# SUSY searches at ATLAS and CMS

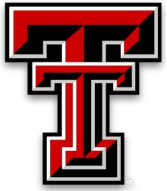
## XXV DAE-BRNS HEP Symposium

## IISER Mohali

DEC 12TH - DEC 16TH

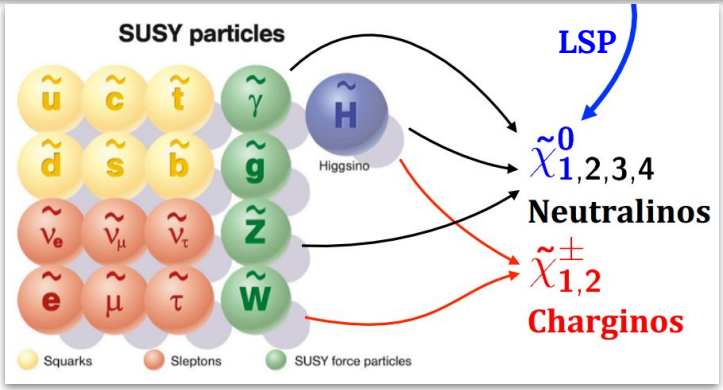
Vinay Hegde

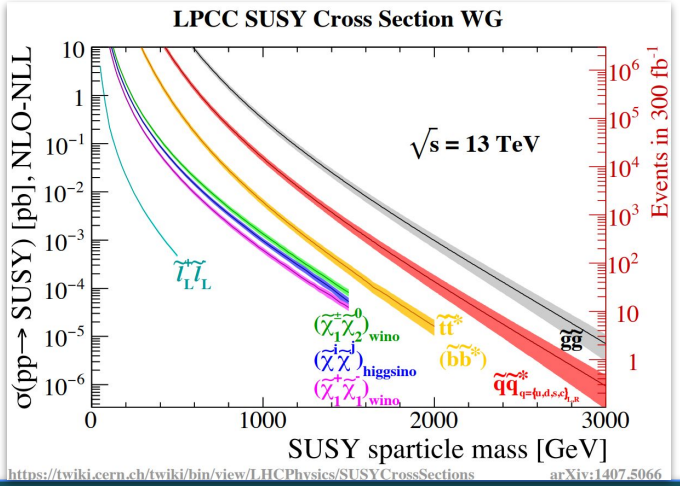
**Texas Tech University**



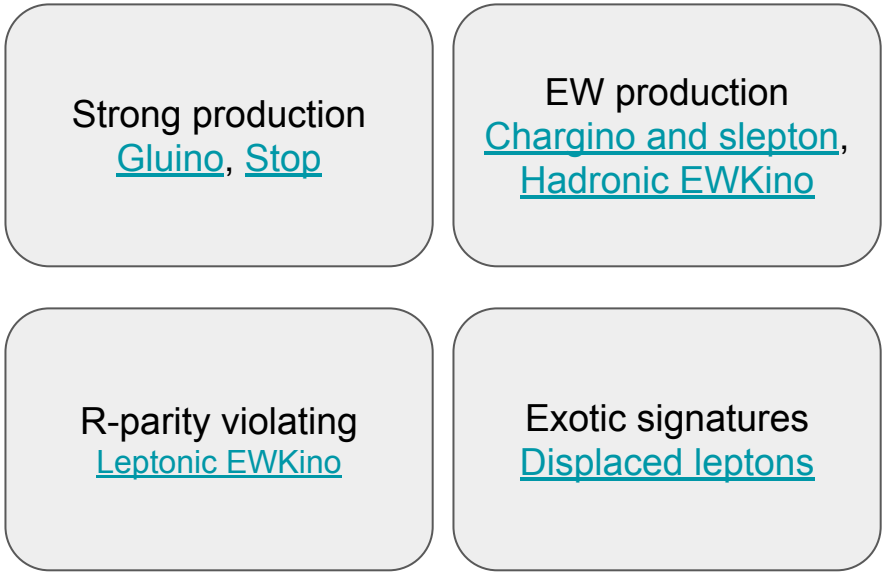
# Motivation

- Supersymmetry (SUSY) is an extension of SM which predicts a super-partner for every SM particle - spin differs by ½ .
- Why is SUSY interesting?
  - can solve hierarchy problem
  - When R-parity is conserved, lightest SUSY particle (LSP) is stable and a viable dark matter candidate.
  - gauge coupling unification.
  - Could explain (g-2)$\mu$ anomaly
- Naturalness → higgsino mass near the EW scale.
- Glunios and squark masses are ~TeV scale → can be probed at LHC and have large corss section.

