The Global Electroweak Fit (and Beyond) with Gfitter

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On behalf of the Gfitter group:
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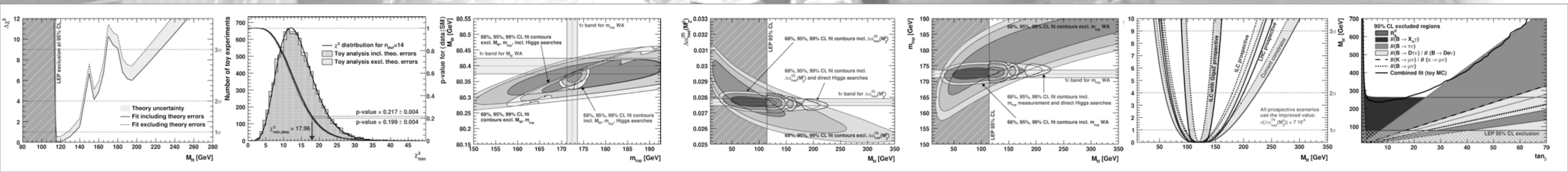
D. Ludwig, K. Mönig,
M. Schott, J. Stelzer

http://cern.ch/Gfitter



Themes

I. Introduction to the Gfitter programme
II. Input to the global electroweak Standard Model fit
III. Fit results
IV. Vacuum stability at high scales (→ Jose Espinosa today, 4:45pm)
V. Two-Higgs-Doublet Model (→ Max Baak today, 4:30pm)
VI. Outlook

Electroweak fits have a long history …

Based on a huge amount of preparatory work

- Needed to understand importance of loop corrections
- Precise Standard Model (SM) predictions and measurements required

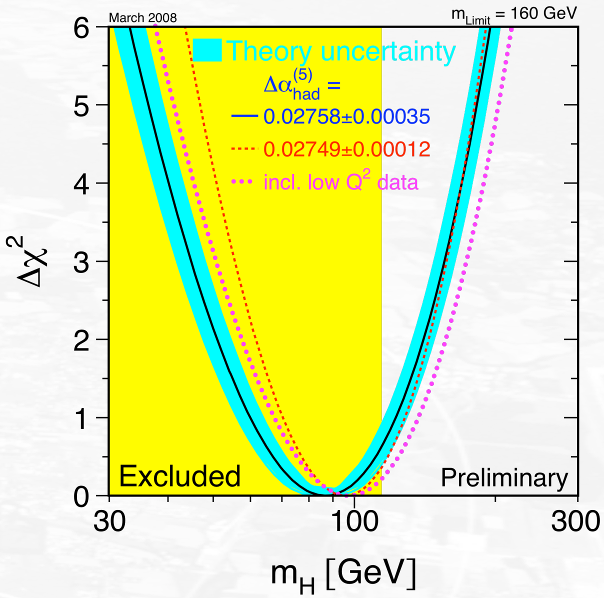
EW fits routinely performed by many groups

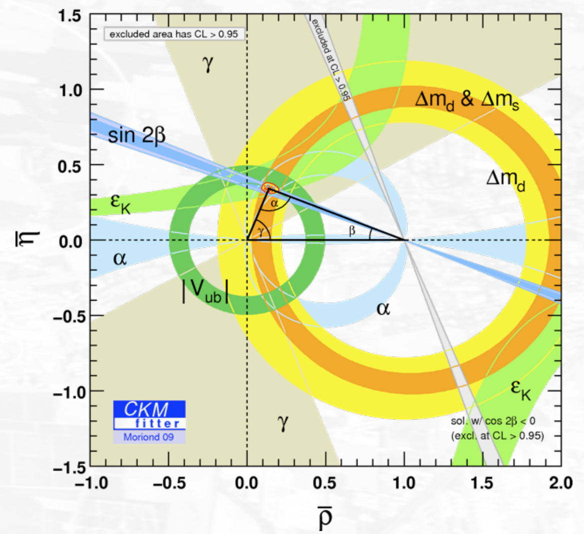
- D. Bardinet al. (ZFITTER), G. Passarinoet al. (TOPAZ0), LEP EW WG (M. Grünewald, K. Mönig *et al*.), J. Erler (GAPP), …
- Important results obtained !

Global SM fits also used at lower energies

- CKMfitter (J. Charles *et al*.), UTfit (M. Bona *et al*.), …
- Mostly concentrating on CKM matrix

Also many groups pursuing global beyond-SM fits





Gfitter

A *Generic Fitting Project for HEP Model Testing*

Goal: provide state-of-the-art model testing tool for LHC era

- Tools used by LEP written in outdated programming language, difficult to maintain in line with theoretical and experimental progress, difficult to include beyond-SM scenarios, limited fitting and statistics capabilities, …

Gfitter software

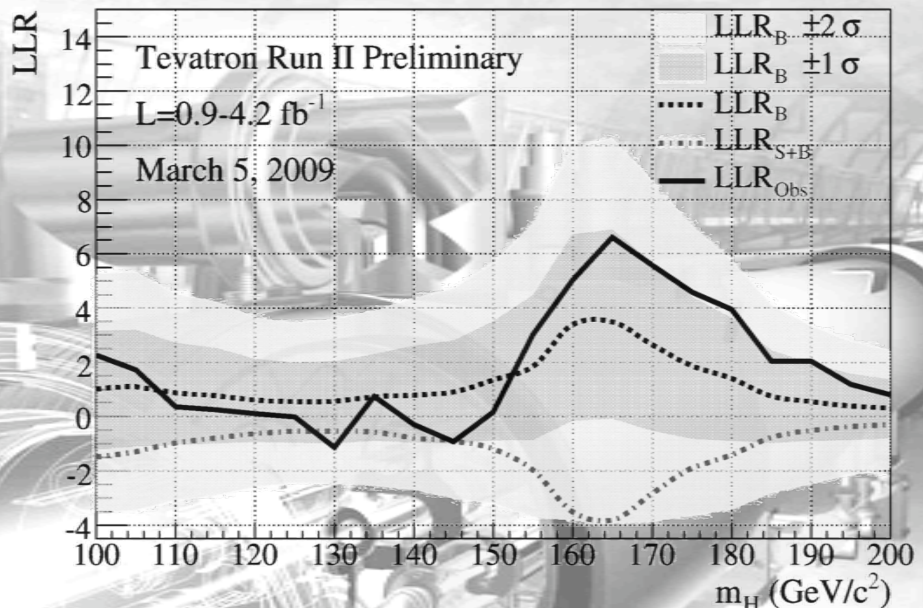
- Modular, object-oriented C++ relying on ROOT, XML and python
- Core package with data handling, fitting and statistics tools
- Independent physics libraries: SM, 2HDM, Oblique parameters, …

Gfitter features

- Consistent treatment of theoretical uncertainties in fit using *R*fit prescription (CKMfitter)
- Various fitting tools: Minuit, Genetic Algorithm and Simulated Annealing (via *T*MVA)
- Full statistics analysis: parameter scans, p-values, MC analyses, goodness-of-fit tests

Main publication: EPJ C60, 543-583,2009 [arXiv:0811.0009]

Fit Inputs



LLR
Tevatron Run II Preliminary
L=0.9-4.2 fb^{-1}
March 5, 2009
LLR$_B$ ±2 σ
LLR$_B$ ±1 σ
LLR$_B$
LLR$_{S+B}$
LLR$_{Obs}$
14
12
10
8
6
4
2
0
-2
-4
100
110
120
130
140
150
160
170
180
190
200
m$_H$ (GeV/c^2)

Theoretical Input

Since the Z boson couples to all fermion-antifermion pairs, it is ideal for measuring and studying the electroweak and strong interactions

State-of-the art calculations, in particular:

- M_W and $\sin^2\theta^f_{eff}$: full two-loop + leading beyond-two-loop form factor corrections
  [M. Awramik et al., Phys. Rev D69, 053006 (2004) and ref.] [M. Awramik et al., JHEP 11, 048 (2006) and refs.]
- Radiator functions: 3NLO prediction of the massless QCD cross section
  [P.A. Baikov et al., Phys. Rev. Lett. 101 (2008) 012022]

Radiative corrections are important !

- Example: consider tree-level electroweak unification relation

$$M_W^2\Big|_{\text{tree-level}} = \frac{M_Z^2}{2}\cdot\left(1+\sqrt{1-\frac{\sqrt{8}\pi\alpha}{G_F M_Z^2}}\right)$$

→ gives: $M_W = (79.964 \pm 0.005)$ GeV

Exp: $M_W = (80.399 \pm 0.023)$ GeV

→ 19 σ discrepancy !

and vertex corrections …

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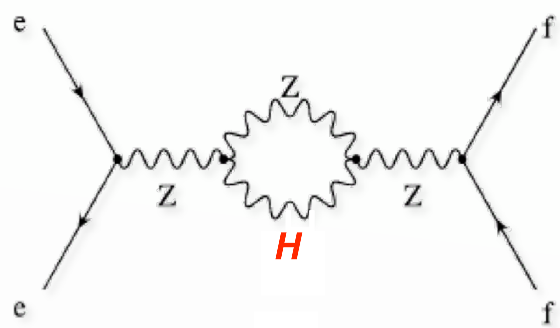
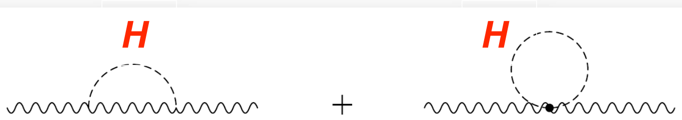
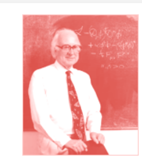
Logarithmic Higgs dependence enters through virtual corrections, *e.g.* :





$$\Delta\rho_{(\text{Higgs})} = \frac{11 G_F m_Z^2 \cos^2\theta_W}{24\sqrt{2}\pi^2} \log\left(\frac{m_H^2}{m_W^2}\right)$$



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Since the Z boson couples to all fermion-antifermion pairs, it is ideal for measuring and studying the electroweak and strong interactions

State-of-the art calculations, in particular:

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Wherever possible, calculations cross-checked against ZFITTER
→ excellent agreement

Free fit parameters are :

- M_Z, M_H, m_t, m_c, m_b, $\Delta\alpha_{\text{had}}(M_Z)$, $\alpha_s(M_Z)$,
- + scale parameters for theoretical uncertainties on M_W ($\sigma(M_W)$ = 4–6 MeV), $\sin^2\theta^f_{\text{eff}}$ ($\sigma(\sin^2\theta^l_{\text{eff}}) = 4.7\cdot10^{-5}$), and for the electroweak form factors ρ^f_Z, κ^f_Z (fully correlated)

Experimental Input

Experimental results:

- Z-pole observables: LEP/SLD results (corrected for ISR/FSR QED effects)
  [ADLO+SLD, Phys. Rept. 427, 257 (2006)]
- M_W and Γ_W: LEP + Tevatron (incl. Moriond-09 result from D0)
  [ADLO, hep-ex/0612034] [D0 Conference Note 5893-CONF] [CDF, Phys Rev. D77, 112001 (2008)]
  [CDF, Phys. Rev. Lett. 100, 071801 (2008)] [CDF+D0, Phys. Rev. D 70, 092008 (2004)]
- m_t: latest Tevatron average [arXiv:0903.2503]
- m_c, m_b: world averages [PDG, J. Phys. G33,1 (2006)]
- $\Delta\alpha_{had}(M_Z)$: [K. Hagiwara et al., Phys. Lett. B649, 173 (2007)] + rescaling mechanism to account for α_s dependency
- Direct Higgs searches at LEP and Tevatron (incl. Moriond-09 Tevatron average)
  [ADLO: Phys. Lett. B565, 61 (2003)] [CDF+D0: arXiv:0903.4001]

Not considered: results on $\sin^2\theta_{eff}$ from

- NuTeV; reason: unclear theoretical uncertainties from QCD effects
  (NLO corrections, nuclear effects of the bound nucleon PDFs)
- APV, fixed target polarised Möller scattering; reason: present experimental accuracy too low

Experimental Input

Parameter	Input value	Free in fit	Source
M_Z [GeV]	91.1875 ± 0.0021	yes	LEP
Γ_Z [GeV]	2.4952 ± 0.0023	–	LEP
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	–	LEP
R^0_ℓ	20.767 ± 0.025	–	LEP
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	–	LEP
A_ℓ $^{(\star)}$	0.1499 ± 0.0018	–	LEP, SLC
A_c	0.670 ± 0.027	–	SLC
A_b	0.923 ± 0.020	–	SLC
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035	–	LEP
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016	–	LEP
R^0_c	0.1721 ± 0.0030	–	LEP, SLC
R^0_b	0.21629 ± 0.00066	–	LEP, SLC
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	–	LEP

Parameter	Input value	Free in fit	Source
M_H [GeV] $^{(\circ)}$	Likelihood ratios	yes	LEP & Tevatron
M_W [GeV]	80.399 ± 0.023	–	LEP & Tevatron
Γ_W [GeV]	2.098 ± 0.048	–	LEP & Tevatron
$\overline{m}_c$ [GeV]	1.25 ± 0.09	yes	
$\overline{m}_b$ [GeV]	4.20 ± 0.07	yes	
m_t [GeV]	173.1 ± 1.3	yes	Tevatron
$\Delta\alpha^{(5)}_{\rm had}(M^2_Z)$ $^{(\dagger\triangle)}$	2768 ± 22	yes	
$\alpha_s(M^2_Z)$	–	yes	
$\delta_{\rm th} M_W$ [MeV]	$[-4, 4]_{\rm theo}$	yes	
$\delta_{\rm th} \sin^2\theta^\ell_{\rm eff}$ $^{(\dagger)}$	$[-4.7, 4.7]_{\rm theo}$	yes	
$\delta_{\rm th}\rho^f_Z$ $^{(\dagger)}$	$[-2, 2]_{\rm theo}$	yes	
$\delta_{\rm th}\kappa^f_Z$ $^{(\dagger)}$	$[-2, 2]_{\rm theo}$	yes	

