Searches for Electroweak Production of Neutralinos, Charginos, and Sleptons with the ATLAS Detector

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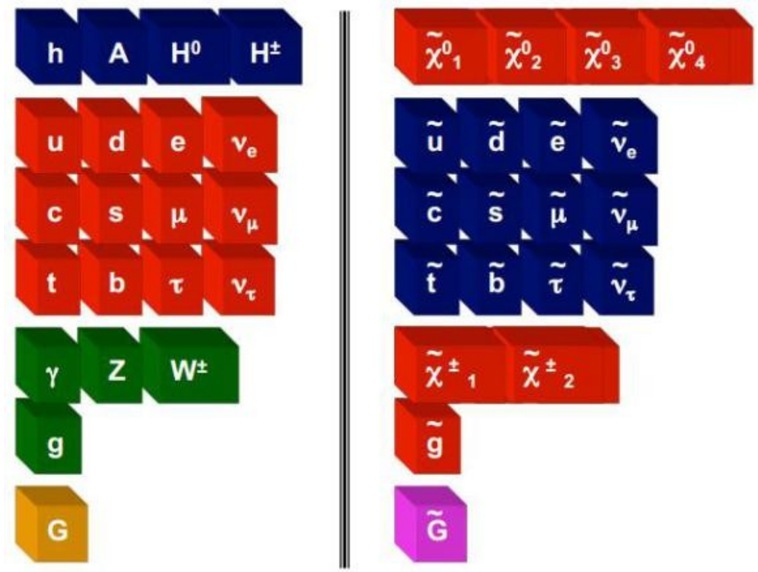
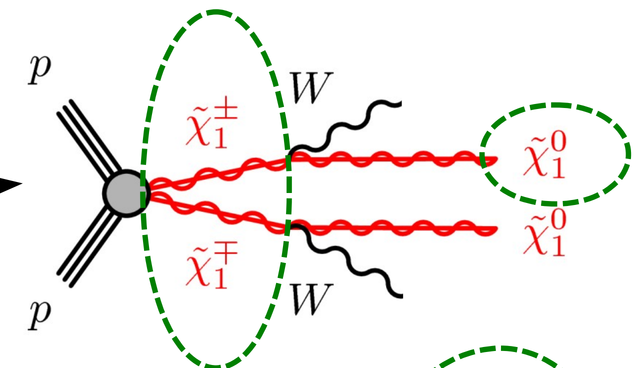
Supersymmetry (SUSY)

- Standard Model superpartners
- Half-unit spin difference; theoretically attractive
- Gaugino-higgsino mixing mass eigenstates:
  - Charginos (C_i, $\tilde{\chi}_i^{\pm}$)
  - Neutralinos (N_j, $\tilde{\chi}_j^0$)

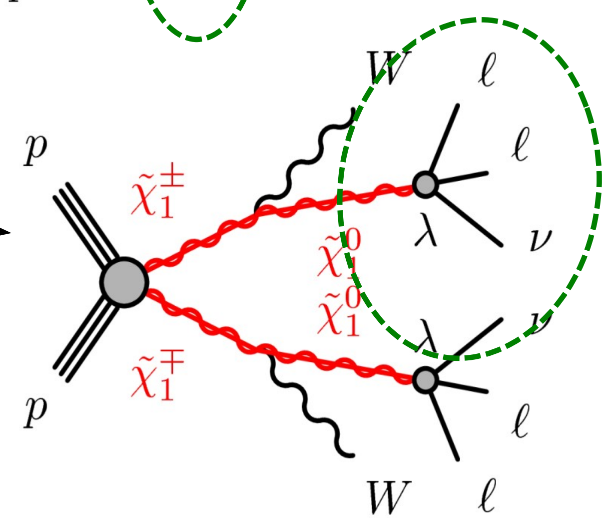


- *R*-parity: $P_R = (-1)^{3(B-L)+2S}$

- Conservation (RPC):
  - Pair-produced sparticles
  - Stable LSP; final state MET

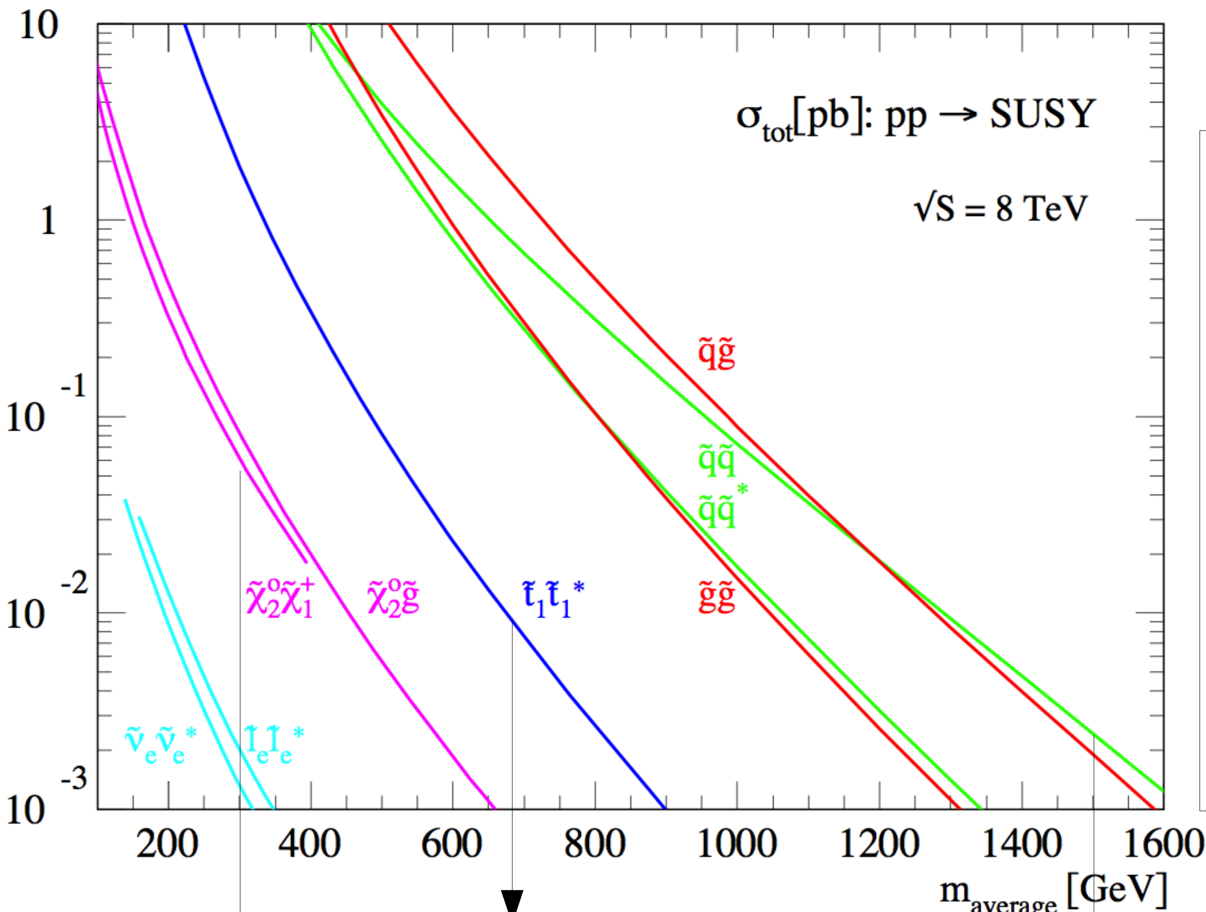


- Violation (RPV):
  - Unstable LSP; multi-object events



Electroweak (EWK) SUSY: Motivation

- Strong SUSY favored for early LHC discovery (larger σ)
- ATLAS/CMS $m_{\tilde{q},\tilde{g}}$ limits now quite stringent
- Naturalness $\Longrightarrow$ light higgsinos $\Longrightarrow$ interest growing in weak SUSY
- EWK production (direct C_i, N_j, and/or sleptons) might be dominant at LHC
- Characteristic multi-lepton signatures with low hadronic activity: low SM BG



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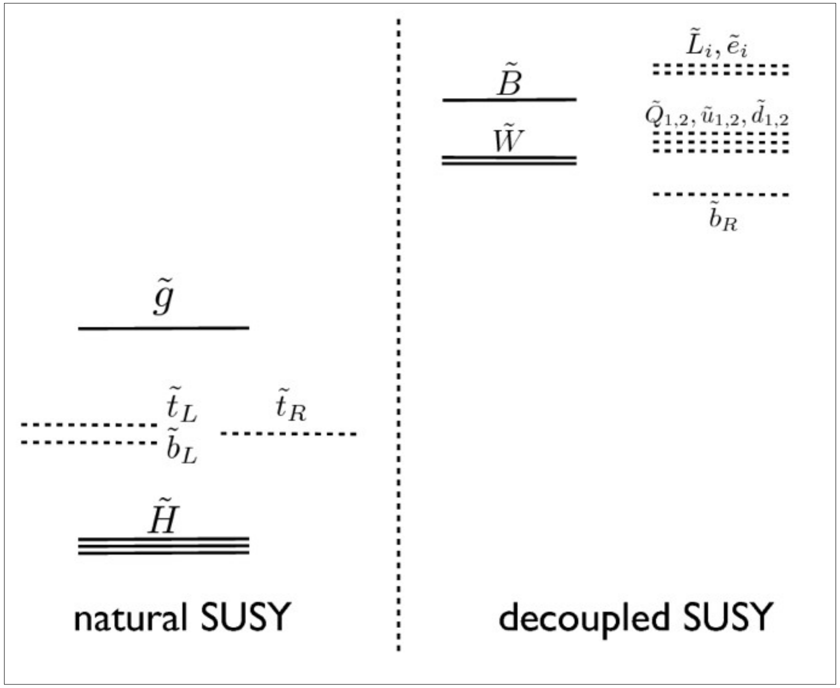


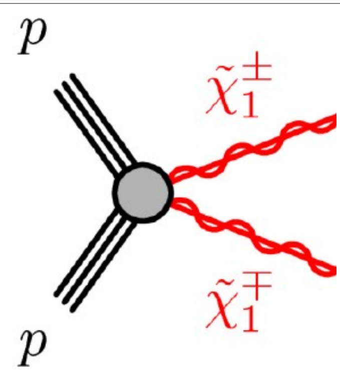
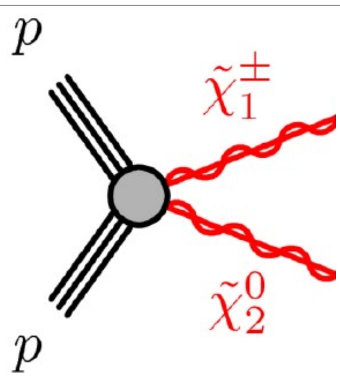
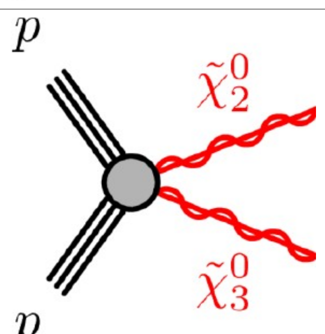
ATLAS limit at 660 GeV

