Search for scalar top quarks in a compressed SUSY scenario

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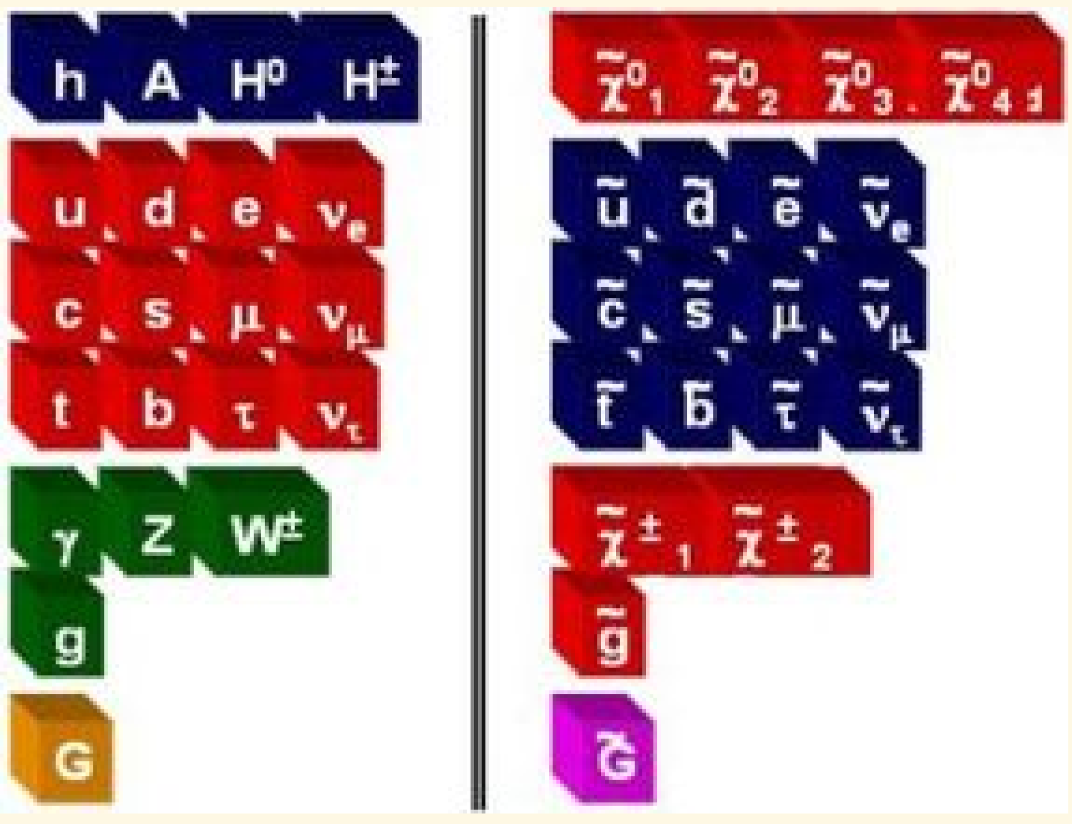
I. Introduction

A search for scalar top quark (stop) production [1] is presented using the CMS detector at the LHC. The results based on the proton-proton data collected at 13 TeV center-of-mass energy in 2016 corresponding to 35.9 fb^{-1} integrated luminosity are summarized. The preparations for the analysis of the full Run 2 CMS dataset quadrupling the statistics are discussed.

