Universidad de Oviedo

ICTEA
Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias

ATLAS EXPERIMENT

CMS Compact Muon Solenoid

Electroweak SUSY searches in ATLAS and CMS

LHCP 2020
Eighth Annual Conference on Large Hadron Collider Physics

25-29 May 2020, Online (World)

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On behalf of the ATLAS and CMS Collaborations

Motivation

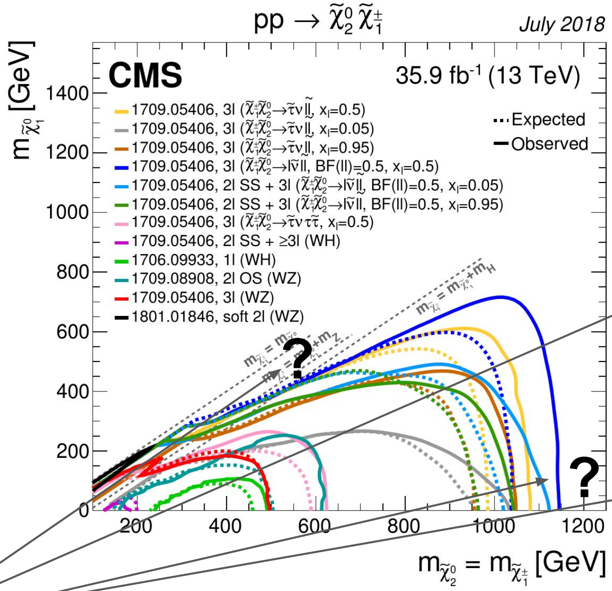
⇢ Still no direct hints of BSM physics in the LHC… but we are not done yet!

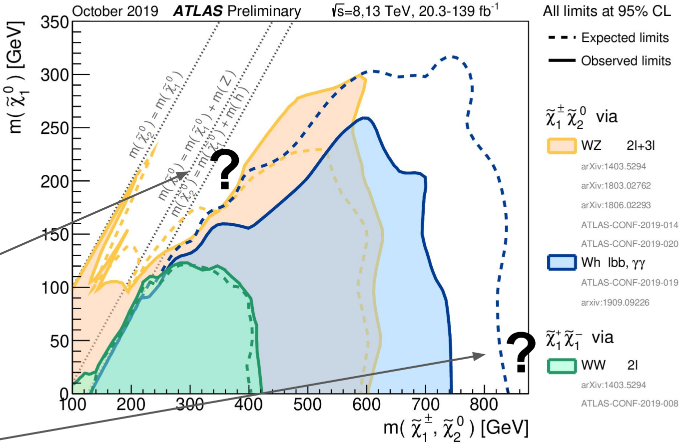
⇢ Strongly charged SUSY partners are preferred when they have similar masses to electroweak ones but current limits have pushed them beyond the TeV scale.

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

⇢ Spectacular effort with 2016 data already being surpassed by full Run II analysis: introducing new exciting strategies!

⇢ Nearly covered the TeV scale, but SUSY might by hiding in the most challenging regions yet.



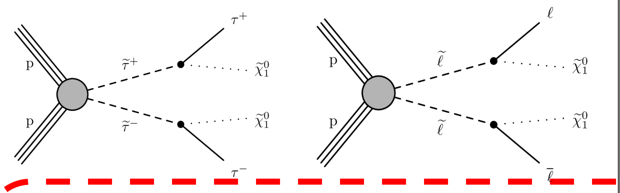


Electroweak SUSY at LHC, a *simplified* overview

⇢ Typical treatment of SUSY modelling at LHC relies on “simplified” models.

⇢ A reduction of the complexity of full SUSY models let us focus on quite defined final state signatures for several possible parameter configurations assuming RPC:

Direct slepton pair production
Decoupled high mass gauginos



ATLAS, 2τ_h Phys. Rev. D 101, 032009 (2020)

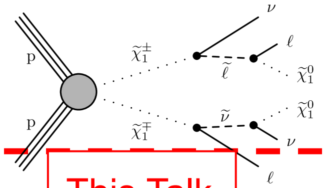
CMS, 2τ_h, 1l1τ_h Eur. Phys. J. C 80 (2020) 189

ATLAS, 2l Eur. Phys. J. C 80 (2020) 123

CMS, soft τ_h + j Phys. Rev. Lett. 124, 041803 (2020)

ATLAS, 2l soft Phys. Rev. D 101, 052005 (2020)

Decay chains involving several SUSY particles (i.e. gaugino through slepton)



This Talk

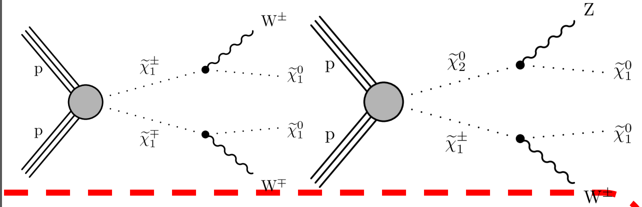
ATLAS, 2l Eur. Phys. J. C 80 (2020) 123

Check Mateusz talk in soft SUSY!

CMS, soft τ_h + j Phys. Rev. Lett. 124, 041803 (2020)

ATLAS, 2l soft Phys. Rev. D 101, 052005 (2020)

Gaugino pair production
Decoupled high mass sleptons



ATLAS, 3l CONF-2020-015

ATLAS, 2l Eur. Phys. J. C 80 (2020) 123

ATLAS, RJR Phys. Rev. D 101, 072001 (2020)

ATLAS, 2γ arXiv:2004.10894 (sub. to JHEP)

CMS, 2γ JHEP 11 (2019) 109

ATLAS. 2b arXiv:1909.0926 (sub. to EPJ C)

ATLAS, 2l soft Phys. Rev. D 101, 052005 (2020)

Slepton pair production

Highlight - Stau production

CMS: Eur. Phys. J. C 80 (2020) 189

ATLAS: Phys. Rev. D 101, 032009 (2020)

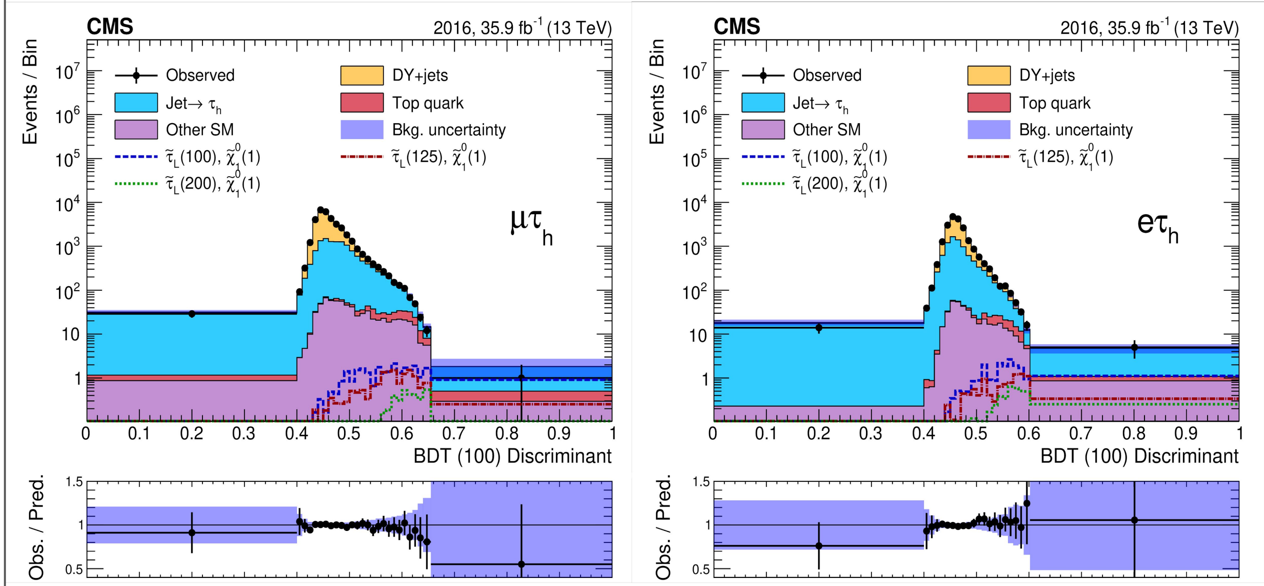
⇢SUSY models with light staus can predict some cosmological observations (DM relic density).

⇢Searches for direct stau pair production carried on by both the ATLAS ($2\tau_h$, 139 fb^{-1}) and CMS (both $2\tau_h$, $1l + 1\tau_h$, 77 fb^{-1}) collaborations.

$1l+1\tau_h$ final state

⇢ 1 light lepton + $1\tau_h$ "simplifies" triggering and selection strategy. MisID of jet->τ_h constitutes a dominant background, along with Z + jets production.

⇢ Several BDT discriminants trained to define signal regions that optimally separate the stau signal from the backgrounds using high level kinematics.



Highlight - Stau production

CMS: Eur. Phys. J. C 80 (2020) 189

ATLAS: Phys. Rev. D 101, 032009 (2020)

⇢A search performed both by ATLAS and CMS, heavily dominated by the misID τ_h in either W+jets or multijet production.

