Supersymmetry searches with 3 leptons in the final state with the ATLAS detector at the LHC.

IoP HEP Meeting

Itzebelt Santoyo-Castillo

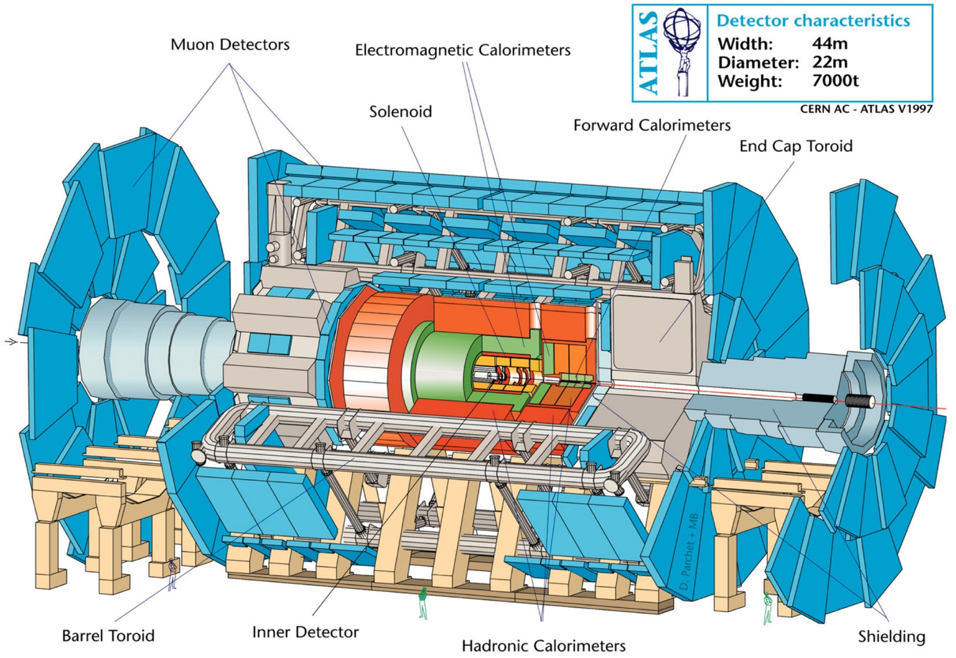
08-April-2014

University of Sussex

CERN

CONACYT
Consejo Nacional de Ciencia y Tecnología

- SUSY
  - Motivation
  - Models

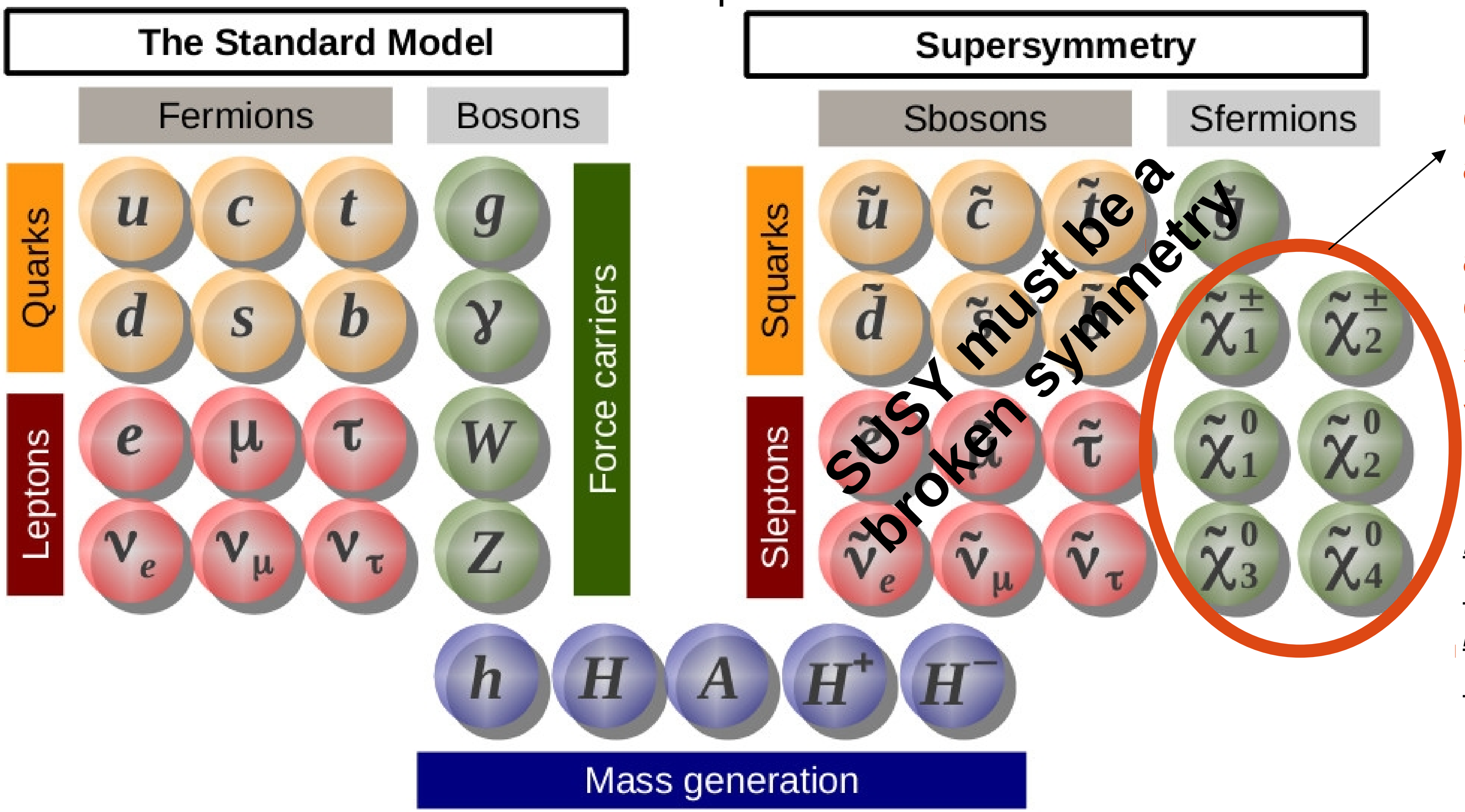


- ATLAS Data
- 3L SUSY Searches
  - Analysis Overview
  - Latest Results (http://arxiv.org/abs/1402.7029)
- Summary

SUSY

Proposes a symmetry between fermions and bosons → New fields differing in spin by ½ with respect to their SM partners

- Solves hierarchy problem
- Provides dark matter candidate*
- Unification of gauge coupling constants

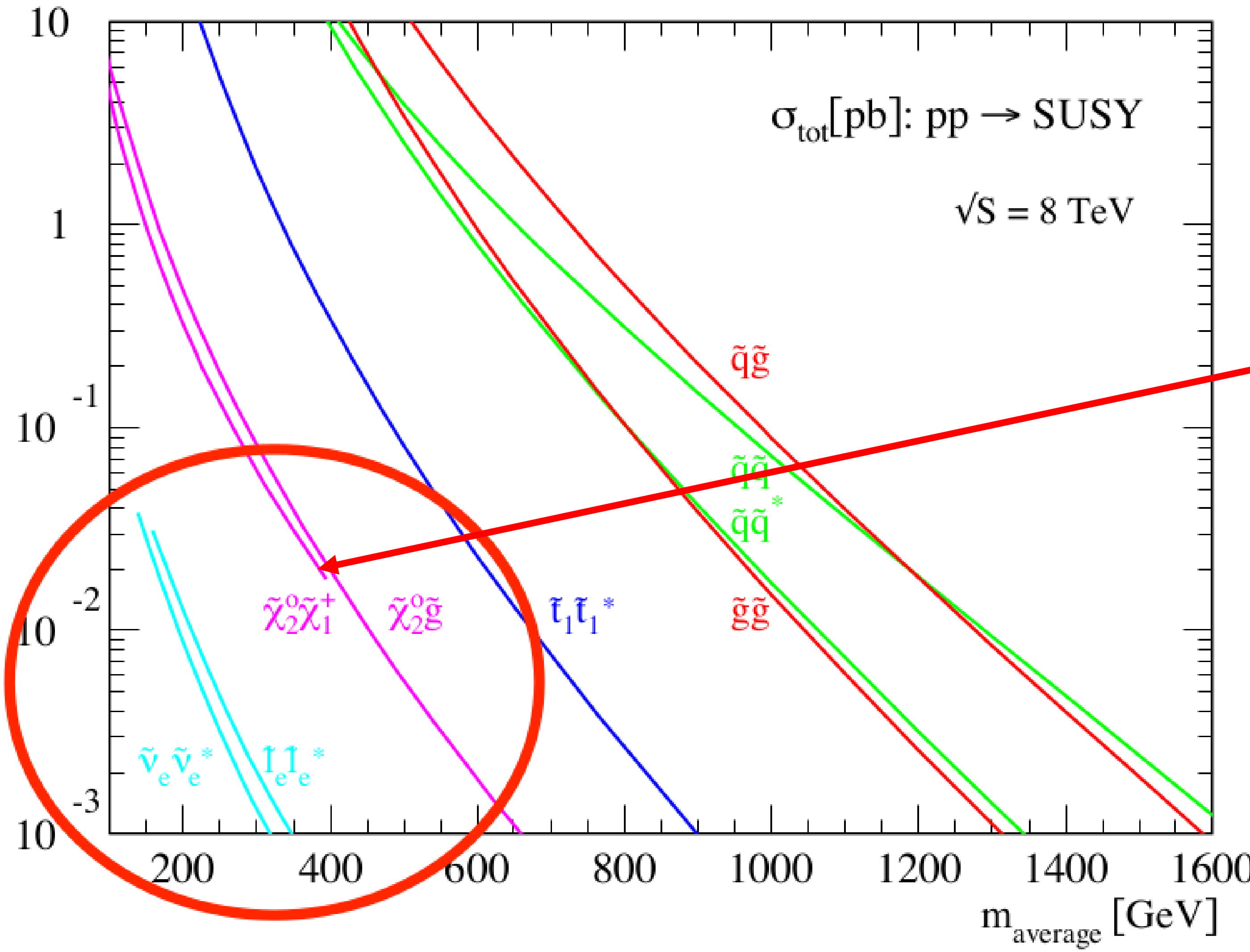


Charginos ($\tilde{\chi}_i^{\pm}$) and neutralinos ($\tilde{\chi}_j^{0}$) are mass eigenstates of the super-partners of SM gauge fields.

*R-Parity Conserving models => *LSP*

In nature, we expect low fine tuning → masses of higgsinos, stops and gluinos must be light

Cross-section of production of SUSY particles



From all SUSY particles that can originate from the p-p collisions, electroweakino production can be a promising discovery mode at the LHC if we assume natural SUSY.

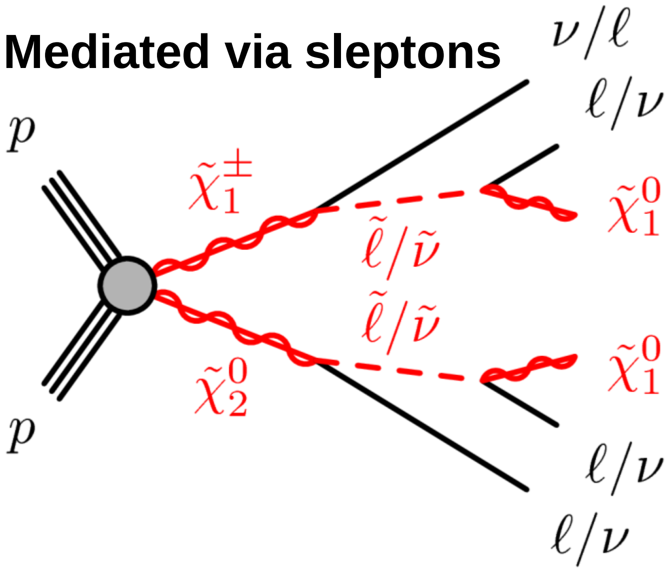
$\tilde{\chi}_1^{\pm}\ \tilde{\chi}_2^0$

In particular, pairs decay into final states with three leptons and missing energy

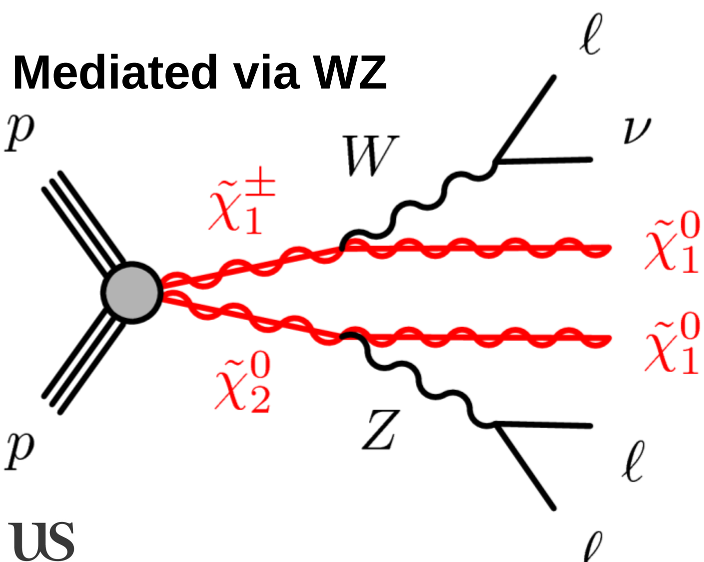
This makes for a clean SUSY signature.

