Sensitivity to new physics from TLEP precision measurements

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working with Marco Ciuchini, Enrico Franco, Maurizio Pierini and Luca Silvestrini

Contents

In this talk, we consider only EW precision observables (EWPO) and model-independent analyses for TLEP sensitivity to NP.

Model-indep. NP

1. Introduction

- EWPO offer a very powerful handle on the mechanism of EWSB and allow us to strongly constrain any NP relevant to solve the hierarchy problem.
- The precise measurements of the Higgs mass at LHC as well as those of the W and top masses at Tevatron make improvement in EW fits.
- The current fit shows good agreement with the SM.
- TLEP would provide excellent sensitivity to NP.

EW precision fit

- We have developed our own C++ codes for EWPO, including up-to-date formulae for higher-order corrections in the on-shell scheme, and tested against ZFITTER.

- We perform a Bayesian analysis with MCMC by using the Bayesian Analysis Toolkit (BAT) library.

  Caldwell, Kollar & Kroninger

- Our fit results are in agreement with those from other groups:

  cf. *Erler with GAPP for PDG* — $\overline{\mathrm{MS}}$, frequentist
  LEP EWWG with ZFITTER;
  Gfitter (Baak et al.);
  Eberhardt et al. with ZFITTER; — $\Big\}$ on-shell, frequentist
  and others......

Current SM fit

Marco Ciuchini, Enrico Franco, S.M. and Luca Silvestrini, JHEP 08 (2013) 106 [arXiv:1306.4644[hep-ph]]

Fit: our fit results

Indirect: determined w/o using the corresponding experimental information

	Data	Fit	Indirect	Pull
$\alpha_s(M_Z^2)$	0.1184 ± 0.0006	0.1184 ± 0.0006	0.1191 ± 0.0027	$+0.3$
$\Delta\alpha_{\rm had}^{(5)}(M_Z^2)$	0.02750 ± 0.00033	0.02740 ± 0.00026	0.02724 ± 0.00042	-0.5
M_Z [GeV]	91.1875 ± 0.0021	91.1878 ± 0.0020	91.198 ± 0.012	$+0.8$
m_t [GeV]	173.2 ± 0.9	173.5 ± 0.8	176.1 ± 2.5	$+1.1$
m_h [GeV]	125.6 ± 0.3	125.6 ± 0.3	97.0 ± 26.9	-0.9
M_W [GeV]	80.385 ± 0.015	80.367 ± 0.007	80.362 ± 0.007	-1.4
Γ_W [GeV]	2.085 ± 0.042	2.0891 ± 0.0006	2.0891 ± 0.0006	$+0.1$
Γ_Z [GeV]	2.4952 ± 0.0023	2.4953 ± 0.0004	2.4953 ± 0.0004	$+0.0$
σ_h^0 [nb]	41.540 ± 0.037	41.484 ± 0.004	41.484 ± 0.004	-1.5
$\sin^2\theta_{\rm eff}^{\rm lept}(Q_{\rm FB}^{\rm had})$	0.2324 ± 0.0012	0.23145 ± 0.00009	0.23144 ± 0.00009	-0.8
$P_\tau^{\rm pol}$	0.1465 ± 0.0033	0.1476 ± 0.0007	0.1477 ± 0.0007	$+0.3$
$\mathcal{A}_\ell$ (SLD)	0.1513 ± 0.0021	0.1476 ± 0.0007	0.1471 ± 0.0007	-1.9
$\mathcal{A}_c$	0.670 ± 0.027	0.6682 ± 0.0003	0.6682 ± 0.0003	-0.1
$\mathcal{A}_b$	0.923 ± 0.020	0.93466 ± 0.00006	0.93466 ± 0.00006	$+0.6$
$A_{\rm FB}^{0,\ell}$	0.0171 ± 0.0010	0.0163 ± 0.0002	0.0163 ± 0.0002	-0.8
$A_{\rm FB}^{0,c}$	0.0707 ± 0.0035	0.0740 ± 0.0004	0.0740 ± 0.0004	$+0.9$
$A_{\rm FB}^{0,b}$	0.0992 ± 0.0016	0.1035 ± 0.0005	0.1039 ± 0.0005	$+2.8$ ← large deviation!
R_ℓ^0	20.767 ± 0.025	20.735 ± 0.004	20.734 ± 0.004	-1.3
R_c^0	0.1721 ± 0.0030	0.17236 ± 0.00002	0.17236 ± 0.00002	$+0.1$
R_b^0	0.21629 ± 0.00066	0.21549 ± 0.00003	0.21549 ± 0.00003	-1.2

- Here we have adopted the recently corrected two-loop formula for R_b^0 (and R_c^0). *Freitas and Huang (12,13)*

  $-2.1\sigma \rightarrow -1.2\sigma$

A global-fitting project

- Our EW codes are a part of our global-fitting project in the Bayesian framework.
- We are developing a tool to combine indirect (EW, Flavour, etc.) and direct (LHC) searches for NP.
- Current members:

  Roma: Jorge de Blas Mateo, Otto Eberhardt, Enrico Franco, Diptimoy Ghosh, SM, Ayan Paul, Luca Silvestrini
  Roma Tre: Marco Ciuchini
  SISSA: Giovanni Grilli di Cortona, Ivan Girardi, Mauro Valli
  CERN: Maurizio Pierini

  11 theorists + 1 experimentalist

- The EW codes will be released to the public soon!

2. TLEP precision on EWPO

	Current data	before TLEP	TLEP-Z	TLEP-Z (pol.)	TLEP-W	TLEP-t
$\alpha_s(M_Z^2)$	0.1184 ± 0.0006	???				
$\Delta\alpha_{\mathrm{had}}^{(5)}(M_Z^2)$	0.02750 ± 0.00033	± 0.00005 (?)				
M_Z [GeV]	91.1875 ± 0.0021		± 0.0001			
m_t [GeV]	173.2 ± 0.9	± 0.5 (?)				± 0.016
m_h [GeV]	125.6 ± 0.3	± 0.15 (?)				
M_W [GeV]	80.385 ± 0.015	± 0.010 (?)			± 0.00064	
Γ_W [GeV]	2.085 ± 0.042				???	
Γ_Z [GeV]	2.4952 ± 0.0023		± 0.0001			
σ_h^0 [nb]	41.540 ± 0.037		???			
$\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}(Q_{\mathrm{FB}}^{\mathrm{had}})$	0.2324 ± 0.0012		???			
P_τ^{pol}	0.1465 ± 0.0033		???			
$\mathcal{A}_\ell$	0.1513 ± 0.0021			± 0.000021		
$\mathcal{A}_c$	0.670 ± 0.027			???		
$\mathcal{A}_b$	0.923 ± 0.020			???		
$A_{\mathrm{FB}}^{0,\ell}$	0.0171 ± 0.0010		???			
$A_{\mathrm{FB}}^{0,c}$	0.0707 ± 0.0035		???			
$A_{\mathrm{FB}}^{0,b}$	0.0992 ± 0.0016		???			
R_ℓ^0	20.767 ± 0.025		± 0.001			
R_c^0	0.1721 ± 0.0030		???			
R_b^0	0.21629 ± 0.00066		± 0.00006			

TLEP precision (for 2 IPs) from arXiv:1308.6176 by the TLEP Design Study Working Group

- TLEP-Z: one-year scan of the Z resonance
- TLEP-Z (pol.): one year at the Z pole with long.-polarized beams
- TLEP-W: one-year (or two years) scan of the WW threshold
- TLEP-t: five-year scan of the ttbar threshold

Other possible improvements

- Hadronic contribution to α:

At present: $\Delta\alpha^{(5)}_{\mathrm{had}}(M_Z^2) = 0.02750 \pm 0.00033$

Burkhardt & Pietrzyk (11)
(see also Davier et al(11); Hagiwara et al(11) ; Jegerlehner(11))

measured with inclusive processes.

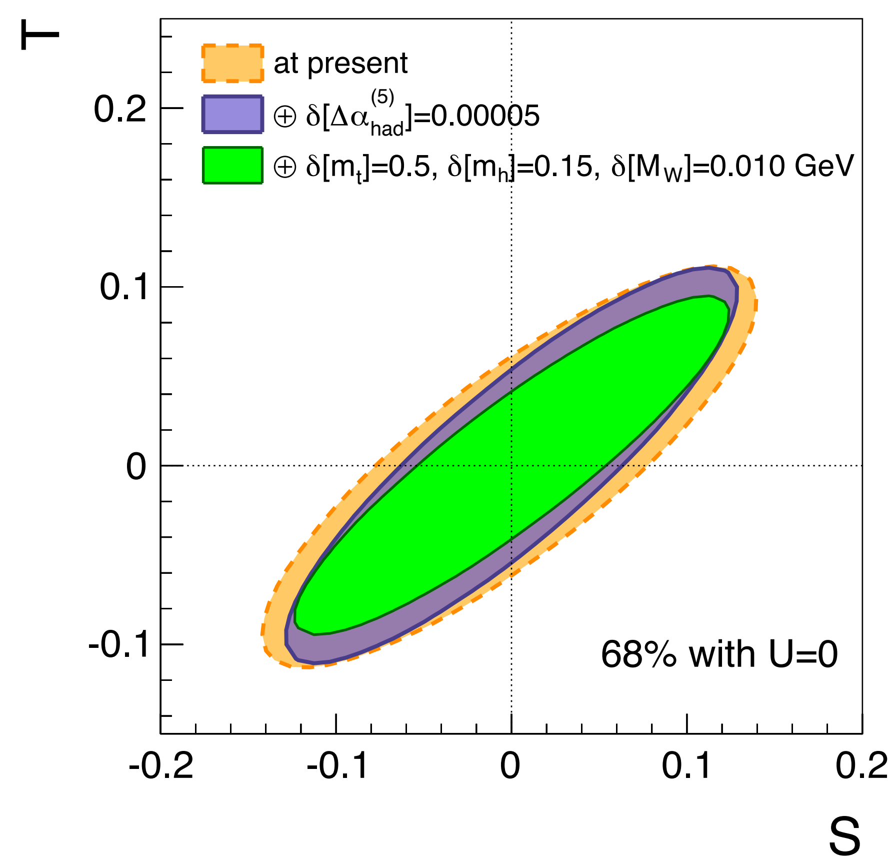
smaller uncertainty (~ 0.00010) if using exclusive processes with pQCD, etc.

⇨ assume $\delta(\Delta\alpha^{(5)}_{\mathrm{had}}(M_Z^2)) \sim 0.00005$ from low-energy exp's.

- Expected future LHC precision:

$$\delta m_t \sim 0.5\ \mathrm{GeV}$$
$$\delta m_h \sim 0.15\ \mathrm{GeV}$$
$$\delta M_W \sim 10\ \mathrm{MeV}$$

⇨ We do not consider them in the current TLEP study, since they do not alter NP fits dramatically.



Parametric and theoretical uncertainties

- We assume that theoretical uncertainties will be reduced by calculating three-loop contributions of $O(\alpha^2\alpha_s)$ and $O(\alpha^3)$.

	TLEP	Parametric uncertainty						Theoretical uncertainty	
	direct	α_s	$\Delta\alpha^{(5)}_{\rm had}$	M_Z	m_t	m_h	Total	current	future
δM_W [MeV]	± 0.64	± 0.36	± 0.91	± 0.13	± 0.10	± 0.14	± 1.00	± 4	± 1
$\delta\,\Gamma_Z$ [MeV]	± 0.1	± 0.3	± 0.0	± 0.0	± 0.0	± 0.0	± 0.3	± 0.5	± 0.1
$\delta\mathcal{A}_\ell$ $[10^{-5}]$	± 2.1	± 1.6	± 13.7	± 0.6	± 0.4	± 0.9	± 13.9	± 37.0	± 11.8

$\delta \sin^2\theta_{\rm eff}^{\rm lept} = 4.7\times 10^{-5} \;\to\; 1.5\times 10^{-5}$

- Parametric uncertainties are dominated by $\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$.

- Theoretical calculations at three-loop level are necessary to reach the TLEP precision.

Our strategy

- For the observables whose TLEP errors are not available, we adopt their current exp. errors.
- We neglect possible correlations among the data.
- We consider two scenarios:

  SM scenario:

  apply the current SM-fit results to the central values of "future data", used in studying TLEP sensitivity to NP.

  NP scenario:

  apply current NP-fit results to the central values of "future data" and demonstrate the power of TLEP in NP searches.

