Electroweak results and fit to the Standard Model

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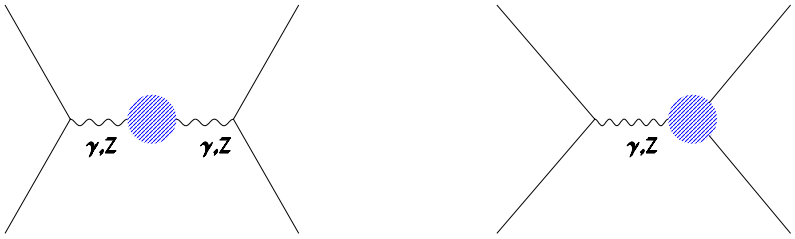
Introduction

At the Z resonance the cross-sections and asymmetries are sensitives to α_s, m_{top} and M_{Higgs} through the radiative corrections

Electroweak corrections (non photonic) to $e^+e^- \to Z, \gamma \to f\bar{f}$



- running of α_{QED}
- correction to ρ and $\sin^2\theta_W$:

  $\rho = \frac{M_W^2}{M_Z^2 \cos^2\theta_W} = 1$ $\qquad$ $\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$

  $\bar{\rho} = 1 + \Delta\rho$ $\qquad$ $\sin^2\theta_W^{\text{eff}} = (1 + \Delta\kappa)\sin^2\theta_W$

Radiative corrections to the W mass

$$M_W^2 = \frac{\pi\alpha}{\sqrt{2}\sin^2\theta_W G_f}(1 + \Delta r)$$

$$\Delta r = \Delta\alpha - \frac{\cos^2\theta_W}{\sin^2\theta_W}\Delta\rho + \Delta r_{rem}$$

$$\Delta\rho,\ \Delta\kappa,\ \Delta r = \text{f}(m_{top}^2,\ \log(M_H))$$

The electroweak measurements

LEP1 and SLC electroweak measurements

- The Z lineshape at LEP1 - final

$$M_Z,\ \Gamma_Z,\ \sigma^0_{had},\ R_l,\ \mathrm{A}^{0,\mathrm{l}}_{\mathrm{FB}}$$

- Measurement of $\mathrm{A_{LR}}$ at SLC - final

- τ polarisation at LEP1 - almost final

- Heavy flavours at LEP1 and SLC:

$$\mathrm{R}^0_{\mathrm{b}},\ \mathrm{R}^0_{\mathrm{c}},\ \mathrm{A}^{0,\mathrm{b}}_{\mathrm{FB}},\ \mathrm{A}^{0,\mathrm{c}}_{\mathrm{FB}},\ <\mathrm{Q_{FB}}>$$
$$A_b,\ A_c$$

  updates from SLD and new $\mathrm{A}^{0,\mathrm{b}}_{\mathrm{FB}}$ from ALEPH and DELPHI

LEP2 and Tevatron: New $\mathrm{M_W}$ from LEP

$$\mathrm{m_{top}},\ \mathrm{M_W}$$

Low energy data: α_{QED}

New $e^+e^- \to q\bar{q}$ data from BES $\Rightarrow$ new experimental determination of $\Delta\alpha^5_{\mathrm{had}}$

New A_{FB}^{b} from ALEPH and DELPHI

DELPHI: A_{FB}^{b} NN (new method)

- High purity b-tagged sample
- b-charge tag: Neural Network based on vertex-charge, jet-charge, leptons, kaons, flavour tagging
- Use double tag method $\Rightarrow$ calibration on data, reduced systematic

$$A_{FB}^{b}(\sqrt{s} = M_Z) = 0.0931 \pm 0.0034 \pm 0.0017$$

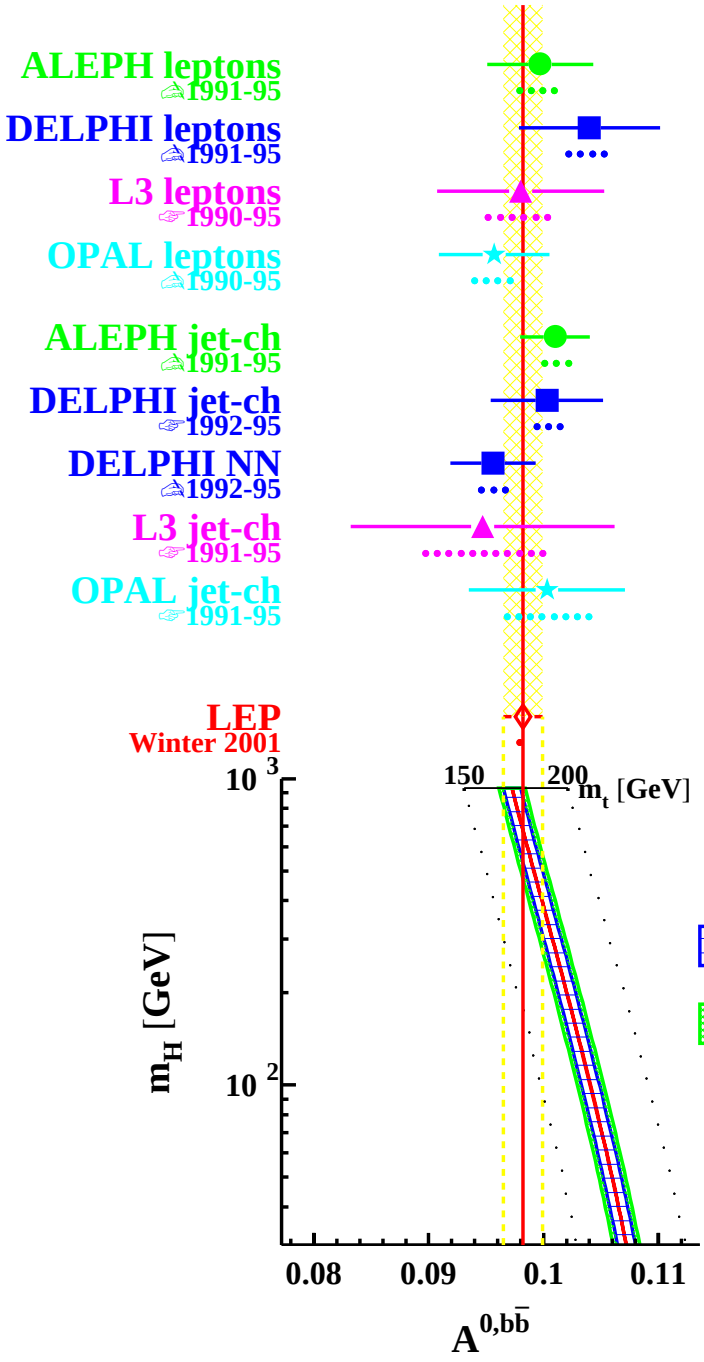
ALEPH: A_{FB}^{b} jet-charge

- Neural Network to tag b-events $\Rightarrow$ statistic increased by 30%
- Improved jet charge estimator
- lower mistag rate and double tag methods $\Rightarrow$ reduction of systematic uncertainties

