



HELLENIC REPUBLIC

**National and Kapodistrian
University of Athens**

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Searches for Supersymmetry using the full CMS Run 2 data set

Costas Vellidis

**National and Kapodistrian University of Athens
on behalf of the CMS Collaboration**

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Outline

- Introduction
- Searches with hadronic final states
- Searches using MVA and multi-parton taggers
- Searches with leptonic final states (e, μ)
- Searches with τ leptons
- Search combinations
- Conclusions

Why (still) Supersymmetry?

- Among the most popular extensions of the Standard Model of elementary particles
 - ▶ Postulates a “mirror” of the SM with “super-partners” differing by $\hbar/2$ unit of spin
 - ▶ Same gauge and flavour structure with the SM \Rightarrow same interactions (but 2+3 charged+neutral Higgs bosons)
 - ▶ Broken at some scale \Rightarrow heavy super-partners
 - ▶ Very rich phenomenology, but very large free parameter space \Rightarrow searches test **simplified models**, with all but 1-2 parameters assumed at an inaccessible scale
 - ▶ Can answer fundamental questions left open by the SM (hierarchy, dark matter, force unification)

SM

Quarks	u	c	t	Bosons	
	d	s	b		
Leptons	e	μ	τ		γ
	ν_e	ν_μ	ν_τ		g
					W
			Z		
			H		

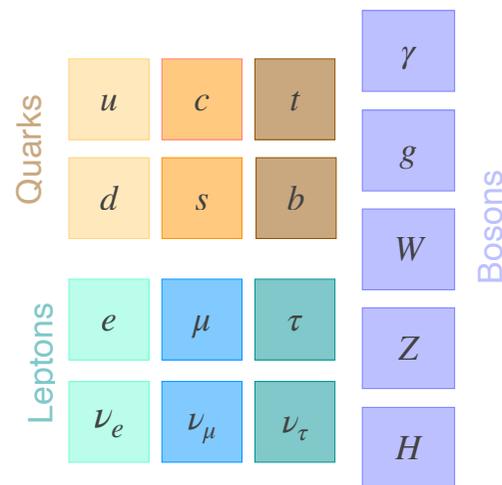
SUSY

Squarks	\tilde{u}	\tilde{c}	\tilde{t}	Guginos	
	\tilde{d}	\tilde{s}	\tilde{b}		
Sleptons	\tilde{e}	$\tilde{\mu}$	$\tilde{\tau}$		$\tilde{\gamma}$
	$\tilde{\nu}_e$	$\tilde{\nu}_\mu$	$\tilde{\nu}_\tau$		\tilde{g}
					\tilde{W}
			\tilde{Z}		
			\tilde{H}		

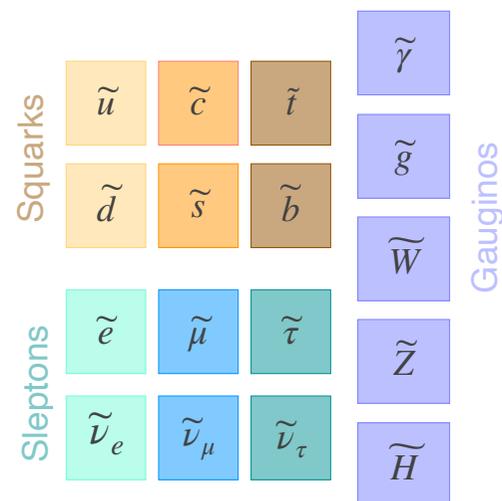
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 - ▶ Can answer fundamental questions left open by the SM (hierarchy, dark matter, force unification)
- Searched at all high-energy colliders for >30 years: LEP, Tevatron, LHC
 - ▶ No signs of it yet, but still far from excluding all scenarios
 - ▶ Parameter space regions difficult to access, extraneous signatures (e.g. long lifetimes) unexplored

SM

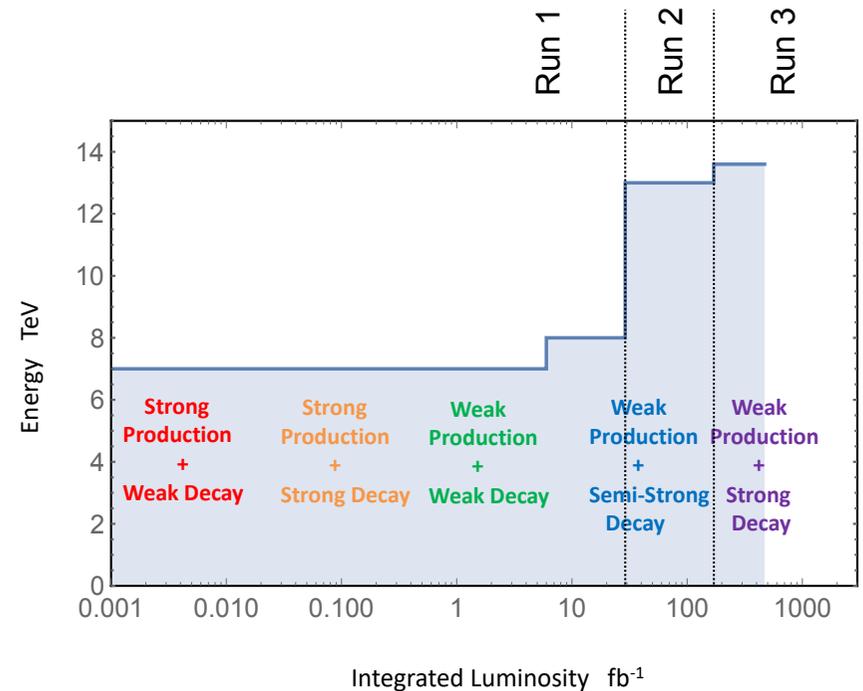
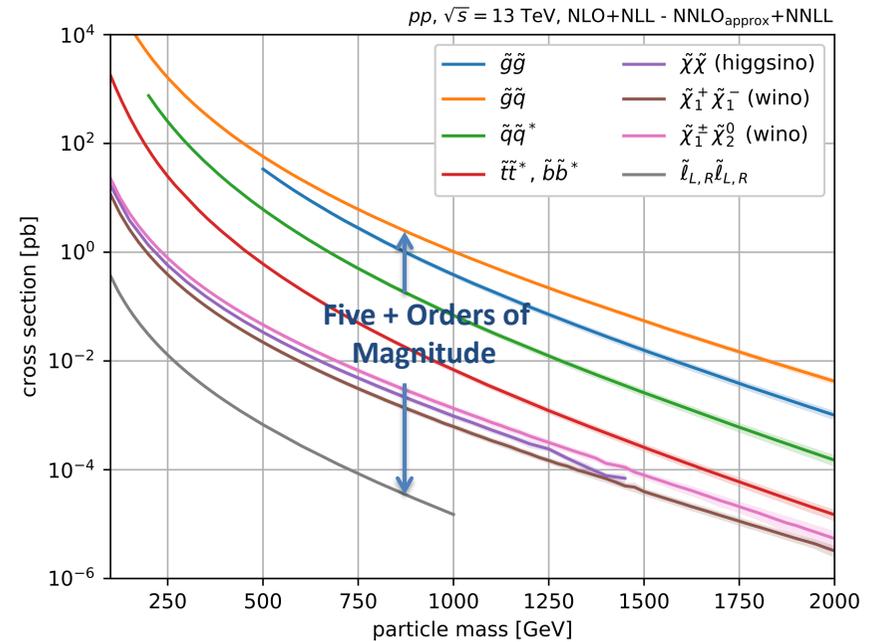


SUSY



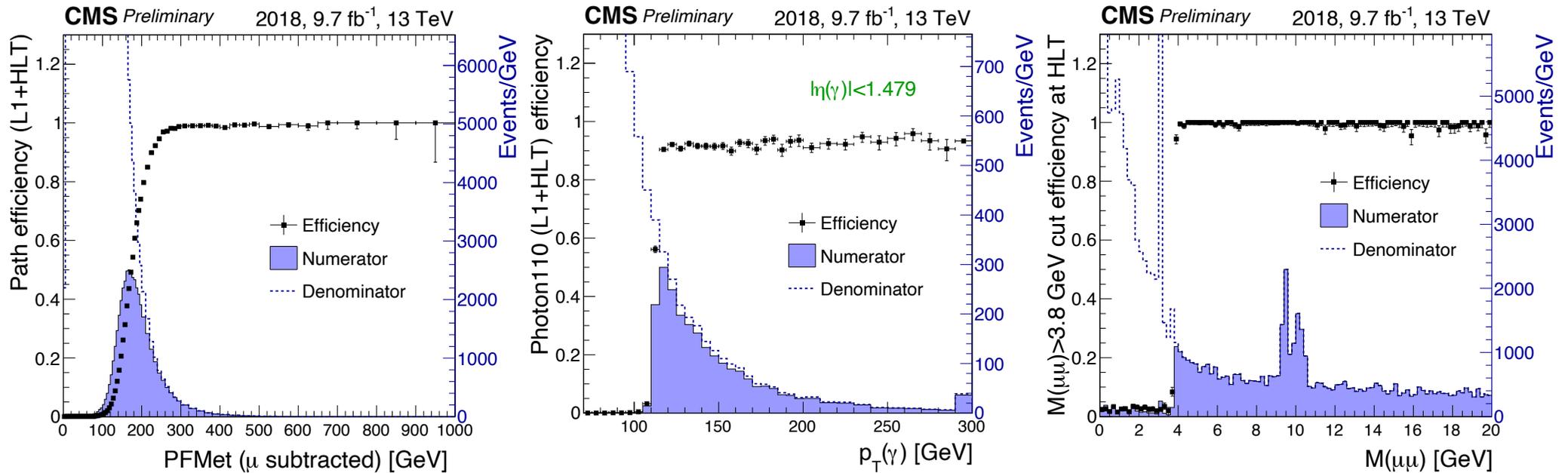
Potential of the LHC Run 2 sample for SUSY searches

- Increasing luminosity:
 - Search for smaller signals
 - Increase signal sensitivity in cases with large backgrounds
- LHC Run 2 dataset, corresponding to $\sim 140 \text{ fb}^{-1}$, is the largest sample ever collected at an energy suitable for searches near the EWK scale
 - Expand the signature space with final states richer and more difficult to access
 - Expand excluded regions of the parameter space of simplified SUSY models



Impact of dedicated triggers

- Use of triggers especially designed for SUSY searches:
 - ▶ Improves data collection efficiency
 - ▶ Enhances data purity
 - ▶ Enables access to difficult phase space regions and difficult topologies



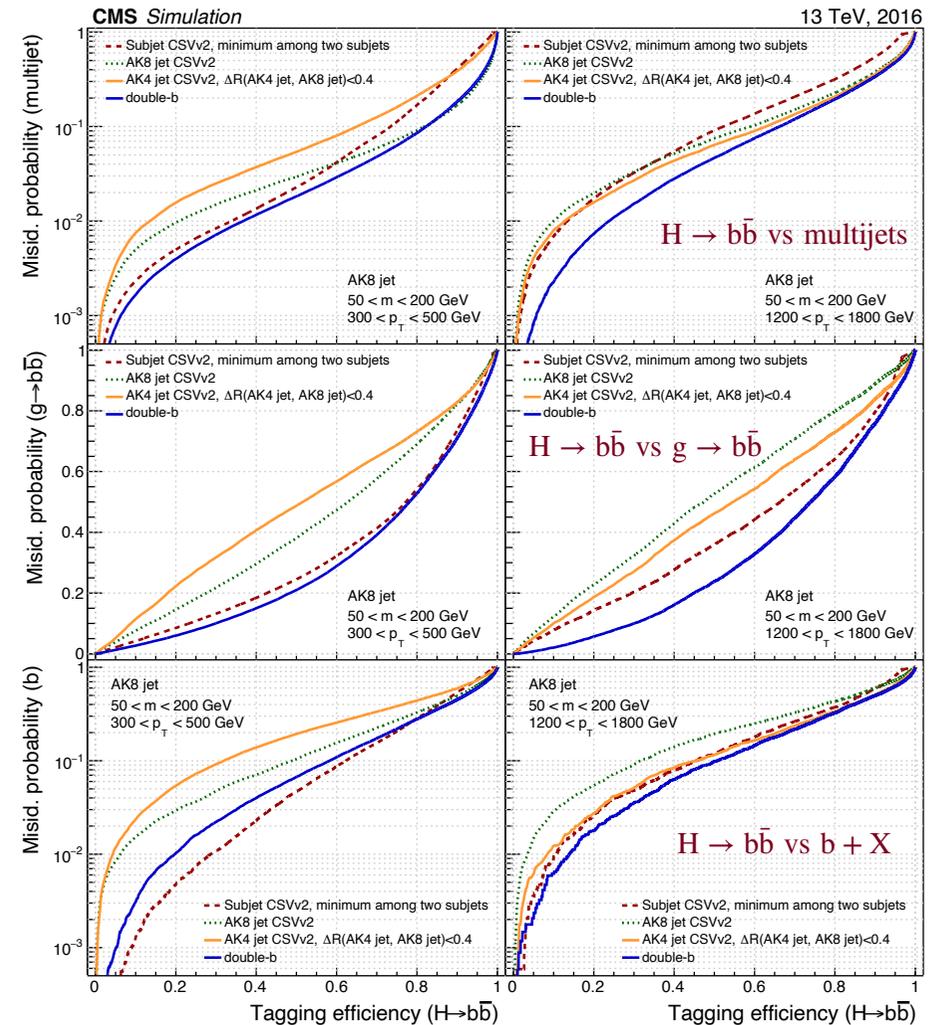
Impact of MVA and heavy-object taggers

- More sophisticated analysis methods complement the increase of the dataset
- MVA/ML in HEP is now quite mature
- Technological advances in MVA make results more reliable and reduce systematics
- Improve signal-background discrimination
 - ▶ **Event classification** using MVA algorithms improves substantially background rejection

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- Technological advances in MVA make results more reliable and reduce systematics
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 - ▶ **Event classification** using MVA algorithms improves substantially background rejection
- Improve **object identification**
 - ▶ Enhance purity of the sample
 - ▶ Great improvements in b/c flavour tagging
 - ▶ MVA techniques for tagging **boosted heavy objects**: heavy bosons, top quarks
 - ▶ Better resolve **complex final states**

BTV-16-002

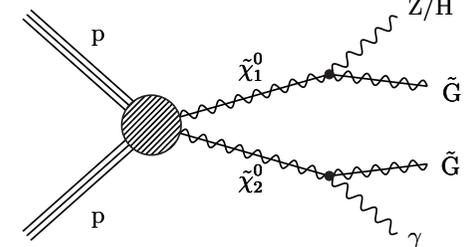
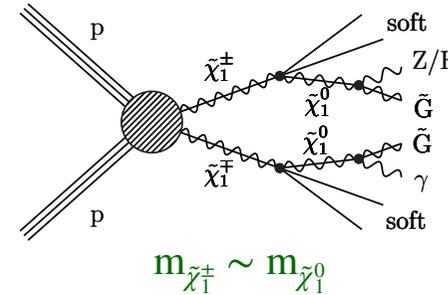
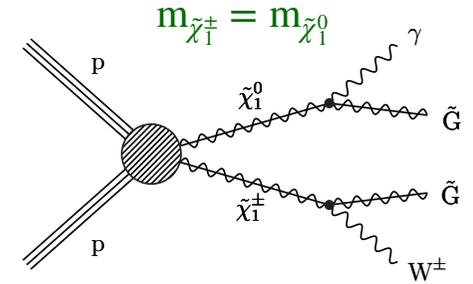
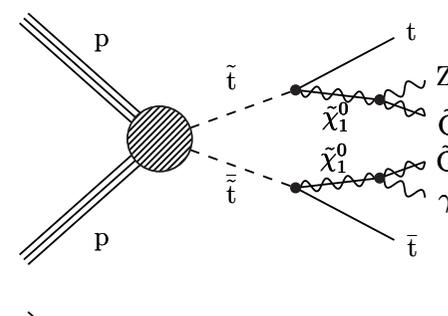
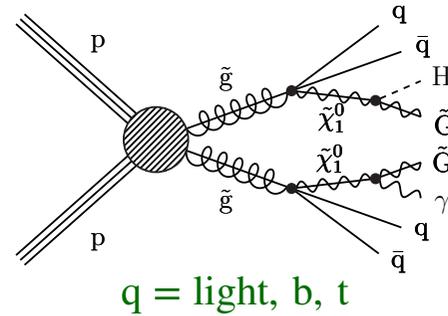


