Searches for natural Supersymmetry with the ATLAS detector

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(on behalf of the ATLAS Collaboration)

Extend the Standard Model?

- The Standard Model is working fine. Why fix it?
  - The Higgs mass suffers from quadratically divergent loop corrections (high level of fine-tuning)

Taken from http://www.quantumdiaries.org/2012/07/01/the-hierarchy-problem-why-the-higgs-has-a-snowballs-chance-in-hell/

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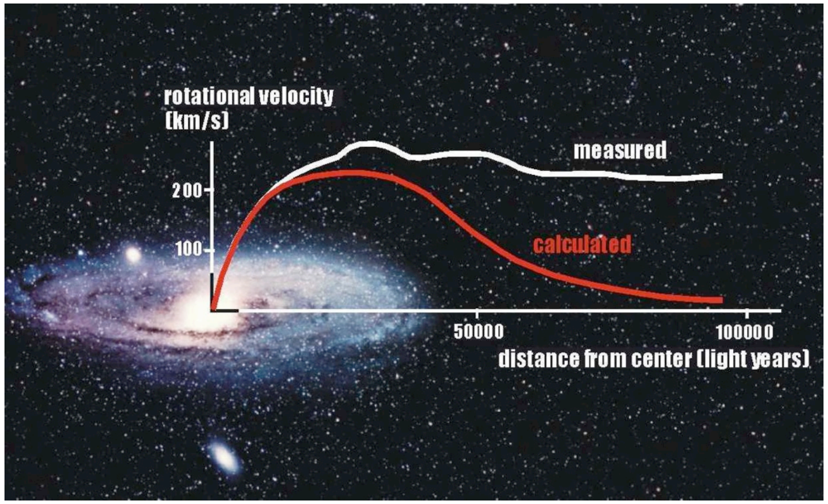

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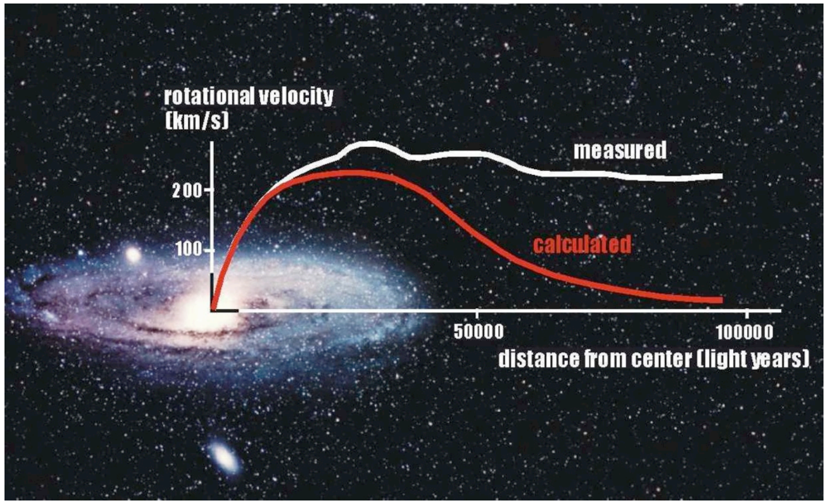
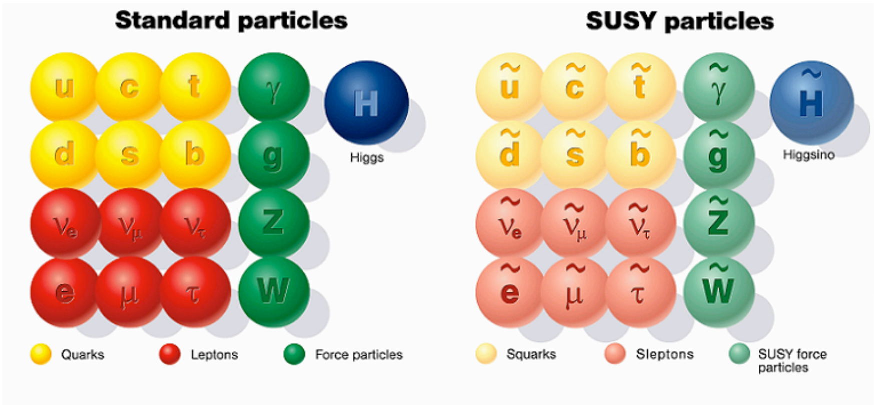


- Cosmological data call for dark matter: not explained within the SM

- Moreover, no unification of the EW and QCD coupling constants, EW symmetry breaking added ad-hoc, etc.

Supersymmetry (SUSY)

- SUSY is **a symmetry that relates bosons and fermions**
  - a new set of fields differing in spin by 1/2 w.r.t. the SM partners (fine tuning problem solved "naturally")



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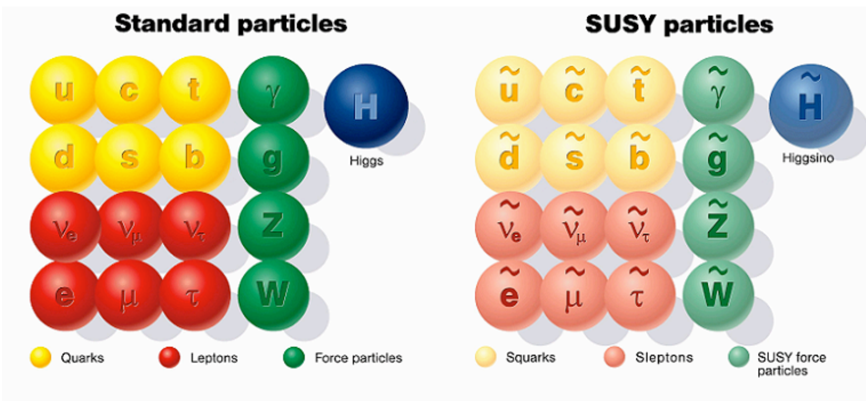

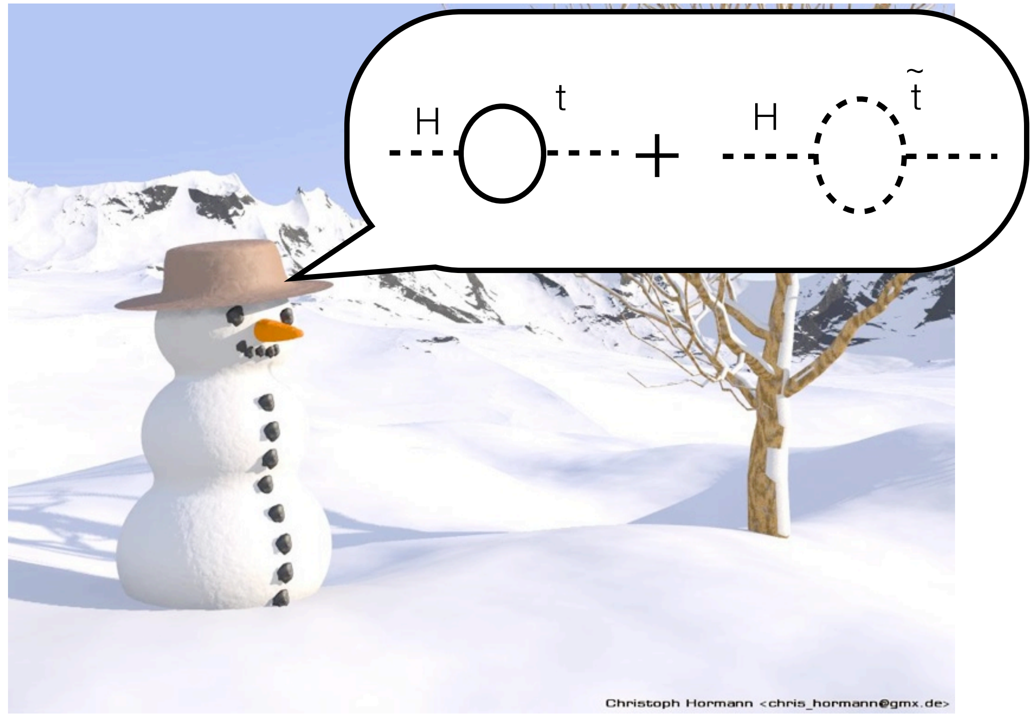

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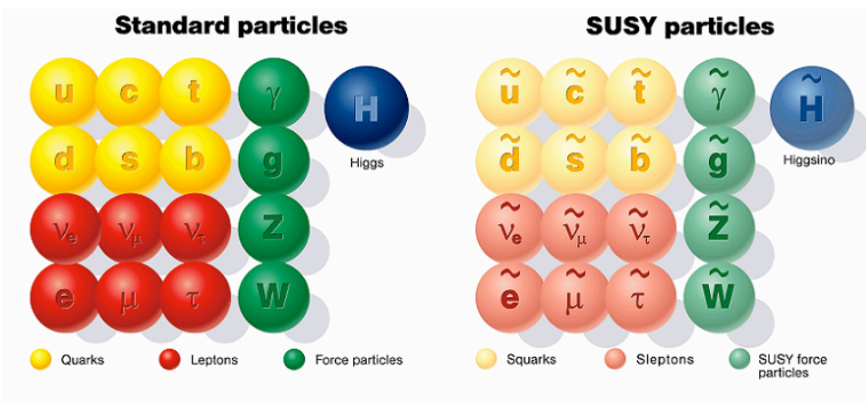

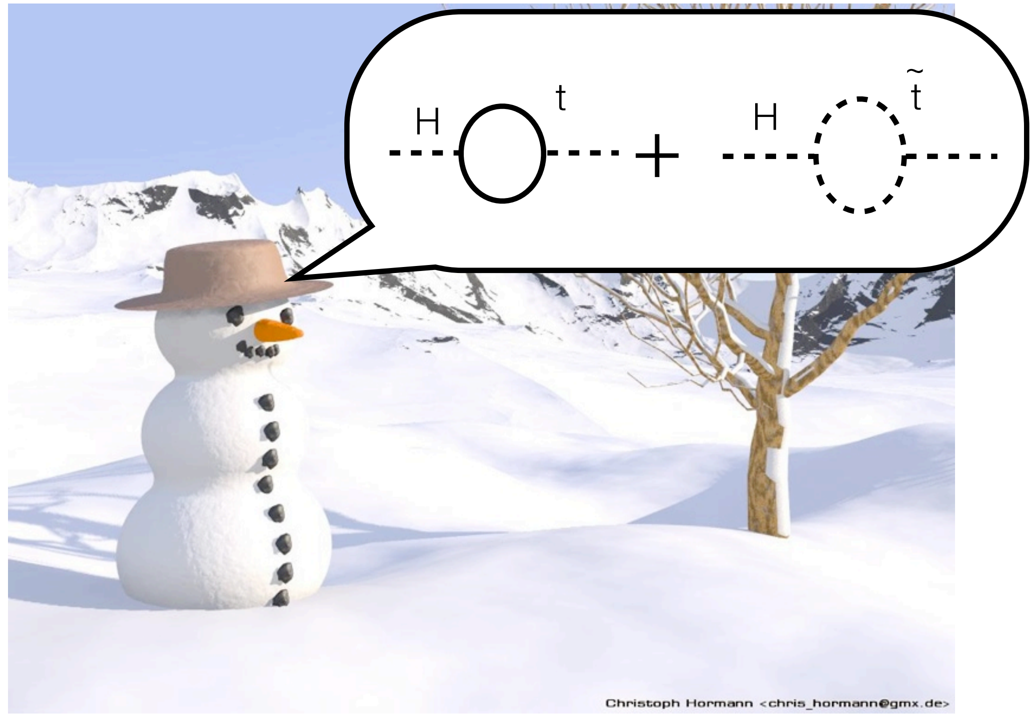

$$W \ni \frac{1}{2}\lambda_{ijk}L_iL_jE^c_k + \lambda'_{ijk}L_iQ_jD^c_k + \frac{1}{2}\lambda''_{ijk}U^c_iD^c_jD^c_k + \mu_iL_iH_u$$

R-parity = $(-1)^{3(B-L)+2s}$
-1 for sparticles
1 for particles

- Lepton and baryon number violation allowed → proton decay
- If R-parity conservation assumed, the **Lightest Supersymmetric Particle (LSP)** is stable: natural Dark Matter candidate

See AOB and backup for RPV

Fine tuning - a deeper look

- SUSY is broken. Supersymmetric particles masses arbitrary?
- One needs to **quantify the fine tuning**:
    - One possible choice: **stability of EW scale** (identified by M_Z) w.r.t. **model parameters** [Nucl. Phys. B306 (63-76) (1987)]

$$m_Z^2 = -2\mu^2 + 2\frac{m_{H_d}^2 - \tan^2\beta \, m_{H_u}^2}{\tan^2\beta - 1}$$

model parameters

$$max_{a_i}\left(\left|\frac{a_i}{m_Z^2}\frac{\partial m_Z^2(a_i)}{\partial a_i}\right|\right) < \Delta$$

tolerated fine tuning

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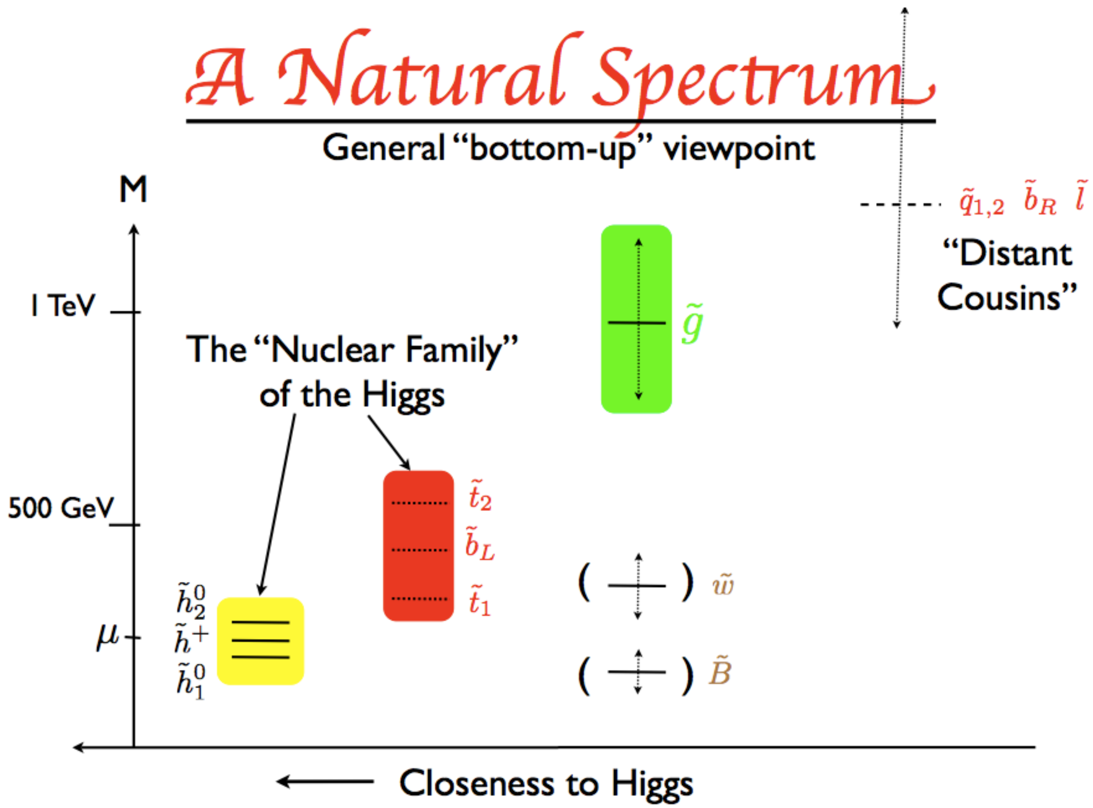
tolerated fine tuning

- **What are the important a_i?**
  - **μ (higgs mass parameter)** enters at tree level → light higgsinos
  - **A_t, M_{Q3}, M_{u3}** are relevant → light stops
  - **gluinos** introduce large corrections to the stop masses → light gluinos
- Looser constraints on the other sparticles

Natural SUSY

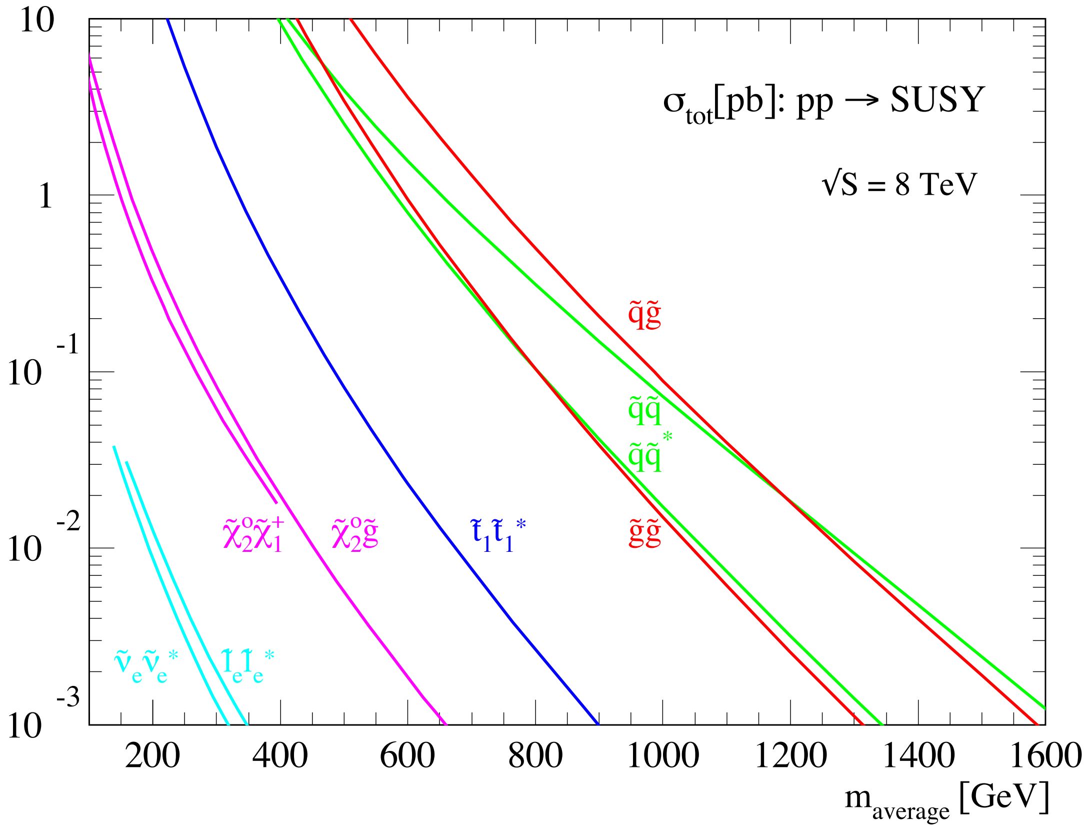
- Prediction:
  - Light $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$ (few hundreds GeV)
  - light (< 1 TeV) stop(s), $\tilde{b}_L$ bound to $\tilde{t}_L$ (same weak isospin multiplet as $\tilde{t}_L$)
  - not-so-heavy gluinos ($m_{\tilde{g}}$ < 1.5-2 TeV)



L. Hall (LBL Workshop, 21-Oct11)

- Unless differently stated, we do not use constrained models in deriving the exclusion limits,.
  - Rather **simplified models** with particle **masses as free parameters**

What processes are we looking for?



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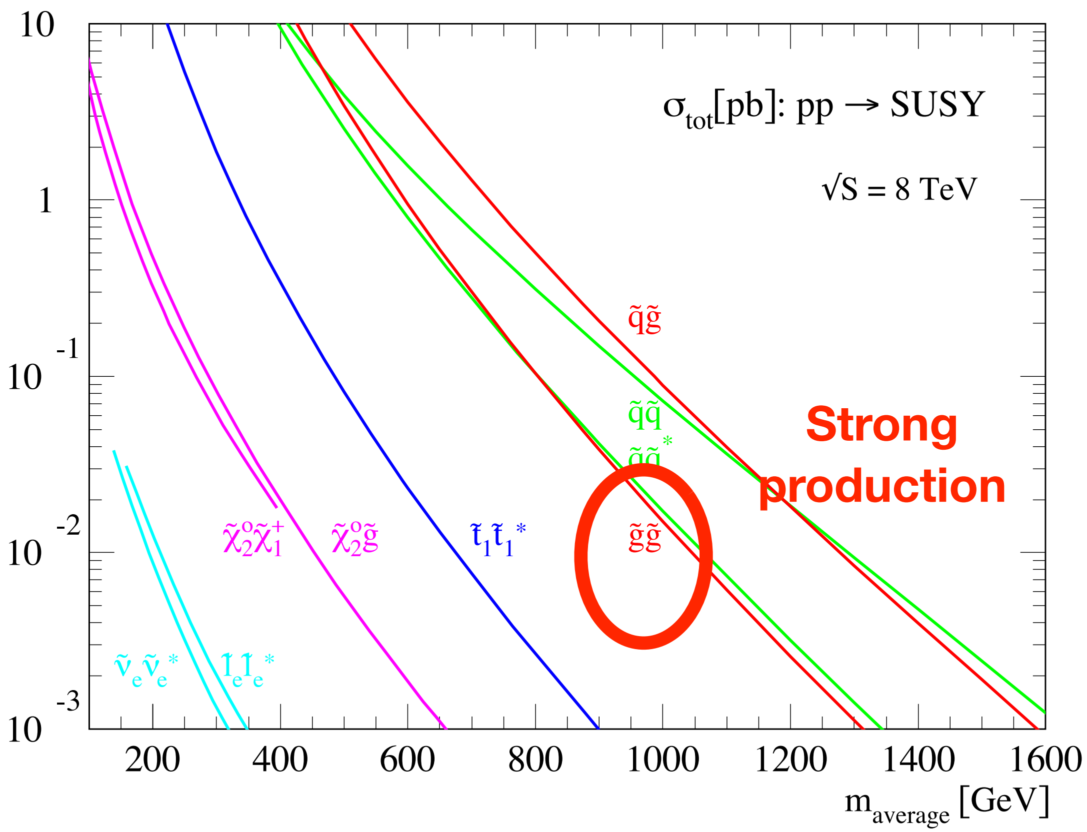

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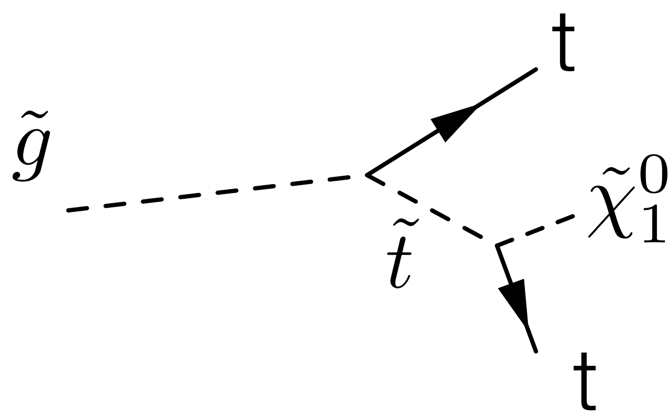

up to 4 top quarks in final state

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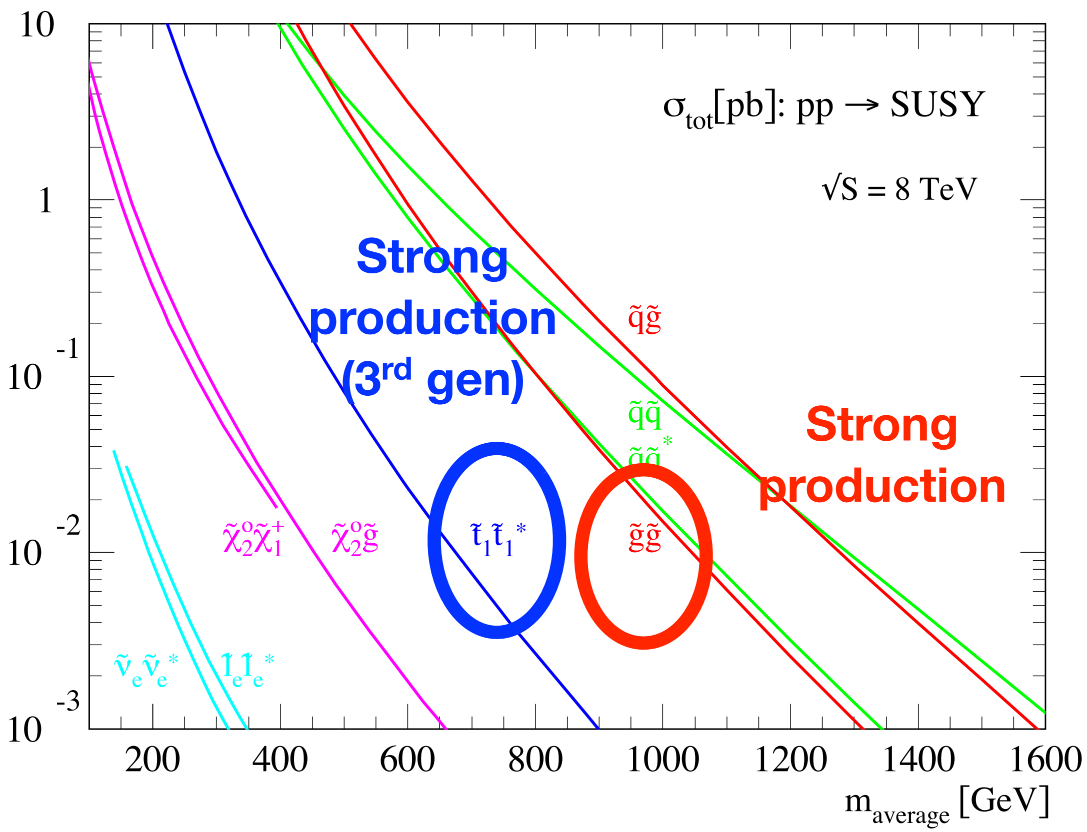

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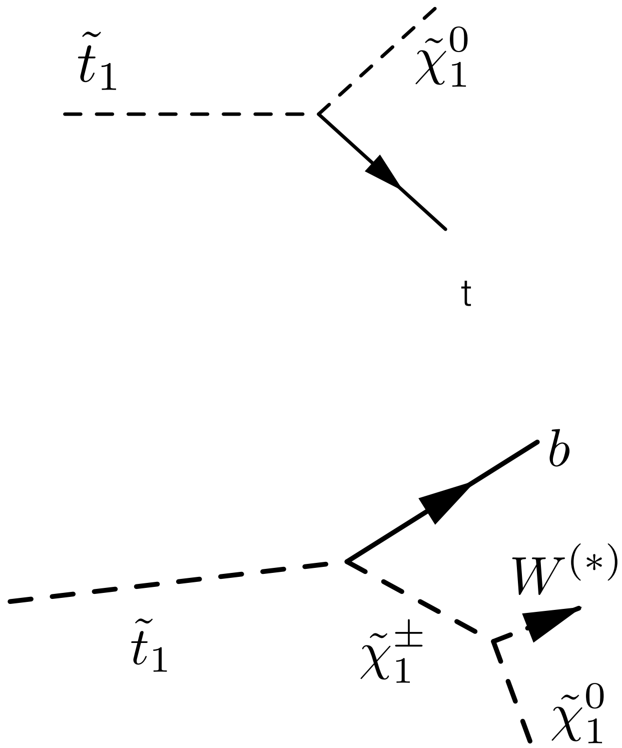

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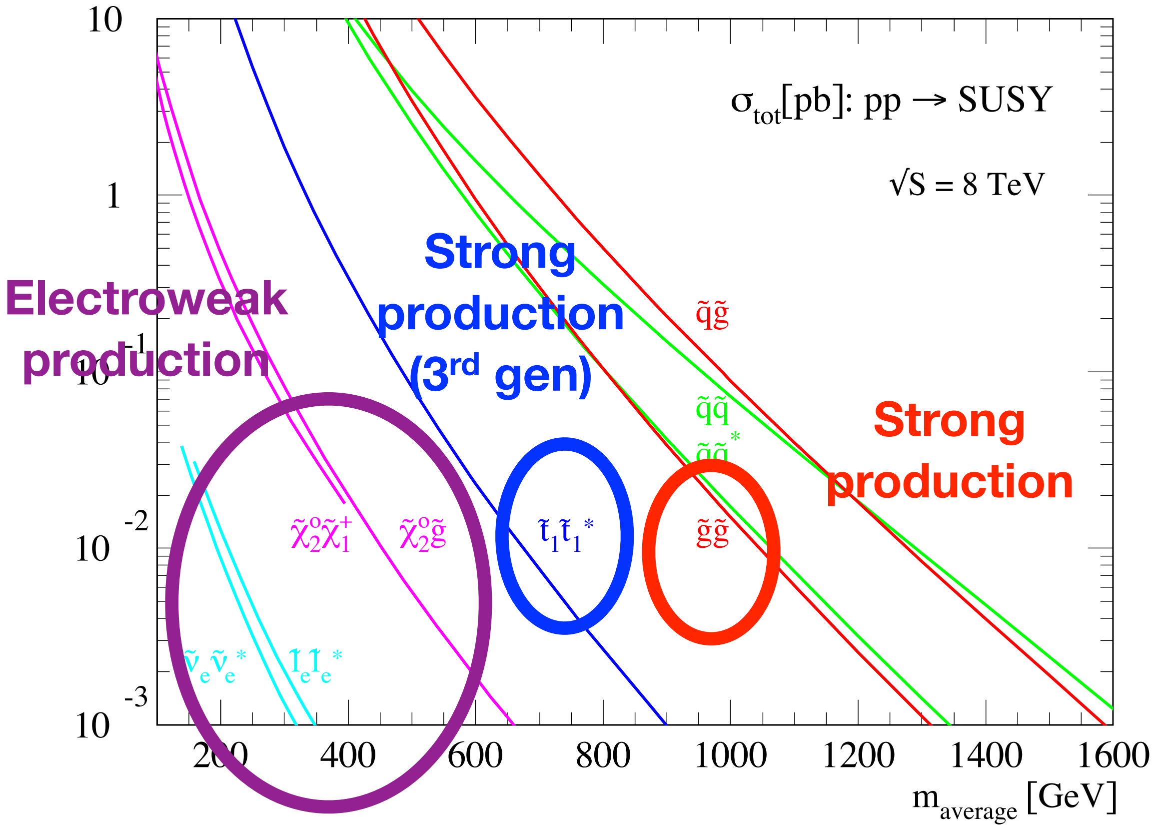

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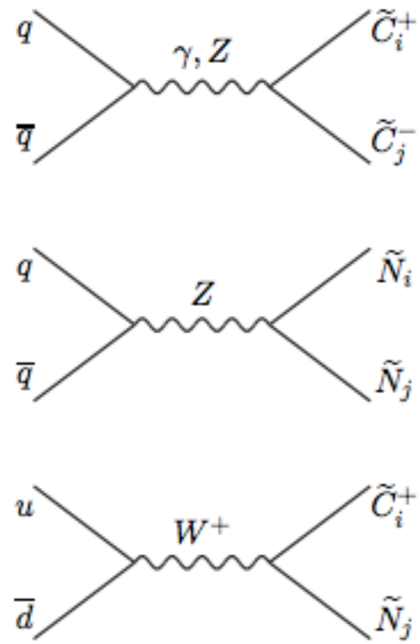

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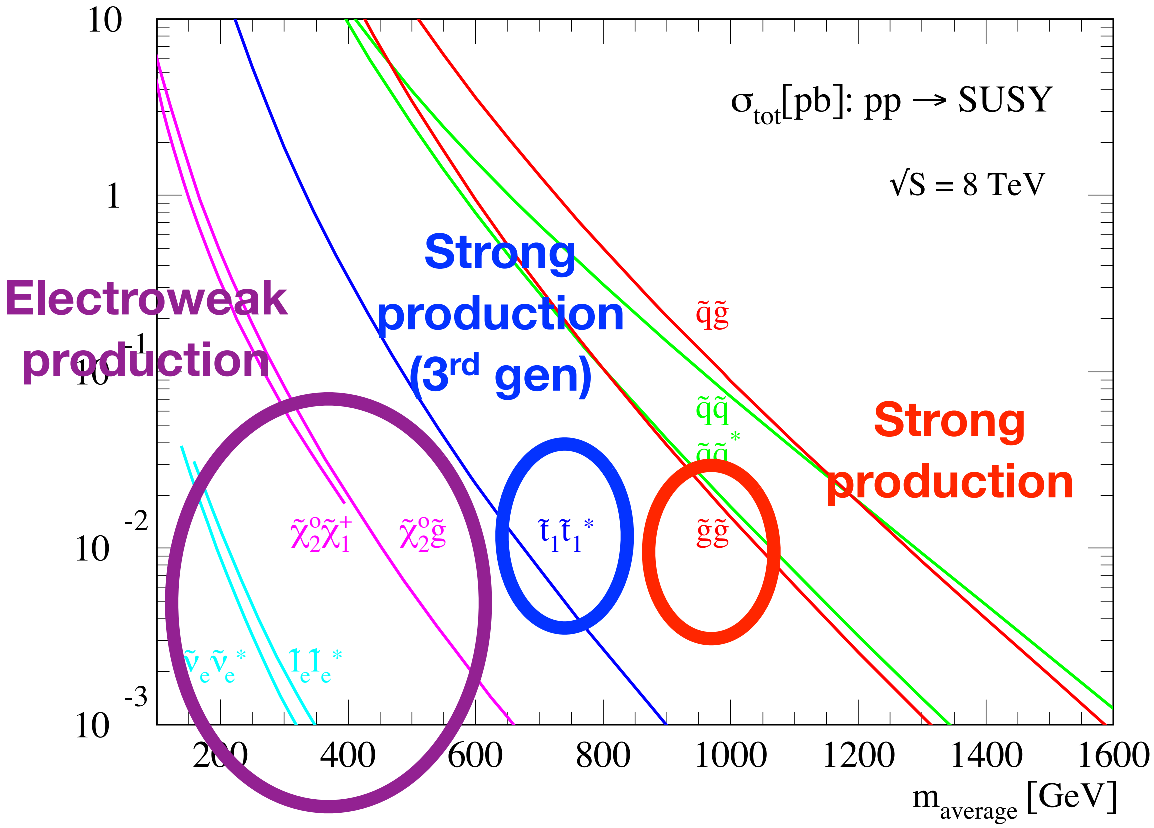

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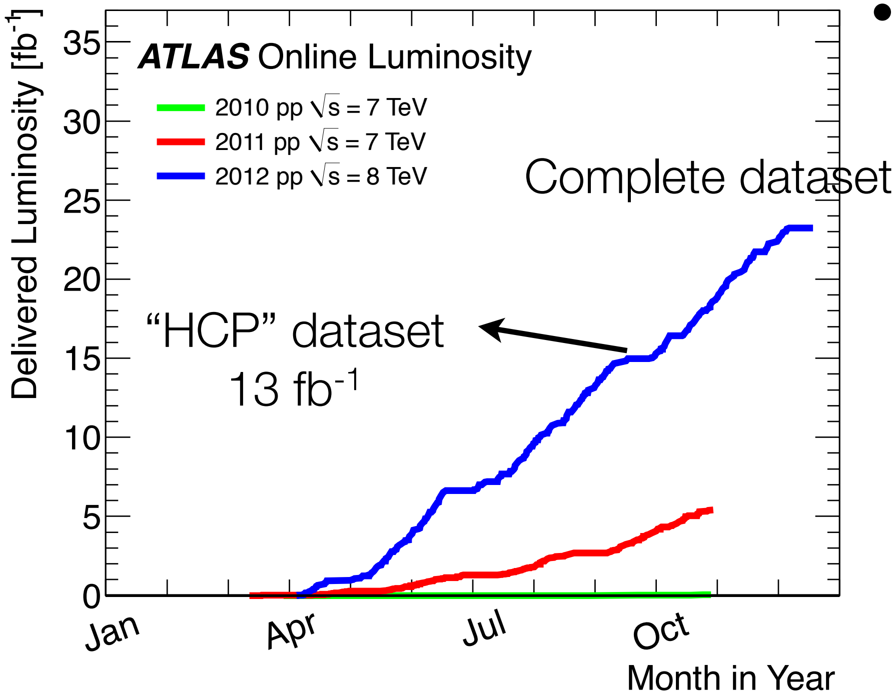
- **ATLAS has set up dedicated search strategies for all production mechanisms**

Experimental setup

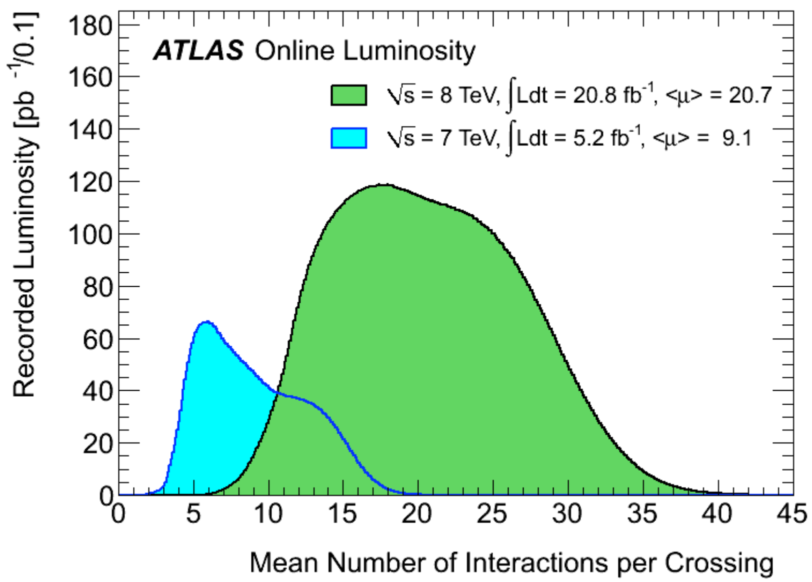
LHC - performance of the machine

- About 22 fb^{-1} collected at $\sqrt{s}$= 8 TeV and 5 fb^{-1} at $\sqrt{s}$= 7 TeV
  - Most of which with more than 95% of the ATLAS detector operational

- **All results** shown in this seminar use **either the "HCP"** (13 fb^{-1}) **or the full** (21 fb^{-1}) dataset ($\sqrt{s}$=8 TeV).



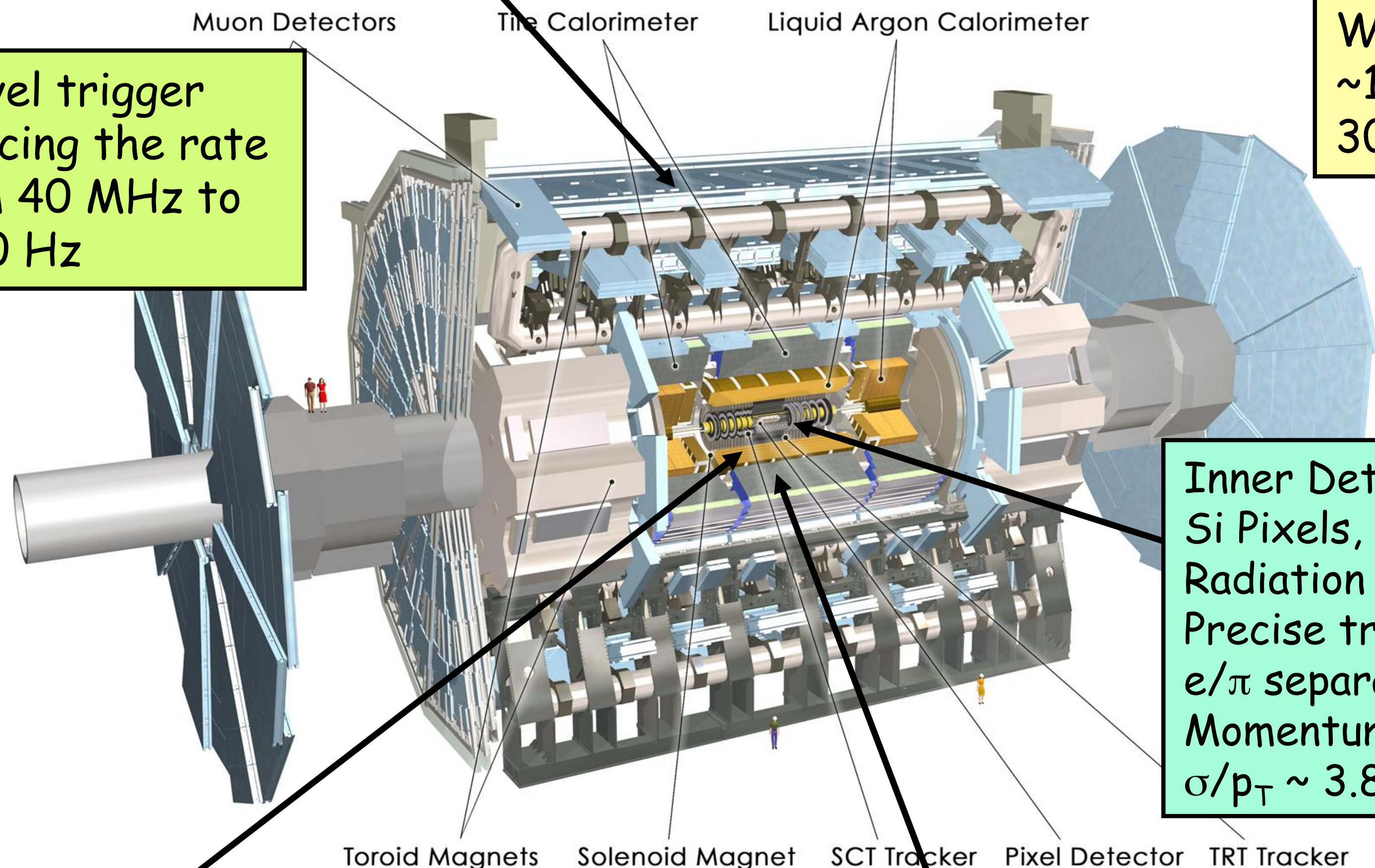
- **Large luminosity** means **large pileup.** Careful pileup suppression strategies developed.



