LNF Spring School 2000

Higgs Searches at LEP

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Overview

- Higgs production at LEP
- Higgs decay : the topologies
- Physics tools : b-tagging and company
- Background and Candidates
- Setting a Confidence Level
- Perspectives : the Y2K
- A touch of wisdom...

Scenarios :

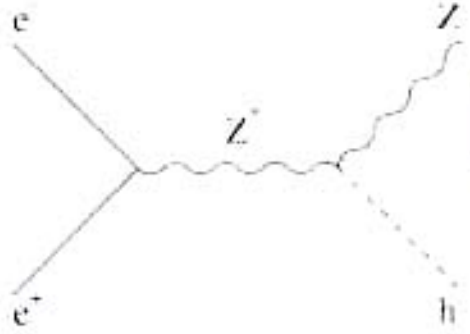
- **Standard Model Higgs**
- **MSSM Higgs**
- **Exotic (if time)**

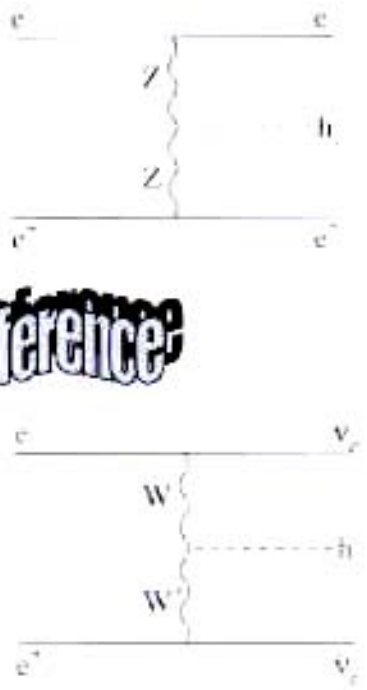
Standard Model Higgs Production at LEP

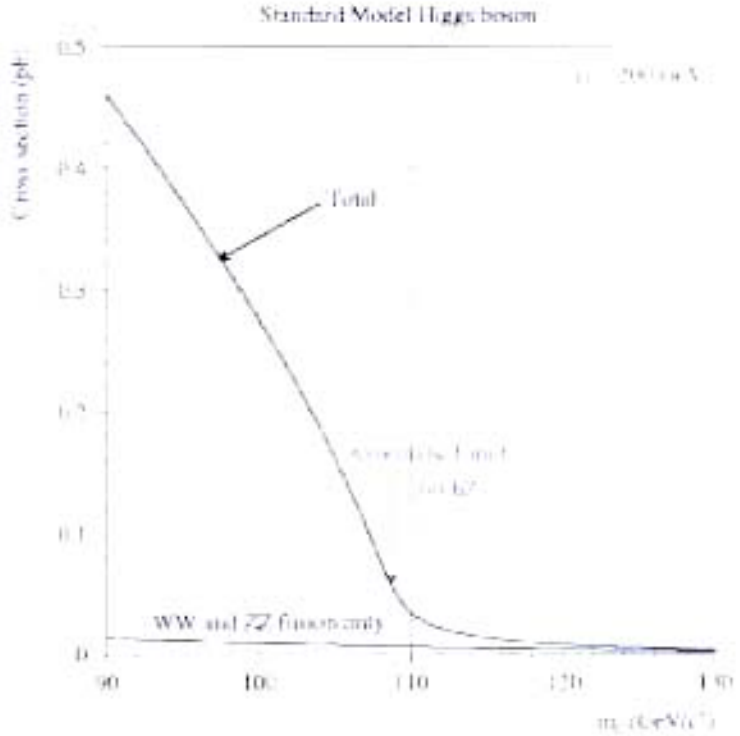
Higgstrahlung by far dominating

IVB fusion

Higgsstrahlung







The Higgs sector in the MSSM

- Two fundamental Higgs Doublets, five physical states
- Two CP-even neutral Higgs bosons, h and H ($m_h < m_H$)
- One CP-odd neutral Higgs boson, A
- A pair of charged Higgs bosons (H^+ and H^-)

- H is too heavy for LEP
- H^+ and H^- at tree level are higher than the W

Many features depending on
- α, mixing angle in the CP-even Higgs sector
- $\tan\beta$, ratio of the vacuum expectation values of the two Higgs field doublets

MSSM Higgs Production at LEP

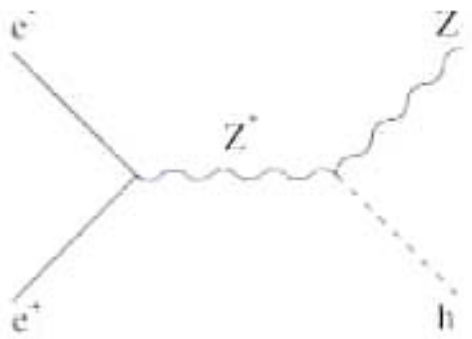
Relative proportion of h and A regulated by α and β

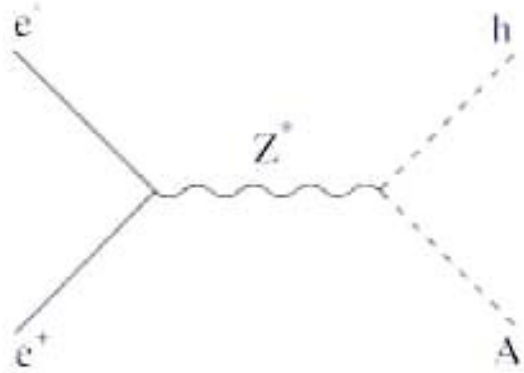
$$\propto \sin^2(\beta-\alpha)$$

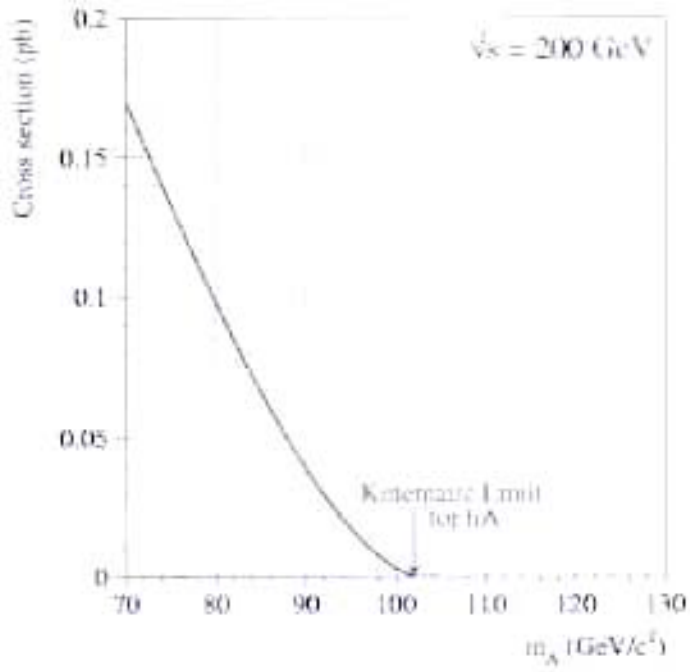
$$\propto \cos^2(\beta-\alpha)$$

Higgsstrahlung

Pair production



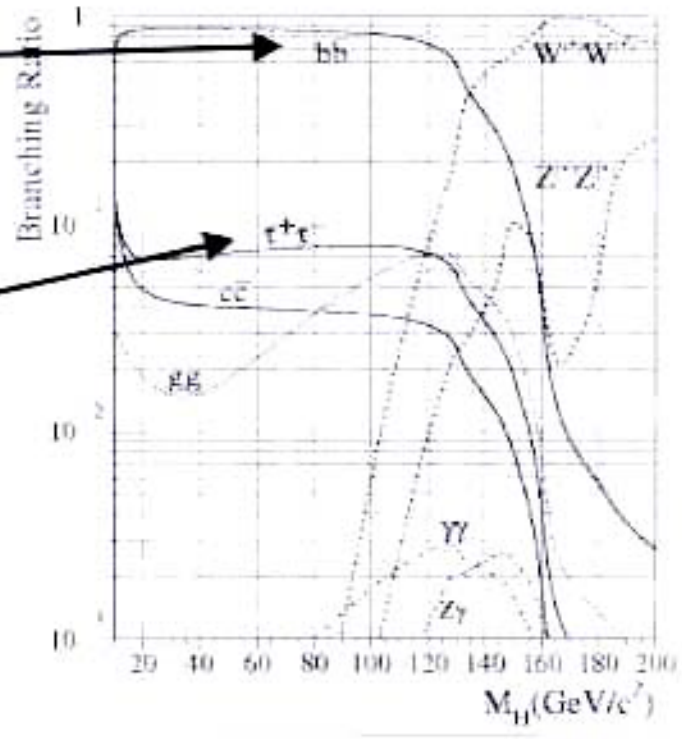




SM Higgs : decay B.R.

