Searches for electroweak SUSY production in leptonic and hadronic final states with the CMS experiment

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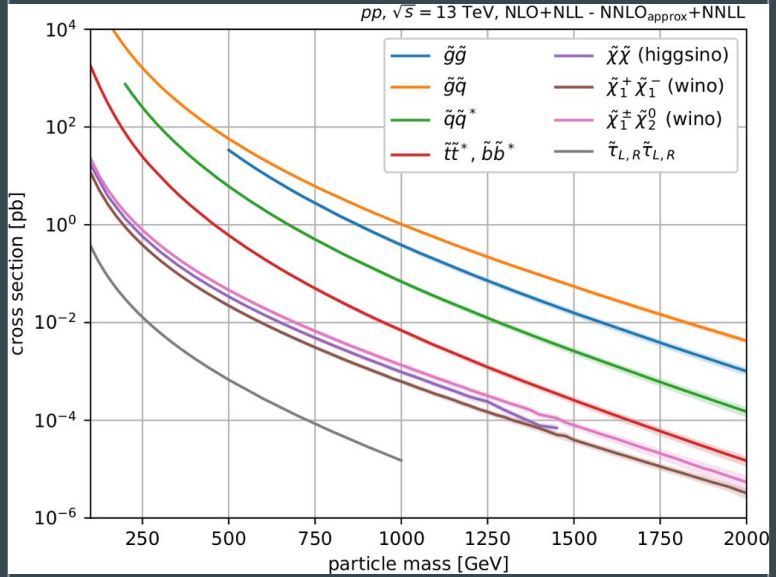
Overview

CMS explores a wide range of SUSY models

STRONG PRODUCTION



- Large cross sections
- Absence of observed signal might indicate:
  - Mass of colored sparticles too high
  - Mass spectrum too compressed

ELECTROWEAK PRODUCTION

Latest results

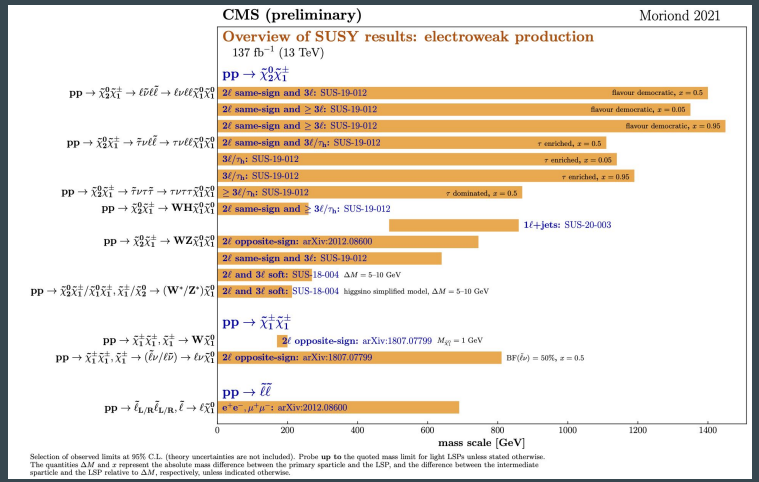
stau production
Talk by Giulia Collura

Gauge Mediated SUSY breaking

slepton production

Chargino/neutralino/ higgsino production

- Smaller cross sections than strong production
- Electroweak production models less constrained



All SUSY papers

All SUSY PAS

Overview

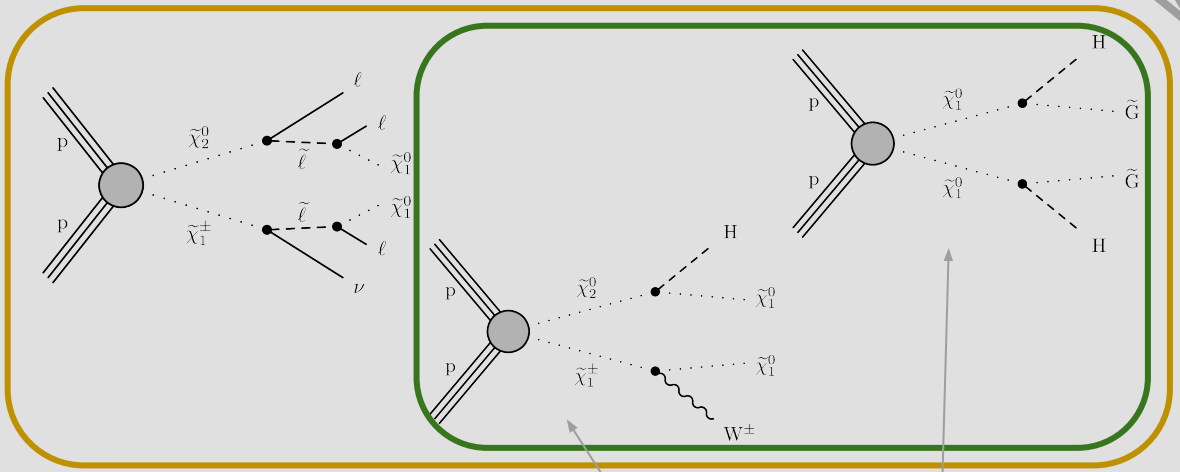
ELECTROWEAK PRODUCTION

Gauge Mediated
SUSY breaking

Chargino/neutralino/
higgsino production

han strong production
models less constrained

Latest Full Run II results from CMS



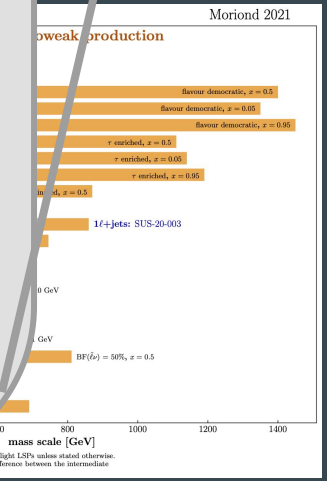
Leptonic final state searches:
arXiv:2106.14246
Submitted to JHEP

Hadronic final state searches:
SUS-20-003 (PAS)
SUS-20-004
NEW

Chargino $\tilde{\chi}_i^\pm$ and neutralino $\tilde{\chi}_i^0$:
Mixed states of Higgsinos and Electroweak gauginos

$$m(\tilde{\chi}_4^0) > m(\tilde{\chi}_3^0) > m(\tilde{\chi}_2^0) > m(\tilde{\chi}_1^0)$$

$$m(\tilde{\chi}_2^\pm) > m(\tilde{\chi}_1^\pm)$$



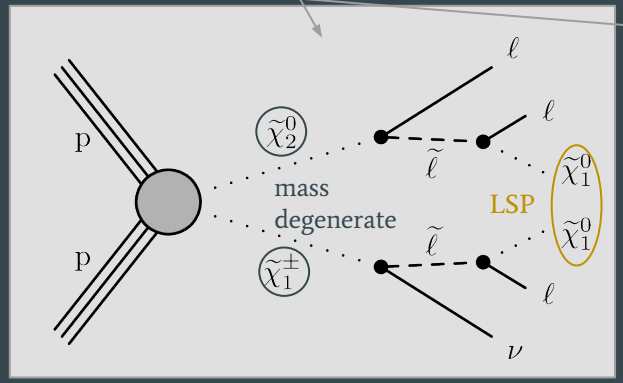
All SUSY papers

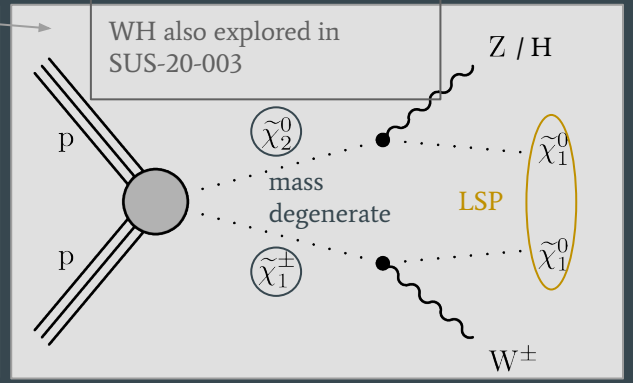
All SUSY PAS

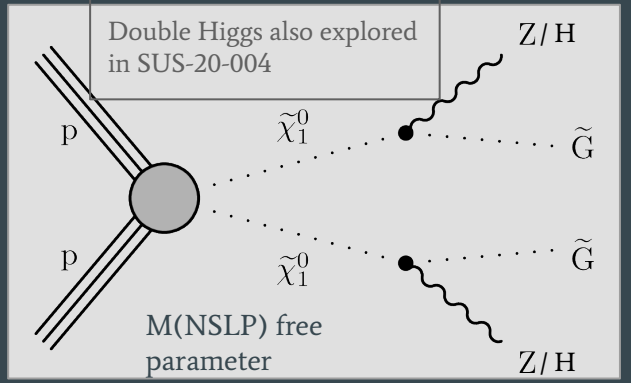
Multilepton search: signal models

- Search for production of neutralinos and charginos
- R-Parity conserved
- Simplified SUSY models
- Targets fully leptonic final states + missing energy
- https://arxiv.org/abs/2106.142 46 "SUS-19-012"

M(LSP) and M(chargino) free parameters







Slepton-mediated decay

WZ/WH-mediated decay

- Sleptons too heavy
- Leptonic SM boson decay

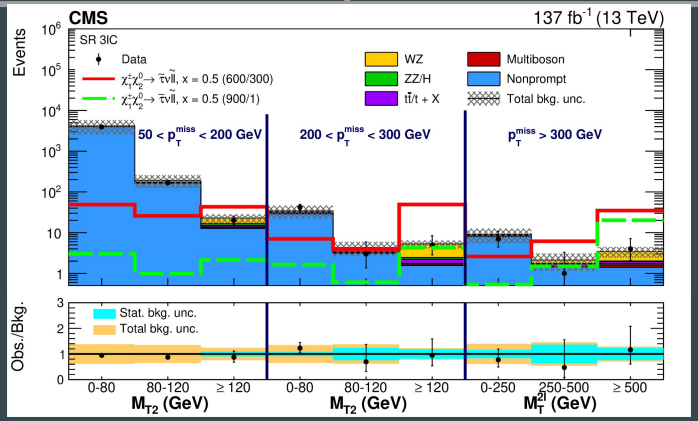
Gauge Mediated SUSY breaking

- Gravitino LSP
- Leptonic SM boson decay

Strategy and selection of multilepton search

Search categories defined according to final states

Final State	Sensitive models
2 SS leptons	"compressed" scenarios Small δm between SUSY particles
3 light leptons, no OSSF	nonresonant lepton production from H decay
3 light leptons, OSSF	flavor democratic
3 leptons including tau	tau enriched tau dominated
4 leptons	Gauge mediated SUSY breaking

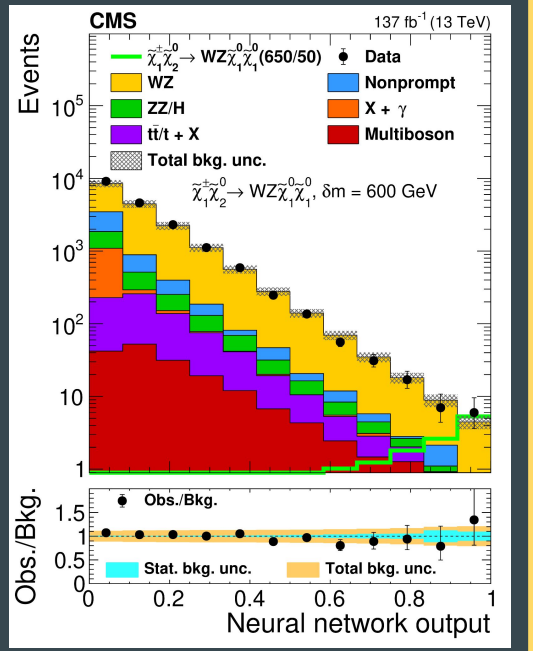


3 light leptons, OSSF

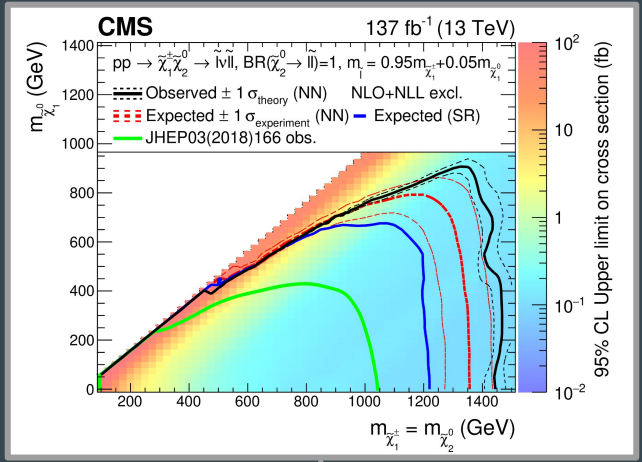
- Highly sensitive to flavor democratic
- Large background from SM

Parametric NN

- Trained for:
  - Slepton mediated
  - WZ-mediated
- Parameter:
  δm = M(chargino)-M(LSP)
- δm driving factor for kinematics



