Window on new physics via the scaling of SM effective operators

David Marzocca - SISSA

Scaling and tuning of EW and Higgs observables

arXiv: 1312.2928

J.Elias-Mirò, S. Gupta, C. Grojean, D.M.

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Rencontres de Moriond EW 2014

SM effective theory

(see talk by A. Pomarol)

We assume $\Lambda_{NP} \gg m_h$

In this case it is possible to describe experiments at the electroweak scale using an effective field theory framework:

We assume L and B conservation

$$\mathcal{L} = \mathcal{L}^{SM} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^{d=6} + (\text{dim} \ > 6)$$

Leading deformations of the SM

59 independent dim-6 operators for 1 family of fermions.

Grzadkowski et al. 1008.4884

EW and Scalar Boson observables

We focus on the following 10 (pseudo-)observables:

$\hat{S}, \hat{T}, W, Y$	$g_1^Z, k_\gamma, \lambda_\gamma$	$c_{\gamma\gamma}$	$c_{\gamma Z}$	c_H
$\lesssim 10^{-3}$	$\lesssim 10^{-2}$	$\lesssim 10^{-3}$	$\lesssim 10^{-2}$	$\lesssim 0.5$

Gfitter 1209.2716

Barbieri, Pomarol, Rattazzi, Strumia hep-ph/0405040

LEP EW Working Group 1302.3415

Pomarol, Riva 1308.2803

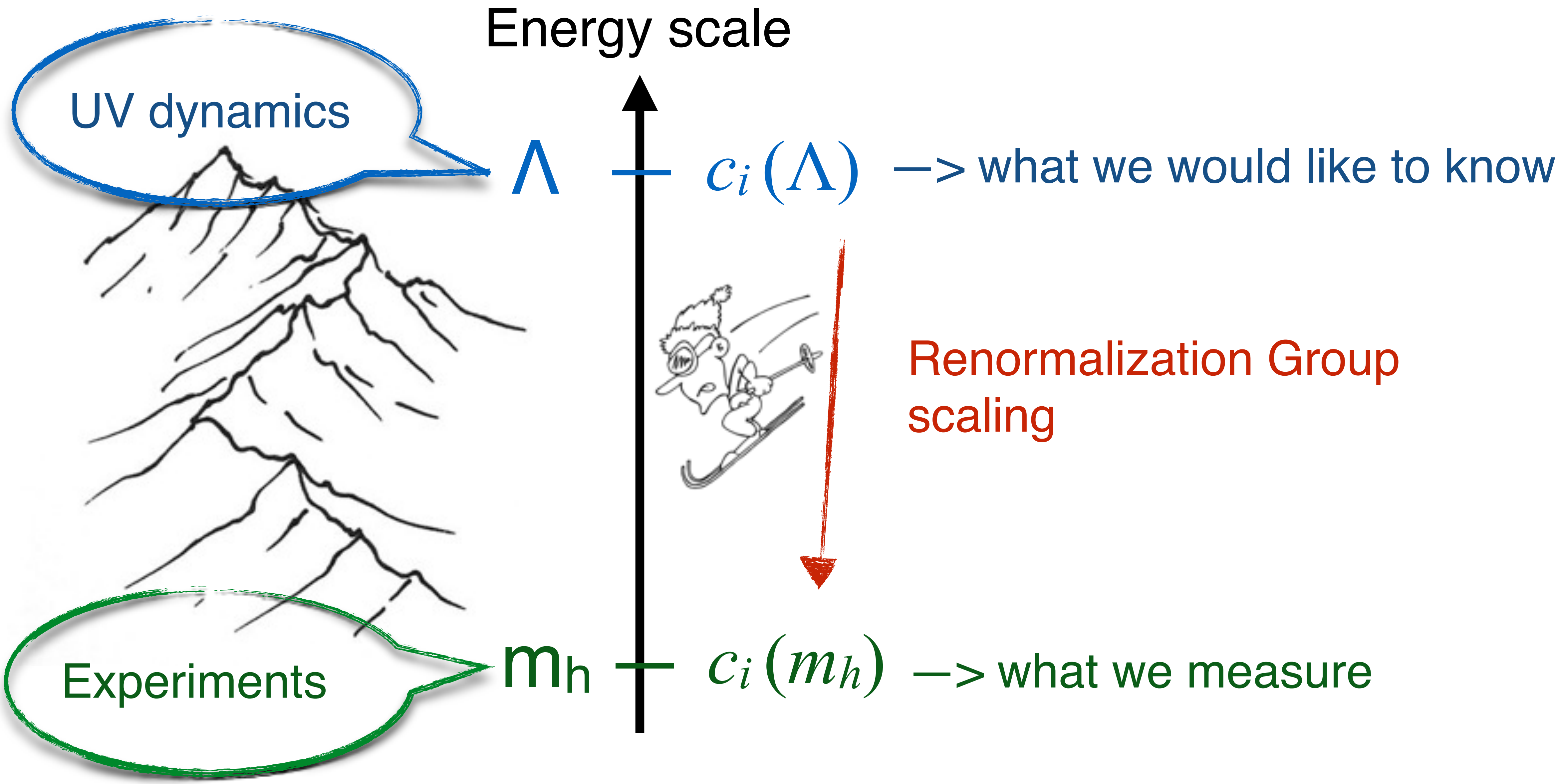
In our basis these are the relevant 10 operators:

$$\begin{aligned}
\mathcal{O}_H &= \frac{1}{2}(\partial^\mu |H|^2)^2 \\
\mathcal{O}_T &= \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2 \\
\mathcal{O}_W &= ig\left(H^\dagger \tau^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu} \\
\mathcal{O}_B &= ig' Y_H \left(H^\dagger \overleftrightarrow{D}^\mu H\right) \partial^\nu B_{\mu\nu}
\end{aligned}$$

$$\begin{aligned}
\mathcal{O}_{2W} &= -\frac{1}{2}(D^\mu W^a_{\mu\nu})^2 \\
\mathcal{O}_{2B} &= -\frac{1}{2}(\partial^\mu B_{\mu\nu})^2 \\
\mathcal{O}_{BB} &= g'^2 |H|^2 B_{\mu\nu} B^{\mu\nu} \\
\mathcal{O}_{WB} &= g g' H^\dagger \sigma^a H W^a_{\mu\nu} B^{\mu\nu} \\
\mathcal{O}_{WW} &= g^2 |H|^2 W^a_{\mu\nu} W^{a\mu\nu} \\
\mathcal{O}_{3W} &= \frac{1}{3!} g \epsilon_{abc} W^{a\,\nu}_{\mu} W^b_{\nu\rho} W^{c\,\rho\mu}
\end{aligned}$$

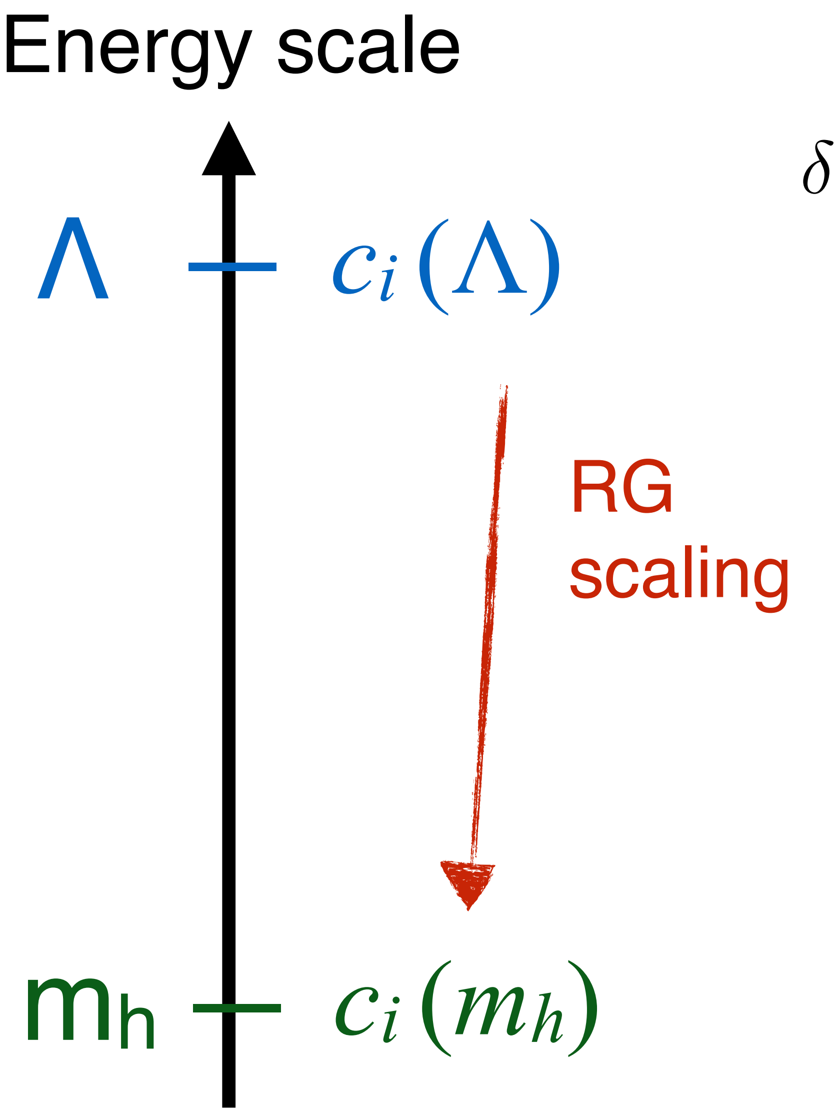
We “rotate" the Wilson coefficients to the *observable basis*.

