LEPC 15, Sept. 1998

Report from the LEP Higgs working group

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On behalf of the LEP Higgs wg

Outline:

- Reminder of last year results
- Combined limits up to $\sqrt{s} = 183$ GeV:
  - SM Higgs
  - MSSM Higgses
  - Charged Higgses (Very Preliminary)
- Towards discovery
- Future goals

Status up to last LEPC, Sept '97 (CERN-EP/98-046)

- Four methods are used to set up 'frequentistic' confidence levels:
  - Method A: Delphi Note 97–158 Phys 737
  - Method B: HEP-EX/ 9706016
  - Method C: HD–PY–96/05

  Based on the Gedanken experiments

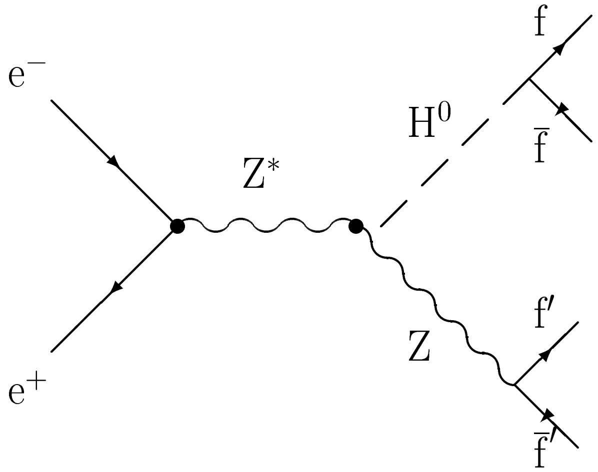
  - Method D: CERN–PPE/97–053

  Based on analytical calculation
- Equal performances (and continuously compared)
- Lower limit on the SM Higgs boson mass up to $\sqrt{s} = 172$ GeV (current PDG limit):

$$\boxed{m_{\mathrm{H}} > 77.5\ \mathrm{GeV\ at\ 95\%\ c.l.}}$$

SM Higgs boson

Dominant production process: Higgs–strahlung



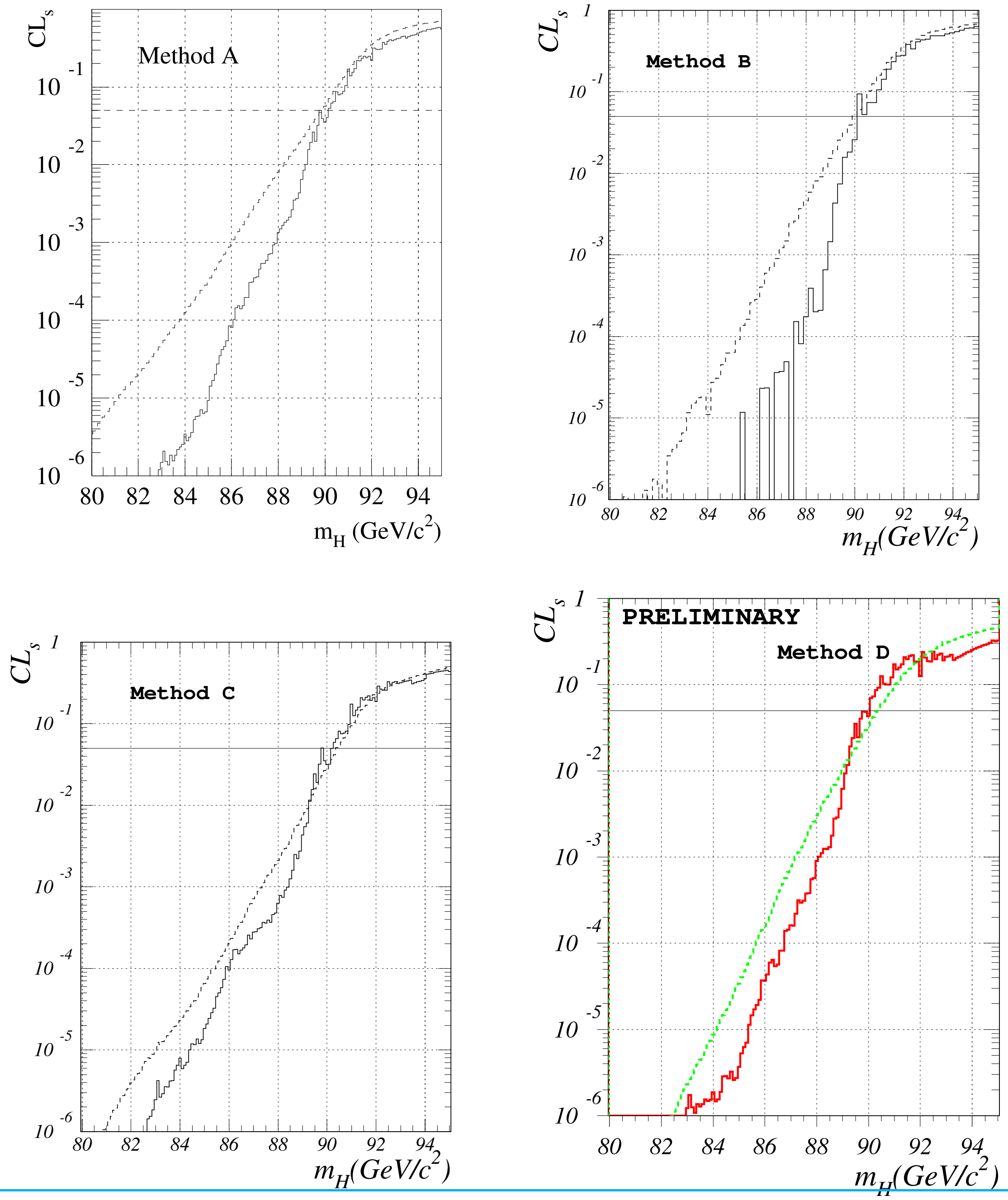
$H^0 \to b\bar{b}$ dominant (BR $\approx 84\%$)

