SUSY search with one isolated lepton at ATLAS

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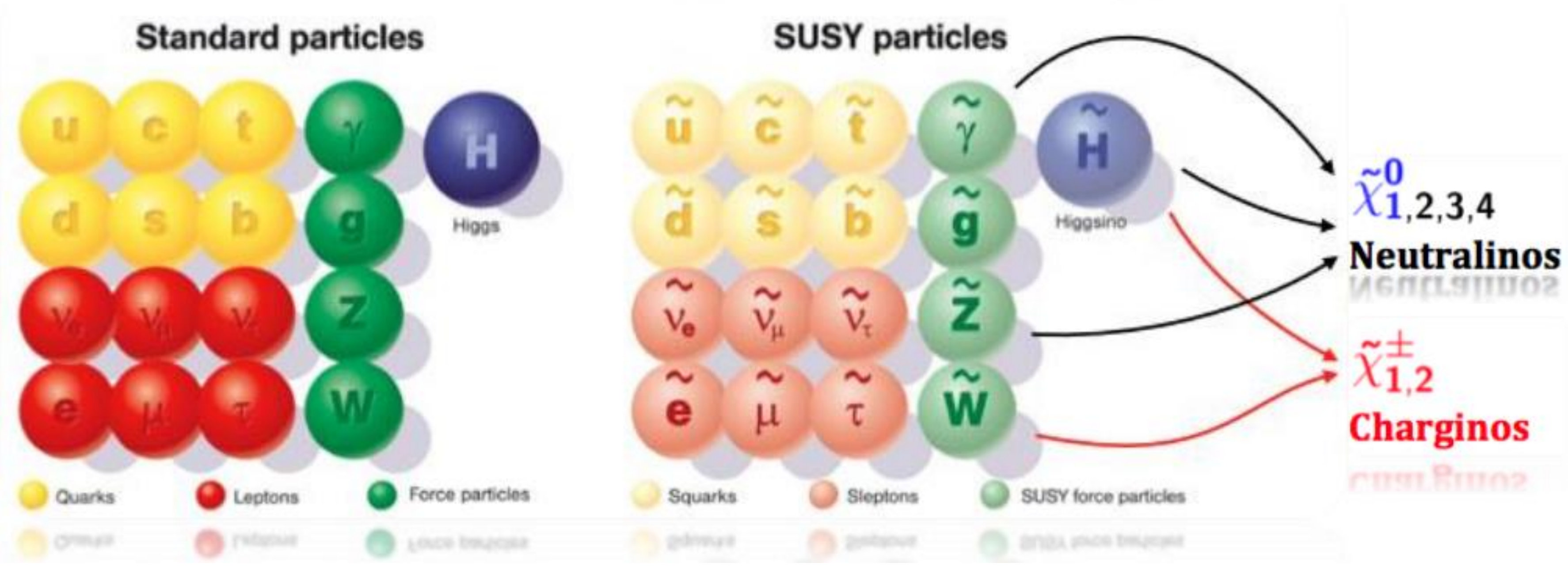
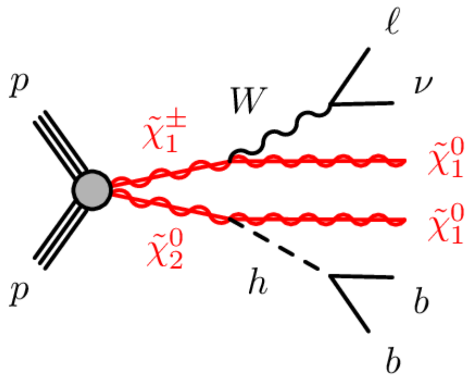
Introduction



- The Supersymmetry is a well motivated and favored extension of the Stand Model (SM):
  - solves hierarchy problem, dark matter candidate…
- This talk will focus on the results of SUSY search with 1l (+2b-jets) at ATLAS with full Run-2 data (139 fb^{-1}, included in the latest paper SUSY-2019-08).

Analysis Overview

- Signature: **1 lepton + MET + 2 b-jets**, decay from **charginos and neutralinos** (via W and Higgs boson)



- Small cross sections, but one lepton requirement can largely suppress QCD backgrounds and 2 b-jets from Higgs can help to increase the sensitivity.
- Dominant backgrounds are **ttbar, single top** and **W+jets** which are studied in dedicated control regions (CR); other backgrounds estimated in Monte Carlo simulation.
- The contributions in SRs are derived using a **simultaneous fit**.

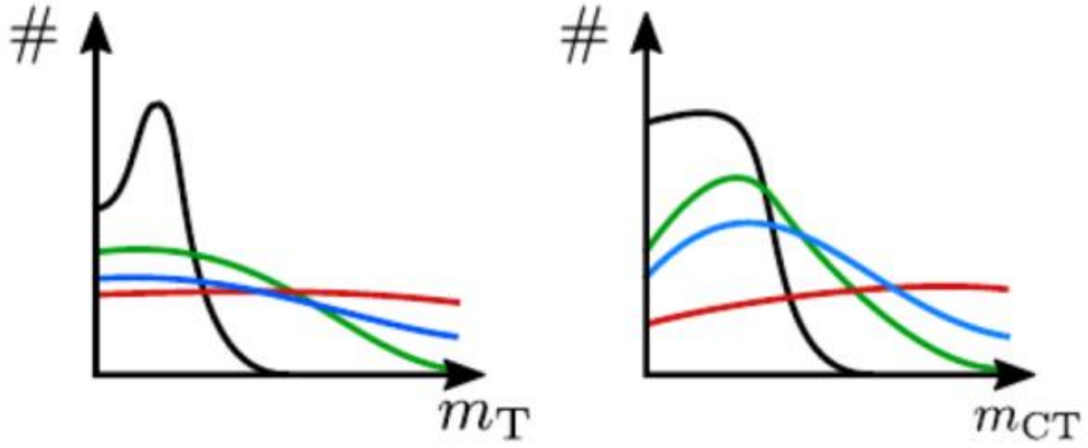
Analysis Overview

Distributions in m_{T} and m_{CT} in general favour very different cuts for different signal points.