$$b\bar{b} \approx 82\%$$

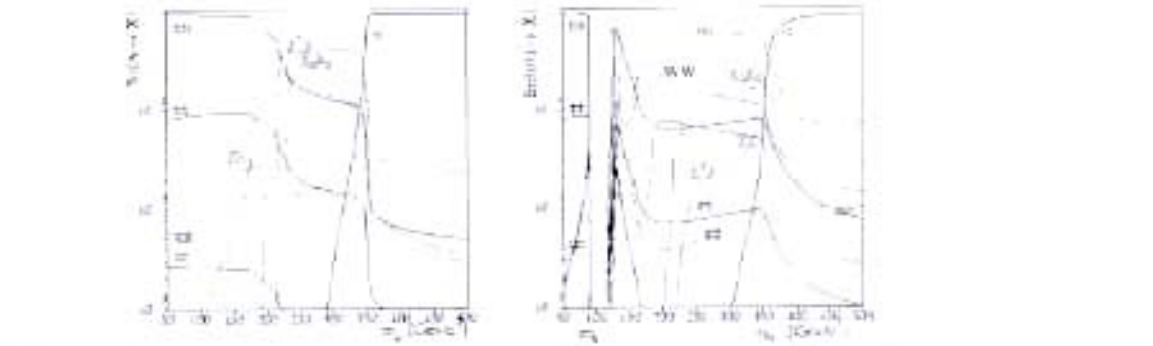
$$\tau^+\tau^- \approx 8\%$$



Decay at LEP
dominated by b's
and to a lesser extent by tau's

The same is true for h and A in MSSM

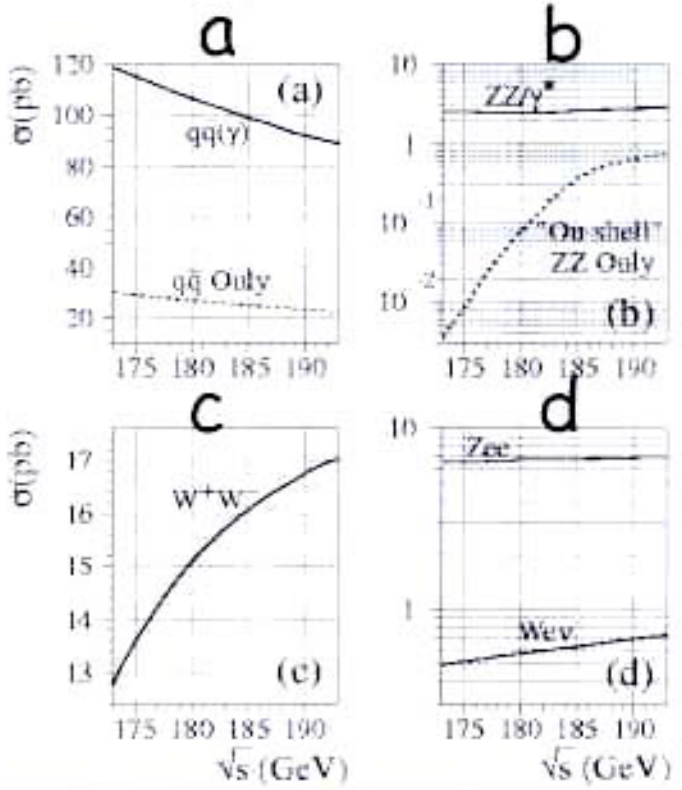
MSSM Higgs : decay B.R.



Computed with the parameters
$\tan\beta = 2$, $\mu = -100$ GeV, $A=0$, $m_{stop}=1000$ GeV, $M_2= 500$ GeV

Backgrounds X-sect

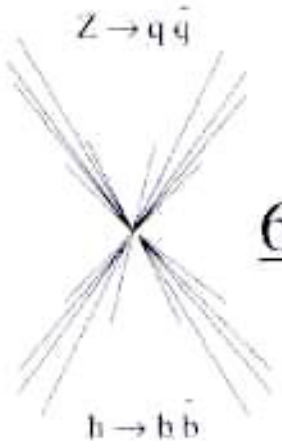
- (a) qq and Z return ($qq\gamma$), large but easy to reject
- (b) ZZ , "irreducible background" for neutral Higgs
- (c) WW, "irreducible" for charged Higgs
- (d) Single W, missing energy but small



