

# Higgs searches at LEP Part II: Exotic Higgs searches

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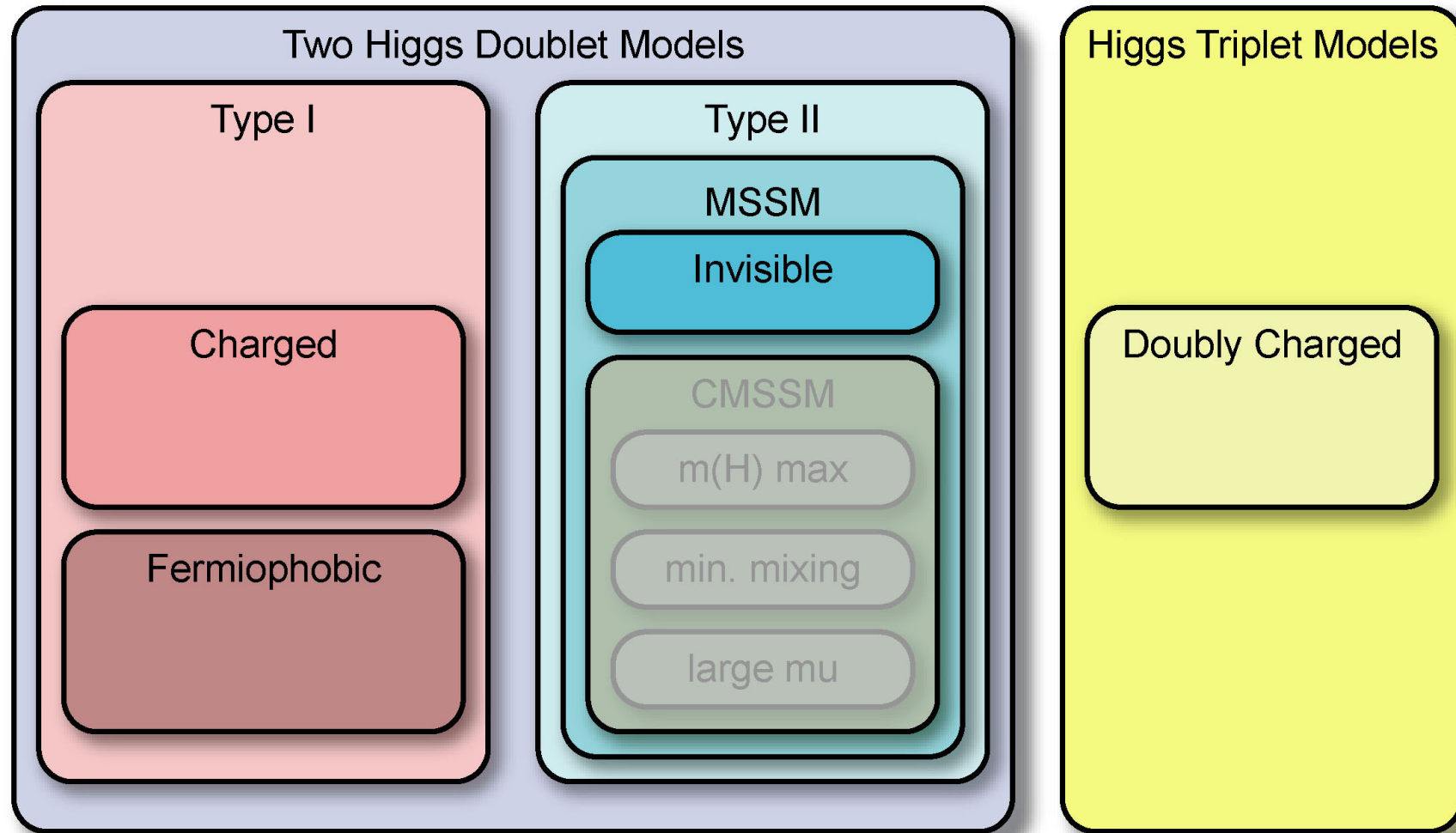


Supersymmetry in the Desert  
June 5-10 2003  
Tucson, Arizona



ETH Institute for  
Particle Physics

# Overview



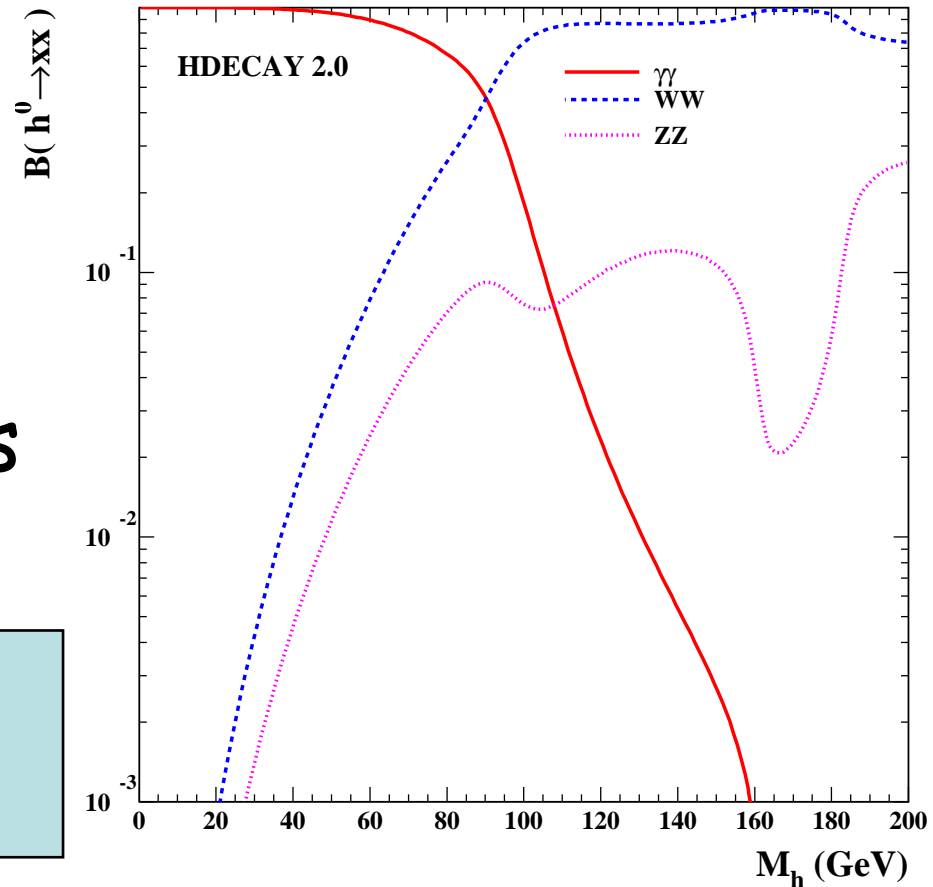
- Fermiophobic Higgs
- Invisible Higgs
- Charged Higgs

- Doubly charged Higgs
- Summary and outlook

# Fermiophobic Higgs: $H \rightarrow \gamma\gamma$

For some parameters in type I 2HDM, the Higgs does not couple to fermions at (tree level)

