Novel flavour-changing neutral currents in the top quark sector

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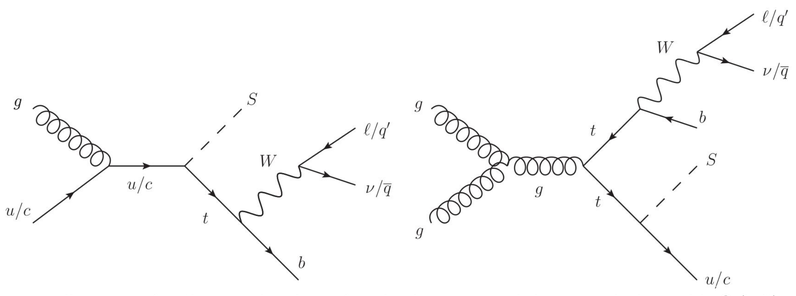
Interactions and constraints

Mediated by leptophilic scalars at the electroweak scale, **flavour-changing neutral currents (FCNC) processes in the top quark sector** can easily arise in scenarios of **new physics**:

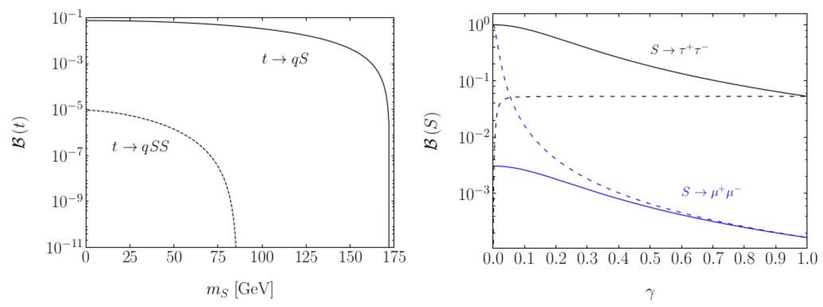
$$\Delta L = -\frac{1}{2}\lambda_{HS} S^2\left(|H|^2 - \frac{v^2}{2}\right) + c_{HS}\frac{(\partial S)^2}{\Lambda^2}|H|^2 + \frac{S}{\Lambda}\overline{\mathbf{f_L}}\mathbf{Y^f} H \mathbf{f_R} + \frac{S^2}{\Lambda^2}\left[c'_{HS}|DH|^2 + \tilde{c}_{HS}\left(|H|^4 - \frac{v^4}{4}\right) + \overline{\mathbf{f_L}}\tilde{\mathbf{Y}}^{\mathbf{f}} H \mathbf{f_R}\right].$$

Experimental analyses currently performed are not significantly sensitive to these interactions and can be improved by dedicated searches.



Feynman diagrams for the production of a single top quark in association with *S* (left) and for the top quark pair production with a FCNC top quark decay into the extra singlet (right).

Three different scenarios were considered:
1) two singlets *S* both decaying into a pair of muons;
2) one singlet *S* decaying into a pair of muons;
3) one singlet *S* decaying into a pair of taus.

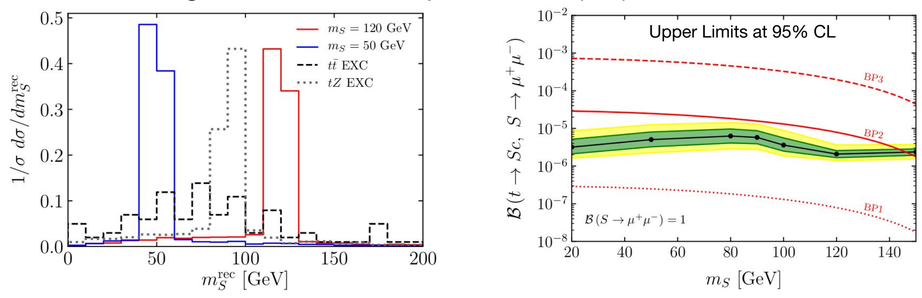


Top branching ratios in function of the mass of scalar S (left) and scalar branching ratios into muons and taus as a function of the $\mathbb{Z}_2$ breaking parameter, γ, for m_S = 100 GeV (right).