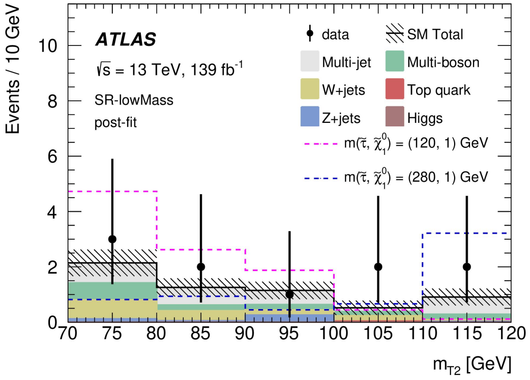
⇢ Similar selection criteria:

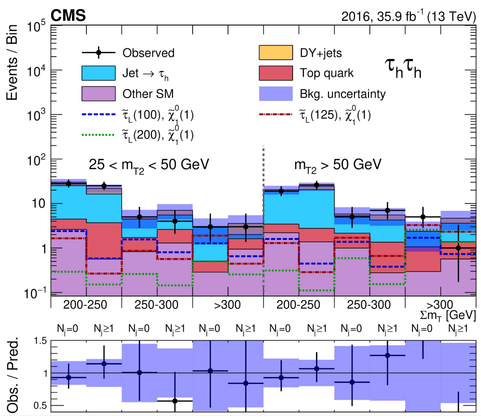
CMS	ATLAS	
$\Delta\phi(\tau_h, \tau_h) > 1.5$	$\Delta\phi(\tau_h, \tau_h) > 0.8$ $\Delta R(\tau_h, \tau_h) < 3.2$	MJet
$p_T^{miss} > 50$ GeV	$p_T^{miss} > 75$ GeV $m(\tau_h \tau_h) > 120$ GeV	DY
$N_{\text{b tag}} = 0$	$N_{\text{b tag}} = 0$ $M_{T2}(\tau_h, \tau_h) > 70$ GeV	tt

⇢ And background estimation: using data driven techniques for the mis ID τ_h in multijet (ATLAS) and multijet/W (CMS)

⇢ATLAS relies on 2 extra tight SRs (low/high mass) + background CRs for the signal extraction fit.

⇢CMS uses an extended fit to regions defined by a three variable binning. Low m_T, low m_{T2} act as "background regions".



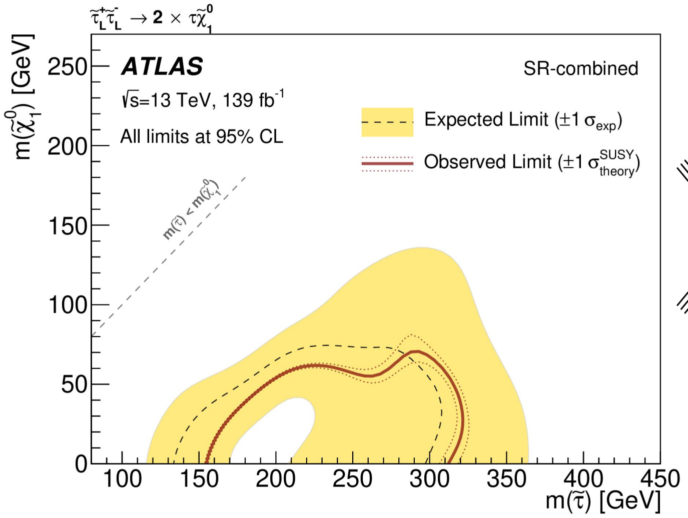


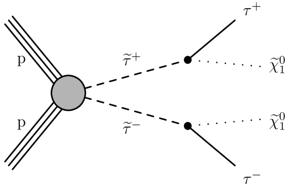
Highlight - Stau production

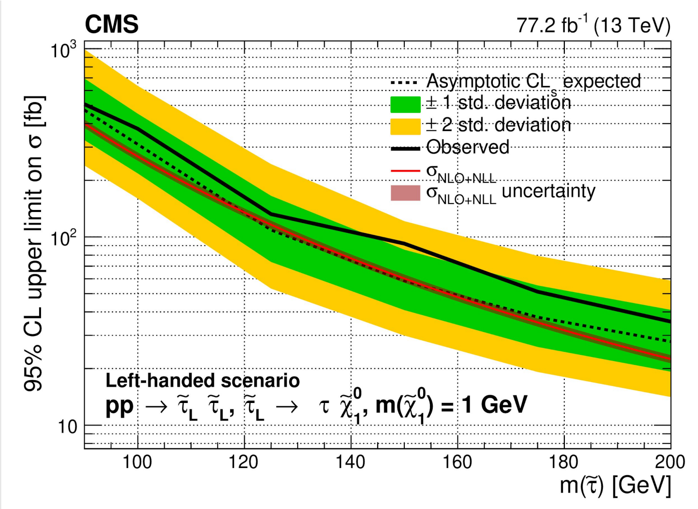
CMS: Eur. Phys. J. C 80 (2020) 189

ATLAS: Phys. Rev. D 101, 032009 (2020)

⇢Interpretations in both terms of left-handed only (here) and degenerated left/right (back up):







⇢Searches reach result complementary:

⇢ATLAS profits from higher statistics in the bulk m_{NLSP} ~ 150-300 GeV

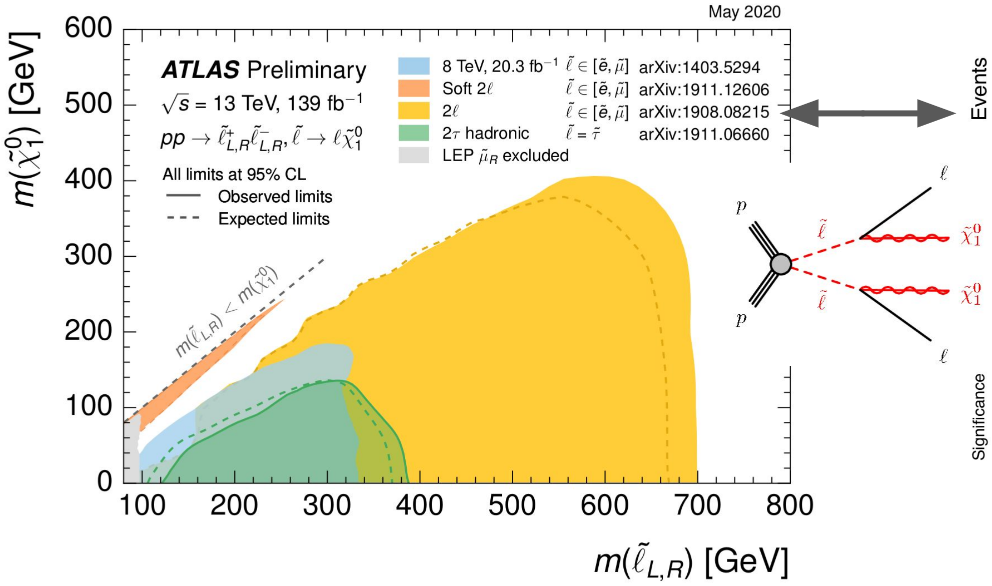
⇢CMS usage of light leptons (lower p_T) provides higher sensitivity in the m_{NLSP}~100-150 GeV.

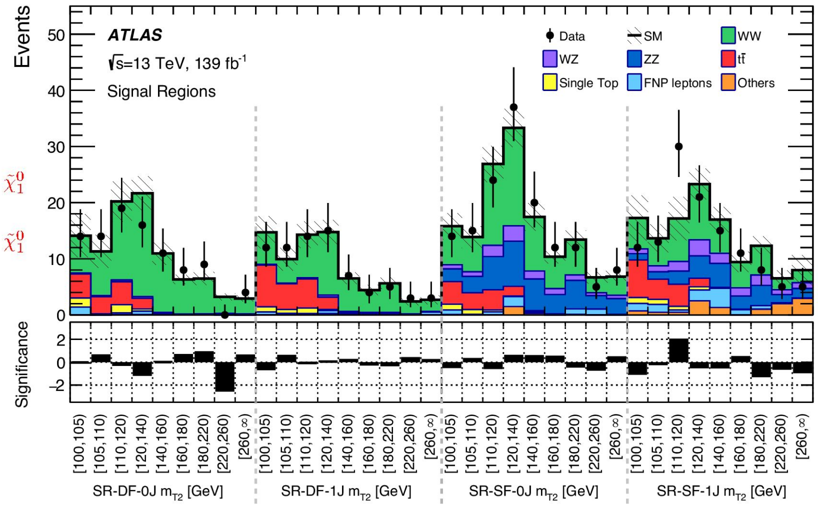
Sleptons (other new searches!)

ATLAS, 2l: [Eur. Phys. J. C 80 (2020) 123]

⇢ A thorough publication by ATLAS looking into final states with two leptons plus significant p_T^{miss}.

⇢Includes also sensitivity to chargino pair production (backup)

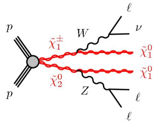




⇢ Updated results on chargino pair production (great improvements since Run I!).

Chargino+neutralino production

Highlight - 3l searches



Look at Mateusz' talk for the soft part of the search!!

