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Exotic or 2HDM Higgs at LEP

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representing the LEP collaborations

Introduction

No evidence of Higgs → motivation for new extensions

In this presentation:

- Anomalous Higgs vector boson couplings
- Higgs decays into invisible particles
- Different scenarios of 2HDM
- Doubly charged Higgs bosons

Results shown here include data collected by the four LEP experiments up to last year (up to 202 GeV)

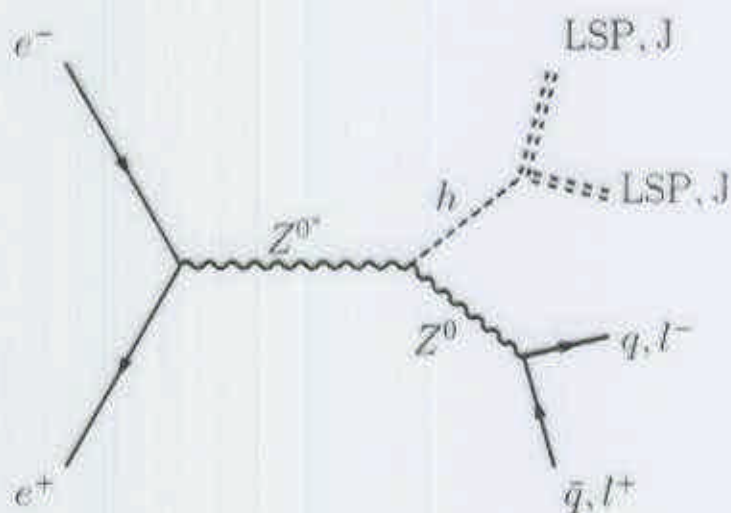
Results are preliminary

New results of this year data and new combinations of the four experiments will be shown later in dedicated presentations

H \rightarrow invisible

Higgs decay to invisible (or nearly invisible) particles:

- $e^+e^- \rightarrow Z^0 h^0 \rightarrow Z \chi_1^0 \chi_1^0$
- $e^+e^- \rightarrow Z^0 h^0 \rightarrow Z J J$
- $e^+e^- \rightarrow Z^0 h^0 \rightarrow Z \chi_1^0 \chi_2^0 \rightarrow Z \chi_1^0 \chi_1^0 Z^*/\gamma$

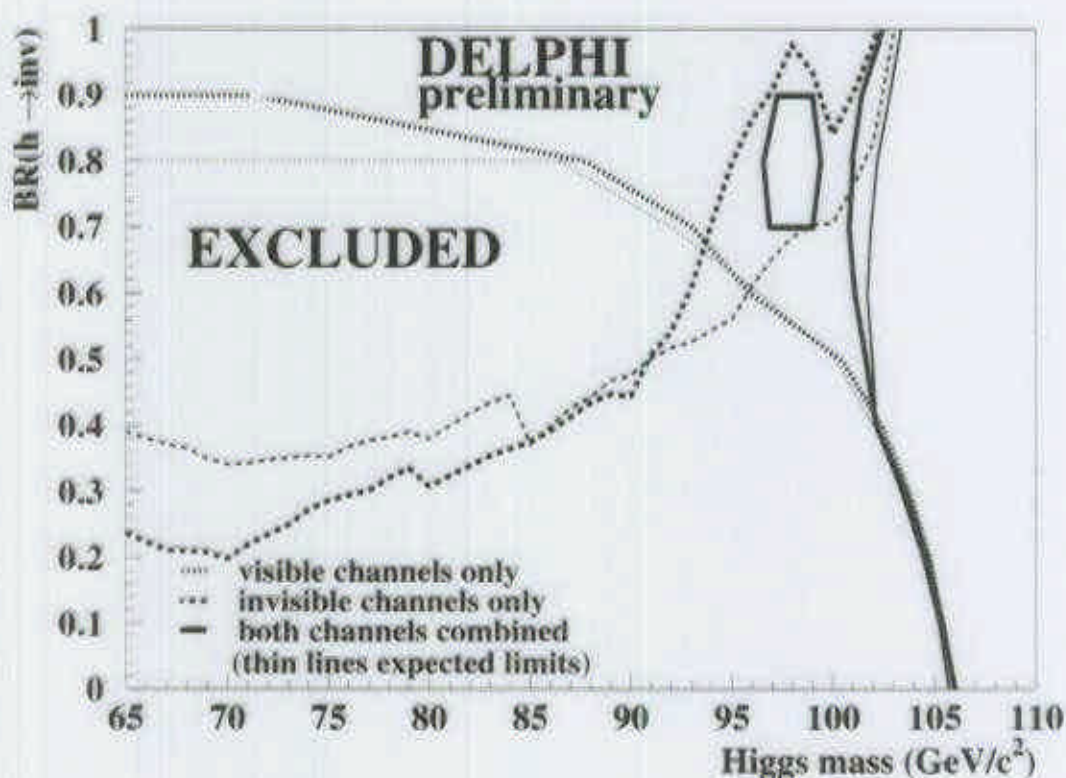


Analysis based on reconstruction of the recoil mass

Results on $H \rightarrow \text{invisible}$

Preliminary lower mass limits for Higgs boson with SM cross-section and 100% invisible decay branching ratio