$$A_{FB}^{b}(\sqrt{s} = M_Z) = 0.0990 \pm 0.0027 \pm 0.0014$$

old value: $A_{FB}^{b}(\sqrt{s} = M_Z) = 0.1017 \pm 0.0038 \pm 0.0032$

$A_{FB}^{b\bar{b}}$ at $\sqrt{s} \approx m_Z$



$0.0949 \pm 0.0040 \pm 0.0023$

$0.1010 \pm 0.0057 \pm 0.0024$

$0.0960 \pm 0.0066 \pm 0.0033$

$0.0910 \pm 0.0044 \pm 0.0020$

$0.0990 \pm 0.0027 \pm 0.0014$

$0.0982 \pm 0.0047 \pm 0.0016$

$0.0931 \pm 0.0034 \pm 0.0015$

$0.0931 \pm 0.0101 \pm 0.0055$

$0.1004 \pm 0.0052 \pm 0.0044$

0.0982 ± 0.0017

Include Total Sys 0.0008
With Common Sys 0.0003

$m_t = 174.3 \pm 5.1$ GeV

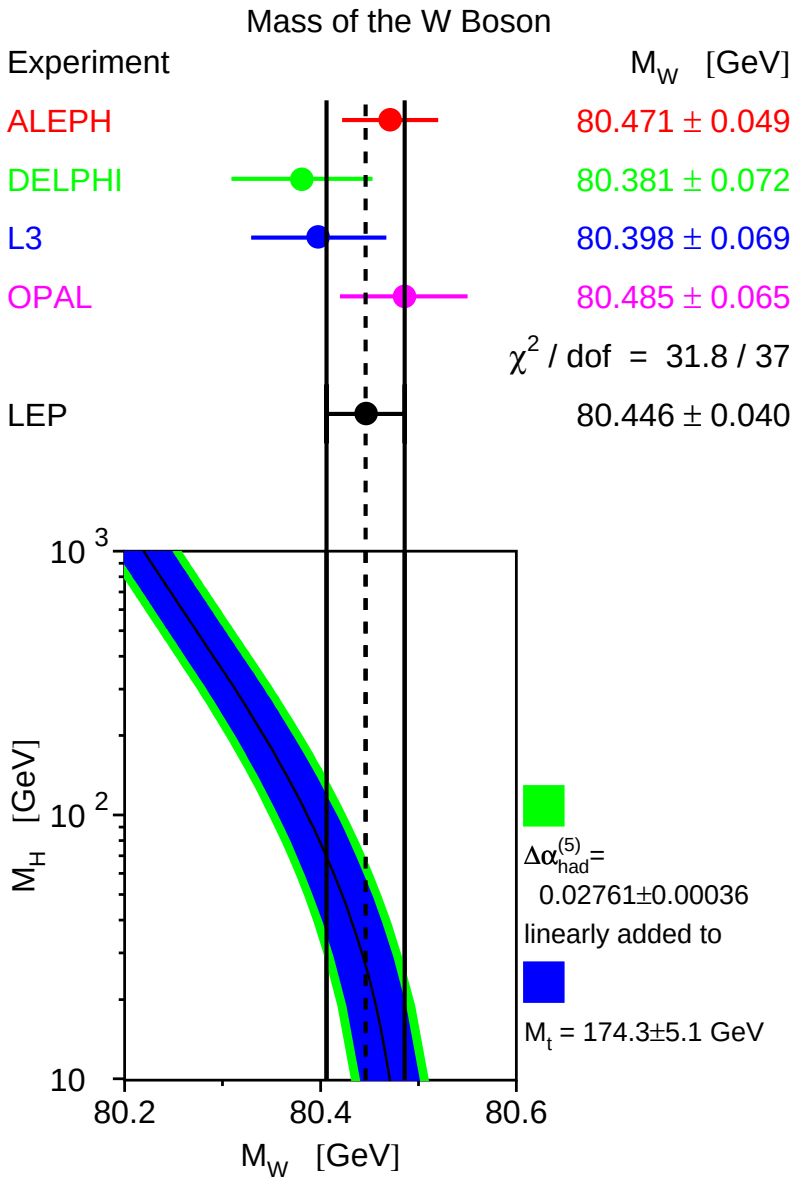
$\Delta\alpha_{had} = 0.02761 \pm 0.00036$

Measurement of $\mathrm{M_W}$ at LEP

- ALEPH and L3 have included data taken in 2000

- Reduction of the systematic uncertainty for ALEPH:
  $\rightarrow$ fragmentation uncertainty reduced from ~ 30 MeV to ~ 15 MeV
  $\rightarrow$ reduction of the uncertainty from final state interaction (BEC and CR)

$\mathrm{q\bar{q}l\bar{\nu}_l}$ and $\mathrm{q\bar{q}q\bar{q}}$ channels are consistent:
$\Delta \mathrm{M_W}(\mathrm{q\bar{q}q\bar{q}} - \mathrm{q\bar{q}l\bar{\nu}_l}) = +18 \pm 46 MeV$
$\Rightarrow$ no bias from FSI is observed



New determination of $\Delta\alpha^5_{\rm had}$

$$\alpha(s) = \frac{\alpha(0)}{1 - \Delta\alpha_l(s) - \Delta\alpha^5_{\rm had}(s) - \Delta\alpha_{top}(s)}$$

$\Delta\alpha^5_{\rm had}$ determined from $R_{had} = \dfrac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$

New $e^+e^- \to q\bar{q}$ data from BES between 2 and 5 GeV

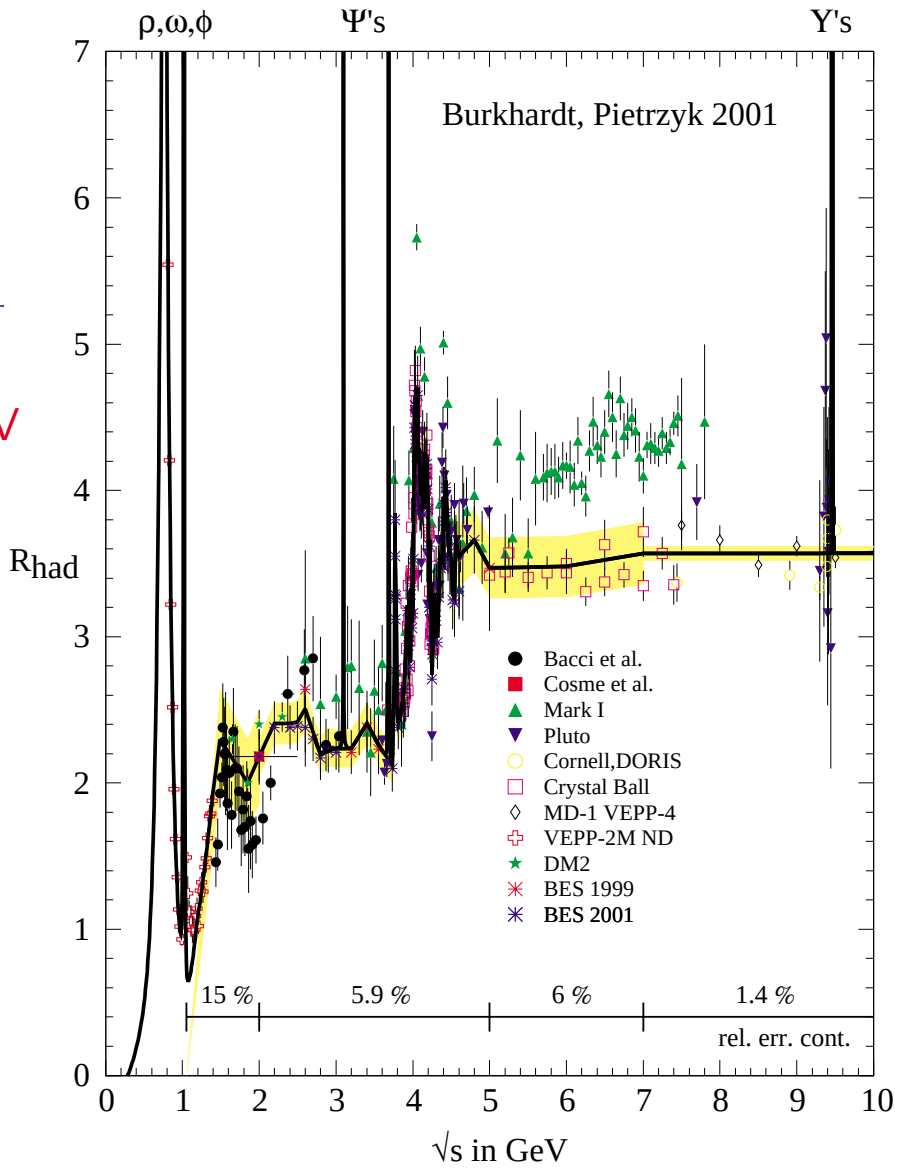
$\Rightarrow$ error reduced by a factor > 2 in this region.

Using:

- only experimental data below 12 GeV
- third order QCD above 12 GeV

$$\Delta\alpha^5_{\rm had}(M_Z) = 0.02761 \pm 0.00036$$

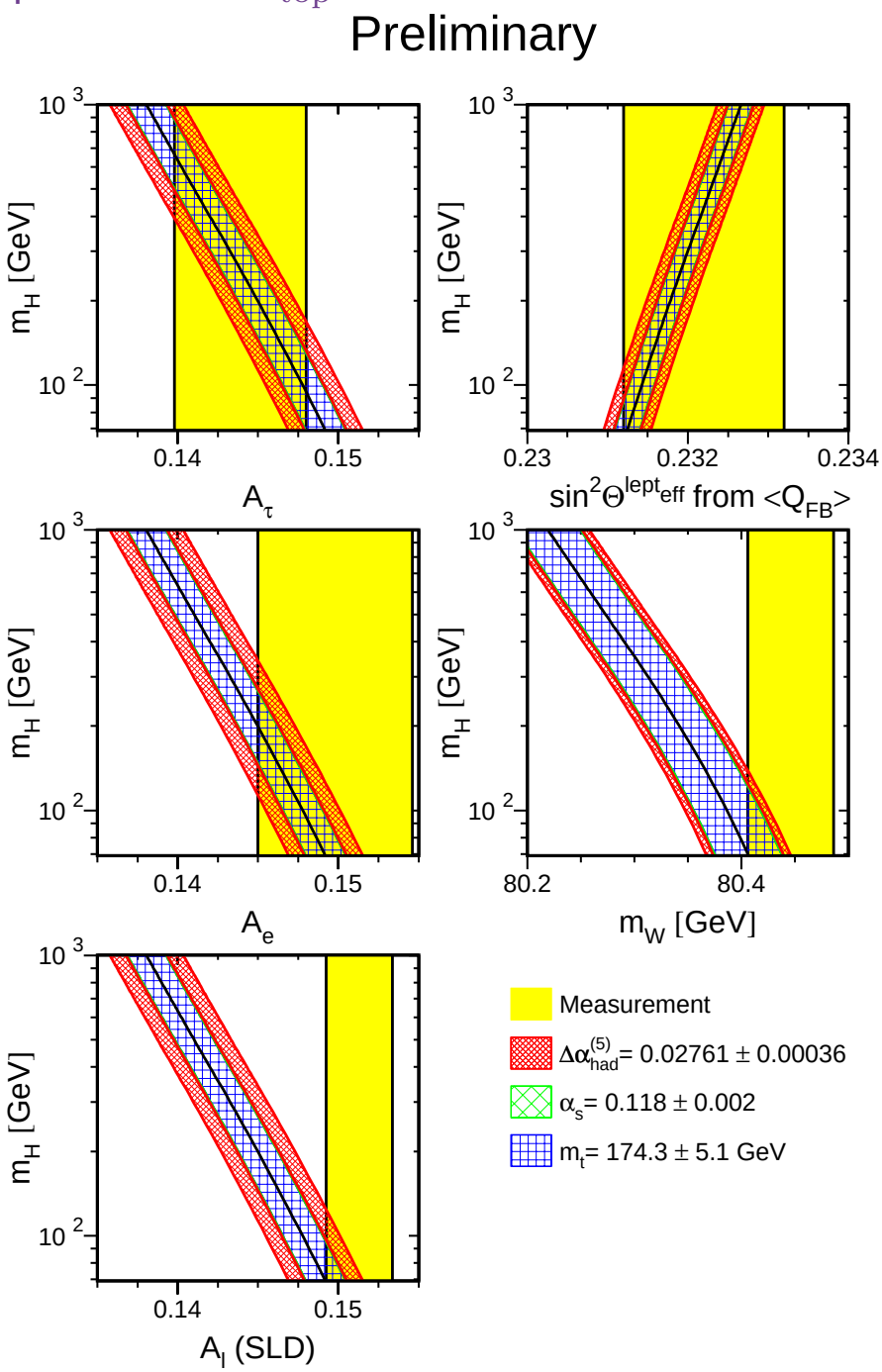
old value: $\Delta\alpha^5_{\rm had}(M_Z) = 0.02804 \pm 0.00065$



