Effective Lagrangian Approach to Top Decay via Flavor Changing Neutral Current

Kazumasa Ohkuma[a], Zenrō Hioki[b] and Akira Uejima[a]   [a] Okayama University of Science,   [b] University of Tokushima

LP2019

Objectives

Possible non-standard tqZ ($q = u, c$) couplings, which induce top decays via Flavor Changing Neutral Current (FCNC), are studied based on following strategies;

- **Model-independent analysis is performed using effective Lagrangian.**
- **All the couplings are handled not only as complex numbers but also as independent parameters.**
- **Constraints on the couplings are given by comparing current experimental data with the theoretical values derived by varying them at the same time.**
- **Possible correlation among the parameters is studied.**

Effective Lagrangian

Assuming that there exists some new physics characterized by an energy scale Λ (e.g., the mass of a typical new particle) and all the non-standard particles are not lighter than the Λ, the standard-model Lagrangian of tqZ interactions describing phenomena around the electroweak scale is extended as

$$\mathcal{L}_{tqZ} = -\frac{g}{2\cos\theta_W}\Big[\bar{\psi}_q(x)\gamma^\mu(f_1^L P_L + f_1^R P_R)\psi_t(x)Z_\mu(x) + \bar{\psi}_q(x)\frac{\sigma^{\mu\nu}}{M_Z}(f_2^L P_L + f_2^R P_R)\psi_t(x)\partial_\mu Z_\nu(x)\Big],$$

where g and θ_W is the $SU(2)$ coupling constant and the weak mixing angle, $P_{L/R} \equiv (1 \mp \gamma_5)/2$. $f_{1,2}^{L,R}$ are non-standard couplings including Λ and vacuum expectation value, and treated as complex numbers independent of each other from the viewpoint of model-independent analysis.

Experimental Data

The following experimental information at 95 % confidence level is used as our input data [ATLAS'17];

- the total decay width of the top quark, Γ^t [GeV].

$$4.8 \times 10^{-2} \le \Gamma^t \le 3.5$$

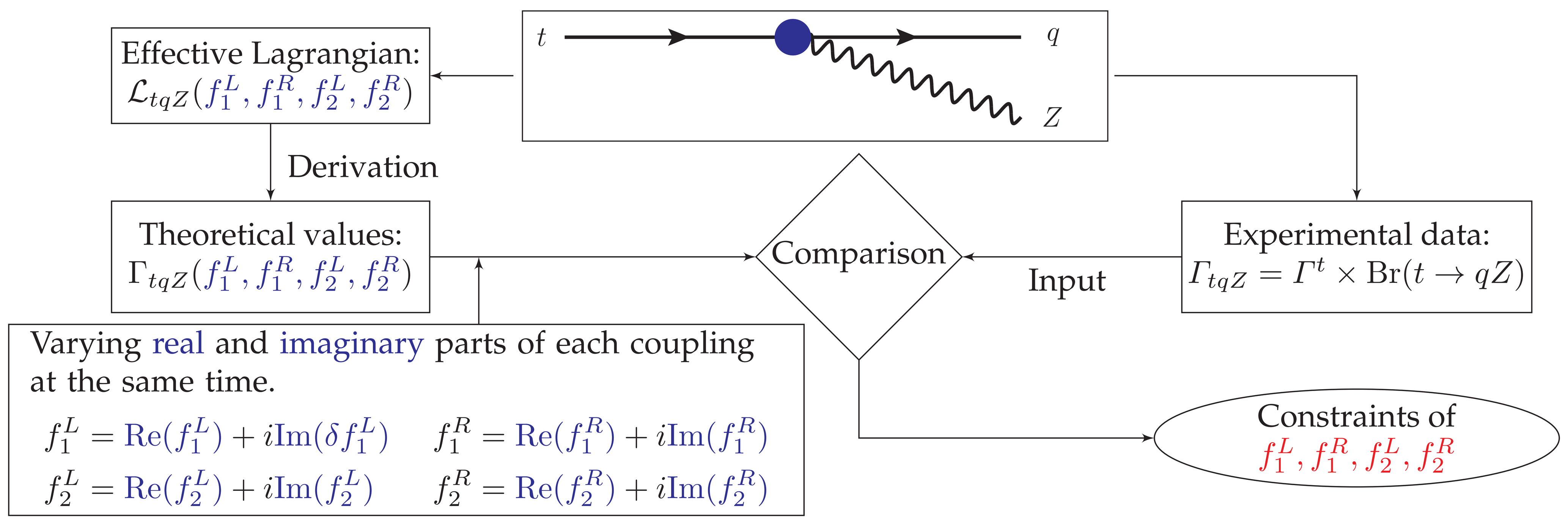
- The upper limits of the branching fractions for $t \to qZ$ decays