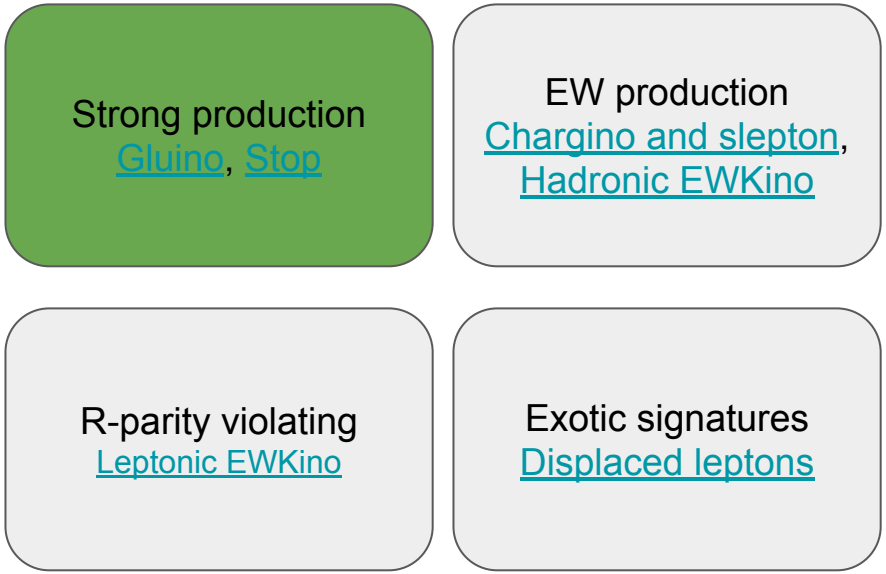


# Overview of SUSY searches



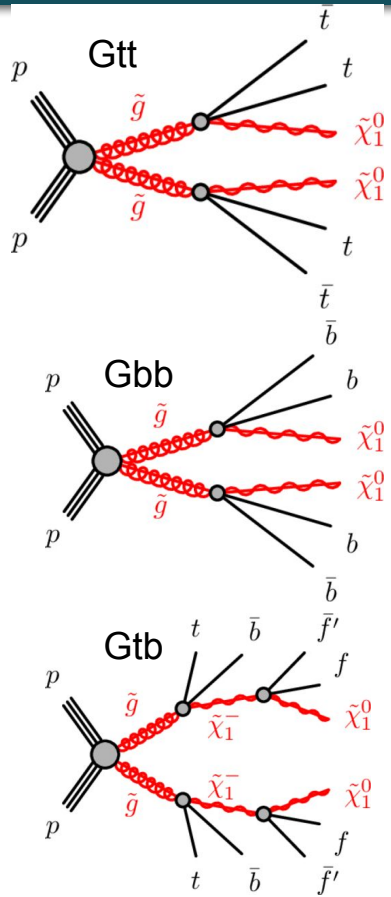
# Overview of SUSY searches



# Gluino search with multi-b + $p_T^{miss}$

SUSY-2018-30

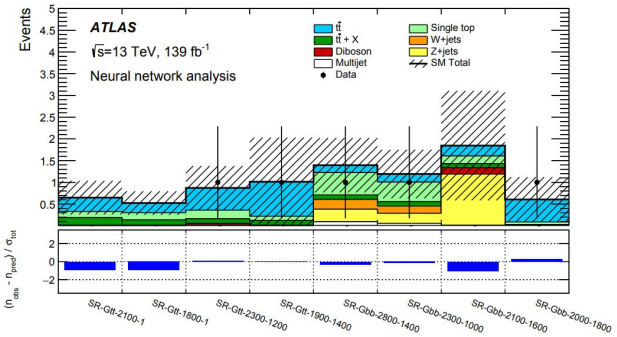
- Three or more b-jets from gluino decay or top decay. $p^T_{miss}$ from neutralinos.
- Targets hadronic and leptonic final states.
- Search regions are defined using cut and count (CC) method and neural network (NN) based method using supervised ML technique.
- Important selection variables: $m_{eff}$ (total visible and invisible $p_T$), transverse mass and large-R jet masses.
  - Used to define SR, CR and VRs.
- NN uses four momenta of small and large-R jets, b-tagging status, leptons, and $\mathbf{p_T^{miss}}$.

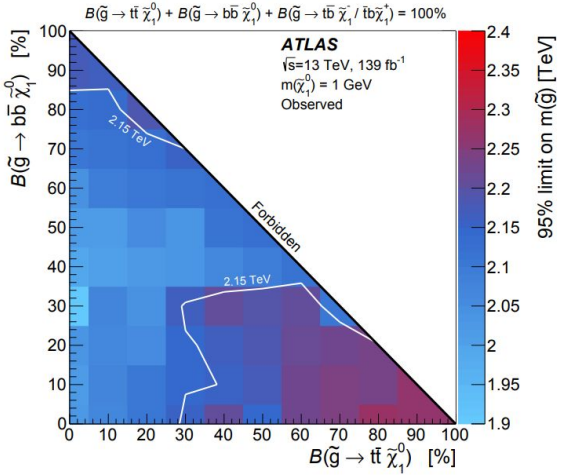


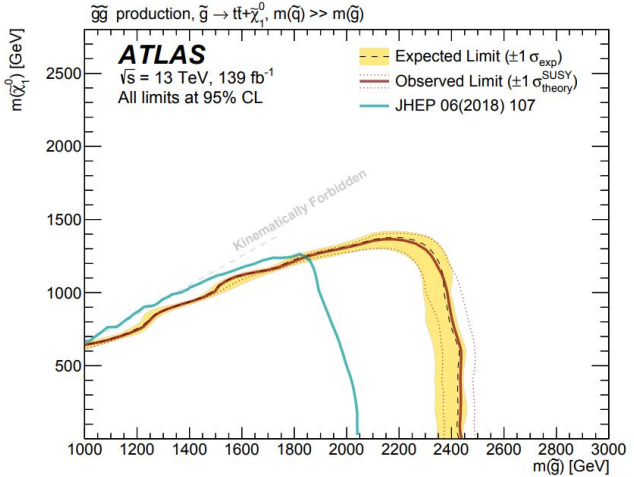
# Results and interpretations

- Dominant background is tt and Z+jets. Estimated by inverting the cuts on key variables and NN discriminator output.
- NN SRs are used for symmetric gluino decays ($\tilde{g}\rightarrow$ bb or tt). Cut and count for mixed decays ($\tilde{g}\rightarrow$ bb or tt or tb.

- Gluino mass limits : upto 2.44 (2.35) TeV for Gtt (Gbb) models. Improvement of 280 (330) GeV compared to previous results.



