Other Higgs Boson Searches

(at LEP)

or

What to do if there are too many people on the
MSM Higgs Working Group

Mark Oreglia
The Enrico Fermi Institute,
The University of Chicago

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Outline:

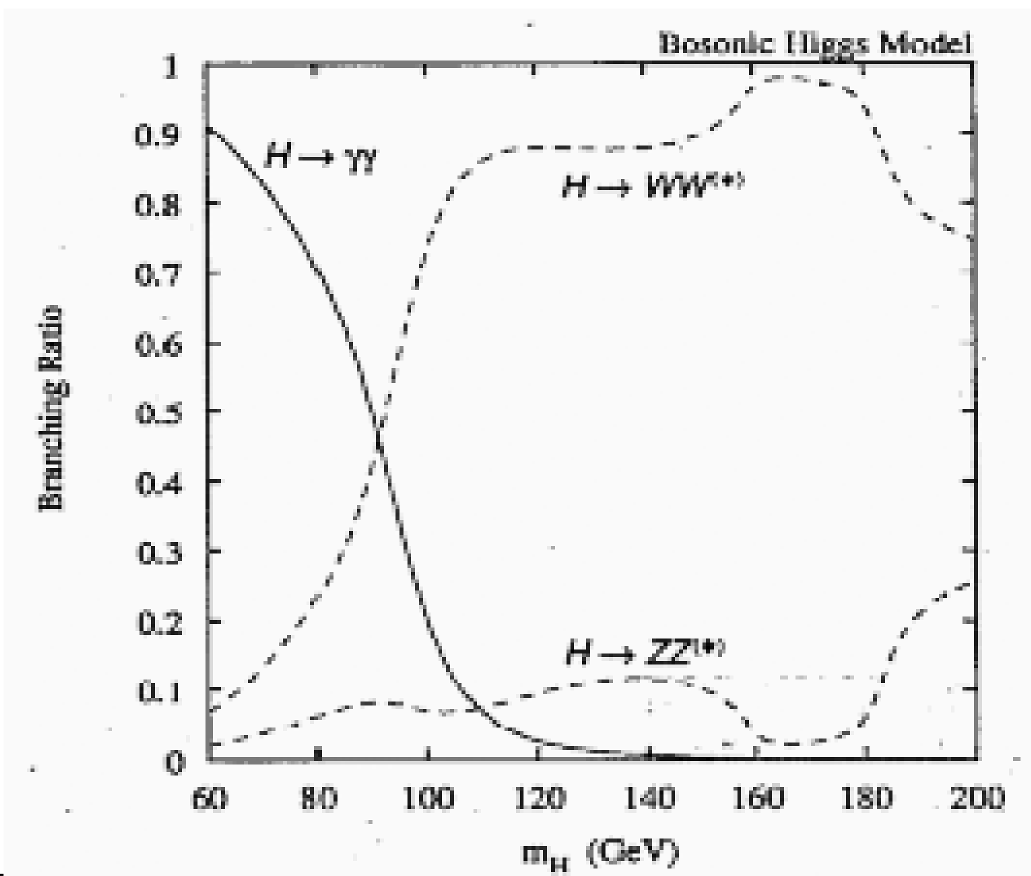
- **Photonic Higgs Couplings**
- **Invisible Higgs Decays**
- **Charged Higgs Bosons**
- **Conclusions**

Higgs Bosons at LEP

- In Minimal Standard Model:
  - production via $e^+e^- \to H^0Z^0$
  - direct limit M_H > 95.2 GeV (189 GeV LEP combined)
  - Yukawa production: $e^+e^- \to f\bar{f}\, h^0$
    - small in MSM (DELPHI 7-120)
- Next level of complexity: 2 Higgs doublet fields (2HDM)
  - 4 ways of coupling doublets to fermions (Types I, I', II, II')
  - MSSM is Type II; 5 Higgs boson
    $e^+e^- \to h^0A^0$
    - charged Higgs have large virtual effects
- Diphoton decay of H^0 is of order 0.001 for M_H near 80 GeV in MSM … occurs via W loop
  - enhanced in Type I model

Fermiophobia

- Extended Higgs sectors:
  - avoid FCNC with constrained Yukawa couplings to fermions
  - keep $\rho = 1$ by incorporating only singlets and doublets; triplets need special care
  - 2HDM of Type-I: all fermion couplings have the form SM $*$ $\cos\alpha/\sin\beta$, so can tune α to turn off fermion couplings



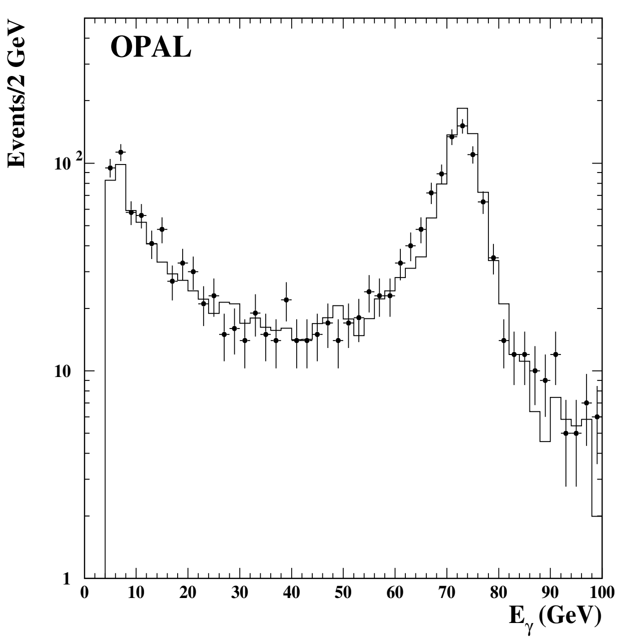
Photonic Enhancers

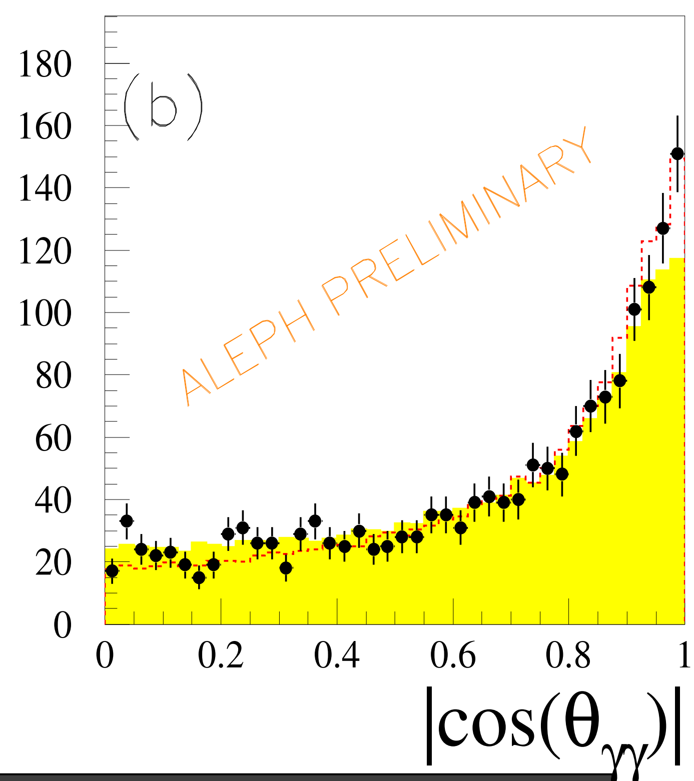
Mechanisms which increase photon couplings:

- 2HDM:
  - Stange, Marciano, Willenbrock
  - Eboli, Gonzalez-Garcia,Lietti, Novaes
  - Akeroyd
- Higgs Triplet Model: Gunion
  - Akeroyd; Georgi, Machacek
- Top-quark Condensate:
  - Wells; Spira and Wells; Baer and Wells
  - Pois, Weiler, Yuan
- Extra Dimensions:
  - Hall and Kolda
- Anomalous Couplings:
  - Hagiwara, Szalapski, Zeppenfield
  - Gamberini, Giudice, Ridolfi
  - Abbasabadi, et al.
- Hypercharge axion: Brustein, Oaknin
- …and more!

