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Searches for electroweak production of supersymmetric gauginos and sleptons with the ATLAS detector

Marco Agustoni - Albert Einstein Center for Fundamental Physics - University of Bern
On behalf of the ATLAS collaboration

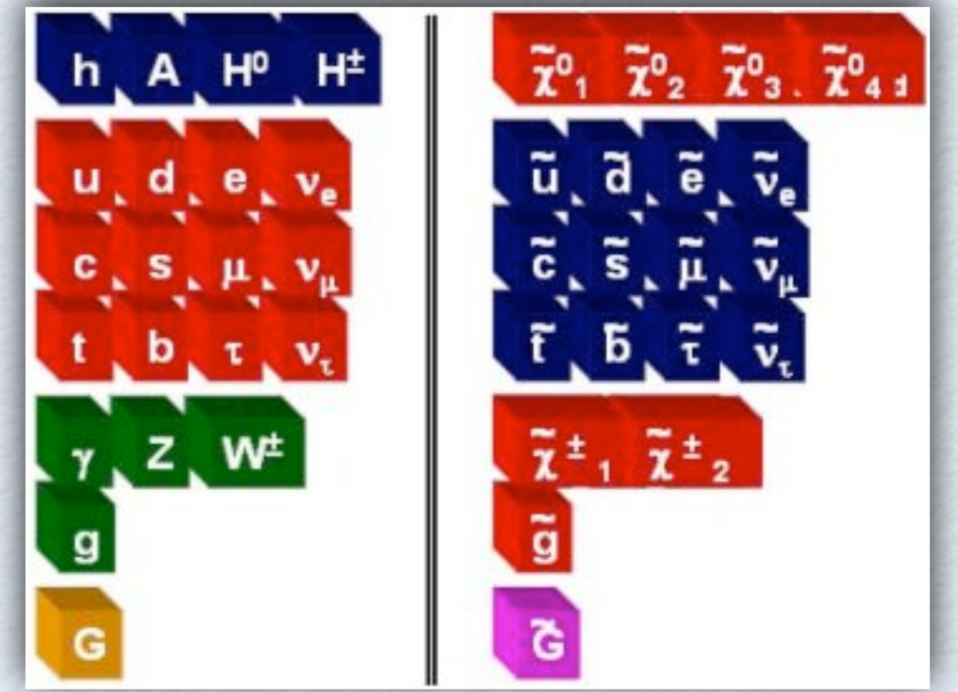
OUTLINE

- Introduction
  - Electroweak production channels
- Atlas SUSY Search Results
  - 3-Lepton final state results
  - 4-Lepton final state results
  - 2-taus final state results
- Summary

The Minimal SUSY Particle Spectrum

The basic idea of the Minimal Supersymmetric Standard Model (MSSM) is the addition to the SM of:

- a Higgs doublet
- a spin-half partner to every boson
- a spin-zero partner to every fermion



The Figure shows the observable states of MSSM particles.

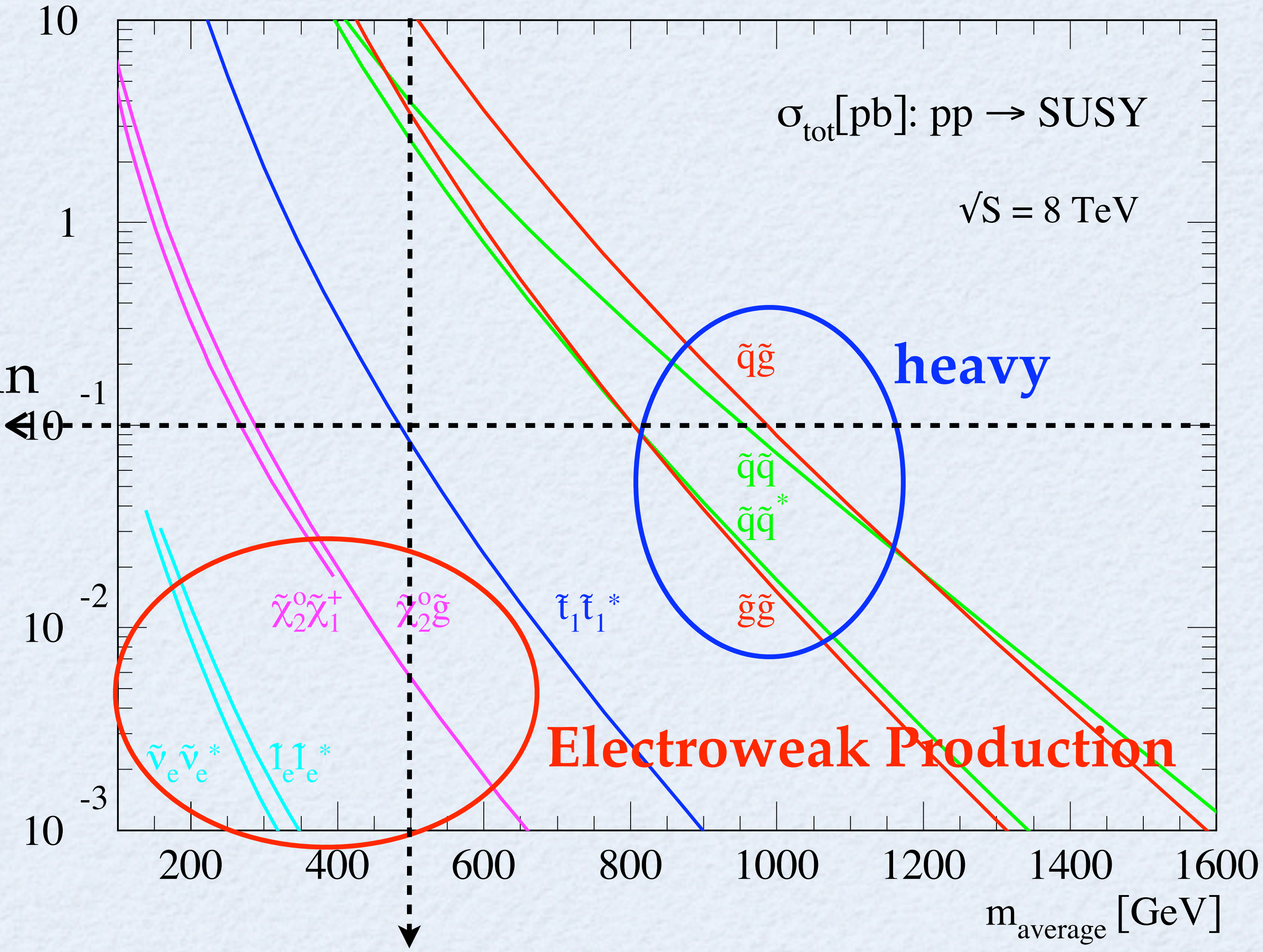
Charginos $\tilde{\chi}_i^{\pm}$ $(i = 1, 2)$ and neutralinos $\tilde{\chi}_j^{0}$ $(j = 1, 2, 3, 4)$ are mixed states of electroweak boson partners and Higgs boson partners.

SUSY production at LHC

We search for SUSY models, where sleptons, $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^{0}$ are light, whereas squarks and gluinos are heavy and out of reach.

Prospino NLO

1k events within 10 fb^{-1}



SUSY produced via color interactions is excluded for masses O(1 TeV).

Neutralinos, charginos and sleptons can be directly produced via Electroweak (EW) production.

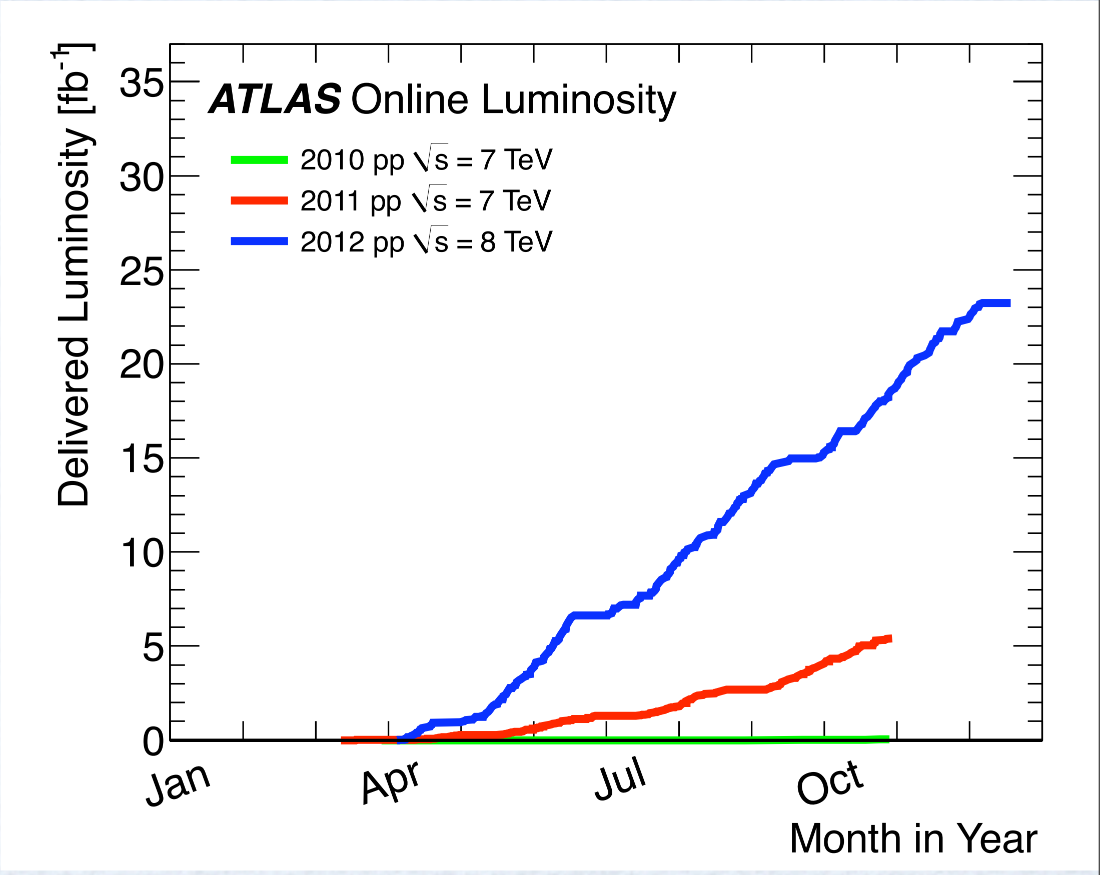
At 500 GeV within 10 fb^{-1}, there should be: 40k gluino pairs, 1k stops, 50 $\tilde{\chi}^{\pm}\tilde{\chi}^{0}$ events.

Electroweak channels

Channel	Analysis
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production	3-leptons **(21 fb^{-1}, 8 TeV)** new
$\tilde{\chi}_2^0\tilde{\chi}_3^0$ production	4-leptons **(e, μ, (τ)) (21 fb^{-1}, 8 TeV)** new
$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production	2-τ **(21 fb^{-1}, 8 TeV)** new [2-leptons **(4.7 fb^{-1}, 7 TeV)**]*

* PLB 718 (2013) 879

- About 21 fb^{-1} collected at $\sqrt{s}$= 8 TeV and 5 fb^{-1} at $\sqrt{s}$= 7 TeV.
- All the results shown in the talk use the full 2012 (21 fb^{-1}) dataset ($\sqrt{s}$= 8 TeV).