Boosted $H \rightarrow b\bar{b}$ tagger

Jets / b-jets / photons

2023 result

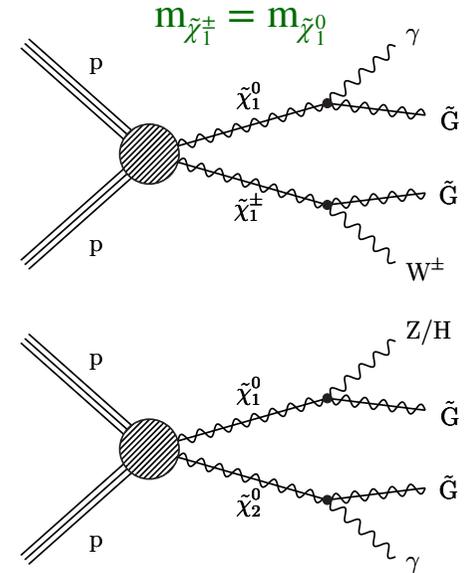
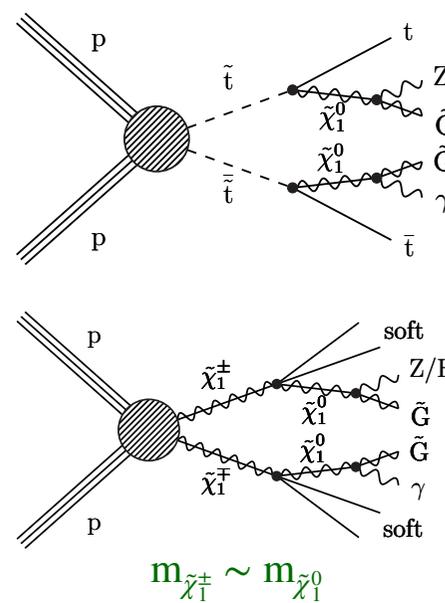
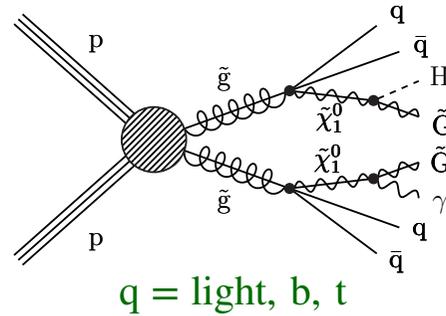
- Search sensitive to GMSB models with \tilde{G} as LSP
- Test wino-like and higgsino-like production
- $m_{\tilde{G}} = 1 \text{ GeV}, m_{\tilde{\chi}_1^0} > 127 \text{ GeV}$



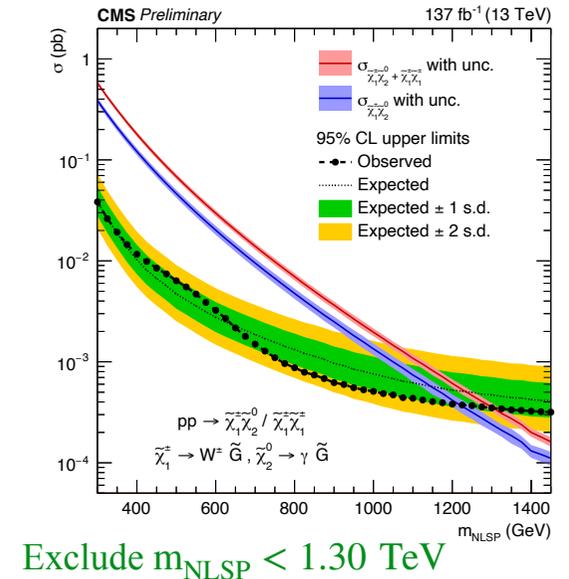
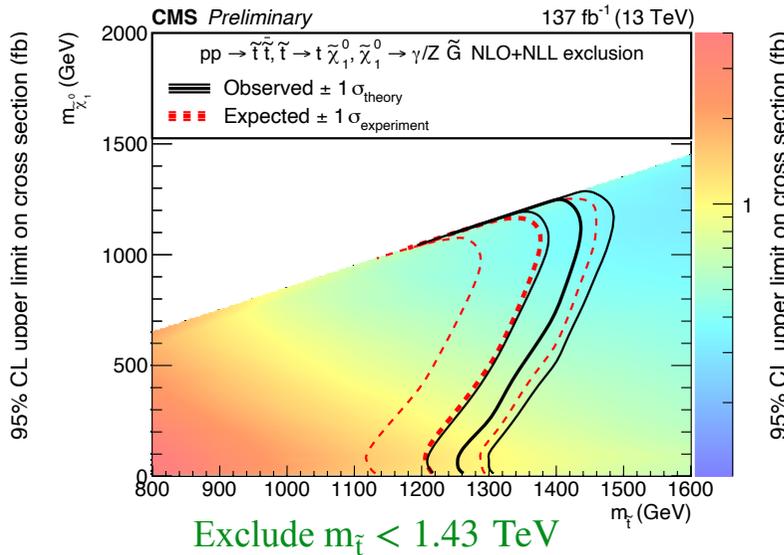
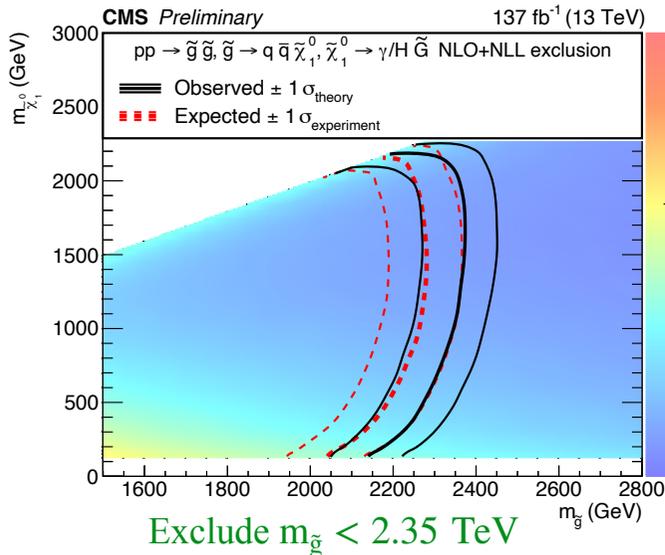
- Require $\geq 1 \gamma + \geq 2 \text{ jets} + \text{MET}$ in the final state
- Identify merged W/Z and merged H using AK8 jets
- Dominant SM backgrounds estimated from data: lost e/μ ($W\gamma/t\bar{t}\gamma + \text{jets}$), misidentified e as γ ($W/t\bar{t} + \text{jets}$), irreducible $Z(\nu\bar{\nu})\gamma + \text{jets}$, and spurious MET ($\gamma + \text{jets}$, multi-jets)

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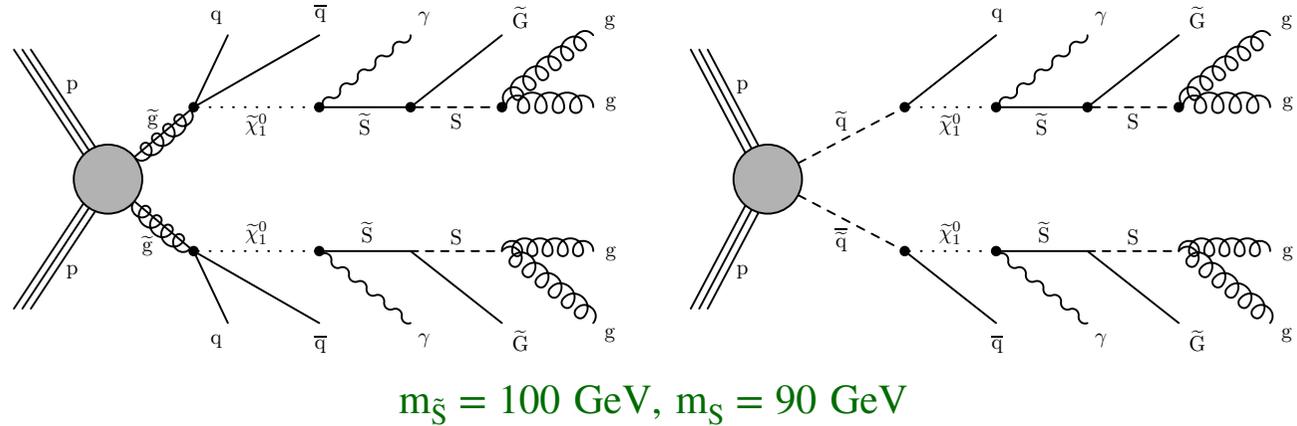


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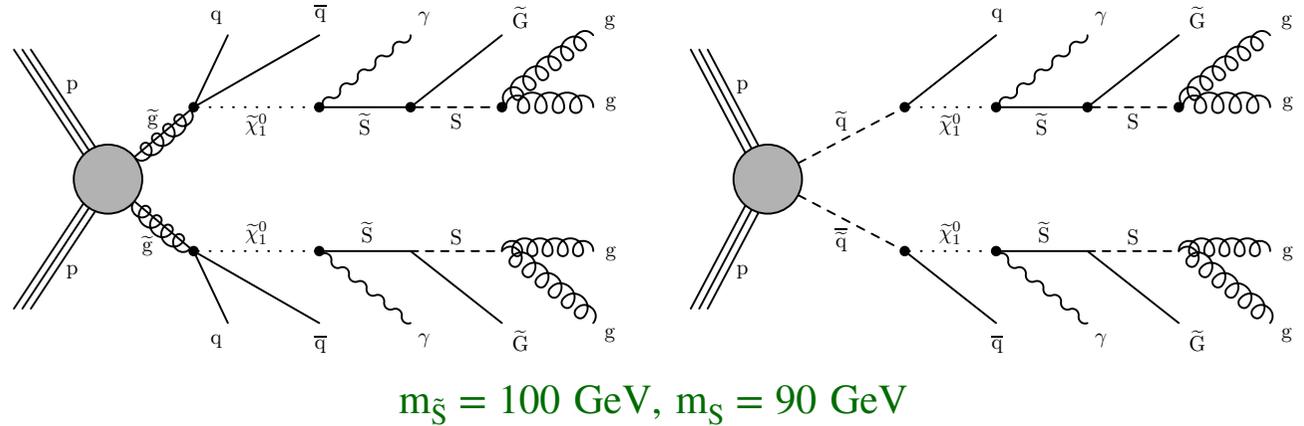
- Search sensitive to minimal extension of MSSM with a scalar singlet S and its super-partner \tilde{S} (singlino)
- GMSB scenario (\tilde{G} as LSP)
- $|m_{\tilde{S}} - m_S|$ small \Rightarrow no MET requirement (“stealth” SUSY)
- Extension of similar Run 1 search



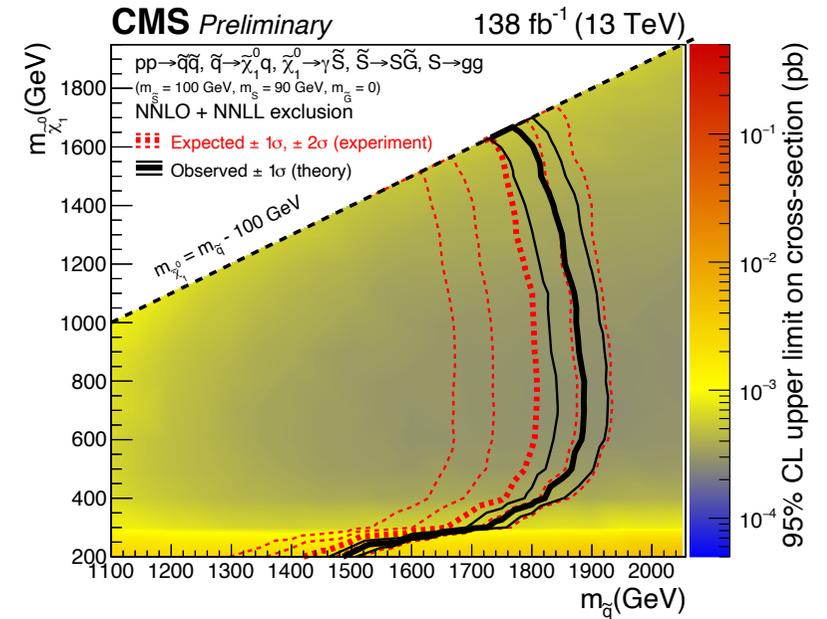
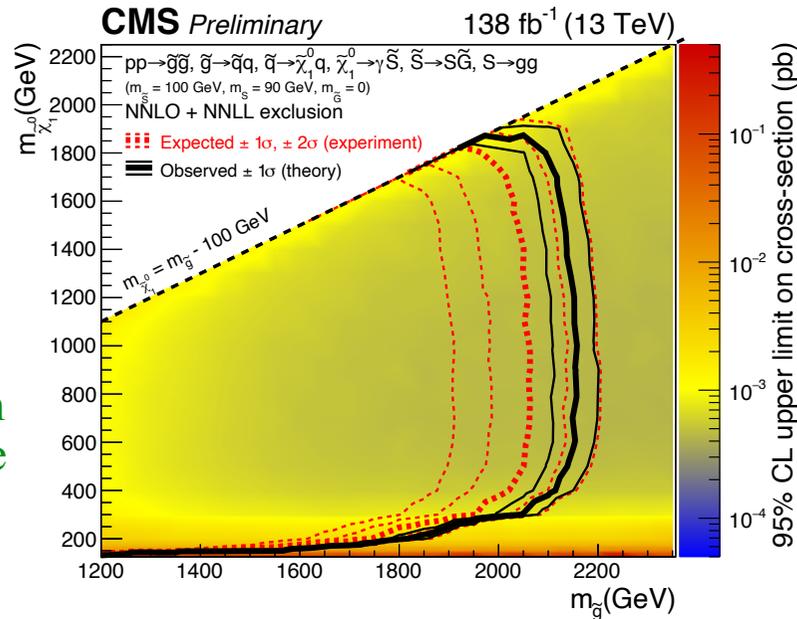
- Require 2 γ , isolated within a cone of $\Delta R=0.3$, and ≥ 4 jets in the final state
- SM backgrounds ($\gamma\gamma + \text{jets}$) estimated from data and then adjusted using simulation

2023 result

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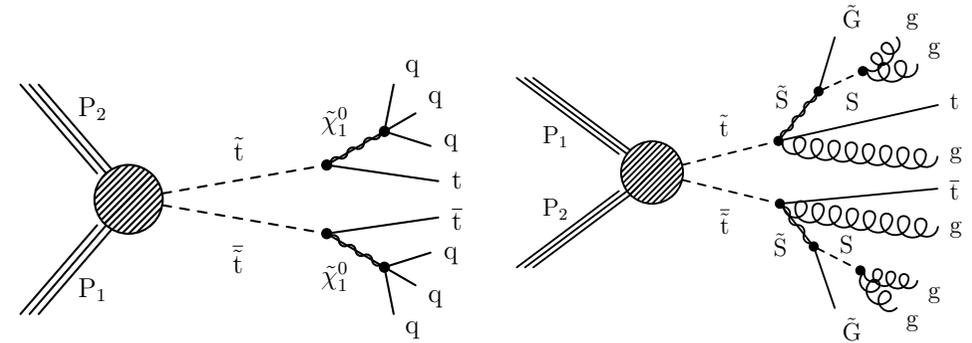
- Exclude $m_{\tilde{g}} (m_{\tilde{q}}) < 2.15 (1.85) \text{ TeV}$
- $\sim 70\%$ improvement in the reach of the exclusion contour in the $(m_{\tilde{q}}, m_{\tilde{\chi}_1^0})$ space



Most stringent limits on these models

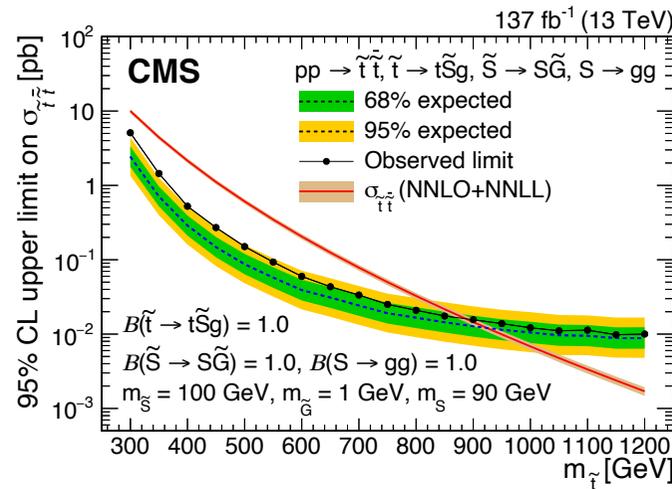
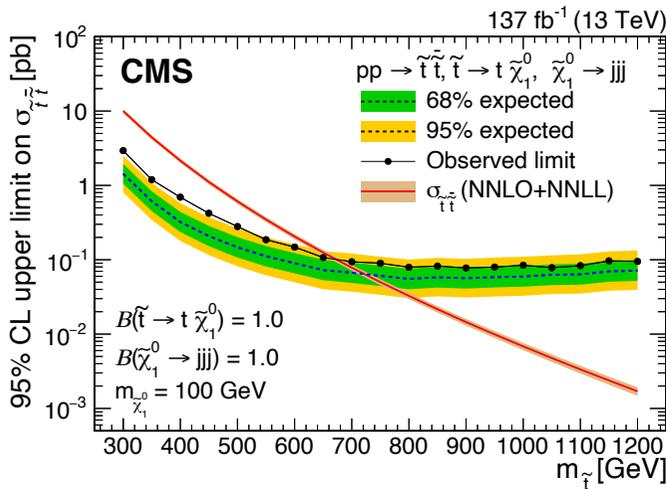
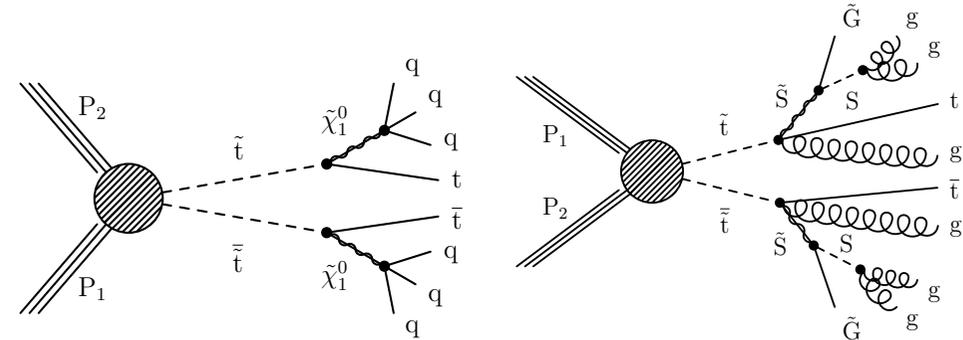
First search of this signal at the LHC

