Electroweak Fits at LEP & SLD

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For the LEP Electroweak Working Group

Special thanks to M. Grünewald, P. Janot, B. Pietrzyk and G. Quast

Electroweak Fits Used for

- Testing the SM at the level of its quantum corrections
- Searching for deviation(s) that may signal presence of new physics
- Predicting the top mass and constraining the Higgs mass
  - Simple example :

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r),$$

High precision required

$\Delta r = \Delta\alpha \quad - \Delta(M_{top}^2/M_Z^2) + \Delta\,(\mathrm{Ln}(M_H/M_Z))$

~6% ~ 3% <1% for MH < 400 GeV

LEP1

- Before LEP

Includes '89 MARKII MZ

1989 - Before LEP				
	Value	Error	Relative	translated into $\sin^2\theta_W$
M_W (GeV)	80.000	0.360	4.5E-03	
M_Z (GeV)	91.120	0.160	1.8E-03	3.7E-02
$\sin^2\theta_W$	0.227	0.006	2.6E-02	

$$a\,, G_m\,, \sin^2 q_W$$ As input parameters

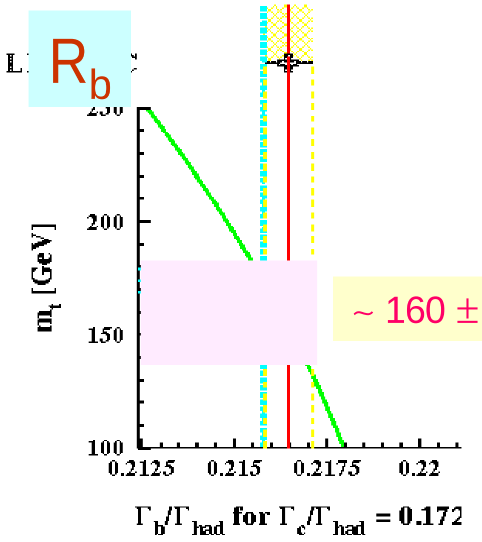
- LEP1
  - Keyword : precision measurements (a lot!)
  - $\Delta x/x$ with a lot of 0 (not in $)
  - Prediction of M_{top}

1995 - End LEP1				
	Value	Error	Relative	translated into $\sin^2\theta_W$
M_W (GeV)	80.356	0.125	1.6E-03	
M_Z (GeV)	91.187	0.002	2.2E-05	1.2E-02

$$a\,, G_m\,, m_Z$$ As input parameters

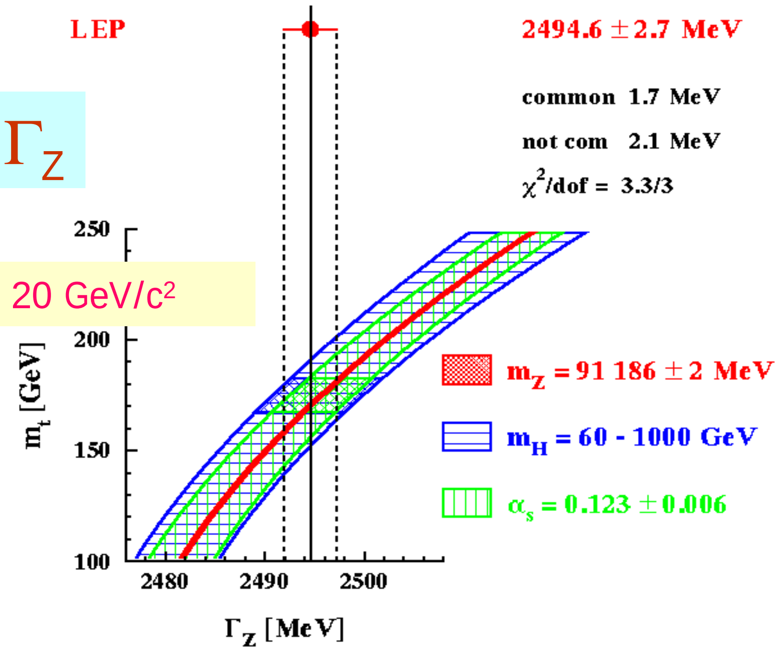
Top Mass Sensitivity

R_b



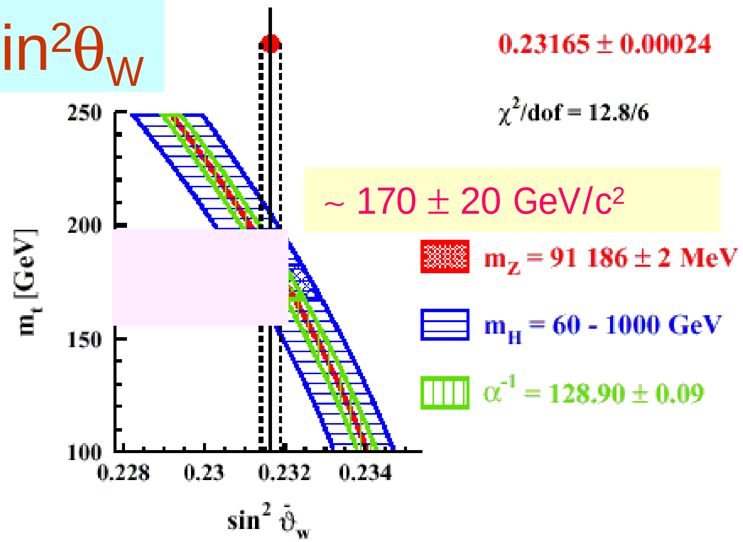
~ 160 ± 25 GeV/c²

Γ_Z



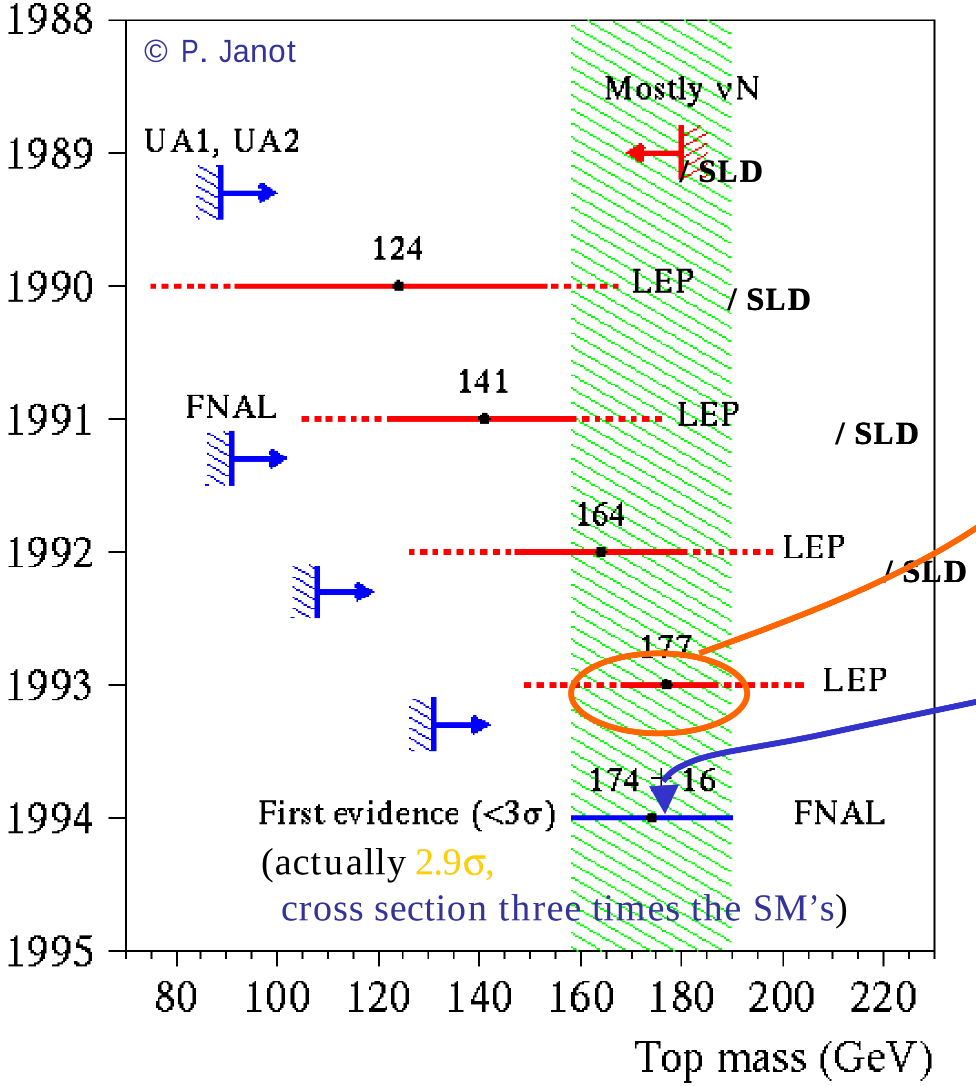
~ 170 ± 20 GeV/c²

$\sin^2\theta_W$



~ 170 ± 20 GeV/c²

Top Quark Hunting



March 1994 : top mass of 177 GeV/c² predicted with a precision of 10 GeV/c²

One month later, FNAL announced the first 3σ evidence of the top.

