SUSY SEARCHES WITH LEPTONS IN ATLAS

Outline

- **Motivations**
  - Natural SUSY
- **3rd Generation**
  - Direct stop production limits, 7 TeV, 4.7/fb
  - Gluino mediated stop production, 2 same-sign leptons, 8 TeV, 5.8/fb
  - Gluino mediated stop, direct sbottom production, 3 leptons, 8 TeV, 13.0/fb
- **Electroweak production**
  - Slepton and chargino pair-production, 2 leptons, 7 TeV, 4.7/fb
  - Chargino-neutralino production, 3 leptons, 8 TeV, 13.0/fb
- **R-parity Violation**
  - NLSP pair-production, 4 leptons, 8 TeV, 13.0/fb
- **Summary**

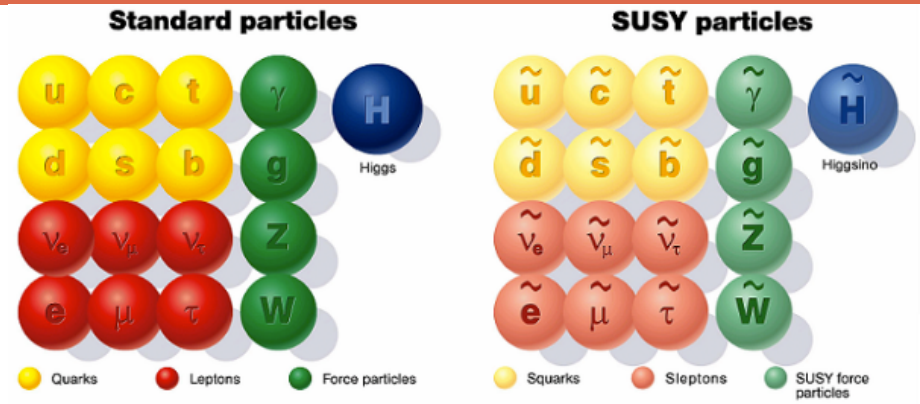
SUperSYmmetry

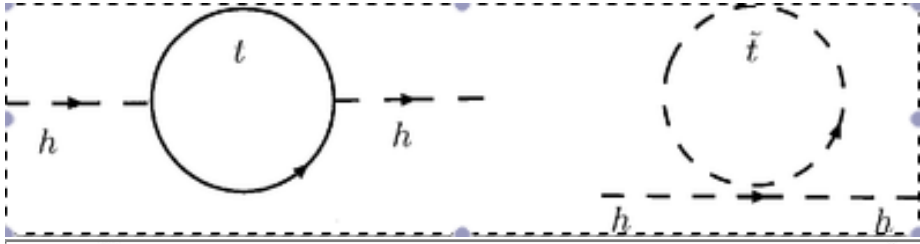
- **Most popular theory beyond the Standard Model**
- **Introduces SUSY partners to each SM particle with spin different by 1/2**

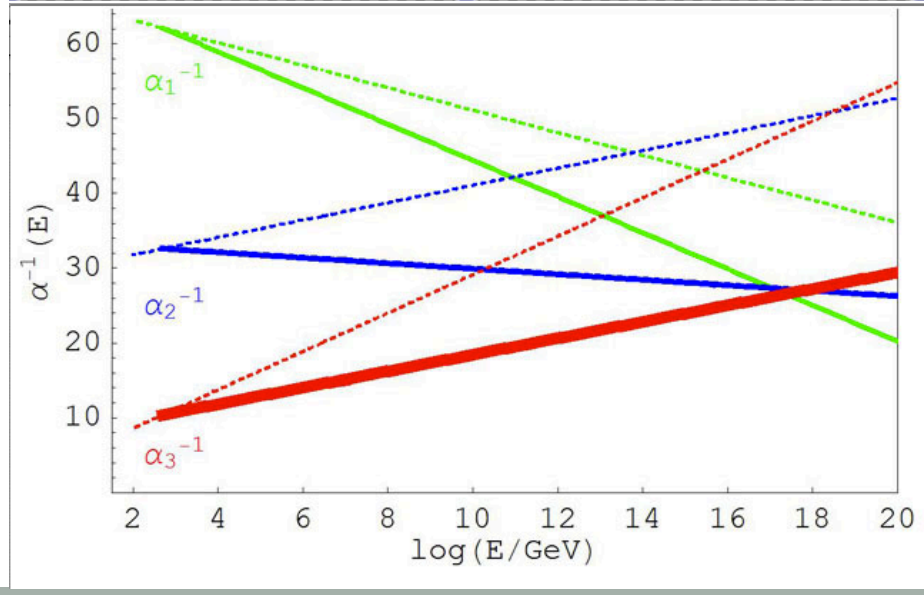
- **Regularizes electroweak scale**
  - Stop must be similar to top in mass
- **Gauginos coupling to the Higgs sector should be light**

- **Unification of gauge couplings at GUT scale**
  - Mass unification at GUT in parallel Implies M1:M2:M3 ~ 1:2:7 at EW
- **Higher GUT scale (~1e17 GeV) prevents GUT-mediated proton decays**

- **R-parity conserving models can provide dark matter candidate**
  - **large missing momentum collider signature**



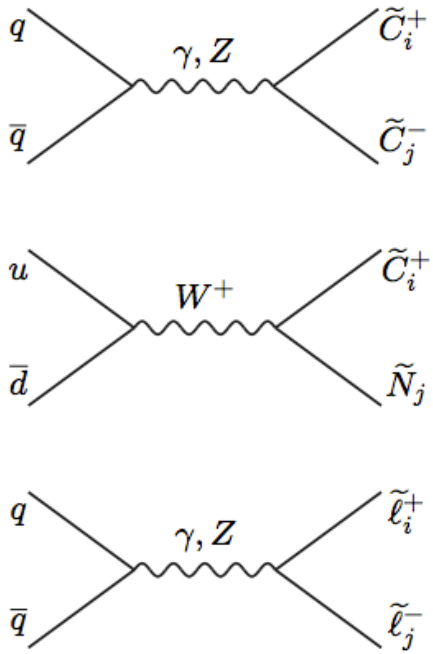


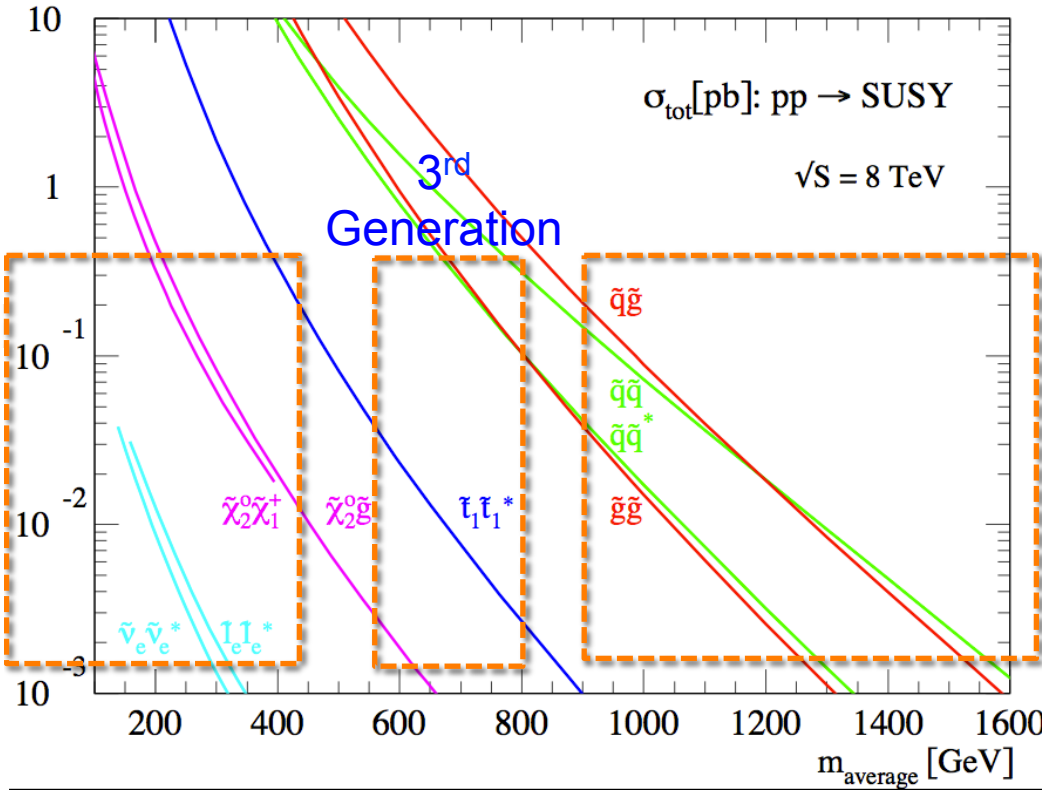


Production of SUSY Particles

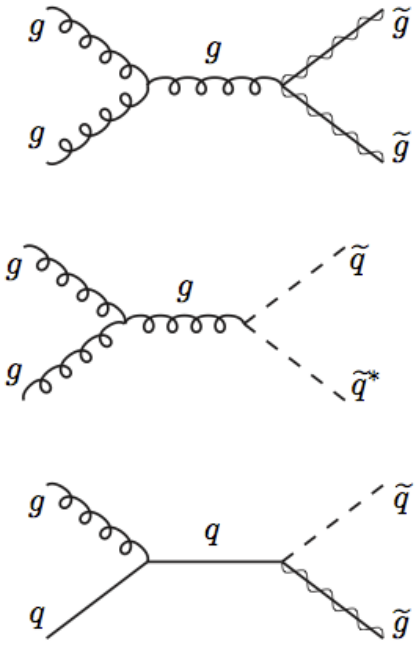
- **Strong production is dominant unless squark and gluino masses are large**
- **Stop has to be light to solve hierarchy problem**
- **Gaugino masses expected to be light as they couple to the Higgs sector**
- **Stop and weak production could be the dominant production at this stage**
- **Large MET signature could be lost due to RPV**