ATLAS limits: 300-600 GeV

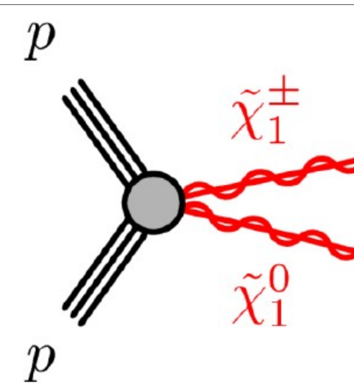
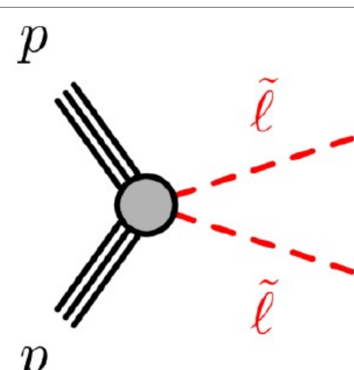
ATLAS limits as high as 1.5 TeV

Overview: ATLAS EWK SUSY Search Strategy

- Simplified models: minimal particle content necessary for multilepton SUSY-like events
- Parametrized with masses; agnostic about couplings, interference terms; topologically generic
- Four ATLAS analyses divided by final state lepton **multiplicity** and **flavor**
- Analyses interpreted in various simplified models

Direct production mode	**Final state(s)**
	• ***2L*** (*e*, *μ*, *τ*) **+ MET** • ***4L*** (*e*, *μ*, *τ*) **+ MET (RPV)**
	• **2*τ* + MET** • ***3L*** (*e*, *μ*) **+ MET**
	• ***4L*** (*e*, *μ*) **+ MET**

- Additional interpretations for ***2L***, **2*τ***, ***4L***
- All analyses use full 2012 8 TeV dataset (~21 fb^{-1})
- Useful terms: Signal region (SR), control region (CR), Validation region (VR)

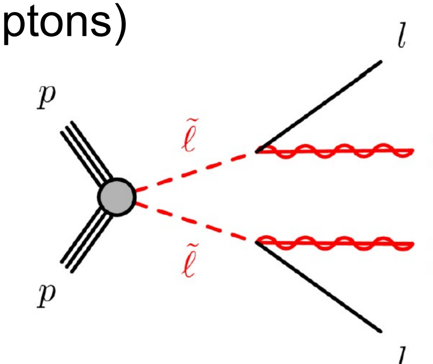
Direct production mode	**Final state(s)**
	• ***4L*** (*e*, *μ*, *τ*) **+ MET (GGM)**
	• ***2L*** (*e*, *μ*) **+ MET**

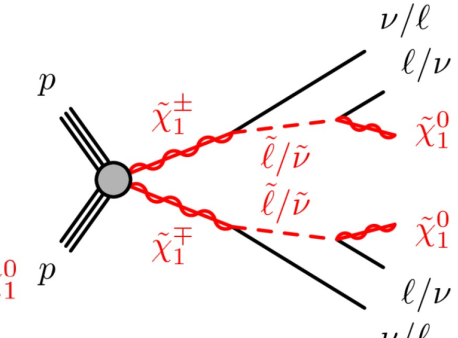
Two Lepton Analysis: Introduction

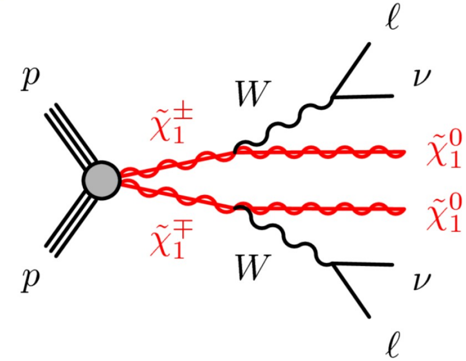
- "Cut & count" analysis targeting direct C_1C_1 and slepton production
- Two mass hierarchies considered for C_1C_1 simplified models:
  - Mass degenerate light sleptons (cascades via sleptons)
  - Heavy sleptons (cascades via *WW*)
- Five SR with two OS leptons; key variable:

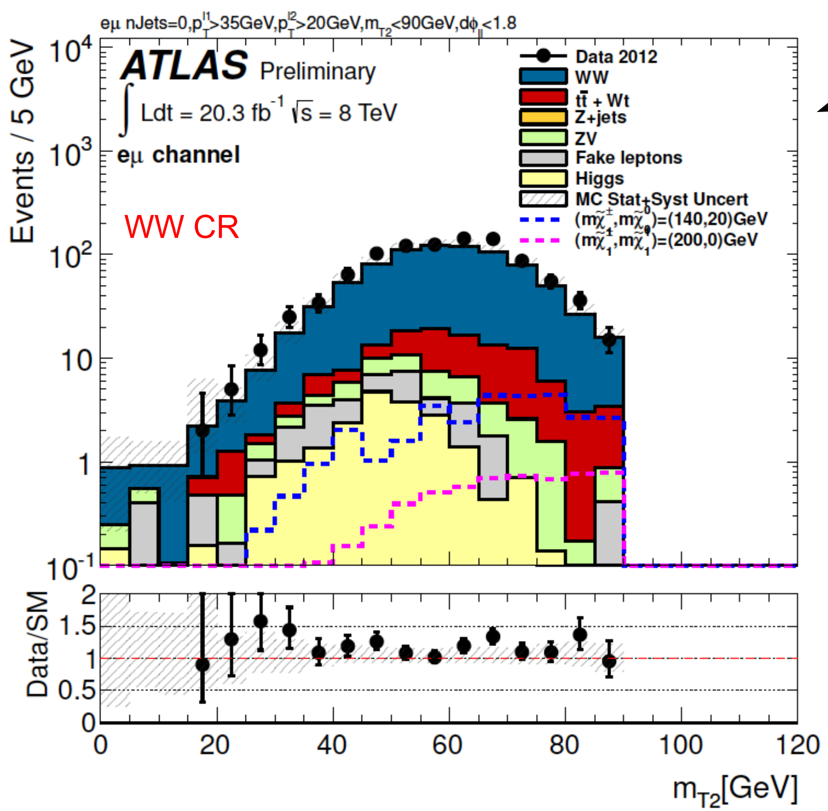
$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\text{miss}} - \mathbf{q}_T)\right)\right]$$

- Leading BGs: *ttbar, WW*
- BG modelling:
  - **Irreducible**: Normalize MC via simultaneous likelihood fit in CRs
  - **Reducible**: data-driven









	SR-$m_{T2,90}$	SR-$m_{T2,110}$	SR-WWa	SR-WWb	SR-WWc
lepton flavour	$e^+e^-, \mu^+\mu^-, e^\pm\mu^\mp$		$e^\pm\mu^\mp$		
$p_T^{\ell 1}$	—		> 35 GeV		
$p_T^{\ell 2}$	—		> 20 GeV		
$m_{\ell\ell}$	Z veto		< 80 GeV	< 130 GeV	—
$p_{T,\ell\ell}$	—		> 70 GeV	< 170 GeV	< 190 GeV
$\Delta\phi_{\ell\ell}$	—		< 1.8 rad		
$E_T^{\text{miss,rel}}$	> 40 GeV		> 70 GeV	—	
m_{T2}	> 90 GeV	> 110 GeV	—	> 90 GeV	> 100 GeV

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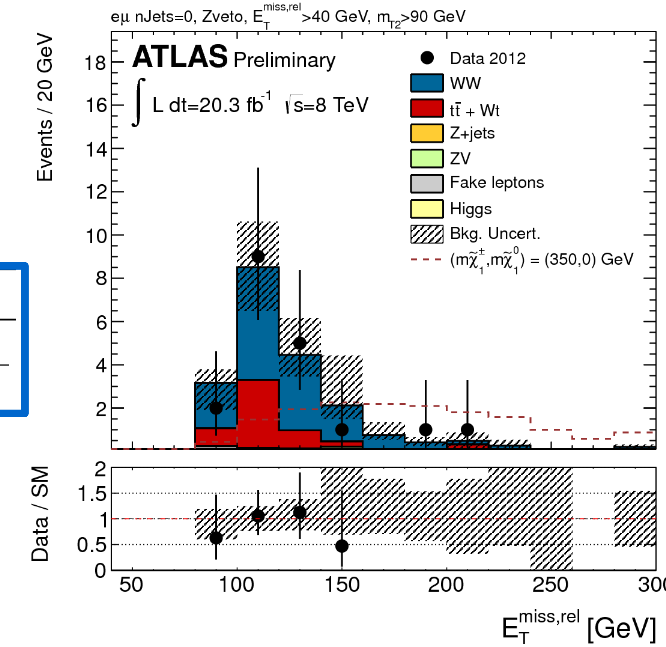
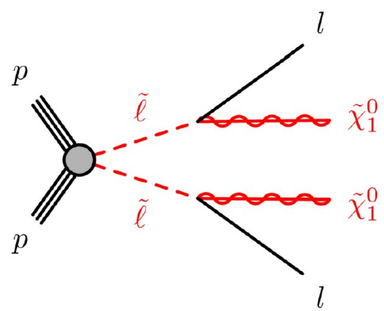
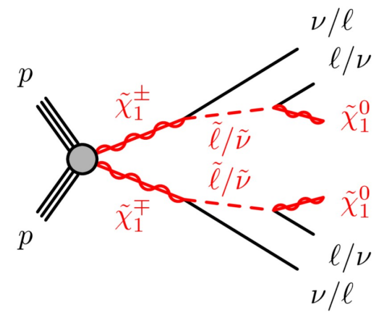
Two Lepton Analysis: Results

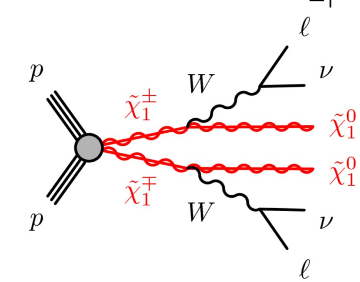
- No significant excesses over SM observed in any SR
- 95% CL upper limits set on visible cross section
- Interpret this null result in SUSY signal models
- Limits on model parameters set at 95% CL

