SUSY at CMS

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On behalf of CMS Collaboration

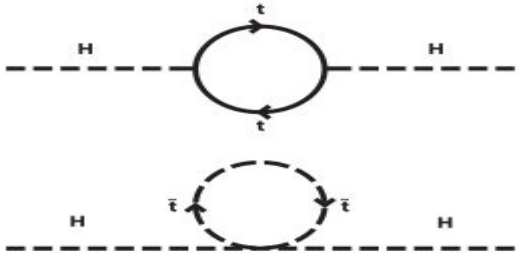
MTA – ELTE Lendület

CMS Compact Muon Solenoid

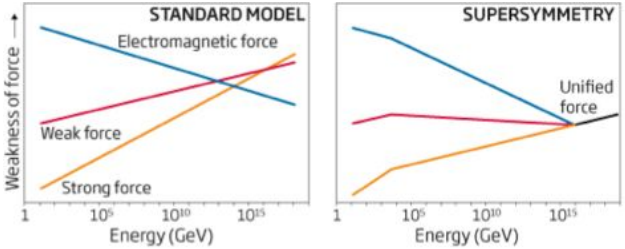
ICNFP 2021

Supersymmetry

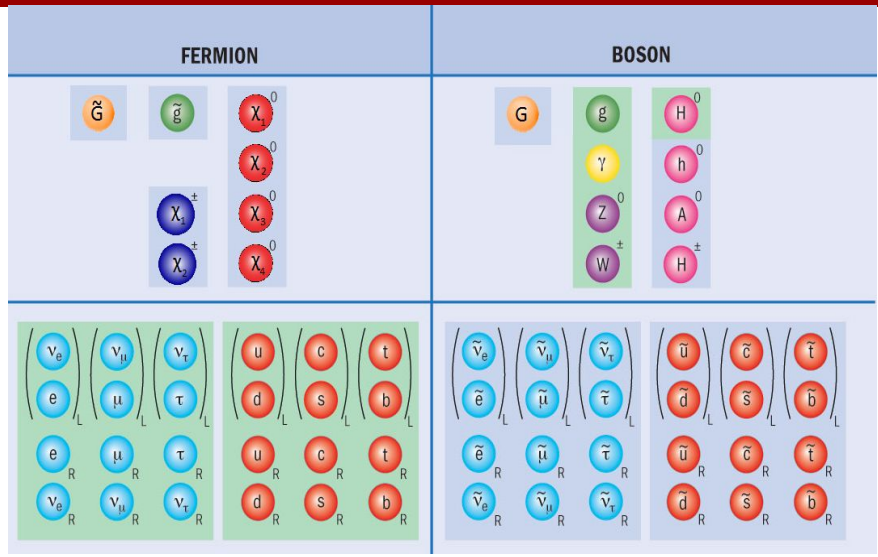
- One of the most studied BSM theories
  - Could solve hierarchy problem



  - Could unify fundamental forces of nature



  - Lightest Supersymmetric Particle (LSP) could be DM candidate in R-parity conserving scenario

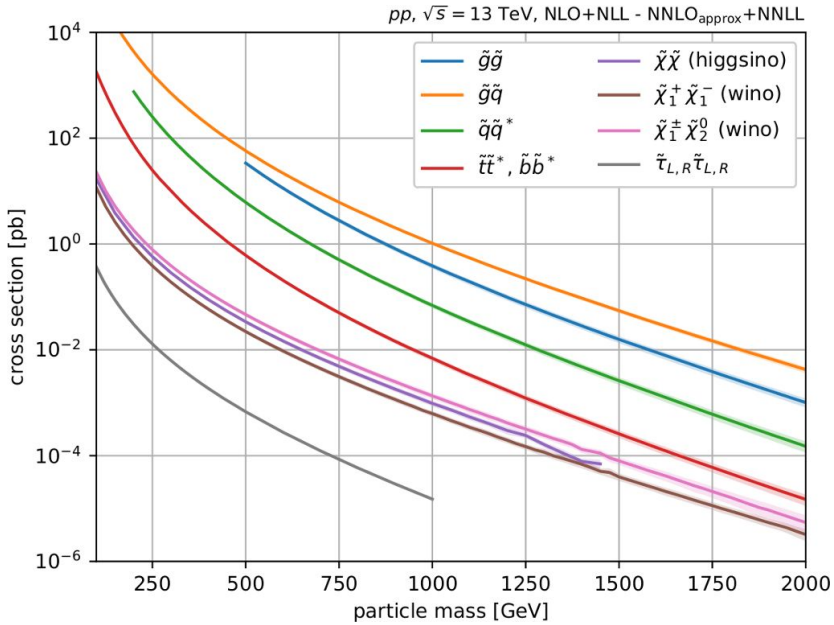


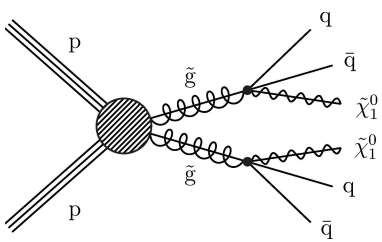
- New particles from SUSY
- Search for SUSY particles (sparticles) in LHC

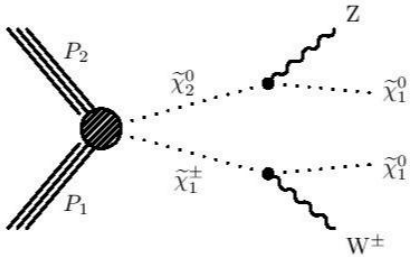
*R-parity = $(-1)^{3(B-L)+2s}$

SUSY at LHC

- Production of SUSY particles in TeV energy scale
- Strong Production: gluinos, stops, sbottoms, squarks (1st & 2nd generation)
  - Large cross section, jetty environment
- Electroweak: charginos, neutralinos and sleptons
  - Smaller cross section, clean signature with leptons
- SUSY models contain many parameters
- In LHC, **Simplified models** are considered
  - Masses and the decay modes of the target particles are only the free parameters
  - The rest of the SUSY particles are set to the masses beyond LHC reach
  - Easier for event generation, optimization studies and result interpretation







