SEARCHES FOR THE NEUTRAL HIGGS BOSONS OF THE MSSM

USING LEP DATA

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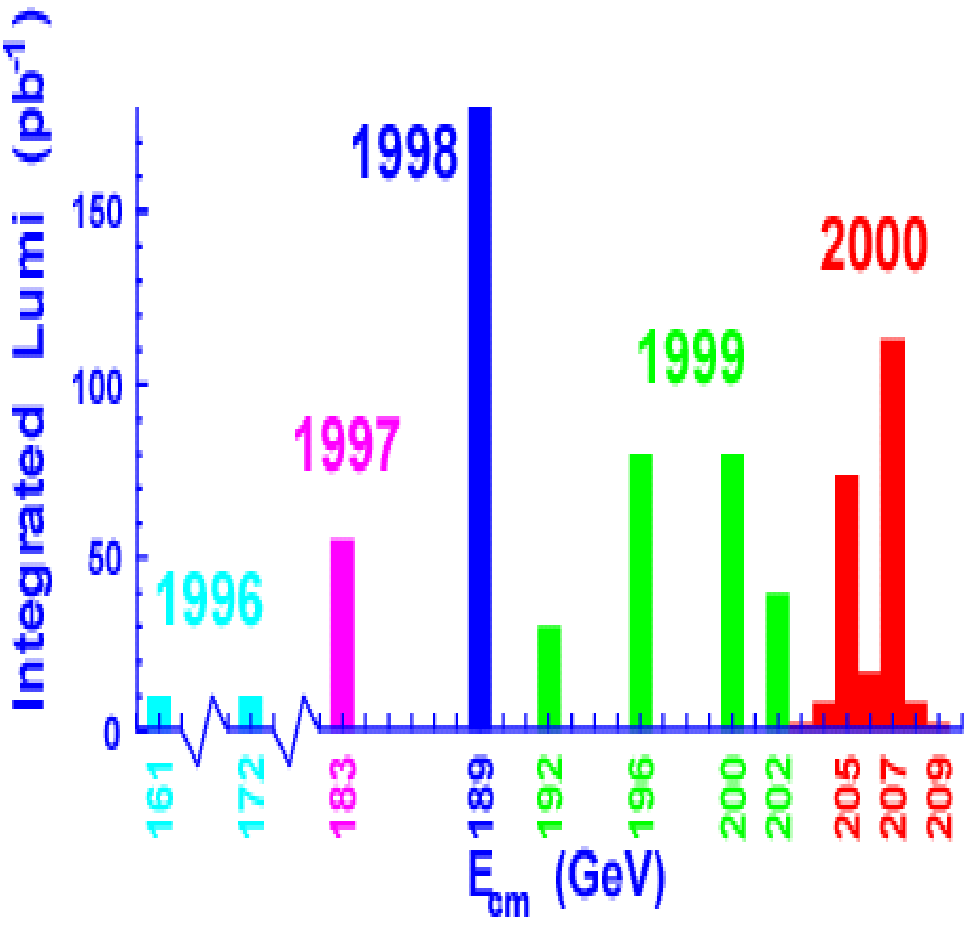
Representing LEP Collaborations

Outline

- LEP performance
- Theoretical framework
- Search for neutral Higgs bosons
  - Search for h^0Z^0
  - Search for h^0A^0
  - Combination

  Mainly from contributed papers for EPS'01 in Budapest
- Updates

LEP Performance



870 pb^{-1} at E > 200 GeV ; 510 pb^{-1} at E > 206 GeV

Type II Two-Higgs Doublet Models (2HDM)

2 complex scalar field doublets :

- ϕ_1 couples to "up-type" fermions
- ϕ_2 couples to "down-type" fermions

8 degrees of freedom :

- 3 longitudinal polarisation states of the gauge bosons W^+ W^- Z^0
- 5 physical scalar Higgs states h^0 H^0 A^0 H^+ H^-

In MSSM $m_h 0 < 135$ GeV/c^2

MSSM Higgs Searches

- SM just 1 unknown parameter m_H
- MSSM 7 parameters in this model
  - M_2 EW scale SU(2) Gaugino mass
    (assume Gaugino masses unified at GUT scale)
  - M_{SUSY} Common sfermion mass (squark, lepton, sneutrino) at the EW scale
  - $\tan\beta$ Ratio of the vacuum expectation values of the two Higgs doublets
  - μ Higgs mass parameter
  - A_0 Common trilinear Higgs-squark coupling parameter
  - M_A^0 Mass of the CP-odd Higgs boson
  - m_{gluino} Gluino mass (via loops)

Three benchmark scenarios :

» No stop-quark mixing scenario
» Max -m_h scenario
» Large-μ scenario

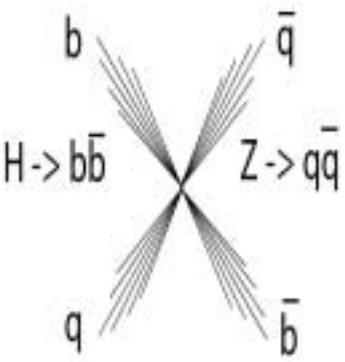
$$e^+e^- \longrightarrow h^0\ Z^0$$

MSSM Higgs Searches $h^0 Z^0$

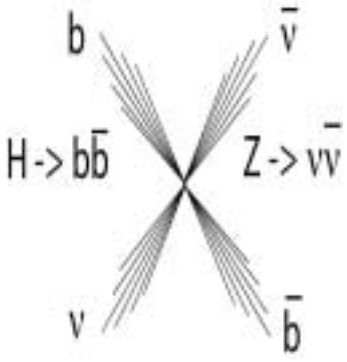
SM Search (**CERN-EP / 2001 – 055)** for $H^0 Z^0$ reinterpreted

