

SUSY (CMS)

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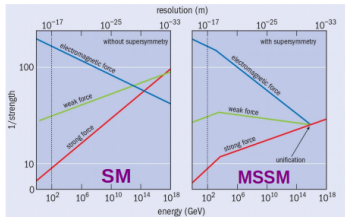
Why look for Beyond Standard Model?

Standard Model (SM) successfully explains the structure of matter and the forces acting between them.

Still, it fails to answer many important questions.

Gauge couplings :

Unification of coupling constant at a single scale



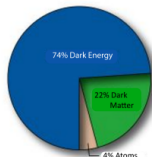
Gravity:

Standard Model doesn't include Gravity

Hierarchy problem :

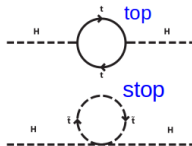
- Divergence in Higgs mass due to divergent terms from couplings to **massive particles**

Higgs mass stabilisation against loop correction



Dark Matter:

- No candidate in Standard Model
- Lightest SUSY particle (LSP)**
is a possible candidate



$$\Delta m_H^2 = -\frac{\lambda_f}{8\pi^2} \lambda_V^2 + \dots$$

$$\Delta m_H^2 = \frac{\lambda_s}{16\pi^2} \lambda_V^2 + \dots$$

Overall recent CMS SUSY program

Aim to give you a feeling of the breadth of the CMS SUSY search program, focus on very new results.

Recent CMS SUSY results

- Stop searches

SUS-19-010 Stop in all hadronic final states

SUS-20-002 Stop hadronic and leptonic combination, top corridor analysis

SUS-21-003 Stop 4 body decays in the compressed scenario with 1ℓ final states

SUS-19-004 R-Parity Violation (RPV) and Stealth searches

- Gluino searches

SUS-21-007 1ℓ with $\Delta\phi$ and top/W tagging

- Electroweak searches (charginos/neutralinos, sleptons)

SUS-21-002 Final states with hadronically decaying WW/WZ/WH

SUS-20-004 Final states with Higgs signature

SUS-19-012 Final states with 3 or more leptons

SUS-21-001 Direct stau pair production

General search strategy

- Select data using trigger based on the final state of targeted signals.
- Identify the SM processes having similar final state as of the signal. SM backgrounds : $t\bar{t}$, W/Z +jets, QCD,..
- Build search variables sensitive to the targeted signals.

examples:

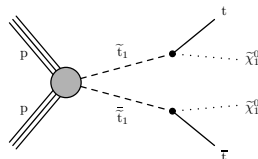
$N_{\text{jets}} = \text{Jet multiplicity}$

$$H_T = \sum_{\text{jets}} p_T, H_T^{\text{miss}} = \left| - \sum_{\text{jets}} \vec{p}_T \right|$$

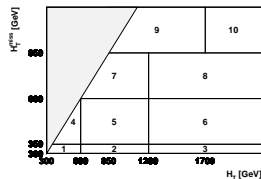
$$\text{MET}/p_T^{\text{miss}} = \left| - \sum_{\text{particles}} \vec{p}_T \right|$$

- Select search variables to design search region (SR)
- Estimate the contribution of SM backgrounds, find the cases where BSM signal is dominant over predicted backgrounds.
- Look for the excess, or set limit on BSM processes at a given Confidence Level

Example :
A SUSY signal



Final state :
Jets and missing energy

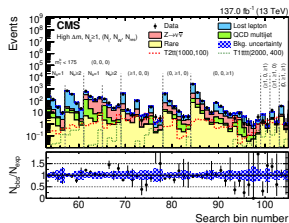
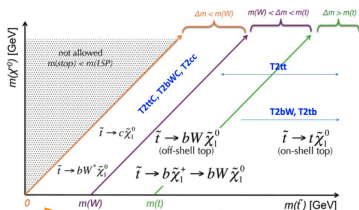
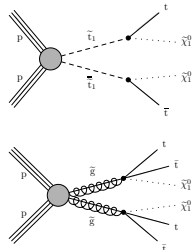


Search Region

Stop searches: all hadronic final state

- Targets direct and gluino-mediated stop production
- Final state : multiple jets, high p_T^{miss} and veto on leptons
- Two SRs sensitive to different signals corresponding to the **high** and **low** Δm ($= m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}$) values
- Deep Neural Network (DNN) based "resolved" tagger for low p_T tops and boosted "merged" top tagger for high p_T tops
- Use of W tagger and soft b tagger
- One benefit of search in all hadronic final state is the large acceptance to the targeted signal compared to the leptonic search.