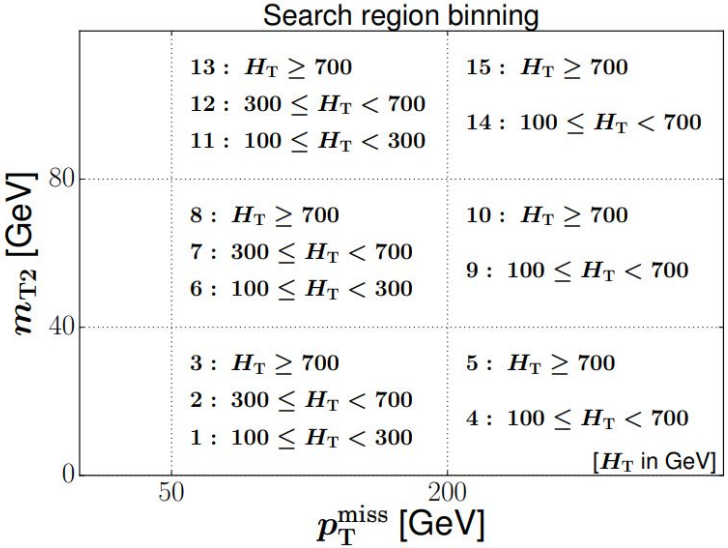



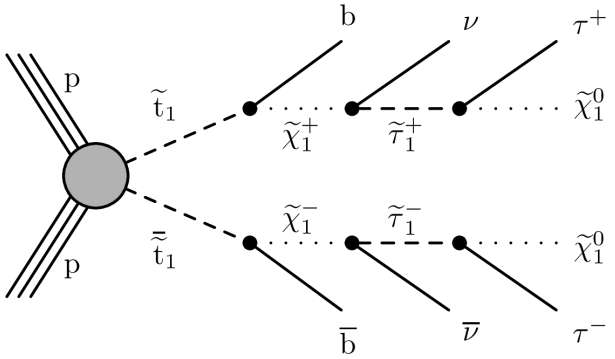



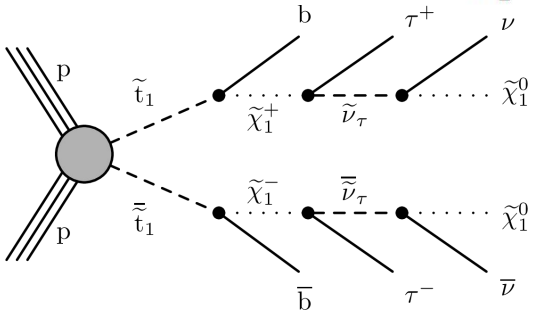
# Stop search with tau final state

SUS-21-004

- Stop search with large $p_T^{miss}$ and $\tau_h\tau_h$ or $\ell\tau_h$ final state.
- Very sensitive to high-tanβ or higgsino-like scenarios in which electroweakinos to tau decay are dominant.

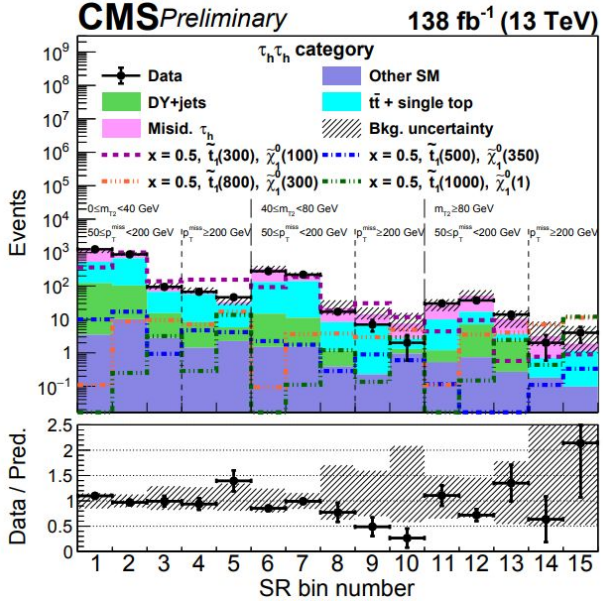


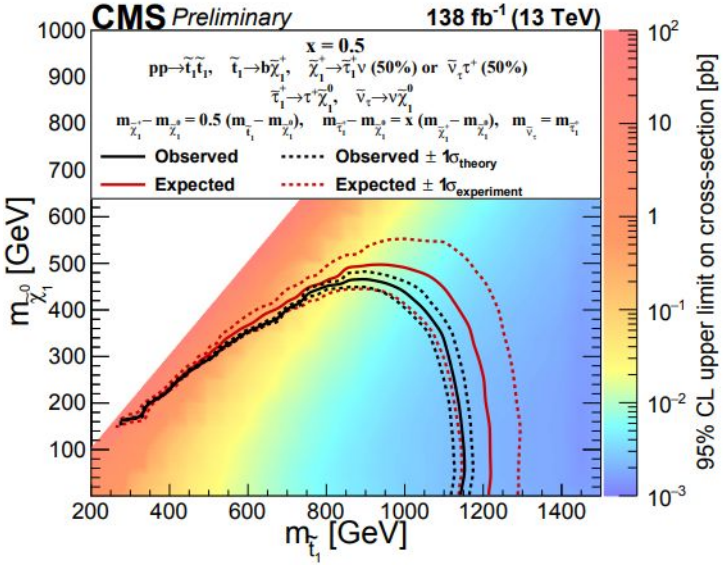



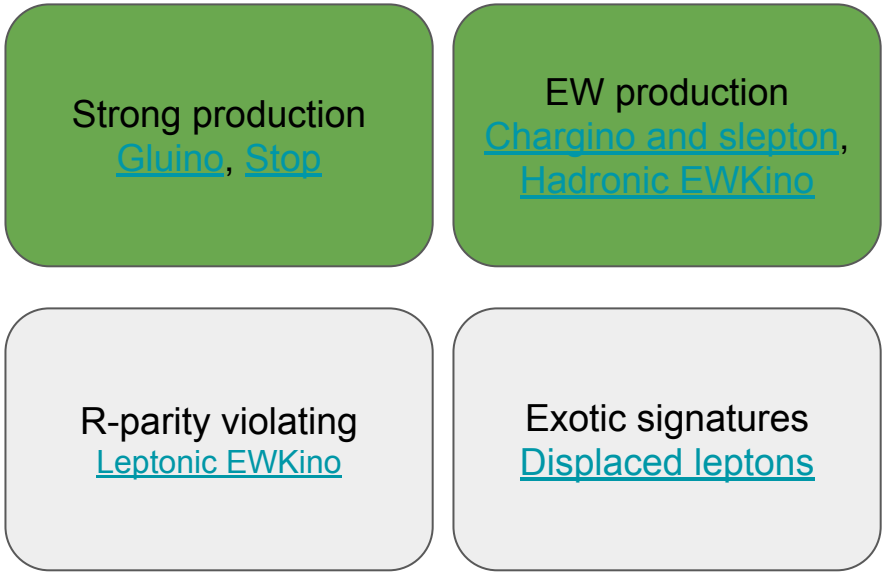
# Results and interpretations

- tt and tW are the dominant background processes with real taus.
- Misidentified taus from tt are the next dominant processes.
- For low LSP masses, stop mass limit is 1150 GeV → tightest limit till date.



