Kick-Off Workshop
of the Helmholtz Alliance
DESY Hamburg
4th December 2007

Electroweak Fits using Gfitter

Martin Goebel
Universität Hamburg

Outline

- What / Who is Gfitter?
- Why a new fit of Standard Model?
- Implementation
- Comparison with ZFitter
- Results
  - Higgs mass estimate
  - Treatment of theoretical uncertainties
  - Goodness of global fit
  - p-value of the SM at different Higgs masses
  - Two-Dimensional Scans
- Summary

What is Gfitter?

- Gfitter - A Generic Fitter Project for HEP Model Testing
  http://cern.ch/Gfitter
- It is built upon ROOT
- Organized in one core statistic/fitting package, and physics plugin packages
  - SM, Two Higgs Doublet, SUSY, etc.
- Dynamic parameter caching
  - Only Recalculation of parameters when needed
- Goal: Perform fully frequentist analysis
  - Present: goodness of fit by toy-analysis
- Transparent fitting and steering card interpretation
  - Usage of XML format

What / Who is Gfitter?

- In steering card only one type of parameter
  - The chosen actions depend on whether the parameter has an associated prediction or not

⇒ This makes Gfitter a flexible tool

- We think it's very user-friendly

Who is Gfitter?

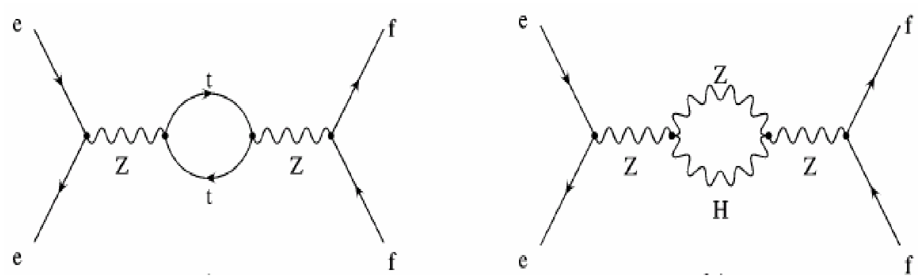
Henning Flächer (CERN)	Andreas Hoecker (CERN)
Martin Goebel (Uni HH / DESY)	Klaus Mönig (DESY)
Johannes Haller (Uni HH / DESY)	Joerg Stelzer (CERN)

Why a new fit of Standard Model?

- Testing and improving of framework with well-known theory
- Existing SM packages written in Fortran
  - Involved usage
  - Hard to change something or update the code
- Physics aim: Determination of observables which don’t match well to the SM (e.g. when the Higgs is measured)
- Usage of EW fit: SM extensions, e.g. 2 Higgs doublet models

Implementation of EW Fit

- Idea: Radiative corrections give precise predictions for ew observables
- Task: Computing all ew observables with five input parameters
- We use the *on-mass-shell (OMS)* scheme (like Zfitter)
  - Complete two loop corrections incl. the known higher order QCD and QED for most of the observables
  - **Quark masses and can be varied in the Fit, too!**



5 free parameters in the fit:

$$\Delta\alpha_{had}^{(5)}(M_Z), \alpha_S(M_Z), M_Z, m_t, M_H$$

Which observables are fitted?

All LEP precision measurements:

$M_Z \quad A_f \quad A_{FB}^{0,f} \quad R_f^0 \quad \sigma_{had}^0 \quad \Gamma_Z \quad \sin^2\Theta_{eff}^{lept}$

SLD measurement of the leptonic asymmetry A_{lep}

Tevatron/LEP world averages:

$M_W \quad \Gamma_W \quad m_{top}$

QED and QCD coupling constants at Z pole

$\Delta\alpha_{had}^{(5)}(M_Z) \qquad \alpha_S(M_Z)$

19 observables – 5 free parameters = 14 dof

Comparison with Zfitter

- Compared in detail the calculations of Zfitter and Gfitter
- Reproduction of Zfitter results!
- Small differences completely understood
  - Due to a different treatment of running QCD effects
  - Implementation of NNLO order RGE for strong coupling constant and running quark masses

Test with identical input, i.e.

$$\Delta\alpha_{had}^{(5)}(M_Z) = 0.02758 \pm 0.00035$$ [BP'05]

Gfitter: $\chi^2_{\min} = 18.0$

$M_H = 76.9 + 33.3 - 24.5$ GeV

Zfitter: $\chi^2_{\min} = 18.0$

$M_H = 76.7 + 33.2 - 24.5$ GeV

Global Standard Model Fit

We use the following best estimate for the contribution to α_{QED} at M_Z:

$$\Delta\alpha_{had}^{(5)}(M_Z) = 0.02768 \pm 0.00022 \pm 0.000022 \cdot (0.118 - \alpha_s(M_Z))^1$$ [HMNT'07]

