

# Status of Higgs Searches



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*Physics at LHC*

*13-17 July 2004 . Vienna . Austria*



# Outline

- Non-SM Higgs searches at LEP
- Search for the SM Higgs at LEP
- Electroweak data and the Higgs mass

## Not covered here:

- Latest news from the Tevatron (talk by B.Tuchming)
- Studies/Prospects for the LHC (talk by P.Sphicas)

All limits at 95% c.l. – All discoveries at  $5\sigma$

# Non-SM Higgs searches

## ■ Fermiophobic Higgs

- $h^0 \rightarrow \gamma\gamma$

## ■ Invisible Higgs

- e.g.  $h^0 \rightarrow$  neutralinos

## ■ Flavour independent Higgs

- $h^0 \rightarrow qq\bar{q}$

## ■ Charged Higgs

- $H^+ \rightarrow c\bar{s}$  or  $\tau^+\nu_\tau$

## ■ Neutral Higgs bosons of the MSSM

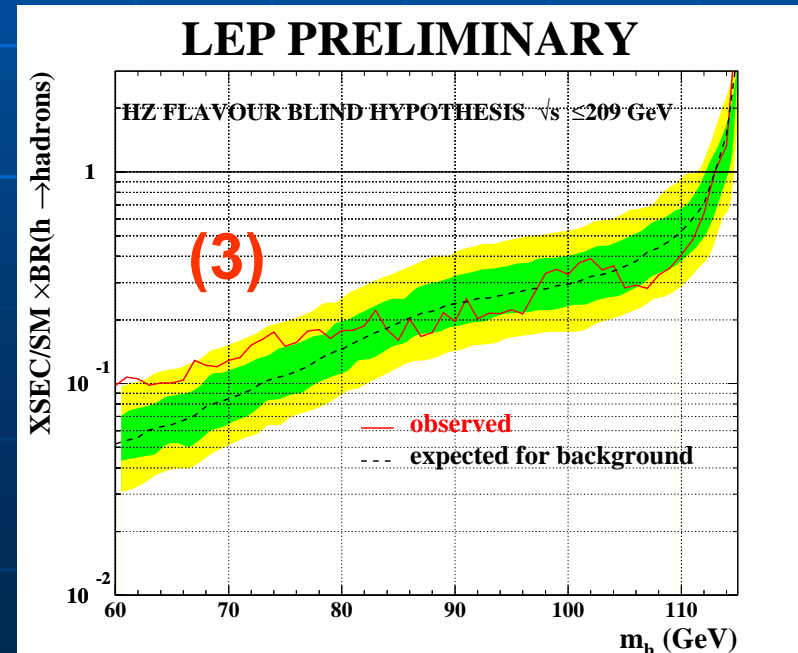
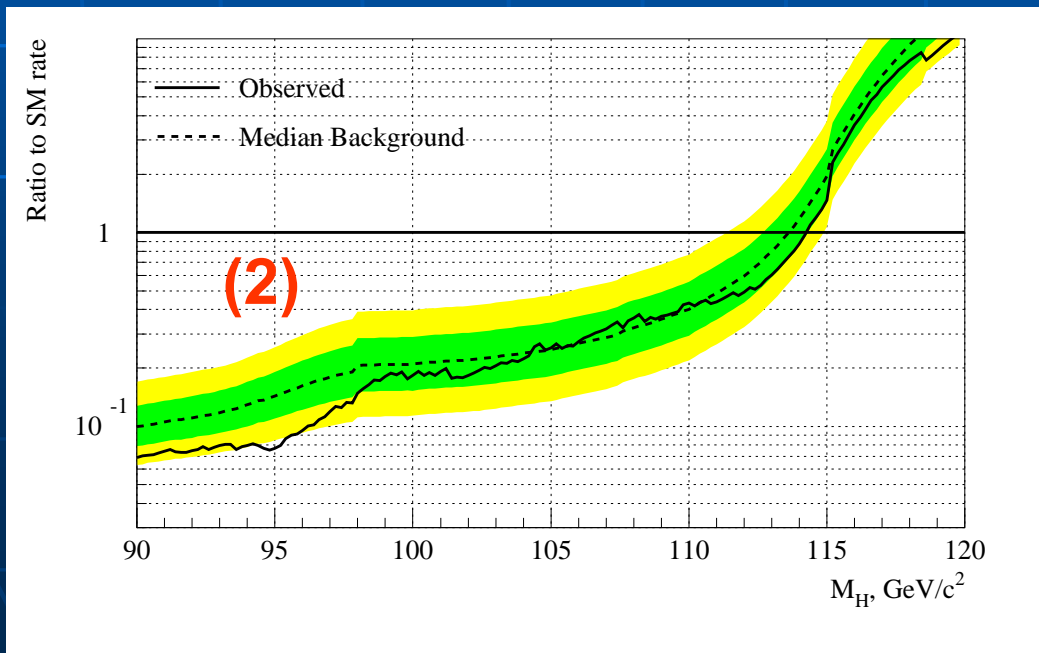
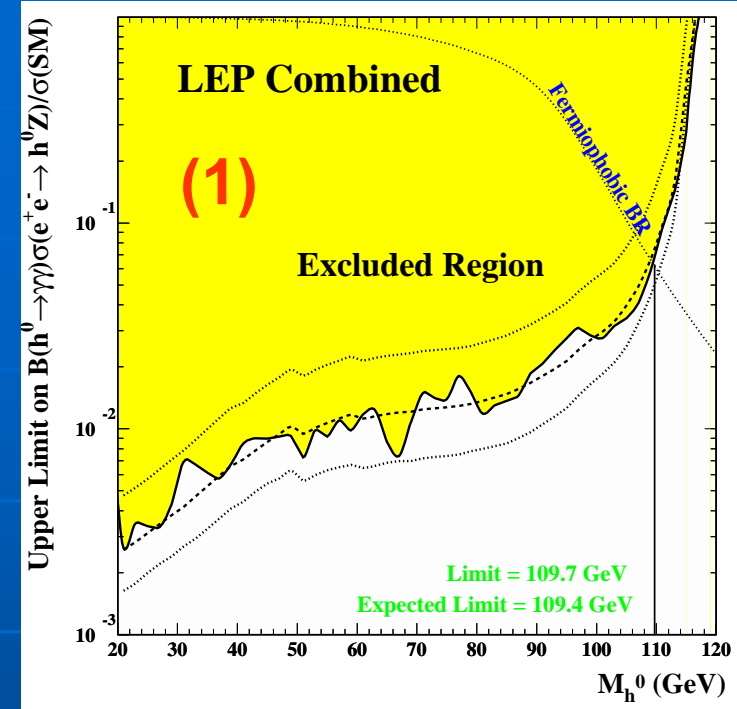
- $e^+e^- \rightarrow hZ/hA$       $h/A \rightarrow b\bar{b}$

# Non-SM Higgs results

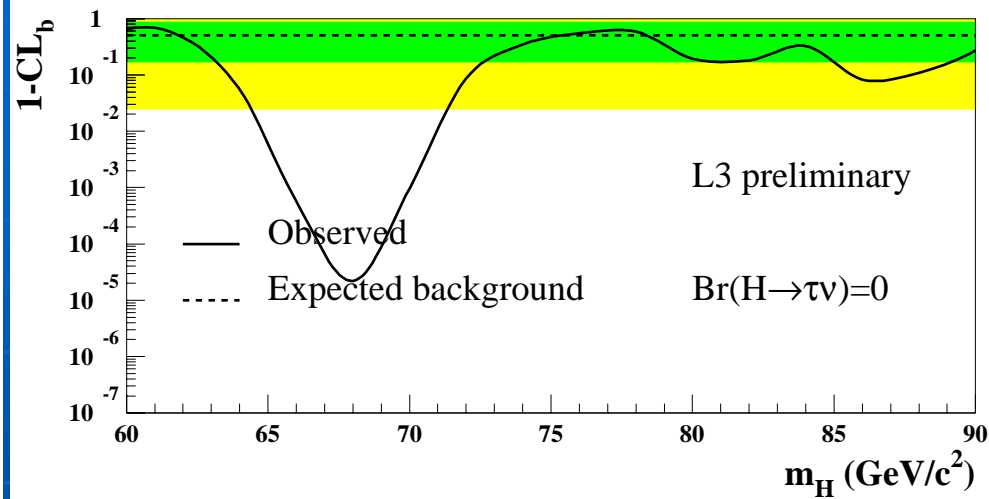
## For SM cross-section

1. Fermiophobic  $m_h > 117.2 \text{ GeV}$
2. Invisible  $m_h > 114.2 \text{ GeV}$
3. Flavour Indep.  $m_h > 112.9 \text{ GeV}$