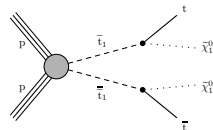
[SUS-19-010](#)



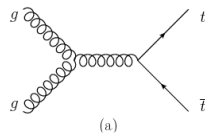
Stop searches: top corridor analysis

- Probe stop in the **top corridor region** with di-lepton final state.
- Challenging as the signal ($T2t\bar{t}$) and SM background ($t\bar{t}$) have similar kinematics.
- Final state: di-lepton with p_T^{miss} and at least two jets.
- Major SM backgrounds : $t\bar{t}$ (91% of total), tW , Drell-Yan
- DNN is used to separate signal from backgrounds.
- Combination with three previous searches with 0, 1 and 2 leptons in the final state is also presented in this analysis.

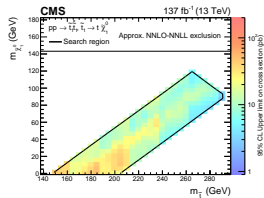
SUS-20-002



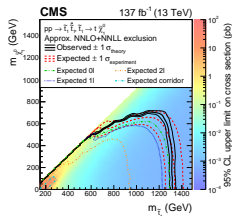
$$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \simeq m_t$$



$t\bar{t}$ production



**Full top corridor region excluded
for the first time by CMS!**

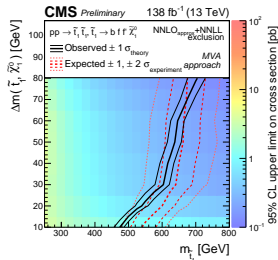
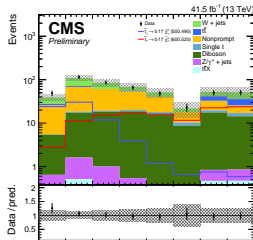
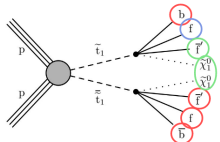


Unblinded top corridor

Stop 4-body decays

- Targets four body decay of the stop to a b-jet, two fermions, and the LSP.
- Cosmological observations may imply that the lightest top squark is almost degenerate with the LSP and 4-body decay could be dominant top squark decays.
- Final state : 1 lepton, jets, p_T^{miss}
- Major SM backgrounds : $W + \text{jets}$ and $t\bar{t} + \text{jets}$

SUS-21-003

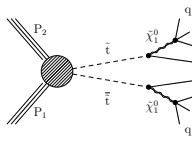


- SUSY signals are considered such that $\Delta m = m(\tilde{t}_1) - m(\tilde{\chi}_1^0) < m(W)$
BDT is trained per each Δm to separate signal and backgrounds.
- Excluded top squark masses up to 480 GeV for $\Delta m = 10$ GeV
and 700 GeV for $\Delta m = 80$ GeV.

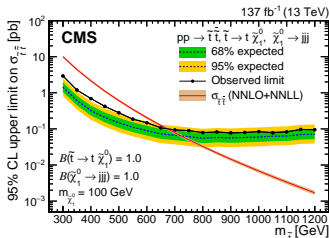
RPV/Stealth searches

- As searches performed at the LHC using events with high p_T^{miss} set ever more stringent lower bounds on the \tilde{t} mass, searches for low- p_T^{miss} alternatives become increasingly important.
- Consider models of R-Parity Violation (RPV) scenarios via stop decays in final states with low p_T^{miss} by providing a mechanism for the LSP, in this case $\tilde{\chi}_1^0$, to decay
- Results are also interpreted for a model where the stop decays through an hidden "stealth" SUSY sector
- Final state : $t\bar{t} + \text{jets}$, with no p_T^{miss}
- Excluded masses up to 670 GeV for RPV and 870 GeV for Stealth SUSY

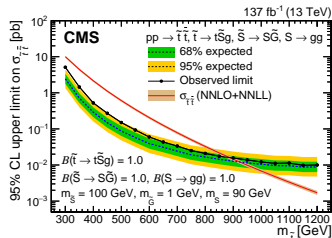
SUS-19-004



RPV model



RPV scenario

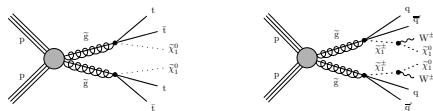
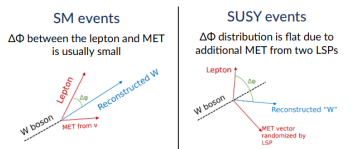


Stealth scenario

Gluino searches: 1ℓ with $\Delta\phi$ and top/W tagging

- Two gluino-pair production simplified models are explored
- Final state : 1 lepton, jets, p_T^{miss}
- SUSY search with 1 lepton, jets and p_T^{miss} in the final state.
- Top quark and W boson tagging algorithms based on machine-learning techniques are employed to suppress the main background contributions.
- Major SM backgrounds : $t\bar{t} \rightarrow 1\ell$, W+Jets and $t\bar{t} \rightarrow 2\ell$ (missing lepton)
- $\Delta\phi$ (ℓ , W) is the main discriminating observable to distinguish signal from backgrounds.

