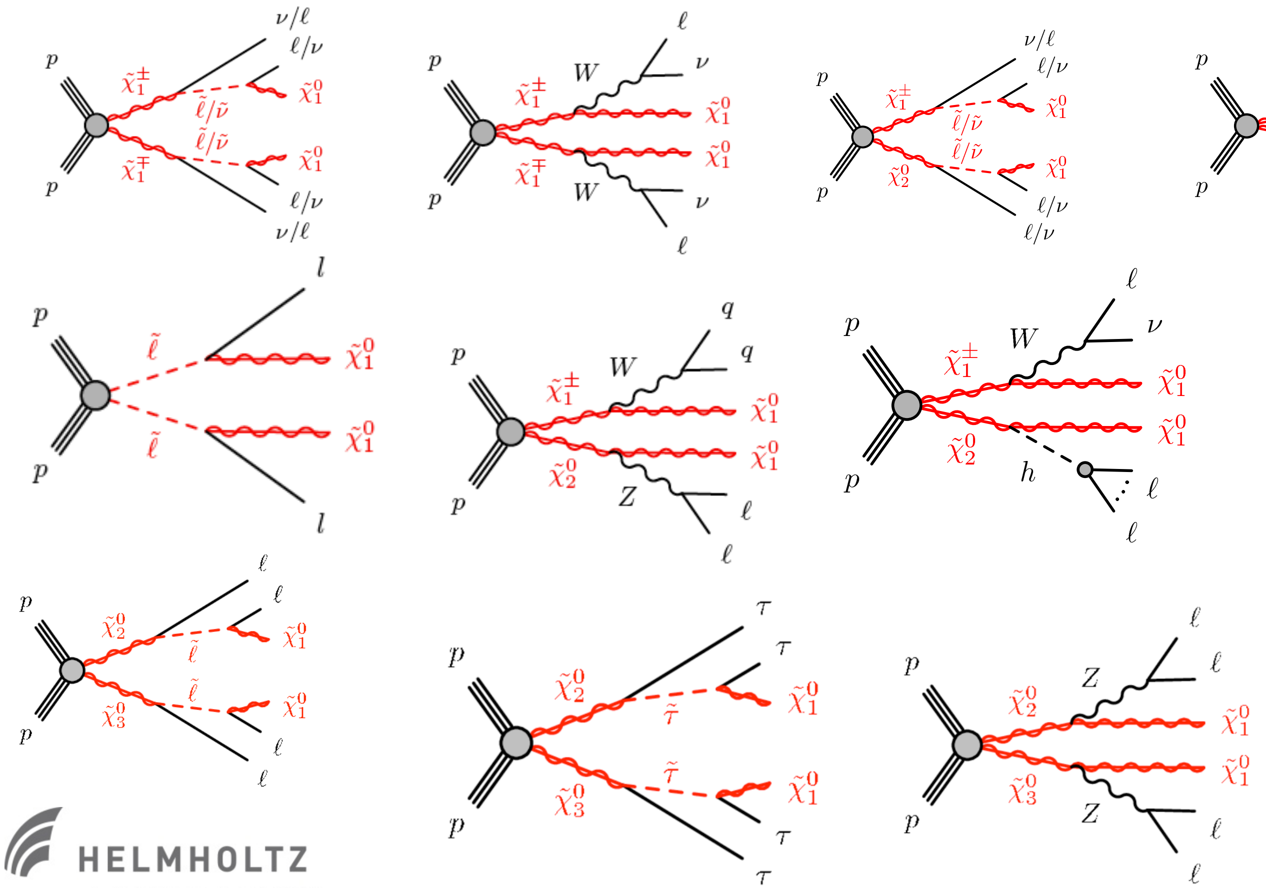
Searches for the production of electroweak supersymmetric particles in final states with two, three and four leptons with the ATLAS experiment



Janet Dietrich
DESY ATLAS group

LHC discussion
2nd of June 2014

HELMHOLTZ
ASSOCIATION

EW SUSY ANALYSES - STATUS

analysis	paper/conference note	comment
2lepton (e,μ)	arxiv:1403.5294	accepted by JHEP
3lepton (e,μ,τ)	arxiv:1402.7029	JHEP 04 (2014)169
4lepton (e,μ, τ)	arxiv:1405.5086	submitted to PRD
2lepton (τ)	paper publication in few days/weeks	under ATLAS review
1lepton (e,μ) + γγ	C1N2->WhN1N1 decay; h→ bb/γγ	
1lepton (e,μ) + b-b		
SS 2lep (e,μ)	C1N2->WhN1N1 decays; h→lvjj	
γ	higgs decays to Graviton+ N1; graviton decays to gravitino+ γ	iterating internal note with edboard, expect publication in several weeks/ few months
γ + b-b	higgsino like N1s; N1-> gravitino + h or γ; h→bb	
1lepton + γ	N1C1 are winos and decay to gravitino	
γγ	bino-like N1, N1->Gγ	
2,3,4 lepton	combination paper	
HL-LHC	conference note	ongoing work

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EW SUSY ANALYSES - STATUS

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I have discussed already electroweak SUSY searches in July 2013:

https://indico.desy.de/getFile.py/access?contribId=0&resId=0&materialId=slides&confId=7885

→ for all analyses the full 2012 ATLAS data set was studied (20.3 fb^{-1})

→ results are updates of published 2013 conference notes:

- optimized signal regions and background estimations
- added new signal regions and decay channels
- combined signal regions and channels

	gravitino	few months
γγ	bino-like N1, N1->Gγ	
2,3,4 lepton	combination paper	
HL-LHC	conference note	ongoing work

2 lepton ANALYSIS

paper:

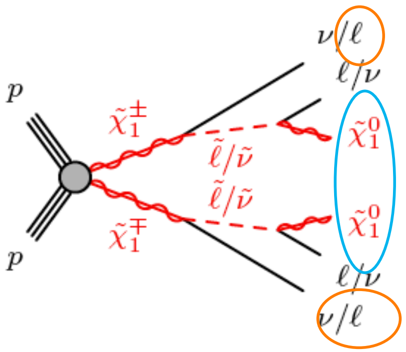
CERN-PH-EP-2014-037 (arXiv: 1403.5294)

→accepted by JHEP

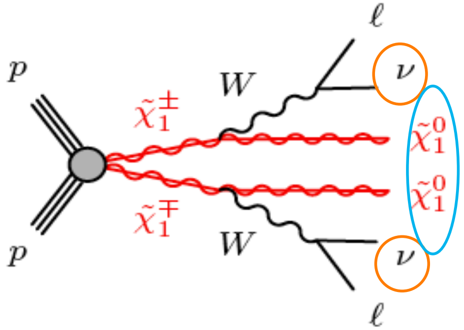
Search for direct production of charginos, neutralinos and sleptons in final states with two leptons and missing transverse momentum in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS detector

2 lepton SUSY MODELS

chargino1-chargino1 production



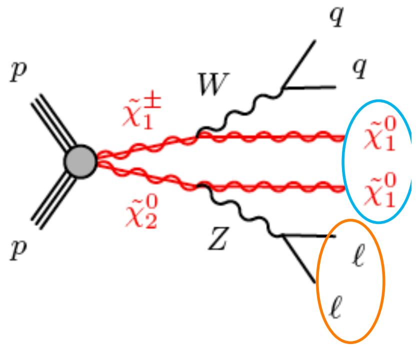
via intermediate sleptons



with on-shell W

E_T^{miss} from neutralino1 (LSPs) and neutrinos
same flavour and different flavour leptons

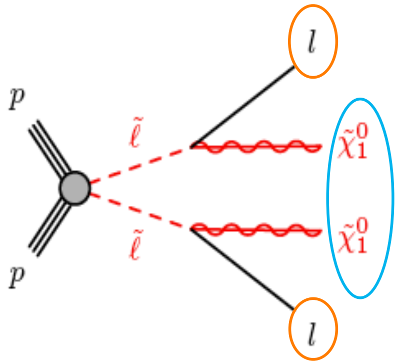
chargino1-neutralino2 production



with on-shell W,Z

E_T^{miss} from neutralino1 (LSPs) + 2 jets in final state
ONLY same flavour leptons (ee, μμ)

slepton pair production



via virtual Z

E_T^{miss} from neutralino1 (LSPs)
ONLY same flavour leptons (ee, μμ)

2 lepton FINAL STATES

- focus on different di-lepton final states

$pp \to \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \to W\tilde{\chi}_1^0\, W\tilde{\chi}_1^0 \to \ell\nu_\ell\tilde{\chi}_1^0\, \ell'\nu_{\ell'}\tilde{\chi}_1^0$

$ee,\ \mu\mu, e\mu$

$pp \to \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \to \tilde{\ell}\nu_\ell(\tilde{\nu}_\ell\ell)\, \tilde{\ell}'\nu_{\ell'}(\tilde{\nu}_{\ell'}\ell') \to \ell\nu_\ell\tilde{\chi}_1^0\, \ell'\nu_{\ell'}\tilde{\chi}_1^0$

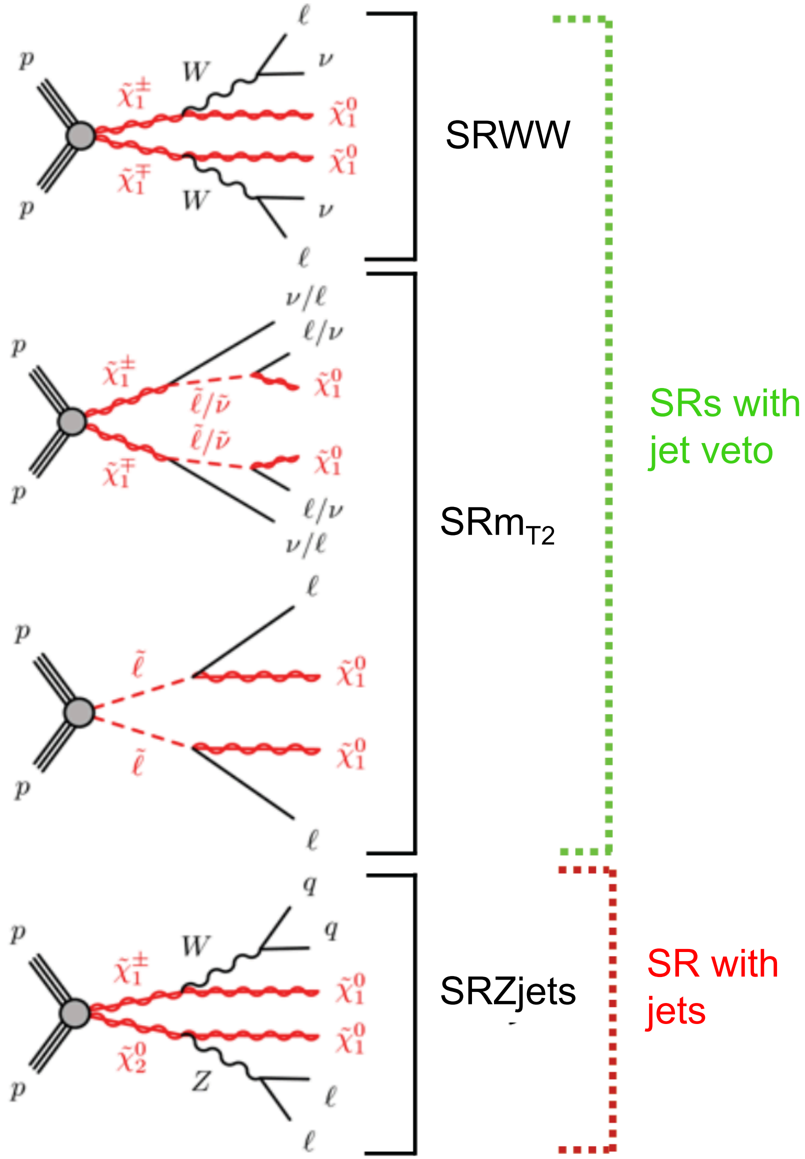
$ee,\ \mu\mu, e\mu$

$pp \to \tilde{\ell}\tilde{\ell} \to \ell\tilde{\chi}_1^0\ell\tilde{\chi}_1^0$

$ee,\ \mu\mu$

$pp \to \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to W\tilde{\chi}_1^0\, Z\tilde{\chi}_1^0 \to qq\tilde{\chi}_1^0\, \ell'\ell'\tilde{\chi}_1^0$