In 2001:

$$m_{\text{top}}^{\text{EW}} = 180.5 \pm 10.0\ \text{GeV}/c^2$$

$$m_{\text{top}}^{\text{direct}} = 174.3 \pm 5.1\ \text{GeV}/c^2$$

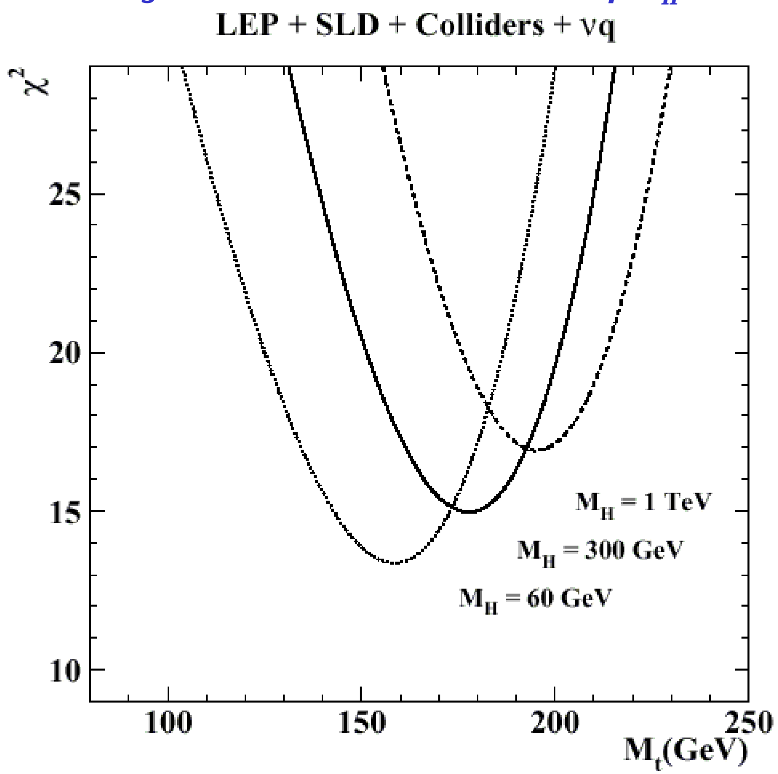
After M_{top}…

- Once M_{top} measured,
  - M_W can also be predicted
  - M_H can be constrained?
    - Strongest constrains on M_H :
      - Asymmetries
      - M_W
- LEP2
  - On the road towards M_H

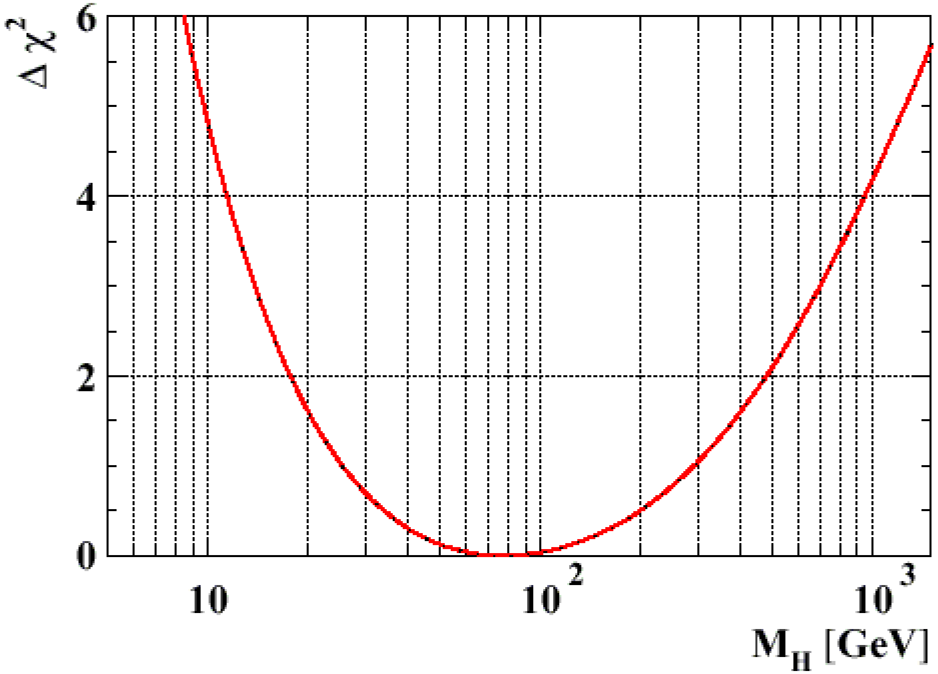
1994 : the First χ^2 Curve

CERN / PPE / 94-187

"It can be seen that the minima of these curves occur at different values of c^2. This suggest the possibility of extracting constraints on the value of m_H"