- Production $e^+ e^- \longrightarrow h^0 Z^0 \quad \div \sin^2(\beta - \alpha)$

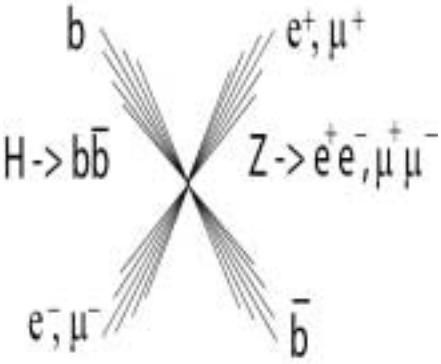
- Topologies



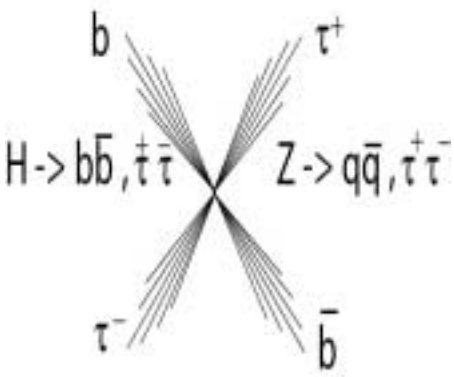
4 jets



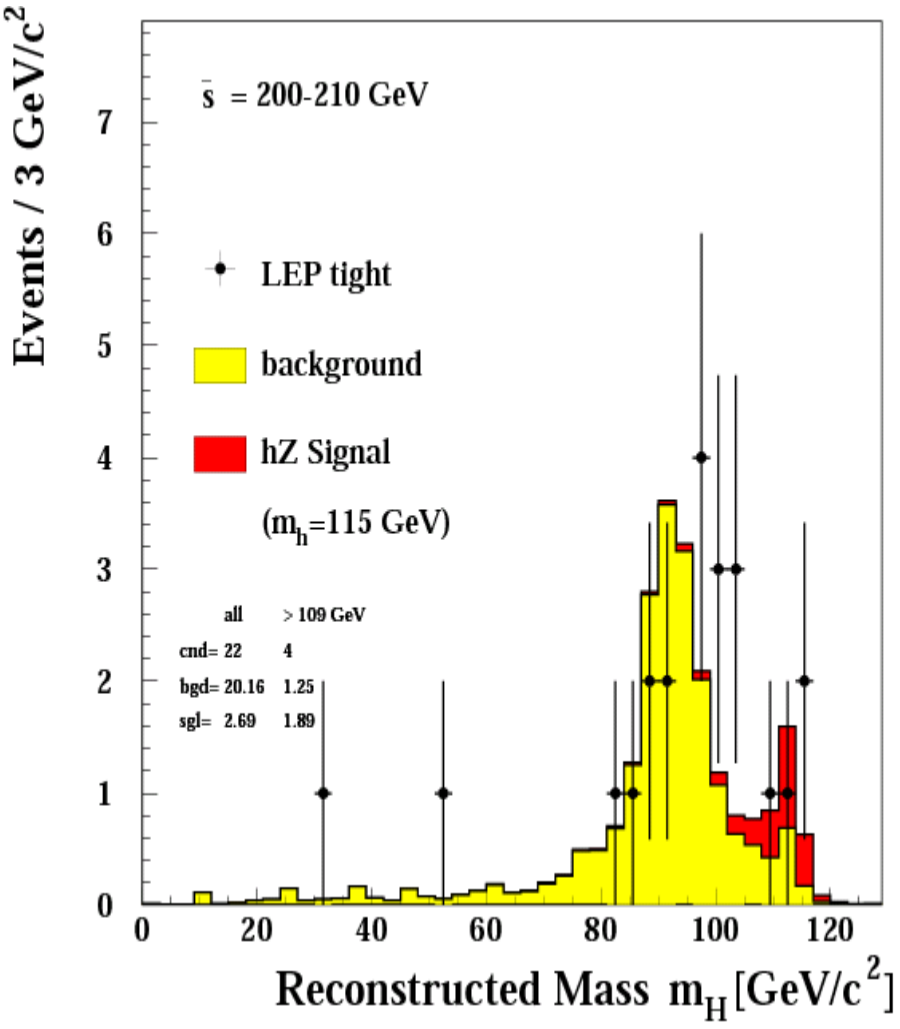
missing energy



leptonic



tau



Tight selection to increase purity
for illustration of the agreement between data and simulation
(not used for limits)