$ee,\ \mu\mu$



2 lepton SIGNAL REGIONS

processes

	Targeted Process	Signal Region
Two Leptons	$\tilde{\ell}^{\pm}\tilde{\ell}^{\mp} \to \ell^{\pm}\tilde{\chi}_1^0 + \ell^{\mp}\tilde{\chi}_1^0$	SR-m_{T2}
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} \to \ell^{\pm}\nu\tilde{\chi}_1^0 + \ell^{\mp}\nu\tilde{\chi}_1^0$	SR-m_{T2}
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} \to W^{\pm}\tilde{\chi}_1^0 + W^{\mp}\tilde{\chi}_1^0 \to \ell^{\pm}\nu\tilde{\chi}_1^0 + \ell^{\mp}\nu\tilde{\chi}_1^0$	SR-WW
	$\tilde{\chi}_2^0\tilde{\chi}_1^{\mp} \to Z\tilde{\chi}_1^0 + W^{\mp}\tilde{\chi}_1^0 \to \ell^{\pm}\ell^{\mp}\tilde{\chi}_1^0 + qq\tilde{\chi}_1^0$	SR-Zjets

SR selection cuts:

= 2 signal leptons with opposite charge + di-lepton trigger

SR	m_{T2}^{90}	m_{T2}^{120}	m_{T2}^{150}	WWa	WWb	WWc	$Zjets$
lepton flavour	DF,SF	DF,SF	DF,SF	DF,SF	DF,SF	DF,SF	SF
central light jets	0	0	0	0	0	0	≥ 2
central b-jets	0	0	0	0	0	0	0
forward jets	0	0	0	0	0	0	0
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	> 10	> 10	> 10	> 10	> 10	> 10	< 10
$m_{\ell\ell}$ [GeV]	—	—	—	< 120	< 170	—	—
$E_T^{miss,rel}$ [GeV]	—	—	—	> 80	—	—	> 80
$p_{T,\ell\ell}$ [GeV]	—	—	—	> 80	—	—	> 80
m_{T2} [GeV]	> 90	> 120	> 150	—	> 90	> 100	—
$\Delta R_{\ell\ell}$	—	—	—	—	—	—	[0.3,1.5]
m_{jj} [GeV]	—	—	—	—	—	—	[50,100]

SRm_{T2} : SR$m_{T2,90}$ for small C1 masses and small slepton-N1 mass gaps,
SR$m_{T2,120,150}$ for higher C1 masses and slepton pair production with larger mass differences
slepton pair production only ee/μμ channel

SRWW: SRWWa for off-shell WW production – like higgs analysis; for C1 masses < 130 GeV,
SRWWb, SRWWc m_{T2} based search for higher C1-N1 mass splitting

SRZjets: ≥2 central jets with p_T > 45 GeV, m(l,l) in Z-mass range, $E_T^{miss,rel}$ cut to suppress Z+jets bg

2 lepton SM BACKGROUNDS

Irreducible backgrounds with two isolated real leptons:

dominating background processes for SRm_{T2} and SRWW:

ttbar, single top Wt, WW

smaller contribution:

ZV (ZZ, WZ)

tiny contribution: Z+jets, higgs

dominating background processes for SRZjets:

Z + jets

smaller contribution:

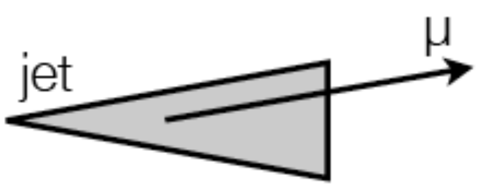
ttbar, single top Wt, WW, ZV

tiny contribution: higgs

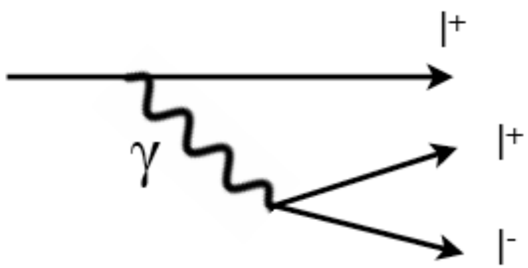
Reducible background with a fake lepton:

- non-prompt leptons originating from light /heavy jets or from conversion mis-identified as real leptons from W, Z or leptonic tau decays
- tiny contribution for all SRs

LF/HF fakes from jets



conversion leptons from photon radiation



2 lepton SM BACKGROUNDS

Process \ SR	SRm_{T2}	SRWW	SRZjets
top	scaling factor		
WW	scaling factor		MC
ZV (WZ, ZZ)	scaling factor		MC
Z + jets	MC		jet smearing
higgs	MC		
fakes	matrix method		

scaling factor

- semi data-driven technique
- define CR close to SRs e.g. by reversing a SR cut
- calculate scaling factor
- scale MC in SR

jet smearing

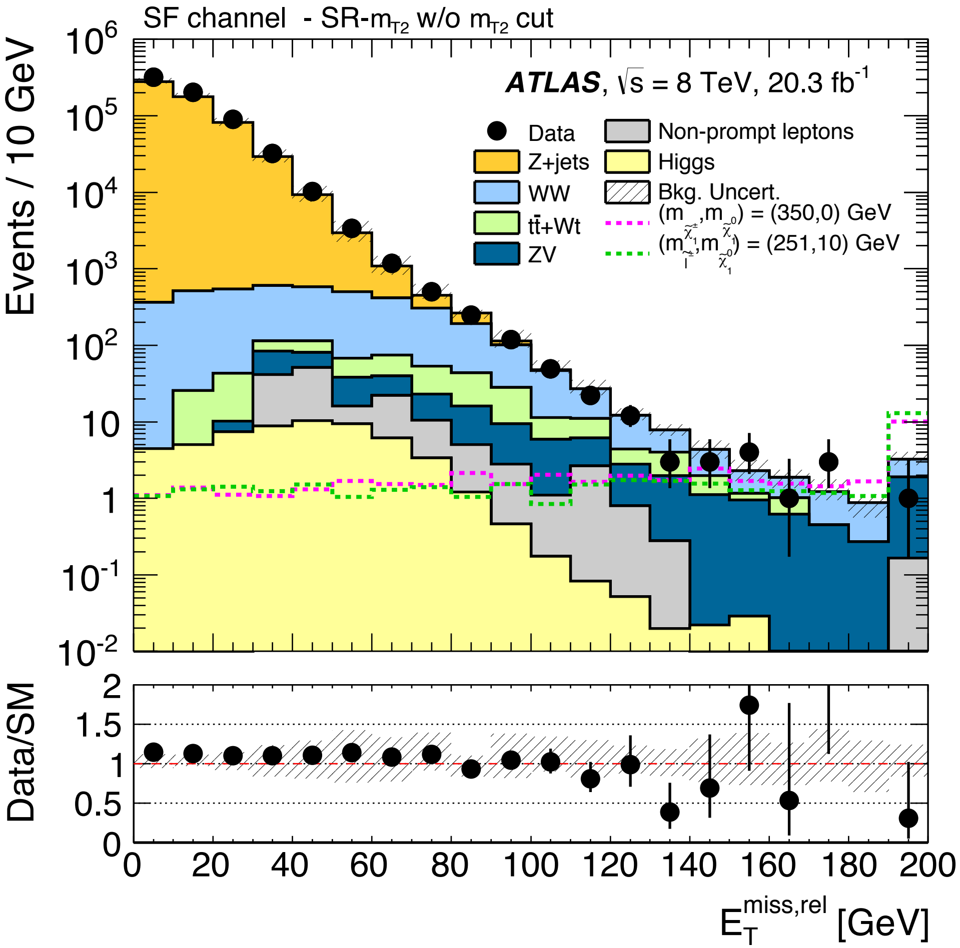
- E_T^{miss} tails from mis-measured jets
- select seed events for Z+jets from data by reversing $E_T^{miss,\ rel}$ cut
- smear jet momenta by random number drawn from jet response function from MC
- pseudo-data E_T^{miss} distribution is normalized to data in another CR and migrated to SR

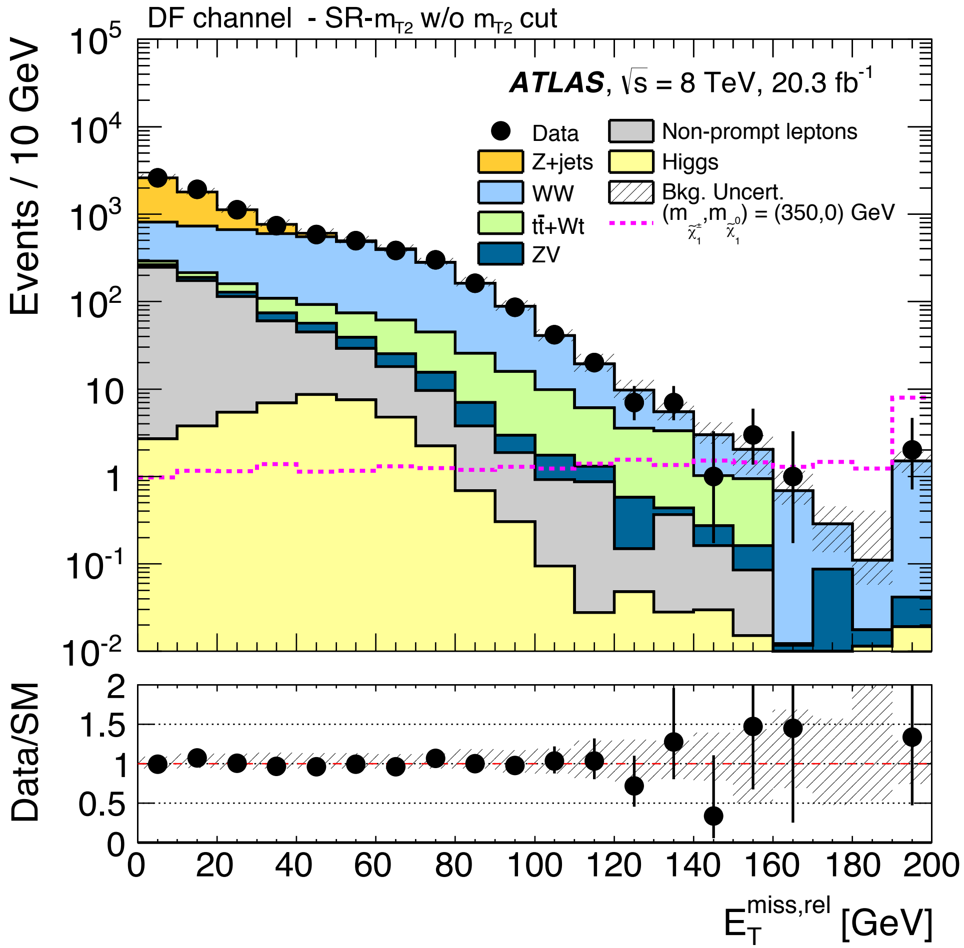
matrix method

- semi-data driven method
- employs a set of linear equations relating kinematic properties of the leptons to be real (R) or fake (F)
- real efficiency (R) is taken from data, fake rate (F) is obtained from MC and corrected for differences between data and MC in each signal and validation region

