Search for Standard Model Higgs Boson at LEP

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- Introduction
- SM Higgs Production and Decay
- Search Topologies
- Results (Data/MC; Mass Plots)
- Statiscal Methods and Limits on m_H
- Conclusion

Preliminary Remarks

I will focus on results obtained with the LEP data, taken during 1999 at $\sqrt{s}$ = 192 - 202 GeV.

Results from Y2K data will be covered by other talks.

Introduction

- **Why do we need Higgs boson ?**
  - — $W^{\pm}$, Z^0 obtain masses via Higgs mechanism (Spontaneous Symmetric Breaking)
  - — Fermions obtain masses via Yukawa coupling to Higgs boson

- **Higgs boson is the only particle not discovered in the Standard Model**

- **EW fit favors light Higgs boson (LEPC of July 20, 2000)**

  $M_H \leq 170$ GeV @95%CL

Introduction

- **LEP Experiments:**

  ALEPH, DELPHI, L3, OPAL

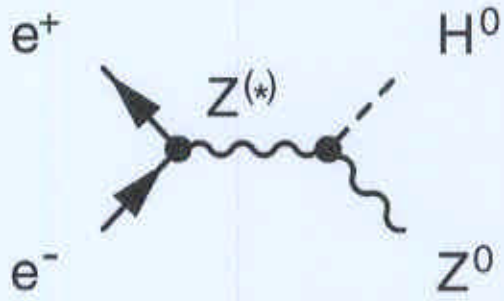
- **LEP runs:**

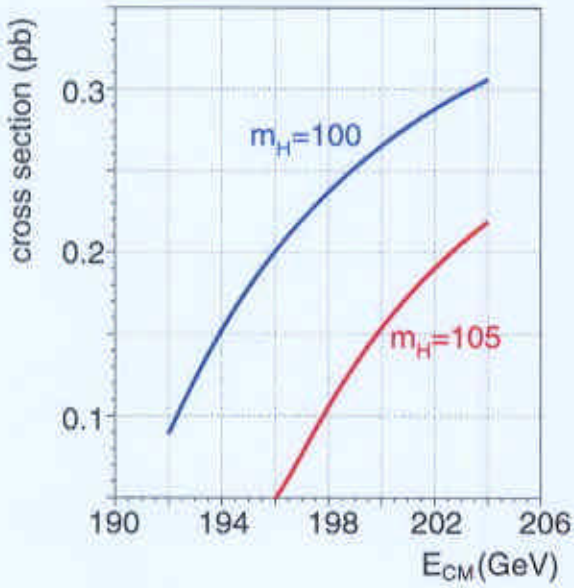
  Delivered integrated luminosity per experiment

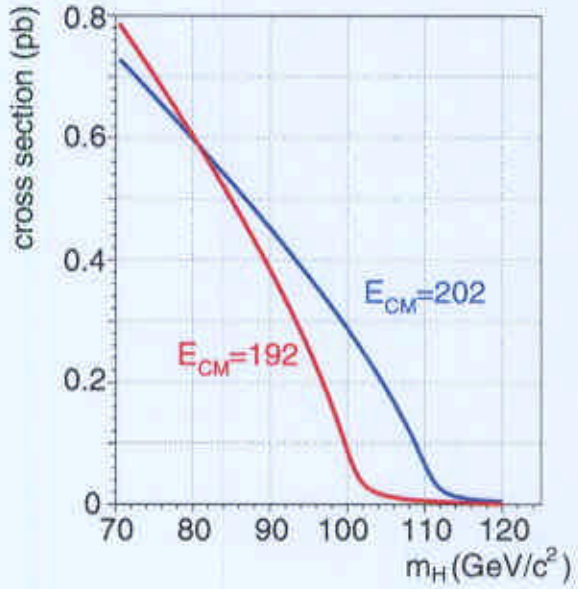
	$\sqrt{s}$ (GeV)	$\int Ldt$ (pb^{-1})
LEP 1		
1989-1995	~ 91	160
LEP 1.5		
Fall 1995&1997	130-136	12
LEP 2		
1996	161-172	20
1997	183	60
1998	189	185
1999	192-202	230

SM Higgs Production

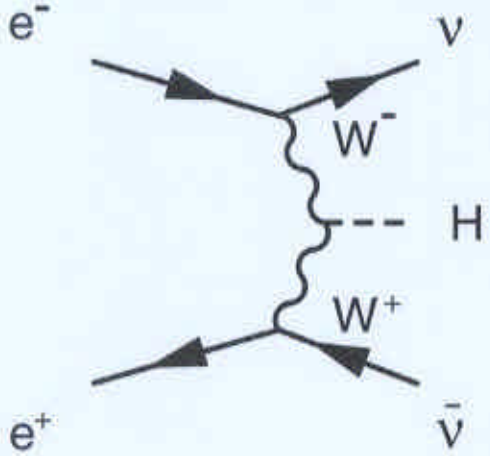
Dominant production mechanism is Higgs-strahlung.

