Searches for direct electroweak production of charginos, neutralinos and sleptons with leptons and MET in ATLAS

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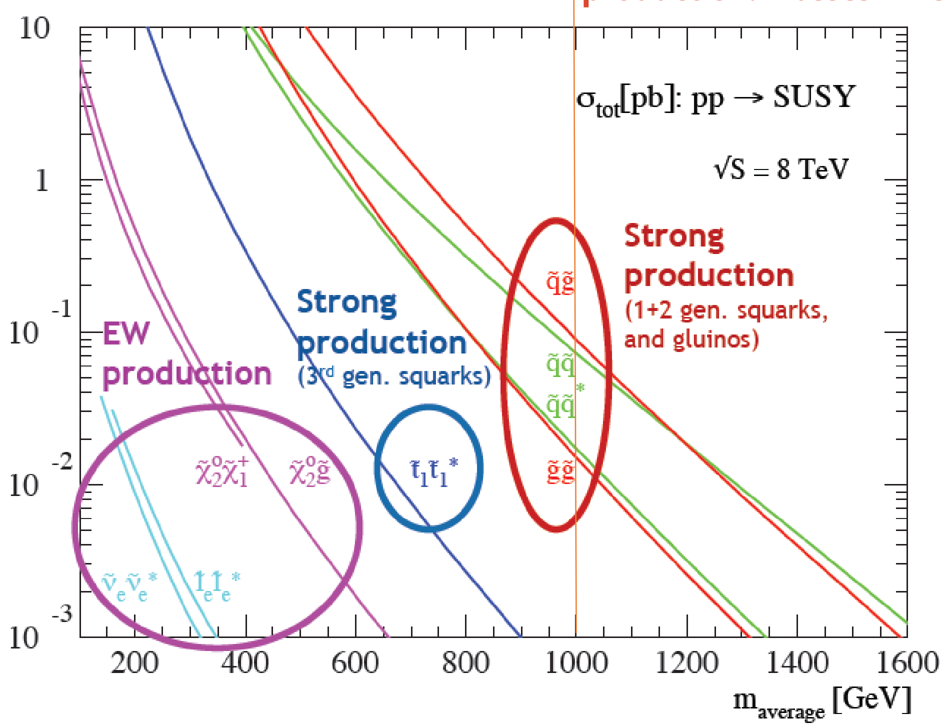
Introduction

- Search for electroweak (EWK) SUSY below the TeV scale is motivated by naturalness arguments.
- EWK production has a low cross-section compared to strong production
  - Very challenging searches
  - But leads to multi-lepton signatures with very low SM background.
- If strong production is suppressed, EWK processes could be the dominant SUSY production at the LHC.



Generic signature: >=1 lepton(s) in the final state arising from the decay of charginos/neutralinos via sleptons/sneutrinos, gauge bosons or Higgs.

EWK benchmark searches

* All analyses are based on 20.3 fb-1 LHC Run-I data.

1 lepton(e/μ)+bb	2 hadronic τ	2 leptons(e/μ)	3 leptons(e/μ/τ)	4 leptons(e/μ/τ)
• ATLAS-CONF-2013-093	• arXiv:1407.0350	• JHEP 05(2014) 071	• JHEP 04(2014) 169	• arXiv:1405.5086
• $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via WH	• $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via stau/sneutrino • $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ via stau/sneutrino • Stau pair	• $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$via WZ • $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ via slepton/sneutrino/WW • Slepton pair	• $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via slepton/stau/sneutrino/WZ/WH	• $\tilde{\chi}_2^0 \tilde{\chi}_3^0$via slepton/stau/ZZ • $\tilde{\chi}_1^\pm \tilde{\chi}_1^0$
• Simplified model	• Simplified model • pMSSM	• Simplified model • pMSSM	• Simplified model • pMSSM	• Simplified model • GGM

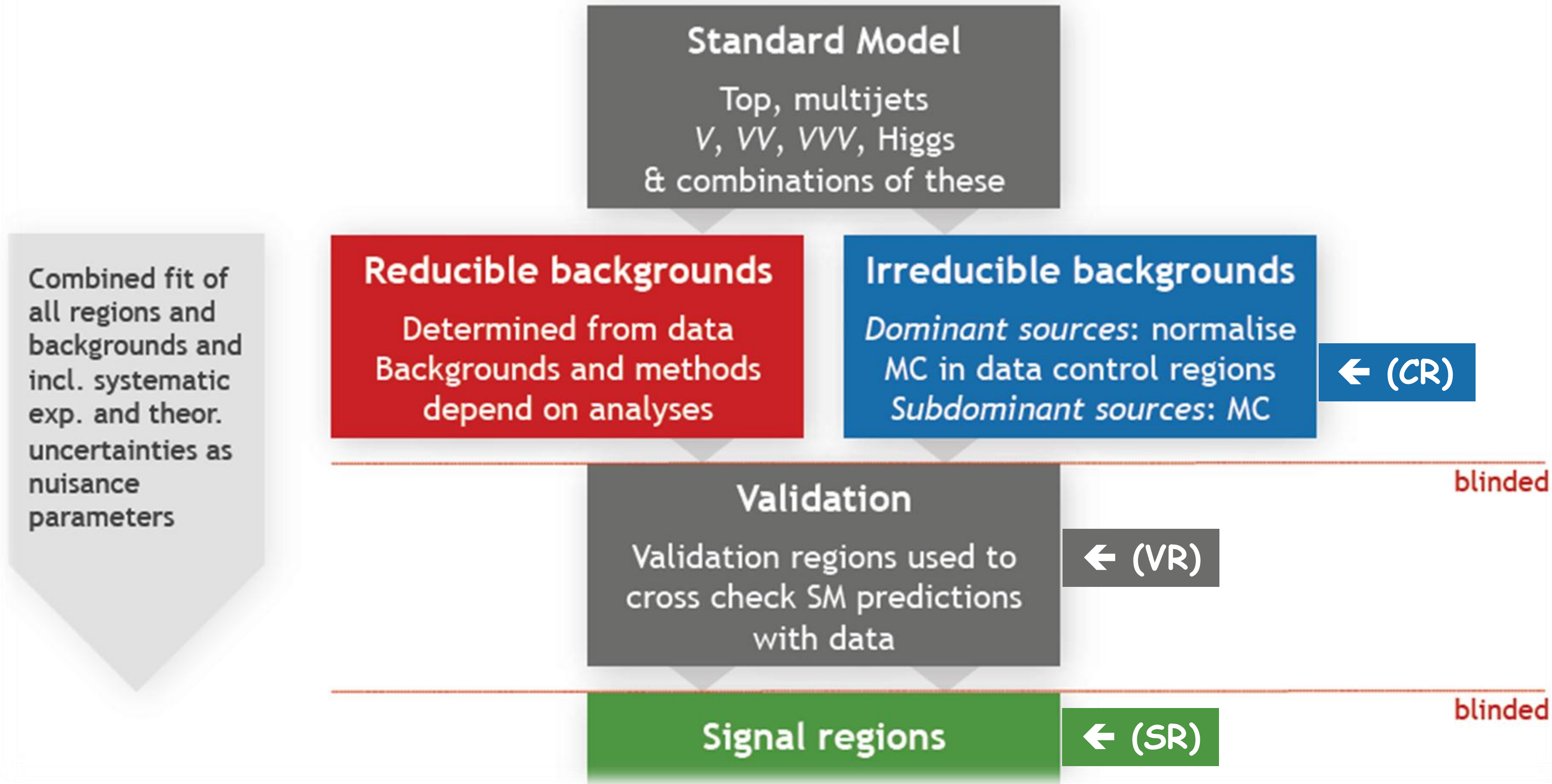
- Simplified model
  - Pure states: no mixing of wino, bino and higgsinos.
  - One decay considered each time: e.g. BR($\tilde{l} \to l\tilde{\chi}_1^0$)=100%.
- Phenomenological MSSM (pMSSM)
  - 19 free parameters (MSSM + phenomenological constraints).
- General gauge mediation (GGM)
  - Specific SUSY breaking mechanism is assumed (gravitino as LSP).

