The search for the electroweak production of supersymmetric particles in events with two leptons and missing energy at ATLAS

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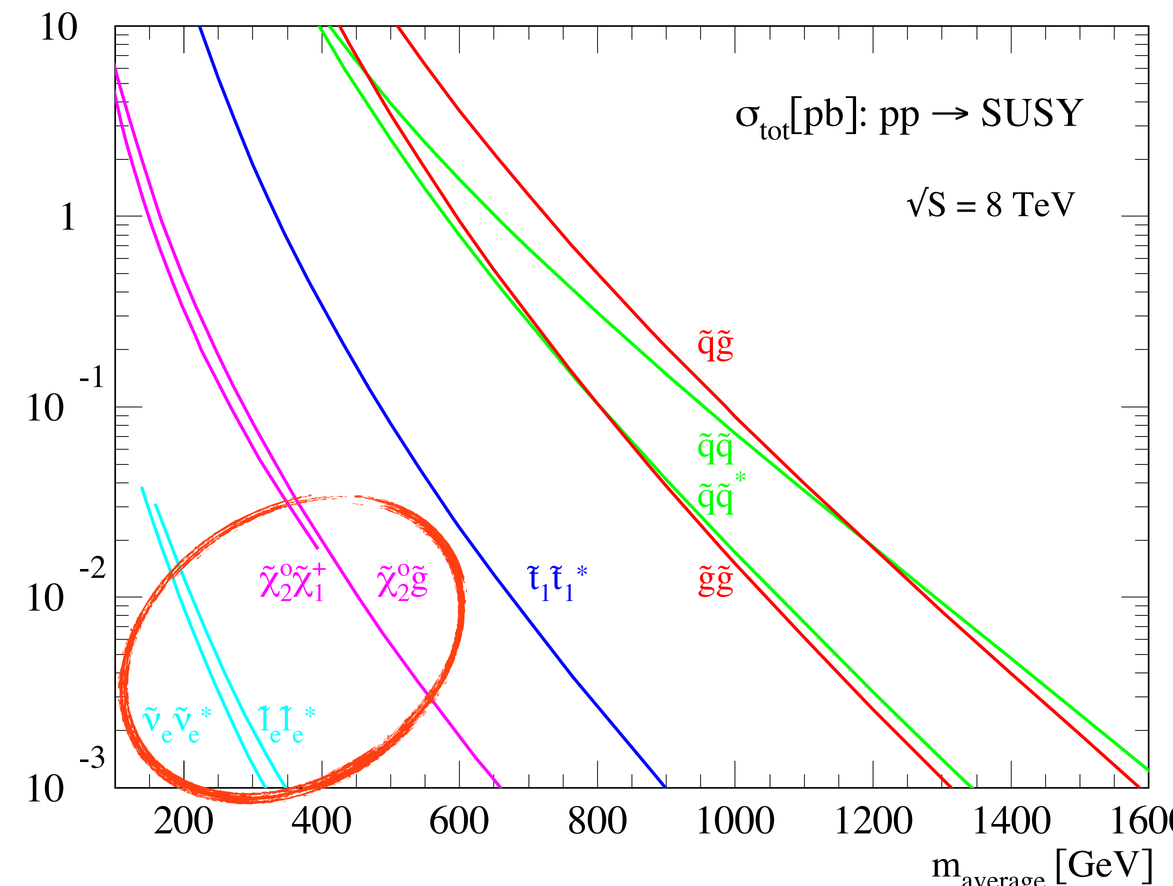
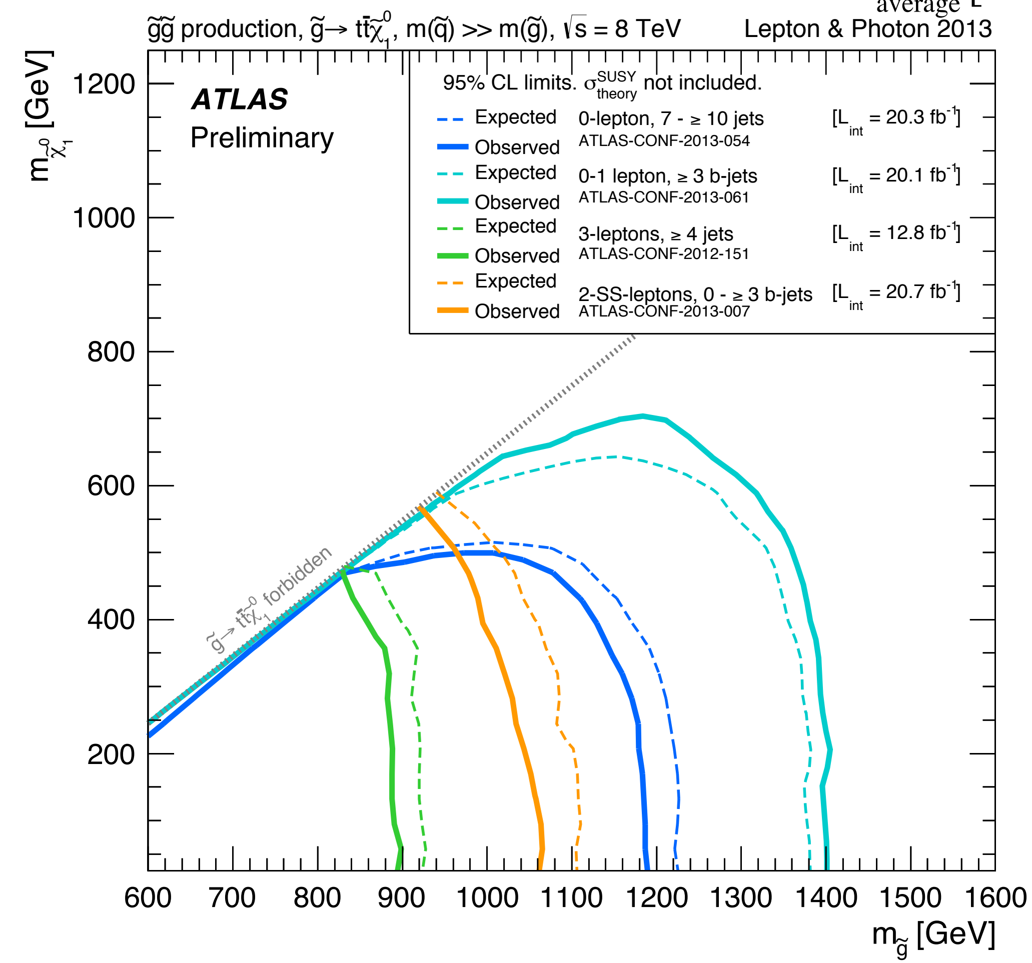
Outline

- Motivation
- Methodology
- Signal regions
- Background estimates
- Results & interpretation
- Conclusions & outlook

Motivation

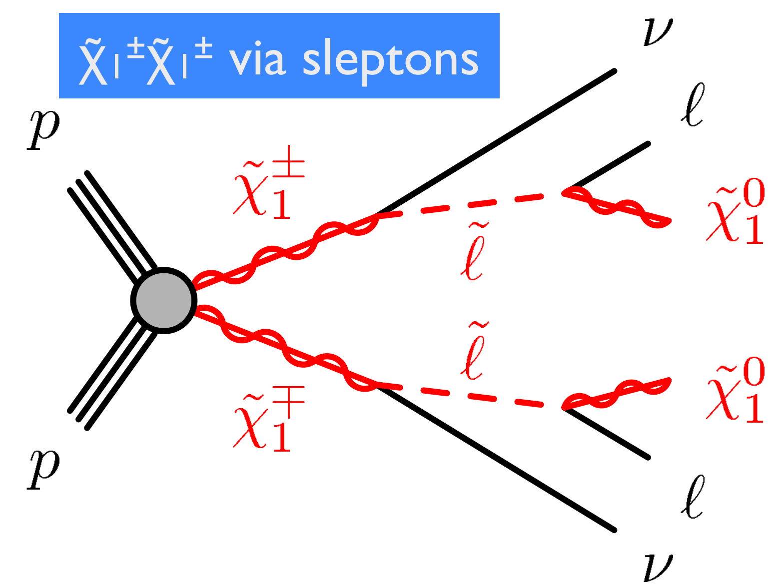
- At proton-proton collider, we expect large coupling to squarks and gluinos due to the strong interactions.
  - Searches have not found any sign of these particles, and set strong limits on their masses (at the TeV scale)
  - Naturalness motivates light gauginos
  - Electroweak SUSY production may be favored at LHC energies
- Focusing on two lepton (e,μ) final states
- Latest public result
  - 20.3 fb^{-1} @ 8 TeV
  - http://cds.cern.ch/record/1547565

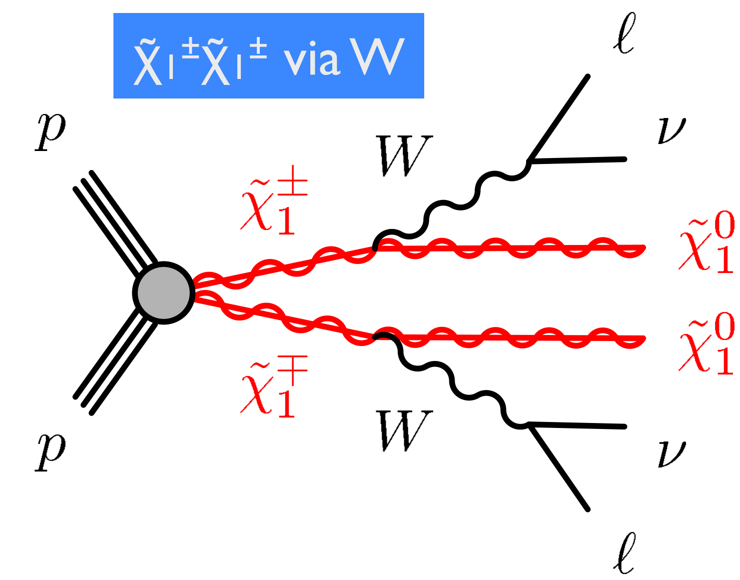


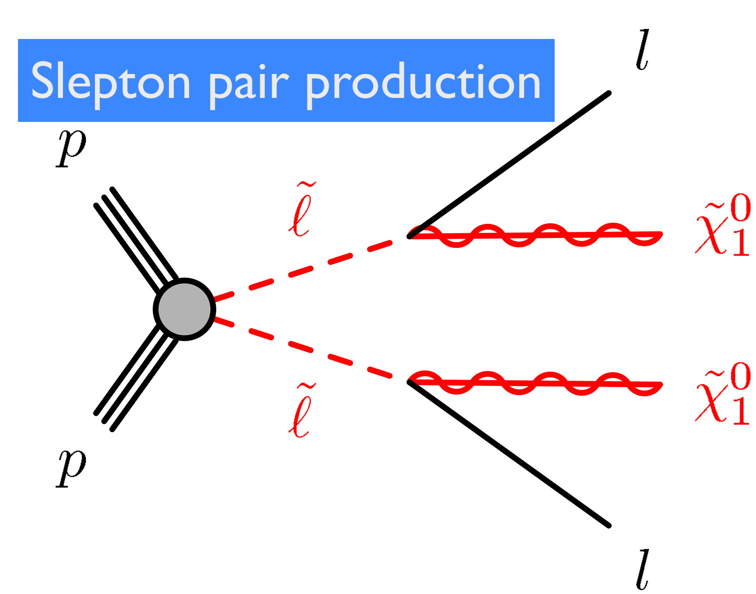


Methodology

- Considering simplified SUSY models
  - Chargino pair production, decaying via sleptons or W bosons
  - Slepton pair production
- Cut-and-count analysis
  - Five signal regions, each targeting different scenarios
- Dominant backgrounds are measured in Monte Carlo, and scale factors are derived in control regions
- Upper limits on the visible cross section are set using a modified frequentist approach (CL_s)