Electroweak Production

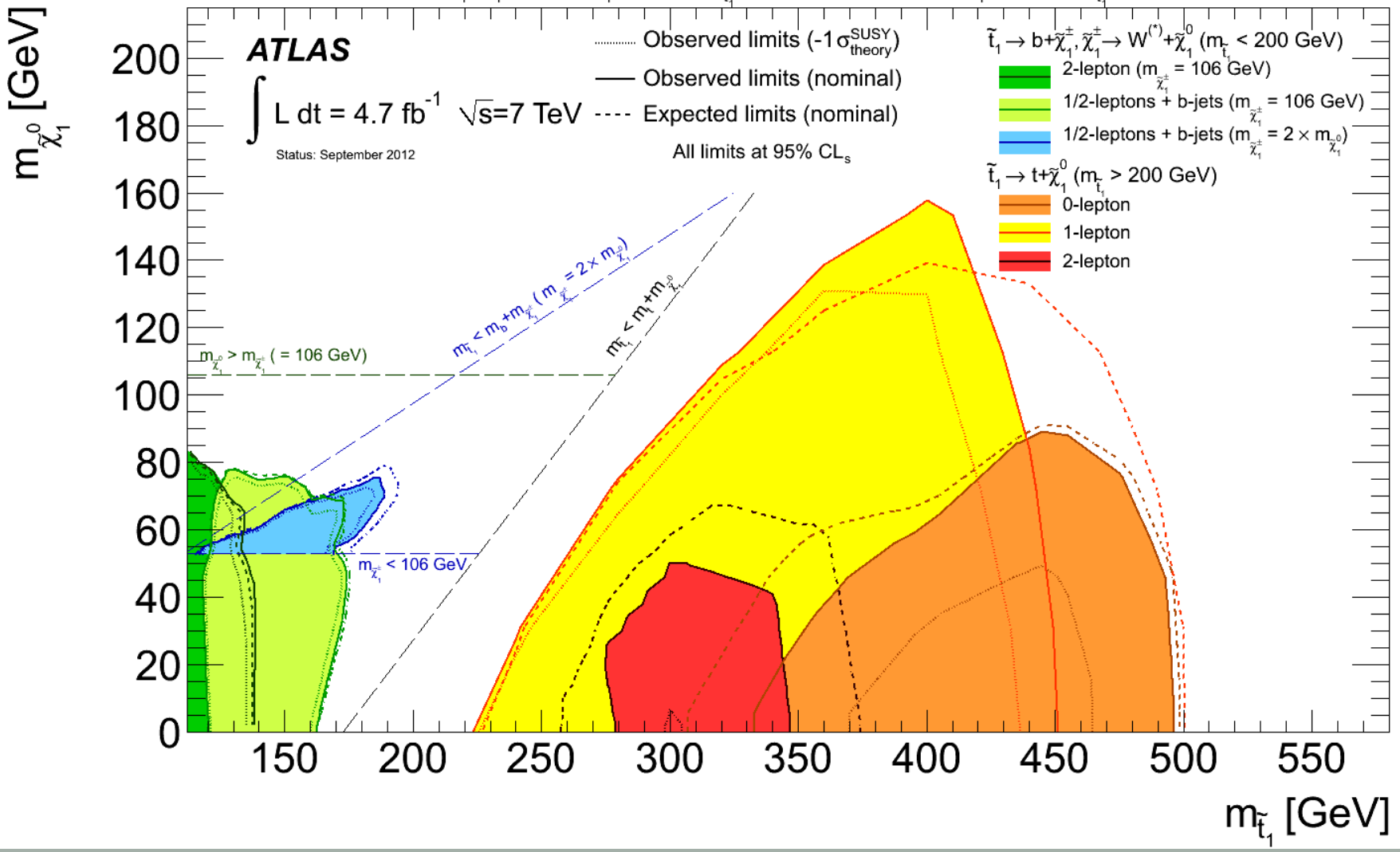




Strong Production

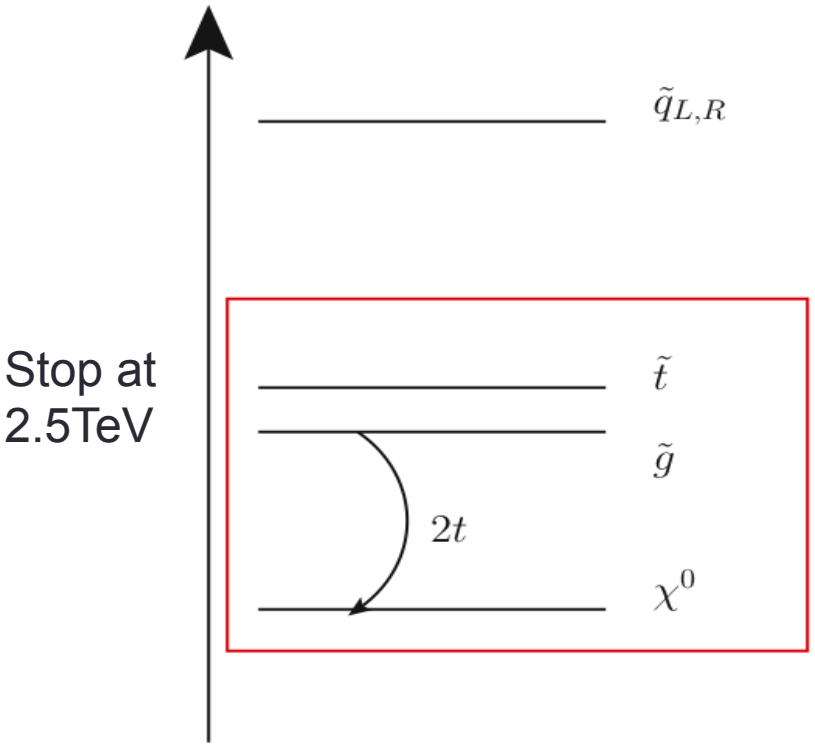


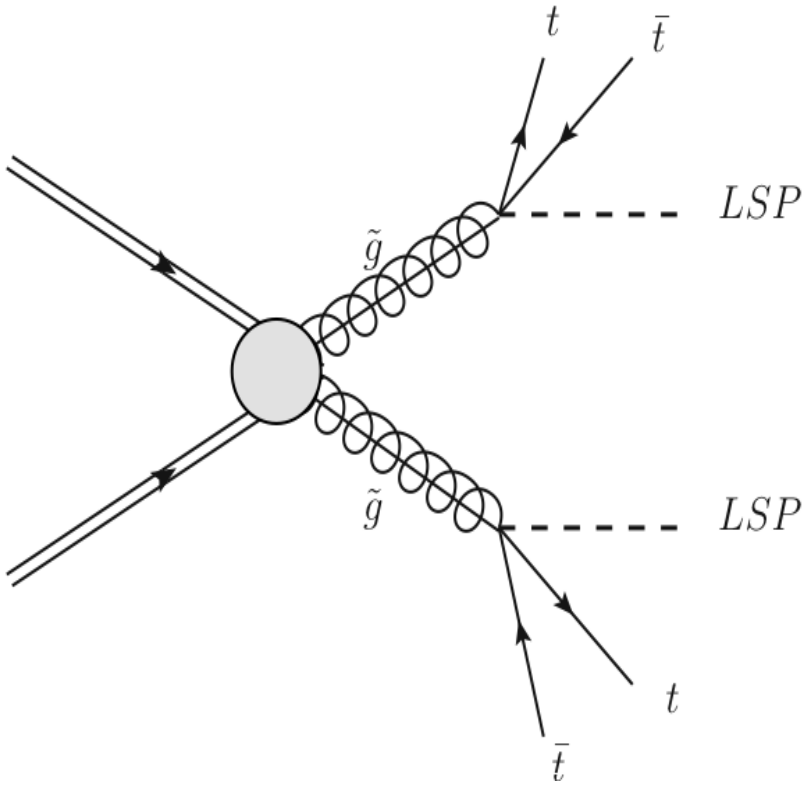
Direct Stop Limits, 7 TeV



Gluino Mediated Stop Searches

- Targeting RPC models where gluino and N1 are the lightest SUSY particles
- Pair-produced gluinos decay to tt + N1 final states via off- shell stops
- Two topologies are used for the search:
  - 2 same-sign (SS) leptons + jets + MET (8 TeV, 5.8/fb)
  - **3 leptons + jets + MET (8TeV, 13/fb)**





2 SS Leptons + Jets Search

Signal region
2 leptons, p_T > 20 GeV, same sign
≥4 jets, E_T > 50 GeV
MET > 150 GeV

- **Background classified into 3 classes:**
- Real SS lepton pair from VV and ttV
  - Estimated from MC
- Fake leptons from semi-leptonic tt
  - Matrix method using fake rates measured in SS control samples
- Charge mis-identification from electrons undergoing bremsstrahlung with subsequent photon conversion
  - Charge mis-ID probability measured in data using OS and SS events forming a Z candidate and applied to MC

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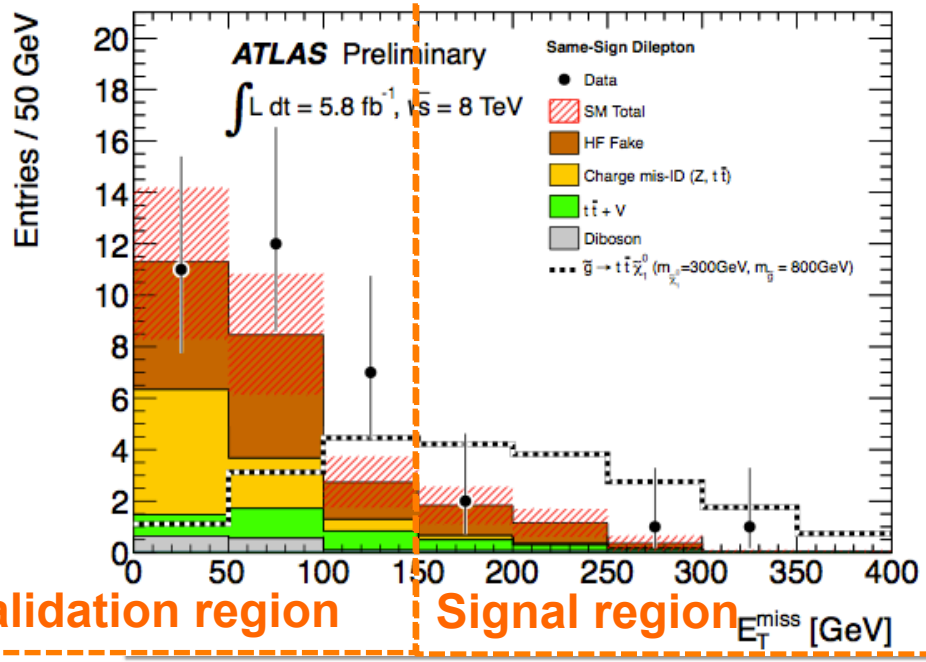
2 LS Leptons + Jets Results



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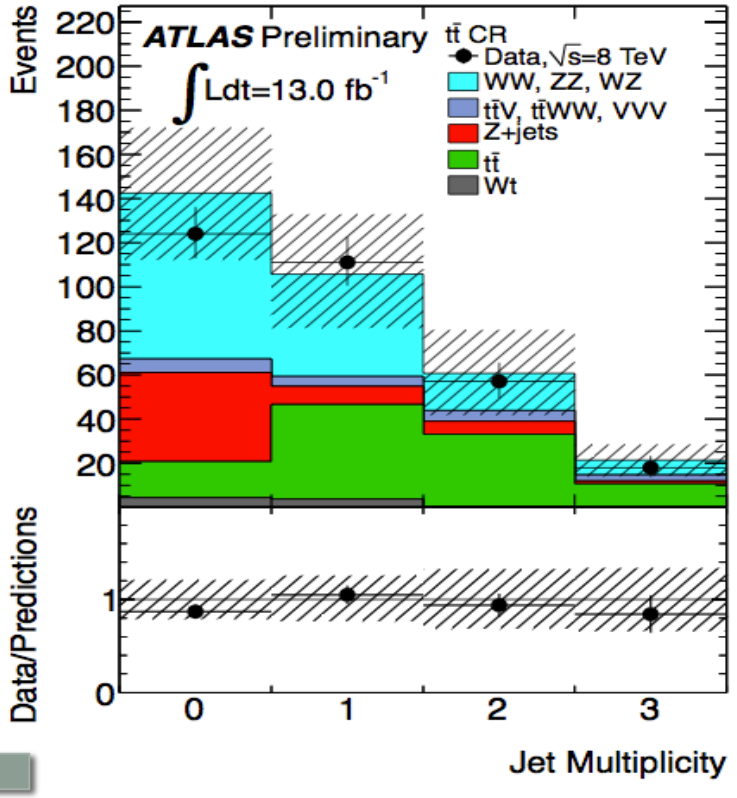
$\sigma_{vis} = \sigma \times$ acceptance $\times$ efficiency < 1.08 fb

Category	ee	$e\mu$	$\mu\mu$	$\ell\ell$
HF fake	0.74 ± 0.53	1.16 ± 0.70	$0.25^{+0.30}_{-0.25}$	2.14 ± 1.08
$t\bar{t} + V$	0.17 ± 0.08	0.44 ± 0.18	0.23 ± 0.10	0.84 ± 0.34
Charge mis-ID (Z,$t\bar{t}$)	0.13 ± 0.06	0.14 ± 0.06	–	0.27 ± 0.10
Diboson	0.04 ± 0.04	0.10 ± 0.05	0.03 ± 0.03	0.18 ± 0.07
Total background	1.1 ± 0.5	1.8 ± 0.7	0.5 ± 0.3	3.4 ± 1.1
Observed in data	1	2	1	4

3 Leptons + Jets Search

Counting Experiment	
≥3 leptons, p_T > 15 GeV	$\|\Sigma q\| = \pm 1$
≥4 jets, E_T > 30 GeV	Third electron with $q=\Sigma q$
MET > 50 GeV	Z-veto

- Irreducible background (ttV, VVV) is estimated from MC
- Reducible background is estimated from MC with correction factors from data
  - Scale factors for electrons/muons and heavy/light flavor
  - Scale factors obtained with likelihood function:
    - four fake-rate scale factors
    - 16 binned distributions in 3 dedicate control regions each with different flavor/charge combinations



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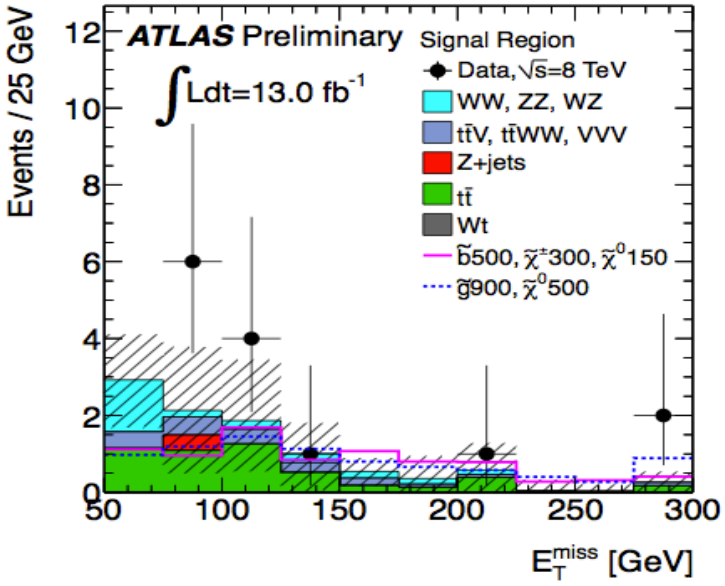
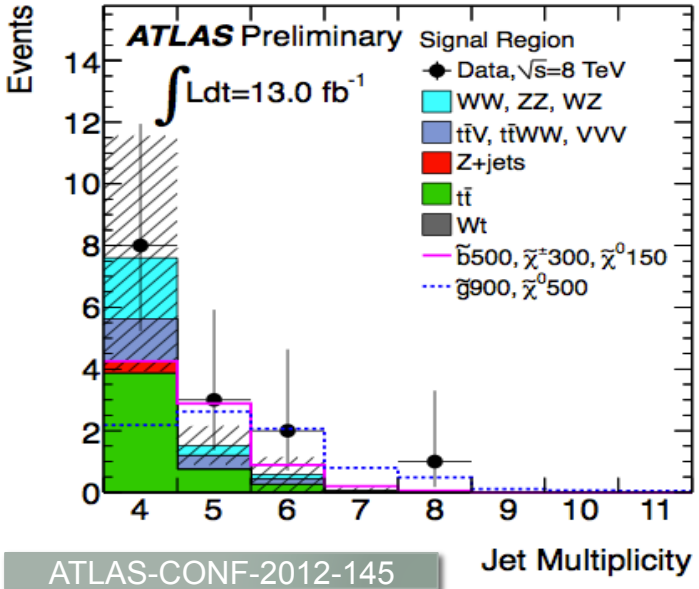
3 Leptons + Jets Results

