https://arxiv.org/abs/2112.07274

https://arxiv.org/abs/2204.04204

Global analysis of electroweak data in the Standard Model and beyond

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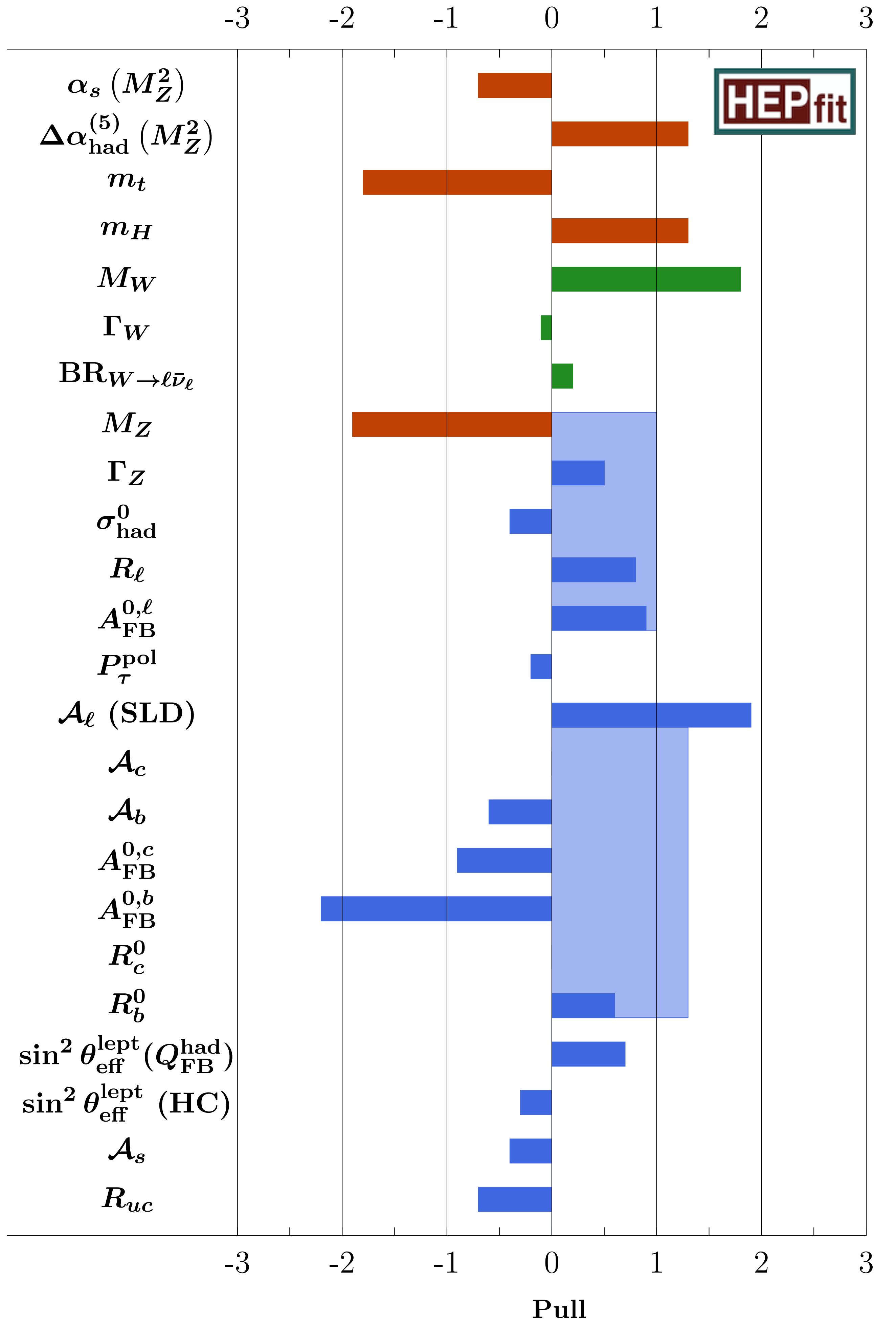
in collaboration with J. de Blas, M. Ciuchini, E. Franco, A. Goncalves, S. Mishima, L. Reina, L. Silvestrini
on behalf of the HEPfit collaboration

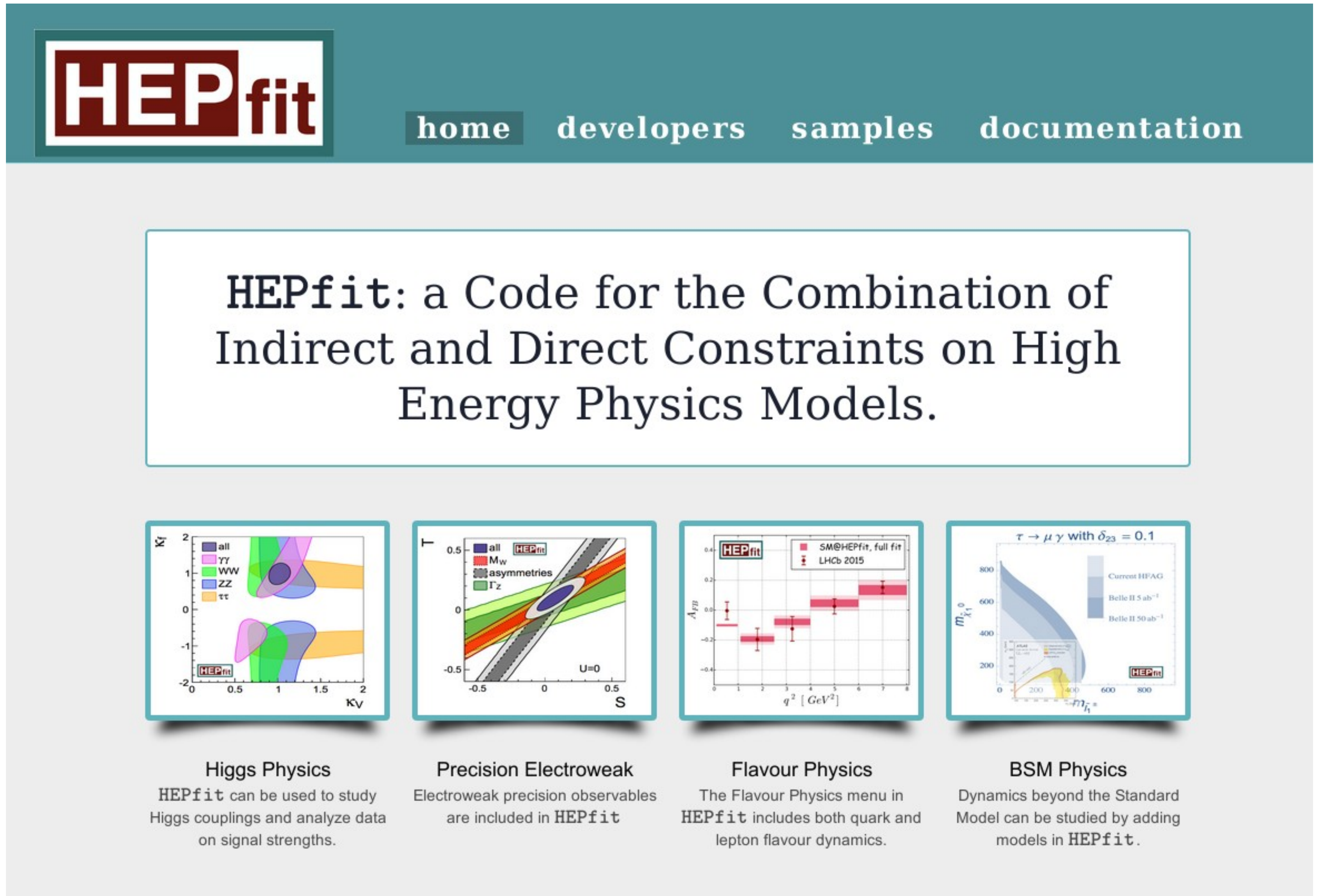
The Electroweak fit

- Exploit the over-constrained EW sector (dictated by rigid symmetry structure) to perform consistency tests of the SM with EW precision observables
  - Set of input parameters (α scheme): GF, α, m_Z, m_H, m_t, $\alpha_S(m_Z)$, $\Delta\alpha_{had}^{(5)}$
  - Compute EW precision observables as functions of these quantities
    - Z-pole observables
    - W observables
  - Compare computations to experimental data to learn the values of the input quantities
  - Extend relations to include BSM effects and determine bounds on New Physics
    - Oblique parameters: S, T, U, …
    - Effective interactions: SMEFT
    - …



The HEPfit library

- Open source library to perform combined fits of HEP observables (including EWfit) in various scenarios
    - Computes EWPO in SM, SMEFT, several kinds of 2HDM, some SUSY (mostly LFV), etc.
    - Allows for Bayesian analysis exploiting MCMC via the **Bayesian Analysis Toolkit**
- Why a Bayesian fit if we have several others based on likelihood-ratios?
    - Answer 1: Why not?
    - Answer 2: when conclusions depend on the statistical approach, there are no solid conclusions
    - Answer 3: because HEPfit is more than an EWfit tool



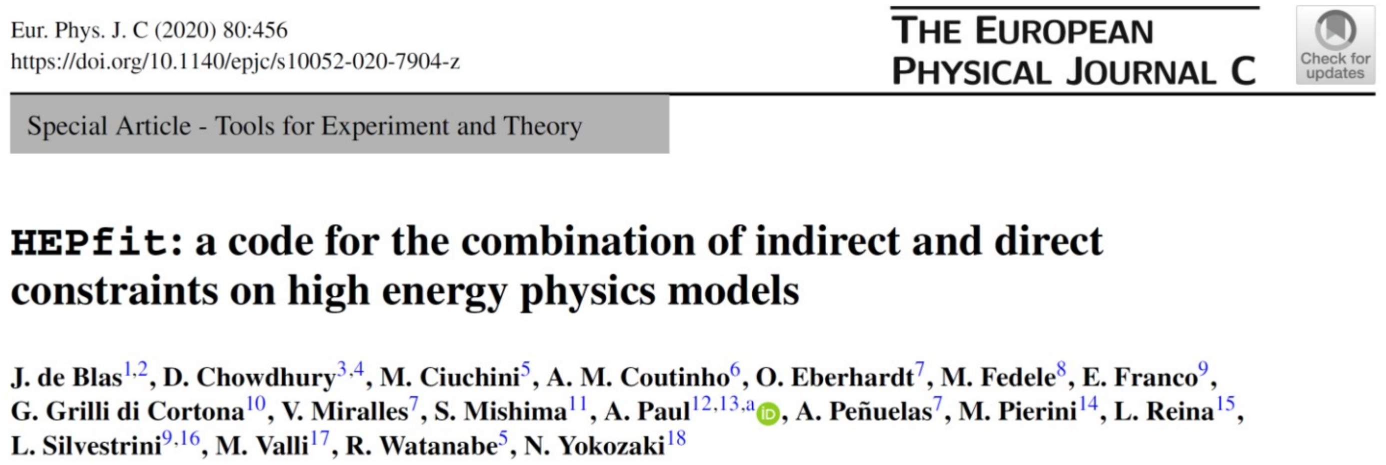
HEPfit: a Code for the Combination of Indirect and Direct Constraints on High Energy Physics Models.