Results for fit parameters:

Parameter Name	Fit Value	Uncertainties $\pm 1\sigma$ (sym.)	-1σ	$+1\sigma$
M_H	75.2	25.7	29.7	-22.4
$\alpha_s(M_Z)$	0.1183	0.0020	0.0020	-0.0020
$\Delta\alpha_{had}^5(M_Z)$	0.02772	0.00022	0.00022	-0.00022
M_Z	91.1875	0.0021	0.0021	-0.0021
m_t	171.28	1.79	1.80	-1.79
$\bar{m}_c$	1.25	0.09	0.09	-0.09
$\bar{m}_b$	4.20	0.07	0.07	-0.07

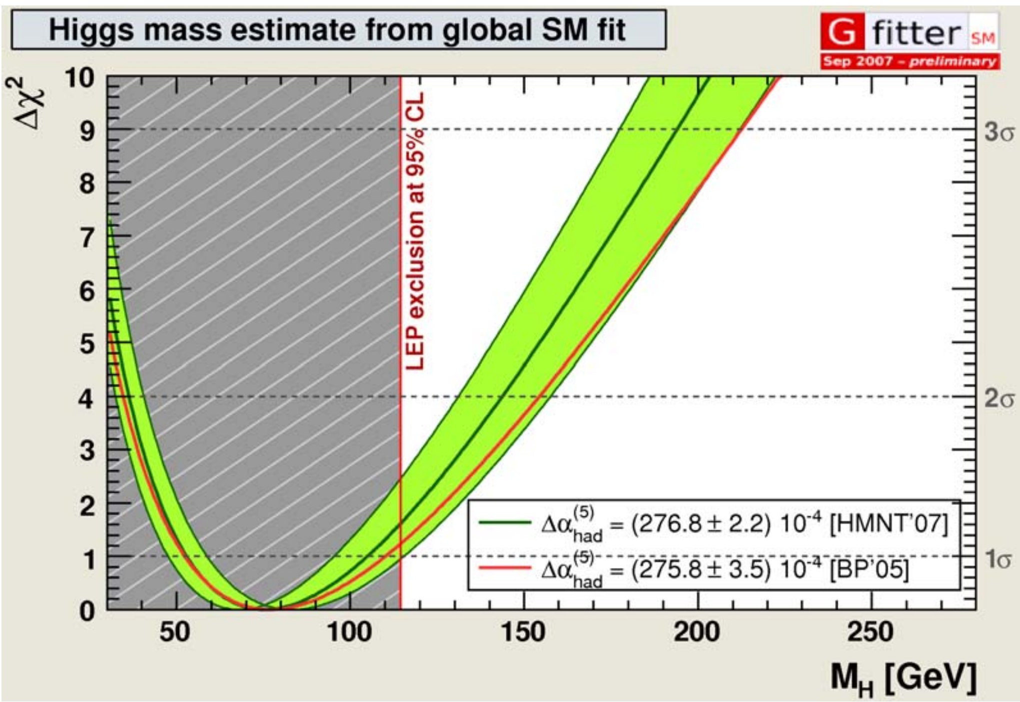
$$\chi^2_{min} / dof = 17.9/14$$

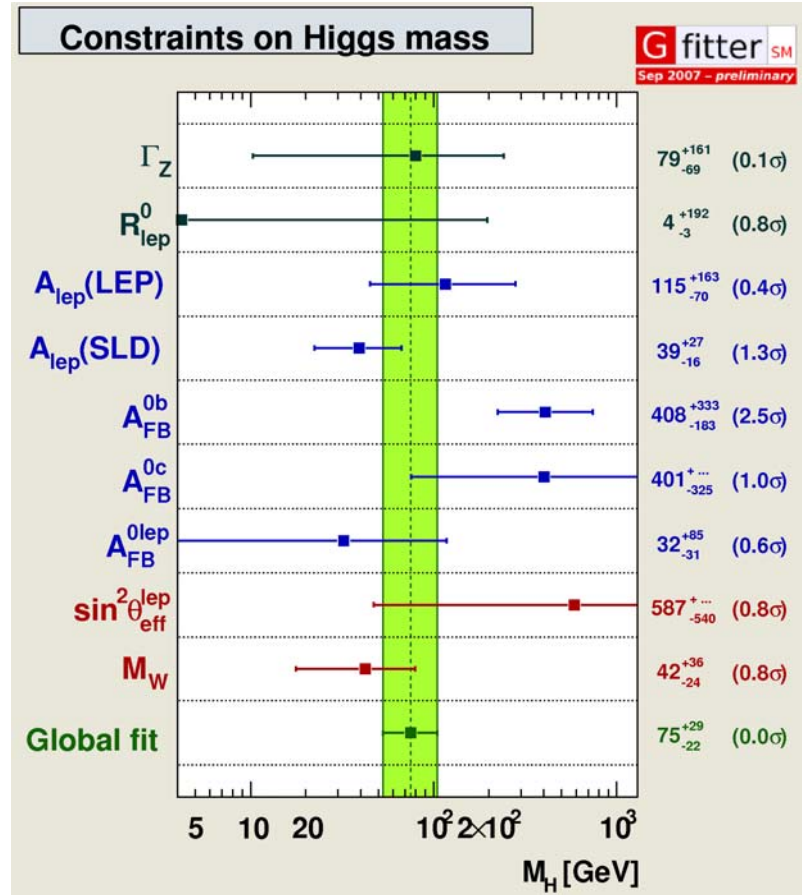
$$M_H = 75.1 + 29.6 - 22.4 \text{ GeV}$$

Correlation matrix:

	M_H	$\alpha_s(M_Z)$	$\Delta\alpha_{had}^5(M_Z)$	M_Z	m_t	$\bar{m}_c$	$\bar{m}_b$
M_H	1	0.052	-0.377	0.098	0.426	-0.001	-0.006
$\alpha_s(M_Z)$		1	0.014	-0.015	0.020	0.008	0.032
$\Delta\alpha_{had}^5(M_Z)$			1	-0.002	-0.006	0.000	-0.001
M_Z				1	-0.025	0.000	0.001
m_t					1	0.000	-0.004
$\bar{m}_c$						1	0.000
$\bar{m}_b$							1

Higgs mass scan

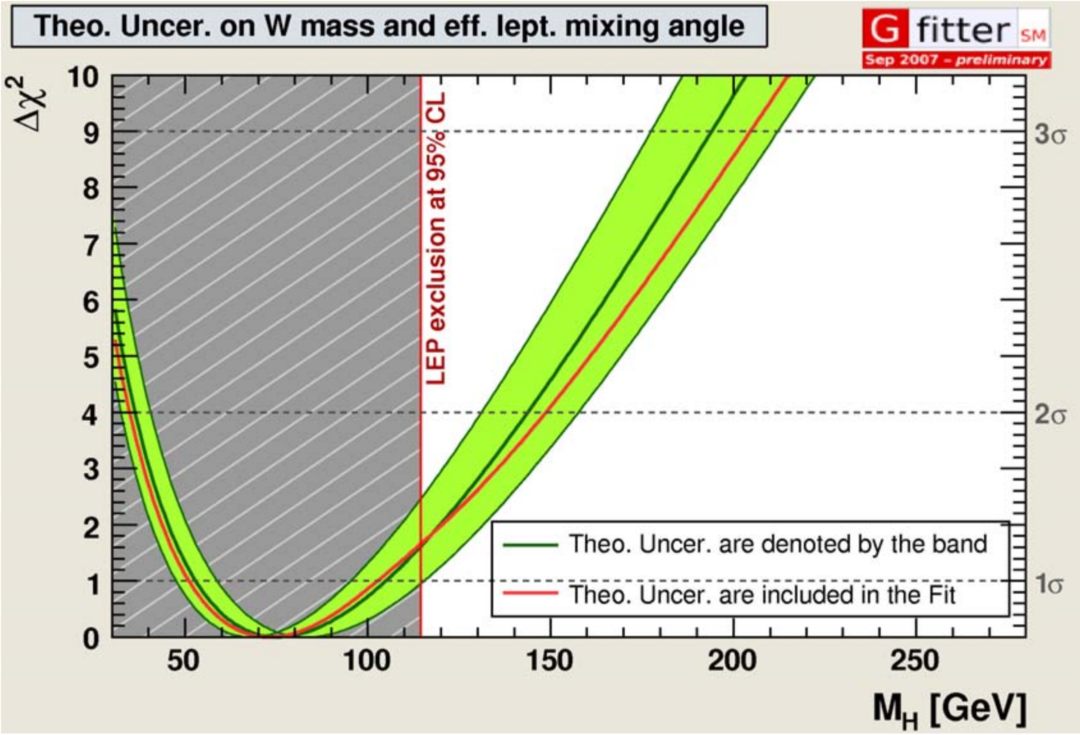




Band vs. including theo. uncertainties

Uncertainties for Theory-Prediction (two main sources)

$$M_W \pm \Delta M_W(theo) \qquad \sin^2\Theta_{eff}^{lept} \pm \Delta\sin^2\Theta_{eff}^{lept}(theo)$$