Object & event selection

Variable	Electrons	Muons
p_T [GeV]	> 10	> 10
$\lvert\eta\rvert$	< 2.47	< 2.4
$\left\lvert\frac{d_0}{\sigma(d_0)}\right\rvert$	< 5	< 3
$z_0 \sin(\theta)$ [mm]	< 0.14 mm	< 1 mm
Track isolation	$< 0.16 \times p_T$	$< 0.12 \times p_T$
Calorimeter isolation	$< 0.18 \times p_T$	-

- Jets:
  - p_T > 20 GeV
  - $|\eta| < 4.9$
  - Containing tracks which are consistent with the primary vertex
  - b-tagging: 80% efficient operating point
- Other criteria:
  - Exactly two leptons (e/μ)
  - Di-lepton triggers
  - Reject events with m_{ll} < 20 GeV (Avoid low mass resonances)

Important variables

- Missing transverse energy (E_T^{miss})
  - Sum all the energy deposits in the calorimeters
  - Correction based on reconstructed electrons, muons, and jets
- Relative missing transverse energy ($E_T^{miss,rel}$)
  - Used to distinguish missing energy from real process from that from mis-measurement of jets or leptons

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

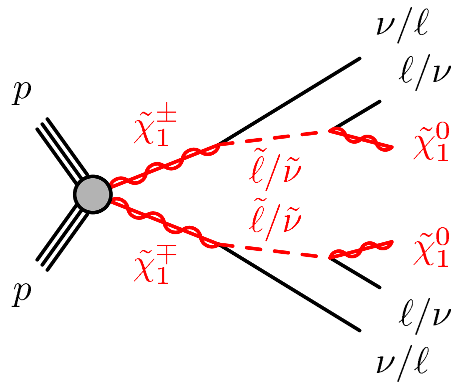
- Stransverse mass (m_{T2})
  - Used to separate signal and background
  - Standard model background have a kinematic edge lower than that of SUSY models

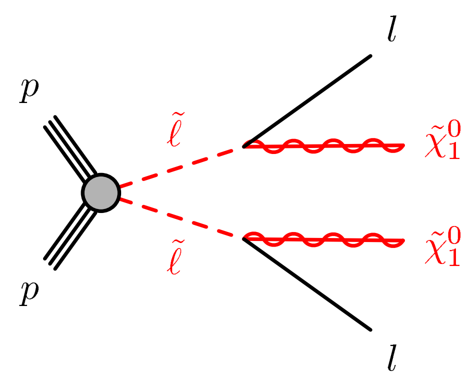
$$m_{\mathrm{T2}} = \min_{\mathbf{q}_{\mathrm{T}}} \left[\max\left(m_{\mathrm{T}}\left(\mathbf{p}_{\mathrm{T}}^{\ell 1}, \mathbf{q}_{\mathrm{T}}\right), m_{\mathrm{T}}\left(\mathbf{p}_{\mathrm{T}}^{\ell 2}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}} - \mathbf{q}_{\mathrm{T}}\right)\right)\right]$$

Signal regions

SR-m_{T2}

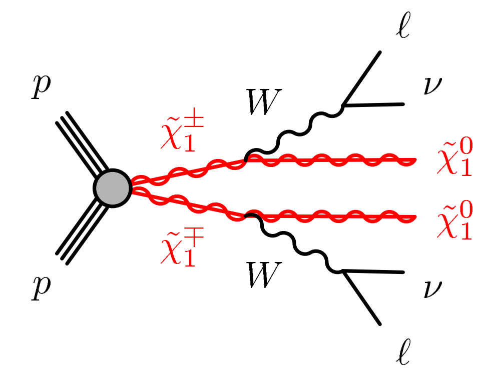
	$SRm_{T2,90}$	$SRm_{T2,110}$
Lepton flavor	e^-e^+, $\mu^-\mu^+$, $e^\pm\mu^\mp$	
Jets	Full jet veto	
m_{ll}	Z veto	
$E_T^{\mathrm{miss,rel}}$	> 40 GeV	
m_{T2}	> 90 GeV	> 110 GeV





SR-WW

	$SRWW_a$	$SRWW_b$	$SRWW_c$
Lepton flavor	$e^\pm\mu^\mp$		
Jets	Full jet veto		
$p_T^{\ell 1}$	$> 35\,GeV$		
$p_T^{\ell 2}$	$> 20\,GeV$		
m_{ll}	< 80 GeV	< 130 GeV	-
p_T^{ll}	> 70 GeV	< 170 GeV	< 190 GeV
$\delta\phi(\ell\ell)$	> 1.8 rad		
$E_T^{\mathrm{miss,rel}}$	> 70 GeV	-	
m_{T2}	-	> 90 GeV	> 100 GeV



- SR-m_{T2}
  - Targets $\chi_1^\pm\chi_1^\pm$ production
    - $\chi_1^\pm$ decays via sleptons
  - Also, direct slepton pair production
  - Two signal regions
    - SR-$m_{T2,90}$: Targets low $\chi_1^\pm$ mass
    - SR-$m_{T2,110}$: Targets high $\chi_1^\pm$ mass

- SR-WW
  - Targets $\chi_1^\pm\chi_1^\pm$ production
    - $\chi_1^\pm$ decays via W boson
  - Three signal regions
    - SR-WWa: Target models with off shell W's
    - SR-WWb,c: Target models with increasing $\chi_1^\pm$-χ_1^0 mass splitting

Signal regions

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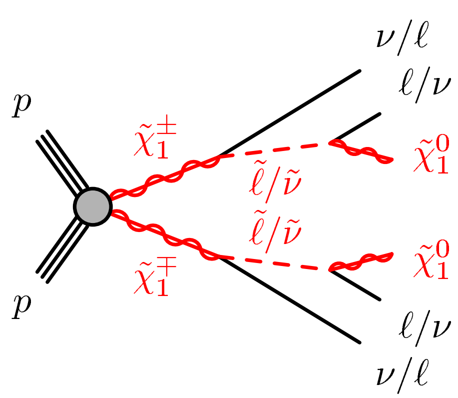

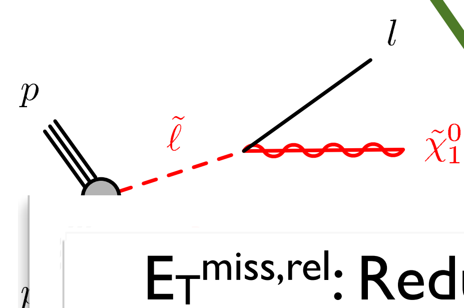

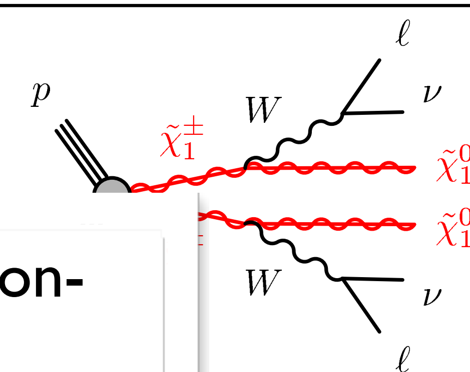

$E_T^{\mathrm{miss,rel}}$: Reduce background from non-prompt leptons & Z+jets

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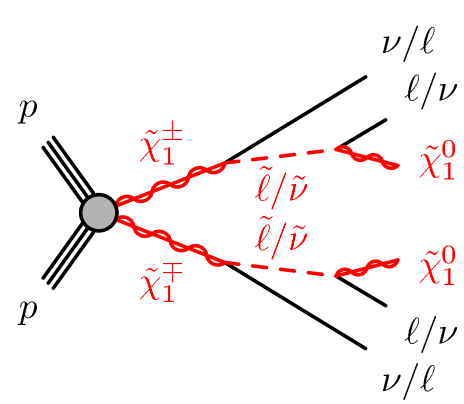
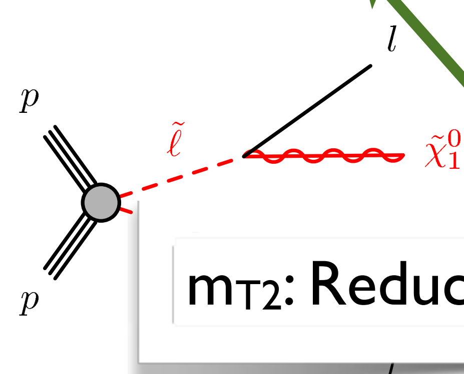
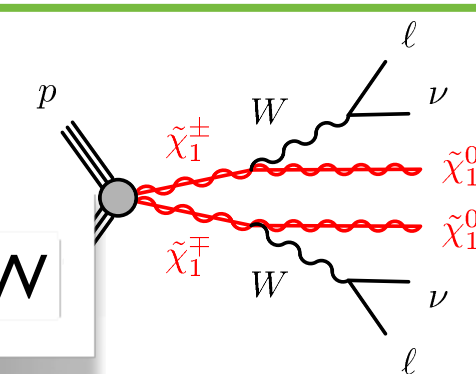
m_{T2}	-	> 90 GeV	> 100 GeV





m_{T2}: Reduce background from WW



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Backgrounds - I

- Standard model sources of di-lepton final states + fake leptons
  - WW
  - $t\bar{t}$ and single top
  - Z+vector boson
  - Non-prompt leptons
  - Z+jets
  - Higgs