Correlation matrix for observables from Z lineshape fit

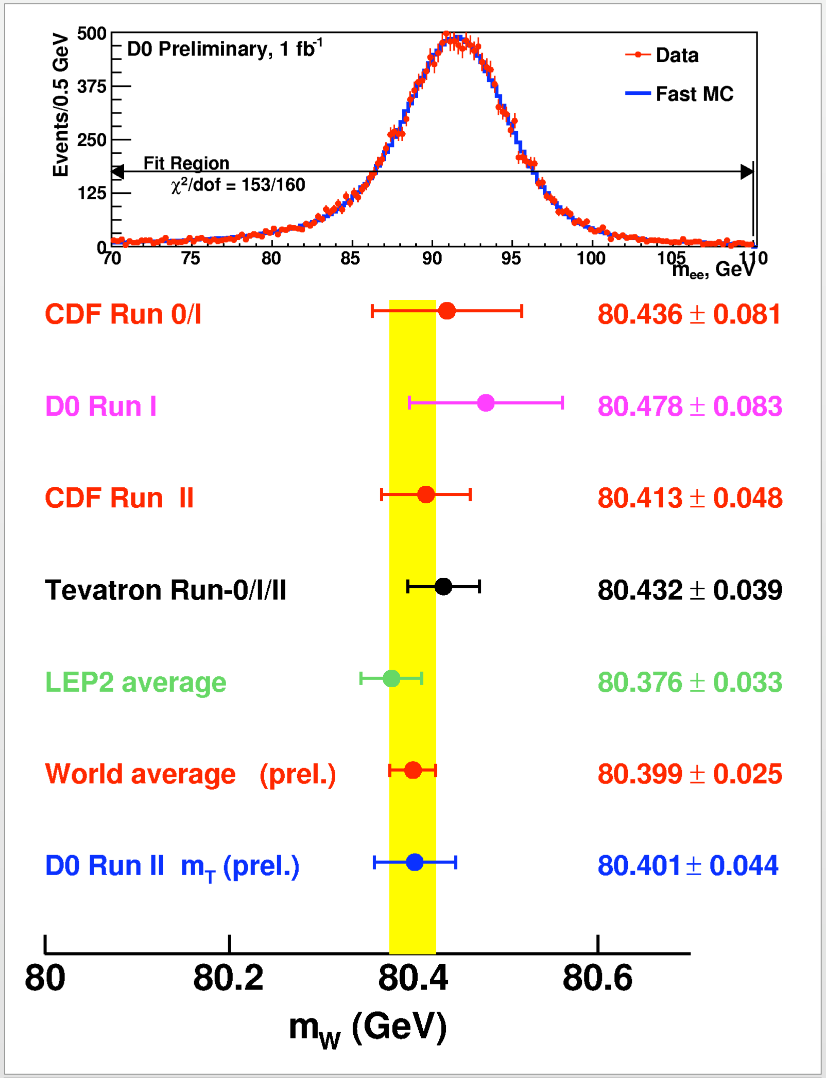
	M_Z	Γ_Z	$\sigma^0_{\rm had}$	R^0_ℓ	$A^{0,\ell}_{\rm FB}$
M_Z	1	−0.02	−0.05	0.03	0.06
Γ_Z		1	−0.30	0.00	0.00
$\sigma^0_{\rm had}$			1	0.18	0.01
R^0_ℓ				1	−0.06
$A^{0,\ell}_{\rm FB}$					1

Correlation matrix for heavy-flavour observables at Z pole

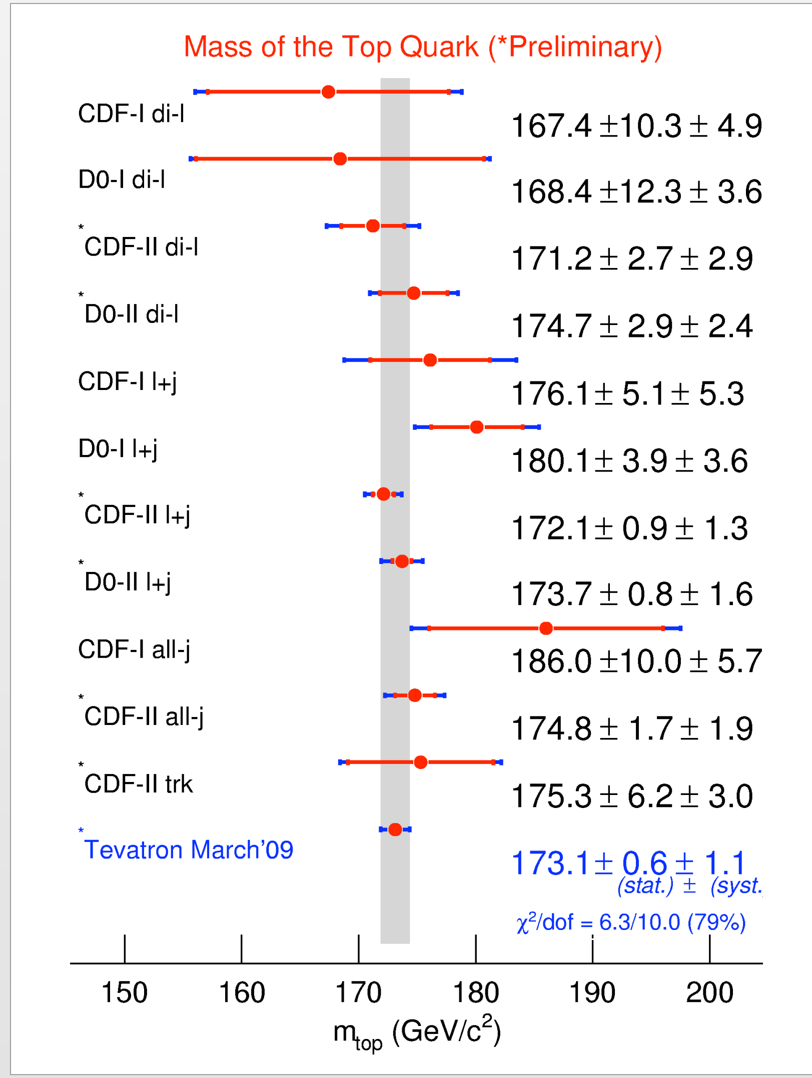
	$A^{0,c}_{\rm FB}$	$A^{0,b}_{\rm FB}$	A_c	A_b	R^0_c	R^0_b
$A^{0,c}_{\rm FB}$	1	0.15	0.04	−0.02	−0.06	0.07
$A^{0,b}_{\rm FB}$		1	0.01	0.06	0.04	−0.10
A_c			1	0.11	−0.06	0.04
A_b				1	0.04	−0.08
R^0_c					1	−0.18

2009 M_W and m_{top} averages

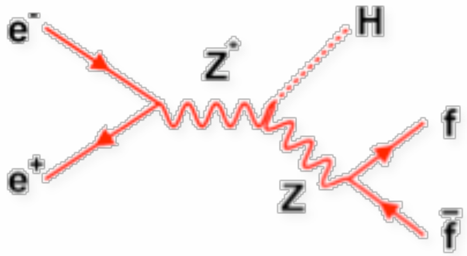
[Latest result: D0 Conference Note 5893-CONF]



[CDF + D0, 3.6 fb⁻¹, arXiv:0903.2503]



Direct Higgs Searches



LEP: Higgs production via “Higgs-Strahlung”

- $ee \to ZH$ ($H \to bb$, $\tau\tau$)
  [ADLO: Phys. Lett. B565, 61 (2003)]

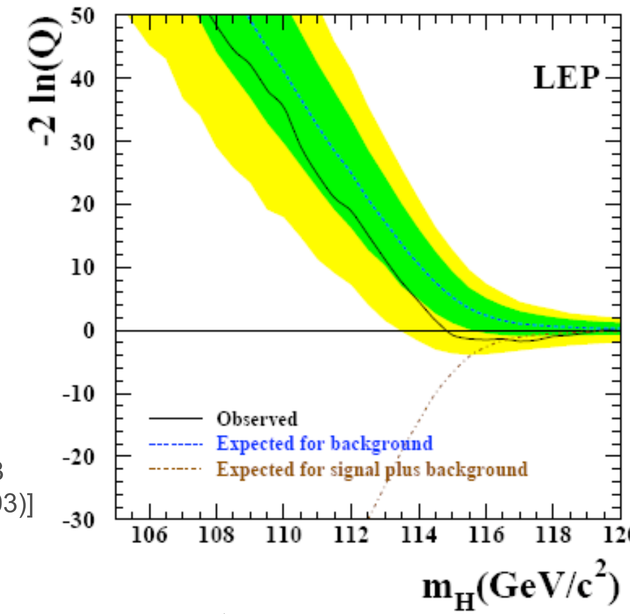
Tevatron: *gg* fusion with $H \to WW$, associated production, weak boson fusion

- $gg \to H \to WW$, $WH \to l\nu bb$, $3W$, $ZH \to \nu\nu(ll)bb$, WBF $\to H \to \gamma\gamma$, $\tau\tau$
  [CDF+D0: arXiv:0903.4001 – up to 4.2 fb^{-1}]

Statistical interpretation in global fit: *two-sided* CL_{S+B}

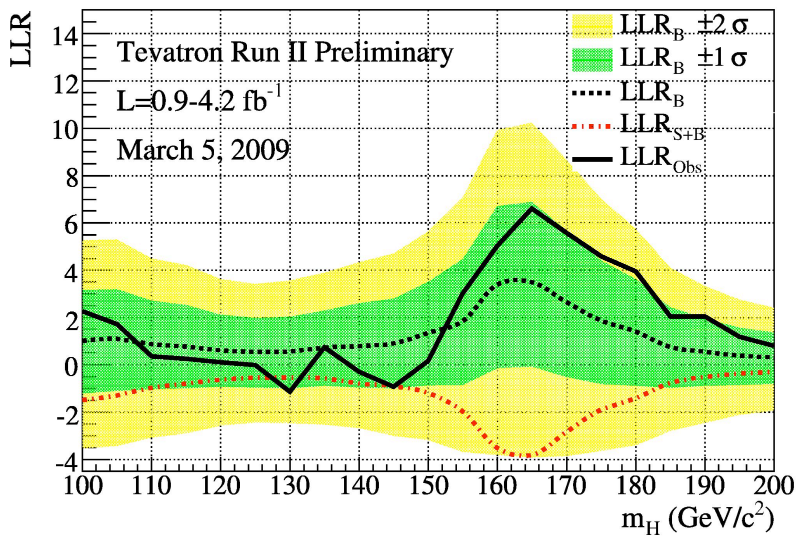
- Experiments measure test statistics LLR = –2ln*Q*, where $Q = L_{S+B} / L_B$
- LLR is transformed by experiments into CL_{S+B} using pseudo-MC experiments
- We transform one-sided CL_{S+B} into a two-sided CL_{S+B} (measure *deviation* from SM !)
- Contribution to χ^2 estimator obtained via inverse error function: $\Delta\chi^2 = \mathrm{Erf}^{-1}\left(1 - CL_{S+B}^{2\text{-sided}}\right)$
- Alternative treatments (thanks to fruitful discussion with Tevatron people):
  - Use one-sided CL_{S+B}: however, different interpretation – want SM Higgs (not *any* Higgs)
  - Directly use $\Delta\chi^2 \approx$ LLR: Bayesian interpretation, lacks pseudo-MC information

Direct Higgs Searches

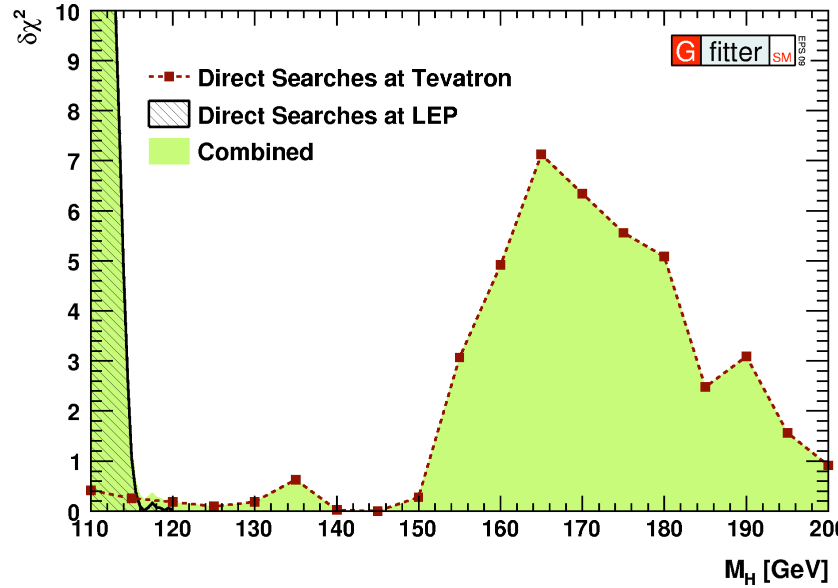


[ADLO: Phys. Lett. B 565, 61 (2003)]

[CDF + D0, up to 4.2 fb^{-1}, arXiv:0903.2503]



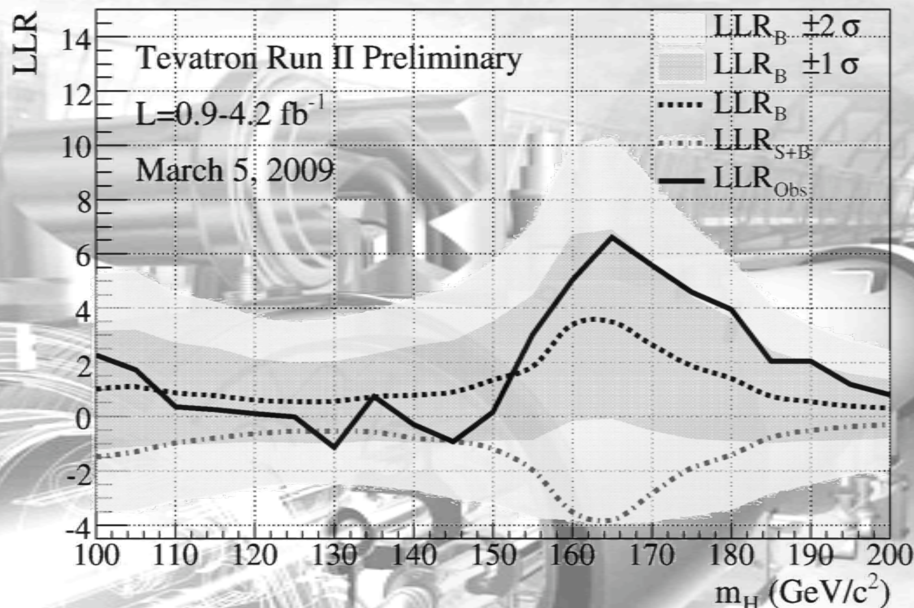
Combined $\delta\chi^2$ input to EW fit:



Fit Results

Distinguish two fit types:

- *Standard Fit:* all data except for direct Higgs searches
- *Complete Fit:* all data including direct Higgs searches



Experimental Input and Fit Results

Parameter	Input value	Free in fit	Results from global EW fits: *Standard fit*	*Complete fit*	*Complete fit w/o exp. input in line*
M_Z [GeV]	91.1875 ± 0.0021	yes	91.1874 ± 0.0021	91.1876 ± 0.0021	$91.1974\,^{+0.0191}_{-0.0159}$
Γ_Z [GeV]	2.4952 ± 0.0023	–	2.4960 ± 0.0015	2.4956 ± 0.0015	$2.4952\,^{+0.0017}_{-0.0016}$
σ^0_{had} [nb]	41.540 ± 0.037	–	41.478 ± 0.014	41.478 ± 0.014	41.469 ± 0.015
R^0_ℓ	20.767 ± 0.025	–	20.742 ± 0.018	20.741 ± 0.018	20.717 ± 0.027
$A^{0,\ell}_{\mathrm{FB}}$	0.0171 ± 0.0010	–	0.01638 ± 0.0002	0.01624 ± 0.0002	$0.01617\,^{+0.0002}_{-0.0001}$
$A_\ell\ ^{(\star)}$	0.1499 ± 0.0018	–	0.1478 ± 0.0010	$0.1472^{+0.0009}_{-0.0008}$	–
A_c	0.670 ± 0.027	–	$0.6682\,^{+0.00045}_{-0.00044}$	$0.6679\,^{+0.00042}_{-0.00036}$	$0.6679\,^{+0.00041}_{-0.00036}$
A_b	0.923 ± 0.020	–	0.93469 ± 0.00010	$0.93463\,^{+0.00007}_{-0.00008}$	$0.93463\,^{+0.00007}_{-0.00008}$
$A^{0,c}_{\mathrm{FB}}$	0.0707 ± 0.0035	–	$0.0741\,^{+0.0006}_{-0.0005}$	0.0737 ± 0.0005	0.0737 ± 0.0005
$A^{0,b}_{\mathrm{FB}}$	0.0992 ± 0.0016	–	0.1036 ± 0.0007	$0.1032\,^{+0.0007}_{-0.0006}$	$0.1037\,^{+0.0004}_{-0.0005}$
R^0_c	0.1721 ± 0.0030	–	0.17225 ± 0.00006	0.17225 ± 0.00006	0.17225 ± 0.00006
R^0_b	0.21629 ± 0.00066	–	0.21578 ± 0.00005	0.21577 ± 0.00005	0.21577 ± 0.00005
$\sin^2\theta^\ell_{\mathrm{eff}}(Q_{\mathrm{FB}})$	0.2324 ± 0.0012	–	0.23142 ± 0.00013	$0.23151\,^{+0.00010}_{-0.00012}$	$0.23149\,^{+0.00013}_{-0.00010}$
M_H [GeV] $^{(\circ)}$	Likelihood ratios	yes	$83^{+30[+75]}_{-23[-41]}$	$116^{+15.6[+36.5]}_{-1.3[-2.2]}$	$83^{+30[+75]}_{-23[-41]}$
M_W [GeV]	80.399 ± 0.023	–	$80.384\,^{+0.014}_{-0.015}$	$80.371\,^{+0.008}_{-0.011}$	$80.361\,^{+0.013}_{-0.012}$
Γ_W [GeV]	2.098 ± 0.048	–	$2.092\,^{+0.001}_{-0.002}$	2.092 ± 0.001	2.092 ± 0.001
$\overline{m}_c$ [GeV]	1.25 ± 0.09	yes	1.25 ± 0.09	1.25 ± 0.09	–
$\overline{m}_b$ [GeV]	4.20 ± 0.07	yes	4.20 ± 0.07	4.20 ± 0.07	–
m_t [GeV]	173.1 ± 1.3	yes	173.2 ± 1.2	173.6 ± 1.2	$179.5\,^{+8.8}_{-5.2}$
$\Delta\alpha^{(5)}_{\mathrm{had}}(M_Z^2)\ ^{(\dagger\triangle)}$	2768 ± 22	yes	2772 ± 22	2764^{+22}_{-21}	2733^{+57}_{-63}
$\alpha_s(M_Z^2)$	–	yes	$0.1192\,^{+0.0028}_{-0.0027}$	0.1193 ± 0.0028	0.1193 ± 0.0028
$\delta_{\mathrm{th}} M_W$ [MeV]	$[-4, 4]_{\mathrm{theo}}$	yes	4	4	–
$\delta_{\mathrm{th}} \sin^2\theta^\ell_{\mathrm{eff}}\ ^{(\dagger)}$	$[-4.7, 4.7]_{\mathrm{theo}}$	yes	4.7	0.8	–
$\delta_{\mathrm{th}} \rho^f_Z\ ^{(\dagger)}$	$[-2, 2]_{\mathrm{theo}}$	yes	2	2	–
$\delta_{\mathrm{th}} \kappa^f_Z\ ^{(\dagger)}$	$[-2, 2]_{\mathrm{theo}}$	yes	2	2	–

Correlation coefficients between free fit parameters

Parameter	$\ln M_H$	$\Delta\alpha_{\rm had}^{(5)}(M_Z^2)$	M_Z	$\alpha_S(M_Z^2)$	m_t	$\overline{m}_c$	$\overline{m}_b$
$\ln M_H$	1	−0.395	0.113	0.041	0.309	−0.001	−0.006
$\Delta\alpha_{\rm had}^{(5)}(M_Z^2)$		1	−0.006	0.101	−0.007	0.001	0.003
M_Z			1	−0.019	−0.015	−0.000	0.000
$\alpha_S(M_Z^2)$				1	0.021	0.011	0.043
m_t					1	0.000	−0.003
$\overline{m}_c$						1	0.000

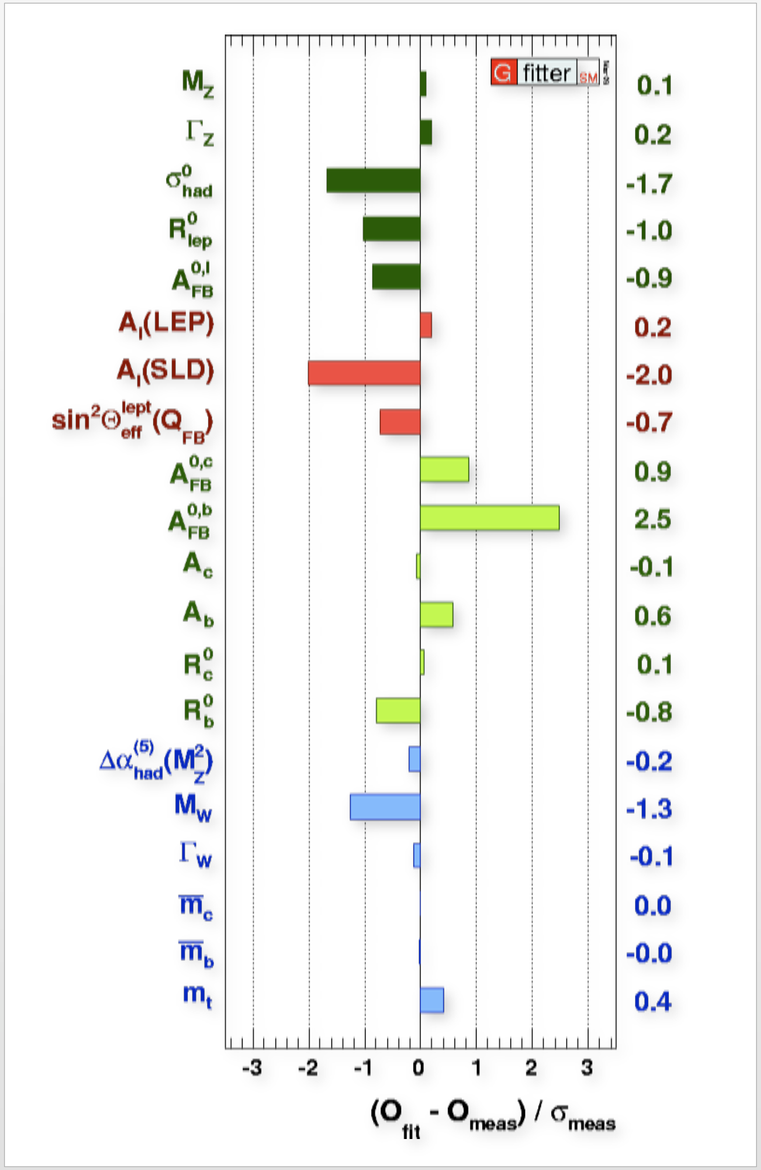
Goodness-of-Fit

Goodness-of-fit:

- *Standard fit*: $\chi^2_{min} = 16.4 \rightarrow \mathrm{Prob}(\chi^2_{min},13) = 0.23$
- *Complete fit*: $\chi^2_{min} = 17.9 \rightarrow \mathrm{Prob}(\chi^2_{min},14) = 0.21$

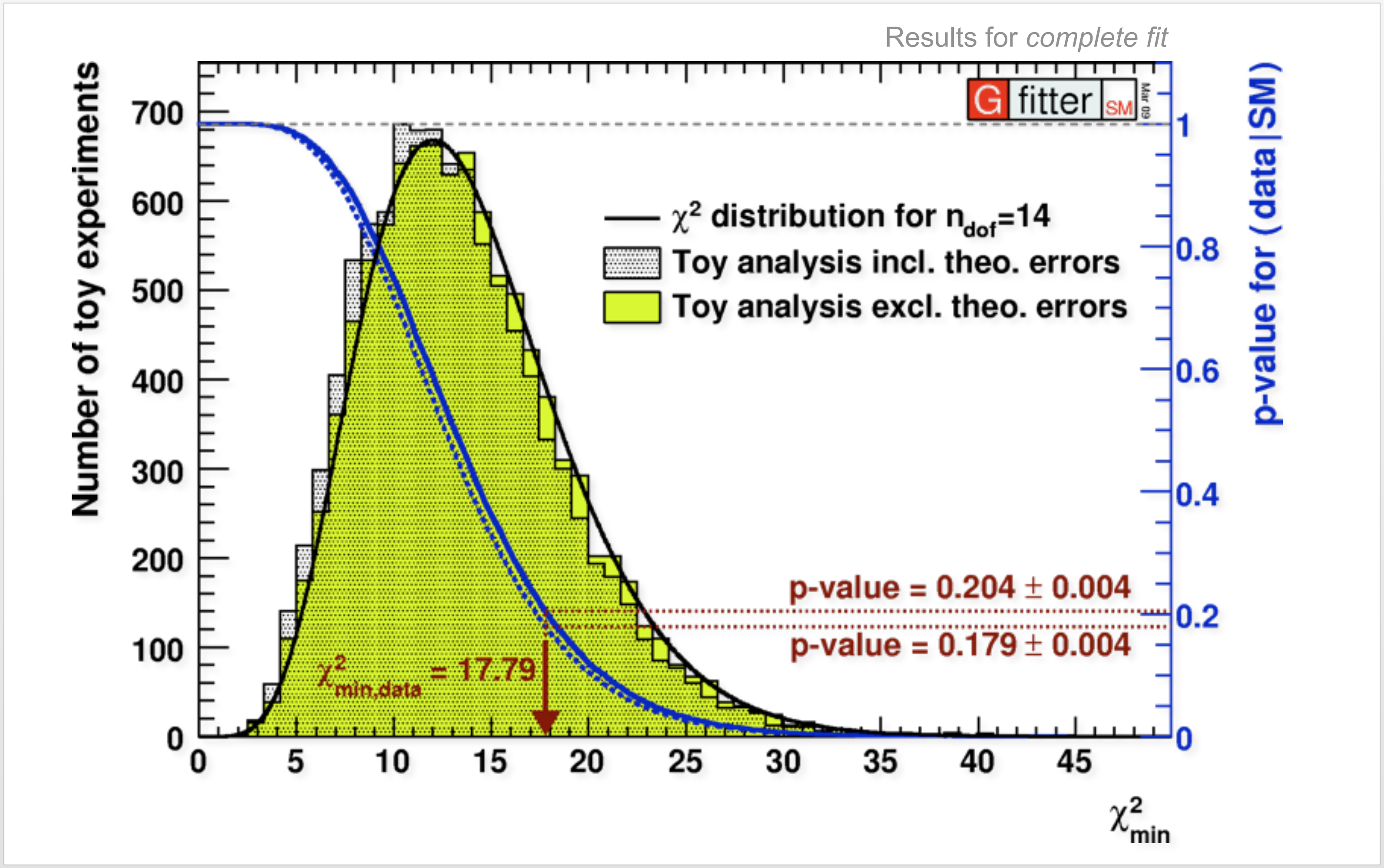
Pull values for complete fit (right figure →)

- No individual pull exceeds 3σ
- FB(b) asymmetry largest contributor to χ^2_{min}
- Small contributions from M_Z, $\Delta\alpha^{had}(M_Z)$, m_c, m_b indicate that their input accuracies exceed fit requirements → parameters could have been fixed in fit



