Searches for supersymmetric partners of third-generation quarks in CMS

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On behalf of CMS Collaboration

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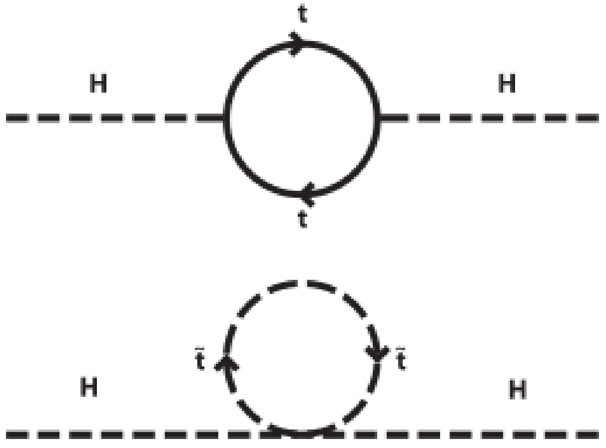
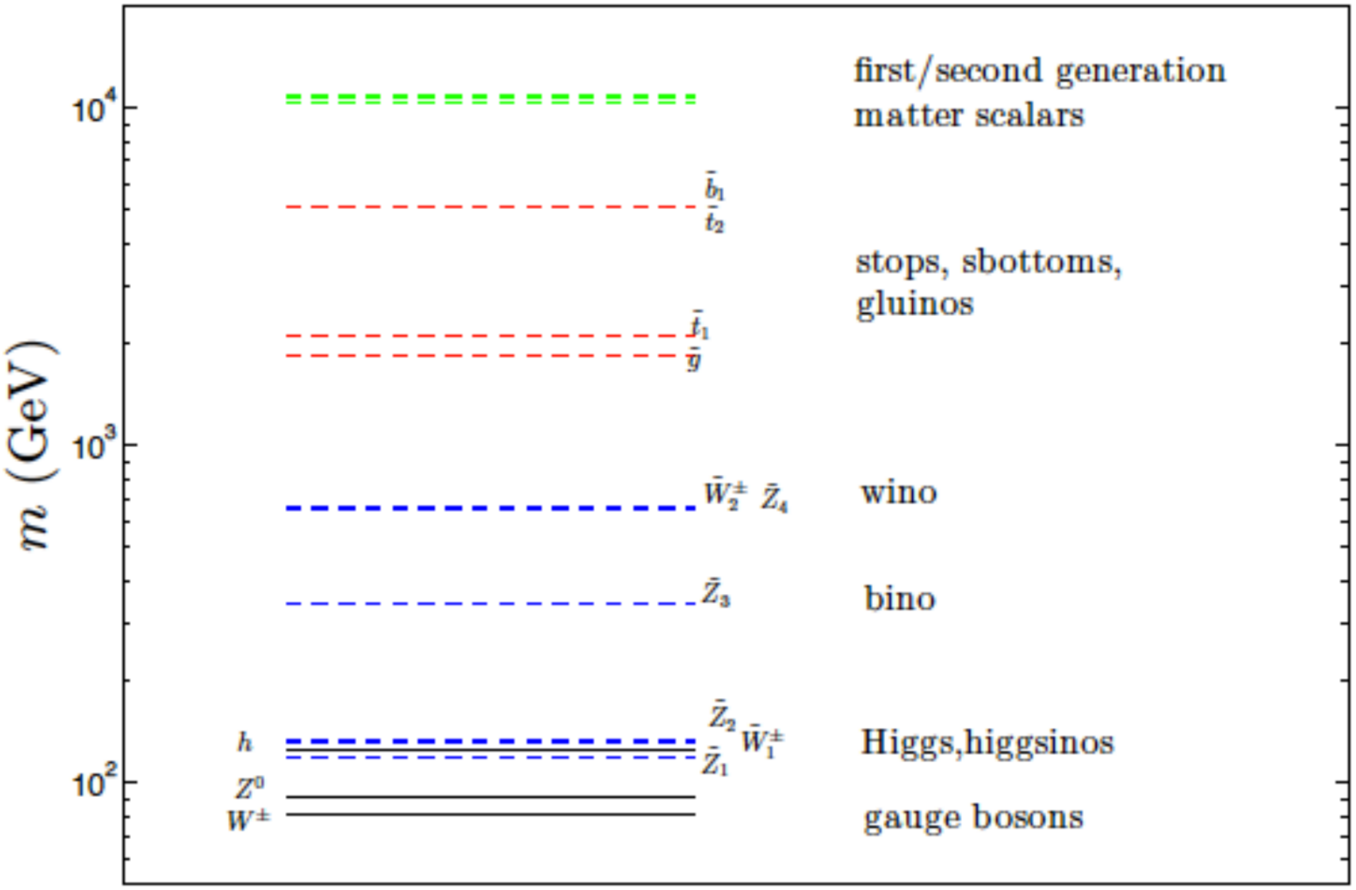
Introduction

Why 3rd-gen squarks?

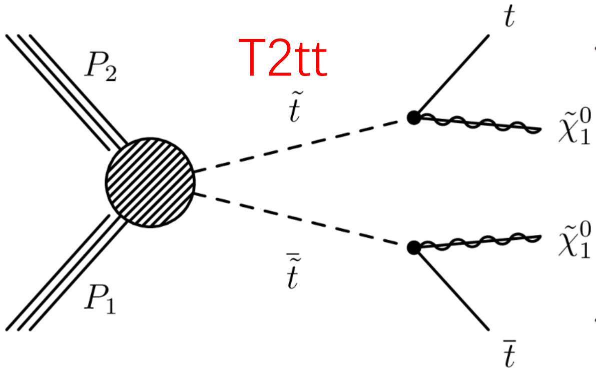


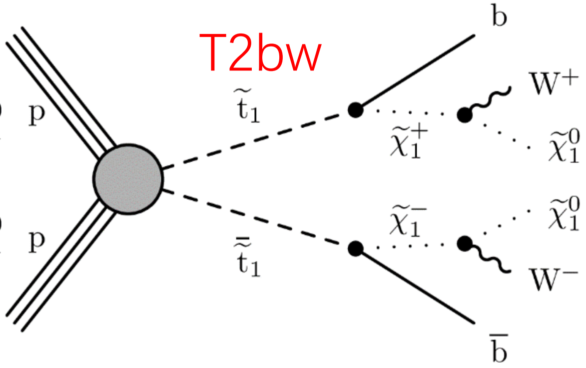
- Tops and bottoms contribute most to the loop correction of Higgs mass
- Unfortunately, SUSY is broken
- Natural models of SUSY: masses of 3rd-gen squarks less than a few TeV

Natural models of SUSY

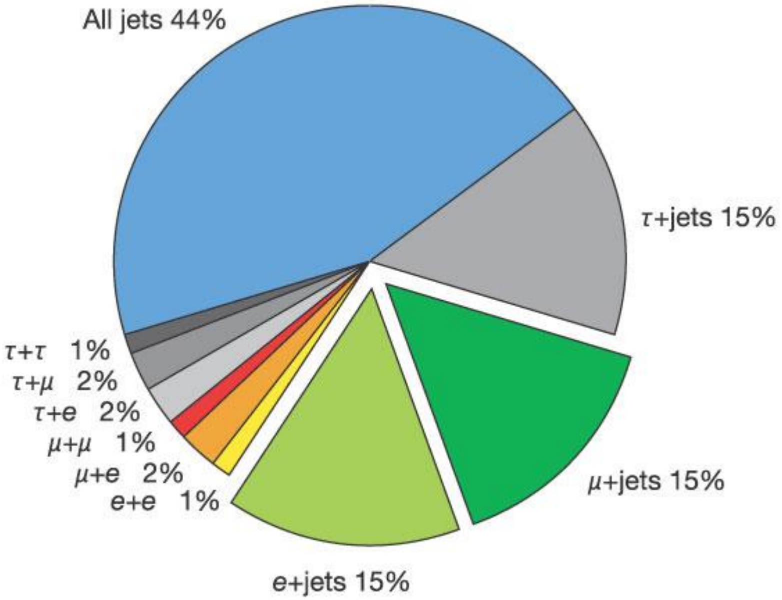


Simplified SUSY models





Simplified SUSY models, assuming 100% branching ratio



CMS 2016 data, 35.9 fb^{-1} @ 13 TeV

- 2 leptons:

SUS-17-001 arXiv:1711.00752

- 1 lepton:

SUS-16-051 arXiv:1706.04402

- 0 lepton:

SUS-16-050 (stop, gluino) arXiv:1710.11188

SUS-16-033 (stop, gluino) arXiv:1704.07781

SUS-16-032 (sbottom) arXiv:1707.07274

- More results:

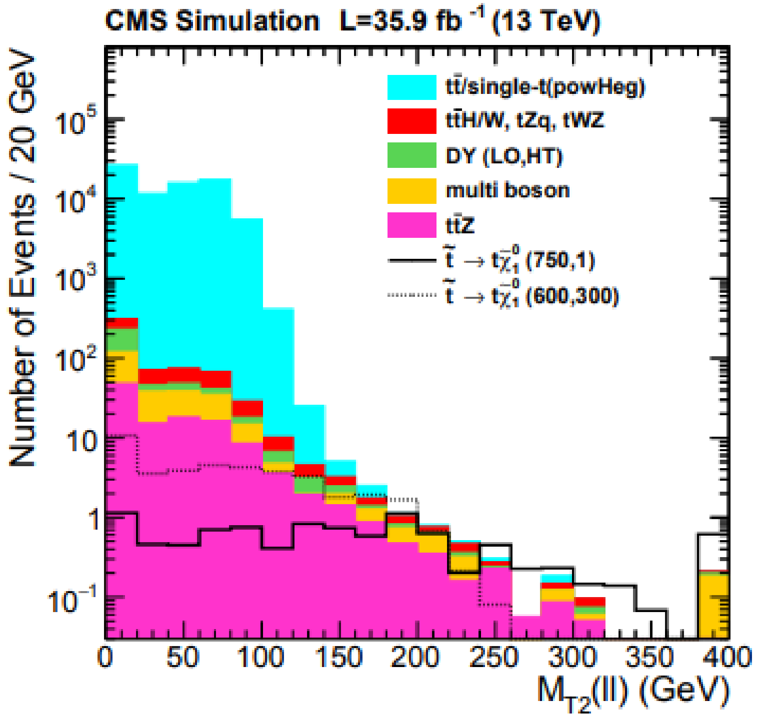
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

sTop search with 2 leptons

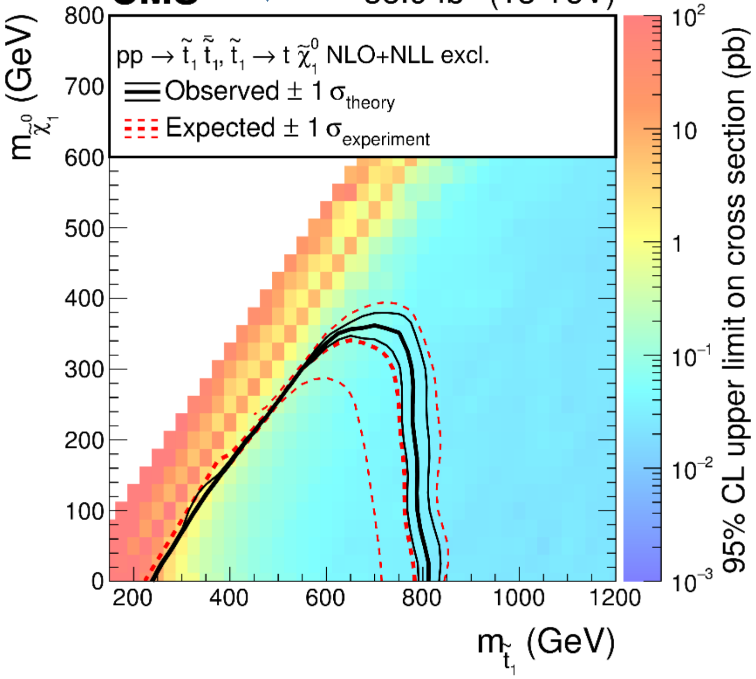
- Search in final states of 2 leptons (e/μ), jets, bjets and MET
- Dominant ttbar background is reduced by M_{T2}(ll)

SUS-17-001

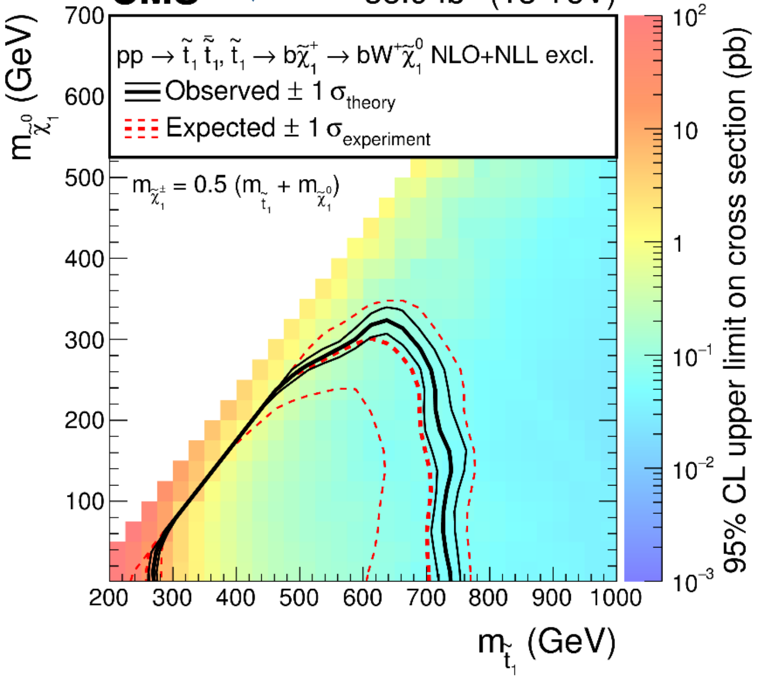
$$M_{T2}(\ell\ell) = \min_{\vec{p}_{T1}^{\,miss} + \vec{p}_{T2}^{\,miss} = \vec{E}_T^{miss}} \left(\max \left[M_T(\vec{p}_T^{\,vis1}, \vec{p}_{T1}^{\,miss}), M_T(\vec{p}_T^{\,vis2}, \vec{p}_{T2}^{\,miss}) \right] \right)$$



T2tt



T2bw

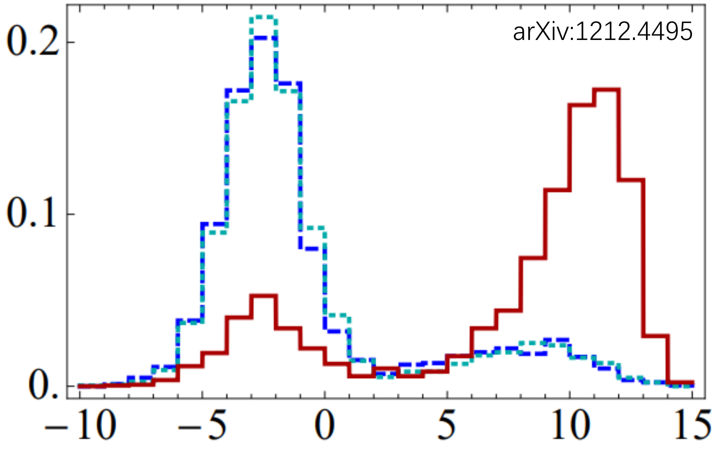


sTop search with 1 lepton

SUS-16-051

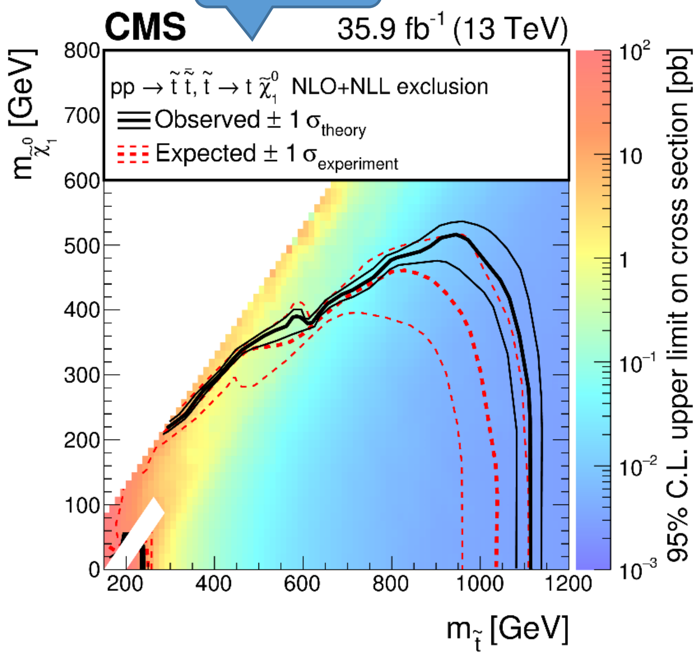
- Search in final states of 1 lepton (e/μ), jets, bjets and MET
- ttbar (1l) background is negligible after M_T cut
- Dominant ttbar (2l) background is reduced by modified topness (t_{mod})

$$t_{\mathrm{mod}} = \ln(\min S), \text{ with } S(\vec{p}_{\mathrm{W}}, p_z, \nu) = \frac{(m_{\mathrm{W}}^2 - (p_\nu + p_\ell)^2)^2}{a_{\mathrm{W}}^4} + \frac{(m_{\mathrm{t}}^2 - (p_{\mathrm{b}} + p_{\mathrm{W}})^2)^2}{a_{\mathrm{t}}^4}.$$

