



EVIDENCE FOR THE HIGGS BOSON AT LEP

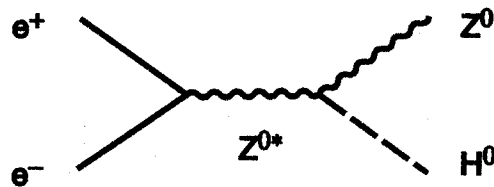
Neutrino Factory and Muon Collider Collaboration
Meeting
February 1-2, 2001

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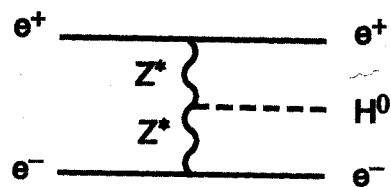
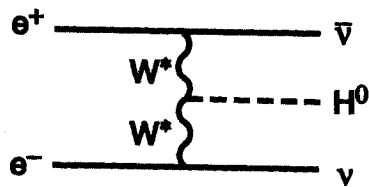
STANDARD MODEL HIGGS SEARCH

- Indirect information from fits to Z^0 line shape (plus other data). Radiative corrections $\propto \log(m_H)$.
- Direct searches at LEP:

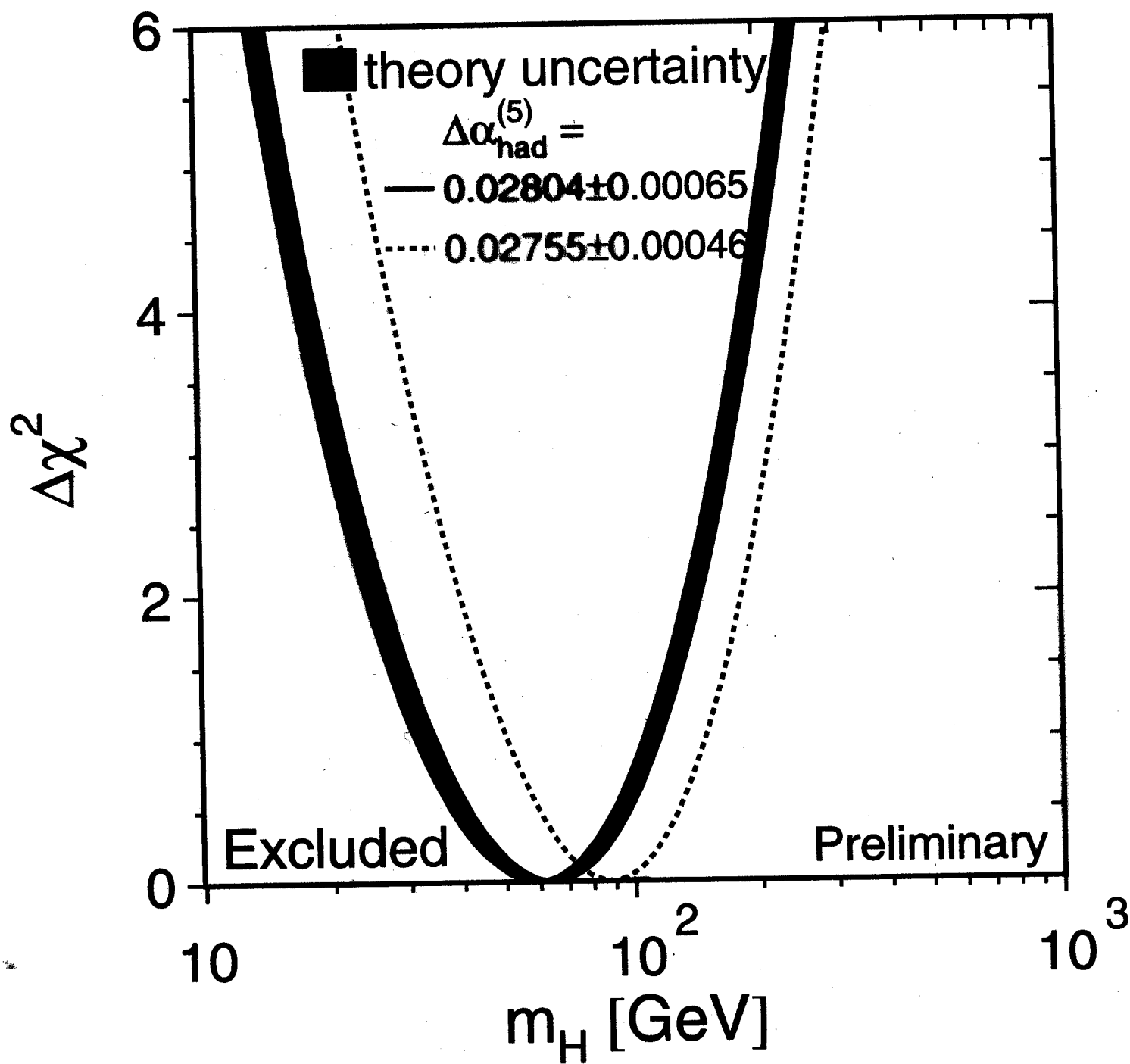
Production from Higgs-strahlung $e^+ e^- \rightarrow Z^0 H^0$