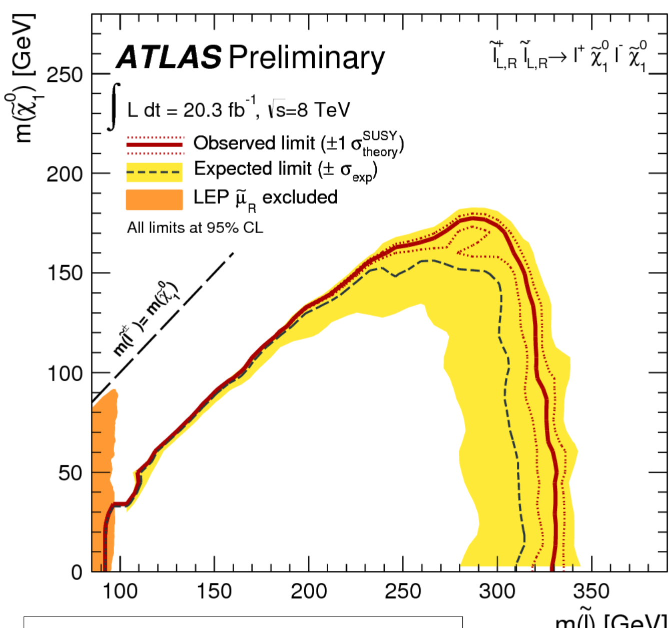
SR-$m_{T2,90}$	e^+e^-	$e^\pm\mu^\mp$	$\mu^+\mu^-$	all
Observed	15	19	19	53
Background total	16.6 ± 2.3	20.7 ± 3.2	22.4 ± 3.3	59.7 ± 7.3

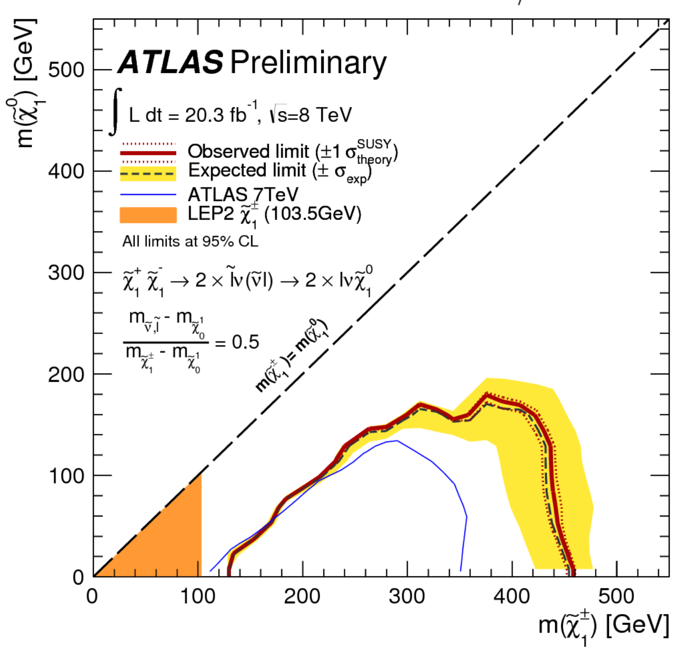


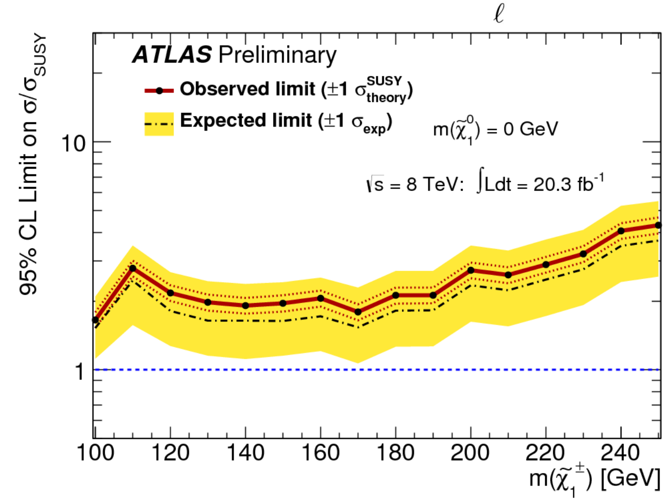












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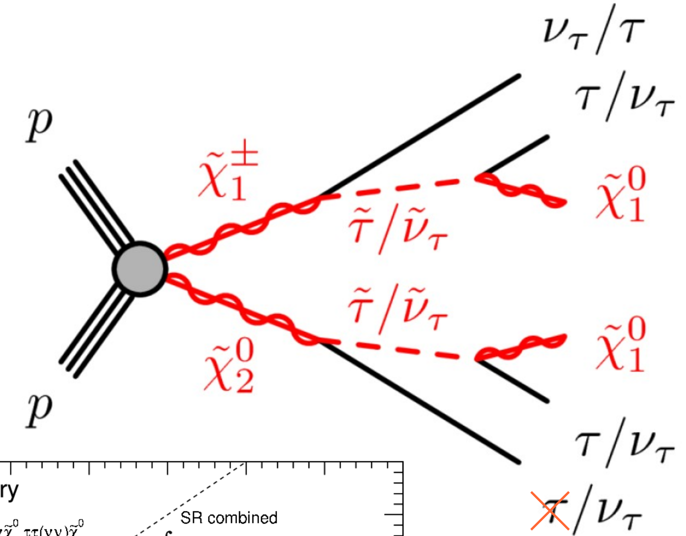
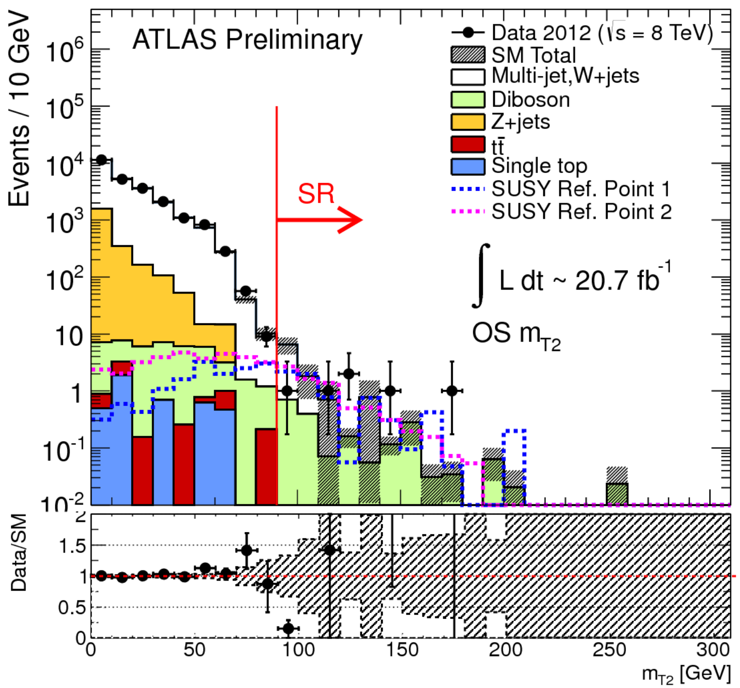
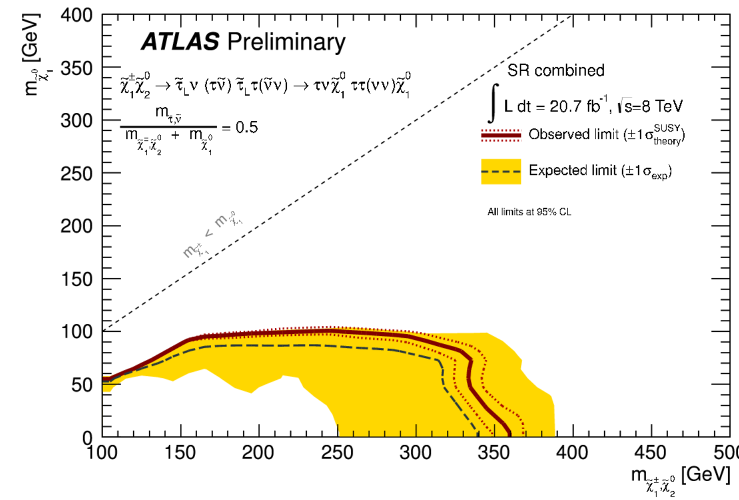
Two Tau Analysis

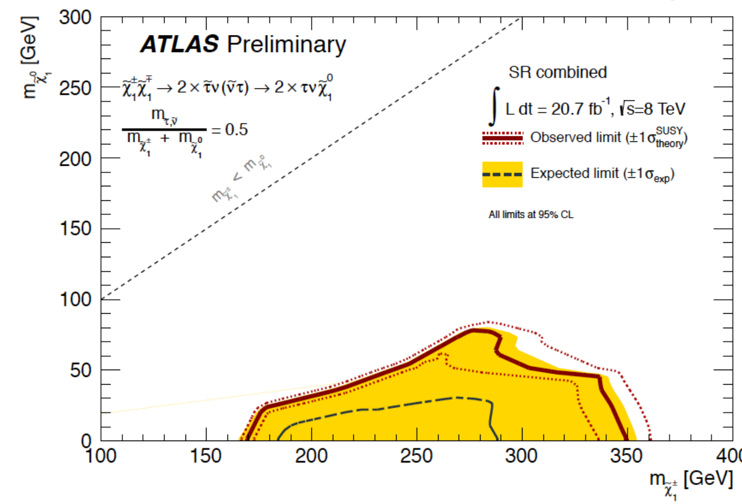
- Targeting direct C_1N_2, C_1C_1 production
- Target models where staus are the only light sleptons
- Two SR with two OS (hadronic) taus; m_{T2} still key variable
- Leading BGs are reducible: *W+j*, QCD
- BG modelling:
  - **Irreducible**: From MC (normalized in CR)
  - **Reducible**: data-driven