Goodness-of-Fit

Toy analysis: p-value for wrongly rejecting the SM = 0.20 ± 0.01–0.02_{theo}



Higgs Mass Constraints

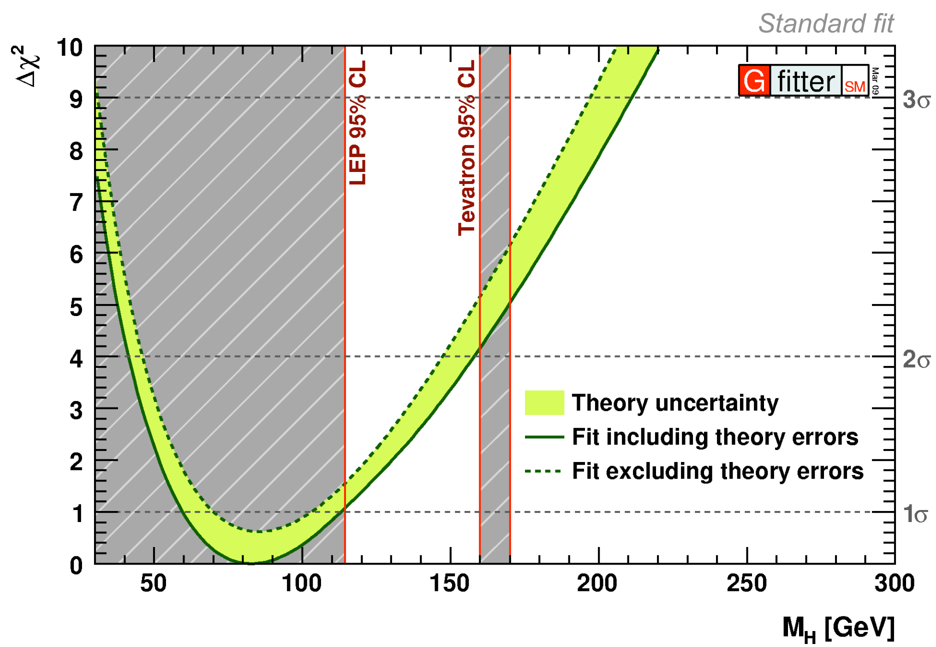
M_H from *Standard fit*:

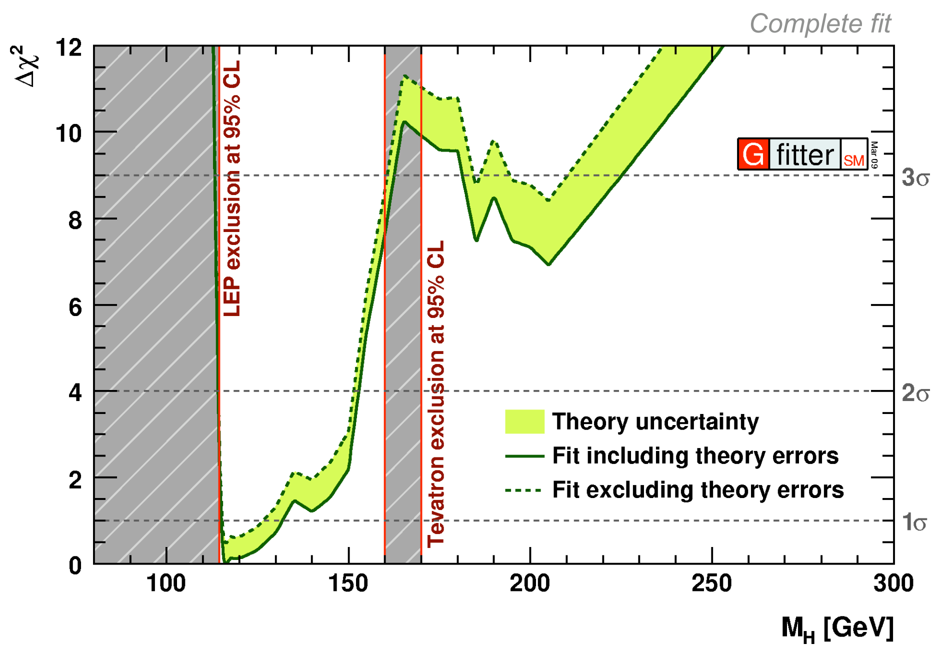
- Central value ±1σ: $M_H = 83^{+30}_{-23}$ GeV
- 2σ interval: [42, 158] GeV

Green band due to *R*fit treatment of theory errors, fixed errors lead to larger χ^2_{min}

M_H from *Complete fit*:

- Central value ±1σ: $M_H = 116^{+16}_{-1.3}$ GeV
- 2σ interval: [114, 153] GeV





Higgs Mass Constraints

M_H from *Standard fit*:

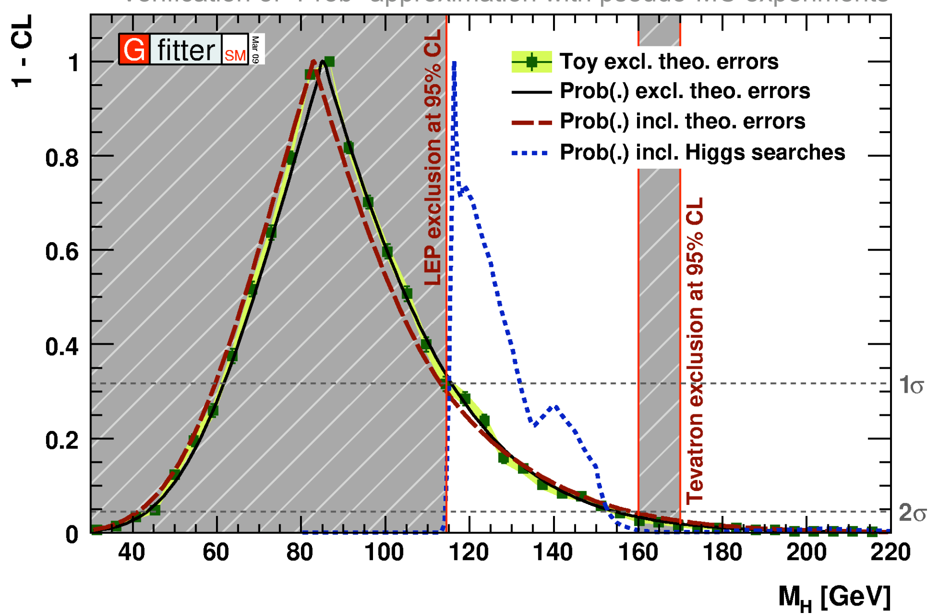
- Central value ±1σ: $M_H = 80\,^{+30}_{-23}$ GeV
- 2σ interval: [42, 158] GeV

Green band due to *R*fit treatment of theory errors, fixed errors lead to larger χ^2_{min}

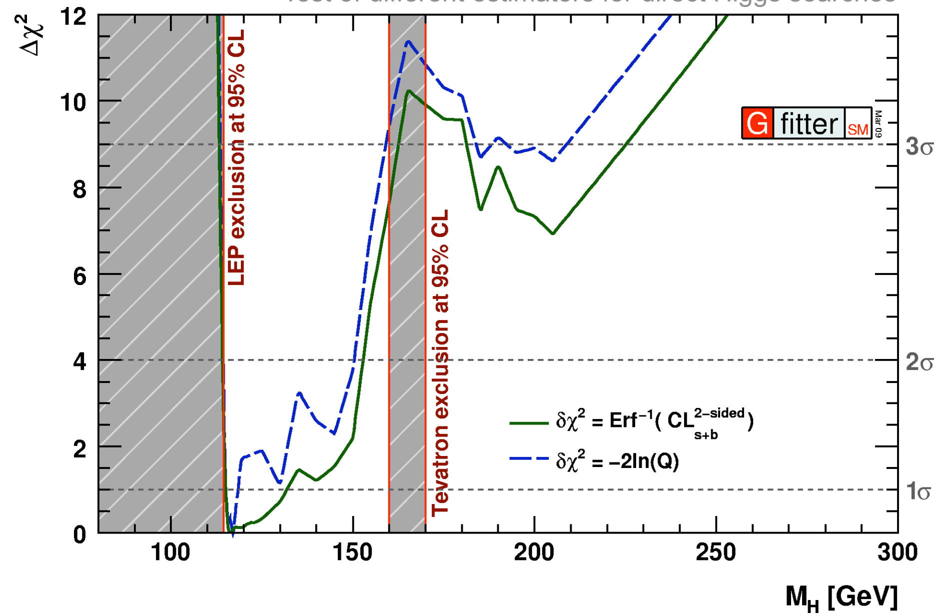
M_H from *Complete fit*:

- Central value ±1σ: $M_H = 116\,^{+16}_{-1.3}$ GeV
- 2σ interval: [114, 153] GeV

Verification of “Prob” approximation with pseudo-MC experiments



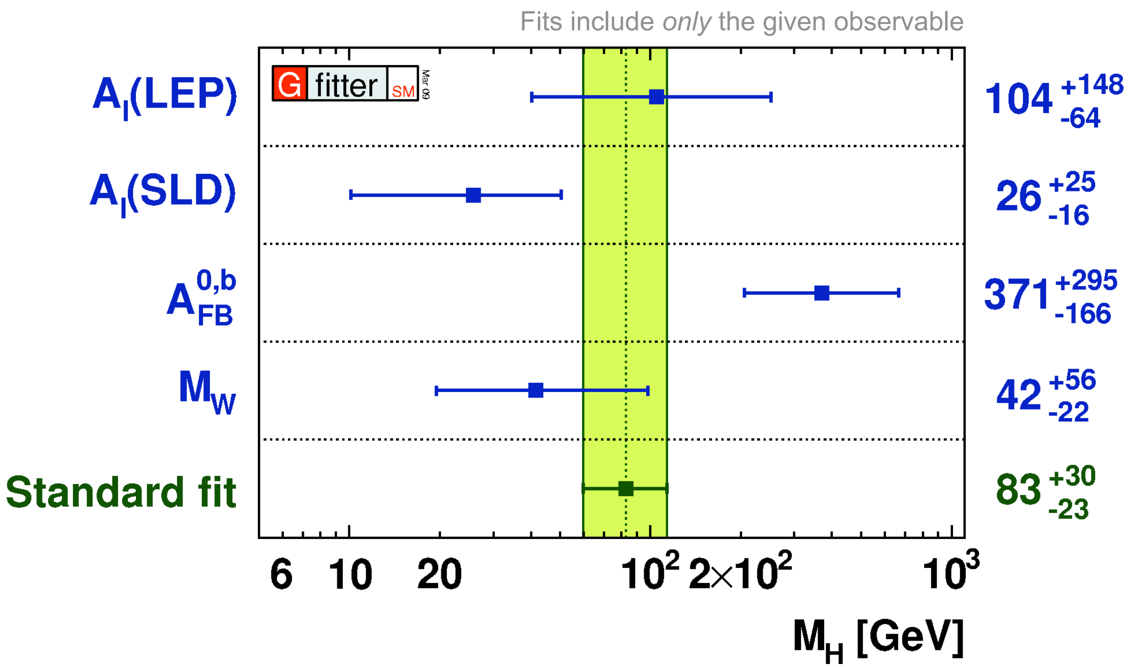
Test of different estimators for direct Higgs searches



Higgs Mass Constraints

Known tension between $A^{0,b}_{FB}$ and A_{lep}(SLD) and M_W:

- Pseudo-MC analysis to evaluate
  " *Probability to observe a $\Delta\chi^2$ = 8.0 when removing the least compatible input* "
  → accounts for "look-elsewhere effect"
- Find: 1.4% (2.5σ)



Top Mass

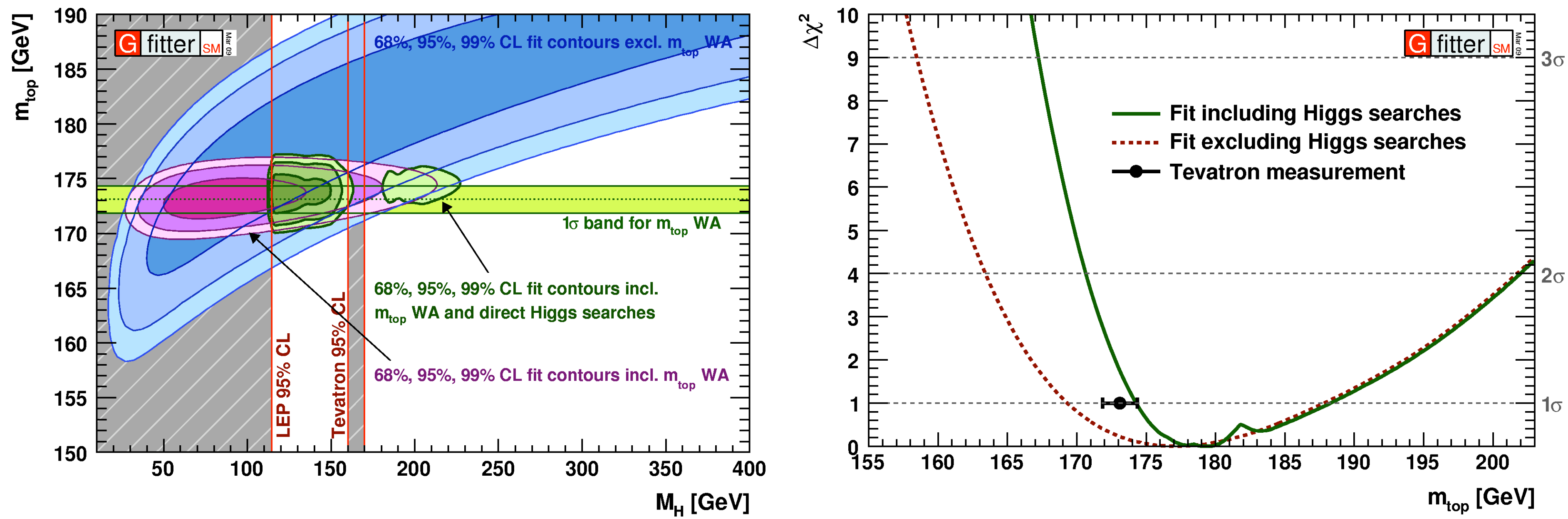
Quadratic sensitivity to m_{top}

- *Standard fit*: $m_{top} = 177.2\,^{+10.5}_{-7.8}$ GeV
- *Complete fit*: $m_{top} = 179.5\,^{+8.8}_{-5.2}$ GeV