- RPV SUSY with trilinear Yukawa coupling λ''_{ijk} , $i, j, k = 1, 2$
- Stealth SUSY with even R-parity singlet scalar S and its superpartner (singlino \tilde{S}) plus gravitino (\tilde{G}) LSP
- Assuming small $|m_S - m_{\tilde{S}}|$ and $m_{\tilde{G}} \Rightarrow$ no MET requirement
- Requiring $1 e/\mu + \geq 7$ jets with ≥ 1 b-tag in the final state
- Dominant SM backgrounds from $t\bar{t} + X$ events
- Signal-background discrimination using NN



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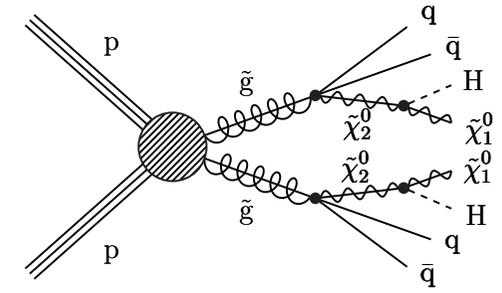
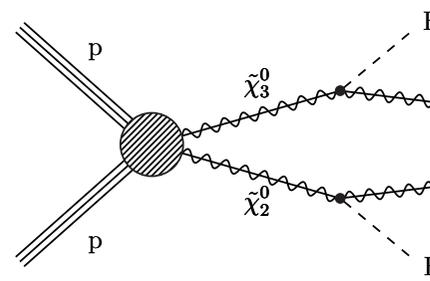
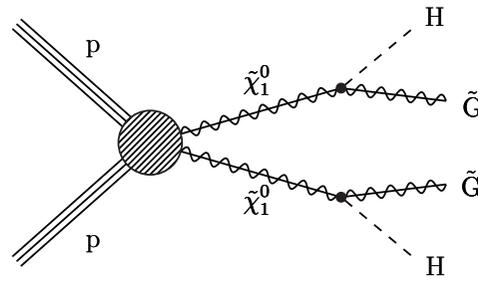
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Exclude $m_{\tilde{t}} < 700$ (900) GeV
in RPV (stealth) SUSY scenario

Higgsino decays to Higgs boson pairs

Higgsino-dominated GMSB with either a neutralino or a goldstino (\tilde{G}) LSP and two $H(b\bar{b})$ in the final state

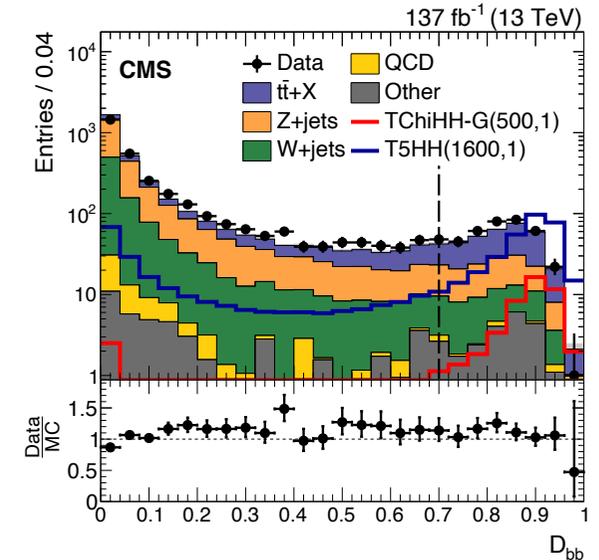


$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_1^\pm / \tilde{\chi}_2^0 \tilde{\chi}_1^\pm / \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 + \text{soft particles} \rightarrow H\tilde{G}H\tilde{G}$

$\tilde{\chi}_2^0 \tilde{\chi}_3^0$ nearly mass-degenerate

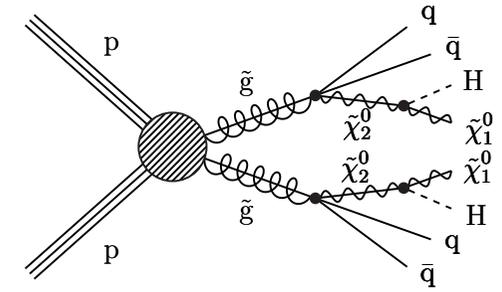
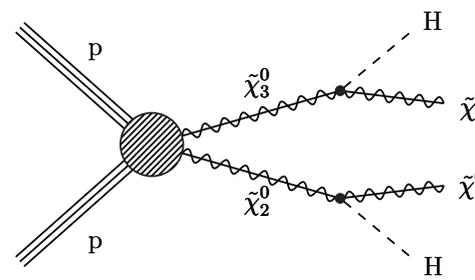
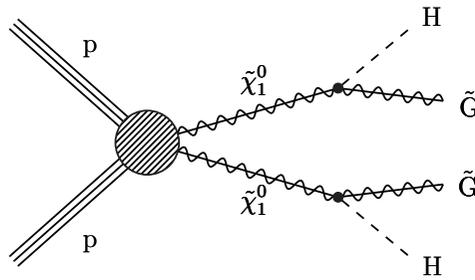
boosted H

- Requiring MET > 150 (300) GeV for resolved (boosted) final states
- Veto events with leptons or isolated tracks
- Identify boosted H bosons with mass-decorrelated bb-tagging (AK8 jets)
- Dominant SM background from lost-lepton $t\bar{t}$ events, estimated from data



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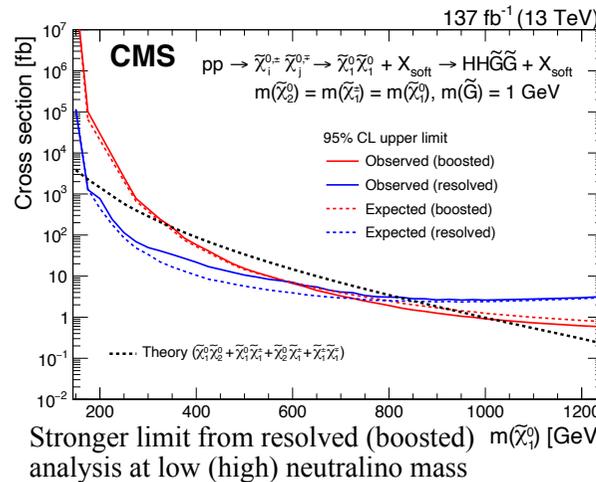
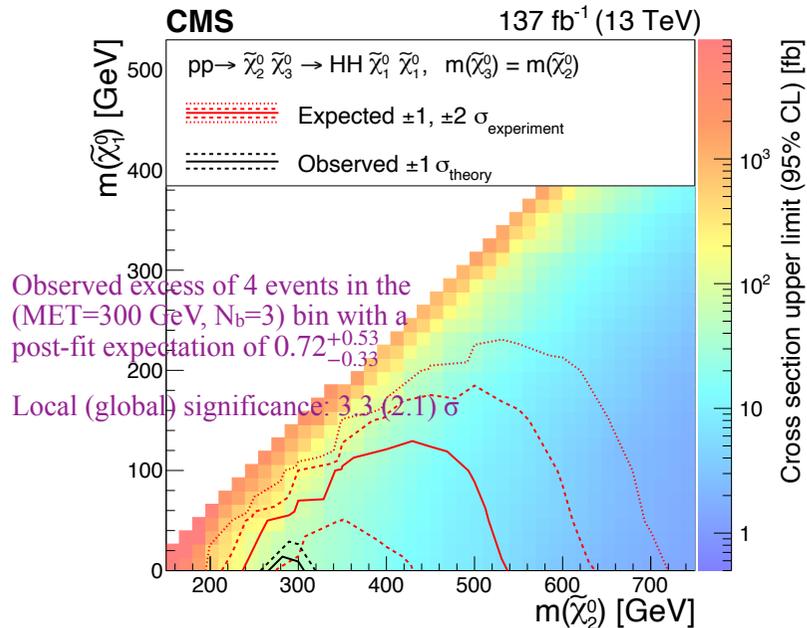
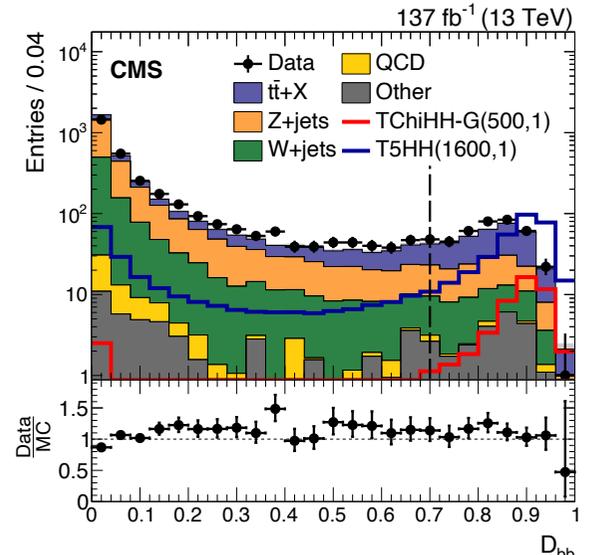


$$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_1^\pm / \tilde{\chi}_2^0 \tilde{\chi}_1^\pm / \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 + \text{soft particles} \rightarrow H\tilde{G}H\tilde{G}$$

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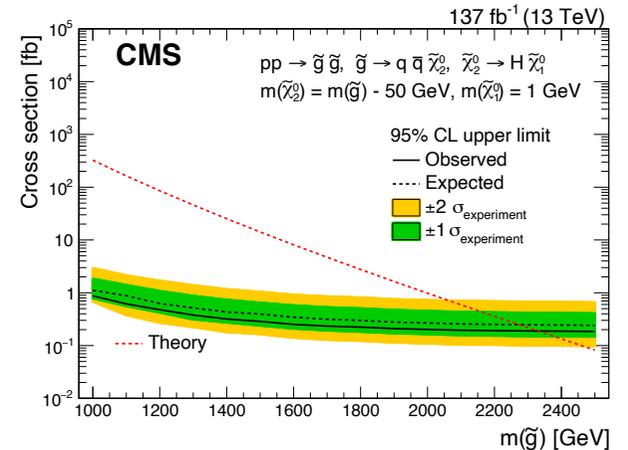
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Stronger limit from resolved (boosted) $m(\tilde{\chi}_1^0)$ analysis at low (high) neutralino mass

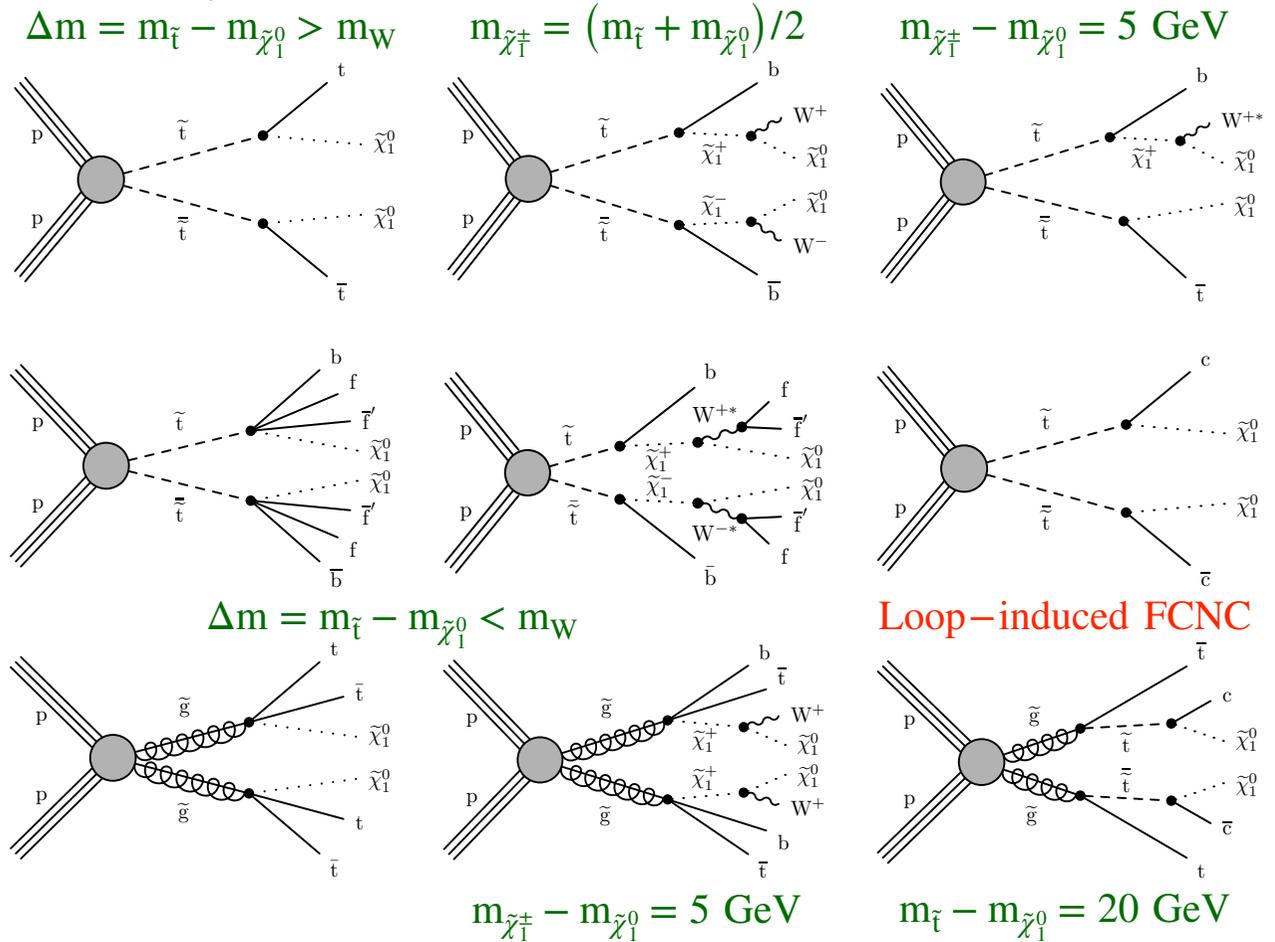
Exclude $m_{\tilde{\chi}_1^0} < 1$ TeV (goldstino LSP), $m_{\tilde{g}} < 2.3$ TeV (neutralino LSP)



Multi-parton taggers — MVA

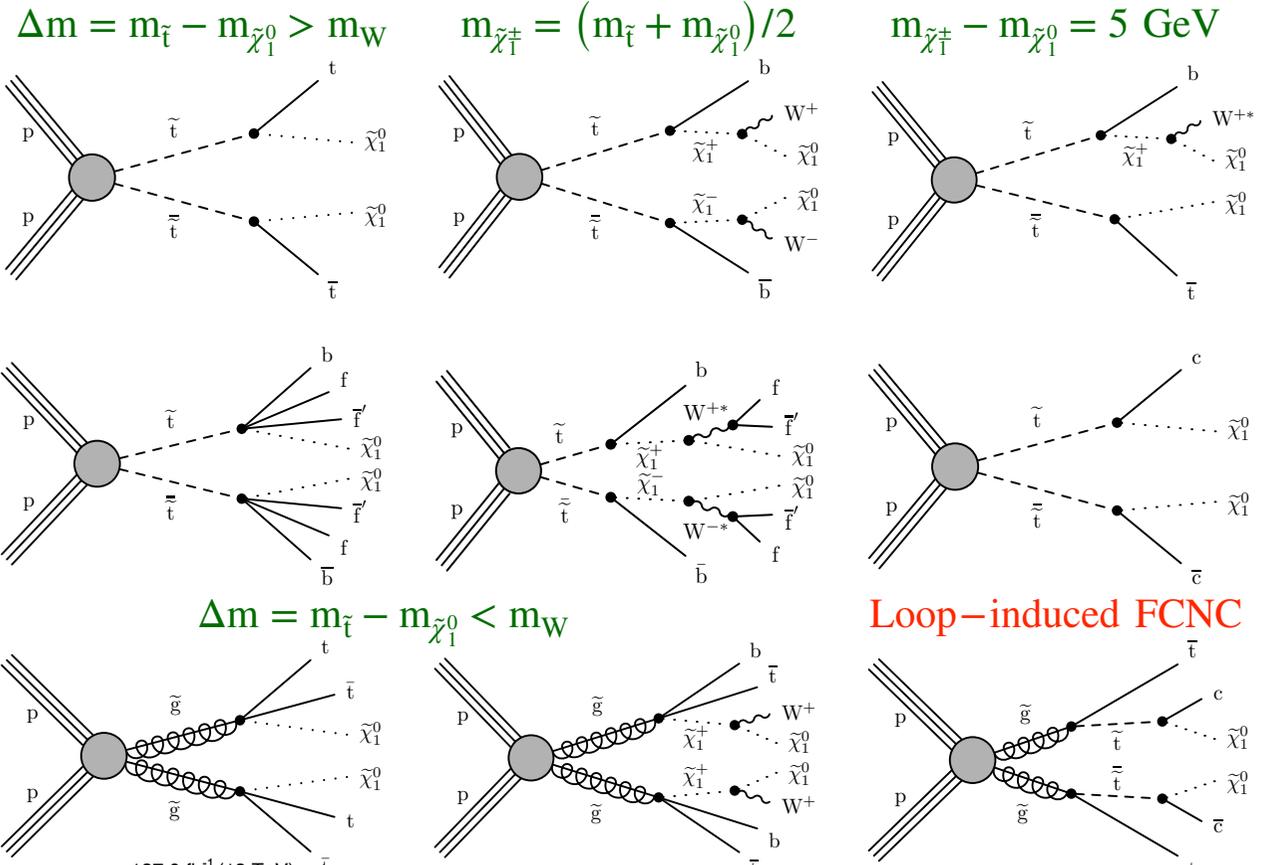
- Test both compressed ($\Delta m < m_W$) and uncompressed ($\Delta m > m_W$) mass spectra
- Merged t/W reconstruction using the DeepAK8 multi-classifier
- Resolved t/W reconstruction using the DeepResolved algorithm