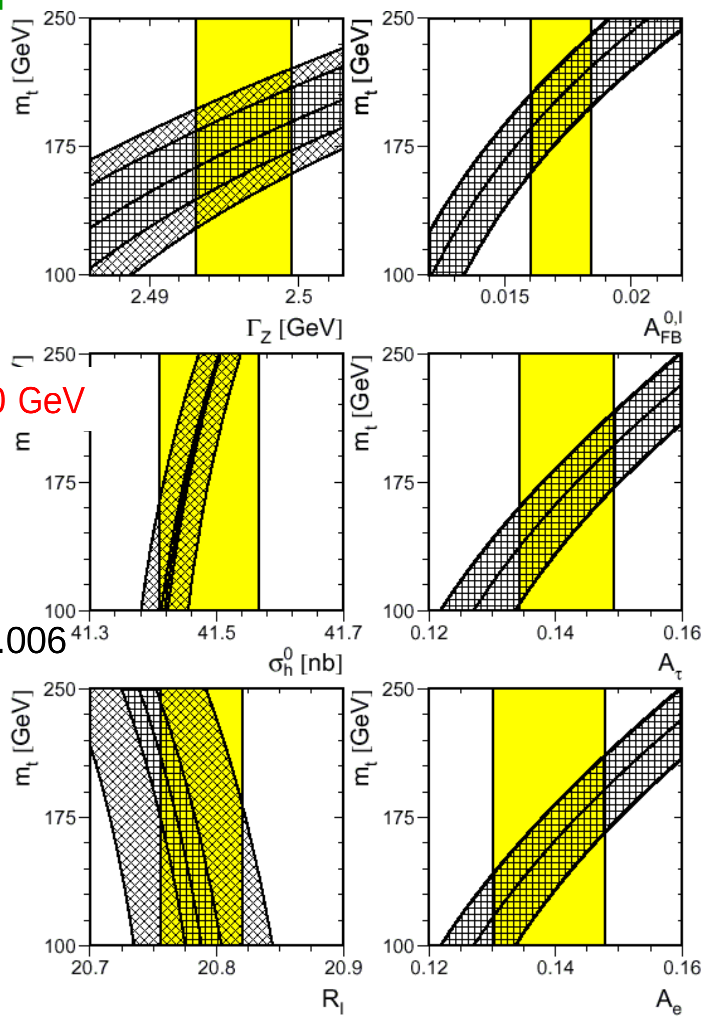
Including M_{top} from CDF



From 1995 to 2001

M_{top}

1995

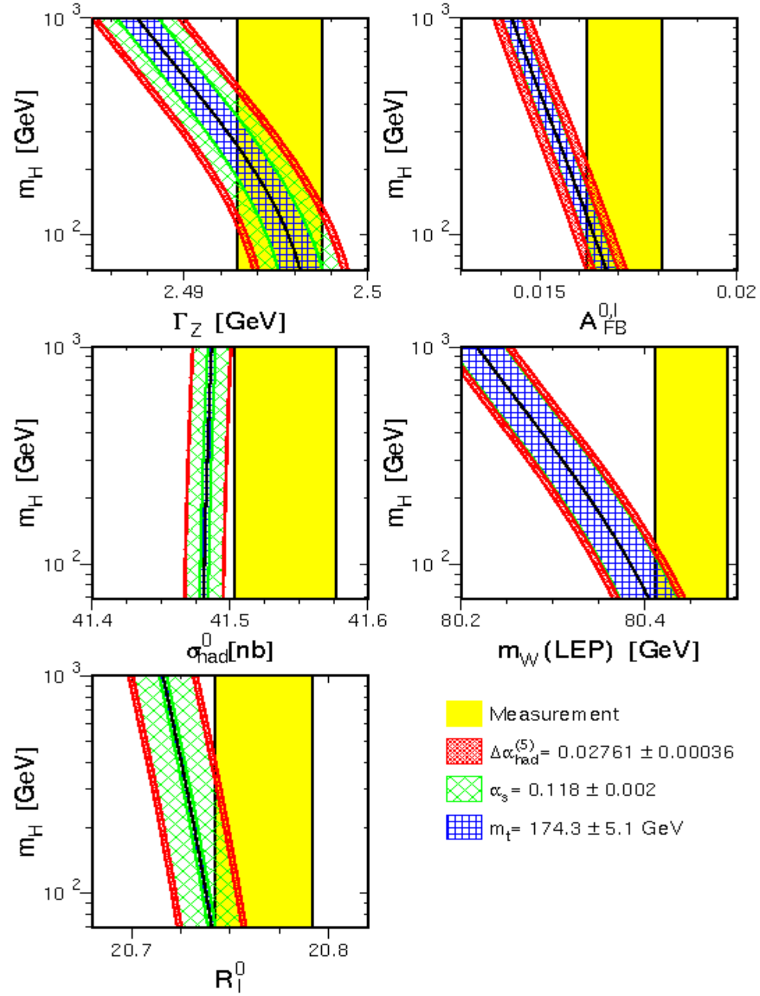


M_H : 60 –1000 GeV

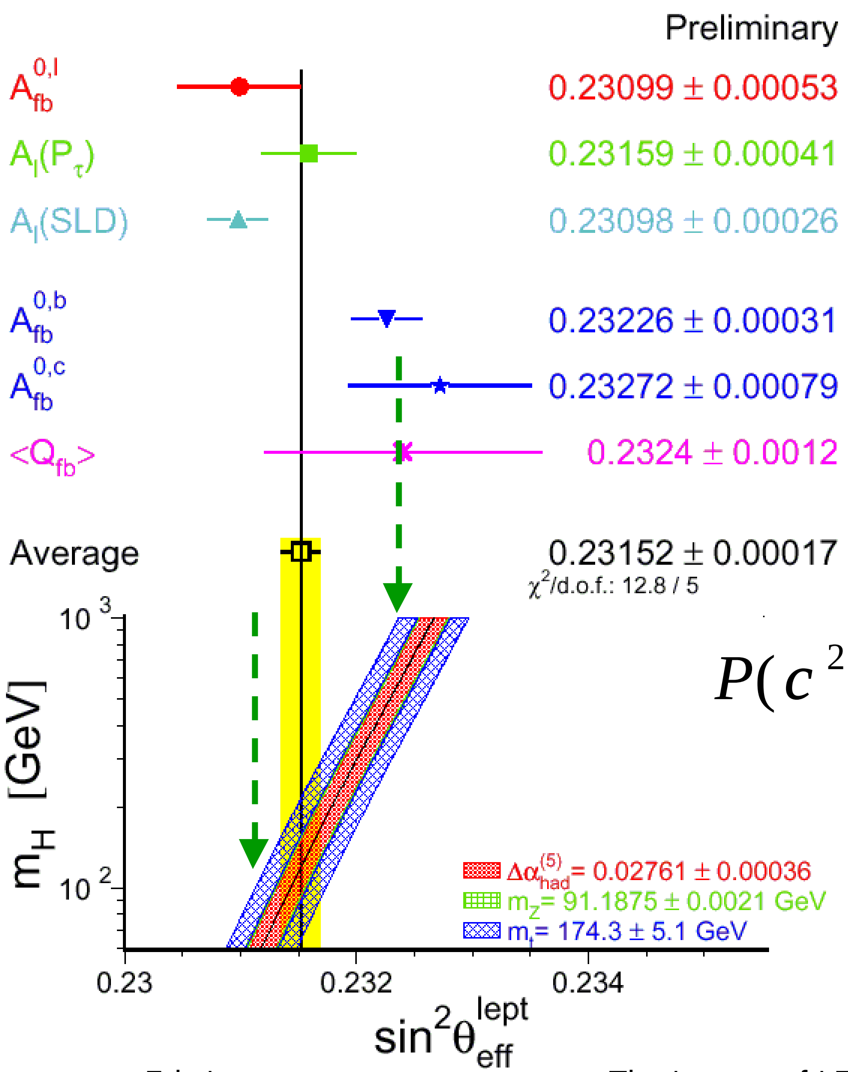
$\alpha_s = 0.123 \pm 0.006$

M_H

2001



The 3.3 σ discrepancy



$\sin^2\theta_W$ from asymmetries

Leptons : 0.23113 ± 0.00021

3.3σ difference

Hadrons : 0.23230± 0.00029

ALL : 0.23152± 0.00017

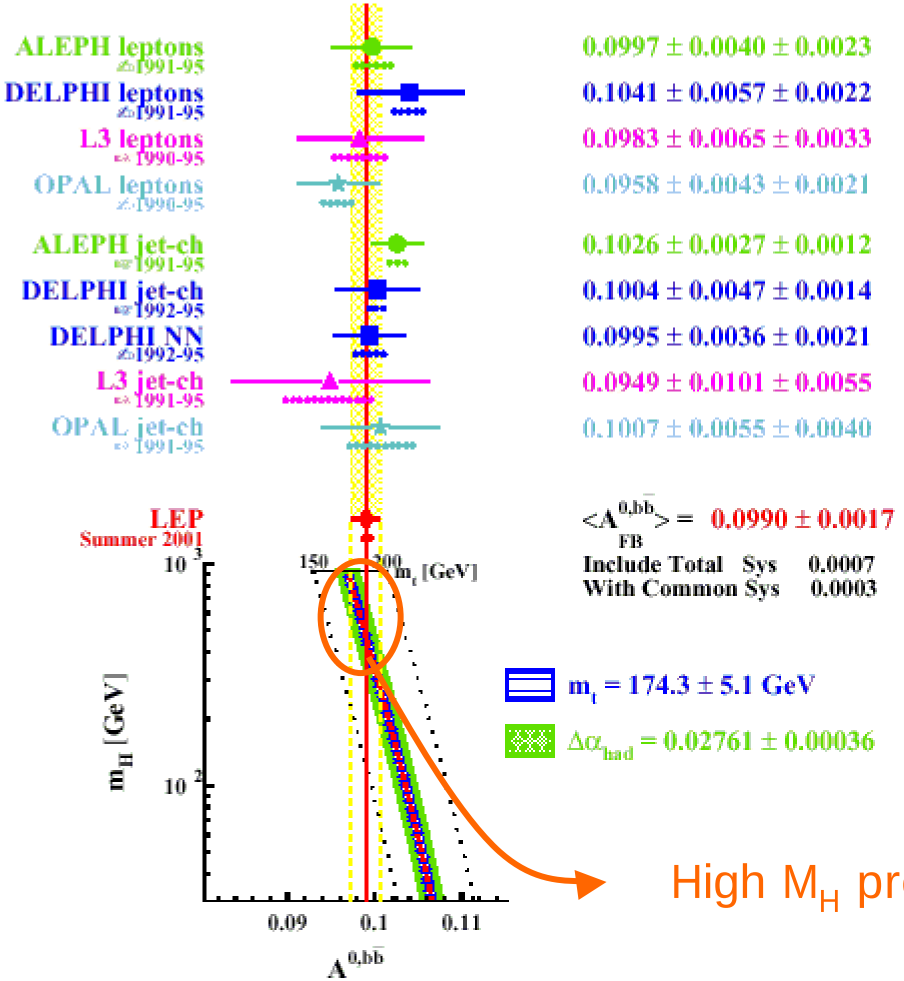
$$P(c^2) \cong 2.5\%$$

Leptons : low M_H

Hadrons : High M_H

$A_{FB}^{0,b\bar{b}}$ Guilty?

b asymmetries



$A_{FB}^{0,b\bar{b}}$ LEP consistent measurements

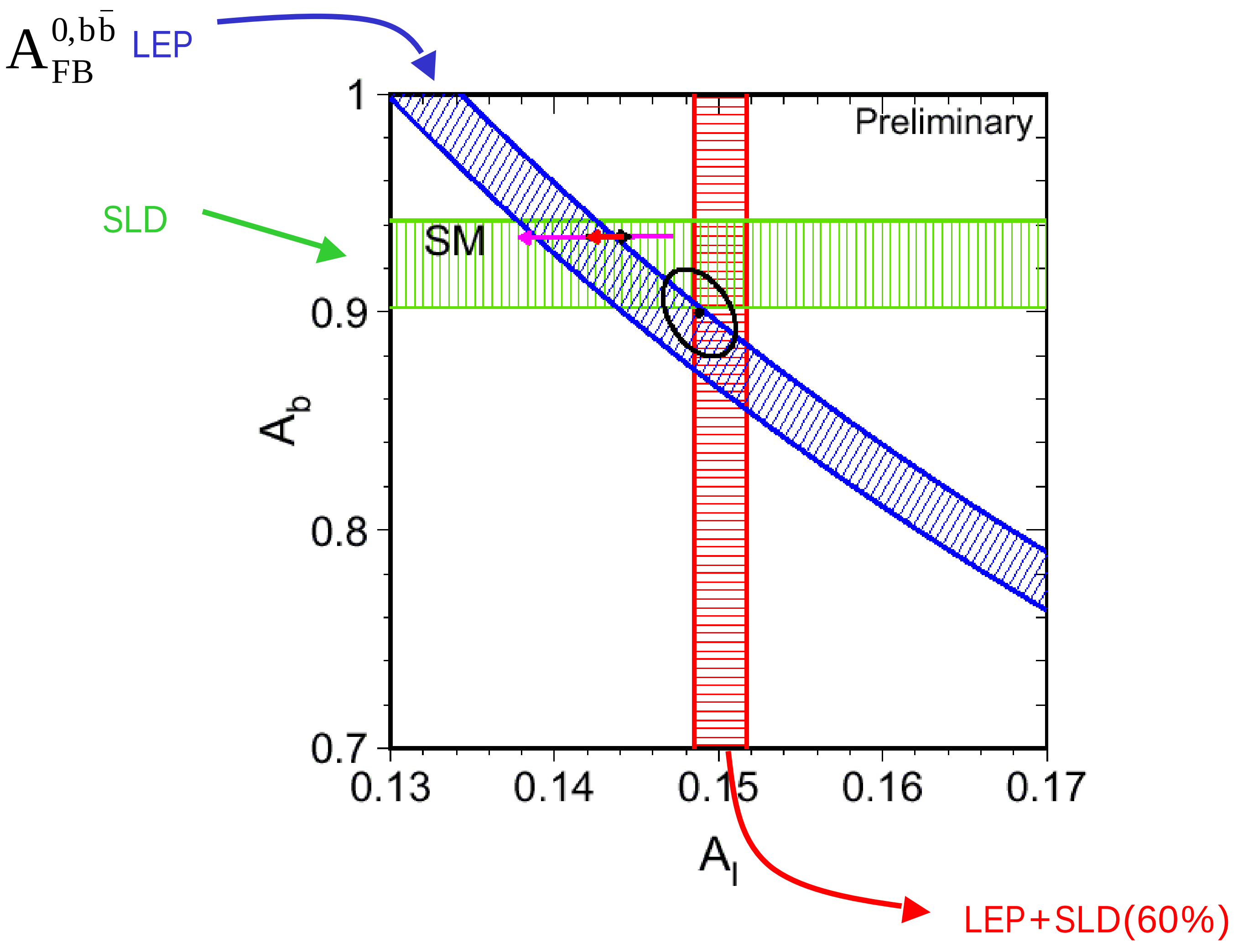
A_b from LEP and SLD consistent within 1σ