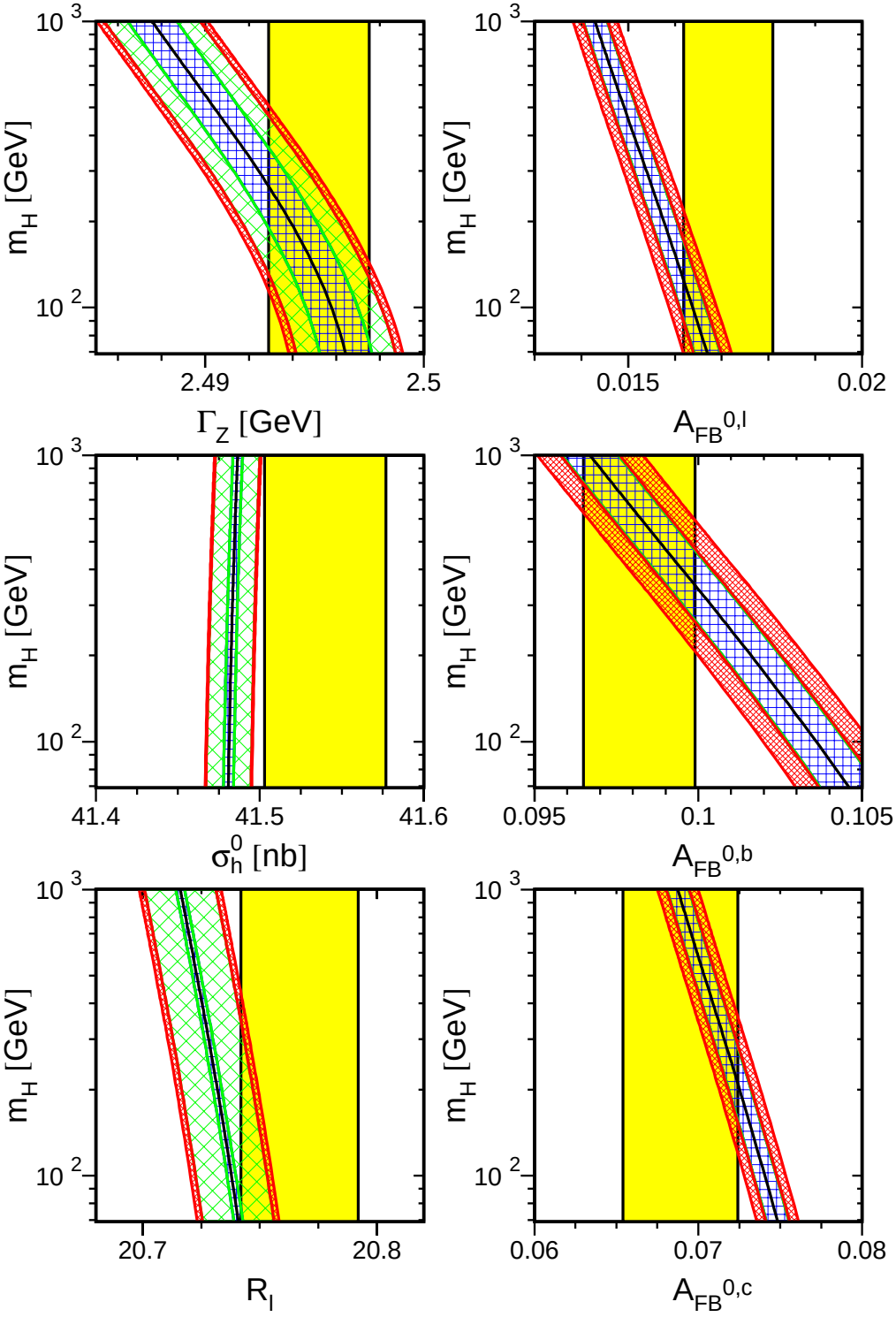
Test of the SM and constraint on M_H

The most sensitive variable to M_H is $\sin^2\theta^{lept}_{eff}$ determined by the asymmetries.

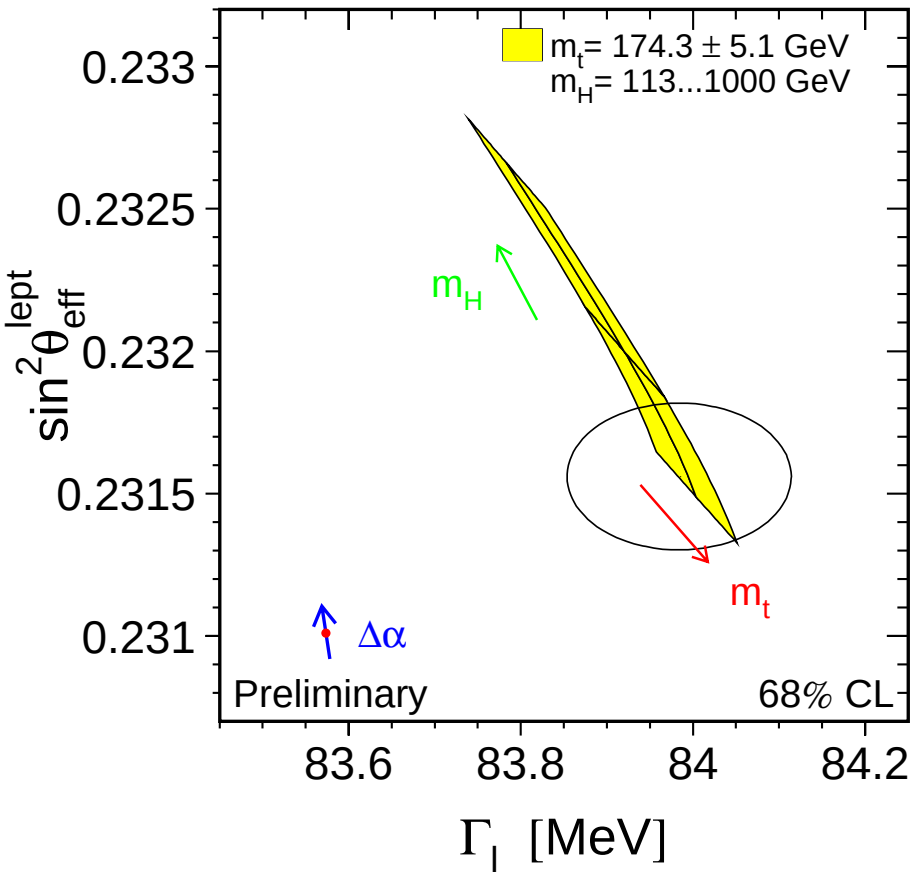
A good sensitivity is also given by M_W, but M_W is very dependent on m_{top}!