Old Treatment:

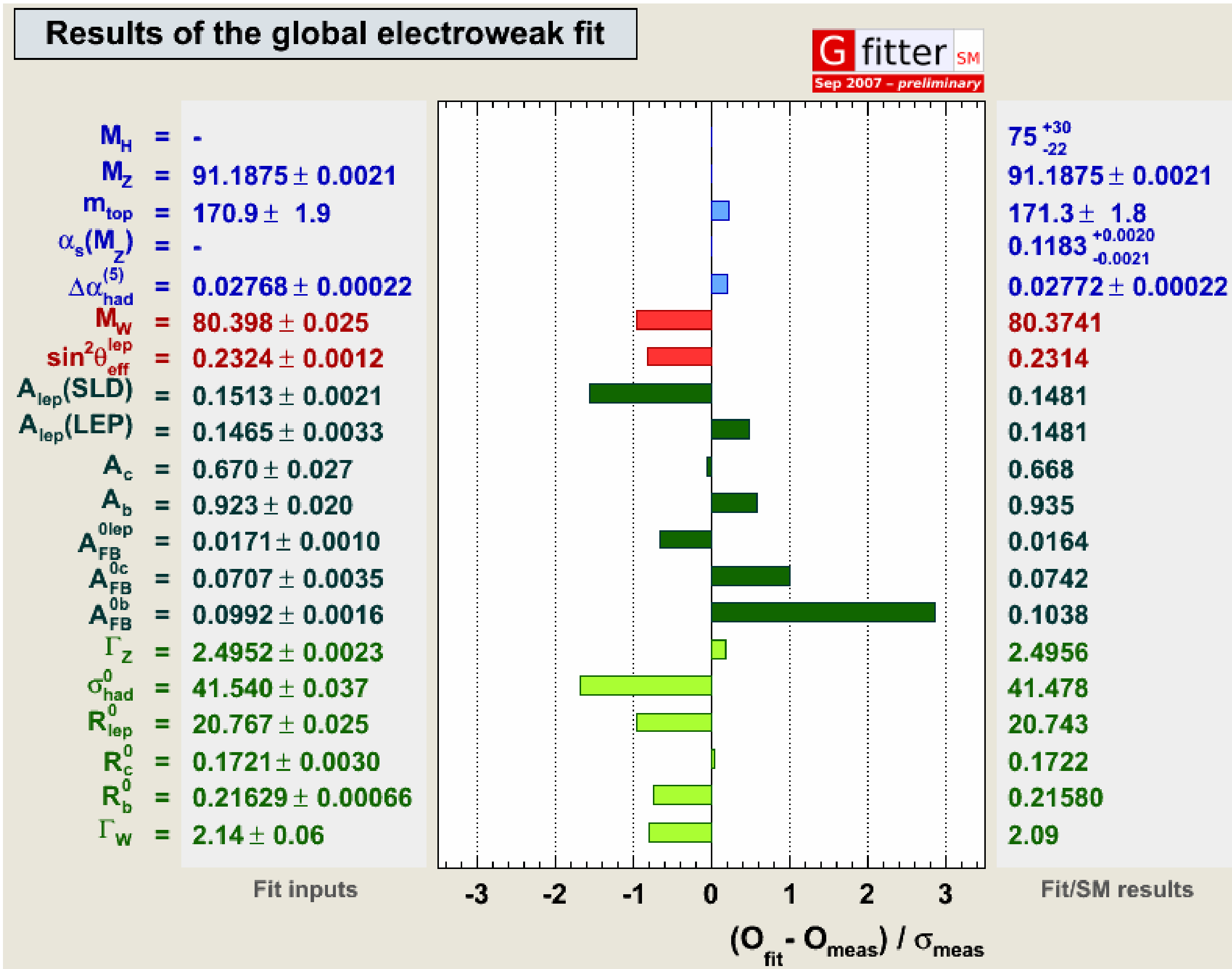
Band was done by **shifting** the predictions by these uncertainties **redoing** the scan and **choosing** the worst cases

New Treatment: (à la RFit)

If measurement

- within theory uncertainty: **no contribution** to χ^2.
- outside theory uncertainty: χ^2 determined by **distance** between **measurement** and **prediction ± uncertainty**