→ look for bosonic decays



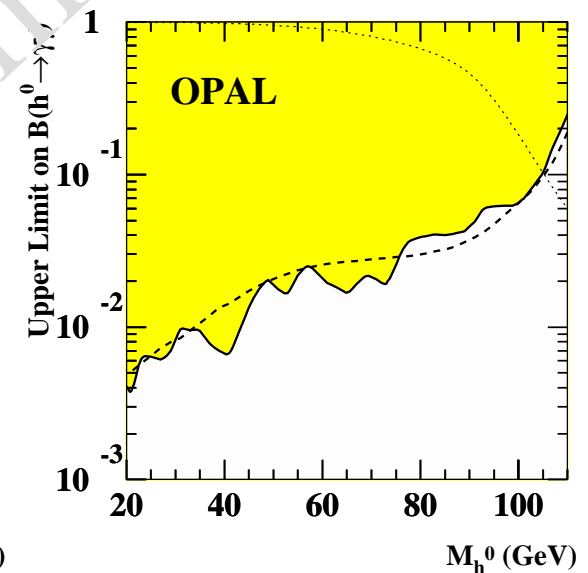
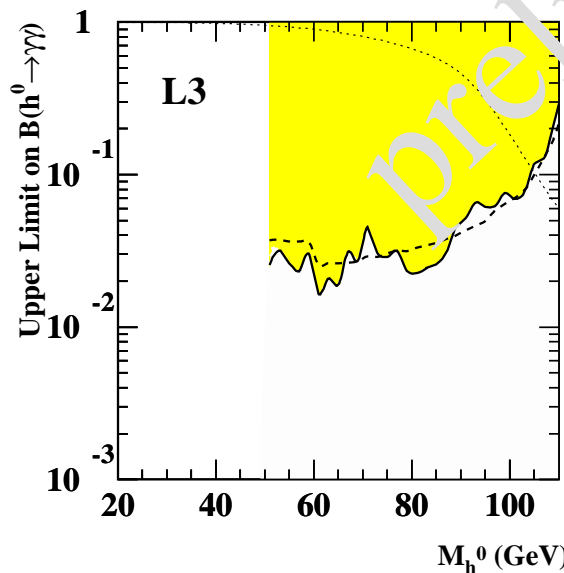
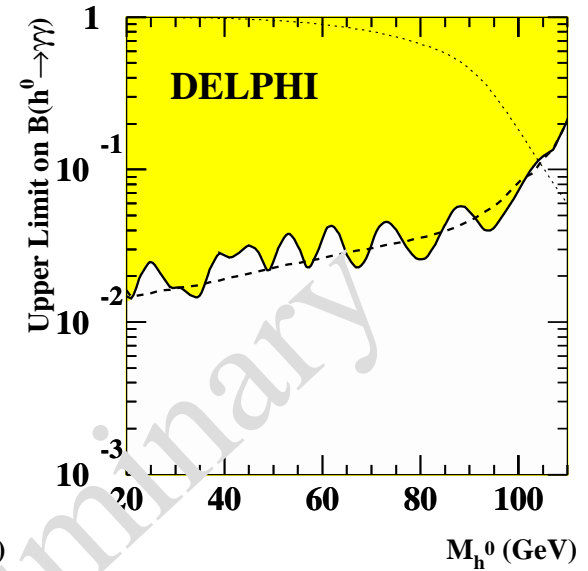
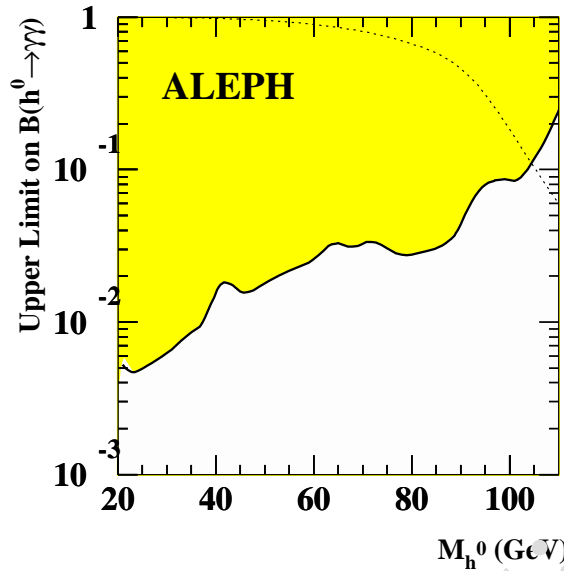
Use SM cross sections and decay channels (without fermions) as a benchmark

# Fermiophobic Higgs: $H \rightarrow \gamma\gamma$

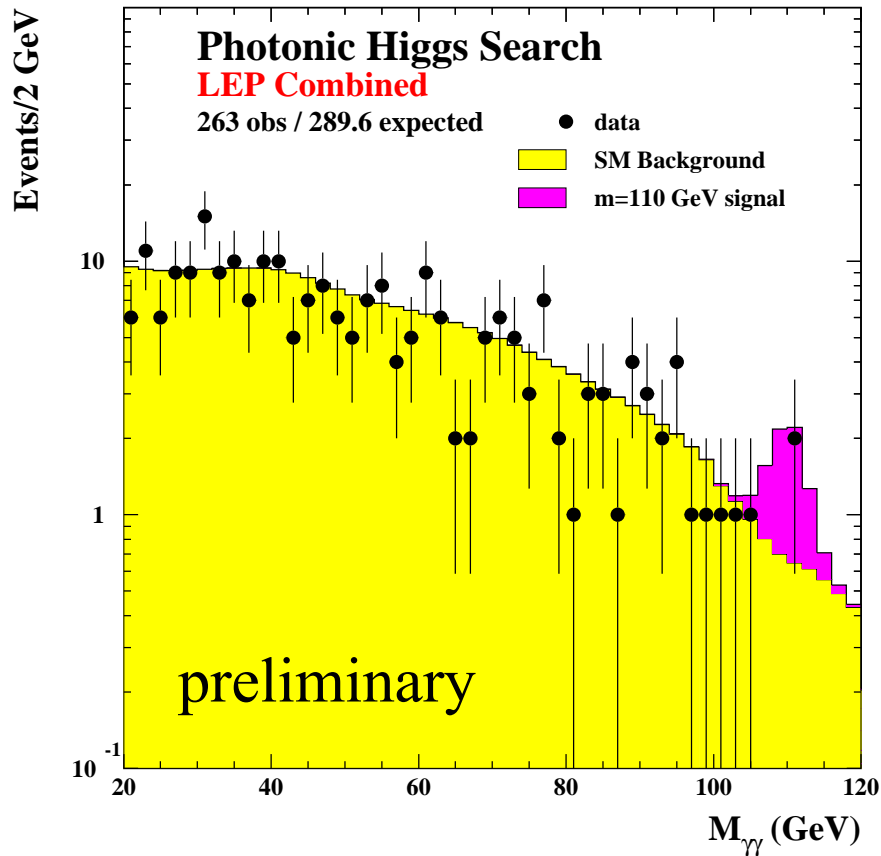
No evidence of a signal seen

Excluded  $\sigma \times BR$  per experiment (expected and observed)

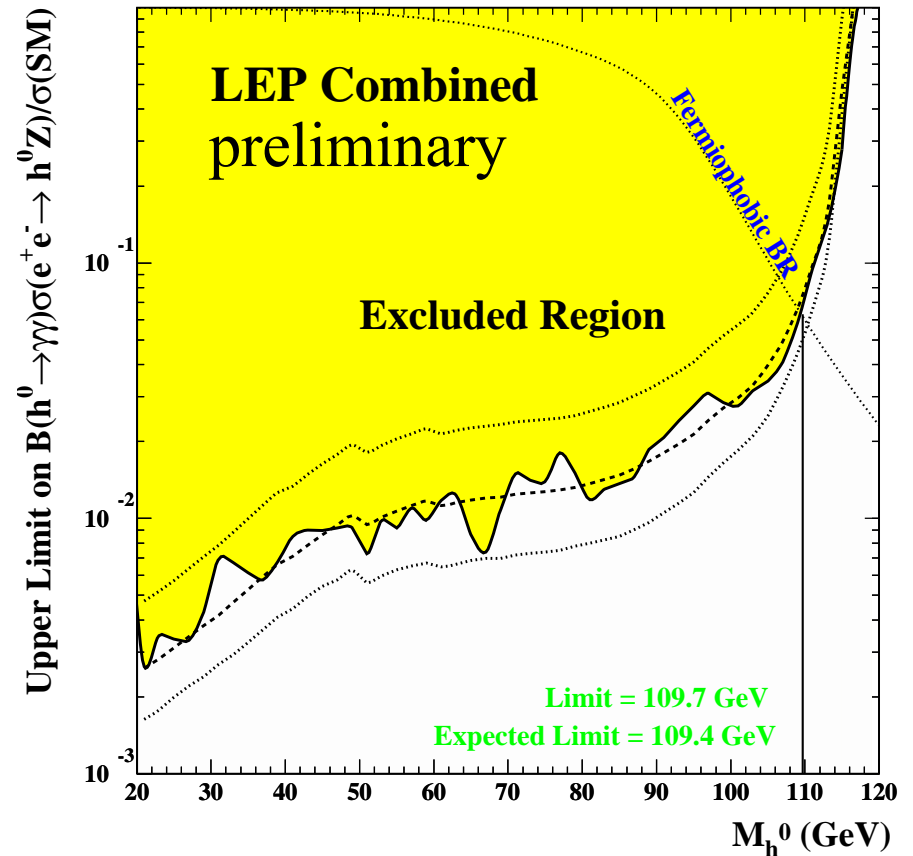
	@95%CL: $m_H > \dots \text{GeV}$
Aleph	104.5
Delphi	104.3
L3	104.7
Opal	105.3