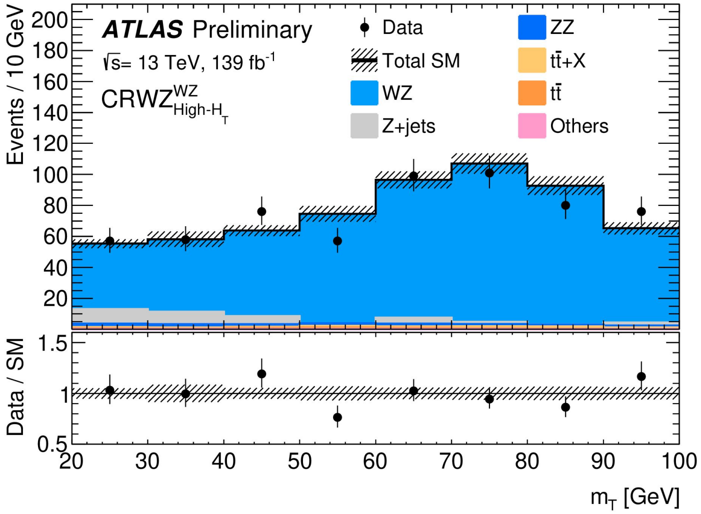
ATLAS, 3l CONF-2020-015

⇢A very recent ATLAS search with 139 fb^{-1} worth of data focusing on three light lepton final states with a selection based on several high level observables.

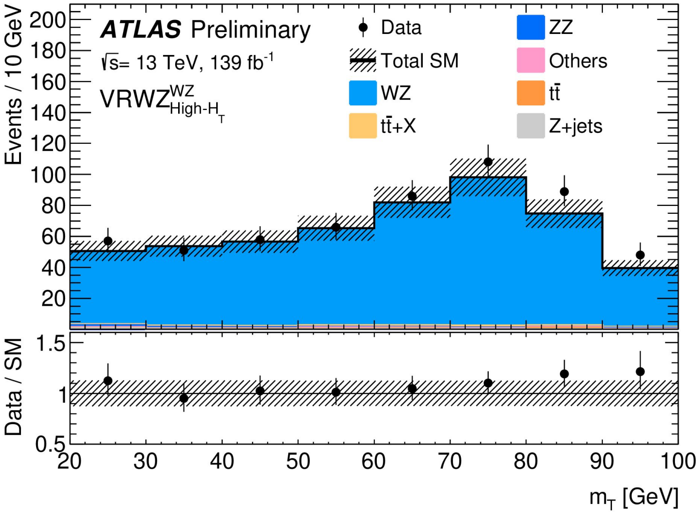
⇢Select three moderate p_T (>25,20,10 GeV) light leptons with different topologies:

- ⇢ WZ-like: OSSF pair with $m_{ll} \in [75,105]$ GeV.
- ⇢ WH-like: OSSF pair with $m_{ll} \notin [75,105]$ GeV or no OSSF pair.

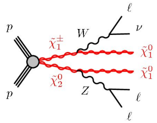
⇢Careful estimation of the WZ background is needed: control regions included in the fit to constrain the WZ behavior. Validation regions used to check this approach outside the fitted regions:



Great overall agreement!

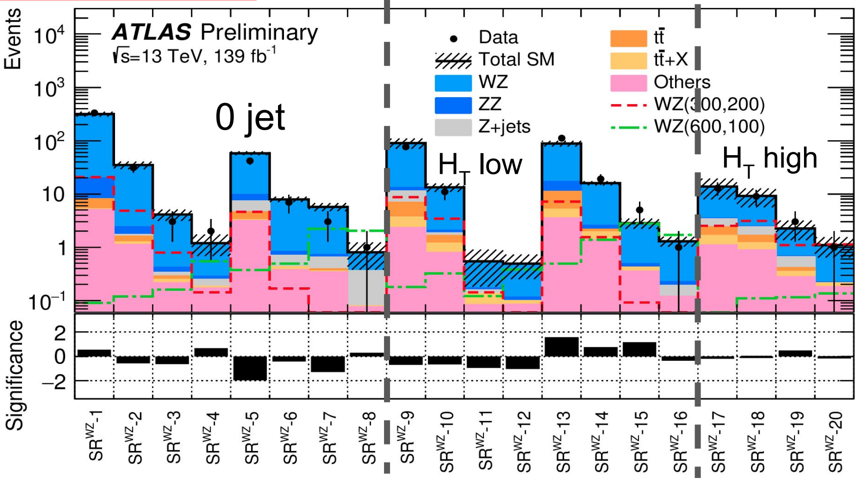


Highlight - 3l searches

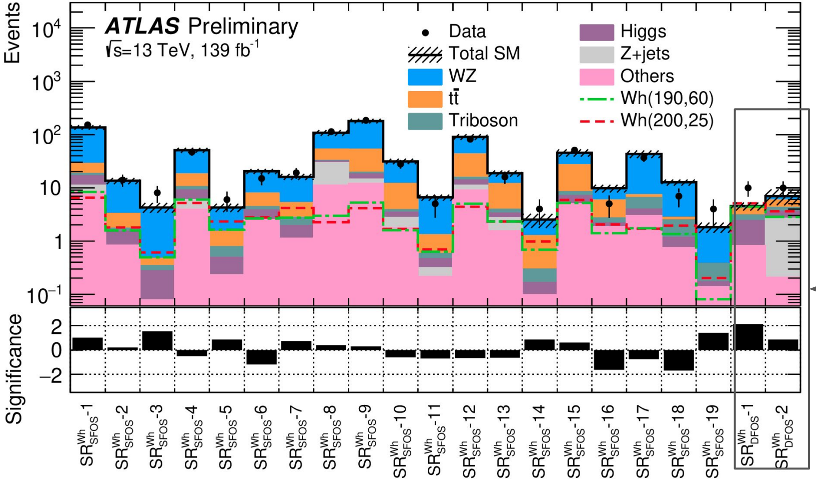


Look at Mateusz' talk for the soft part of the search!!

ATLAS, 3l CONF-2020-015



- WZ-like regions categorized in ISR jet presence:
  - 0 jet: 2 m_T x 4 p_T^{miss} bins.
  - Low H_T: 2 m_T x 4 p_T^{miss} bins.
  - High H_T: 4 p_T^{miss} bins. High jet multiplicity means quite relevant (~30%) theoretical uncertainties.

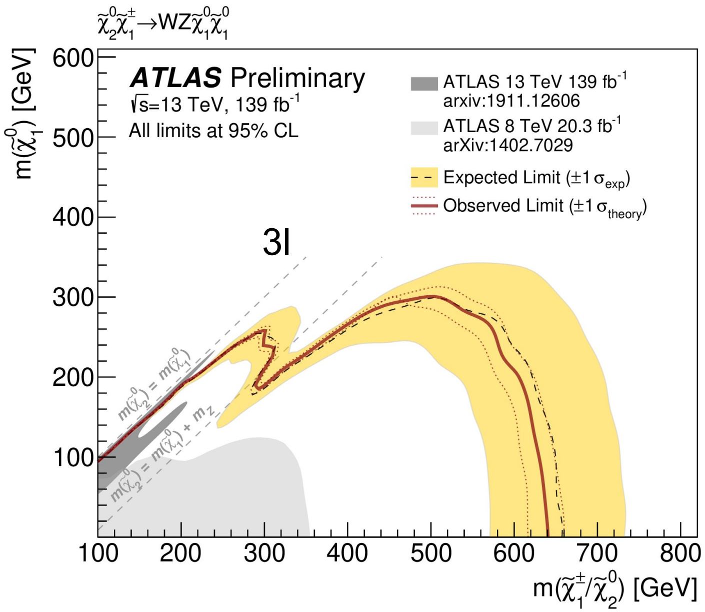


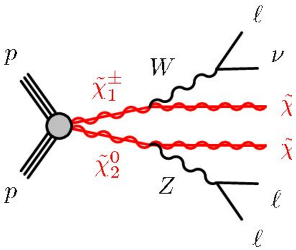
- WH-like regions include a much more complex tt-enhanced SM background.
- Similar signal region strategy to the on-Z case but with:
  - DSOF: selecting events with close-by leptons targeting the Higgs decay. Strong signal sensitivity, but also prone to high fake lepton background.

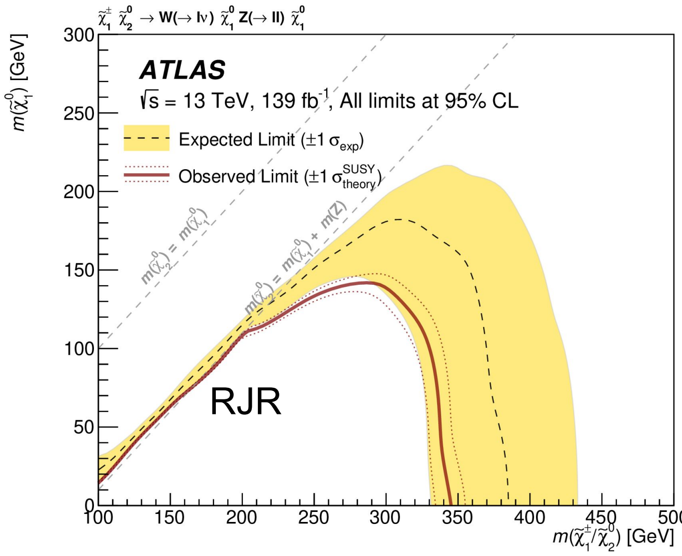
WZχχ - (+ other new searches!)

ATLAS, 3l RJR [Phys. Rev. D 101, 072001 (2020)]

ATLAS, 3l CONF-2020-015







⇢ Current exclusion reach dominated by the more “traditional” analysis over the eRJR approach.

⇢ Both analysis statistically limited, but different sources of systematics provide different ways of evolution in the future. Stay tuned for the higher statistics cases!