- $H^0(\to b\bar{b})Z(\to q\bar{q}) \sim 60\%$
- $H^0(\to b\bar{b})Z(\to \nu\bar{\nu}) \sim 17\%$
- $H^0(\to b\bar{b})Z(\to \ell^+\ell^-)$ and $H^0(\to \tau^+\tau^-)Z(\to q\bar{q}) \sim 14\%$

Individual mass limits up to 183 GeV				
	A*	D*	L	O*
Obs. limit (GeV)	87.9	85.7	87.6	88.3
Exp. limit (GeV)	85.5	86.5	85.0	86.2

* Preliminary

SM Higgs LEP combined limit



LEP mass limit up to 183 GeV					
	A	B	C	D	Spread (GeV)
Obs. limit (GeV)	90.1	90.1	89.8	90.1	± 0.15
Exp. limit (GeV)	90.0	89.9	90.4	90.5	± 0.30

gain of $\sim 2 - 3$ GeV with respect to the individual results

$\boxed{m_{\mathrm{H}} > 89.8 \text{ GeV at } 95\% \text{ c.l.}}$

ICHEP98-Vancouver

Higgs sector in the MSSM

2 CP–even neutral Higgses	$\mathrm{h}^0, \mathrm{H}^0$	$m_\mathrm{h} < m_\mathrm{H}$
1 CP–odd neutral Higgs	A^0	
2 charged Higgses	$\mathrm{H}^\pm$	

MSSM tree–level mass relations:

$$m_\mathrm{h} < m_\mathrm{Z} < m_\mathrm{H}$$
$$m_{\mathrm{W}^\pm} < m_{\mathrm{H}^\pm}$$

Significately changed by radiative corrections:

$$\Delta m_\mathrm{h}^2 \sim \frac{m_\mathrm{top}^4}{m_\mathrm{W}^2} (\log \frac{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}{m_\mathrm{top}^4} + ..)$$

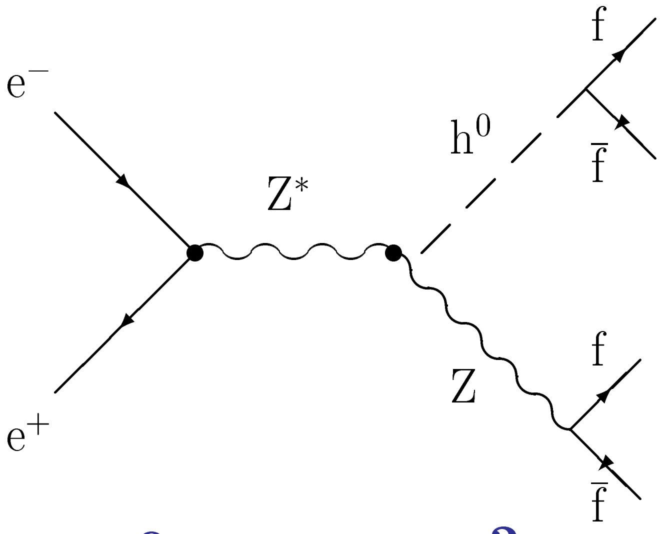
but still $m_\mathrm{h} \lesssim 130$ GeV for any MSSM parameter choice

Note strong dependence on m_top and $m_{\tilde{t}}$.

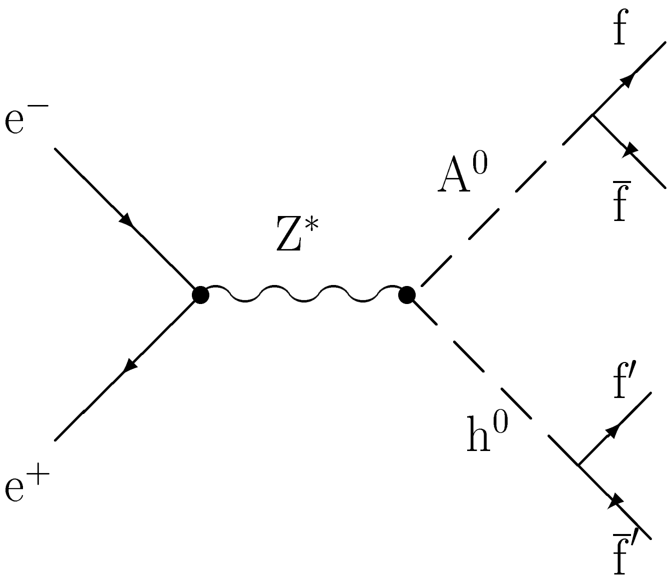
On the other side, still almost always:

$$m_{\mathrm{W}^\pm} \lesssim m_{\mathrm{H}^\pm}$$

Production mechanisms at LEP



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



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

$\overline{\lambda}$ = kinematic factor

Complementary processes!!!