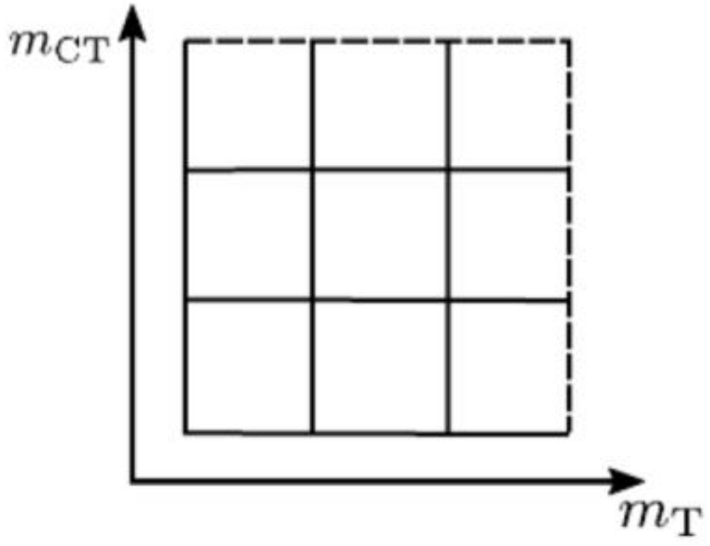
- Define signal regions with different bins in these observables.
- Signal regions otherwise share a (more or less) common set of requirements.

Simultaneous likelihood fit in all signal region bins (since all orthogonal to each other)

- Allows to explicitly consider the varying shapes between **background** and signal.
- Results in an increase in sensitivity.



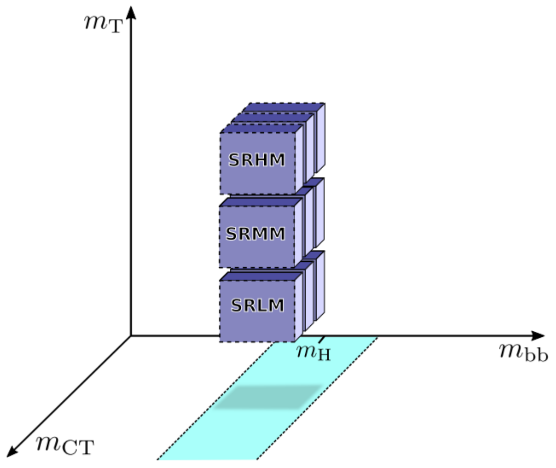
Background distribution against different signal model points in red, blue and green.



Definition of signal regions binned in m_{T} and m_{CT}.

Signal Regions

- Three signal regions with increasing $\mathbf{m_T}$ requirement
  - 3-step signal region optimization
  - Targeting increasing mass differences between chargino/neutralino and LSP
  - Share common set of kinematic requirements (apart from m(l, b))
- Binned in m_{CT} for model-dependent fit (excl. SRs)
  - 3 bins in m_{CT} each (in total 9 SRs), can perform 2D shapefit simultaneously
- No bins for model-independent fit (disc. SRs)
  - No m_T upper cut and no m_{CT} bins



	SR-LM	SR-MM	SR-HM
N_{lepton}	$= 1$		
p_T^ℓ [GeV]	$> 7(6)$ for $e(\mu)$		
N_{jet}	$= 2$ or 3		
$N_{b\text{-jet}}$	$= 2$		
E_T^{miss} [GeV]	> 240		
$m_{b\bar{b}}$ [GeV]	$\in [100, 140]$		
$m(\ell, b_1)$ [GeV]	–	–	> 120
m_T [GeV] (excl.)	$\in [100, 160]$	$\in [160, 240]$	> 240
m_{CT} [GeV] (excl.)	$\{\in [180, 230], \in [230, 280], > 280\}$		
m_T [GeV] (disc.)	> 100	> 160	> 240
m_{CT} [GeV] (disc.)	> 180		

Background estimation

- **Dominant backgrounds: ttbar, single top, W+jets**
  - Use dedicated CRs to derive normalization factors for SRs
  - VRs used to validate extrapolation from CRs to SRs
  - All regions share the same selection as the SR for all variables except m(l, b)
- **Small backgrounds: Z+jets, diboson, multiboson, ttV, tth, Vh**
  - Estimated from MC simulation