RG scaling of the coefficients



The coefficient mix among themselves along this RG flow.

RG scaling of the coefficients



$$\delta(\text{obs})_i|_{m_h} = \hat{c}_i(m_h) = \hat{c}_i(\Lambda) - \frac{1}{16\pi^2}\hat{\gamma}_{ij}\hat{c}_j(\Lambda)\log\left(\frac{\Lambda}{m_h}\right)$$

We computed the relevant anomalous dimension matrix

A well known example:

Barbieri et al. 0706.0432

$$\hat{S} = \hat{c}_S(m_Z) = \hat{c}_S(\Lambda) + \frac{g^2}{16\pi^2}\frac{1}{6}\hat{c}_H \log\frac{\Lambda}{m_Z} + \ldots$$

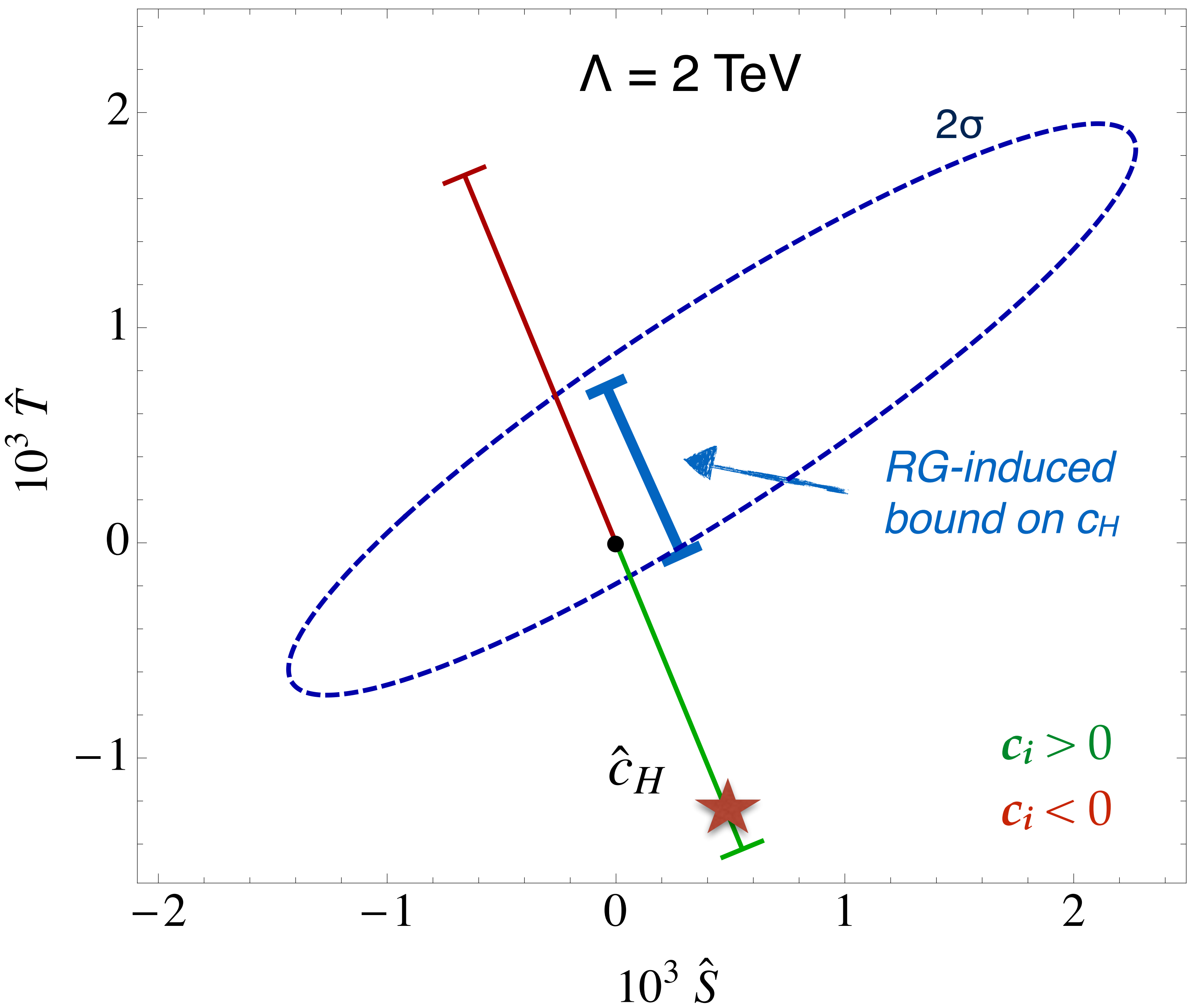
$$\hat{T} = \hat{c}_T(m_Z) = \hat{c}_T(\Lambda) - \frac{g'^2}{16\pi^2}\frac{3}{2}\hat{c}_H \log\frac{\Lambda}{m_Z} + \ldots$$