- Simulate one process only.
- Minimal particle content
- Assumptions on the BR.
- The relevant particle masses are the only free parameters

Mediated via sleptons



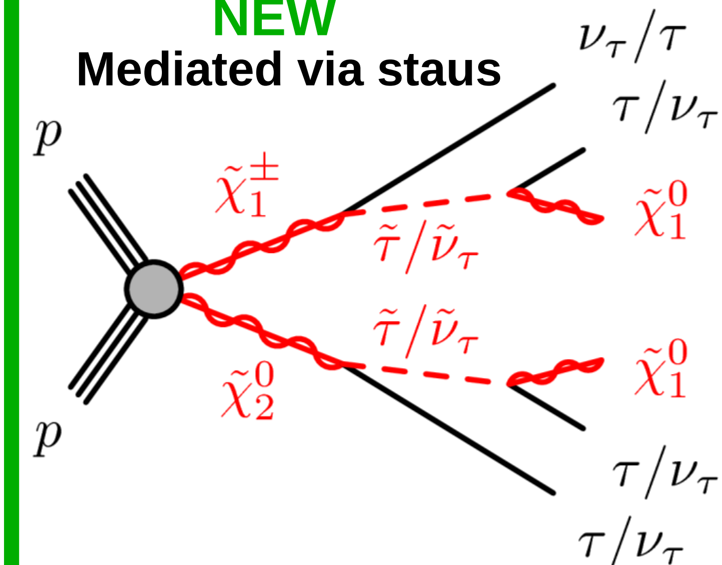
Mediated via WZ



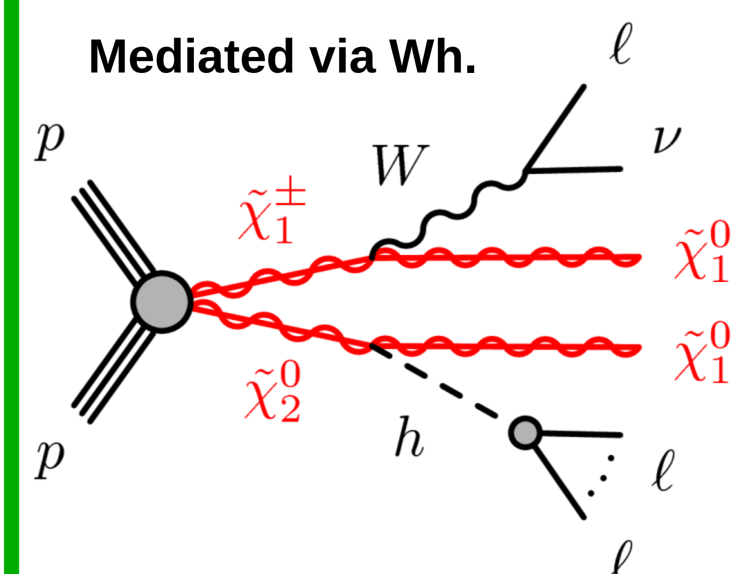
We explore four simplified models where the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ are the only directly produced SUSY particles, these are classified according to the intermediate particles in the decay chain:

NEW

Mediated via staus



Mediated via Wh.



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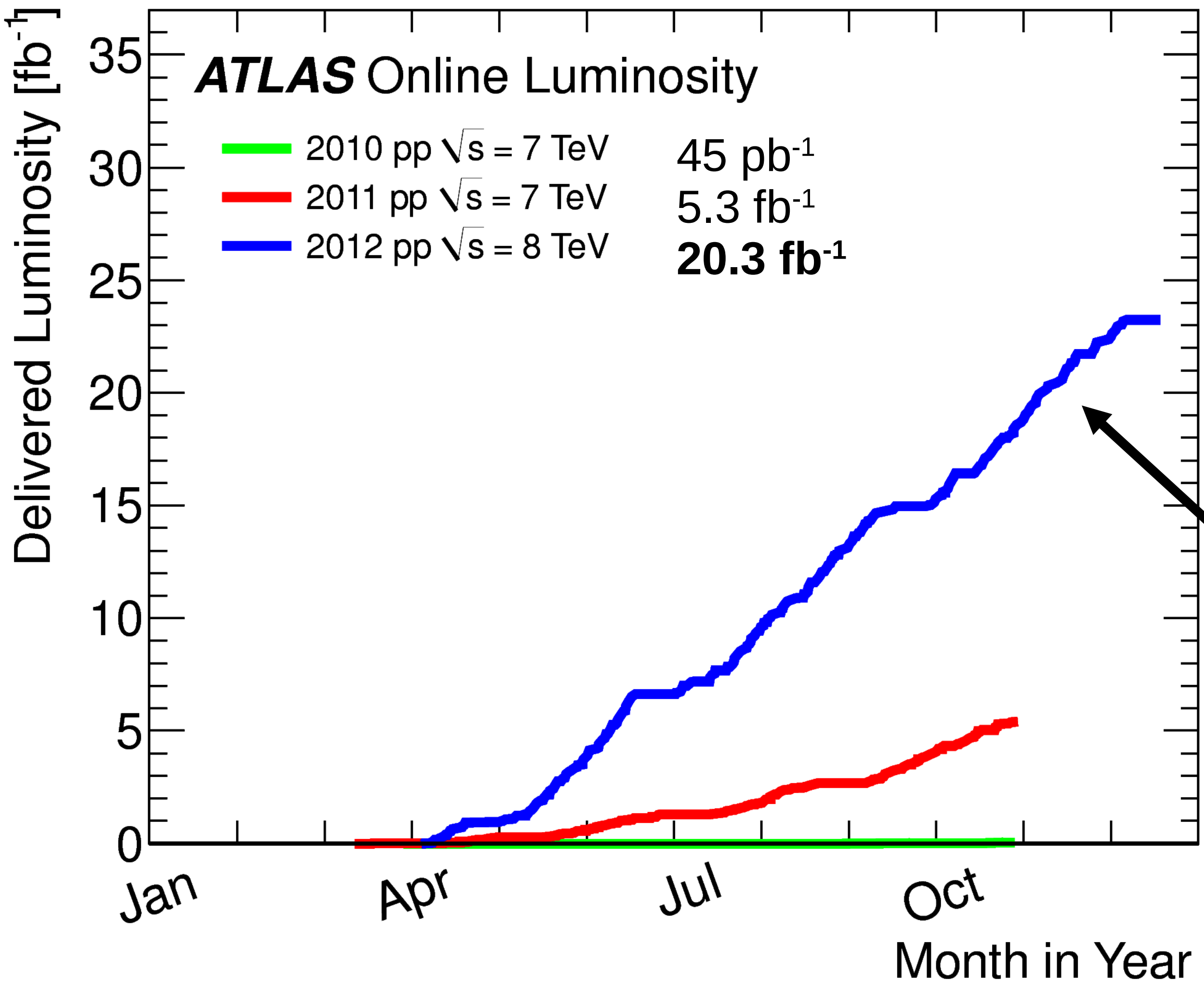
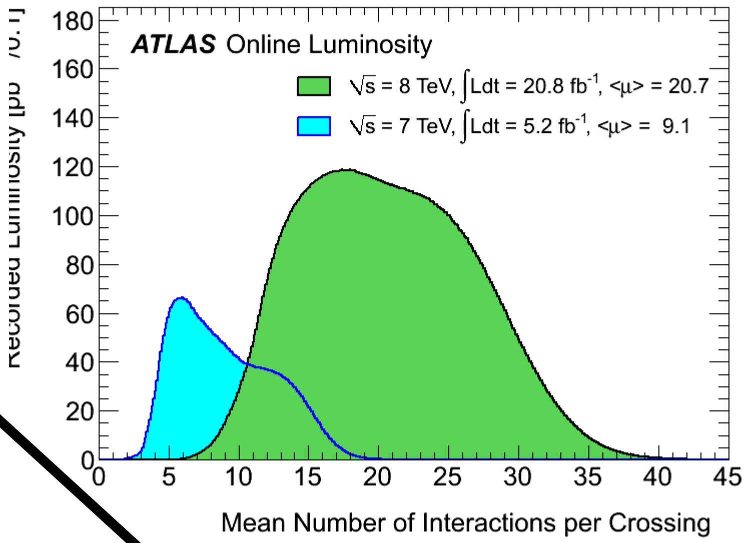
Delivered Data



CHALLENGES

High levels of pile-up come with higher luminosity.



The results presented here explore the full 2012 dataset

3L analysis:: Event Selection

- Select event with exactly 3 leptons (e, μ, τ).

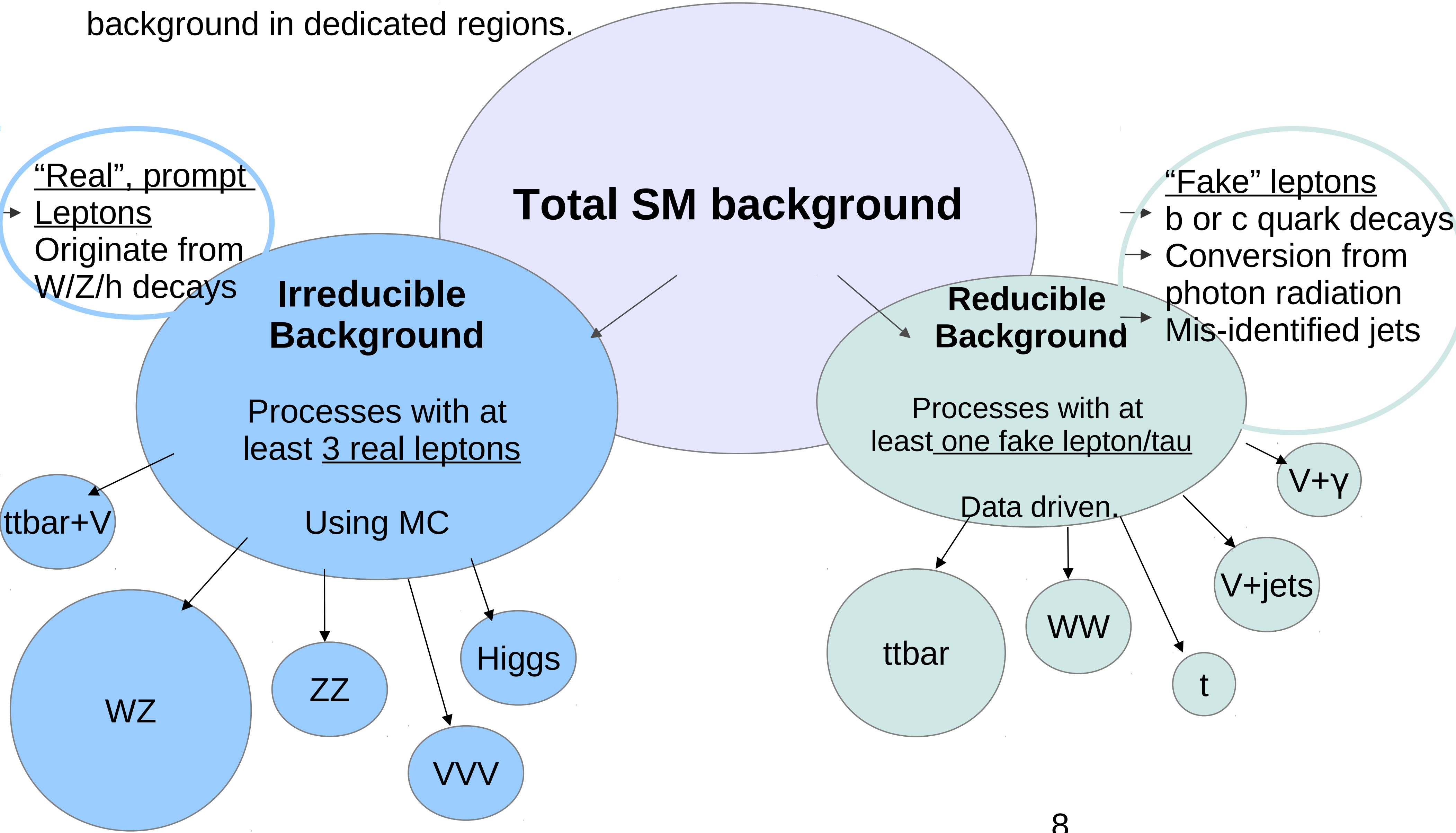
- Exploring three different tau multiplicities in the final state
  - 0Tau+3(e,mu)
  - 1Tau+2(e,mu)
  - 2Tau+1(e,mu)

- Veto events containing b-tagged jets.

- Require high missing transverse energy .