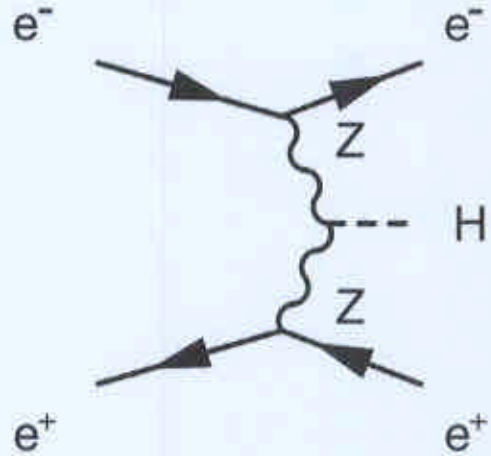






Small contributions from WW- and ZZ- fusion

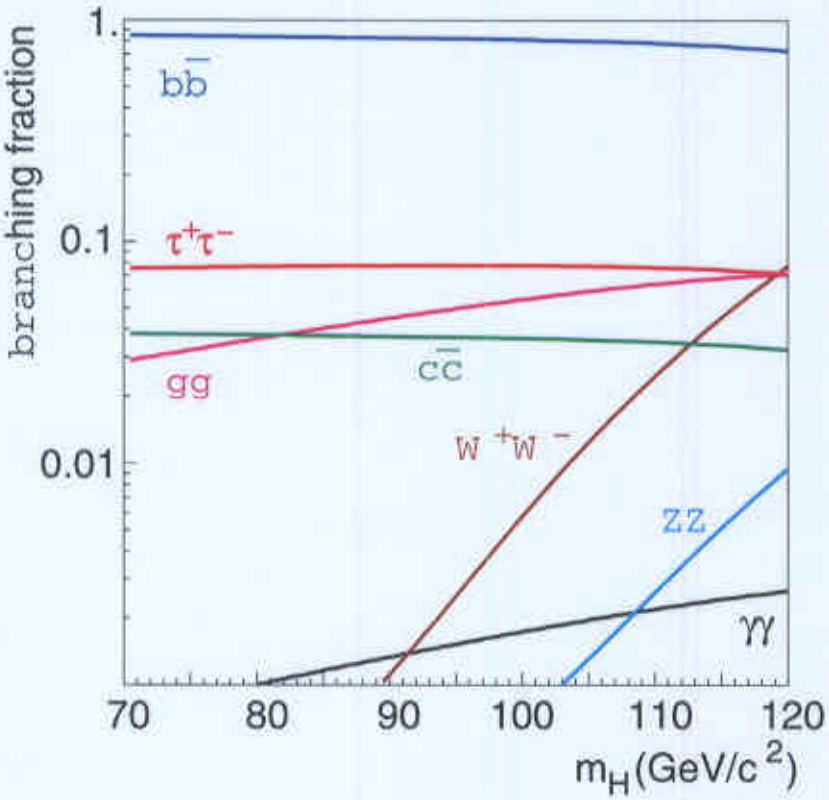




Become important if m_H is close to threshold.

SM Higgs Decay

Higgs couples most strongly to massive particles.

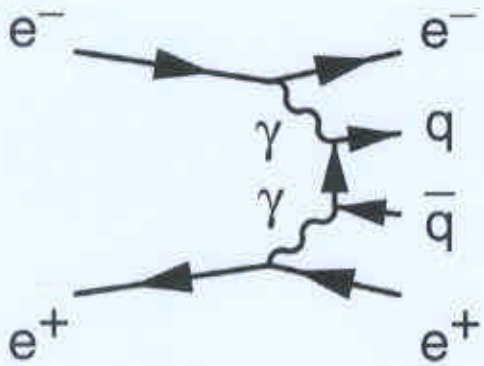


$H \rightarrow b\bar{b}$ (80~90%), $\tau^+\tau^-$ (~8%)

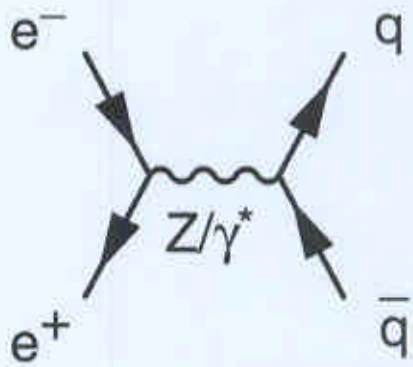
$Z \rightarrow q\bar{q}$, $\nu\bar{\nu}$, l^+l^-, $\tau^+\tau^-$

Use b-tagging to reduce background.