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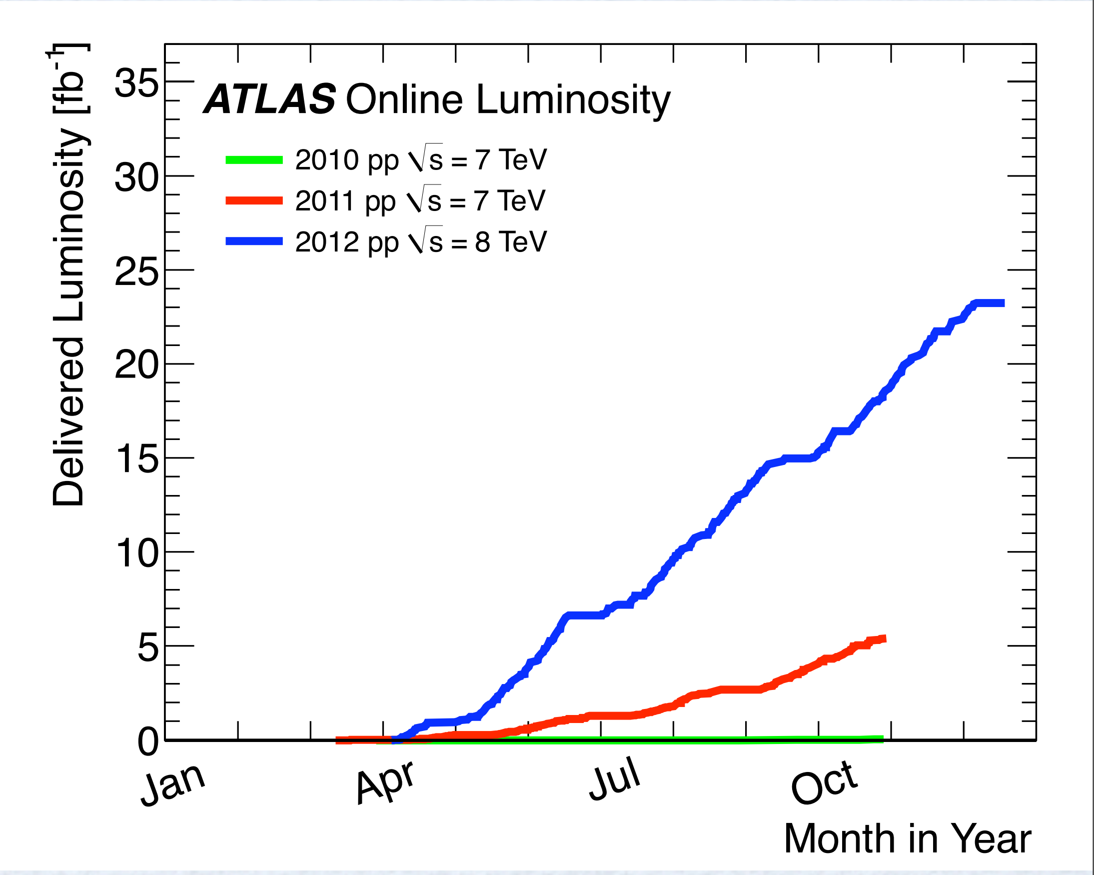


Examples of other EW production analysis (7 TeV):

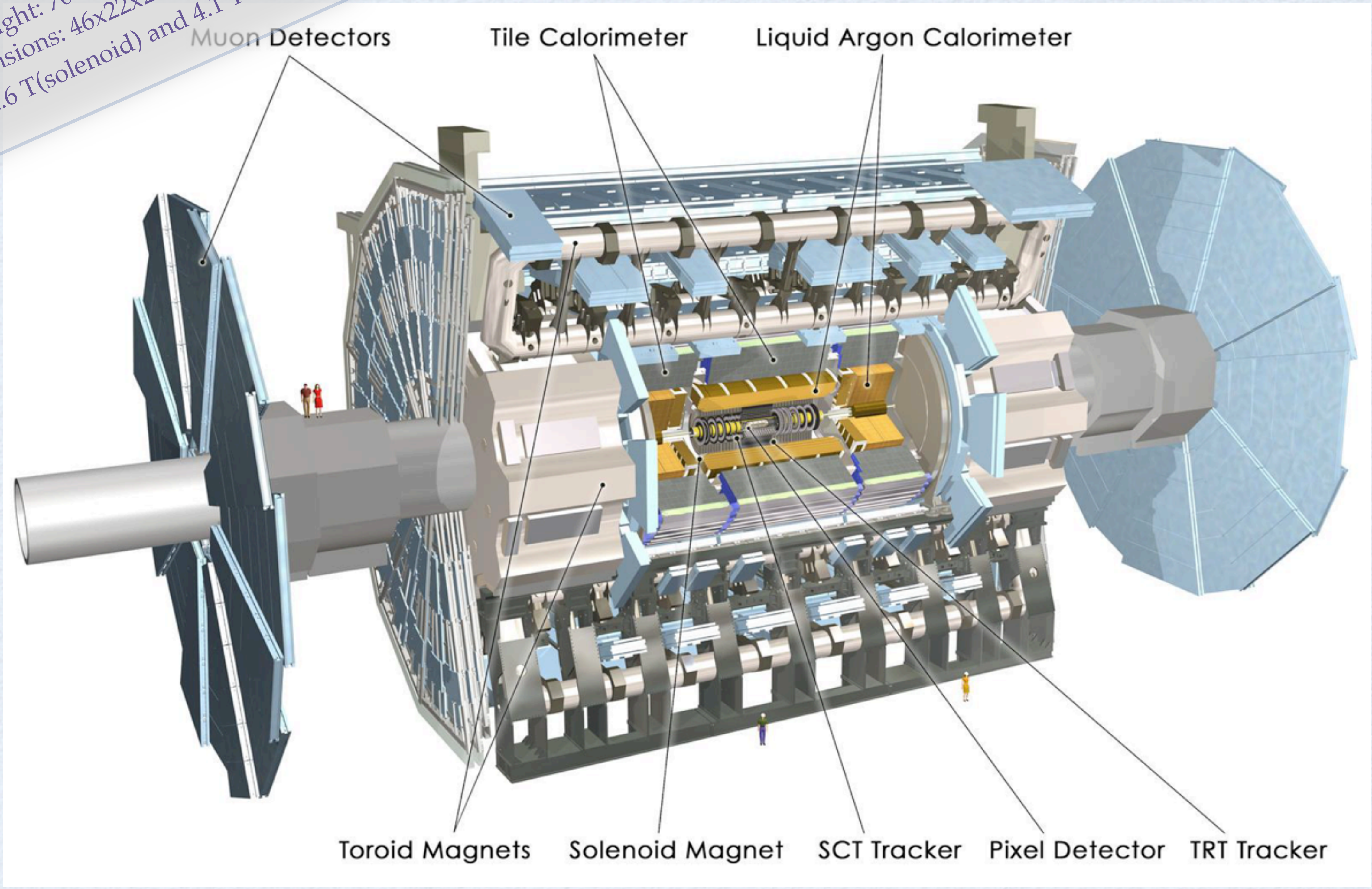
long-lived chargino pair production (JHEP01(2013)131)

GGM Analysis (PLB 719 (2013) 261, ATLAS-CONF-2012-144)

GMSB search for non-pointing photons (ATLAS-CONF-2013-016)

Experimental Setup

The ATLAS Detector
Weight: 7000 tons
Dimensions: 46x22x22 m^3
Magnetic Field 2.6 T(solenoid) and 4.1 T (toroid)

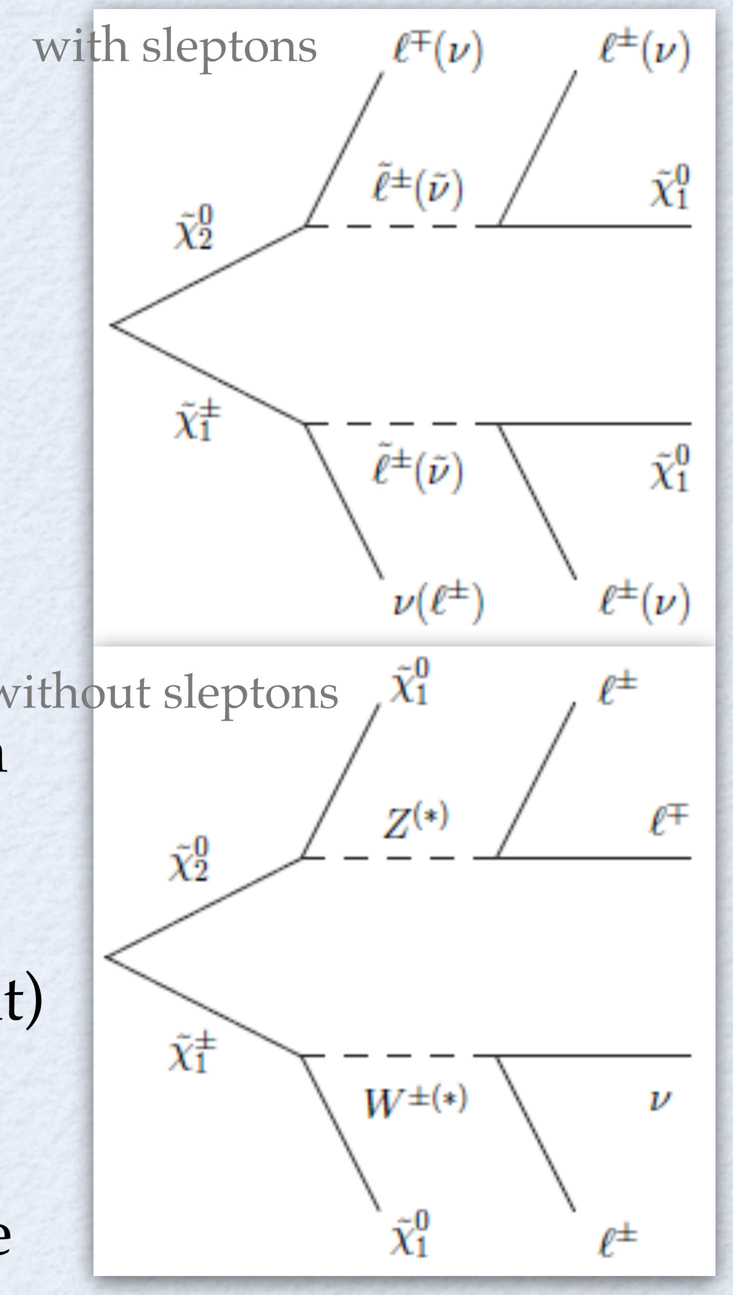


Analysis & Results

3-Lepton Analysis

[ATLAS-CONF-2013-035]

	Z depleted			Z enriched		
Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
m_{SFOS} [GeV]	<60	60–81.2	<81.2 or >101.2	81.2–101.2	81.2–101.2	81.2–101.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	>50	>75	>75	75–120	75–120	>120
m_{T} [GeV]	–	–	>110	<110	>110	>110
p_{T} 3^{rd} ℓ [GeV]	>10	>10	>30	>10	>10	>10
SR veto	SRnoZc	SRnoZc	–	–	–	–
Target	Low mass splitting	No-slep off-shell Z	Slepton bulk	WZ-like	No-slep on-shell Z	No-slep bulk