Higgs Physics
HEPfit can be used to study Higgs couplings and analyze data on signal strengths.

Precision Electroweak
Electroweak precision observables are included in HEPfit

Flavour Physics
The Flavour Physics menu in HEPfit includes both quark and lepton flavour dynamics.

BSM Physics
Dynamics beyond the Standard Model can be studied by adding models in HEPfit.



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THE EUROPEAN PHYSICAL JOURNAL C

Special Article - Tools for Experiment and Theory

HEPfit: a code for the combination of indirect and direct constraints on high energy physics models

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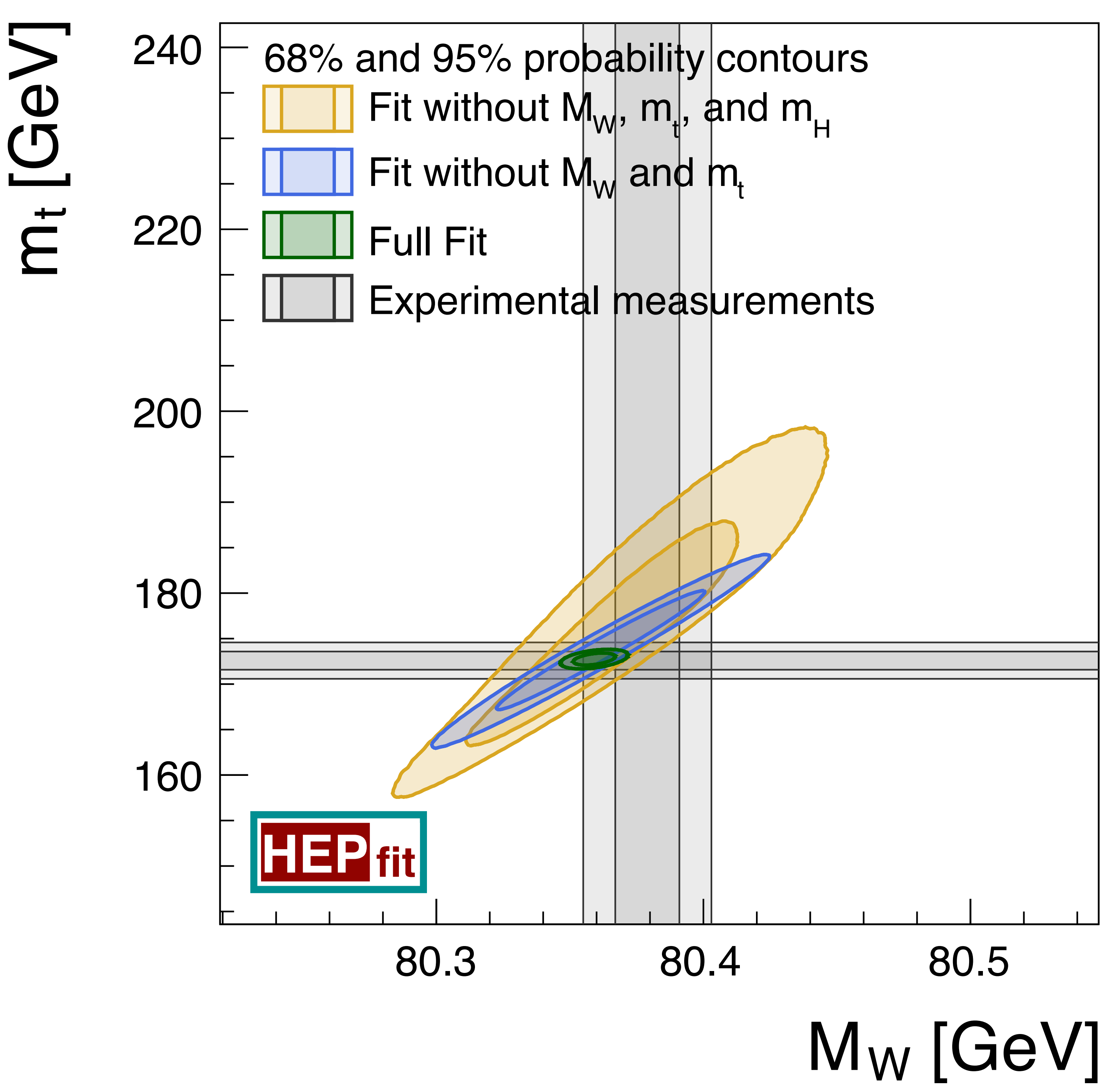
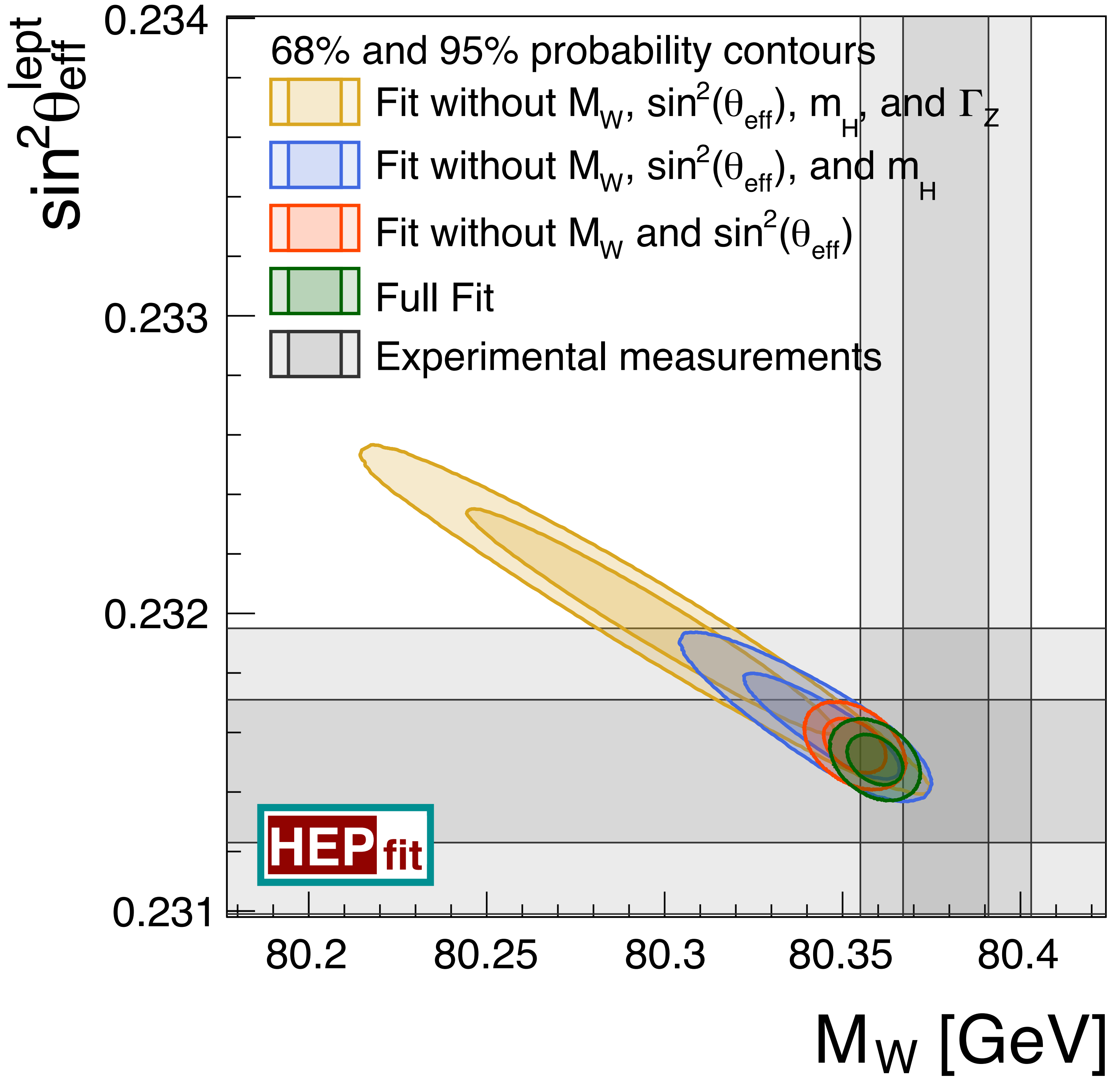
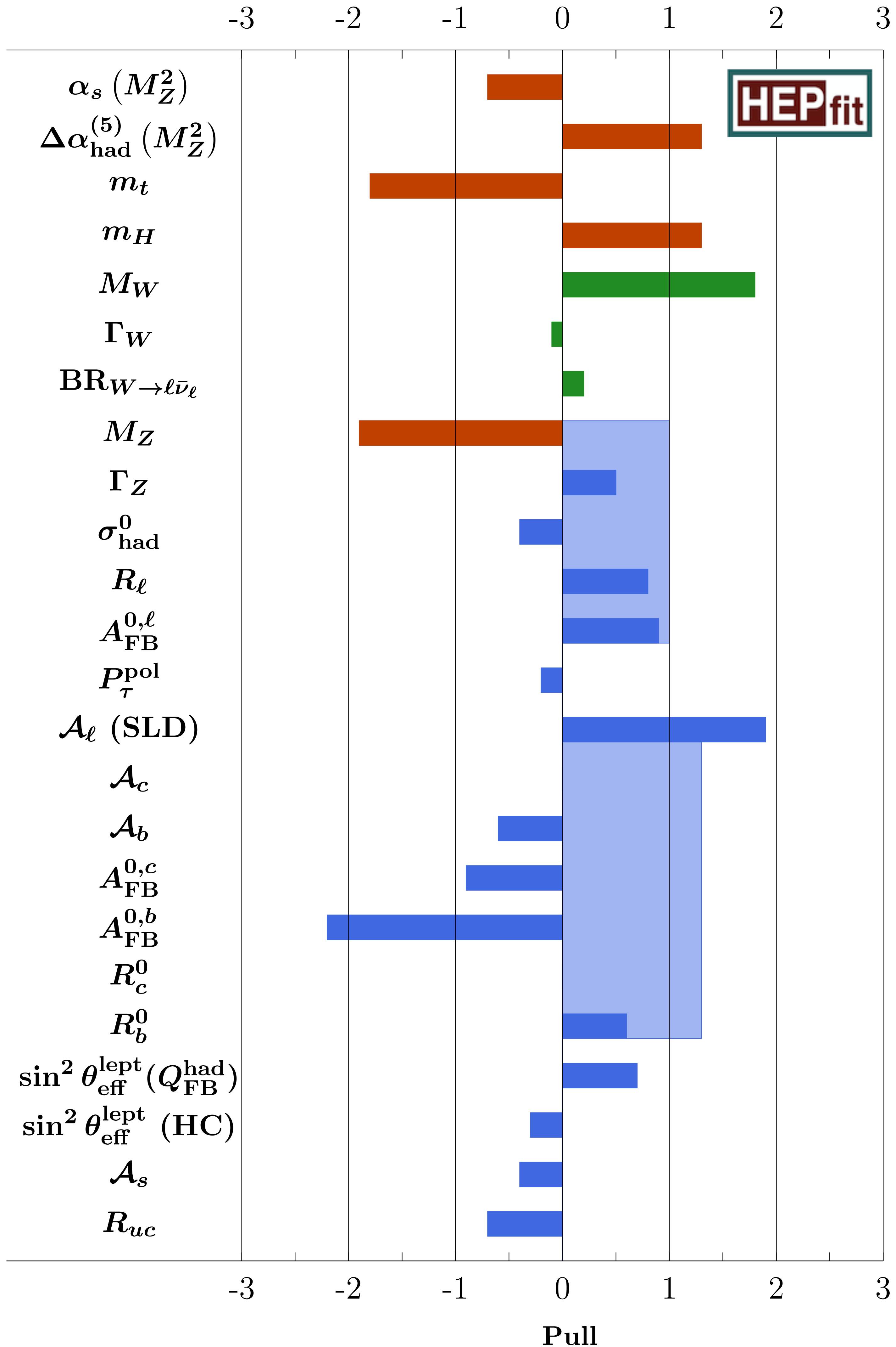
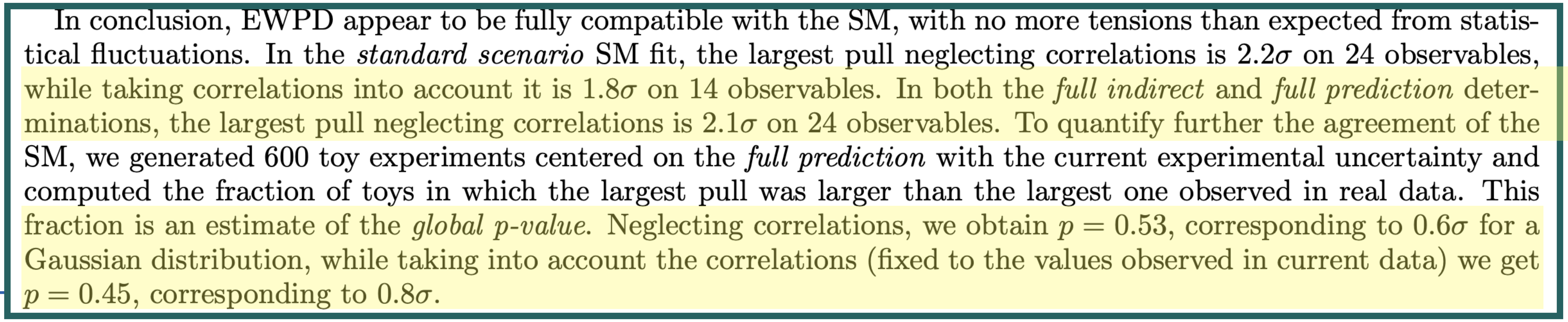
https://arxiv.org/abs/1910.14012