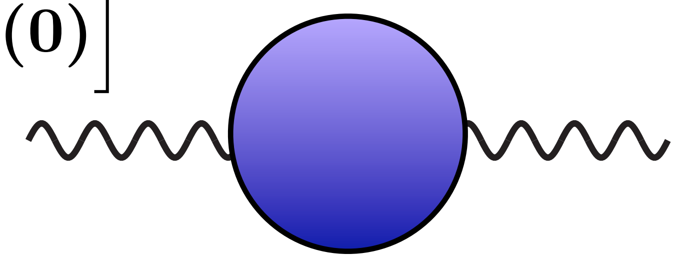
3. Oblique parameters

- Suppose that dominant NP effects appear in the vacuum polarizations of the gauge bosons:

$$S = -16\pi\Pi'_{30}(0) = 16\pi\left[\Pi^{\mathrm{NP}\prime}_{33}(0) - \Pi^{\mathrm{NP}\prime}_{3Q}(0)\right]$$

$$T = \frac{4\pi}{s_W^2 c_W^2 M_Z^2}\left[\Pi^{\mathrm{NP}}_{11}(0) - \Pi^{\mathrm{NP}}_{33}(0)\right]$$

$$U = 16\pi\left[\Pi^{\mathrm{NP}\prime}_{11}(0) - \Pi^{\mathrm{NP}\prime}_{33}(0)\right]$$



Kennedy & Lynn (89); Peskin & Takeuchi (90,92)

- When the EW symmetry is realized linearly, U is associated with a dim. 8 operator and thus small.
- EWPO depend on the three combinations:

$$\delta M_W,\ \delta\Gamma_W \propto -S + 2c_W^2\,T + \frac{(c_W^2 - s_W^2)\,U}{2s_W^2}$$

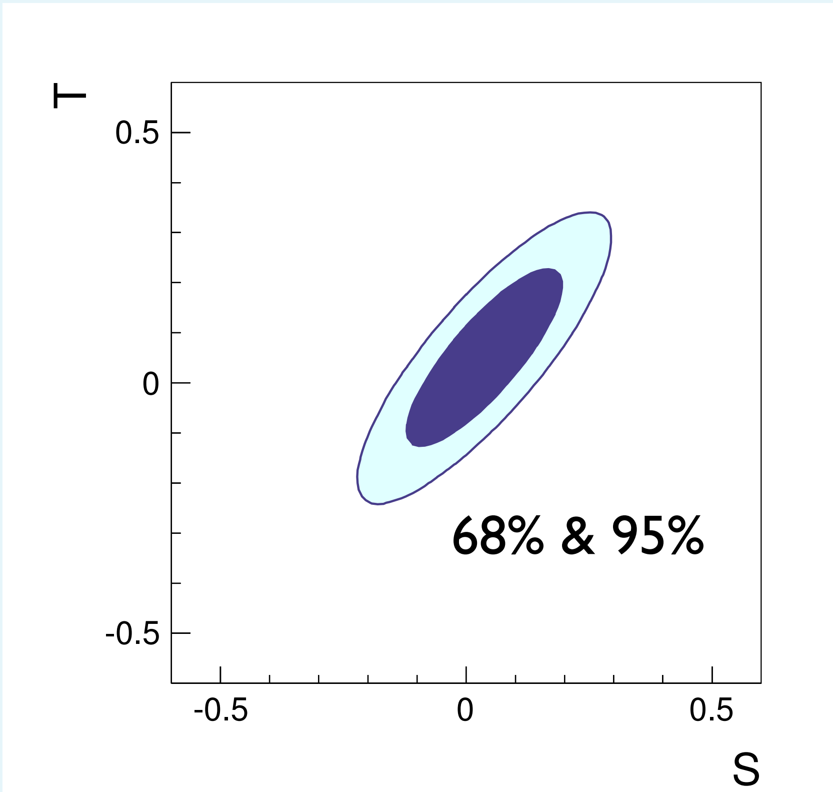
$$\delta\Gamma_Z \propto -10(3 - 8s_W^2)\,S + (63 - 126s_W^2 - 40s_W^4)\,T$$

$$\text{others} \propto S - 4c_W^2 s_W^2\,T$$

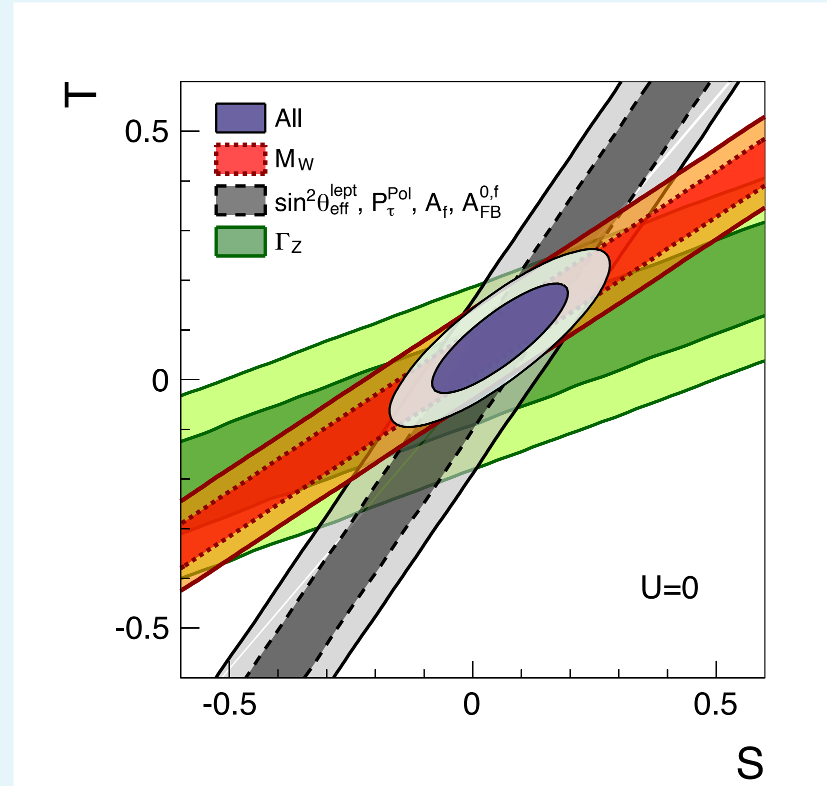
Current fit results for S, T and U

Current fit

$U \neq 0$



$U = 0$



Parameter	STU fit	ST fit with $U=0$
S	0.04 ± 0.10	0.06 ± 0.09
T	0.05 ± 0.12	0.08 ± 0.07
U	0.03 ± 0.09	—

See also, e.g., Erler (12); Gfitter (12,13)

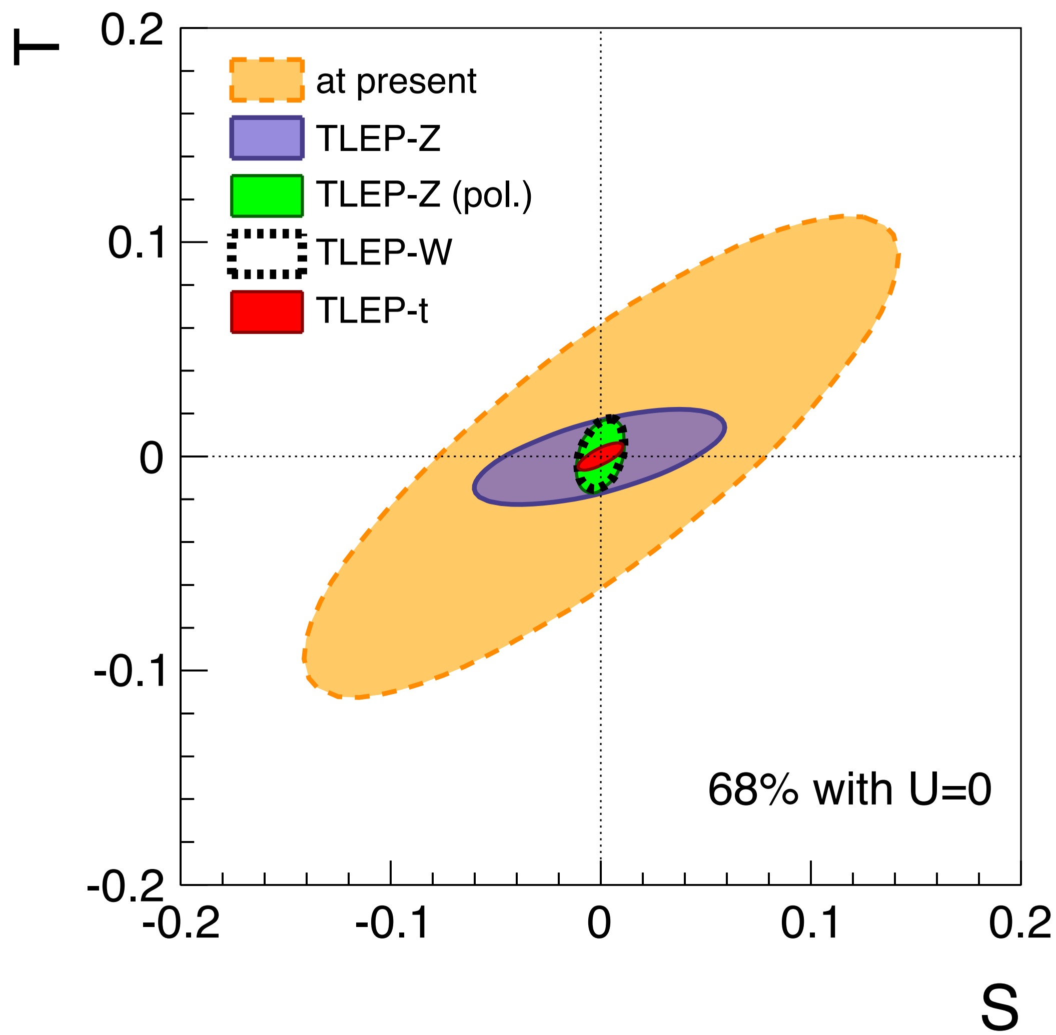
➡ No evidence for NP currently.

TLEP sensitivity to S and T ($U = 0$)