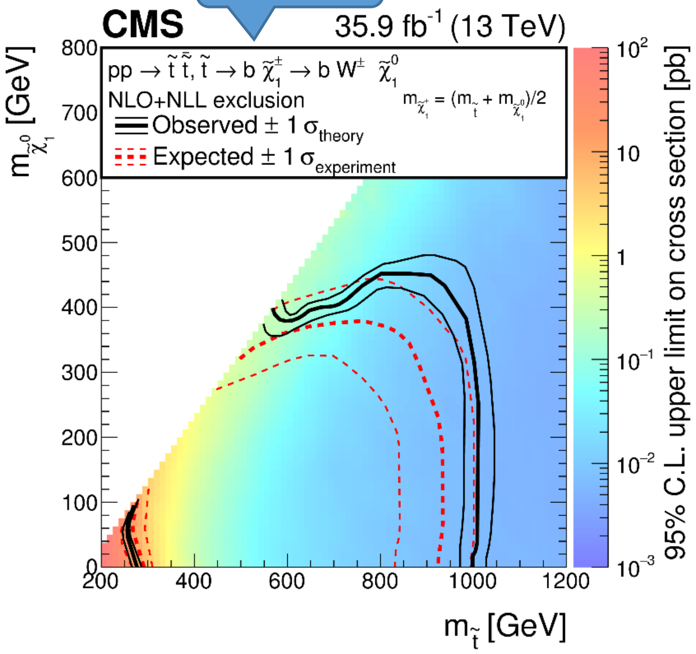


Unit-normalized topness
Red: T2tt. Blue: ttbar dilepton.
Cyan: ttbar one lepton, one τ

T2tt



T2bw

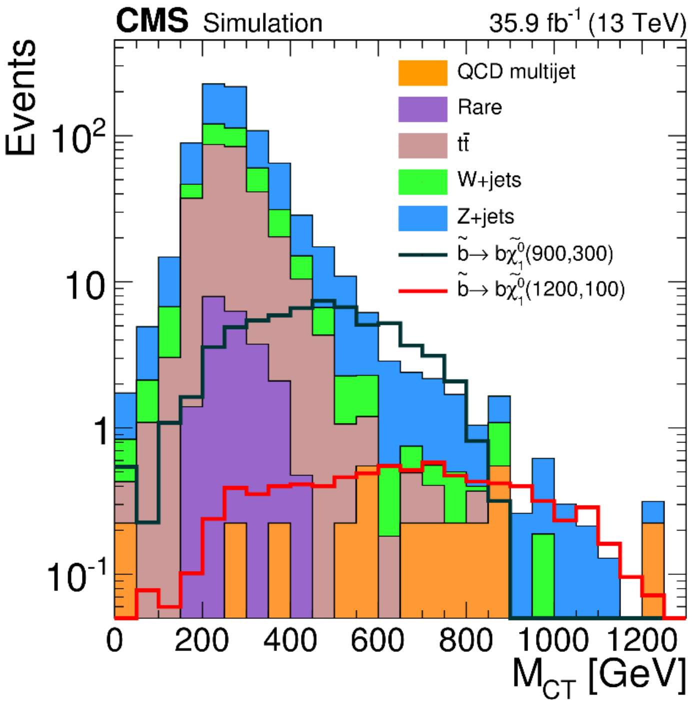


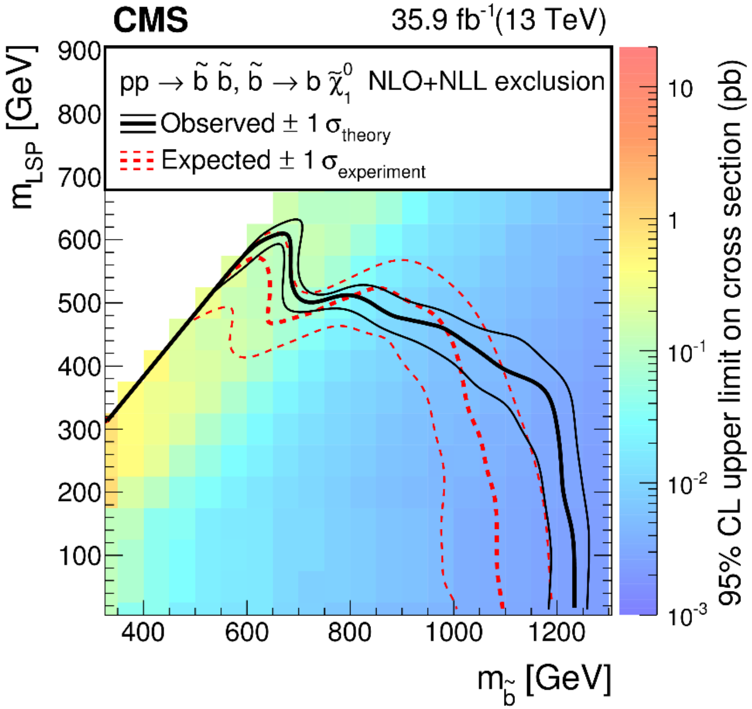
sBottom search with 0 lepton

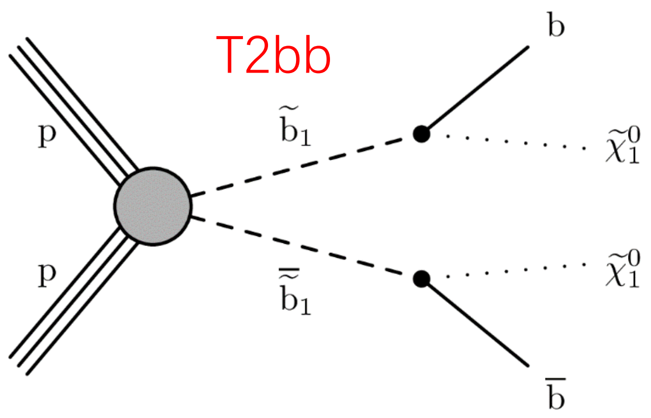
SUS-16-032

- Search in final states of 0 lepton, jets, bjets and MET
- Both leading and sub-leading jets be b-tagged
- ttbar background is reduced by $M_{T2}(bb)$
- $Z(\nu\nu)+jets$ and ttbar further reduced by contransverse mass (M_{CT}^2)

$$= [E_T(j_1) + E_T(j_2)]^2 - [\mathbf{p}_T(j_1) - \mathbf{p}_T(j_2)]^2$$
$$= 2p_T(j_1)p_T(j_2)(1 + \cos\Delta\phi(j_1, j_2)),$$