Interpretation of multilepton search results



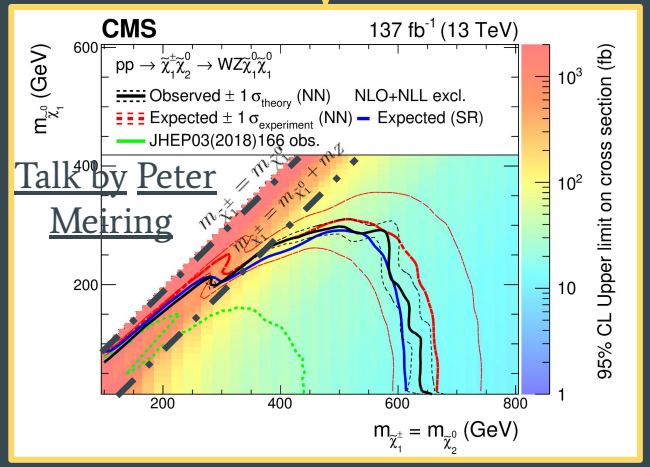
"Flavor democratic" slepton mediated

Major improvements from full Run II and NN

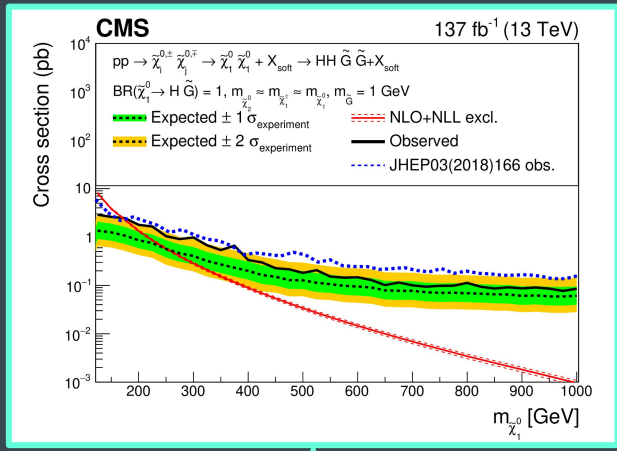
No significant excess observed

WZ-mediated:

WZ corridor has been closed



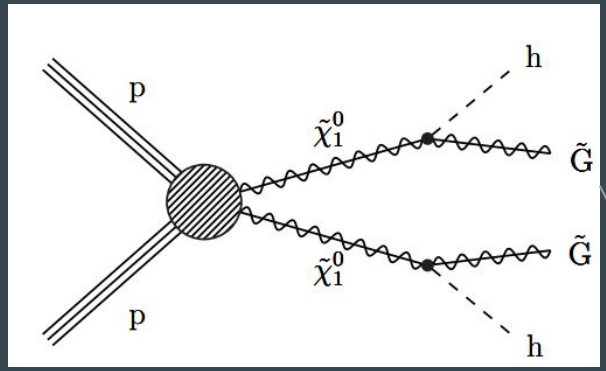
Talk by Peter Meiring

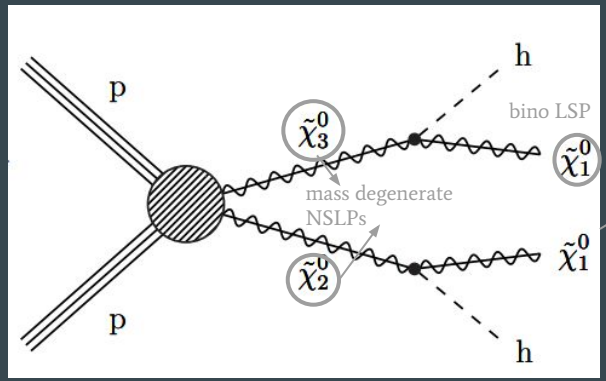


GMSB HH-mediated

SUS-20-004: Search for higgsinos in two Higgs bosons and missing transverse energy

NEW





- Using H→bb (BR ≈ 60%)
- R-parity conserved → Missing energy from LSP
- Final state: multiple (b-tagged) jets + missing energy

Gauge mediated SUSY breaking:
- Boost to cross section from different production channels
- Parameter of interest: NLSP mass

Simplified SUSY model:
- Parameters of interest: LSP and NLSP masses

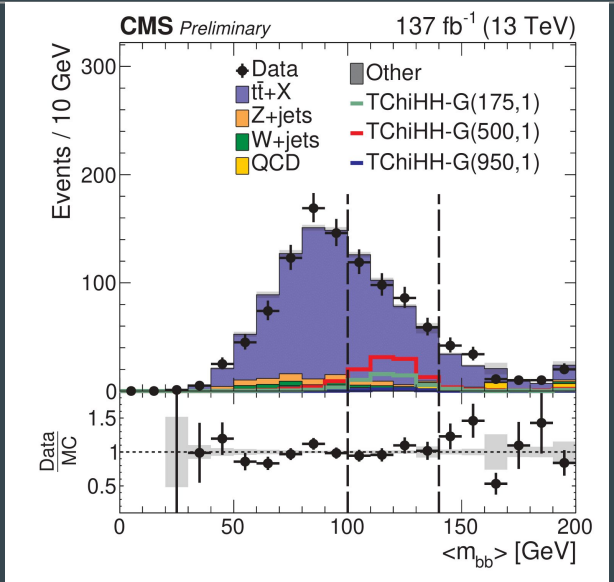
Strong production models in backup

Strategy of HH+MET search

To be sensitive to large range of sparticle mass:
2 approaches for H reconstruction

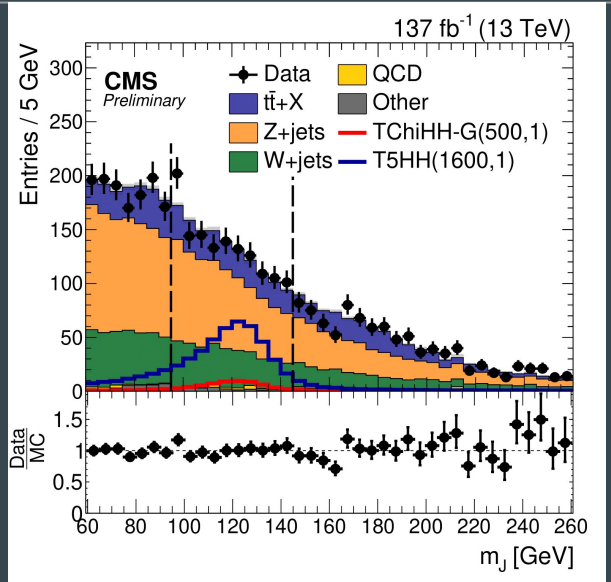
Resolved scenario

H→bb reconstructed as two separate jets

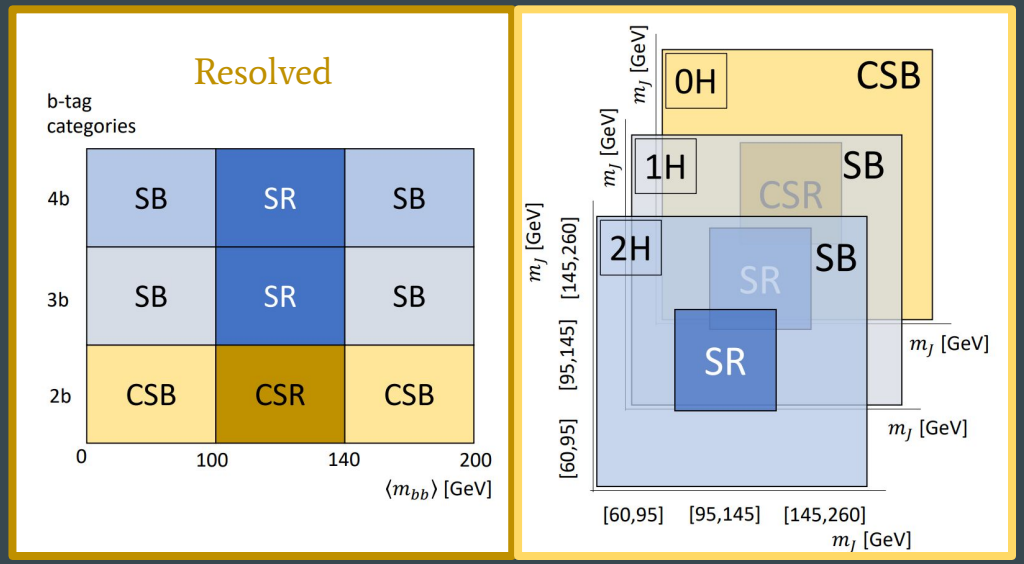


Boosted scenario

H→bb reconstructed as single wide jet



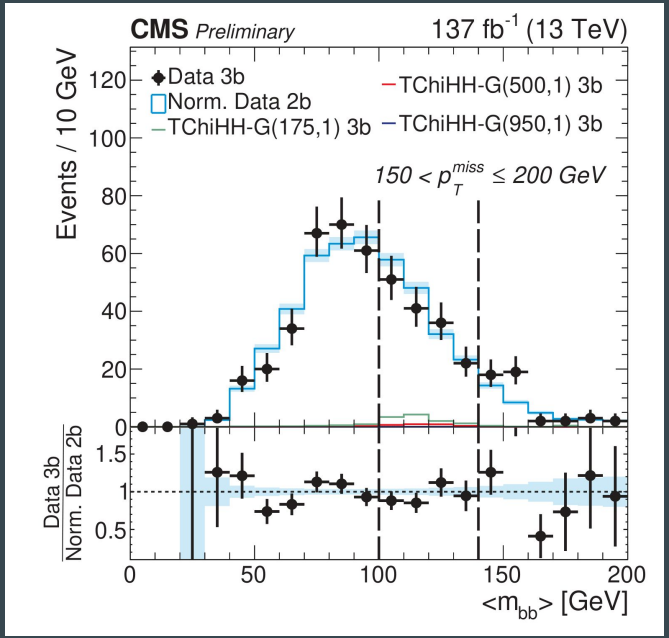
HH+MET Background estimation



ABCD method to estimate SM background

$$N_{SR} = \kappa \frac{N_{CSR}}{N_{CSB}} N_{SB},$$

with κ a correction factor for correlations determined in MC



Resolved scenario:

- Mass of Higgs boson candidates and number of b-tagged jets as discriminating variables

Boosted scenario:

- Number of double b-tagged wide jets and mass of wide jets as discriminating variables

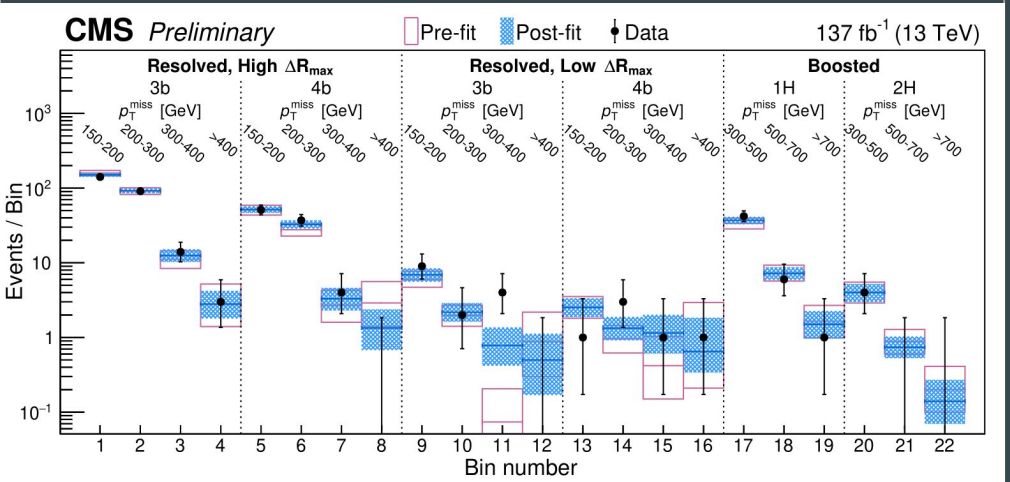
Results and interpretation of HH+MET search

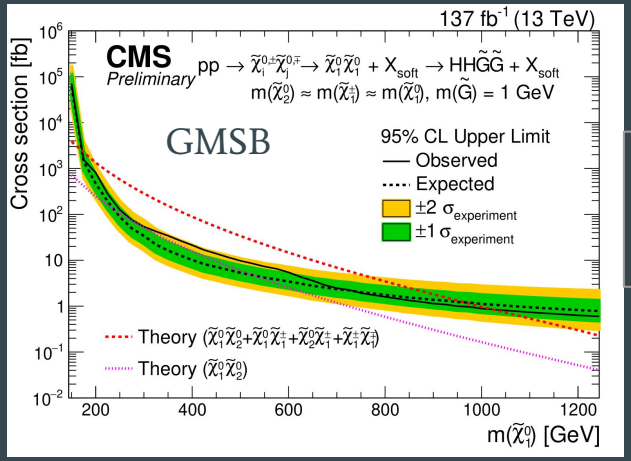
Maximum likelihood fit to data according to the CLs method

Boosted scenario cleaned of overlap with resolved

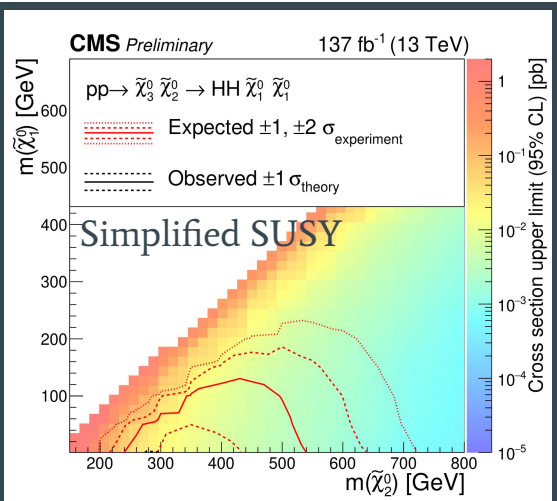
No compelling excess of events observed:

- Single bin not within stat. unc.
- Prediction based on 2 events
- Global significance: 1.9 sd