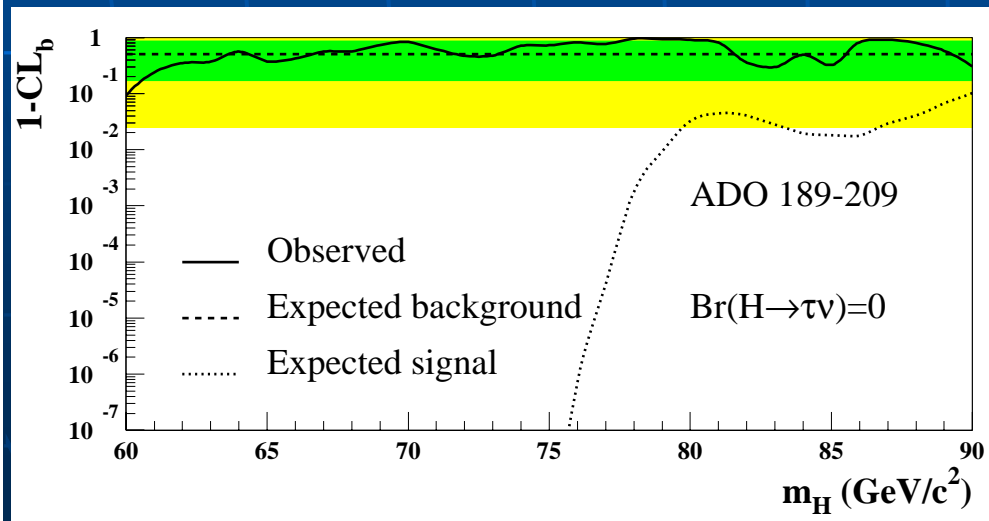
[ LEPHWG '01 ]



# Charged Higgs results

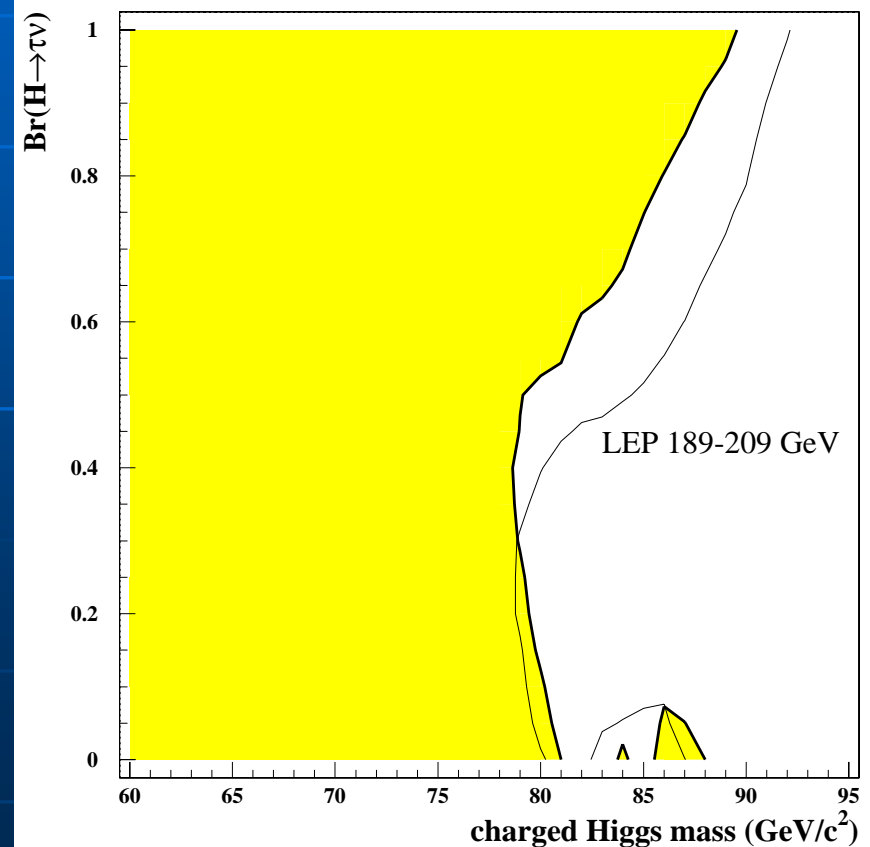


L3 excess at  $\sim 68\text{GeV}$ , mainly in cscs channel, not seen by ADO



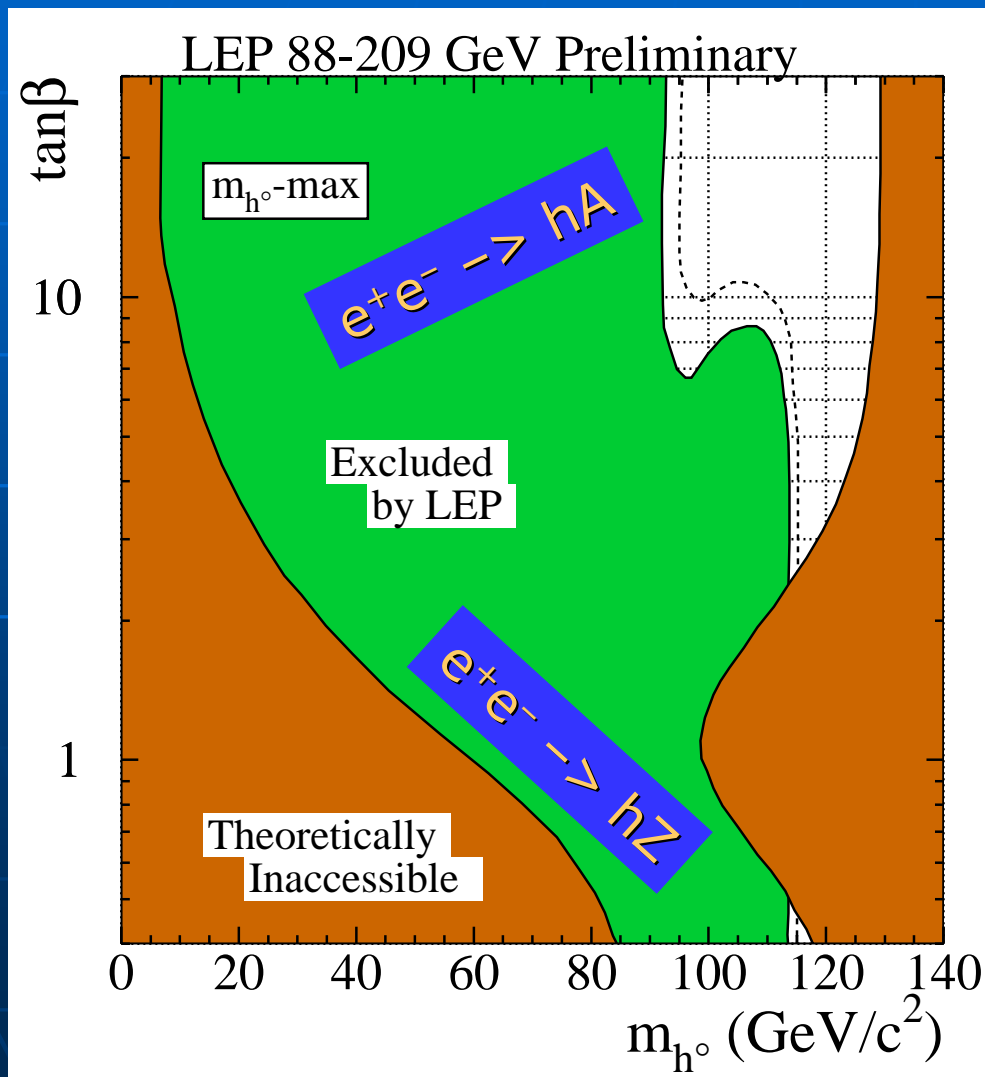
Independent of  $Br(H \rightarrow \tau\nu)$   
 $m_H > 78.6\text{GeV}$

