Search for Electroweak production of supersymmetric gauginos and sleptons with the ATLAS detector

Mhamad Kassem Ayoub
Institute of High Energy Physics
On behalf of the ATLAS collaboration

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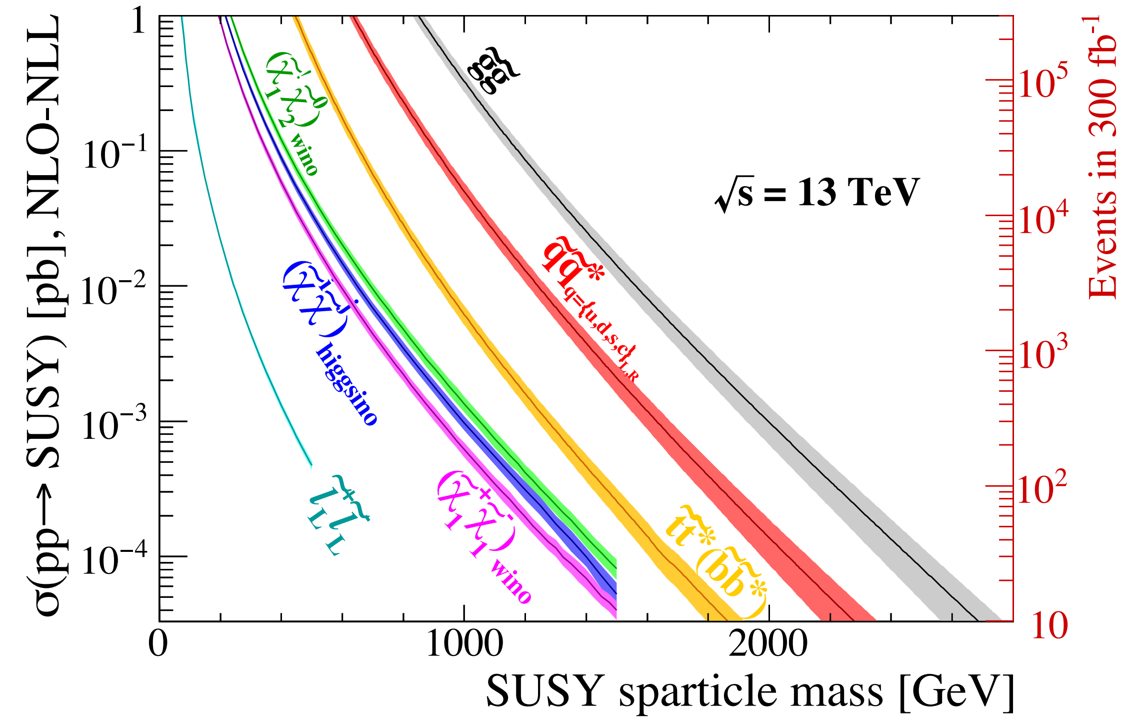
Institute of High Energy Physics

Introduction

- The Search for SUSY in ATLAS is based on a well defined signature oriented strategy:
  - Gluino and squarks
  - 3rd generation squarks
  - **Electroweak SUSY production: Gauginos and sleptons**
  - R-parity violation scenarios and long-lived particles



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections

Natural SUSY: electroweakino and stops to stabilise the weak scale

If strongly produced particles are too heavy, gauginos/sleptons production may be the dominant SUSY cross-section at the LHC

SUSY electroweak searches in ATLAS - Overview

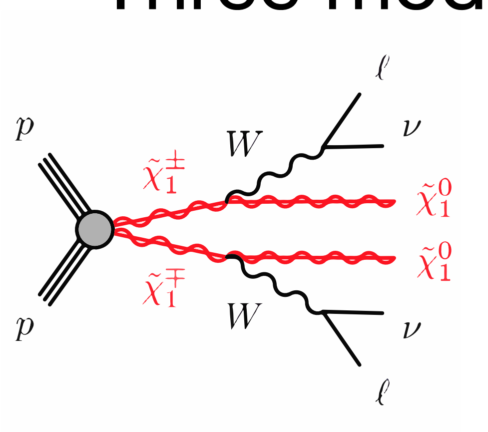
Analysis	Publications	Luminosity
2 leptons	ATLAS-CONF-2019-008(link)	139 fb^{-1}
staus	Eur.Phys.J.C78(2018)154	36 fb^{-1}
compressed scenario	Phys.Rev.D97(2018)052010	36 fb^{-1}
two or three leptons	Eur.Phys.J.C78(2018)995	36 fb^{-1}
four or more leptons	Phys.Rev.D98(2018)032009	36 fb^{-1}
Higgsinos in multi-b final states	Phys.Rev.D98(2018)092002	36 fb^{-1}
recursive jigsaw	Phys.Rev.D98(2018)092012	36 fb^{-1}
WH	arXiv:1812.09432	36 fb^{-1}

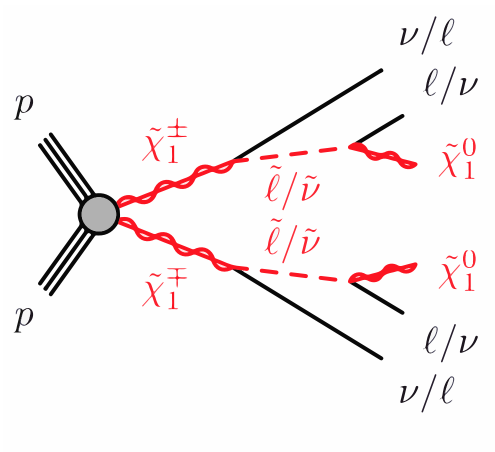
Presented here

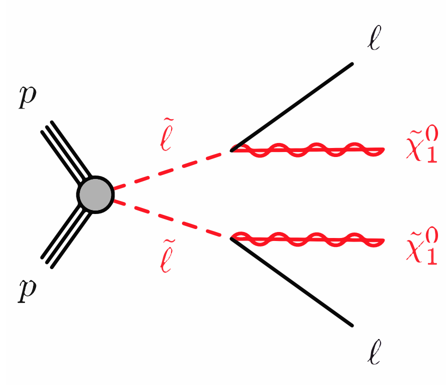
Two leptons

- Search for electroweak production of charginos and sleptons with two leptons (electrons or muons) in the final state

- Three models are considered:





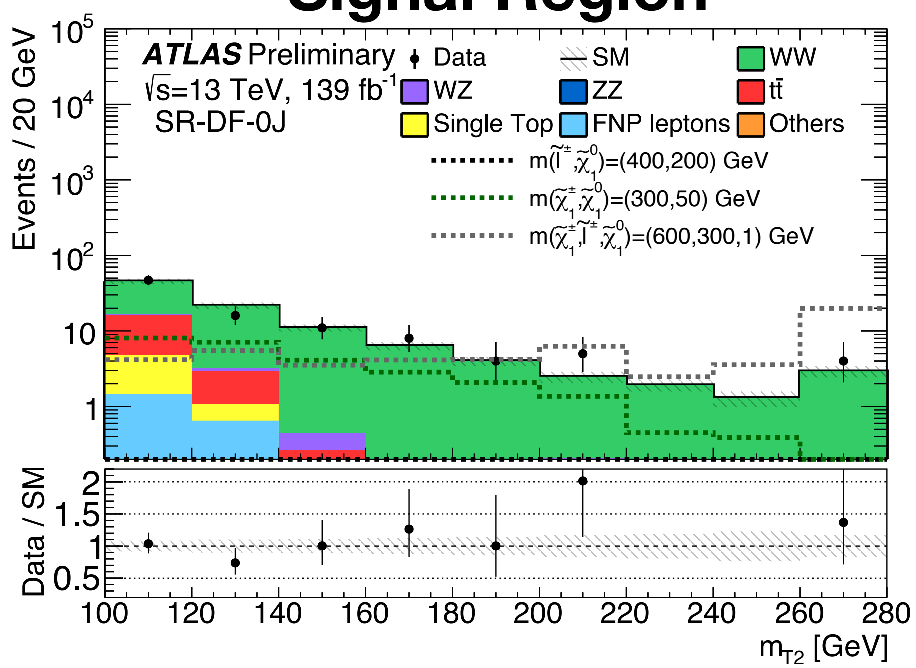


➡ **Signal region:** two (same/opposite flavors) light leptons and high MET

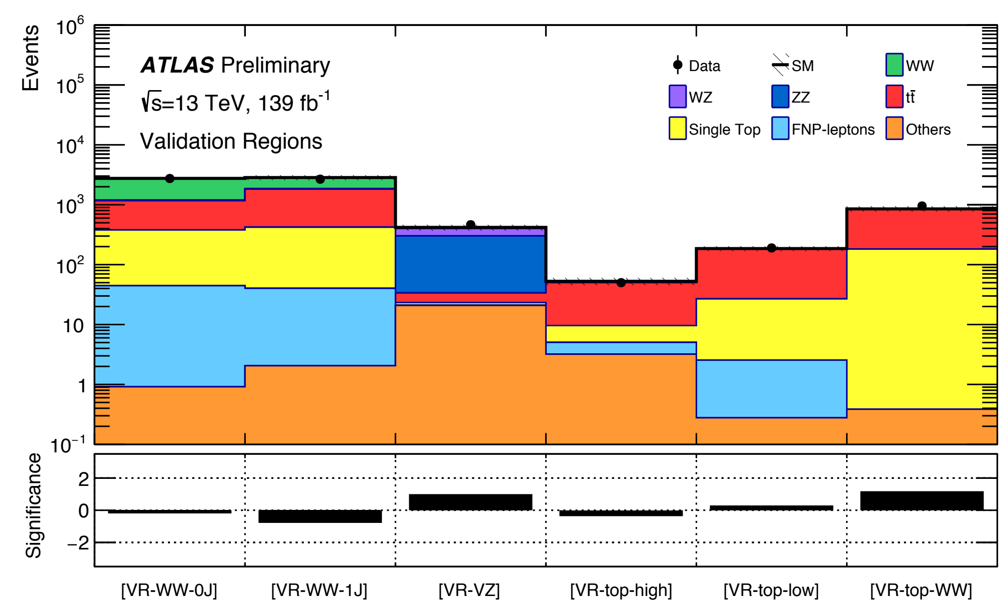
- Binned in mT2 for model-dependent exclusions

- **Background:**
  - **Irreducible**: diboson and top (Monte-Carlo)
  - **Reducible**: from fake leptons (data-driven)