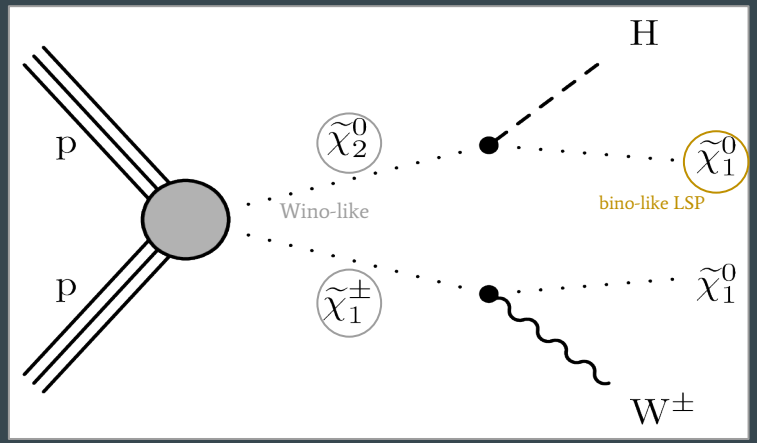


multilepton exclusion up to 200 GeV



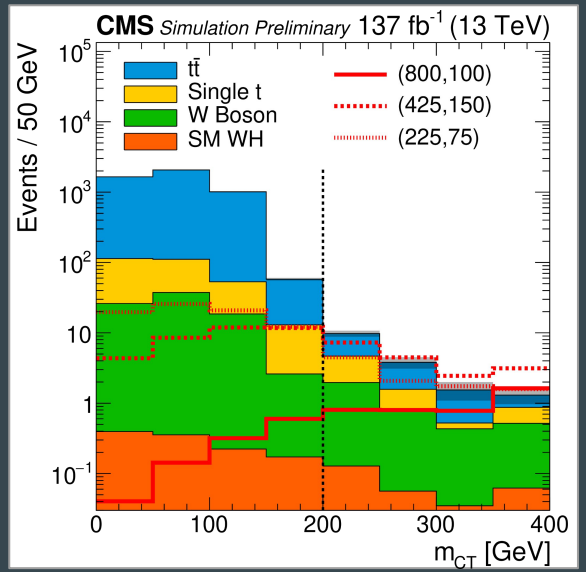
SUS-20-003

"Search for chargino-neutralino production in final states with a Higgs boson and a W boson"



Backgrounds:

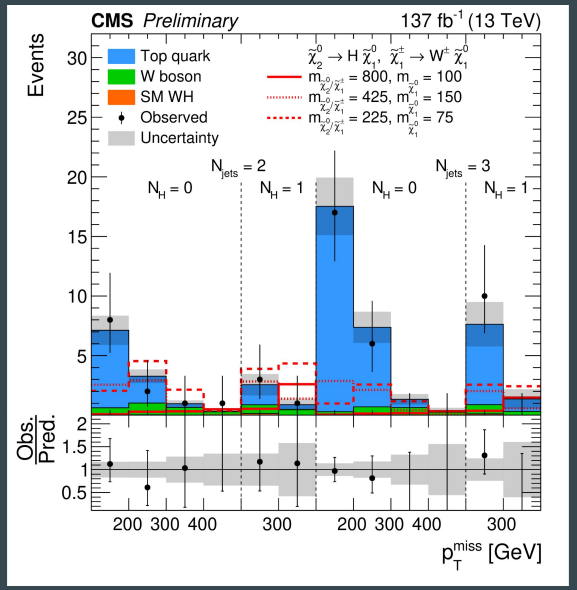
- Main contributions: top quark production and W boson production
- Estimated from data using transfer factors from CR to SR
- Transfer factors from background enriched CR in MC
- Validated in data



- **leptonic W decay**
  → single lepton
- **H →bb (BR ~ 60%)**
  → 2 b-tagged jets or single wide jet with H-tag from DNN

Results and interpretation of single lepton search

Binned maximum likelihood for SUSY signal strength, yield of backgrounds and nuisance parameters performed:
No excesses observed

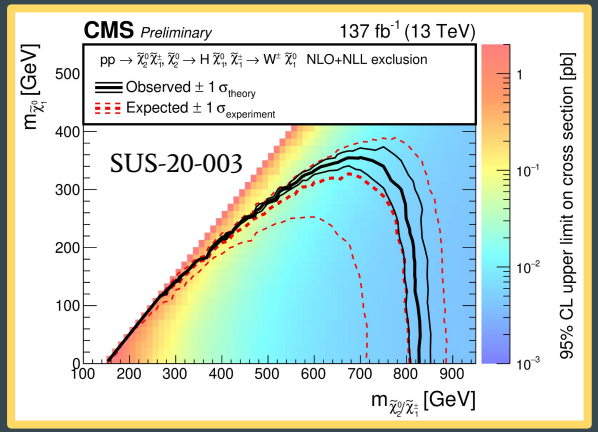


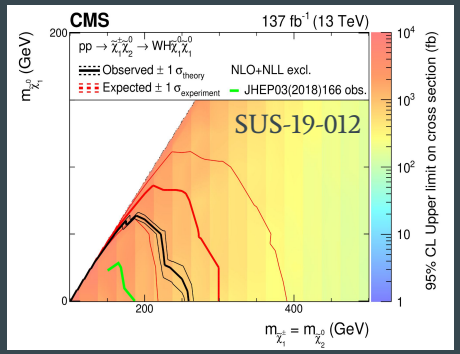
Analysis excludes:

- Charginos up to 820 GeV
- LSP up to 350 GeV

Much more stringent exclusion compared to leptonic final state explored in SUS-19-012

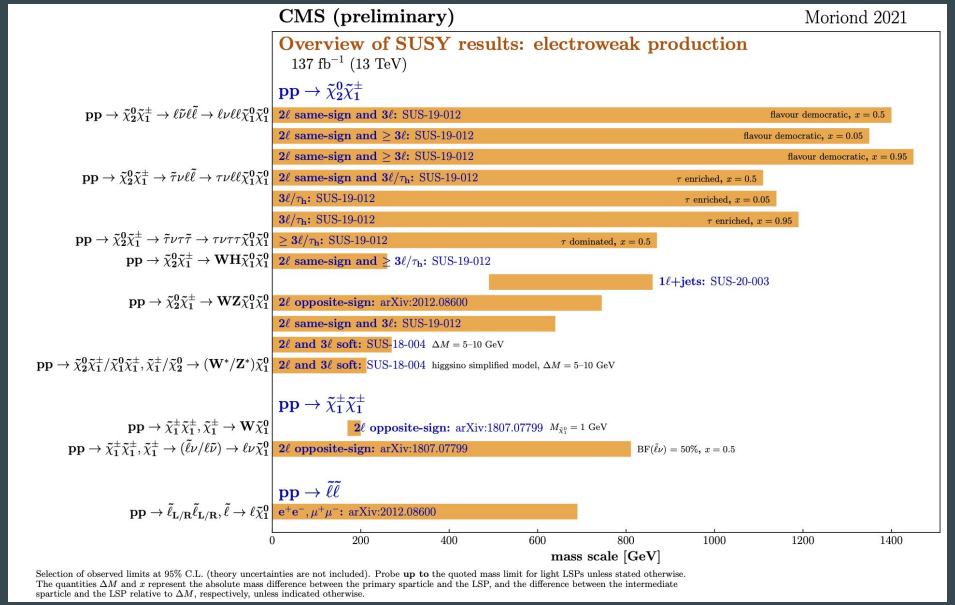
Improvement of 350 GeV on chargino masses and 250 GeV on neutralino masses compared to previous iteration of this analysis





Conclusions

- Three analyses searching for electroweak production of SUSY using full Run II data presented
- No significant excesses observed
- Exclusion limits further expanded
- Further updates in electroweak SUSY production to follow
- Looking forward to Run III!

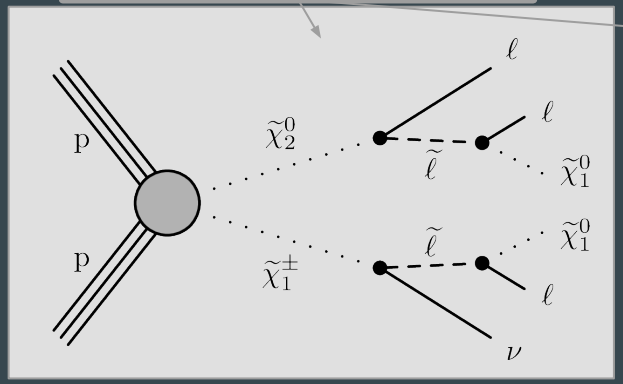


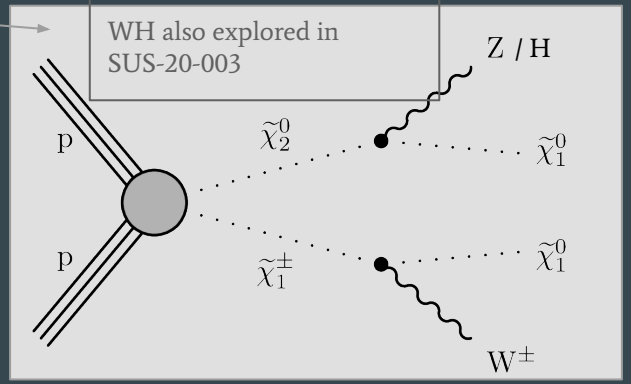
BACKUP

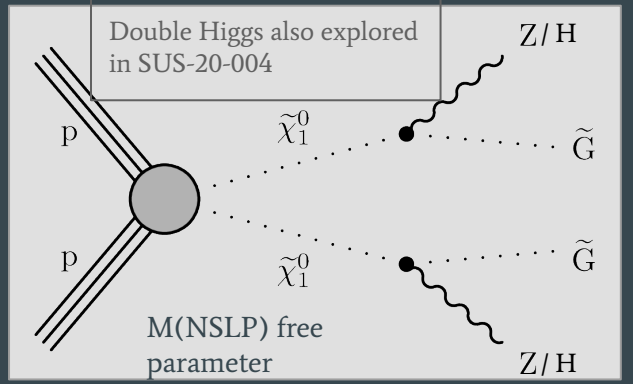
SUS-19-012: signal models

- Search for production of neutralinos and charginos
- R-Parity conserved
- Simplified SUSY models
- Targets fully leptonic final states + missing energy
- https://arxiv.org/abs/2106.142 46

M(LSP) and M(chargino) free parameters







- Different flavor scenarios depending on composition of chargino/neutralino:
  - **"Flavor democratic":** Equal probability for all lepton flavors
  - **Tau enriched:** Chargino decay favors taus
  - **Tau dominated:** Exclusive decay to taus

- Sleptons too heavy
- Forced decay to SM bosons and LSP
- Leptonic SM boson decay
- BR ~3%: Much lower than slepton mediated decay

- Gauge Mediated SUSY breaking
- Higgsino-like chargino/neutralino
- ~ massless gravitino
- ~ mass degenerate charginos/neutralinos
- Effective NLSP production

SUS-19-012: Backgrounds

Estimated from simulation and validated in control regions in data:

- WZ: Additional validation of MT distribution for effects from:
  - mispairing of leptons
  - MET resolution
- ZZ
- tX/ttX
- Triboson
- Internal/external conversion

4 Types of SM backgrounds:

- SM events with 3 or more prompt leptons or SS dilepton
- External and internal conversions of photons
- Nonprompt backgrounds
- Charge mismeasurement

Estimated using data-driven "tight-to-loose" method:

- Main contributions:
  - ttbar
  - DY
- Light lepton ratio measured in single lepton QCD-enriched events
- Tau ratio measured separately for tt and DY control regions
- Background estimation from applying ratio to "sideband" of SR where one or more leptons fails tight selection
- Tau: ttbar or DY ratio applied depending on major contribution in the SR

Electron sign misid probability from simulated DY, ttbar and diboson production

- Validated and normalized in DY control region

Muon sign misid probability found negligible in MC
→ Estimated from MC

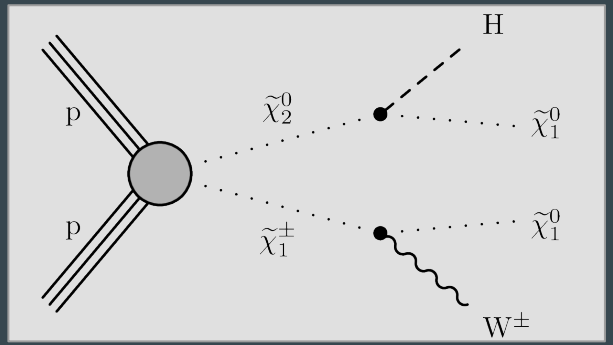
SUS-19-012: Strategy and selection

Search categories defined according to:

- Number of leptons
- Flavor content
- OSSF pairs

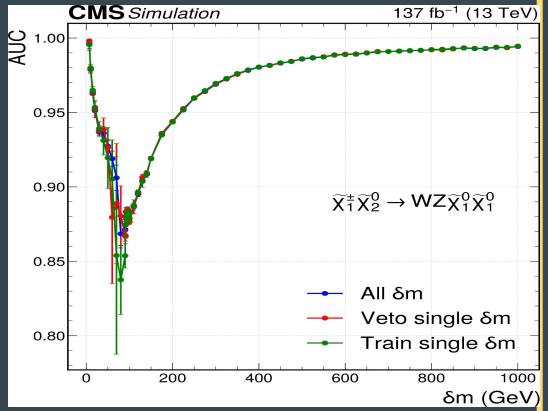
3 light leptons, no OSSF

- Sensitive to nonresonant lepton production from H decay
- Targets H→WW (BR ~ 20%)
- SRs binned in min(ΔR(l, l))



3 light leptons, OSSF

- Highly sensitive to flavor democratic
- Large background from SM
- 2 strategies:
  - A set of SR
  - Parametric Neural network