Tevatron average: (173.1 ± 1.3) GeV

For Standard fit with free m_{top} find: $m_H = 116\,^{+184}_{-61}$ GeV

Fits include *only* the given observable



Top Mass

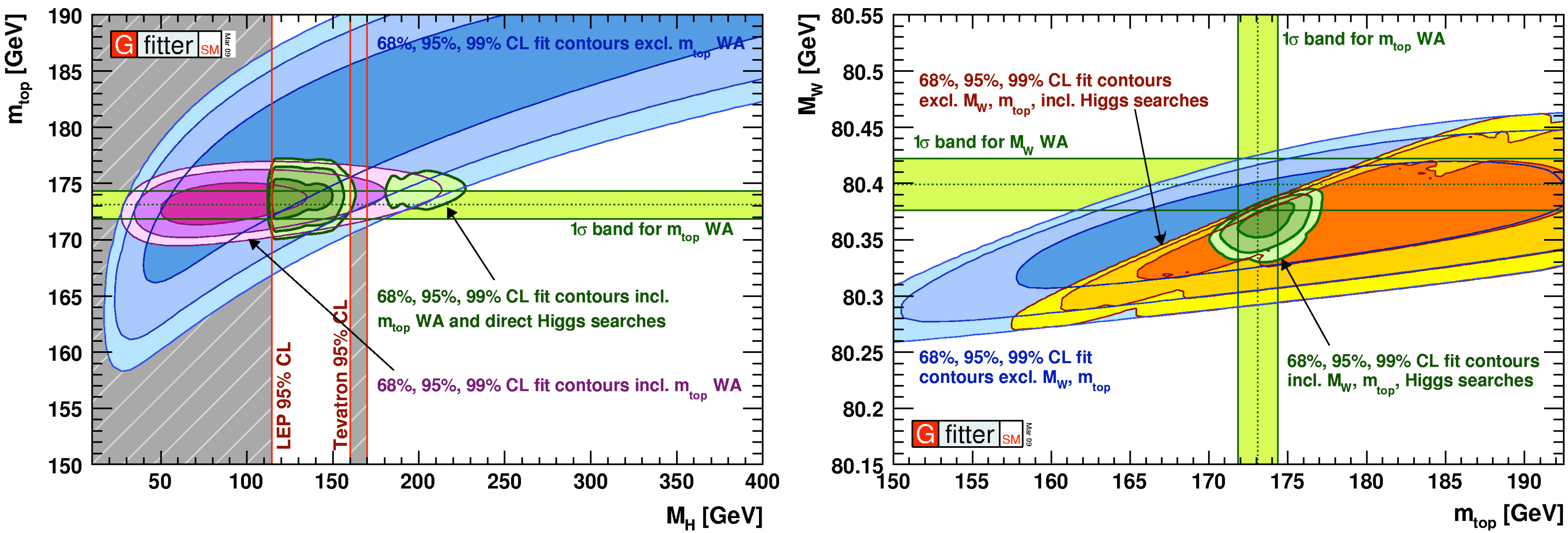
Quadratic sensitivity to m_{top}

- *Standard fit*: $m_{top} = 177.2\,^{+10.5}_{-7.8}$ GeV
- *Complete fit*: $m_{top} = 179.5\,^{+8.8}_{-5.2}$ GeV

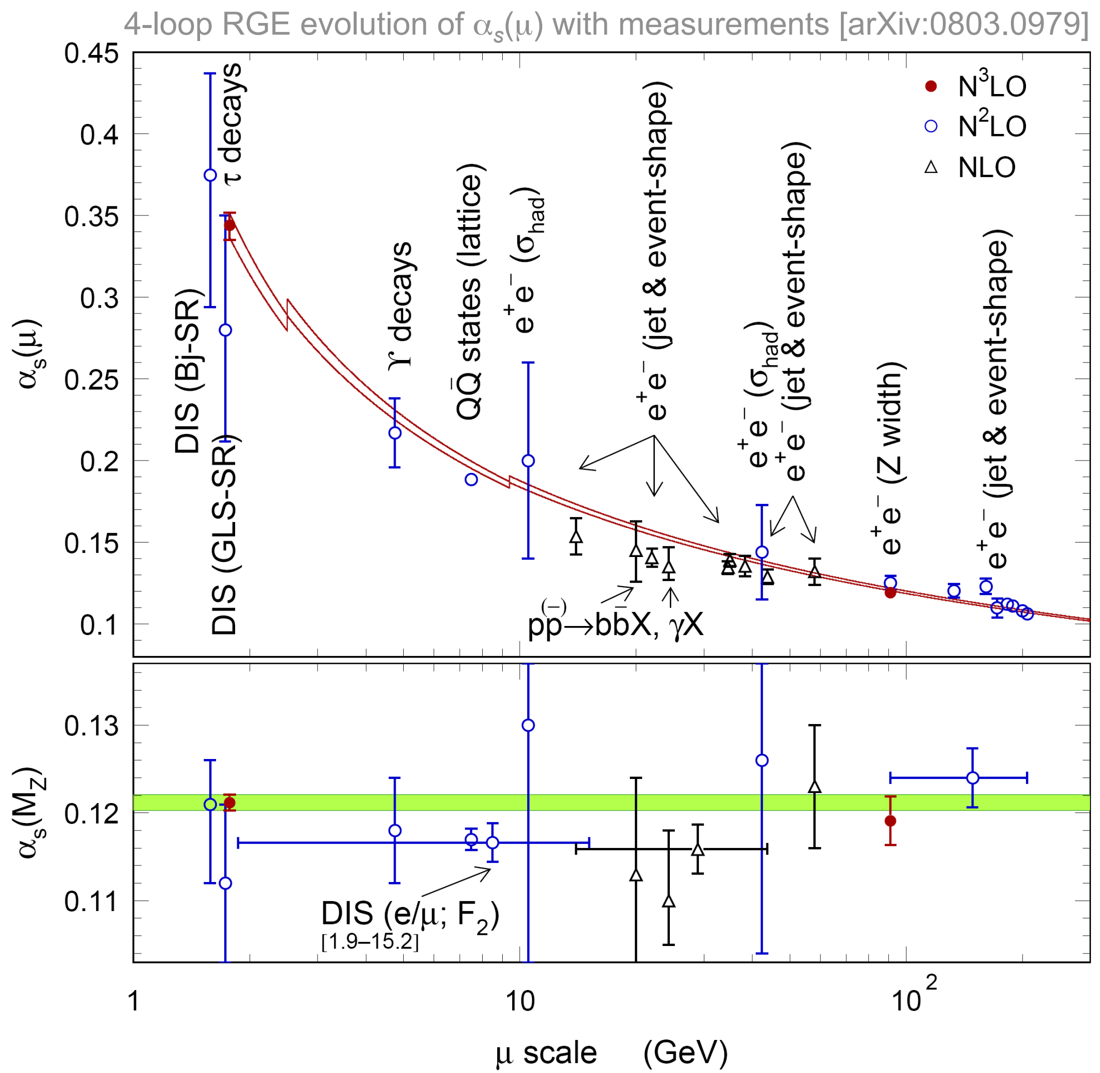
Tevatron average: (173.1 ± 1.3) GeV

For Standard fit with free m_{top} find: $m_H = 116\,^{+184}_{-61}$ GeV

Fits include *only* the given observable



NNNLO Determination of α_s



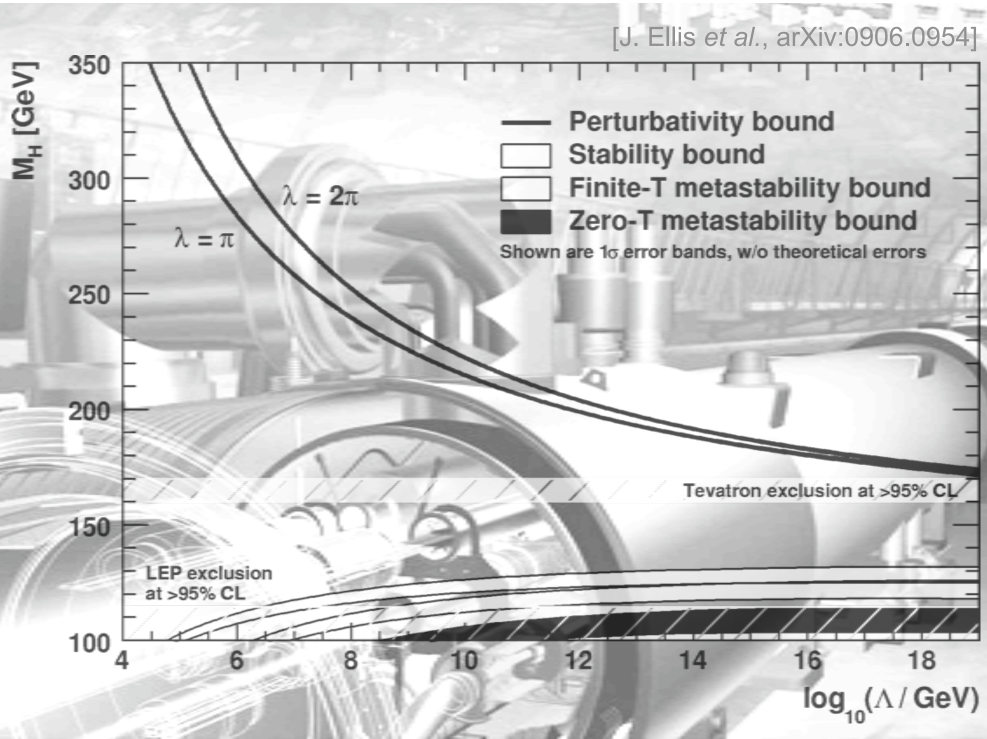
From Complete Fit:

$\alpha_s(M_Z) = 0.1193 \pm 0.0028 \pm 0.0001$

- First error experimental
- Second error theoretical (!)
  [incl. variation of renorm. scale from $M_Z/2$ to $2M_Z$ and massless terms of order/beyond $a_S^5(M_Z)$ and massive terms of order/beyond $a_S^4(M_Z)$]
- Excellent agreement with N³LO result from hadronic τ decays
  [M. Davier et al., arXiv:0803.0979]

  $\alpha_s(M_Z) = 0.1212 \pm 0.0005_{exp} \pm 0.0008_{theo} \pm 0.0005_{evol}$
- Best current test of asymptotic freedom property of QCD !

The Fate of the Standard Model



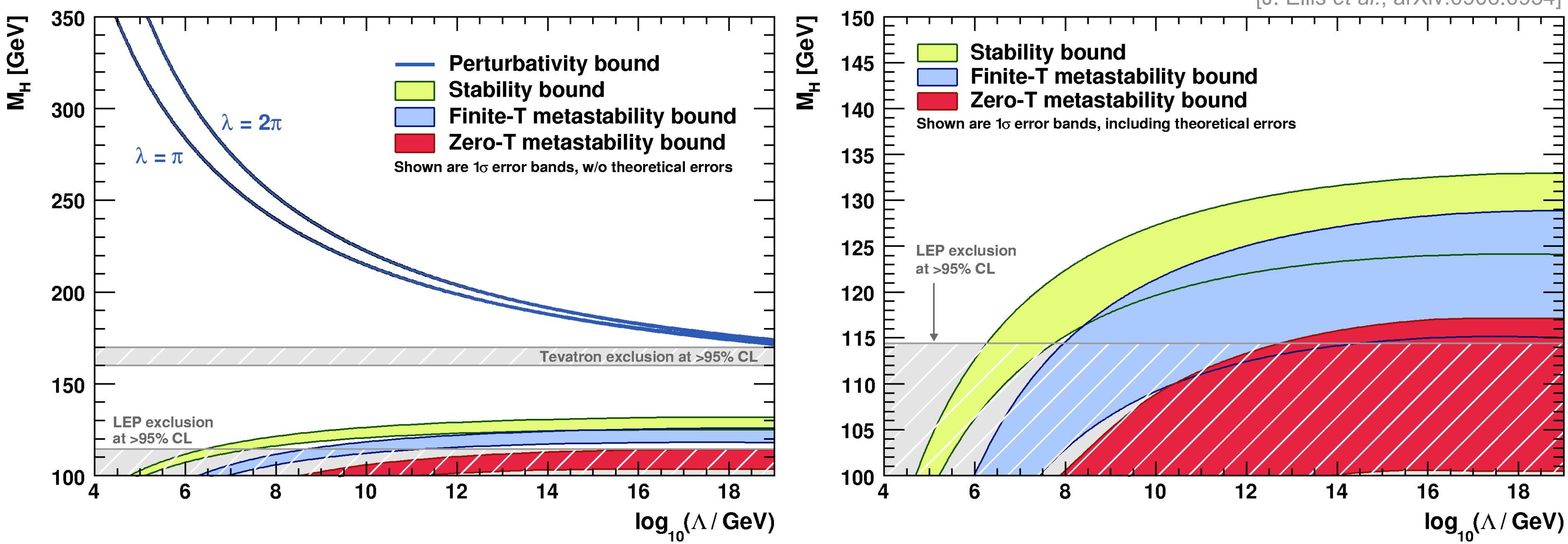
Driving the SM to M_{Planck}

As (well) known, the behaviour of the quartic Higgs couplings as function of the cut-off scale Λ puts bounds on M_H

- For too large M_H, the couplings become non-perturbative ("triviality" or "blow-up" scenario)
- For too small M_H, the vacuum becomes unstable

  → obtain three lower bounds on M_H from different requirement: **absolute stability, finite-*T* and zero-*T* metastability**

[J. Ellis *et al.*, arXiv:0906.0954]

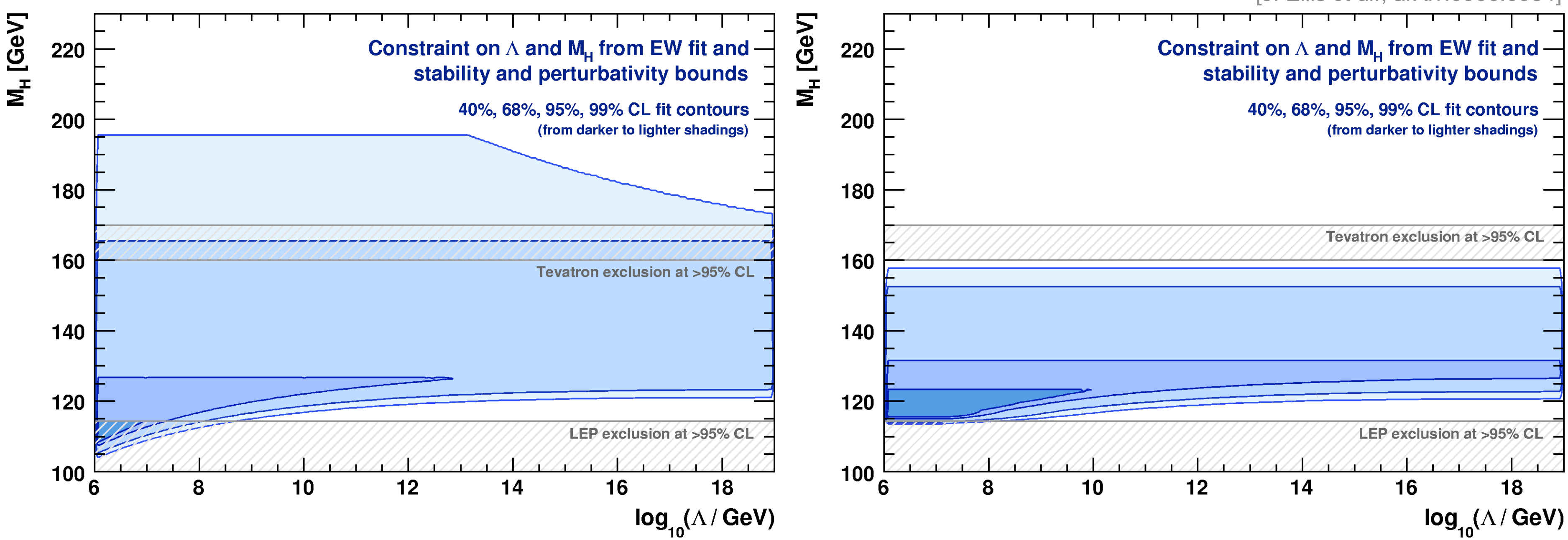


Convolve Bounds with M_H Constraints

Can we obtain likelihoods on vacuum stability (or, likewise, the cut-off = new physics scale Λ) from constraint on M_H ?

