

# Higgs searches with DELPHI



**U. Schwickerath, CERN**

DELPHI Collaboration

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**All results are preliminary**

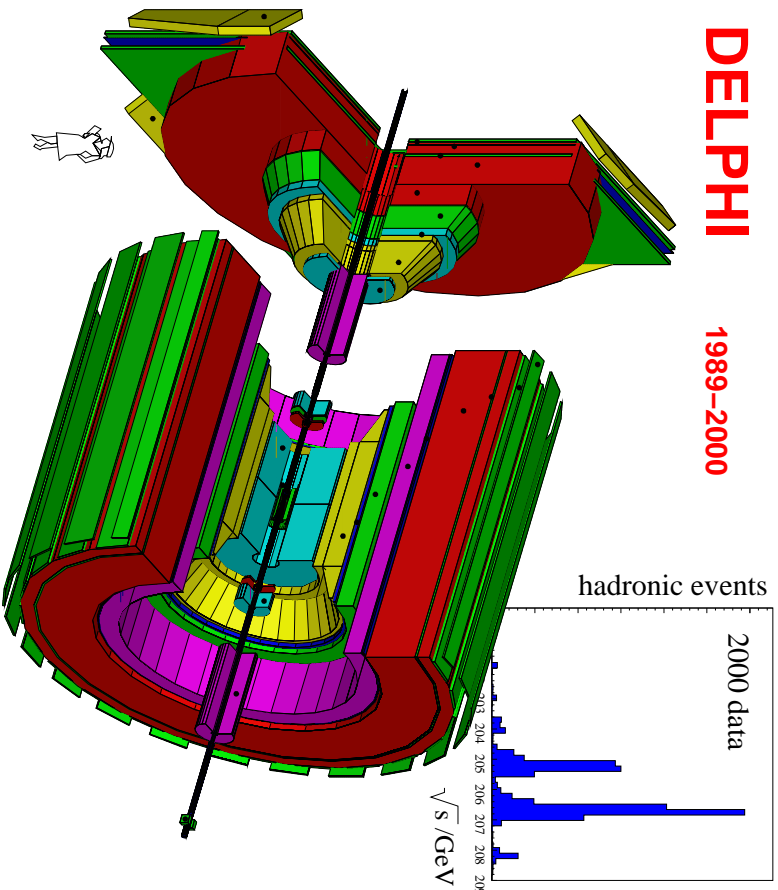


## Outline

- Introduction
- SM Higgs boson searches
  - Hqq channel
  - $H\nu\nu$  channel
  - charged lepton channels
- Higgs bosons beyond the SM
  - hA searches
  - charged Higgs boson searches
  - invisible Higgs decays
- Prospects
- Conclusions



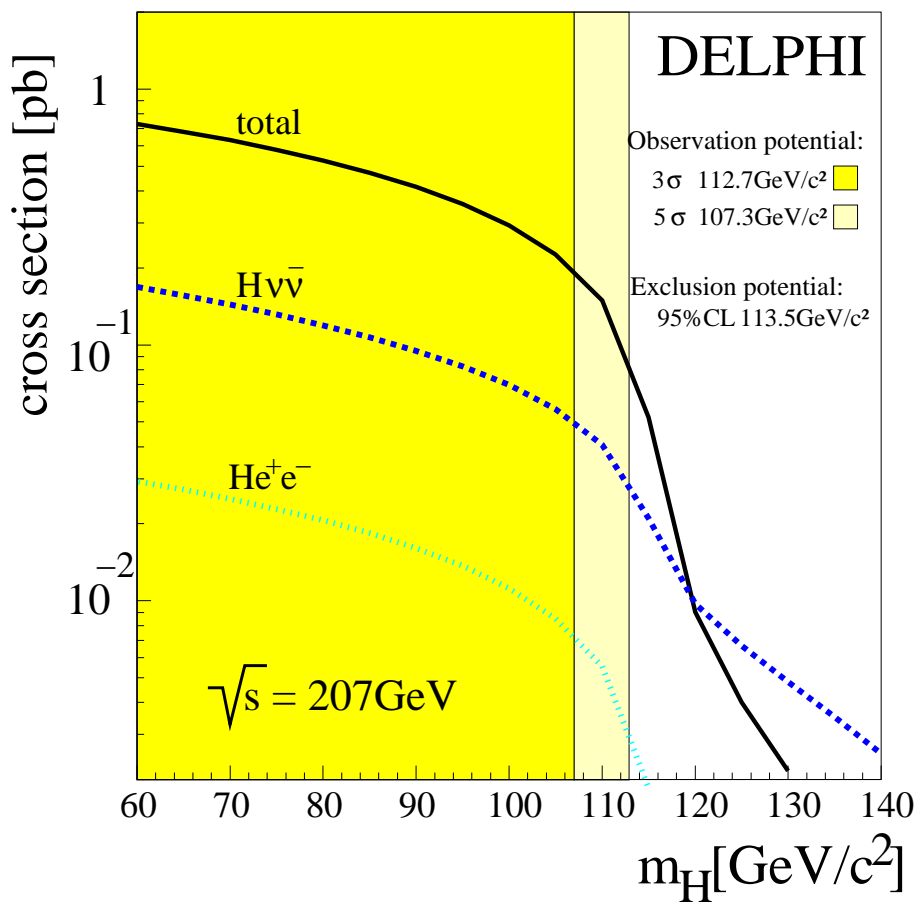
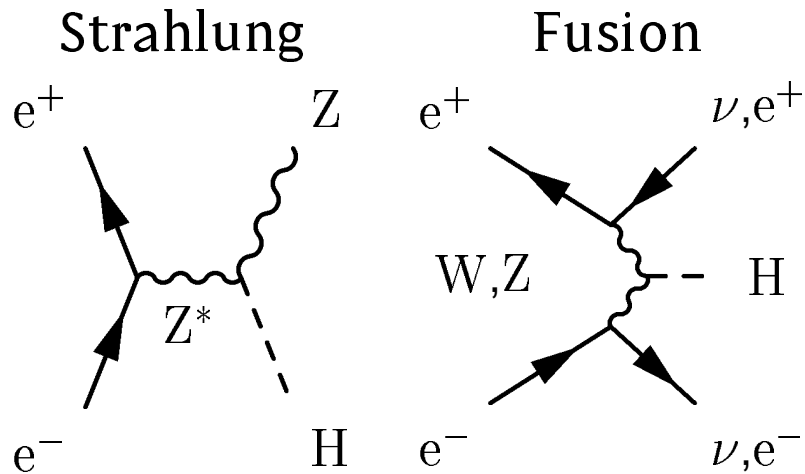
## DELPHI data taking in the year 2000