Search for $t \to Sq$, $S \to l^+ l^-$

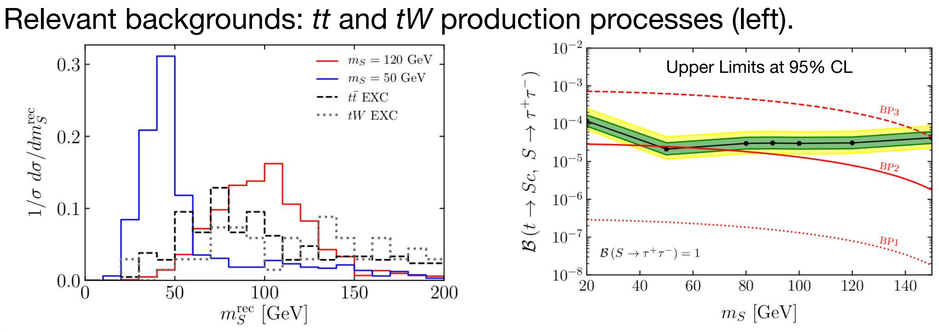
For $pp \to tS$, $S \to \mu^+ \mu^-$, the following set of cuts is applied:
- exactly three leptons;
- at least one jet;
- exactly one b-tagged jet;
- exactly one S candidate with a OSSF pair of muons;
- total mass of the system lower than 1 TeV;
- cut on the invariant mass of the top quark and scalar *S* candidates within a window of 30 and 50 GeV from the reference masses.

Dominant backgrounds: *tt* and *tZ* production (left).



For $S \to \tau^+ \tau^-$:
- exactly one lepton;
- at least three jets;
- exactly one b-tagged jet;
- total transverse mass below 500 GeV;
- mass of the reconstructed scalar *S* within a window of 30 GeV.

Relevant backgrounds: *tt* and *tW* production processes (left).



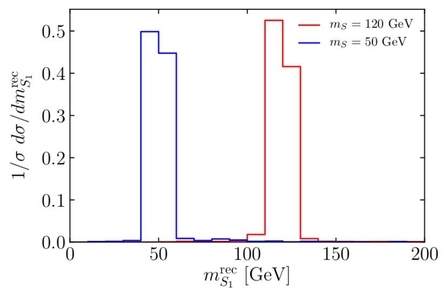
Search for $t \to SSq$, $S \to \mu^+ \mu^-$

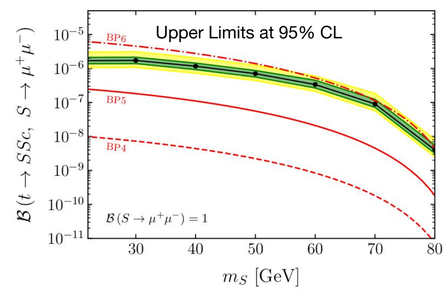
Generation of signal and background events
Centre-of mass energy: 13 TeV
Full simulation: MadGraph, Pythia and Delphes
Signal events: UFO model implemented with Feynrules assuming seven benchmark masses of *S* - 20, 50, 80, 90, 100, 120 and 150 GeV
Background processes: *tW*, *ttV*, *VV*, *ZVV*, *tt*, *V* + jets and *tZ*, with *V* = *W*,*Z*

Reconstruction:
The scalar *S* was reconstructed by requiring an opposite sign and same flavour pair (OSSF) of leptons. The reconstruction of the top quark is done through a jet tagged as a bottom quark and the *W* boson hadronically reconstructed. The muons reconstructing the two scalars are those minimizing $|m_{S_1}^{\rm rec} - m_{S_2}^{\rm rec}|$. For the remaining scenarios, the *W* boson is reconstructed with one lepton and the missing transverse momentum.

Selection cuts:
- exactly four leptons;
- at least three jets;
- exactly one b-tagged jet;
- exactly two S candidates with a OSSF pair of muons;
- total mass of the system lower than 1 TeV;
- cut on the invariant mass of the top quark and scalar *S* candidates within a window of 30 and 50 GeV from the reference masses.

After the selection, the proposed analysis becomes essentially background-free.





Conclusions

Using an effective field theory approach, **new top flavour-changing neutral currents** arise in models of new physics **with light pseudo-scalar singlet *S***.

Three new dedicated searches were proposed in full detail where the following limits at 95% confidence level (CL) were obtained assuming an integrated luminosity of 150 fb^{-1}:

- For $pp \to tSS$, $S \to \mu^+ \mu^-$, the upper limit on the production cross section is 10^{-3} pb. The strongest limits on the **branching ratio** for $t \to SSq$ are obtained for a m_S of 80 GeV with the value of **5 (25) x 10^{-10}** for up quark (charm quark).

- For $pp \to tS$, $S \to \mu^+ \mu^-$, a production cross section higher than 10^{-3} pb can be tested that can be translated into a **branching ratio** (with a m_S of 150 GeV) for $t \to Sq$ of **5 (15) x 10^{-7}** for up quark (charm quark).

- For $pp \to tS$, $S \to \tau^+ \tau^-$, the upper limit on the production cross section is 10^{-2} pb. For a m_S of 50 GeV, the stringent limits on the branching ratio for $t \to Sq$ are **11 (12) x 10^{-6}** for up quark (charm quark).

Prospects for higher luminosities can also be predicted by scaling the statistical significance with $\sqrt{L}$. For a luminosity of 3 ab^{-1}, scales of order 3, 200 and 160 TeV can be probed in each of the channels, respectively.

The work presented in this poster can be found in more detail in the arXiv:2005.09594 publication or through the QR code in the right.

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