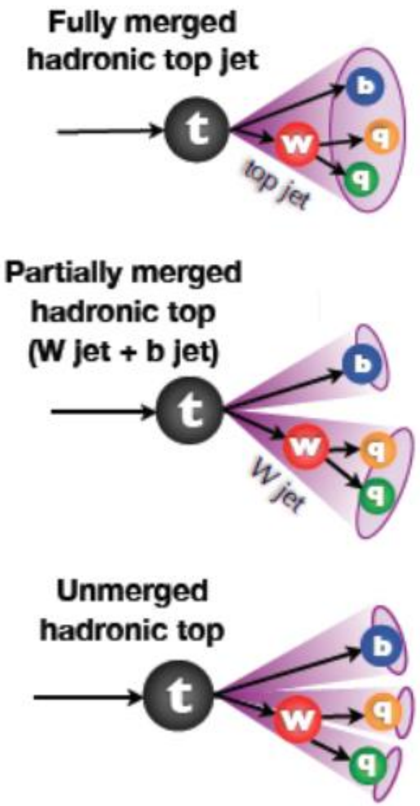
sTop search with 0 lepton

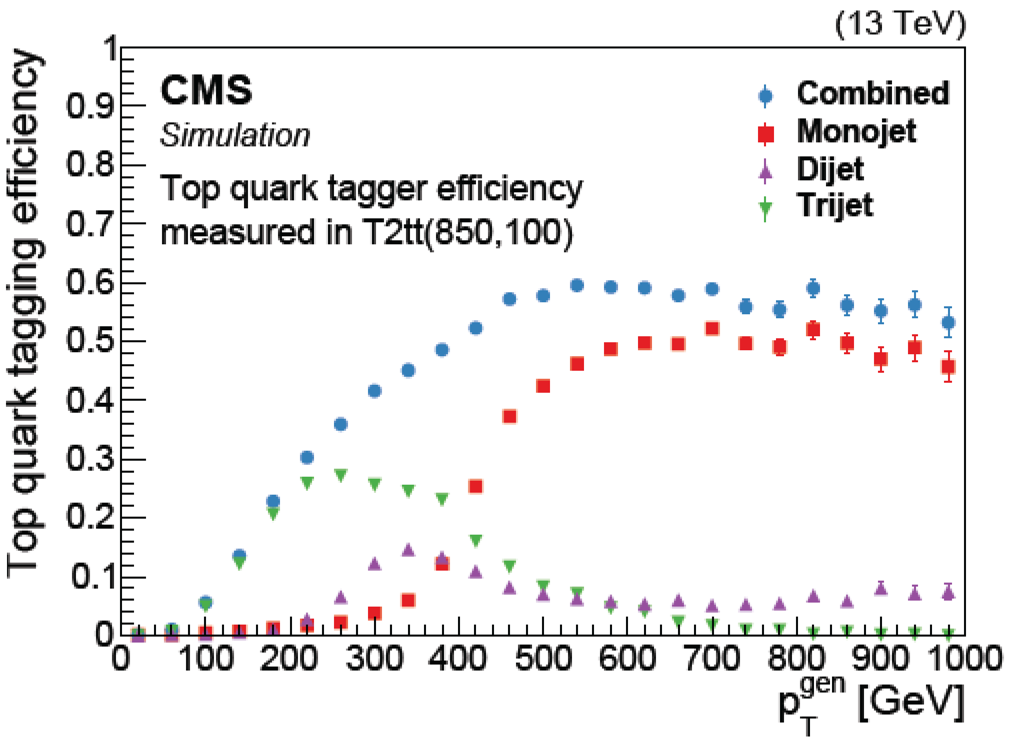
- Search in final states of 0 lepton, tagged tops, jets, bjets and MET
- Dominant ttbar background is reduced by $M_{T2}(tt)$

SUS-16-050

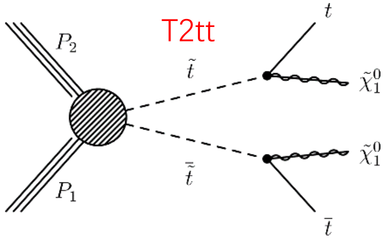
Top tagger Algorithm

- First tag fully merged tops
- Anti-kt jet with radius parameter = 0.8 (AK8)
- Tagged boosted (p_T > 400) top
- Then tag partially merged tops
- Tagged AK8 boosted (p_T > 200) W combined with a nearby AK4 jet
- Last tag unmerged (resolved) tops
- Combine three resolved AK4 jets (random forest algorithm)



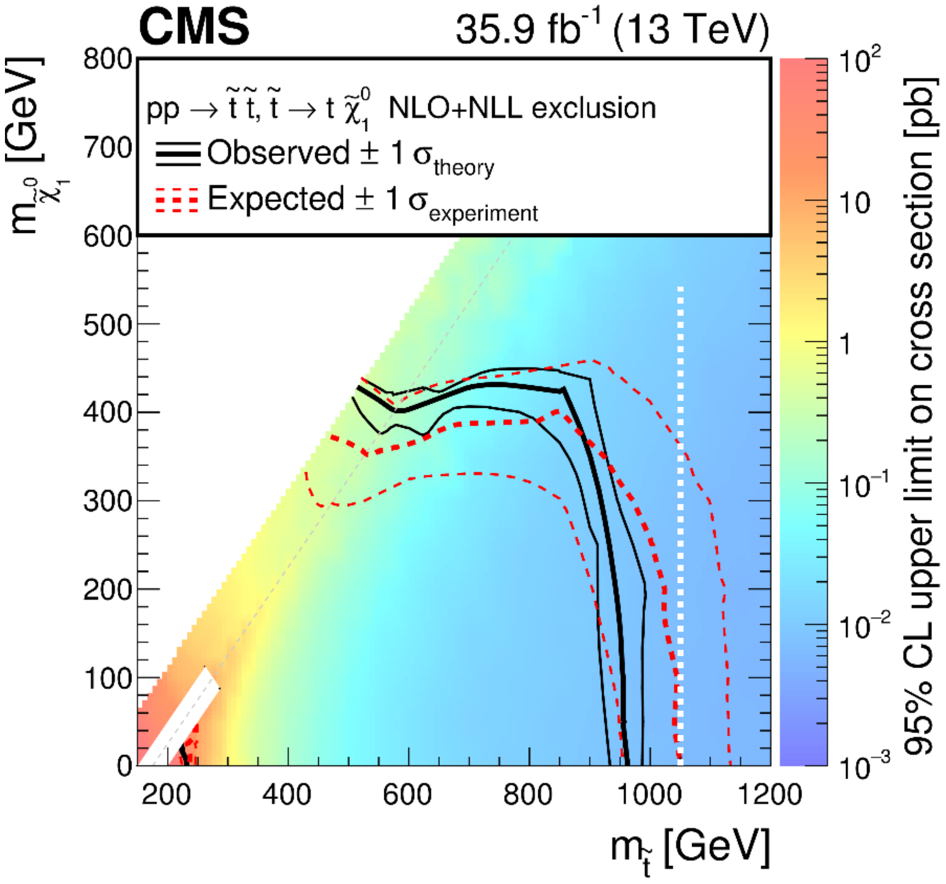


sTop search with 0 lepton



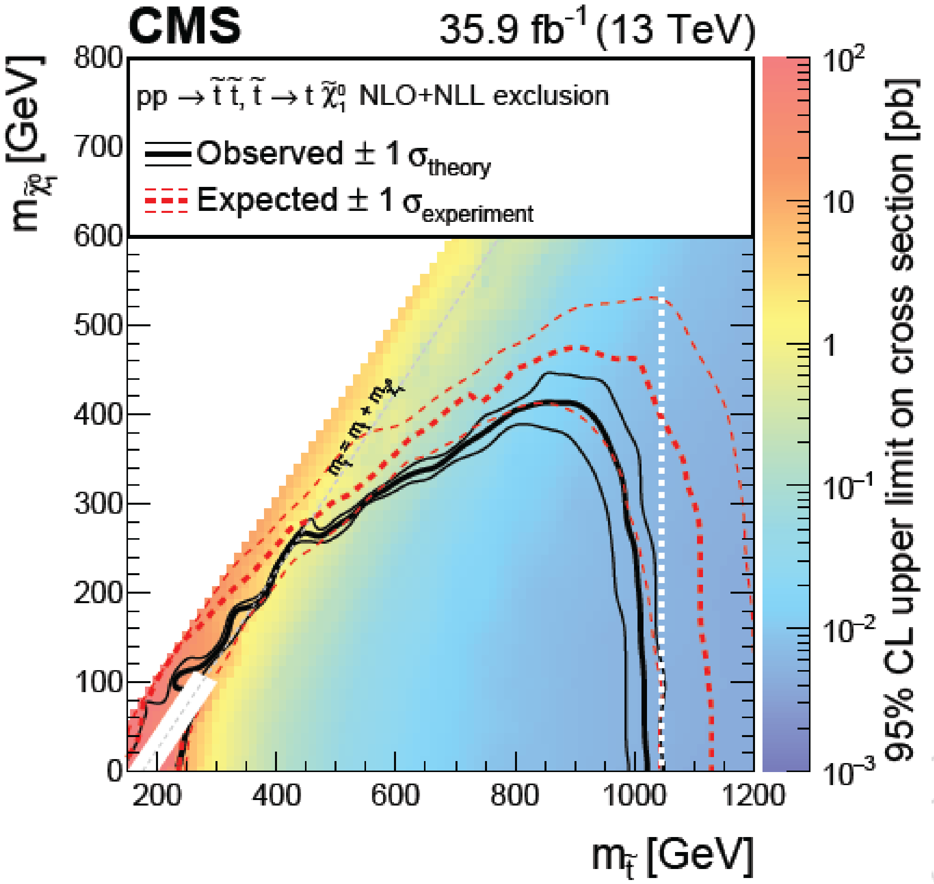
Limits without top tagger

[SUS-16-033]