Photons

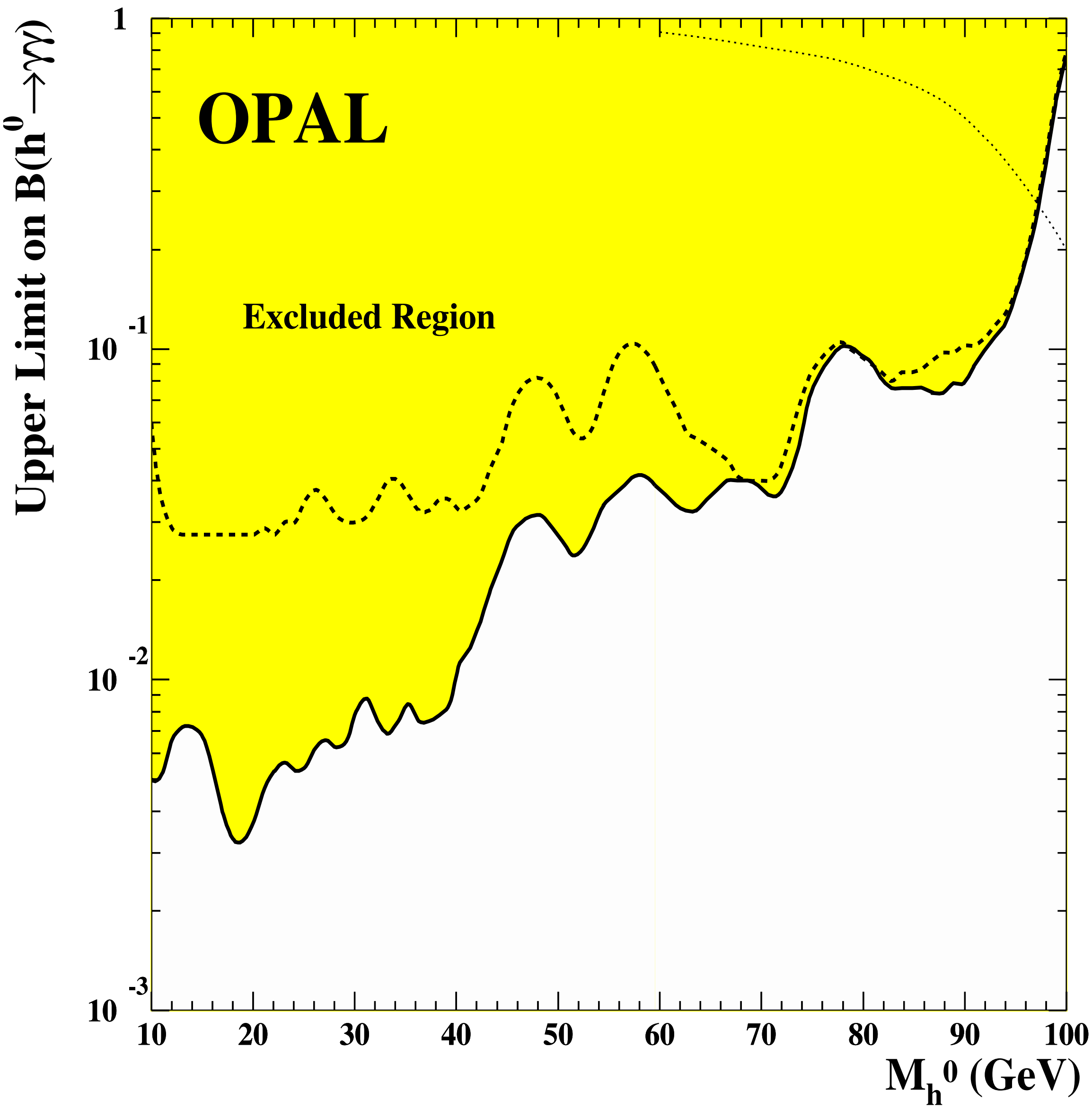
- The analyses in this section require 2 or 3 energetic photons…low backgrounds
- photon modelling from PYTHIA was not so good for analyses in the central region; KK2F is much better, but still discrepant at the 10% level
- for hZ specific modes, recoil mass cut is very effective
- main backgrounds from ISR and 4f





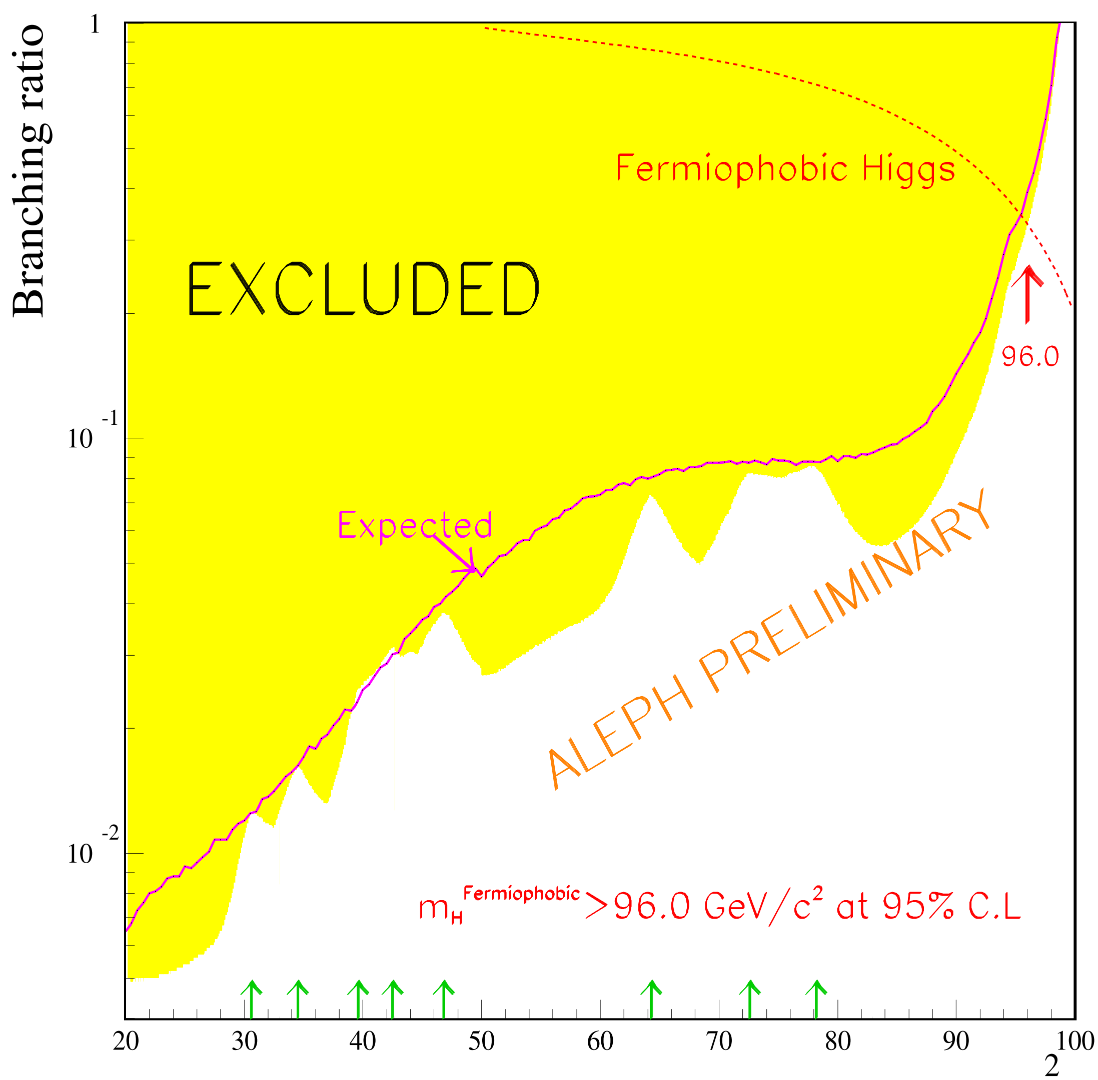
OPAL

- CERN EP/99-084, Tampere 6-56
- 182.6 pb^{-1} at 189, + 91-183 GeV data
- 96.2 GeV fermiophobic limit



