Electroweak production SUSY searches in CMS

LHCP 2018
Sixth Annual Conference on Large Hadron Collider Physics

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On behalf of the CMS Collaboration

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Motivation

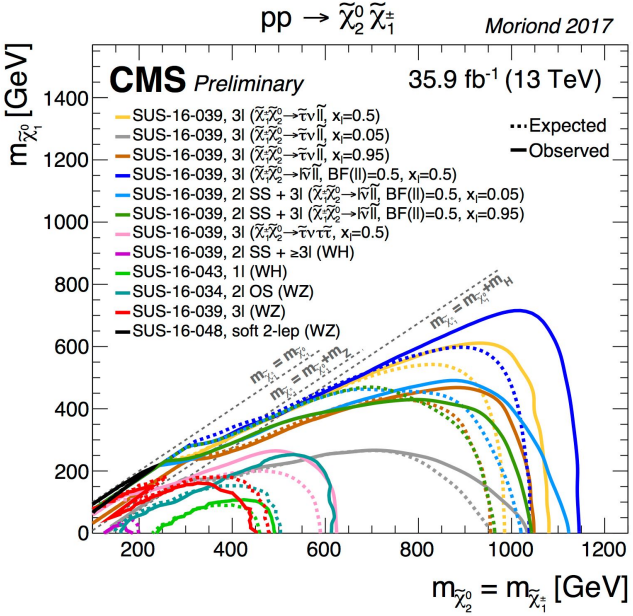
⇢ Still no direct hints of BSM physics in the LHC… but we are not done yet!

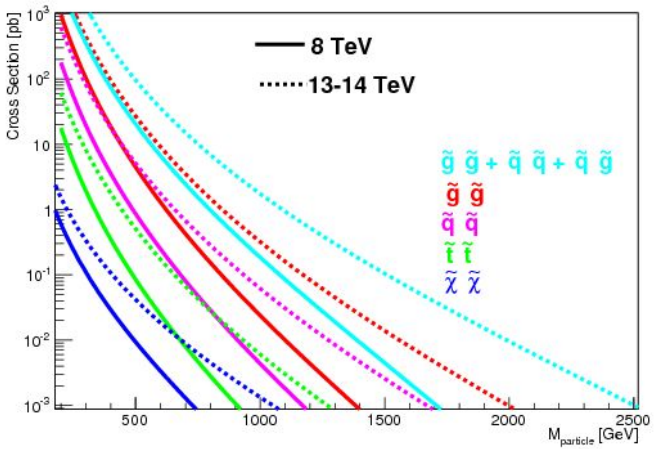
⇢ Strongly charged SUSY partners are preferred when they have similar masses to electroweak ones but current limits have pushed them beyond the TeV scale.

⇢ The electroweak sector could be the key in finding SUSY.

⇢ Spectacular effort during 2016 and 2017.

⇢ Started to reach sensitivity to the TeV scale





Halkiadakis, Eva et al. Ann.Rev.Nucl.Part.Sci. 64 (2014)

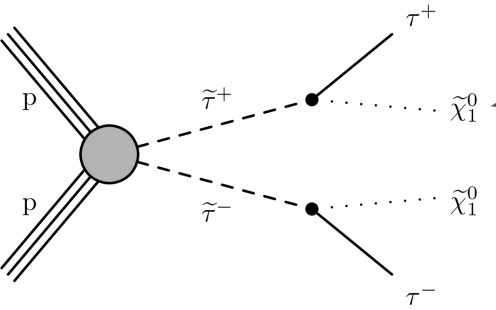
Light slepton models

Remember: neutralinos and charginos are mixings of the Higgsinos and the electroweak boson's partners

⇢ Models where the sleptons are amongst the lightest SUSY partners.

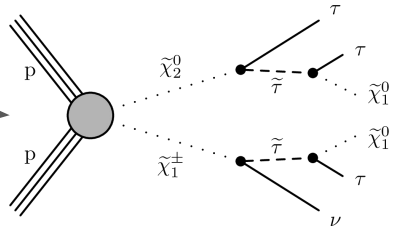
Direct slepton pair production

Slepton-mediated chargino/neutralino decay



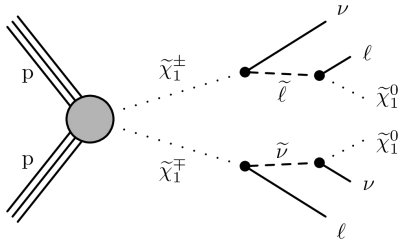
SUS-17-002 (CDS)

- τ pair (leptonic) + p_T^{miss}



SUS-17-003 (CDS)

- Hadronic τ pairs + p_T^{miss}

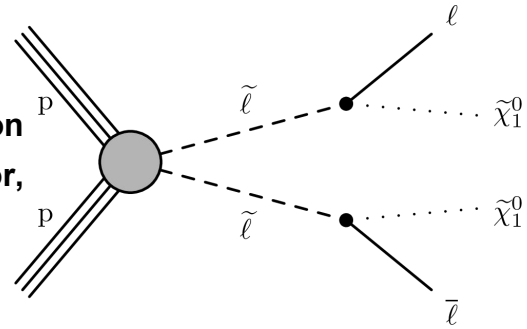


SUS-17-010 (CDS)

- Jet inclusive off-Z double lepton final states (opposite sign) + p_T^{miss}

SUS-17-009 (CDS)

- Jetless, off-Z double lepton final states (same flavor, opposite sign) + p_T^{miss}



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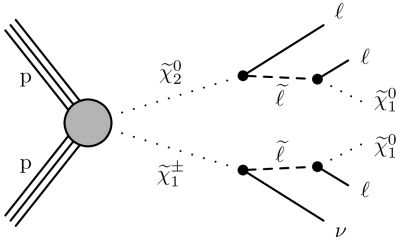
- Multileptonic final states (including light leptons and hadronic τ) + p_T^{miss}

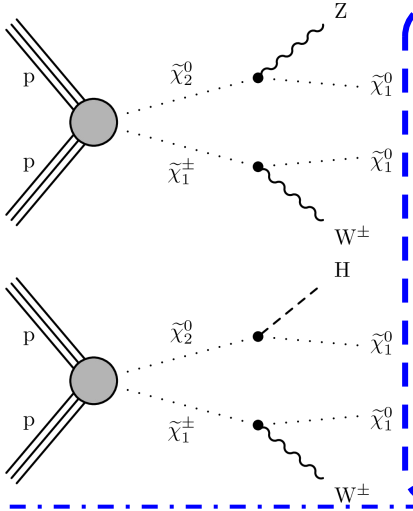


Heavy slepton models

- Models where the sleptons are too heavy. Charginos and neutralinos decay to SM bosons.
- Include Gauge Mediated Supersymmetry Breaking (GMSB) scenarios with near massless gravitinos.