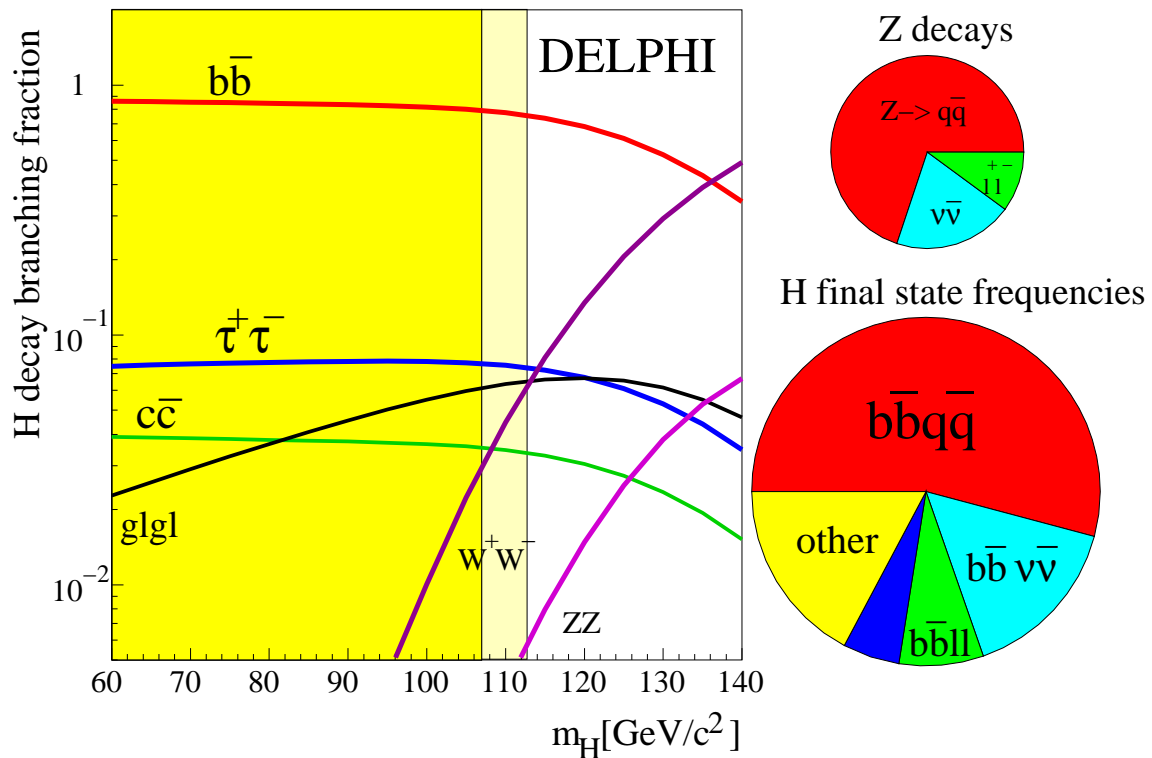
- about 225  $\text{pb}^{-1}$  recorded data between 200 and 209 GeV
- about 688  $\text{pb}^{-1}$  in total above WW threshold
- death of one TPC sector in September



## Production of the SM Higgs at LEP



## Decay properties of the SM Higgs at LEP

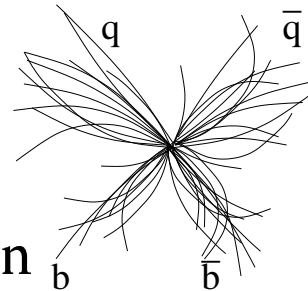


- analysis optimisation for  $H \rightarrow b\bar{b}$
- quoted efficiencies include small fraction of other Higgs decay modes



## 4-jet channel

$H \rightarrow \text{any but } \tau, Z \rightarrow q\bar{q}$

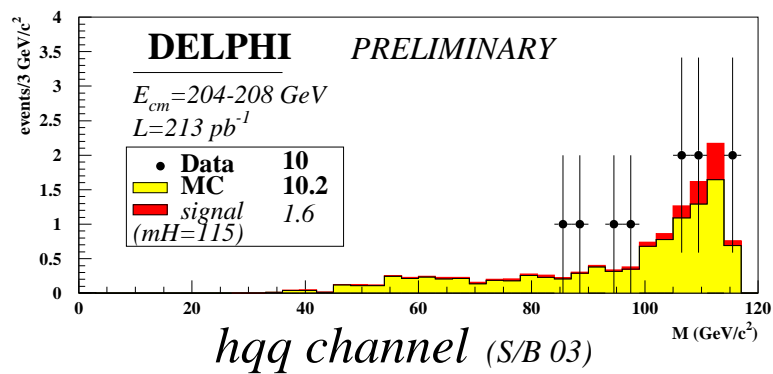
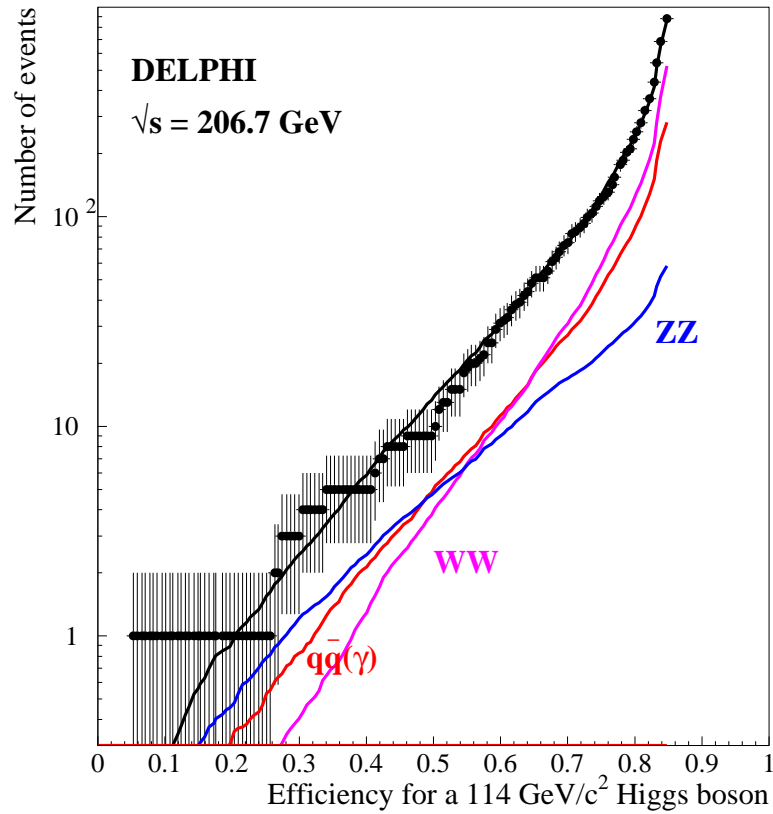


- cut based 4-jet preselection
- NNW with 13 input variables:
  - Anti-QCD (8)
  - WW and ZZ compatibility (4)
  - sum of the two largest jet btags in the event (1)
- likelihood based pairing strategy

Cut	data	background	eff. [%]
Presel.	2266	2342	85.0
intermed.	398	423.7	79.0
tight	8	7.4	36.0