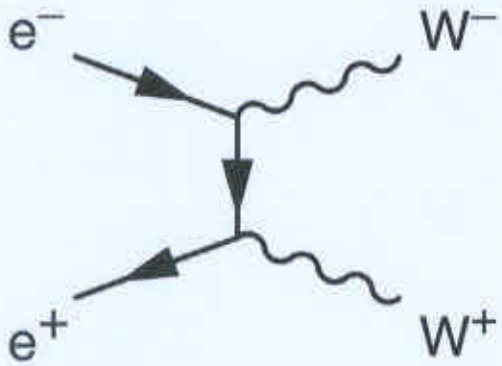
Backgrounds



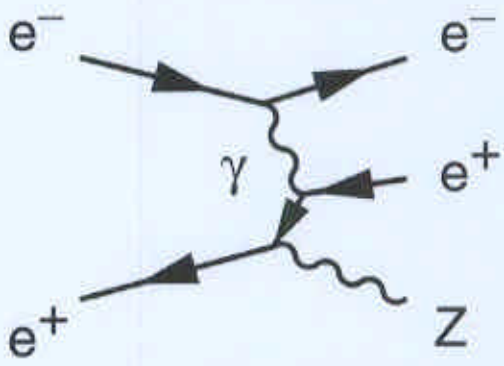
$\sigma_{\gamma\gamma} \approx 2nb$



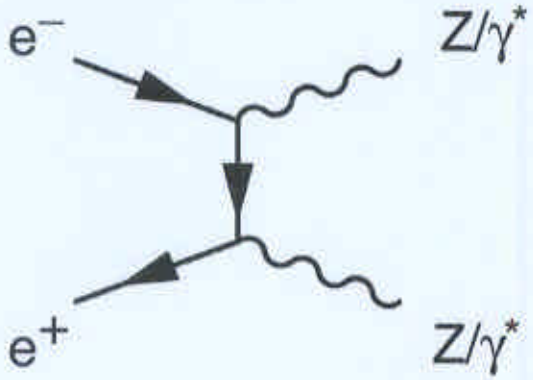
$\sigma_{q\bar{q}} \approx 100pb$



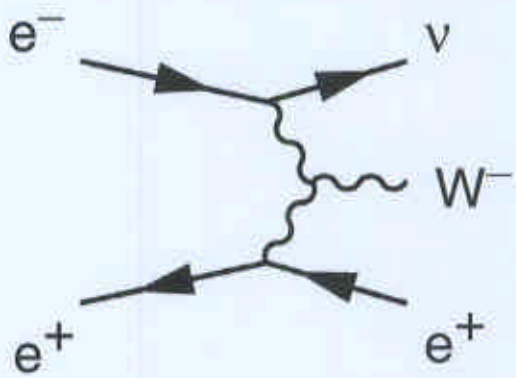
$\sigma_{WW} \approx 17pb$



$\sigma_{eeZ} \approx 7pb$

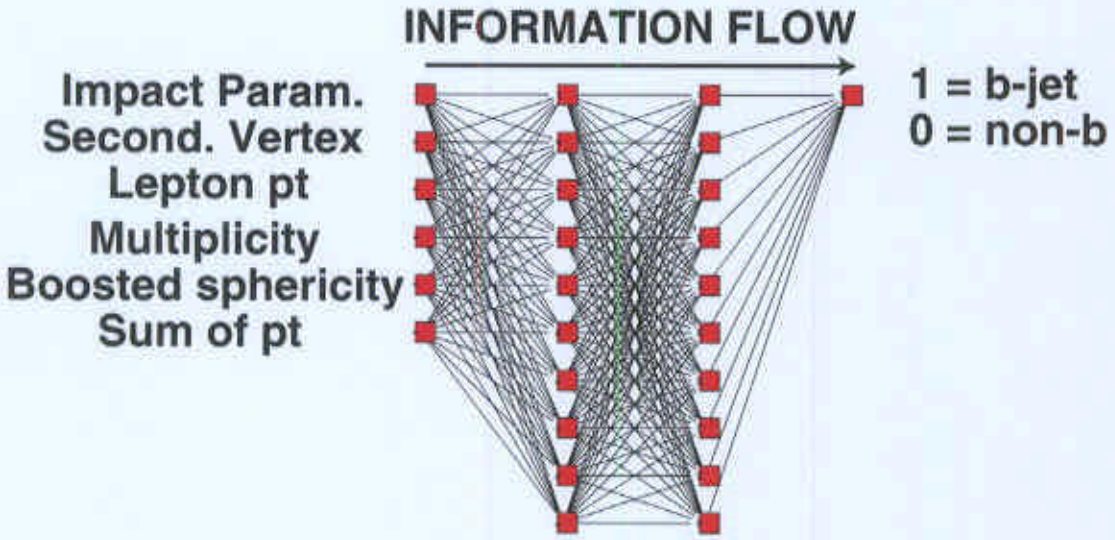


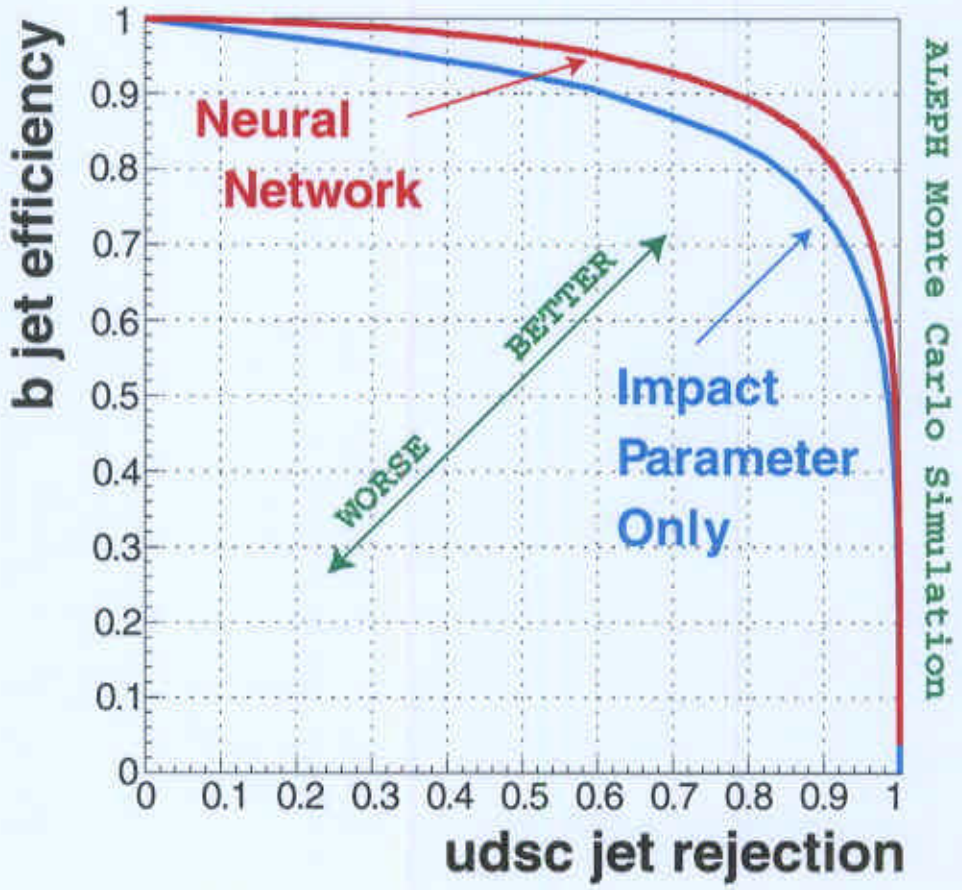
$\sigma_{ZZ} \approx 3pb$



$\sigma_{We\nu} \approx 0.8pb$

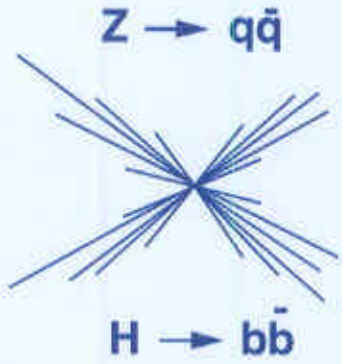
b-tagging





at 90% rejection, neural network has
~ 8% better b-jet efficiency

Topologies — 4 jets



BR ~ 65%

