Searches for electroweak production of supersymmetry, R-parity violating signatures and events with long-lived particles with the ATLAS detector

Itzebelt Santoyo Castillo

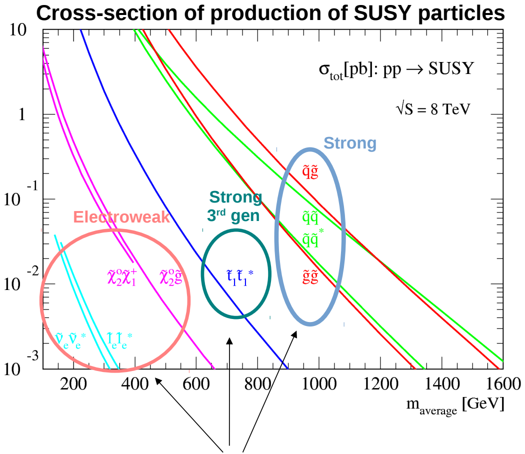
On behalf of the ATLAS Collaboration

University of Sussex

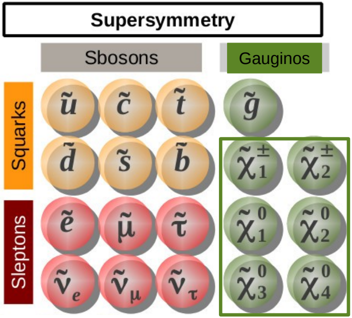
LLWI 2015

ATLAS

Introduction



Search strategies developed by ATLAS target all these SUSY production modes

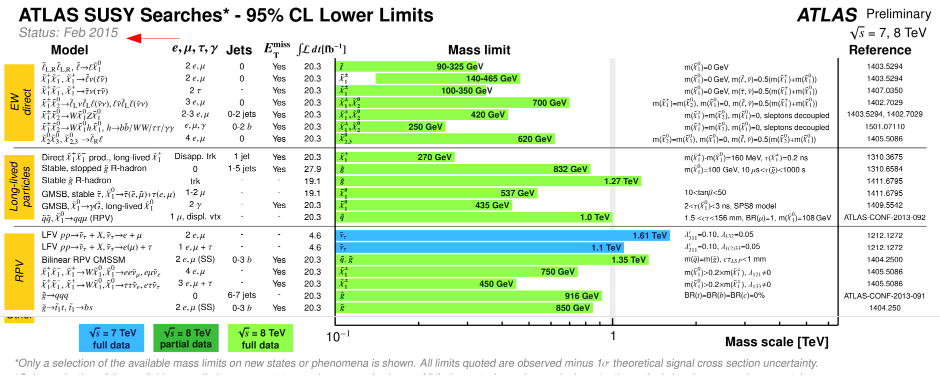


Stringent limits on strong production (squarks and gluinos) with masses above 1 TeV.

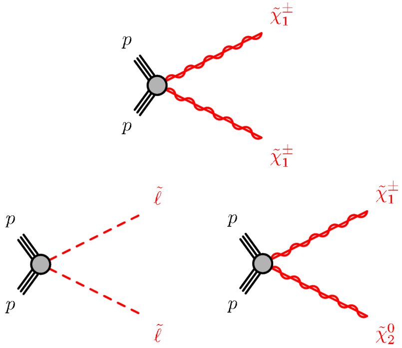
See talk from C.W Kalderon

Run 1 Results from ATLAS

Focus of this talk is on the recent results from electroweak, RPV and long lived Supersymmetry searches with the 2012 data collected by ATLAS

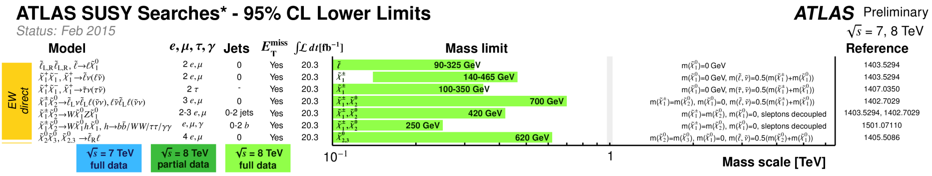


Electroweak SUSY



Electroweak (EWK) production can be dominant at the LHC.

