Status and Perspectives of LEP Searches for the Higgs Boson(s)

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Including results from LEP Collaborations:

ALEPH DELPHI L3 OPAL

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"BEYOND the DESERT"
Accelerator, Non-Accelerator and Space Approaches into the Next Millennium

Outline

- Overview on the SM and MSSM Higgs Boson(s)

- SM and MSSM Higgs Boson(s)
  - Main channels
  - Search topologies and analysis procedures
  - Higgs Boson(s) results:
    - LEP combined at $\sqrt{s} = 183$ GeV
    - Experiments at $\sqrt{s} = 189$ GeV

- LEP prospects for SM Higgs Bosons

- Summary and conclusions.

Theory Higgs Boson(s)

- Higgs Boson searches prominent position at

  LEP (e^+e^- collider)

- Dominant models:

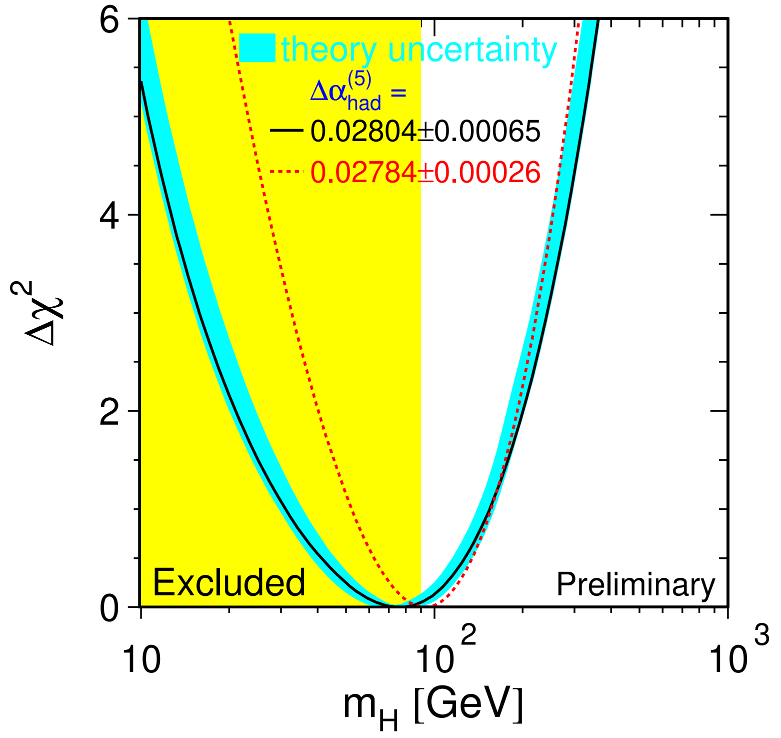
Standard Model: SM	Minimal Supersymmetric Standard Model: MSSM
H^0	h^0, H^0(CP–Even) A^0(CP-odd) $H^\pm$

ALEPH,DELPHI,L3,OPAL

Running Period	$\sqrt{s}$ GeV	Luminosity pb^{-1} per experiment
1989–1995	$\sim m_Z$	$\sim$ 160
1995+1997	130, 136	$\sim$ 12
1996	161, 172	$\sim$ 20
1997	183	$\sim$ 60
1998	189	$\sim$ 180
1999	192, 196, 200	$\sim$ 150 (?)
2000	$\sim$ 200	$\sim$ 200 (?)

Theory SM Higgs Bosons

- Estimate of the Higgs mass from electroweak data $\longrightarrow$ in favour of a light Higgs.



- High–precision measurements sensitive to Higgs mass via $\mathrm{Log}(m_H)$ terms in radiative corrections:

$$m_H = 76^{+79}_{-43}\ \mathbf{GeV/c^2}$$

(central value at a 68 % CL)

- Present upper 95 % CL limit on the Higgs mass in SM, no direct search included:

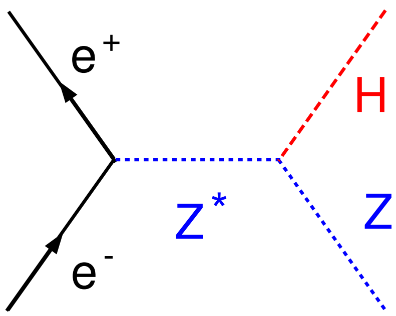
$$m_H < 230\ \mathbf{GeV/c^2}$$

$\Rightarrow$ Good chance for LEP to find the Higgs

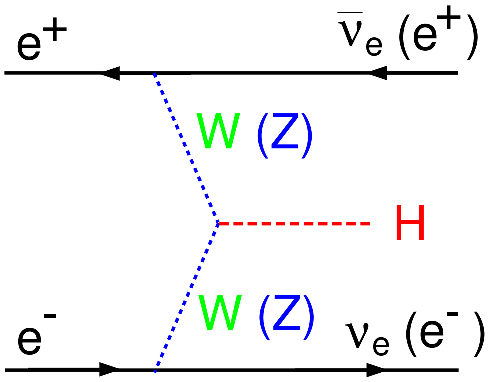
Theory SM Higgs Bosons

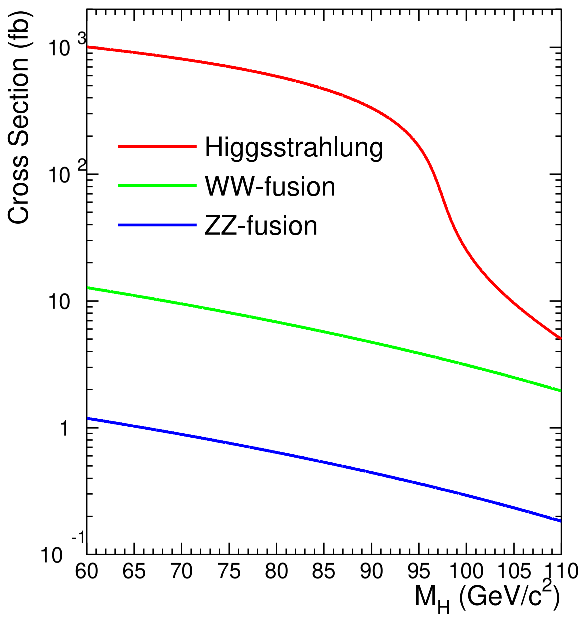
- Production in e^+e^- collisions at LEP2