3L analysis:: Background Estimation

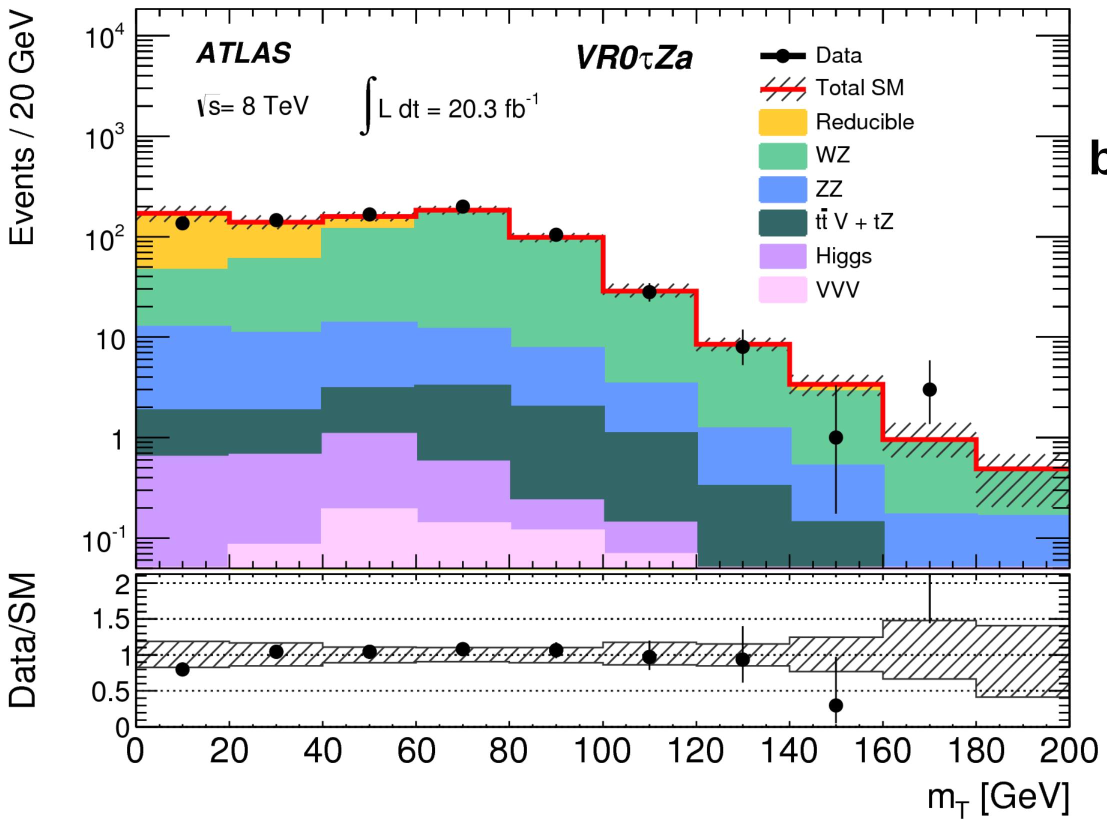
We want to estimate the Standard Model background in dedicated regions.



3L analysis:: Validation Regions**

We estimate the Standard Model background in dedicated regions:

Thorough validation of the modelling of our main backgrounds WZ, ttbar, W/Z+jets using these VR



Excellent agreement seen between data and expectation

**more details in the backup

3L analysis:: Signal regions**

Tau multiplicity →

	0 tau		1 tau	2 tau	
SR	SR0τa	SR0τb	SR1τ	SR2τa	SR2τb
	Binned SR 20 bins: 5 mSFOS 2 mT 2 missingET	**New Signal Regions >=0 Taus (including a SFOS veto)**			
SUSY Scenario →	$\tilde{\ell}$,WZ-mediated	Wh-mediated	Wh-mediated	$\tilde{\tau}_L$-mediated	Wh-mediated

Five signal regions targeting different scenarios

mSFOS:= mass of a pair of light leptons with opposite charge and same flavour closest to the Z

mT:= transverse mass of the third lepton (not part of SFOS) and missingET coming from the W.

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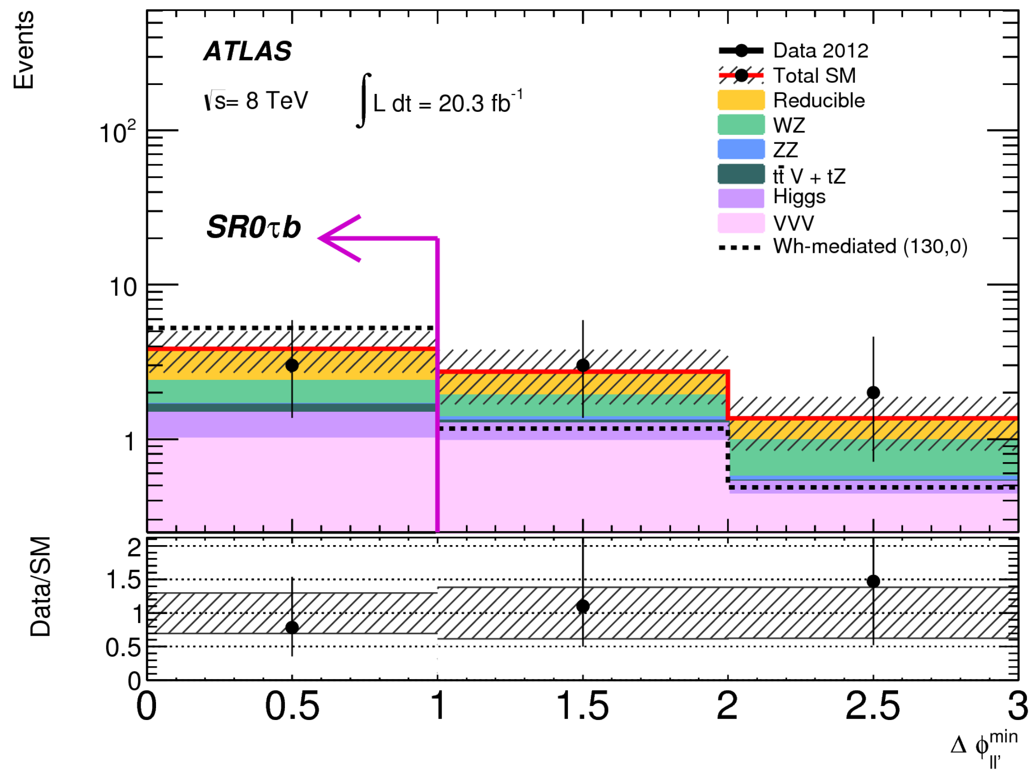
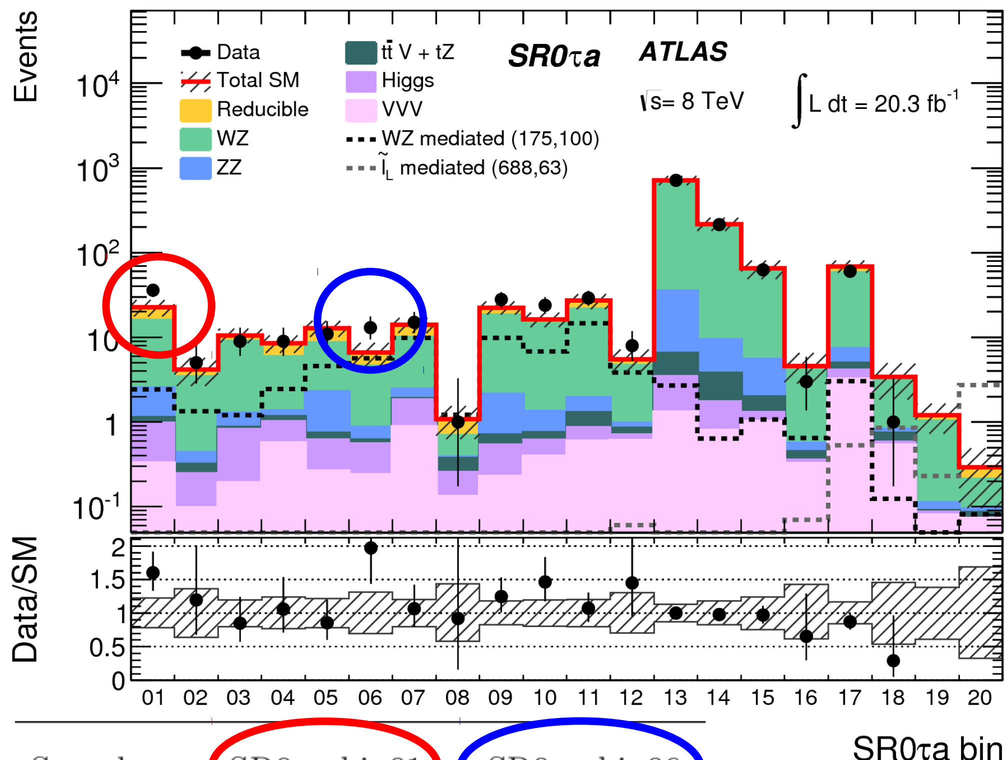
3L analysis:: Results: 0taus+3(e,mu)

SR0τb



SR0τa



Sample	SR0τa-bin01	SR0τa-bin06
WZ	$13.2^{+3.4}_{-3.2}$	3.7 ± 1.6
ZZ	$1.4^{+0.6}_{-0.5}$	$0.25^{+0.14}_{-0.11}$
$t\bar{t}V + tZ$	0.14 ± 0.05	$0.047^{+0.022}_{-0.021}$
VVV	0.33 ± 0.33	0.24 ± 0.24
Higgs	0.66 ± 0.26	$0.33^{+0.13}_{-0.12}$
Reducible	6.7 ± 2.4	2.0 ± 0.8
Total SM	23 ± 4	$6.6^{+1.9}_{-1.8}$
Data	36	13
p_0 (σ)	0.02 (2.16)	0.03 (1.91)

Upward fluctuations in bin01 and bin06

Full breakdown in backup

Overall very good agreement between data and expectation

[http://arxiv.org/abs/1402.7029]

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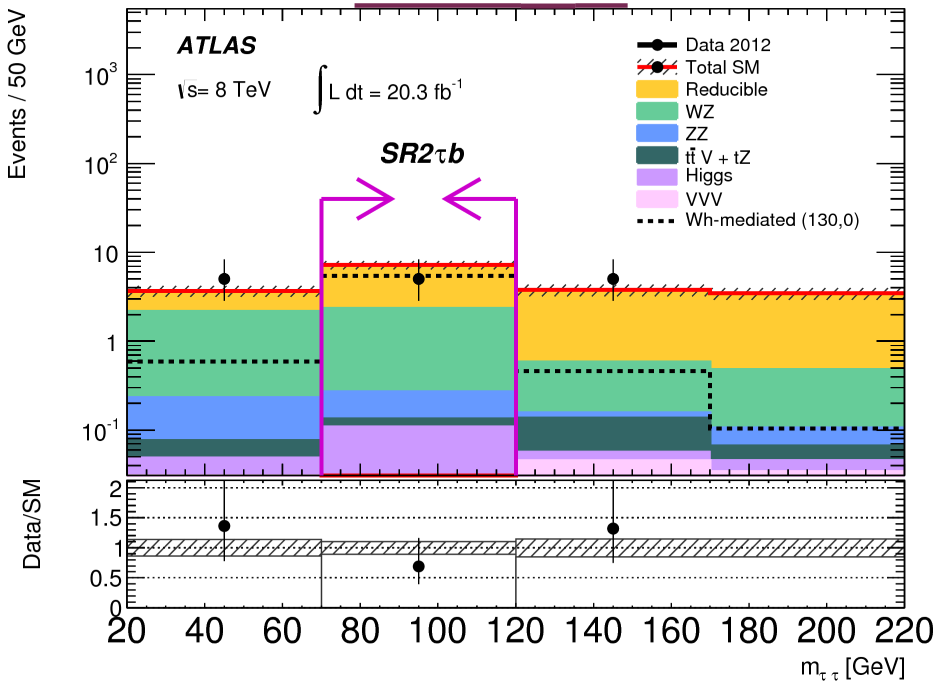
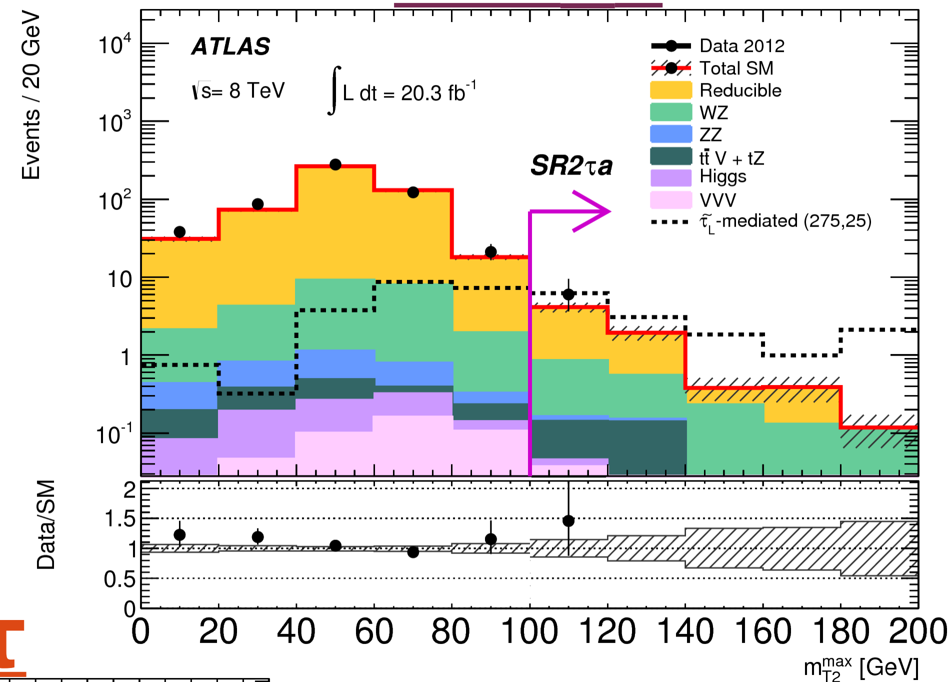
[http://arxiv.org/abs/1402.7029]

