Higgs boson searches at LEP

On behalf of the

LEP Higgs working group

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Higgs search results:

- Standard Model
- MSSM
- charged, $H^{\pm}$
- invisible
- fermiophobic
- flavour independent (NEW)

All Y2K data now included

PRELIMINARY RESULTS

Standard Model Higgs

- previous LEP combination presented at the LEPC on Nov. 3, 2000.

What has changed in the meantime?

- ALEPH, DELPHI, L3 and OPAL published their first findings in Nov.–Dec. 2000
- L3 has already submitted its final results (Phys. Lett. B, June 2001)

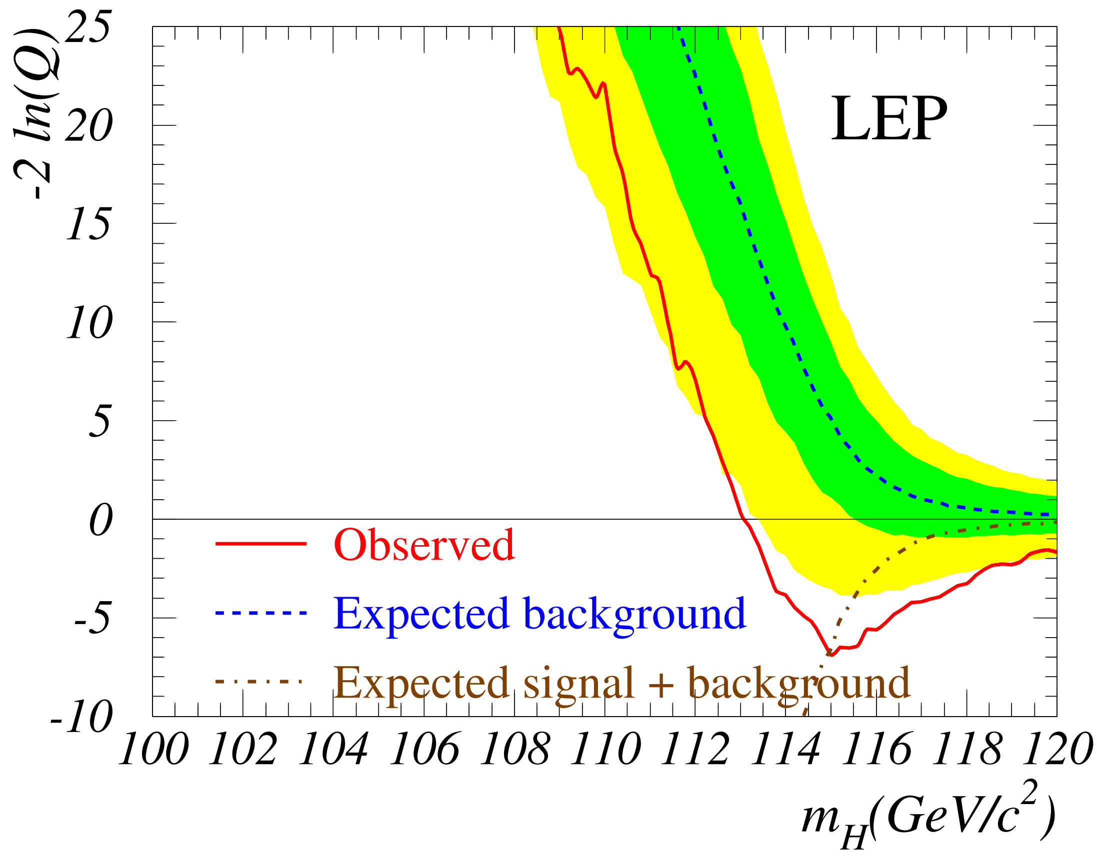
The combined results presented in this talk reflect the latest published results from A, D, L and O (red).

Likelihood ratio, Q

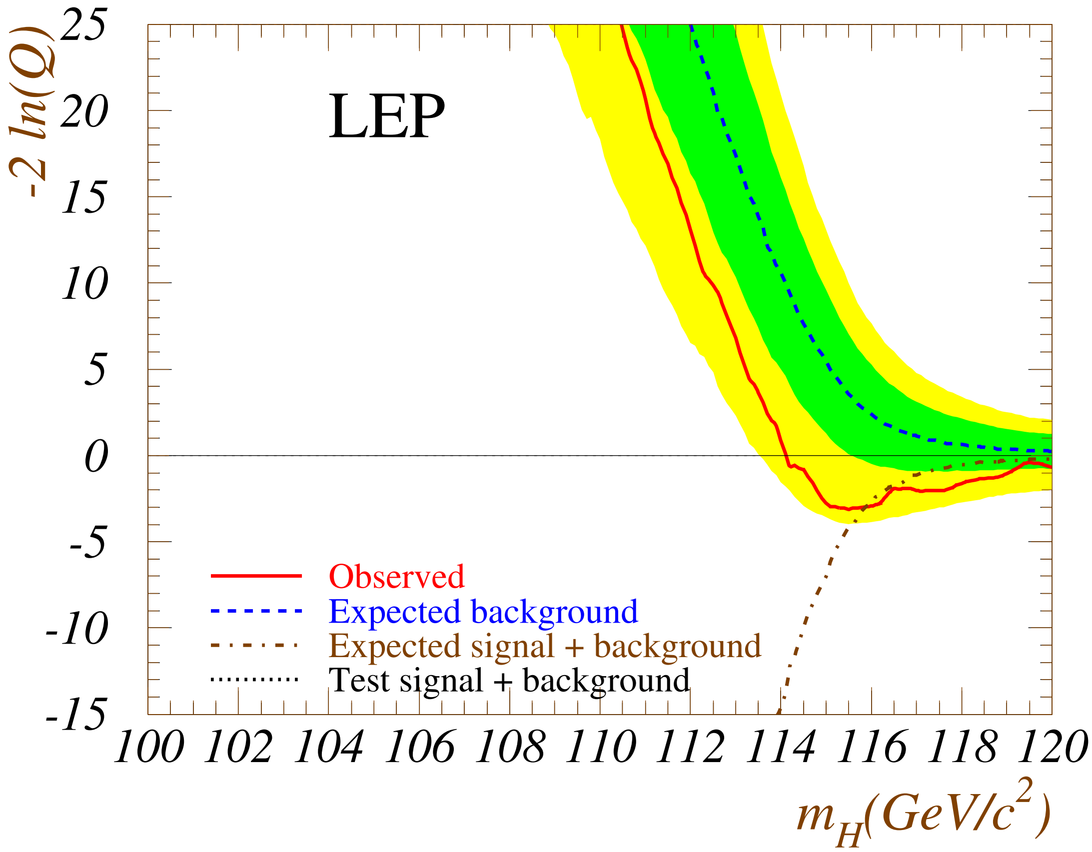
$$Q = \frac{L_{s+b}}{L_b} = \frac{P(n_{obs}; s+b) \times (S(\vec{x}_i) + B(\vec{x}_i))}{P(n_{obs}; b) \times B(\vec{x}_i)}$$

$$-2\ln Q(m_h) = 2s_{tot} - 2\sum_i^{n_{obs}} \ln\left(1 + \frac{s_i}{b_i}\right)$$

(➜ combined result: Nov. 3, 2000)



Combined likelihood ratio, Q



— observed

- - - median expected background

· · · median expected background + $m_{\mathrm{h}} = 115$ GeV

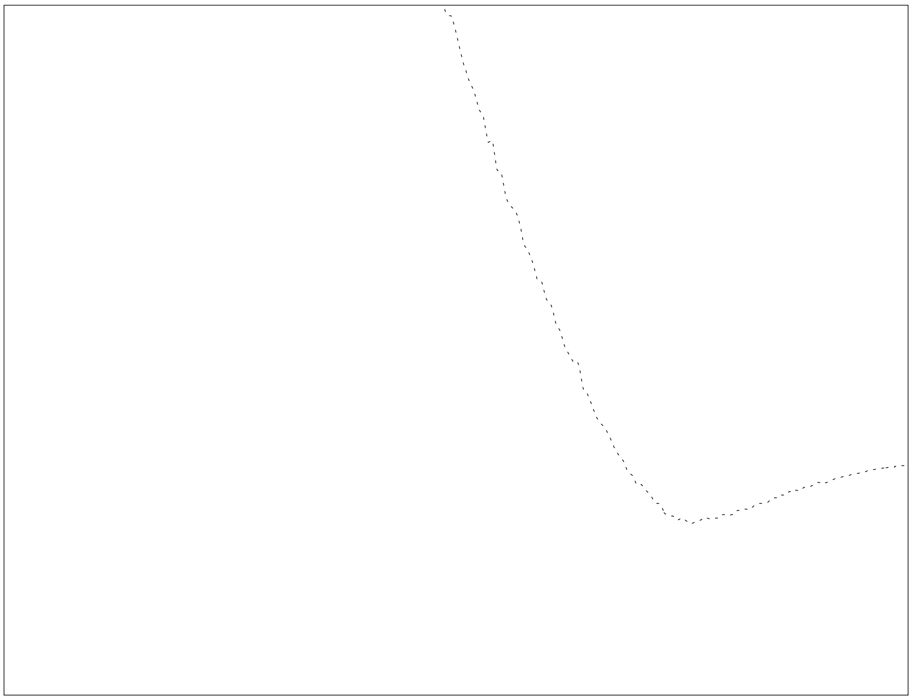
➜ maximum likelihood ratio at:

$$m_{\mathrm{h}} = 115.6 \text{ GeV}$$

➜ probability of background fluctuation at $\approx 2\ \sigma$ level

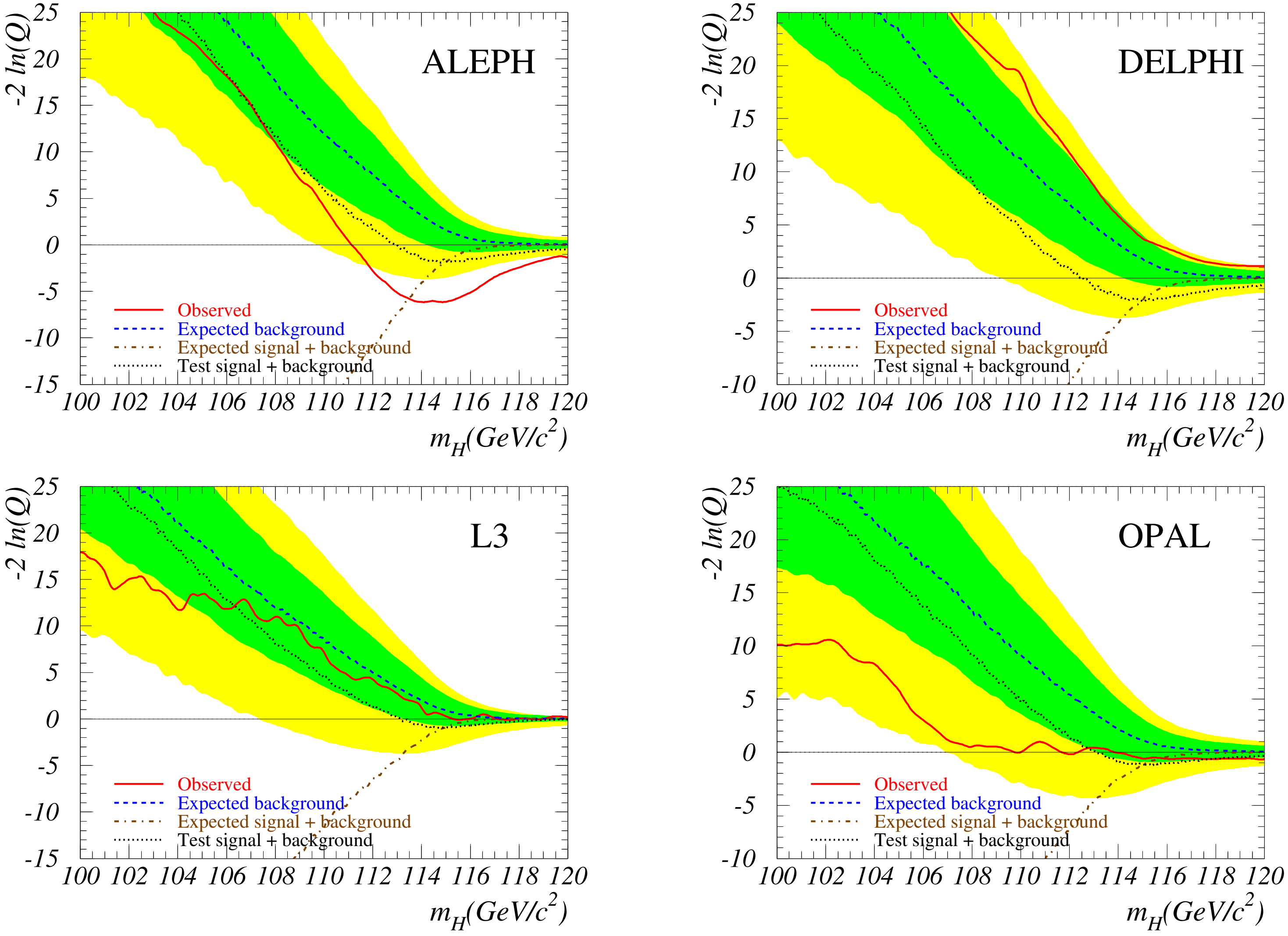
“Tail test”

Expected log likelihood ratio curve
for m_{h} =115 GeV



(✗ ...not yet available for m_{h} =115.6 GeV)

A,D,L,O Likelihood ratios



Changes to likelihood ratio @ m_{h} =115 GeV

$$-2\ln Q(m_{\mathsf{h}}) = 2s_{\mathrm{tot}} - 2\sum_{i}^{\mathrm{n_{obs}}} \ln(1+\frac{s_i}{b_i})$$

	Nov. 3, 2000	July 10, 2001	Δ	Comments
ALEPH	-7.61	-6.13	+1.5	+ 10.2 pb^{-1} ■: 2D correlation
DELPHI	+3.01	+3.64	+0.6	+12.5 pb^{-1} ▲
L3	-1.71	+0.36	+2.1	+16.5 pb^{-1} ■ ● ●
OPAL	-0.59	-0.74	-0.25	+16 pb^{-1} (hq$\bar{\mathrm{q}}$ cand.) ■●▲◆: bgd. $\nearrow$ 5%
Total	-6.90	-2.87	+4.0	+55.2 pb^{-1} data

Improved sensitivity / understanding in channel
4-jets (■), $\not{E}$(●), leptonic (▲) and tau (◆) channels.

Comparison with previous combination

Comparison at 115 GeV:

- log likelihood ratio: $-2\ln Q$
- significance of observed excess

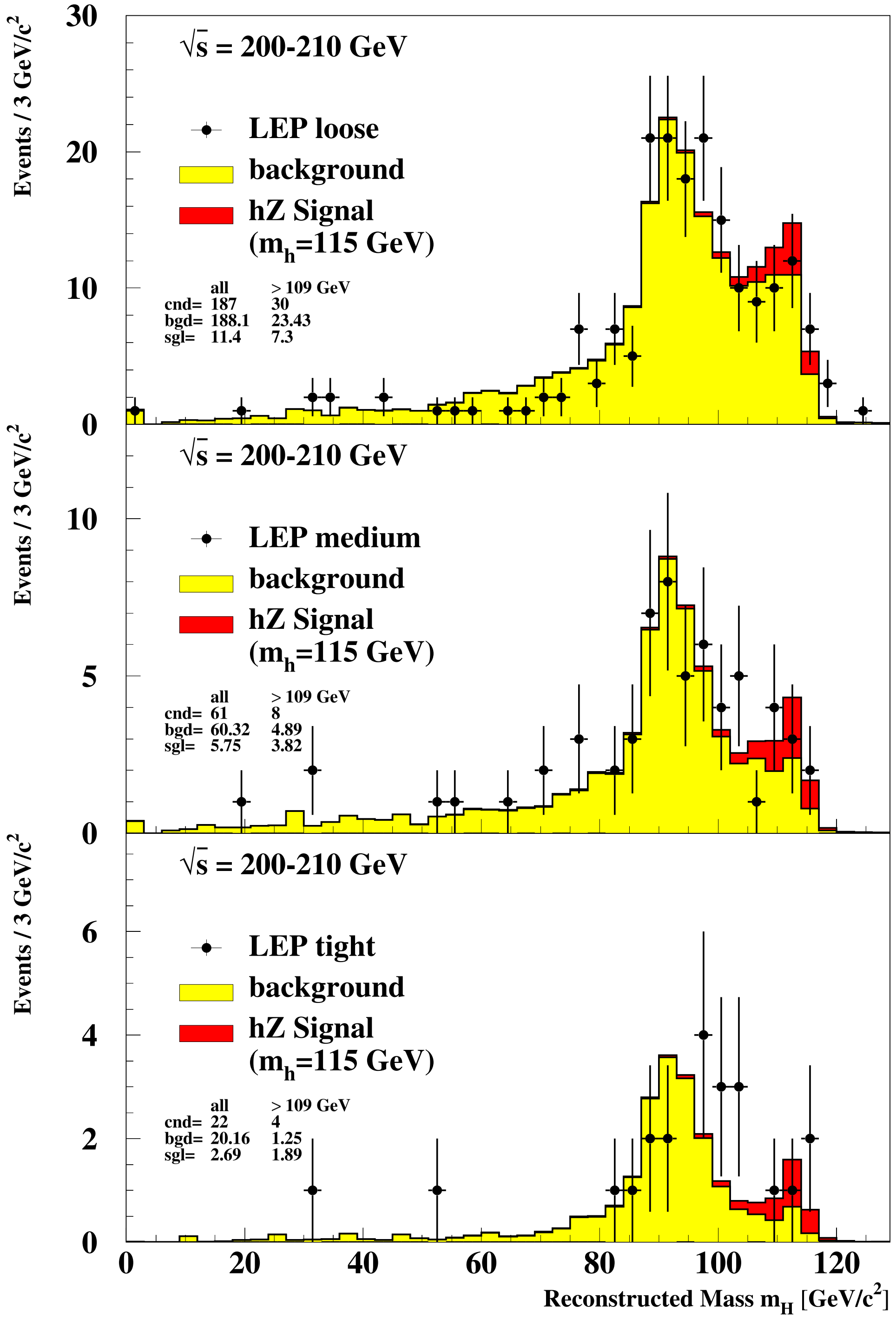
Channel	Nov. 3, 2000		July 10, 2001	
	$-2\ln Q$	σ	$-2\ln Q$	σ
$\mathrm{hq\bar{q}}$	-5.15	2.58	-4.70	2.45
$\mathrm{h}\nu\bar{\nu}$	-2.27	1.93	+0.81	0.86
$\mathrm{he^+e^-}$, $\mathrm{h}\mu^+\mu^-$	+0.55	0.39	+1.04	0.15
$\mathrm{hZ} \to \tau^+\tau^-\mathrm{q\bar{q}}$, $\mathrm{b\bar{b}}\tau^+\tau^-$	-0.03	0.77	-0.03	0.77

Largest changes are in missing energy channel and, to a lesser extent in four-jet channel.

