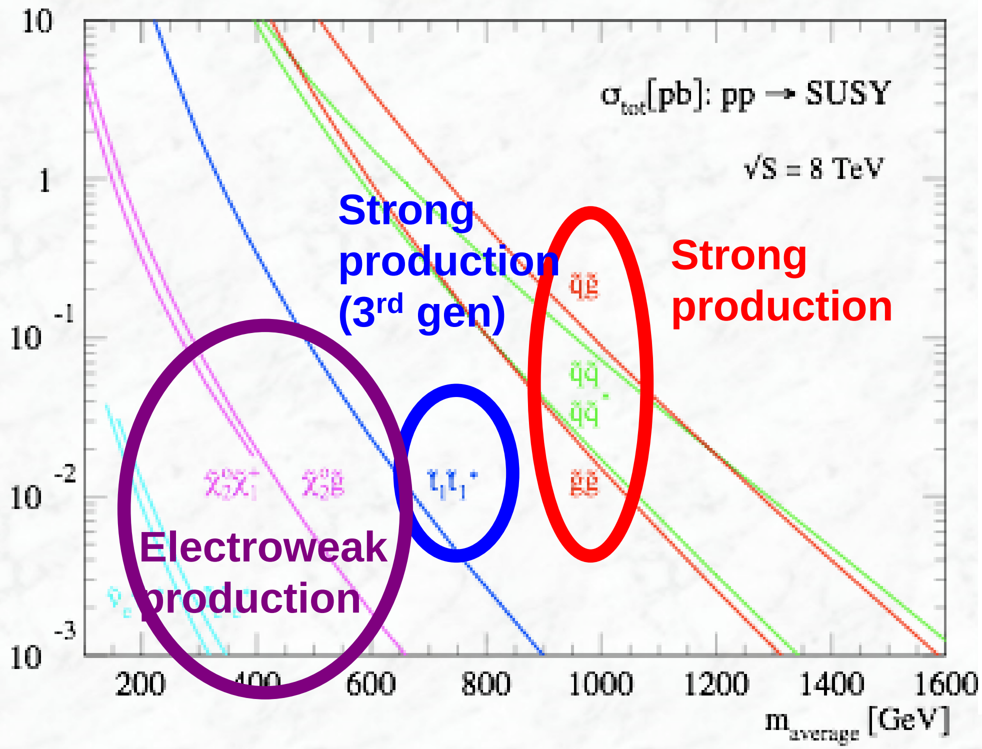
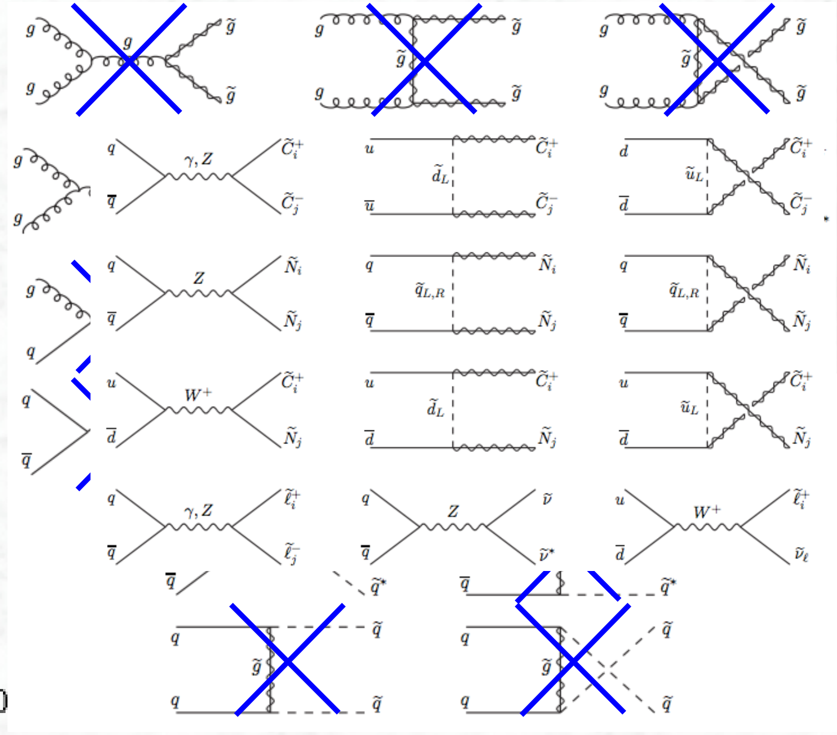
What do the LHC data say ?

What processes are we looking for?



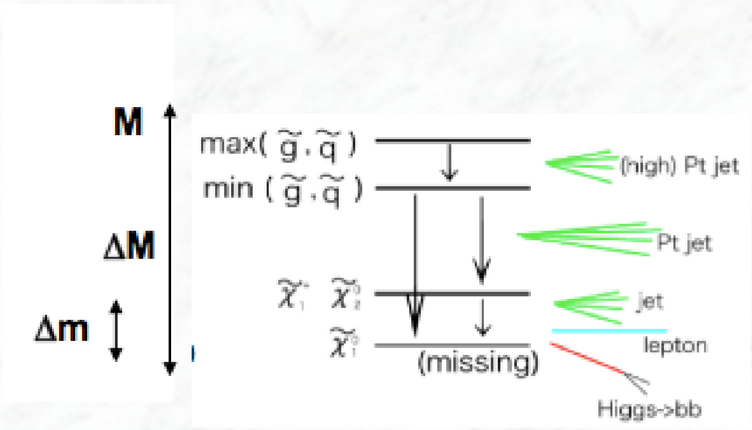


- **ATLAS has set up dedicated search strategies for all production mechanism**

- **Only strong production (mainly 3rd generation) covered in this lecture**

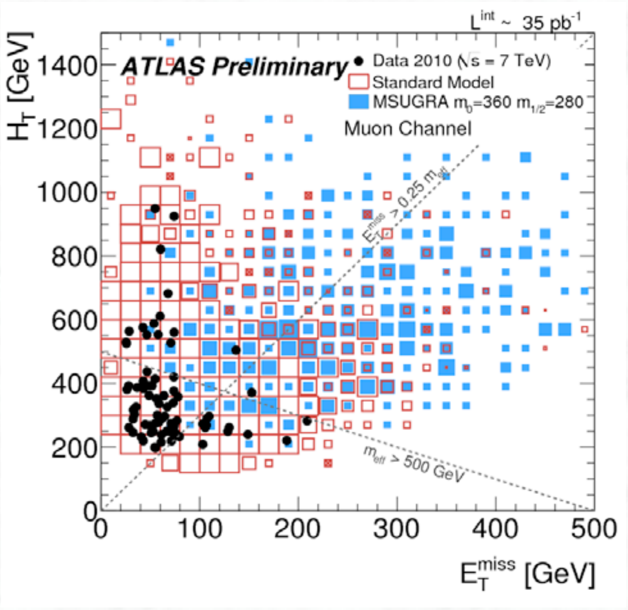
What we are typically doing

- Heavy sparticles produced in the primary collision
- They decay into lighter objects, emitting (high) p_T jets and possibly other objects (leptons, photons) and MET (LSP)
- A "typical" SUSY event will have large E_T^{miss} and large H_T
- Useful variables:



$$H_T = \sum_{jets} p_T^{jets} (+ \sum_{l} p_T^{l} + ...)$$

$$M_{eff} = E_T^{miss} + H_T$$

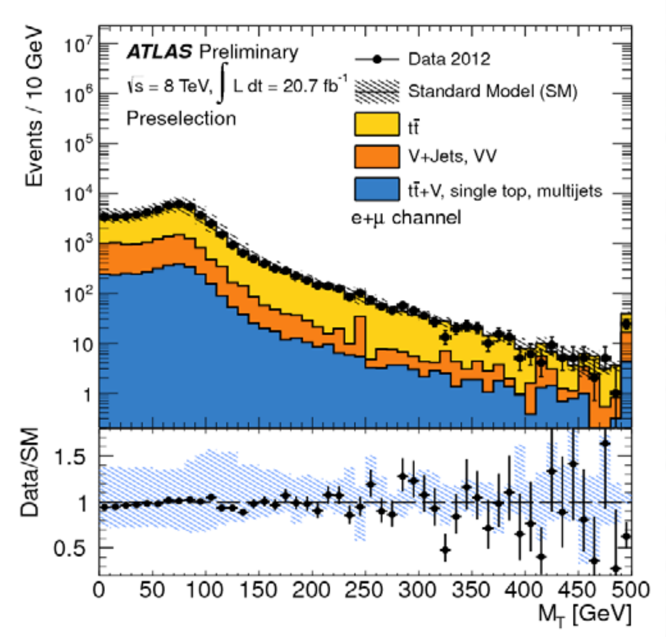


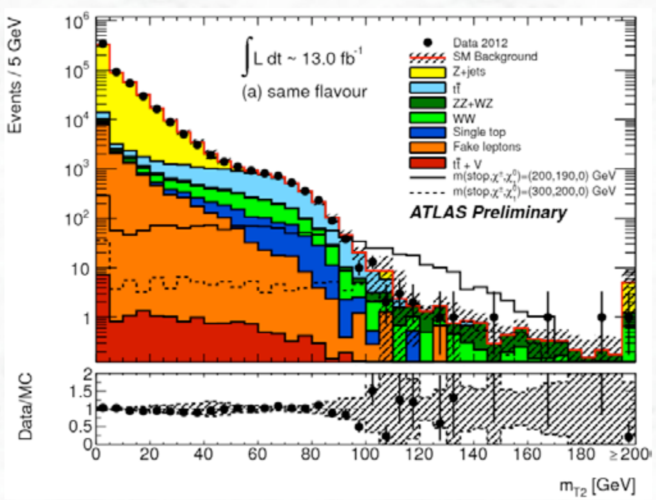
- But also other variables with well defined kinematical end point for the SM background
- **M_T (lepton-MET):** end point at M_W if produced in W decay