	3μ	$1e2SS\mu$	$1e2OS\mu$	$2SSe1\mu$	$2OSe1\mu$	$3e$	3ℓ
Z+jets and $Z+b\bar{b}$+jets	-	-	-	-	-	$0.4^{+0.4}_{-0.4}$	$0.4^{+0.4}_{-0.4}$
$t\bar{t}$ and Wt	0.7 ± 0.8	0.5 ± 0.5	$1.5^{+0.9}_{-0.8}$	$0.9^{+1.0}_{-0.9}$	$1.0^{+0.9}_{-0.8}$	$0.2^{+0.4}_{-0.2}$	$4.9^{+2.6}_{-2.0}$
WW, WZ, and ZZ	$0.7^{+0.4}_{-0.3}$	-	$0.8^{+0.3}_{-0.5}$	-	$0.3^{+0.3}_{-0.2}$	0.6 ± 0.6	$2.4^{+1.3}_{-1.2}$
$t\bar{t}+W$ and $t\bar{t}+Z$, and VVV	0.3 ± 0.2	0.2 ± 0.2	0.6 ± 0.5	0.3 ± 0.2	0.4 ± 0.3	0.2 ± 0.1	2.0 ± 1.0
Total SM	1.8 ± 1.0	0.8 ± 0.5	2.9 ± 1.2	$1.2^{+1.2}_{-1.0}$	$1.7^{+1.1}_{-1.0}$	$1.4^{+0.9}_{-0.8}$	$9.7^{+3.8}_{-3.4}$
Signal1	$1.3^{+0.4}_{-0.5}$	$1.2^{+0.3}_{-0.4}$	$2.2^{+0.6}_{-0.7}$	$1.2^{+0.3}_{-0.4}$	$2.2^{+0.6}_{-0.8}$	$0.7^{+0.2}_{-0.3}$	$8.9^{+2.2}_{-3.0}$
Signal2	0.9 ± 0.3	$1.2^{+0.3}_{-0.4}$	$2.0^{+0.5}_{-0.6}$	$1.4^{+0.4}_{-0.5}$	2.0 ± 0.6	$0.8^{+0.3}_{-0.3}$	$8.3^{+1.9}_{-2.3}$
Data	1	2	3	1	4	3	14





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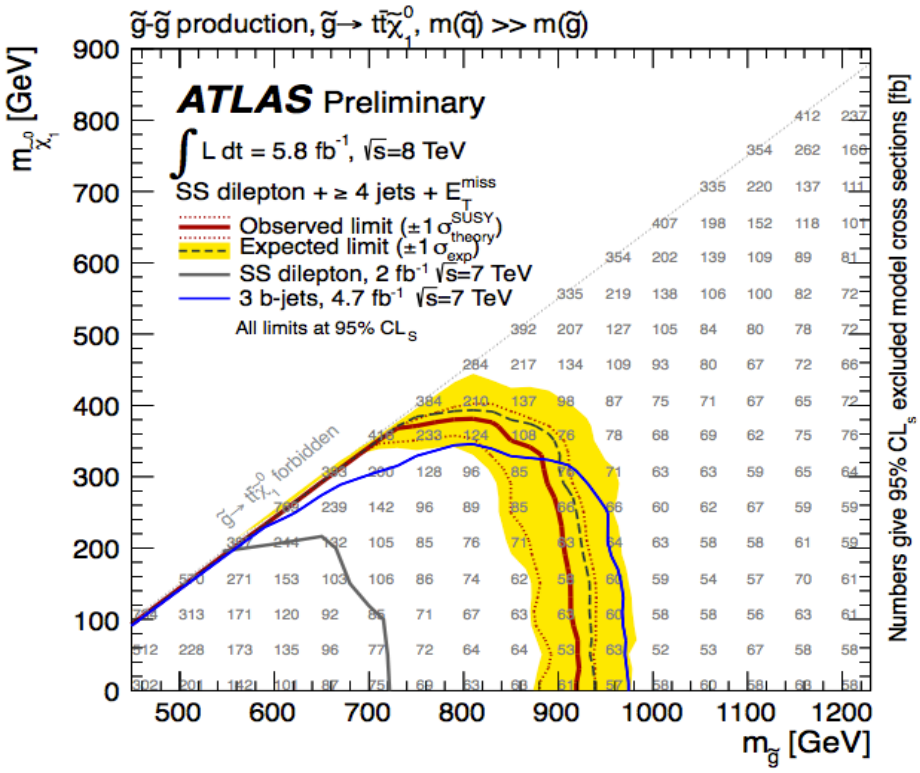
Gluino Mediated Stop Limits

2 SS L + jets + MET



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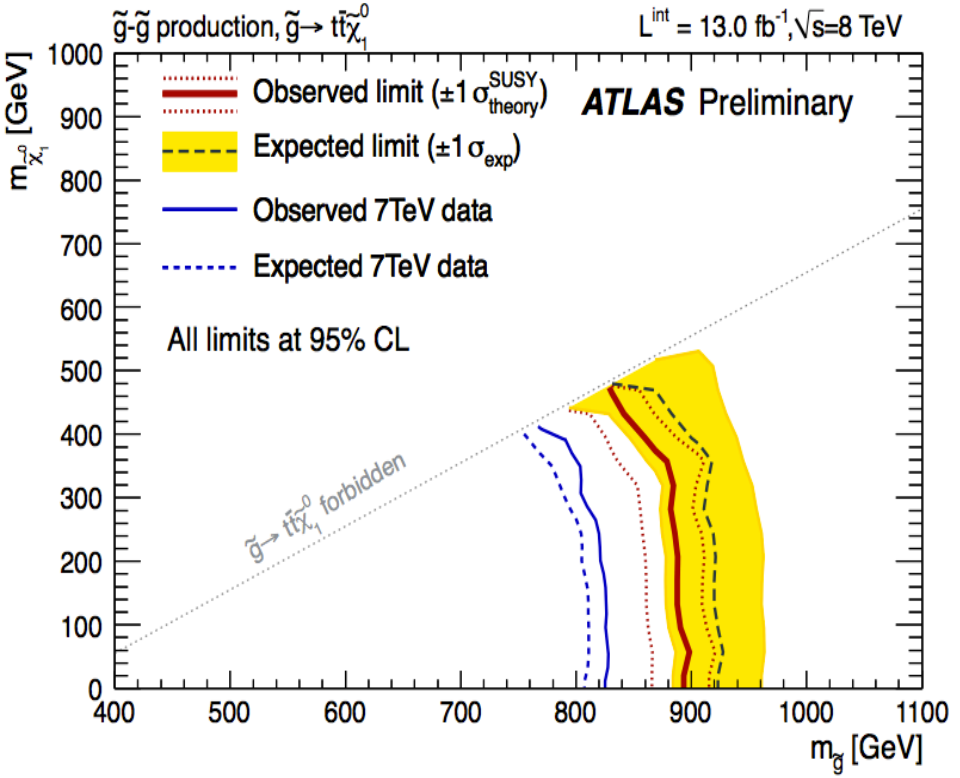
3L + jets + MET



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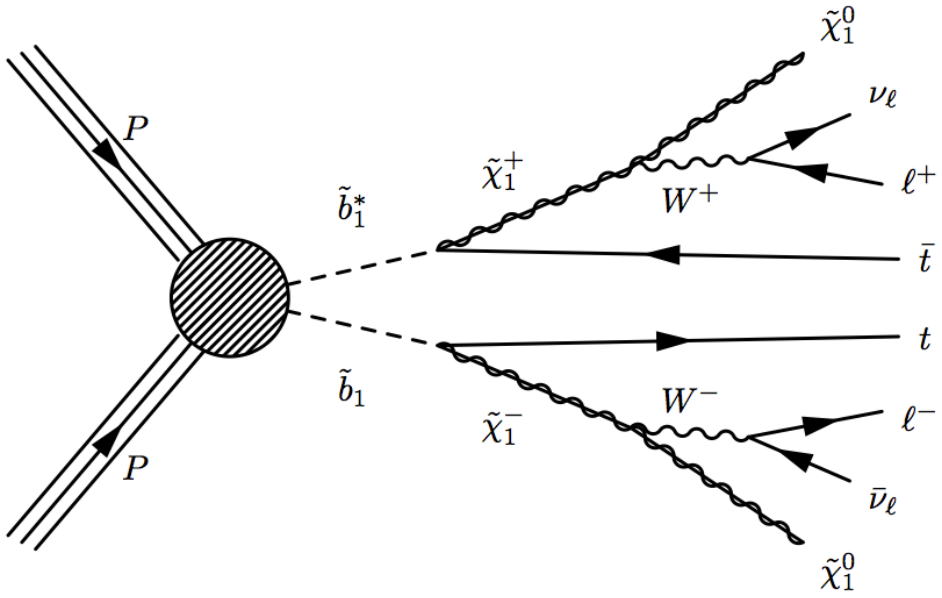
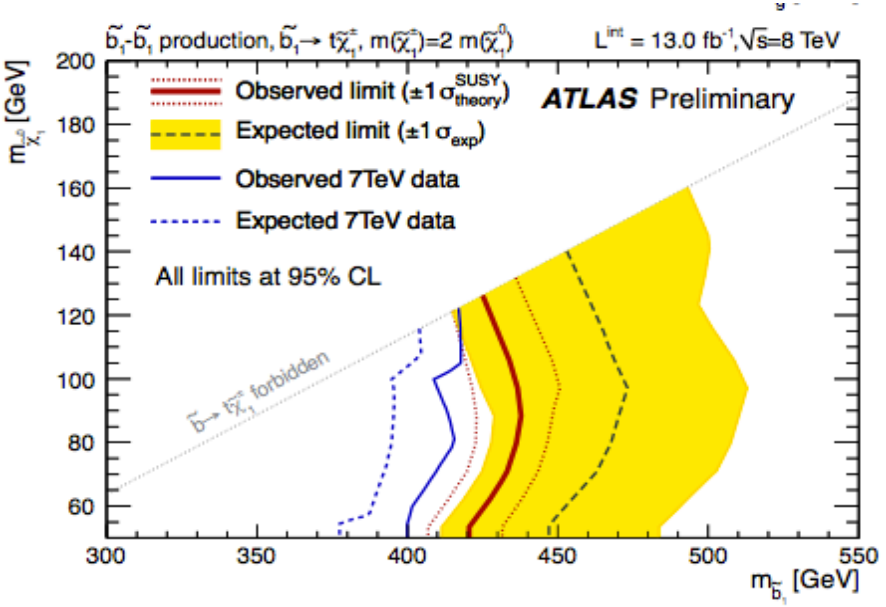
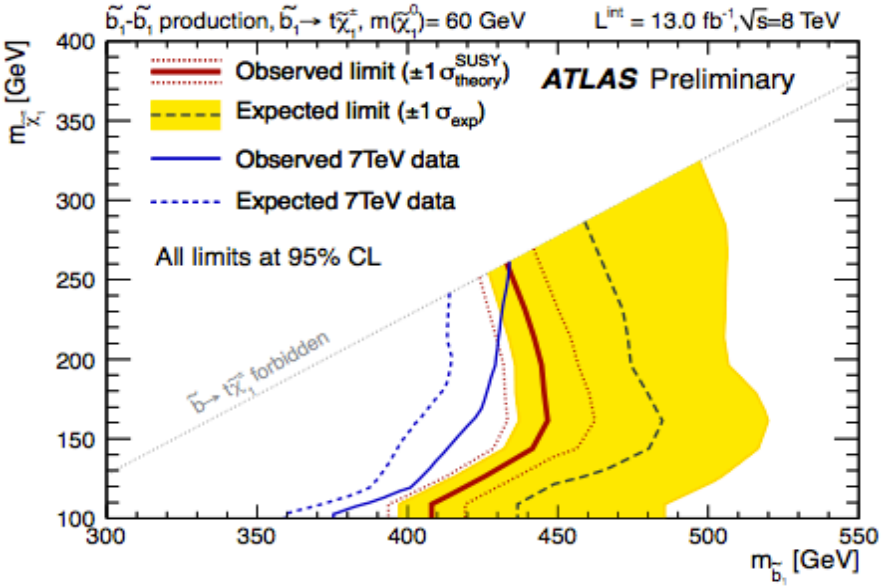
Direct Sbottom Search

In the 3L + jets final state

- Sbottom → top + C1
  - C1 into W + N1
  - With $m_{C1} = 2 \times m_{N1}$
  - With $m_{N1} = 60$ GeV







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EW 2 Leptons Search

- Four SR optimized for direct slepton production and different Chargino/ Neutralino decay modes.
- 7 TeV, 4.7/fb

