Searches for Supersymmetry

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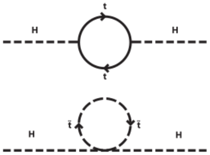
Synopsis

Why Supersymmetry

The most studied extension of the SM among any BSM theory. Advantages:



- Could solve the hierarchy problem through the one loop stop correction;
- Could unify the fundamental interactions of nature;
- Could provide a dark matter candidate, if R-Parity is conserved;

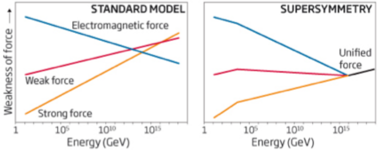
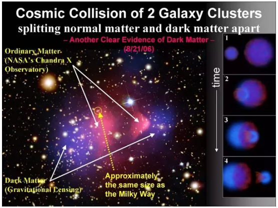


Figure 3 – Force unification in the Standard Model compared to supersymmetry
http://www.newscientist.com/data/images/ns/cms/dn20248/dn20248-2_534.jpg



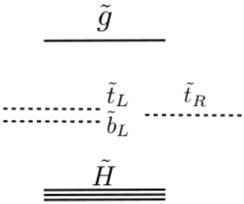
Naturalness guides most of the SUSY searches

- Naturalness requirement by the tree-level relation in MSSM:

$$\frac{-m_Z^2}{2} = |\mu|^2 + m_{H_u}^2$$

The masses of the superpartners with the closest ties to the Higgs must not be too far above the weak scale;

- Higgsinos should not be too heavy because their mass is controlled by μ;
- The stop and gluino masses, correcting $m_{H_u}^2$ at one and two-loop order, also cannot be too heavy.
- The masses of the rest of the superpartners, including the squarks of the first two generations, are not important for naturalness and can be out of the LHC reach;



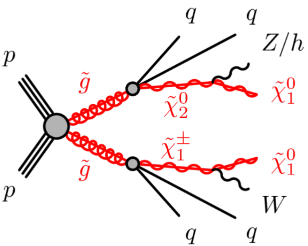
natural SUSY

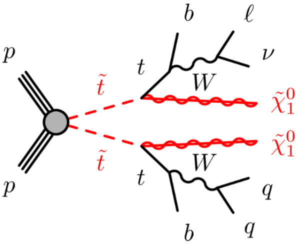
10.1007/JHEP09(2012)035,arXiv:1110.6926 [hep-ph]

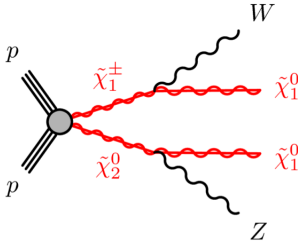
SUSY models considered in the searches

Simplified models are mostly used for event generation, optimization studies and for interpretation.

- Practical and minimal;
- Contain few parameters because they contain only a subset of new particles;
- Masses and decay modes of the particles under study are the only free parameters;
- The rest of the SUSY particles are set to masses beyond the LHC reach.







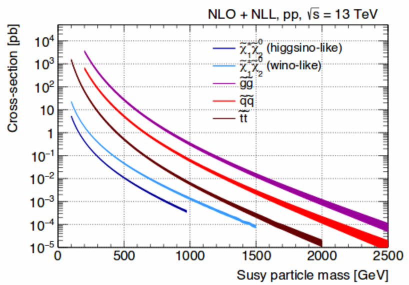
SUSY at the LHC

- Dedicated SUSY searches for all production mechanisms
    - strong production: squarks (1^{st} and 2^{nd} generation) and gluinos;

      Large cross sections, jetty environment
    - 3^{rd} generation: stops and sbottoms;

      two orders of magnitude smaller cross sections, presence of $b-$tagged jets
    - Electroweak: charginos, neutralinos and sleptons

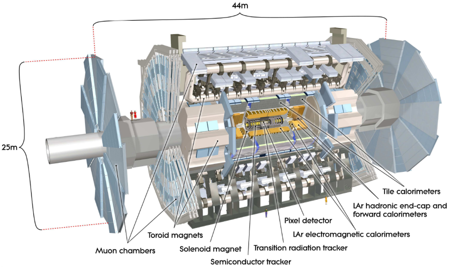
      significantly smaller cross sections, clean signatures with leptons

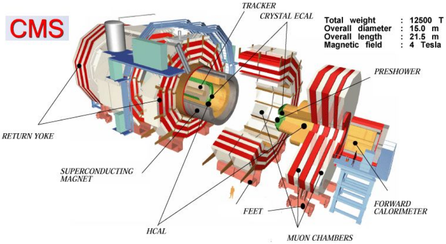


- Decay modes
    - Extensive coverage of signatures;
    - Simple to complex final states including prompt and long-lived particle decays;
    - $R-$Parity conserved and violated;
- Simplified models for model-dependent exclusion limits.
- Model-independent upper limits, HEP data
- Interpretation on more realistic models (pMSSM) is also provided at the end of a Run.

CMS and ATLAS experiments

- General purpose detectors;





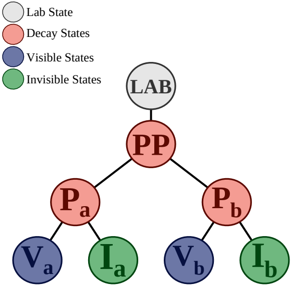
- Rich program on SUSY searches from both ATLAS and CMS;
- ATLAS public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
- CMS public results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

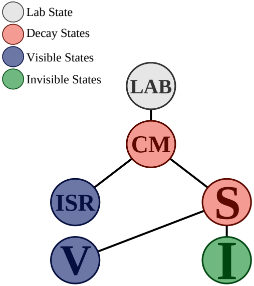
SUSY search strategies at the LHC

- Identify the signal hypothesis and the signature (final state) to be studied;
    - The signal hypothesis can be any of the SUSY production mechanisms;
    - A given signal hypothesis is studied in different final states (lepton and/or jet multiplicities and missing transverse momentum) depending on the decay modes of the unstable particles;
- Design triggers to most efficiently collect data with the target characteristics;
- Use the objects defining the final state to construct kinematic variables (discriminants);
- Design signal regions (SR) sensitive to the signal hypothesis;
    - Simple cut and count analysis (regions are inclusive);
    - Exclusive (binned) SR based on the shape of a given variable (m_{T2});
    - Recursive Jigsaw Reconstruction (reference frames);
    - Machine learning with multivariate analysis approach;
- Careful examination and evaluation of the systematic uncertainties;
- Estimation of the SM backgrounds.

Recursive Jigsaw reconstruction

A method for decomposing measured properties event-by-event to provide a basis of kinematic variables. Achieved by approximating the rest frames of intermediate particle states in each event.





- Assign reconstructed objects to the two hemispheres of the decay trees (mass minimization);
- A natural basis of kinematic observables calculated by recursively evaluating the momentum and energy of different objects in these reference frames.

Phys. Rev. D 96 (2017) 11200
Phys. Rev. D 95, 035031 (2017)

Background estimation strategies

Caveat: This is the norm but there are quite a few exceptions

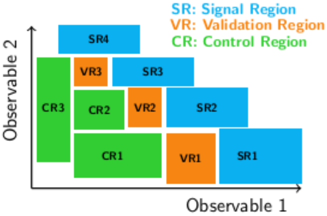
Reducible background

Receives contributions from non-prompt leptons. Estimation based on data-driven techniques (Matrix Method, Fake Factor);

Irreducible backgrounds

Normalize Monte Carlo predictions ($t\bar{t}, VV, ..$) to data in dedicated Control Regions (CR);

- Extracted Normalization Factor (NF) is validated in Validation Regions(VR);
- Final background estimation comes from a simultaneous likelihood fit of Signal Regions (SR) and CR;


SR: Signal Region
VR: Validation Region
CR: Control Region

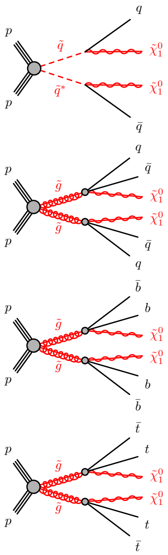
Backgrounds producing "fake" $E_{\mathrm{T}}^{\mathrm{miss}}$ due to jet mismeasurement

Contributions from this category are suppressed by requiring the jets and $E_{\mathrm{T}}^{\mathrm{miss}}$ to not point in the same direction ($\Delta\phi(jets, E_{\mathrm{T}}^{\mathrm{miss}})$)

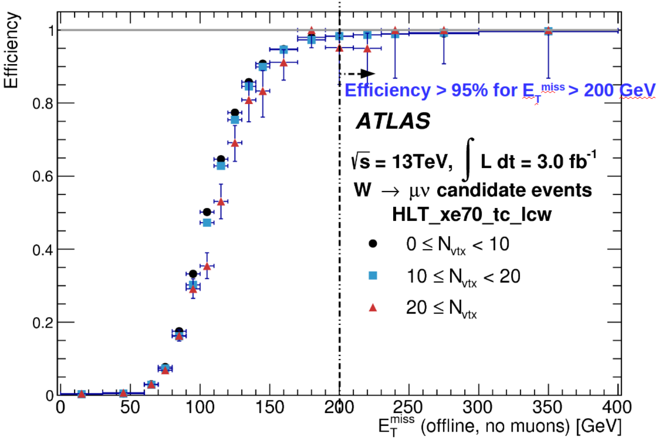
Small backgrounds

Contributions from these sources are taken directly from Monte Carlo predictions.