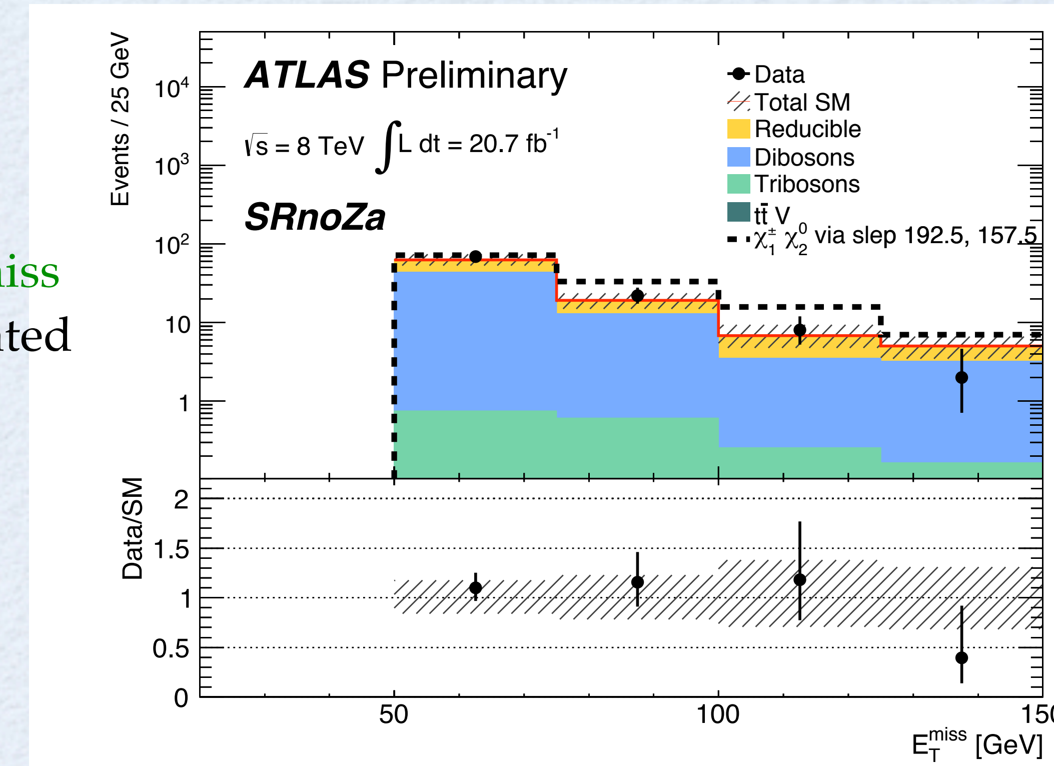
In this Analysis two kinds of Signal Regions (SR), which differ from each other by the presence or not of a reconstructed di-leptonic Z.

- Z-depleted regions: target decays via sleptons (assumed to be light) or via off-shell bosons.
- Z-enriched regions: target decays via on-shell bosons (sleptons are assumed to be heavy).
- Final state with 3 leptons and ETmiss given by neutrinos and neutralinos.

3-Lepton Results

Irreducible Background:

- Dominated by di-boson (WZ, ZZ) production, taken direct from MC.
- Systematic uncertainties on cross-sections, jet energy resolutions and ETmiss energy scale dominate Z-depleted regions. Z-enriched regions are dominated by WZ acceptance and cross-section uncertainties.



Reducible Backgound (at least one fake lepton)

- Dominated by top quark and Z+jets production, determined from data.
- Systematic uncertainties dominated by dependence of misidentification probability on ETmiss in SRnoZ (a,b) and by uncertainty of data driven estimates in SRnoZc and SRZ (a,b,c).

Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
Tri-boson	1.7 ± 1.7	0.6 ± 0.6	0.8 ± 0.8	0.5 ± 0.5	0.4 ± 0.4	0.29 ± 0.29
ZZ	14 ± 8	1.8 ± 1.0	0.25 ± 0.17	8.9 ± 1.8	1.0 ± 0.4	0.39 ± 0.28
$t\bar{t}V$	0.23 ± 0.23	0.21 ± 0.19	$0.21^{+0.30}_{-0.21}$	0.4 ± 0.4	0.22 ± 0.21	0.10 ± 0.10
WZ	50 ± 9	20 ± 4	2.1 ± 1.6	235 ± 35	19 ± 5	5.0 ± 1.4
Σ SM irreducible	65 ± 12	22 ± 4	3.4 ± 1.8	245 ± 35	20 ± 5	5.8 ± 1.4
SM reducible	31 ± 14	7 ± 5	1.0 ± 0.4	4^{+5}_{-4}	1.7 ± 0.7	0.5 ± 0.4
Σ SM	**96 ± 19**	**29 ± 6**	**4.4 ± 1.8**	**249 ± 35**	**22 ± 5**	**6.3 ± 1.5**
Data	**101**	**32**	**5**	**273**	**23**	**6**
p_0-value	0.41	0.37	0.40	0.23	0.44	0.5

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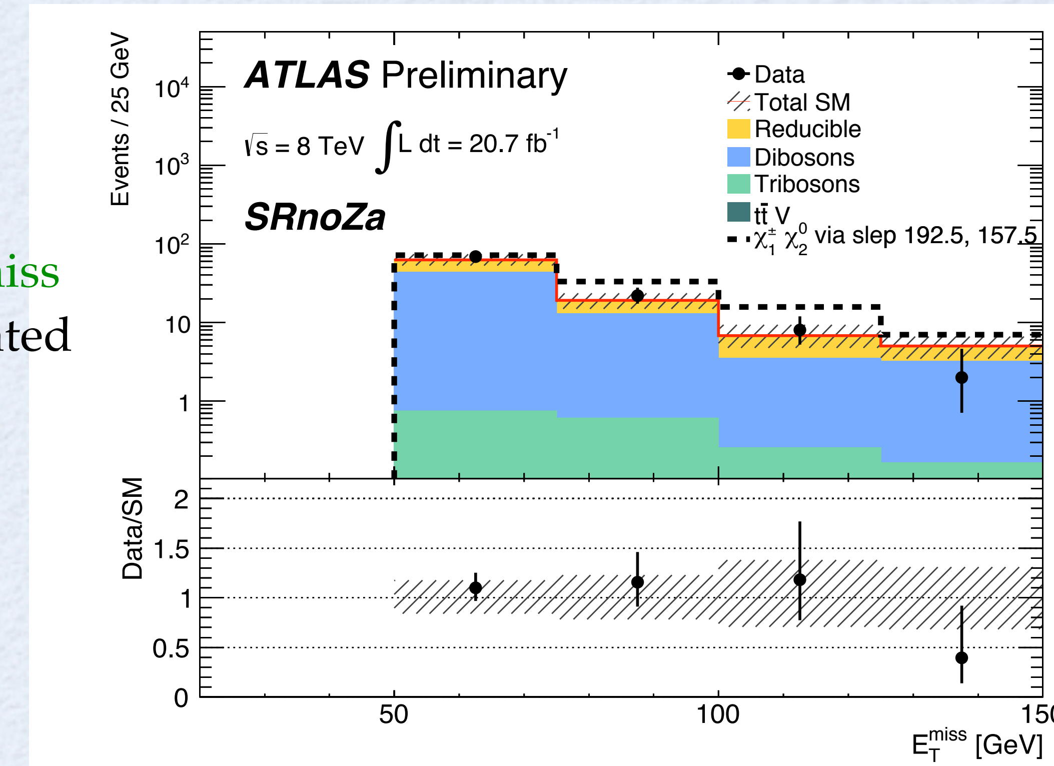

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Since no significant excess is observed, we set exclusion limits.

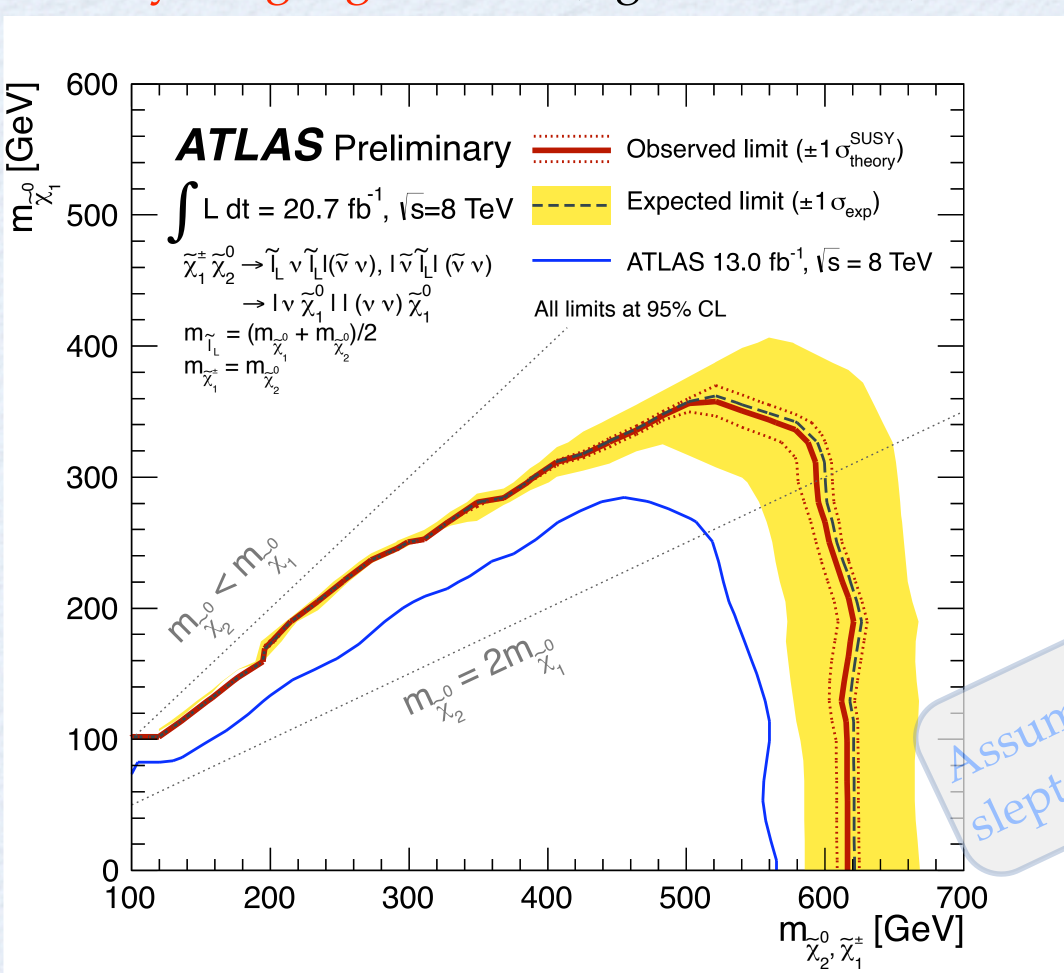
3-Lepton Interpretations

Results are interpreted using the Simplified Model, in which we set the masses of both chargino and neutralino 'by hand' within an interesting interval range.
chargino and second neutralino masses are assumed to be degenerated $m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0}$