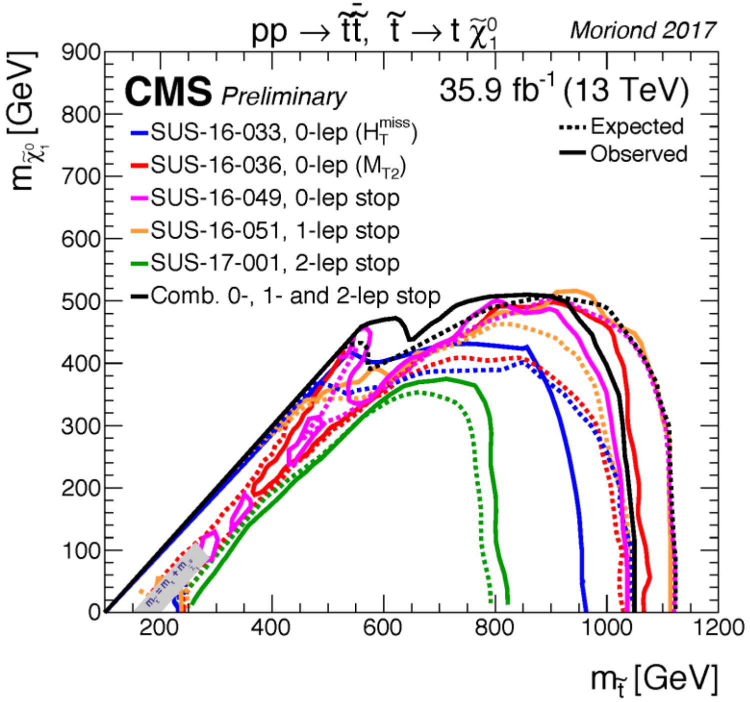
Limits with top tagger

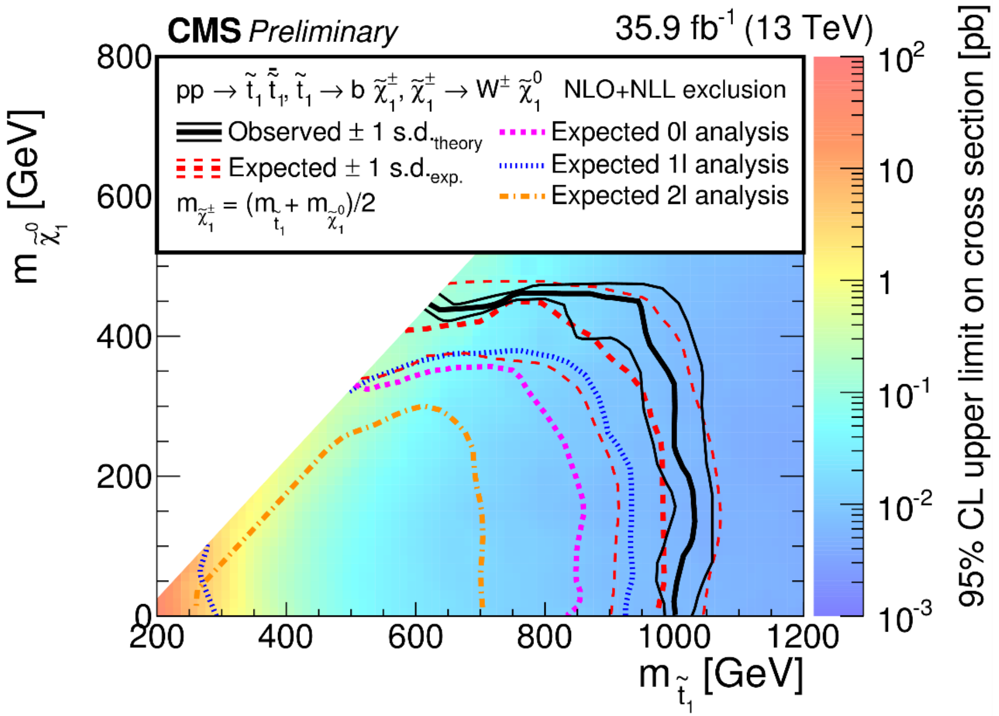
[SUS-16-050]

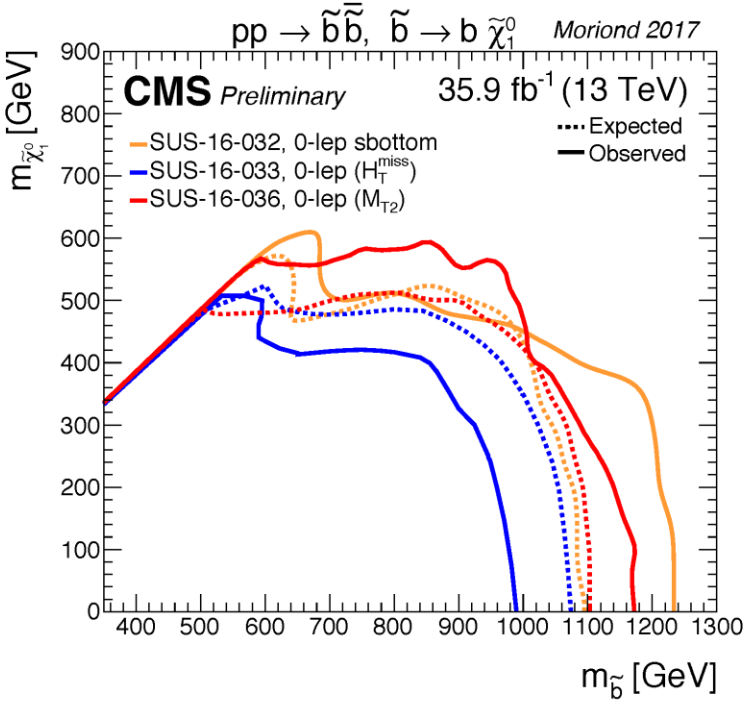


Summary

- Combined limits for T2tt, T2bw and T2bb







- Now working on 2016 + 2017 data (~80 fb^{-1})
- Can we catch SUSY with double statistics?

Thanks for your attention!

Backup slides

M_{T2} detail

- Also known as The Stransverse Mass
- Author website: http://www.hep.phy.cam.ac.uk/~lester/mt2/

$$\not{p}_T = \mathbf{p}_{T\tilde{\chi}_a} + \mathbf{p}_{T\tilde{\chi}_b}. \qquad (9)$$

If $\mathbf{p}_{T\tilde{\chi}_a}$ and $\mathbf{p}_{T\tilde{\chi}_b}$ were obtainable, then one could form two transverse masses, and using the relationship (8) obtain,

$$m_{\tilde{l}}^2 \geq \max\{m_T^2(\mathbf{p}_{Tl^-}, \mathbf{p}_{T\tilde{\chi}_a}), m_T^2(\mathbf{p}_{Tl^+}, \mathbf{p}_{T\tilde{\chi}_b})\} \qquad (10)$$

However, not knowing the form of the splitting (9), the best we can say is that:

$$m_{\tilde{l}}^2 \geq M_{T2}^2 \equiv \min_{\not{p}_1 + \not{p}_2 = \not{p}_T} \left[\max\left\{m_T^2(\mathbf{p}_{Tl^-}, \not{p}_1), m_T^2(\mathbf{p}_{Tl^+}, \not{p}_2)\right\}\right] \qquad (11)$$

Topness details

- Original paper: arXiv:1212.4495

$$t_{\mathrm{mod}} = \ln(\min S), \text{ with } S(\vec{p}_{\mathrm{W}}, p_z, \nu) = \frac{(m_{\mathrm{W}}^2 - (p_\nu + p_\ell)^2)^2}{a_{\mathrm{W}}^4} + \frac{(m_{\mathrm{t}}^2 - (p_{\mathrm{b}} + p_{\mathrm{W}})^2)^2}{a_{\mathrm{t}}^4}. \quad (7)$$