A_b(LEP) =	0.891 ± 0.022
A_b(SLD) =	0.922 ± 0.020
Comb.	0.899 ± 0.013
SM Fit	0.935

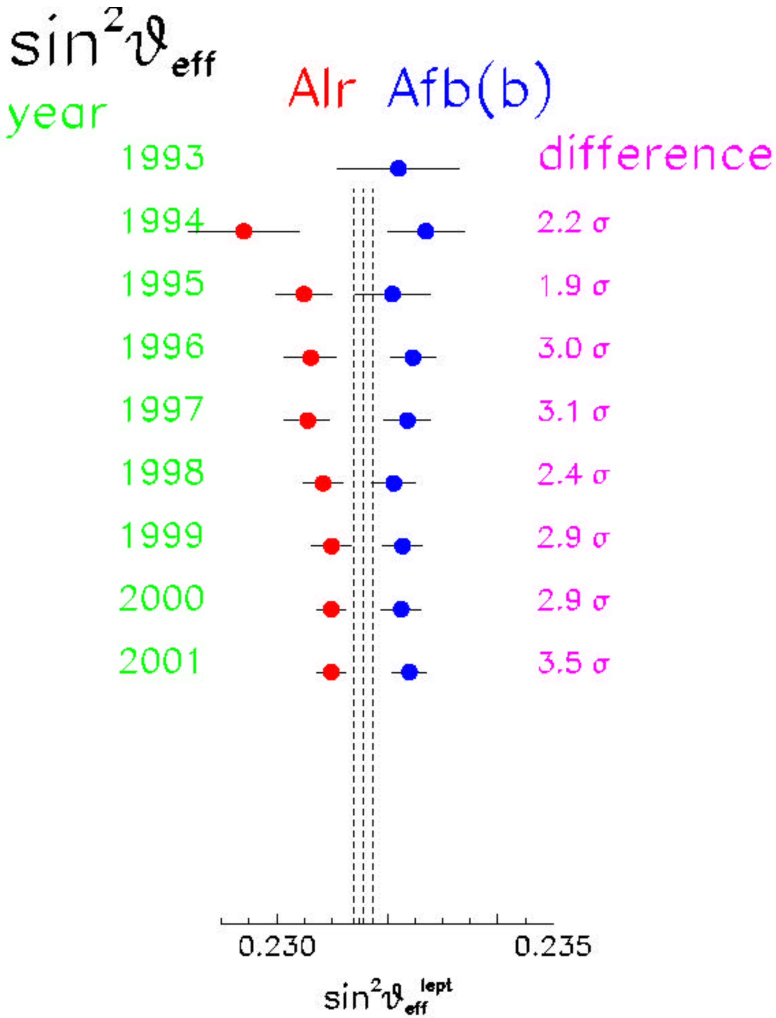
Comb. vs SM Fit: 2.9σ

High M_H preferred

b quark vs leptons couplings



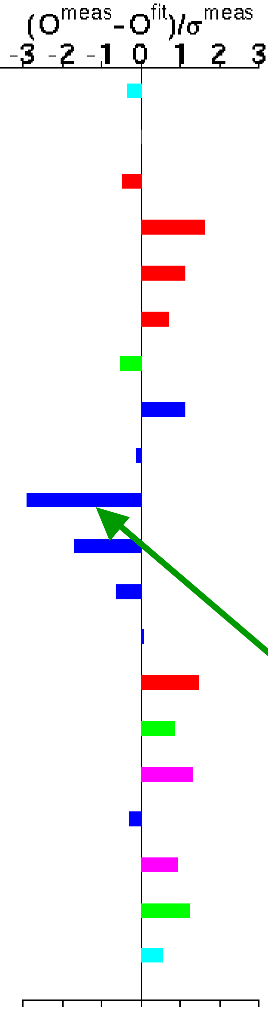
A_{LR} & A_{FB} vs time



Difference did not increased with precision of measurements

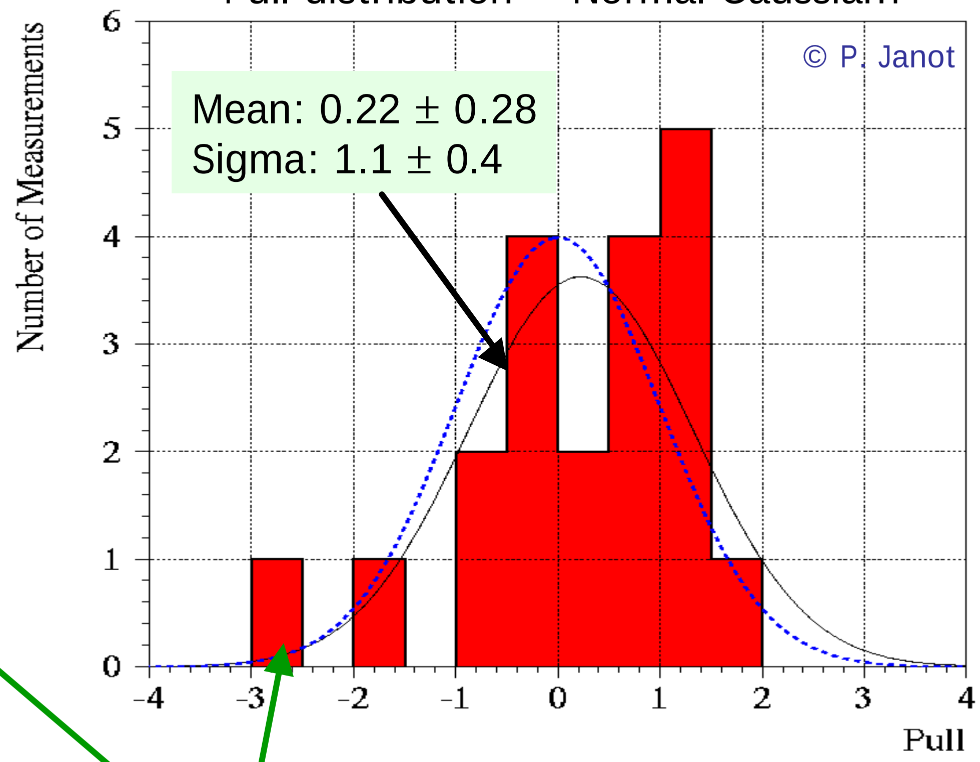
Internal Consistency : OK

Measurement		Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.35
m_Z [GeV]	91.1875 ± 0.0021	.03
Γ_Z [GeV]	2.4952 ± 0.0023	-.48
σ^0_{had} [nb]	41.540 ± 0.037	1.60
R_l	20.767 ± 0.025	1.11
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.69
$A_l(P_\tau)$	0.1465 ± 0.0033	-.54
R_b	0.21646 ± 0.00065	1.12
R_c	0.1719 ± 0.0031	-.12
$A^{0,b}_{fb}$	0.0990 ± 0.0017	-2.90
$A^{0,c}_{fb}$	0.0685 ± 0.0034	-1.71
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.06
A_l(SLD)	0.1513 ± 0.0021	1.47
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.86
$m_W^{(LEP)}$ [GeV]	80.450 ± 0.039	1.32
m_t [GeV]	174.3 ± 5.1	-.30
$m_W^{(TEV)}$ [GeV]	80.454 ± 0.060	.93
$\sin^2\theta_W(\nu N)$	0.2255 ± 0.0021	1.22
$Q_W(Cs)$	-72.50 ± 0.70	.56



χ^2/dof = 23/15

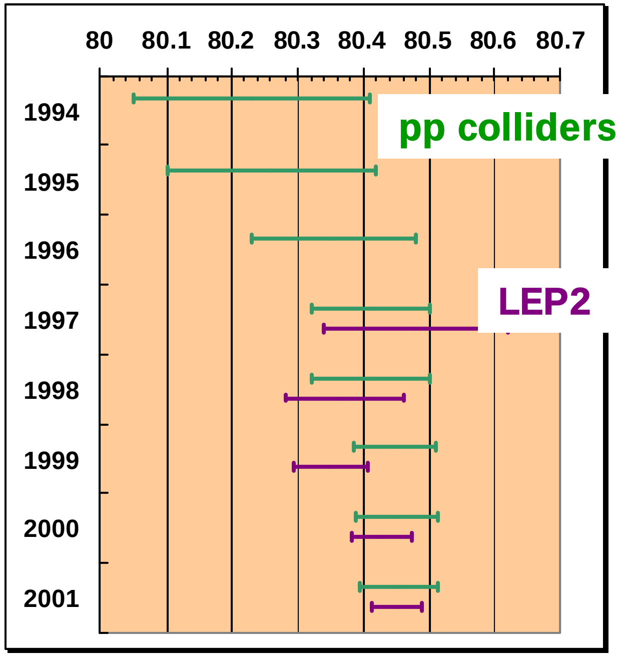
Pull distribution = Normal Gaussian?