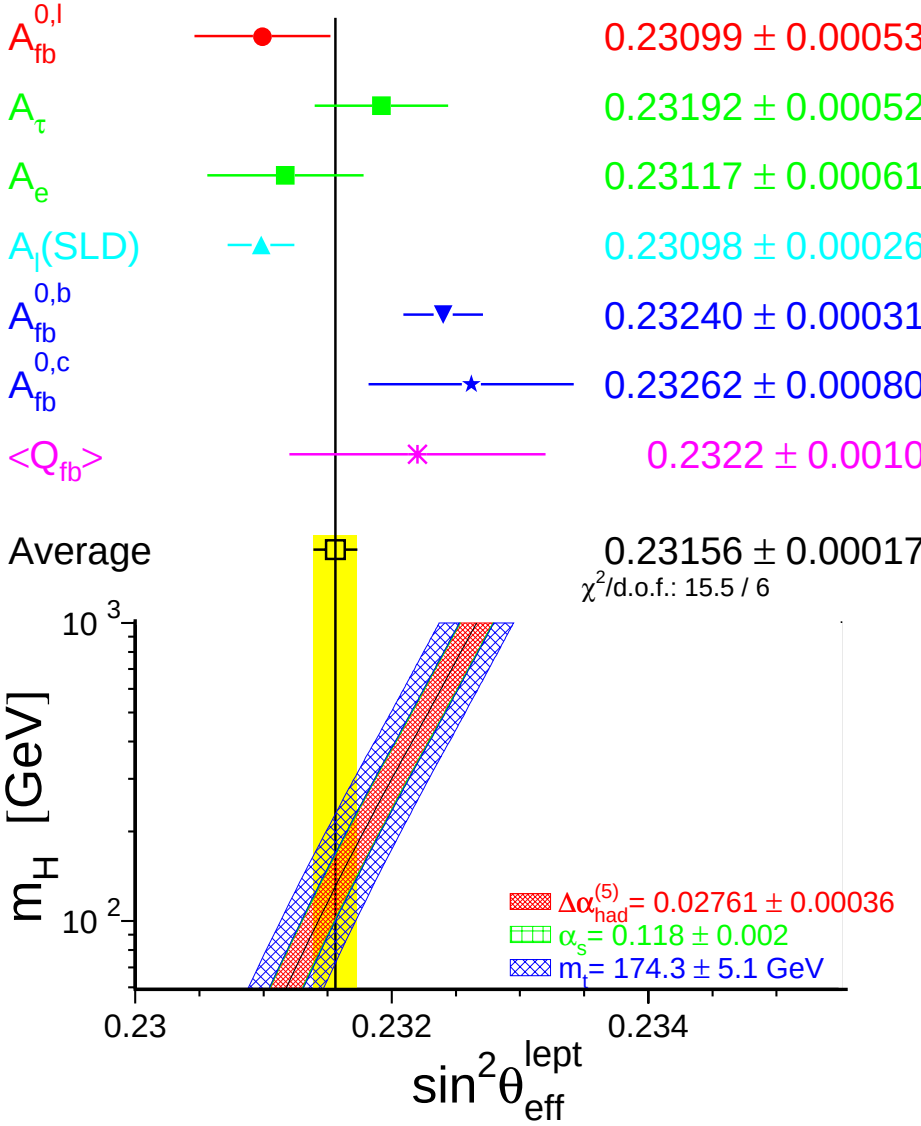


Preliminary



$\sin^2\theta^{\mathrm{lept}}_{\mathrm{eff}}$





Test of the Standard Model

Use electroweak measurements at LEP1 and SLC $\Rightarrow$ indirect determination of m_{top} and M_W and constraint on M_H

$$\mathrm{Log}(M_H) = 1.94^{+0.34}_{-0.37}$$

$$M_H = 87^{+119}_{-43}\ \mathrm{GeV}$$

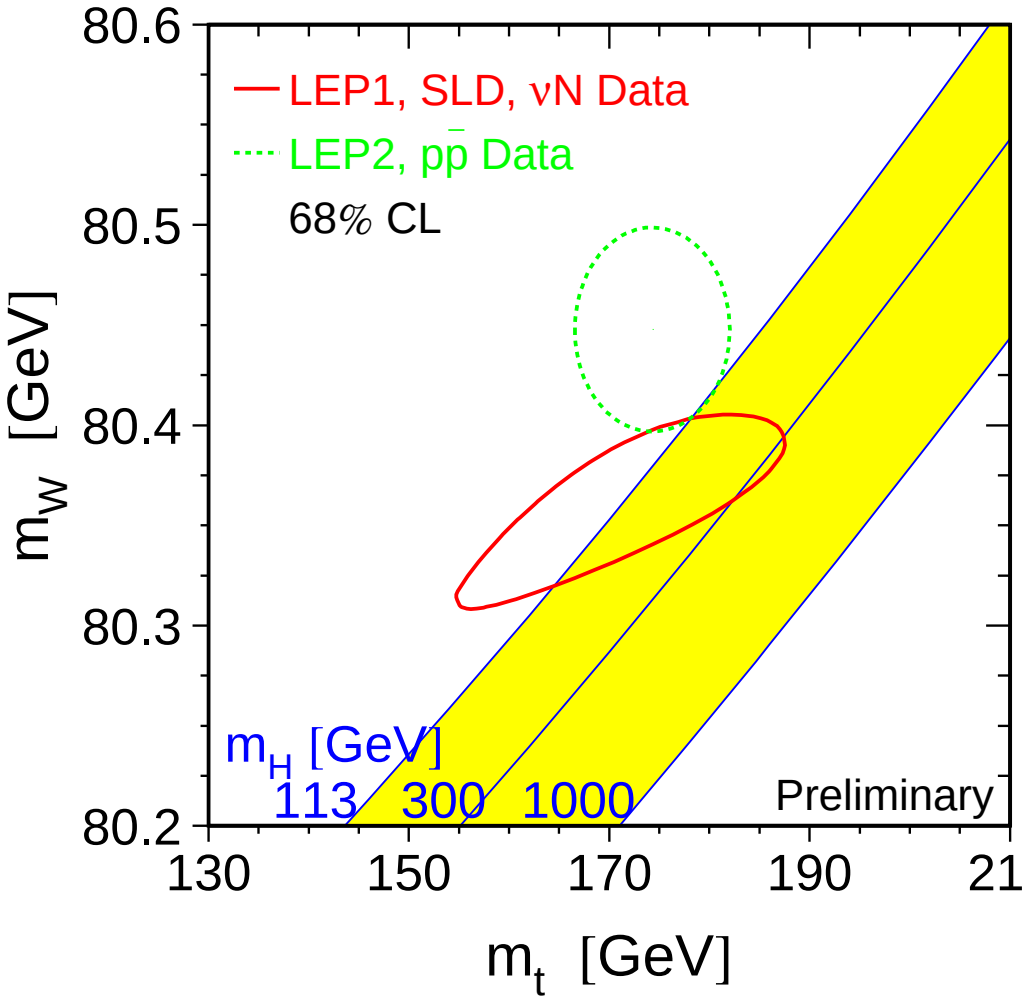
$$m_{top} = 168.3^{+11.9}_{-9.3}\ \mathrm{GeV}$$

$$M_W = 80.357 \pm 0.033\ \mathrm{GeV}$$

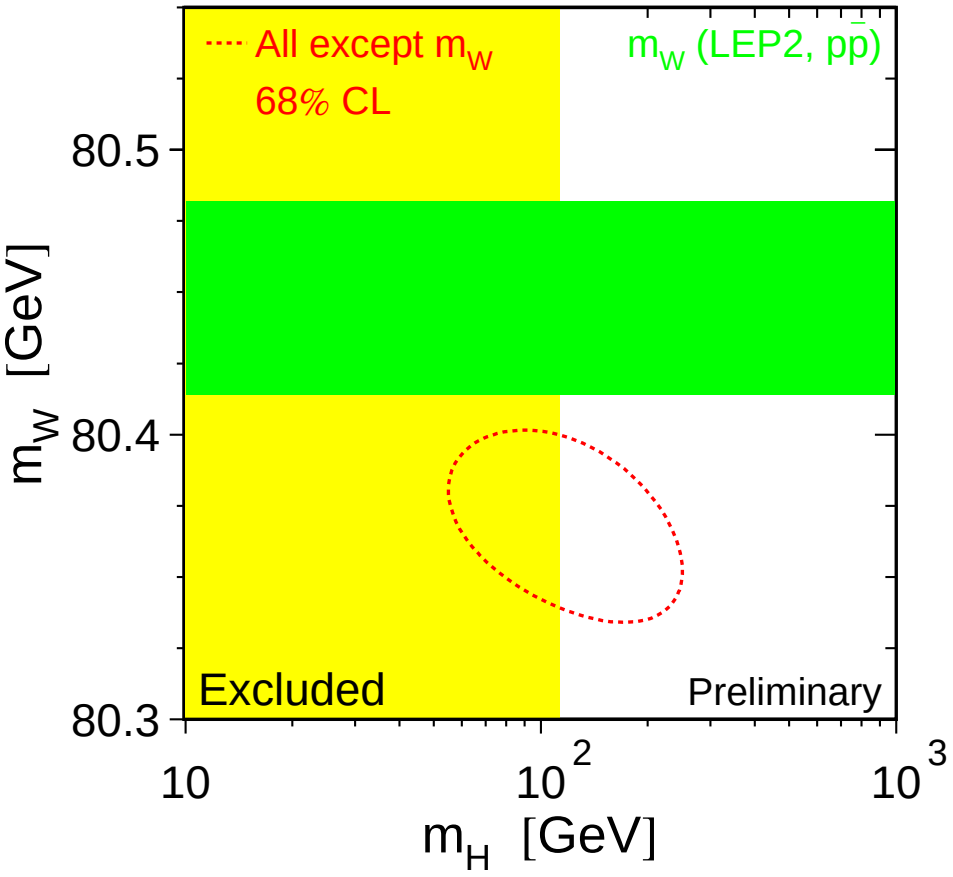
Good agreement with the direct measurements:

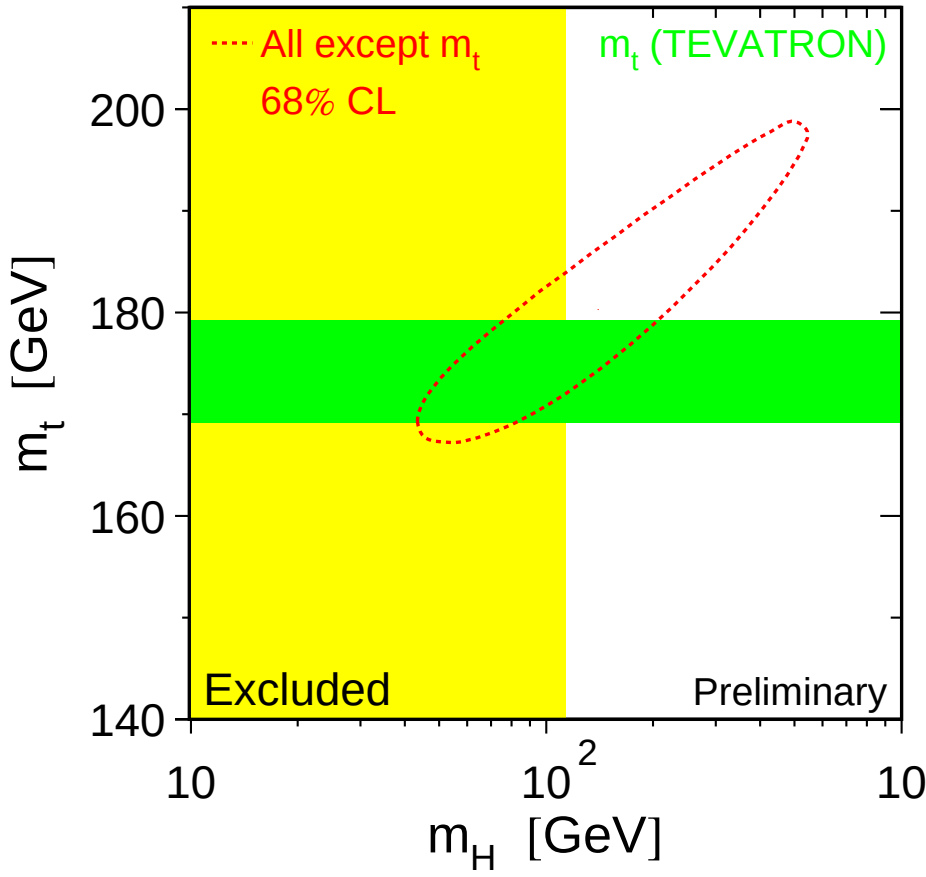
$$m_{top} = 174.3 \pm 5.1\ \mathrm{GeV}$$

$$M_W = 80.448 \pm 0.034\ \mathrm{GeV}$$



Correlations between M_H, m_{top} and M_W





Global fit with all the data

Include also the direct measurement of m_{top} and M_W

$$\mathrm{Log}(M_H) = 1.99 \pm 0.21$$

$$M_H = 98^{+58}_{-38} \text{ GeV}$$

$$m_{top} = 175.7 \pm 4.4 \text{ GeV}$$

$$M_W = 80.393 \pm 0.019 \text{ GeV}$$

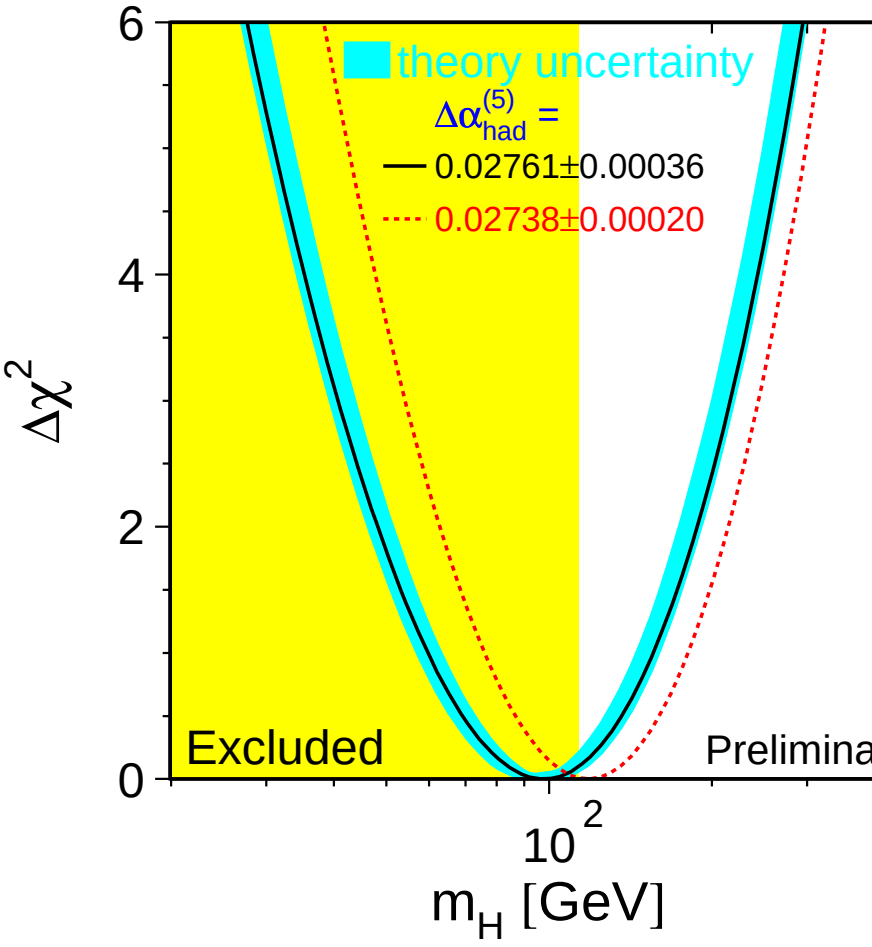
$\Rightarrow M_H < 212$ GeV (95% C.L.)

$\chi^2 = 25/15$ - probability is only 4%!

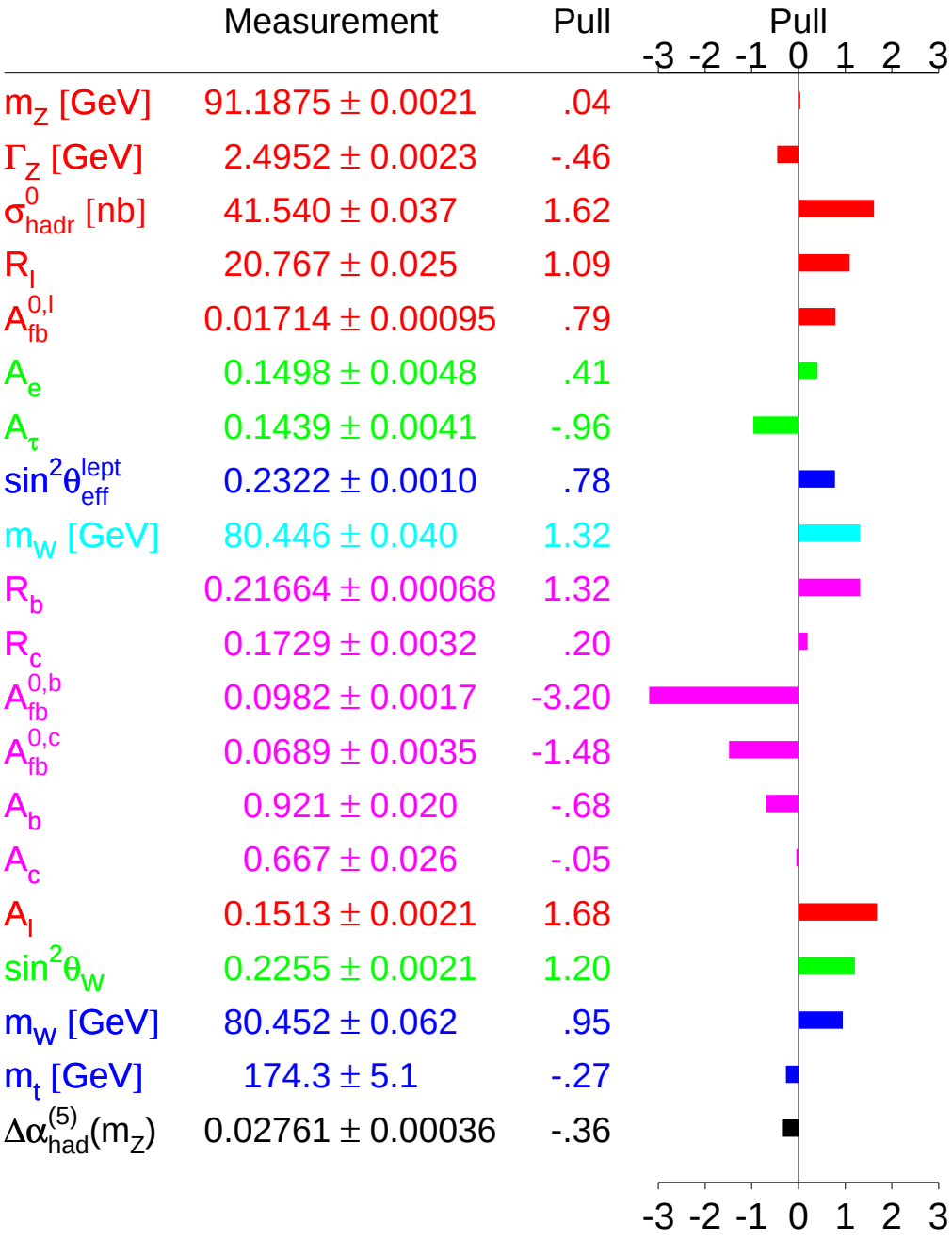
new value of $\Delta\alpha^5_{had}$ shifts M_H by $+35$GeV