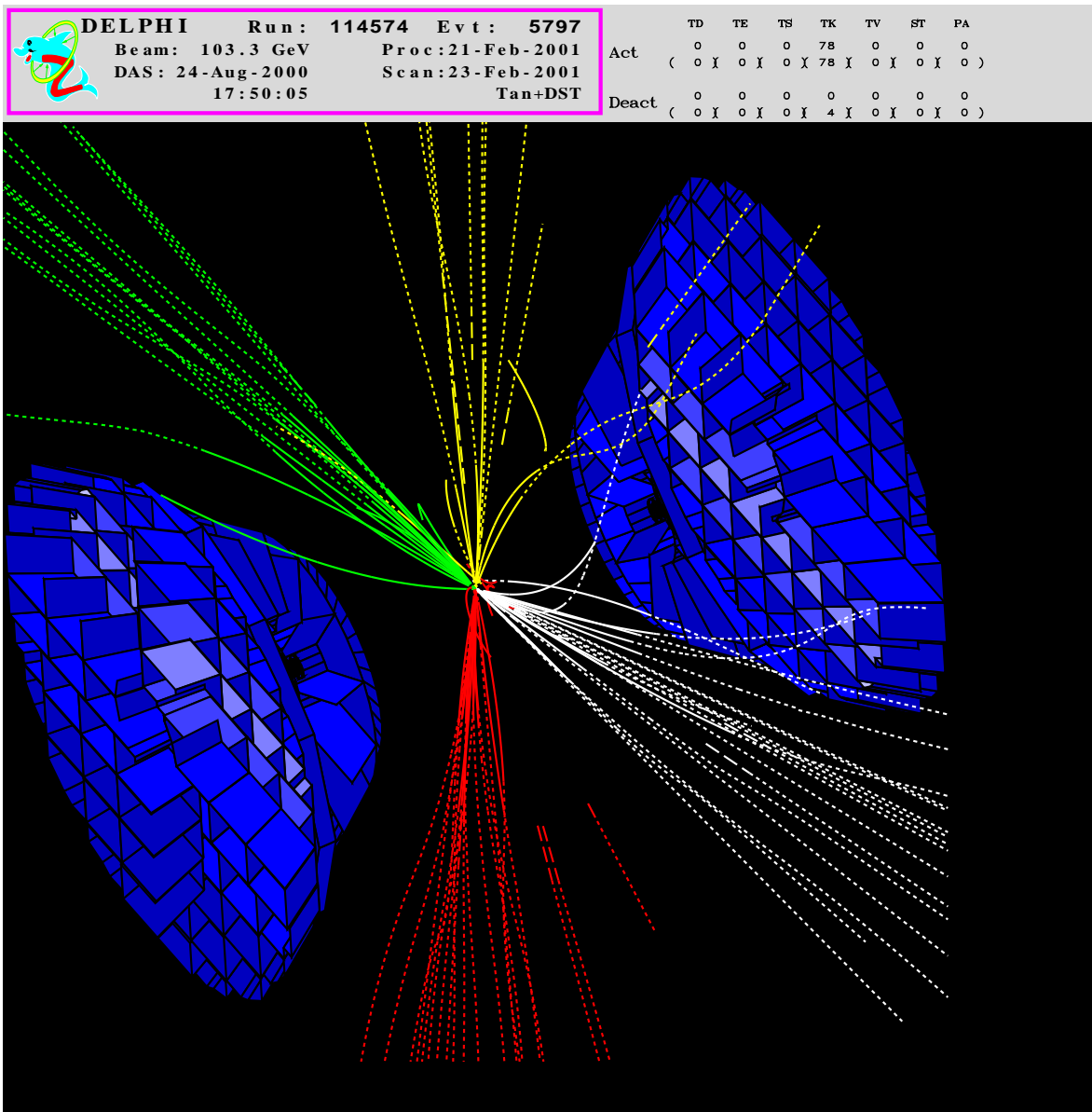


## 4-jet channel: results



No indication for signal production

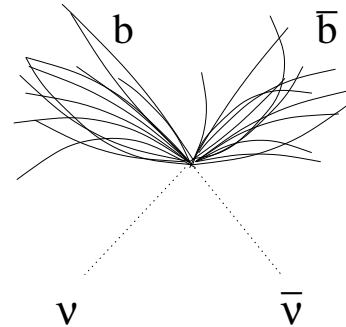






## Missing energy channel

$$H \rightarrow \text{any}, Z \rightarrow \nu\bar{\nu}$$

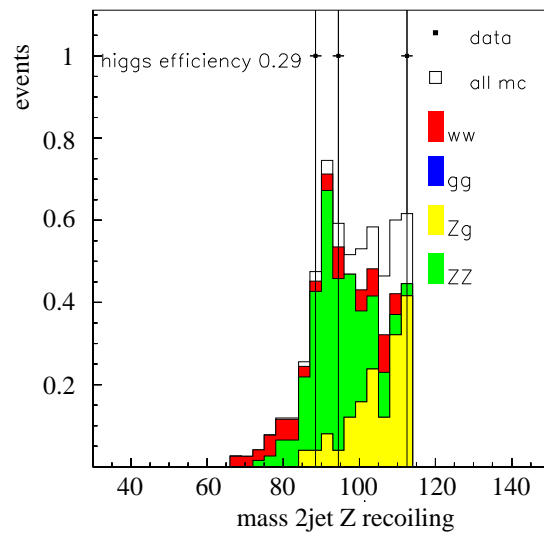
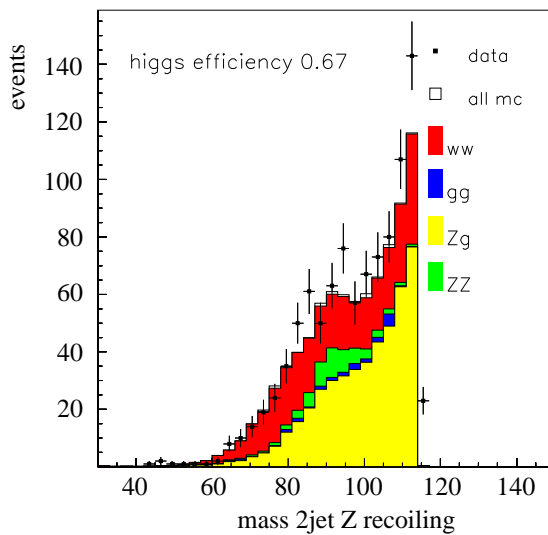
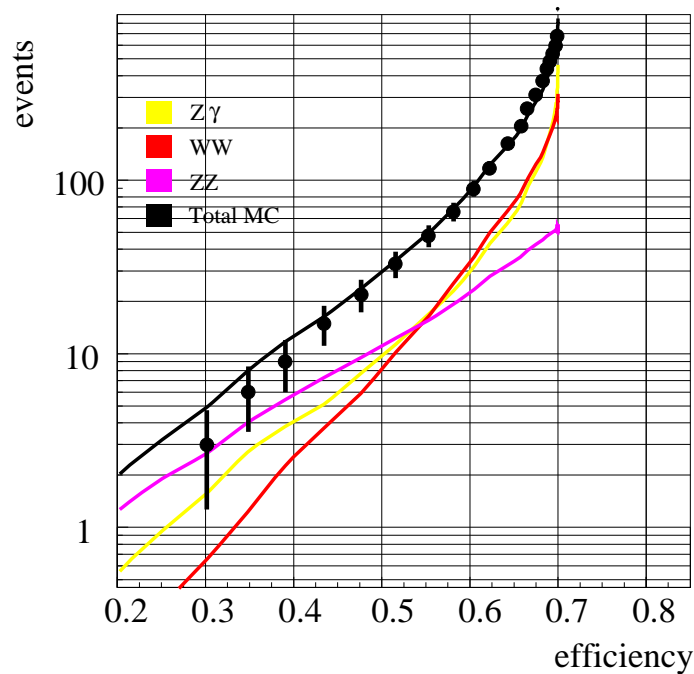


- four step sequential preselection
- final selection done by likelihood function

Cuts	data	background	eff. [%]
bhabha $\gamma\gamma$	17503	17753	86.1
$q\bar{q}(\gamma)$	1808	1681	78.3
$W^+W^-$	1357	1189	75.5
final presel.	970	851	66.9



