The global electroweak fit with Gfitter in the light of new precision measurements

Roman Kogler

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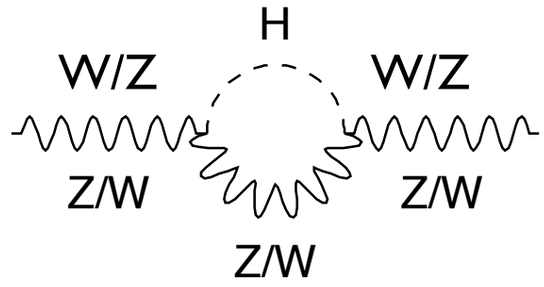
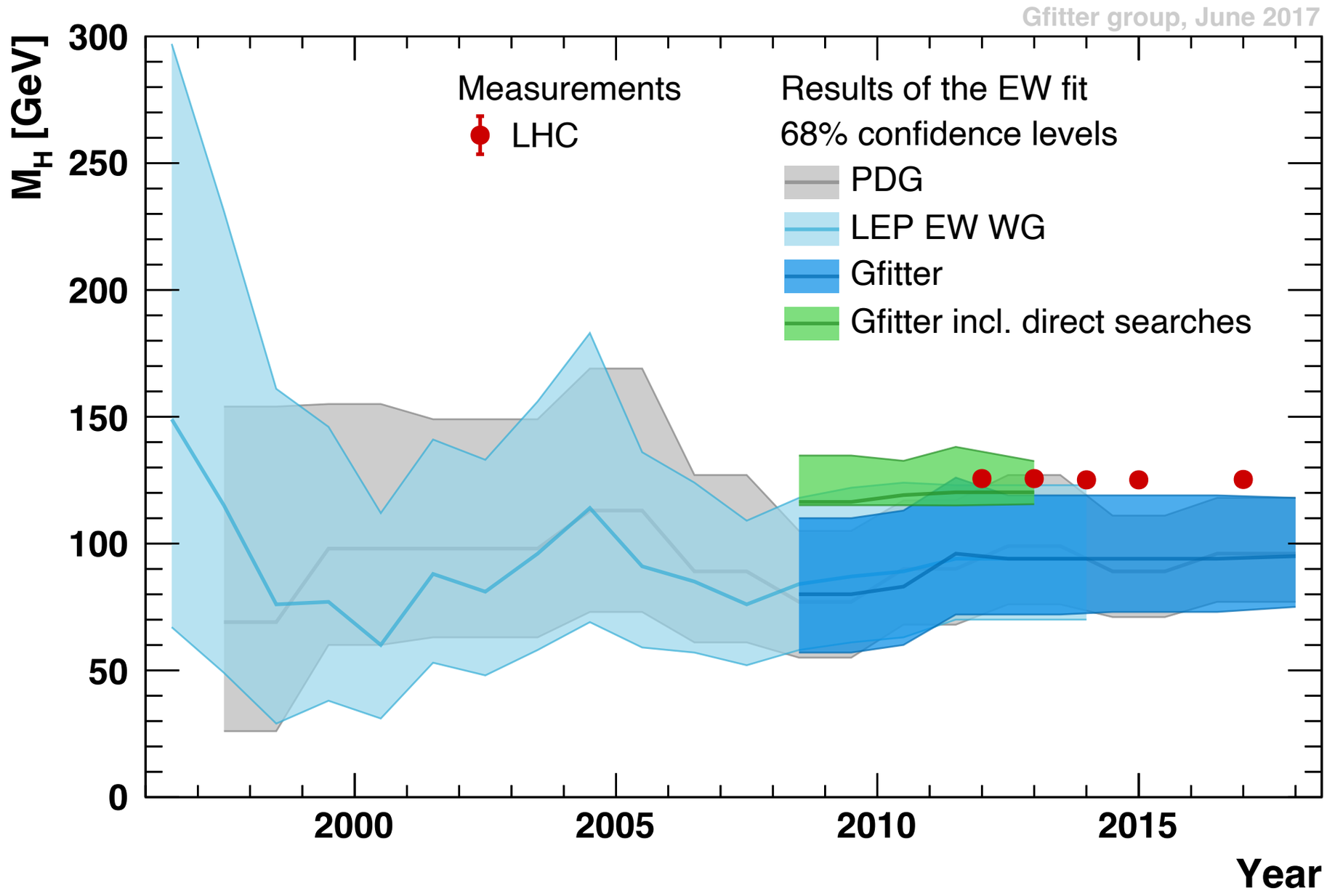
The Gfitter group:
Y. Fischer (Univ. Hamburg), J. Haller (Univ. Hamburg), A. Hoecker (CERN), RK (DESY),
K. Mönig (DESY), M. Schott (Mainz), J. Stelzer (CERN)

The EW Fit: Predicting m_H



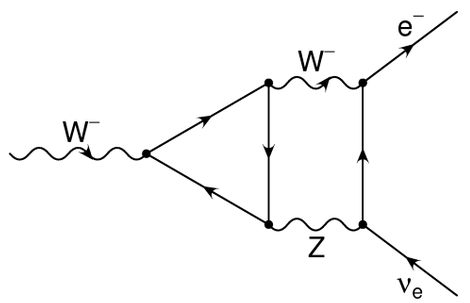
$$\propto \ln \frac{M_H^2}{M_W^2}$$



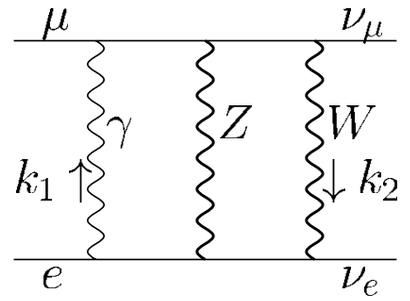
- Predictions from loop effects since 1997
- The fits have always been able to predict m_H correctly

Calculations

All observables calculated at 2-loop level



"fermionic"



"bosonic"

- **M_W** : full EW one- and two-loop calculation of fermionic and bosonic contributions
  [M Awramik et al., PRD 69, 053006 (2004), PRL 89, 241801 (2002)]
  + 4-loop QCD correction [Chetyrkin et al., PRL 97, 102003 (2006)]
- **$\sin^2\theta^l_{eff}$** : same order as M_W, calculations for leptons and all quark flavours
  [M Awramik et al, PRL 93, 201805 (2004), JHEP 11, 048 (2006), Nucl. Phys. B813, 174 (2009)]
- **partial widths Γ_f**: fermionic corrections in two-loop for all flavours (includes predictions for σ^0_{had}) [A. Freitas, JHEP04, 070 (2014)]
- **Radiator functions**: QCD corrections at N³LO
  [Baikov et al., PRL 108, 222003 (2012)]
- **Γ_W** : only one-loop EW corrections available, negligible impact on fit
  [Cho et al, JHEP 1111, 068 (2011)]
- **all calculations**: one- and two-loop QCD corrections and leading terms of higher order corrections

Experimental Input

Fit is overconstrained

- All free parameters measured ($\alpha_s(M_Z)$ unconstrained in fit)
  - Most input from e^+e^- colliders
    - M_Z : 0.002%
  - Crucial input from hadron colliders:
    - m_t : 0.4%
    - M_W : 0.02%
    - M_H : 0.2%
  - Remarkable precision (<1%)

M_H [GeV]	125.1 ± 0.2	LHC
M_W [GeV]	80.369 ± 0.016	LEP
Γ_W [GeV]	2.085 ± 0.042	Tev.
M_Z [GeV]	91.1875 ± 0.0021	
Γ_Z [GeV]	2.4952 ± 0.0023	
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	
R^0_ℓ	20.767 ± 0.025	LEP
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	
A_ℓ $^{(\star)}$	0.1499 ± 0.0018	SLD
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	
$\sin^2\theta^\ell_{\rm eff}({\rm Tev + LHC})$	0.23141 ± 0.00026	Tev. LHC
A_c	0.670 ± 0.027	SLD
A_b	0.923 ± 0.020	
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035	
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016	LEP
R^0_c	0.1721 ± 0.0030	
R^0_b	0.21629 ± 0.00066	
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	low E
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	
m_t [GeV]$^{(\triangledown)}$	172.47 ± 0.68	LHC
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2761 ± 9	low E