Dominant SM backgrounds: $Z(\nu\bar{\nu}) + \text{jets}$ (lost-lepton $t\bar{t} \rightarrow \ell + \text{jets}$) in compressed (uncompressed) scenario and QCD multi-jets for both scenarios, estimated from MC and data



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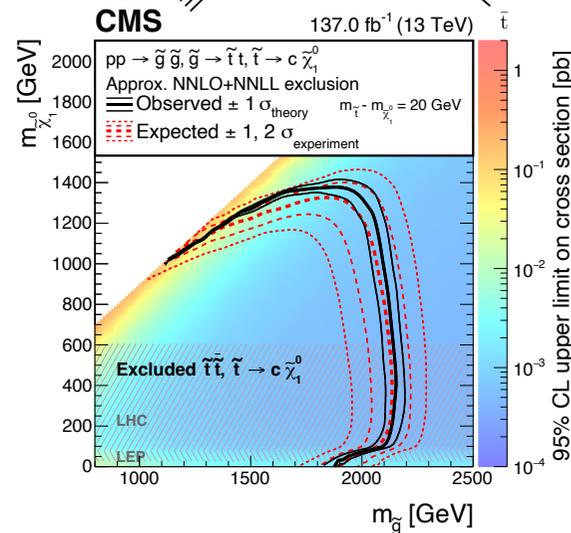
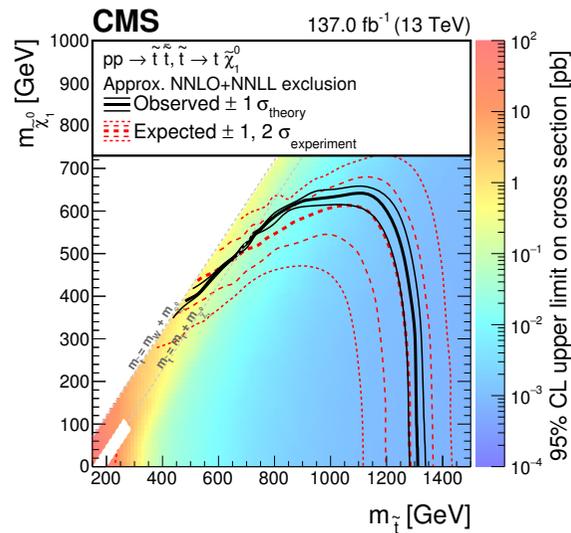


$\Delta m = m_{\tilde{t}} - m_{\tilde{\chi}_1^0} < m_W$

Loop-induced FCNC

$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 5 \text{ GeV}$

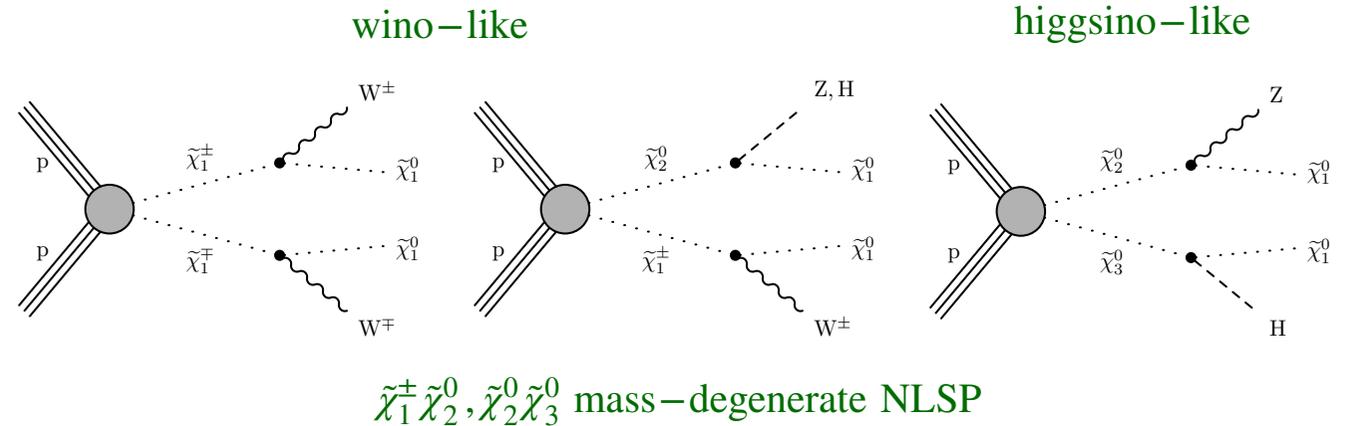
$m_{\tilde{t}} - m_{\tilde{\chi}_1^0} = 20 \text{ GeV}$



Exclude up to $m_{\tilde{t}} = 1310 \text{ GeV}$,
 $m_{\tilde{g}} = 2260 \text{ GeV}$, and up to $m_{\tilde{\chi}_1^0} = 1400 \text{ GeV}$
 in the gluino production model, pushing previous limits higher by 100-300 GeV

Employ DNN to tag W/Z/H/t/other and subcategorize decays by flavour

- Z/H \rightarrow $b\bar{b}$ bb-tagger + DNN for boosted AK8 jets
- $V \rightarrow q\bar{q}^{(\prime)}$ V-tagger + adversarial DNN for V=W/Z vs. QCD jet discrimination with de-correlated m_j and DNN score
- Search optimized in b-veto (VV) and b-tag (VH) search regions (SR)

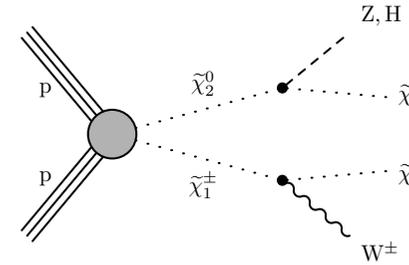
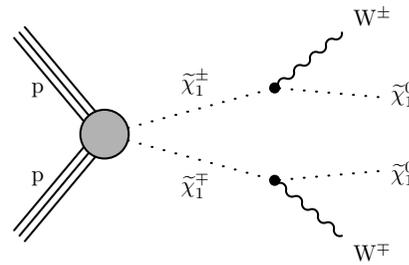


Dominant SM backgrounds: $W(\ell\nu)/Z(\nu\bar{\nu}) +$ jets (b-veto SR) and $t\bar{t}$ (b-tag SR), estimated by combined simulation and data-driven methods

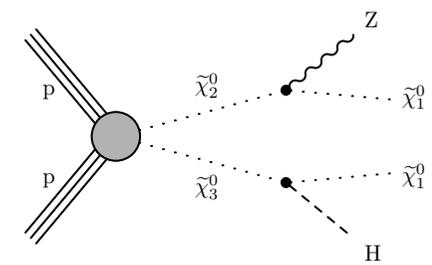
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wino-like

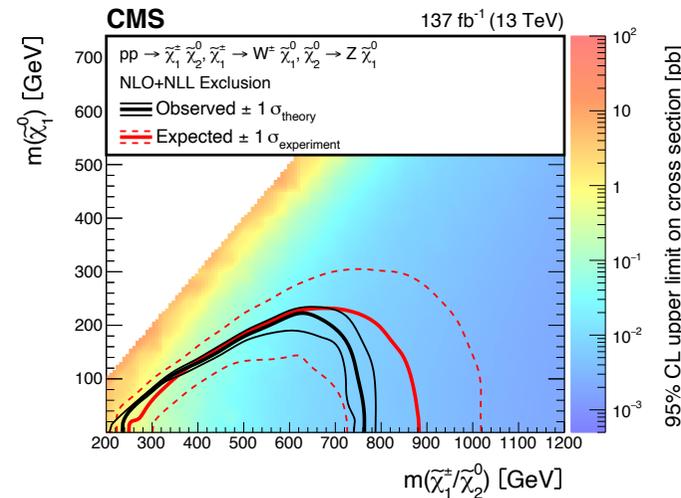
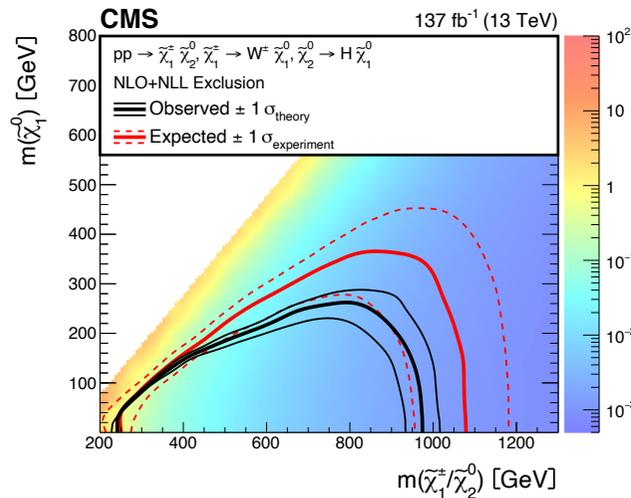


higgsino-like



$\tilde{\chi}_1^\pm \tilde{\chi}_2^0, \tilde{\chi}_2^0 \tilde{\chi}_3^0$ mass-degenerate NLSP

Dominant SM backgrounds: W($\ell\nu$)/Z($\nu\bar{\nu}$) + jets (b-veto SR) and $t\bar{t}$ (b-tag SR), estimated by combined simulation and data-driven methods

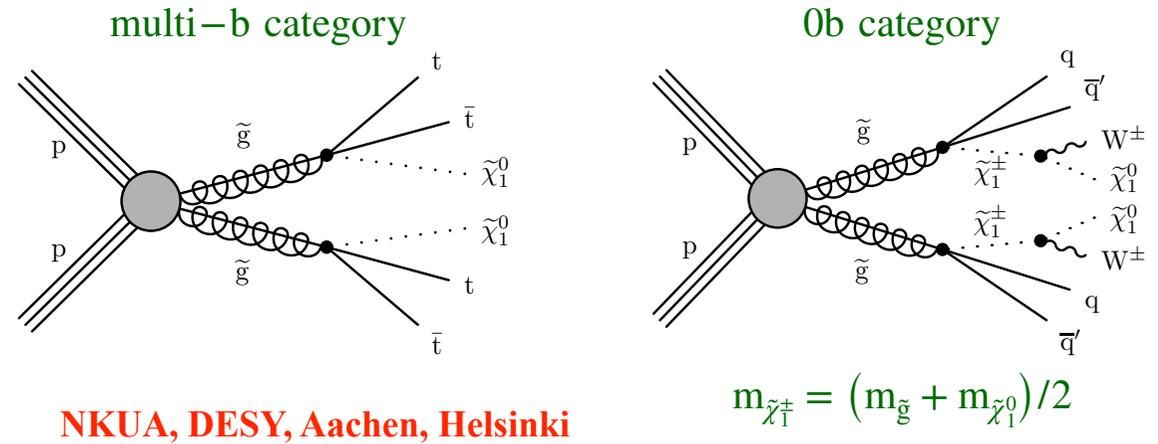


For low-mass LSP, exclude $m_{NLSP} < 670 / 760 / 970$ GeV in WW / WZ / WH final states

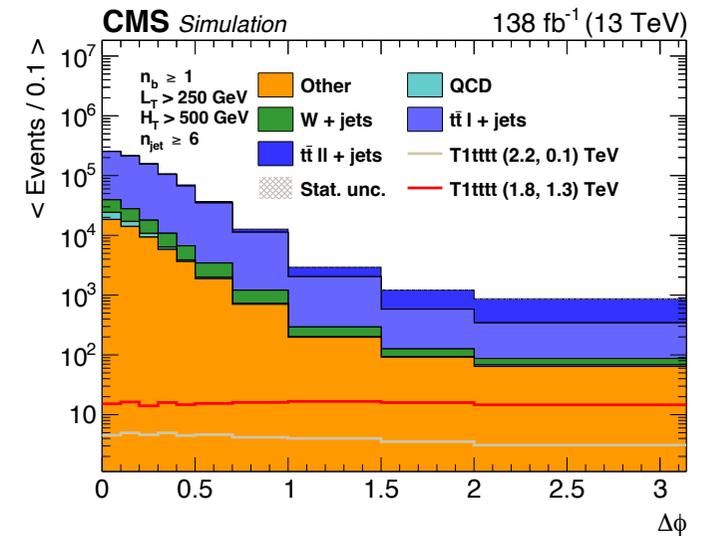
Gluginos in lepton+jets final states using heavy-object tagging

SUS-21-007

- Search for 4 top quarks + MET or 4 light quarks + 2 W bosons + MET final states, where one W from a top quark or from a chargino decay to an $e/\mu + \nu$
- Exploit sensitive variable $\Delta\phi(\ell, W(\ell, \nu))$, where W is reconstructed from the lepton and MET
- Explore uncompressed ($m_{\tilde{\chi}_1^0} \ll m_{\tilde{g}}$) and compressed mass spectra looking for resolved ($p_T < 400 / 200$ GeV) or boosted ($p_T > 400 / 200$ GeV) top quarks / W bosons using the DeepAK8 tagger



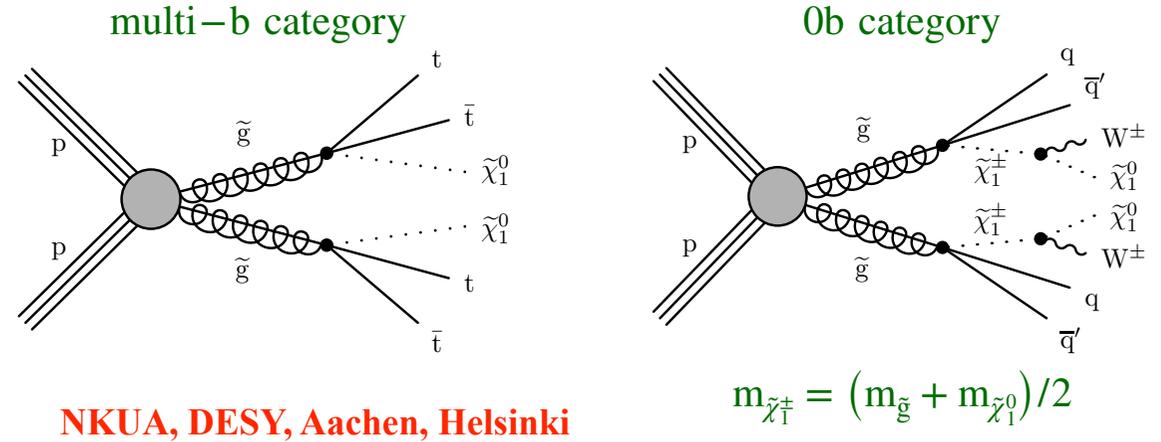
Dominant SM backgrounds: $t\bar{t}$, W + jets, and QCD multi-jets, estimated by combined simulation and data-driven methods



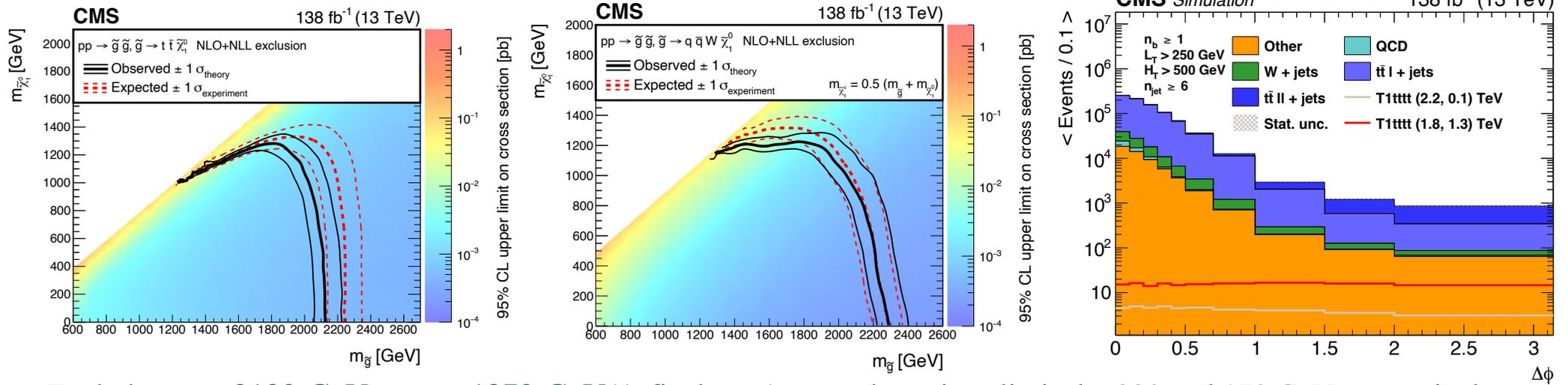
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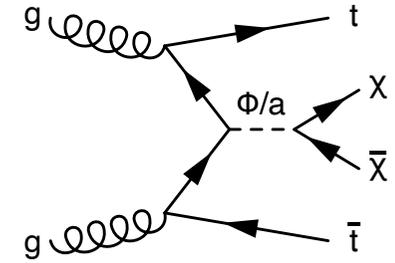
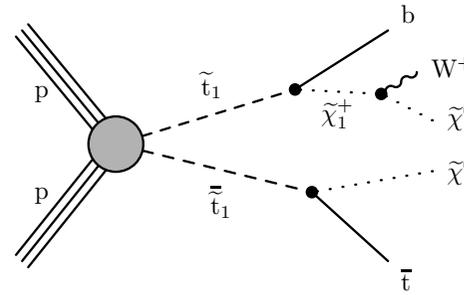
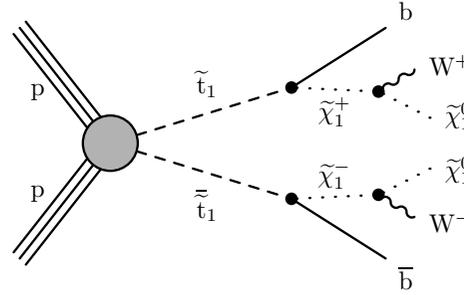
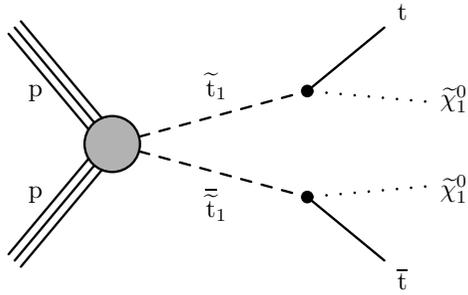


