Higgs Searches at L3/LEP
$\sqrt{s} = 189$ GeV

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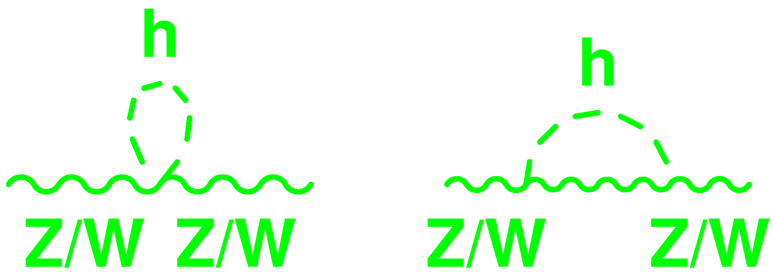
Blois
June 27 - July 3, 1999

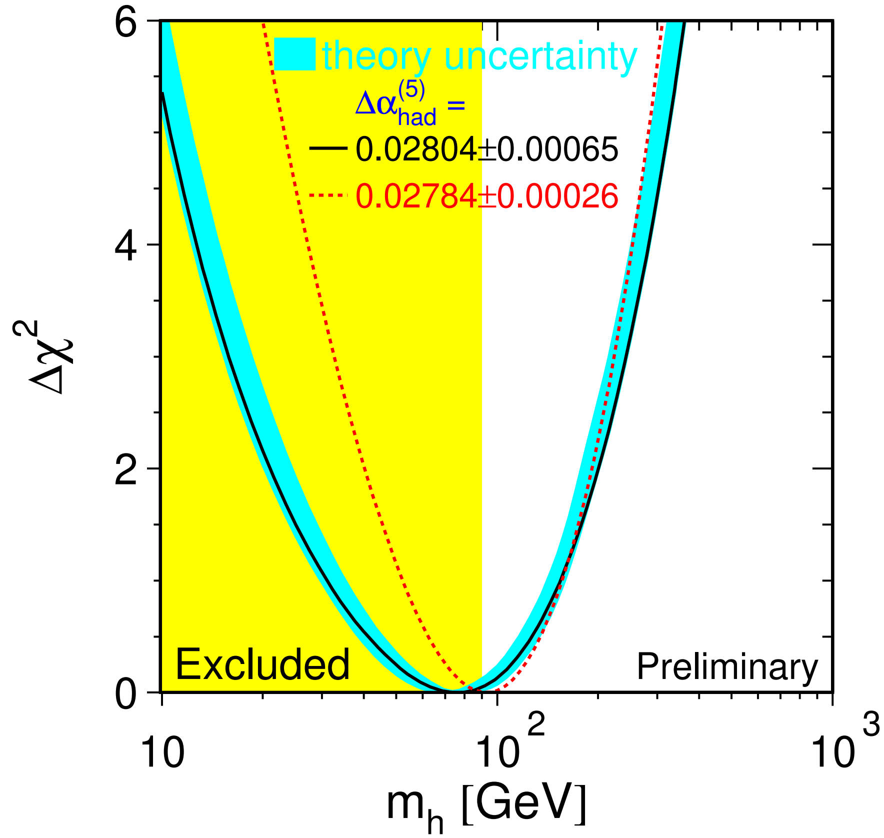
- SM Higgs Search
- MSSM Higgs Search

Electroweak Fits

Electroweak precision measurements sensitive to m_h through radiative corrections



$$\log\left(\frac{m_h}{\mathrm{GeV}}\right) = 1.85^{+0.31}_{-0.39} \pm 0.03$$



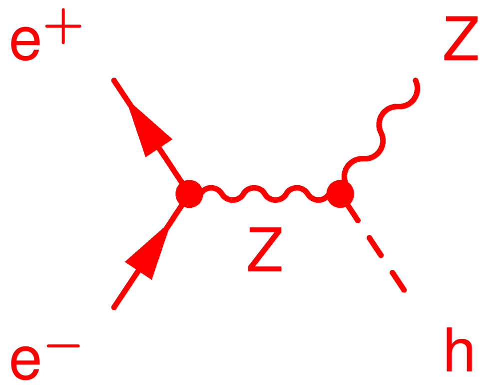
$$m_h = 71^{+75}_{-42} \pm 5 \text{ GeV}$$

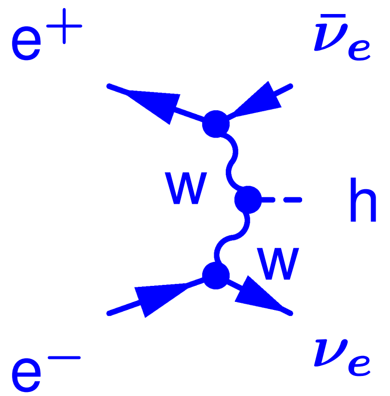
$$m_h < 220 \text{ GeV at } 95\ \% \text{ CL}$$

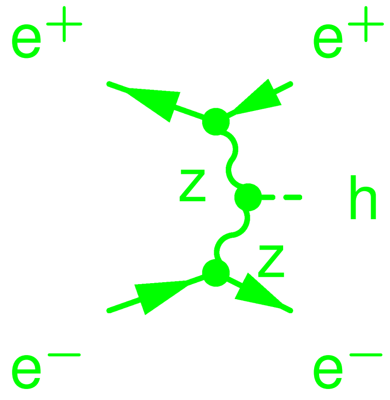
LEP has a good chance of finding the SM Higgs !