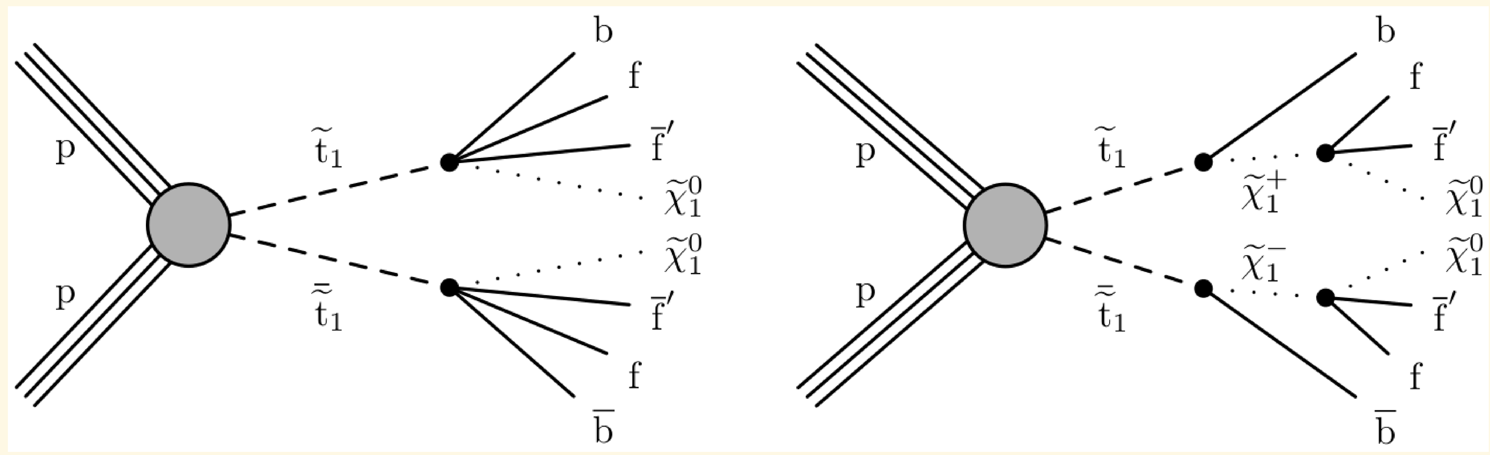


The supersymmetric extension of the Standard Model predicts a partner for each known particle

So far, no evidence has been found for the production of supersymmetric (SUSY) particles and stringent limits are placed on the SUSY parameter space.
Dark matter abundance and consideration for natural supersymmetry prefer certain models with a compressed mass spectrum, meaning that multiple supersymmetric states are nearly degenerate in mass.
A previous search for stop pair-production [1] targeted this compressed region, where the mass difference ΔM between the neutralino acting as the lightest supersymmetric particle (LSP) and the stop is small. In the measurement a prompt decay of the stop was assumed. However, the mass spectrum influences the stop lifetime, and a significant decay length is expected in the low ΔM case, affecting the event reconstruction.
An effort has started in view of the analysis of the full Run 2 dataset to improve the reconstruction and identification efficiency of leptons (electrons, in particular) with large impact parameter, and to reoptimize the analysis, including the b-tagging requirements.

II. Theory: Stop production with compressed mass spectrum

Supersymmetric particles are assumed to be created in pairs if the underlying theory respects R-parity conservation. $P_R = -1^{3B+L+2s}$ is a multiplicative quantum number defined with the baryon number (B), the lepton number (L), and the spin (s) of the particle such that SM particles have $P_R = +1$, and supersymmetric partners $P_R = -1$. R-parity conservation is motivated by experimental results (such as the absence of proton decay). It leads to pair production of superpartners in high particle interactions, as well as to cascade decays of SUSY particles to the LSP, which is stable.
In case of a compressed supersymmetric particle spectrum, the significant missing transverse energy ($p_{\mathrm{T}}^{\mathrm{miss}}$) emerging from the neutral and weakly interacting neutralino LSP leaving the detector unobserved is accompanied by soft (low-momentum) visible decay products.
In this work, the mass difference between the produced primary scalar top quark ($\tilde{\mathrm{t}}_1$) and the neutralino LSP ($\tilde{\chi}_1^0$) is assumed not exceed the W boson mass. Then, the usually dominant two-body decay to a top quark (t) and a neutralino is kinematically forbidden, as well as the three-body decay to a b quark, a $\mathrm{W}^{\pm}$ and a neutralino. We thus consider stop production in two alternatives:

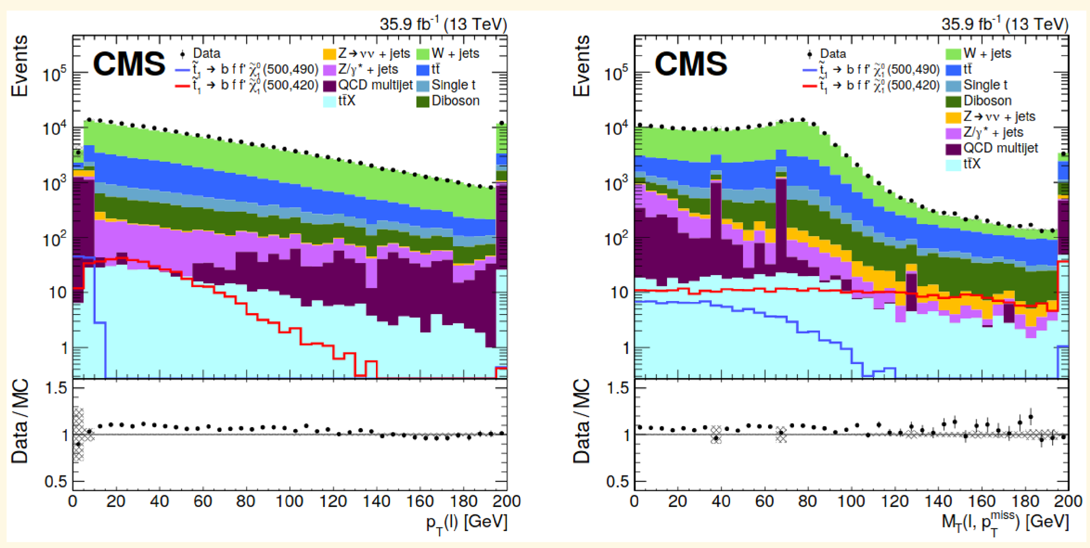


Stop pair-production followed by a 4-body decay directly (left) or via chargino-mediation (right)

The final states of the two decay modes are very similar, the difference lies in the intermediate state. In the case of the 4-body decay, we can only reconstruct the mass of $\tilde{\mathrm{t}}_1$, but in the chargino-mediated decay, the mass of the chargino ($\tilde{\chi}_1^{\pm}$) also appears as a parameter.

III. Analysis strategy

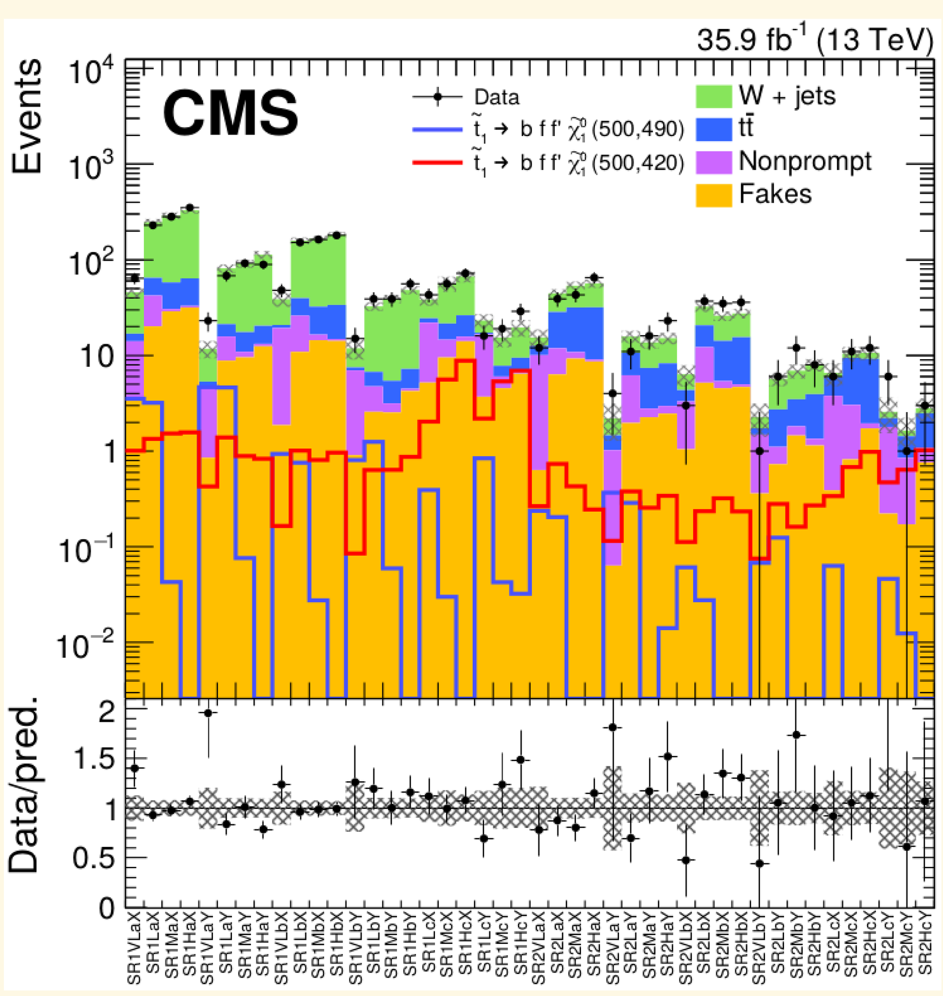
The selection targets final states with a soft lepton (electron or muon) and - for intermediate ΔM - a soft b-jet. To optimize the sensitivity for the signal, a cut-and-count approach is used. The data are triggered by requiring large $p_{\mathrm{T}}^{\mathrm{miss}}$. A preselection is then applied to ensure high trigger efficiency and the presence of a lepton.
The selected events are split into multiple signal and control regions using certain discriminating variables (related to lepton kinematics, missing transverse momentum and hadronic activity) to differentiate between signal and background.