Searches for squarks and gluinos

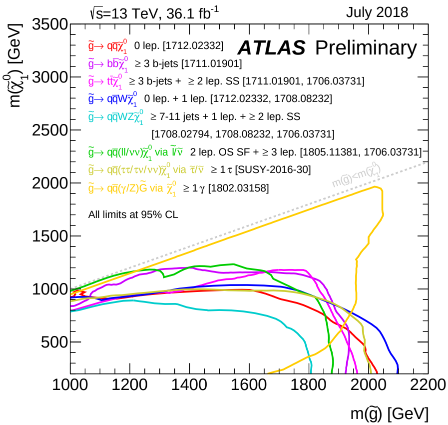


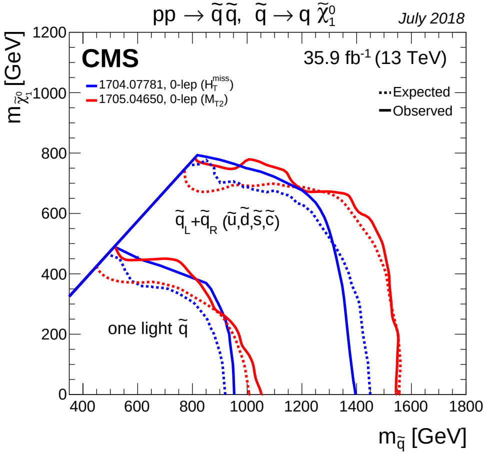
Strongly produced → high jet activity
Event selection based on $E_{\mathrm{T}}^{\mathrm{miss}}$ triggers



Efficiency > 95% for $E_{\mathrm{T}}^{\mathrm{miss}}$ > 200 GeV

Summary plots for squarks and gluinos



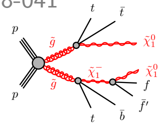


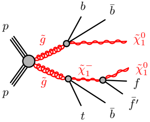
- Gluino masses up to 2 TeV are excluded at 95% CL;
  With 300 fb^{-1} at $\sqrt{s}$ =14 TeV limits are expected to reach 2.4 TeV
- Squark masses up to around 1.6 TeV are excluded at 95% CL;
  With 300 fb^{-1} at $\sqrt{s}$ =14 TeV limits are expected to reach 1.8 TeV

NO significant improvements are expected with the full Run II dataset

Searches for gluinos

ATLAS-CONF-2018-041





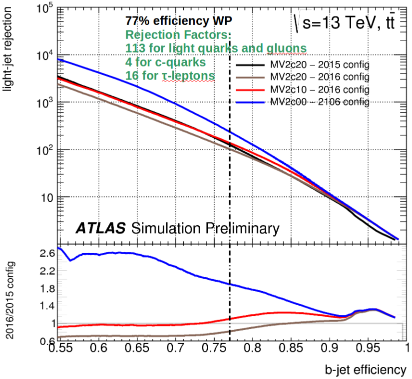
Search for gluino pair production in multi-b jet and 0/1-lepton final state with $\boldsymbol{L} = \mathbf{80~fb^{-1}}$

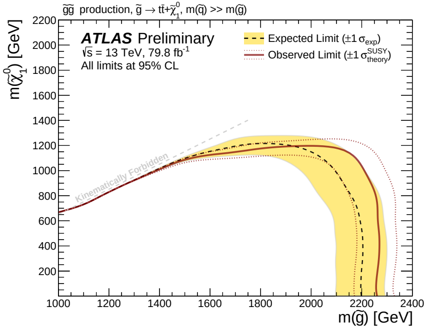
Variable gluino branching ratio: $\tilde{g} \to t\bar{b}\tilde{\chi}_1^-$, $\tilde{\chi}_1^- \to ff'\tilde{\chi}_1^0$, $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$, $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$

Mass difference between $\tilde{\chi}_1^-$ and $\tilde{\chi}_1^0$ is fixed to 2 GeV

Analysis strategies: inclusive cut and count and multi-bin;

Main bkg: $t\bar{t}$ in association with heavy and light flavour jets





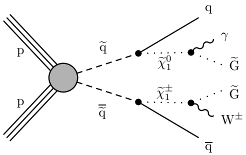
Search for GMSB in $1\ell + 1\gamma + E_{\mathrm{T}}^{\mathrm{miss}}$

CMS-PAS-SUS-17-012

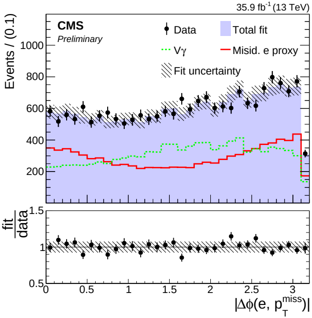
Search for both strong and EWKino production

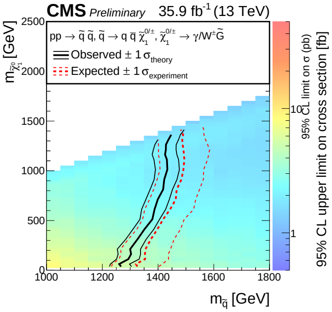
Dominant bkgs

- Jet misidentified as photon, or photon originating from nearby vertex;
- Jet misidentified as lepton, non-prompt leptons;



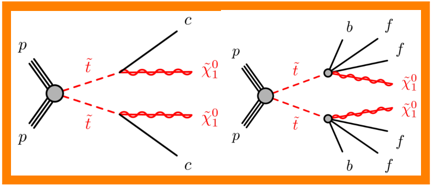
- Electroweak processes $W\gamma$ and $Z\gamma$, $E_{\mathrm{T}}^{\mathrm{miss}}$ shape taken from simulation and normalization is determined by a two-component signal plus bkg template fit



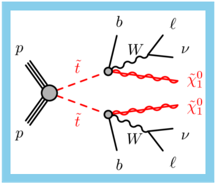


Searching for stop quarks

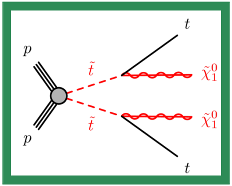
Compressed region Four-body decays

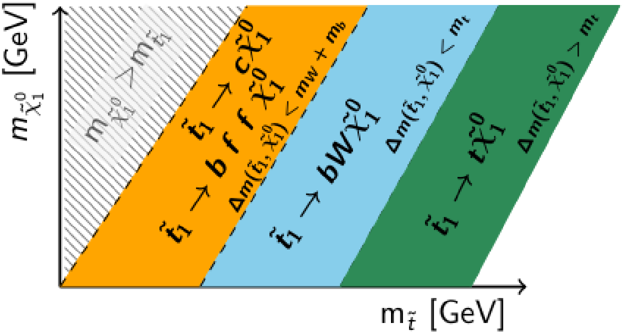


Intermediate mass Three-body decays

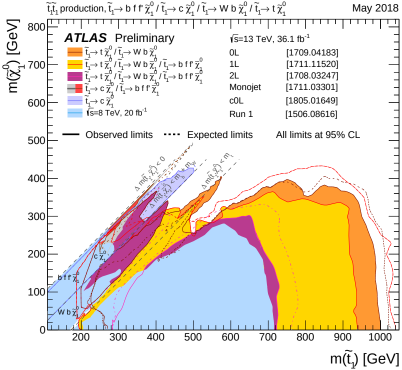


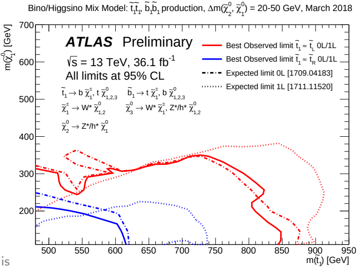
High Mass Boosted topologies





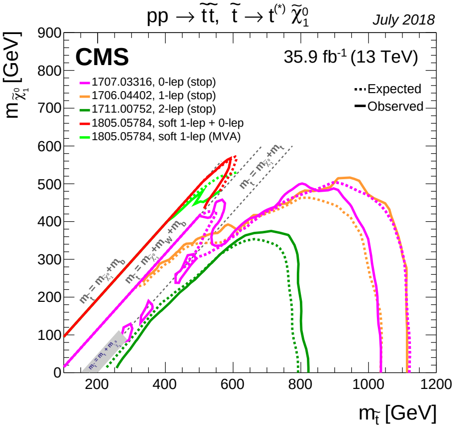
ATLAS stop summary plot

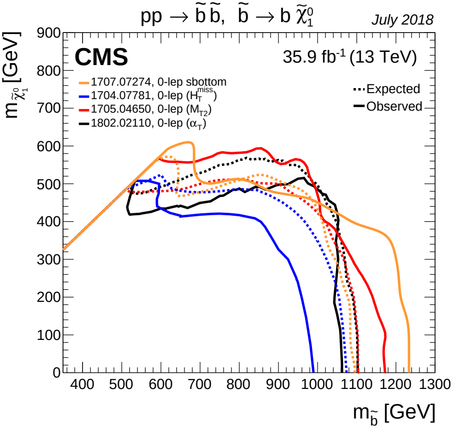




- Dedicated stop searches for each region of the 2D $m_{\tilde{t}} - m_{\tilde{\chi}^0_1}$ plane
- Stop branching ratios are 100%.
- Most difficult regions are in the transition regions $m_{\tilde{t}} - m_{\tilde{\chi}^0_1} = m_t$ and $m_{\tilde{t}} - m_{\tilde{\chi}^0_1} = m_W$
- Limits become weaker as the neutralino mass increases;
- Interpretations are also provided for well tempered neutralino;
- Weaker limits in Bino/Higgsino LSP models with compressed mass spectra.

CMS stop and sbottom summary plots





- Similar sensitivities and exclusion contours from CMS at high mass, while in the compressed regon CMS has better sensitivity mostly due to the lower p_T thresholds of leptons;
  With 300 fb^{-1} at $\sqrt{s} = 14$ TeV limits will be around 1.2 TeV
- Stops (sbottoms) with masses up to 1.1 (1.2) TeV are excluded at 95% CL;
  With 300 fb^{-1} at $\sqrt{s}$ =14 TeV limits are expected to be close 1.4 TeV

NO significant improvements are expected with the full Run 2 dataset

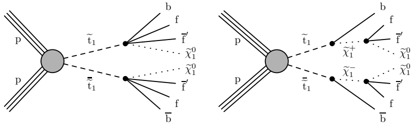
Stop in compressed scenarios

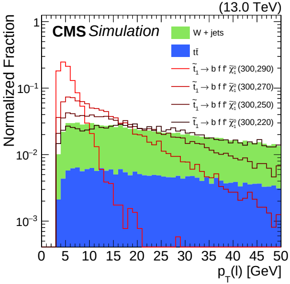
CMS-SUS-17-005

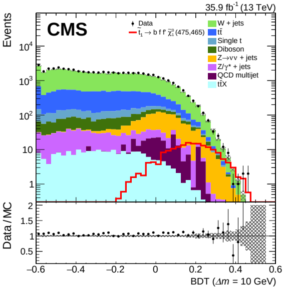
Search for stops with $m_{\tilde{t}} - m_{\tilde{\chi}_1^0} < m_W$;

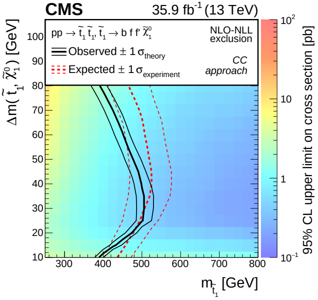
Events are selected with an highly energetic ISR jet, large $E_{\mathrm{T}}^{\mathrm{miss}}$ and soft leptons ($p_T > 3.5$ GeV).