Direct bound (from experiment)

In **absence of tuning or correlations** each term should be bounded approximately by the same value.

RG-induced bounds

Bound from Gfitter
1209.2716

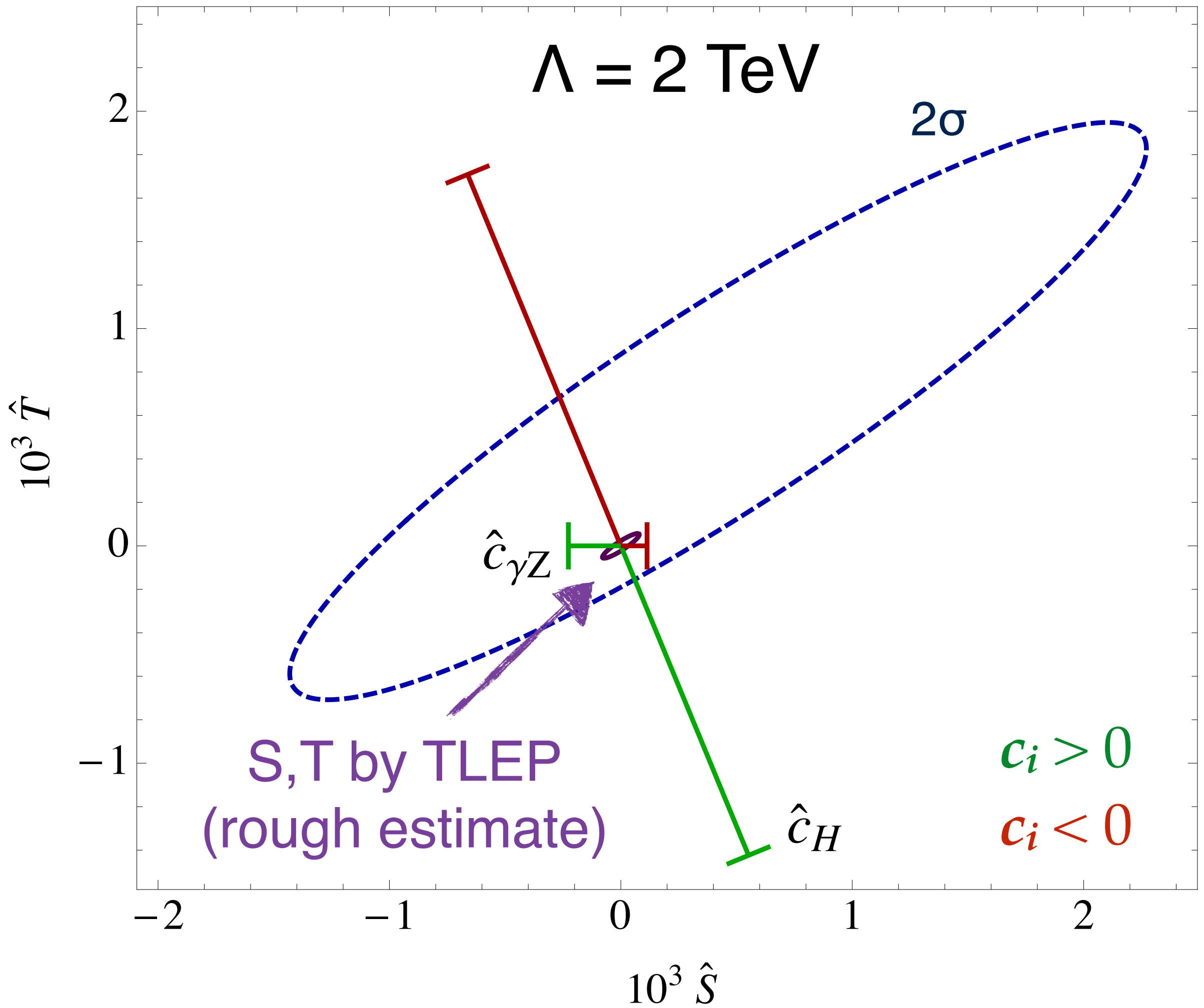


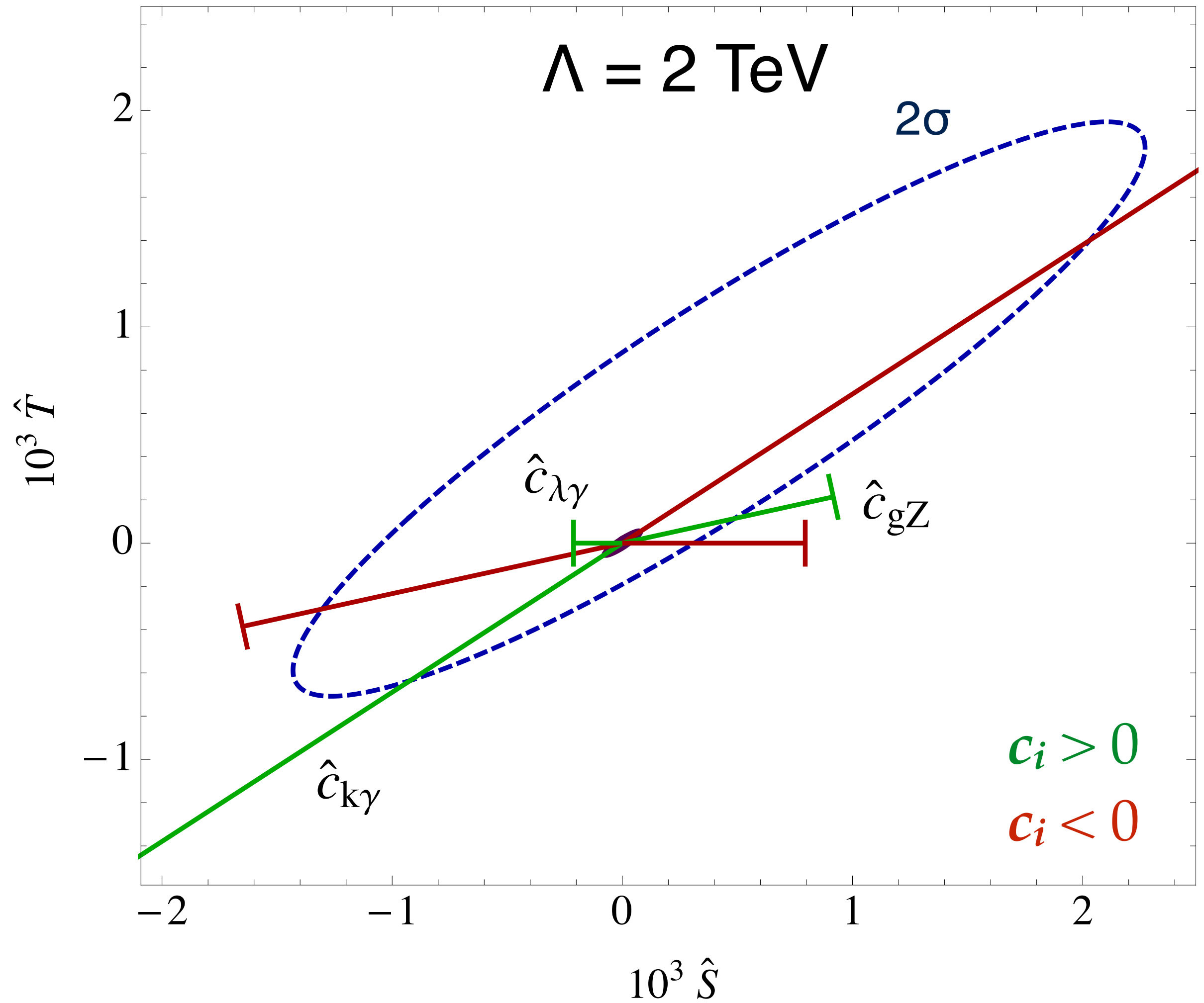
The length of the lines corresponds to the present 2σ direct bounds.