Plus small contribution from WW and ZZ fusion



$m_H < 170 \text{ GeV}, 95\% \text{ C.L.}$



STANDARD MODEL HIGGS SEARCH CHANNELS

- "Four Jet Channel:" $e^+e^- \rightarrow Z^0 H^0 \rightarrow q\bar{q}b\bar{b}$ (60%)
- "Missing Energy Channel:" $e^+e^- \rightarrow Z^0 H^0 \rightarrow \nu\bar{\nu}b\bar{b}$
(18% + W^+W^- fusion)
- "Tau Channel:" $e^+e^- \rightarrow Z^0 H^0 \rightarrow \tau^+\tau^-q\bar{q}$ (3%)
and $q\bar{q}\tau^+\tau^-$ (5.6%)
- "Electron and Muon Channels:" $e^+e^- \rightarrow Z^0 H^0 \rightarrow e^+e^-b\bar{b}$
and $\mu^+\mu^-b\bar{b}$ (6% + Z^0Z^0 fusion)

LEP2 RUNNING

LEP, the e^+e^- storage ring at CERN, began running above the Z^0 resonance in 1995-96 (LEP2).

October-November 1995: 130-140 GeV checkout run
(LEP1.5) ✓

1996: 161 GeV ($\sim 10 \text{ pb}^{-1}$) ✓
172 GeV ($\sim 10 \text{ pb}^{-1}$) ✓

1997: 183 GeV ($\sim 55 \text{ pb}^{-1}$) ✓

1998: 189 GeV ($\sim 175 \text{ pb}^{-1}$) ✓

1999: 192 GeV ($\sim 29 \text{ pb}^{-1}$) ✓
196 GeV ($\sim 78 \text{ pb}^{-1}$) ✓
200 GeV ($\sim 78 \text{ pb}^{-1}$) ✓
202 GeV ($\sim 38 \text{ pb}^{-1}$) ✓

2000: 200–209 GeV ($\sim 200 \text{ pb}^{-1}$) ✓
(Running in mini-ramp mode.)

THE END (!)

Primary physics goals:

Measurement of W boson mass with $\sim 40 \text{ MeV}$ error

Searches – Higgs boson, supersymmetric particles, etc.



OVERALL STATUS OF LEP STANDARD MODEL HIGGS SEARCH

September 5 LEPC:

ALEPH - 3 $e^+e^- \rightarrow HZ \rightarrow bbqq$ (four-jet) candidates
(background = 0.3 events) compatible with $m_H \sim 114$ GeV.

DELPHI - 1 $e^+e^- \rightarrow HZ \rightarrow bbqq$ candidate, also compatible with
 $m_H \sim 114$ GeV.

L3 and OPAL compatible with background only.

→ Extend end of LEP run for 1 month.

November 3 LEPC:

ALEPH - No new events. Still 3 $e^+e^- \rightarrow HZ \rightarrow bbqq$ (four-jet)
candidates.

DELPHI - The previously reported four-jet event did not pass b -
tagging after reprocessing. Compatible with background.

L3 - Reported new candidates in four-jet and missing-energy
channels.

OPAL - Reported new candidates in four-jet and missing-
energy channels.