2 lepton RESULTS SRmT2

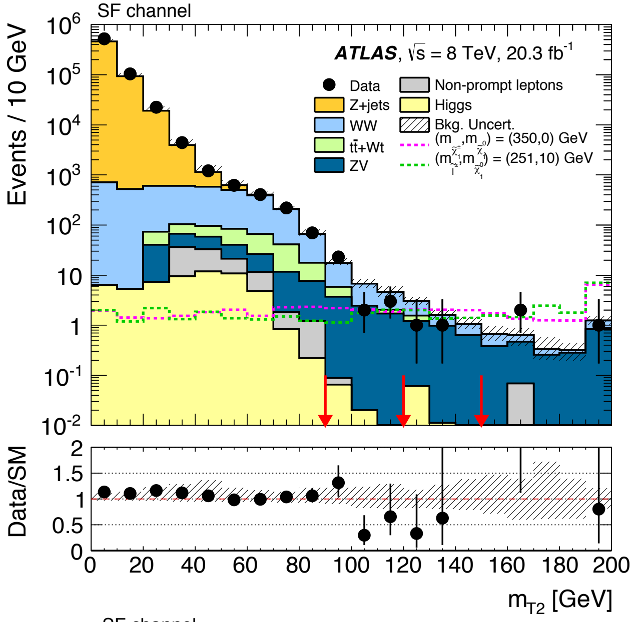
> $E_T^{miss, rel}$ distribution before applying the final m_{T2} cuts

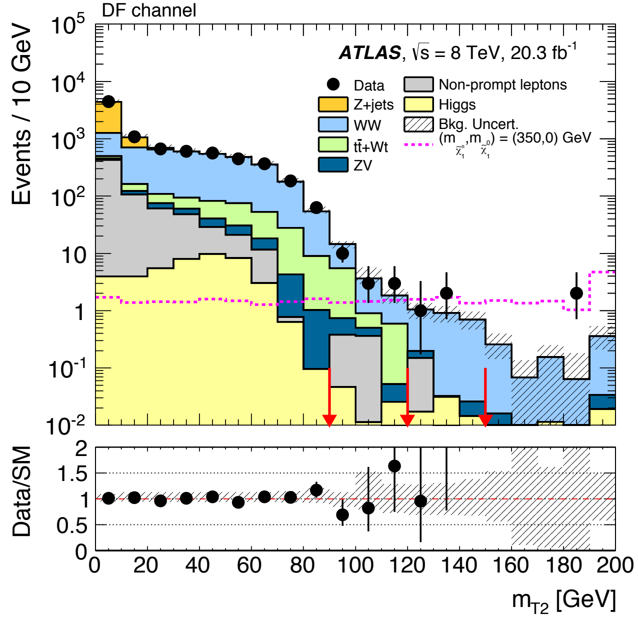




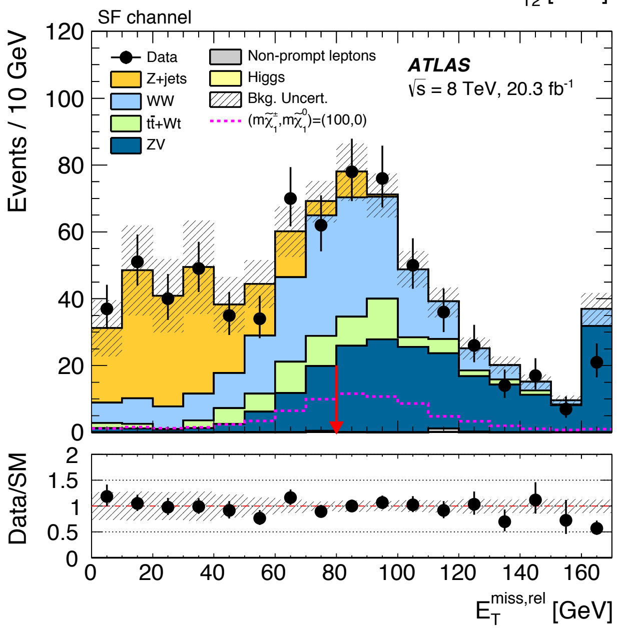
2 lepton SR WW and SR Zjets

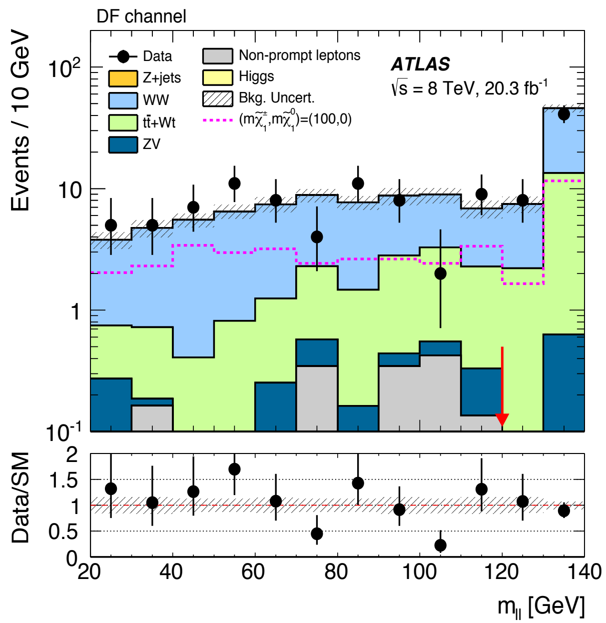
SRZjets





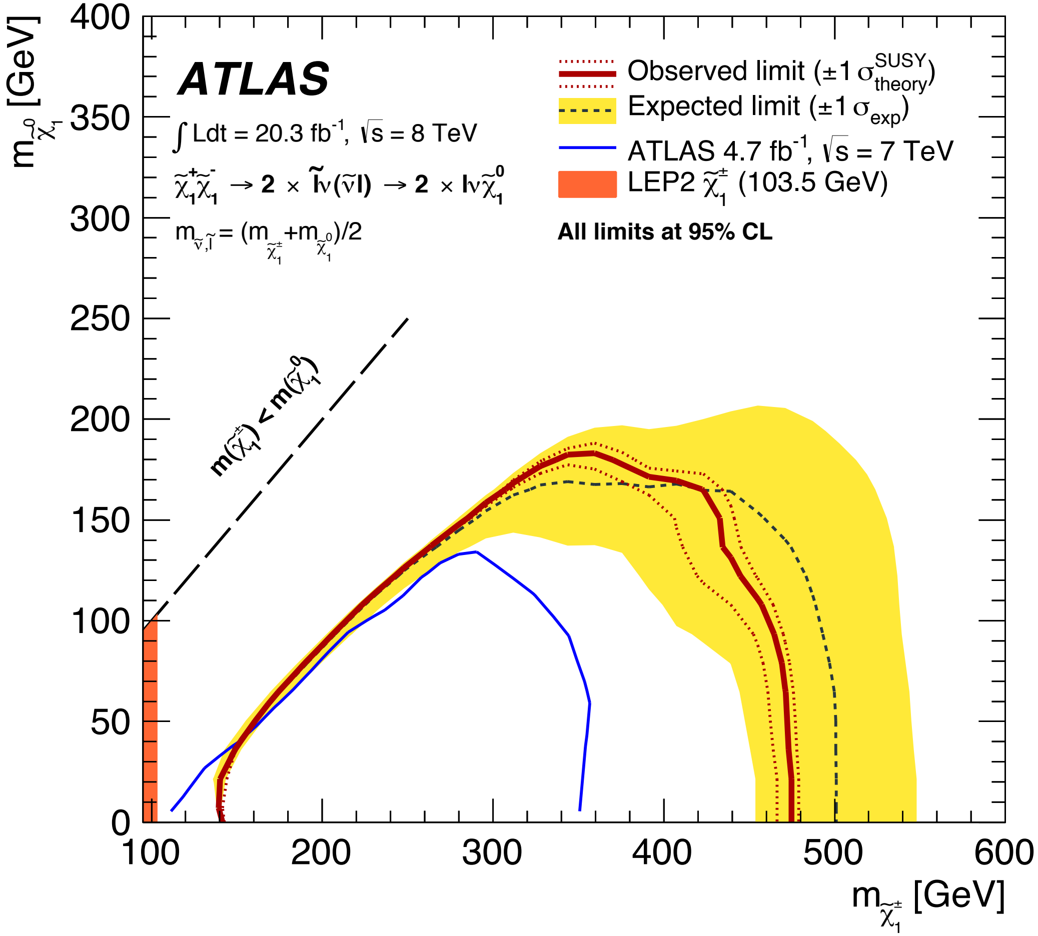
SR WWa

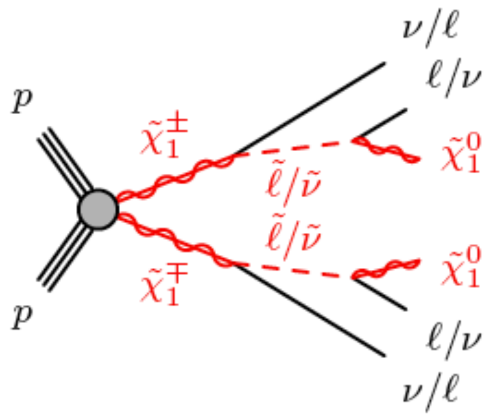




2 lepton RESULTS SRmT2 – chargino pair production

> 95% exclusion region in the chargino1-neutralino1 plane for simplified models with chargino-chargino production via slepton decay



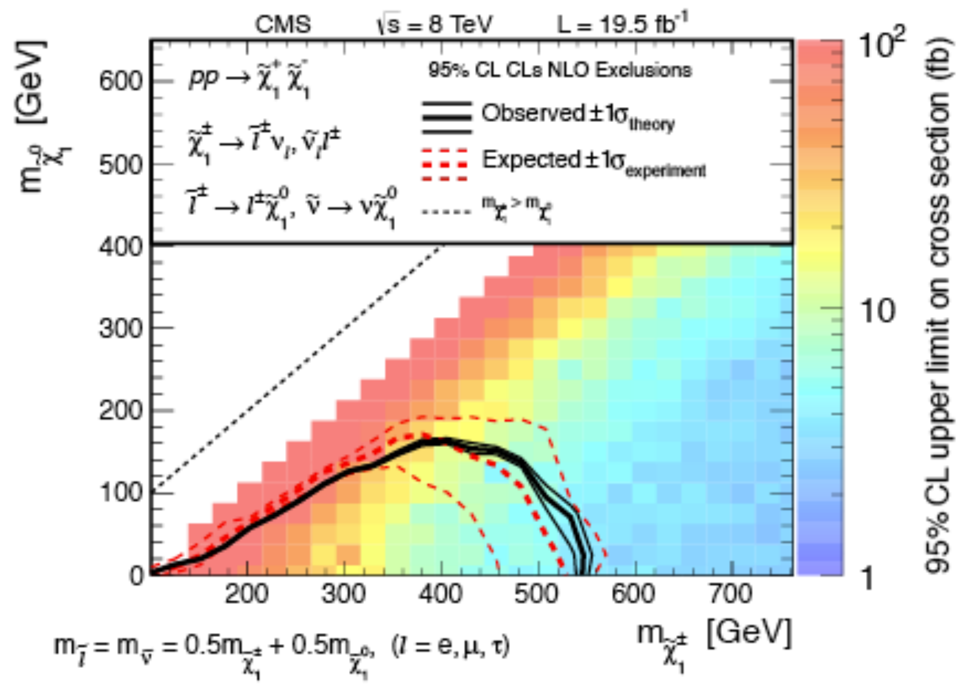


for a massless LSP, models with chargino masses between 140 GeV and 465 GeV are excluded