Search Strategies:

- h^0Z similar to SM Higgs search for SM decays
- Dedicated h^0A^0 and $h^0(\rightarrow A^0A^0, \chi_1^0\chi_1^0)Z$ analyses

$\sqrt{s}$ (GeV)	Search channels
91	$hA\rightarrow AAA\rightarrow b\bar{b}b\bar{b}b\bar{b}$
	$hA\rightarrow q\bar{q}\tau^+\tau^-, \tau^+\tau^-q\bar{q}$
	$AAA\rightarrow 6\tau, 4q2\tau, 2q4\tau$
	$Zh\rightarrow \nu\bar{\nu}\ AA\rightarrow \nu\bar{\nu}\ 4q, \nu\bar{\nu}\ 2q2\tau, \nu\bar{\nu}\ 4\tau$
	$Zh\rightarrow\ q\bar{q}h(\rightarrow$invisible$)$
133	$hA\rightarrow b\bar{b}b\bar{b}$
	$AAA\rightarrow b\bar{b}b\bar{b}b\bar{b}$
161, 172	$hA\rightarrow b\bar{b}b\bar{b}$
	$hA\rightarrow q\bar{q}\tau^+\tau^-, \tau^+\tau^-q\bar{q}$
	$AAA\rightarrow b\bar{b}b\bar{b}b\bar{b}$
183	$hA\rightarrow b\bar{b}b\bar{b}$
	$hA\rightarrow b\bar{b}\tau^+\tau^-, \tau^+\tau^-b\bar{b}$
	$Zh\rightarrow\ q\bar{q}A(\rightarrow b\bar{b})A(\rightarrow b\bar{b})$
	$Zh\rightarrow\ \nu\bar{\nu}A(\rightarrow b\bar{b})A(\rightarrow b\bar{b})$
	$Zh\rightarrow\ \ell^+\ell^-A(\rightarrow b\bar{b})A(\rightarrow b\bar{b})$

Theoretical interpretation
(LEP2 workshop benchmarks)

Assumed unification of

- **squark masses ($M_{\rm SUSY}$) at the EW scale**
- **squark tri–linear couplings (A) at the EW scale**

Free parameters: ($m_{\rm A}$, $\tan\beta$, μ, $M_{\rm SUSY}$, A)

- **Benchmark scans:**
  $M_{\rm SUSY}$ = 1 TeV, $m_{\rm top} \sim$ 175 GeV
  Variation of $m_{\rm A}$ up to 1 TeV
  and $\tan\beta$ up to 50
  - minimal squark mixing:
    A=0 TeV, μ =-0.1 TeV
  - maximal squark mixing:
    A=$\sqrt{6}$ TeV, μ = -0.1 TeV

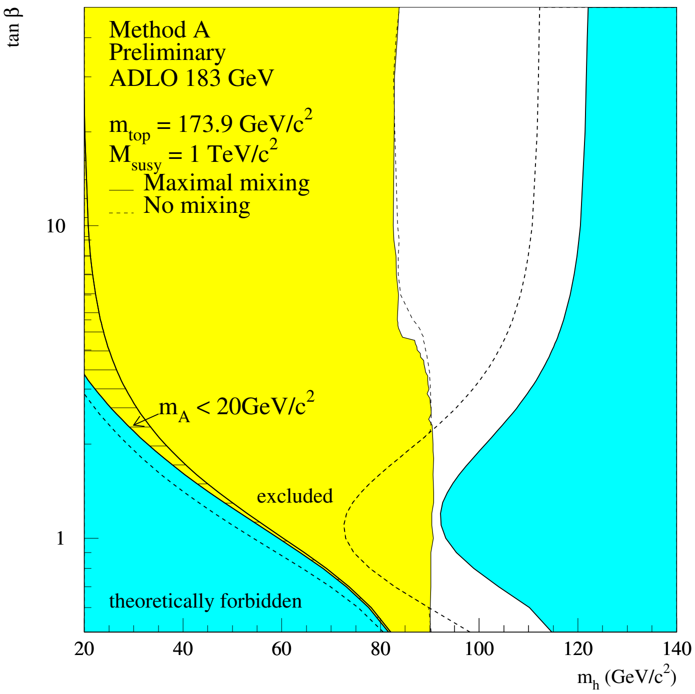
Individual mass limits (GeV)