A complementary approach

Look for kinematic variables which have a **well defined kinematical end-point for Standard Model processes**

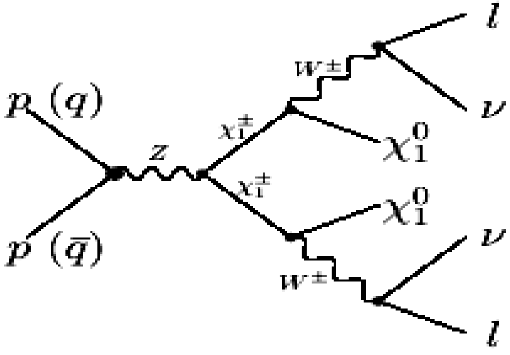
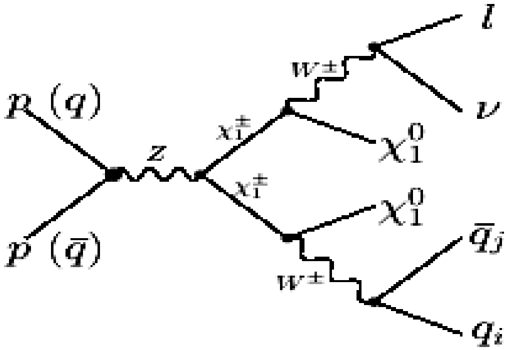
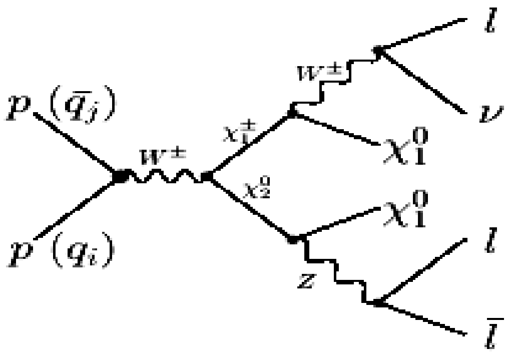
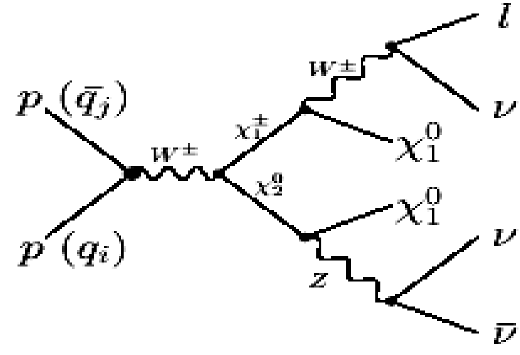
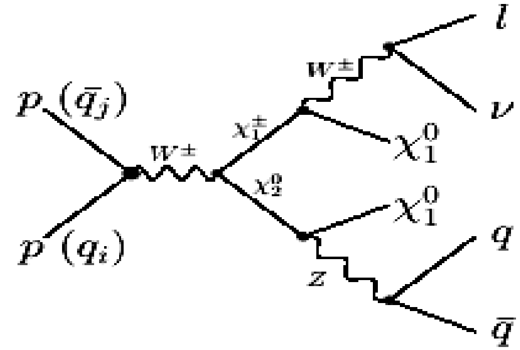
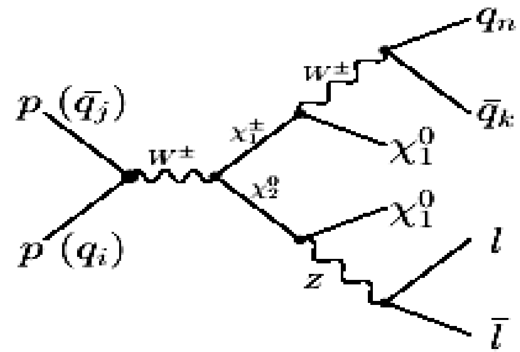
- An example: **the transverse mass** in events where **a W boson is produced** and **decays into a lepton and a neutrino**
- Beyond m_W, **the Standard Model background decreases fast**
- Think about m_{T2} in events with 2 leptons:
  - It will have **a kinematical end-point at m_W for the SM background**





$$m_{T2}(\mathbf{p}_T^{\ell_1}, \mathbf{p}_T^{\ell_2}, \mathbf{p}_T^{\text{miss}}) = \min_{\mathbf{q}_T + \mathbf{r}_T = \mathbf{p}_T^{\text{miss}}} \left\{ \max[\, m_T(\mathbf{p}_T^{\ell_1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell_2}, \mathbf{r}_T)\,] \right\}$$

SUSY final states, there are many ….

process	final states
	2ℓ 2ν $\not{E}_T$
	1ℓ $2j$ ν $\not{E}_T$
	3ℓ ν $\not{E}_T$
	ℓ 3ν $\not{E}_T$
	ℓ ν $2j$ $\not{E}_T$
	2ℓ $2j$ $\not{E}_T$

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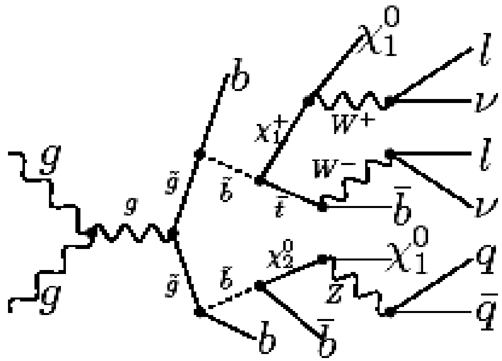
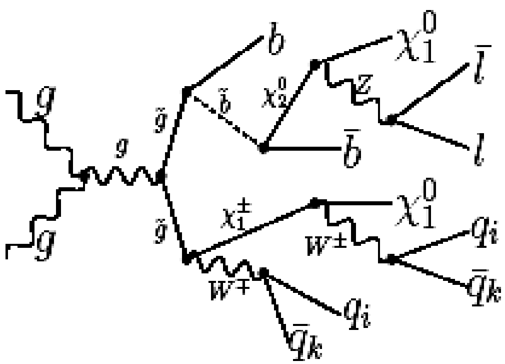
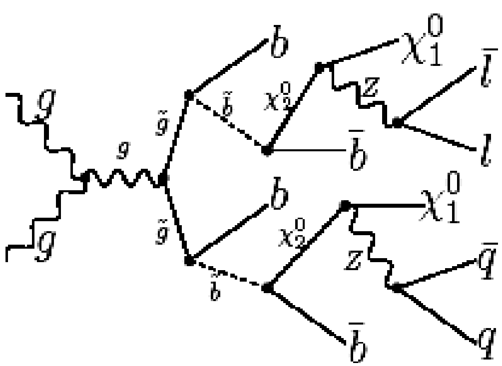
<tr><td>
</td><td>2ℓ
2ν
$6j$
$\not{E}_T$</td></tr>
<tr><td>
</td><td>2ℓ
$6j$
$\not{E}_T$</td></tr>
<tr><td>
</td><td>2ℓ
$6j$
$\not{E}_T$</td></tr>
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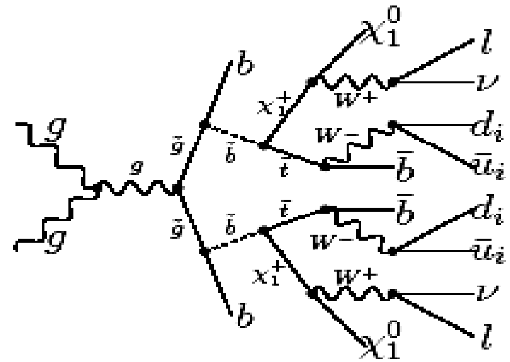
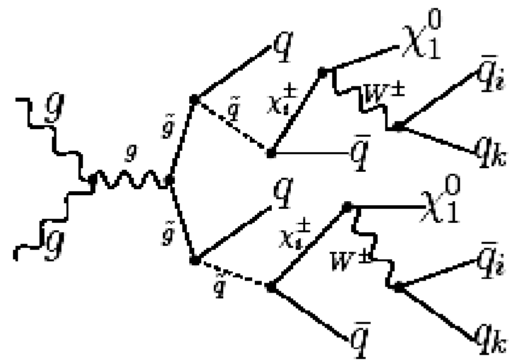
<tr><td>
</td><td>2ℓ
2ν
$8j$
$\not{E}_T$</td></tr>
<tr><td>
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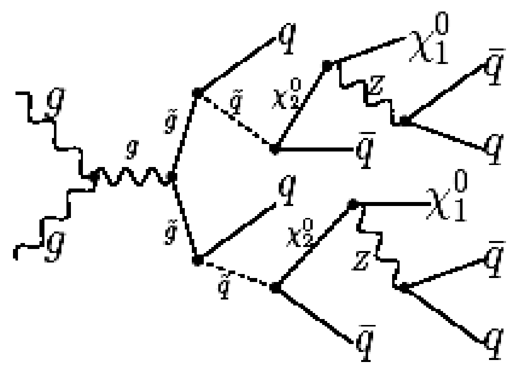
$\not{E}_T$</td></tr>
<tr><td>
</td><td>$8j$
$\not{E}_T$</td></tr>
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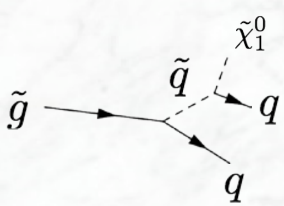
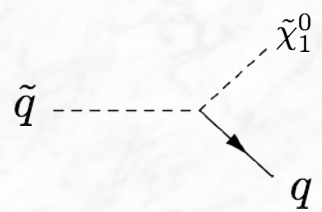
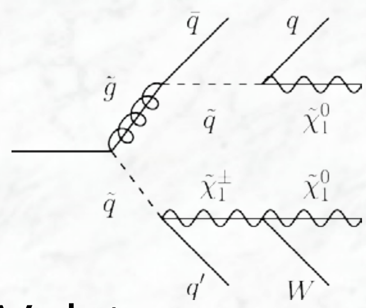
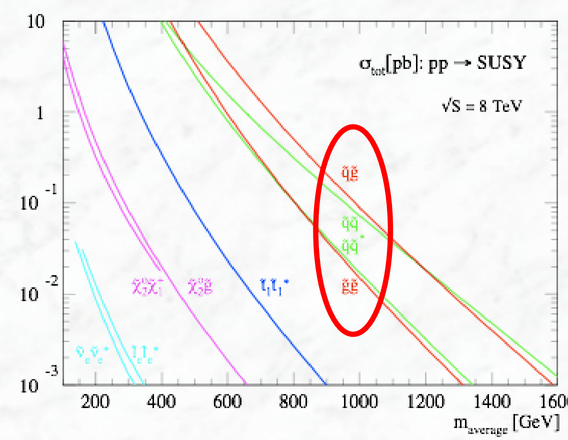
Strong production