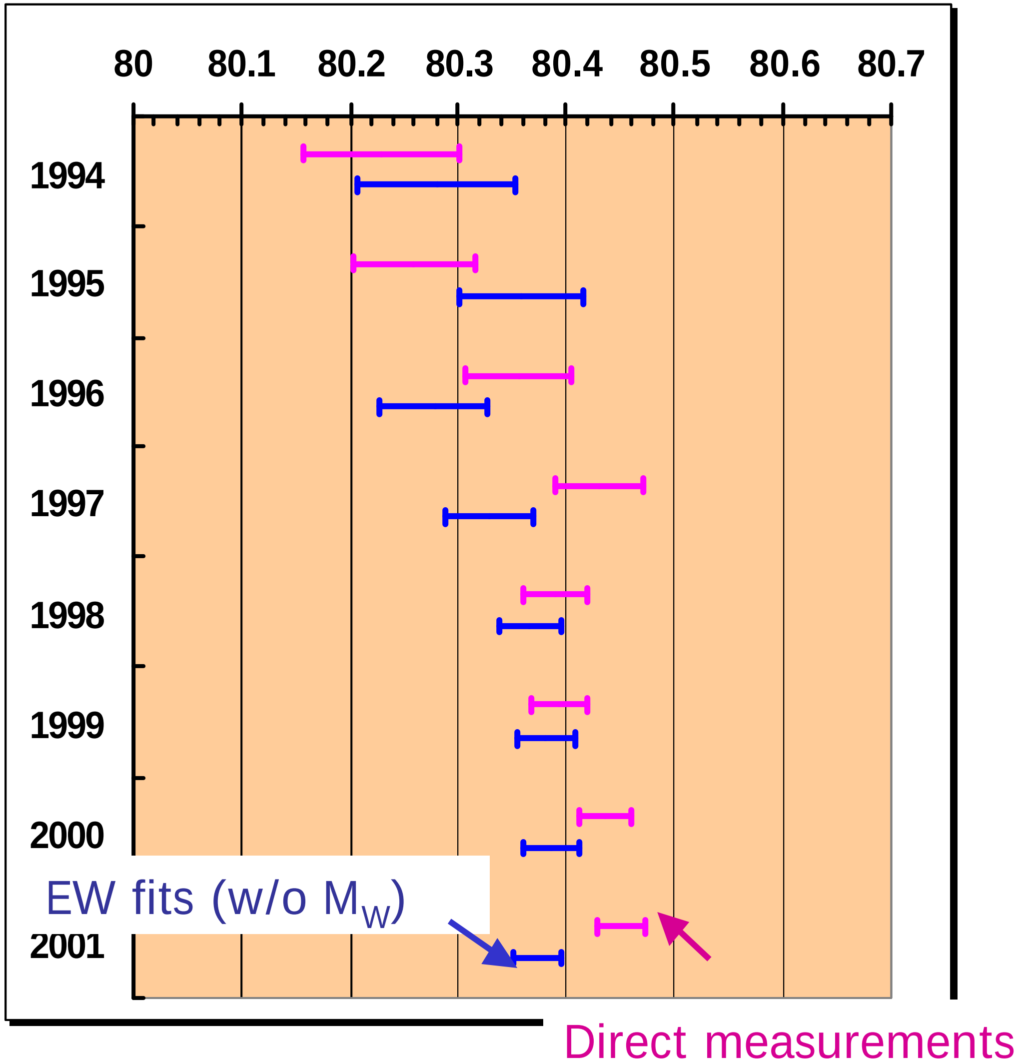


Largest discrepancy **(-2.9s)** well inside statistical expectation;

$P(c^2) = 8\%$

W Mass vs Time

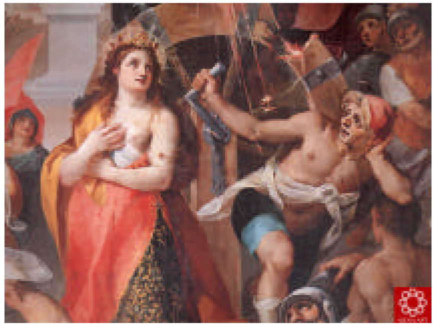




Precision of direct measurements of M_w (34 MeV) now similar to EW fits (23 MeV)

Accuracy of Calculations

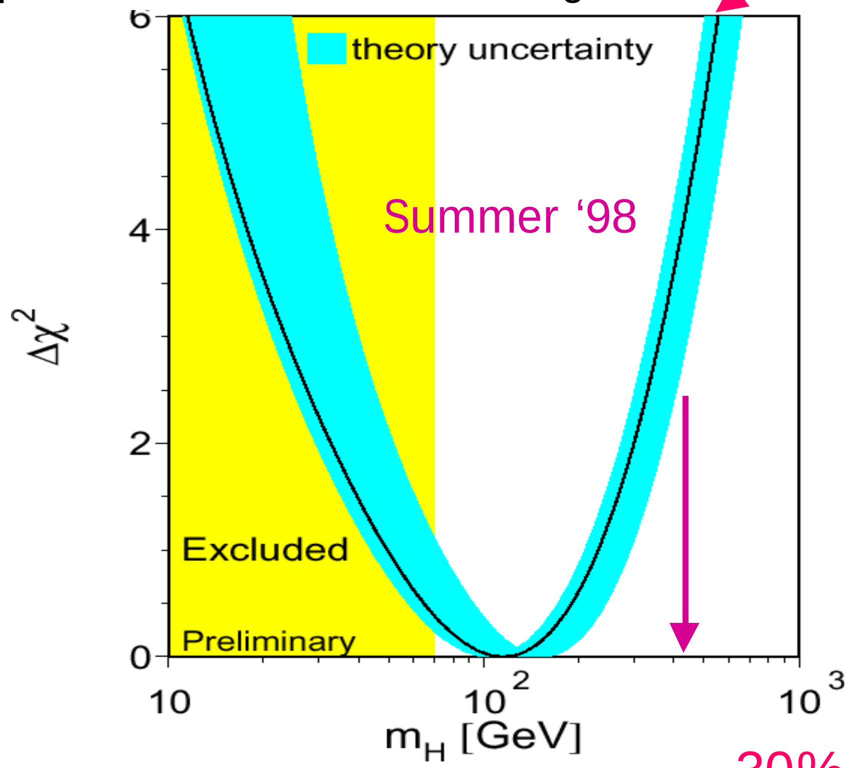
- Sensitivity small ~ln(M_H/M_Z)
  - Need for precise calculations
- Accuracy :
  - Parametric errors (our job)
  - Uncertainties due to truncations of series (our theoretical colleagues)
- Calculations should match accuracy of high precision data
  - Implemented in ZFITTER & TOPAZ0
  - Run and compare...

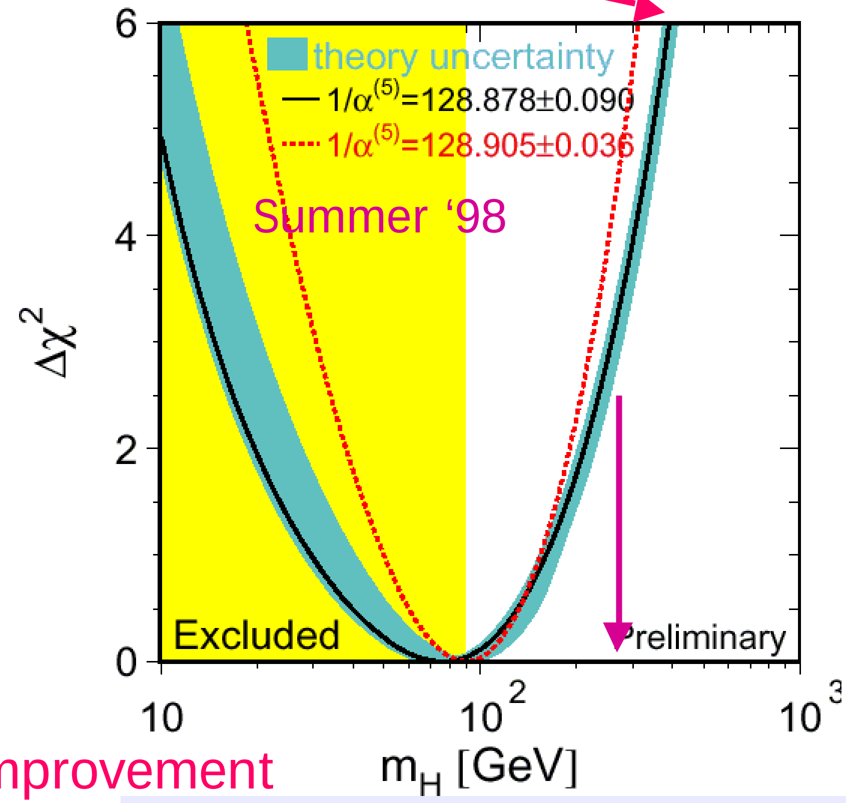


From '97 to '98

$? \, (a^2 m_t^2 / m_W^2)$ Terms (Degrassi et al. '96/'97)

Blue band : ZFITTER vs TOPAZ0
comparison for various internal flags





30% improvement

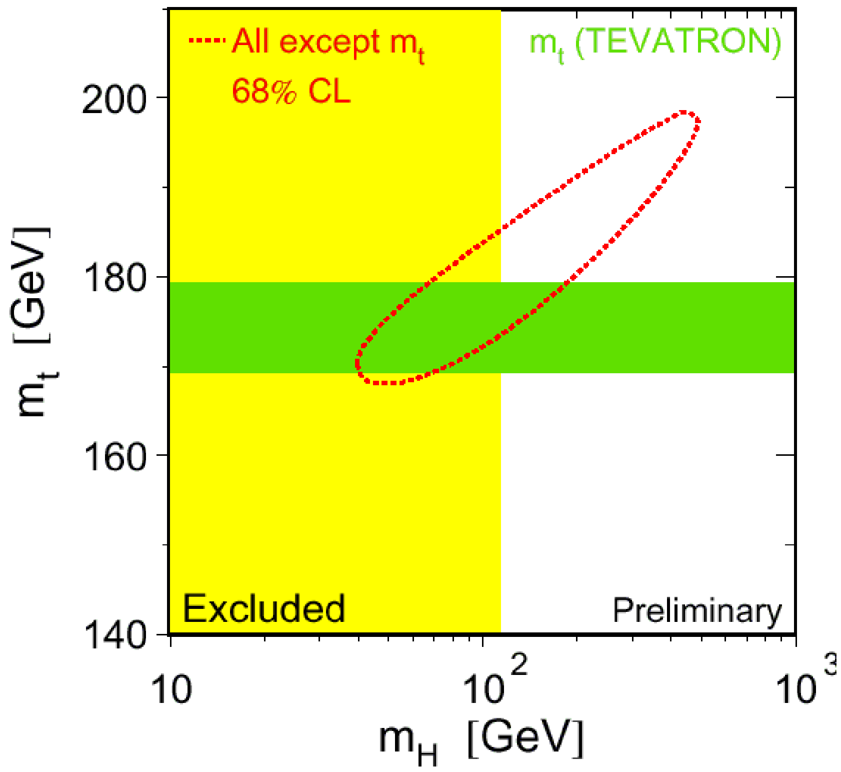
$m_{\text{Higgs}} \leq 420 \text{ GeV}/c^2$ at 95% C.L.