Fit result @Fall 2021





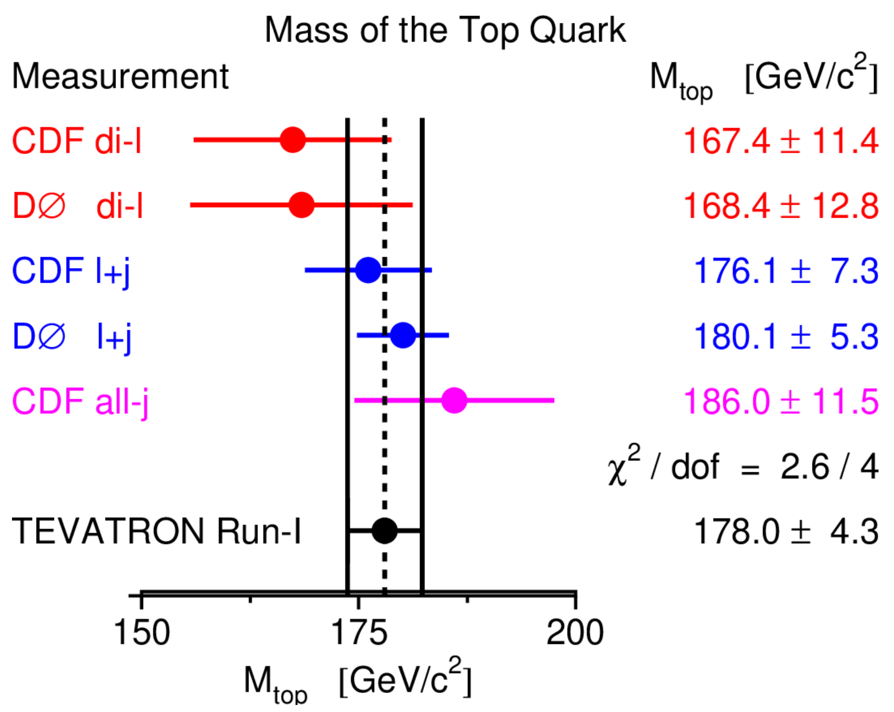


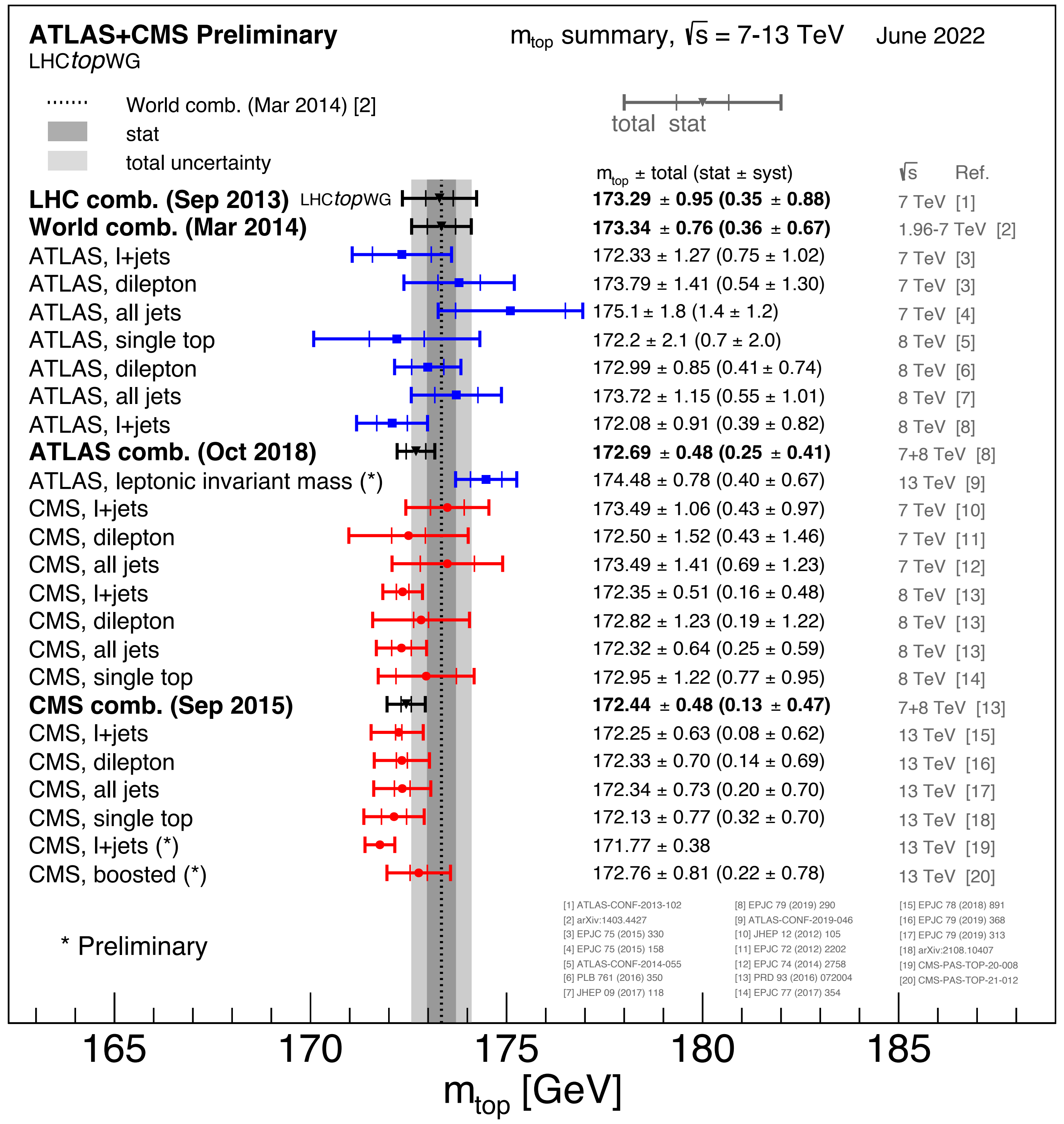


In conclusion, EWPD appear to be fully compatible with the SM, with no more tensions than expected from statistical fluctuations. In the *standard scenario* SM fit, the largest pull neglecting correlations is 2.2σ on 24 observables, while taking correlations into account it is 1.8σ on 14 observables. In both the *full indirect* and *full prediction* determinations, the largest pull neglecting correlations is 2.1σ on 24 observables. To quantify further the agreement of the SM, we generated 600 toy experiments centered on the *full prediction* with the current experimental uncertainty and computed the fraction of toys in which the largest pull was larger than the largest one observed in real data. This fraction is an estimate of the *global p-value*. Neglecting correlations, we obtain $p = 0.53$, corresponding to 0.6σ for a Gaussian distribution, while taking into account the correlations (fixed to the values observed in current data) we get $p = 0.45$, corresponding to 0.8σ.

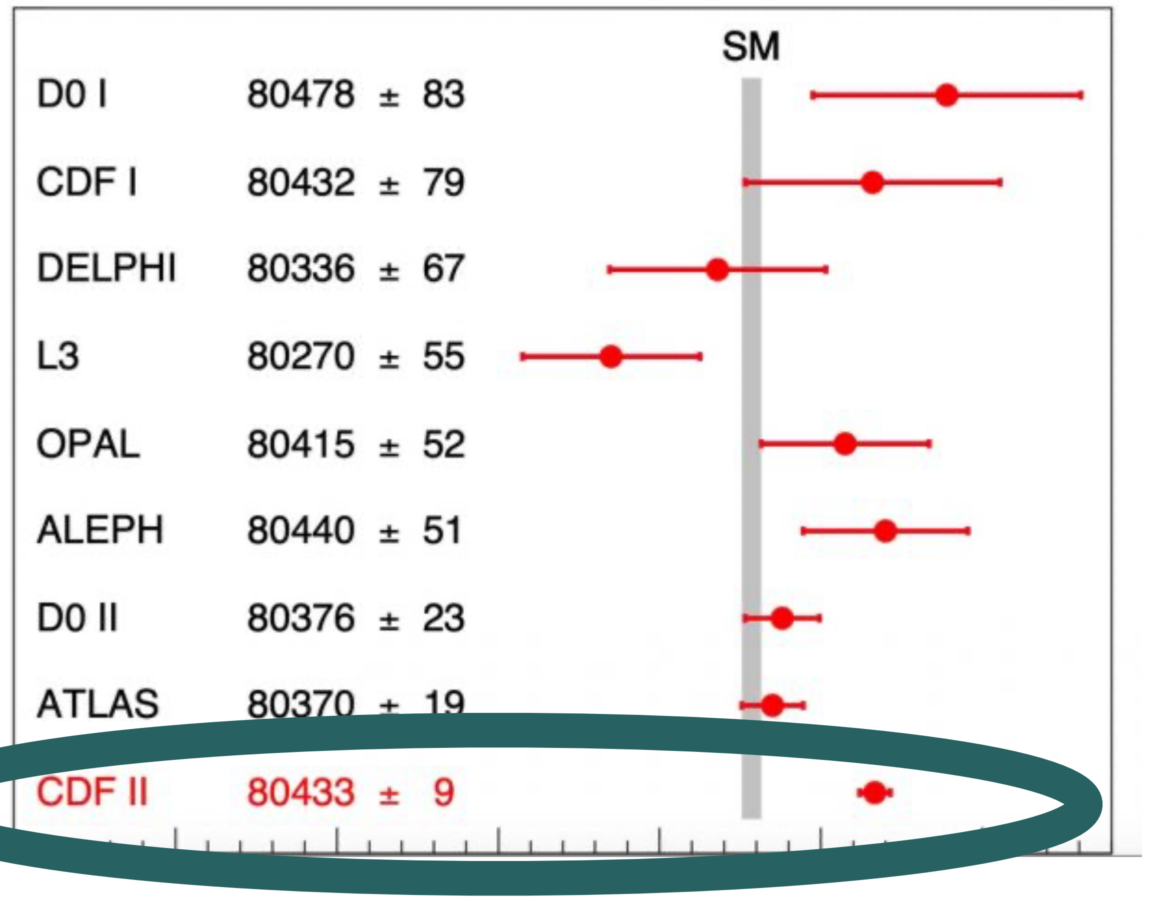
New precision reached, with some question mark

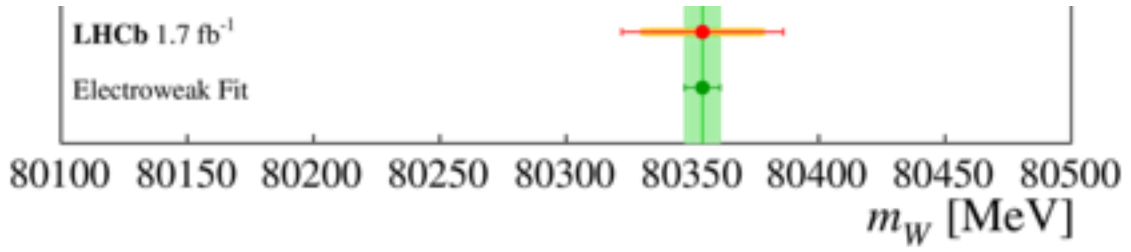
- ◉ To which extent are these new measurements compatible to previous measurements?
  - ➡Not addressed here
  - ➡This is up to the experimental collaborations to establish (see talk by S. Amoroso)





- ◉ Assuming that they are, can we learn something about New Physics