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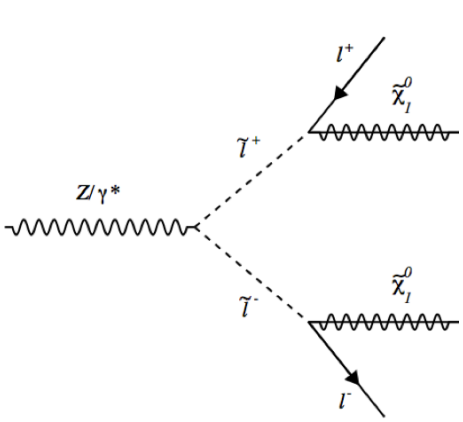
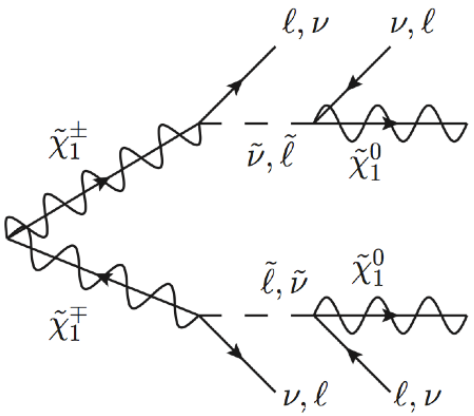
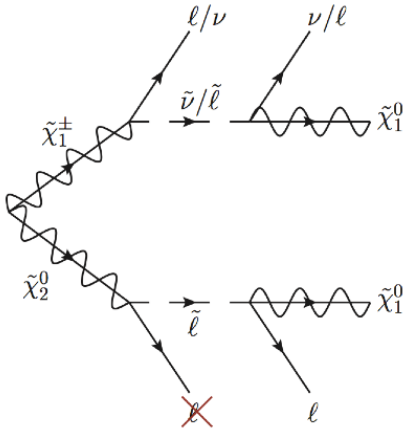
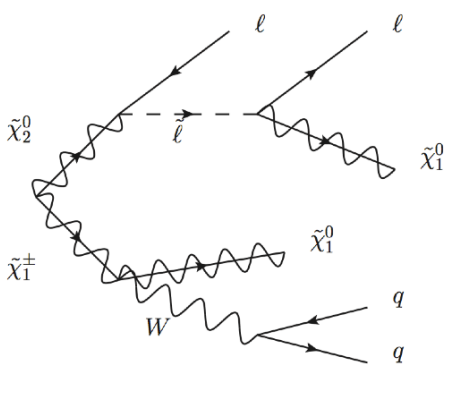
SR-	m_{T2}	OSjveto	SSjveto	2jets
charge	OS	OS	SS	OS
flavour	any	any		SF
m_{ll}	Z-veto	Z-veto	-	Z-veto
signal jets	$= 0$	$= 0$		≥ 2
signal b-jets	-	-		$= 0$
$E_T^{miss,rel.}$	> 40	> 100		> 50
other	$m_{T2} > 90$	-		m_{CT}-veto



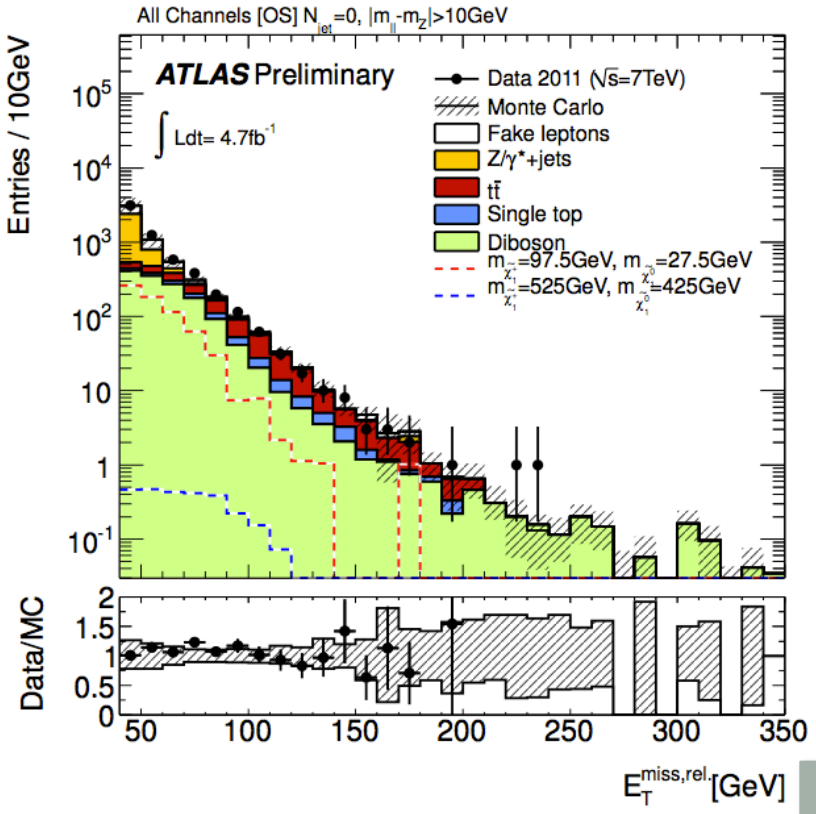


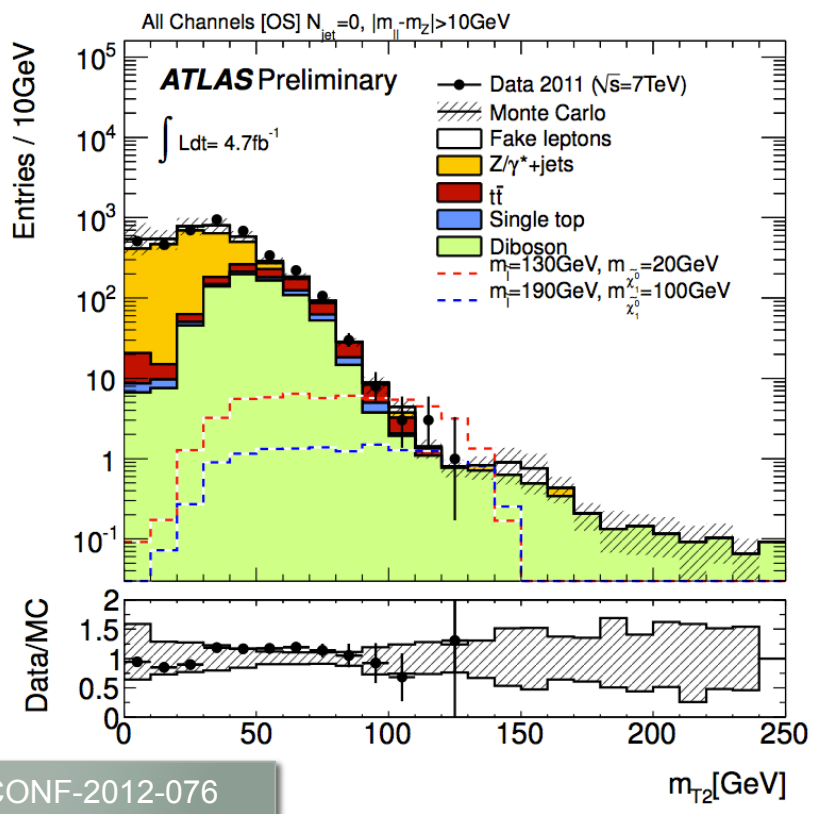




Background Estimation

- **mT2 signal region**
  - tt, Z+j normalized to data in control regions
  - WW from MC simulation
  - reducible background (W+j, and QCD) from loose lepton sample using the loose to tight efficiency





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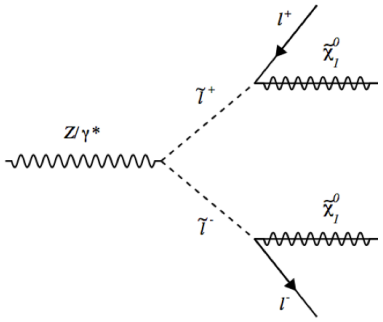
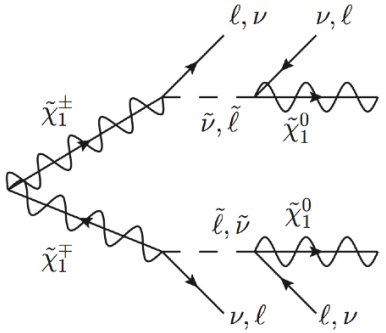
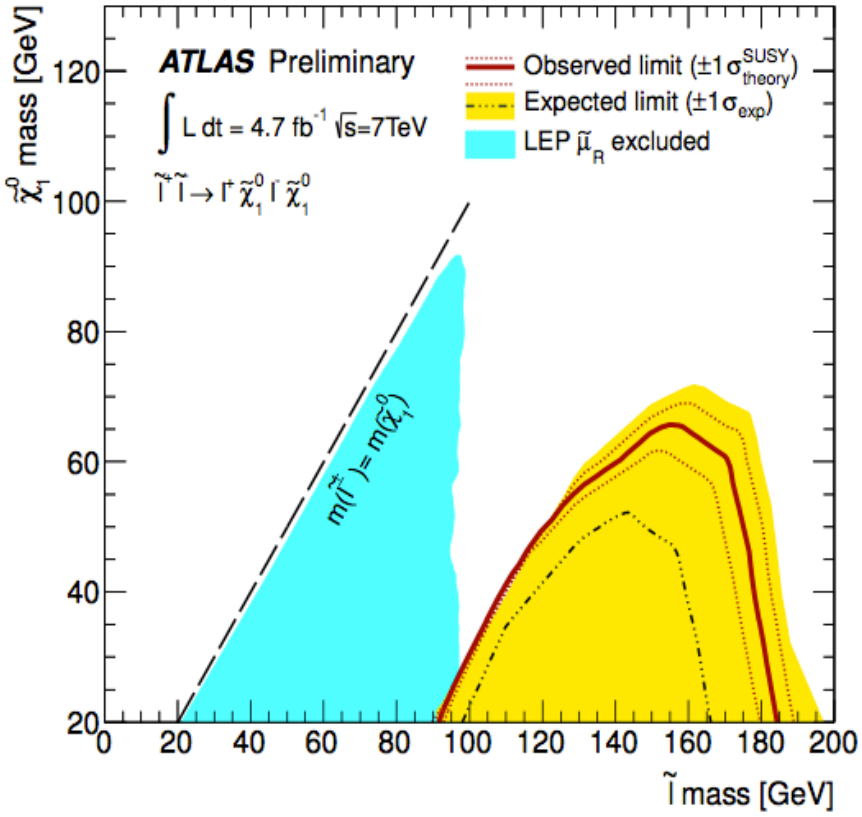
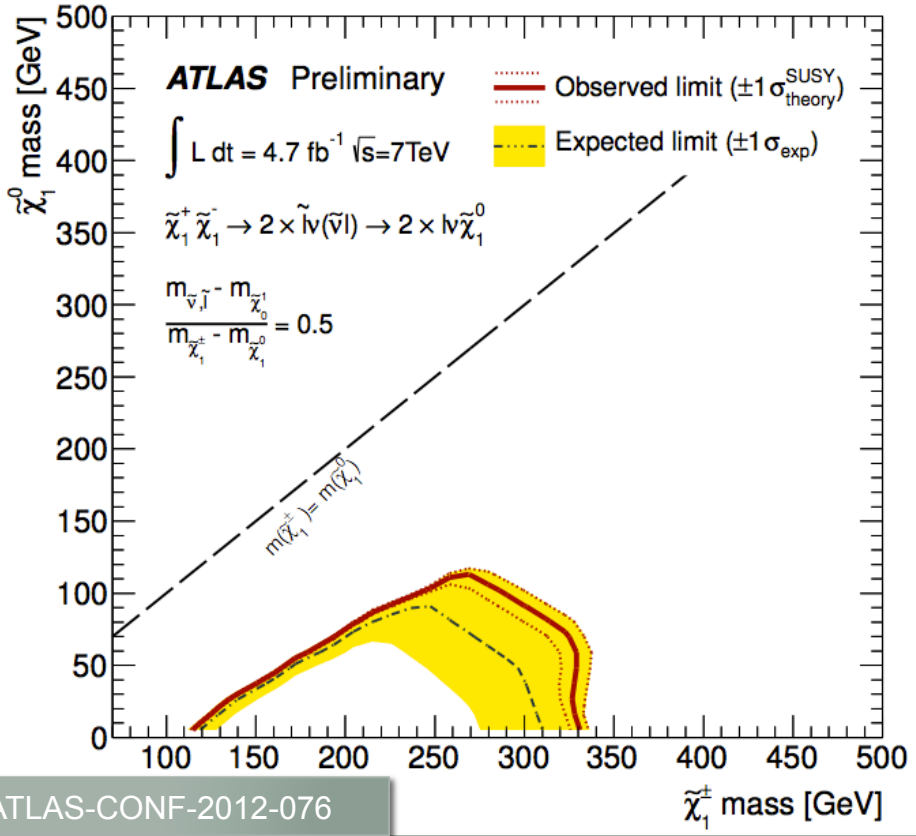
Direct Slepton and Chargino Limits



- **mT2 SF signal region**
- **Direct sleptons within the pMSSM model**
- **Direct Charginos with Simplified Models, Chargino1 and Neutralino1 masses, light sleptons**







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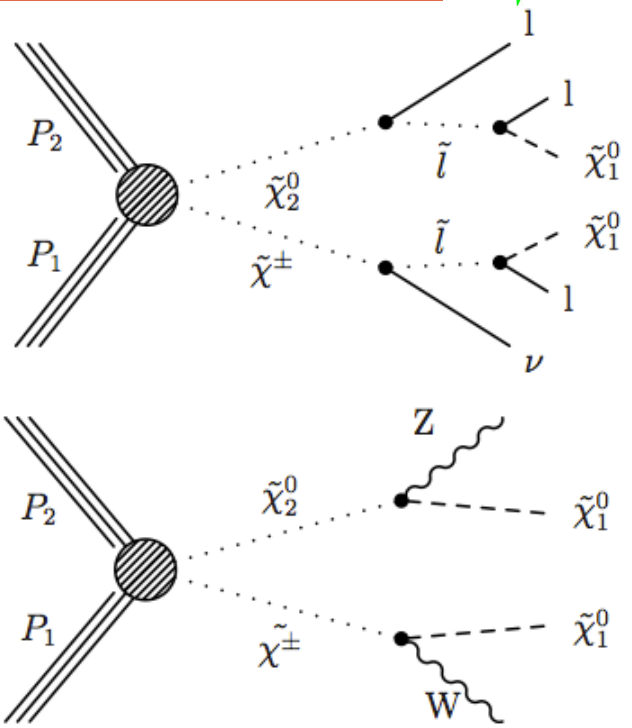
EW 3 Leptons Search

NEW!