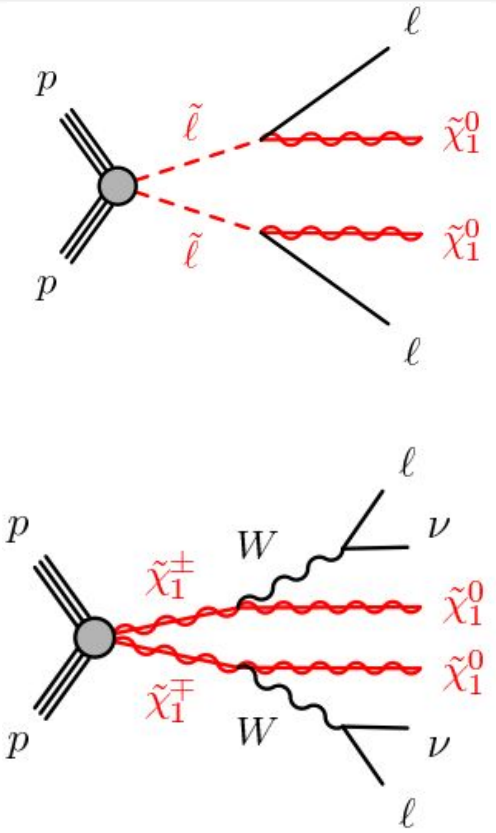
# Overview of SUSY searches



# Search for charginos and sleptons

SUSY-2019-02

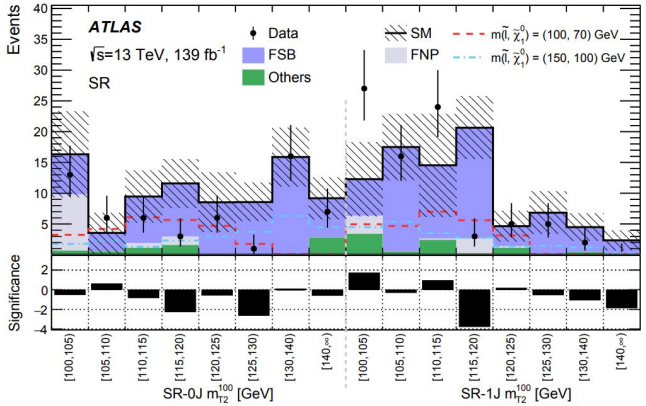
- Targets pair production of sleptons and charginos with small mass splitting (≲W mass) between the parent and LSP.
- EW scale SUSY with light smuon and LSP can explain $(g-2)_\mu$ anomaly [1][2].
- Event selection makes use of $p_T^{miss}$, low hadronic activity, absence of b-jets and dilepton invariant mass.
- Slepton search region: opposite sign same flavor leptons. Bkg estimation uses different flavor opposite sign.
- Chargino search: signal is similar to SM WW. An ML based BDT is used.

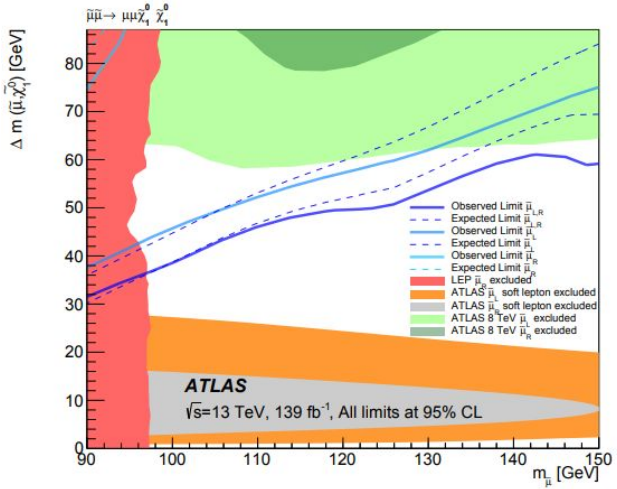


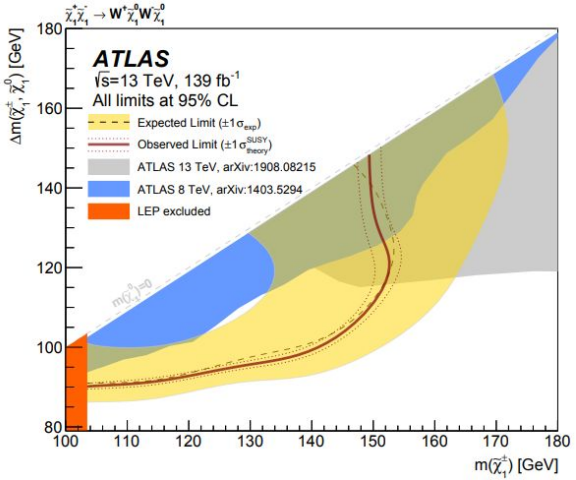
# Results and interpretations

SUSY-2019-02

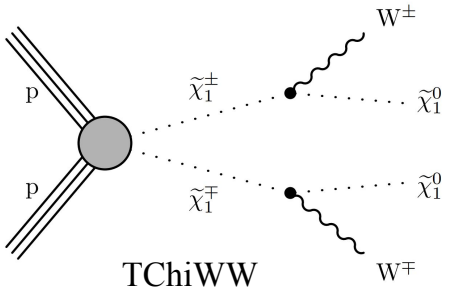
- No significant excess beyond the SM predictions.
- Slepton masses up to 150 GeV are excluded for 50 GeV mass-splitting.
- For ~100 GeV mass-splitting, chargino limits are up to 140 GeV.
- In certain regions, this search surpasses previous limits from LEP, ATLAS and CMS.