Fit Results



Results without theory uncertainties

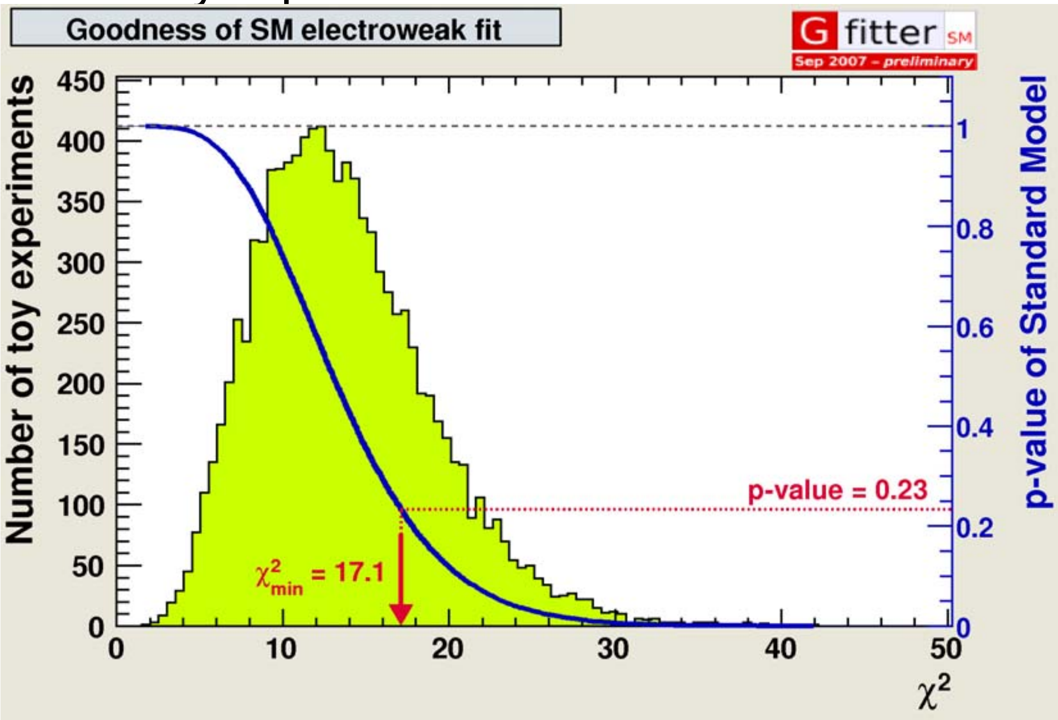
Results for some Observables

Goodness of global fit

by using toy analysis

- Execute the SM fit
- Generate toy sample by random sampling from Gaussian distributions around initial fit results (Correlations are taken into account)
- Refit with new values for observables, achieve a new χ^2