CR	**TR-LM**	**TR-MM**	**TR-HM**	**WR**	**STR**	
$m_{b\bar{b}}$ [GeV]		<100 or >140		$\in [50, 80]$	>195	
m_{T} [GeV]	$\in [100, 160]$	$\in [160, 240]$	>240	$\in [50, 100]$	>100	
m_{CT} [GeV]		<180		>180	>180	
VR	**VR-onLM**	**VR-onMM**	**VR-onHM**	**VR-offLM**	**VR-offMM**	**VR-offHM**
$m_{b\bar{b}}$ [GeV]		$\in [100, 140]$		$\in [50, 80] \cup [160, 195]$	$\in [50, 80] \cup [160, 195]$	$\in [50, 75] \cup [165, 195]$
m_{T} [GeV]	$\in [100, 160]$	$\in [160, 240]$	>240	$\in [100, 160]$	$\in [160, 240]$	>240
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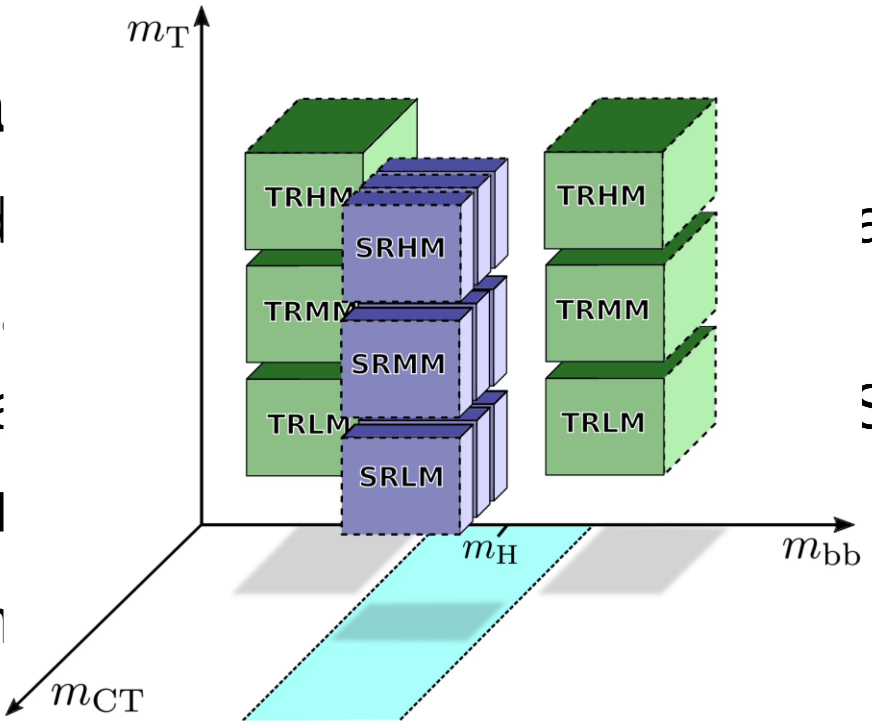

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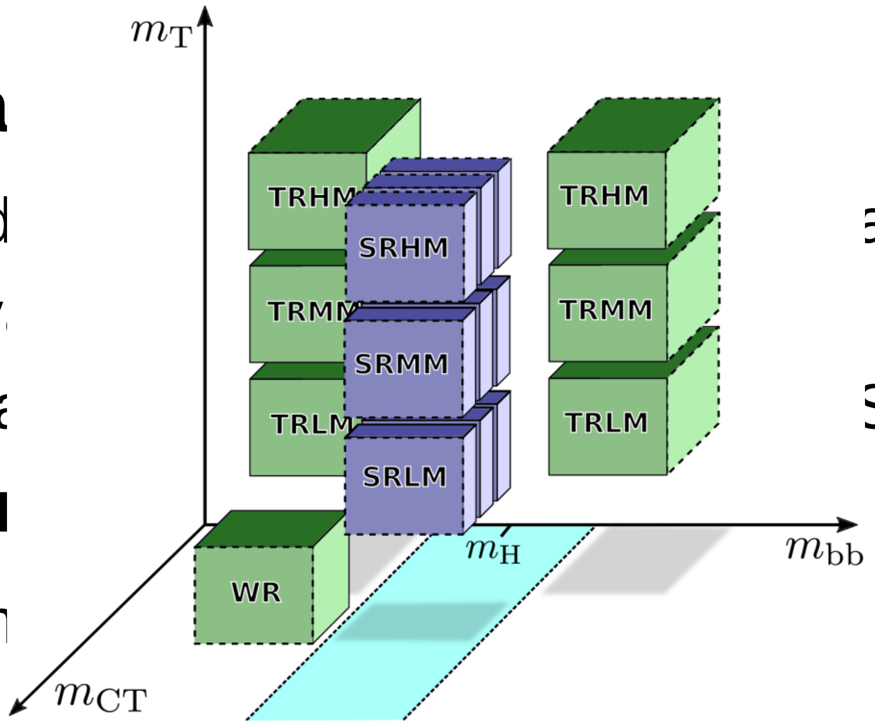