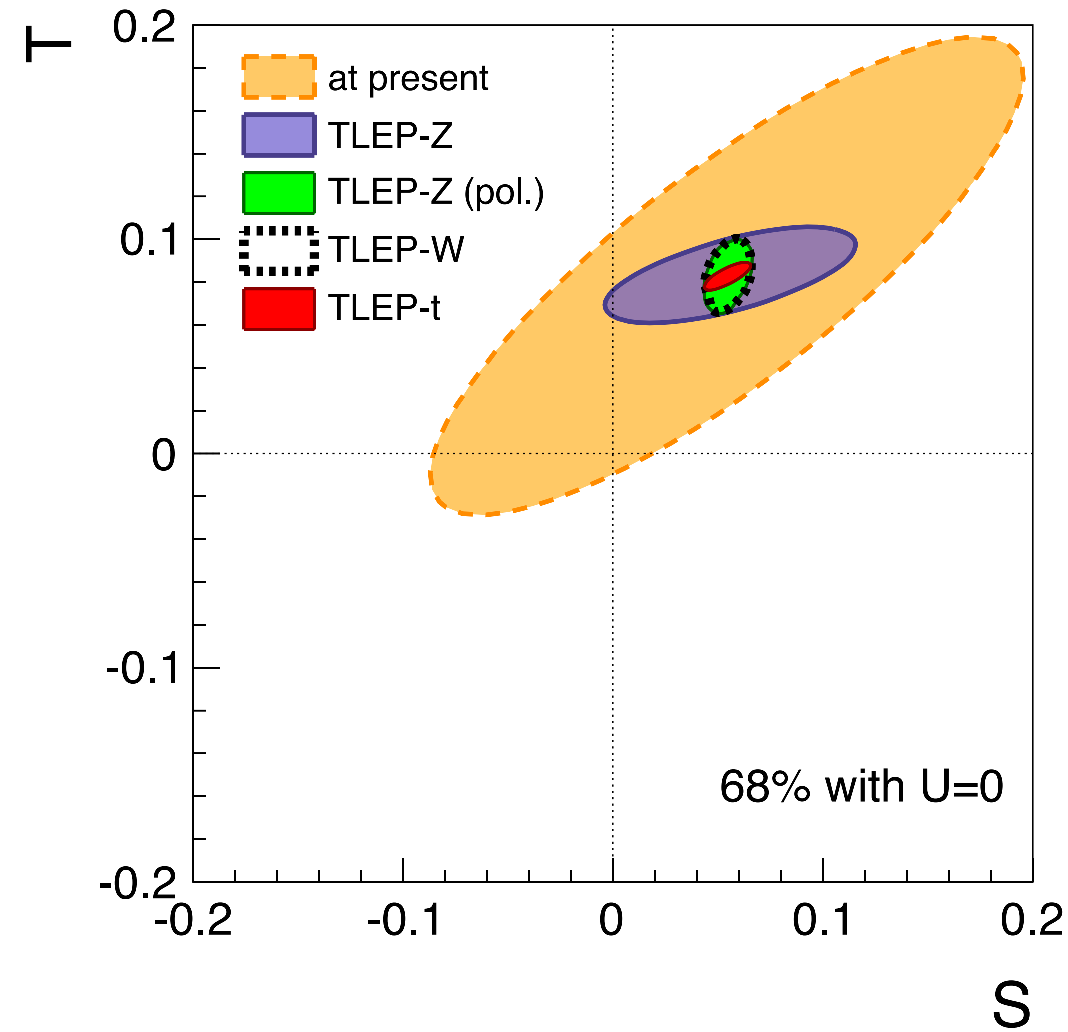
- In the case of $U = 0$,

$$\delta S \sim 7 \times 10^{-3}, \qquad \delta T \sim 4 \times 10^{-3}$$

SM scenario

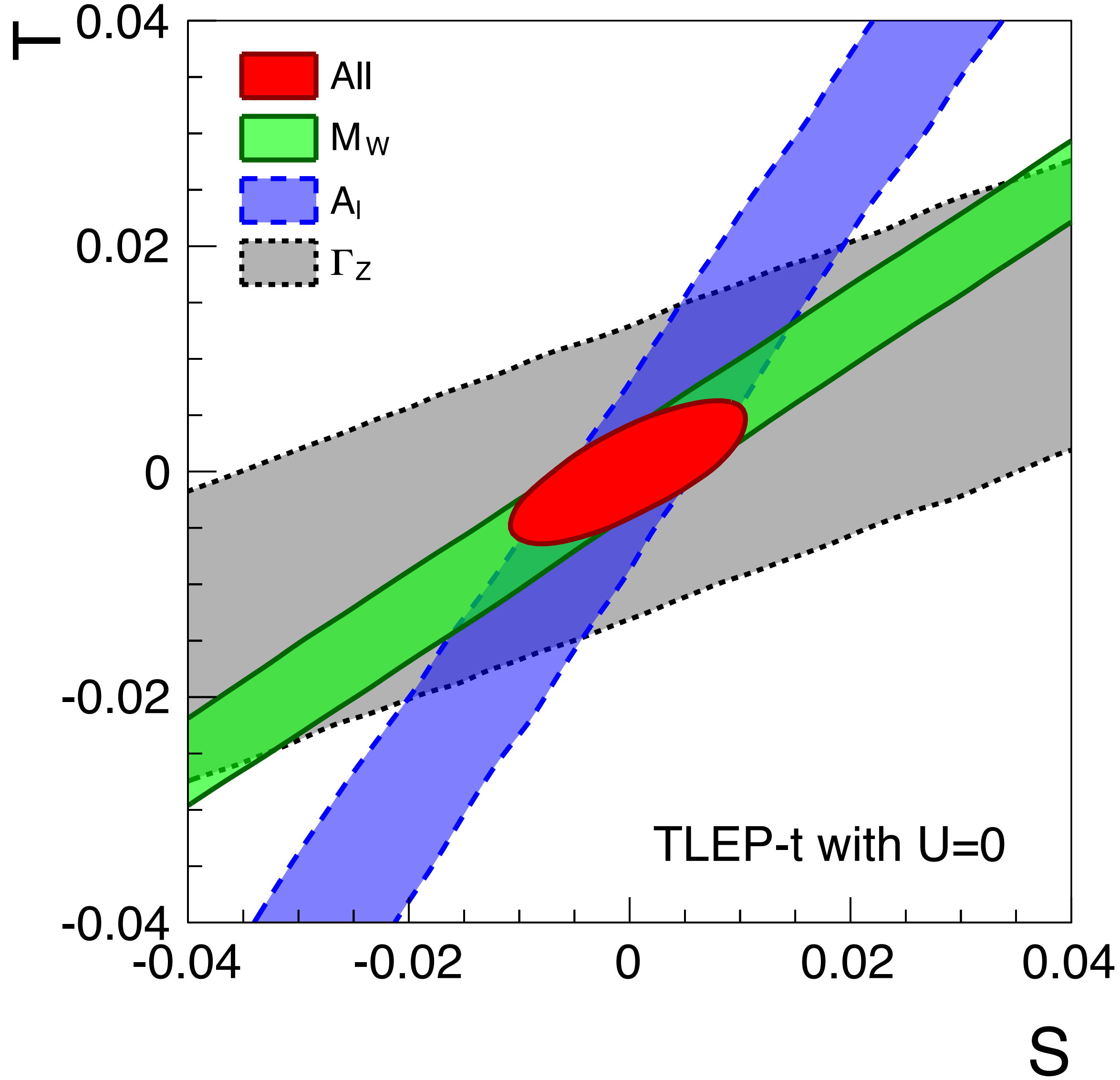


NP scenario



Individual constraints on S and T ($U = 0$)

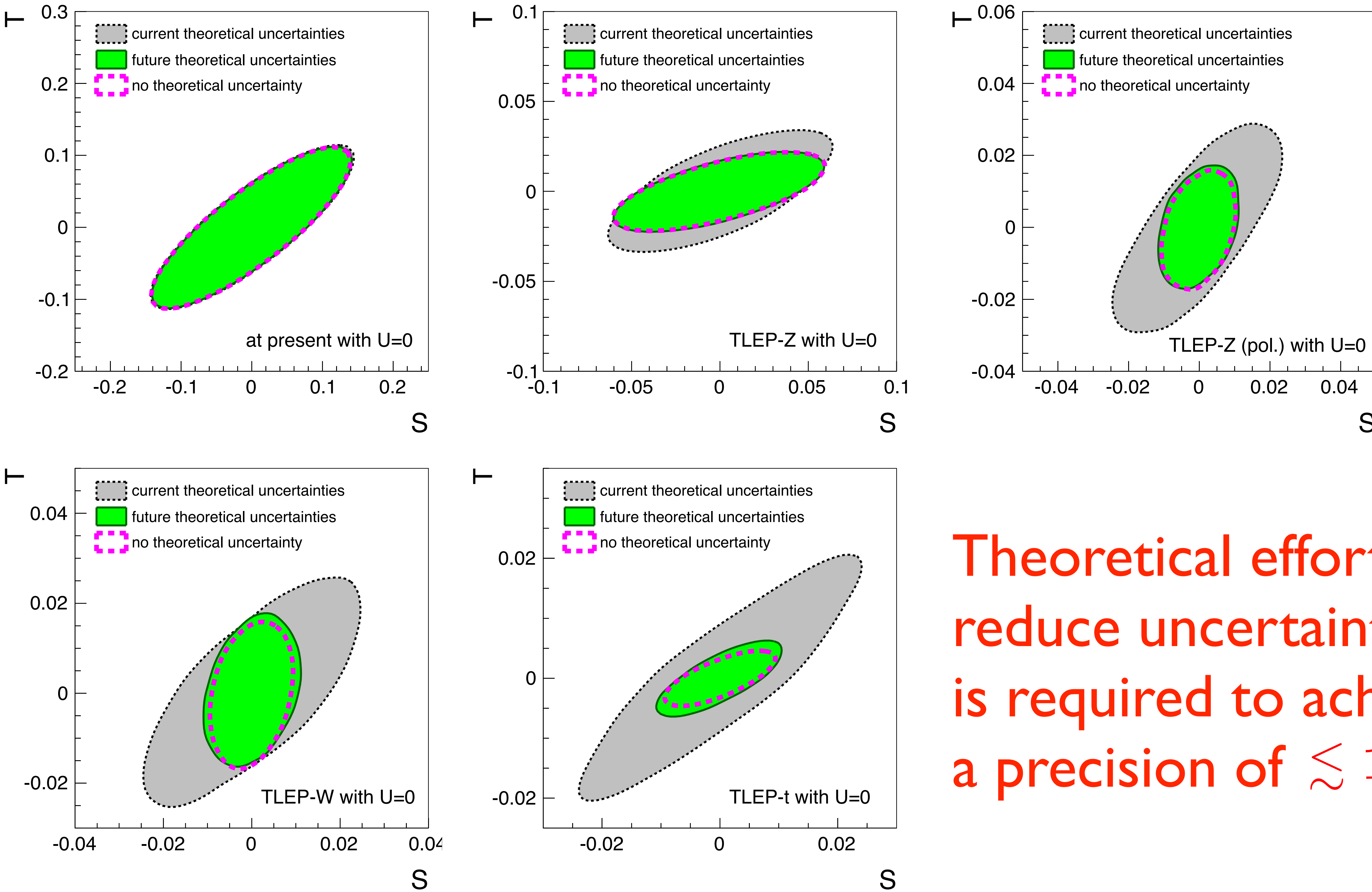
SM scenario



Mw gives the most stringent constraint after TLEP-t.

Impact of theoretical uncertainties ($U = 0$)

SM scenario



Theoretical effort to reduce uncertainties is required to achieve a precision of $\lesssim 10^{-2}$.

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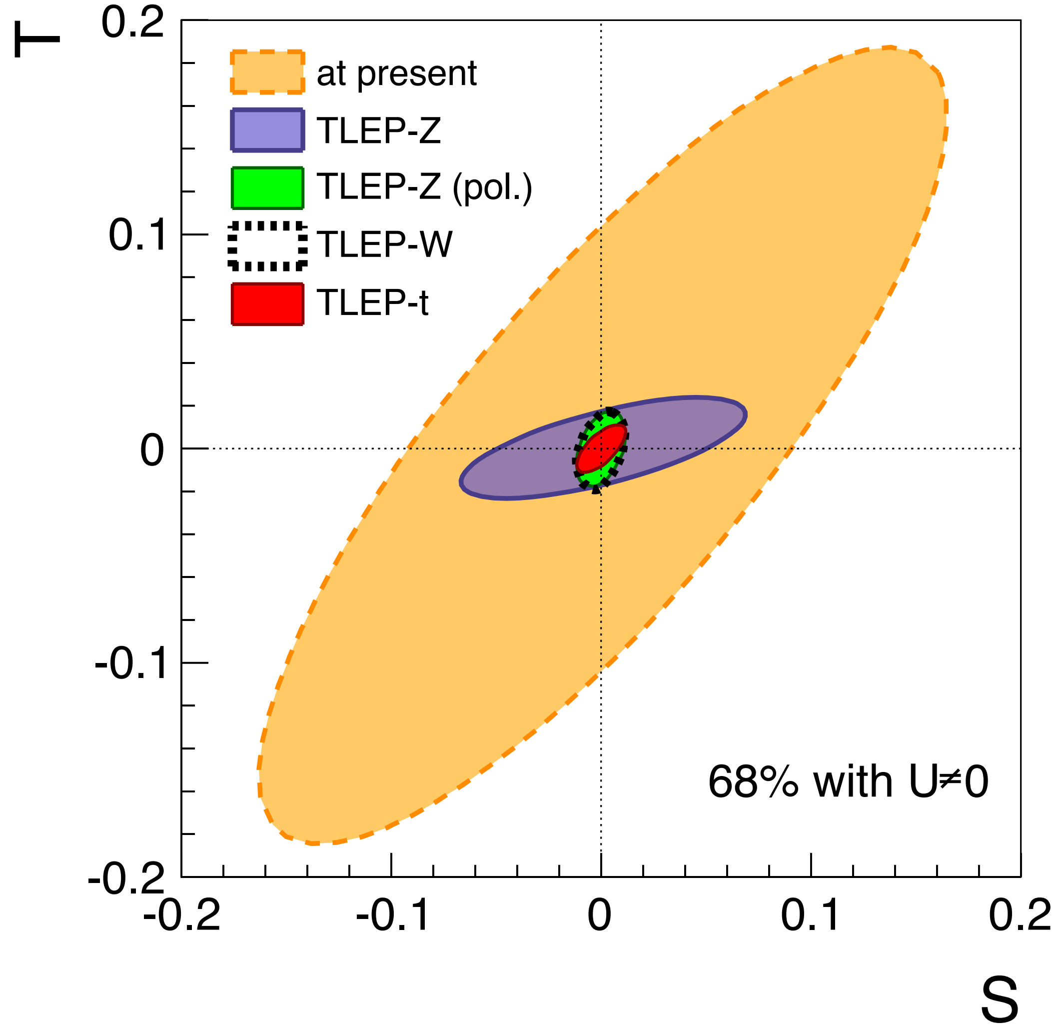
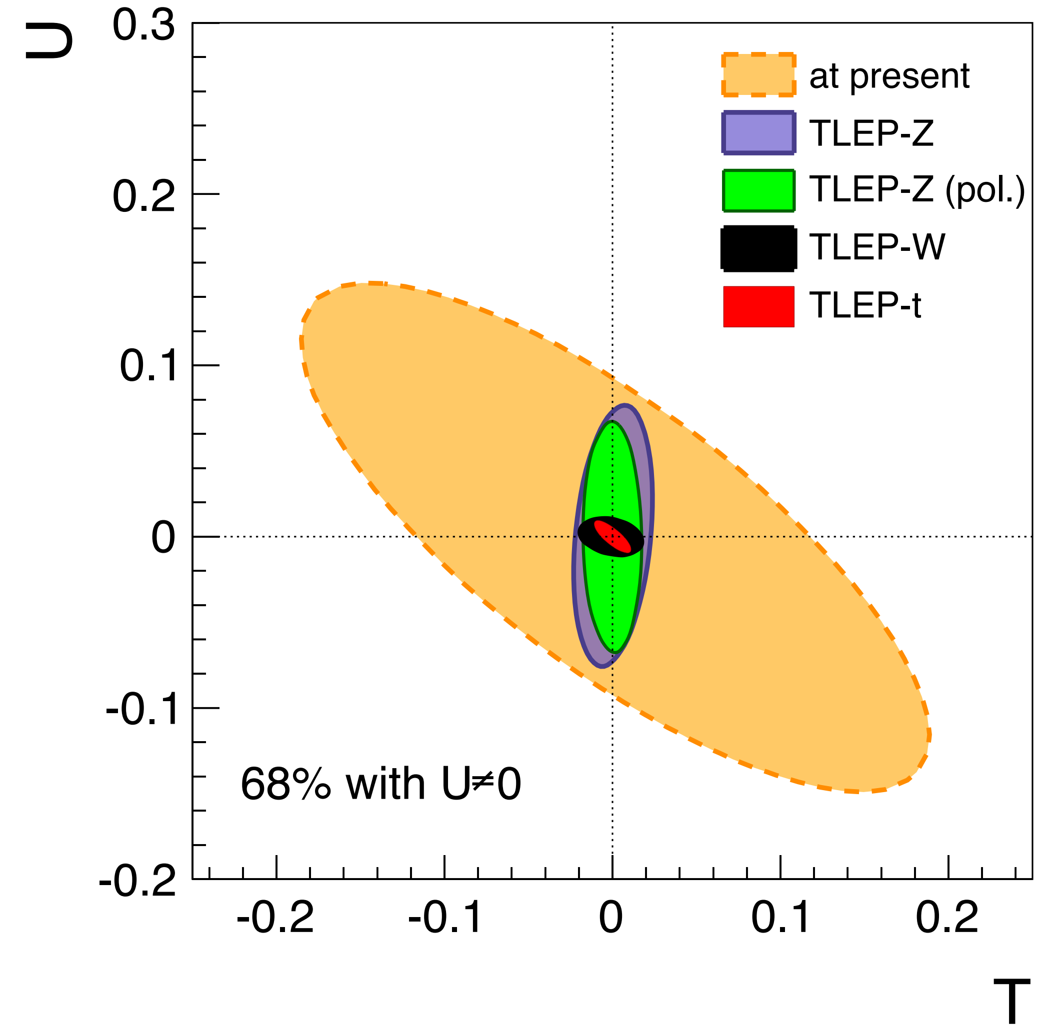
TLEP sensitivity to S, T and U ($U \neq 0$)