- ALEPH 106.4 GeV/c^2
- DELPHI 102.5 GeV/c^2
- L3 100.5 GeV/c^2
- OPAL 101.0 GeV/c^2



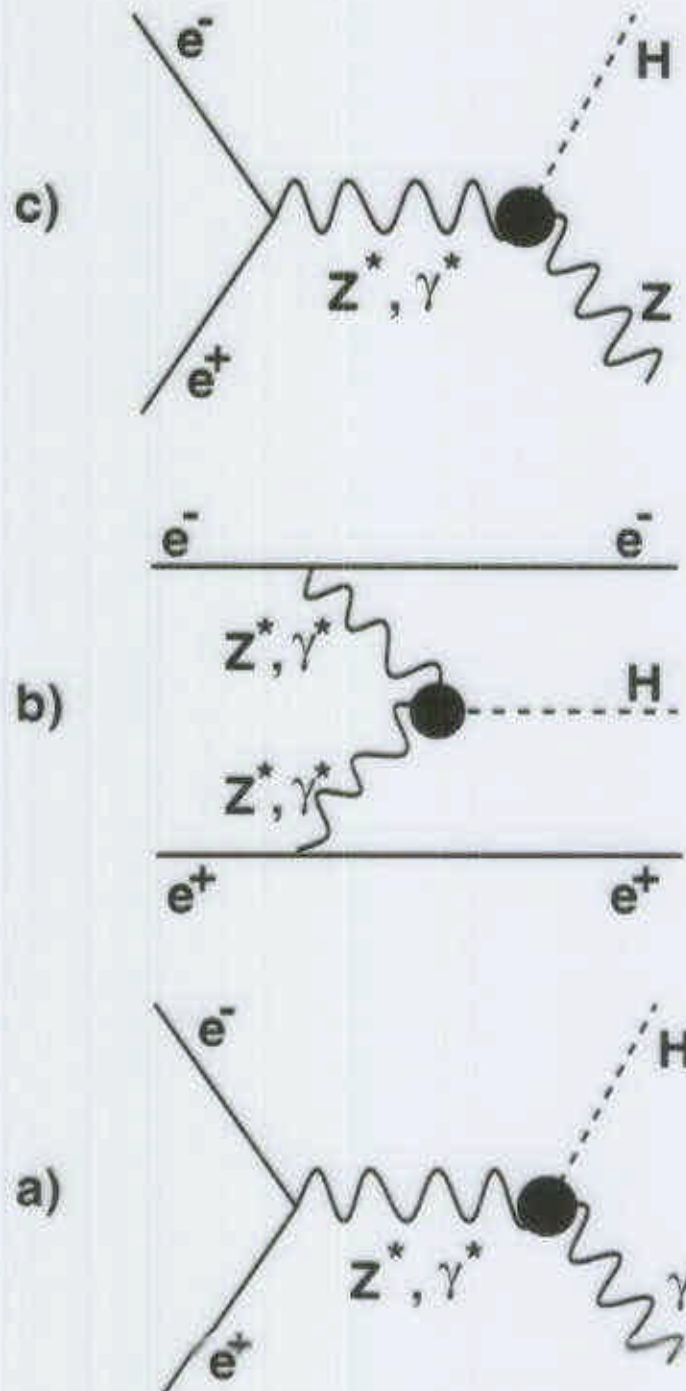
Invisible results combined with visible Higgs analyses: lower mass limit for any BR 96.6 GeV/c^2

Anomalous Higgs couplings

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Anomalous $HZ\gamma$, $H\gamma\gamma$ and HZZ couplings:

- $BR(H \rightarrow \gamma\gamma)$
- $\sigma(e^+e^- \rightarrow H\gamma)$ or $\sigma(e^+e^- \rightarrow e^+e^-H)$ or $\sigma(e^+e^- \rightarrow HZ)$