  - ➡ Oblique correction scheme (S,T,U, etc.)
  - ➡ SMEFT





Fit setup adding new measurements

- Input parameters $\underbrace{\alpha,\ G_F}_{\text{fixed}},\alpha_s(M_Z),\ M_Z,\ M_H,\ m_t,\ \Delta\alpha_{had}^{(5)}$
- Observables from LEP, Tevatron, and LHC
- Recent changes
  - new top mass
    - 2016 Tevatron combination
    - ATLAS Run 1 and Run2 results
    - CMS Run 1 and Run 2 results
    - Recent CMS l+j measurement [m_t=(171.77±0.38) GeV]

before

after

Theory intrinsic uncertainties on input parameters

$\delta_{th}M_W$ = 4 MeV , $\delta_{th}\sin^2 q_W = 5 \times 10^{-5}$

$\delta_{th}\Gamma_Z$ = 0.4 MeV, $\delta_{th}\sigma^0_{had}$ = 6 pb

$\delta_{th}R^0_l$ = 0.006, $\delta_{th}R^0_c$ = 0.00005

$\delta_{th}R^0b$ = 0.0001

details on backup

previous average

m_t=172.58 ±0.45 GeV

→

new average

m_t=171.79 ± 0.38 GeV

"standard"

new average

m_t=171.79 ±1.00 GeV

"conservative"

Waiting for official Tevatron+LHC averages to be released

Fit setup adding new measurements

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$\delta_{th}R^0 b = 0.0001$

- Recent changes
  - new W mass
    - All LEP 2 measurements D0 measurement
    - ~~Previous Tevatron average~~
    - ATLAS and LHCb measurements
    - Recent CDF measurement [M_W=(80.4335±0.0094) GeV]

before

after

Using the PDG rescaling prescription

previous average
$M_W = 80.379 \pm 0.012$ GeV ⟶

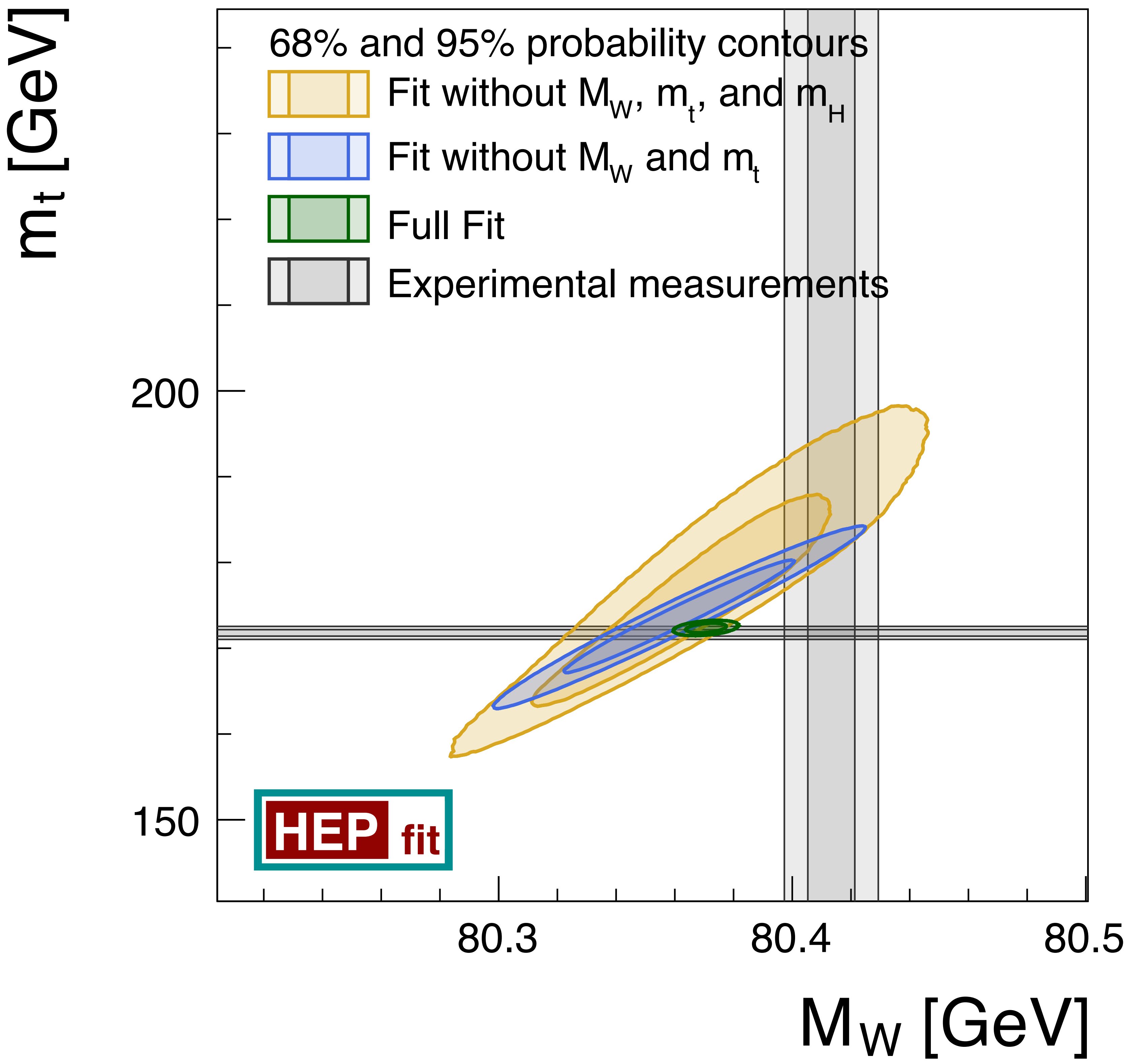
new average
$M_W = 80.4133 \pm 0.0088$ GeV
“standard”