Higgs–Strahlung



WW/ZZ Fusion



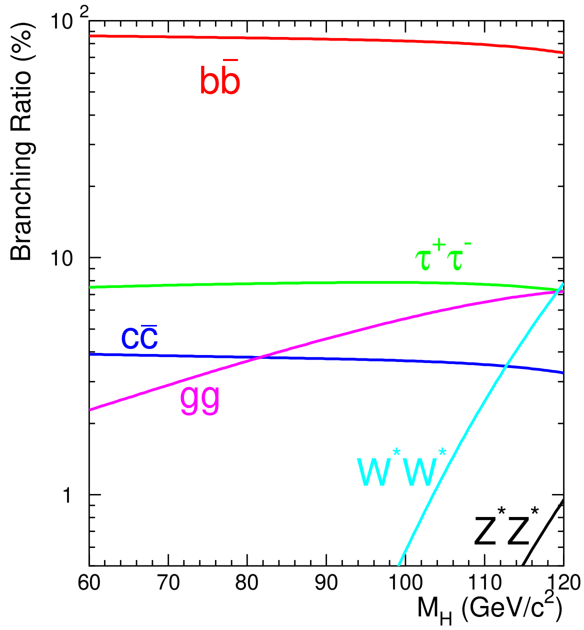


For 95 $\mathbf{GeV/c^2}$ Higgs:

- $\sigma = 170$ fb
- $\sqrt{s} = \mathbf{189}$ GeV
- $L = 180\ \mathrm{pb}^{-1}$/exp.
- $n = 30$ evts./exp.

Theory SM Higgs Bosons

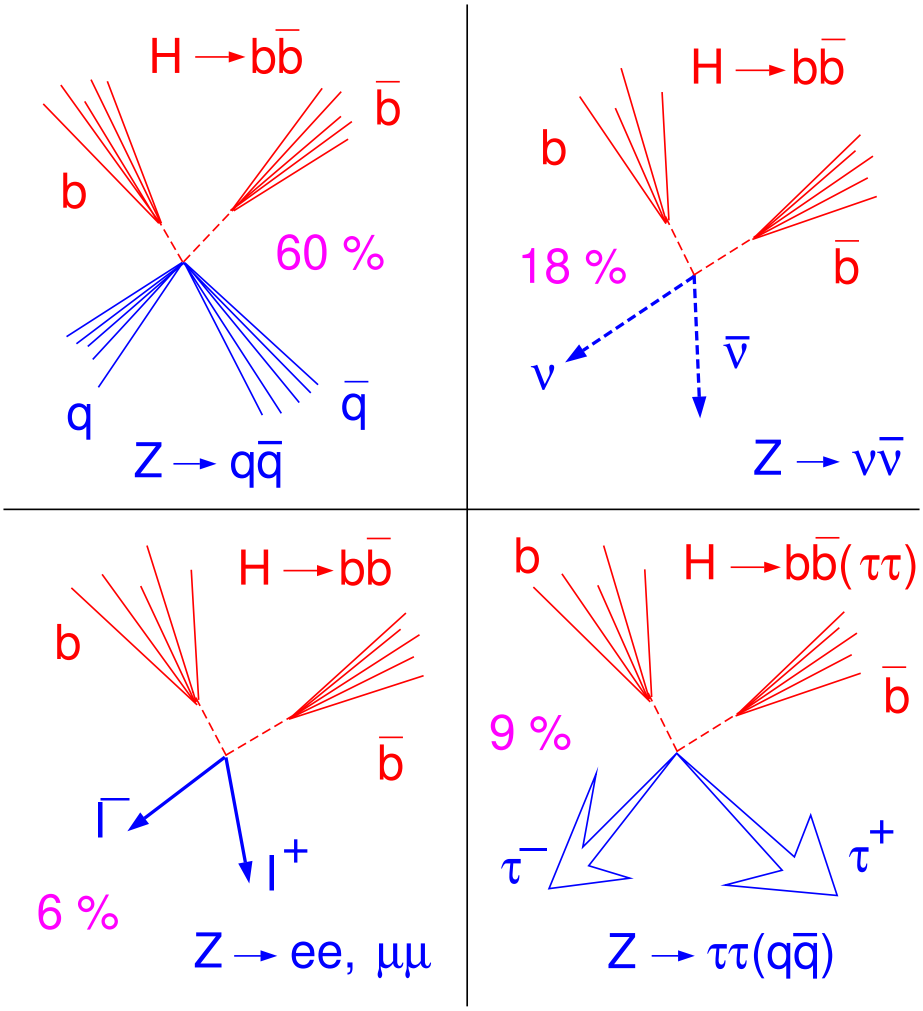
- SM higgs boson signatures and rates



Mains decays

$m_H = 95$ **GeV/c²**

$b\bar{b}$	$\sim$	84 %
$\tau^-\tau^+$	$\sim$	8 %
$g\bar{g}$	$\sim$	5 %
$c\bar{c}$	$\sim$	3 %



Search Topologies: 4 Jets

- Signal H$q\bar{q}$

$$\mathrm{BR}(H \to b\bar{b}) \cdot \mathrm{BR}(Z \to q\bar{q}) \approx 60\ \%$$

- Background processes

$$\mathrm{q\bar{q}}(\gamma),\ \mathbf{W^+W^-},\ \mathbf{ZZ},\ \mathbf{W^\pm e^\mp \nu_e},\ \mathbf{Ze^+e^-}$$