The error on $\mathrm{Log}(M_H)$ arising from $\Delta\alpha^5_{had}$ is reduced from 0.2 to 0.1 $\Rightarrow$ it is no longer the dominant error

Use ZFITTER and TOPAZ0 for the fit



Winter 2001


Measurement
Pull
Pull
-3 -2 -1 0 1 2 3
m_Z [GeV] 91.1875 ± 0.0021 .04
Γ_Z [GeV] 2.4952 ± 0.0023 -.46
σ^0_{hadr} [nb] 41.540 ± 0.037 1.62
R_l 20.767 ± 0.025 1.09
$A^{0,l}_{fb}$ 0.01714 ± 0.00095 .79
A_e 0.1498 ± 0.0048 .41
A_τ 0.1439 ± 0.0041 -.96
$\sin^2\theta^{lept}_{eff}$ 0.2322 ± 0.0010 .78
m_W [GeV] 80.446 ± 0.040 1.32
R_b 0.21664 ± 0.00068 1.32
R_c 0.1729 ± 0.0032 .20
$A^{0,b}_{fb}$ 0.0982 ± 0.0017 -3.20
$A^{0,c}_{fb}$ 0.0689 ± 0.0035 -1.48
A_b 0.921 ± 0.020 -.68
A_c 0.667 ± 0.026 -.05
A_l 0.1513 ± 0.0021 1.68
$\sin^2\theta_W$ 0.2255 ± 0.0021 1.20
m_W [GeV] 80.452 ± 0.062 .95
m_t [GeV] 174.3 ± 5.1 -.27
$\Delta\alpha^{(5)}_{had}(m_Z)$ 0.02761 ± 0.00036 -.36
-3 -2 -1 0 1 2 3

Summary of fits

	all data except direct M_W and m_{top}	all data except direct m_{top}	all data except direct M_W	all data
m_{top} [GeV]	$168.3^{+11.9}_{-9.3}$	$180.3^{+11.7}_{-9.2}$	173.3 ± 4.8	175.7 ± 4.4
M_H [GeV]	87^{+119}_{-43}	139^{+203}_{-77}	121^{+76}_{-48}	98^{+58}_{-38}
$\mathrm{Log}(M_H/\mathrm{GeV})$	$1.94^{+0.37}_{-0.30}$	$2.14^{+0.39}_{-0.35}$	$2.08^{+0.21}_{-0.22}$	$1.99^{+0.20}_{-0.21}$
$\alpha_s(M_Z^2)$	0.1188 ± 0.0027	0.1188 ± 0.0029	0.1190 ± 0.0027	0.1184 ± 0.0027
χ^2/d.o.f.	21/12	25/14	22/13	25/15
$\sin^2\theta^{\mathrm{eff}}_{\mathrm{lept}}$	0.23155 ± 0.00016	0.23144 ± 0.00015	0.23156 ± 0.00016	0.23142 ± 0.0001
$\sin^2\theta_W$	0.22344 ± 0.00063	0.22259 ± 0.00045	0.22322 ± 0.00045	0.22273 ± 0.0003
M_W [GeV]	80.357 ± 0.033	80.401 ± 0.023	80.368 ± 0.023	80.393 ± 0.019

Using $\Delta\alpha^5_{\mathrm{had}}(M_Z) = 0.02761 \pm 0.00036$ (Burkhardt, Pietrzyk)

Direct measurements: $m_{top} = 174.3 \pm 5.1$ GeV

$M_W = 80.448 \pm 0.034$ GeV

The uncertainty on the Higgs mass

Using a parametrisation (Degrassi et al.) for
$\sin^2\theta^{\rm lept}_{\rm eff}, {\rm M_W} = {\rm f}({\rm m_{top}}^2, {\rm Log(M_H)}, \alpha_{\rm QED})$.

with $\sin^2\theta^{\rm lept}_{\rm eff}$ alone:

$$\sigma(\mathrm{Log(M_H)}) = \pm 0.14(sin^2\theta^{eff}_{lept}) \mp 0.10(\alpha_{QED}) \pm 0.13(\mathrm{m_{top}})$$

with $\mathrm{M_W}$ alone:

$$\sigma(\mathrm{Log(M_H)}) = \mp 0.24(M_W) \mp 0.05(\alpha_{QED}) \pm 0.26(\mathrm{m_{top}})$$

$\Rightarrow$ need to improve the precision on $\mathrm{m_{top}}$ in order to increase the power of $\mathrm{M_W}$!

Assuming: $\sigma(\mathrm{m_{top}}) = 3$ GeV and $\sigma(M_W) = 25$ MeV
(LEP2 +Tevatron Run IIa)

with $\sin^2\theta^{\rm lept}_{\rm eff}$ alone:

$$\sigma(\mathrm{Log(M_H)}) = \pm 0.14(sin^2\theta^{eff}_{lept}) \mp 0.10(\alpha_{QED}) \pm 0.08(\mathrm{m_{top}})$$

with $\mathrm{M_W}$ alone:

$$\sigma(\mathrm{Log(M_H)}) = \mp 0.18(M_W) \mp 0.05(\alpha_{QED}) \pm 0.15(\mathrm{m_{top}})$$

Combination of direct search and indirect measurements

From G. Degrassi

Using:

- the November LEPC likelihood $\mathcal{R}(\mathrm{M_H})$
- a χ^2 obtained with indirect measurements
- a uniform prior in Log($\mathrm{M_H}$)

Probability distribution function $f(\mathrm{M_H}) \propto \frac{\mathcal{R}(\mathrm{M_H})e^{(-\chi^2/2)}}{\mathrm{M_H}}$