3L analysis:: Results: 2taus+1e,mu (top) 1tau+2e,mu (bottom)

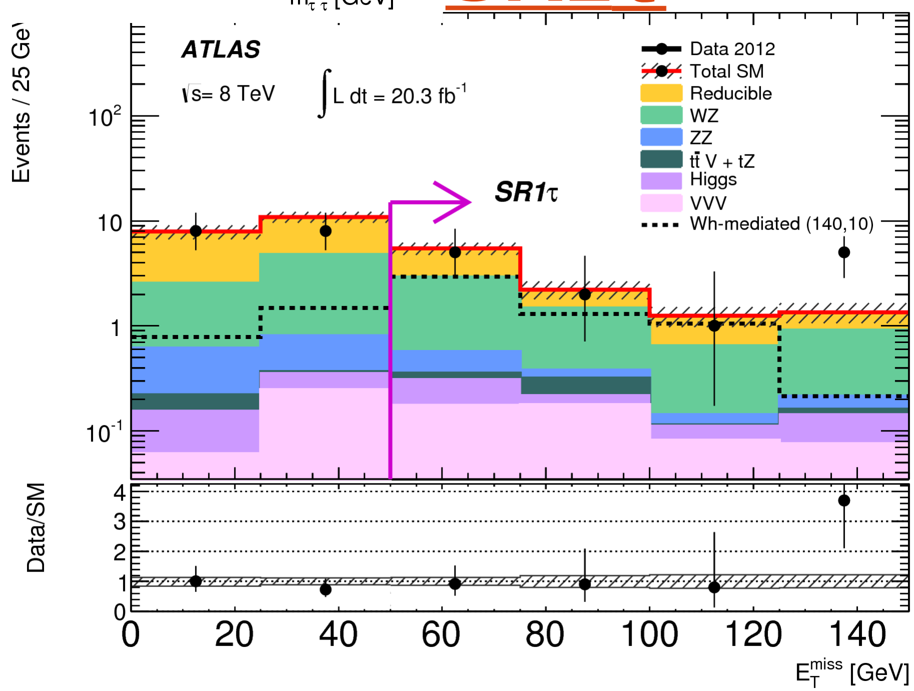
SR2τb



SR2τa



SR1τ



Uncertainties are statistical and systematic.

Overall very good agreement between data and expectation

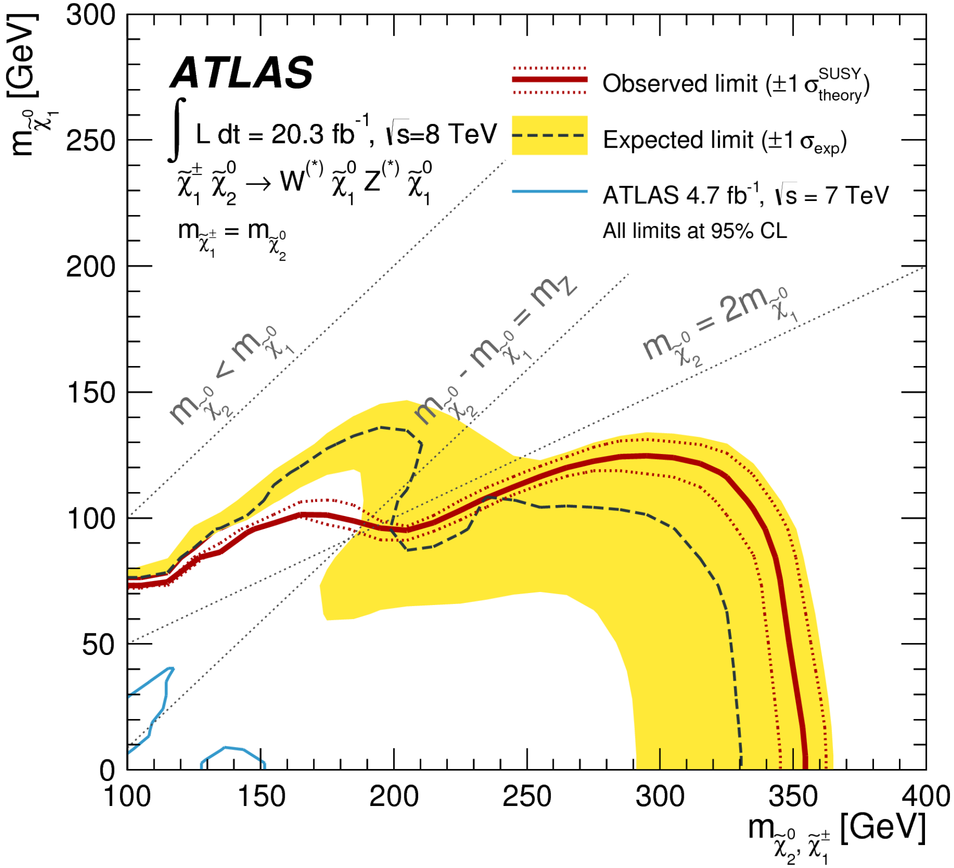
We interpret these results in

5 pMSSM models*
and
4 simplified models*

By statistically combining all orthogonal signal regions (choosing between SR2a and SR2b).

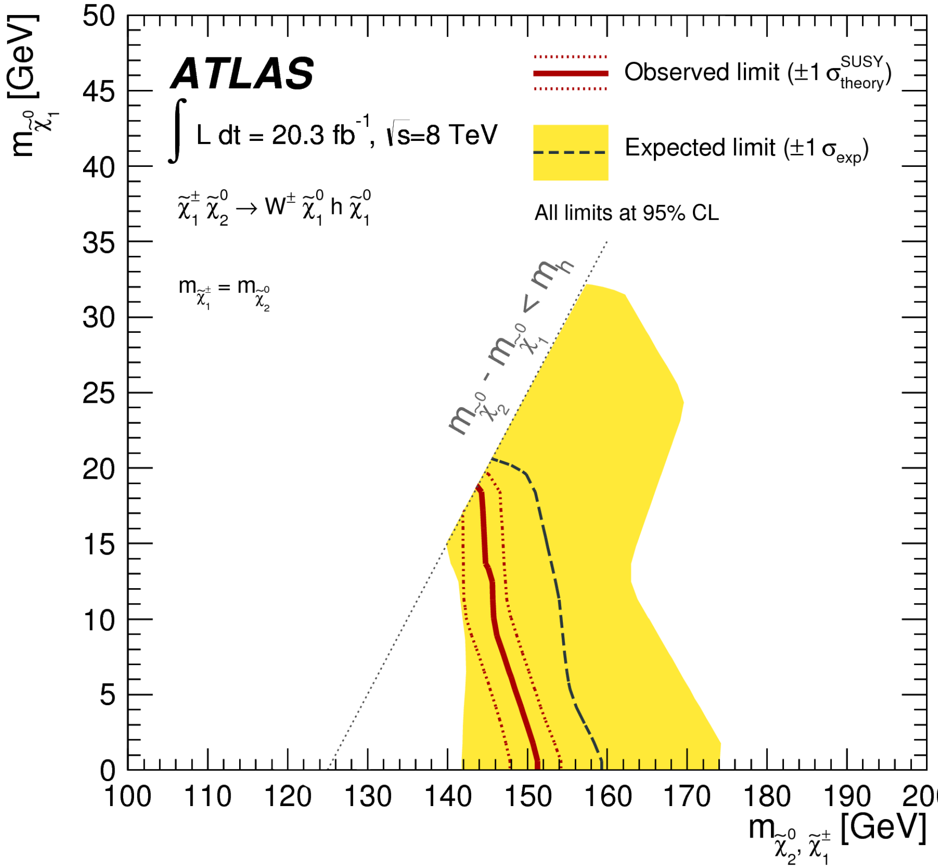
*****more details in the backup

Improved limits
Via WZ



Statistical combination of SR0a, SR0b, SR1SS, SR2a

New limits
Via Wh



Statistical combination of SR0a, SR0b, SR1SS, SR2b

Summary*

First ATLAS SUSY paper including SM higgs decays

A search for direct production of gauginos in 3 lepton final state with 20.3 fb-1 of all the 8 TeV data has been presented.

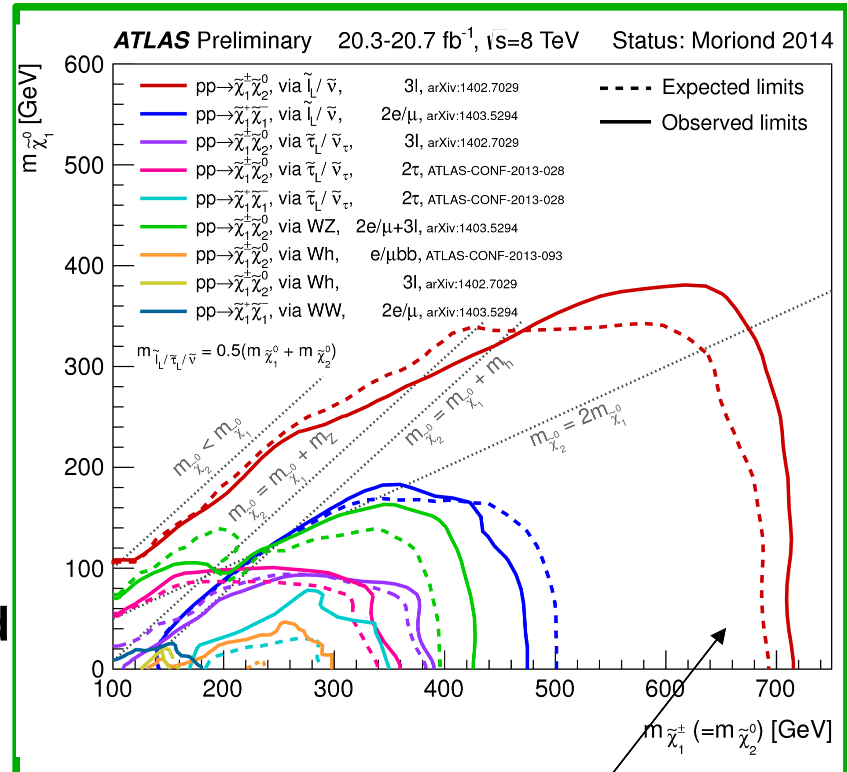
New and improved sensitivity for many different SUSY scenarios

- * <u>Inclusion of hadronic taus</u> in the final state
- * SR re-optimisation in 3(e,mu)+0tau channels
  - Binned approach
  - <u>SFOS veto.</u>
- * Interpretation in new models.

No significant deviation from SM observed

- * Exclusion limits were set on 9 models:

  5 pMSSM and 4 simplified models



reference

World-leading limits set on mass of charginos and neutralinos

Paper accepted by JHEP.