- Targeting generic strong production of gluinos and squarks.
- The exact decay chain depends on the SUSY mass hierarchy



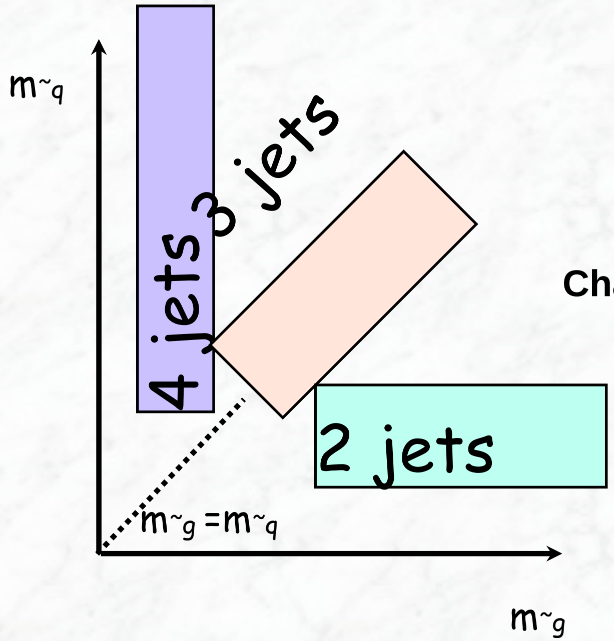






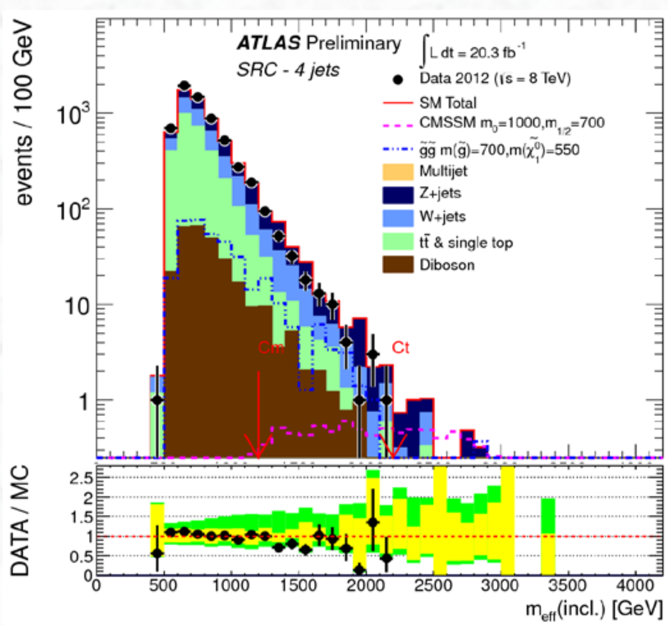
- Two analyses drive the limit with 8 TeV data

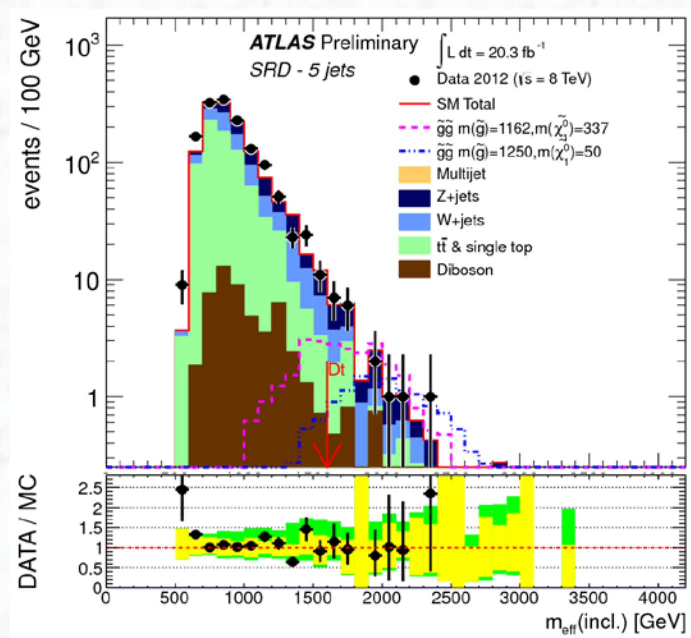
	0-lepton (ATLAS-CONF-2012-109)	1-lepton (ATLAS-CONF-2012-104)
leptons	Veto any e or μ above 10 GeV	One isolated e or μ above 25 GeV
jets	2 to 6 jets with p_T > 60 GeV (leading jet p_T > 130 GeV)	4 jets with p_T > 80 GeV
Other selections	MET > 160 GeV, reject multijet with cuts on MET/M_{eff}, and angle between jets and MET	MET > 250 GeV, M_T > 100 GeV, additional selection on MET/M_{eff}
Final selection	M_{eff}	M_{eff}



	Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets	High mass
Trigger requirements	E_T^{miss}	> 130	> 130	> 130	> 130
	Leading jet p_T	> 130	> 130	> 130	> 130
Channel definition	Second jet p_T	> 40	> 40	> 40	> 80
	Third jet p_T	–	> 40	> 40	> 80
	Fourth jet p_T	–	–	> 40	> 80
Reduce QCD	$\Delta\phi(\text{jet}, E_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
	E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
Enhance signal	m_{eff} [GeV]	> 1000	> 1000	> 500/1000	> 1100

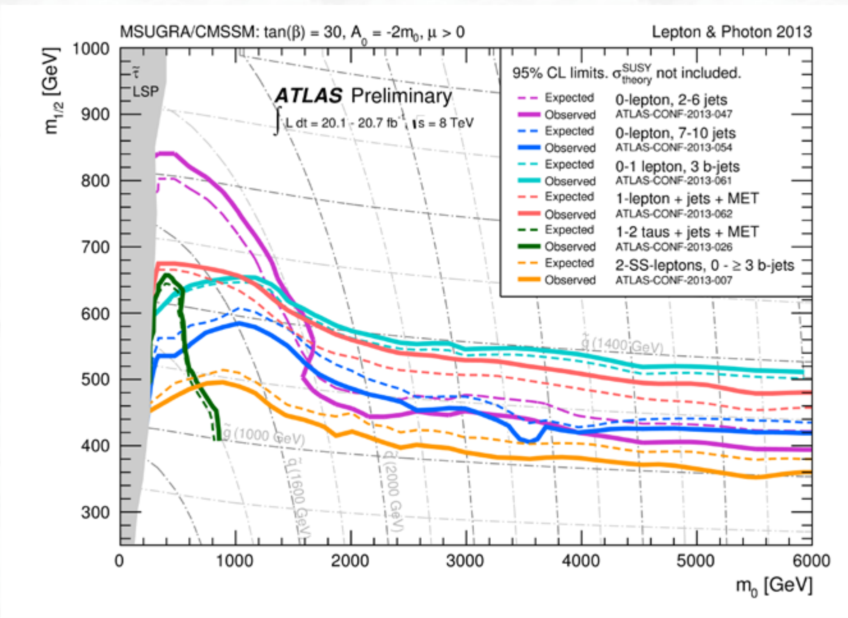
$$m_{eff} = \sum_{i=1}^{n} |\vec{p}_T^{\,jet\ i}| + E_T^{miss}$$