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









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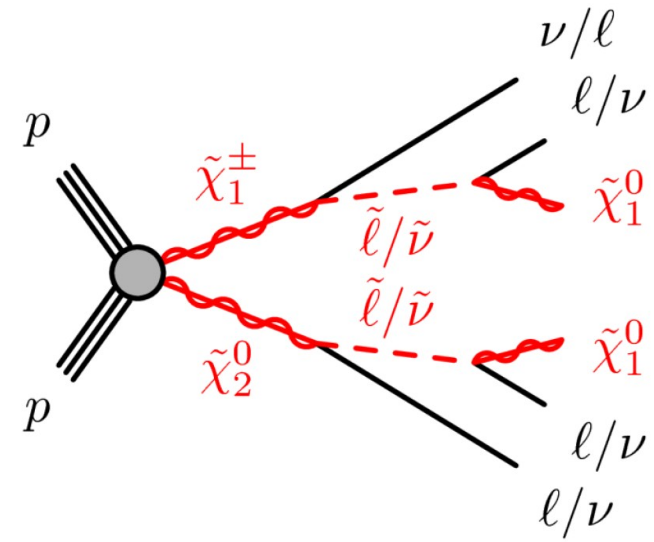
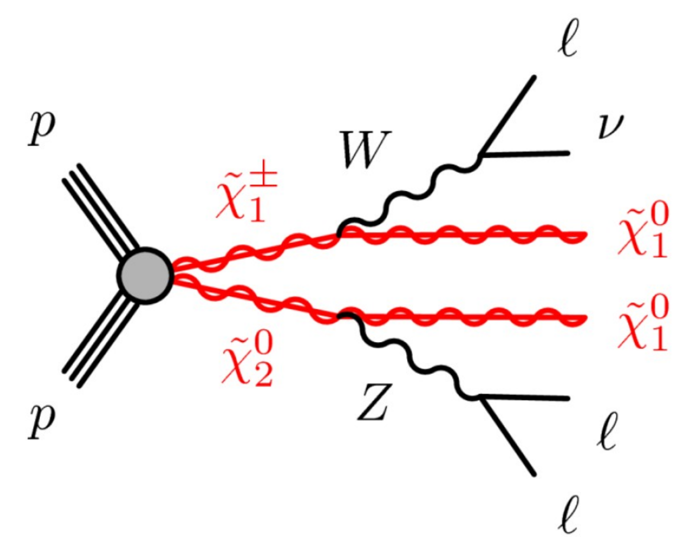
Three Lepton Analysis: Introduction

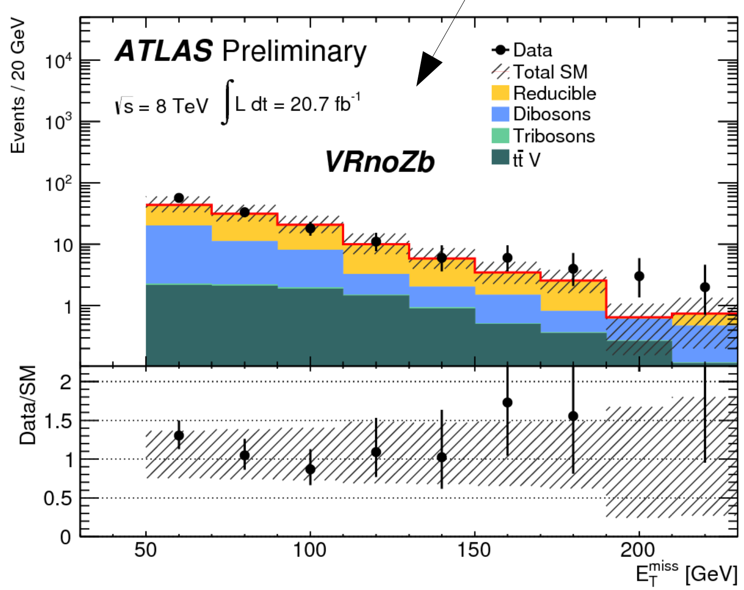
- Targeting direct C_1N_2 production
- Two classes of simplified model:
  - Mass degenerate light sleptons
  - Heavy sleptons
- Six SR; Z-enriched, Z-depleted; targeted optimization
- Leading BG: WZ
- **Irreducible** BG: From MC (validated in dedicated regions)
- **Reducible** BG: data-driven matrix method
  - Efficiencies and fake rates relate kinematic lepton properties and R/F composition

$$\begin{pmatrix} N_{TT} \\ N_{TL'} \\ N_{L'T} \\ N_{L'L'} \end{pmatrix} = \begin{pmatrix} \epsilon_1\epsilon_2 & \epsilon_1 f_2 & f_1\epsilon_2 & f_1 f_2 \\ \epsilon_1(1-\epsilon_2) & \epsilon_1(1-f_2) & f_1(1-\epsilon_2) & f_1(1-f_2) \\ (1-\epsilon_1)\epsilon_2 & (1-\epsilon_1)f_2 & (1-f_1)\epsilon_2 & (1-f_1)f_2 \\ (1-\epsilon_1)(1-\epsilon_2) & (1-\epsilon_1)(1-f_2) & (1-f_1)(1-\epsilon_2) & (1-f_1)(1-f_2) \end{pmatrix} \cdot \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

  - f_{MC} corrected with fake rate SF measured in dedicated CR
  - Invert matrix to obtain reducible BG estimate
  - Validated in four VR







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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	–	–	–	–

Three Lepton Analysis: Results

- 95% CL limits set on visible cross section and on simplified model parameters
- Loose signal regions ("a"): sensitivity to compressed scenarios
- Tight signal regions ("b," "c"): sensitivity to larger mass splittings

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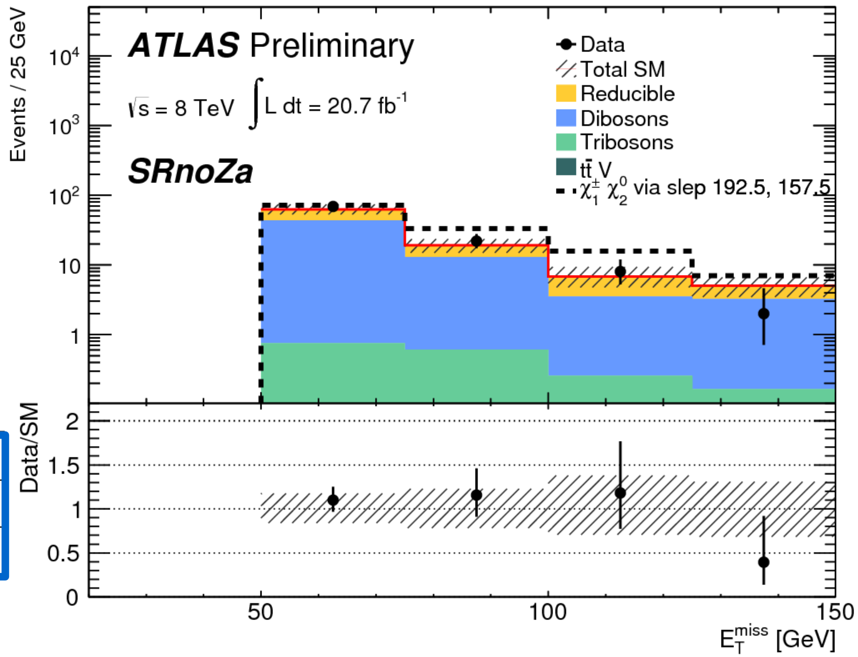
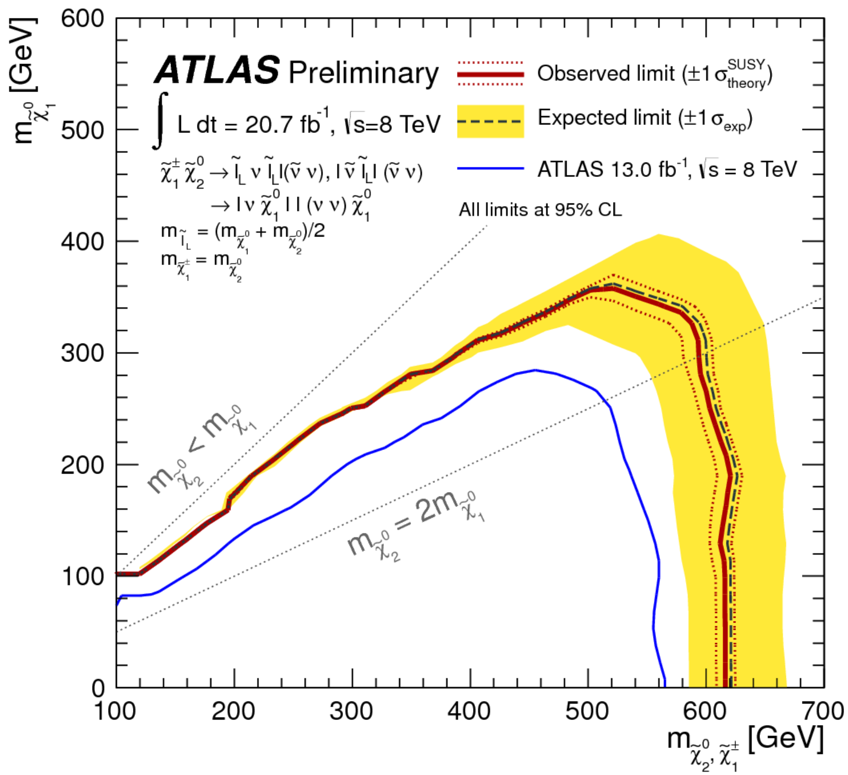
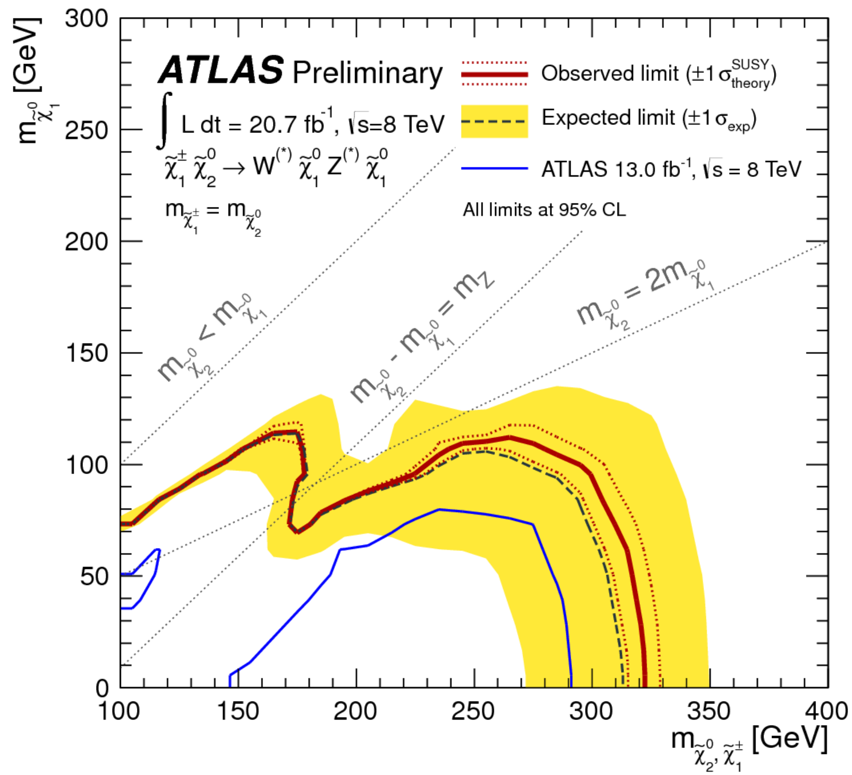