# Fermiophobic Higgs: $H \rightarrow \gamma\gamma$



Higgs candidate mass distribution



Excluded  $\sigma \times \text{BR}$

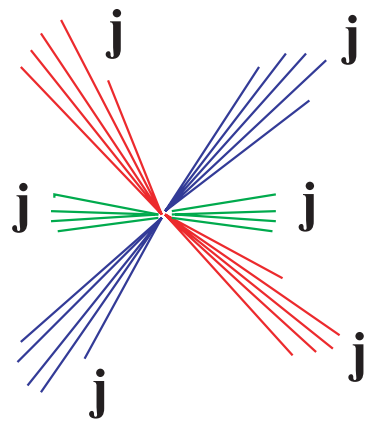
$m_H > 109.7 \text{ GeV (95\% CL)}$   
(preliminary)

# Fermiophobic Higgs: $H \rightarrow WW^*/ZZ^*$

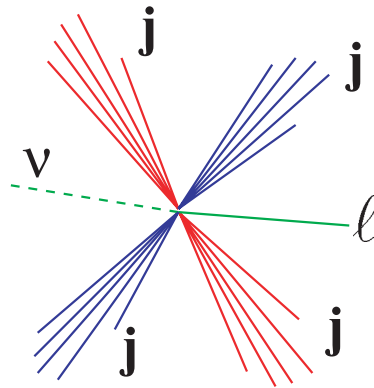
$HZ \rightarrow WW^*Z / ZZ^*Z$  becomes important for  $m_H > 90 \text{ GeV}$

Signatures searched for (92% of all  $HZ \rightarrow WW^*Z$  decays):

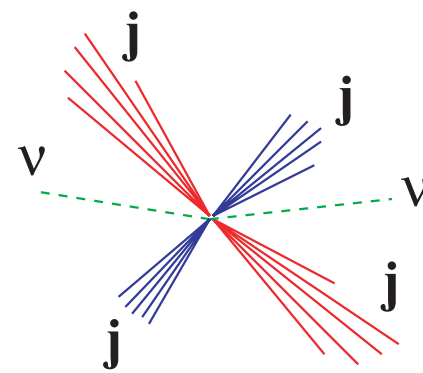
qqqqqq (30%)



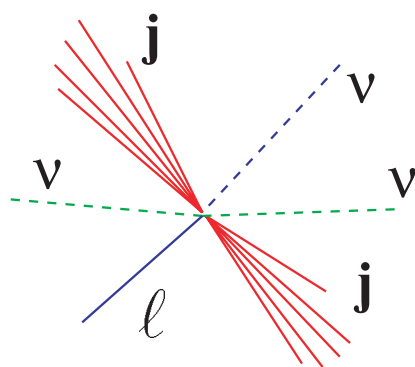
qqqqlv (30%)



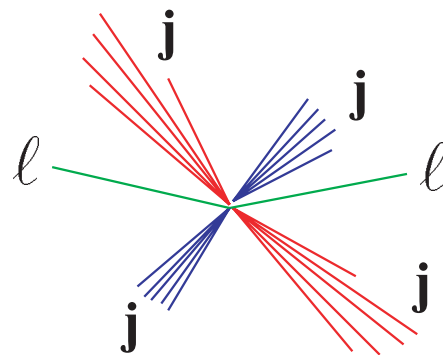
qqqqvv (10%)



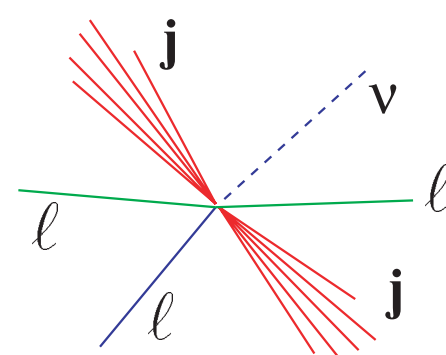
qqlvvv (10%)



qqqqll (6%)

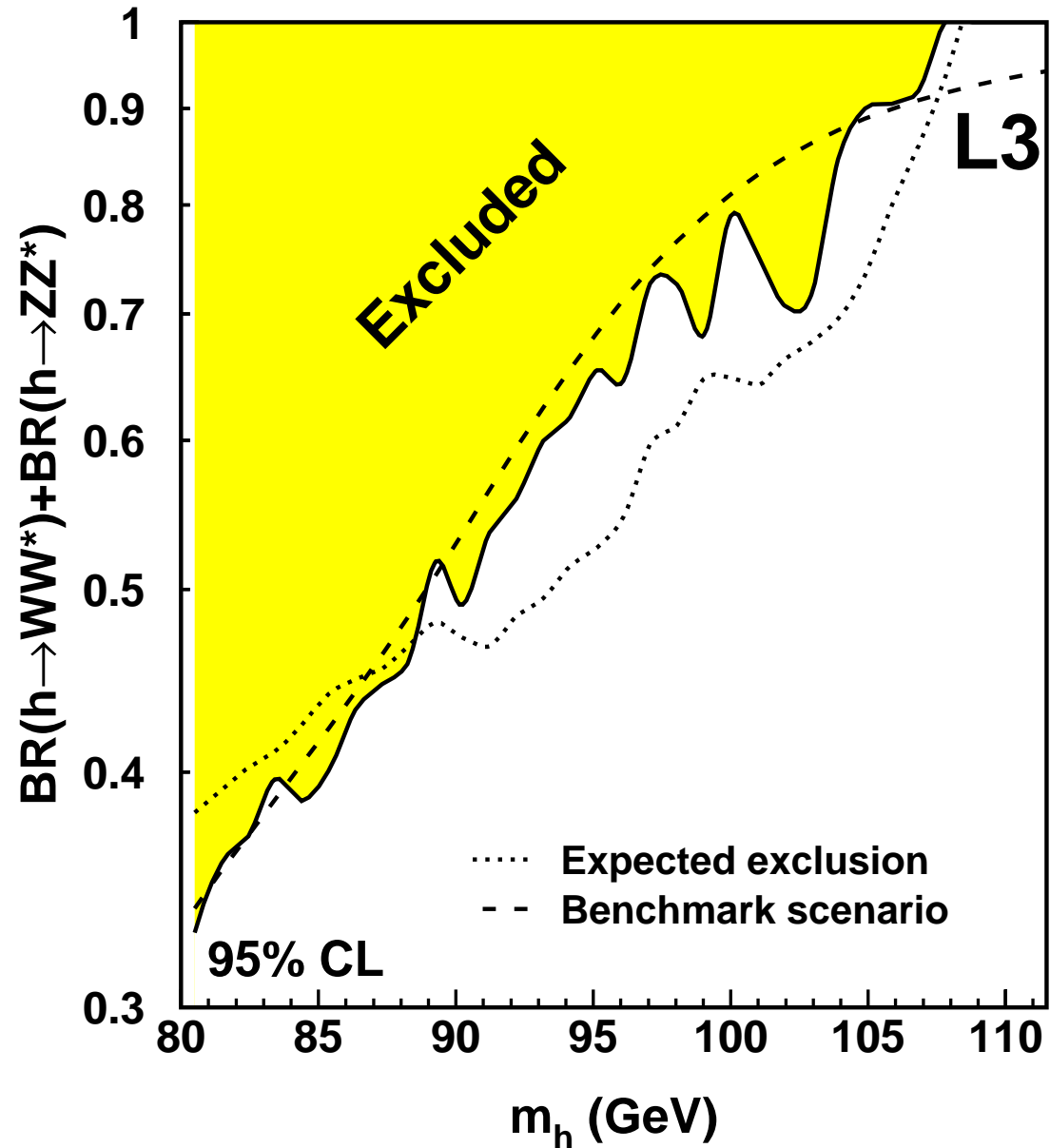


qqlllv (6%)