Signal Region



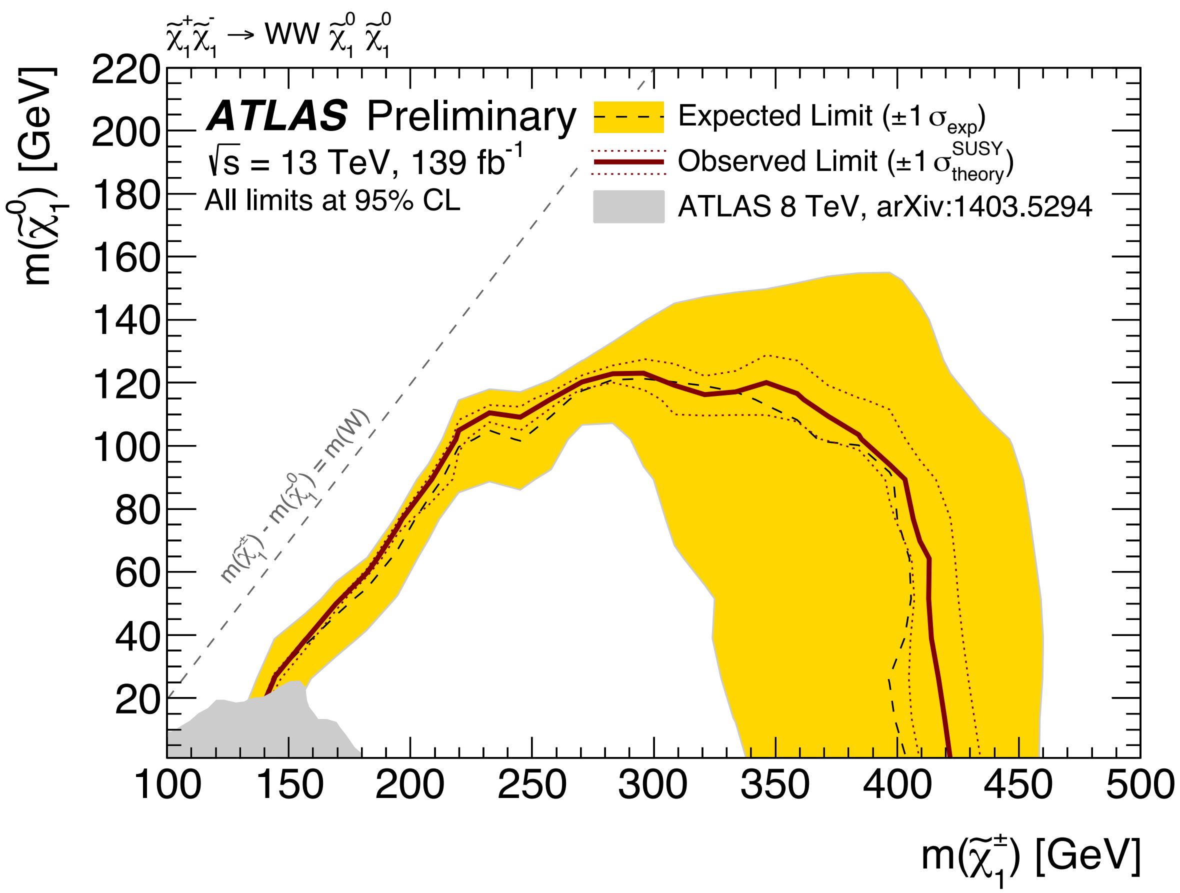
Validatio regions

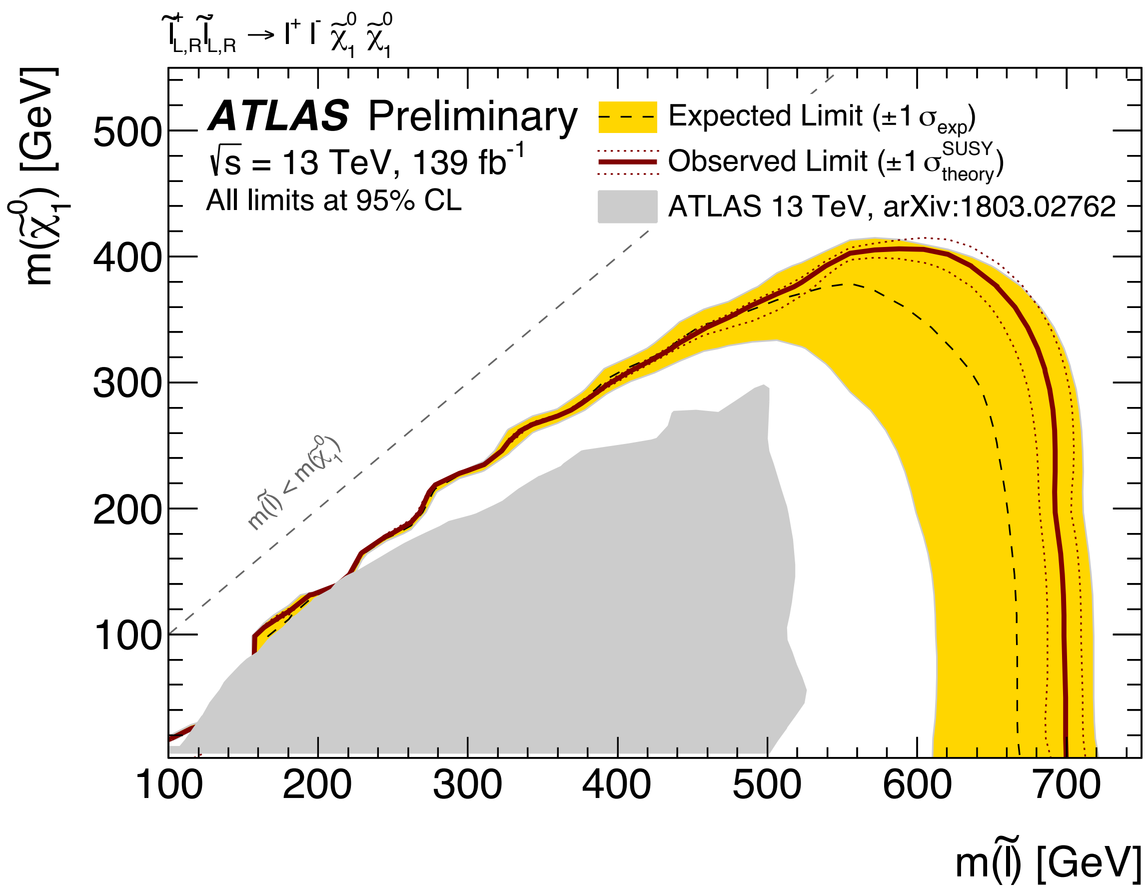


Good modelling in the validation regions

Two leptons: exclusion limits

- Statistical interpretation is performed for the three scenarios
- No significant deviation from the Standard Model is observed in any of the signal regions





- Results significantly improved compare to Run1 and early Run2 exclusion limits for the same scenarios

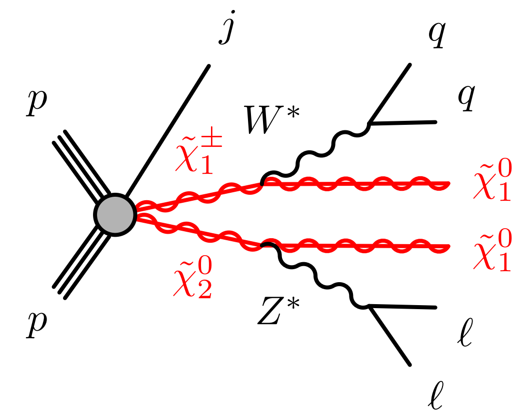
Compressed scenarios

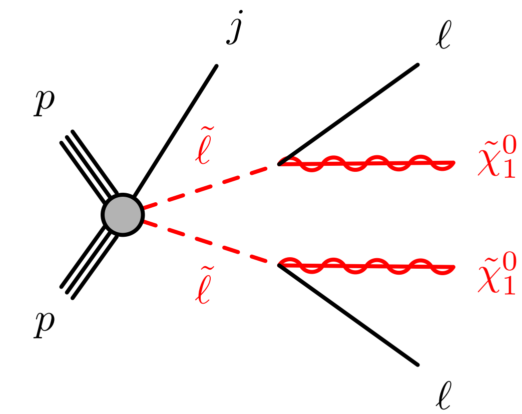
- Compressed search: scenarios involving small mass differences between heavier SUSY particles and LSP in three models

  1. Higgsino is light and Electroweakino states are Higgsino-dominated

  2. Wino and bino are lights and Electroweakino states (C1 & N2) are wino-dominated (LSP bino-dominated)

  3. Pair production of sleptons



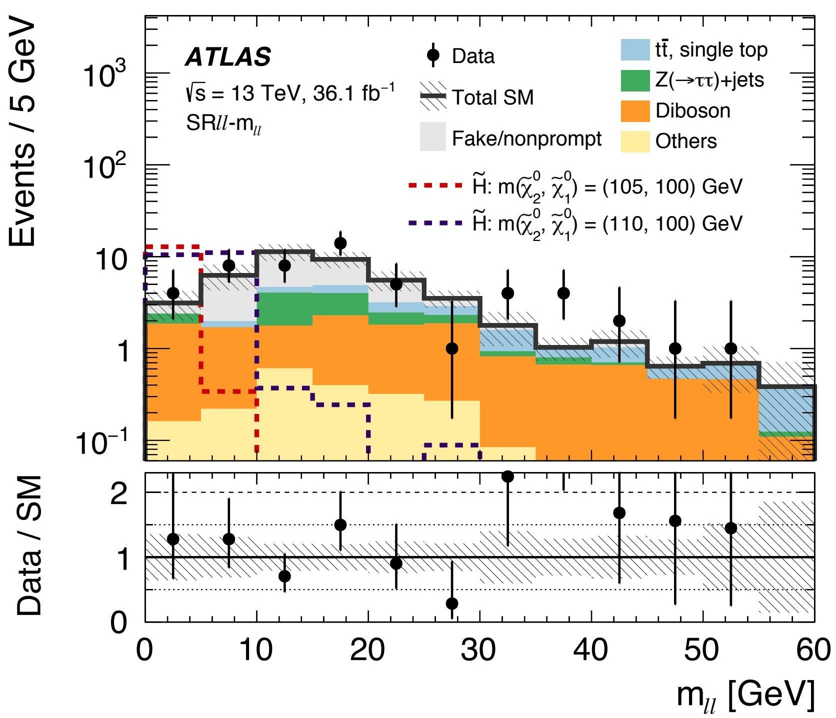


Background:

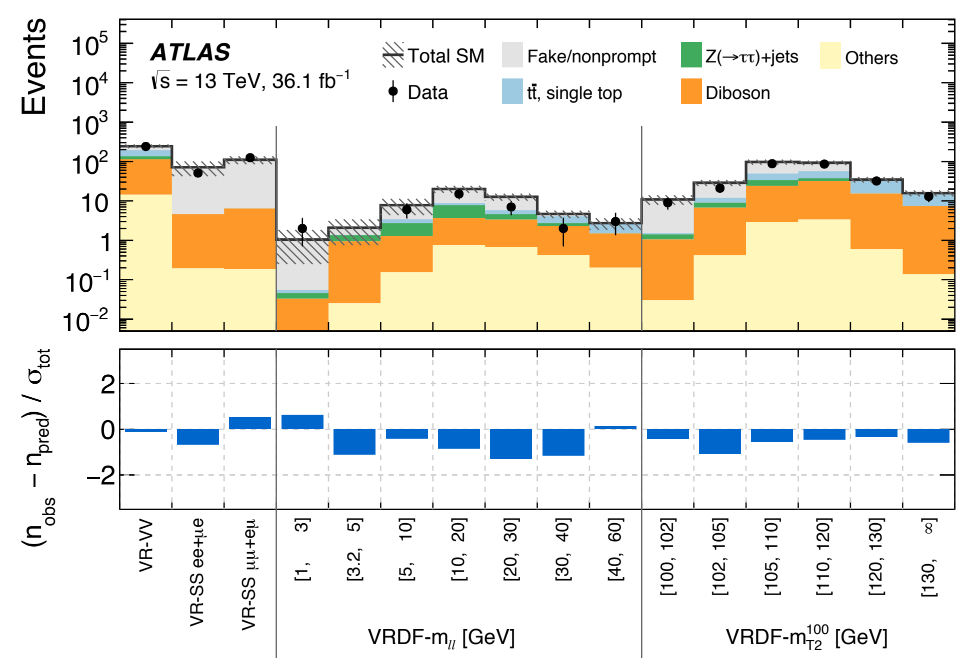
- **Irreducible: top, diboson and Zττ+jets (Monte-Carlo) and normalised using control regions**