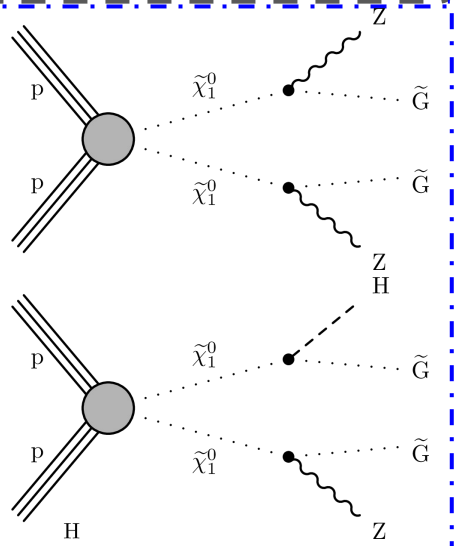
Chargino/Neutralino decay to SM bosons

Chargino/neutralino pair production in GMSB models



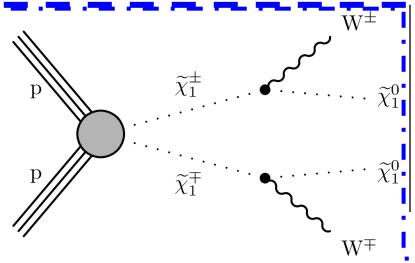
Combined result JHEP 03 (2018) 160

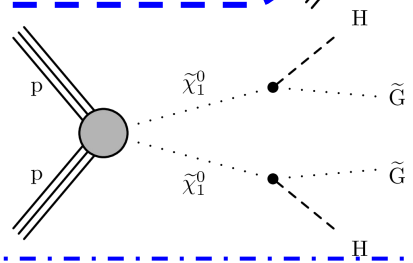
- JHEP 03 (2018) 166 Multileptons + p_T^{miss}
- JHEP 03 (2018) 076 Two leptons on-Z + p_T^{miss}
- JHEP 11 (2017) 029 Lepton + two b-jets + p_T^{miss}
- Phys. Lett. B 779 (2018) 166 Two photons + p_T^{miss}
- Phys.Rev. D 97 (2018) 032007 Four b-tagged jets + p_T^{miss}
- Submitted to Phys. Lett. B Soft two leptons



SUS-17-010 (CDS)

- Jet inclusive off-Z double lepton final states (same flavor, opposite sign) + p_T^{miss}





Jetless off-Z double lepton

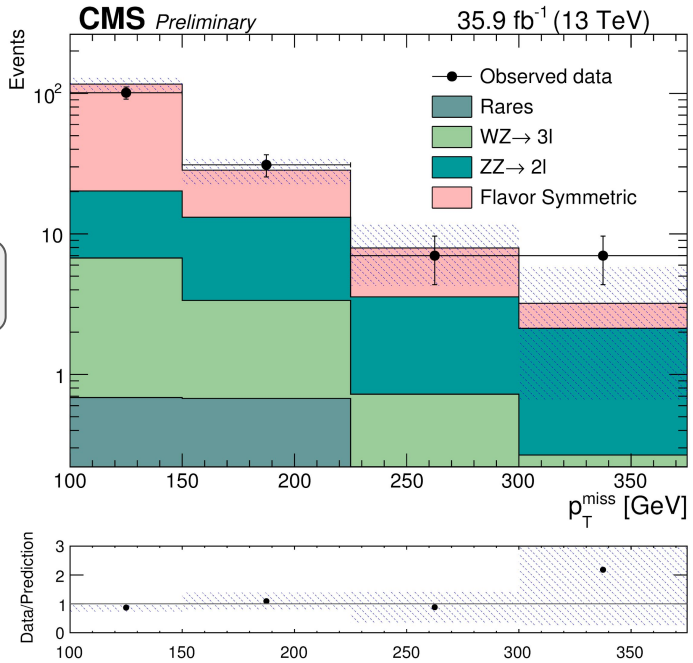
SUS-17-009 (CDS)

- Events with a pair of opposite charge same flavor (OCSF) leptons.
- Stransverse mass variable:

Kinematical endpoint at m_W for tt, WW backgrounds

$$M_{T2}(\ell\ell) = \min_{\vec{p}_T^{miss1}+\vec{p}_T^{miss2}=\vec{p}_T^{miss}} \left(\max \left[M_T(\vec{p}_T^{lep1}, \vec{p}_T^{miss1}), M_T(\vec{p}_T^{lep2}, \vec{p}_T^{miss2}) \right] \right)$$

Reduce tt, QCD	Reduce resonances	Reduce WW, tt	Sensitive to multiple m_{LSP}
N_{jets}	$m_{\ell\ell}$ [GeV]	$M_{T2}(\ell\ell)$ [GeV]	p_T^{miss} [GeV]
0 (>25 GeV)	>20 and not in [76, 106]	>90	100–150, 150–225, 225–300, >300



Dominated by multiple effects that alter the shape of p_T^{miss}

Source of uncertainty	Uncertainty (%)
Jet energy scale	1-15
Fast simulation p_T^{miss} modeling	0-20
Unclustered energy shifted p_T^{miss}	0-8
Muon energy scale shifted p_T^{miss}	0-20
Electron energy scale shifted p_T^{miss}	0-4

Jet inclusive off-Z double lepton

- Selecting events with an OC lepton pair. Veto third lepton.
- Minimal requirements to reject resonances.

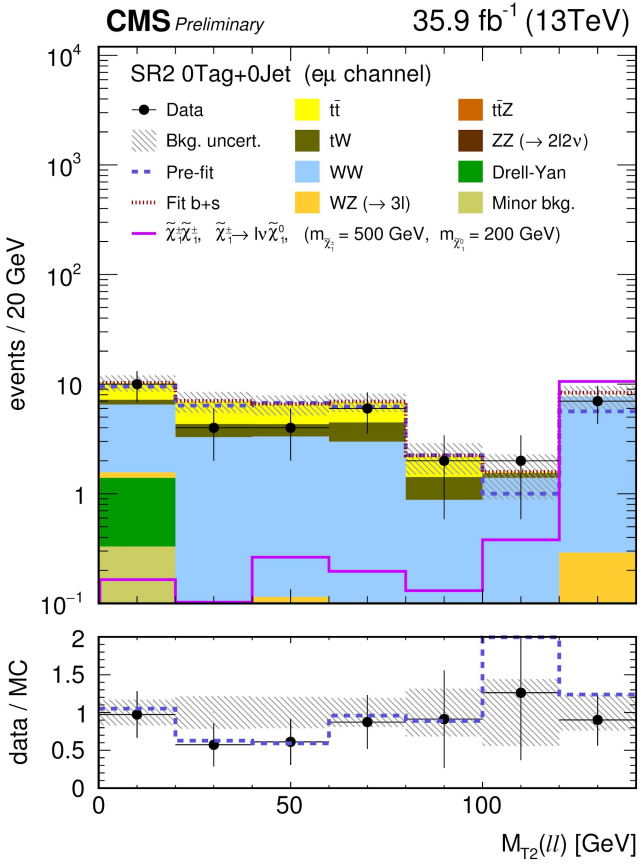
Baseline selection (common)

Variable	Selection
$m_{\ell\ell}$	$\geq 20\,\mathrm{GeV}$
$\lvert m_{\ell\ell} - m_Z \rvert$	$> 15\,\mathrm{GeV}$ only for ee and $\mu\mu$ events
p_T^{miss}	$\geq 140\,\mathrm{GeV}$

- Search strategy based on multiple bins on N_{Jets}- $N_{b\text{-}Tag}$ classified by lepton composition.
- Exploit shape differences in the $M_{T2}(ll)$ variable (multiple bins).