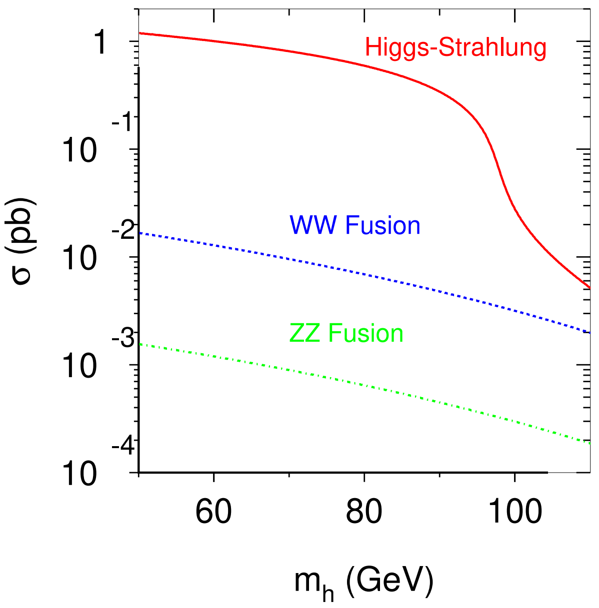
Production and Decay of the SM Higgs

SM Higgs Production









SM Higgs Decay

$h \rightarrow b\bar{b}$:

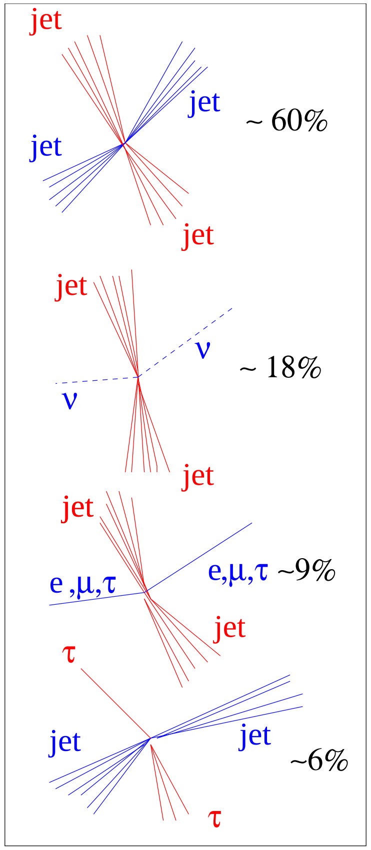
$\approx 86\%$

$h \rightarrow \tau^+\tau^-$:

$\approx 8\%$

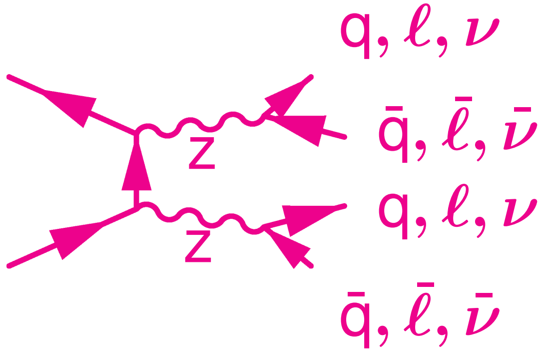
smaller contributions from

$h \rightarrow c\bar{c}, gg$

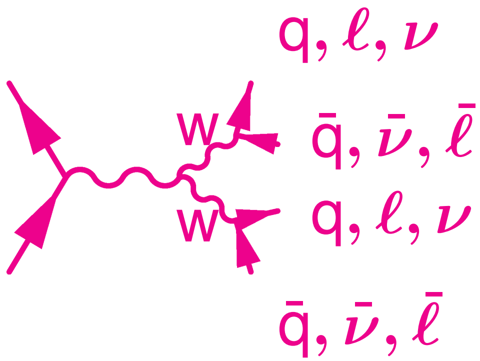


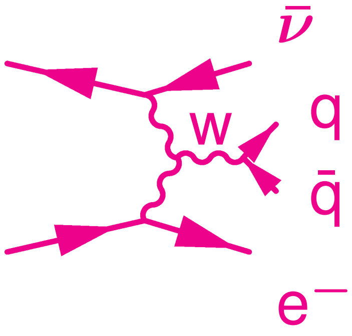
Background

ZZ:

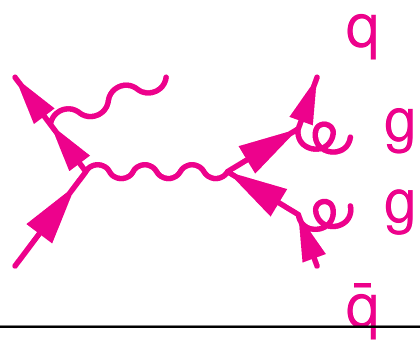


WW and Single-W:

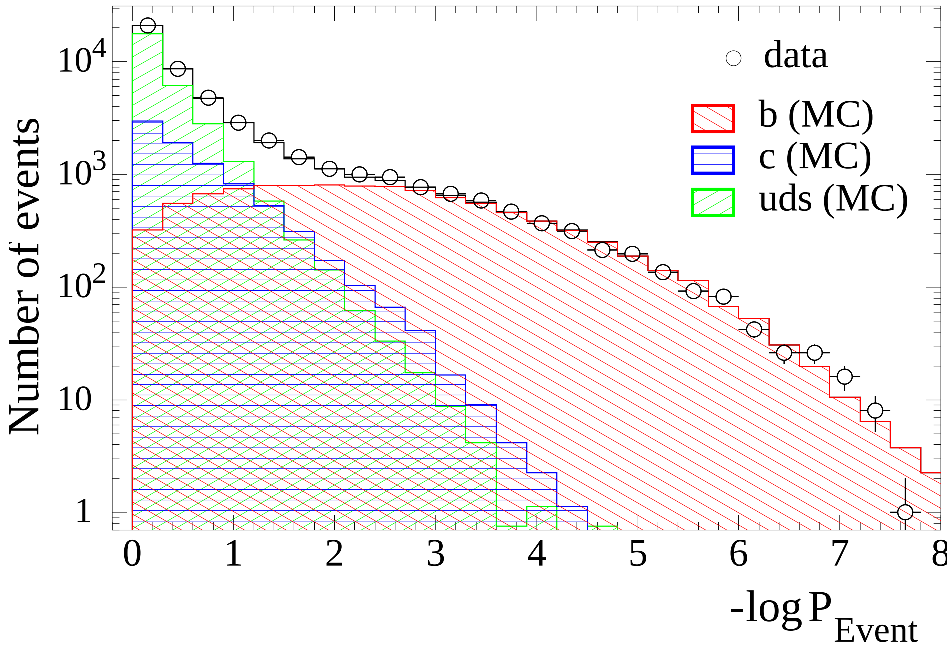




qq:



B-tagging essential !