- **Reducible: fake leptons (data-driven)**

- Final state: two low momentum leptons (electron or muons)



Agreement btw data and expected SM background in SR

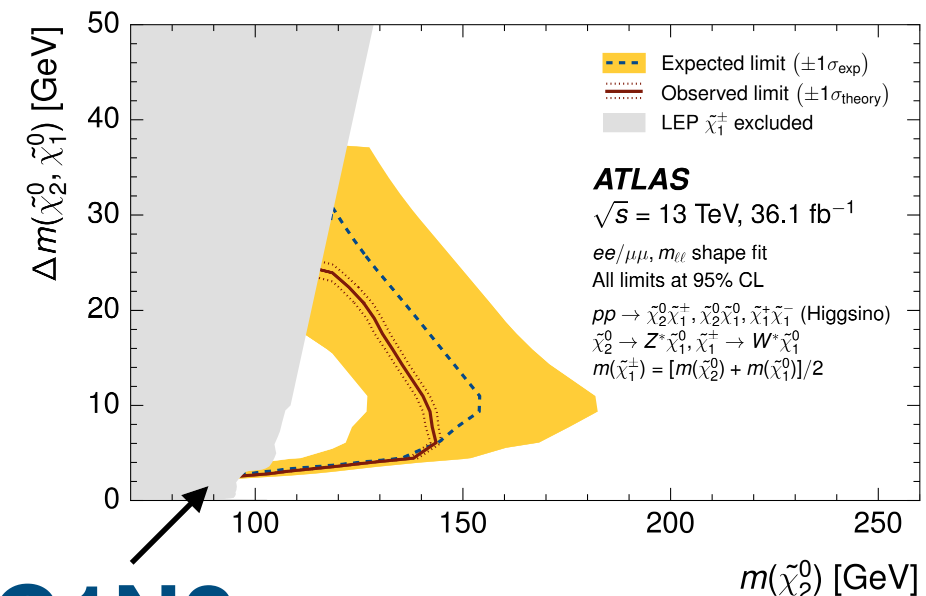


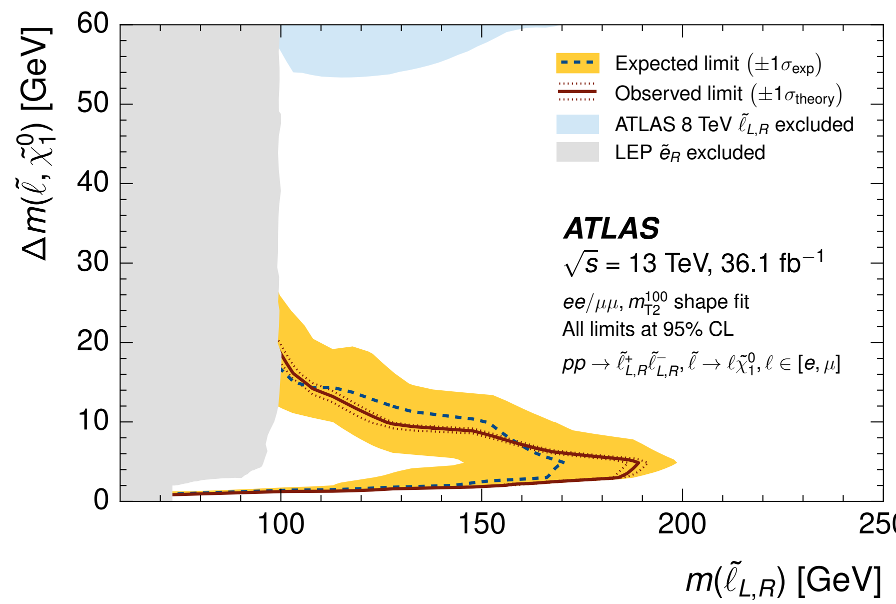
Good data/ background agreement in validation regions

Compressed scenarios - interpretation

- No significant excesses of the data above the expected background are observed

Higgsino model (Higgsinos are light)

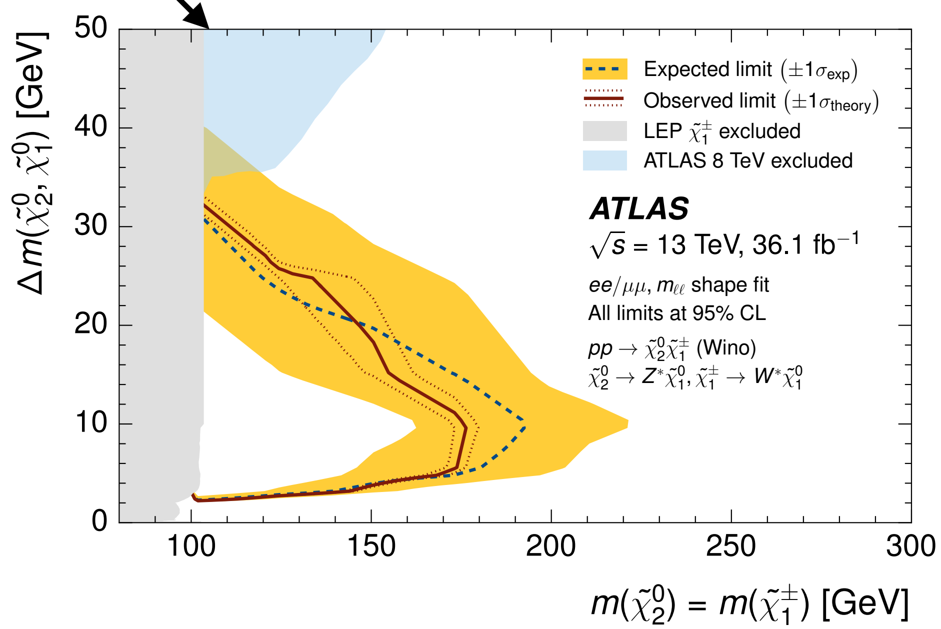




Sleptons

C1N2

Wino model (winos and binos are light)



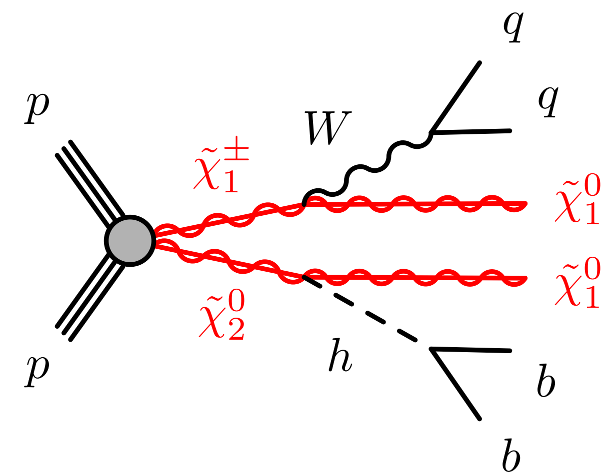
- Exclusion limits produced using shape fit in the exclusive signal regions
  - Using $\mathbf{m_{ll}}$ for WZ (invariant mass of the two light leptons)
  - Using $\mathbf{m_{T2}}$ for sleptons

WH

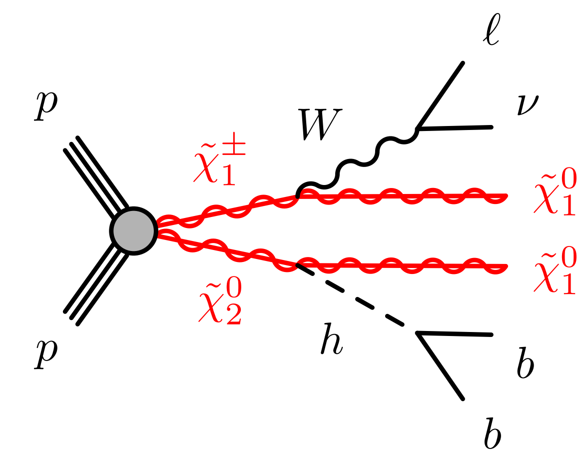
- A search for chargino-neutralino pair production with a W boson and a standard Model-like Higgs boson in the final state

- Four sub-channels are studied:
  - <u>**0lbb, 1lbb**, diphoton and multilepton</u>
  - Dominant ones are considered here