SM scenario



SM scenario



- The precision on U is greatly improved from TLEP-Z (pol.) to TLEP-W.

$$\delta S \sim 7 \times 10^{-3}, \quad \delta T \sim 7 \times 10^{-3}, \quad \delta U \sim 6 \times 10^{-3}$$

4. HVV coupling

- only a Higgs below cutoff + custodial symmetry:

$$\mathcal{L} = \frac{v^2}{4}\mathrm{Tr}\left(D_\mu\Sigma^\dagger D^\mu\Sigma\right)\left(1 + 2a\frac{h}{v} + \cdots\right) + \cdots$$

Σ : Goldstone bosons

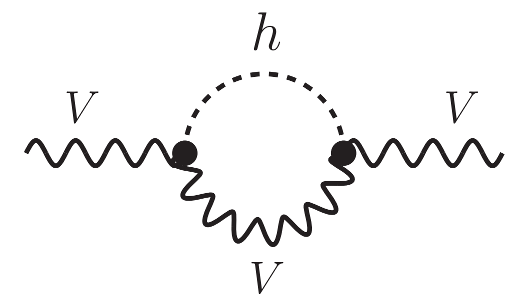
$a = 1$ in the SM

⇨ The HVV coupling contributes to S and T at one-loop.

$$S = \frac{1}{12\pi}(1 - a^2)\ln\left(\frac{\Lambda^2}{m_h^2}\right)$$

$$T = -\frac{3}{16\pi c_W^2}(1 - a^2)\ln\left(\frac{\Lambda^2}{m_h^2}\right)$$

$$\Lambda = 4\pi v/\sqrt{|1 - a^2|}$$



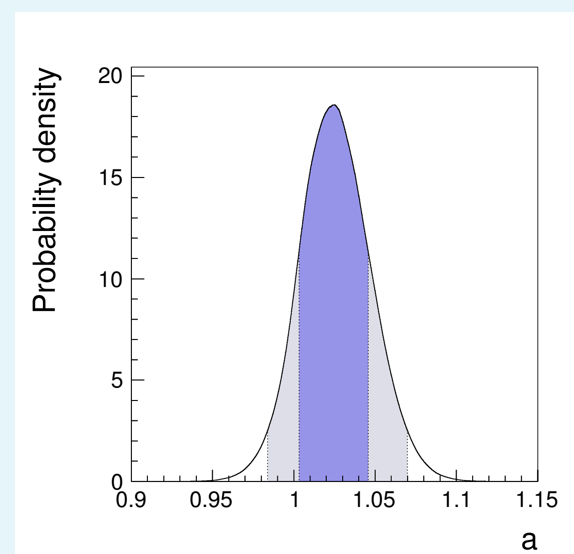
Barberi, Bellazzini, Rychkov & Varagnolo (07)

Current fit

$$a = 1.024 \pm 0.021$$

⇩

$$\Lambda \gtrsim 17\ \mathrm{TeV}\ @\,95\%\ \ \text{for}\ a < 1$$



Implication on composite Higgs models

- $a > 1$ ⇨ $W_L W_L$ scattering is dominated by isospin 2 channel

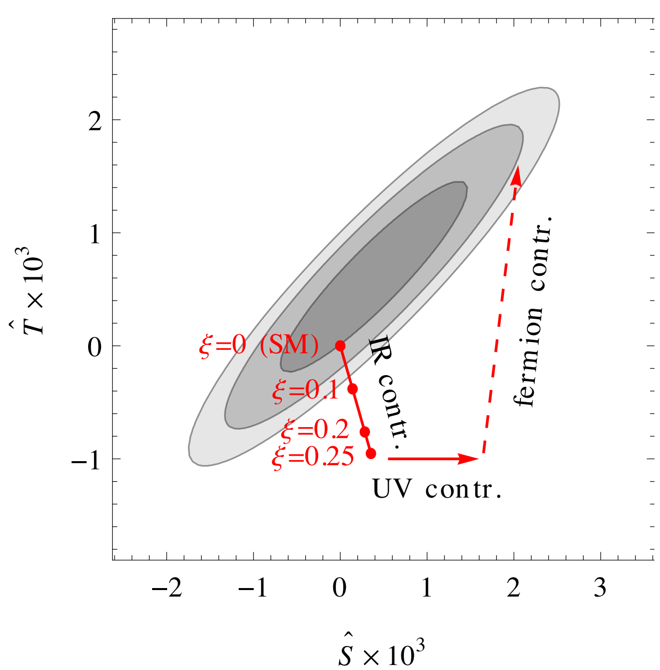
  Falkowski, Rychkov & Urbano (12)

- Composite Higgs models typically generate $a < 1$.

$$\xi = \left(\frac{v}{f}\right)^2 = 1 - a^2 \quad \text{in minimal composite Higgs models}$$

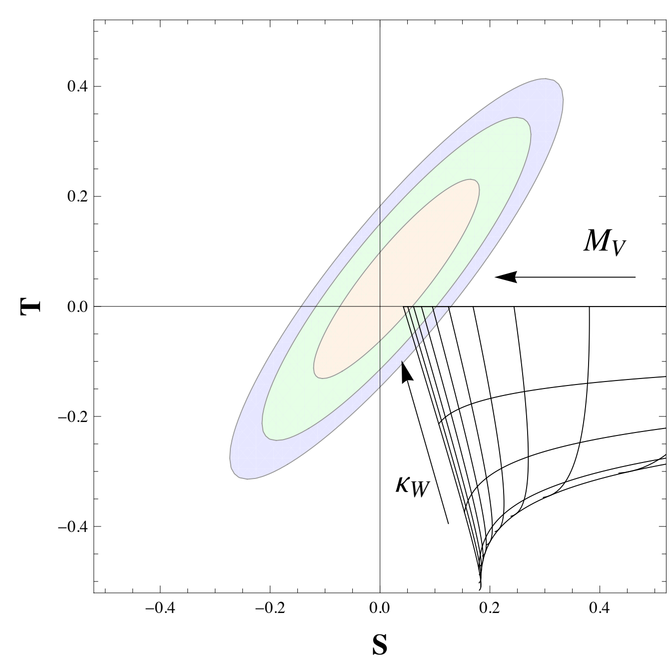
- Extra contributions to S and T are required to fix the EW fit under $a < 1$.

fermionic resonances



Grojean et al. (13); Azatov et al. (13)

vector/axial-vector resonances



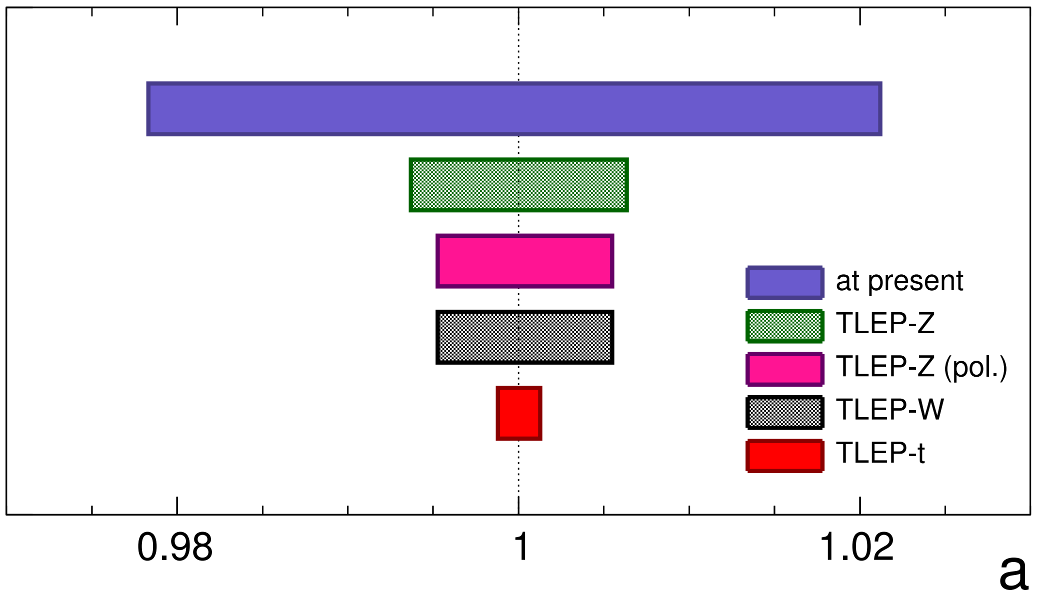
$M_V = 1.5, \ldots, 6.0$ TeV

$\kappa_W = \frac{M_V^2}{M_A^2} = 0, \ldots, 1$

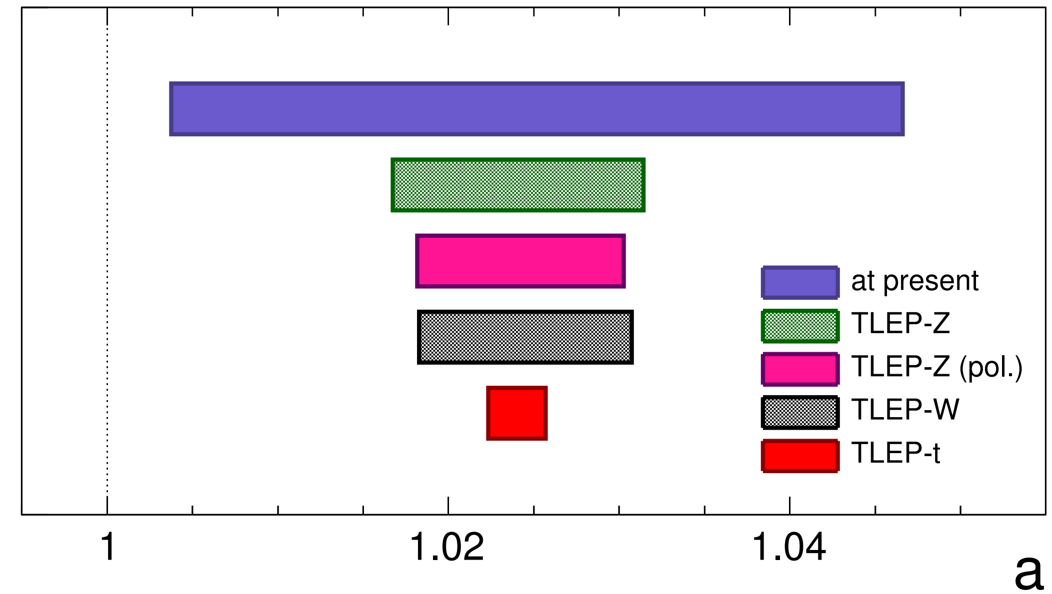
Pich et al. (13)

TLEP sensitivity to the HVV coupling

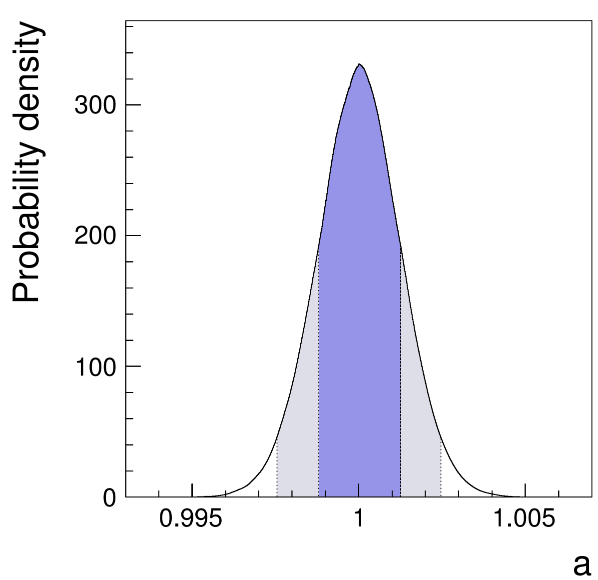
SM scenario



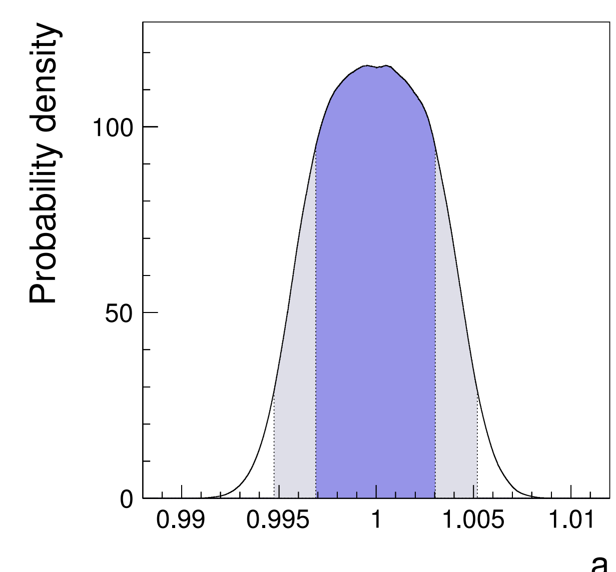
NP scenario



The HVV coupling can be measured with a precision of $\lesssim \mathbf{2 \times 10^{-3}}$.