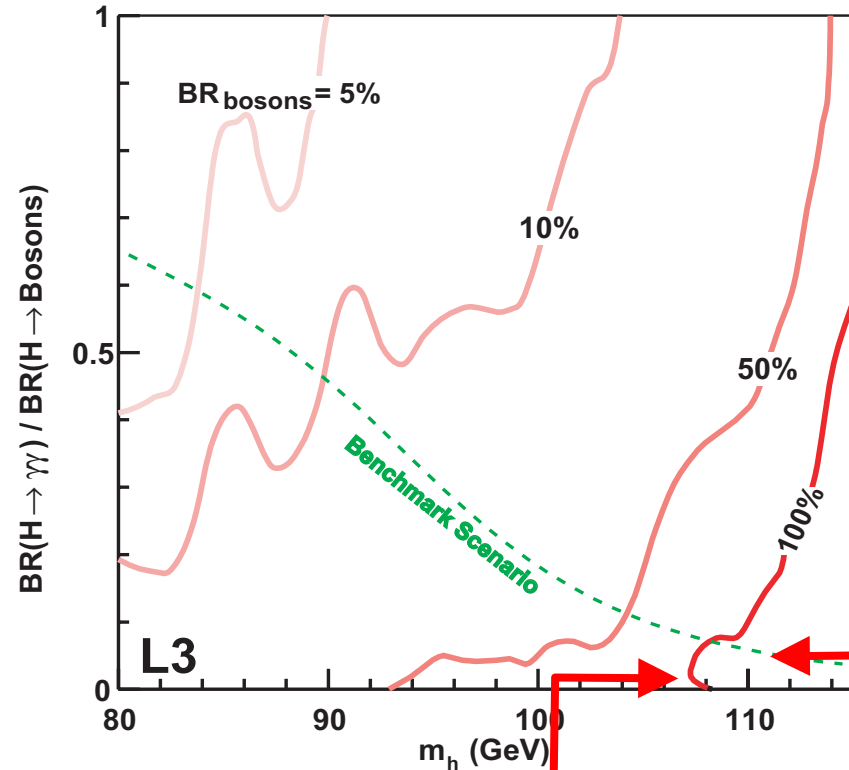
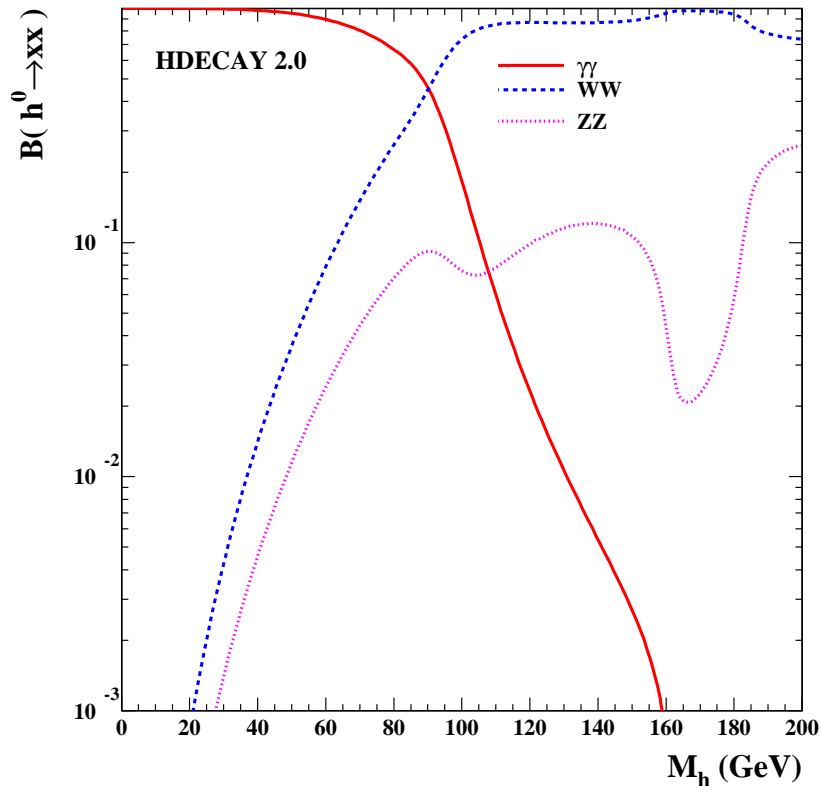


# Fermiophobic Higgs: $H \rightarrow WW^*/ZZ^*$

Exclusion of  $WW^*$   
and  $ZZ^*$  branching  
ratio **assuming only  
bosonic Higgs  
decays**



# Fermiophobic Higgs: $H \rightarrow WW^*/ZZ^*$



Exclusion of  $WW^*$  and  $ZZ^*$  branching ratio leaving the fraction of bosonic Higgs decays as a parameter

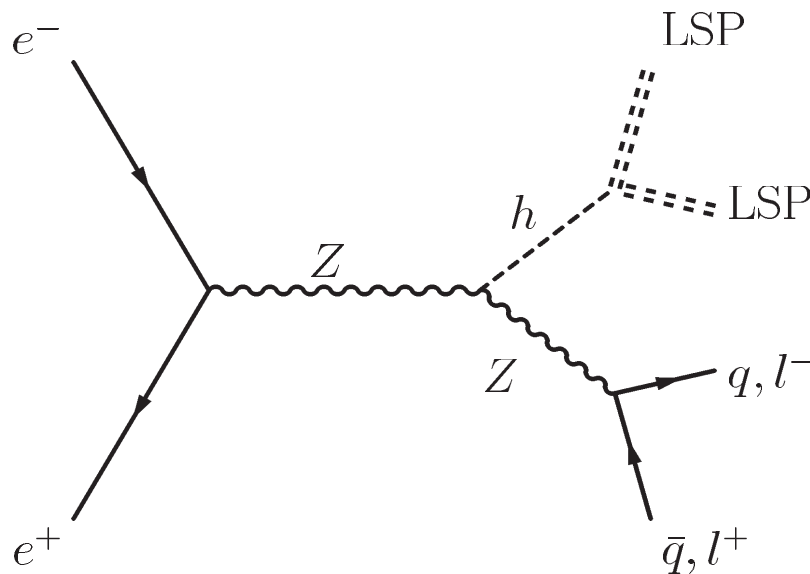
$m_H > 107 \text{ GeV}$  (95% CL)  
 (if H decays only into bosons)

$m_H > 108.3 \text{ GeV}$  (95% CL)  
 (Fermiophobic Benchmark)



# Invisible Higgs

- Look for invisible Higgs decays, e.g. from  $H \rightarrow$  neutralinos
- assume **standard Model production mechanism and cross section**