75% Efficiency / 80% Purity

on $Z \rightarrow b\bar{b}$ at $\sqrt{s} = 91$ GeV

Analysis Strategy

Data Sample:

L3 in 1998: 176.4 pb^{-1} at 189 GeV

Analysis Strategy:

- Mass-independent selection of high multiplicity events
- Kinematic fit $\Rightarrow$ reconstructed Higgs mass
- Construction of a final discriminant combining B-tag/NNout with Higgs mass

$\Rightarrow$ **Mass dependent discriminant variable, calculated for every Higgs mass hypothesis**

The hZ $\longrightarrow$ $b\bar{b}q\bar{q}$ Channel

Signature: 4 jets, high multiplicity, full energy in detector, balanced in momentum

Main Background:

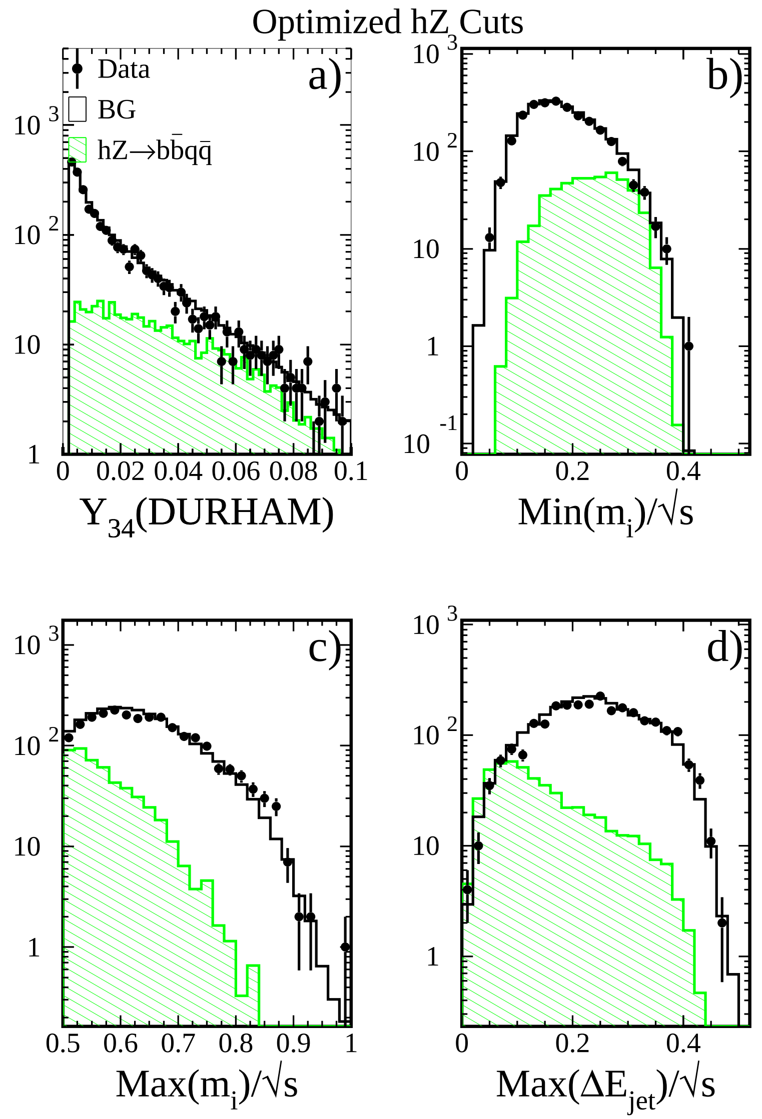
$q\bar{q}$ and WW, ZZ $\longrightarrow$ $q\bar{q}q\bar{q}$

Analysis:

B-tag, Y^{D}_{34}, jet masses, maximal energy difference between any two jets

289 data, 270 background, 62% efficiency for 95 GeV

Final discriminant made of B-tag and $\chi^2(m_h, m_Z)$



The hZ $\rightarrow$ b$\bar{\text{b}}\nu\bar{\nu}$ Channel

Signature: 2 acoplanar jets, missing transverse momentum, high multiplicity

Main Background:

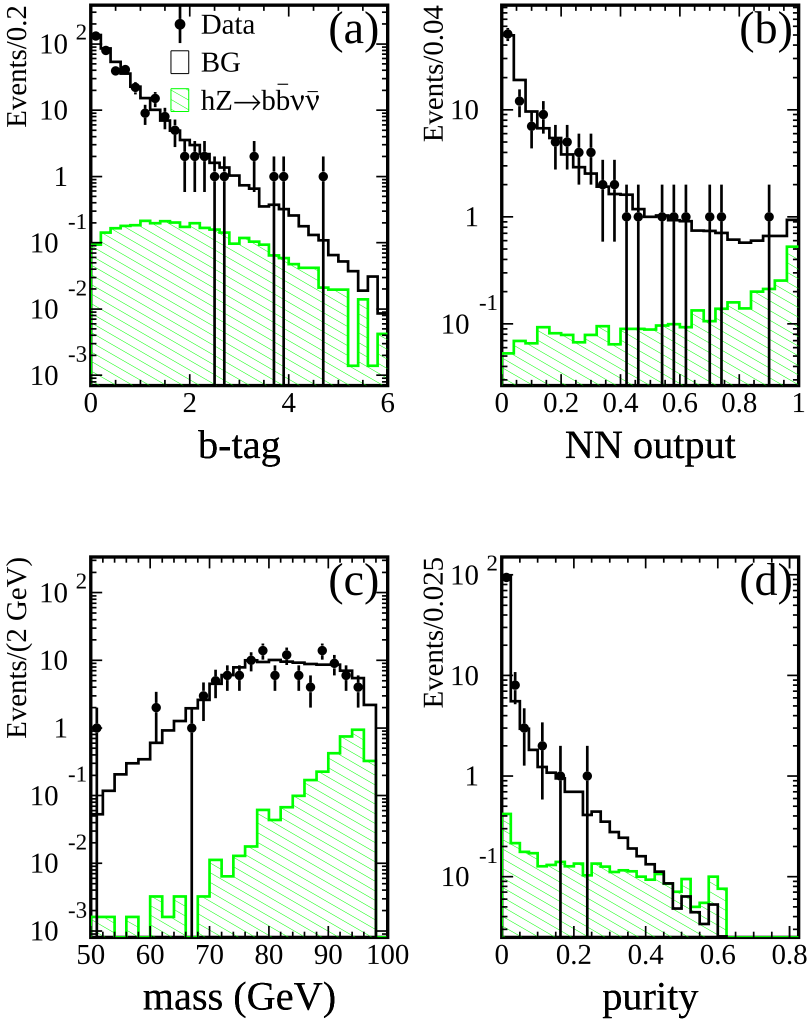
WW $\rightarrow$ q$\bar{\text{q}}\tau\nu$, Weν, ZZ $\rightarrow$ q$\bar{\text{q}}\nu\bar{\nu}$, q$\bar{\text{q}}(\gamma)$