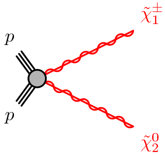
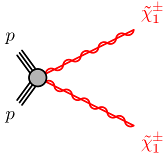
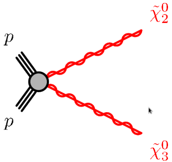
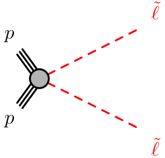
- **Low cross sections**
- **Multileptonic signatures with large missing transverse energy**
- **Suppressed SM backgrounds**



*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

EWK RPC Search Strategy

Signature-based analyses characterised by lepton multiplicity (L) and missing transverse energy

Channel				
1L+$bb/\gamma\gamma$	**via** Wh			
* **2L** (e,μ)	**via** WZ, Wh (SS)	**via** $\tilde{\ell}/\tilde{\nu}$, WW		**with** $\tilde{\ell} = \tilde{e}, \tilde{\mu}$
* **2L** (τ)	**via** $\tilde{\tau}/\tilde{\nu}$	**via** $\tilde{\tau}/\tilde{\nu}$		**with** $\tilde{\ell} = \tilde{\tau}$
* **3L** (e,μ,τ)	**via** $\tilde{\ell}, \tilde{\tau}, WZ, Wh$			
** **4L** (e,μ,τ)			**via** $\tilde{\ell}, \tilde{\tau}, ZZ$	

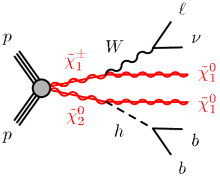
Supersymmetric Models

- Simplified Models (**discussed here**)
  - One simulated process with 100% BR
- (**) General Gauge Mediation (GGM)
  - gauge-mediated SUSY breaking mechanism with gravitino as the LSP

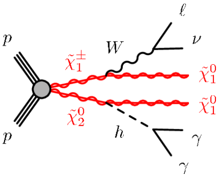
NEW! *WH* combination

arXiv:1501.07110

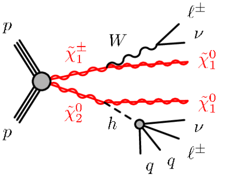
$1\ell + 2$ bb $+ E_T^{miss}$



$1\ell + 2$ photons $+ E_T^{miss}$



$\ell^\pm\ell^\pm + \geq 1$ jet $+ E_T^{miss}$



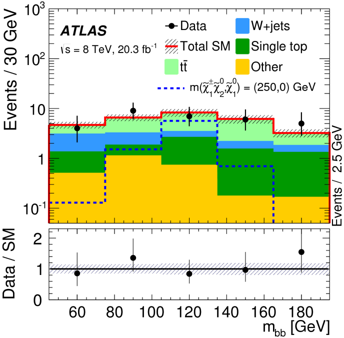
Simplified models:
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ decays via *Wh*

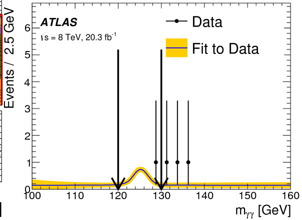
- $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$ wino, mass degenerate
- $\tilde{\chi}_1^0$ bino

Strategy

- all 3 signatures combined
- 2 signal regions exploiting m_T^W, m_{CT} and requiring m_{bb} to be around the Higgs mass
- *W*+jets and $t\bar{t}$ SM background processes dominate
- 2 signal regions exploiting $m_T^{W\gamma}$, and $\Delta\phi(W,\gamma)$
- *VH* and $t\bar{t}$H SM background processes dominate
- 6 signal regions exploiting m_{eff}, and m_T
- *VV* and non-prompt lepton SM background processes dominate