WW, $t\bar{t}$ and single top, Z+vector boson: Dedicated control region for each background/signal region combination

Non-prompt leptons: Estimated with Matrix method (negligible in SRs)

Z+jets, Higgs: Taken from MC (negligible in SRs)

- Dominant backgrounds prediction is measured in Monte Carlo and corrected using a dedicated control region
- Other background estimates are taken from Monte Carlo and matrix method

Backgrounds - II

- Measure scale factor in control region to account for data/Monte Carlo disagreement

$$\mathcal{S} = \frac{\left[N^{\mathrm{CR}}_{\mathrm{data}} - N^{\mathrm{CR}}_{\mathrm{MC,other\,bkgd}}\right]}{N^{\mathrm{CR}}_{\mathrm{MC,target\,bkgd}}}$$

- Measure transfer factor from control region to signal region in Monte Carlo

$$\mathcal{T} = \frac{N^{\mathrm{SR}}_{\mathrm{MC,target\,bkgd}}}{N^{\mathrm{CR}}_{\mathrm{MC,target\,bkgd}}}$$

- Compute estimated background contribution to signal region

$$N^{\mathrm{SR}}_{\mathrm{data,target\,bkgd}} = \mathcal{S} \times \mathcal{T} \times N^{\mathrm{CR}}_{\mathrm{MC,target\,bkgd}}$$

WW control regions

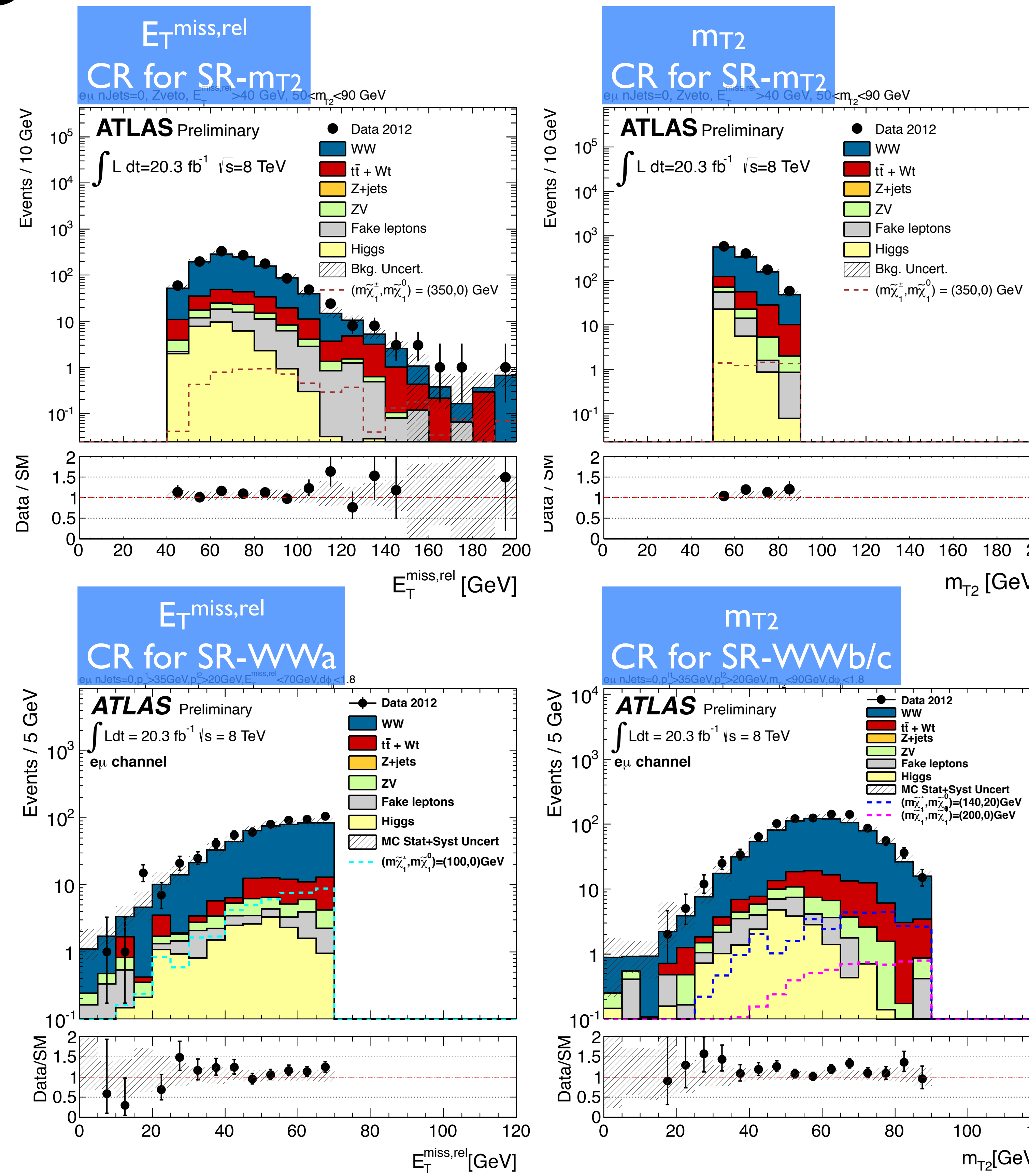
ATLAS-CONF-2013-049

Signal region	$SRm_{T2,90}$	$SRm_{T2,110}$
Lepton flavor	$e^{\pm}\mu^{\mp}$	
Jets	Full jet veto	
m_{ll}	Z veto	
$E_{\mathrm{T}}^{\mathrm{miss,rel}}$	> 40 GeV	
m_{T2}	50-90	

Signal region	$SRWW_a$	$SRWW_b$	$SRWW_c$
Lepton flavor	$e^{\pm}\mu^{\mp}$		
Jets	Full jet veto		
m_{ll}	-		
$\delta\phi(\ell\ell)$	> 1.8 rad		
$E_{\mathrm{T}}^{\mathrm{miss,rel}}$	< 70 GeV	-	
m_{T2}	-	< 90 GeV	

- Non-WW contamination:
  - Top: 13%
  - Z+vector boson: 3%
- Scale factors:

SR-m_{T2}	1.12 ± 12.5%
SR-WW	1.16–1.19 ± 6–8%



Top control regions

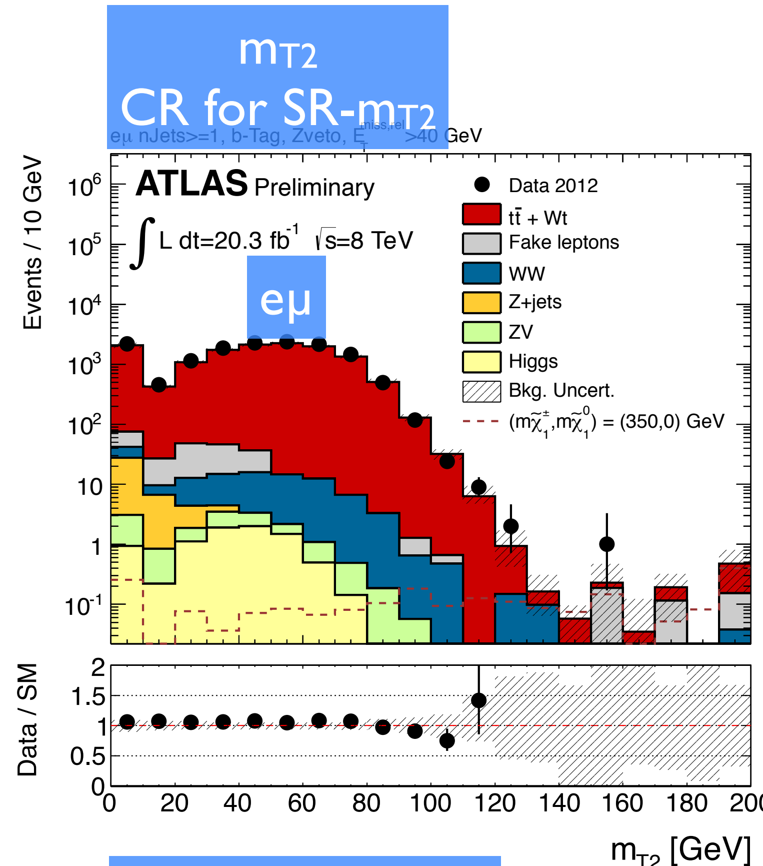
ATLAS-CONF-2013-049

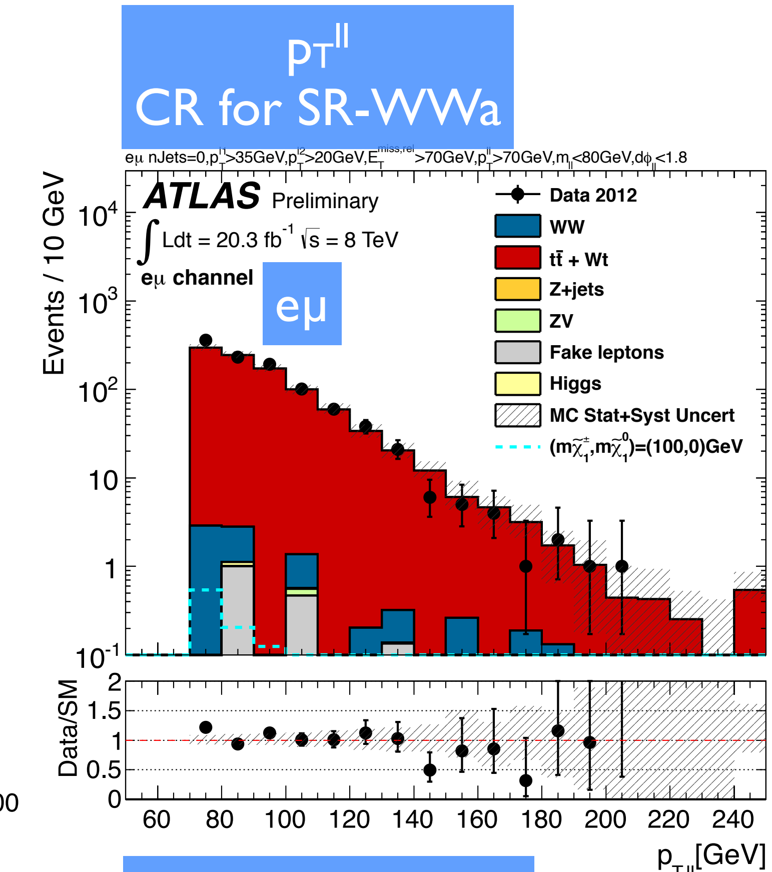
Signal region	$SRm_{T2,90}$	$SRm_{T2,110}$
Lepton flavor	e^-e^+, $\mu^-\mu^+$, $e^\pm\mu^\mp$	
B-tagged jets	≥ 1	
Signal jets	≥ 2	
m_{ll}	Z veto	
$E_T^{\text{miss,rel}}$	> 40 GeV	
m_{T2}	50-90	