new average
$M_W = 80.4133 \pm 0.015$ GeV
“conservative”

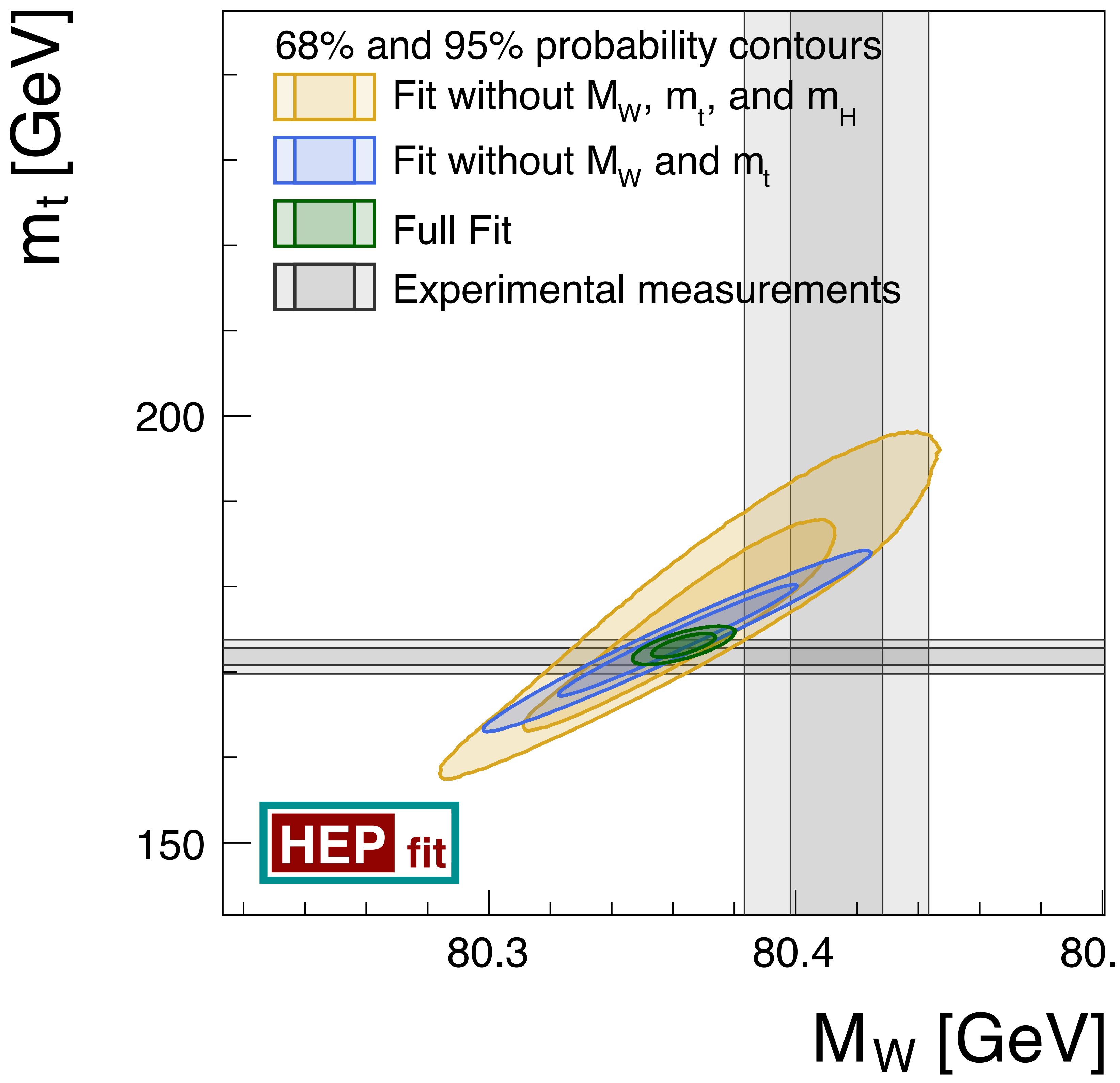
Waiting for official Tevatron+LHC averages to be released

Impact of the new m_W and m_t measurements

Model	Pred. M_W [GeV] *standard average*	Pull	Pred. M_W [GeV] *conservative average*	Pull
SM	80.3499 ± 0.0056	$6.5\,\sigma$	80.3505 ± 0.0077	$3.7\,\sigma$