M_W average from LEP and LHC

Poor-man's combination until Tevatron M_W is understood

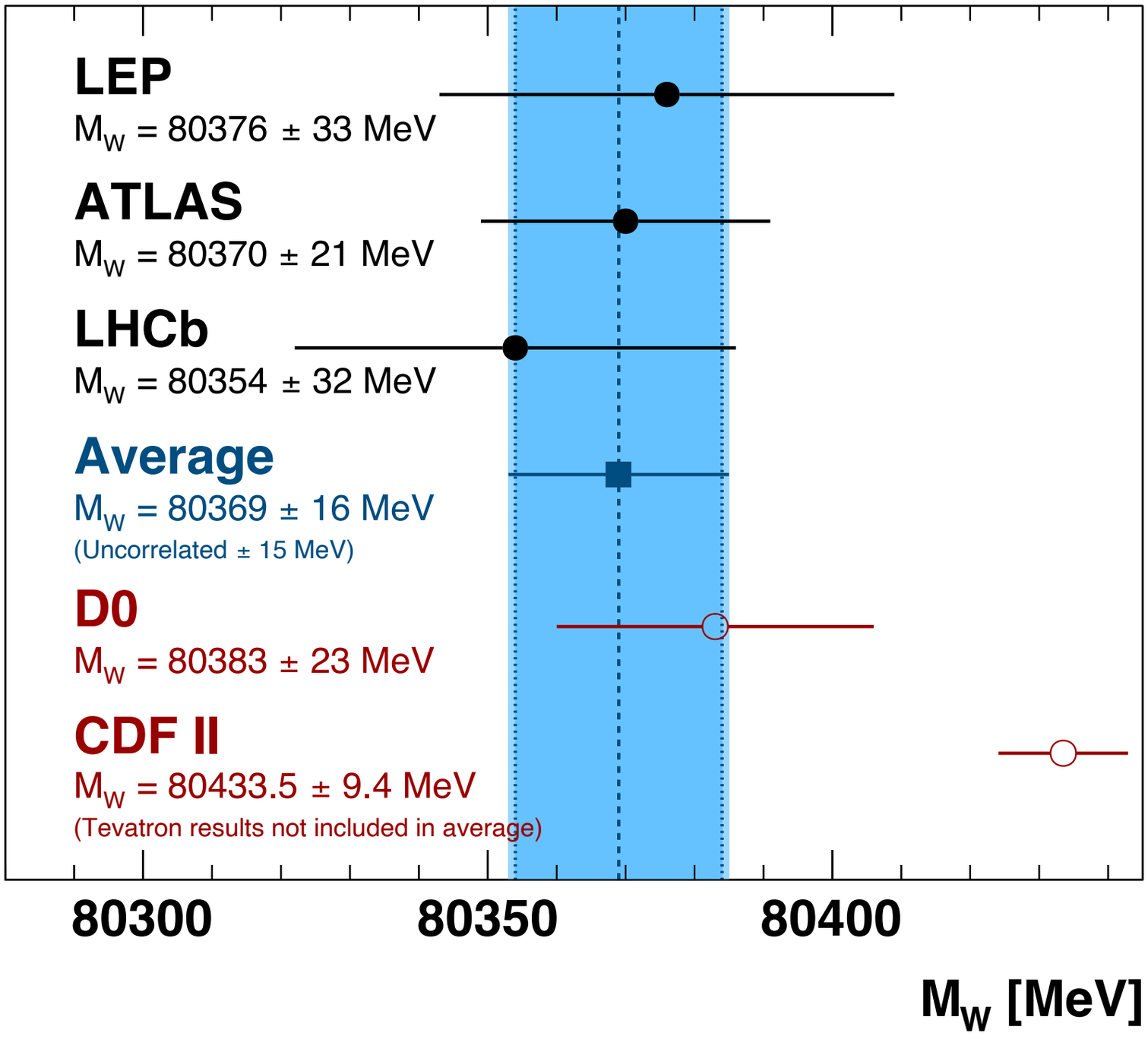
Average of LEP and LHC:

- LEP combination: $80\,376 \pm 25_{\text{stat}} \pm 22_{\text{syst}}$ MeV
- ATLAS: $80\,370 \pm 7_{\text{stat}} \pm 11_{\text{exp syst}} \pm 14_{\text{model}} \pm 8_{\text{PDF}}$ MeV
- LHCb: $80\,354 \pm 23_{\text{stat}} \pm 10_{\text{exp syst}} \pm 17_{\text{model}} \pm 9_{\text{PDF}}$ MeV
- Assume correlations:
  - ATLAS/LHCb: model between 0 and 1, PDF between 0 and -0.5
  - LEP/LHC: none
- M_W(LHC) = 80366 ± 19 MeV
- Combine with LEP (fully uncorrelated):

  M_W(LEP+LHC) = 80369 ± 16 MeV

  (Same result if all three measurements combined in one step, with χ^2/ndf = 0.28/2)
- Previous TEV+LEP+ATLAS combination: 80379 ± 13 MeV

Our M_W Combination



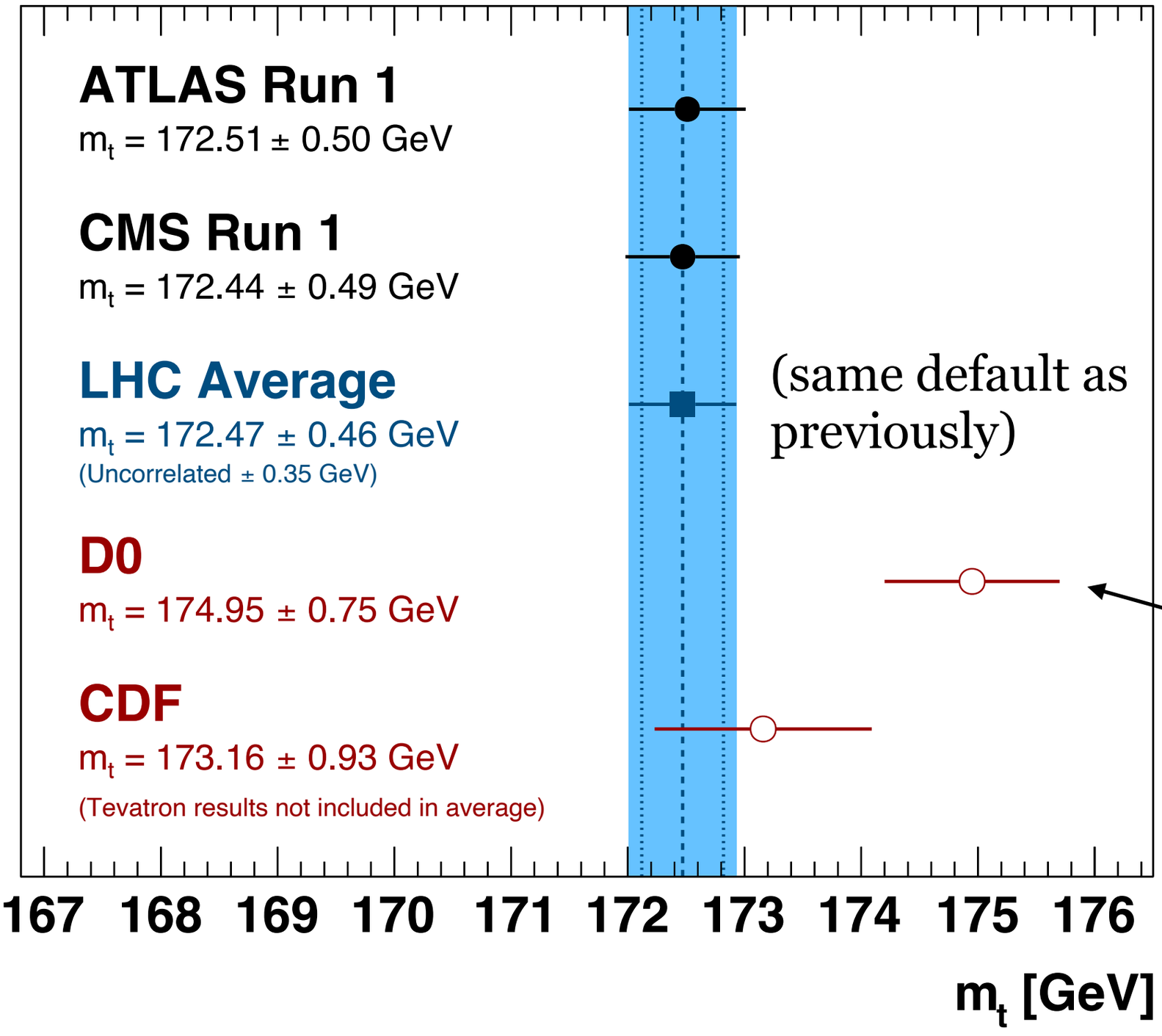
Compatibility between our average and CDF II:

χ^2 / ndf = 12.1 - 16.4
for correlations between 0 and 0.3 (*)

p-value: $5 \cdot 10^{-4}$ to $5 \cdot 10^{-5}$ corresponds to 3.5 - 4.0 σ

(*) Note: correlation of 0.3 obtained by fully correlating model and PDF uncertainties

Top Quark Mass



(same default as previously)

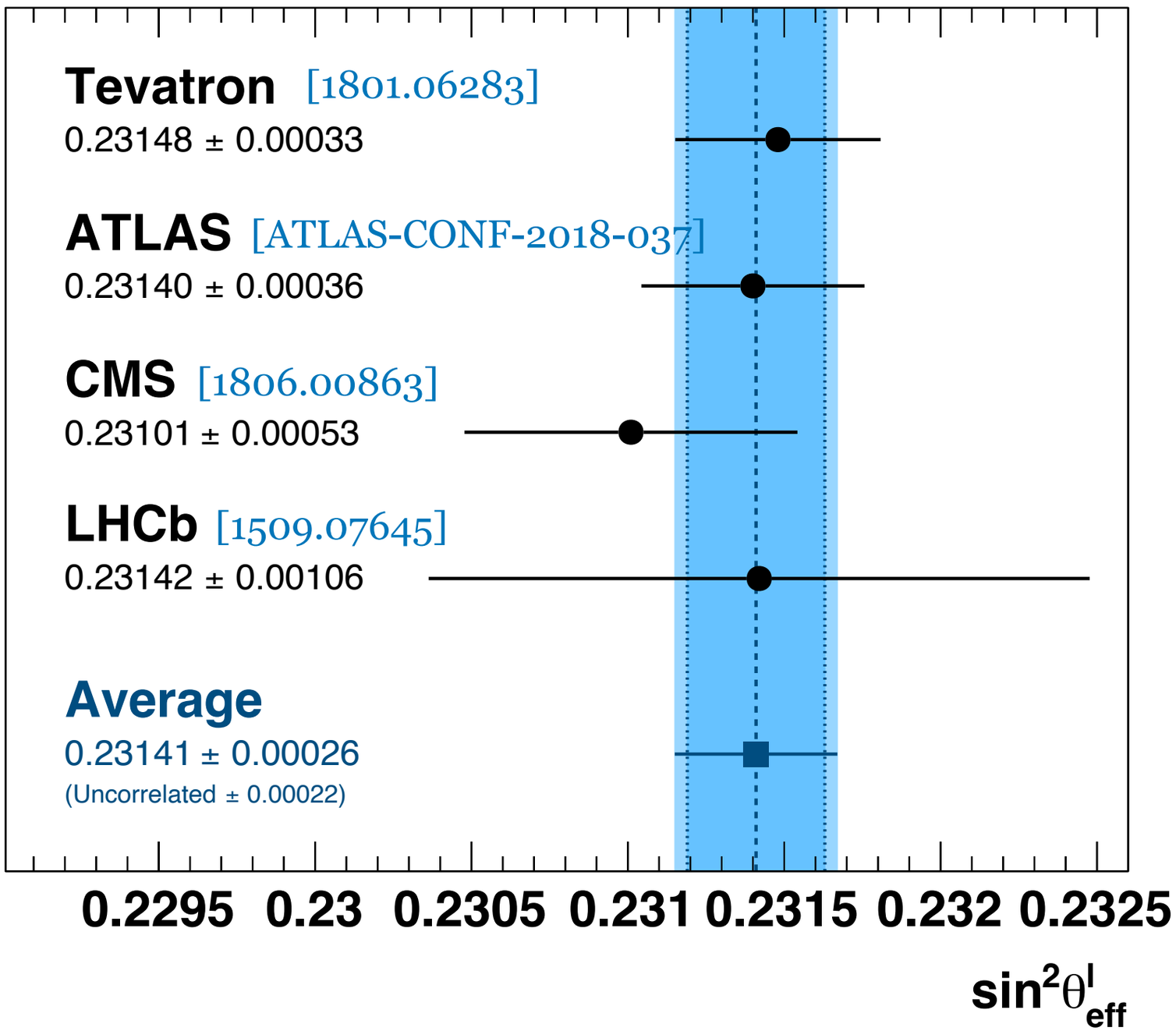
Poor-man's combination until LHC TOP WG results are finalised