- Non-perturbativity excluded at 95.7% CL → raise to 99.1% with Tevatron Higgs searches !
- Cannot distinguish between vacuum stability, metastability or collapse scenarios
  → requires M_H > 122 GeV to exclude collapse scenario at 95% CL

[J. Ellis *et al.*, arXiv:0906.0954]

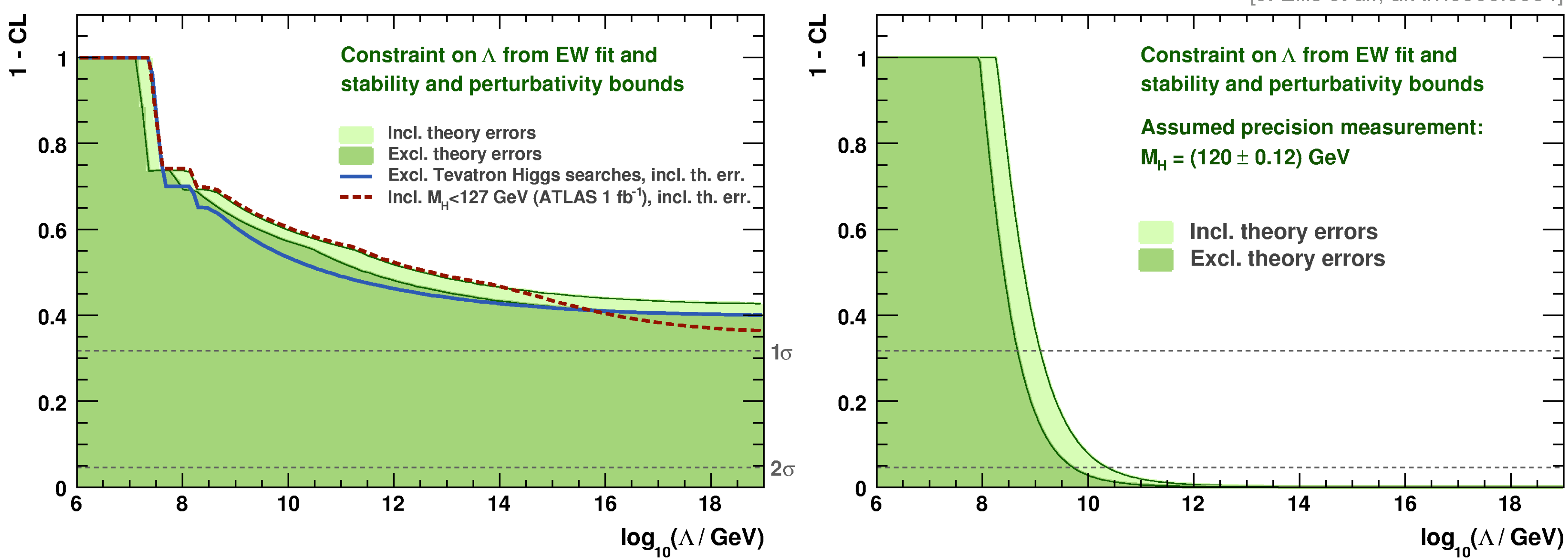


Convolve Bounds with M_H Constraints

Can we obtain likelihoods on vacuum stability (or, likewise, the cut-off = new physics scale Λ) from constraint on M_H ?

- Requiring absolute vacuum stability (at all times), one can obtain upper bound Λ
  - Left plot: current situation → no significant information
  - Right plot: case for precise M_H measurement of **120 GeV**

[J. Ellis *et al.*, arXiv:0906.0954]



Convolve Bounds with M_H Constraints

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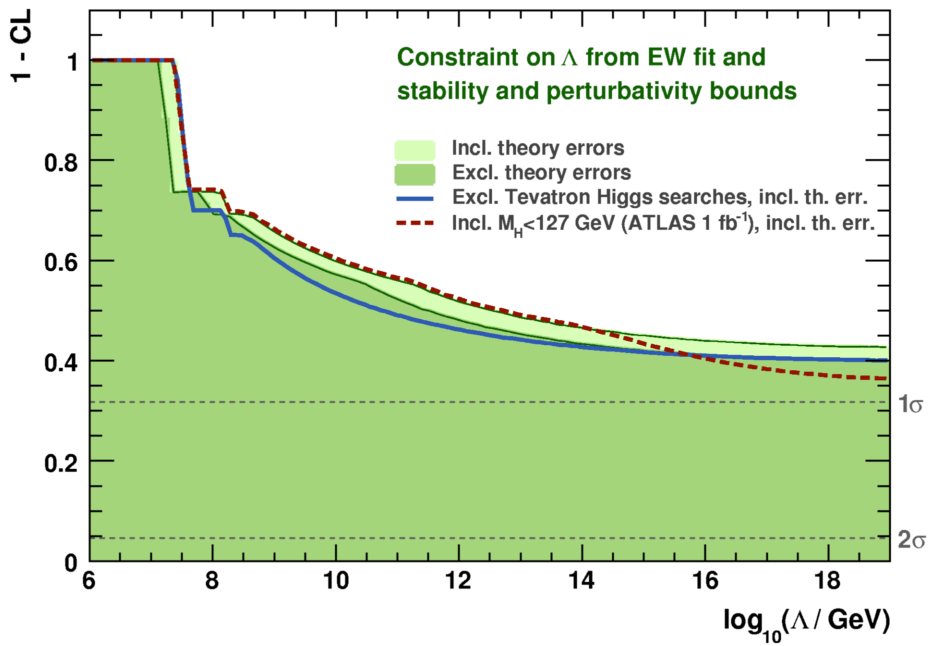
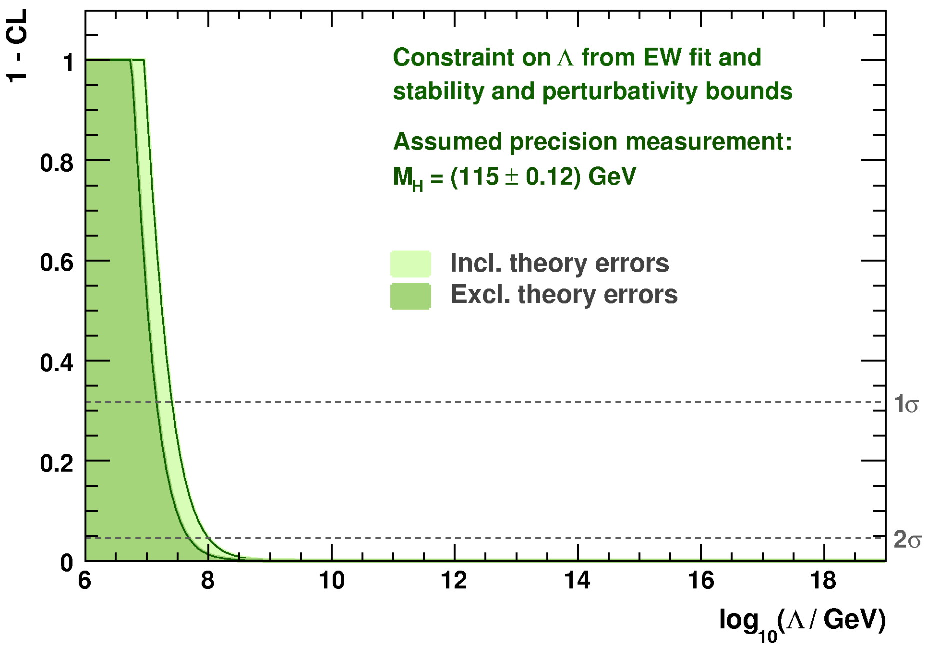
- Requiring absolute vacuum stability (at all times), one can obtain upper bound Λ
  - Left plot: current situation → no significant information
  - Right plot: case for precise M_H measurement of **115 GeV**

[J. Ellis *et al.*, arXiv:0906.0954]





Convolve Bounds with M_H Constraints

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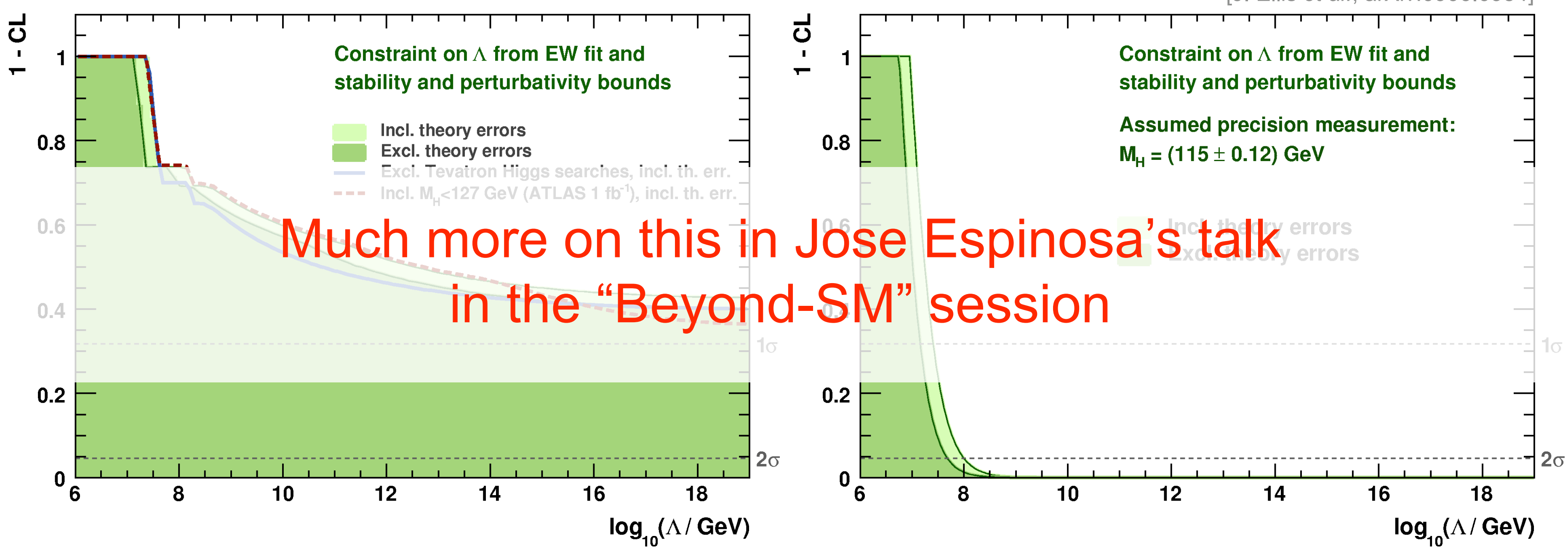
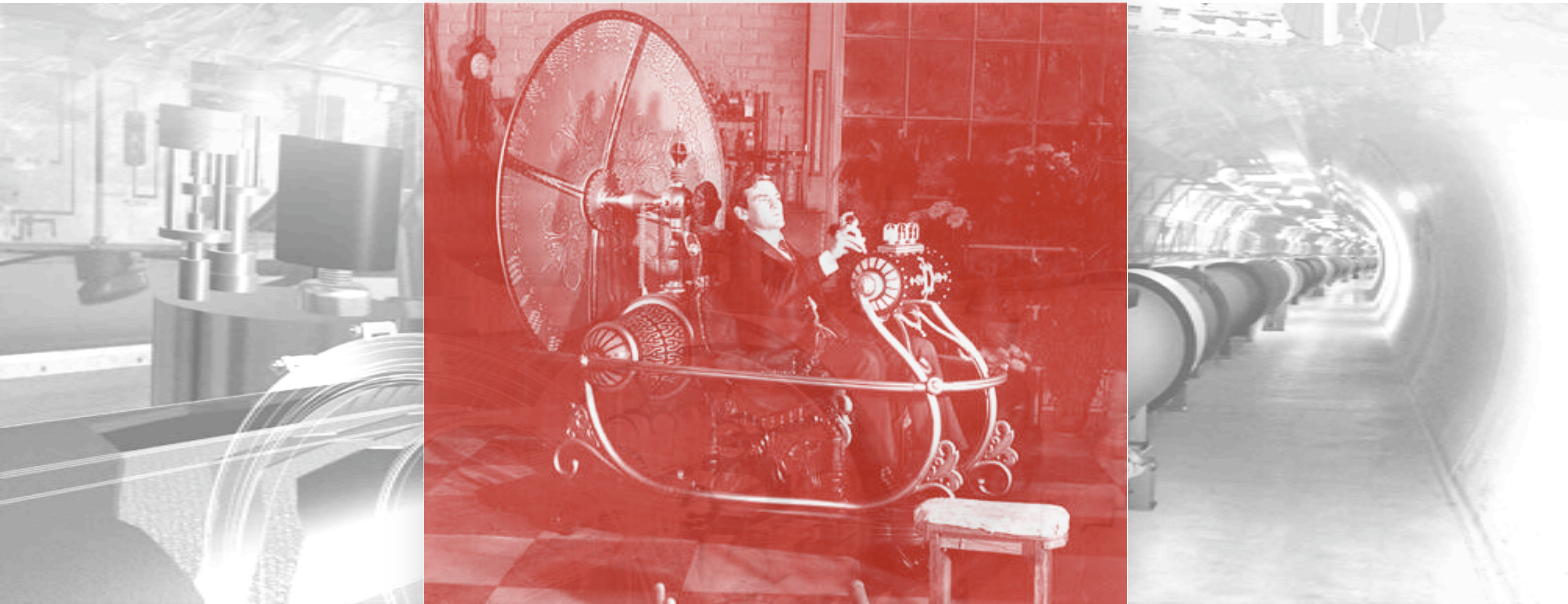