** Targeting chargino, neutralino and slepton production.*

** R-parity conservation is assumed in models presented here.*

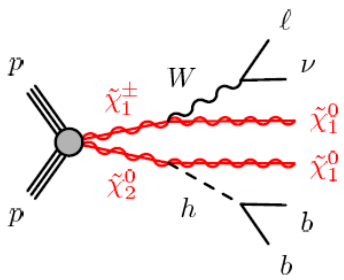
SM Background Modelling

- SUSY searches rely on accurate modelling of the Standard Model backgrounds.



1 lepton(e/μ)+bb

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



* Wino-like $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{0}$ (mass degenerate); bino-like $\tilde{\chi}_1^{0}$

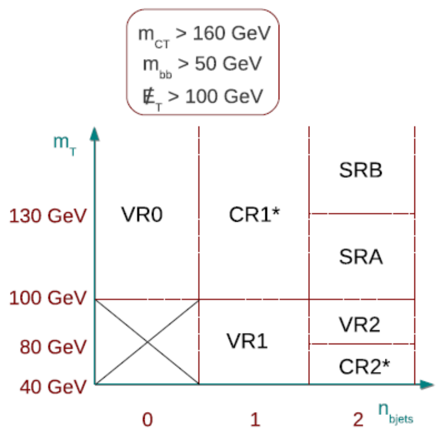
* Assume 100% branching of $\tilde{\chi}_1^{\pm}$ via W and $\tilde{\chi}_2^{0}$ via 125GeV SM-like lightest higgs

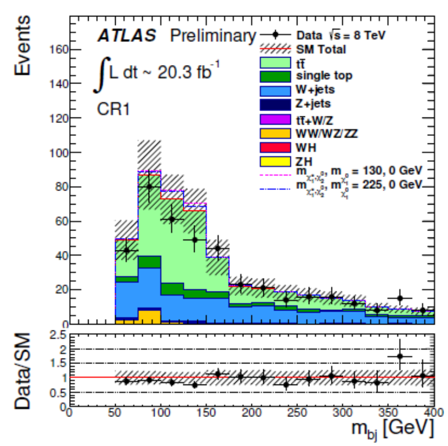
* For on shell higgs: $\triangle M(\tilde{\chi}_2^{0}, \tilde{\chi}_1^{0}) > 125$GeV

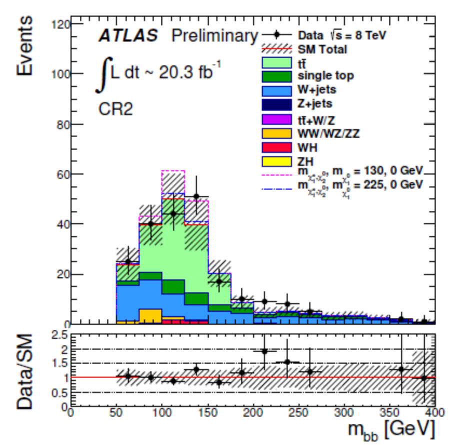
* 125GeV SM-like higgs has highest BR for h→bb.

First search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ production via Higgs from the LHC!

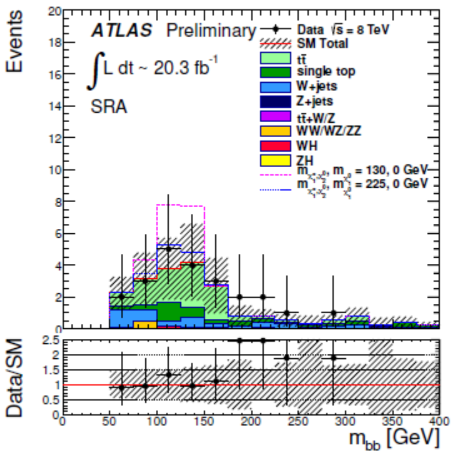
- Search for events with one lepton(e,μ), MET and 2 b-tagged jets consistent with a SM higgs at 125 GeV.
- 2 SRs designed targeting large $\triangle M(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^{0}, \tilde{\chi}_1^{0})$ and low/high $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^{0}$ masses.
- Main backgrounds: ttbar, W+jets
  - Reduced using mCT(mass of pair produced particles with semi-invisible decay)
  - In background fit, only mbb sidebands are used to avoid signal contamination impact.

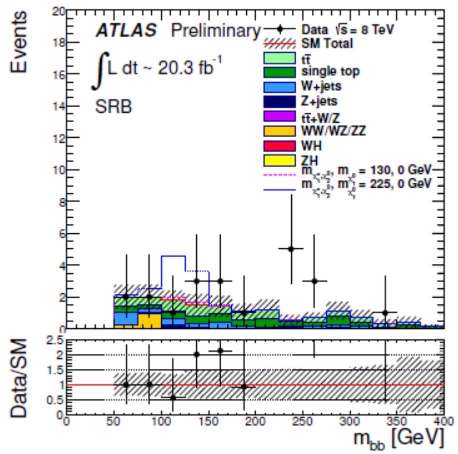






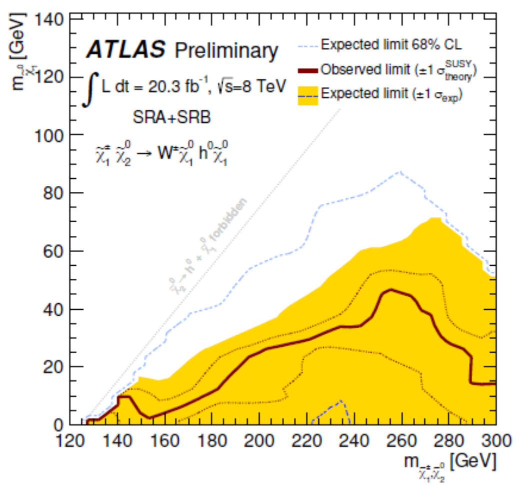
1 lepton(e/μ)+bb



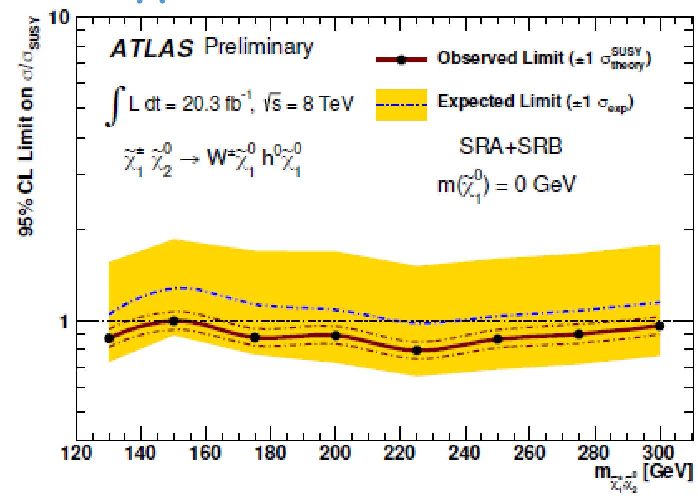


- No excess observed beyond SM expectation.

Exclusion limit



1D upper limit for massless LSP

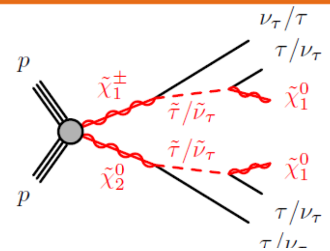


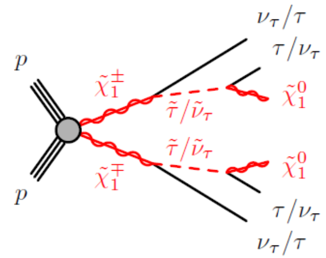
arXiv:1407.0350

2 hadronic τ

NEW!

