SUSY searches in ATLAS and CMS

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Corfu, 2018
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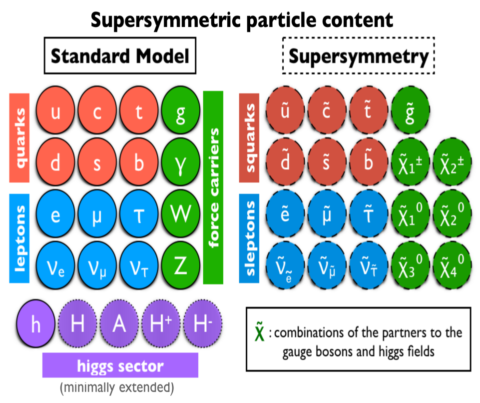
September 7, 2018

- Supersymmetry: one of the most popular Standard Model (SM) extensions
  - Each SM particle has its own supersymmetric partner or superpartner.
  - Each superpartner of the SM particle has spin differing by 1/2 unit.
  - Provides a dark matter candidate (for R-parity conserving theory).
  - Provides the unification of fundamental forces at high energies.
  - Provides a solution to the fine-tuning problem of the Higgs mass.



- Unfortunately, all the inclusive/wide searches did not find SUSY.
- Big jump in luminosity and energy is not possible in near future.
- Need to check if there is any hole in the search grid.

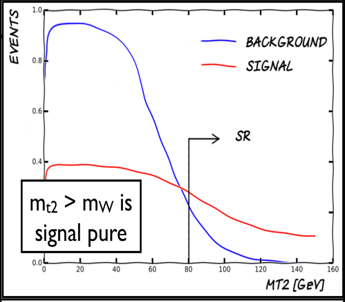
A General Approach to SUSY Search:

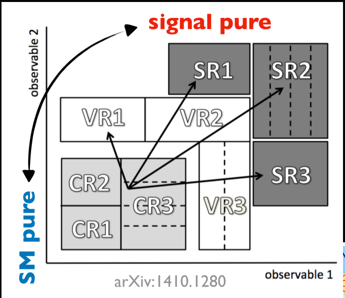
Strategy: Event selection

- Look for a signal pure region (**SR**) by applying cuts on observables that enhance the signal significance.
- Estimate the background: may be fully data-driven technique, or semi data driven technique where control regions (**CR**) are used to constrain the MC predicitons.
- Use Validation Regions (**VR**) to validate the background estimate.

Unblinding

- The data in SR are not looked at unless the background estimations are properly understood and validated.
- Understand the systematic uncertainty.
- Being satisfied, look for data in SR: any excess goes to test for discovery and no excess sets upper limits in SUSY xsec and parameters.





- Strong SUSY search

Strong SUSY Production

- Still one of the benchmarks of the SUSY search in LHC.
  - Higher cross-section than the electroweak production.
  - Relatively easy to search for compared to electroweak production.
  - In general: looking for high p_T particles and large E_T^{miss} .

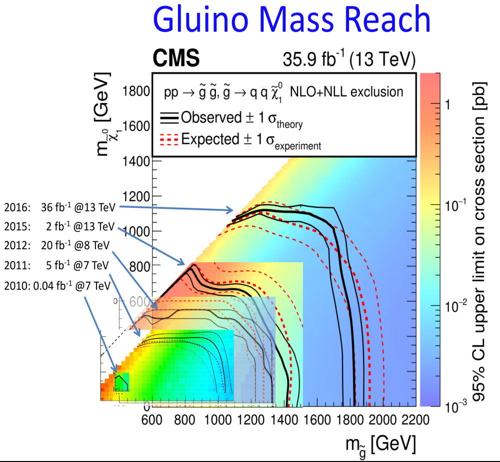


Figure: courtesy: Keith Ulmer, SUSY2017

Impressive Strong SUSY search programs by both CMS and ATLAS

Short Title	Journal reference	Date	√s (TeV)	L	Links
Gluino pair, squark pair, stop pair, long-lived; pixel ionisation NEW	Submitted to PLB	13-AUG-18	13	36 fb^{-1}	Documents | 1808.04095 | Inspire Internal
Gluino pair, squark pair; 2 leptons, Z boson, edge	Submitted to EPJC	29-MAY-18	13	36 fb^{-1}	Documents | 1805.11381 | Inspire HepData | Briefing | Internal
Stop pair; charm tagging	Submitted to JHEP	04-MAY-18	13	36 fb^{-1}	Documents | 1805.01649 | Inspire HepData | Briefing | Internal
Gluino pair; jets, RPV	Submitted to PLB	10-APR-18	13	36 fb^{-1}	Documents | 1804.03568 | Inspire Internal
Stop pair; taus	Phys. Rev. D 98 (2018) 032008	27-MAR-18	13	36 fb^{-1}	Documents | 1803.10178 | Inspire HepData | Internal
Gluino pair, squark pair, chargino-neutralino pair; photons	Phys. Rev. D 97 (2018) 092006	09-FEB-18	13	36 fb^{-1}	Documents | 1802.03158 | Inspire HepData | Internal
Gluino pair, squark pair, gluino-squark; 0 lepton	Phys. Rev. D 97 (2018) 112001	06-DEC-17	13	36 fb^{-1}	Documents | 1712.02332 | Inspire HepData | Internal
Gaugino pair, gluino pair; disappearing track	JHEP 06 (2018) 022	06-DEC-17	13	36 fb^{-1}	Documents | 1712.02118 | Inspire HepData | Internal
Stop pair, WIMP DM pair; 1 lepton	JHEP 06 (2018) 108	30-NOV-17	13	36 fb^{-1}	Documents | 1711.11520 | Inspire HepData | Internal
MET + jet search 13 TeV 2016	JHEP 01 (2018) 126	09-NOV-17	13	36 fb^{-1}	Documents | 1711.03301 | Inspire HepData | Internal
Gluino pair; 0-1 leptons, many b-jets	JHEP 06 (2018) 107	06-NOV-17	13	36 fb^{-1}	Documents | 1711.01901 | Inspire HepData | Internal
Stop pair; dijet pairs, RPV	Eur. Phys. J. C 78 (2018) 250	19-OCT-17	13	37 fb^{-1}	Documents | 1710.07171 | Inspire HepData | Internal
Stop pair; 2 leptons, b-jets, RPV	Phys. Rev. D 97 (2018) 032003	16-OCT-17	13	36 fb^{-1}	Documents | 1710.05544 | Inspire HepData | Internal
Gluino pair, squark pair; displaced vertices	Phys. Rev. D 97 (2018) 052012	13-OCT-17	13	33 fb^{-1}	Documents | 1710.04901 | Inspire HepData | Internal
Stop pair; 0 lepton	JHEP 12 (2017) 085	13-SEP-17	13	36 fb^{-1}	Documents | 1709.04183 | Inspire HepData | Internal
Sbottom pair, stop pair; 0-1 leptons, b-jets	JHEP 11 (2017) 195	30-AUG-17	13	36 fb^{-1}	Documents | 1708.09266 | Inspire HepData | Internal
Gluino pair, squark pair; 1 lepton	Phys. Rev. D 96 (2017) 112010	28-AUG-17	13	36 fb^{-1}	Documents | 1708.08232 | Inspire HepData | Internal
Stop pair; 2 leptons	Eur. Phys. J. C77 (2017) 898	10-AUG-17	13	36 fb^{-1}	Documents | 1708.03247 | Inspire HepData | Internal
Gluino pair, squark pair; 0 lepton, high jet multiplicity	JHEP12 (2017) 034	10-AUG-17	13	36 fb^{-1}	Documents | 1708.02794 | Inspire HepData | Internal

Figure: List of Recent Strong SUSY Publications by ATLAS

Impressive Strong SUSY search programs by both CMS and ATLAS

Supersymmetry Publications

101	SUS-18-001	Constraints on models of scalar and vector leptoquarks decaying to a quark and a neutrino at $\sqrt{s} = 13$ TeV	Accepted by PRD	25 May 2018
99	SUS-16-038	Search for natural and split supersymmetry in proton-proton collisions at $\sqrt{s} = 13$ TeV in final states with jets and missing transverse momentum	JHEP 05 (2018) 025	6 February 2018
96	SUS-16-040	Search for R-parity violating supersymmetry in pp collisions at $\sqrt{s} = 13$ TeV using b jets in a final state with a single lepton, many jets, and high sum of large-radius jet masses	Accepted by PLB	24 December 2017
94	SUS-16-046	Search for gauge-mediated supersymmetry in events with at least one photon and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV	PLB 780 (2018) 118	21 November 2017
92	SUS-16-050	Search for supersymmetry in proton-proton collisions at 13 TeV using identified top quarks	PRD 97 (2018) 012007	30 October 2017
90	SUS-16-042	Search for supersymmetry in events with one lepton and multiple jets exploiting the angular correlation between the lepton and the missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV	PLB 780 (2018) 384	28 September 2017
84	SUS-16-047	Search for supersymmetry in events with at least one photon, missing transverse momentum, and large transverse event activity in proton-proton collisions at $\sqrt{s} = 13$ TeV	JHEP 12 (2017) 142	19 July 2017
79	SUS-16-037	Search for supersymmetry in pp collisions at $\sqrt{s} = 13$ TeV in the single-lepton final state using the sum of masses of large-radius jets	PRL 119 (2017) 151802	12 May 2017
78	SUS-16-036	Search for new phenomena with the M_{T2} variable in the all-hadronic final state produced in proton-proton collisions at $\sqrt{s} = 13$ TeV	EPJC 77 (2017) 710	12 May 2017
77	SUS-16-033	Search for supersymmetry in multijet events with missing transverse momentum in proton-proton collisions at 13 TeV	PRD 96 (2017) 032003	25 April 2017

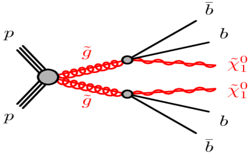
Supersymmetry Publications

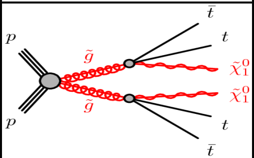
100	SUS-17-005	Search for top squarks decaying via four-body or chargino-mediated modes in single-lepton final states in proton-proton collisions at $\sqrt{s} = 13$ TeV	Submitted to JHEP	15 May 2018
97	SUS-16-048	Search for new physics in events with two soft oppositely charged leptons and missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV	Submitted to PLB	5 January 2018
93	SUS-17-001	Search for top squarks and dark matter particles in opposite-charge dilepton final states at $\sqrt{s} = 13$ TeV	PRD 97 (2018) 032009	2 November 2017
92	SUS-16-050	Search for supersymmetry in proton-proton collisions at 13 TeV using identified top quarks	PRD 97 (2018) 012007	30 October 2017
89	SUS-16-034	Search for new phenomena in final states with two opposite-charge, same-flavor leptons, jets, and missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV	JHEP 03 (2018) 076	26 September 2017
86	SUS-16-045	Search for supersymmetry with Higgs boson to diphoton decays using the razor variables at $\sqrt{s} = 13$ TeV	PLB 779 (2018) 166	1 September 2017
85	SUS-16-032	Search for the pair production of third-generation squarks with two-body decays to a bottom or charm quark and a neutralino in proton-proton collisions at $\sqrt{s} = 13$ TeV	PLB 778 (2018) 263	23 July 2017
83	SUS-15-009	Search for natural supersymmetry in events with top quark pairs and photons in pp collisions at $\sqrt{s} = 8$ TeV	JHEP 03 (2018) 167	10 July 2017
82	SUS-16-049	Search for direct production of supersymmetric partners of the top quark in the all-jets final state in proton-proton collisions at $\sqrt{s} = 13$ TeV	JHEP 10 (2017) 005	10 July 2017
80	SUS-16-051	Search for top squark pair production in pp collisions at $\sqrt{s} = 13$ TeV using single lepton events	JHEP 10 (2017) 019	14 June 2017
78	SUS-16-036	Search for new phenomena with the M_{T2} variable in the all-hadronic final state produced in proton-proton collisions at $\sqrt{s} = 13$ TeV	EPJC 77 (2017) 710	12 May 2017
74	SUS-16-009	Search for supersymmetry in the all-hadronic final state using top quark tagging in pp collisions at $\sqrt{s} = 13$ TeV	PRD 96 (2017) 012004	8 January 2017
73	SUS-16-008	Searches for pair production of third-generation squarks in $\sqrt{s} = 13$ TeV pp collisions	EPJC 77 (2017) 327	12 December 2016

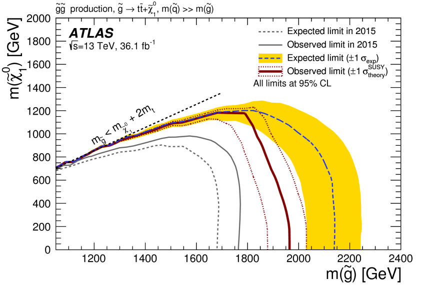
Figure: List of Recent Strong SUSY Publications by CMS

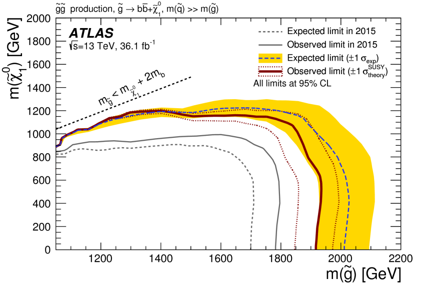
Multi-b search in ATLAS: Previous result

- In 2017 (arXiv: 1711.01901), ATLAS searched for SUSY with final states with E_T^{miss} and multiple b-jets with 36.1 fb^{-1} of data.
- The target signal was gluino decaying to b and t quarks.
- No significant excess was found (slight excess in the multibin search), hence mass limits were set.
- The limit set to $\tilde{\chi}_1^0$ mass was 300 GeV and gluino masses of less than 1.97 (1.92) TeV when gluinos decay via top (bottom).