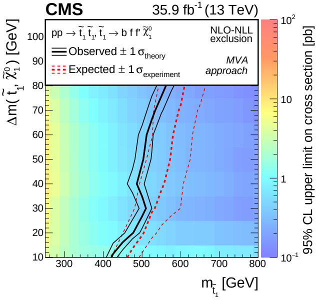
Two analysis techniques: a sequential selection and a multivariate technique (BDT)











ATLAS:1805.01649 (charm tagging)

Searches for sbottom

ATLAS-CONF-2018-040

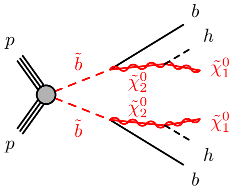
Searches performed with $\boldsymbol{L = 80\ \mathrm{fb}^{-1}}$

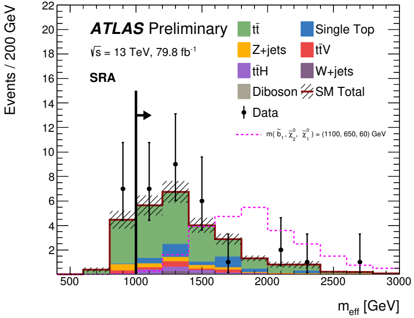
Signature with at least three b-tag jets.

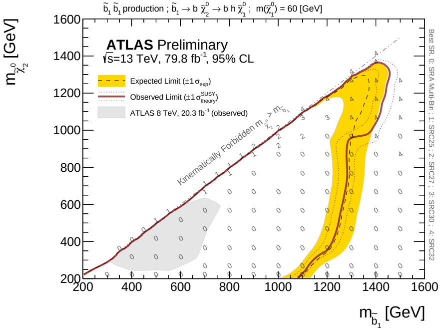
Signal regions for both boosted and compressed topologies.

Main bkgs from $t\bar{t}$ and $Zb\bar{b}$ production. MC normalized to data in CRs.

Dominant unc.: Theoretical and modeling unc. of $t\bar{t}$ and $Zb\bar{b}$ (11%-22%)

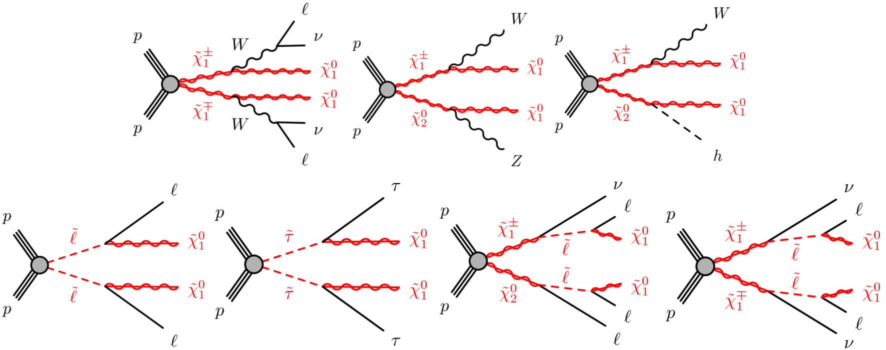


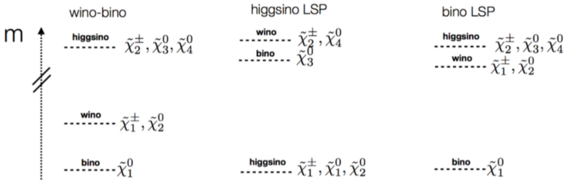




Searches for electroweak SUSY

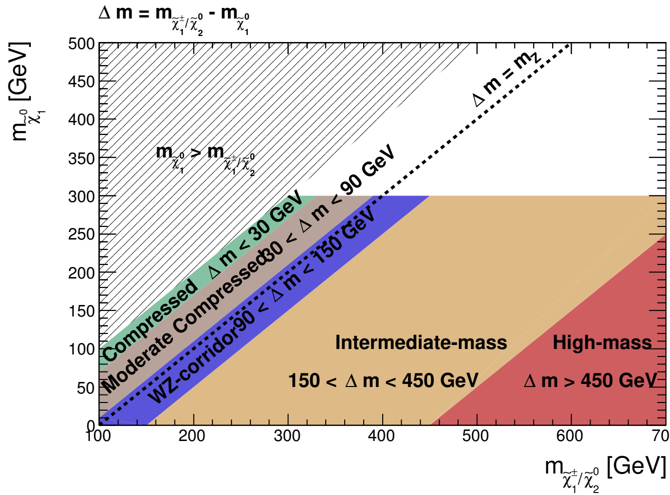
Small cross-sections, low jet activity, clean signatures with leptons





- Higgsinos expected to be light in natural SUSY
- For pure Higgsino LSP mass splitting can be as small as $\mathcal{O}(100)$ MeV.

The workhorse for EWK production - $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow WZ\tilde{\chi}_1^0\tilde{\chi}_1^0$

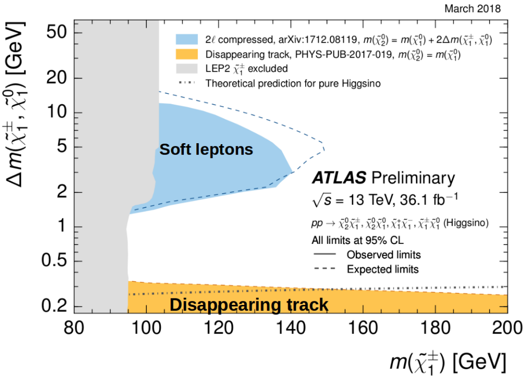


Compressed Very soft leptons $m_{\ell\ell}$ edge	**Moderate Compressed** Take advantage of the $m_{\ell\ell}$ edge	**WZ-Corridor** tough final state products similar to SM	**Int mass** less E_T^{miss} rely on scaleless variables	**High mass** Low cross-sections boosted objects

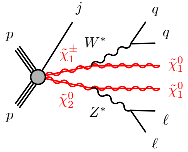
Searching for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ in compressed scenarios

In "natural" SUSY models, Higgsinos should be light

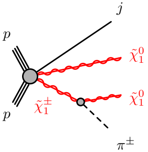
- Searches from both ATLAS and CMS
  2-lepton soft: CMS:1801.01846, ATLAS:1712.08119
  Main background: fake and non-prompt leptons
- Disappearing track: ATLAS:1712.02118

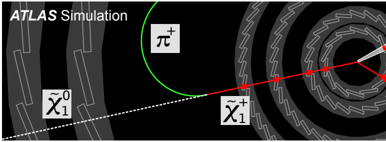


Challenging signatures due to soft leptons (p_T >3.5 GeV)



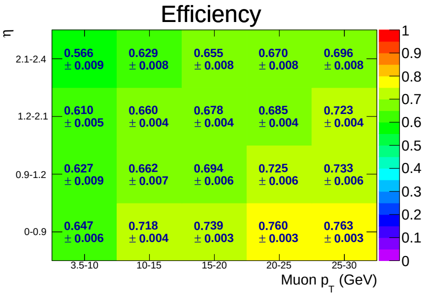
Search for long-lived $\tilde{\chi}_1^\pm$ through disappearing track signature



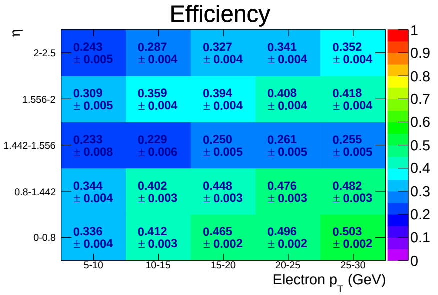


Soft lepton efficiencies

Link to CMS soft lepton performance



η	3.5-10	10-15	15-20	20-25	25-30
2.1-2.4	0.566 ± 0.009	0.629 ± 0.008	0.655 ± 0.008	0.670 ± 0.008	0.696 ± 0.008
1.2-2.1	0.610 ± 0.005	0.660 ± 0.004	0.678 ± 0.004	0.685 ± 0.004	0.723 ± 0.004
0.9-1.2	0.627 ± 0.009	0.662 ± 0.007	0.694 ± 0.006	0.725 ± 0.006	0.733 ± 0.006
0-0.9	0.647 ± 0.006	0.718 ± 0.004	0.739 ± 0.003	0.760 ± 0.003	0.763 ± 0.003



η	5-10	10-15	15-20	20-25	25-30
2-2.5	0.243 ± 0.005	0.287 ± 0.004	0.327 ± 0.004	0.341 ± 0.004	0.352 ± 0.004
1.556-2	0.309 ± 0.005	0.359 ± 0.004	0.394 ± 0.004	0.408 ± 0.004	0.418 ± 0.004
1.442-1.556	0.233 ± 0.008	0.229 ± 0.006	0.250 ± 0.005	0.261 ± 0.005	0.255 ± 0.005
0.8-1.442	0.344 ± 0.004	0.402 ± 0.003	0.448 ± 0.003	0.476 ± 0.003	0.482 ± 0.003
0-0.8	0.336 ± 0.004	0.412 ± 0.003	0.465 ± 0.002	0.496 ± 0.002	0.503 ± 0.002

- The efficiency refers to the reconstruction + identification + isolation + vertexing requirements for generator-level leptons from *W* decay in a simulated sample of ttbar events;
- Soft muons (56% - 65%), Soft electrons (24% - 34%)
- Improving the efficiencies on soft leptons could have a significant impact in our searches for scenarios with compressed spectra.

Searching for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to WZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ through RJR

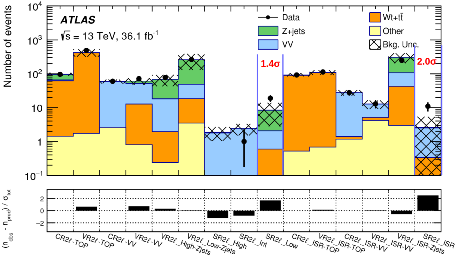
1806.02293

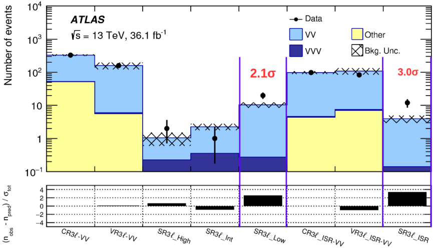
An extensive search for charginos and neutralinos decaying to on-shell W and Z.

$[2\ell, 3\ell]\times[\text{High,Int,Low,ISR}]=8$ SRs

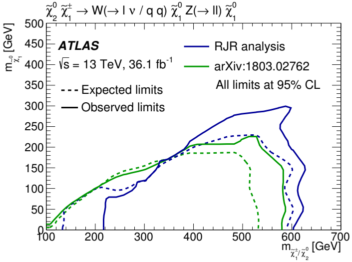
Moderate excesses observed in the **Low** and **ISR** regions.