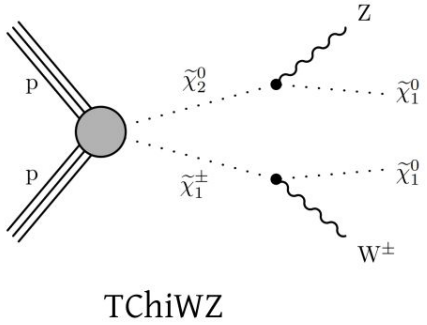



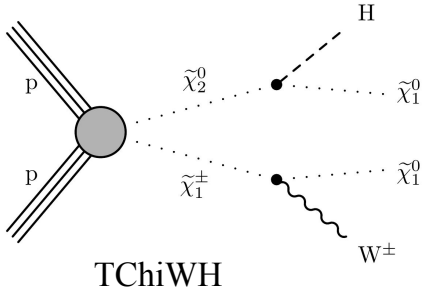
# WX + $p_T^{miss}$ final state search



TChiWW



TChiWZ

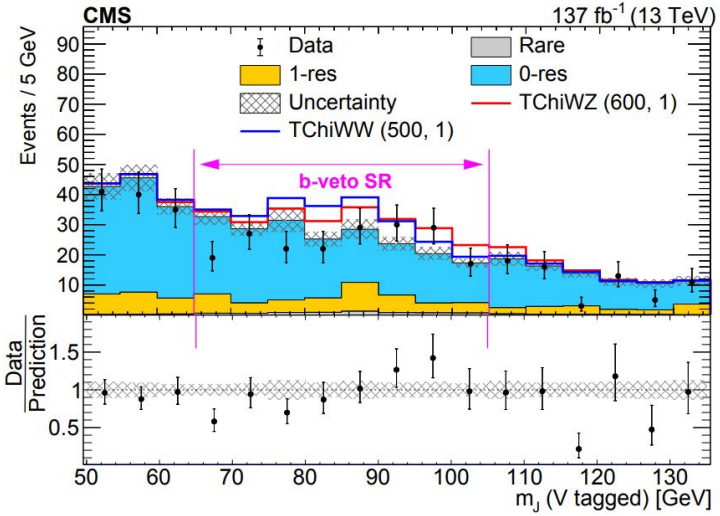


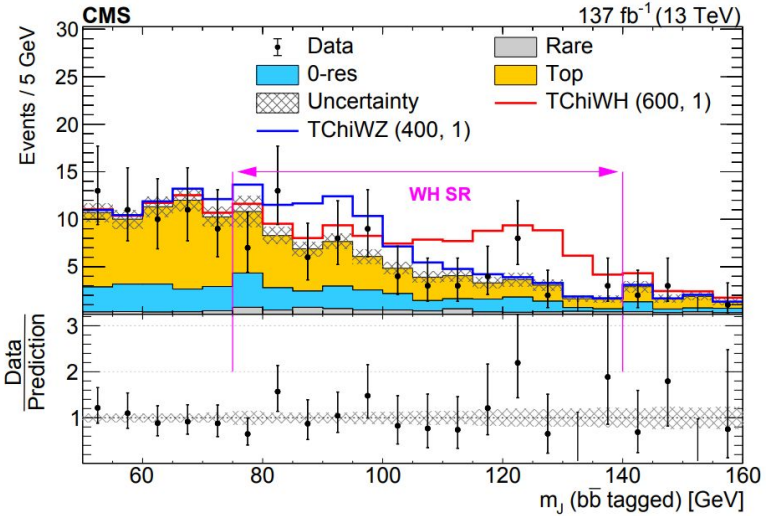
TChiWH

- 2 bosons decay hadronically, giving 2 AK8 jets.
- Search regions are designed based on the number of b-jet tags.
- Dominant backgrounds: tt, W($\ell\nu$) and Z($\nu\nu$)+jets.

# Backgrounds and results

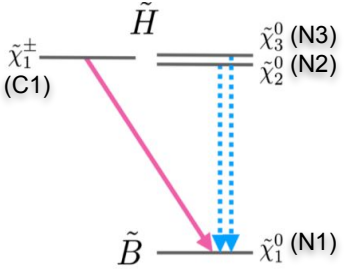
- Deep neural networks to discriminate QCD jets vs W/Z/H to qq decays.
- Z($\nu\nu$), W($l\nu$) and tt are the dominant SM backgrounds - estimation from leptonic regions and inverting the DNN discriminator.
- No significant deviations from SM predictions.

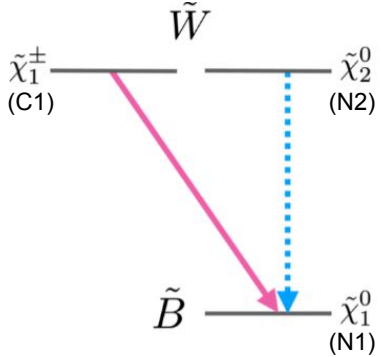


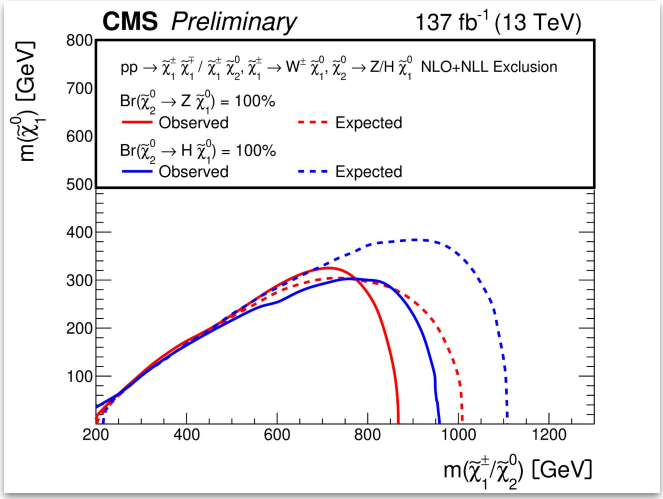
# Interpretations - beyond simplified models

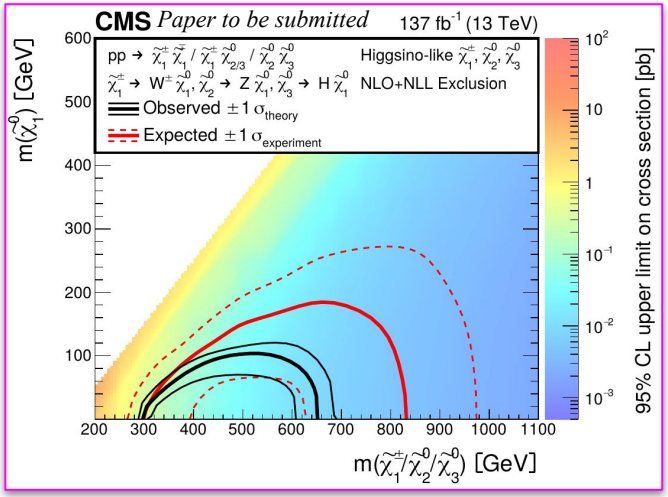
- Interpretations: SMS and wino and higgsino scenarios.
- Realistic wino scenarios involve $\chi^{\pm}_1\chi^{\pm}_1$ and $\chi^{\pm}_1\chi^{0}_2$ production.
- Large mass splitting between EWKinos→ hadronic searches are more sensitive.
- Search is also sensitive to higgsino models with $\chi^0_2 \rightarrow \chi^0_1 + Z, \chi^0_3 \rightarrow \chi^0_1 + H$.