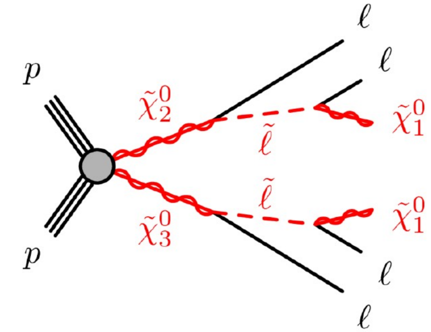
Selection	SRnoZa	SRnoZb	SRnoZc	SRZa	SRZb	SRZc
Σ SM	**96 ± 19**	**29 ± 6**	**4.4 ± 1.8**	**249 ± 35**	**22 ± 5**	**6.3 ± 1.5**
Data	**101**	**32**	**5**	**273**	**23**	**6**

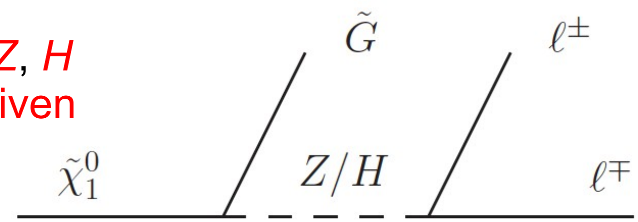


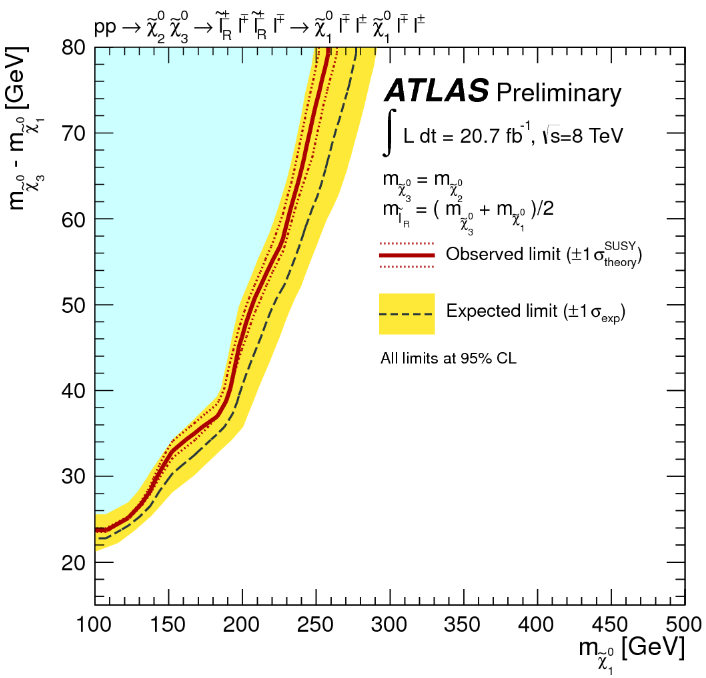


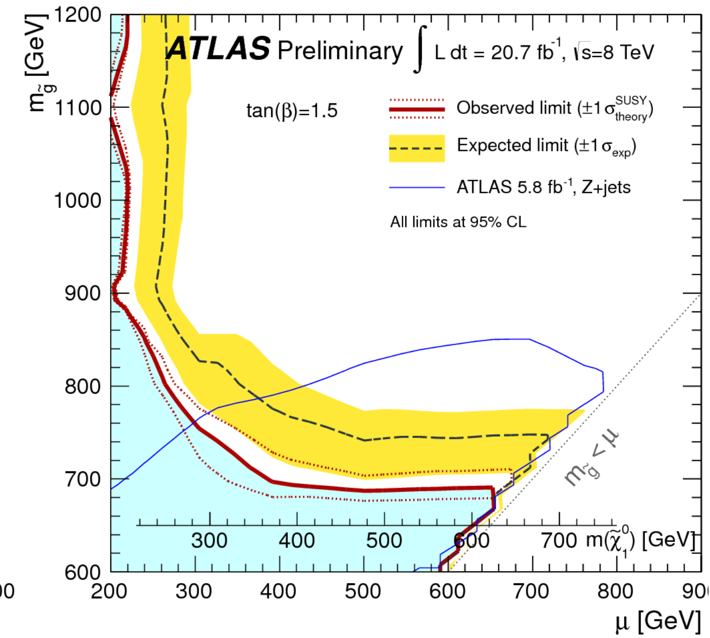
Four Lepton Analysis (RPC)

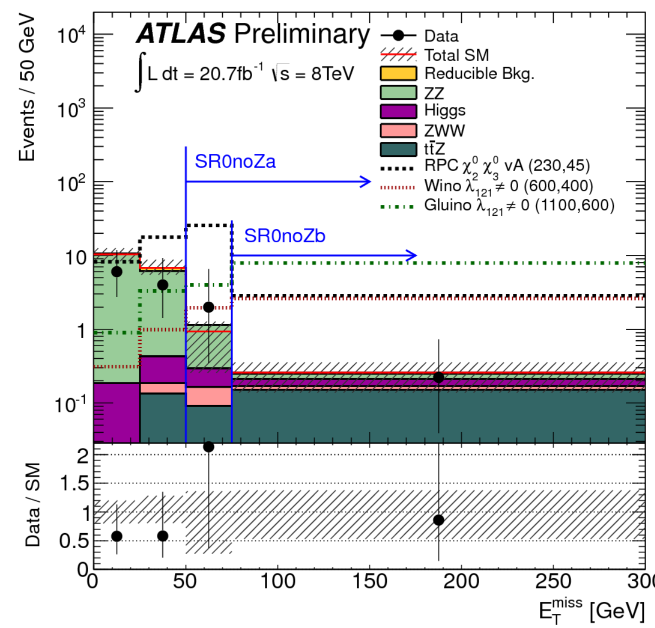
- Inclusive (≥4L) analysis targeting RPC N_2N_3 production and general gauge mediation (GGM)
- Two sets of mass hierarchies considered for N_2N_3 simplified models
- GGM: higgsino-like N_1 decays via gravitino LSP; high m_{gluino}
  - Two models (tanβ = 1.5, tanβ = 30) to probe $N_1 \to (Z,H)$G
- Three targeted SR
- Very sensitive/versatile search (low BG); leading BGs: *ZZ*, *ttbarZ*, *H*
- **Irreducible** BG: from MC (validated in VRs); **reducible**: data-driven
- See talk by W. Ehrenfeld for four lepton RPV results











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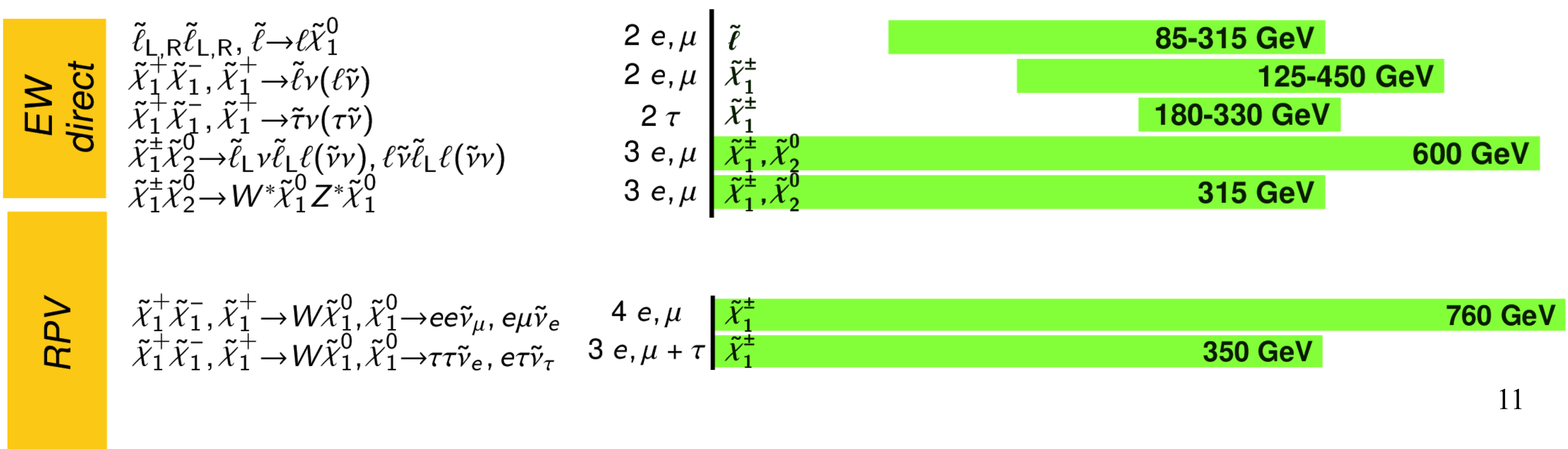
Conclusions

- EWK production may be the dominant SUSY mode at LHC energies
- ATLAS searches for EWK SUSY using full 8 TeV 2012 dataset have been presented; two underlying processes targeted:
    - Direct chargino/neutralino production with subsequent cascades via sleptons and/or gauge bosons
    - Direct slepton production
- No significant excesses observed over Standard Model predictions
- 95% CL upper limits placed on visible cross sections and interpreted in simplified model (RPC and RPV), pMSSM, and GGM scenarios; good sensitivity to natural SUSY
- Re-analysis of 2012 data (in progress) is expected to improve sensitivity in all channels



Additional Slides

2L: BG Modeling

- Dedicated CR for top, *WW* and *ZV* (hadronic jet/HF/conversion fake lepton BG matrix method; others from MC)
- Each SR has set of (kinematically similar) CRs
- In CR, extract SF for SR: $N_B^{SR} = \left[\frac{N^{CR} - N^{CR}_{other}}{N^{CR}_{B,MC}} \right] \times N^{SR}_{B,MC}$
- Done via simultaneous likelihood fit in SR and CR (systematics as nuisance parameters; SFs float in fit)
- Systematics:

	SR-$m_{T2,90}$			SR-$m_{T2,110}$			SR-WW ($e^{\pm}\mu^{\mp}$)		
	e^+e^-	$\mu^+\mu^-$	$e^{\pm}\mu^{\mp}$	e^+e^-	$\mu^+\mu^-$	$e^{\pm}\mu^{\mp}$	a	b	c
MC statistics	7.7	6.1	7.5	12	8.2	14	2.9	8.5	11
Jet	9.5	17	12	14	13	6.8	3.1	5.0	7.0
Lepton	3.9	0.5	4.8	5.2	0.5	1.2	1.1	1.7	5.3
Soft term	1.9	3.2	6.0	3.0	1.0	0.7	1.0	4.6	4.3
b-tagging	0.2	0.2	0.2	0.2	0.3	0.2	0.4	0.7	0.5
Fake lepton	1.0	0.7	0.6	1.5	1.9	3.0	0.1	1.2	1.2
Luminosity	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Theory & modelling	9.7	9.4	11	32	36	43	12	14	14
Total	14	15	16	36	38	45	12	17	20

