Search for stop production at LHC CMS

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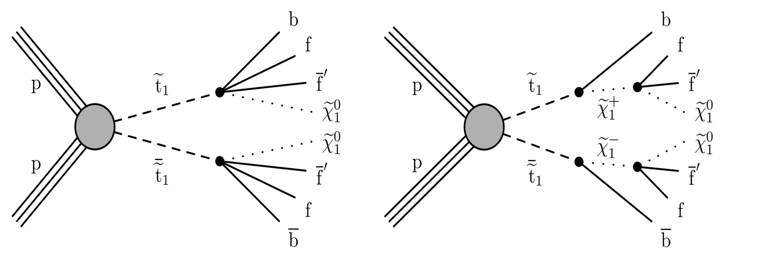
Abstract

A search for top squarks decaying via four-body or chargino-mediated modes to a single-lepton final state with significant missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV is being performed by the CMS experiment at CERN LHC. This poster demonstrates the very first results of adjusting one of the parameters in this search, and the planned steps to conclude the optimisation of the event selection for the analysis of the full Run 2 data collected in 2016-2018 corresponding to approximately 150 fb^{-1}.

Top squark pair production and decay

- Supersymmetry predicts a scalar partner ($\tilde{f}_{R,L}$) for every left- and right-handed fermion ($f_{R,L}$) described by the Standard Model.
- If R-parity, a quantum number (defined as $P_R = (-1)^{3(B-L)+2s}$ with s for spin, B for baryon and L for lepton number) is conserved, these particles would be pair-produced and their decay chains would end with the lightest supersymmetric particle (LSP), which is stable and here considered to be the neutral and weakly interacting neutralino ($\tilde{\chi}^0_1$), a dark matter candidate.
- Given the large mass of the top quark (t), when supersymmetry is broken, the mass splitting between the two squark mass eigenstates ($\tilde{t}_{1,2}$) can be the largest among all squarks, thus the lighter scalar top quark ($\tilde{t}_1$) is often the lightest squark, and can be almost degenerate with the LSP.
- This motivates the search for a four-body $\tilde{t}_1$ decay: $\tilde{t}_1 \to bf\bar{f}'\tilde{\chi}^0_1$, where the fermions $f, \bar{f}'$ can be either quarks or leptons.



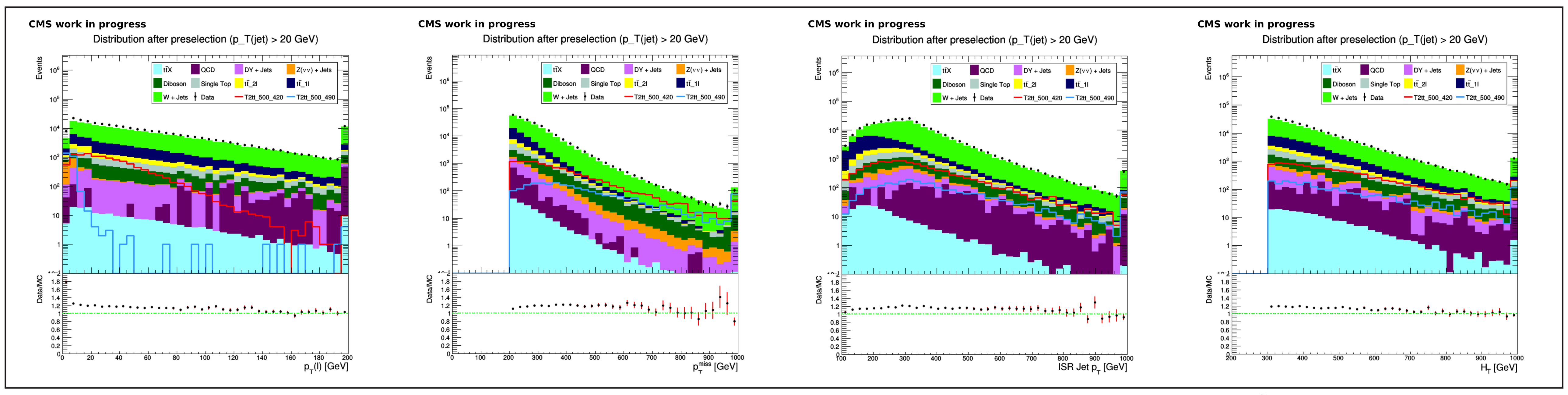
Top squark pair production at the LHC with four-body (left) or chargino-mediated (right) decays.