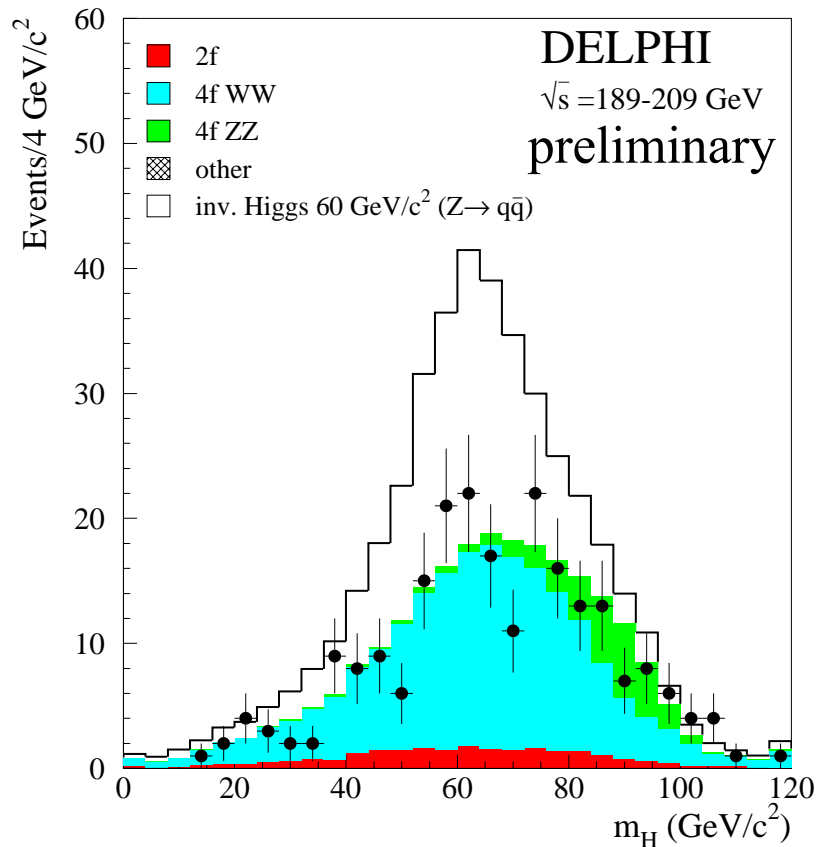


→ two signatures:

- **two jets + missing mass**
- **two charged leptons + missing mass**

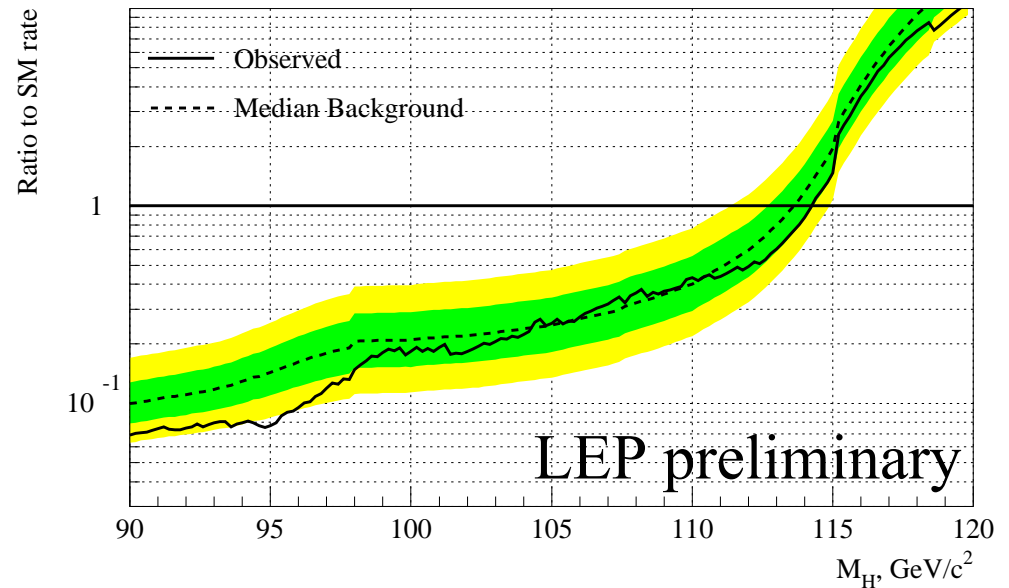
# Invisible Higgs

Higgs candidate mass:



no evidence of a signal  
seen in LEP combination

LEP Limit on relative  
production rate:

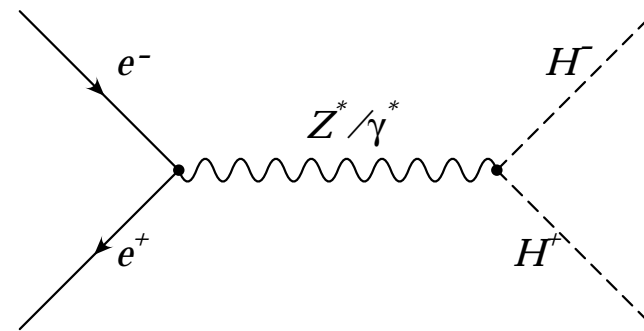


no evidence of a signal  
seen in LEP combination

$m_H > 114.4 \text{ GeV} (95\% \text{ CL})$   
(preliminary)