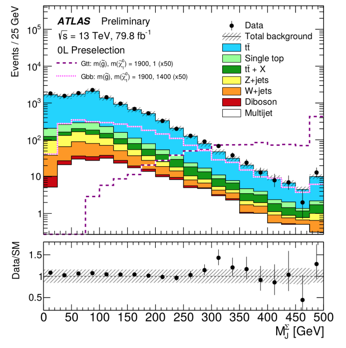


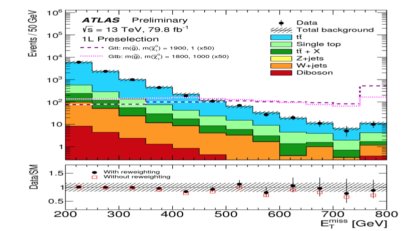


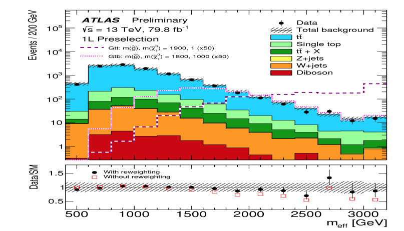




- ATLAS updated the result with 79.8 fb^{-1} of data.
- Event selection:
  - Multi-b events ($\geq$ 3 or $\geq$4 b-jets for different SRs).
  - Jets $\geq$ 5 up to $\geq$ 9 for different SRs.
  - $E_T^{miss} > 300 - 600$ GeV.
  - High M_{eff} and $m_{T,min}^{b-jets}$.
  - Selecting 0 or 1 lepton events.
- One powerful variable to discriminate signal from background was total jet mass variable: $M_J^{\Sigma} = \sum_{i\leq 4} m_{J,i}$ where $m_{J,i}$ is the mass of the large radius (R$=$ 1.0) re-clustered jet i in the event.

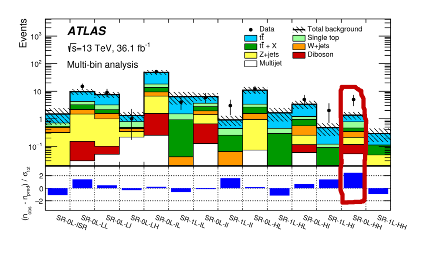


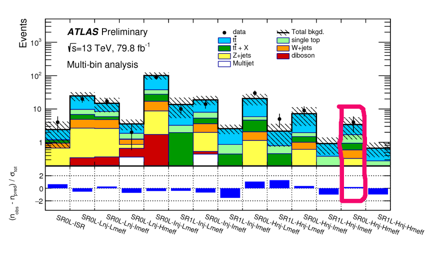




Multi-b search: Updated Results

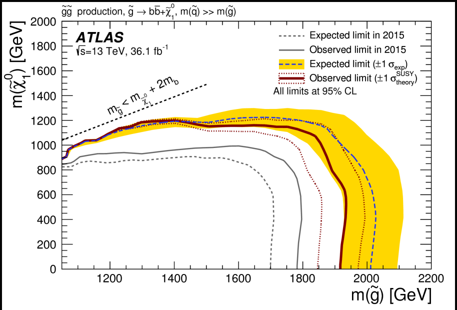
- There was a small excess in the multibin search previously.
- The excess is not confirmed in the recent result.

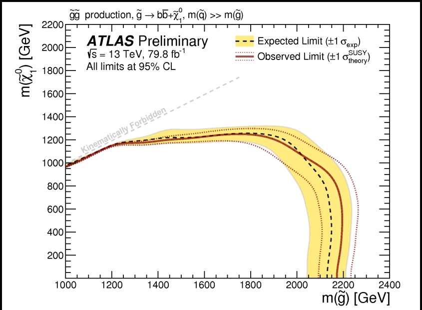




Multi-b search: Updated Results

- The limit on the gluino mass is pushed further.





- The mass limit on gluino is pushed to 2.1 TeV.

- In general, GMSB searches look for multilepton (when $\tilde{\chi}_1^0 \to Z/h\tilde{G}$) or photons (when $\tilde{\chi}_1^0 \to \gamma\tilde{G}$).
- But $\tilde{\chi}_1^\pm \to W\tilde{G}$ also possible when the wino content in NLSP is significant.

Event selection:

- At least one isolated photon ($p_T > 35$ GeV in $|\eta| < 1.4442$) and at least one isolated electron (muon) ($p_T > 25$ GeV in $|\eta| < 2.5(2.4)$, electrons in barrel-endcap transition region excluded.)
- $E_T^{miss} > 120$ GeV and $M_T > 100$ GeV.

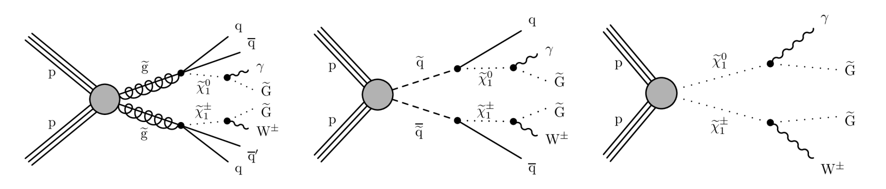
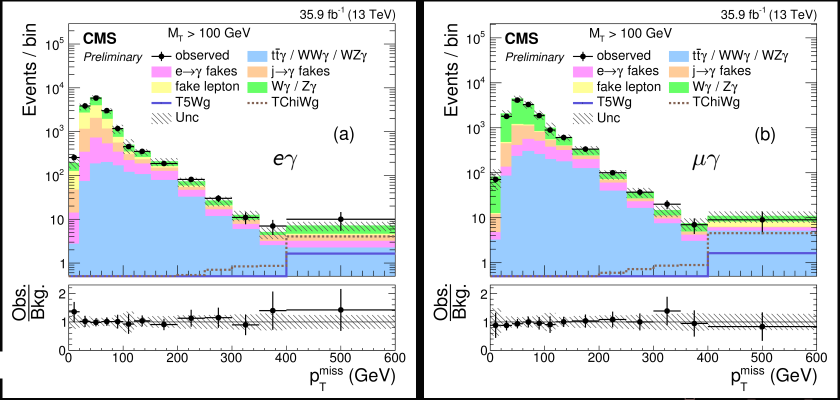


Figure: T5Wg (left), T6Wg (center) and TChiWg (right) models

Final Result:

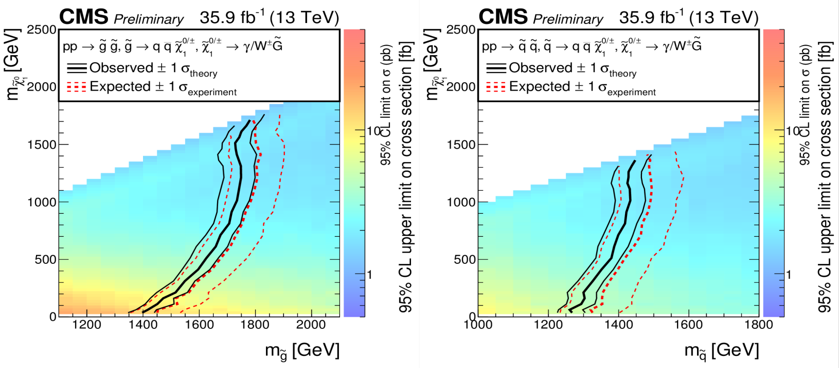
Background estimation

- Without prompt photon: Photon that originates from pile up - determined from data by finding the rate of misidentification of photons.
- Without prompt lepton: Lepton that comes from mis-identified jets, hadronization of heavy flavor quarks - estimated from data.
- Rare electroweak processes: WWγ, WZγ and $t\bar{t}\gamma$-found from simulation.



GMSB search with one photon and one lepton:

- No excess was found.
- Set limits on mass of squark/gluino and neutralino.
- Gluino mass upto 1.7 TeV and squark mass upto 1.4 TeV is excluded.



(a) (b)

Figure: The left plot is interpretation with T5Wg model and the right with T6Wg model

SUSY with charm quarks (arXiv:1805.01649)

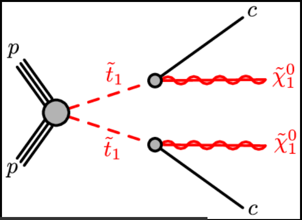
- This ATLAS search targets direct $\tilde{c}$ pair production ($\tilde{c} \rightarrow c\tilde{\chi}_0^1$) as well as stop decays ($\tilde{t} \rightarrow c\tilde{\chi}_0^1$).

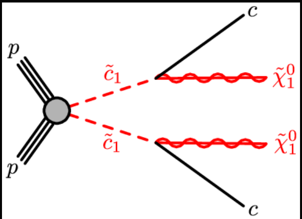
Event selection:

- Requires 0 lepton
- At least 2 jets with at least 1 charm-tagged jets.
- Leading jet $p_T > 250$ GeV.
- $\Delta\phi_{min}(\text{jet}, E_T^{miss}) > 0.4$.
- $E_T^{miss} > 500$ GeV.

Charm-tagged jets

- The challenge for this analysis is to identify charm-tagged jets.





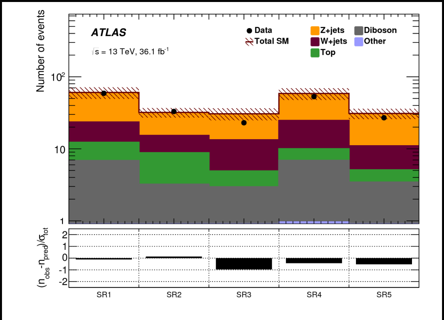
Identifying charm-tagged jets

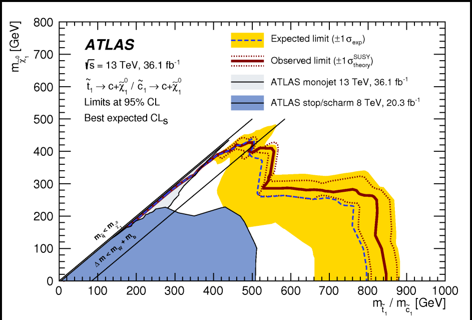
- Multivariate discriminants, MV2c100 and MV2c1100 are used to distinguish between c-jets and jets containing bottom quarks (b-jets), and between c-jets and light flavor jets respectively.
- MV2c100: trained with b-jets as signal and background exclusively of c-jets.
- MV2c1100: trained with c-jets as signal and background exclusively of light-flavor jets.
- 'Tight' working point selected: charm-tagging efficiency of 18%, b-jet rejection factor of 20, a light-flavor jet rejection factor of 200 and hadronic τ jet rejection factor of 6 (evaluated in simulated $t\bar{t}$ sample).
- The c-jet tagging rate was found from data rich in $t\bar{t}$ events, where c-jets came from W decay.
- Adequate correction factor were applied to simulated samples in order to match with the tagging rate in data.

Reject hadronically decaying τ

- To reject hadronically decaying τ-leptons: the transverse mass $m_T^c = \sqrt{2 \cdot E_T^{miss} p_T^c \cdot (1 - cos(\Delta\phi(E_T^{miss}, p_T^c)))}$ was used.
- $m_T^c > 120$ GeV could reduce the hadronic τ background to less than 5%.

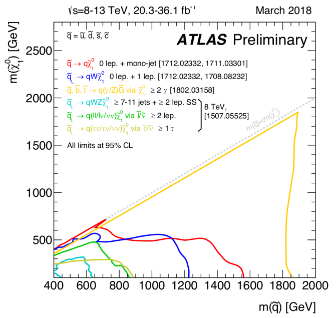
- Depending on Δm, there are five different signal regions.
- Most significant background is Z+jets (50-60% in all SRs): estimated using simulated sample.
- Other backgrounds: W+jets (W$\rightarrow \tau\nu_\tau$), diboson and $t\bar{t}$ all estimated from MC.

