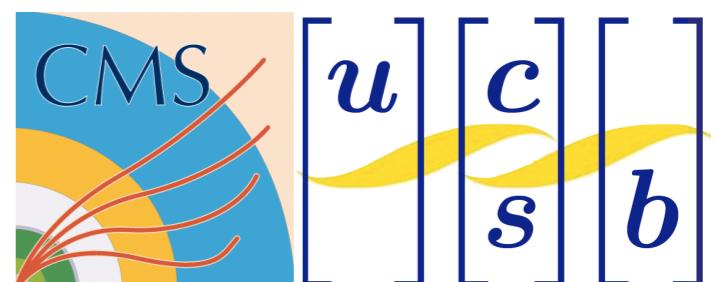


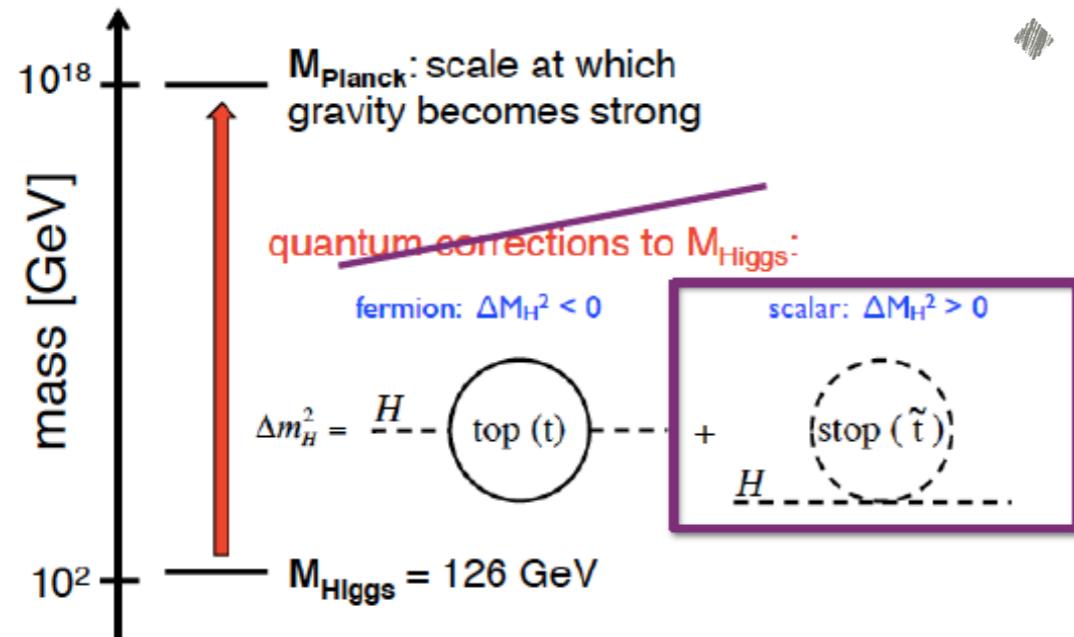
# Searches for Production of Third Generation Squarks at CMS

Indara Suarez (UCSB)  
on behalf of the CMS Collaboration

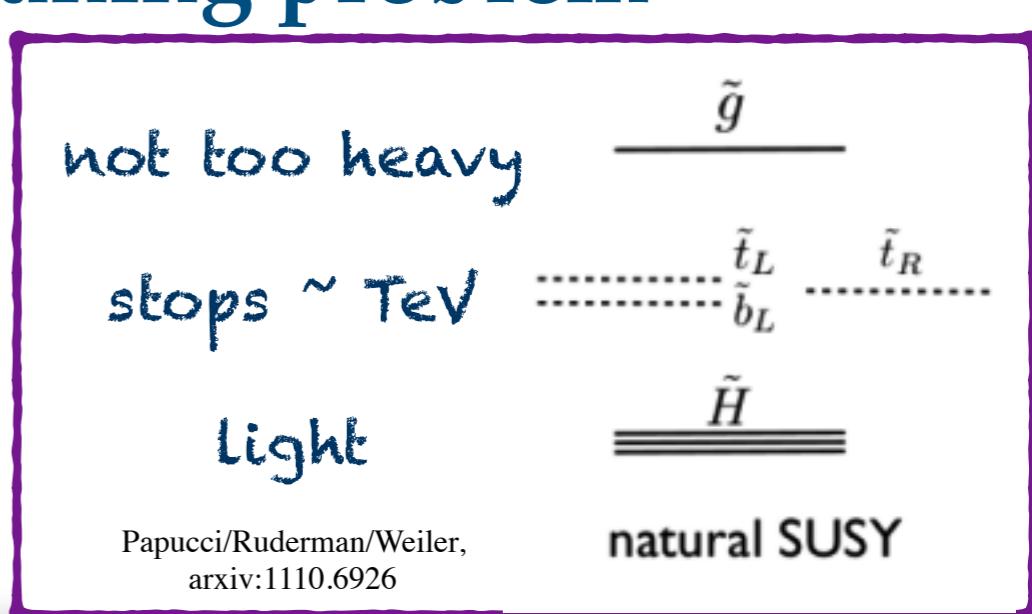
EPS Conference on High Energy Physics  
July 6, 2017



# Motivation



- ◆ Third generation squarks (stop:  $\tilde{t}$  and sbottom:  $\tilde{b}$ ) play an important role in cancelling the **SM fine-tuning problem**
- ◆ Natural SUSY scenarios predict light third generation squarks - can be produced at the LHC
- ◆ Decays to lightest supersymmetric particle (LSP)
- ◆ LSP: light, stable DM candidate

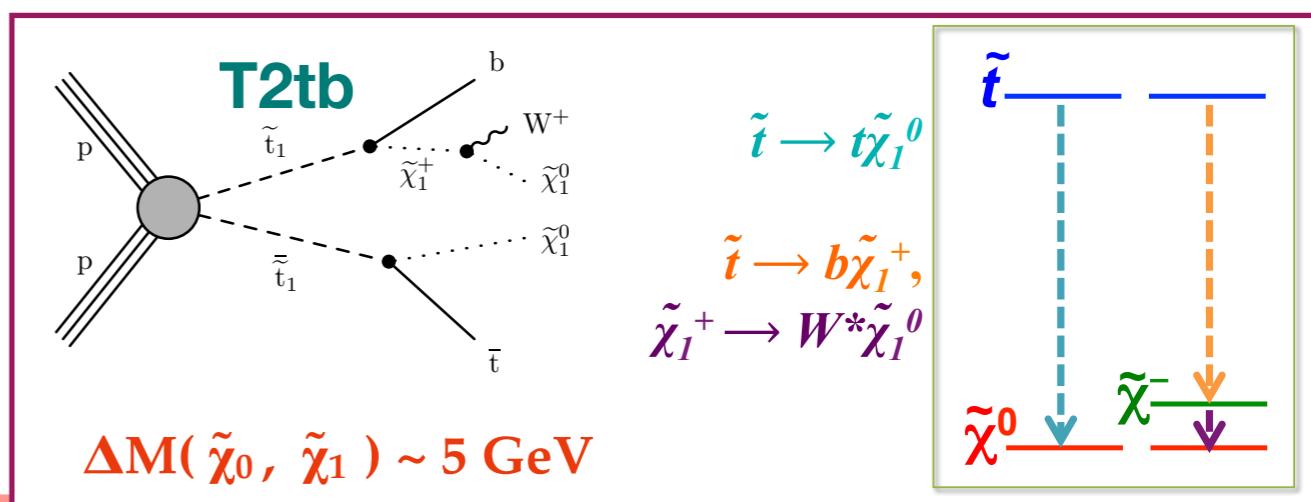
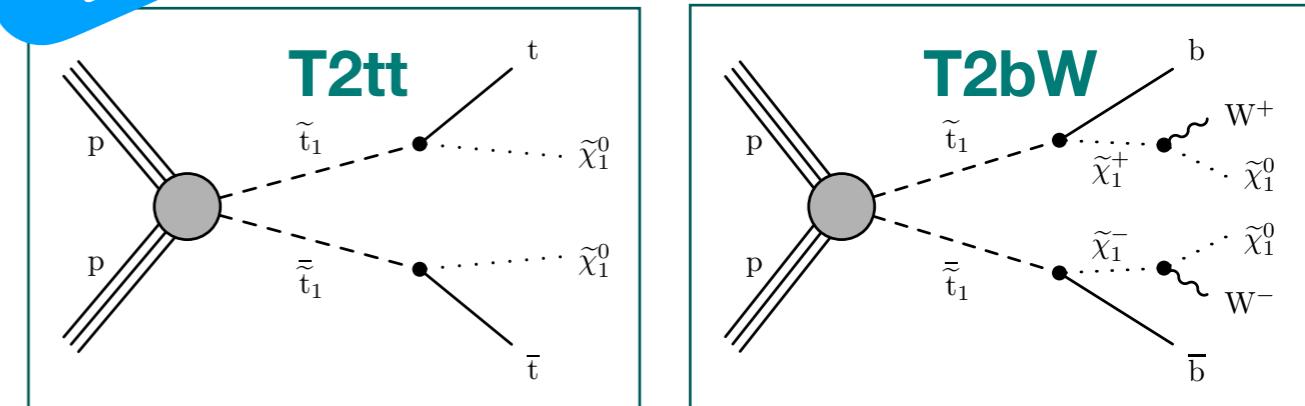
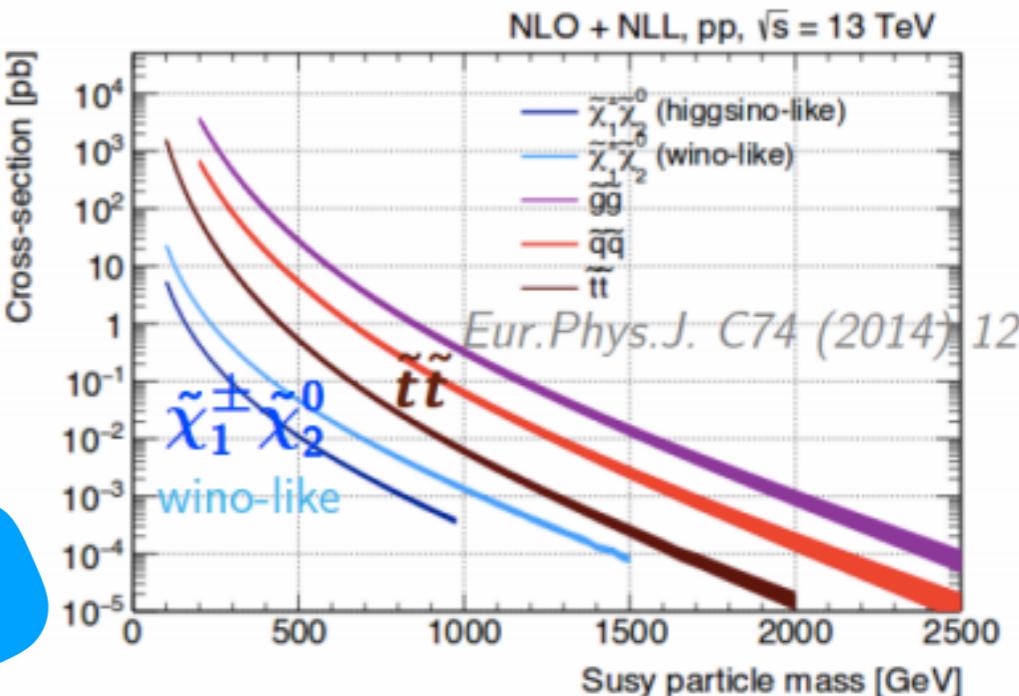


# Searches for Third Generation Squarks

Comprehensive search program  
in CMS with new  
 $35.9 \text{ fb}^{-1}$  of 13 TeV data.