CERN-EP / 2001 - 055

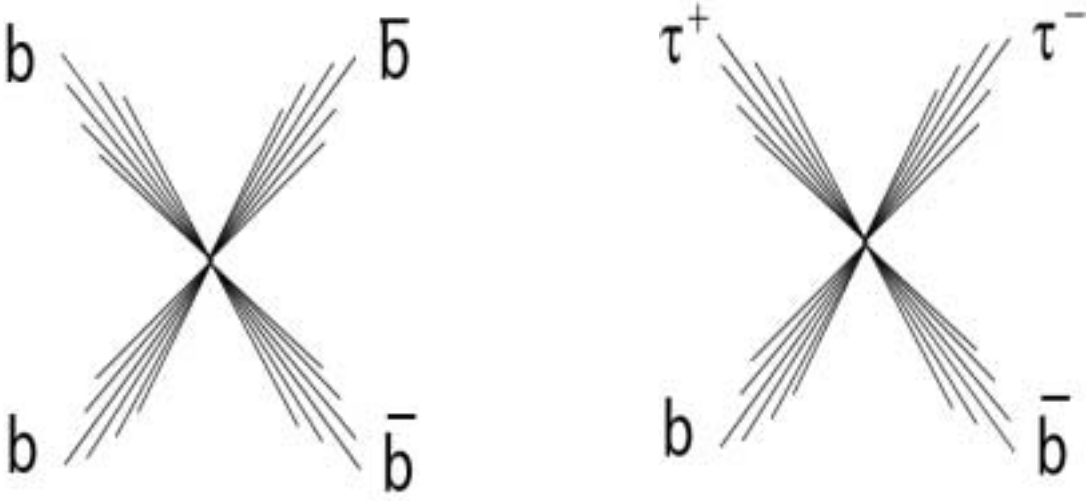
$$e^+e^- \longrightarrow h^0\ A^0$$

LHWG Note 2001-04

- Production $e^+ e^- \longrightarrow h^0A^0 \quad \div \cos^2(\beta - \alpha)$

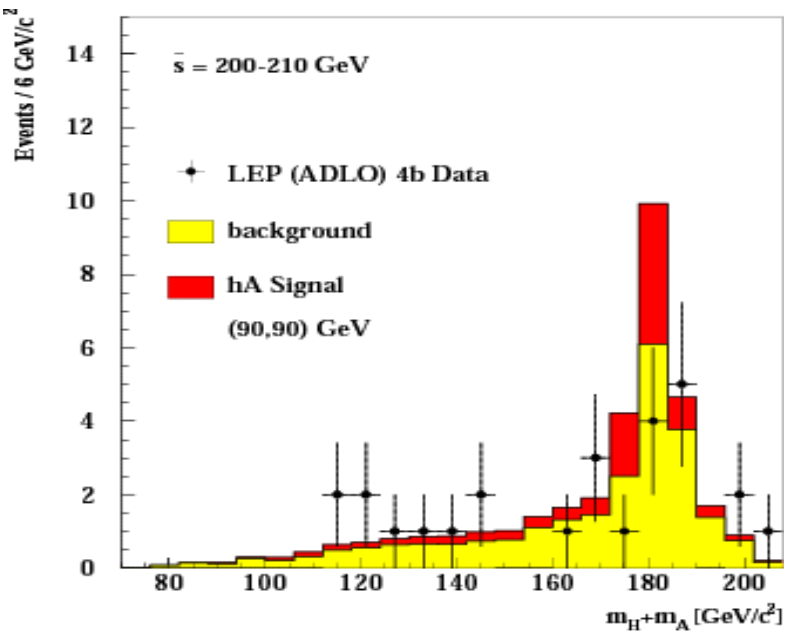
- Topologies

  Predominently

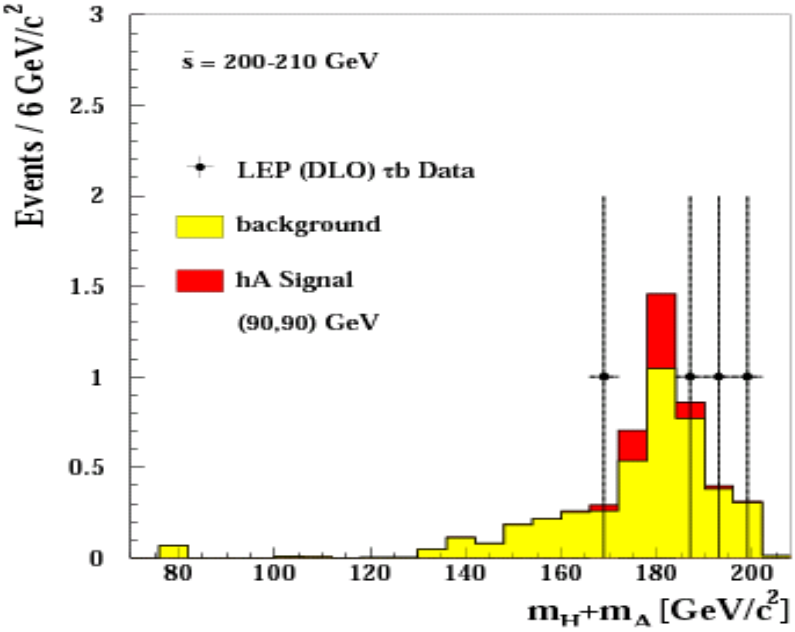


MSSM Higgs Searches $\mathbf{h^0\ A^0}$

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



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

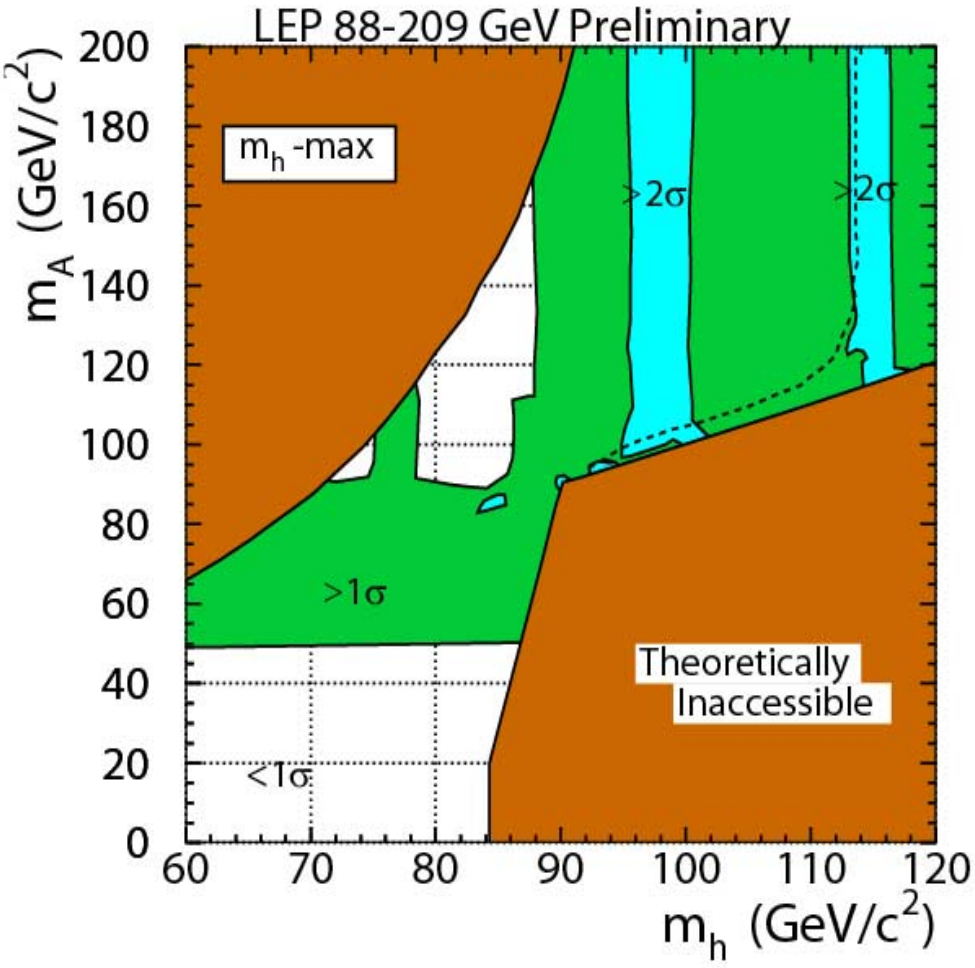


MSSM Higgs Searches $h^0 A^0$

Year 2000 data LHWG Note 2001-04	ALEPH	DELPHI	L3	OPAL
$h^0 A^0$ —> b b b b channel				
Total Int. luminosity (pb^{-1}) Data Total background Efficiency (mh = mA = 90 GeV/c^2) Expected signal (mh = mA = 90 GeV/c^2)	217 10 5.5 47% 3.5	224 5 6.5 47% 3.6	217 13 9.4 42% 3.2	208 11 10.3 48% 3.4
$h^0 A^0$ —> b b $\tau^+ \tau^-$ channel				
Total Int. luminosity (pb^{-1}) Data Total background Efficiency (mh = mA = 90 GeV/c^2) Expected signal (mh = mA = 90 GeV/c^2)	217 3 3.0 41% 0.6	224 5 6.0 25% 0.4	217 2 3.0 33% 0.4	205 5 4.5 43% 0.6
Obs. (exp. Med.) limit for m_h Obs. (exp. Med.) limit for m_A	89.6 (91.7) 90.0 (92.1)	89.7 (88.8) 90.7 (89.7)	83.2 (88.1) 83.9 (88.3)	79.3 (85.1) 80.6 (86.9)

$h^0 A^0$ and $h^0 Z^0$ Full Combination

Distribution of CL_b in the (m_h^0, m_A^0) plane



LHWG Note 2001-04

In the domains labelled $\geq 1\sigma$ and $\geq 2\sigma$
the observation shows an excess above the SM prediction

Structures on the $m_h = m_A$ line could arise from $\mathbf{h^0 A^0}$
Vertical structures could be due to the features of the $\mathbf{h^0 Z^0}$

Effects $\geq 2\sigma$ are consistent with the expectation
for $\mathbf{H^0 Z^0}$, $\mathbf{h^0 Z^0}$ and $\mathbf{h^0 A^0}$ production
for some MSSM parameter combinations such as

m_A	m_h	m_H	tanβ	M_{SUSY}	M_2	μ	A	σ_{HZ}^{208}	σ_{hA}^{208}
90	90.0	114.0	16	1000	500	500	0	118	44
100	99.3	114.0	16	1000	500	-500	0	97	8