Generator ← (Theory & modelling)

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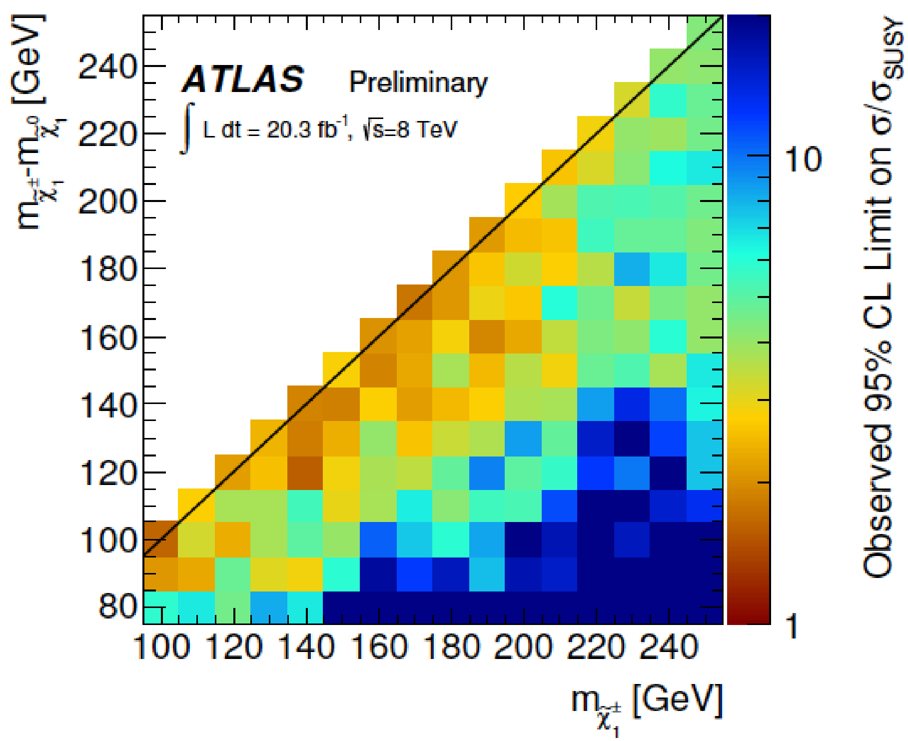
2L: Complete Results

- Observations in all SR:

SR-$m_{T2,90}$	e^+e^-	$e^\pm\mu^\mp$	$\mu^+\mu^-$	all
Observed	15	19	19	53
Background total	16.6 ± 2.3	20.7 ± 3.2	22.4 ± 3.3	59.7 ± 7.3
WW	9.3 ± 1.6	14.1 ± 2.2	12.6 ± 2.0	36.1 ± 5.1
ZV ($V = W$ or Z)	6.3 ± 1.5	0.8 ± 0.3	7.3 ± 1.7	14.4 ± 3.2
Top	$0.9^{+1.1}_{-0.9}$	5.6 ± 2.1	2.5 ± 1.8	8.9 ± 3.9
Higgs	0.11 ± 0.04	0.19 ± 0.05	0.08 ± 0.04	0.38 ± 0.08
Fake	$0.00^{+0.18}_{-0.00}$	$0.00^{+0.14}_{-0.00}$	$0.00^{+0.15}_{-0.00}$	$0.00^{+0.28}_{-0.00}$
Signal expectation				
$(m_{\tilde{\ell}}, m_{\tilde{\chi}_1^0}) = (191, 90)$ GeV	21.6	0	21.6	43.2
$(m_{\tilde{\ell}}, m_{\tilde{\chi}_1^0}) = (251, 10)$ GeV	12.2	0	12.5	24.7
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (350, 0)$ GeV	11.7	16.6	10.5	38.8
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (425, 75)$ GeV	4.3	6.7	4.4	15.4
Observed $\sigma^{95}_{\rm vis}$ (fb)	0.44	0.51	0.47	0.81
Expected $\sigma^{95}_{\rm vis}$ (fb)	$0.50^{+0.22}_{-0.15}$	$0.57^{+0.25}_{-0.17}$	$0.58^{+0.25}_{-0.17}$	$1.00^{+0.41}_{-0.28}$

SR-$m_{T2,110}$	e^+e^-	$e^\pm\mu^\mp$	$\mu^+\mu^-$	all
Observed	4	5	4	13
Background total	6.1 ± 2.2	4.4 ± 2.0	6.3 ± 2.4	16.9 ± 6.0
WW	2.7 ± 1.5	3.6 ± 2.0	2.9 ± 1.6	9.1 ± 4.9
ZV ($V = W$ or Z)	2.7 ± 1.4	0.2 ± 0.1	3.4 ± 1.8	6.3 ± 3.3
Top	0.7 ± 0.7	0.6 ± 0.4	0.0 ± 0.0	1.3 ± 1.0
Higgs	0.05 ± 0.03	0.12 ± 0.04	0.05 ± 0.02	0.22 ± 0.05
Fake	$0.00^{+0.09}_{-0.00}$	$0.00^{+0.13}_{-0.00}$	$0.00^{+0.12}_{-0.00}$	$0.00^{+0.28}_{-0.00}$
Signal expectation				
$(m_{\tilde{\ell}}, m_{\tilde{\chi}_1^0}) = (191, 90)$ GeV	12.3	0	12.0	24.3
$(m_{\tilde{\ell}}, m_{\tilde{\chi}_1^0}) = (251, 10)$ GeV	10.5	0	11.2	21.7
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (350, 0)$ GeV	9.5	14.0	8.7	32.2
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (425, 75)$ GeV	3.7	1.1	3.8	8.5
Observed $\sigma^{95}_{\rm vis}$ (fb)	0.27	0.35	0.28	0.54
Expected $\sigma^{95}_{\rm vis}$ (fb)	$0.33^{+0.16}_{-0.10}$	$0.33^{+0.16}_{-0.09}$	$0.33^{+0.16}_{-0.10}$	$0.62^{+0.23}_{-0.16}$

	SR-WWa	SR-WWb	SR-WWc
Observed	123	16	9
Background total	117.9 ± 14.6	13.6 ± 2.3	7.4 ± 1.5
Top	15.2 ± 6.6	2.7 ± 1.1	1.0 ± 0.7
WW	98.6 ± 14.6	10.2 ± 2.1	5.9 ± 1.3
ZV ($V = W$ or Z)	3.4 ± 0.8	$0.26^{+0.31}_{-0.26}$	0.29 ± 0.14
Higgs	0.76 ± 0.14	0.21 ± 0.06	0.10 ± 0.04
fake	$0.02^{+0.33}_{-0.02}$	$0.26^{+0.30}_{-0.26}$	$0.12^{+0.17}_{-0.12}$
Signal expectation			
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (100, 0)$ GeV	31	N/A	N/A
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (140, 20)$ GeV	N/A	8.2	N/A
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (200, 0)$ GeV	N/A	N/A	3.3
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (110, 113)$ GeV	18	4.3	N/A
Observed $\sigma^{95}_{\rm vis}$ (fb)	1.94	0.58	0.43
Expected $\sigma^{95}_{\rm vis}$ (fb)	$1.77^{+0.66}_{-0.49}$	$0.51^{+0.21}_{-0.15}$	$0.37^{+0.18}_{-0.11}$



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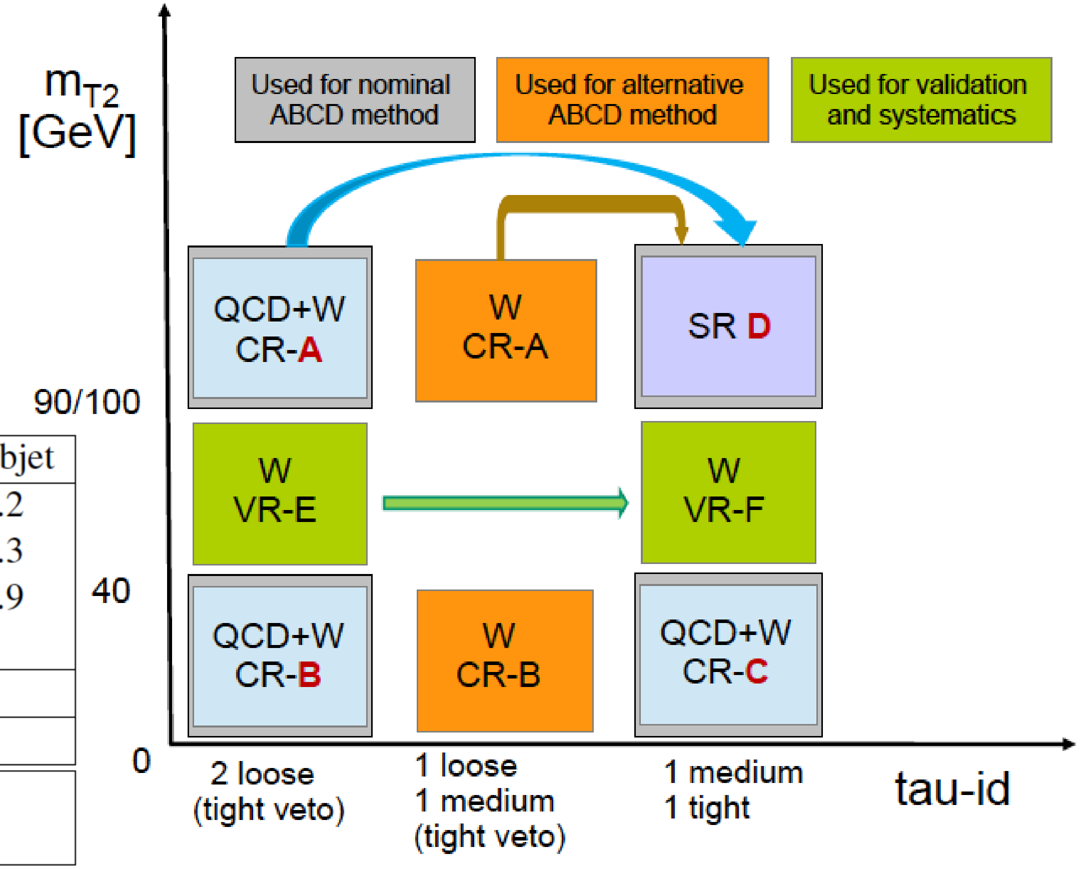
2T: Additional Details