[ LEPHWG '01 ]



# MSSM neutral Higgs results

[ LEPHWG '01 ]



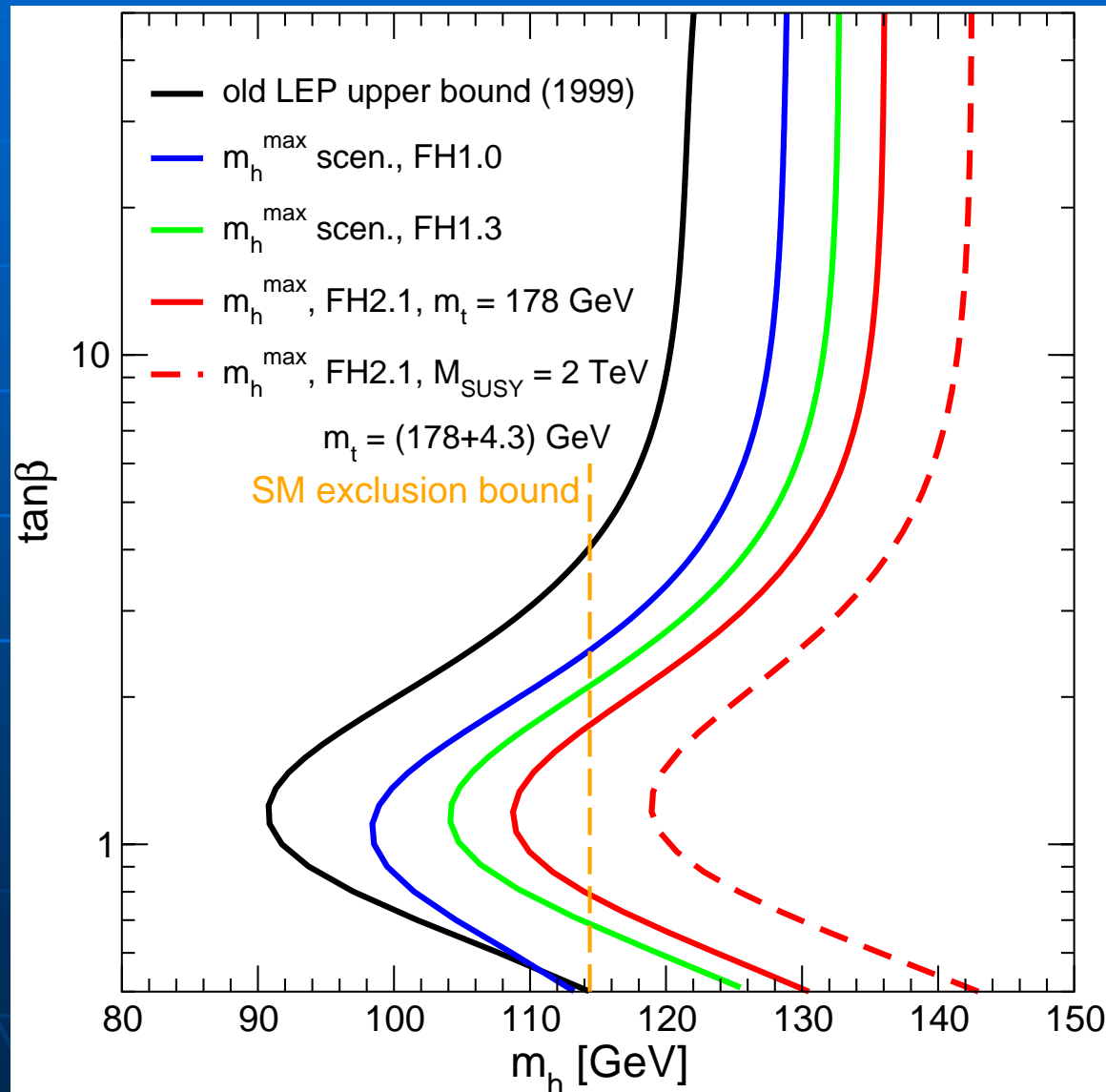
- Excluded for all tan $\beta$

- $m_h > 91.0$  GeV
- $m_A > 91.9$  GeV

- The range of tan $\beta$  that is fully covered depends on the theoretical upper bound on  $m_h$

# Effects on $m_h$ upper bound

[ S.Heinemeyer, G.Weiglein '04 ]



- Two-loop corrections pushed the  $m_h$  upper bound up a few GeV

- $\Delta m_h \sim \Delta M_t$



Current exclusion is  
 $0.8 < \tan\beta < 1.8$   
 (was  $0.5 \rightarrow 2.4$ )

- Almost no exclusion for  $M_{\text{SUSY}} = 2\text{TeV}$
- Implications for LSP limit? (talk by J.F.Grivaz)

# The SM Higgs search @ LEP

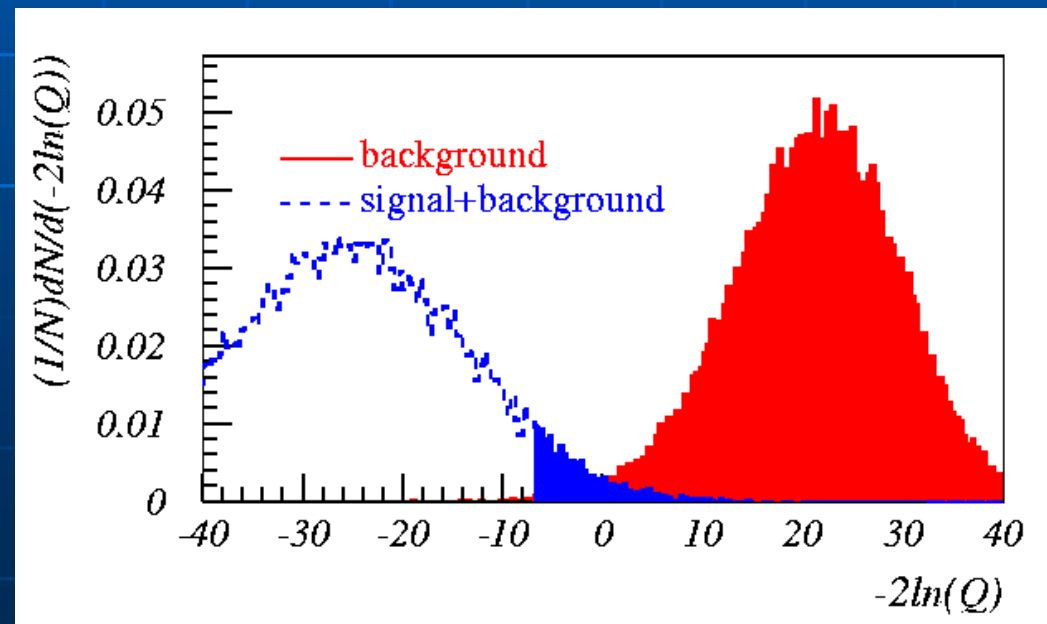


# Reminder on confidence levels

“The results of the experiment were inconclusive, so we had to use statistics...”