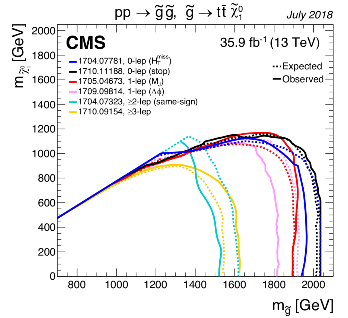




- charm squark mass upto 850 GeV was excluded.

- In simplified model approach, the mass limits are the following:
  - $M_{\tilde{g}} \lesssim \mathcal{O}(1\ \text{TeV}) - \mathcal{O}(2\ \text{TeV})$ @95% CL
  - $M_{\tilde{q}} \lesssim \mathcal{O}(0.5\ \text{TeV}) - \mathcal{O}(1.5\ \text{TeV})$ @95% CL
  - $M_{\tilde{t}} \lesssim \mathcal{O}(0.7\ \text{TeV}) - \mathcal{O}(1.1\ \text{TeV})$ @95% CL

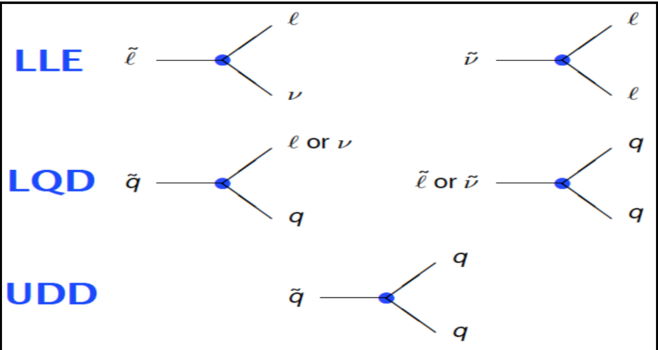




R-Parity violating SUSY

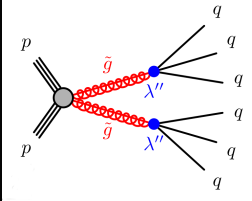
- Since no sign of SUSY in RPC scenarios, the RPV scenarios are getting momentum.
- For the RPV scenario:
  - No stable SUSY particle - no candidate for dark matter

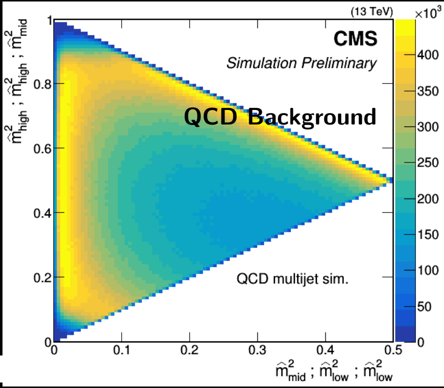
$$W_{\mathrm{RPV}} = \underbrace{\frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k}_{(\Delta L, \Delta B) = (1,0)} + \underbrace{\lambda'_{ijk} L_i Q_j \bar{D}_k}_{(\Delta L, \Delta B) = (1,0)} + \underbrace{\frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}_{(\Delta L, \Delta B) = (0,1)}$$

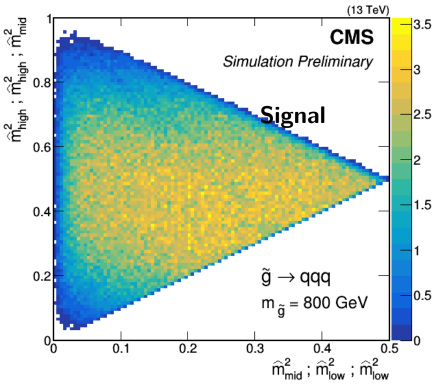


Search for pair-produced three-jet resonances (CMS PAS EXO-17-030)

- This CMS analysis searches for pair-produced resonances, each decaying into three quarks.
- This is allowed through $\lambda'' \neq 0$.
- Use of Dalitz plot variables of normalized dijet masses within each jet triplet to discriminate signal and background.





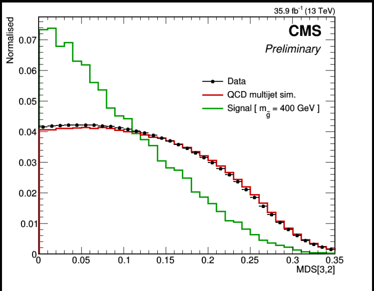


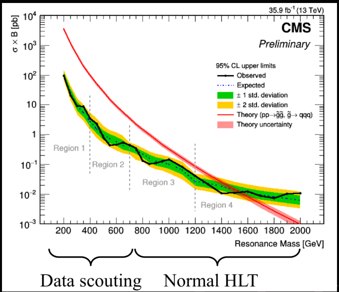
Challenge:

- This search included region for low masses where normal trigger must be relaxed.
- But then event size is huge: $H_T > 410$ GeV and AK4 jet $p_T > 20$ GeV triggered at 2 kHz!

Solution:

- Had to use particle flow scouting trigger.
  - Only feasible by storing minimal amount of information for each event: jets, leptons and photons as reconstructed at HLT.
  - This makes the event size of 10 KB/event, a managable number.

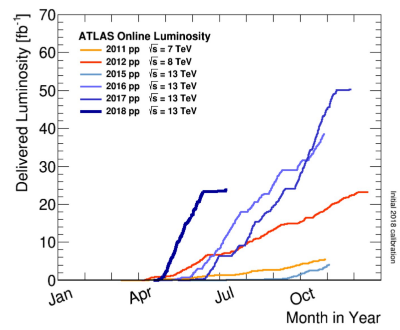


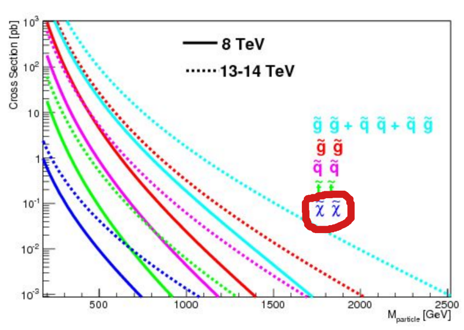


- Electroweak SUSY search

Why Electroweak SUSY?

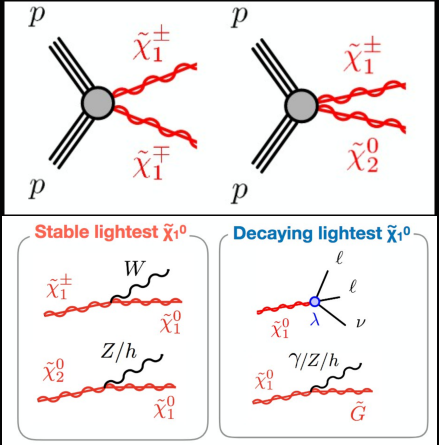
- Dominate over the strong production if the squark and gluinoes are too heavy: LHC cannot produce them.
- The strong SUSY limits are already in ∼TeV scale.
  - Electroweak SUSY has lower cross-sections, hence making the electroweak SUSY production promising.
  - Large mass ranges of EWK SUSY is still left to probe.
- This talk:
  - Impossible to cover all the searches.
  - Show classical signature searches.



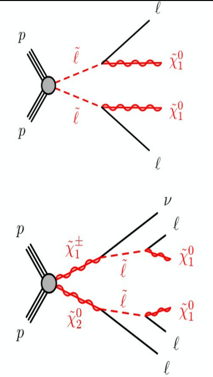


Classical SUSY EWK signals

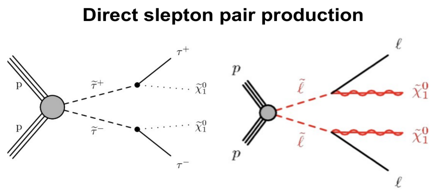
- Neutralino and chargino production

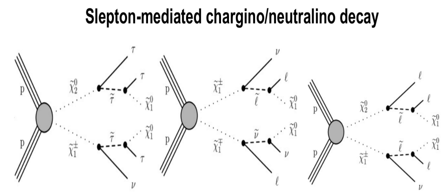


- Slepton production



- Leptons and E_T^{miss} gives the cleanest signature.
- Main background to consider: diboson.
- To reduce $t\bar{t}$, jet vetoes are used.

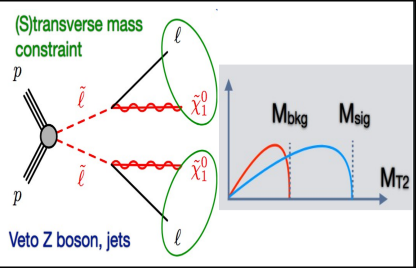


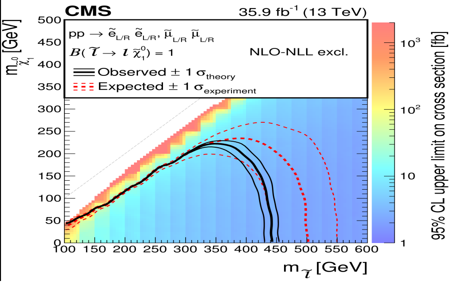


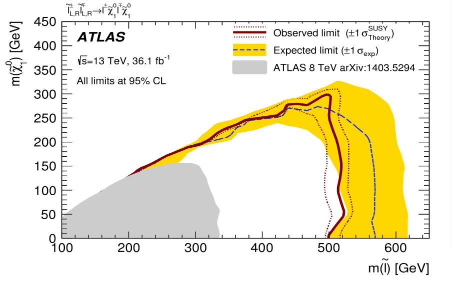
Topology	Final State	ATLAS	CMS
Direct light slepton	2L0J+E_T^{miss} 2 soft leptons+E_T^{miss}	**1803.02762** (slepton mass ∼500 GeV) Phys. Rev. D 97, 052010 (2018) (∼200 GeV for $\Delta M \sim$ 10 GeV)	**1806.05264** (for left/right handed slepton mass 290 GeV/400 GeV)
Direct stau	2τs+E_T^{miss}	Phys. Rev. D 93, 052002(2016)	**1807.02048**
chargino/neutralino via light slepton	2L0J/3J+E_T^{miss}	**1803.02762** (∼ 750 GeV limit on m($\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0$))	**1807.07799 (2L)** ∼800 GeV for $\tilde{\chi}_1^{\pm}$and 320 GeV for $\tilde{\chi}_2^0$
chargino/neutralino via stau	2τs+E_T^{miss}	Eur. Phys. J. C 78 (2018) ∼ 1.1 TeV limit in m($\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0$)	**1807.02048** up to 560 GeV depending on config

Direct light sleptons: (CMS:1806.05264, ATLAS:1803.02762)

- dileptons: opposite charge, same flavour
- Veto in jets
- upper bound on mass of pair-produced particles each decaying to l+LSP.
- $m_{T2} > 90$ (100) GeV gets rid of WW.
- binned in E_T^{miss} for CMS, m_{ll} and m_{T2} for ATLAS.
- Dominant background: $t\bar{t}$ and WW
- No significant excess found.







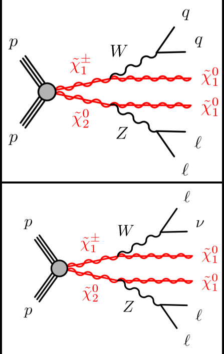
Summary of Gaugino Searches

Topology	Final state	ATLAS	CMS
$\tilde{\chi}_1^\pm \tilde{\chi}_1^\pm$ *via WW*	**2L0J + MET**	**ATLAS-CONF-2018-042**	**1807.07799**
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ ***via WZ***	2 soft leptons + MET	Phys. Rev. D 97, 052010 (2018)	Phys. Lett. B 782 (2018) 440
	2L/3L + MET	1803.02762	JHEP 03 (2018) 166 JHEP 03 (2018) 076
	2L/3L + MET RJR	**1806.02293**	
	3L+HT		JHEP 03 (2018) 160 (specific treatment of the "WZ corridor")
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ *via Wh*	Wh	Eur. Phys. J. C (2015) 75:208 (Run1)	JHEP 11 (2017) 029 Phys. Lett. B 779 (2018) 166 JHEP 03 (2018) 166
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ *via Zh*	Zh	Eur. Phys. J. C (2015) 75:208 (Run1)	JHEP 03 (2018) 076 Phys. Lett. B 779 (2018) 166 JHEP 03 (2018) 166
$\tilde{\chi}_2^0 \tilde{\chi}_3^0$ *via ZZ*	4L	Phys. Rev. D. 90, 052001 (2014) (Run1)	JHEP 03 (2018) 076 JHEP 03 (2018) 166 Eur. Phys. J. C 74 (2014) 3036 (Run 1)
Combination			**JHEP 03 (2018) 160**

Figure: Taken from Reina Camacho Toro, SUSY2018

Signal models studied:

- chargino-neutralino pair production with decays via W/Z bosons, final state of two or three leptons, jets and E_T^{miss} .
- Scenarios with large and intermediate mass splitting betweeen parent and LSP.
- Challenging case is when the mass splitting is close to the mass of Z boson mass, because then signal is similar to SM.