$m_{\text{Higgs}} \leq 262 \text{ GeV}/c^2$ at 95% C.L.

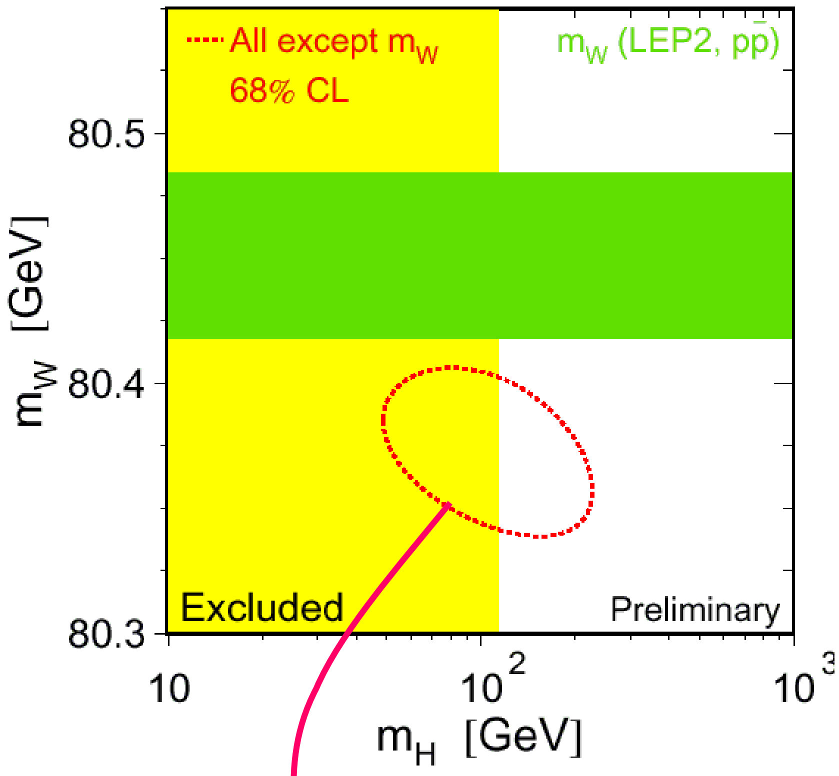
M_H from M_{top} & M_W

2001

M_{top} vs M_H



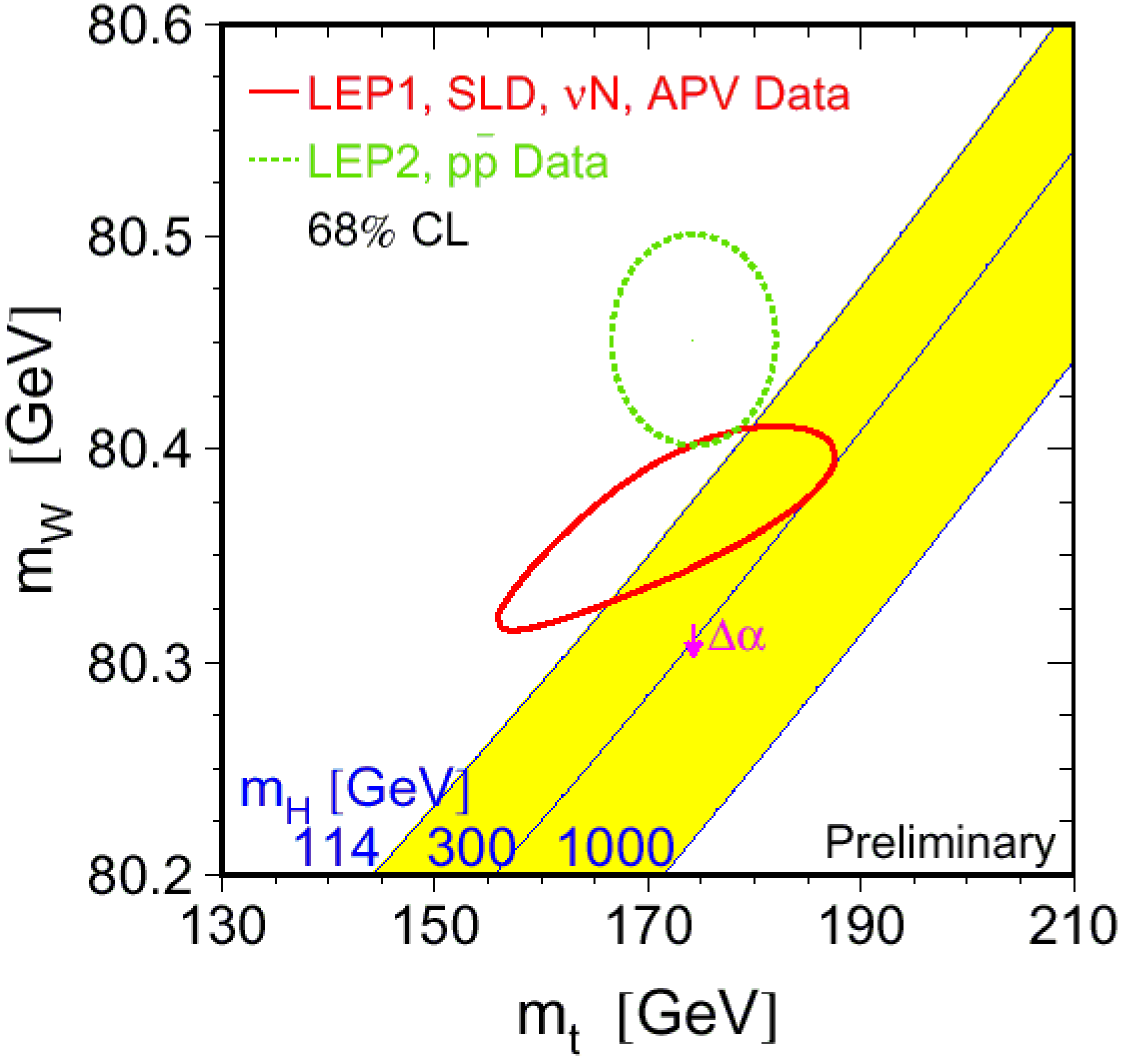
M_W vs M_H



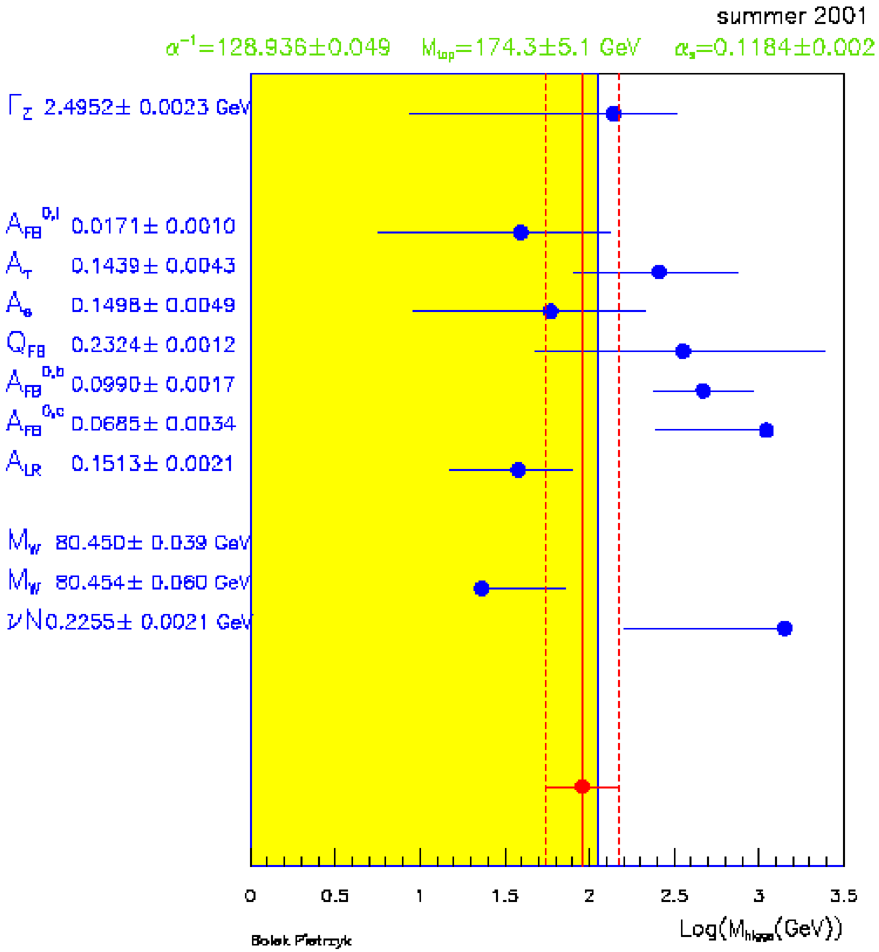
Mostly M_{top} ΔM_{top} = 5 GeV $\Rightarrow$ ΔM_W = 30 MeV