- Many channels/properties to combine. Strategy:
  - Assume a signal (e.g. SM Higgs:  $m=115\text{GeV}$ )
  - Put all the properties of signal/bkg in one **estimator  $\epsilon$**  (e.g. Likelihood Ratio:  $Q=L(s+b)/L(b)$ )
  - Use a large number of **toy expts** with bkg only or signal+bkg, and find the distributions of  $\epsilon$  (frequentist approach)
- Find  $\epsilon_{\text{data}}$  and then

$$\text{CL}_b = \int_{\epsilon_{\text{data}}}^{+\infty} \epsilon_b$$



# The SM Higgs saga (I)

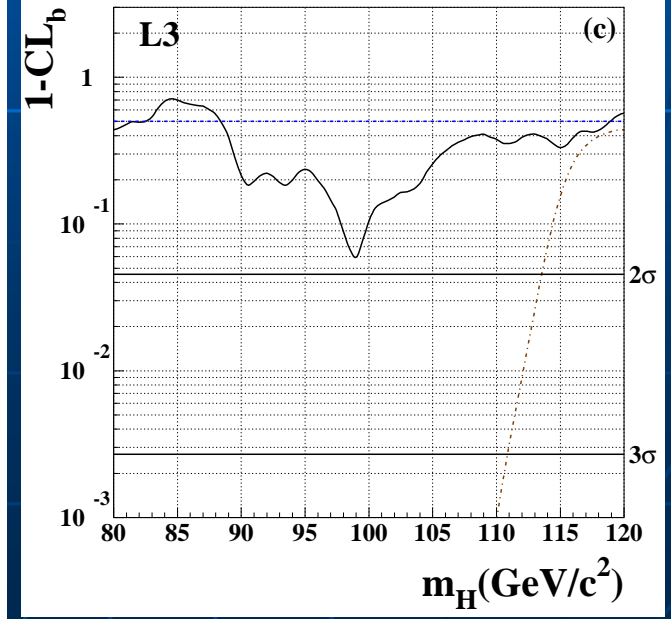
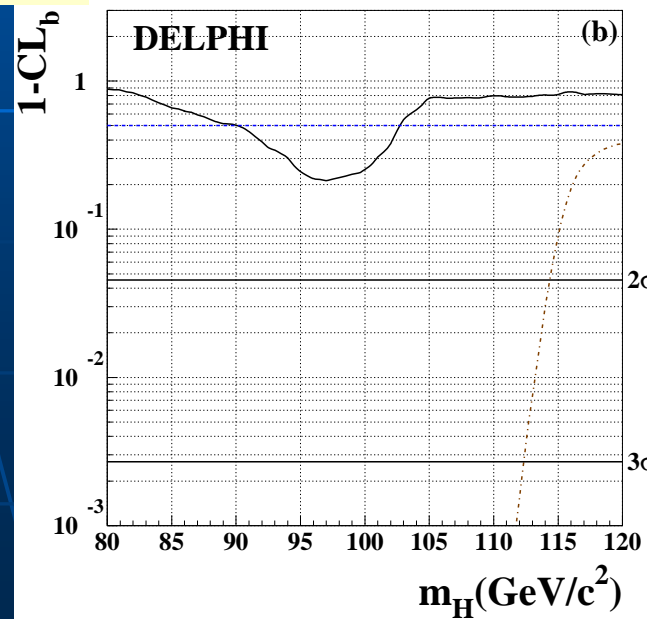
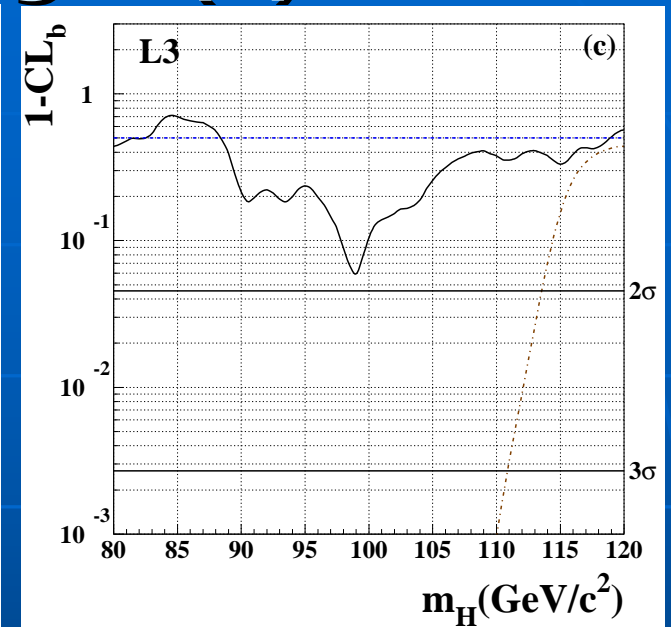
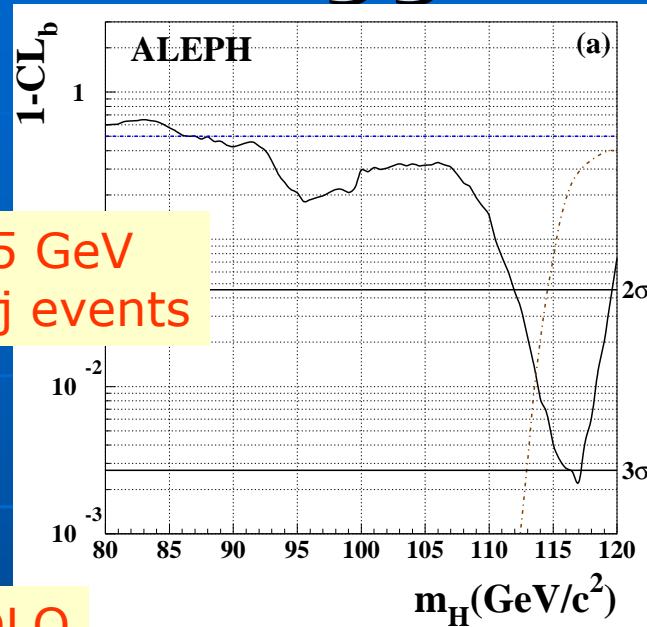
ALEPH excess near 115 GeV  
due to 2-3 "golden" 4-j events

Nothing observed by DLO

At  $m_H = 115 \text{ GeV}$ :