$$\hat{S} = \hat{c}_S(m_Z) = \hat{c}_S(\Lambda) + \frac{g^2}{16\pi^2}\frac{1}{6}\hat{c}_H \log\frac{\Lambda}{m_Z} + \ldots$$

$$\hat{T} = \hat{c}_T(m_Z) = \hat{c}_T(\Lambda) - \frac{g'^2}{16\pi^2}\frac{3}{2}\hat{c}_H \frac{\Lambda}{m_Z} + \ldots$$

Generalizing to the other observables we considered:





Thank you.

To know more, also regarding 3 operators with gluons, have a look at:

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Backup

“Observable" coefficients

$$\hat{c}_i \sim \frac{m_W^2}{\Lambda^2} c_i$$

EW oblique parameters:

$$\hat{T} = \hat{c}_T(m_W) = \frac{v^2}{\Lambda^2} c_T(m_W) \ , \quad \hat{S} = \hat{c}_S(m_W) = \frac{m_W^2}{\Lambda^2} \left[c_W(m_W) + c_B(m_W) + 4 c_{WB}(m_W) \right]$$

$$Y = \hat{c}_Y(m_W) = \frac{m_W^2}{\Lambda^2} c_{2B}(m_W) \ , \qquad W = \hat{c}_W(m_W) = \frac{m_W^2}{\Lambda^2} c_{2W}(m_W)$$

Anomalous triple gauge couplings:

$$\delta g_1^Z \equiv \hat{c}_{gZ}(m_W) = -\frac{m_W^2}{\Lambda^2} \frac{1}{c_{\theta_W}^2} c_W(m_W) \ , \qquad \delta\kappa_\gamma \equiv \hat{c}_{\kappa\gamma}(m_W) = \frac{m_W^2}{\Lambda^2} 4 c_{WB}(m_W)$$

$$\lambda_Z \equiv \hat{c}_{\lambda\gamma}(m_W) = -\frac{m_W^2}{\Lambda^2} c_{3W}(m_W) \ ,$$

SM scalar couplings:

$$\Delta\mathcal{L}_H \supset \frac{\hat{c}_H}{2} \frac{(\partial_\mu h)^2}{2} + \frac{\hat{c}_{\gamma\gamma} e^2}{m_W^2} \frac{h^2}{2} \hat{A}_{\mu\nu} \hat{A}^{\mu\nu} + \frac{\hat{c}_{\gamma Z} \ eg}{m_W^2 c_{\theta_W}} \frac{h^2}{2} \hat{A}_{\mu\nu} \hat{Z}^{\mu\nu}$$

$$\hat{c}_H(m_h) = \frac{v^2}{\Lambda^2} c_H(m_h),$$

$$\hat{c}_{\gamma\gamma}(m_h) = \frac{m_W^2}{\Lambda^2} \left(c_{BB}(m_h) + c_{WW}(m_h) - c_{WB}(m_h) \right),$$

$$\hat{c}_{\gamma Z}(m_h) = \frac{m_W^2}{\Lambda^2} \left(2 c_{\theta_W}^2 c_{WW}(m_h) - 2 s_{\theta_W}^2 c_{BB}(m_h) - (c_{\theta_W}^2 - s_{\theta_W}^2) c_{WB}(m_h) \right)$$

Beyond S, T, W, Y

To be completely general on the possible NP scenarios in electroweak precision observables from LEP1 and LEP2, in our basis one should consider two more operators:

$$\mathcal{O}_L = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{L}_L \gamma^\mu L_L) \ , \quad \mathcal{O}_{LL}^{1,2} = (\bar{L}^1{}_L \sigma^a \gamma^\mu L_L^1)(\bar{L}_L^2 \sigma^a \gamma^\mu L_L^2)$$

The first one contributes to lepton couplings to the Z boson,
the second one to the measurement of the Fermi constant.