- Analysis procedures:

$$\epsilon(m_{H^0} = 95\mathrm{GeV}) \approx 30\%\text{–}47\%$$

ALEPH

- ANN
- Cut based analysis

DELPHI

- Probabilistic analysis

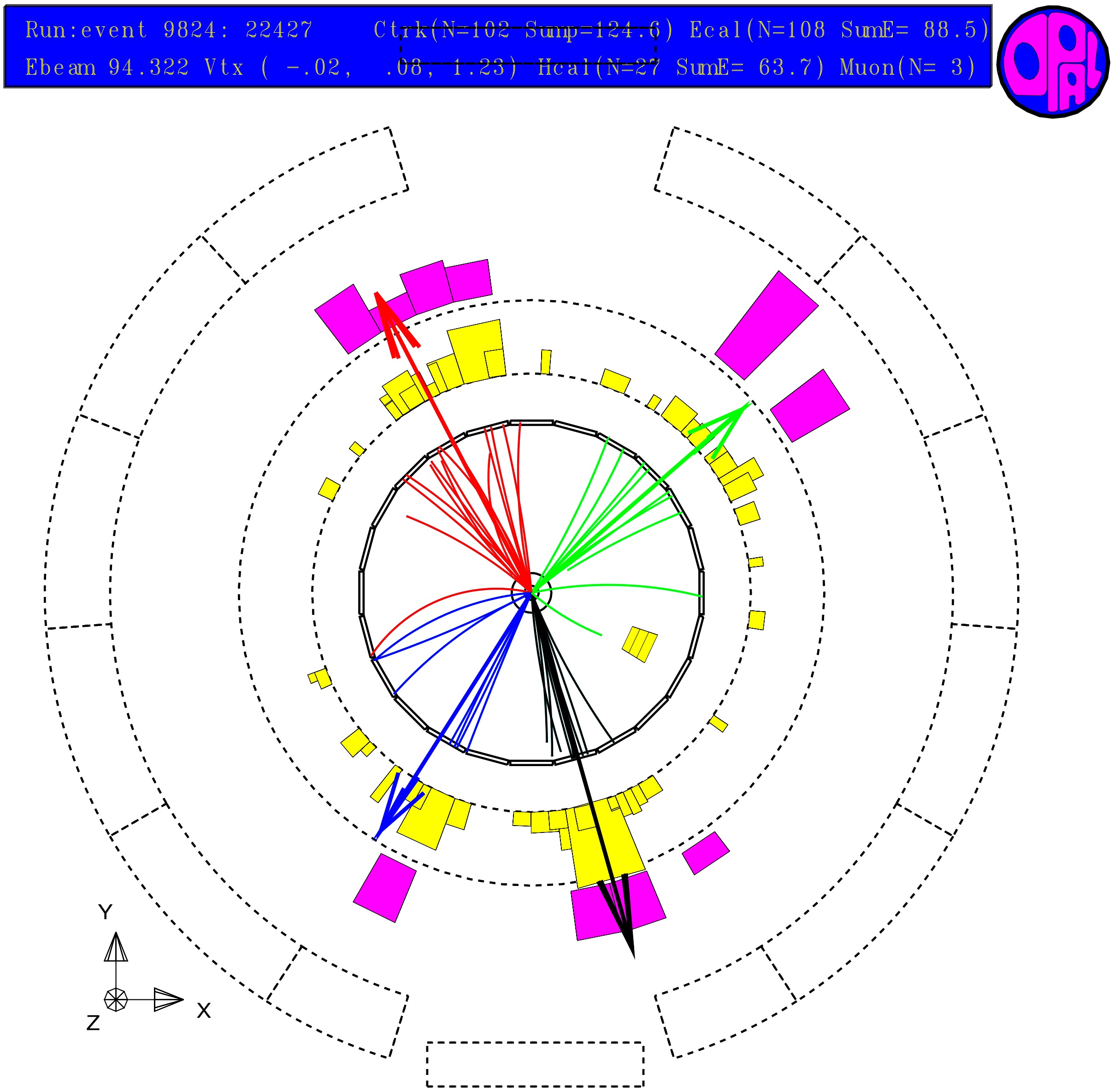
L3

- Cut optimisation
- ANN

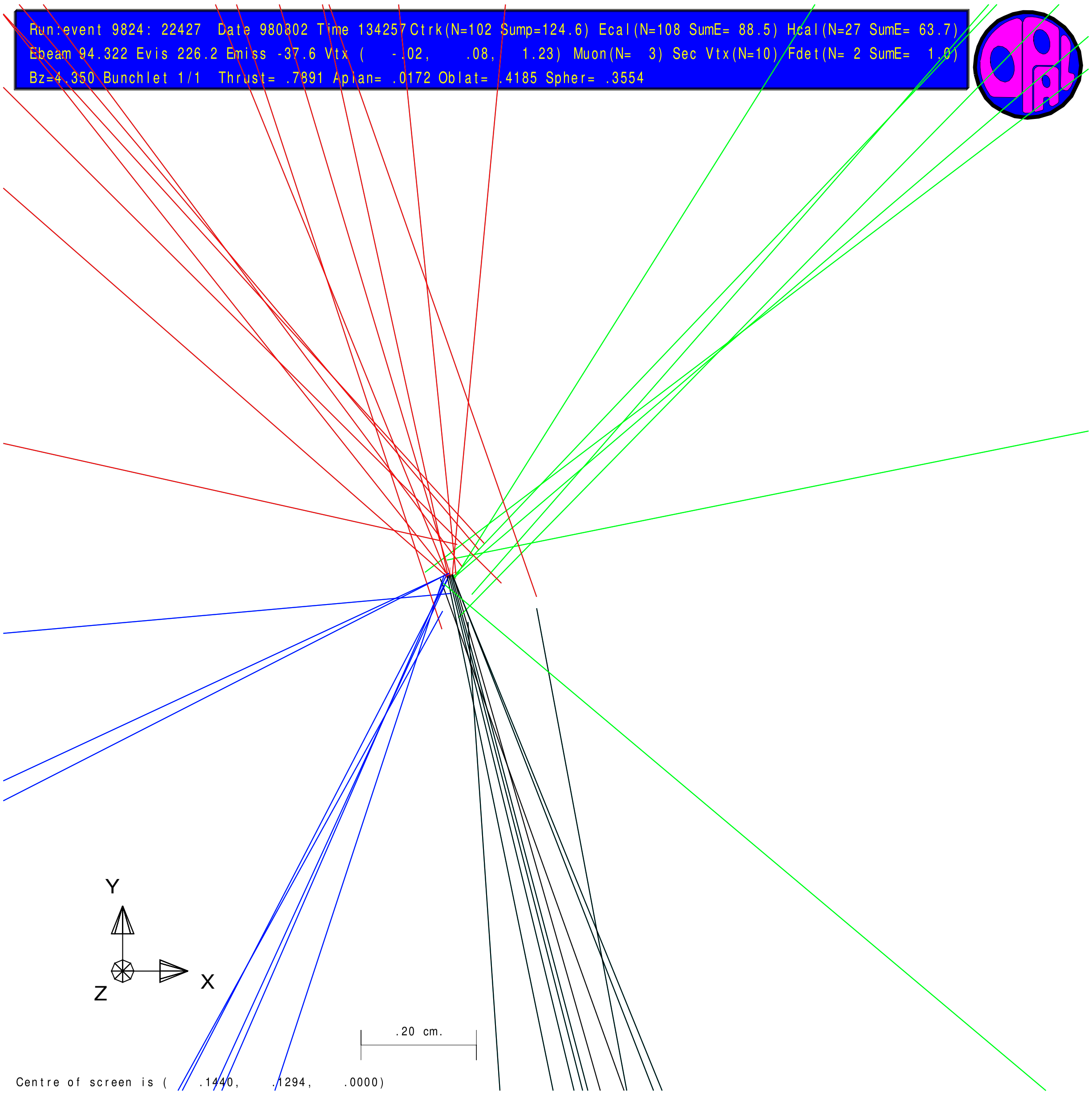
OPAL

- Likelihood

OPAL 4 Jet Candidate

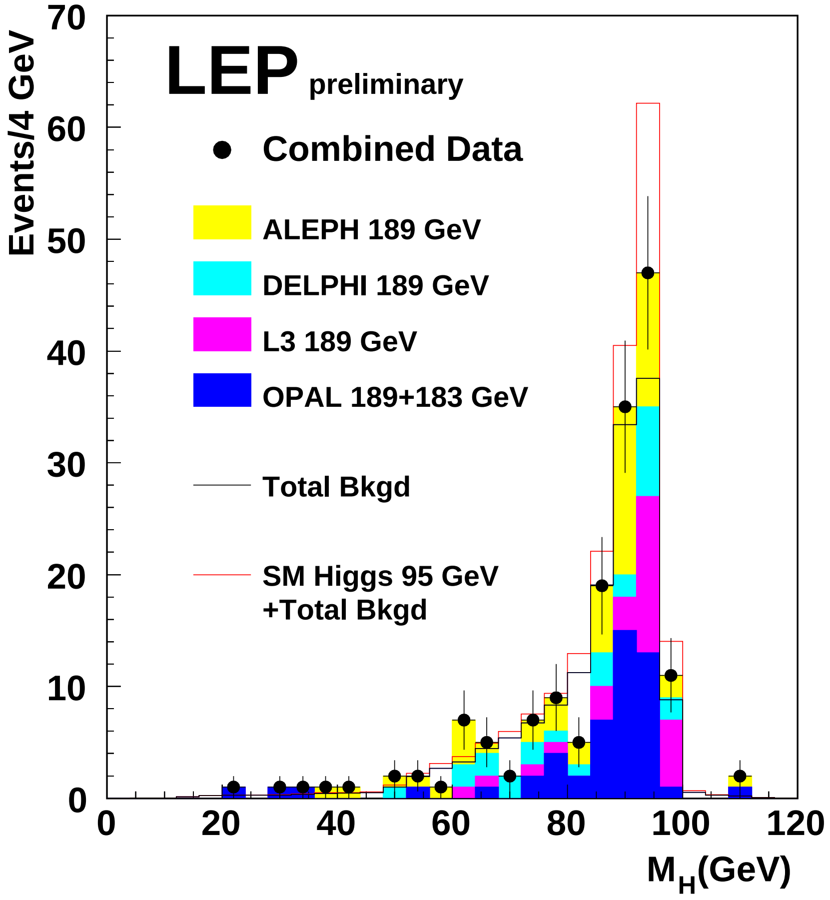


OPAL 4 Jet Candidate



SM Higgs results

- LEP combined m_{H^0} mass distributions