Additional theoretical uncertainty of 0.5 GeV

Deviation of 3 - 4σ w.r.t. LHC average

Depending on assumed correlations
Tevatron combination: incompatibility of 2.3-3σ

Effective Weak Mixing Angle



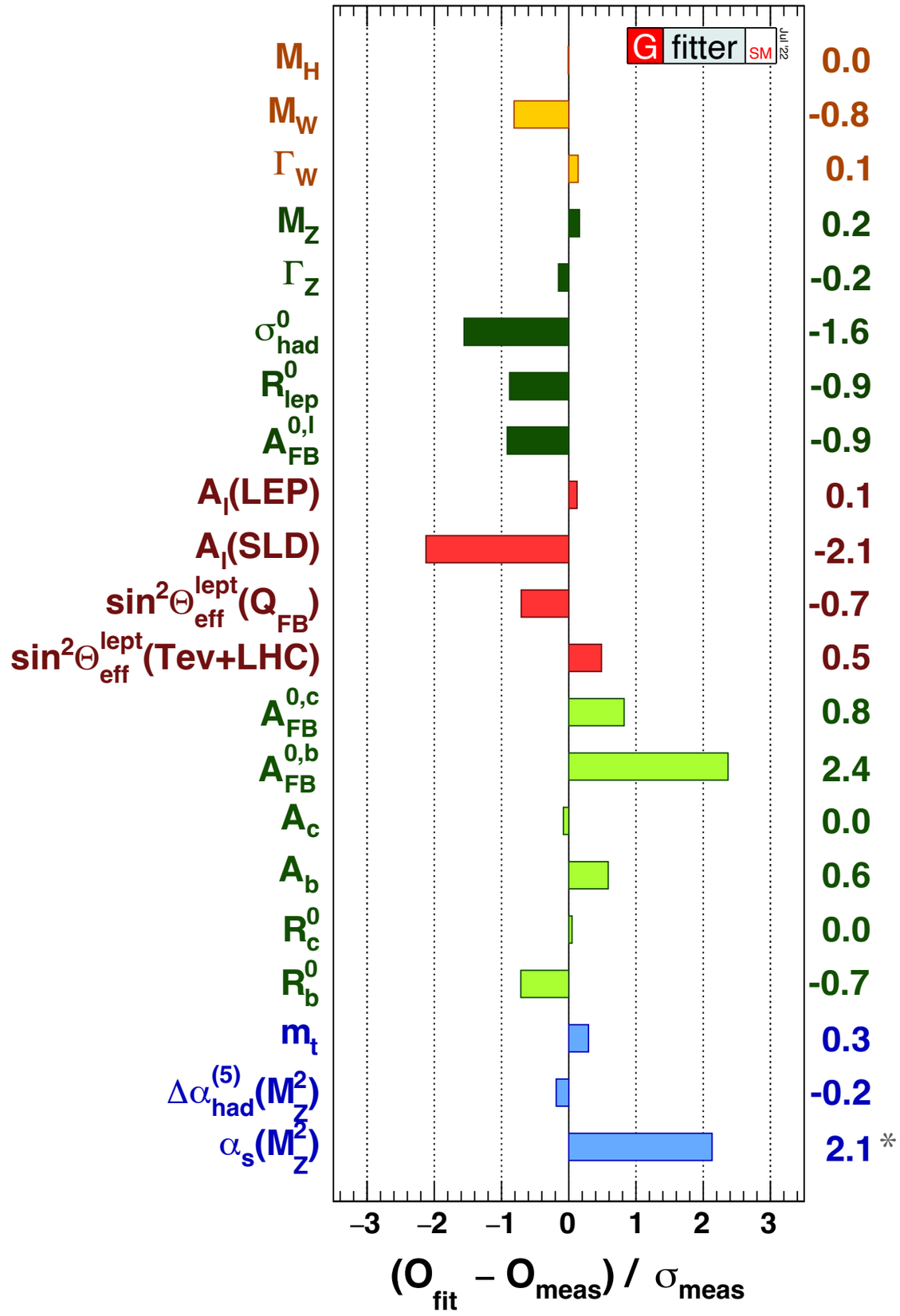
SM Fit

χ^2_{min} / ndf = 16.62 / 15
p value = 0.34

- M_W: −0.8σ (−1.5σ previously (Δ))
  - central value smaller by 2 MeV
  - uncertainty reduced by 1 MeV
  - measurement lower

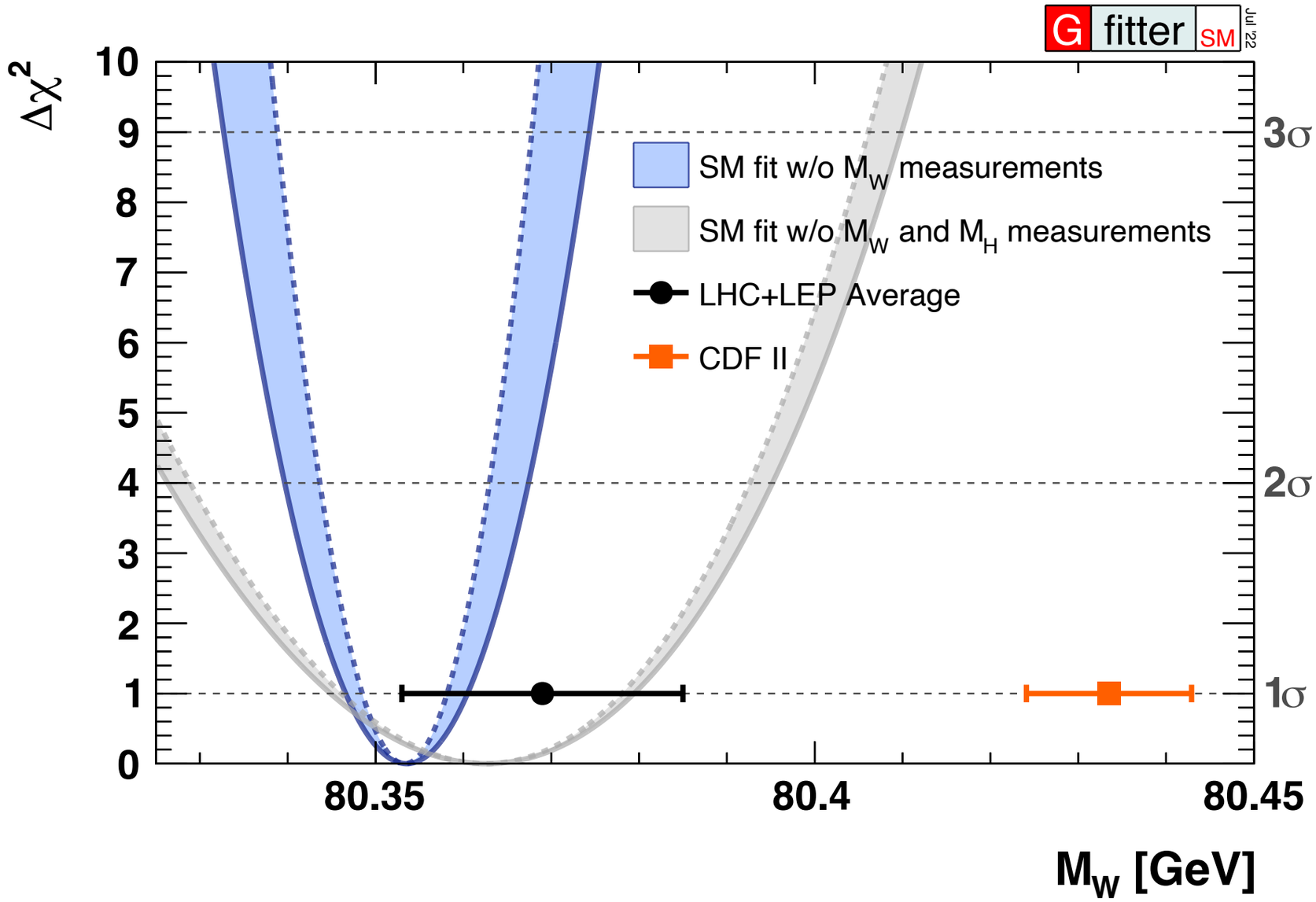
- m_t: 0.3σ (0.5σ previously (Δ))
  - central value: 175.9 → 177.2 GeV
  - uncertainty increased by 0.3 GeV
  - can reach ±0.9 GeV with perfect knowledge of M_W