- **4 jet events**
- **One pair compatible with M_Z**

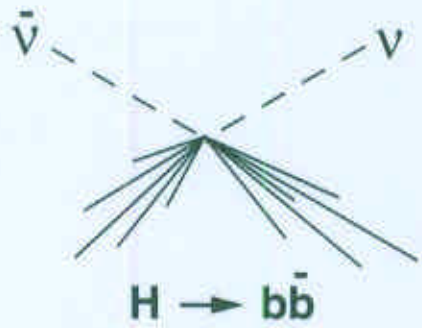
  4C or 5C fit to improve energy and mass resolutions

- **2 b jets or 4 b jets**
- **Treatment of HZ/hA overlap**

Number of Selected Events ($\sqrt{s}$ =192-202 GeV)

	ALEPH	DELPHI	L3	OPAL	Total
Data	**30**	**161**	**72**	**33**	**296**
MC	**46.4**	**175.4**	**73.5**	**27.7**	**323.0**

Topologies — $H\nu\bar{\nu}$



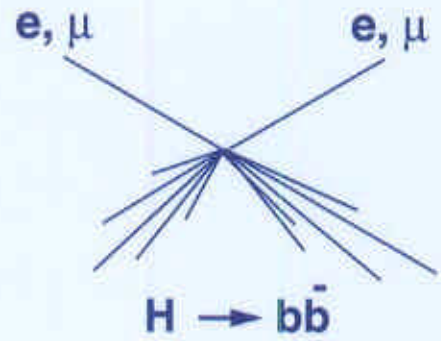
BR ~ 20%

- **Missing energy**
- **2 acoplanar b jets**
- **Recoil mass of b jets compatible with M_Z**

Number of Selected Events ($\sqrt{s}$ =192-202 GeV)

