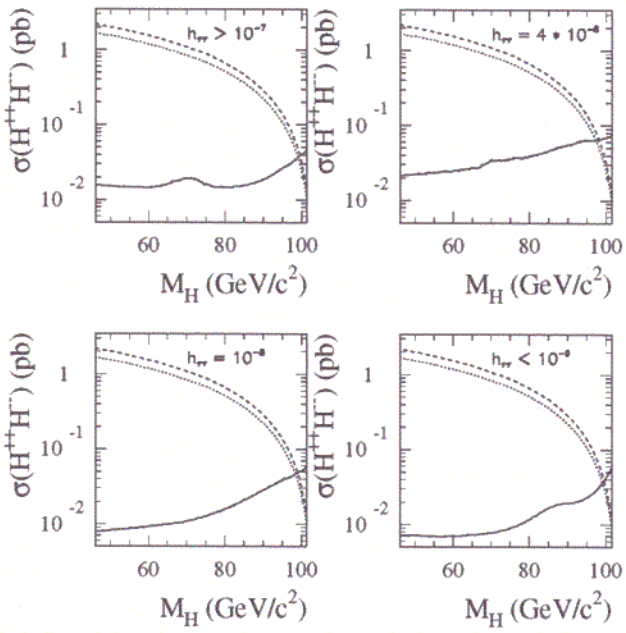
OPAL/DELPHI set limits for $h_{\tau\tau} > 10^{-7}$ at