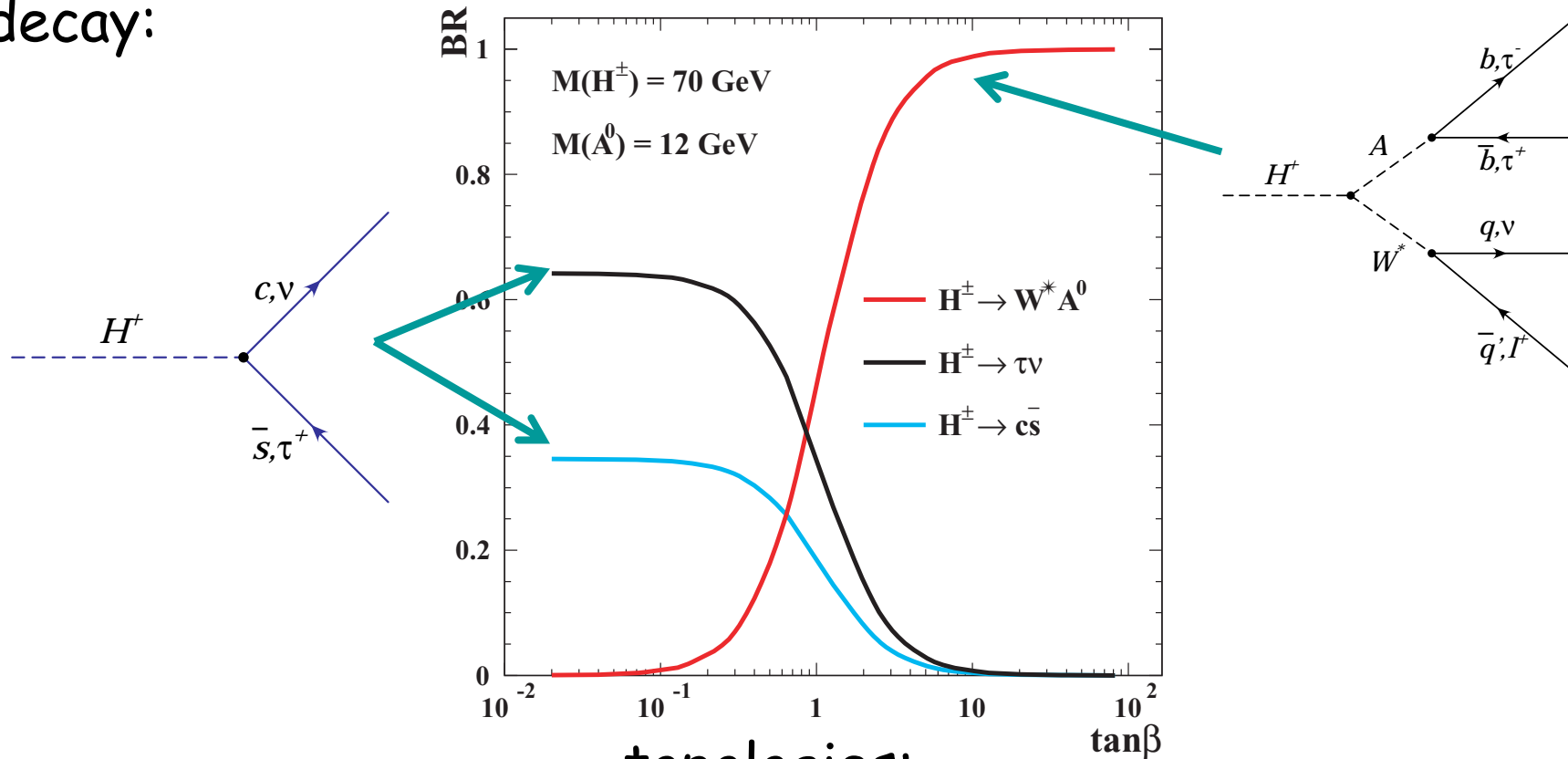
# Charged Higgs

- In the MSSM: Heavier than the  $W$  (at tree level)
- even stronger argument:
  - no FCNC at tree level ( $b \rightarrow sy$  measurements)
  - $m(H^\pm) > 370 \text{ GeV}$  (Nucl.Phys.B527:21-43)
  - not accessible at LEP II
- In type I 2HDMs: no such constraint
- production process at LEP:



# Charged Higgs

decay:



topologies:

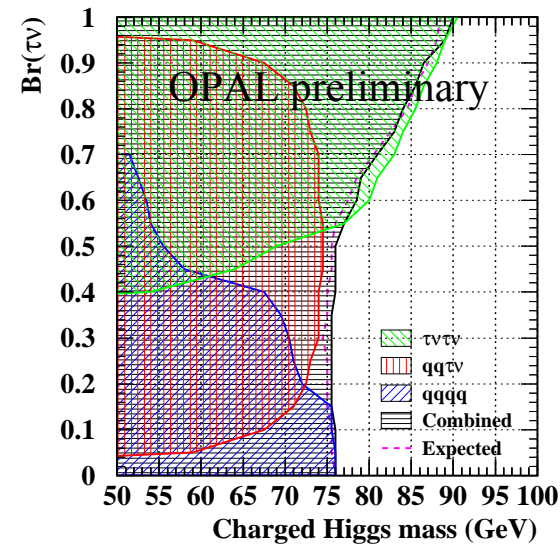
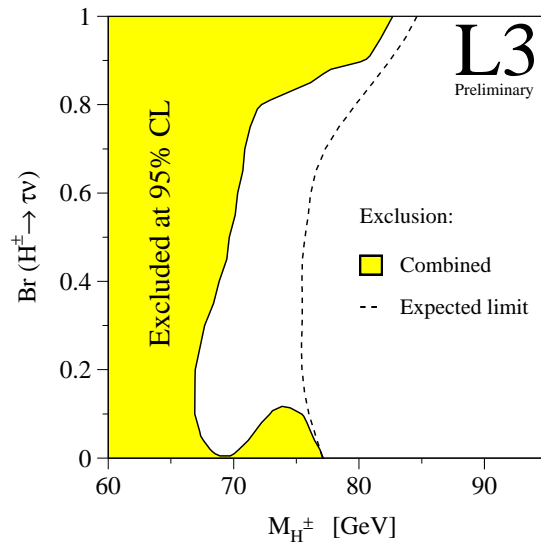
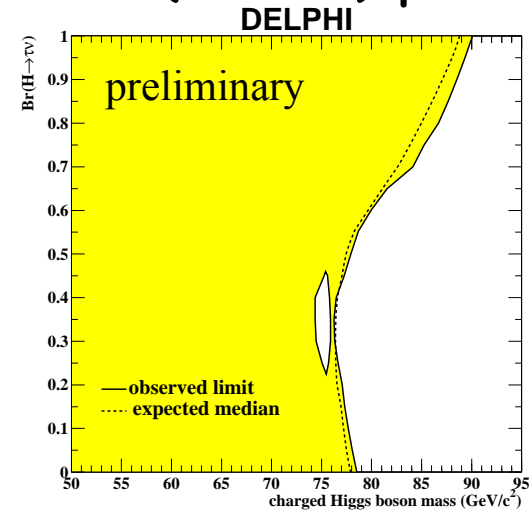
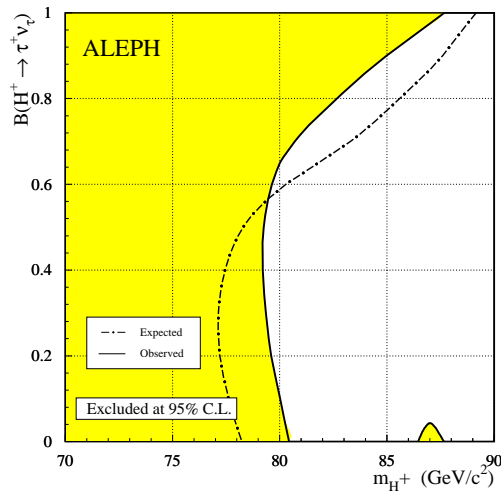
CSCS  
 CSTV  
 TVTV

$\left\{ \begin{array}{l} qqbb \\ \dots \end{array} \right\} \otimes \left\{ \begin{array}{l} qqbb \\ lvbb \\ TV \\ \dots \end{array} \right\}$