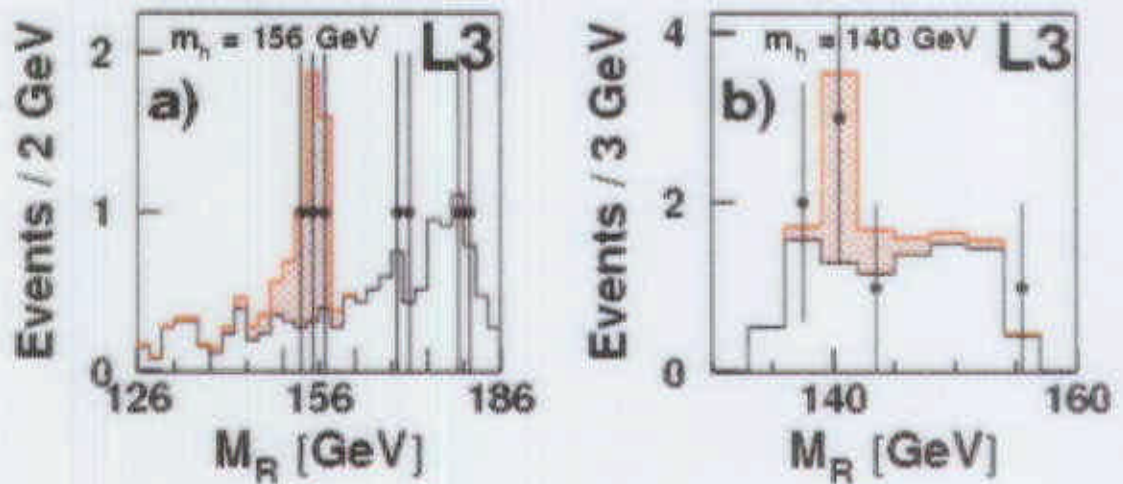


Search for anomalous Higgs couplings

Experimental signatures:

- Extend the mass range for H search
- Excess of events with one, two or three photons
- Monochromatic peak in single photon energy spectrum
- Resonance in di-photon mass spectrum

Reconstructed mass for $\gamma\gamma\gamma$ and $b\bar{b}\gamma$ final states



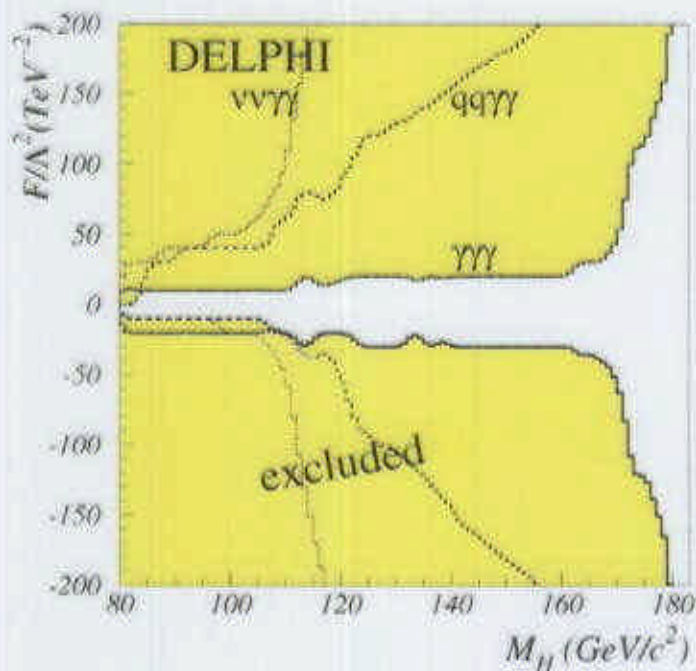
Limits on anomalous couplings

Limits for the coefficients defining the anomalous couplings can be set

$$\mathcal{L}_{eff} = \sum_{i=1}^n \frac{f_i}{\Lambda^2} O_i$$

where the O_i are the operators representing the anomalous couplings. Λ is the typical energy scale of the new interactions and f_i are the constants defining the strength of each term

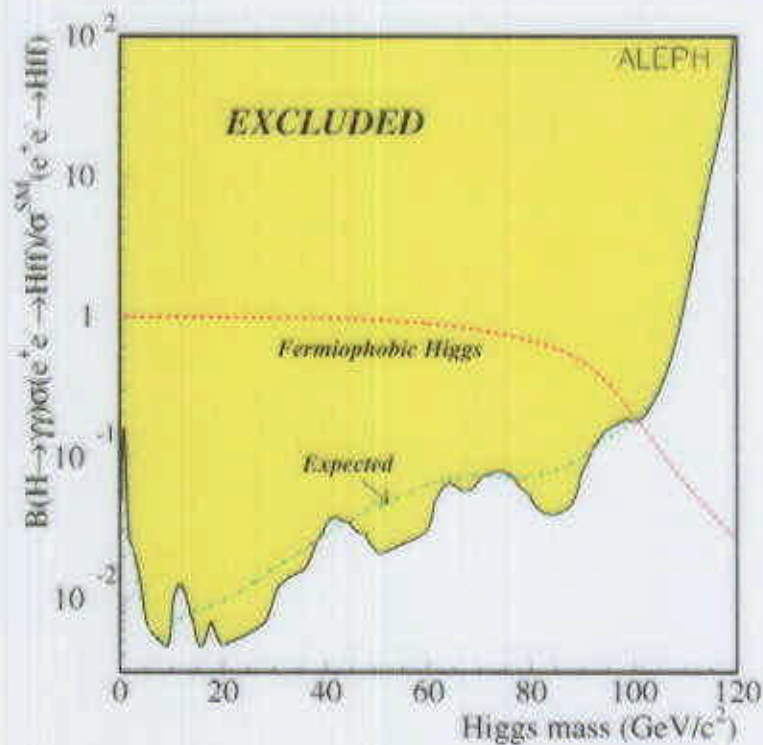
DELPHI limit for anomalous couplings with the assumption of all f_i having a common value F (six operators: $f_{\phi,1}$, f_{BW} , f_B , f_W , f_{BB} and f_{WW})