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via stau/sneutrino	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via stau/sneutrino	Direct stau pair





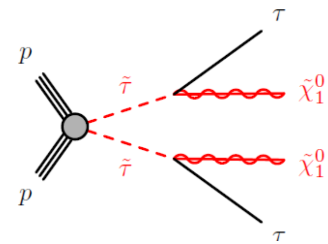
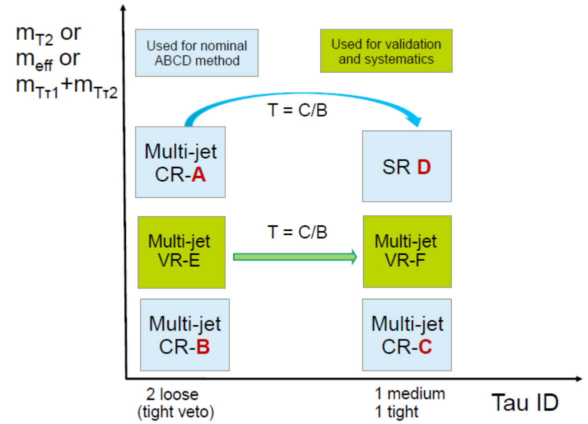


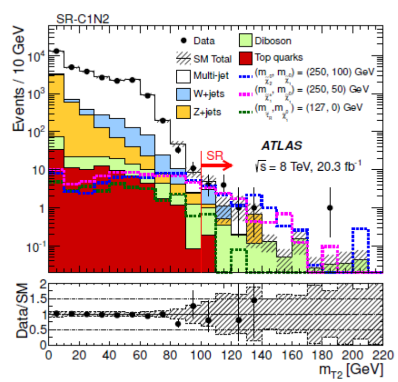
Illustration of "ABCD" method

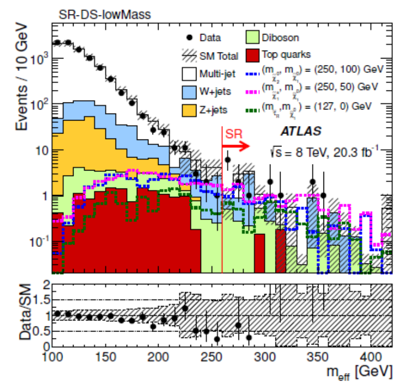


* $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0$(pure wino, mass degenerate); $\tilde{\chi}_1^0$(pure bino)
* $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0$ decay 100% to final state with (s)taus in simplified mode

First search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ production with hadronic tau decays from the LHC!

- **4 SRs designed targeting different models: one for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$; one for $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$; two for direct stau model, targeting high/low mass region.**
- **Main background:**
  - **W+jets(25-50%): one fake tau + one real tau**
  - **multi-jet(13%-30%): two fake taus ← estimated by data-driven "ABCD" method**



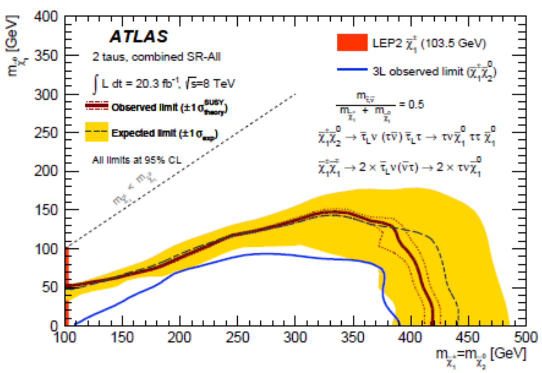


arXiv:1407.0350

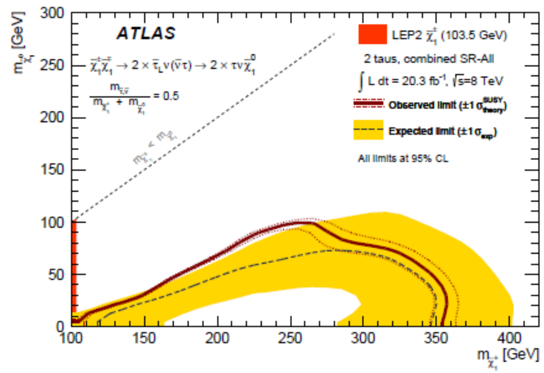
2 hadronic τ

NEW!

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}+\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via stau/sneutrino

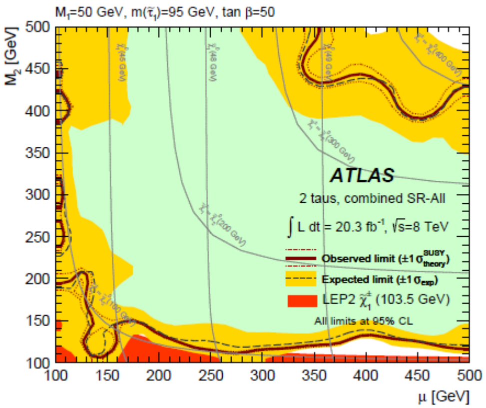


$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via stau/sneutrino

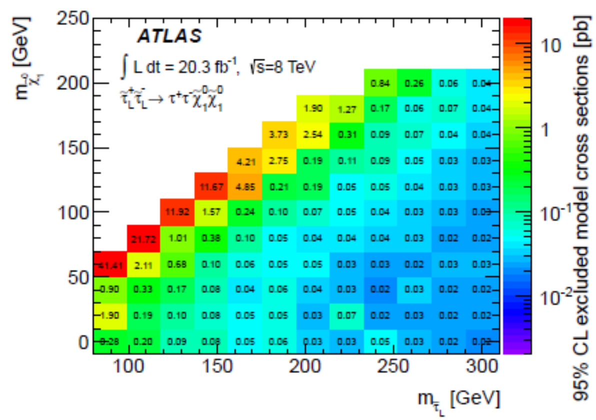


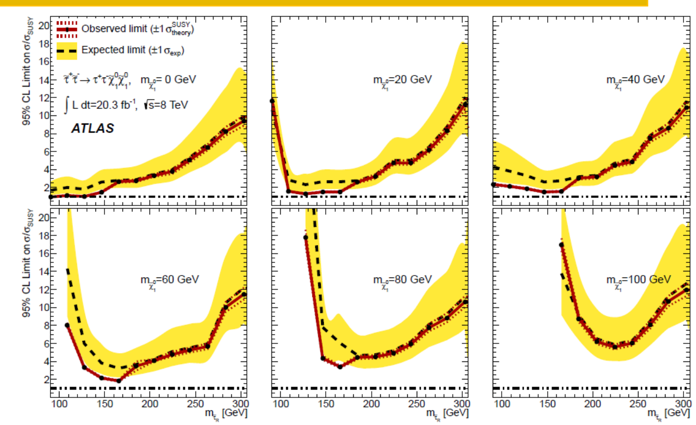
- No excess beyond SM expectation.
- Upper limits have been set on the direct stau pair production cross-section /signal strength.

pMSSM stau-enriched



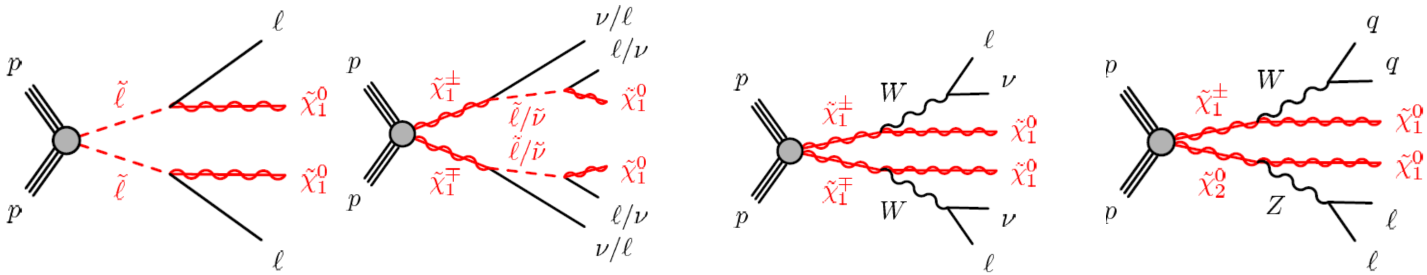
Direct stau pair





2 leptons(e/μ)