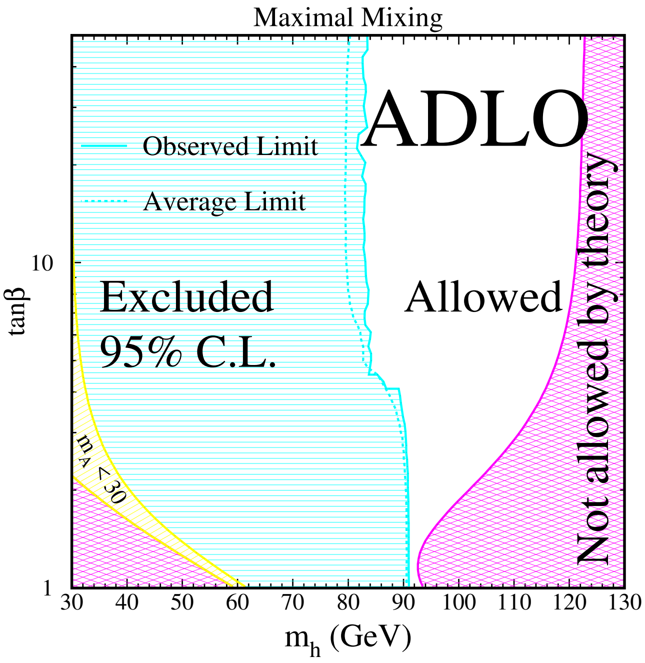
up to $\sqrt{s}$ =183 GeV

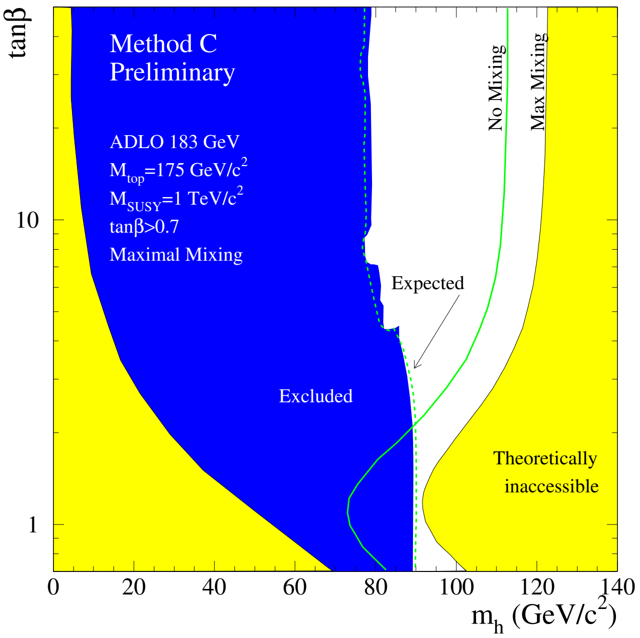
	A*	D*	L	O*
h^0 Obs. limit	72.2	74.4	70.7	70.5
h^0 Exp. limit	69.0	70.3	68.2	67.4
A^0 Obs. limit	76.1	75.3	71.0	72.0
A^0 Exp. limit	72.0	70.9	68.8	68.4