Limits on $H \rightarrow \gamma\gamma$

Preliminary lower mass limits for a Higgs boson with SM production cross-section and no coupling to fermions (fermiophobic scenario):

- ALEPH 100.7 GeV/c²
- DELPHI 96 GeV/c²
- L3 99.2 GeV/c²
- OPAL 102.3 GeV/c²



2HDM models

Experimental constraints for extensions of SM

$$\rho = \frac{m_W^2}{m_Z^2 \cos^2 \theta_w} \sim 1 \rightarrow \text{additional doublets}$$

Most natural extension is 2HDM (MSSM is an example)

Absence of flavour changing neutral currents

→ limited fermionic couplings:

- Type II: the first doublet ϕ_1 couples to the down type fermions and the other doublet ϕ_2 couples to up type fermions.
- Type I : only the second doublet ϕ_2 couples to fermions.

Production and decay modes depend on masses and parameters α and β

Two complementary processes for lightest neutral Higgs bosons:

- $e^+e^- \rightarrow h^0 Z^0 : \sigma_{h^0 Z^0} = \sin^2(\beta - \alpha) \sigma_{HZ}^{SM}$
- $e^+e^- \rightarrow h^0 A^0 : \sigma_{h^0 A^0} = \cos^2(\beta - \alpha) \bar{\lambda} \sigma_{\nu\nu}^{SM}$

where $\bar{\lambda}$ is the phase space suppression factor near the threshold

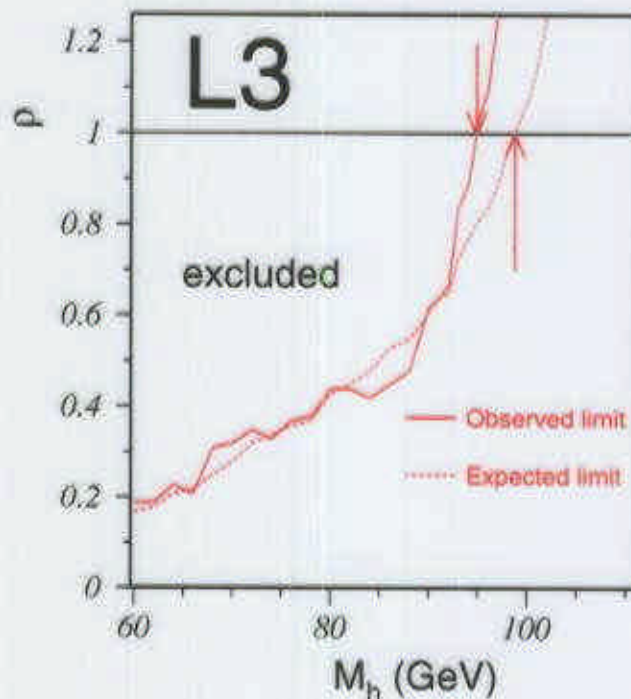
Searches for 2HDM(II) h^0, A^0

Different final states analysed to scan α, β and Higgs boson masses (complemented by Z^0 width measurements)

- $h^0, A^0 \rightarrow b\bar{b}, \tau^+\tau^-$
- $h^0, A^0 \rightarrow q\bar{q}, gg$
- $h^0 \rightarrow A^0A^0 \quad (m_{A^0} < m_{h^0}/2)$

Limits given as multidimensional parameter scans or projections with some parameter assumptions