- Produced with **large cross-sections** & within **discovery reach of the LHC**
- Run 2:  $\sim 8X$  gain in cross-section,  $> 3X$  more data
- Dedicated searches with various production modes (direct production or gluino mediated)
- decay chains explored to maximize phase space covered
- signal topologies (boosted, compressed...)

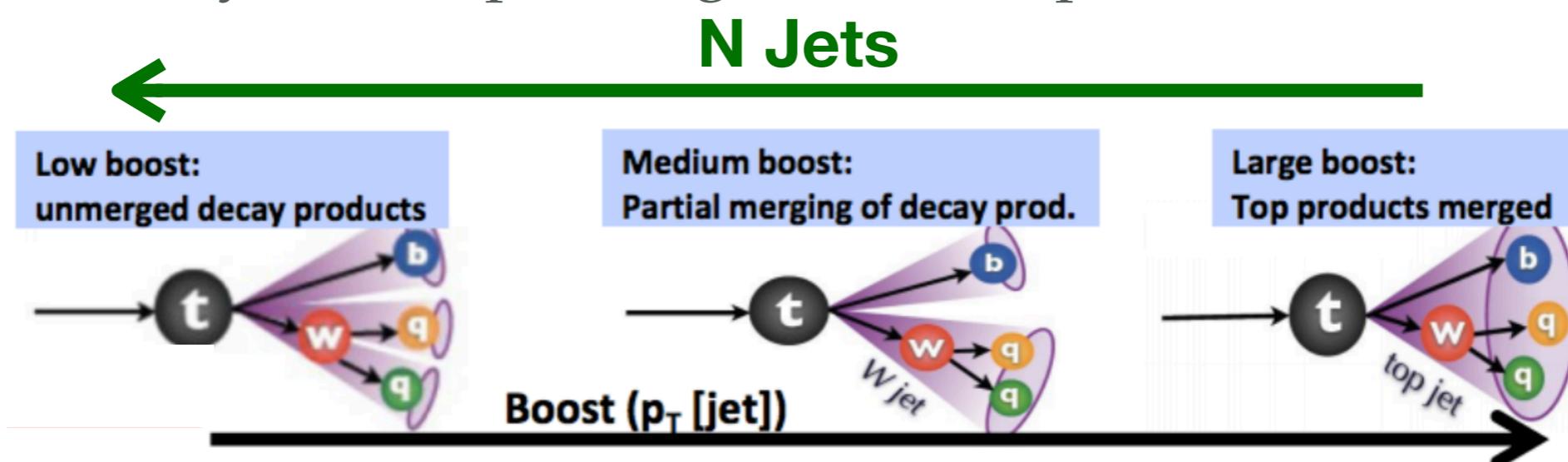
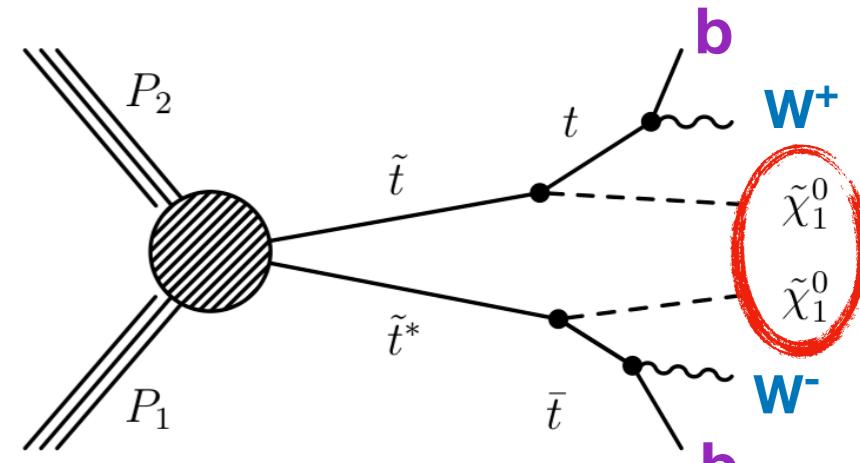
focus of  
this talk



# Search Strategy

## Searches in final states with 0, 1, 2 leptons + N jets (with X b-tags) + MET (from LSP)

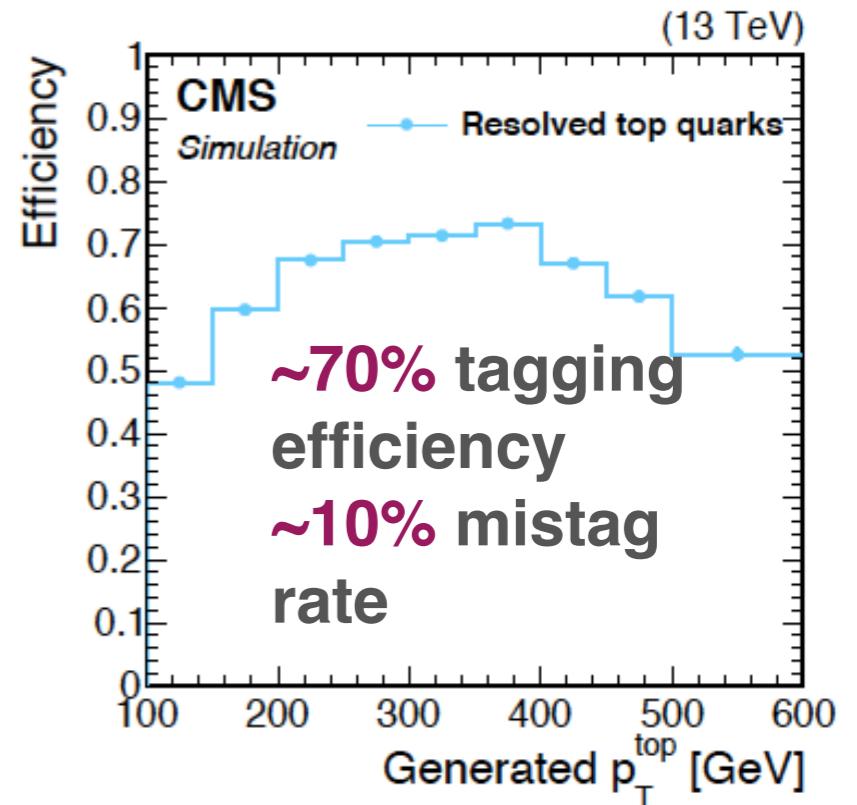
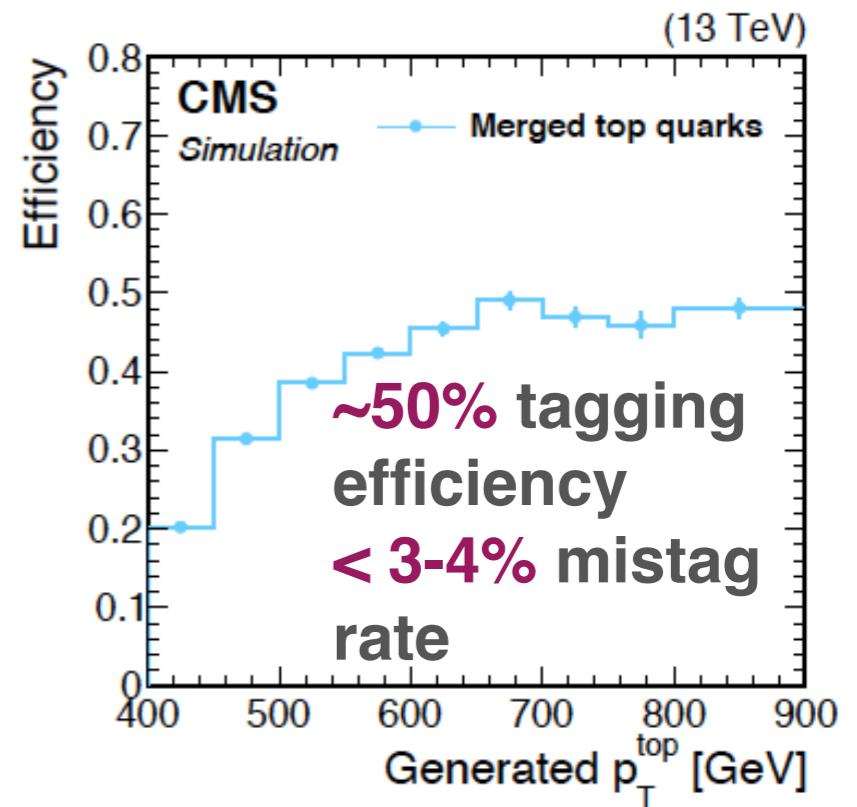
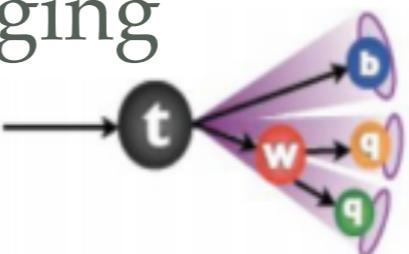
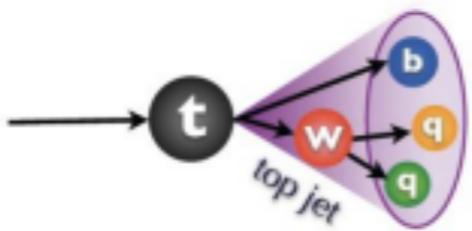
- ◆ Signal topology
  - ◆ 0, 1, or 2 leptons from W decays
  - ◆ Missing transverse momentum (MET) from neutralinos
  - ◆  $\geq 2$  jets (some b-tagged jets) depends on:
    - ◆ number of leptons in final state
    - ◆ boost of system depending on  $\Delta m(\text{stop}, \text{LSP})$