Distributions of lepton transverse momentum p_T and transverse mass M_T calculated from the lepton and the missing transverse momenta after the preselection. Lower (higher) p_T and M_T regions are more sensitive to signals with smaller (larger) mass gaps. [1]

IV. Signal and control regions

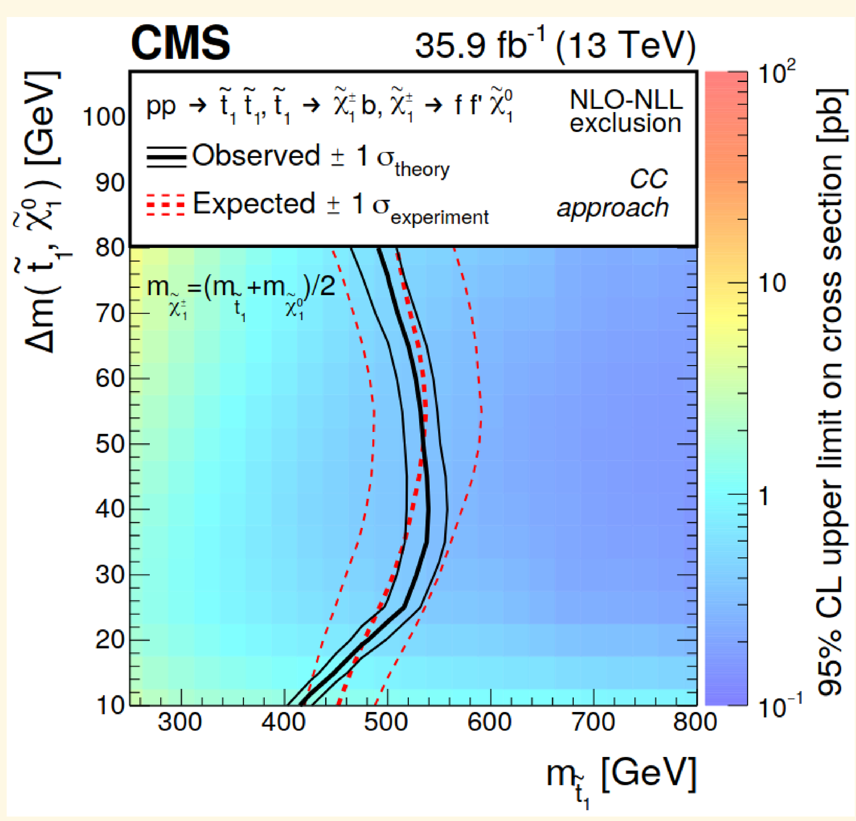
The main background comes from W + jet production with small contributions from top pairs, as well as non-prompt and misidentified leptons. To validate the background estimation control regions featuring high-momentum leptons are used.
Two signal regions are defined (SR1, SR2) that correspond to small and intermediate mass differences. These are further divided into 44 mutually exclusive regions using lepton p_{T}, M_{T} and variables that take into account correlations between $p_{\mathrm{T}}^{\mathrm{miss}}$ and hadronic activity.