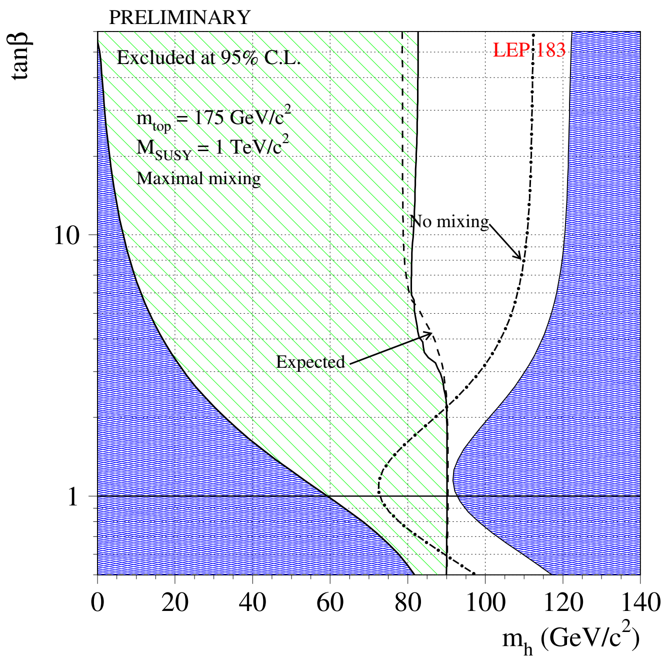
* Preliminary

LEP combined results up to 183 GeV

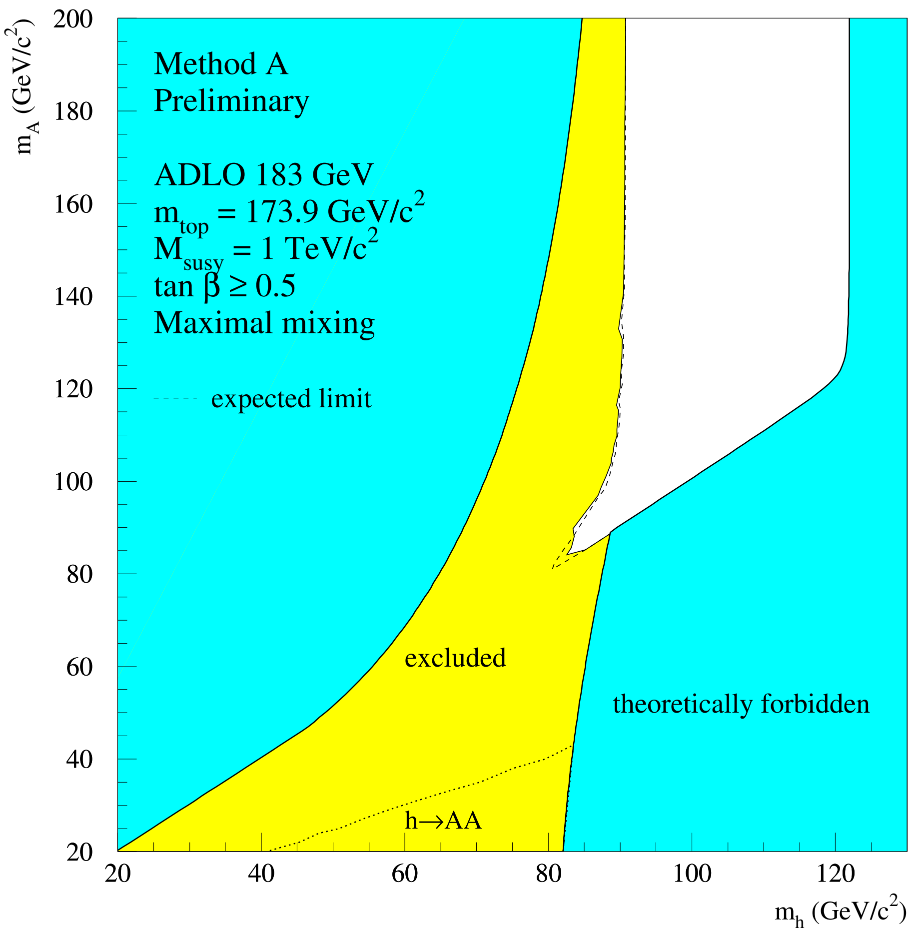








No Mixing: Excluded $0.8 \lesssim \tan\beta \lesssim 2.1$



LEP mass limit up to 183 GeV (Preliminary)

	A	B	C	D	Spread
h^0 Obs. limit	82.6	81.9	78.8	80.5	±1.9
h^0 Exp. limit	80.5	79.4	76.3	79.0	±2.1
A^0 Obs. limit	82.9	81.6	79.1	82.6	±1.9
A^0 Exp. limit	80.9	79.8	76.3	79.0	±2.3

Gain of about 10 GeV wrt the individual experiments

$$m_h > 78.8 \text{ GeV}, m_A > 79.1 \text{ GeV}$$

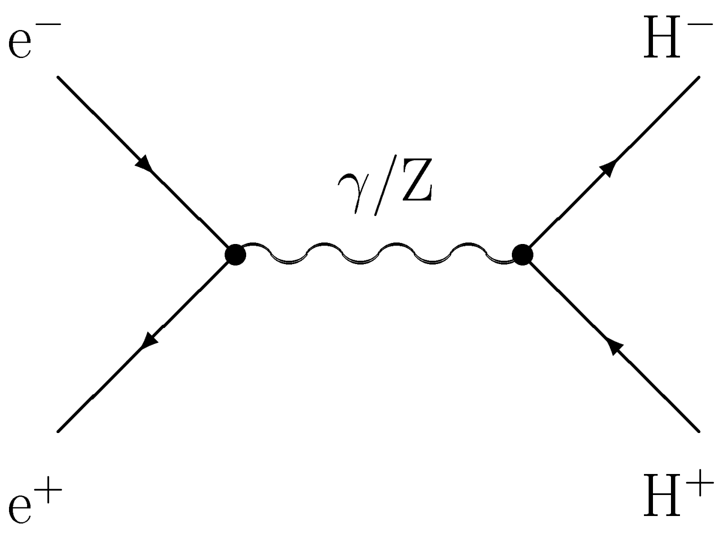
Progress with respect to ICHEP98-Vancouver

Charged Higgs bosons

MSSM: too high mass to be produced at LEP for almost all sets of MSSM parameters

General two doublet Higgs model: charged Higgs boson mass is a free parameter

Production process: $e^+e^- \rightarrow H^+H^-$



Cross section depends only on $m_{H^\pm}$ not on $\tan\beta$

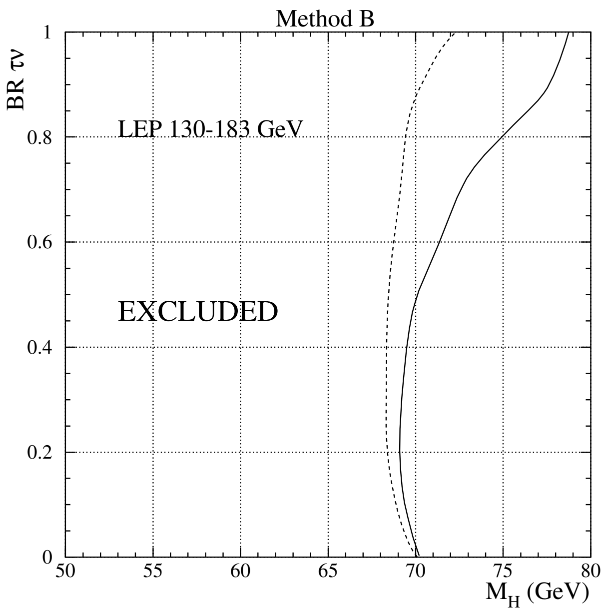
Assuming BR($H^{\pm} \rightarrow \tau\nu$)+BR($H^{\pm} \rightarrow cs$)=1,
the following final states are investigated:

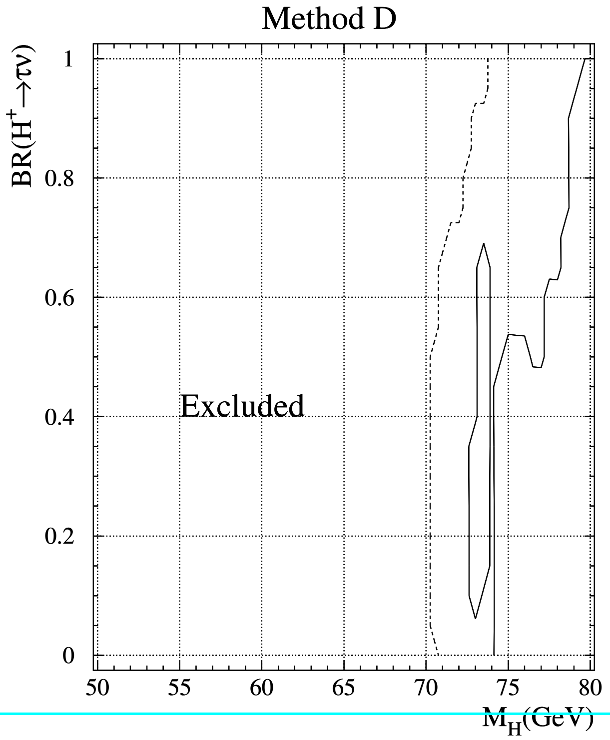
- Hadronic: $e^+e^- \rightarrow H^+H^- \rightarrow cscs$
- Semileptonic: $e^+e^- \rightarrow H^+H^- \rightarrow \tau\nu cs$
- Leptonic: $e^+e^- \rightarrow H^+H^- \rightarrow \tau\nu\tau\nu$