Neural network analysis:

B-tag, transverse imbalance, recoil mass of jets, angular information, χ^2_{fit}

109 data, 116 Background, 62% Efficiency for 95 GeV

Final discriminant made of NNout and mass $\Rightarrow$ Purity



The hZ $\rightarrow b\bar{b}\ell^+\ell^-(\tau^+\tau^- q\bar{q})$ Channels

Signature: 2 jets + 2 leptons

Main Background:

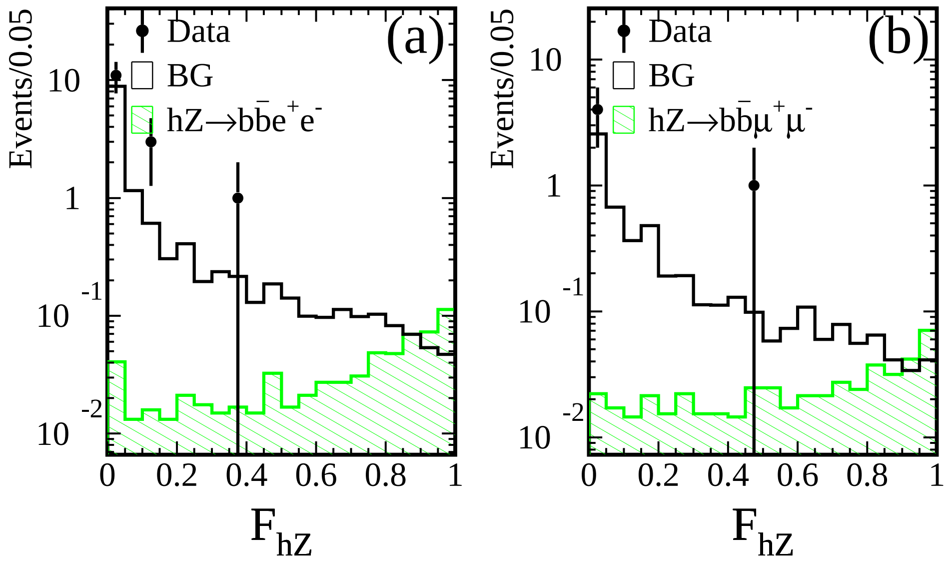
ZZ$\rightarrow q\bar{q}\ell\ell$, WW $\rightarrow q\bar{q}\ell\nu$

Analysis:

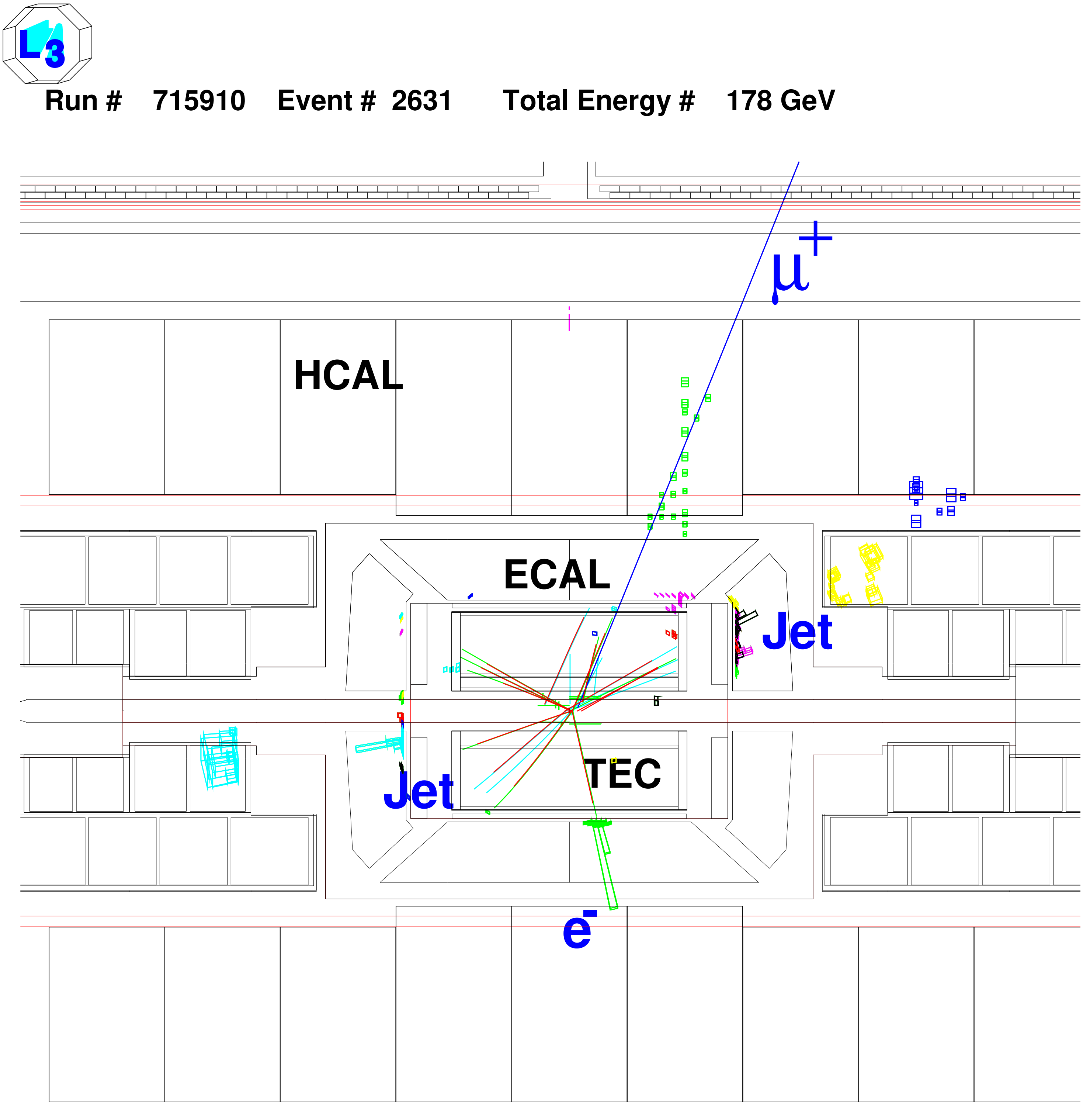
Lepton identification and isolation, invariant mass of leptons (jets) consistent with m_Z