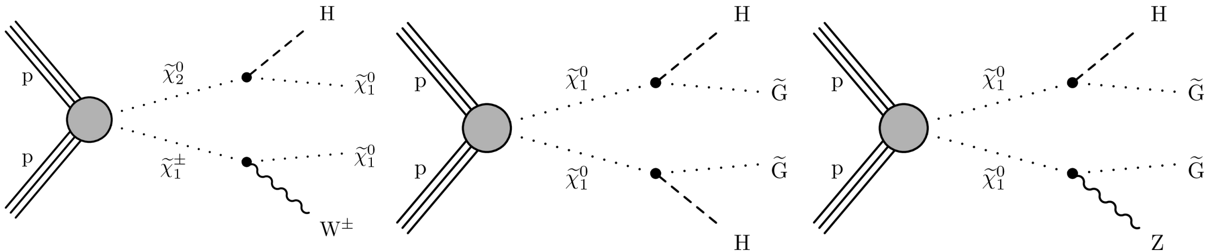
Highlight - 2γ final states

CMS: JHEP 11 (2019) 109

ATLAS: arXiv:2004.10894 (sub. to JHEP)

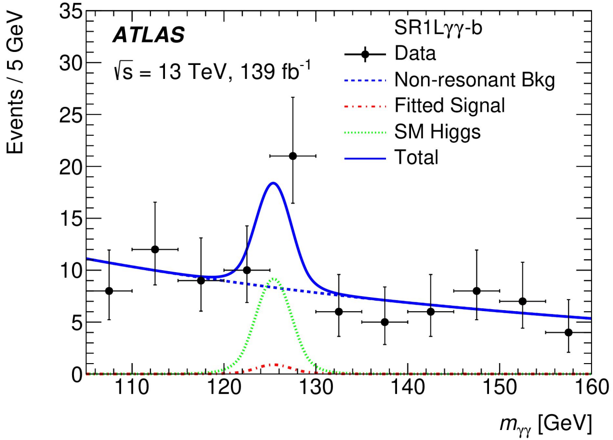
⇢ A set of new results targeting the H⟶2γ decay from ATLAS (139 fb^{-1}) and CMS (79 fb^{-1}).

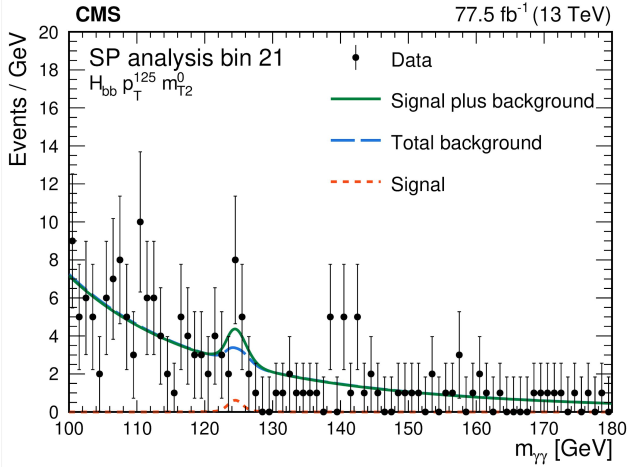
⇢ Usually produced in association with other massive boson and neutralinos. Both collaborations look at multiple final states:



CMS: W→lν ATLAS: W→lν, W→qq’	CMS: H→bb, inclusive ATLAS: inclusive H	CMS: Z→bb, Z→ll

⇢ Both signal extraction strategy relying on precise fits to analytic forms for the signal and background contributions.





WHχχ (+ other new searches!)

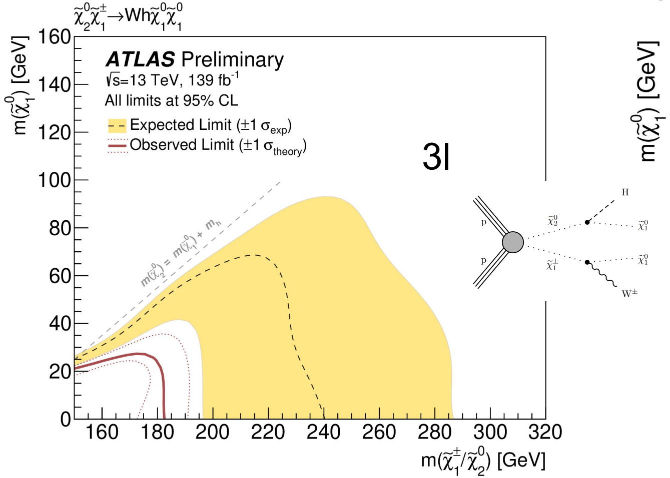
ATLAS, 3l CONF-2020-015

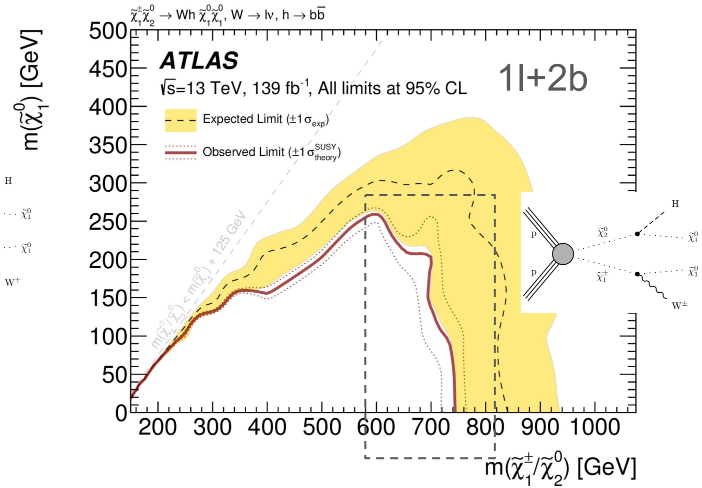
ATLAS 1l2b arXiv:1909.0926 (sub. to EPJ C)

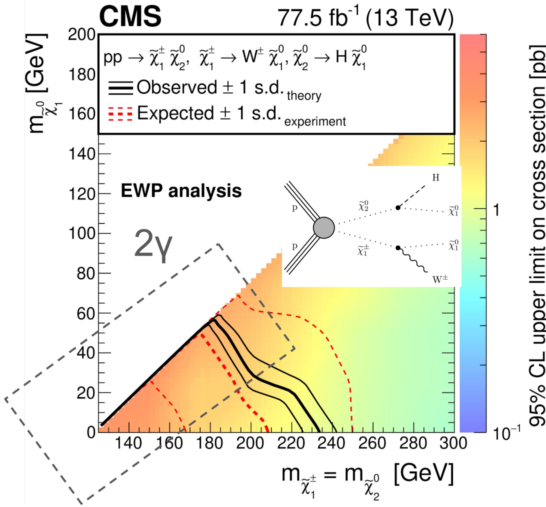
CMS 2γ: JHEP 11 (2019) 109

ATLAS 2γ: arXiv:2004.10894 (sub. to JHEP)

- Quite interesting set of new interpretations in the WHχχ production.
- Same model is targeted by 1l+2b and the 2γ searches:
- Check more information in the back-up and public results.







- Core of the sensitivity comes from high statistics given by the H ⟶ bb decay.
- High purity of the H ⟶ 2γ decay provides a handle in the most compressed scenarios.
  - Theoretical uncertainties (Scale/QCD) still relevant for the reach of the H ⟶ 2γ searches.
- 3l can be a handle in the mixed WZ/WH models (not here)⟶Depends on bino/higgsino mixing.

Conclusions

- Great quantity of new high quality results in SUSY searches during the last year (...)
  - Stau production (Eur. Phys. J. C 80 (2020) 189, Phys. Rev. D 101, 032009 (2020)).
  - Slepton production (Eur. Phys. J. C 80 (2020) 123).
  - Gaugino pair production (arXiv:1909.0926, JHEP 11 (2019) 109, arXiv:2004.10894, Phys. Rev. D 101, 072001 (2020), CONF-2020-015).
- (…) but still more to come forward with the statistical power of the Run II luminosity.
- Electroweak SUSY is a thriving field of research, pushing the boundaries of new physics.
- Stay tuned for new and exciting news!
- For the (over a coffee!) post-talk discussion, follow this zoom link during the break (same pass).

Thanks for your attention!