Muon Spectrometer ($|\eta|<2.7$) : air-core toroids with gas-based muon chambers
Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

3-level trigger reducing the rate from 40 MHz to ~200 Hz

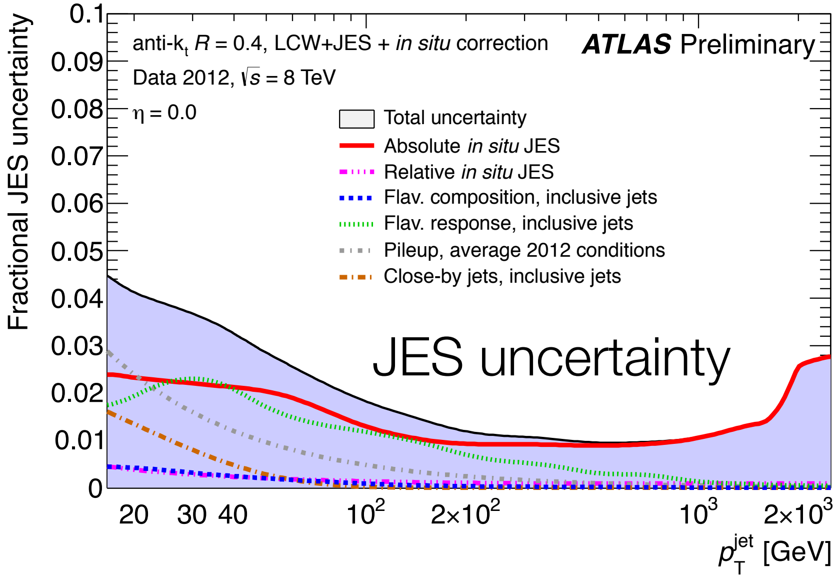


Inner Detector ($|\eta|<2.5$, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\text{GeV}) \oplus 0.015$

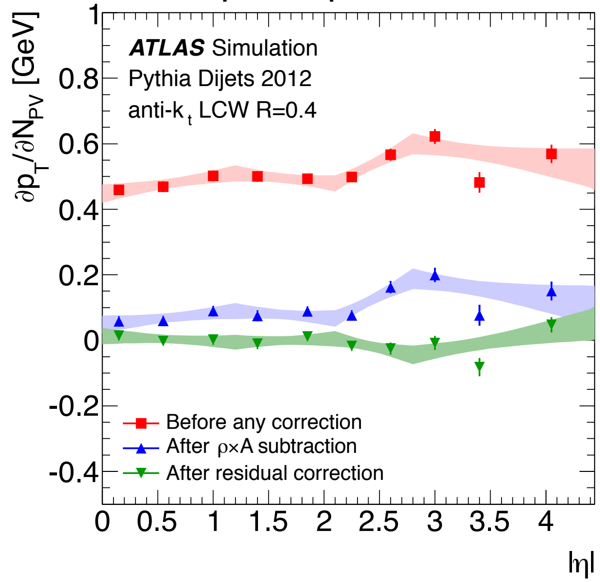
EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

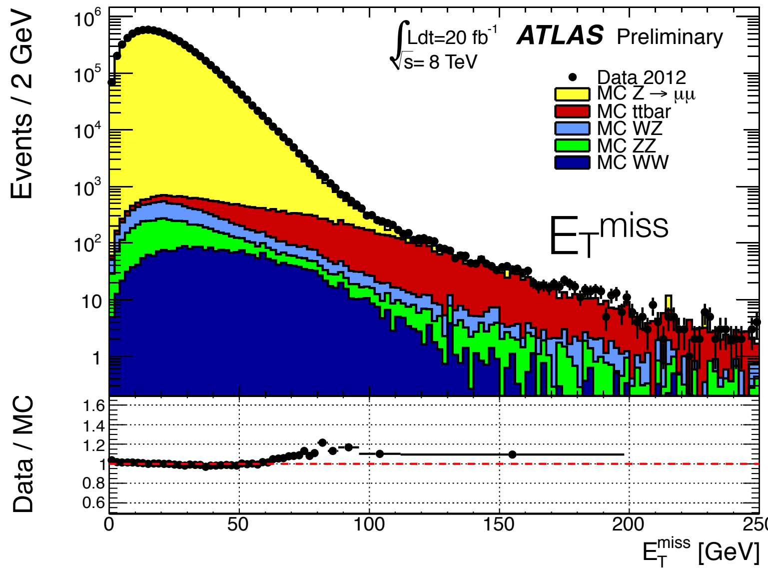
HAD calorimetry ($|\eta|<5$): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

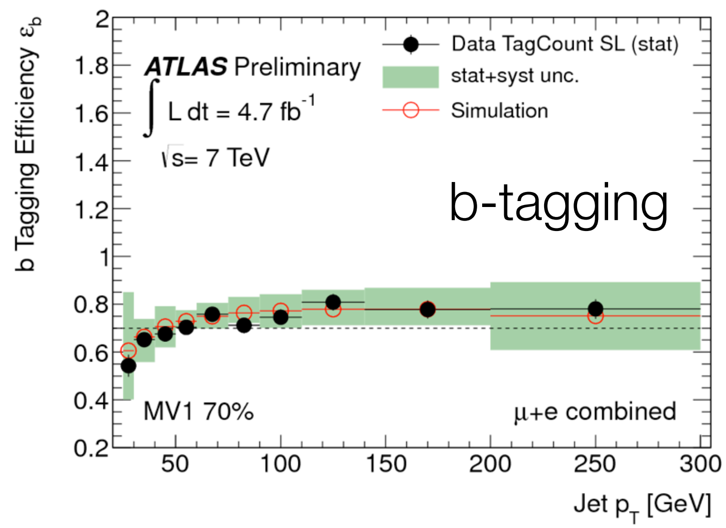
Performance highlights



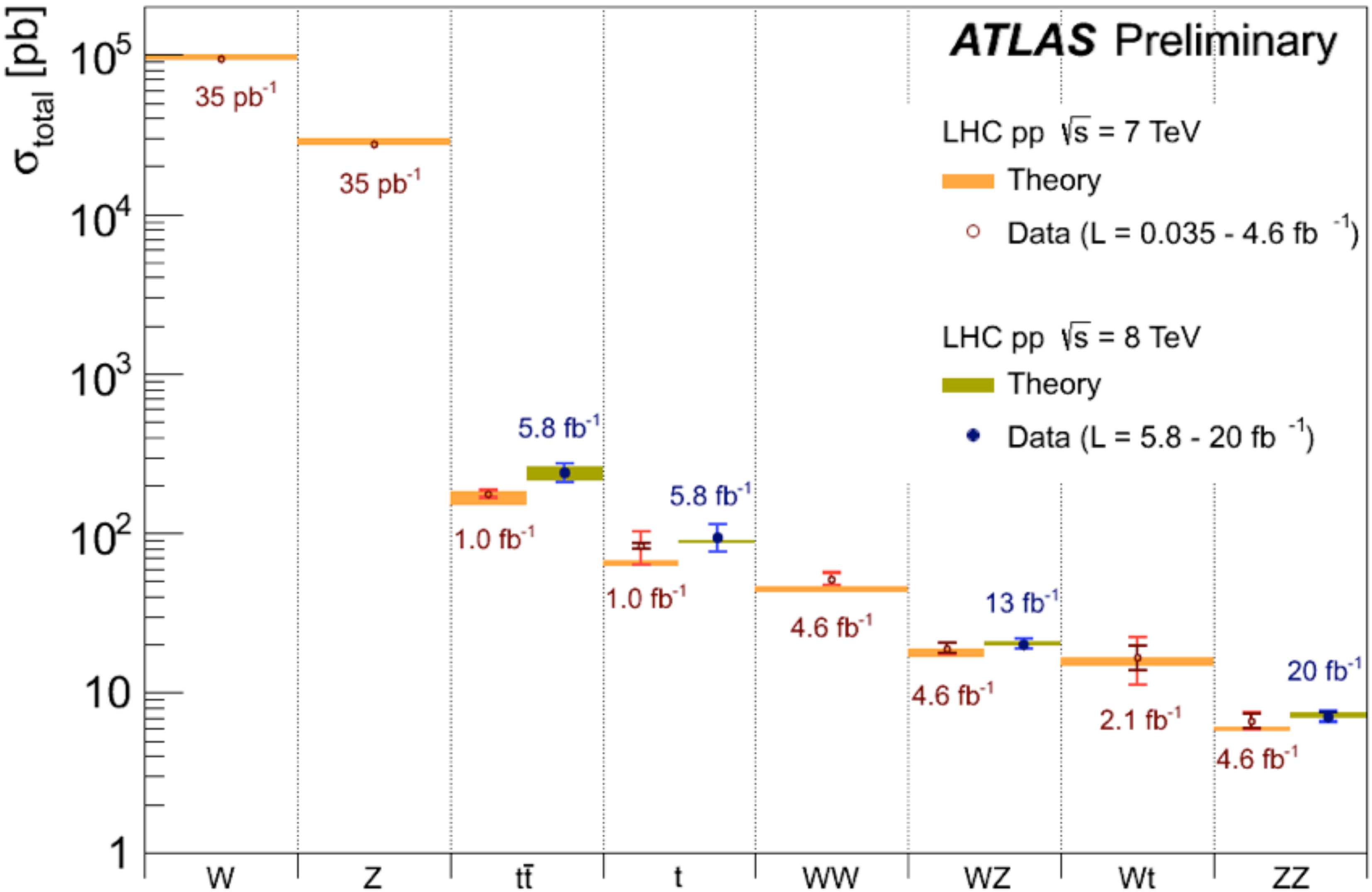
Effect of pileup corrections







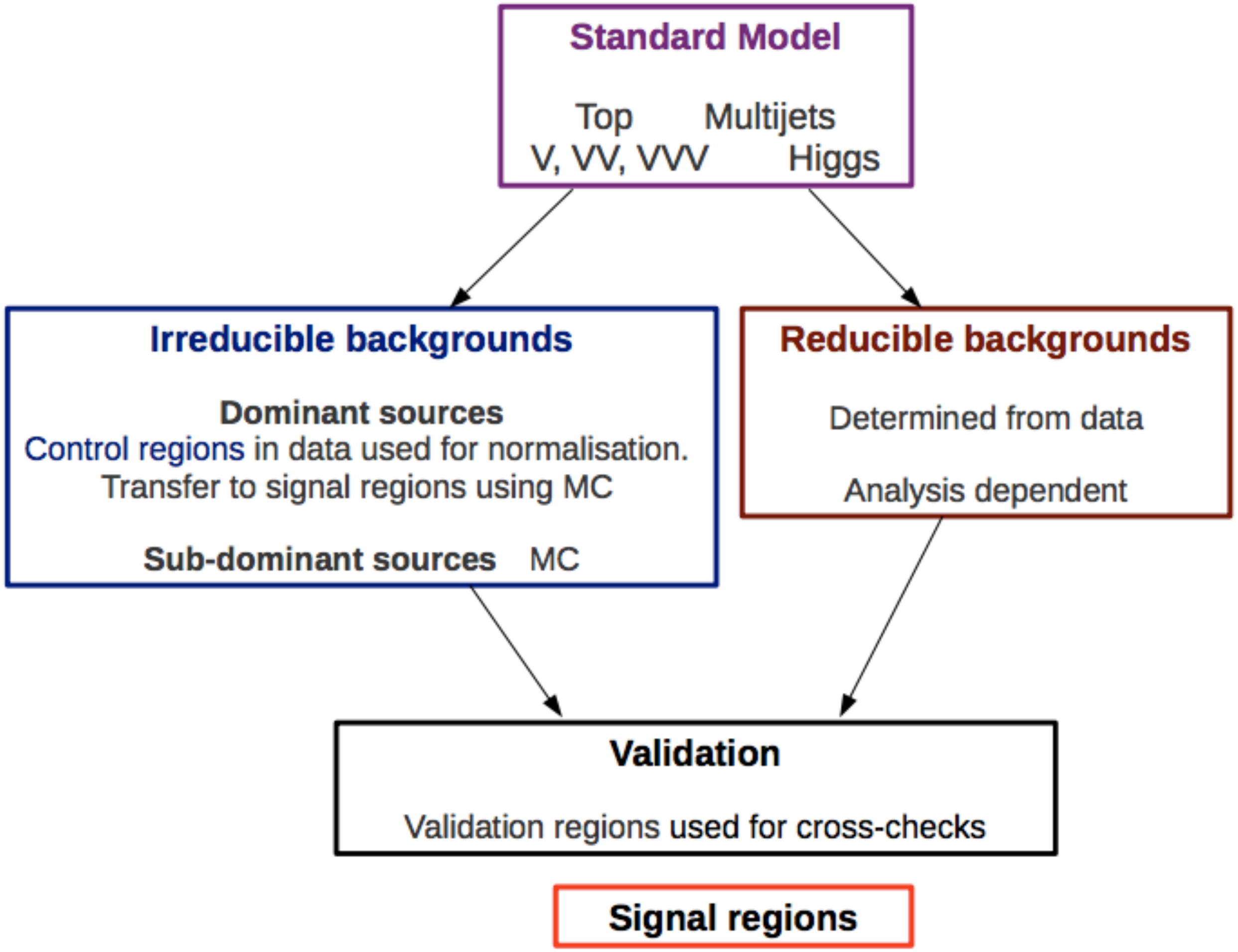
The Standard Model in one slide



Background estimation

Standard Model background estimation

- Doing **SUSY searches** means primarily **understanding the Standard Model background**.



Fake E_T^{miss} background estimate

- Large E_T^{miss} can be induced by a jet mis-measurement.
- Relevant for processes with high cross section and no “real” E_T^{miss} (multi-jet, $Z \rightarrow ll$)

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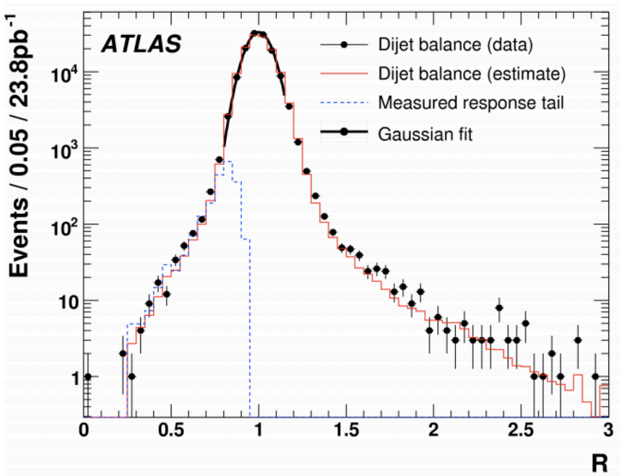
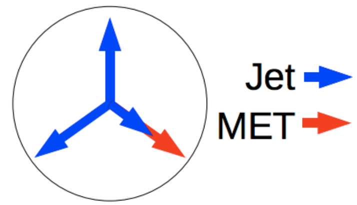


- Derive a **“jet response function”** from MC and **adapt it to data**:
  - **core:** p_T balance in di-jet events
  - **tail:** three-jet (Mercedes) events



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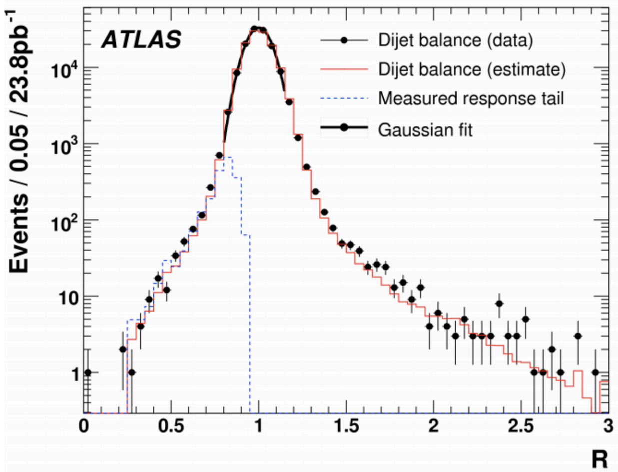

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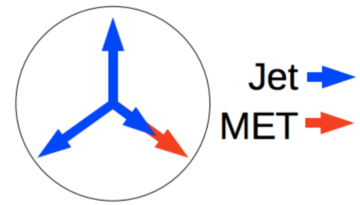
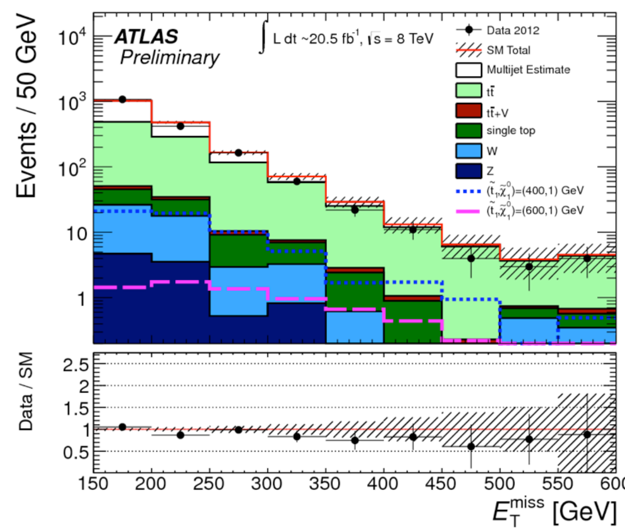


- Use response function to smear jets in real data events with low MET:
  - Obtain events with large "fake" E_T^{miss}
- Validate the estimation in a dedicated control region



Fake lepton background estimate

- General approach to **fake lepton background estimation** based on a loose/tight matrix method
- Example with 1 lepton (easily extendable to multi-lepton signatures):

- A fake lepton lepton can arise from:
  - Off-axis HF semileptonic decays
  - Photon conversion

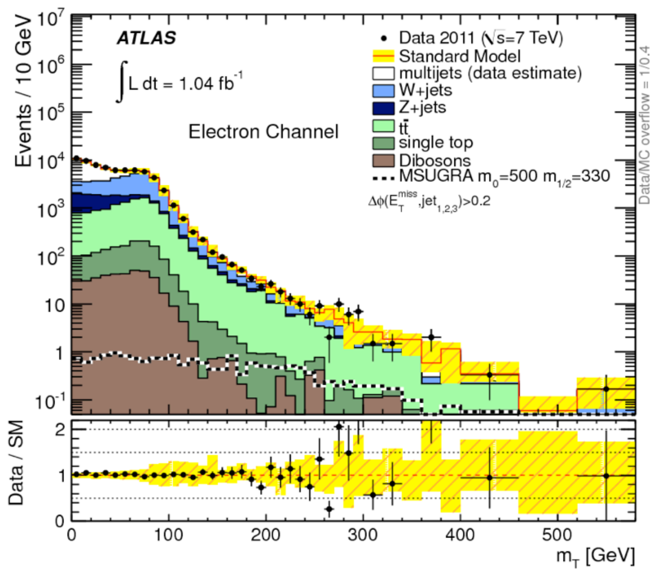
- Strategy: **define a "loose"** (pre-selected) **and a "tight"** (signal) lepton selection.
- Then, solve the following system of equations

$$N^{loose} = N^{loose}_{real} + N^{loose}_{fake}$$
$$N^{tight} = \varepsilon_{real} N^{loose}_{real} + \varepsilon_{fake} N^{loose}_{fake}$$

Need to be measured independently from data

Simply count how many of them

$$N^{tight}_{fake} = \frac{\varepsilon_{fake}}{\varepsilon_{real} - \varepsilon_{fake}} \left(N^{loose} \varepsilon_{real} - N^{tight} \right)$$



Irreducible background estimate

- Normalisation of **irreducible backgrounds** done in **dedicated CR**

$$N^i_{SR} = \frac{N^{i,MC}_{SR}}{N^{i,MC}_{CR}}(N^{i,data}_{CR} - \sum_{j=process} N^{j,MC}_{CR}) = T(N^{i,data}_{CR} - \sum_{j=process} N^{j,MC}_{CR})$$

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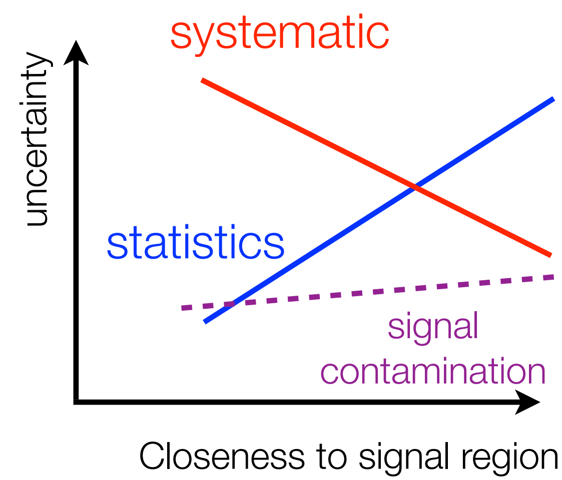

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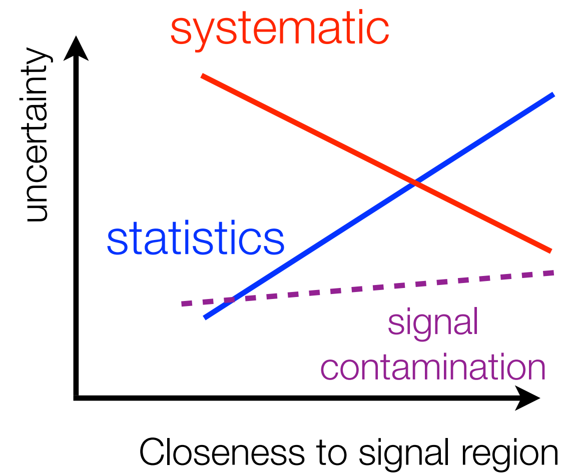


Background (and uncertainty) determination **verified with the use of the validation regions**

Calculation done **performing a combined fit** to all CR (signal contamination accounted for exclusion)

- Typical uncertainties considered:

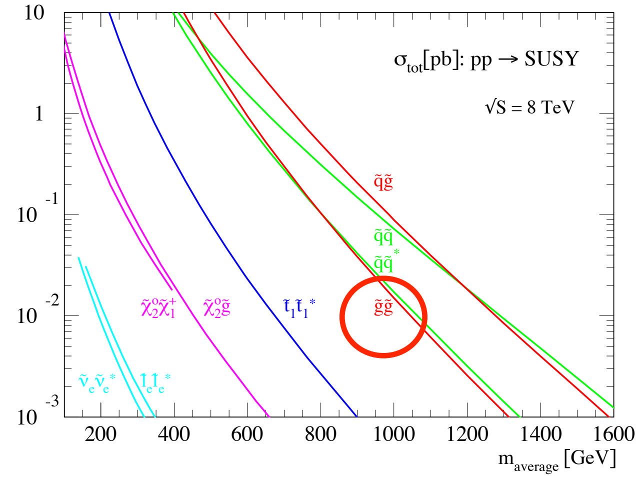
Experimental uncertainties:
-Trigger efficiency
-Jet energy scale and resolution
-Lepton energy scale and efficiency
-E_T^{miss} soft component
-b-tagging
-Luminosity
-pileup modelling

Theory uncertainties:
-Generator modelling (μ_F,μ_R, ME/PS matching, α_s scale choice when possible - otherwise compare generators)
- PS uncertainties (typically compare Pythia and Herwig)
- PDF choice

Gluino production

Gluino mediated stop/sbottom production

- If gluinos are light, they can be produced in pairs and decay through (on- or off-shell) stops/ sbottoms
  - **gluino mediated stop/sbottom production**



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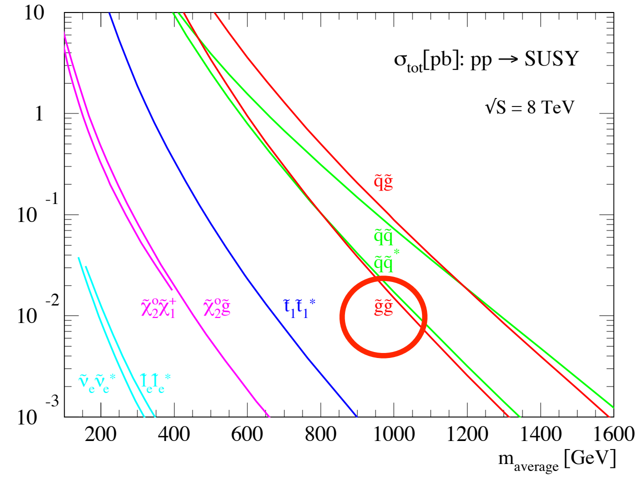

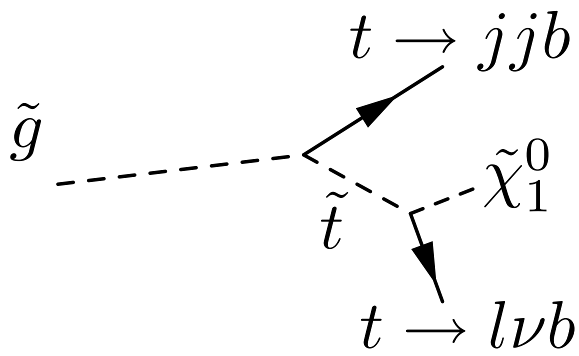

- If gluino pair production dominant (and only stops not too heavy), then the decay is

$$\tilde{g} \to \tilde{t}t$$

- Final state that contains **up to 4 b-jets, up to 12 jets, up to 4 leptons (possibly same sign)**

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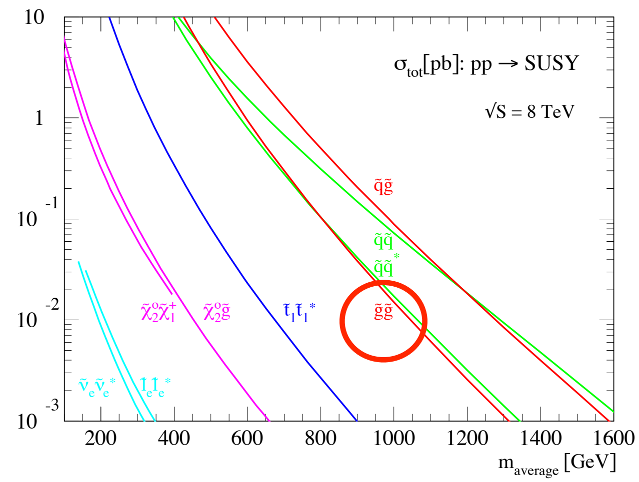

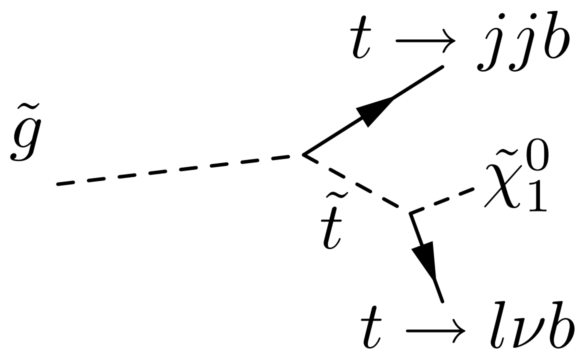

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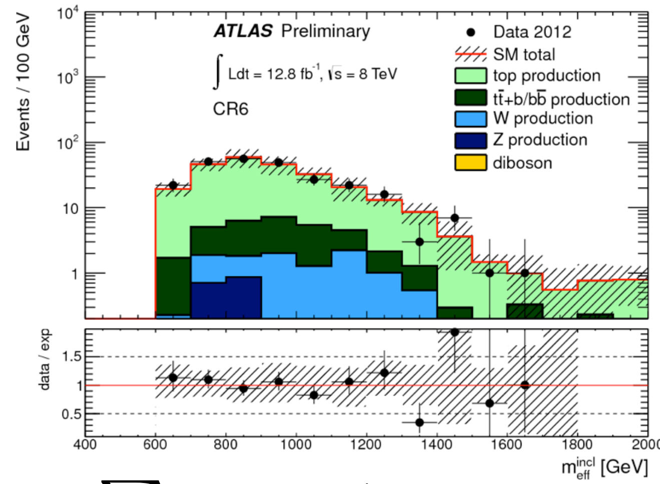
- Several different analyses target this final state:
  - **0-lepton, 3-b jets plus MET** (up to 6 jets) - ATLAS-CONF-2012-145
  - **2 SS leptons + MET + (b-)jets** - ATLAS-CONF-2013-007

- **Not discussed in this seminar:**
  - **multijet (up to 9 jets)** - ATLAS-CONF-2012-103
  - **3-leptons + MET** - ATLAS-CONF-2012-151

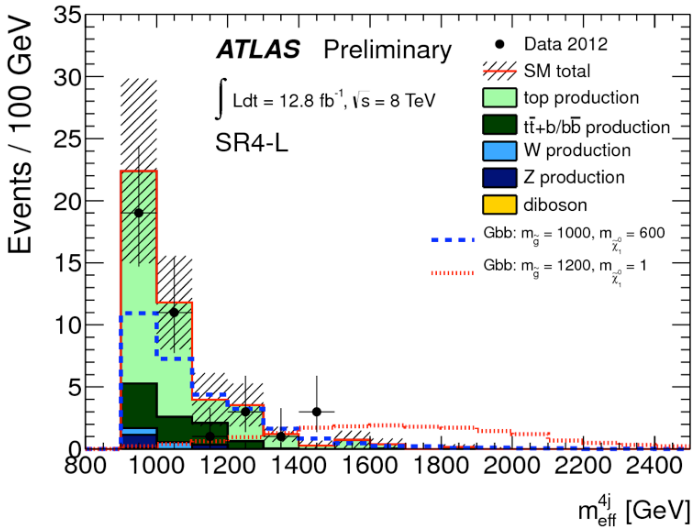
0-lepton - 3 b-jets

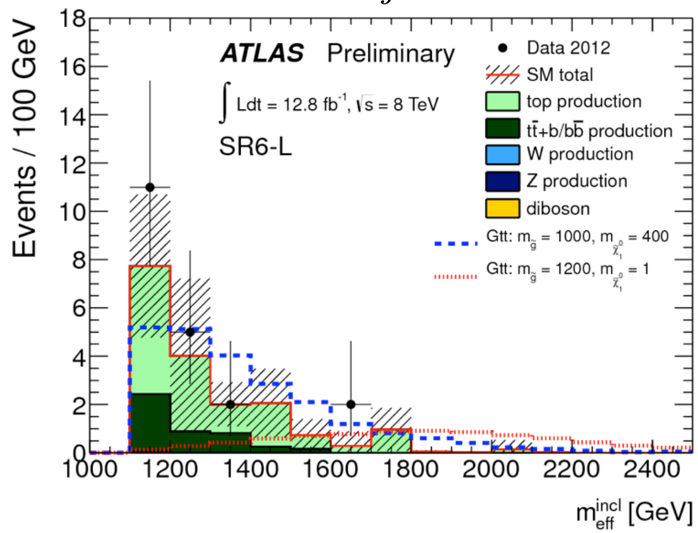
- **Highest sensitivity to gbb/gtt** for a large $\tilde{\chi}^0_1$ mass range is with a **0-lepton, 3 b-jets**
- Two sets of SR: either **at least 4** ($\tilde{g}$->bb$\tilde{\chi}_1^0$) or **at least 6** ($\tilde{g}$->tt$\tilde{\chi}_1^0$) jets
- **top pair production** dominant background, normalised in 1-L control regions



Common criteria: lepton veto, $p_T^{j_1} > 90$ GeV, $E_T^{miss} > 200$ GeV, ≥ 3 b-jets, $E_T^{miss}/m_{eff}^{4j} > 0.2$, $\Delta\phi_{min}^{4j} > 0.4$			
SR	N_J ($p_T > 50$ GeV)	p_T b-jets	m_{eff}
SR4-L/M/T	≥ 4 jets	> 50 GeV	$m_{eff}^{4j} > 900/1100/1300$ GeV
SR6-L/M/T	≥ 6 jets	> 30 GeV	$m_{eff}^{incl} > 1100/1300/1500$ GeV

$$m_{eff} = \sum_{jets} p_T + E_T^{miss}$$





Three b-jets - results

- In case of **no excess**:
  - First: 95% CL **model independent** limits on $\sigma_{vis} = \sigma \times A \times \varepsilon$
  - Then **compute A x ε for specific models** and extract exclusion curve

SR	95% CL UL on N_{BSM}		95% CL UL on $\sigma \times \mathcal{A} \times \varepsilon$ [fb]	
	Observed	Expected	Observed	Expected
SR4-L	17.9	$20.5^{+8.0}_{-5.2}$	1.4	1.6
SR4-M	7.6	$8.8^{+3.5}_{-2.1}$	0.59	0.69
SR4-T	6.5	$5.0^{+2.2}_{-1.1}$	0.51	0.39
SR6-L	17.0	$15.5^{+6.2}_{-3.8}$	1.3	1.2
SR6-M	5.9	$6.6^{+2.8}_{-1.5}$	0.46	0.52
SR6-T	5.1	$4.6^{+1.9}_{-0.6}$	0.40	0.36

Three b-jets - results

- In case of **no excess**:
  - First: 95% CL **model independent** limits on $\sigma_{vis} = \sigma \times A \times \varepsilon$
  - Then **compute A x ε for specific models** and extract exclusion curve

- Model assumptions:
  - **$\tilde{g} \rightarrow tt\tilde{\chi}_1^0$ (BR: 100%) via off-shell stop** (little dependency on the stop mass).
  - Only free parameters: $m_{\tilde{g}}$, $m_{\tilde{\chi}}$

SR	95% CL UL on N_{BSM}		95% CL UL on $\sigma \times \mathcal{A} \times \varepsilon$ [fb]	
	Observed	Expected	Observed	Expected
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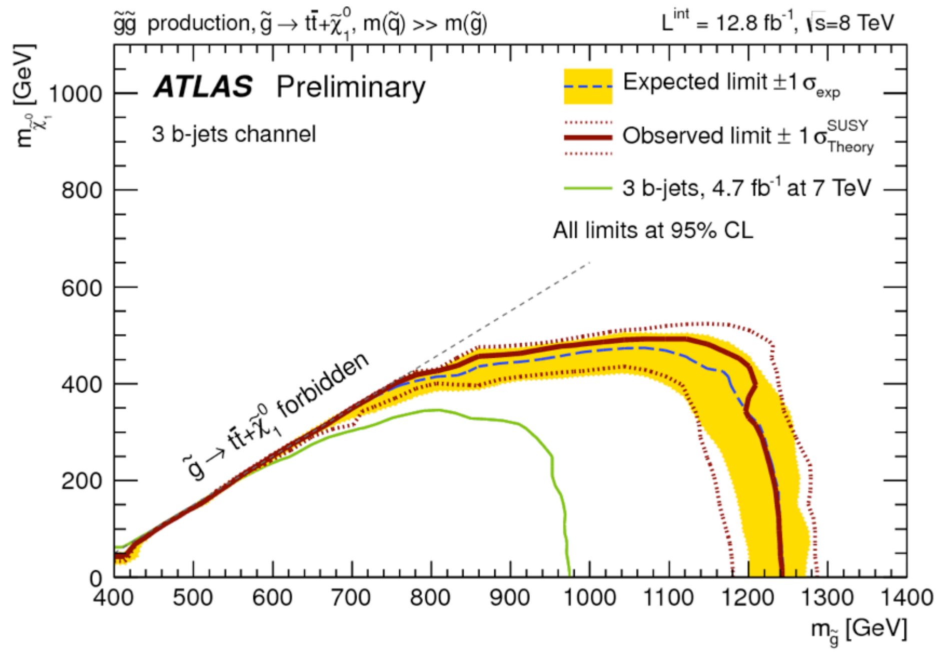
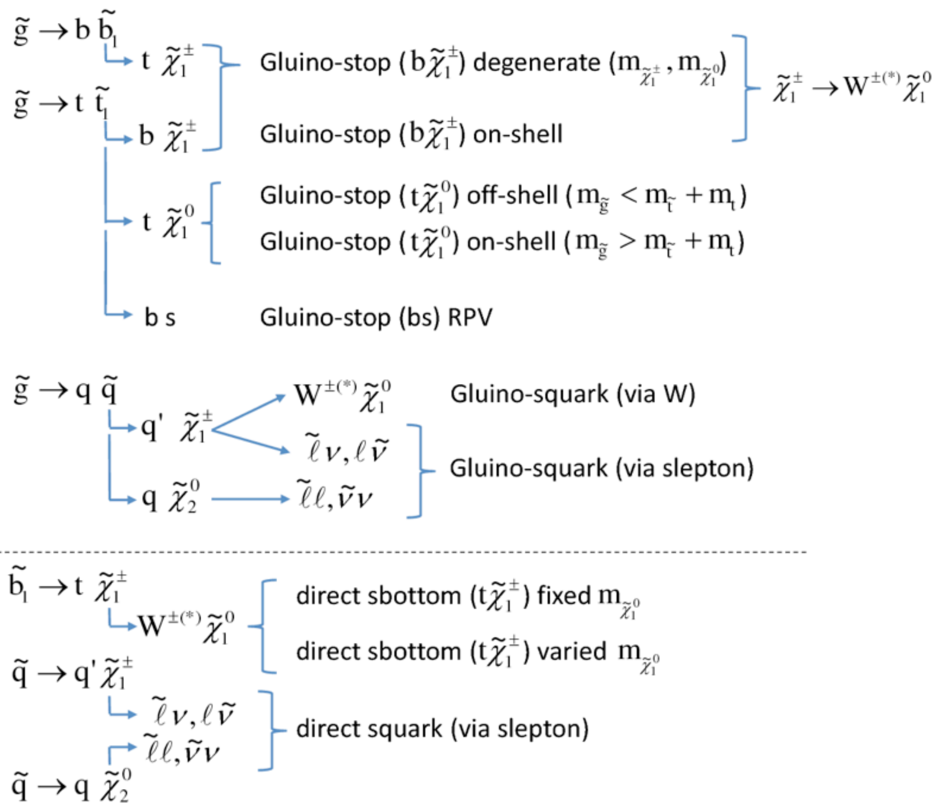


Same-Sign (SS) leptons

NEW FOR MORIOND '13

ATLAS-CONF-2012-007

- Generic signature sensitive to new physics. SS expected in many SUSY scenarios



gluino is a majorana fermion - SS final states **enhanced**

- Results use the **full 2012 dataset**
- With respect to ATLAS-CONF-2012-105:
  - New signal regions defined (with and without b-jets)
  - Sensitivity **extended to other gluino decay modes** and to **direct sbottom production**

SS leptons - signal region definitions

- Signal regions definition based on:
  - **jet and b-jet multiplicity**
  - **m_T** between leading lepton and E_T^{miss}
  - **E_T^{miss} and M_{eff}**

$$m_{eff} = \sum_j p_T^j + \sum_l p_T^l + E_T^{miss}$$

$$m_T = \sqrt{2p_T^\ell E_T^{miss}(1 - \cos\Delta\phi(E_T^{miss}, \ell)}$$

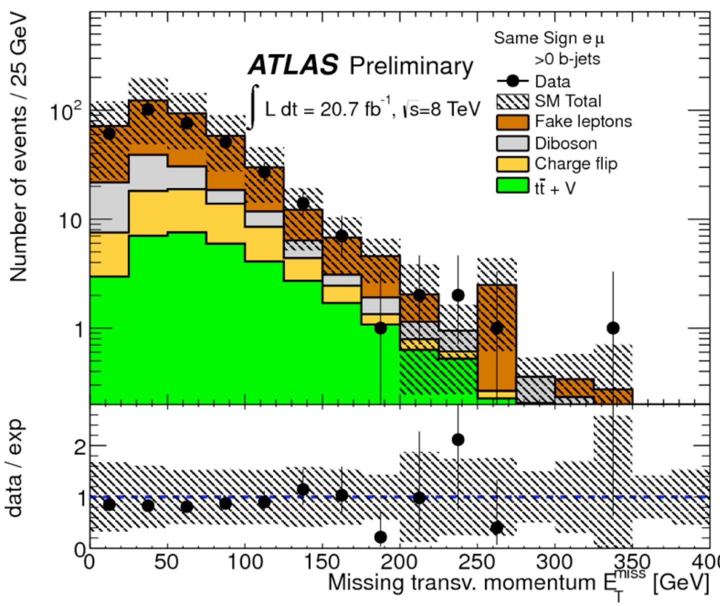
Signal region	N_{b-jets}	Signal cuts (discovery case)	Signal cuts (exclusion case)
SR0b	0	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV m_T> 100 GeV, m_{eff}>400 GeV	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV, m_T> 100 GeV, binned shape fit in m_{eff} for m_{eff} >300 GeV
SR1b	≥1	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV m_T>100 GeV, m_{eff}>700 GeV	$N_{jets} \geq 3$, E_T^{miss}> 150 GeV, m_T>100 GeV, binned shape fit in m_{eff} for m_{eff}>300 GeV
SR3b	≥3	$N_{jets} \geq 4$ -	$N_{jets} \geq 5$, E_T^{miss}< 150 GeV or m_T< 100 GeV

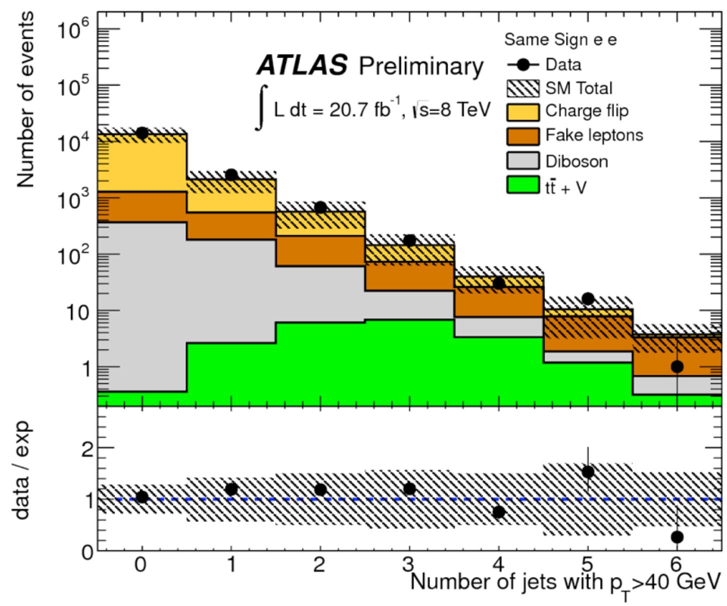
SS leptons - background estimation

- Background processes:
  - **Irreducible background:** ttV, diboson→MC used
  - **Reducible background** (e.g. tt, Z) estimated with matrix method
    - **charge flip (for electrons)**: estimated with SS to OS ratio on the Z→ee peak