- ◆ Useful heavy object identification developed for searches

# Heavy Object Identification

- ◆ Used in all hadronic searches
  - ◆ **soft b-tagging** for signal models with b-jet  $p_T < 20$  GeV: requiring the presence of a secondary vertex
  - ◆ **Merged top/W tagging** for boosted models: using anti-kt  $\Delta R=0.8$  jets, with soft-drop mass and N-subjettiness
  - ◆ **Resolved top tagging** for models with less boost: reconstruct tops from 3 anti-kt  $\Delta R=0.4$  jet combinations using b-tagging algorithm & BDT



# Backgrounds

- ◆ Searches are in the tails of MET
- ◆ Mass variables (i. e.  $M_T$ , MT2, topness-like) also useful

|  | 0 -leps   | 1 - lep   | 2 - leps                               |
|--|---|---|--|
| <b>Lost Lepton: due to acceptance/ID/Iso</b> | More MET than expected in hadronic ttbar & WJets events | Additional MET causes ttbar & single top events with $M_T(l, \text{MET}) > M_W$ |  |
| <b>Mismeasurement of Jets</b>                | extra MET from QCD (large cross section)                |   | large MET in ttbar & single top events |
| <b>off-shell W's</b>                         |   | Large real MET from events with $M_{W^*} > 80 \text{ GeV}$                      |  |
| <b><math>Z \rightarrow \nu\nu</math></b>     | large real MET from invisible Z decays in TTZ           |   |  |

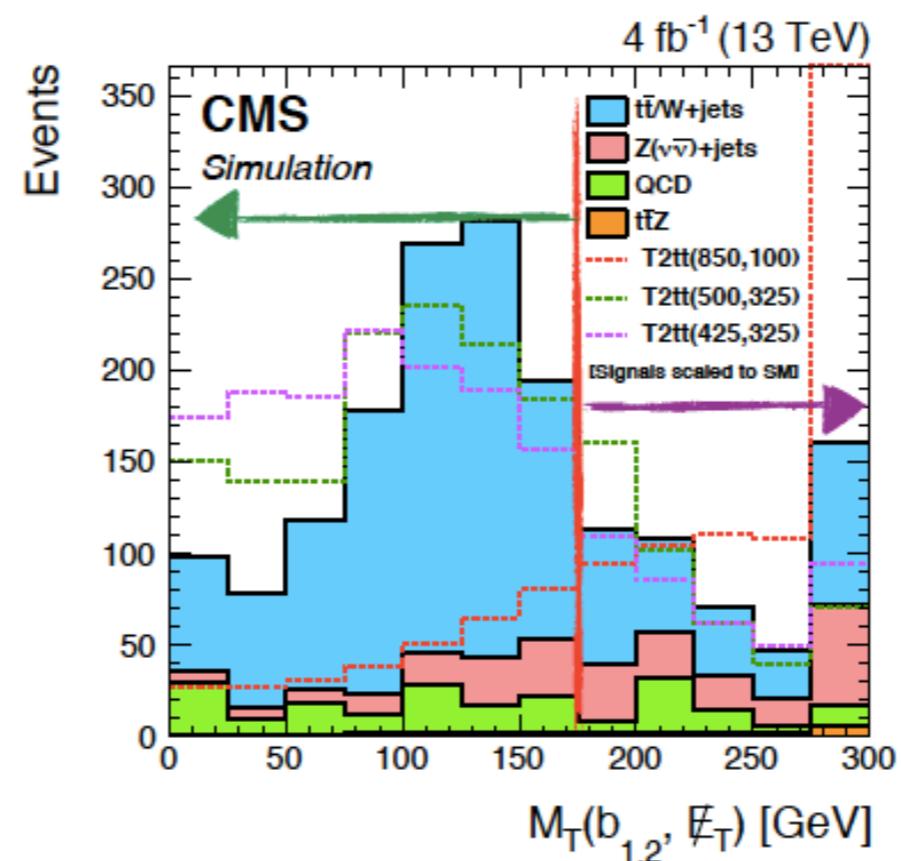
- ◆ BGs estimated from data driven methods

# 0-lepton Search

- Baseline:  $\text{MET} > 250 \text{ GeV}$ ,  $\geq 2$  jets, lepton vetoes
- Divide signal regions into high and low  $\Delta m$ (stop, LSP) to account for a variety of signal kinematics

$$M_T(b_{1,2}, E_T) \equiv \begin{cases} 0, & N_b = 0, \\ m_T(b, E_T), & N_b = 1, \\ \text{Min}[m_T(b_1, E_T), m_T(b_2, E_T)], & N_b \geq 2, \end{cases}$$

| <u>Low <math>\Delta m</math> Category</u> |   |
|---|---|
| •   | $N_j \geq 2, N_b \geq 0$                  |
| •   | $M_T(b) < 175 \text{ GeV}$                |
| •   | Veto top/W tags                           |
| •   | ISR tagging                               |
| •   | Soft-b tagging                            |
| •   | $\Delta\phi(j_1, \text{MET}) > 0.5$ ,     |
| •   | $\Delta\phi(j_{23}, \text{MET}) > 0.15$ , |
| •   | $\text{MET}/\sqrt{H_T} > 10$              |



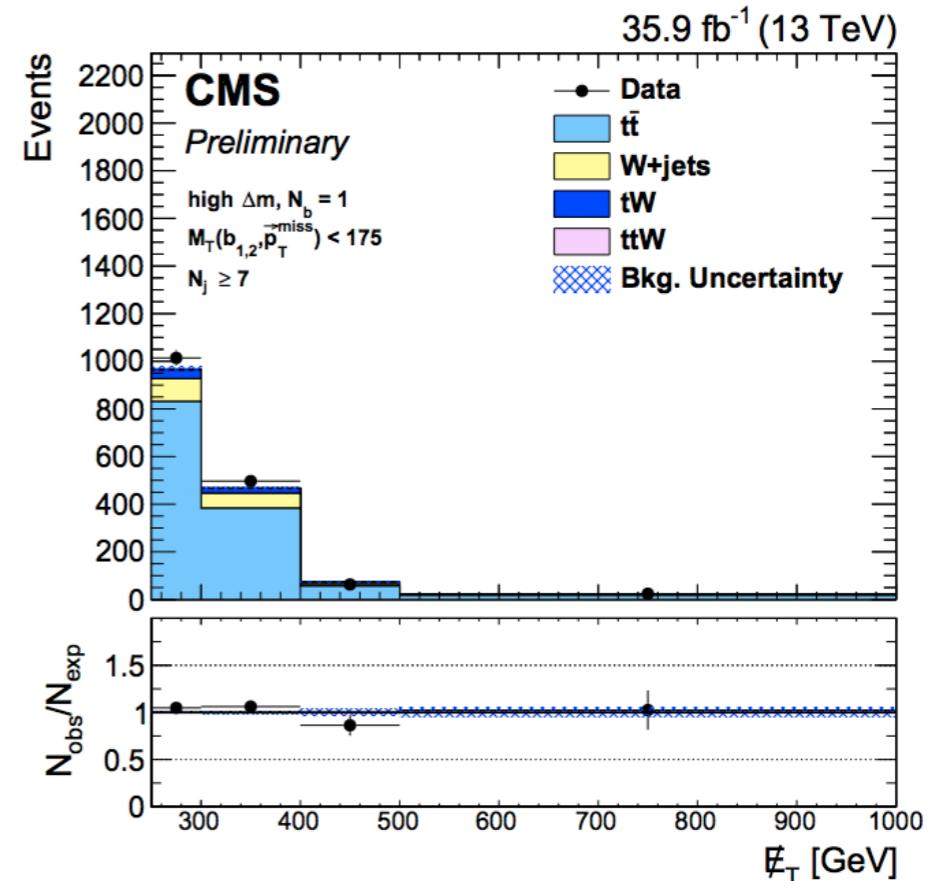
| <u>High <math>\Delta m</math> Category</u> |  |
|--|--|
| •  | $N_j \geq 5, N_b \geq 1$                 |
| •  | $M_T(b) > 175 \text{ GeV}$ (*)           |
| •  | top/W tagging                            |
| •  | $\Delta\phi(j_{1234}, \text{MET}) > 0.5$ |

\* A small set of high  $\Delta m$  category also uses  $M_T(b) < 175 \text{ GeV}$ , but requires  $N(\text{res-top}) \geq 1$

# 0-lepton BG Estimation

- ◆ Lost lepton estimated from 1-lepton control sample
  - ◆ invert lepton vetoes
  - ◆  $m_T(\text{lep}, \text{MET}) < 100 \text{ GeV}$  for signal suppression
  - ◆ calculate  $TF_{\text{LLB}}$  ( $1 \rightarrow 0$  lepton transfer factor) to estimate BG