Dominant SM backgrounds: $t\bar{t}$, W + jets, and QCD multi-jets, estimated by combined simulation and data-driven methods



- Exclude $m_{\tilde{g}} < 2130$ GeV, $m_{\tilde{\chi}_1^0} < 1270$ GeV (4t final state), extend previous limits by 320 and 170 GeV, respectively
- Exclude $m_{\tilde{g}} < 2280$ GeV, $m_{\tilde{\chi}_1^0} < 1220$ GeV (4q final state), extend previous limits by 380 and 270 GeV, respectively

Top squarks “in the corridor”

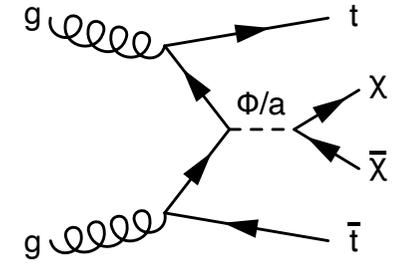
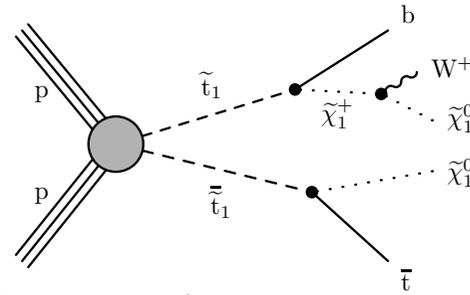
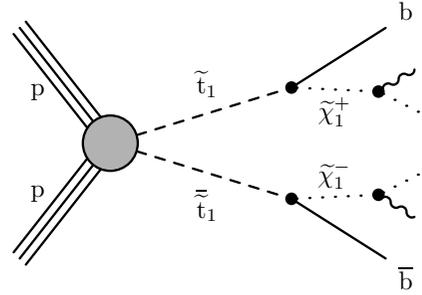
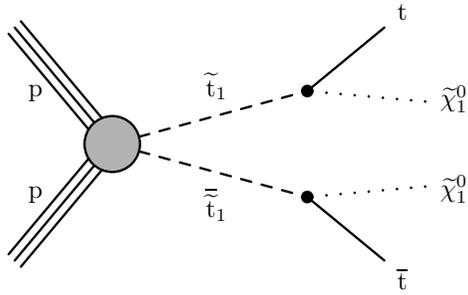


- Combination of previous searches in final states with 0, 1, 2 leptons + new search in the “corridor”* ($m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \sim m_t$), with opposite-sign dilepton final states, kinematically very similar to SM $t\bar{t}$ events
- Employ a DNN to discriminate signal in the corridor from SM $t\bar{t}$ events
- Explore alternative model $gg \rightarrow t\bar{t}\chi\bar{\chi}$ with a DM spinor χ of mass $m_\chi = 1$ GeV and a (pseudo) scalar mediator a (φ) with couplings $g_{SM} = g_{DM} = 1$ to both visible (t) and dark (χ) sectors

Dominant SM background from $t\bar{t}$ events, estimated by the DNN

* Defined with boundaries $\Delta m_{\text{Corr}} = \left| \Delta m(\tilde{t}_1, \tilde{\chi}_1^0) - m_t \right| < 30$ GeV and $m_{\tilde{\chi}_1^0} < 275$ GeV, assuming $m_t = 175$ GeV

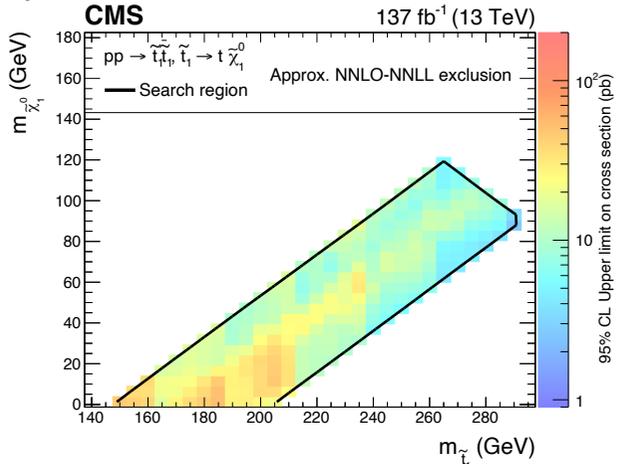
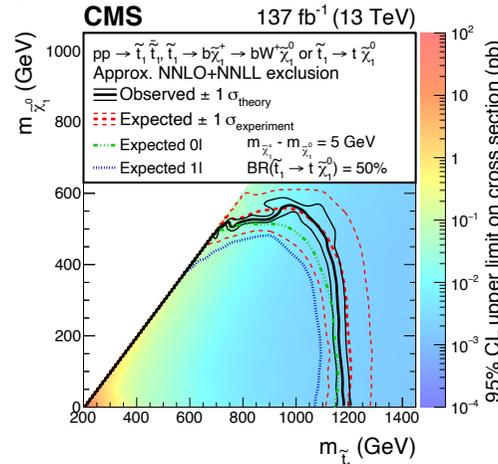
Top squarks “in the corridor”



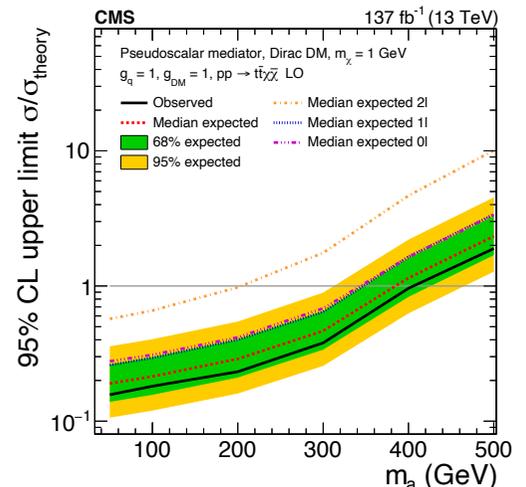
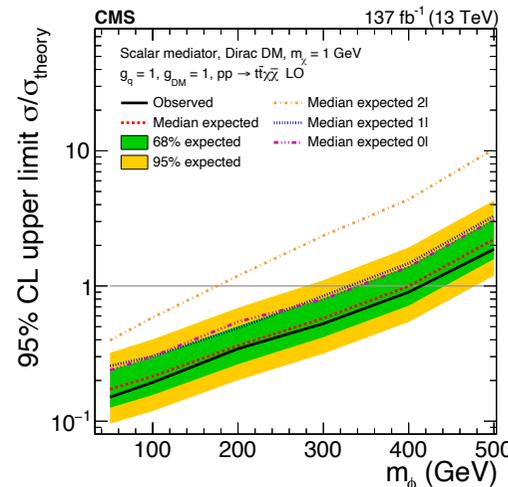
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Exclude $m_{\tilde{t}_1} < 1325$ GeV ($m_{\tilde{\chi}_1^0} = 0$), $m_{\tilde{\chi}_1^0} < 700$ GeV ($m_{\tilde{t}_1} = 1150$ GeV) (combined search)
 Exclude $145 < m_{\tilde{t}_1} < 295$ GeV, $0 < m_{\tilde{\chi}_1^0} < 100$ GeV in corridor, **first time with CMS data**



Exclude DM model for mediator masses up to 420 GeV

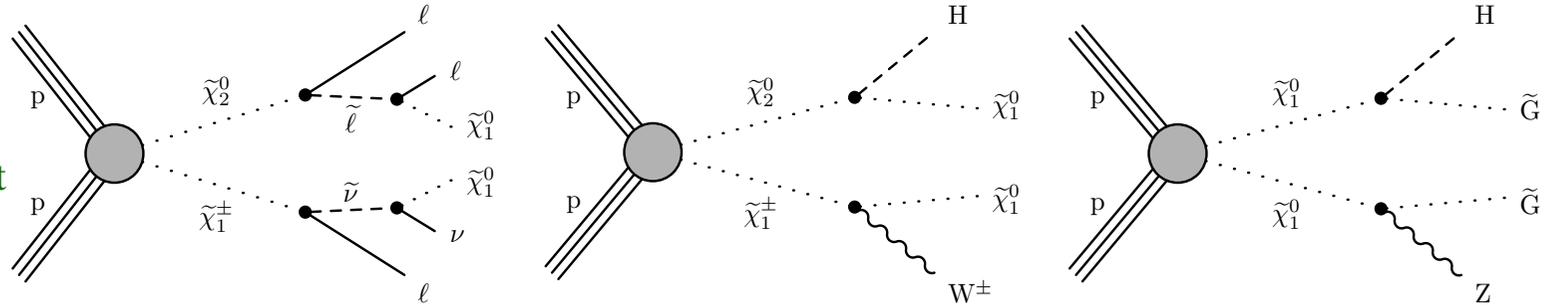
Electrons and muons

Multi-leptons

$$m_{\tilde{\ell}} = x m_{\tilde{\chi}_2^0} + (1 - x) m_{\tilde{\chi}_1^0}$$

$x = 0.5 \Rightarrow$ identical ℓ spectra

$x = 0.05$ or $0.95 \Rightarrow$ one ℓ soft



- Dominant prompt lepton backgrounds: conversions (2ℓ), WZ (3ℓ) and ZZ (4ℓ) events, and top quark production, estimated from simulation and validated in control samples
- Dominant non-prompt lepton backgrounds: $t\bar{t}$ and DY production, estimated by tight-to-loose ratio methods

- Search optimized in event categories with 2, 3, 4 leptons based on sign and flavour

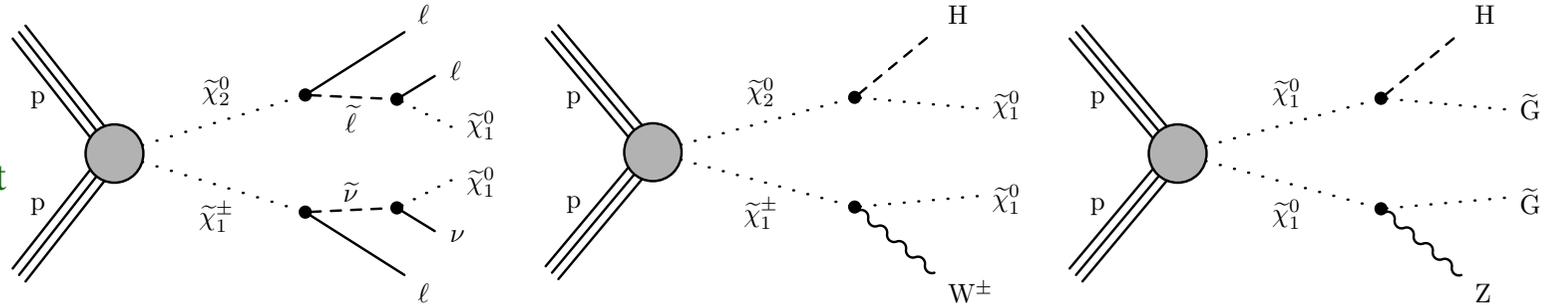
Sensitive to mass-degenerate wino- or higgsino-like chargino-neutralino and to neutralino-neutralino (GMSB) production