Validation regions defined at low E_T^{miss}

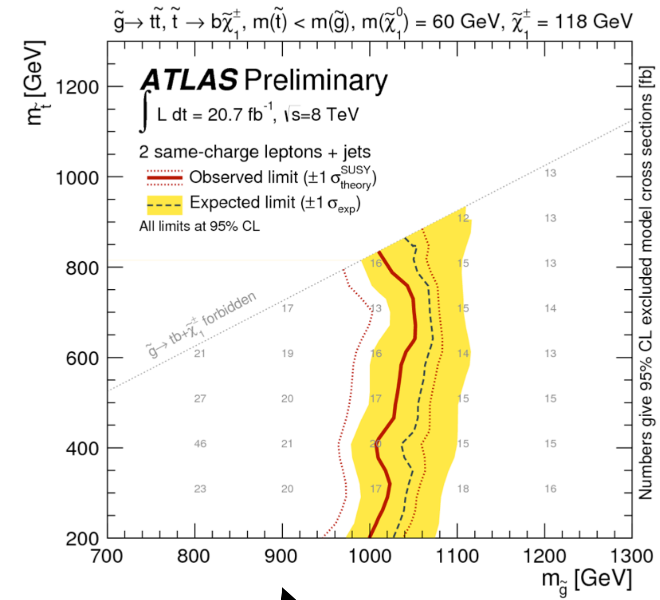
Event classes	VR-diboson	VR-ttW	VR-ttZ
Observed events	54	9	4
Expected background events	74 ± 13	4.2 ± 1.9	8.0 ± 2.0
Expected $t\bar{t}$+V events	1.6 ± 0.8	2.7 ± 1.5	3.2 ± 1.1
Expected diboson events	60 ± 7	0.4 ± 0.1	3.9 ± 1.3
Expected fake lepton events	12 ± 11	1.1 ± 1.1	0.9 ± 0.5
Expected charge mis-meas. events	0	0	0

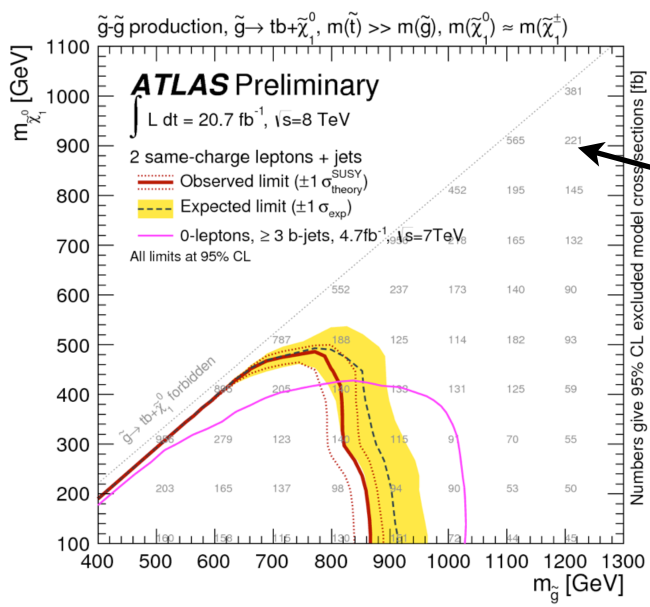




SS leptons - results

B) Exclusion case	SR0b	SR1b	SR3b
Observed events	5	11	1
Expected background events	7.5 ± 3.2	10.1 ± 3.9	1.8 ± 1.3
Expected $t\bar{t} + V$ events	0.5 ± 0.4	3.4 ± 1.5	0.6 ± 0.4
Expected diboson events	3.4 ± 1.1	1.4 ± 0.7	< 0.1
Expected fake lepton events	3.4 ± 2.9	4.4 ± 3.1	1.0 ± 1.1
Expected charge mis-measurement events	0.2 ± 0.1	0.8 ± 0.3	0.1 ± 0.1
p_0	0.5	0.39	0.5

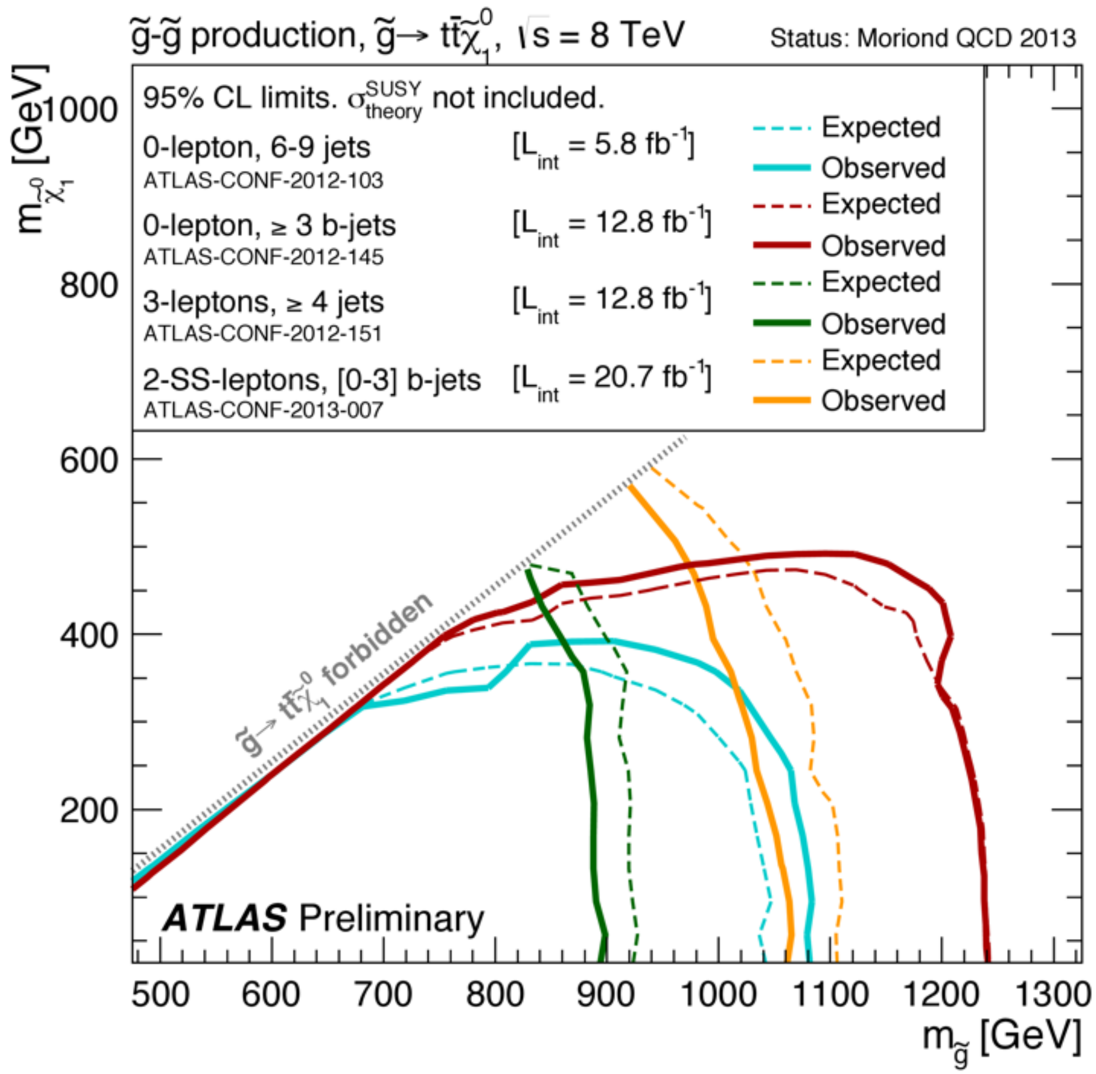




$$\tilde{g} \rightarrow t\tilde{t} \rightarrow tb\tilde{\chi}_1^{\pm}$$

with different hypotheses on the chargino mass

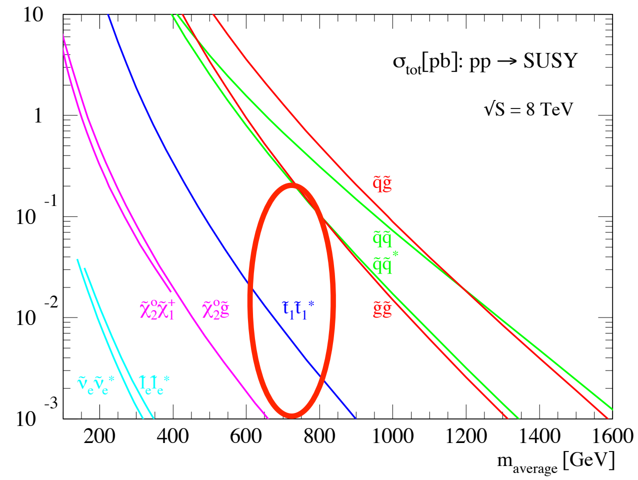
Summary on gluino-mediated stop production



Direct stop/sbottom production

direct 3rd generation squark production

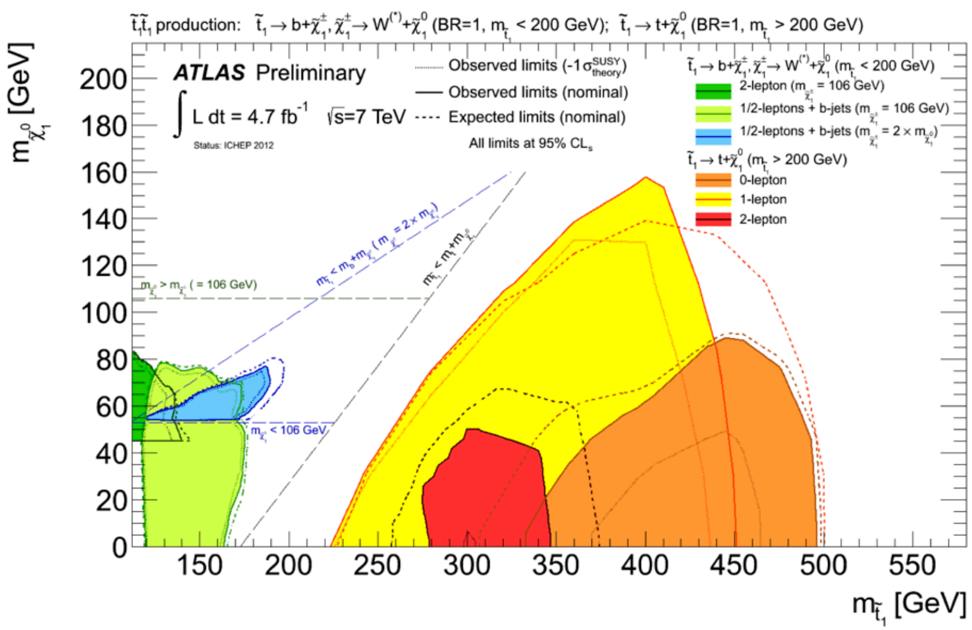
- The **stops/sbottoms** constrained by naturalness to be **not heavier than ~ 1 TeV**
- Wide, dedicated effort for both **direct stop and direct sbottom production search** in ATLAS



- Sbottom decays:
  - $\tilde{b}_1 \to b\tilde{\chi}_1^0$: 0-lepton (2b + MET)
  - $\tilde{b}_1 \to t\tilde{\chi}_1^\pm$: 2-leptons SS (already discussed), 3-leptons

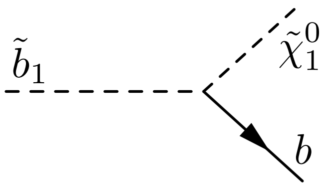
- Stop decays:
  - $\tilde{t}_1 \to t\tilde{\chi}_1^0$: 0-lepton, 1-lepton, 2-leptons
  - $\tilde{t}_1 \to b\tilde{\chi}_1^\pm$: 1-lepton, 2-leptons, 0-lepton (2b + MET)
  - Final states containing Z bosons: natural GMSB with χ_1^0 NLSP or $t_2 \to t_1$ Z transitions

2011 stop status



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

ATLAS-CONF-2012-165

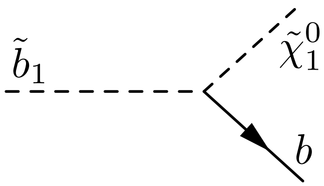


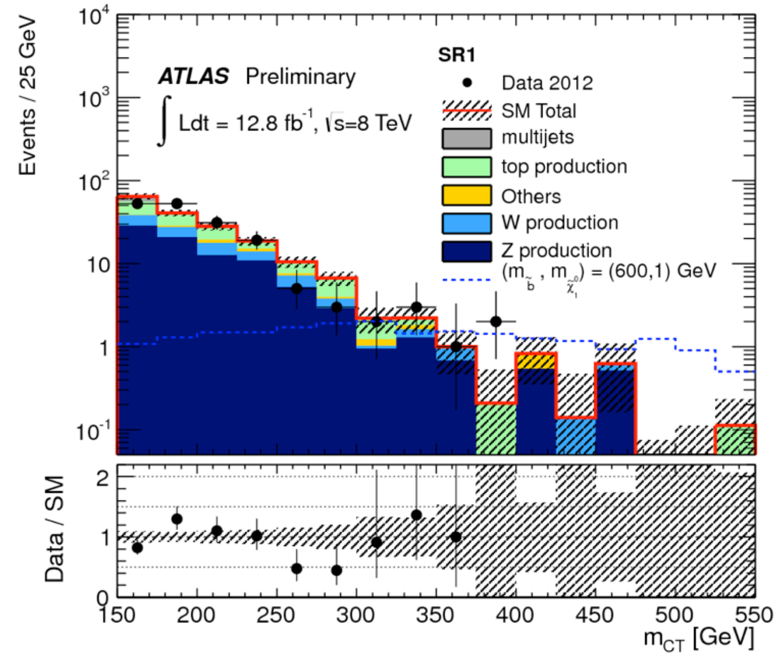
- $m_{CT}(bb)$: boost-corrected contransverse mass
  - It has an end-point at $(m_{prod}^2 - m_{inv}^2)/m_{prod}$

- **for large $\Delta m(\tilde{b}, \tilde{\chi}_1^0)$:**
  - 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
- **for small $\Delta m(\tilde{b}, \tilde{\chi}_1^0)$:**
  - Focus on events with a hard ISR jet produced

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

ATLAS-CONF-2012-165





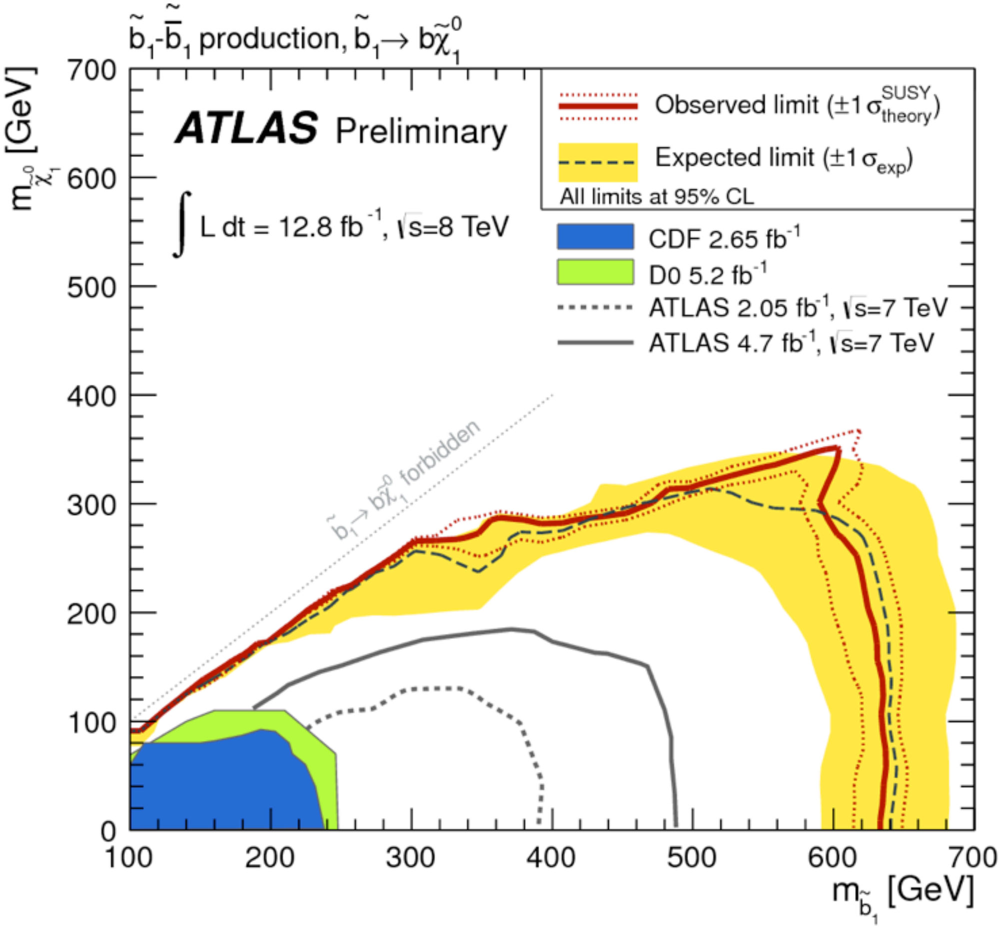
- m_{CT}(bb): boost-corrected contransverse mass
  - It has an end-point at $(m_{prod}^2 - m_{inv}^2)/m_{prod}$

- **for large Δm(b̃, $\tilde{\chi}_1^0$):**
  - Look for 2 b-jets (veto on third jet), large E_T^{miss}
  - Use M_{CT} to suppress top; Main background: Z (→νν)+b-jets
- **for small Δm(b̃, $\tilde{\chi}_1^0$):**
  - Focus on events with a hard ISR jet produced

Signal region	Bkg. estimate	Obs. data	95% CL UL on σ_{vis} (fb)	
			expected	observed
SR1 ($m_{CT} > 150$ GeV)	176 ± 25	172	4.2	4.1
SR1 ($m_{CT} > 200$ GeV)	71 ± 11	66	1.9	1.7
SR1 ($m_{CT} > 250$ GeV)	25 ± 4	16	0.96	0.61
SR1 ($m_{CT} > 300$ GeV)	7.4 ± 1.7	8	0.58	0.62
SR2	95 ± 11	104	2.5	3.0
SR3a	203 ± 35	207	4.2	4.2
SR3b	27 ± 5	21	1.0	0.74

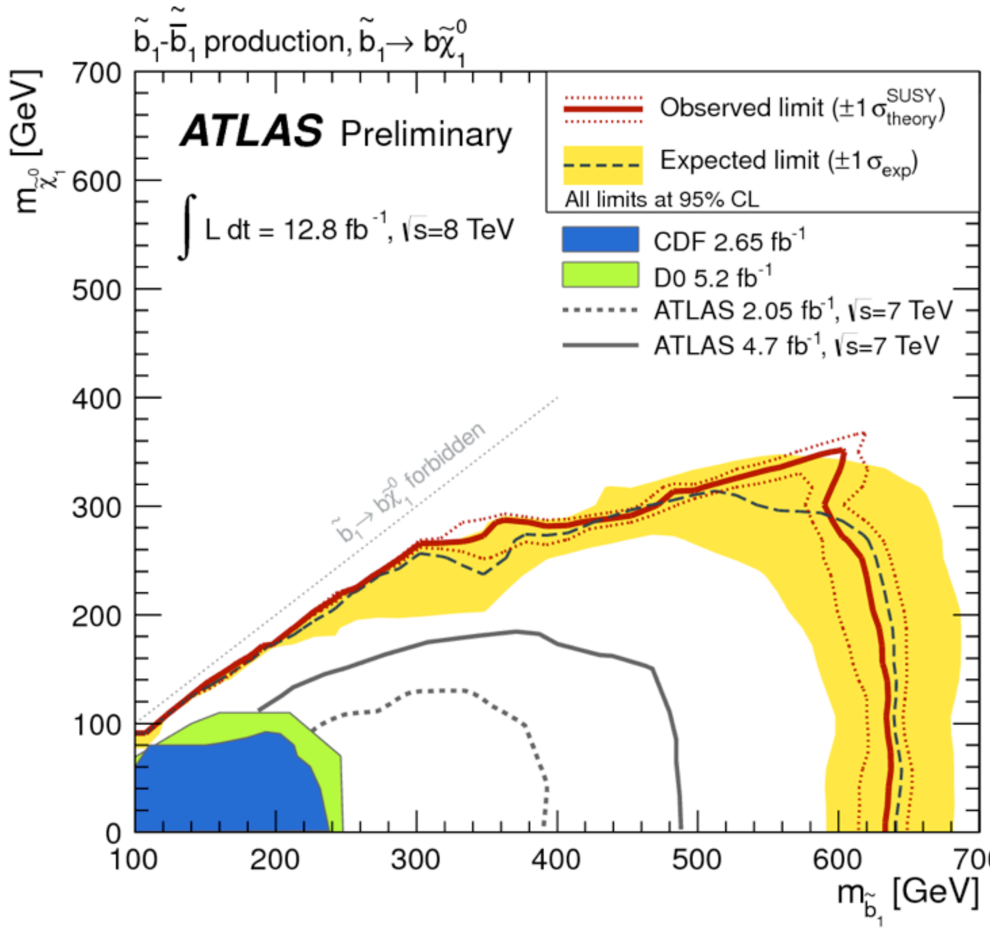
Direct sbottom search summary

2 b-jets + MET

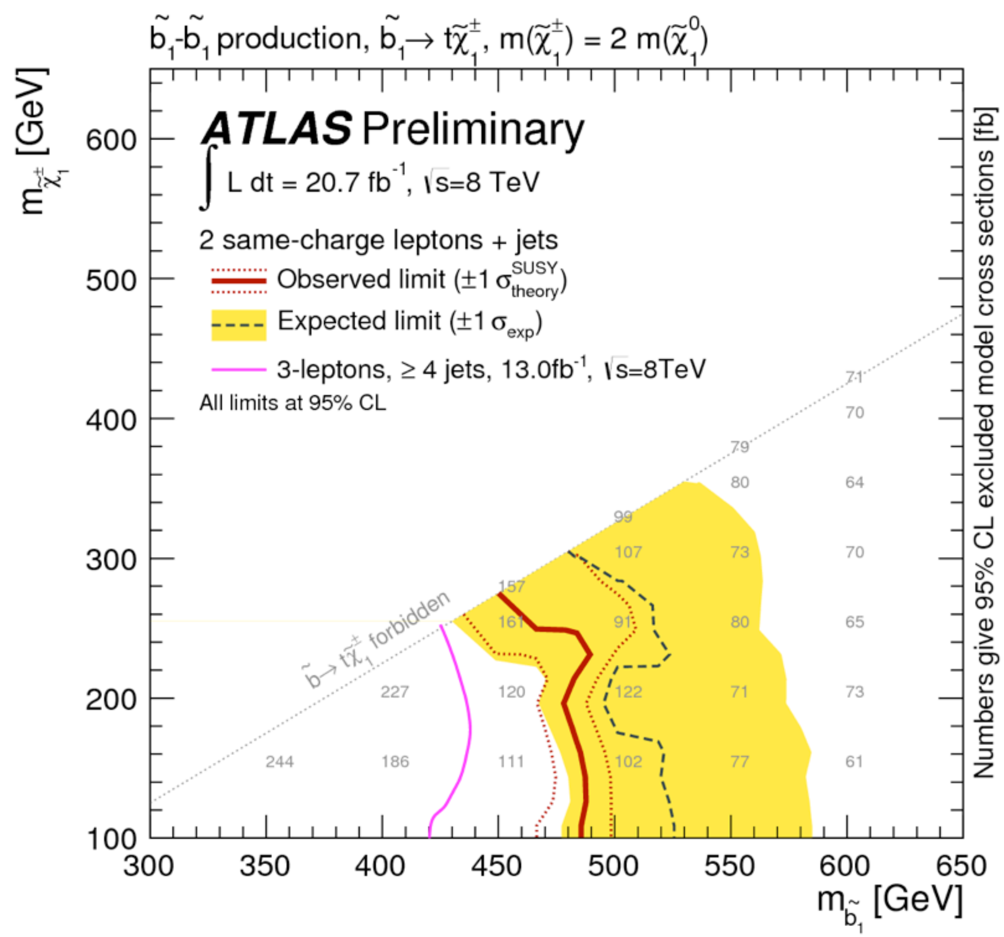


Direct sbottom search summary

2 b-jets + MET



SS-dileptons



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

NEW FOR MORIOND '13

ATLAS-CONF-2013-024

- **Basic idea:** reconstruct two hadronic top quarks and investigate E_T^{miss} distribution
- At high E_T^{miss}, background **dominated by semileptonic tt** decays (with a hadronic tau)

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

NEW FOR MORIOND '13

ATLAS-CONF-2013-024

- **Basic idea:** reconstruct two hadronic top quarks and investigate E_T^{miss} distribution
- At high E_T^{miss}, background **dominated by semileptonic tt** decays (with a hadronic tau)

		Signal
	Trigger	E_T^{miss}
Lepton veto	N_{lep}	0
	p_T^{ℓ}	< 10 (10)
	$p_T^{\ell_2}$	—
	$m_{\ell\ell}$	—
Signal definition	N_{jet}	≥ 6
	p_T^{jet}	$>$ 80,80,35,...35
	$N_{b\text{-jet}}$	≥ 2
	m_{jjj}	80 to 270
	E_T^{miss}	$>$ 200, 300, 350
Multijet rejection	$E_T^{miss,track}$	> 30
	$\Delta\phi(E_T^{miss}, E_T^{miss,track})$	$< \pi/3$
	$m_T(\ell, E_T^{miss})$	—
	$\Delta\phi(\text{jet}, E_T^{miss})$	$> \pi/5$
Top rejection	$m_T(b\text{-jet}, E_T^{miss})$	> 175
	Tau veto	yes

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

NEW FOR MORIOND '13

ATLAS

ATLAS-CONF-2013-024

- **Basic idea:** reconstruct two hadronic top quarks and investigate E_T^{miss} distribution
- At high E_T^{miss}, background **dominated by semileptonic tt** decays (with a hadronic tau)
- **top and Z→νν** evaluated in dedicated control regions
- Residual **multijet background** evaluated with jet smearing method

		Signal	$t\bar{t}$ CR	Z+jets CR	Multijet CR
	Trigger	E_T^{miss}	single electron (muon)	two electron (muon)	E_T^{miss}
Lepton veto	N_{lep}	0	1	2	0
	p_T^{ℓ}	< 10 (10)	> 35 (35)	> 20 (20)	< 10 (10)
	$p_T^{\ell_2}$	—	< 10 (10)	> 20 (10)	—
	$m_{\ell\ell}$	—	—	81 to 101	—
Signal definition	N_{jet}	≥ 6	≥ 6	≥ 6	≥ 6
	p_T^{jet}	$>$ 80,80,35,...35	$>$ 80,80,35,...35	$>$ 80,80,35,...35	$>$ 80,80,35,...35
	$N_{b\text{-jet}}$	≥ 2	≥ 2	≥ 2	≥ 2
	m_{jjj}	80 to 270	0 to 600	80 to 270	—
Multijet rejection	E_T^{miss}	$>$ 200, 300, 350	$>$ 200, 300, 350	> 70	> 160
	$E_T^{miss,track}$	> 30	> 30	> 30	> 30
	$\Delta\phi(E_T^{miss}, E_T^{miss,track})$	$< \pi/3$	$< \pi/3$	$< \pi/3$	$> \pi/3$
	$m_T(\ell, E_T^{miss})$	—	40 to 120	—	—
	$\Delta\phi(\text{jet}, E_T^{miss})$	$> \pi/5$	$> \pi/10$	$> \pi/5$	$< \pi/5$
Top rejection	$m_T(b\text{-jet}, E_T^{miss})$	> 175	—	> 175	> 175
	Tau veto	yes	no	yes	no

$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ - 1-lepton

NEW FOR THIS SEMINAR

ATLAS

ATLAS-CONF-2013-037

- Results updated for **full 2012 dataset**
- High E_T^{miss} for the signal because of LSP. Multiple signal regions:
  - relying mostly on **a harsh selection on E_T^{miss} and m_T**
  - tag one b-jet, **reconstruct one hadronic top mass**
- **Dominant background:** dileptonic ttbar decays (one lepton is **either lost or a tau**). W+ HF also relevant

$\tilde{t}_1 \to t\tilde{\chi}^0_1$ - 1-lepton

NEW FOR THIS SEMINAR

ATLAS-CONF-2013-037

- Results updated for **full 2012 dataset**
- High E_T^{miss} for the signal because of LSP. Multiple signal regions:
  - relying mostly on **a harsh selection on E_T^{miss} and m_T**
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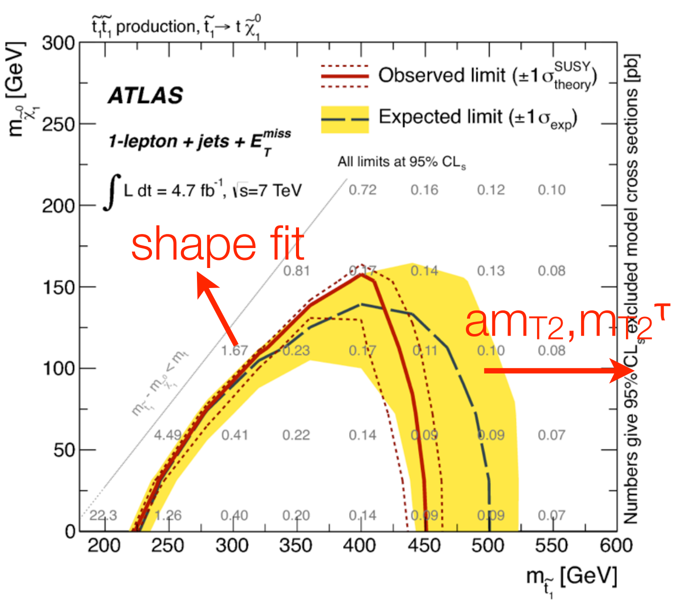
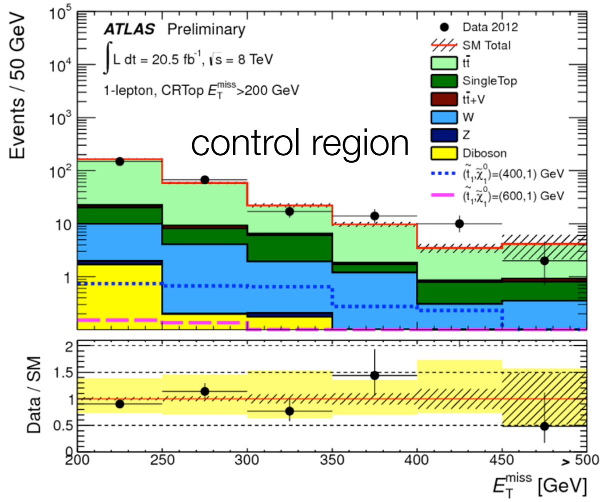


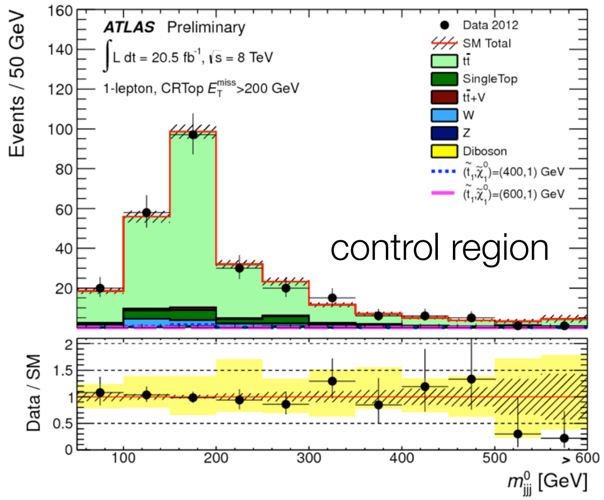
- Dedicated new optimization
  - additional **transverse mass variables** improves sensitivity **at high stop mass**
  - m_T/E_T^{miss} shape fit improves toward diagonal

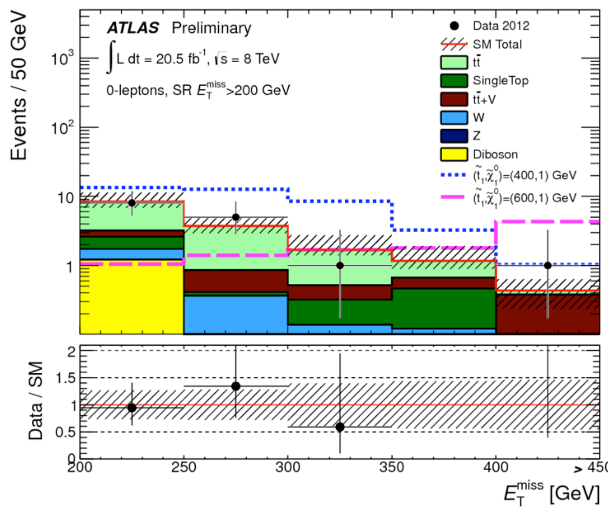
Requirement	SRtN1_shape	SRtN2	SRtN3
$\Delta\phi(j_1, \vec{p}_T^{miss}) >$	0.8	-	0.8
$\Delta\phi(j_2, \vec{p}_T^{miss}) >$	0.8	0.8	0.8
E_T^{miss} [GeV] >	100$^{(\star)}$	200	275
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	5	13	11
m_T [GeV] >	60$^{(\star)}$	140	200
m_{eff} [GeV] >	-	-	-
am_{T2} [GeV] >	-	170	175
m_{T2}^{τ} [GeV] >	-	-	80
$m_{had-top}$	Yes	Yes	Yes
$N^{iso-trk} = 0$	-	-	-
Number of b-jets ≥	1	1	1
p_T (leading b-jet) [GeV] >	25	25	25
p_T (second b-jet) [GeV] >	-	-	-

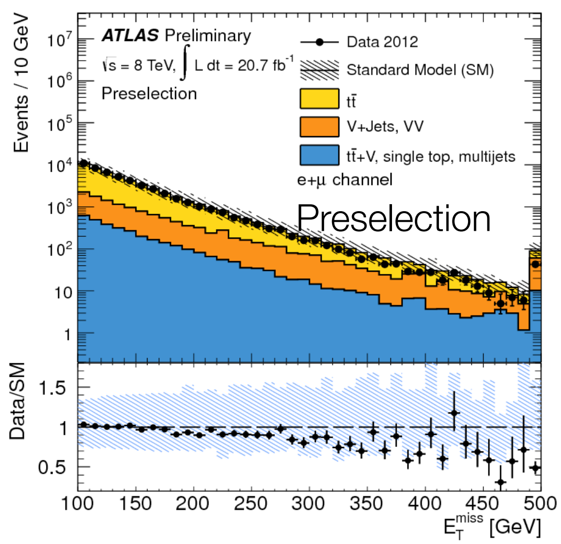
Data/MC agreement

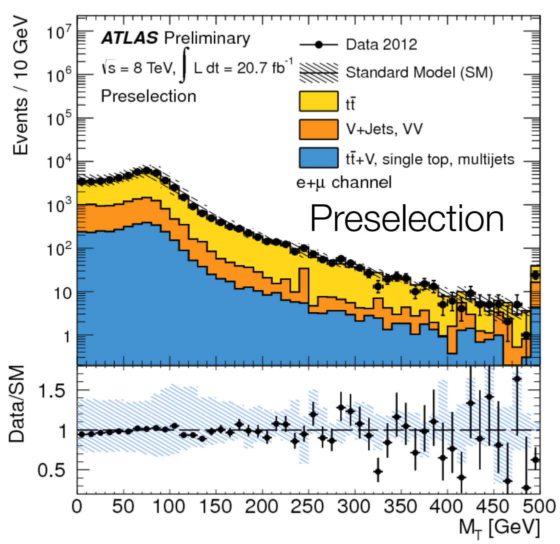
Signal region

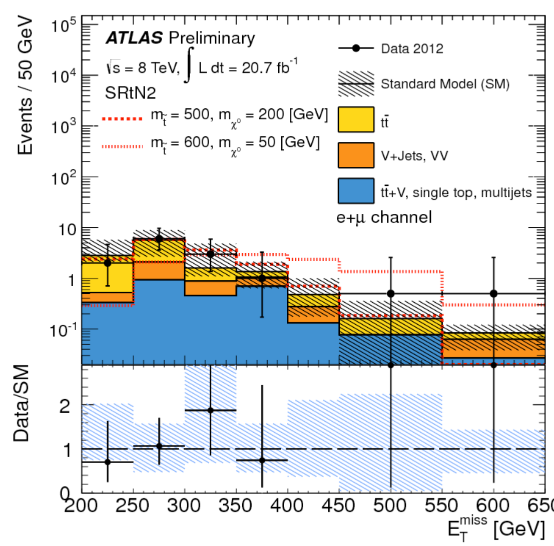






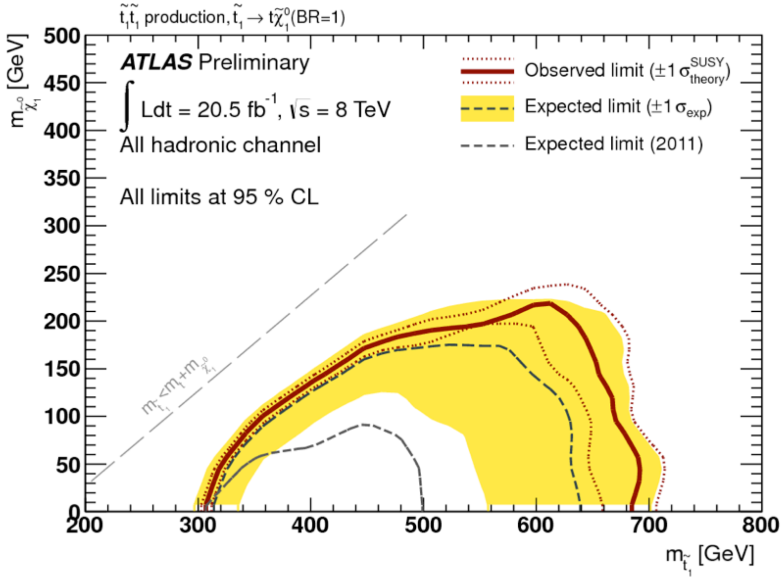


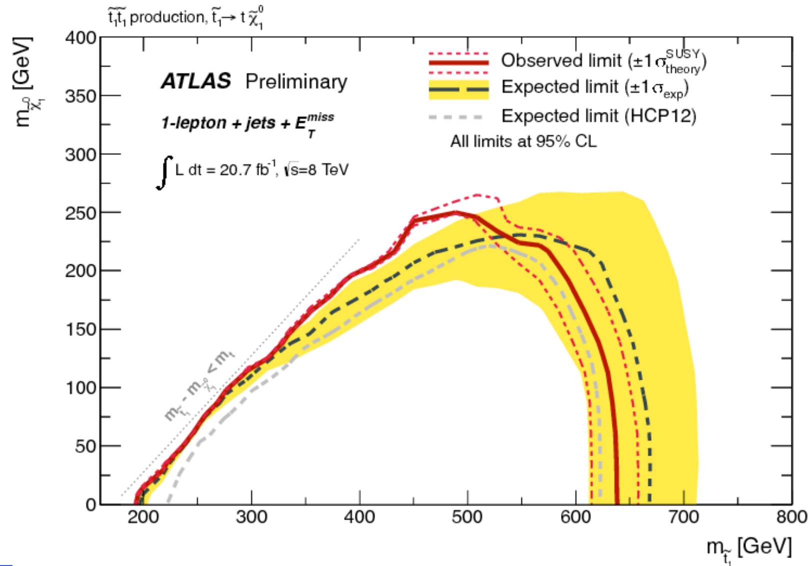




$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ - Results (21 fb^{-1})

- **No excess** in any of the signal regions considered (see backup for details)
- Model:
  - stop pair production only, $\tilde{\mathbf{t}}_1$ **mostly** $\tilde{\mathbf{t}}_\mathbf{R}$, $\tilde{\chi}_1^0$ bino-like
  - BR($t\tilde{\chi}_1^0$) = 100%





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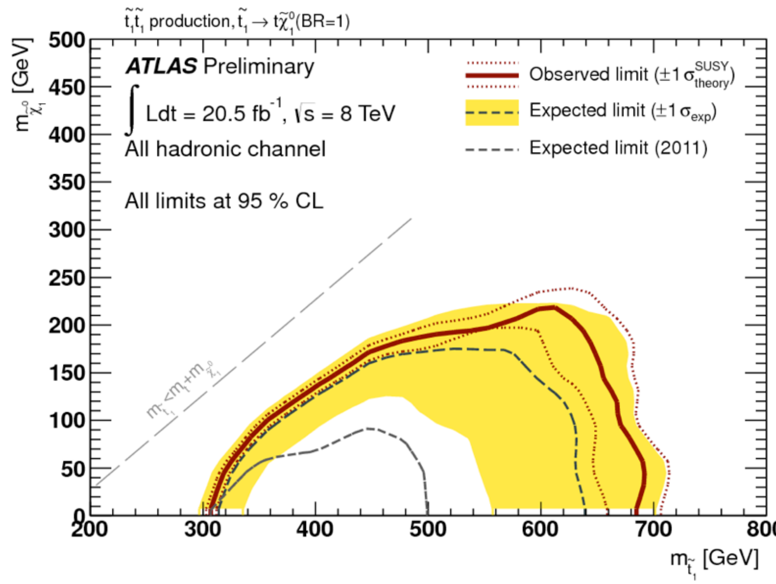
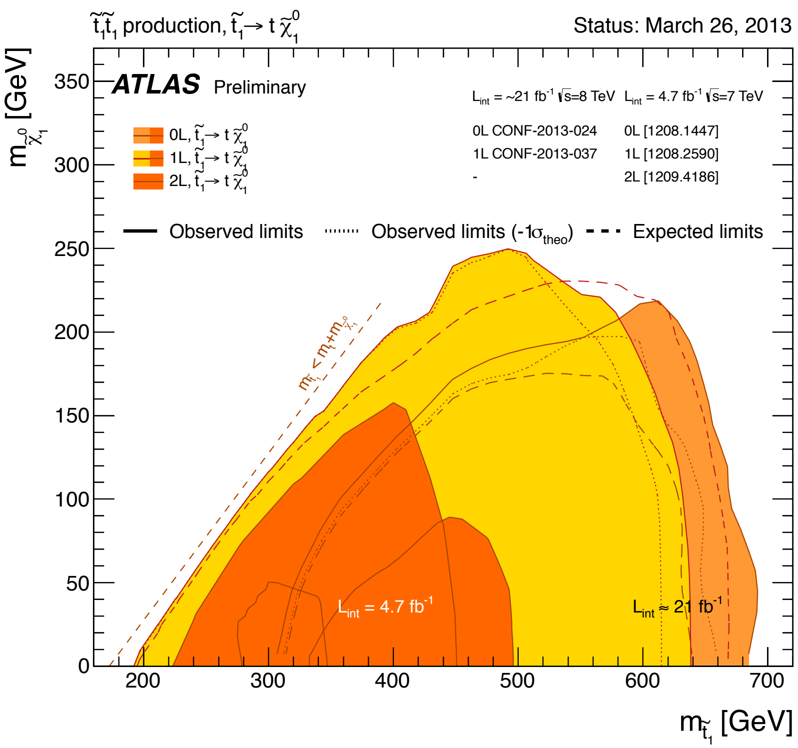
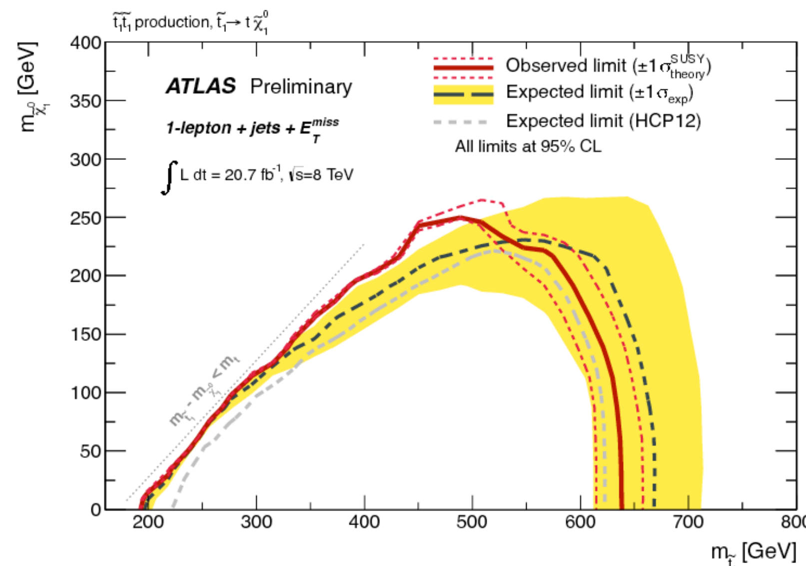
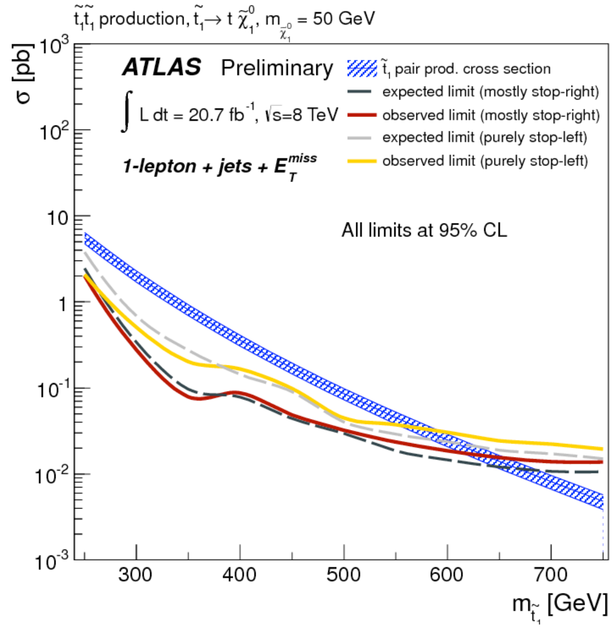






$\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$ - more results

- Dependency on the model chosen:
    - stop chirality - if the **top quark is left handed**:
        - 1-lepton **slightly penalised** by lepton **decreased acceptance**
        - 0-lepton **almost insensitive** to the top chirality.