Much more on this in Jose Espinosa's talk in the "Beyond-SM" session

Prospects for the Standard Model Fit



Prospects for LHC, ILC and ILC with Giga-Z

Assumed experimental improvements for prospective study:

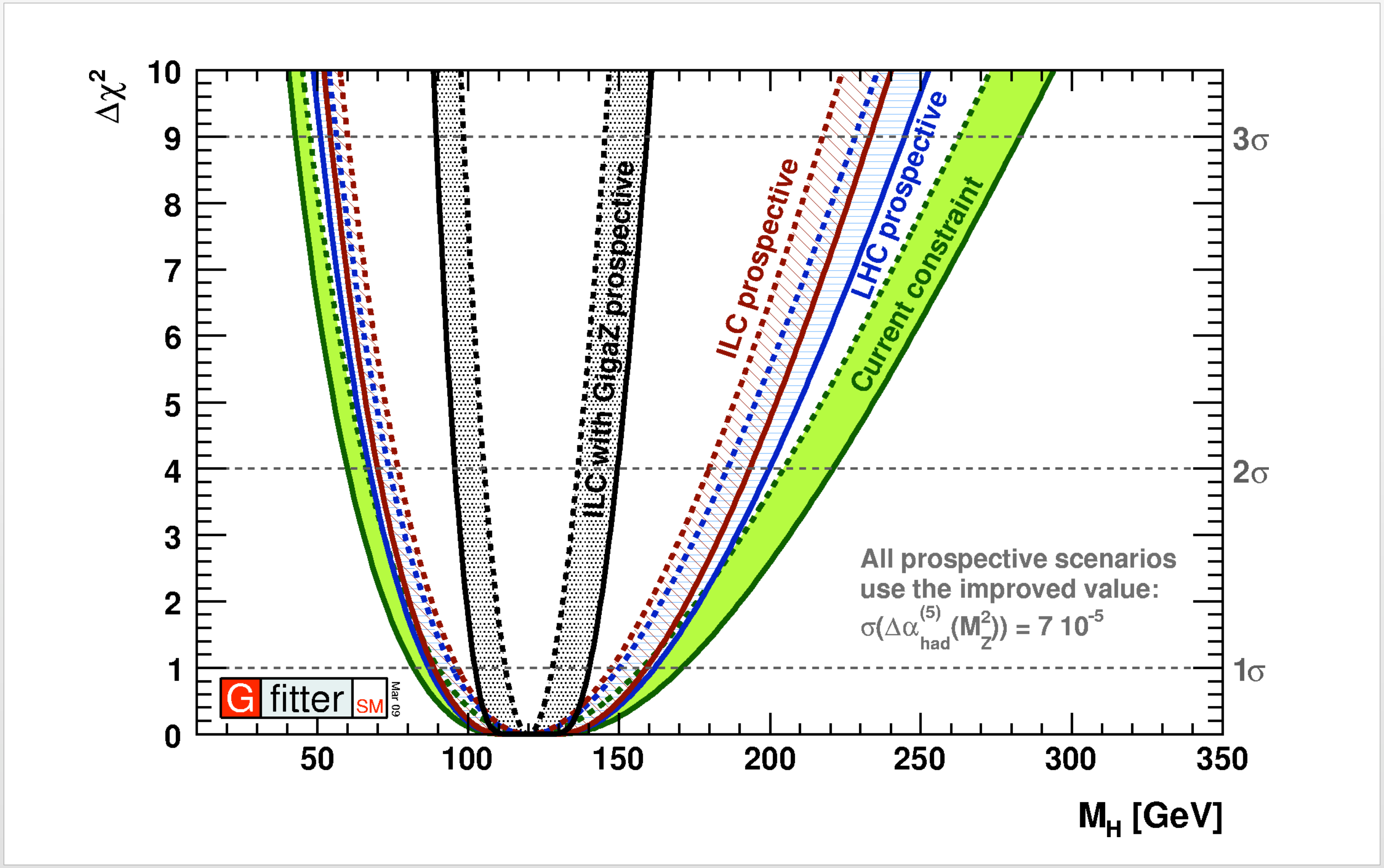
- LHC: M_W, m_{top}
- ILC: M_W, m_{top}
- Giga-Z: M_W, m_{top}, $\sin^2\theta^l_{eff}$, R_{lep}
- ISR-based (BABAR) and BESIII cross-section measurements should improve $\Delta\alpha^{had}(M_Z)$

Quantity	Expected uncertainty			
	Present	LHC	ILC	GigaZ (ILC)
M_W [MeV]	23	15	15	6
m_t [GeV]	1.3	1.0	0.2	0.1
$\sin^2\theta^\ell_{eff}$ $[10^{-5}]$	17	17	17	1.3
R^0_ℓ $[10^{-2}]$	2.5	2.5	2.5	0.4
$\Delta\alpha^{(5)}_{had}(M_Z^2)$ $[10^{-5}]$	22 (7)	22 (7)	22 (7)	22 (7)
$M_H(= 120\text{ GeV})$ [GeV]	${}^{+54}_{-40}$ $\left({}^{+51}_{-38}\right)$ $\left[{}^{+38}_{-30}\right]$	${}^{+45}_{-35}$ $\left({}^{+42}_{-33}\right)$ $\left[{}^{+30}_{-25}\right]$	${}^{+42}_{-33}$ $\left({}^{+39}_{-31}\right)$ $\left[{}^{+28}_{-23}\right]$	${}^{+26}_{-23}$ $\left({}^{+20}_{-18}\right)$ $\left[{}^{+8}_{-8}\right]$
$\alpha_s(M_Z^2)$ $[10^{-4}]$	28	28	28	6

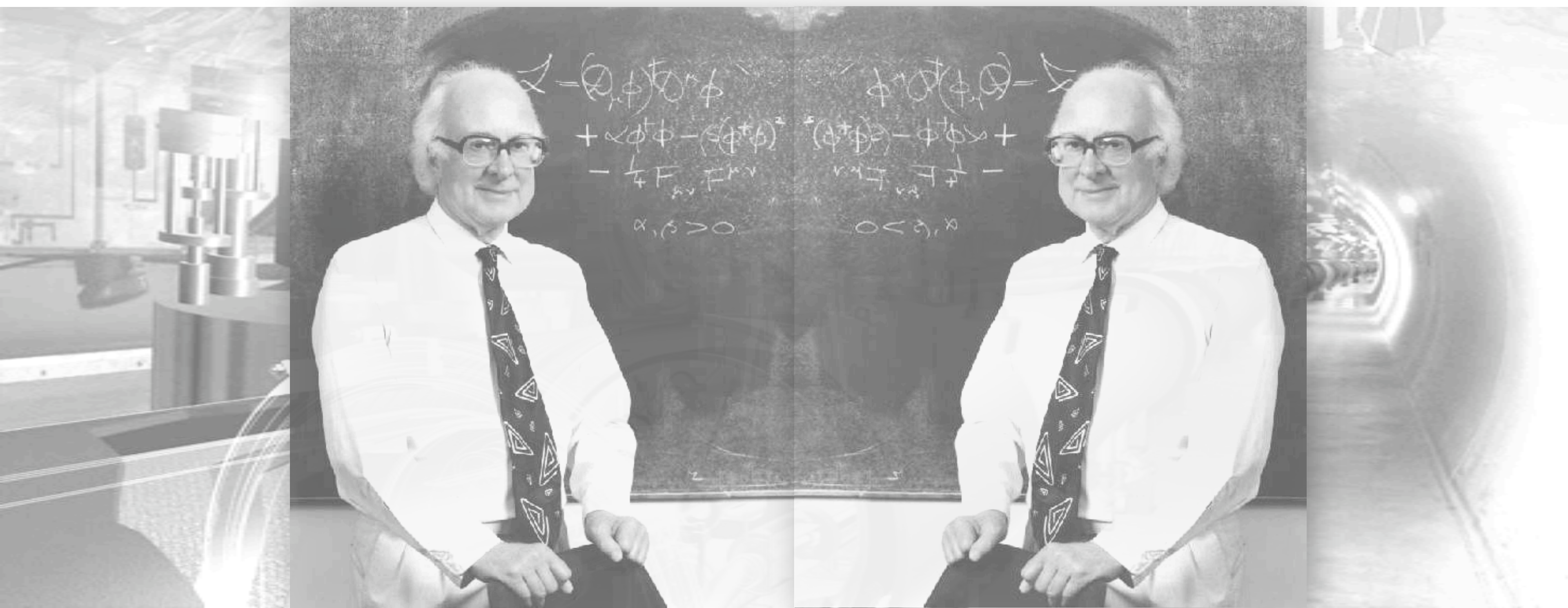
Input from: [ATLAS, Physics TDR (1999)] [CMS, Physics TDR (2006)] [A. Djouadi et al., arXiv:0709.1893][I. Borjanovic, EPJ C39S2, 63 (2005)] [S. Haywood et al., hep-ph/0003275] [R. Hawkings, K. Mönig, EPJ direct C1, 8 (1999)] [A. H. Hoang et al., EPJ direct C2, 1 (2000)] [M. Winter, LC-PHSM-2001-016]

Prospects for LHC, ILC and ILC with Giga-Z

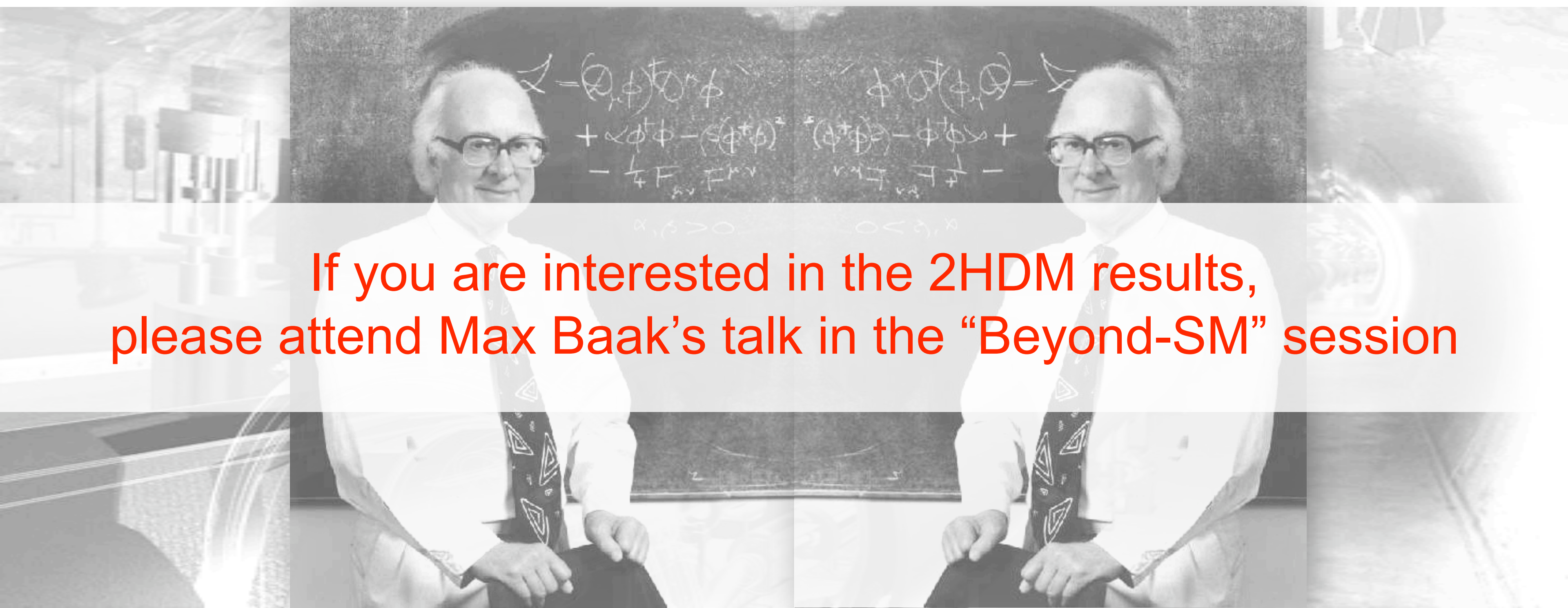
Results on M_H, including (solid) and excluding (dotted) theoretical errors



The Two-Higgs-Doublet Model (2HDM)



The Two-Higgs-Doublet Model (2HDM)



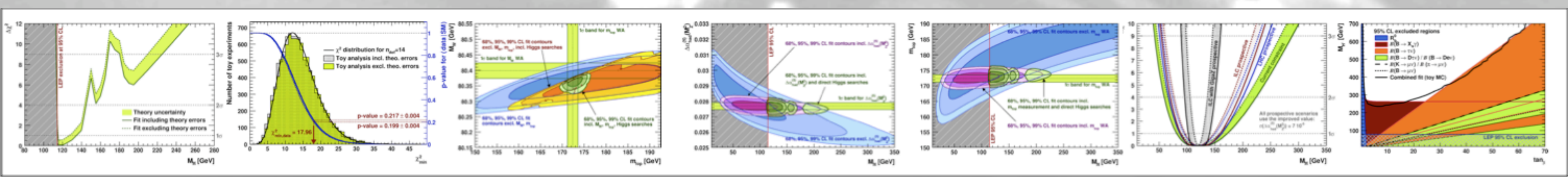
If you are interested in the 2HDM results,
please attend Max Baak's talk in the "Beyond-SM" session


What’s Next ?