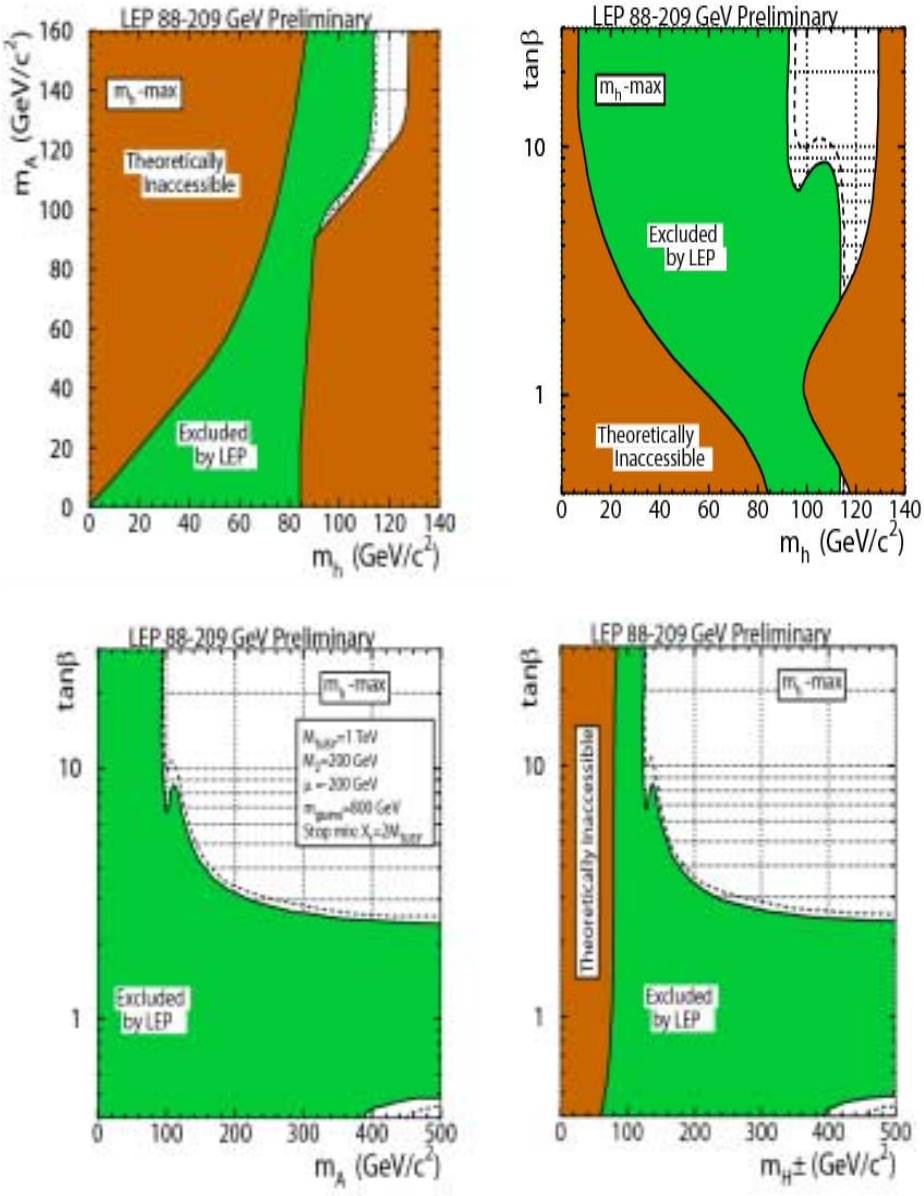
Masses in GeV
Cross-sections in fb

Communication of André Sopczak

Max- m_h scenario

LHWG

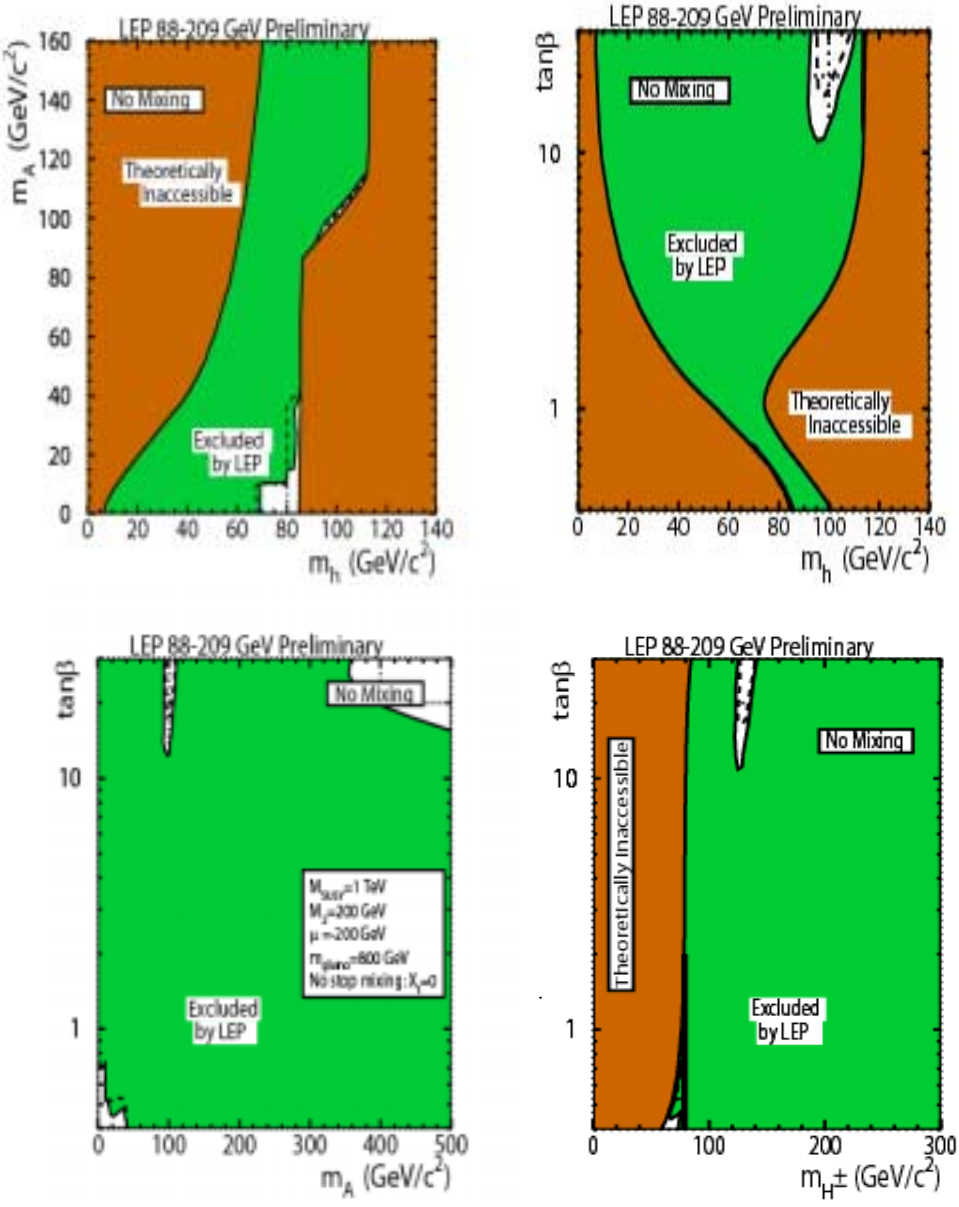
Note 2001-04



No stop - mixing scenario

LHWG

Note 2001-04



Observed and expected limits

for m_h^0 and m_A^0

for the "mh-max" scenario and the "no-mixing" scenario

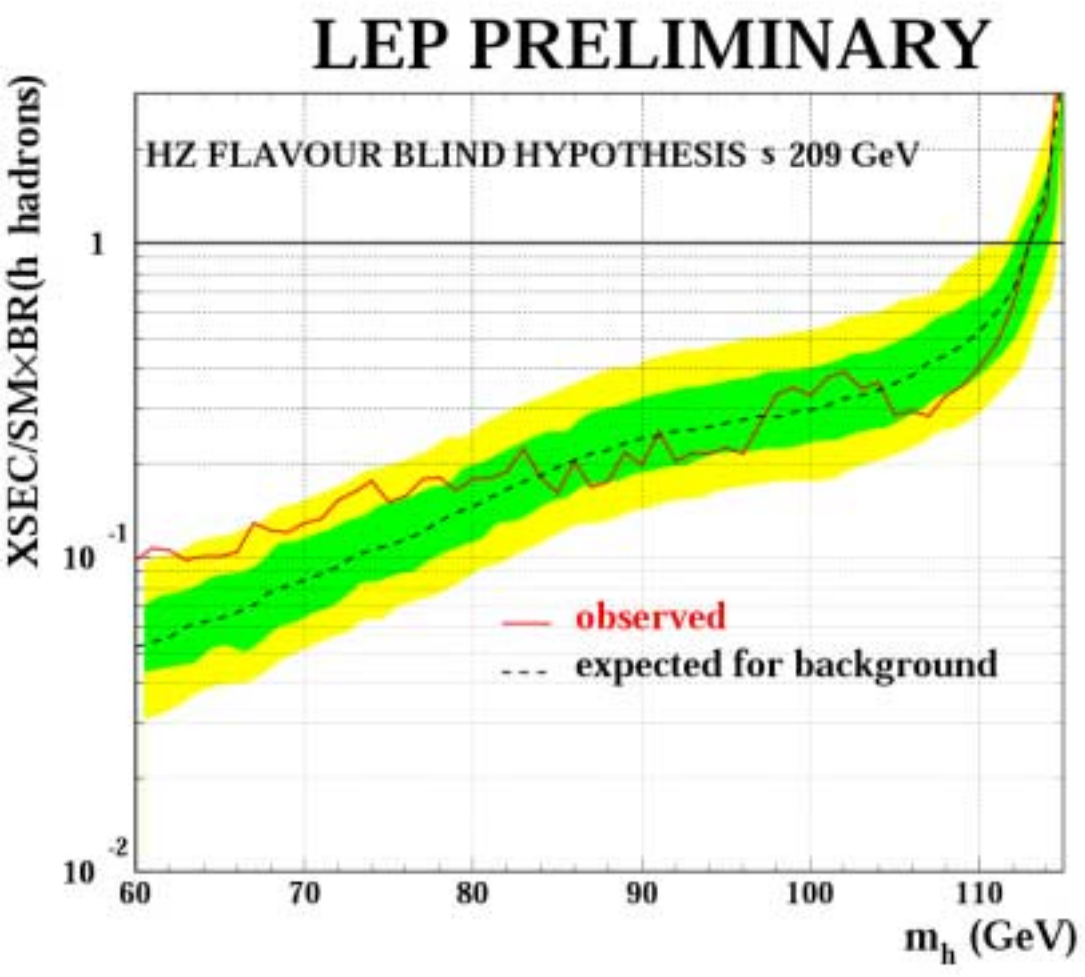
Scenario	m_h^o limit (GeV/c^2)	m_A^0 limit (GeV/c^2)	Excluded tanβ Observed limit (expected limit)
m_h^o -max	91.0 (94.6)	91.9 (95.0)	$0.5 < \tan\beta < 2.4$ ($0.5 < \tan\beta < 2.6$)
no-mixing	91.5 (95.0)	92.2 (95.3)	$0.7 < \tan\beta < 10.5$ ($0.8 < \tan\beta < 16.0$)

LHWG Note 2001-04

Large μ scenario

designed to illustrate choices of the MSSM parameters for which h^0 does not decay into a pair of b quarks

⇒ include the flavour-independent searches in this scenario

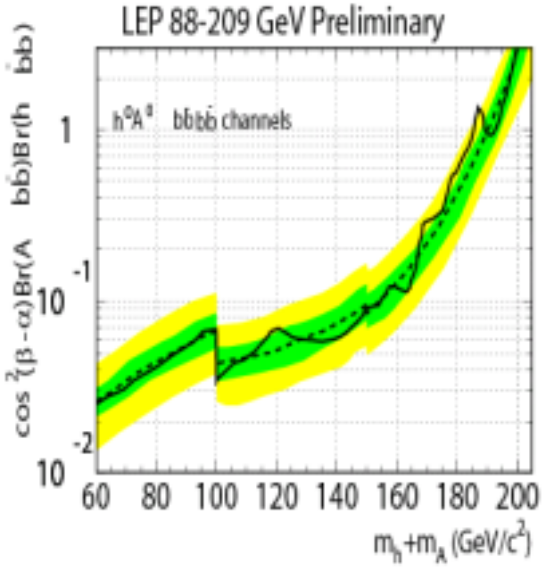


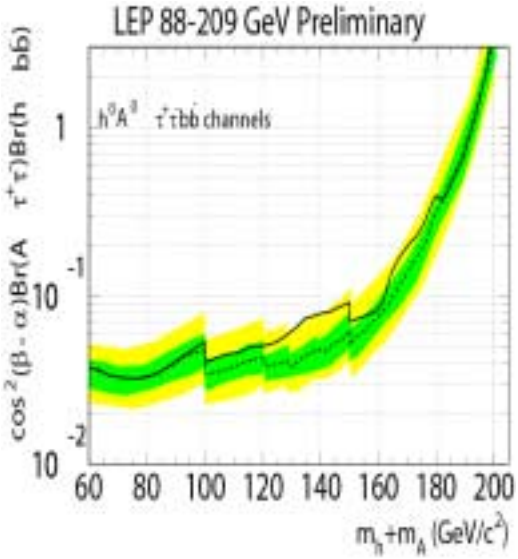
Adds enough sensitivity to exclude this scenario at the 95% CL

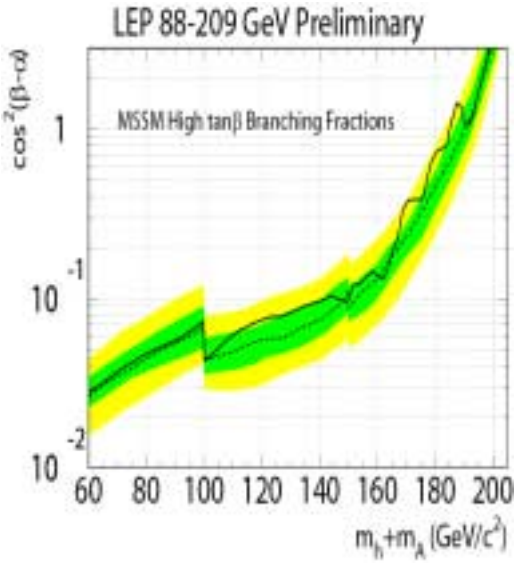
Coupling strength limits

$m_h^0 \approx m_A^0$

energy dependence of $e^+e^- \rightarrow h^0 A^0$ cross-section from the "mh-max" scenario







$\tan \beta > 10$

Br $(h^0 \rightarrow bb) = 0.94$

Br $(A^0 \rightarrow bb) = 0.92$

Br $(h^0 \rightarrow \tau^+ \tau^-) = 0.06$

Br $(A^0 \rightarrow \tau^+ \tau^-) = 0.08$

LHWG Note 2001-04

Updates

ALEPH

- year 2000 data sample fully reprocessed
  (final detector calibrations, alignment constants)
- precise knowledge of the LEP c.m. energy
  propagated to final results (~ -140 MeV, essentially affects hZ)
- additional simulated evt samples
  → more accurate prediction of the SM background
- algorithm to reject beam-related backgrounds (4-jet channel)

L3

- year 2000 data sample fully reprocessed
  (final detector calibrations, alignment constants)
- precise knowledge of the LEP c.m. energy propagated to final results
- improved efficiency

OPAL

- H^0Z^0 channel analyses to be upgraded by EPS HEP 2002
- h^0A^0 channel update with the final calibration comes soon