(Δ) previous results: [1803.01853]



(*) comparison to PDG value, not included in fit as input parameter

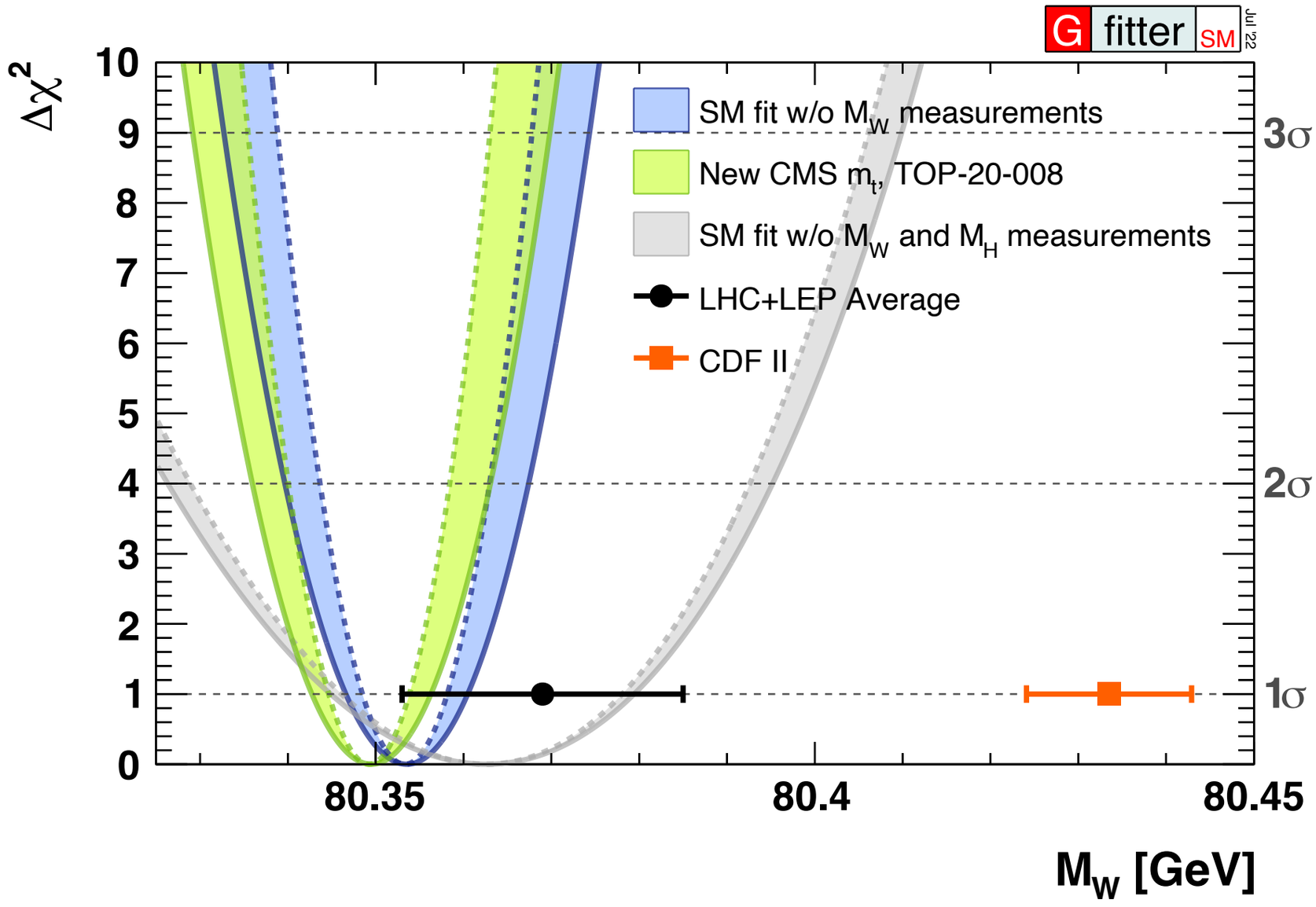
W Mass



Prediction: M_W = 80.354 ± 0.007 GeV

- Agreement within 1σ between prediction and LHC+LEP average
- CDF II measurement disagrees with prediction by 6.8σ

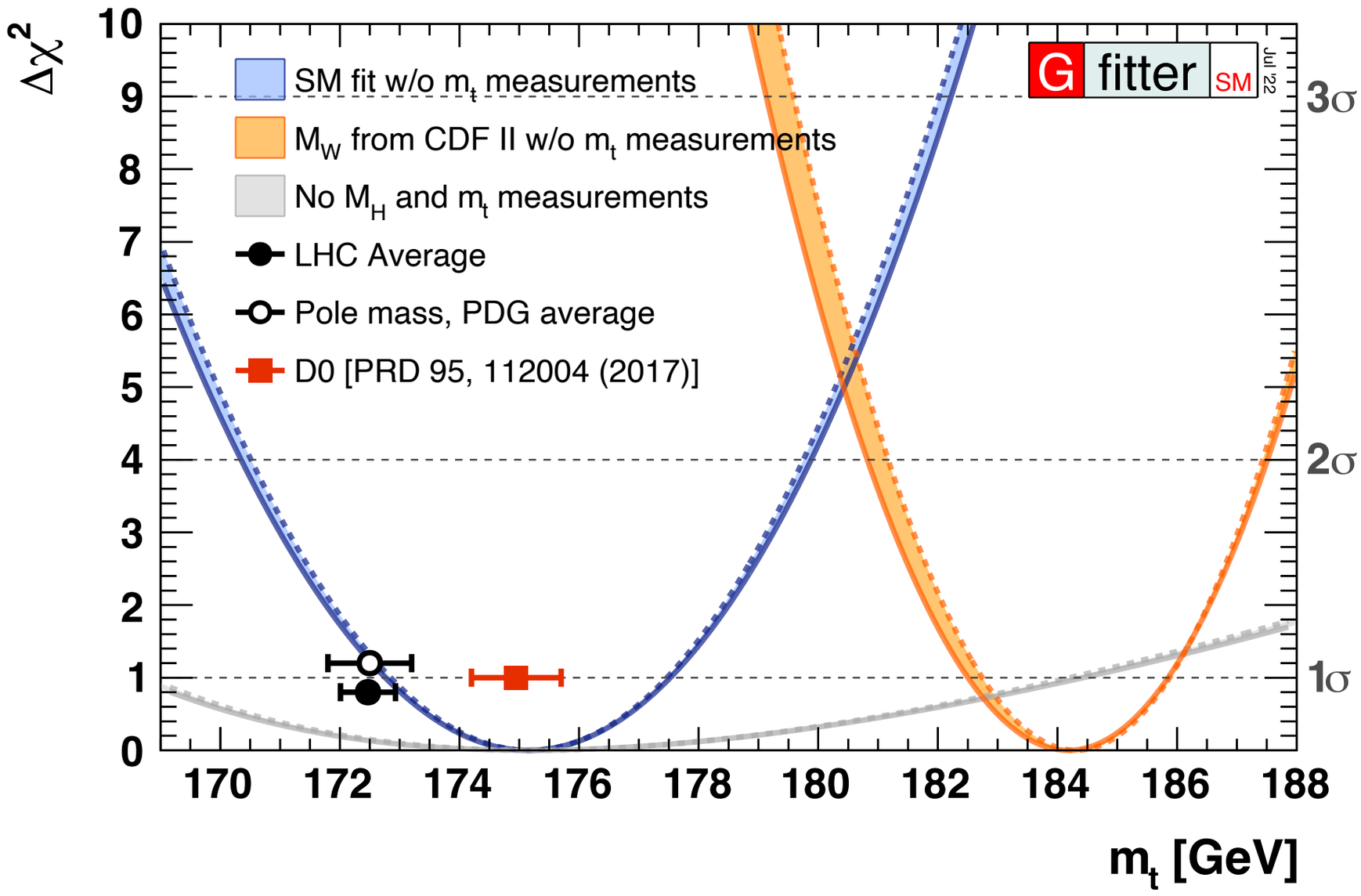
W Mass



New CMS $m_t = 171.77 \pm 0.04\ (\text{stat}) \pm 0.38\ (\text{syst})$ GeV

- $M_W = 80.349 \pm 0.007$ GeV (5 MeV smaller)
- Disagreement with CDF II measurement larger