→ BUT WATCH FOR TAILS AS $q\bar{q}g$ → $b\bar{b}$

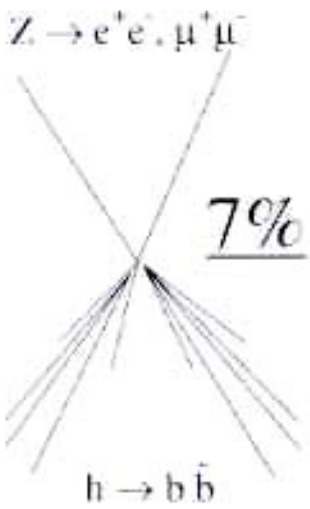
The topologies

The Physics Tools



63%

four jets

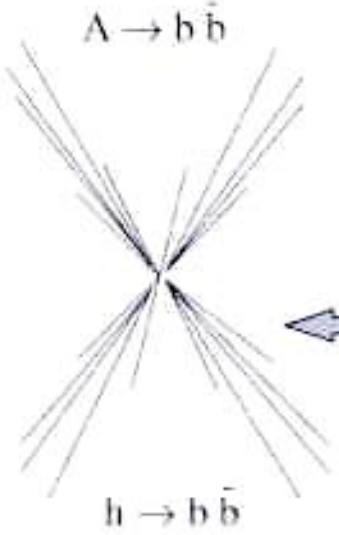


7%

lepton id

20%

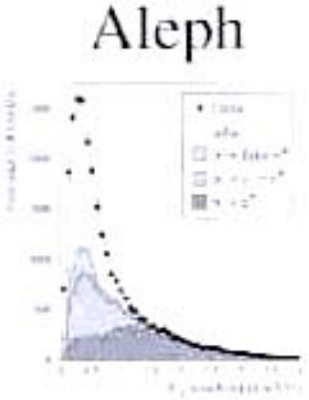
missing energy

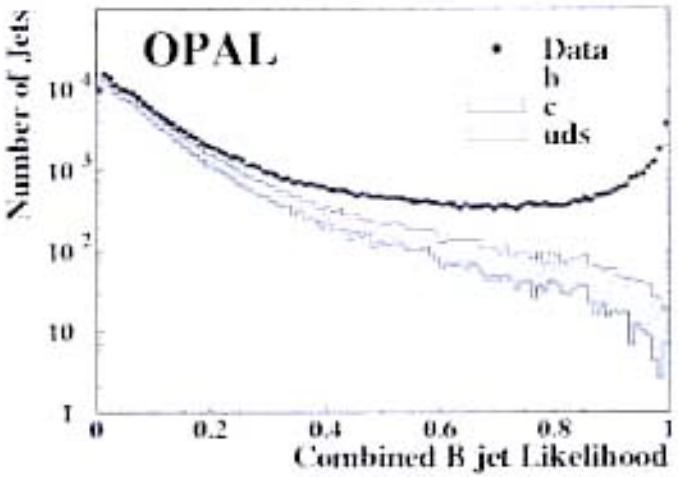


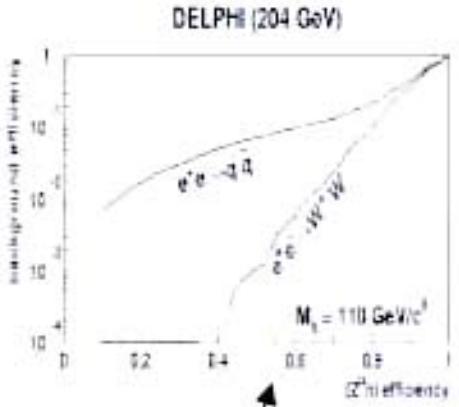
lots of b-tagging

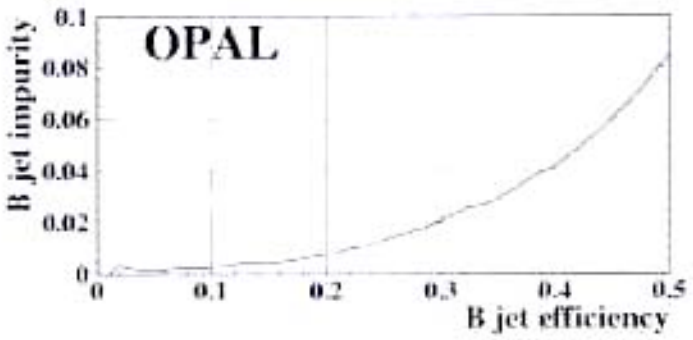
b's can be replaced by taus

b tagging



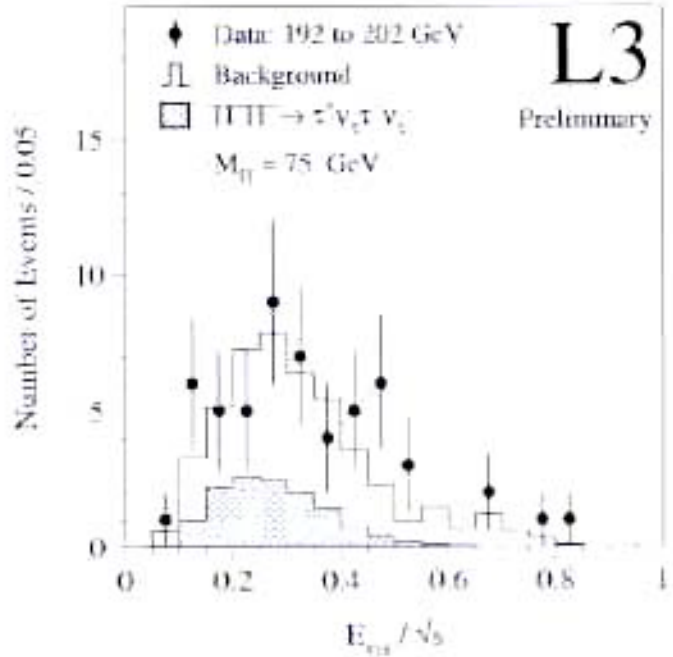


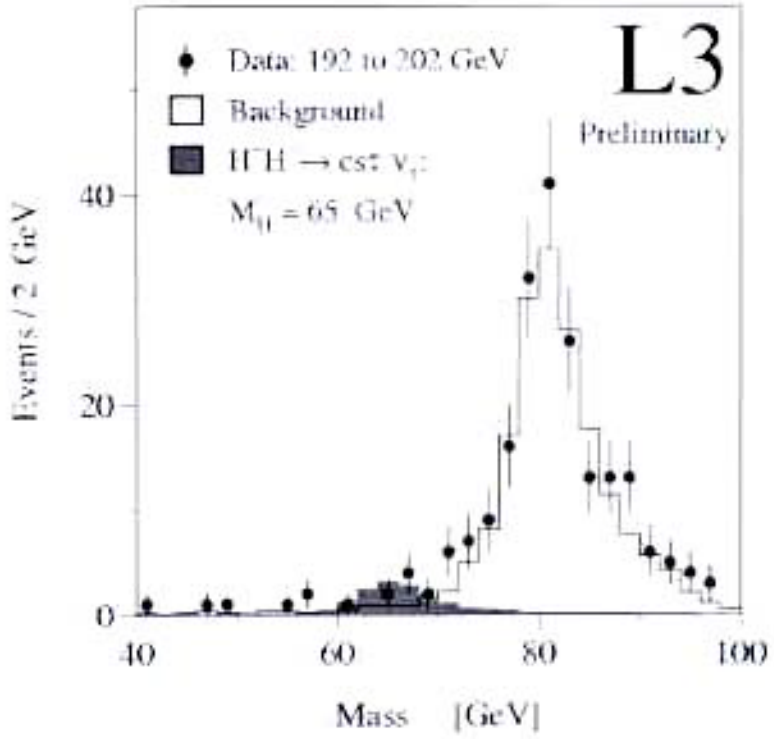




- Use
  - secondary vertices
  - lepton P_T
  - event shape
- Combine them with Neural Network

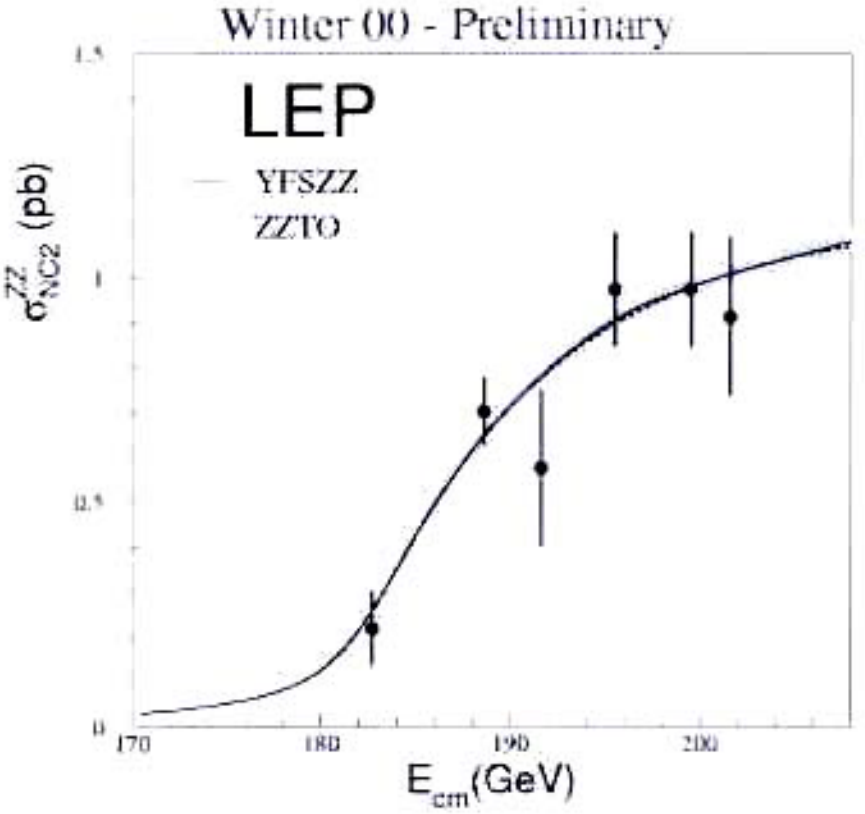
Energy flow,
Jet reconstruction,
Missing energy,
Reconstructed Mass





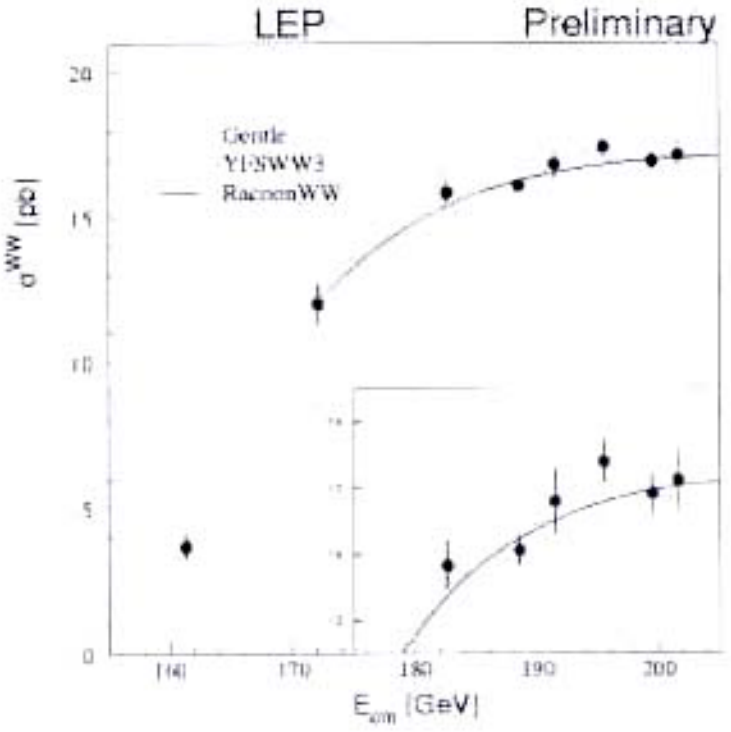
Backgrounds : the ZZ

"If we see the ZZ why should we miss the HZ ??"

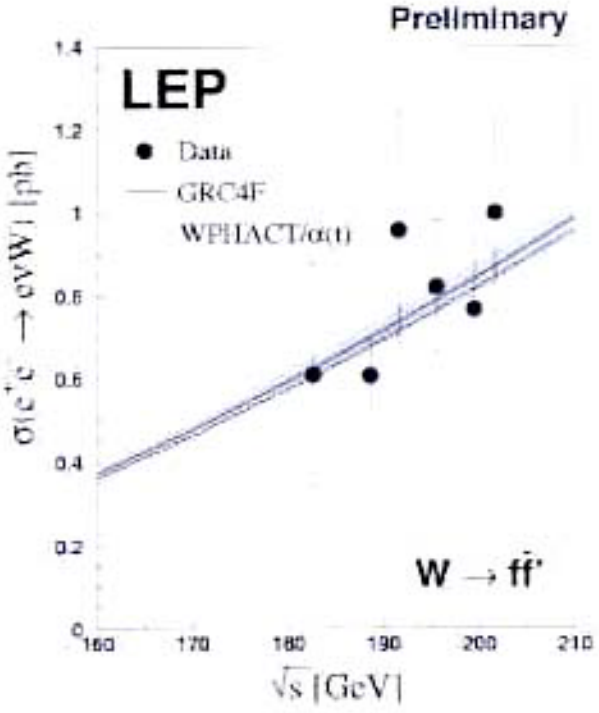


Backgrounds : the W's

In pairs...