Solution

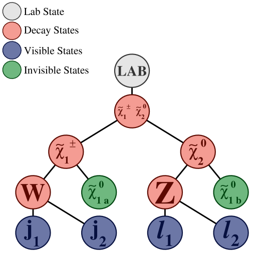
- Use of Recursive Jigsaw Reconstruction (RJR) technique to discriminate against Z+Jets backgrounds.

Signal regions:

- Eight regions targeting different mass differece.
- 2L×[ISR, Low, Intermediate, high], 3L×[ISR, Low, Intermediate, high]

RJR

- A technique to recursively reconstruct the decay chain of pair produced heavy particles.
- Reconstructed view of the event gives rise to a natural basis of kinematic observables, calculated by evaluating the momentum and energy of different objects in these reference frames.

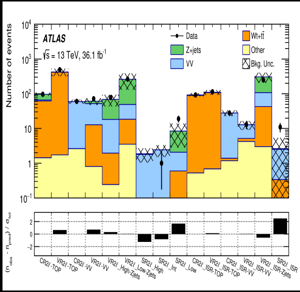


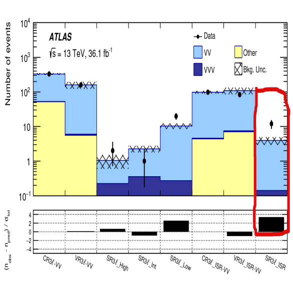
Background reduction

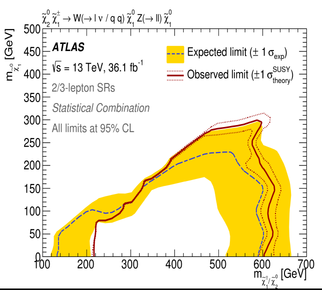
- Background processes are reduced by testing whether each event exhibits the anticipated properties of the imposed decay tree under investigation.
- For the 2L channel, the lepton pair must be associated with the same visible collection, and jets should be associated with the other visible collection.
- The remaining unknowns in the event are associated with the two collections of invisible particles.
- This is done by identifying the smallest Lorentz invariant function of the visible particles' four vectors that ensures the invisible particle mass estimators remain non-negative.
- In each of these newly constructed rest frames, all relevant momenta are defined and can be used to construct a set of variables such as multi-object invariant masses and angles between objects.

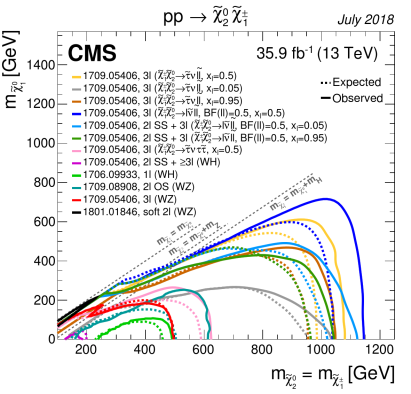
$2L/3L+E_T^{miss}$ RJR Result:

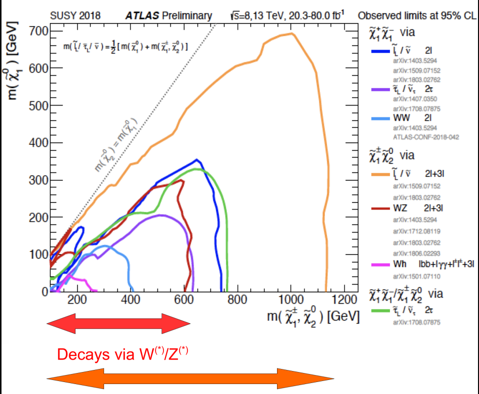
- 3.0 σ excess in 3 lepton ISR region (compressed scenario)
  - Not present in the conventional 2L/3L analysis with the same dataset.





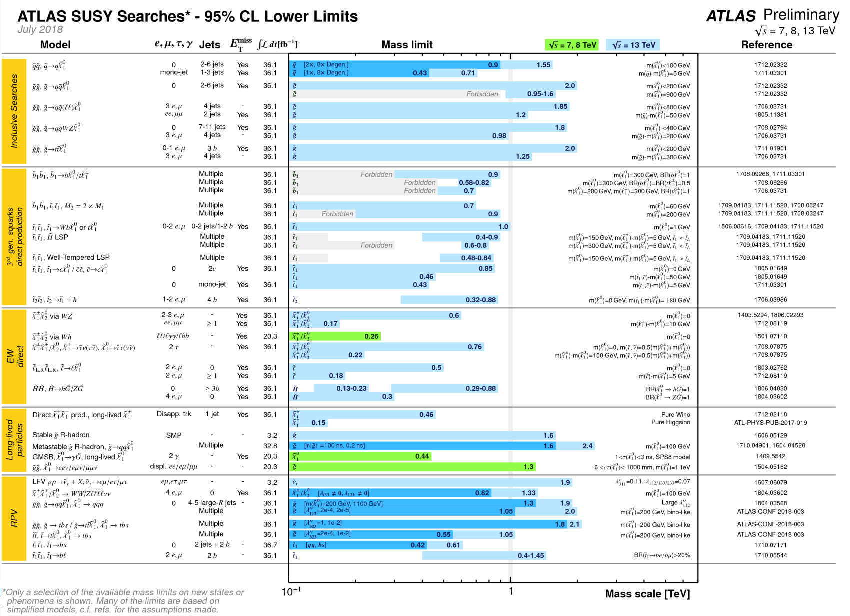




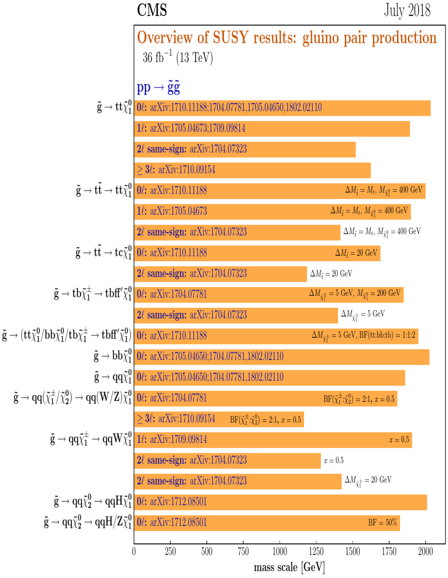


[1] mass limits at 95% CL using simplified model

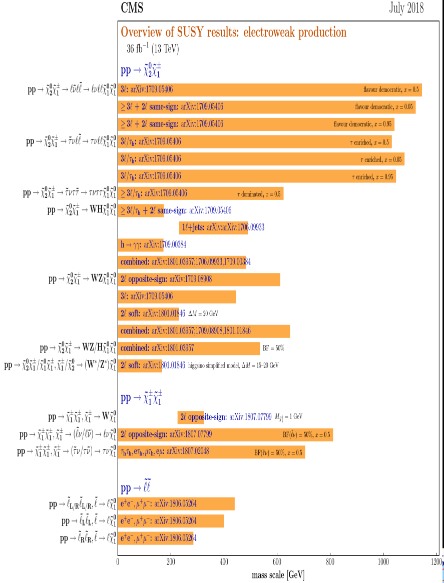
Summary of mass limits from ATLAS



Summary of mass limits from CMS



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.



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.

Conclusion

- A brief overview of present SUSY searches from both ATLAS and CMS is shown here.
- Impressive search programs from both the experiments.
- All the results shown here were published in ATLAS and CMS SUSY public websites.
- Higher mass limits put by generic strong SUSY searches:
  - Need to think outside of the box.
  - If any corner of the phase-space still remains unprobed.
  - Improve the search strategies/reconstruction processes.
- With more statistics, the EWK SUSY search is becoming more and more interesting.
  - Large mass ranges of EWK SUSY is still unprobed.
- There are plenty of analyses going on right now with Run 2 dataset (80-150 fb^{-1}).
  - The search for SUSY at the LHC is not done yet.
  - May be, SUSY is right around the corner.

Acknowledgements

- Hannsjorg Weber, Fermilab
- Jonathan Long, UIUC
- Daniel Joseph Antrim, UC Irvine
- Reina Camacho Toro, LPNHE/CNRS
- Jordi Duarte-Campderros, Tel-Aviv University

- Back Up

List of triggers used: Strong searches

- Multi-b analysis:
  - E_T^{miss} trigger with thresholds 70 GeV (2015), 100 GeV (early 2016) and 110 GeV (late 2016/2017).
- GMSB
  - $e\gamma$: diphoton trigger with $p_T$greater than 30 GeV (leading) and 18 GeV (sub-leading).
  - $\mu\gamma$: a combination of two muon-photon triggers, one requiring the presence of an isolated photon with $p_T > 30$ GeV and a muon with $p_T > 17$ GeV, and the other using symmetric p_T thresholds of 38 GeV for both objects, with no isolation criteria.
- Charm quark search
  - E_T^{miss} trigger with threshold 70 GeV (110 GeV) for data of 2015 (2016).
- RPV jet search
  - For high mass region, events collected by the OR of two different triggers: the first requires $H_T \geq 800$ GeV with AK4 jet $p_T \geq 40$ GeV; and the second requires at least four jets with $p_T \geq 70$ GeV and $H_T \geq 750$ GeV.
  - For low mass, PF scouting trigger was used.

List of triggers used: EWK searches

- Direct slepton search
  - ATLAS: a trigger selection requiring either two electrons, two muons or an electron plus a muon. The trigger-level thresholds on the p_T value of the leptons involved in the trigger decision are in the range 8âĂȘ22 GeV and are looser than those applied offline to ensure that trigger efficiencies are constant in the relevant phase space.
  - CMS: dilepton trigger - triggers that include loose isolation criteria on both leptons require $p_T > 23$ GeV (electron) or 17 GeV (muon) on the highest p_T lepton. The other lepton is then required to have $p_T > 12$ GeV (electrons) or 8 GeV (muons).
- RJR analysis
  - dielectron, dimuon or electron+muon trigger
  - For Z+jets, these events was selected with single photon trigger.

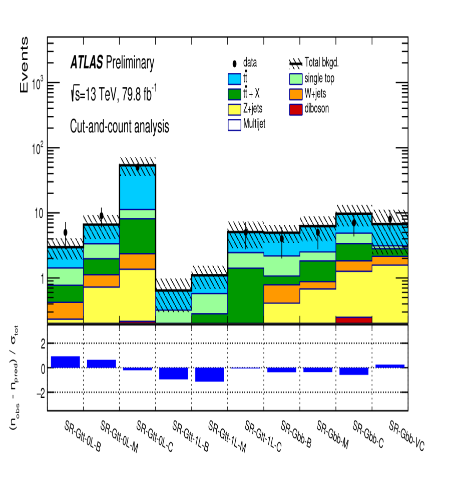
MV2 algorithm

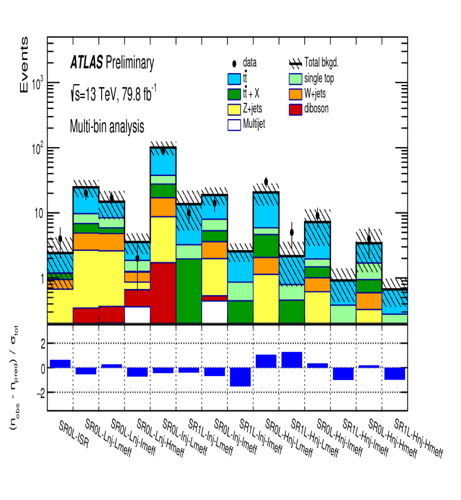
In the domain of b-tagging, a new algorithm has been developed, referred to as MV2c20. It is based on a boosted decision tree approach, which utilises jet properties and variables based on the reconstructed charged particle tracks as input.

- To make the Dalitz variable, invariant mass of three dijet pairs inside a triplet, with mass m_{12}, m_{23} and m_{13} are taken.
- Normalized dijet invariant mass: $\hat{m}(3,2)^2_{i,j} = \frac{m^2_{ij}}{m^2_{ijk}+m^2_i+m^2_j+m^2_k}$ where i,j,k belongs to 1,2 and 3. (m_i's are the mass of individual jets and m_{ijk} is the mass of the triplet.)
- For signal triplets, the lack of internal resonance and evenly spread out jets makes the Dalitz variables close to the value 1/3, implying a symmetric decay where the jets have uniform geometric separation in the center-of-mass frame of gluino.
- Triplets made of jets arising from QCD are more asymmetric and lack this feature, resulting in their $\hat{m}(3,2)^2_{i,j}$ being closer to 0 or 1.
- The three $\hat{m}(3,2)^2_{i,j}$ are sorted from largest to smallest, and labeled $\hat{m}(3,2)^2_{high}$, $\hat{m}(3,2)^2_{mid}$ and $\hat{m}(3,2)^2_{low}$.
- When plotted against one another in a Dalitz plot as shown, the signal peaks in the center closer to the value 1/3 while the QCD clusters around the edges.
- Mass distance square, $MDS[3,2] = \sum_{i>j}(\hat{m}_{ij} - \sqrt{1/3})^2$.
- This distance measure will result in a low value for signal-like topologies.