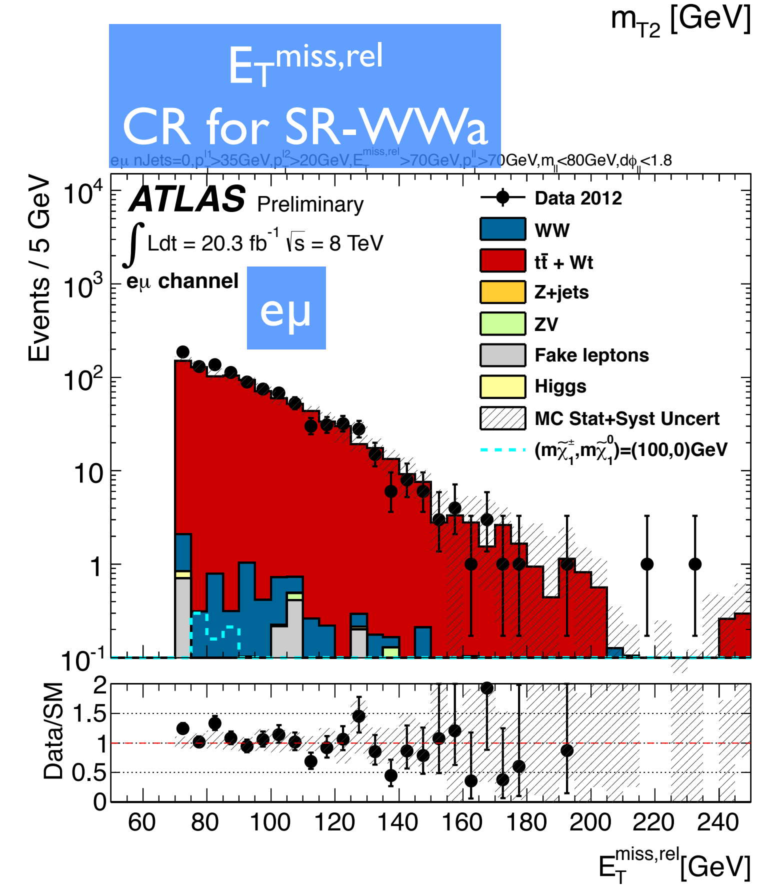
Signal region	$SRWW_a$	$SRWW_b$	$SRWW_c$
Lepton flavor	$e^\pm\mu^\mp$		
B-tagged jets	≥ 1		
Signal jets	≥ 1		
m_{ll}	< 80 GeV	< 130 GeV	-
p_T^{ll}	> 70 GeV	< 170 GeV	< 190 GeV
$\delta\phi(\ell\ell)$	> 1.8 rad		
$E_T^{\text{miss,rel}}$	> 70 GeV	-	
m_{T2}	-	< 90 GeV	< 100 GeV

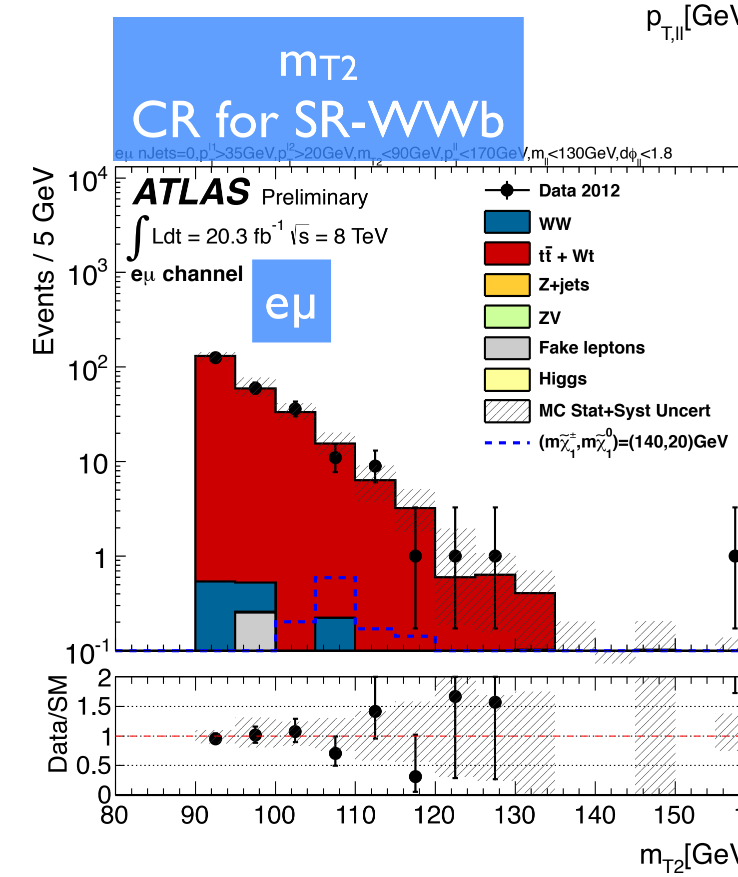
- Non-top contamination:
  - SR-m_{T2}: 2%
  - SR-WW: <1%
- Scale factors (derived in eμ)

SR-m_{T2}	1.05 ± 4.8%
SR-WW	0.98-1.07 ± 4-13%







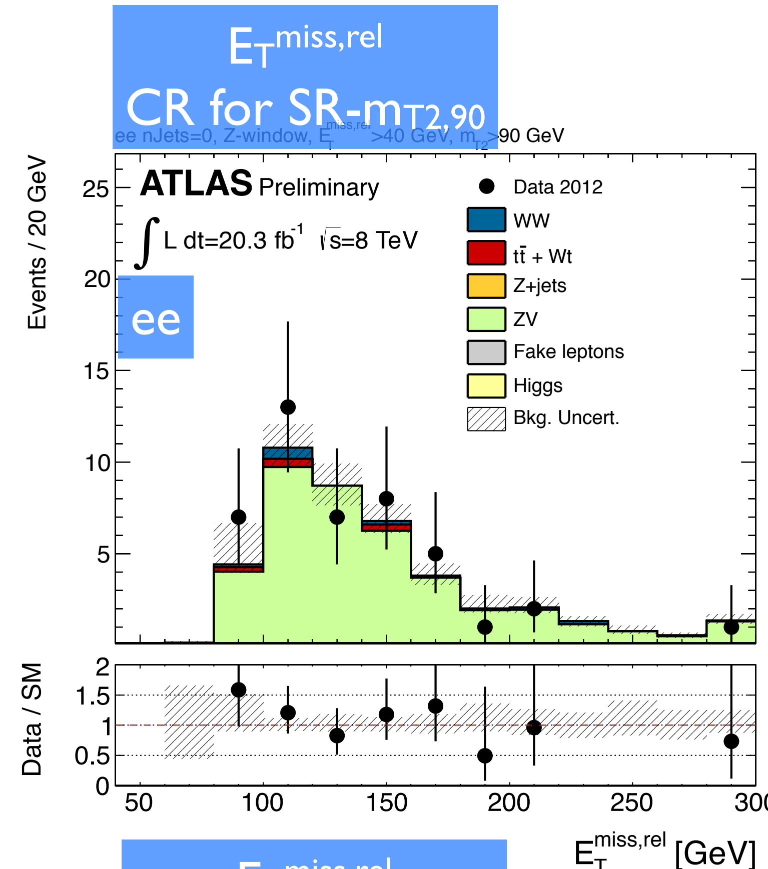


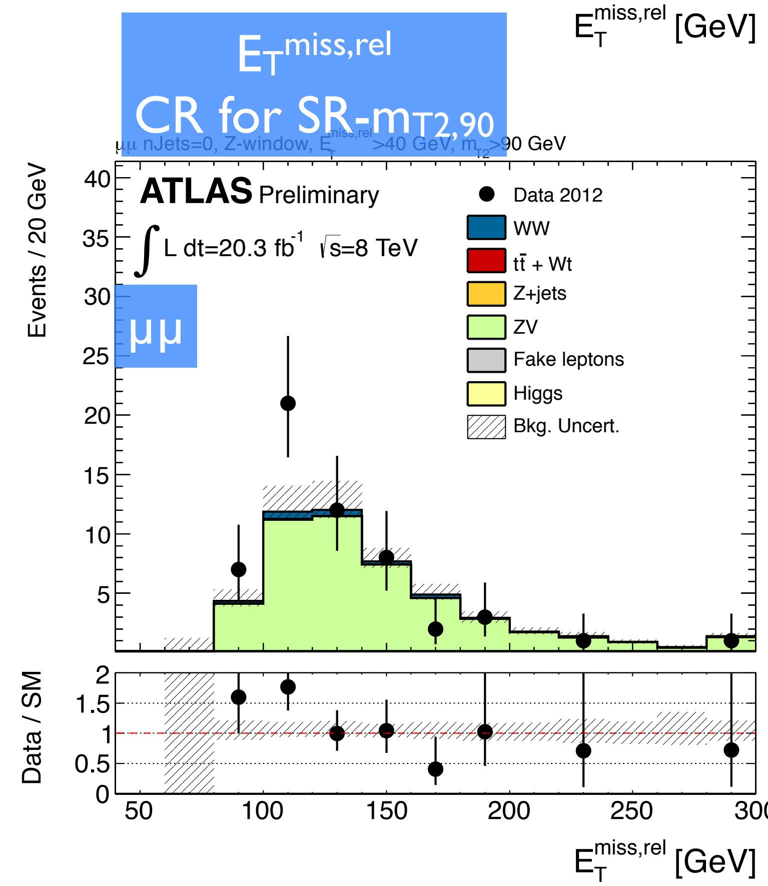
Z+vector control regions

Signal region	$SRm_{T2,90}$	$SRm_{T2,110}$
Lepton flavor	e^-e^+, $\mu^-\mu^+$	
Jets	Full jet veto	
m_{ll}	Z window	
$E_T^{\mathrm{miss,rel}}$	> 40 GeV	
m_{T2}	> 90 GeV	> 110 GeV