	ALEPH	DELPHI	L3	OPAL	Total
Data	7	108	157	6	278
MC	11.0	105.7	145.0	9.3	271.0

Topologies — Hll



BR ~ 6.7%

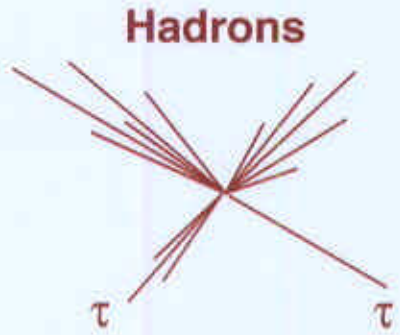
- **2 energetic, isolated l**
- **$M_{ll} = M_Z$**
- **Good reconstructed M_H resolution**

M_H = Recoil mass of 2 lepton

Number of Selected Events ($\sqrt{s}$ =192-202 GeV)

	ALEPH	DELPHI	L3	OPAL	Total
Data	**26**	**19**	**35**	**10**	**90**
MC	**28.5**	**20.8**	**29.4**	**8.1**	**86.8**

Topologies — ττqq



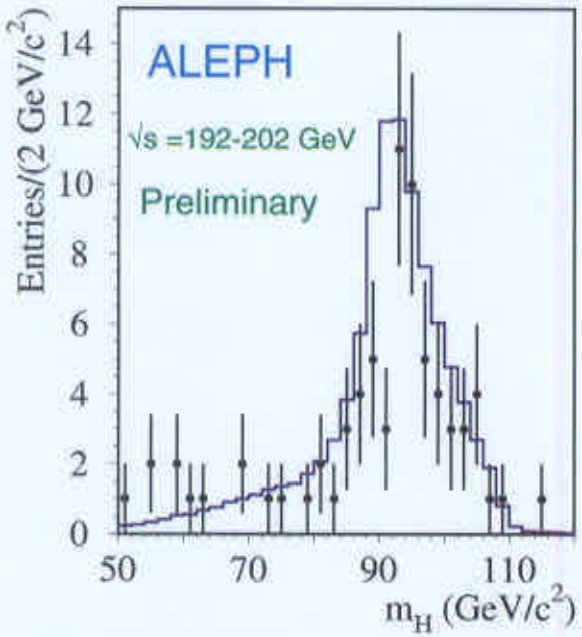
BR ~ 9%

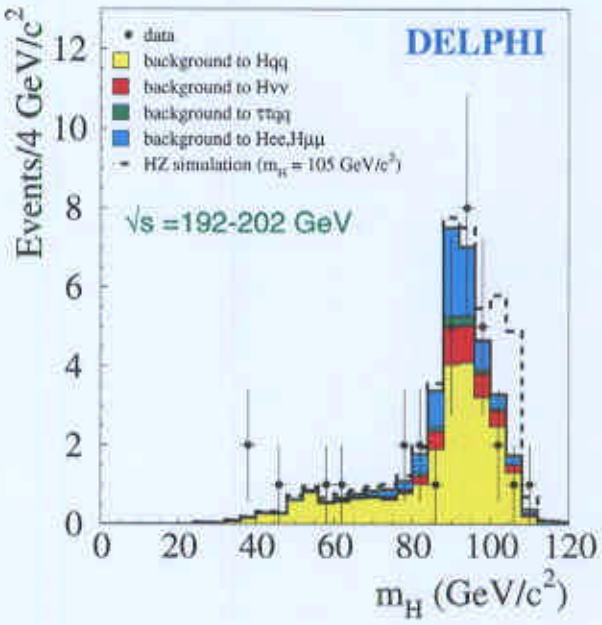
- **2τ + 2 jets**
- **$M_{\tau\tau}$ or $M_{qq} = M_Z$**
- **Treatment of HZ/hA overlap**

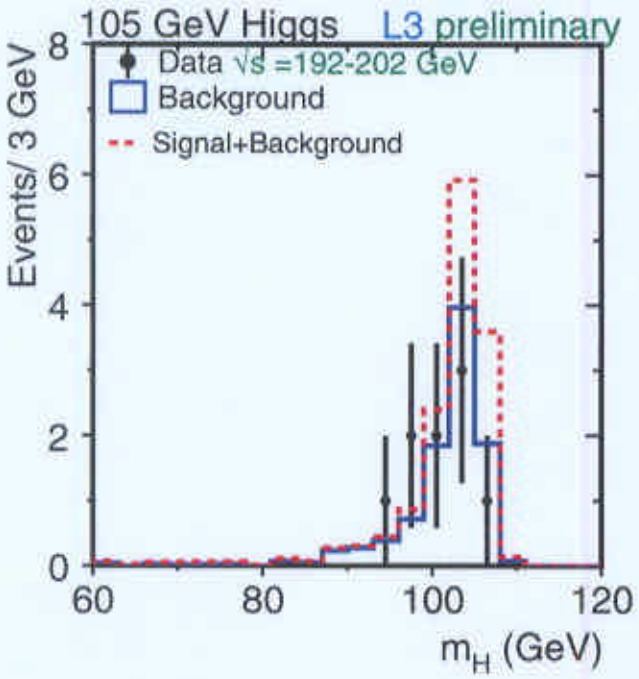
Number of Selected Events ($\sqrt{s}$ =192-202 GeV)