# Charged Higgs ( $\tan \beta \ll 1$ )

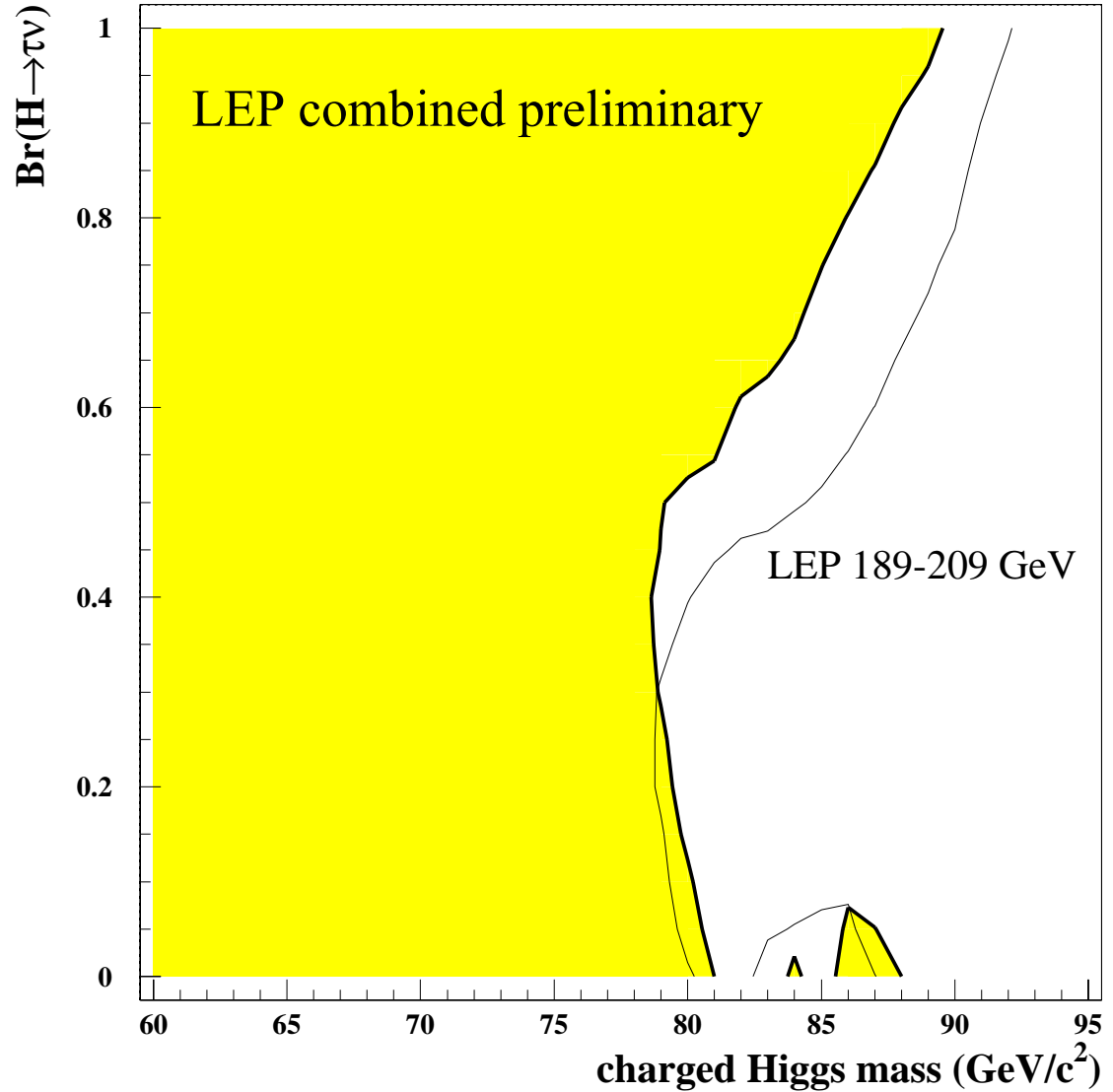
No evidence of a signal

Excluded regions in the  $m_H$  vs.  $BR(H \rightarrow \tau\nu)$  plane



# Charged Higgs ( $\tan \beta \ll 1$ )

Excluded regions in the  $m_H$  vs.  $BR(H \rightarrow \tau\nu)$  plane for all four LEP experiments combined



# Charged Higgs ( $\tan \beta \ll 1$ )

No convincing evidence for a signal found  
**observed** and expected limits (@95% CL)

	topology	Aleph	Delphi	L3	Opal	LEP
$BR(H \rightarrow TV)$ = 0	cscs	80.7	77.4	67.7	76.2	81.0
		78.1	77.0	76.5	77.1	80.2
$BR(H \rightarrow TV)$ = 1	T <sub>V</sub> T <sub>V</sub>	83.4	85.4	82.8	84.5	89.6
		86.9	89.3	84.7	86.5	92.1
Lowest observed		78.0	73.8	65.6	72.2	78.6

Preliminary limits; for each experiment from LEP HWG

# Charged Higgs ( $W^*A$ decays)

- **DELPHI**: look for events with b quark content and:

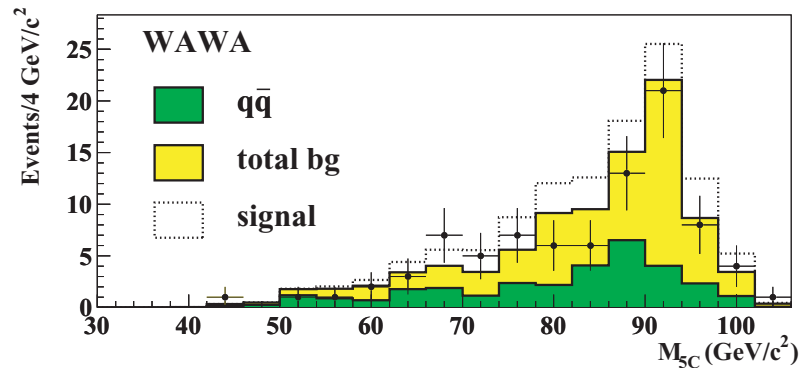
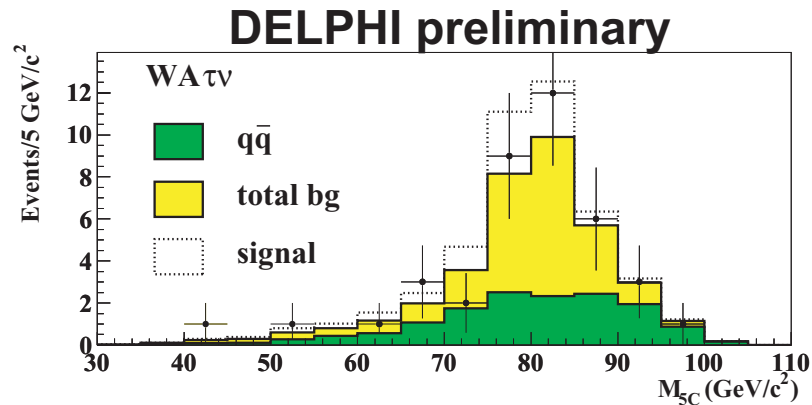
Signature		Channel covered
1 $\tau$ , missing energy	$\geq 2$ jets	$W^*A_{\tau\nu}$
no missing energy	$\geq 4$ jets	$W^*AW^*A$

- **Opal**: dedicated search for:

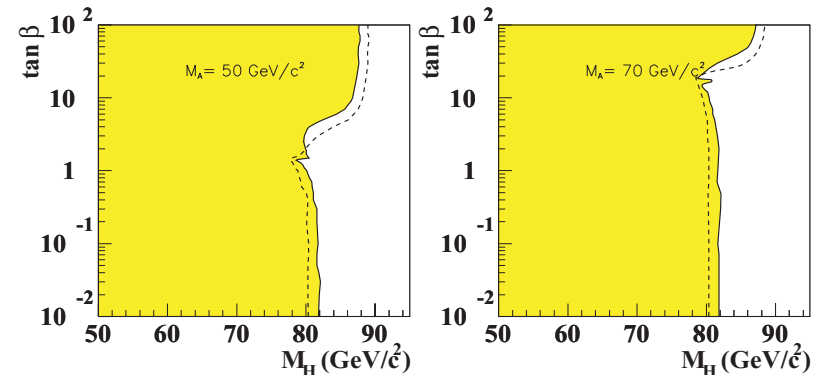
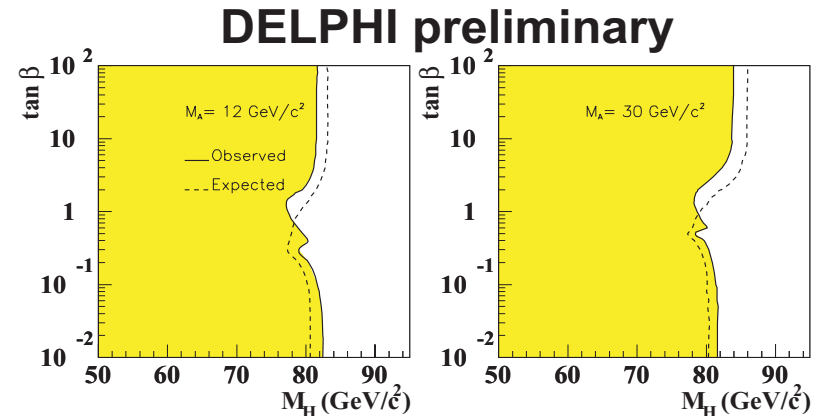
$(qqbb)(qqbb)$	$(lvbb)(qqbb)$	$(\tau\nu)(qqbb)$



# Charged Higgs ( $W^*A$ decays)



Higgs candidate mass  
 ( $m_{H^\pm} = 80 \text{ GeV} / m_A = 30 \text{ GeV}$ )