SUSY Searches in CMS

- Dedicated searches for different SUSY production mechanism
- Extensive coverage of various signal topologies
- Variety of final state signature

CMS Searches	SUSY Production			Interesting features
	R-parity Conserving		R-parity Violating	
	Strong SUSY	Electroweak SUSY		
0 lepton or Hadronic	✓	✓		Search with N_{jets} and MET Inclusive searches with other hadronic variables and Heavy tagged objects
1 lepton	✓	✓	✓	Use of kinematic variables derived from lepton and jets
Multi-leptons	✓	✓	✓	Utilize the combination of leptons with different flavours and charges

Additional Searches

- Long lived sparticles with
  - disappearing tracks
  - Displaced jets/leptons
- Stealth SUSY
- Compressed SUSY
  - Low mass difference between targeted sparticles

General Search Strategy

Select data using the trigger depending on the final state of targeted signals

Full Run2 data corresponding to 137 fm^{-1} luminosity

Identify the SM processes having same final state as of the signals

SM backgrounds
ttbar, W/Z+jets, QCD, DY, VV..

Build search variables sensitive to signal hypothesis

Jet multiplicity N_{jets}

MET or p_T^{miss} $\left|\sum_{\text{Reconstructed Particles}} -\vec{p_T}\right|$

HT $\sum_{jets} |\vec{P_T}|$

MHT or H_T^{miss} $\left|\sum_{\text{Jets}} -\vec{p_T}\right|$

Transverse mass $m_T^2 = m^2 + p_x^2 + p_y^2$

MT2 $\min_{\vec{p}_T^{X(1)}+\vec{p}_T^{X(2)}=\vec{p}_T^{miss}} \left[\max\left(M_T^{(1)}, M_T^{(2)}\right)\right]$

Tagged heavy objects like b, top, W, Z and H

Selection on the search variables to design the search region (SR)

Cut and count analysis in inclusive SRs

Exclusive SR based on the shape of a chosen variable

Machine learning with MVA approach

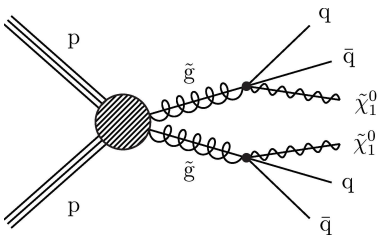
Estimation of SM backgrounds

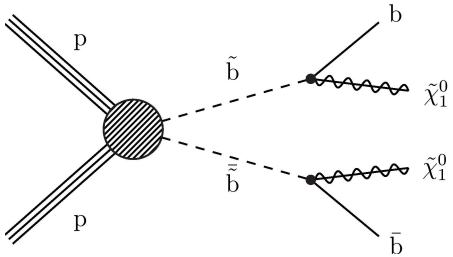
Comparison between estimated backgrounds and observed data including all the uncertainties

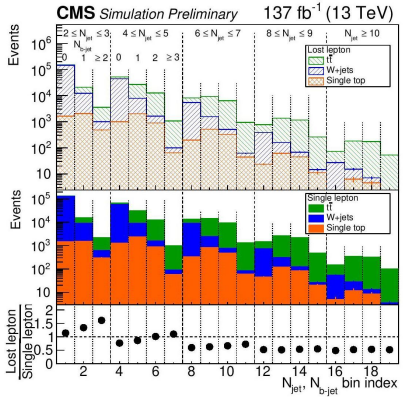
Strong SUSY with Jet & MET

JHEP

- Targets gluino and squarks in hadronic final state
- 4D SR with N_{jets}, N_{bjets}, HT and MHT
- Data driven estimation for major backgrounds
  - *Lost Lepton (*Missing leptons (e and μ) or hadronically decaying τ): Single lepton CR is used







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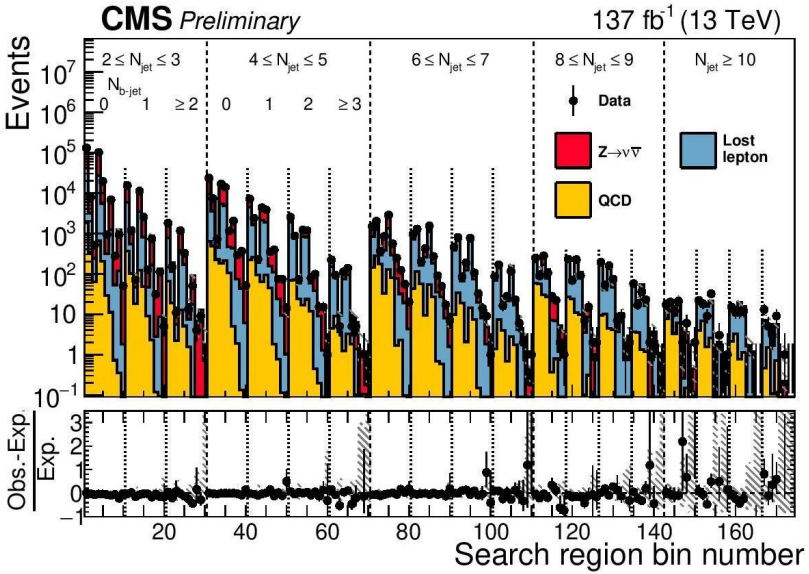


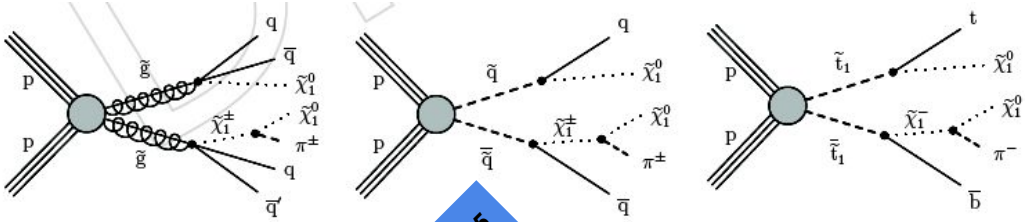
- *Z(→νν)+jets:* Combination of Z(→l^+l^-)+jets and γ+jets CRs
- *QCD multijets:* Inverted $\Delta\phi$ CR