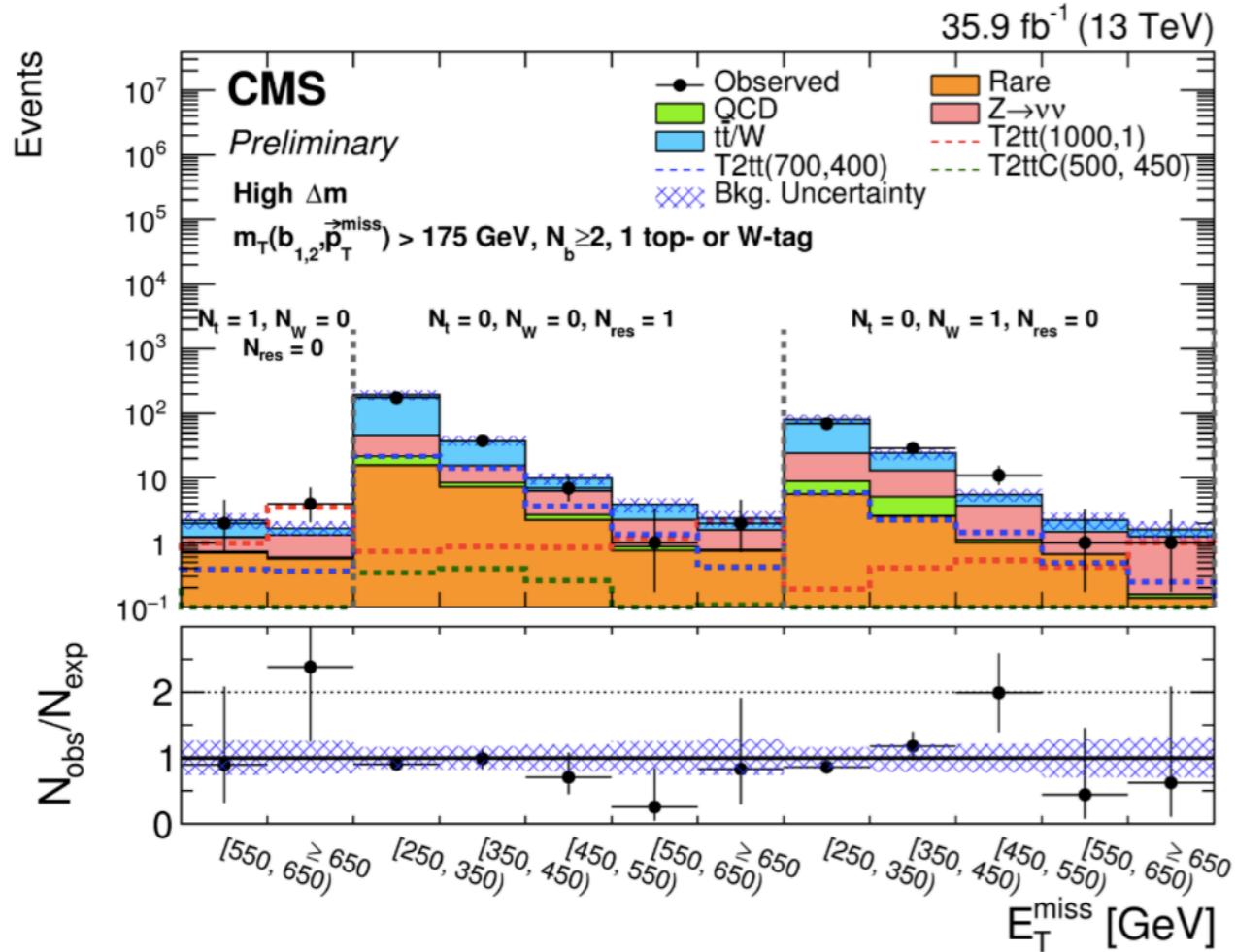
$$N_{\text{pred}}^{\text{LLB}} = TF_{\text{LLB}} \cdot N_{\text{data}}^{1\ell}$$



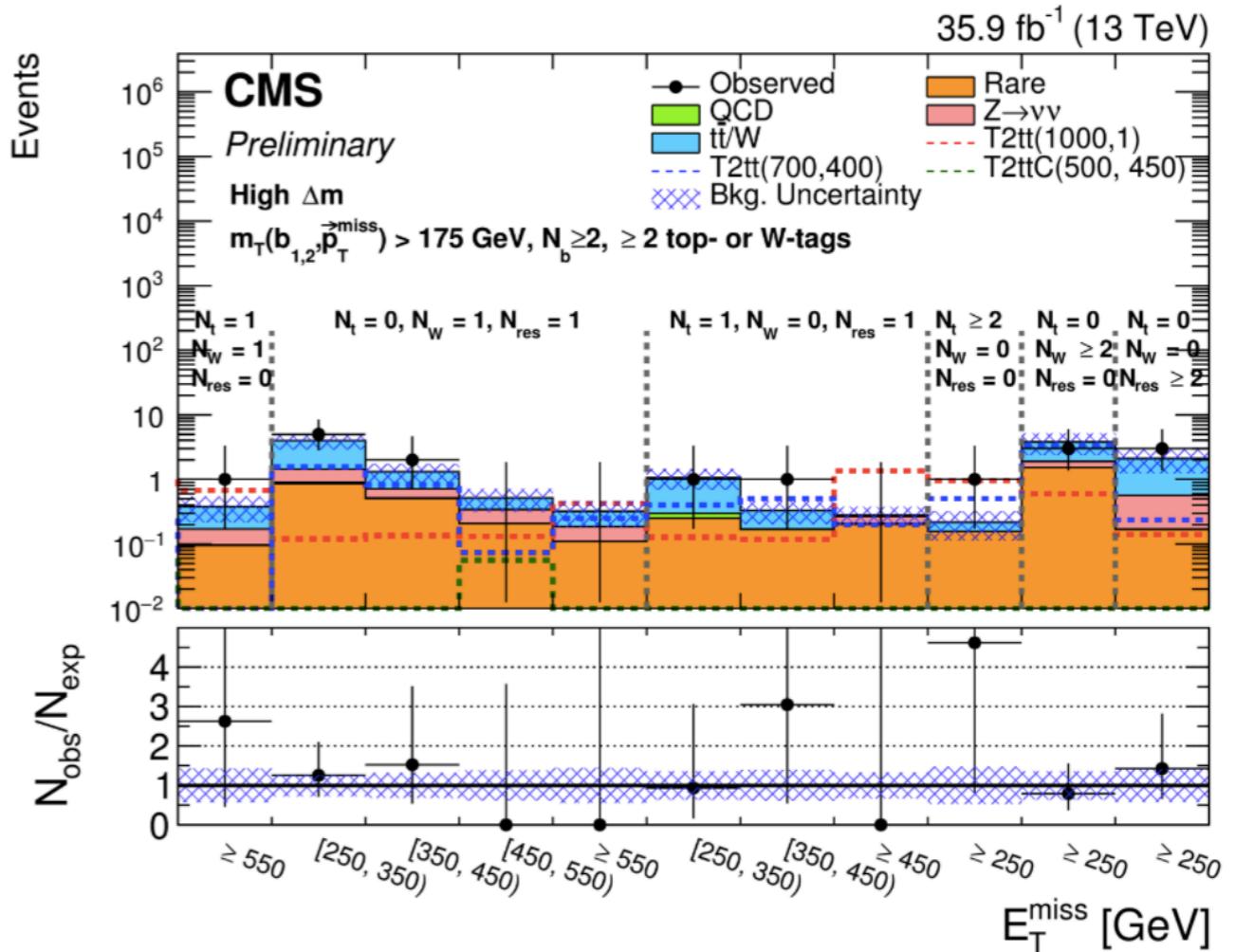
- ◆  $Z \rightarrow \nu\nu$  using  $Z \rightarrow ll$  and  $\gamma + \text{jets}$  control samples
- ◆ QCD using low  $\Delta\varphi(\text{jets}, \text{MET})$  control sample

# 0-lepton Results

1 top or W tags

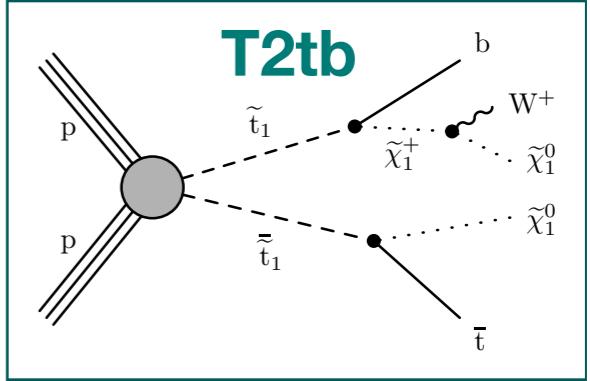
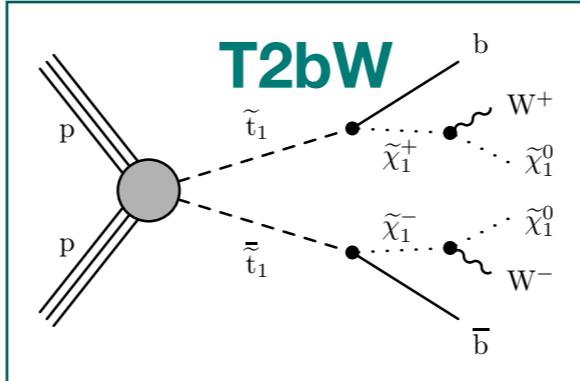
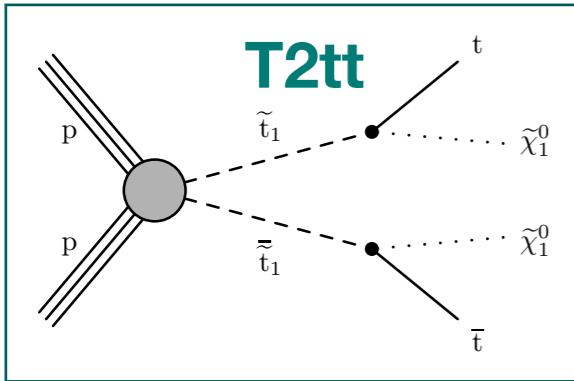