Using observables from LEP1 (Z pole) and LEP2 it is possible to constrain the relevant 6 Wilson coefficients at the per mil level.
This would require a complete fit of LEP observables, which was beyond the purpose of our work.

The order of magnitude of our RG-induced bound will not change.

RG-induced bounds

Coupling	Direct Constraint	RG-induced Constraint
$\hat{c}_S(m_t)$	$[-1,2]\times 10^{-3}$	-
$\hat{c}_T(m_t)$	$[-1,2]\times 10^{-3}$	-
$\hat{c}_Y(m_t)$	$[-3,3]\times 10^{-3}$	-
$\hat{c}_W(m_t)$	$[-2,2]\times 10^{-3}$	-
$\hat{c}_{\gamma\gamma}(m_t)$	$[-1,2]\times 10^{-3}$	-
$\hat{c}_{\gamma Z}(m_t)$	$[-0.6,1]\times 10^{-2}$	$[-2,6]\times 10^{-2}$
$\hat{c}_{\kappa\gamma}(m_t)$	$[-10,7]\times 10^{-2}$	$[-5,2]\times 10^{-2}$
$\hat{c}_{gZ}(m_t)$	$[-4,2]\times 10^{-2}$	$[-3,1]\times 10^{-2}$
$\hat{c}_{\lambda\gamma}(m_t)$	$[-6,2]\times 10^{-2}$	$[-2,8]\times 10^{-2}$
$\hat{c}_H(m_t)$	$[-6,5]\times 10^{-1}$	$[-2,0.5]\times 10^{-1}$

—> from S,T

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From the h→γγ constraint:

$$\hat{c}_{\kappa\gamma} \in [-0.2, 0.3]\ ,$$
$$\hat{c}_{\lambda\gamma} \in [-0.05, 0.10]$$

RG mixing

$$\left(\hat{c}_S, \hat{c}_T, \hat{c}_Y, \hat{c}_W, \hat{c}_{\gamma\gamma}, \hat{c}_{\gamma Z}, \hat{c}_{\kappa\gamma}, \hat{c}_{gz}, \hat{c}_{\lambda\gamma}, \hat{c}_H\right)^t (m_t) \simeq$$

$$\begin{pmatrix}
0.9 & 0.003 & -0.03 & -0.08 & -0.02 & -0.02 & -0.04 & 0.05 & -0.01 & 0.001 \\
0.03 & 0.8 & -0.02 & -0.009 & 0 & 0 & -0.03 & 0.01 & 0 & -0.003 \\
0.001 & 0 & 0.9 & 0 & 0 & 0 & -0.001 & 0.001 & 0 & 0 \\
0 & 0 & -0.001 & 0.8 & 0 & 0 & 0 & -0.003 & 0 & 0 \\
0 & 0 & 0 & 0 & 0.9 & 0 & 0.006 & 0 & 0.02 & 0 \\
0 & 0 & 0 & 0 & 0 & 0.9 & 0.007 & 0 & 0.03 & 0 \\
0 & 0 & 0 & 0 & -0.02 & -0.02 & 0.9 & 0 & -0.01 & 0 \\
0.0004 & -0.0007 & -0.0004 & 0.1 & 0 & 0 & -0.0004 & 0.9 & 0 & -0.0007 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.9 & 0 \\
-0.02 & 0.03 & 0.01 & -0.4 & 0 & 0 & 0.02 & -0.3 & 0 & 0.8
\end{pmatrix}
\begin{pmatrix}
\hat{c}_S(\Lambda) \\ \hat{c}_T(\Lambda) \\ \hat{c}_Y(\Lambda) \\ \hat{c}_W(\Lambda) \\ \hat{c}_{\gamma\gamma}(\Lambda) \\ \hat{c}_{\gamma Z}(\Lambda) \\ \hat{c}_{\kappa\gamma}(\Lambda) \\ \hat{c}_{gz}(\Lambda) \\ \hat{c}_{\lambda\gamma}(\Lambda) \\ \hat{c}_H(\Lambda)
\end{pmatrix}$$

Λ = 2 TeV