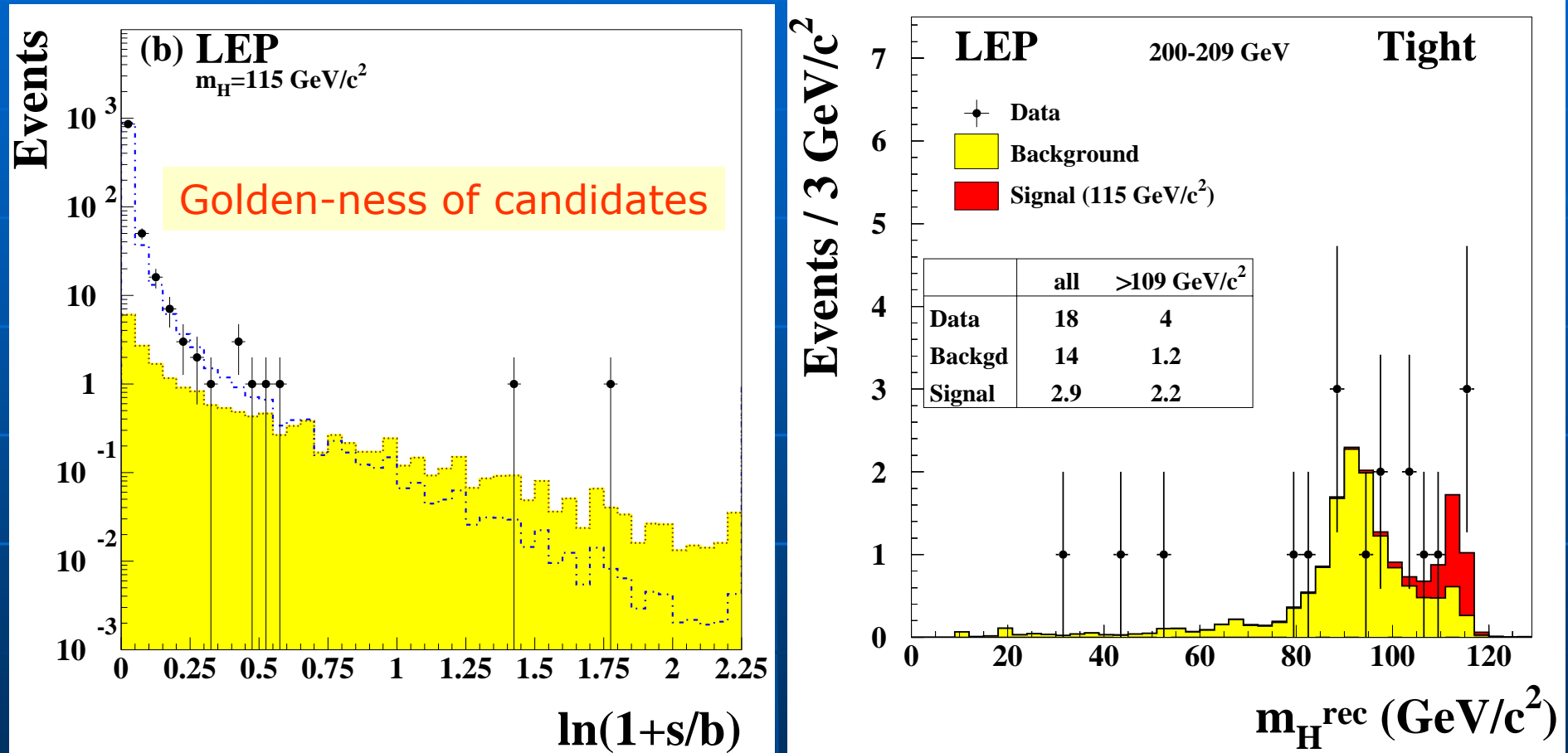
- ALEPH:  $2.7\sigma$  ( $< 5\sigma$ )
- LEP:  $1.7\sigma$  ( $< 5\sigma$ )

[ LEPHWG '03 ]

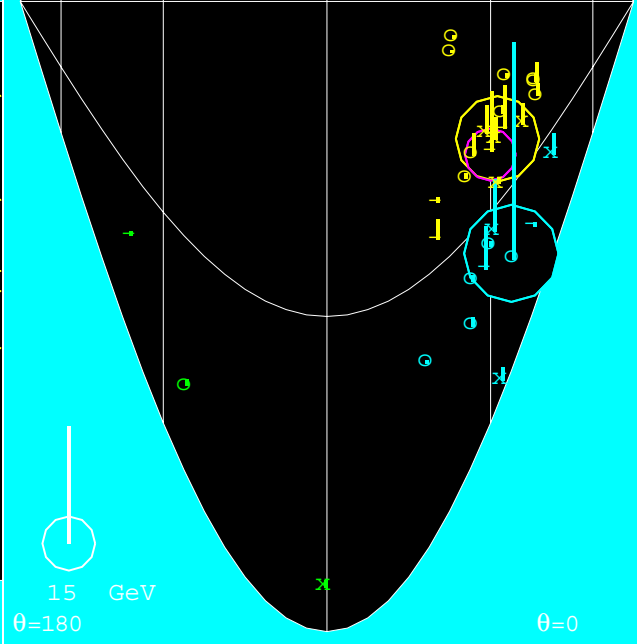
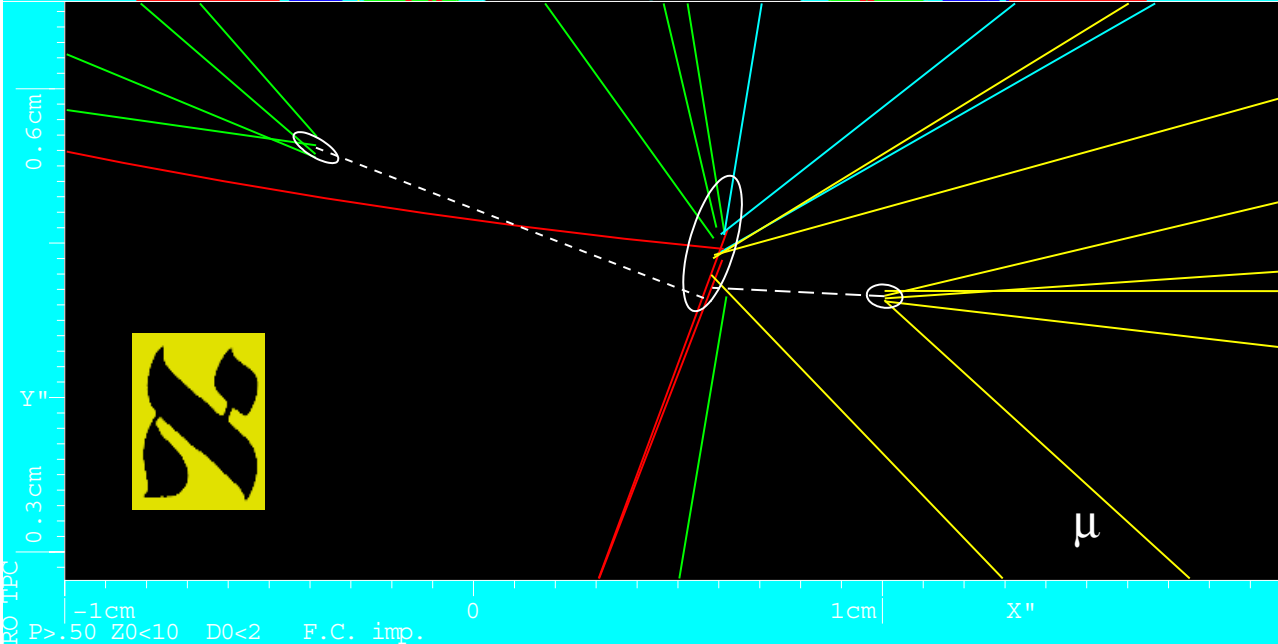
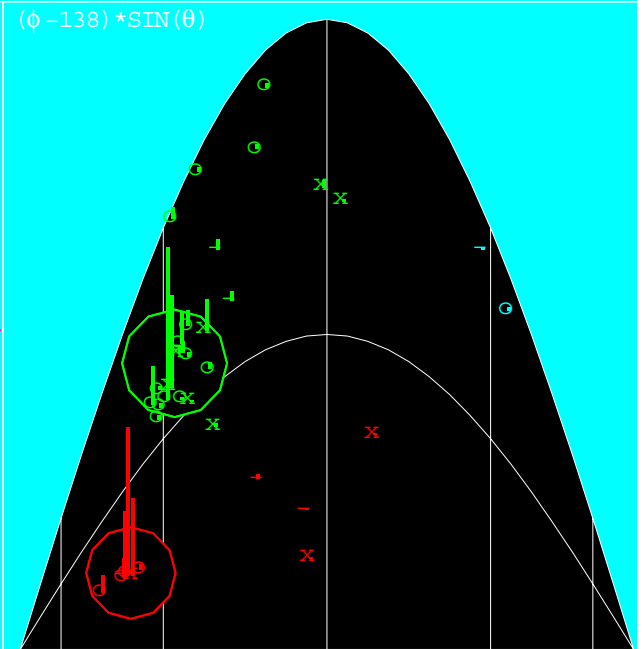
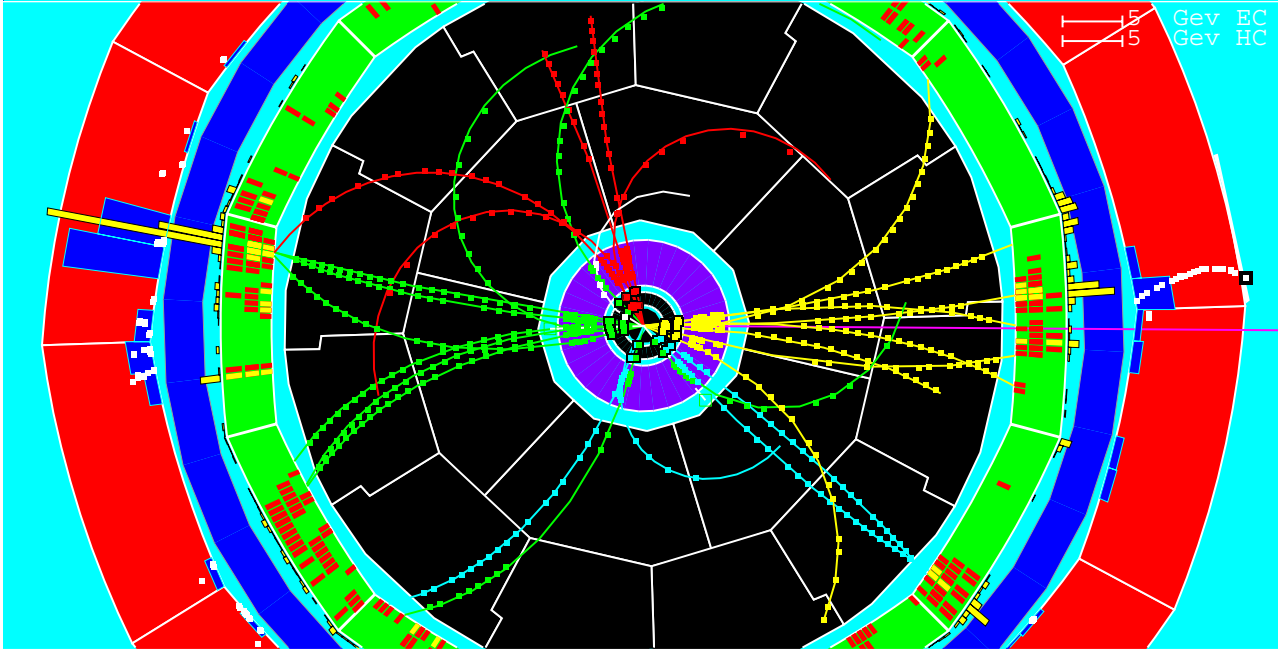