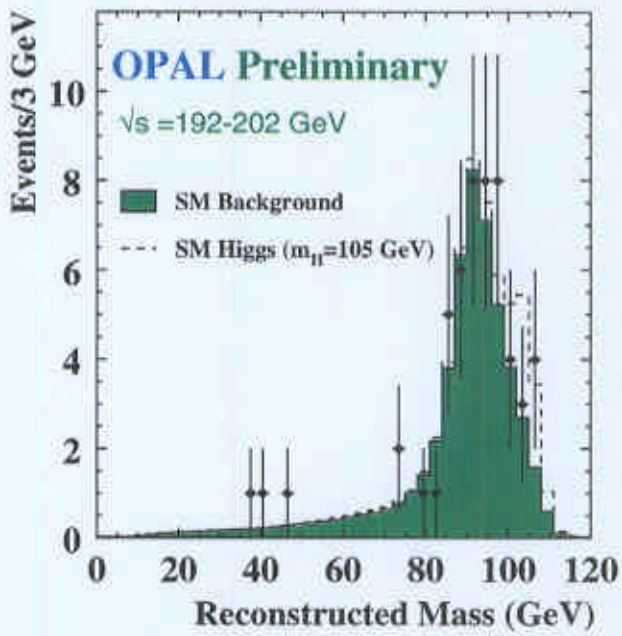
	ALEPH	DELPHI	L3	OPAL	Total
Data	11	6	19	4	40
MC	11.9	6.9	22.3	6.4	47.5

Mass Plots





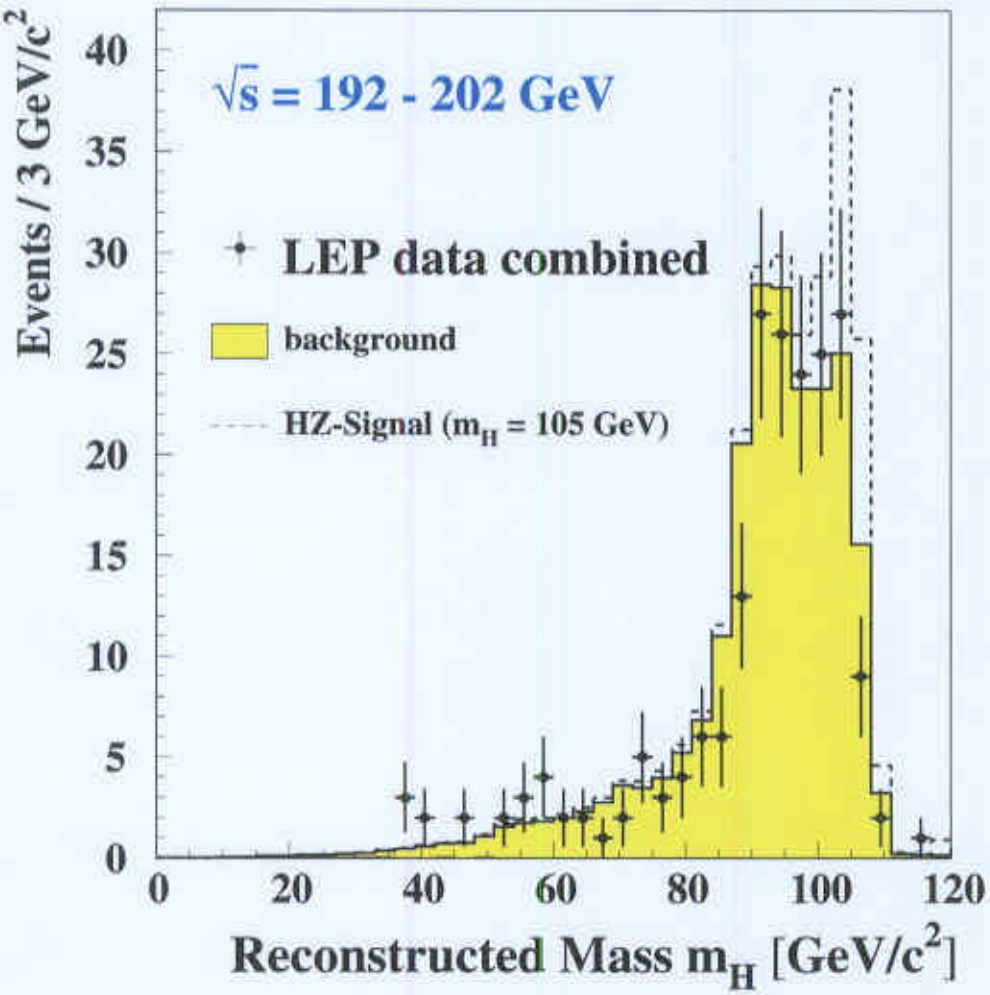




Number of Selected Events in All Channels (√s=192-202GeV)