if no theory progress



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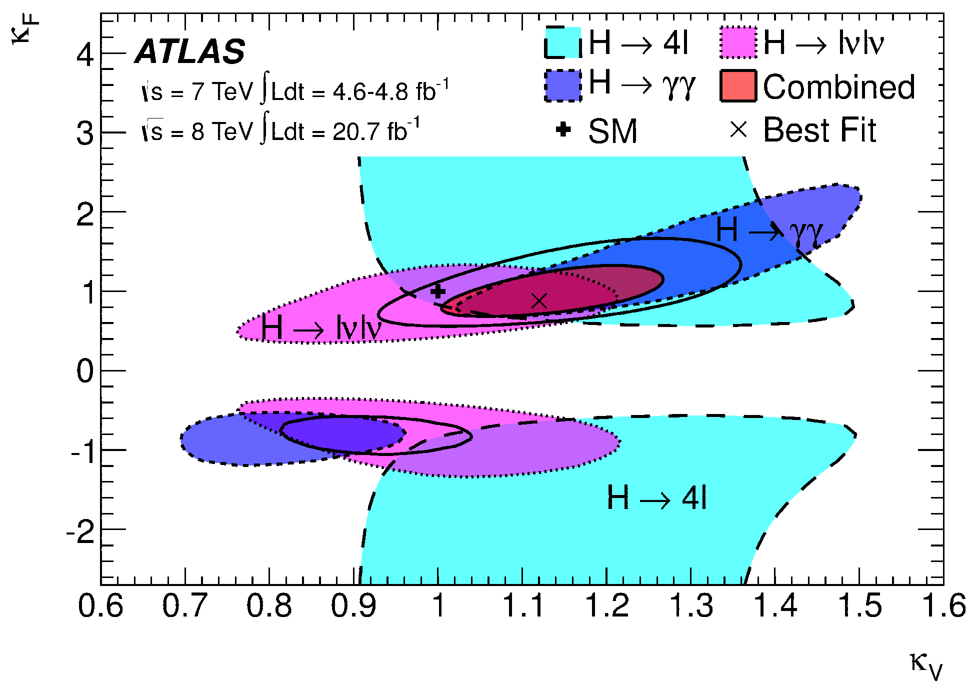
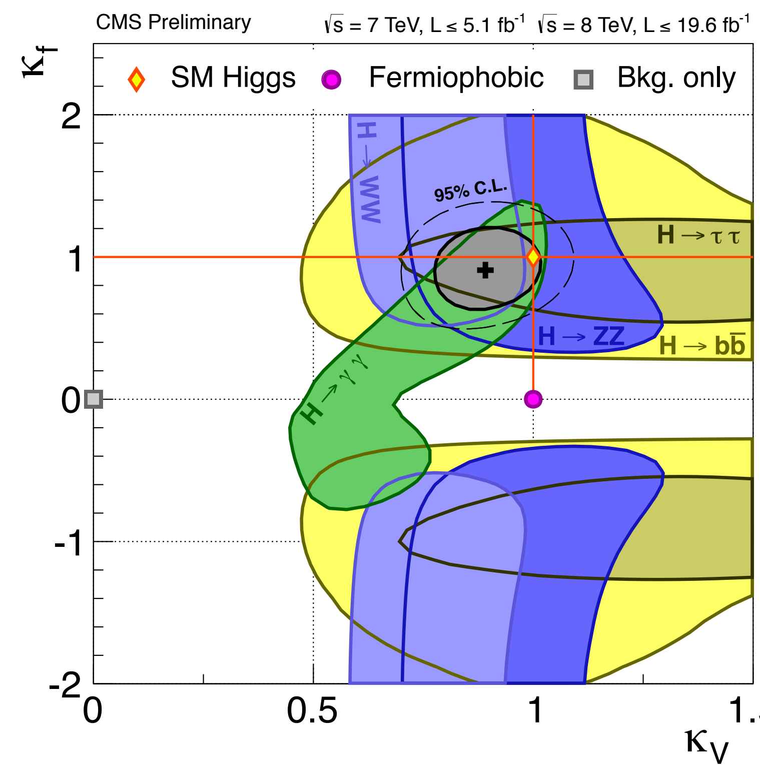
Other measurements of HVV couplings

- Current LHC measurements:

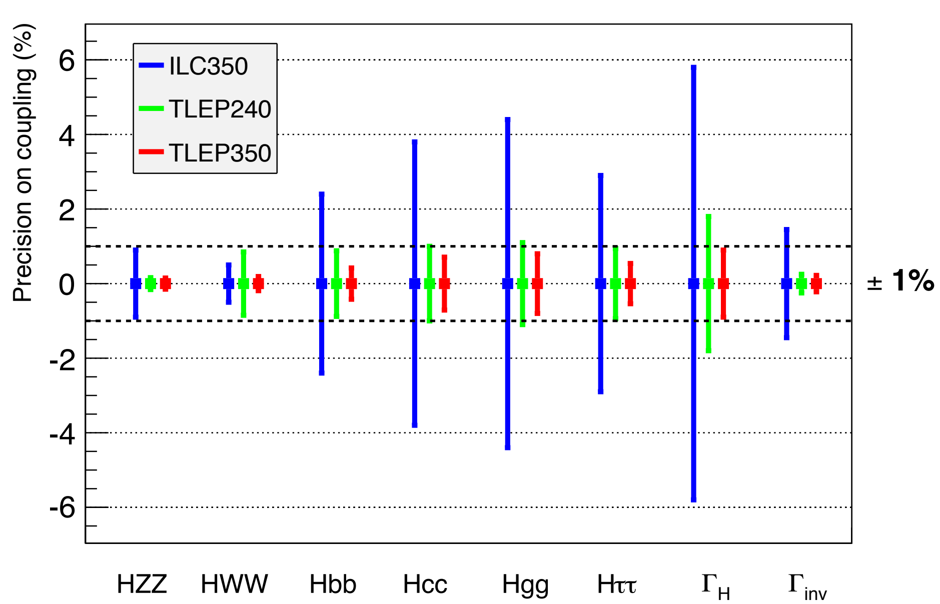


$$\kappa_V \in [1.05,\ 1.22]\ @\,68\%$$



$$\kappa_V \in [0.81,\ 0.97]\ @\,68\%$$

- Measurements of Higgs decays at TLEP



TLEP Design Study Working Group (13)

Similar precision to the EW precision fit

⇨ Compare two measurements!

5. Dim. 6 operators

- We consider NP-induced dimension six operators:

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{C_i}{\Lambda^2}\mathcal{O}_i$$

Barbieri & Strumia (99)

$$\begin{aligned}
\mathcal{O}_{WB} &= (H^\dagger \tau^a H) W^a_{\mu\nu} B^{\mu\nu} \\
\mathcal{O}_{H} &= |H^\dagger D_\mu H|^2 \\
\mathcal{O}_{LL} &= \frac{1}{2}(\overline{L}\gamma_\mu \tau^a L)^2 \\
\mathcal{O}'_{HL} &= i(H^\dagger D_\mu \tau^a H)(\overline{L}\gamma^\mu \tau^a L) \\
\mathcal{O}'_{HQ} &= i(H^\dagger D_\mu \tau^a H)(\overline{Q}\gamma^\mu \tau^a Q) \\
\mathcal{O}_{HL} &= i(H^\dagger D_\mu H)(\overline{L}\gamma^\mu L) \\
\mathcal{O}_{HQ} &= i(H^\dagger D_\mu H)(\overline{Q}\gamma^\mu Q) \\
\mathcal{O}_{HE} &= i(H^\dagger D_\mu H)(\overline{E}\gamma^\mu E) \\
\mathcal{O}_{HU} &= i(H^\dagger D_\mu H)(\overline{U}\gamma^\mu U) \\
\mathcal{O}_{HD} &= i(H^\dagger D_\mu H)(\overline{D}\gamma^\mu D)
\end{aligned}$$

$\mathcal{O}_{WB}$ → *S parameter*

$\mathcal{O}_{H}$ → *T parameter*

$\mathcal{O}_{LL}$, $\mathcal{O}'_{HL}$ → *Fermi constant*

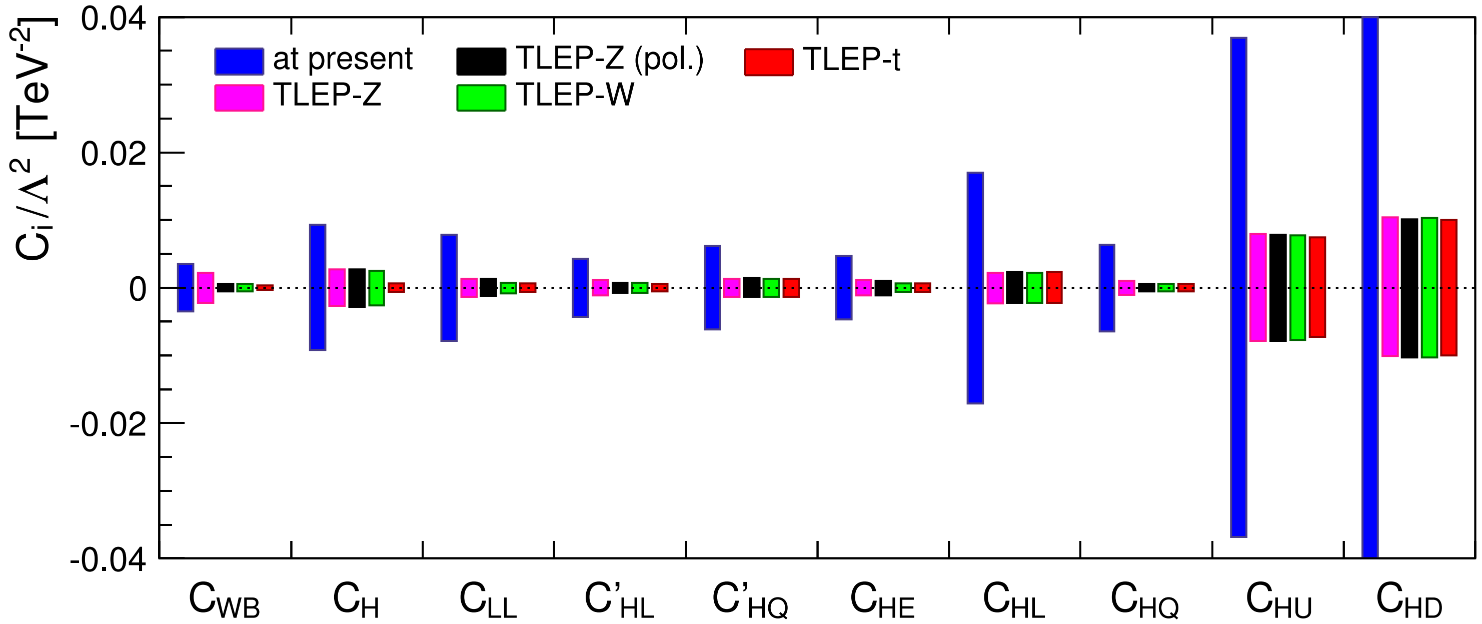
$\mathcal{O}'_{HL}$, $\mathcal{O}'_{HQ}$, $\mathcal{O}_{HL}$, $\mathcal{O}_{HQ}$ → *Left-handed $Zf\bar{f}$ couplings*

$\mathcal{O}_{HE}$, $\mathcal{O}_{HU}$, $\mathcal{O}_{HD}$ → *Right-handed $Zf\bar{f}$ couplings*

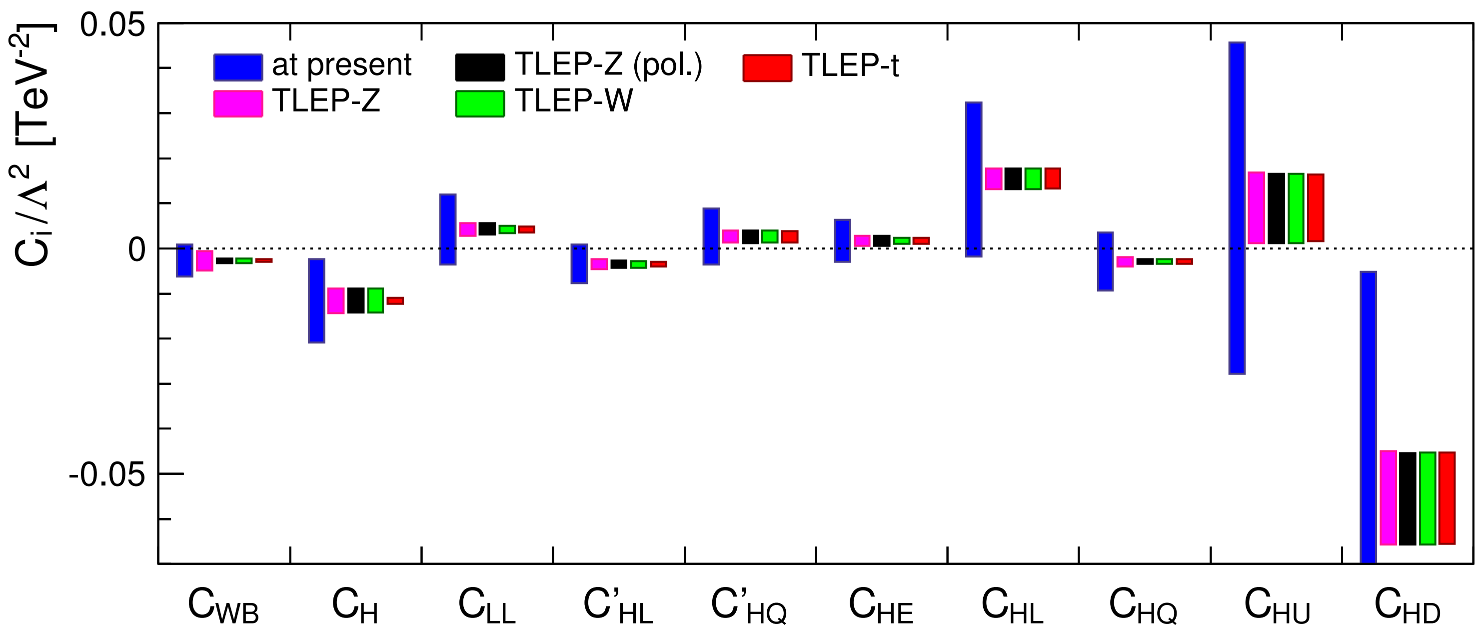
- assume flavour universality.
- switch on one operator at a time.