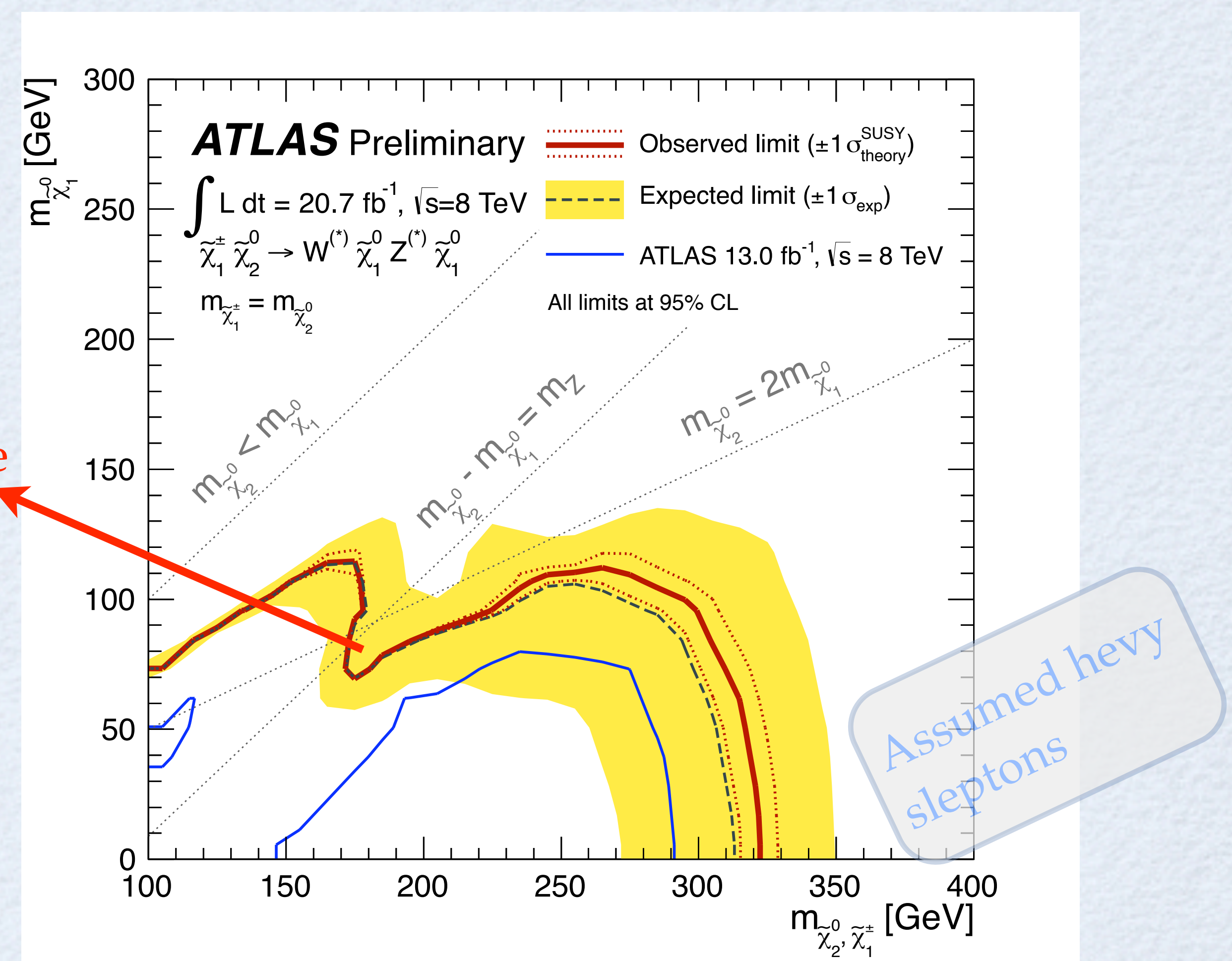
Limits are calculated using a combined likelihood fit of all SR, taking into account systematics via nuisance parameters.

Observed and expected 95% CL limit contours for chargino and neutralino production with:

- decay via sleptons (left-hand side plot) with $m_{\tilde{l}_L} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0})/2$
- decay via gauge bosons (right-hand side).



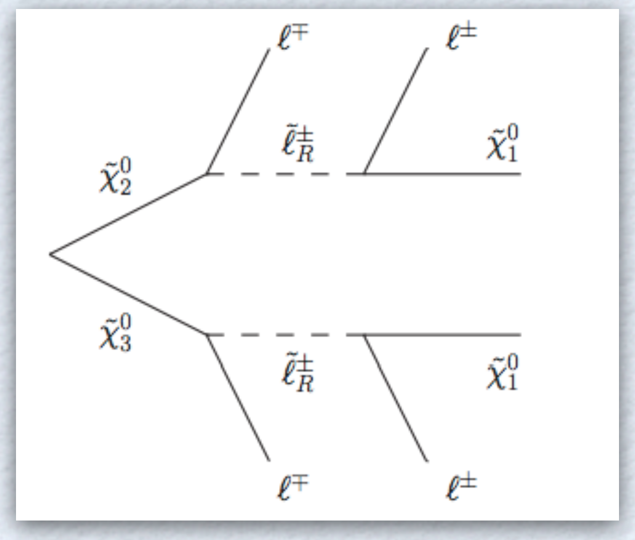
WZ-like events



4-Lepton Analysis

ATLAS-CONF-2013-036

This analysis is sensitive to both RPC and RPV scenarios:



- **RPC Signal Models**:

  $\tilde{\chi}_2^0\tilde{\chi}_3^0$ production (low mass splitting) and decay mode $\tilde{\chi}_{2,3}^0 \rightarrow \tilde{l}_R^{\pm} l^{\mp} \rightarrow \tilde{\chi}_1^0 l^{\mp} l^{\pm}$

  Assume *BR = 100%* equally to e or μ (no τ for now)

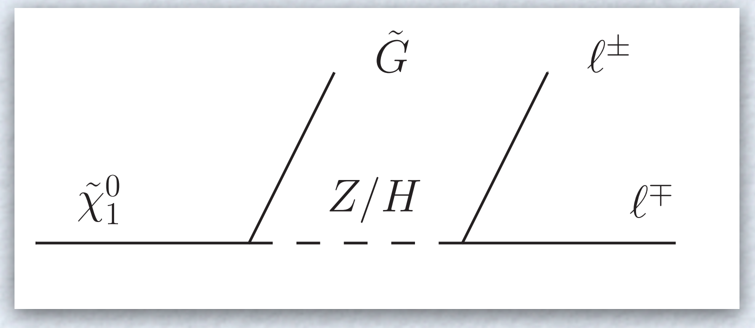
  Final state with 4 charged leptons, ETmiss from neutralinos

- **RPC General Gauge Mediated (GGM) Signal Models**:

  In GGM SUSY braking models, the gravitino $\tilde{G}$ (~ massless) is the LSP

  Higgsino-like neutralino (NLSP) has decay mode $\tilde{\chi}_1^0 \rightarrow h\tilde{G}$ *or* $\rightarrow Z\tilde{G}$

  Final states with 4 charged leptons ETmiss from gravitino



- **RPV Signal Models**:

  Lepton number violated for decays in light leptons (λ_{121}) and taus (λ_{133})

  LSP can decay as $\tilde{\chi}_1^0 \rightarrow \nu_{i/j} l_{j/i}^{\pm} l_k^{\mp}$ leading to a final state with high lepton multiplicities

  Final states with 4-6 charged leptons, ETmiss from neutrinos.

4-Lepton Signal Regions

Two kinds of SR are defined for each allowed tau multiplicity:

- **Regions vetoing Z candidates**: remove events with any pair, triplet (at least 1 SFOS) or quadruplet (two SFOS) of light leptons with invariant mass inside [81.2, 101.2] GeV (extended veto).

  These regions target both RPC and RPV scenarios.

- **Regions requiring Z candidates**: ideal for GGM scenarios.

Selected events must contain ≥ 4 signal leptons, where only combinations with ≥ 3 light leptons (e, μ) are considered.

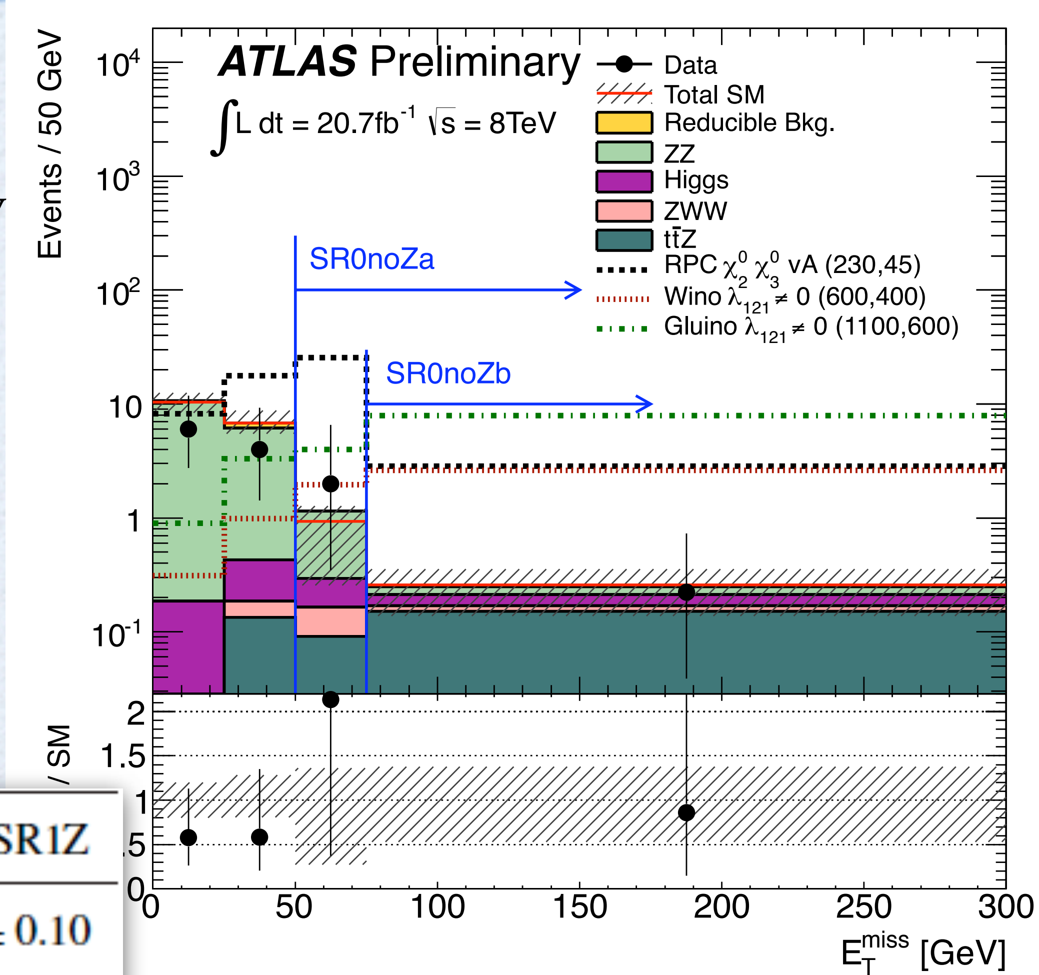
	SR	$N(\ell = e, \mu)$	$N(\tau)$	Z Candidate	E_T^{miss} [GeV]		m_{eff} [GeV]	Scenario	
vetoing Z	SR0noZa	≥4	≥0	extended veto	>50			RPC	loose ETmiss thresholds
	SR0noZb	≥4	≥0	extended veto	>75	or	>600	RPV	moderate/high ETmiss thresholds
	SR1noZ	=3	≥1	extended veto	>100	or	>400	RPV	
requiring Z	SR0Z	≥4	≥0	request	>75			GGM	
	SR1Z	=3	≥1	request	>100			GGM	

4-Lepton Results

Irreducible Background:

- SR without taus (SR0) dominated by four real leptons, which come mainly from ZZ and ttbarZ processes. SRs with 1 tau (SR1) dominated by important contribution of jets, which fakes taus

- Systematic uncertainties on cross-sections and MC modelling.



Reducible Backgound:

- Essentially no reducible background.