EVOLUTION ... BY EXPERIMENT

(values quoted @ $m_H = 115$ GeV)

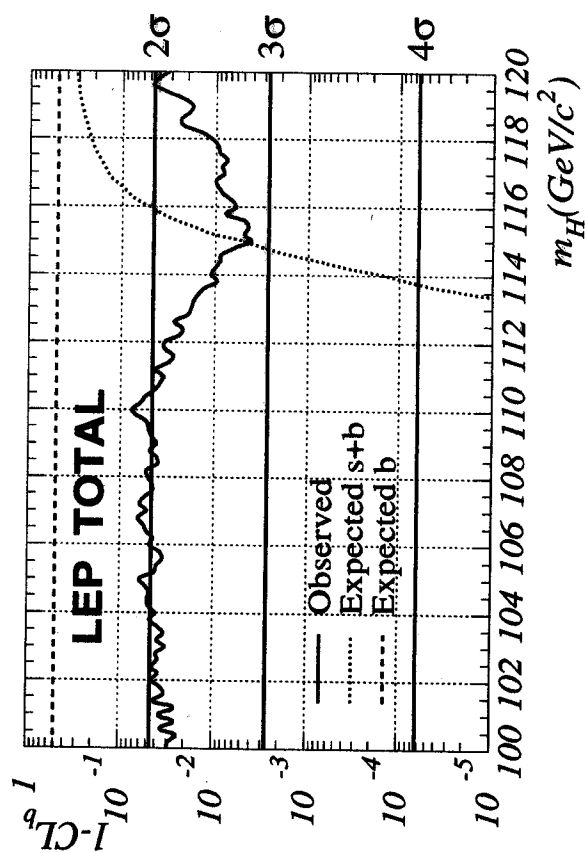
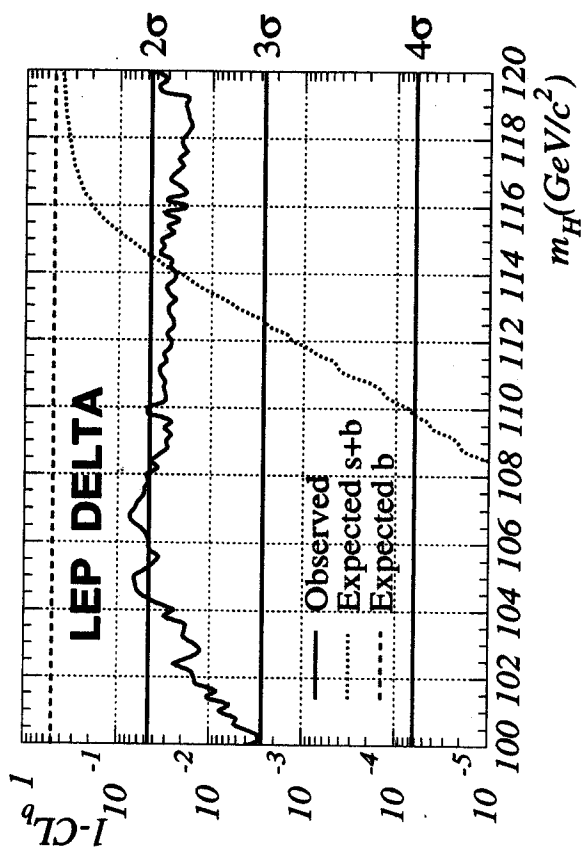
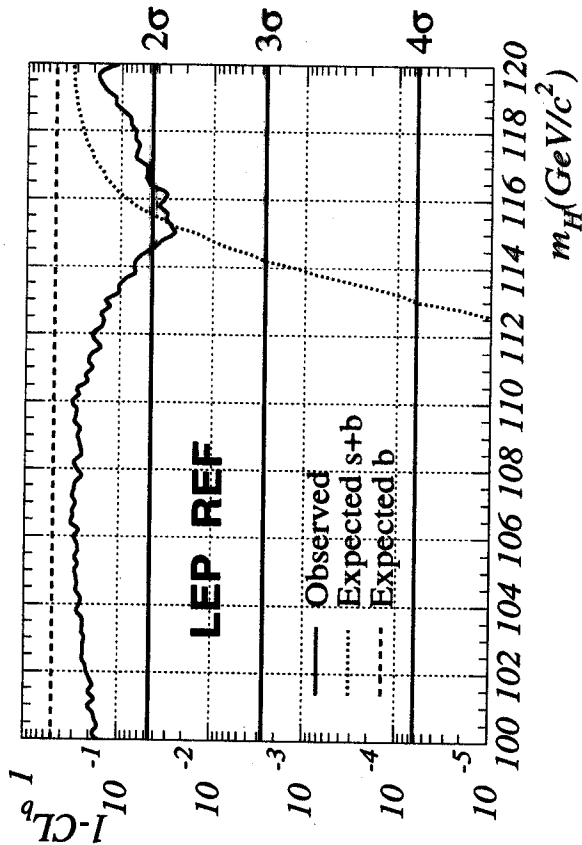
ALEPH	$1 - CL_b$	
REF	1.6×10^{-4}	3.8σ
DEL	0.43	bkgd-like
TOT	6.5×10^{-4}	3.4σ