TLEP sensitivity to dim. 6 operators

SM scenario



NP scenario



Improvements by a factor of 5 to 10!

Missing information on TLEP uncertainties are required for a more complete analysis.

TLEP sensitivity to NP scale

- The fit result for C_i/Λ^2 can be interpreted as a lower bound on the NP scale by fixing the coupling.

SM scenario, in units of TeV

Coefficient	at present $C_i=-1$	at present $C_i=1$	TLEP-Z $C_i=-1$	TLEP-Z $C_i=1$	TLEP-Z (pol.) $C_i=-1$	TLEP-Z (pol.) $C_i=1$	TLEP-W $C_i=-1$	TLEP-W $C_i=1$	TLEP-t $C_i=-1$	TLEP-t $C_i=1$
C_{WB}	12.0	12.0	15.2	15.2	31.3	31.1	31.3	31.5	38.3	38.9
C_H	7.4	7.4	13.6	13.6	13.9	13.7	14.0	14.1	27.9	27.8
C_{LL}	8.1	8.1	19.3	19.3	19.9	19.9	25.4	25.5	27.6	27.7
C'_{HL}	10.9	10.9	21.2	21.1	25.9	25.7	25.8	25.8	31.2	30.9
C'_{HQ}	9.0	9.1	19.5	19.3	19.5	19.4	19.4	19.2	19.6	19.6
C_{HL}	10.4	10.4	21.5	21.5	21.5	21.9	28.6	28.5	28.3	28.4
C_{HQ}	5.4	5.5	14.9	14.9	15.0	14.9	15.1	15.0	15.0	15.0
C_{HE}	8.9	8.9	22.2	22.2	30.2	30.0	30.1	30.3	31.2	31.2
C_{HU}	3.7	3.7	8.0	8.0	8.1	8.1	8.1	8.1	8.3	8.3
C_{HD}	3.2	3.2	7.1	7.0	7.1	7.1	7.0	7.1	7.1	7.1

➡ The TLEP measurements would push up the lower bound of the NP scale significantly!

6. Summary

- TLEP will strengthen greatly the power of the EW fit.

  $\delta S \sim 7 \times 10^{-3}, \quad \delta T \sim 4 \times 10^{-3}$ for $U \neq 0$

  $\delta a \lesssim 2 \times 10^{-3}$

  δC_i would be reduced by a factor of 5 to 10.

- TLEP precision on all the EWPO are needed for a more complete analysis of the dim. 6 operators.

- Especially, the precision on $\mathcal{A}_b$ and $A_{\mathrm{FB}}^{0,b}$ are required to study TLEP sensitivity to NP in the Zbb couplings.

Current fit

Parameter	Fit result
δg_R^b	0.018 ± 0.007
δg_L^b	0.0026 ± 0.0014
δg_V^b	0.021 ± 0.008
δg_A^b	-0.015 ± 0.006

Backup

Comparison to ZFITTER

- For a given set of the input parameters,

	ZFITTER	OURS	$\frac{\text{OURS}-\text{ZFITTER}}{\text{ZFITTER}} * 100$	Exp uncertainty
M_W	80.362216	80.362499	0.00035 %	0.02 %
Γ_W	2.0906748	2.0887391	−0.093 %	2.0 %
Γ_Z	2.4953142	2.4951814	−0.0053 %	0.09 %
σ_h^0	41.479103	41.483516	0.011 %	0.09 %
$\sin^2\theta_{\rm eff}^{\rm lept}(Q_{\rm FB}^{\rm had})$	0.23149326	0.23149297	−0.00012 %	0.52 %
$P_\tau^{\rm Pol}$	0.14724705	0.14724926	0.0015 %	2.2 %
A_ℓ	0.14724705	0.14724926	0.0015 %	1.4 %
A_c	0.66797088	0.66799358	0.0034 %	4.0 %
A_b	0.93460981	0.93464051	0.0033 %	2.2 %
$A_{\rm FB}^{0,\ell}$	0.016261269	0.016261758	0.0030 %	5.5 %
$A_{\rm FB}^{0,c}$	0.073767554	0.073771169	0.0049 %	5.0 %
$A_{\rm FB}^{0,b}$	0.10321390	0.10321884	0.0048 %	1.6 %
R_ℓ^0	20.739702	20.735130	−0.022 %	0.12 %
R_c^0	0.17224054	0.17222362	−0.0098 %	1.7 %
R_b^0	0.21579927	0.21578277	−0.0077 %	0.31 %

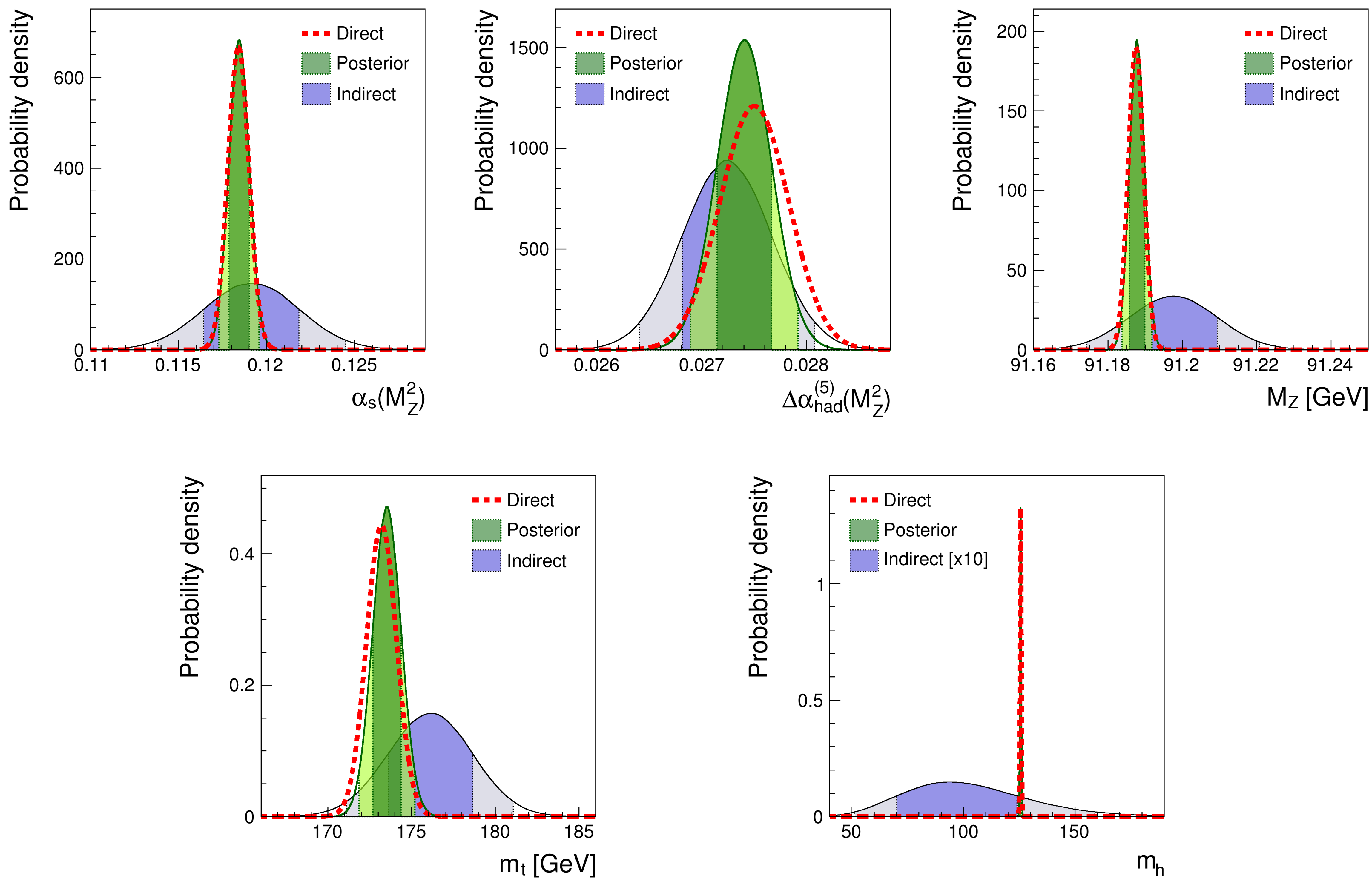
with the old Rb

Our results are in agreement with ZFITTER v6.43.

Current parametric uncertainties

	Prediction	α_s	$\Delta\alpha_{\rm had}^{(5)}$	M_Z	m_t
M_W [GeV]	80.362 ± 0.008	± 0.000	± 0.006	± 0.003	± 0.005
Γ_W [GeV]	2.0888 ± 0.0007	± 0.0002	± 0.0005	± 0.0002	± 0.0004
Γ_Z [GeV]	2.4951 ± 0.0005	± 0.0003	± 0.0003	± 0.0002	± 0.0002
σ_h^0 [nb]	41.484 ± 0.004	± 0.003	± 0.000	± 0.002	± 0.001
$\sin^2\theta_{\rm eff}^{\rm lept}(Q_{\rm FB}^{\rm had})$	0.23149 ± 0.00012	± 0.00000	± 0.00012	± 0.00001	± 0.00003
$P_\tau^{\rm pol}$	0.1472 ± 0.0009	± 0.0000	± 0.0009	± 0.0001	± 0.0002
$\mathcal{A}_\ell$ (SLD)	0.1472 ± 0.0009	± 0.0000	± 0.0009	± 0.0001	± 0.0002
$\mathcal{A}_c$	0.6680 ± 0.0004	± 0.0000	± 0.0004	± 0.0001	± 0.0001
$\mathcal{A}_b$	0.93464 ± 0.00008	± 0.00000	± 0.00007	± 0.00001	± 0.00001
$A_{\rm FB}^{0,\ell}$	0.0163 ± 0.0002	± 0.0000	± 0.0002	± 0.0000	± 0.0000
$A_{\rm FB}^{0,c}$	0.0738 ± 0.0005	± 0.0000	± 0.0005	± 0.0001	± 0.0001
$A_{\rm FB}^{0,b}$	0.1032 ± 0.0007	± 0.0000	± 0.0006	± 0.0001	± 0.0002
R_ℓ^0	20.734 ± 0.004	± 0.004	± 0.002	± 0.000	± 0.000
R_c^0	0.17235 ± 0.00002	± 0.00001	± 0.00001	± 0.00000	± 0.00001
R_b^0	0.21550 ± 0.00003	± 0.00001	± 0.00000	± 0.00000	± 0.00003