Strong SUSY with MT2

EPJC

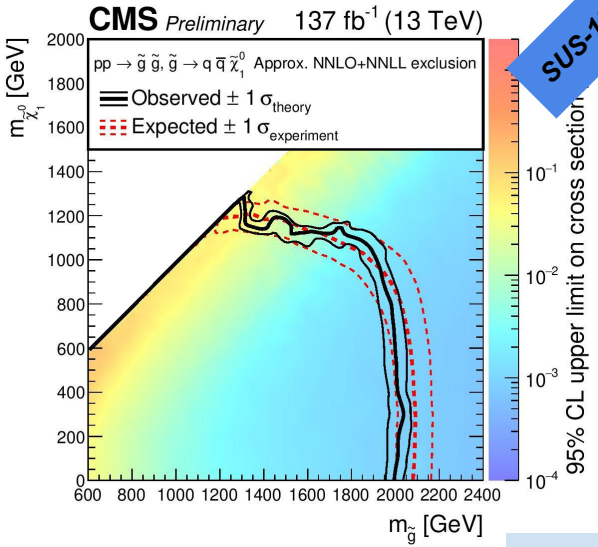
Similar search as inclusive jets+MET search

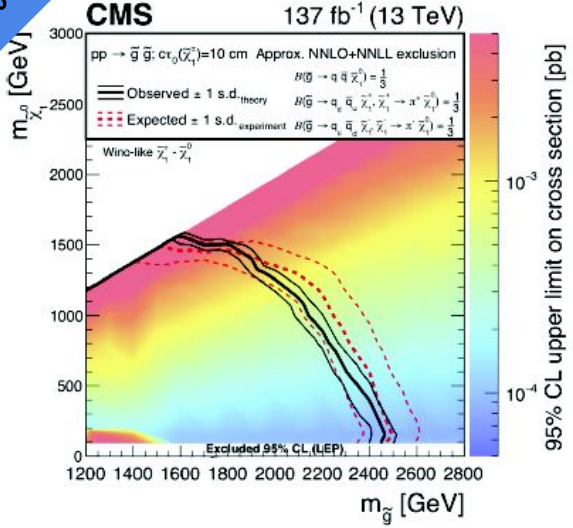
Sensitive search variables: N_{jets}, N_{bjets}, HT and MT2



- Complementing MT2 search in compressed region with ***disappearing track*** analysis
- Gluino and squarks decays to neutralino via a chargino
- For chargino-neutralino mass splitting ~100 MeV, chargino decays inside tracker: chargino track disappear
- Requirement of disappearing track (short track) suppress SM background to a large extend

SUS-19-005





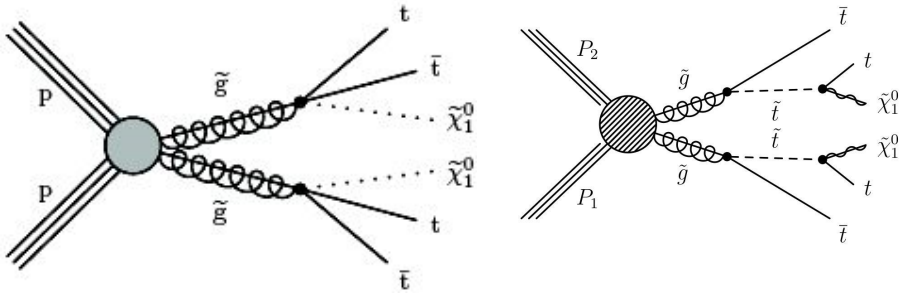
Exclusion improved by hundreds of GeV

1L Gluino Search with Large Jet Mass

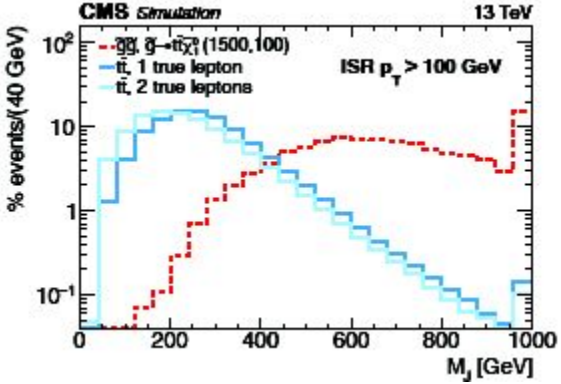
- Gluino search with one high p_T lepton, multiples jets including b-jets and large MET
- Lepton transverse mass (m_T) and large jet mass (M_j) are the key search variables

$$m_T = \sqrt{2p_T^{\ell} p_T^{\text{miss}}[1-\cos(\Delta\phi_{\ell,\vec{p}_T^{\text{miss}}})]} \qquad M_J = \sum_{J_i=\text{large-}R\text{ jets}} m(J_i)$$

PRD



Backgrounds are estimated using ABCD method in the 2D phase space of m_T and M_j



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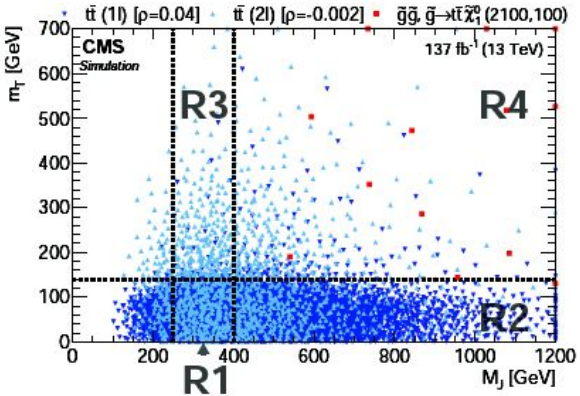
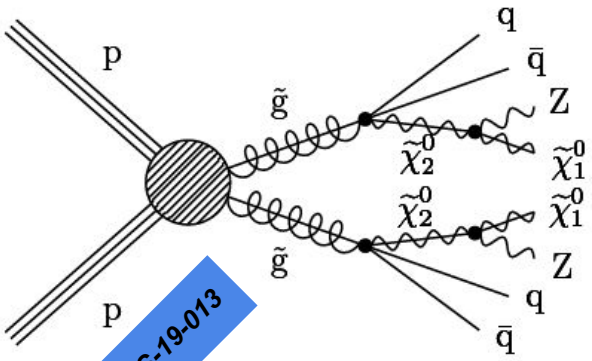