# The SM Higgs saga (II)

[ LEPHWG '03 ]



Overall, numbers consistent with Higgs production at  $\sim 115\text{-}116 \text{ GeV}$



RO tpc  
P>.50 Z0<10 D0<2 F.C. imp.

# Candidate 54698/4881

(recorded on 14/06/2000)

## ■ Properties

- Two clear b-jets (dec. length, inv. mass of tracks in vertex)
  - Event well-measured:  $P_{\text{mis}}$  in direction of jet with  $\mu$  from vertex
  - Planar event, as in threshold production of two heavy particles
  - b-jets: 55GeV & 59GeV, like in a decay almost at rest
  - Non-b jets: 43GeV & 49GeV, like in a Z decay almost at rest
  - Raw invariant mass of non-b jets 92.3GeV
  - non-b jets: leading parton effect, low multiplicity (q vs. gluon)
- Impossible to be a WW, almost impossible to be bbgg, very unlikely a  $ZZ^* \rightarrow qqbb$  and if it is...
- One candidate is not a discovery, but if  $m_H \sim 116\text{GeV}$  this was the first Higgs ever observed!

# Electroweak fits to the Higgs

# E/weak data and the Higgs

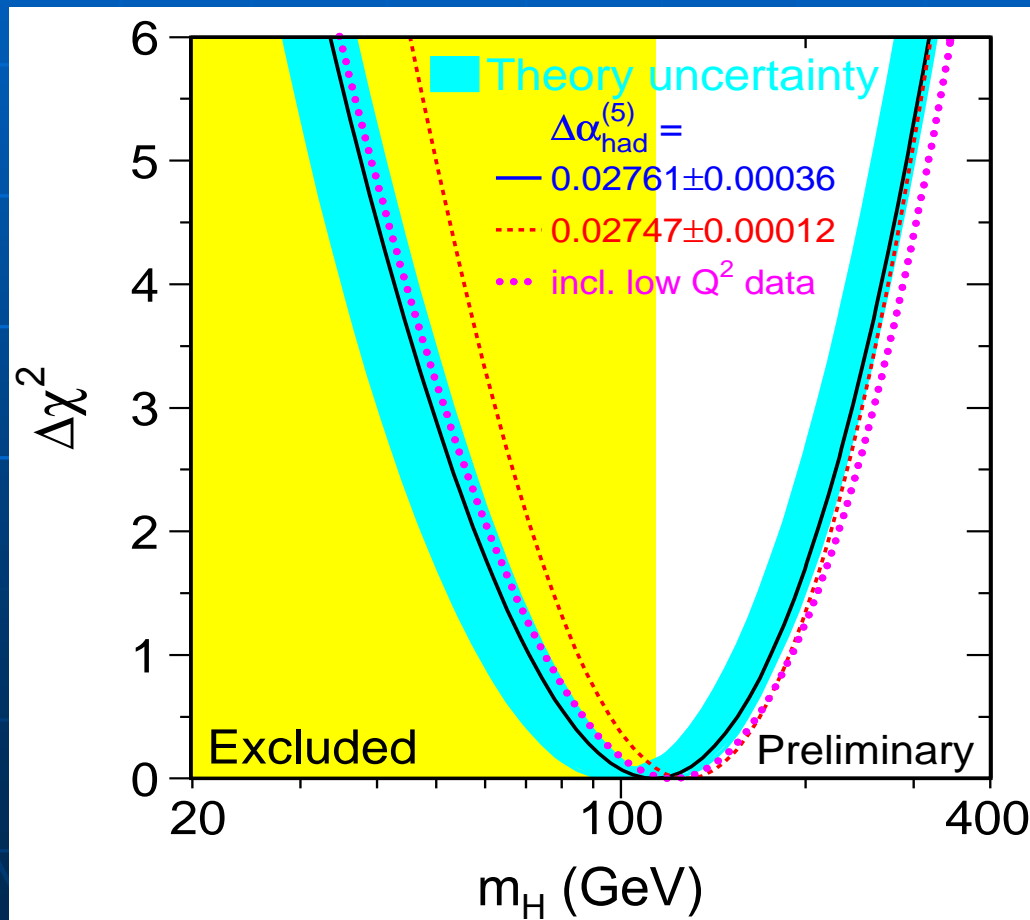
$$\log_{10} M_H = 2.05 \pm 0.20$$

A 10% measurement!