Individual mass limits up to 183 GeV				
	A*	D*	L*	O*
Obs. limit (GeV)	59	56.6	57.5	59
Exp. limit (GeV)	57	56.0	58.8	62

* Preliminary

Very preliminary combined results

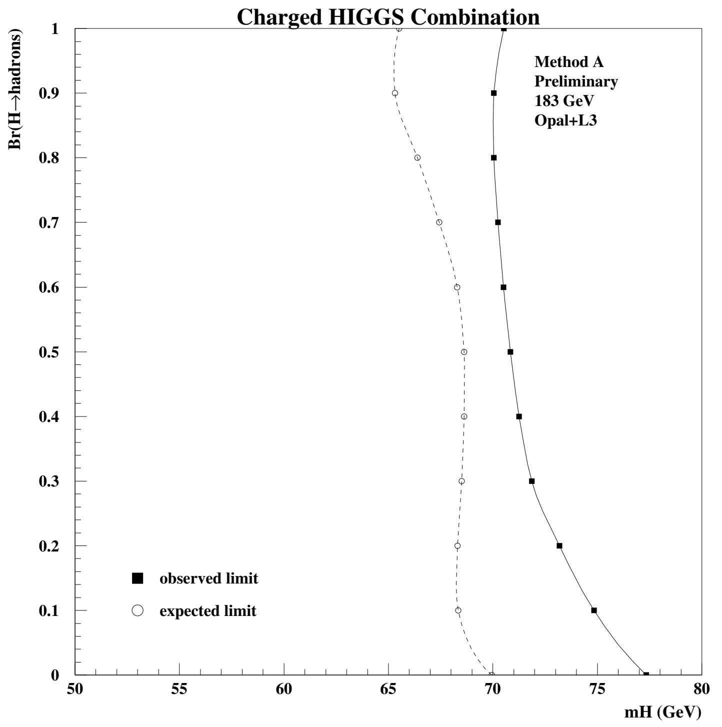




LEP mass limit up to 183 GeV			
	B	D	Spread (GeV)
Obs. limit (GeV)	68	72	± 2
Exp. limit (GeV)	69	70	± 0.5

Gain of about 10–15 GeV wrt the individual experiments

Combination is under–way for the other methods: for example method A



Extension of statistical methods to discovery

$$\mathrm{CL_s} = \frac{\mathrm{CL_{s+b}}}{\mathrm{CL_b}} = \frac{\mathrm{P(X_{s+b} < X_{obs})}}{\mathrm{P(X_b < X_{obs})}}$$

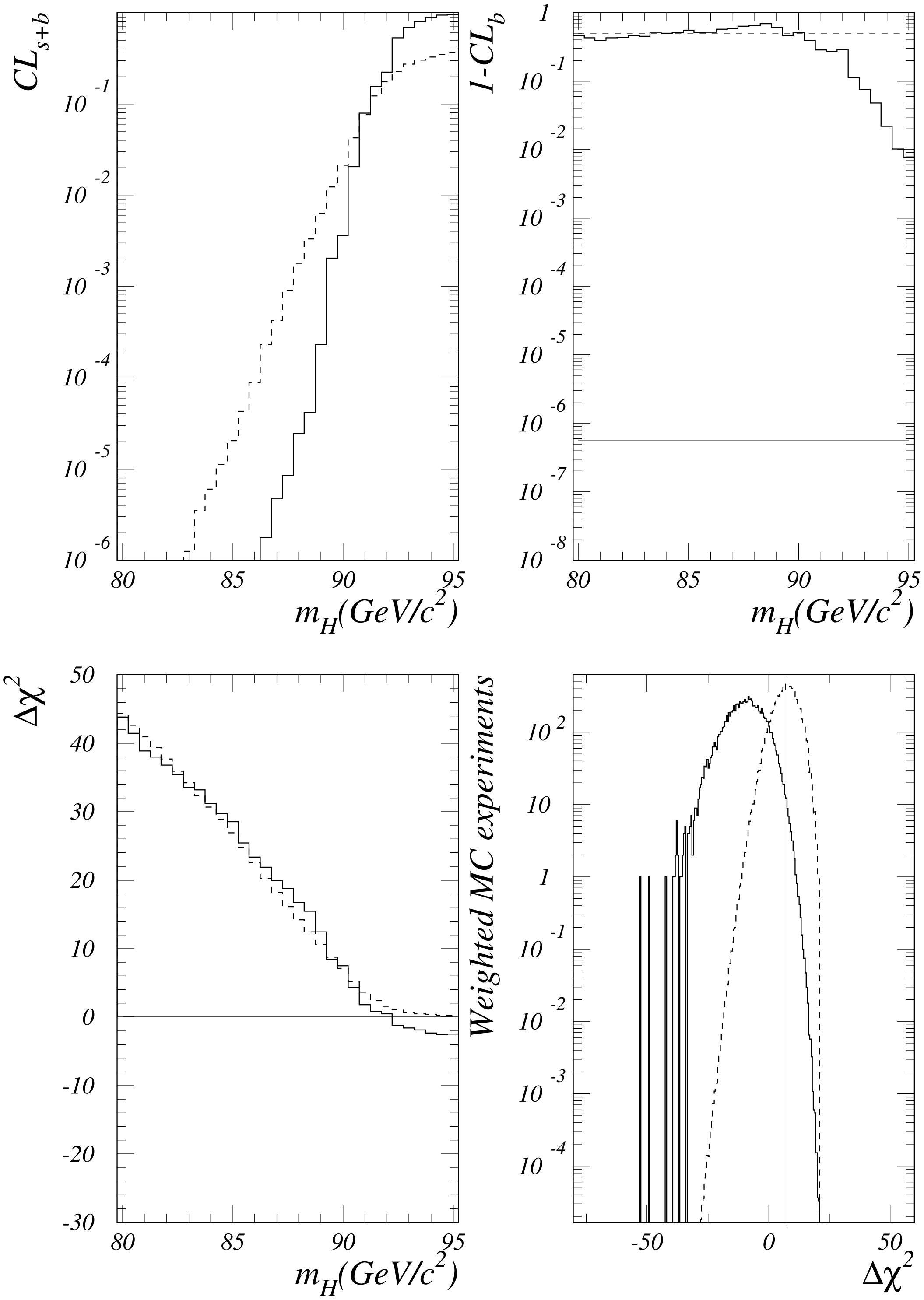
- **Discovery threshold is (commonly) set when the probability that a background fluctuaction can account for the observation is less then the probability corresponding to a 5σ gaussian flucuaction (i.e. $\mathrm{CL_b} > 1 - 5.7 * 10^{-7}$)**