M_{T2} modelling for the backgrounds is crucial
Also different effects in the resolution of p_T^{miss}

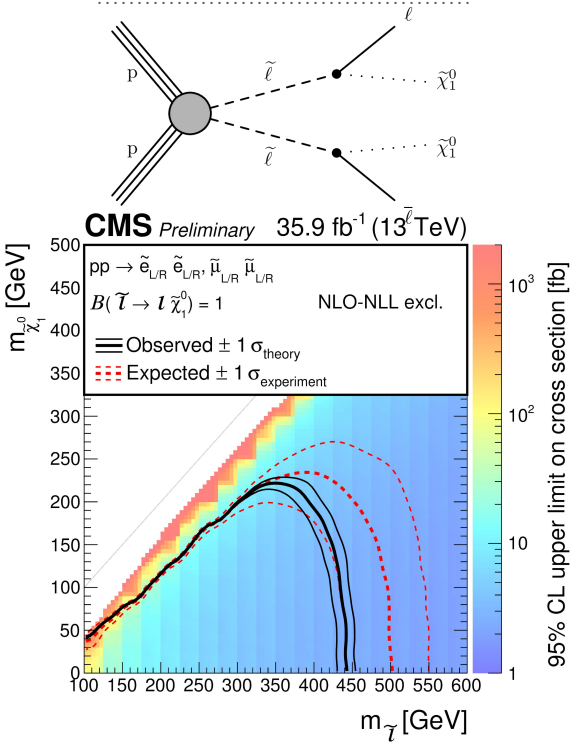
Systematic	Change in yields	Change in $M_{T2}(\ell\ell)$ shape
JES	1-6%	3-15%
Unclustered energy	1-2%	2-16%
$M_{T2}(\ell\ell)$ shape (Top)	-	4-18%
$M_{T2}(\ell\ell)$ shape (WW)	-	1-15%
$M_{T2}(\ell\ell)$ shape (Drell-Yan)	-	1-13%



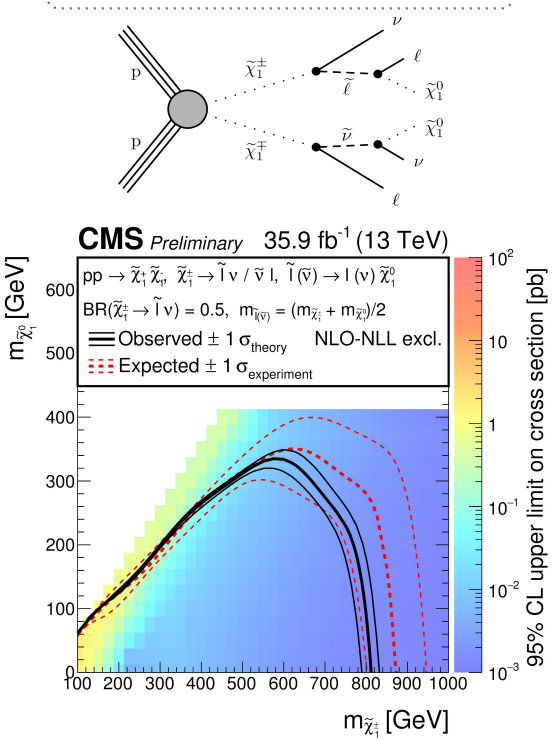
Double lepton final state interpretations

- Common points: light sleptons models.
- Additional interpretation on terms of chargino pair production.

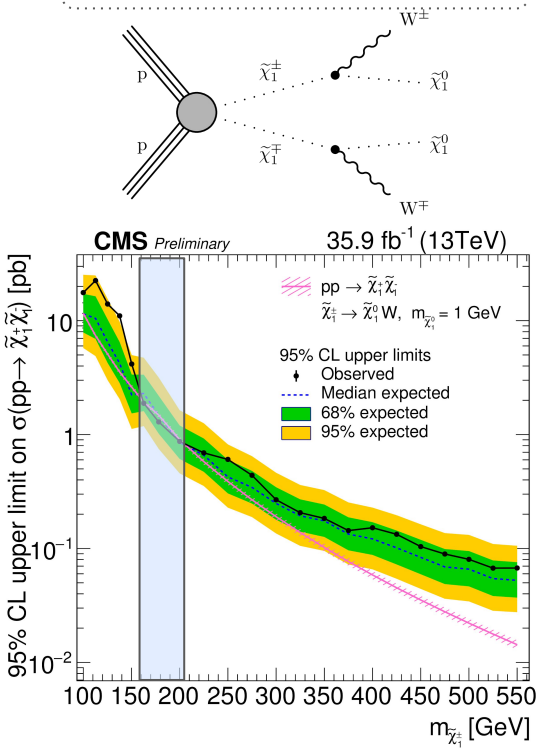
SUS-17-009 (Jetless)



SUS-17-010 (Jet inclusive)



SUS-17-010 (Jet inclusive)



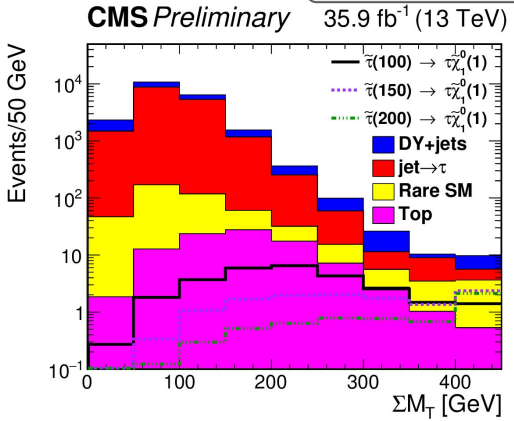
Hadronic τ pair final state

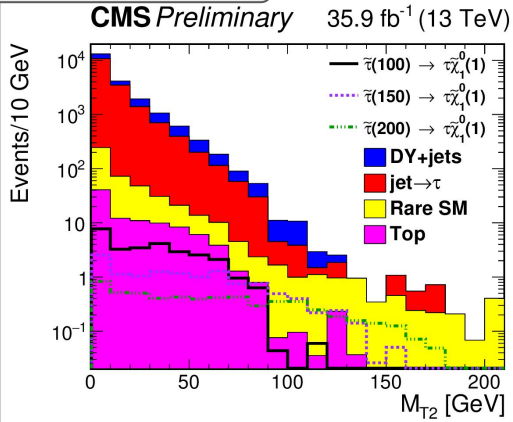
SUS-17-003 (CDS)

- Requiring exactly two reconstructed high-p_T OC hadronic τ with no b-tagged jets in the event.
- Define three dedicated signal regions:

2τ and 0 b-jets

SR1	$M_{T2} > 90\,\text{GeV}$ $\lvert\Delta\phi(l_1,l_2)\rvert > 1.5$	Targets high stau masses
SR2	$40\,\text{GeV} < M_{T2} < 90\,\text{GeV}$ $\Sigma M_T > 350\,\text{GeV}$ $E_T^{miss} > 50\,\text{GeV}$ $\lvert\Delta\phi(l_1,l_2)\rvert > 1.5$	Targets compressed scenarios
SR3	$40\,\text{GeV} < M_{T2} < 90\,\text{GeV}$ $300\,\text{GeV} < \Sigma M_T < 350\,\text{GeV}$ $E_T^{miss} > 50\,\text{GeV}$ $\lvert\Delta\phi(l_1,l_2)\rvert > 1.5$	Targets compressed scenarios





	SR1	SR2	SR3
Non-prompt and misidentified taus	$0.68^{+0.90}_{-0.68}$	2.49 ± 1.83	<1.24
Drell-Yan background	$0.80^{+0.97}_{-0.80}$	< 0.71	< 0.71
Top-quark related background	$0.02^{+0.03}_{-0.02}$	0.73 ± 0.31	1.76 ± 0.68
Rare SM processes	0.72 ± 0.38	0.20 ± 0.15	$0.20 \pm^{+0.25}_{-0.20}$
Total background	$\mathbf{2.22}^{+1.37}_{-1.12}$	$\mathbf{4.35}^{+1.75}_{-1.53}$	$\mathbf{3.70}^{+1.52}_{-1.08}$
Left (150,1)	1.25 ± 0.40	2.91 ± 0.59	1.53 ± 0.33
Right (150,1)	1.09 ± 0.26	1.27 ± 0.20	0.74 ± 0.17
Mixed (150,1)	1.04 ± 0.22	1.39 ± 0.27	0.92 ± 0.15
Observed	**0**	**5**	**2**

Dominated by low statistics

- Relevant Background sources:

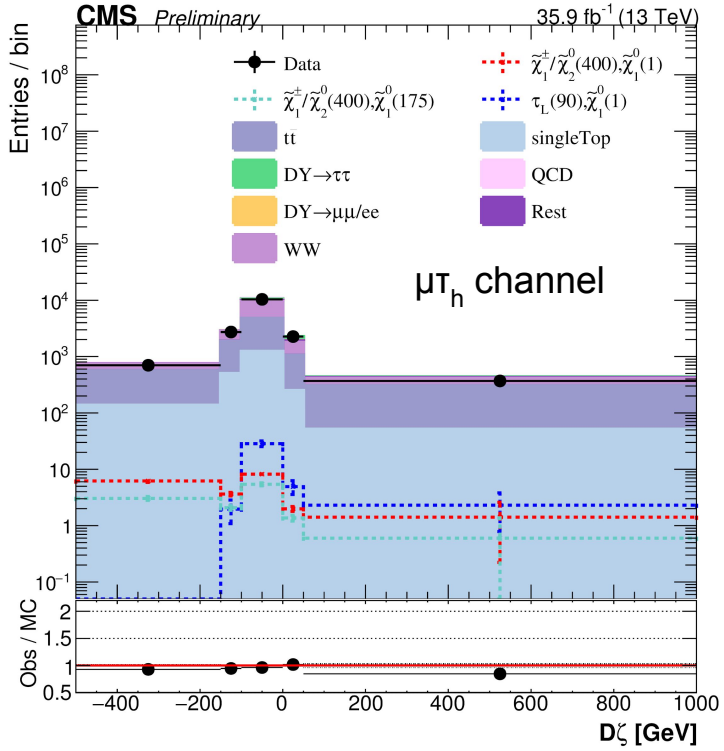
1) QCD or W+jets ("fake" τ): estimated from sideband region of loosely isolated τ.

2) Drell-Yan: simulation is corrected by scale factors derived in Z→μμ data control region.

τ pair production (semileptonic/dileptonic)

SUS-17-002 (CDS)

- Events with either an eμ OC pair or an hadronically decaying τ and a light lepton forming an OC pair.
- Veto b-tagged jets. Allow only up to one jet.

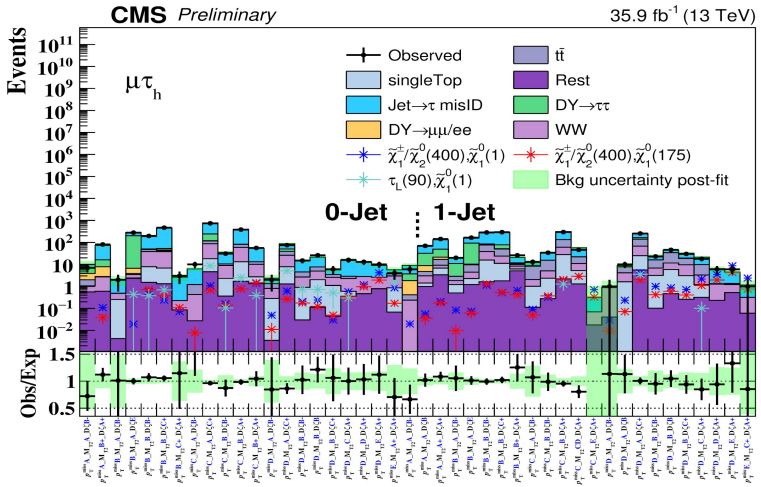


- ζ = bisector between the two leptons. Discriminant variables:

$$P_{\zeta,\mathrm{miss}} = \vec{p}_{\mathrm{T}}^{\mathrm{miss}} \cdot \vec{\zeta} \qquad P_{\zeta,\mathrm{vis}} = (\vec{p}_{\mathrm{T}}(\ell_1) + \vec{p}_{\mathrm{T}}(\ell_2)) \cdot \vec{\zeta}$$

$$D\zeta = P_{\zeta,\mathrm{miss}} - 0.85 P_{\zeta,\mathrm{vis}}$$

- Search strategy: 3D-bins of Dζ, p_T^{miss} and M_{T2} + jet categories.

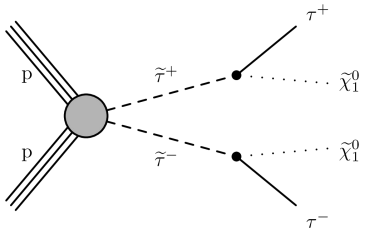


Tau pair production interpretations

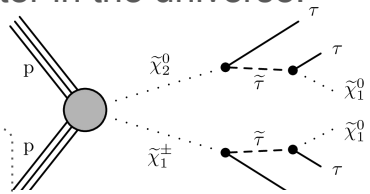
SUS-17-002 (CDS)

SUS-17-003 (CDS)

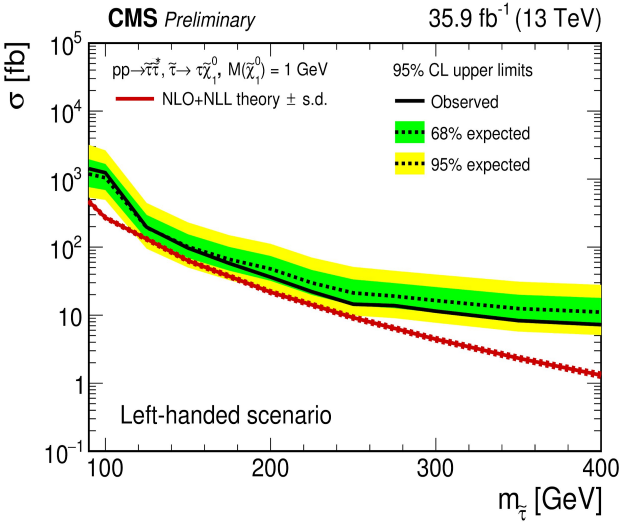
- Stau pair production model. Special interest in the compressed scenarios.
- $\tilde{\tau}\chi_1^0$ mechanism could explain the current observed relic density of dark matter in the universe.