Candidate weights @ m_{h} =115 GeV

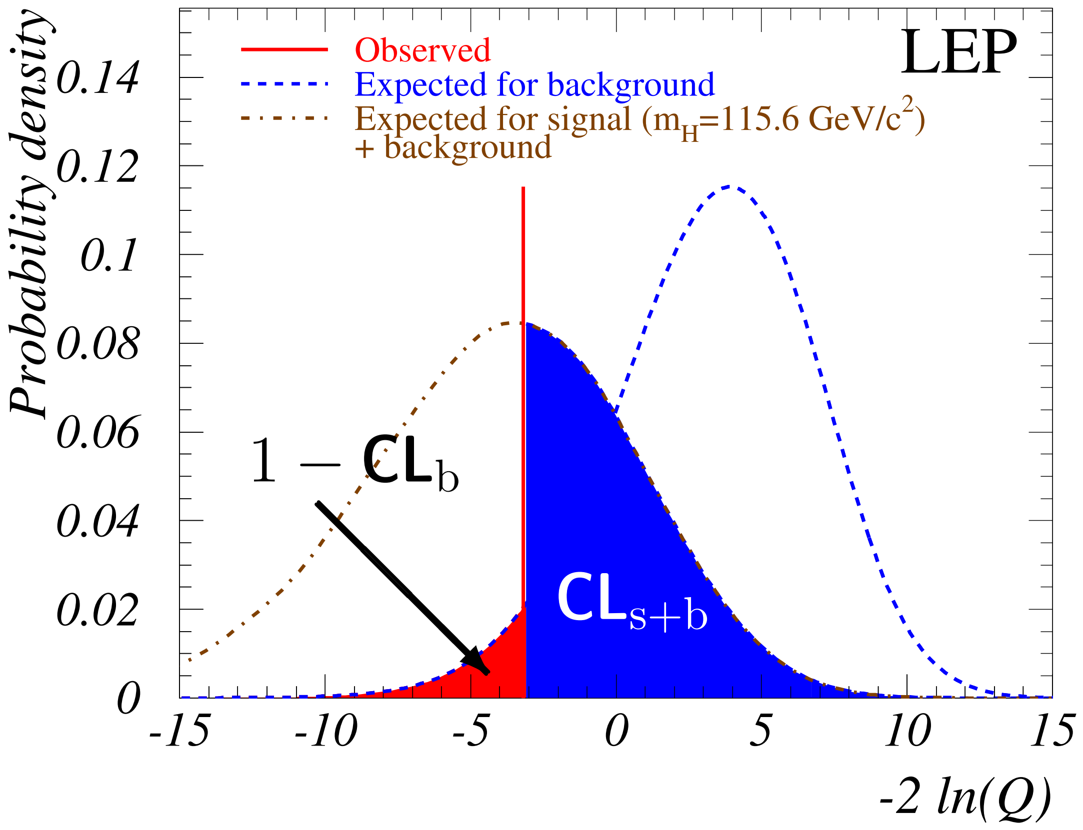
	Expt	E_{cm}	Channel	M_H^{rec} (GeV)	$\ln(1+s/b)$ @115 GeV
1	A	206.7	4-jet	114.3	1.73
2	A	206.7	4-jet	112.9	1.21
3	A	206.5	4-jet	110.0	0.64
4	L	206.4	E-miss	115.0	0.53
5	O	206.6	4-jet	110.7	0.53
6	D	206.7	4-jet	114.3	0.49
7	A	205.0	Lept	118.1	0.47
8	A	208.1	Tau	115.4	0.41
9	A	206.5	4-jet	114.5	0.40
10	O	205.4	4-jet	112.6	0.40
11	D	206.7	4-jet	97.2	0.36
12	L	206.4	4-jet	108.3	0.31
13	A	206.5	4-jet	114.4	0.27
14	A	207.6	4-jet	103.0	0.26
15	O	205.4	E-miss	104.0	0.25
16	A	206.5	4-jet	110.2	0.22
17	L	206.4	E-miss	110.1	0.21
18	O	206.4	E-miss	112.1	0.20
19	D	206.7	4-jet	110.1	0.20
20	L	206.4	E-miss	110.1	0.18

Reconstructed mass distributions



LEP combined result

Observation vs. simulated experiments for b-only, b+s(m_h =115.6 GeV)



Compatibility with

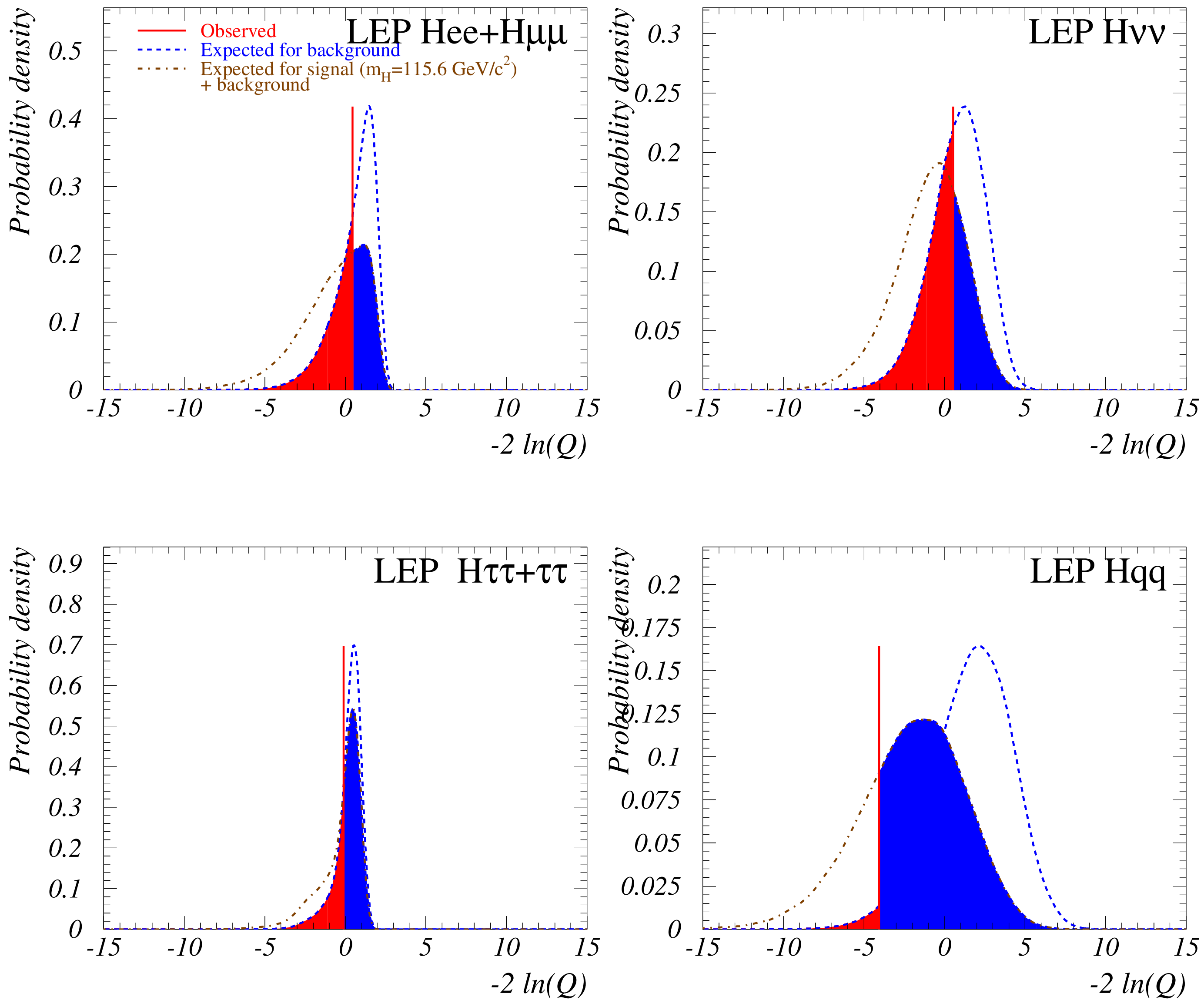
➜ background, $1 - CL_b = 3.5\%$

➜ background + $m_h = 115.6$ GeV, $CL_{s+b} = 43.5\%$

Observation vs. simulated experiments

b-only, b+s(m_h =115.6 GeV)

by search topology:



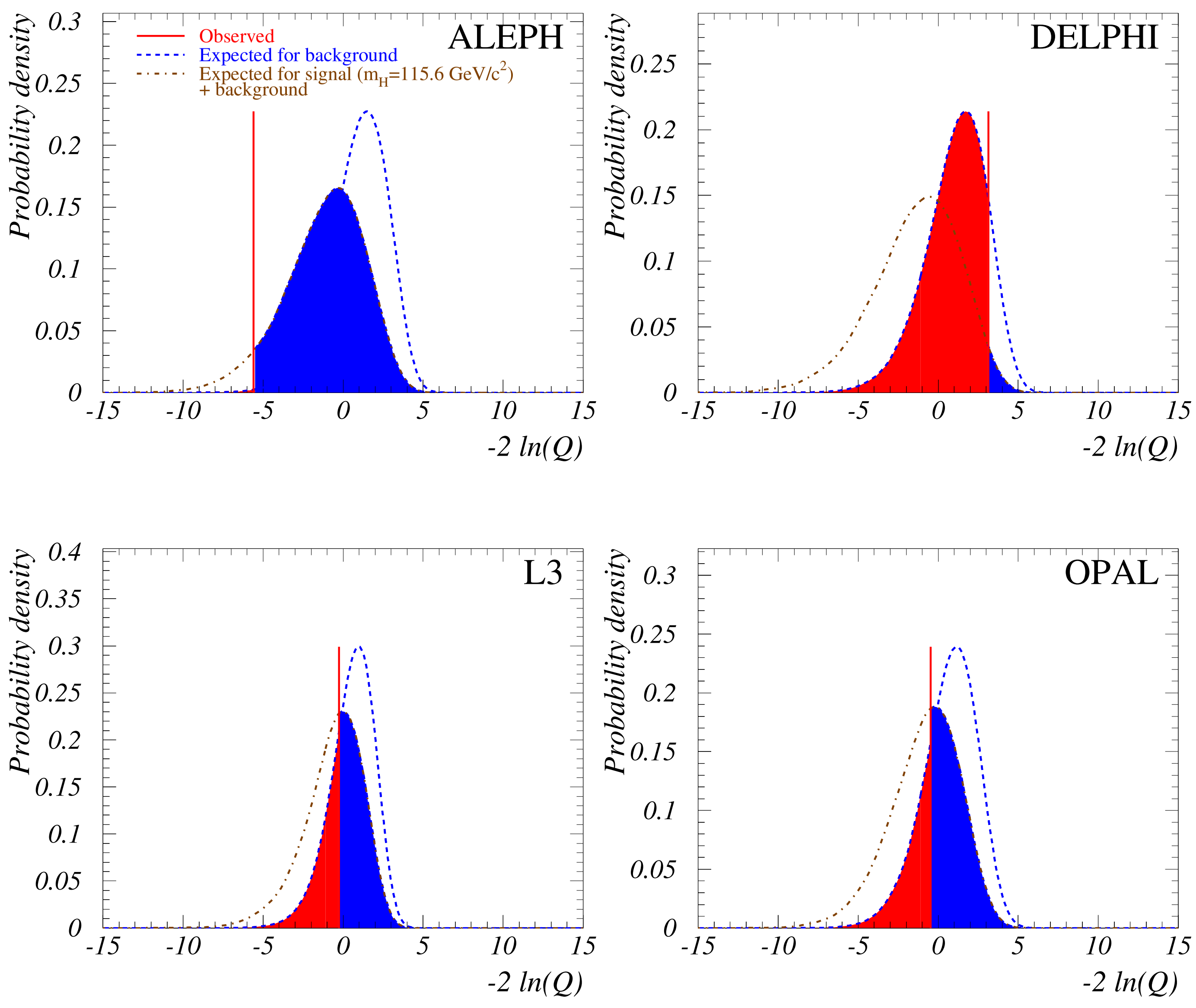
➜ separation of curves:

$\propto$ sensitivity to m_h =115.6 GeV hypothesis

Observation vs. simulated experiments

b-only, b+s(m_h =115.6 GeV)

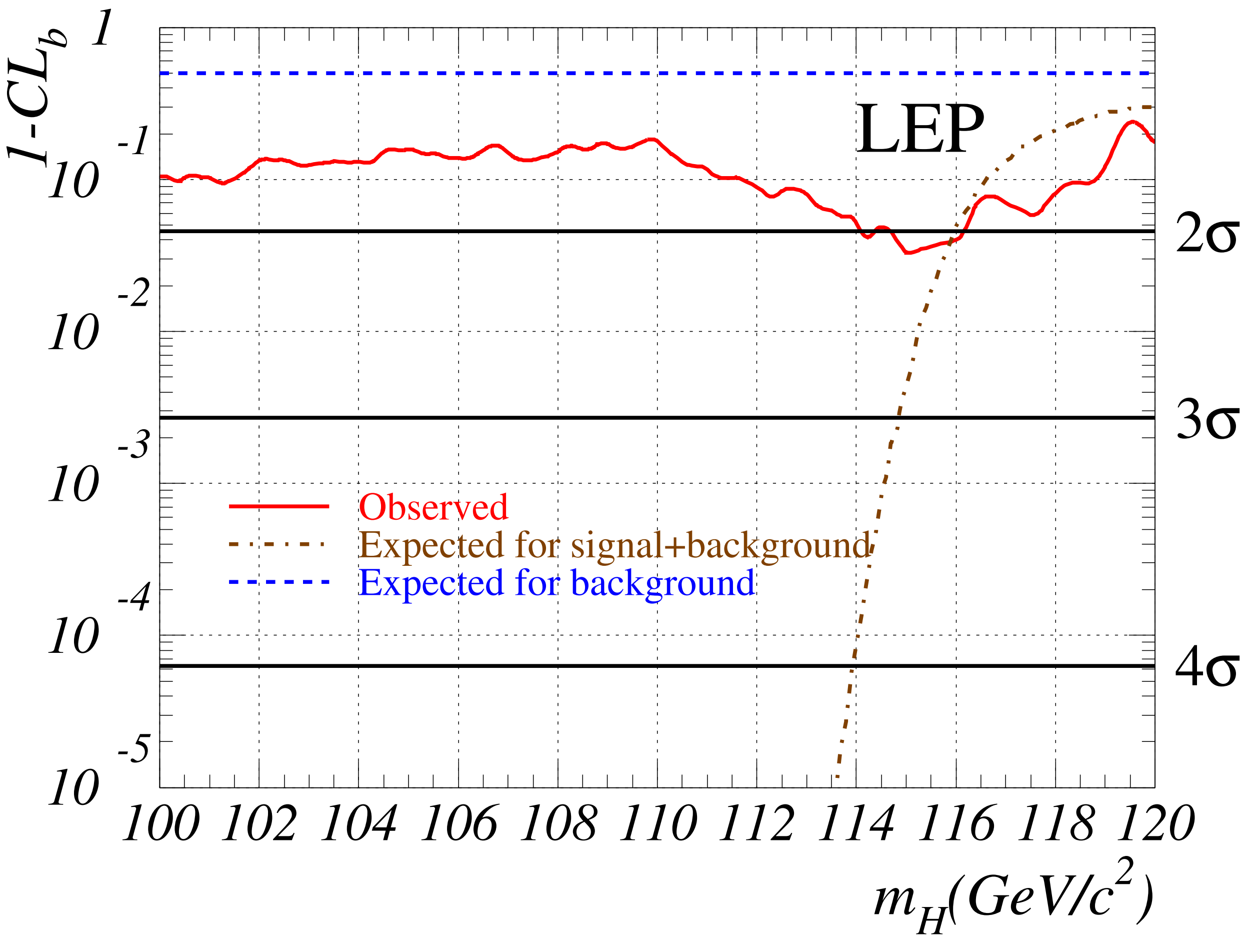
by experiment:



➜ separation of curves:

$\propto$ sensitivity to m_h =115.6 GeV hypothesis

Background fluctuation probability:1-CL$_b$

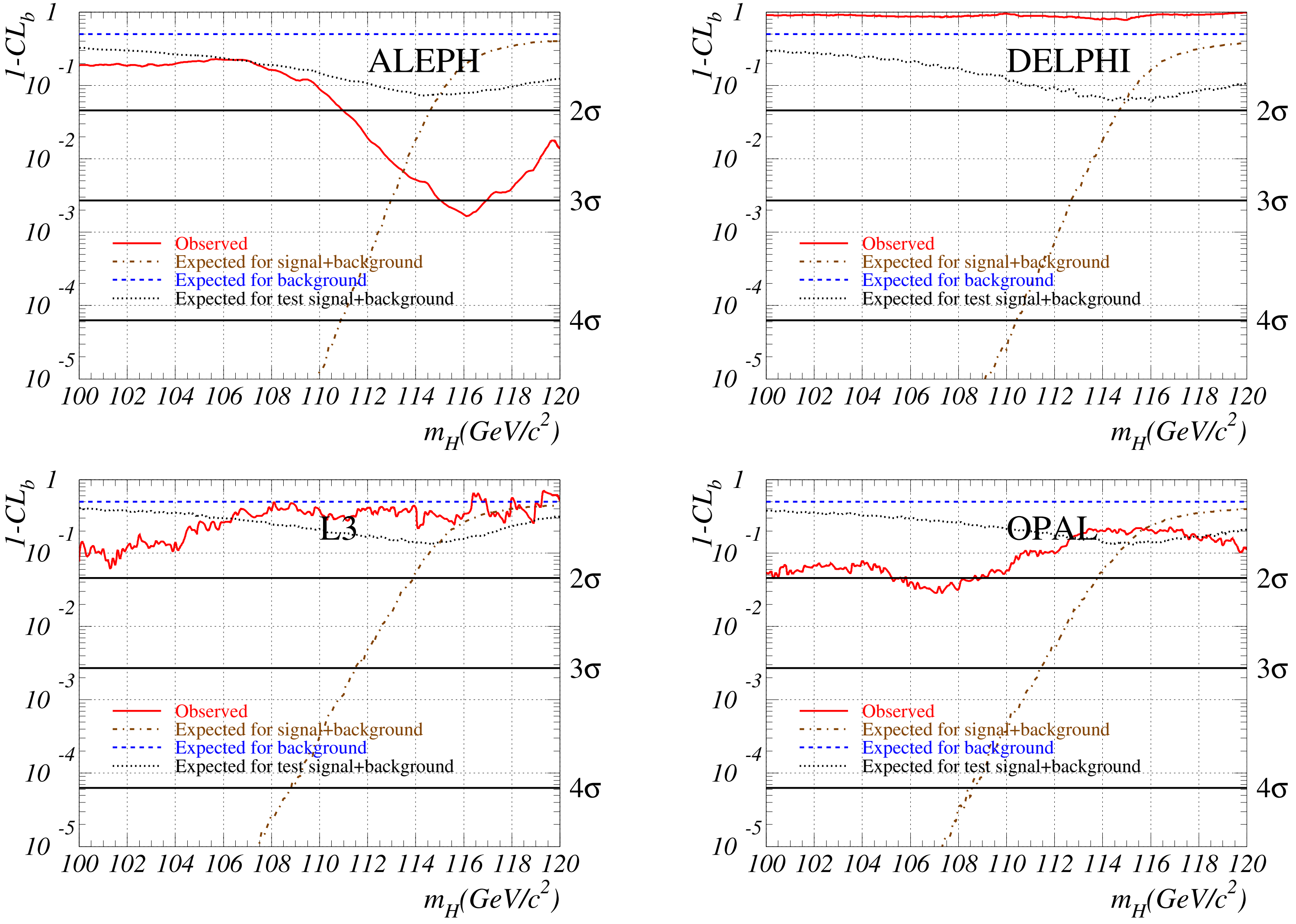


- background fluctuation probability
at m_h =115.6 GeV: $1 - \mathrm{CL}_b$ = 3.5%

- at the 95% C.L.:

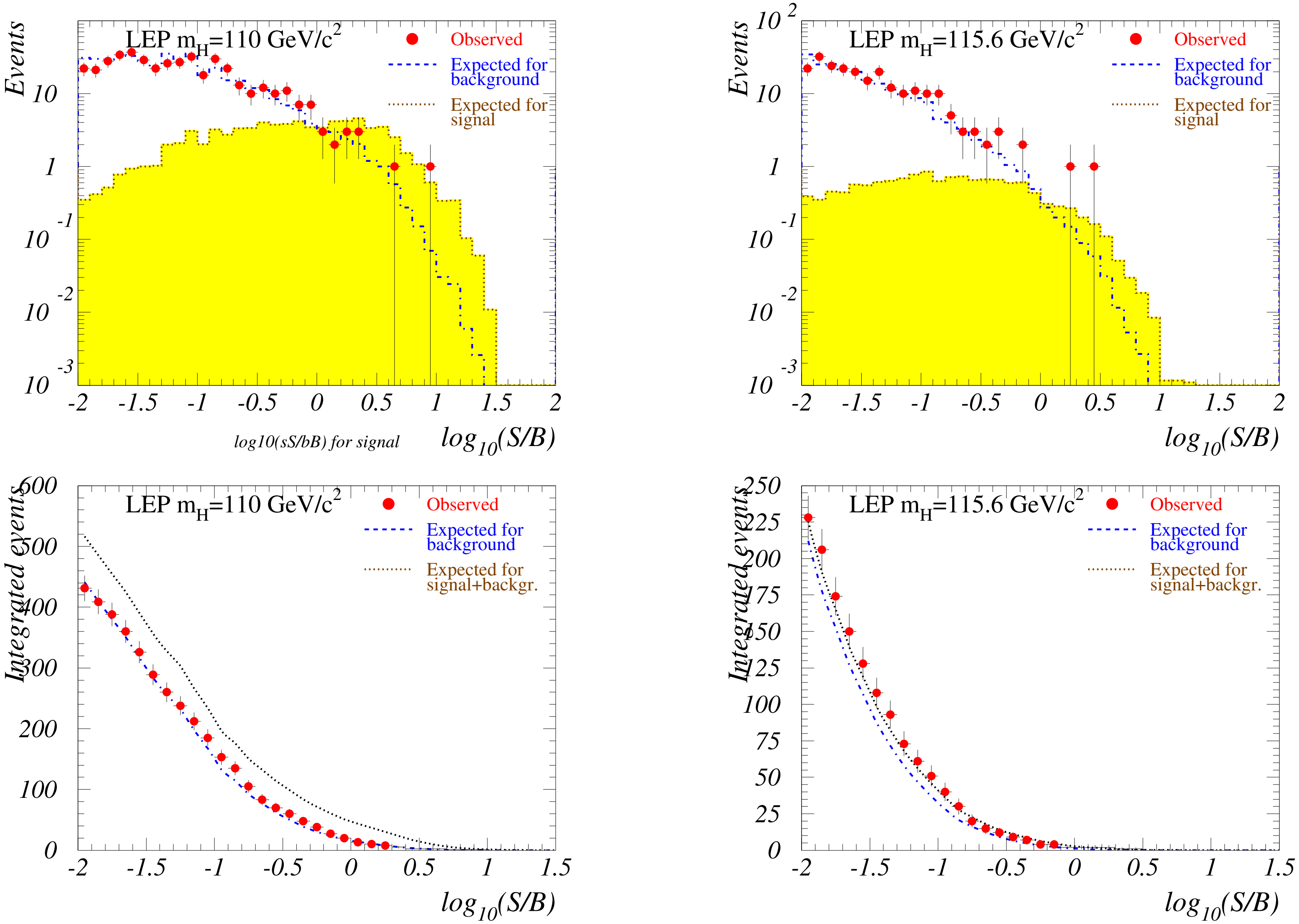
$m_h >$ 114.1 (115.4 exp.) GeV

A,D,L,O 1-CL_b



ALEPH
DELPHI
L3
OPAL
1-CLb
Observed
Expected for signal+background
Expected for background
Expected for test signal+background
2σ
3σ
4σ
mH(GeV/c2)

Event weight distributions: 110 / 115.6 GeV



Standard Model Higgs boson

- current LEP-combined result corresponds to 2.1σ excess over the background
- maximum likelihood occurs at

$$m_{\mathrm{h}} = 115.6 \text{ GeV}$$

- at the 95% CL:

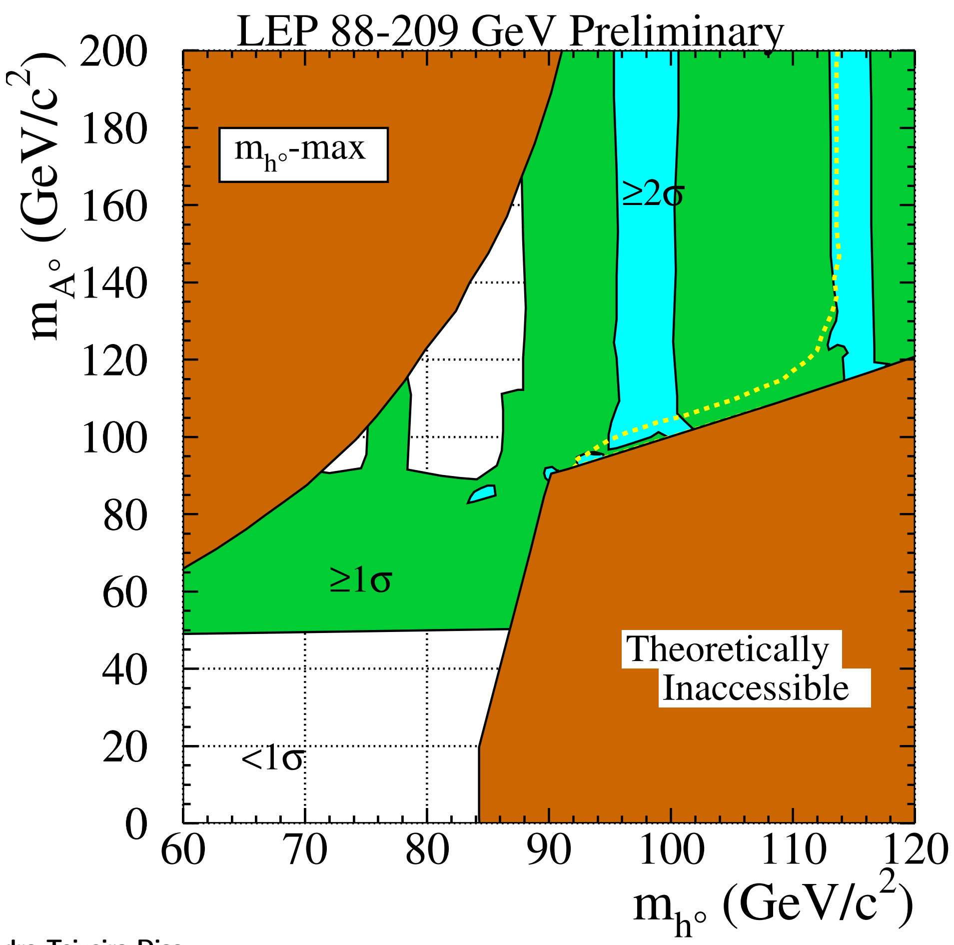
$$m_{\mathrm{h}} > 114.1 \text{ (115.4 exp.) GeV}$$

- 3 out of 4 experiments still have to publish their final results:

➜ Final combined results to appear towards the end of 2001.