Gluino Search with Z & MET

- Large mass difference between $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$ results in highly energetic Z
- Hadronically decaying boosted Z is tagged using high p_T, wide-cone (radius of 0.8) jet
- Requirement of two energetic Z-tagged jets and high MET greatly suppresses the SM backgrounds
- MET and soft drop masses of the leading and sub-leading jets are two search variables

  SR
  - ➢ soft drop mass [70, 100] GeV
  - ➢ Binned in MET
- Background estimated from jet mass sideband using mass shape variable
- Then modelled in MET bins using MET shape



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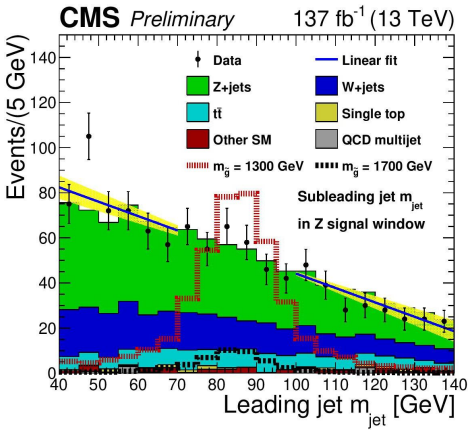
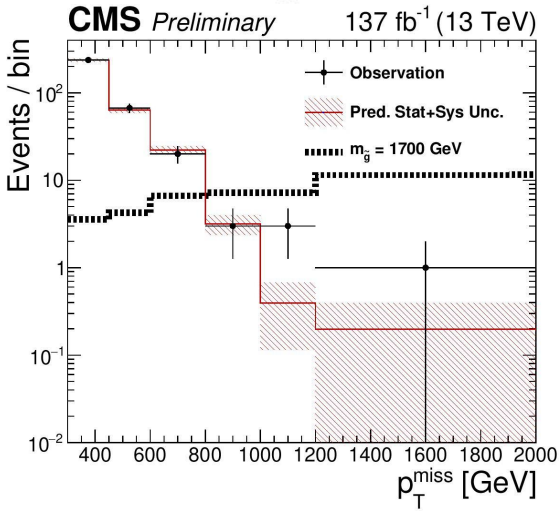
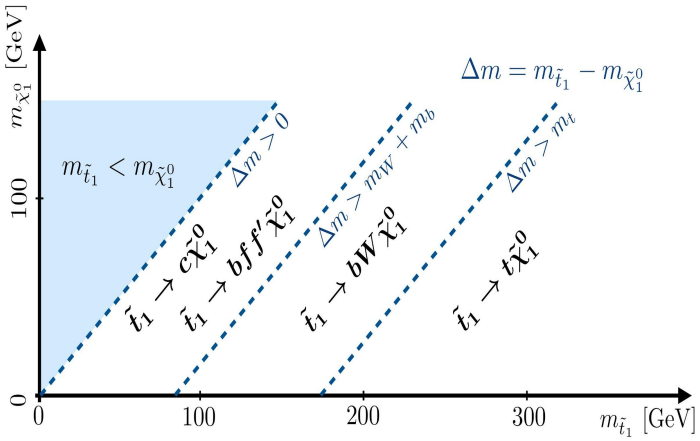


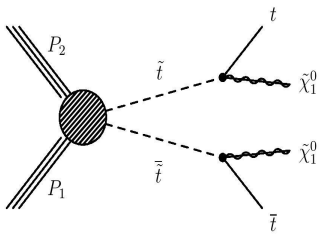


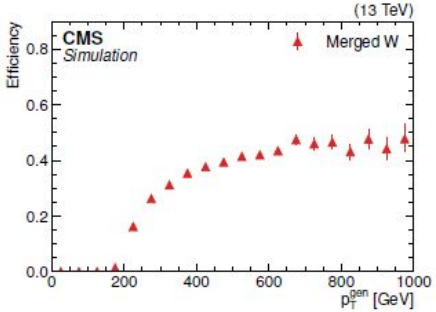
0L Stop Search with Top Tagger

- Targets stop and gluino
- Two SRs sensitive to the different signals corresponding to the high and low Δm(stop, neutralino) values
- Identification of top quark in wide p_T range
  - Merged tagging algorithm for boosted tops
  - **Deep Neural Network** based Resolved tagger for low p_T tops
- Use of W tagger and soft b tagger

arXiv







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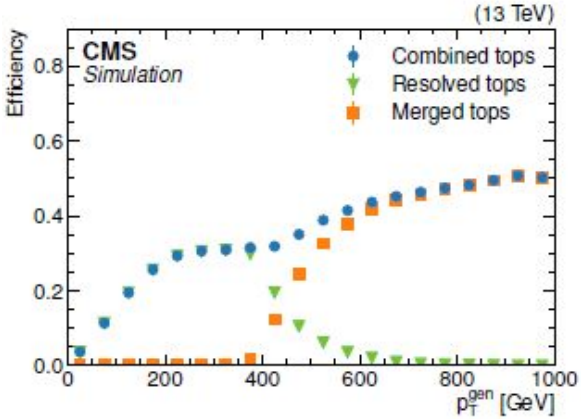