Direct slepton pair	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via slepton/sneutrino	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via WW	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ via WZ



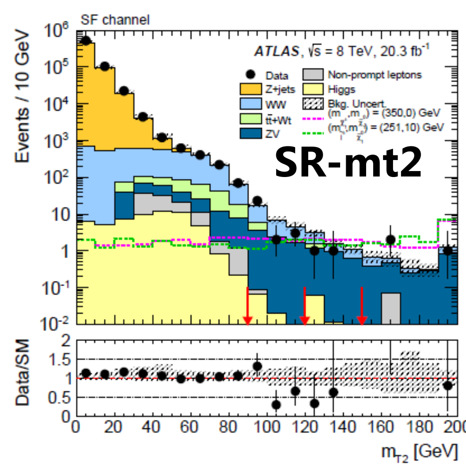
* $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{0}$ (pure wino, mass degenerate); $\tilde{\chi}_1^{0}$ (pure bino)

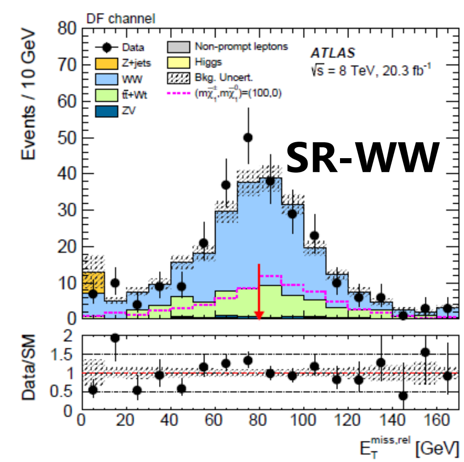
[SR-mt2] 3SRs: slepton mediated

[SR-WW] 3SRs: WW mediated

[SR-WZ] 1SRs:WZ mediated

- 7 SRs designed targeting different models.
  - The same flavor and different flavor are considered separately in each SR.
- Main backgrounds: top-quark(ttbar and Wt) and dibosons.
  - For SM ttbar and WW: mt2 has an upper end-point at the W mass.





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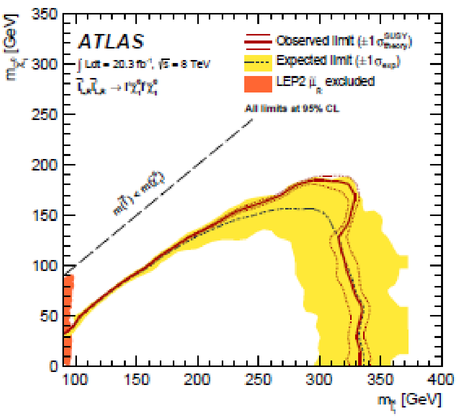
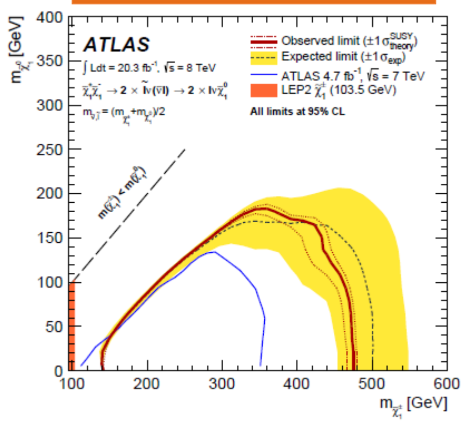
2 leptons(e/μ)

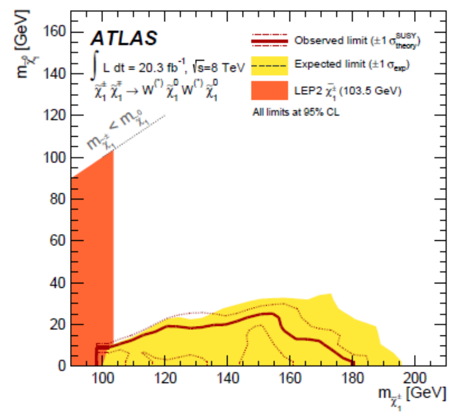
Direct slepton pair



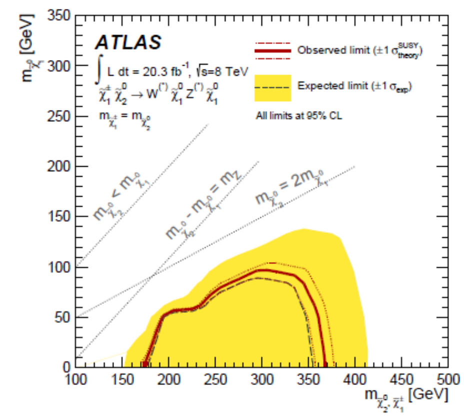
$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via slepton/sneutrino



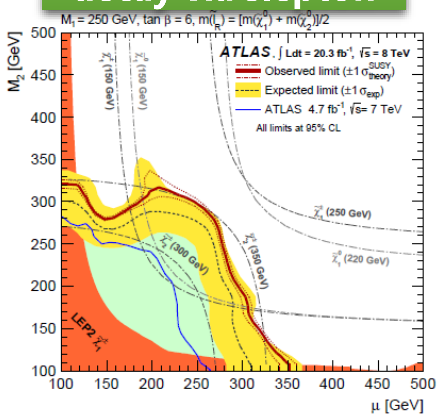
$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via WW



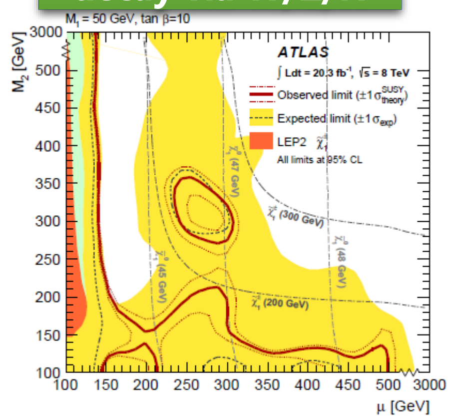
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ via WZ



pMSSM decay via slepton



pMSSM decay via W/Z/H



- No excess beyond SM expectation.
- $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ via slepton: Large improvement w.r.t 7TeV results (blue line).
- The exclusions are further extended by combining with three lepton analysis (shown later).