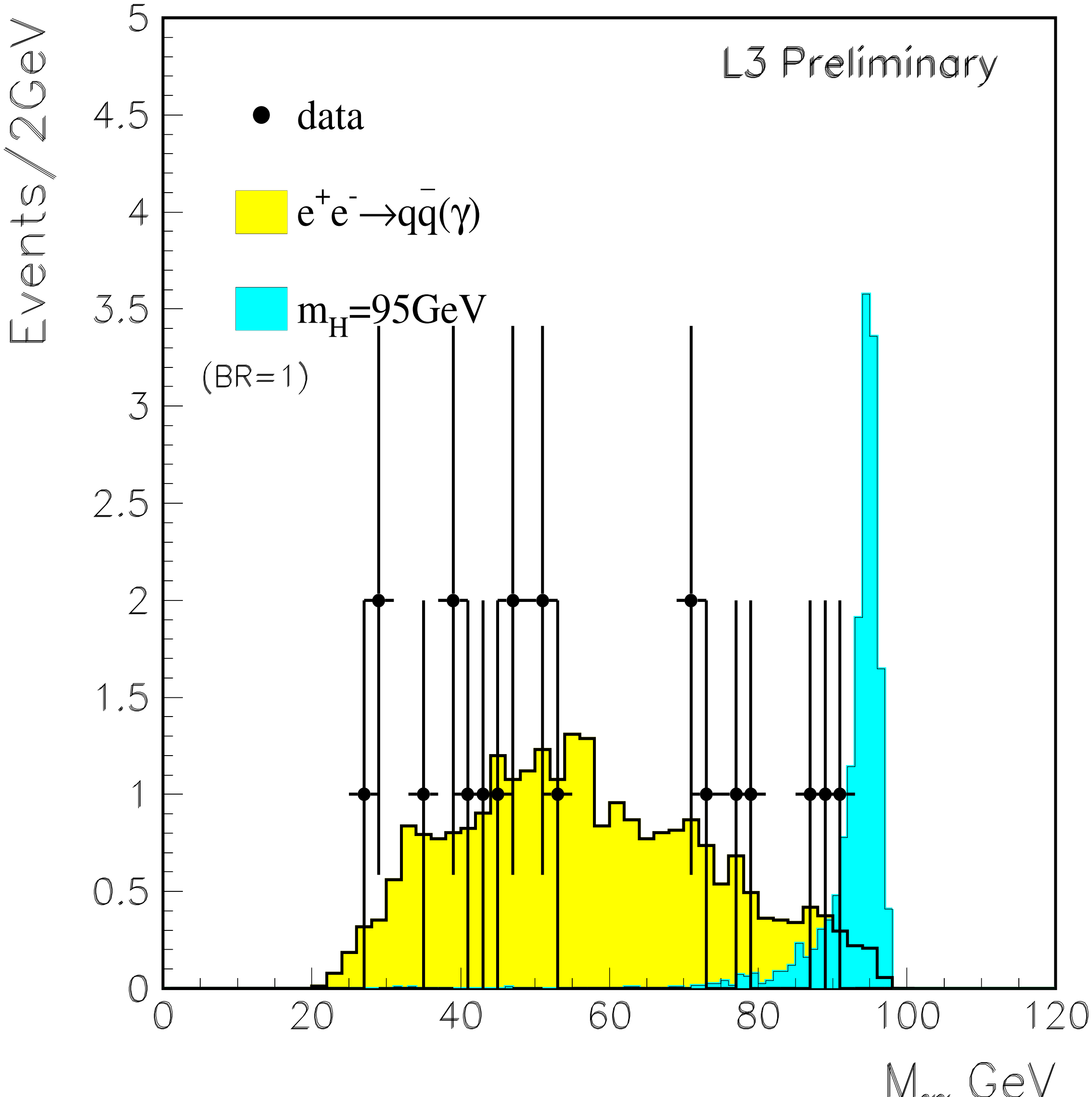
ALEPH

- ALEPH CONF 99-030, Tampere 7-412
- 421 pb^{-1} from E_{cm}= 91 - 189 GeV
- fermiophobic limit at 96.0 GeV

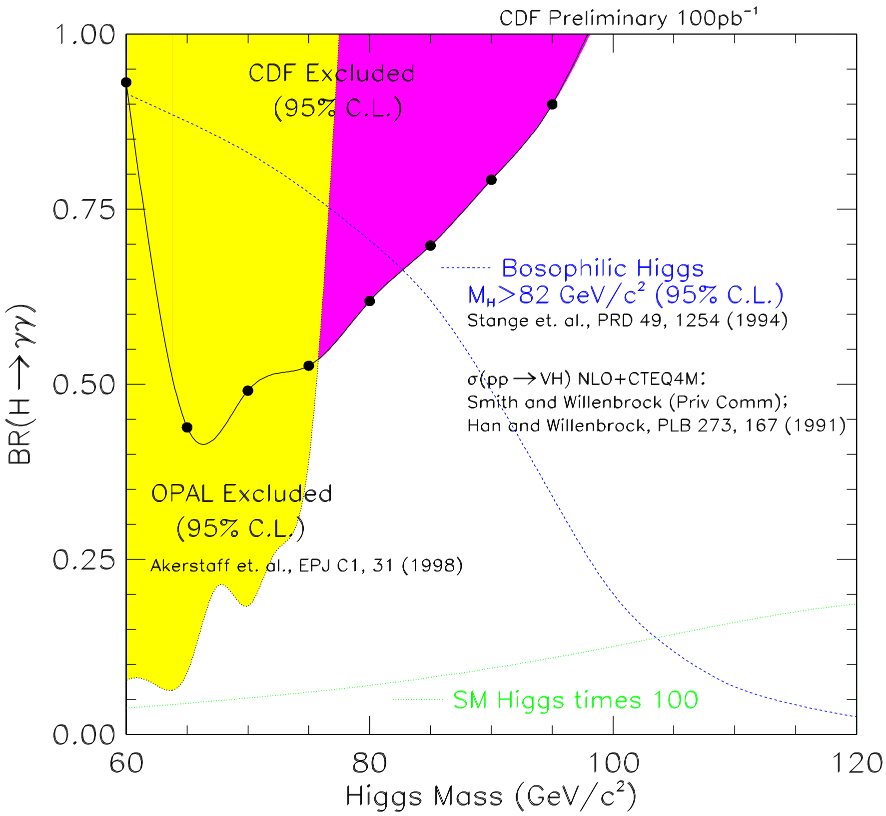


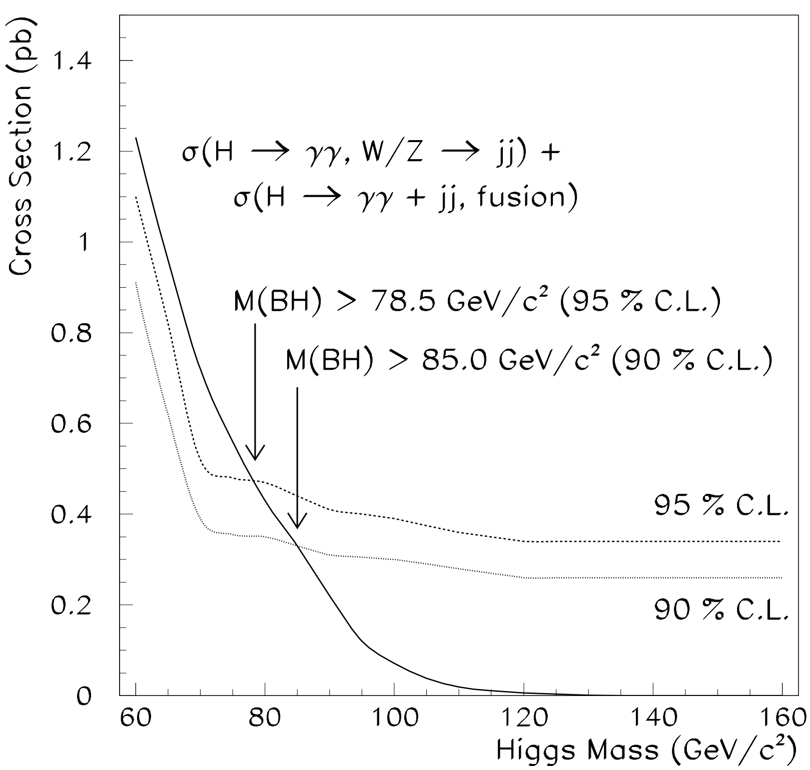
L3

- L3 Note 2429, Tampere 7-238
- 176 pb^{-1} at 189
- fermiophobic limit at 96 GeV



Also from D0 and CDF:

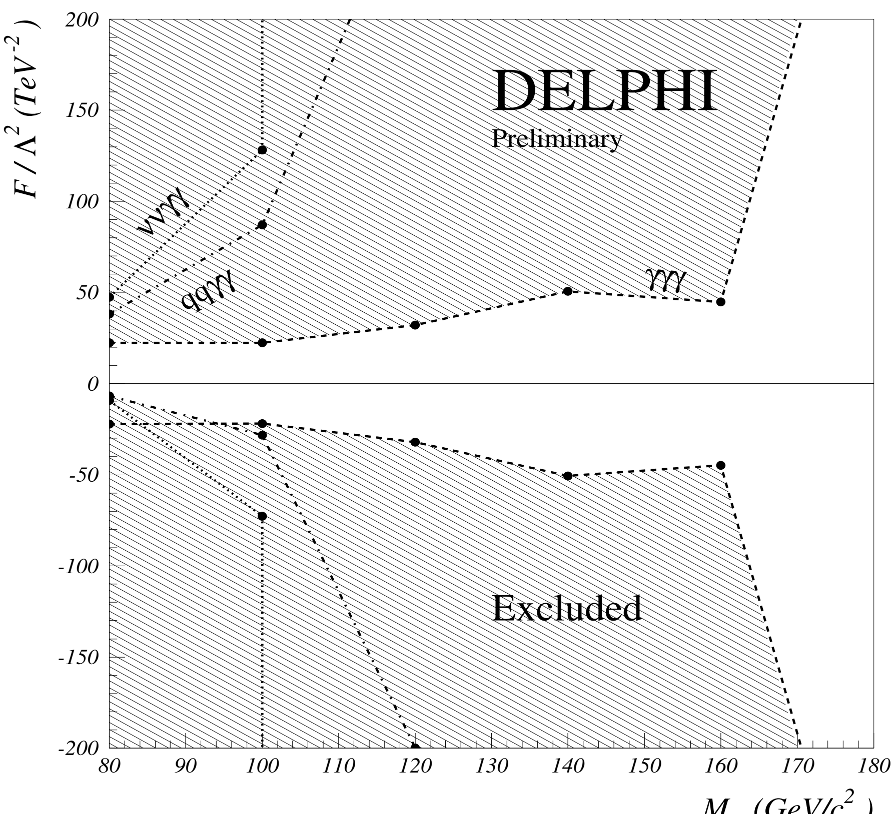




D0 contributed paper #452A

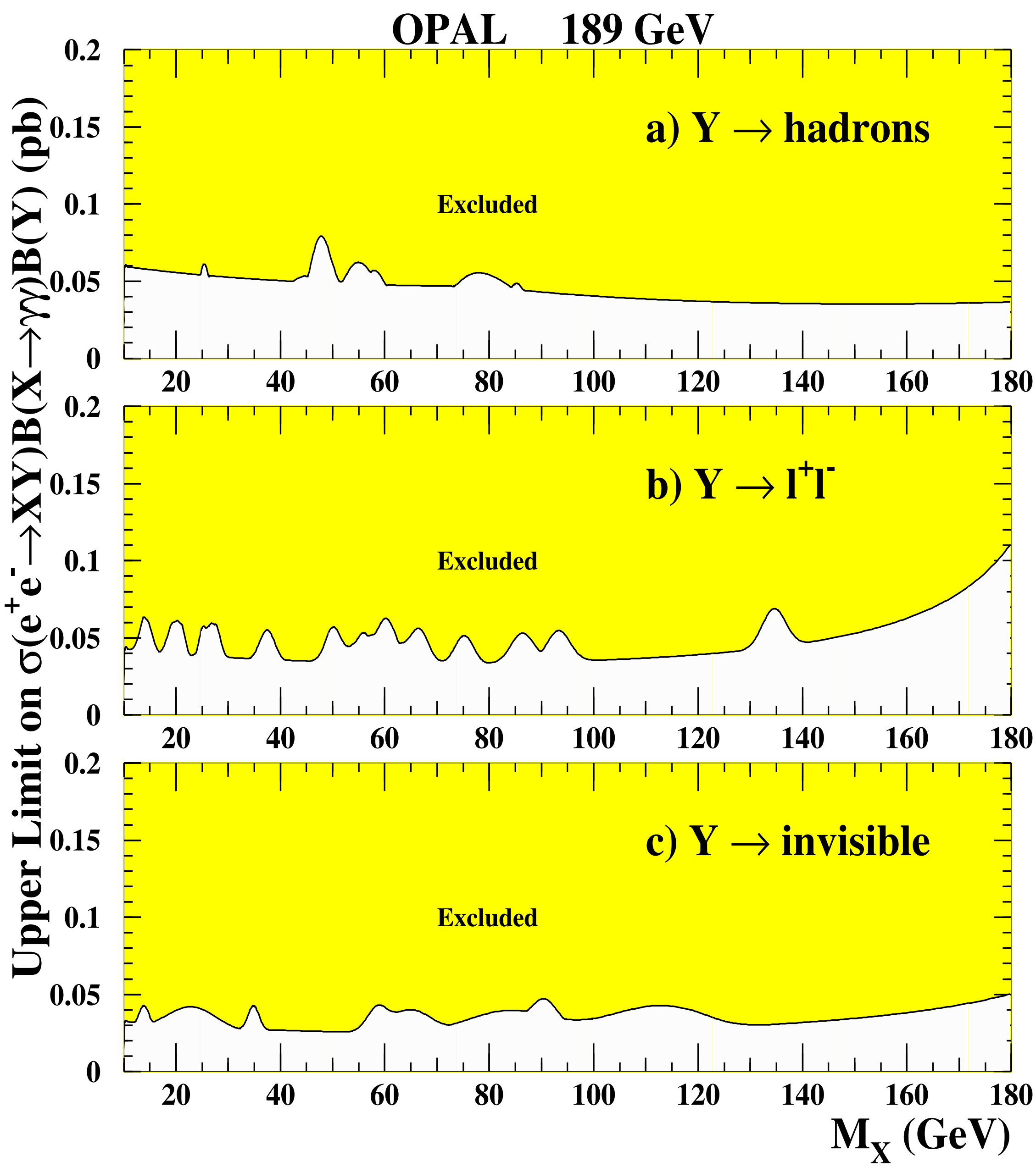
DELPHI

- DEPHI 99-72, Tampere 7-116
- 153 pb^{-1} from 189 GeV
- fermiophobic limit of 96 GeV
- Also, nice study of anomalous couplings
  - photonic couplings can be enhanced by nonzero values of f_B, f_{BB}, f_W, f_{WW}
  - there is also a scale parameter Λ
  - these lead to nonzero $H\gamma\gamma$ and $HZ\gamma$
  - see DELPHI's CERN-EP/99-58



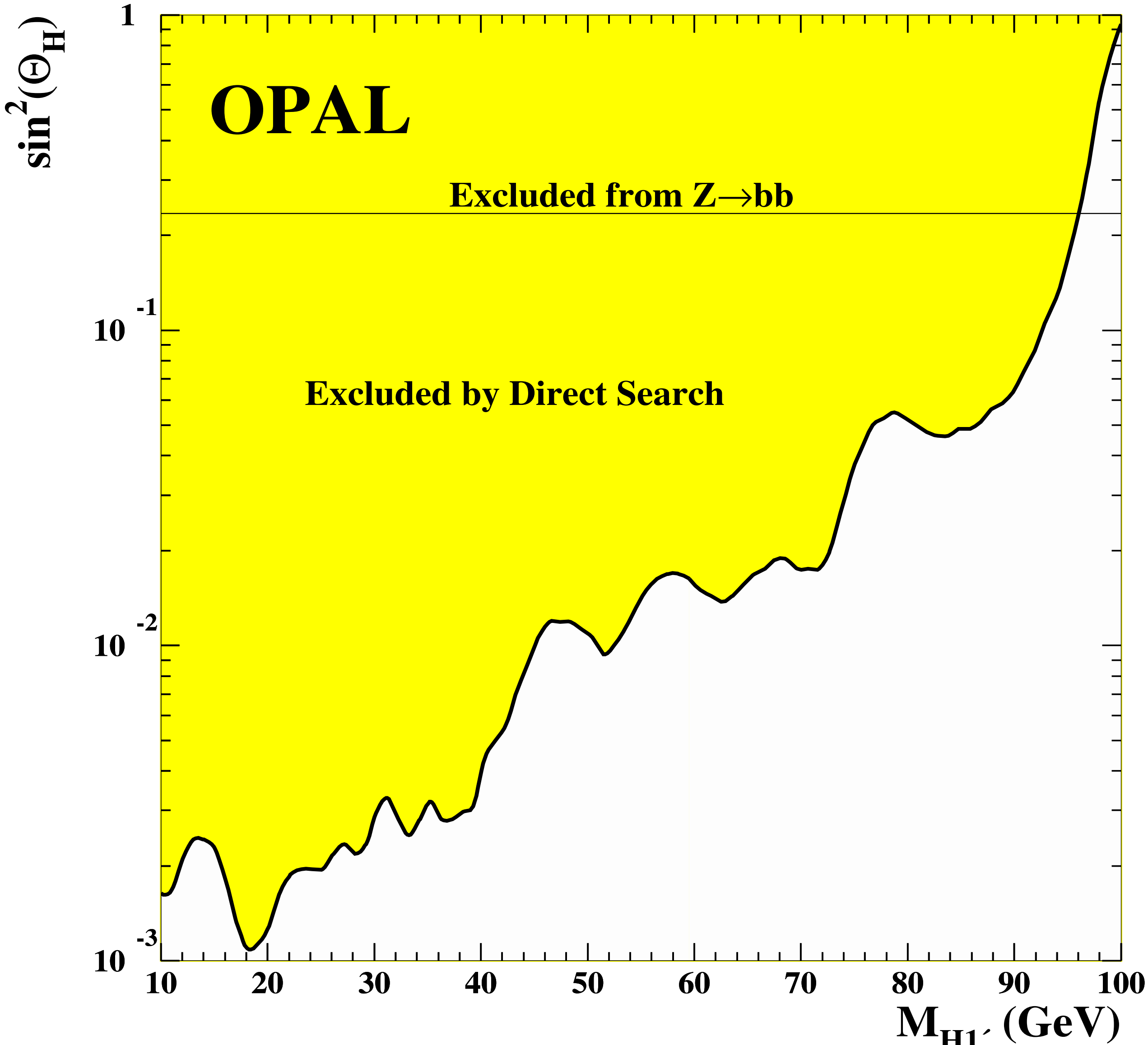
OPAL also has Cross Section limits

- For $e^+e^- \to X^0Y^0$
- results valid for scalar/scalar, scalar/vector



Higgs Triplet Model

- IF the H_1 and H'_1 do not mix, as is indicated by other constraints (see Akeroyd), then H_1 is fermiophobic, and the preceeding analyses give good limits in the model:

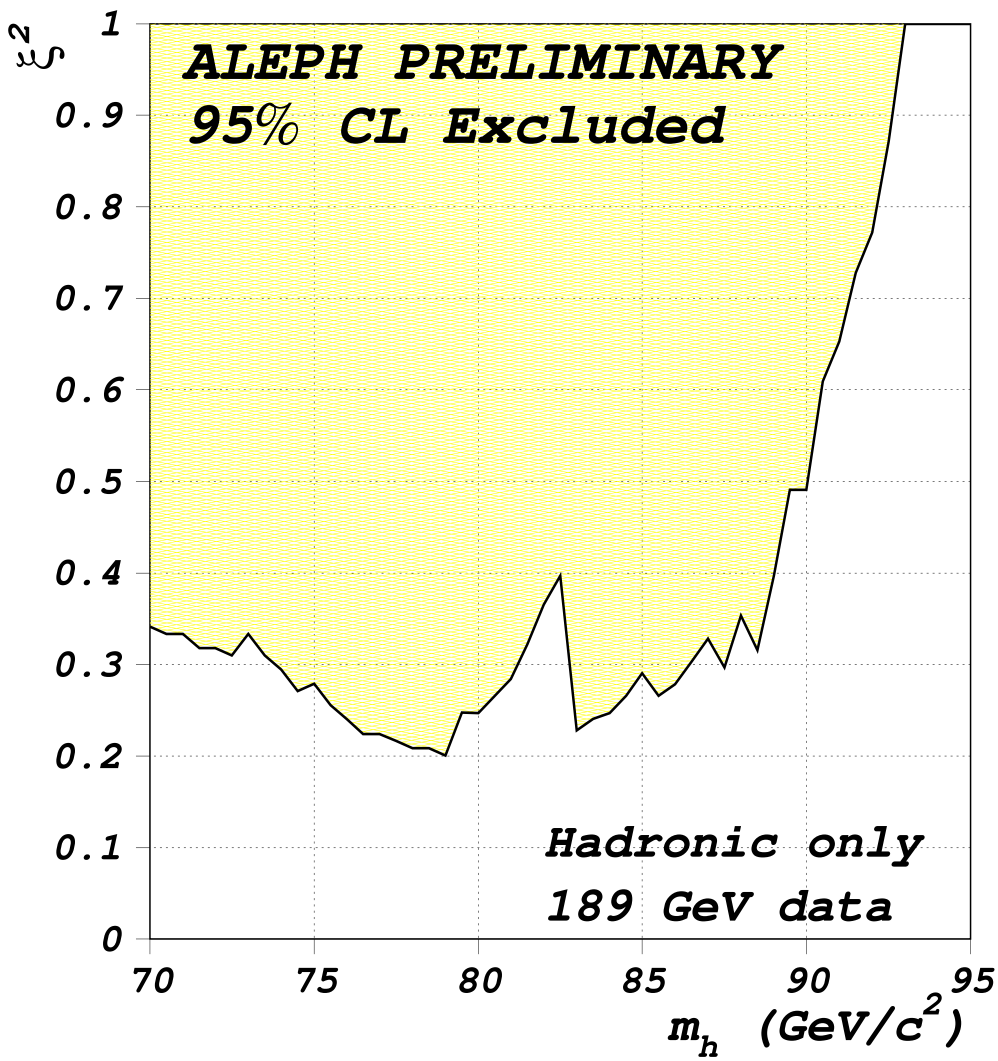


Invisible Higgs

- Searches for $e^+e^- \to h^0Z^0$
- h decays into undetected particles
  - for instance, $h^0 \to \chi_1^0\chi_1^0$
  - also: $h^0 \to \chi_1^0\chi_2^0, \chi_2^0 \to \chi_1^0 Z^0$
  - …but mass dependent
- hZ production at $\xi^2 \times \sigma_{SM}(e^+e^- \to h^0Z^0)$
- events characterized by large missing E and acoplanar dijet or dileptons having invariant mass close to M_Z
- backgrounds predominantly from 4-fermion processes and WW
  - leptons: require recoil mass = Z
  - jets: build ANN to discriminate from irreducible background as best one can … very similar to SM Higgs search

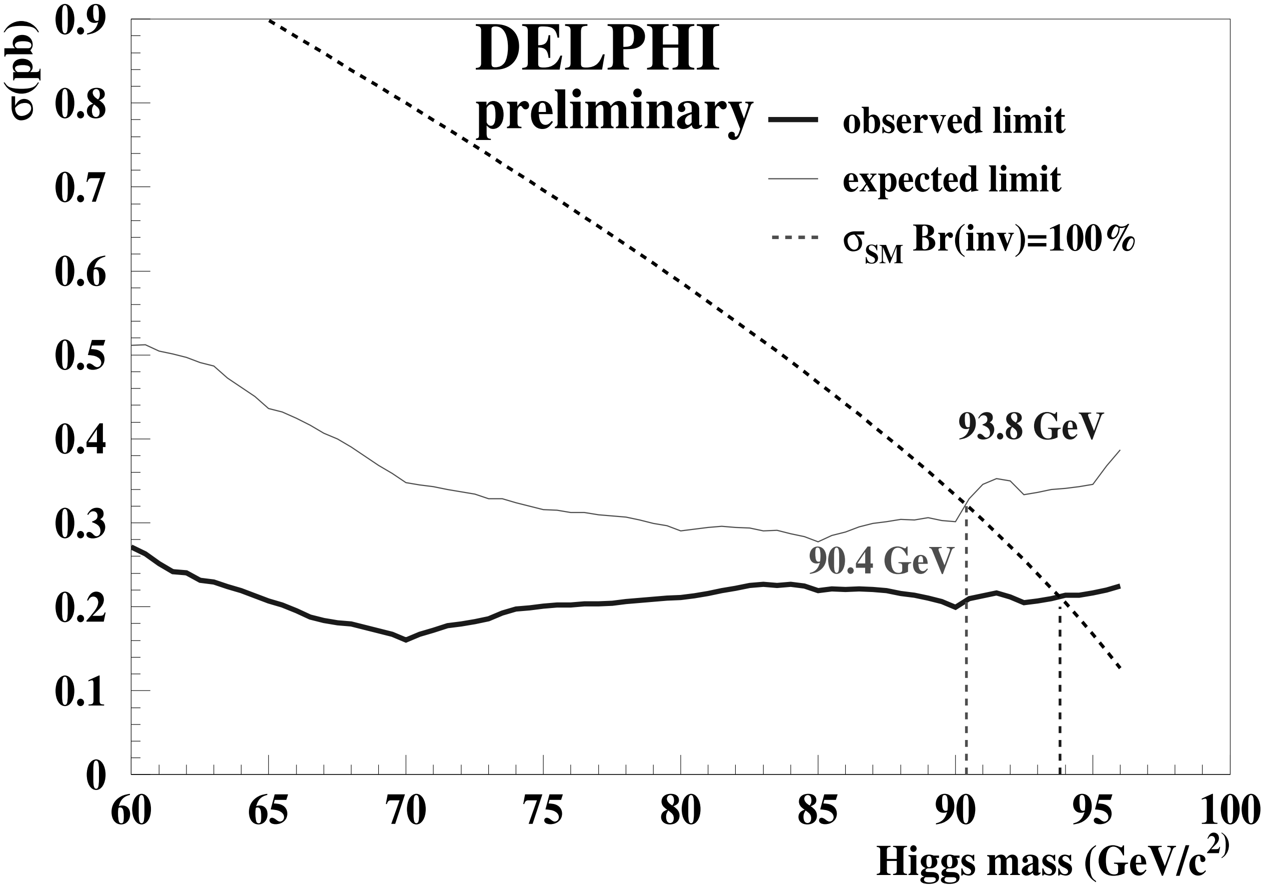
ALEPH

- ALEPH 99-013, Tampere 7-413
- 175.5 pb^{-1} of 189 GeV data
- 33 candidates, 33.6 expected background
- limit of 92.8 GeV (expected: 94.0)