See plot on next page

95% upper limit on $\mathrm{M_H}$ goes up by about 20 GeV

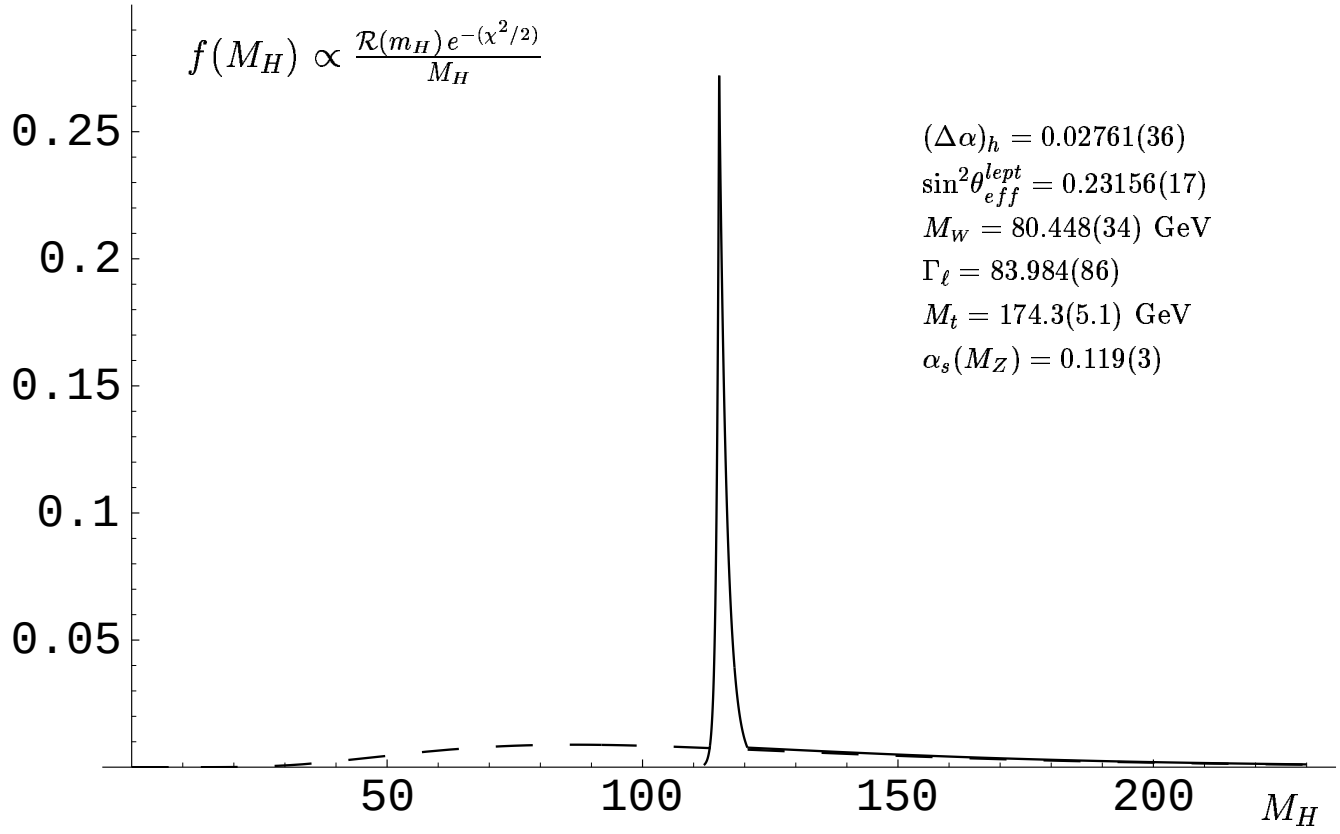


Figure 1: Probability distribution functions using only indirect information (dashed line, $\mathcal{R} \equiv 1$) and employing also the experimental results from direct searches (solid one). The spike reflects the excess of events recorded at Lep at $M_H \sim 115$ GeV (Likelihood ratio $\mathcal{R} \sim 30$).

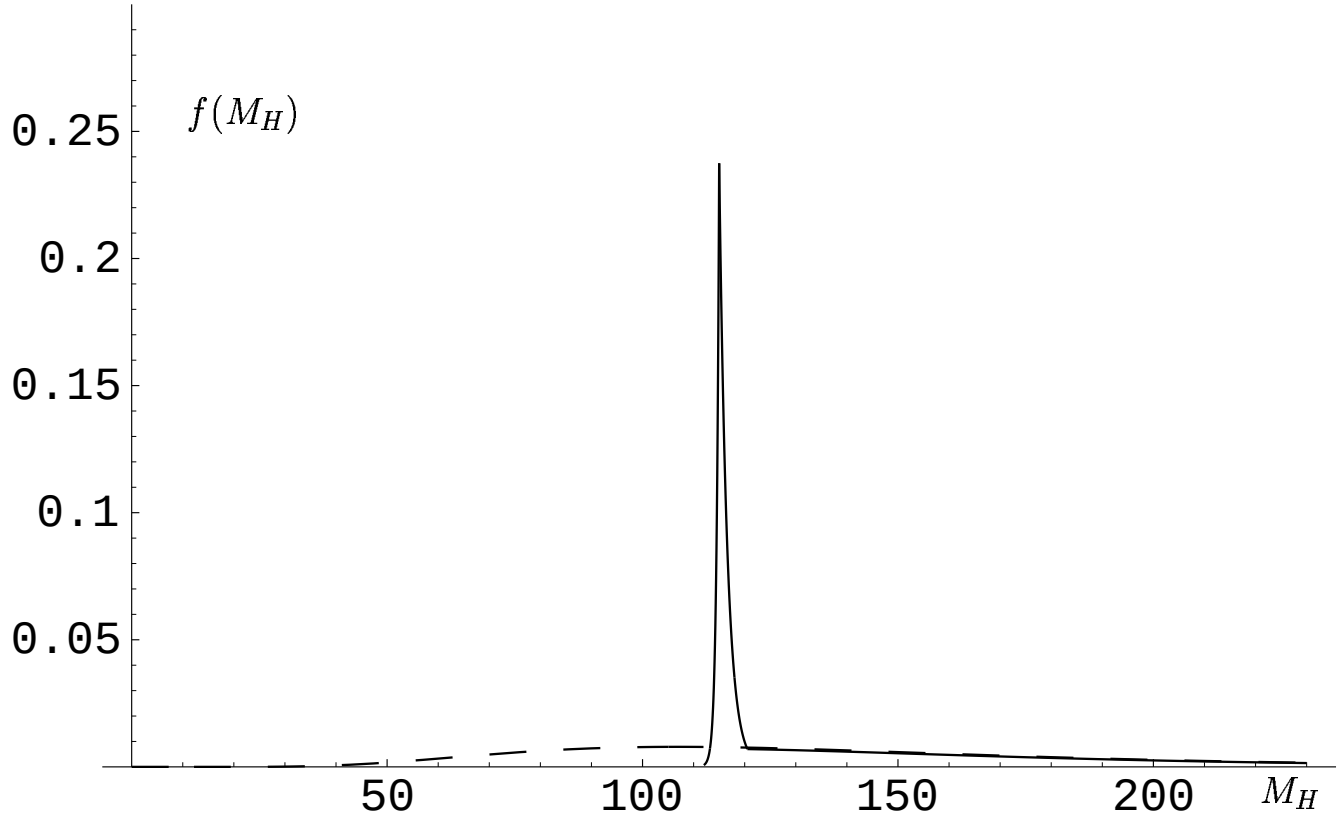


Figure 2: Same as Figure 1 but with $(\Delta\alpha)_h = 0.02738(20)$

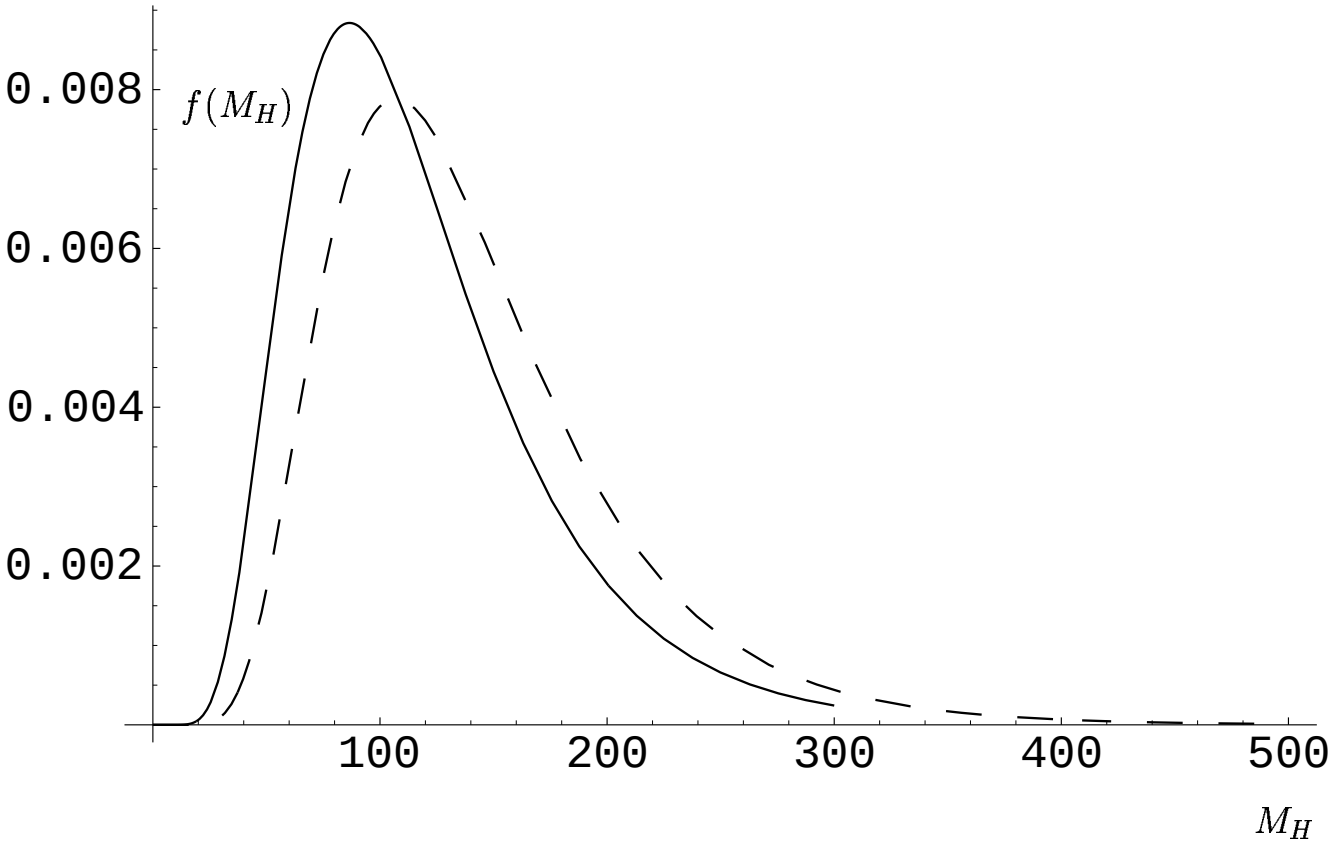


Figure 3: Probability distribution functions using only indirect information (dashed line $(\Delta\alpha)_h = 0.02738(20)$, solid line $(\Delta\alpha)_h = 0.02761(36)$).