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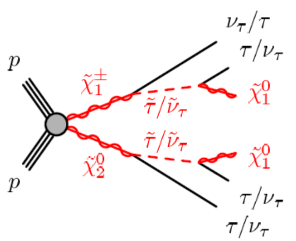
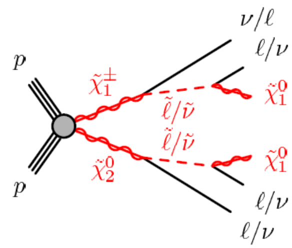
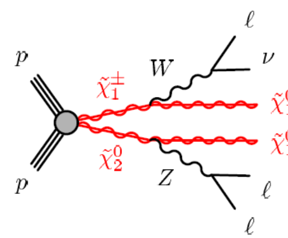
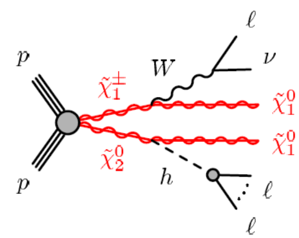
3 leptons(e/μ/τ)

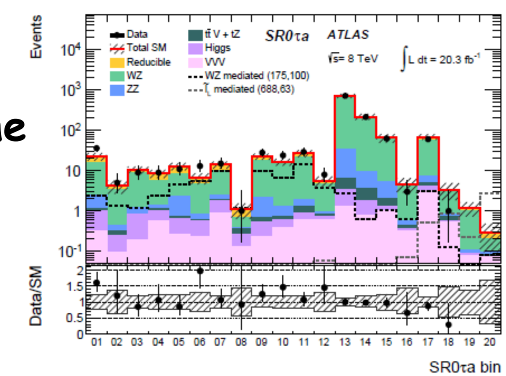
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via stau/sneutrino	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via slepton/sneutrino	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via WZ	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via WH

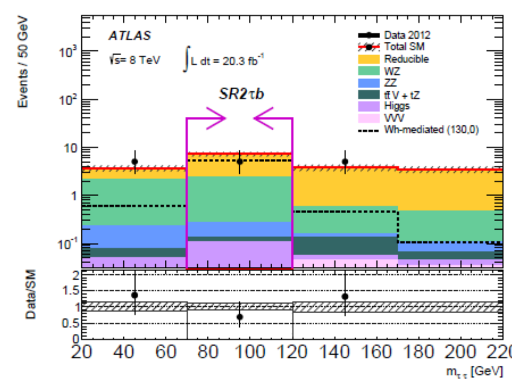





* $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ (pure wino, mass degenerate); $\tilde{\chi}_1^0$(pure bino)

1 SR: 2 taus + light lepton	1 SR: 0 tau + light leptons *characterized by 20 independent bins*	3 SRs: 0,1,2 taus + light leptons

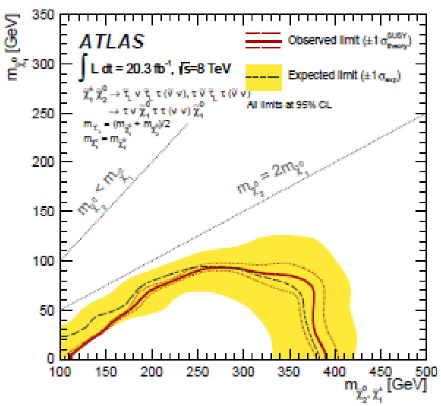
- Analysis includes up to 2 hadronic taus.
- 5 SRs are defined according to the flavor and charge of the leptons, targeting different models.
- Main backgrounds: diboson, triboson, ttbarV, tZ and VH.



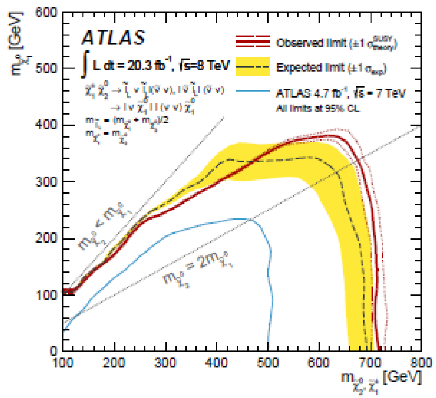


3 leptons(e/μ/τ)

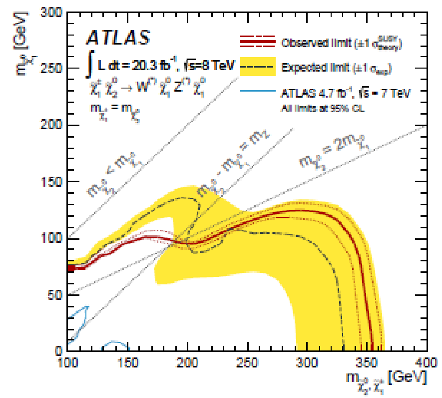
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via stau/sneutrino



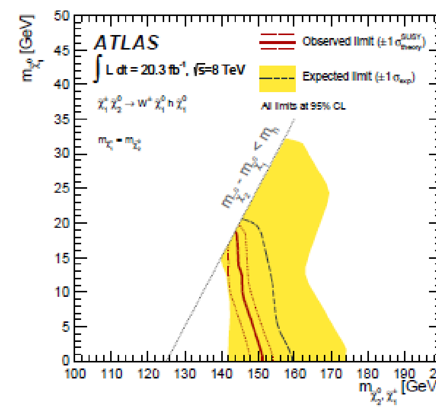
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via slepton/sneutrino



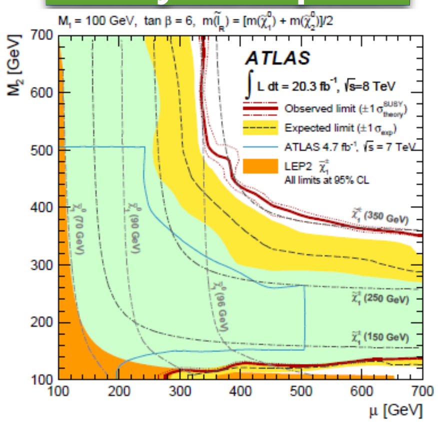
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via WZ



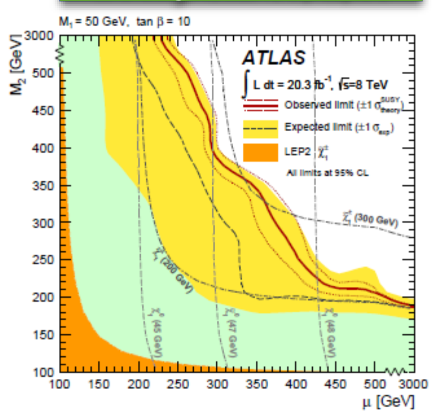
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via WH



pMSSM decay via slepton



pMSSM decay via W/Z/H



- No excess beyond SM expectation.
- $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via slepton/WZ: Large improvement w.r.t 7TeV results (blue line).
- The exclusions are further extended by combining with two lepton analysis (shown later).

Combination of 2- and 3-lepton analysis

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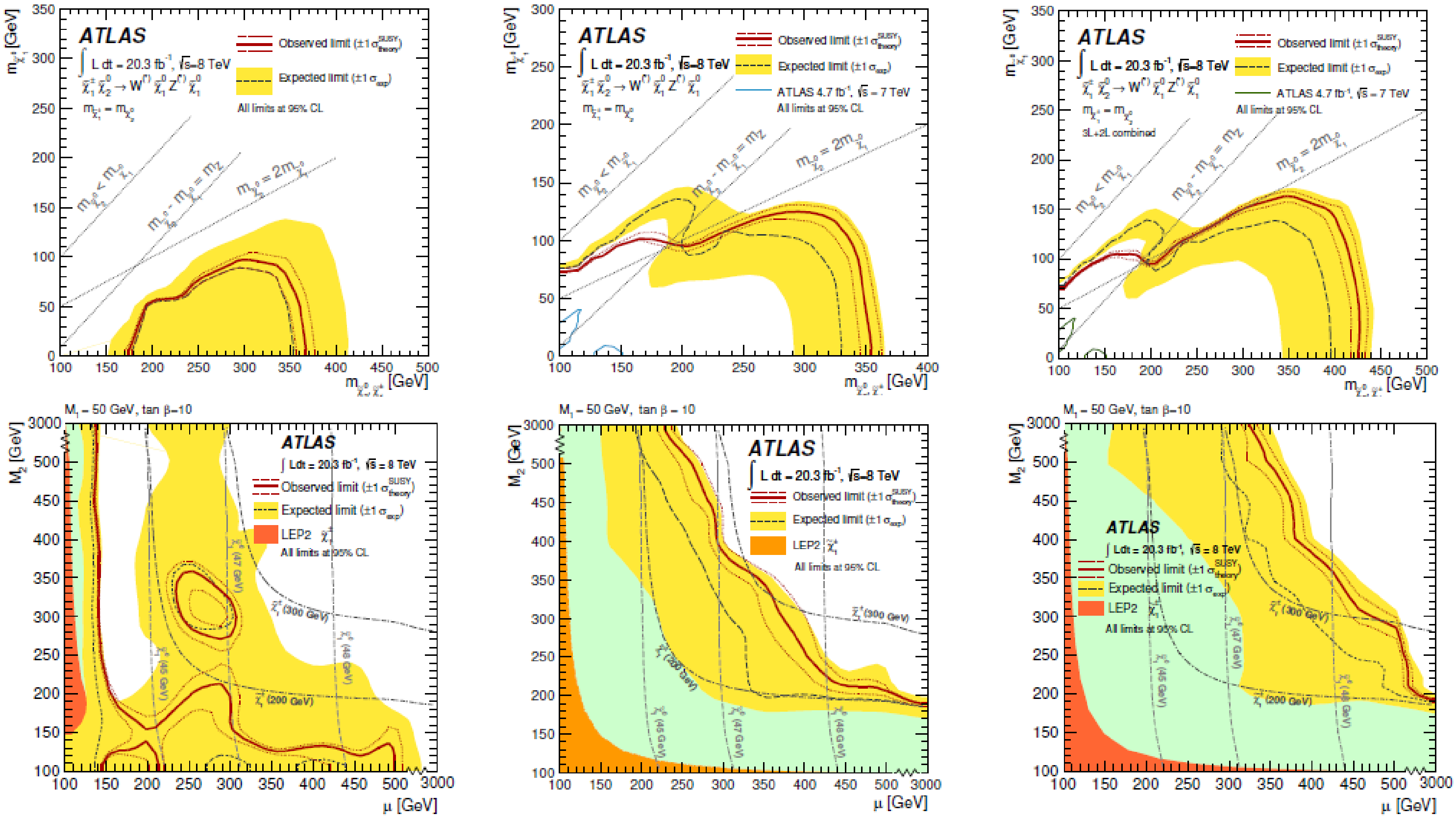
2 lepton results	3 lepton results	Combined results