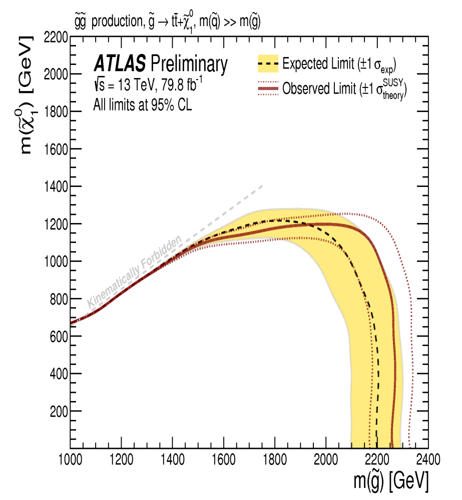
- $H^{F}_{n,m} = \sum_{i=1}^{n} |\vec{p}^{F}_{vis,i}| + \sum_{j=1}^{n} |\vec{p}^{F}_{inv,j}|$.
- F represents the rest frame where the momenta are evaluated, n and m represent the number of visible and invisible momentum vectors considered.
- $H^{PP}_{n,1}$: behaves similarly to the effective mass.
- $H^{PP}_{1,1}/H^{PP}_{4,1}$:Behaves similarly to the $E_T^{miss}\ /m_{eff}$. Utilized solely in the 2l low mass signal region to mitigate the effects of Z+jets backgrounds.
- $p^{lab}_{T,PP}/(p^{lab}_{T,PP} + H^{PP}_{T\ n,1})$: compares the magnitude of the vector sum of the transverse momenta of all objects associated with the PP system in the lab frame ($p^{lab}_{T,PP}$) to the overall transverse scale variable considered.

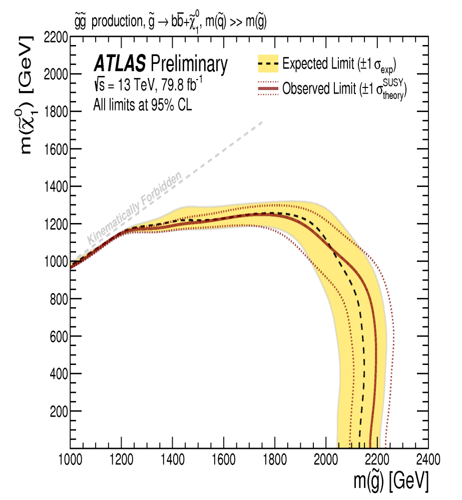
MultiB Search: 1





MultiB Search: 2





MultiB Search: 3

Gtt 1-lepton

Criteria common to all regions: ≥ 1 signal lepton, $N_{b\text{-jets}} \geq 3$

Targeted kinematics	Type	N_{jet}	m_{T}	$m_{\text{T,min}}^{b\text{-jets}}$	$E_{\text{T}}^{\text{miss}}$	$m_{\text{eff}}^{\text{incl}}$	M_J^{Σ}
Region B (Boosted, Large Δm)	SR	≥ 5	> 150	> 120	> 500	> 2200	> 200
	CR	$= 5$	< 150	–	> 300	> 1700	> 150
Region M (Moderate Δm)	SR	≥ 6	> 150	> 160	> 450	> 1800	> 200
	CR	$= 6$	< 150	–	> 400	> 1500	> 100
Region C (Compressed, small Δm)	SR	≥ 7	> 150	> 160	> 350	> 1000	–
	CR	$= 7$	< 150	–	> 350	> 1000	–

Gtt 0-lepton

Targeted kinematics	Type	N_{lepton}	$N_{b\text{-jets}}$	N_{jet}	$\Delta\phi_{\text{min}}^{4j}$	m_{T}	$m_{\text{T,min}}^{b\text{-jets}}$	$E_{\text{T}}^{\text{miss}}$	$m_{\text{eff}}^{\text{incl}}$	M_J^{Σ}
Region B (Boosted, Large Δm)	SR	$= 0$	≥ 3	≥ 7	> 0.4	–	> 60	> 350	> 2600	> 300
	CR	$= 1$	≥ 3	≥ 6	–	< 150	–	> 275	> 1800	> 300
Region M (Moderate Δm)	SR	$= 0$	≥ 3	≥ 7	> 0.4	–	> 120	> 500	> 1800	> 200
	CR	$= 1$	≥ 3	≥ 6	–	< 150	–	> 400	> 1700	> 200
Region C (Compressed, moderate Δm)	SR	$= 0$	≥ 4	≥ 8	> 0.4	–	> 120	> 250	> 1000	> 100
	CR	$= 1$	≥ 4	≥ 7	–	< 150	–	> 250	> 1000	> 100

Gbb

Criteria common to all regions: $N_{\text{jet}} \geq 4$

Targeted kinematics	Type	N_{lepton}	$N_{b\text{-jets}}$	$\Delta\phi_{\text{min}}^{4j}$	m_{T}	$m_{\text{T,min}}^{b\text{-jets}}$	$E_{\text{T}}^{\text{miss}}$	m_{eff}	Others
Region B (Boosted, Large Δm)	SR	$= 0$	≥ 3	> 0.4	–	–	> 400	> 2800	–
	CR	$= 1$	≥ 3	–	< 150	–	> 400	> 2500	–
Region M (Moderate Δm)	SR	$= 0$	≥ 4	> 0.4	–	> 90	> 450	> 1600	–
	CR	$= 1$	≥ 4	–	< 150	–	> 300	> 1600	–
Region C (Compressed, small Δm)	SR	$= 0$	≥ 4	> 0.4	–	> 155	> 450	–	–
	CR	$= 1$	≥ 4	–	< 150	–	> 375	–	–
Region VC (Very Compressed, very small Δm)	SR	$= 0$	≥ 3	> 0.4	–	> 100	> 600	–	$p_{\text{T}}^{j_1} > 400$, $j_1 \neq b$, $\Delta\phi^{j_1} > 2.5$
	CR	$= 1$	≥ 3	–	< 150	–	> 600	–	

High-N_{jet} regions									
Criteria common to all regions: $N_{b\text{-jets}} \geq 3$									
Targeted kinematics	Type	N_{lepton}	$\Delta\phi^{4j}_{\text{min}}$	m_{T}	N_{jet}	$m^{b\text{-jets}}_{\text{T,min}}$	M^{Σ}_{J}	$E^{\text{miss}}_{\text{T}}$	m_{eff}
High-m_{eff} (HH) (Large Δm)	SR-0L	$= 0$	> 0.4	–	≥ 7	> 100	> 200	> 400	> 2500
	SR-1L	≥ 1	–	> 150	≥ 6	> 120	> 200	> 500	> 2300
	CR	≥ 1	–	< 150	≥ 6	> 60	> 150	> 300	> 2100
Intermediate-m_{eff} (HI) (Intermediate Δm)	SR-0L	$= 0$	> 0.4	–	≥ 9	> 140	> 150	> 300	[1800, 2500]
	SR-1L	≥ 1	–	> 150	≥ 8	> 140	> 150	> 300	[1800, 2300]
	CR	≥ 1	–	< 150	≥ 8	> 60	> 150	> 200	[1700, 2100]
Low-m_{eff} (HL) (Small Δm)	SR-0L	$= 0$	> 0.4	–	≥ 9	> 140	–	> 300	[900, 1800]
	SR-1L	≥ 1	–	> 150	≥ 8	> 140	–	> 300	[900, 1800]
	CR	≥ 1	–	< 150	≥ 8	> 130	–	> 250	[900, 1700]

Intermediate-N_{jet} regions										
Criteria common to all regions: $N_{b\text{-jets}} \geq 3$										
Targeted kinematics	Type	N_{lepton}	$\Delta\phi^{4j}_{\text{min}}$	m_{T}	N_{jet}	$\text{j}_1 = b$ or $\Delta\phi^{\text{j}_1} \leq 2.9$	$m^{b\text{-jets}}_{\text{T,min}}$	M^{Σ}_{J}	$E^{\text{miss}}_{\text{T}}$	m_{eff}
Intermediate-m_{eff} (II) (Intermediate Δm)	SR-0L	$= 0$	> 0.4	–	[7, 8]	✓	> 140	> 150	> 300	[1600, 2
	SR-1L	≥ 1	–	> 150	[6, 7]	–	> 140	> 150	> 300	[1600, 2
	CR	≥ 1	–	< 150	[6, 7]	✓	> 100	> 150	> 300	[1600, 2
Low-m_{eff} (IL) (Low Δm)	SR-0L	$= 0$	> 0.4	–	[7, 8]	✓	> 140	–	> 300	[800, 16
	SR-1L	≥ 1	–	> 150	[6, 7]	–	> 140	–	> 300	[800, 16
	CR	≥ 1	–	< 150	[6, 7]	✓	> 130	–	> 300	[800, 16

Low-N_{jet} regions

Criteria common to all regions: $N_{b\text{-jets}} \geq 3$

Targeted kinematics	Type	N_{lepton}	$\Delta\phi^{4j}_{min}$	m_T	N_{jet}	$j_1 = b$ or $\Delta\phi^{j_1} \leq 2.9$	$p_T^{j_4}$	$m^{b\text{-jets}}_{T,min}$	E_T^{miss}	m_{eff}
High-m_{eff} (LH) (Large Δm)	SR	= 0	> 0.4	–	[4, 6]	–	> 90	–	> 300	> 2400
	CR	≥ 1	–	< 150	[4, 5]	–	-	–	> 200	> 2100
Intermediate-m_{eff} (LI) (Intermediate Δm)	SR	= 0	> 0.4	–	[4, 6]	✓	> 90	> 140	> 350	[1400, 240
	CR	≥ 1	–	< 150	[4, 5]	✓	> 70	–	> 300	[1400, 200
Low-m_{eff} (LL) (Low Δm)	SR	= 0	> 0.4	–	[4, 6]	✓	> 90	> 140	> 350	[800, 1400
	CR	≥ 1	–	< 150	[4, 5]	✓	> 70	–	> 300	[800, 1400

ISR regions

Criteria common to all regions: $N_{b\text{-jets}} \geq 3$, $\Delta\phi^{j_1} > 2.9$, $p_T^{j_1} > 400$ GeVand $j_1 \neq b$

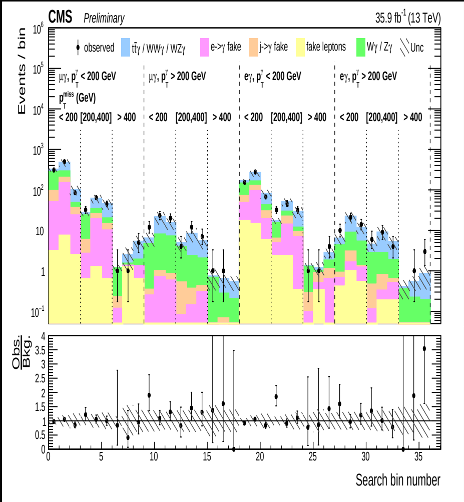
Type	N_{lepton}	$\Delta\phi^{4j}_{min}$	m_T	N_{jet}	$m^{b\text{-jets}}_{T,min}$	E_T^{miss}	m_{eff}
SR	= 0	> 0.4	–	[4, 8]	> 100	> 600	< 2200
CR	≥ 1	–	< 150	[4, 7]	–	> 400	< 2000

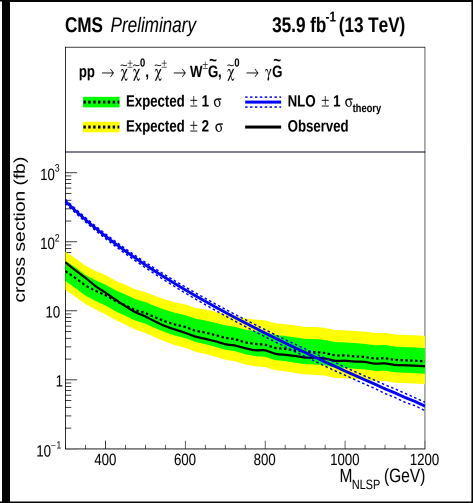
	SR-Gtt-1L		
Targeted kinematics	B	M	C
Observed events	0	0	5
Fitted background	0.64 ± 0.34	1.1 ± 0.4	5.1 ± 2.2
$t\bar{t}$	0.32 ± 0.23	0.52 ± 0.30	2.6 ± 1.7
Single-top	0.17 ± 0.22	0.29 ± 0.19	1.0 ± 1.0
$t\bar{t} + X$	0.15 ± 0.09	0.27 ± 0.15	1.4 ± 0.7
Z+jets	< 0.01	< 0.01	0.0018 ± 0.0015
W+jets	< 0.01	0.009 ± 0.031	0.007 ± 0.008
Diboson	< 0.01	< 0.01	< 0.01
MC-only background	0.8	1.1	5.3