$$0.20 \approx 0.13 \oplus 0.13 \oplus 0.08$$

exp.  $\Delta M_t$   $\Delta \alpha(M_Z^2)$



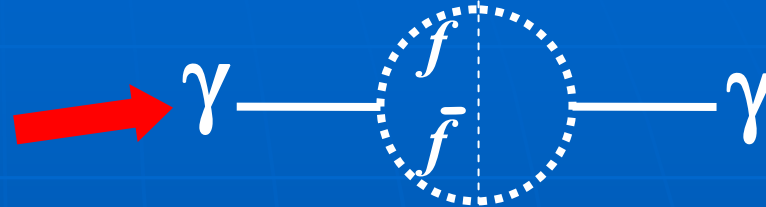
- ~30% improvement wrt 4 years ago:

$$0.28 \approx 0.14 \oplus 0.15 \oplus 0.19$$

[ LEPEWWG '04 ]

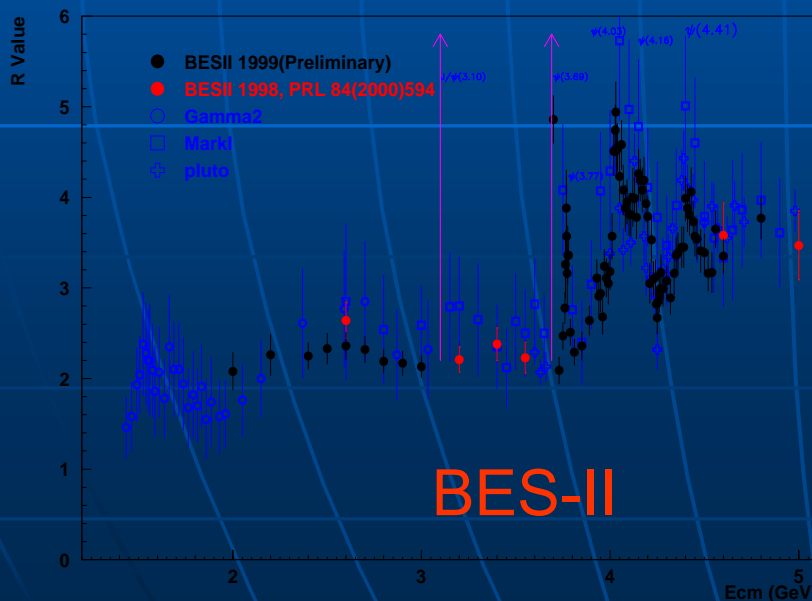
# Determining $\alpha(M_Z^2)$

$$\alpha(s) = \frac{\alpha_0}{[1 - \Delta\alpha(s)]}$$



$$R(s) = \sigma(e^+e^- \rightarrow \text{hadrons}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$$

$$\Delta\alpha_{\text{had}}^{(5)}(s) = -\frac{s}{4\pi^2\alpha_0} \text{P} \left( \int_{4m_\pi^2}^{E_{\text{cm}}^2} ds' \frac{R^{\text{data}}(s')}{s'(s'-s)} + \int_{E_{\text{cm}}^2}^{\infty} ds' \frac{R^{\text{PQCD}}(s')}{s'(s'-s)} \right)$$



- Detailed scans of  $e^+e^- \rightarrow \text{hadrons}$  from BES-II, CMD-2:

$$\Delta(\Delta\alpha_{\text{had}}^{(5)}): 9.0 \times 10^{-4} \rightarrow 3.6 \times 10^{-4}$$

[B.Pietrzyk, H.Burhardt '03]

- Using PQCD down to 1.8 GeV

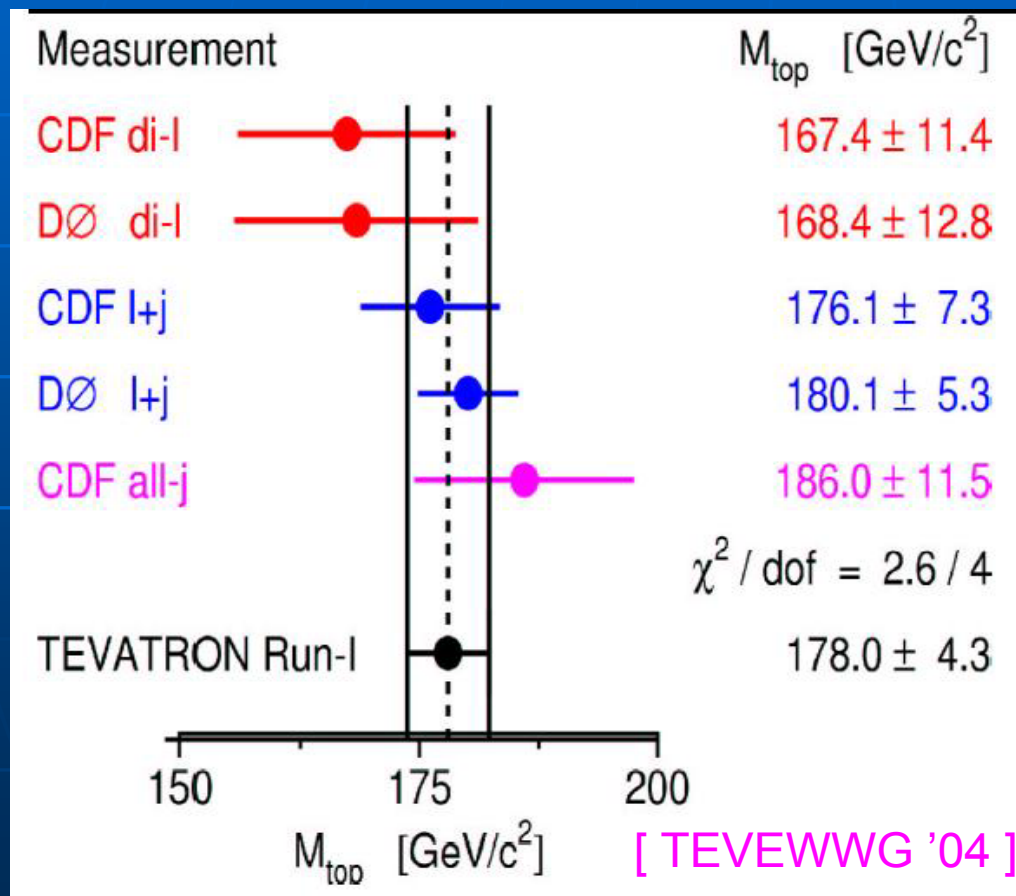
$$\Delta(\Delta\alpha_{\text{had}}^{(5)}) \rightarrow 1.2 \times 10^{-4}$$

- Soon, results from DAΦNE

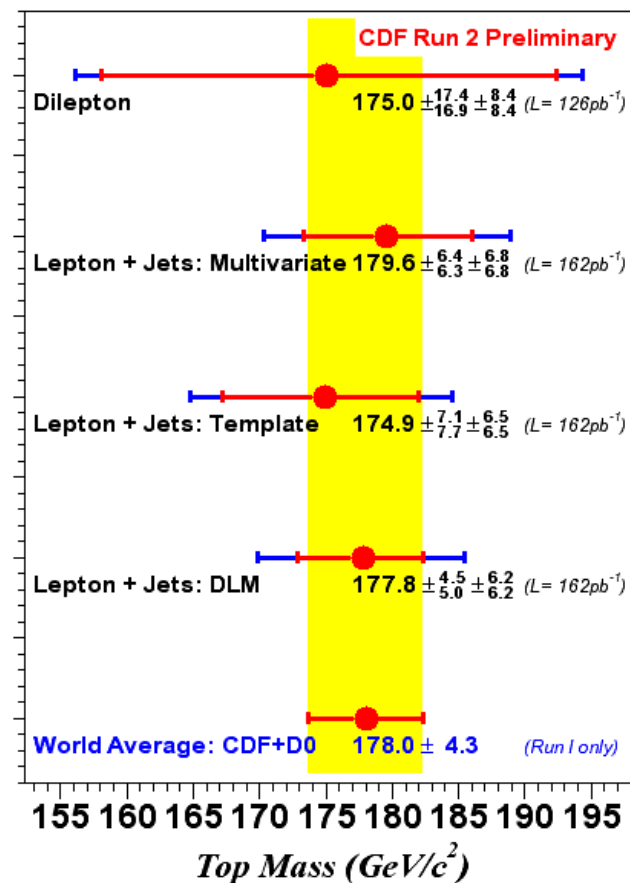


# The top mass

New  $D\bar{0}$  measurement on Run-I  $l+j$  sample using event-by-event likelihoods