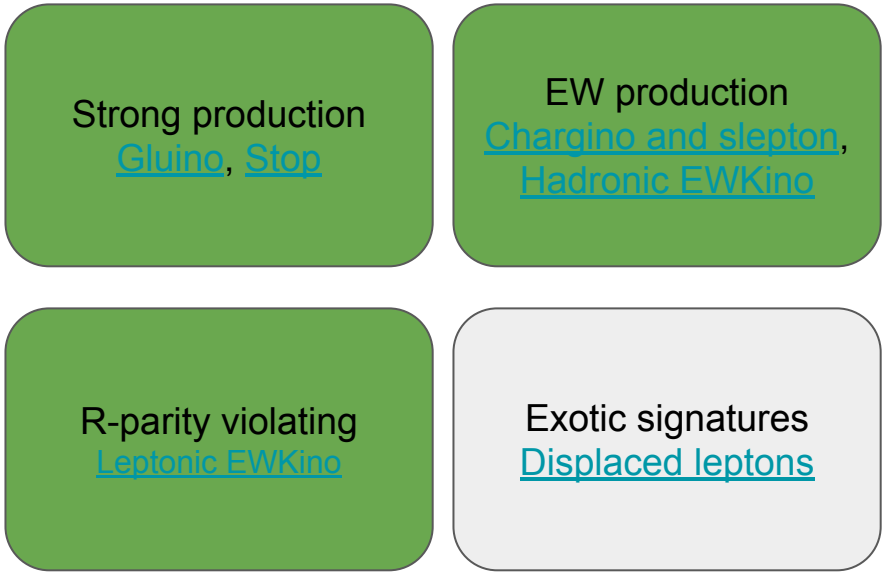




Wino scenario



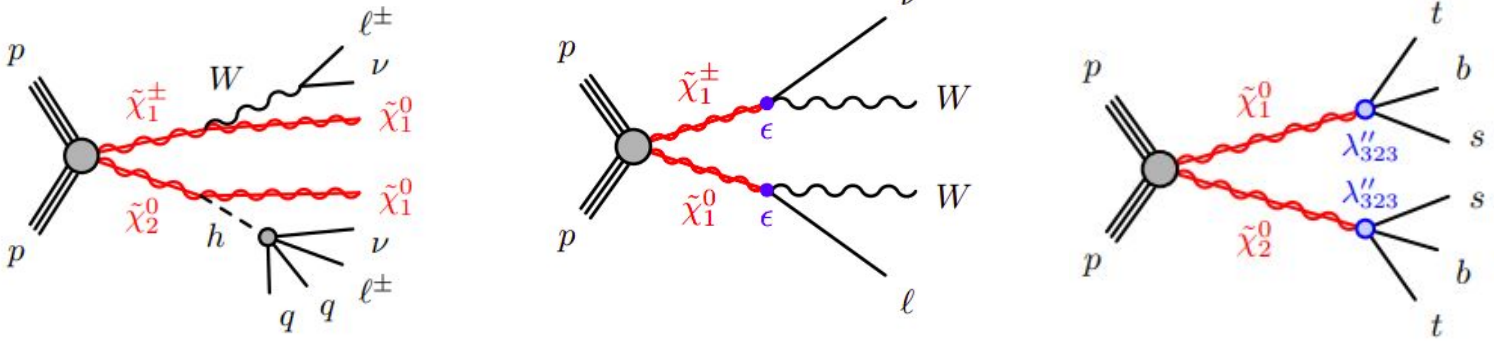
# Overview of SUSY searches



# EWKino search with 2 or more leptons

ATLAS-CONF-2022-057

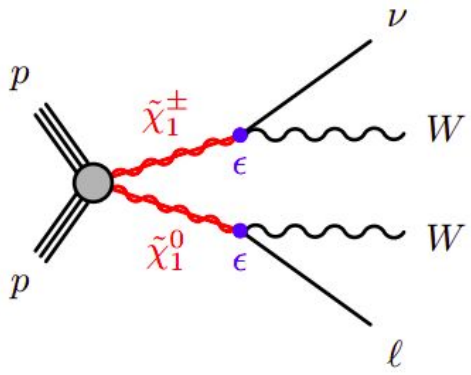
- Wino and higgsino search with 2 same sign (SS) or 3 leptons, $p_T^{miss}$ and jets. RPC and RPV decays of EWKino are considered.
- SM process with SS leptons are rare → able to probe higgsinos.
- $W^{\pm}W^{\pm}$, WZ and ttV are the dominant irreducible backgrounds.
- $m_{T2}$, $p_T^{miss}$, $m_{eff}$ etc are used to define SR and CR.

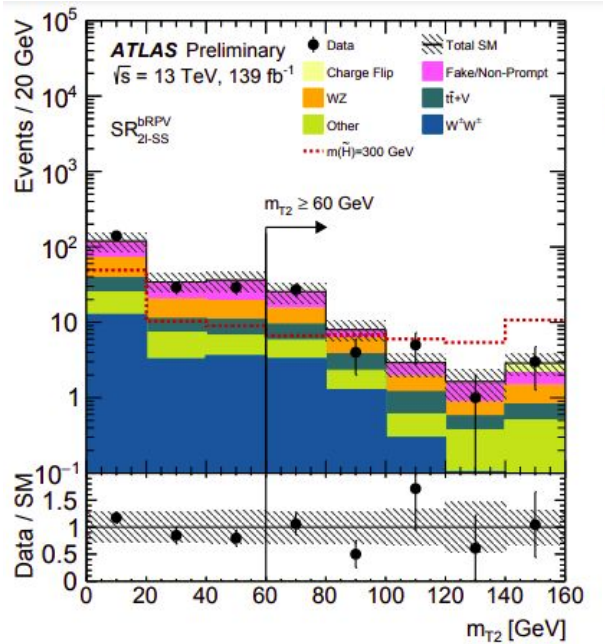


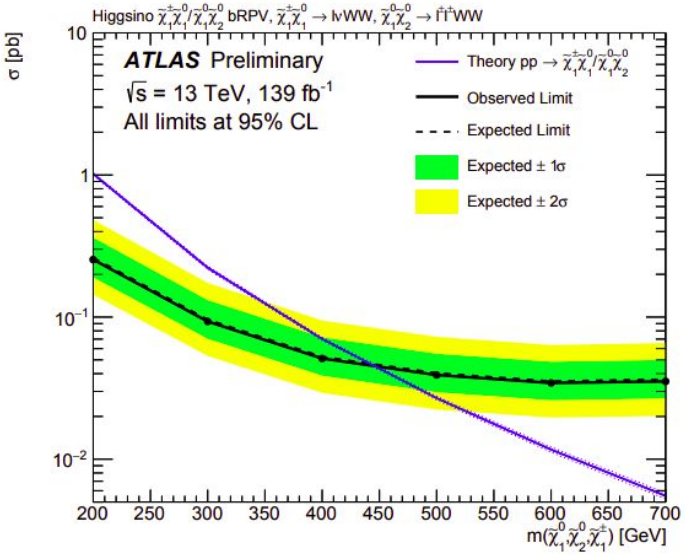
# Results and interpretation

ATLAS-CONF-2022-057

- For wino-bino Wh models, NLSP masses up to 525 GeV have been excluded.
- Higgsino masses up to 440 GeV are excluded.
- These are the first experimental limits on bRPV models.