- No control region for SR-WW
- Negligible contribution from non-Z+vector boson sources
  - Z+jets events m_{T2} requirement
  - Confirmation Z+jets contribution is negligible in high-m_{T2} region
- Scale factors

SR-m_{T2}	0.96-1.06 ± 15-16%





Results & interpretation - I

ATLAS-CONF-2013-049

SR-$m_{T2,90}$

	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\pm$	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	$0.00^{+0.18}_{-0.00}$	$0.00^{+0.14}_{-0.00}$	$0.00^{+0.15}_{-0.00}$	$0.00^{+0.28}_{-0.00}$
Observed $\sigma^{95}_{\mathrm{vis}}$ [fb]	0.44	0.47	0.51	0.81
Expected $\sigma^{95}_{\mathrm{vis}}$ [fb]	$0.50^{+0.22}_{-0.15}$	$0.58^{+0.25}_{-0.17}$	$0.57^{+0.25}_{-0.17}$	$1.00^{+0.41}_{-0.28}$

SR-$m_{T2,110}$

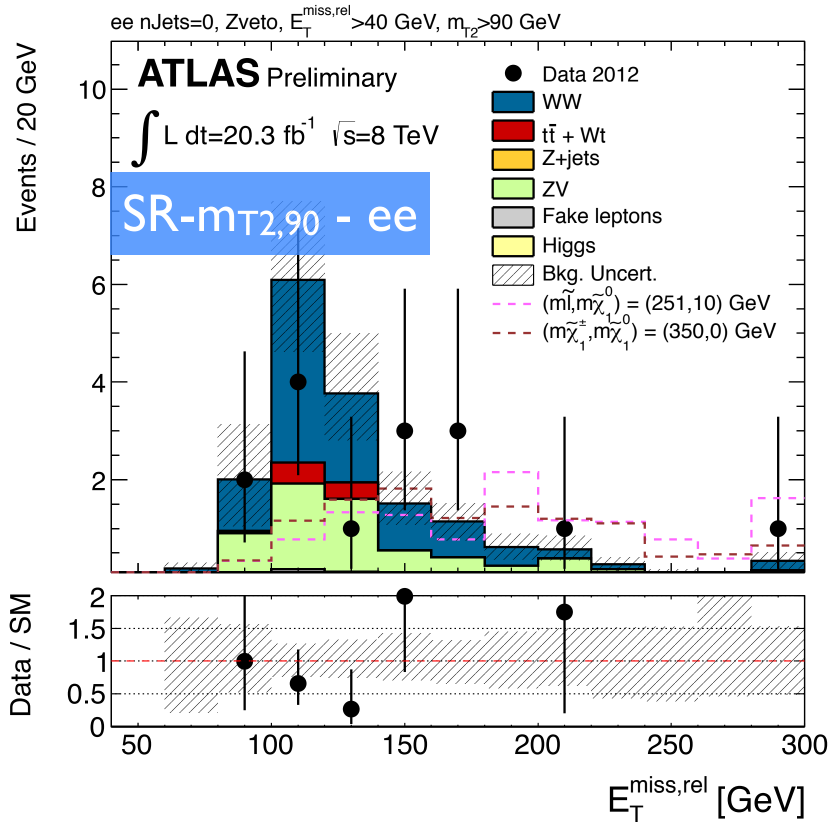
	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\pm$	all
Observed	4	5	4	13
Background total	6.1 ± 2.2	4.4 ± 2.0	6.3 ± 2.4	16.9 ± 6.0
WW	2.7 ± 1.5	3.6 ± 2.0	2.9 ± 1.6	9.1 ± 4.9
ZV ($V = W$ or Z)	2.7 ± 1.4	0.2 ± 0.1	3.4 ± 1.8	6.3 ± 3.3
Top	0.7 ± 0.7	0.6 ± 0.4	0.0 ± 0.0	1.3 ± 1.0
Higgs	0.05 ± 0.03	0.12 ± 0.04	0.05 ± 0.02	0.22 ± 0.05
Fake	$0.00^{+0.09}_{-0.00}$	$0.00^{+0.13}_{-0.00}$	$0.00^{+0.12}_{-0.00}$	$0.00^{+0.28}_{-0.00}$
Observed $\sigma^{95}_{\mathrm{vis}}$ [fb]	0.27	0.35	0.28	0.54
Expected $\sigma^{95}_{\mathrm{vis}}$ [fb]	$0.33^{+0.16}_{-0.10}$	$0.33^{+0.16}_{-0.09}$	$0.33^{+0.16}_{-0.10}$	$0.62^{+0.23}_{-0.16}$

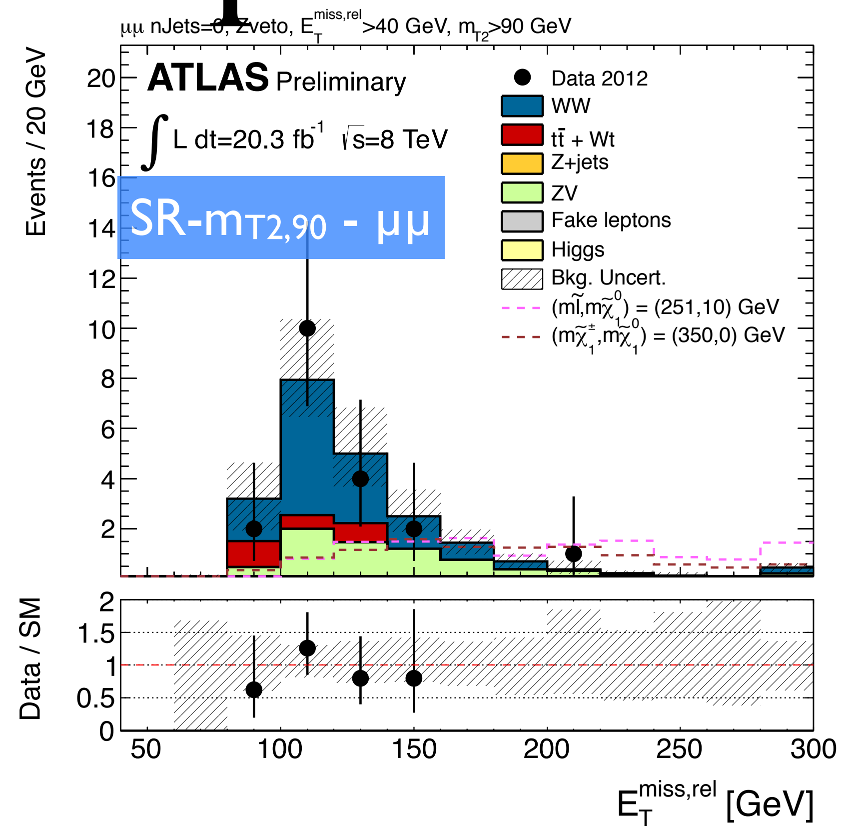
SR-WW

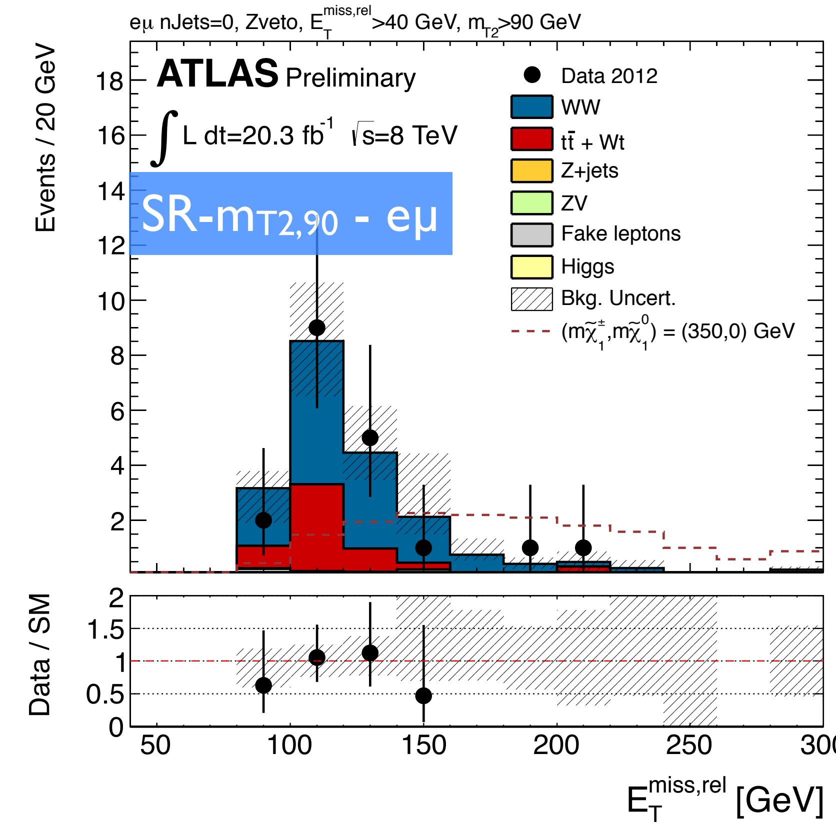
	$SRWW_a$	$SRWW_b$	$SRWW_c$
Observed	123	16	9
Background total	117.9 ± 14.6	13.6 ± 2.3	7.4 ± 1.5
Top	15.2 ± 6.6	2.7 ± 1.1	1.0 ± 0.7
WW	98.6 ± 14.6	10.2 ± 2.1	5.9 ± 1.3
ZV ($V = W$ or Z)	3.4 ± 0.8	$0.26^{+0.31}_{-0.26}$	0.29 ± 0.14
Higgs	0.76 ± 0.14	0.21 ± 0.06	0.10 ± 0.04
fake	$0.02^{+0.33}_{-0.02}$	$0.26^{+0.30}_{-0.26}$	$0.12^{+0.17}_{-0.12}$
Observed $\sigma^{95}_{\mathrm{vis}}$ [fb]	1.94	0.58	0.43
Expected $\sigma^{95}_{\mathrm{vis}}$ [fb]	$1.77^{+0.66}_{-0.49}$	$0.51^{+0.21}_{-0.15}$	$0.37^{+0.18}_{-0.11}$