- **The mass of discovery is defined as the mass corresponding to the highest value of the test–statistic**

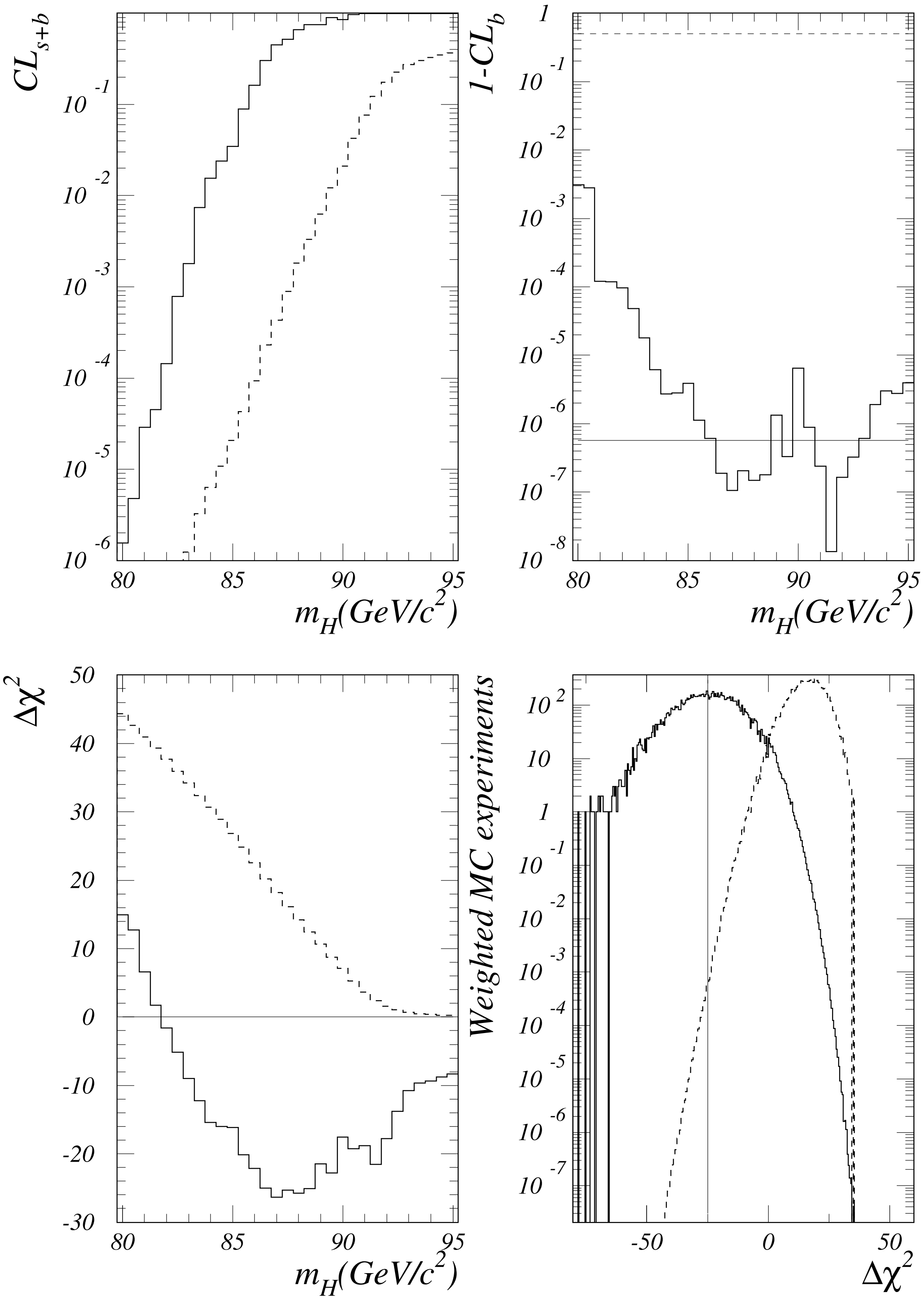
- **Expressing the c.l. of discovery means to look everywhere in the mass region to take into account possible background fluctuactions at mass values other than the discovery mass. Using confidence levels "for exclusion" leads to an somewhat optimistic (but correctable) approach to the discovery result**

