Higgs searches at LEP

Francesca Di Lodovico

ETH–Zürich

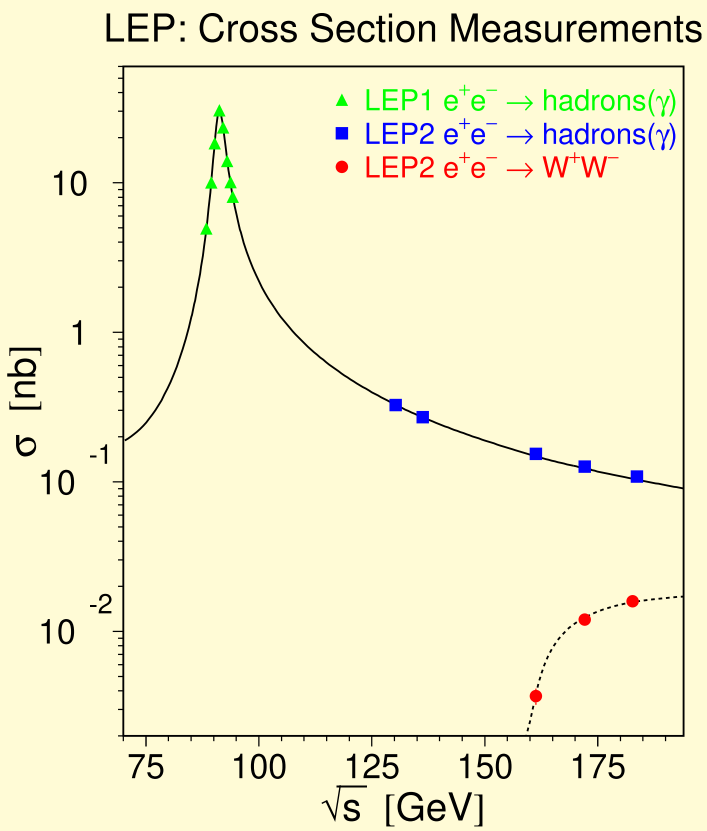
On behalf of the four LEP Collaborations

Outline:

- Standard Model Higgs boson
- MSSM Higgs bosons
- Charged Higgs bosons

Many thanks to: S. de Jong, M. Dittmar, M. Felcini, P. Gay, M. Girone, T. Junk, S. Katsanevas, A. Kopp, F. Pauss, V. Ruhlmann-Kleider, A. Sopczak

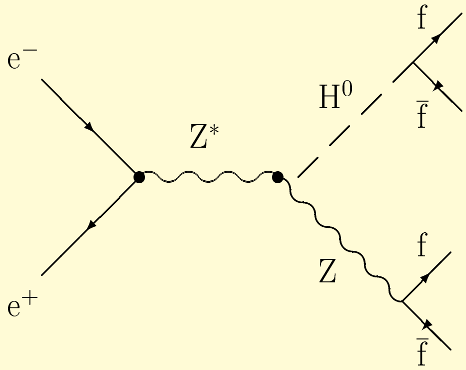
Expected and measured cross sections for SM processes

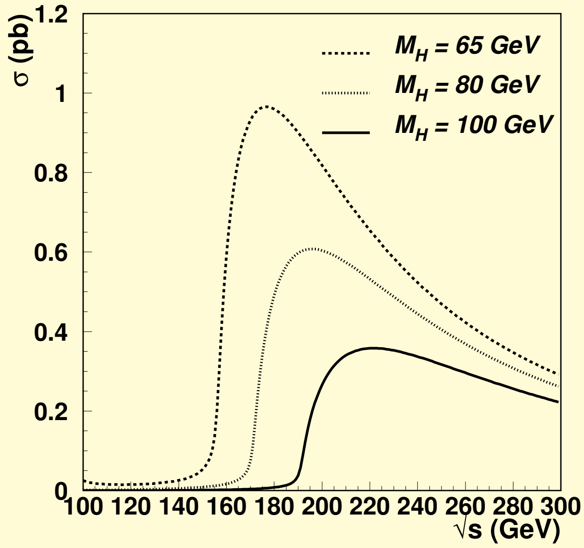


Collected data samples		
	$\sqrt{s}$	$\int \mathcal{L}$ / experiment
	130–140 GeV	~ 5 pb^{-1}
	161 GeV	~ 10 pb^{-1}
	172 GeV	~ 10 pb^{-1}
	183 GeV	~ 55 pb^{-1}
1998 (not included)	189 GeV	~ 150 pb^{-1} ~ 35 pb^{-1} up to now
1999–2000	~ 200 GeV	~ 200 pb^{-1}

SM Higgs boson

Dominant production process: Higgs–strahlung





From searches up to $\sqrt{s}$ = 172 GeV:

$\boxed{m_{\mathrm{H}} > \text{77.5 GeV at 95\% CL}}$

Expected Signal Events		
m_{H} (GeV)	$\sqrt{s}$ = 183 GeV $\int\mathcal{L}$ = 55 pb^{-1}	$\sqrt{s}$ = 200 GeV $\int\mathcal{L}$ = 200 pb^{-1}
80	30	121
90	9	89
100	0.01	53

$e^+e^- \to H^0Z$ signatures

$H^0 \to b\bar{b}$ dominat (BR $\approx$ 84%)

- **Four–Jet Channel**

  $H^0 \to b\bar{b}, Z \to q\bar{q}$: 58.8 %

- **Missing Energy Channel**

  $H^0 \to b\bar{b}, Z \to \nu\bar{\nu}$: 16.8 %

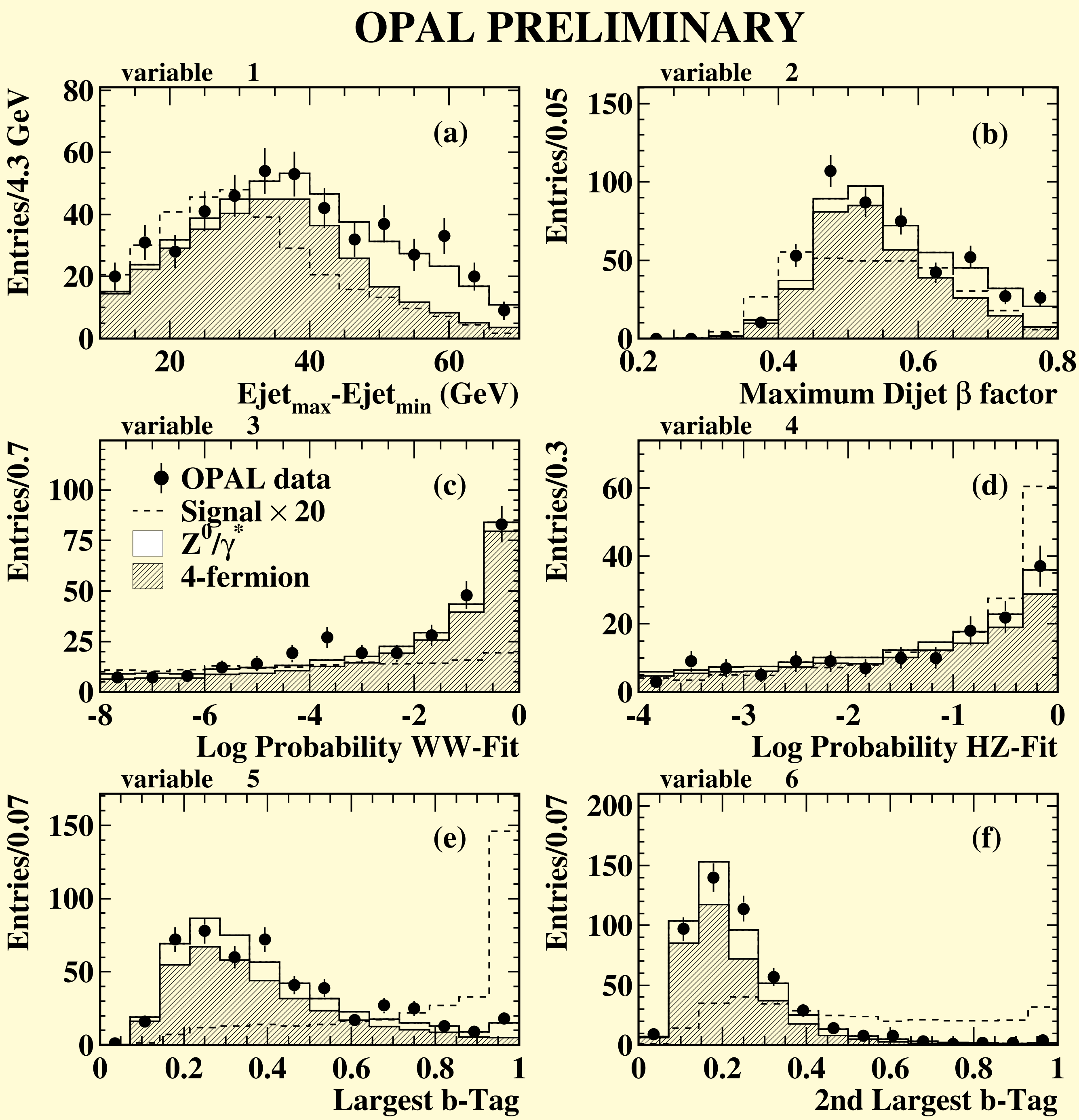
- **Leptonic Channels**

  $H^0 \to b\bar{b}, Z \to e^+e^- + \mu^+\mu^- + \tau^+\tau^-$

  and $H^0 \to \tau^+\tau^-, Z \to q\bar{q}$: 13.9 %

Dominant final states (m_{H^0} = 85.0 GeV)				
$Z \to$ | $H^0 \to$	$b\bar{b}$	$c\bar{c}$	gg	$\tau^+\tau^-$
$q\bar{q}$	58.8 %	2.6 %	2.9 %	5.5 %
$\nu\bar{\nu}$	16.8 %	0.8 %	0.8 %	1.6 %
$\ell^+\ell^-$ (ℓ= e or μ or τ)	2.8 %	0.1 %	0.1 %	0.3 %