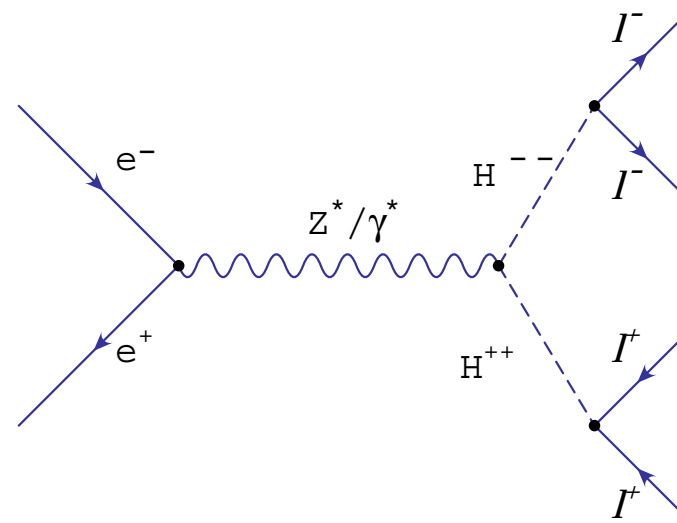
Excluded regions in the  $m_{H^\pm}$   
 vs.  $\tan \beta$  plane for different  
 values of  $m_A$

preliminary:  $m_{H^\pm} > 76.6 \text{ GeV}$  (95% CL)

# Doubly charged Higgs

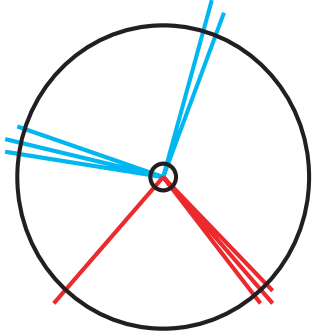
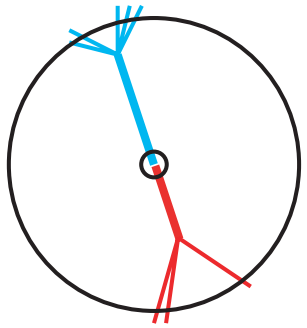
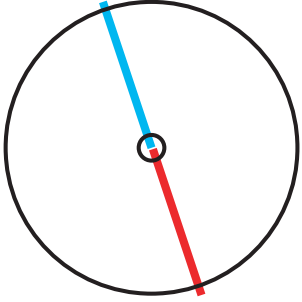
- Appear naturally in left-right symmetric models
- couple **only to charged leptons, weak gauge bosons and Higgs bosons**
- indirect limits on  $H^{\pm\pm} \rightarrow e^\pm e^\pm$ ,  $H^{\pm\pm} \rightarrow \mu^\pm \mu^\pm$  and  $H^{\pm\pm} \rightarrow e^\pm \mu^\pm$  exist already

- Production at LEP:



# Doubly charged Higgs

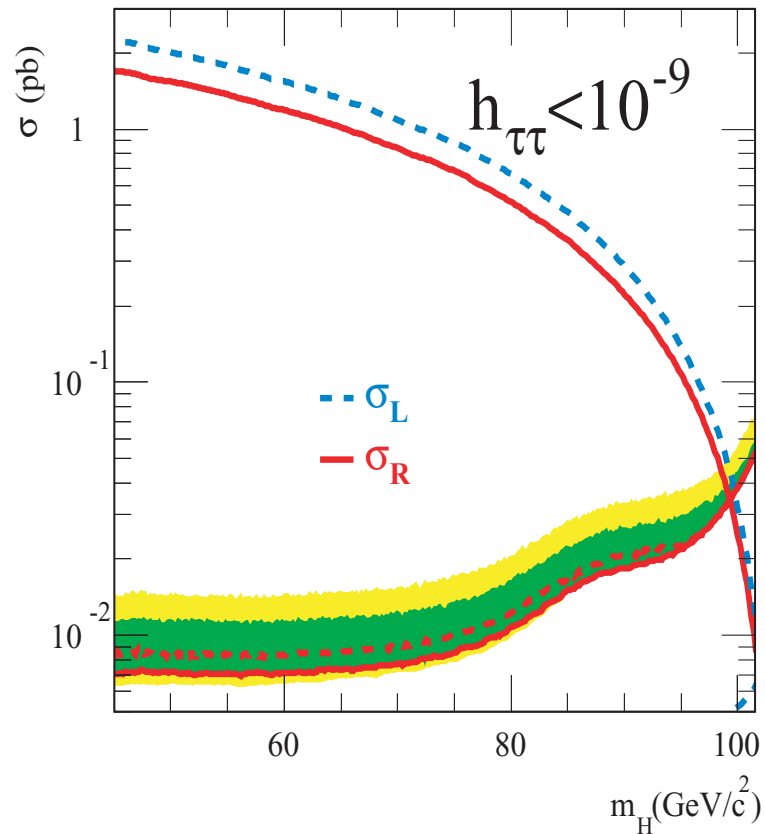
Three different event topologies are distinguished (depending on Yukawa coupling  $h_{ll}$  and Higgs mass)

Higgs lifetime		
short	intermediate	long
		
Four leptons	Tracks with kinks	Stable heavy particles
$h_{ll} \gtrsim 10^{-7}$	$h_{ll} \lesssim 10^{-7}$	

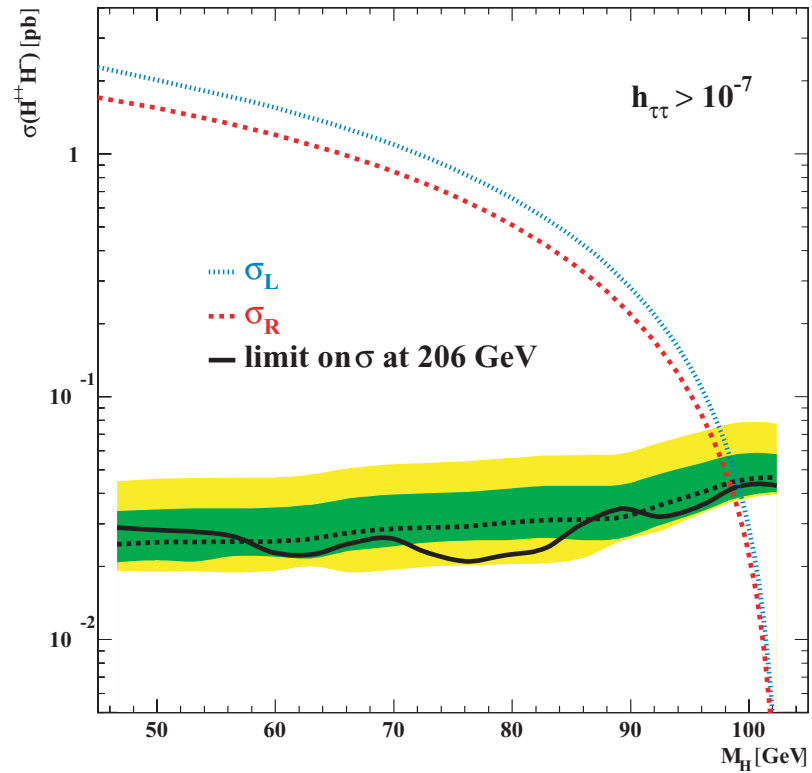
# Doubly charged Higgs

No evidence of a signal

DELPHI



OPAL



$m(H^{\pm\pm}) > 97.3 \text{ GeV @ 95\% CL (Delphi } H^--_R)$

# Summary

No Higgs signals found  
Limits @ 95% CL:

$H \rightarrow \gamma\gamma$	109.7 GeV	LEP	preliminary
Fermiophobic	108.3 GeV	L3	published
Invisible	114.4 GeV	LEP	preliminary
Charged ( $\tan \beta \ll 1$ )	78.6 GeV	LEP	preliminary
Doubly charged	97.3 GeV	Delphi Opal	Published

# Outlook

- expect final LEP combinations of
  - $H \rightarrow \gamma\gamma$
  - Invisible Higgs decays
  - Charged Higgs ( $\tan \beta \ll 1$ )soon (i.e. end of 2003)
- Not covered here:
  - general 2HDM parameter scan (OPAL)
  - Yukawa production at LEP1 (OPAL)
  - Low mass  $A$  search (OPAL)
  - Anomalous Higgs couplings (L3)