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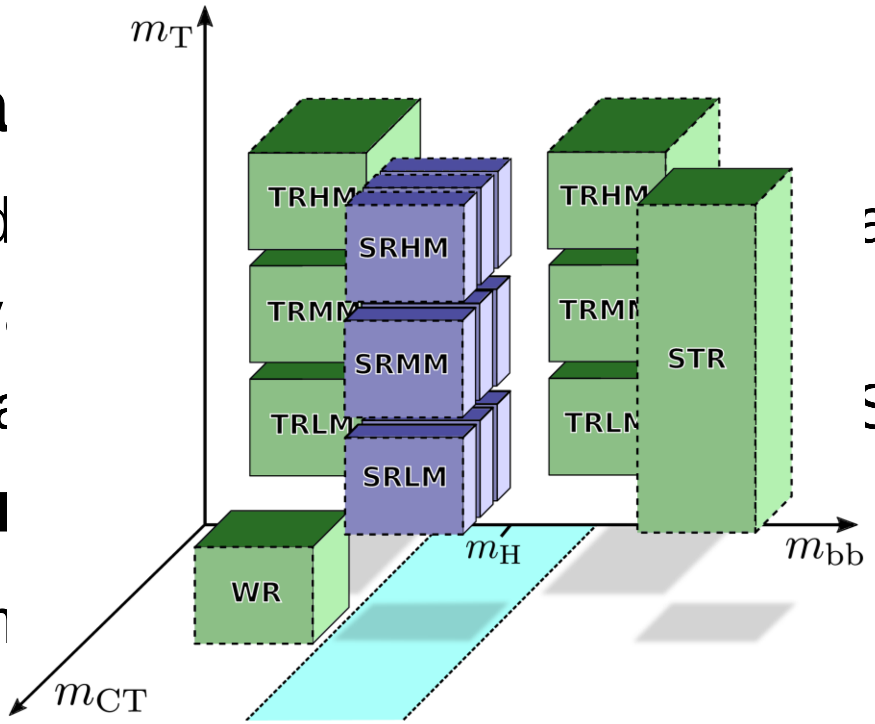

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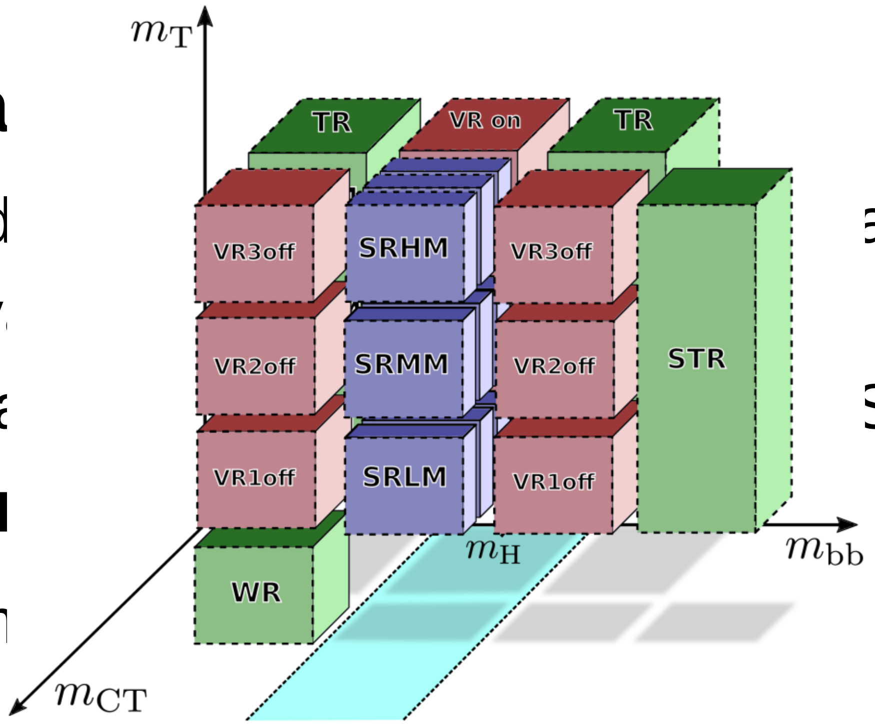