WZ Mediated

pMSSM, no $\tilde{\ell}$,

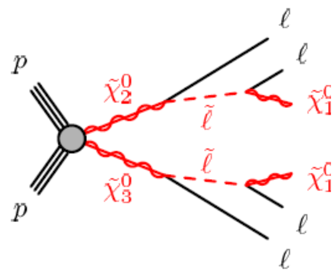


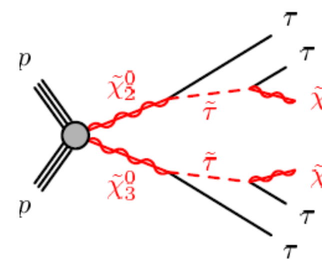
- Improved exclusion limits with combination!

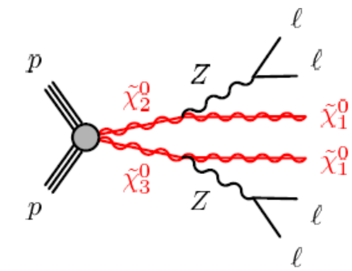
arXiv:1405.5086

4 leptons(e/μ/τ)

$\tilde{\chi}_2^0\tilde{\chi}_3^0$ via slepton	$\tilde{\chi}_2^0\tilde{\chi}_3^0$ via stau	$\tilde{\chi}_2^0\tilde{\chi}_3^0$ via ZZ



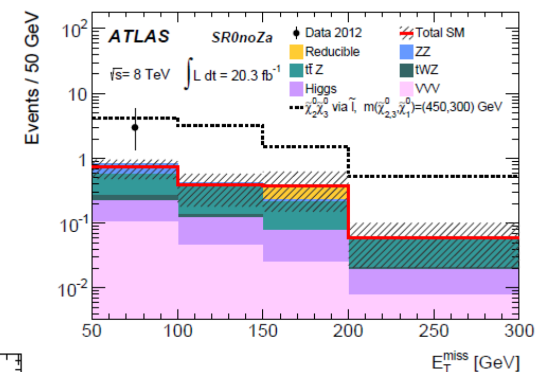




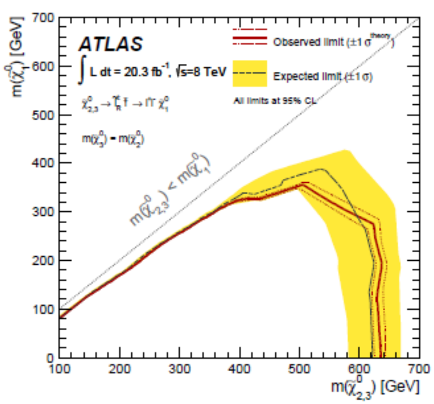
RPC-Simplified mode:

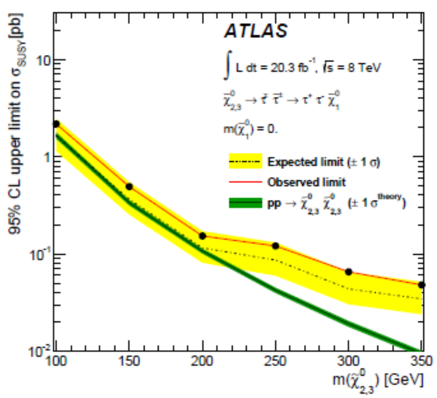
*higgsino-like $\tilde{\chi}_2^0, \tilde{\chi}_3^0$(mass degenerate)

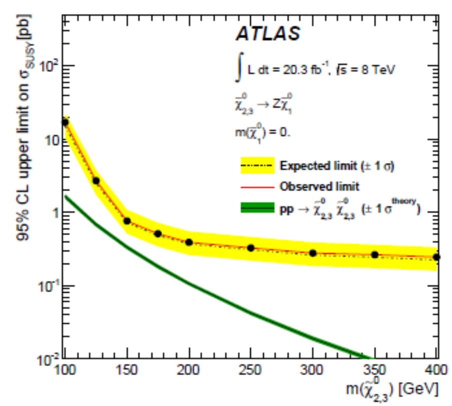
*bino-like $\tilde{\chi}_1^0$



- 9 SRs are defined for different models with Z-veto/Z-window.
- Main SM background: ZZ/gamma*, Z/gamma*+X
  - Reduced by multi-lepton(tau) requirements, Z-veto, Etmiss cut.



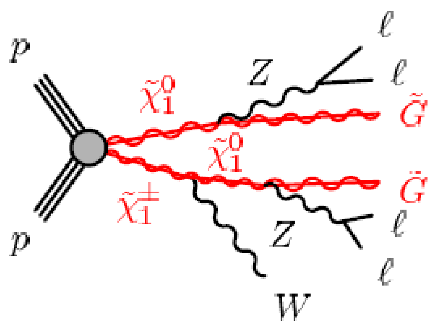




- No excess beyond SM expectation.
- Upper limits have been set on the production cross-section for $\tilde{\chi}_2^0\tilde{\chi}_3^0$ via stau/ZZ model.