$m_{H_L^{++}} > 99.0/99.6$ GeV $m_{H_R^{++}} > 98.5/99.1$ GeV

OPAL

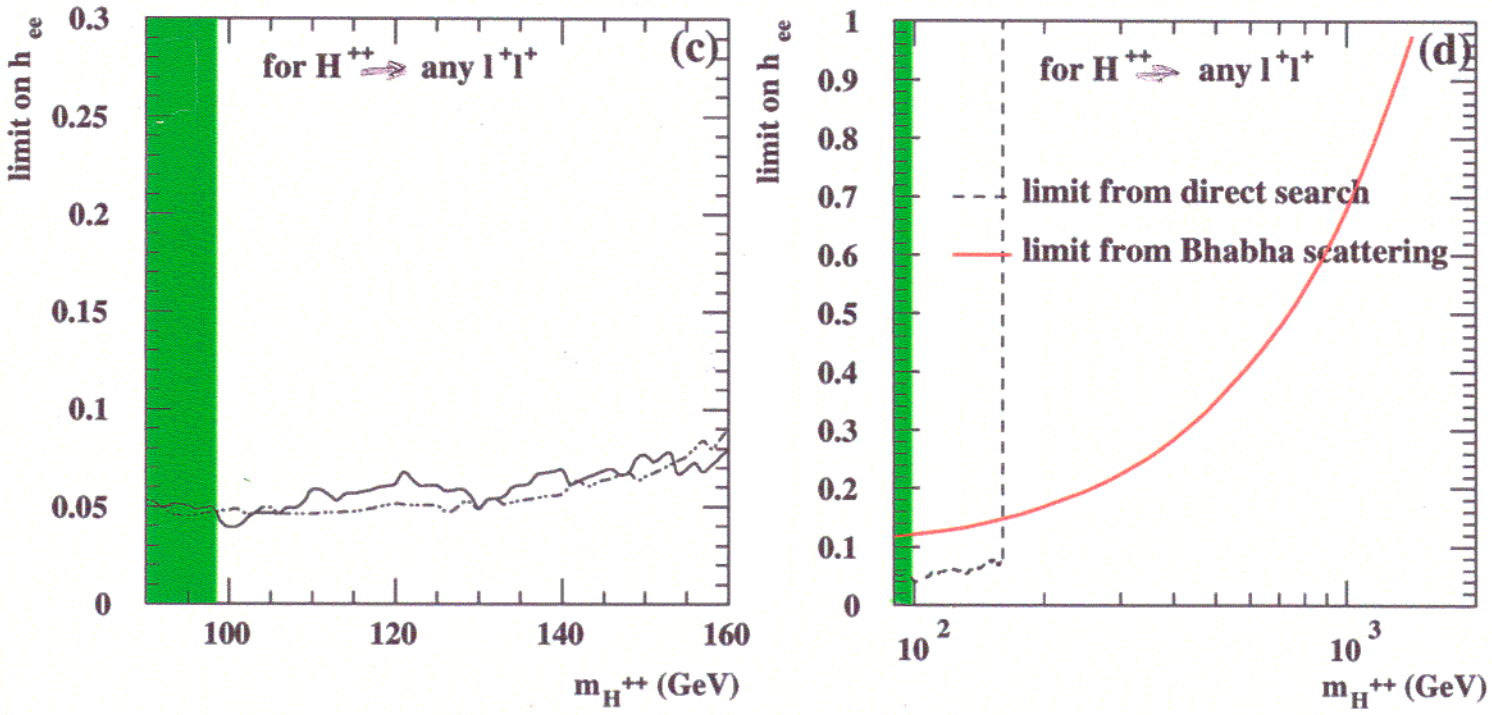


DELPHI



$m_{H^{++}} > 97.3$ GeV for any lifetime.

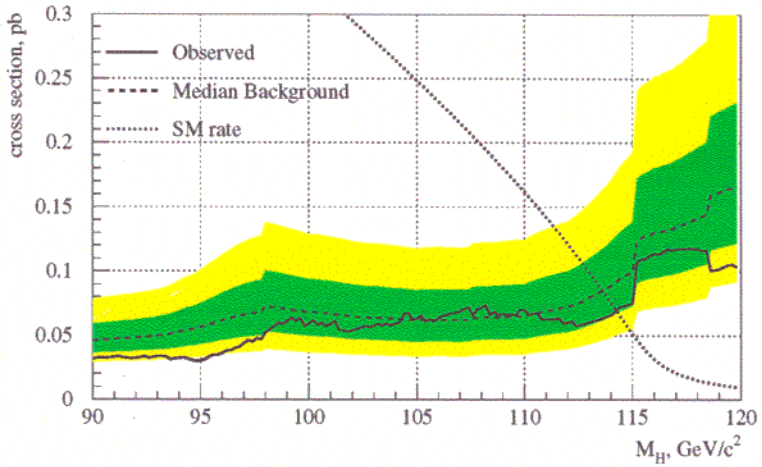
Singly produced H^{++}



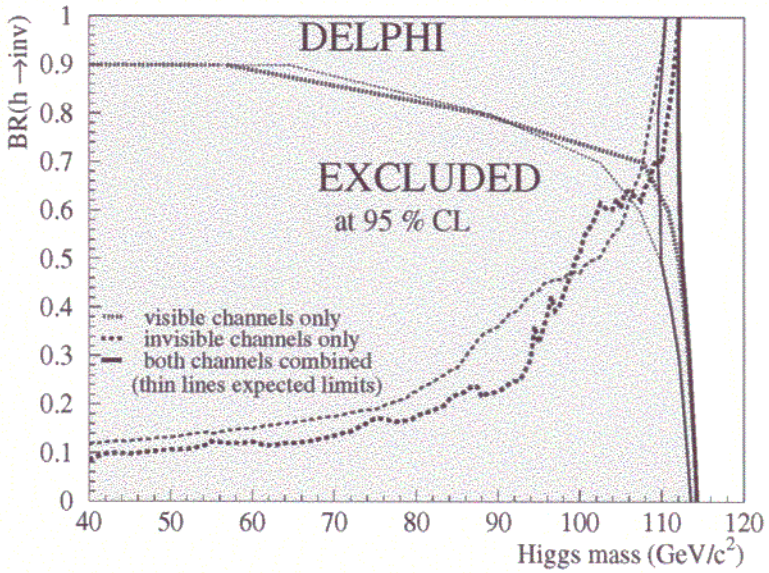
- h_{ee} <0.08 for $m_{H^{++}}$ <160 GeV
- also indirect constraints from Bhabha scattering.