- The final states considered contain missing transverse momentum (p_T^{miss}), exactly one lepton (ℓ, which can be either an electron (e) or a muon (μ)), and a high transverse momentum jet from initial state radiation to boost the $\tilde{t}_1\bar{\tilde{t}}_1$ system.

Preselection

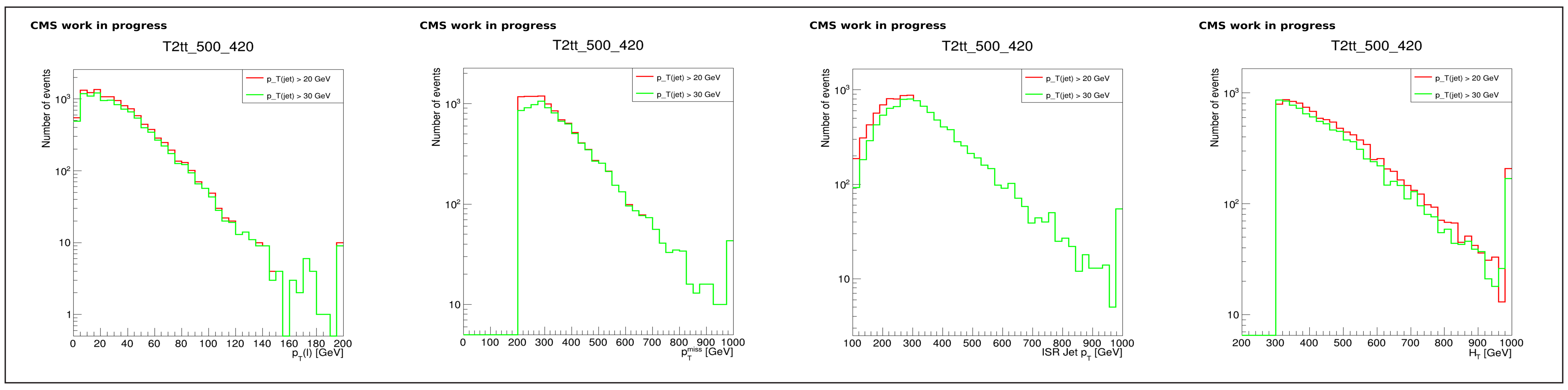
The first step in data processing is the preselection of the targeted event topology.

- The neutralinos in the $\tilde{t}_1$ decay escape detection and manifest as missing transverse momentum, so events with $p_T^{miss} > 200$ GeV are selected.
- Further suppression of SM processes such as W+jets is achieved by imposing the additional requirement of $H_T > 300$ GeV, where H_T is defined as the scalar p_T sum of all jets.
- Jets from initial-state radiation (ISR jets) are selected as the leading jet with pseudorapidity $|\eta| < 2.4$, and transverse momentum $p_T^{ISR} > 100$ GeV.
- To reduce the contribution from $t\bar{t}$ production, events are required to have at most two jets with $p_T > 60$ GeV, and if there are two such jets, their azimuthal angle must be less than 2.5 radians.
- There has to be at least one identified electron ($p_T(e) > 5$ GeV) or muon ($p_T(\mu) > 3.5$ GeV) within the reconstruction acceptance, and events with τ leptons or additional electrons or muons with $p_T(\ell) > 20$ GeV are rejected.



Distribution of kinematic variables after the preselection. From left to right: $p_T(\ell)$, p_T^{miss}, p_T^{ISR} and H_T

When studying the hadronic activity in the event (for example, via the variable H_T), the selection criteria on the jets is important. Thus, the first step of re-optimisation was to study the effect of the transverse momentum requirement ($p_T^{jet} > 20$ GeV or $p_T^{jet} > 30$ GeV) on the reconstructed jets.



The effect of the jet transverse momentum requirement for a hypothetical signal with $m(\tilde{t}_1) = 500$ GeV and $m(\tilde{\chi}^0_1) = 420$ GeV