- Observations are consistent with Standard model prediction
- Set limits on the cross section of non-Standard Model processes

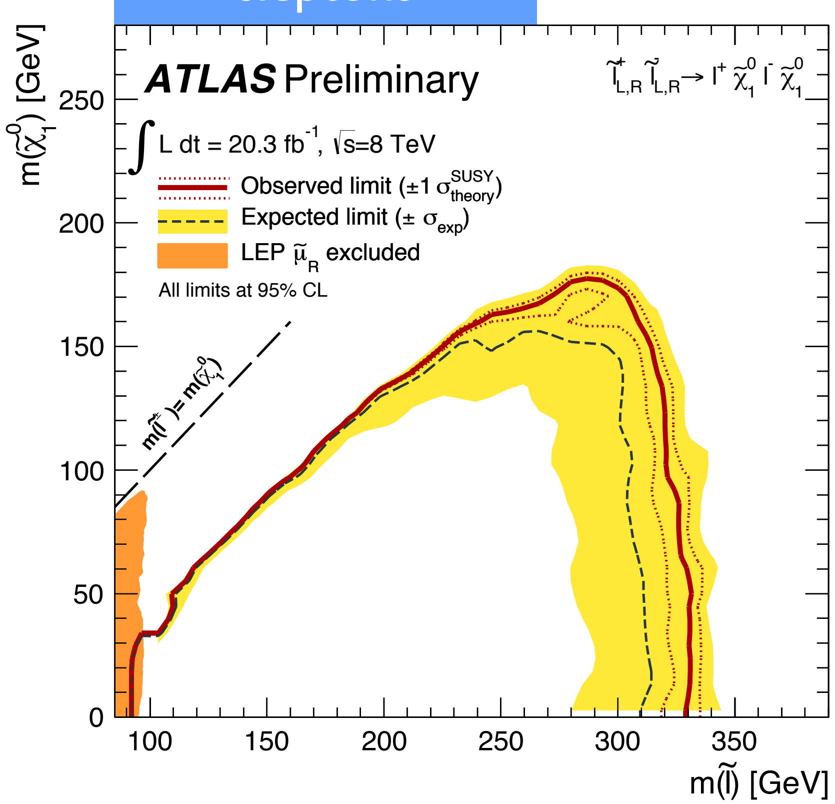
Results & interpretation - II



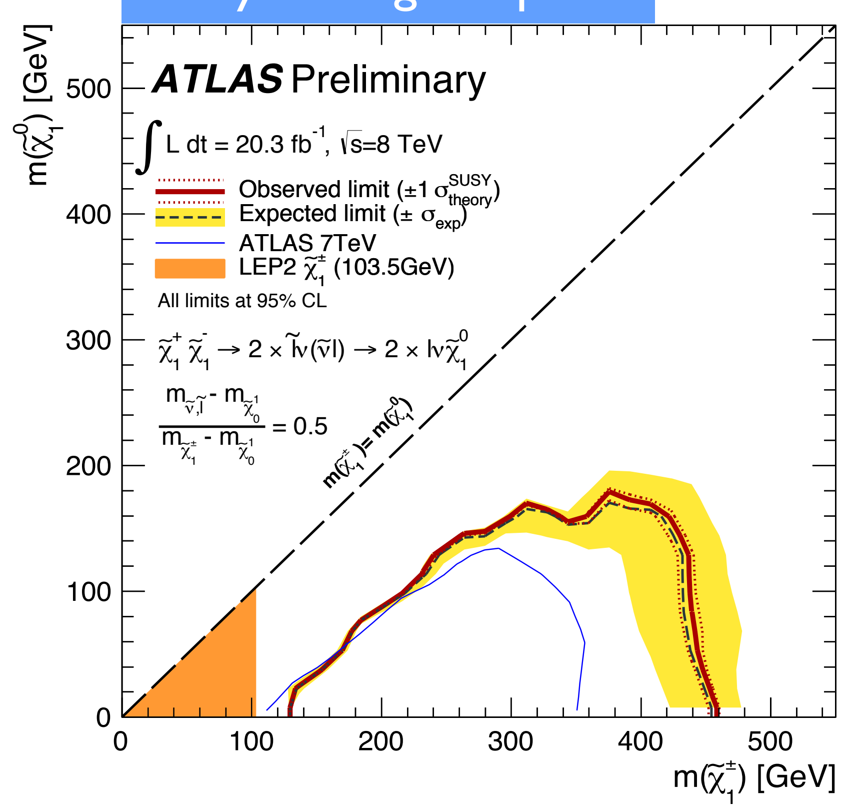




Right+left-handed sleptons

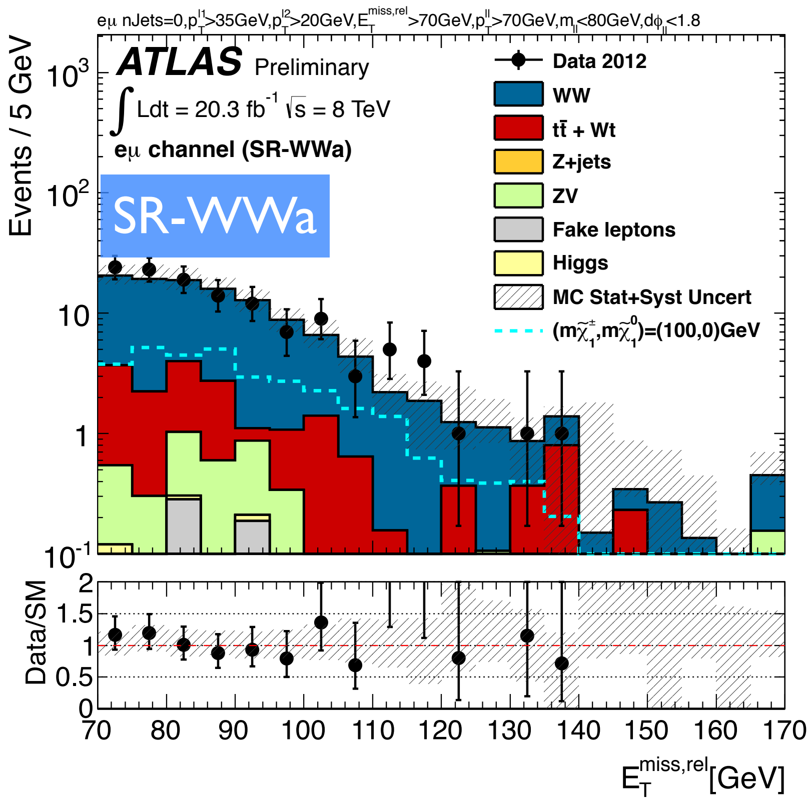


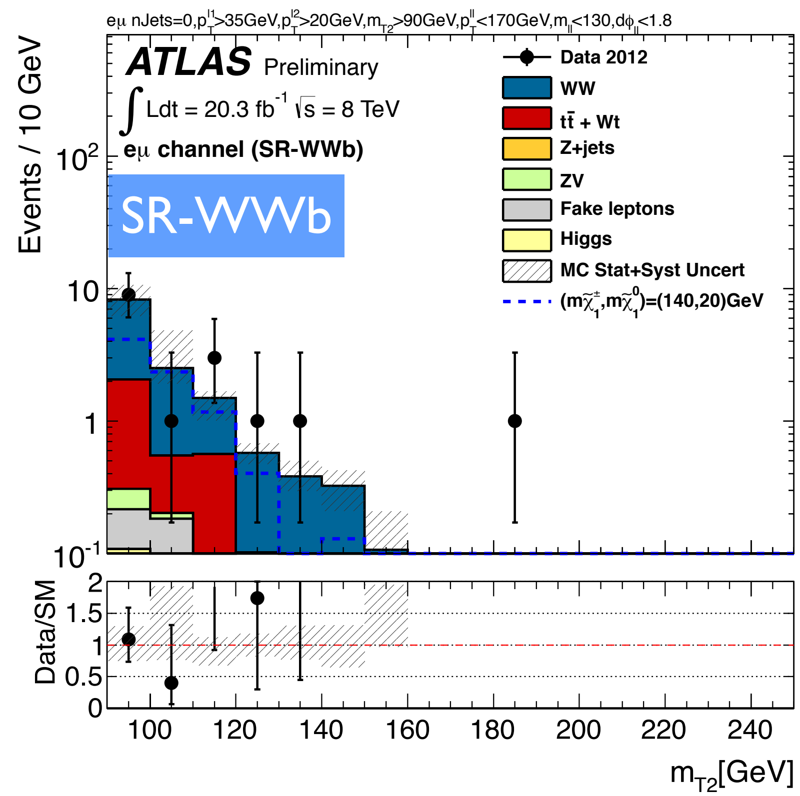
$\chi_1^{\pm}\chi_1^{\pm}$ production decay through sleptons

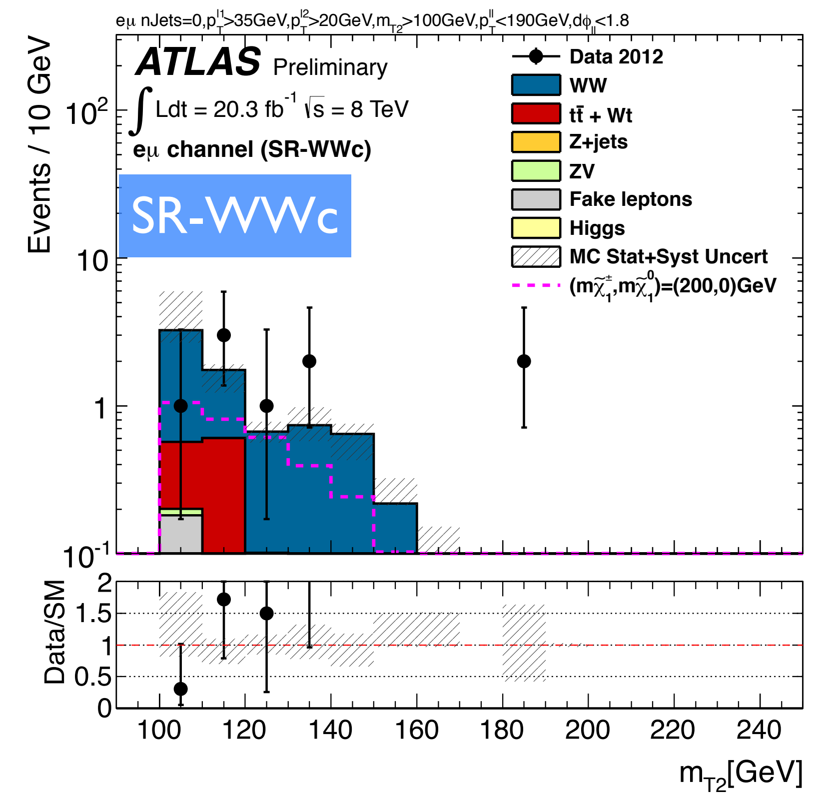


- Combination performed by taking best performing signal region for each model
- Direct slepton production:
  - Slepton masses between 90 GeV and 320 GeV excluded
- $\chi_1^{\pm}$ pair production (decay via slepton):
  - $\chi_1^{\pm}$ masses between 130 GeV and 450 GeV excluded