Higgs boson with invisible decays

- in SUSY, $h \to \chi_1^0 \chi_1^0$ can be opened
- search for acoplanar jets or leptons



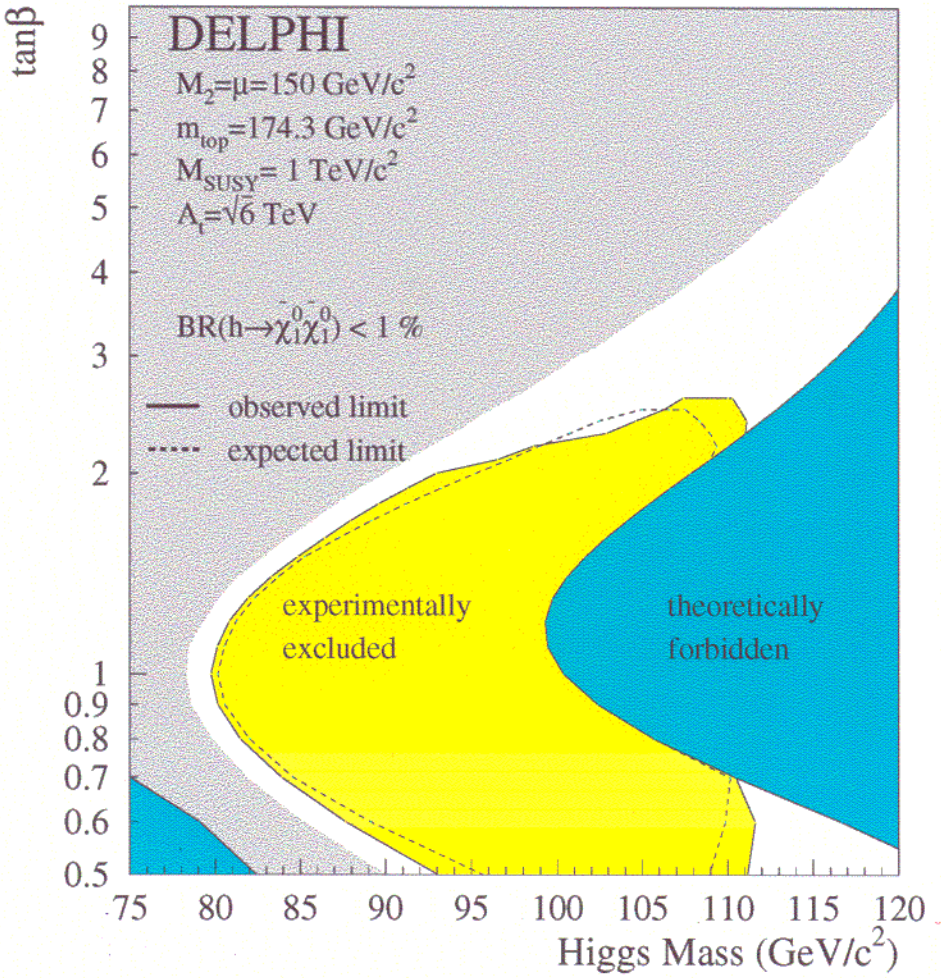
LEP combination 2001
$m_h > 114.2$ (expected 113.6) GeV
for BR(h $\to$ invis.) = 100%



DELPHI new and final
$m_h > 112.0$ GeV
for any BR(h $\to$ invis.)

Impact on the MSSM

such a set of MSSM parameters shows that this decay should be included in a more general scan.



Summary

- Various models for Higgs bosons beyond the SM have been examined
- No evidence for any signal has been found

- Large amount of LEP2 data ($\sim 3000 pb^{-1}$) allows to set stringent limits on Higgs masses/cross-sections.

- Very interesting new ideas appear for this conference
  (bosonic decay of the charged Higgs, doubly-charged, CPX scenario, ...)

- All combinations are still to come, in particular for the MSSM.

STAY tuned !