Electroweak Precision Observables in the SM4 with General Flavour Structure

Martin Wiebusch
in collaboration with Patrick Gonzalez and Jürgen Rohrwild

[arXiv:1105.3434]

Karlsruhe Institute of Technology

Istanbul, October 2011

Introduction

The enlarged CKM matrix of the SM4 contains

- new complex phases $(\delta_{14}, \delta_{24})$,
- additional mixing angles $(\theta_{14}, \theta_{24}, \theta_{34})$.

$$\theta_{14}, \theta_{24}, \theta_{34} = 0 \quad \Rightarrow \quad V^{\mathrm{CKM4}} = \begin{pmatrix} & & & 0 \\ & V^{\mathrm{CKM3}} & & 0 \\ & & & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

The additional flavour structure can

- make electroweak baryogenesis viable,
- relax some of the tensions in B physics measurements

Flavour and EWPOs

- Flavour observables still allow large mixing angles in the SM4
  [Bobrowski, Lenz, Riedl, Rohrwild, arXiv:0902.4883]
- Scenarios with very large mixing are ruled out by Electroweak precision observables.
  [Chanowitz, arXiv:0904.3570]
  [Eberhardt, Lenz, Rohrwild, arXiv:1005.3505]

⇒ There is some non-trivial interplay between constraints from flavour physics and EWPOs.

Z Pole Observables

LEP and SLC measured

- Z total width
- $Z \to f\bar{f}$ partial widths
- asymmetries

at permille level accuracy.

EW form factors: $$\Gamma^{\mu}_{Zf\bar{f}} = ie\gamma^{\mu}[g_V^f - g_A^f\gamma_5] \quad .$$

partial widths: $$\Gamma(Z \to f\bar{f}) = \alpha M_Z \frac{N_c^f}{3}\mathcal{R}_f[|g_V^f|^2 + |g_A^f|^2] \quad ,$$

asymmetries: $$\mathcal{A}_f = \frac{2\,\mathrm{Re}\,g_V^f\,\mathrm{Re}\,g_A^f}{(\mathrm{Re}\,g_V^f)^2 + (\mathrm{Re}\,g_A^f)^2} \quad .$$

Oblique Electroweak Parameters

New physics contributions to EWPOs can be absorbed into three parameters S, T and U assuming that

- new physics enters only through gauge boson self-energies
- the scale of new physics is $\gg M_Z$

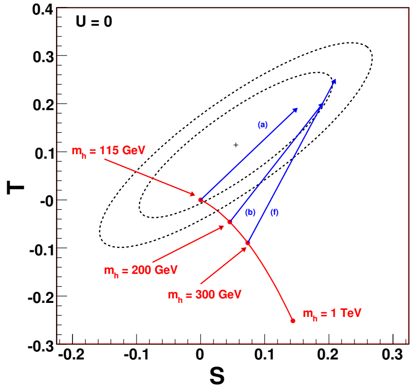
$$\alpha S = 4c_W^2 s_W^2 \left[\Sigma'_{ZZ}(0) - \Sigma'_{\gamma\gamma}(0) - \frac{c_W^2 - s_W^2}{c_W s_W}\Sigma'_{\gamma Z}(0)\right]$$

$$\alpha T = \frac{\Sigma_{WW}(0)}{M_W^2} - \frac{\Sigma_{ZZ}(0)}{M_Z^2}$$

$$\alpha U = 4s_W^2[\Sigma'_{WW}(0) - c_W^2\Sigma'_{ZZ}(0) - s_W^2\Sigma'_{\gamma\gamma}(0) - 2c_W s_W \Sigma'_{\gamma Z}(0)]$$

Electroweak Fit

- Express all EWPOs in terms of S, T and U
- Determine SM parameters ($\alpha(M_Z)$, α_s, M_Z, m_t, m_H) and S, T, U simultaneously from a fit. (LEP EWWG)



[Kribs et al. arXiv:0706.3718]

S and T in the SM4

In a given model S, T and U can be calculated:

$$S = \frac{N_c}{6\pi} \sum_{f=1}^{4} \left[1 - \frac{1}{3} \ln \frac{m_{u_f}^2}{m_{d_f}^2} \right] + \frac{1}{6\pi} \sum_{f=1}^{4} \left[1 + \ln \frac{m_{\nu_f}^2}{m_{l_f}^2} \right] \quad ,$$

$$T = \frac{N_c}{16\pi s_W^2 c_W^2 M_Z^2} \left[\sum_{q=u,d,s,\ldots,t',b'} m_q^2 - \sum_{f,f'=1}^{4} |V_{ff'}^{\mathrm{CKM4}}|^2 F_T(m_{u_f}^2, m_{d_{f'}}^2) \right]$$
$$+ \frac{1}{16\pi s_W^2 c_W^2 M_Z^2} \left[\sum_{l=\nu_e,e^-,\ldots,\nu',\ell'^-} m_l^2 - \sum_{f,f'=1}^{4} |U_{ff'}^{\mathrm{PNMS4}}|^2 F_T(m_{\nu_f}^2, m_{l_{f'}}^2) \right] \quad ,$$