- **Targeting C1-N2 direct production**
- **Both decays via intermediate sleptons or gauge bosons**
  - Z-enriched and Z-depleted
- **Targeting models with either small or large mass splitting**
  - moderate or large MET & mT cuts
- **Lepton pT > 10GeV**
- **8 TeV, 13.0/fb, dilepton triggers**



Selection	SR1a	SR1b	SR2
Targeted $\tilde{\chi}_2^0$ decay	$\tilde{l}^{(*)}$ or Z^*		on-shell Z
$\lvert m_{\mathrm{SFOS}} - m_Z \rvert$	> 10 GeV		< 10 GeV
Number of b-jets	0		any
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 75 GeV		> 120 GeV
m_{T}	any	> 110 GeV	> 110 GeV
p_{T} of leptons	> 10 GeV	> 30 GeV	> 10 GeV

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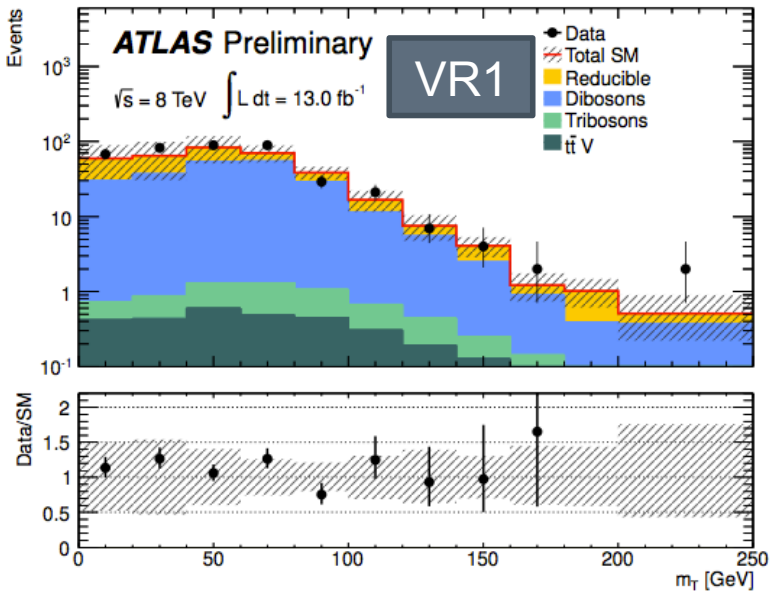
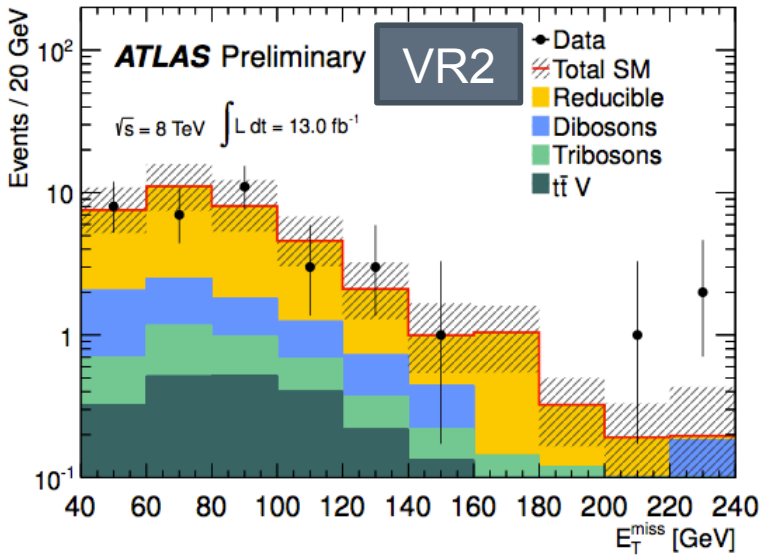
Background Estimation

- **Dominant Irreducible WZ**
  - Normalized in dedicated region to data via simultaneous fit accounting for potential signal contamination in control region
- **Remaining Irreducible from MC simulation**
- **Fake leptons with data-driven matrix method**
  - Using loose lepton data sample plus fake rates and efficiencies to solve system of equations

Selection	VR1	VR2	VR3
$\lvert m_{\mathrm{SFOS}} - m_Z \rvert$	> 10 GeV	SFOS veto	< 10 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$ min	30 GeV	50 GeV	30 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$ max	75 GeV	–	50 GeV
$t\bar{t}$+V	3.1 ± 1.2	2.5 ± 0.8	3.9 ± 1.9
triboson	4 ± 4	2.1 ± 2.1	0.7 ± 0.7
ZZ	64 ± 17	0.41 ± 0.23	49 ± 4
WZ (normalised)	161 ± 19	4.5 ± 0.7	385 ± 50
Reducible Bkg.	121 ± 50	27 ± 13	185 ± 70
Total Bkg.	353 ± 60	36 ± 14	624 ± 90
Data	391	36	692





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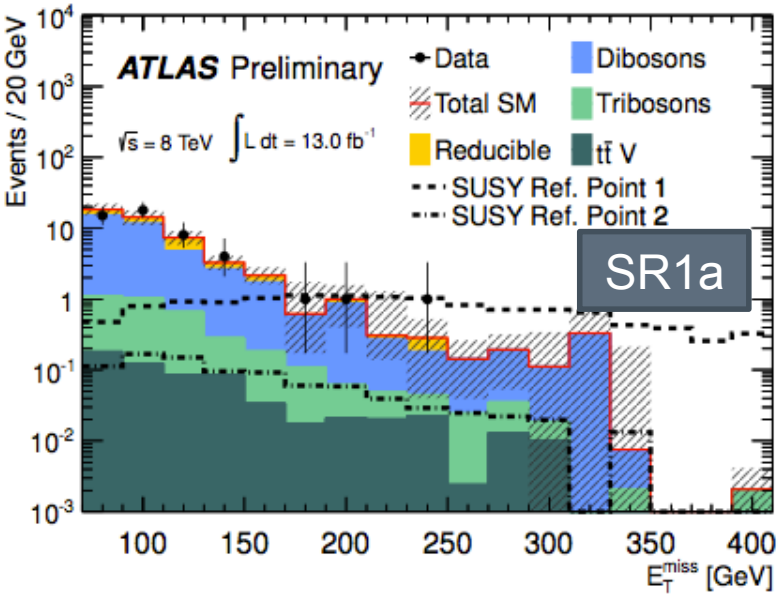
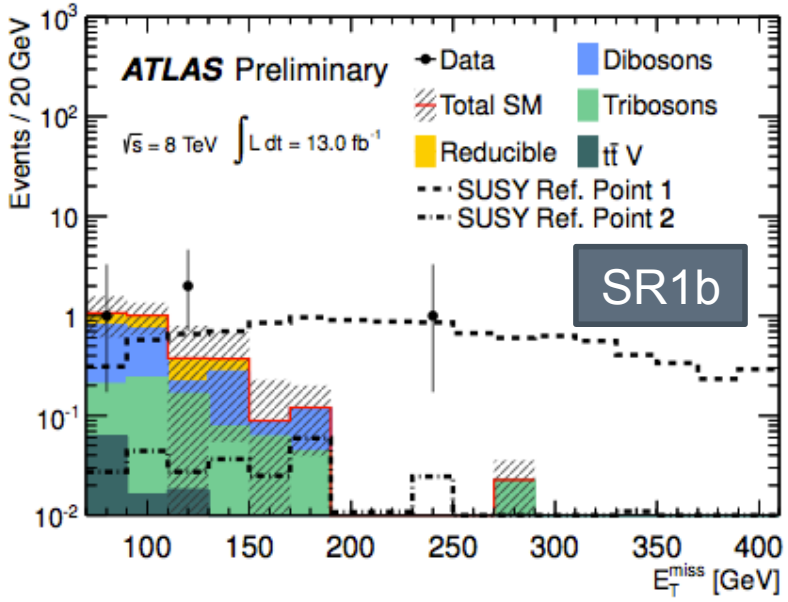
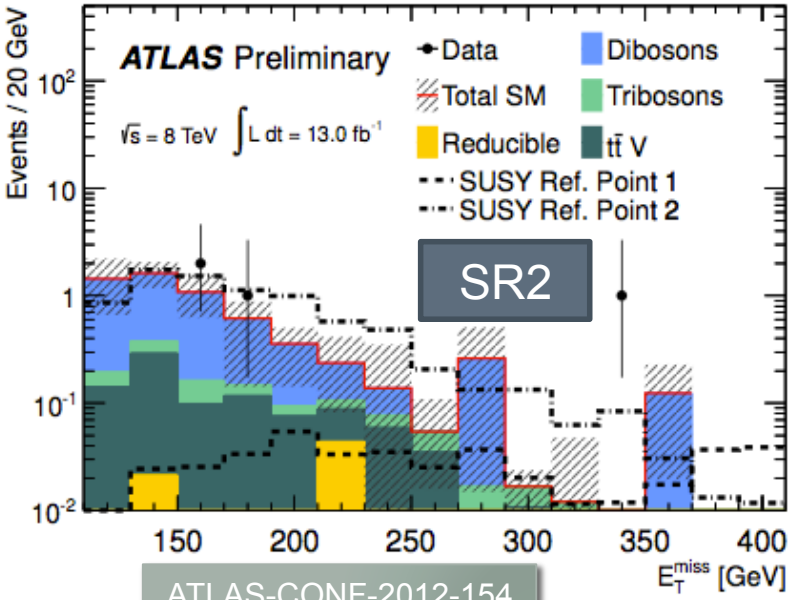
3 Leptons Results

Selection	SR1a	SR1b	SR2
$t\bar{t}$+V	0.62 ± 0.28	0.13 ± 0.07	0.9 ± 0.4
triboson	3.0 ± 3.0	0.7 ± 0.7	0.34 ± 0.34
ZZ	2.0 ± 0.7	0.30 ± 0.23	0.10 ± 0.10
WZ (normalised)	34 ± 4	1.2 ± 0.6	4.7 ± 0.8
Reducible Bkg.	10 ± 6	0.8 ± 0.4	$0.012^{+1.6}_{-0.012}$
Total Bkg.	50 ± 8	3.1 ± 1.0	$6.1^{+2.0}_{-1.2}$
Data	48	4	4
SUSY Ref. Point 1	13.9 ± 1.0	11.4 ± 0.9	0.5 ± 0.1
SUSY Ref. Point 2	0.9 ± 0.1	0.3 ± 0.1	8.0 ± 0.6
Visible σ (exp)	< 1.5 fb	< 0.4 fb	< 0.5 fb
Visible σ (obs)	< 1.3 fb	< 0.5 fb	< 0.4 fb







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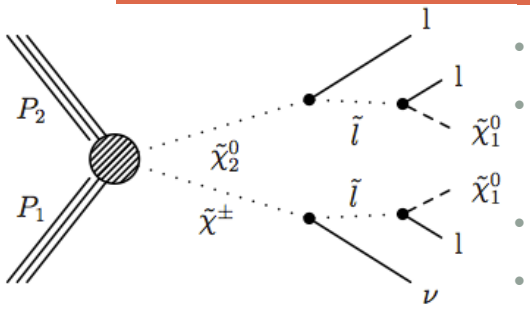
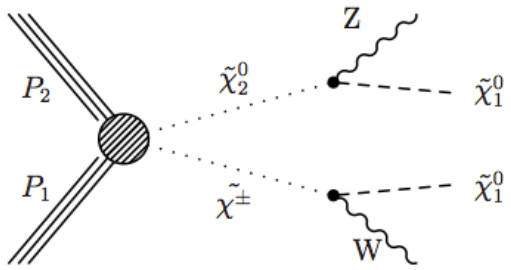
C1-N2 Simplified Models Limits