## Missing energy channel: results



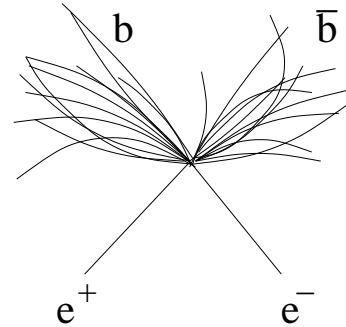
No indication for signal production



## Hee channel

$$H \rightarrow \text{any}, Z \rightarrow e^+e^-$$

- sequential cut analysis
- final cut in btag



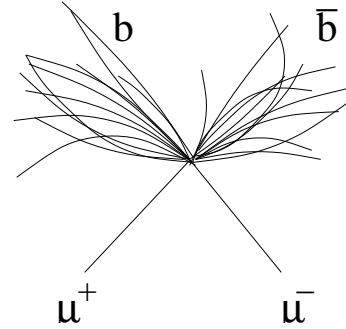
Cut	data	background	eff. [%]
Presel.	1242	1171.6	77.9
Ident.	168	195.9	65.6
El.ene.	68	78.7	63.3
Fit pr.	31	30.2	60.1
Jet Iso.	13	14.6	57.0
Mass sel.	7	11.6	56.7
btag	1	3.5	49.3

No indication for signal production



## H $\mu\mu$ channel

$$H \rightarrow \text{any}, Z \rightarrow \mu^+ \mu^-$$



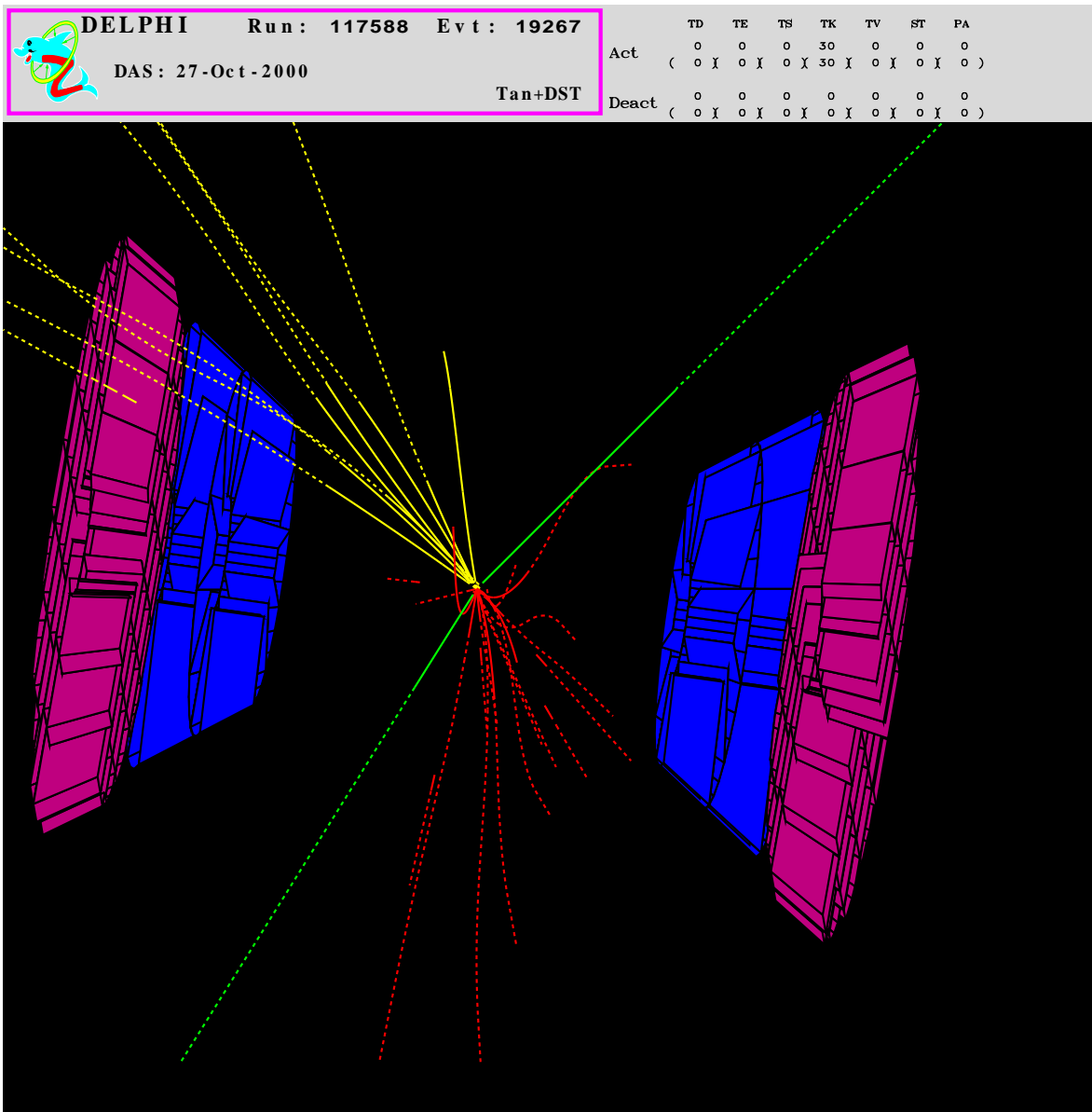
- sequential cut analysis
- final cut in btag

Cut	data	background	eff. [%]
Presel	3780	3763.9	81.
Dil. ang.	2858	2812.7	81.
momentum	991	893.6	78.
Muon Id.	26	27.1	73.
Isolation	12	15.4	71.
5C - Fit	7	10.6	68.
B tag	3	5.8	61.

No indication for signal production



## H $\mu\mu$ channel: candidate event

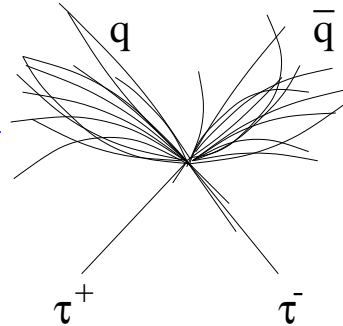


$$M_{qq} = 94 \text{ GeV}/c^2, M_{\mu\mu} = 85 \text{ GeV}/c^2, \text{large btag}$$



## $H_{\tau\tau}$ and $\tau\tau Z$ channel

$H \rightarrow \text{any but } \tau, Z \rightarrow \tau^+\tau^-$   
 $H \rightarrow \tau^+\tau^-, Z \rightarrow q\bar{q}$