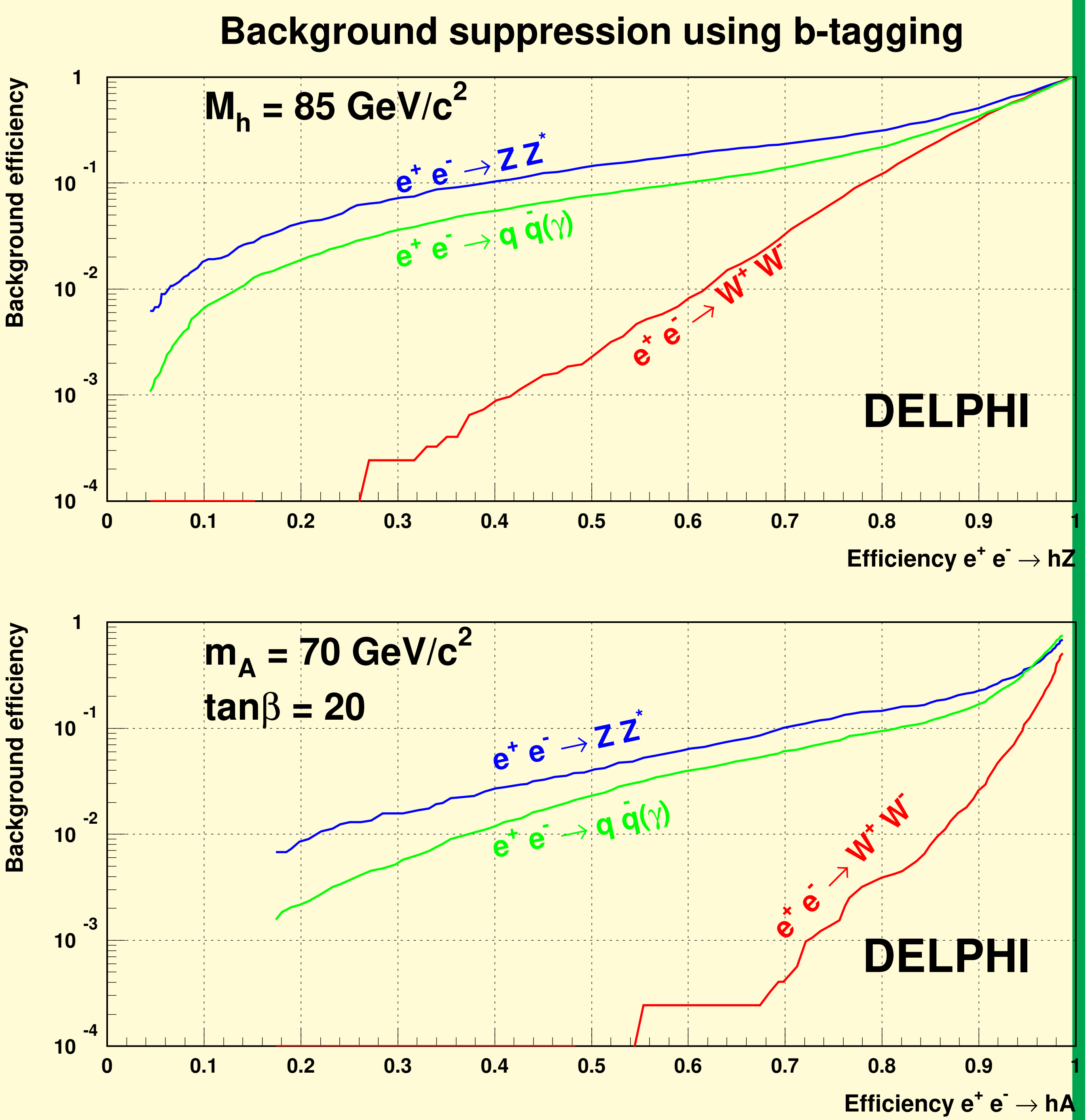
After Selection of four jet events



Signal efficiency= 79.9 % for m_{H} = 80 GeV

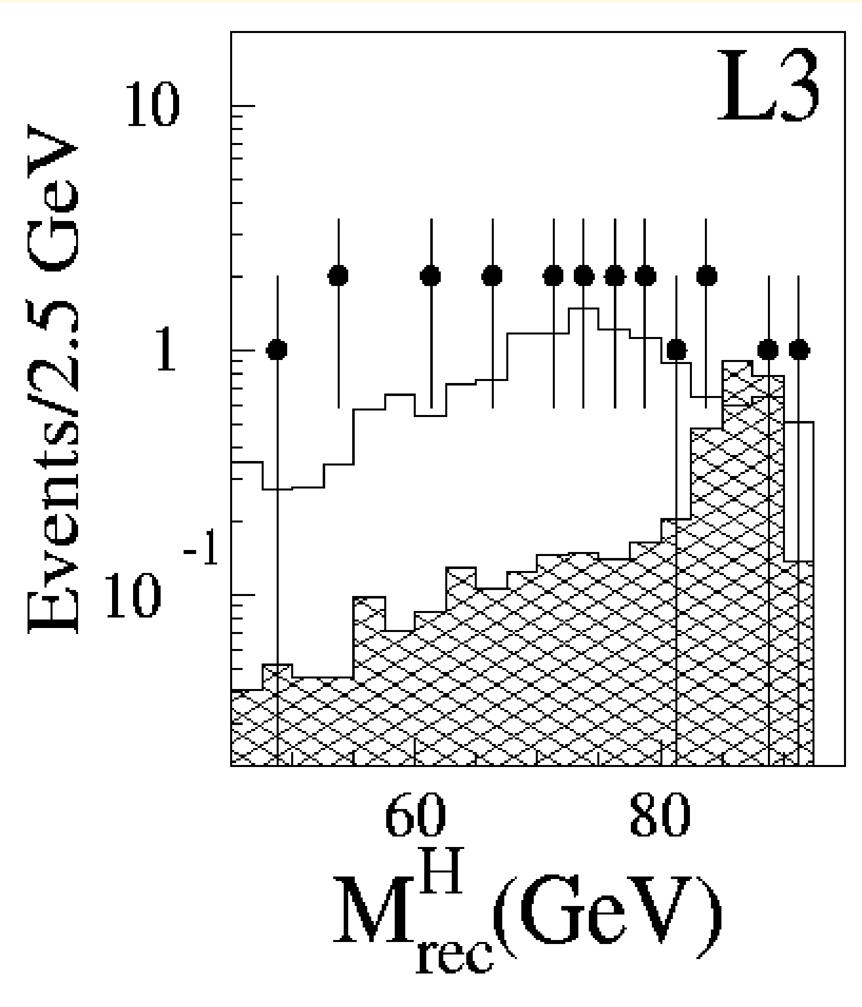
Background= 472.2 Data= 488

B–tagging performances



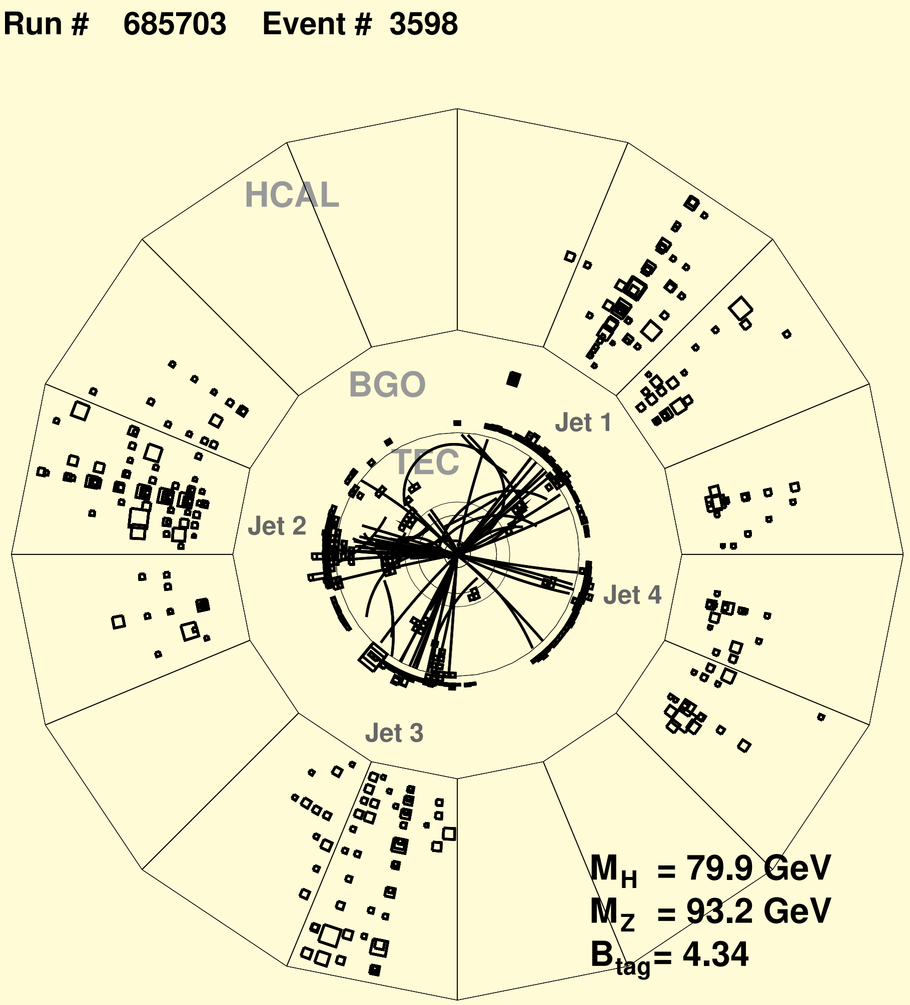
Four Jet Channel

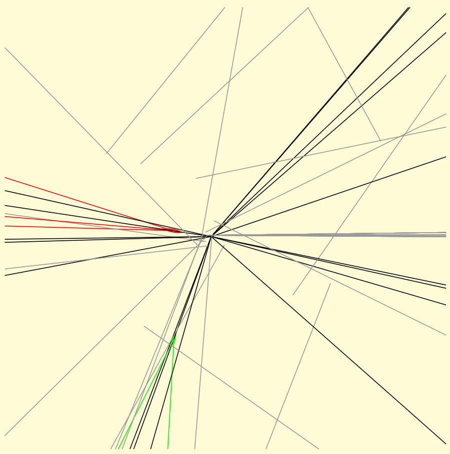