This equation uses the mass constraints for the particles and also the assumption that $\vec{p}_{\mathrm{T}}^{\mathrm{miss}} = \vec{p}_{\mathrm{T,W}} + \vec{p}_{\mathrm{T},\nu}$. The first term constrains the W boson whose lepton decay product is the detected lepton, while the second term constrains the top quark for which the lepton from the W boson decay is lost in the reconstruction. Once again, we consider all possible pairings of b jet candidates with up to three jets with highest CSV discriminator values. The calculation of modified topness uses the resolution parameters $a_{\mathrm{W}} = 5\,\mathrm{GeV}$ and $a_{\mathrm{t}} = 15\,\mathrm{GeV}$, which determine the relative weighting of the mass shell conditions. We select events with $t_{\mathrm{mod}} > 6.4$. The definition of

Contransverse mass details

- Original paper: arXiv:0802.2879
- Cut at contransverse mass = 150 GeV

Consider 'symmetric' events in which identical cascade decay chains of the form

$$\delta \to \alpha v$$

where v_i are the visible products of each decay chain, $\mathbf{p_T}(v_i)$ is the tranverse momentum vector of v_i and

$$E_T(v_i) \equiv \sqrt{p_T^2(v_i) + m^2(v_i)}. \tag{1.2}$$

It can be shown [9] that M_{CT} is in general bounded from above by a quantity dependent upon the masses $m(\delta)$ and $m(\alpha)$. If $m(v_1) = m(v_2) \equiv m(v)$ then the distribution of event M_{CT} values possesses an end-point at:

$$M_{CT}^{\max}[m^2(v)] = \frac{m^2(v)}{m(\delta)} + \frac{m^2(\delta) - m^2(\alpha)}{m(\delta)}. \tag{1.3}$$

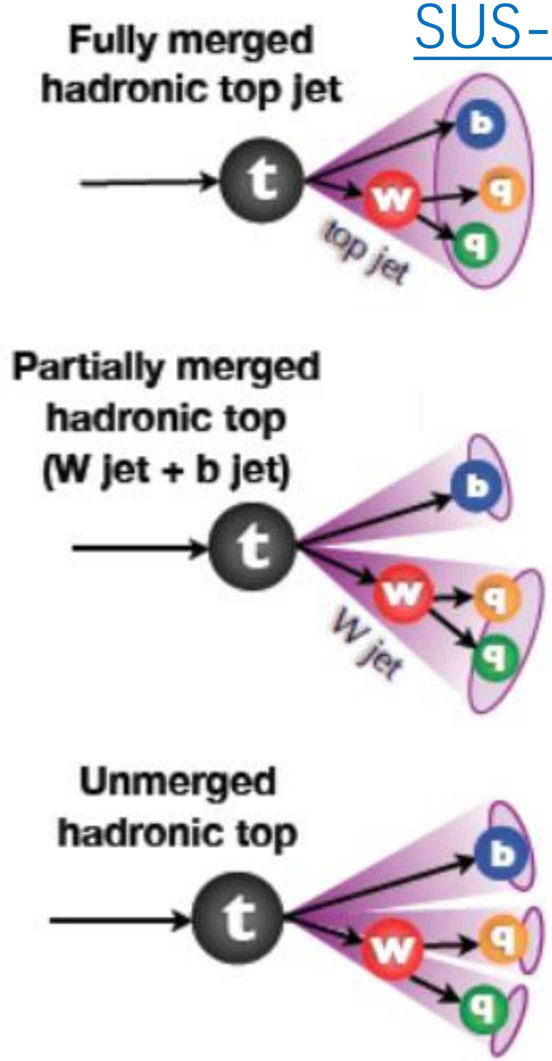
Top tagger - Algorithm

SUS-16-050

- First tag fully merged tops
- Anti-kt jet with radius parameter = 0.8 (AK8)
- Tagged boosted (p_T > 400) top

- Then tag partially merged tops
- Tagged AK8 boosted (p_T > 200) W combined with a nearby AK4 jet
- Cone radius R = 1
- Combined mass consistent with top mass (100-250)
- W mass/combined mass consistent with m_W/m_t (0.85 - 1.25)

- Last tag unmerged (resolved) tops
- Combine three resolved AK4 jets (random forest algorithm)
- Cone radius R = 1.5
- No more than one of the three jets can be b tagged
- Combined mass consistent with top mass (100-250)



Top tagger - Details

1. mass of the trijet system
2. mass of each dijet combination
3. angular separation and momenta of the jets in the trijet rest frame
4. b tagging discriminator value of each jet
5. quark-versus-gluon-jet discriminator value of each jet

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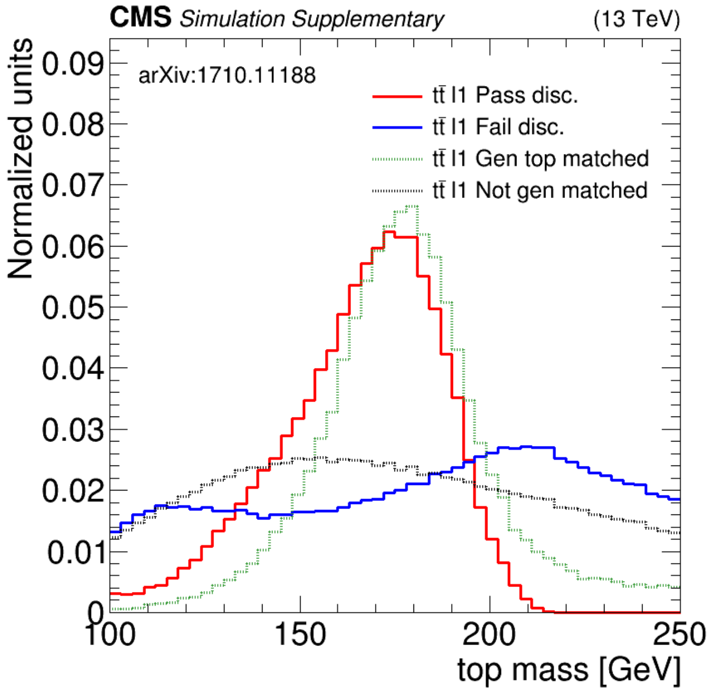
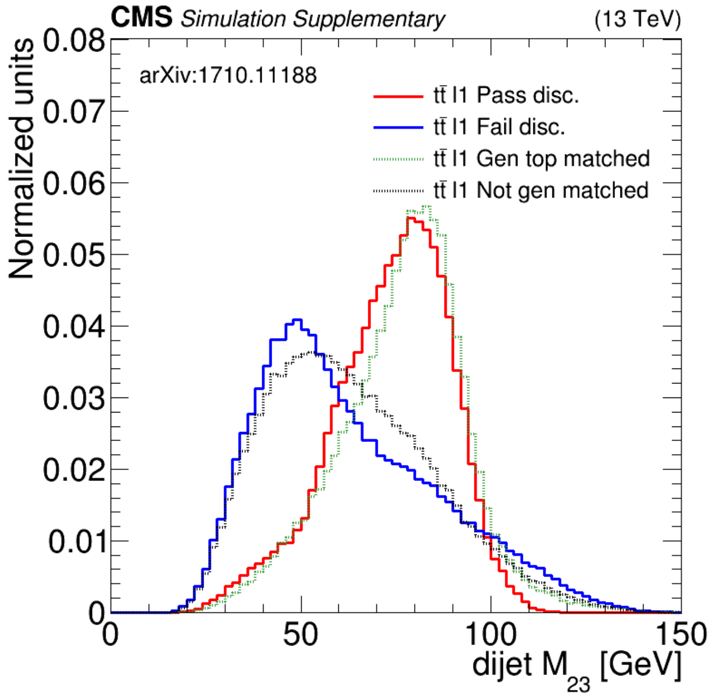
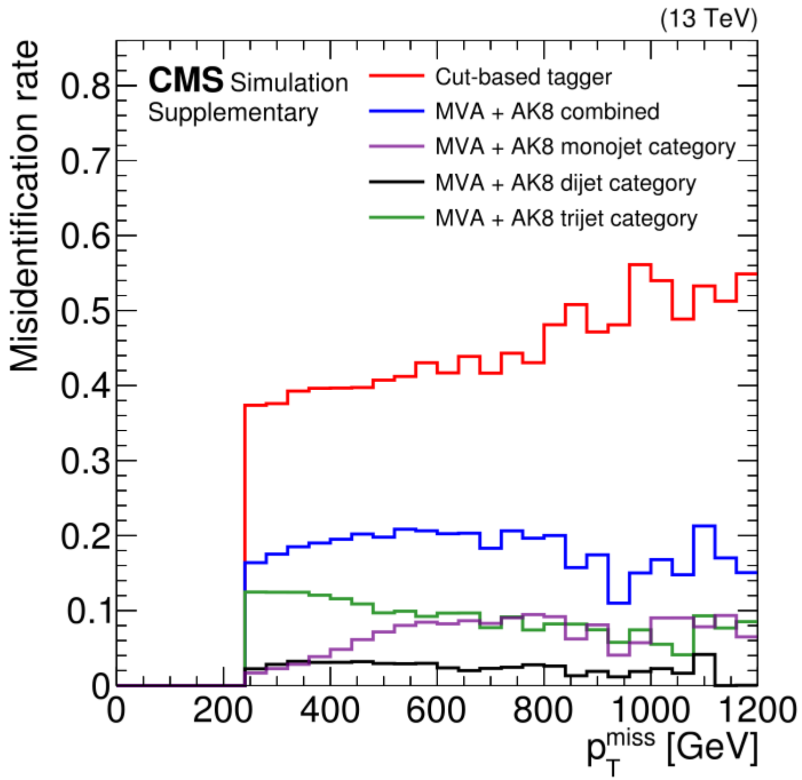
5 input parameters for random forest algorithm