- $\sqrt{s} \approx 189$ GeV, $\mathcal{L} \approx 180$ pb^{-1}/exp.

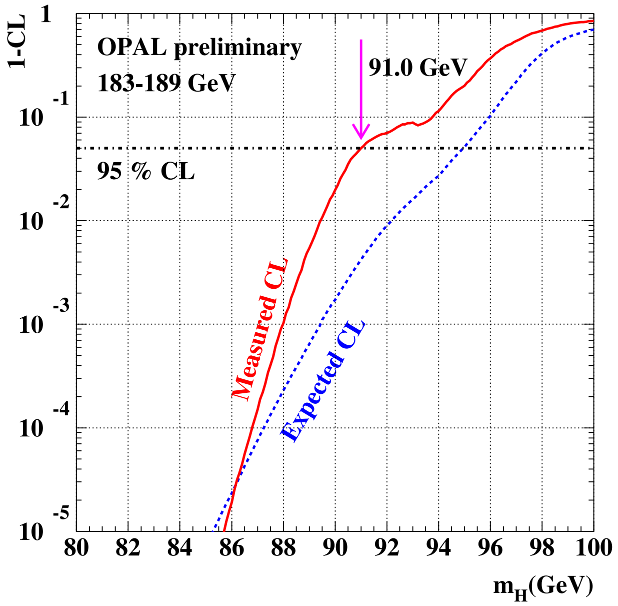


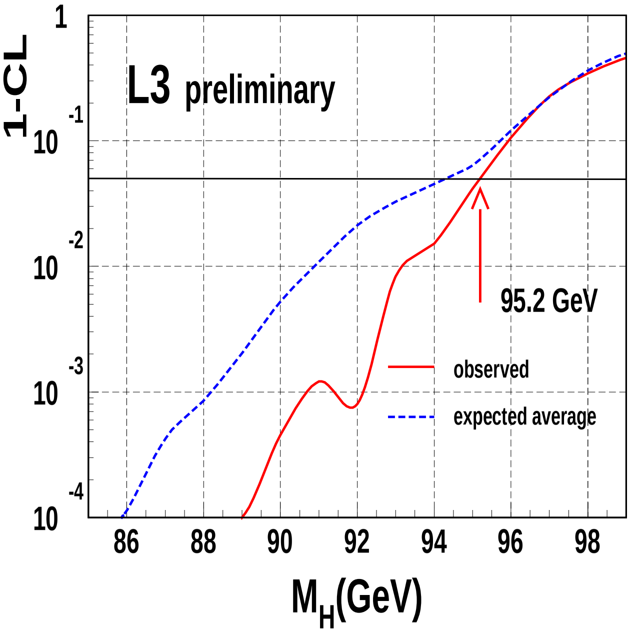
	Obs. Data	Bck. Exp.	Exp. Signal $m_{H^0} = 95$ GeV/c^2
ALEPH	53	44.6	13.8
DELPHI	26	31.3	10.1
L3	30	30.3	9.9
OPAL	50	43.9	12.6
Total	159	150.3	46.4
Δm	47	37.5	42.6

- $\Delta m = 92$–96 GeV/c^2

SM Higgs results

- Limit calculations





- 1997: $\sqrt{s} = 183$ GeV, L $\approx 55\ pb^{-1}$/exp.