Reconstructed m_{H} after cuts



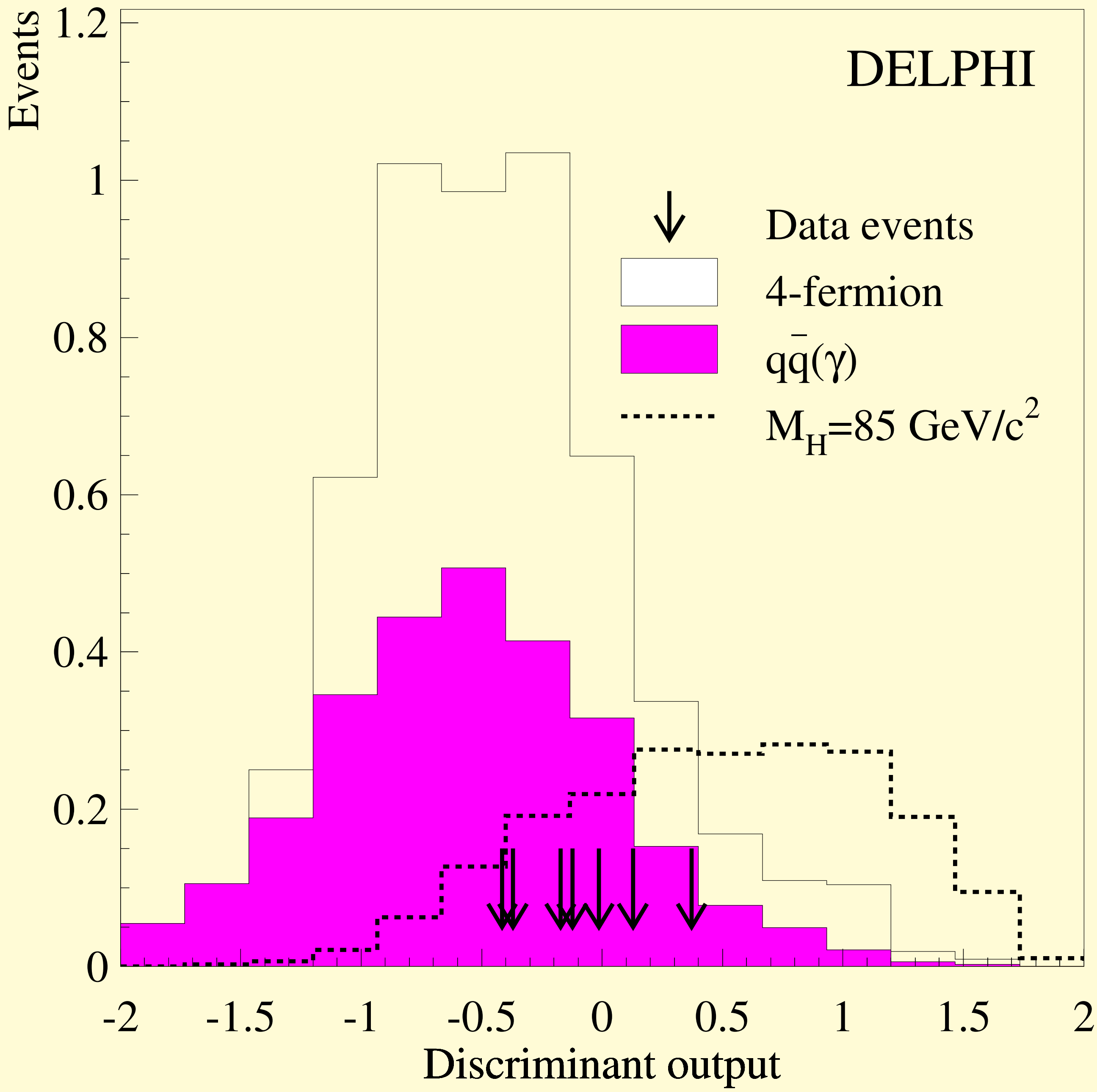
Number of events after all the cuts for L3

- Data: 15
- Background: 18.1
- Signal (m_{H} = 85 GeV): 6.3


Run # 685703 Event # 3598
HCAL
BGO
TEC
Jet 1
Jet 2
Jet 3
Jet 4
M_H = 79.9 GeV
M_Z = 93.2 GeV
B_{tag}= 4.34