$\geq 2$  top or W tags

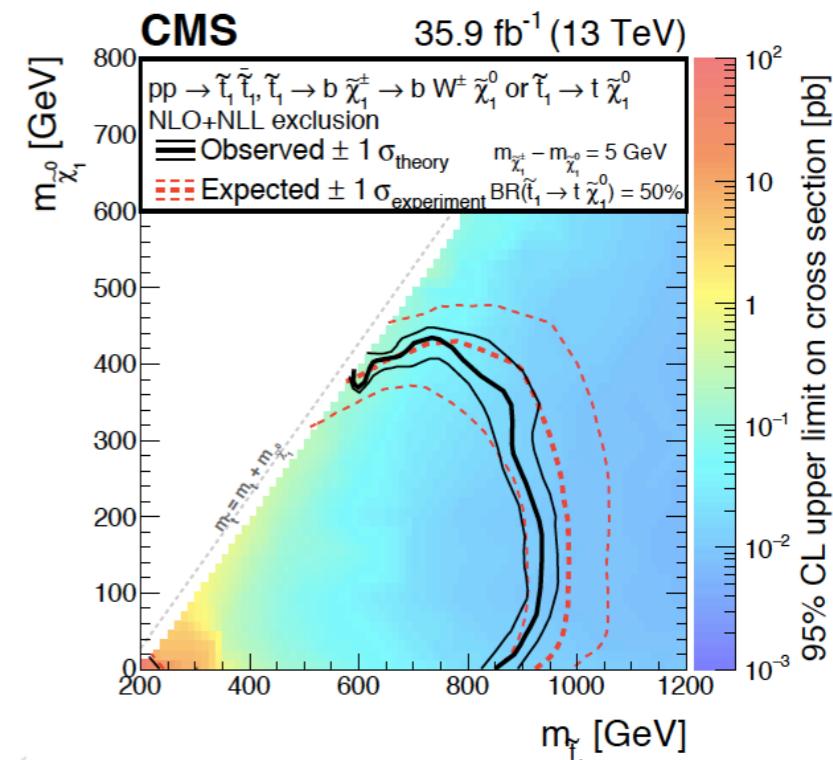
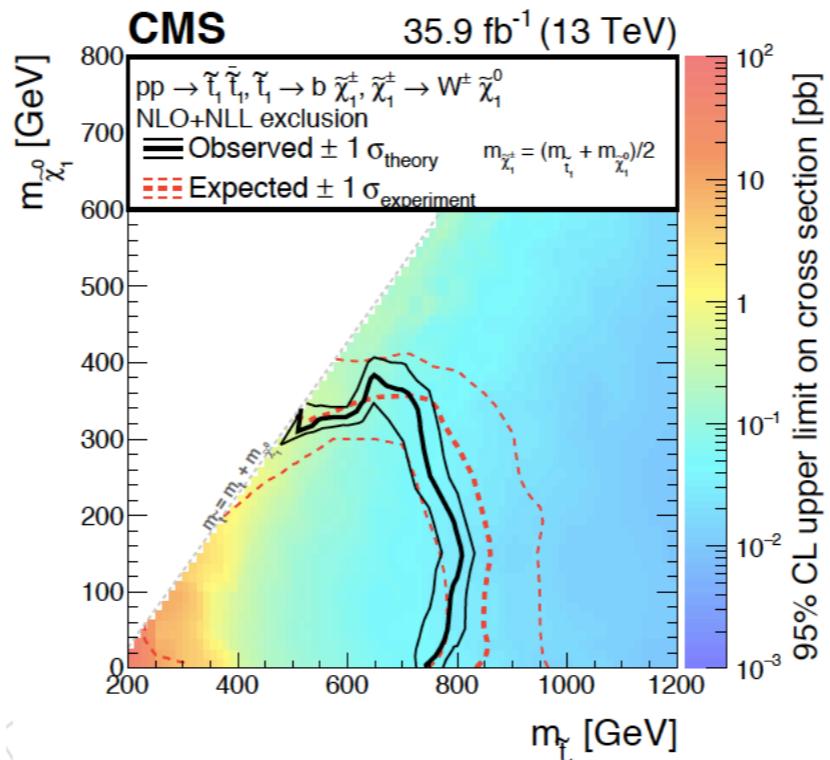
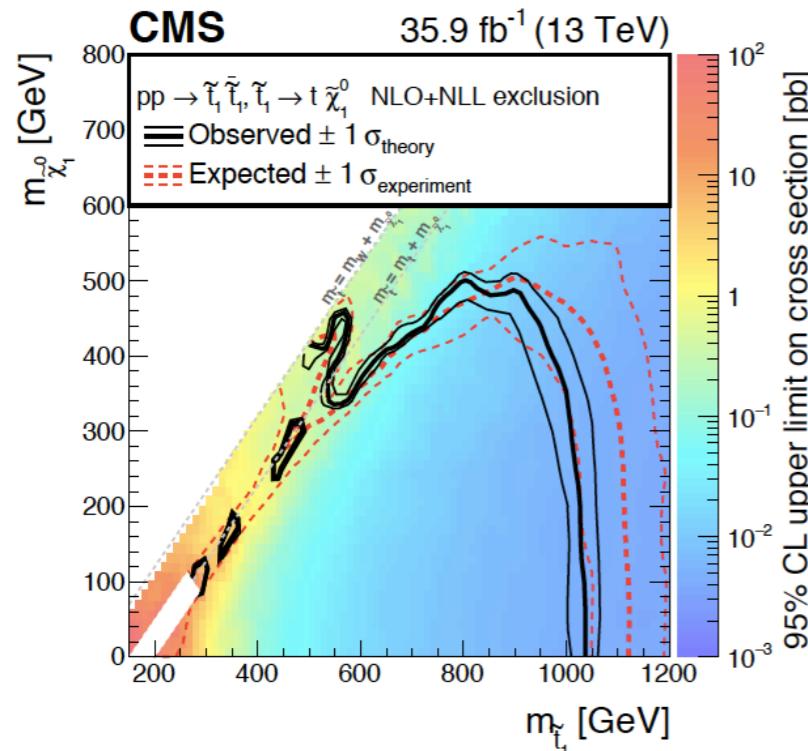


Good agreement between data and prediction  
within uncertainties

# Interpretations



$$\Delta M(\tilde{\chi}_0, \tilde{\chi}_1) \sim 5 \text{ GeV}$$



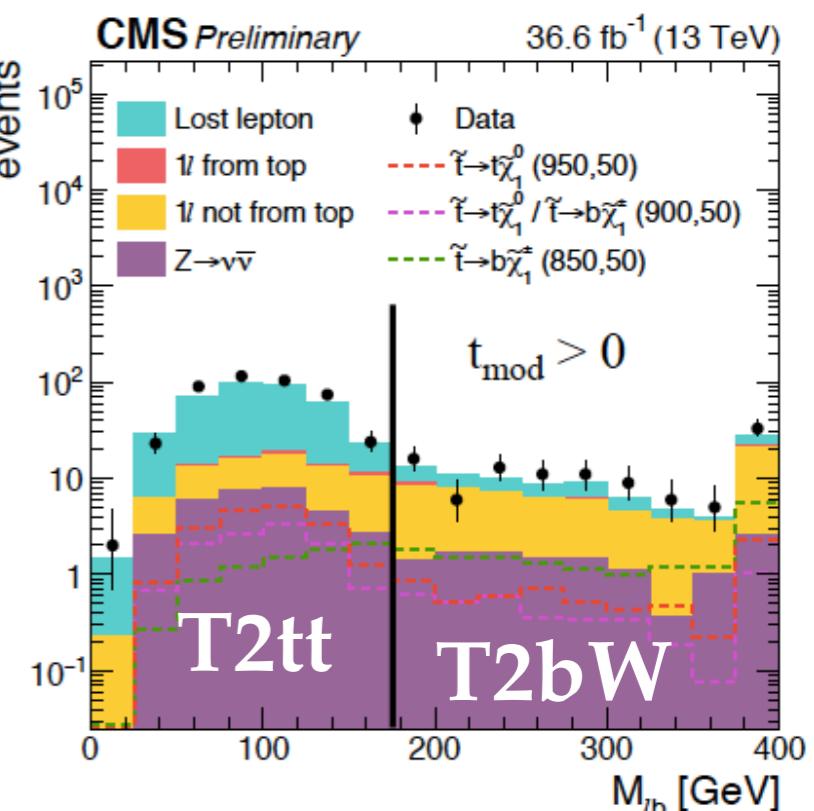
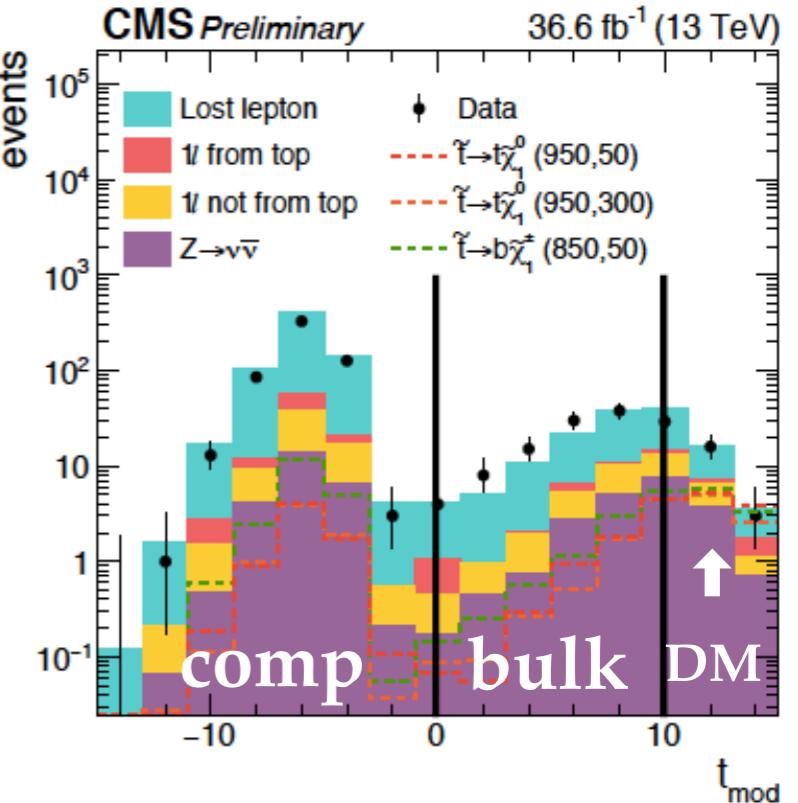
$M_{\text{stop}} < 1040 \text{ GeV},$   
 $M_{\text{LSP}} < 500 \text{ GeV}$

$M_{\text{stop}} < 800 \text{ GeV},$   
 $M_{\text{LSP}} < 360 \text{ GeV}$

$M_{\text{stop}} < 940 \text{ GeV},$   
 $M_{\text{LSP}} < 440 \text{ GeV}$

# 1-lepton Search

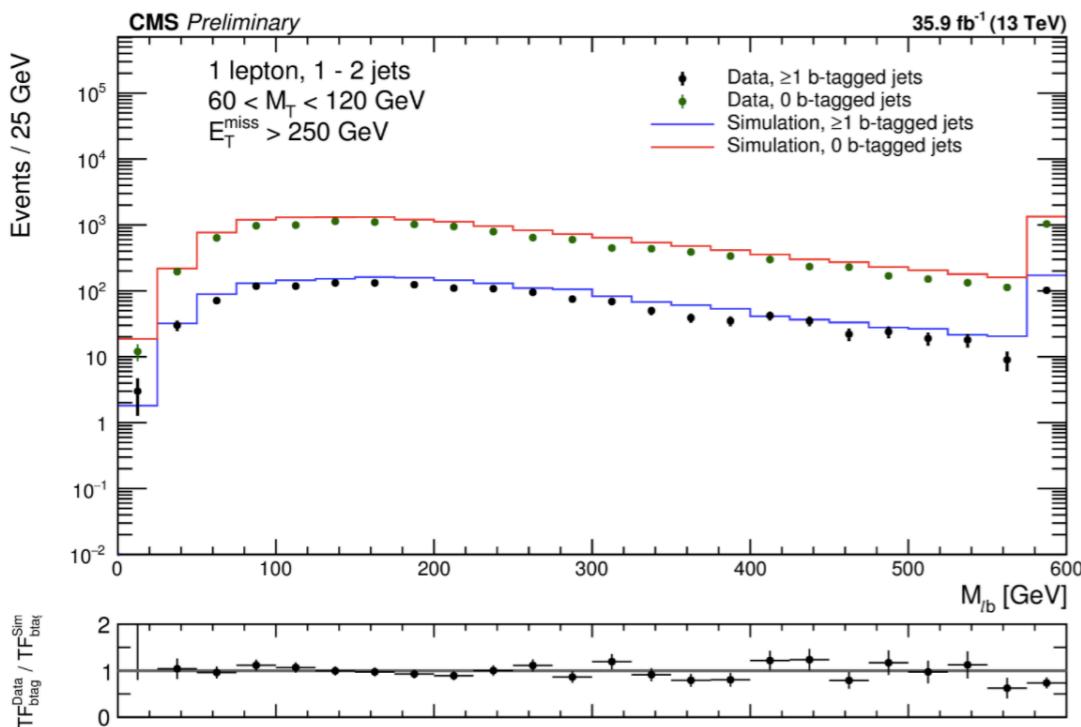
- ◆ Baseline: exactly 1 lepton, 2nd lepton vetoes,  $\geq 2$  jets,  $\geq 1$  (medium) b-tagged jets,  $\min\Delta\phi(j_{1,2}, \text{MET}) > 0.8$ ,  $M_T > 150$  GeV,  $\text{MET} > 250$  GeV
- ◆ Categorization by binning in:
  - ◆ MET and N-jets
  - ◆ modified topness: strong discriminator
  - ◆  $M_{lb}$  (medium b-jet closest to lepton)
    - ◆ high  $M_{lb}$  region ( $M_{lb} > 175$  GeV) is dominated by  $W+jets$
    - ◆ Optimized the b-tagging in that region
      - ◆  $\geq 1$  tight b-tagged jets helps in signal discrimination.