Thursday, March 28, 2013

$\tilde{t}_1 \to t\tilde{\chi}_1^0$ - more results

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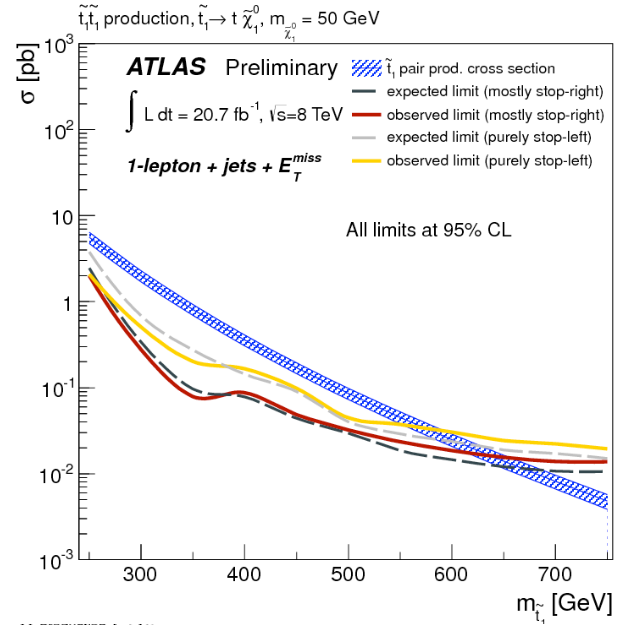
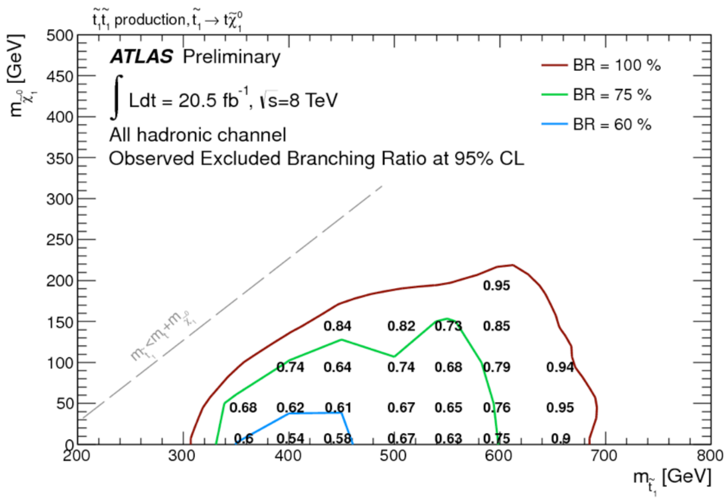
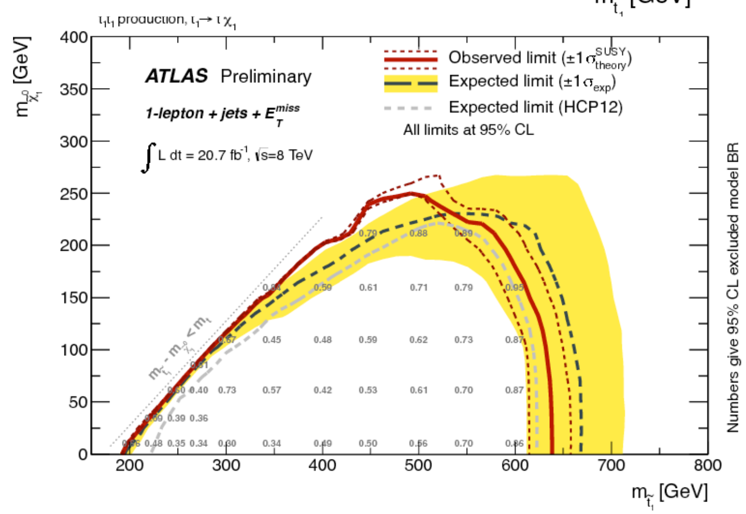


- What if BR is not 100%?
- limits as a function of the BR (assumes the other decay mode is invisible)





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

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

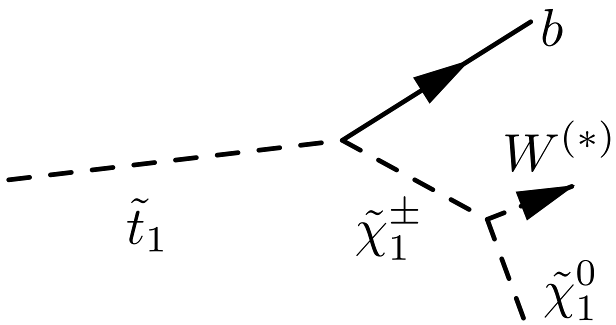
Hypothesis	Targeted signature (3 players at 8 TeV)
gaugino universality: $m_{\chi\pm} \sim 2m_{\chi0}$	2-leptons - large leptons M_{T2} 1-lepton (dedicated SR)
stop-chargino mass degeneracy $m_{\chi\pm} \sim m_{t1}$ - 10 GeV	2-leptons - large leptons MT2
neutralino-chargino mass degeneracy (favoured if $\tilde{\chi}_1^0, \tilde{\chi}_1^{\pm}$ higgsino-like): $m_{\chi\pm} \sim m_{\chi0}$	2 b-jets + MET; 0-lepton
Fixed chargino mass at 150 GeV	2-leptons - large leptons M_{T2} 1-lepton (dedicated SR)

Requirement	SRbC1	SRbC2	SRbC3
$\Delta\phi(j_1, \vec{p}_T^{miss}) >$	0.8	0.8	0.8
$\Delta\phi(j_2, \vec{p}_T^{miss}) >$	0.8	0.8	0.8
E_T^{miss} [GeV] >	150	160	160
$E_T^{miss} / \sqrt{H_T}$ [GeV$^{1/2}$] >	7	8	8
m_T [GeV] >	120	120	120
m_{eff} [GeV] >	-	550	700
am_{T2} [GeV] >	-	175	200
m_{T2}^{τ} [GeV] >	-	-	-
$m_{had-top}$	-	-	-
$N^{iso-trk} = 0$	Yes	Yes	Yes
Number of b-jets ≥	1	2	2
p_T (leading b-jet) [GeV] >	25	100	120
p_T (second b-jet) [GeV] >	-	50	90

First player

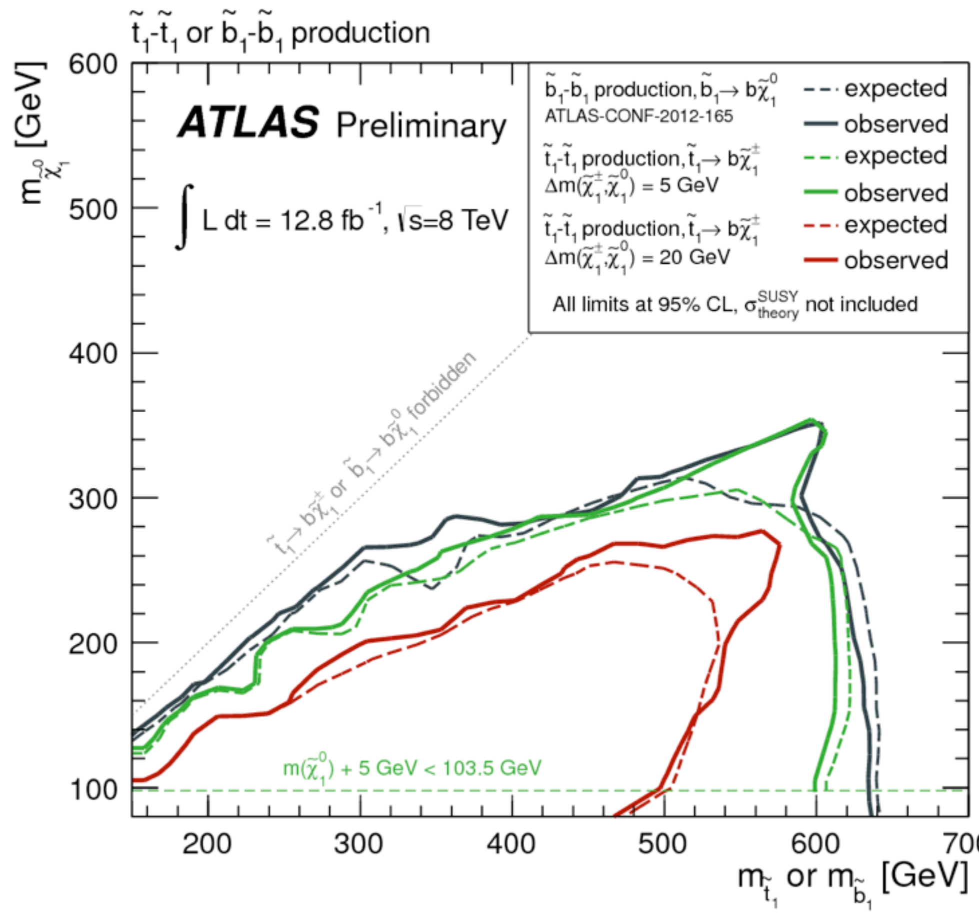
- **Dedicated optimisation** of the **1-lepton analysis**:
  - **drop the top mass requirement**
  - Soften **requirements on E_T^{miss}** (and its significance)
  - Introduce a **cut on m_{eff}**

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



Second player

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



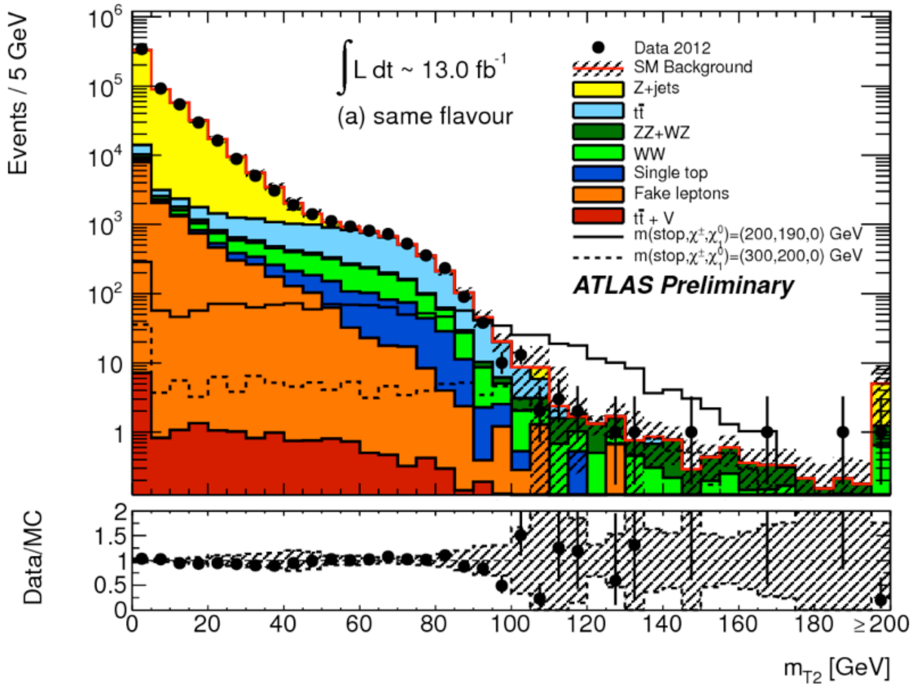
$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$ - Summary

Third player (2 leptons)

ATLAS-CONF-2012-167

- Basic idea: the dilepton M_{T2} has an upper bound for events where they come from Ws

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



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

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ATLAS-CONF-2012-167

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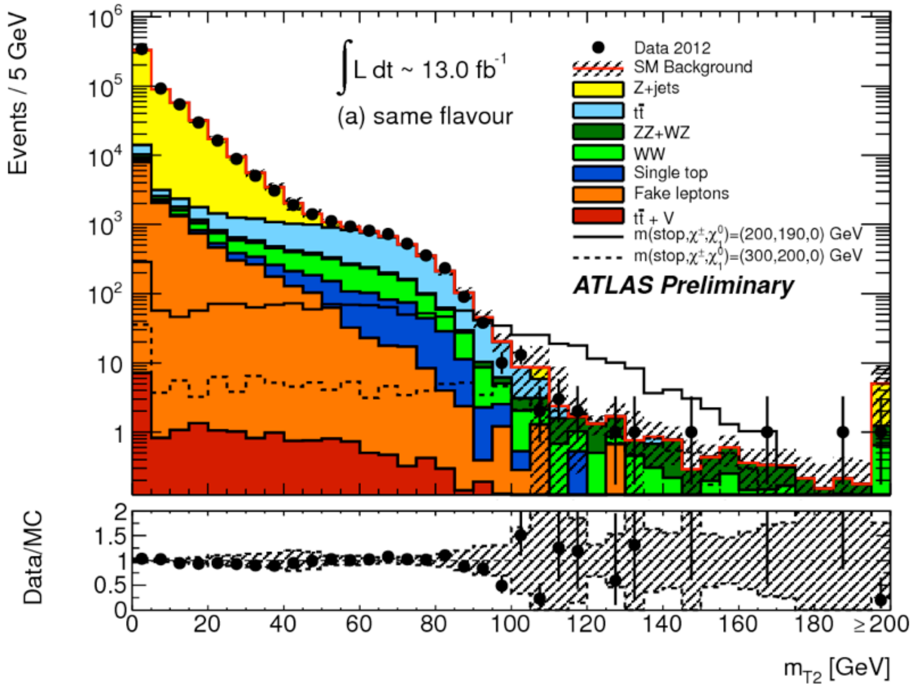
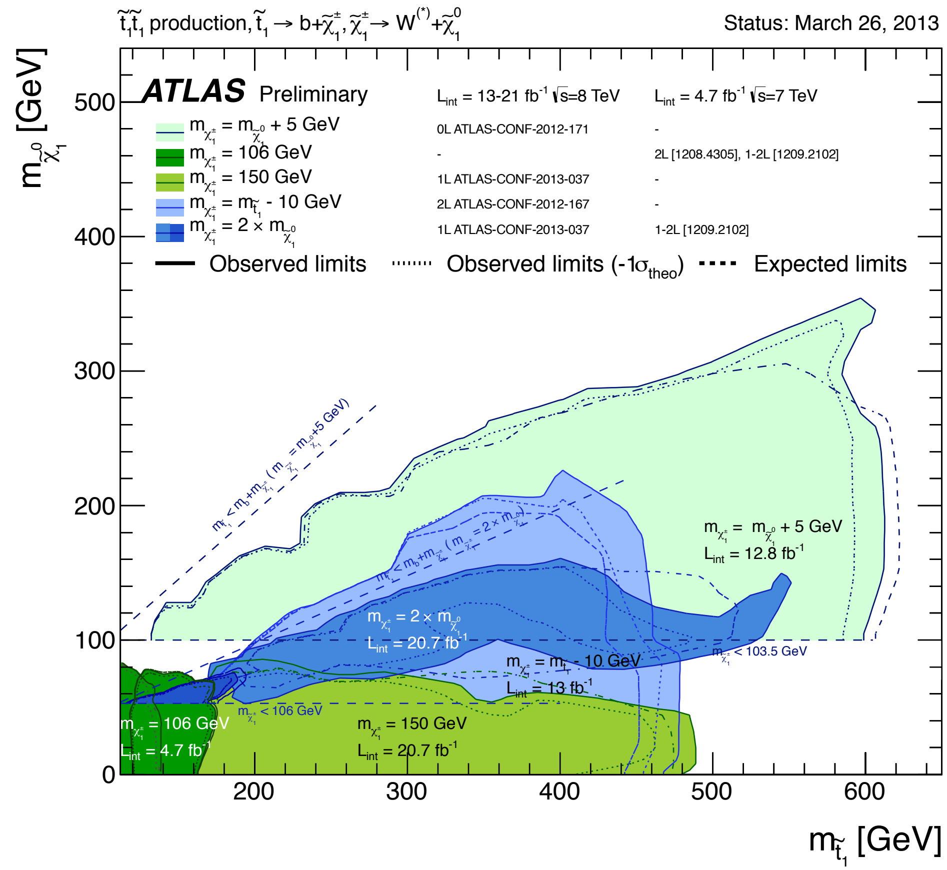
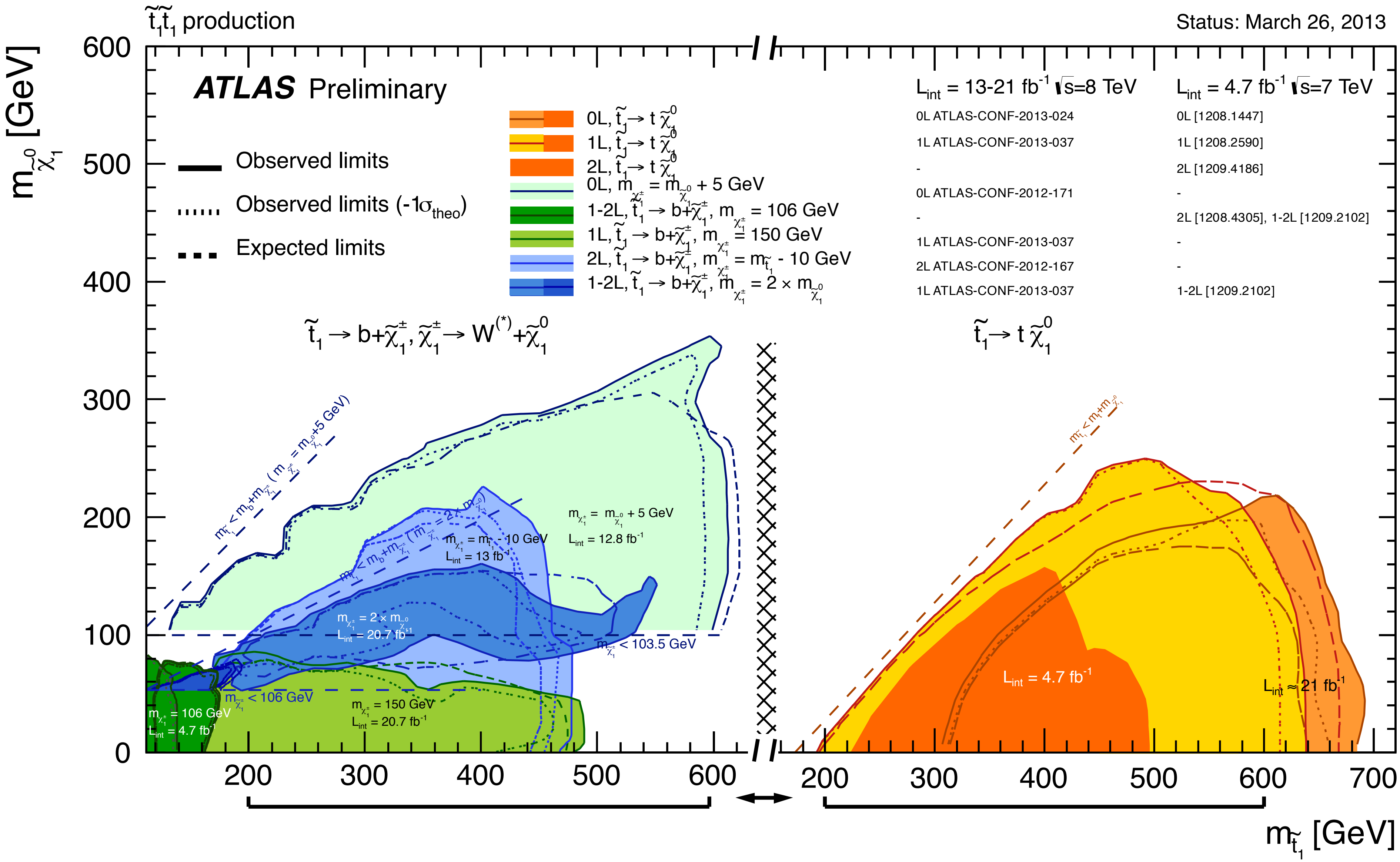


And the summary



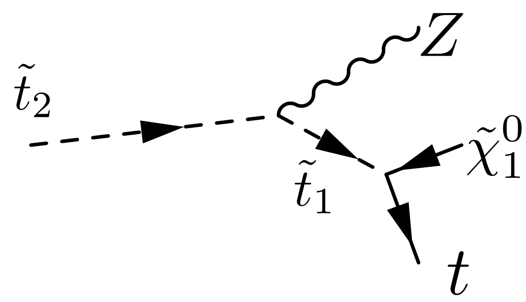
Stop summary



More on direct stop - final states with Z

NEW FOR MORIOND '13

- If $m(\tilde{t}_1) \sim m(t) + m(\tilde{\chi}_1^0)$ then looking for $\tilde{t}_2$ might be useful
  - Natural GMSB models can have similar final states
  - Dedicated 2L and 3L approaches (requiring a reconstructed on-shell Z from OS)



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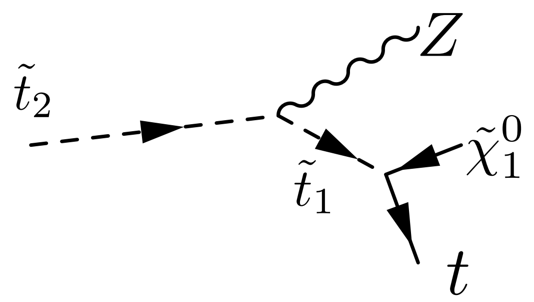
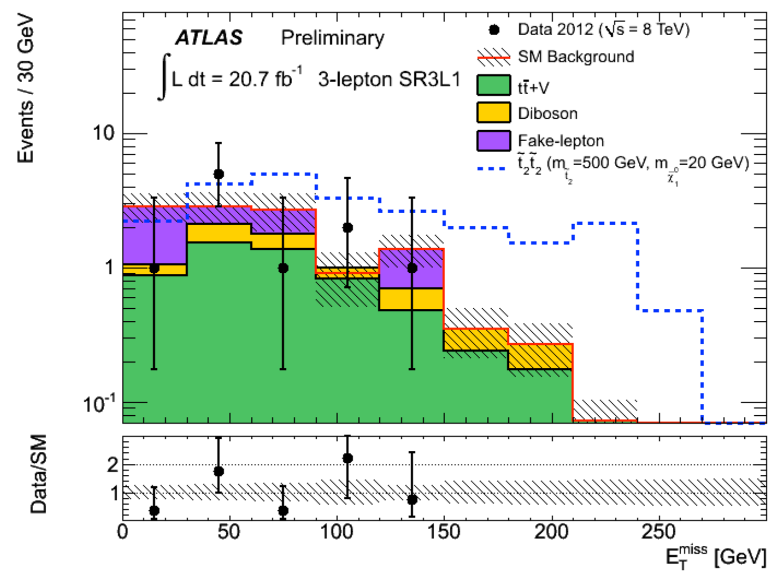
NEW FOR MORIOND '13



- **Fake lepton** background estimated with **matrix method**
- Residual **Z+jets contribution** to 2L analysis estimated with **jet smearing method**

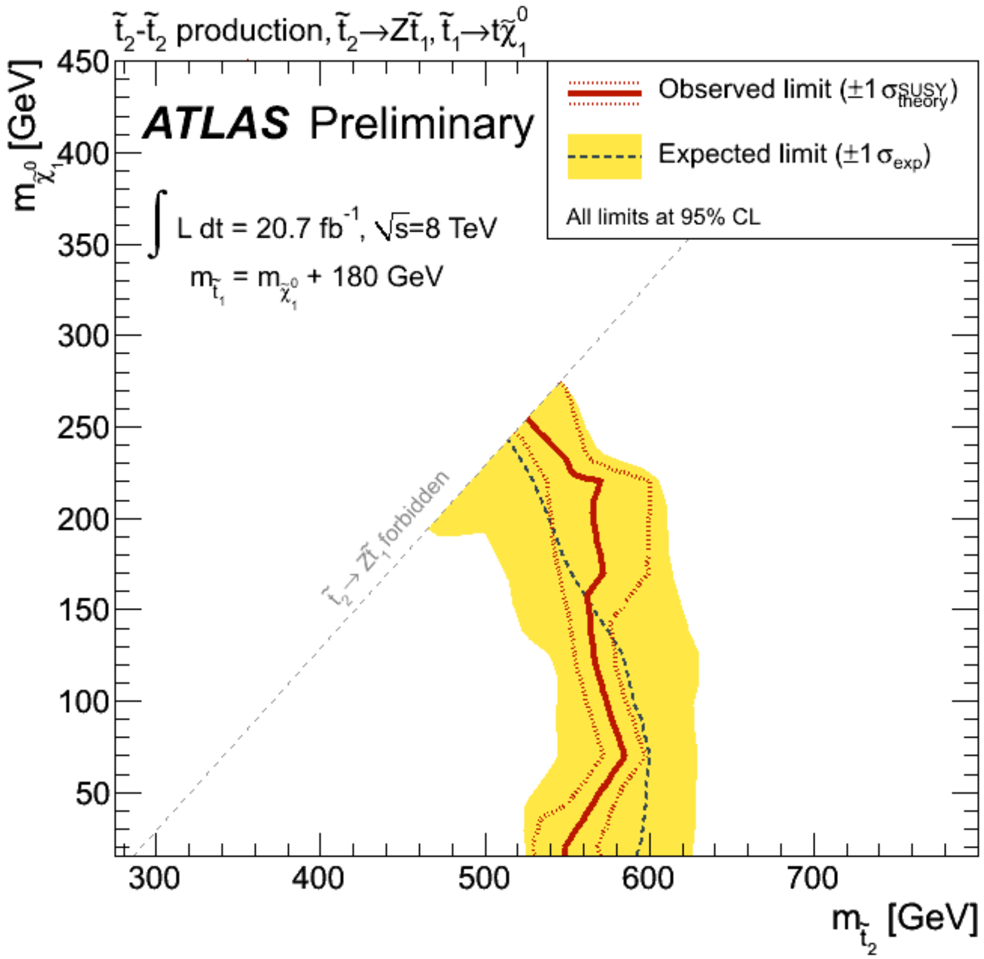
No excess above SM predictions



	SR2L1A	SR2L1B	SR2L2	SR3L1	SR3L2
N^{lepton}	2			≥ 3	
$\lvert m_{\ell\ell} - m_Z \rvert$	< 5 GeV	< 10 GeV	< 5 GeV	< 10 GeV	
$N^{b\text{-jets}}$	≥ 1			≥ 1	
N^{jets}	3, 4		≥ 5	≥ 5	
$p_T(\text{jet}_1)$	> 30 GeV			> 50 GeV	> 40 GeV
$p_T(\text{jet}_N)$	> 30 GeV			> 30 GeV	> 40 GeV
E_T^{miss}	> 160 GeV	> 200 GeV	> 160 GeV	> 60 GeV	
$p_T(\ell\ell)$	> 80 GeV	> 160 GeV	> 80 GeV	-	> 75 GeV
$\Delta\phi^{\ell\ell}$	< 1.5 rad			-	
$p_T(\ell_1)$	> 25 GeV			> 40 GeV	> 60 GeV

final states with Z

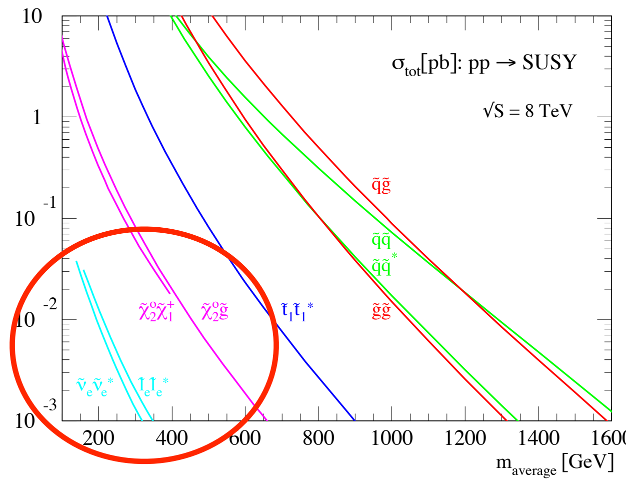
- Simplified model with $\tilde{t}_2$,$\tilde{t}_1$ and $\tilde{\chi}_1^0$ only (3L)
- $m_{t2} = m_{\chi 1}$ + 180 GeV
- $\tilde{t}_1$ production included in the sample



Electroweak production

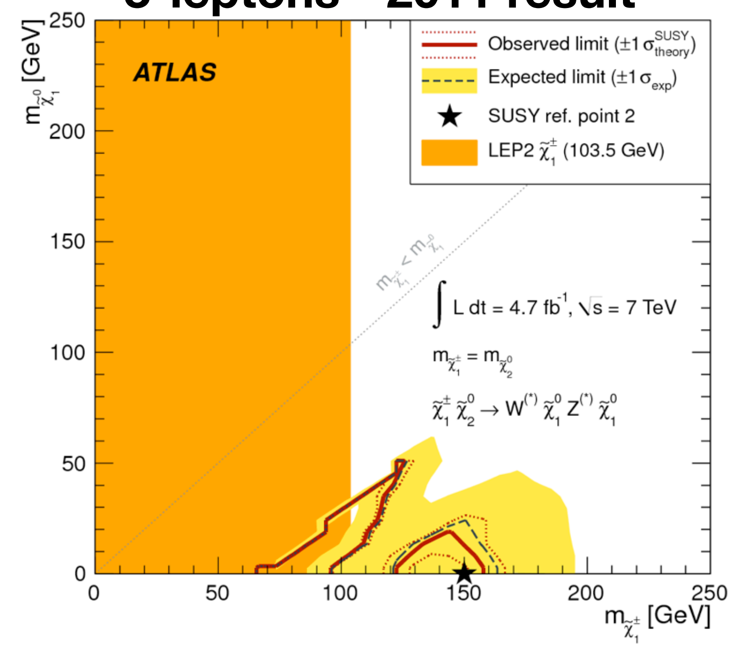
Electroweak $\tilde{\chi}^0$, $\tilde{\chi}^{\pm}$ production

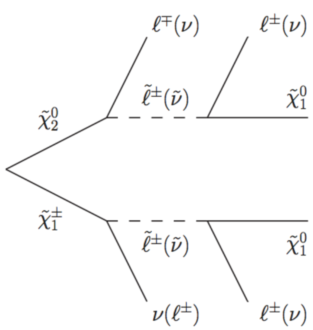
- Neutralinos and chargino masses of **few hundreds GeV** expected in natural SUSY models
- LHC has sensitivity to the **EW coupling-suppressed cross sections**

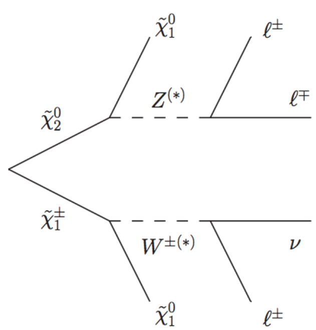


- Give rise to **multi-lepton final states**
  - Very **low SM background** expected
  - Decays through **sleptons** (BR to leptons 100% - optimistic) or **WZ-like** (challenging) decays assumed

3-leptons - 2011 result







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

Production channel	Analysis
chargino pair production	**2-leptons** (e, μ) (4.7 fb^{-1}, 7 TeV), **2-τ** (21 fb^{-1}, 8 TeV)
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production	**2-leptons** (e, μ) (4.7 fb^{-1}, 7 TeV), **3-leptons** (21 fb^{-1}, 8 TeV)
$\tilde{\chi}_2^0 \tilde{\chi}_3^0$ production	**4-leptons** (e, μ, (τ)) (21 fb^{-1}, 8 TeV)

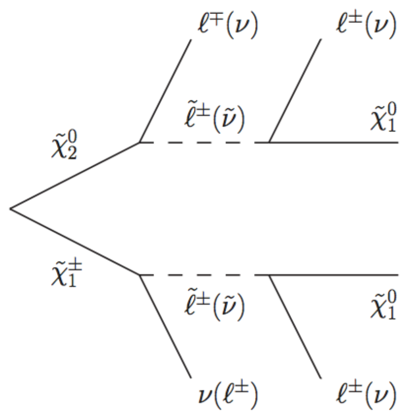
- **2-leptons and 2-τ** analysis also sensitive to **direct slepton production**
- 4-leptons analysis primary target is **R-parity violating chargino production**

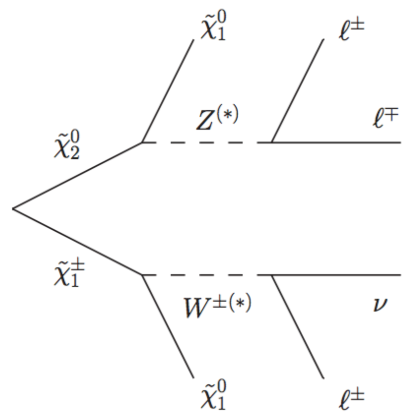
$\tilde{\chi}^0$, $\tilde{\chi}^\pm$ production - 3 leptons

NEW FOR THIS SEMINAR

ATLAS

- Two series of signal regions defined (based on the presence of a reconstructed di-leptonic Z)
- **Irreducible background** (dominated by di-boson production) **taken from MC**
- No attempt for hadronic tau reconstruction



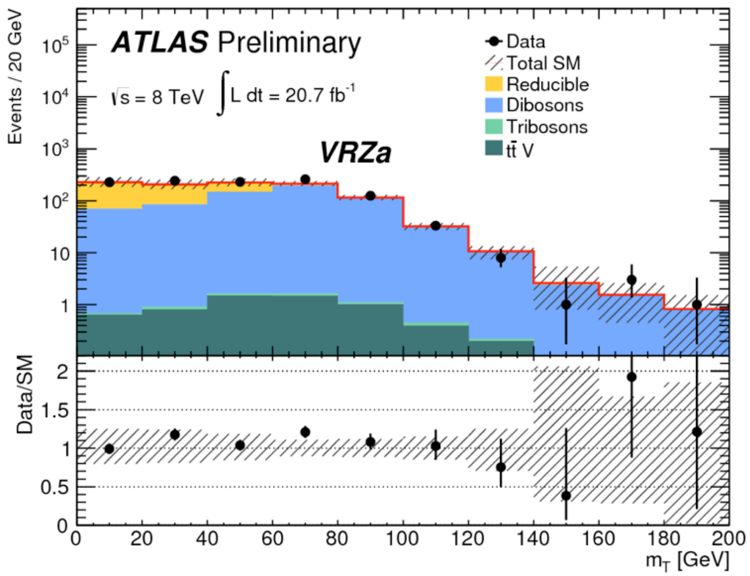


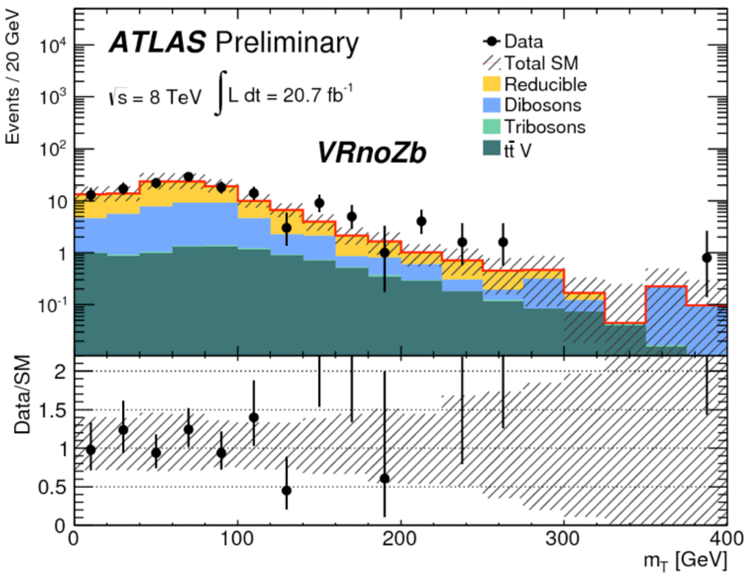
- **Reducible (fake lepton) background** estimated with a **matrix method**

	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_T^{miss} [GeV]	>50	>75	>75	75–120	75–120	>120
m_T [GeV]	–	–	>110	<110	>110	>110
p_T 3rd 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**

m_T: transverse mass using non SFOS lepton

3-leptons background prediction validation



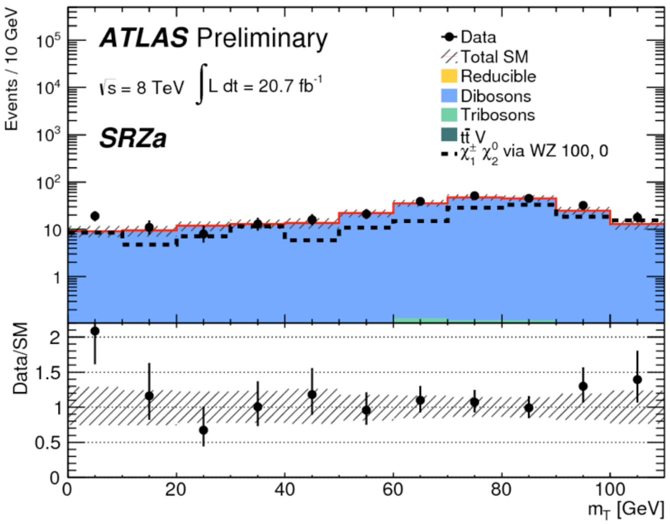


- Background prediction **validated** in dedicated regions with **different background composition**

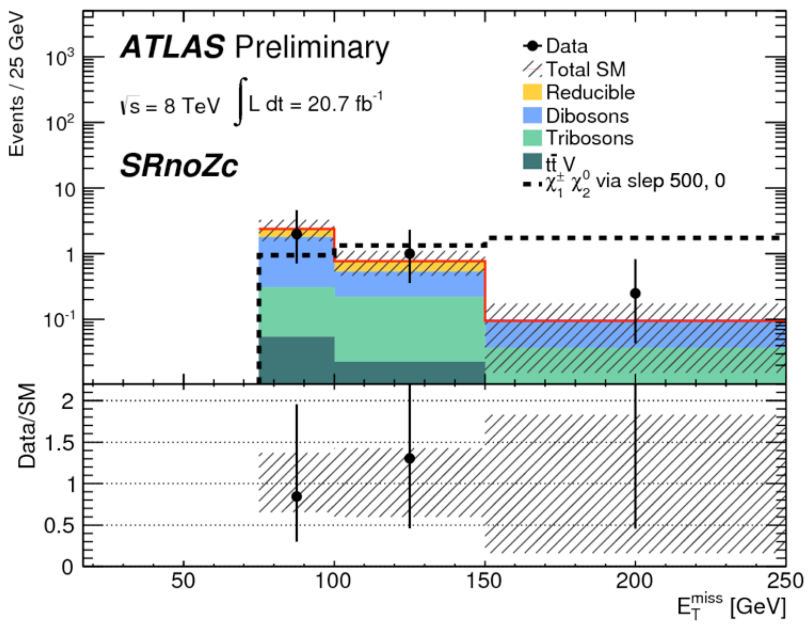
Selection	VRnoZa	VRnoZb	VRZa	VRZb
m_{SFOS} [GeV]	<81.2 or >101.2	<81.2 or >101.2	81.2–101.2	81.2–101.2
b-jet	veto	request	veto	request
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	35–50	>50	30–50	>50
Dominant process	WZ^*, Z^*Z^*, Z^*+jets	$t\bar{t}$	WZ, Z+jets	WZ