$\mathrm{H}^0\nu\nu$ Channel

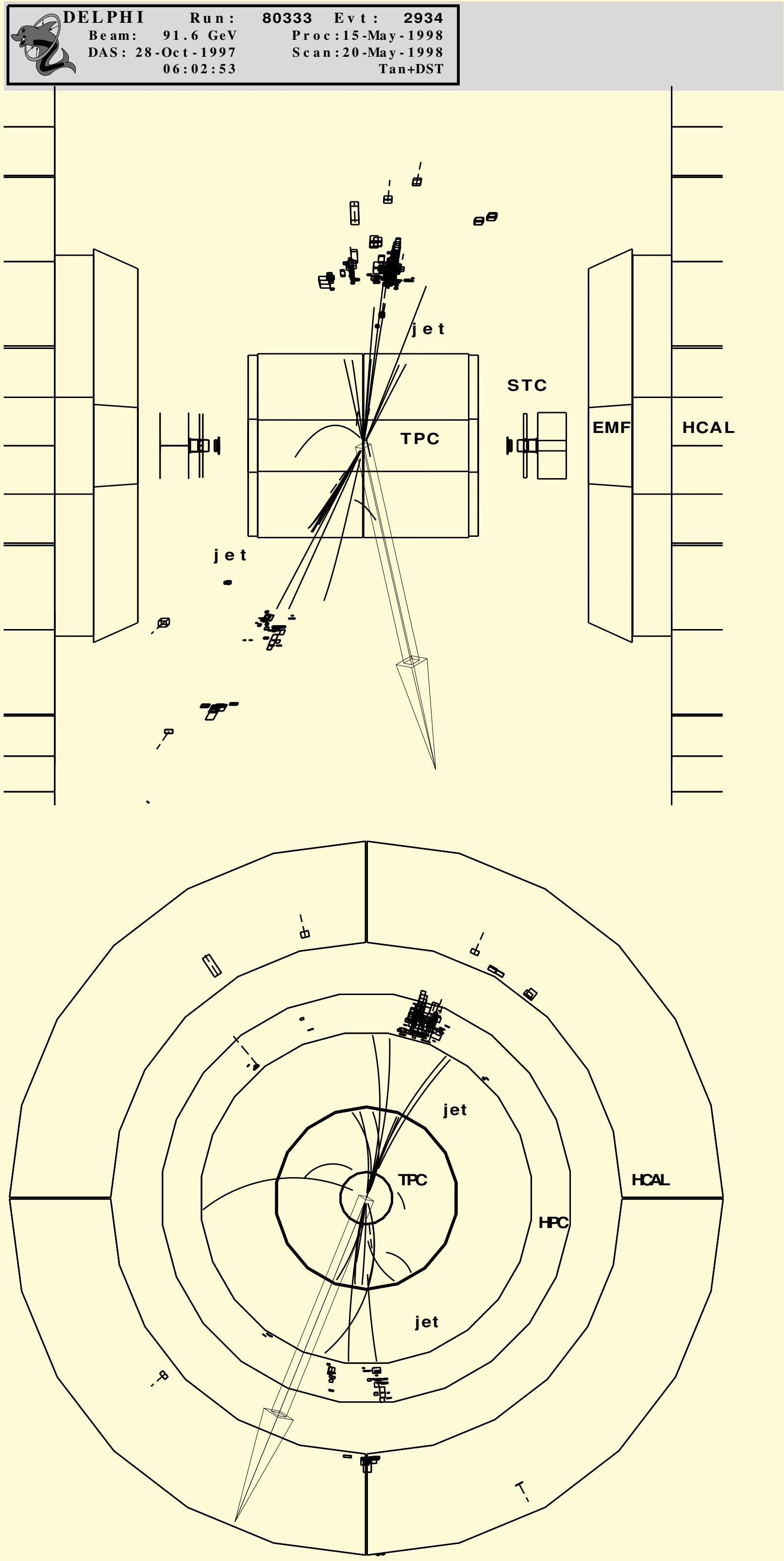


DELPHI: Data= 7, Bkgd = 5.5,

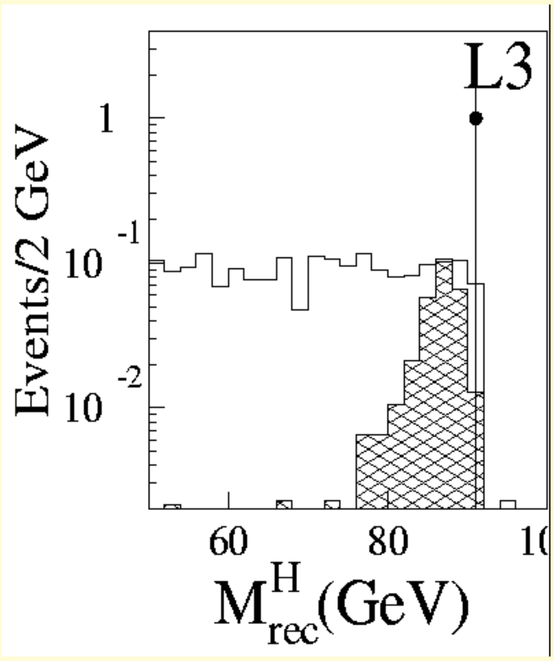
Signal efficiency (m_{H} = 85 GeV) = 50%

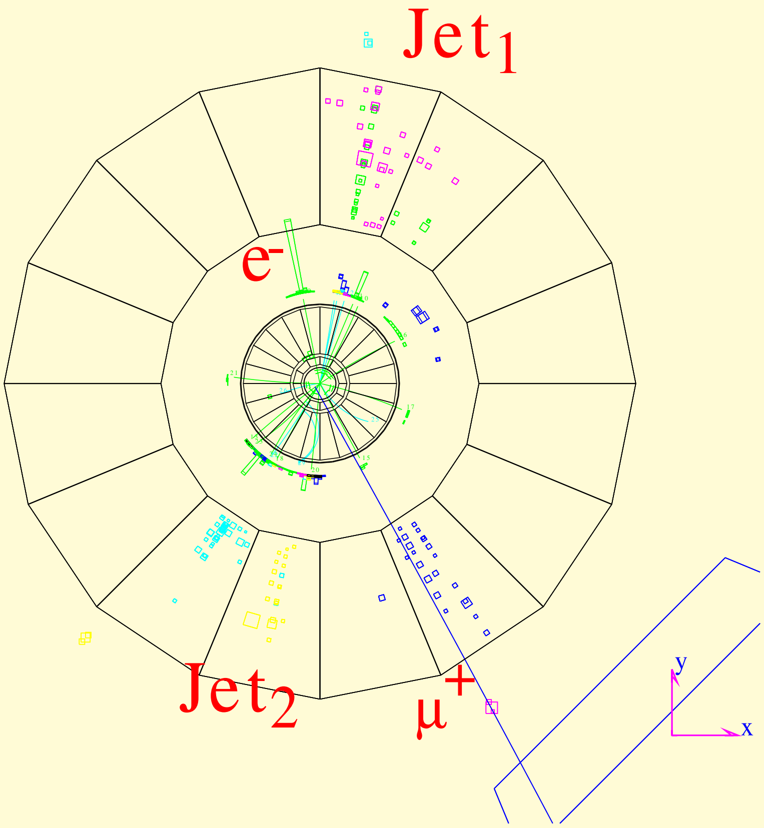
Data events with the highest discriminant value

$\mathrm{M_{vis}} = 88$ GeV (Assuming $\mathrm{M_{mis}} = \mathrm{M_Z}$)



Tau channels

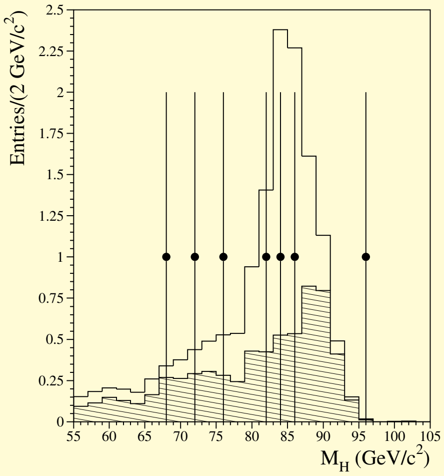


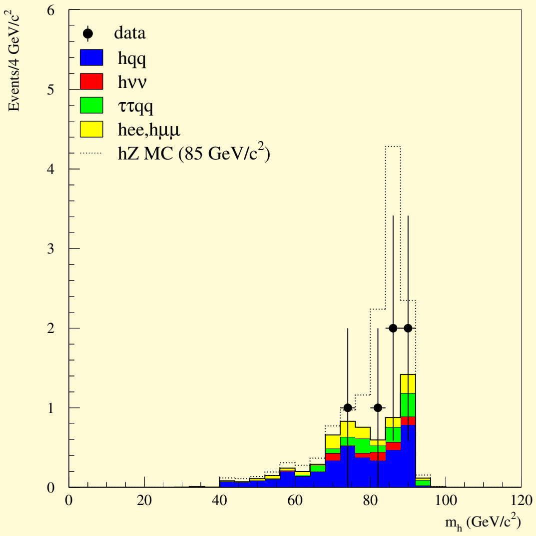


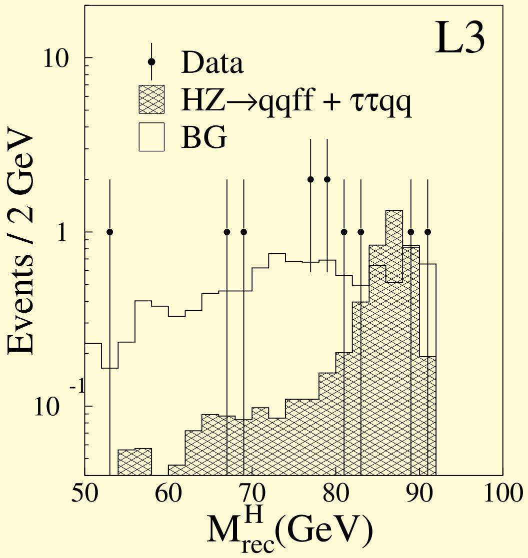
$M^{Z}_{qq} = 90.3$ GeV, $M^{H}_{\tau\tau} = 91.2$ GeV

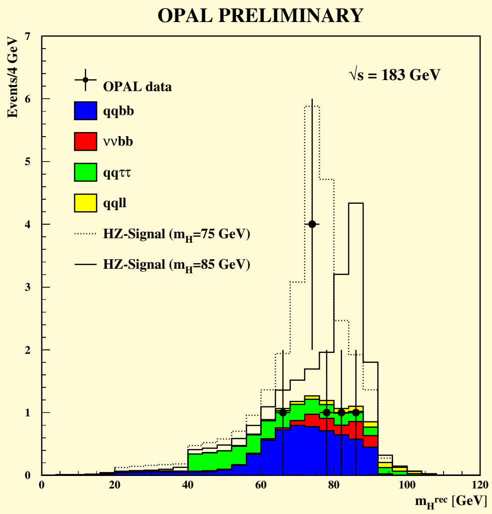
L3: Data= 1, Bkgd = 0.6, Signal (m_{H} = 85 GeV) = 0.4

Mass distributions (summed up all channels)



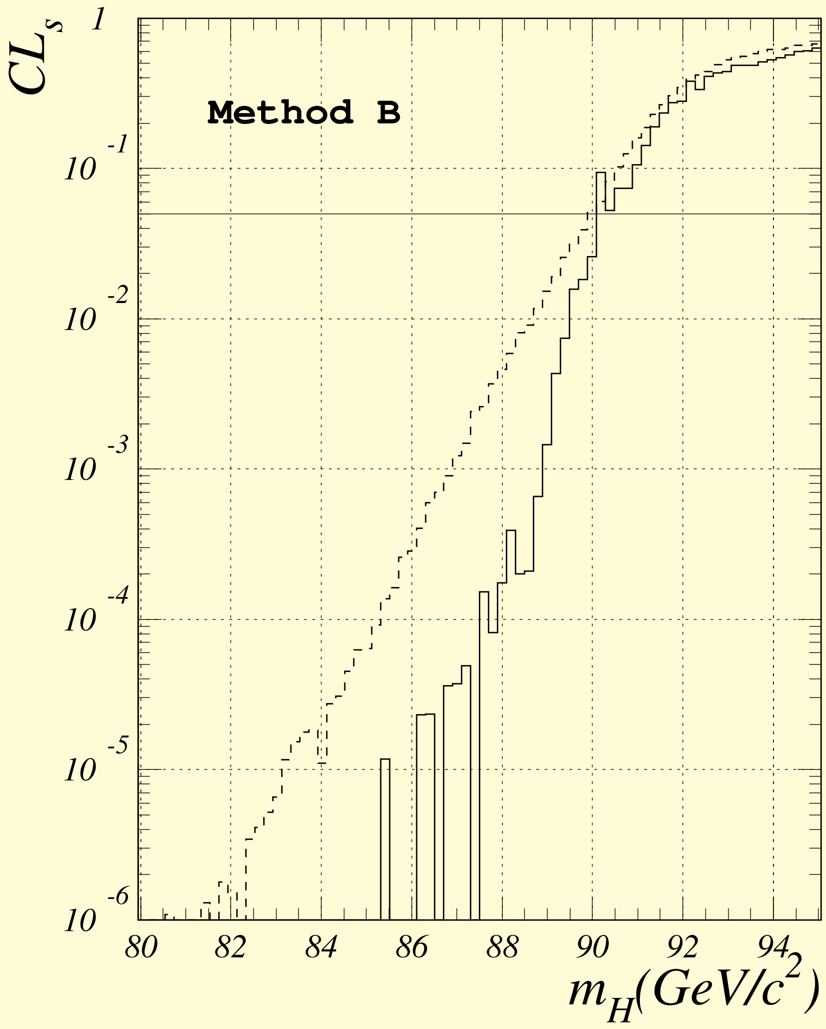






	ALEPH	DELPHI	L3	OPAL
Data	7	6	18	8
Bkgd	7.2	6.3	24.2	9.8
Signal ($m_{\rm H}$=85 GeV)	8.3	6.7	9.6	7.5