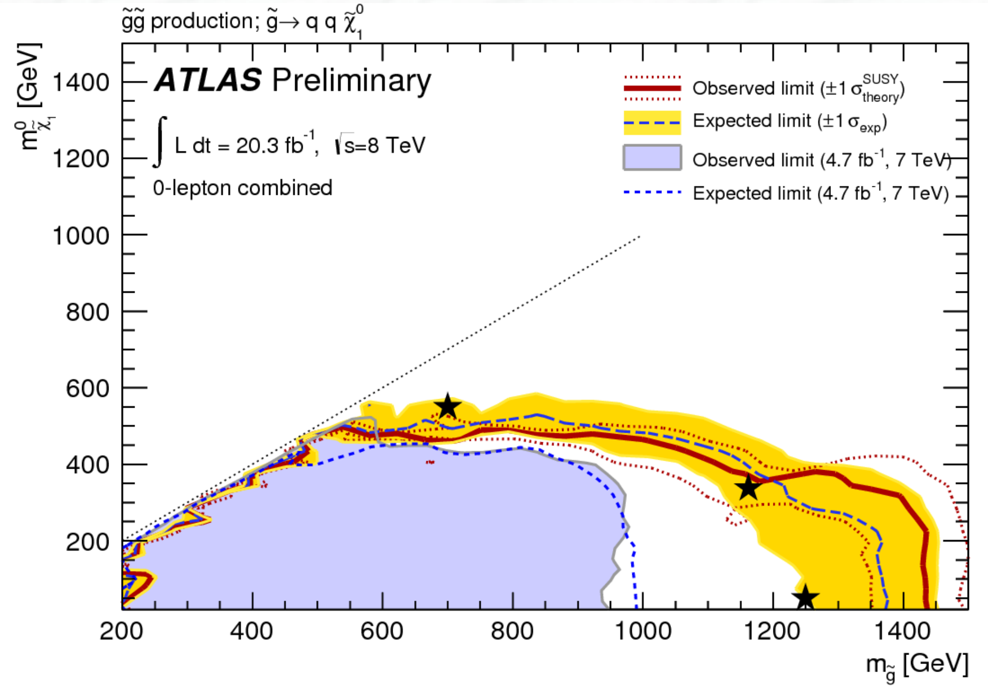




Strong production

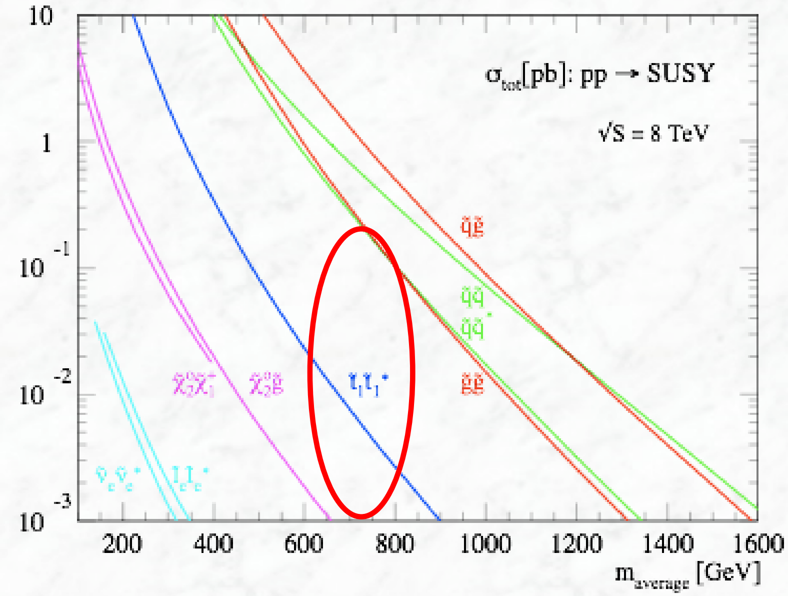
- **No excess** above SM in any of the signal regions:
  - interpreted **first as a model-independent 95% C.L. limit on σ_{vis}** of BSM processes
  - then as **an exclusion limit in specific SUSY models**



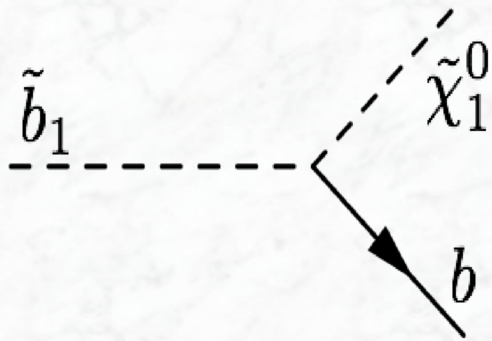


direct 3rd generation squark production

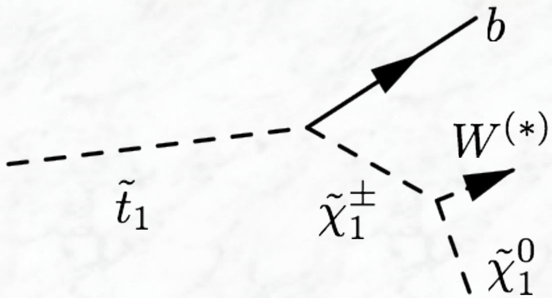
- The **stops/sbottoms** constrained by naturalness to be **not heavier than ~ 1 TeV**



- Sbottom decays:
- $\tilde{b}_1 \rightarrow b\tilde{X}_1^0$
- $\tilde{b}_1 \rightarrow t\tilde{X}_1^{\pm}$

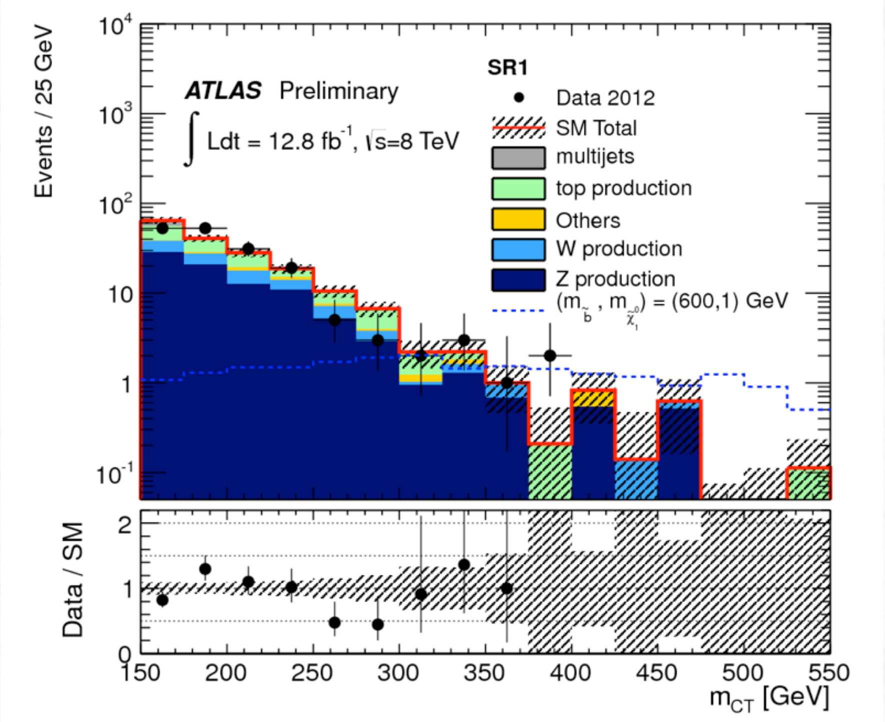


- Stop decays:
- $\tilde{t}_1 \rightarrow t\tilde{X}_1^0$
- $\tilde{t}_1 \rightarrow b\tilde{X}_1^{\pm}$