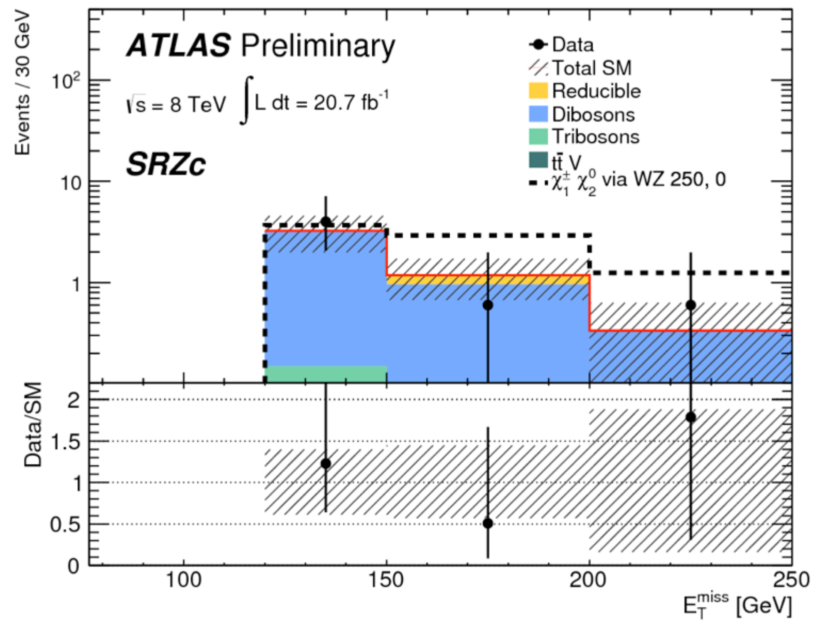
Selection	VRnoZa	VRnoZb	VRZa	VRZb
Tri-boson	1.4 ± 1.4	0.5 ± 0.5	0.6 ± 0.6	0.26 ± 0.26
ZZ	$(1.3 \pm 0.9) \times 10^2$	4.5 ± 2.8	108 ± 23	6.9 ± 2.2
$t\bar{t}V$	2.9 ± 1.2	21 ± 7	7.4 ± 2.6	26 ± 8
WZ	110 ± 21	34 ± 15	$(5.5 \pm 0.9) \times 10^2$	$(1.4 \pm 0.4) \times 10^2$
Σ SM irreducible	$(2.4 \pm 0.9) \times 10^2$	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



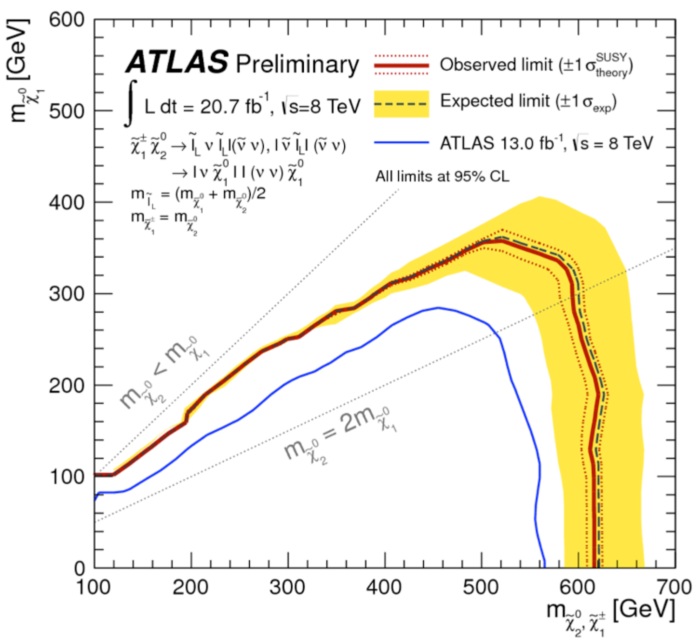
Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
Tri-boson	1.7 ± 1.7	0.6 ± 0.6	0.8 ± 0.8	0.5 ± 0.5	0.4 ± 0.4	0.29 ± 0.29
ZZ	14 ± 8	1.8 ± 1.0	0.25 ± 0.17	8.9 ± 1.8	1.0 ± 0.4	0.39 ± 0.28
$t\bar{t}V$	0.23 ± 0.23	0.21 ± 0.19	$0.21^{+0.30}_{-0.21}$	0.4 ± 0.4	0.22 ± 0.21	0.10 ± 0.10
WZ	50 ± 9	20 ± 4	2.1 ± 1.6	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

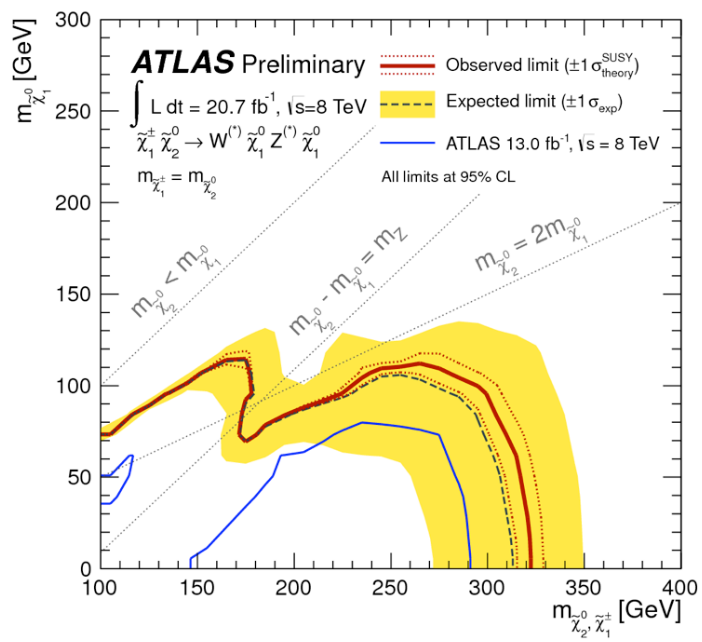




3-leptons interpretation

- **Signal interpretation** (simplified models) assumes **wino-like $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$, bino-like $\tilde{\chi}_1^0$: $m(\tilde{\chi}_2^0) = m(\tilde{\chi}_1^\pm)$**
- **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**





Electroweak production - 2-taus final states

- Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ ($\tilde{\chi}_1^{\pm} \rightarrow \tilde{\tau}_L\nu, \tau\tilde{\nu}$) **and** $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ ($\tilde{\chi}_2^{0} \rightarrow \tilde{\tau}_L\tau$) production (and decay via staus) investigated with 2τ final states (strategy similar to stop m_{T2})

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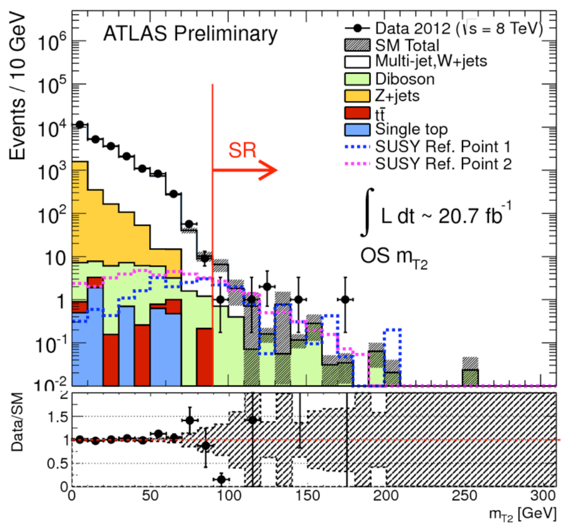
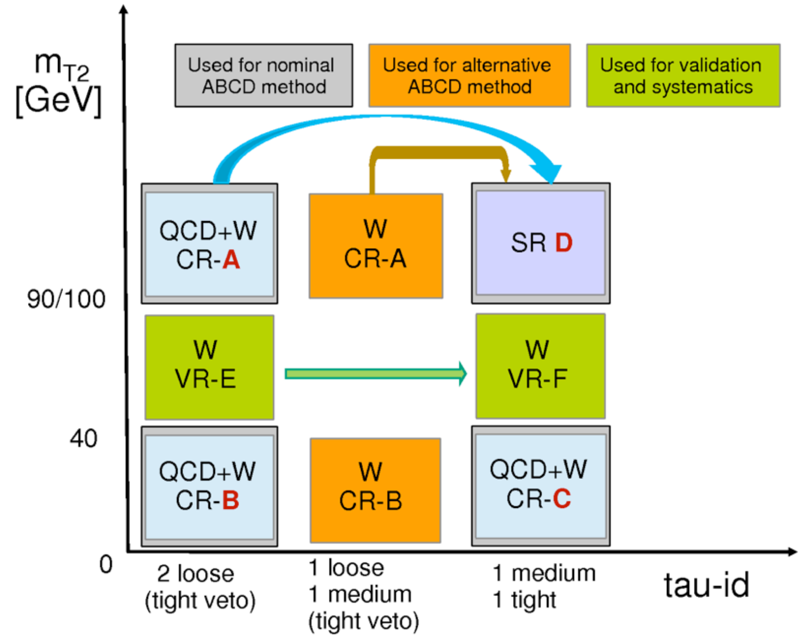


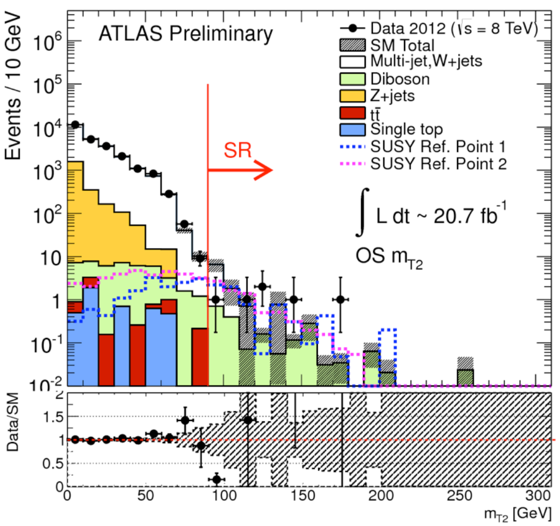
ATLAS-CONF-2013-028

Electroweak production - 2-taus final states

- Direct $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ ($\tilde{\chi}_1^{\pm} \rightarrow \tilde{\tau}_L\nu, \tau\tilde{\nu}$) **and** $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ ($\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_L\tau$) production (and decay via staus) investigated with 2τ final states (strategy similar to stop m_{T2})

NEW FOR MORIOND '13

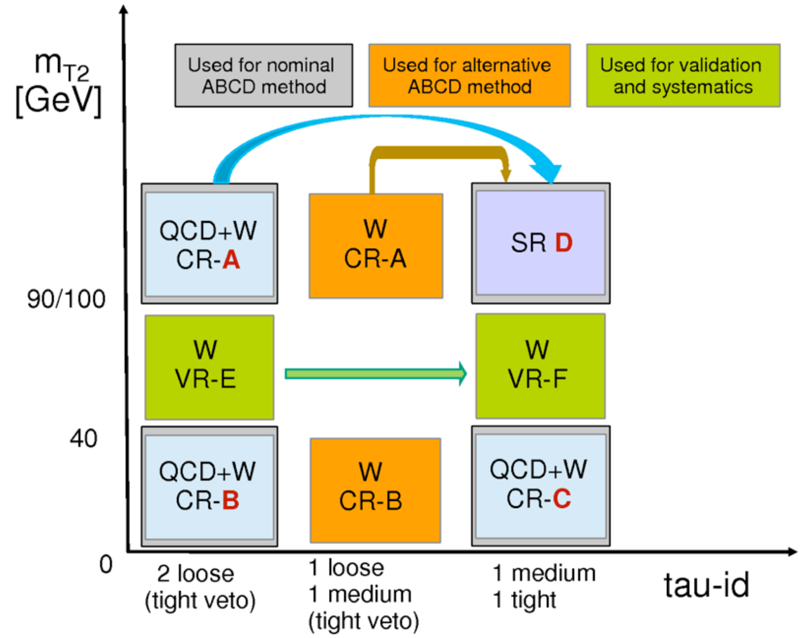


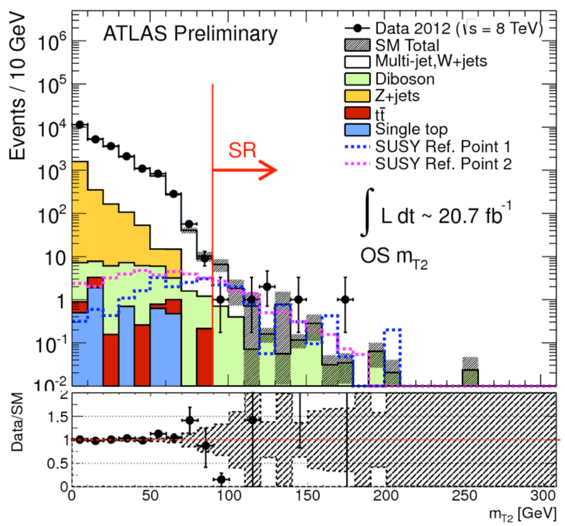


Electroweak production - 2-taus final states

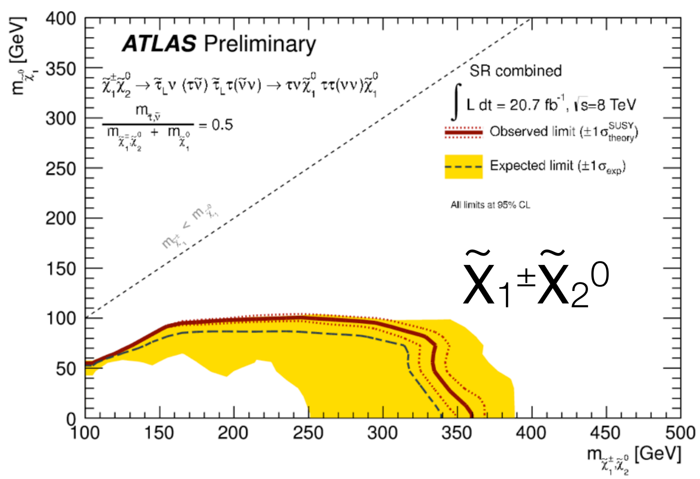
- Direct $\tilde{\chi}_1^\pm\tilde{\chi}_1^\pm$ ($\tilde{\chi}_1^\pm \rightarrow \tilde{\tau}_L\nu, \tau\tilde{\nu}$) **and** $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ ($\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_L\tau$) production (and decay via staus) investigated with 2τ final states (strategy similar to stop m_{T2})

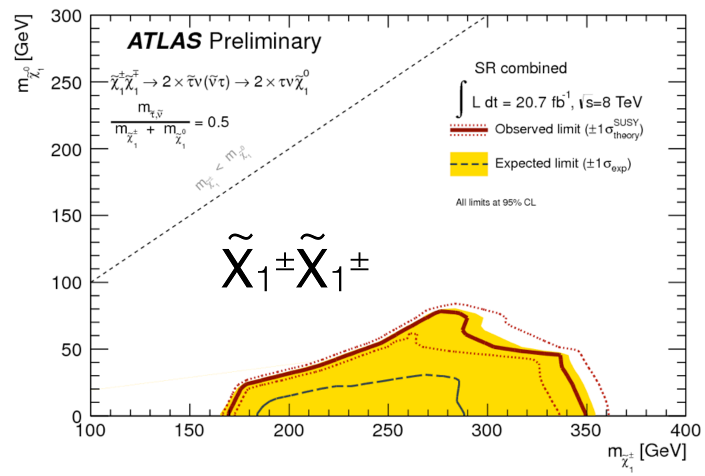
NEW FOR MORIOND '13





$m_\tau = (m_{\chi\pm} + m_{\chi 0})/2$



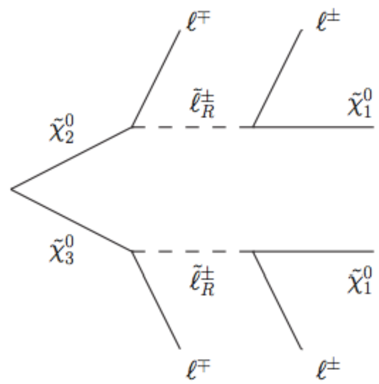


4-leptons

NEW FOR THIS SEMINAR

ATLAS-CONF-2013-036

- Analysis sensitive to both **RPC and RPV scenarios**
- One of the four leptons **can be a hadronically decaying tau** (relevant for RPV modes)



- Z-veto (extended to include triplets and quadruplets of leptons) applied in some signal regions
- **Irreducible background** dominated by ZZ and ttZ production
  - **Reducible background** relevant only for the signal regions with taus

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

4-leptons

NEW FOR THIS SEMINAR

ATLAS-CONF-2013-036

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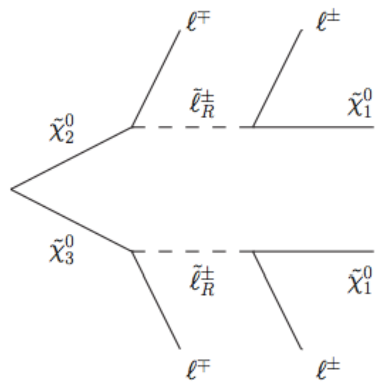
- One of the four leptons **can be a hadronically decaying tau** (relevant for RPV modes)



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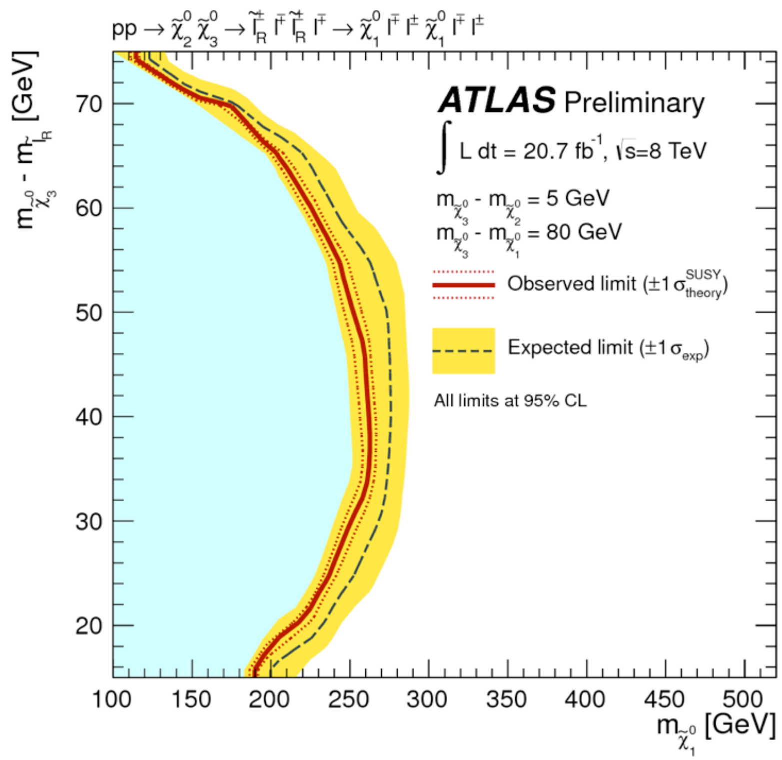
SR0noZa	≥4	≥0	extended veto	>50			RPC
SR0noZb	≥4	≥0	extended veto	>75	or	>600	RPV
SR1noZ	=3	≥1	extended veto	>100	or	>400	RPV
SR0Z	≥4	≥0	request	>75			GGM
SR1Z	=3	≥1	request	>100			GGM

- Left: **$\tilde{\chi}_3^0$ and $\tilde{\chi}_2^0$ nearly mass degenerate.** $\Delta m(\tilde{\chi}_3^0, \tilde{\chi}_1^0)$ = 80 GeV. Plot $\Delta m(\tilde{\chi}_3^0, l)$ Vs. $m(\tilde{\chi}_1^0)$

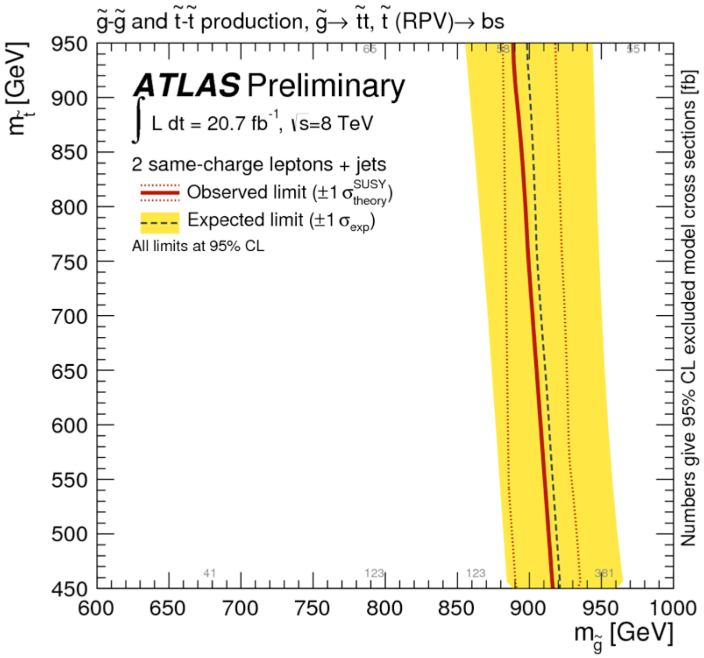


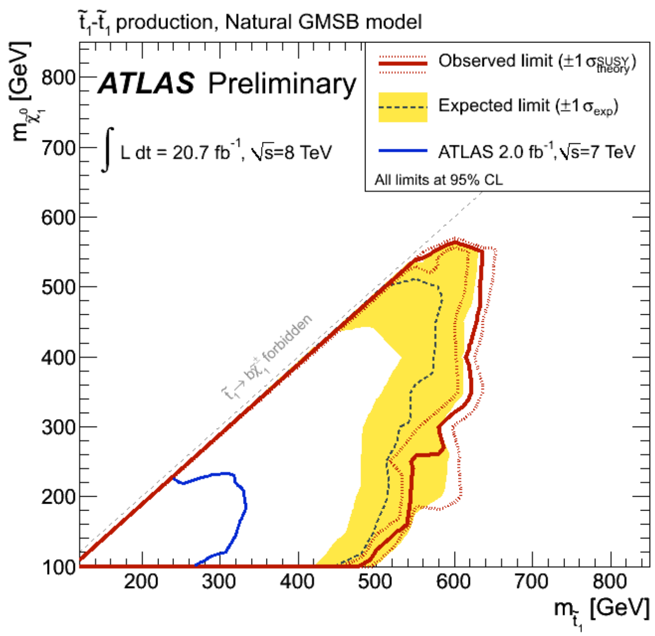
AOB

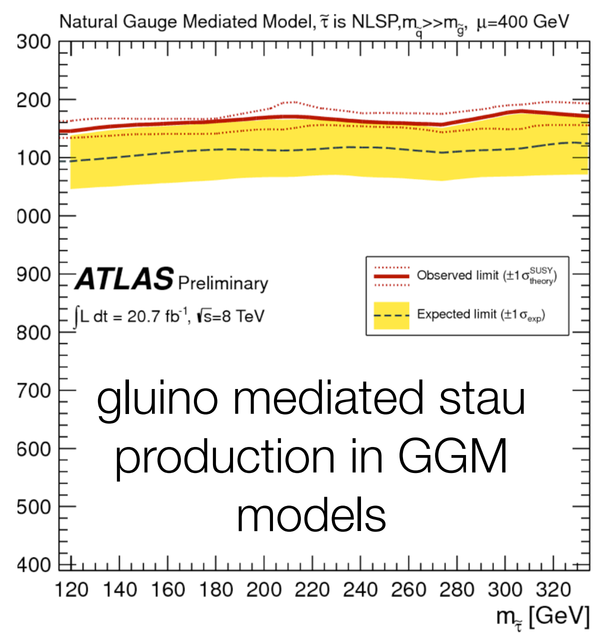
More results

- SS dilepton analysis
- g→tt̃→tbs (λ_{323} = 1)
- Natural GMSB; tanβ = 5; maximal mixing for stop;

1. $\tilde{g} \to g\tilde{\chi}_i^0 \to g\tau\,\tilde{\tau} \to g\tau\tau\tilde{G}$, with $i = 1,2$
2. $\tilde{g} \to q\bar{q}\tilde{\chi}_i^0 \to q\bar{q}\tau\,\tilde{\tau} \to q\bar{q}\tau\tau\tilde{G}$, with $i = 1,2$
3. $\tilde{g} \to qq'\tilde{\chi}_1^\pm \to qq'\tilde{\nu}_\tau\,\tilde{\tau} \to qq'\tilde{\nu}_\tau\tau\tilde{G}$



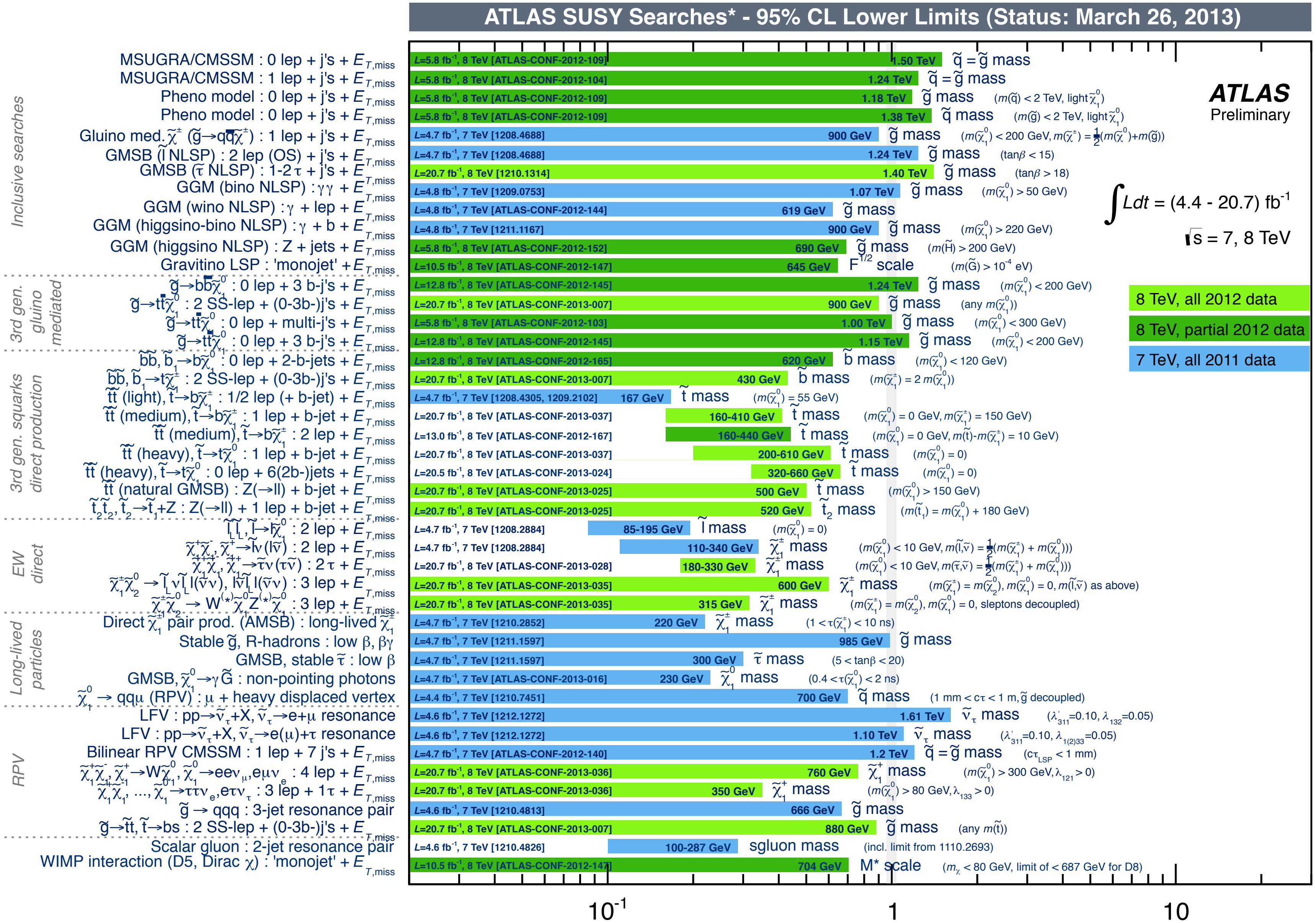




gluino mediated stau production in GGM models

ATLAS-CONF-2013-007 ATLAS-CONF-2013-025 ATLAS-CONF-2013-026

Summary



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

Summary

- The **LHC sensitivity** is well within **the realm of natural SUSY** (and attacked from many different perspectives)
  - **Gluino mediated stop production:** gluino masses up to ~1.2 TeV are excluded with a variety of assumptions.
  - **direct stop production:** largely excluded (up to m ~ 600-650 GeV) assuming BR 100% in either $b\tilde{\chi}_1^{\pm}$ or $t\tilde{\chi}_1^0$
  - Quickly **gaining sensitivity** to the EW production even **for decays not involving sleptons**
- The **startup of the LHC** has been a fruitful and exciting period for SUSY searches
  - **Exciting times ahead with the LHC run at design $\sqrt{s}$!**

BACKUP

SUSY

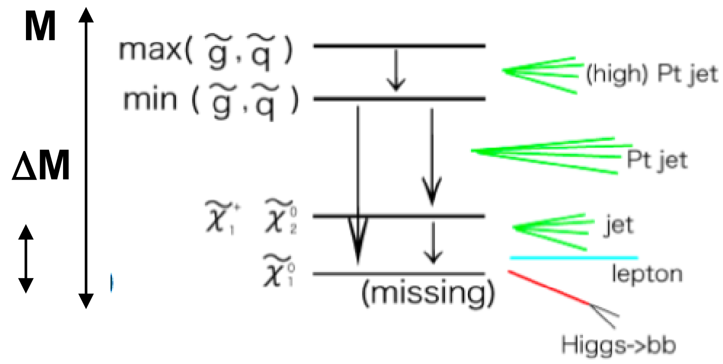
What we are typically doing

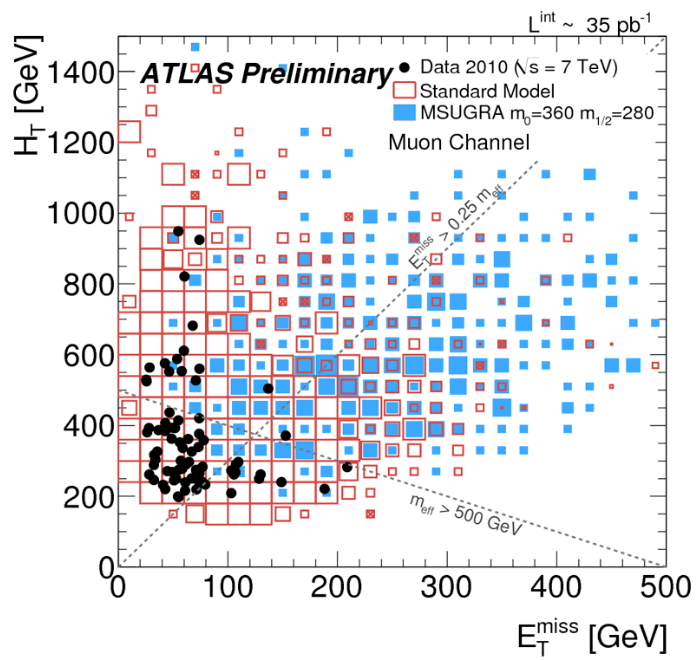
- Heavy sparticles produced in the primary collision
- They decay into lighter objects, emitting (high) P_T jets and possibly other objects (leptons, photons) and MET (LSP)
- A "typical" SUSY event will have large MET and large H_T
- Useful variables:

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

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

- 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
  - **M_{T2}, M_{CT}:** assume pair produced heavy particles with visible and invisible decays





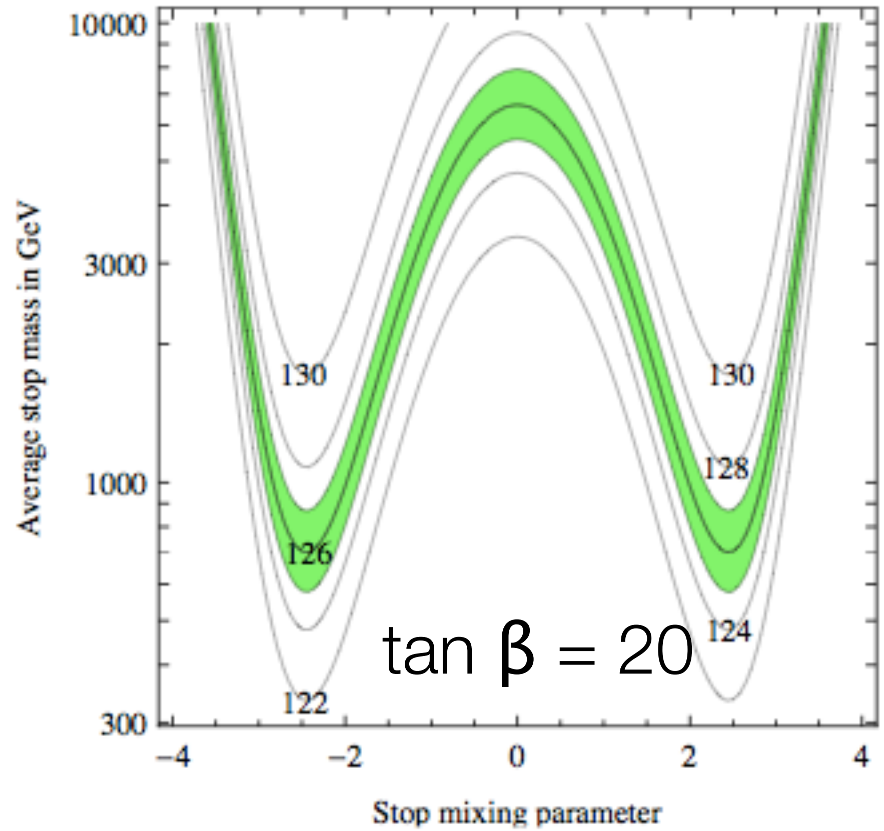
Higgs and SUSY

$$X_t = (A_t + \mu \cot\beta)/m_S$$

$$m_h^2 = m_Z^2 \cos^2\beta + \frac{3y_t^2 m_t^2}{(4\pi)^2}\left[\log\left(\frac{m_S^2}{m_t^2}\right) + X_t^2\left(1 - \frac{X_t^2}{12}\right)\right]$$

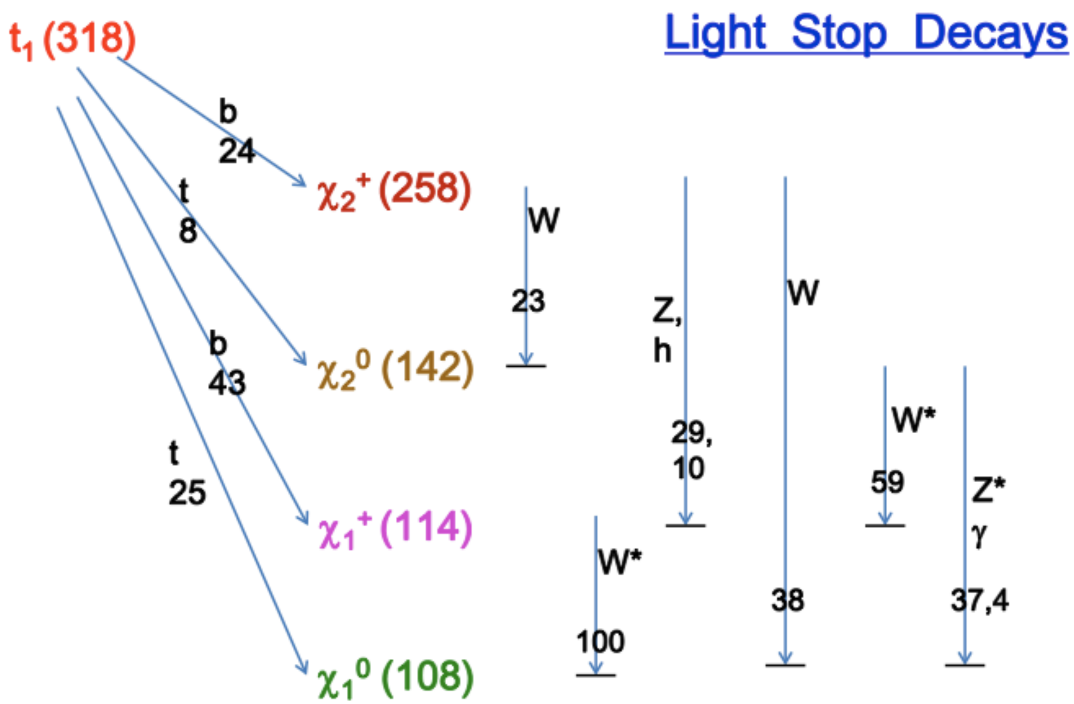
- The Higgs mass depend on the average stop mass and X_t
- m_h=126 GeV still allows for a light t_1

arXiv:1212.6847



What is missing? (3^{rd} gen)

- My own to-do list for the next **few months/years**:
    - Improve limits at **high stop mass**:
        - boosted top reconstruction?
- **Mixed decays (50% $\tilde{t}_1 \to t\tilde{\chi}_1^0$, 50% $\tilde{t}_1 \to b\tilde{\chi}_1^\pm$)** still not considered (and somewhat favoured, actually)
- Complete the investigation in **the low mass region** (exclude independently of the stop parameters and mass hierarchy).