	SR-Gtt-0L		
Targeted kinematics	B	M	C
Observed events	5	9	50
Fitted background	3.0 ± 1.1	6.6 ± 2.6	54 ± 17
$t\bar{t}$	1.5 ± 0.7	3.2 ± 1.8	42 ± 16
Single-top	0.7 ± 0.6	1.4 ± 0.7	3.2 ± 3.4
$t\bar{t} + X$	0.35 ± 0.19	0.9 ± 0.4	5.7 ± 3.1
Z+jets	0.2 ± 0.5	0.6 ± 1.7	1.1 ± 2.9
W+jets	0.19 ± 0.17	0.4 ± 0.4	1.0 ± 1.0
Diboson	< 0.01	0.06 ± 0.04	0.19 ± 0.13
Multijet	0.04 ± 0.04	0.029 ± 0.029	0.030 ± 0.030
MC-only background	3.3	7.2	52

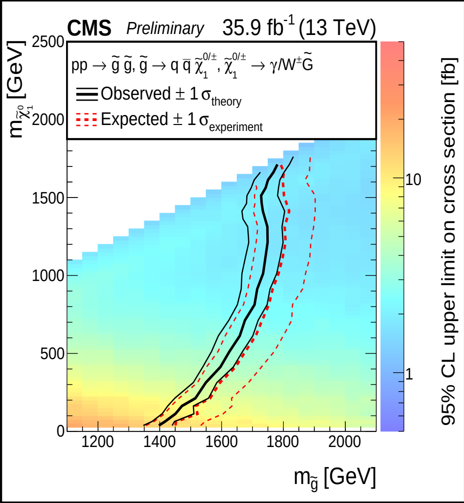
	SR-Gbb			
Targeted kinematics	B	M	C	VC
Observed events	4	5	7	8
Fitted background	4.9 ± 1.5	6.3 ± 2.6	9.7 ± 3.5	7 ± 4
$t\bar{t}$	2.8 ± 0.9	3.7 ± 2.1	4.8 ± 1.4	3.6 ± 2.2
Single-top	1.1 ± 0.7	0.7 ± 0.4	1.5 ± 1.6	0.30 ± 0.26
$t\bar{t} + X$	0.29 ± 0.17	0.9 ± 0.5	1.5 ± 0.8	0.67 ± 0.35
Z+jets	0.3 ± 0.8	0.5 ± 1.3	1.0 ± 2.6	1 ± 4
W+jets	0.4 ± 0.4	0.20 ± 0.23	0.6 ± 0.5	0.6 ± 0.5
Diboson	0.03 ± 0.14	0.19 ± 0.24	0.25 ± 0.19	0.16 ± 0.11
Multijet	0.08 ± 0.08	< 0.01	< 0.01	< 0.01
MC-only background	4.5	7.0	9.0	7

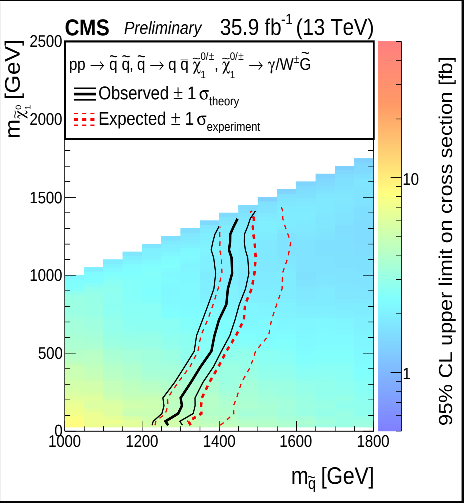
PhotonLeptonMET Search: 1

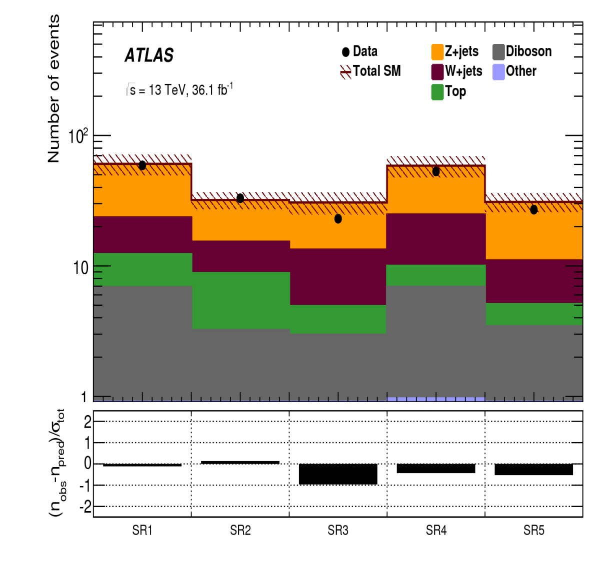


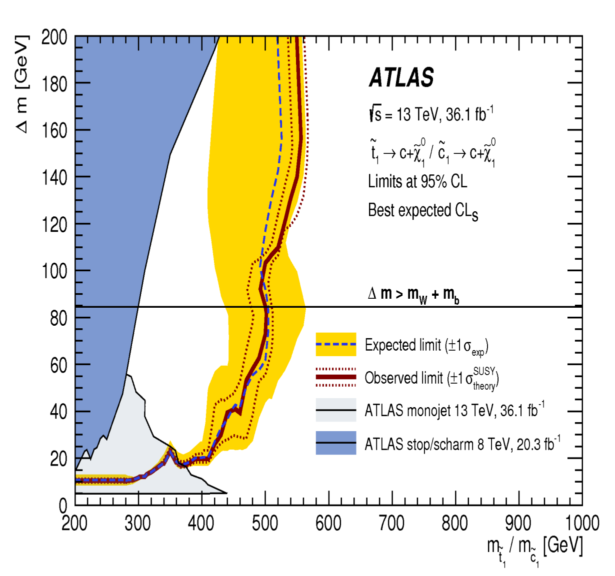


PhotonLeptonMET Search: 2






ATLAS
√s = 13 TeV, 36.1 fb⁻¹
Data
Total SM
Z+jets
W+jets
Top
Diboson
Other
Number of events
10²
10
1
(n_obs-n_pred)/σ_tot
2
1
0
-1
-2
SR1
SR2
SR3
SR4
SR5

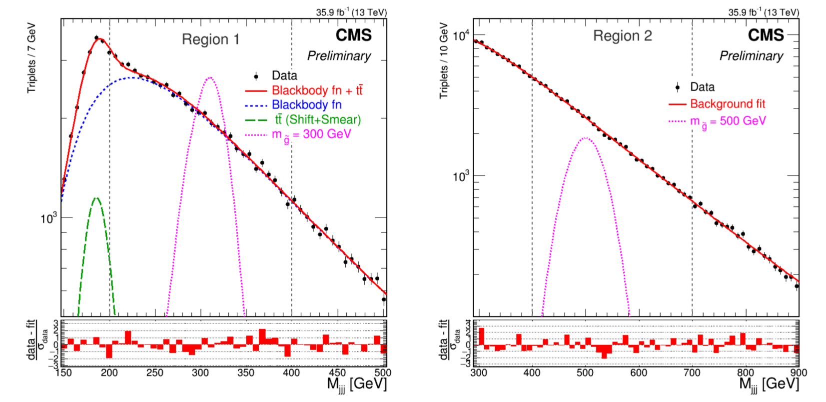

ATLAS
√s = 13 TeV, 36.1 fb-1
t̃1 → c+χ̃01 / c̃1 → c+χ̃01
Limits at 95% CL
Best expected CLs
Δ m > mW + mb
Expected limit (±1 σexp)
Observed limit (±1 σSUSYtheory)
ATLAS monojet 13 TeV, 36.1 fb-1
ATLAS stop/scharm 8 TeV, 20.3 fb-1
Δ m [GeV]
mt̃1 / mc̃1 [GeV]

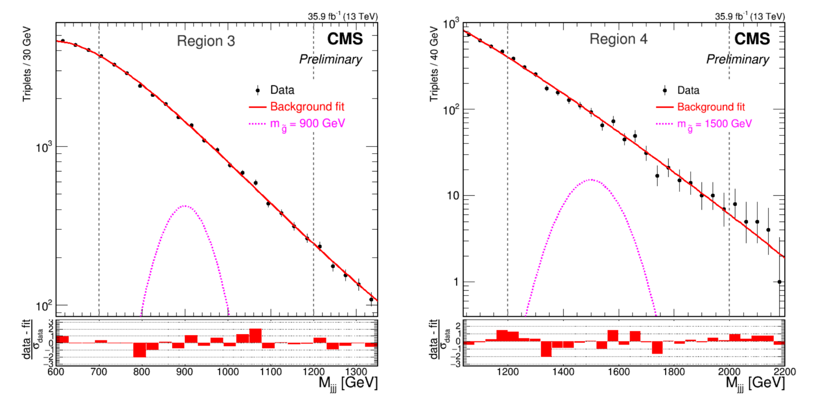
	SR1	SR2	SR3	SR4	SR5
Trigger	E_T^{miss} triggers				
Leptons	0 e AND 0 μ				
E_T^{miss} [GeV]	> 500				
$\Delta\phi_{min}(\text{jet}, E_T^{miss})$ [rad]	> 0.4				
$N_{c-\text{jets}}$	≥ 1				
N_{jets}	≥ 2	≥ 3	≥ 3	≥ 3	≥ 3
Leading jet c-tag veto	yes	yes	yes	yes	no
p_T^{j1} [GeV]	> 250	> 250	> 250	> 250	> 300
p_T^{j2} [GeV]	–	–	> 100	> 140	> 200
p_T^{j3} [GeV]	–	–	> 80	> 120	> 150
p_T^{c1} [GeV]	< 100	> 60	> 80	> 100	> 150
m_T^c [GeV]	$\in (120, 250)$	$\in (120, 250)$	$\in (175, 400)$	> 200	> 400

Source \ Region	SR1 [%]	SR2 [%]	SR3 [%]	SR4 [%]	SR5 [%]
μ_Z	6.7	9.3	12	11	13
μ_W	4.5	5.6	4.8	4.4	3.9
μ_{Top}	2.9	7.7	2.2	2.0	2.1
JES	7.9	5.0	6.8	5.2	5.6
c-tagging	6.7	8.9	9.3	8.1	7.0
W/Z+jets scale variations	11	5.8	7.6	6.5	5.2
W/Z+jets resummation scale	7.8	3.7	2.5	5.6	4.7
W/Z+jets PDF	7.7	7.1	14	15	9.1
Total	18	15	19	18	16

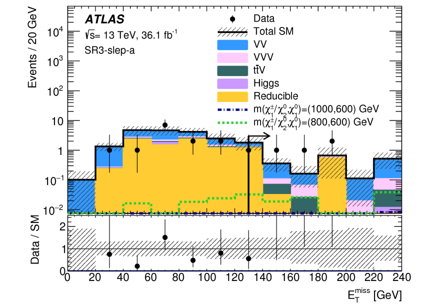
Yields	SR1	SR2	SR3	SR4	SR5
Observed	59	33	23	53	27
Total SM	61 ± 11	32 ± 5	31 ± 6	59 ± 11	31 ± 5
Z+jets	37.1 ± 7.8	16.7 ± 3.2	17 ± 5	34 ± 8	20 ± 4
W+jets	11.2 ± 5.1	6.5 ± 2.3	8.4 ± 2.0	15 ± 4	5.9 ± 1.5
Top	5.4 ± 2.0	5.6 ± 2.6	2.0 ± 2.0	3.1 ± 1.8	1.7 ± 0.7
Diboson	6.3 ± 2.1	2.7 ± 1.7	2.4 ± 0.7	5.9 ± 2.3	3.2 ± 1.6
Other	0.6 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	1.0 ± 0.1	0.3 ± 0.1
Signal benchmarks					
$(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) = (450, 425)$ GeV	22.7 ± 4.0	9.1 ± 2.6	1.6 ± 1.0	1.84 ± 0.71	0.45 ± 0.27
$(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) = (500, 420)$ GeV	18.3 ± 3.4	19.7 ± 4.9	15.2 ± 4.1	8.0 ± 2.2	1.26 ± 0.64
$(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) = (500, 350)$ GeV	5.4 ± 2.0	11.6 ± 3.3	26.1 ± 6.7	18.7 ± 5.4	3.0 ± 1.1
$(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) = (600, 350)$ GeV	1.91 ± 0.87	3.2 ± 1.3	10.5 ± 3.0	24.0 ± 5.9	7.0 ± 2.2
$(m_{\tilde{t}_1}, m_{\tilde{\chi}_1^0}) = (900, 1)$ GeV	0.67 ± 0.19	0.61 ± 0.21	1.61 ± 0.50	11.7 ± 2.0	10.2 ± 1.8
$\langle\sigma_{\text{vis}}\rangle^{95}_{obs}$ [fb]	0.67	0.46	0.33	0.59	0.40
S^{95}_{obs}	24.2	16.6	11.9	21.3	14.3
S^{95}_{exp}	$24.4^{+13.2}_{-7.6}$	$16.0^{+5.6}_{-4.4}$	$15.0^{+5.2}_{-3.1}$	$24.9^{+9.6}_{-7.1}$	$15.3^{+6.8}_{-2.2}$
$p(s = 0)$	0.5	0.41	0.5	0.5	0.5