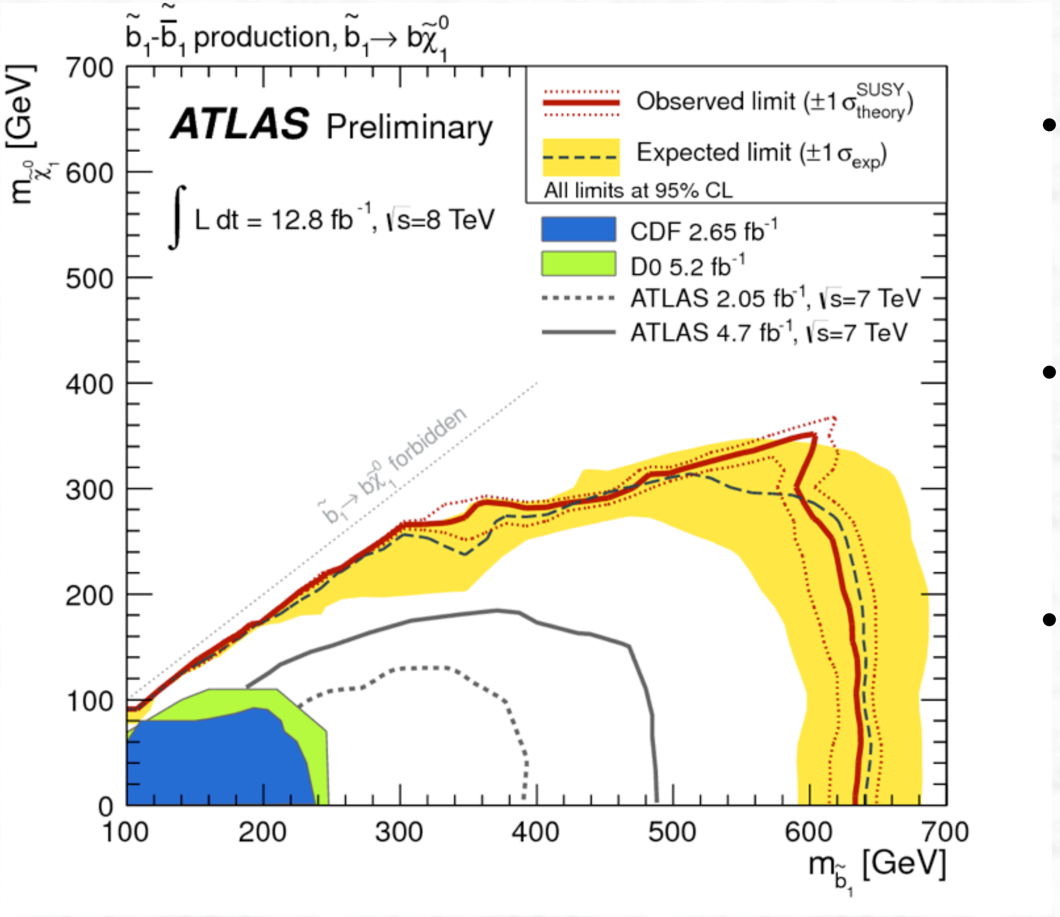
direct sbottom - 2 b-jets + E_T^{miss}

- m_{CT}(bb): similar concept as for m_{T2}
- It has an end-point at $(m_{prod}^2 - m_{inv}^2)/m_{prod}$



- Look for 2 b-jets (veto on third jet), large E_T^{miss}
- Use M_{CT} to suppress top; Main background: Z ($\rightarrow \nu\nu$)+b-jets

Direct sbottom search limits

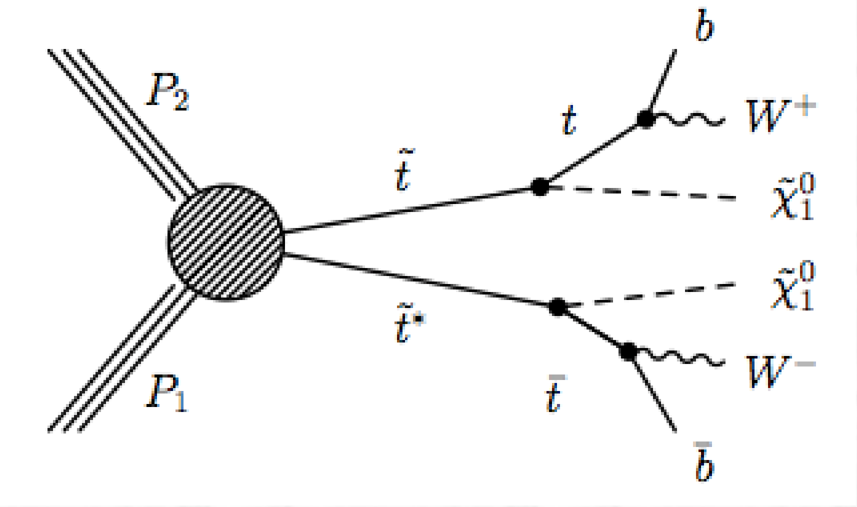


- Plot sbottom mass on one axis, neutralino mass on the other axis:
- The sbottom mass determines the cross section
- The neutralino mass determines the kinematics

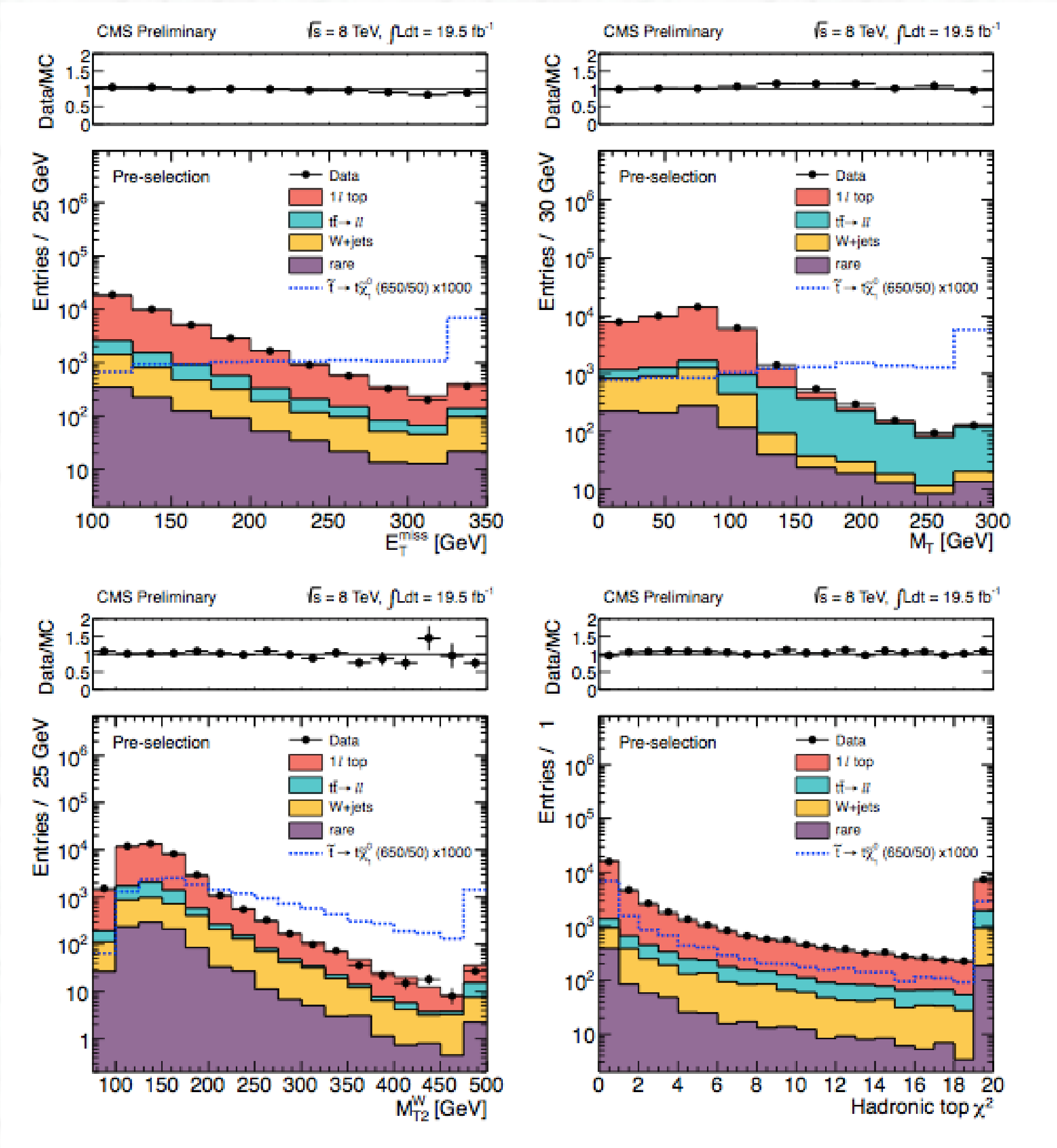
Direct stop search limits

$$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$$

- **Complex final state with many handles**
- Analysed in final states with 0/1/2 leptons