DELPHI	$1 - CL_b$	
REF	0.67	bkgd-like
DEL	0.52	bkgd-like
TOT	0.68	bkgd-like

L3	$1 - CL_b$	
REF	0.84	bkgd-like
DEL	9.0×10^{-3}	2.6σ
TOT	6.8×10^{-2}	1.8σ

OPAL	$1 - CL_b$	
REF	0.47	bkgd-like
DEL	6.2×10^{-2}	1.9σ
TOT	1.9×10^{-1}	1.3σ

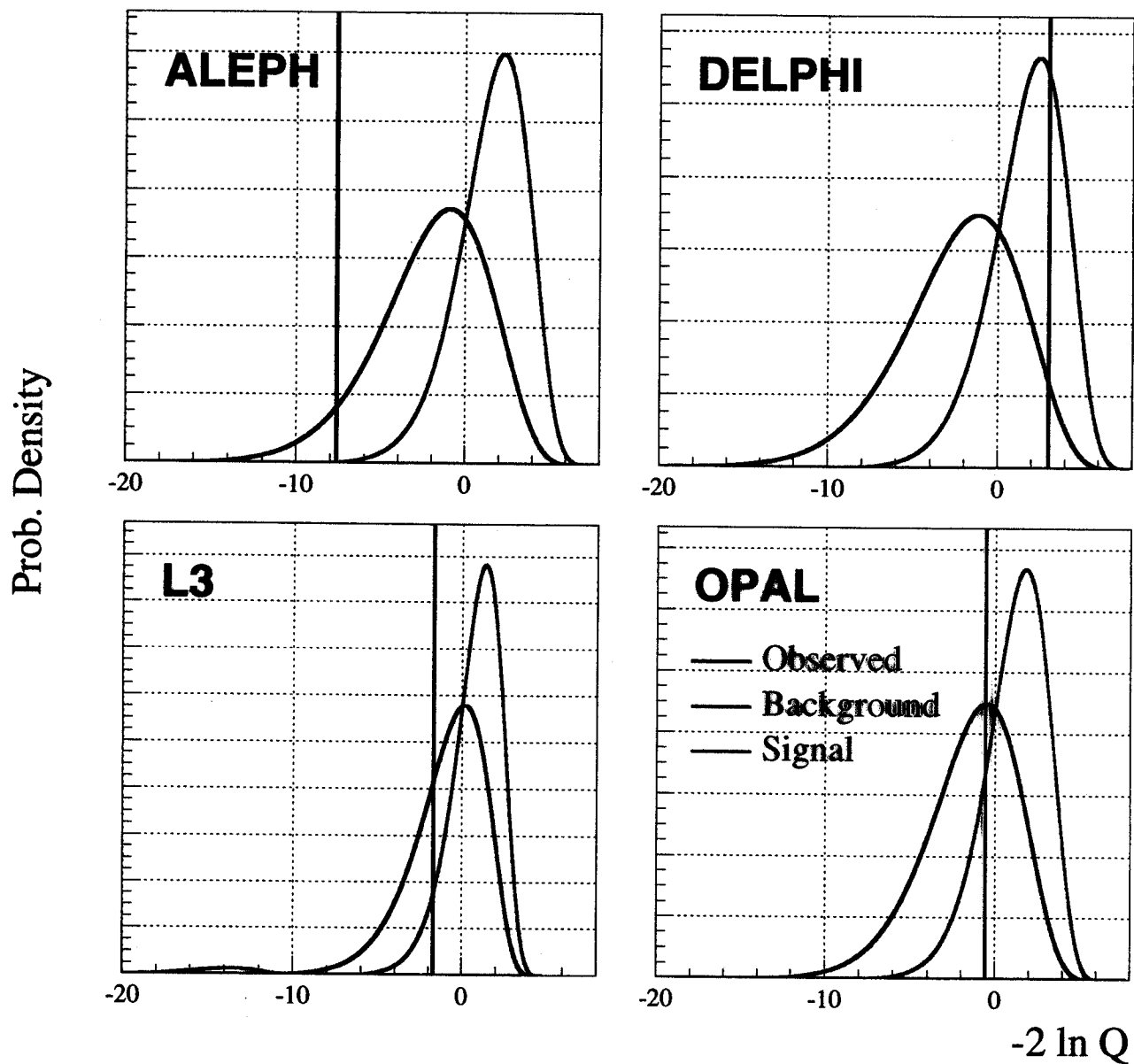
$1 - CL_b \dots \text{REF, DELTA, TOTAL}$