MSSM: m_{h}-max benchmark

$1 - \mathsf{CL_b}$ in $(m_{\mathsf{h}}, m_{\mathsf{A}})$:



➜ $e^+e^- \rightarrow$ hA searches:

$\sim 2\sigma$ excess for

$(m_{\mathsf{h}}, m_{\mathsf{A}}) \approx$ (83,83), (93,93) GeV

➜ $e^+e^- \rightarrow$ hZ searches:

$\geq 2\sigma$ excess for

$m_{\mathsf{h}} =$ 97 & 115 GeV

excluded at 95% CL (- - -):

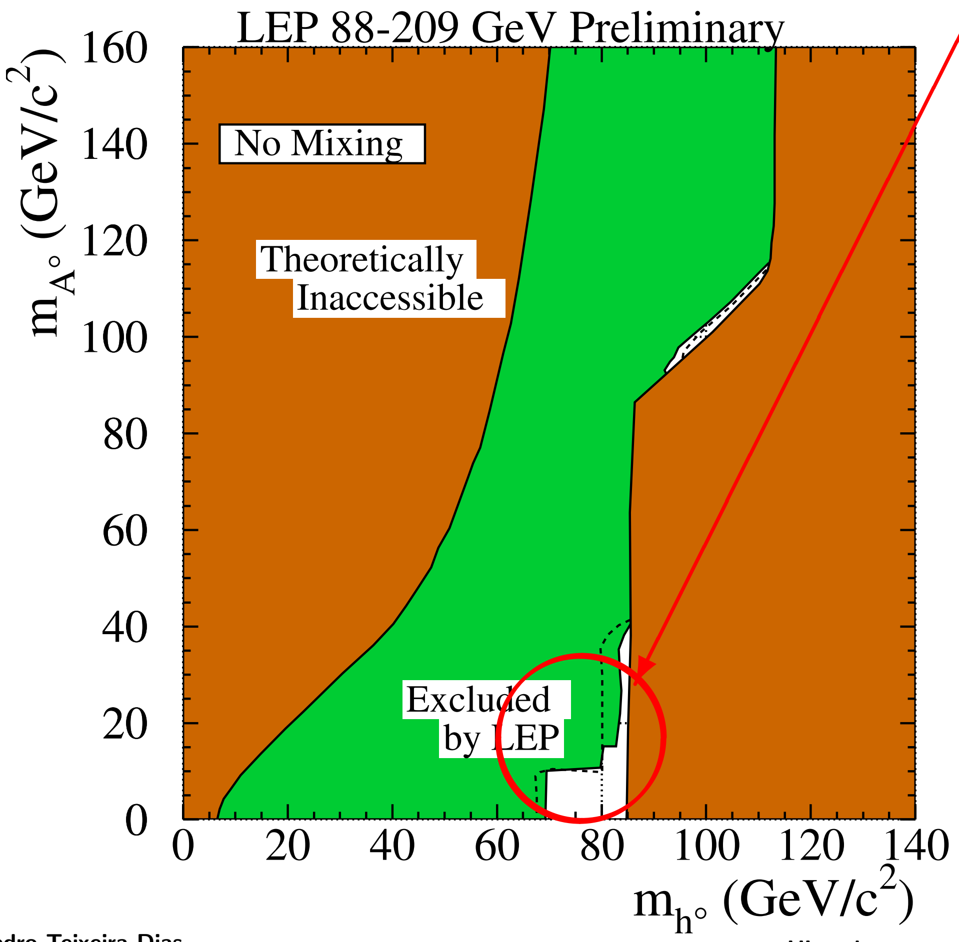
$m_{\mathsf{h}} <$ **91.0** (95.0 exp.) GeV

$m_{\mathsf{A}} <$ **91.9** (94.6 exp.) GeV

0.5 $< \tan\beta <$ **2.4**

MSSM: no-mixing benchmark

$(m_{\mathsf{h}}, m_{\mathsf{A}})$ **95% CL exclusion:**



- $e^+e^- \longrightarrow hZ \longrightarrow$ AAZ, **but no** A $\longrightarrow b\bar{b}$ **!**

  occurs for

  $\tan\beta <$ **0.7 &** $m_{\mathsf{H}^\pm} <$ **74 GeV**

- **Use** $\mathsf{H}^\pm$ **direct searches to exclude this ...?**

  ... but: $\mathsf{B}(\mathsf{H}^\pm \longrightarrow \mathsf{W}^\pm\mathsf{A}) \neq 0$

  $\Rightarrow$ **under investigation**

excluded at 95% CL (for $\tan\beta >$**0.7):**

$m_{\mathsf{h}} <$ **91.5 (95.0 exp.) GeV**

$m_{\mathsf{A}} <$ **92.2 (95.3 exp.) GeV**

0.7 $< \tan\beta <$ **10.5**

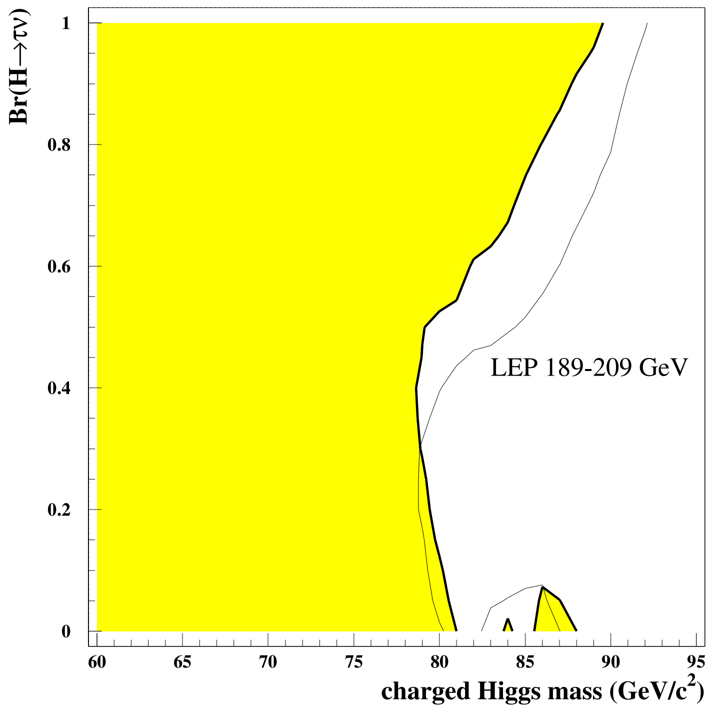
Charged Higgs, $H^{\pm}$

Assume $B(H^+ \to c\bar{s}) + B(H^+ \to \tau^+\nu) \doteq 1$

➜ $e^+e^- \to H^+H^- \to c\bar{s}s\bar{c},\ c\bar{s}\tau^-\bar{\nu},\ \tau^+\nu\tau^-\bar{\nu}$

- L3 observe a large excess in the 4-jets channel

➜ compatibility with ALEPH, DELPHI, OPAL is being investigated.



LEP combined search excludes (95%CL)

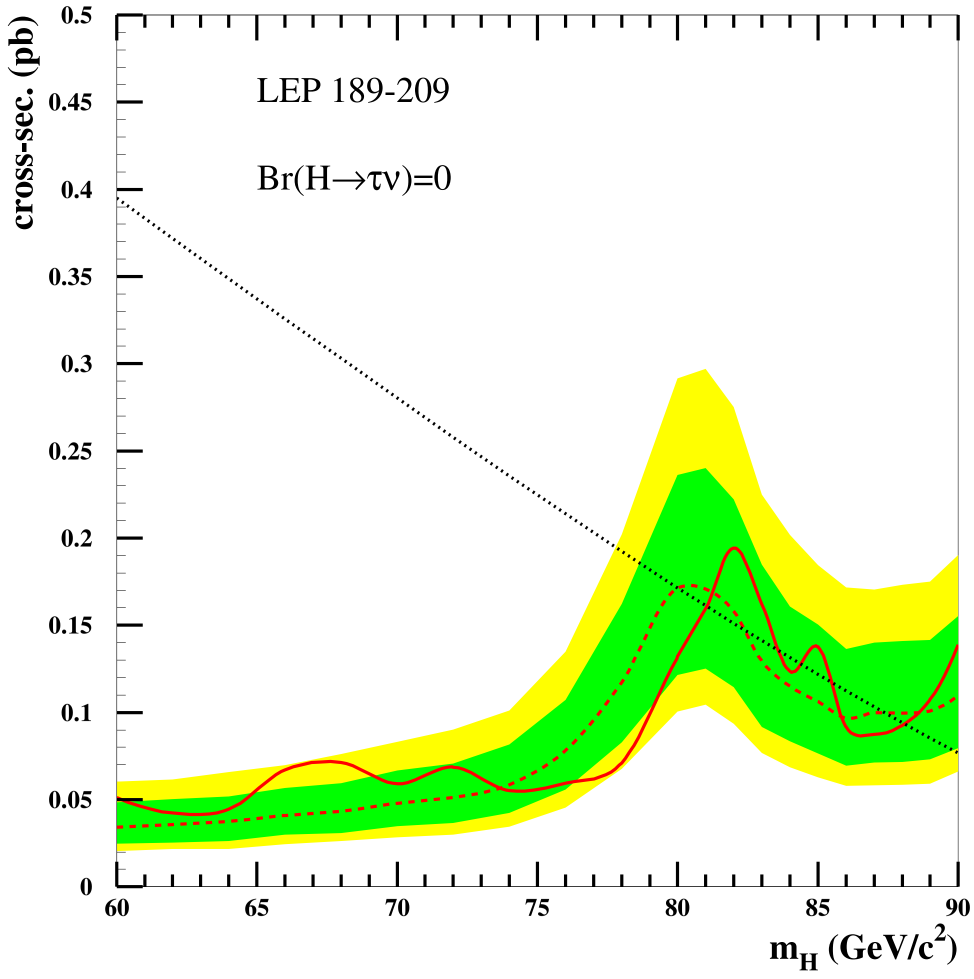
$m_{H^{\pm}} <$ 78.6 (78.8 exp.) GeV

for any $B(H^+ \to \tau^+\nu)$

Cross-section limits, $\mathrm{H}^{\pm}$

Upper bound on production cross-section,

for $\mathrm{B}(\mathrm{H}^+ \rightarrow \tau^+\nu = 0)$:



$\cdots$ **predicted cross-section for $\sqrt{s} = 206$ GeV**

Invisible Higgs

e.g., $\mathrm{h} \to \chi\chi$ $(\chi = \mathrm{LSP})$

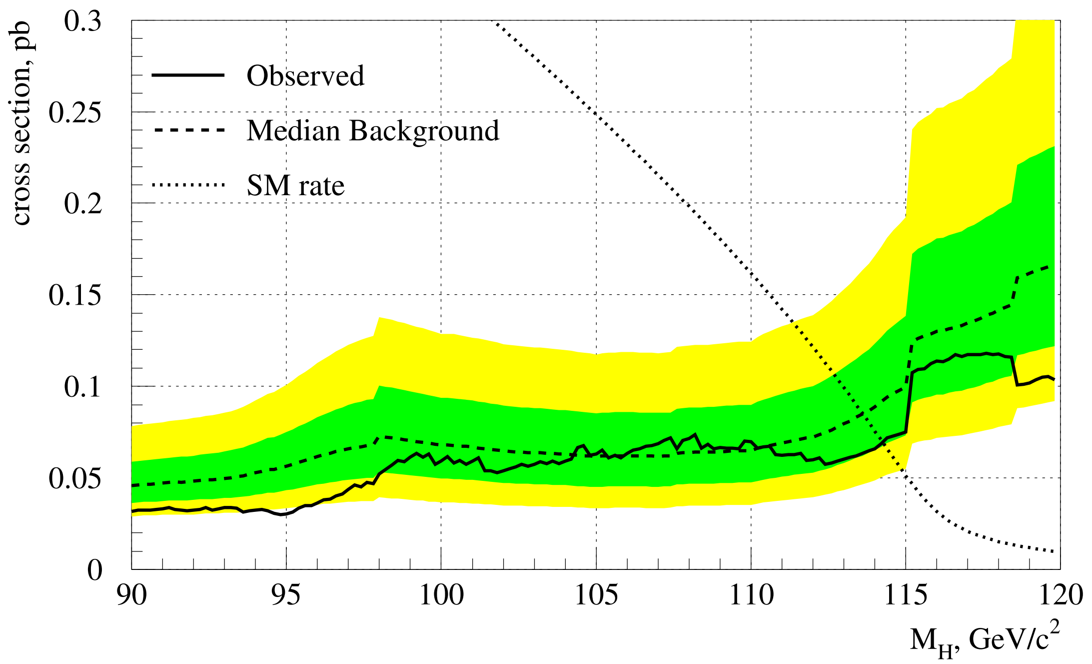
Search for $\mathrm{h} \to \mathrm{inv.} + \mathrm{Z} \to \mathrm{q\bar{q}},\ \ell^+\ell^-$:

- acoplanar jets / leptons

- $m_{\mathrm{h}} > 114.4$ (113.5 exp.) GeV

Upper bound on production cross-section:

(for SM Higgs σ, and $\mathrm{B(h \to inv.)}$=100%)

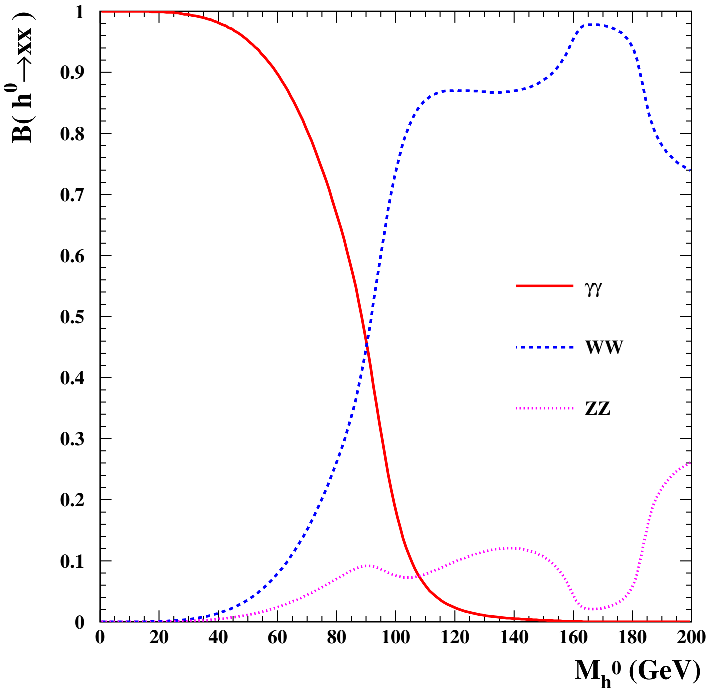


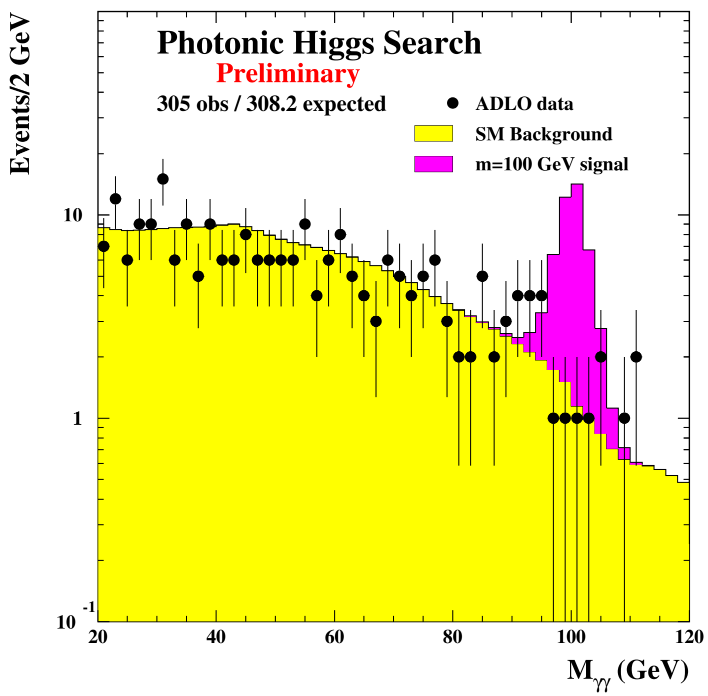
$\cdots$ predicted cross-section for $\sqrt{s} = 206$ GeV

Fermiophobic Higgs

$\mathrm{h} \not\to \mathrm{f\bar{f}}$; ✓ $\mathrm{h} \to \gamma\gamma,\ \mathrm{W^+W^-},\ \mathrm{ZZ}$

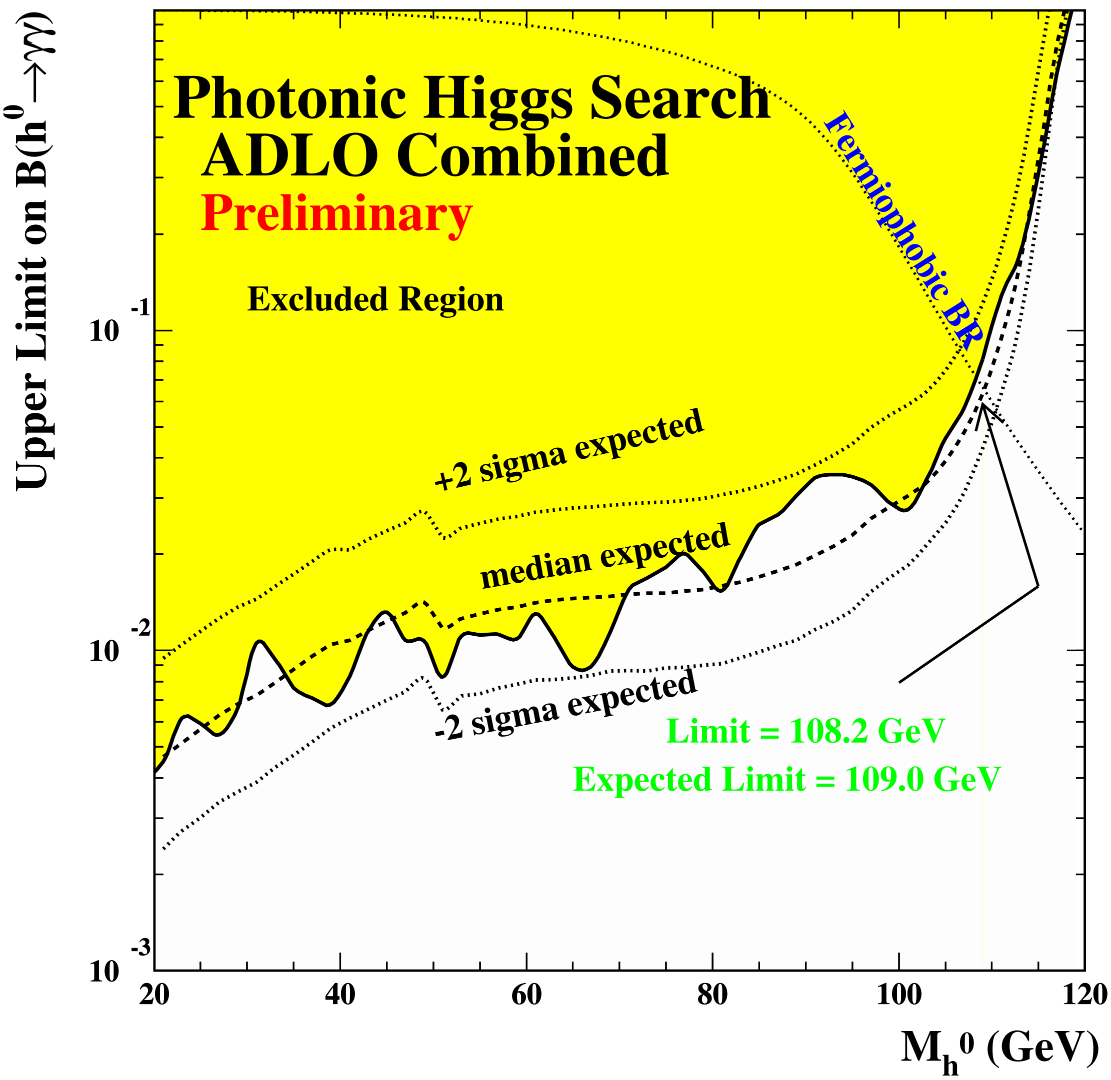
➜ <u>benchmark:</u> SM Higgs production rate