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m_{CT} [GeV]		<180			>180	

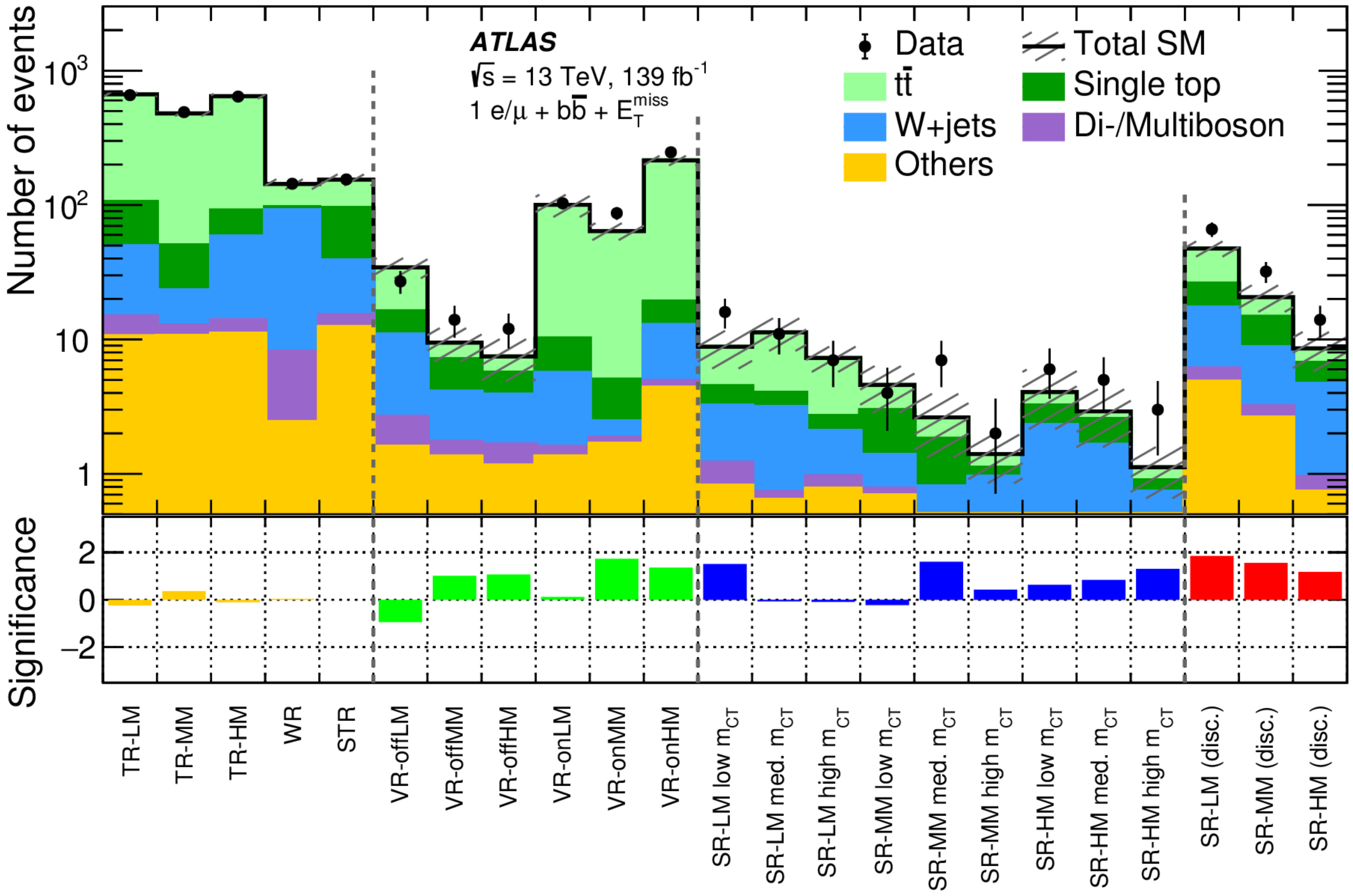
Systematic uncertainties

- **Experimental systematics**
  - Dominant: JES, JER, MET, pile-up
  - Less significant than theoretical uncertainties in all SRs
- **Theoretical uncertainties**
  - Calculate the uncertainties on transfer factors for dominant backgrounds
  - For small backgrounds, normalize to loose preselection to avoid double count scale uncertainties with the xsec
  - Uncertainties for signals are evaluated using truth samples (in a relaxed SR in case of low stat)

Signal Region	SR-LM	SR-MM	SR-HM
Total background expectation	27	8.6	8.1
Total uncertainty	±4 [15%]	±2.2 [25%]	±2.7 [34%]
Theoretical systematic uncertainties			
$t\bar{t}$	±2.6 [10%]	±0.6 [7%]	±0.33 [4%]
Single top	±0.8 [2.7%]	±1.1 [12%]	±1.9 [23%]
W+jets	±0.23 [0.9%]	±0.07 [0.8%]	±0.19 [2.3%]
Other backgrounds	±0.13 [0.5%]	±0.15 [1.7%]	±0.08 [1.0%]
MC statistical uncertainties			
MC statistics	±1.7 [6%]	±1.1 [13%]	±1.2 [14%]
Uncertainties in the background normalisation			
Normalisation of dominant backgrounds	±1.3 [5%]	±1.6 [18%]	±1.3 [16%]
Experimental systematic uncertainties			
$E_{\mathrm{T}}^{\mathrm{miss}}$/JVT/pile-up/trigger	±1.8 [7%]	±0.4 [4%]	±0.4 [5%]
Jet energy resolution	±1.6 [6%]	±0.5 [6%]	±0.4 [5%]
b-tagging	±1.1 [4%]	±0.29 [3.4%]	±0.13 [1.5%]
Jet energy scale	±0.9 [3.2%]	±0.9 [10%]	±0.29 [4%]
Lepton uncertainties	±0.32 [1.2%]	±0.09 [1.0%]	±0.19 [2.3%]