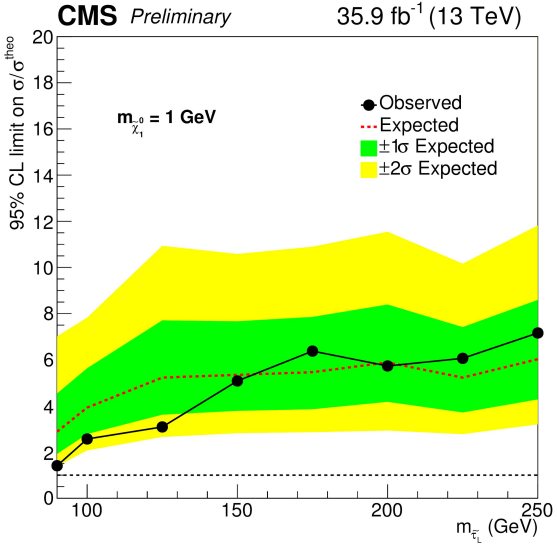


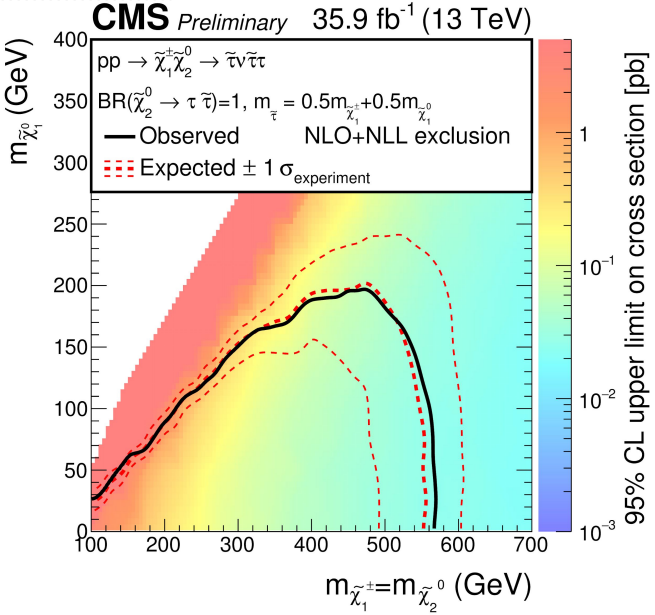
SUS-17-002 (CDS)



SUS-17-003 (CDS)







Chargino/neutralino pair production combination

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→ Statistical combination of all CMS analysis targeting direct decays of neutralino/chargino pairs to SM bosons (heavy sleptons electroweak SUSY scenarios). 6 main publications of CMS.

JHEP 11 (2017) 029

JHEP 03 (2018) 076

JHEP 03 (2018) 166

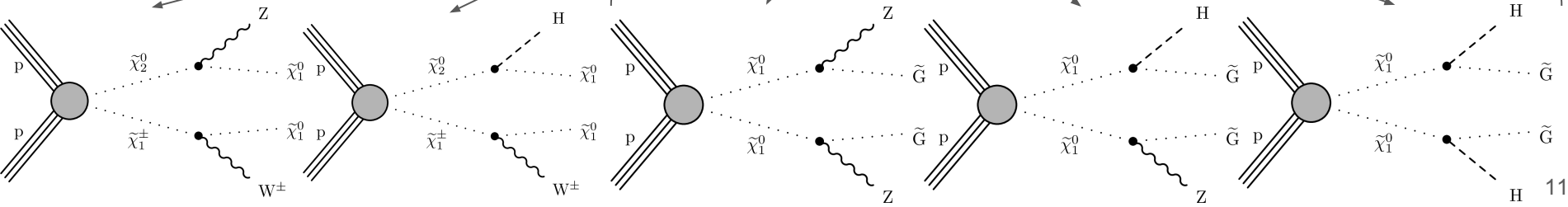
Search	Signal topology WZ	WH	ZZ	ZH	HH
1ℓ 2b		✓			
4b					✓
2ℓ on-Z	✓		✓	✓	
2ℓ soft	✓				
$\geq 3\ell$	✓	✓	✓	✓	✓
$H(\gamma\gamma)$		✓		✓	✓