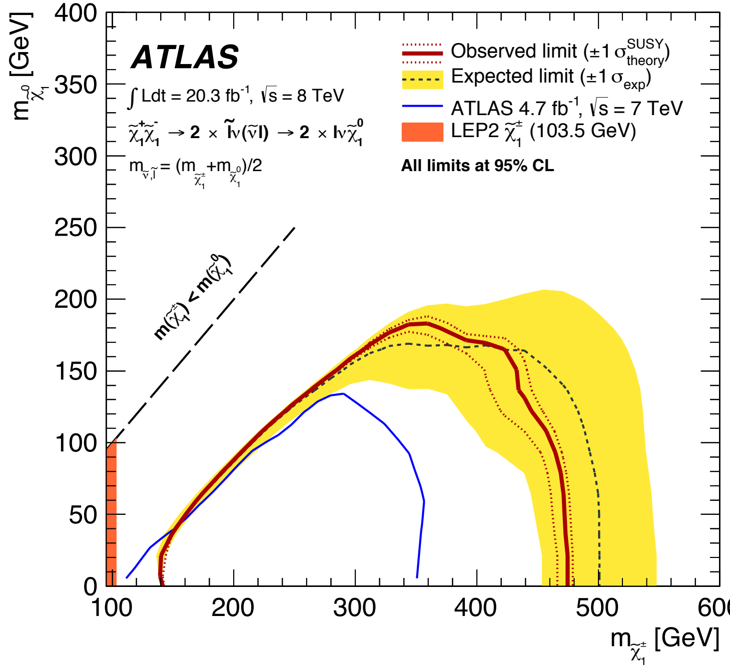
COMPARISON WITH CMS

new CMS paper: published 29th of May: arxiv: 1405.7570, submitted to EPJC

CMS



ATLAS

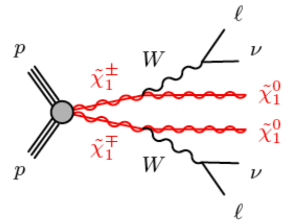


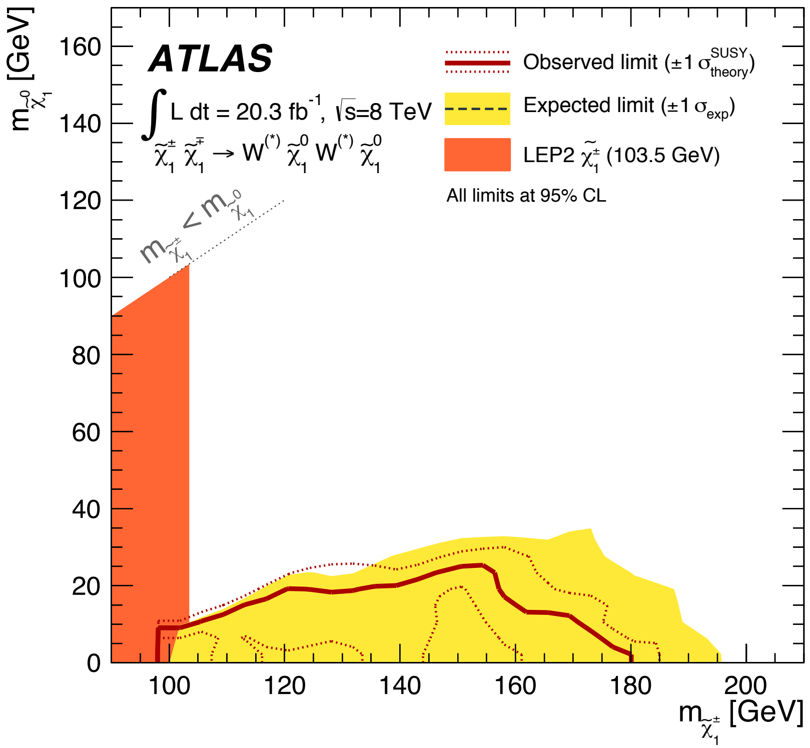
limit: 540 GeV
including τ

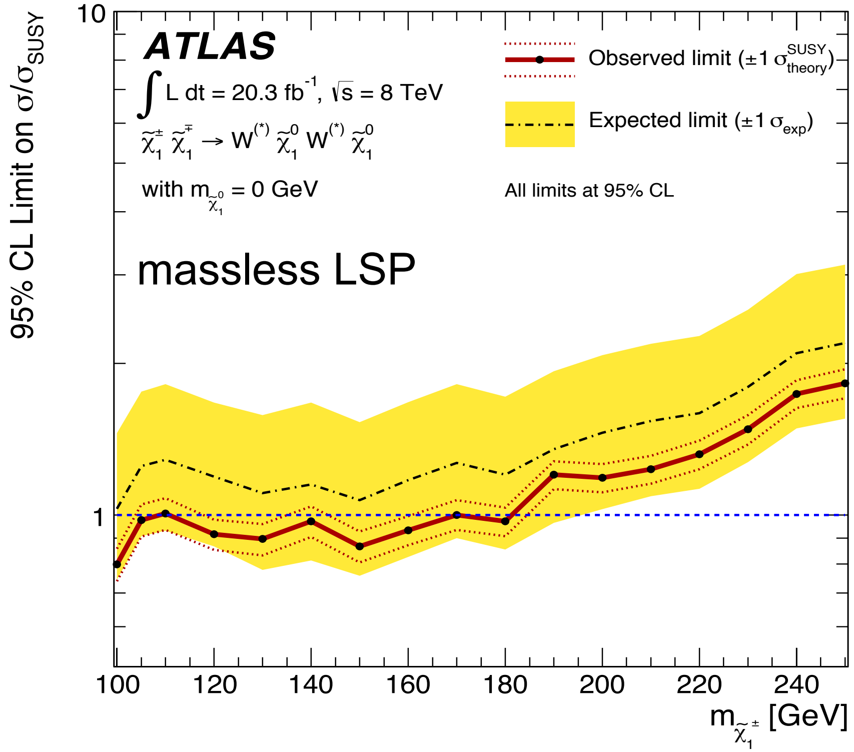
limit: 465 GeV
no τ s included!

2 lepton RESULTS SR WW – chargino pair-production

- 95% exclusion region in the chargino1-neutralino1 plane for simplified models with chargino-chargino production via W mediated decay



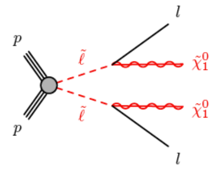


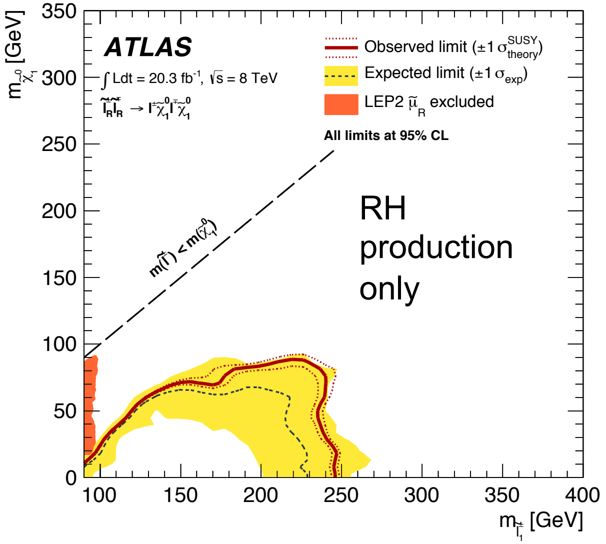


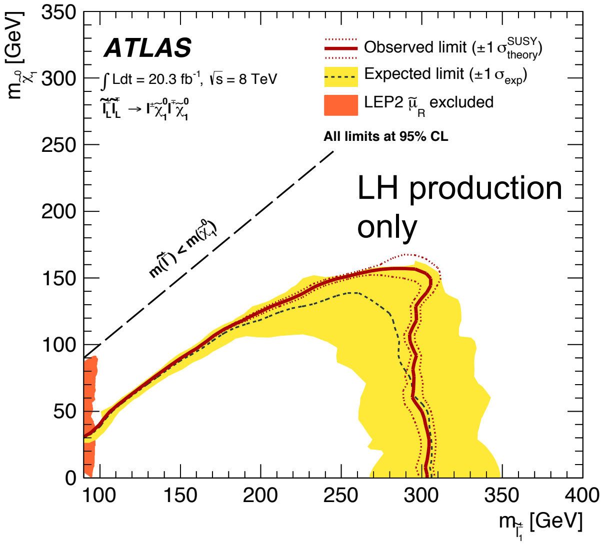
for a massless LSP, models with chargino masses between 100 GeV -105 GeV, 120 GeV- 135 GeV and 145 GeV- 160 GeV are excluded
→ first time a hadron collider has set limits in this channel!

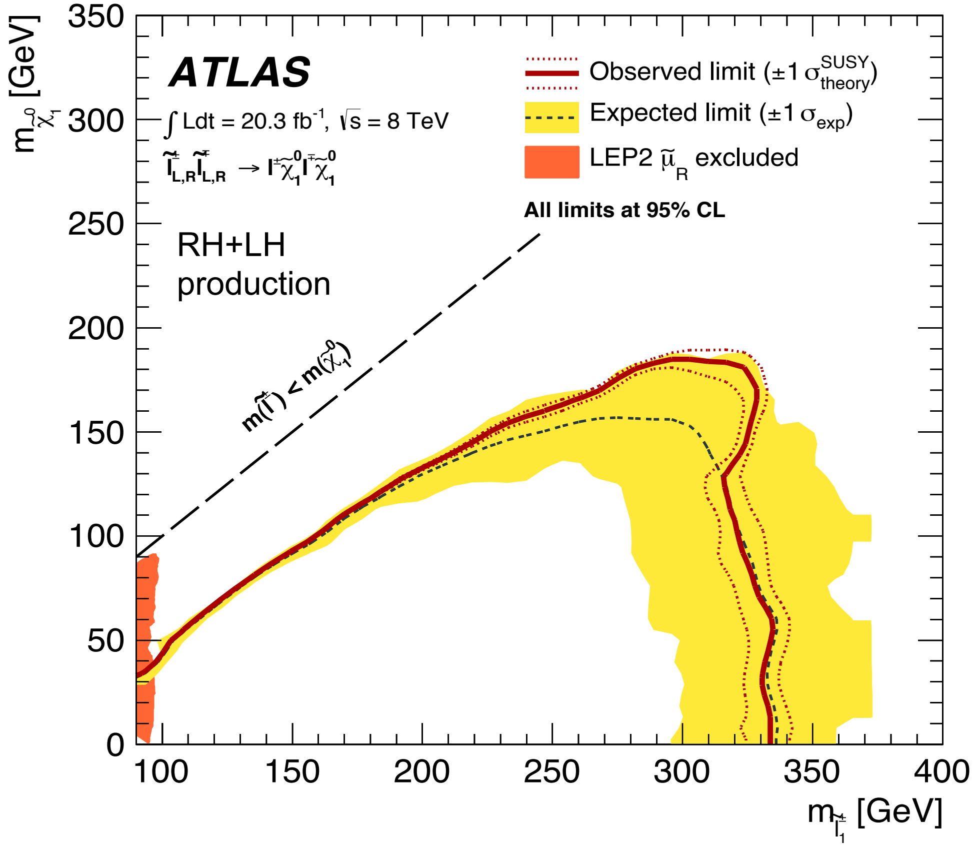
2 lepton RESULTS SRmT2 – slepton pair production