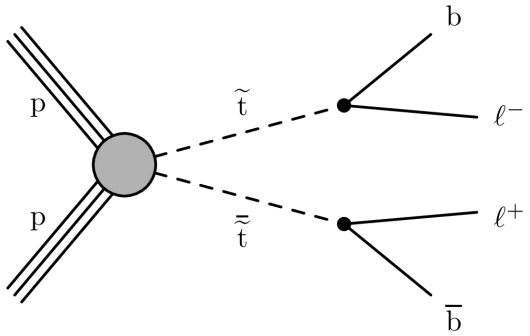



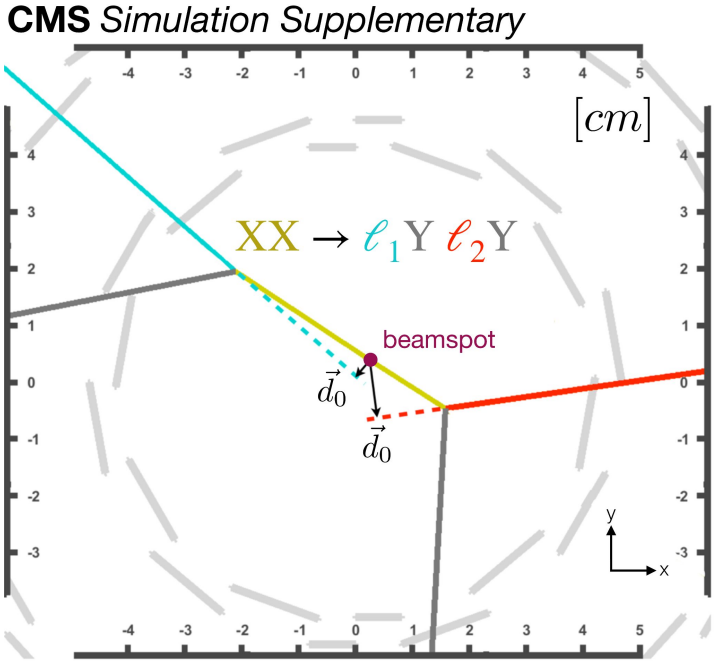
# Overview of SUSY searches

# Long-lived particles decaying to leptons

EXO-18-003

- When the couplings are small or available phase space for the decay is small, particles can be long lived.
- Sensitive to proper decay lengths $10^{-3}$ to $10^{3}$ cm.
- Muon triggers w/o requiring its origin to be primary vertex and photon triggers are used.

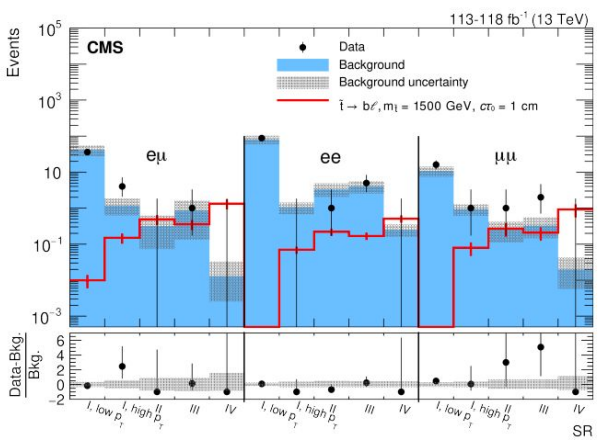


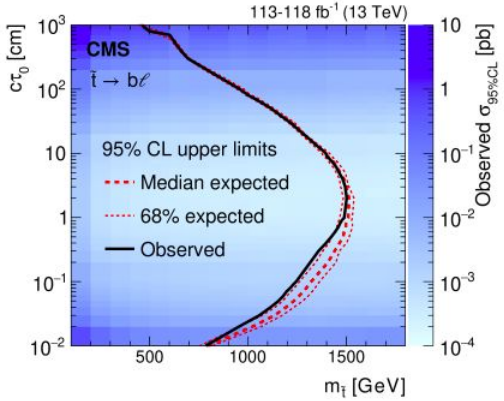



# Results and interpretations

EXO-18-003

- Background rejection:
  - Timing of muons are used to reject cosmic muon background.
  - The distance between muons (dR) > 0.2 to reduce heavy flavor hadron decays.
- Observations do not deviate from predictions by 2 s.d.
- Stop mass limits are  from 100 to 460 GeV, with maximum limit around 1500 GeV.
- Search also places most stringent limits for H→ scalars models.