Sample	SR0noZa	SR0noZb	SR1noZ	SR0Z	SR1Z
ZZ	0.6 ± 0.5	0.50 ± 0.26	0.19 ± 0.05	1.2 ± 0.4	0.49 ± 0.10
ZWW	0.12 ± 0.12	0.08 ± 0.08	0.05 ± 0.05	0.6 ± 0.6	0.13 ± 0.13
$t\bar{t}Z$	0.73 ± 0.34	0.75 ± 0.35	0.16 ± 0.12	2.3 ± 0.9	0.29 ± 0.24
Higgs	0.26 ± 0.07	0.22 ± 0.07	0.23 ± 0.06	0.58 ± 0.15	0.14 ± 0.05
Irreducible Bkg.	1.7 ± 0.8	1.6 ± 0.6	0.62 ± 0.21	4.8 ± 1.8	1.1 ± 0.4
Reducible Bkg.	$0^{+0.16}_{-0}$	$0.05^{+0.14}_{-0.05}$	1.4 ± 1.3	$0^{+0.14}_{-0}$	$0.3^{+1.0}_{-0.3}$
Total Bkg.	1.7 ± 0.8	1.6 ± 0.6	2.0 ± 1.3	4.8 ± 1.8	$1.3^{+1.0}_{-0.5}$
Data	2	1	4	8	3
p_0-value	0.29	0.5	0.15	0.08	0.13

4-lepton Results

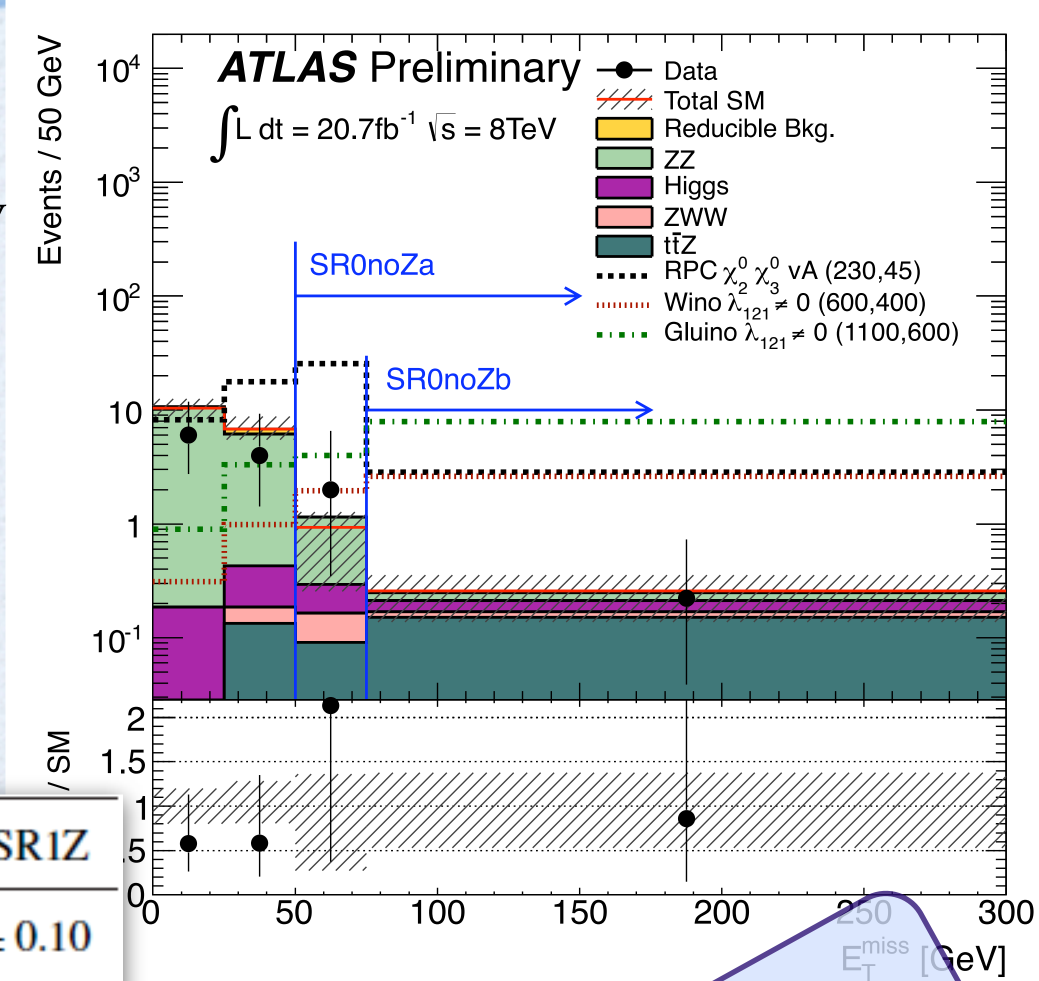
Irreducible Background:

- SR without taus (SR0) dominated by four real leptons, which come mainly from ZZ and ttbarZ processes. SRs with 1 tau (SR1) dominated by important contribution of jets, which fakes taus

- Systematic uncertainties on cross-sections and MC modelling.

Reducible Backgound:

- Essentially no reducible background.



Sample	SR0noZa	SR0noZb	SR1noZ	SR0Z	SR1Z
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Data	2	1	4	8	3
p_0-value	0.29	0.5	0.15	0.08	0.13

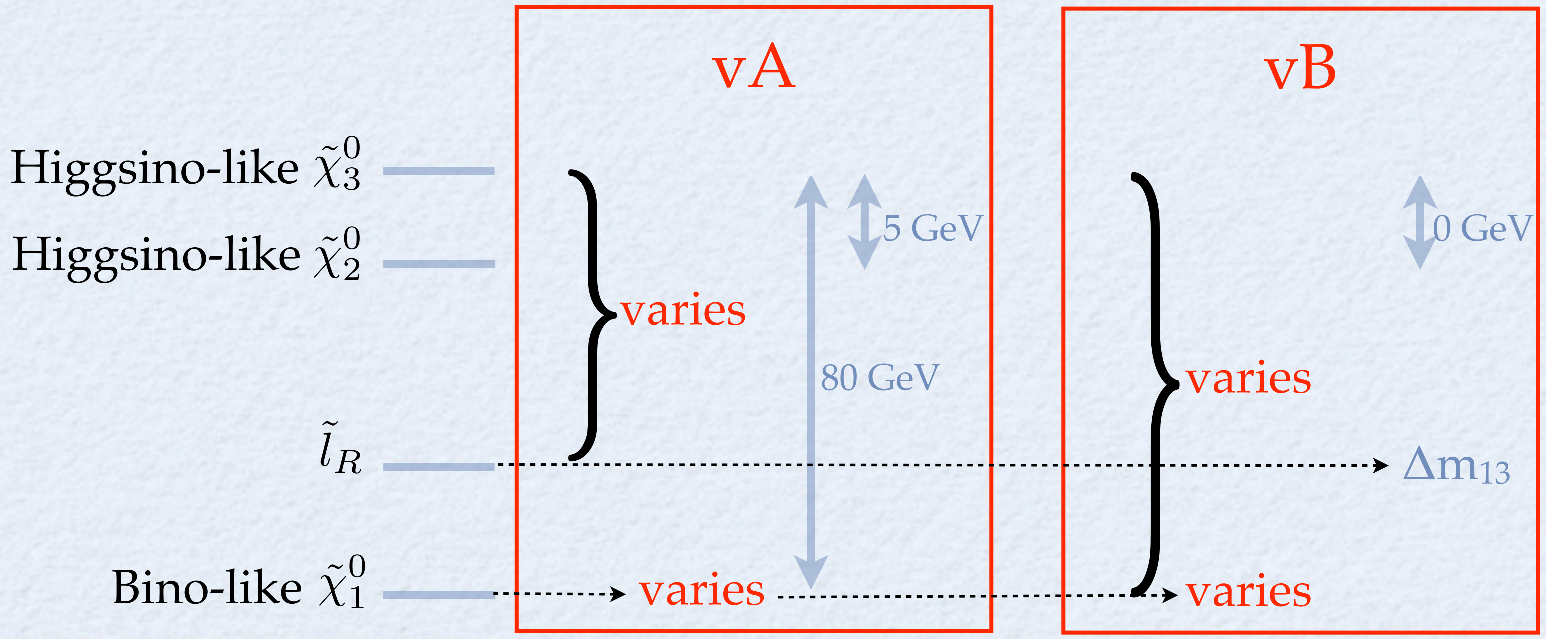
➡ Since no significant excess is observed, we set exclusion limits.

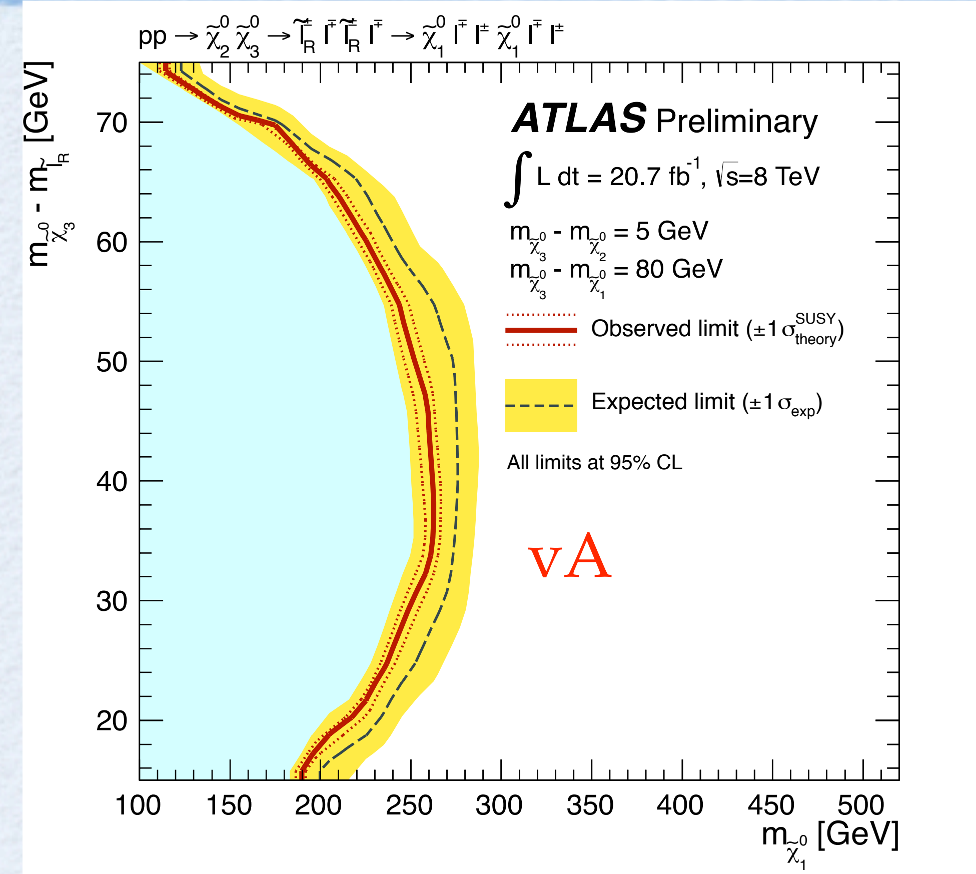
4-Leptons interpretations (RPC)