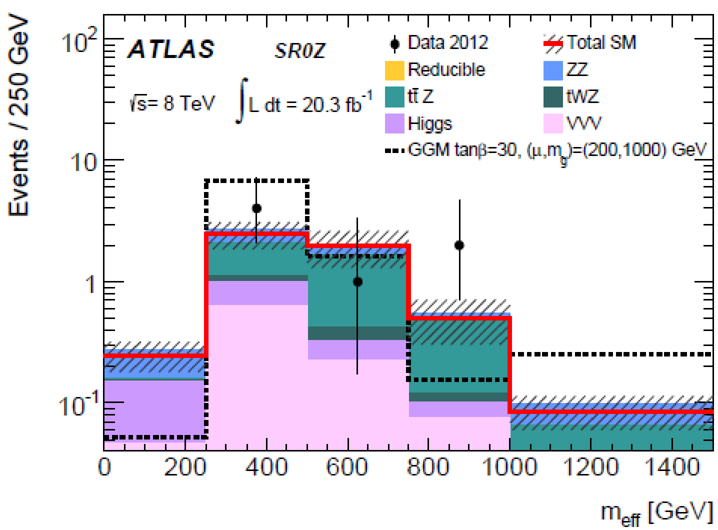
4 leptons(e/μ/τ)

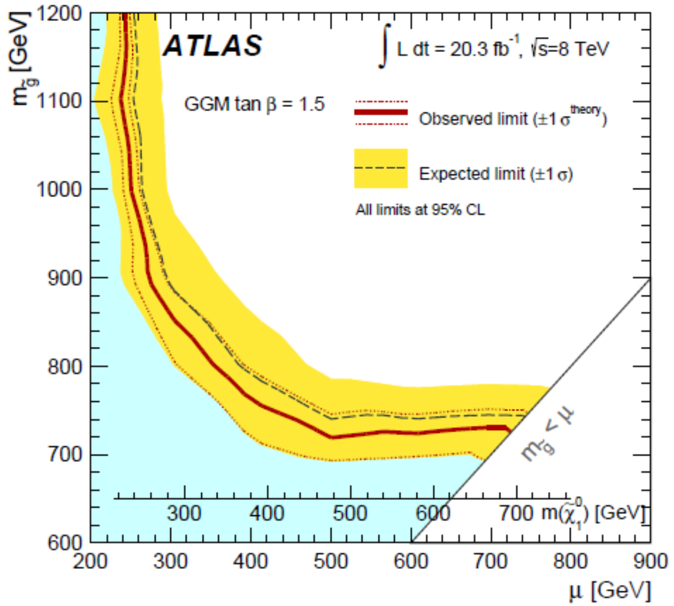
$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0$



RPC-GGM mode:

- A generalization of GMSB
- Gravitino as LSP
- higgsino-like $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_1^{\pm}$ co-NLSPs
- SR: Z window required

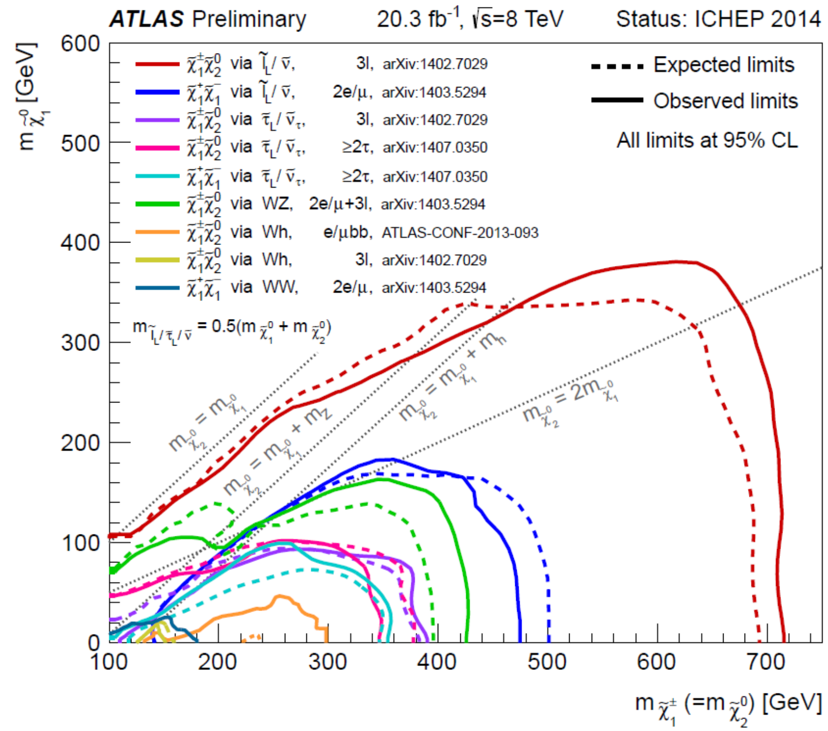




Summary

Light gauginos are favoured by naturalness.

- Search for direct gaugino/slepton production using 8TeV LHC Run-I data.
  - The analyses based on different lepton multiplicity/flavor.
  - No significant excess observed beyond SM expectation.
  - Large areas of parameter space have been excluded in Simplified model as well as pMSSM scenarios.



Looking forward to 13/14 TeV LHC Run-II data !

THANK YOU ☺

Extra slides

Discriminating variables

$E_T^{miss, rel}$ projection of E_T^{miss} on perpendicular axis

Reduces mis-measured E_T^{miss}

$$E_{\mathrm{T}}^{\mathrm{miss,rel.}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi_{\ell,j} \geq \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} \times \sin \Delta\phi_{\ell,j} & \text{if } \Delta\phi_{\ell,j} < \pi/2 \end{cases}$$

m_{T2} stransverse mass

kinematic endpoint ~ mass of decaying particle

$$m_{\mathrm{T2}} = \min_{\mathbf{q}_{\mathrm{T}}} \left[\max \left(m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}^{\ell 1}, \mathbf{q}_{\mathrm{T}}), m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}^{\ell 2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}} - \mathbf{q}_{\mathrm{T}}) \right) \right]$$

where $m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}, \mathbf{q}_{\mathrm{T}}) = \sqrt{2(p_{\mathrm{T}} q_{\mathrm{T}} - \mathbf{p}_{\mathrm{T}} \cdot \mathbf{q}_{\mathrm{T}})}$

m_{CT} without boost-correction:

$$m_{\mathrm{CT}}^2(v_1, v_2) = [E_{\mathrm{T}}(v_1) + E_{\mathrm{T}}(v_2)]^2 - [\mathbf{p}_{\mathrm{T}}(v_1) - \mathbf{p}_{\mathrm{T}}(v_2)]^2 ,$$

where v_1 and v_2 denote the visible particles or particle aggregates. with:

- b_1 and b_2 as aggregates
- lepton (e or μ) is the downstream vector combined with $E_{\mathrm{T}}^{\mathrm{miss}}$ for boost-correction

In $1l + \bar{b}b + E_T^{miss}$ analysis, m_{CT} is designed to build an endpoint in ttbar:

$$m_{\mathrm{CT}}^{\max} \approx \frac{m_{\mathrm{heavy}}^2 - m_{\mathrm{invisible}}^2}{m_{\mathrm{heavy}}}$$

$$m_{\mathrm{CT}}^{\max} \approx \frac{m_t^2 - m_W^2}{m_t} \approx 135\ GeV$$

$$m_{\mathrm{eff}} = E_{\mathrm{T}}^{\mathrm{miss}} + p_{\mathrm{T}}^{\tau 1} + p_{\mathrm{T}}^{\tau 2}$$

1 lepton(e/μ)+bb

Dominant systematics:

- jet energy scale 9.0% (11.0%)
- b-tagging 4.0%
- theoretical ones 40%(20%)
- largest is single top 27% (16%).

A combination of single-electron and single-muon triggers.
electron trigger: 24 GeV (isolated) and 60 GeV (non-isolated).
muon trigger: 24 GeV and 36 GeV.

arXiv:1407.0350

2 hadronic τ

Di-tau trigger: p_T > 40 (25) GeV.

Source	W+jets	Diboson	Z+jets	Top
MC statistics	16–36%	15–28%	44–80%	23–50%
Theoretical uncertainty	17–30%	17–27%	25–30%	10–20%
Tau ID and trigger	10–18%	20–21%	10–20%	22–28%
Tau Energy Scale	12–20%	3–13%	4–12%	2–7%
Others	1–10%	3–9%	5–10%	10–20%
Total	34–48%	35–44%	58–85%	43–62%

Table 8. Summary of the systematic uncertainties for the multi-jet background estimation. The total uncertainty is the sum in quadrature of each source.