Overall very good agreement between data and expectation

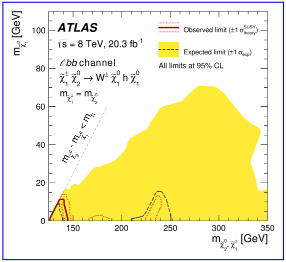




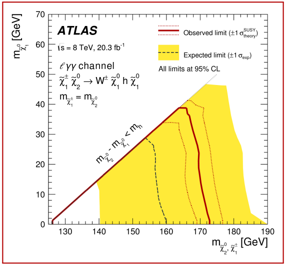
NEW! *WH* combination

arXiv:1501.07110

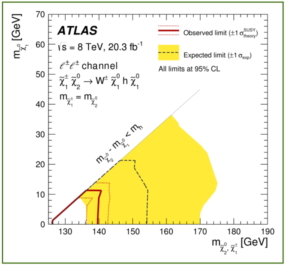
$1\ell + 2\ bb + E_T^{miss}$



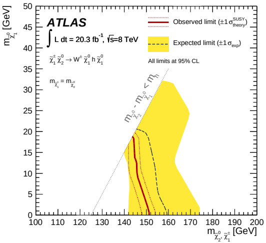
$1\ell + 2$ photons $+ E_T^{miss}$



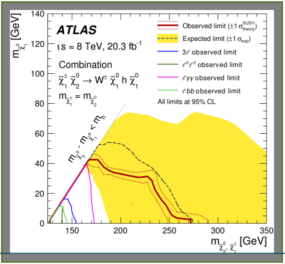
$\ell^{\pm}\ell^{\pm} + \geq 1$ jet $+ E_T^{miss}$



$3\ell + E_T^{miss}$ (arXiv:1402.7029)



Combination + 3L

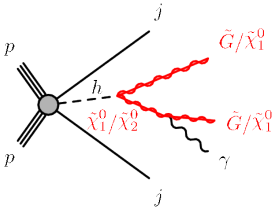


- No significant deviation from SM
- **Combination of all 3 channels + 3L analysis shows the best exclusion** (mind the axis range)
- Excluding charginos with mass up to 250 GeV for massless LSP

VBF Higgs

Higgs-boson production via vector-boson-fusion (VBF) decaying into neutralinos and/or gravitinos

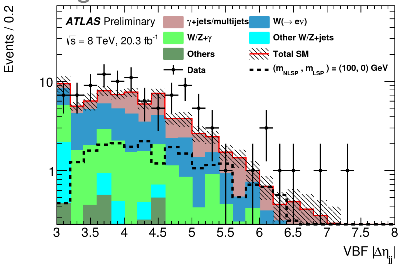
- Interpretation in GMSB and NMSSM models



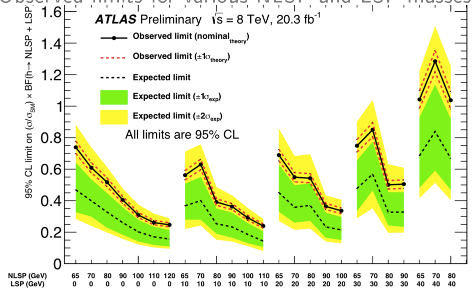
Analysis Design

- Event Selection: lepton veto, $\geq$ 2 jets, $\geq$ 1 photon, $E_{\mathrm{T}}^{\mathrm{miss}}$
- event selection optimized to exploit VBF di-jet topology m_{jj}, $\Delta\eta(jj)$
- main backgrounds multi-jets and gamma+jets

No significant deviation from SM.

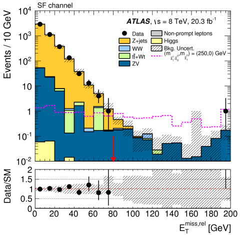


Observed limits for various NLSP and LSP masses.

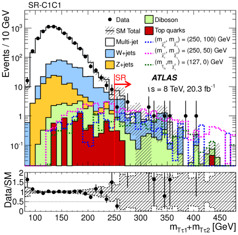


EWK SUSY Summary

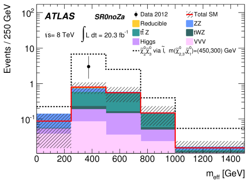
$2L(e,\mu)+E_{T}^{miss}$



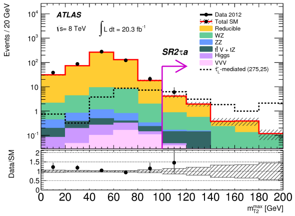
$2\tau+E_{T}^{miss}$



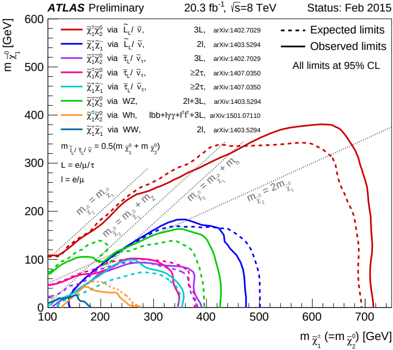
$4L+E_{T}^{miss}$



$3L+E_{T}^{miss}$



No significant deviation from SM



- Wide variety of signatures and decays explored
- Combination of final states possible due to orthogonality
- Utilise different kinematic variables to reduce SM backgrounds, such as dibosons, V+jets and $t\bar{t}$