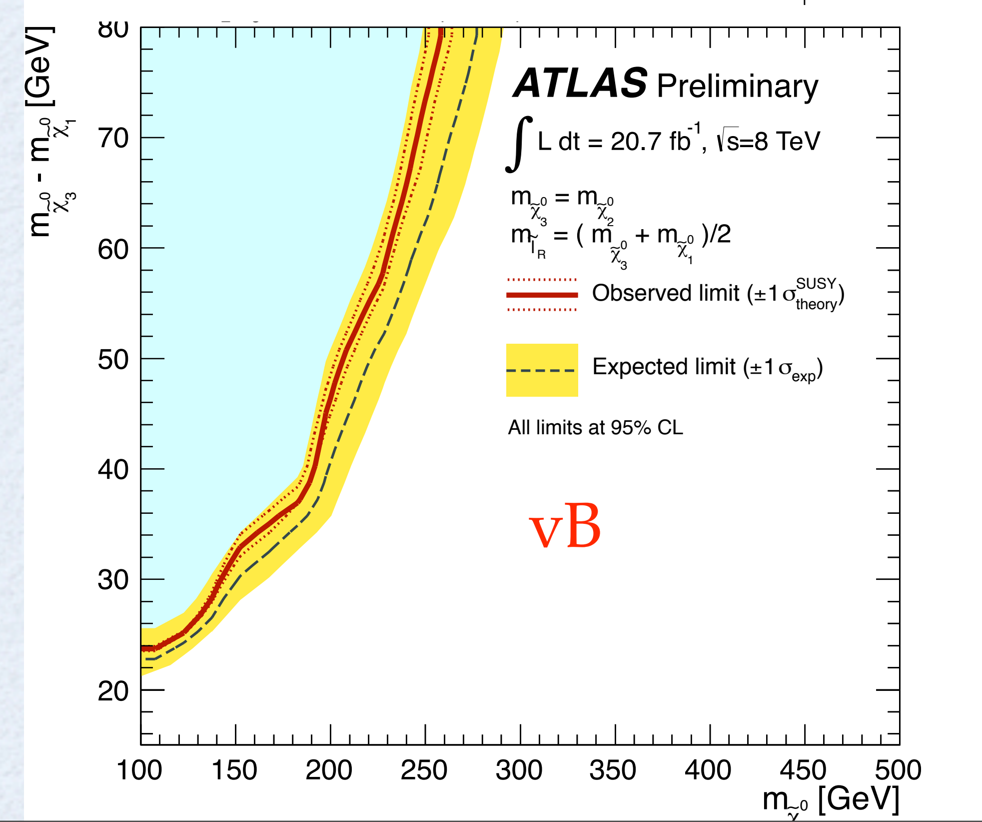
Two simplified models (vA, vB) are considered, where only the masses of $\tilde{\chi}^0_3, \tilde{\chi}^0_2, \tilde{\chi}^0_1, \tilde{l}_R$ are light.

Limits are set using the signal region SR0noZa. Both vA and vB have the same decay mode.

- in vA: $\Delta m(\tilde{\chi}^0_3, \tilde{l}_R)$ varies and is plotted vs the variation of $\tilde{\chi}^0_1$ whereas $\Delta m(\tilde{\chi}^0_3, \tilde{\chi}^0_1)$ is fix.
- in vB: $\Delta m(\tilde{\chi}^0_3, \tilde{\chi}^0_1)$ varies and is plotted vs the variation of $\tilde{\chi}^0_1$ whereas $m_{\tilde{l}_R}$ is always put in the middle between $\tilde{\chi}^0_1$ and $\tilde{\chi}^0_3$ masses.



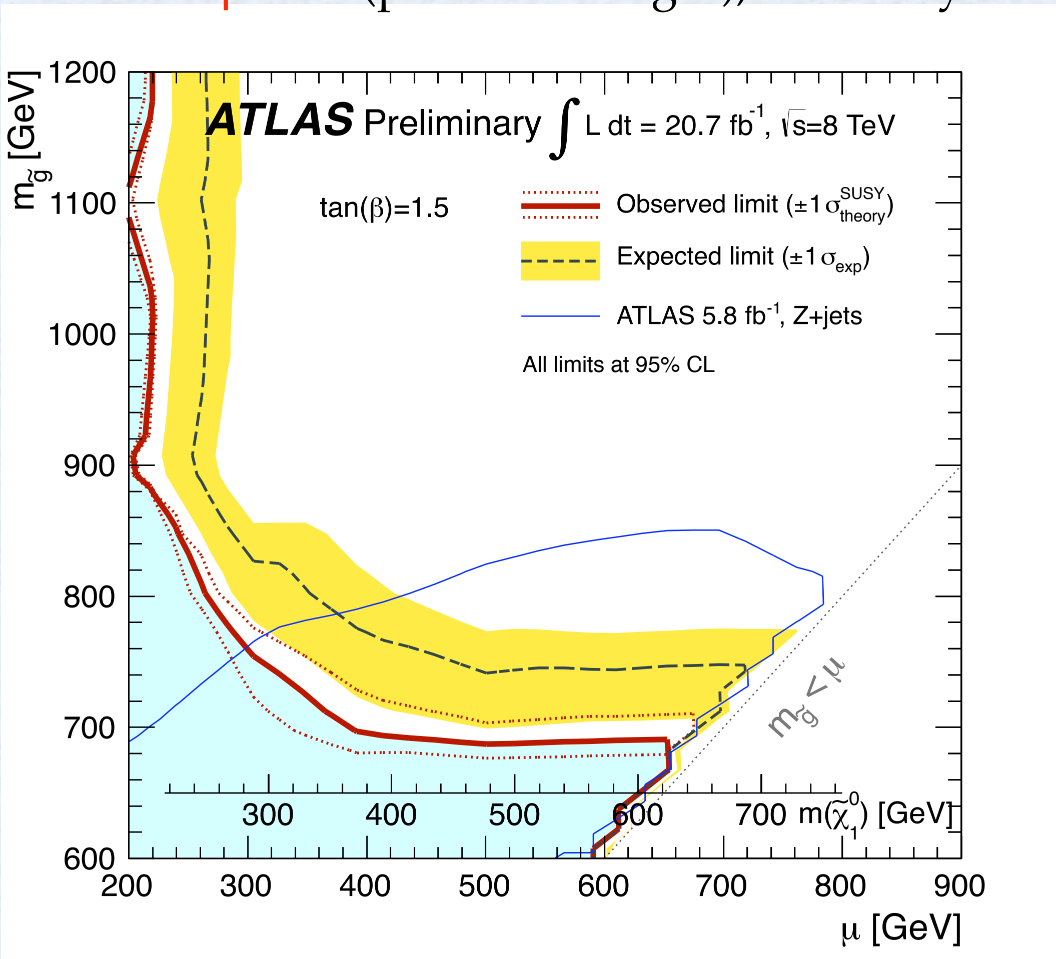


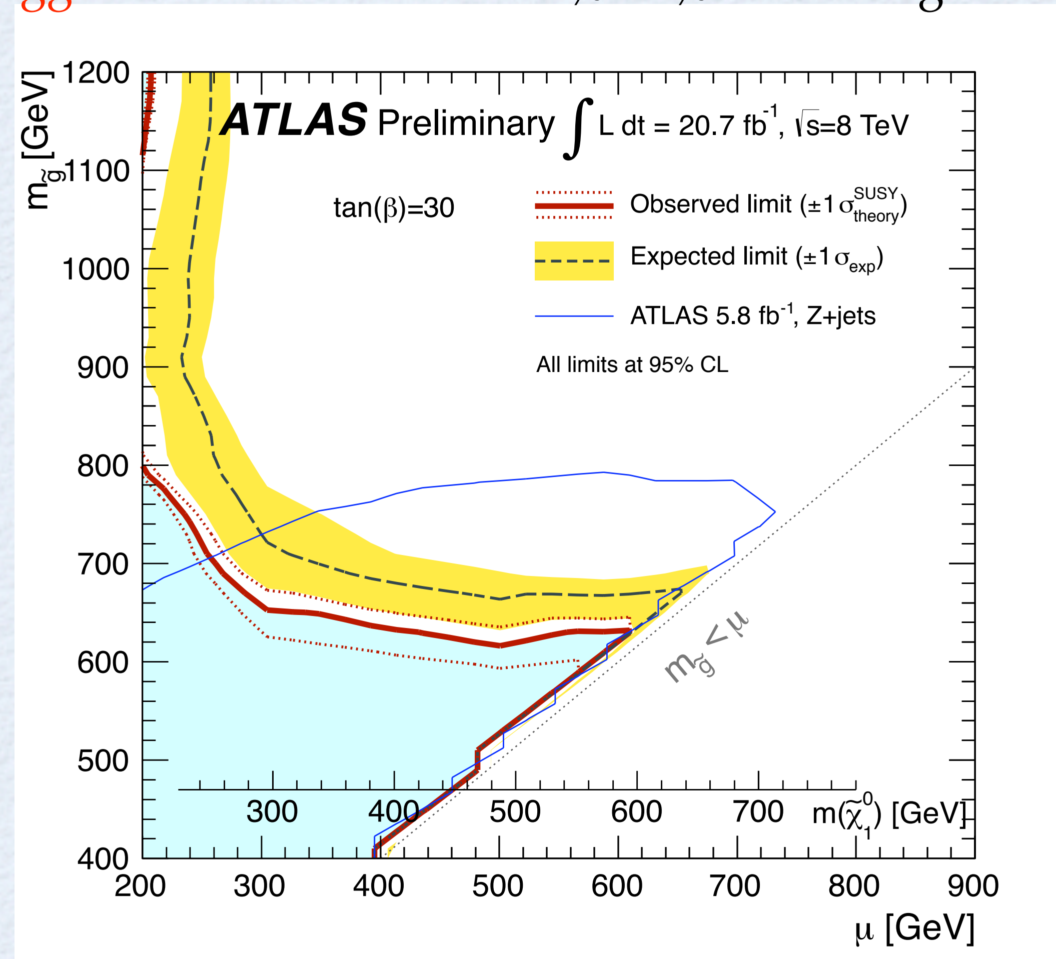


4-Leptons Interpretations (GGM)

Observed and expected 95% CL limit contours for the GGM models:

- with tanβ = 1.5 (plot on the left), the decay mode is via Z-boson with BR of 97%.
- with tanβ = 30 (plot on the right), the decay mode is via Higgs-boson with a BR of 20%-50% increasing with μ.





There is more sensitivity to exclude the production of gravitino with:

- pair-production of gluinos for low gluino masses.
- production of charginos and neutralinos for high gluino masses.