> 95% exclusion region in the slepton-neutralino1 plane for simplified models with slepton pair production (smuon/selections with equal masses)







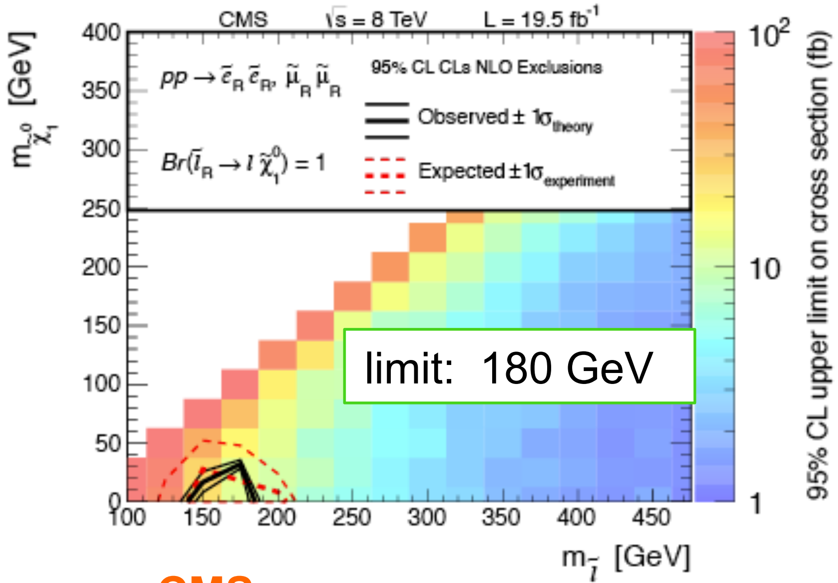


- for a massless LSP, models with slepton masses between 90 GeV and 325 GeV are excluded
- sensitivity decreases with smaller mass splitting: limit for 100 GeV LSP: sleptons between 160 GeV - 310 GeV

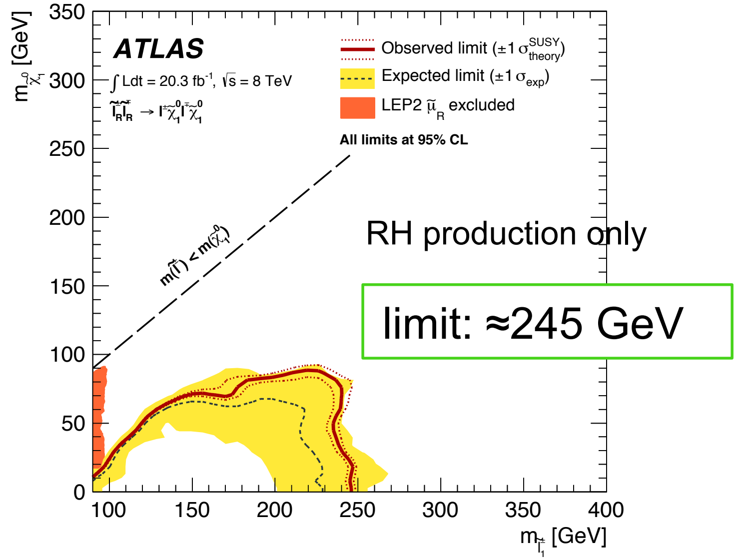
COMPARISON WITH CMS

new CMS paper: published 29th of May: arxiv: 1405.7570, submitted to EPJC

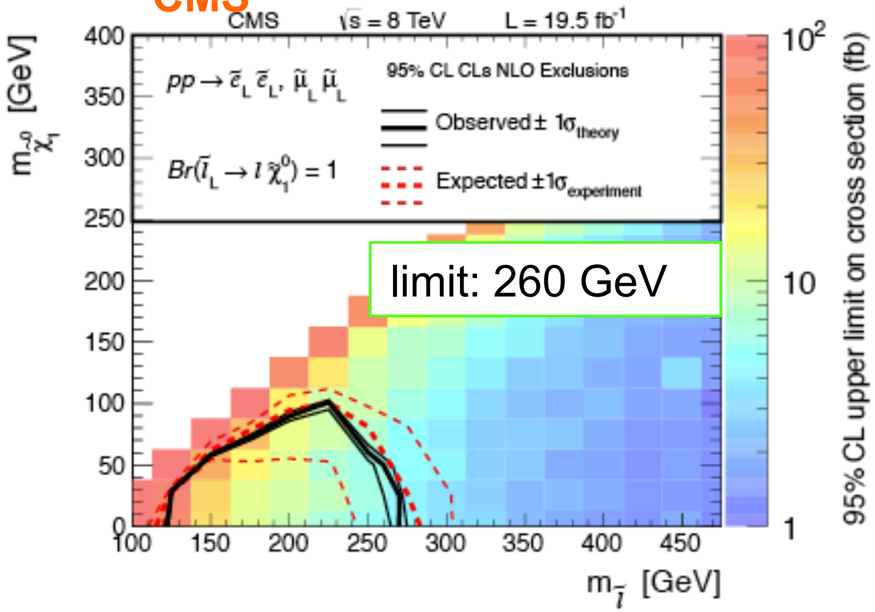
CMS



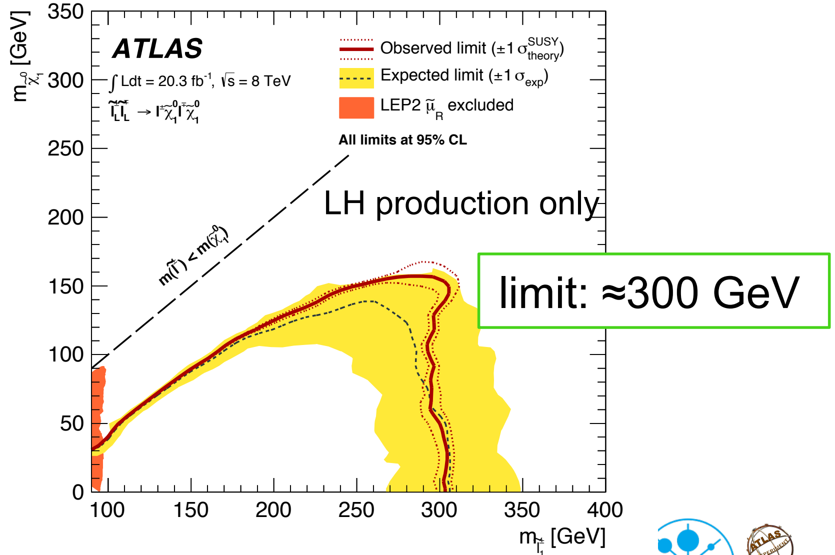
ATLAS



CMS

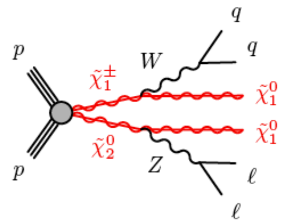


ATLAS

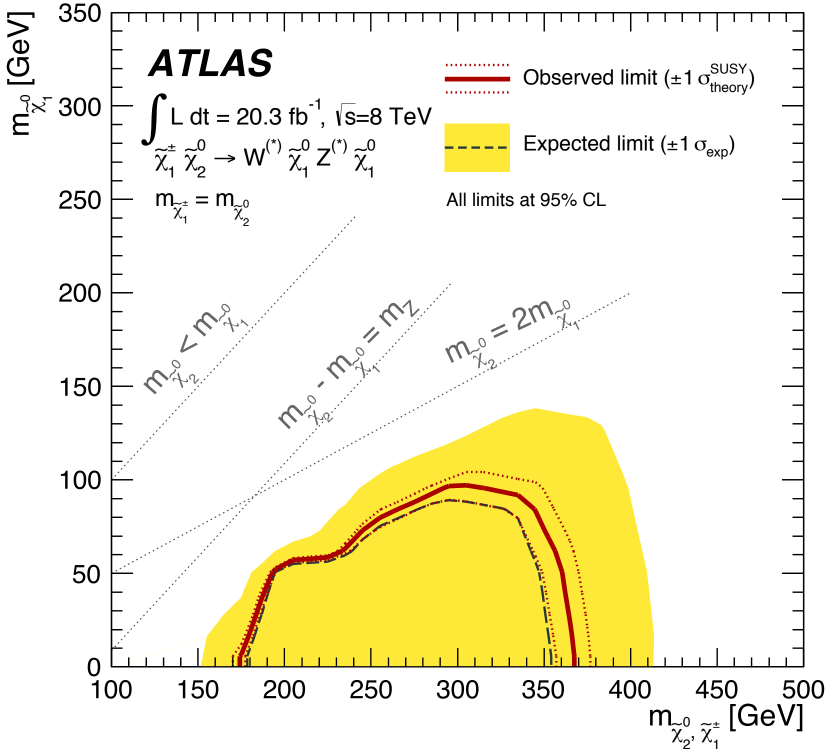


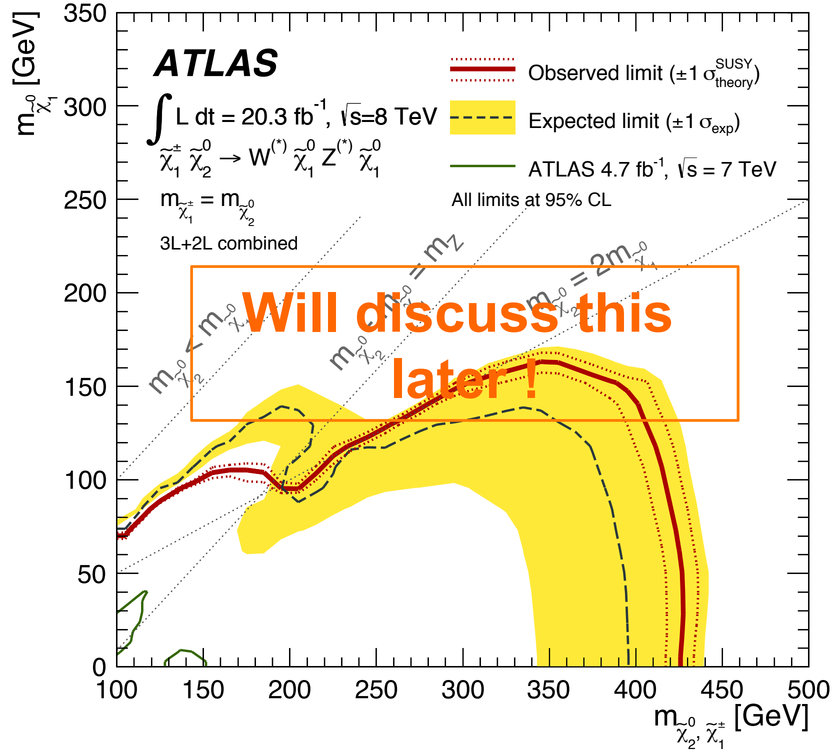
RESULTS – SR Zjets chargino-neutralino2 production