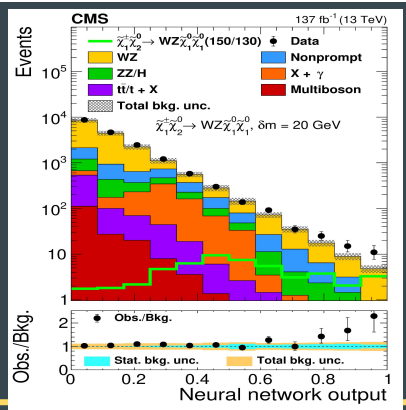


Parametric NN

- Parametric in δm = M(NLSP)-M(LSP)
- Relatively small difference between different mass points but equal δm
- Training for slepton mediated (for 3 different slepton mass points) and WZ decay models

Set of SRs:

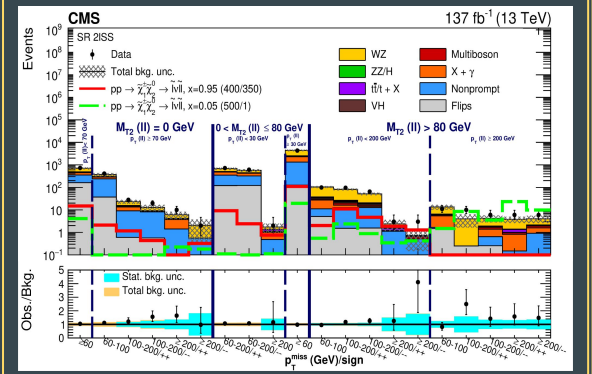
- Binned in MT, missing transverse energy, HT and M(l, l)



SUS-19-012: Strategy and selection

2 lepton, same sign

- Sensitive in "compressed" scenarios (soft leptons):
  - Small δm
  - slepton mass close to NSLP or LSP mass
- SRs binned in MT2, pT(l, l), missing transverse energy

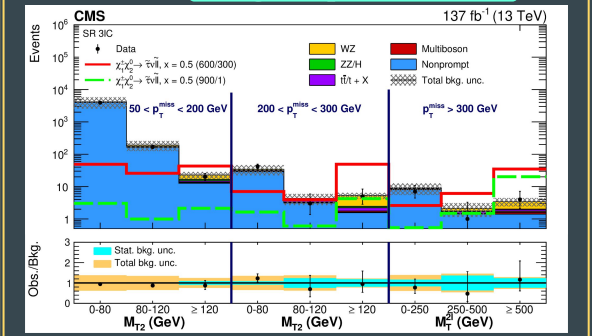


3 leptons, ⩾1 τ□

- Sensitive to right-handed sleptons and scenarios where other sleptons are too heavy
- SR strategy for different final states:
  - OSSF light leptons + tau
  - OSOF light leptons + tau
  - SSOF light leptons + tau
  - 1 light lepton + 2 taus

Sensitive to tau enriched scenarios

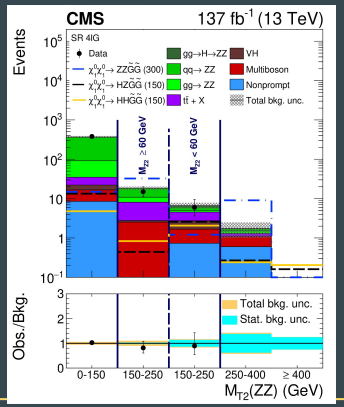
Tau dominated



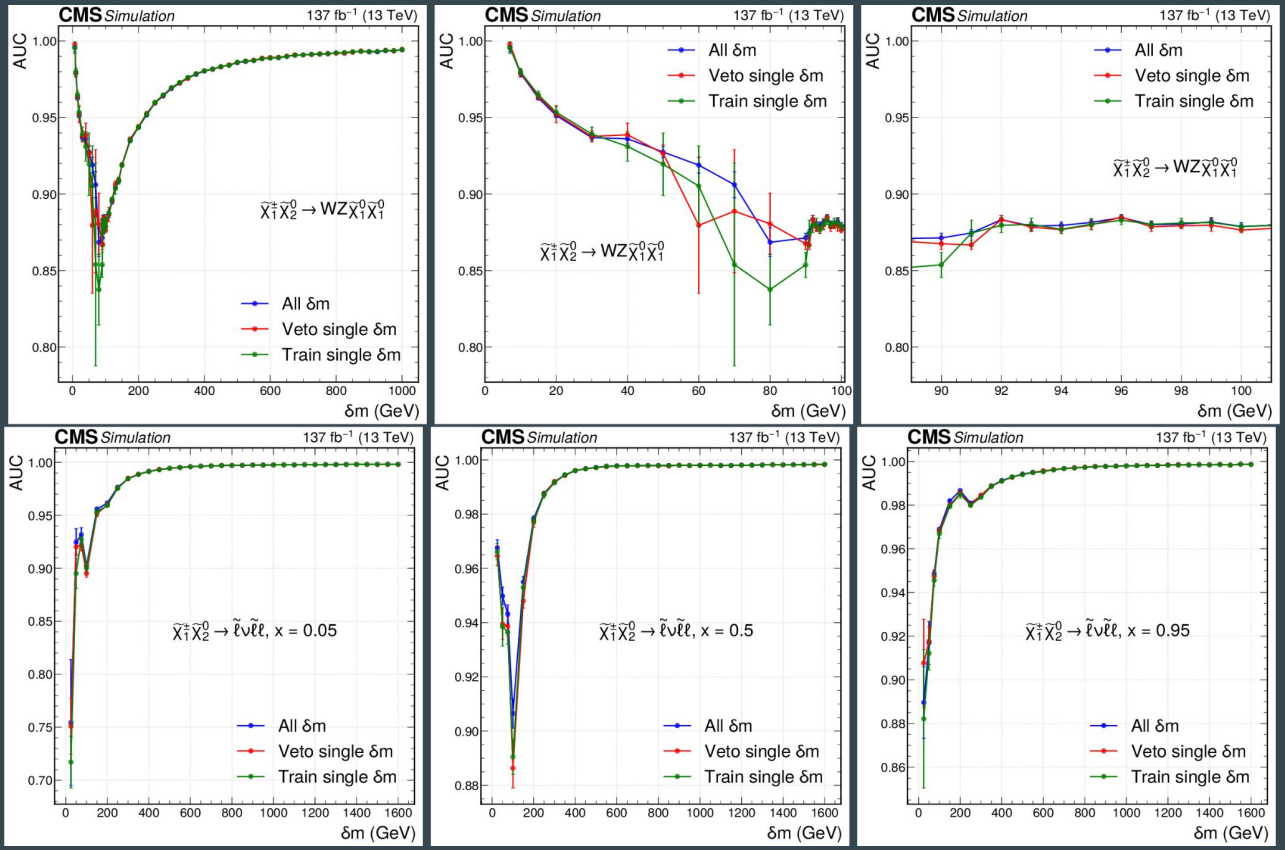
4 leptons

- Sensitive to gauge mediated models
- SRs for different final states:
  - 4 light leptons, 2 OSSF
  - 4 leptons including taus or without 2

Targets decays with 2 Z bosons



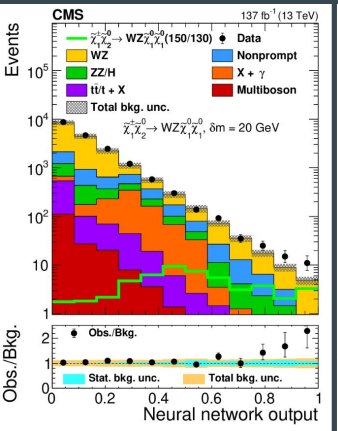
SUS-19-012: NN

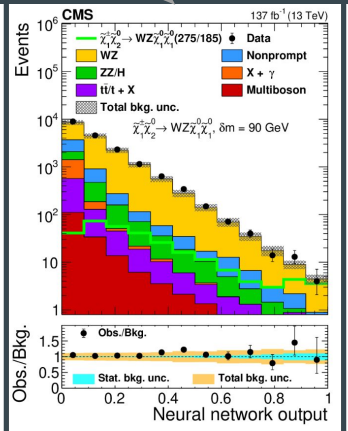

CMS Simulation
137 fb⁻¹ (13 TeV)
AUC
δm (GeV)
All δm
Veto single δm
Train single δm
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to WZ\tilde{\chi}_1^0\tilde{\chi}_1^0$
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to \tilde{\ell}\nu\tilde{\ell}\ell$, x = 0.05
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to \tilde{\ell}\nu\tilde{\ell}\ell$, x = 0.5
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to \tilde{\ell}\nu\tilde{\ell}\ell$, x = 0.95