No big change is expected in the results

DELPHI

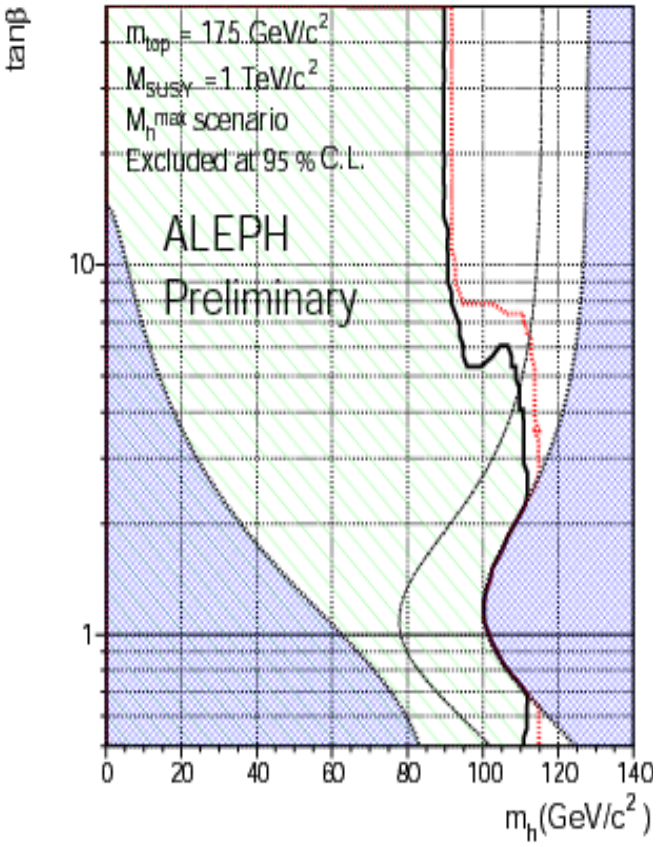
- final reprocessing of data
- New MC simulation samples
  (statistics x 4, Pythia → KK2F, Excalibur →WPHACT generators used)
- Dedicated b-tagging for hA → bbbb channel analysis

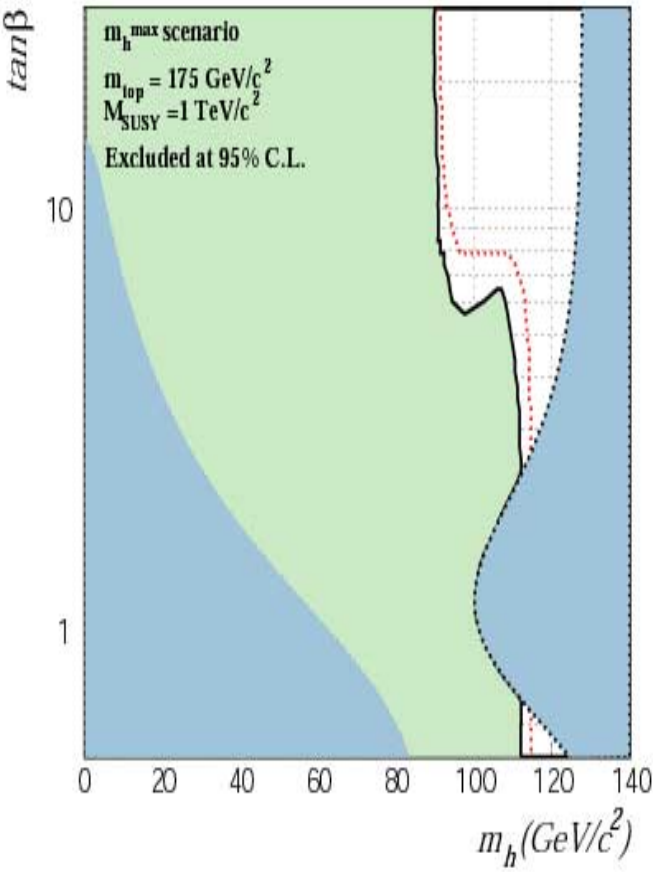
Only small changes expected

Updates

ALEPH mh-max scenario

New ! Final!





Excluded regions (95% CL)

m_h < 89.6 (91.7) GeV/c^2

m_A < 90.0 (92.1) GeV/c^2

0.7 < tanβ < 2.2

ALEPH 2001-022

m_h < 89.8 (91.3) GeV/c^2

m_A < 90.1 (91.6) GeV/c^2

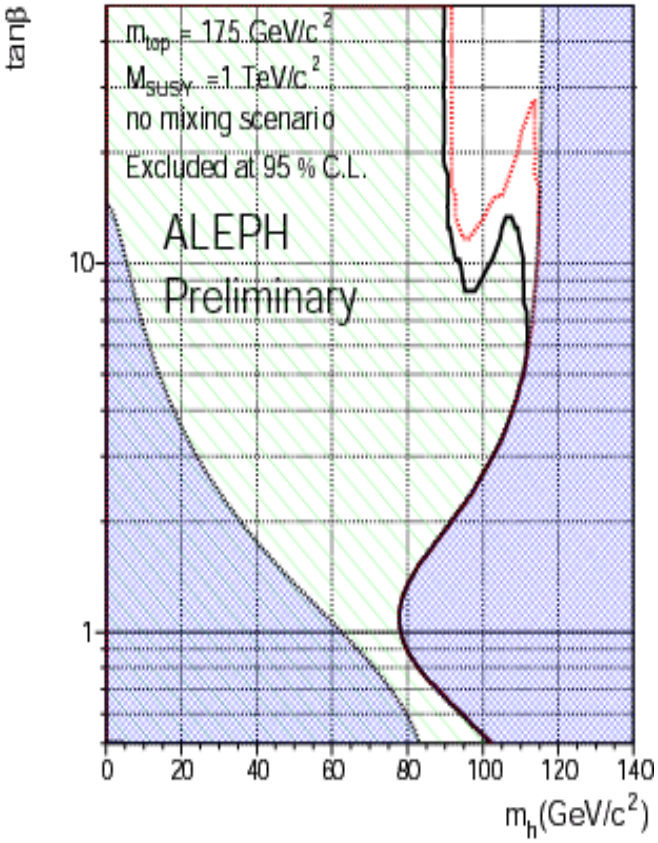
0.7 < tanβ < 2.2

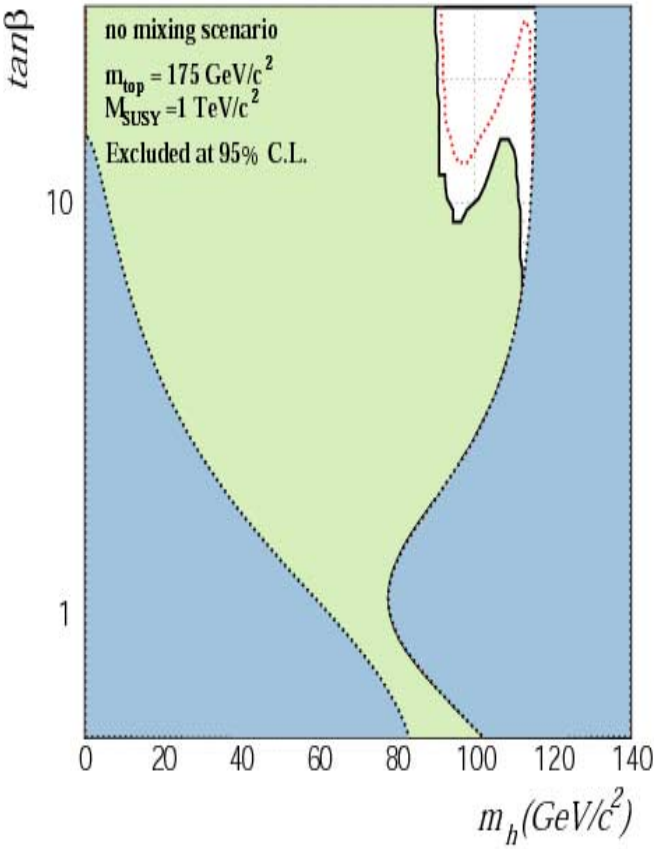
Phys.Lett.,B: 526 (2002), pp. 191 - 205

Updates

ALEPH · no-mixing scenario

New ! Final!