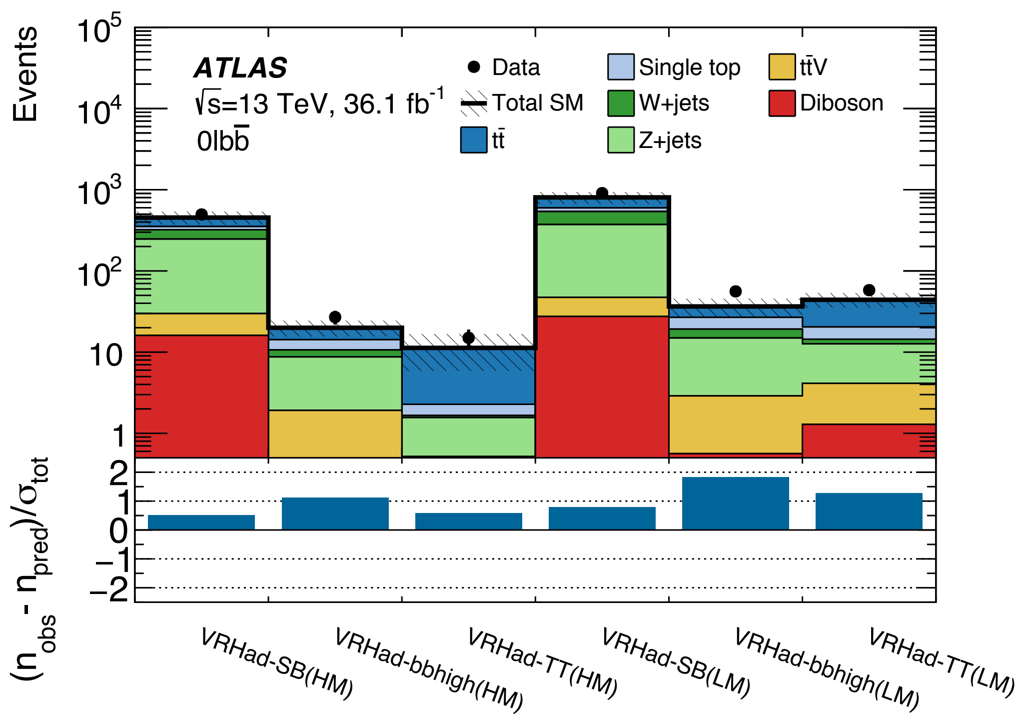
0lbb

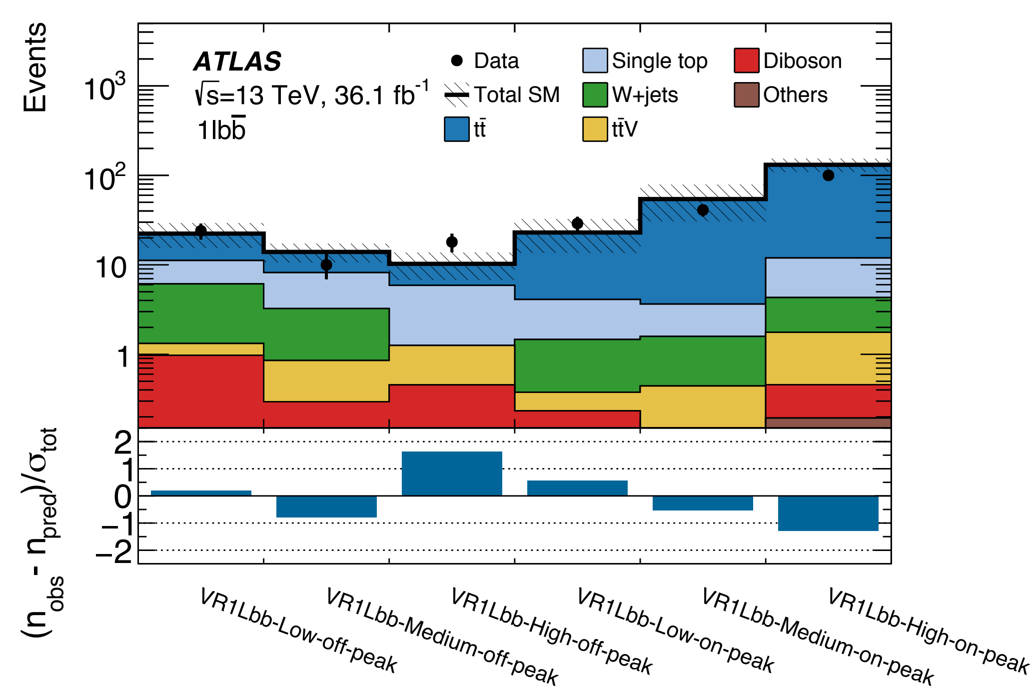


1lbb



- Background estimated using MC simulation (ttbar dominated)

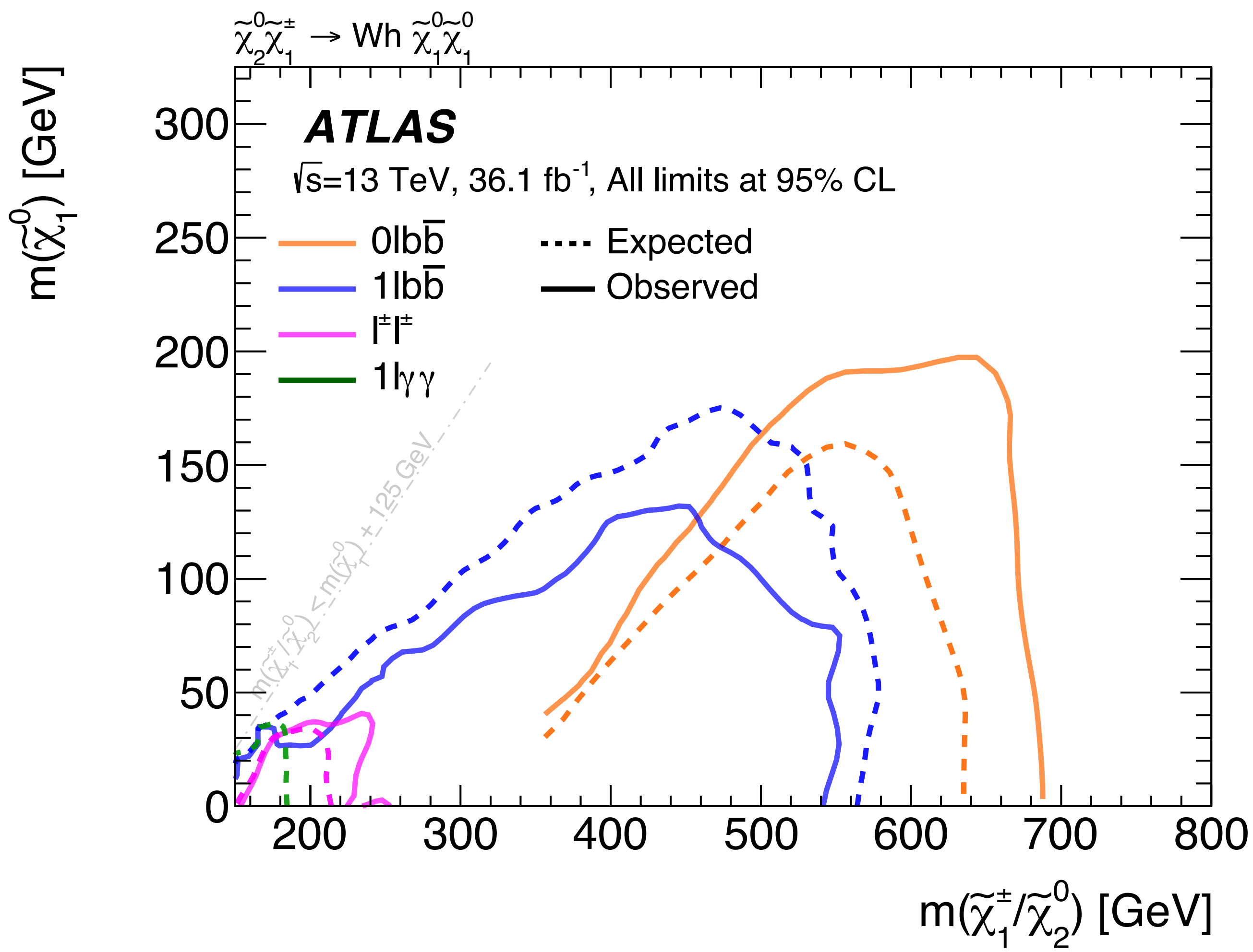




Good modelling in the background validation regions for both 0lbb and 1lbb

WH - interpretation

- No significant differences between the observed and expected yields
- Exclusion limits are set using the different signal regions



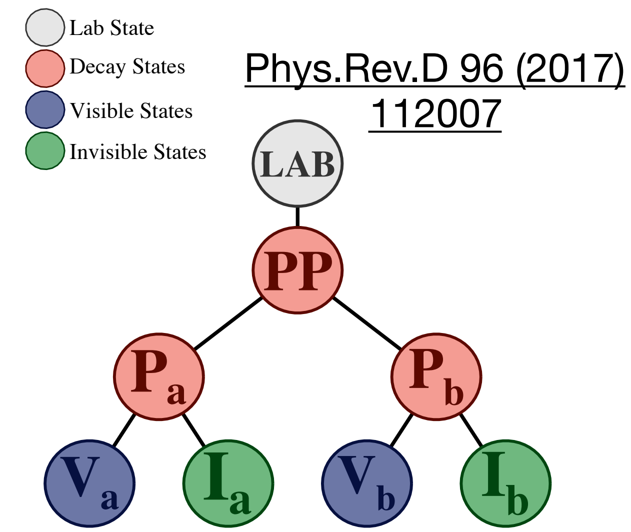
✓ Large branching ratio of Higgs boson into b-quark pairs => good sensitivity at high masses of charginos and next-to-lightest neutralinos

Electroweak production with recursive jigsaw

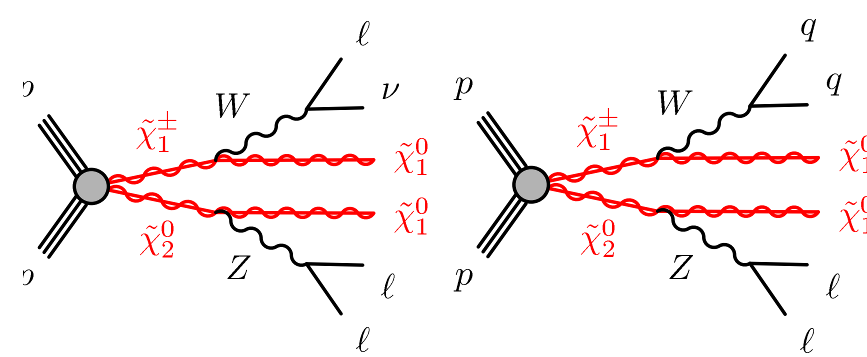
- A search for chargino-neutralino pair production via W and Z boson with two or three light leptons (e, μ)

  - Using jigsaw reconstruction to construct kinematic variables to separate signal and background