Higgs mass and B-tag are combined in likelihood $\Rightarrow$ F_{hZ}

	Efficiency	Bkgd	Data
hee	77%	13.2	15
$h\mu\mu$	57%	5.5	5
$h\tau\tau(\tau\tau q\bar{q})$	30%(30%)	17.1	12



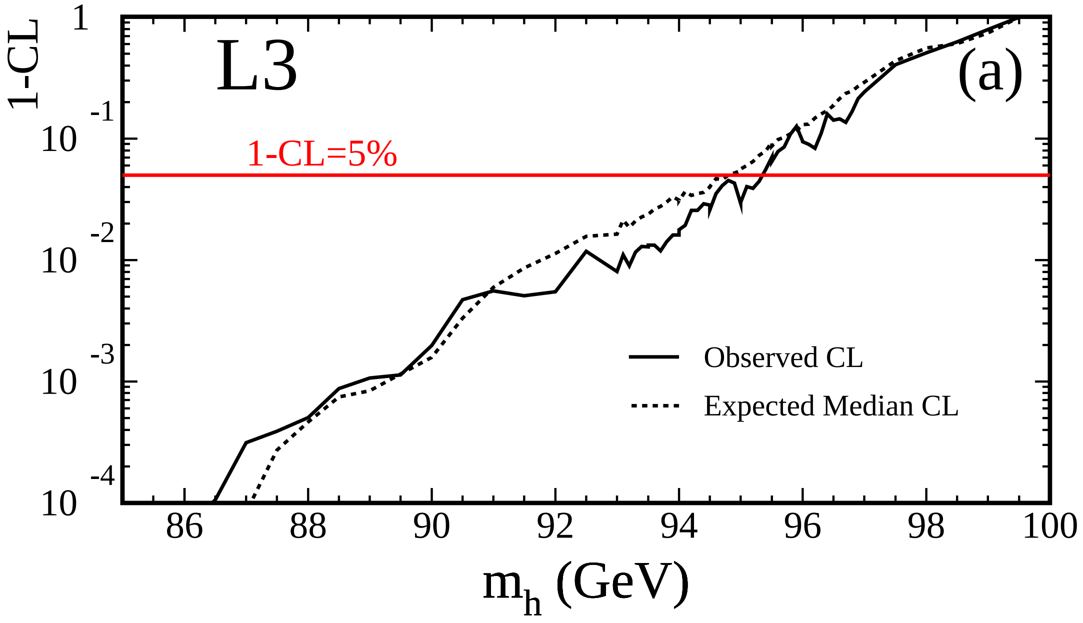
$hZ \rightarrow \tau^+\tau^- q\bar{q}$ Candidate