Low and ISR SRs contain mutually exclusive events





Statistical combination of the two- and three-lepton SRs



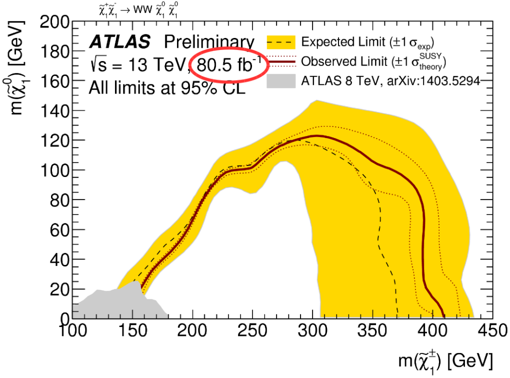
Excess not present in previous ATLAS search 1803.02762

BUT the two searches select different kind of events see back-up

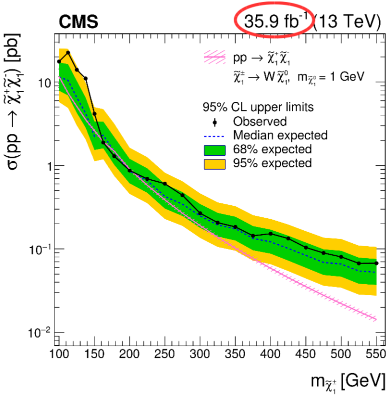
Search for pair production of charginos

- $\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow WW\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow 2\ell + E_{\mathrm{T}}^{\mathrm{miss}}$
- Both ATLAS and CMS use $\boldsymbol{m_{T2}}$ **as the main discriminant** of the analysis

ATLAS-CONF-2018-042



CMS:1807.07799

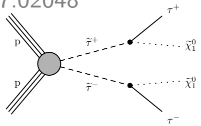


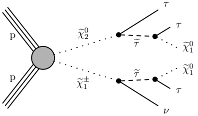
- Better sensitivity from ATLAS due to the statistically larger sample

Search for stau production

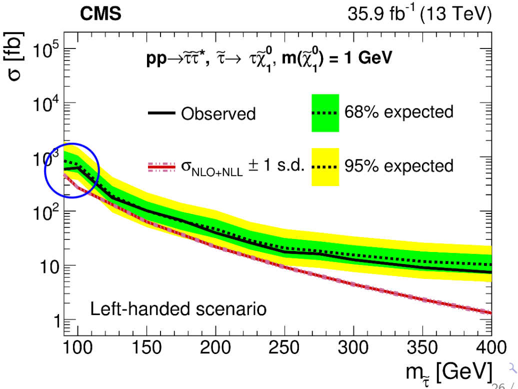
1807.02048

- A comprehensive search for processes involving staus;
- Two tau final states, with both leptonic and hadronic decays
- Light stau and small Δm can yield right DM relic density via stau-neutralino coannihilation.



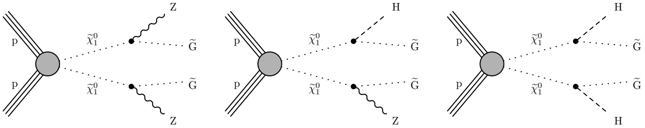


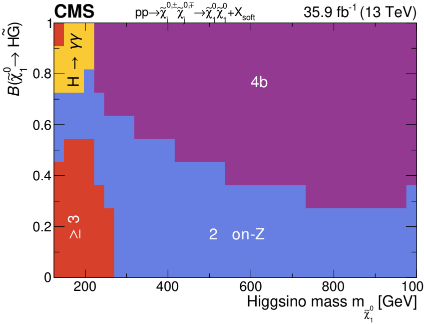
- Limiting factors for direct stau production: small production cross-section, statistical uncertainties in the control samples, experimental unc. (JES/JER, uncluster energy contributing to $E_{\mathrm{T}}^{\mathrm{miss}}$)
- Strongest limits achieved for a left handed $\tilde{\tau}$ scenario of 90 GeV ($1.26\times\sigma_{NLO+NLL}$).

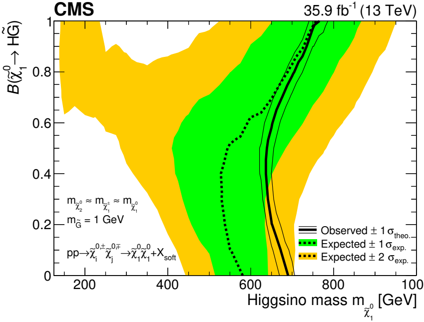


Search for Higgsinos in GMSB scenarios

CMS:1801.03957







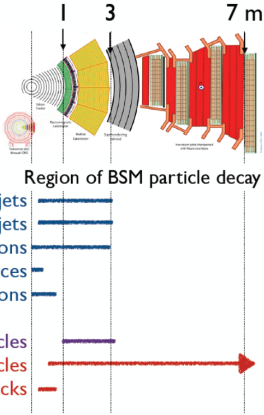
- The $4b$ search drives the exclusion at large values of $\mathcal{B}(\tilde{\chi}_1^0\to H\tilde{G})$;
- on-Z dilepton and multilepton searches are competing at lower values of $\mathcal{B}(\tilde{\chi}_1^0\to H\tilde{G})$
- ATLAS:1806.04030 (4b), 1804.03602 (4ℓ)

Searches for RPV SUSY and long lived particles

- Many viable RPV scenarios; LSP decays→no large $E_{\mathrm{T}}^{\mathrm{miss}}$
- Challenging signatures due to the different decay topologies, triggering..
- Searches for non-prompt particles complement the prompt searches.
- Long-lived particles can also arise in RPC SUSY e.g. from decays via very virtual particles (split SUSY) or very compressed mass spectra.
- Reduced SM background outside the beamspot. Contributions arise from detector noise, cosmic rays, reconstruction failure...estimated from data-driven techniques

Non-prompt signatures and target models:

from W. Wulsin



Region of BSM particle decay

displaced jets → Hidden valley, RPV SUSY, stealth SUSY
lepton jets → dark photons
displaced leptons → Hidden valley, RPV SUSY, displaced SUSY
displaced vertices → Split SUSY, RPV, GMSB
displaced / delayed photons → GMSB

stopped particles → split SUSY gluino, stop, ...
heavy stable charged particles → gluino, stop, GMSB slepton, chargino ...
disappearing tracks → degenerate chargino

Seach for gluino $R-$hadron LLP

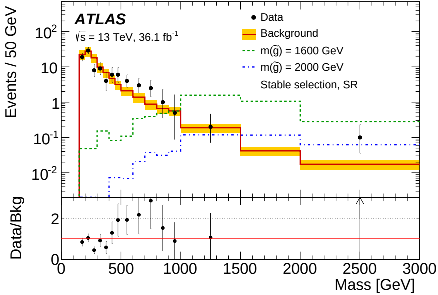
ATLAS:1808.04095

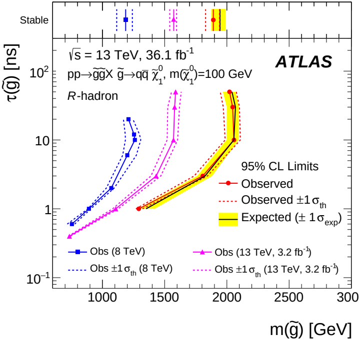
Measure ionisation energy loss (dE/dx) in the pixel detector to search for stable and metastable non-relativistic long-lived particles;

SRs: one sensitive to decaying $R-$hadrons and one for stable ones;

Background estimed from data and covers both the rate of high momentum tracks in events with large $E_{\mathrm{T}}^{\mathrm{miss}}$ and the probability of measuring a high ionisation energy for those tracks;

Results are interpreted assuming the pair production of $R-$hadrons as composite colourless states of a long-lived gluino and SM partons.





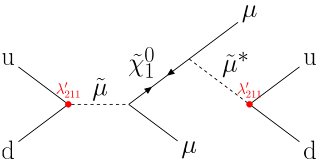
Second generation slepton production

CMS-PAS-SUS-17-008

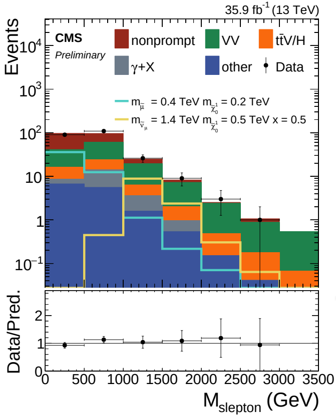
Search for resonant production of second generation sleptons via RPV coupling.

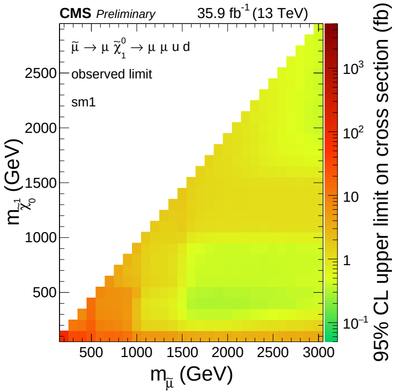
Final state with two same-sign muons and at least two jets.