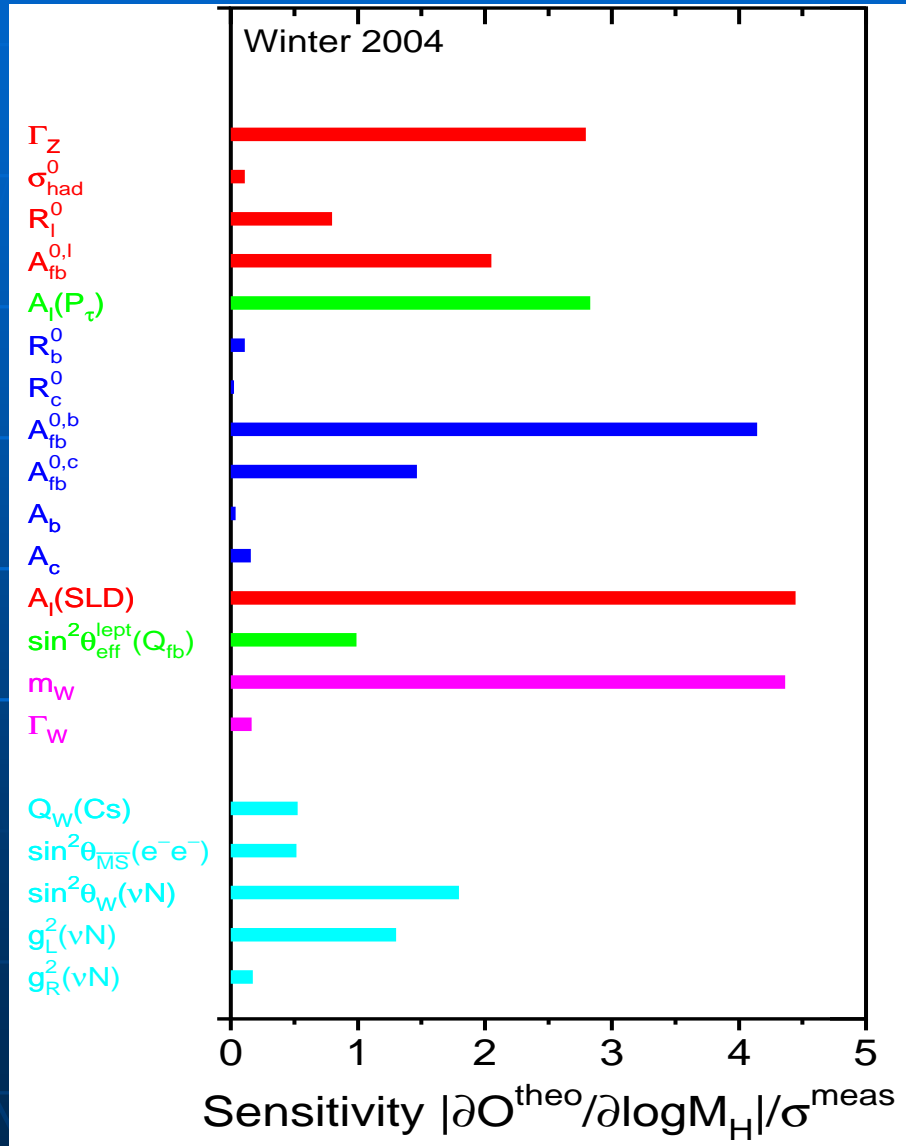


## CDF Run-II preliminary



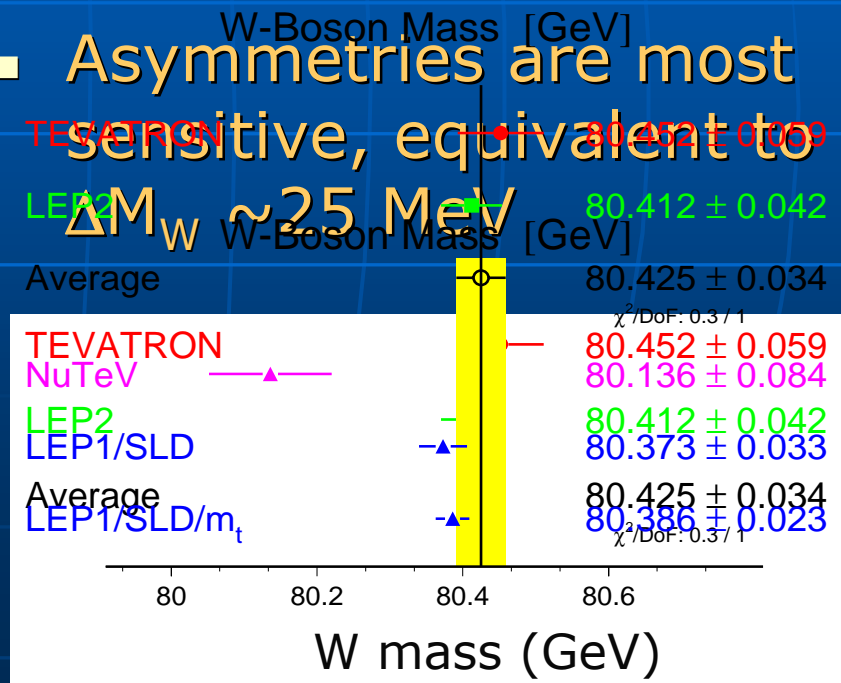
A lot of effort on Jet Energy Scale for Run-II

# Sensitivity to $\Delta(\log M_H)$



$\log(m_H)$ from	Exp. error
Z widths	0.30
$M_W$	0.23
$\sin^2\theta_{eff}$	0.18

- Asymmetries are most sensitive, equivalent to  $\Delta M_W \sim 25 \text{ MeV}$



# Future Prospects

- Assuming no discovery before 2007, emphasis will be on electroweak fits
- In “Physics at LHC – 2007” expect:
  - Uncertainty from  $\alpha$  negligible
  - $\Delta m_t \sim 3\text{GeV}$
  - $\Delta m_W \sim 25\text{MeV}$
- This will give

$$\Delta(\log_{10} M_H) \approx 0.10(\text{exp}) \oplus 0.09(\text{top}) \oplus 0.04(\alpha) \approx 0.14$$

# Summary

- **Legendary contribution from LEP to the Higgs**
  - SM Higgs  $> 114.4\text{GeV}$  @ 95% c.l.
  - The SM Higgs saga still adds some spice to future prospects
  - If  $m_H \sim 116\text{GeV}$ , then LEP saw the first couple of Higgs bosons
- **E/weak data continue to tighten the  $m_H$  range**
  - $\log(m_H) = 2.05 \pm 0.20 \rightarrow m_H < 237\text{GeV}$  @ 95% c.l.
  - Tevatron ( $m_t, m_W$ ) main input in the next three years

	<i>Predicted (GeV)</i>	<i>Observed (GeV)</i>
<i>W mass</i>	$80.386 \pm 0.023$	$80.425 \pm 0.034$
<i>Top mass</i>	$178.5 \pm 9.7$	$178.0 \pm 4.3$
<i>Higgs mass</i>	$113 + 62 - 42$	???