Event counts for data and estimated background together with predictions for stop signal with different mass assumptions in the signal [1]

V. Results

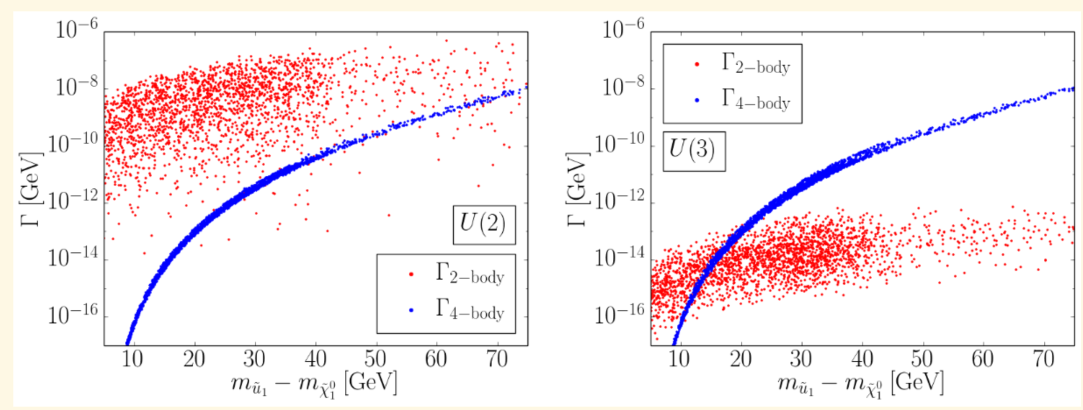
No evidence for direct stop production followed by prompt decay is found.



Cross-section times branching ratio upper limits for the chargino-mediated decay mode as a function of the stop mass and the mass difference, with the observed and expected exclusion regions indicated [1]

VI. Future plans

In the $\Delta M < m_{\mathrm{W}}$ region, two competing decays have to be considered: the 4-body decay discussed above and a two-body decay to a neutralino and a c quark. The decay widths of these modes depend on the mass difference [2].



The width of the 4-body decay decreases as the spectrum becomes more compressed, while the width of the two-body mode depends on the flavour mixing model. According to these calculations [2], the stop travels some distance before decaying, therefore the final state objects will have a large impact parameter. Lepton reconstruction and identification and b-jet tagging need to be revisited.
For lepton selection, the impact parameter requirements (1 mm in the transverse and 5 mm in the longitudinal direction) need to be relaxed and special treatment for decay length on the cm scale need to be introduced.
A soft b-jet tagger has been developed which - if implemented - can potentially improve the analysis sensitivity.

VII. Summary

- A search has been conducted for scalar top quarks in a compressed mass spectrum scenario targeting 4-body decay modes.
- Results based on the 2016 pp CMS data at $\sqrt{s} = 13$ TeV are in accordance with SM background, and are used to set 95% CL limits on the stop production cross section.
- Mass limits assuming 100% branching ratio are derived and reach 420 GeV and 560 GeV for the 4-body and chargino-mediated modes for the lightest stop.
- As the spectrum gets compressed, $\tilde{\mathrm{t}}_1$ lifetime increases, and further optimization of lepton, especially electron reconstruction, as well as b-tagging is pursued.

VIII. References

[1] The CMS collaboration., A.M. Sirunyan et al., JHEP 09 (2018) 065
[2] R. Gröber, M.M. Mühlleitner, E. Popenda and A. Wlotzka, Eur. Phys. J. C 75 (2015) 420