ADLO	$1 - CL_b$	
REF	2.5×10^{-2}	2.2σ
DEL	2.2×10^{-2}	2.3σ
TOT	4.2×10^{-3}	2.9σ

Results by Experiments

for TOTAL data set, @ $m_H = 115$ GeV



Finally, the increase of the observed significance obtained with the data samples analysed and presented at the four LEPC meetings held in 2000 (20-Jul, 5-Sept, 10-Oct and 3-Nov) is displayed in Fig. 4, in comparison with an online estimate of the significance expected in the signal-plus-background hypothesis [6]. This progressive and regular increase further demonstrates that the effect seen in the data does not result from an early statistical fluctuation, which would then have been reduced by the additional statistics.

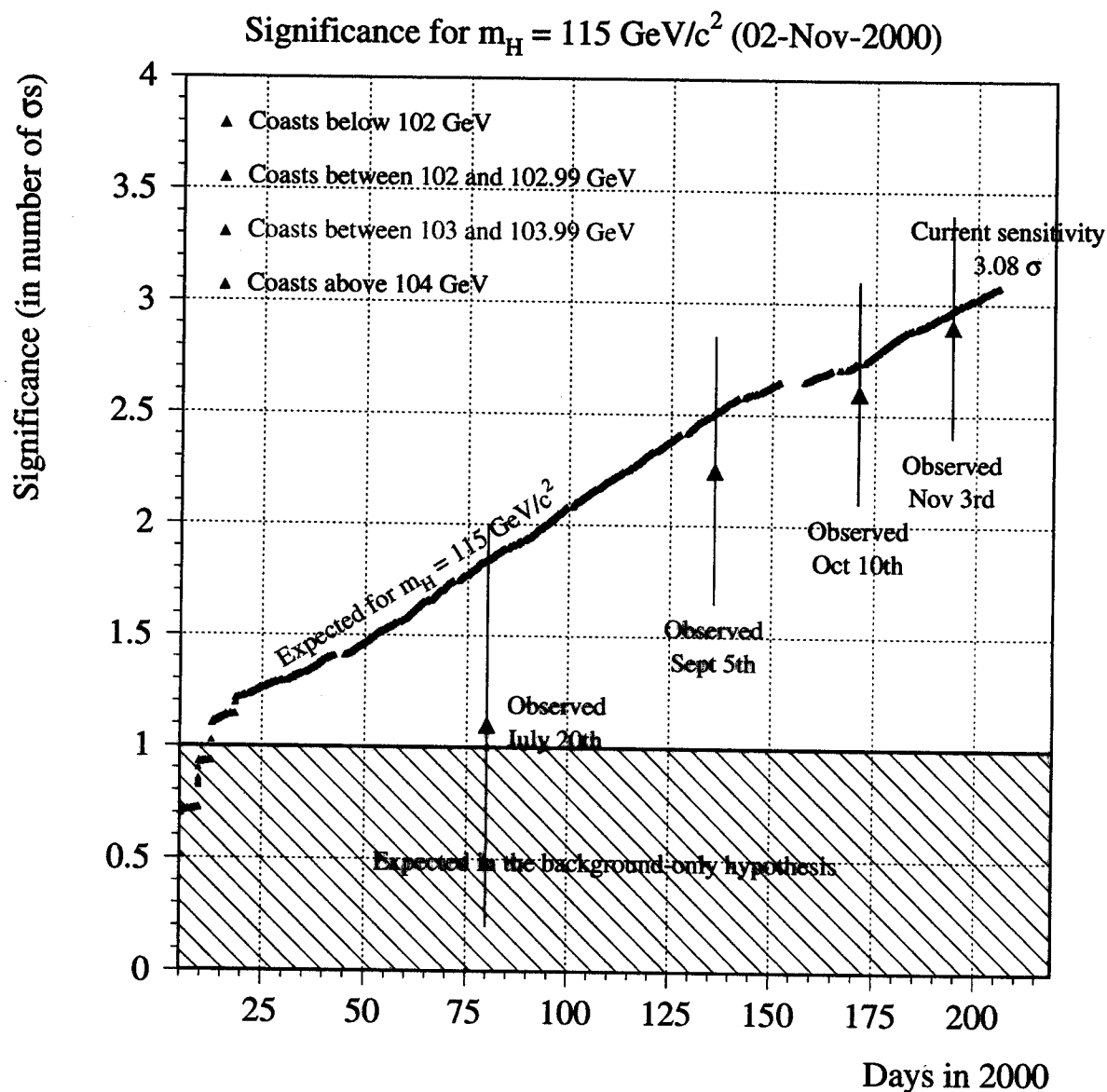


Figure 4: Increase of the observed combined significance at $m_H = 115 \text{ GeV}/c^2$ in 2000, compared with an online estimate of the significance expected in the signal-plus-background hypothesis. The error bars are statistical only, with large point-to-point correlation. Also indicated (hatched region) is the expectation in the background-only hypothesis.

NOVEMBER 3 LEPC MEETING (continued)

Combined LEP: 2.9 s.d. excess all channels, ADLO combined.

$$m_H = 115.0^{+1.3}_{-0.9} \text{ GeV (these are } 2 \sigma \text{ errors)}$$

$m_H > 113.5 \text{ GeV, 95\% C.L. (115.3 GeV expected).}$

NOVEMBER 3 LEPC MEETING (continued)

EXCITING!

Request was made for LEP run in 2001, to allow $\sim 200 \text{ pb}^{-1}$ per experiment at $E_{\text{cm}} > 208 \text{ GeV}$. This would allow a 5 s.d. discovery for $m_H = 115.0$. The increased energy was made possible by installing a newly refurbished superconducting rf module and by repairing weak cavities. It was estimated that 200 pb^{-1} per experiment would take conservatively about 6 months.

- The request was NOT approved.
- The LEP detectors were forced to dismantle.
- All four experiments have published.
- Next: publish combination.

LEP Jamboree February 27.

ii) What is the Higgs discovery potential if LEP operates in 2001?