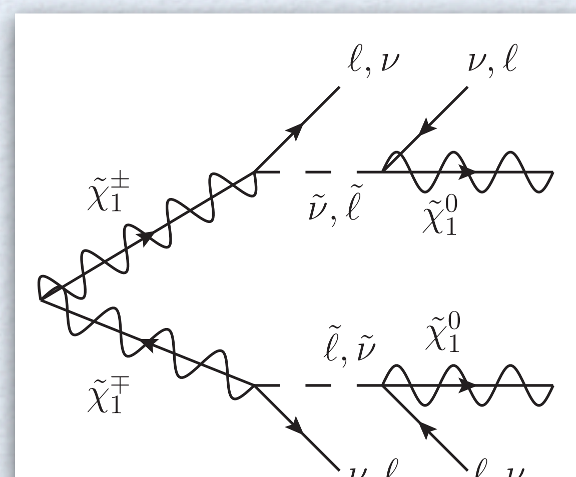
2-TAU ANALYSIS

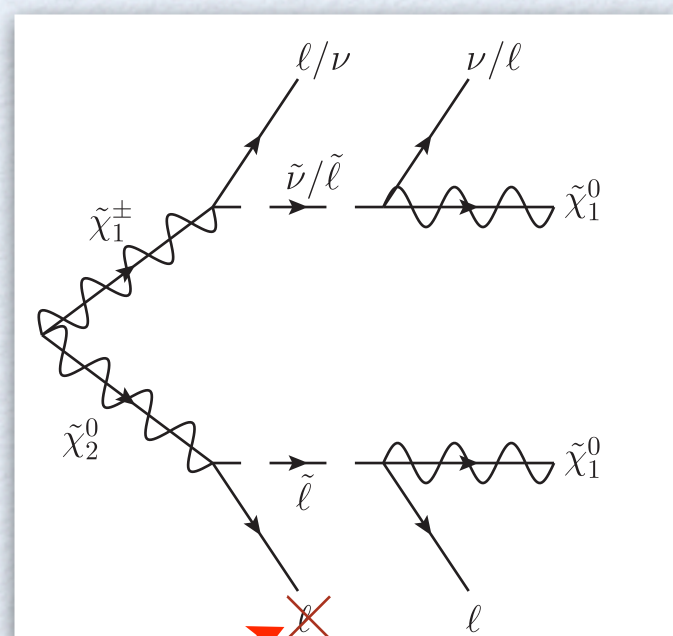
ATLAS-CONF-2013-028

Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}(\tilde{\chi}_1^{\pm} \rightarrow \tilde{\tau}_L \nu, \tau\tilde{\nu})$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}(\tilde{\chi}_2^{0} \rightarrow \tilde{\tau}_L \tau)$ production with 100% BR to final state with (s)taus.

- Final states containing at least 2 hadronically decaying taus
- At least one tau pair has opposite sign (OS).
- Events with additional light leptons are vetoed.

Staus and tau sneutrinos are assumed to be mass degenerate.





not reconstructed since $m_{\tilde{\chi}_2^0} \approx m_{\tilde{l}}$ assumed

Two SR are defined requiring particular cuts on ETmiss and m_{T2} in order to improve the signal over background ratio.

Signal region	requirements
OS m_{T2}	at least 1 OS tau pair jet veto Z-veto E_T^{miss}> 40 GeV m_{T2}> 90 GeV
OS m_{T2}-nobjet	at least 1 OS tau pair b-jet veto Z-veto E_T^{miss}> 40 GeV m_{T2}> 100 GeV

Irreducible Background (estimated from MC):

- real taus coming from di-boson, Z+jets or top production. Systematics dominated by tau-related uncertainties.

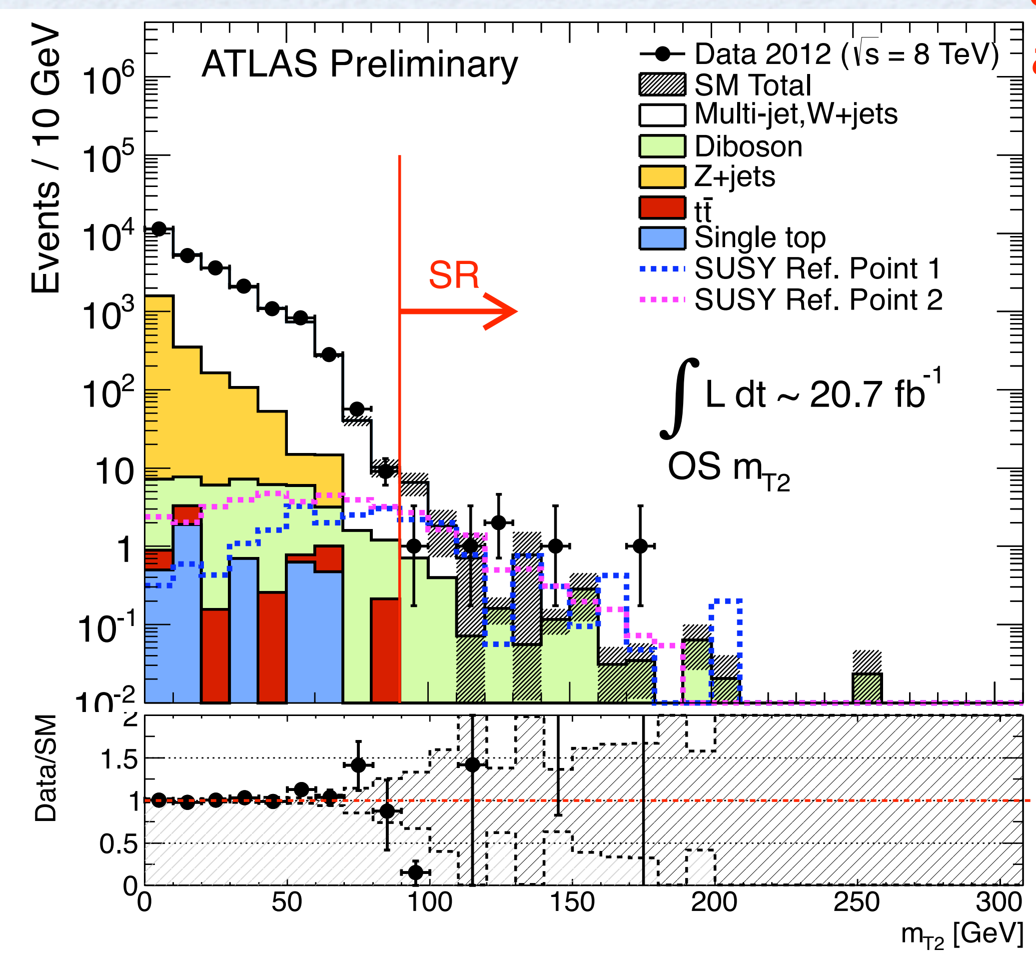
Reducible Background (estimated from data):

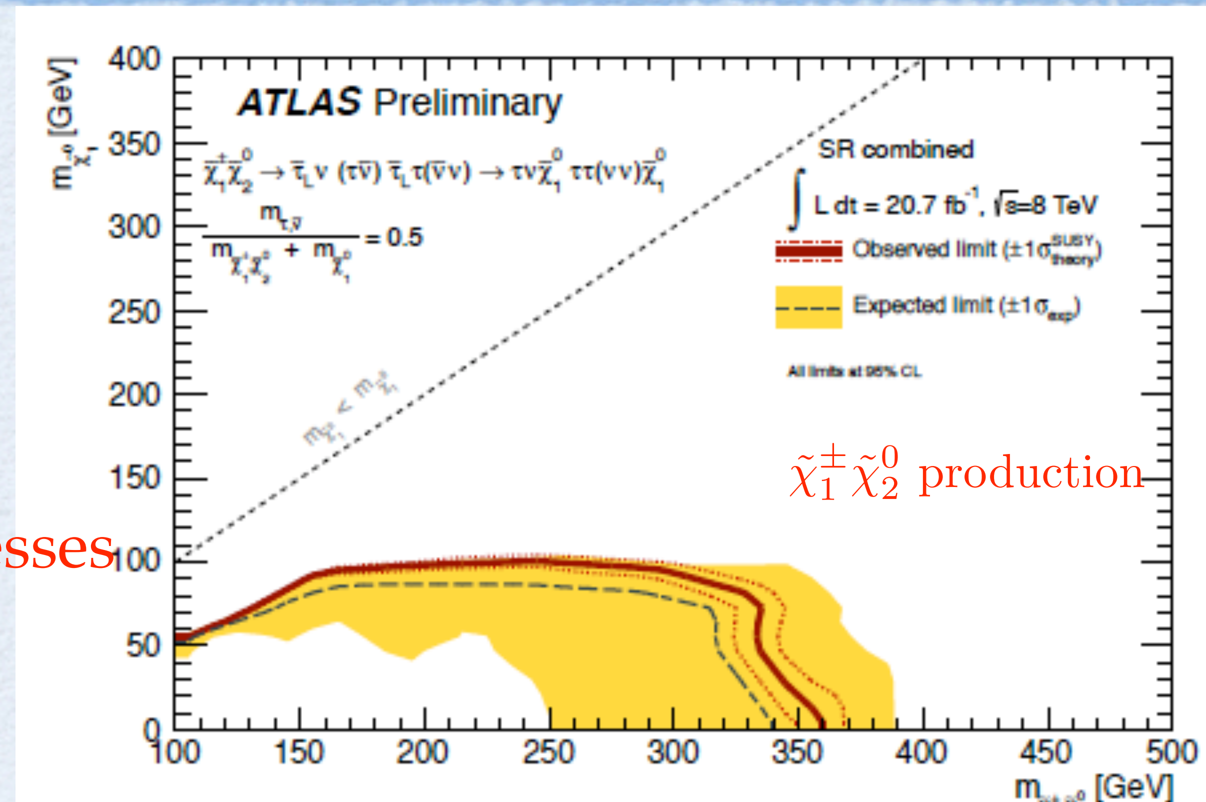
- at least one fake tau coming from misidentified jets (W +jets) . Systematics dominated by limited statistics in control regions.

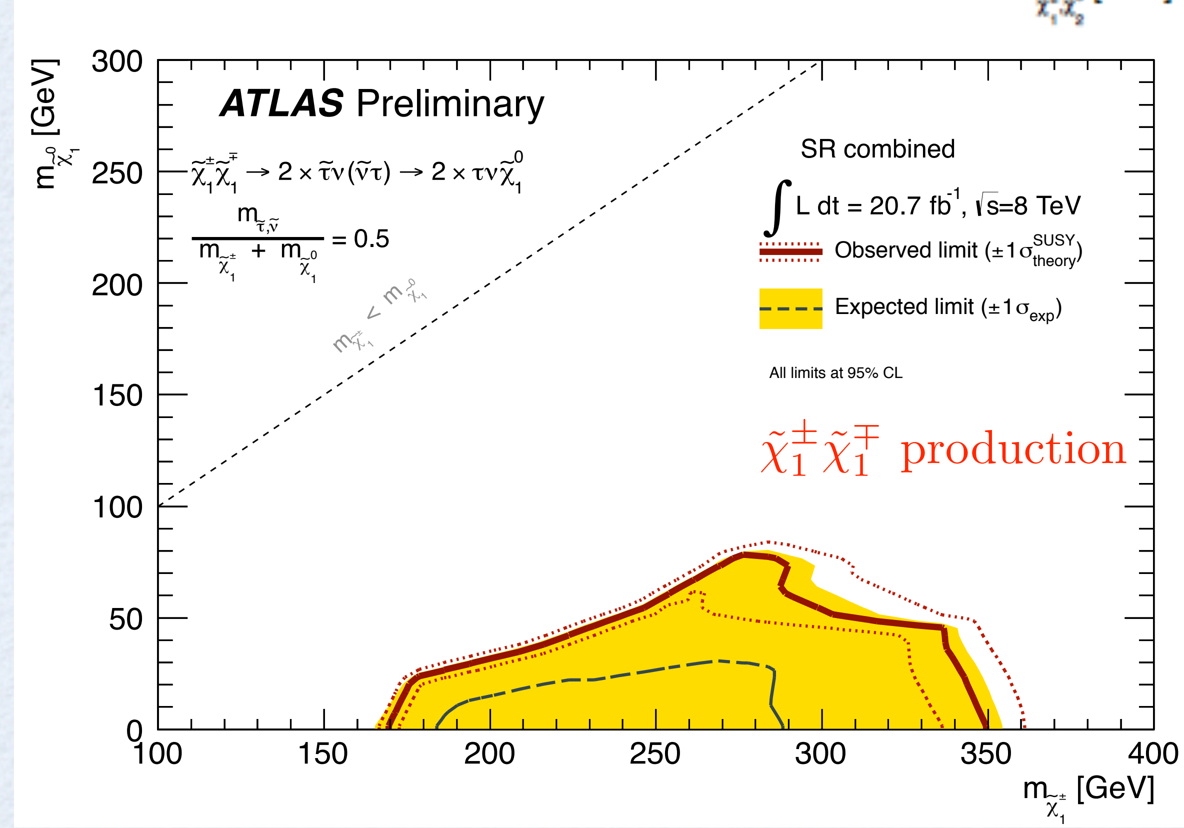
2-tau Results and interpretations

SM process	SR OS m_{T2}	SR OS m_{T2} -nobjet
top	0.2 ± 0.5 ± 0.1	1.6 ± 0.8 ± 1.2
Z+jets	0.28 ± 0.26 ± 0.23	0.4 ± 0.3 ± 0.3
diboson	2.2 ± 0.5 ± 0.5	2.5 ± 0.5 ± 0.9
multi-jet & W+jets	8.4 ± 2.6 ± 1.4	12 ± 3 ± 3
SM total	11.0 ± 2.7 ± 1.5	17 ± 4 ± 3
data	6	14

no significant excesses are observed







SUMMARY

- In this talk results for direct EW production of gauginos and sleptons have been shown.
- Three different kind of analysis: 3-Lepton, 4-Lepton (with RPC and RPV), 2-Lepton (with taus only) final state with missing transverse energy have been considered.
- No excesses have been found in any channel of EW production of supersymmetric gauginos and sleptons with the ATLAS detector.
- Limits of exclusion have been extended in simplified model grids: RPC, RPV and GGM.