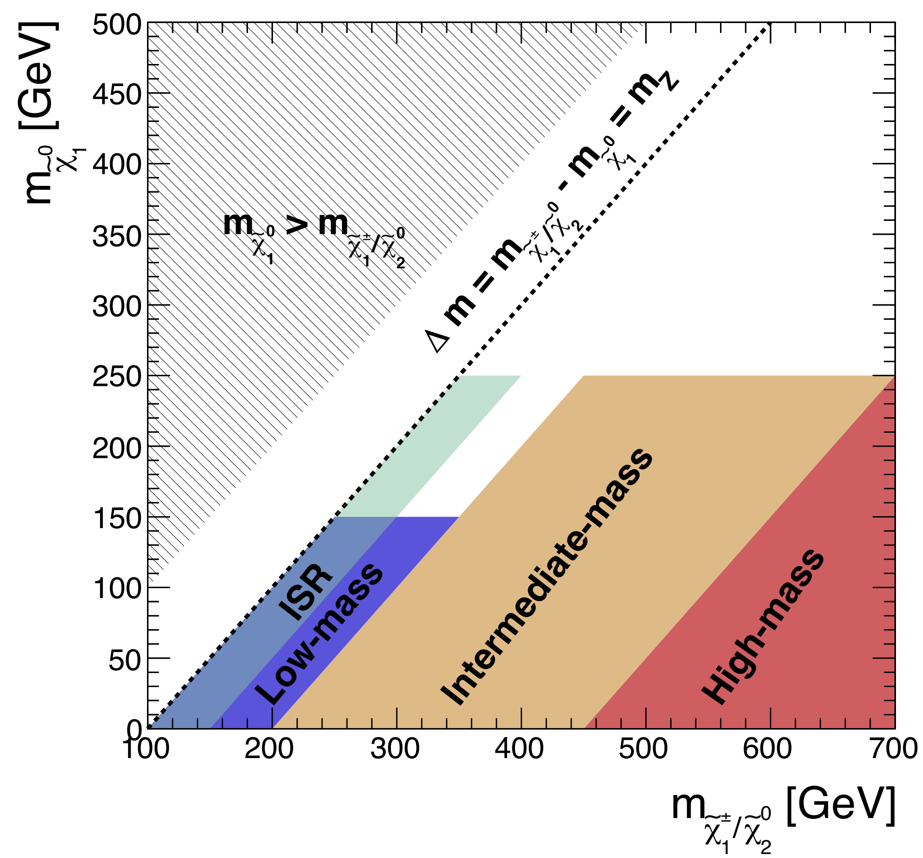
Phys.Rev.D 96 (2017) 112007

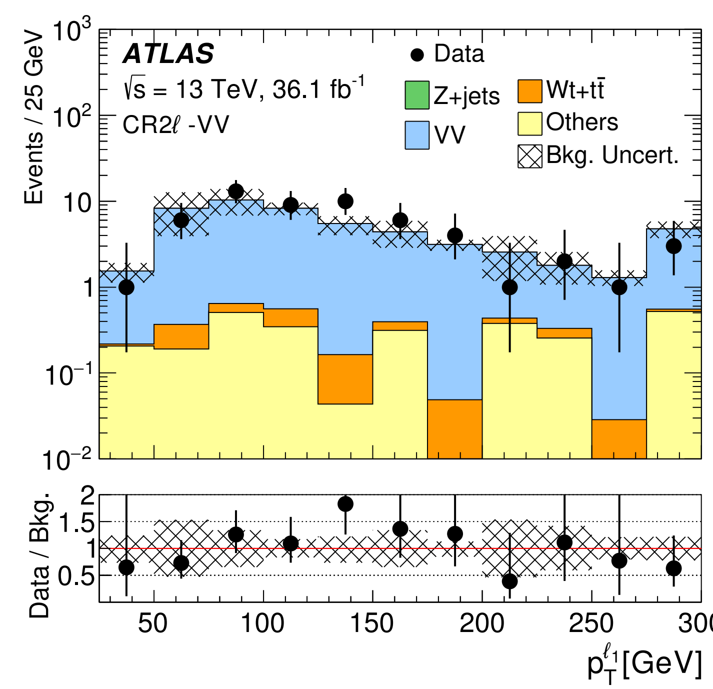


- Both 2l and 3l signal regions are designed to cover **High**, **Intermediate** and **Low** masses and mass splitting



+ models with ISR

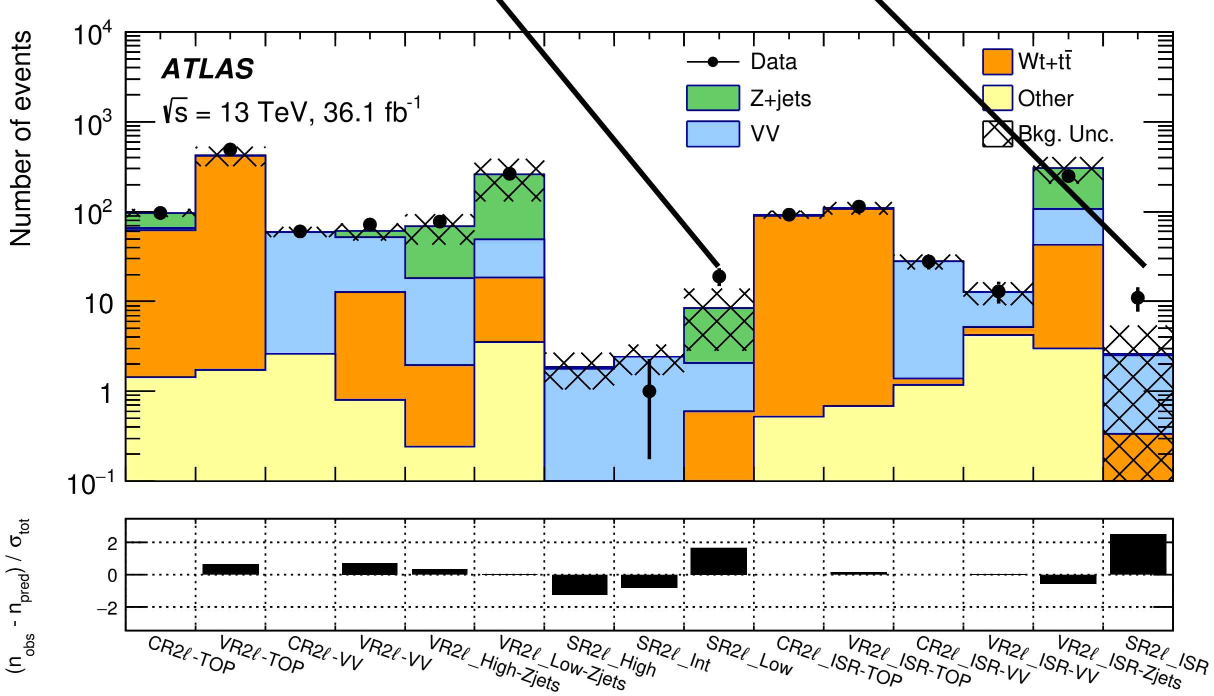


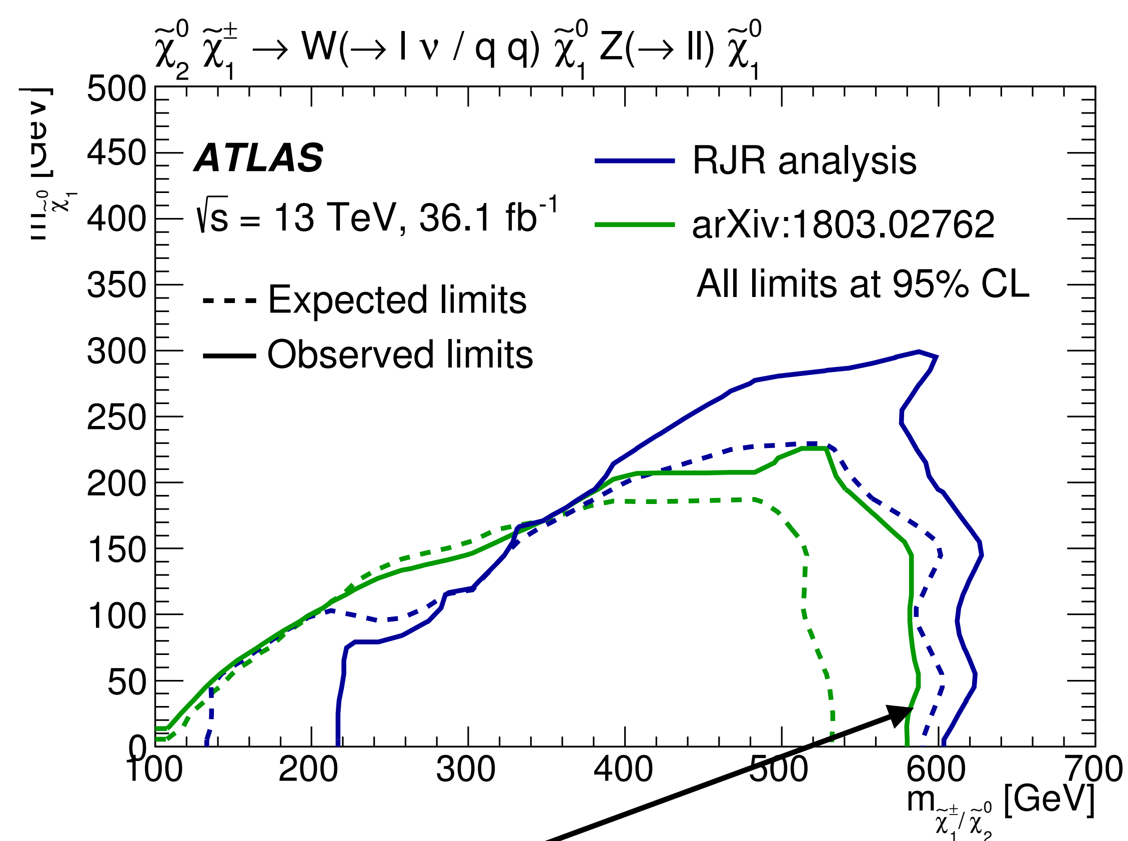


Good modelling in all validation and control regions

RJR - interpretation

- Intermediate and high mass signal models: No excess
- Low mass and ISR signal model: mild excess



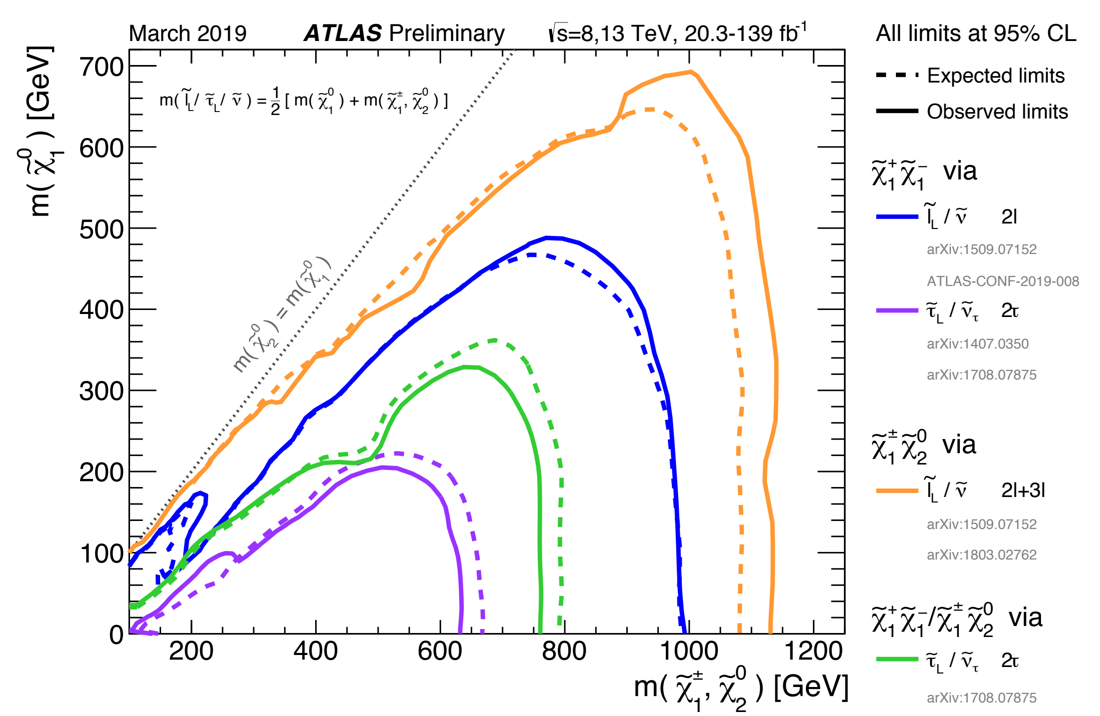


✓ A region of the phase space not excluded by alternative 2l/3l search is excluded by RJR search