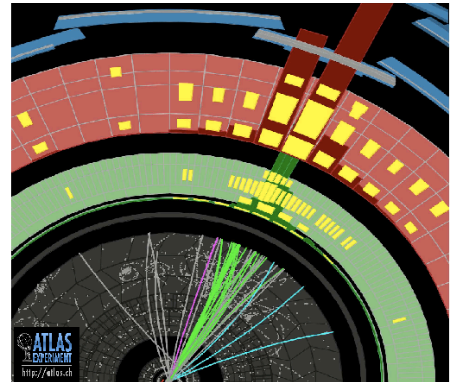


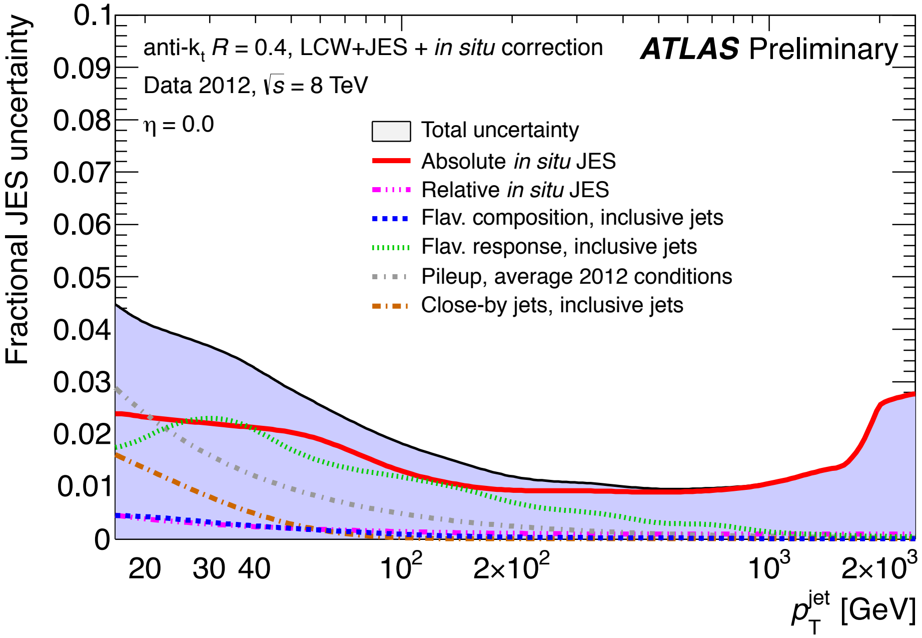
Taken from https://indico.cern.ch/contributionDisplay.py?sessionId=75&contribId=58&confId=181298

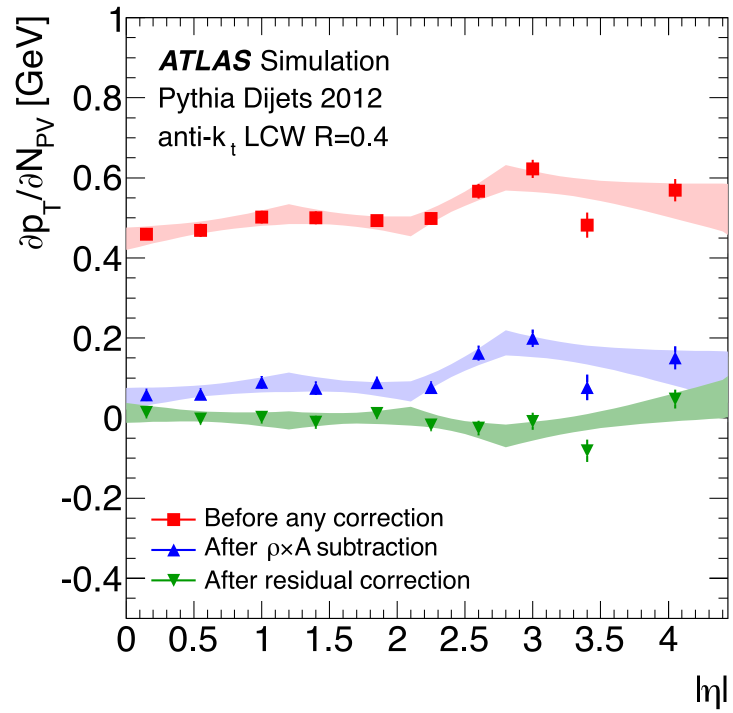
Performance

Jet measurement

- **Constantly improving** on jet measurement and pileup suppression techniques
- **Jet energy scale** known up to the ~1% level
- **Pileup subtraction** based on jet area method

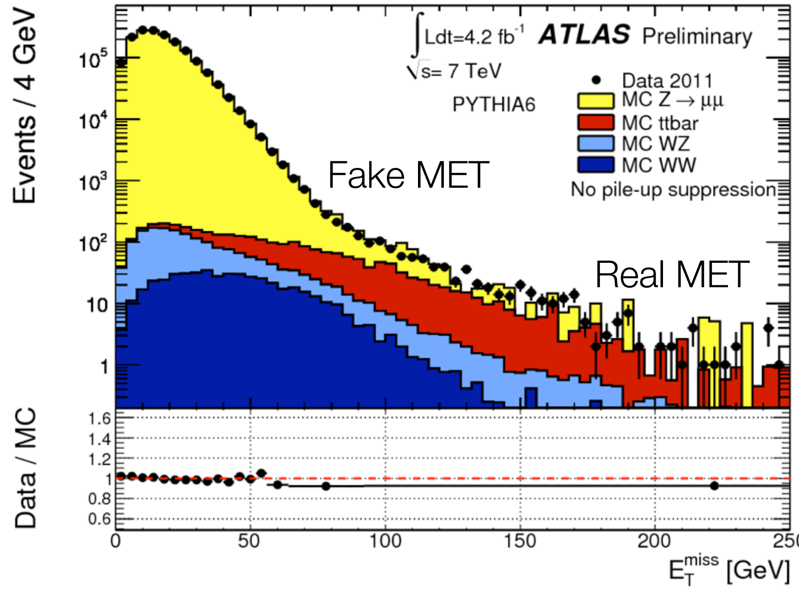






Missing transverse momentum and b-tagging

- Missing E_T (E_T^{miss}) reconstructed from the vectorial sum of **all final state objects:**
- each **with a dedicated calibration.**



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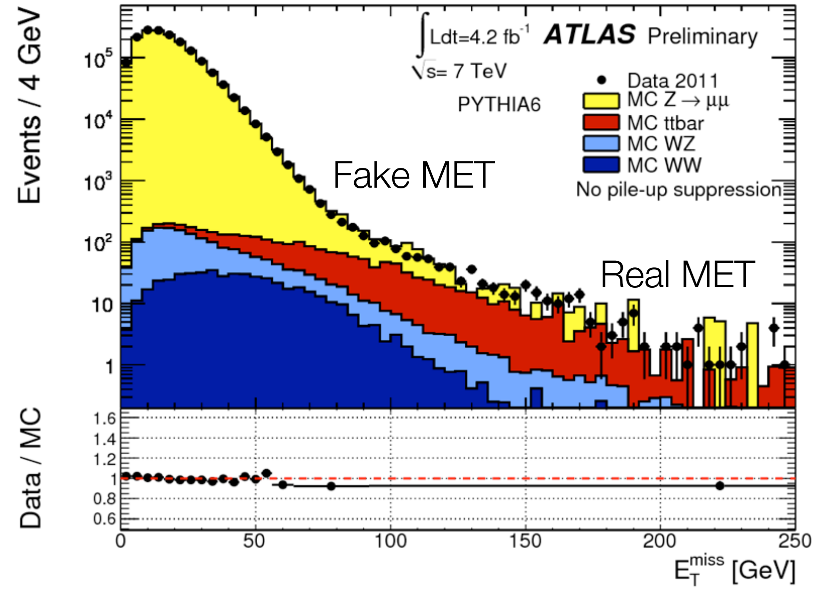
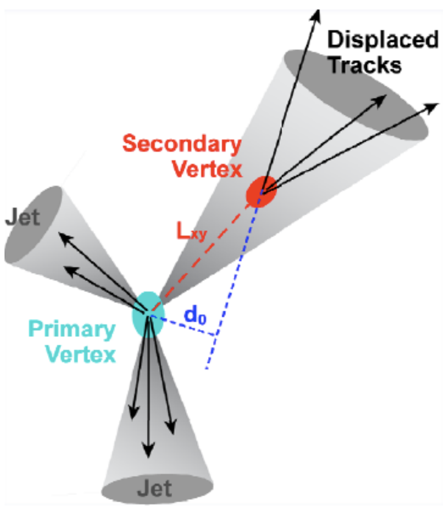
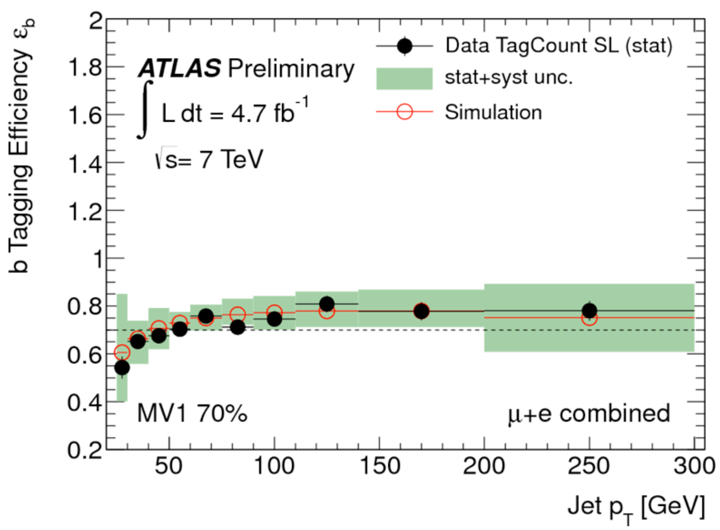


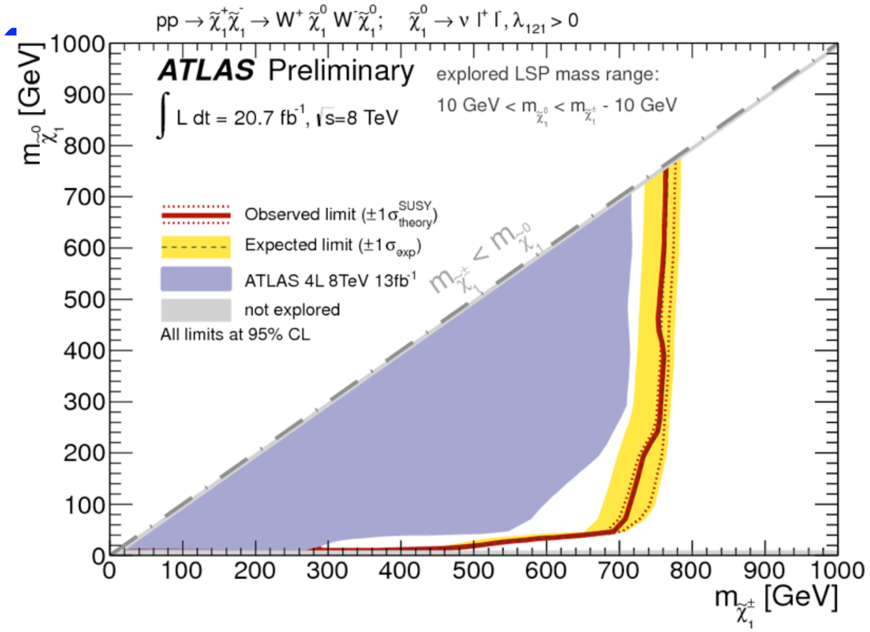


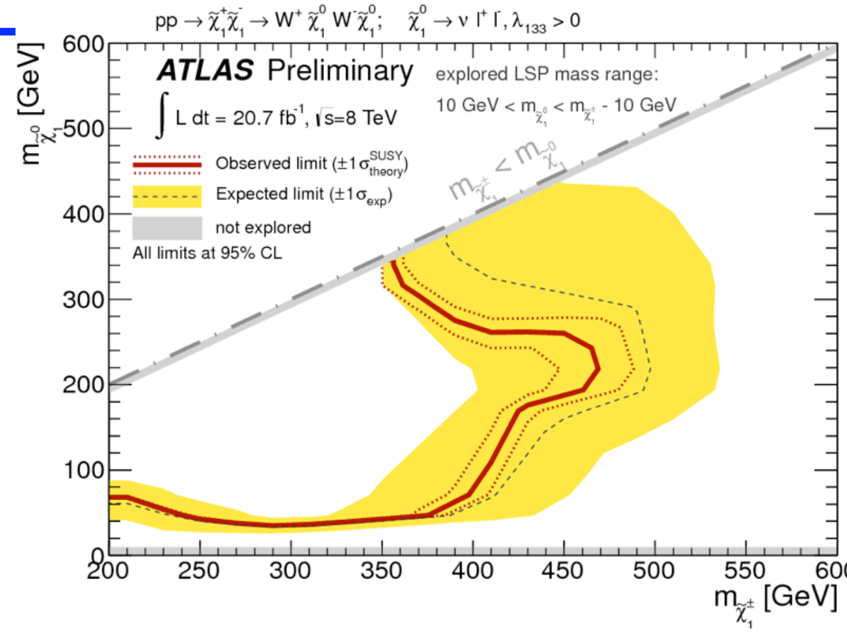


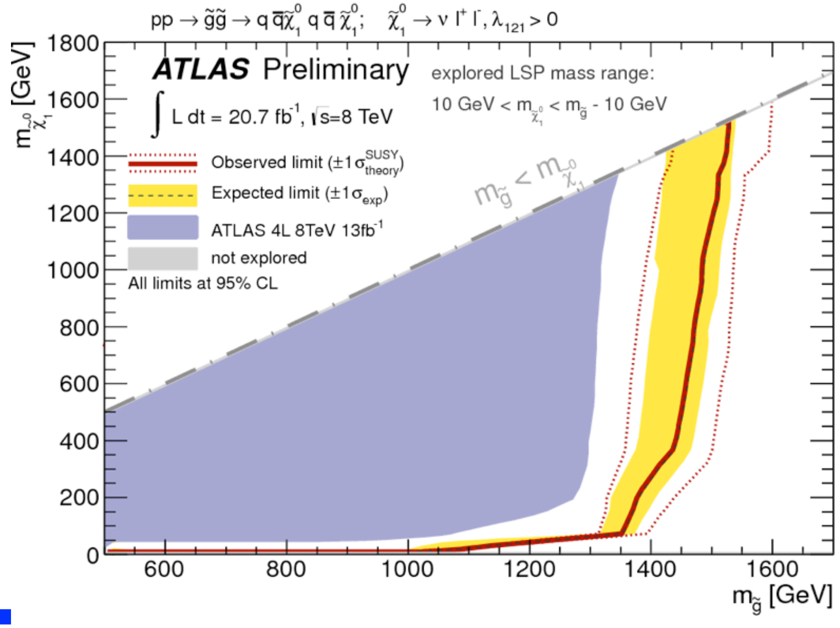
- **b-tagging:** neural network algorithm combining informations about **secondary vertex displacement** and **impact parameters of jets**
- efficiencies **generally well reproduced by MC**. Systematic uncertainties **of the order of 10-15%**

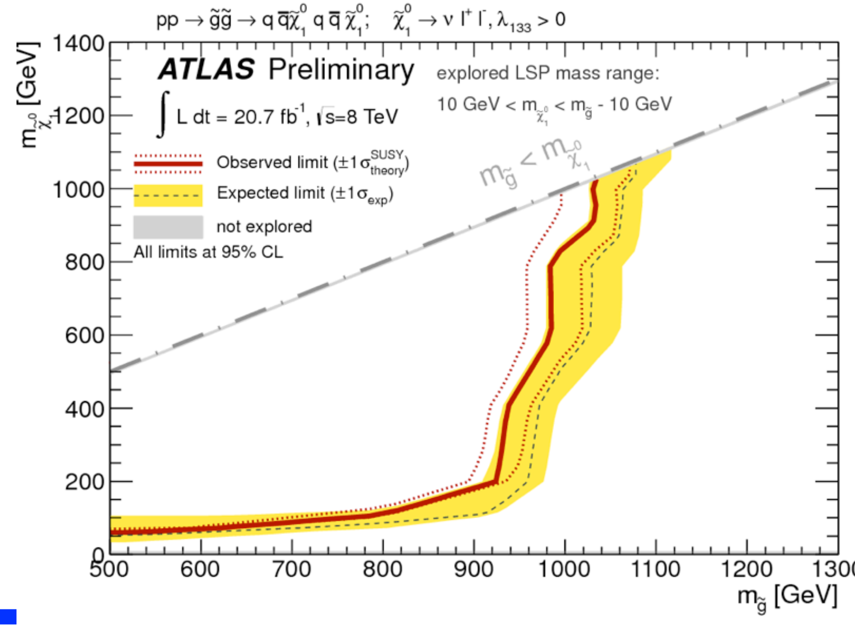
RPV

RPV modes (4-lepton analysis)





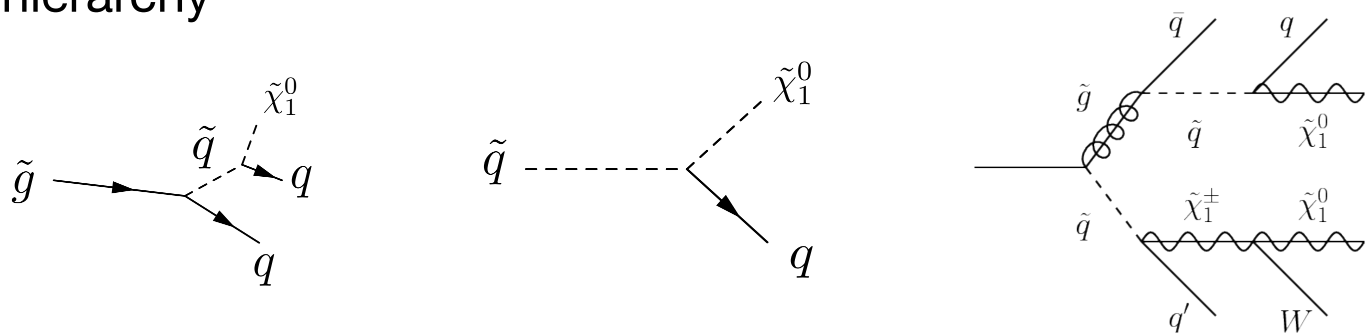


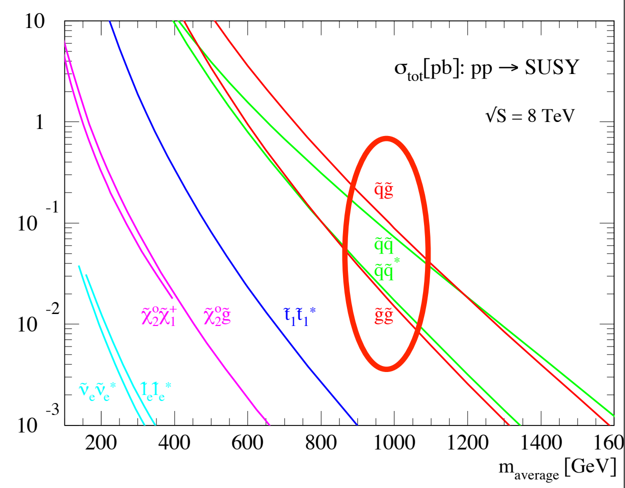


strong production

Strong production

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





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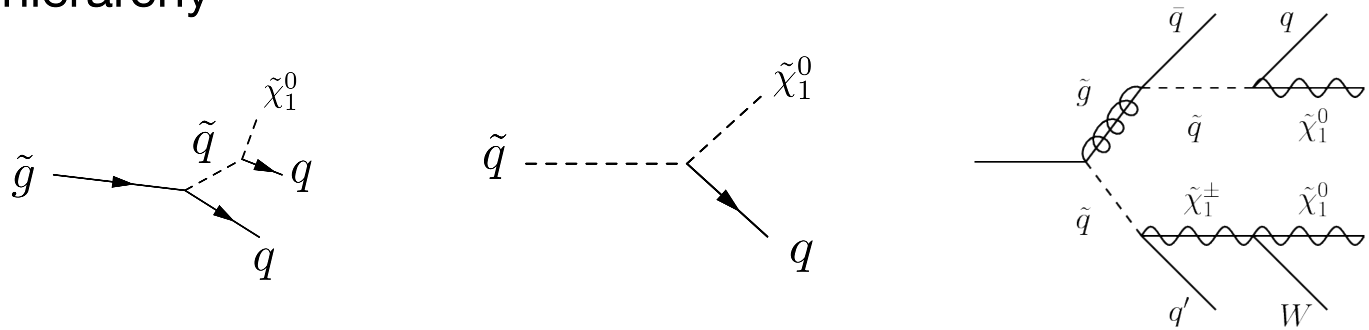
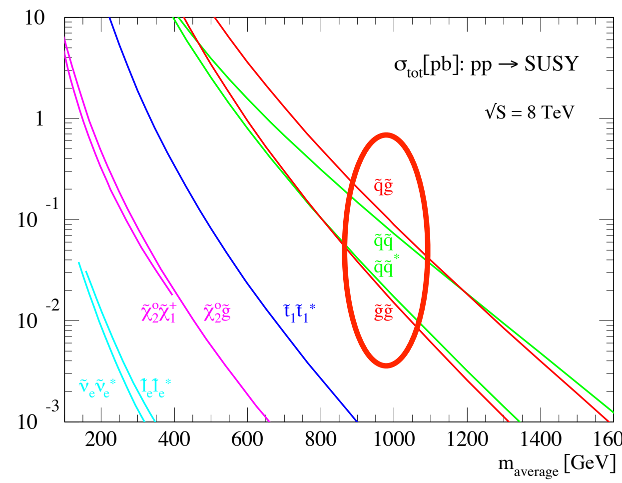




- Two analyses drive the limit with 8 TeV data

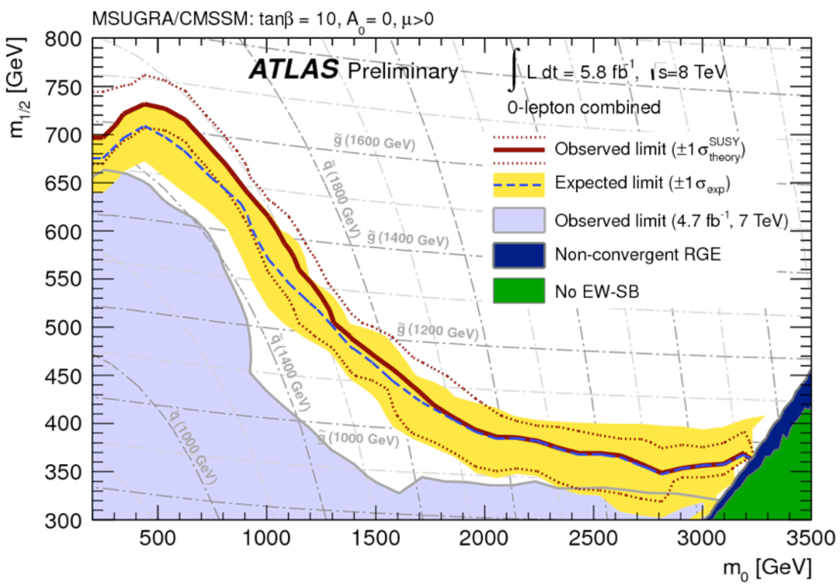
	0-lepton (ATLAS-CONF-2012-109)	1-lepton (ATLAS-CONF-2012-104)
leptons	Veto any e or μ above 10 GeV	One isolated e or μ above 25 GeV
jets	2 to 6 jets with $p_T > 60$ GeV (leading jet $p_T > 130$ GeV)	4 jets with $p_T > 80$ GeV
Other selections	MET > 160 GeV, reject multijet with cuts on MET/M_{eff}, and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

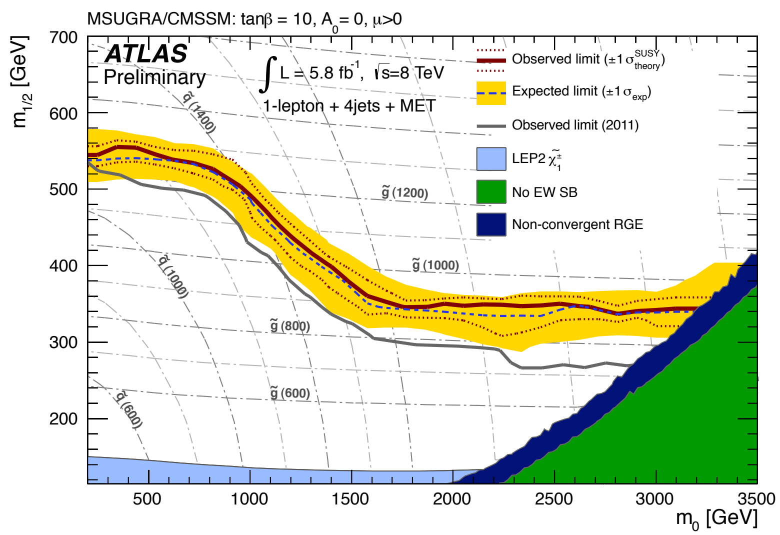
Strong production

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

1-lepton	Signal region: Electron	Signal region: Muon
Observed events	10	4
Fitted background events	9.0 ± 2.8	7.7 ± 3.2
Fitted $t\bar{t}$ events	6.0 ± 2.2	2.6 ± 1.9
Fitted W/Z+jets events	1.5 ± 0.7	4.2 ± 2.3
Fitted other background events	1.0 ± 0.7	0.9 ± 0.3
Fitted multijet events	0.4 ± 0.6	0.0 ± 0.0
MC expected SM events	9.5	11.5
MC expected $t\bar{t}$ events	5.7	4.6
MC expected W/Z+jets events	2.4	6.0
MC expected other background events	1.0	0.8
Data-driven multijet events	0.4	0.0

1-lepton	$\langle\epsilon\sigma\rangle^{95}_{obs}$ [fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B
Electron	1.69	9.9	$9.3^{+3.3}_{-2.6}$	0.59
Muon	1.09	6.4	$8.3^{+3.4}_{-2.3}$	0.19





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**

$$\sigma_{vis} = \sigma \cdot A \cdot \varepsilon$$

1-lepton	Signal region Electron	Signal region Muon
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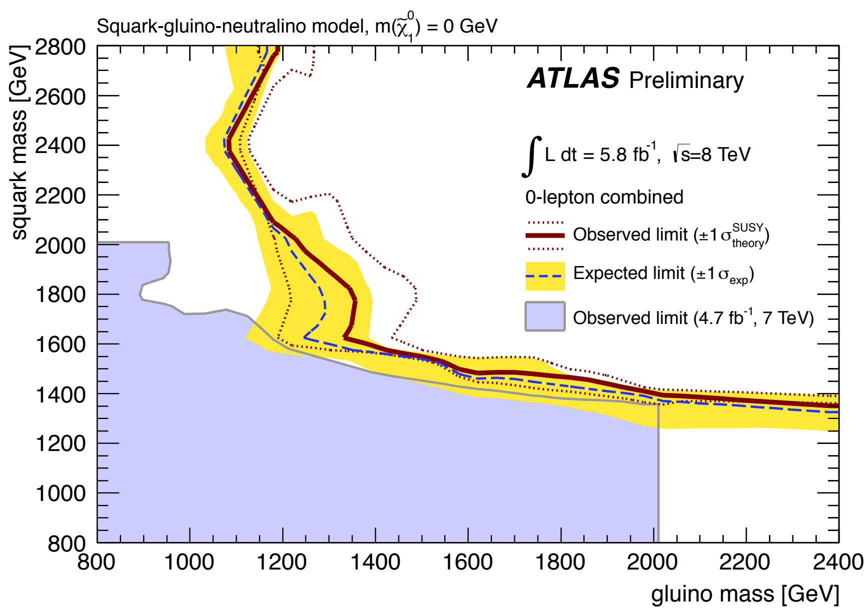

1-lepton

	Signal region	
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Electron	1.69	9.9	$9.3^{+3.3}_{-2.6}$	0.59
Muon	1.09	6.4	$8.3^{+3.4}_{-2.3}$	0.19

- Simpified models: **assume degenerate 1st and 2nd generation squarks.** The only possible production processes are gg,gq,qq
- only possible processes (depending on masses)

$$\tilde{g} \longrightarrow qq\tilde{\chi}_1^0, \tilde{g} \longrightarrow \tilde{q}\tilde{\chi}_1^0, \tilde{q} \longrightarrow q\tilde{\chi}_1^0$$

Squark (gluino) masses below 1.3/1.4 (1.1) TeV excluded for any gluino (squark) mass

0-lepton results

Signal Region	A-loose	A-medium	B-medium	C-loose	C-medium	E-loose	E-medium
MC expected events							
Diboson	53.1	18.2	11.1	6.2	0.9	0.0	0.0
W+jets	264.1	53.5	51.9	62.9	16.4	2.1	1.9
Z/γ^*+jets	338.2	74.7	50.4	55.0	16.1	1.0	0.8
$t\bar{t}$ + single top	74.9	8.1	14.2	42.6	5.3	2.1	1.6
Fitted background events							
Diboson	53 ± 23	18 ± 9	11 ± 6	6 ± 4	0.9 ± 0.6	–	–
Multi-jets	0.6 ± 0.6	0.1 ± 0.1	0.2 ± 0.2	–	–	–	–
W+jets	180 ± 140	33 ± 35	32 ± 34	40 ± 40	8 ± 8	1.2 ± 1.3	0.9 ± 1.1
Z/γ^*+jets	354 ± 21	81 ± 8	59 ± 6	67 ± 6	18.5 ± 3.0	2.0 ± 1.0	0.6 ± 0.5
$t\bar{t}$ + single top	67 ± 16	7.6 ± 3.5	14 ± 5	39 ± 7	5.3 ± 2.0	2.5 ± 0.9	2.0 ± 1.4
Total bkg	650 ± 130	140 ± 33	115 ± 30	155 ± 31	33 ± 8	5.7 ± 1.7	3.5 ± 1.7
Observed	643	111	106	156	31	9	7
p_0	0.498	0.500	0.500	0.486	0.498	0.161	0.108
UL on N_{BSM}	224.8	33.9	43.8	65.7	17.9	10.4	9.9
UL on σ_{BSM} (fb)	38.8	5.84	7.55	11.3	3.09	1.79	1.71

Signal Region	A-tight	B-tight	C-tight	D-tight	E-tight
MC expected events					
Diboson	3.3	0.2	0.0	0.8	2.6
W+jets	6.6	5.6	2.1	3.4	3.3
Z/γ^*+jets	7.4	4.5	1.9	1.3	1.3
$t\bar{t}$ + single top	1.0	1.1	0.6	1.8	2.7
Fitted background events					
Diboson	3.3 ± 3.1	0.2 ± 1.4	–	0.8 ± 0.4	2.6 ± 2.0
Multi-jets	–	–	–	0.4 ± 0.5	0.1 ± 0.2
W+jets	3 ± 4	2.7 ± 3.4	0.3 ± 0.5	–	0.8 ± 1.3
Z/γ^*+jets	6.8 ± 2.2	5.1 ± 1.7	2.0 ± 1.1	2.5 ± 1.1	1.2 ± 0.7
$t\bar{t}$ + single top	0.8 ± 0.8	0.8 ± 0.9	0.6 ± 0.5	2.6 ± 1.6	5.1 ± 3.3
Total bkg	14 ± 5	8.7 ± 3.4	2.8 ± 1.2	6.3 ± 2.1	10 ± 4
Observed	10	7	1	5	9
p_0	0.499	0.500	0.499	0.500	0.499
UL on N_{BSM}	8.9	7.3	3.3	6.0	9.3
UL on σ_{BSM} (fb)	1.53	1.26	0.57	1.03	1.60

CR	SR background	CR process	CR selection
CRY	$Z(\rightarrow \nu\nu)$+jets	γ+jets	Isolated photon
CRQ	QCD jets	QCD jets	Reversed $\Delta\phi(\text{jet}, E_T^{\text{miss}})_{\text{min}}$ and $E_T^{\text{miss}}/m_{\text{eff}}(Nj)$ cuts
CRW	$W(\rightarrow \ell\nu)$+jets	$W(\rightarrow \ell\nu)$+jets	30 GeV $< m_T(\ell, E_T^{\text{miss}}) <$ 100 GeV, b-veto
CRT	$t\bar{t}$ and single-t	$t\bar{t} \rightarrow bbqq'\ell\nu$	30 GeV $< m_T(\ell, E_T^{\text{miss}}) <$ 100 GeV, b-tag

3-b jets

Common criteria: lepton veto, $p_T^{j_1} > 90$ GeV, $E_T^{miss} > 150$ GeV, $= 2$ b-jets, $E_T^{miss}/m_{eff}^{4j} > 0.2$, $\Delta\phi_{min}^{4j} > 0.4$				
CR	N_J ($p_T > 50$ GeV)	p_T b-jets	m_{eff}	corresponding SR
CR4	≥ 4 jets	> 50 GeV	$m_{eff}^{4j} > 500$ GeV	SR4-L, SR4-M, SR4-T
CR6	≥ 6 jets	> 30 GeV	$m_{eff}^{incl} > 600$ GeV	SR6-L, SR6-M, SR6-T

Table 2: Definition of the two control regions used to estimate the $t\bar{t}$ background.

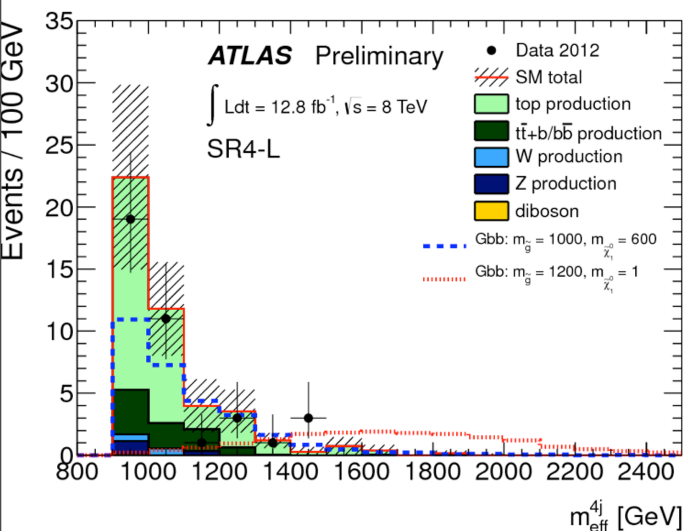
Common criteria: lepton veto, $p_T^{j_1} > 90$ GeV, $\geqslant 3$ b-jets, $E_T^{miss}/m_{eff}^{4j} > 0.2$, $\Delta\phi_{min}^{4j} > 0.4$				
VR	N_J ($p_T > 50$ GeV)	p_T b-jets	E_T^{miss} [GeV]	m_{eff} [GeV]
VR4-1	≥ 4 jets	> 50 GeV	$150 < E_T^{miss} < 200$	$m_{eff}^{4j} > 500$
VR4-2	≥ 4 jets	> 50 GeV	$E_T^{miss} > 200$	$500 < m_{eff}^{4j} < 900$
VR6-1	≥ 6 jets	> 30 GeV	$150 < E_T^{miss} < 200$	$m_{eff}^{incl} > 600$
VR6-2	≥ 6 jets	> 30 GeV	$E_T^{miss} > 200$	$600 < m_{eff}^{incl} < 1100$

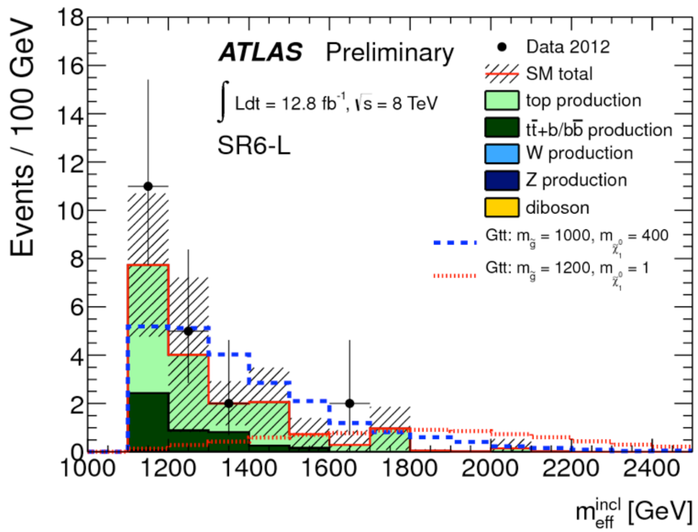
channel	CR4	VR4-1	VR4-2
Observed events	2518	249	158
Total background events	2518 ± 80	291 ± 50	176 ± 30
(MC prediction)	(2400 ± 700)	(280 ± 100)	(170 ± 60)
$t\bar{t}$ + jets events	1936 ± 200	217 ± 40	126 ± 24
(MC prediction)	(1800 ± 600)	(210 ± 70)	(120 ± 40)
$t\bar{t} + b/b\bar{b}$ events	155 ± 150	46 ± 46	25 ± 25
single top events	125 ± 45	12 ± 5	8 ± 3
$t\bar{t} + W/Z$ events	28 ± 15	3 ± 2	4 ± 2
W/Z events	269 ± 120	12 ± 7	13 ± 8
diboson events	5 ± 3	–	–
Gbb : $m_{\tilde{g}} = 1000$ GeV, $m_{\tilde{\chi}_1^0} = 600$ GeV	39 ± 16	12 ± 2	29 ± 5
Gbb : $m_{\tilde{g}} = 1200$ GeV, $m_{\tilde{\chi}_1^0} = 1$ GeV	8.9 ± 5.5	0.1 ± 0.1	0.1 ± 0.1

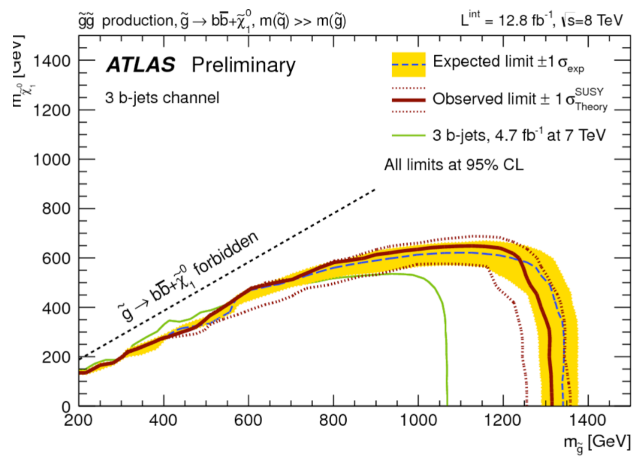
channel	CR6	VR6-1	VR6-2
Observed events	255	52	34
Total background events	255 ± 20	55 ± 15	32 ± 9
(MC prediction)	(255 ± 100)	(55 ± 26)	(32 ± 17)
$t\bar{t}$ + jets events	205 ± 30	35 ± 8	20 ± 5
(MC prediction)	(205 ± 80)	(35 ± 16)	(20 ± 11)
$t\bar{t} + b/b\bar{b}$ events	24 ± 24	16 ± 16	9 ± 9
single top events	10 ± 4	2 ± 1	1 ± 1
$t\bar{t} + W/Z$ events	5 ± 3	1 ± 1	1 ± 1
W/Z events	11 ± 6	1 ± 1	2 ± 1
diboson events	–	–	–
Gtt : $m_{\tilde{g}} = 1000$ GeV, $m_{\tilde{\chi}_1^0} = 400$ GeV	15 ± 5	5.9 ± 0.6	8.6 ± 0.8
Gtt : $m_{\tilde{g}} = 1200$ GeV, $m_{\tilde{\chi}_1^0} = 1$ GeV	3.6 ± 1.6	0.2 ± 0.1	0.1 ± 0.1

channel	SR4-L	SR4-M	SR4-T
Observed events	38	8	4
Total background events	46 ± 10	10.7 ± 2.9	2.9 ± 1.0
(MC prediction)	(44 ± 17)	(10.3 ± 4.6)	(2.7 ± 1.3)
$t\bar{t}$ + jets events	30 ± 6	7.0 ± 1.8	2.4 ± 0.9
(MC prediction)	(29 ± 11)	(6.6 ± 2.5)	(2.3 ± 1.1)
$t\bar{t} + b/b\bar{b}$ events	8.1 ± 8.3	2.5 ± 2.5	0.1 ± 0.2
single top events	3.5 ± 1.3	0.4 ± 0.5	0.2 ± 0.1
$t\bar{t} + W/Z$ events	1.4 ± 0.8	0.5 ± 0.3	0.2 ± 0.1
W/Z events	2.6 ± 1.9	0.4 ± 0.6	–
diboson events	–	–	–
Gbb : $m_{\tilde{g}}$ = 1000 GeV, $m_{\tilde{\chi}_1^0}$ = 600 GeV	30 ± 7	11 ± 3	3.8 ± 1.3
Gbb : $m_{\tilde{g}}$ = 1200 GeV, $m_{\tilde{\chi}_1^0}$ = 1 GeV	17 ± 2	17 ± 2	15 ± 2

channel	SR6-L	SR6-M	SR6-T
Observed events	20	4	2
Total background events	18 ± 6	6.3 ± 2.4	2.2 ± 1.3
(MC prediction)	(18 ± 9)	(6.3 ± 3.4)	(2.2 ± 1.8)
$t\bar{t}$ + jets events	12 ± 4	4.3 ± 1.9	1.7 ± 1.0
(MC prediction)	(12 ± 6)	(4.3 ± 2.4)	(1.7 ± 1.5)
$t\bar{t} + b/b\bar{b}$ events	4.6 ± 5.0	1.3 ± 1.4	0.2 ± 0.3
single top events	0.6 ± 0.3	0.4 ± 0.2	0.2 ± 0.1
$t\bar{t} + W/Z$ events	0.8 ± 0.4	0.3 ± 0.2	0.1 ± 0.1
W/Z events	0.1 ± 0.1	–	–
diboson events	–	–	–
Gtt : $m_{\tilde{g}}$ = 1000 GeV, $m_{\tilde{\chi}_1^0}$ = 400 GeV	18 ± 3	8.8 ± 2.2	3.6 ± 1.2
Gtt : $m_{\tilde{g}}$ = 1200 GeV, $m_{\tilde{\chi}_1^0}$ = 1 GeV	8.2 ± 0.4	7.8 ± 0.5	6.8 ± 0.6

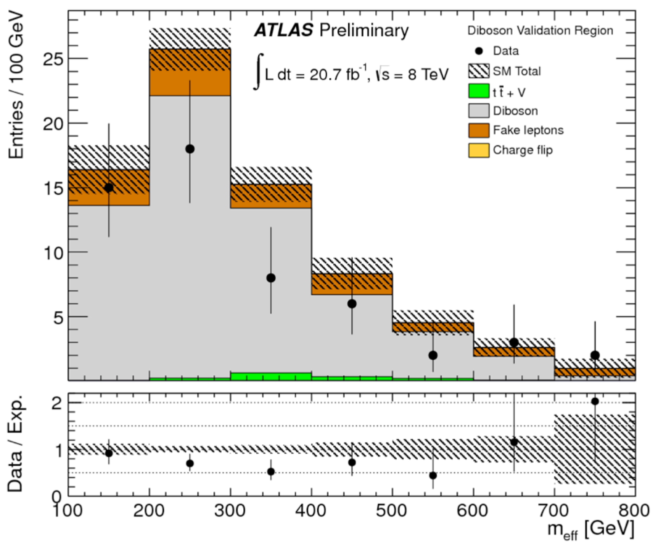




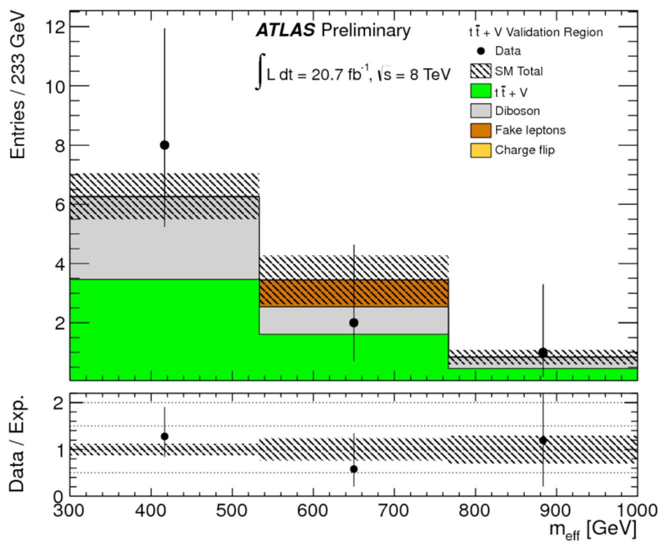


SS - dilepton

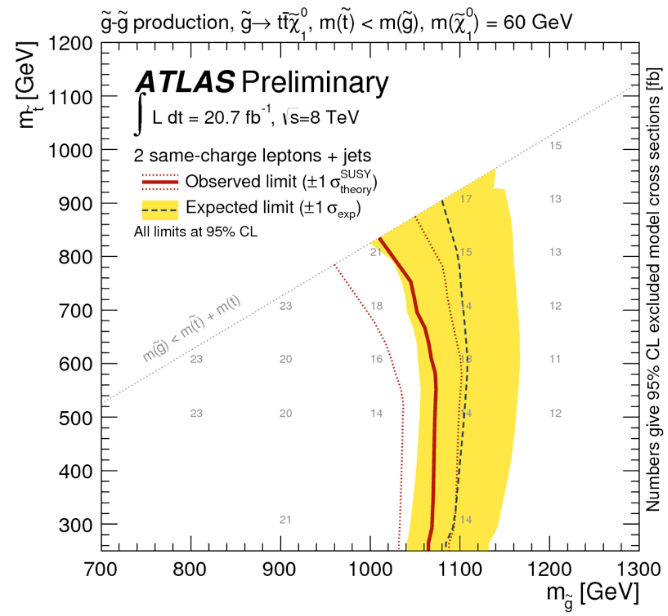
SS-dilepton



diboson VR

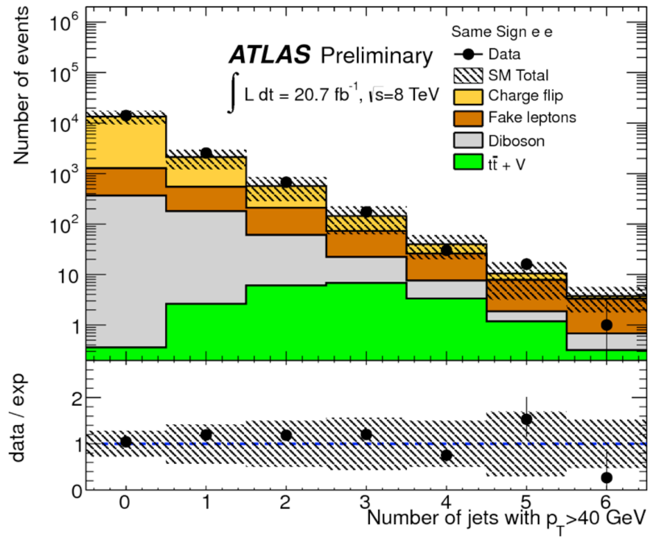


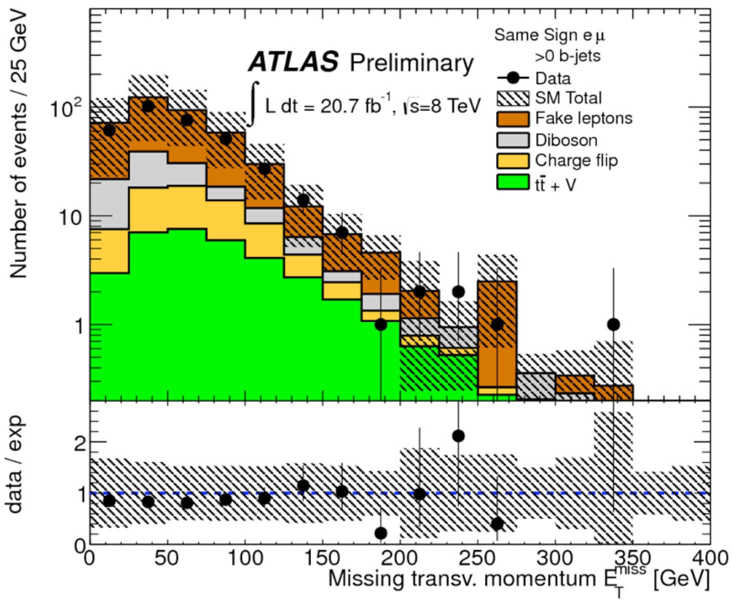
ttV VR



SS leptons - background estimation

- Background processes:
  - Prompt leptons: ttV, diboson→MC used
  - "Fake lepton" (e.g. tt, Z) estimated with matrix method
  - charge flip (for electrons): estimated with SS to OS ratio on the Z→ee peak