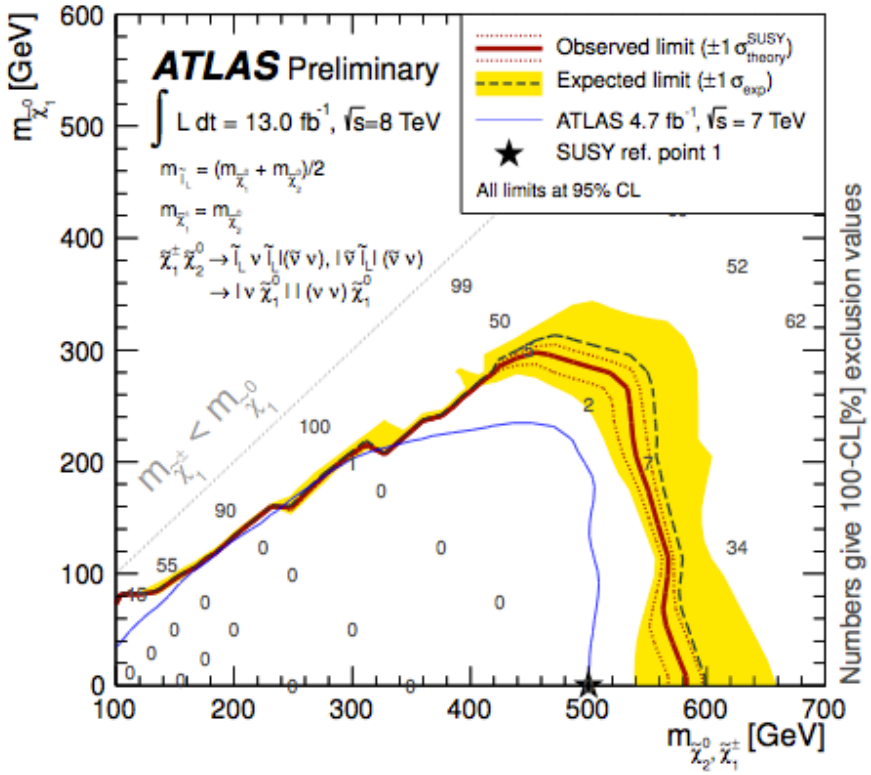
$m_{\tilde{\nu}} = m_{\tilde{\ell}_L} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_1^\pm})/2$

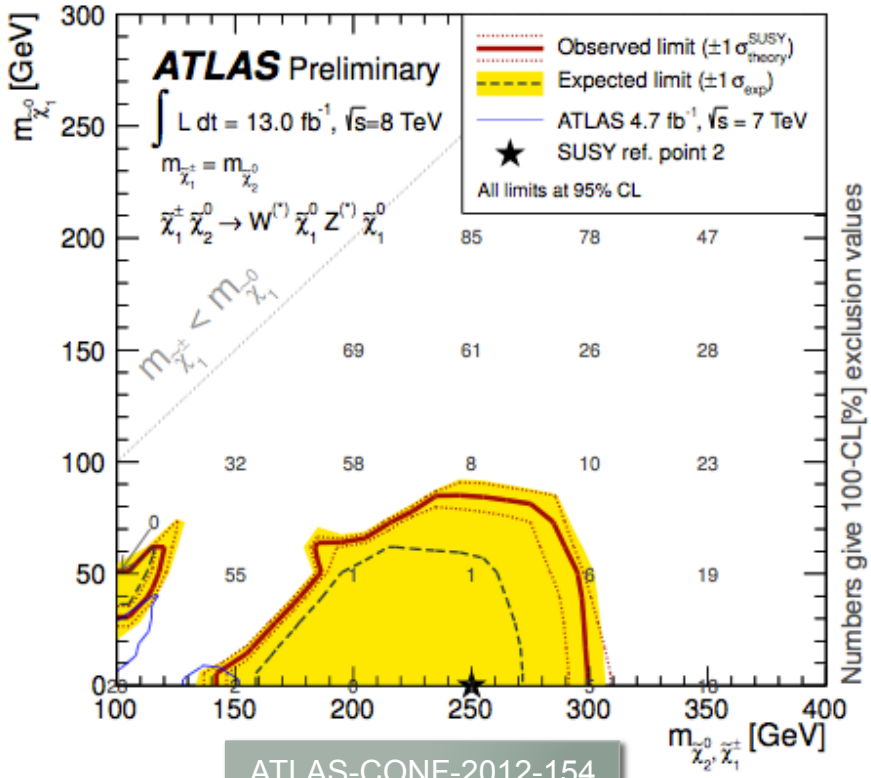
$\mathrm{BR}(\tilde{e}_L, \tilde{\mu}_L, \tilde{\tau}_L, \tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau) = 1/6$

- **Simplified models**
- Mass degenerate, wino like Chargino1 and Neutralino2
- Neutralino1, bino like
- **Free parameters: Chargino and neutralino masses**
- Other particle masses are set to high values



On-shell Z, off-shell Z
No Higgs decays





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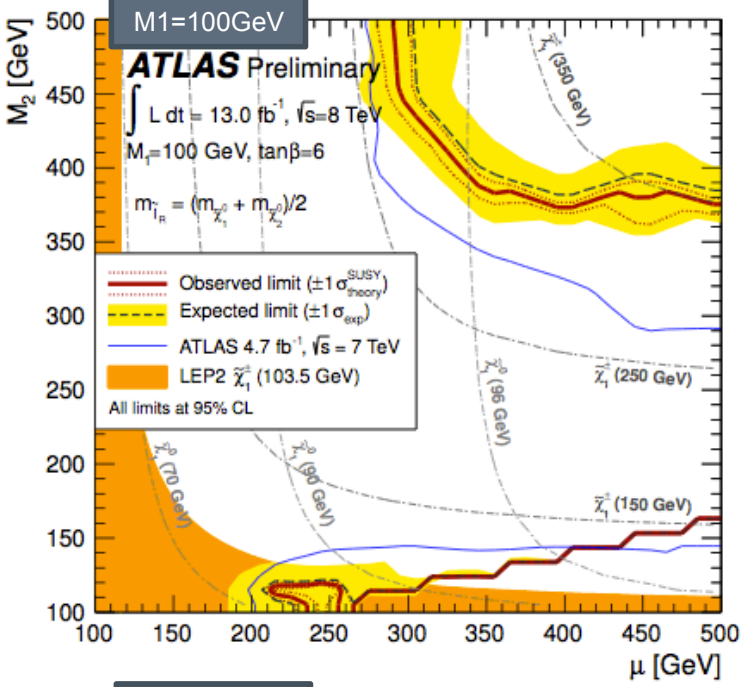
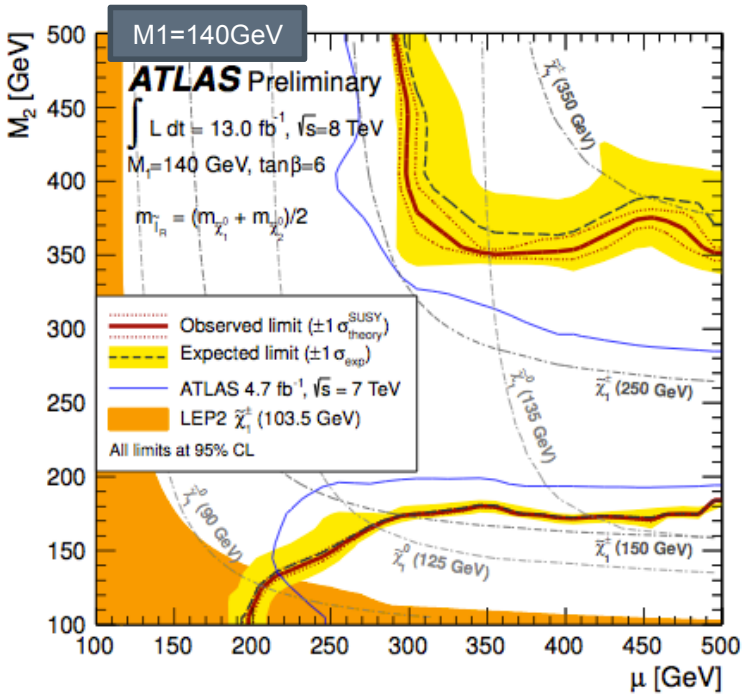
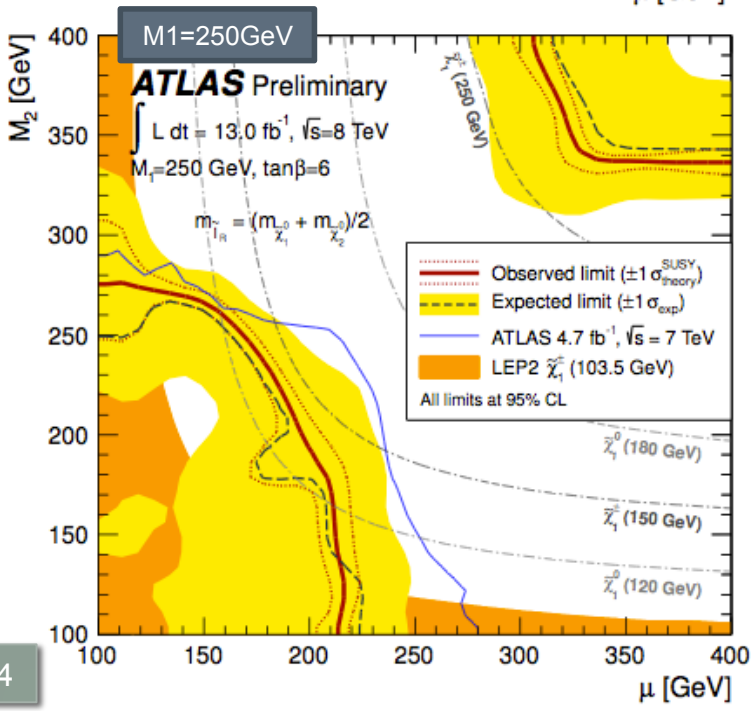
3L pMSSM Limits

- **pMSSM**: **number of free parameters reduced to 19 (from 105) by the following assumptions**
  - CP conservation, minimal flavour violation, negligible trilinear couplings for 1st and 2nd generation, degenerate 1st and 2nd generation sfermion masses
- Heavy squarks, gluinos and left-handed sleptons, tanβ=6, m_A=500GeV $m_{\tilde{\ell}_R} = (m_{\tilde{\chi}_2^0} + m_{\tilde{\chi}_1^0})/2$
- Right-handed slepton masses
- **Free parameters remain: M1, M2, μ**





- Blue lines 2L+3L ATLAS 7TeV



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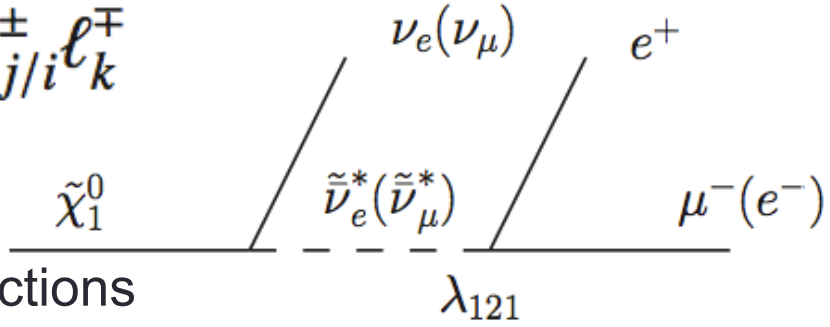
RPV 4 Leptons Search

NEW!

$W_{RPV} = \lambda_{ijk} L_i L_j \bar{E}_k$ $\quad \tilde{\chi}_1^0 \to \nu_{i/j} \ell^{\pm}_{j/i} \ell^{\mp}_k$

λ_{121} or λ_{122}



- Sparticles **pair-produced** via gauge interactions
- Decay to LSPs via gauge interactions
- LSPs decay **promptly** to 2 leptons and neutrino via RPV
- 4 Lepton (electron, muon) final state
- **Moderate MET and high Meff signature**
- 8 TeV, 13.0/fb
- Lepton pT > 10GeV
- Dilepton triggers

$$m_{\text{eff}} = E_{\text{T}}^{\text{miss}} + \sum_{\mu} p_{\text{T}}^{\mu} + \sum_{e} E_{\text{T}}^{e} + \sum_{j} E_{\text{T}}^{j}$$

Selection	SR1	SR2
Number of leptons	≥ 4	≥ 4
SFOS pair	–	–
Z-candidate	Z-veto	Z-veto
$E_{\text{T}}^{\text{miss}}$/GeV	> 50	–
m_{eff}/GeV	–	> 300