An example from method A: real data up to $\sqrt{s}$ = 183 GeV

$$\mathrm{CL_s} = \frac{\mathrm{CL_{s+b}}}{\mathrm{CL_b}} = \frac{\mathrm{P(X_{s+b} < X_{obs})}}{\mathrm{P(X_b < X_{obs})}}$$



Fake experiment with m_h = 87.5 GeV

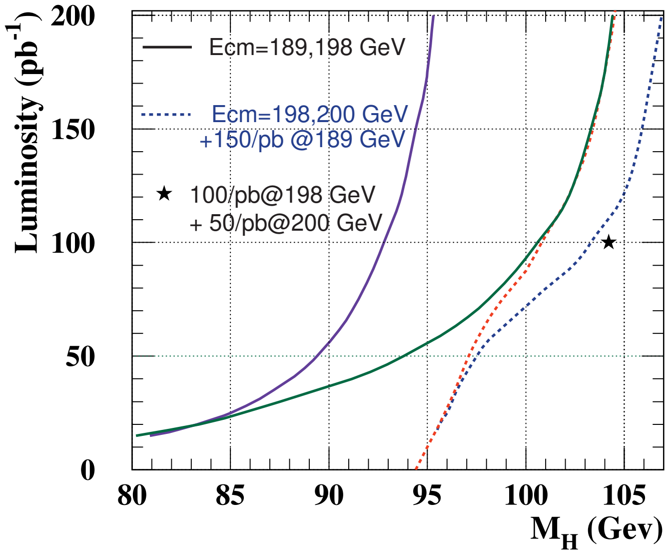


Method A, prospects for SM Higgs boson

at $\sqrt{s} = 189 - 200$ GeV

E.Gross, A.L.Read, D.Lellouch, CERN–EP/98–094

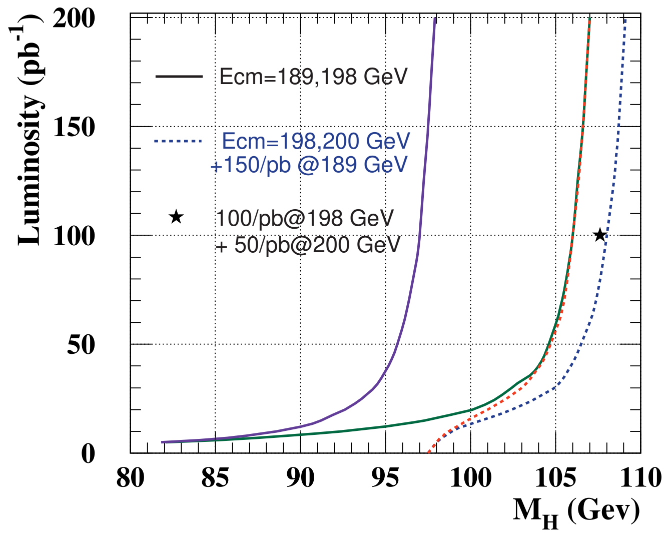
Discovery case



$$150\text{pb}^{-1}/\text{exp}@189\text{GeV} \rightarrow 94.5\text{GeV}$$

$$+100\text{pb}^{-1}/\text{exp}@198\text{GeV} + 50\text{pb}^{-1}/\text{exp}@200\text{GeV} \rightarrow 104.2\text{GeV}$$

Exclusion case



$$150\text{pb}^{-1}/\text{exp}@189\text{GeV} \rightarrow 97.5\text{GeV}$$

$$+100\text{pb}^{-1}/\text{exp}@198\text{GeV} + 50\text{pb}^{-1}/\text{exp}@200\text{GeV} \rightarrow 107.6\text{GeV}$$

Future goals

- SM: “combination is stable”, waiting final results from Collaborations
- MSSM: working on
  - understanding the “spreads”
  - wider MSSM parameters scan
  - interpretation of results in 2HDM
- Charged Higgs: working on understanding inputs
- Develop strategies for discovery

Time scale

- Finalize results at 183 GeV as soon as published by the Collaborations and inputs/spreads are understood
- Combine results up to $\sqrt{s} = 189$ GeV when preliminary results for all the sample are given by the Collaborations

Combined results up to $\sqrt{s} = 183$ GeV

- **SM Higgs boson:**
  $m_{\mathrm{H}^0} > 89.8$ **GeV (ICHEP98–Vancouver)**
- **MSSM Higgs bosons (preliminary):**
  $m_{\mathrm{h}} > 78.8$ **GeV,** $m_{\mathrm{A}} > 79.1$ **GeV**
  (progress with respect to ICHEP98)
- **Charged Higgs bosons:**
  first look to combined results

Acknowledgements

The LEP working group for Higgs boson searches wishes to thank the four LEP Collaborations for having provided experimental inputs