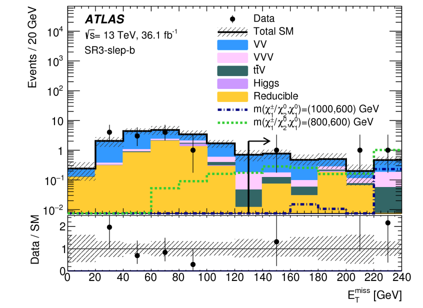
Three jets search: 1

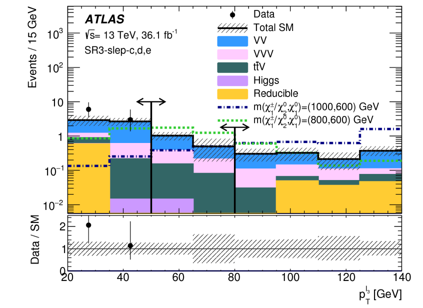



35.9 fb^{-1} (13 TeV)
Region 3
CMS
Preliminary
Data
Background fit
$m_{\tilde{g}}$ = 900 GeV
Triplets / 30 GeV
$\frac{\text{data - fit}}{\sigma_{\text{data}}}$
M_{jjj} [GeV]
35.9 fb^{-1} (13 TeV)
Region 4
CMS
Preliminary
Data
Background fit
$m_{\tilde{g}}$ = 1500 GeV
Triplets / 40 GeV
$\frac{\text{data - fit}}{\sigma_{\text{data}}}$
M_{jjj} [GeV]

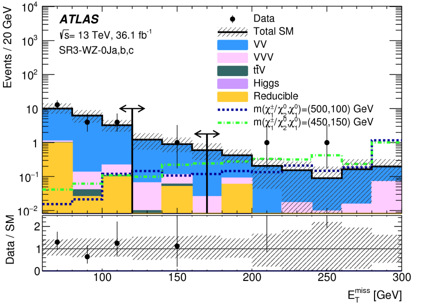
LightSlepton Search, ATLAS: 1

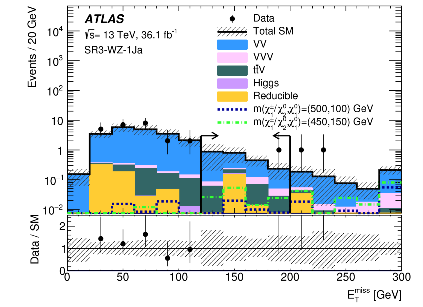


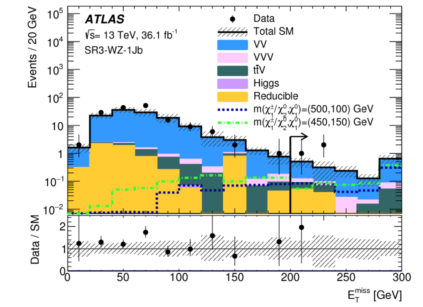


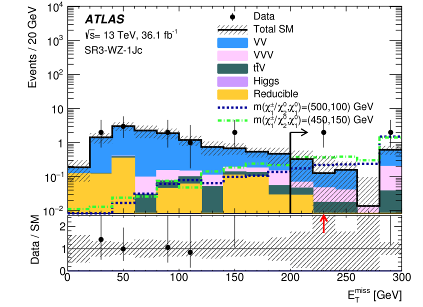


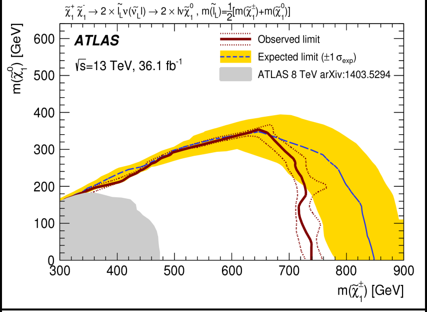
LightSlepton Search, ATLAS: 2

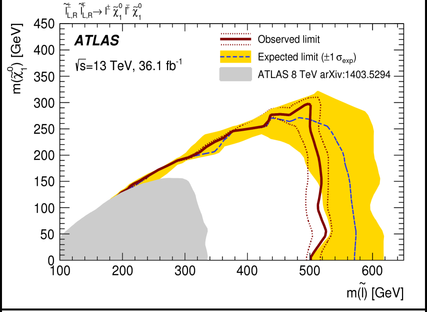


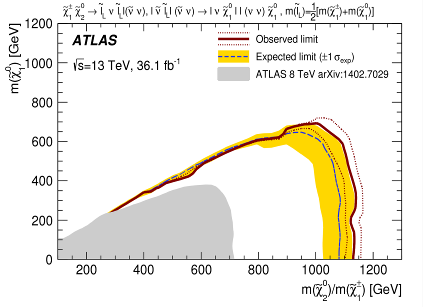


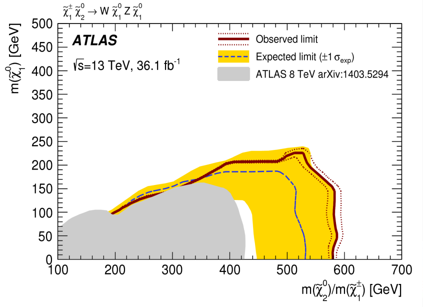





χ̃₁⁺ χ̃₁⁻ → 2 × l̃_L ν(ν̃_L l) → 2 × lνχ̃₁⁰ , m(l̃_L)=½[m(χ̃₁^±)+m(χ̃₁⁰)]
ATLAS
√s=13 TeV, 36.1 fb⁻¹
Observed limit
Expected limit (±1 σ_exp)
ATLAS 8 TeV arXiv:1403.5294
m(χ̃₁⁰) [GeV]
m(χ̃₁^±) [GeV]
0
100
200
300
400
500
600
300
400
500
600
700
800
900


l̃_{L,R}^± l̃_{L,R}^∓ → l^± χ̃₁⁰ l^∓ χ̃₁⁰
ATLAS
√s=13 TeV, 36.1 fb⁻¹
Observed limit
Expected limit (±1 σ_exp)
ATLAS 8 TeV arXiv:1403.5294
m(χ̃₁⁰) [GeV]
m(l̃) [GeV]
0
50
100
150
200
250
300
350
400
450
100
200
300
400
500
600


χ̃₁^± χ̃₂⁰ → l̃_L ν l̃_L l(ν̃ ν), l ν̃ l̃_L l (ν̃ ν) → l ν χ̃₁⁰ l l (ν ν) χ̃₁⁰ , m(l̃_L)=½[m(χ̃₁^±)+m(χ̃₁⁰)]
ATLAS
√s=13 TeV, 36.1 fb⁻¹
Observed limit
Expected limit (±1 σ_exp)
ATLAS 8 TeV arXiv:1402.7029
m(χ̃₁⁰) [GeV]
m(χ̃₂⁰)/m(χ̃₁^±) [GeV]
0
200
400
600
800
1000
1200
200
400
600
800
1000
1200

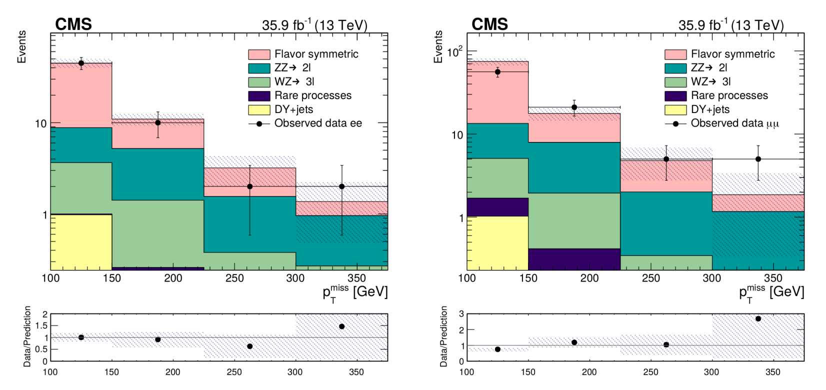

χ̃₁^± χ̃₂⁰ → W χ̃₁⁰ Z χ̃₁⁰
ATLAS
√s=13 TeV, 36.1 fb⁻¹
Observed limit
Expected limit (±1 σ_exp)
ATLAS 8 TeV arXiv:1403.5294
m(χ̃₁⁰) [GeV]
m(χ̃₂⁰)/m(χ̃₁^±) [GeV]
0
50
100
150
200
250
300
350
400
450
500
100
200
300
400
500
600
700

2ℓ+jets signal region definitions				
	SR2-int	SR2-high	SR2-low-2J	SR2-low-3J
$n_{\text{non-}b\text{-tagged jets}}$	≥ 2		2	3–5
$m_{\ell\ell}$ [GeV]	81–101		81–101	86–96
m_{jj} [GeV]	70–100		70–90	70–90
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 150	> 250	> 100	> 100
p_{T}^{Z} [GeV]	> 80		> 60	> 40
p_{T}^{W} [GeV]	> 100			
m_{T2} [GeV]	> 100			
$\Delta R_{(jj)}$	< 1.5			< 2.2
$\Delta R_{(\ell\ell)}$	< 1.8			
$\Delta\phi_{(\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}},Z)}$			< 0.8	
$\Delta\phi_{(\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}},W)}$	0.5–3.0		> 1.5	< 2.2
$E_{\mathrm{T}}^{\mathrm{miss}}/p_{\mathrm{T}}^{Z}$			$0.6 - -1.6$	
$E_{\mathrm{T}}^{\mathrm{miss}}/p_{\mathrm{T}}^{W}$			< 0.8	
$\Delta\phi_{(\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}},\mathrm{ISR})}$				> 2.4
$\Delta\phi_{(\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}},\mathrm{jet1})}$				> 2.6
$E_{\mathrm{T}}^{\mathrm{miss}}/p_{\mathrm{T}}^{\mathrm{ISR}}$				0.4–0.8
$\lvert\eta(Z)\rvert$				< 1.6
$p_{\mathrm{T}}^{\mathrm{jet3}}$ [GeV]				> 30

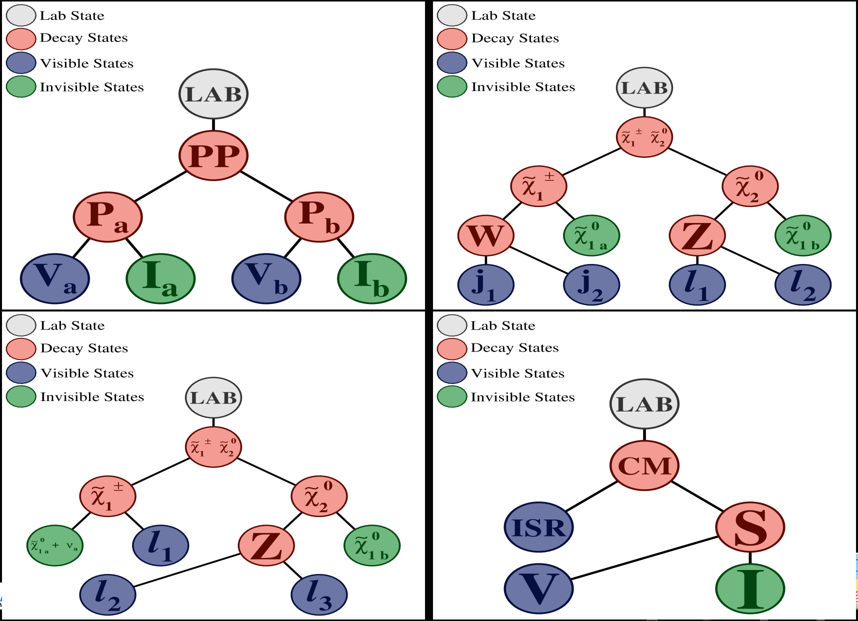
3ℓ exclusive signal region definitions

m_{SFOS} [GeV]	$E_{\text{T}}^{\text{miss}}$ [GeV]	$p_{\text{T}}^{\ell_3}$ [GeV]	$n_{\text{non-}b\text{-tagged jets}}$	$m_{\text{T}}^{\text{min}}$ [GeV]	$p_{\text{T}}^{\ell\ell\ell}$ [GeV]	$p_{\text{T}}^{\text{jet1}}$ [GeV]	Bins
<81.2	> 130	20–30 > 30		> 110			SR3-slep-a SR3-slep-b
>101.2	> 130	20–50 50–80 > 80		> 110			SR3-slep-c SR3-slep-d SR3-slep-e
81.2–101.2	60-120 120–170 > 170		0	> 110			SR3-WZ-0Ja SR3-WZ-0Jb SR3-WZ-0Jc
81.2-101.2	120–200 > 200	> 35	≥ 1	> 110 110–160 > 160	< 120	> 70	SR3-WZ-1Ja SR3-WZ-1Jb SR3-WZ-1Jc