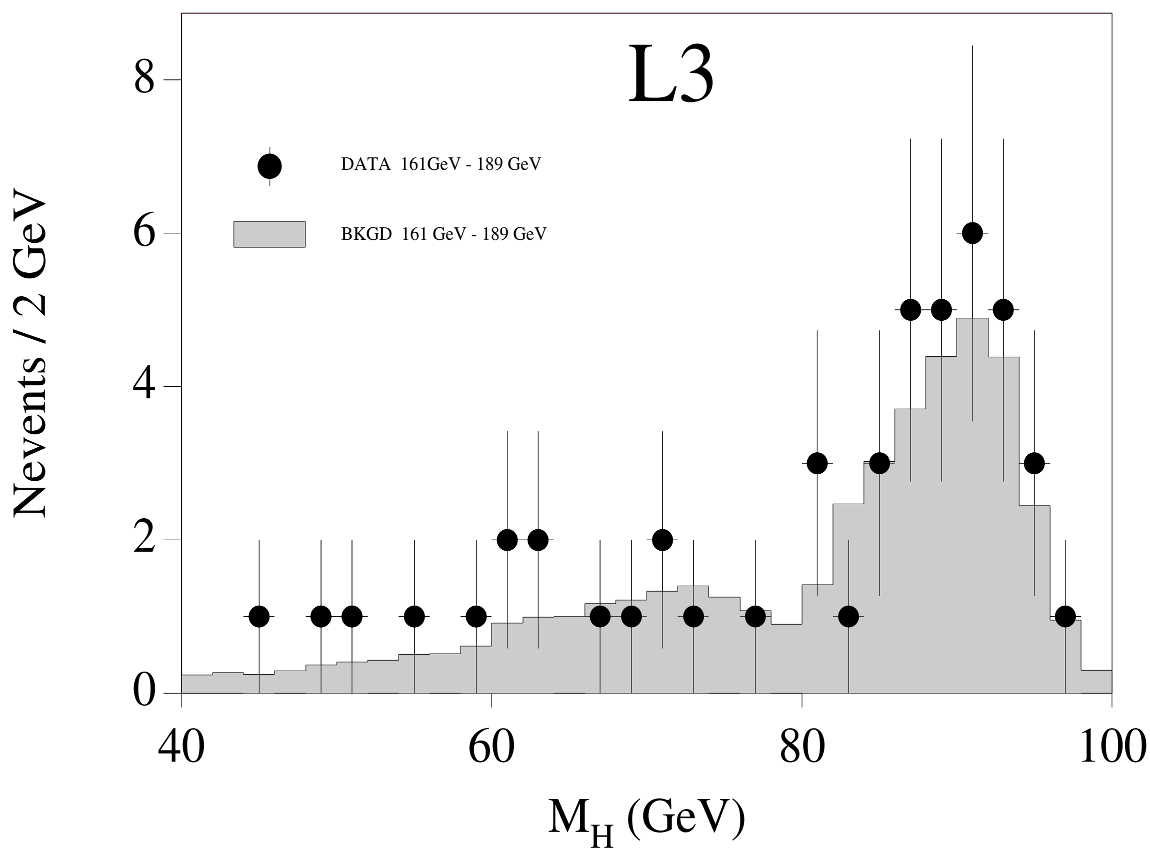
DELPHI

- DELPHI 99-83, Tampere 6-214
- 155.3 pb^{-1} of 189 GeV data, + 91-183data
- only muons in lepton channel
- 60 candidates, expected background = 69.9
- mass limit = 93.8 (expected = 90.4)



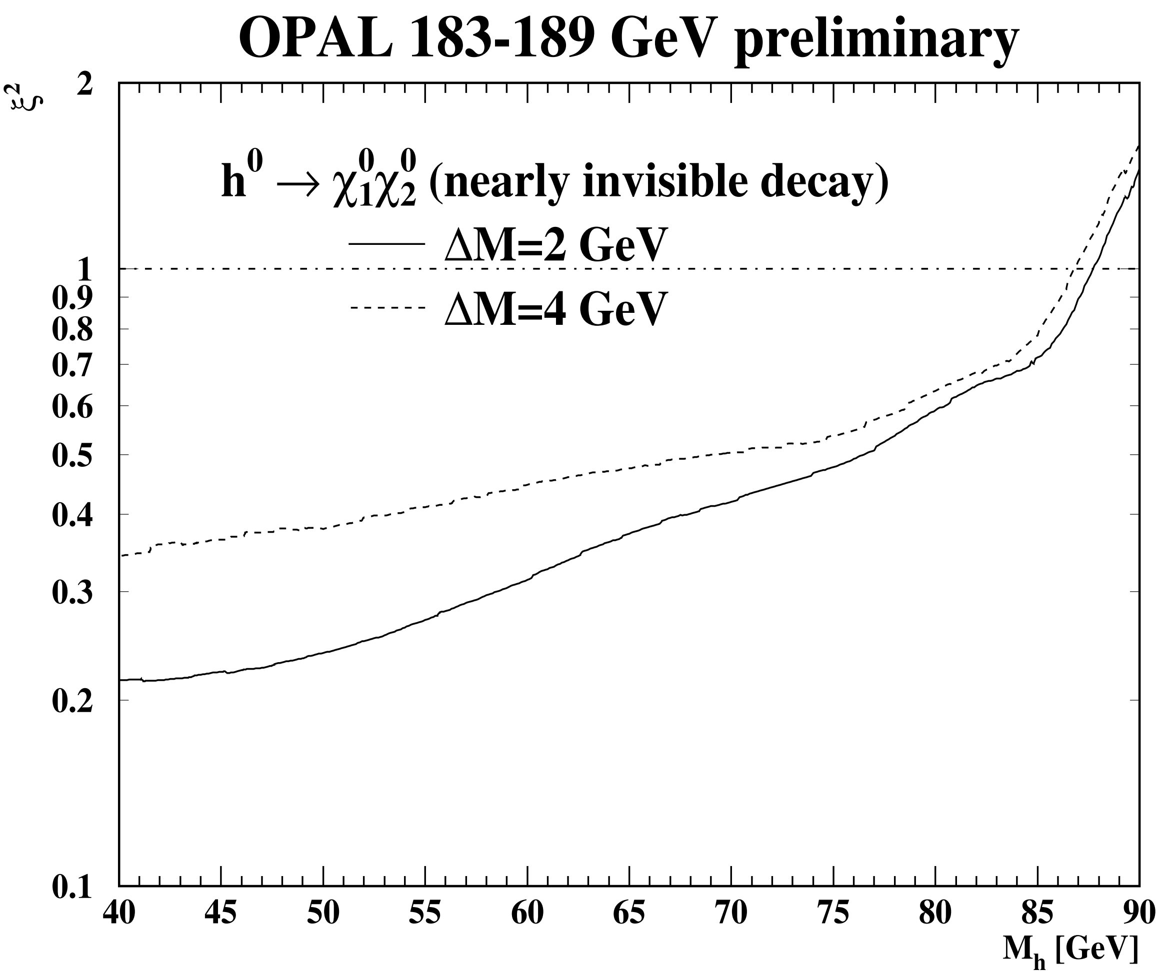
L3

- L3 Note 2435, Tampere 7-237
- 176.4 pb^{-1} at 189, + 183 GeV data
- 39 candidates, expected background = 41.6
- mass limit = 95.0 (expected = 92.2)



OPAL

- OPAL PN 399
- 178.4 pb^{-1} of 189 GeV data, + 183 GeV
- 59 candidates, expected bkgd = 61.6
- mass limit = 90.6 (expected = 93.3)
- "nearly" invisible mode gives limits of 87.7 and 86.7 GeV for ΔM = 2 and 4 GeV



Charged Higgs Bosons

- Pair production: $e^+e^- \rightarrow H^+H^-$
- Occur in all common extensions
  - 2HDM…couplings specified
  - Triplet…limits from loop corrections to Z width
- … but H decay rate is model dependent
- leptonic, hadronic, and mixed modes defined by H decay final states:

$$H \rightarrow \tau\nu_\tau, H \rightarrow c\bar{s}$$

- 2HDM, Type I (Akeroyd):
  - look for $H^+ \rightarrow W^+A^0$
- mature analyses:
  - leptonic: missing E, acoplanarity
  - hadronic: jets
- Main background: W^+W^-
  - irreducible… a problem
  - but still good progress in furthering the limits by 6-9 GeV over those from 183

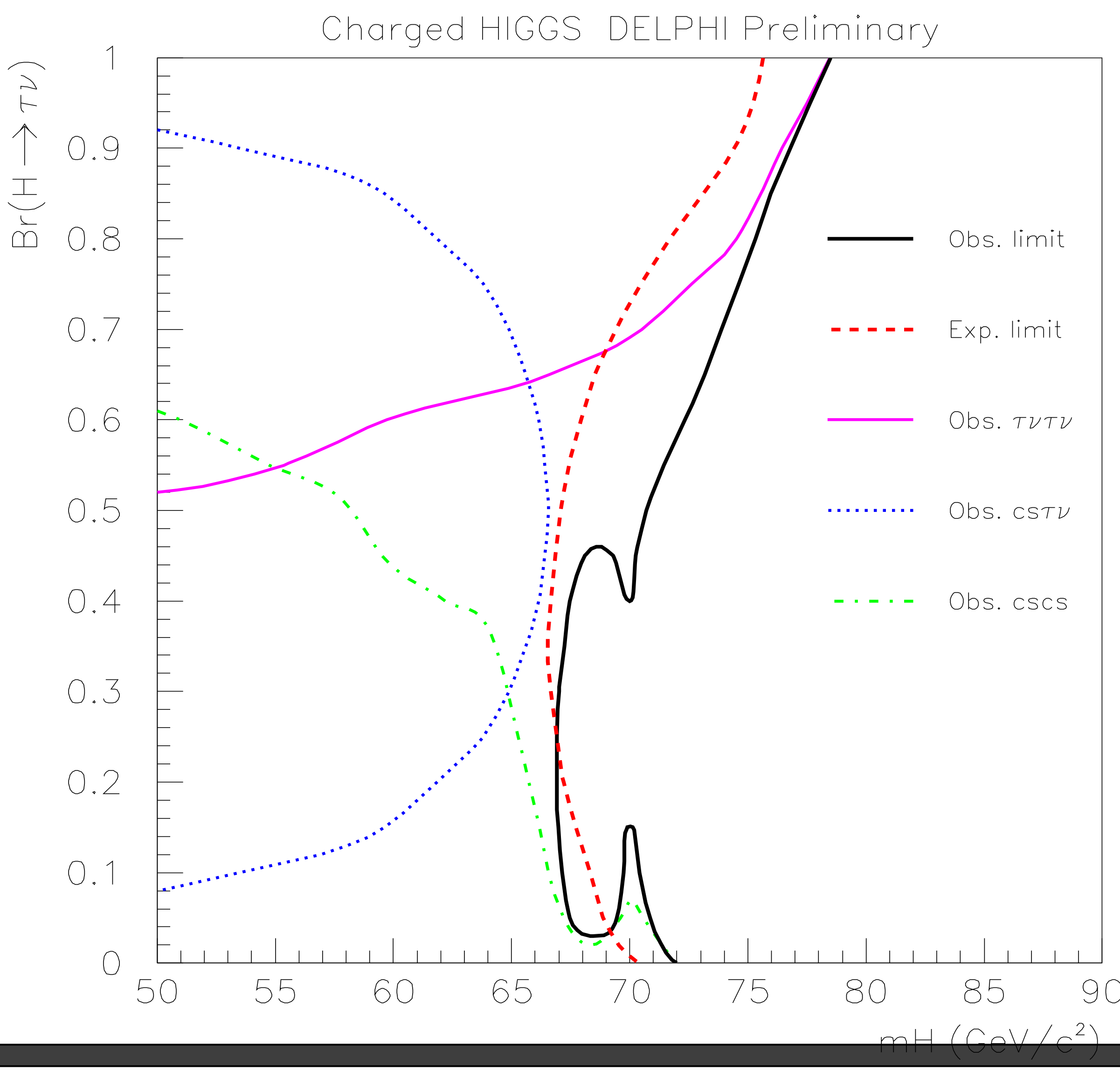
Charged Higgs Analysis

- Each collaboration is using something new for the 189 GeV analysis
- No indication of a signal