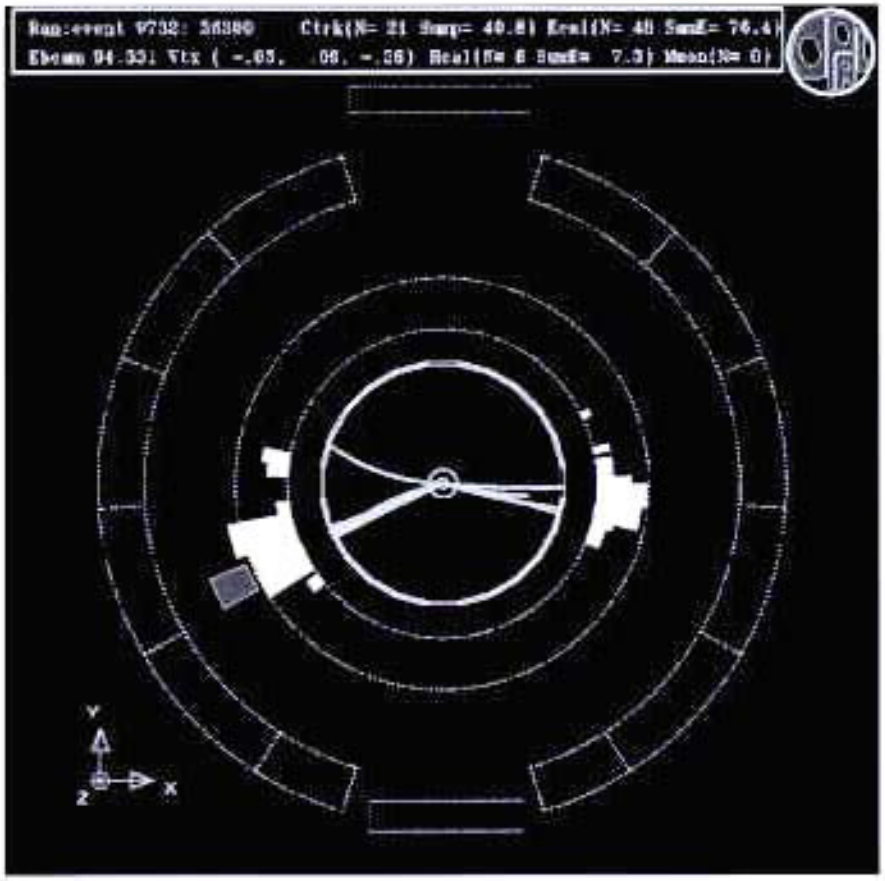


...and single !