- 95% exclusion region in the chargino1-neutralino1 plane for simplified models with W,Z decays



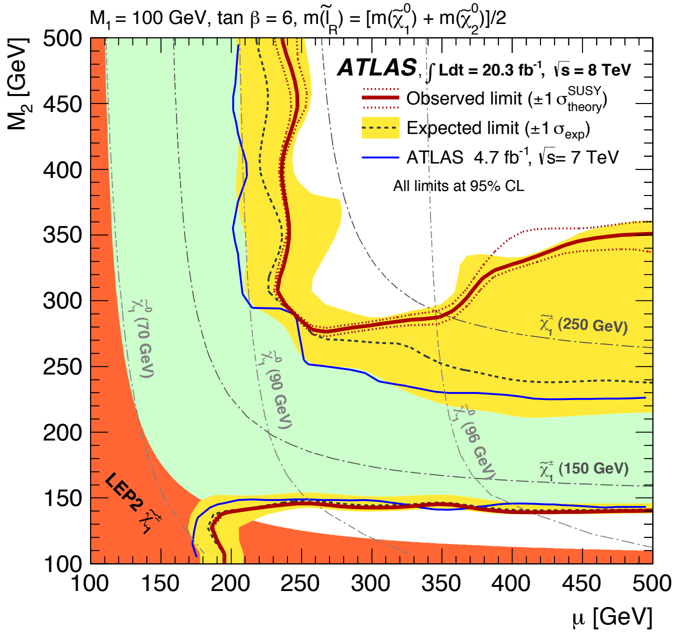
2Lep + 3 Lep combination

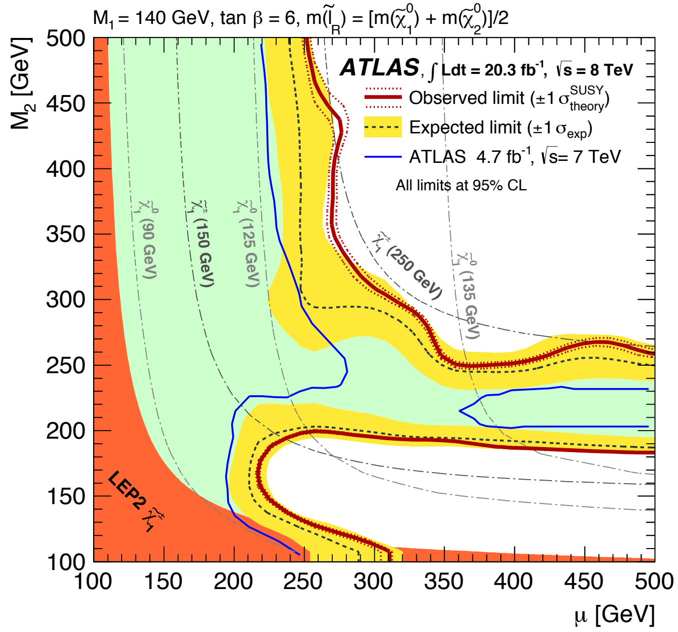


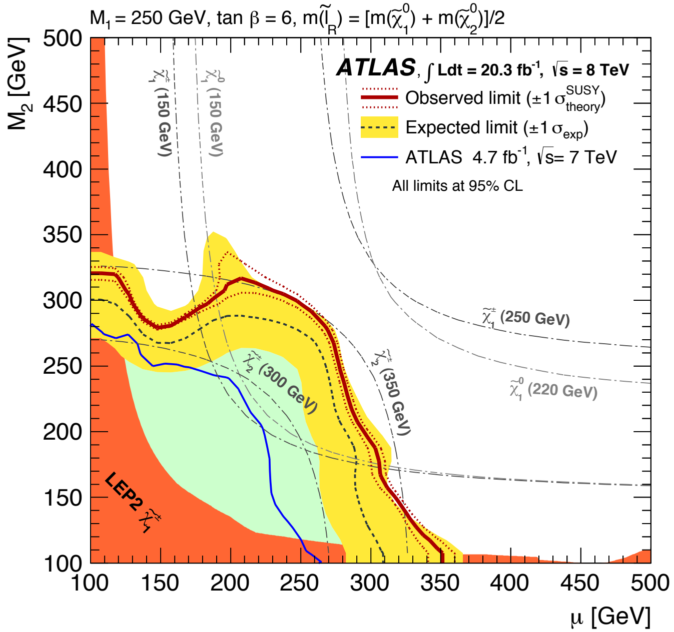


- for a massless LSP, models with chargino masses between 180 GeV - 355 GeV are excluded

2 lepton pMSSM grid







- pMSSM limits for tanβ = 6 and M1= 100 GeV, M1=140 GeV and M1 = 250 GeV
- processes with mainly chargino-neutralino2 production and decays via RH sleptons

$$\tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R \ell \rightarrow \tilde{\chi}_1^0 \ell \ell$$

areas with -1σ expected limit are in green

3 lepton ANALYSIS

paper:

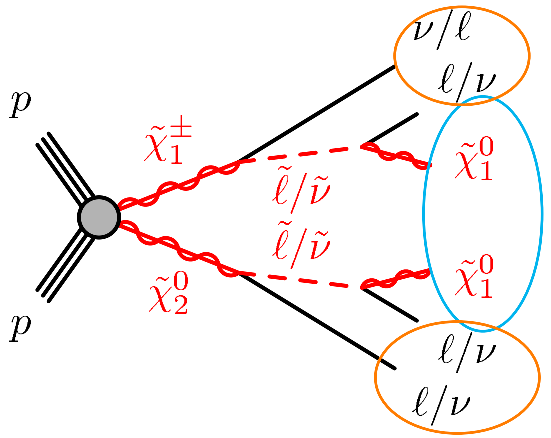
JHEP 04 (2014)169 (arXiv:1402.7029)

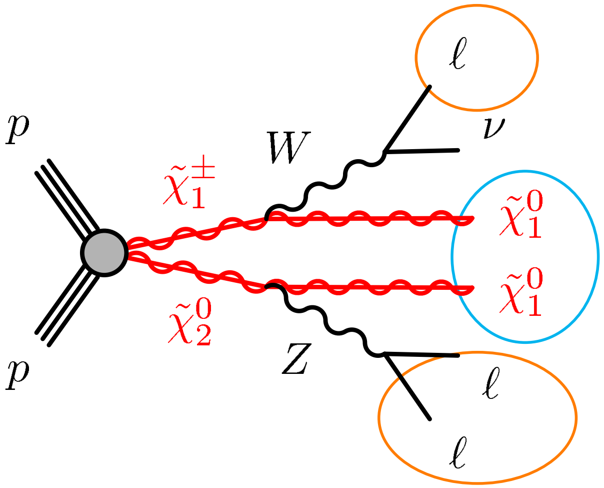
Search for direct production of charginos and neutralinos in events with three leptons and missing transverse momentum in $\sqrt{s} = 8\ \mathrm{TeV}\ pp$ collisions with the ATLAS detector

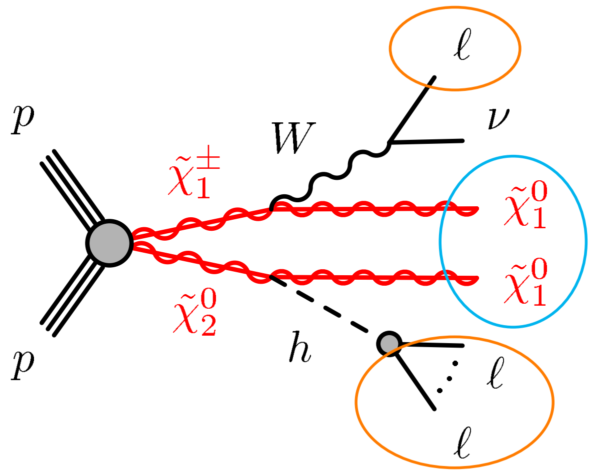
3 lepton SUSY MODELS

chargino-neutralino2 production

E_T^{miss} from neutralino1 (LSPs) and neutrinos
same flavour and different flavour leptons







$\tilde{\chi}_2^0 \to \tilde{\ell}\ell \to \ell\bar{\ell}\tilde{\chi}_1^0$

$\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0 \to \ell\bar{\ell}\tilde{\chi}_1^0$

$\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0 \to \ell\bar{\ell}\tilde{\chi}_1^0$

neutralino decay via sleptons

neutralino decay via on-offshell WZ bosons

neutralino decay via lightest higgs

- probe four simplified models with assumption: N2, C1 are wino like, N1 is bino like and m(N2)= m(C1)
- slepton decays: m(sneutrinos)= m(sleptons) = {M(N2)+ M(N1)}/2; BR 50% each
- WH decays: 100% BR to lightest Higgs boson M(h)= 125 GeV
- results are interpreted in pMSSM scenarios: masses of coloured sparticles, CP-odd higgs boson and LH sleptons are set to high values to allow direct production of C1, N2 via W/Z bosons and decays via RH sleptons, gauge bosons and Higgs boson;M(h) = 125 GeV (tuned by mixing in top-sector)

3 lepton SIGNAL REGIONS

- electrons and muons are collectively referred to as "light leptons"→ incl. leptonic tau decays
- "taus" refers to hadronically decaying taus

>= 3 leptons, separated from each other by ΔR > 0.3 + >=1 must be e or μ
events pass single or double lepton trigger
if tagged e, μ form a same-flavor OS pair, both leptons with m(l,l) < 12 GeV are rejected
→defined 5 SRs according to flavor, charge of leptons

Signal region	SR0τa	SR0τb	SR1τ	SR2τa	SR2τb
Flavour/sign	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	$\ell^\pm\ell^\pm\ell'^\mp$	$\tau^\pm\ell^\mp\ell^\mp$, $\tau^\pm\ell^\mp\ell'^\mp$	$\tau\tau\ell$	$\tau^+\tau^-\ell$
b-tagged jet	veto	veto	veto	veto	veto
$E_{\mathrm{T}}^{\mathrm{miss}}$	binned	> 50	> 50	> 50	> 60
Other	m_{SFOS} binned m_{T} binned	$p_{\mathrm{T}}^{3^{\mathrm{rd}}\ell} > 20$ $\Delta\phi_{\ell\ell'}^{\mathrm{min}} \leq 1.0$	$p_{\mathrm{T}}^{2^{\mathrm{nd}}\ell} > 30$ $\sum p_{\mathrm{T}}^{\ell} > 70$ $m_{\ell\tau} < 120$ m_{ee} Z veto	$m_{\mathrm{T2}}^{\mathrm{max}} > 100$	$\sum p_{\mathrm{T}}^{\tau} > 110$ $70 < m_{\tau\tau} < 120$
Target model	$\tilde{\ell}$,WZ-mediated	Wh-mediated	Wh-mediated	$\tilde{\tau}_L$-mediated	Wh-mediated