# 1-lepton BG Estimation

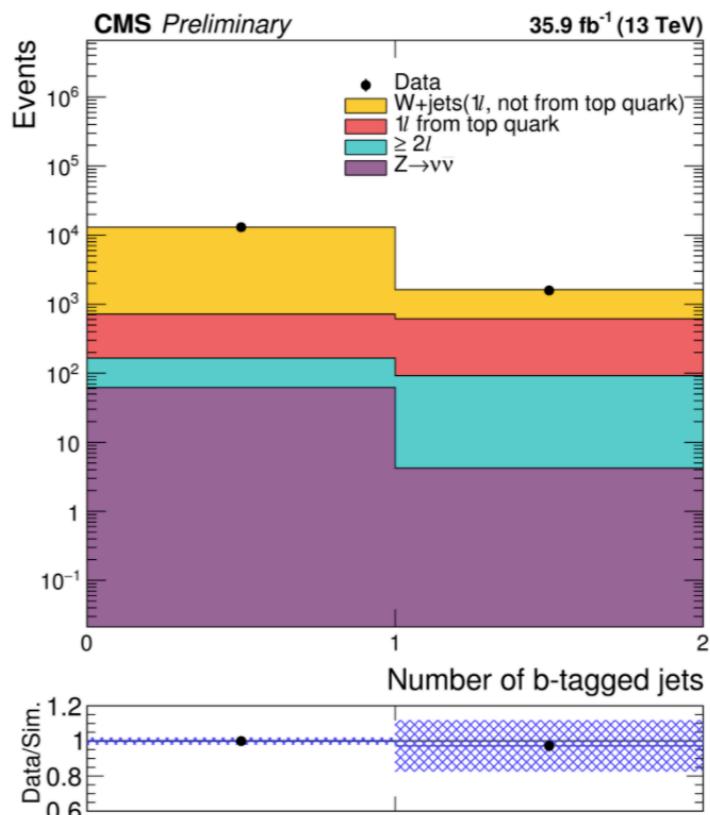
|                        | 1 lepton                    | 2 leptons  | 3 leptons                             |
|------------------------|-----------------------------|--|---------------------------------------|
| 0 b-tagged jets        | <b>W+jets<br/>dominated</b> |  | <b>WZ<br/>dominated</b>               |
| $\geq 1$ b-tagged jets | <b>Signal<br/>region</b>    | <b><math>t\bar{t}/tW \rightarrow 2l</math><br/>dominated</b> | <b><math>ttZ</math><br/>dominated</b> |

- W+Jets estimate from 0 btag control sample using jet with highest b-tag value as b-jet in M(l,b)



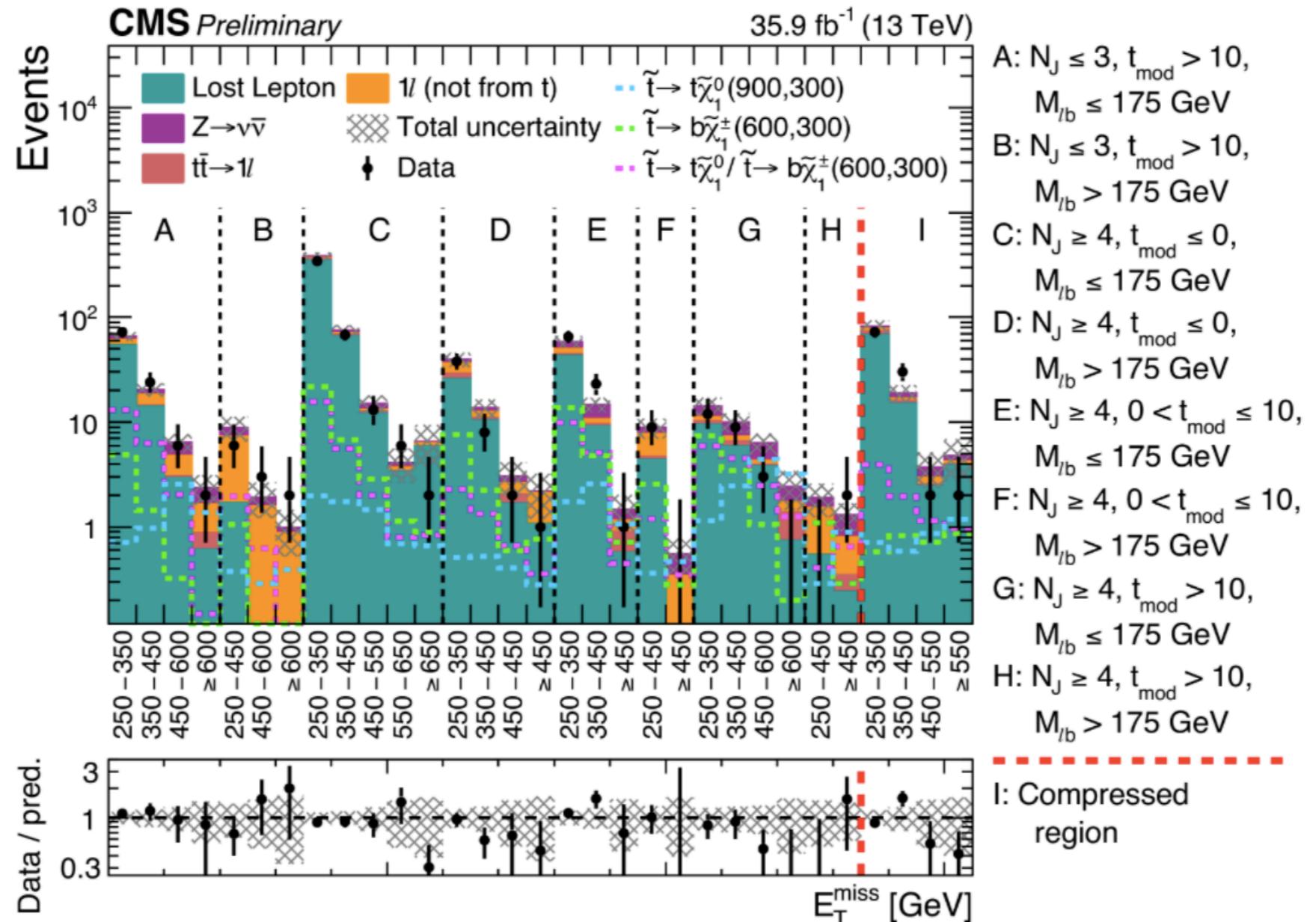
Normalization only

- Important systematic uncertainties



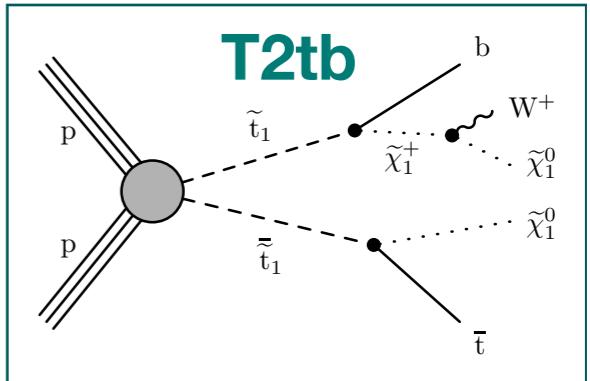
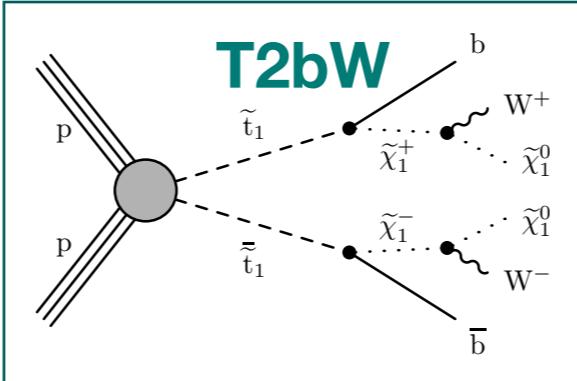
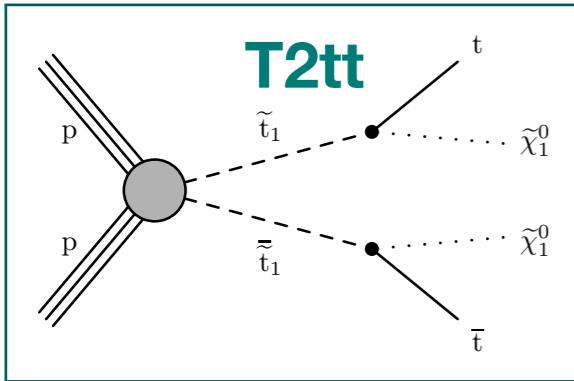
- lost lepton contamination in control sample
- 40% W+( $\geq 1$ b) in SRs, W+b(b) cross-section