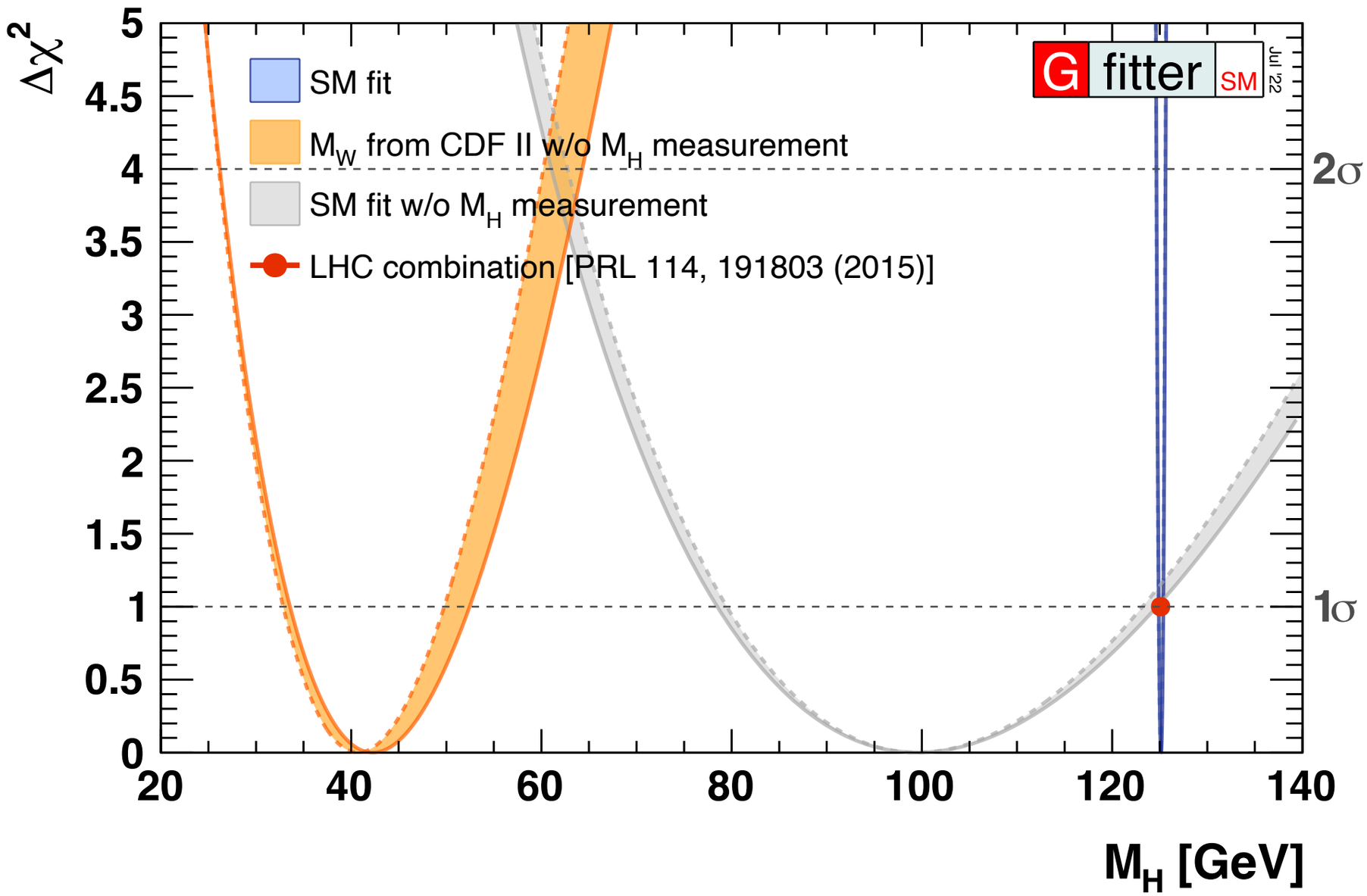
Top Quark Mass



Prediction: $m_t = 175.2 \pm 2.4$ GeV

- Compatible with LHC average within 1σ
- Prediction using CDF II M_W: $m_t = 184.2 \pm 1.7$ GeV

M_H



Prediction: $m_H = 99.5\ ^{+25.2}_{-21}$ GeV

- Prediction using CDF II M_W: $m_H = 42.3^{+10.2}_{-8.7}$ GeV (about 8σ)
- CDF II M_W results in small $M_H < 47$ GeV @ 95% CL

SM Fit with M_W from CDF II

χ^2 / ndf = 62.6 / 15
p-value = $8.9 \cdot 10^{-8}$
corresponds to 5.1σ

largest pull in M_W (80.3817 GeV)

would shift M_Z up by 1.3σ

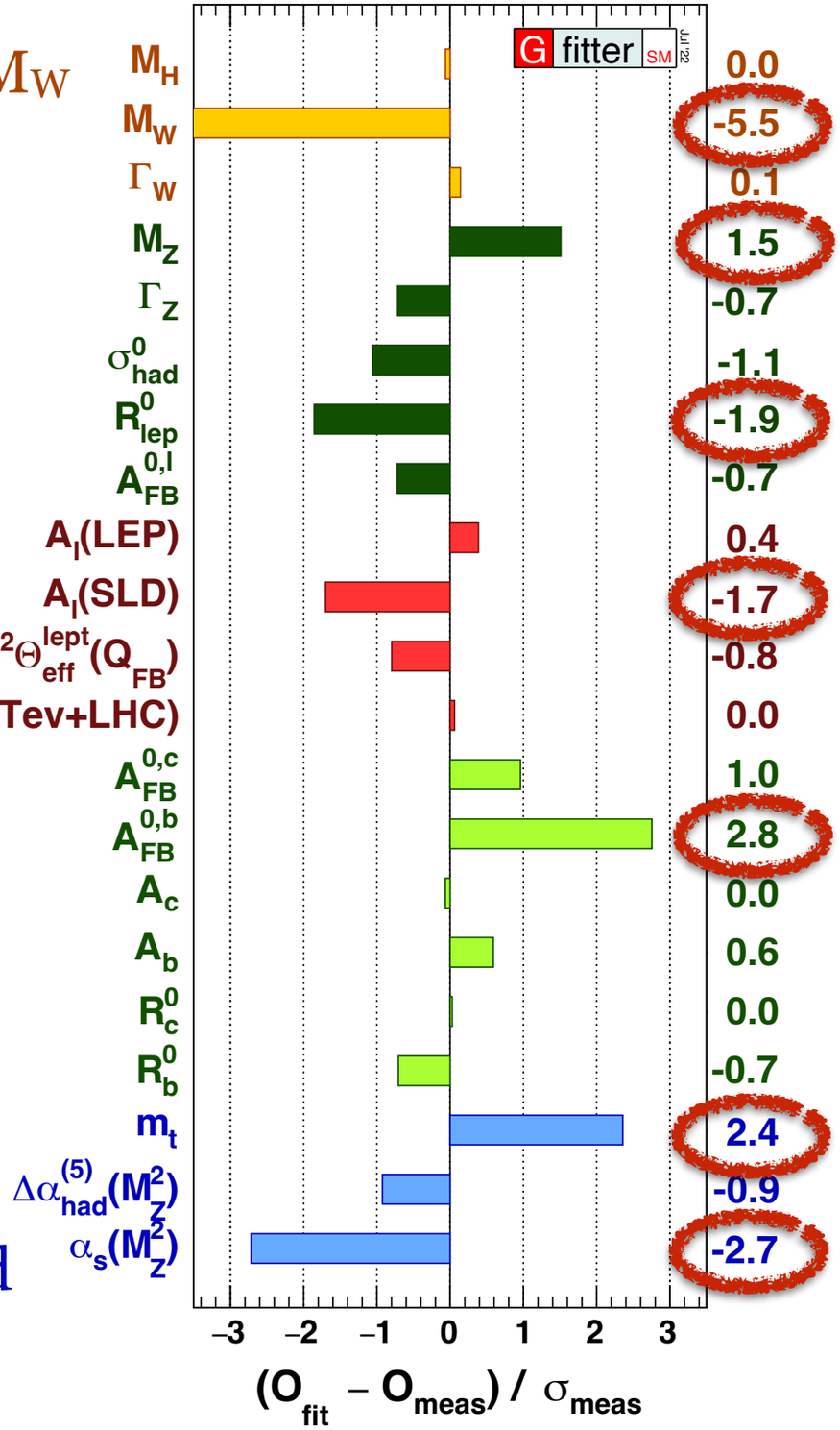
R^0_{lep} down by 1σ

Smaller pull in A_ℓ(SLD)

Larger pull in A^b_{FB}

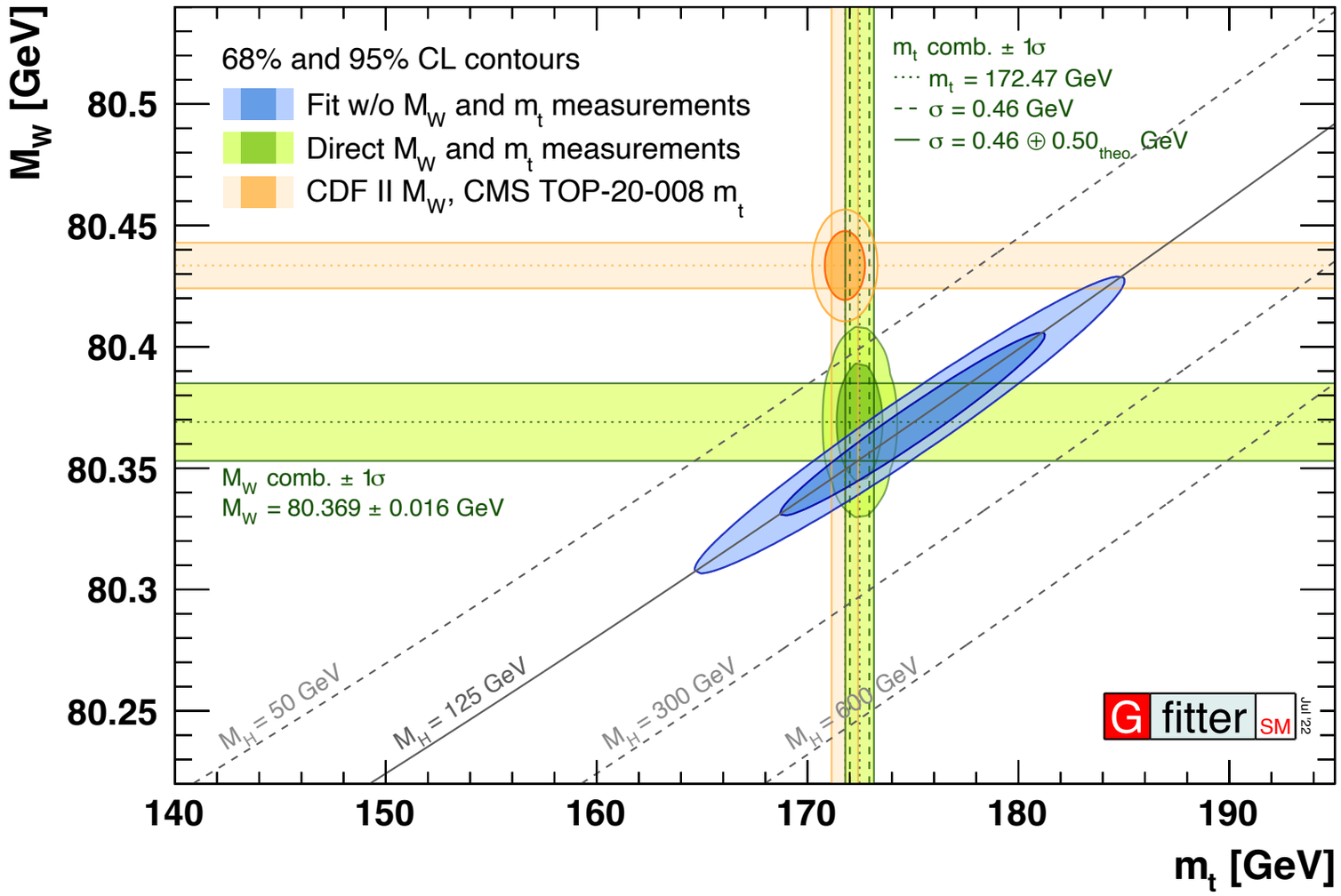
m_t preferred higher (174.07 GeV)