  89.7 $\mathrm{GeV/c^2}$

- 1998: $\sqrt{s} = 189$ GeV, L $\approx 180\ pb^{-1}$/exp.

Higgs limits $\mathrm{GeV/c^2}$

	1997		1998	
	Exp.	Obs.	Exp.	Obs.
Aleph	85.2	87.9	95.7	90.2
Delphi	86.5	85.7	94.8	95.2
L3	85.0	87.6	94.4	95.2
Opal	86.2	88.3	94.9	91.0

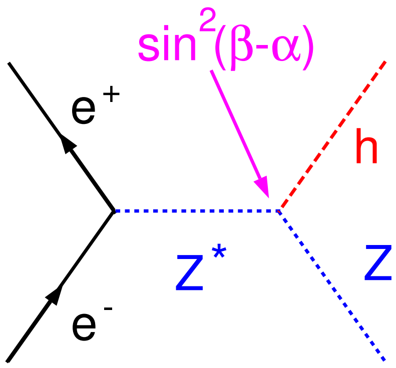
- Higgs mass Boson lower bound, at 95 % CL

Theory MSSM neutral Higgs Bosons

- MSSM: low mass prediction for lightest higgs

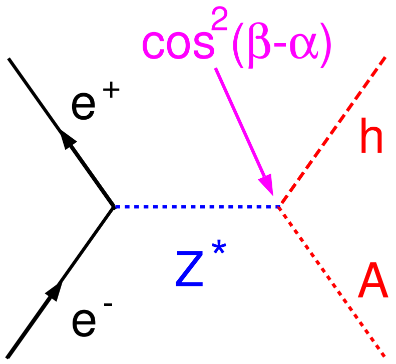
$$m_h \lesssim 140\ \mathrm{GeV}/c^2$$

- MSSM neutral Higgs productions



Higgs strahlung

$$\sigma_{hZ} = \sin^2(\beta-\alpha)\cdot\sigma^{SM}_{HZ}$$



Associate production

$$\sigma_{hA} = \cos^2(\beta-\alpha)\cdot\bar{\lambda}\cdot\sigma^{SM}_{\nu\bar{\nu}}$$

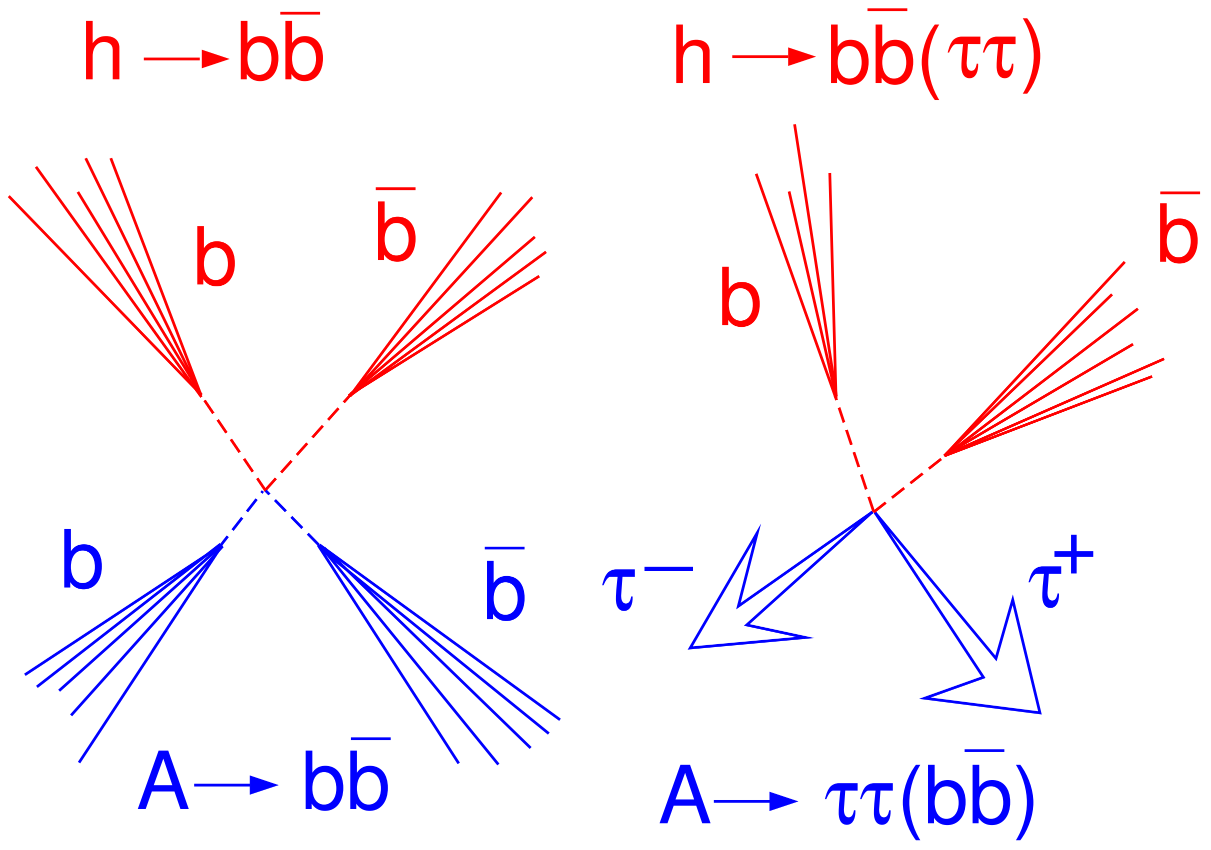
$\bar{\lambda}$: kinematic factor $m_h,\ m_A,\ \sqrt{s}$