Leptonic (1L & 2L) Stop search

- Stop search in one lepton final state

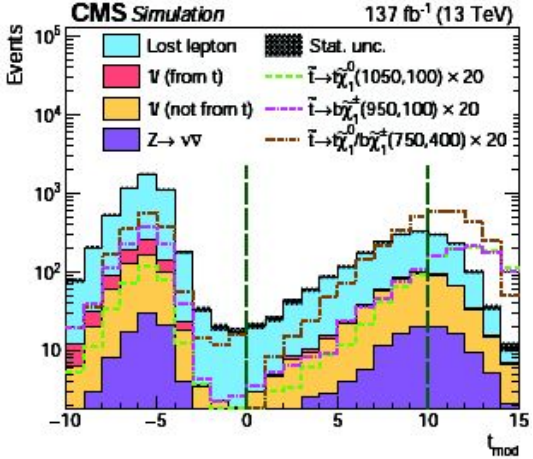
JHEP

- M_T to suppress ttbar/W+jets
- Modified topness (t_{mod}) to discriminate leptonic ttbar

$$t_{\mathrm{mod}} = \ln(\min S), \text{ with } S = \frac{\left(m_W^2 - (p_\nu + p_\ell)^2\right)^2}{a_W^4} + \frac{\left(m_t^2 - (p_b + p_W)^2\right)^2}{a_t^4}$$

- Hadronic top tagger categories
- Use of W and soft b tagger

SUS-19-009



- Stop search in di lepton final state

EPJC

- MET significance (S) to suppress Drell-Yan
- m_{T2}(ll) and m_{T2}(blbl) to suppress ttbar
- Categorize in same and different flavor dilepton region

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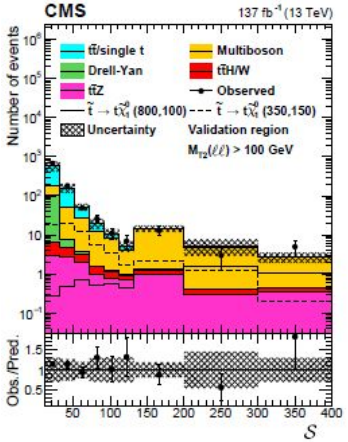
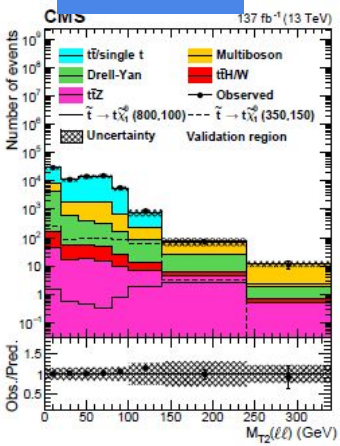
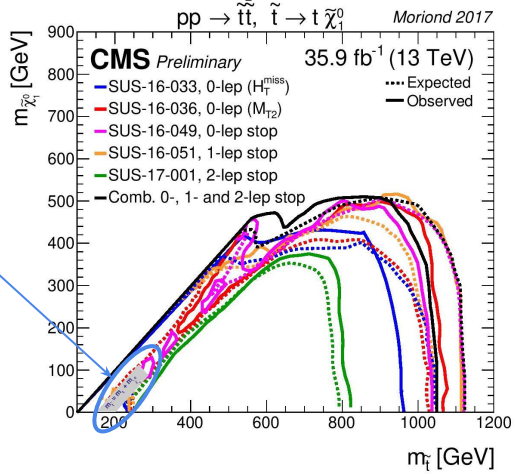


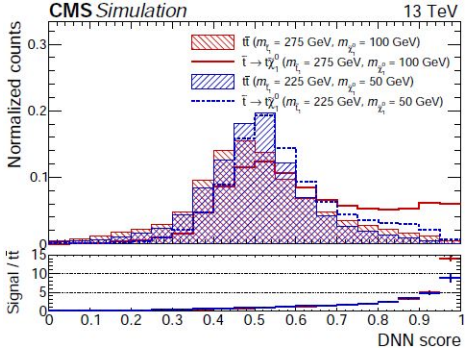


Stop Search in Top Corridor

- Probe the stop in the top corridor *m(stop)-m(LSP) ~ m(top)*
- Challenging due to the similarity between signal and ttbar background
- Search in dilepton final state with MET and at least two jets
- Utilize DNN to distinguish signal from ttbar background



Exclusion limit combined from 0, 1, 2L and corridor stop searches



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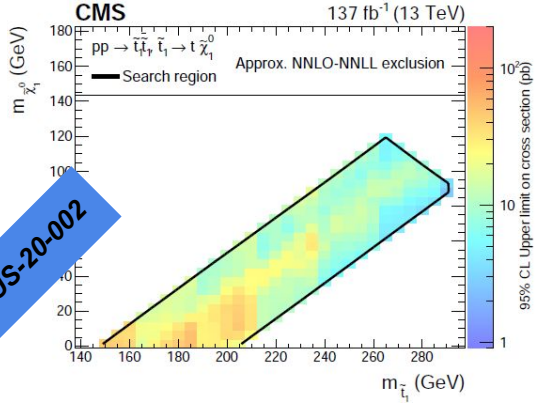
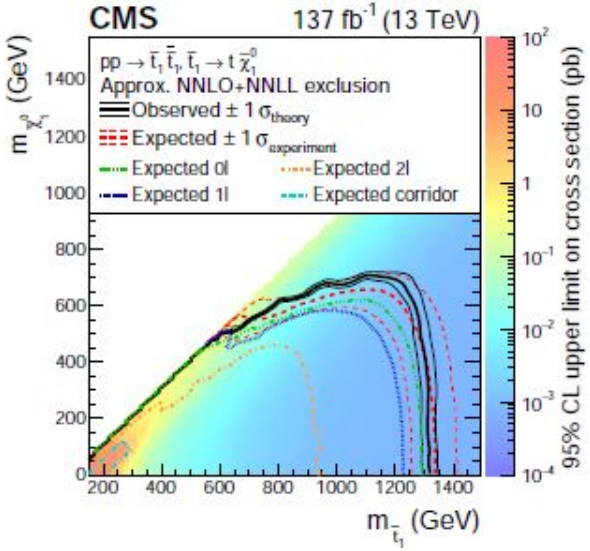
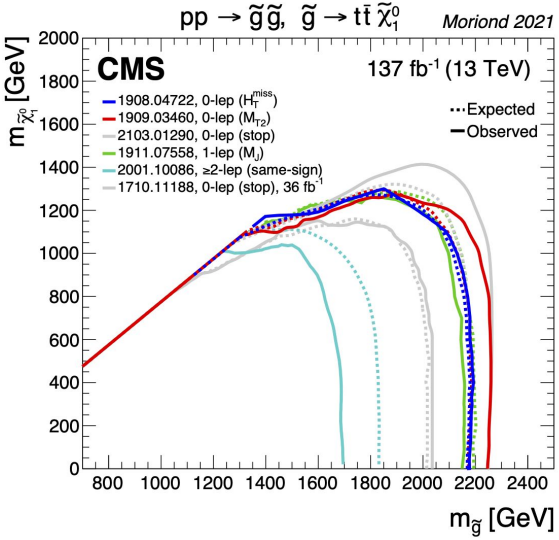