Phys.Rev. D 97 (2018) 032007

Submitted to Phys. Lett. B

Phys. Lett. B 779 (2018) 166

GMSB models



Combined results

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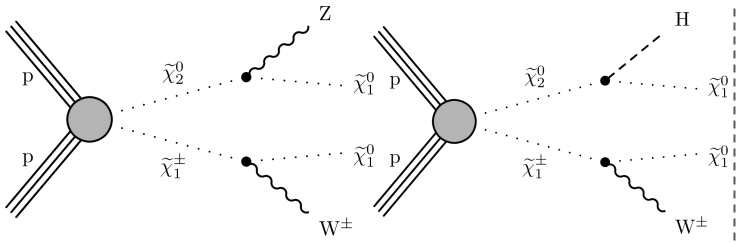
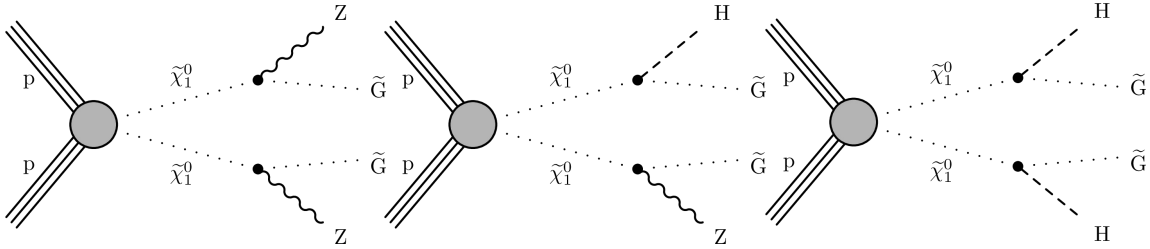
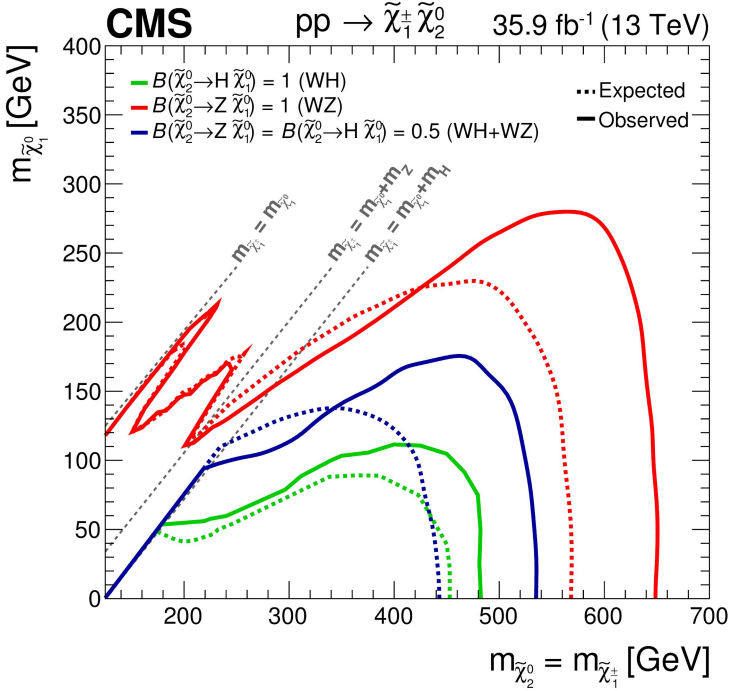
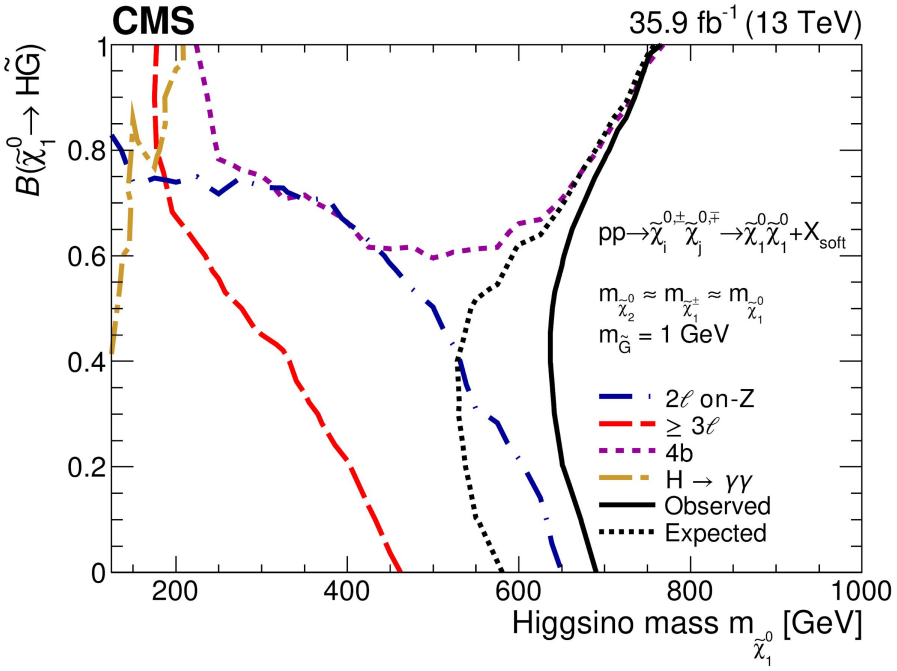
→ Setting even higher limits in the electroweak SUSY energy scale.









Conclusions

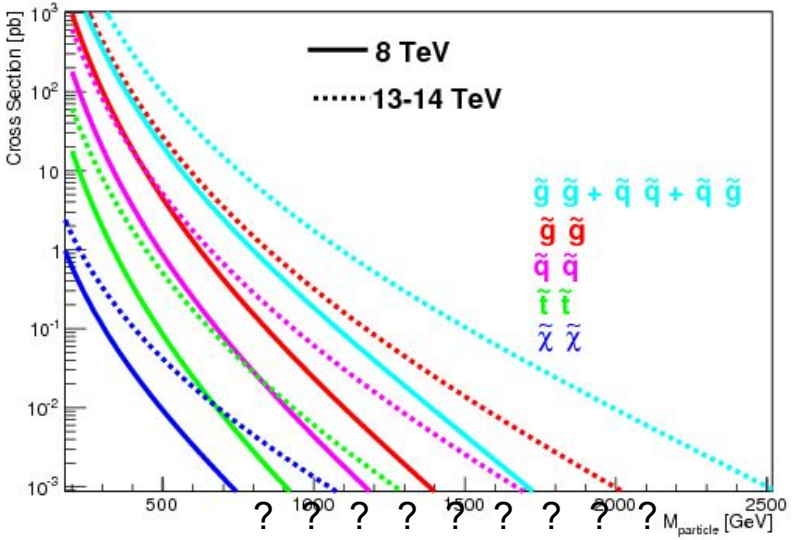
- Great quantity of new high quality results in SUSY searches during the last year.

- Constantly increasing our sensitivity, reaching new limits in our search for BSM physics.

- Expect the new data, both from 2017 and 2018, to provide further insight in our searches.

- What could be hiding close to the TeV scale?

- It's the time to study electroweak SUSY!



Back-Up

Multilepton final states

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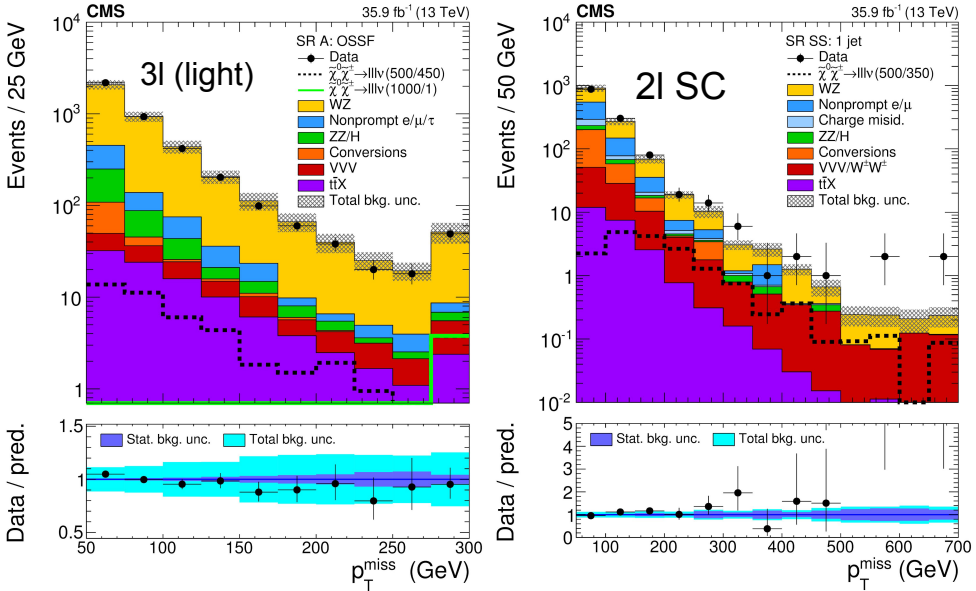
- Recent results (Moriond 2017) in slepton mediated chargino-neutralino decays.
- Events with 3 or more leptons (including taus) or a SC pair.