$\alpha_s(M_Z)$ preferred low (0.1155)



Summary

- SM very consistent using M_W from LEP+LHC
- Need to resolve tension with CDF II M_W experimentally
- Looking forward to m_t and M_W combinations from Collaborations



We cannot know M_W and $\sin^2\theta^l_{eff}$ precisely enough

(theoretically and experimentally)

G fitter www.cern.ch/gfitter

Additional Material

Effective Weak Mixing Angle

Private combination of $\sin^2(\theta^\ell_{\text{eff}})$ measurements:

+ Tevatron combination [1801.06283]
+ ATLAS 8 TeV (ATLAS-CONF-2018-037)
+ CMS 8 TeV [1806.00863]
+ LHCb 7+8 TeV [1509.07645]

Assumptions

Correlate PDF unc: 100% between ATLAS/CMS
50% between Tev/ATLAS-CMS
50% between LHCb/ATLAS-CMS
30% between Tev/LHCb

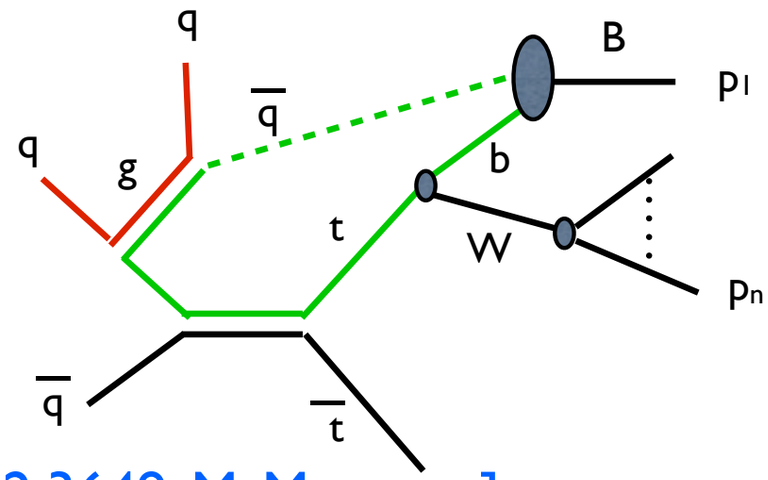
$$\mathbf{\sin^2(\theta^\ell_{\text{eff}}) = 0.23141 \pm 0.00026} \quad (\chi^2/\text{ndf} = 0.74/3)$$

Uncertainty of 0.00028 for fully correlated PDF uncertainties, 0.00022 for no correlation

Theoretical Uncertainties

- estimated using a geometric series ($a_n = a\, r^n$), example: $\mathcal{O}(\alpha^2\alpha_s) = \frac{\mathcal{O}(\alpha^2)}{\mathcal{O}(\alpha)}\,\mathcal{O}(\alpha\alpha_s)$
  - similar results from scale variations
- reasonable estimates for all observables
- exception: m_t !

$$M^2_{exp} = \left(\sum_{i=1,\ldots,n} p_i\right)^2$$



[A. Hoang arXiv:1412.3649, M. Mangano]

- kin definition, relation to m^{pole} unknown
- uncertainties from colour structure, hadronisation and $m^{pole} \rightarrow m_t(m_t)$ smaller

important

Observable	Exp. error	Theo. error
M_W	15 MeV	4 MeV
$\sin^2\theta^l_{\text{eff}}$	$1.6 \cdot 10^{-4}$	$0.5 \cdot 10^{-4}$
Γ_Z	2.3 MeV	0.5 MeV
σ^0_{had}	37 pb	6 pb
R^0_b	$6.6 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$
m_t	0.76 GeV	0.5 GeV

- 10 additional free parameters, Gaussian likelihood
- important missing higher order terms:
  - $O(\alpha^2\alpha_s)$, $O(\alpha\alpha_s^2)$, $O(\alpha^2_{bos})$ (in some cases), $O(\alpha^3)$, $O(\alpha_s^5)$ (rad. functions)

SM Fit

Parameter	Input value	Free in fit	Fit Result	w/o exp. input in line	w/o exp. input in line, no theo. unc
M_H [GeV]	125.1 ± 0.2	yes	$125.1^{+0.2}_{-0.2}$	$99.5^{+25.2}_{-21.0}$	$99.5^{+23.7}_{-20.0}$
M_W [GeV]	80.369 ± 0.016	–	80.356 ± 0.006	80.354 ± 0.007	80.353 ± 0.005
Γ_W [GeV]	2.085 ± 0.042	–	2.091 ± 0.001	2.091 ± 0.001	2.091 ± 0.001
M_Z [GeV]	91.1875 ± 0.0021	yes	91.1878 ± 0.0021	91.1956 ± 0.0105	91.1959 ± 0.0100
Γ_Z [GeV]	2.4952 ± 0.0023	–	2.4948 ± 0.0014	2.4943 ± 0.0016	2.4942 ± 0.0016
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	–	41.482 ± 0.015	41.472 ± 0.016	41.472 ± 0.015
R^0_ℓ	20.767 ± 0.025	–	20.745 ± 0.017	20.727 ± 0.026	20.726 ± 0.026
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	–	0.01619 ± 0.0001	0.01618 ± 0.0001	0.01617 ± 0.0001
A_ℓ $^{(\star)}$	0.1499 ± 0.0018	–	0.1469 ± 0.0005	0.1469 ± 0.0005	0.1468 ± 0.0003
$\sin^2\theta^\ell_{\rm eff}(Q_{\rm FB})$	0.2324 ± 0.0012	–	0.23154 ± 0.00006	0.23153 ± 0.00006	0.23154 ± 0.00004
$\sin^2\theta^\ell_{\rm eff}({\rm Tev}+{\rm LHC})$	0.23141 ± 0.00026	–	0.23154 ± 0.00006	0.23154 ± 0.00006	0.23155 ± 0.00004
A_c	0.670 ± 0.027	–	0.6678 ± 0.00021	0.6678 ± 0.00021	0.6678 ± 0.00014
A_b	0.923 ± 0.020	–	0.93475 ± 0.00004	0.93475 ± 0.00004	0.93474 ± 0.00002
$A^{0,c}_{\rm FB}$	0.0707 ± 0.0035	–	0.0736 ± 0.0003	0.0736 ± 0.0003	0.0736 ± 0.0002
$A^{0,b}_{\rm FB}$	0.0992 ± 0.0016	–	0.1030 ± 0.0003	0.1031 ± 0.0003	0.1030 ± 0.0002
R^0_c	0.1721 ± 0.0030	–	$0.17225^{+0.00009}_{-0.00008}$	0.17225 ± 0.00008	0.17225 ± 0.00006
R^0_b	0.21629 ± 0.00066	–	0.21582 ± 0.00011	0.21581 ± 0.00011	0.21581 ± 0.00004
$\overline{m}_c$ [GeV]	$1.27^{+0.07}_{-0.11}$	yes	$1.27^{+0.07}_{-0.11}$	–	–
$\overline{m}_b$ [GeV]	$4.20^{+0.17}_{-0.07}$	yes	$4.20^{+0.17}_{-0.07}$	–	–
m_t [GeV]$^{(\triangledown)}$	172.47 ± 0.68	yes	172.67 ± 0.65	$175.15^{+2.37}_{-2.39}$	$175.17^{+2.30}_{-2.32}$
$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$ $^{(\dagger\triangle)}$	2761 ± 9	yes	2759 ± 10	2728 ± 39	2728 ± 37
$\alpha_s(M_Z^2)$	–	yes	$0.1198^{+0.0030}_{-0.0029}$	0.1198 ± 0.0030	0.1199 ± 0.0028

$^{(\star)}$Average of LEP ($A_\ell = 0.1465 \pm 0.0033$) and SLD ($A_\ell = 0.1513 \pm 0.0021$) measurements, used as two measurements in the fit. The fit w/o the LEP (SLD) measurement gives $A_\ell = 0.1469 \pm 0.0005$ ($A_\ell = 0.1467 \pm 0.0005$). $^{(\triangledown)}$Combination of experimental (0.46 GeV) and theory uncertainty (0.5 GeV).$^{(\dagger)}$In units of 10^{-5}. $^{(\triangle)}$Rescaled due to α_s dependency.