Multi-leptons

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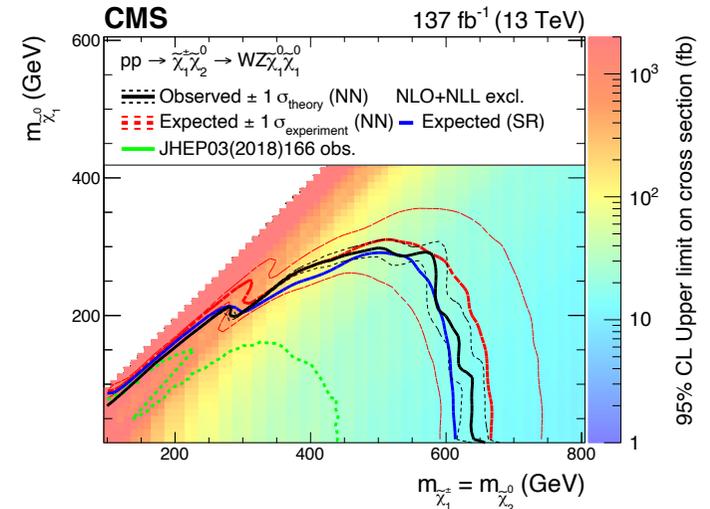
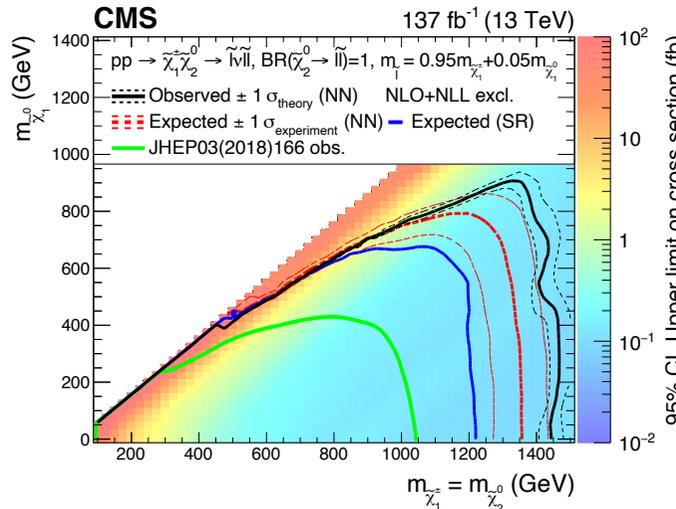
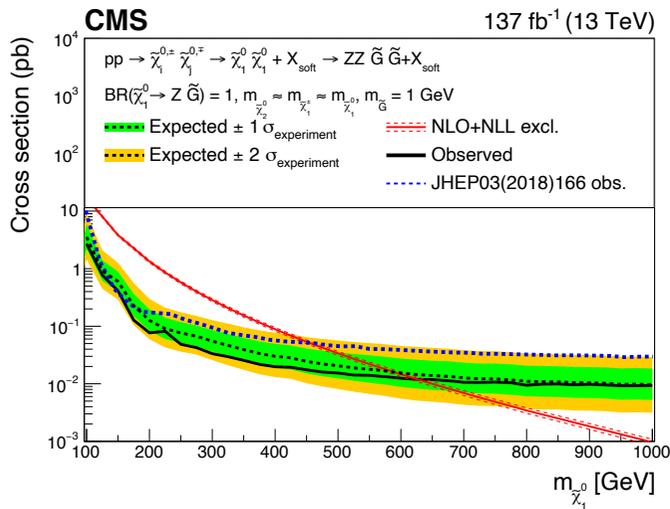
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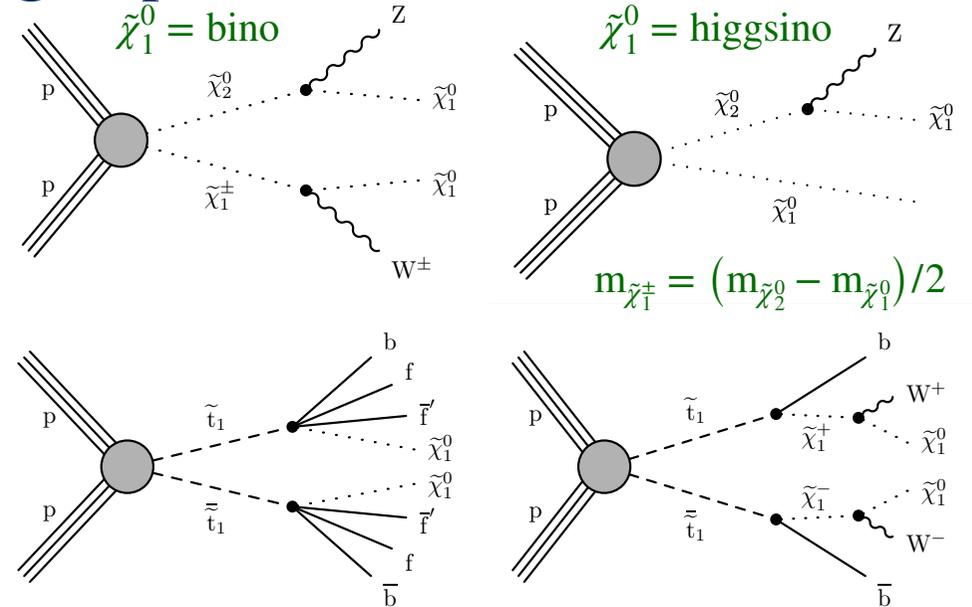
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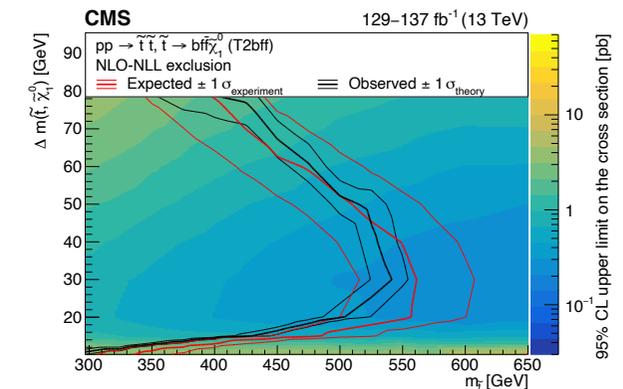
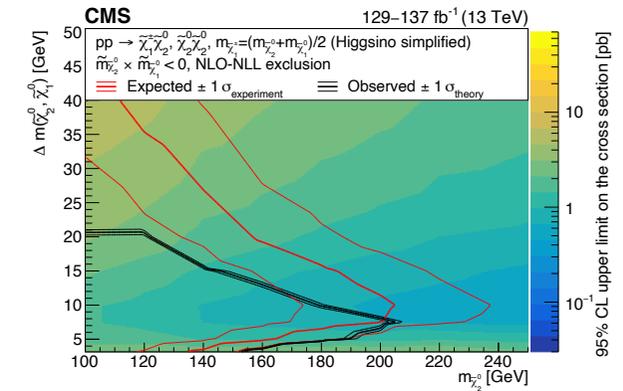
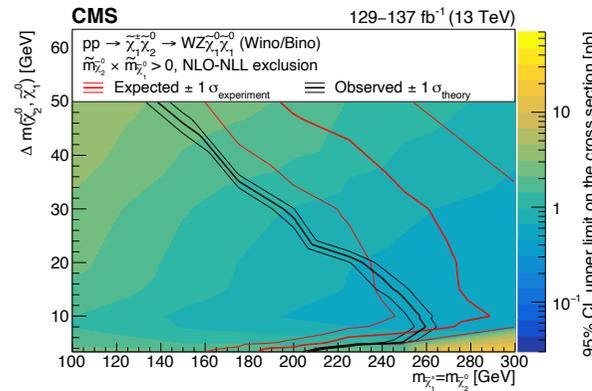
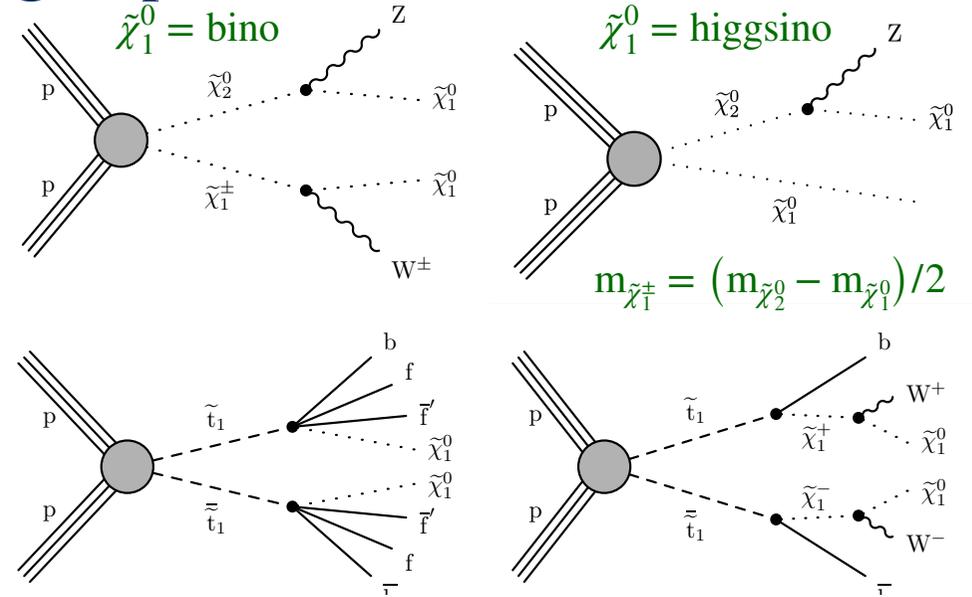
- Exclude $m_{\tilde{\chi}_1^\pm} < 1450$ GeV in 3ℓ events using parametric NN
- Exclude $m_{\tilde{\chi}_1^\pm} < 970$ GeV in 3τ events for right-handed sleptons
- Exclude $m_{\tilde{\chi}_1^\pm} < 650$ (250) GeV in events with WZ (WH) pair in final state
- Exclude $m_{\tilde{\chi}_1^0} < 600$ GeV in events with Z or H bosons in final state

Most stringent $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production limits for $m_{\text{NLSP}} - m_{\text{LSP}} \sim m_Z$

- Search sensitive to compressed mass spectra in electroweakino and stop pair production
- Include 3ℓ final state w.r.t. previous iteration of the analysis by CMS (2016 data)
- Require 2 or 3 e (μ) in the event with $5 < p_T < 30$ GeV, including one OS pair
- Require one ISR jet with $p_T > 25$ GeV to induce significant MET > 125 GeV
- Search optimized in MET bins
- Search variables: $m_{\ell\ell}$ in electroweakino production and $p_{T,\max}^{\ell}$ in \tilde{t} production
- Dominant SM backgrounds from DY, $t\bar{t}$, WV production + non-prompt / misidentified leptons from W+jets (2ℓ) and $t\bar{t}$ (3ℓ), constrained from SS $\ell\ell$ sample

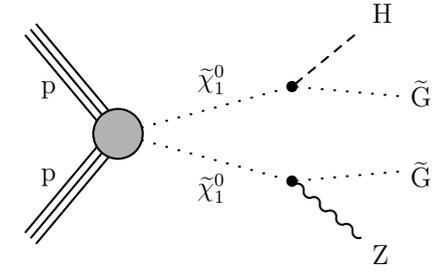
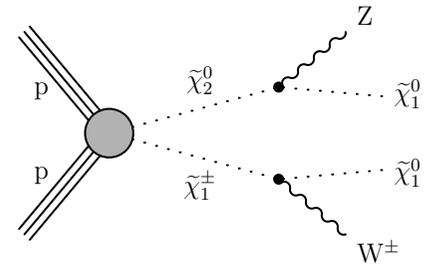
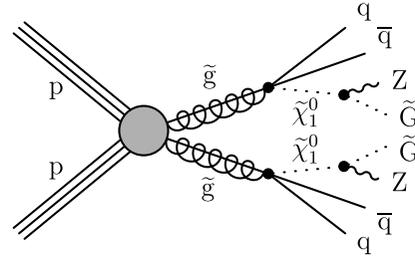
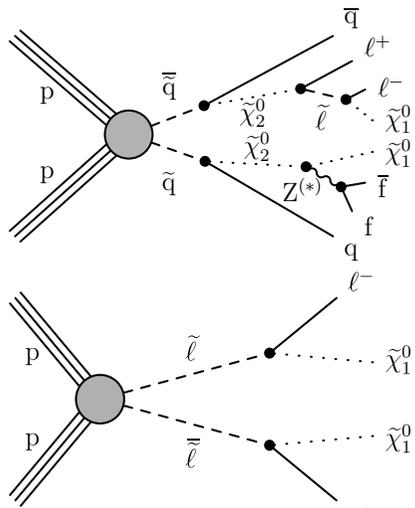


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- Dominant SM backgrounds from DY, $t\bar{t}$, WV production + non-prompt / misidentified leptons from W +jets (2ℓ) and $t\bar{t}$ (3ℓ), constrained from SS $\ell\ell$ sample
- Exclude $m_{\tilde{\chi}_2^0/\tilde{\chi}_1^\pm} < 275$ GeV for $\Delta m = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} = 10$ GeV (wino-bino)
- Exclude $m_{\tilde{\chi}_2^0/\tilde{\chi}_1^\pm} < 205$ (150) GeV for $\Delta m = 7.5$ (3) GeV (higgsino)
- Exclude $m_{\tilde{t}} < 540$ (480) GeV for $\Delta m = 30$ GeV in 4-body decays



Opposite-sign leptons “on the Z edge”

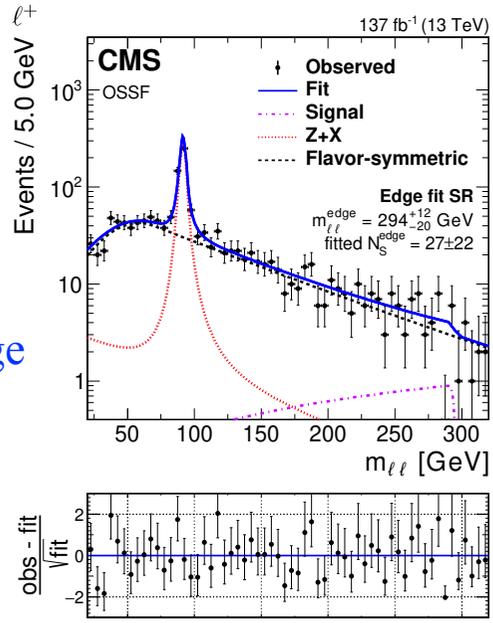
SUS-20-001



$$m_{\tilde{\chi}_1^0} = 100 \text{ GeV}$$

$$m_{\tilde{\ell}} = (m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0})/2$$

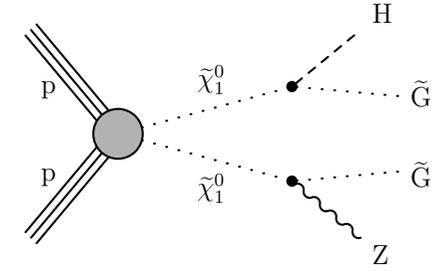
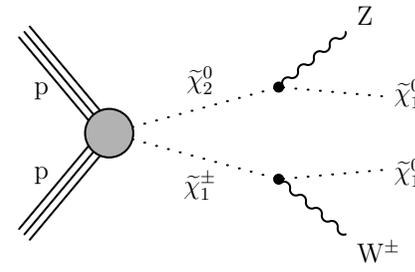
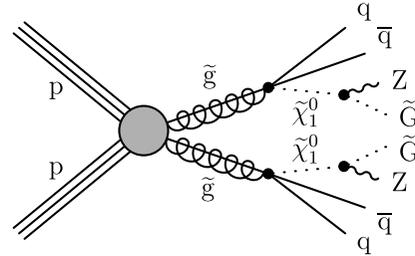
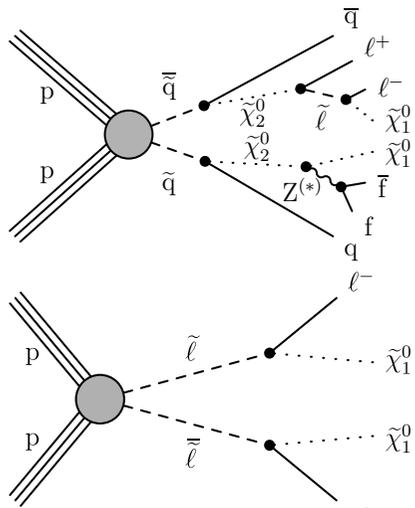
- Search sensitive to GMSB scenarios
- $m_{\ell\ell} = m_Z$ for on-shell Z decay
- $m_{\ell\ell} \Rightarrow$ kinematic edge for $\tilde{\chi}_2^0 \rightarrow \tilde{\ell} \rightarrow \tilde{\chi}_1^0$ cascade decays
- $m_{\ell\ell} \Rightarrow$ continuum for $\tilde{\ell}\tilde{\ell}$ decays



- Fitting $m_{\ell\ell}$ for the kinematic edge, binning $m_{\ell\ell}$ or MET and N_{jets} for the other scenarios
- Dominant SM backgrounds: $t\bar{t}$, DY+jets with instrumental MET, and VZ with ν 's in the final state, estimated from data and simulation

Opposite-sign leptons “on the Z edge”

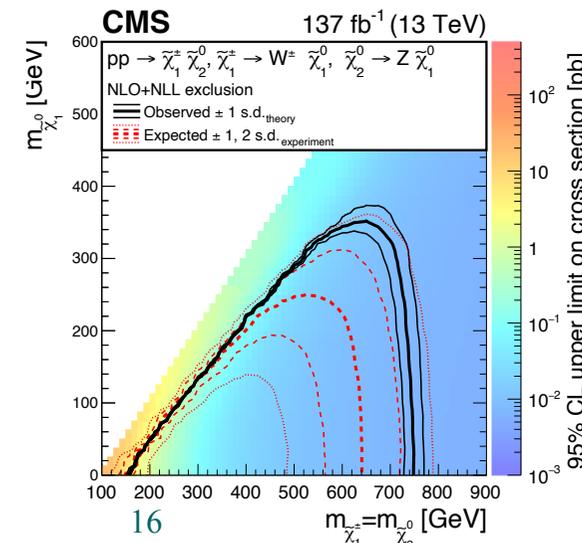
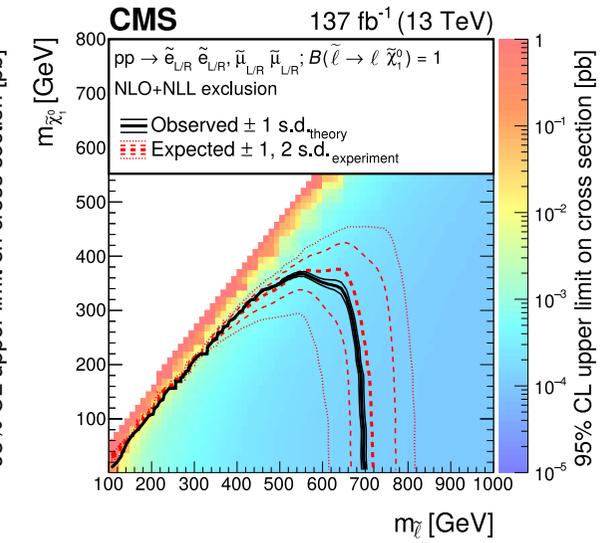
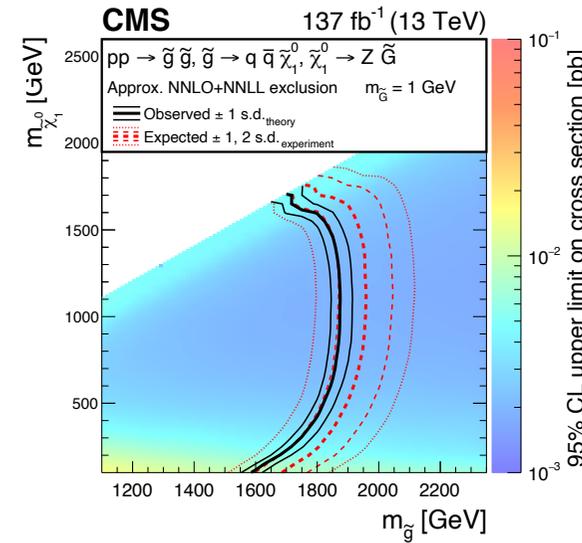
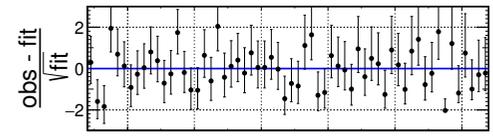
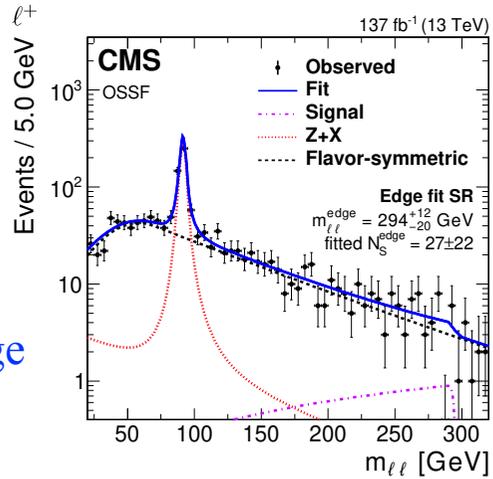
SUS-20-001



$$m_{\tilde{\chi}_1^0} = 100 \text{ GeV}$$

$$m_{\tilde{Z}} = (m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0})/2$$

- Search sensitive to GMSB scenarios
- $m_{\ell\ell} = m_Z$ for on-shell Z decay
- $m_{\ell\ell} \Rightarrow$ kinematic edge for $\tilde{\chi}_2^0 \rightarrow \tilde{\ell} \rightarrow \tilde{\chi}_1^0$ cascade decays
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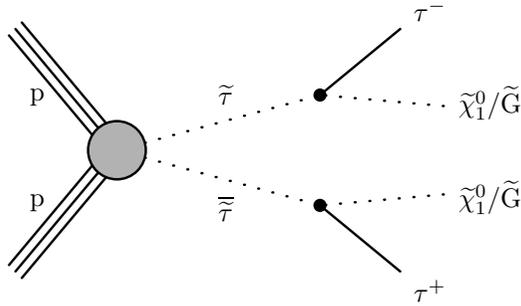