Higgs mass limits



Mass Limits (GeV)					
	ALEPH PREL	DELPHI PREL	L3 PUBL	OPAL PREL	LEP PREL
$m_{\rm H}$	87.9	85.7	87.6	84.4	~ 90
$< m_{\rm H} >$	85.5	86.5	85.0	86.5	~ 90

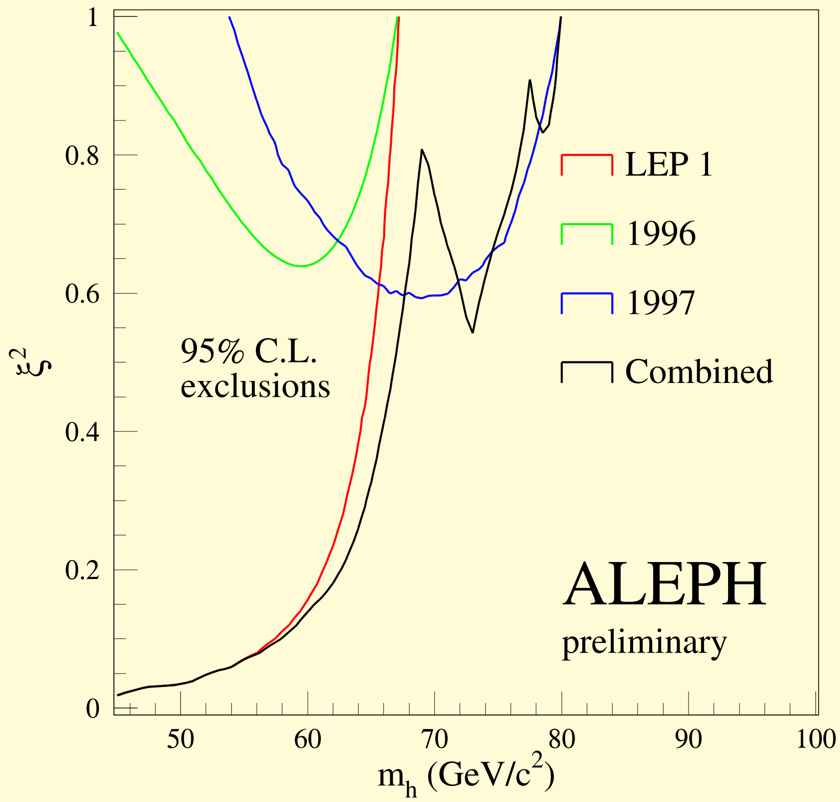
Invisible Higgs

$\mathrm{e^+e^-} \to \mathrm{H^0}(\to$invisible final states$)\mathrm{Z}(\to \ell\ell, \mathrm{qq})$

In MSSM could be: $\mathrm{H^0} \to \chi\chi$

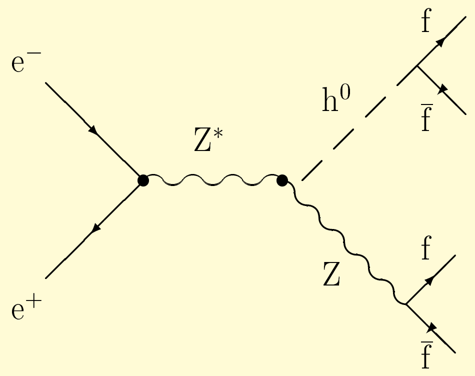
No evidence of signal is observed: new limits are set

Cross section parametrized as: $\xi^2\sigma(\mathrm{e^+e^-} \to \mathrm{H^0Z})_{\mathrm{SM}}$

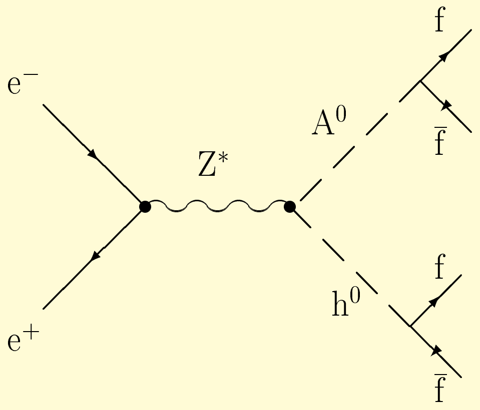


Mass Limits for $\xi^2 = 1$			
	ALEPH PREL	DELPHI PREL	L3 PUBL up to $\sqrt{s}$ = 172 GeV
m_{H}(GeV)	80.0	79.2	69.6

SUSY: MSSM



$$\sigma(\mathrm{e^+e^-} \to \mathrm{h^0Z}) = \sin^2(\beta - \alpha)\sigma_{\mathrm{SM}}$$



$$\sigma(\mathrm{e^+e^-} \to \mathrm{h^0A^0}) = \cos^2(\beta - \alpha)\overline{\lambda}\sigma_{\mathrm{SM}}$$

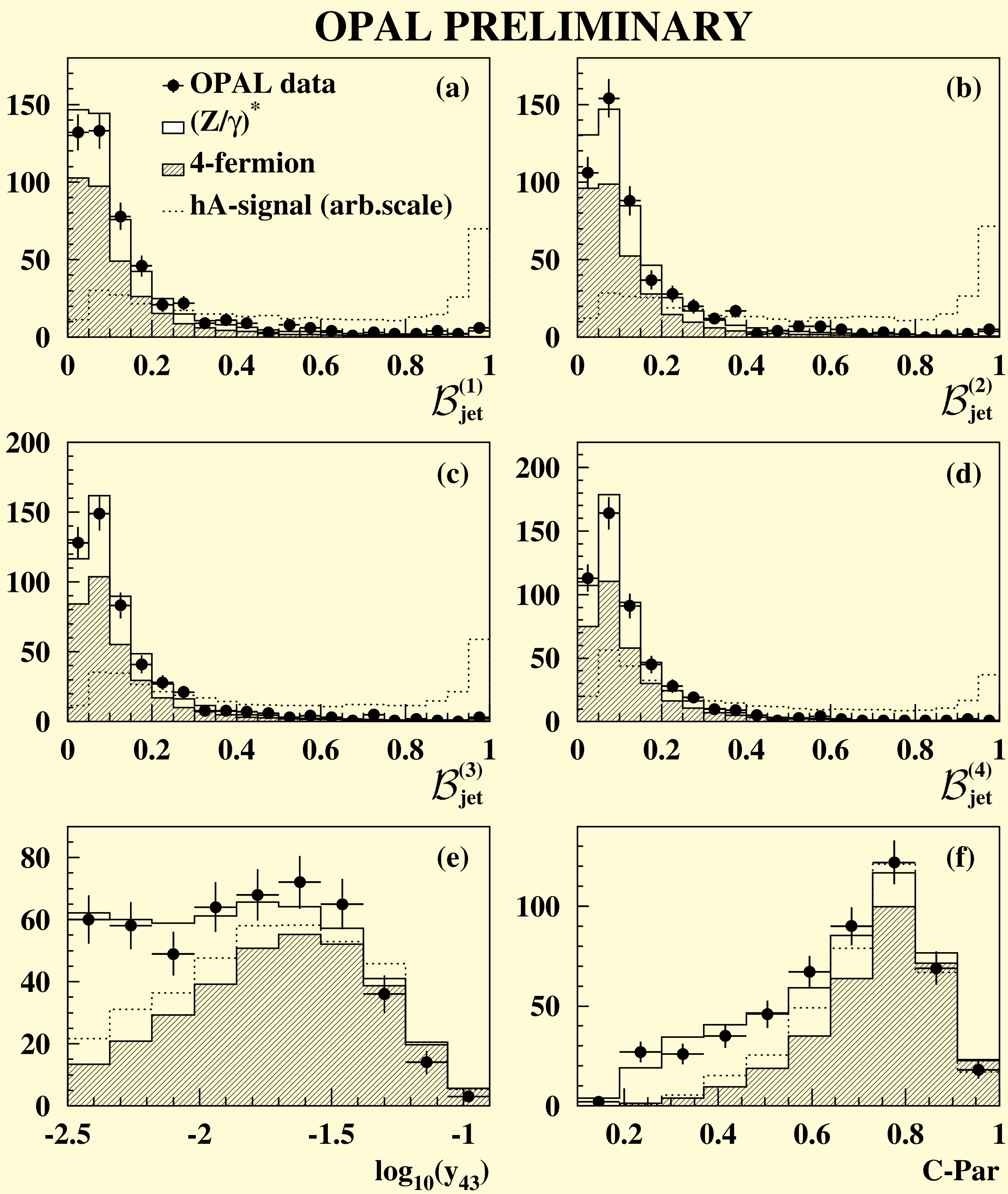
($\overline{\lambda} = \lambda_{\mathrm{Ah}}^{3/2}/[\lambda_{\mathrm{Zh}}^{1/2}(12\mathrm{m}_{\mathrm{Z}}^2/\mathrm{s} + \lambda_{\mathrm{Zh}})]$, λ_{ij}= momentum factor of the two–particle phase space)

Complementary processes!!!