Current	Future expectation (@HL-LHC)
$\mathrm{Br}(t \to uZ) < 1.7 \times 10^{-4}$	$\mathrm{Br}(t \to uZ) < 8.5 \times 10^{-5}$
$\mathrm{Br}(t \to cZ) < 2.3 \times 10^{-4}$	$\mathrm{Br}(t \to cZ) < 1.2 \times 10^{-4}$

Then, multiplying the minimum (maximum) value of Γ^t by $\mathrm{Br}(t \to uZ/cZ)$, the partial decay widths for each process, Γ_{tqZ} [GeV], which are input data in our analysis are obtained as

$$0 \le \Gamma_{tuZ} < 8.1 \times 10^{-6}\ \ (5.9 \times 10^{-4}),$$
$$0 \le \Gamma_{tcZ} < 1.1 \times 10^{-5}\ \ (8.0 \times 10^{-4}).$$

Schematic View of our Approach

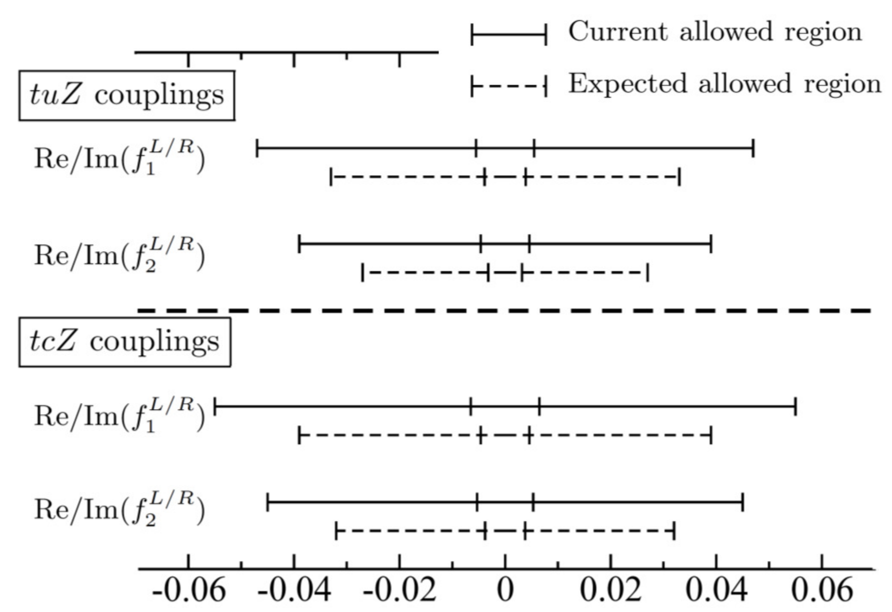


Allowed regions of tqZ

- Current constraints on the tuZ-coupling parameters: Those over (under) the dashed lines in the rows denoted as Min. and Max. are the minimum and maximum of the allowed ranges coming from $\Gamma_{tuZ} = 8.1 \times 10^{-6}$ (5.9×10^{-4}).

	f_1^L		f_1^R		f_2^L		f_2^R	
	$\mathrm{Re}(f_1^L)$	$\mathrm{Im}(f_1^L)$	$\mathrm{Re}(f_1^R)$	$\mathrm{Im}(f_1^R)$	$\mathrm{Re}(f_2^L)$	$\mathrm{Im}(f_2^L)$	$\mathrm{Re}(f_2^R)$	$\mathrm{Im}(f_2^R)$
Min.	-5.5×10^{-3} / -4.7×10^{-2}	-5.5×10^{-3} / -4.7×10^{-2}	-5.5×10^{-3} / -4.7×10^{-2}	-5.5×10^{-3} / -4.7×10^{-2}	-4.6×10^{-3} / -3.9×10^{-2}	-4.6×10^{-3} / -3.9×10^{-2}	-4.6×10^{-3} / -3.9×10^{-2}	-4.6×10^{-3} / -3.9×10^{-2}
Max.	5.5×10^{-3} / 4.7×10^{-2}	5.5×10^{-3} / 4.7×10^{-2}	5.5×10^{-3} / 4.7×10^{-2}	5.5×10^{-3} / 4.7×10^{-2}	4.6×10^{-3} / 3.9×10^{-2}	4.6×10^{-3} / 3.9×10^{-2}	4.6×10^{-3} / 3.9×10^{-2}	4.6×10^{-3} / 3.9×10^{-2}