# 1-lepton Results

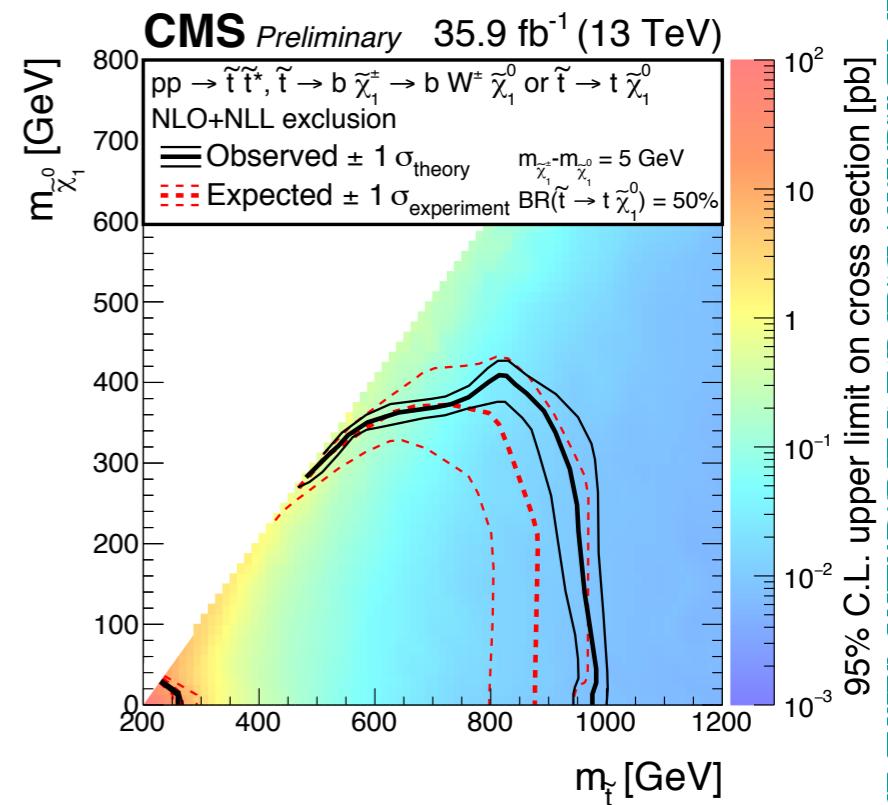
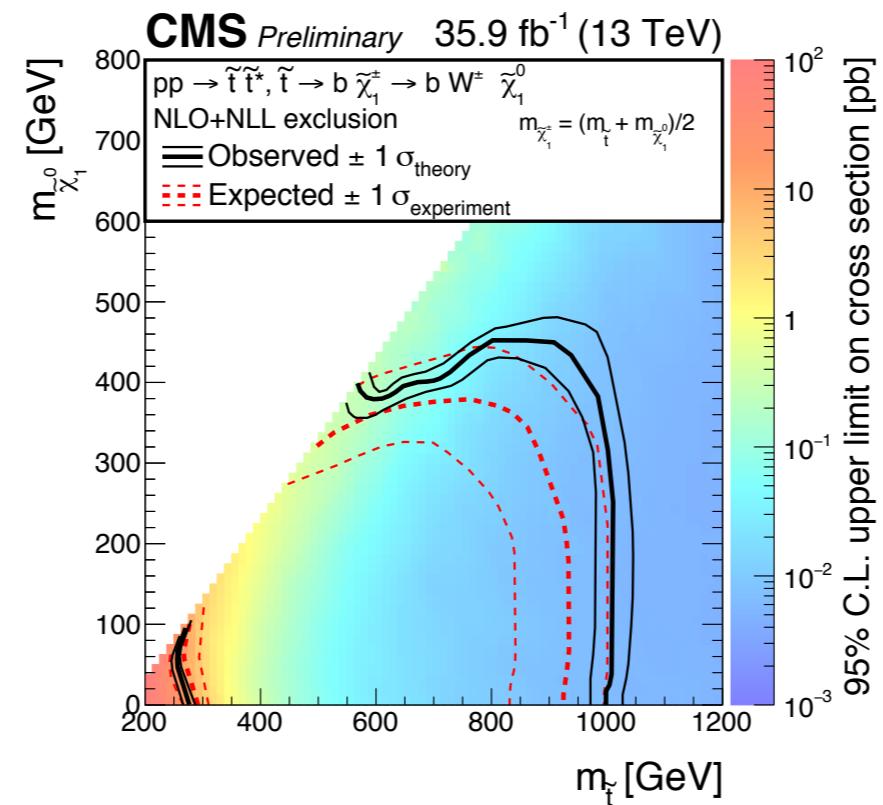
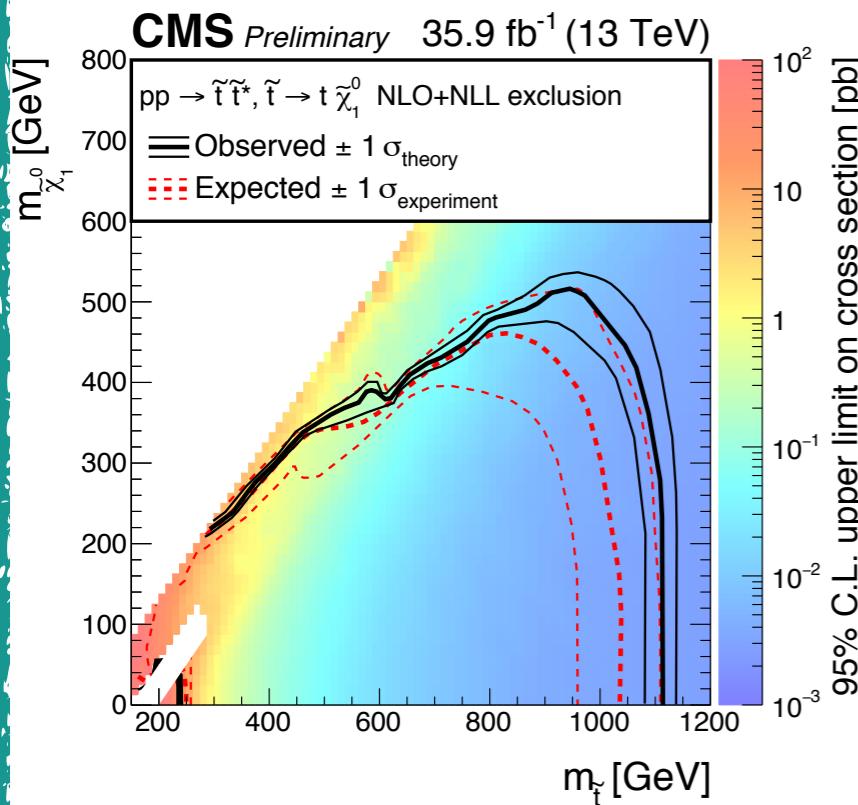


Good agreement between data and prediction  
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# Interpretations



$\Delta M(\tilde{\chi}_0, \tilde{\chi}_1) \sim 5 \text{ GeV}$



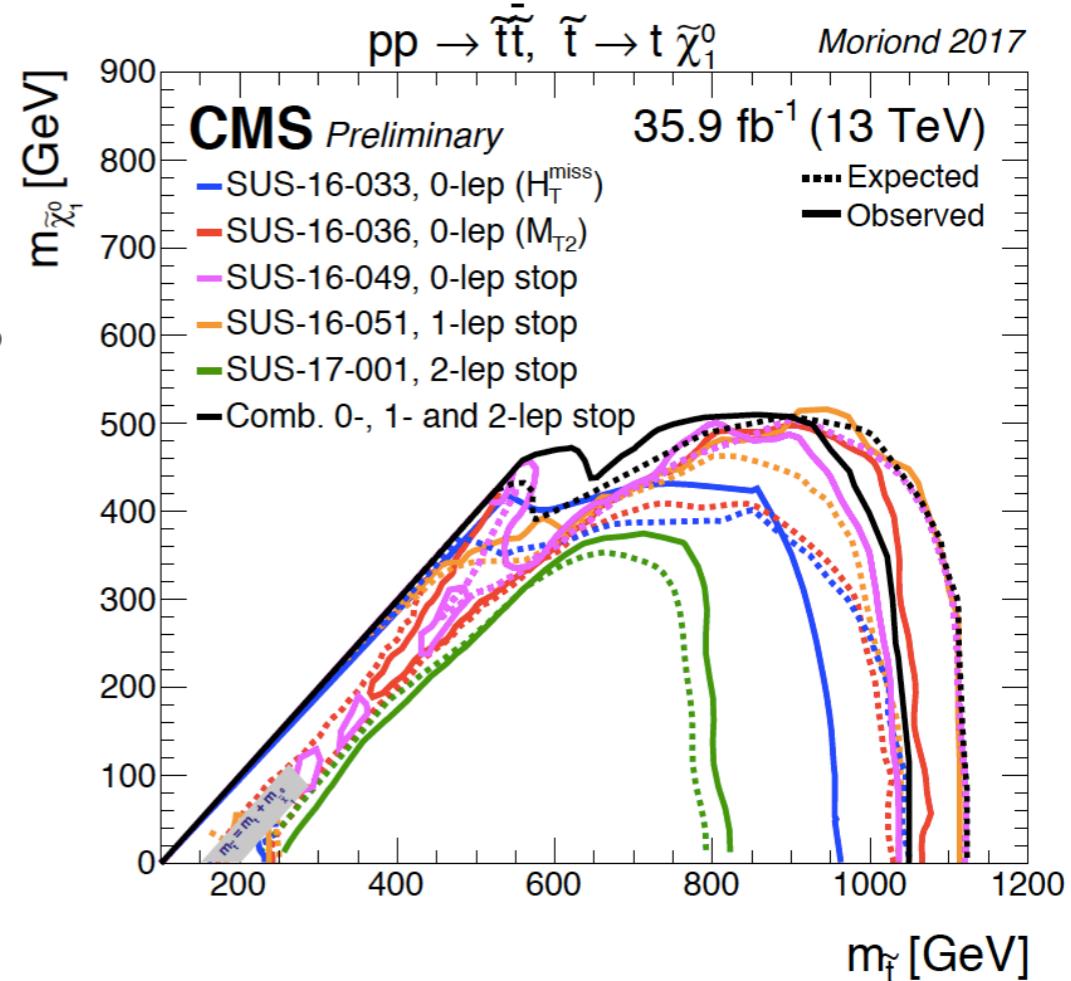
$M_{\text{stop}} < 1120 \text{ GeV},$   
 $M_{\text{LSP}} < 515 \text{ GeV}$  at  
**950 GeV stop mass**  
(incl. compressed analysis)

$M_{\text{stop}} < 1025 \text{ GeV},$   
 $M_{\text{LSP}} < 460 \text{ GeV}$  at  
**800 GeV stop mass**

$M_{\text{stop}} < 980 \text{ GeV},$   
 $M_{\text{LSP}} < 400 \text{ GeV}$  at  
**825 GeV stop mass**

# Summary

- ◆ Searches for third generation squarks using  $35.9 \text{ fb}^{-1}$  of 13 TeV data
  - ◆ explore a wide variety of topologies
  - ◆ make use of heavy object identification
- ◆ No significant deviation from the standard model is observed
  - ◆ Mass limits reach or exceed the 1 TeV barrier: Natural SUSY dead?
  - ◆ Limits subject to the SMS simplifications
- ◆ With more data, can probe more difficult regions of phase space