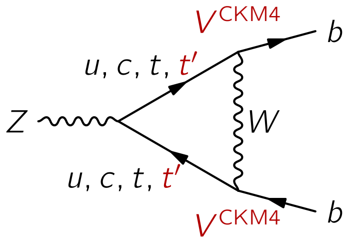
with

$$F_T(m_1^2, m_2^2) = 2 \frac{m_1^2 m_2^2}{m_1^2 - m_2^2} \ln \frac{m_1^2}{m_2^2} \quad .$$

[Eberhardt, Lenz, Rohrwild, arXiv:1005.3505]

Non-Oblique Corrections

For $\theta_{14}, \theta_{24}, \theta_{34} \neq 0$ new physics does *not* only enter through gauge boson self-energies.



For $\theta_{14} = \theta_{24} = 0$:

$$\delta g_L^b = \frac{\alpha \sin^2 \theta_{34}}{16\pi s_W^2 c_W^2 M_Z^2}(m_{t'}^2 - m_t^2) \quad .$$

[Chanowitz, arXiv:1007.0043]

Generic Approach

- Define new physics contributions to the form factors:

$$\delta g_V^f = g_V^{f,\text{SM4}} - g_V^{f,\text{SM3}} \quad , \quad \delta g_A^f = g_A^{f,\text{SM4}} - g_A^{f,\text{SM3}} \quad .$$

- For $M_W^{\text{SM4}}, M_Z^{\text{SM4}}, \alpha^{\text{SM4}} = M_W^{\text{SM3}}, M_Z^{\text{SM3}}, \alpha^{\text{SM3}}$ the quantities δg_V^f and δg_A^f are IR finite.
- Write the observables as

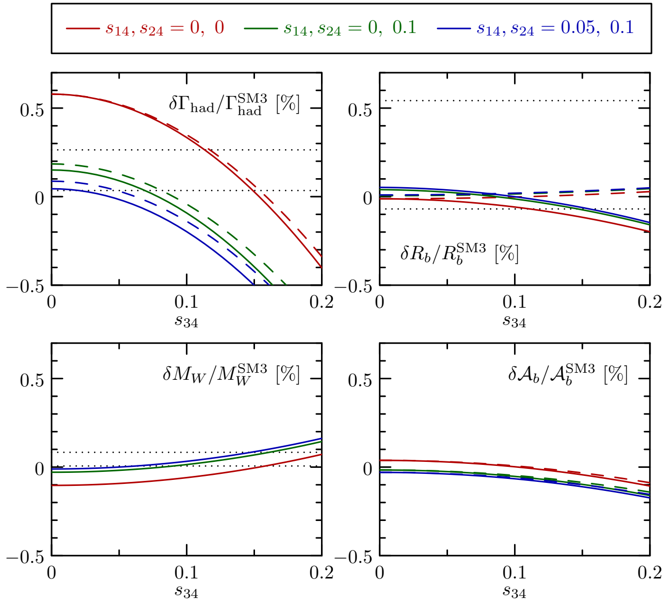
$$\Gamma(Z \to f\bar{f})^{\text{SM4}} = \Gamma(Z \to f\bar{f})^{\text{SM3}} + \delta\Gamma(Z \to f\bar{f}) \quad ,$$
$$\mathcal{A}_f^{\text{SM4}} = \mathcal{A}_f^{\text{SM3}} + \delta\mathcal{A}_f \quad .$$

- Express $\delta\Gamma(Z \to f\bar{f})$, $\delta\mathcal{A}_f$ (to first order) in terms of δg_V^f and δg_A^f.

Advantages of the Generic Approach

- Use state-of-the-art calculations of the SM3 observables, including multiloop corrections. [ZFitter]
- Use automated tools for computing δg_V^f and δg_A^f at one-loop. [FeynArts/FormCalc]
- The calculation can be re-done in a different model by simply supplying a different FeynArts model file.

Size of Non-Oblique Corrections



[Gonzalez, Rohrwild, MW, arXiv:1105.3434]

Conclusions/Outlook

- The non-trivial interplay between EWPO and Flavour constraints calls for a combined fit of EWPO and Flavour observables.
- Non-oblique contributions to the EWPOs should be included correctly.
- Computation of EWPOs in the "generic approach" is currently being included in the CKMFitter software.
- First fit results should be ready soon...