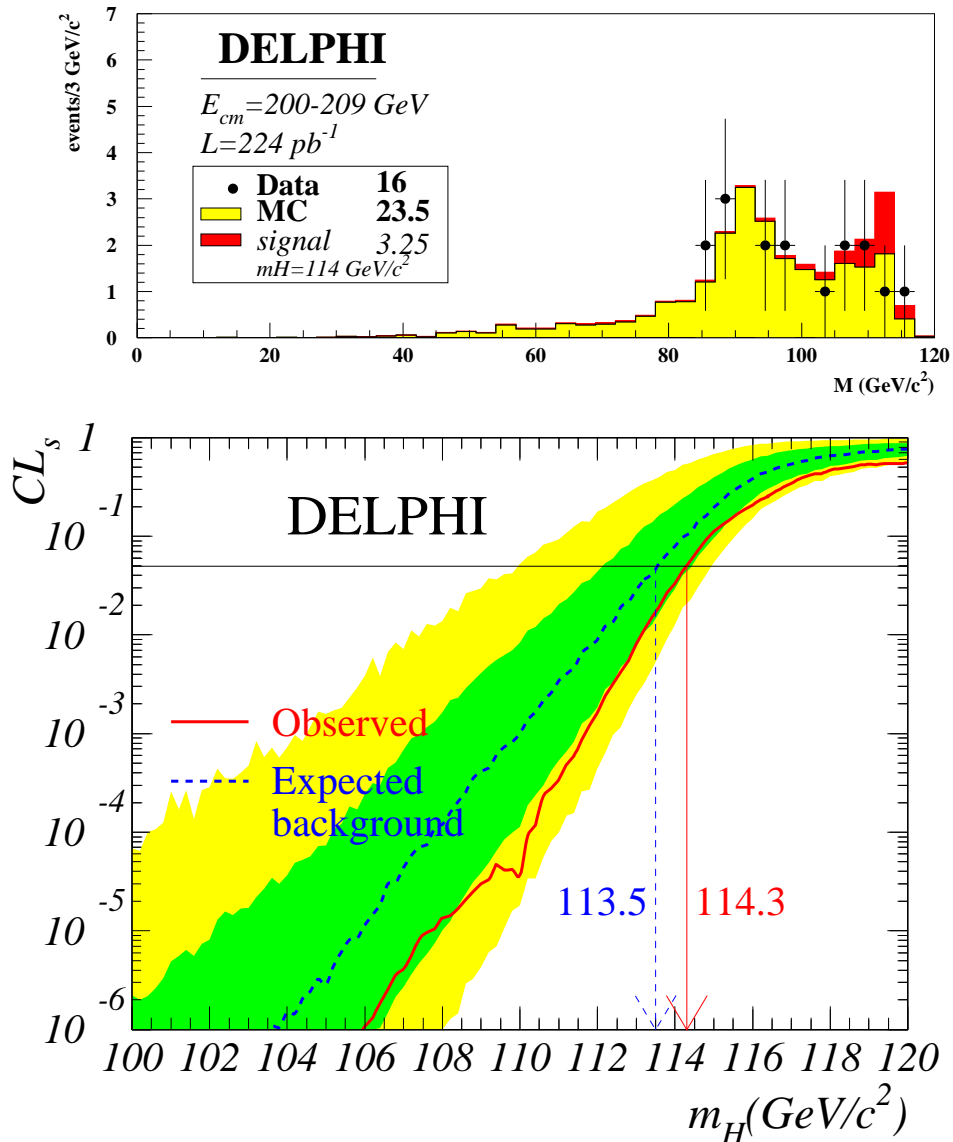
- covers also MSSM  $h, A \rightarrow \tau^+\tau^-$  channels
- likelihood function to select  $\tau$  candidates
- sequential cuts for final selection

Cut	data	background	eff. [%]
Presel.	9180	8876.0	98.1
final	5	7.15	15.9

No indication for Higgs production



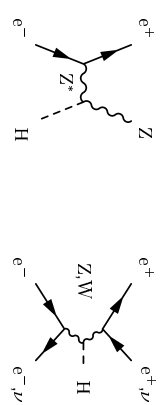
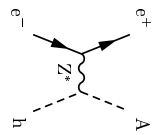
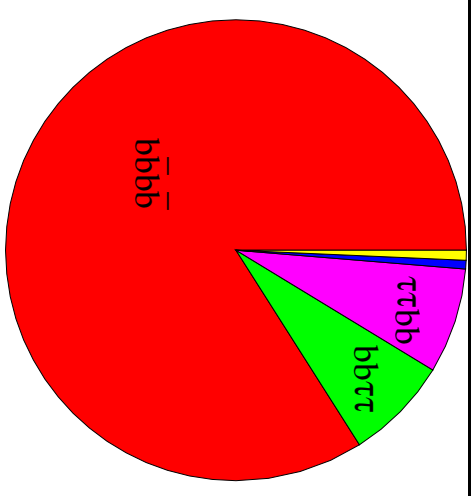
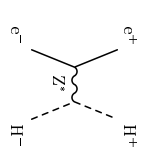
## SM results: DELPHI combined limits



$M_H > 114.3 \text{ GeV}/c^2$  (113.5  $\text{GeV}/c^2$  exp.)



Beyond the SM: 2-doublet model, MSSM, ...

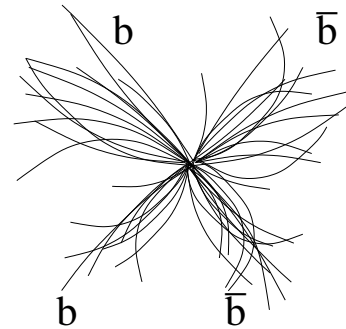
production	decays
<p><b><math>h, H</math></b></p> 	<p><math>b\bar{b}</math></p> <p><math>\tau^+\tau^-</math></p> <p>...</p> <p><math>\tilde{\chi}^0\tilde{\chi}^0</math></p>
<p><b><math>A</math></b></p> 	
<p><b><math>H^\pm</math></b></p> 	<p><math>c\bar{s}c s</math></p> <p><math>c s \tau \nu</math></p> <p><math>\tau^+\nu\tau^-\bar{\nu}</math></p> <p>...</p>





## $e^+e^- \rightarrow hA$ searches

$$h \rightarrow b\bar{b}, A \rightarrow b\bar{b}$$

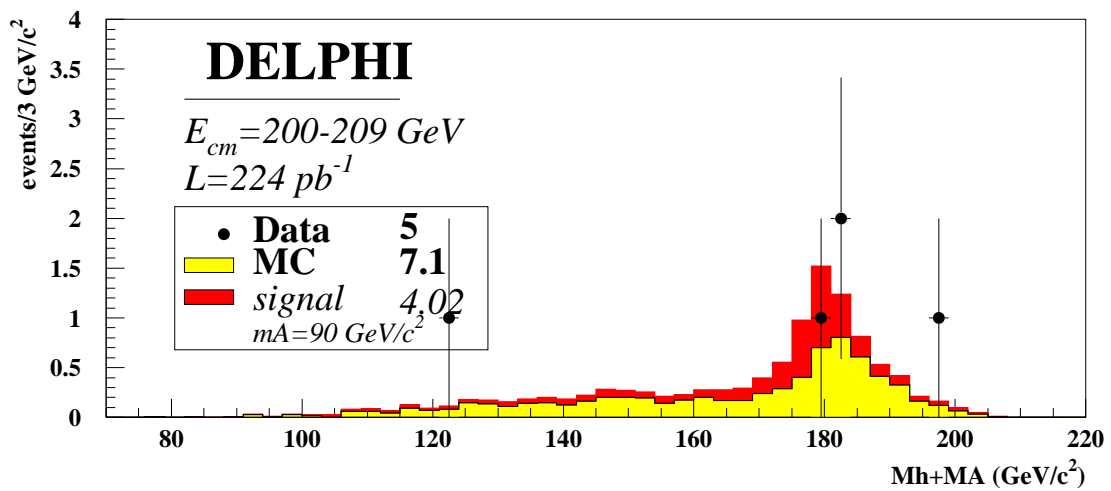
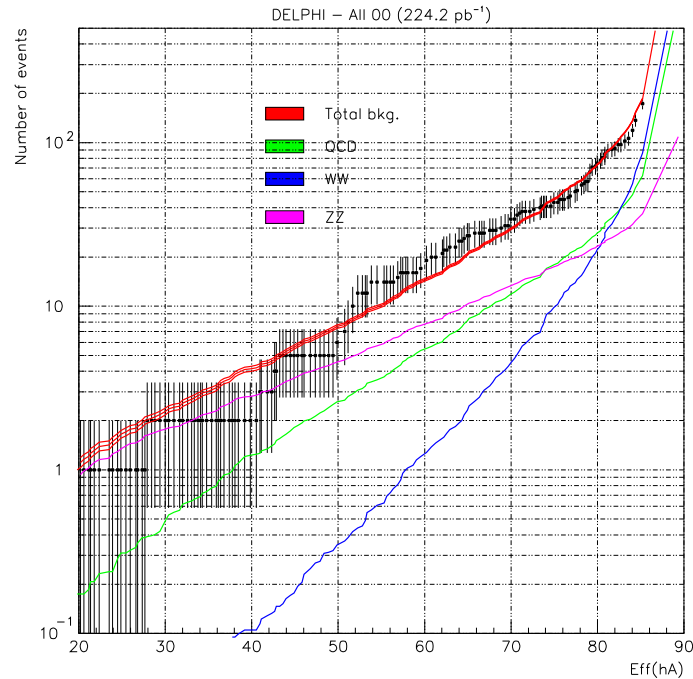