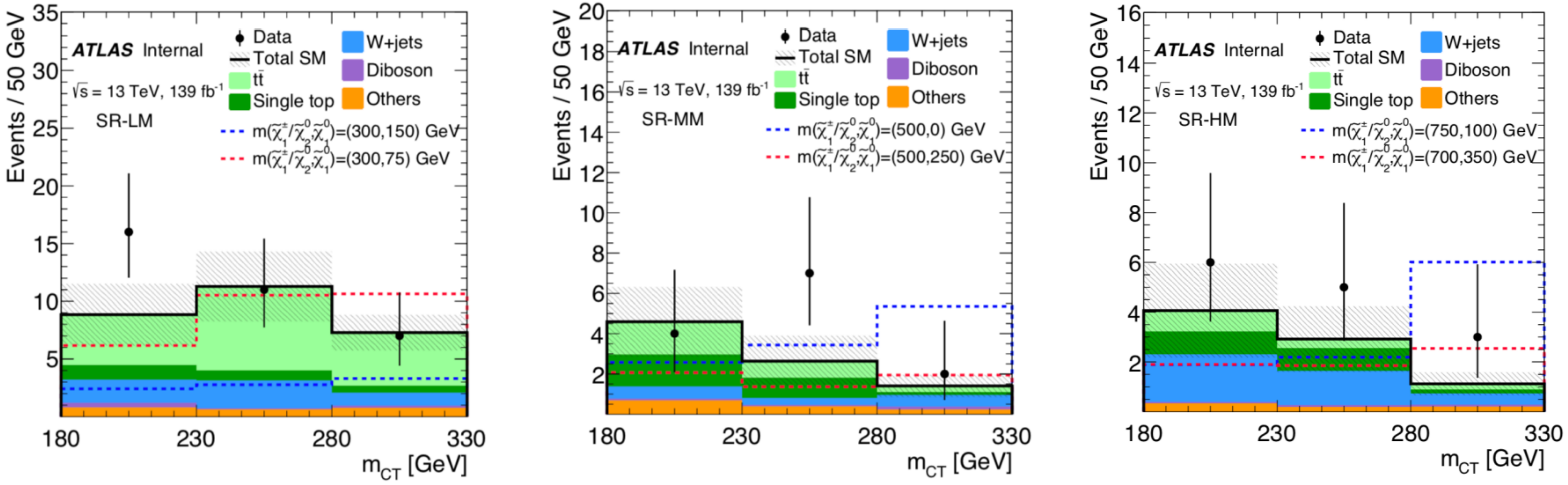
Summary plot in all regions

- Both stat and syst uncertainties included
- Good agreement in all CRs
- Small discrepancies in VRs
- Kind of consequent (but not significant) offset in SRs



Distributions in SRs

- Post-fit distributions of mCT in SRs
- Both stat and syst uncertainties included
- Contributions from signals (pre-fit) also included

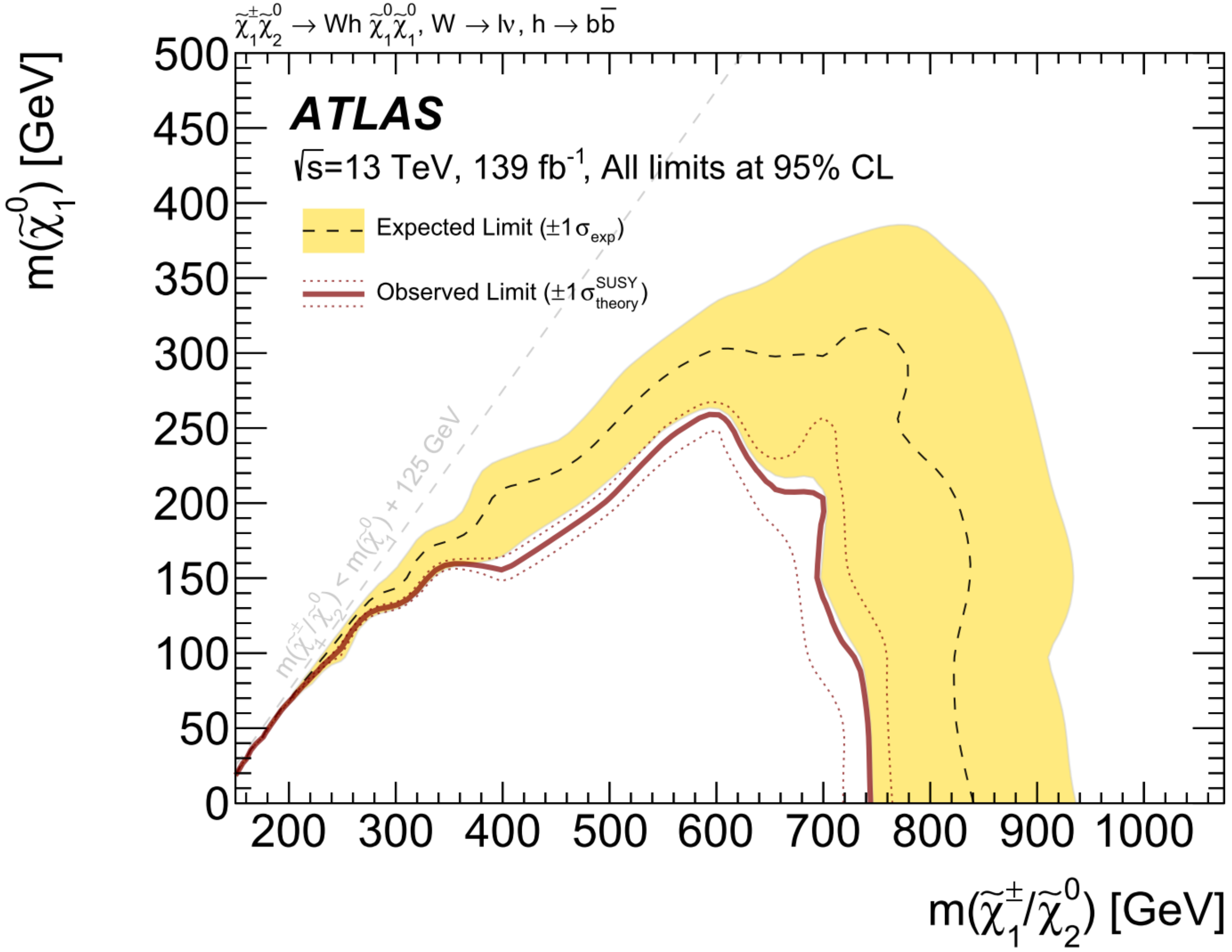


Model independent upper limits

- Calculate the **model independent** upper limits for each discovery SR: the **visible cross-section**, the **observed and expected 95% CL upper limits on the BSM event yield**, **one-sided discovery p-value** and **the significance**.
- Model dependent limits are shown in next slide (interpreted in simplified model)