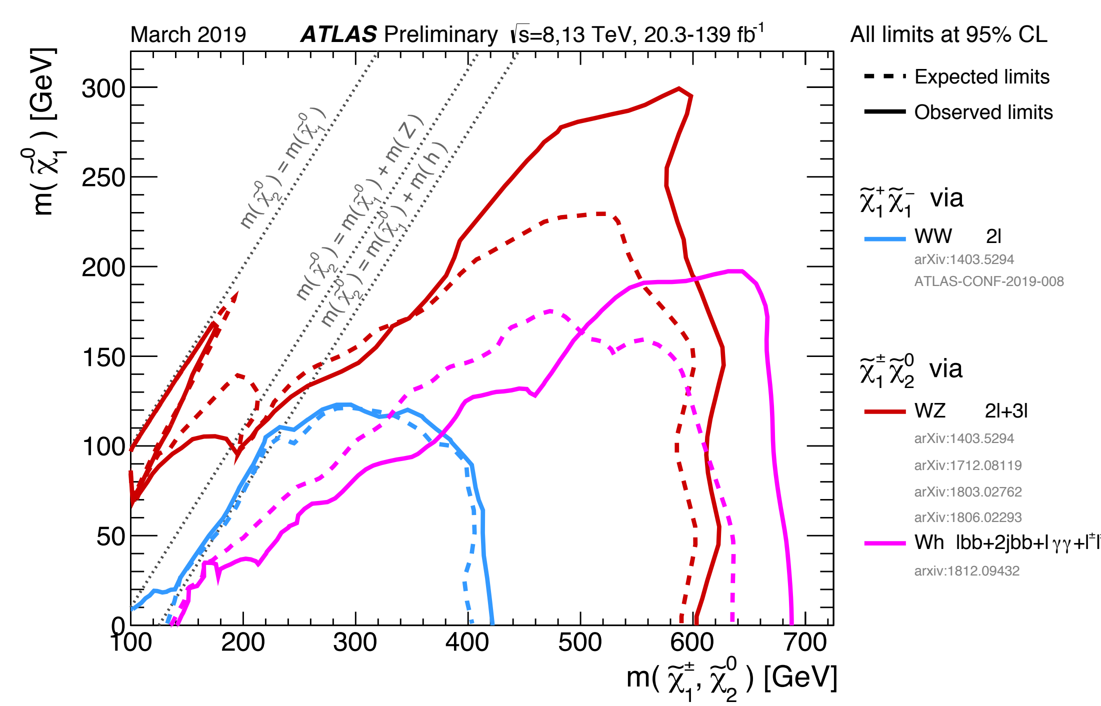
Summary and conclusion

- A rich electroweak SUSY search program is reached in ATLAS
  - Selected results for searches with the full Run2 dataset (140 fb^{-1}) and the partial 36fb^{-1} dataset are shown
- No significant excess seen in the electroweak sector so far
- Many searches with the full Run2 dataset are ongoing

Lepton mediated searches



Boson mediated searches



x

Backup

SUSY electroweak searches in ATLAS - Overview

	Analysis	Paper	Luminosity
(presented here)	**Charginos and sleptons via 2 leptons**	ATLAS-CONF-2019-008	139 fb^{-1}
	Chargino-neutalino decays via staus	Eur.Phys.J.C78(2018)154	36 fb^{-1}
(presented here)	**Gauginos and sleptons production - compressed scenario**	Phys.Rev.D97(2018)052010	36 fb^{-1}
	Electroweak production with two or three leptons	Eur.Phys.J.C78(2018)995	36 fb^{-1}
	Electroweak production with four or more leptons	Phys.Rev.D98(2018)032009	36 fb^{-1}
	Higgsinos in multi-b final states	Phys.Rev.D98(2018)092002	36 fb^{-1}
(presented here)	**Charginos-neutralino production with RJR**	Phys.Rev.D98(2018)092012	36 fb^{-1}
(presented here)	**Charginos-neutralino production via WH**	arXiv:1812.09432	36 fb^{-1}

Presented here

Charginos and sleptons via two leptons + MET

- Events are required to have two opposite charge light leptons each with pT > 25 GeV

Signal region (SR)	SR-DF-0J	SR-DF-1J	SR-SF-0J	SR-SF-1J
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$	$= 1$	$= 0$	$= 1$
$m_{\ell\ell}$ [GeV]	>100		>121.2	
$E_{\mathrm{T}}^{\text{miss}}$ [GeV]	>110			
$E_{\mathrm{T}}^{\text{miss}}$ significance	>10			
$n_{b\text{-tagged jets}}$	$= 0$			

Binned SRs	
m_{T2} [GeV]	$\in [100,105)$
	$\in [105,110)$
	$\in [110,120)$
	$\in [120,140)$
	$\in [140,160)$
	$\in [160,180)$
	$\in [180,220)$
	$\in [220,260)$
	$\in [260,\infty)$
Inclusive SRs	
m_{T2} [GeV]	$\in [100,\infty)$
	$\in [160,\infty)$
	$\in [100,120)$
	$\in [120,160)$

mT2 variable

Signal regions Binned in mT2 for model-dependent exclusions

What is mT2:

The stransverse mass m_{T2} [82, 83] is a kinematic variable used to bound the masses of a pair of particles that are presumed to have each decayed semi-invisibly into one visible and one invisible particle. It is defined as

$$m_{T2}(\mathbf{p}_{T,1}, \mathbf{p}_{T,2}, \mathbf{q}_T) = \min_{\mathbf{q}_{T,1}+\mathbf{q}_{T,2}=\mathbf{q}_T} \left\{ \max[\ m_T(\mathbf{p}_{T,1}, \mathbf{q}_{T,1}), m_T(\mathbf{p}_{T,2}, \mathbf{q}_{T,2})\ ] \right\}, \quad (1)$$

where m_T indicates the transverse mass[4], $\mathbf{p}_{T,1}$ and $\mathbf{p}_{T,2}$ are the transverse-momentum vectors of the two leptons, and $\mathbf{q}_{T,1}$ and $\mathbf{q}_{T,2}$ are vectors with $\mathbf{p}_T^{miss} = \mathbf{q}_{T,1} + \mathbf{q}_{T,2}$. The minimisation is performed over all the possible decompositions of $\mathbf{q}_T$. For $t\bar{t}$ or WW decays, assuming an ideal detector with perfect momentum resolution, $m_{T2}(\mathbf{p}_{T,\ell_1}, \mathbf{p}_{T,\ell_2}, \mathbf{p}_T^{miss})$ has a kinematic endpoint at the mass of the W boson [83]. Signal models with sufficient mass splittings between the $\tilde{\chi}_1^{\pm}$ and the $\tilde{\chi}_1^0$ feature m_{T2} distributions that extend beyond the kinematic endpoint expected for the dominant SM backgrounds. Therefore, events in this search are required to have high m_{T2} values.