THANKS FOR YOUR ATTENTION!

Additional Slides

Variables

$$m_T = \sqrt{2p_T^l \cdot E_T^{miss} - 2\mathbf{p}_T^l \cdot \mathbf{p}_T^{miss}}$$

$$m_{T2} = \min_{q_T + r_T = p_T^{miss}} \left[max \left(m_T(\mathbf{p}_T^{l_1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{l_2}, \mathbf{r}_T) \right) \right]$$

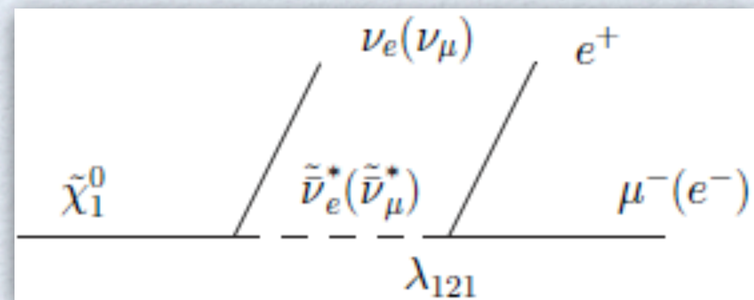
$$m_{eff} = E_T^{miss} + \sum_{\mu} p_T^{\mu} + \sum_{e} p_T^{e} + \sum_{\tau} p_T^{\tau} + \sum_{jet} p_T^{jet}$$

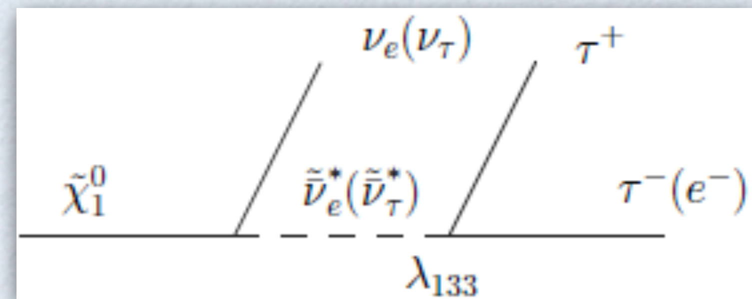
MC samples

- Background:
  - Diboson: Sherpa (Powheg for systematic studies)
  - Triboson: MadgraphPythia
  - ttbar: Powheg
  - ttbar+V: Alpgen (Madgraph for systematic studies and for ttbar+WW)
  - Single t: AcerMC, MC@NLO
  - V+jets: AlpgenPythia
  - Higgs: Pythia
- Signal:
  - Herwig++

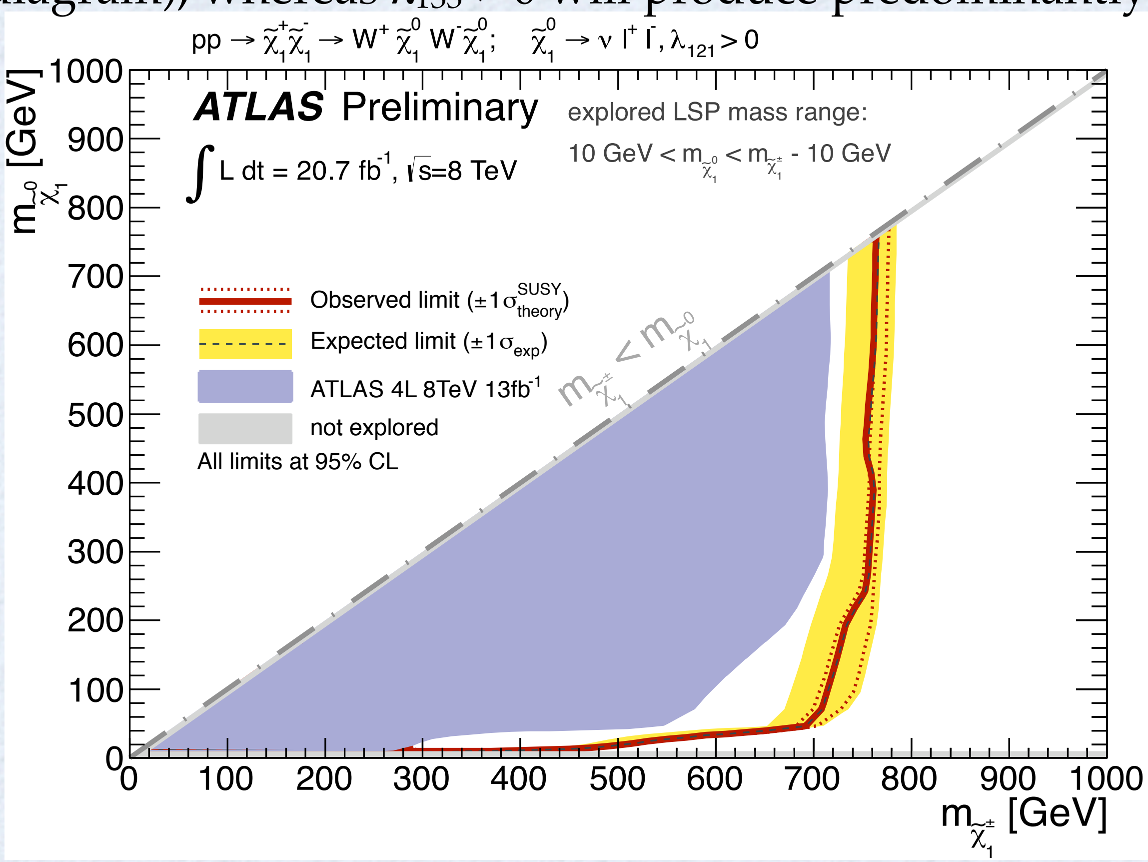
4-Leptons Interpretations (RPV)

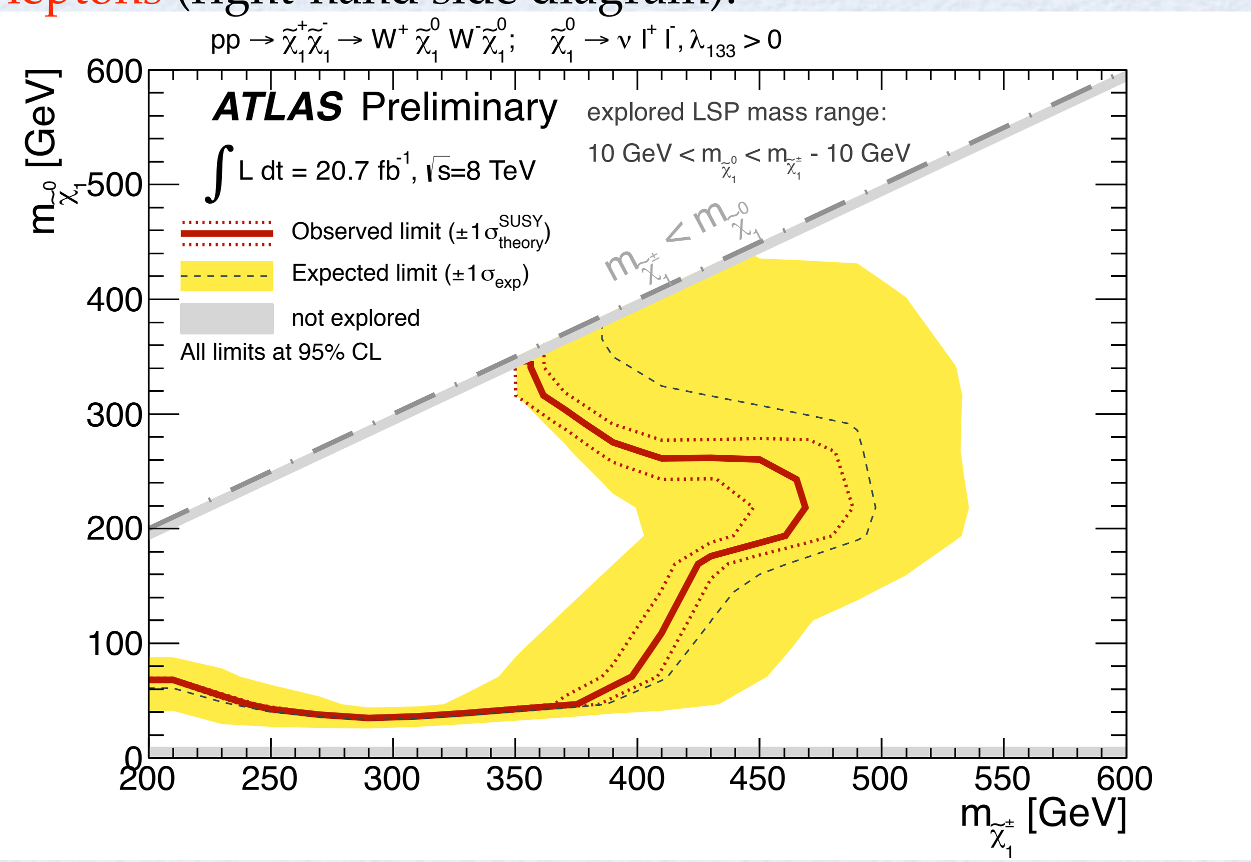
This is an example of $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ production, where the NLSP $\tilde{\chi}_1^{\pm}$ are wino-like and decay as $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm(*)}\tilde{\chi}_1^0$





In RPV scenario with $\lambda_{121} \neq 0$ the LSP decay leads to events with electrons and muons in the final state (left-hand side diagram), whereas $\lambda_{133} \neq 0$ will produce predominantly tau leptons (right-hand side diagram).





- SR0noZb is used to set limits in $\lambda_{121} \neq 0$ model (left-hand side plot).
- The statistical combination of SR0Z, SR0noZb, SR1Z and SR1noZ regions is used to set limits in $\lambda_{133} \neq 0$ model (right-hand side plot) to maximise the sensitivity.

More RPV 4-lepton plots