	ALEPH	DELPHI	L3	OPAL	Total
Data	74	294	283	53	704
MC	97.8	308.8	270.7	51.5	728.8

LEP Combined Mass Plot

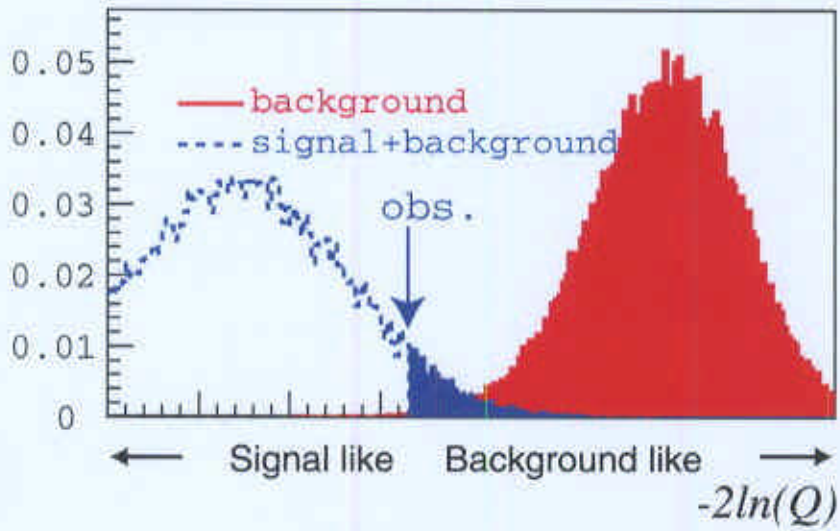


LEP Combined mass plot for SM Higgs :

With supplementary requirement that the contributions from the four experiments be roughly equal

For illustration only
Do not draw quantitative conclusions

Confidence Levels



- **Estimator (Test-statistic):**

  An Estimator is a value to quantify the "signal-ness" of an observation

  $$X = -2\ln(Q)$$

  where $Q = L(s+b) / L(b)$

- **Definition of CL_{s+b} and CL_b :**

  Given an observed value of the estimator $X_{observed}$, calculate confidence levels on the Signal+Background and Background-only hypotheses —

  $$CL_{s+b} = P\,(X_{s+b} \geq X_{observed})$$

  $$CL_b = P\,(X_b \geq X_{observed})$$

CL_s Calculation

Two methods to define CL_s

(A) Generalized Bayesian Method:

$$CL_s = \frac{CL_{s+b}}{CL_b}$$

Used in DELPHI, L3, OPAL and LEP combined results
(See A. Read, CERN 2000-005)

(B) Signal Estimator Method:

$$CL_s = CL_{s+b} + (1-CL_b)\, e^{-s}$$

Used in ALEPH results
(See S. Jin and P. MCNamara, Physics/9812030, CERN 2000-005)

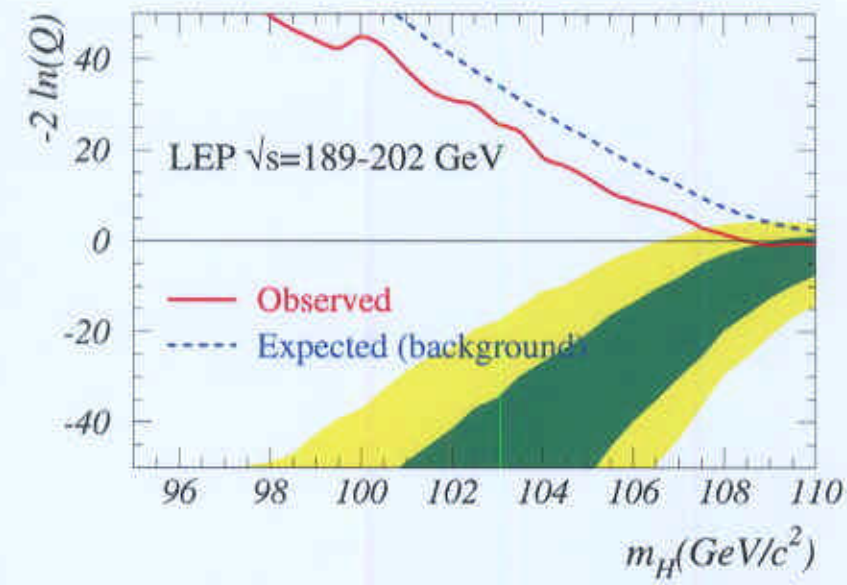
— Both methods satisfy:

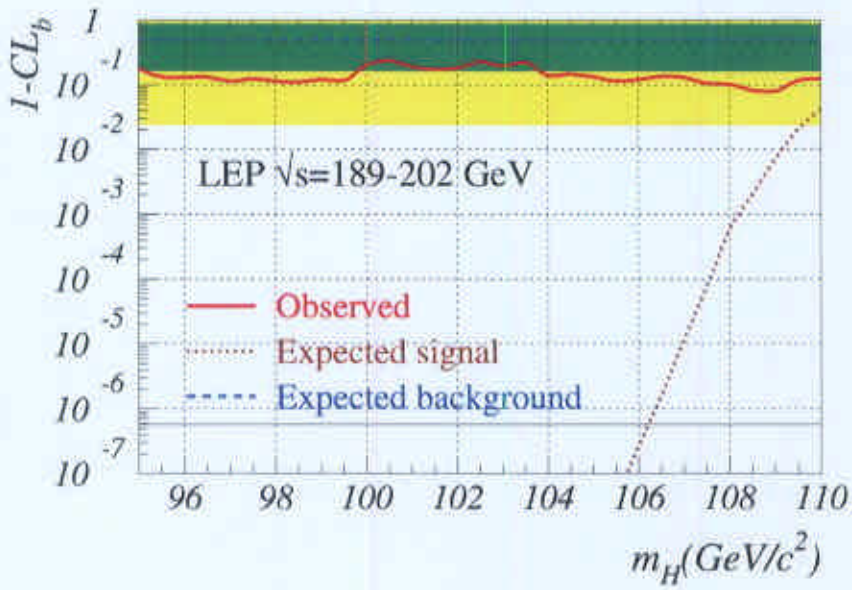
$$CL_s = e^{-s} \quad \textit{for 0 event observed}$$

which is independent of background expectation

— Signal Estimator method gives ~0.5 GeV better sensitivity for the exclusion on m_H than Generalized Bayesian method.

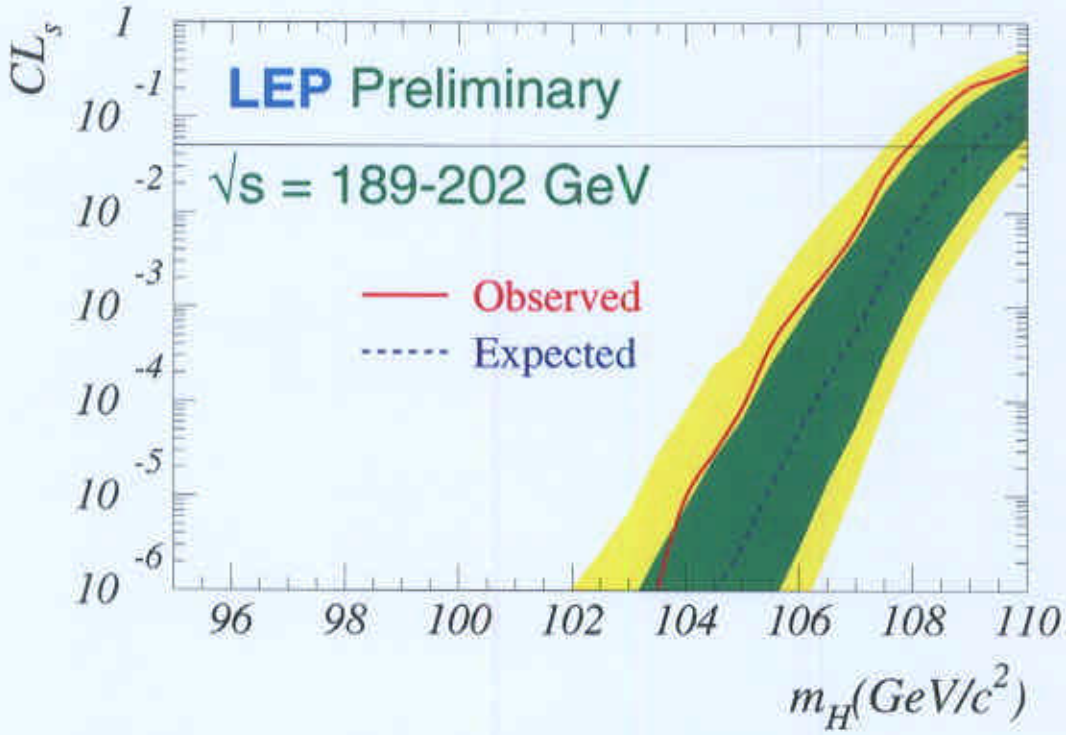
Likelihood Ratio and CL_b





- Slight overall excess: ~1σ
  No evidence for signal
- Expected 1 - CL_b from s+b Gedanken experiments shows 5σ discovery potential for $m_H \leq 106.3$ GeV/c^2

Lower Limits on m_H



- **LEP Combined Limits at 95% CL :**

  Observed : $m_H \geq 107.9$ GeV/c^2

  Expected : $m_H \geq 109.1$ GeV/c^2

- **95% CL limits on m_H (GeV/c^2) from each experiment**

	ALEPH	DELPHI	L3	OPAL
Observed	107.7	106.1	107.0	103.0
Expected	107.8	105.7	105.0	105.2

* The expected limit is calculated from background-only hypotheses, which represents the sensitivity of an experiment.

Conclusion

- **No evidence for SM Higgs in 1999 data collected at LEP**

- **LEP Combined Limits on m_H at 95% CL :**

  Observed : $m_H \geq 107.9$ GeV/c^2

  Expected : $m_H \geq 109.1$ GeV/c^2