[SUS-21-007](#)

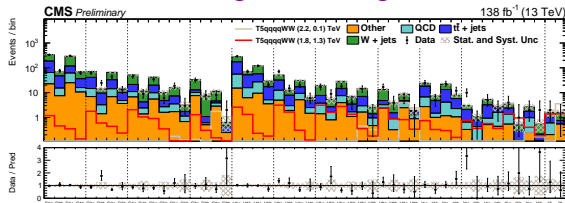


multi b-tags

0 b-tags

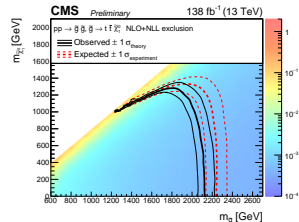
- We use a combination of two top taggers:
 - low Δm (gluino, LSP) \Rightarrow Resolved top \rightarrow tagged using Resolved top tagger
 - high Δm (gluino, LSP) \Rightarrow Merged top \rightarrow tagged using DeepAK8 top tagger

0 b-tags search region

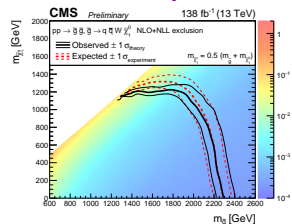


- Good agreement between the data and the prediction is observed.
- **Multi-b analysis:**
 $m(\tilde{g}) < 2120$ GeV and $m(\tilde{\chi}_1^0) < 1270$ GeV are excluded
- **0-b analysis:**
 $m(\tilde{g}) < 2280$ GeV and $m(\tilde{\chi}_1^0) < 1220$ GeV are excluded
- With respect to previous results, this corresponds to an improvement on gluino (neutralino) masses by about 320 (170) GeV for multi-b analysis and 380 (270) GeV for 0-b analysis.

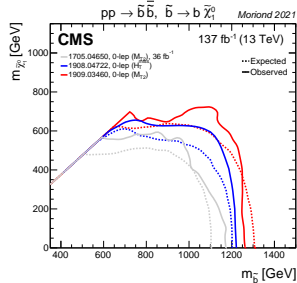
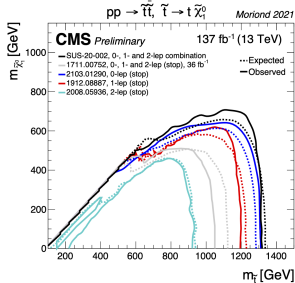
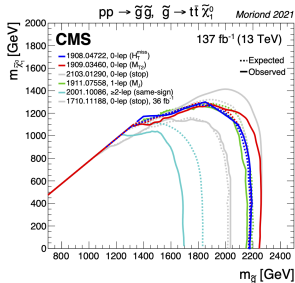
Multi-b analysis



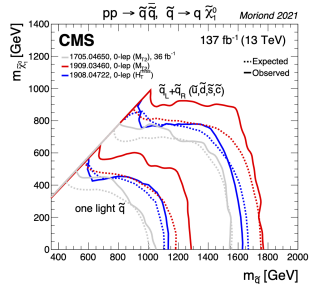
0-b analysis



Gluino/squark searches: Summary

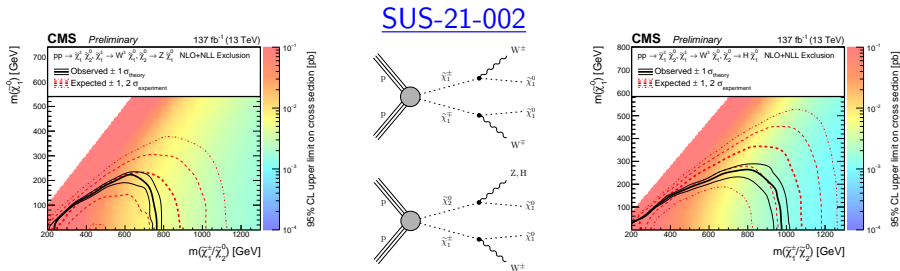


- Gluino masses excluded up to 2.3 TeV.
- Stop masses excluded up to 1.3 TeV.
- Sbottom masses excluded up to 1.25 TeV.
- Single (degenerate) squark masses excluded up to 1.3 (1.8) TeV.



Electroweakino searches: all hadronic final states

- Hadronically decaying WW, WZ, WH in the final states
- Anti- k_T jets with clustering size, $R = 0.8$ for reconstruction of W/Z/H.
- W taggers for tagging W bosons
bb-vs-light tagger for tagging H/Z bosons decaying into $b\bar{b}$
- SR is defined based on the number of b-tagged jets and W and H boson candidate.