Excluded regions (95% CL)

$m_h < 89.8$ (91.3) GeV/c^2

$m_A < 90.1$ (91.6) GeV/c^2

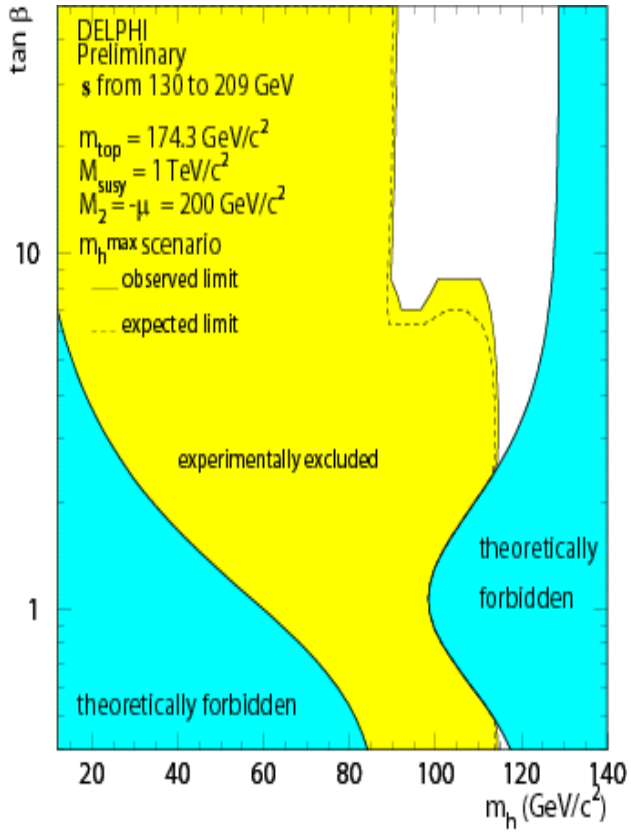
$0.5 < \tan\beta < 6.0$ · $0.5 < \tan\beta < 6.2$

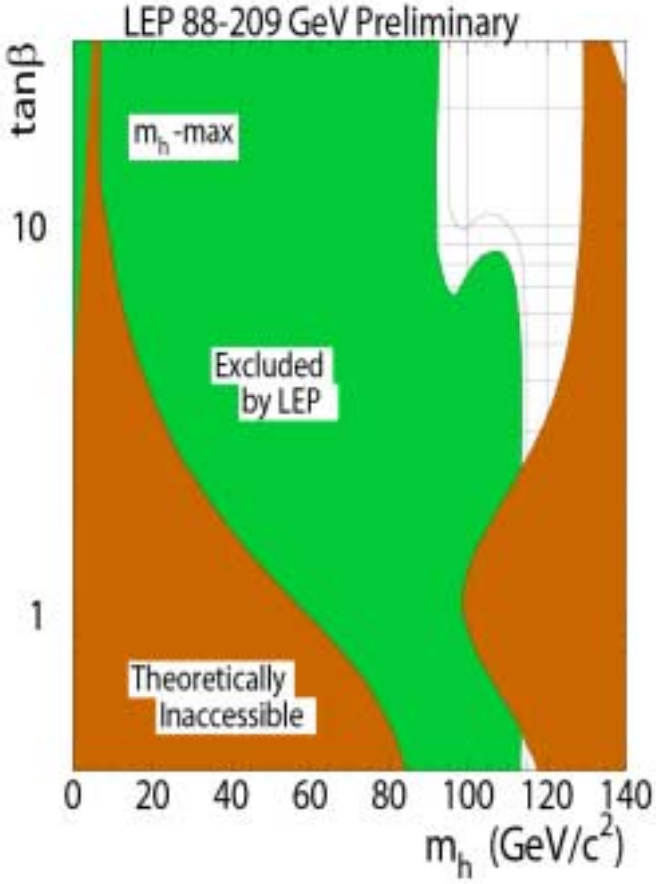
ALEPH 2001-022 **Phys.Lett.,B: 526 (2002), pp. 191 - 205**

Updates

DELPHI mh-max scenario

New !





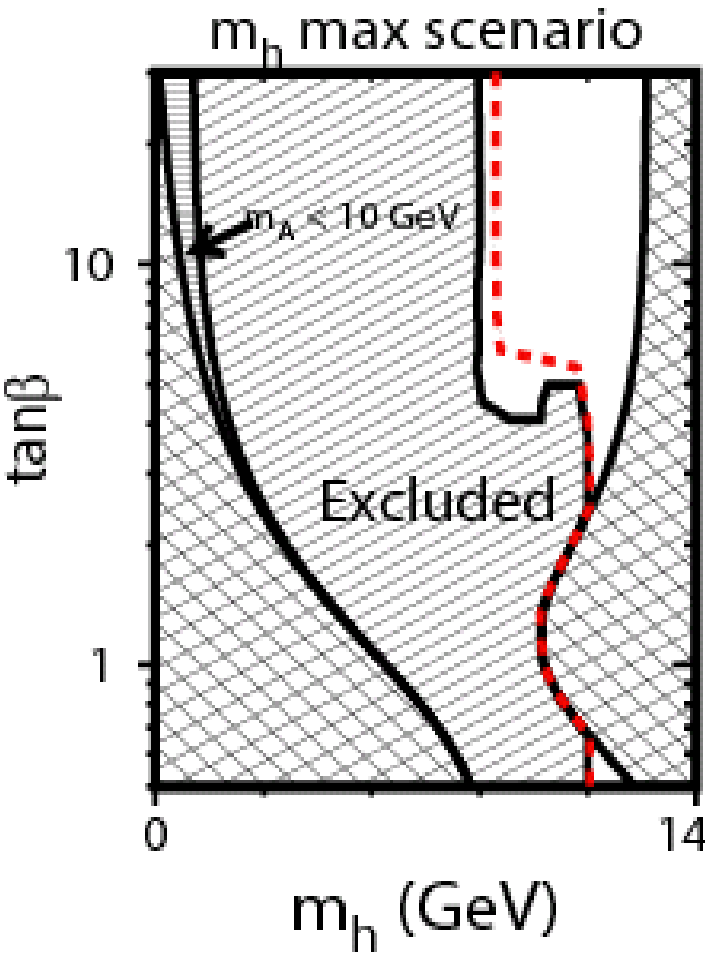
Excluded regions (95% CL)