- sequential preselection as for SM  $Hq\bar{q}$
- additional cuts against QCD
- likelihood for final selection

Cut	data	background	eff. [%]
presel.	1803	1933.5	89.2
intermed.	129	145.2	84.1
s/b=0.3	24	18.7	63.9
s/b=1	2	3.1	35.2



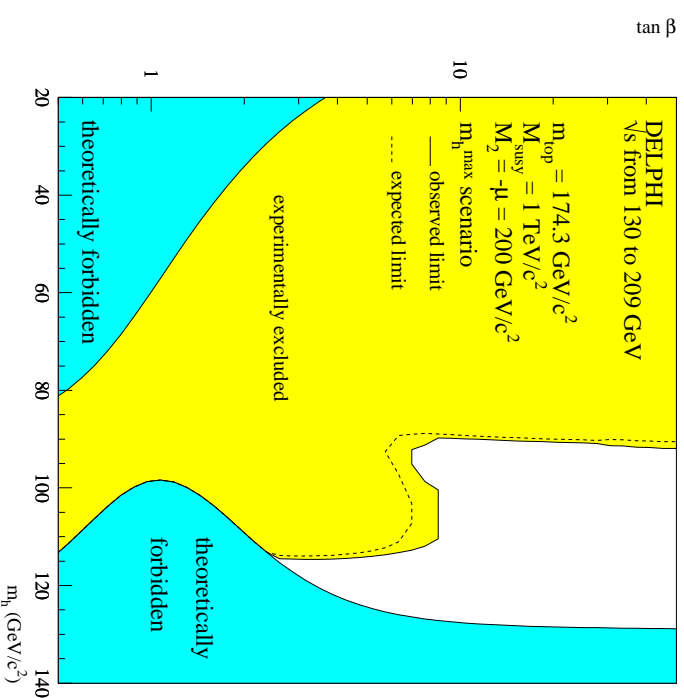
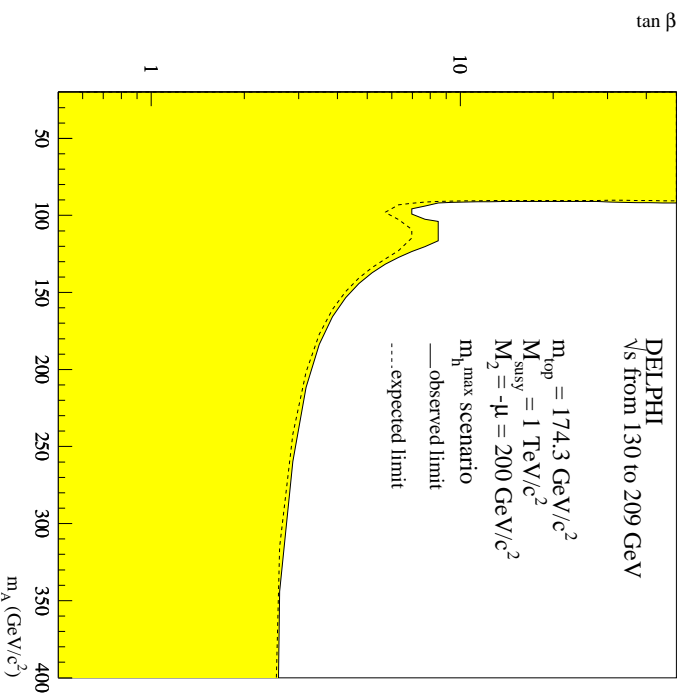
# $e^+e^- \rightarrow hA$ searches



Compatible with background expectation



# Interpretation in the MSSM: $m_h^{max}$ scenario



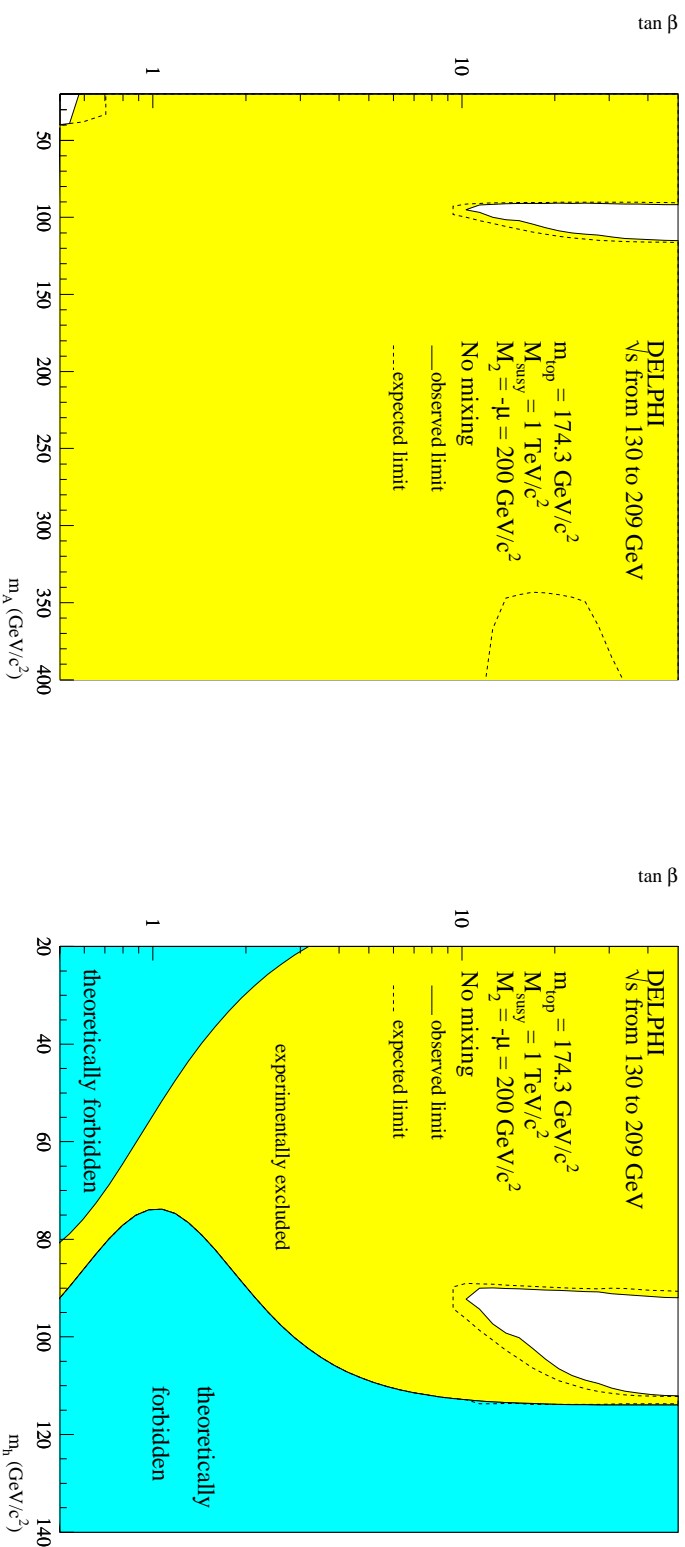
95% CL exclusion limits,  $m_h^{max}$  scenario:

$$m_A > 90.9 \text{ GeV}/c^2 \text{ (90.1 GeV}/c^2), m_h > 89.8 \text{ GeV}/c^2 \text{ (89.0 GeV}/c^2)$$

$$0.49 < \tan \beta < 2.36 \text{ (0.54 < \tan \beta < 2.36)}$$



## Interpretation in the MSSM: No mixing scenario



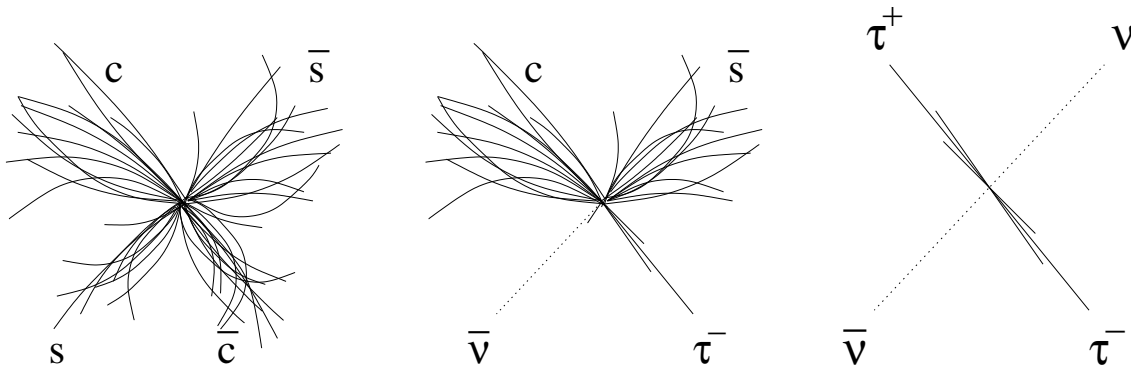
95% CL exclusion limits, no mixing scenario:

$$m_A > 90.8 \text{ GeV}/c^2 \quad (90.0 \text{ GeV}/c^2), \quad m_h > 90.0 \text{ GeV}/c^2 \\ (89.1 \text{ GeV}/c^2) \quad 0.59 < \tan \beta < 9.36 \quad (0.72 < \tan \beta < 9.36)$$



## Charged Higgs boson searches

$$H^+ H^- \rightarrow c\bar{s}c\bar{s}, c\bar{s}\tau\nu, \tau\nu\tau\nu$$



- sequential preselection
- likelihood analyses for all 3 channels
- limited by  $WW$  background

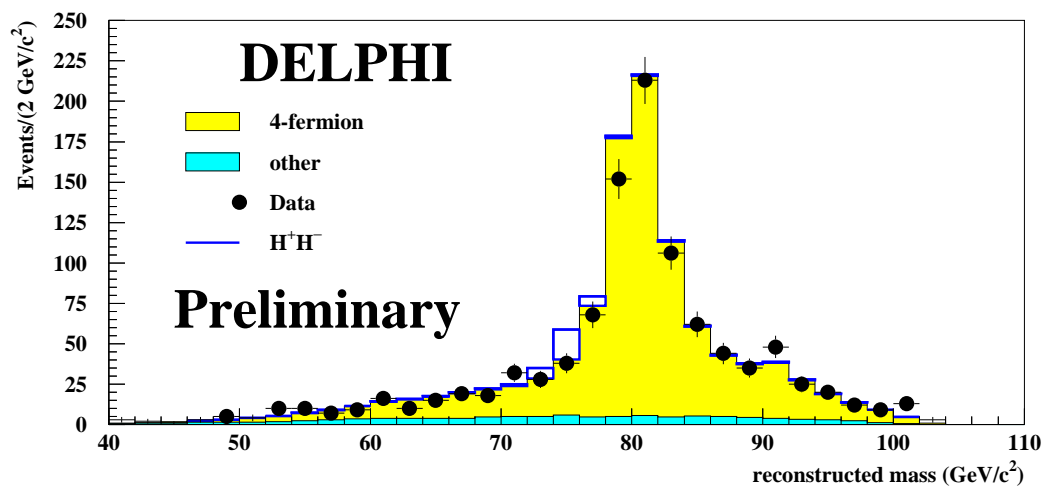
Channel	data	background	eff. [%]
$c\bar{s}c\bar{s}$	1040	1058.5	34
$c\bar{s}\tau\nu$	498	498.2	35
$\tau\nu\tau\nu$	64	63.7	34

(efficiencies are given for a 70 GeV/c<sup>2</sup> signal)  
 (189 GeV <  $\sqrt{s}$  < 208 GeV)