Limit for $\sigma(e^+e^- \rightarrow hZ \rightarrow q\bar{q}f\bar{f})$

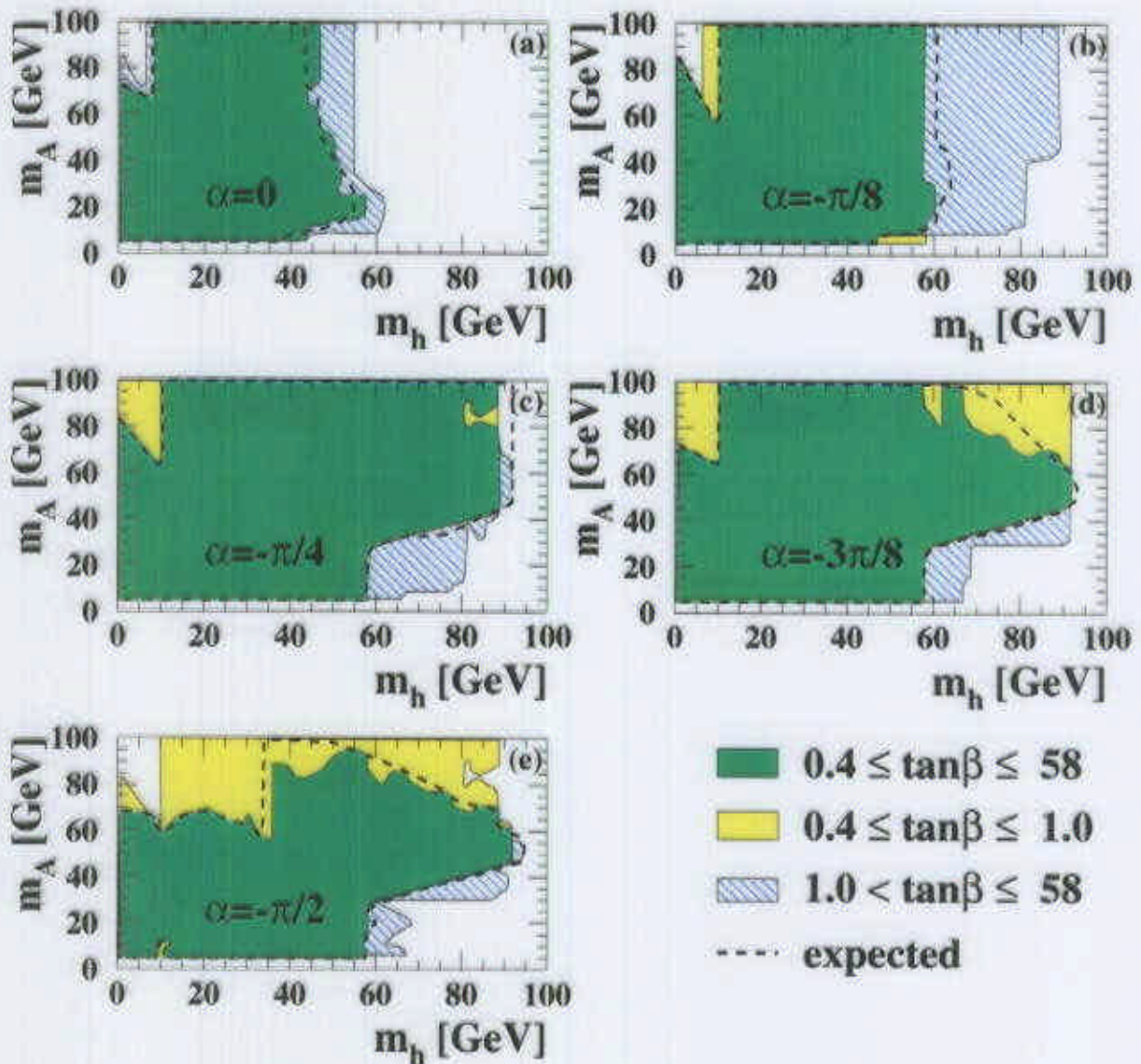


L3: $\sigma(e^+e^- \rightarrow h^0Z \rightarrow q\bar{q}Z)$ below SM value for $m_{h^0} < 94.8 \text{ GeV}/c^2$