SR0τa: optimized for slepton mediated decays and WZ mediated scenarios; SFOS lepton pair + different slices in m_{SFOS} with 4 bins = 20 disjoint bins
SR0τb: for Wh scenario, vetos SFOS lepton pairs to suppress WZ bg
SR1τ: 1τ + >= 2 SS e or μ; for Wh scenarios; to increase sensitivity for h→ττ, cut on m(τ,l)
SR2τ: for stau scenarios, m_{T2} = highest value from 2 leptons
SR2τb: for Wh scenarios, two OS τ leptons for h→ττ decays

All SR are orthogonal except for SR2τa and SR2τb

3 lepton SM backgrounds

number of τ	SR	SM backgrounds	signal grids
0	SR0a	WZ, ttbar	sleptons, WZ
0	SR0b	WZ, ttbar	WH
1	SR1SS	WZ, ttbar, WW	WH
2	SR2a	WZ, ttbar, WW, W/Z + jets	staus
2	SR2b	WW, ttbar	WH

3 lepton SM BACKGROUNDS

Irreducible backgrounds with at least three isolated real leptons:

diboson (WZ, ZZ), , triboson VVV (WWW, ZZZ, ZWW) and

top-antitop Z/W, tZ, higgs boson

- define validation regions and determine scaling factors
- for each τ multiplicity: VRs are defined with either low or high E_T^{miss} and b-tagged jet
-in SRs without τ :
 Z- veto and Z-request regions are tested

Reducible background with at least one fake lepton/tau:

leptons from a semileptonic decay of heavy-flavour quarks,

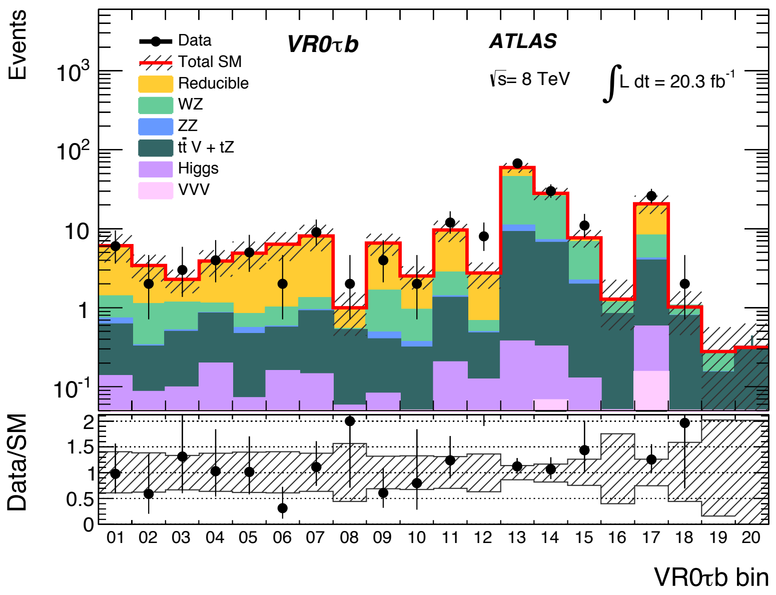
lepton from misidentified light-flavour quark or gluon jet or

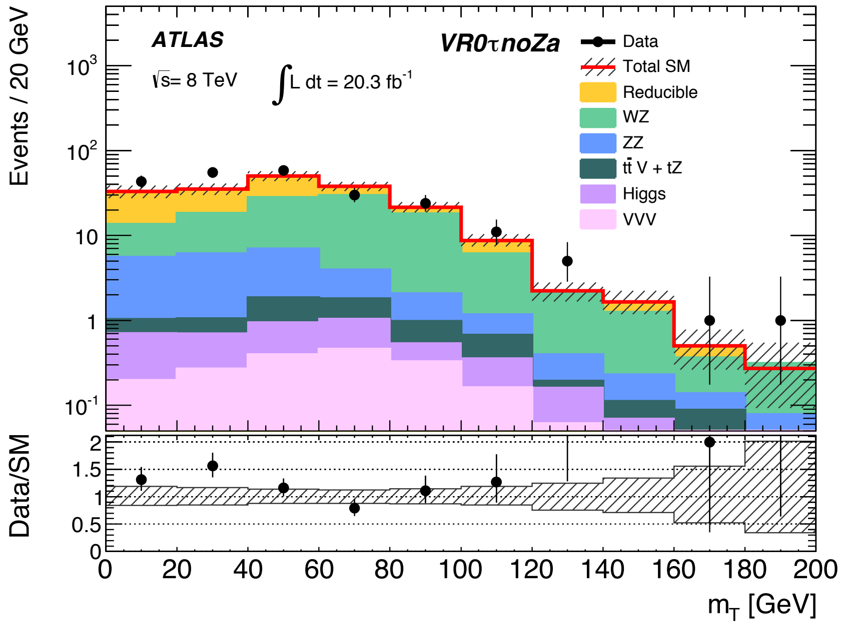
electron from photon conversion in single- and pair-

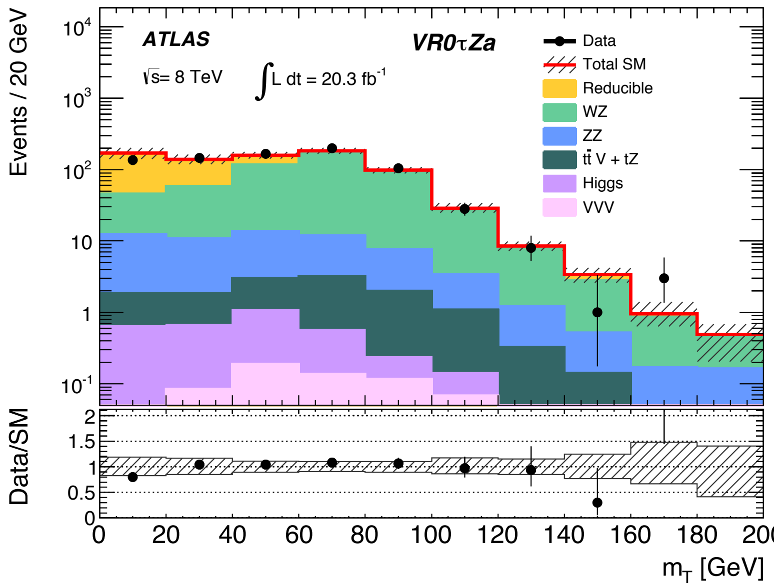
production of top quarks, WW, W+ jets, Z+jets