- Summary of Current and expected constraints on the tuZ and tcZ couplings



- The allowed regions of tqZ couplings are within $|f_{1/2}^{L/R}| < \mathcal{O}(10^{-3}) \sim \mathcal{O}(10^{-2})$.
- The tuZ couplings are more strongly restricted than the tcZ couplings.
- Both the real and imaginary parts of $f_1^{L/R}$ and $f_2^{L/R}$ in each of the tuZ and tcZ couplings have the same minimum and maximum limits, respectively.
- The allowed regions are expected to be narrowed by about 30 % if the assumed branch fractions are realized at the HL-LHC with 3000fb^{-1} luminosity.

Discussion

The maximum and minimum values of flavor-changing neutral tqZ couplings allowed by the present experimental data of the total decay widths and Branching rate were derived by varying all the couplings, $\mathrm{Re/Im}(f_{1/2}^{L/R})$, independently at the same time.

- The allowed region derived by treating all the coupling constants as complex-number parameters (8 parameter analysis) could be about 1.8 times larger than that region derived by only one coupling being treated as a parameter (1 parameter analysis) because cancellations could happen among the contributions originated from those couplings.

  e.g. tuZ couplings case;

1 parameter analysis	8 parameter analysis
$-3.0 \times 10^{-3} < \mathrm{Re}(f_1^L) < 3.0 \times 10^{-3}$	$-5.5 \times 10^{-3} < \mathrm{Re}(f_1^L) < 5.5 \times 10^{-3}$
$-2.5 \times 10^{-3} < \mathrm{Re}(f_2^L) < 2.5 \times 10^{-3}$	$-4.6 \times 10^{-3} < \mathrm{Re}(f_2^L) < 4.6 \times 10^{-3}$

- There are strong correlations between $\pm\mathrm{Re/Im}(f_1^{L/R})$ and $\mp\mathrm{Re/Im}(f_2^{R/L})$;

  e.g. Following table is allowed minimum and maximum values of the tuZ couplings for $\Gamma_{tuZ} = 8.1 \times 10^{-6}$ in the case that $\mathrm{Re}(f_1^L)$ is fixed to 5.5×10^{-3} which is allowed maximum value. It is found that a strong correlation exists between $\mathrm{Re}(f_1^L)$ and $\mathrm{Re}(f_2^R)$.

	f_1^L		f_1^R		f_2^L		f_2^R	
	$\mathrm{Re}(f_1^L)$	$\mathrm{Im}(f_1^L)$	$\mathrm{Re}(f_1^R)$	$\mathrm{Im}(f_1^R)$	$\mathrm{Re}(f_2^L)$	$\mathrm{Im}(f_2^L)$	$\mathrm{Re}(f_2^R)$	$\mathrm{Im}(f_2^R)$
Min.	$\mathbf{5.5 \times 10^{-3}}$ (Fixed)	-1.0×10^{-3}	-1.0×10^{-3}	-1.0×10^{-3}	-8.0×10^{-4}	-8.0×10^{-4}	$\mathbf{-4.2 \times 10^{-3}}$	-8.0×10^{-3}
Max.		1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}	8.0×10^{-4}	8.0×10^{-4}	$\mathbf{-3.4 \times 10^{-3}}$	8.0×10^{-3}

References

This presentation is based on following references;

- Z. Hioki, K. Ohkuma and A. Uejima, "Studying flavor-changing neutral tqZ couplings: Current constraints and future prospects," arXiv:1809.01389 [hep-ph]. To appear in Modern Physics Letters A
- Z. Hioki, K. Ohkuma and A. Uejima, Work in progress

Contact Information

Kazumasa OHKUMA (presenter)

Email kazumasa.ohkuma@gmail.com