Parameter scans of 2HDM

Parameter scan with free m_h , m_A and different values of $\tan\beta$ and α

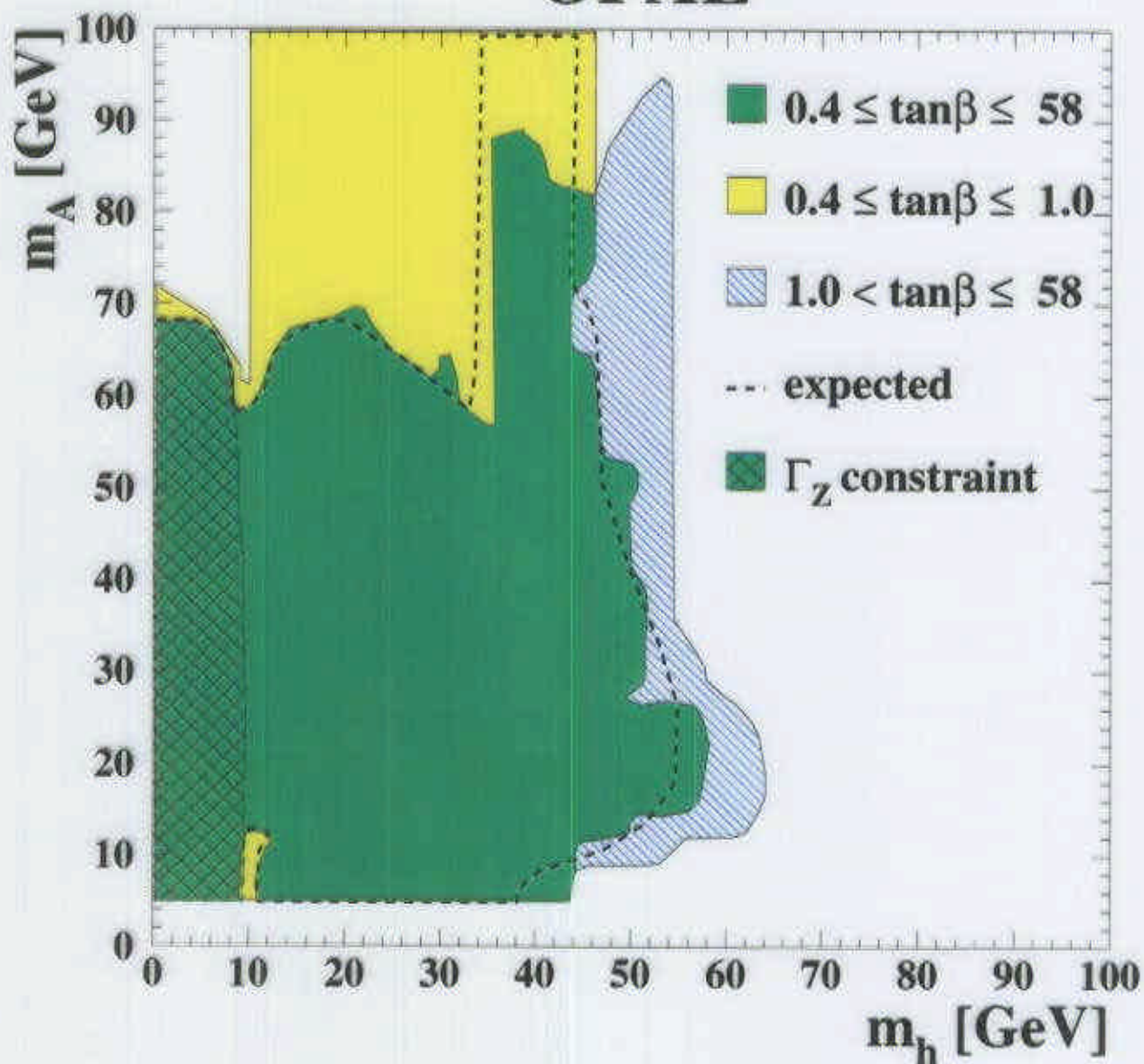
OPAL



Parameter scans of 2HDM

α independent scan of m_h , m_A and $\tan\beta$

OPAL

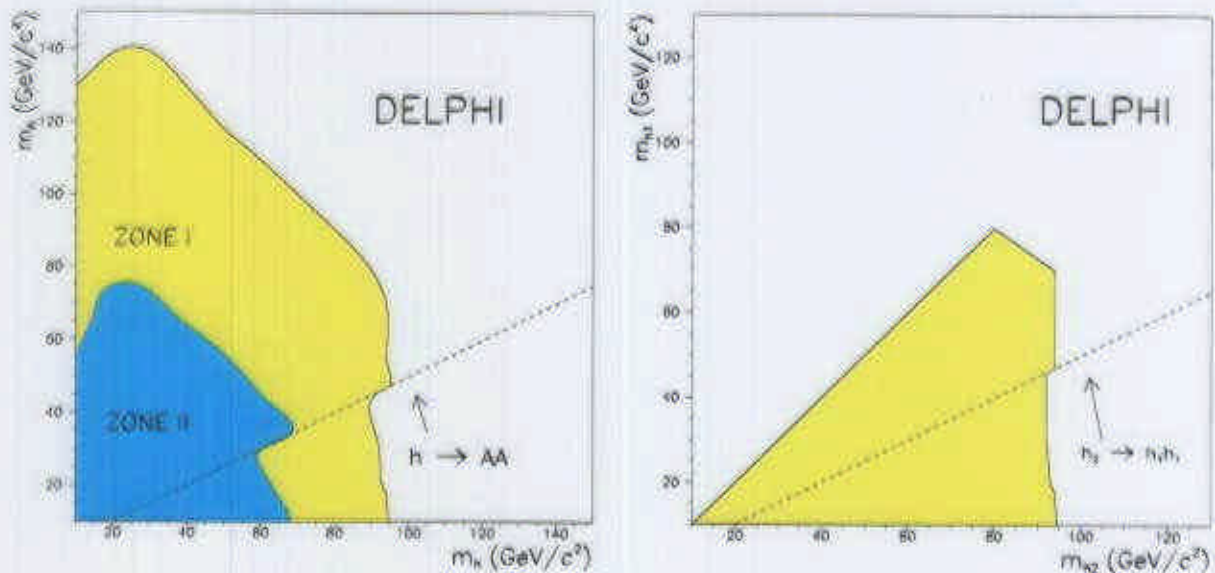


CP-violation in 2HDM

CP violation in the SUSY sector: three neutral Higgs bosons (h_1 , h_2 and h_3 sorted in mass) with undefined CP properties

Sum rule holds: $C_{h_1 Z}^2 + C_{h_2 Z}^2 + C_{h_1 h_2}^2 = 1$.