Although the statistical significance would suggest a probability of only about 0.2% that the present excess is due to a background fluctuation, the committee considers the conservative likelihood of a Higgs near 115 GeV to be about "50/50" based on the present data. If there is indeed a Higgs at a mass of 115 GeV, then a 200 pb⁻¹ sample at 208 GeV is expected to lead to a 5.3 σ discovery. This would correspond to a signal of about 20 events (of which 2 may be lepton events, $H\bar{e}e/H\mu\mu$), and a background of 10 events. The committee noted that there is unfortunately no single channel that is background-free. If the Higgs mass is at the upper end of the present uncertainty, at 116 GeV, then the expected significance would be reduced to 4.3 σ (14 signal, 1.4 lepton and 7 background events) - and, with a downward fluctuation, could be as low as 3.8 σ . Therefore, even if the present events are due to a Higgs, there is roughly a 20% probability that its mass is too high for a 1-year extension to establish a discovery. In summary, the committee considers there are sizable prospects for a Higgs discovery if LEP operates in 2001.

In addition to these aspects, several other points were raised. It was recognised that the LHC is a superior machine for the Higgs and that LEP is operating at its very limit. On the other hand, LEP is well-placed to resolve the question of a Higgs near 115 GeV in the short term and, because of its low backgrounds, is the best machine to measure the HZZ coupling.

In conclusion, the committee finds the combined evidence for a Higgs near 115 GeV already to be quite significant and considers that there are sizable prospects for a major discovery to be made at LEP, but also a non-negligible risk that no definite conclusion would be reached. Therefore, considering only LEP and its operation costs, the committee considers that an extension in 2001 to collect 200 pb⁻¹ above 208 GeV would be justified. However the committee also recognises that an extension could have a serious impact on the LHC and, in view of this, there was no consensus to recommend an extension.

4. Next LEPC meeting

The date of the next meeting of the LEPC is Tuesday, 6 March 2001, and the presently-foreseen date for the LEPC in the remainder of 2001 is 13 November.

J. Kirkby