Compressed

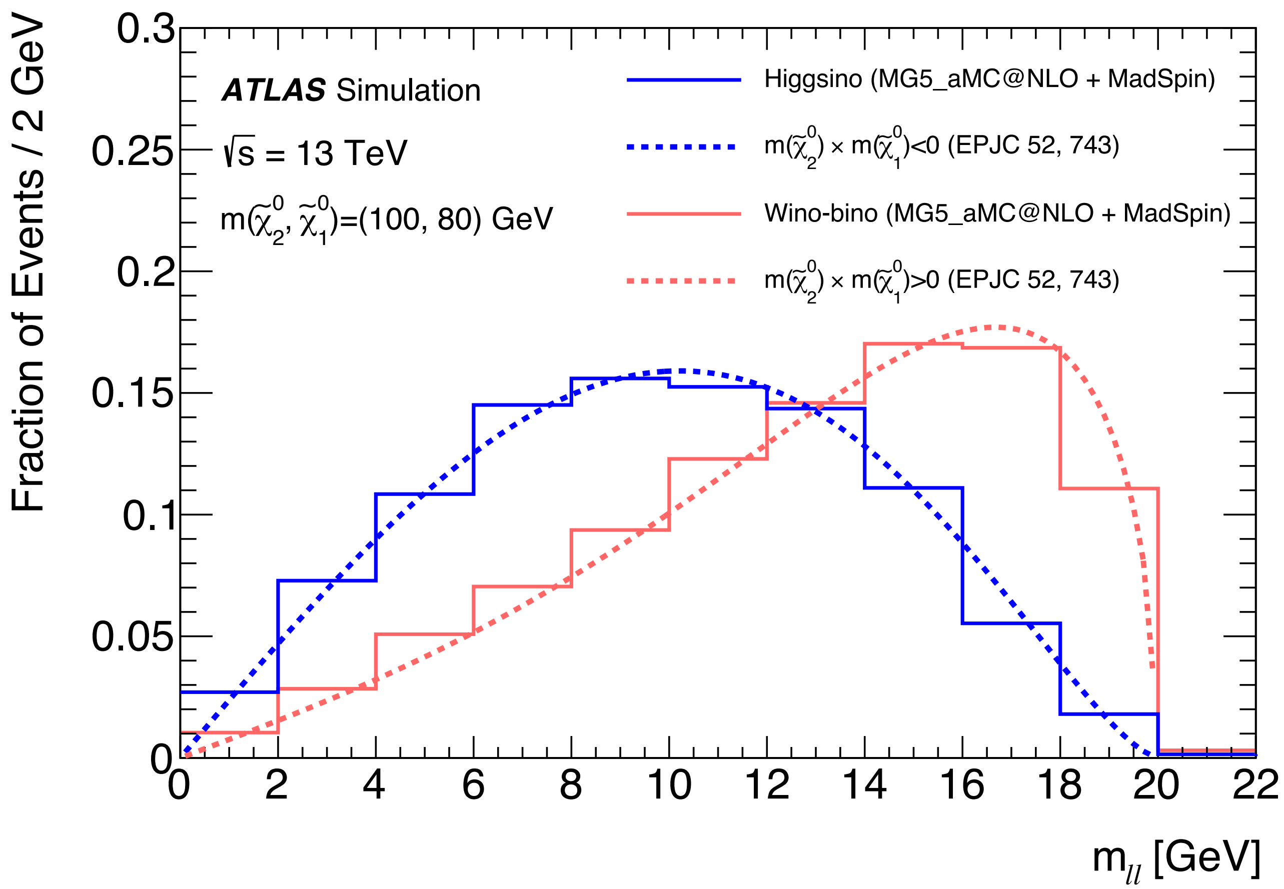
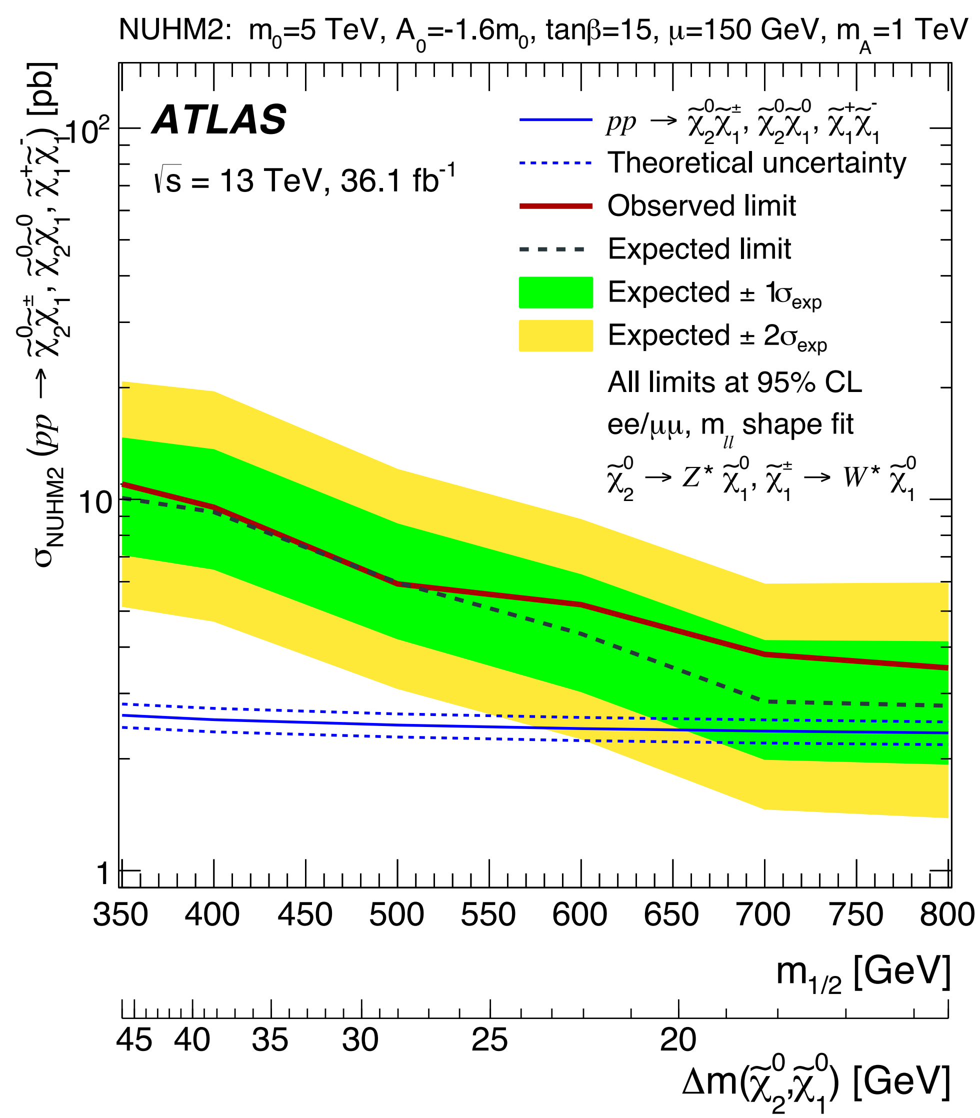
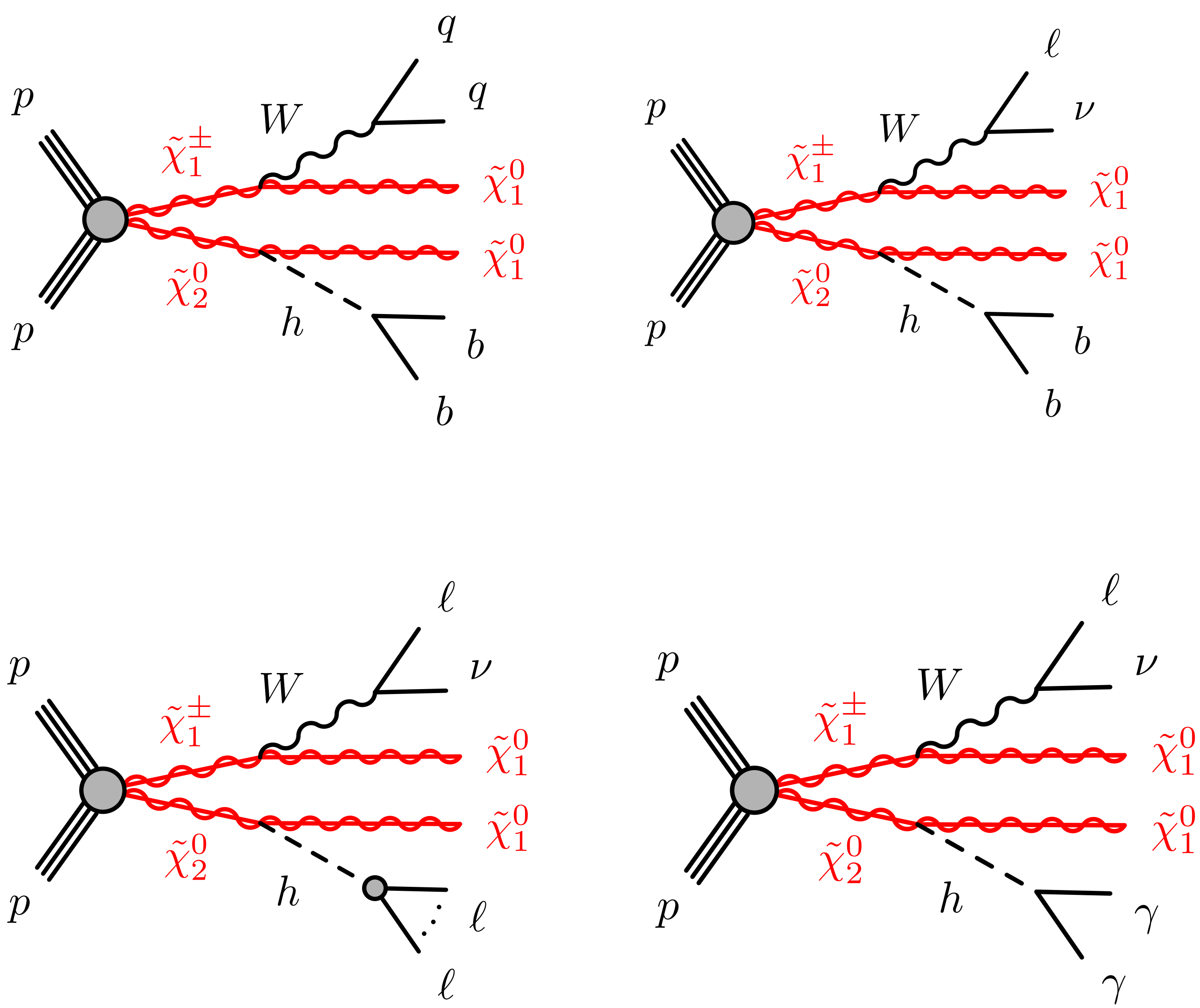


FIG. 2. Dilepton invariant mass ($m_{\ell\ell}$) for Higgsino and wino-bino simplified models. The endpoint of the $m_{\ell\ell}$ distribution is determined by the difference between the masses of the $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^0$. The results from simulation (solid line) are compared with an analytic calculation of the expected line shape (dashed line) presented in Ref. [48], where the product of the signed mass eigenvalues ($m(\tilde{\chi}_2^0) \times m(\tilde{\chi}_1^0)$) is negative for Higgsino and positive for wino-bino scenarios.