*more details in the backup

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Backup

3L analysis:: Validation Regions

We estimate the Standard Model background in dedicated regions:

	N(ℓ)	N(τ)	Flavour/sign	Z boson	E_T^{miss}	N(b-tagged jets)	Target process
VR0τnoZa	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	m_{SFOS} & $m_{3\ell}$ veto	35–50	–	WZ^*, Z^*Z^*, Z^*+jets
VR0τZa	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	request	35–50	–	WZ, Z+jets
VR0τnoZb	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	m_{SFOS} & $m_{3\ell}$ veto	> 50	1	$t\bar{t}$
VR0τZb	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	request	> 50	1	WZ
VR0τb	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	binned	binned	1	WZ, $t\bar{t}$
VR1τa	2	1	$\tau^{\pm}\ell^{\mp}\ell^{\mp}$, $\tau^{\pm}\ell^{\mp}\ell'^{\mp}$	–	35–50	–	WZ, Z+jets
VR1τb	2	1	$\tau^{\pm}\ell^{\mp}\ell^{\mp}$, $\tau^{\pm}\ell^{\mp}\ell'^{\mp}$	–	> 50	1	$t\bar{t}$
VR2τa	1	2	$\tau\tau\ell$	–	35–50	–	W+jets, Z+jets
VR2τb	1	2	$\tau\tau\ell$	–	> 50	1	$t\bar{t}$

VR0:= 0 taus

VR1:= 1 tau

VR2:= 2 taus

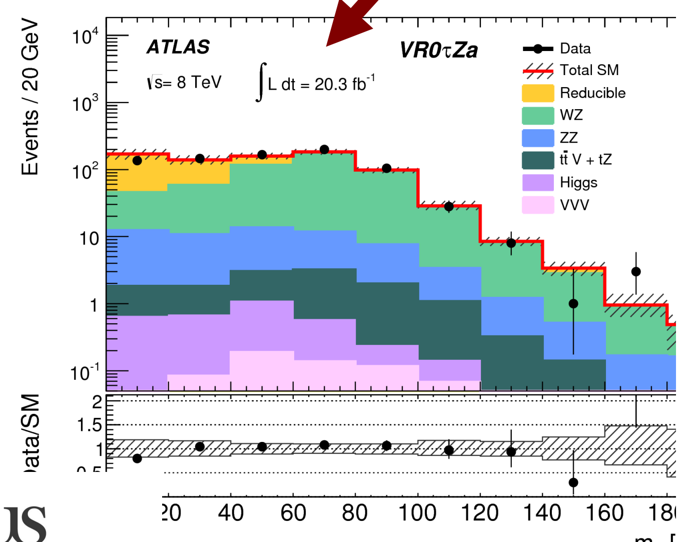
"a" regions:
low missing ET
"b" regions:
High missing ET
Request 1 b-jet

Thorough validation of the modelling of our main backgrounds WZ, ttbar, W/Z+jets using these VR

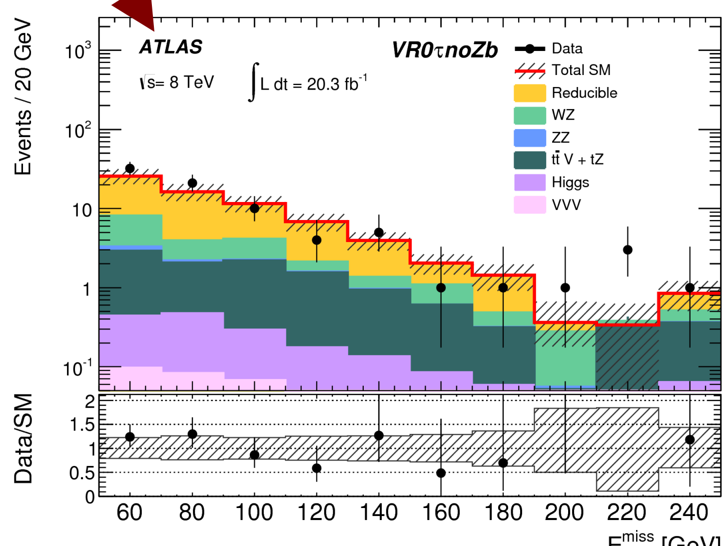
3L analysis:: Background Modelling

Irreducible background estimated with MC.
Reducible background estimated with data-driven method.

Sample	VR0τnoZa	VR0τZa	VR0τnoZb	VR0τZb	VR1τa	VR1τb	VR2τa	VR2τb
WZ	91 ± 12	471 ± 47	$10.5^{+1.8}_{-2.0}$	58 ± 7	14.6 ± 1.9	1.99 ± 0.35	$14.3^{+2.4}_{-2.5}$	1.9 ± 0.4
ZZ	19 ± 4	48 ± 7	0.62 ± 0.12	2.6 ± 0.4	$1.76^{+0.29}_{-0.28}$	0.138 ± 0.028	1.8 ± 0.4	0.12 ± 0.04
$t\bar{t}V + tZ$	3.2 ± 1.0	$10.1^{+2.3}_{-2.2}$	9.5 ± 3.1	18 ± 4	0.9 ± 0.9	2.8 ± 1.3	1.0 ± 0.7	1.7 ± 0.7
VVV	1.9 ± 1.9	0.7 ± 0.7	$0.35^{+0.36}_{-0.35}$	0.18 ± 0.18	0.4 ± 0.4	0.08 ± 0.08	0.12 ± 0.12	$0.06^{+0.07}_{-0.06}$
Higgs	2.7 ± 1.3	2.7 ± 1.5	1.5 ± 1.0	0.71 ± 0.29	0.57 ± 0.34	0.5 ± 0.5	0.6 ± 0.4	0.5 ± 0.5
Reducible	73^{+20}_{-17}	261 ± 70	47^{+15}_{-13}	19 ± 5	71 ± 9	22.7 ± 2.8	630^{+9}_{-12}	162^{+6}_{-8}
Total SM	191^{+24}_{-22}	794 ± 86	69^{+15}_{-14}	98 ± 10	89^{+10}_{-9}	28.2 ± 3.2	648^{+10}_{-13}	166^{+6}_{-8}
Data	228	792	79	110	82	26	656	158



WZ modelling validated



ttbar modelling validated

Excellent agreement seen between data and expectation

3L analysis:: Signal regions

	0 tau		1 tau	2 tau	
SR	SR0τa	SR0τb	SR1τ	SR2τa	SR2τb
Flavour/sign	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	$\ell^\pm\ell^\pm\ell'^\mp$	$\tau^\pm\ell^\mp\ell^\mp$, $\tau^\pm\ell^\mp\ell'^\mp$	$\tau\tau\ell$	$\tau^+\tau^-\ell$
b-tagged jet	veto	veto	veto	veto	veto
$E_{\mathrm{T}}^{\mathrm{miss}}$	binned	> 50	> 50	> 50	> 60
Other	m_{SFOS} binned m_{T} binned	$p_{\mathrm{T}}^{3^{\mathrm{rd}}\ell} > 20$ $\Delta\phi_{\ell\ell'}^{\mathrm{min}} \leq 1.0$	$p_{\mathrm{T}}^{2^{\mathrm{nd}}\ell} > 30$ $\sum p_{\mathrm{T}}^{\ell} > 70$ $m_{\ell\tau} < 120$ m_{ee} Z veto	$m_{\mathrm{T2}}^{\mathrm{max}} > 100$	$\sum p_{\mathrm{T}}^{\tau} > 110$ $70 < m_{\tau\tau} < 120$
Target model	$\tilde{\ell}$,WZ-mediated	Wh-mediated	Wh-mediated	$\tilde{\tau}_L$-mediated	Wh-mediated

New Signal Regions

**20 bins:
5 mSFOS
2 mT
2 missingET

**more details in the backup

3L analysis:: Signal regions

TOTAL OF 20 BINS

SR	SR0τa
Flavour/sign	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$
b-tagged jet	veto
$E_{\mathrm{T}}^{\mathrm{miss}}$	binned
Other	m_{SFOS} binned m_{T} binned
Target model	$\tilde{\ell}$,WZ-mediated

Binned Signal Region

	5 mSFOS bins	**2 mT bins**	**2 MET bins**	
SR0τa bin	m_{SFOS}	m_{T}	$E_{\mathrm{T}}^{\mathrm{miss}}$	3ℓ Z veto
1	12–40	0–80	50–90	no
2	12–40	0–80	>90	no
3	12–40	>80	50–75	no
4	12–40	>80	>75	no
5	40–60	0–80	50–75	yes
6	40–60	0–80	>75	no
7	40–60	>80	50–135	no
8	40–60	>80	>135	no
9	60–81.2	0–80	50–75	yes
10	60–81.2	>80	50–75	no
11	60–81.2	0–110	>75	no
12	60–81.2	>110	>75	no
13	81.2–101.2	0–110	50–90	yes
14	81.2–101.2	0–110	>90	no
15	81.2–101.2	>110	50–135	no
16	81.2–101.2	>110	>135	no
17	>101.2	0–180	50–210	no
18	>101.2	>180	50–210	no
19	>101.2	0–120	>210	no
20	>101.2	>120	>210	no

Dominant systematic uncertainties in all signal regions generally <u>statistical and from theory</u>

Theoretical uncertainties

	SR0τa	SR0τb	SR1τ	SR2τa	SR2τb
Cross-section	4–25%	37%	9%	3.1%	3.0%
Generator	3.2–35%	11%	3.1%	6%	< 1%
Statistics on irreducible background	0.8–26%	8%	5%	5%	3.1%
Statistics on reducible background	0.4–29%	14%	8%	13%	12%
Electron misidentification probability	0.3–10%	1.3%	< 1%	–	–
Muon misidentification probability	0.1–24%	2.2%	< 1%	–	–
τ misidentification probability	–	–	8%	4%	5%

From data-driven method

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3L analysis:: Observed events in SR

Irreducible background estimated with MC.
Reducible background estimated with data-driven method.

Overall, good agreement with predicted SM background

Sample	SR0τa-bin01	SR0τa-bin02	SR0τa-bin03	SR0τa-bin04	SR0τa-bin05	SR0τa-bin06
WZ	$13.2^{+3.4}_{-3.2}$	3.0 ± 1.4	7.8 ± 1.6	$4.5^{+1.1}_{-1.0}$	6.3 ± 1.6	3.7 ± 1.6
ZZ	$1.4^{+0.6}_{-0.5}$	0.12 ± 0.06	0.40 ± 0.14	0.20 ± 0.18	1.5 ± 0.5	$0.25^{+0.14}_{-0.11}$
$t\bar{t}V + tZ$	0.14 ± 0.05	0.07 ± 0.04	$0.04^{+0.05}_{-0.04}$	0.14 ± 0.13	0.11 ± 0.08	$0.047^{+0.022}_{-0.021}$
VVV	0.33 ± 0.33	0.10 ± 0.10	0.19 ± 0.19	0.6 ± 0.6	$0.26^{+0.27}_{-0.26}$	0.24 ± 0.24
Higgs	0.66 ± 0.26	0.15 ± 0.08	0.64 ± 0.22	$0.46^{+0.18}_{-0.17}$	$0.36^{+0.14}_{-0.15}$	$0.33^{+0.13}_{-0.12}$
Reducible	6.7 ± 2.4	0.8 ± 0.4	$1.6^{+0.7}_{-0.6}$	2.7 ± 1.0	$4.3^{+1.6}_{-1.4}$	2.0 ± 0.8
Total SM	23 ± 4	4.2 ± 1.5	10.6 ± 1.8	$8.5^{+1.7}_{-1.6}$	$12.9^{+2.4}_{-2.3}$	$6.6^{+1.9}_{-1.8}$
Data	36	5	9	9	11	13

Uncertainties are statistical and systematic.

1-2 sigma upward fluctuations

3L analysis:: Observed events in SR

Irreducible background estimated with MC.
Reducible background estimated with data-driven method.

Overall, good agreement with predicted SM background

Sample	SR0τa-bin07	SR0τa-bin08	SR0τa-bin09	SR0τa-bin10	SR0τa-bin11	SR0τa-bin12
WZ	7.6 ± 1.3	$0.30^{+0.25}_{-0.24}$	$16.2^{+3.2}_{-3.1}$	$13.1^{+2.5}_{-2.6}$	19 ± 4	3.7 ± 1.2
ZZ	$0.55^{+0.16}_{-0.14}$	$0.012^{+0.008}_{-0.007}$	$1.43^{+0.32}_{-0.28}$	$0.60^{+0.12}_{-0.13}$	0.7 ± 1.2	0.14 ± 0.09
$t\bar{t}V + tZ$	$0.04^{+0.15}_{-0.04}$	$0.12^{+0.13}_{-0.12}$	$0.16^{+0.09}_{-0.12}$	0.12 ± 0.10	$0.41^{+0.24}_{-0.22}$	0.12 ± 0.11
VVV	0.9 ± 0.9	$0.13^{+0.14}_{-0.13}$	$0.23^{+0.24}_{-0.23}$	0.4 ± 0.4	0.6 ± 0.6	0.6 ± 0.6
Higgs	$0.98^{+0.29}_{-0.30}$	0.13 ± 0.06	0.32 ± 0.11	$0.22^{+0.10}_{-0.11}$	0.28 ± 0.12	0.12 ± 0.06
Reducible	$4.0^{+1.5}_{-1.4}$	$0.40^{+0.27}_{-0.26}$	$4.1^{+1.3}_{-1.2}$	$1.9^{+0.9}_{-0.8}$	$5.7^{+2.1}_{-1.9}$	$0.9^{+0.5}_{-0.4}$
Total SM	14.1 ± 2.2	1.1 ± 0.4	$22.4^{+3.6}_{-3.4}$	16.4 ± 2.8	27 ± 5	$5.5^{+1.5}_{-1.4}$
Data	15	1	28	24	29	8

Uncertainties are statistical and systematic.

3L analysis:: Observed events in SR

Irreducible background estimated with MC.
Reducible background estimated with data-driven method.