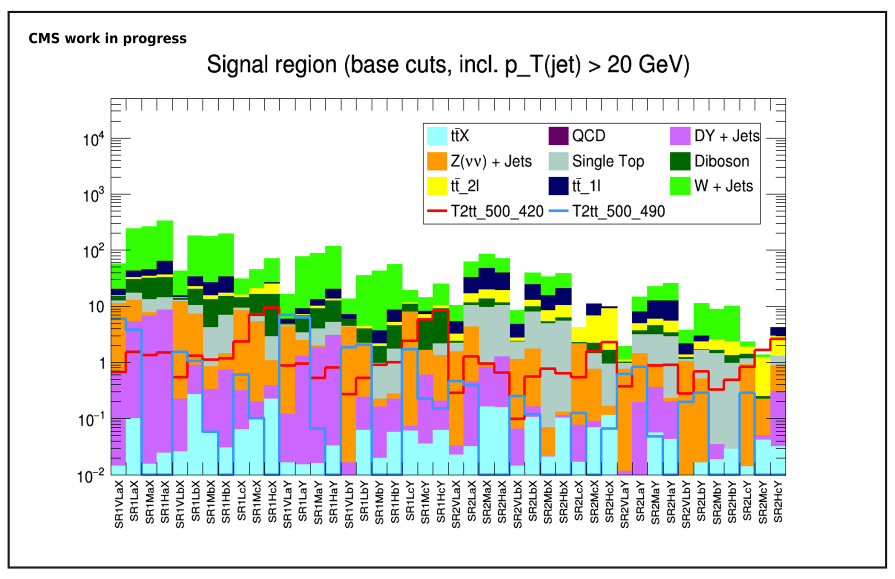
Signal and control regions

Events are further divided into subregions based on kinematic variables as shown by the table. There are 44 signal regions, each signed with a 5-component code that can be built using the notation indicated in the table, e.g. SR1McY, where

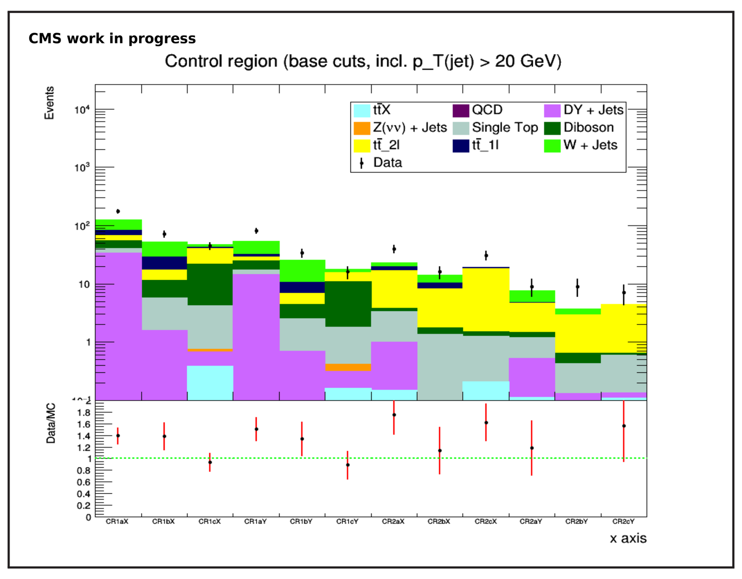
Variable	SR1a	SR1b	SR1c	SR2a	SR2b	SR2c
	Common to all SRs					
Number of hard jets	≤2					
$\Delta\phi$(hard jets) (rad)	<2.5					
p_T^{miss} (GeV)	>300					
Lepton rejection	no τ, or additional ℓ with $p_T > 20$ GeV					
	SR1			SR2		
H_T (GeV)	>400			>300		
p_T(ISR jet) (GeV)	>100			>325		
Number of b jets	0			≥1 soft, 0 hard		
$\|\eta(\ell)\|$	<1.5			<2.4		
	SR1a	SR1b	SR1c	SR2a	SR2b	SR2c
M_T (GeV)	<60	60–95	>95	<60	60–95	>95
$Q(\ell)$	−1	−1	any	any	any	any
$p_T(\mu)$ (GeV)	3.5–5 (VL)	3.5–5 (VL)	—	3.5–5 (VL)	3.5–5 (VL)	—
$p_T(e,\mu)$ (GeV)	5–12 (L)	5–12 (L)	5–12 (L)	5–12 (L)	5–12 (L)	5–12 (L)
	12–20 (M)	12–20 (M)	12–20 (M)	12–20 (M)	12–20 (M)	12–20 (M)
	20–30 (H)	20–30 (H)	20–30 (H)	20–30 (H)	20–30 (H)	20–30 (H)
	>30 (CR)	>30 (CR)	>30 (CR)	>30 (CR)	>30 (CR)	>30 (CR)
C_T (GeV)	$300 < C_{T1} < 400$ (X) $C_{T1} > 400$ (Y)			$300 < C_{T2} < 400$ (X) $C_{T2} > 400$ (Y)		

- "SR1" refers to the selection $H_T > 400$ GeV, $p_T^{ISR} > 100$ GeV, no b jets and $|\eta(\ell)| < 1.5$,
- "M" indicates the lepton $p_T(\ell)$ requirement of 12 - 20 GeV,
- "c" indicates the transverse mass selection (calculated from the lepton and the missing transverse momentum) $M_T > 95$ GeV, and
- "Y" points to the $C_{T1} > 400$ GeV region, where $C_{T1} = \min(p_T^{miss}, H_T - 100\ \text{GeV})$.