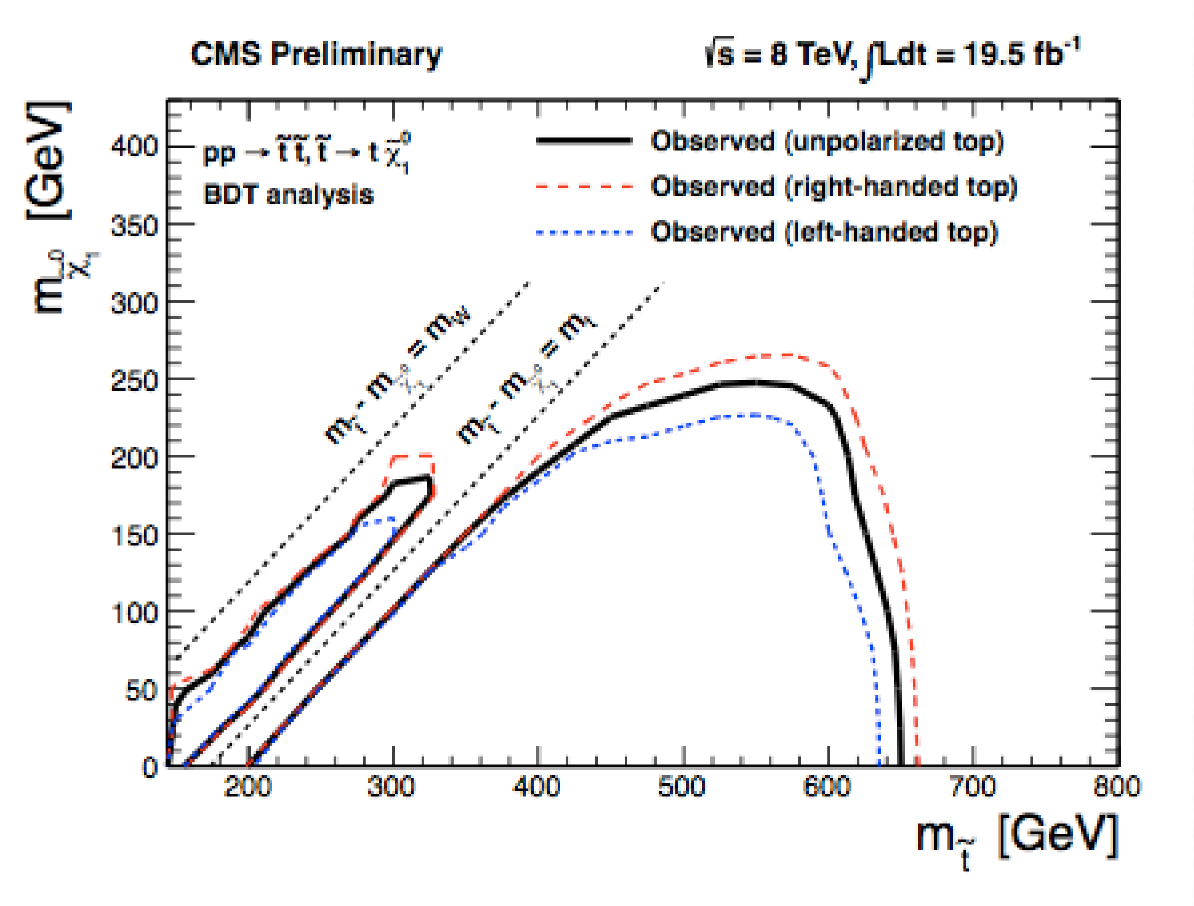
1-lepton stop (CMS)



Basic selection:
- 1 lepton,
- 4 jets and
- large MET.

Additional selections based on the hadronic top reconstruction on M_T like quantities allows to suppress the ttbar background

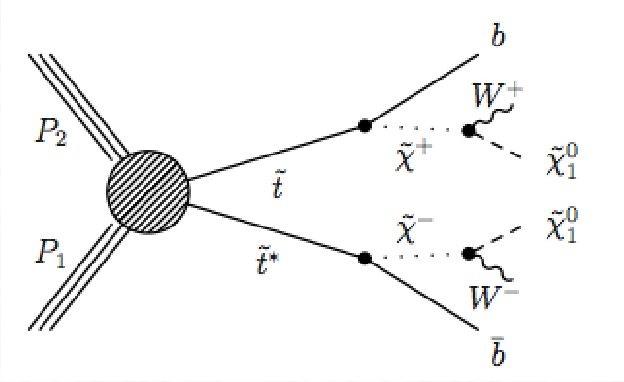
1-lepton stop (CMS)



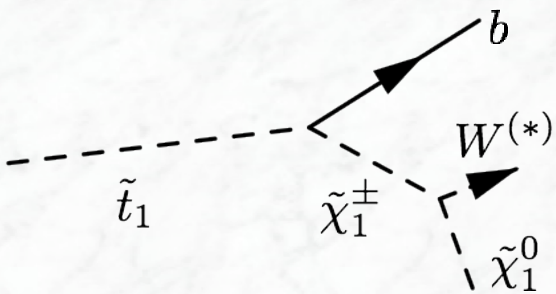
$$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$$

- With respect to $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$, the mass of the chargino is one additional degree of freedom

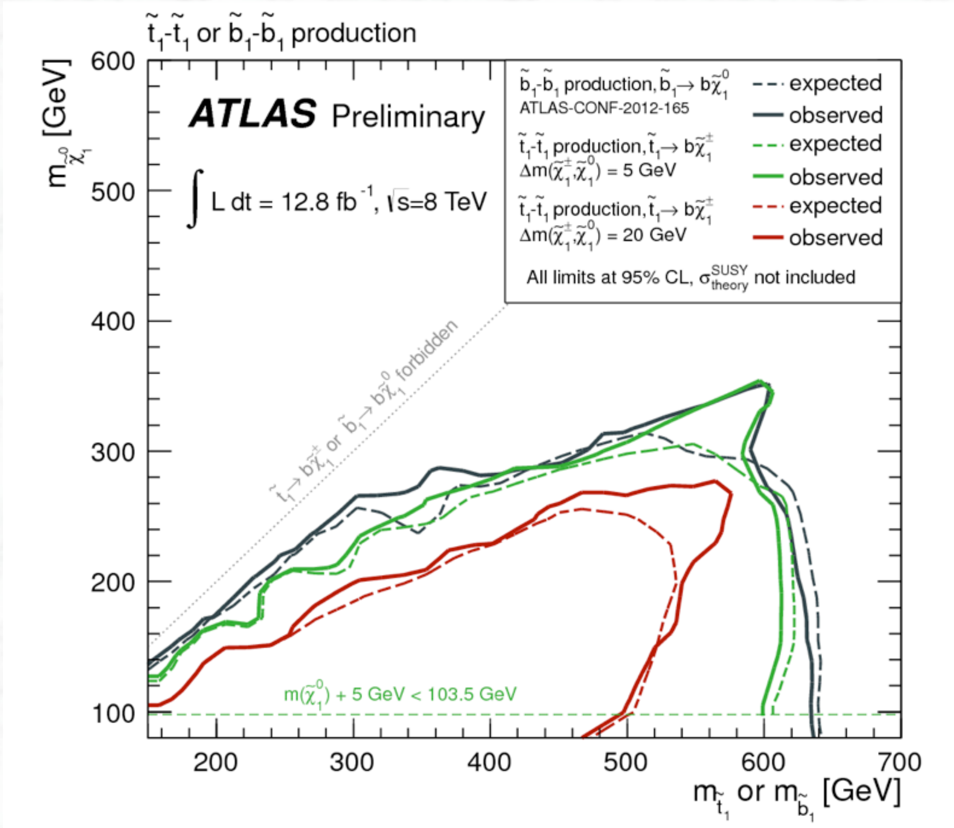
Hypothesis	Targeted signature (3 players at 8 TeV)
gaugino universality: $m_{\chi\pm} \sim 2m_{\chi 0}$	2-leptons - large leptons M_{T2} 1-lepton (dedicated SR)
stop-chargino mass degeneracy $m_{\chi\pm} \sim m_{t1}$ - 10 GeV	2-leptons - large leptons MT2
neutralino-chargino mass degeneracy (favoured if $\tilde{\chi}_1^0, \tilde{\chi}_1^{\pm}$ higgsino-like): $m_{\chi\pm} \sim m_{\chi 0}$	2 b-jets + MET; 0-lepton
Fixed chargino mass at 150 GeV	2-leptons - large leptons M_{T2} 1-lepton (dedicated SR)