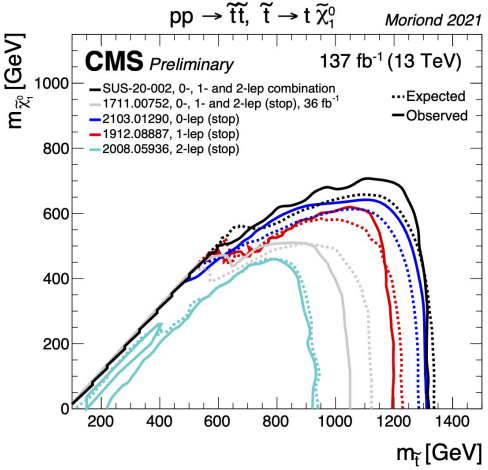


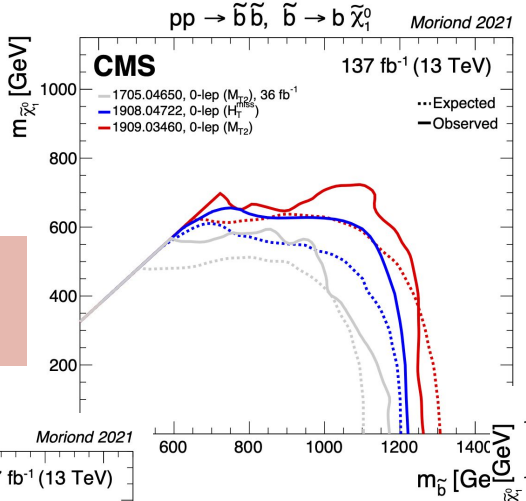
Strong SUSY results



Gluino excluded up to 2.3 TeV

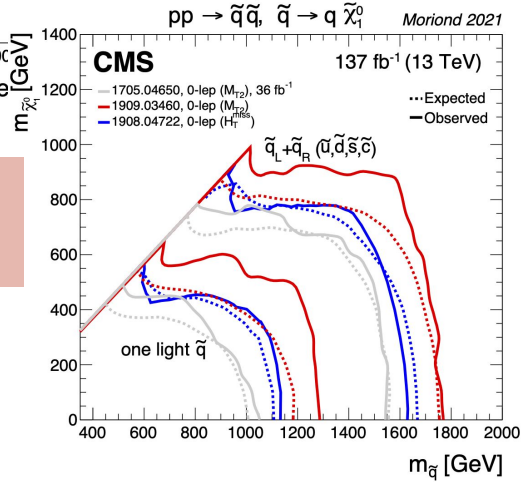
Stop excluded up to 1.3 TeV





Sbottom excluded up to 1.25 TeV

Single (degenerate) squark is excluded up to 1.3 (1.8) GeV

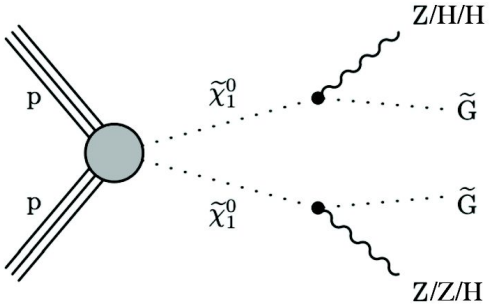


Electroweak SUSY in 2L(SS) & Multileptons

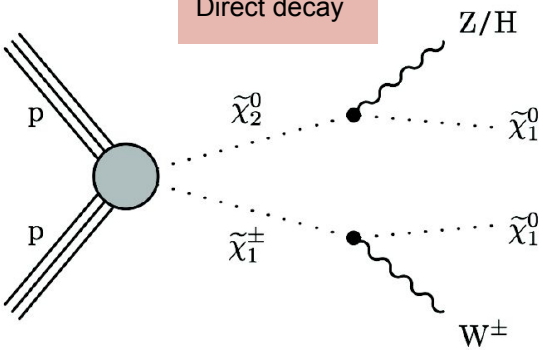
- Search for pair produced chargino/neutralino
- Final state with same sign di leptons or 3/4 lepton (up to 2 τ_h)
- Consider three decay topologies