Current direct and indirect measurements



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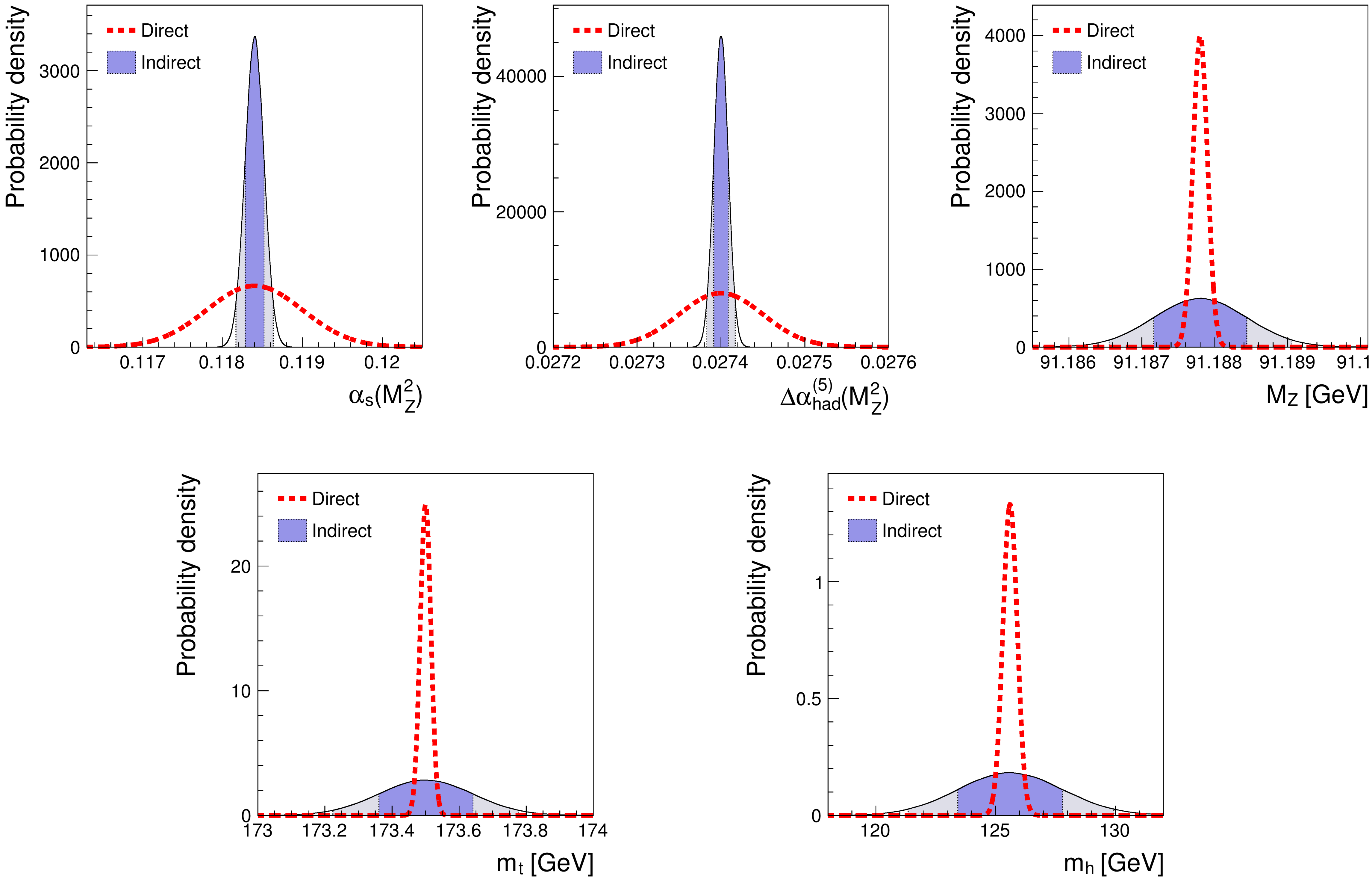
Future direct and indirect measurements



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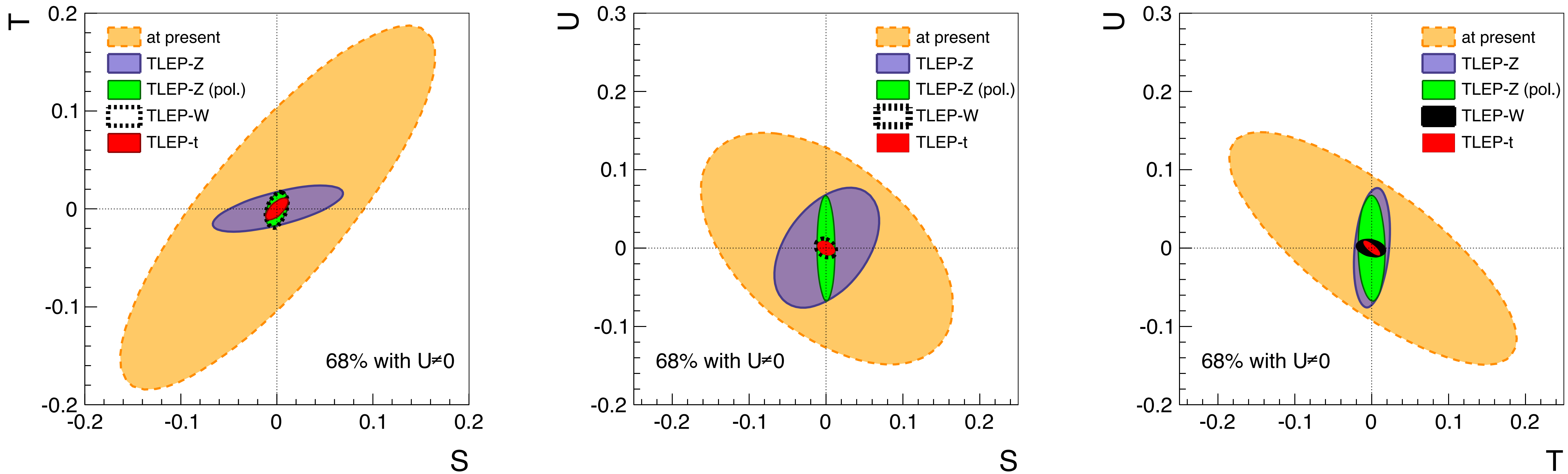
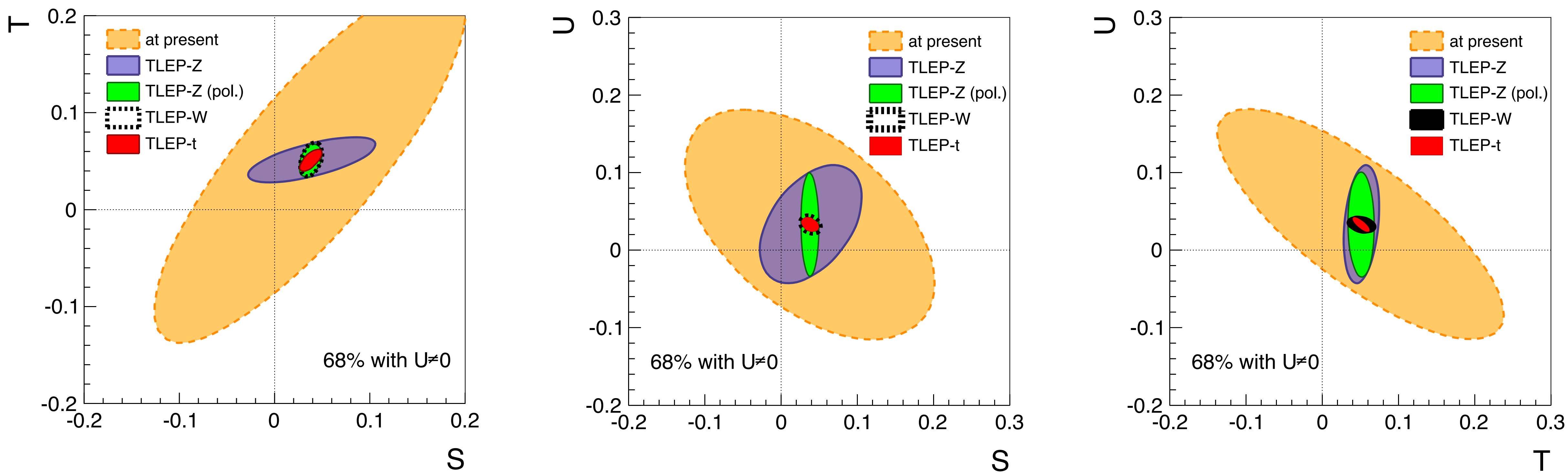
TLEP sensitivity to S, T and U

SM scenario



NP scenario



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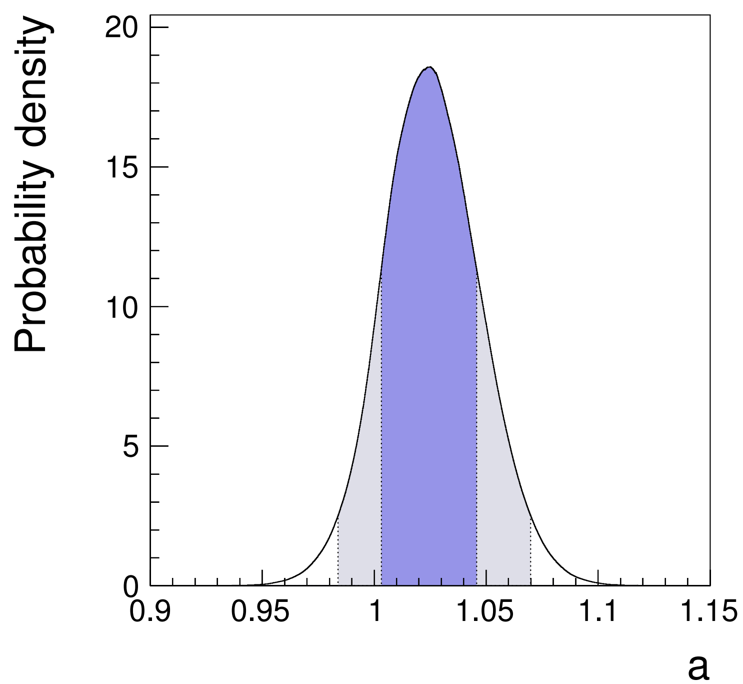
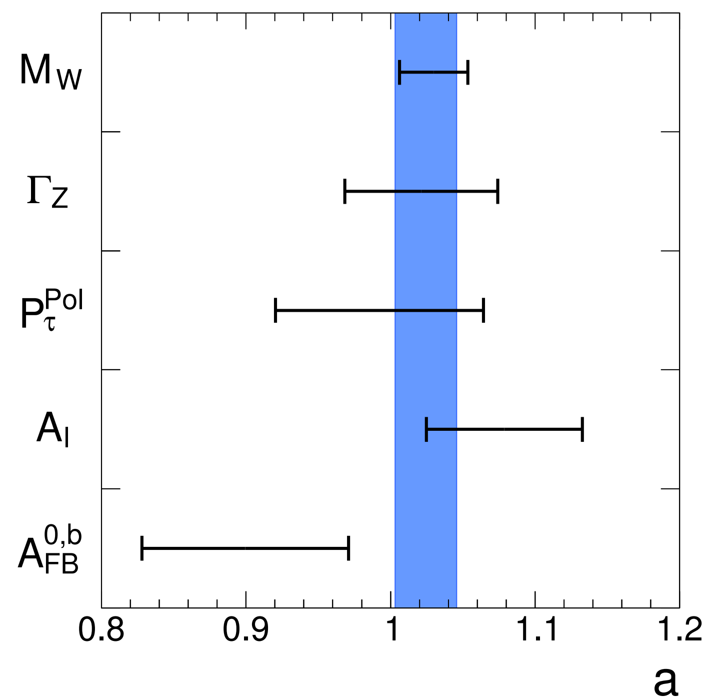
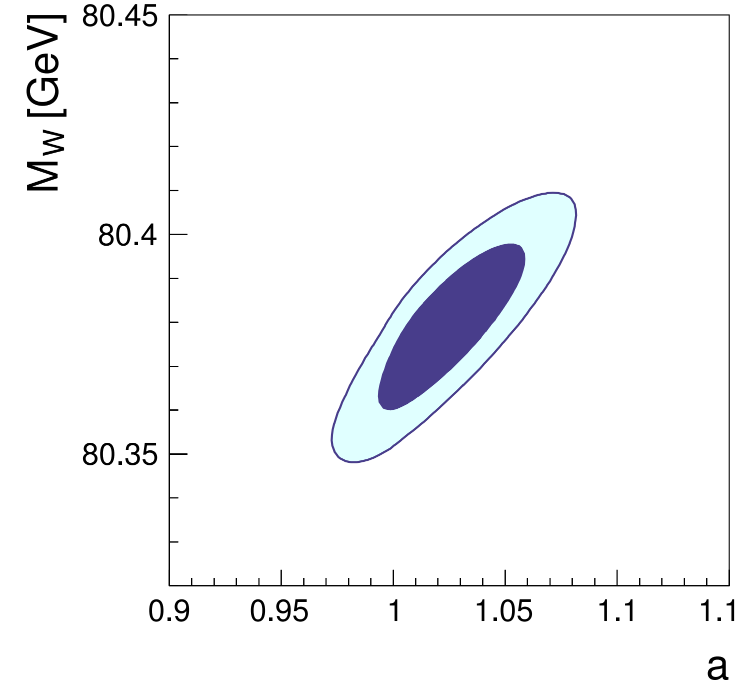
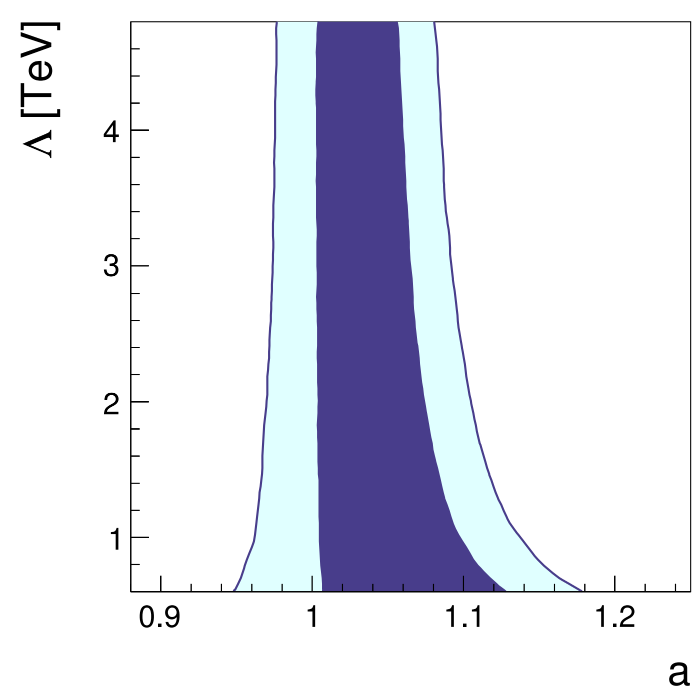
Current fit to the HVV coupling







$$\Lambda < \frac{4\pi v}{\sqrt{|1-a^2|}}$$



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Current fit to dim. 6 operators