What's Next?

http://cern.ch/Gfitter

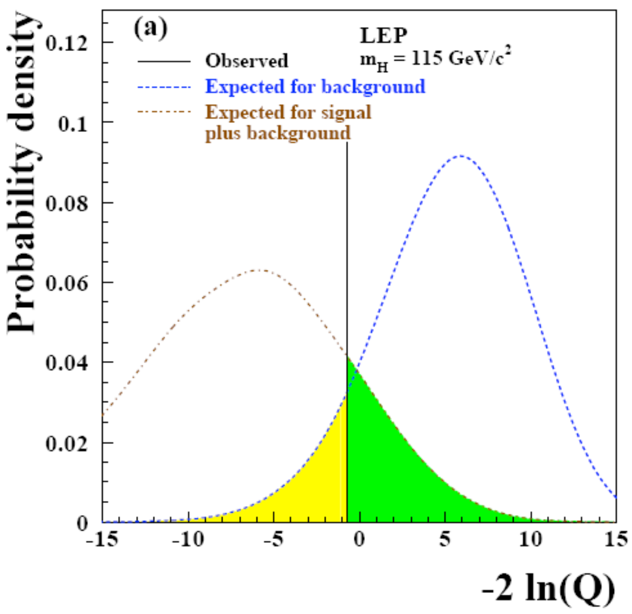
- Gfitter is growing:
  - New members: Max Baak, Matthias Schott (CERN), and Doerthe Ludwig (DESY)
- Maintain SM package in line with experimental and theoretical progress
- Maintain and improve Gfitter core package, improve fitter efficiency
- Extend SM fit to "oblique" parameters ($\varepsilon_{1,2,3}$ and S, T, U)
  - For SM fit and Little Higgs corrections and more new physics models
- Maintain and extend 2HDM package
  - Extend to more rare decays
- Long-term goal: MSSM



Backup

Using Direct Higgs Searches in Fit

The collaborations quantify the level of agreement of the data with the "s+b" hypothesis by CL_{s+b} using toy MC experiments



For insertion in fit:

- Only the tail of large values is integrated (corresponds to "too few Higgs-like events" in simple counting experiment)
- In the SM fit, we are interested in any kind of deviation from the "s+b" hypothesis (including the case of "too many Higgs-like events")

➡ Transform 1-sided into 2-sided CL:

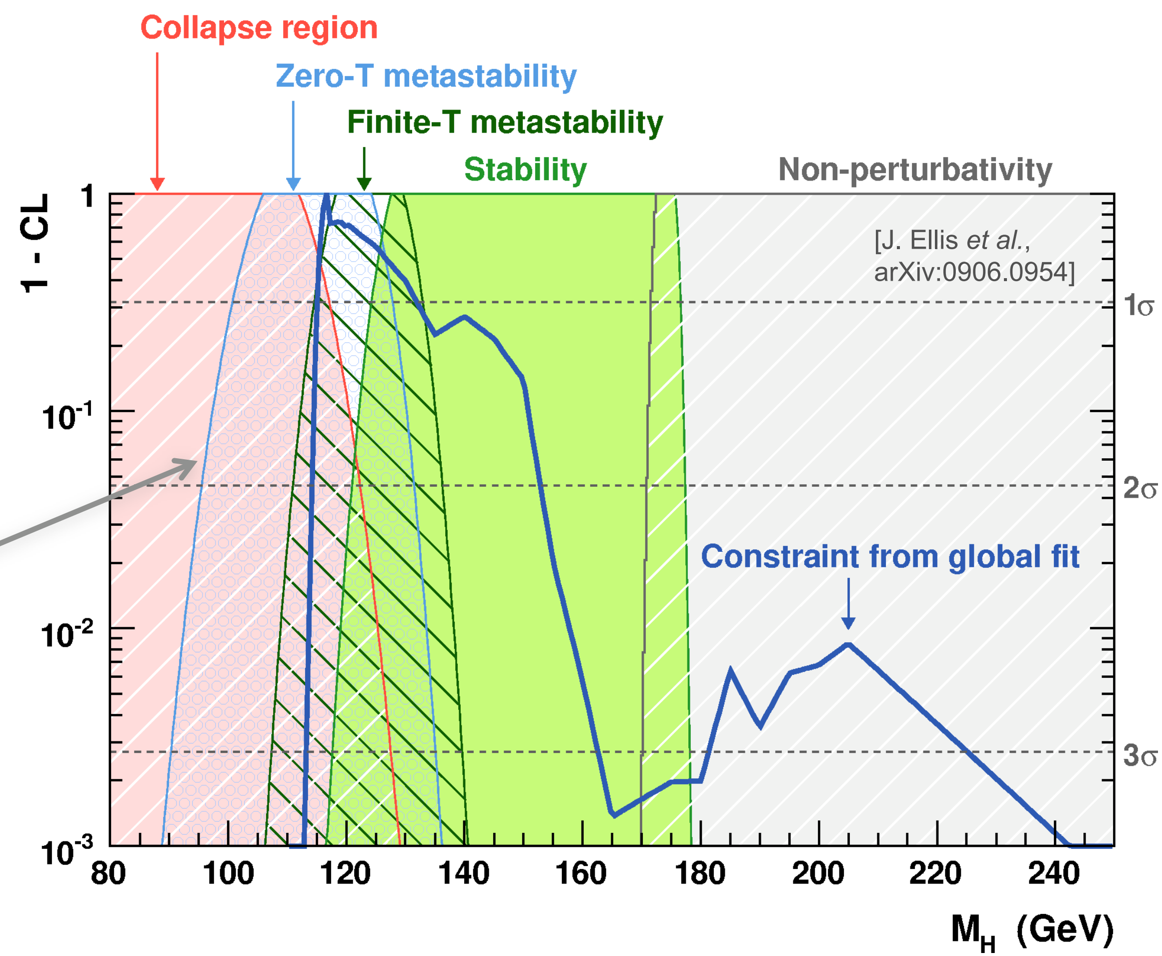
for: $CL_{s+b} \leq 0.5$: $CL_{s+b}^{[2\text{-sided}]} = 2\, CL_{s+b}$

for: $CL_{s+b} > 0.5$: $CL_{s+b}^{[2\text{-sided}]} = 2\,(1 - CL_{s+b})$

Transform into a contribution to χ^2 via: $\delta\chi^2 = \mathrm{Erf}^{-1}\left(1 - CL_{S+B}^{2\text{-sided}}\right)$

Driving the SM to M_{Planck}

At M_{Planck}, the following bounds are obtained, depending on stability criterion

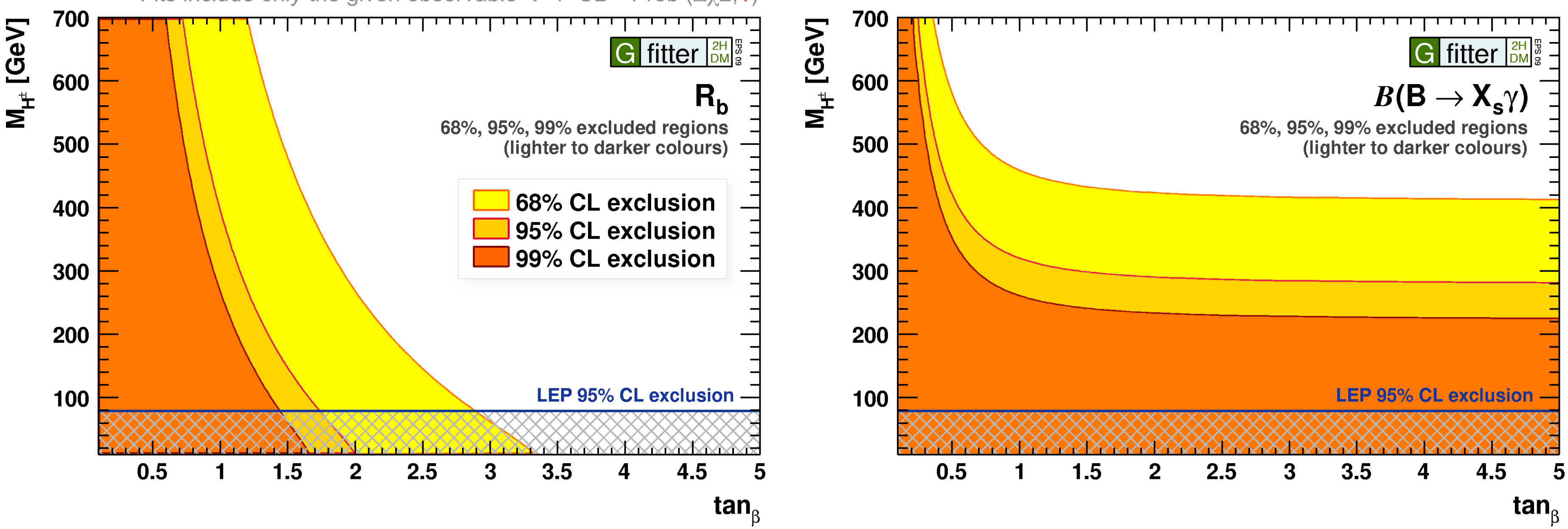


Uncertainty in bounds due to m_{top}, α_s dependence and theoretical errors

Extend SM by adding another scalar Higgs doublet (2HDM):

- *Type-II* 2HDM: one doublet couples to up-type, one doublet couples to down-type quarks
- 6 free parameters: $M_{H\pm}$, M_{A0}, M_{H0}, $\underline{M_h}$, $\tan\beta = v_2 / v_1$, α (governing h–H^0 mixing)
- So far: only looked at processes sensitive to charged Higgs: $M_{H\pm}$, $\tan\beta$:
  - $Z \rightarrow bb$ width ratio: R^0_b
  - Radiative and leptonic meson decays: $B \rightarrow X_s\gamma$, $B \rightarrow \mu\nu / \tau\nu$, $K \rightarrow \mu\nu / \pi \rightarrow \mu\nu$
  - Semi-leptonic B decay: $B \rightarrow D\tau\nu$

Fits include *only* the given observable → 1–CL = Prob (Δχ2,1)



Tension (2.4σ) in $B \to \tau\nu$ branching fraction between measurement and SM

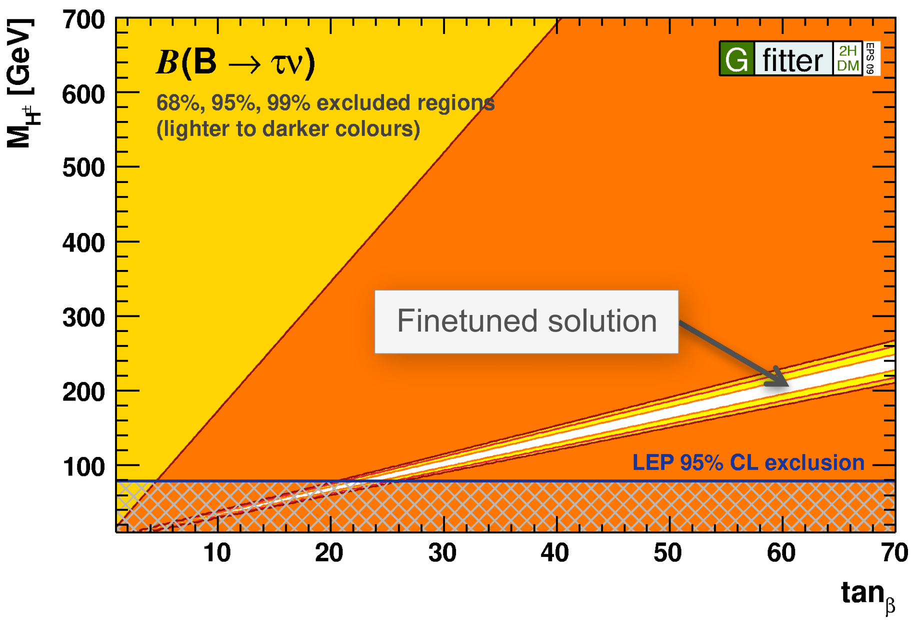
- Measurement: $BR(B \to \tau\nu) = (1.73 \pm 0.35) \times 10^{-4}$ [BABAR + Belle average, FPCP 2009]
- Theoretical prediction: $BR(B \to \tau\nu) \sim (m_\tau f_B |V_{ub}|)^2$

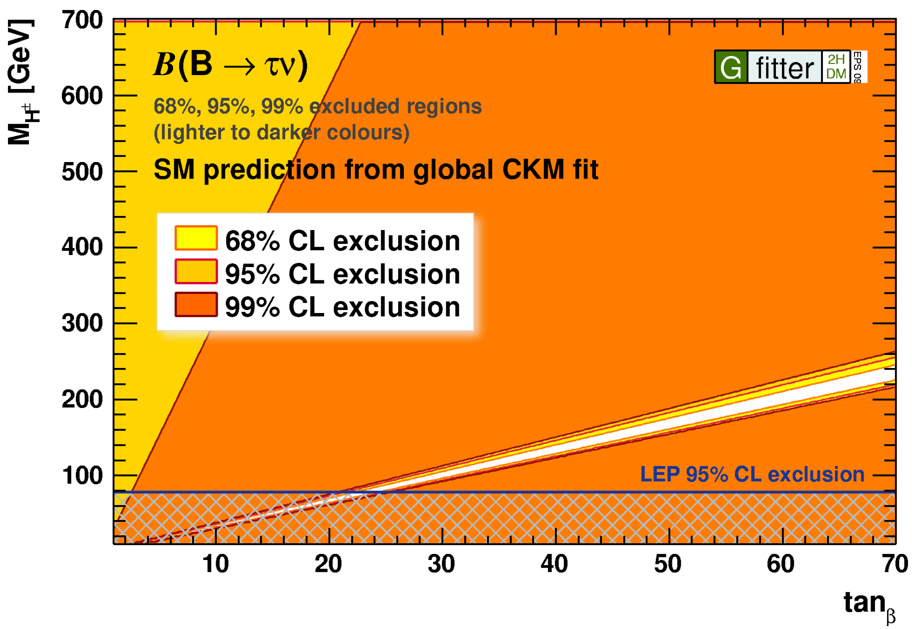
use: f_B = (190 ± 13) MeV [HPQCD 2009 using NRQCD, Davies at FPCP'09]]

$|V_{ub}|$ = $(3.70 \pm 0.33) \times 10^{-3}$ [using incl. + excl. averages from HFAG 2009]

$BR(B \to \tau\nu) = (0.87\,^{+0.21}_{-0.18}) \times 10^{-4}$ [using above values for f_B and $|V_{ub}|$]

$BR(B \to \tau\nu) = (0.80\,^{+0.15}_{-0.09}) \times 10^{-4}$ [using global CKM fit, CKMfitter Group FPCP 2009]





2HDM – Combined Fit

$M_{H\pm} > 270$ GeV (95% CL). Strong exclusion for large $\tan\beta$ from $B \to \tau\nu$