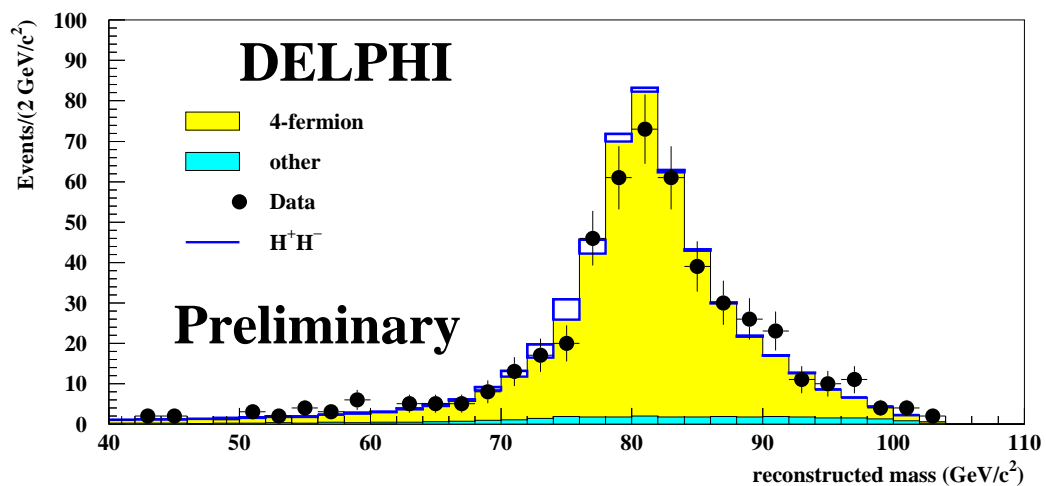


## Charged Higgs bosons: mass distributions

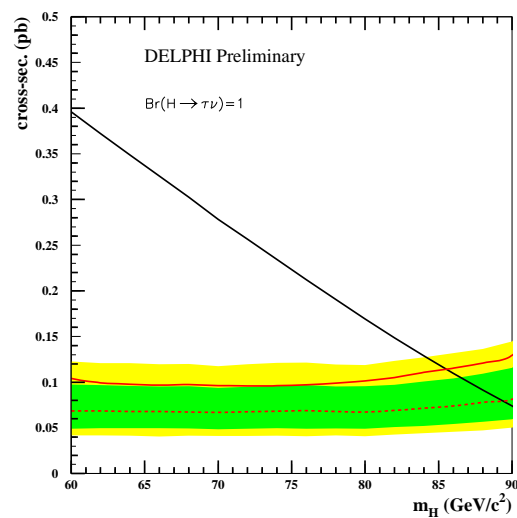
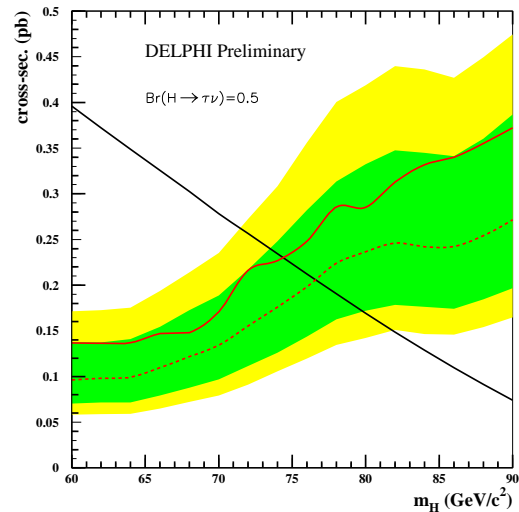
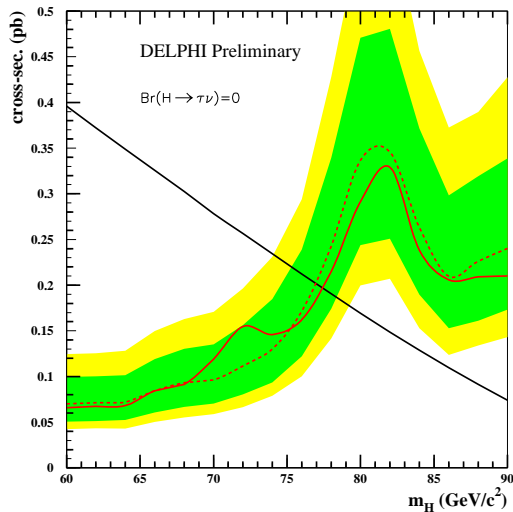
### hadronic channel



### semileptonic channel



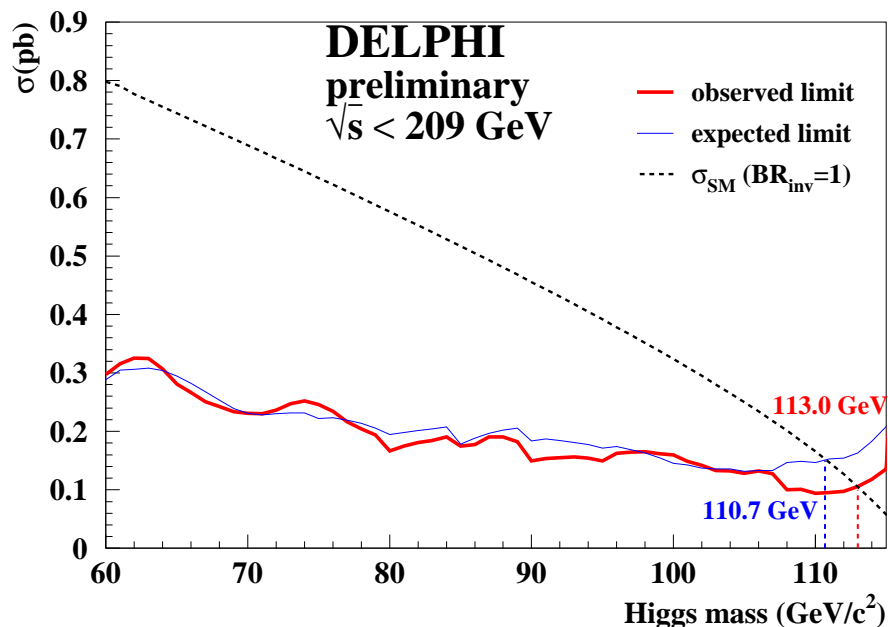
## Charged Higgs bosons: cross section limits



## Invisible Higgs decays

$$H \rightarrow inv, Z \rightarrow q\bar{q}, l^+l^-$$

- iterated discriminant analysis in hadronic channel
- sequential cuts for leptonic channels



BR 100%  $m_H > 113.0 \text{ GeV}/c^2$  (110.7  $\text{GeV}/c^2$  exp.)

Any BR  $m_H > 112.6 \text{ GeV}/c^2$  (109.8  $\text{GeV}/c^2$  exp.)





# DELPHI Higgs Limits Summary

framework	observed	expected	remarks
SM	114.3 GeV/c <sup>2</sup>	113.5 GeV/c <sup>2</sup>	-
$H^+H^-$	73.8 GeV/c <sup>2</sup>	75.4 GeV/c <sup>2</sup>	any BR( $H^\pm \rightarrow \tau\nu$ )
$H_{inv}$	113.0 GeV/c <sup>2</sup>	110.7 GeV/c <sup>2</sup>	BR( $H \rightarrow inv$ )=1
$H_{inv} + H_{vis}$	112.6 GeV/c <sup>2</sup>	109.8 GeV/c <sup>2</sup>	any BR( $H \rightarrow inv$ )
MSSM $m_A$	90.9 GeV/c <sup>2</sup>	90.1 GeV/c <sup>2</sup>	$m_h^{max}$ scenario
$m_h$	89.8 GeV/c <sup>2</sup>	89.0 GeV/c <sup>2</sup>	
$\tan\beta$	0.49 ... 2.36	0.54 ... 2.36	
MSSM $m_A$	90.8 GeV/c <sup>2</sup>	90.0 GeV/c <sup>2</sup>	no mixing
$m_h$	90.0 GeV/c <sup>2</sup>	89.1 GeV/c <sup>2</sup>	
$\tan\beta$	0.59 ... 9.36	0.72 ... 9.36	

All numbers are preliminary!



## Prospects ...

Other Higgs-related analyses are on the way:

- general MSSM scan
- $h \rightarrow AA, A \rightarrow Zh$
- flavour blind / non  $b\bar{b}$  Higgs decays:
  - $h \rightarrow \gamma\gamma$
  - $h \rightarrow W^+W^-$
  - $h \rightarrow$  gluon gluon
  - $h \rightarrow s\bar{s}$



## Conclusions

- We had a very successful data taking in 2000, the last year of LEP.
- During LEP2 DELPHI accumulated about  $688 \text{ pb}^{-1}$  above the  $WW$  threshold.
- Even after the end of LEP DELPHI is still a very active collaboration.
- No indication for a Higgs signal has been found.
- Many thanks to everybody who provided information to prepare this talk!