RPV Supersymmetry

$$W_{\not R_p} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k + \kappa_i L_i H_2$$

A quantum number relating lepton (L) and baryon (B) numbers is known as R-parity (R_p), defined as:

$$R_p = (-1)^{3(B-L)+2S}$$

R-parity violation (RPV) implies:

- **Proton decay in some scenarios (depending on the λ couplings)**
- **LSP is no longer stable and can decay to SM particles with λ couplings**

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Feb 2015

ATLAS Preliminary

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

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt [fb^{-1}]$	Mass limit		Reference
RPV	LFV $pp \to \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \to e + \mu$	2 e, μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp \to \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \to e(\mu) + \tau$	1 $e, \mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.35 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \to W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e, μ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 750 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{121} \neq 0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+ \to W\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to \tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e, \mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{133} \neq 0$	1405.5086
	$\tilde{g} \to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g} \to \tilde{t}_1 t, \tilde{t}_1 \to bs$	2 e, μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250

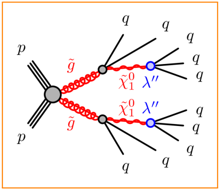
$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

10^{-1} 1 Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

NEW!

RPV Multijet searches

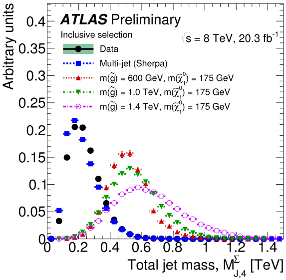


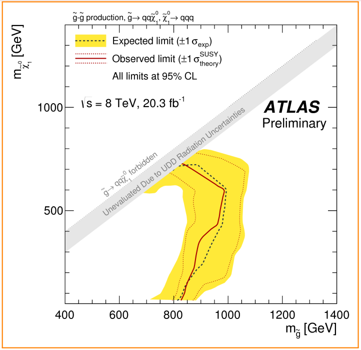
Analysis Design

- High jet multiplicities, no missing transverse energy requirements
- Discrimination using the sum of the masses of the 4 leading large-R (R=1.0) jets ($M^{\Sigma}_{J,4}$, η, jet p_{T}
- QCD background processes dominate, estimated with data-driven method using jet mass templates derived in a 3-jet control region
- 3 signal regions are defined with at least 4 large-R jets (2/3 binned in $M^{\Sigma}_{J,4}$)

- RPV "UDD" decays lead to a final state characterised by many partons (can be heavy flavor)
- Gluino pair decays to ten or more quarks via intermediate neutralinos
- Direct gluino decays to six quarks is also explored

Overall very good agreement between data and expectation





In the 10-quark model, gluinos are excluded for $m(\tilde{g}) < 1$ TeV for neutralino masses with $m(\tilde{\chi}^0_1) = 500$ GeV.

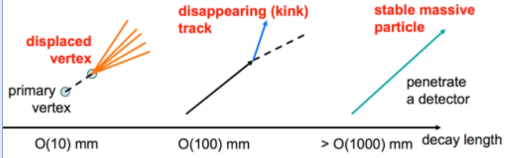
Long-Lived Supersymmetry

Long Lived Particles (LLP) are predicted by a wide variety of models : Hidden Sectors, RPV violating decays, Split-SUSY, AMSB, GMSB,

Signatures include:

- **Disappearing tracks**
- **Stopped gluino or squark R-hadrons**
- **Non-pointing and delayed photons**
- **Stable LLPs**
- **Displaced vertices**