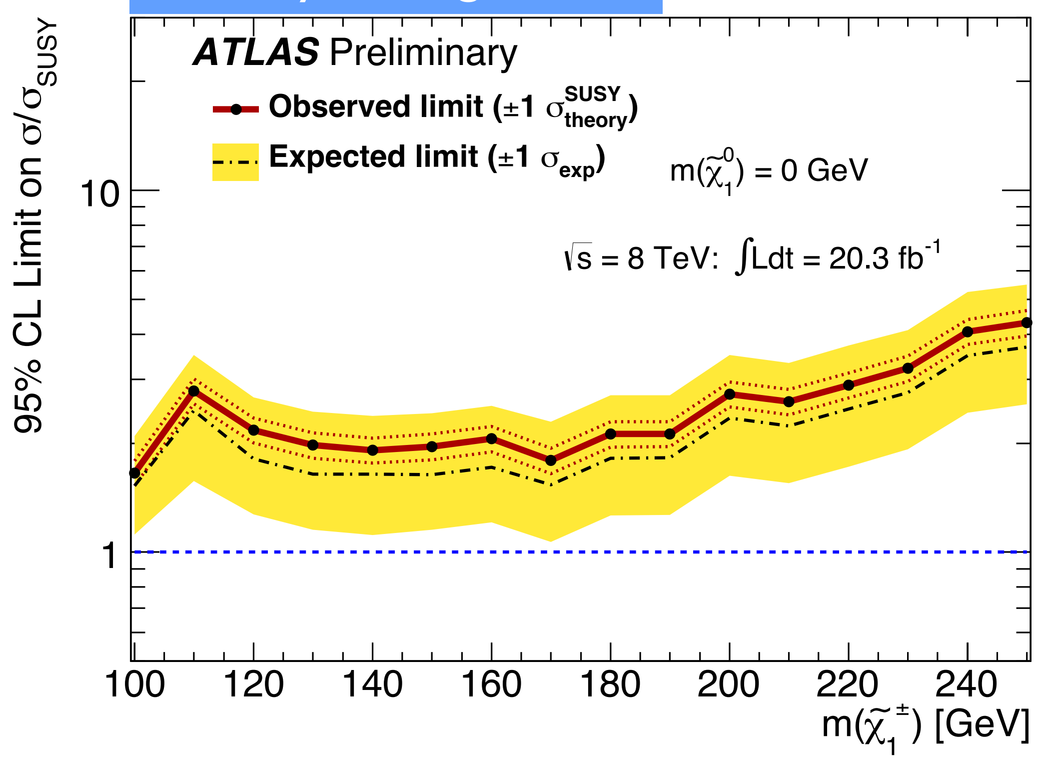
Results & interpretation - III







$\chi_1^\pm \chi_1^\pm$ production decay through Ws



- $\chi_1^\pm$ pair production (decay via W):
  - Excluded cross-section above model cross section by factor 1.9-2.8 in $\chi_1^\pm$ mass range 100-190 GeV

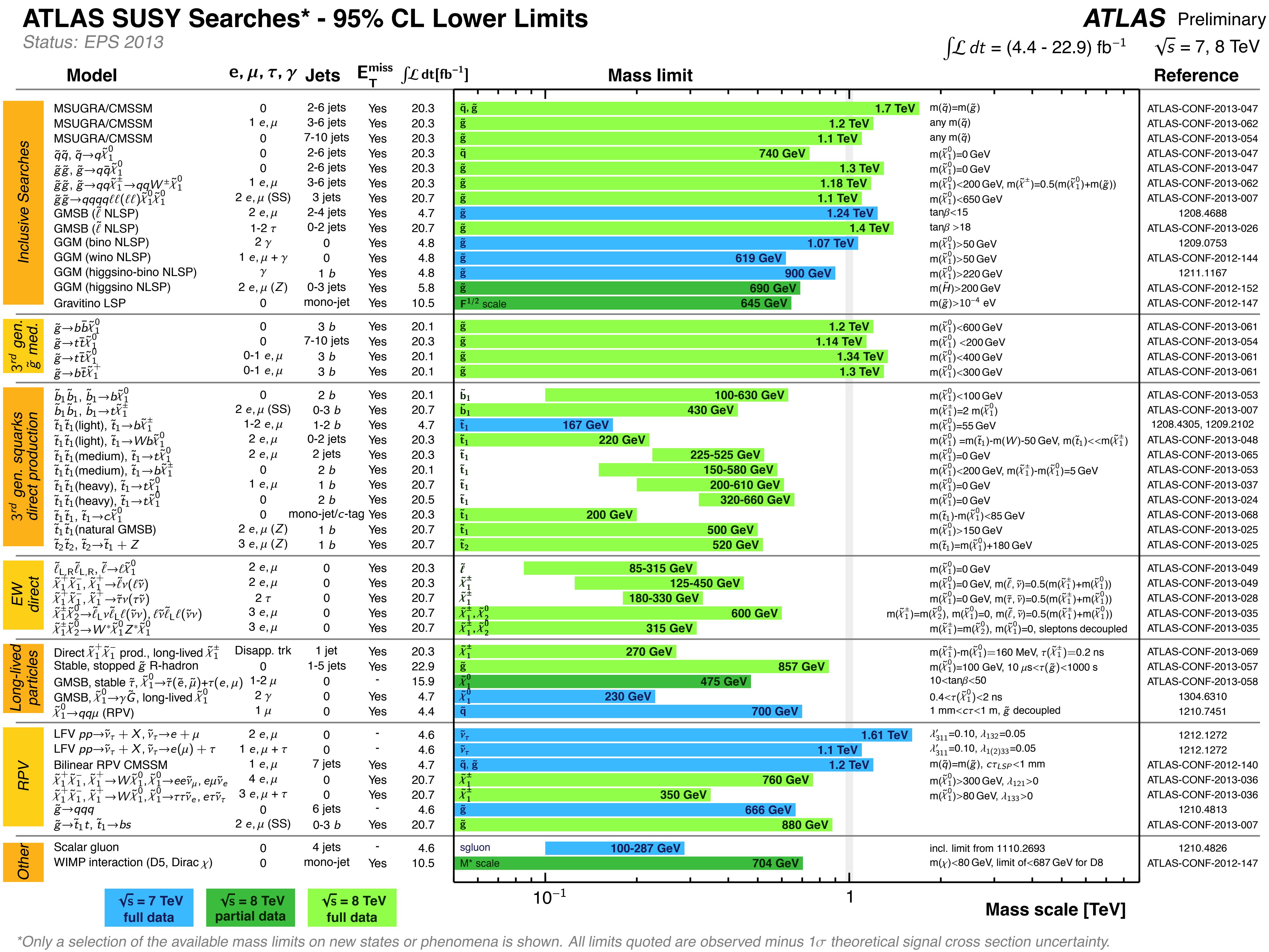
Conclusions

- Latest results for the search for direct production of charginos and sleptons in the two lepton channel have been shown
- Observations are consistent with the Standard Model predictions
- Limits are set on the mass of sleptons and charginos
- Limits are set on the production cross section of charginos which decay via a W boson
- Outlook:
  - We plan to update these results in a summer paper
  - Plan to add new channels targeting $\chi_2^0\chi_1^\pm$
  - Two leptons consistent with a Z-boson
  - Same sign leptons
    - Target scenarios with low mass splitting between $\chi_2^0/\chi_1^\pm$ and χ_1^0

Thank you for listening!