SRs binned in $M_{slepton} = m_{\mu\mu+jets}$ and $M_{\tilde{\chi}_1^0} = m_{\mu_2 j_1 j_2}$



simplified model 1



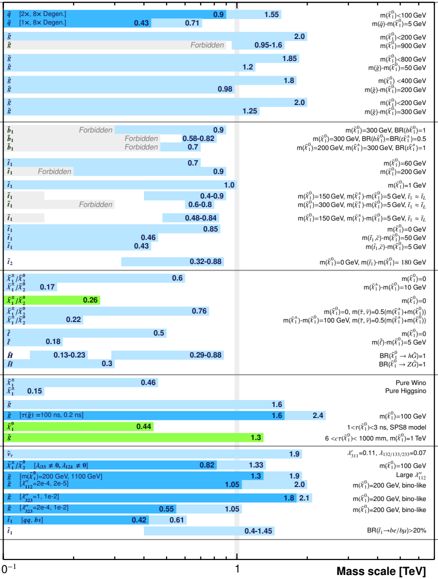


ATLAS SUSY Searches* - 95% CL Lower Limits

July 2018

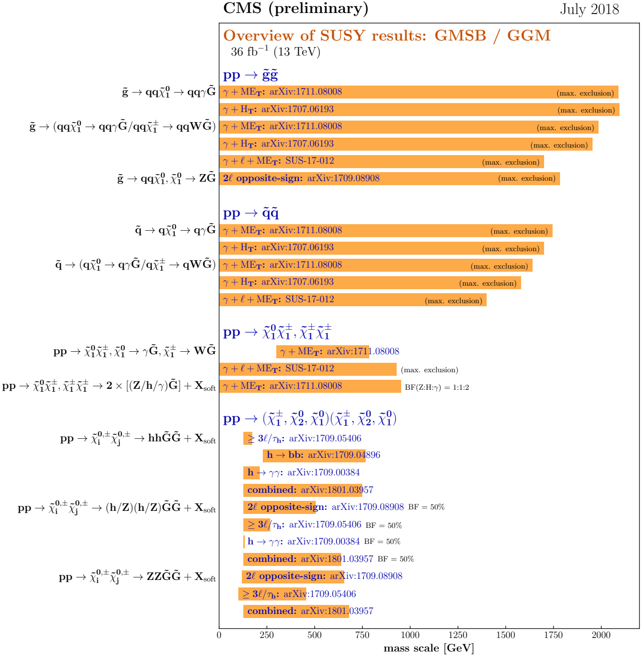
ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV



	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$	0	2-6 jets	Yes	36.1	$\tilde{q}$ [2×, 8× Degen.] 0.9 1.55	m($\tilde{\chi}^0_1$)<100 GeV	1712.02332
		mono-jet	1-3 jets	Yes	36.1	$\tilde{q}$ [1×, 8× Degen.] 0.43 0.71	m($\tilde{q}$)-m($\tilde{\chi}^0_1$)=5 GeV	1711.03301
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0	2-6 jets	Yes	36.1	$\tilde{g}$ 2.0	m($\tilde{\chi}^0_1$)<200 GeV	1712.02332
						$\tilde{g}$ Forbidden 0.95-1.6	m($\tilde{\chi}^0_1$)=900 GeV	1712.02332
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}^0_1$	3 e, μ	4 jets	-	36.1	$\tilde{g}$ 1.85	m($\tilde{\chi}^0_1$)<800 GeV	1706.03731
		$ee, \mu\mu$	2 jets	Yes	36.1	$\tilde{g}$ 1.2	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=50 GeV	1805.11381
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}^0_1$	0	7-11 jets	Yes	36.1	$\tilde{g}$ 1.8	m($\tilde{\chi}^0_1$) <400 GeV	1708.02794
		3 e, μ	4 jets	-	36.1	$\tilde{g}$ 0.98	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=200 GeV	1706.03731
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e, μ	3 b	Yes	36.1	$\tilde{g}$ 2.0	m($\tilde{\chi}^0_1$)<200 GeV	1711.01901
		3 e, μ	4 jets	-	36.1	$\tilde{g}$ 1.25	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=300 GeV	1706.03731
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_1/t\tilde{\chi}^\pm_1$		Multiple		36.1	$\tilde{b}_1$ Forbidden 0.9	m($\tilde{\chi}^0_1$)=300 GeV, BR($b\tilde{\chi}^0_1$)=1	1708.09266, 1711.03301
			Multiple		36.1	$\tilde{b}_1$ Forbidden 0.58-0.82	m($\tilde{\chi}^0_1$)=300 GeV, BR($b\tilde{\chi}^0_1$)=BR($t\tilde{\chi}^\pm_1$)=0.5	1708.09266
			Multiple		36.1	$\tilde{b}_1$ Forbidden 0.7	m($\tilde{\chi}^0_1$)=200 GeV, m($\tilde{\chi}^\pm_1$)=300 GeV, BR($t\tilde{\chi}^\pm_1$)=1	1706.03731
	$\tilde{b}_1\tilde{b}_1, \tilde{t}_1\tilde{t}_1$, $M_2 = 2\times M_1$		Multiple		36.1	$\tilde{t}_1$ 0.7	m($\tilde{\chi}^0_1$)=60 GeV	1709.04183, 1711.11520, 1708.03247
			Multiple		36.1	$\tilde{t}_1$ Forbidden 0.9	m($\tilde{\chi}^0_1$)=200 GeV	1709.04183, 1711.11520, 1708.03247
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	0-2 e, μ	0-2 jets/1-2 b	Yes	36.1	$\tilde{t}_1$ 1.0	m($\tilde{\chi}^0_1$)=1 GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1$, $\tilde{H}$ LSP		Multiple		36.1	$\tilde{t}_1$ 0.4-0.9	m($\tilde{\chi}^0_1$)=150 GeV, m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=5 GeV, $\tilde{t}_1 \approx \tilde{t}_L$	1709.04183, 1711.11520
			Multiple		36.1	$\tilde{t}_1$ Forbidden 0.6-0.8	m($\tilde{\chi}^0_1$)=300 GeV, m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=5 GeV, $\tilde{t}_1 \approx \tilde{t}_L$	1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1$, Well-Tempered LSP		Multiple		36.1	$\tilde{t}_1$ 0.48-0.84	m($\tilde{\chi}^0_1$)=150 GeV, m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=5 GeV, $\tilde{t}_1 \approx \tilde{t}_L$	1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}$, $\tilde{c}\to c\tilde{\chi}^0_1$	0	2c	Yes	36.1	$\tilde{t}_1$ 0.85	m($\tilde{\chi}^0_1$)=0 GeV	1805.01649
						$\tilde{t}_1$ 0.46	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=50 GeV	1805.01649
		0	mono-jet	Yes	36.1	$\tilde{t}_1$ 0.43	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=5 GeV	1711.03301
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + h$	1-2 e, μ	4 b	Yes	36.1	$\tilde{t}_2$ 0.32-0.88	m($\tilde{\chi}^0_1$)=0 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)= 180 GeV	1706.03986
EW direct	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via WZ	2-3 e, μ	-	Yes	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.6	m($\tilde{\chi}^0_1$)=0	1403.5294, 1806.02293
		$ee, \mu\mu$	≥ 1	Yes	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.17	m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=10 GeV	1712.08119
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via Wh	$\ell\ell/\ell\gamma\gamma/\ell bb$	-	Yes	20.3	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.26	m($\tilde{\chi}^0_1$)=0	1501.07110
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2$, $\tilde{\chi}^+_1\to\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}^0_2\to\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.76	m($\tilde{\chi}^0_1$)=0, m($\tilde{\tau}$, $\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	1708.07875
						$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.22	m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=100 GeV, m($\tilde{\tau}$, $\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	1708.07875
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e, μ	0	Yes	36.1	$\tilde{\ell}$ 0.5	m($\tilde{\chi}^0_1$)=0	1803.02762
		2 e, μ	≥ 1	Yes	36.1	$\tilde{\ell}$ 0.18	m($\tilde{\ell}$)-m($\tilde{\chi}^0_1$)=5 GeV	1712.08119
	$\tilde{H}\tilde{H}$, $\tilde{H}\to h\tilde{G}/Z\tilde{G}$	0	$\geq 3b$	Yes	36.1	$\tilde{H}$ 0.13-0.23 0.29-0.88	BR($\tilde{\chi}^0_1 \to h\tilde{G}$)=1	1806.04030
		4 e, μ	0	Yes	36.1	$\tilde{H}$ 0.3	BR($\tilde{\chi}^0_1 \to Z\tilde{G}$)=1	1804.03602
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	Yes	36.1	$\tilde{\chi}^\pm_1$ 0.46	Pure Wino	1712.02118
						$\tilde{\chi}^\pm_1$ 0.15	Pure Higgsino	ATL-PHYS-PUB-2017-019
	Stable $\tilde{g}$ R-hadron	SMP	-	-	3.2	$\tilde{g}$ 1.6		1606.05129
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}^0_1$		Multiple		32.8	$\tilde{g}$ [$\tau(\tilde{g})$ =100 ns, 0.2 ns] 1.6 2.4	m($\tilde{\chi}^0_1$)=100 GeV	1710.04901, 1604.04520
	GMSB, $\tilde{\chi}^0_1\to\gamma\tilde{G}$, long-lived $\tilde{\chi}^0_1$	2 γ	-	Yes	20.3	$\tilde{\chi}^0_1$ 0.44	1<τ($\tilde{\chi}^0_1$)<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}^0_1\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{g}$ 1.3	6 <$c\tau$($\tilde{\chi}^0_1$)< 1000 mm, m($\tilde{\chi}^0_1$)=1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	3.2	$\tilde{\nu}_\tau$ 1.9	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2 \to WW/Z\ell\ell\ell\ell\nu\nu$	4 e, μ	0	Yes	36.1	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ [$\lambda_{i33} \neq 0, \lambda_{12k} \neq 0$] 0.82 1.33	m($\tilde{\chi}^0_1$)=100 GeV	1804.03602
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^0_1, \tilde{\chi}^0_1 \to qqq$	0	4-5 large-R jets	-	36.1	$\tilde{g}$ [m($\tilde{\chi}^0_1$)=200 GeV, 1100 GeV] 1.3 1.9	Large λ''_{112}	1804.03568
			Multiple		36.1	$\tilde{g}$ [λ''_{112}=2e-4, 2e-5] 1.05 2.0	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{g}\tilde{g}$, $\tilde{g} \to tbs$ / $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1, \tilde{\chi}^0_1 \to tbs$		Multiple		36.1	$\tilde{g}$ [λ''_{323}=1, 1e-2] 1.8 2.1	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}$, $\tilde{t}\to t\tilde{\chi}^0_1, \tilde{\chi}^0_1 \to tbs$		Multiple		36.1	$\tilde{g}$ [λ''_{323}=2e-4, 1e-2] 0.55 1.05	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	36.7	$\tilde{t}_1$ [qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e, μ	2 b	-	36.1	$\tilde{t}_1$ 0.4-1.45	BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544

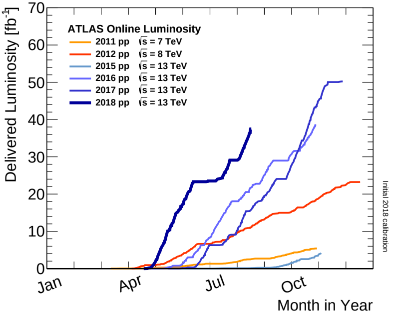
*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

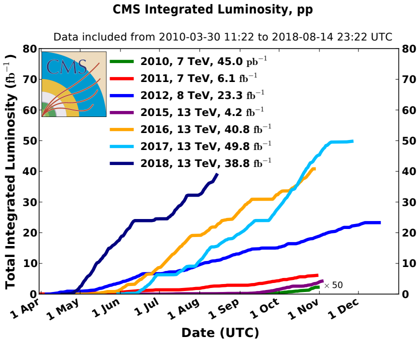


Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

Conclusions

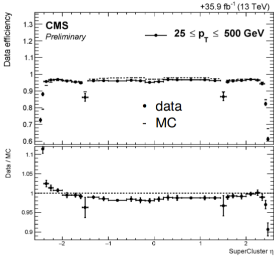
- A wide and rich program on SUSY searches from both ATLAS and CMS Collaborations;
- So far no hints for SUSY at the LHC;
- LHC performance is better than ever, SUSY maybe hiding in the corners of the parameter space still unexplored.. STAY TUNED