χ^2 / ndf = 16.62 / 15
p-value = 0.34

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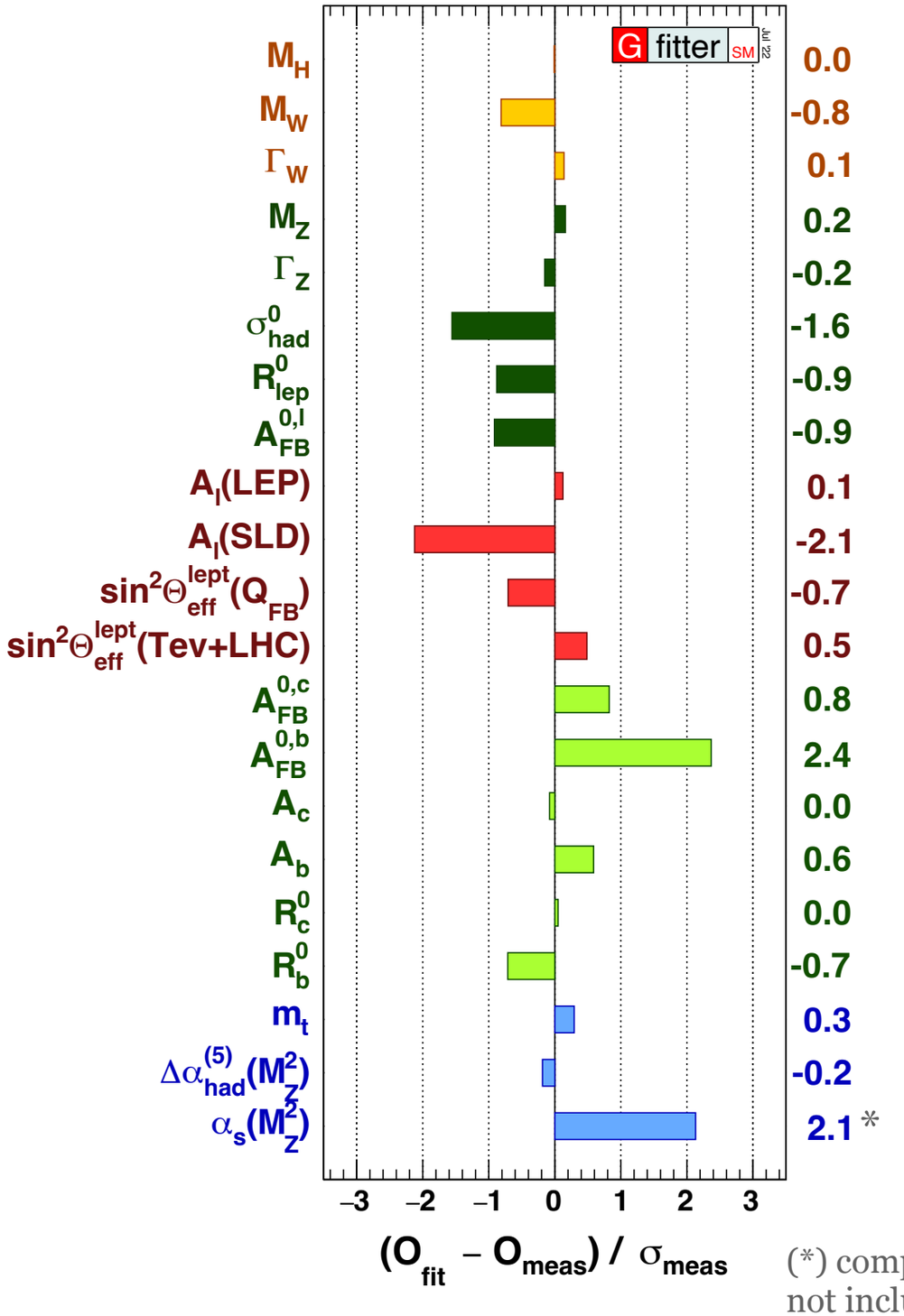
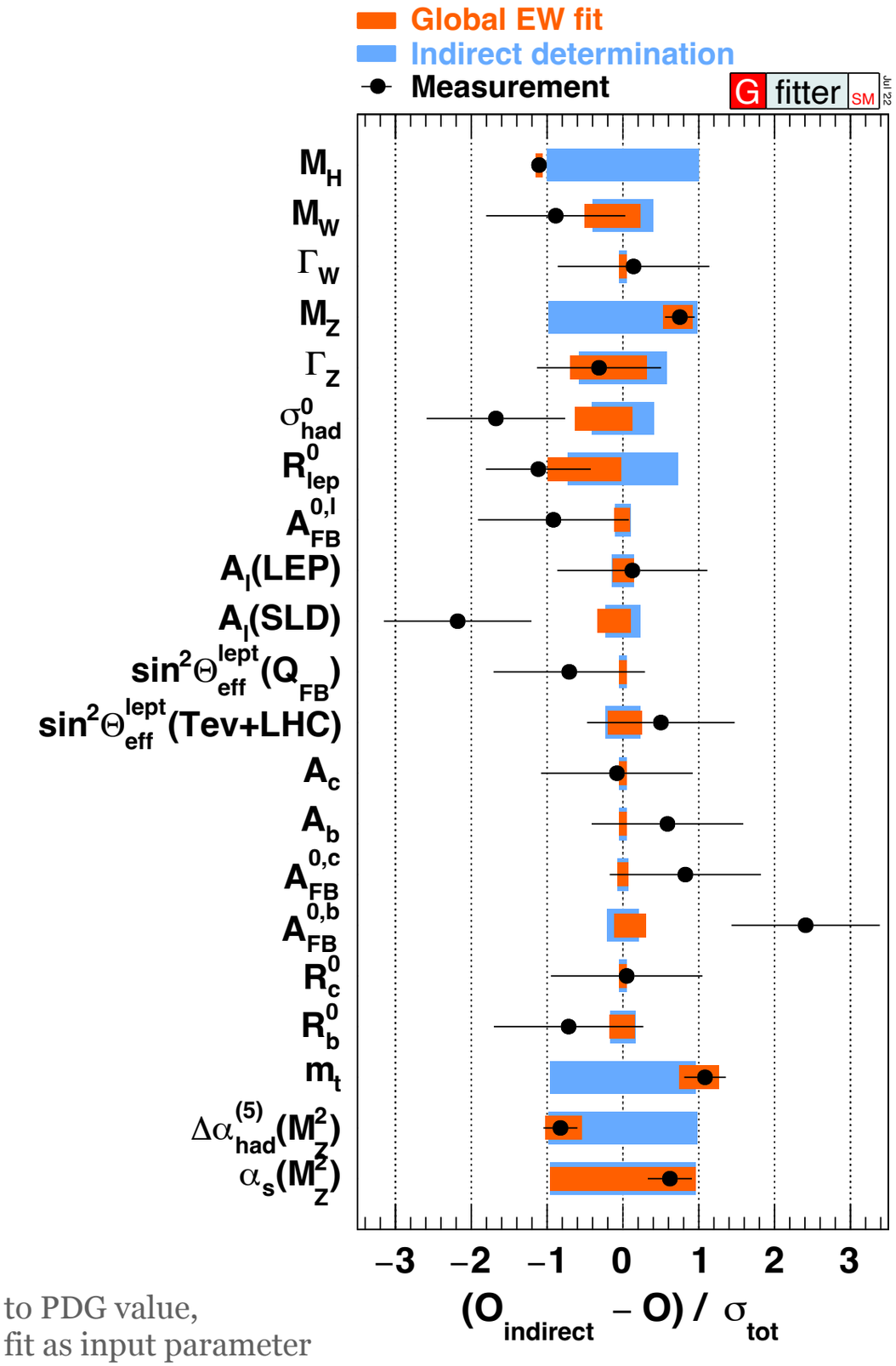
p-value = 0.34