- Prompt lepton background validated in VR:
  - dibosons: 2 jets, no b-tags, intermediate E_T^{miss}
  - ttW: 2 SS leptons, 2 b-tags, intermediate E_T^{miss}
  - ttZ: 3 leptons (SF, OS pair compatible with Z), 1 or 2 b-tags, intermediate E_T^{miss}

Event classes	VR-diboson	VR-ttW	VR-ttZ
Observed events	54	9	4
Expected background events	74 ± 13	4.2 ± 1.9	8.0 ± 2.0
Expected $t\bar{t}$+V events	1.6 ± 0.8	2.7 ± 1.5	3.2 ± 1.1
Expected diboson events	60 ± 7	0.4 ± 0.1	3.9 ± 1.3
Expected fake lepton events	12 ± 11	1.1 ± 1.1	0.9 ± 0.5
Expected charge mis-meas. events	0	0	0

direct sbottom

Signal region definition

SR1:

- 2 b-jets (130, 50) GeV
- veto 3rd jet (above 50 GeV)
- $m_{\mathrm{CT}} >$ 150, 200, 250, 300 GeV

SR2:

- 2 b-jets (60, 60)
- veto 3rd jet (above 50 GeV)
- $E_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV
- $m_{\mathrm{CT}} > 100$ GeV
- HT,2 $<$ 50 GeV

$$\mathrm{HT,2} = \sum_{\mathrm{jet}>2}^{\mathrm{jet\ N}} p_{\mathrm{T}}$$

SR3 (a):

- ISR jet 130 GeV, anti *b*-tagged
- 2 *b*-jets (30, 30) GeV
- $\Delta\Phi(E_{\mathrm{T}}^{\mathrm{miss}}, jet1) > 2.5$
- p_{T} *b*-jet 1 < 110 GeV
- HT,3 $<$ 50 GeV

SR3 (b):

- all SR3(a) cuts
- $E_{\mathrm{T}}^{\mathrm{miss}} > 250$
- p_{T} jet1 > 150 GeV

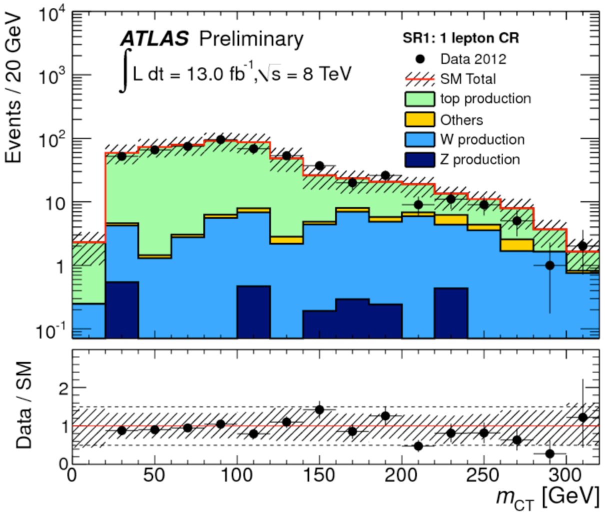
Control region definition

- Background estimation

Control region definition

- Background estimation

- top/W control region:
  - 2 b-jets
  - 1-lepton, 40 GeV < M_T < 100 GeV, similar selection as SR
  - At high M_{CT} W and top both relevant

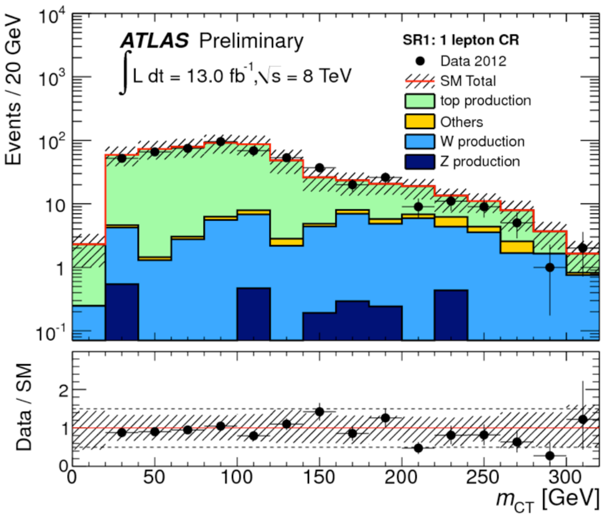


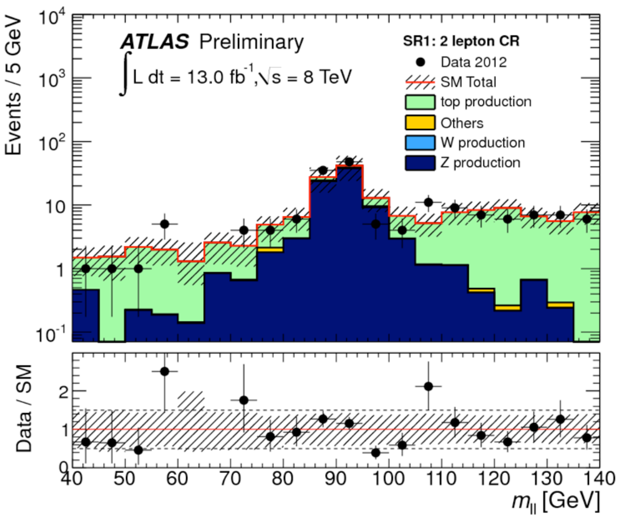
Control region definition

- Background estimation

- top/W control region:
  - 2 b-jets
  - 1-lepton, 40 GeV < M_T < 100 GeV, similar selection as SR
  - At high M_{CT} W and top both relevant

- Z control region:
  - 2 b-jets
  - 2-lepton same flavour, select the Z peak
  - "Mimic" MET by "neutrinising" the leptons





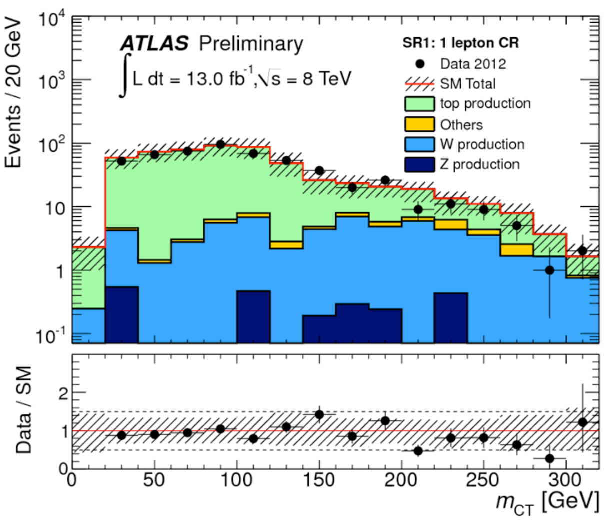
Control region definition

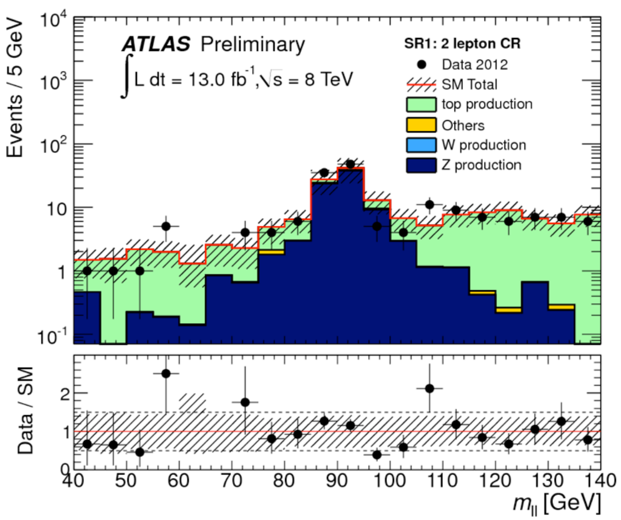
- Background estimation

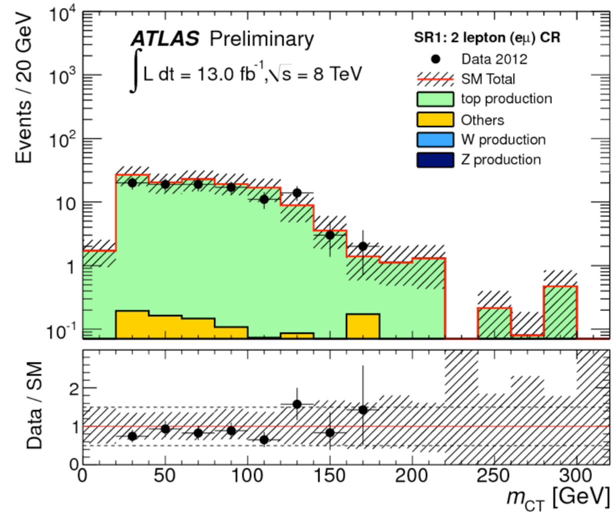
- top/W control region:
  - 2 b-jets
  - 1-lepton, 40 GeV < M_T < 100 GeV, similar selection as SR
  - At high M_{CT} W and top both relevant

- Z control region:
  - 2 b-jets
  - 2-lepton same flavour, select the Z peak
  - "Mimic" MET by "neutrinising" the leptons

- top control region:
  - 2 b-jets
  - 2-lepton different flavour
  - Very pure top control region







Control region counts and systematics

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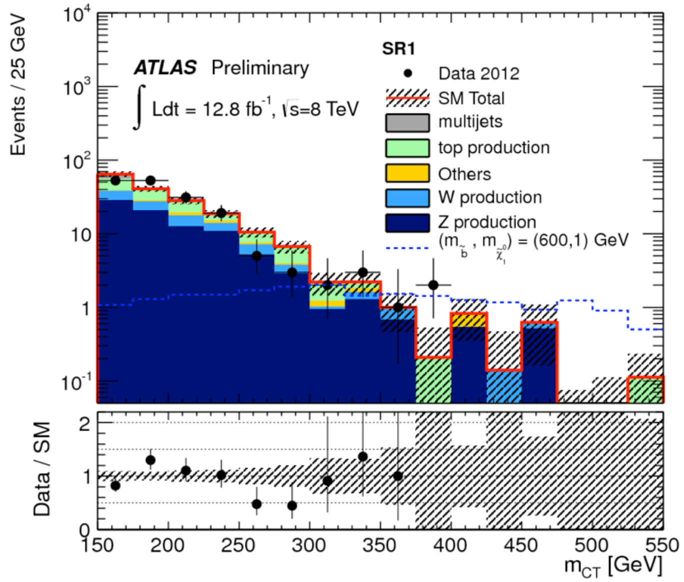
Channel	CR1L_SR1	CR2L_SR1	CR2LDF_SR1
Observed events	104	102	51
Fitted bkg events	104 ± 11	102 ± 11	51 ± 7
Top production	70 ± 16	18 ± 4	50 ± 7
Z production	1.5 ± 0.4	82 ± 12	—
W production	25 ± 19	—	—
Others	$8 \pm 4.$	2.4 ± 1.3	0.8 ± 0.4

- Normalisation factors for the backgrounds in control regions close to 1 for top, to 1.2 for Z



- Systematic uncertainties:
  - b-tagging uncertainties (~15%)
  - jet energy scale uncertainty (~10%)
  - Z production theoretical uncertainties (5%)

- Results **compatible with SM background predictions** in all signal regions

Channel	SR1, m_{CT} selection				SR2	SR3	
	150 GeV	200 GeV	250 GeV	300 GeV		SR3a	SR3b
Observed	**172**	**66**	**16**	**8**	**104**	**207**	**21**
SM Total	176 ± 25	71 ± 11	25 ± 4	7.4 ± 1.7	95 ± 11	203 ± 35	27 ± 5
Top production	45 ± 13	17 ± 6	7 ± 3	1.6 ± 0.6	15 ± 4	146 ± 40	15 ± 5
Z production	85 ± 15	36 ± 6	12 ± 2	4.0 ± 0.9	60 ± 9	27 ± 9	7 ± 2
W production	28 ± 23	12 ± 10	4 ± 3	1 ± 1	15 ± 5	22 ± 7	4 ± 1
Others	6 ± 3	4 ± 2	1.4 ± 0.8	0.7 ± 0.4	4 ± 2	4 ± 2	1.5 ± 0.9
Multijet production	12 ± 12	2 ± 2	0.2 ± 0.2	0.01 ± 0.01	0.6 ± 0.6	4 ± 4	—

0-lepton, 2-b jets stop searches

- 95% C.L. model independent upper limits on BSM event yield and σ_{vis}

Signal region	Bkg. estimate	Obs. data	95% CL UL on BSM event yield		95% CL UL on σ_{vis} (fb)	
			expected	observed	expected	observed
SR1 ($m_{CT} > 150$ GeV)	176 ± 25	172	55	54	4.2	4.1
SR1 ($m_{CT} > 200$ GeV)	71 ± 11	66	25	22	1.9	1.7
SR1 ($m_{CT} > 250$ GeV)	25 ± 4	16	12.5	7.9	0.96	0.61
SR1 ($m_{CT} > 300$ GeV)	7.4 ± 1.7	8	7.5	8.0	0.58	0.62
SR2	95 ± 11	104	32	39	2.5	3.0
SR3a	203 ± 35	207	54	54	4.2	4.2
SR3b	27 ± 5	21	13.1	9.6	1.0	0.74

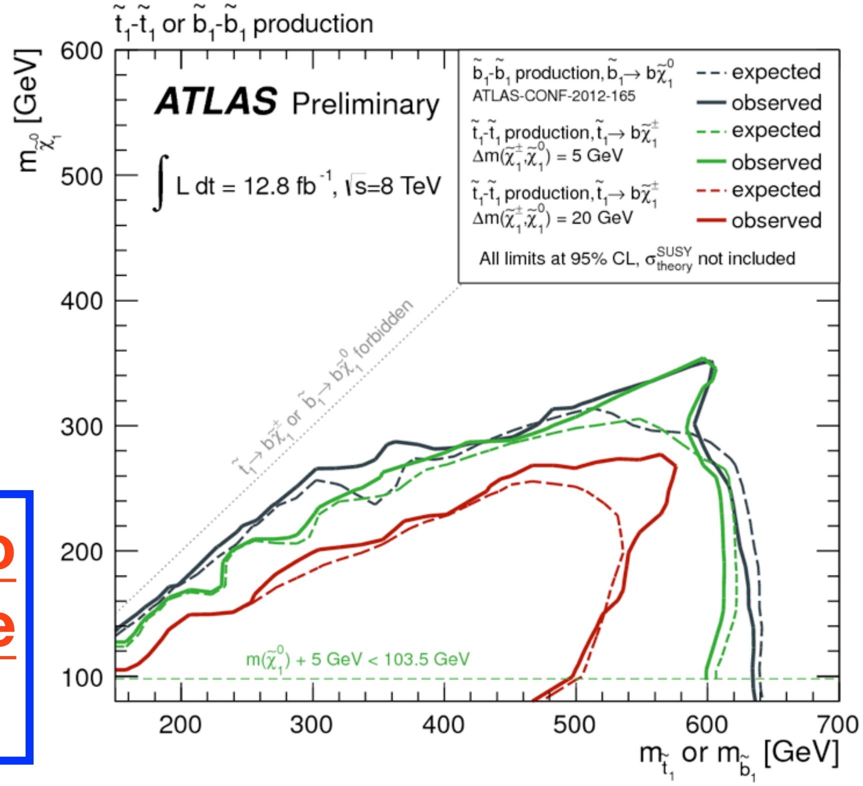
0-lepton, 2-b jets stop searches

- 95% C.L. model independent upper limits on BSM event yield and σ_{vis}

Signal region	Bkg. estimate	Obs. data	95% CL UL on BSM event yield		95% CL UL on σ_{vis} (fb)	
			expected	observed	expected	observed
SR1 ($m_{CT} > 150$ GeV)	176 ± 25	172	55	54	4.2	4.1
SR1 ($m_{CT} > 200$ GeV)	71 ± 11	66	25	22	1.9	1.7
SR1 ($m_{CT} > 250$ GeV)	25 ± 4	16	12.5	7.9	0.96	0.61
SR1 ($m_{CT} > 300$ GeV)	7.4 ± 1.7	8	7.5	8.0	0.58	0.62
SR2	95 ± 11	104	32	39	2.5	3.0
SR3a	203 ± 35	207	54	54	4.2	4.2
SR3b	27 ± 5	21	13.1	9.6	1.0	0.74

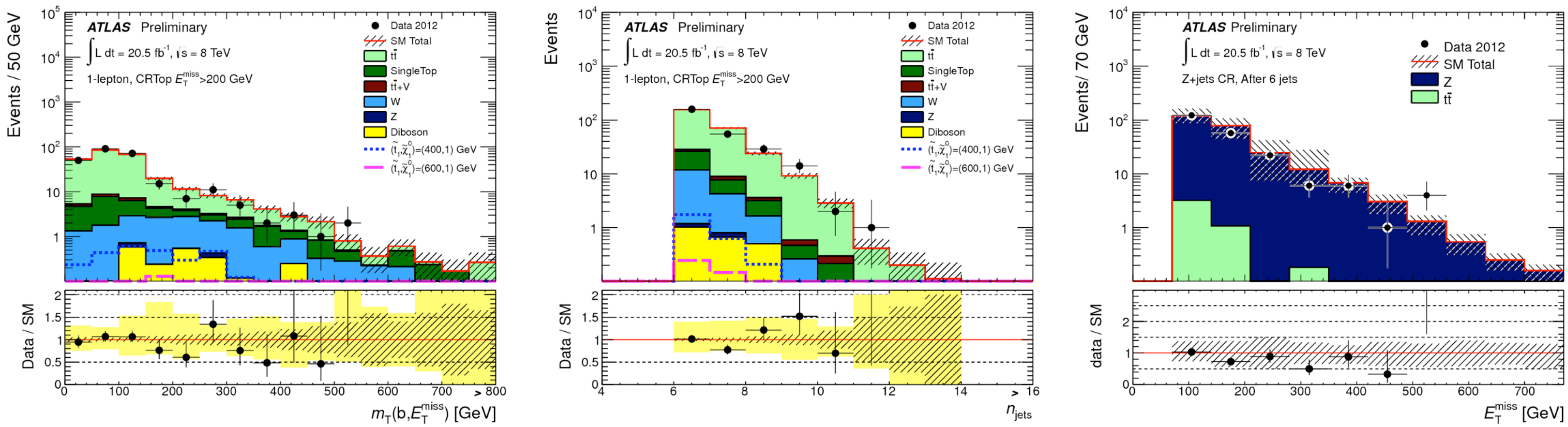
- 95% C.L. limit **very similar for the sbottom and the stop case if $\Delta m(\tilde{\chi}_1^\pm,\tilde{\chi}_1^0)$ = 5 GeV**
- A clear **loss of acceptance** (because of lepton and jet veto) if **$\Delta m(\tilde{\chi}_1^\pm,\tilde{\chi}_1^0)$ = 20 GeV**

- **$\tilde{t}\rightarrow b\tilde{\chi}_1^\pm$ (BR 100%) excluded up to $m_{\tilde{t}}$ ~ 600 GeV for nearly degenerate chargino and neutralino masses**



direct stop

0-lepton stop



Signal region	$\langle\epsilon\sigma\rangle^{95}_{obs}$[fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B
SR1	0.49	10.0	$10.6^{+5.5}_{-1.7}$	0.39
SR2	0.17	3.6	$5.3^{+3.2}_{-1.7}$	0.20
SR3	0.19	3.9	$4.5^{+1.9}_{-0.7}$	0.27

Number of events	**SR1**	**SR2**	**SR3**
Observed	15	2	1
Expected background	17.5 ± 3.2	4.7 ± 1.5	2.7 ± 1.2
Expected $t\bar{t}$	9.8 ± 2.6	1.9 ± 1.3	0.9 ± 0.7
Expected $t\bar{t} + W/Z$	1.7 ± 1.0	0.7 ± 0.4	0.51 ± 0.30
Expected Z+jets	2.1 ± 1.0	1.2 ± 0.5	0.8 ± 0.4
Expected W+jets	1.2 ± 0.8	0.32 ± 0.29	$0.19^{+0.23}_{-0.19}$
Expected single-top	1.5 ± 0.9	0.5 ± 0.4	$0.3^{+0.5}_{-0.3}$
Expected multijet	0.12 ± 0.12	0.01 ± 0.01	< 0.01
Expected diboson	1.2 ± 1.2	< 0.22	< 0.22
Fit input expectation $t\bar{t}$	9.9	1.7	0.6

Uncertainty	**SR1**	**SR2**	**SR3**
Total	18%	33%	45%
Background sample sizes (data and simulation)	10%	17%	21%
Jet energy scale and resolution	10%	10%	25%
$t\bar{t}$ theory	10%	19%	22%
Z+jets theory	4%	8%	8%
$t\bar{t} + W/Z$ theory	5%	8%	10%

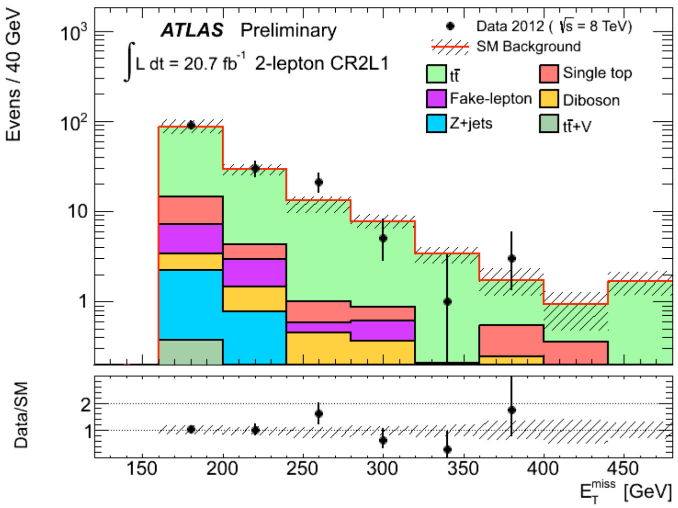
Z in stop decays

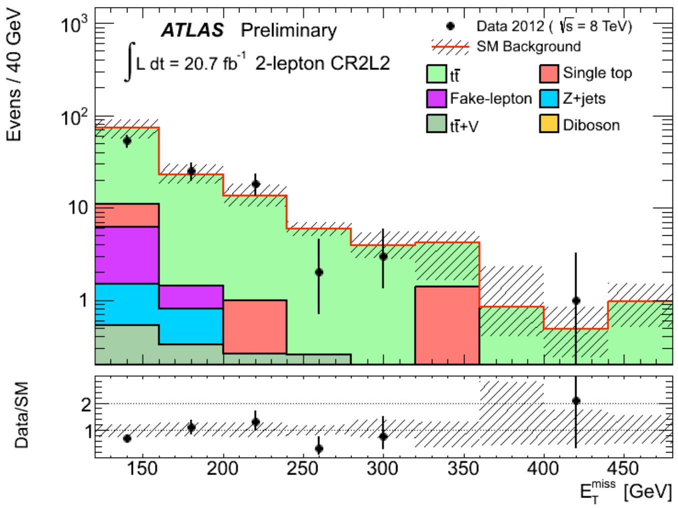
	CR2L1		CR2L2	
lepton flavour	$ee, \mu\mu$	$e\mu$	$ee, \mu\mu$	$e\mu$
$N^{b\text{-jets}}$	≥ 1			
$\Delta\phi^{\ell\ell}$	< 1.5 rad			
N^{jets}	3, 4		≥ 5	
$\lvert m_{\ell\ell} - m_Z \rvert$	≥ 10 GeV, < 50 GeV	< 50 GeV	≥ 10 GeV, < 50 GeV	< 50 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 160 GeV		> 120 GeV	
$p_{\mathrm{T}}(\ell\ell)$	> 80 GeV			

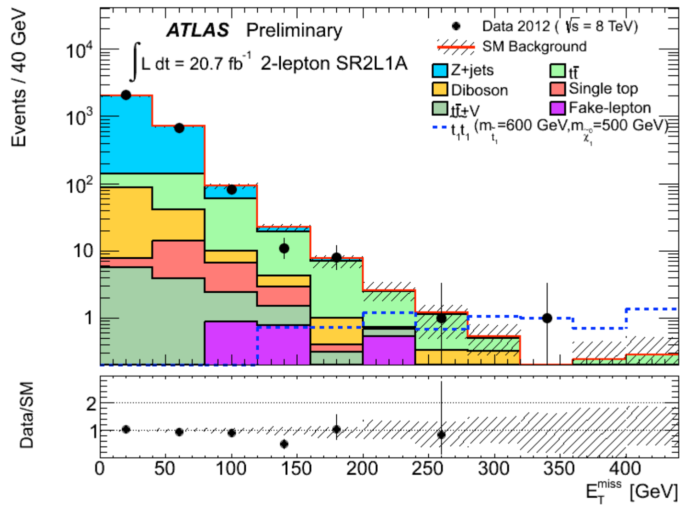
	SR2L1A	SR2L1B	SR2L2	SR3L1	SR3L2
Data	10	1	2	4	2
Total SM	12.4 ± 2.3	2.7 ± 1.2	3.8 ± 1.4	5.8 ± 2.0	1.2 ± 0.6
Diboson	1.4 ± 1.2	0.8 ± 0.7	0.3 ± 0.3	1.0 ± 0.6	0.3 ± 0.2
$t\bar{t} + V$	0.9 ± 0.7	0.36 ± 0.09	1.4 ± 0.4	3.3 ± 1.4	1.1 ± 0.5
Fake-lepton	0.3 ± 0.5	0.0 ± 0.02	0.0 ± 0.03	1.5 ± 1.0	-0.2 ± 0.3
$t\bar{t}$	8.6 ± 2.2	1.1 ± 0.7	1.9 ± 1.3		
Z+jets	0.9 ± 0.3	0.13 ± 0.07	0.2 ± 0.1		
Single top	0.09 ± 0.06	0.4 ± 0.6	< 0.2		
$t\bar{t}$ (before fit)	8.2 ± 3.3	1.0 ± 0.7	2.7 ± 2.7		

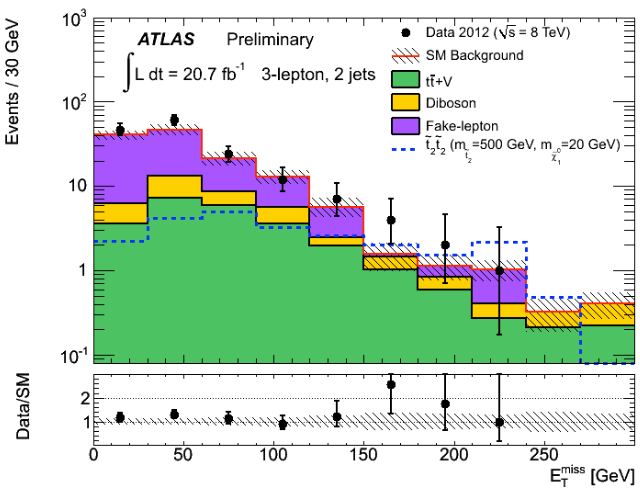
Obs. (exp.) upper limits	SR2L1A	SR2L1B	SR2L2	SR3L1
$N_{\text{non-SM}}$	7.5 (9.0)	3.5 (4.1)	4.2 (5.2)	5.5 (6.4)
σ_{vis} [fb]	0.36 (0.43)	0.17 (0.20)	0.20 (0.25)	0.27 (0.31)

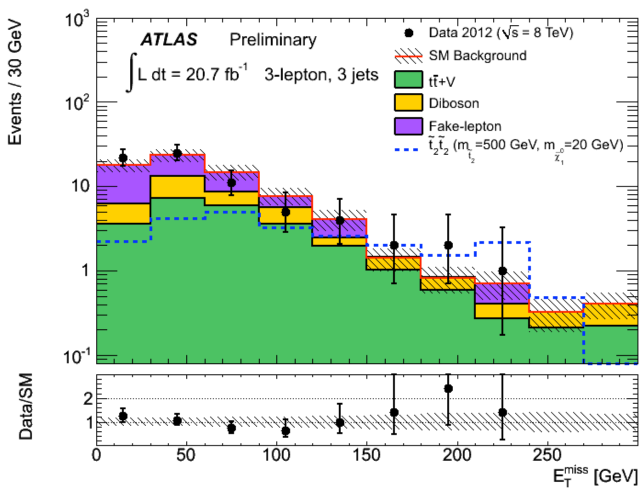
Z in stop decays

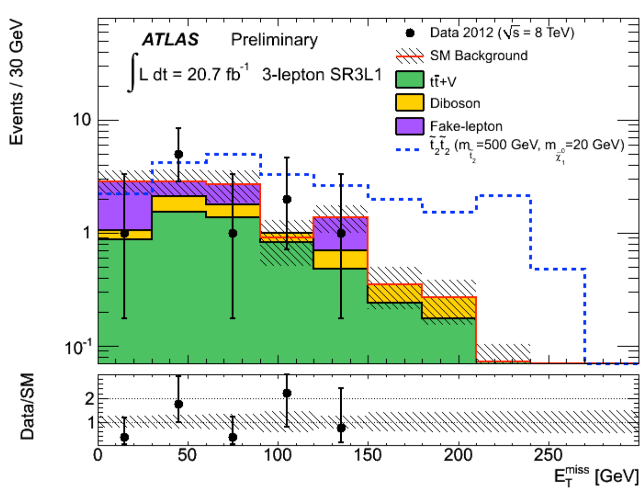






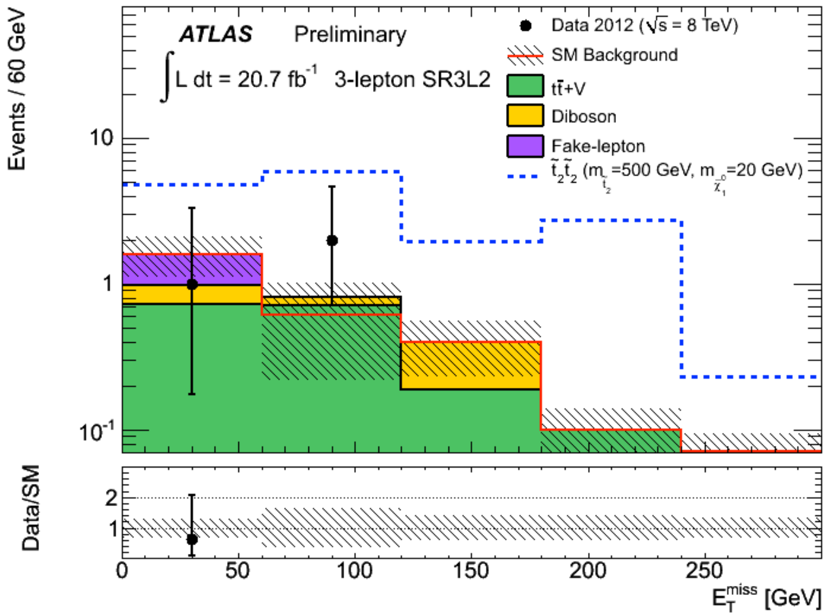


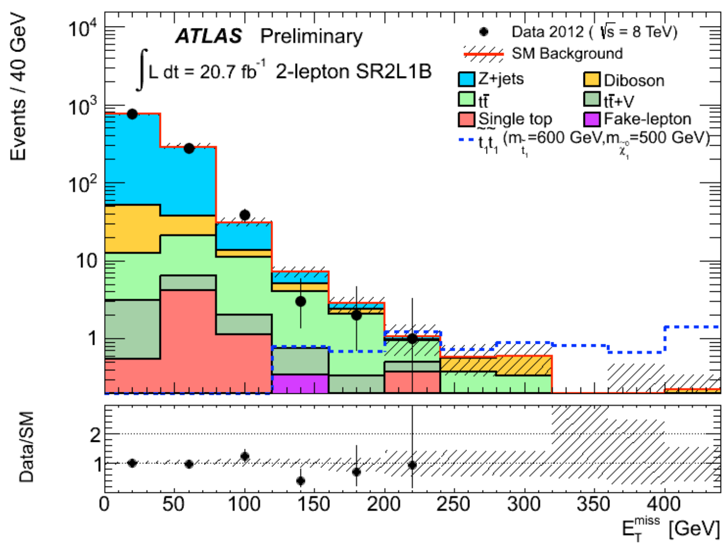


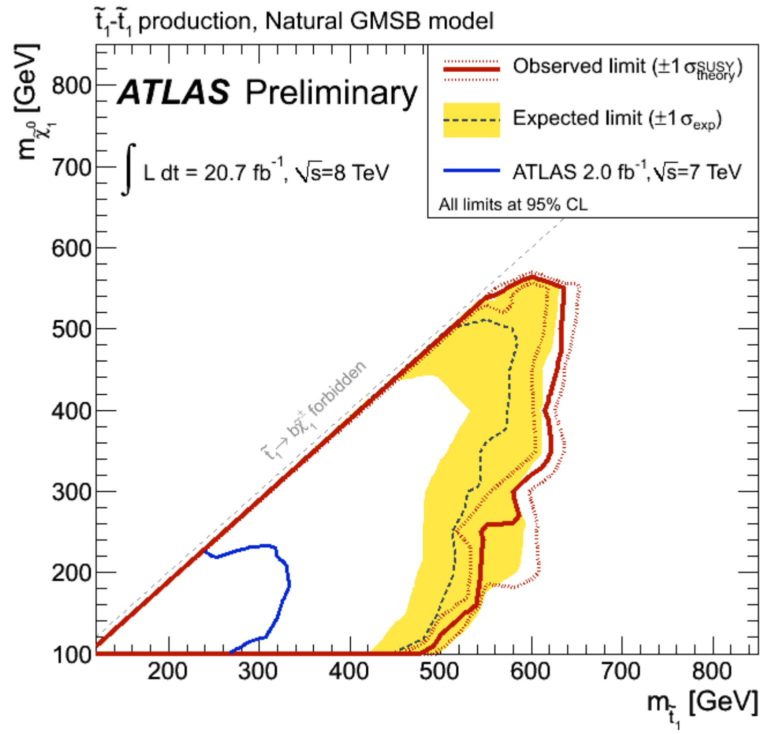


Z in stop decays

- Natural GMSB limit (2L) - Higgs mass set to 126 GeV; tanβ = 5; maximal mixing for stop;
- $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ assumed to be higgsino-like

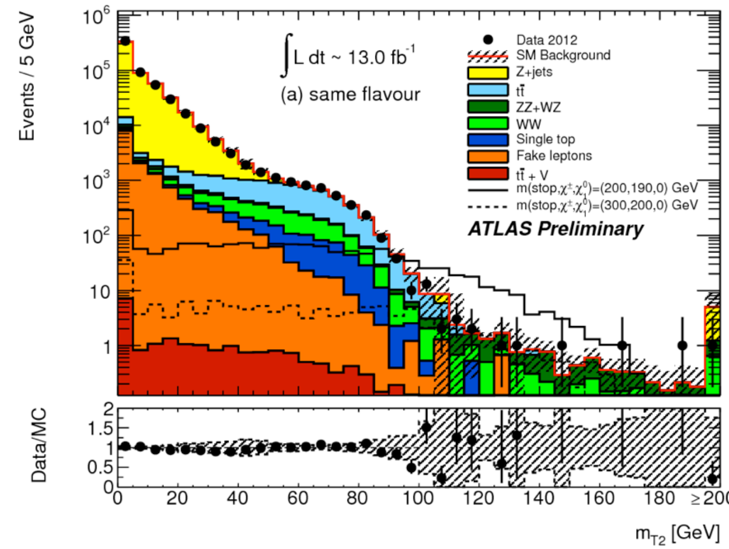






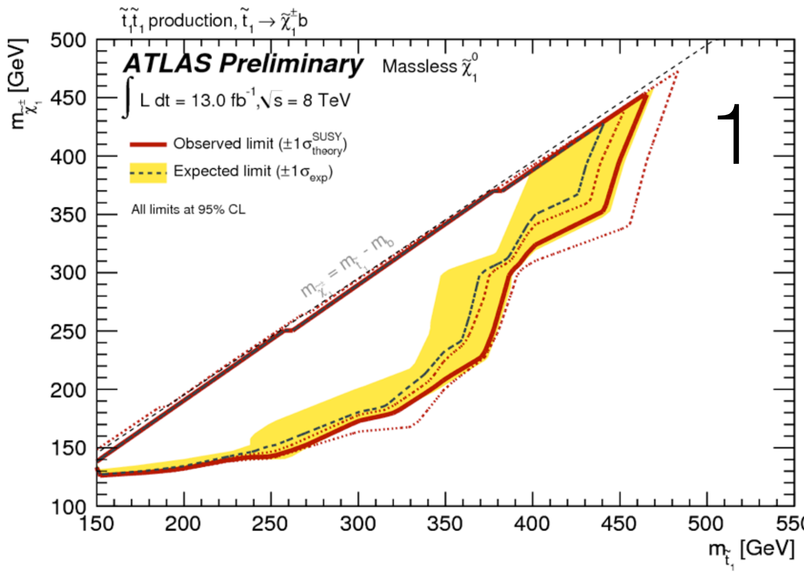
2-leptons stop searches

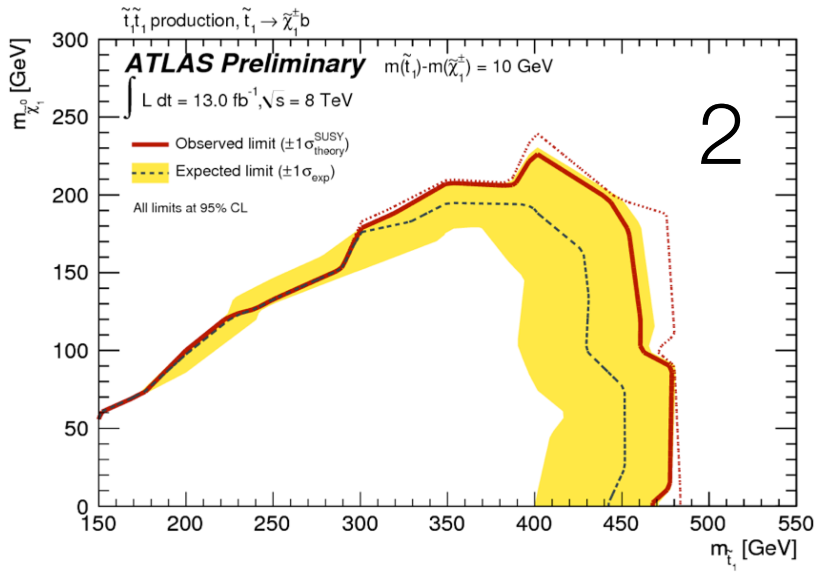
- A dedicated two-lepton analysis addresses best the case $t_1 \to bX_1^{\pm}$ (BR 100% and $X_1^{\pm} \to W^{\pm}X_1^0$) if $\Delta m(t_1,X_1^{\pm})$ not too small
- Same and different flavour leptons considered
- Main SM background: tt, WZ
- Basic variable used to reject tt, WW: M_{T2}



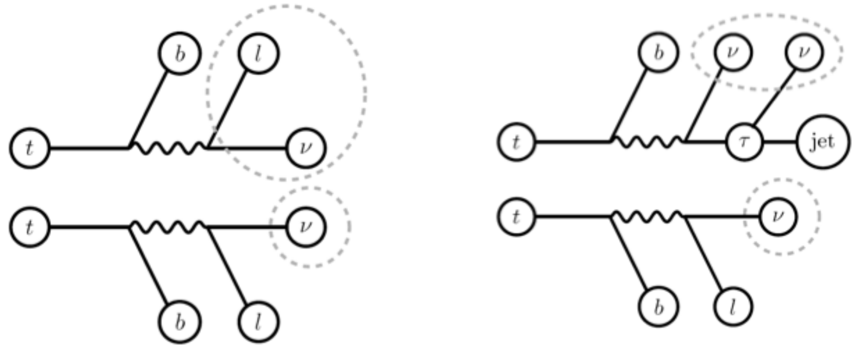
$$m_{T2}(\mathbf{p}_T^{\ell_1}, \mathbf{p}_T^{\ell_2}, \mathbf{p}_T^{miss}) = \min_{\mathbf{q}_T + \mathbf{r}_T = \mathbf{p}_T^{miss}} \left\{ \max[\, m_T(\mathbf{p}_T^{\ell_1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell_2}, \mathbf{r}_T) \,] \right\}$$