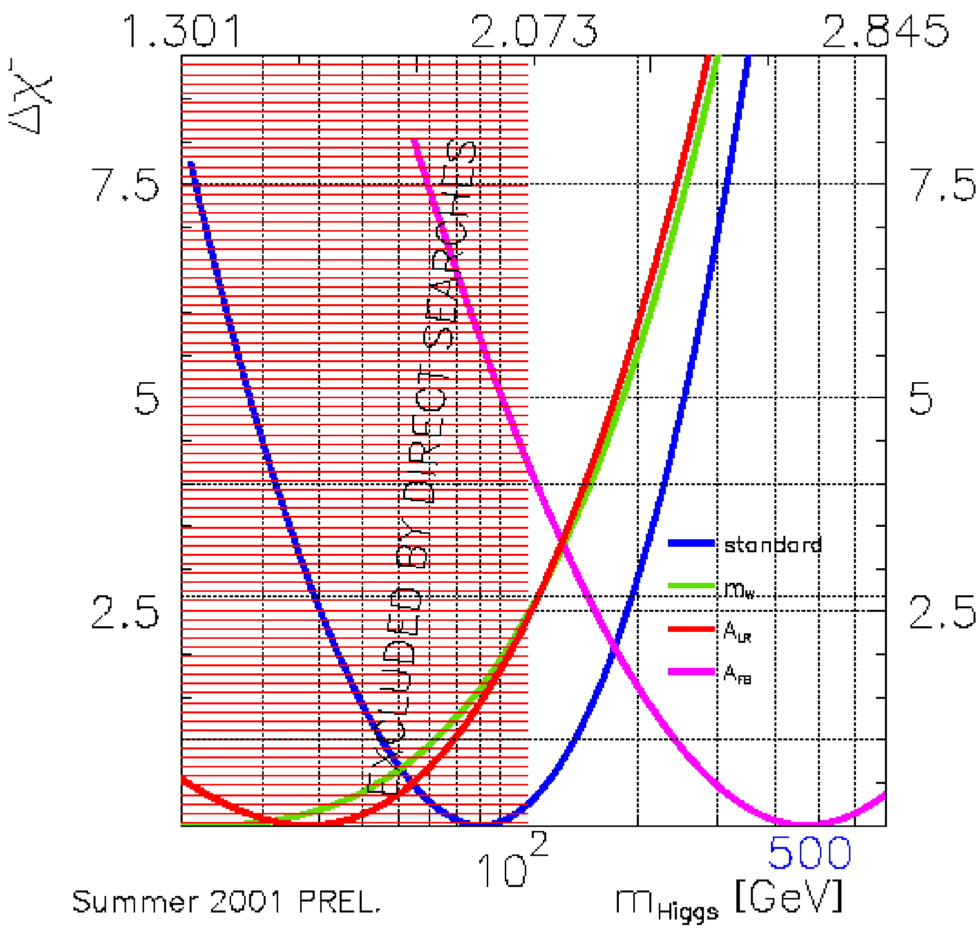
M_w vs M_{top}

2001



M_H from various measurements





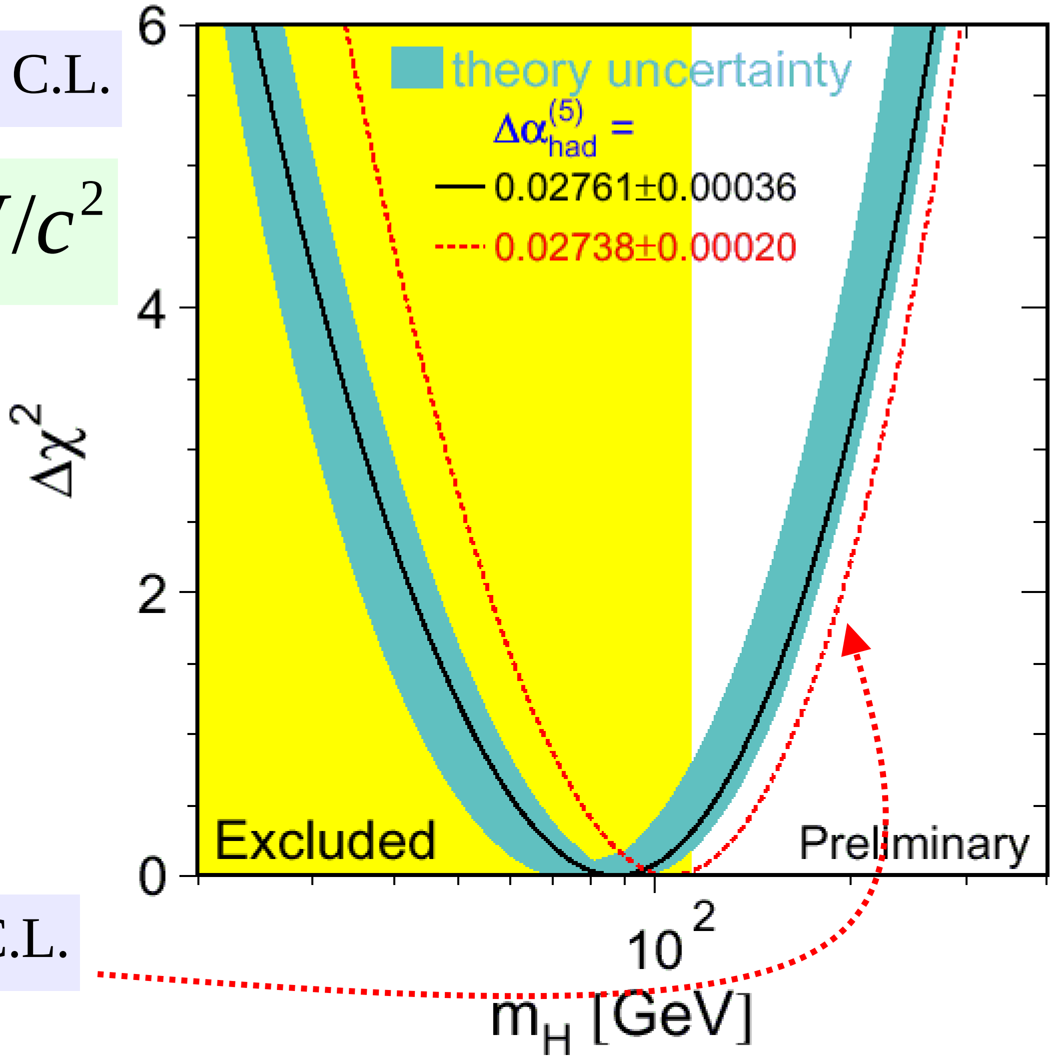
Higgs Mass as of Today

$m_{\text{Higgs}} \leq 196\ \text{GeV}/c^2$ at 95% C.L.

$$m_{\text{Higgs}}^{\text{EW}} = 88^{+53}_{-35}\ \text{GeV}/c^2$$

Same precision on M_H as on M_{top} before LEP

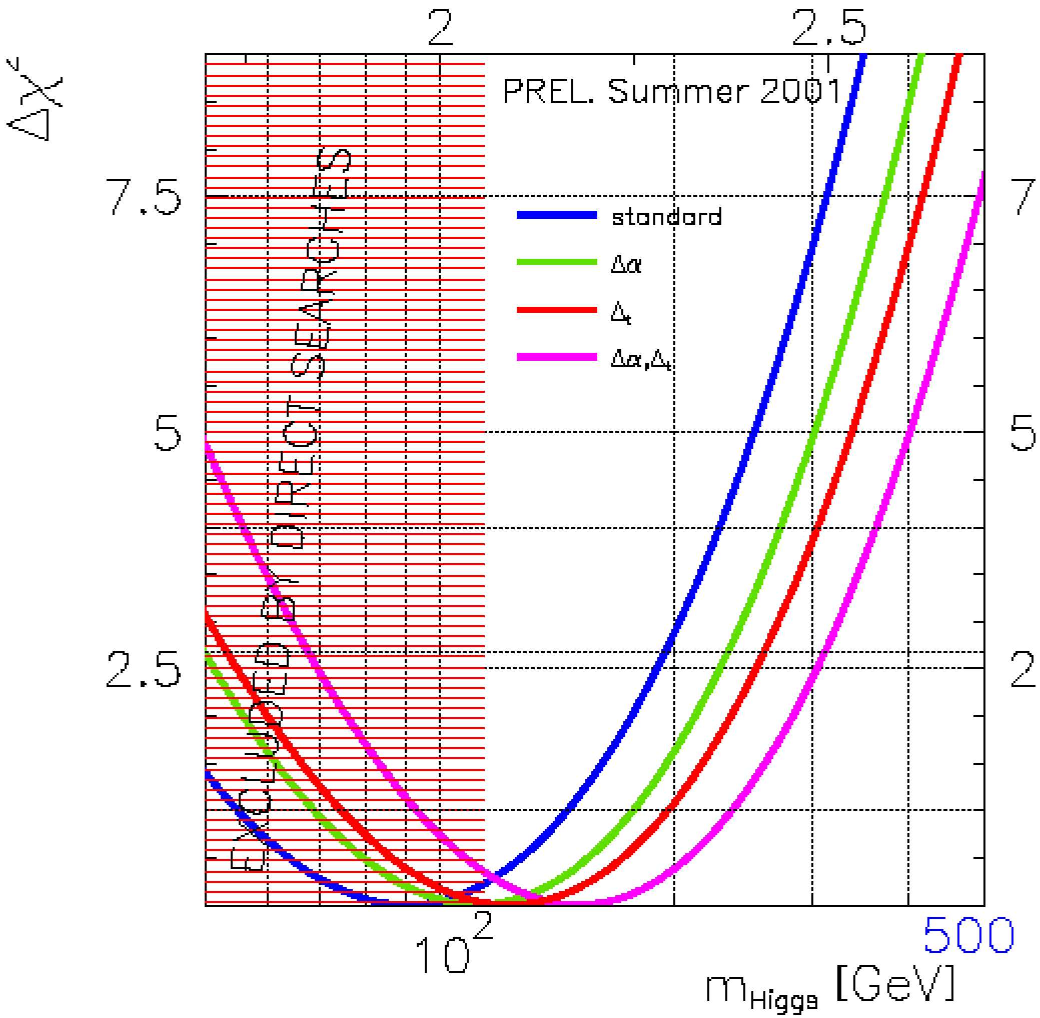
$\Delta M_H / M_H = 0.5$



Small dependence of limit on $\Delta a_{had}^{(5)}$

$m_{\text{Higgs}} \leq 222\ \text{GeV}/c^2$ at 95% C.L.