10000 toy experiments

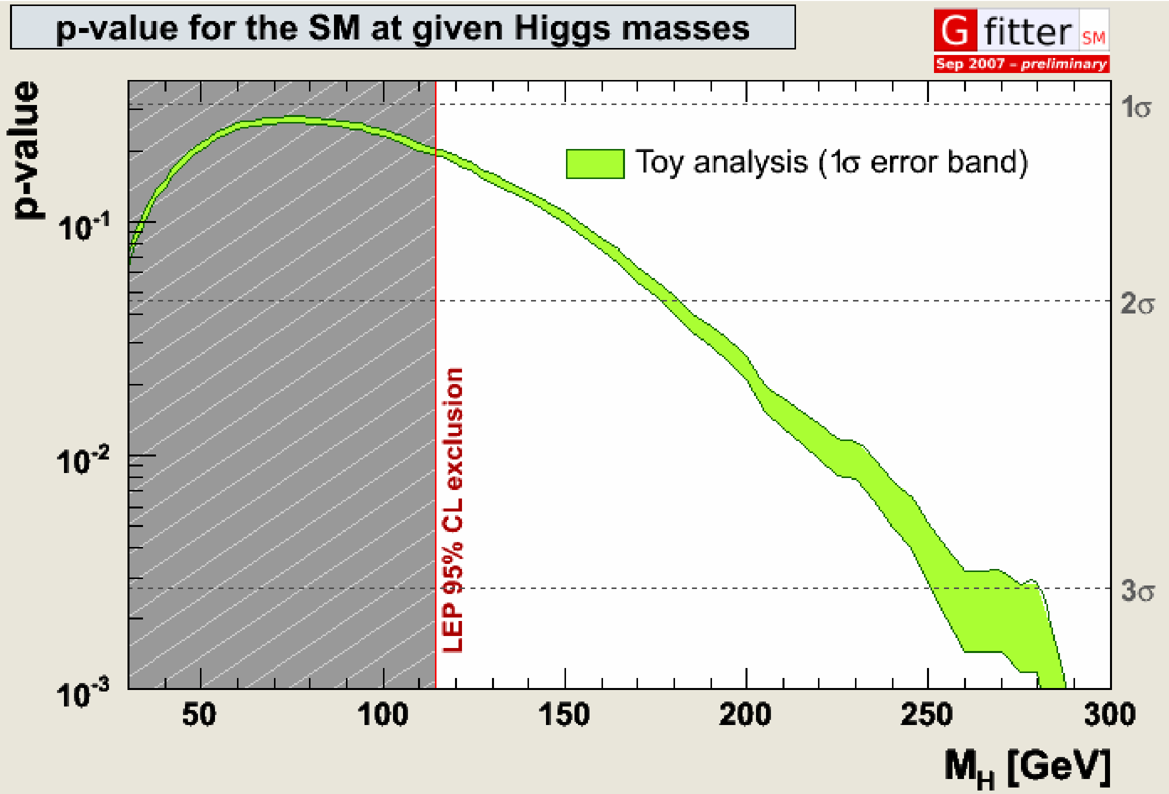


p-value: Probability for getting a χ^2 larger than the χ^2 of the fit

$$p-\text{value} \approx 0.23$$

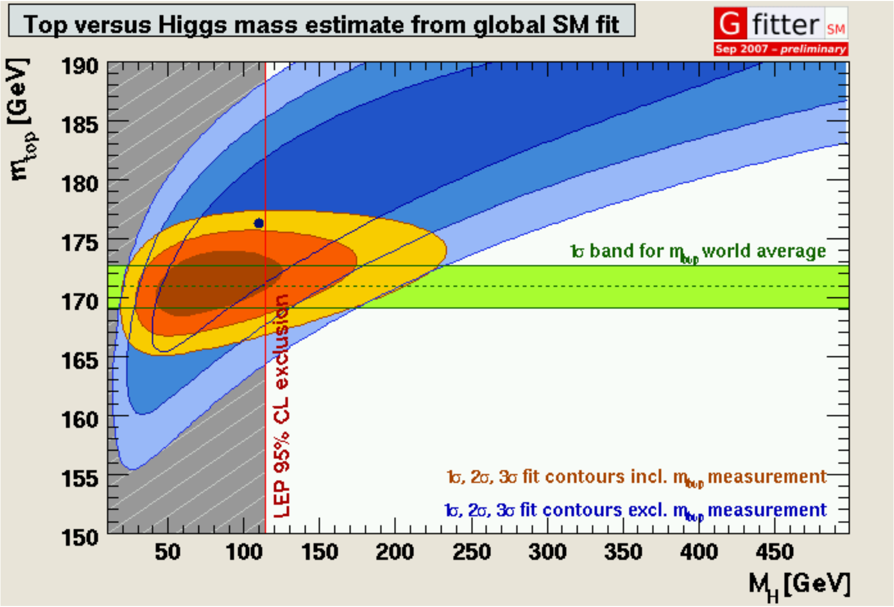
p-value vs. Higgs mass

What is the p-value for electroweak fit
for given Higgs masses (assuming negligible errors)?