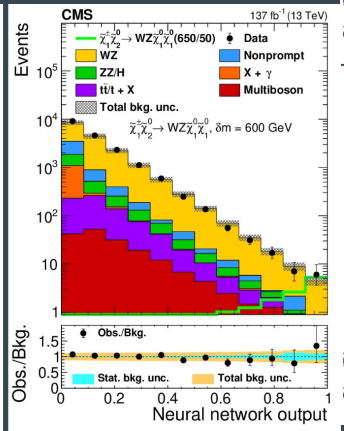
SUS-19-012: NN

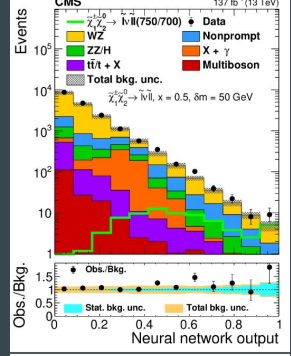
slepton mediated

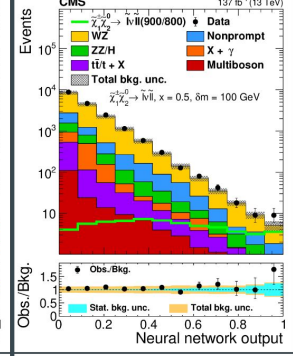
WZ mediated

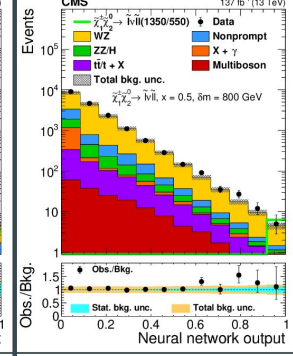


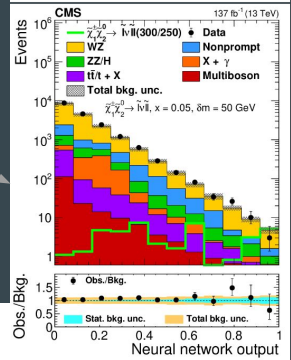


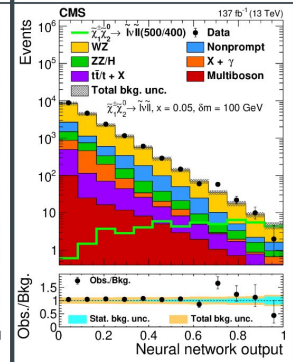


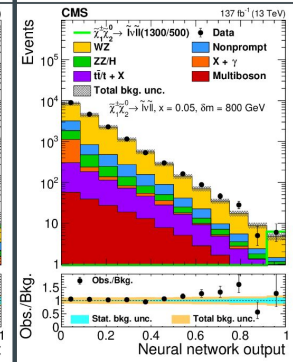


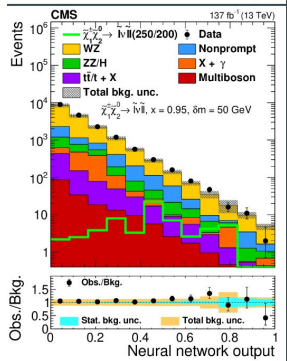


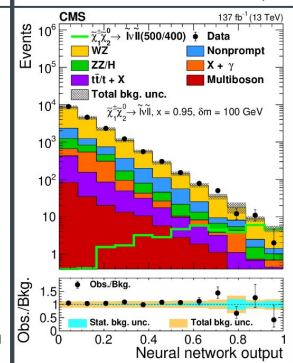


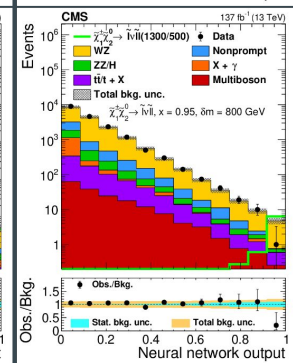




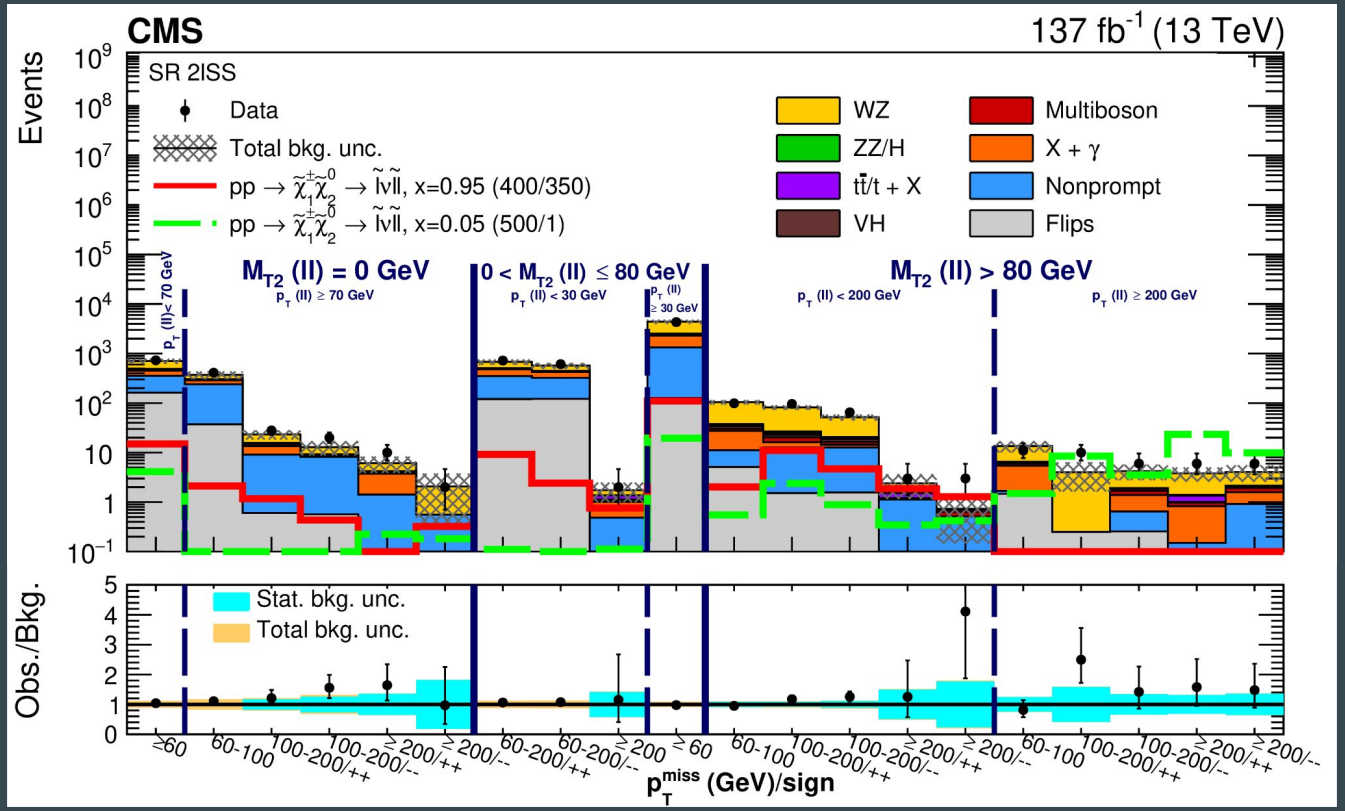








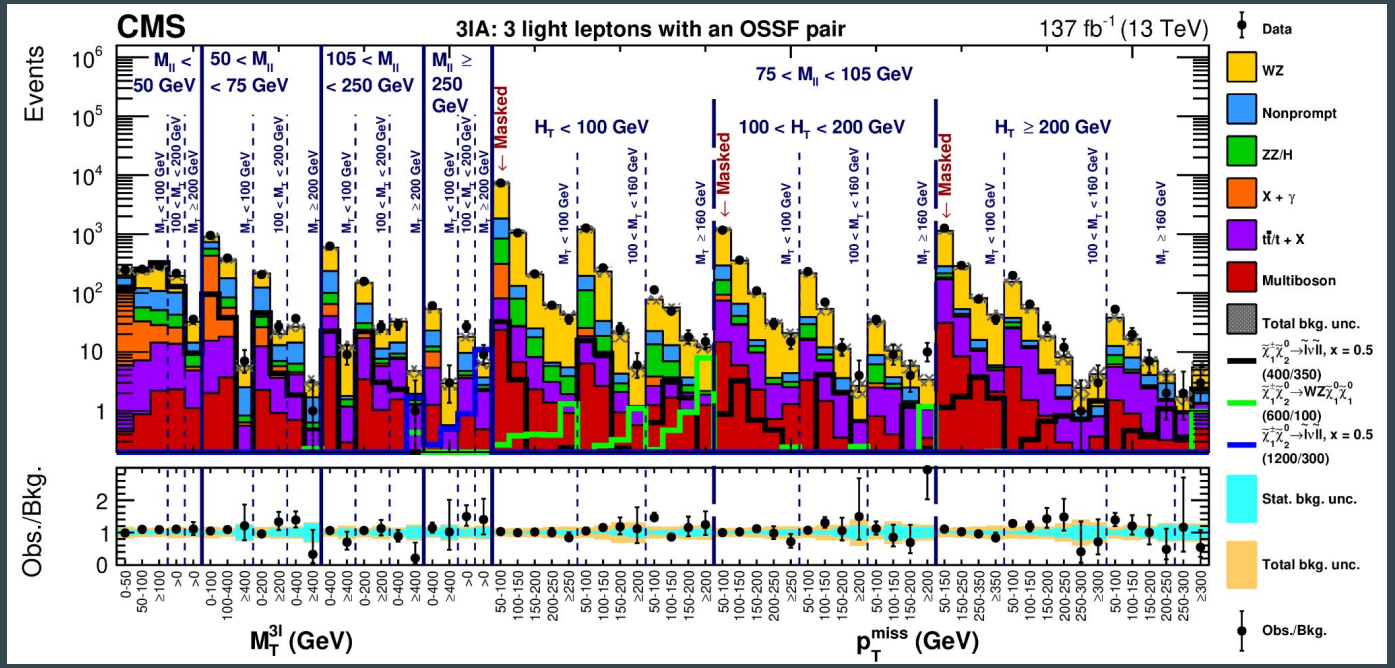
SUS-19-012: Search Regions



2 same sign light leptons

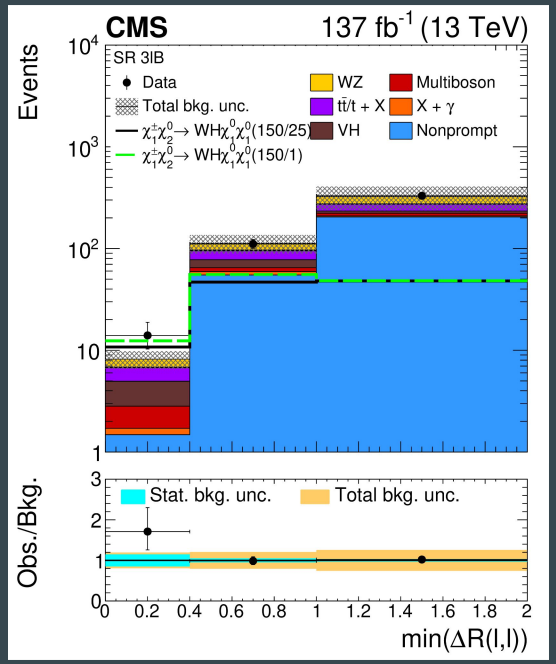
“2lSS”

SUS-19-012: Search Regions

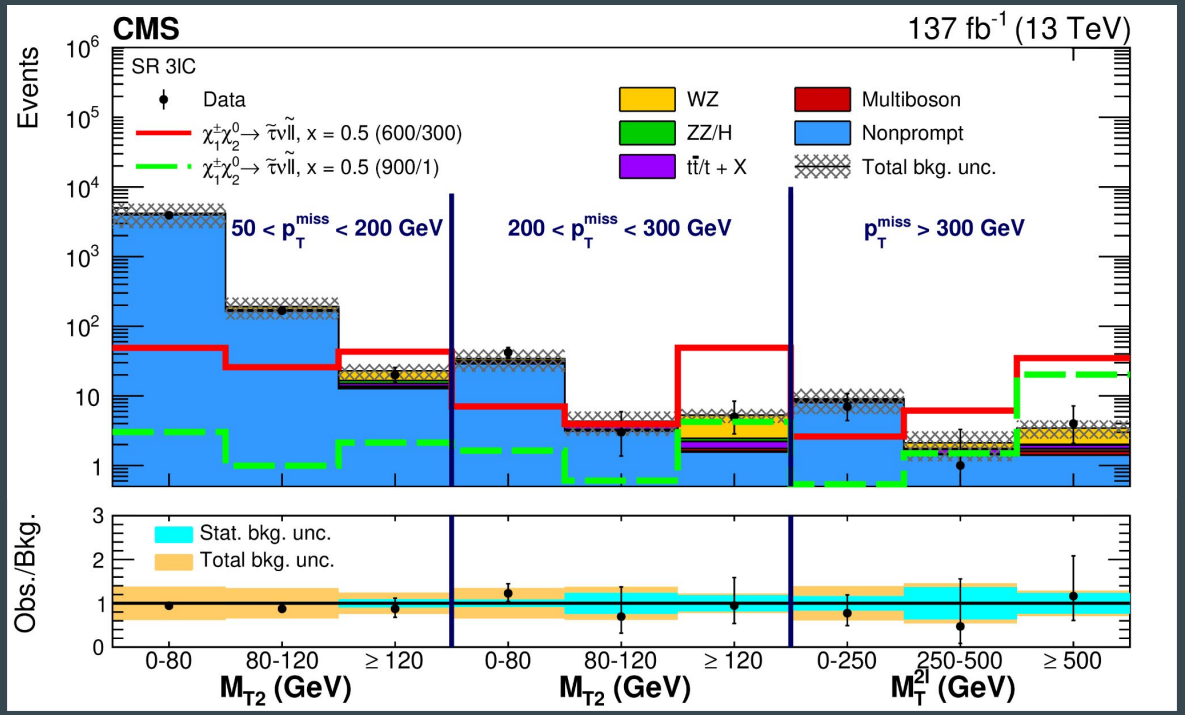


SUS-19-012: Search Regions

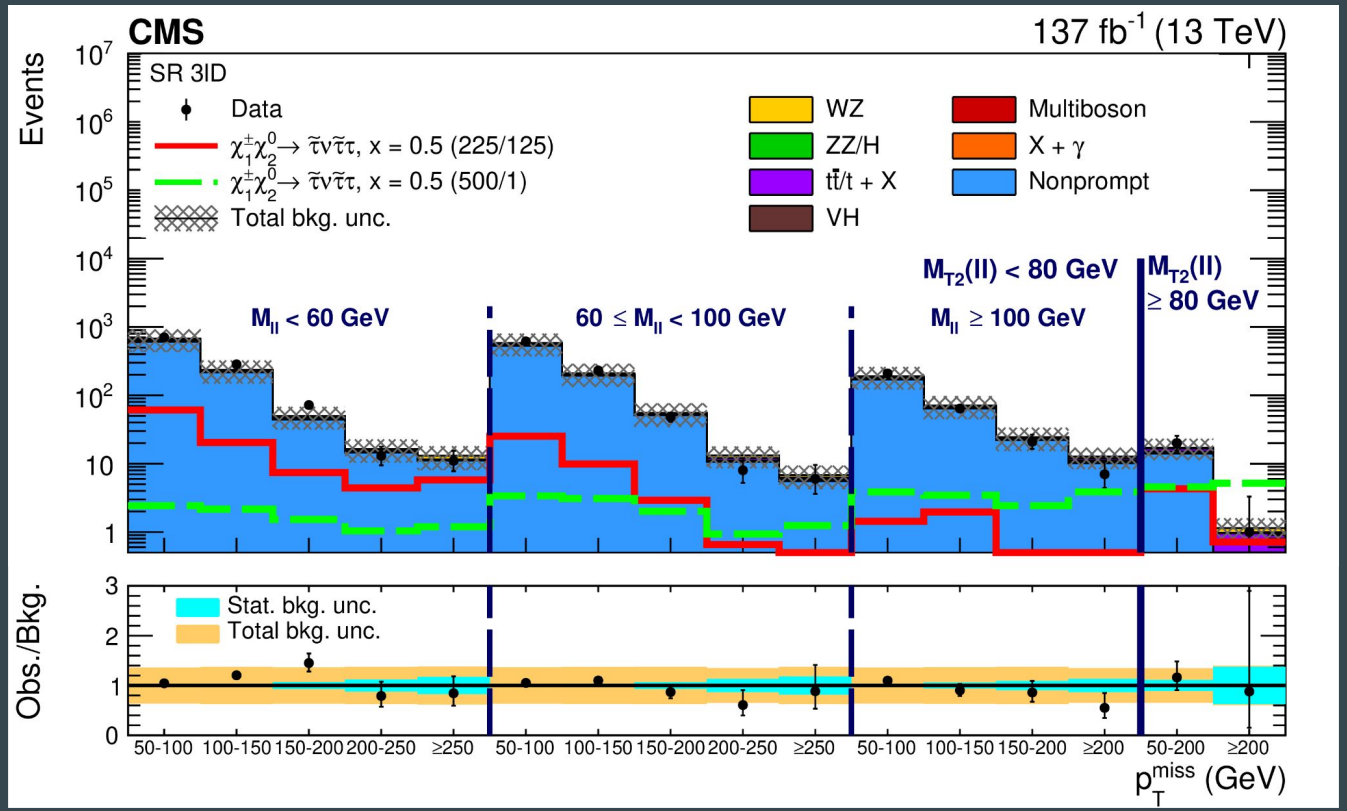
3 light leptons
No OSSF pair
"3lB"