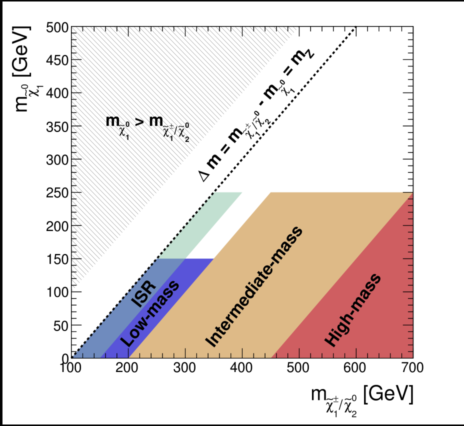
LightSlepton Search, CMS: 1



RJR Search: 1


Lab State
Decay States
Visible States
Invisible States
LAB
PP
P_a
P_b
V_a
I_a
V_b
I_b
Lab State
Decay States
Visible States
Invisible States
LAB
$\tilde{\chi}_1^{\pm}\ \tilde{\chi}_2^0$
$\tilde{\chi}_1^{\pm}$
$\tilde{\chi}_2^0$
W
$\tilde{\chi}_{1\,a}^0$
Z
$\tilde{\chi}_{1\,b}^0$
j_1
j_2
l_1
l_2
Lab State
Decay States
Visible States
Invisible States
LAB
$\tilde{\chi}_1^{\pm}\ \tilde{\chi}_2^0$
$\tilde{\chi}_1^{\pm}$
$\tilde{\chi}_2^0$
$\tilde{\chi}_{1\,a}^0 + \nu_a$
l_1
Z
$\tilde{\chi}_{1\,b}^0$
l_2
l_3
Lab State
Decay States
Visible States
Invisible States
LAB
CM
ISR
S
V
I

RJR Search: 2



ISR
Low-mass
Intermediate-mass
High-mass
$m_{\tilde{\chi}_1^0} > m_{\tilde{\chi}_1^\pm/\tilde{\chi}_2^0}$
$\Delta m = m_{\tilde{\chi}_1^\pm/\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} = m_Z$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{\chi}_1^\pm/\tilde{\chi}_2^0}$ [GeV]

Region	n_{leptons}	n_{jets}	$n_{b\text{-tag}}$	$p_T^{\ell_1,\ell_2}$ [GeV]	$p_T^{j_1,j_2}$ [GeV]	$m_{\ell\ell}$ [GeV]	m_{jj} [GeV]	m_T^W [GeV]
CR2ℓ-VV	$\in [3,4]$	≥ 2	$=0$	> 25	> 30	$\in (80,100)$	> 20	$\in (70,100)$ if $n_{\text{leptons}} = 3$
CR2ℓ-Top	$= 2$	≥ 2	$=1$	> 25	> 30	$\in (80,100)$	$\in (40,250)$	-
VR2ℓ-VV	$= 2$	≥ 2	$=0$	> 25	> 30	$\in (80,100)$	$\in (40,70)$ or $\in (90,500)$	-
VR2ℓ-Top	$= 2$	≥ 2	$=1$	> 25	> 30	$\in (20,80)$ or > 100	$\in (40,250)$	-
VR2ℓ_High-Zjets	$= 2$	≥ 2	$= 0$	> 25	> 30	$\in (80,100)$	$\in (0,60)$ or $\in (100,180)$	-
VR2ℓ_Low-Zjets	$= 2$	$= 2$	$= 0$	> 25	> 30	$\in (80,100)$	$\in (0,60)$ or $\in (100,180)$	-
SR2ℓ_High	$= 2$	≥ 2	$= 0$	> 25	> 30	$\in (80,100)$	$\in (60,100)$	-
SR2ℓ_Int	$= 2$	≥ 2	$= 0$	> 25	> 30	$\in (80,100)$	$\in (60,100)$	-
SR2ℓ_Low	$= 2$	$= 2$	$= 0$	> 25	> 30	$\in (80,100)$	$\in (70,90)$	-

RJR Search: 4

Region	$H^{\mathrm{PP}}_{4,1}$ [GeV]	$H^{\mathrm{PP}}_{1,1}$ [GeV]	$\frac{p^{\mathrm{lab}}_{\mathrm{T\,PP}}}{p^{\mathrm{lab}}_{\mathrm{T\,PP}}+H^{\mathrm{PP}}_{\mathrm{T}\,4,1}}$	$\frac{\min(H^{\mathrm{P_a}}_{1,1},H^{\mathrm{P_b}}_{1,1})}{\min(H^{\mathrm{P_a}}_{2,1},H^{\mathrm{P_b}}_{2,1})}$	$\frac{H^{\mathrm{PP}}_{1,1}}{H^{\mathrm{PP}}_{4,1}}$	$\Delta\phi^{\mathrm{P}}_{\mathrm{V}}$	$\min\Delta\phi(j_1/j_2,\vec{p}^{\,\mathrm{miss}}_{\mathrm{T}})$
CR2ℓ-VV	>200	-	<0.05	>0.2	-	$\in(0.3,2.8)$	-
CR2ℓ-Top	>400	-	<0.05	>0.5	-	$\in(0.3,2.8)$	-
VR2ℓ-VV	>400	>250	<0.05	$\in(0.4,0.8)$	-	$\in(0.3,2.8)$	-
VR2ℓ-Top	>400	-	<0.05	>0.5	-	$\in(0.3,2.8)$	-
VR2ℓ_High-Zjets	>600	-	<0.05	>0.4	-	$\in(0.3,2.8)$	-
VR2ℓ_Low-Zjets	>400	-	<0.05	-	$\in(0.35,0.60)$	-	-
SR2ℓ_High	>800	-	<0.05	>0.8	-	$\in(0.3,2.8)$	-
SR2ℓ_Int	>600	-	<0.05	>0.8	-	$\in(0.6,2.6)$	-
SR2ℓ_Low	>400	-	<0.05	-	$\in(0.35,0.60)$	-	>2.4

Region	n_{leptons}	$N_{\text{jet}}^{\text{ISR}}$	$N_{\text{jet}}^{\text{S}}$	n_{jets}	$n_{b\text{-tag}}$	$p_T^{\ell_1,\ell_2}$ [GeV]	$p_T^{j_1,j_2}$ [GeV]
CR2ℓ_ISR-VV	$\in [3,4]$	≥ 1	≥ 2	> 2	$= 0$	> 25	> 30
CR2ℓ_ISR-Top	$= 2$	≥ 1	$= 2$	$\in [3,4]$	$= 1$	> 25	> 30
VR2ℓ_ISR-VV	$\in [3,4]$	≥ 1	≥ 2	≥ 3	$= 0$	> 25	> 20
VR2ℓ_ISR-Top	$= 2$	≥ 1	$= 2$	$\in [3,4]$	$= 1$	> 25	> 30
VR2ℓ_ISR-Zjets	$= 2$	≥ 1	≥ 1	$\in [3,5]$	$= 0$	> 25	> 30
SR2ℓ_ISR	$= 2$	≥ 1	$= 2$	$\in [3,4]$	$= 0$	> 25	> 30

Region	m_Z [GeV]	m_J [GeV]	$\Delta\phi^{\rm CM}_{\rm ISR,I}$	$R_{\rm ISR}$	$p^{\rm CM}_{\rm T\,ISR}$ [GeV]	$p^{\rm CM}_{\rm T\,I}$ [GeV]	$p^{\rm CM}_{\rm T}$ [GeV]
CR2ℓ_ISR-VV	$\in (80,100)$	> 20	> 2.0	$\in (0.0,0.5)$	> 50	> 50	< 30
CR2ℓ_ISR-Top	$\in (50,200)$	$\in (50,200)$	> 2.8	$\in (0.4,0.75)$	> 180	> 100	< 20
VR2ℓ_ISR-VV	$\in (20,80)$ or > 100	> 20	> 2.0	$\in (0.0,1.0)$	> 70	> 70	< 30
VR2ℓ_ISR-Top	$\in (50,200)$	$\in (50,200)$	> 2.8	$\in (0.4,0.75)$	> 180	> 100	> 20
VR2ℓ_ISR-Zjets	$\in (80,100)$	< 50 or > 110	-	-	> 180	> 100	< 20
SR2ℓ_ISR	$\in (80,100)$	$\in (50,110)$	> 2.8	$\in (0.4,0.75)$	> 180	> 100	< 20

Region	n_{leptons}	n_{jets}	$n_{b\text{-tag}}$	$p_{\text{T}}^{\ell_1}$ [GeV]	$p_{\text{T}}^{\ell_2}$ [GeV]	$p_{\text{T}}^{\ell_3}$ [GeV]
CR3ℓ-VV	$=3$	<3	$=0$	>60	>40	>30
VR3ℓ-VV	$=3$	<3	$=0$	>60	>40	>30
SR3ℓ_High	$=3$	<3	$=0$	>60	>60	>40
SR3ℓ_Int	$=3$	<3	$=0$	>60	>50	>30
SR3ℓ_Low	$=3$	$=0$	$=0$	>60	>40	>30

Region	$m_{\ell\ell}$ [GeV]	m_{T}^{W} [GeV]	$H_{3,1}^{\mathrm{PP}}$ [GeV]	$\frac{p_{\mathrm{T\,PP}}^{\mathrm{lab}}}{p_{\mathrm{T\,PP}}^{\mathrm{lab}}+H_{\mathrm{T}\,3,1}^{\mathrm{PP}}}$	$\frac{H_{\mathrm{T}\,3,1}^{\mathrm{PP}}}{H_{3,1}^{\mathrm{PP}}}$	$\frac{H_{1,1}^{\mathrm{P_b}}}{H_{2,1}^{\mathrm{P_b}}}$
CR3ℓ-VV	$\in (75, 105)$	$\in (0, 70)$	> 250	< 0.2	> 0.75	–
VR3ℓ-VV	$\in (75, 105)$	$\in (70, 100)$	> 250	< 0.2	> 0.75	–
SR3ℓ_High	$\in (75, 105)$	> 150	> 550	< 0.2	> 0.75	> 0.8
SR3ℓ_Int	$\in (75, 105)$	> 130	> 450	< 0.15	> 0.8	> 0.75
SR3ℓ_Low	$\in (75, 105)$	> 100	> 250	< 0.05	> 0.9	–

Region	n_{leptons}	n_{jets}	$n_{b\text{-tag}}$	$p_T^{\ell_1}$ [GeV]	$p_T^{\ell_2}$ [GeV]	$p_T^{\ell_3}$ [GeV]
CR3ℓ_ISR-VV	$= 3$	≥ 1	$= 0$	> 25	> 25	> 20
VR3ℓ_ISR-VV	$= 3$	≥ 1	$= 0$	> 25	> 25	> 20
SR3ℓ_ISR	$= 3$	$\in [1, 3]$	$= 0$	> 25	> 25	> 20

Signal Region	SR2ℓ_High	SR2ℓ_Int	SR2ℓ_Low	SR2ℓ_ISR
Total uncertainty [%]	42	38	70	103
Z+jets data-driven estimate	42	31	69	96
VV theoretical uncertainties	28	27	6	34
MC statistical uncertainties	16	12	5	9
VV fitted normalization	13	14	2	16
FNP leptons	-	5	13	12
Jet energy resolution	5	10	4	3
Jet energy scale	1	2	< 1	3
E_T^{miss} modeling	3	4	< 1	< 1
$t\bar{t}$ fitted normalization	< 1	< 1	2	2
Lepton reconstruction / identification	< 1	< 1	< 1	< 1

Signal Region	SR3ℓ_High	SR3ℓ_Int	SR3ℓ_Low	SR3ℓ_ISR
Total uncertainty [%]	44	22	19	26
VV theoretical uncertainties	18	9	12	19
MC statistical uncertainties	37	17	8	10
VV fitted normalization	8	7	9	11
FNP leptons	7	< 1	3	5
Jet energy resolution	4	< 1	7	3
Jet energy scale	7	< 1	2	3
E_T^{miss} modeling	2	< 1	1	4
Lepton reconstruction / identification	3	4	2	2