Cross-section upper limit



Electroweak production via WH

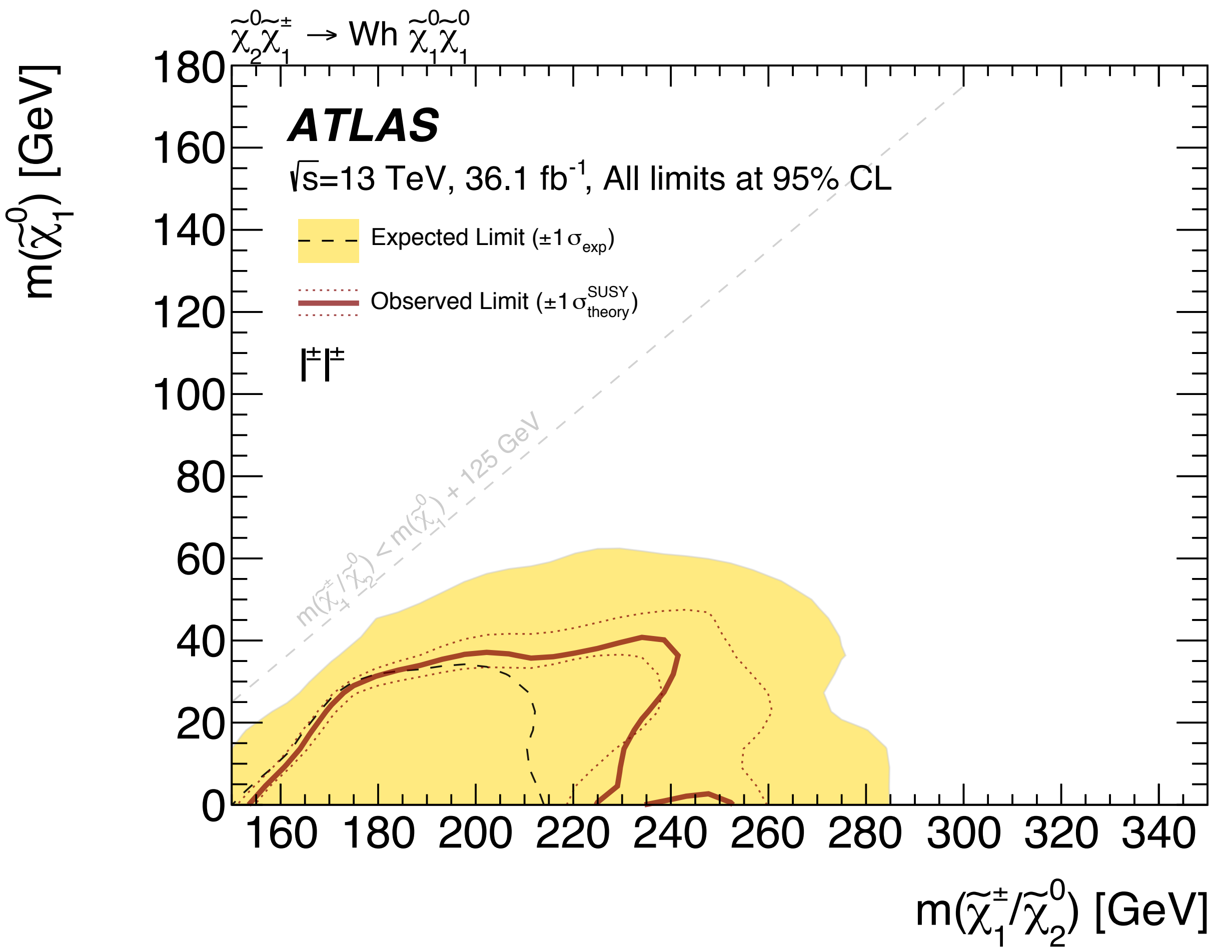


Signal regions

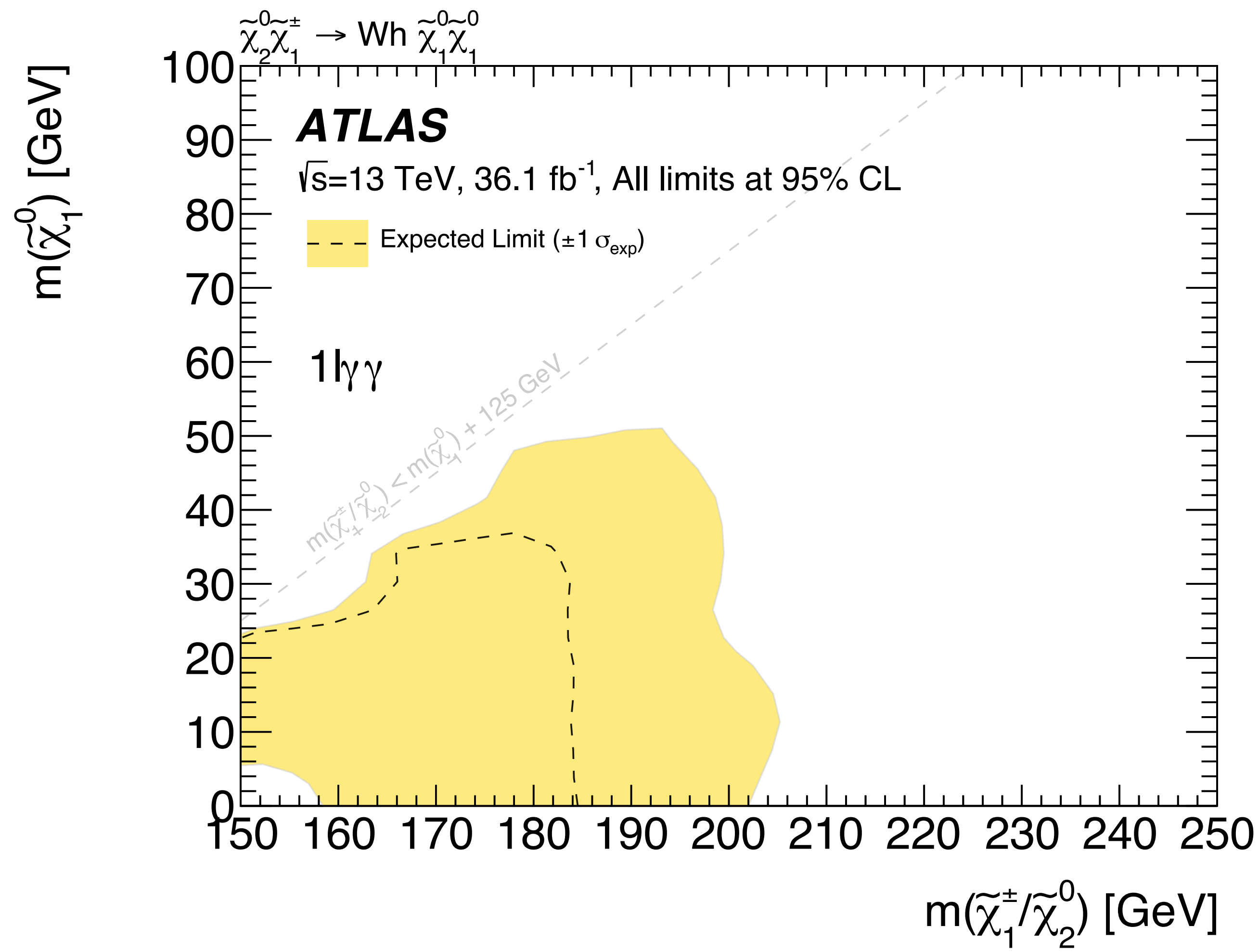
Variable	SRHad-High	SRHad-Low
N_{lepton}	$= 0$	$= 0$
N_{jet} ($p_{\mathrm{T}} > 30$ GeV)	$\in [4,\ 5]$	$\in [4,\ 5]$
$N_{b\text{-jet}}$	$= 2$	$= 2$
$\Delta\phi^{4j}_{\mathrm{min}}$	> 0.4	> 0.4
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 250	> 200
m_{eff} [GeV]	> 900	> 700
$m_{b\bar{b}}$ [GeV]	$\in [105, 135]$	$\in [105, 135]$
$m_{q\bar{q}}$ [GeV]	$\in [75, 90]$	$\in [75, 90]$
m_{CT} [GeV]	> 140	> 190
$m_{\mathrm{T}}^{b,\mathrm{min}}$ [GeV]	> 160	> 180

Electroweak production via WH

Multi-leptons



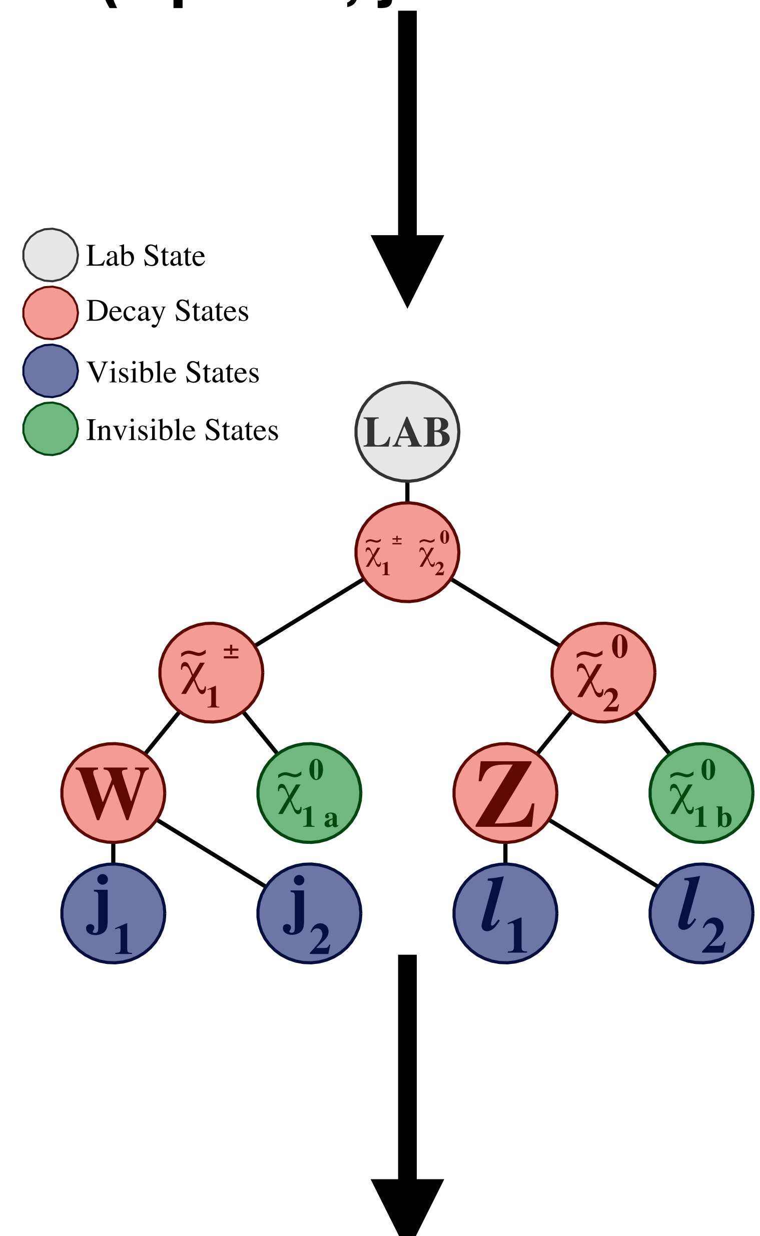
1l-diphoton



Electroweak production with recursive jigsaw

- The RJR technique:
  - It is a method to decompose measured properties event-by-event to provide a basis of kinematic variables
  - This is achieved by approximating the rest frames of intermediate particle states in each event.
  - This gives rise to a natural basis of kinematic observables calculated by recursively evaluating the momentum and energy of different objects in these reference frames.

Reconstructed objects as inputs (leptons, jets and MET)



Kinematic variables to discriminate S from B

Set of variables

(i) $H^{\rm PP}_{n,1}$: scale variable as described above. Behaves similarly to the effective mass, $m_{\rm eff}$ (defined as the scalar sum of the transverse momenta of the visible objects and $E_{\rm T}^{\rm miss}$), used in previous ATLAS SUSY searches.

(ii) $H^{\rm PP}_{1,1}/H^{\rm PP}_{4,1}$: provides additional information in testing the balance of the two scale variables. This provides excellent discrimination against unbalanced events where the large scale is dominated by a particular object $p_{\rm T}$ or by large $E_{\rm T}^{\rm miss}$. Behaves similarly to the $E_{\rm T}^{\rm miss}/m_{\rm eff}$. Utilized solely in the 2ℓ low mass signal region to mitigate the effects of Z + jets backgrounds, in cases where one high $p_{\rm T}$ jet dominates.

(iii) $p^{\rm lab}_{\rm TPP}/(p^{\rm lab}_{\rm TPP} + H^{\rm PP}_{{\rm T}n,1})$: compares the magnitude of the vector sum of the transverse momenta of all objects associated with the PP system in the lab frame ($p^{\rm lab}_{\rm TPP}$) to the overall transverse scale variable considered. This quantity tests for significant boost in the transverse direction. For signal events this quantity peaks sharply towards zero while for background processes the distribution is broader. A test of how much a given process resembles the imposed PP system in the decay tree.

(iv) $H^{\rm PP}_{{\rm T}3,1}/H^{\rm PP}_{3,1}$: a measure of the fraction of the momentum that lies in the transverse plane.

(i) $p^{\rm CM}_{\rm T\,ISR}$: the magnitude of the vector-summed transverse momenta of all jets assigned to the ISR system.

(ii) $p^{\rm CM}_{\rm T\,I}$: the magnitude of the vector-summed transverse momenta of the invisible system. Behaves similarly to $E_{\rm T}^{\rm miss}$.

(iii) $p^{\rm CM}_{\rm T}$: the magnitude of the vector-summed transverse momenta of the CM system.

(iv) $R_{\rm ISR} \equiv \vec{p}^{\,\rm CM}_{\rm I} \cdot \hat{p}^{\rm CM}_{\rm TS}/p^{\rm CM}_{\rm TS}$: serves as an estimate of $m_{\tilde{\chi}^0_1}/m_{\tilde{\chi}^0_2/\tilde{\chi}^\pm_1}$. This corresponds to the fraction of the momentum of the S system that is carried by its invisible system I, with momentum $\vec{p}^{\,\rm CM}_{\rm I}$ in the CM frame. As $p^{\rm CM}_{\rm TS}$ grows it becomes increasingly hard for backgrounds to possess a large value in this ratio—a feature exhibited by compressed signals [13].

(v) $N^{\rm S}_{\rm jet}$: number of jets assigned to the signal system (S).

Electroweak production with recursive jigsaw