3 leptons: 2 OSSF light leptons + 1 tau



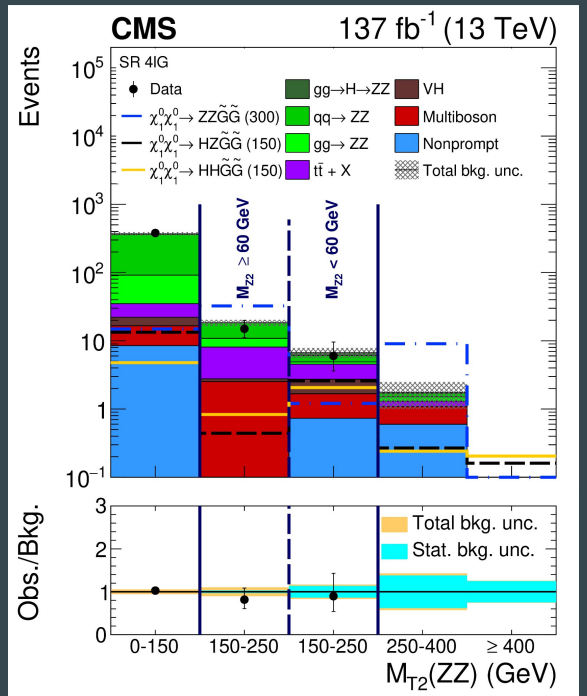
SUS-19-012: Search Regions



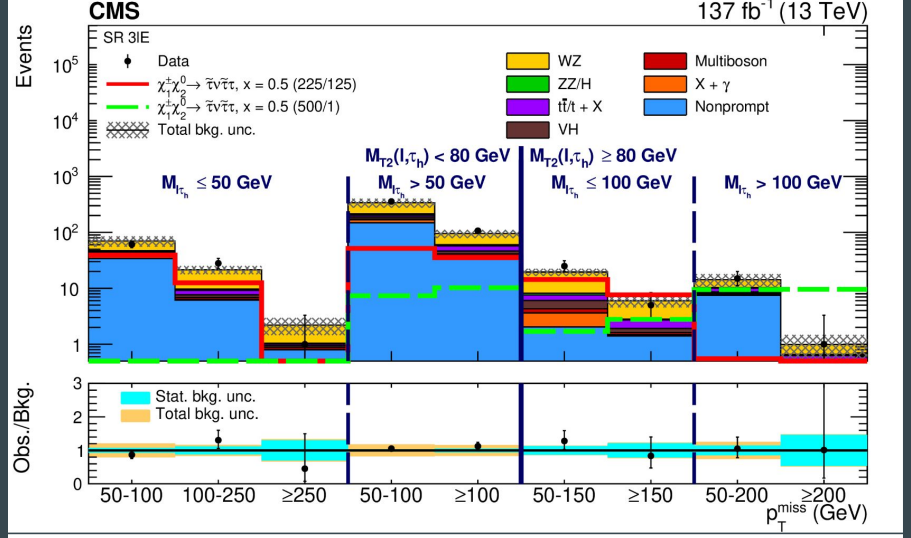
3 leptons:
2 OSOF light leptons +
1 tau

SUS-19-012: Search Regions

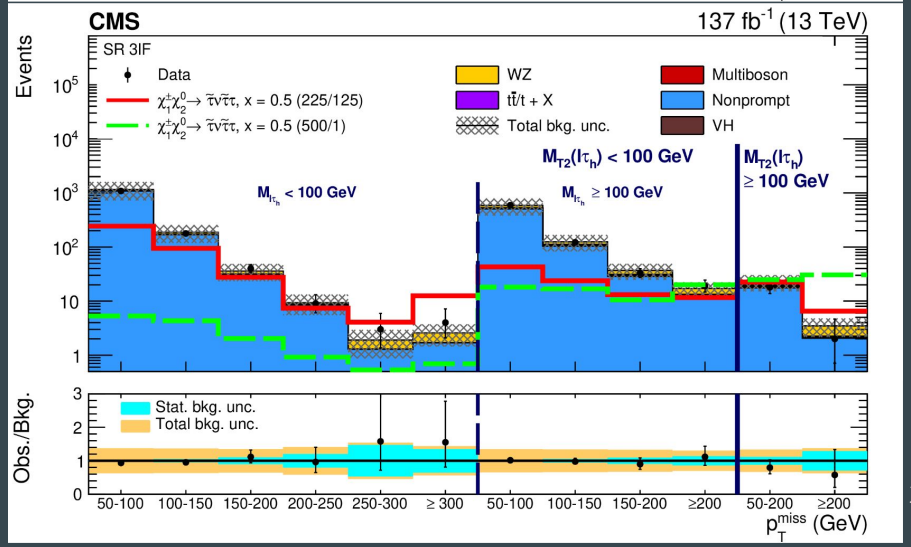
4 leptons,
2 OSSF pairs



3 leptons:
2 SS light
leptons + 1
tau

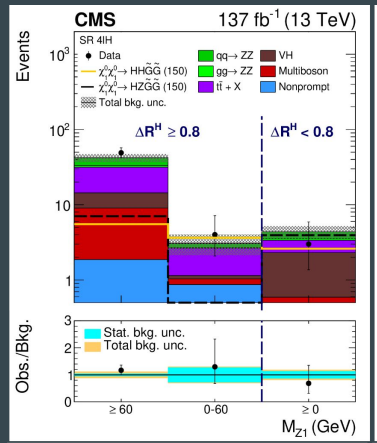


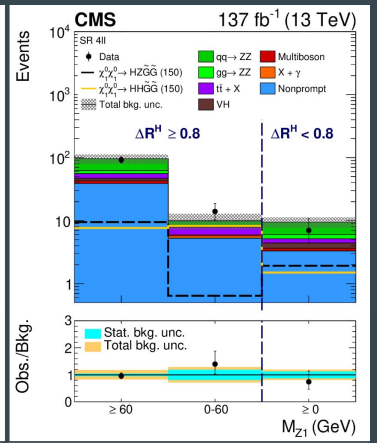
3 leptons:
1 light
lepton
2 tau



SUS-19-012: Search Regions

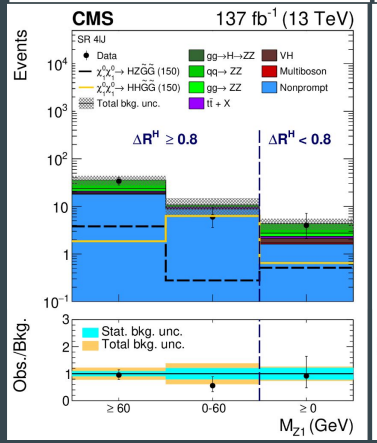
4 light leptons,
no OSSF pairs

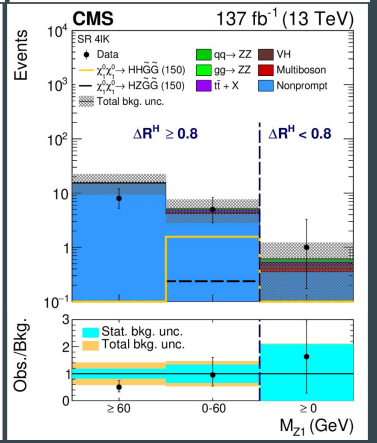




3 light leptons + 1 tau

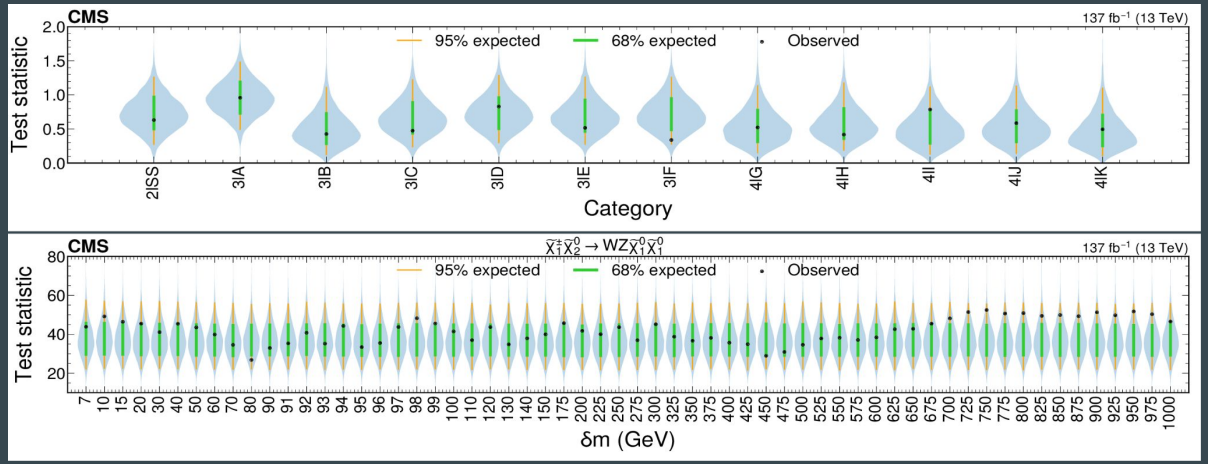
2 light leptons + 2
tau
2 OSSF





2 light leptons +
2 tau
1 or less OSSF

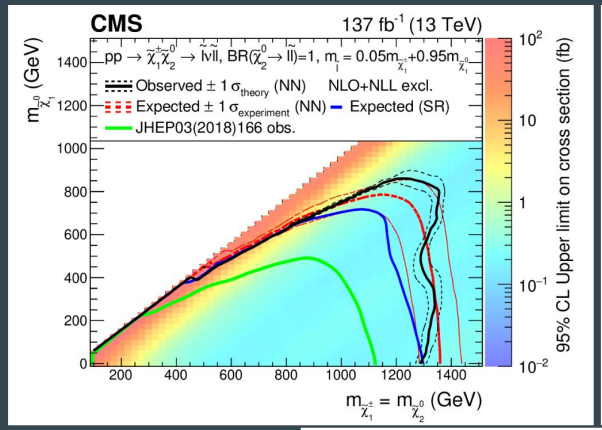
SUS-19-012: Results

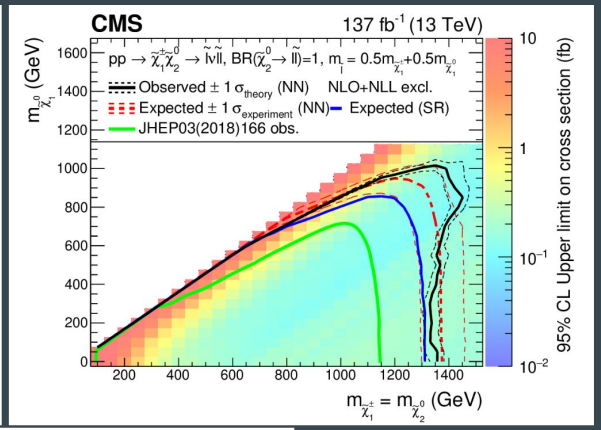


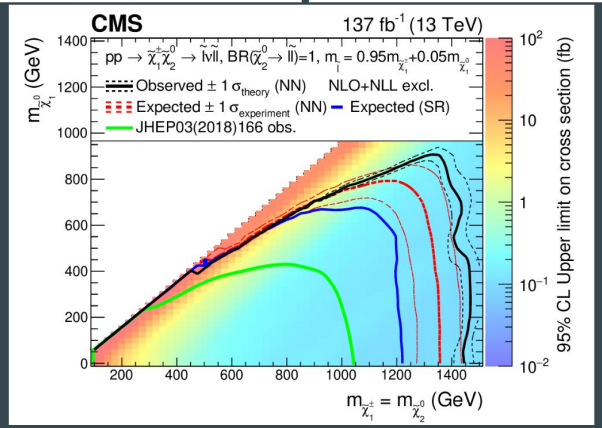
No significant excess observed:

- Shaded area:
  Expected test statistic distributions from background-only fit
- Points:
  Observed test statistic