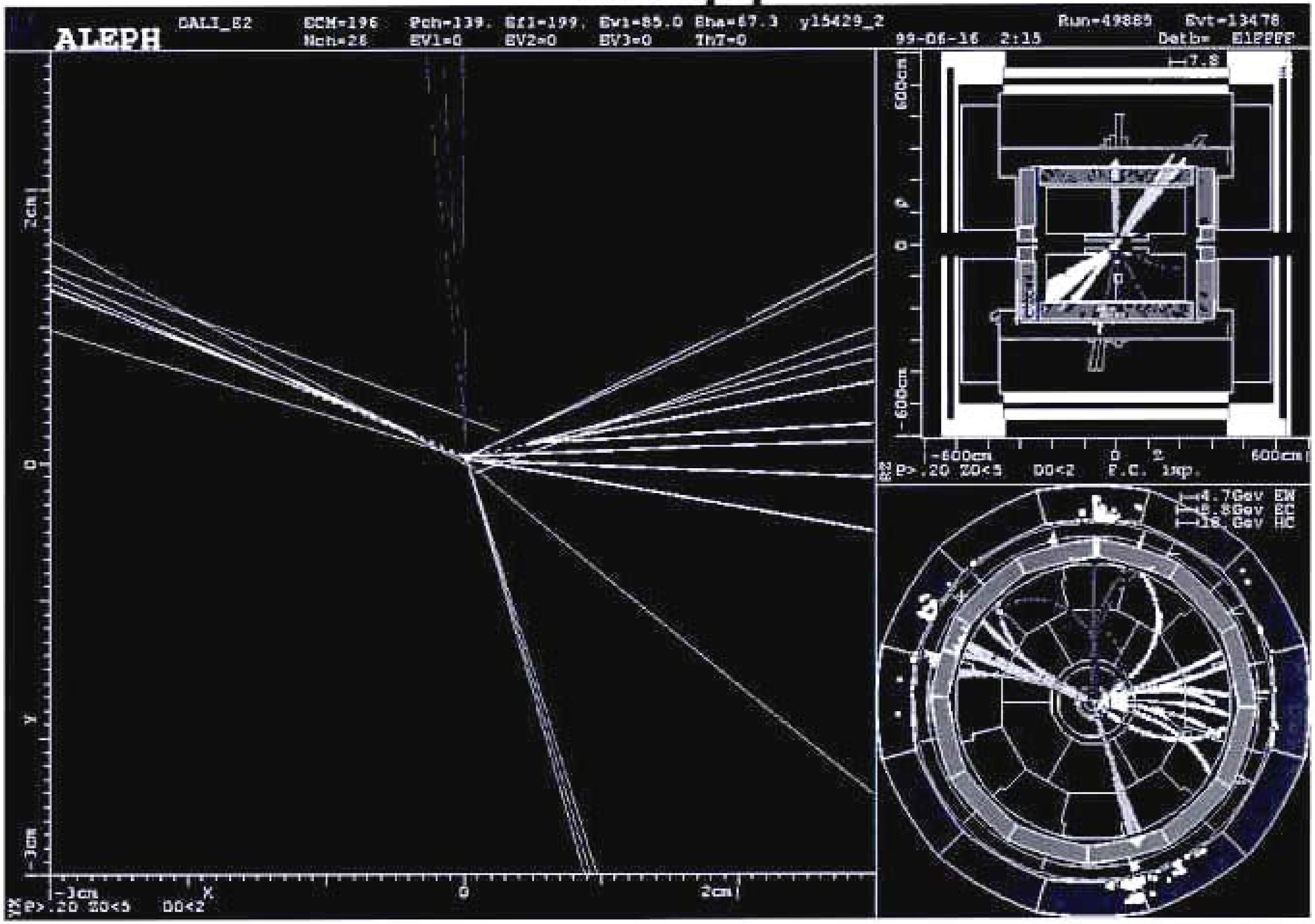
Candidates

qqνν

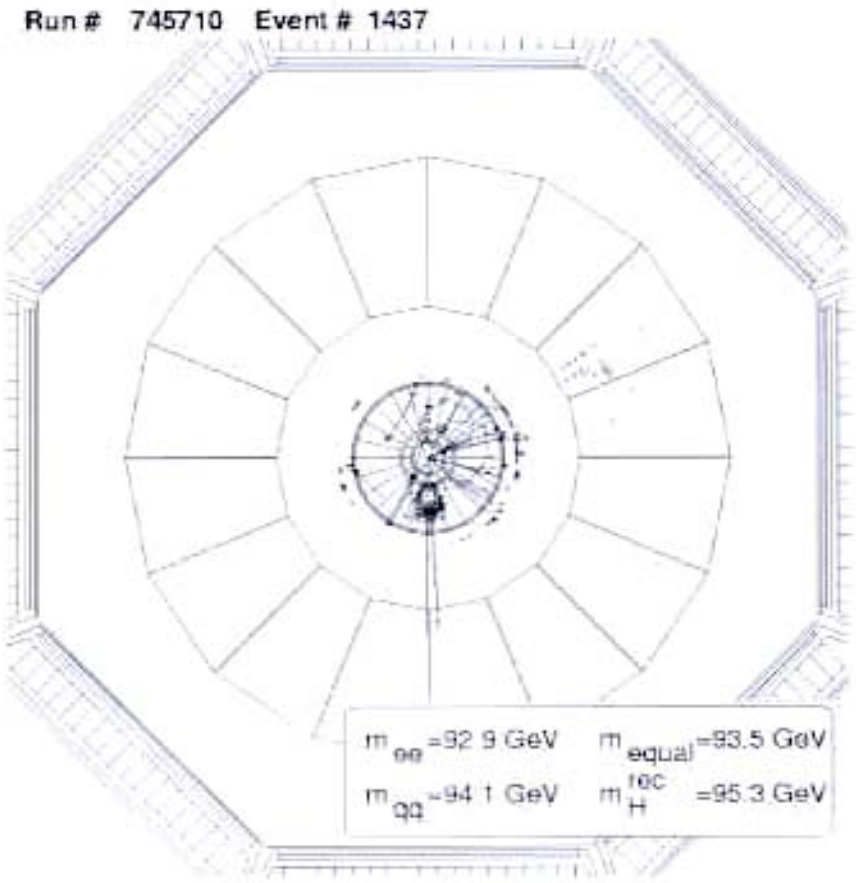


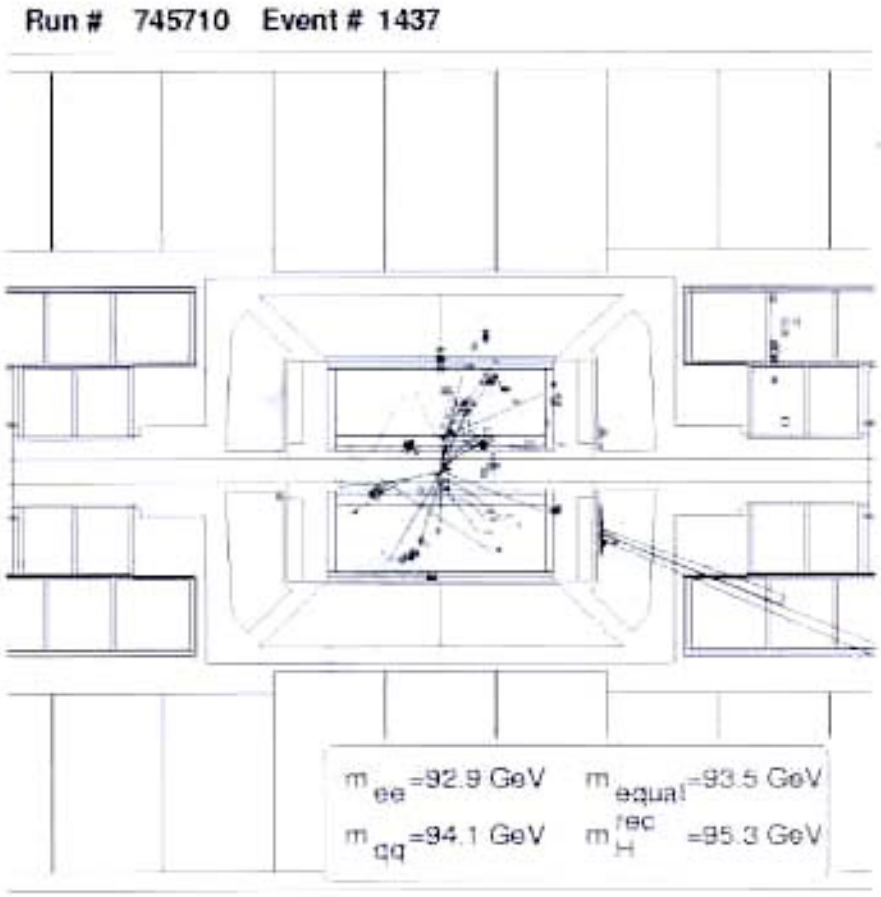
qqqq

bbqq

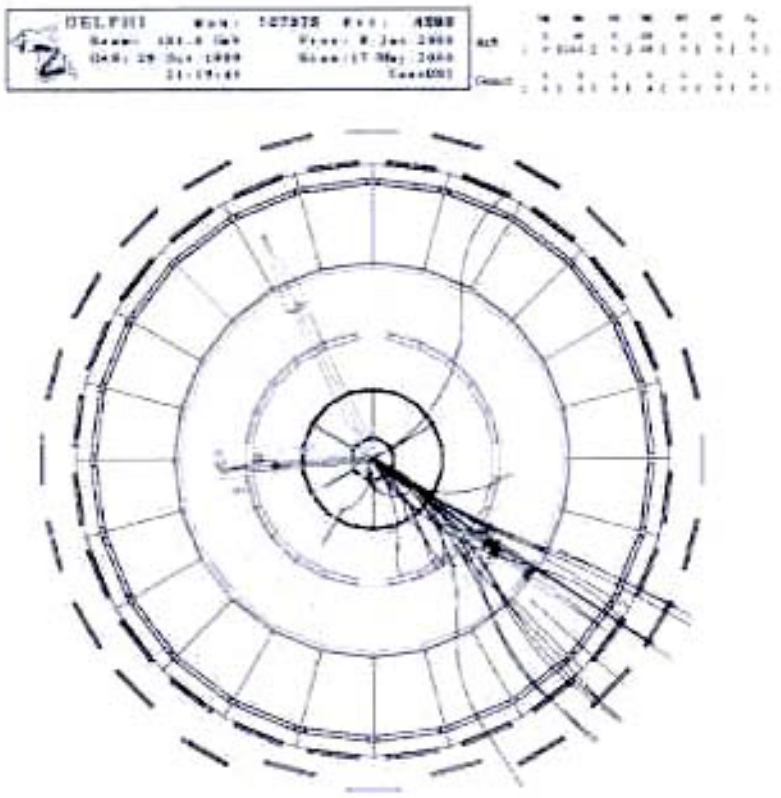

ALEPH
DALI_E2
ECM=196
Pch=139.
Efl=199.
Ew1=85.0
Eha=67.3
y15429_2
Nch=26
EV1=0
EV2=0
EV3=0
ThT=0
Run=49885
Evt=13478
99-06-16 2:15
Detb= E1FFFF
600cm
-600cm
0
2cm
-3cm
2cm
YX ρ>.20 Z0<5 D0<2
4.7Gev EW
8.8Gev EC
18. Gev HC

eeqq

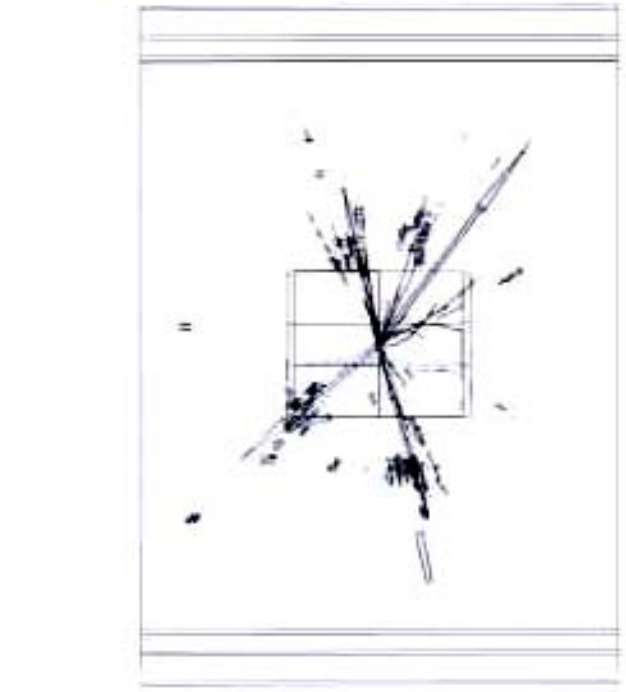

Run # 745710 Event # 1437
m_{ee}=92.9 GeV m_{equal}=93.5 GeV
m_{qq}=94.1 GeV m_{H}^{rec}=95.3 GeV


Run # 745710 Event # 1437
m_{ee}=92.9 GeV m_{equal}=93.5 GeV
m_{qq}=94.1 GeV m_{H}^{rec}=95.3 GeV