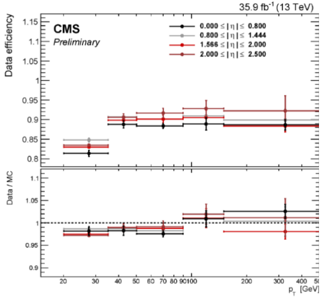


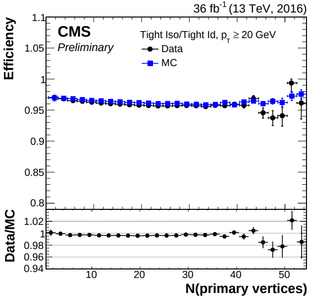


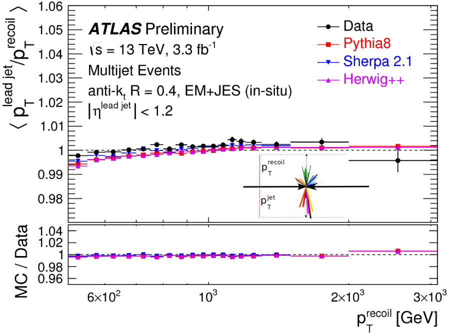
Back-up

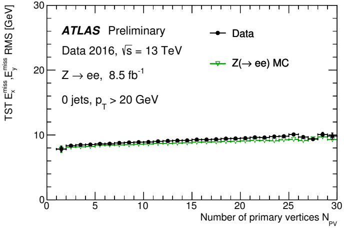
Object performance











A key process for understanding and constraining the SM backgrounds in data.

Commonly used discriminants

- Missing transverse momentum: $E_{\mathrm{T}}^{\mathrm{miss}} = | - \sum_{i}^{n\ \ visible} \ \vec{p}_T^{visible}|$
- Hadronic transverse energy: $H_T = \sum_{i}^{n\ \ jets} p_T^{jet}$
- Leptonic transverse energy: $L_T = \sum_{i}^{n\ \ leptons} \ p_T^{lepton}$
- Effective mass: $m_{eff} = E_{\mathrm{T}}^{\mathrm{miss}} + H_T + L_T$
- alphaT: $a_T = E_T^{j_2}/M_T$
- Transverse mass: $m_T = \sqrt{2p_T^{\ell} E_{\mathrm{T}}^{\mathrm{miss}}(1 - cos\Delta\phi)}$
- Stransverse mass: $m_{T2} = min\left[max\left(m_T(\boldsymbol{p_T^{\ell 1}}, \boldsymbol{q_T}), m_T(\boldsymbol{p_T^{\ell 2}}, \boldsymbol{p_T^{miss}} - \boldsymbol{q_T})\right)\right]$
- RJ scale variables: $H_{n,m}^{\mathrm{F}} = \sum_{i=1}^{n} |\vec{p}_{\mathrm{vis},\ i}^{\,\mathrm{F}}| + \sum_{j=1}^{m} |\vec{p}_{\mathrm{inv},\ j}^{\,\mathrm{F}}|$

Systematic uncertainties

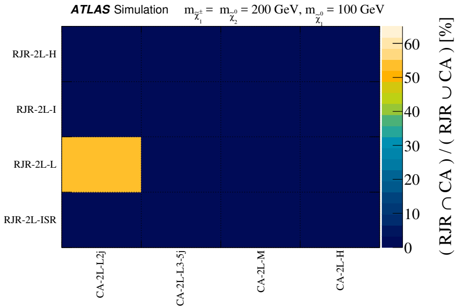
Careful examination and evaluation of all systematic sources affecting the result

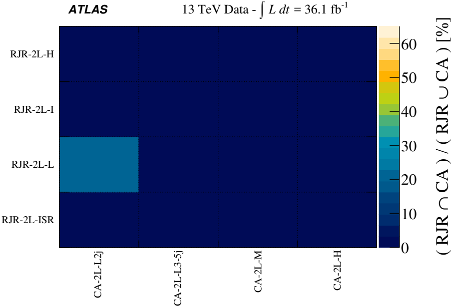
- Experimental uncertainties:
  - lepton reconstruction, identification and isolation efficiencies
  - lepton/jet energy scale and resolution
  - Flavor jet tagging efficiencies
  - $E_{\mathrm{T}}^{\mathrm{miss}}$ modeling
  - pile-up
- Theory uncertainties:
  - Vary the renormalization, factorization and merging scales used to generate the MC samples, as well as the PDFs. ISR uncertainties are also included for the signal MC
  - Generator comparisons (e.g. $t\bar{t}$ POWHEG vs aMC@NLO)
  - other additional uncertainties, e.g. single top interference
- Uncertainties from the data-driven background estimation techniques

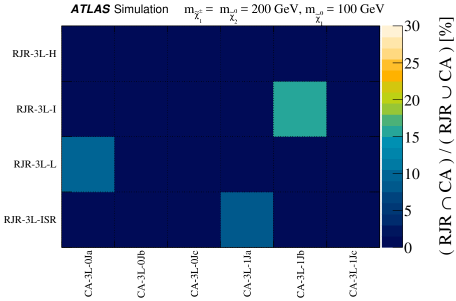
The impact on the number of expected events is determined by varying a given systematic between extremes ($\pm 1\sigma$)

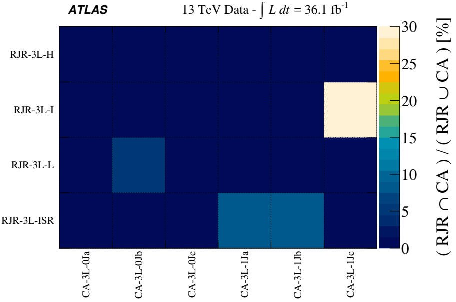
The uncertainties in different kinematic regions are treated as correlated

Overlap of events between RJ and CA

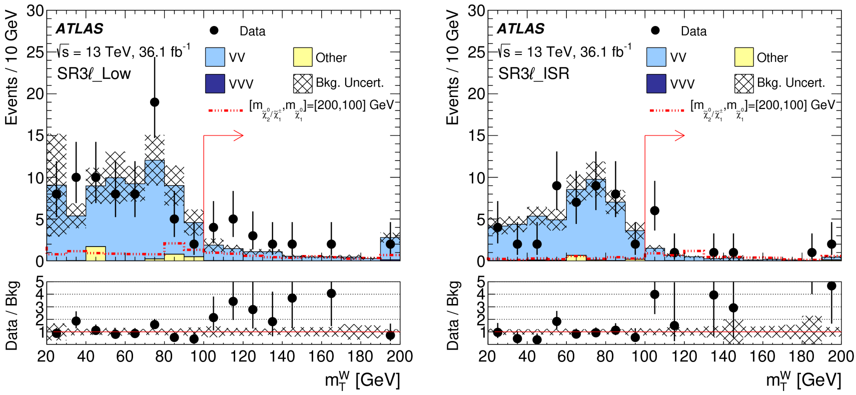








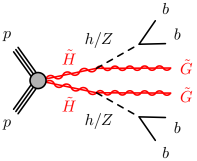
N-1 plots for 2/3ℓ SUSY EWK RJ analysis

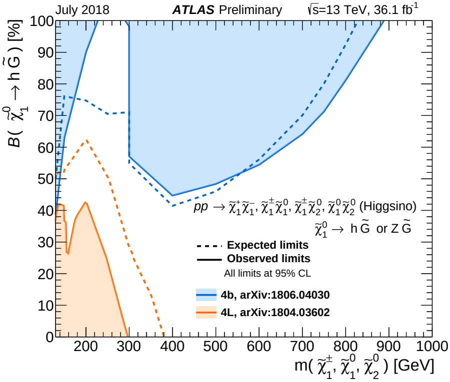


Search for Higgsinos in GGM scenarios

A search in multi $b-$jet final state.
Two complementary analyses, targeting high- and low-mass signals
Higgsinos with masses between 130 and 230 GeV and between 290 and 880 GeV excluded at 95% CL.
1806.04030

Four-lepton signal regions with up to two hadronically decaying taus
Higgsino masses are excluded up to 295 GeV, at 95% CL
1804.03602





The two search channels nicely complement each other

Neutralinos in higgs decays

ATLAS-CONF-2018-019

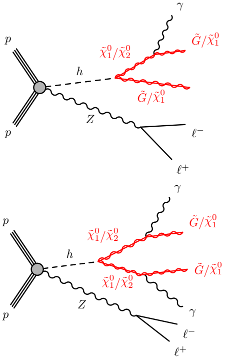
Search for *Zh* production with the *h* decaying either to two neutralinos or to a neutralino and a gravitino.

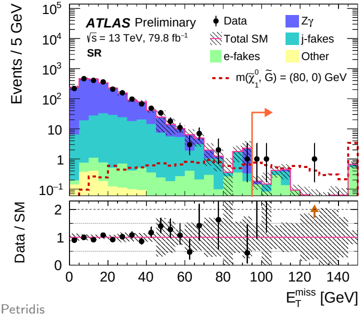
Motivated by GMSB ($\tilde{G}$ LSP) and nMSSM models (singlino, $\tilde{\chi}_1^0$ LSP)

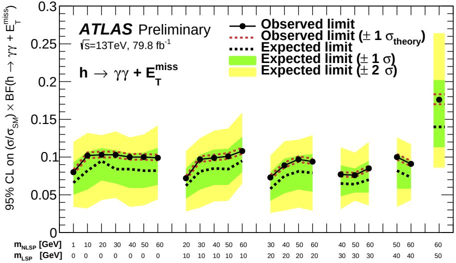
Single and di-photon $+E_{\mathrm{T}}^{\mathrm{miss}}$ final states are examined

Discrimination of the hypotheticla signal from the SM bkgs by exploiting the balance of the *Z* and $\gamma E_{\mathrm{T}}^{\mathrm{miss}}$ systems

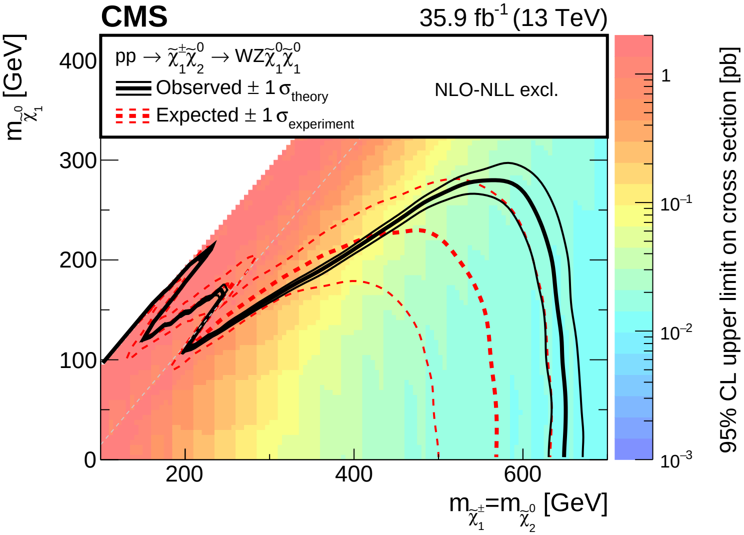
Upper limits at 95% CL of less than 11% (18%) on the cross-section times branching fraction of each process are observed for massless gravitinos (massive neutralinos).