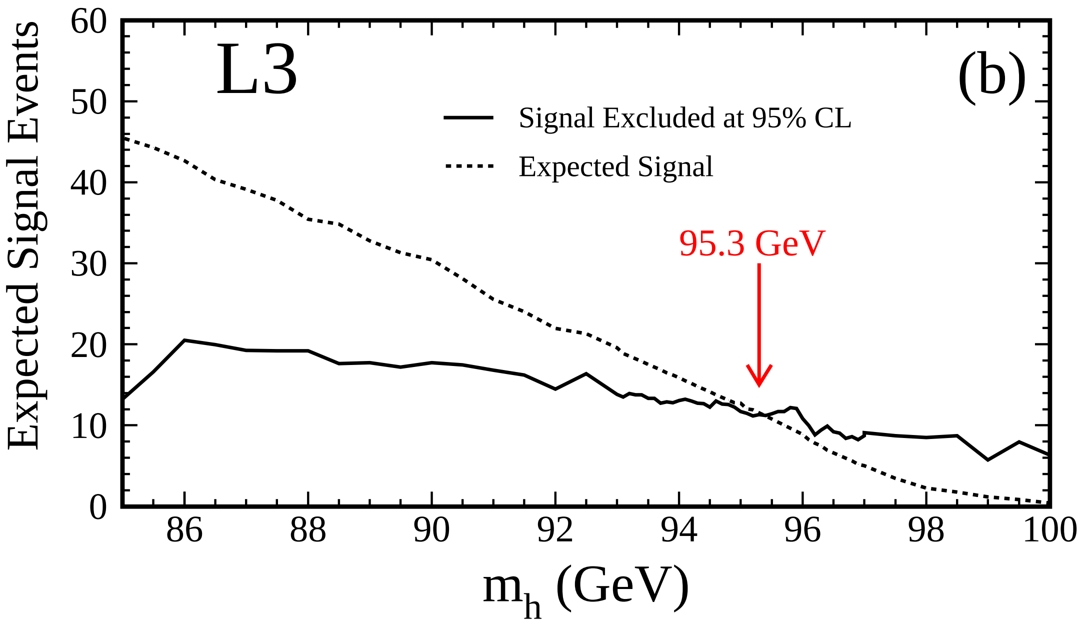


$$m_{\tau\tau} = 84.4 \text{ GeV}$$

$$m_{qq} = 95.1 \text{ GeV}$$

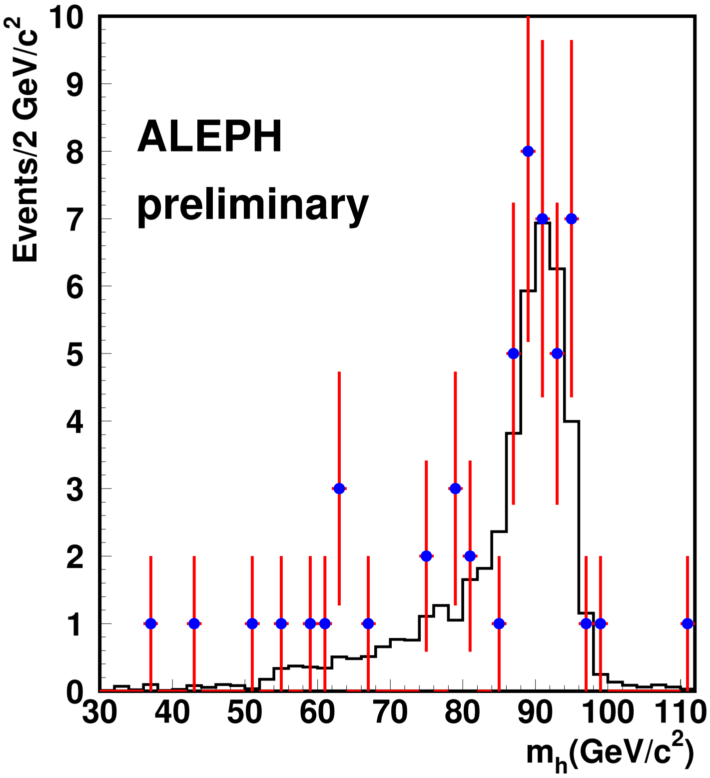
SM Higgs Mass Limits

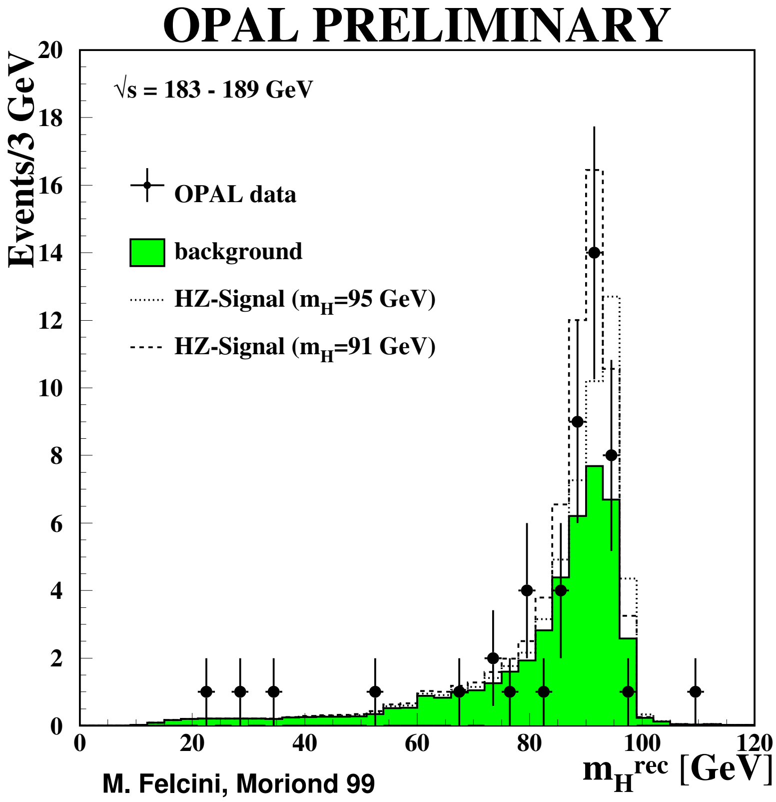




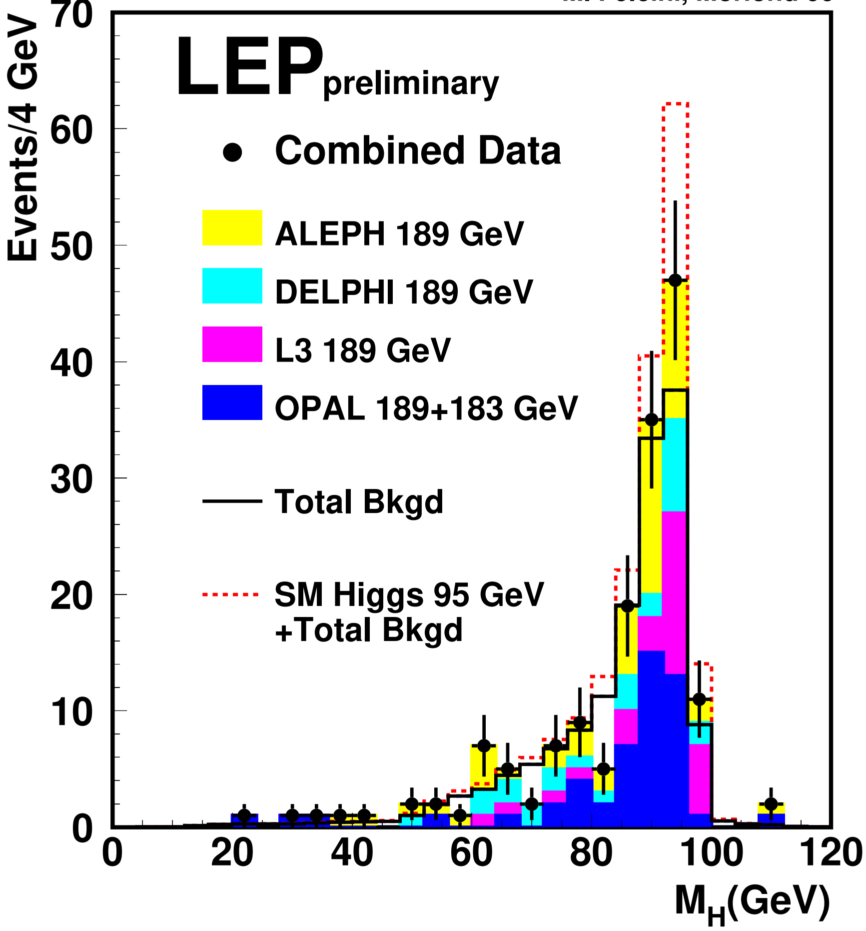
ALEPH	$m_h > 90.2$ GeV
DELPHI	$m_h > 94.1$ GeV
OPAL	$m_h > 91.0$ GeV

Mass Distributions





M. Felcini, Moriond 99



The Higgs Sector in the MSSM

5 physical Higgs bosons:

2 CP-even neutral Higgses	h,H	$m_h < m_H$
1 CP-odd neutral Higgs	A	
2 charged Higgses	$H^{\pm}$	
(VEV ratio)	$\tan\beta = \nu_2/\nu_1$	
(mixing angle of h,H)	α	