Systematic Source	SR-C1N2	SR-C1C1	SR-DS-highMass	SR-DS-lowMass
Correlation	4.9%	1.6%	8.0%	14%
Non-multi-jet subtraction in Region A	8.0%	12%	21%	13%
Non-multi-jet subtraction in Region B	1.0%	0.4%	1.2%	0.5%
Non-multi-jet subtraction in Region C	2.7%	1.4%	3.6%	2.0%
Number of events in Region A	61%	38%	133%	57%
Number of events in Regions C and B	1.0%	2.0%	8.4%	1.5%
Total	62%	40%	135%	60%

SR-C1N2	SR-C1C1	SR-DS-highMass	SR-DS-lowMass
≥ 2 OS taus	2 OS taus	≥ 2 OS taus	≥ 2 OS taus
b-jet veto	jet veto	looser jet-veto	looser jet-veto
Z-veto	Z-veto	Z-veto	Z-veto
		$\Delta R(\tau,\tau) < 3$	$\Delta R(\tau,\tau) < 3$
$E_T^{miss} > 40$ GeV	$m_{T2} > 30$ GeV	$m_{T2} > 60$ GeV	$m_{T2} > 30$ GeV
$m_{T2} > 100$ GeV	$m_{T\tau 1} + m_{T\tau 2} > 250$ GeV	$m_{eff} > 230$ GeV	$m_{eff} > 260$ GeV

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2 leptons(e/μ)

A combination of two-lepton triggers: the p_T thresholds are 18–25 GeV for the higher-p_T lepton 8–14 GeV for the other lepton.

Table 4. Systematic uncertainties (in %) on the total background estimated in different signal regions. Because of correlations between the systematic uncertainties and the fitted backgrounds, the total uncertainty can be different from the quadratic sum of the individual uncertainties.

	m_{T2}^{90}		m_{T2}^{120}		m_{T2}^{150}		WWa		WWb		WWc		Zjets
	SF	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF
CR statistics	5	3	6	4	8	4	5	5	5	3	6	4	1
MC statistics	5	7	7	12	10	23	3	4	5	8	6	10	14
Jet	4	1	2	1	5	7	3	6	4	2	4	3	11
Lepton	1	2	1	1	4	1	1	3	2	3	1	8	4
Soft-term	3	4	1	1	2	8	<1	2	3	5	1	6	5
b-tagging	1	2	<1	<1	<1	<1	1	1	1	2	<1	1	2
Non-prompt lepton	<1	1	<1	<1	1	<1	1	1	1	2	<1	1	<1
Luminosity	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2
Modelling	11	13	21	31	18	40	6	6	8	10	15	19	42
Total	13	16	24	34	23	47	9	11	12	14	17	24	47

Table 1. Signal region definitions. The criteria on $|m_{\ell\ell} - m_Z|$ are applied only to SF events. The two leading central light jets in SR-Zjets must have $p_T > 45$ GeV.

SR	m_{T2}^{90}	m_{T2}^{120}	m_{T2}^{150}	WWa	WWb	WWc	Zjets
lepton flavour	DF,SF	DF,SF	DF,SF	DF,SF	DF,SF	DF,SF	SF
central light jets	0	0	0	0	0	0	≥ 2
central b-jets	0	0	0	0	0	0	0
forward jets	0	0	0	0	0	0	0
$\|m_{\ell\ell} - m_Z\|$ [GeV]	> 10	> 10	> 10	> 10	> 10	> 10	< 10
$m_{\ell\ell}$ [GeV]	—	—	—	< 120	< 170	—	—
$E_T^{miss,rel}$ [GeV]	—	—	—	> 80	—	—	> 80
$p_{T,\ell\ell}$ [GeV]	—	—	—	> 80	—	—	> 80
m_{T2} [GeV]	> 90	> 120	> 150	—	> 90	> 100	—
$\Delta R_{\ell\ell}$	—	—	—	—	—	—	[0.3,1.5]
m_{jj} [GeV]	—	—	—	—	—	—	[50,100]

3 leptons(e/μ/τ)

Trigger	p_T threshold [GeV]
Single Isolated e	25
Single Isolated μ	25
Double e	14,14 25,10
Double μ	14,14 18,10
Combined $e\mu$	14(e),10(μ) 18(μ),10(e)

Table 9. Summary of the dominant systematic uncertainties in the background estimates for each signal region. Uncertainties are quoted relative to the total expected background. For the 20 bins of the SR0τa the range of the uncertainties is provided.

	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%

Table 3. Summary of the selection requirements for the signal regions. The index of the signal region corresponds to the number of required τ leptons. The SR0τa bin definitions are shown in table 4. Energies, momenta and masses are given in units of GeV. The signal models targeted by the selection requirements are also shown.

Signal region	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_T^{miss}	binned	> 50	> 50	> 50	> 60
Other	m_{SFOS} binned m_T binned	$p_T^{3rd\,\ell} > 20$ $\Delta\phi^{min}_{\ell\ell'} \leq 1.0$	$p_T^{2nd\,\ell} > 30$ $\sum p_T^\ell > 70$ $m_{\ell\tau} < 120$ m_{ee} Z veto	$m_{T2}^{max} > 100$	$\sum p_T^\tau > 110$ $70 < m_{\tau\tau} < 120$
Target model	$\tilde{\ell}$,WZ-mediated	Wh-mediated	Wh-mediated	$\tilde{\tau}_L$-mediated	Wh-mediated

SR0τa bin	m_{SFOS}	m_T	E_T^{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

4 leptons(e/μ/τ)

Trigger channel	p_T or E_T threshold [GeV]
Single isolated e/μ	25
Double e	14, 14 25, 10
Double μ	14, 14 18, 10
$e+\mu$	$14(e)$, $10(\mu)$ $18(\mu)$, $10(e)$

Experimental		Theoretical	
Jet energy scale	2.4%	σ: $t\bar{t}+Z/WW$ [75, 76]	30%
Jet energy resolution		$A\epsilon$: $t\bar{t}+Z$	30–40%
	5.5%	σ: ZZ/γ^*	5%
e efficiency	3.5%	$A\epsilon$: ZZ/γ^*	5–20%
τ efficiency	3.3%	σ: VVV/tWZ	50%
E_T^{miss} energy scale	2.7%	$\sigma A\epsilon$: Vh/VBF [72]	20%
E_T^{miss} resolution	2.7%	$\sigma A\epsilon$: ggF/$t\bar{t}h$ [72]	100%
Luminosity	2.8%	Reducible	
Trigger	5%	$\geq 0\tau$ SRs	$\sim 100\%$
MC sample size	$\lesssim 30\%$	$\geq 1\tau/2\tau$ SRs	30–50%

	N(ℓ)	N(τ)	Z-veto	E_T^{miss} [GeV]		m_{eff} [GeV]
SR0noZa	≥ 4	≥ 0	SFOS, SFOS+ℓ, SFOS+SFOS	>50		–
SR1noZa	=3	≥ 1	SFOS, SFOS+ℓ	>50		–
SR2noZa	=2	≥ 2	SFOS	>75		–
SR0noZb	≥ 4	≥ 0	SFOS, SFOS+ℓ, SFOS+SFOS	>75	or	>600
SR1noZb	=3	≥ 1	SFOS, SFOS+ℓ	>100	or	>400
SR2noZb	=2	≥ 2	SFOS	>100	or	>600
	N(ℓ)	N(τ)	Z-requirement	E_T^{miss} [GeV]		
SR0Z	≥ 4	≥ 0	SFOS	>75		–
SR1Z	=3	≥ 1	SFOS	>100		–
SR2Z	=2	≥ 2	SFOS	>75		–

- The SM background processes are classified into --
  - "irreducible" background
    - "real" leptons: prompt and isolated; directly produced from sparticles or weak bosons.
  - "reducible" background
    - "fake" leptons: originate from a misidentified light-flavour quark or gluon jet (referred to as "light flavour").
    - "non-prompt" leptons can originate from a semileptonic decay of a heavy-flavour quark, or an electron from a photon conversion.