bbνν



bbqq

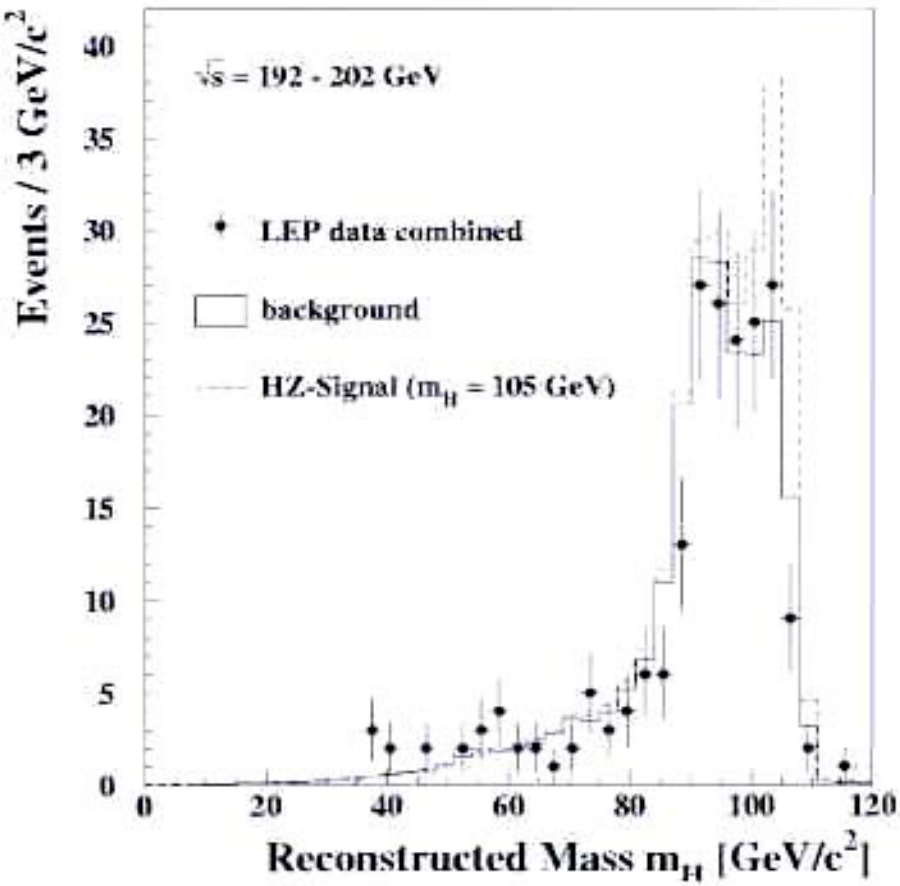


Reconstructed Higgs mass

Data of 4 LEP exp at $\sqrt{s} = 192 \div 202\ \mathrm{GeV}$
combined

$$\int L = 900\ \mathrm{pb}^{-1}$$

201 events found
220 expected
Higgs at 105 GeV gives 40.7 evts



The 95% Confidence Level

Setting a limit on the Confidence Level of an experiment with bkg
⟹ Background Subtraction

Example

$$CL_{s+b} = \sum_{i=0}^{n} \left[\exp(-(s+b)) \frac{(s+b)^i}{i!} \right] \cdot shape_i^n$$

Counting experiment

We want to use the mass, b content, etc, of the n events

Are you Bayesian or Frequentist ?

The Modified Frequentist approach
Used to set the 95% CL exclusion

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

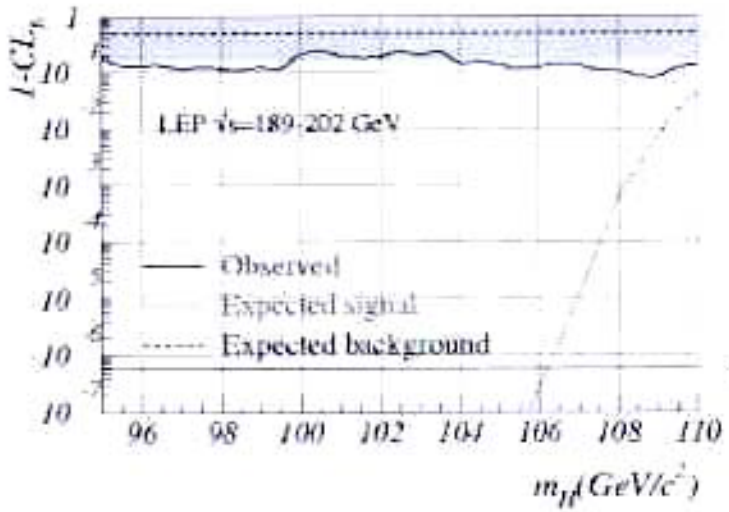
" In the signal hypothesis the probability that I get a worst result is less than 5%"

Tool for discovery : CL_b

" The background hypothesis is falsified by a fluctuation of X sigma"

The CL_b from the SM Higgs analysis of the 4 LEP exp.

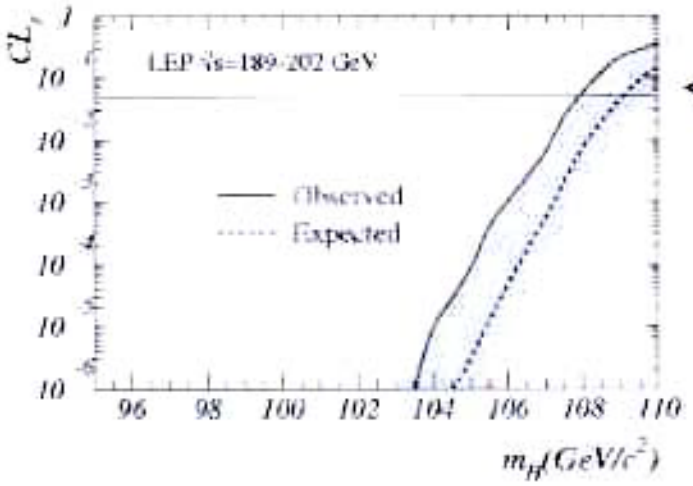
It tells us that the bkg is ok and we have not found the Higgs, yet...



5 σ

The CL_s from the SM Higgs analysis of the 4 LEP exp.

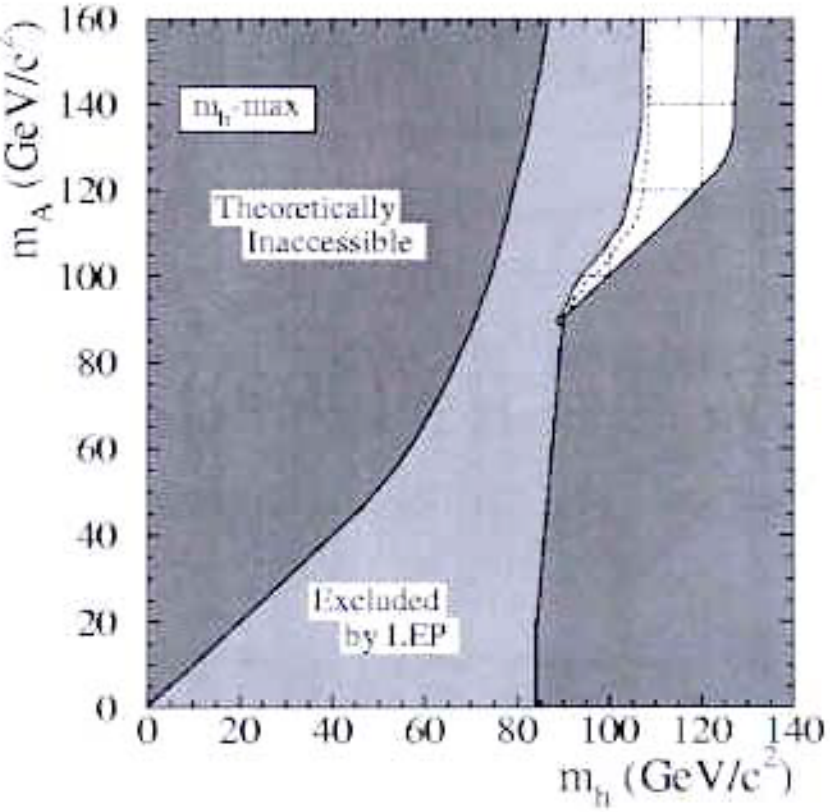
It tells us that the observed Higgs mass is > 107.9 GeV @ 95% CL
The expected sensitivity on the Higgs mass is > 109.1 GeV @ 95% CL