[Links to public results  
on next page](#)

Public material includes aggregated signal regions & correlation matrix to facilitate theory reinterpretations



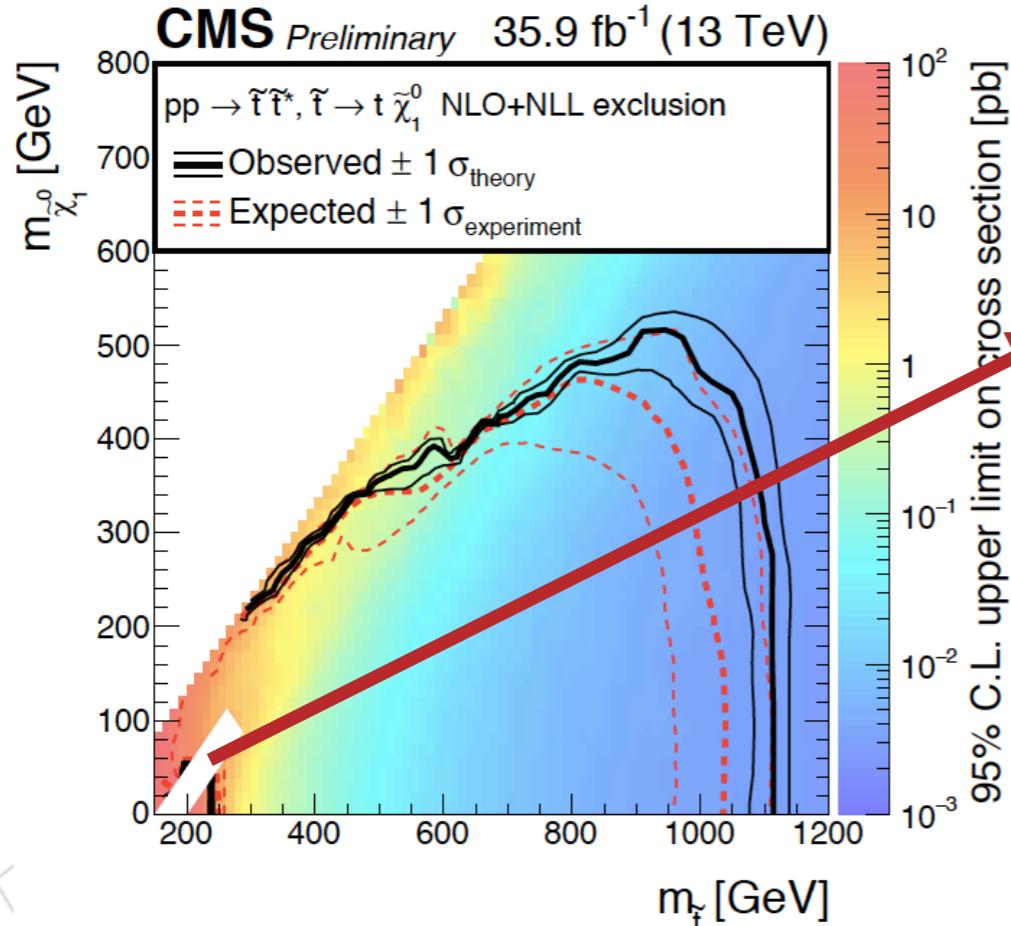
# Links to CMS Public Results



Full Set of CMS Results: <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS>

- ◆ **Search for direct top squark pair production in the all-hadronic final state in proton-proton collisions at  $\sqrt{s}=13$  TeV**
  - ◆ <http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS-16-049/index.html>
- ◆ **Search for supersymmetry using hadronic top quark tagging in 13 TeV pp collisions**
  - ◆ <http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS-16-050/index.html>
- ◆ **Search for top squark pair production in pp collisions at  $\sqrt{s} = 13$  TeV using single lepton events**
  - ◆ <http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS-16-051/index.html>
- ◆ **Search for direct stop pair production in the dilepton final state at  $\sqrt{s} = 13$  TeV**
  - ◆ <http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS-17-001/index.html>
- ◆ **Search for direct production of bottom and top squark pairs in proton-proton collisions at  $\sqrt{s} = 13$  TeV**
  - ◆ <http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS-16-032/index.html>

# The White Band



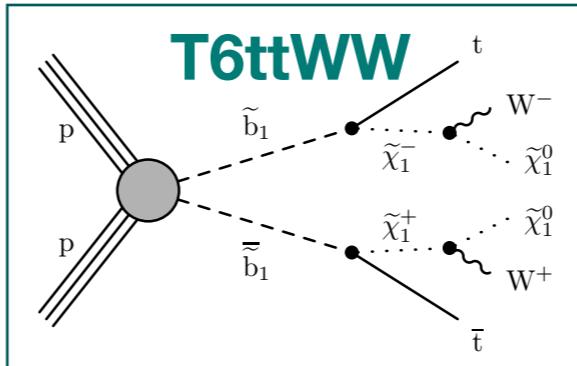
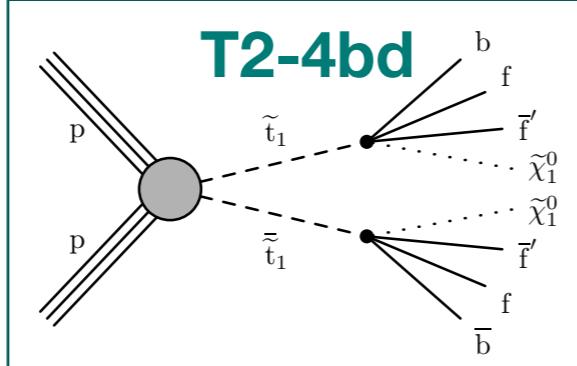
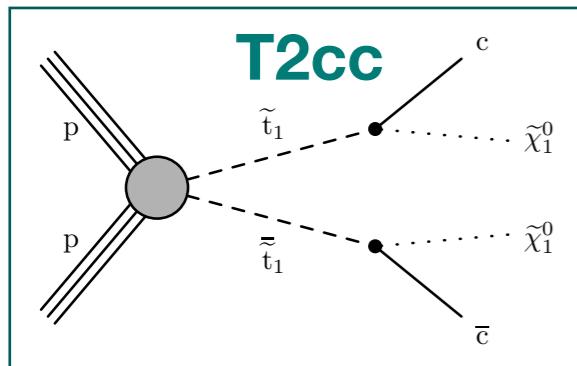
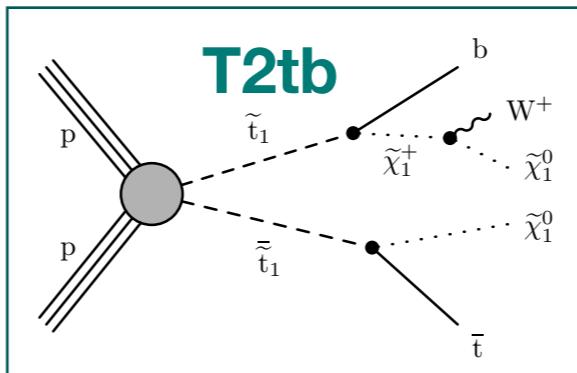
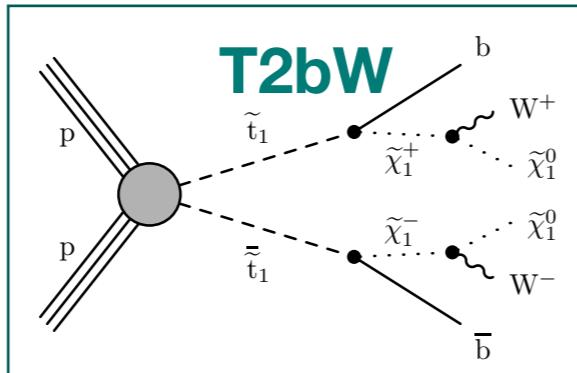
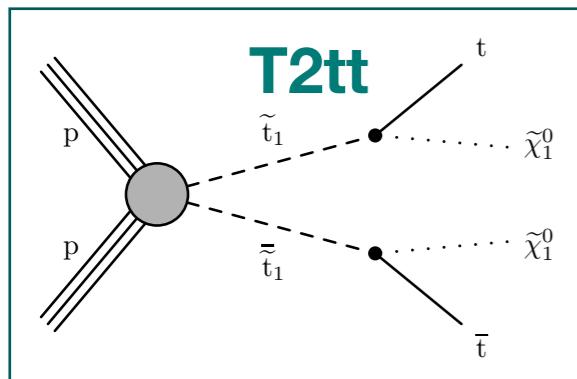
T2tt

- ◆ Region where:  
 $|m_{\tilde{t}} - m_t - m_{\tilde{\chi}_1^0}| < 25 \text{ GeV}, m_{\tilde{t}} < 275 \text{ GeV}$
- ◆ No limit established due to the selection efficiency of top squark events changing rapidly and becoming very sensitive to details of the model and the simulation.

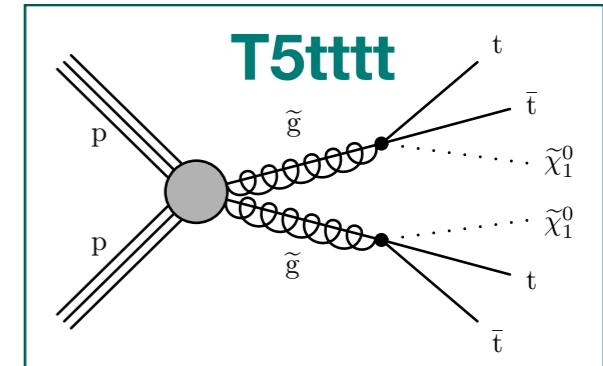
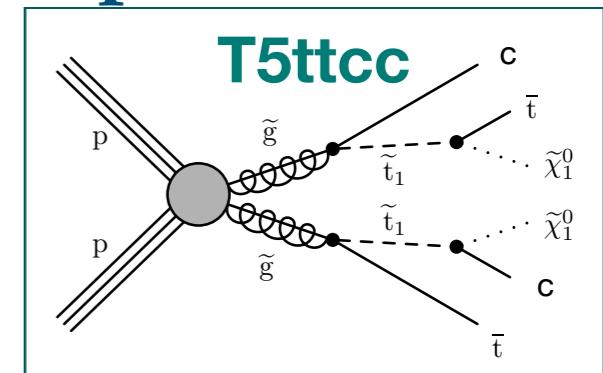
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Comprehensive search program in CMS  
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## Direct Production



## Gluon-mediated production



Searches in final states with  
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