Overall, good agreement with predicted SM background

Sample	SR0τa-bin13	SR0τa-bin14	SR0τa-bin15	SR0τa-bin16	SR0τa-bin17	SR0τa-bin18
WZ	613 ± 65	207^{+33}_{-32}	58^{+12}_{-13}	$3.9^{+1.6}_{-1.4}$	50^{+7}_{-6}	2.3 ± 1.3
ZZ	29 ± 4	5.5 ± 1.5	$3.5^{+1.1}_{-1.0}$	$0.12^{+0.08}_{-0.07}$	$2.4^{+0.7}_{-0.6}$	0.08 ± 0.04
$t\bar{t}V + tZ$	$2.9^{+0.7}_{-0.6}$	$2.0^{+0.7}_{-0.6}$	$0.67^{+0.29}_{-0.28}$	$0.08^{+0.10}_{-0.08}$	0.8 ± 0.5	$0.15^{+0.16}_{-0.15}$
VVV	1.3 ± 1.3	0.8 ± 0.8	1.0 ± 1.0	0.33 ± 0.33	3.2 ± 3.2	0.5 ± 0.5
Higgs	2.2 ± 0.7	0.98 ± 0.20	0.31 ± 0.11	0.033 ± 0.018	0.95 ± 0.29	0.05 ± 0.04
Reducible	68^{+21}_{-19}	$2.2^{+1.9}_{-2.0}$	1.2 ± 0.6	$0.14^{+0.25}_{-0.14}$	$11.3^{+3.5}_{-3.2}$	0.27 ± 0.20
Total SM	715 ± 70	219 ± 33	65 ± 13	$4.6^{+1.7}_{-1.5}$	69^{+9}_{-8}	3.4 ± 1.4
Data	714	214	63	3	60	1

Uncertainties are statistical and systematic.

3L analysis:: Observed events in SR

Overall, good agreement with predicted SM background

Irreducible background estimated with MC.
Reducible background estimated with data-driven method.

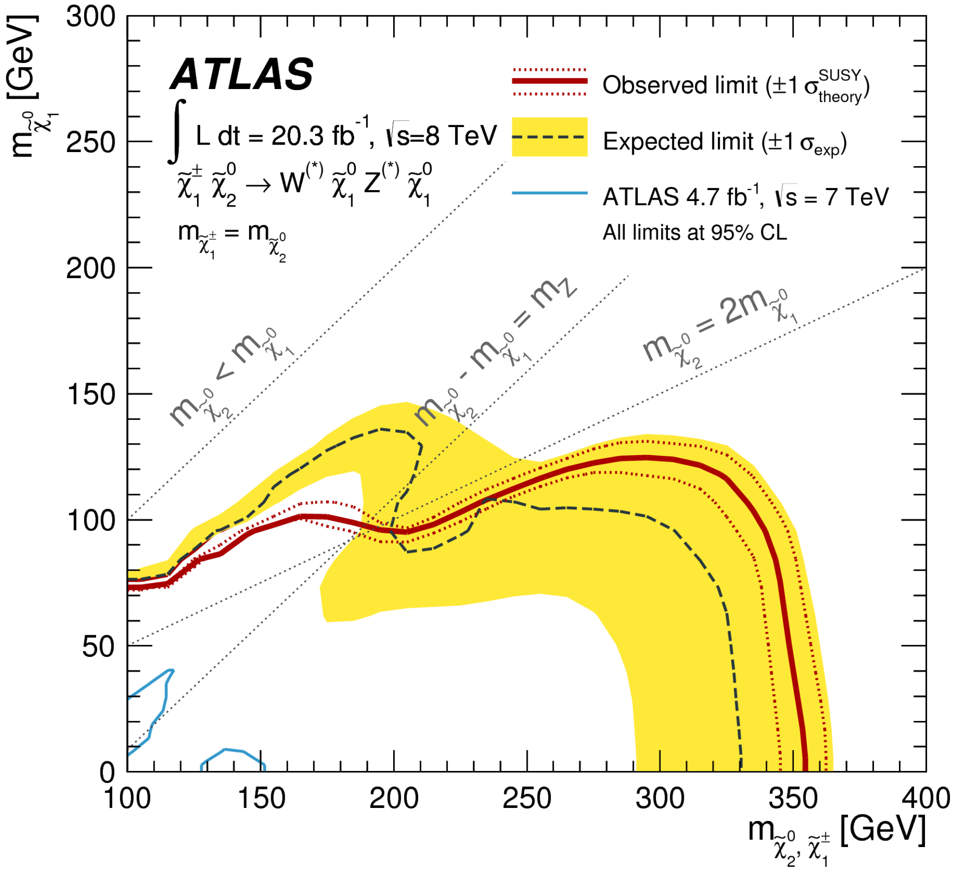
Sample	SR0τa-bin19	SR0τa-bin20	SR0τb	SR1τ	SR2τa	SR2τb
WZ	0.9 ± 0.4	0.12 ± 0.11	0.68 ± 0.20	4.6 ± 0.6	$1.51^{+0.35}_{-0.33}$	$2.09^{+0.30}_{-0.31}$
ZZ	0.021 ± 0.019	0.009 ± 0.009	0.028 ± 0.009	0.36 ± 0.08	$0.049^{+0.016}_{-0.014}$	0.135 ± 0.025
$t\bar{t}V + tZ$	$0.0023^{+0.0032}_{-0.0019}$	$0.012^{+0.016}_{-0.012}$	$0.17^{+0.32}_{-0.17}$	$0.16^{+0.18}_{-0.16}$	$0.21^{+0.27}_{-0.21}$	$0.023^{+0.015}_{-0.018}$
VVV	0.08 ± 0.08	$0.07^{+0.08}_{-0.07}$	1.0 ± 1.0	0.5 ± 0.5	0.09 ± 0.09	0.031 ± 0.033
Higgs	0.007 ± 0.006	0.0009 ± 0.0004	0.49 ± 0.17	0.28 ± 0.12	0.021 ± 0.010	0.08 ± 0.04
Reducible	$0.17^{+0.16}_{-0.15}$	$0.08^{+0.11}_{-0.08}$	1.5 ± 0.4	4.3 ± 0.8	5.1 ± 0.7	4.9 ± 0.7
Total SM	1.2 ± 0.4	$0.29^{+0.18}_{-0.17}$	3.8 ± 1.2	10.3 ± 1.2	6.9 ± 0.8	$7.2^{+0.7}_{-0.8}$
Data	0	0	3	13	6	5

Uncertainties are statistical and systematic.

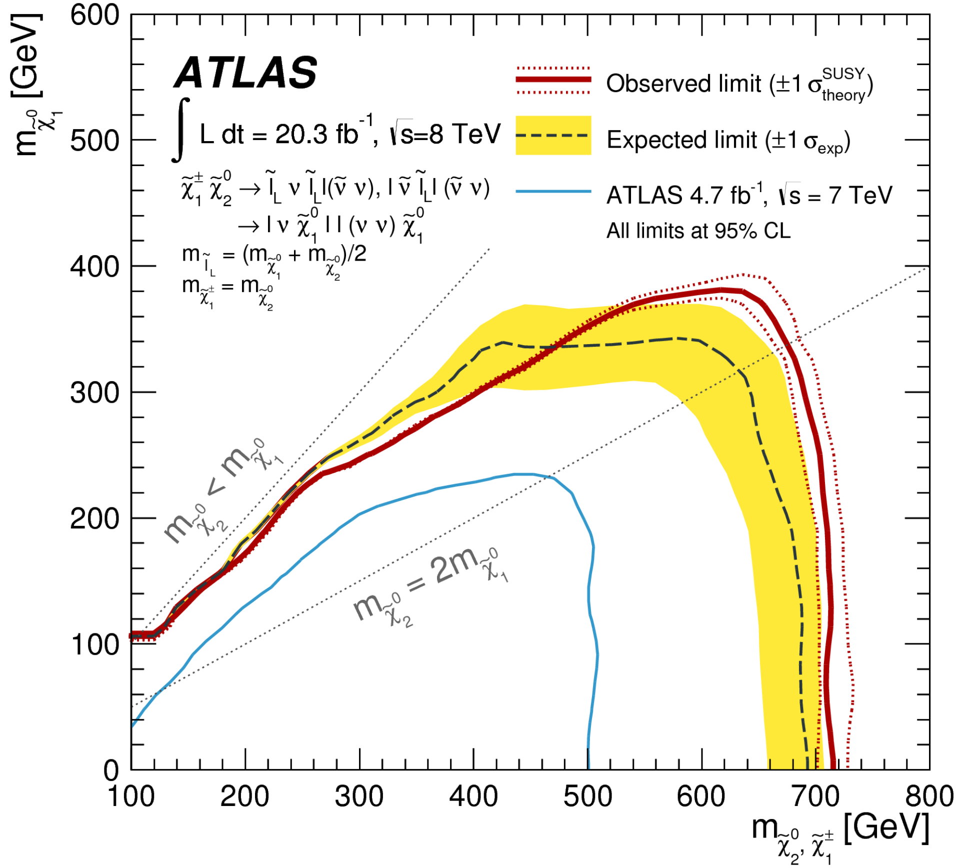
Statistical combination of SR0a, SR0b, SR1SS, SR2a