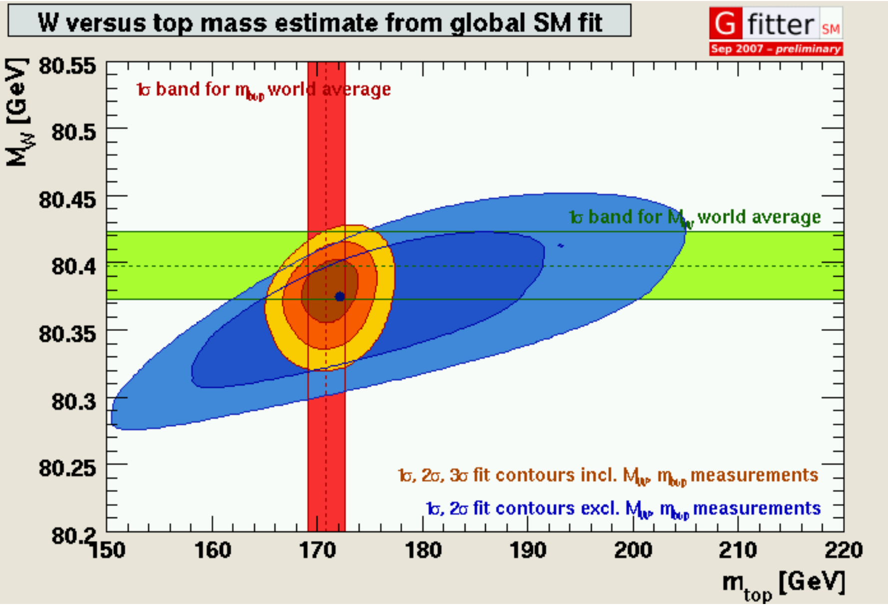


- Compute p-values for fixed Higgs masses using toy experiment method
- Here: p-value is greater than for fit with free Higgs mass
  - Higgs mass fixed
  - Decreased n_{dof} by one

Two-Dimensional Scans



- When top mass excluded: allowed band rather big
- Good constraint if top mass is included

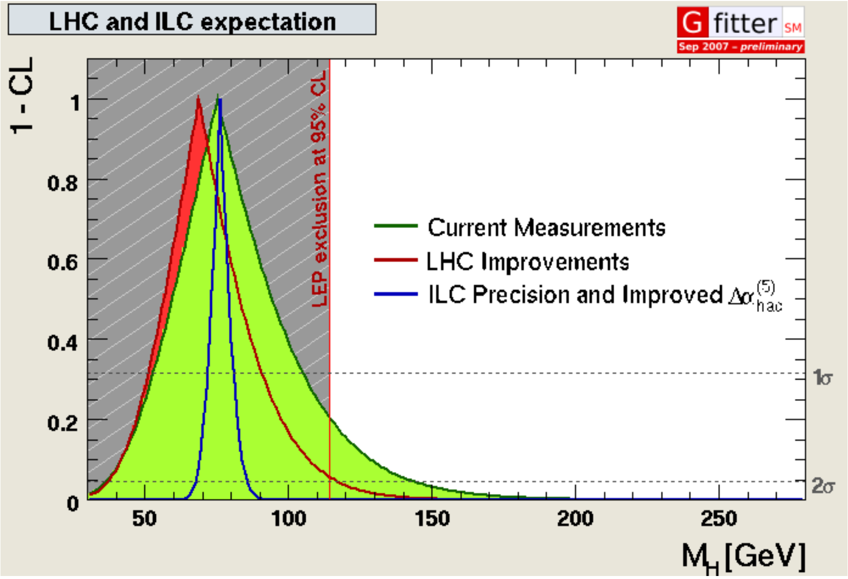


- Current values agree with the Fit Results
- However need more precision on W and top mass

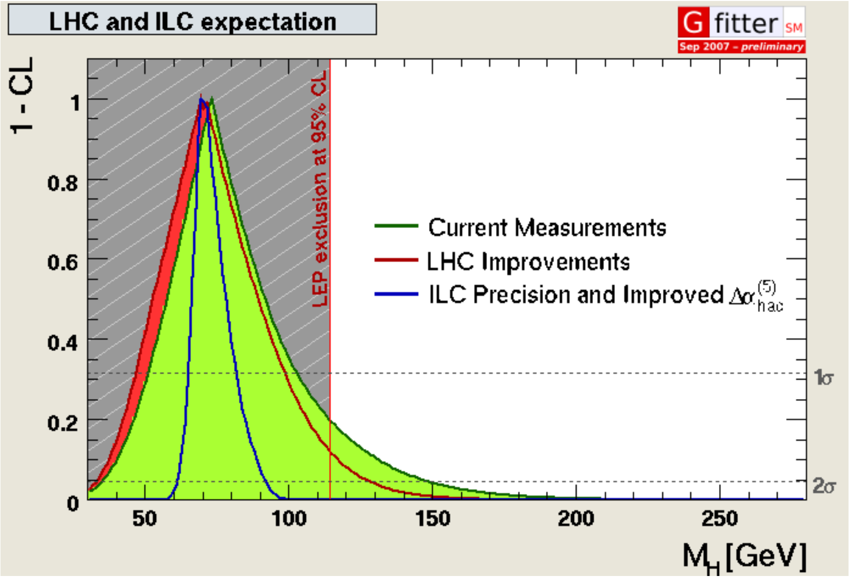
Precision from LHC and ILC

Current	LHC	ILC
$\delta(m_{top}) = 1.8 GeV$	$\delta(m_{top}) = 1.0 GeV$	$\delta(m_{top}) = 0.1 GeV$
$\delta(M_W) = 25 MeV$	$\delta(M_W) = 15 MeV$	$\delta(M_W) = 6 MeV$
$\delta(\Delta\alpha_{had}^{(5)}) = 0.00022$	$\delta(\Delta\alpha_{had}^{(5)}) = 0.00022$	$\delta(\Delta\alpha_{had}^{(5)}) = 0.00005$
$\delta(\sin^2\Theta_{eff}^{lept}) = 0.00017$	$\delta(\sin^2\Theta_{eff}^{lept}) = 0.00017$	$\delta(\sin^2\Theta_{eff}^{lept}) = 0.000013$

Excluding theory uncertainties



Including theory uncertainties



→ Need more precision in theory prediction, too!