Category	Selection	Categorization
2l SC	$p_{\mathrm{T}}^{\mathrm{miss}} > 60\,\mathrm{GeV}$ $m_{ll} > 12\mathrm{GeV}$ $\lvert m_{l^+l^-}^{\mathrm{loose}} - m_{\mathrm{Z}}\rvert > 15\mathrm{GeV}$	30 SR $N_{\mathrm{jets}}, M_T(l), p_{\mathrm{T}}^{\mathrm{miss}}, p_{\mathrm{T}}^{ll}$
3 (l+τ)	$p_{\mathrm{T}}^{\mathrm{miss}} > 50\,\mathrm{GeV}$ $m_{ll} > 12\mathrm{GeV}$ $\lvert m_{3l} - m_{\mathrm{Z}}\rvert > 15\mathrm{GeV}$	108 SR $M_{ll}, M_T(l), p_{\mathrm{T}}^{\mathrm{miss}}, M_{T2}(l_1, l_2)$

High multiplicity of signal regions
Designed for increased sensitivity
to a broad range of SUSY models



- Specific treatments for background:

1) WZ: normalized to data in a dedicated control region. Dedicated studies on its uncertainty per signal region.

2) Non-prompt leptons: extrapolated from selection with looser lepton requirements. Lepton ID specifically designed for great reductions of the non-prompt presence.

Multilepton interpretations

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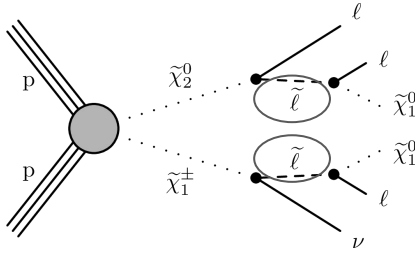
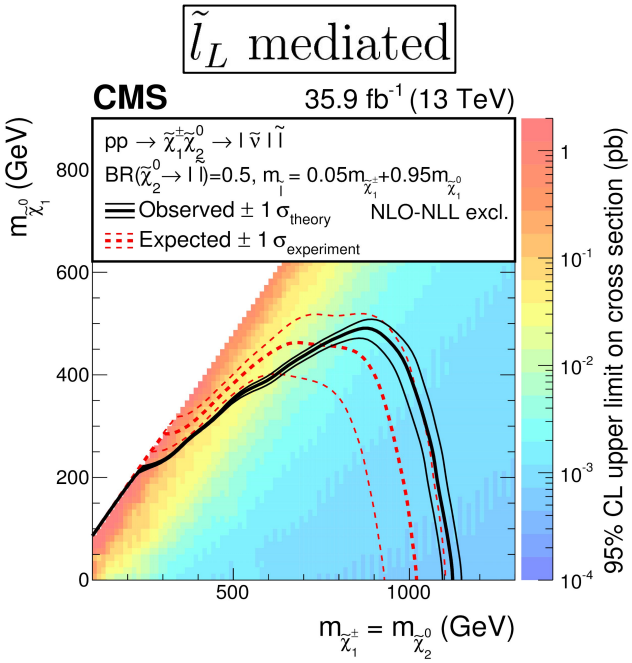
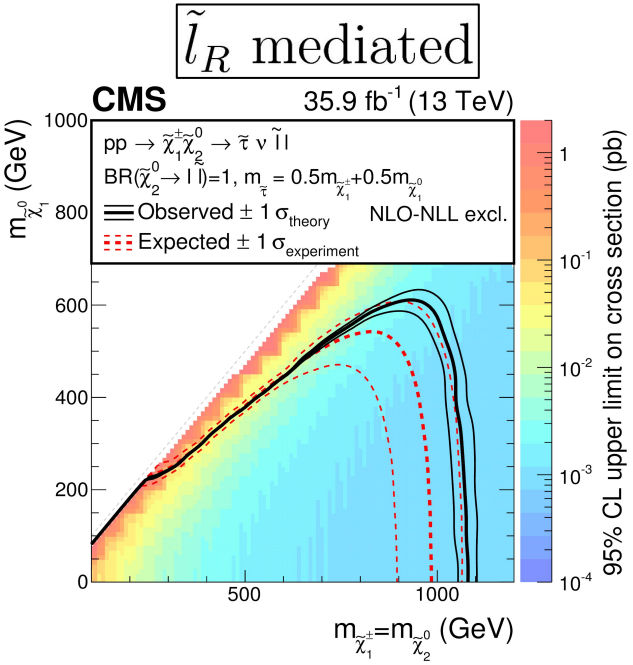
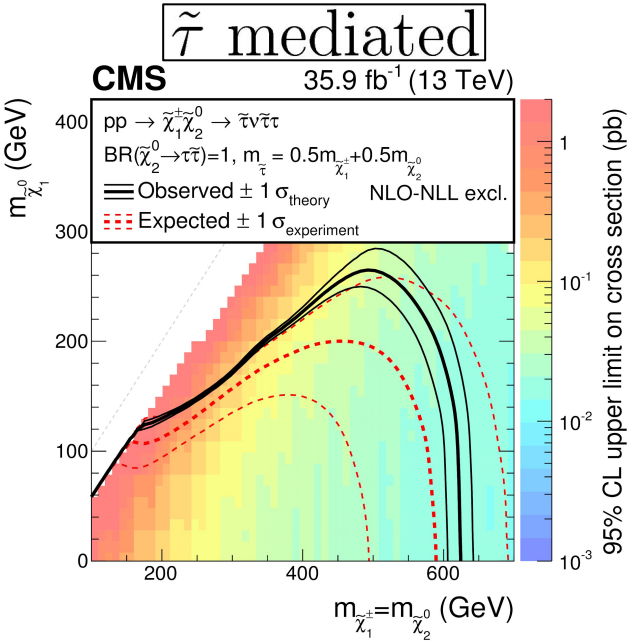
→ Multiple interpretations in the slepton mediated chargino-neutralino pair decay scenario based on the mass splitting of the particles and the preferred flavor and chirality of the mediating slepton.









Chargino/neutralino pair production combination

JHEP 03 (2018) 160

→ Statistical combination of all CMS analysis targeting direct decays of neutralino/chargino pairs to SM bosons (heavy sleptons electroweak SUSY scenarios). Results from 6 main publications of CMS as well as a new optimization.

	Search	Signal topology: WZ	WH	ZZ	ZH	HH
JHEP 11 (2017) 029	1ℓ 2b		✓			
Phys.Rev. D 97 (2018) 032007	4b					✓
Submitted to Phys. Lett. B	2ℓ on-Z	✓		✓	✓	
Phys. Lett. B 779 (2018) 166	2ℓ soft	✓				
JHEP 03 (2018) 166	$\geq 3\ell$	✓	✓	✓	✓	✓
Phys. Lett. B 779 (2018) 166	$H(\gamma\gamma)$		✓		✓	✓

→ (Very) Short summaries:

1) 1l + 2b: require additional high p_T^{miss}, includes a M_T cut (to decrease tt) and requires $m_{bb} \in [90,150]$ GeV. p_T^{miss} bins for signal extraction.