MSSM tree-level mass relations:

$m_h < m_Z < m_H$

$m_{W^\pm} < m_{H^\pm}$

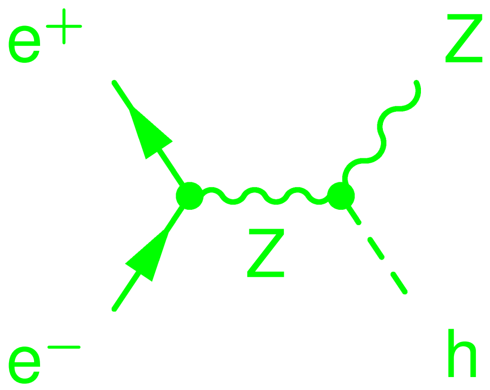
Radiative Corrections:

highly dependent on m_{top} and stop mixing

still: $m_h < 135$ GeV

Production and Decay of h and A

Higgs-strahlung

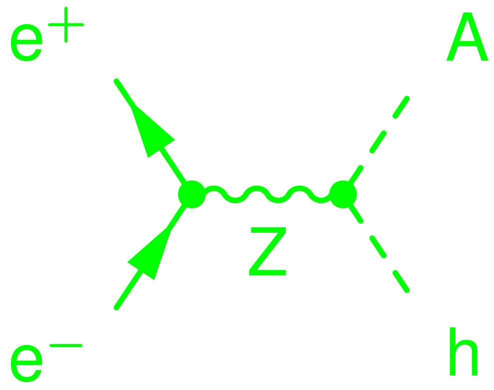


$$\sigma \propto \sin^2(\beta - \alpha)$$

- dominant at low $\tan\beta$
- SM topologies

$\longrightarrow$ recycle SM searches

Pair Production



$$\sigma \propto \cos^2(\beta - \alpha)$$

- dominant at high $\tan\beta$ ($m_h \approx m_A$)
- dedicated searches for
  $hA \longrightarrow b\bar{b}b\bar{b}$ and
  $hA \longrightarrow b\bar{b}\tau^+\tau^-(\tau^+\tau^- b\bar{b})$

The hA $\rightarrow$ b$\bar{b}$b$\bar{b}$ Channel

- Dedicated hA selection
- Relative rate of hZ and hA changes with $\tan\beta$
- Events that pass both selections are assigned to category hA' and hZ' in dependence of