- Decay modes

h	$\rightarrow$	$b\bar{b}$	$\sim H_{SM}$	if $m_h > 2m_A$
		$\tau^\pm\tau^\mp$		$h \rightarrow 2A$
				can be dominant
A	$\rightarrow$	$b\bar{b}$	92 %	
		$\tau^\pm\tau^\mp$	8 %	

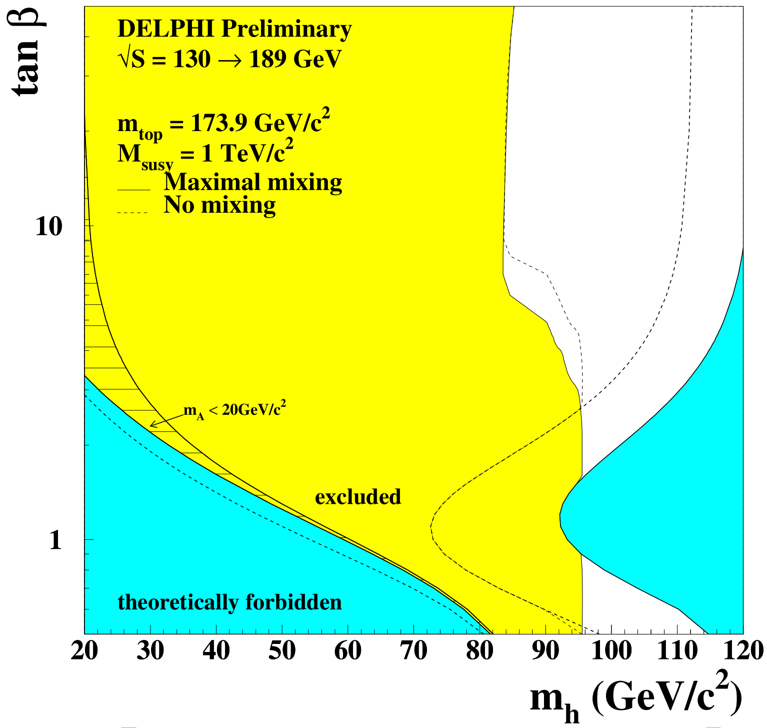
MSSM Search Topologies

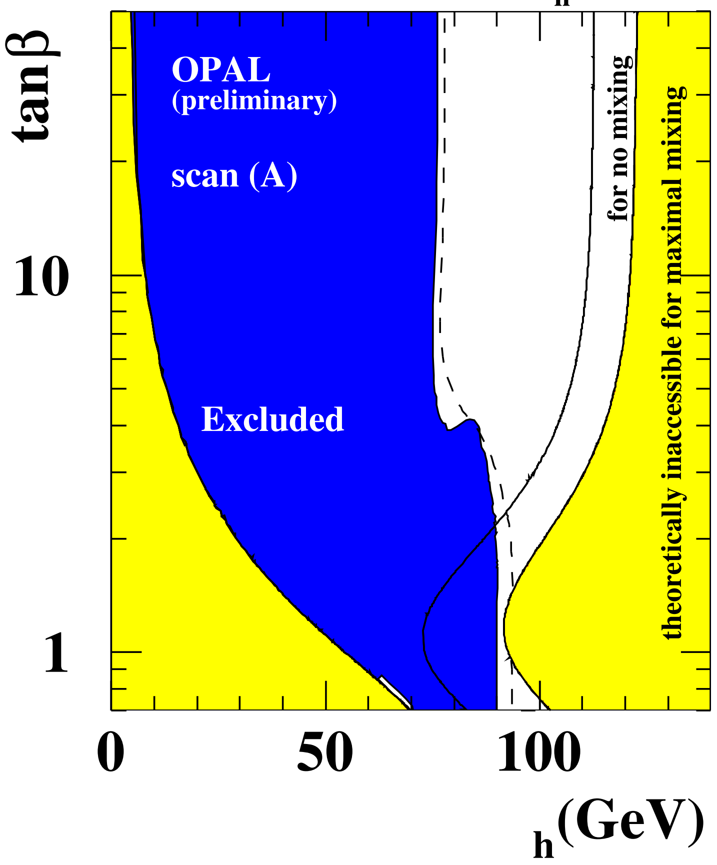
- hZ Analysis
  - Re–use SM HZ analysis
  - Also considering $h \to AA$
- hA analysis
  - Identical to 4 jet SM ...
  - BUT strong emphasis on b–tag



MSSM neutral Higgs results

- $\sqrt{s} = 189$ GeV, L $\approx 180\ pb^{-1}$/exp.
- $\tan\beta$ vs m_h, excluded regions at 95 %CL





MSSM neutral Higgs results

- LEP 1997 combined results , $\sqrt{s} = 183$ GeV, L $\approx 55\ pb^{-1}$/exp.

$m_h > 79.6\ \mathbf{GeV/c^2}$ $\quad m_A > 80.2\ \mathbf{GeV/c^2}$ $\quad \tan\beta > 0.8$

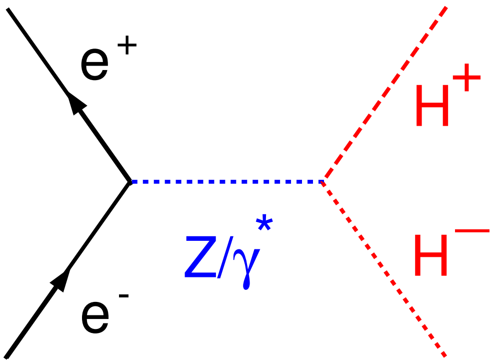
- LEP 1998 individual results , $\sqrt{s} = 189$ GeV, $\approx 180\ pb^{-1}$/exp.

	m_h GeV/c^2		m_A GeV/c^2		
	Exp.	Obs.	Exp.	Obs.	$\tan\beta$
Aleph	82.6	80.8	82.7	81.2	> 1.0
Delphi	80.5	83.5	81.6	84.5	> 0.5
L3	77.8	77.0	77.9	78.0	> 1.0
Opal	76.4	74.8	78.2	76.5	> 1.0