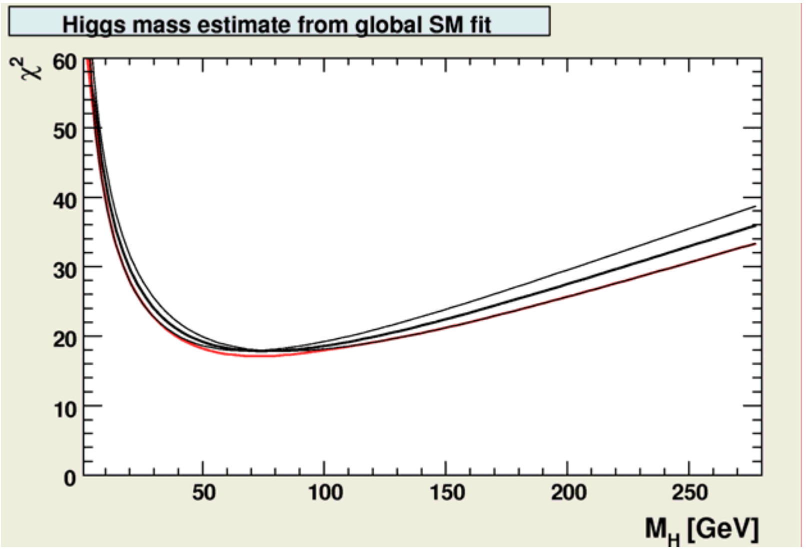
Summary

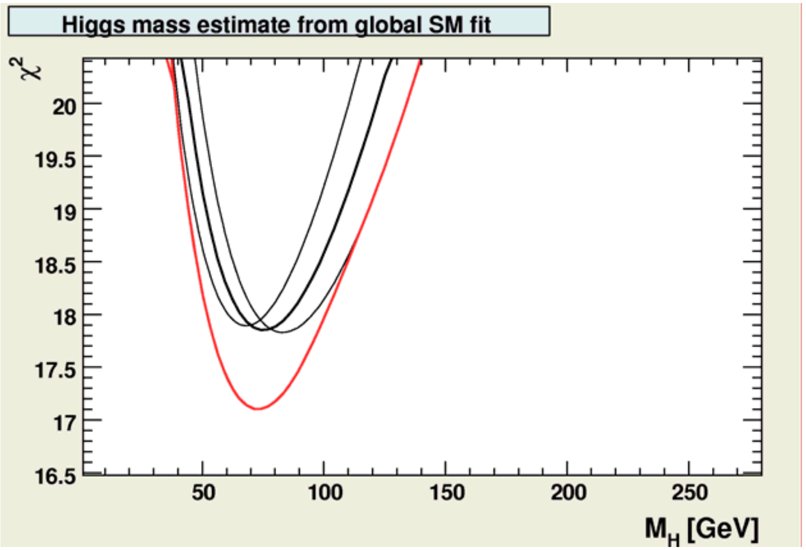
- Gfitter is a generic Fitting Tool for HEP analysis testing
  - user friendly, C++, ROOT based
  - RFit treatment of theoretical uncertainties
  - a lot of analysis tools provided (Toy tests, etc.)
  - Scanning of all parameters (w and w/o theory prediction) → flexible
  - caching of theory predictions → fast
- The SM package of Gfitter
  - Exact reproduction of Zfitter results
  - Results: M_H<150 GeV at 95% CL
  - p-value of SM = 0.23
  - Improvement by LHC and ILC
- **Next steps:**
  - Include LEP Higgs Search
  - Two Higgs Doublet Models, MSSM
- Additional information to Gfitter and SM fit can be found on:

http://cern.ch/Gfitter

Additional Information

Treatment of theo. uncertainties





NEW: If prediction is within theory-uncertainty, no contribution to $\chi 2$. If not, $\chi 2$ determined by the distance between measurement and prediction $\pm$ uncertainty

OLD: Predictions are shifted by the theoretical errors, many possibilities (black lines)