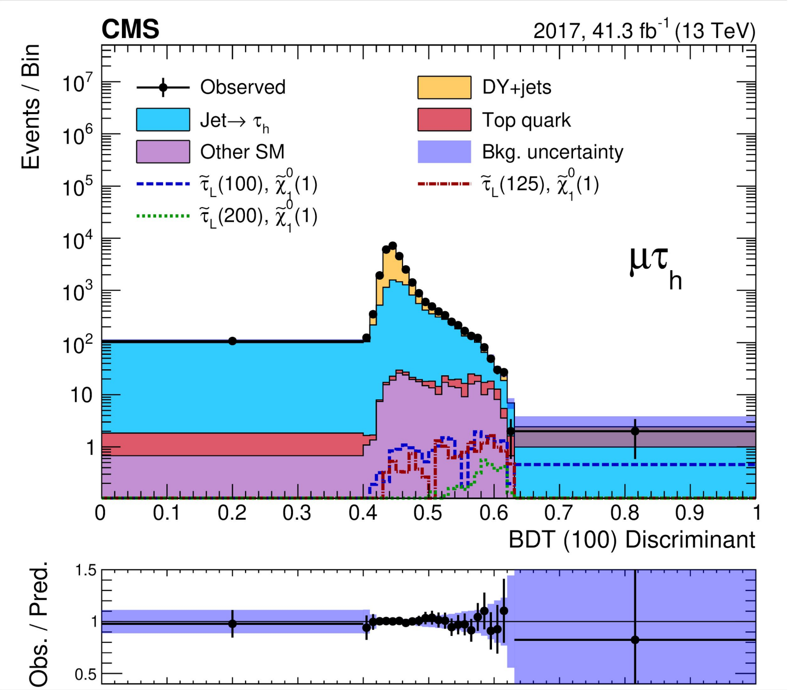
Back-Up

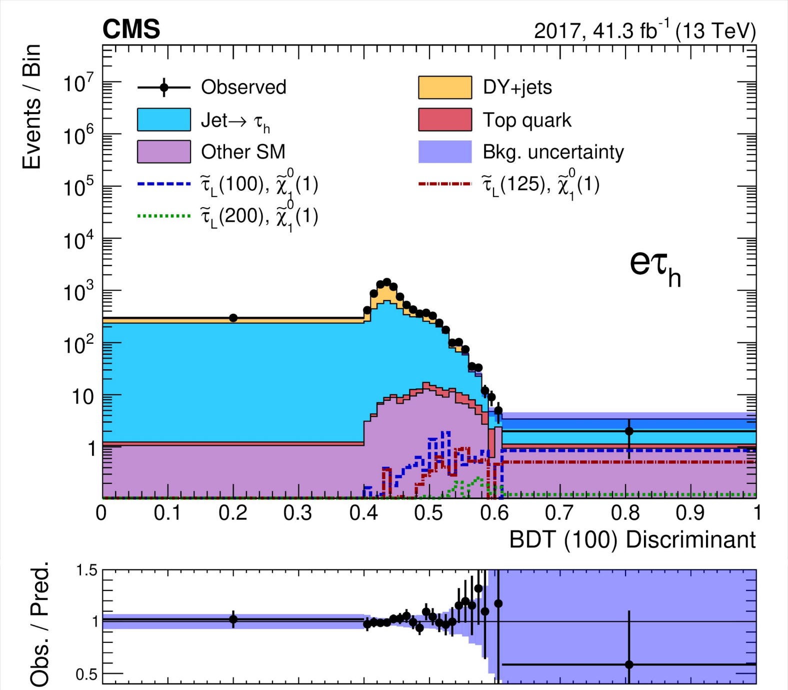
Stau pair production - 1l 1τ_h

CMS: Eur. Phys. J. C 80 (2020) 189

ATLAS: Phys. Rev. D 101, 032009 (2020)

⇢Same BDT distributions as in slide 4 but for the 2017 year data:

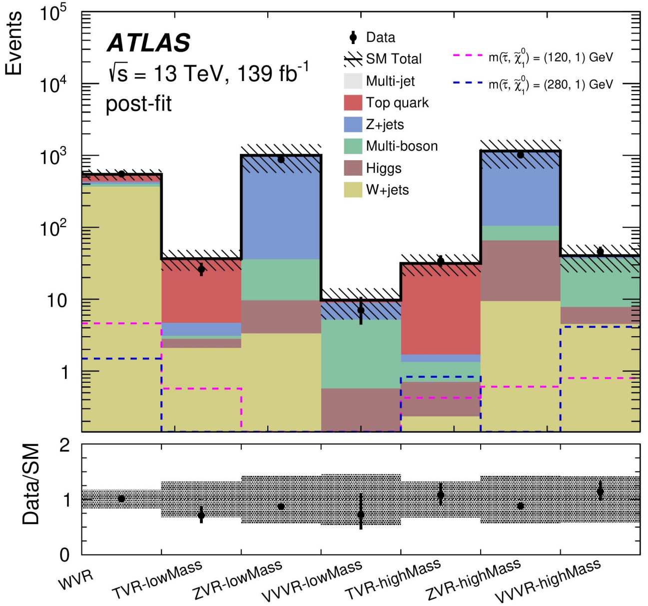


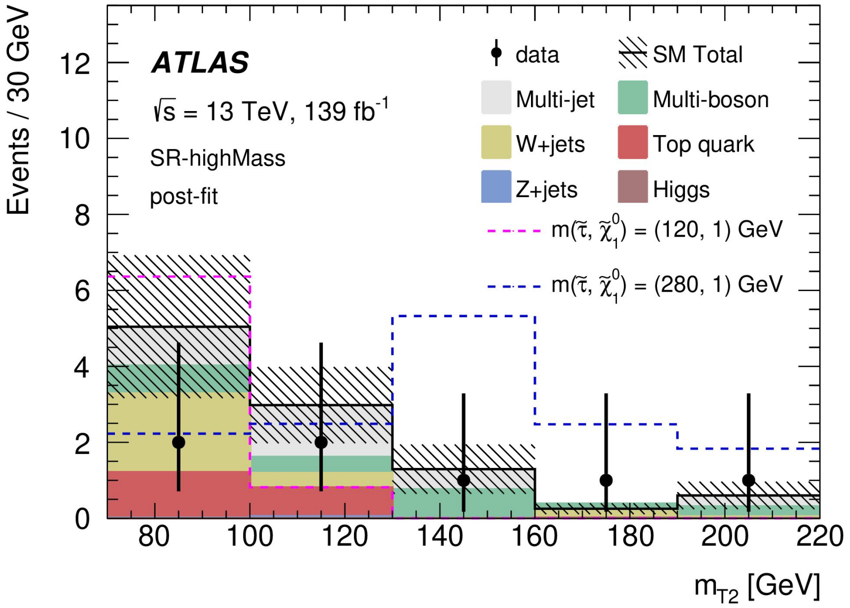


Stau pair production-2τ_h ATLAS

CMS: [Eur. Phys. J. C 80 (2020) 189]
ATLAS: [Phys. Rev. D 101, 032009 (2020)]

⇢Distributions in the high mass search region and validation regions

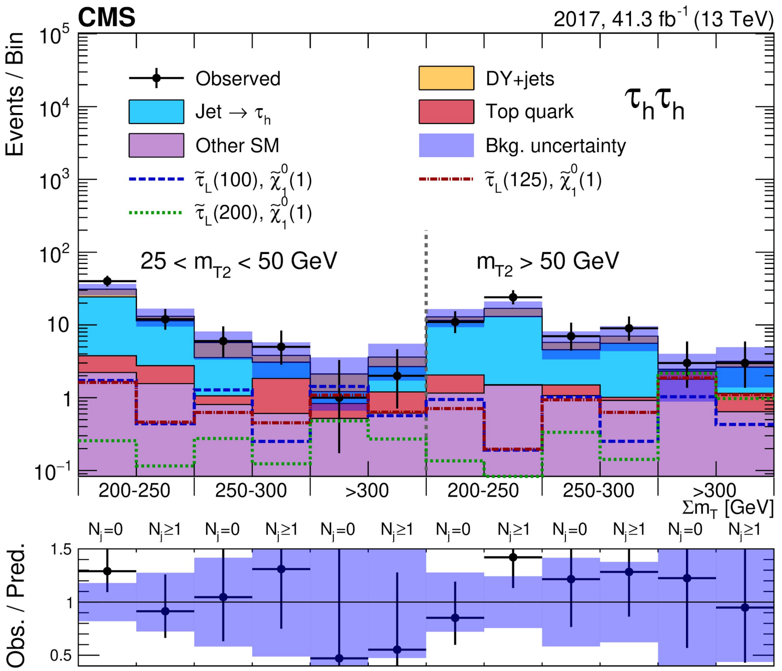




Stau pair production-2τ_h CMS

CMS: **Eur. Phys. J. C 80 (2020) 189**
ATLAS: **Phys. Rev. D 101, 032009 (2020)**

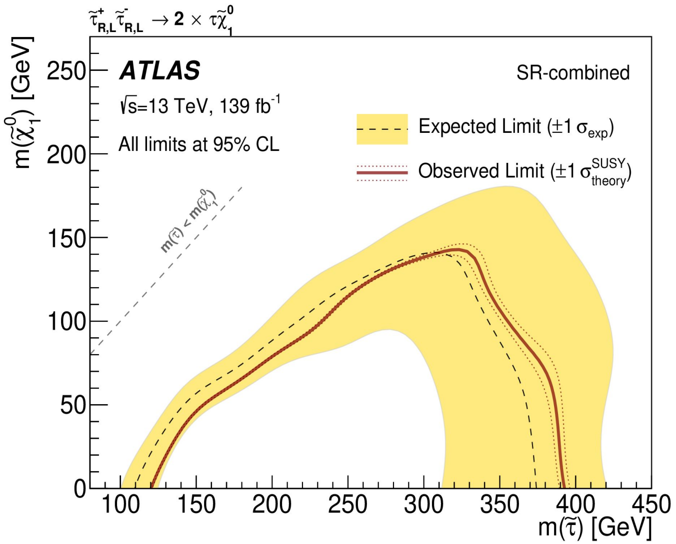
⇢Search regions with data taken during the 2017 year.