Improved limits

Via WZ



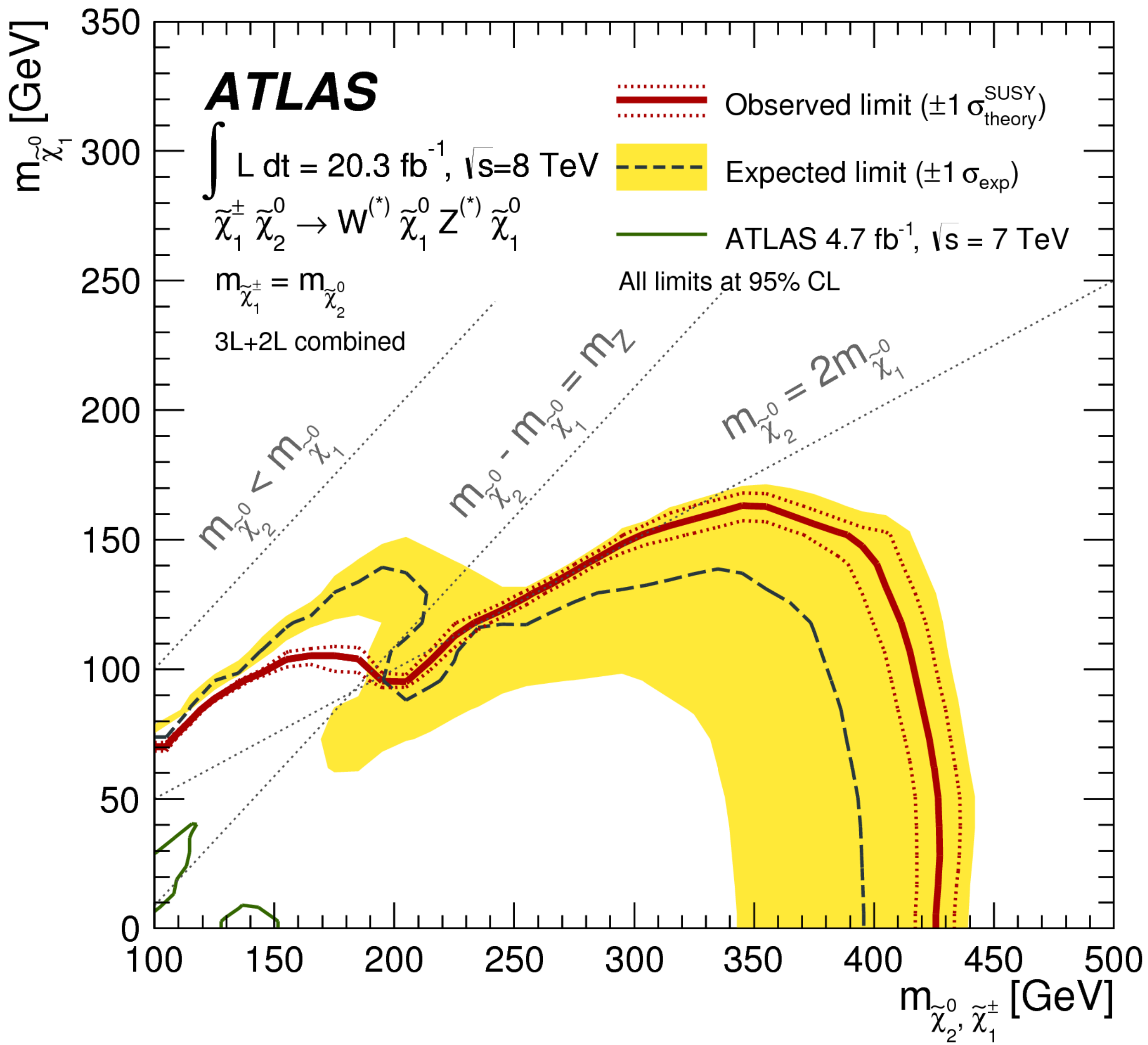
Via Sleptons



Statistical combination of 3L (SR0a, SR0b, SR1SS, SR2a) + 2L

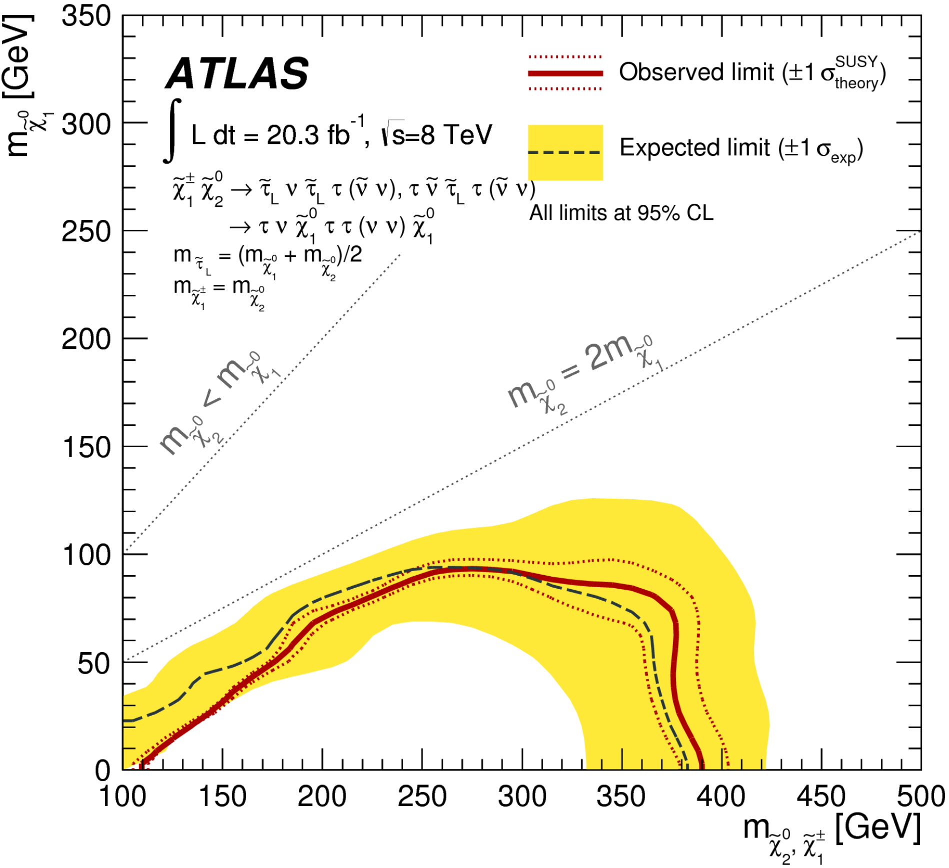
Via WZ

Improved limits 2L + 3L combination



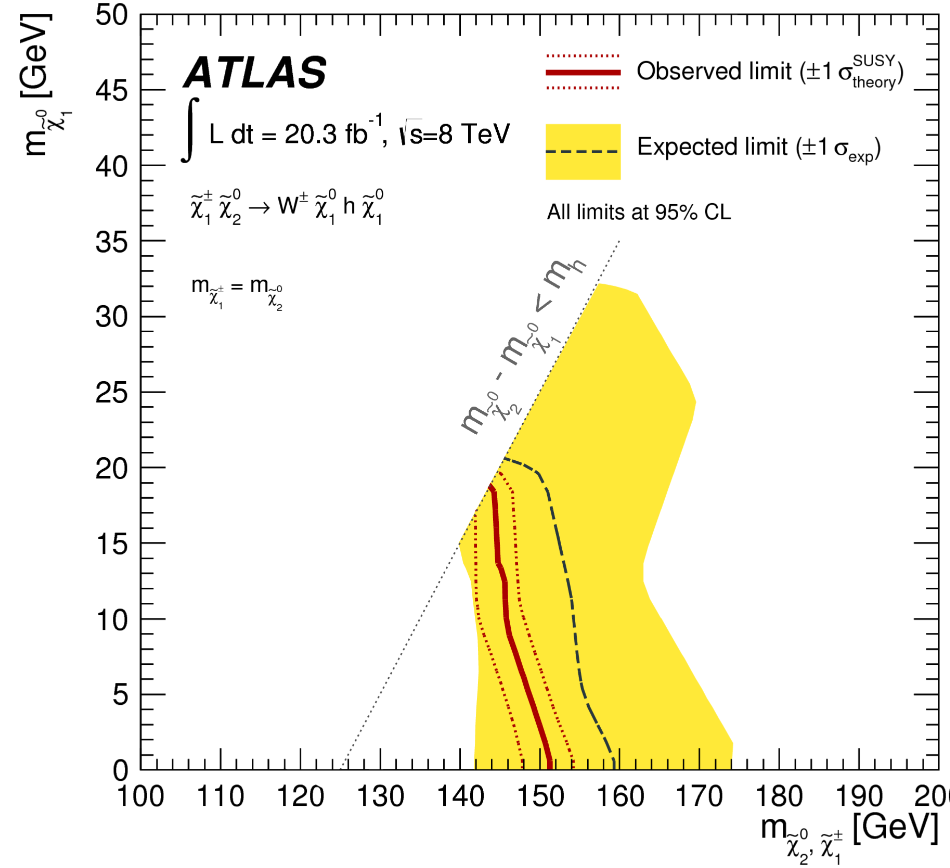
NEW Limits

Via staus



Statistical combination of SR0a, SR0b, SR1SS, SR2a

Via Wh



Statistical combination of SR0a, SR0b, SR1SS, SR2b

Assumptions:

- h^0 higgs mass tuned to 125 GeV
- R-slepton masses set to $m_{\tilde{\ell}_R} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0})/2$

Gaugino mixing

SU(1) gaugino mass: M_1

SU(2) gaugino mass: M_2

Higgsino mass: μ

pMSSM includes many sparticles with different masses and many decay modes

The analysis presented here explores **five** pMSSM models

Decays via Sleptons(R) x 3

- Low tan β (6)
- M_1=100/140/250 GeV

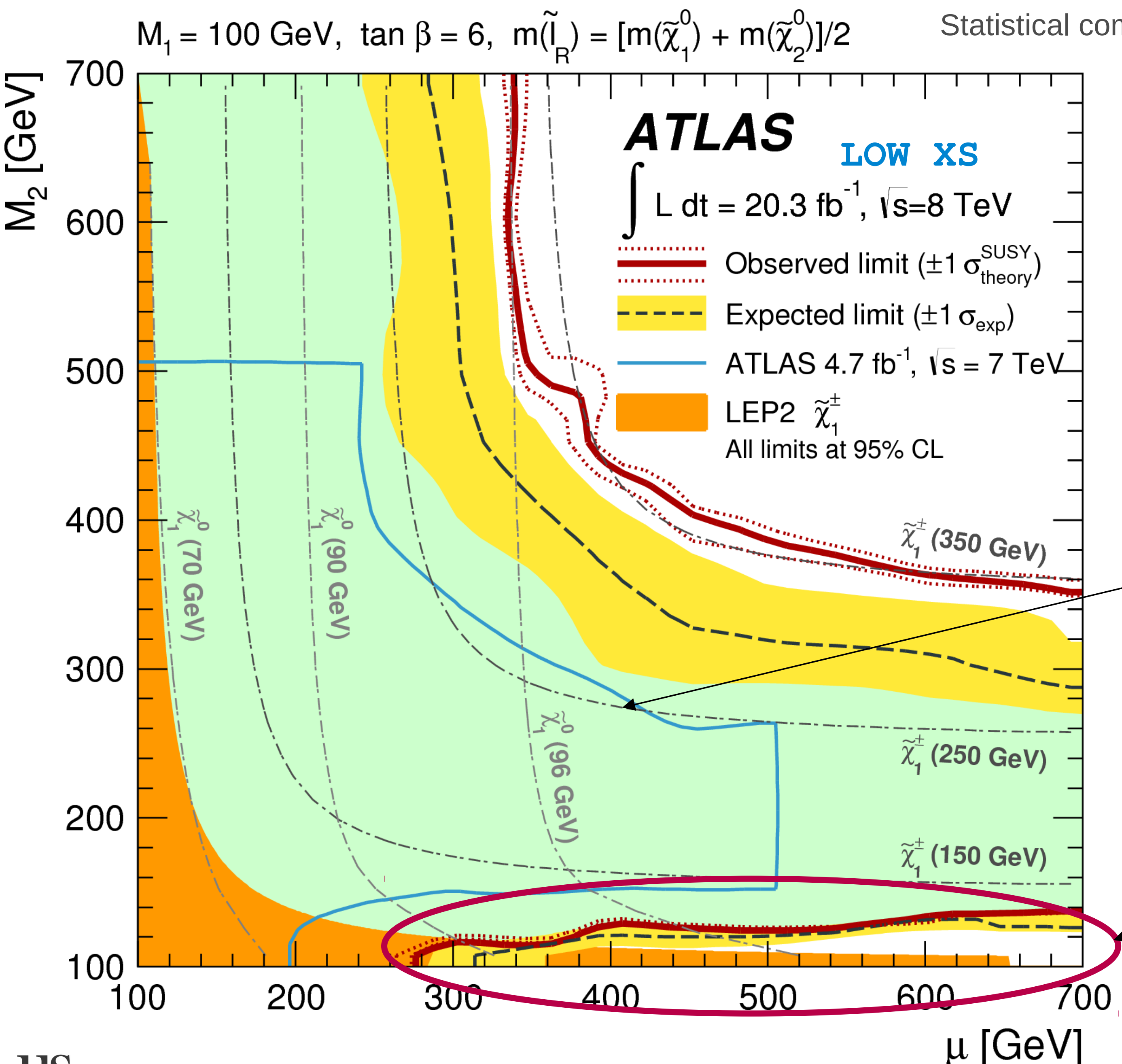
Decays via W/Z/h New

- Low tan β (10)
- M_1=50 GeV

Decays via Staus(R) New

- High tan β (50)
- M_1=75 GeV

Statistical combination of SR0a, SR0b, SR1SS, SR2a



Decays via sleptons(R)

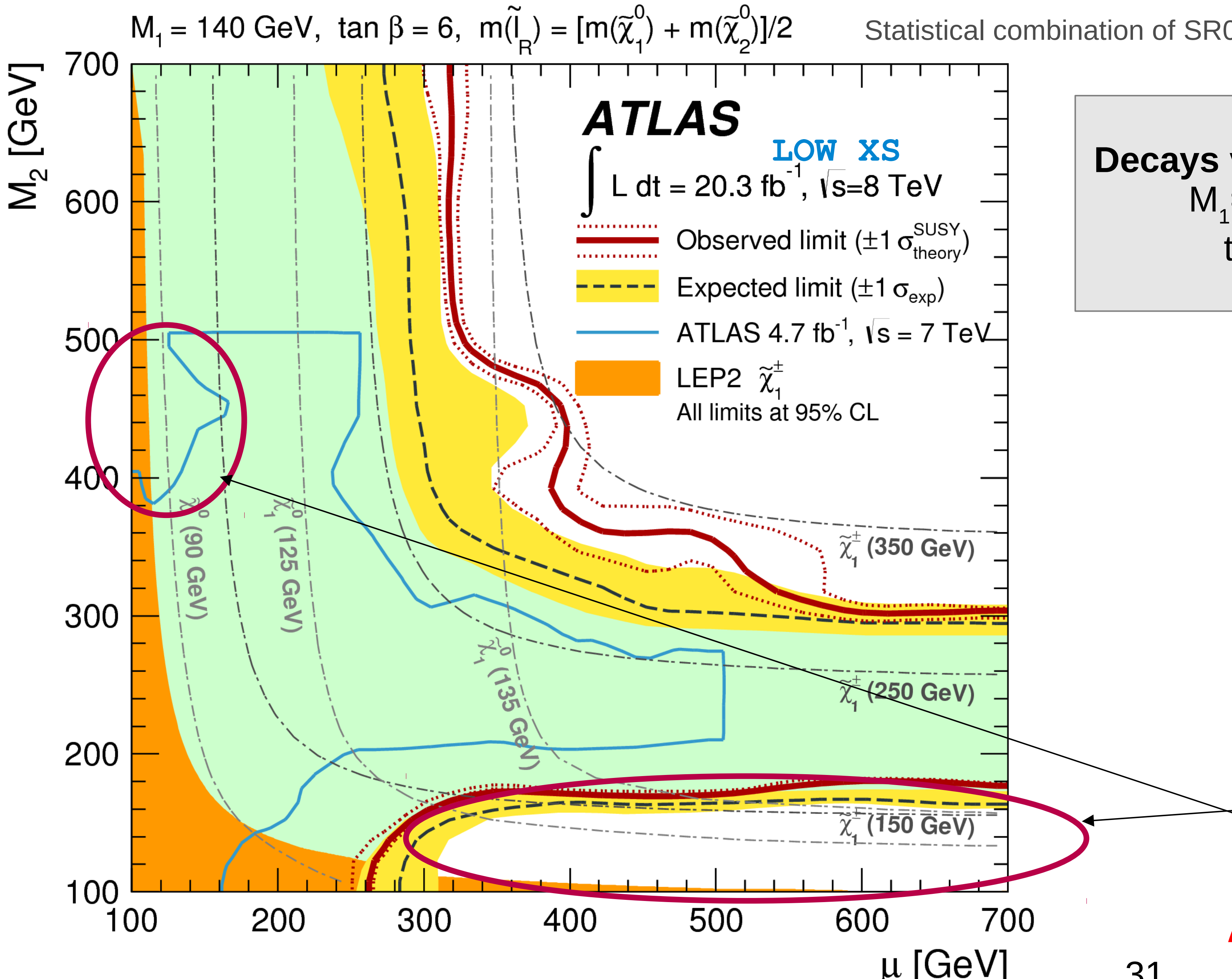
M_1=100 GeV

tan β= 6

Small

$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$

Statistical combination of SR0a, SR0b, SR1SS, SR2a



Decays via sleptons(R)