Mode	Data	Bkgd	Eff, mH=70	95% CL Limit (GeV)
ALEPH				65.5 (69.5 expected)
lepton	20	15.5	40%	
hadron	263	295.4	45%	
mixed	19	22.6	29%	
DELPHI				66.9 (66.5 expected)
lepton	15	15.8	34%	
hadron	145	141.3	19%	
mixed	55	55.9	32%	
L3				67.5 (70.2 expected)
lepton	30	32.5	31%	
hadron	335	359.4	38%	
mixed	134	132.0	40%	
OPAL				68.7 (68.5 expected)
lepton	31	26.2	48%	(test mass = 70 GeV)
hadron	156	153.8	25%	
mixed	65	60.1	40%	

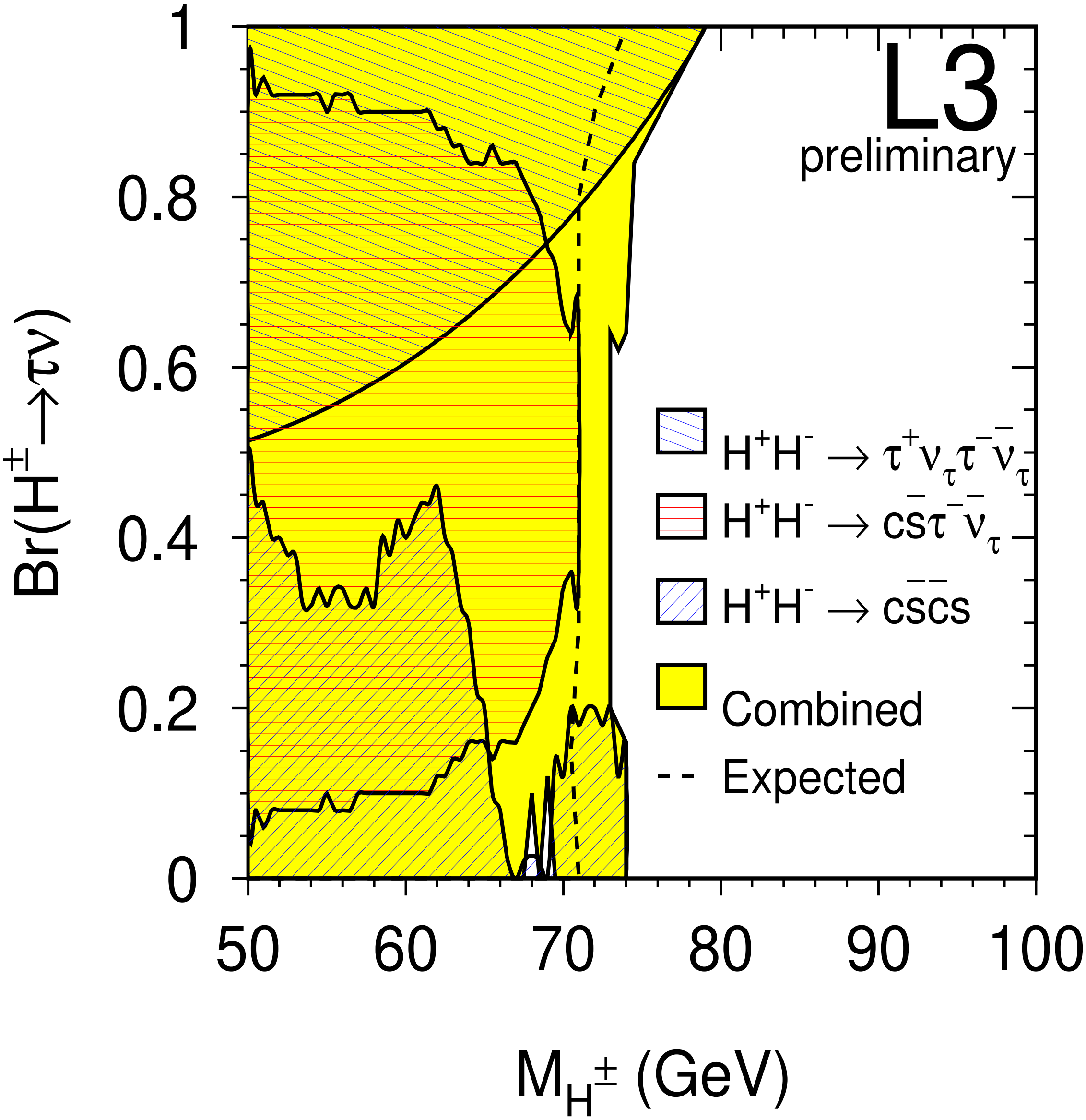
DELPHI

- DELPHI 99-92, Tampere 7-377
- 153.8 pb^{-1} at 189 GeV, plus 183
- lepton channel uses τ polarization
- hadron mode has anti-WW likelihood
- 66.9 GeV limit



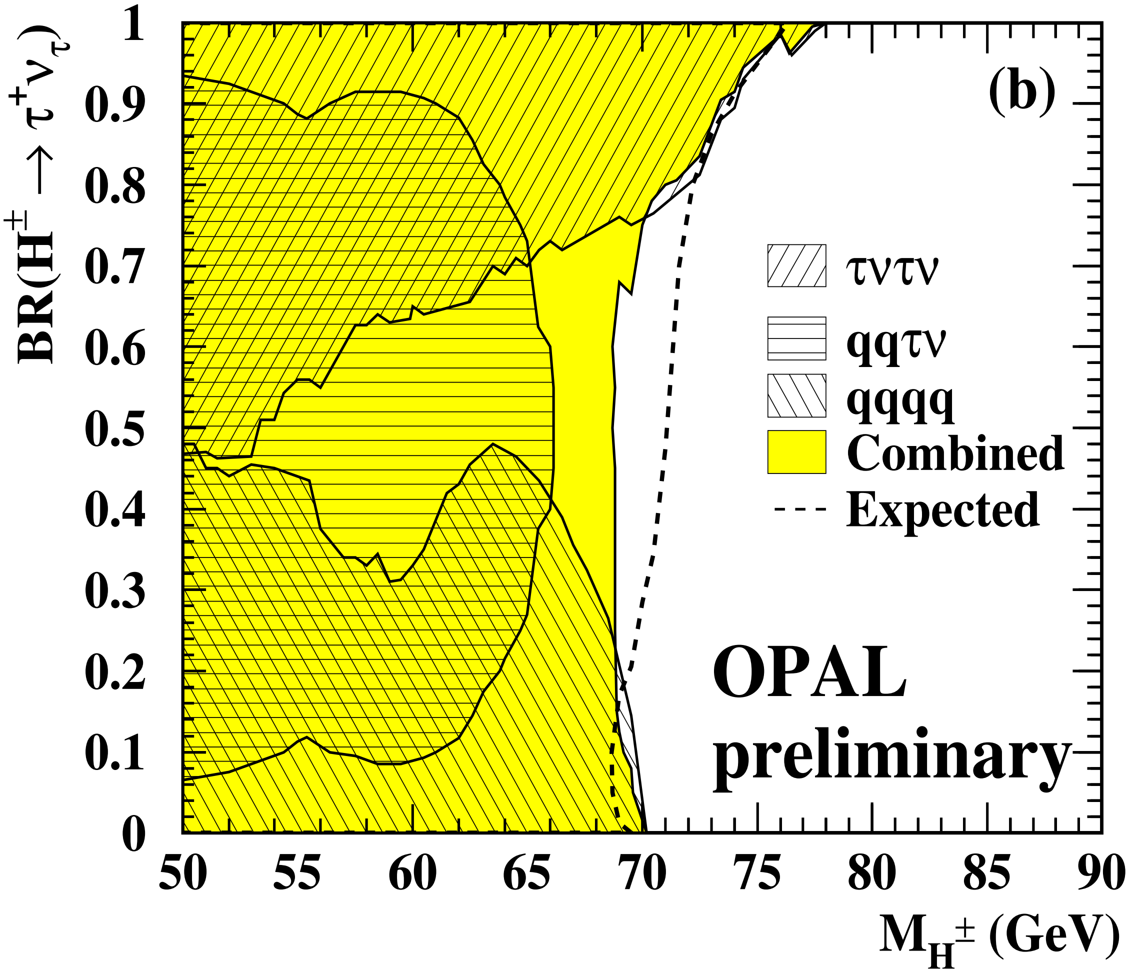
L3

- L3 Note 2379, Tampere 7-236
- 176.4 pb^{-1} of 189 GeV
- hadron channel: 5C kinematic fit
- 67.5 GeV limit