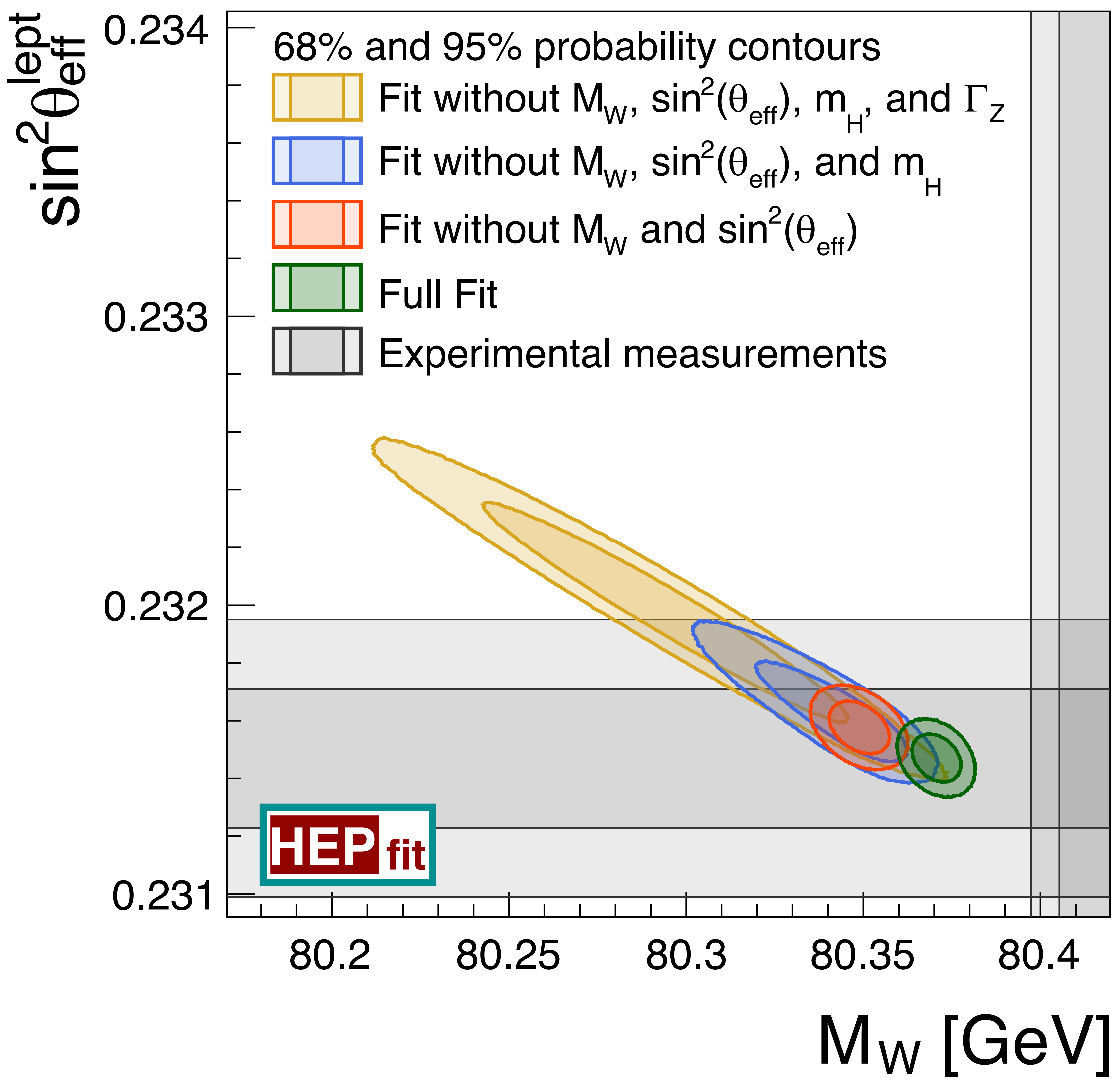
“standard” scenario



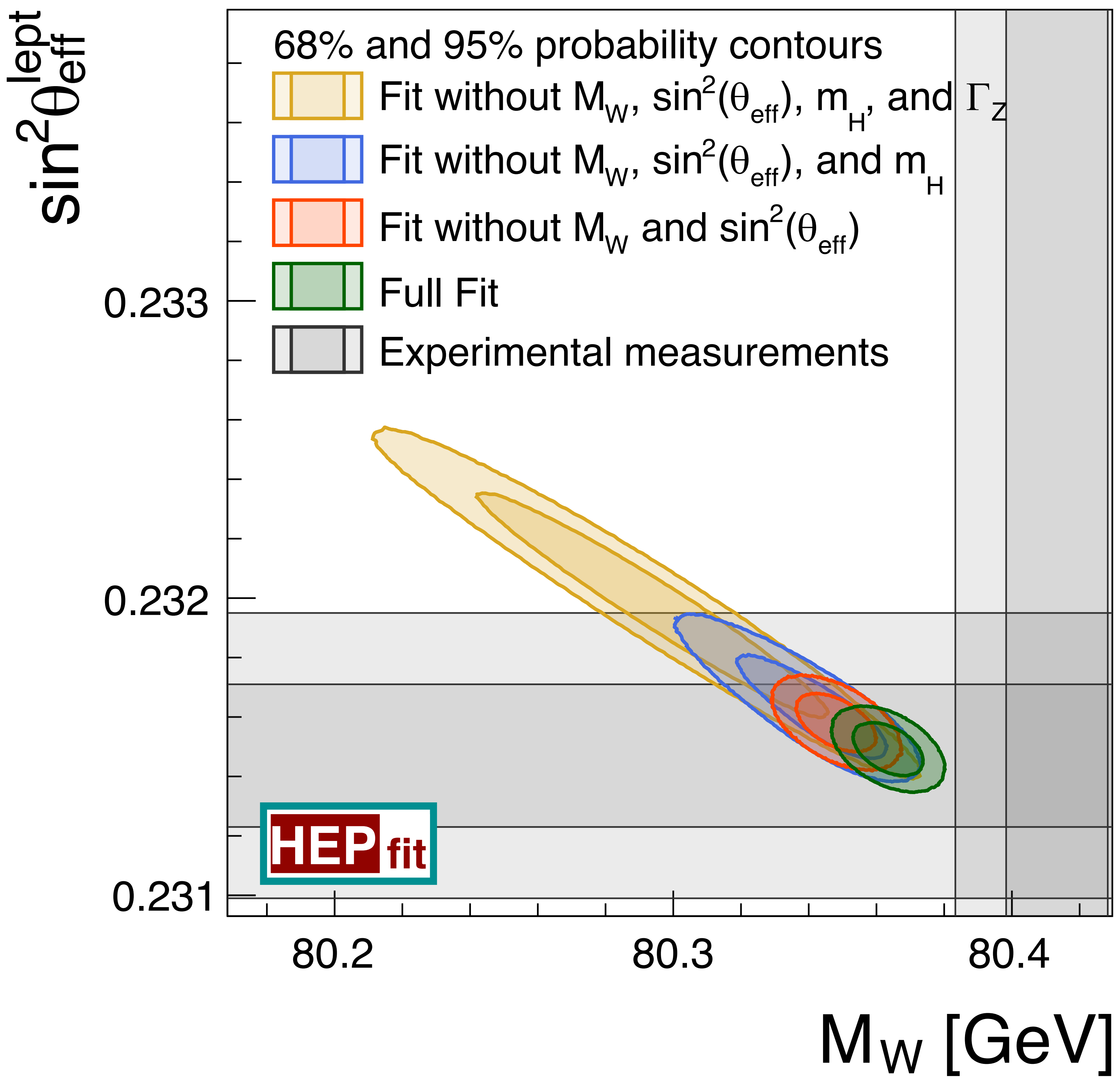
“conservative” scenario

Impact of the new m_W and m_t measurements

Model	Pred. M_W [GeV]	Pull	Pred. M_W [GeV]	Pull
	standard average		*conservative average*	
SM	80.3499 ± 0.0056	$6.5\,\sigma$	80.3505 ± 0.0077	$3.7\,\sigma$



"standard" scenario



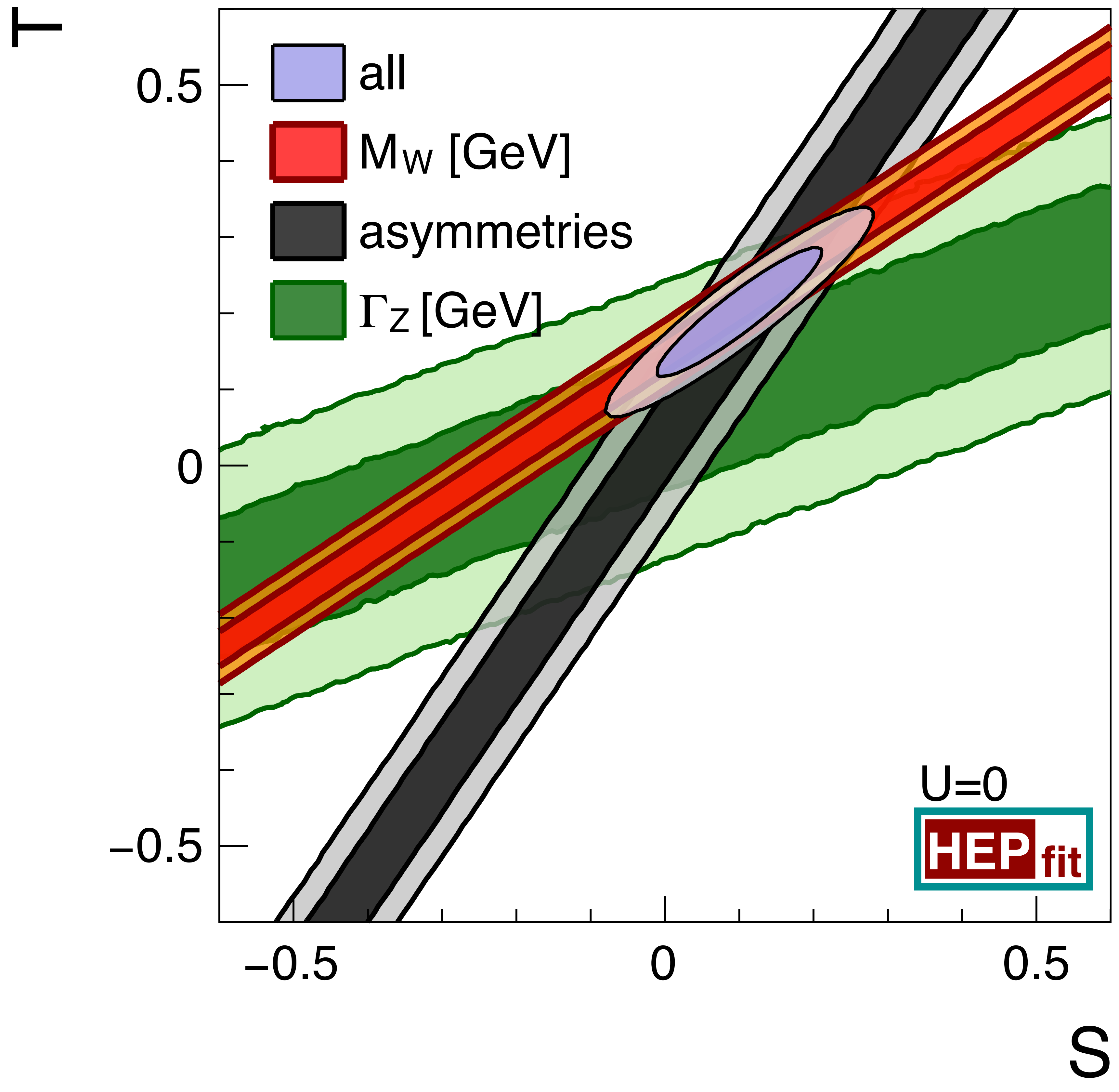
"conservative" scenario

Fitting Oblique Corrections: S, T (with U=0)

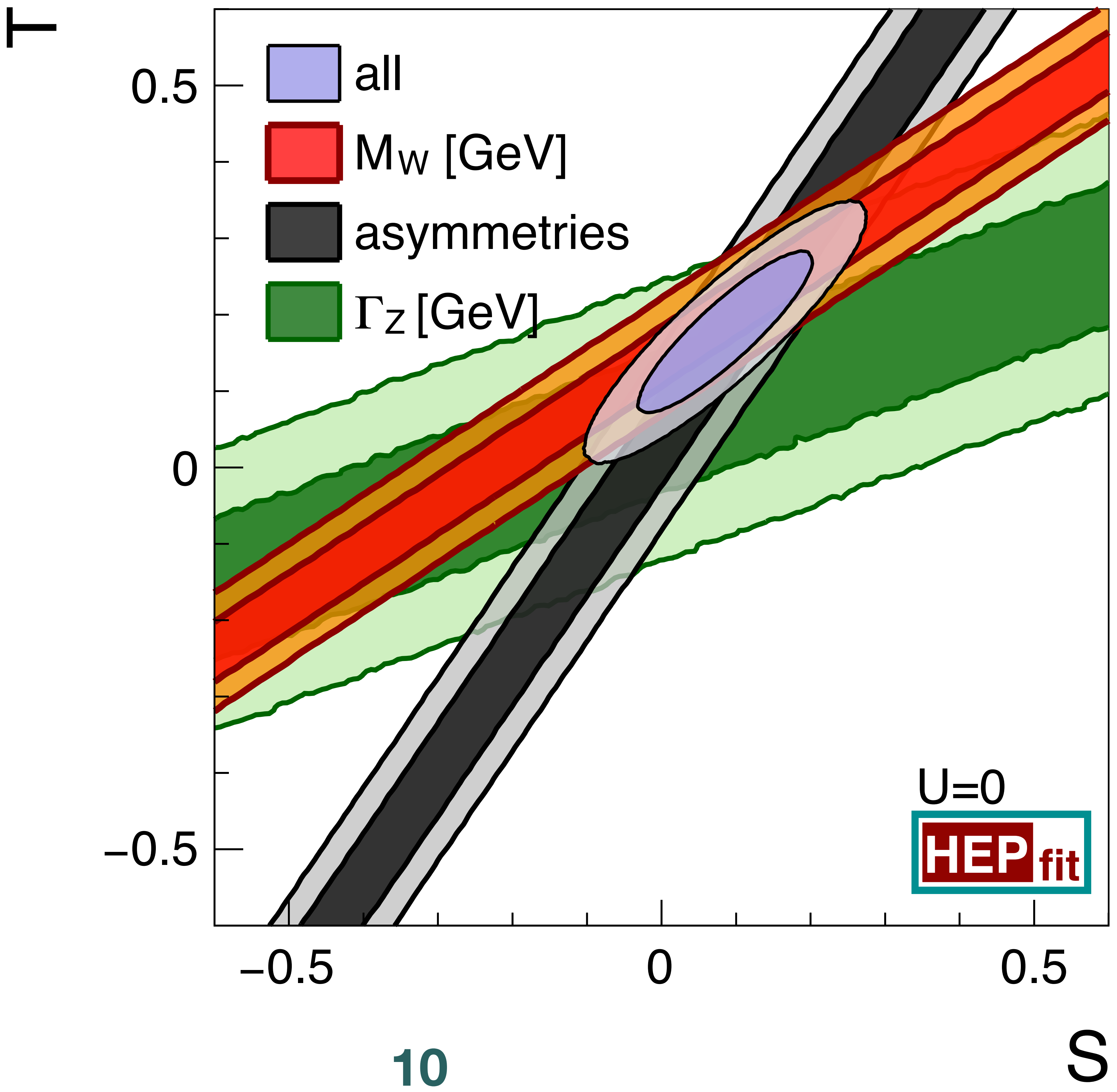
A large T value can compensate for the W mass, reducing the fit pull close to 1σ