- Higgs mass Boson lower bound, at 95 % CL

Charged Higgs

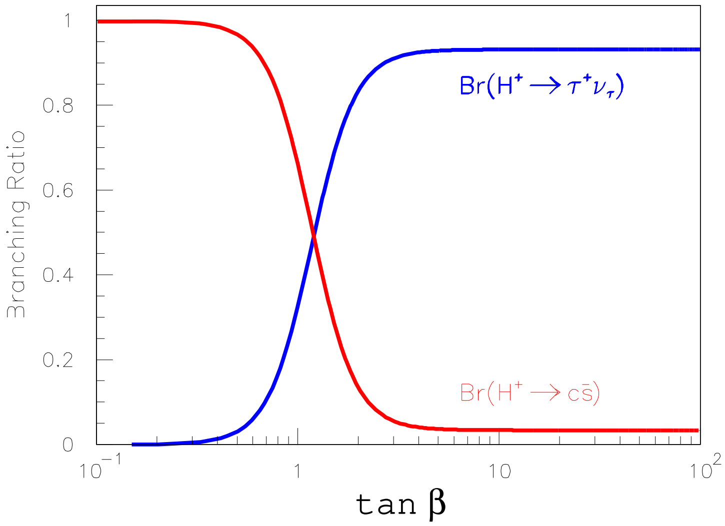
- Charged Higgs production



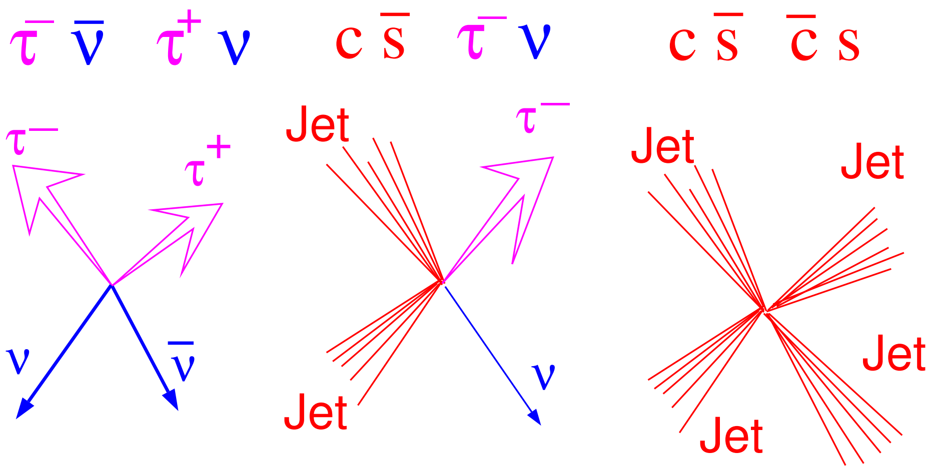
- Pairs of Charged Higgs bosons produced via s–channel

- Possible decays:
  - $H^+ \to \tau^+\nu$
  - $H^+ \to c\bar{s}$

- BR Model dependant



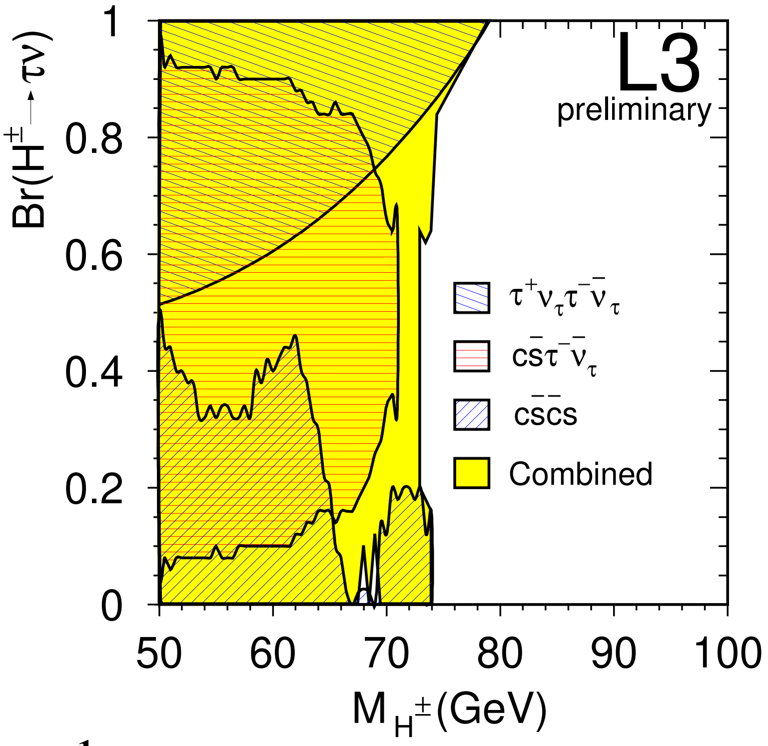
- Final states and signatures:

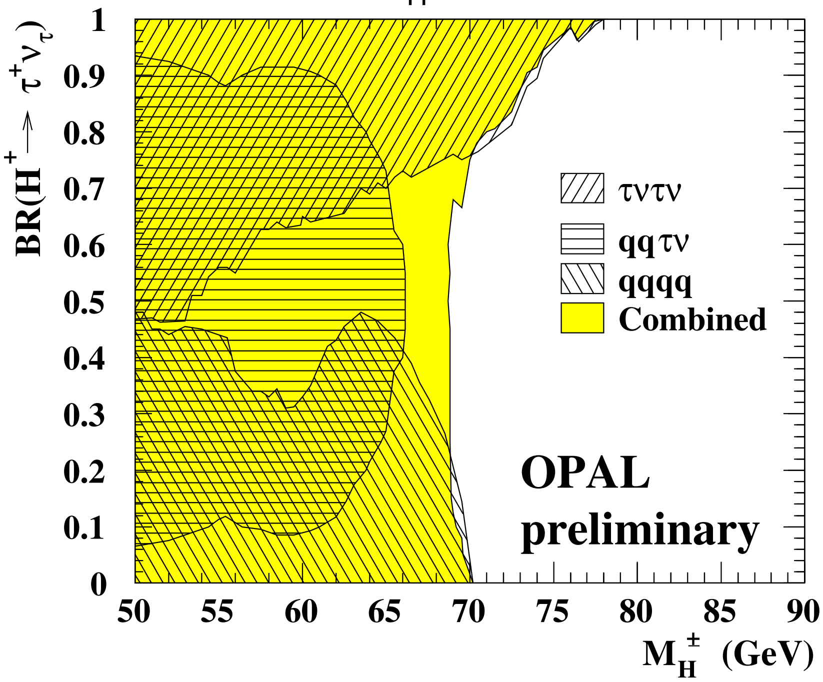


Charged Higgs results

- $\sqrt{s} \approx 189$ GeV, $\mathcal{L} \approx 180$ pb^{-1}/exp.
- Excluded regions at 95 %CL