Regions with high lepton transverse momentum ($p_T(\ell) > 30$ GeV) are used as control regions (CR) for the background prediction.



Expected signal and background (BG) yields in all SRs with $p_T^{jet} > 20$ GeV.

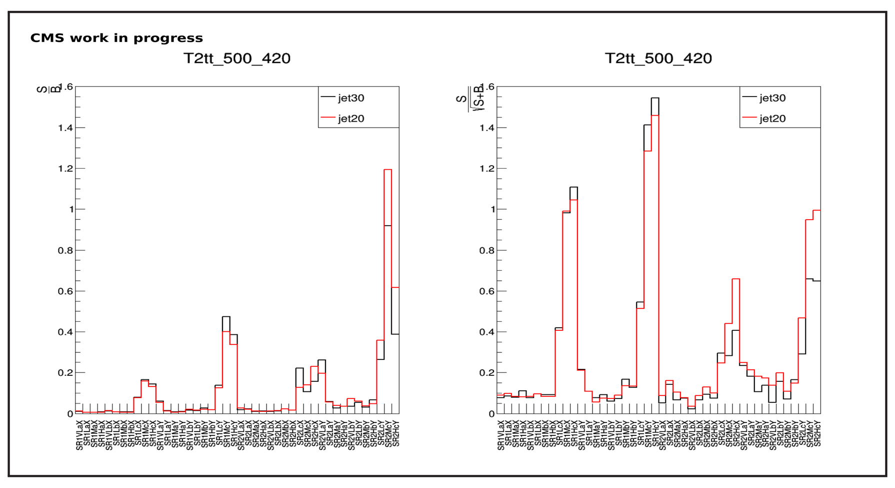


Observed data and expected BG yields in all CRs with $p_T^{jet} > 20$ GeV.

Results on sensitivity

The goal of the event selection optimisation is to increase the sensitivity of the signal detection.

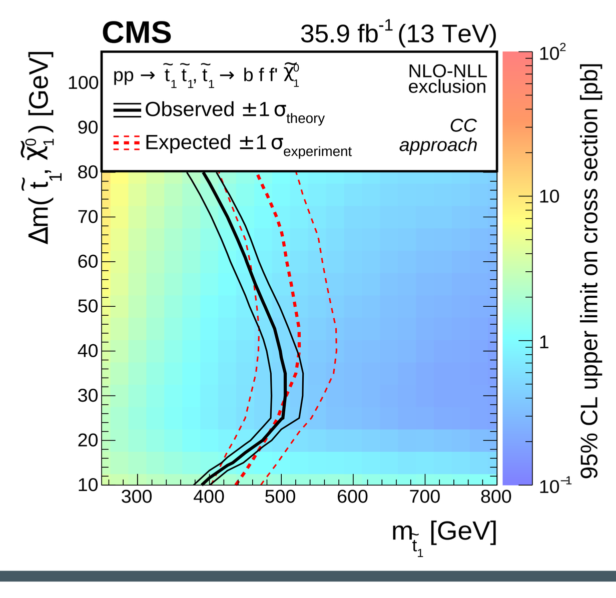
The signal over background ratio (left) as well as the statistical sensitivity (right) for $p_T^{jet} > 20$ GeV (red) and $p_T^{jet} > 30$ GeV (black) for a hypothetical signal with $m(\tilde{t}_1) = 500$ GeV and $m(\tilde{\chi}^0_1) = 420$ GeV.



High S/B ratio indicates a more sensitive measurement. The statistical significance of a region is estimated by $S/\sqrt{S+B}$. Different signal regions favour different jet selections, so a combined significance of all channels is necessary to conclude the study.

Future plans

The next step is to determine the expected exclusion region in the stop quark mass $m(\tilde{t}_1)$ and Δm (mass difference between $\tilde{t}_1$ and $\tilde{\chi}^0_1$) plane to find the optimal lower limit for transverse momentum of jets and identified b-jets. As an example, the exclusion plot is represented from the 2016 analysis [1].



Further plans include the study of lepton identification criteria to decrease the nonprompt lepton background and the significant systematic uncertainty corresponding to it.

References

[1] CMS Collaboration, Search for stop quarks decaying via four-body or chargino-mediated modes in single-lepton final states in proton-proton collisions at $\sqrt{s} = 13$ TeV, JHEP (2018) 65. https://doi.org/10.1007/JHEP09(2018)065