Limits in CP conserving and CP-violating 2HDM. Higgs decays to $b\bar{b}$ (yellow) or any $q\bar{q}$ (blue). DELPHI data up to 189 GeV.

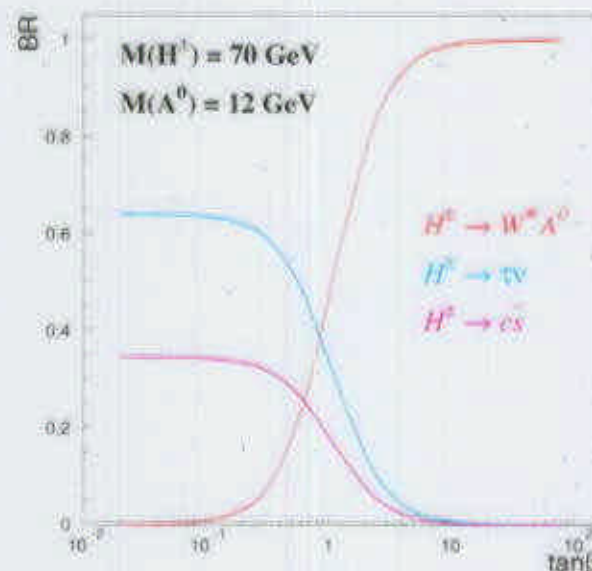


H^+H^- in 2HDM(I)

Masses below $40 \text{ GeV}/c^2$ excluded by Z width measurements
 \rightarrow consider masses above $40 \text{ GeV}/c^2$

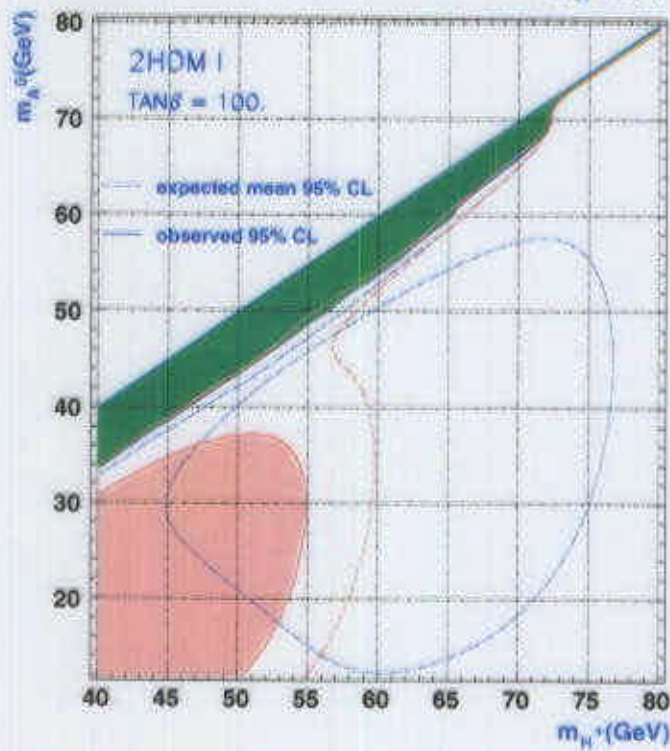
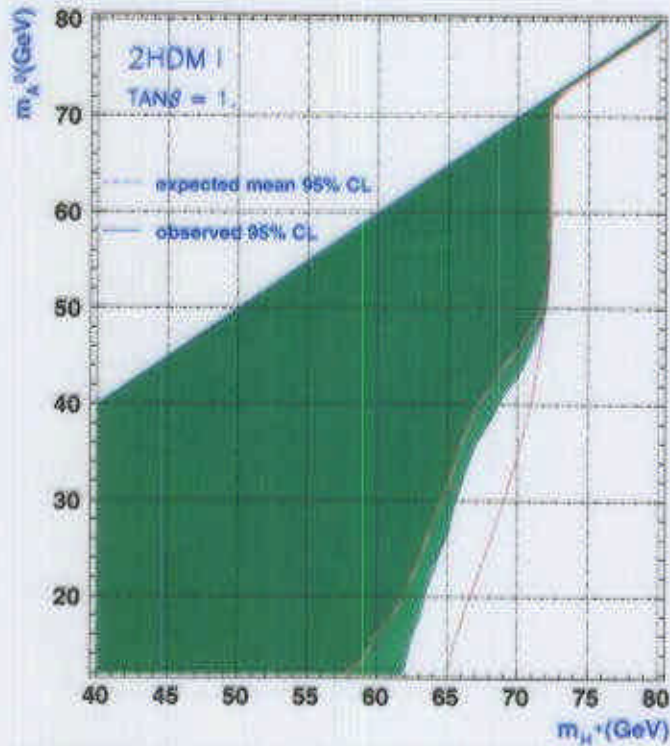
2HDM(I) charged Higgs boson at LEP:

- All fermions couple to the same Higgs doublet, making $H^+ \rightarrow W^+ A^0$ the dominant decay mode at high $\tan(\beta)$.
- Both fermionic and bosonic decays considered to scan the parameter space
- Use the $q\bar{q}q\bar{q}$, $q\bar{q}\tau\nu$, $\tau\nu\tau\nu$ analyses
- Search for additional multijet final states ($W^+ \rightarrow q\bar{q}(l\nu)$, $A^0 \rightarrow b\bar{b}$)



H^+H^- in 2HDM(I) results

Opal limits for m_{H^\pm} and m_{A^0} in 2HDM(I)



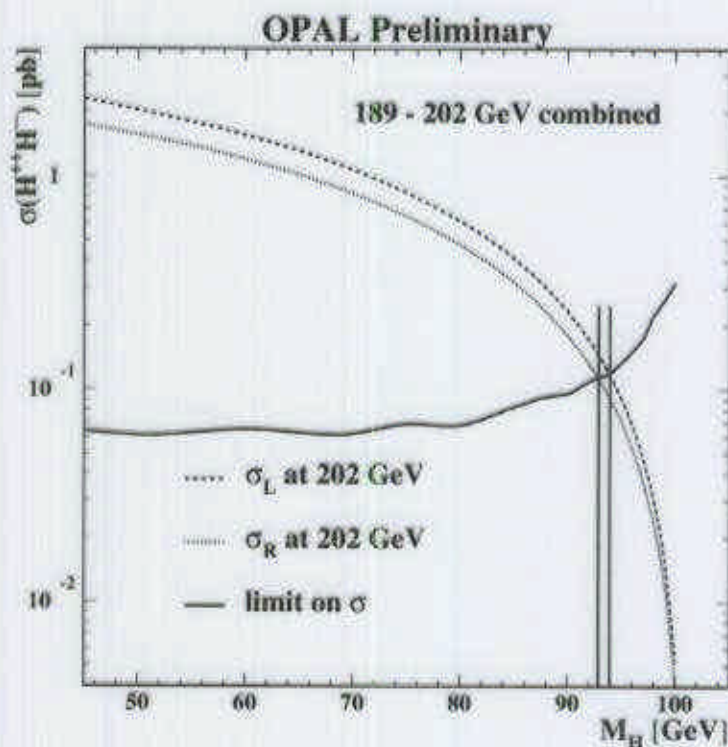
Doubly charged Higgs bosons

Left-right symmetric SUSY models with automatic R-parity conservation can lead to H^{++} of the order of $100 \text{ GeV}/c^2$

Dominant decay to same sign lepton pairs

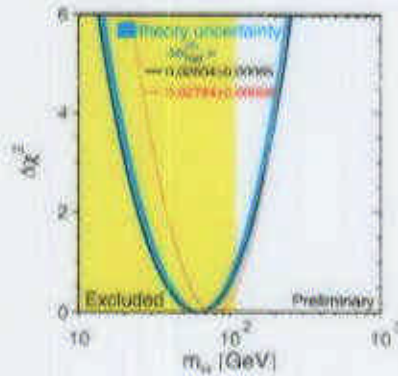
- Stringent limits for $H^{++} \rightarrow e^+e^+$ from high energy Bhabha exchange
- Stringent limits for $H^{++} \rightarrow \mu^+\mu^+$ from the absence of muonium to antimuonium transitions
- Search for $e^+e^- \rightarrow H^{++}H^{--} \rightarrow \tau^+\tau^+\tau^-\tau^-$

OPAL lower mass limit $92.8 \text{ GeV}/c^2$



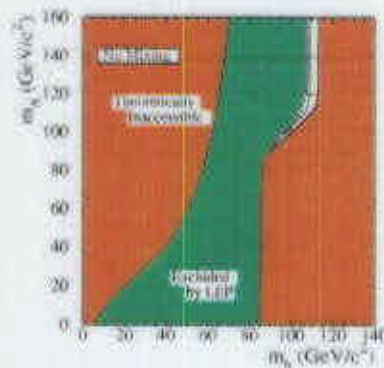
Conclusions

No sign of Higgs in SM



Electro weak fit for SM Higgs mass (by LEP EW working group)

MSSM largely excluded



MSSM scan with no mixing (LEP combination, CERN-EP-2000-055)

Motivation for tests of different extensions

New analyses of more exotic final states

No evidence of signal yet \rightarrow searches continue

Contributions

"Exotic or 2HDM Higgs at LEP"

ICHEP2000 contributions used as material for the presentation:

- Anomalous Higgs couplings (A_260, D_367, L_432, L_415, O_157, O_177)
- $H \rightarrow \text{invisible}$ (A_Moriond2000, D_276, L_434, O_226, O_177)
- Limits for 2HDM(II) (D_102, L_433, O_222, O_227)
- H^\pm in 2HDM(I) (O_223)
- $H^{++}H^{--}$ (O_244)

where (X_123) shows for each contribution the first letter of the name of the LEP experiment (Alep, Delphi, L3 or Opal) and the ICHEP2000 abstract number of the contribution