# Search for Supersymmetry with a Highly-Compressed Mass Spectrum in the Single Soft Lepton Channel with the CMS Experiment at the LHC

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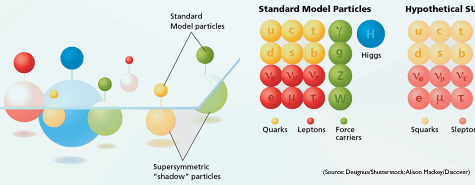
## Supersymmetry

Supersymmetry (SUSY) postulates that for every Standard Model (SM) particle there exists a corresponding superpartner state, which differs by half-integer spin:



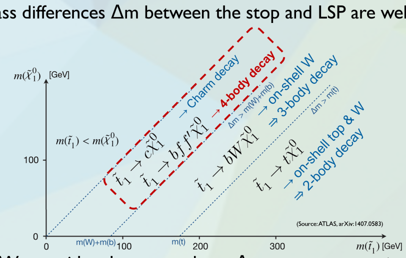

SUSY is one of the most promising candidates to solve central problems with the SM:

- Naturalness or Hierarchy problem
- Unification of strong and electroweak gauge couplings at the GUT scale
- Nature of dark matter: if the lightest supersymmetric particle (LSP) is stable, it is a viable dark matter candidate

## Compressed SUSY

- Natural SUSY favours low masses of the top squark (stop)
- The co-annhilation of light stops and LSPs can reproduce the correct cosmological dark matter abundance

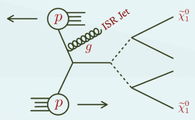
⇒ small mass differences Δm between the stop and LSP are well motivated:



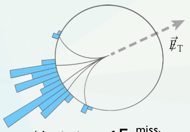

- We consider the cases where: $\Delta m = m_{stop} - m_{LSP} < m_W$
- We also consider the decay with an intermediate chargino

## Analysis Strategy

Compressed regions are challenging to study, as the visible decay products have low momentum and generally do not pass detector acceptance thresholds. This difficulty can be mitigated by the system being boosted by initial-state radiation (ISR), allowing the decay products to become detectable:




(depiction of ISR)



(depiction of $E_T^{miss}$)

We perform a search for SUSY with a compressed mass spectrum using the full 2016 dataset of proton-proton collisions at $\sqrt{s}$ = 13 TeV, recorded by the CMS Experiment and corresponding to an integrated luminosity of 35.9 $fb^{-1}$.

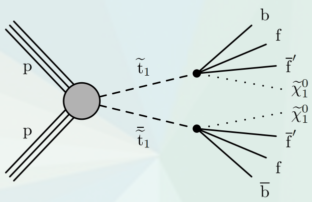
The signal events are characterised by:

- a low-momentum lepton
- a high-momentum jet (ISR)
- moderate missing transverse energy ($E_T^{miss}$)

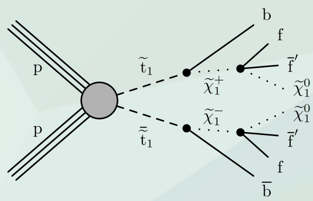
## Simplified Models

We interpret in a Simplified Model (SMS), decoupled from the particular multi-parameter SUSY theory, with a reduced particle content.

The signal models our analysis considers involve the pair-production of stops:



***Four-body stop decay*** *into a lepton and neutrino (quark-antiquark pair), b-quark jet and LSP*

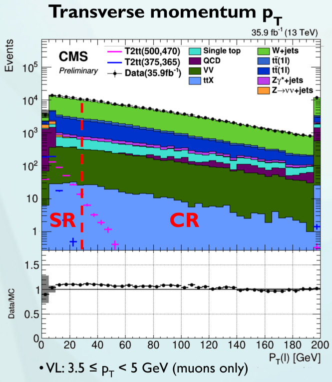


***Chargino-mediated stop decay*** *(chargino mass assumed halfway between stop and LSP)*

The neutralino ($\tilde{\chi}_1^0$) is considered as the LSP. We consider the single-lepton topology.
The neutralinos and neutrino escape the detector and are detected in the form of $E_T^{miss}$.