Search Strategies:

- $\mathrm{h}^0\mathrm{Z}$ similar to SM Higgs search
- Dedicated $\mathrm{h}^0\mathrm{A}^0 \rightarrow \mathrm{bbbb}, \tau\tau\mathrm{bb}$ analyses
  - no more Z–mass constraint
  - even more emphasis on b–tag

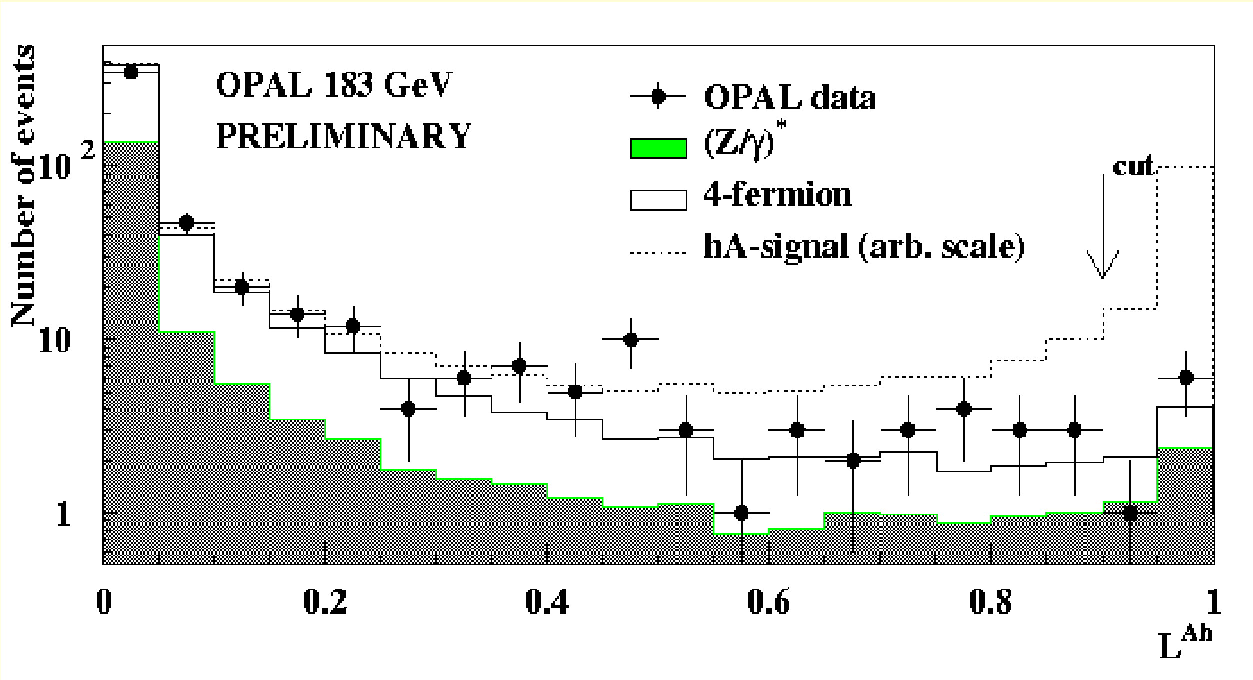
$h^0A^0 \rightarrow b\bar{b}b\bar{b}$



Opal: Data= 502, Bkgd = 507.1,

Signal efficiency ($m_{\rm h} = m_{\rm A}$ = 70 GeV) = 73%

$h^0 A^0 \to b\bar{b}b\bar{b}$



Number of events after all the cuts for OPAL

- Data: 7
- Background: 6.3
- Signal ($m_{\rm h}$ = $m_{\rm A}$ = 70 GeV): 51%

Theoretical interpretations

Assumptions: unification of

- scalar fermion masses (m_0) at the GUT scale
- gaugino masses (M_2) at the EW scale
- scalar fermion tri–linear couplings (A) at the EW scale

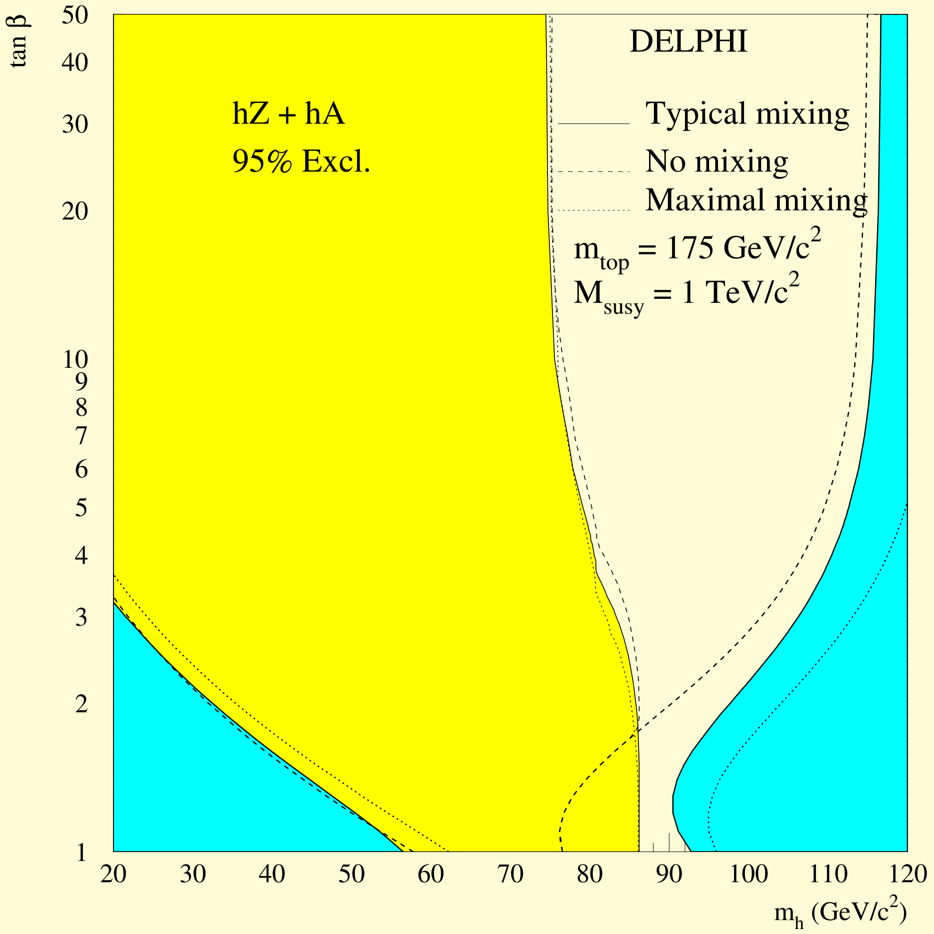
Free parameters:

$$(m_{\mathrm{A}}, \tan\beta, \mu, m_0, M_2, \mathrm{A})$$

- **Benchmark scans:**

  m_0=M_2=1Tev, m_{top} = 175 GeV
  Variation of m_{A} up to 1 TeV and $\tan\beta$ up to 50

  - minimal mixing: A=0 TeV, μ =-0.1 TeV
  - typical mixing: A=1 TeV, μ =-1 TeV
  - maximal mixing: A=$\sqrt{6}$ TeV, μ = -0.1 TeV



Higgs limits at 95 % CL (GeV)					
	ALEPH	DELPHI	L3(PUB.)	OPAL	LEP *
m_{h}	72.2	74.4	70.7	70.0	~ 80
m_{A}	76.1	75.2	71.0	70.5	~ 80