Signal Region	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$[fb]	S^{95}_{obs}	S^{95}_{exp}	$\mathrm{CL_B}$	p_0	Z
SR-LM(disc.)	0.26	36.8	$20.0^{+8.0}_{-5.4}$	0.97	0.03	1.88
SR-MM(disc.)	0.18	24.8	$15.3^{+6.2}_{-4.6}$	0.94	0.06	1.54
SR-HM(disc.)	0.11	14.7	$9.7^{+3.3}_{-2.7}$	0.89	0.10	1.30

Model dependent limits



- Small excess → observed limit weaker than expected limit
- Exclusion extends to 740 GeV for massless LSP

Summary

- The SUSY search with 1 lepton + 2b-jets + MET in the final state is performed with full Run-2 data (139 fb^{-1}) in ATLAS.

- Observed small but not significant excess in the SRs
  → Not ready for the discovery
  → Extend the limits to 740 GeV for massless LSP

- New efforts for 1l analysis are ongoing: inclusive search, machine learning… Stay tuned!


The End

Object definition

Electrons

Cut	Value/description
Preselected Electron	
Algorithm	AuthorElectron
Acceptance	$p_T > 7\text{GeV}, \lvert\eta^{\text{clust}}\rvert < 2.47$
Quality	LooseAndBLayerLLH
IP	$\Delta z_0 \sin(\theta)$<0.5 mm
Signal Electron	
Acceptance	$p_T > 7$ GeV
Quality	TightLLH
Isolation	FCLoose for $p_T < 200$ GeV FCHighPtCaloOnly for $p_T > 200$ GeV
IP	$d_0/\sigma(d_0) < 5$

Muons

Cut	Value/description
Preselected muon	
Acceptance	$p_T > 6$ GeV, $\lvert\eta\rvert < 2.7$
Quality	Medium
IP	$\Delta z_0 \sin(\theta)$<0.5 mm
Signal muon	
Acceptance	$p_T > 6$ GeV, $\lvert\eta\rvert < 2.5$
Isolation	FCLoose
IP	$d_0/\sigma(d_0) < 3$

Jets

Cut	Value/description
Preselected jet	
Algorithm	anti-k_t-4, Topo
Acceptance	$p_T > 20$ GeV, $\lvert\eta\rvert < 4.5$
Signal jet	
Acceptance	$p_T > 30$ GeV, $\lvert\eta\rvert < 2.8$
JetVertexTagger	JVT @ 92 % working point for $p_T < 120$ GeV and $\lvert\eta\rvert < 2.8$
Signal b-jet	
b-tagger Algorithm	MV2c10 @ 77 % working point
Acceptance	$p_T > 20$ GeV, $\lvert\eta\rvert < 2.5$

- **Missing transverse momentum**
  - Computed using baseline/preselected objects: electrons, muons, jets, photons and track soft term.
  - Using *tight* working point, no fJVT.
- **Overlap removal**
  - EleMuOR: Electrons sharing ID track with muons are rejected.
  - EleEleOR: If electron shares same ID track with other electron, the one with lower p_T is rejected.
  - MuJetOR: Jets within dR=0.2 of muon are rejected (or if matched through ghost association).
  - EleJetOR: Electrons close to jet are removed (sliding cone size).
  - JetMuOR: Muons close to jet are removed (sliding cone size).

Discriminating variables

Definition of all ROIs by using kinematic properties of *b*-jets, lepton and E_T^{miss}:

- **m_{bb}:** preferentially select *b*-jets from Higgs boson decays by requiring $100 < m_{bb} < 140$.
- **m_T:** aims to reconstruct leptonically decaying *W* boson, has kinematic endpoint at m_W for semileptonic ttbar and *W*+jets.
- **m_{CT}:** contransverse mass of *b*-jets, has kinematic endpoint for ttbar background.
- **$m(\ell, b_1)$:** invariant mass of lepton and leading *b*-jet, provides good discrimination against top backgrounds, esp. for high-mass signal points.

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos[\Delta\phi(\boldsymbol{p}_{\mathrm{T}}^{\ell}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})])} \qquad m_{\mathrm{CT}} = \sqrt{2 p_{\mathrm{T}}^{b_1} p_{\mathrm{T}}^{b_2} (1 + \cos \Delta\phi_{bb})}$$