➜ only $\mathrm{h} \to \gamma\gamma$ searches included in this combined result

Fermiophobic Higgs



at the 95% CL:

- $m_{\mathsf{h}} >$ 108.2 (109.0 exp.) GeV
- $\mathsf{B}(\mathsf{h} \to \gamma\gamma) <$ 6%

Flavour-blind Higgs searches

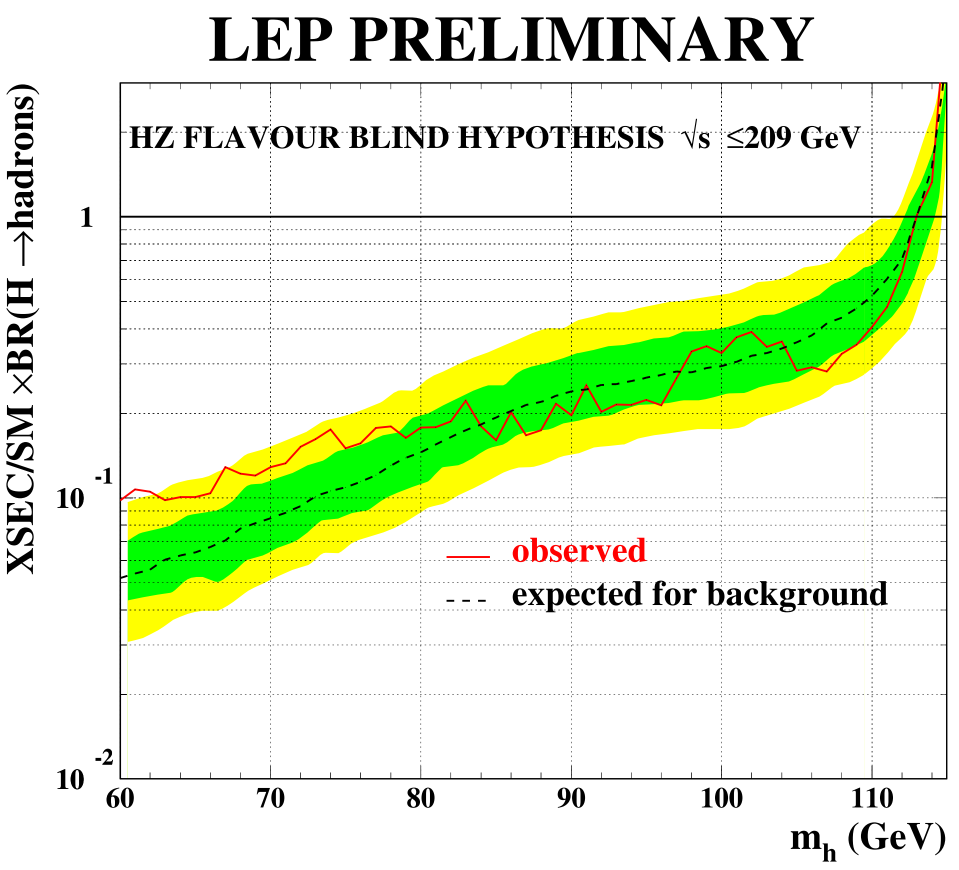
➜ $h \longrightarrow q\bar{q}$, gg

dedicated searches, not relying on b-tagging:

- improved sensitivity if supressed $h \longrightarrow b\bar{b}$
- less model-dependent search results

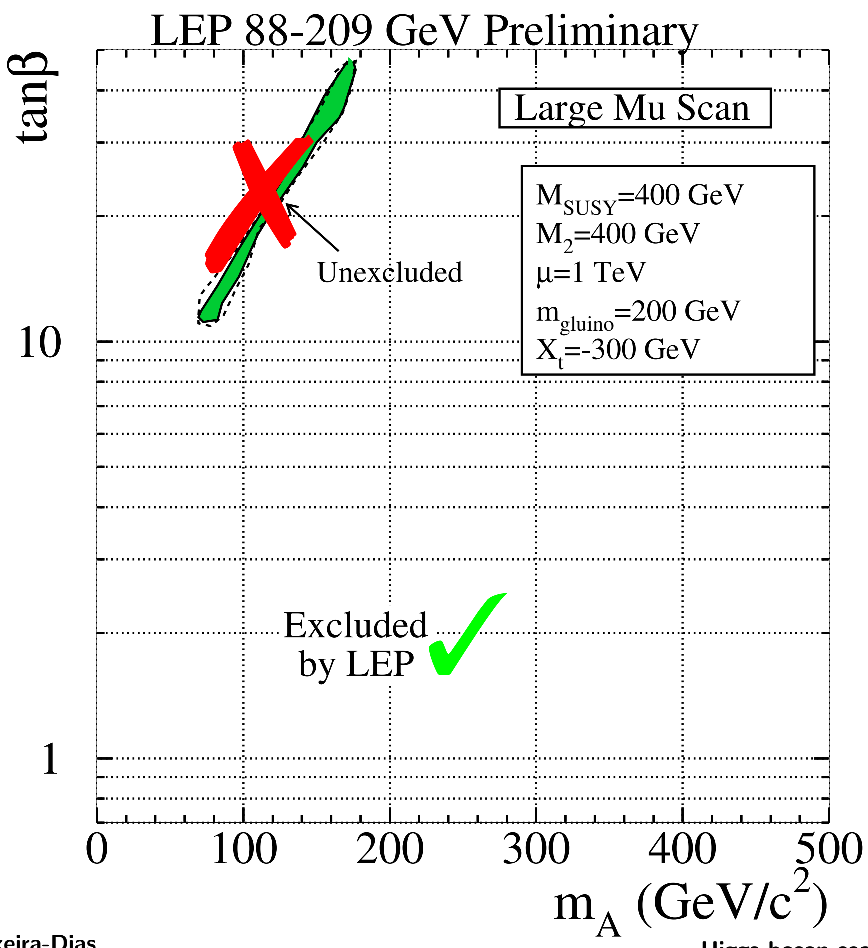
For SM Higgs σ and B(h →hadrons)=100%:

- $m_h >$ 112.9 (113.0 exp.) GeV



MSSM: large-μ benchmark

$(m_\mathrm{h}, \tan\beta)$ **plane:**



- **scenario designed to** **suppress** $\mathrm{h} \longrightarrow \mathrm{b\bar{b}}$
- **previous exclusion (at right) based only on** $\mathrm{h} \longrightarrow \mathrm{b\bar{b}},\ \tau^+\tau^-$
- **new flavour-independent searches** $\Rightarrow$ **cover** $\mathrm{h} \longrightarrow \mathrm{c\bar{c}}$ **&** $\mathrm{h} \longrightarrow$**gg**
- **All points excluded @ 95% CL !!**

LEP Higgs WG notes

Search for the Standard Model Higgs Boson at LEP

ALEPH, DELPHI, L3 and OPAL Collaborations

The LEP working group for Higgs boson searches

Searches for the Neutral Higgs Bosons of the MSSM: Preliminary Combined Results Using LEP Data Collected at Energies up to 209 GeV

Search for Charged Higgs bosons: Preliminary Combined Results Using LEP data

Searches for Invisible Higgs bosons: Preliminary combined results using LEP data collected at energies up to 209 GeV

Searches for Higgs Bosons Decaying into Photons: Preliminary Combined

Using LEP Data

Generalised search for hadronic decays of Higgs bosons at LEP-2

The LEP working group for Higgs boson searches

➜ will be available from

http://lephiggs.web.cern.ch/LEPHIGGS/www/Welcome.html