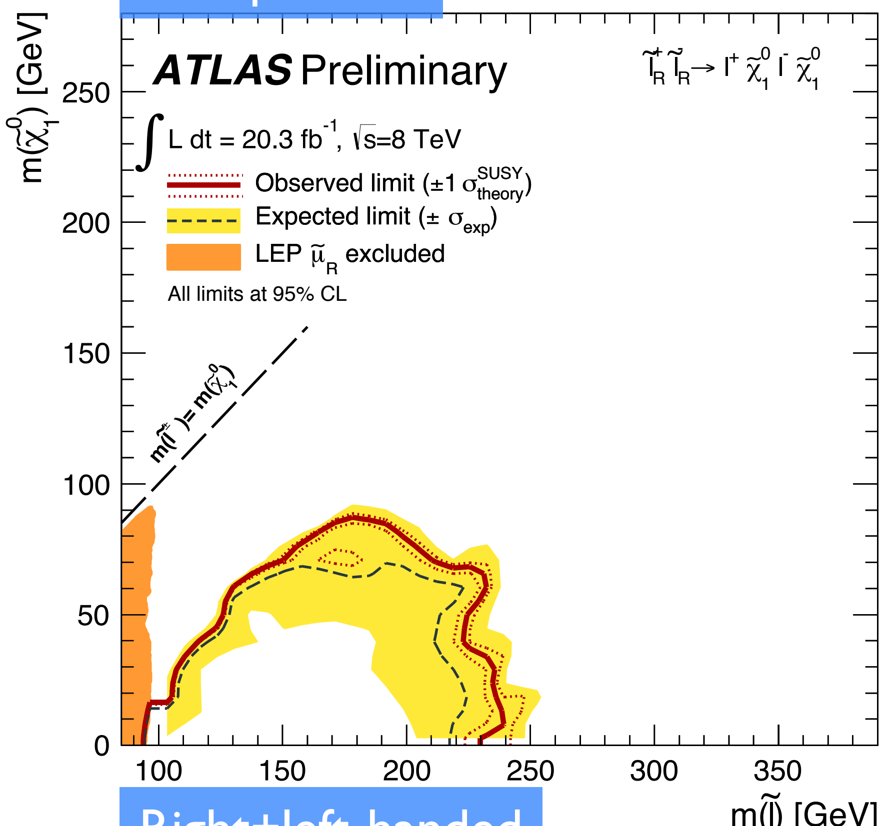
Backup

ATLAS SUSY reach

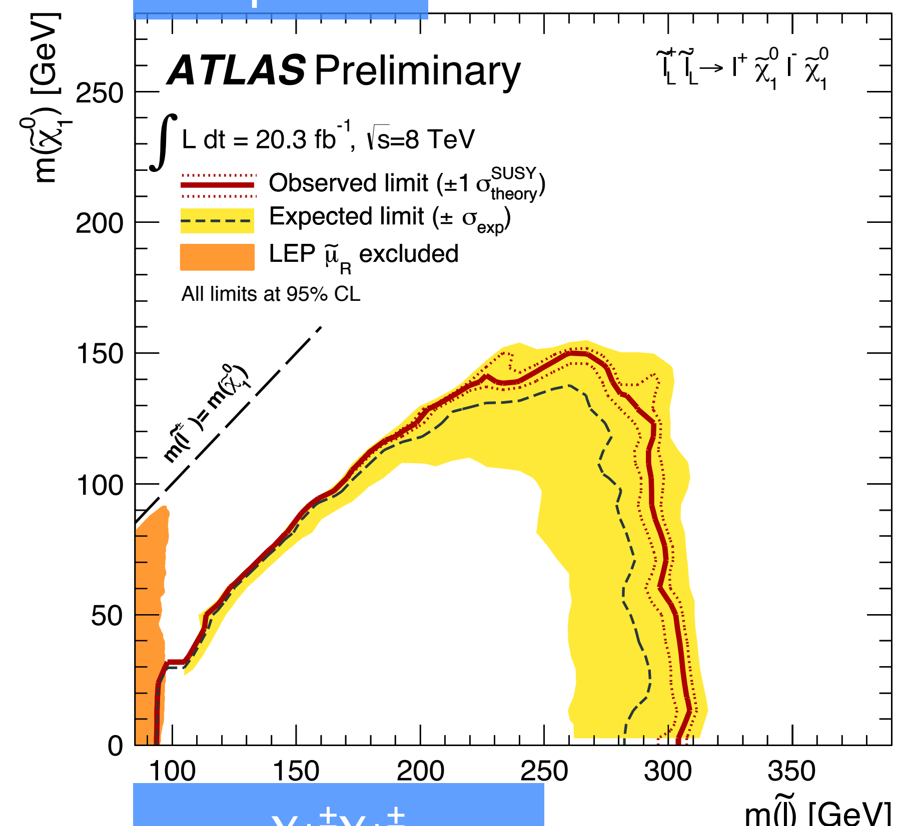


Results & interpretation - II

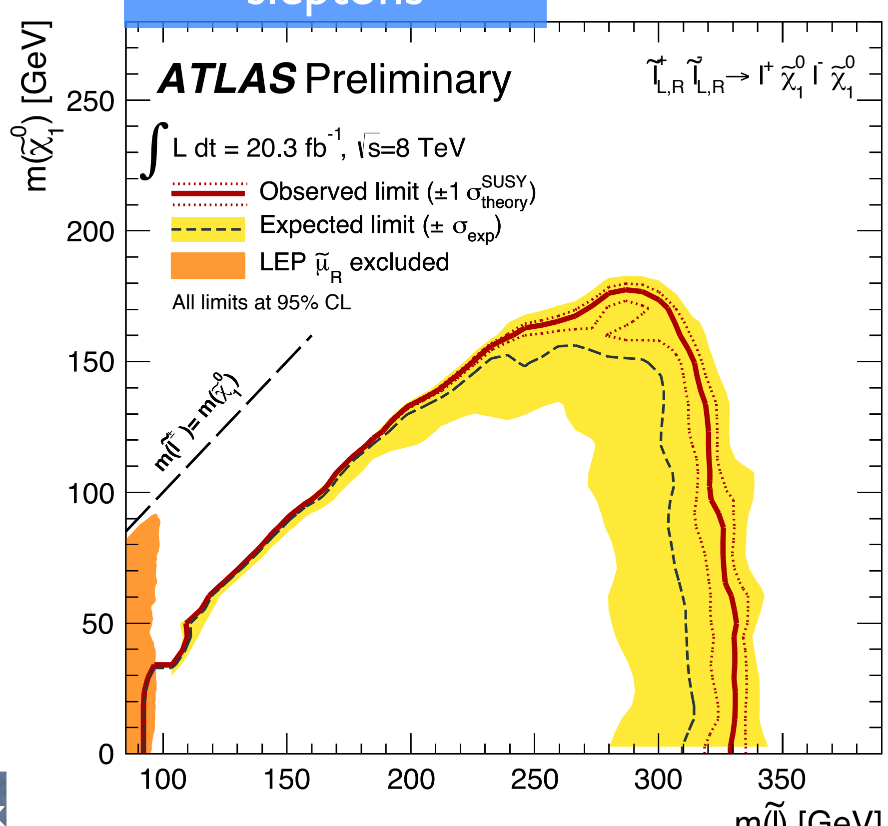
Right-handed sleptons



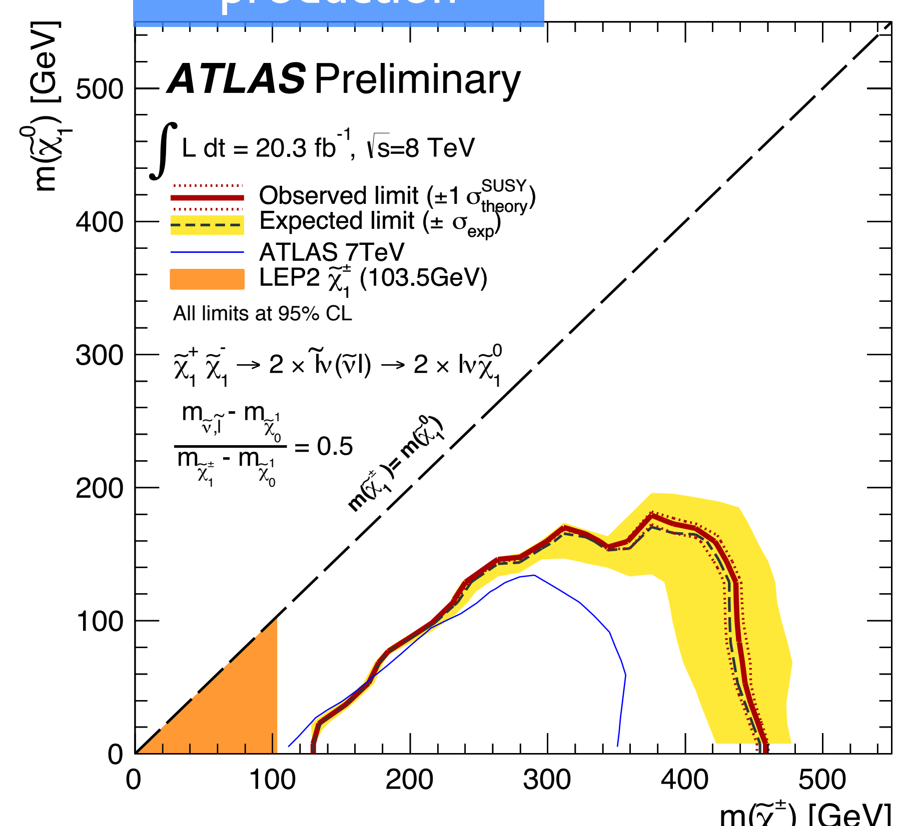
Left-handed sleptons



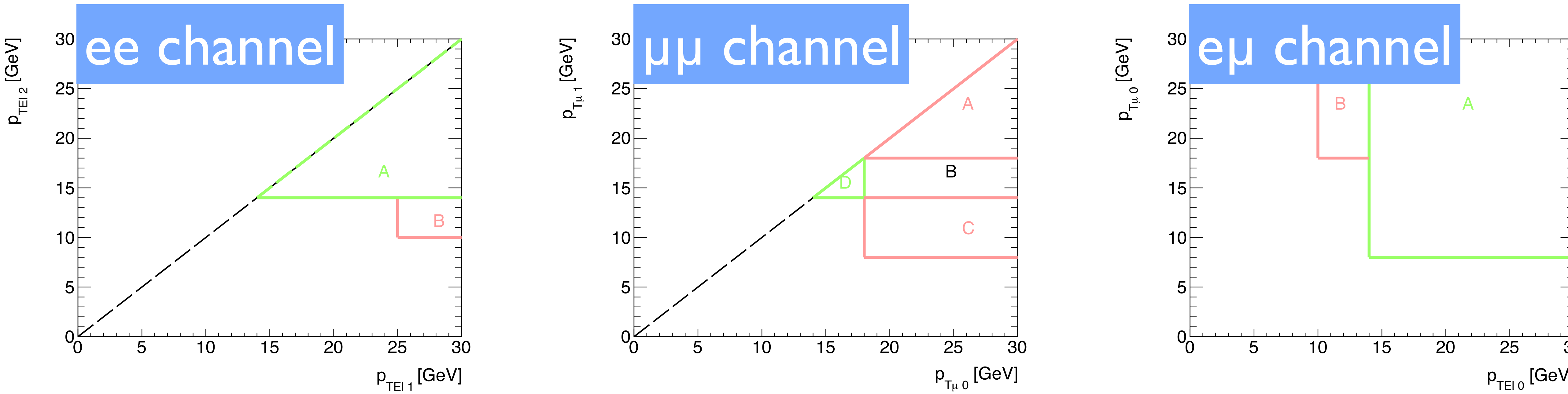
Right+left-handed sleptons



$\chi_1^\pm \chi_1^\pm$ production



Trigger Scheme



ee channel	Leading p_T	Sub-leading p_T
Region A	12	12
Region B	24	7
μμ channel	**Leading p_T**	**Sub-leading p_T**
Region A	18	8
Region B	18	8
	13	13
Region C	18	8
Region D	13	13
eμ channel	**Electron p_T**	**Muon p_T**
Region A	12	8
Region B	7	18