SUS-19-012: Interpretation

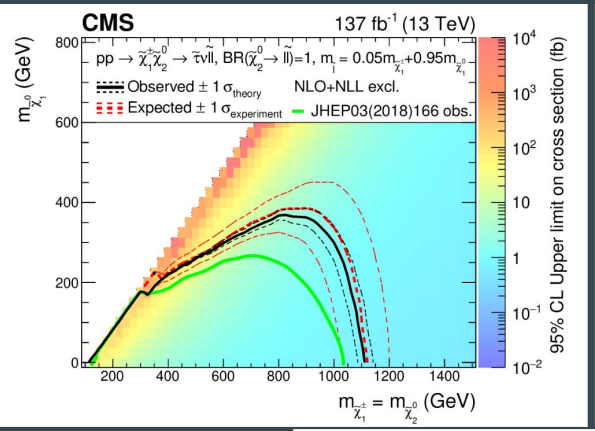


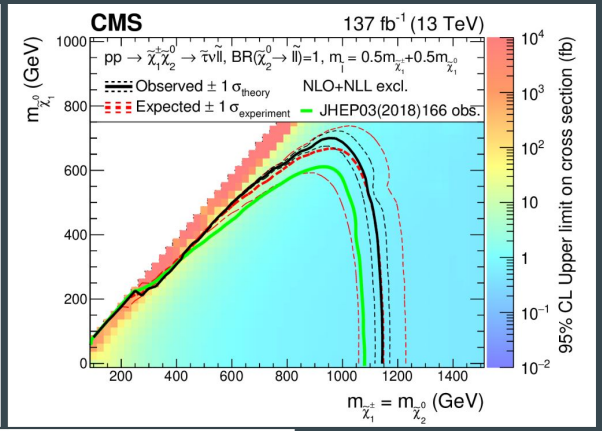


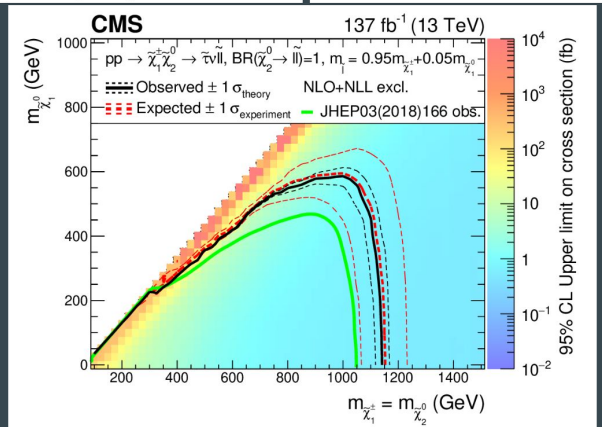


Slepton-mediated flavor democratic decays

SUS-19-012: Interpretation

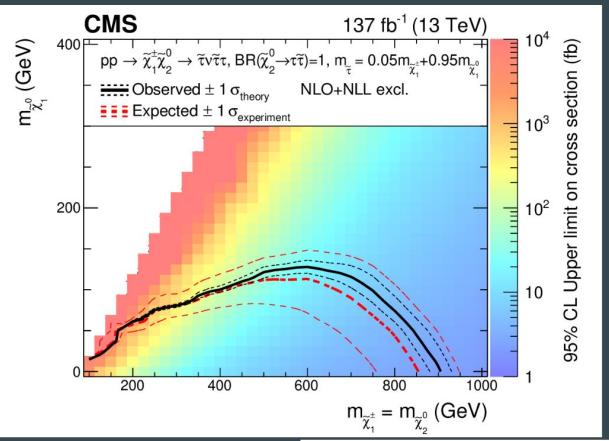


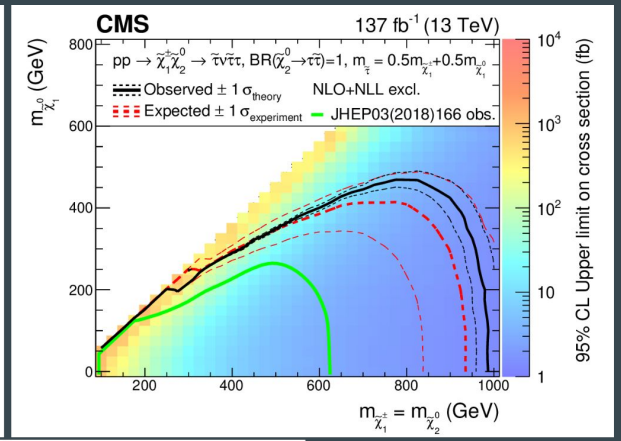


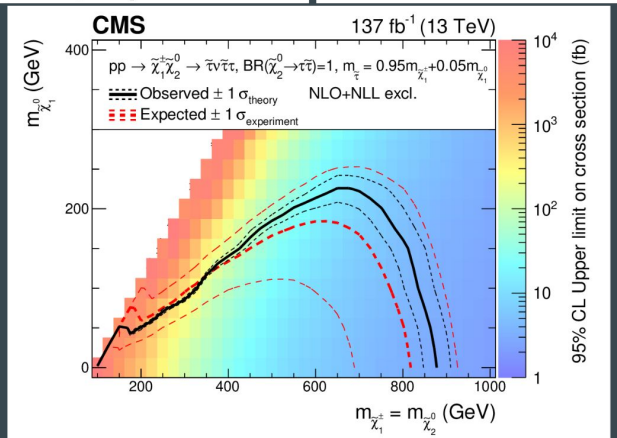


Slepton-mediated tau-enriched decays

SUS-19-012: Interpretation







Slepton-mediated tau-dominated decays

SUS-19-012: Interpretation

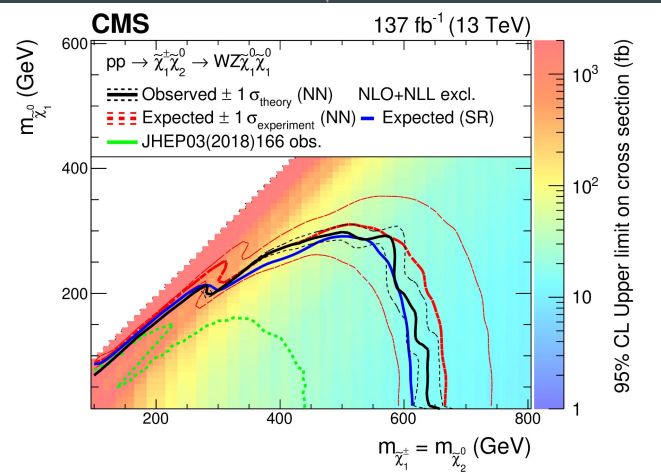
GMSB ZZ decay

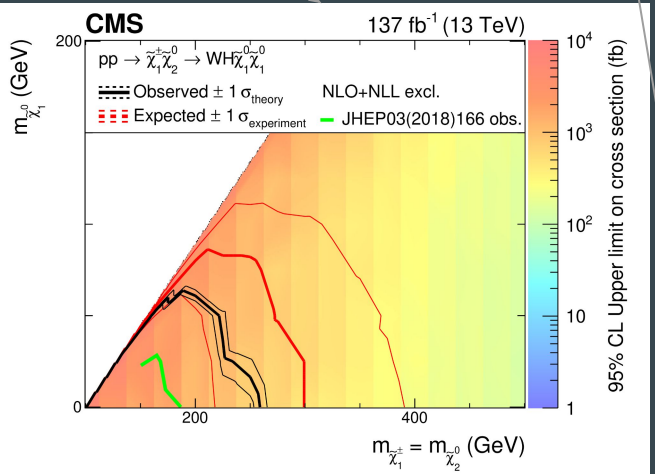
GMSB HZ decay

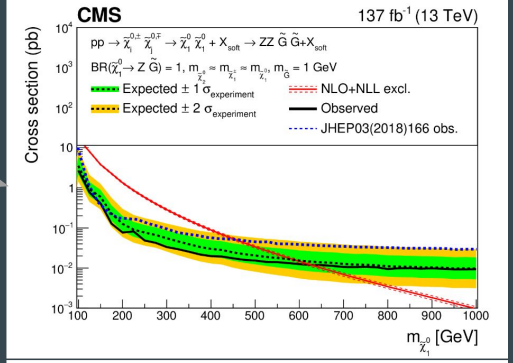
WZ-mediated decay

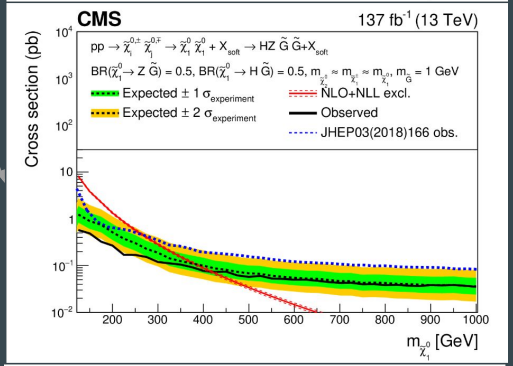
WH-mediated decay

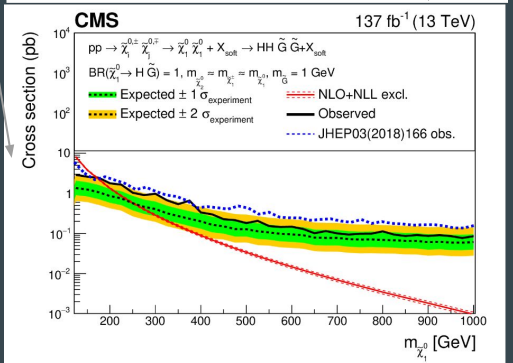
GMSB HH decay





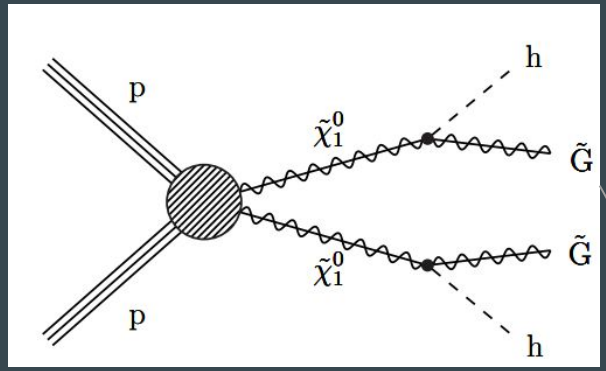


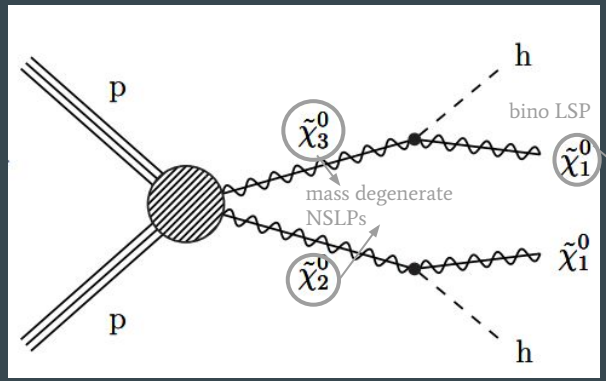




SUS-20-004: Search for higgsinos in two Higgs bosons and missing transverse energy

NEW





- Using H→bb (BR ≈ 60%)
- R-parity conserved → Missing energy from LSP
- Final state: multiple (b-tagged) jets + missing energy

Gauge mediated SUSY breaking:
- Chargino/Neutralino dominated by higgsino content
- Effective NLSP production
- Massless goldstino/gravitino
- Parameter of interest: NLSP mass

Simplified SUSY model:
- More generic model
- Bino LSP and higgsino NLSP not nearly mass degenerate
- Only regard specific production: ~17% of sum of all cross sections
- Parameters of interest: LSP and NLSP masses

SUS-20-004: Strategy and selection

To be sensitive to large range of sparticle mass:
2 approaches for H reconstruction

Resolved scenario

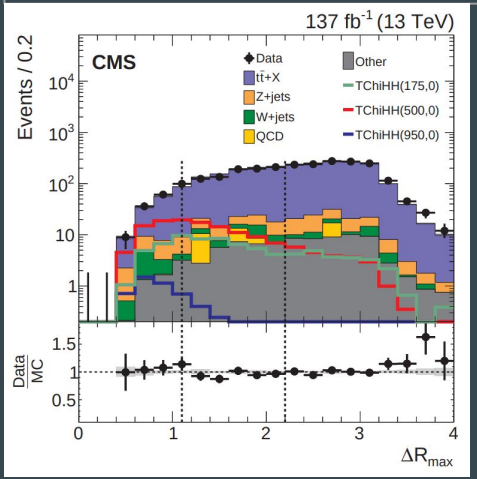
H→bb reconstructed as two separate jets

- **4 or 5 regular jets**, subset of which is b-tagged
- Form Higgs boson candidates from pairs with **smallest Δm(bb)** (absolute mass difference between pairs)
- Δm(bb) < 40 GeV
- <m(bb)> < 200 GeV
- max(ΔR(bb)) required to small

Boosted scenario

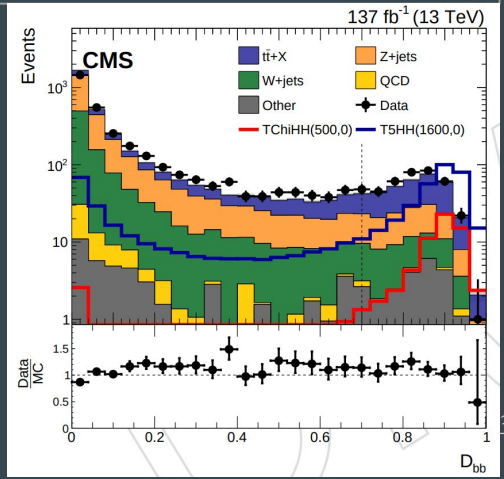
H→bb reconstructed as single wide jet

- Selection of wide (AK8) jets as H candidates
- Requirement on double b-tagging discriminator
- Compute mJ using "soft drop" algorithm
- Requirement of mJ in large Higgs mass window
- No restriction on number of regular jets

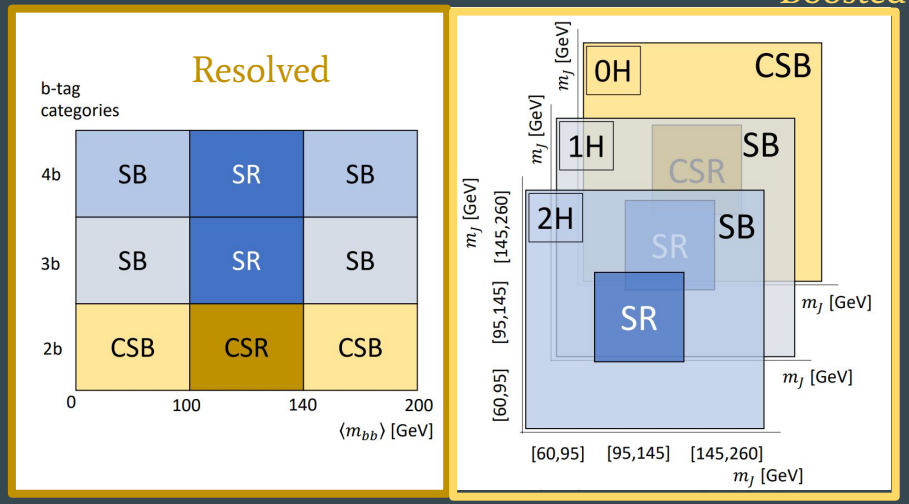


Baseline selection:

- Large missing energy (>150 GeV and > 300 GeV)
- Veto on leptons or isolated tracks
- Jets not aligned with missing energy



SUS-20-004: Background estimation



ABCD method to estimate SM background

$$N_{SR} = \kappa \frac{N_{CSR}}{N_{CSB}} N_{SB},$$

with κ a correction factor for correlations determined in MC as:

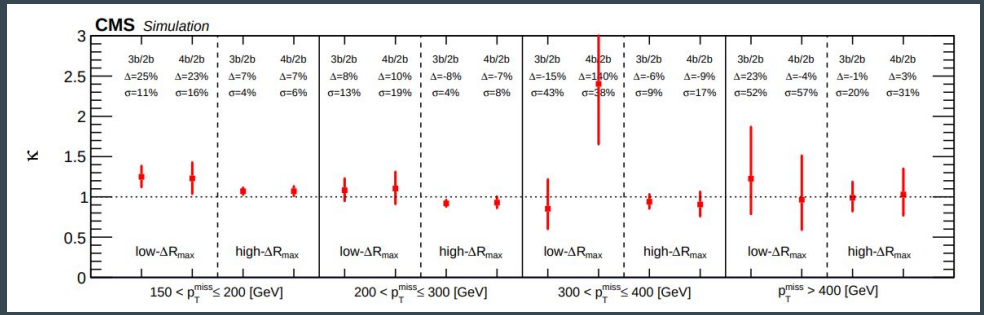
$$\kappa = \frac{N_{SR} N_{CSB}}{N_{SB} N_{CSR}}$$