CMS limits on charginos and neutralinos



Strong production in two-lepton final state

1805.11381

Search targets the pair production of squarks and gluinos

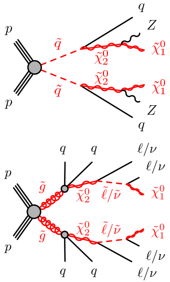
Production mechanisms:

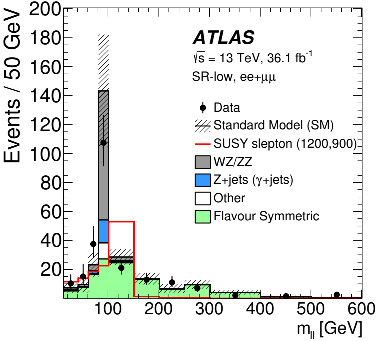
$\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$ producing a dilepton pair consistent with the Z mass

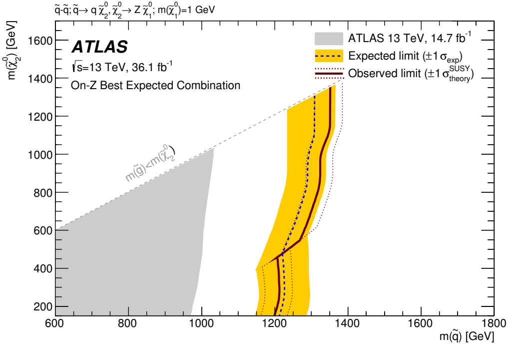
$\tilde{\chi}_2^0 \to \ell\ell\tilde{\chi}_1^0$ yielding a kinematic endpoint in the dilepton invariant mass spectrum

Gluinos and squarks excluded up to masses of 1.85 TeV and 1.3 TeV at 95% CL.

Excess in Run 1 not confirmed



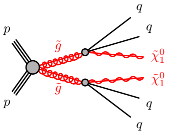


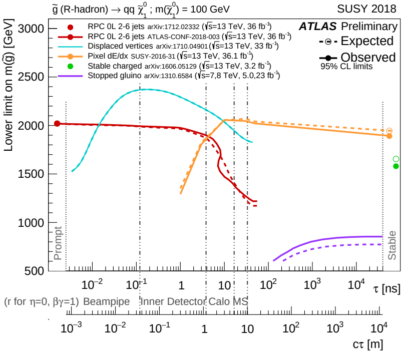


LLP/RPV reiterpretation

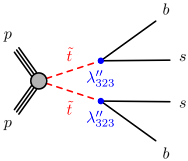
Reinterpretation of searches for SUSY in models with:

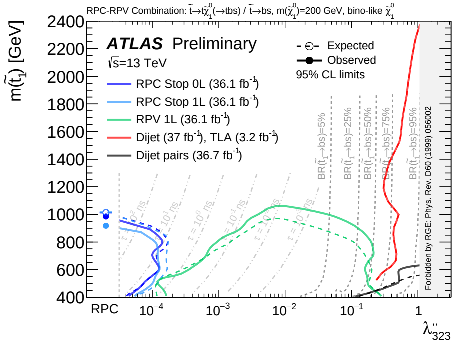
long-lived $R - hadrons$





variable RPV coupling strength

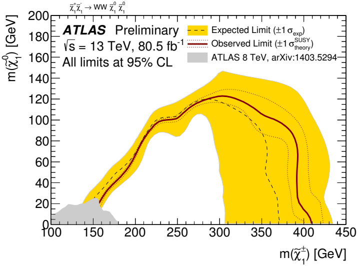


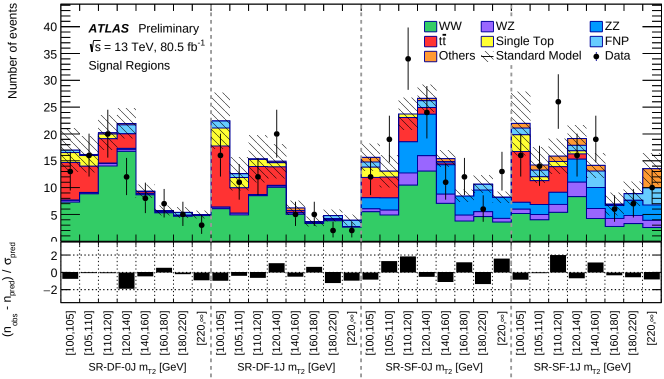


Pair production of charginos

ATLAS-CONF-2018-042

- $\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow WW\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow 2\ell + E_{\mathrm{T}}^{\mathrm{miss}}$
- Analysis performed with $\boldsymbol{L}$ **=80 fb^{-1}**
- Challenging due to small cross sections and background contributions from SM *WW*
- Inclusive and binned SRs (in m_{T2})
- CMS:1807.07799

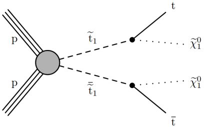


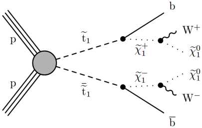


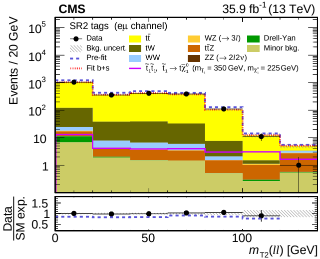
Search for stops

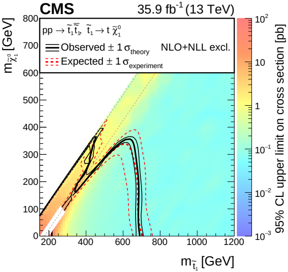
CMS:1807.07799

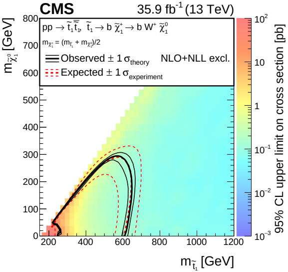
Search for pair production of top squarks in two lepton final state.
Dedicated search in the intermediate region $m_W < \Delta m < m_t$
Multi-bin search binned in m_{T2}, $E_{\mathrm{T}}^{\mathrm{miss}}$, $b-$tag jet multiplicity and ISR jets.











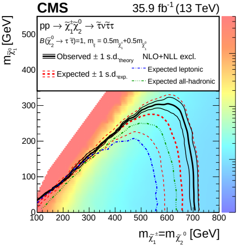
$\tilde{t} \rightarrow b\tilde{\chi}_1^{\pm} \rightarrow bW\tilde{\chi}_1^0$: a lower bound of $\Delta m \approx 2m_W$ is set by the assumption on $m_{\tilde{\chi}_1^{\pm}}$

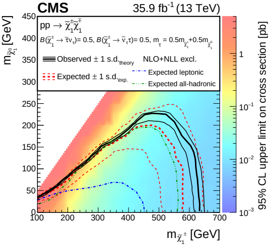
ATLAS:1708.03247

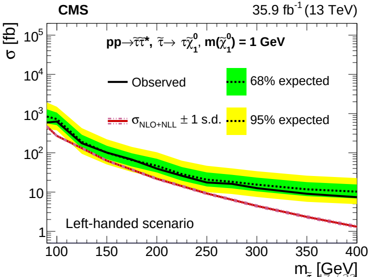
Search for processes involving staus

CMS:1807.02048

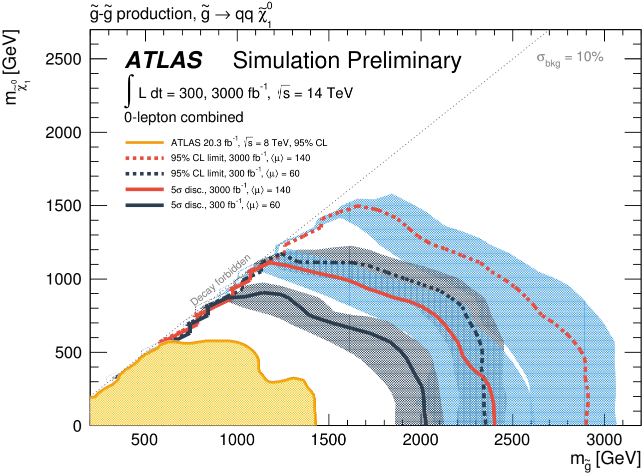
- Light stau and small Δm can yield right DM relic density via stau-neutralino coannihilation.
- A comprehensive search for all processes with staus.
- Both leptonic and hadronic decay modes of the τ leptons are considered.
- No excess above the expected standard model background has been observed.
- For a left-handed $\tilde{\tau}$ of 90 GeV decaying to a nearly massless LSP, the observed limit is 1.26 times the expected production cross section in the simplified model.
- ATLAS:1708.07875