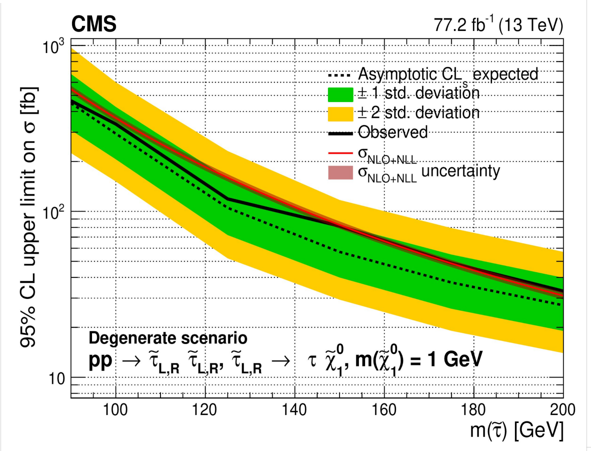


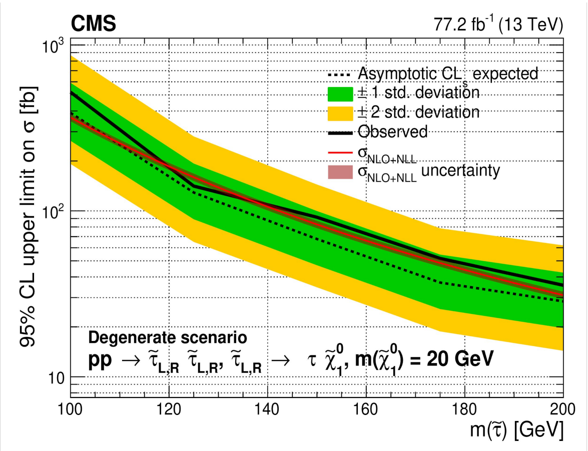
Stau pair production-Interpretation

CMS: [Eur. Phys. J. C 80 (2020) 189]
ATLAS: [Phys. Rev. D 101, 032009 (2020)]

⇢Interpretations in terms of degenerated left/right staus:



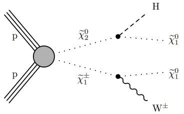




⇢As in the left handed interpretation, both searches limited by:

- MisID τ_h background: ATLAS ~15% (multijet inclusive), CMS ~5-50% (multijet/W+jets per region).
- τ_h selection and identification criteria: ATLAS ~10-30% (depend on process and region), CMS ~ 5-50% (depends on process and region).

1l + 2b final states



[arXiv:1909.0926 (sub. to EPJ C)](arXiv:1909.0926)

⇢ A search for SUSY targeting scenarios of heavy sleptons in which gauginos decay to a WH+2LSP final state. Select the leptonic W decay (1l) and the b quark decay of the Higgs (2b).

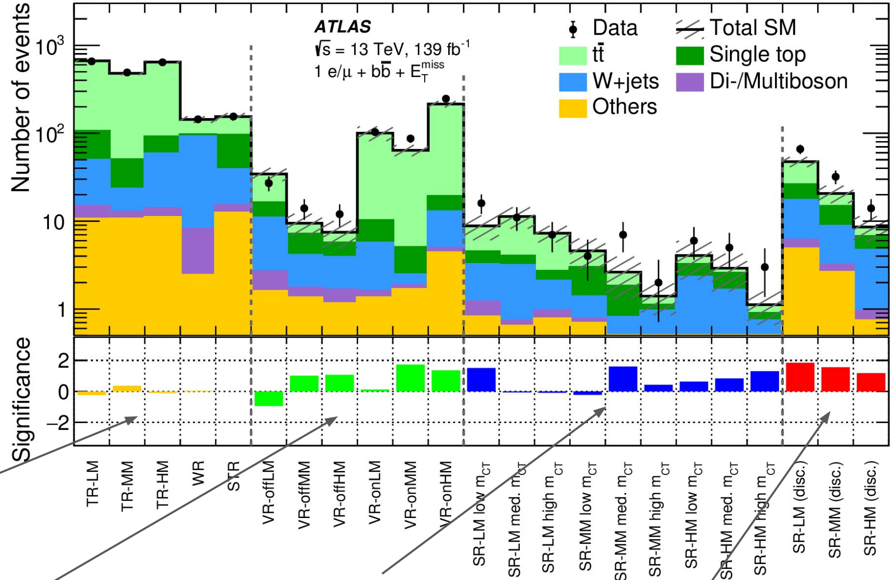
⇢Extremely tight selection motivated by trigger requisites and reduction of W+jets/tt background:

$$p_T^{miss} > 240 \text{ GeV} \qquad N_{\text{jets}} = 2 \text{ or } 3$$

$$m_{bb} \in [100, 140] \text{ GeV}$$

⇢ Main backgrounds are estimated through several control regions included in the signal extraction fit (...).

⇢ And validated in additional intermediate validation regions used to check the final normalization/unc. results of the background fit.



⇢ Several signal sensitive regions defined with moderate (100-160GeV) to high (> 240GeV) $m_T(l)$ criteria and binned on $m_{CT}(b_1,b_2)$ for the signal extraction fit.

⇢ Aggregated (disc.) signal regions built with looser model-independent criteria, not included in the signal extraction.

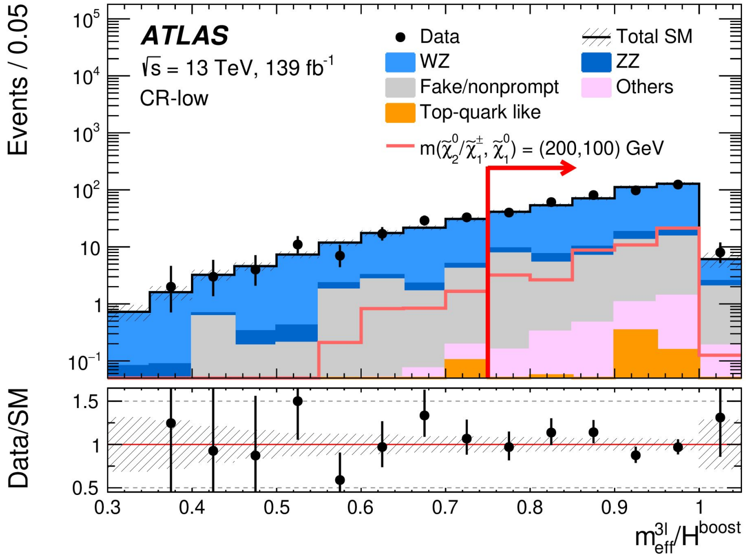
3l searches (RJR)

ATLAS, 3l RJR Phys. Rev. D 101, 072001 (2020)

⇢ATLAS search with 139 fb^{-1} worth of data focusing on three light lepton final states.

⇢Based on the Recursive Jigsaw Reconstruction (RJR) technique to “get back to” the chargino/neutralino kinematics from the laboratory frame measurements.

⇢ Use of high level variables to emulate the RJR quantities (eRJR) and select different configuration topologies (what is boosted and where):



⇢In this example:

⇢ m_{eff}^{3l} ~ Scalar sum of p_T^{lep} + p_T^{miss}

⇢ H^{boost} ~ Scalar sum of p^{lep} + p^{miss} in the p-p frame (rec. p^{miss} from lepton p + mass constrain).

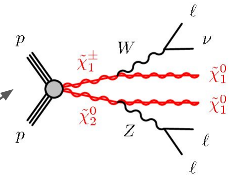
⇢Boosting back to the p-p system using the 3l+ν 4-momenta.

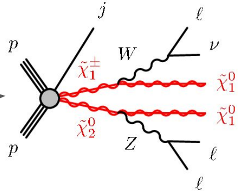
⇢Signal models peaking at high value quotients: most of the original available energy retained by the leptonic system in the transverse plane.

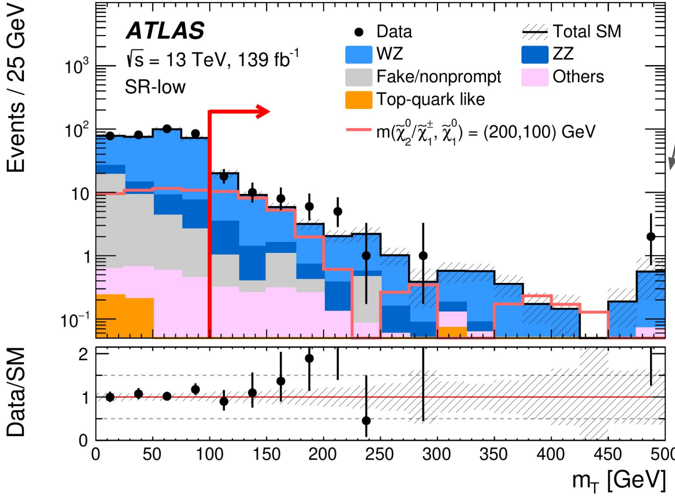
3l searches (RJR)

ATLAS, 3l RJR [Phys. Rev. D 101, 072001 (2020)]

- Final event selection targeting two main topologies:
  - Events in which leptons include most of the final system energy (SR low).
  - Events with energetic ISR jets, well separated from p_T^{miss} (SR ISR).

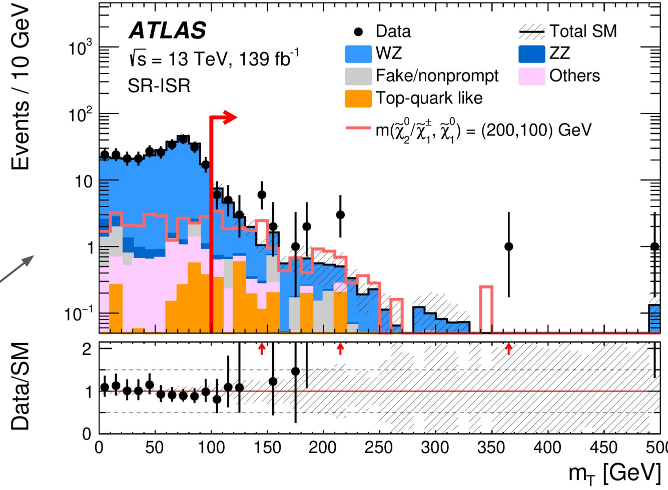






Low mass region with high (>60, 40, 30 GeV) p_T leptons and no ISR jet

ISR region with mid (>25, 25, 20 GeV) p_T leptons and at least an ISR jet



- Some small excesses in the tails (integrated to define the signal regions) but not extremely significant.