Resolved scenario:

- Mass of Higgs boson candidates and number of b-tagged jets as discriminating variables
- Further discrimination by splitting in missing transverse energy (MET) and ΔR bins

Boosted scenario:

- Number of double b-tagged wide jets and mass of wide jets as discriminating variables
- Further discrimination by splitting in missing transverse energy (MET)



SUS-20-004: Results and interpretation

Signal yield extraction from maximum likelihood fit to data according to the CLs method

Boosted scenario cleaned of overlap with resolved

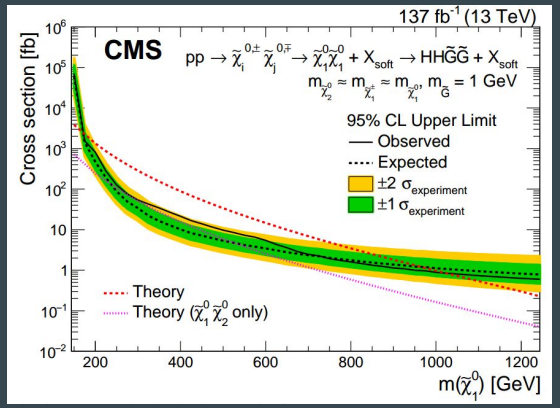
No compelling excess of events observed:

- Single bin not within stat. unc.
- In resolved scenario for
  - $\Delta R < 1.1$
  - $N(B) = 3$
  - $300\ \text{GeV} < \text{MET} < 400\ \text{GeV}$

  4 observed yields vs 0.074 expected
- Prediction based on 2 events
- Frequentist local significance: 3.2 sd
- Global significance: 1.9 sd
- Models considered do not predict such excess

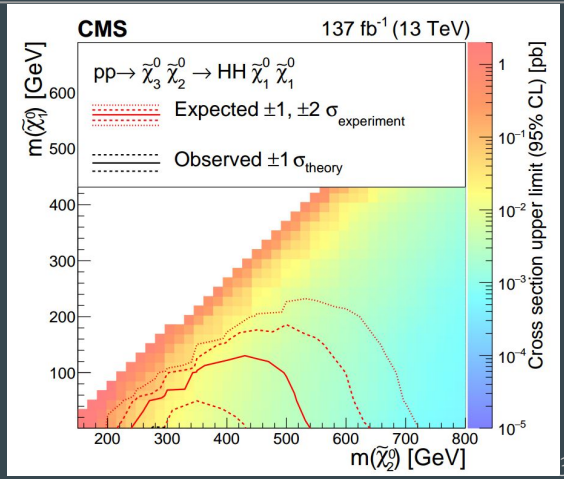
Gauge mediated SUSY breaking

- NLSP mass excluded from 175 GeV to 1025 GeV
- SUS-19-012 exclusion up to 200 GeV

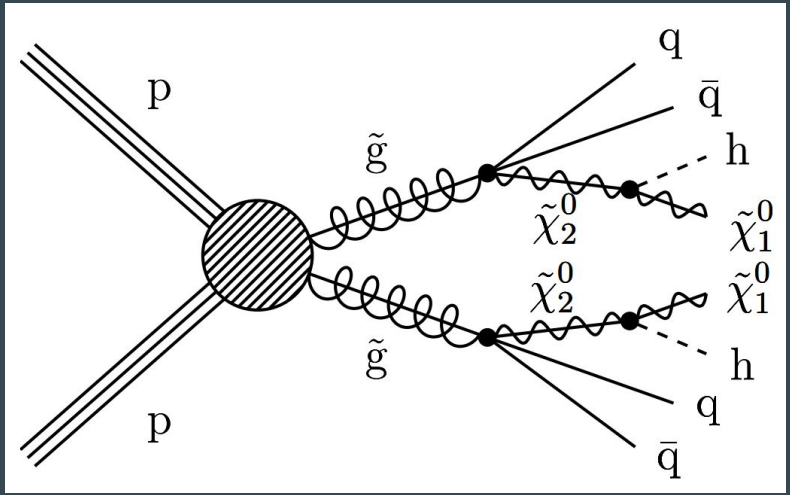


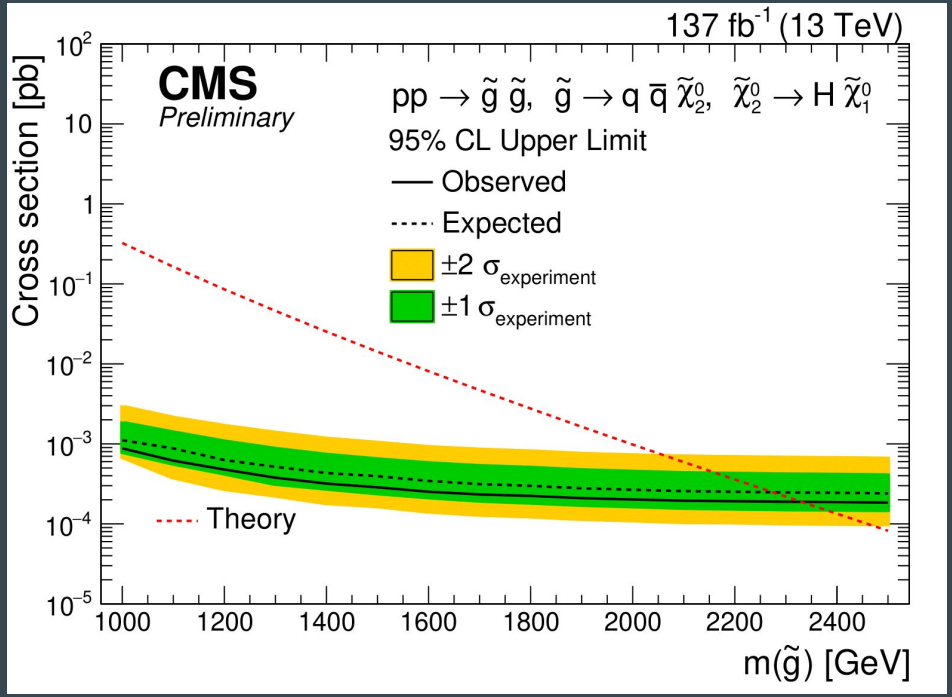
Simplified SUSY

- Expected limits up to 520 GeV for NSLP and 120 GeV for LSP
- Observed cross sections below theoretical cross sections for entire plane



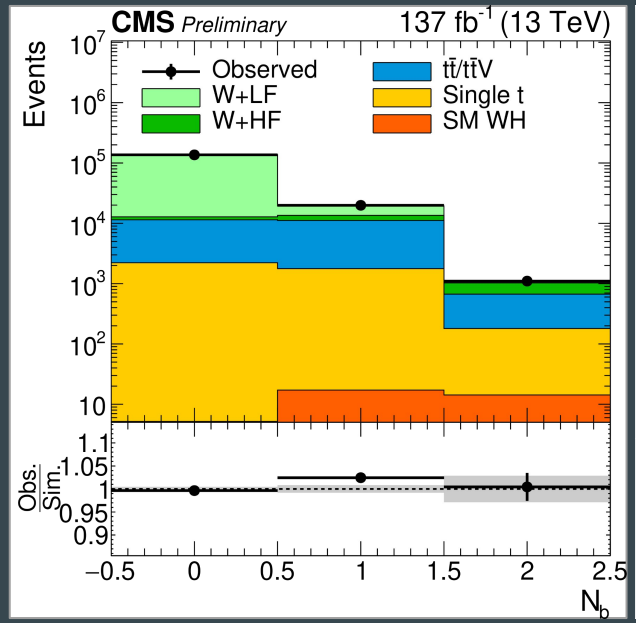
SUS-20-004: Strong production

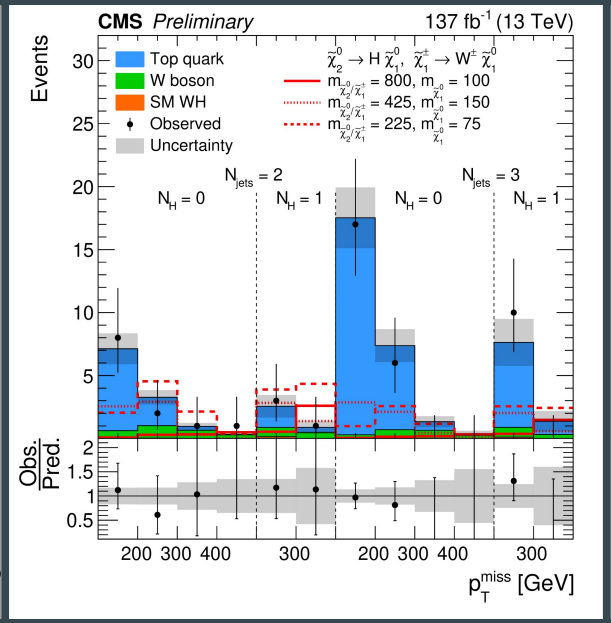


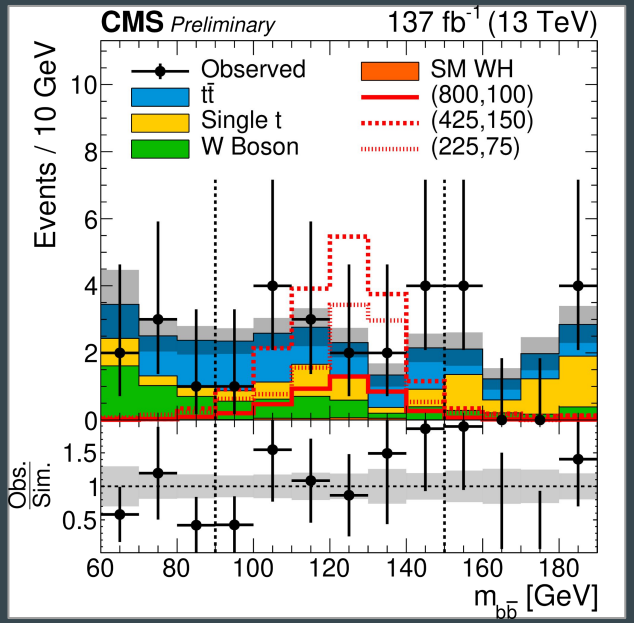


Back to main slide

SUS-20-003

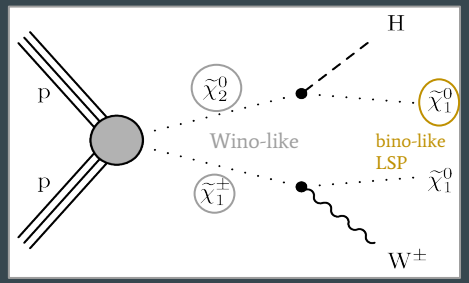

CMS Preliminary
137 fb-1 (13 TeV)
Events
Observed
W+LF
W+HF
tt̄/tt̄V
Single t
SM WH
Obs./Sim.
Nb


CMS Preliminary
137 fb-1 (13 TeV)
Events
Top quark
W boson
SM WH
Observed
Uncertainty
Njets = 2
Njets = 3
NH = 0
NH = 1
Obs./Pred.
pTmiss [GeV]

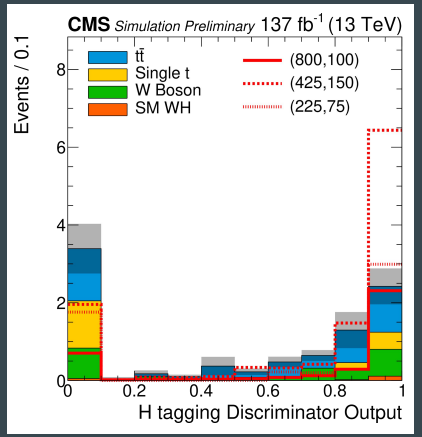

CMS Preliminary
137 fb-1 (13 TeV)
Events / 10 GeV
Observed
tt̄
Single t
W Boson
SM WH
(800,100)
(425,150)
(225,75)
Obs./Sim.
mbb̄ [GeV]

SUS-20-003

"Search for chargino-neutralino production in final states with a Higgs boson and a W boson"

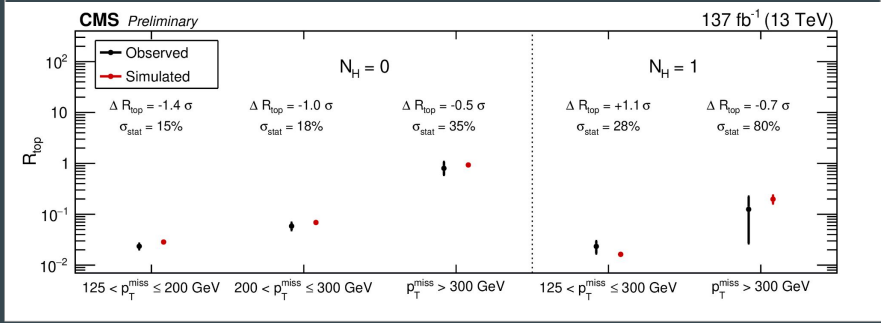


- **leptonic W decay** → single lepton
- **H →bb (BR ~ 60%)** → 2 b-tagged jets or single wide jet with H-tag from DNN



Backgrounds:

- Main contributions: top quark production and W boson production
- Estimated from data using transfer factors from CR to SR
- Transfer factors determined from background enriched CR in simulation
- Validated in data



Event Selection:

- 1 isolated lepton
- MET > 125 GeV
- 2-3 "regular" (AK4) jets with exactly 2 b-tagged jets consistent with H mass
- No isolated tracks or veto tau candidates
- MT > 150 GeV to remove W backgrounds
- High M(CT) to remove tt background (with endpoint at top quark mass)

Categorization:

- Number of small-R jets
- Number of H-tagged wide jets
- Missing transverse energy