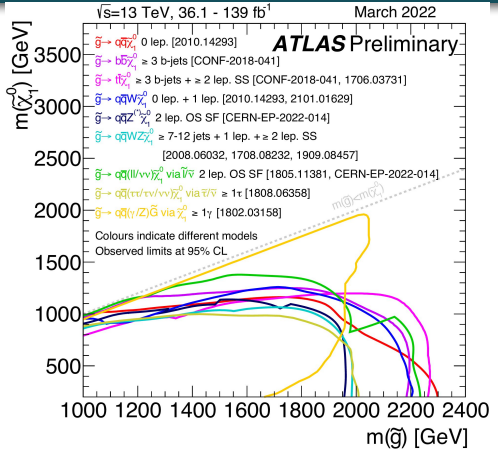


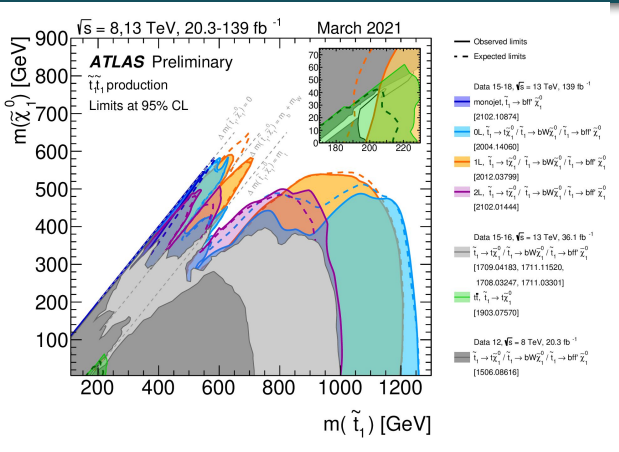



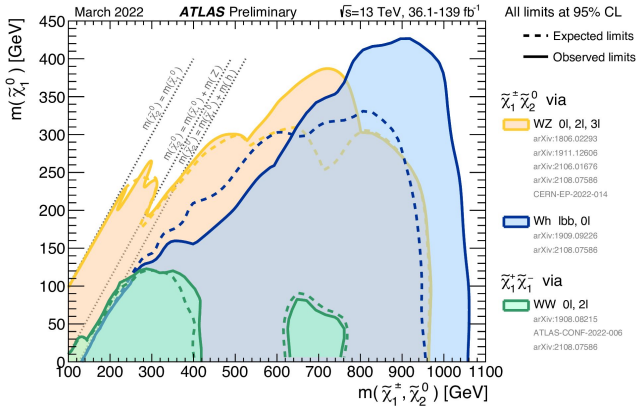
# Outlook

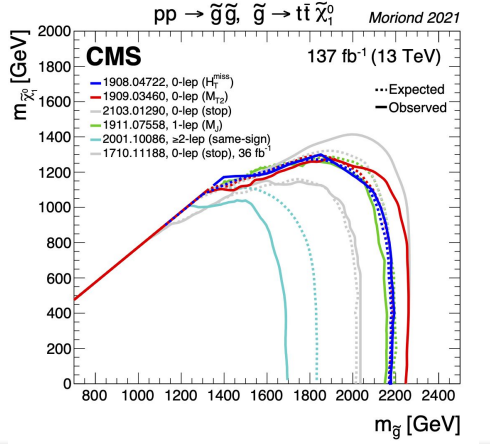
- Guinos, stops, sbottoms and higgsinos are motivated by naturalness arguements; EWKinos by dark matter and $(g-2)_{\mu}$ results.
- Gluinos/stops/sbottoms: strongly constrained by Run 2 data. But we haven't explored all of the SUSY parameter space.
- For higgsino searches: special techniques to target compressed regions. Hadronic searches are important for high mass and high mass splitting.
- RPV searches: a lot of unexplored parameter space. Leptonic searches can probe these with new ML techniques.

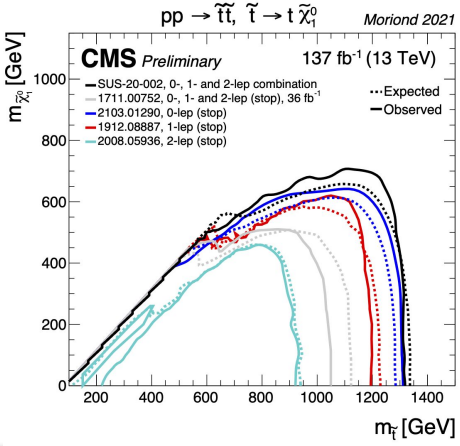
# Summary of SUSY searches

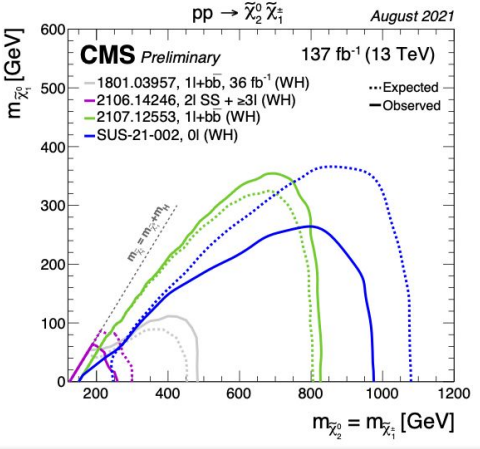


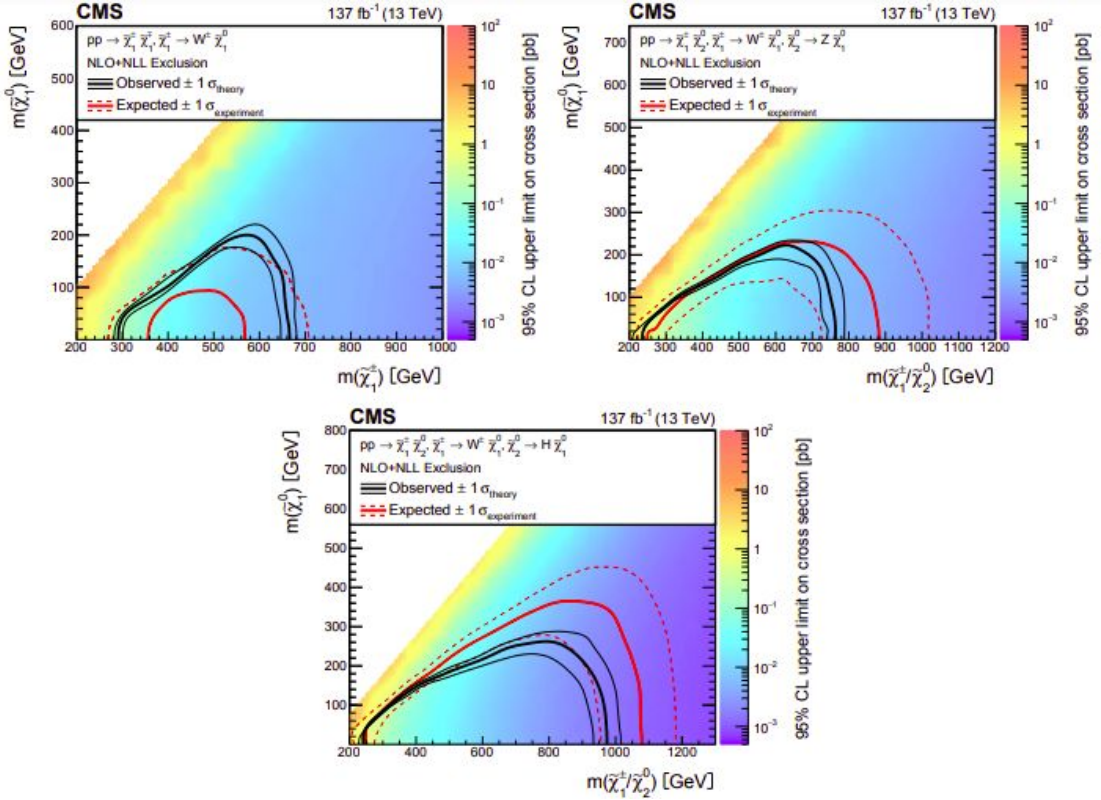



# Additional info

# Simplified model interpretations




WW exclusion: 290 - 670 GeV WZ: 230 - 760 GeV WH: 200 - 970 GeV