2γ final states

Look at Mark's talk for the sbottom interpretation!

CMS: JHEP 11 (2019) 109

ATLAS: arXiv:2004.10894 (sub. to JHEP)

⇢Searches by both ATLAS (137 fb^{-1}) and CMS (77 fb^{-1}) in the double photon final state.

⇢Selecting a pair of photons with high invariant mass $m_{\gamma\gamma} \in [105,160]$ GeV (> 100 GeV) for ATLAS (CMS) and -in consequence- high p_T photons:

⇢Classify phase space of VH+2LSP based on different decays of the other massive boson:

Channel	ATLAS selection	CMS Selection	Target
Dileptonic	-	$N_\ell \geq 2; \lvert m_{ll} - m_Z \rvert < 20$ GeV	$ZH\chi_1^0\chi_1^0$
Leptonic	$N_\ell \geq 1$	$N_\ell \geq 1$; !Dileptonic	$WH\chi_1^0\chi_1^0$(leptonic W)
Hadronic	$N_{jets} \geq 2; m_{jj} \in [40, 120]$ GeV; $N_\ell = 0$	-	$WH\chi_1^0\chi_1^0$(hadronic W)
b tagged	-	$N_b \geq 2; m_{bb} \in [60, 95] \Vert [95, 140]$ GeV	$HH\tilde{G}\tilde{G}$ $HZ\tilde{G}\tilde{G}$
"Rest"	!(Leptonic or hadronic)	!(Di)Leptonic or b tagged	All

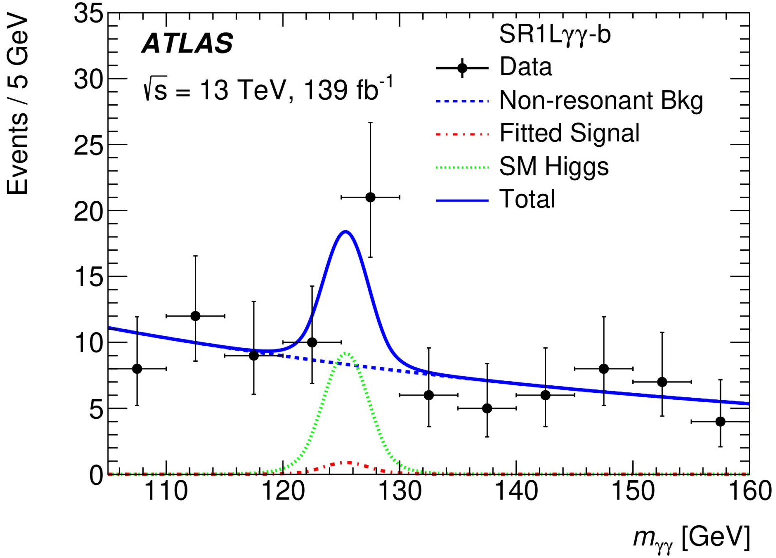
2γ final states

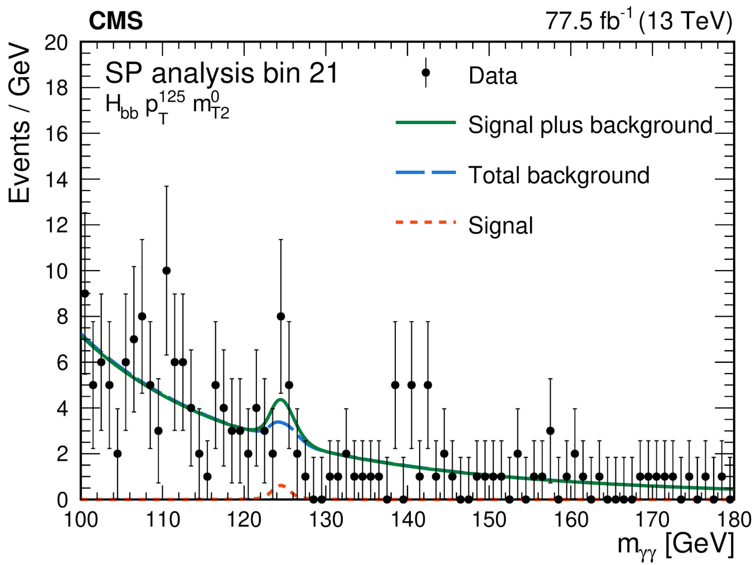
CMS: [JHEP 11 (2019) 109]

ATLAS: [arXiv:2004.10894 (sub. to JHEP)]

⇢ Signal extraction follows quite a similar approach, fitting the 2γ invariant mass distribution to an analytic form including:

- ⇢ Non resonant background: compare several functional forms, choose according to minimal bias.
- ⇢ Resonant (Higgs) background: double sided crystal ball.
- ⇢ Resonant signal: double sided crystal ball.



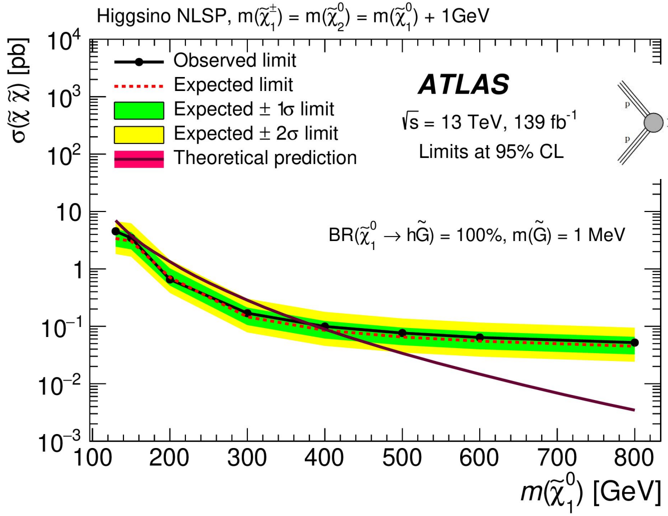


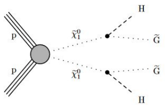
Diphoton HH interpretation

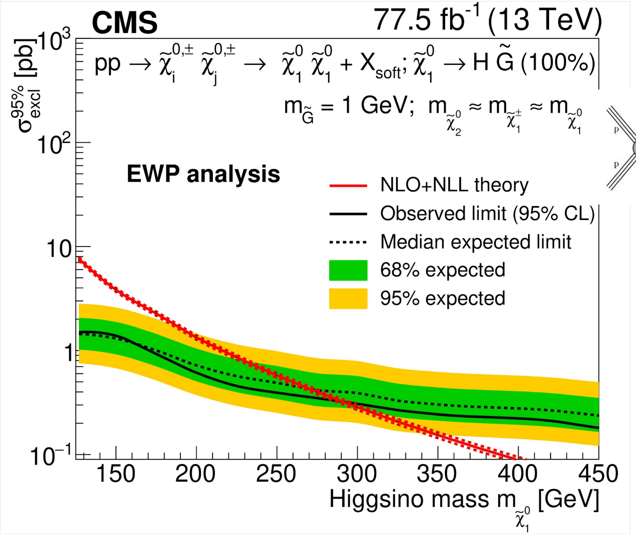
CMS 2γ: [JHEP 11 (2019) 109]

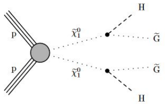
ATLAS 2γ: [arXiv:2004.10894 (sub. to JHEP)]

⇢ Interpretations from both ATLAS and CMS in terms of gauge mediated symmetry breaking (GMSB). General assumption is near degenerate set of neutralinos that, effectively, can be summed up into lightest neutralino pair production (+soft non detected particles) which decay to near massless gravitinos:

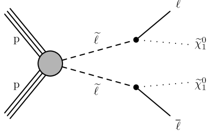








Dilepton final states



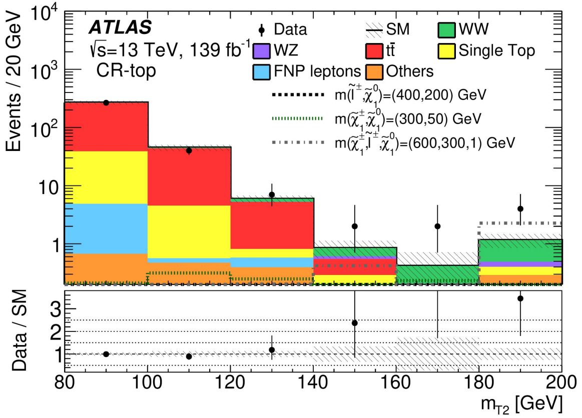
[Eur. Phys. J. C 80 (2020) 123]

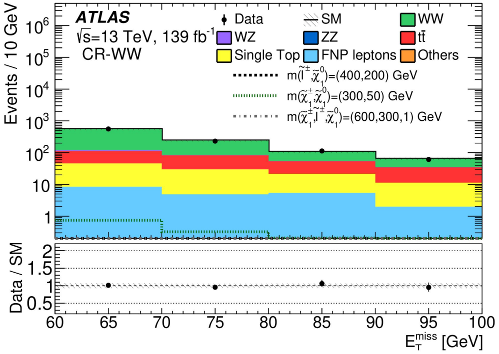
⇢ A search for SUSY in dileptonic final states (off-Z, m_{ll} > 100 GeV) performed with 139 fb^{-1} of data by ATLAS.