- Fitting $m_{\ell\ell}$ for the kinematic edge, binning $m_{\ell\ell}$ or MET and N_{jets} for the other scenarios
- Dominant SM backgrounds: $t\bar{t}$, DY+jets with instrumental MET, and VZ with ν 's in the final state, estimated from data and simulation

- Exclude $m_{\tilde{g}} < 1870 \text{ GeV}$, $m_{\tilde{q}}(m_{\tilde{b}}) < 1800(1600) \text{ GeV}$
- Exclude $m_{\tilde{\chi}_1^\pm}(m_{\tilde{\chi}_2^0}) < 750(800) \text{ GeV}$, $m_{\tilde{Z}} < 700 \text{ GeV}$
- Extend previous CMS limits by few hundred GeV

Tau leptons

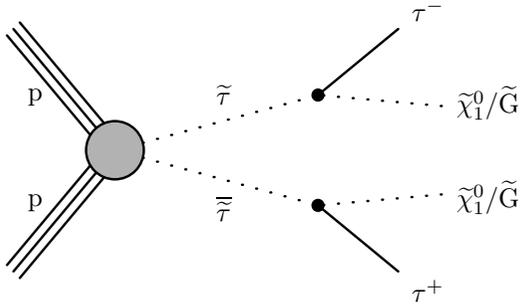
Direct tau slepton pair production



- Sensitive to early-Universe $\tilde{\tau}-\tilde{\chi}^0$ co-annihilation models explaining observed DM relic density
- Including search for GMSB-inspired long-lived $\tilde{\tau}$ with gravitino LSP ($m_{\tilde{G}} \simeq 0$) not included in previous $\tilde{\tau}$ searches at LHC and LEP
- Select opposite-charge HPS τ_h pairs with DeepTau discriminant from QCD jets

Dominant SM backgrounds from DY and misidentified $\tau\tau$ (flavour dependent), estimated by data-driven methods

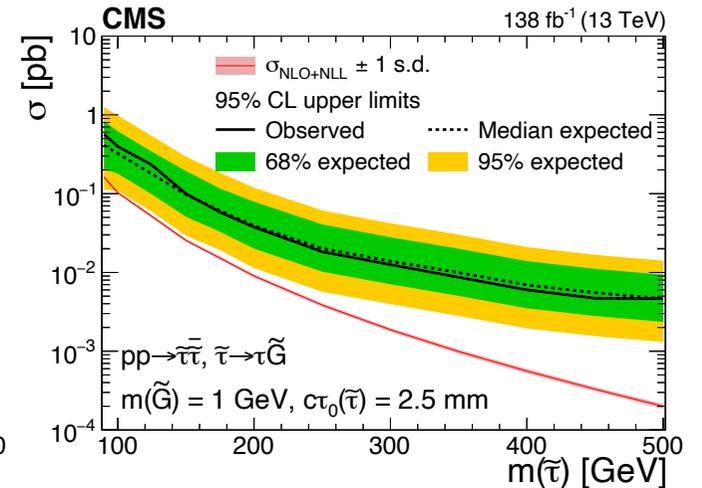
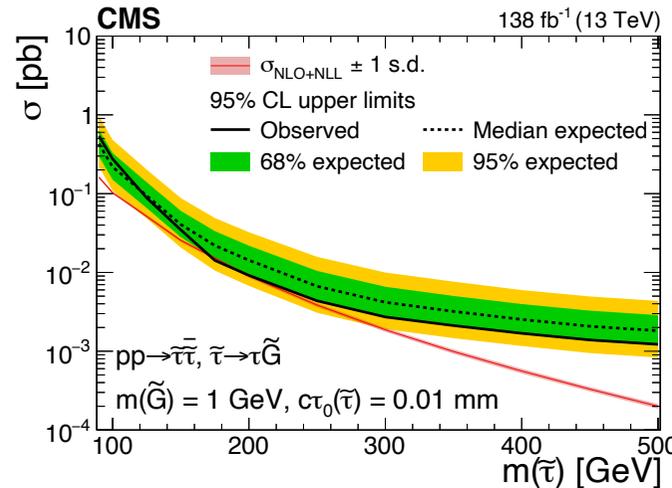
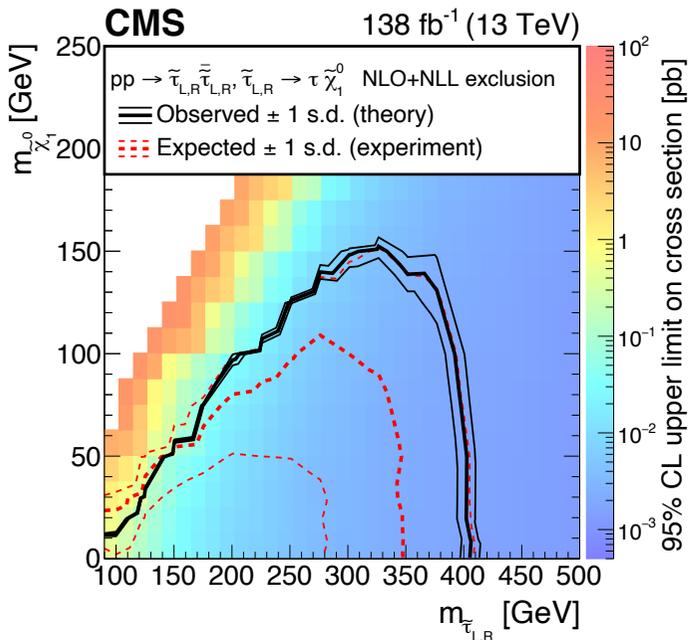
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- Select opposite-charge HPS τ_h pairs with DeepTau discriminant from QCD jets

Dominant SM backgrounds from DY and misidentified $\tau\tau$ (flavour dependent), estimated by data-driven methods

- Exclude $90 < m_{\tilde{\tau}} < 400$ GeV for nearly massless $\tilde{\chi}_1^0$
- Exclude $150 < m_{\tilde{\tau}} < 220$ GeV for $c\tau_0(\tilde{\tau}) = 0.1$ mm

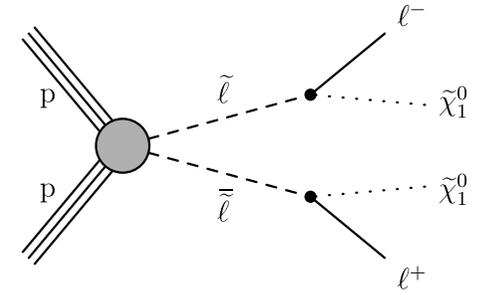


Combinations

- Combined exclusion limits from all searches for electroweakino and slepton production with the full Run 2 sample

2023 result

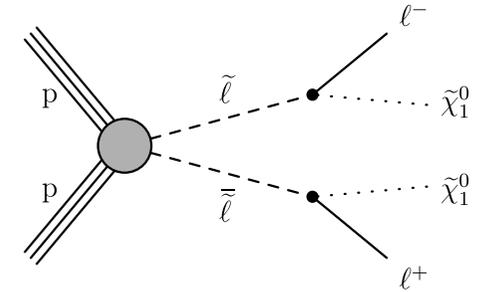
- Included limits on
 - gaugino-like chargino-neutralino production
 - higgsino-like neutralino pair production in a GMSB scenario
 - higgsino-bino interpretation
 - slepton pair production
- Improved soft opposite-sign dilepton analysis with a parametric $m_{\ell\ell}$ binning, adjusting boundaries to equal signal quantiles in all bins for each mass point
- Added interpretation of soft opposite-sign dilepton analysis with a slepton pair production model
First search of slepton pair production in the compressed mass scenario



- Combined exclusion limits from all searches for electroweakino and slepton production with the full Run 2 sample

2023 result

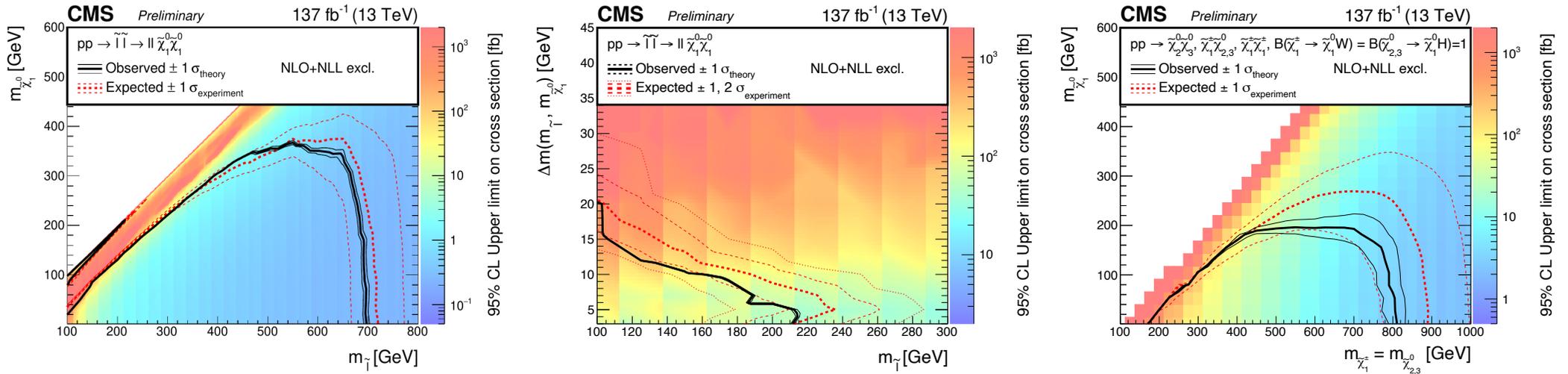
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- Added interpretation of soft opposite-sign dilepton analysis with a slepton pair production model

First search of slepton pair production in the compressed mass scenario



- For $\Delta m(\tilde{\ell}, \tilde{\chi}_1^0) = 5$ GeV, exclude $m_{\tilde{\ell}} < 215$ GeV in SOS analysis

- Combination excludes $m_{\tilde{\ell}} < 700$ GeV for $m_{\tilde{\chi}_1^0} < 50$ GeV

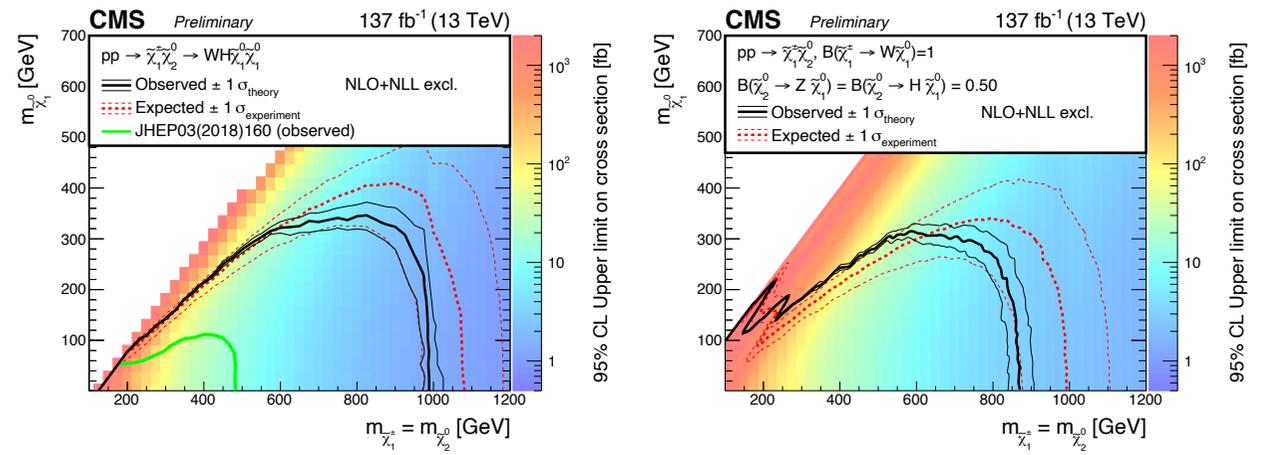
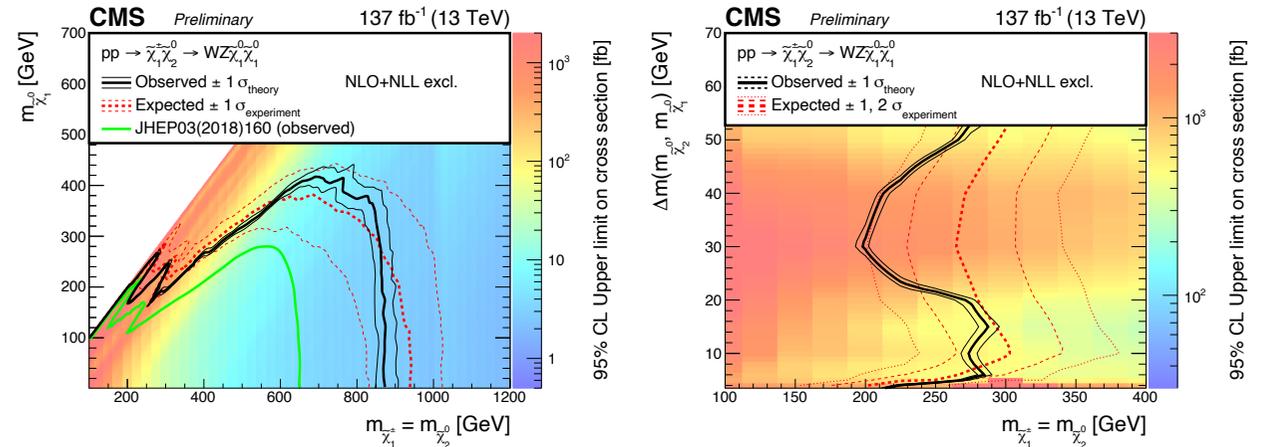
Higgsino-bino interpretation

- Exclude $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_2^0} < 800$ GeV for $m_{\tilde{\chi}_1^0} < 50$ GeV

Costas Vellidis

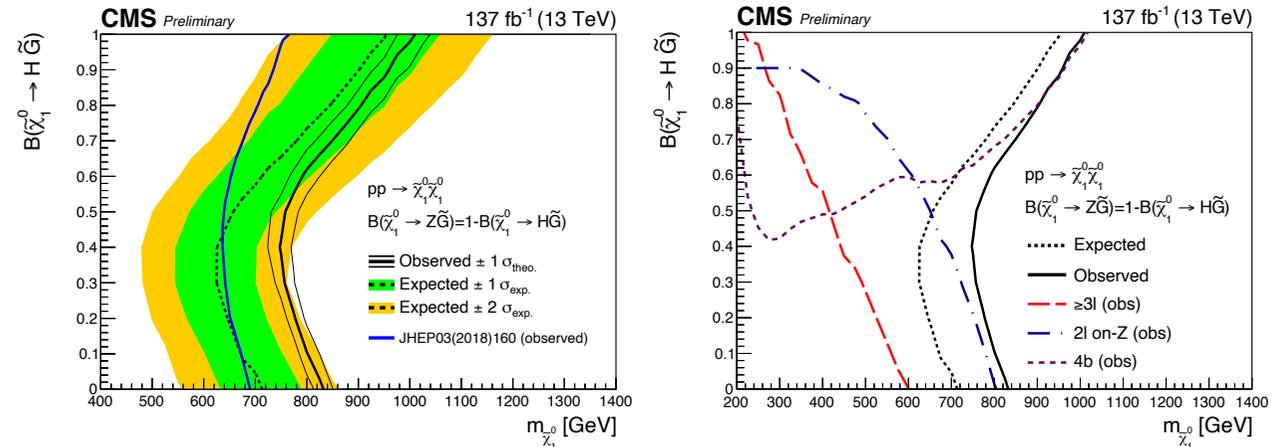
Chargino-neutralino production:

- Exclude $m_{\tilde{\chi}_1^\pm} < 875, 990, 875$ GeV with $m_{\tilde{\chi}_1^0} < 50$ GeV in the WZ, WH, and mixed final state
- Extend previous CMS limits by 225, 510, and 340 GeV, respectively



Neutralino pair production:

- For nearly massless LSP, exclude $m_{NLSP} < 750$ GeV independently of $\mathcal{B}(\tilde{\chi}_1^0 \rightarrow H\tilde{G})$
- Extend previous CMS limit by 100 GeV



Conclusions: the way ahead

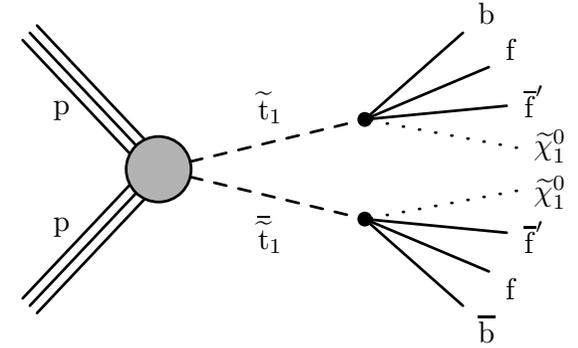
- Great progress in SUSY searches achieved by CMS using the Run 2 sample
 - ▶ Extended exclusion regions in the parameter space of a large set of simplified models
 - ▶ Introduced many new techniques to improve sensitivity beyond baseline luminosity increase, paving the way to Run 3