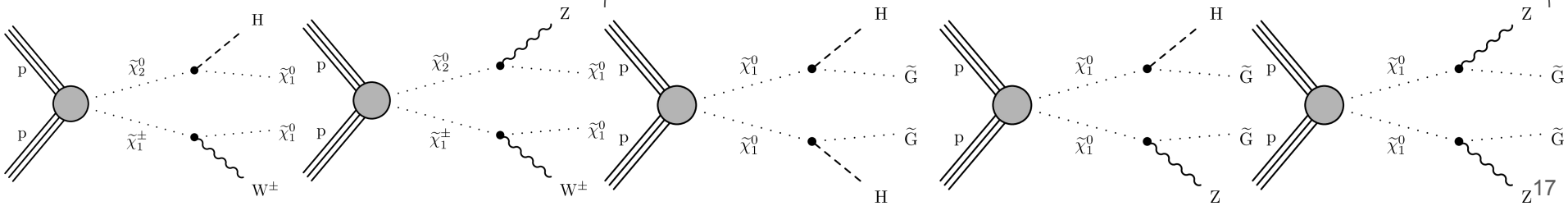
2) 4b: reconstructs the two H→bb masses and requires consistency between them. Categorizes in number of tightly b-tagged jets and mean measured Higgs' boson mass for signal extraction.

3) H→γγ: specific γγbb category sensitive to HH and HZ. Using razor variables as discriminant. Fit to the $m_{\gamma\gamma}$ spectrum.

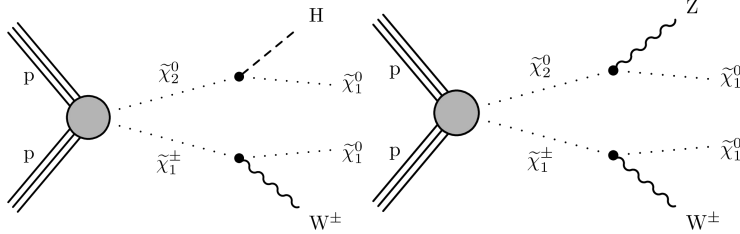
4) On-Z 2l: multiple categories (llqq and llbb) targeting different final state topologies. Uses p_T^{miss} bins for signal extraction.

-) ≥3l and soft 2l: more on the compressed SUSY talk.

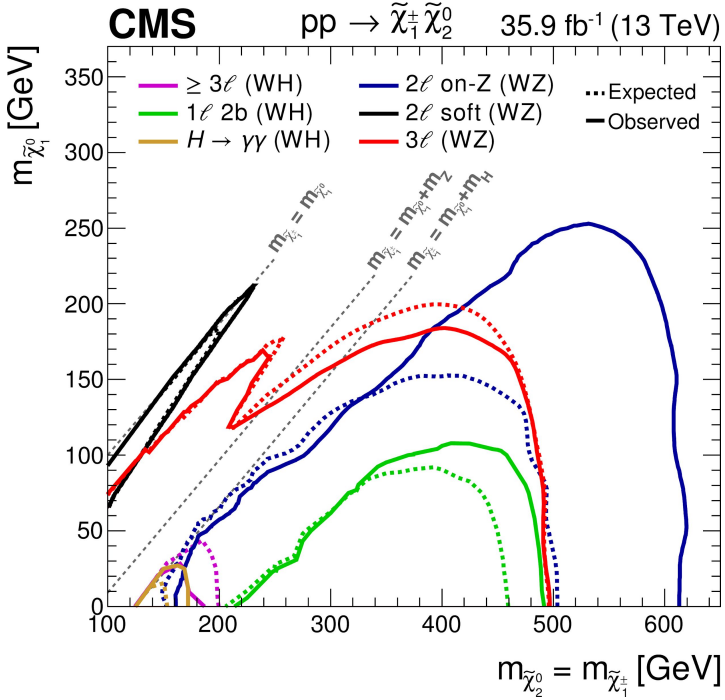
GMSB models

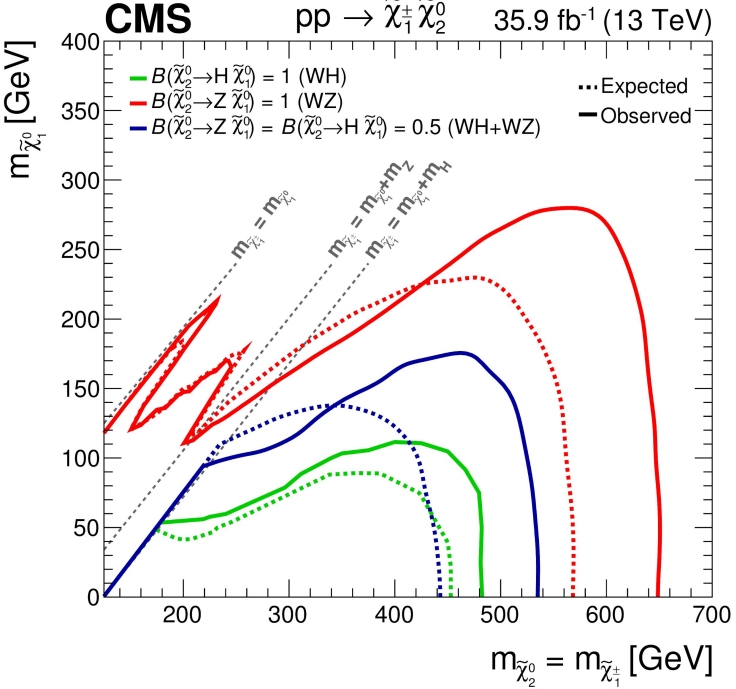


Chargino + neutralino interpretation

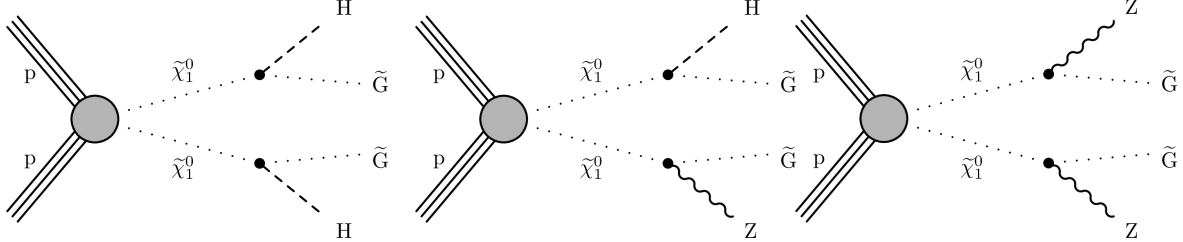


⇢ An additional reinterpretation of multiple analysis in terms of the mixed model between the two cases was also performed.





GMSB models interpretation



- Clear improvement from the combination is seen for the more Z-like neutralinos.
- Further reach in this specific channel is to be expected mostly from the 4b and on-Z 2l targeted searches.