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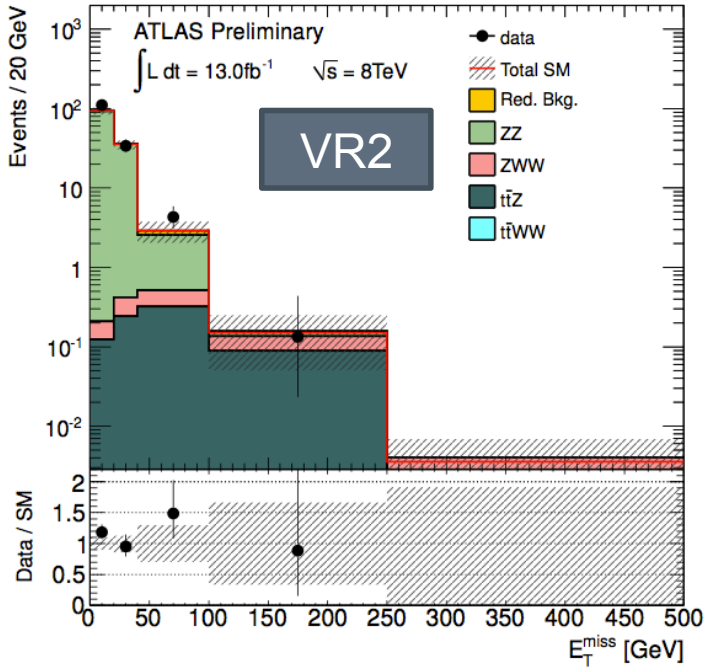
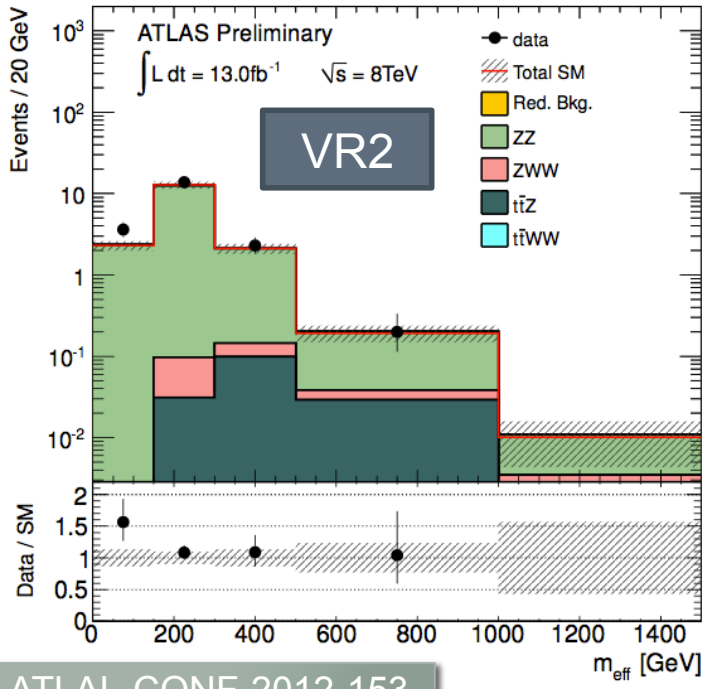
Background Estimation

- **MC simulation for irreducible 4 real leptons**
- **Data-driven for processes with 1-2 fake leptons**
  - Weight non-isolated events with Fake Ratio

Selection	VR1	VR2	VR3
Number of leptons	3	≥ 4	≥ 4
SFOS pair	SFOS-veto	SFOS requirement	–
Z-candidate	Z-veto	Z requirement	Z-veto
E_T^{miss}/GeV	> 50	–	< 50
m_{eff}/GeV	–	–	< 300
ZZ	$0.43^{+0.32}_{-0.32}$	135^{+13}_{-13}	$3.9^{+1.7}_{-1.7}$
ZWW	$0.29^{+0.29}_{-0.29}$	$1.2^{+1.2}_{-1.2}$	$0.018^{+0.018}_{-0.018}$
$t\bar{t}Z$	$0.44^{+0.23}_{-0.23}$	$2.0^{+1.0}_{-1.0}$	$0.011^{+0.011}_{-0.011}$
$t\bar{t}WW$	$0.057^{+0.031}_{-0.031}$	$(2.5^{+2.3}_{-2.3})\times10^{-3}$	$(4^{+1}_{-4})\times10^{-3}$
WZ (†)	$4.4^{+0.9}_{-0.8}$	–	–
$t\bar{t}W$ (†)	$2.1^{+0.7}_{-0.7}$	–	–
WWW (†)	$1.9^{+1.9}_{-1.9}$	–	–
Irreducible Bkg.	10^{+4}_{-4}	138^{+15}_{-15}	$3.9^{+1.7}_{-1.7}$
Reducible Bkg.	19^{+46}_{-6}	$1.2^{+1.5}_{-1.2}$	$0.0^{+0.40}_{-0.0}$
Total Bkg.	29^{+46}_{-7}	139^{+14}_{-14}	$3.9^{+1.5}_{-1.5}$
Data	35	159	0





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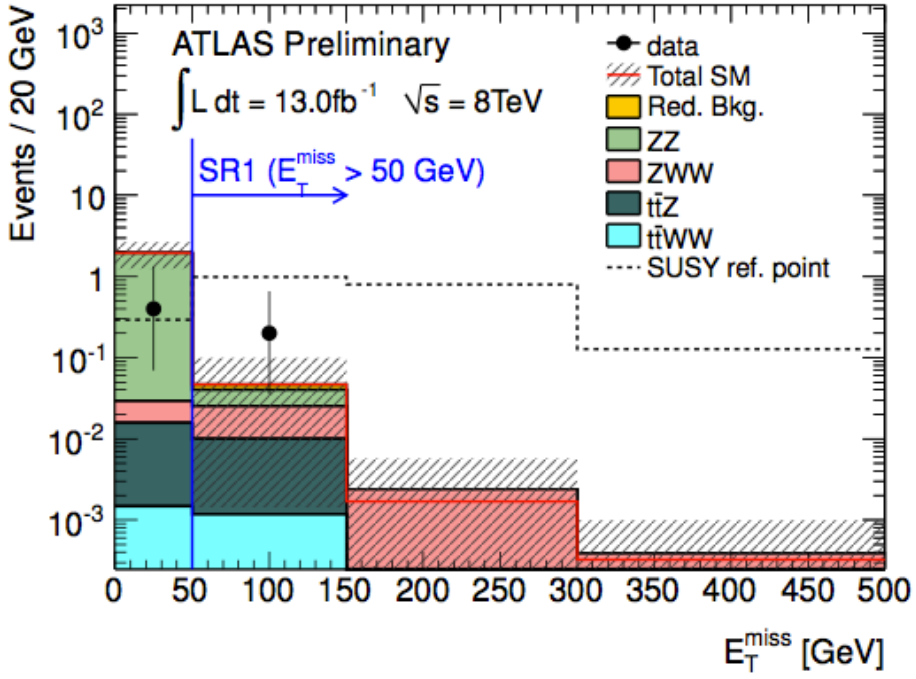
4 Leptons Results

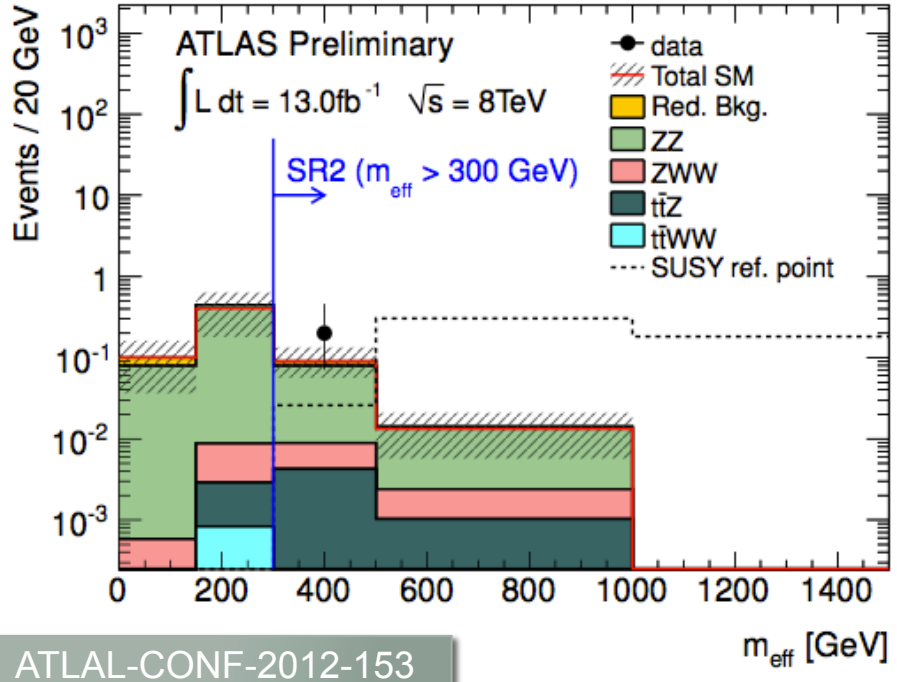
Selection	SR1	SR2
ZZ	$0.07^{+0.22}_{-0.07}$	$1.0^{+0.4}_{-0.4}$
ZWW	$0.10^{+0.10}_{-0.10}$	$0.09^{+0.09}_{-0.09}$
$t\bar{t}Z$	$0.045^{+0.028}_{-0.028}$	$0.06^{+0.04}_{-0.04}$
$t\bar{t}WW$	$(6^{+6}_{-5})\times10^{-3}$	$(3.3^{+4.8}_{-3.3})\times10^{-3}$
Irreducible Bkg.	$0.22^{+0.27}_{-0.21}$	$1.1^{+0.5}_{-0.4}$
Reducible Bkg.	$0.028^{+0.107}_{-0.028}$	$0.10^{+0.14}_{-0.10}$
Total Bkg.	$0.25^{+0.29}_{-0.25}$	$1.2^{+0.5}_{-0.4}$
Data	1	2

Selection	SR1	SR2
p_0-value (σ)	0.037 (1.8)	0.16 (1.0)
σ_{vis} (exp)	< 0.28 fb	< 0.28 fb
σ_{vis} (obs)	< 0.34 fb	< 0.38 fb

- No significant excess found, set limits

$\sigma_{vis} = \sigma \times \text{acceptance} \times \text{efficiency}$





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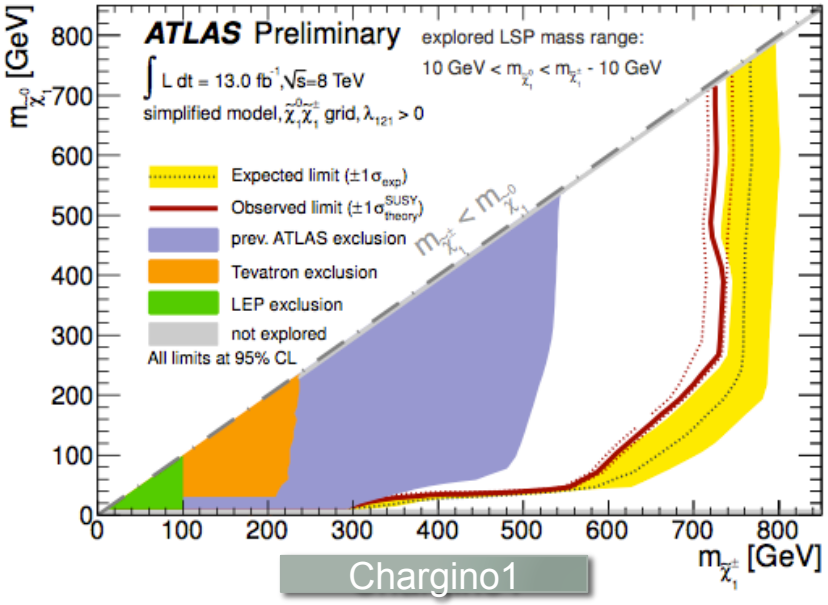
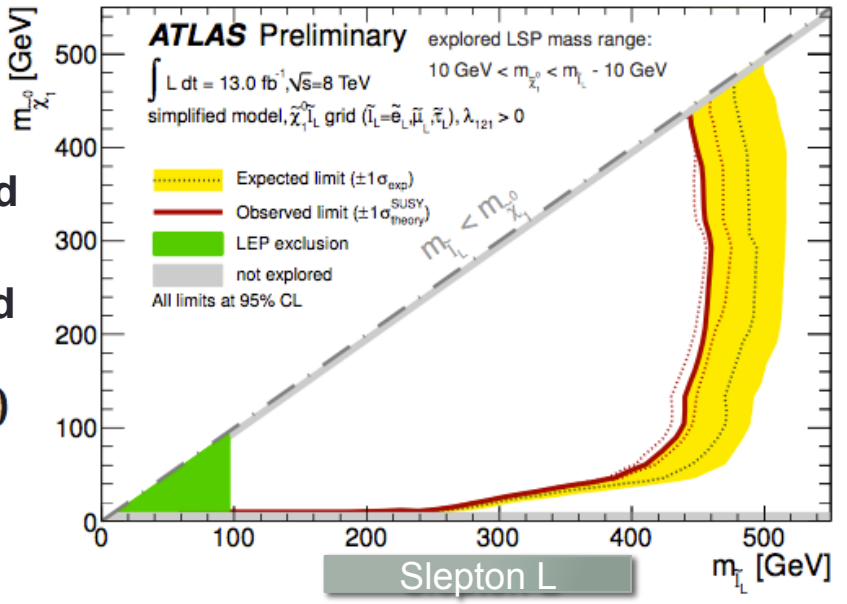
RPV NLSP-N1 Simplified Models