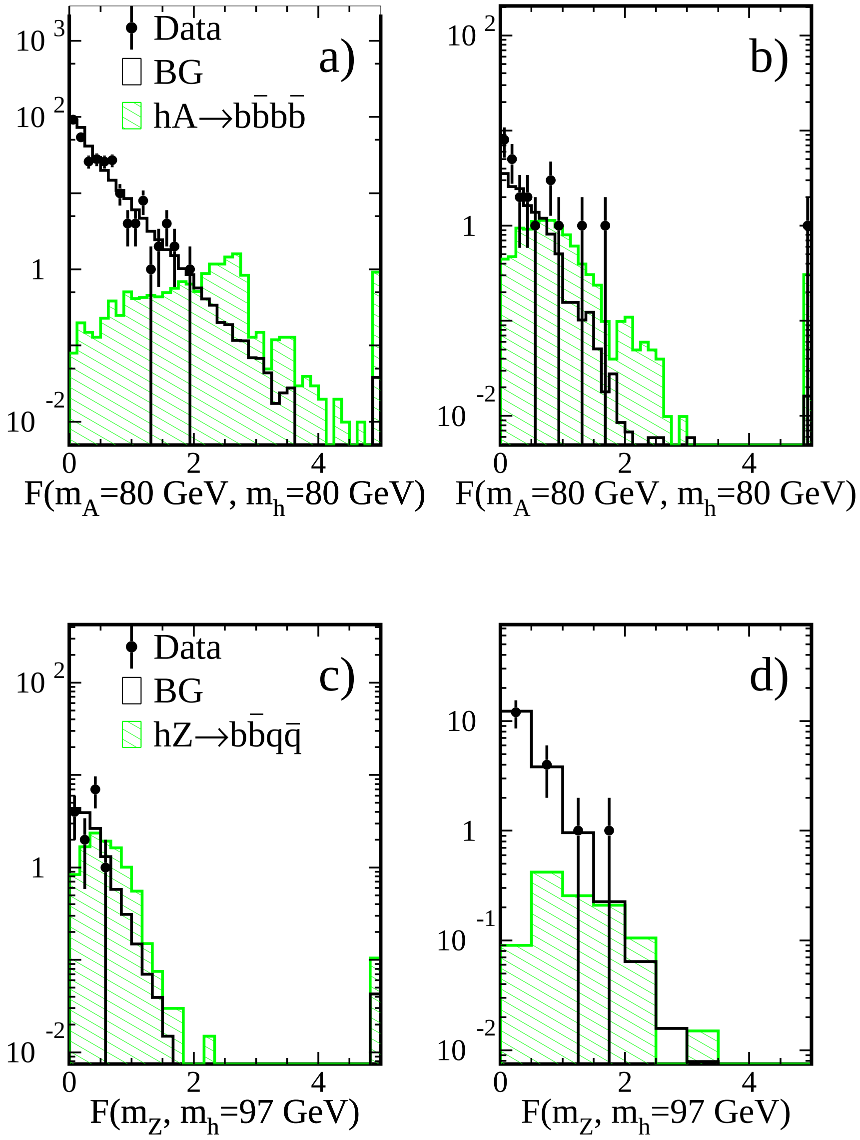
$$\sigma_{hZ} P(\chi^2(m_Z, m_h))$$

and

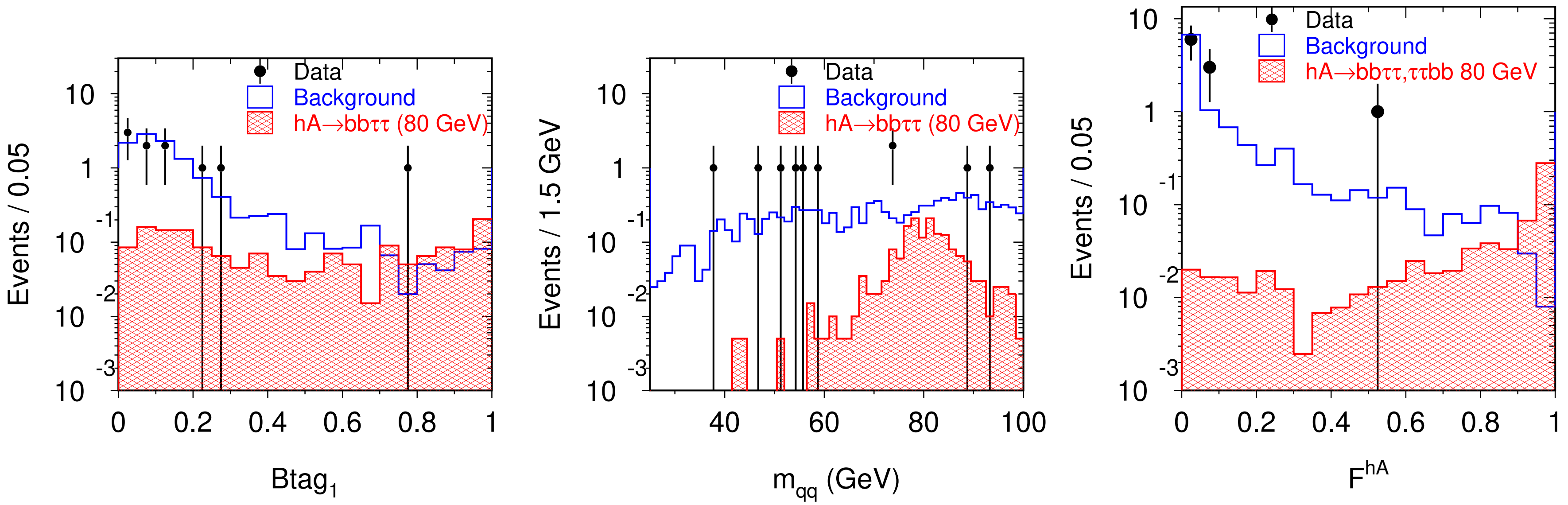
$$\sigma_{hA} P(\chi^2(m_A, m_h))$$

$\Rightarrow$ 4 event categories:

hZ, hZ', hA and hA'



The hA $\rightarrow b\bar{b}\tau^+\tau^-(\tau^+\tau^-b\bar{b})$ Channels



- Final variable is likelihood combination of b-tag,$m_{\tau\tau}$ and m_{qq}
- Events are uniquely assigned to a channel depending on the cross section weighted likelihood

Interpretation

LEP Benchmark Scan

Constrained MSSM with GUT assumptions (little impact on Higgs masses, but reduces number of free parameters)

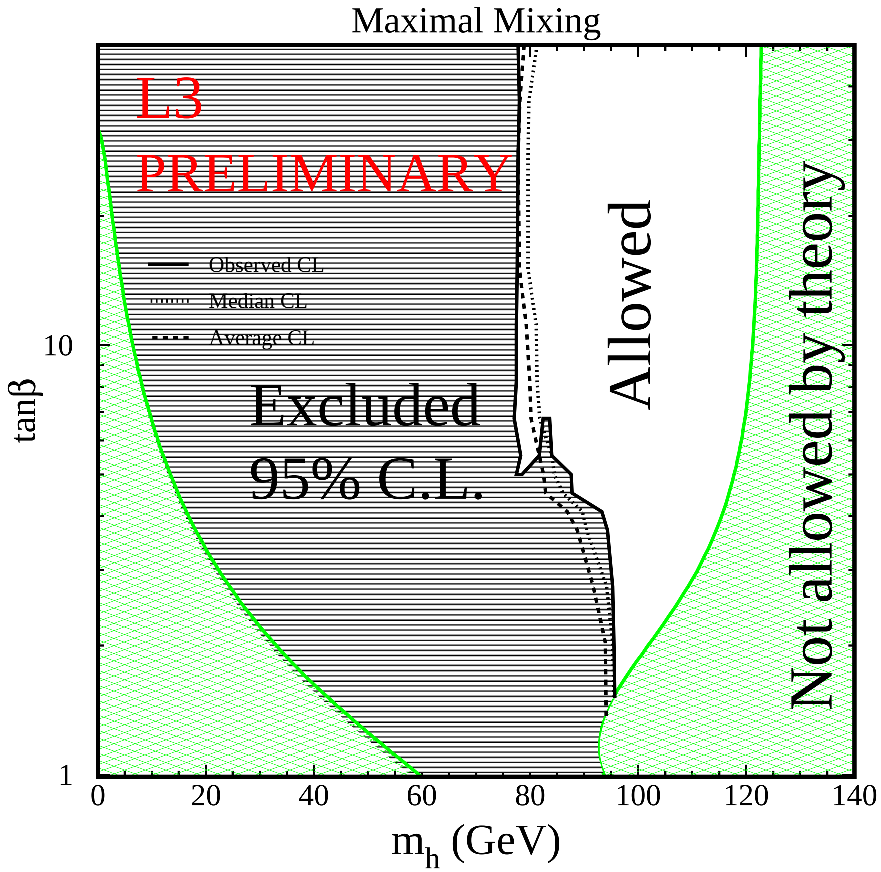
$M_2 = 1$ TeV $\quad m_0 = 1$ TeV

$\mu = -0.1$ TeV

Minimal Mixing: $A = 0$

Maximal Mixing: $A = \sqrt{6}$ TeV

(m_{top} fixed to 175 GeV)



however: new two loop calculations from Hollik *et al.* (hep-ph/9812472 *submitted to Eur. Phys. J. C.*)

$\longrightarrow$ upper theoretical bound moves up ?

LEP Comparison

Lower Higgs mass limits in the MSSM

	m_h (GeV)	m_A (GeV)	
ALEPH	80.8	81.2	$(\tan\beta > 1)$
DELPHI	83.5	84.5	$(\tan\beta > 0.5)$
L3	77.0	78.0	$(\tan\beta > 1)$
OPAL	74.8	76.5	$(\tan\beta > 1)$

Conclusions

- 1998 very successful year for LEP with the highest luminosity ever obtained allowing high sensitivity in Higgs search
- Still no Higgs bosons found
- New mass limits set

New data at 192 and 196 GeV
are on the way!

$\Downarrow$

Higgs searchers $\Rightarrow$ Higgs finders ?