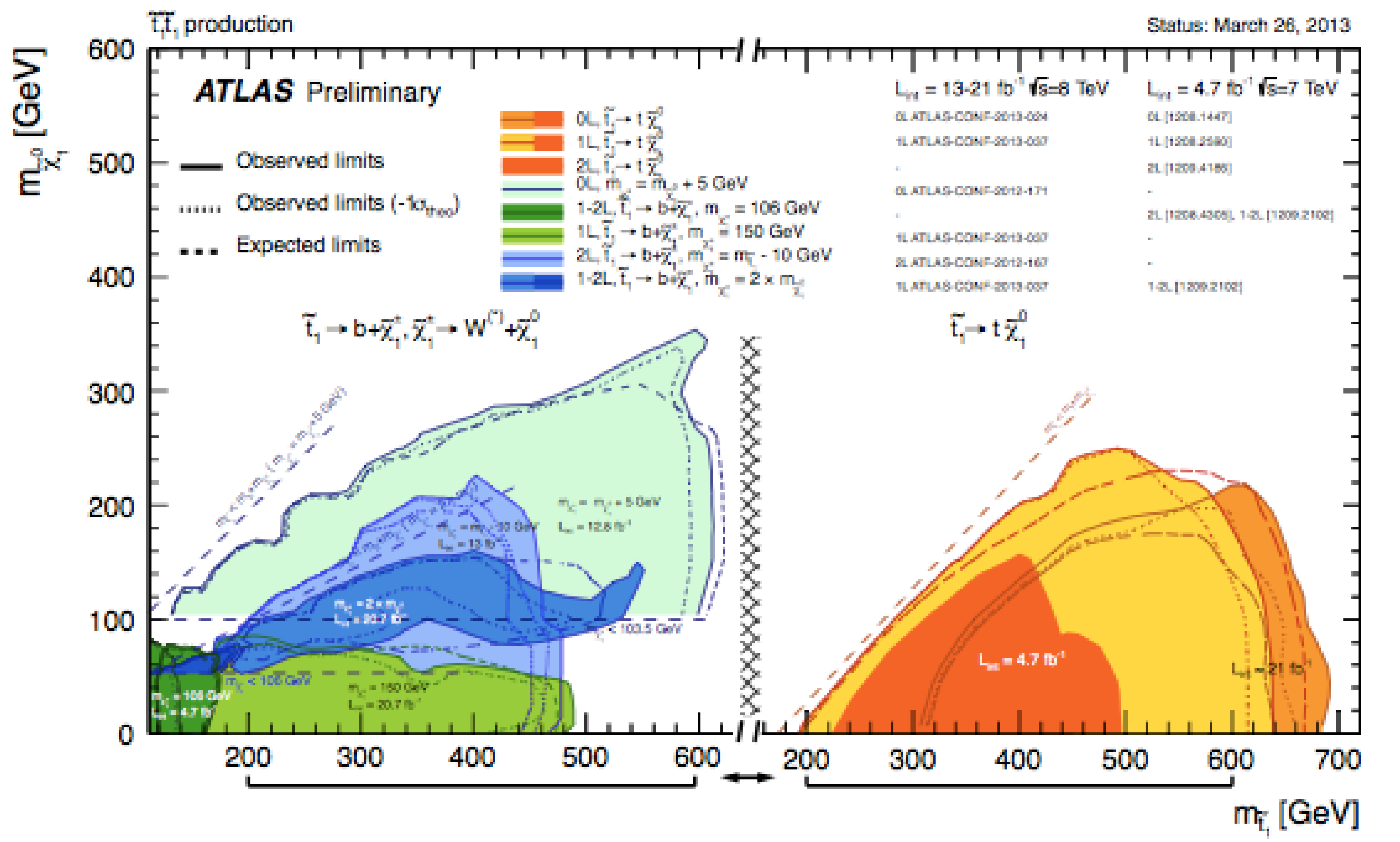
$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$



- 2 b + E_T^{miss} analysis already discussed
- **Same signal regions** as for direct sbottom sensitive to **$\tilde{t}_1 \rightarrow \tilde{b} X_1^{\pm}$ for small $\Delta m(X_1^{\pm}, X_1^0)$**
- Loss of acceptance due to lepton and jet veto

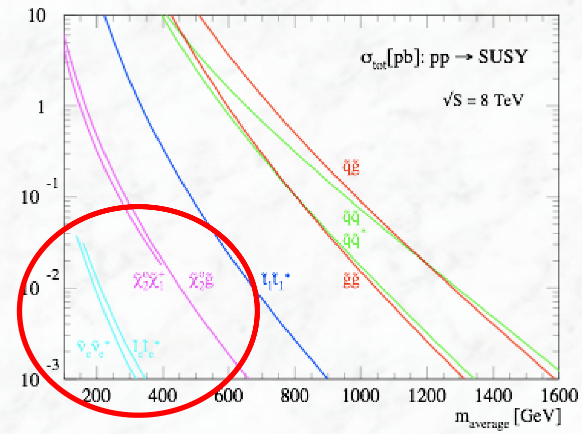


Stop summary



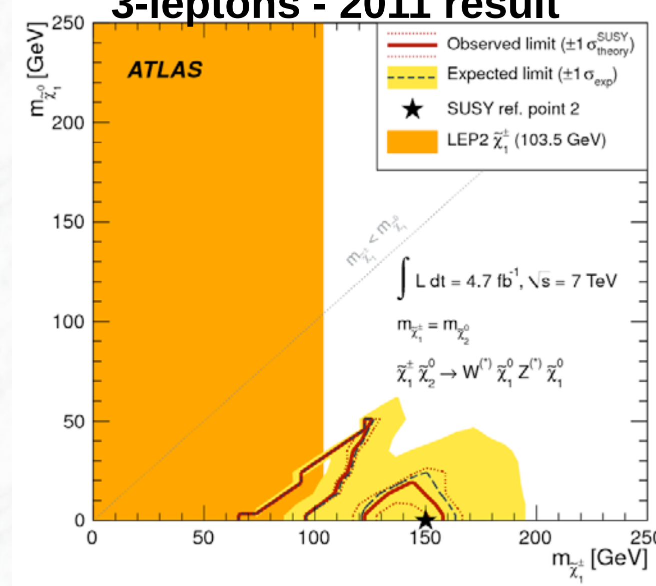
Electroweak $\tilde{\chi}^0$, $\tilde{\chi}^{\pm}$ production

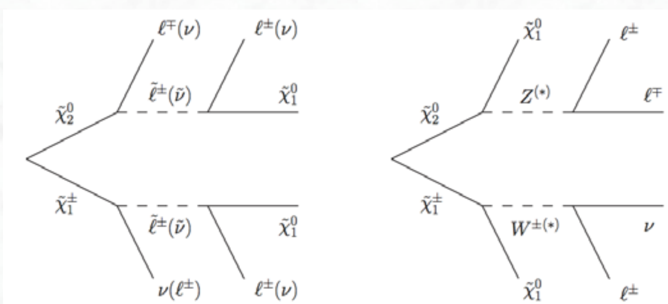
- Neutralinos and chargino masses of **few hundreds GeV** expected in natural SUSY models
- LHC has sensitivity to the **EW coupling-suppressed cross sections**



- Give rise to **multi-lepton final states**
  - Very **low SM background** expected
  - Decays through **sleptons** (BR to leptons 100% - optimistic) or **WZ-like** (challenging) decays assumed

3-leptons - 2011 result

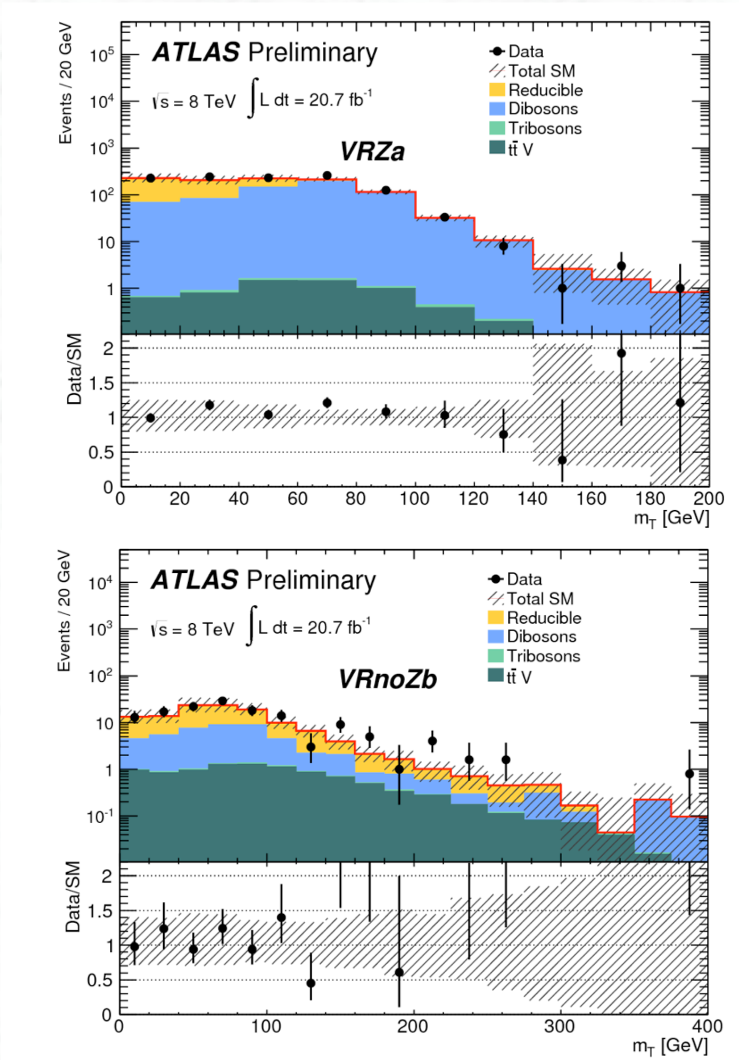




Electroweak $\tilde{\chi}^0$, $\tilde{\chi}^{\pm}$ production

Production channel	**Analysis**
chargino pair production	**2-leptons**
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production	**2-leptons**, **3-leptons**
$\tilde{\chi}_2^0\tilde{\chi}_3^0$ production	**4-leptons**