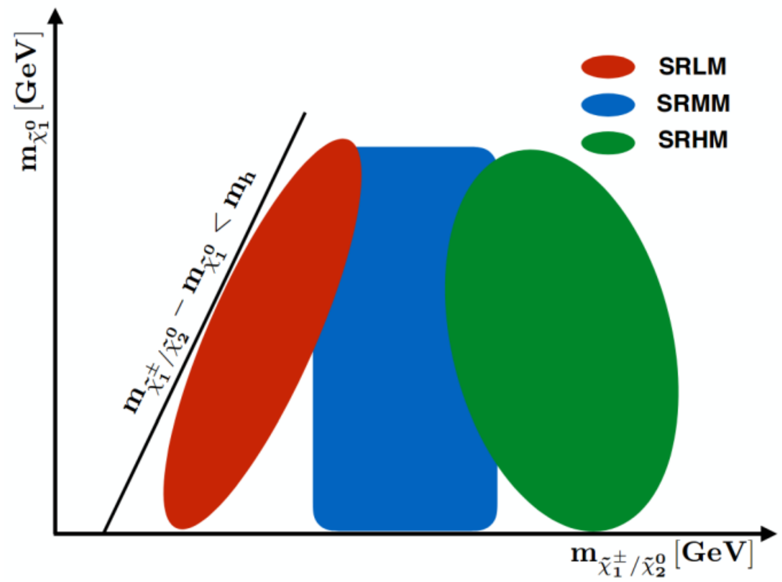
Previous analysis

- Results based on 2015+2016 data: (arXiv:1812.09432)

Preselection: Exactly 1 lepton, 2-3 jets and exactly 2 b-jets.

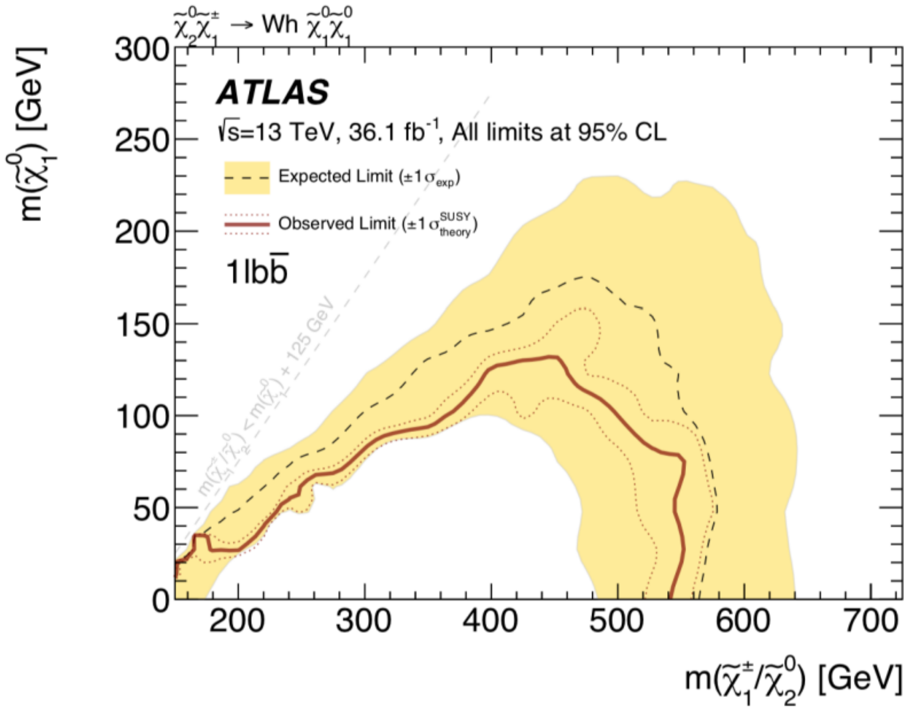
Observable	SR LM	SR MM	SR HM
m_{bb} [GeV]		[105 – 135]	
E_T^{miss} [GeV]		> 200	
m_{CT} [GeV]		> 160	
m_T [GeV]	[100 – 140]	[140 – 200]	> 200

3 signal region bins in m_T



simultaneous likelihood fit (shape fit in m_T)

proper background estimation: CRs for dominant backgrounds



Exclusion up to chargino/neutralino mass of 540 GeV for massless LSP

Theory uncertainty calculation

- **For dominant backgrounds:**
  - Uncertainty on the transfer factors.
  - Normalisation region is the sum of all control regions.
  - Statistical uncertainty is only added if a separate systematic sample with different generator is used.

$$TF^{\text{Process}}_{\text{Syst}}(CR_i \rightarrow R_j) = \frac{N(R_j, MC)}{N(CR_i, MC)}$$

$$\Delta TF^{\text{Process}}_{\text{Syst}} = \frac{TF^{\text{Variation}}_{\text{Syst}} - TF^{\text{Nominal}}_{\text{Syst}}}{TF^{\text{Nominal}}_{\text{Syst}}} = \frac{TF^{\text{Variation}}_{\text{Syst}}}{TF^{\text{Nominal}}_{\text{Syst}}} - 1 = \frac{\frac{A}{B}}{\frac{C}{D}} - 1$$

$$\Delta TF_{stat} = \left(\Delta TF^{\text{Process}}_{\text{Syst}} + 1\right)\sqrt{\left(\frac{\sigma_A}{A}\right)^2 + \left(\frac{\sigma_B}{B}\right)^2 + \left(\frac{\sigma_C}{C}\right)^2 + \left(\frac{\sigma_D}{D}\right)^2}$$

- **For small backgrounds:**
  - Normalise to loose preselection such that scale uncertainties are not double counted with cross-section uncertainty.

$$\Delta N^{\text{sys}}_{\text{region}} = \frac{N^{\text{sys}}_{\text{region}} \cdot N^{\text{nominal}}_{\text{preselection}}}{N^{\text{sys}}_{\text{preselection}} \cdot N^{\text{nominal}}_{\text{region}}} - 1$$