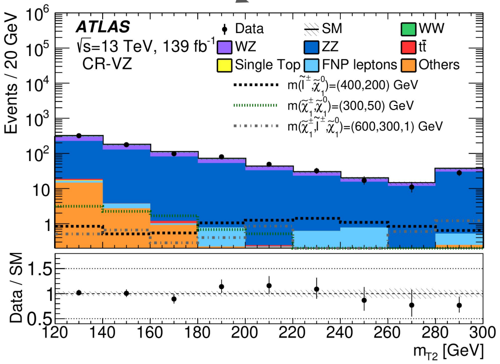
⇢ Simple selection to avoid the top-enriched and Z+jets backgrounds: $N_{\mathrm{b\ tag}} = 0 \quad p_T^{miss} > 100\ \mathrm{GeV}$

⇢Main background sources controlled in several control regions included in the signal extraction fit:

Region	CR-WW	CR-VZ	CR-top
Lepton flavour	DF	SF	DF
$n_{b\text{-tagged jets}}$	$= 0$	$= 0$	$= 1$
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$	$= 0$	$= 0$
m_{T2} [GeV]	$\in$ [60,65]	> 120	> 80
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	$\in$ [60,100]	> 110	> 110
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	$\in$ [5,10]	> 10	> 10
$m_{\ell_1\ell_2}$ [GeV]	> 100	$\in$ [61.2,121.2]	> 100



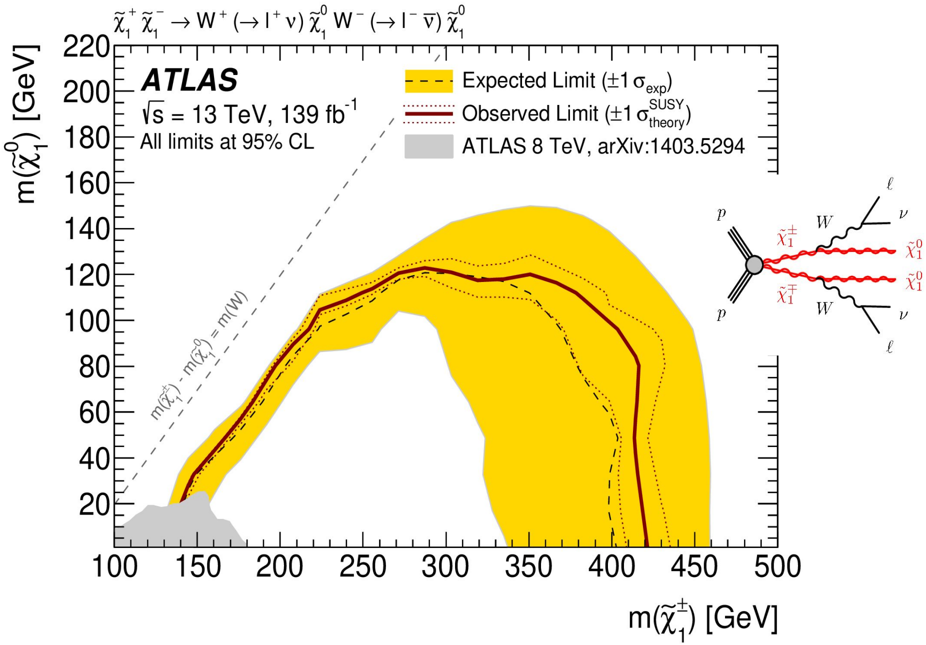


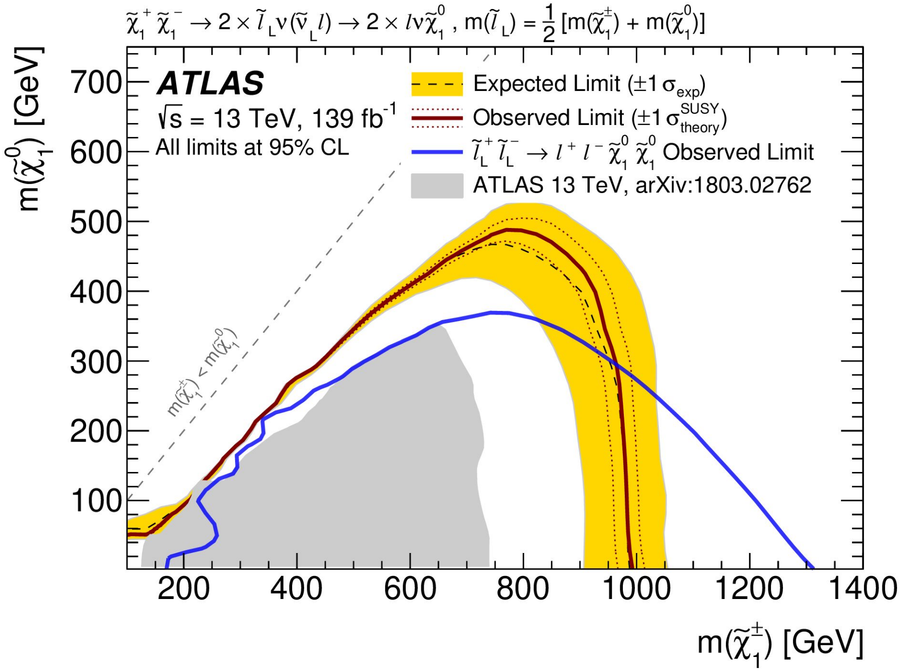


Eur. Phys. J. C 80 (2020) 123

Dilepton final states

⇢Top enriched control region of the dilepton analysis and exclusion region in the chargino pair production decaying through sleptons model.

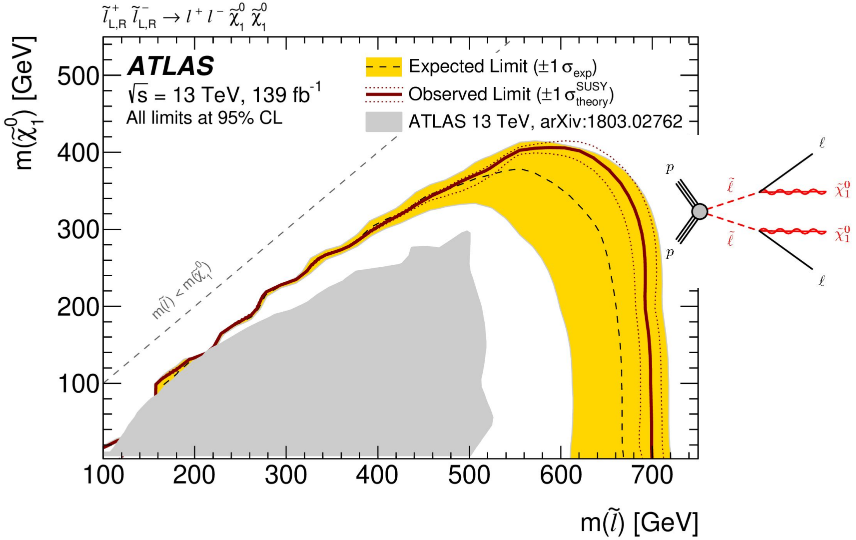


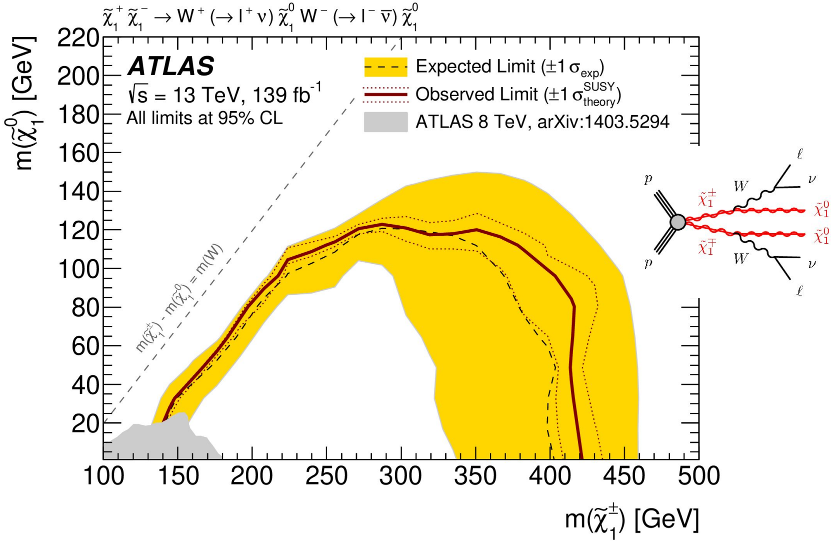


Eur. Phys. J. C 80 (2020) 123

Dilepton final states

⇢ Interpretations performed for direct slepton pair production and direct chargino pair production with direct SM/slepton mediated (back-up) decays:





⇢ Dominant source of uncertainty is data statistics, but several notable sources of systematics in terms of background normalization uncertainties: WW (3-7%), tt (3-8%) and jet energy scale (2-3%).