Parametric Errors

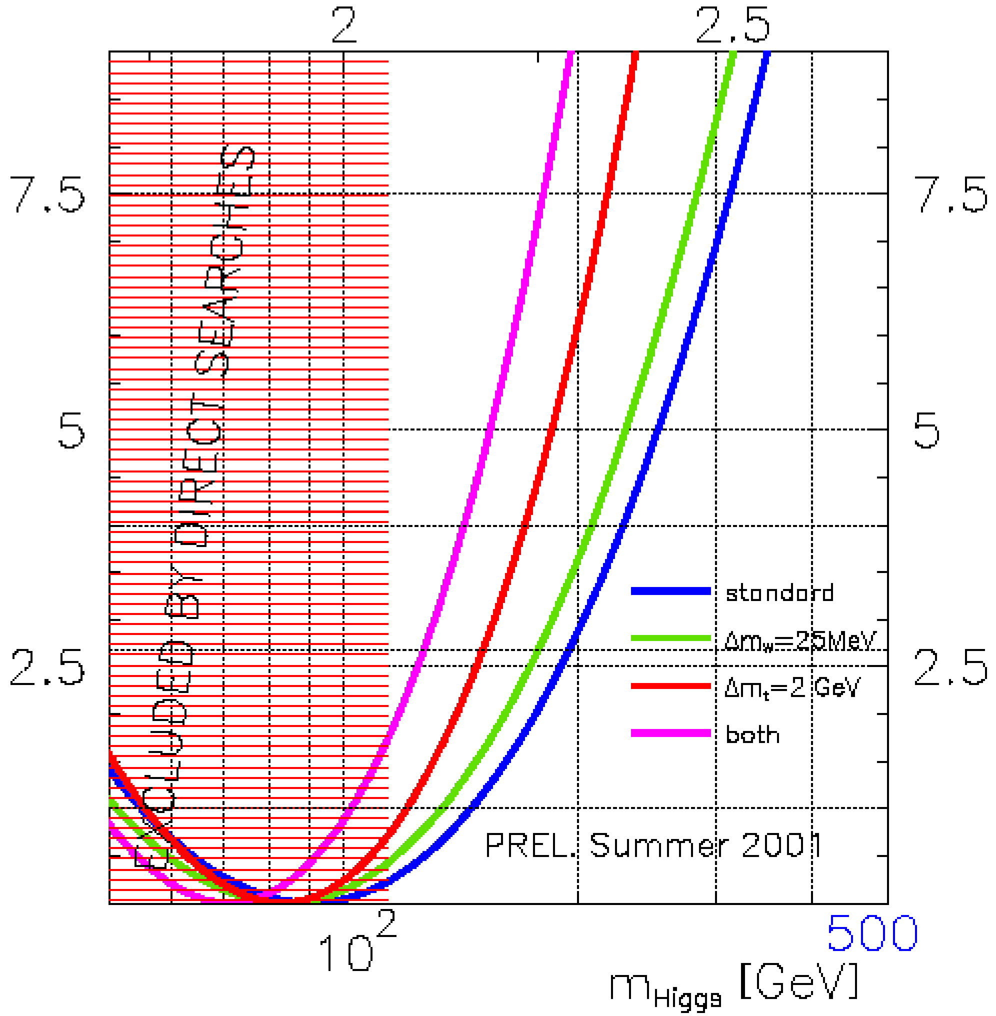


If α an M_{top} are changed by 1 sigma

$$m_{\text{Higgs}} \leq 300 \text{ GeV}/c^2$$

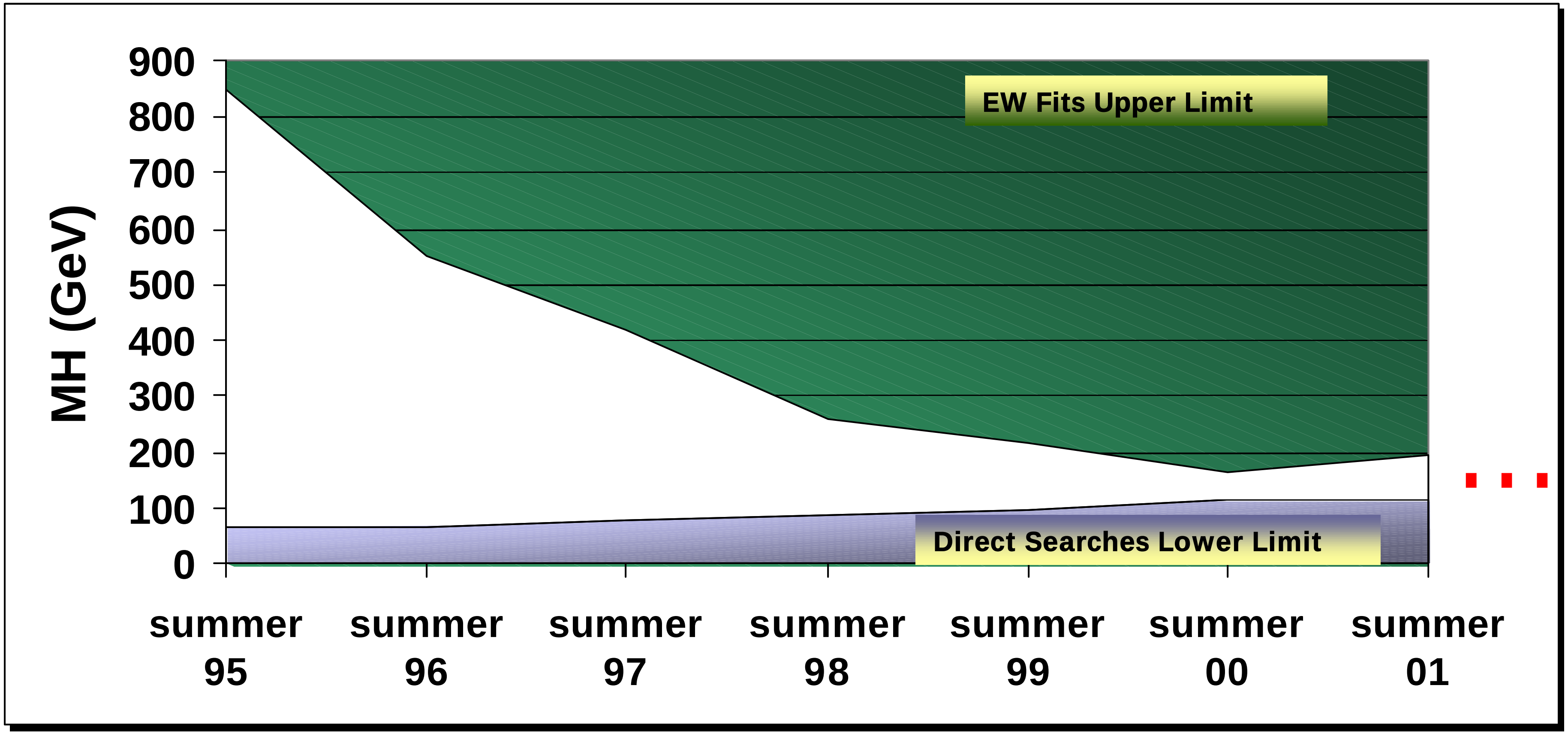
Near Future?

- ALL LEP2 data
  - ΔM_w = 25 MeV ? (34 now)
  - Central value may change, LEP energy not final !
  - $\Delta M_H \approx$ 35-50 GeV
- FERMILAB run II
  - ΔM_{top} = 2 GeV ? (5 now)
  - $\Delta M_H \approx$ 30-40 GeV
- Both
  - $\Delta M_H \approx$ 20 GeV



Minimum changes due to changes of relative weights of ≠ measurements

The Shadow of the Higgs



Ten Years of GREAT Physics

- Internal consistency of the standard model tested with great precision, 3 to 5 times better than anticipated;
- The mass of the top quark was predicted several years before it has been discovered
- The measurements led to the prediction of a relatively light Higgs boson (around 100 GeV/c2), with the same precision (50%) as on top quark mass before LEP, it should be round the corner...
- Impressive cooperation of machine and experimental physics and theoreticians.

Back in 1989...

THEORY OF PRECISION ELECTROWEAK EXPERIMENTS

G. Altarelli

CERN -- Geneva

Rapporteur talk at the XIV International Symposium on
Lepton and Photon Interactions
Stanford, August 7-12, 1989

"Indeed LEP2 is a formidable discovery machine and I am confident that the low-lying fringes of the rich spectroscopy associated with all conceivable scenarios for new physics will already be observed at LEP2"