- Reducible BG (leading W+j and QCD) estimated with ABCD method
- Irreducible (top, diboson) from MC
- Systematics:

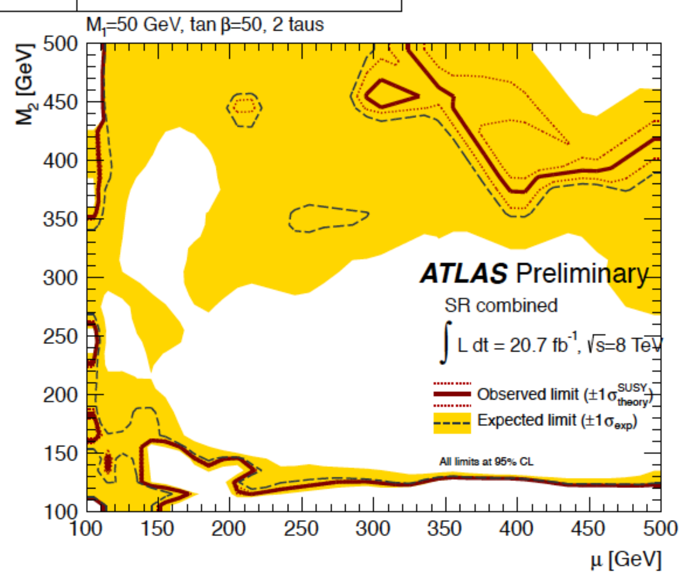
Syst. Sources	SR OS-m_{T2}	SR OS-m_{T2}-nobjet
Correlation	5%	1%
Transfer factor difference	15%	24%
Subtraction of other backgrounds	2%	6%
Number of events in Region A	31%	27%
Total	35%	37%



- Results:

SM process	SR OS m_{T2}	SR OS m_{T2} -nobjet
top	0.2 ± 0.5 ± 0.1	1.6 ± 0.8 ± 1.2
Z+jets	0.28 ± 0.26 ± 0.23	0.4 ± 0.3 ± 0.3
diboson	2.2 ± 0.5 ± 0.5	2.5 ± 0.5 ± 0.9
multi-jet & W+jets	8.4 ± 2.6 ± 1.4	12 ± 3 ± 3
SM total	11.0 ± 2.7 ± 1.5	17 ± 4 ± 3
data	6	14
SUSY Ref. point 1	6.8 ± 1.0	9.2 ± 1.2
SUSY Ref. point 2	7.5 ± 0.7	8.9 ± 0.7

- Additional interpretation:



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3L: Matrix Method

- System of linear equations relates kinematic properties of leptons (LHS) to real/fake lepton composition (RHS)

$$\begin{pmatrix} N_{TT} \\ N_{TL'} \\ N_{L'T} \\ N_{L'L'} \end{pmatrix} = \begin{pmatrix} \epsilon_1\epsilon_2 & \epsilon_1 f_2 & f_1\epsilon_2 & f_1 f_2 \\ \epsilon_1(1-\epsilon_2) & \epsilon_1(1-f_2) & f_1(1-\epsilon_2) & f_1(1-f_2) \\ (1-\epsilon_1)\epsilon_2 & (1-\epsilon_1)f_2 & (1-f_1)\epsilon_2 & (1-f_1)f_2 \\ (1-\epsilon_1)(1-\epsilon_2) & (1-\epsilon_1)(1-f_2) & (1-f_1)(1-\epsilon_2) & (1-f_1)(1-f_2) \end{pmatrix} \cdot \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

  - Loose (*L*): baseline leptons, tight (*T*): signal leptons, L' : $L \neg T$
  - *R*: real, *F*: fake
  - *ε*: probability that *LR* lepton is *T*, *f*: probability that *LF* lepton is *T*
- Only 4x4 matrix is needed (vs. 8x8); 99% leading lepton real
- Efficiencies measured in dedicated control region
- Fake rates obtained in each region XR by summing over types and processes:

$$f_{XR} = \sum_{i,j} (SF^i \times R^{ij}_{XR} \times f^{ij})$$

SF_i: scale factor for fake type *i*
R^{ij}_{XR}: fraction of fake type *i* from process *j* in XR

- Matrix then inverted to obtain F estimate:

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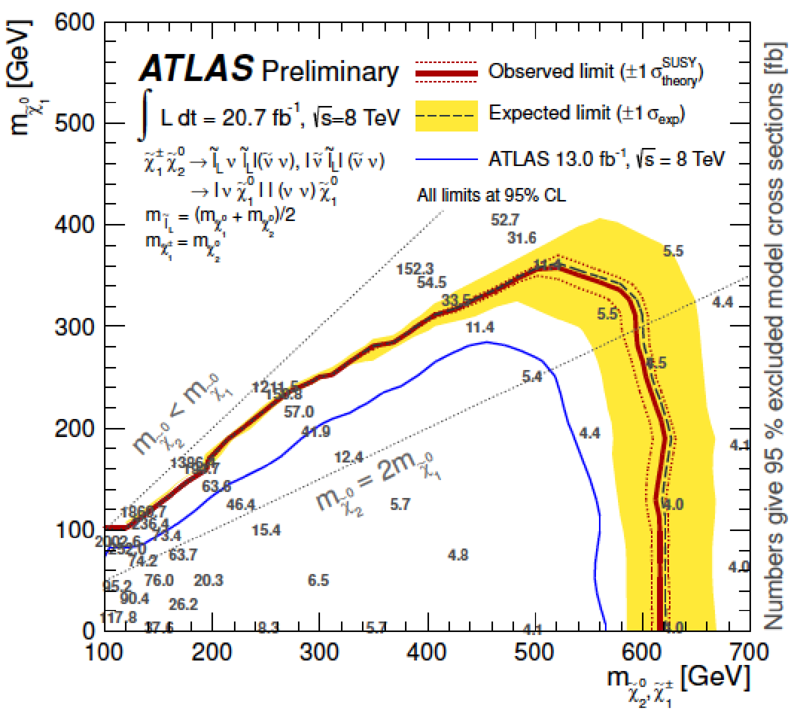
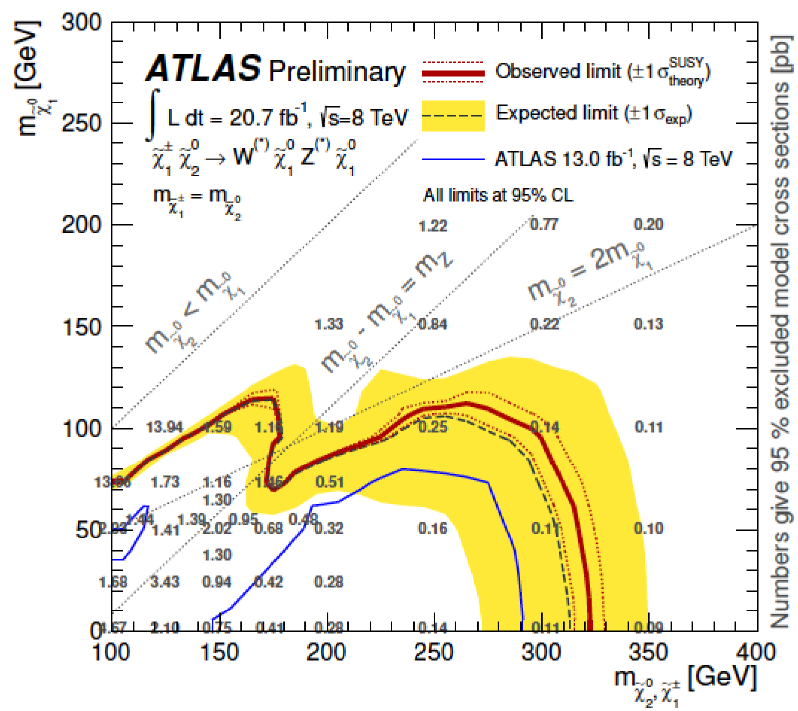
$$N_{Fake\to TT} = \epsilon_1 f_2 \times N_{RF} + f_1\epsilon_2 \times N_{FR} + f_1 f_2 \times N_{FF}$$

3L: Additional Details

- Leading systematics: MC statistics (~4%), BG σ (~11%), MC generator (~18%); total ~ 15-30%
- Complete breakdown of 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
N_{signal} excluded (exp)	39.3	16.3	6.2	67.9	13.2	6.7
N_{signal} excluded (obs)	41.8	18.0	6.8	83.7	13.9	6.5
$\sigma_{\mathrm{visible}}$ excluded (exp) [fb]	1.90	0.79	0.30	3.28	0.64	0.32
$\sigma_{\mathrm{visible}}$ excluded (obs) [fb]	2.02	0.87	0.33	4.04	0.67	0.31





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4L: Additional Details

- Reducible BG (HF, LF, conversion leptons) from data-driven weighting method (WZ, ttbar, etc.)
- $N_{red} \sim [N_{\mathrm{data}}(3\ell_S + \ell_L) - N_{\mathrm{MCirr}}(3\ell_S + \ell_L)] \times F(\ell_L)$

$$- [N_{\mathrm{data}}(2\ell_S + \ell_{L_1} + \ell_{L_2}) - N_{\mathrm{MCirr}}(2\ell_S + \ell_{L_1} + \ell_{L_2})] \times F(\ell_{L_1}) \times F(\ell_{L_2})$$

- Leading systematics: BG σ and generator (total ~50%)