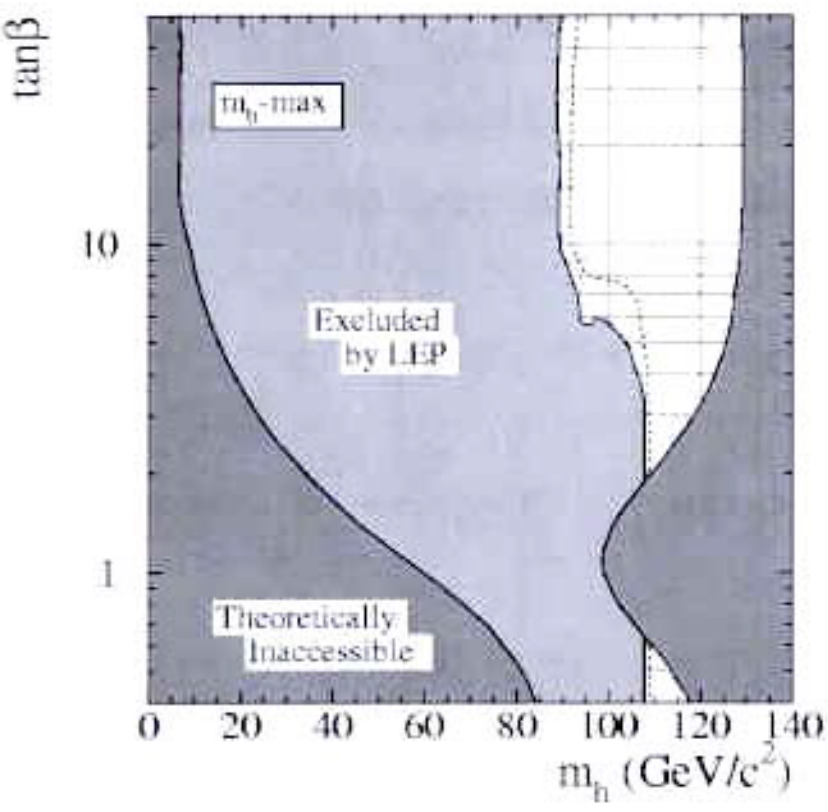


95% CL

Exclusion limits on the MSSM Higgs

A benchmark representative of a conservative set of SUSY parameters

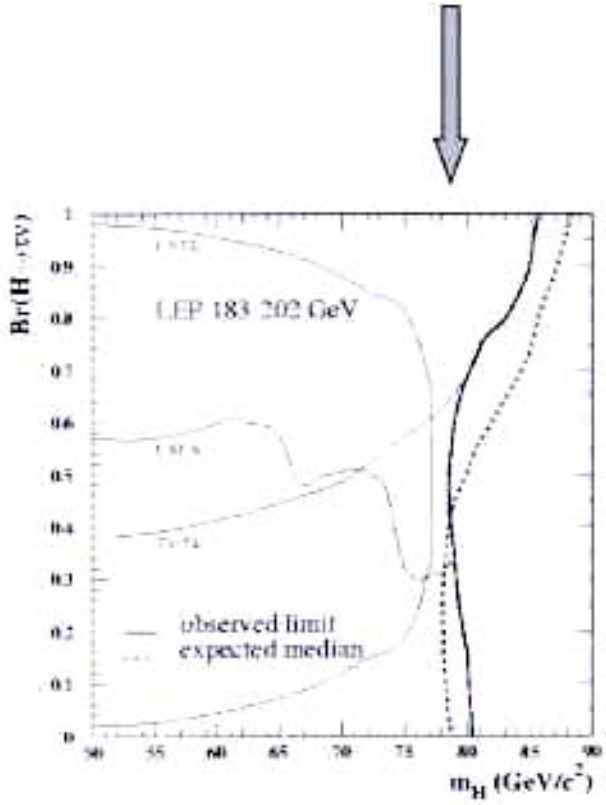




The charged Higgs limits

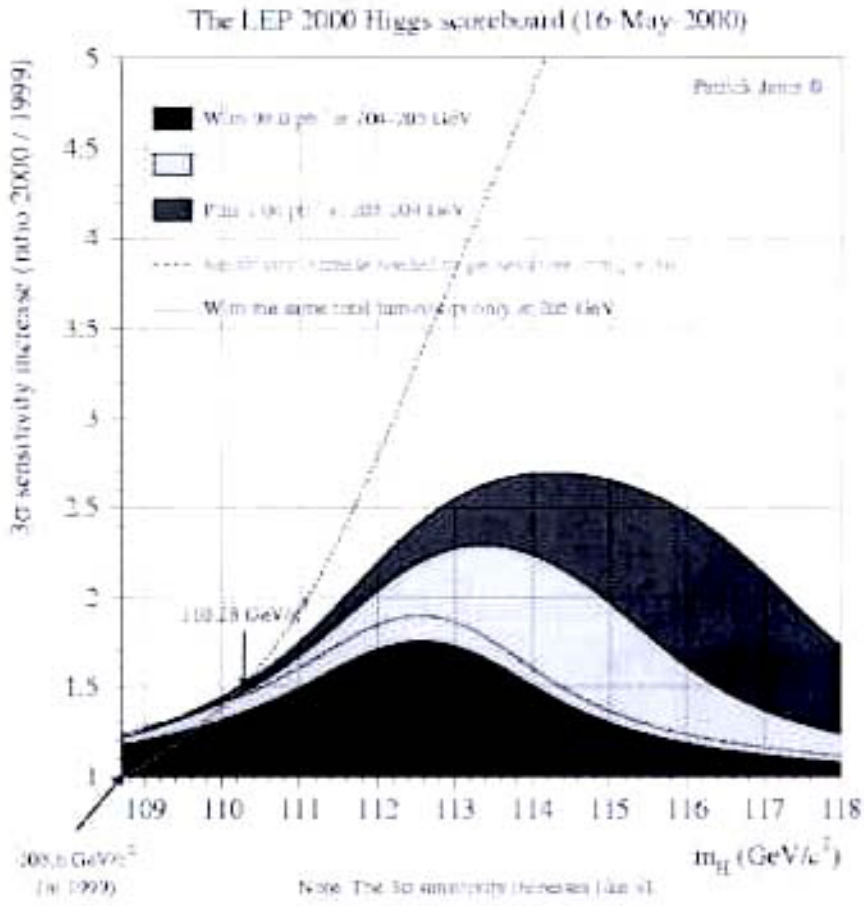
Reached the W mass limit

Decaying to τν an cs



Y2K LEP Running

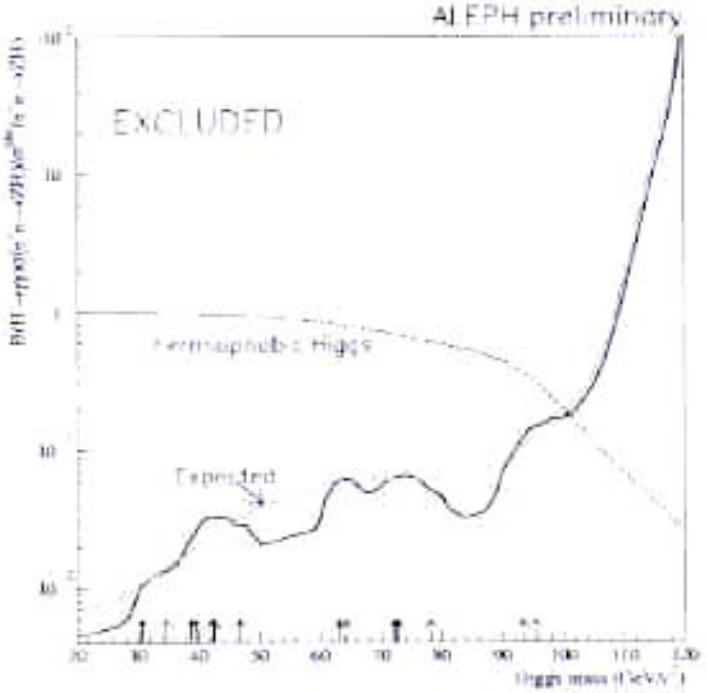
- More RF gradient (7.5 MV/m vs 7.1MV/m)
- Reinstalled Cu cavities (extra 20 MV)
- Slightly more bending length with horizontal orbit correctors
- Less RF margin
- Smaller RF central frequency
- Mini Ramp
- Maybe 2 on 2 bunches
- Improving turnaround time