Conclusions: the way ahead

- Great progress in SUSY searches achieved by CMS using the Run 2 sample
 - ▶ Extended exclusion regions in the parameter space of a large set of simplified models
 - ▶ Introduced many new techniques to improve sensitivity beyond baseline luminosity increase, paving the way to Run 3
- Where to look for SUSY next
 - ▶ Difficult topologies (example in this talk: top squark decays in the “corridor”)
 - ▶ Narrow phase space (example in this talk: soft opposite-sign lepton analysis)
 - ▶ Long-lived particle signatures (example in this talk: direct tau slepton production search)
- Double data sample from LHC Run 3 will improve sensitivity
- Special triggers will allow reaching new signatures (e.g. Level-1 displaced μ triggers to search for final states with LLP)
- High-Luminosity LHC: a whole new era of searches for physics Beyond the Standard Model, with all levers (sample size, detector & trigger technology, analysis power) advanced to a substantially higher level

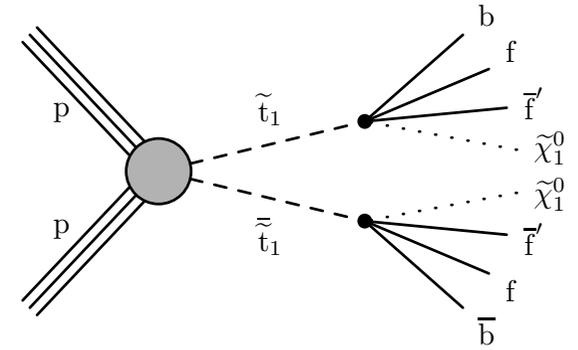
Backup

- Search sensitive to the scenario $m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < m_W$ (favours 4-body \tilde{t}_1 decay)
- Decays with a leptonic and an hadronic \tilde{t}_1 + a hard ISR jet
- Extending previous CMS search using only 2016 data

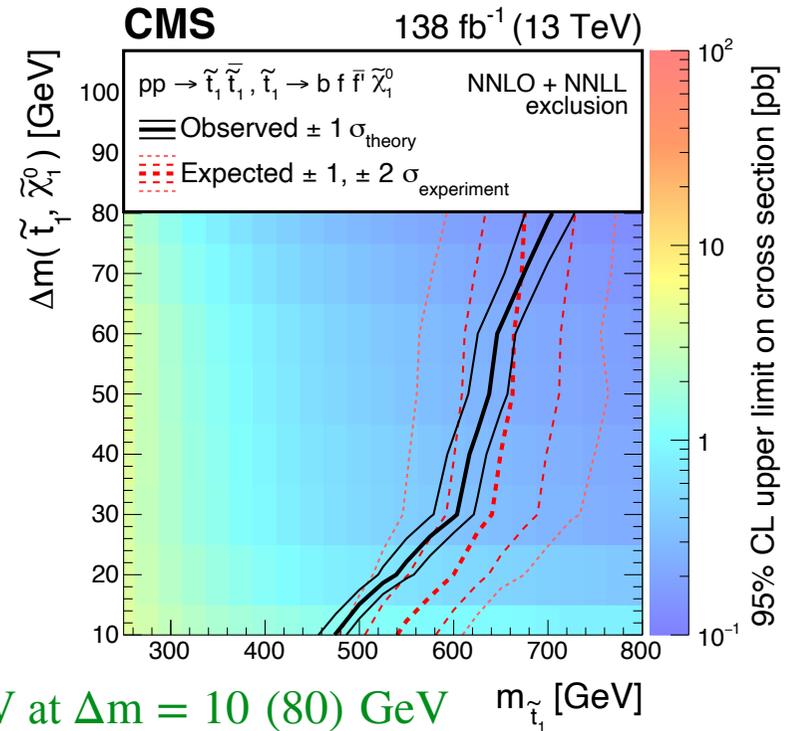
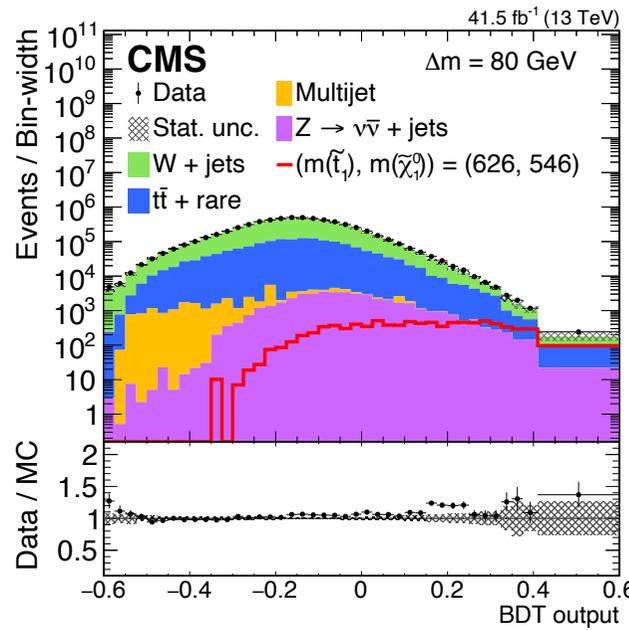
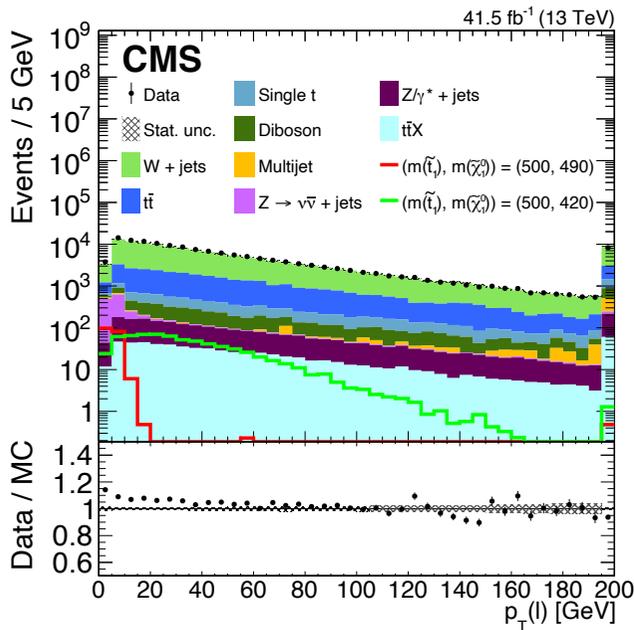


- Requiring 1 e/μ + ≥ 1 jets + MET in the final state
- Dominant SM backgrounds from $t\bar{t}$, V + jets, $Z(\nu\bar{\nu})$ + jets (non-prompt leptons) events, estimated from data
- BDT-based event selection, optimized in 10-GeV bins of $\Delta m = (m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0}) \in [10,80]$ GeV

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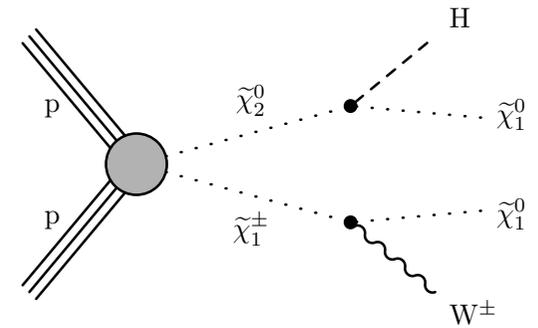
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Exclude $m_{\tilde{t}} < 480$ (700) GeV at $\Delta m = 10$ (80) GeV $m_{\tilde{t}_1}$ [GeV]

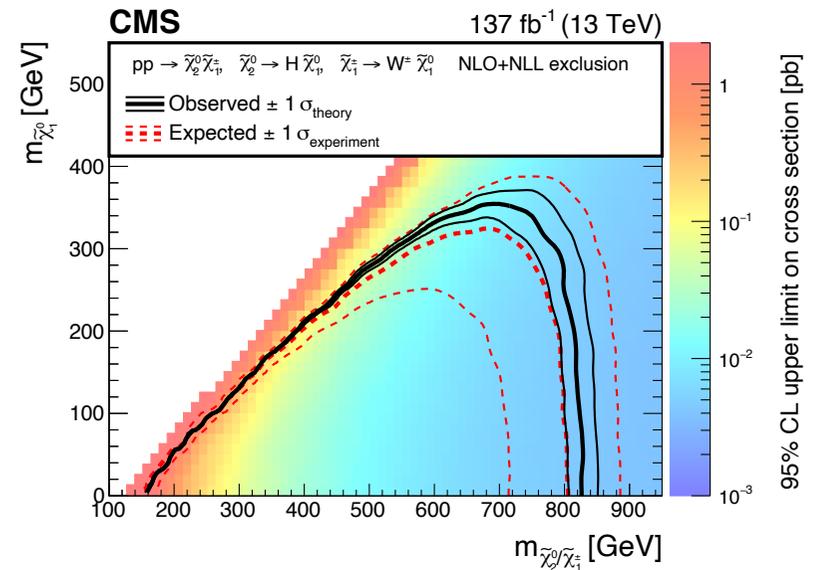
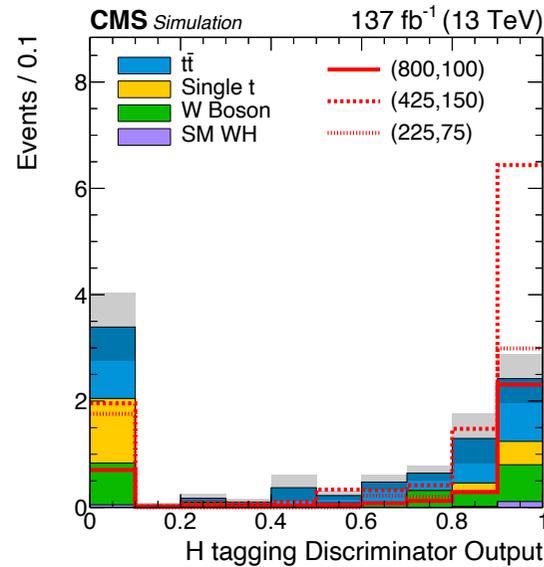
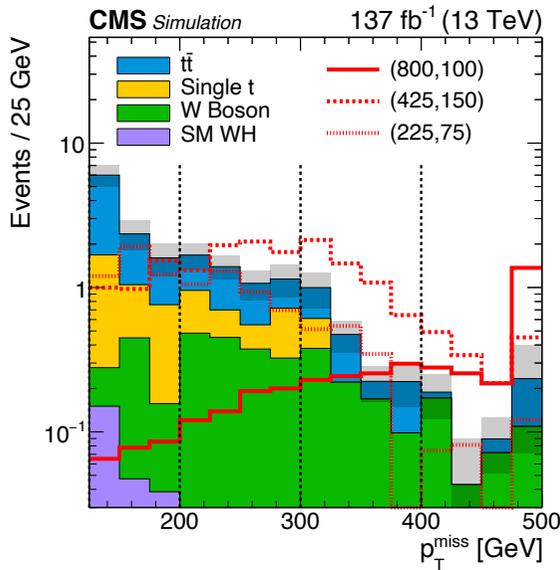
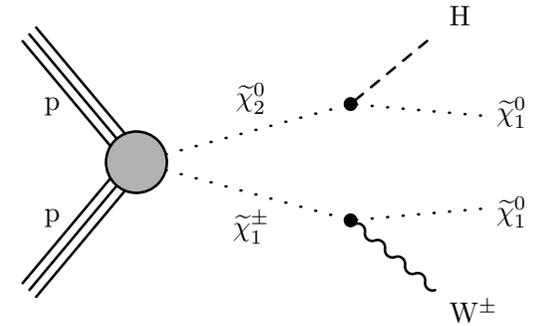
Search for mass-degenerate chargino-neutralino production

- Identify boosted H bosons with mass-decorrelated bb-tagging (AK8 jets)
- Dominant SM backgrounds from t , $t\bar{t}$, $t\bar{t} + V$, $W+X$ (=jets, V, H) events, estimated from data and simulation

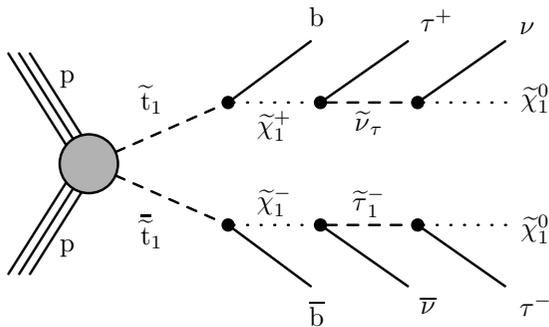


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Exclude $m_{\text{NLSP}} < 820 \text{ GeV}$ and $m_{\text{LSP}} < 350 \text{ GeV}$ for $m_{\text{NLSP}} = 700 \text{ GeV}$



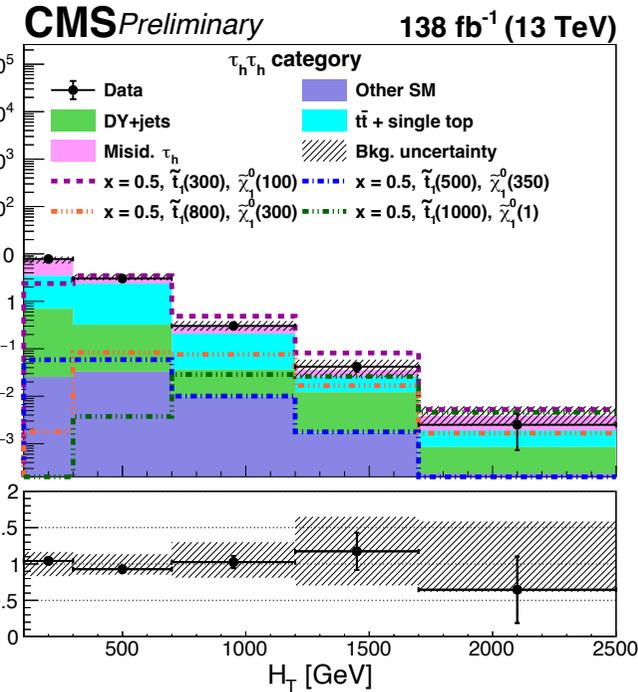
$$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 0.5 (m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0})$$

$$m_{\tilde{\nu}_\tau} = m_{\tilde{t}_1}$$

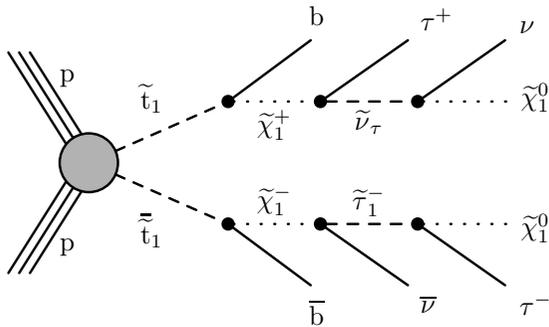
$$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} = x (m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0})$$

$$x = 0.25, 0.50, 0.75$$

- Sensitive to high- $\tan\beta$ or higgsino-like scenarios, where 3rd-generation Yukawa couplings are large
- Include $bb\tau_h\tau_h$ and $bb\tau_\ell\tau_h$, $\ell = e, \mu$ final states (87% branching fraction), without considering τ polarization
- Tag b-jets with DeepJet and HPS τ_h with DeepTau discriminant from QCD jets



- Require 2 opposite-charge τ leptons in the event
- Dominant SM backgrounds from $t\bar{t}$ and tW events, estimated from combined MC and data



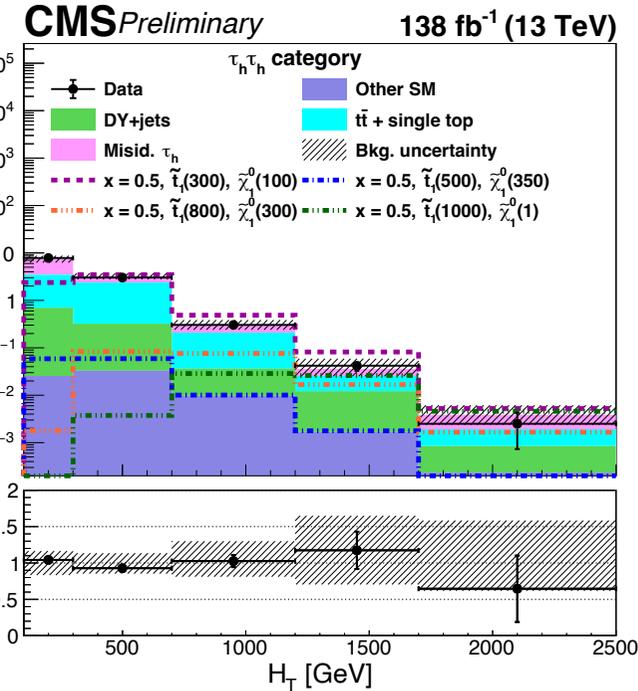
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- Require 2 opposite-charge τ leptons in the event
- Dominant SM backgrounds from $t\bar{t}$ and tW events, estimated from combined MC and data
- Exclude $m_{\tilde{t}_1} < 1150$ GeV for $m_{\tilde{\chi}_1^0} = 1$ GeV and $m_{\tilde{\chi}_1^0} < 450$ GeV for $m_{\tilde{t}_1} = 900$ GeV
- Most stringent exclusion limits to data for the signal models considered in this study