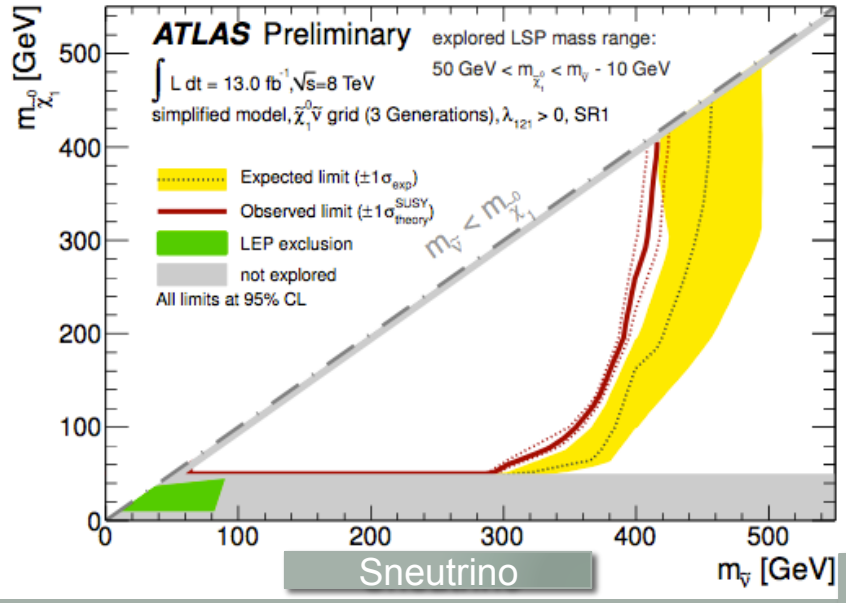


Chargino1

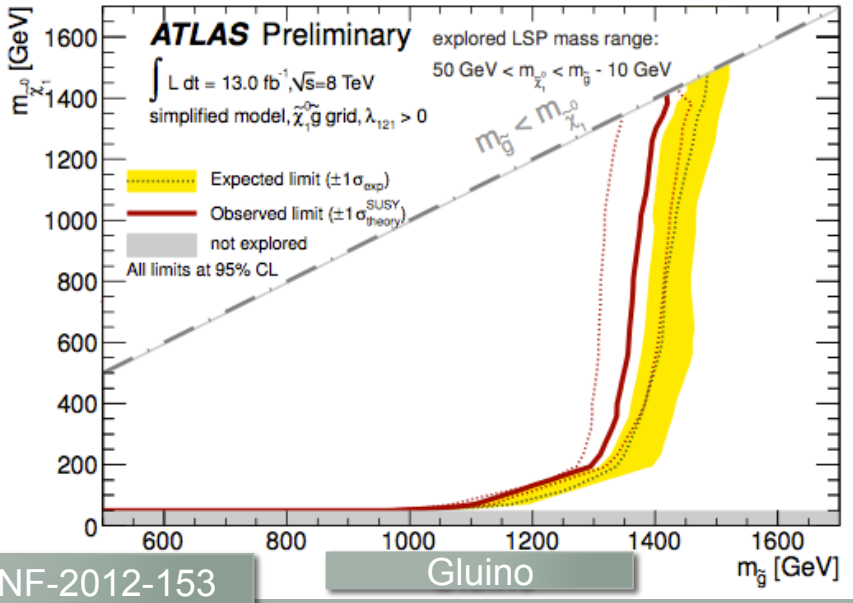
- **Simplified Models**
- **NLSP and LSP only** $\lambda_{121} > 0$
- **Similar limits for** $\lambda_{122} > 0$



Slepton L



Sneutrino



Gluino

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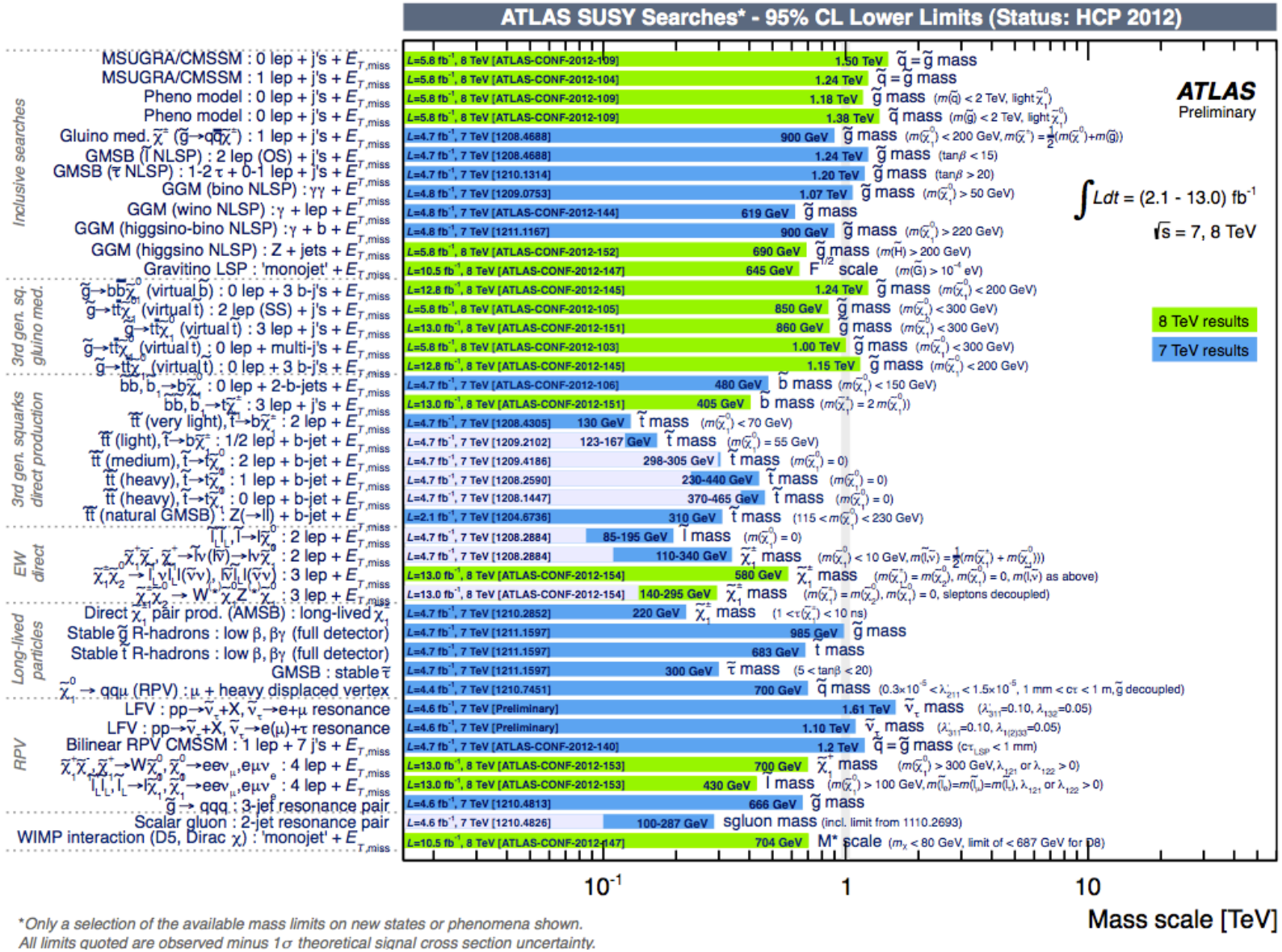
ATLAS SUSY Grand Summary

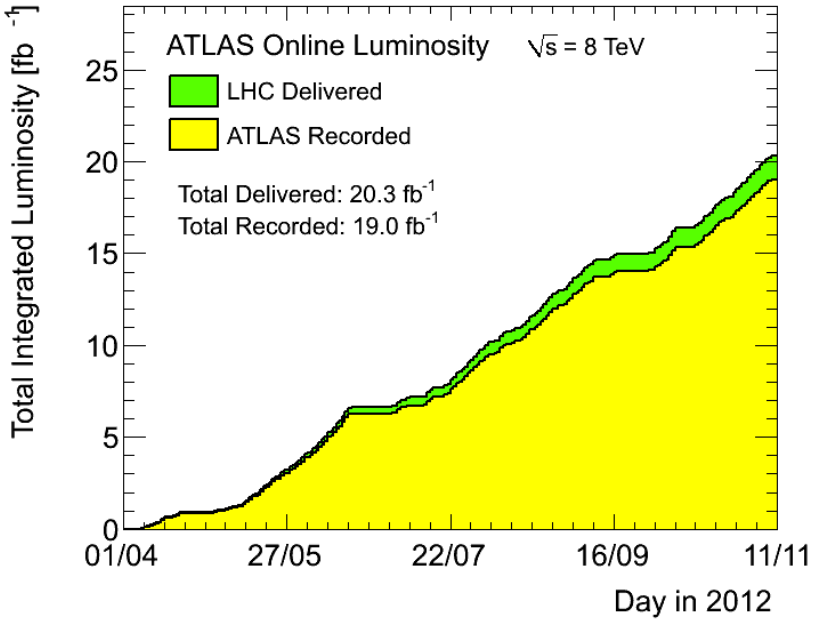


*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Summary and Outlook

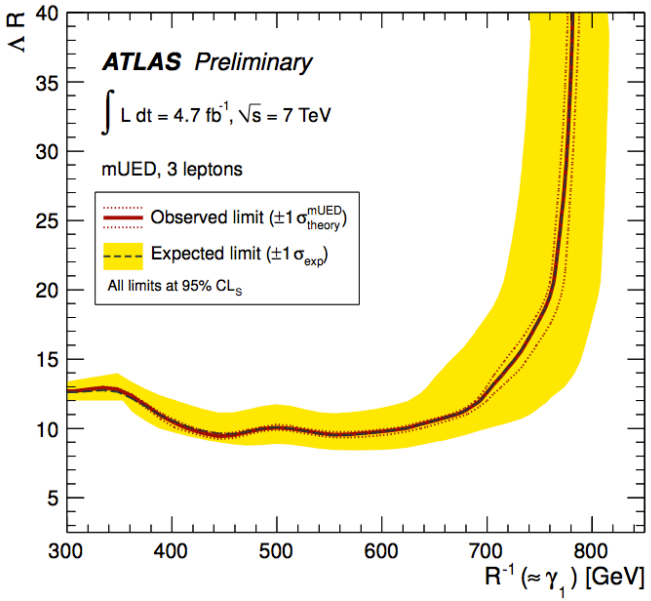
- **Excellent performance of LHC and ATLAS in 2012**
- **Broad spectrum of SUSY leptonic searches, focusing on Natural SUSY**
- **Setting stringent limits in the SUSY parameter space**
  - C1N2: w sleptons ~580GeV, wo sleptons 150-300GeV
  - RPV: Winos ~710GeV, sleptonsL~450GeV, sneutrinos~410GeV, gluinos~1300GeV
- More data already available from the 8 TeV run, expected ~25/fb by end of the year
- Optimize search strategy
  - Extend to higher masses
  - Focus on processes preferred by naturalness
  - Explore further final states

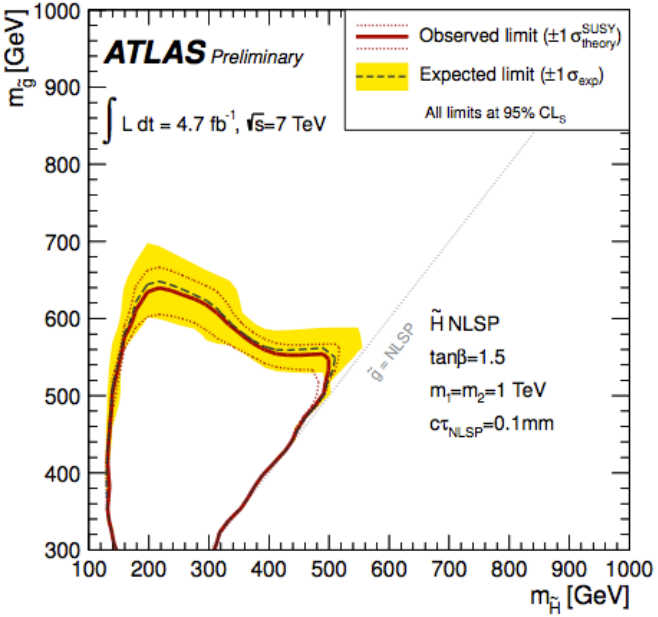


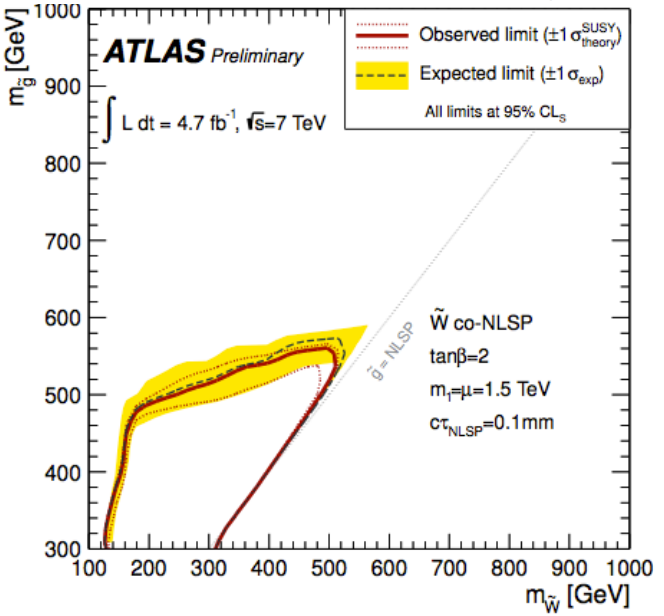
Additional Interpretations, 3L 7 TeV

- **mUED**
  - 1 extra dimension, S^1/Z_2 orbifold of size R
  - Λ cut-off scale of the effective theory
  - KK-photon is the lightest stable KK-particle
- **GGM**
  - Strong production through gluinos
  - LSP ~massless Gravitino
  - NLPS Higgsino (left),
  - Wino-like Chargino1, Neutralino1 (right)

$$\tilde{H} \rightarrow \gamma\tilde{G}$$
$$\tilde{H} \rightarrow Z\tilde{G}$$
$$\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$$
$$\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$$
$$\tilde{\chi}_1^{\pm} \rightarrow W^{\pm}\tilde{G}$$







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