Conclusion

Most significant new inputs:

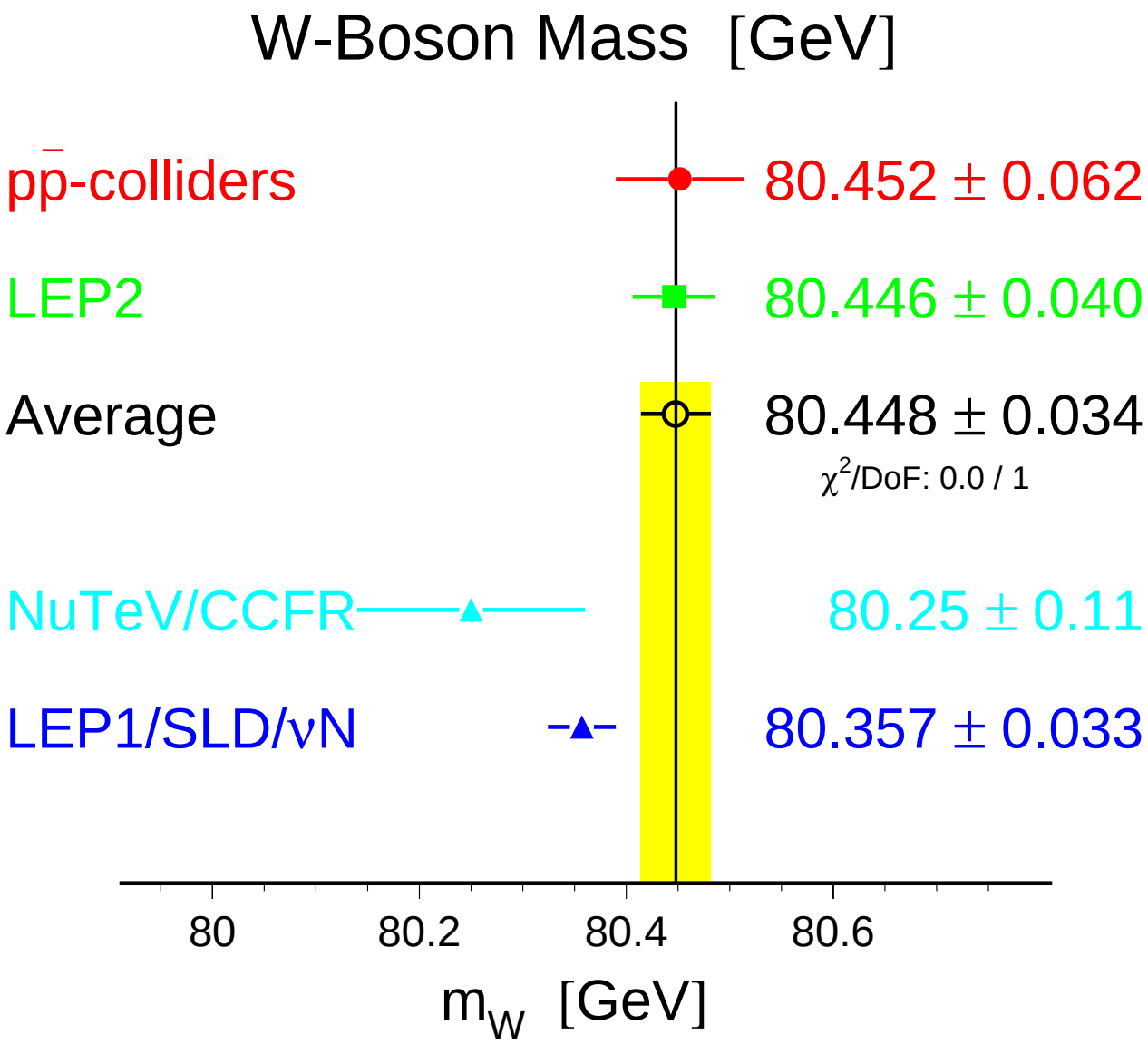
- $\mathrm{A_{FB}^{b}}$ from LEP $\Rightarrow$ new $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$
- $\mathrm{M_W}$ from LEP $\Rightarrow$ error on direct $\mathrm{M_W}$: 34 MeV
- new $\Delta\alpha^5_{\mathrm{had}}$ including new BES data

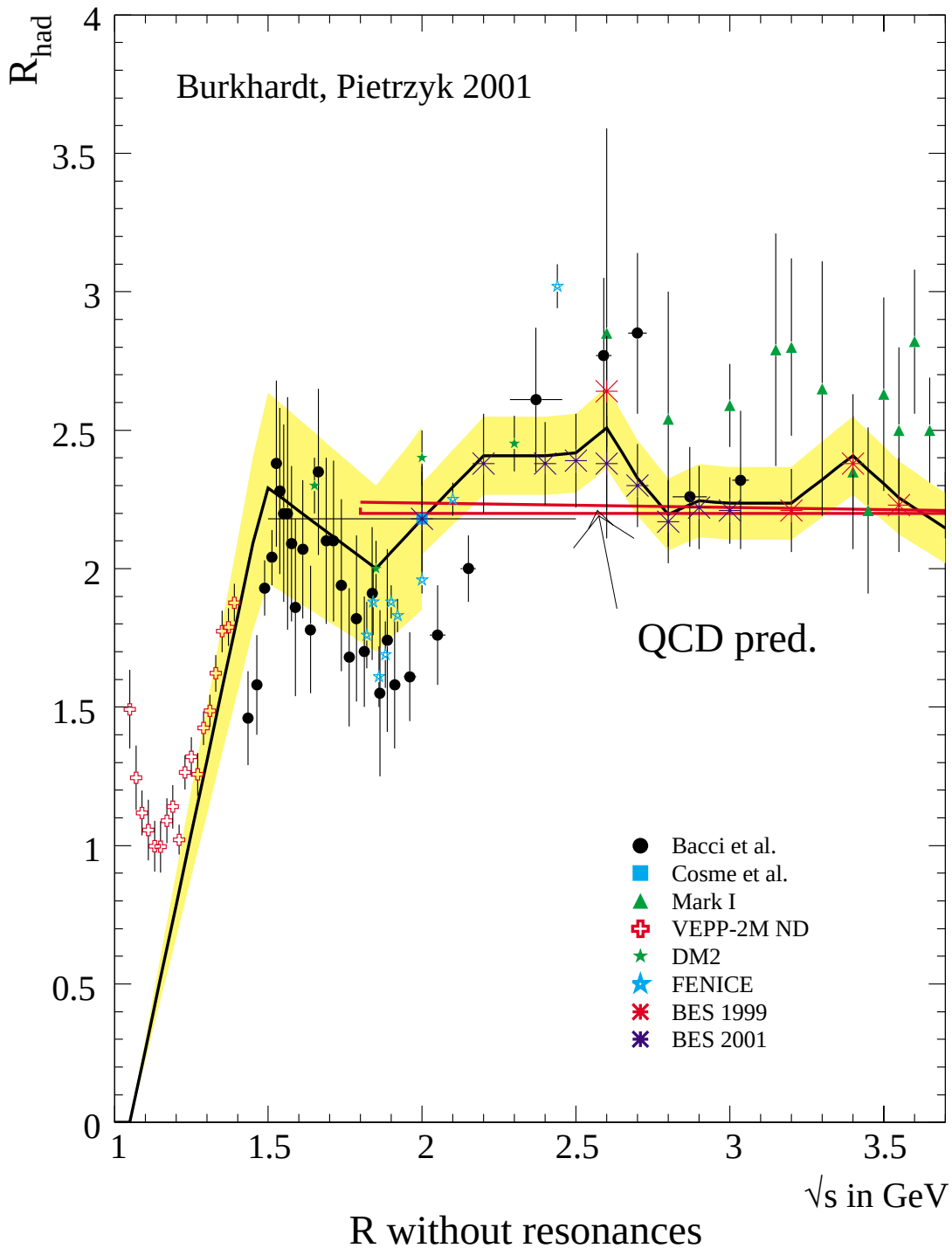
The Standard Model is consistent with observation: indirect determinations of $\mathrm{m_{top}}$ and $\mathrm{M_W}$ agree with the direct measurements

Data prefer a low Higgs mass (except $\mathrm{A_{FB}^{0,b}}$,$\mathrm{A_{FB}^{0,c}}$):

$$\mathrm{M_H} = 98^{+58}_{-38}\ \mathrm{GeV}$$

$$\Rightarrow \mathrm{M_H} < 212\ \mathrm{GeV}\ (95\%\ \mathrm{C.L.})$$


W-Boson Mass [GeV]
p̄p-colliders
80.452 ± 0.062
LEP2
80.446 ± 0.040
Average
80.448 ± 0.034
χ²/DoF: 0.0 / 1
NuTeV/CCFR
80.25 ± 0.11
LEP1/SLD/νN
80.357 ± 0.033
80
80.2
80.4
80.6
m_W [GeV]


Burkhardt, Pietrzyk 2001
R_{had}
QCD pred.
Bacci et al.
Cosme et al.
Mark I
VEPP-2M ND
DM2
FENICE
BES 1999
BES 2001
0
0.5
1
1.5
2
2.5
3
3.5
4
1
1.5
2
2.5
3
3.5
√s in GeV
R without resonances