Br($H^{\pm} \to \tau\nu$) vs $m_{H^{\pm}}$





Charged Higgs results

- LEP 1997 combined results , $\sqrt{s} = 183$ GeV, L $\approx 55\ pb^{-1}$/exp.

$$m_{H^\pm} > 69.0\ \mathbf{GeV/c^2}$$

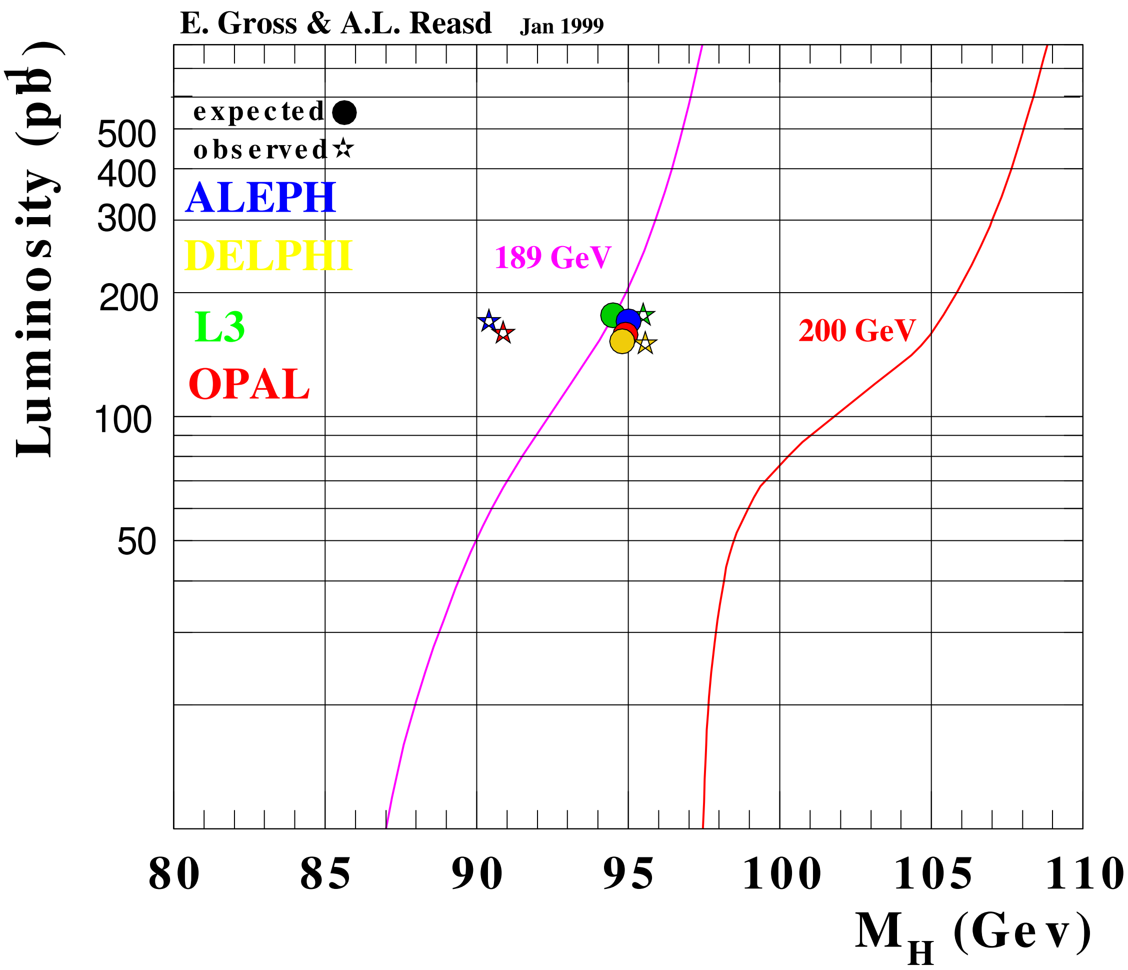
- LEP 1998 individual results, $\sqrt{s} \approx \mathbf{189}$ GeV, $\mathcal{L} \approx 180$ pb^{-1}/exp.

	$m_{H^\pm}$ $\mathbf{GeV/c^2}$			
	BR($H^+ \to$ any)		BR($H^+ \to \tau^+\nu$)=0	BR($H^+ \to \tau^+\nu$)=1
	Exp.	Obs.	0.	1.
Aleph	68.5	62.5	70.0	73.0
Delphi	69.1	65.1	71.9	78.1
L3	70.0	67.5	79.0	74.0
Opal	68.0	68.7	70.0	76.0

- Higgs mass Boson lower bound, at 95 % CL

LEP prospects for Higgs Bosons

- Run 1999 has just started ...
  - Energy steps: $\sqrt{s} = 192, 196, 200$ GeV
  - So far $\approx 21\ pb^{-1}$/exp. at $\sqrt{s} = 192$ GeV
  - Luminosity: L $\geq 150\ pb^{-1}$/exp (?)
- Run 2000
  - Energy: $\sqrt{s} = 200$ GeV
  - Luminosity: L $\geq 200\ pb^{-1}$/exp (?)
- What can be achieved with 200 GeV runs ?



CERN-EP/98–094, Prospects by E. Gross et al.

Summary – Conclusions

- Excellent LEP performances up to 1998 and beginning 1999

- No evidence for Higgs Bosons

Limits $\mathbf{GeV/c^2}$ at 95 % CL

	SM	MSSM		Charged Higgs
	m_{H^0}	m_h	m_A	$m_{H^\pm \to \text{any}}$
Aleph	90.2	80.8	81.2	62.5
Delphi	95.2	83.5	84.5	65.1
L3	95.2	77.0	78.0	67.5
Opal	91.0	74.8	76.5	68.7

- Run 1999/2000, exciting years ...

- High energy runs $\sqrt{s} \approx 200$ GeV

- Large integrated luminosity L $\geq 300\ pb^{-1}$

- Wait for the Higgs discovery at LEP ... ?