All these signatures depend on lifetime



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Feb 2015

ATLAS Preliminary

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

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Mass limit		Reference
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$ 270 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	1310.3675
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 $\mu s<\tau(\tilde{g})<1000$ s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$ 1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}_1^0$ 537 GeV	$10<\tan\beta<50$	1411.6795
	GMSB, $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	$\tilde{\chi}_1^0$ 435 GeV	$2<\tau(\tilde{\chi}_1^0)<3$ ns, SPS8 model	1409.5542
	$\tilde{q}\tilde{q}$, $\tilde{\chi}_1^0 \rightarrow qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	$1.5 < c\tau < 156$ mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092

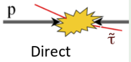
$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

10^{-1} — 1 — **Mass scale [TeV]**

Stable Massive Particles

arXiv:1411.6795

GMSB

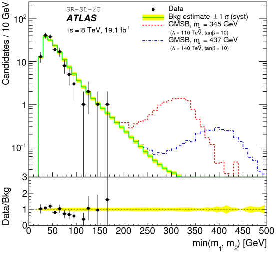


- Interpreted in many SUSY models, e.g. GMSB (τ_1 as NLSP)
- Four different signatures probed: stable sleptons, leptoSUSY, charginos and R-hadrons (bound states composed of the LLP and light SM quarks or gluons)
- GMSB: two muon-like SMPs, high β values
- Signal discrimination using mass measurements ($m = \frac{p}{\beta\gamma}$), with p taken from the charge particle track, time measurement (β) in the calorimeters and muon system, and energy loss ($\beta\gamma$) measured in the pixel detector

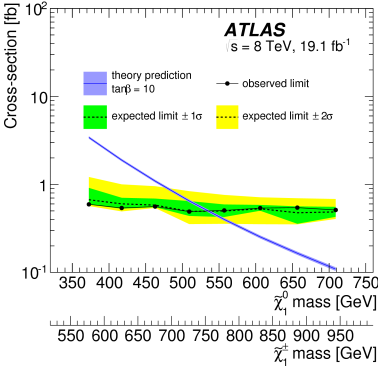
Analysis Design

- Events selected with two SMPs and $0.2 < \beta < 0.95$
- High p_{T} muons with mis-measured β as the dominating background, taken from data
- Discriminating variables: β (taken from ToF), $\beta\gamma$ (can be measured by energy loss $\frac{dE}{dx}$ in pixel detector)

Overall very good agreement between data and expectation



Exclusion range $m_{\tilde{\chi}_1^{\pm}} < 537$ GeV



Summary

- The ATLAS SUSY search for electroweak production, R-parity violating and LLP scenarios using the full 8 TeV data delivered by the LHC during RunI was presented
- New and improved sensitivity for a wide variety of SUSY scenarios
- No significant deviation from SM observed
- Stringent exclusion limits are set on masses of SUSY particles
- Higher energy offers possibility of fast discovery in Run-2 for strongly produced SUSY (e.g. in RPV or LLP) but for EWK production the cross-section gain is smaller, hence, more luminosity will be required.

Stay tuned for Run II

Backup

Standard Model Background Modelling

Some SUSY processes can be SM-like.
SUSY searches rely on accurate modelling of SM background.

Standard Model Background

Irreducible
(prompt leptons)

Reducible
(non-prompt leptons)

Dominant sources: normalised to data in dedicated **Control Regions**

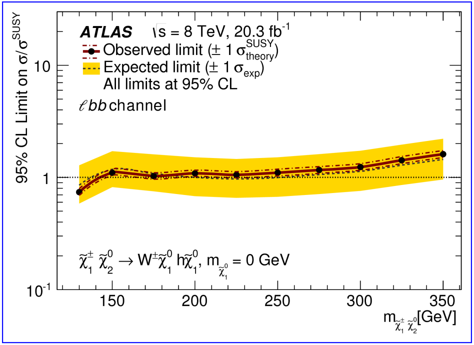
Sub-dominant sources: estimated with MC-simulated data

Data-driven estimation analyses dependent

All predictions are thoroughly validated using dedicated **Validation Regions**

Signal Regions

$1\ell + 2\ \mathrm{bb} + E_{\mathrm{T}}^{\mathrm{miss}}$



- 95% CL (normalised) upper limits on the cross section as a function of $m(\tilde{\chi}_1^{\pm})$ for a massless LSP