Model	Pred. M_W [GeV]	Pull	Pred. M_W [GeV]	Pull
	standard average		*conservative average*	
SM	80.3499 ± 0.0056	$6.5\,\sigma$	80.3505 ± 0.0077	$3.7\,\sigma$
ST	80.366 ± 0.029	$1.6\,\sigma$	80.367 ± 0.029	$1.4\,\sigma$

“standard” scenario



“conservative” scenario



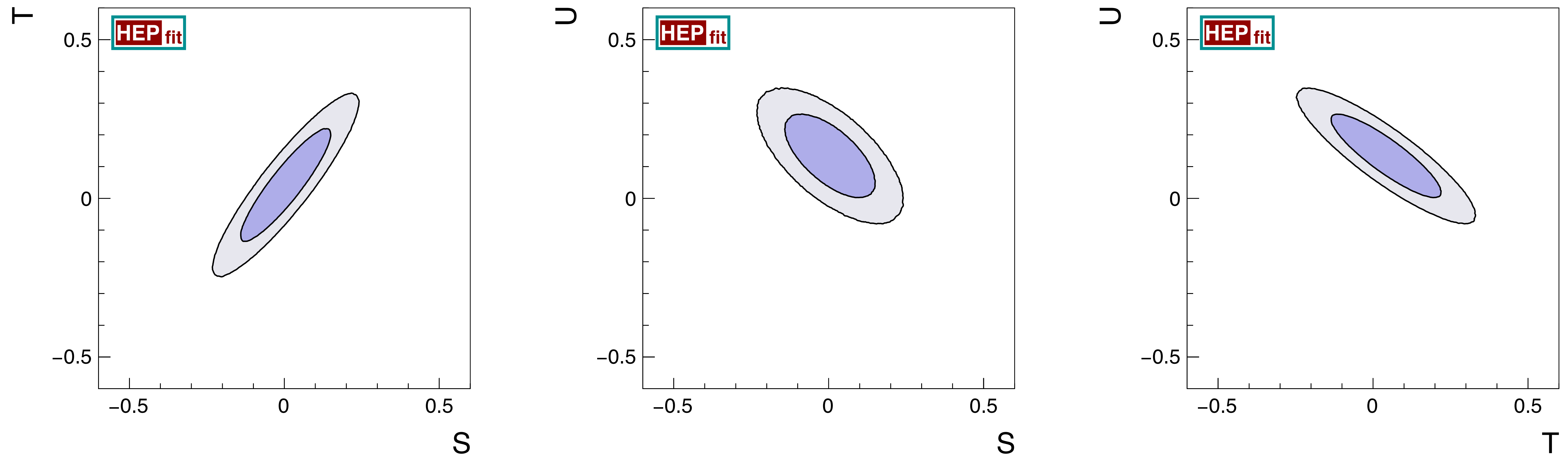
	Result	Correlation	
	$(\mathrm{IC}_{\mathrm{ST}}/\mathrm{IC}_{\mathrm{SM}} = 25.0/80.2)$		
S	0.100 ± 0.073	1.00	
T	0.202 ± 0.056	0.93	1.00
U	–	–	–

Fitting Oblique Corrections: S, T, U

A large U value can compensate for the W mass, without pulling S and T

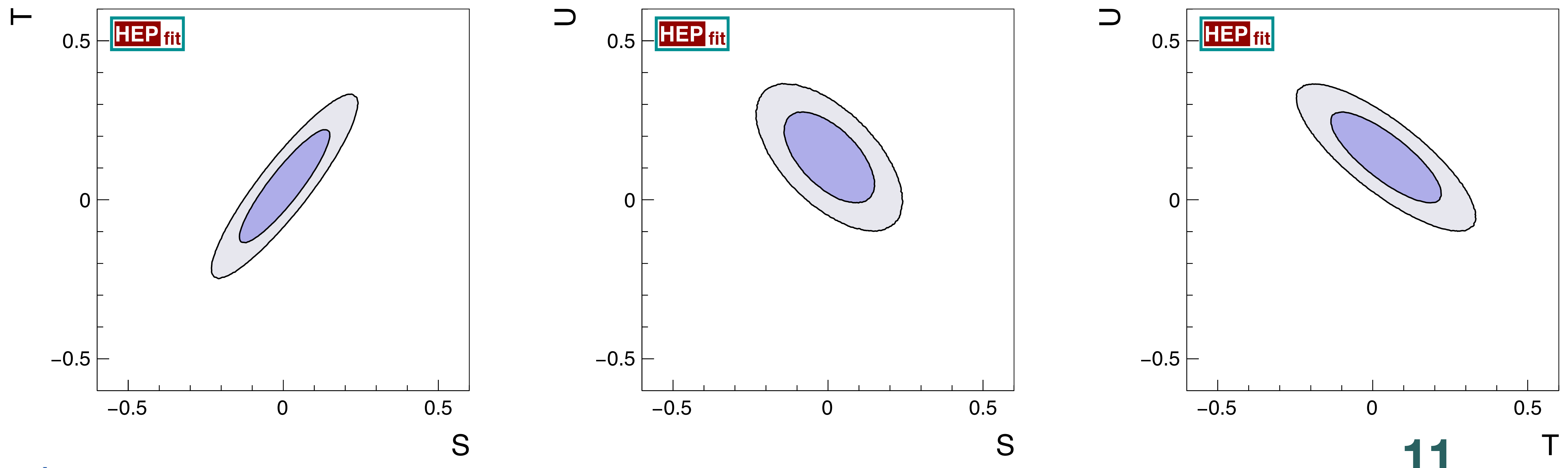
Model	Pred. M_W [GeV]	Pull	Pred. M_W [GeV]	Pull
	standard average		*conservative average*	
SM	80.3499 ± 0.0056	$6.5\,\sigma$	80.3505 ± 0.0077	$3.7\,\sigma$
ST	80.366 ± 0.029	$1.6\,\sigma$	80.367 ± 0.029	$1.4\,\sigma$
STU	80.32 ± 0.54	$0.2\,\sigma$	80.32 ± 0.54	$0.2\,\sigma$

“standard” scenario



Result	Correlation		
$(\mathrm{IC}_{\mathrm{STU}}/\mathrm{IC}_{\mathrm{SM}} = 25.3/80.2)$			
0.005 ± 0.096	1.00		
0.040 ± 0.120	0.91	1.00	
0.134 ± 0.087	−0.65	−0.88	1.00

“conservative” scenario



Beyond Oblique Corrections: SMEFT analysis

$$\mathcal{O}^{(1)}_{\phi l} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{l}_L \gamma^\mu l_L)\ ,$$
$$\mathcal{O}^{(3)}_{\phi l} = (\phi^\dagger i \overleftrightarrow{D}^i_\mu \phi)(\bar{l}_L\, \sigma_i \gamma^\mu l_L)\ ,$$
$$\mathcal{O}_{\phi e} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{e}_R \gamma^\mu e_R)\ ,$$
$$\mathcal{O}^{(1)}_{\phi q} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{q}_L \gamma^\mu q_L)\ ,$$
$$\mathcal{O}^{(3)}_{\phi q} = (\phi^\dagger i \overleftrightarrow{D}^i_\mu \phi)(\bar{q}_L\, \sigma_i \gamma^\mu q_L)$$
$$\mathcal{O}_{\phi u} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{u}_R \gamma^\mu u_R)\ ,$$
$$\mathcal{O}_{\phi d} = (\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{d}_R \gamma^\mu d_R)\ ,$$