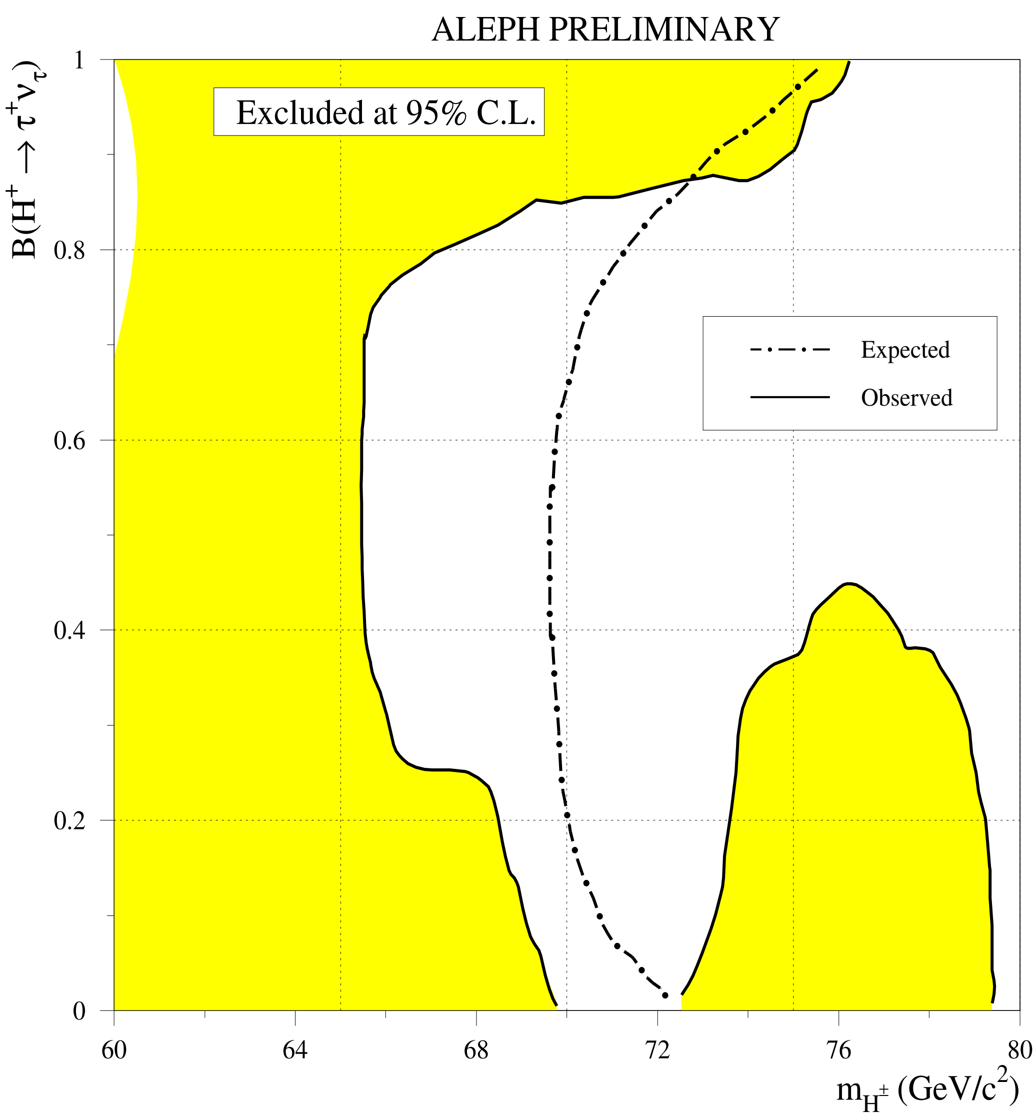
OPAL

- OPAL-PN/99-373, Tampere 7-65
- 179.1 pb^{-1} of 189 GeV
- lepton: τ ANN, mass-binned analysis
- hadron: 5C fit
- limit: 68.7 GeV



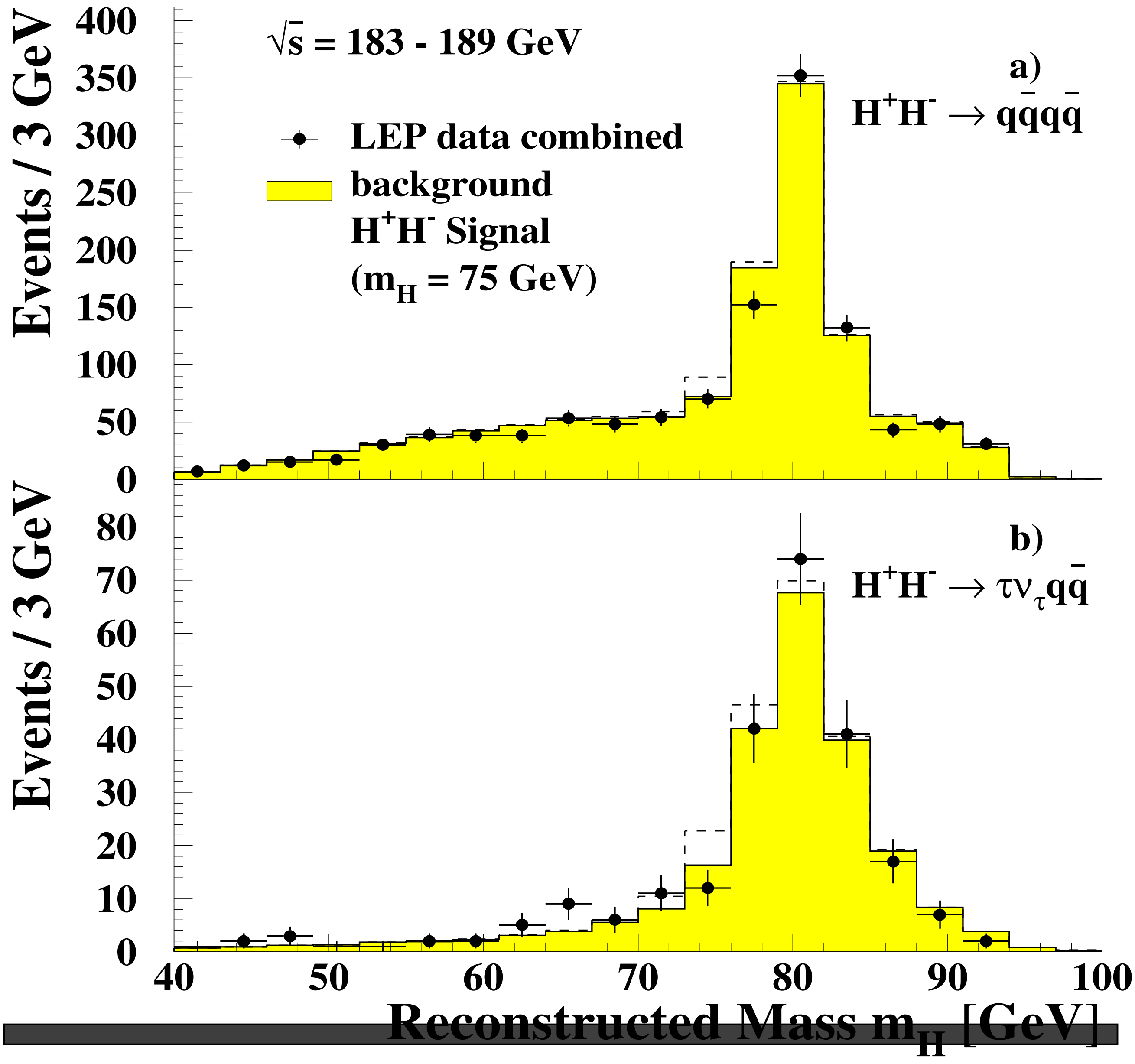
ALEPH

- ALEPH 99-070, Tampere 7-414
- 176 pb^{-1} of 189 GeV data, plus 130-183
- new lepton mode analysis
- hadron mode use 5C fit
- 65.5 GeV limit



189 GeV LEP Combined

- 77.3 GeV combined limit for this conference: ALEPH 99-081, DELPHI 99-142, L3 Note 2442, OPAL TN-614



Conclusions

- LEP and FNAL have searched for:
  - h^0 with enhanced photonic couplings
  - charged H
  - h^0 into undetected particles
- Event candidates in all searches are (very!) consistent with Standard Model backgrounds
- Limits can be placed on models which extend the minimal sector, particularly the 2HDM and HTM (triplet model)
- worst cases:
  - fermiophobic: M > 96 GeV
  - charged: M > 77.3 GeV
  - invisible: cross section limits up to 90 GeV and higher