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

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

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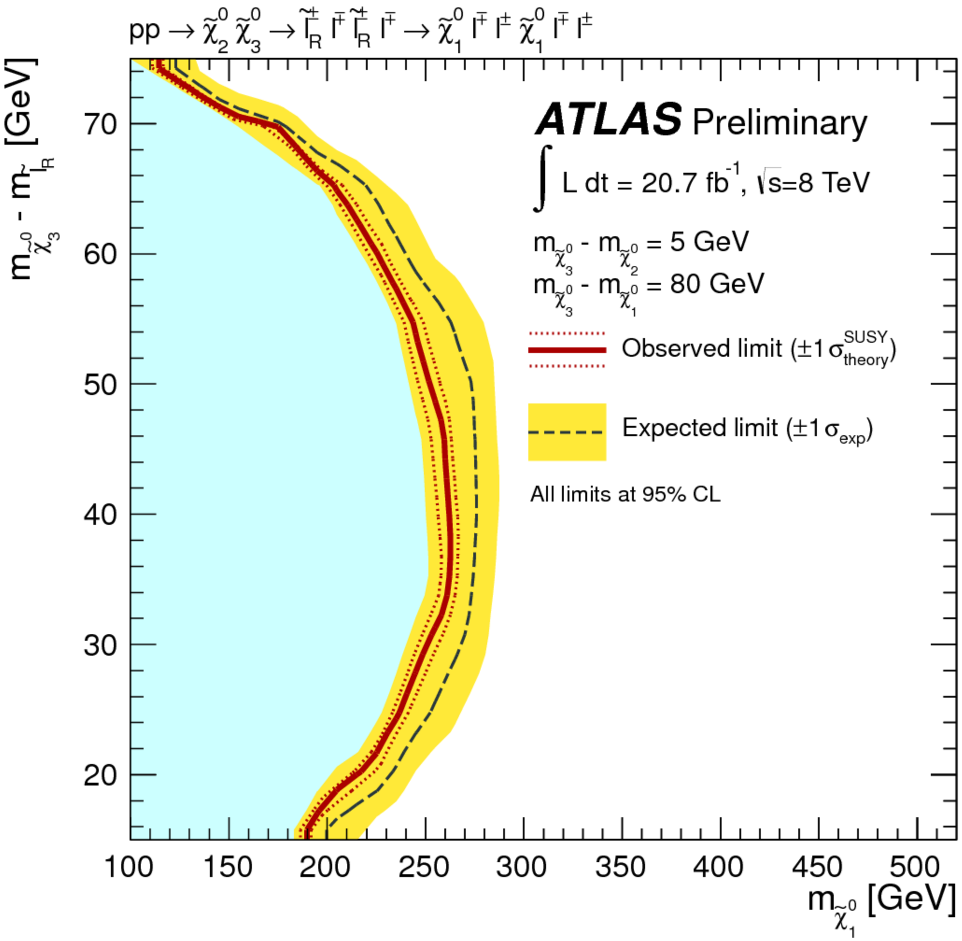
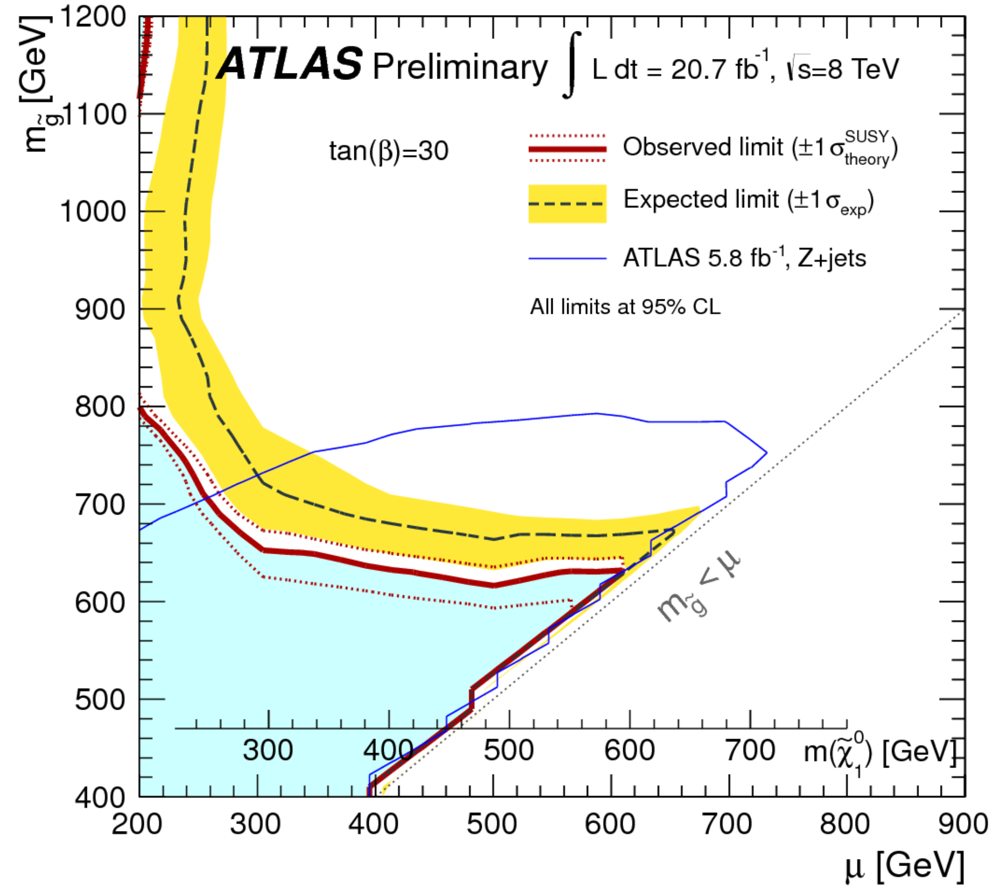
4L: Additional RPC Limits



N_2N_3 simplified model



GGM

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Four Lepton Analysis (RPV)

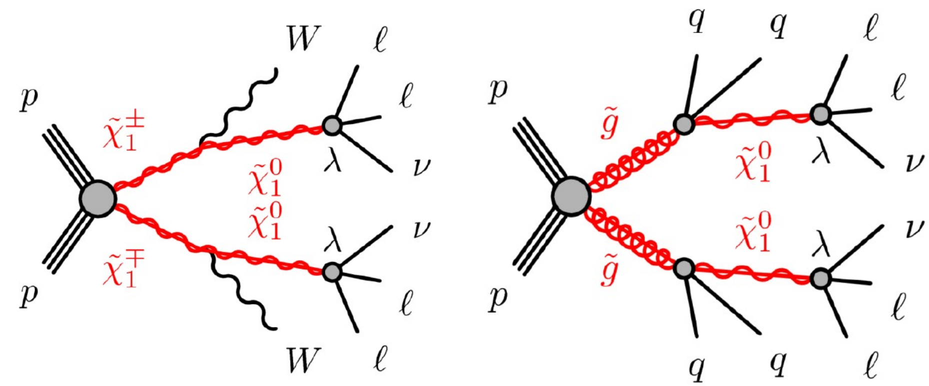
- Two additional SR targeting RPV scenarios; use:

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

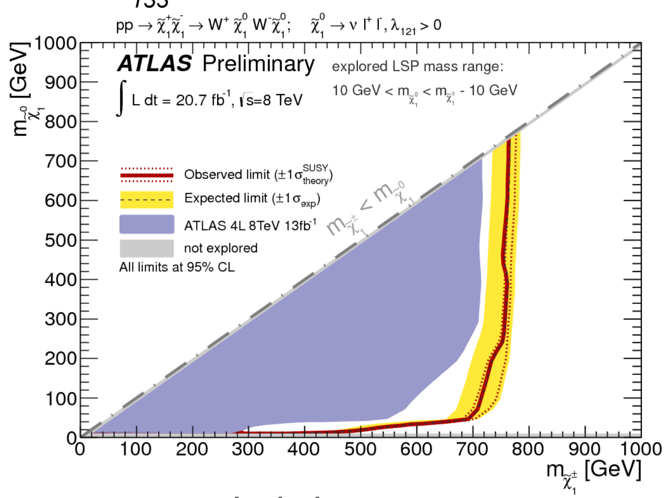
- Consider two cases for RPC NLSP pair-production:
  - Wino-like
  - Gluino (not EWK)
- Bino-like N_1 LSP then promptly decays to $LL\nu$
- Two small Yukawa couplings considered:

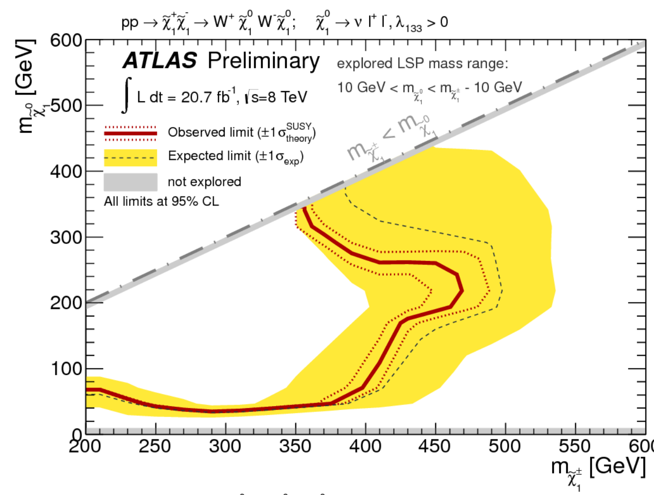
$$\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k + \kappa_i L_i H_2$$

  - $\lambda_{121} \neq 0$: e, μ FS; $\lambda_{133} \neq 0$: e, τ FS

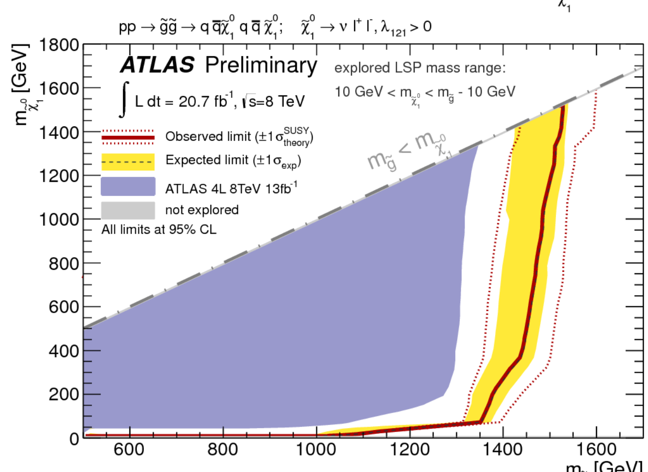


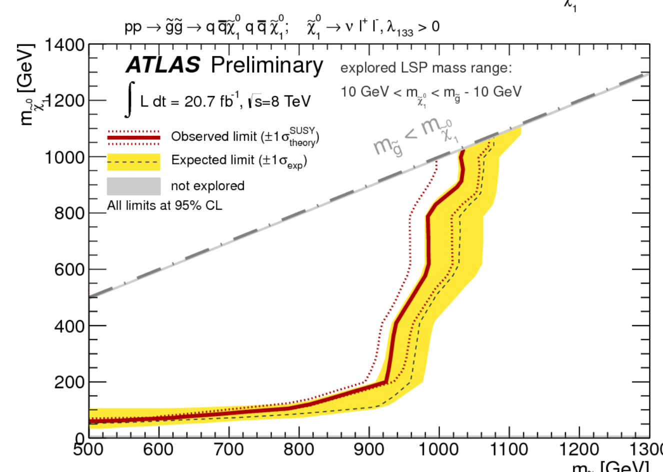
Stronger limits than in RPC scenarios





See talk by W. Ehrenfeld for more details





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