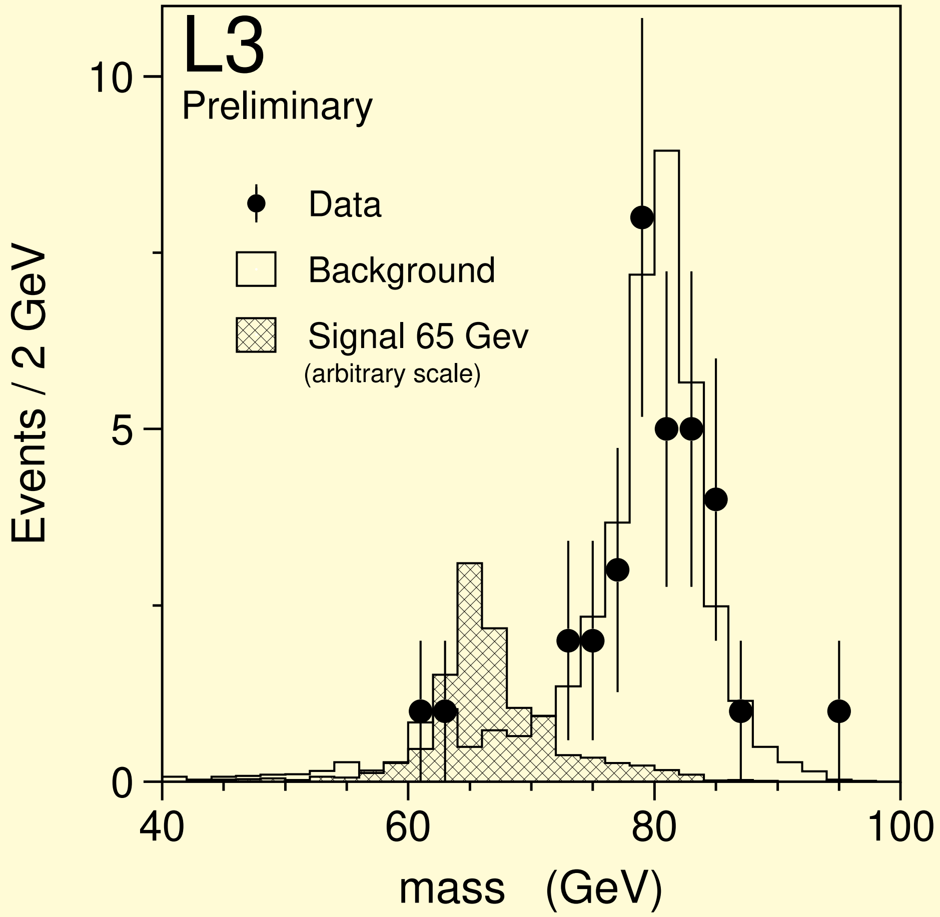
* Maximal Mixing only

Lower limit on $\tan\beta$ for Minimal Mixing $\sim$ 2

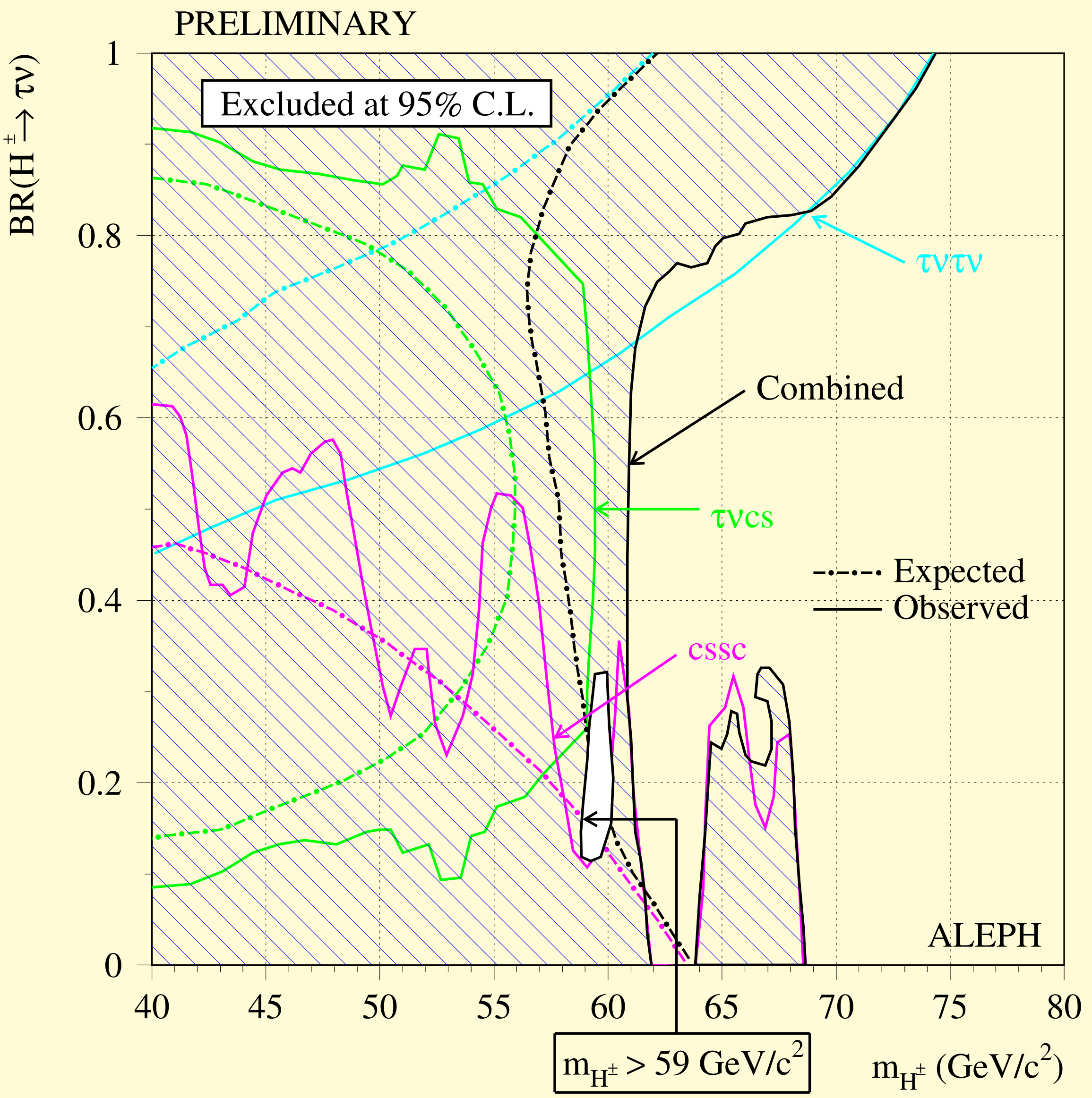
Charged Higgs bosons

- Pair–production: $e^+e^- \to H^+H^-$
- $H^\pm$ decay into the heaviest particles kinematically allowed with Branching Ratios depending on the model
- Final states studied:
  - Hadronic: $e^+e^- \to H^+H^- \to cscs$
    - Four jets in the event
    - Equal mass constraint
  - Semileptonic: $e^+e^- \to H^+H^- \to \tau\nu cs$
    - Isolated lepton + pair of acoplanar jets + missing energy
  - Leptonic: $e^+e^- \to H^+H^- \to \tau\nu\tau\nu$
    - Dilepton events with missing transverse momentum

Mass distribution for $m_{\mathrm{H}^{\pm}}$ =65 GeV, $\tau\nu cs$ channel



	$\tau\nu cs$		
	Data	Bkgd	Signal Efficiency ($m_{\mathrm{H}^{\pm}}$ =60 GeV)
ALEPH	2	1.5	31%
DELPHI	3	1.4	20%
L3	27	30.9	42%
OPAL (172 GeV)	0	1.3	37%



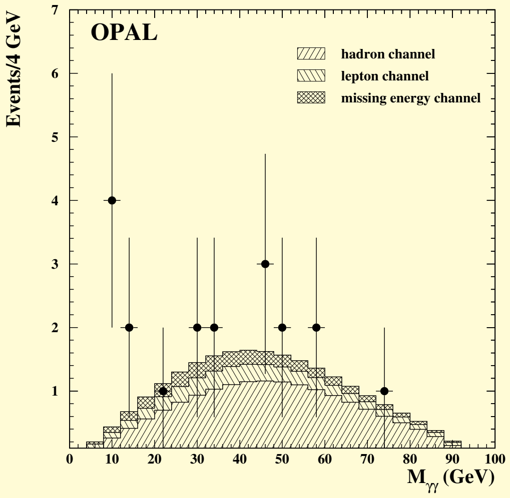
Charged mass limit at 95 % CL (GeV)			
ALEPH PREL	DELPHI PREL	L3 PREL	OPAL PUBL up to $\sqrt{s}$ = 172 GeV
59.0	56.5	57.0	52.0

Lep combined result is coming soon

$\mathrm{e^+e^-} \to \mathrm{H^0}(\to \gamma\gamma)\mathrm{Z}(\to \ell\ell, \nu\nu, \mathrm{qq})$

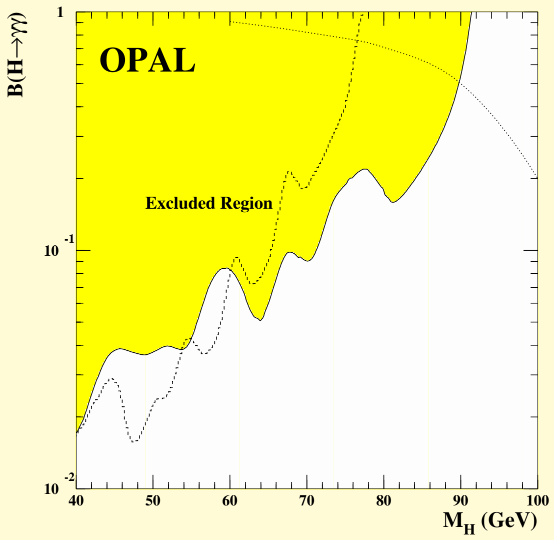
SM: BR($H^0 \to \gamma\gamma$) $\approx 10^{-3}$ for m_{H} = 90 GeV

$\to$ BR could be enhanced in models beyond the SM



Data: 19, Background: 23.1

Upper limit on m_{H} as a finction of the BR, assuming $\sigma^{\mathrm{SM}}_{\mathrm{HZ}}$