## Event Selection

**Transverse momentum $p_T$**




- VL: 3.5 ≤ $p_T$ < 5 GeV (muons only)
- L: 5 ≤ $p_T$ < 12 GeV
- M: 12 ≤ $p_T$ < 20 GeV
- H: 20 ≤ $p_T$ < 30 GeV

- The online selection (**trigger**) is based on $E_T^{miss}$
- **Preselection** cuts applied on discriminating variables: high $E_T^{miss}$ and $H_T$, veto on extra hard ($p_T$ > 20 GeV) leptons and QCD-multijet rejection, to focus on relevant parameter space
- Determination of **Signal Regions** (**SRs**) to enhance signal-to-background ratio: two sets of SRs targeted at different Δm's defined by a soft lepton with $p_T$ < 30 GeV:

**SR1** (low Δm):
- Veto b-jets (too soft to detect)
- Lepton |η| <1.5

**SR2** (high Δm):
- Allow for a soft (30 < $p_T$ < 60 GeV) b-jet

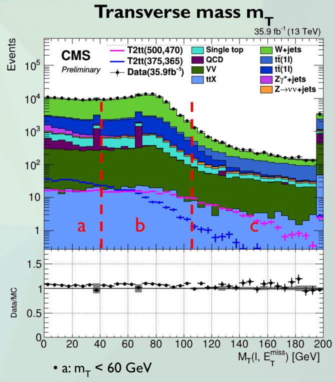
**Common cuts (increasing sensitivity):**

- Bins in lepton $p_T$: VL, L, M, H
- Bins in $m_T$ regions (a, b, c) around W-peak
- Splitting in terms of a simultaneous selection on $E_T^{miss}$ and, $H_T$ (SR1) or ISR jet-$p_T$ (SR2):

$$C_{T1} \equiv \min(E_T^{miss}, H_T - 100\,\mathrm{GeV}) \qquad C_{T2} = \min(E_T^{miss}, p_T(\mathrm{ISR\ jet}) - 25\,\mathrm{GeV})$$

X: 300 < $C_T$ < 400 GeV and Y: $C_T$ > 400 GeV

**Transverse mass $m_T$**




- a: $m_T$ < 60 GeV
- b: 60 ≤ $m_T$ < 95 GeV
- c: $m_T$ ≥ 95 GeV

$$M_T = \sqrt{2E_T^{miss} P_T (1 - cos(\Delta\phi))}$$

## Background Estimation

The estimation of the dominant backgrounds in the analysis is done with a combined approach, using both data and Monte-Carlo (MC) simulation.

**Control Regions** (**CRs**) were chosen such that they are dominated by the relevant backgrounds, from which one can make a precise extrapolation to the SRs.

Estimation of the dominant **prompt** backgrounds from **W+Jets** and **tt-bar**:

- CRs defined by inverting the lepton $p_T$ selection ($p_T$ > 30 GeV)
- Data/simulation scale factors determined in CRs
- Scale factors applied to the SRs to find the expected background contribution
- Method tested in various adjacent **Validation Regions** (**VRs**)

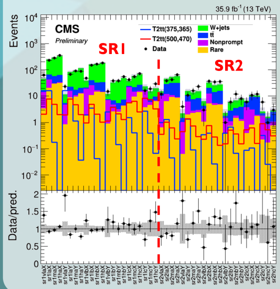
Estimation of the **nonprompt** backgrounds (QCD-multijet, Z→νν):

- Probability that a nonprompt lepton passes the analysis cuts, "Tight-to-Loose" ratio $\varepsilon_{TL}$, determined in a QCD-enriched **Measurement Region** (**MR**), as a function of lepton $p_T$ and η
- "Loose-not-Tight" **Application Regions** (**ARs**) defined by loosening the isolation and impact parameter ($d_{xy}$, $d_z$) requirements for leptons with respect to SRs
- $\varepsilon_{TL}$ ratio applied to ARs to determine expected nonprompt contribution in the SRs

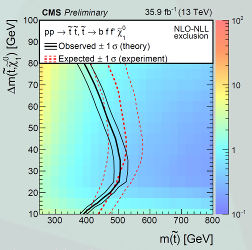
## Results

- Several sources of background and signal **systematic** uncertainties are taken into account, such as the MC modelling of $p_T$ and jet multiplicity distributions in W+Jets and tt-bar samples
- The predicted yields in the SRs are compared to observation: no significant deviation from the Standard Model is observed.
- We set upper **limits** on the top squark pair-production cross section at 95% CL:

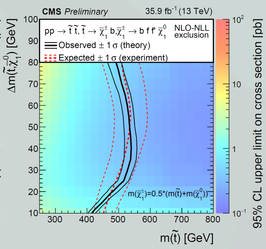
**Data vs. Prediction:**




**Four-body:**




**Chargino-mediated:**




*(assuming a 100% branching ratio to prompt stop decays in SMS)*