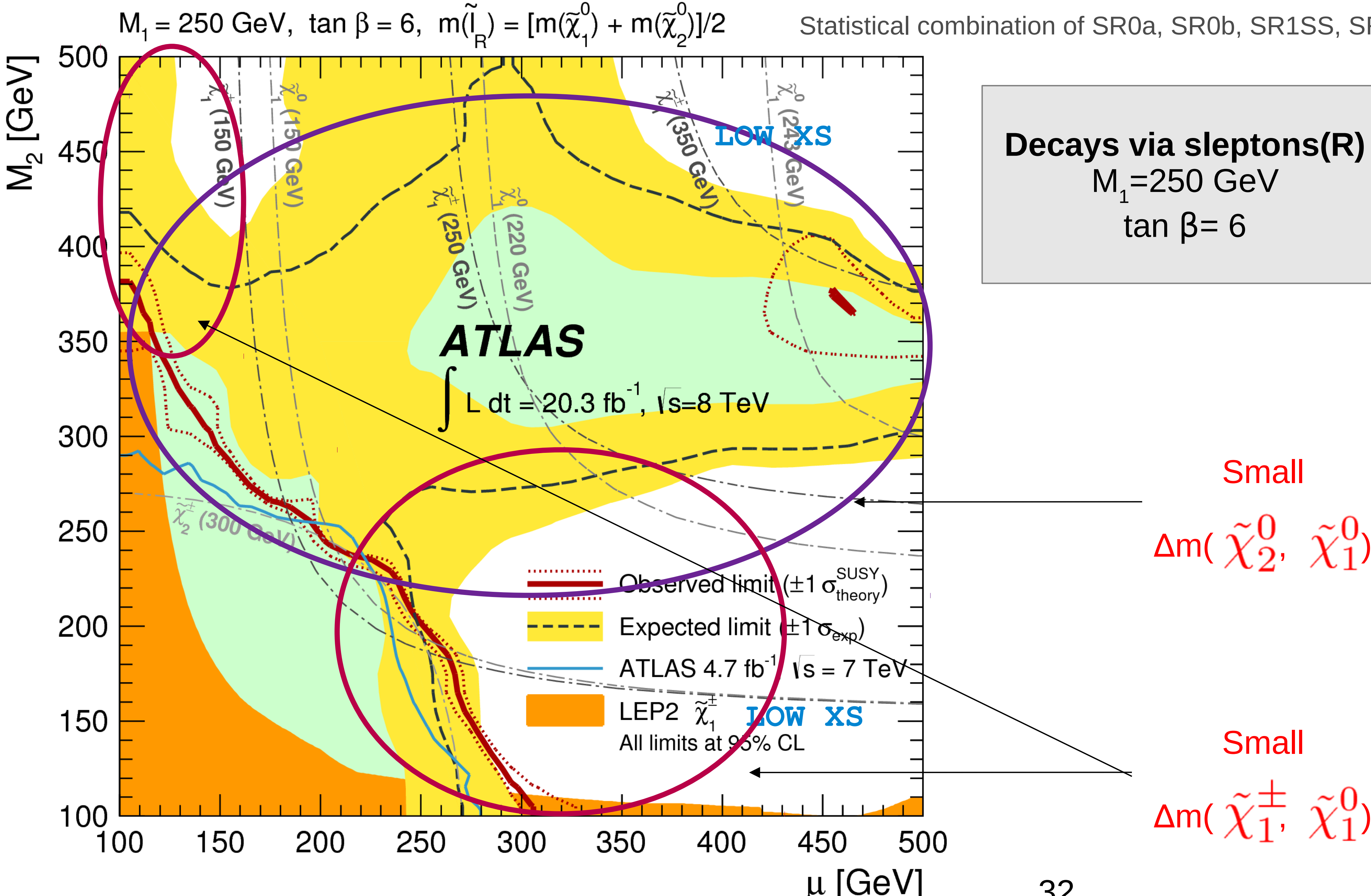
M_1=140 GeV

tan β= 6

Small

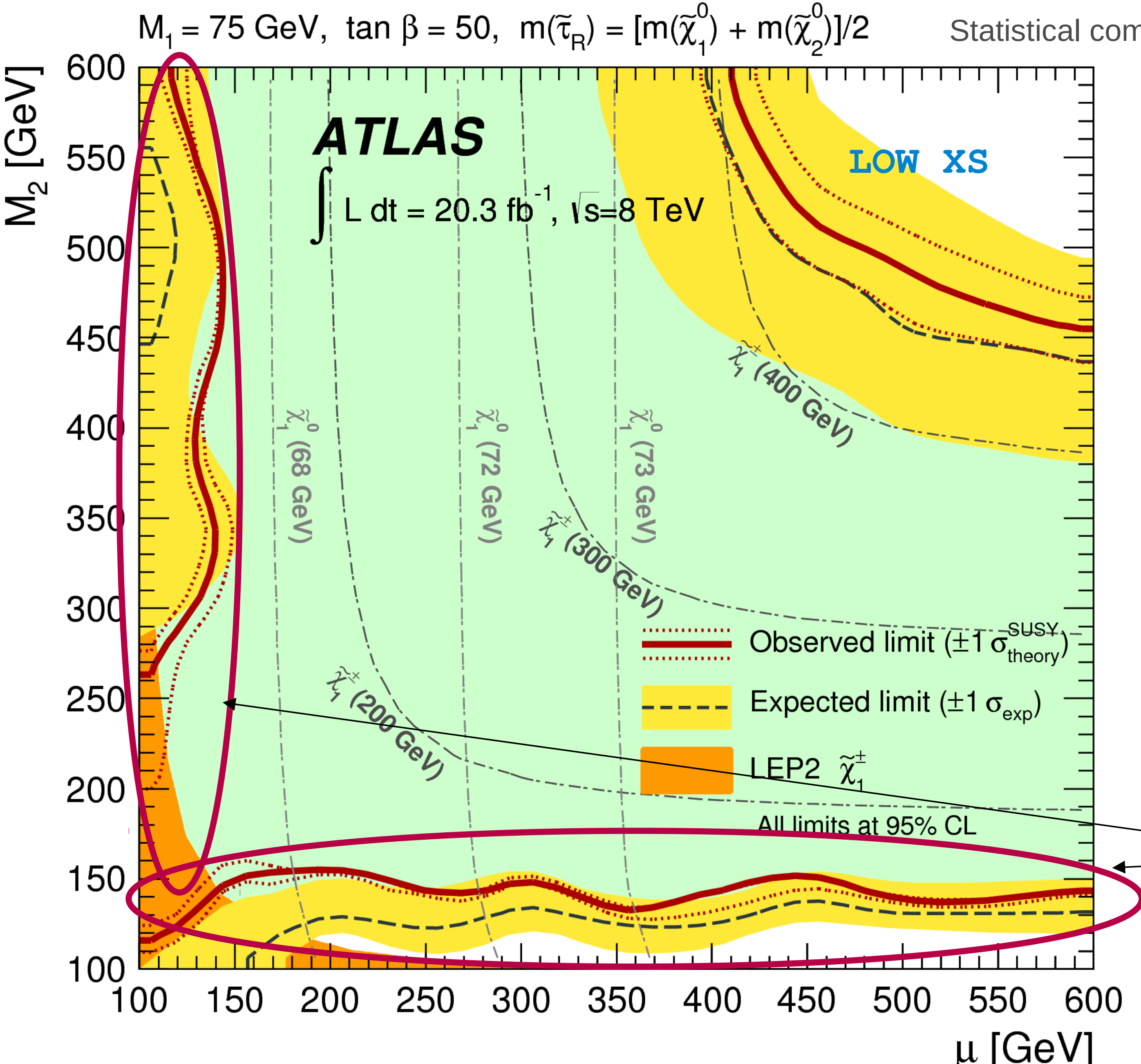
$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$

Statistical combination of SR0a, SR0b, SR1SS, SR2a



Decays via sleptons(R)
M_1=250 GeV
tan β= 6

University of Sussex

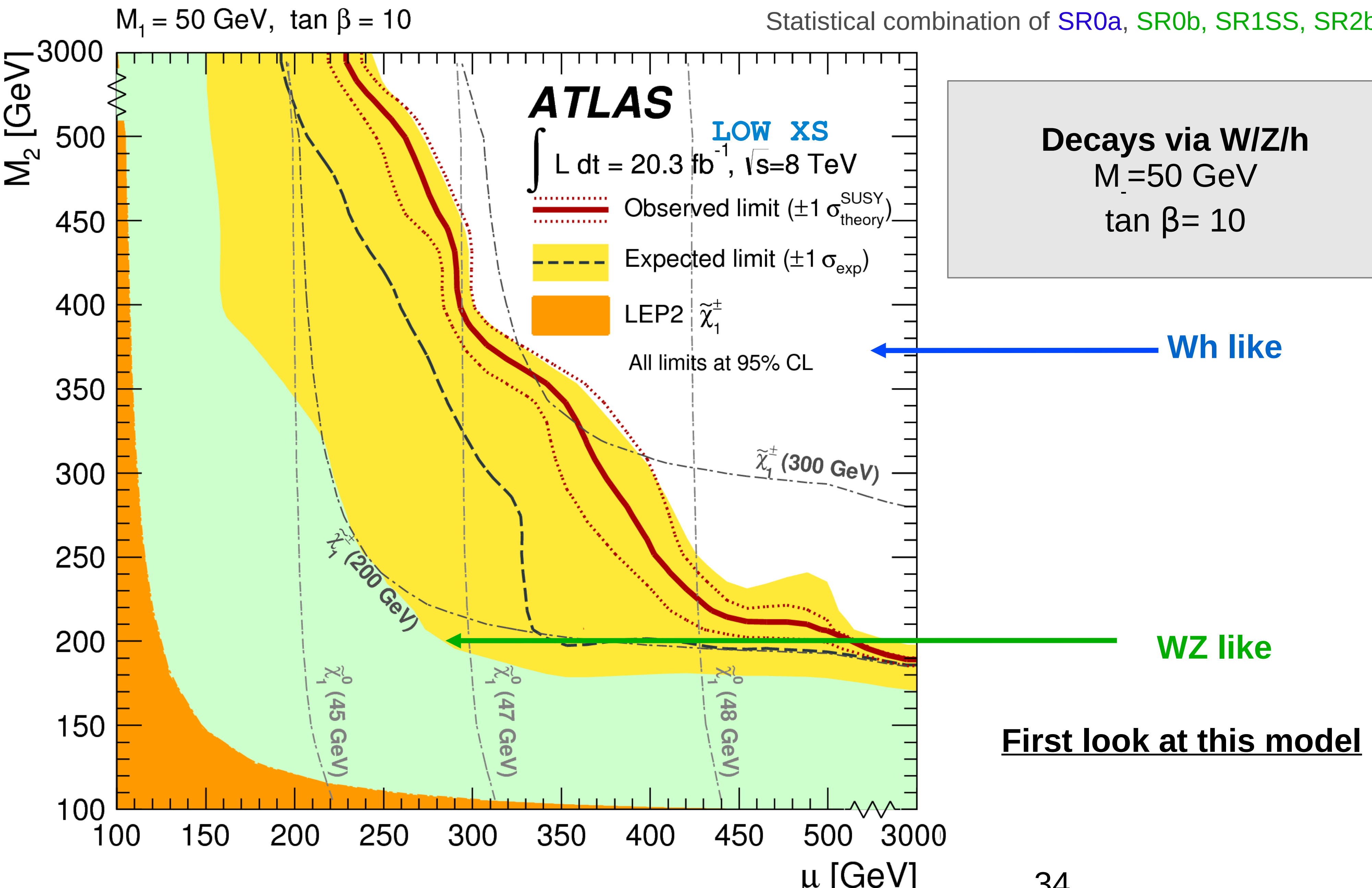


Statistical combination of SR0a, SR0b, SR1SS, SR2a

Decays via staus(R)
M_1=75 GeV
tan β= 50

First look at this model

Small
$\Delta m(\tilde{\chi}_2^0 \ \tilde{\chi}_1^0)$



Decays via W/Z/h
M_1=50 GeV
tan β= 10

First look at this model