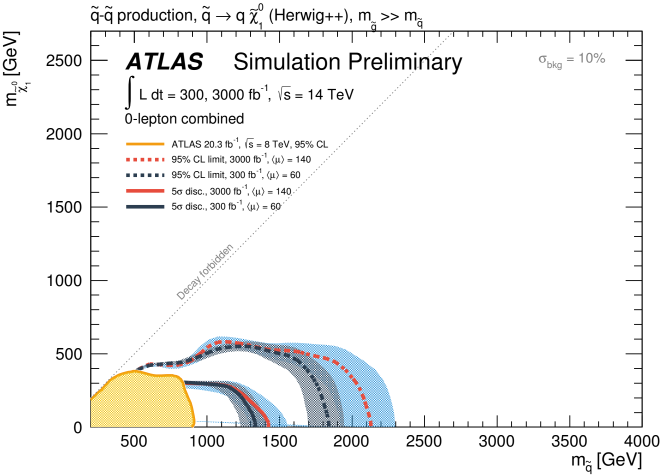




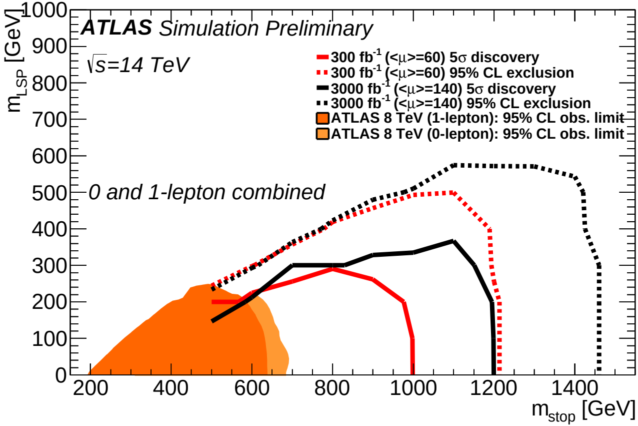
Gluino Sensitivity at $\sqrt{s} = 14$ TeV



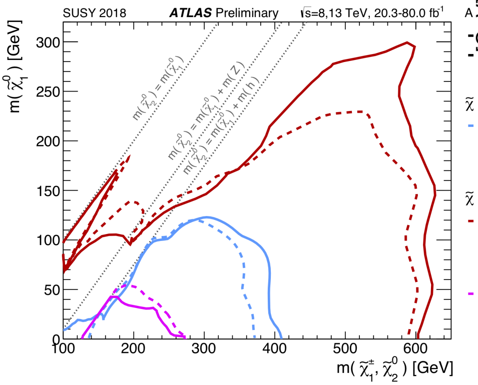
Squark Sensitivity at $\sqrt{s} = 14$ TeV

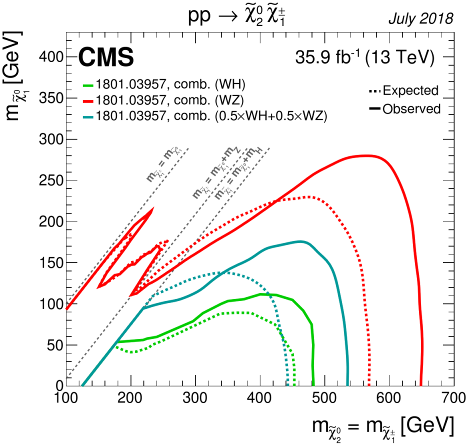


Top Squark Sensitivity at $\sqrt{s} = 14$ TeV

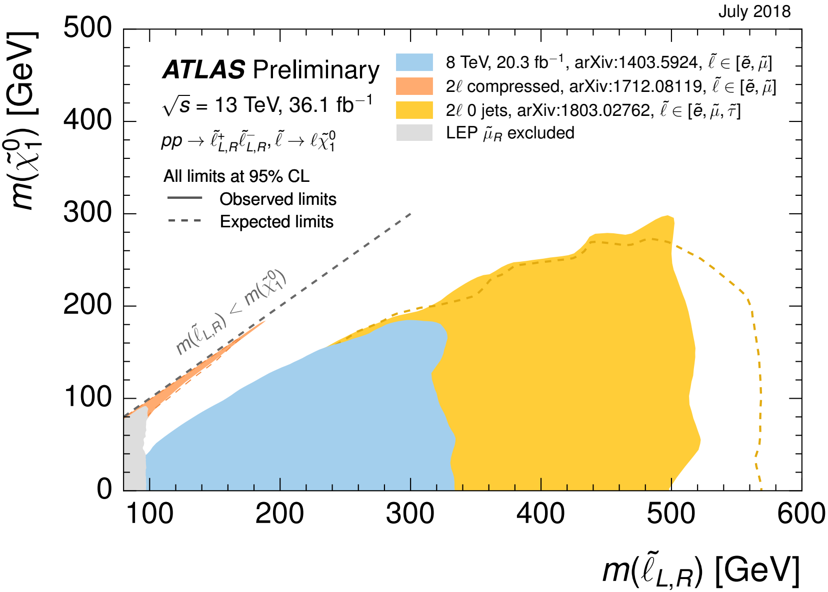


Summary plots for EWK production





Summary plots for slepton production



Mass measurement for gluino $R-$ hadron LLP

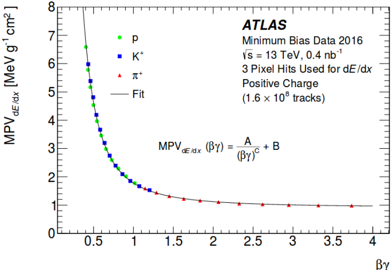
The parametric function describing the relationship between the most probable value of the energy loss ($MPV_{dE/dx}$) and $\beta\gamma$ is:

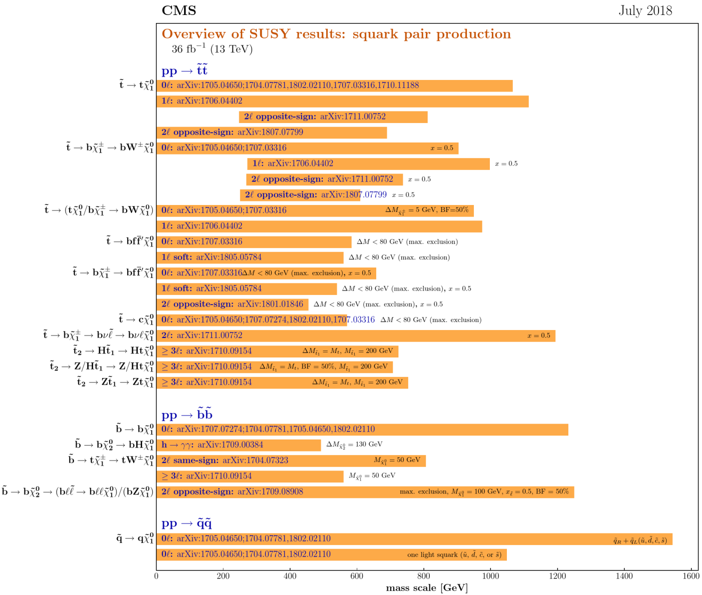
$$MPV_{dE/dx} = A/(\beta\gamma)^C + B$$

The A, B and C calibration constants were measured using low-momentum pions, kaons and protons.

The $MPV_{dE/dx}$ is extracted from a fit to the distribution of dE/dx values for each particle species.

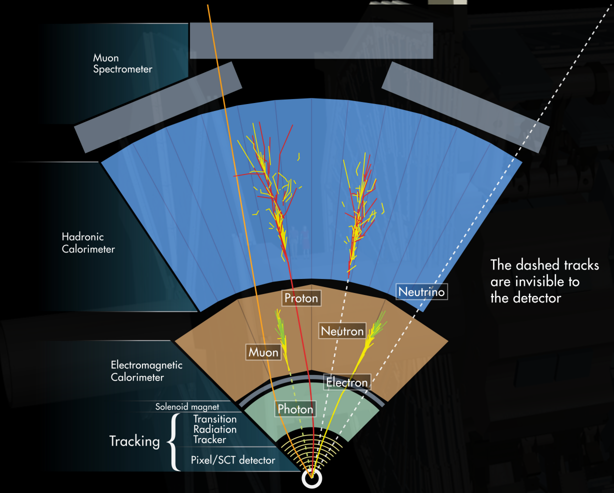
Given a measured value of dE/dx and momentum, and assuming unit charge, the mass m is calculated from the equation above by numerically solving the equation $MPV_{dE/dx}(p/m) = dE/dx$ for the unknown m, where the $MPV_{dE/dx}$ is approximated by the truncated-mean measurement of dE/dx.



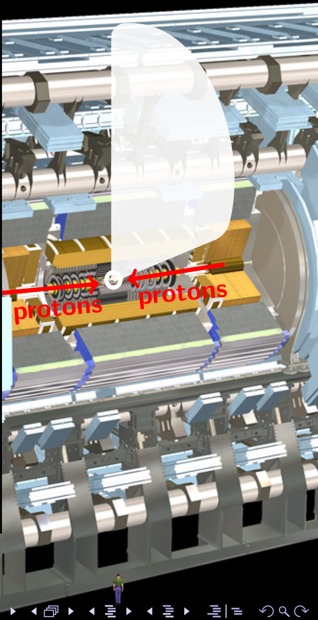


Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary particle and the LSP, and the difference between the intermediate particle and the LSP relative to ΔM, respectively, unless indicated otherwise.

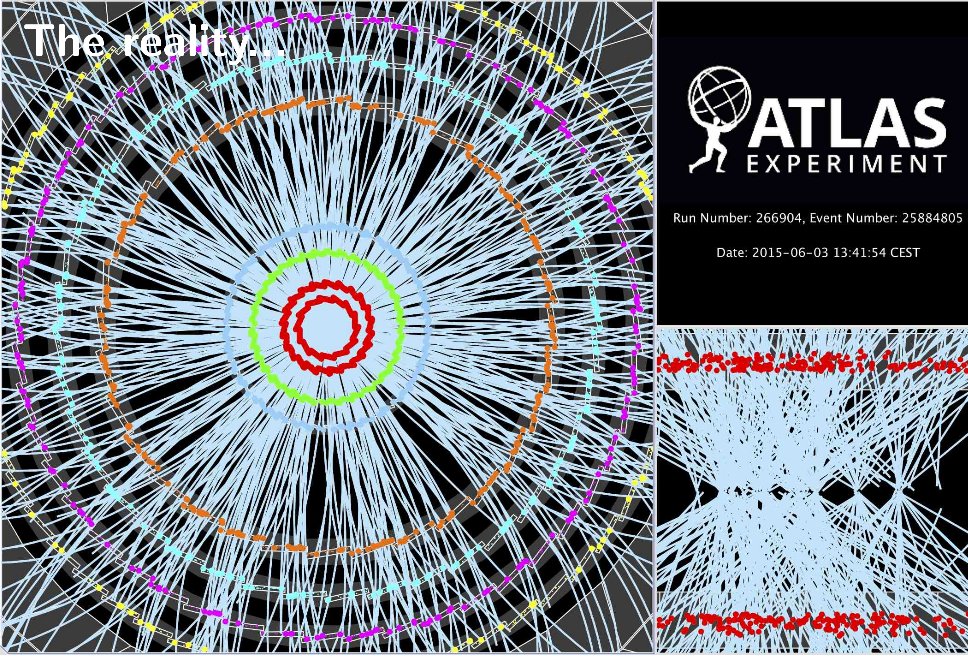
Object reconstruction



The dashed tracks are invisible to the detector



The reality...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