Gauge Mediated decay with gravitino as LSP

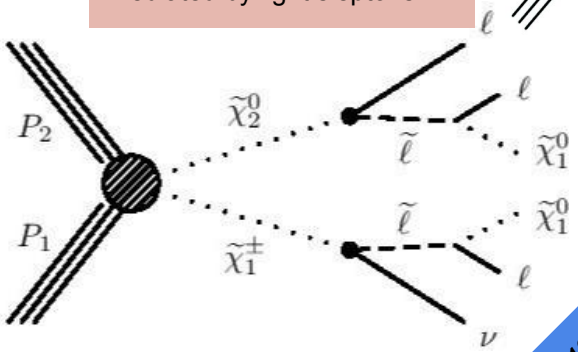
arXiv



Direct decay

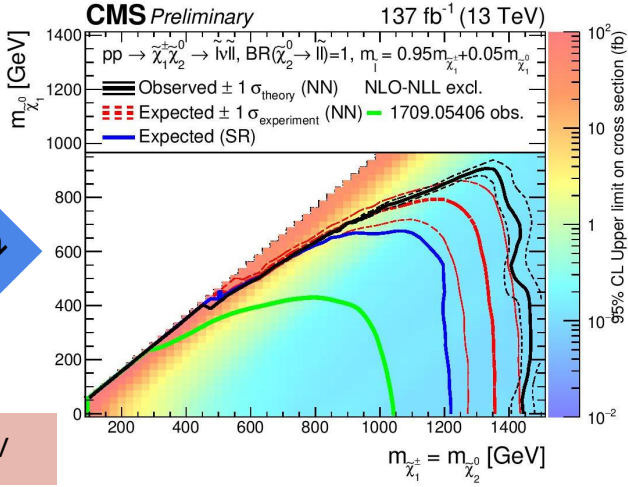


Mediated by light sleptons



- Parametric NN with δm(chargino,LSP) to increase search sensitivity

SUS-19-012

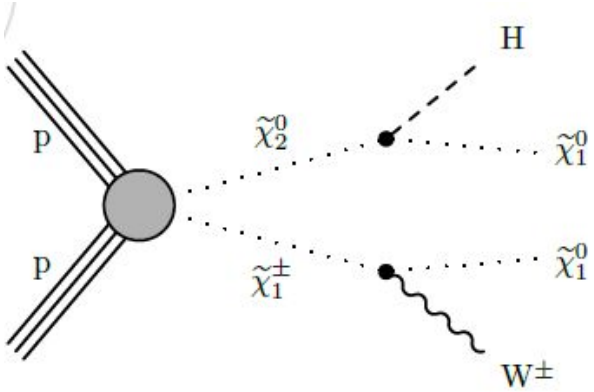


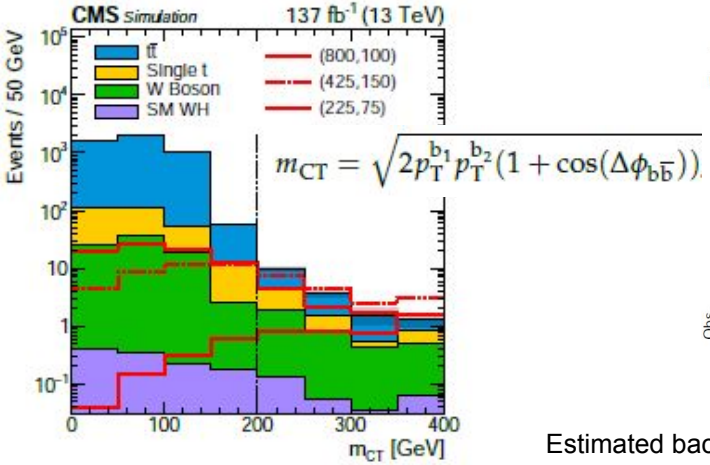
Exclude EWkino up to 1.4 TeV

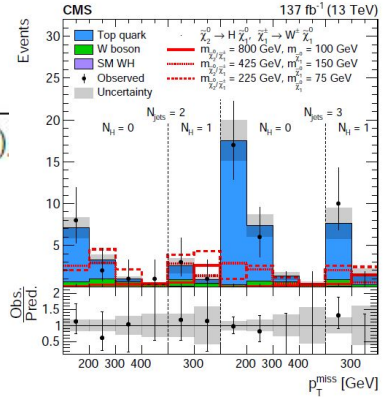
Electroweak SUSY in WH Final State (1L)

- Signature with leptonic W and H →bb
- Boosted H tagging with AK8 jets targets high mass-splitting (between chargino/neutralino and LSP) models
- Requirement of two b jets
- m_T and m_{CT} to suppress SM backgrounds

arXiv







Estimated backgrounds and observed data in SR

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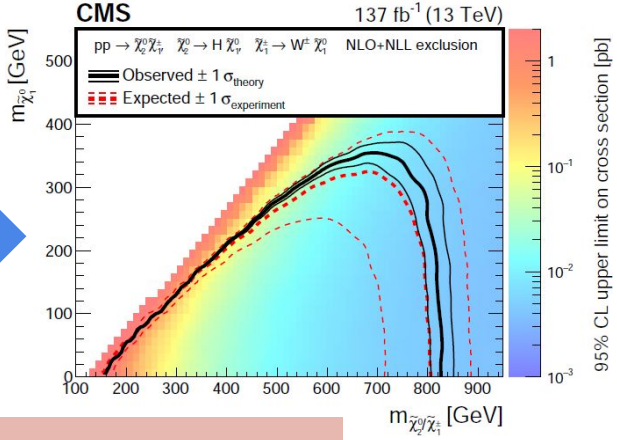
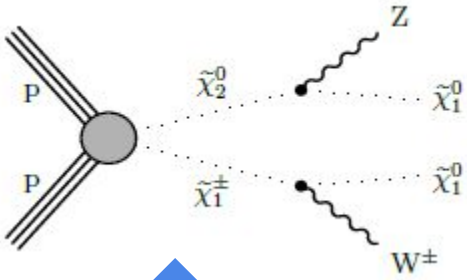


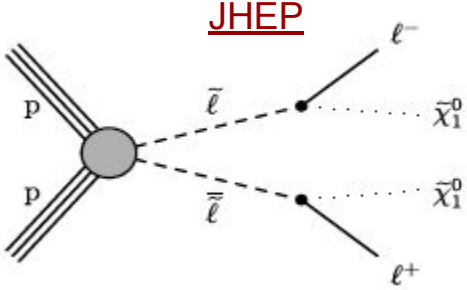
Exclude EWkino up to 800 GeV

Electroweak SUSY in 2L(OSSF)

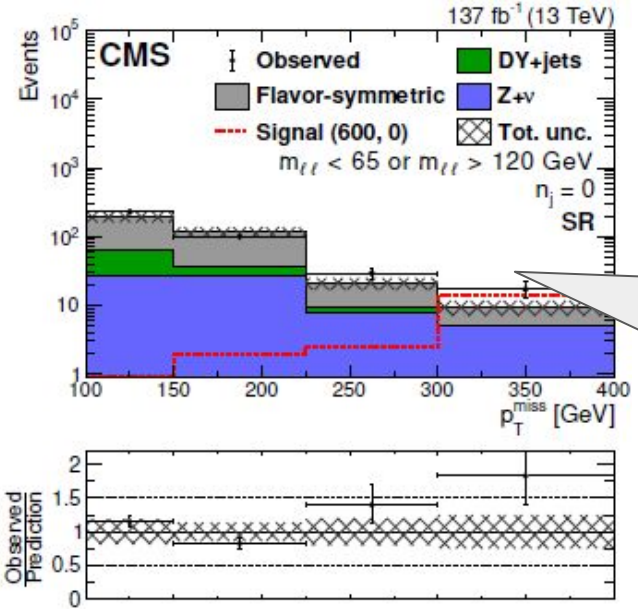
- Target signal decay modes with two opposite sign same flavor leptons
- Consider direct slepton pair production