3-leptons background prediction validation

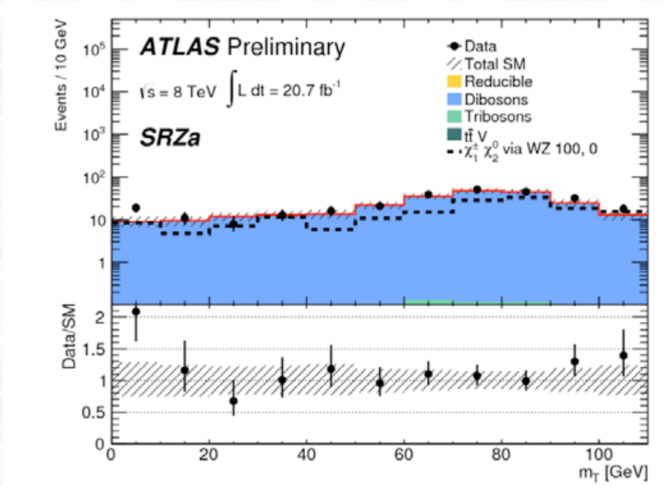


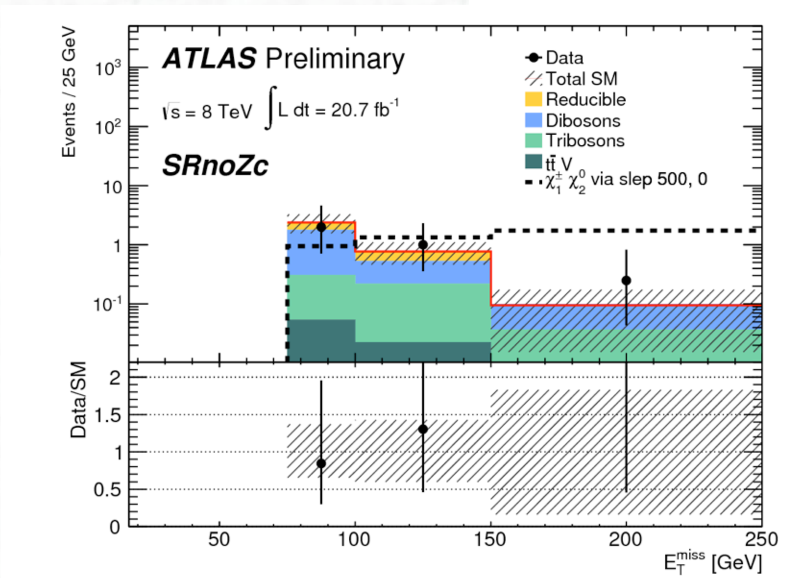
- Background prediction **validated** in dedicated regions with **different background composition**

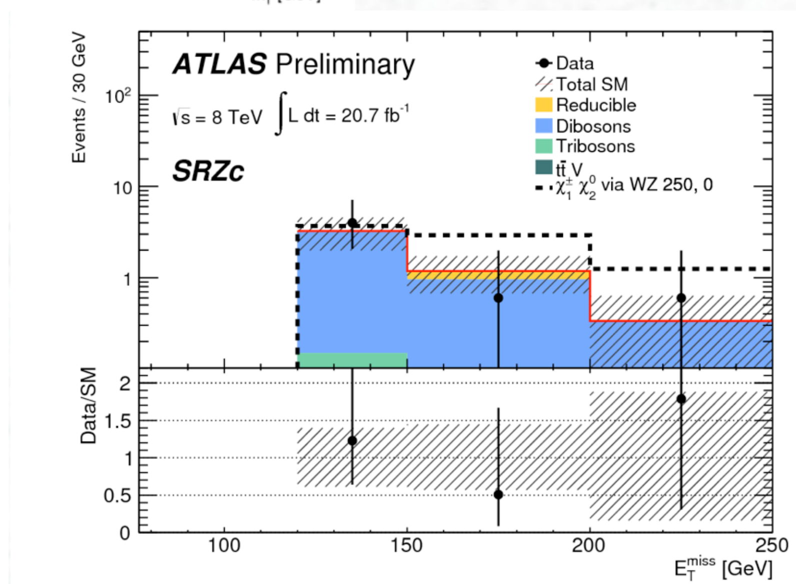
Selection	VRnoZa	VRnoZb	VRZa	VRZb
m_{SFOS} [GeV]	<81.2 or >101.2	<81.2 or >101.2	81.2–101.2	81.2–101.2
b-jet	veto	request	veto	request
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	35–50	>50	30–50	>50
Dominant process	WZ^*, Z^*Z^*, Z^*+jets	$t\bar{t}$	WZ, Z+jets	WZ

Selection	VRnoZa	VRnoZb	VRZa	VRZb
Tri-boson	1.4 ± 1.4	0.5 ± 0.5	0.6 ± 0.6	0.26 ± 0.26
ZZ	$(1.3 \pm 0.9) \times 10^2$	4.5 ± 2.8	108 ± 23	6.9 ± 2.2
$t\bar{t}V$	2.9 ± 1.2	21 ± 7	7.4 ± 2.6	26 ± 8
WZ	110 ± 21	34 ± 15	$(5.5 \pm 0.9) \times 10^2$	$(1.4 \pm 0.4) \times 10^2$
Σ SM irreducible	$(2.4 \pm 0.9) \times 10^2$	60 ± 16	$(6.6 \pm 0.9) \times 10^2$	$(1.7 \pm 0.4) \times 10^2$
SM reducible	$(1.5 \pm 0.6) \times 10^2$	$(0.7 \pm 0.4) \times 10^2$	$(3.8 \pm 1.4) \times 10^2$	27 ± 13
Σ SM	$(3.9 \pm 1.1) \times 10^2$	$(1.3 \pm 0.5) \times 10^2$	$(10.4 \pm 1.7) \times 10^2$	$(2.0 \pm 0.4) \times 10^2$
Data	463	141	1131	171

3-leptons results

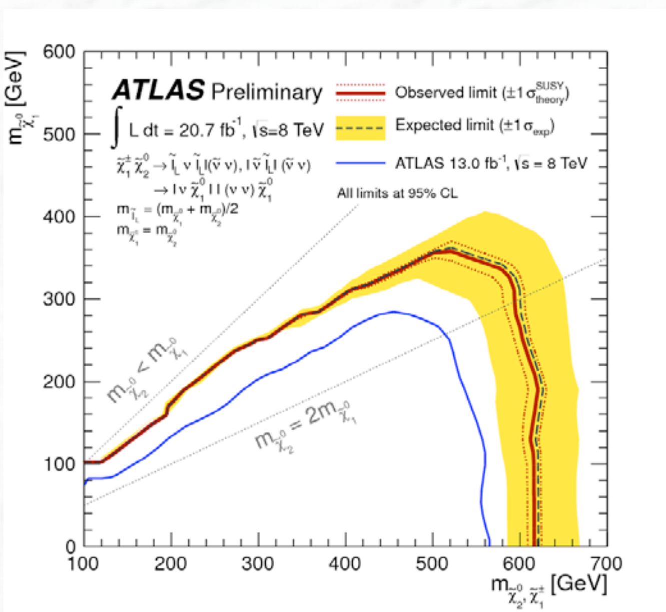


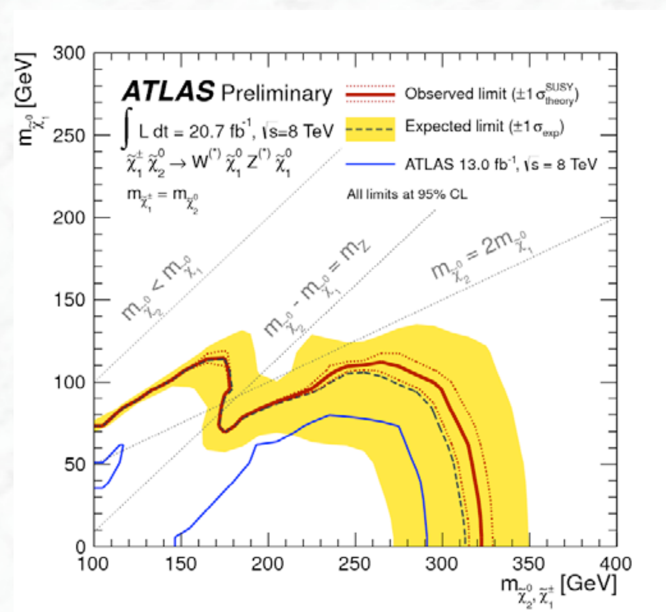




3-lepton interpretation

- **Signal interpretation** (simplified models) assumes **wino-like $\tilde{X}_2^0$ and $\tilde{X}_1^\pm$, bino-like $\tilde{X}_1^0$: m($\tilde{X}_2^0$) = m($\tilde{X}_1^\pm$)**
- **Degenerate neutralino-chargino mass** excluded **up to 610 GeV** if **decay via sleptons** is assumed
- masses **up to 310 GeV excluded** even for the **decay through W/Z bosons**





Further reading, available on the web:

- S. Martin, “A Supersymmetry Primer”, hep-ph/97093
  http://arxiv.org/abs/hep-ph/9709356

- D.I. Kazakov, „Beyond the Standard Model“, CERN school 2004
  http://doc.cern.ch/yellowrep/2006/2006-003/p169.pdf

- J. Ellis, Supersymmetry for Alp Hikers

  http://arxiv.org/abs/hep-ph/0203114

Lehrbücher:

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