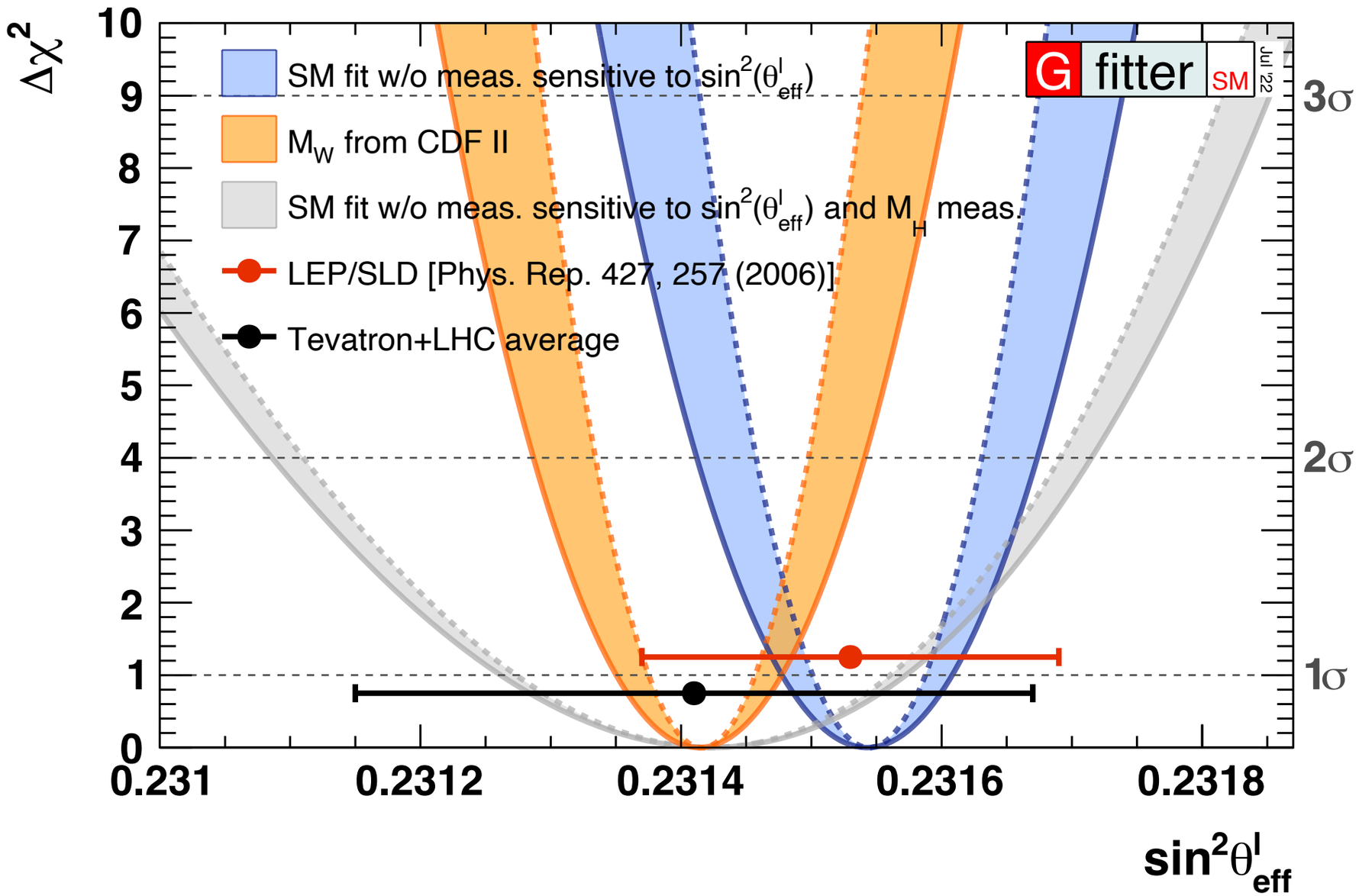
SM Fit





(*) comparison to PDG value,
not included in fit as input parameter

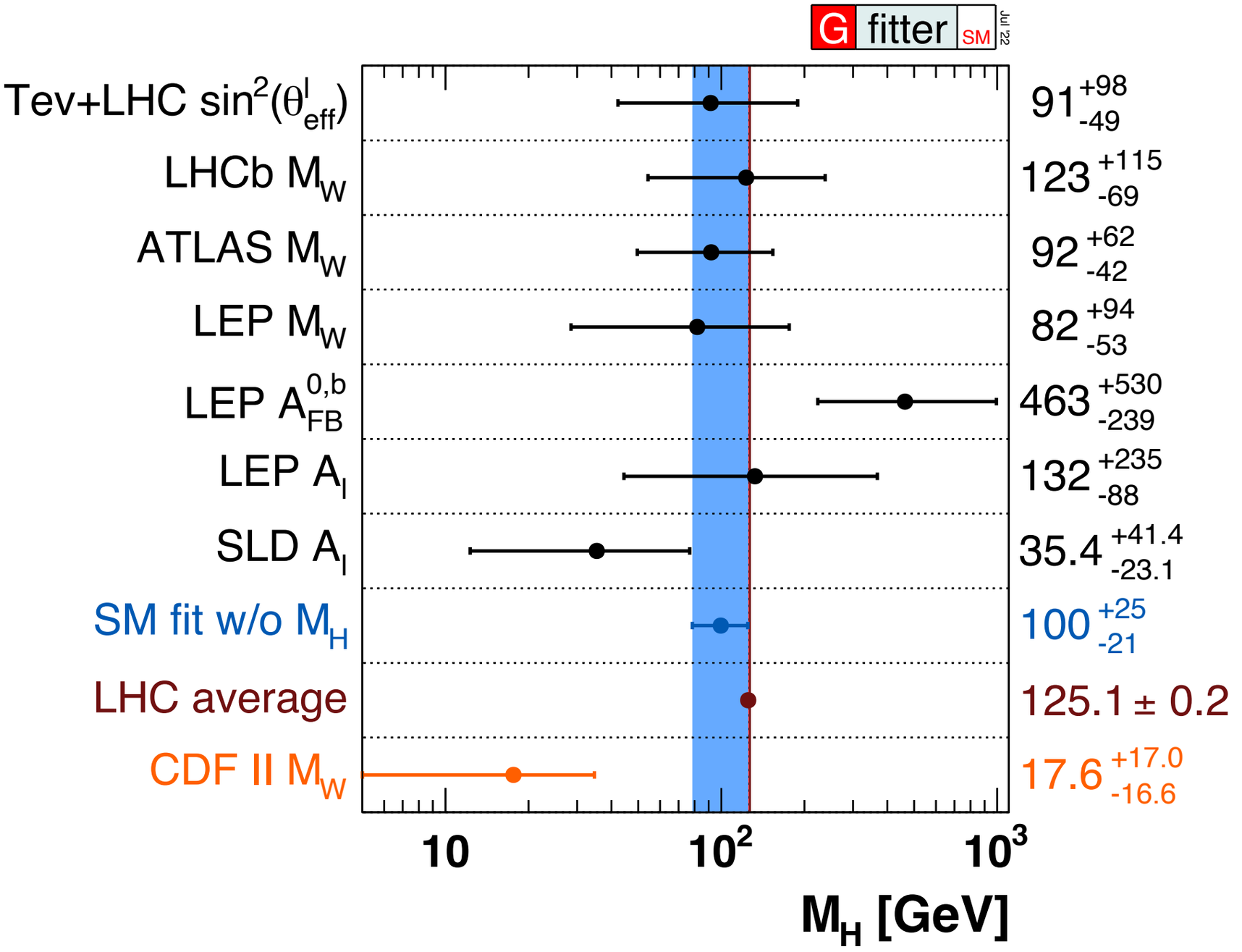
Effective Weak Mixing Angle



Impact of CDF II W mass not as large

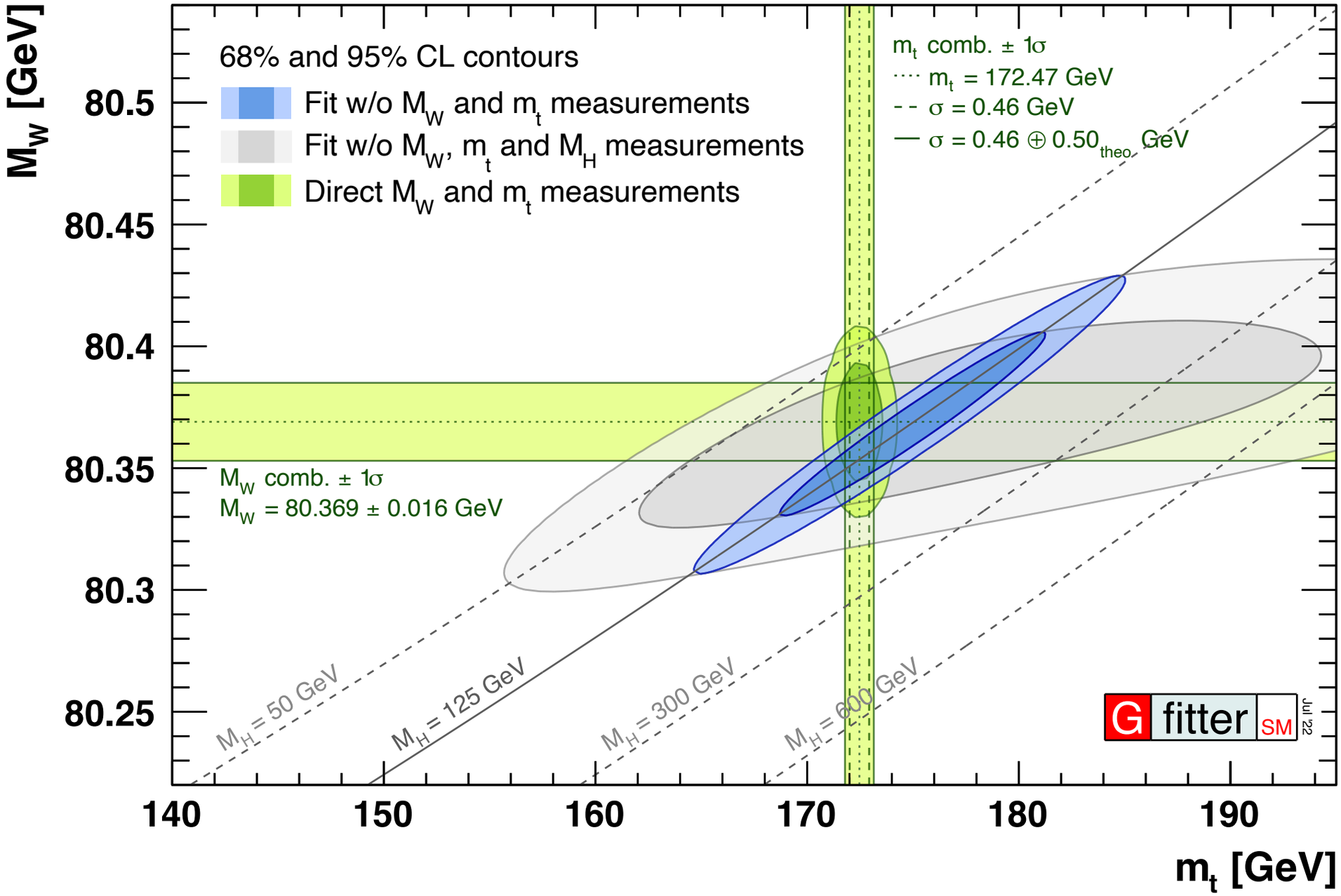
- Predictions compatible with Tev/LHC and LEP/SLD averages within 1σ

M_H Main Observables



CDF II M_W results in low Higgs Mass: $M_H < 47$ GeV @ 95% CL

M_W and m_t


68% and 95% CL contours
Fit w/o M_W and m_t measurements
Fit w/o M_W, m_t and M_H measurements
Direct M_W and m_t measurements
m_t comb. ± 1σ
m_t = 172.47 GeV
σ = 0.46 GeV
σ = 0.46 ⊕ 0.50$_{theo}$ GeV
M_W comb. ± 1σ
M_W = 80.369 ± 0.016 GeV
M_H = 50 GeV
M_H = 125 GeV
M_H = 300 GeV
M_H = 600 GeV
G fitter SM
Jul 22
M_W [GeV]
80.5
80.45
80.4
80.35
80.3
80.25
140
150
160
170
180
190
m_t [GeV]

M_W and $\sin^2\theta^{\ell}_{eff}$