sTop search with 0 lepton

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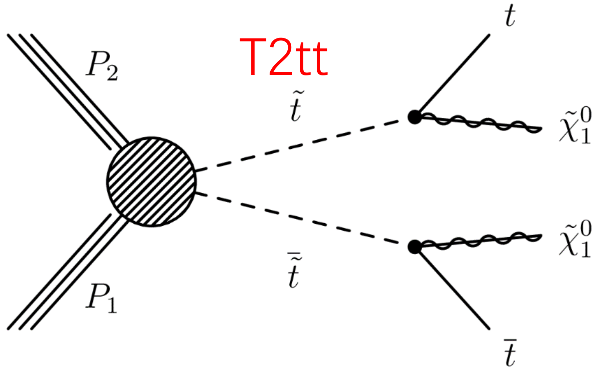

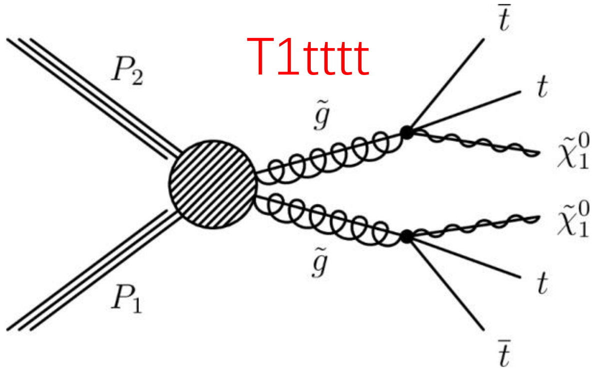

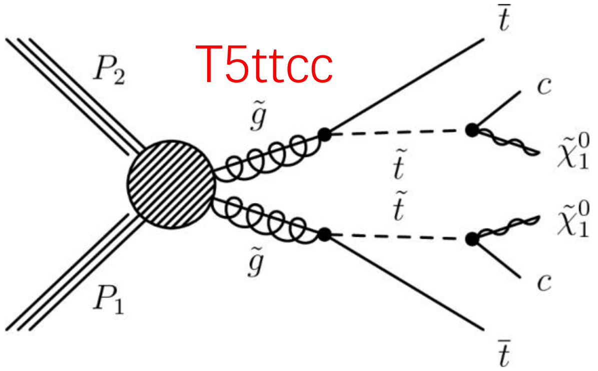

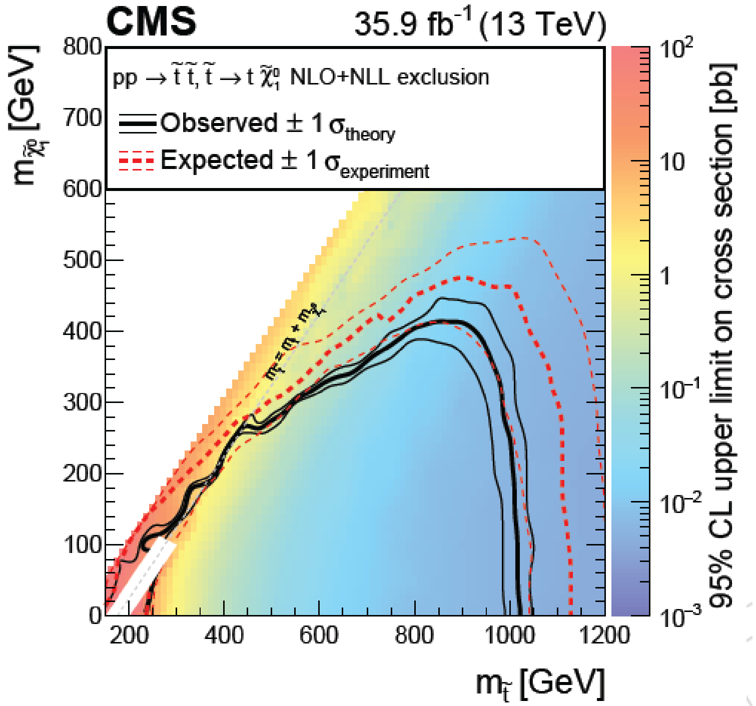

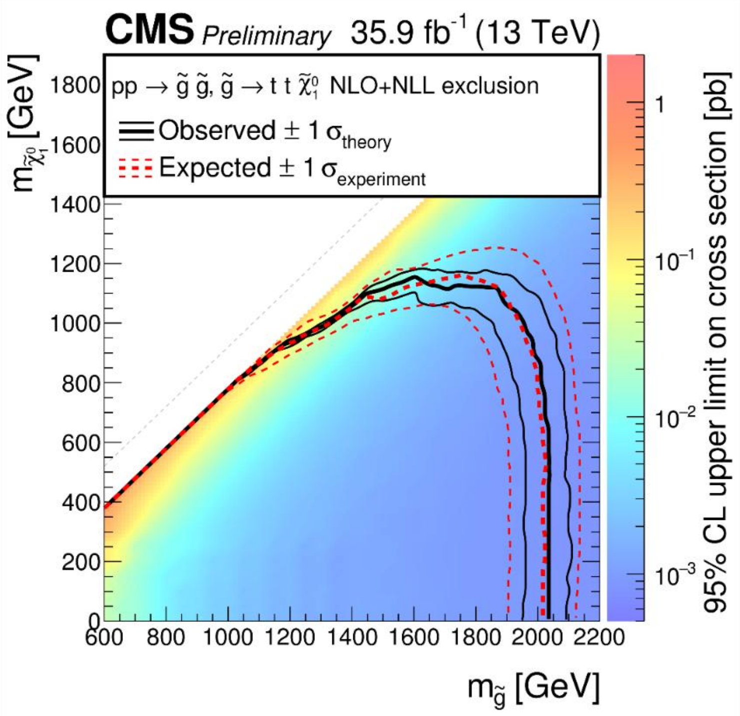

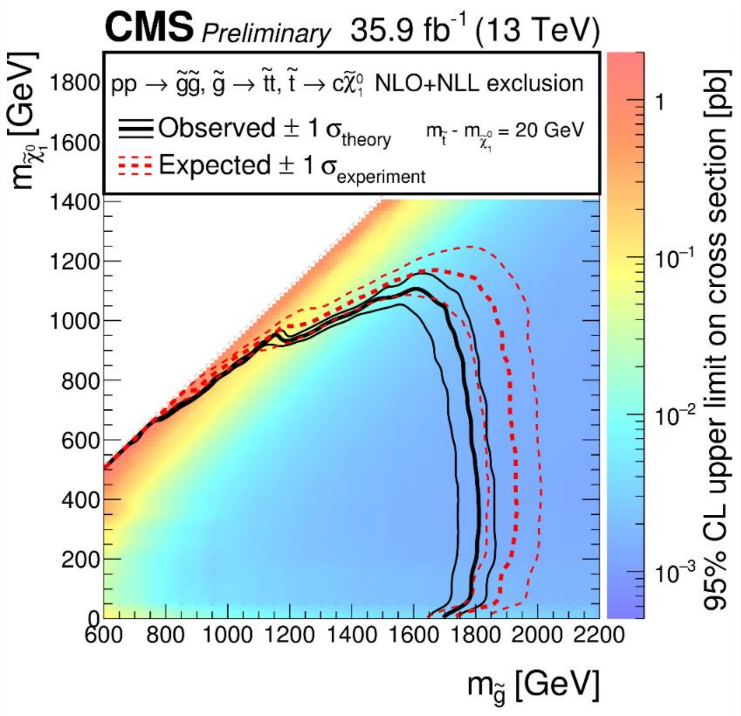

LL systematic uncertainties

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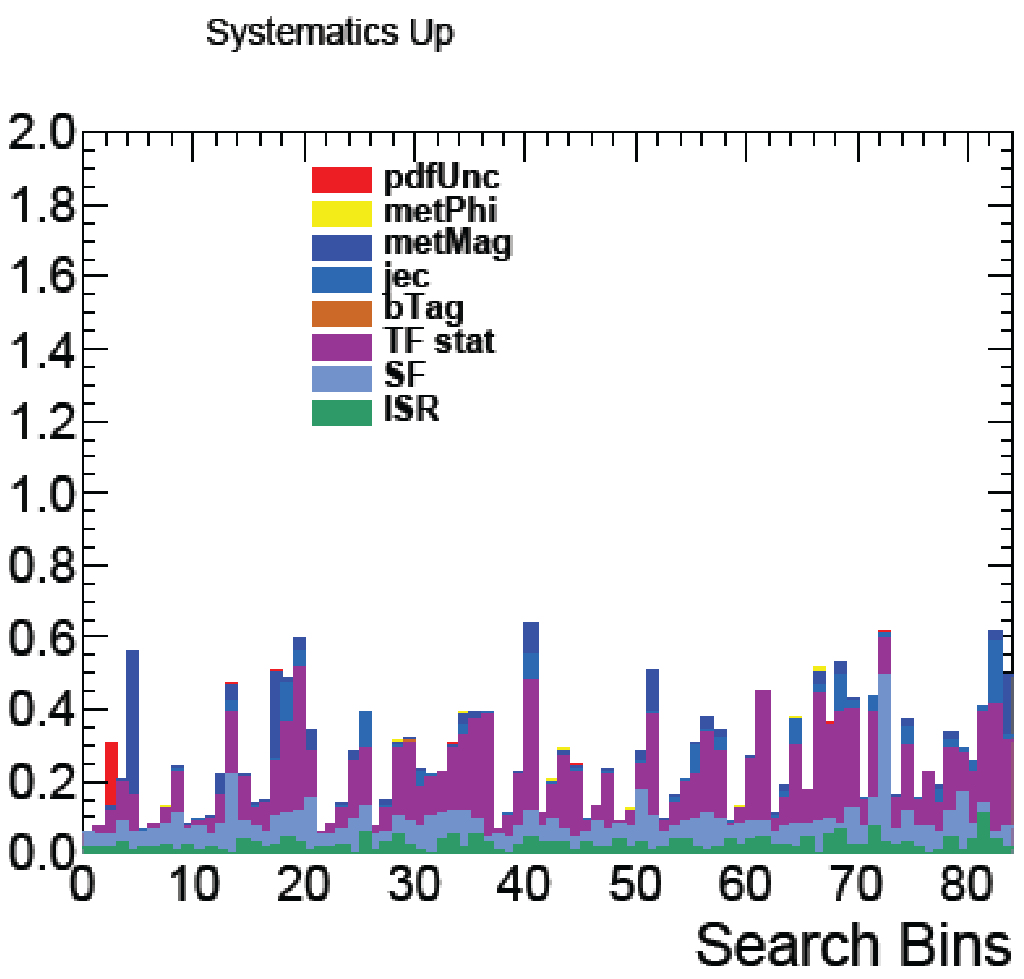

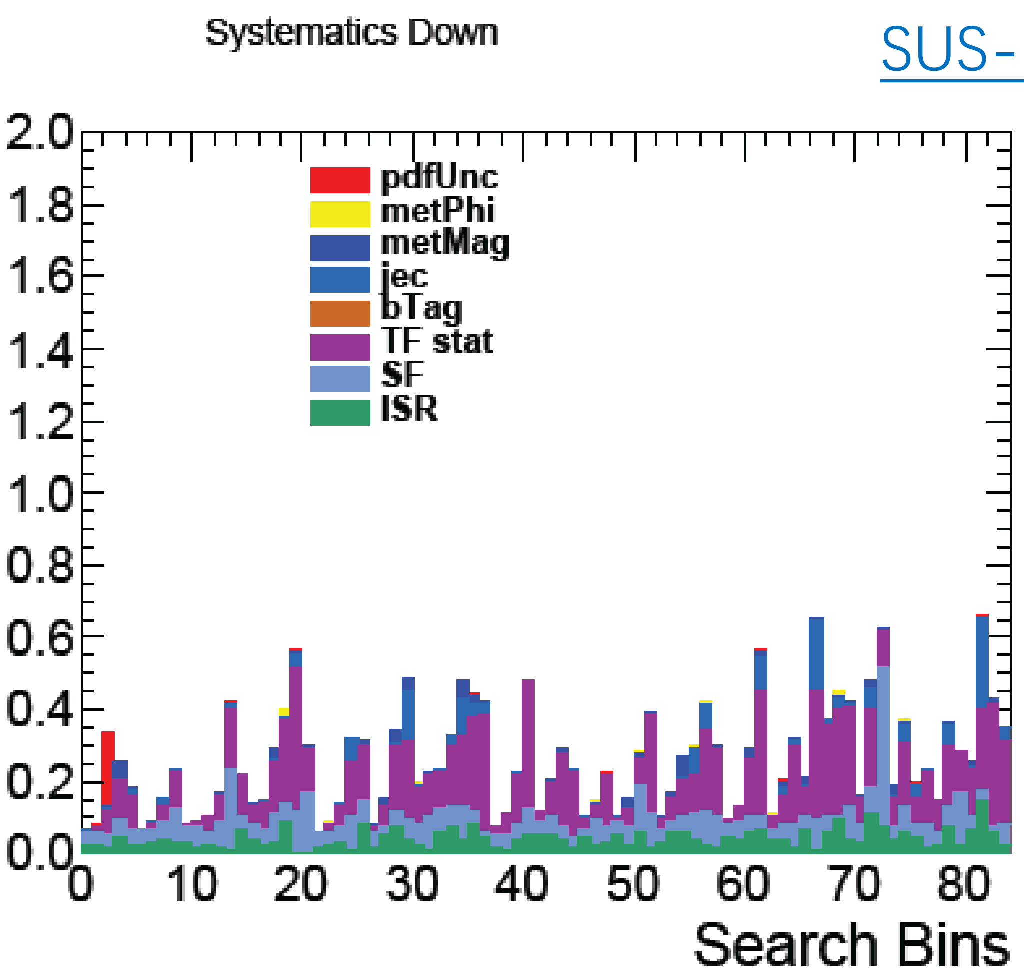

Signal systematic uncertainties

SUS-16-050

Table 35: In T2tt SMS, the signal systematic sources and their typical ranges. The correlation of the uncertainty across signal bins is indicated in the last column.

Source	Typical Values	Correlated?
MC statistics	1-100%	No
Luminosity	2.6%	Yes
Renormalization and factorization scales	0-2.4%	Yes
"ISR" recoil	0-46%	Yes
b-tagging efficiency, heavy flavor	0-17%	Yes
b-tagging efficiency, light flavor	0-17%	Yes
Lepton veto	0-4.7%	Yes
Jet energy scale	0-20%	Yes
MET uncerntainty	0-24%	Yes
Trigger	0-2.6%	Yes
Full/fastsim scale for top reco.	0-19%	Yes
top tagger efficiency data/MC difference	0-14%	Yes

Abstract

Supersymmetric partners of third-generation quarks play a crucial role in models of natural supersymmetry. The talk reports on results of searches for top and bottom squarks, based on pp collisions recorded during LHC Run 2 by the CMS experiment. The searches cover final states with 0, 1, or 2 leptons and are interpreted in simplified models that cover different kinematic domains defined by the mass difference between the squark and the lightest supersymmetric particle.