- For nearly massless $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$ masses excluded up to 760 and 970 GeV in case of $\tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \rightarrow H \tilde{\chi}_1^0$, respectively.
- Improved DNN hadronic W/Z/H taggers now allow us to search for electroweakinos in hadronic final states.

Electroweakino searches: HH final states

- Higgs boson production is expected to be prominent in the decays of a variety of new, heavy particles, such as those arising in theories based on SUSY

- Final state : p_T^{miss} and two Higgs bosons, each decaying in to $b\bar{b}$

- A **combined** phase space

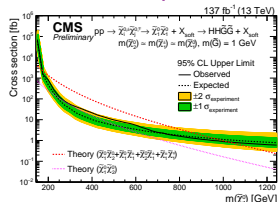
Resolved region : Higgs contained in 2 AK4 jets

$p_T^{\text{miss}} > 150$ GeV, 4-5 AK4 jets, ≥ 2 b-jets, $100 < m_{b\bar{b}} < 140$ GeV.

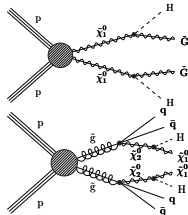
Boosted region : Higgs contained in a single AK8 jet

$p_T^{\text{miss}} > 300$ GeV, ≥ 2 AK8 jets, $95 < m_{\text{jet}} < 145$ GeV

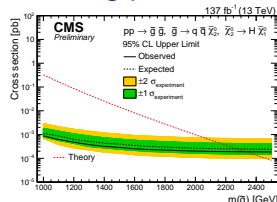
Electroweak production



SUS-20-004



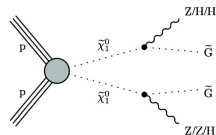
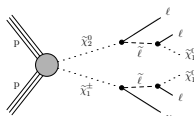
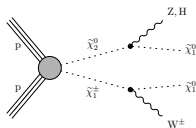
Strong production



- For electroweak production, neutralino masses is excluded from 175 to 1025 GeV.
- For strong production, gluino masses is excluded up to 2330 GeV.

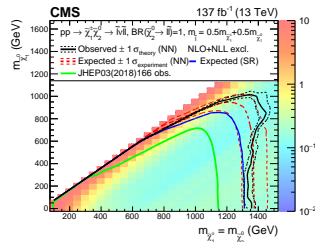
Electroweakino searches: multi-lepton final states

- Pair production of chargino/neutralino
- Consider three decay topology : direct decay, mediated by sleptons, and gauge mediated decay with gravitino as LSP.
- Sensitivity is driven by final state containing 3-4 leptons, with up to $2\tau_h$



- SR is binned in terms of di-lepton p_T , p_T^{miss} and m_{T2}
- DNN with parameter $\Delta M = m_{\text{NLSP}} - m_{\text{LSP}}$ is trained to increase search sensitivity.
- Excludes electroweakinos up to 1.4 TeV.

[SUS-19-012](#)

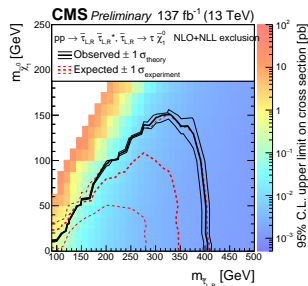
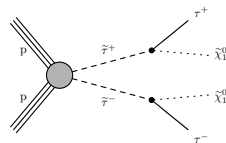


Slepton searches

Direct stau($\tilde{\tau}$) pair production

- Consider different mixtures of left and right handed $\tilde{\tau}$
- Models with light $\tilde{\tau}$ as NLSP can explain cosmological dark matter relic density via $\tilde{\tau}$ -LSP coannihilation
- Consider GMSB scenario where $\tilde{\tau}$ is long-lived, decay length of $\tilde{\tau}$ is 0.01 - 10mm
- Final state: $2\tau_h$ and large p_T^{miss}
- Uses DNN based "DeepTau" algorithm to tag hadronically decaying τ
- SR is binned in $N_{\text{jets}}, p_T, m_{T2}, m_T$
- Excluded $m(\tilde{\tau})$ up to ~ 400 GeV.

[SUS-21-001](#)



e, μ slepton pair production [SUS-20-001](#)

- Final state : OS SF leptons and large p_T^{miss}
- Excluded slepton masses up to ~ 700 GeV

Summary and outlook

- Many new SUSY results using full Run2 data are already public, more to come in the near future.
- Cannot do justice to all results — only highlighted a few recent ones.

CMS Public SUSY Results:

<http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS/index.html>

- Unfortunately, no observation of BSM signature yet, only limits are being pushed further.
- Run3 in full swing.
- Exciting times ahead!