- With quark-flavour universality

Coefficient	C_i/Λ^2 [TeV^{-2}] at 95%	Λ [TeV] $C_i = -1$	$C_i = 1$
C_{WB}	$[-0.0096, 0.0042]$	10.2	15.4
C_H	$[-0.030, 0.007]$	5.8	12.3
C_{LL}	$[-0.011, 0.019]$	9.5	7.2
C'_{HL}	$[-0.012, 0.005]$	9.2	14.1
C'_{HQ}	$[-0.010, 0.015]$	10.2	8.2
C_{HL}	$[-0.007, 0.010]$	12.3	10.0
C_{HQ}	$[-0.019, 0.049]$	7.3	4.5
C_{HE}	$[-0.014, 0.008]$	8.4	11.0
C_{HU}	$[-0.065, 0.083]$	3.9	3.5
C_{HD}	$[-0.16, 0.05]$	2.5	4.7

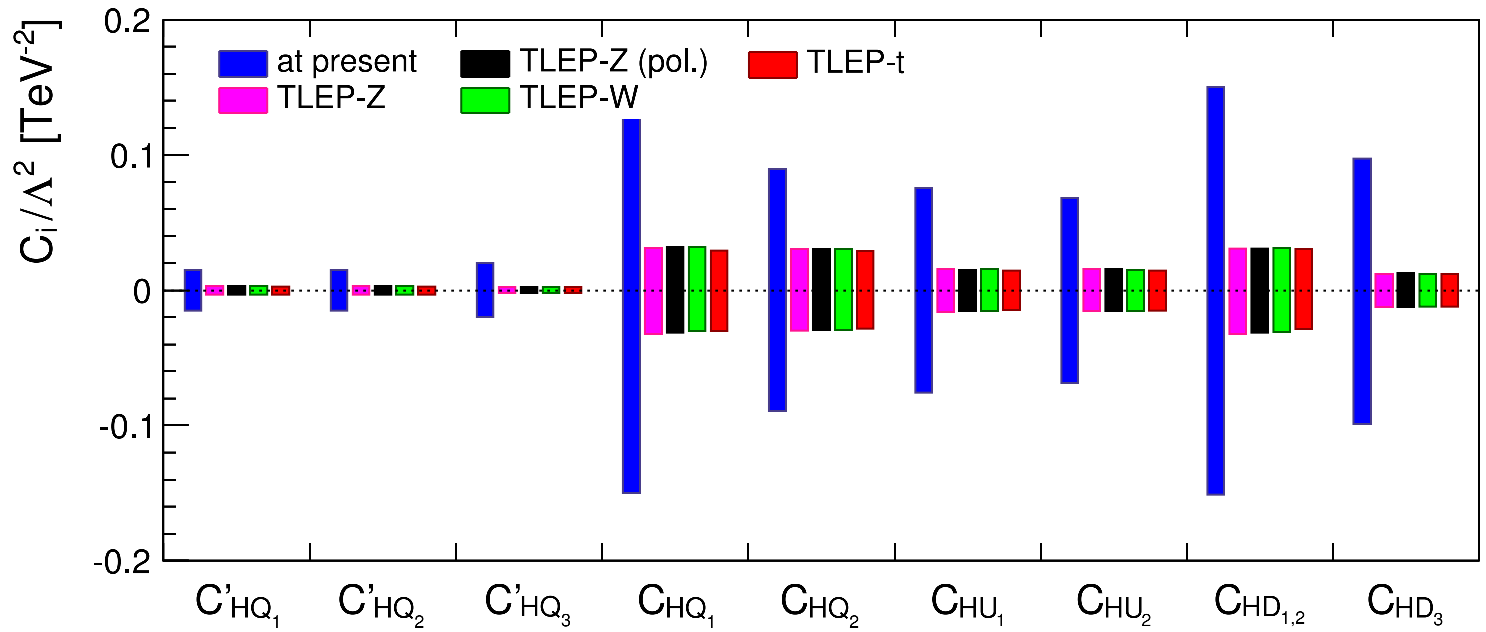
- Without quark-flavour universality

Coefficient	C_i/Λ^2 [TeV^{-2}] at 95%	Λ [TeV] $C_i = -1$	$C_i = 1$
C'_{HQ_1}	$[-0.028, 0.032]$	6.0	5.6
C'_{HQ_2}	$[-0.028, 0.032]$	6.0	5.6
C'_{HQ_3}, C_{HQ_3}	$[-0.020, 0.059]$	7.1	4.1
C_{HQ_1}	$[-0.28, 0.32]$	1.9	1.8
C_{HQ_2}	$[-0.17, 0.17]$	2.4	2.4
C_{HU_1}	$[-0.14, 0.16]$	2.7	2.5
C_{HU_2}	$[-0.12, 0.16]$	2.9	2.5
C_{HD_1}, C_{HD_2}	$[-0.32, 0.28]$	1.8	1.9
C_{HD_3}	$[-0.40, 0.00]$	1.6	39.5

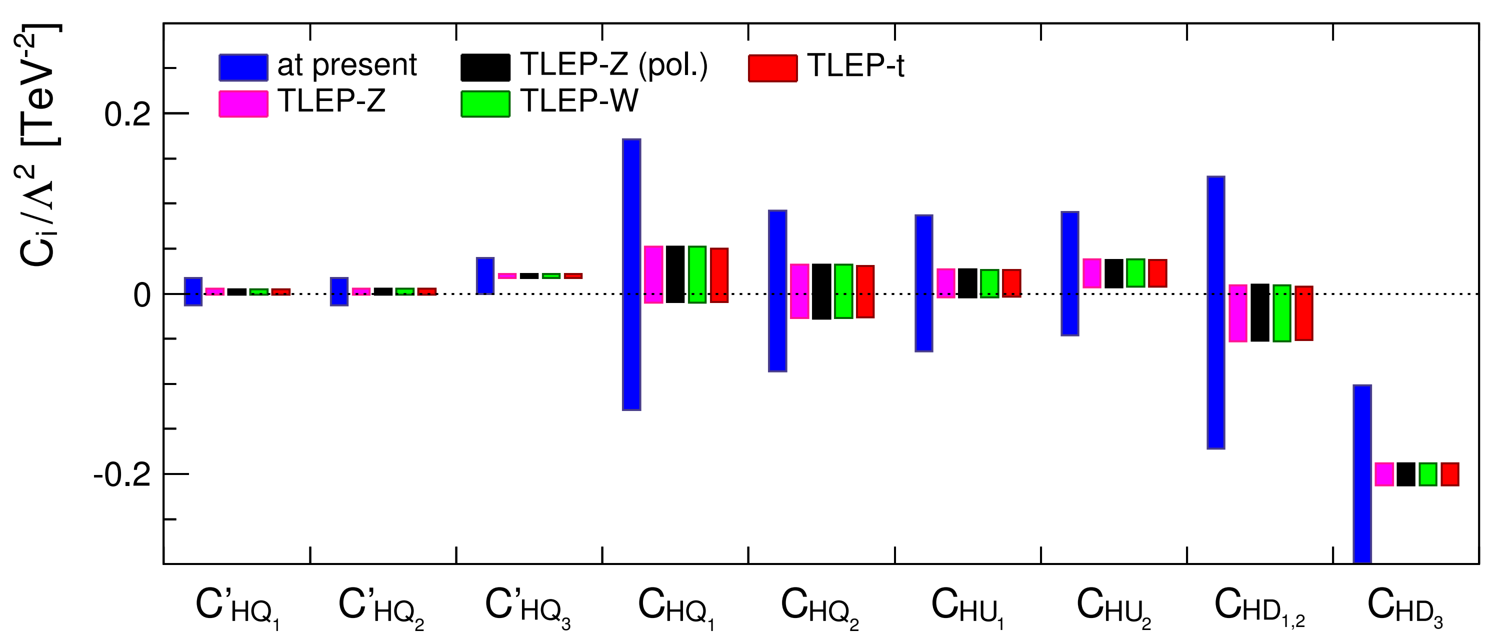
TLEP sensitivity to dim. 6 operators

- Without quark-flavour universality

SM scenario



NP scenario



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TLEP sensitivity to NP scale

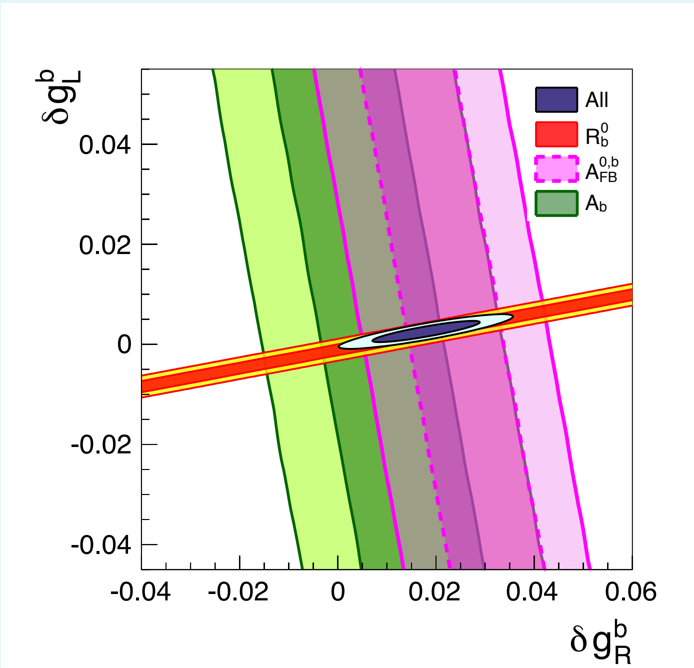
- Without quark-flavour universality

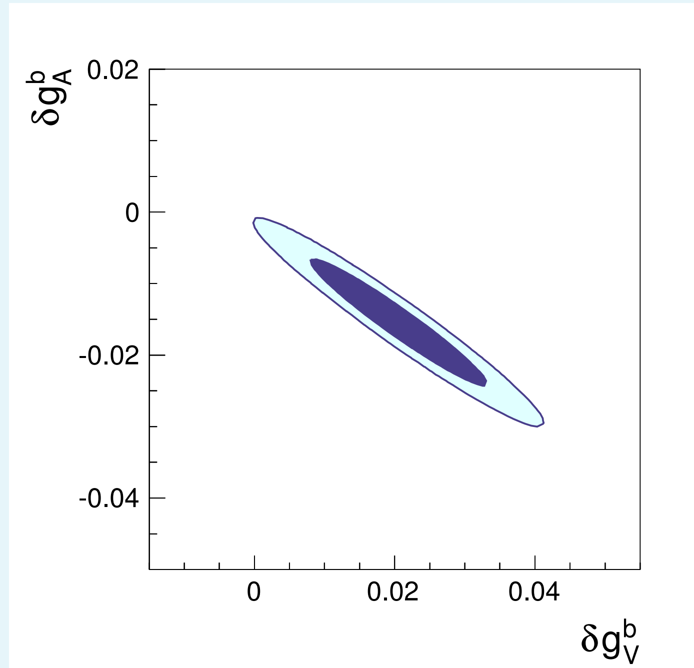
SM scenario, in units of TeV

Coefficient	at present $C_i=-1$	at present $C_i=1$	TLEP-Z $C_i=-1$	TLEP-Z $C_i=1$	TLEP-Z (pol.) $C_i=-1$	TLEP-Z (pol.) $C_i=1$	TLEP-W $C_i=-1$	TLEP-W $C_i=1$	TLEP-t $C_i=-1$	TLEP-t $C_i=1$
C'_{HQ_1}	5.8	5.8	12.7	12.7	12.7	12.8	12.8	12.8	13.0	13.1
C'_{HQ_2}	5.8	5.8	12.6	12.7	12.7	12.7	12.8	12.8	13.1	13.2
C'_{HQ_3}, C_{HQ_3}	5.0	5.0	14.9	15.0	15.0	15.0	15.1	15.1	15.1	15.1
C_{HQ_1}	1.8	1.8	4.0	4.0	4.0	4.0	4.1	4.0	4.1	4.2
C_{HQ_2}	2.4	2.4	4.1	4.1	4.1	4.1	4.2	4.2	4.2	4.2
C_{HU_1}	2.6	2.6	5.7	5.6	5.7	5.8	5.7	5.7	5.9	5.9
C_{HU_2}	2.7	2.7	5.7	5.7	5.8	5.7	5.7	5.7	5.9	5.8
C_{HD_1}, C_{HD_2}	1.8	1.8	4.0	4.0	4.0	4.0	4.1	4.0	4.2	4.1
C_{HD_3}	2.3	2.3	6.4	6.4	6.4	6.4	6.5	6.5	6.5	6.5

Zb$\bar{\text{b}}$ couplings

Current fit





Parameter	Fit result
δg_R^b	0.018 ± 0.007
δg_L^b	0.0026 ± 0.0014
δg_V^b	0.021 ± 0.008
δg_A^b	-0.015 ± 0.006

See also Batell et al. (13), etc.

- Deviation from the SM due to $A_{\mathrm{FB}}^{0,b}$
- $\delta R_b^0 \sim 6.6 \times 10^{-4} \;\rightarrow\; \delta R_b^0 \sim 6 \times 10^{-5}$ at TLEP
- TLEP precision on $\mathcal{A}_b$ and $A_{\mathrm{FB}}^{0,b}$?

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