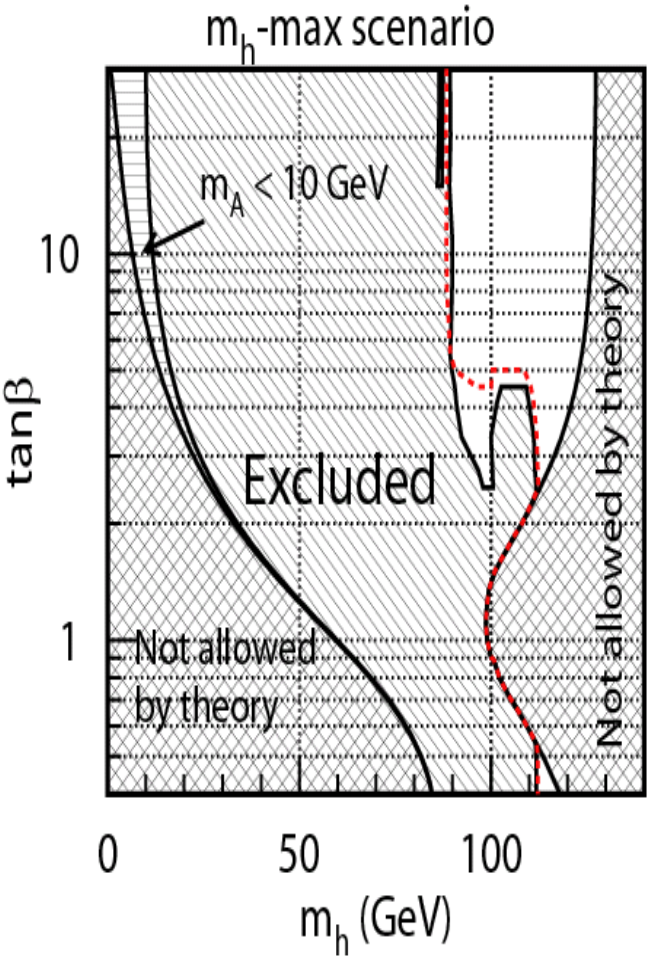
$0.49 < \tan\beta < 2.36$ **DELPHI 2001-078 CONF 506**

$0.5 < \tan\beta < 2.4$ **DELPHI 2002-021 TALK 31**

L3 mh-max scenario

New ! Still preliminary





Excluded regions (95% CL)

$m_h < 86.0$ (88.4) GeV/c^2

$m_A < 86.5$ (88.6) GeV/c^2

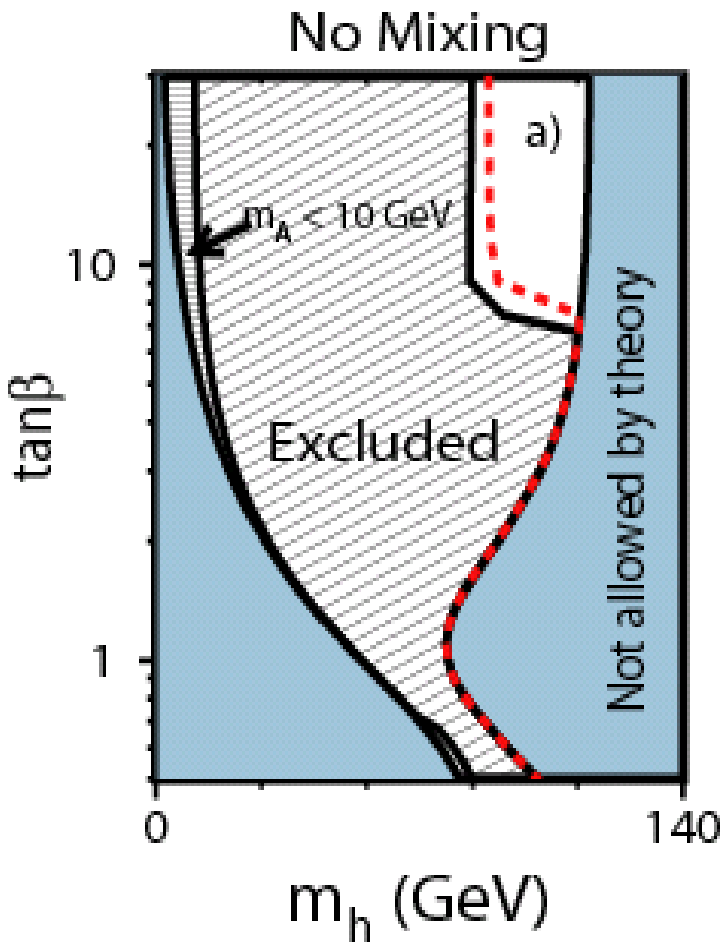
$0.55 < \tan\beta < 2.2$

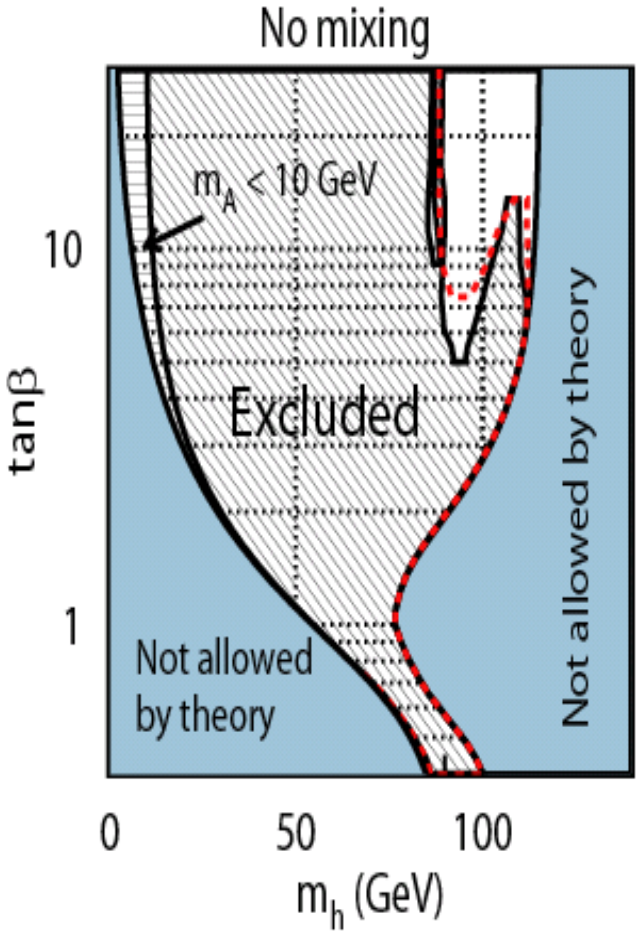
L3 Note 2692

L3 Note 2735

L3 no-mixing scenario

New ! Still preliminary





Excluded regions (95% CL)

$m_h < 85.5$ (88.5) GeV/c^2

$m_A < 86.3$ (88.6) GeV/c^2

$0.4 < \tan\beta < 4.9$

L3 Note 2692

L3 Note 2735

Updates

- New, final results for ALEPH
- New, almost final results for L3
- OPAL

  - H^0Z^0 channel analyses to be upgraded by EPS HEP 2002
  - h^0A^0 channel update with the final calibration comes soon

  No big change is expected in the results

- Final results for DELPHI expected to be published very soon.
- Final combination of the 4 experiments starting now

  New, final LEP results expected to be ready for EPS HEP 2002