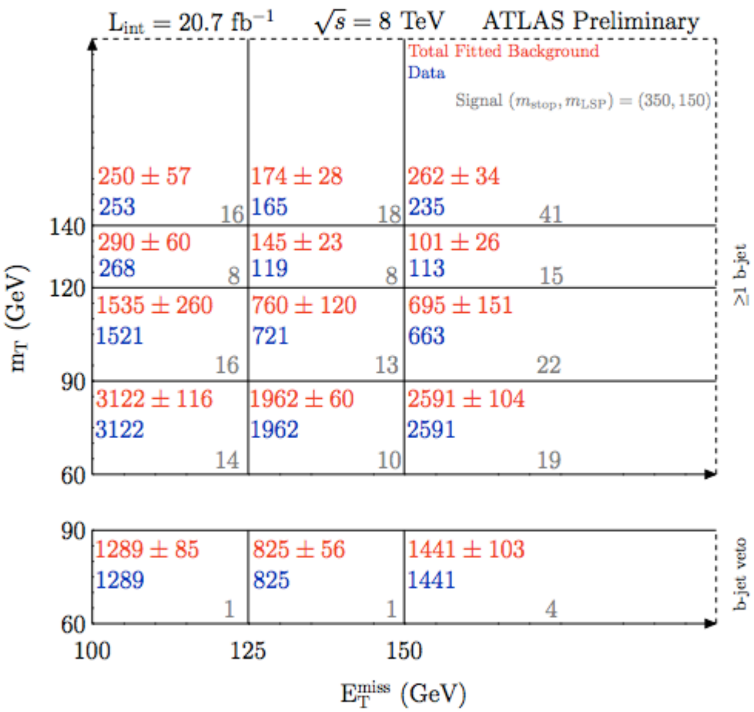
The exclusion limit concentrated in regions with small $\Delta m(t_1,X_1^{\pm})$





1-lepton





Upper limits	N_{non-SM} Obs.	N_{non-SM} Exp.	σ_{vis} [fb] Obs.	σ_{vis} [fb] Exp.
SRtN2	10.7	10.0	0.5	0.5
SRtN3	8.5	6.7	0.4	0.3
SRbC1	83.2	97.6	4.0	4.7
SRbC2	19.5	15.7	0.9	0.8
SRbC3	7.6	7.6	0.4	0.4
SRtN1_shape				
$100 < E_T^{miss} < 125$ GeV	85.7	89.8	4.1	4.3
$125 < E_T^{miss} < 150$ GeV	49.8	45.0	2.4	2.2
$E_T^{miss} > 150$ GeV	38.9	55.5	1.9	2.7

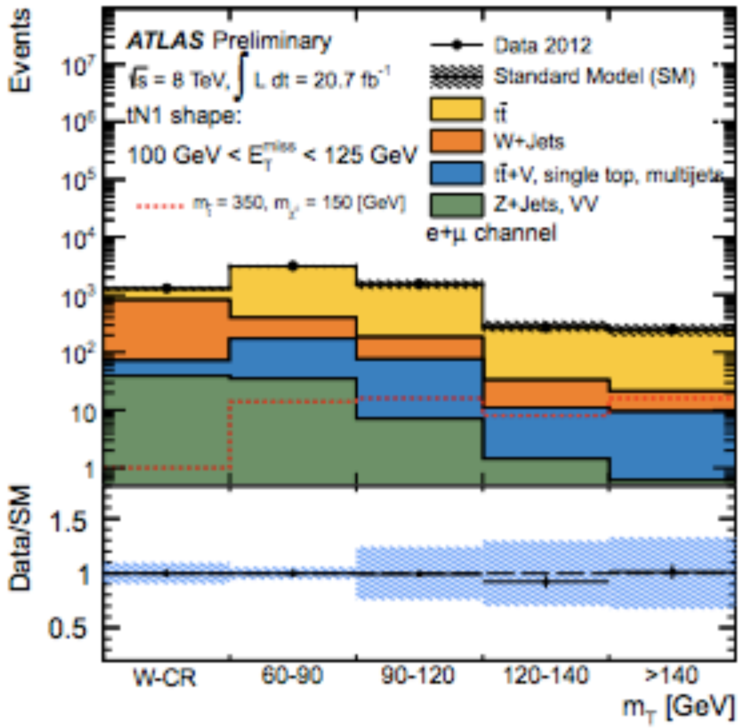
Regions	WCR-SRbC1	TCR-SRbC1	TVR-SRbC1	SRbC1
Observed events	2358	2944	785	456
Total background (fit)	2358 ± 151	2944 ± 119	806 ± 123	482 ± 76
$t\bar{t}$	440 ± 180 (440)	2160 ± 210 (2170)	630 ± 100 (630)	400 ± 90 (400)
$t\bar{t}+V$	2.8 ± 1.6	14 ± 8	5.9 ± 3.4	14 ± 7
W+jets	1780 ± 240 (2080)	540 ± 170 (630)	120 ± 40 (140)	45 ± 17 (52)
Z+jets, VV, multijet	100 ± 80	37 ± 28	5 ± 5	5 ± 4
Single top	39 ± 25	190 ± 90	46 ± 31	19 ± 10
Regions	WCR-SRbC2	TCR-SRbC2	TVR-SRbC2	SRbC2
Observed events	1139	264	76	25
Total background (fit)	1139 ± 45	264 ± 19	75 ± 26	18 ± 5
$t\bar{t}$	130 ± 80 (150)	204 ± 29 (240)	61 ± 25 (71)	9 ± 5 (11)
$t\bar{t}+V$	1.3 ± 0.9	2.5 ± 1.5	1.0 ± 0.7	2.4 ± 1.3
W+jets	940 ± 100 (1000)	26 ± 12 (28)	5.8 ± 2.7 (6.2)	3.3 ± 2.0 (3.4)
Z+jets, VV, multijet	50 ± 40	1.3 ± 1.2	0 ± 0	0 ± 0
Single top	16 ± 13	30 ± 14	7 ± 5	3.4 ± 1.5
Regions	WCR-SRbC3	TCR-SRbC3	TVR-SRbC3	SRbC3
Observed events	665	144	39	6
Total background	665 ± 33	144 ± 17	42 ± 9	7 ± 3
$t\bar{t}$	60 ± 40 (80)	106 ± 23 (141)	31 ± 8 (42)	2.4 ± 1.5 (3.1)
$t\bar{t}+V$	0.8 ± 0.6	1.8 ± 1.1	0.6 ± 0.5	0.8 ± 0.6
W+jets	560 ± 60 (610)	17 ± 8 (19)	4.7 ± 2.0 (5.2)	1.7 ± 1.7 (1.9)
Z+jets, VV, multijet	33 ± 26	$0.5^{+1.2}_{-0.5}$	0 ± 0	0 ± 0
Single top	10 ± 7	18 ± 9	6 ± 4	2.0 ± 1.0

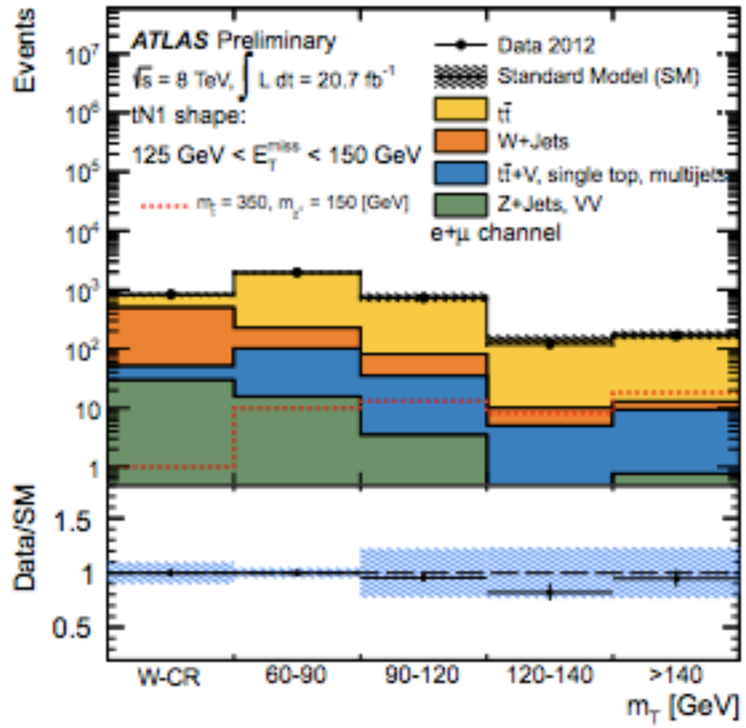
Regions	WCR-SRtN2	TCR-SRtN2	TVR-SRtN2	SRtN2
Observed events	165	204	23	14
Total background (fit)	165 ± 15	204 ± 16	29 ± 10	13 ± 3
$t\bar{t}$	31 ± 18 (30)	139 ± 26 (138)	22 ± 8 (22)	7.5 ± 2.9 (7.5)
$t\bar{t} + V$	0.4 ± 0.3	1.4 ± 0.8	0.4 ± 0.3	2.2 ± 1.2
W+jets	122 ± 28 (157)	44 ± 19 (57)	4.6 ± 2.6 (5.9)	1.5 ± 0.8 (1.9)
Z+jets, VV, multijet	11 ± 9	5 ± 4	$0.1^{+0.3}_{-0.1}$	0.4 ± 0.3
Single top	$1.3^{+2.4}_{-1.3}$	14 ± 10	2.1 ± 1.9	1.1 ± 0.5

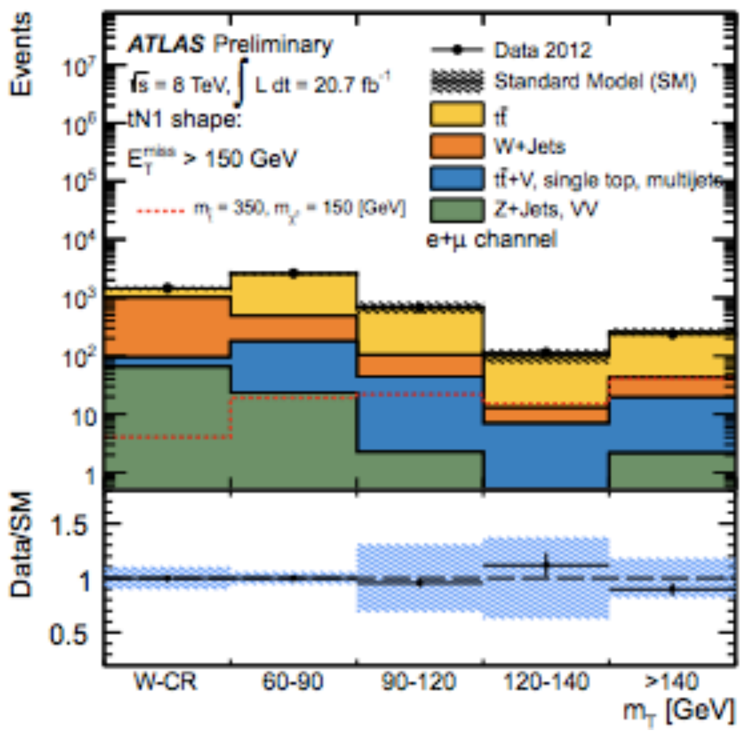
Regions	WCR-SRtN3	TCR-SRtN3	TVR-SRtN3	SRtN3
Observed events	149	175	22	7
Total background (fit)	149 ± 25	175 ± 19	28 ± 14	5 ± 2
$t\bar{t}$	20 ± 15 (24)	96 ± 33 (118)	19 ± 12 (24)	1.8 ± 1.0 (2.2)
$t\bar{t} + V$	0.3 ± 0.3	1.5 ± 0.9	0.48 ± 0.35	1.0 ± 0.7
W+jets	117 ± 29 (131)	55 ± 25 (61)	5.3 ± 2.6 (5.9)	1.5 ± 1.3 (1.6)
Z+jets, VV, multijet	10 ± 8	3.8 ± 3.5	$0.1^{+0.6}_{-0.1}$	$0.14^{+0.19}_{-0.14}$
Single top	$1.6^{+1.8}_{-1.6}$	19 ± 11	2.6 ± 1.9	0.53 ± 0.24

Not reviewed, for internal circulation only

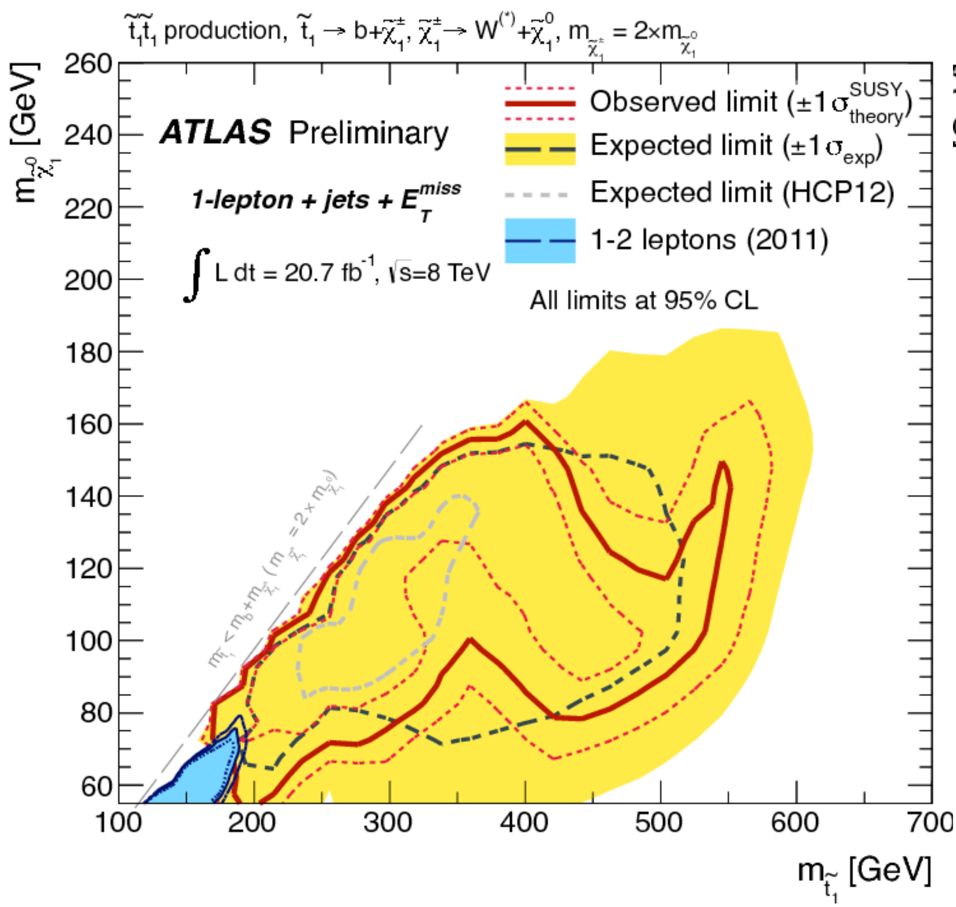
	= 0b-jet	≥ 1b-jet			
$100 < E_T^{miss} < 125$ GeV	$60 < m_T < 90$ GeV	$60 < m_T < 90$ GeV	$90 < m_T < 120$ GeV	$120 < m_T < 140$ GeV	$m_T > 140$ GeV
Observed events	1289	3122	1521	268	253
Total background (fit)	1289 ± 85	3122 ± 116	1535 ± 260	291 ± 61	250 ± 57
$t\bar{t}$	480 ± 140 (430)	2720 ± 170 (2410)	1350 ± 249 (1200)	260 ± 60 (230)	230 ± 50 (200)
$t\bar{t} + V$	2.0 ± 1.0	9 ± 4	5.6 ± 2.8	1.9 ± 0.9	2.8 ± 1.3
W+jets	730 ± 170 (880)	230 ± 120 (270)	110 ± 50 (130)	22 ± 11 (26)	12 ± 10 (14)
Z+jets, VV, multijet	39 ± 35	35 ± 35	7 ± 6	$1.4^{+2.3}_{-1.4}$	$0.6^{+0.9}_{-0.6}$
Single top	31 ± 18	130 ± 70	60 ± 40	8 ± 6	6 ± 4
$125 < E_T^{miss} < 150$ GeV	$60 < m_T < 90$ GeV	$60 < m_T < 90$ GeV	$90 < m_T < 120$ GeV	$120 < m_T < 140$ GeV	$m_T > 140$ GeV
Observed events	825	1962	721	119	165
Total background (fit)	825 ± 56	1962 ± 60	755 ± 119	145 ± 23	174 ± 28
$t\bar{t}$	330 ± 120 (290)	1740 ± 100 (1510)	670 ± 110 (590)	135 ± 21 (118)	162 ± 27 (141)
$t\bar{t} + V$	1.4 ± 0.9	7.0 ± 3.5	3.9 ± 2.2	1.3 ± 0.7	2.9 ± 1.3
W+jets	450 ± 130 (640)	130 ± 60 (180)	47 ± 25 (68)	5 ± 5 (7)	3^{+5}_{-3} (5)
Z+jets, VV, multijet	30 ± 24	16^{+27}_{-16}	3.4 ± 3.4	0.4 ± 0.4	$0.8^{+1.0}_{-0.8}$
Single top	19 ± 12	78 ± 35	27 ± 19	$3.4^{+3.5}_{-3.4}$	5.7 ± 1.9
$E_T^{miss} > 150$ GeV	$60 < m_T < 90$ GeV	$60 < m_T < 90$ GeV	$90 < m_T < 120$ GeV	$120 < m_T < 140$ GeV	$m_T > 140$ GeV
Observed events	1441	2591	663	113	235
Total background (fit)	1441 ± 103	2591 ± 104	695 ± 151	101 ± 26	262 ± 34
$t\bar{t}$	430 ± 180 (420)	2100 ± 180 (2030)	590 ± 120 (570)	88 ± 23 (85)	220 ± 40 (210)
$t\bar{t} + V$	2.7 ± 1.7	14 ± 8	5.7 ± 3.5	2.2 ± 1.2	10 ± 5
W+jets	920 ± 210 (1110)	310 ± 120 (380)	59 ± 28 (72)	6.0 ± 3.5 (7.3)	24 ± 14 (29)
Z+jets, VV, multijet	60 ± 60	24 ± 22	2^{+5}_{-2}	$0.4^{+0.6}_{-0.4}$	2.1 ± 1.8
Single top	27 ± 20	140 ± 80	37 ± 26	4 ± 4	7 ± 5


ATLAS Preliminary
√s = 8 TeV, ∫ L dt = 20.7 fb-1
tN1 shape:
100 GeV < ETmiss < 125 GeV
mt = 350, mχ = 150 [GeV]
Data 2012
Standard Model (SM)
tt̄
W+Jets
tt̄+V, single top, multijets
Z+Jets, VV
e+μ channel
Events
Data/SM
W-CR
60-90
90-120
120-140
>140
mT [GeV]

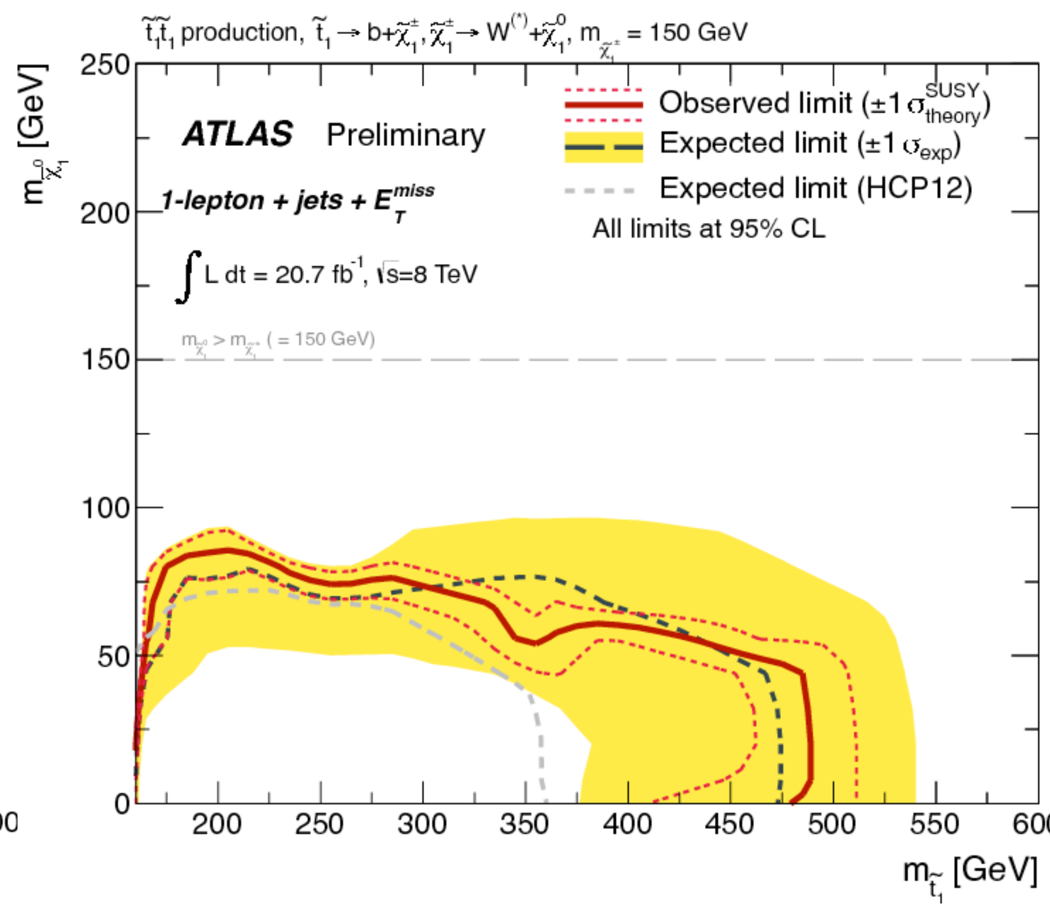

ATLAS Preliminary
√s = 8 TeV, ∫ L dt = 20.7 fb-1
tN1 shape:
125 GeV < ETmiss < 150 GeV
mt = 350, mχ = 150 [GeV]
Data 2012
Standard Model (SM)
tt̄
W+Jets
tt̄+V, single top, multijets
Z+Jets, VV
e+μ channel
Events
Data/SM
W-CR
60-90
90-120
120-140
>140
mT [GeV]


ATLAS Preliminary
√s = 8 TeV, ∫ L dt = 20.7 fb-1
tN1 shape:
ETmiss > 150 GeV
mt = 350, mχ = 150 [GeV]
Data 2012
Standard Model (SM)
tt̄
W+Jets
tt̄+V, single top, multijets
Z+Jets, VV
e+μ channel
Events
Data/SM
W-CR
60-90
90-120
120-140
>140
mT [GeV]

1-lepton



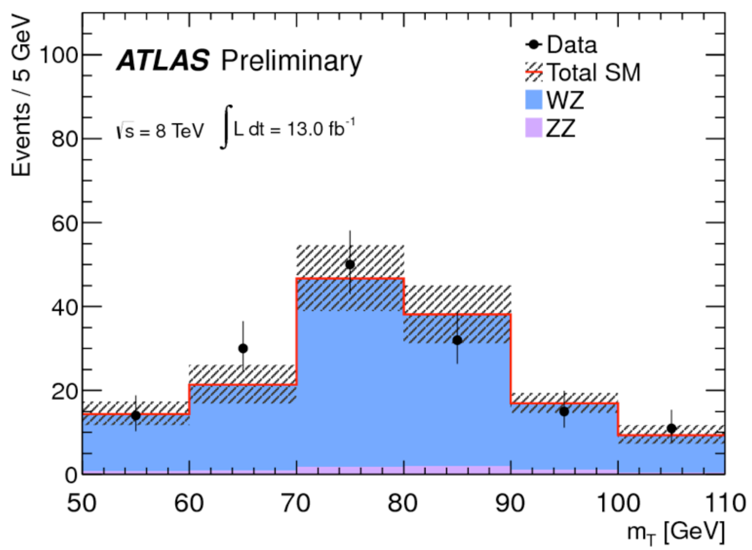
t̃₁t̃₁ production, t̃₁ → b+χ̃₁±, χ̃₁± → W(*)+χ̃₁⁰, m_χ̃₁± = 2×m_χ̃₁⁰
ATLAS Preliminary
1-lepton + jets + E_T^miss
∫L dt = 20.7 fb⁻¹, √s=8 TeV
Observed limit (±1 σ^SUSY_theory)
Expected limit (±1 σ_exp)
Expected limit (HCP12)
1-2 leptons (2011)
All limits at 95% CL
m_χ̃₁⁰ [GeV]
m_t̃₁ [GeV]
260
240
220
200
180
160
140
120
100
80
60
100
200
300
400
500
600
700

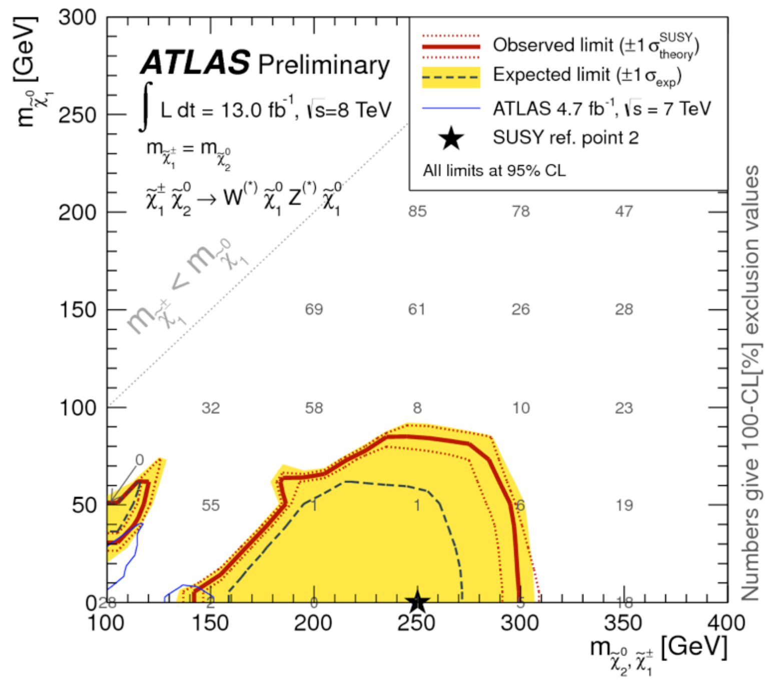


t̃₁t̃₁ production, t̃₁ → b+χ̃₁±, χ̃₁± → W(*)+χ̃₁⁰, m_χ̃₁± = 150 GeV
ATLAS Preliminary
1-lepton + jets + E_T^miss
∫L dt = 20.7 fb⁻¹, √s=8 TeV
Observed limit (±1 σ^SUSY_theory)
Expected limit (±1 σ_exp)
Expected limit (HCP12)
All limits at 95% CL
m_χ̃₁⁰ [GeV]
m_t̃₁ [GeV]
250
200
150
100
50
0
200
250
300
350
400
450
500
550
600

EW production

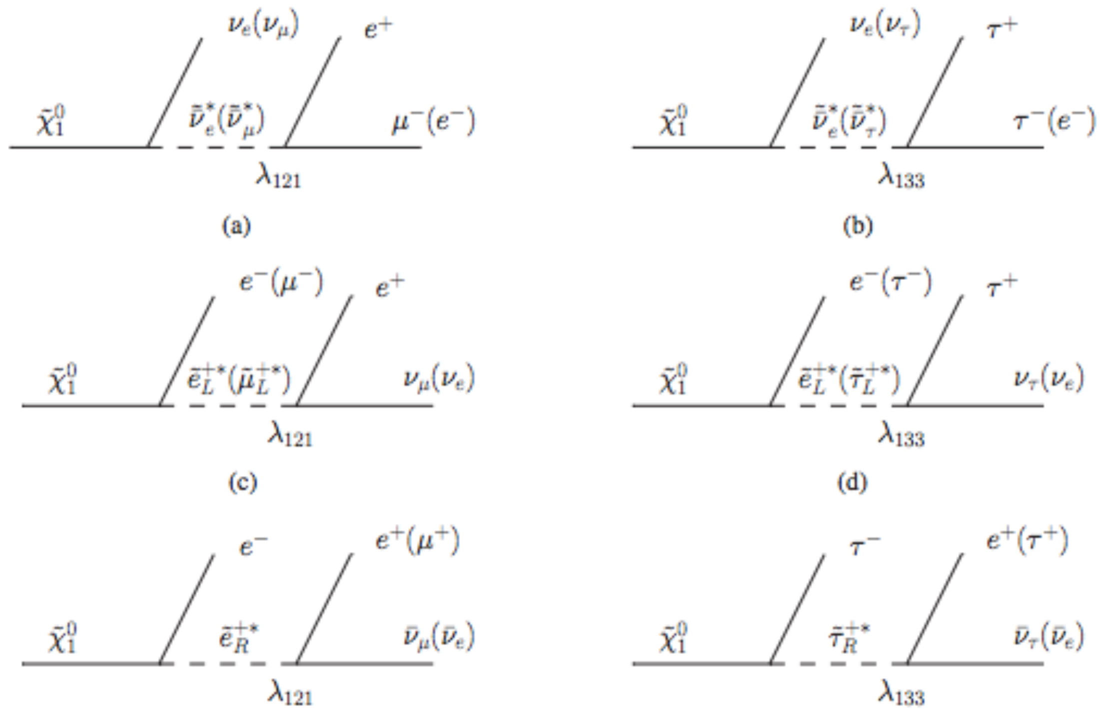
- SRZa populated almost only by WZ events
- Similar region was used with 2013 fb^{-1} as a control region for WZ, finding a scale factor of 1.0 ± 0.1



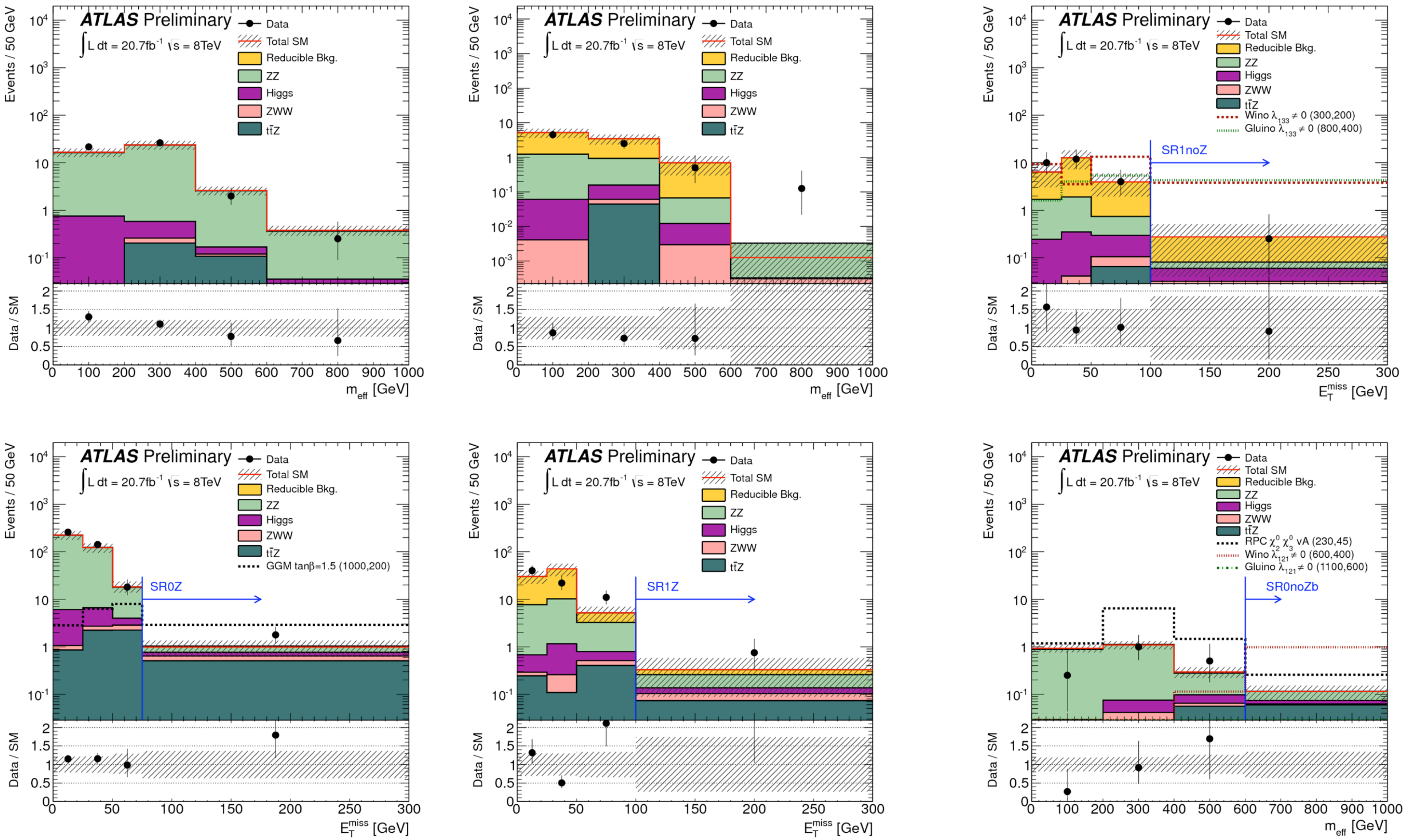


4-leptons

Sample	VR0noZ	VR1noZ	VR0Z	VR1Z
ZZ	7.2 ± 3.6	1.45 ± 0.30	167 ± 38	8.0 ± 1.2
ZWW	0.031 ± 0.031	0.027 ± 0.027	0.35 ± 0.35	0.10 ± 0.10
$t\bar{t}Z$	$0^{+0.05}_{-0}$	$0^{+0.10}_{-0}$	1.5 ± 0.7	0.18 ± 0.14
Higgs	0.17 ± 0.05	0.23 ± 0.05	4.5 ± 0.9	0.64 ± 0.16
Irreducible Bkg.	7.4 ± 3.6	1.70 ± 0.34	173 ± 39	8.9 ± 1.4
Reducible Bkg.	$0.3^{+0.7}_{-0.3}$	7.9 ± 3.6	$2.0^{+2.6}_{-2.0}$	28 ± 10
Total Bkg.	7.7 ± 3.4	9.6 ± 3.6	175 ± 37	37 ± 10
Data	3	10	201	31
CL_b	0.10	0.54	0.51	0.30



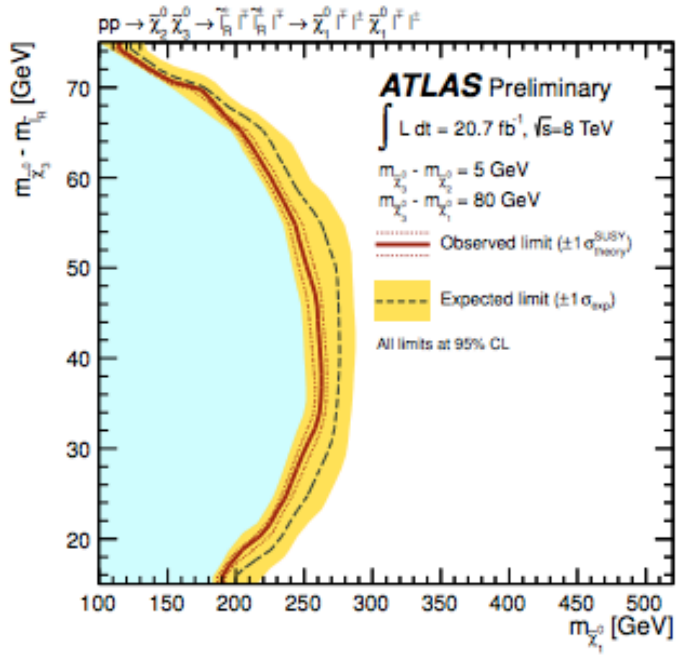
VR	$N(\ell = e,\mu)$	$N(\tau)$	Z Candidate	E_T^{miss}[GeV]		m_{eff}[GeV]	Dominant Background
VR0noZ	≥4	≥0	extended veto	<50	and	<400	Z^*Z^*
VR1noZ	=3	≥1	extended veto	<50	and	<400	Z^*Z^*, WZ^*, Z^*+jets
VR0Z	≥4	≥0	request	<50			ZZ
VR1Z	=3	≥1	request	<50			ZZ, WZ, Z+jets

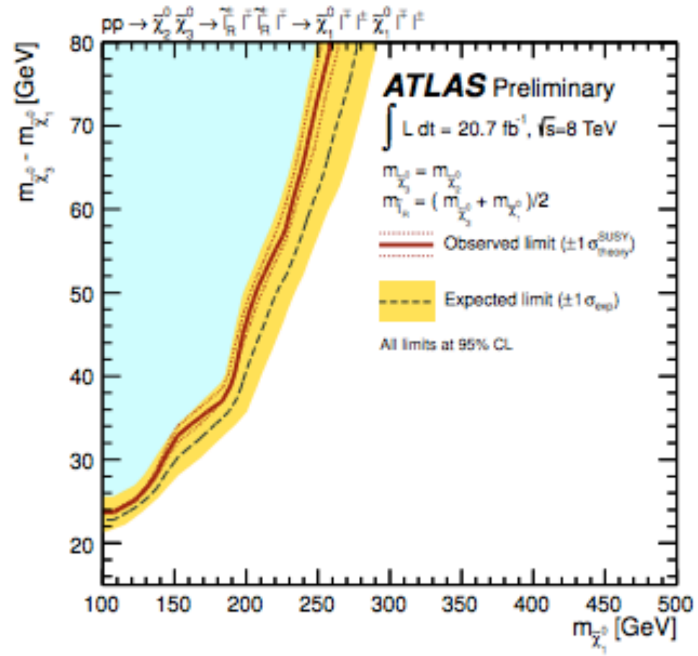

ATLAS Preliminary
∫L dt = 20.7fb⁻¹ √s = 8TeV
Data
Total SM
Reducible Bkg.
ZZ
Higgs
ZWW
tt̄Z
Events / 50 GeV
Data / SM
m_eff [GeV]
SR1noZ
Wino λ133 ≠ 0 (300,200)
Gluino λ133 ≠ 0 (800,400)
E_T^miss [GeV]
SR0Z
GGM tanβ=1.5 (1000,200)
SR1Z
SR0noZb
RPC χ̃⁰₂ χ̃⁰₃ νA (230,45)
Wino λ121 ≠ 0 (600,400)
Gluino λ121 ≠ 0 (1100,600)

4-leptons - results

- Left: **$\tilde{\chi}_3^0$ and $\tilde{\chi}_2^0$ nearly mass degenerate**. $\Delta m(\tilde{\chi}_3^0, \tilde{\chi}_1^0) = 80$ GeV. Plot $\Delta m(\tilde{\chi}_3^0, \tilde{l})$ Vs. $m(\tilde{\chi}_1^0)$
- Right: **$\tilde{\chi}_3^0$ and $\tilde{\chi}_2^0$ mass degenerate**. $m(\tilde{l}) = (m(\tilde{\chi}_3^0) + m(\tilde{\chi}_1^0))/2$. Plot $\Delta m(\tilde{\chi}_3^0, \tilde{\chi}_1^0)$ Vs. $m(\tilde{\chi}_1^0)$

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	$0^{+0.14}_{-0}$	$0.29^{+0.97}_{-0.29}$
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
N_{signal} excluded (exp)	3.9	3.6	5.3	6.7	4.5
N_{signal} excluded (obs)	4.7	3.7	7.5	10.4	6.5
$\sigma_{visible}$ excluded (exp) [fb]	0.19	0.17	0.26	0.32	0.22
$\sigma_{visible}$ excluded (obs) [fb]	0.23	0.18	0.36	0.50	0.31

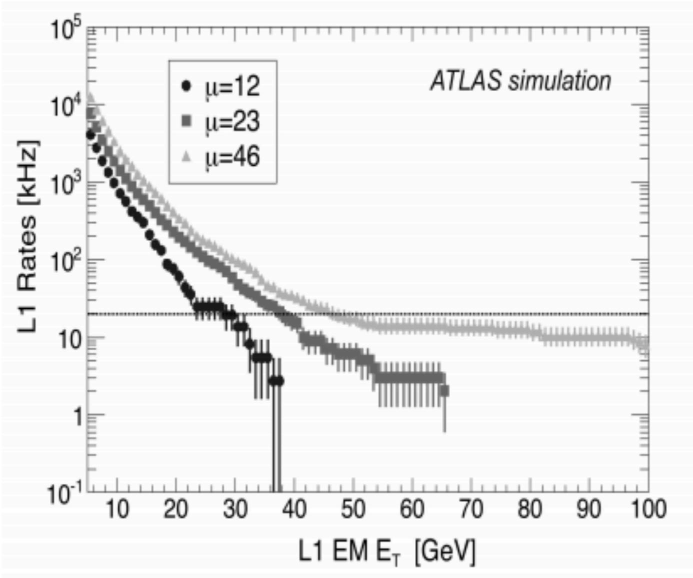


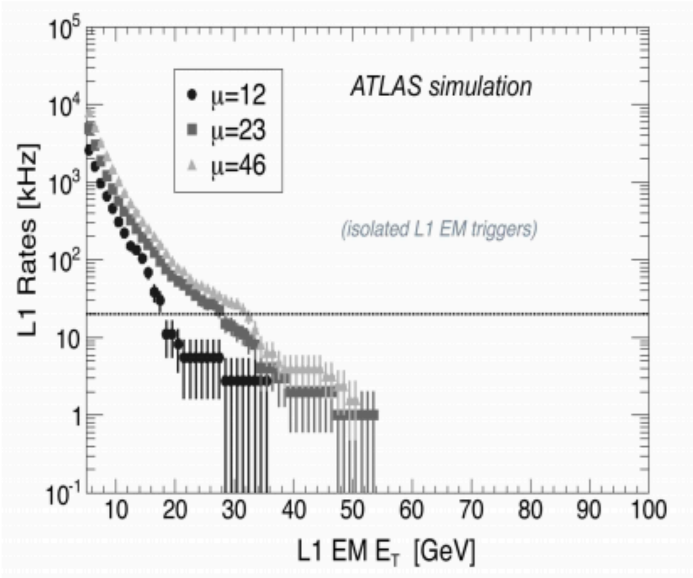


prospects

Prospects for SUSY searches at 13/14 TeV

- LHC is **foreseen to run at 13/14 TeV** after 2015 and **integrate about 300 fb^{-1}**.
- Increased **energy and pileup conditions** (highly dependent on the bunch spacing)
  - Impact mainly on trigger conditions:
    - Short term: improve on trigger strategy - trigger on topologies
    - Long term: dedicated hardware/software upgrades: improved calorimeter readout at early trigger stages, single track trigger, etc.
- Expect to deal with **increased p_T thresholds** at the beginning, especially for leptons (lowest unprescaled lepton trigger of p_T > 33 GeV w.r.t. current 25 GeV





Prospects with 13/14 TeV

- Project the sensitivity of the analyses to **13/14 TeV**
- ...assuming **realistic running conditions** and no improvement on the analyses (!)
- A lot still to be said about EW scale SUSY