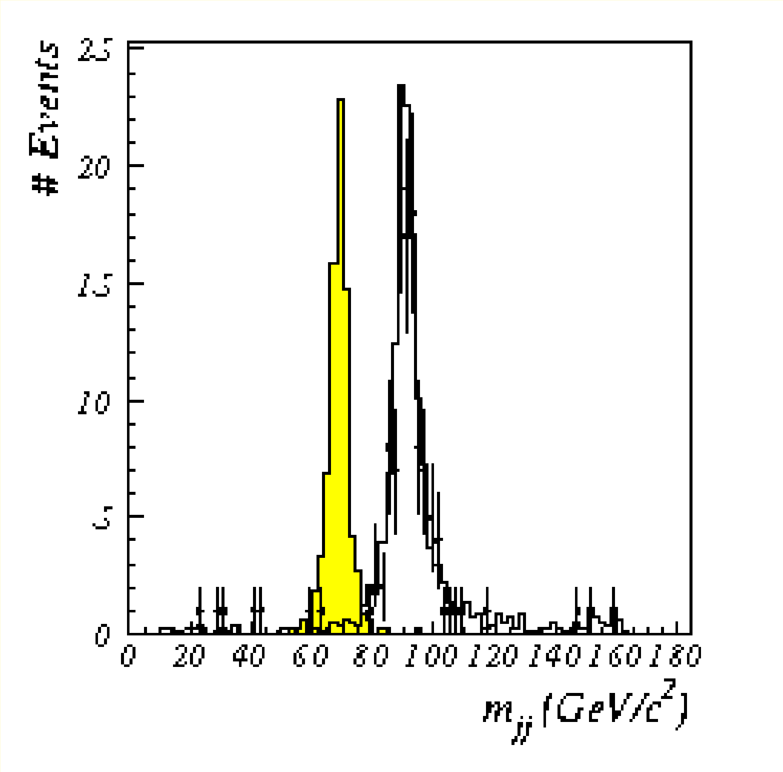


Extension of the analysis to $\mathrm{e^+e^-} \to \mathrm{X}(\to \gamma\gamma)\mathrm{Y}(\to \mathrm{ff})$

Upper limits on $\sigma(\mathrm{e^+e^-} \to \mathrm{XY})\mathrm{BR}(\mathrm{X} \to \gamma\gamma)\mathrm{BR}(\mathrm{Y} \to \mathrm{ff})$ are set

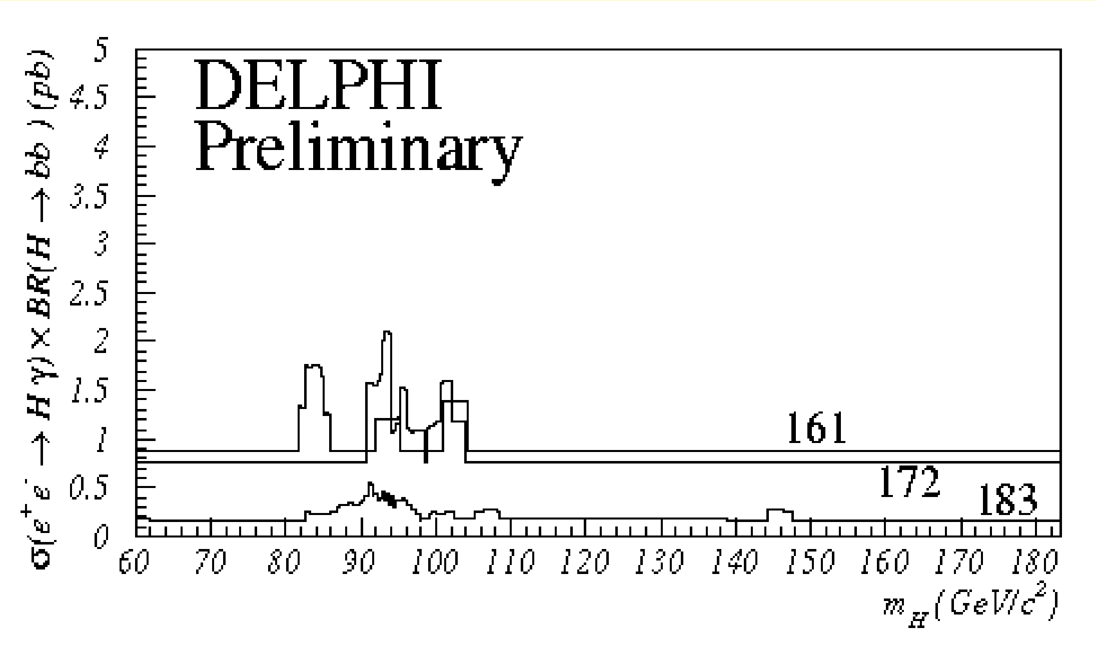
$e^+e^- \rightarrow H^0(\rightarrow bb, \gamma\gamma)\gamma$

SM: higher order process $\rightarrow$ small cross section



Data: 21, Bkgd: 23, Efficiency ($m_{\mathrm{H}} = 70$ GeV): 37%

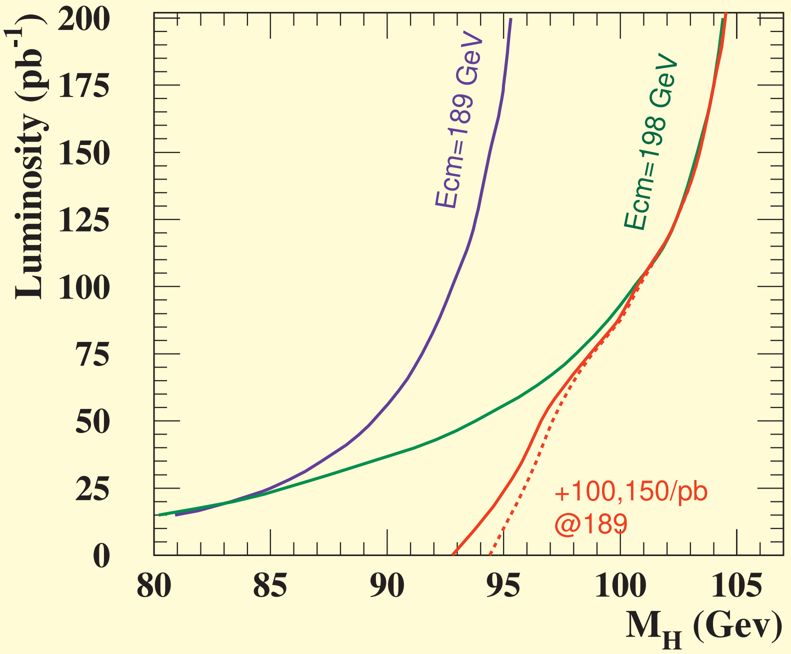
Limit on $\sigma($ e$^+e^- \rightarrow H^0\gamma)BR(H^0 \rightarrow bb)$



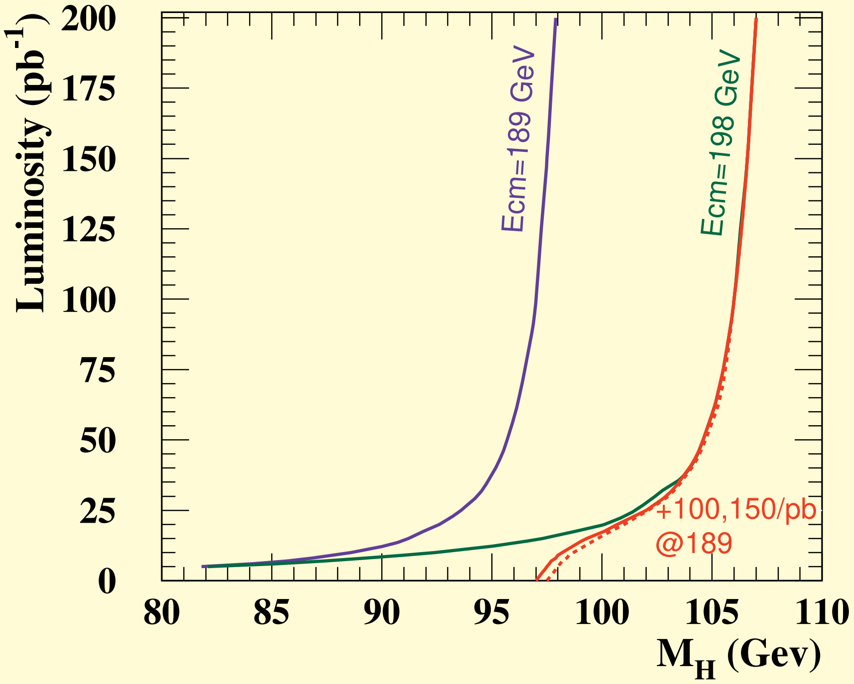
Foreseen for 1998-2000

Discovery contours for SM Higgs

(E. Gross, A. Read, D. Lellouch)



Exclusion contours for SM Higgs



Conclusions

Perfomed Higgs searches in a variety of final states:
NEW LIMITS ARE SET:

- SM: $m_{\mathrm{H}^0} > 90$ GeV
- MSSM: $m_{\mathrm{h}^0} > 80$ GeV, $m_{\mathrm{A}^0} > 80$ GeV
- Charged Higgs: $m_{\mathrm{H}^\pm} > 59.0$ GeV

Looking forward to find the Higgs boson(s) in '98!!