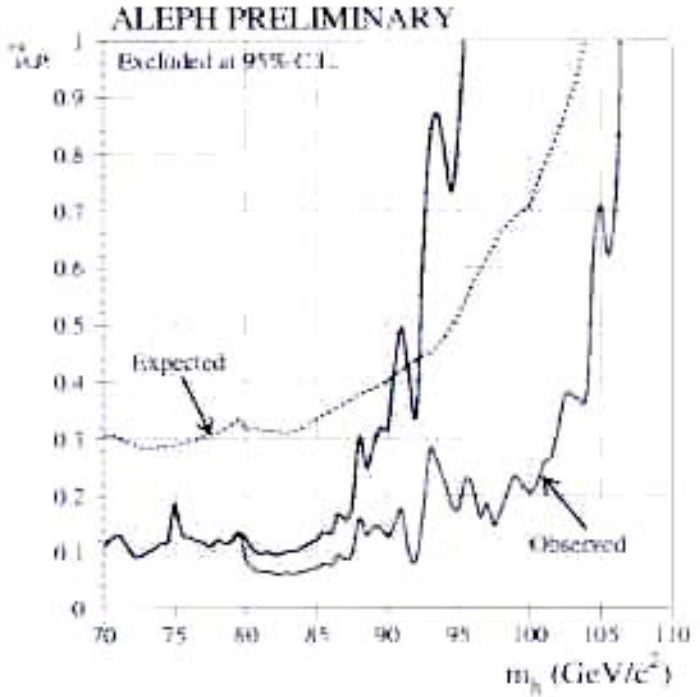


Exotics : the Fermiophobic and the Invisible Higgs

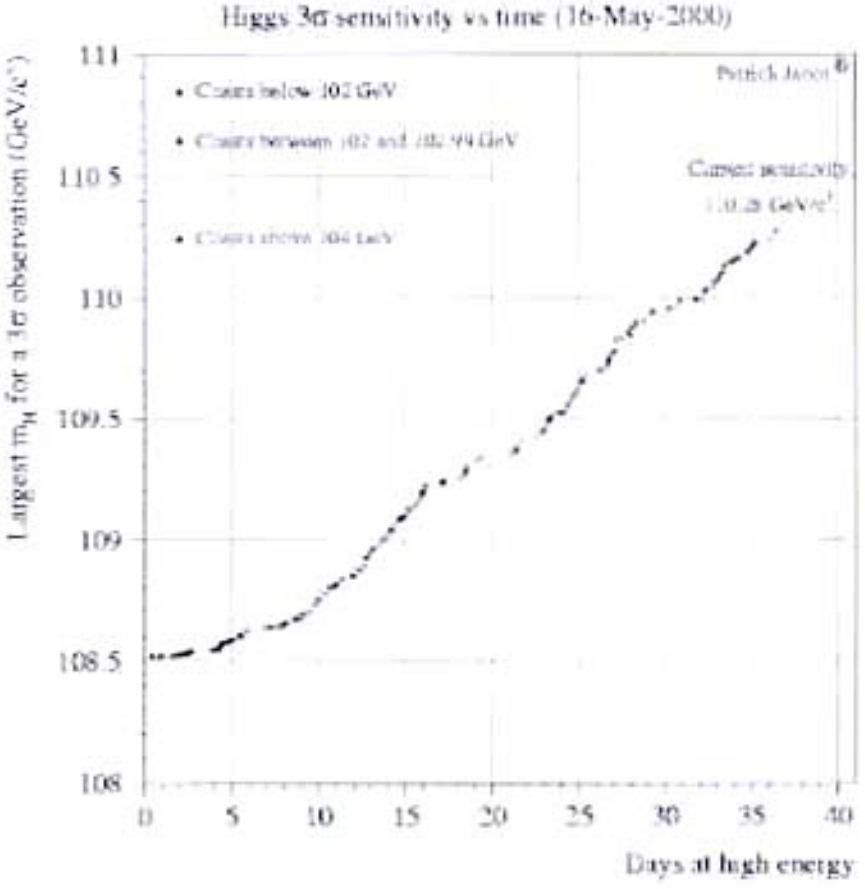
$$\frac{B(H \to \gamma\gamma)\sigma\left(e^+e^- \to HZ\right)}{\sigma^{SM}\left(e^+e^- \to HZ\right)}$$

$$\xi^2\sigma\left(e^+e^- \to HZ\right)$$



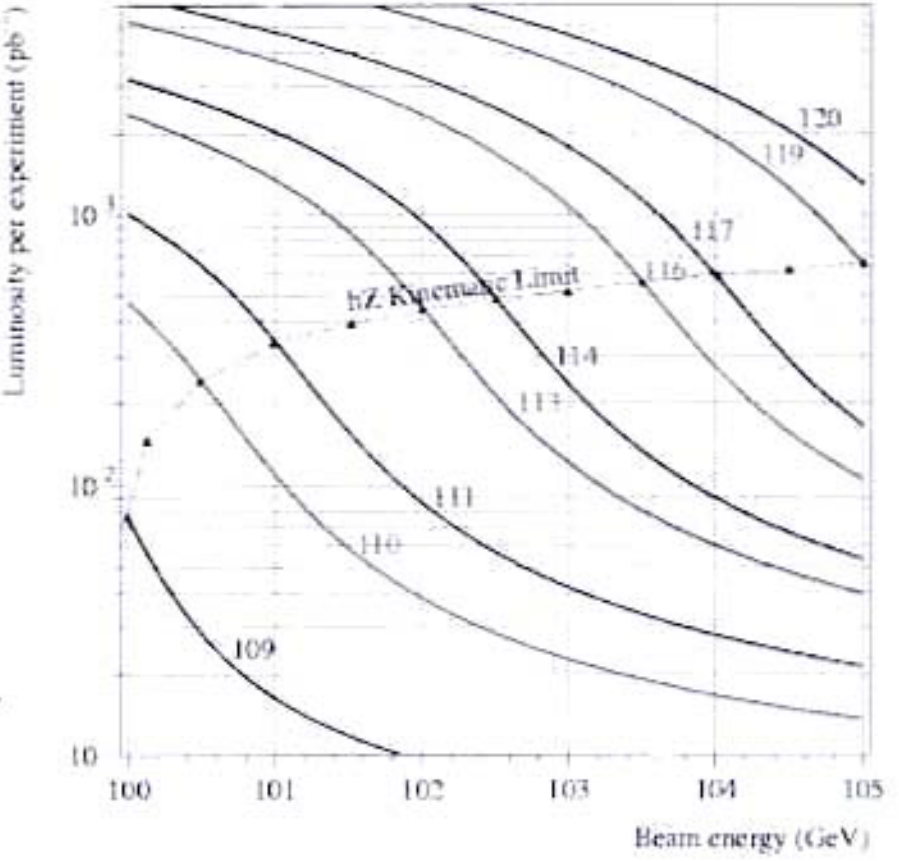


Trying to catch it .....



Online Higgs sensitivity limit

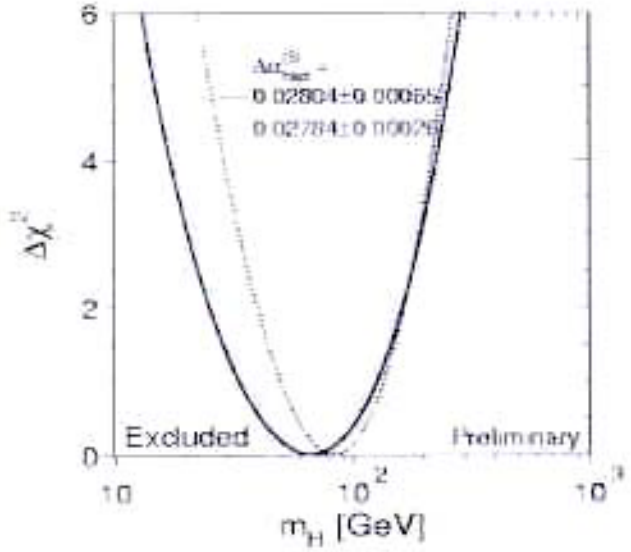
Higgs limit : Luminosity vs energy

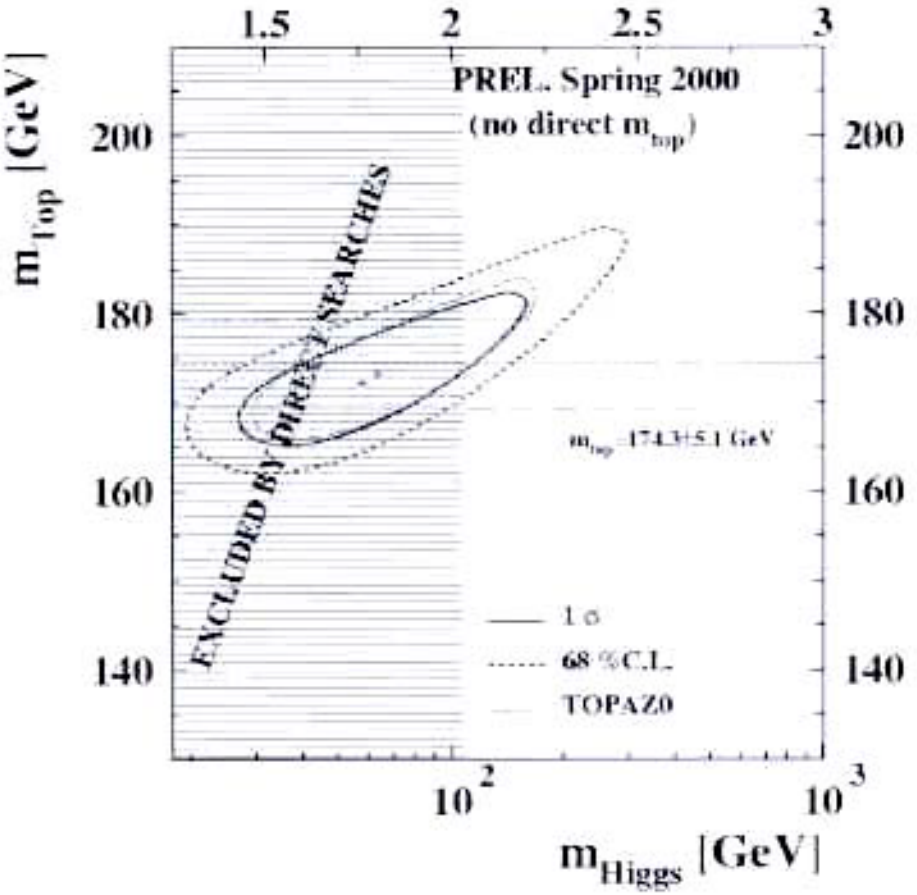


Squeezing the Higgs .....

- Higgs limit from EW precision measurements
- Higgs sensitivity trough logaritmic dependence of radiative corrections

$$m_{Higgs} \leq 188\,\text{GeV}\ 95\%$$





Conclusions

- Lower bound of 107.9 GeV on the SM Higgs mass
- In the MSSM $m_{h,(A)} > 88.3$ (88.4) GeV for $\tan\beta > 0.4$
- Excluded $0.7 < \tan\beta < 1.8$
- Charged Higgs mass > 78.6 GeV for any BR
- LEP is going extremely well in year 2000, we are heading toward a sensitivity of 114 GeV, maybe more .....