JHEP

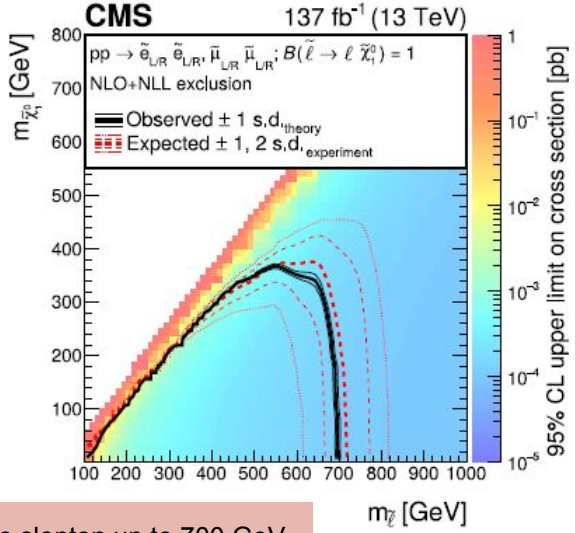


SUS-20-001



Discrepancy in the last bin:
Local significance of 1.6 s.d.

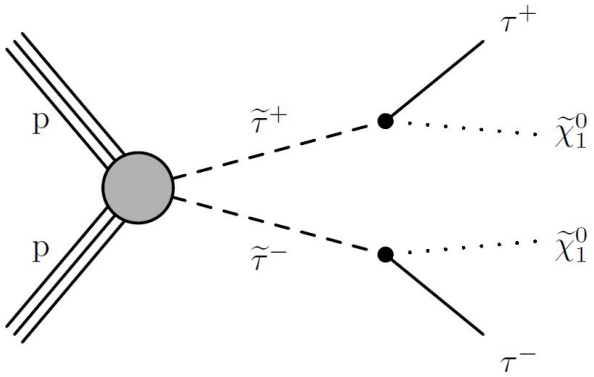
Overall no significance excess



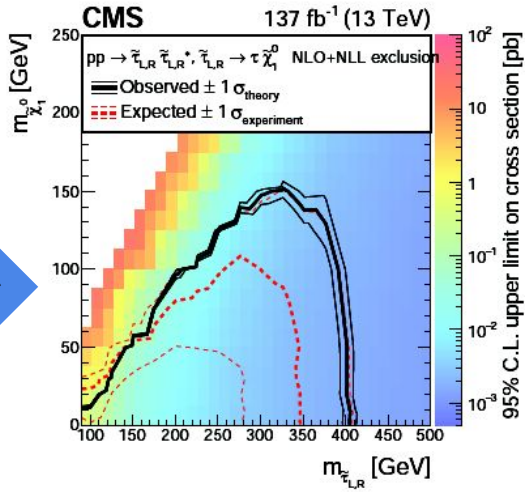
Exclude slepton up to 700 GeV

Search for Stau in Hadronic Final State

- Search for pair produced stau
  - pure LH, pure RH, and degenerate production (LH+RH)
- Also consider GMSB scenario where stau is long lived
  - cτ(stau) 0.01 - 10mm
- Final state: two hadronic taus + missing energy from LSP
- SR binned in N_{jets}, MT2, $p_T(\tau 1)$, $\sum_{MT} = MT(\tau 1) + MT(\tau 2)$
- Selection on tau IP for displaced stau signal



SUS-21-001



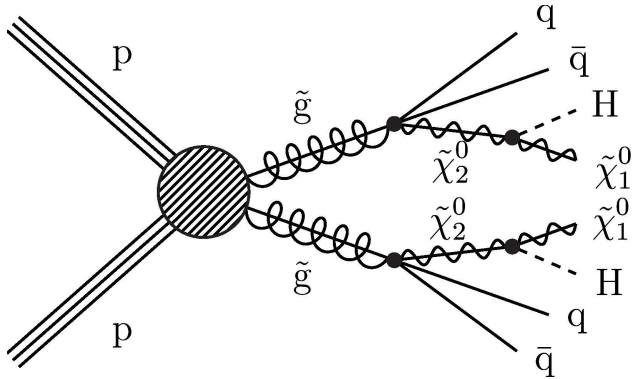
Exclude stau up to 400 GeV

Other Searches

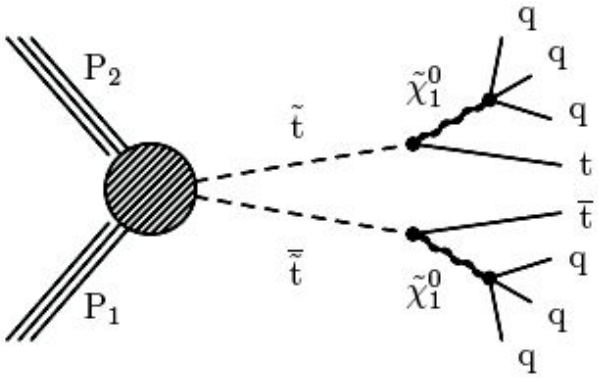
Strong and electroweak SUSY search
in two SS or three charged lepton final state
SUS-19-008

Electroweak SUSY search
in WW, WZ and WH hadronic final state
SUS-21-002

Strong and electroweak SUSY search
With Higgs and MET
SUS-20-004



Stealth/RPV stop search
SUS-20-004, PRD



Summary

- A highlight of SUSY searches in CMS with full Run2 data
  - A wide range of signal models
  - Advanced and improved techniques compared to the previous round of analyses
  - Brand new analyses
- So far no sign of SUSY
- Extend the exclusion limits up to several hundred of GeV
- *Stay tuned* for SUSY search in the unexplored parameter space with Run3 & HL data at LHC

Thank You!

Back Up