Zff/Wff vertex corrections

Only 8 independent combinations enter EWPO

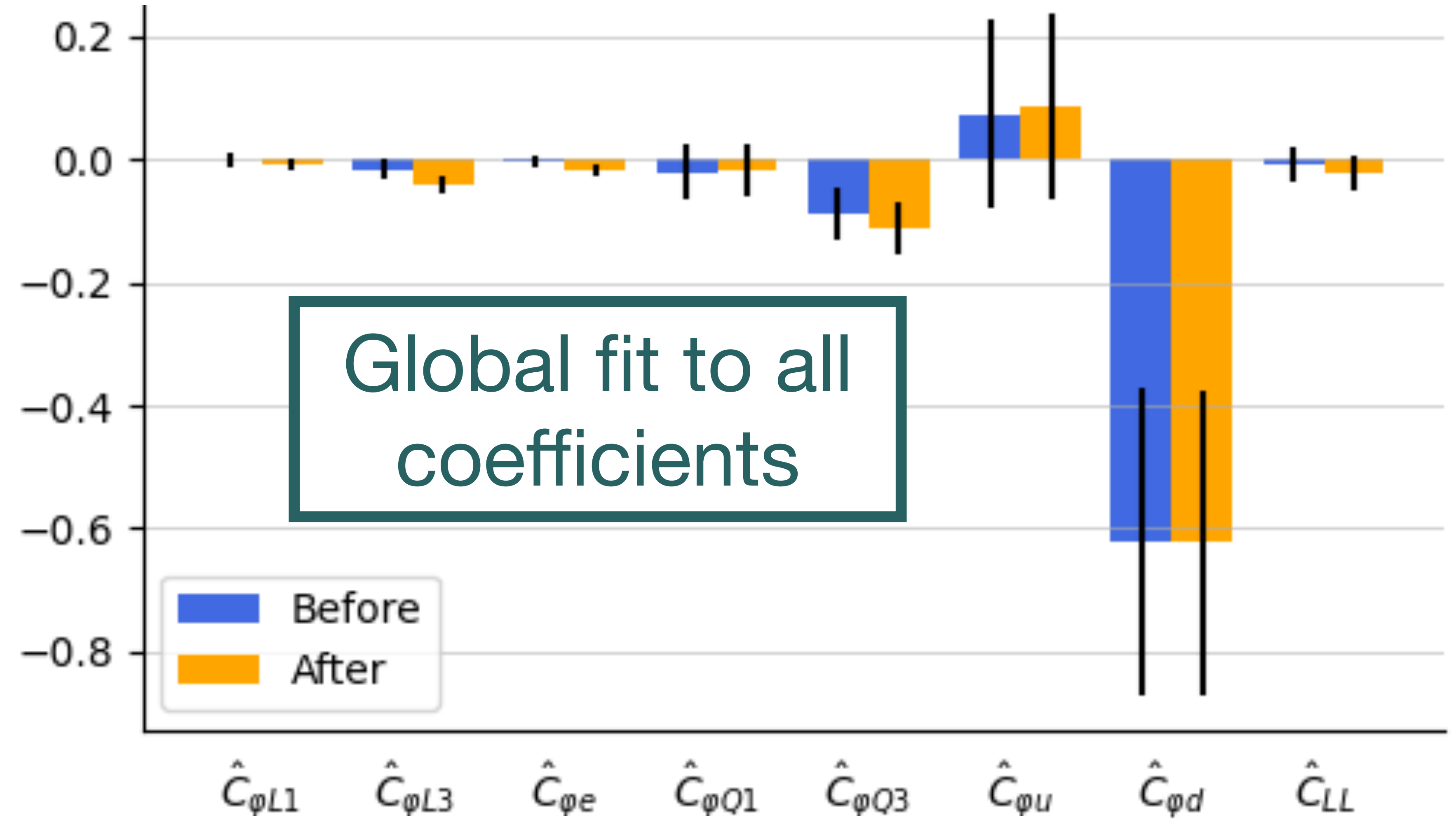
$$\hat{C}^{(1)}_{\varphi f} = C^{(1)}_{\varphi f} - \frac{Y_f}{2} C_{\varphi D}, \quad f = l, q, e, u, d,$$
$$\hat{C}^{(3)}_{\varphi f} = C^{(3)}_{\varphi f} + \frac{c_w^2}{4 s_w^2} C_{\varphi D} + \frac{c_w}{s_w} C_{\varphi WB}, \quad f = l, q,$$
$$\hat{C}_{ll} = \frac{1}{2}((C_{ll})_{1221} + (C_{ll})_{2112}) = (C_{ll})_{1221},$$

$$\mathcal{O}_{\phi WB} = (\phi^\dagger \sigma_i \phi)\, W^i_{\mu\nu} B^{\mu\nu}\ ,$$
$$\mathcal{O}_{\phi D} = (\phi^\dagger D^\mu \phi)^* \,(\phi^\dagger D_\mu \phi)\ ,$$

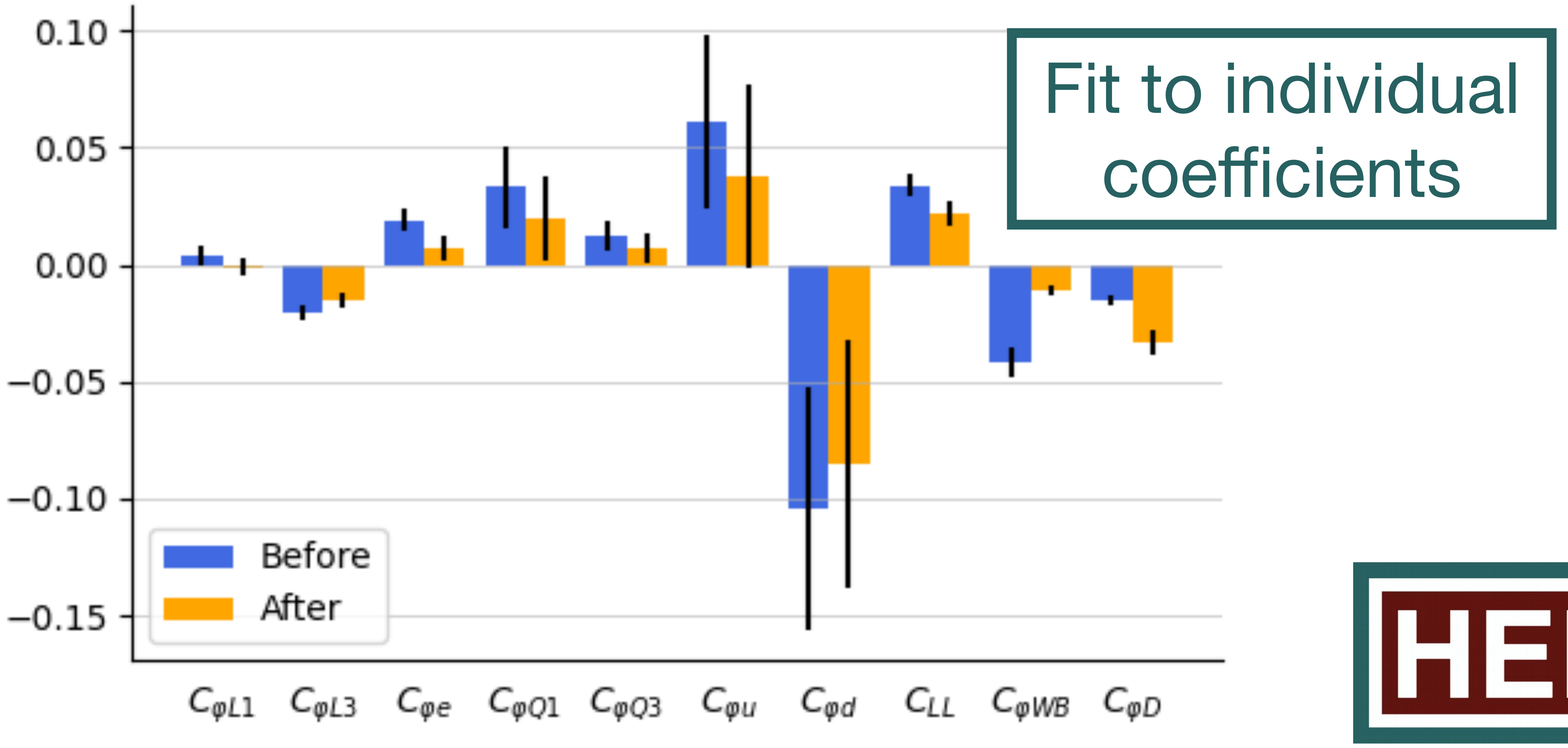
W/Z propagators ⟷ S,T

$$\mathcal{O}_{ll} = (\overline{l_L} \gamma^\mu l_L)(\overline{l_L} \gamma^\mu l_L) \longrightarrow G_F$$

Model	Pred. M_W [GeV] *standard average*	Pull	Pred. M_W [GeV] *conservative average*	Pull
SMEFT	80.66 ± 1.68	$-0.1\,\sigma$	80.66 ± 1.68	$-0.1\,\sigma$



Global fit to all coefficients



Fit to individual coefficients

A unique combination of coefficients enters the W mass: $\left(\hat{C}^{(3)}_{\phi\ell} - \frac{\hat{C}_{\ell\ell}}{2}\right)$

Conclusions

- Since decades, the EW fit has been one of our most effective tools to test the SM and probe the presence of new physics at higher energy scale
- The recent update of mW and mt measurements represent a further step forward in precision
- But the new mW measurement by CDF challenges the consistency of the fit
- Certainly, new physics effects can compensate for that
    - Invoking large T (if U=0) or U oblique correction
    - Adjusting the value of the $\hat{C}^{(3)}_{\phi\ell} - \frac{\hat{C}_{\ell\ell}}{2}$ combination of SMEFT coefficients
- On the other hand, this doesn't address the issue of compatibility between experimental measurements
    - Something that we tried to mitigate inflating the uncertainty on the average (PDG style)
    - Something that requires (ongoing) scrutiny by the experiments

HEPfit

Backup Slides

Top Mass combination

- To combine mt measurements, we need some correlation model
  - we assume a linear correlation between systematic uncertainties from different measurements $\rho_{ij}^{sys} = \min(\sigma_i, \sigma_j)/\max(\sigma_i, \sigma_j)$ which results in the “standard average” $m_t = 171.79 \pm 0.38$
- Doing so, we observe a tension between some set of measurements (ATLAS and CMS l+jets)
  - By applying the PDG procedure, the uncertainty explodes to 1.7 GeV. We don’t think this reflects what we know about the W mass=, so we discarded this value
  - Instead, we infuriated the error up to 1 GeV (“conservative” scenario) which in any case has little impact on the fit (parametric uncertainties are subleasing with respect to experimental errors on EWPO)