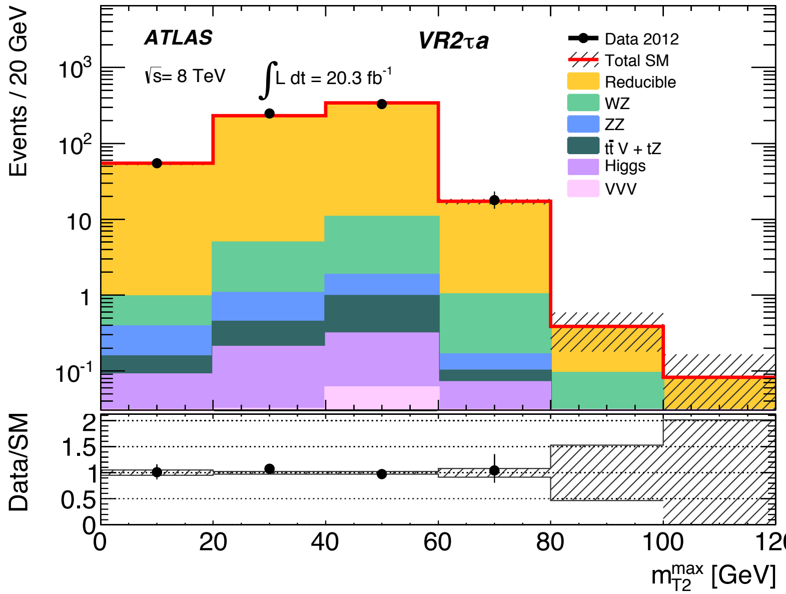
modeled with Matrix Method

3 lepton – VALIDATION REGIONS

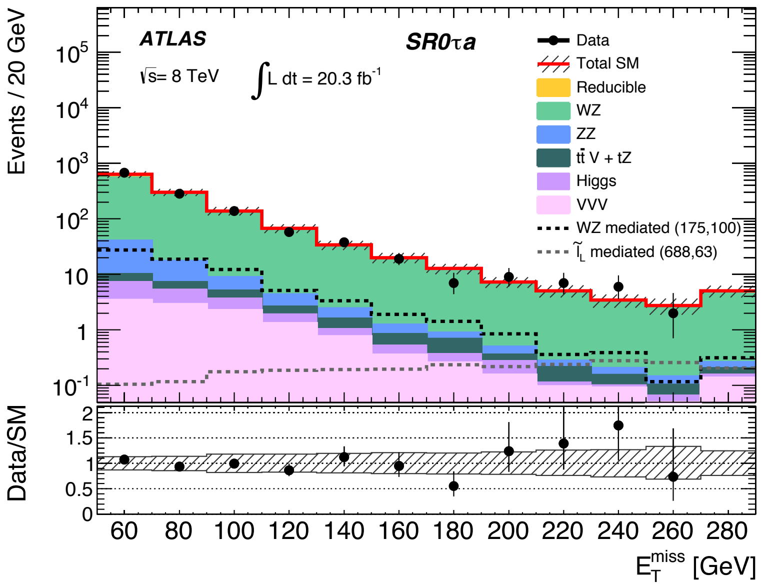


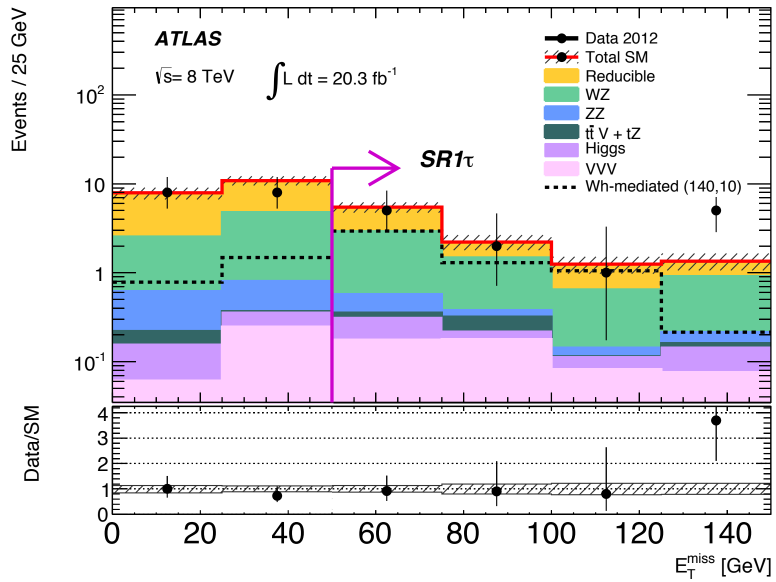


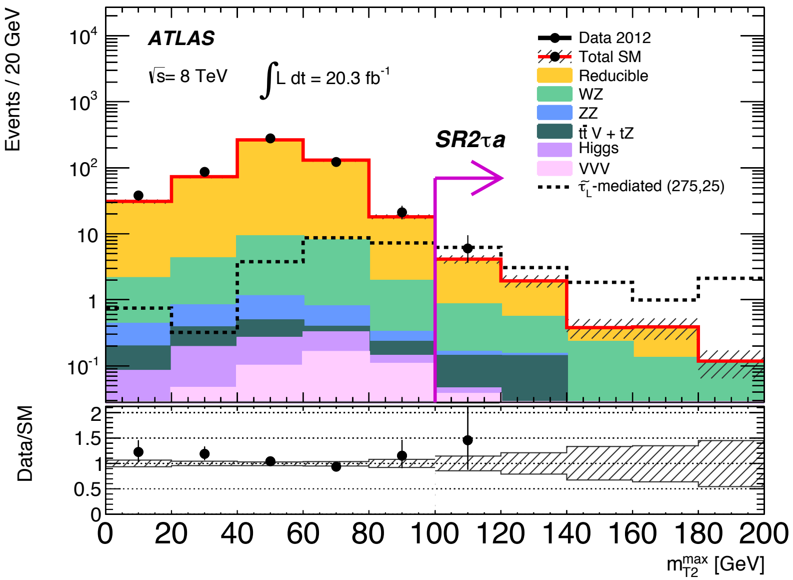


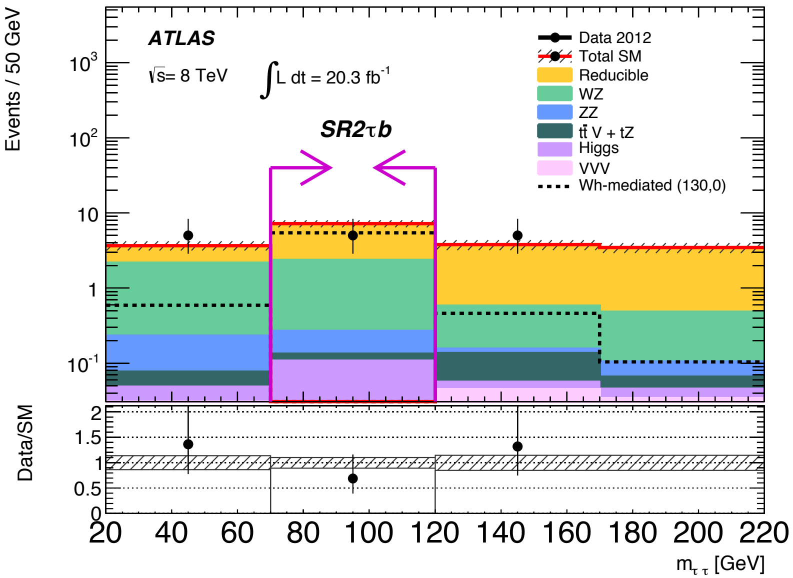


3 lepton - SIGNAL REGIONS

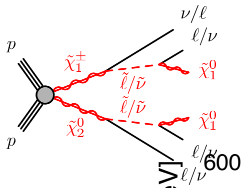




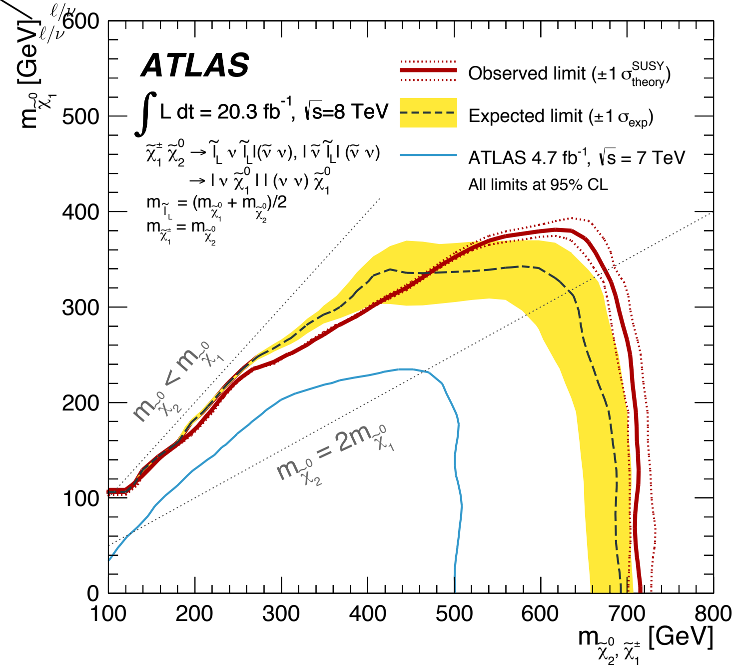




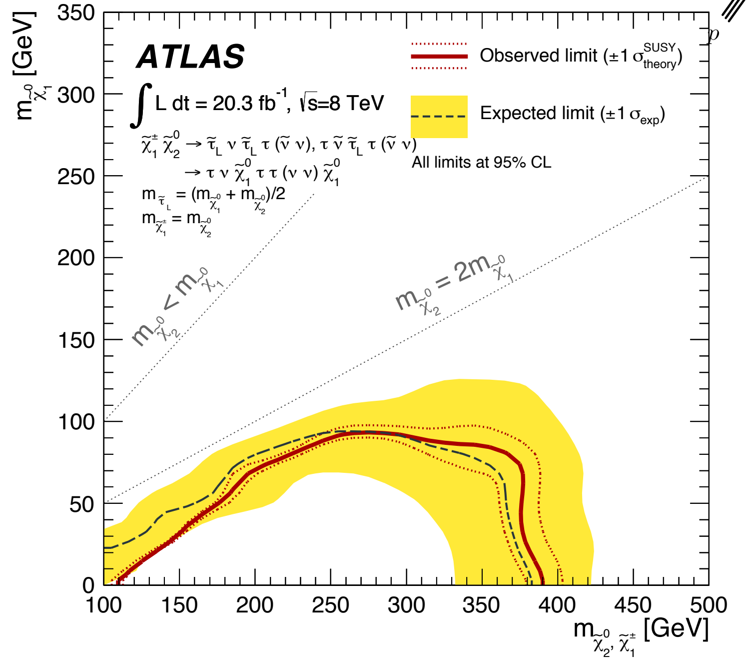
3 lepton RESULTS – slepton/stau decays

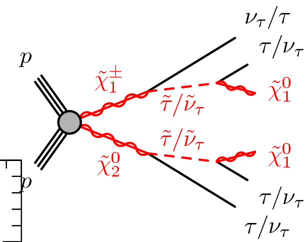


decays via selectron/smuon



decays via staus





- observed and expected 95% CL exclusion contours for chargino and neutralino production in the left-handed slepton-mediated (left) and stau-mediated (right) simplified models
- SR0a, SR0b, SR1, SR2a are all used and statistically combined
- selectron/smuon models:

N2/C1 up to 700 GeV are excluded for massless LSP

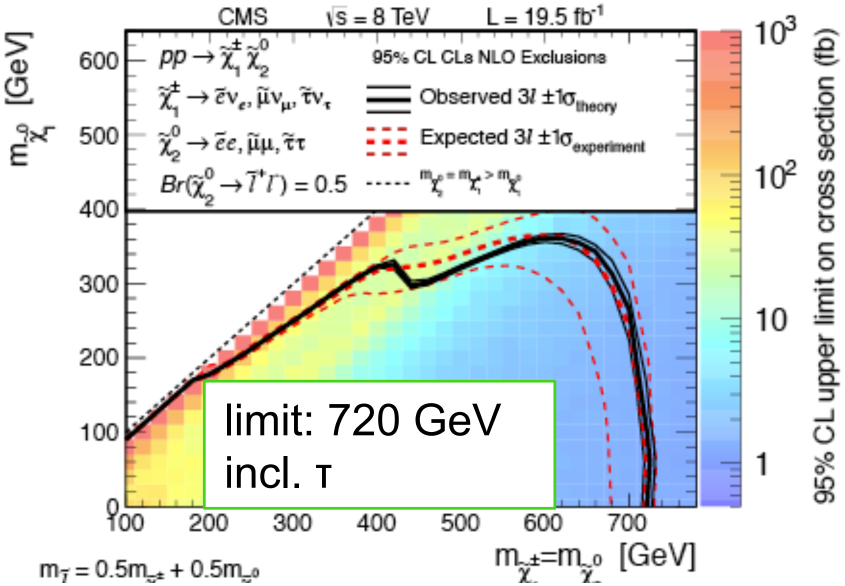
SR0 offers best exlusion limit for high N2/C1 masses, low m(SFOS) regions for small N2/C1 masses

- stau models:

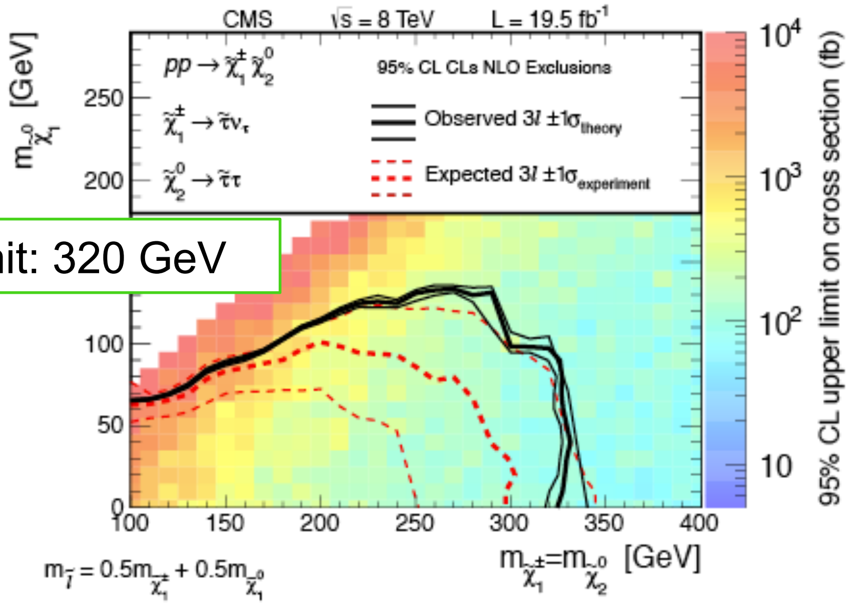
N2/C1 masses up to 380 GeV are excluded; SR2a offers best limit for high N2/C1 masses

COMPARISON WITH CMS

CMS

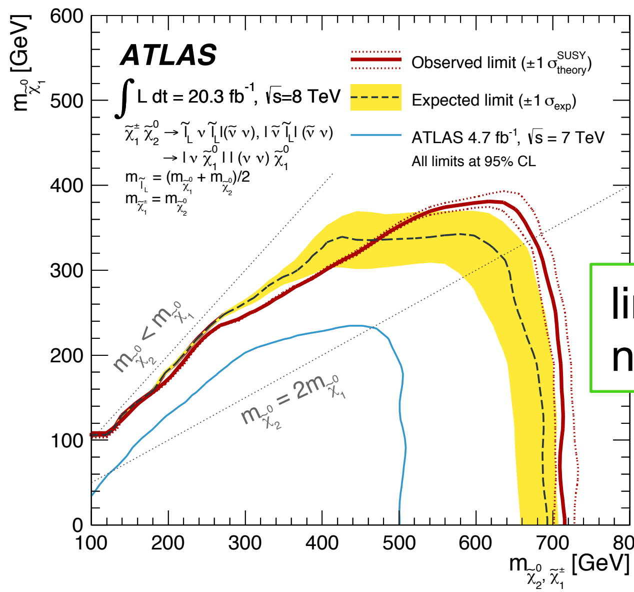


limit: 720 GeV
incl. τ

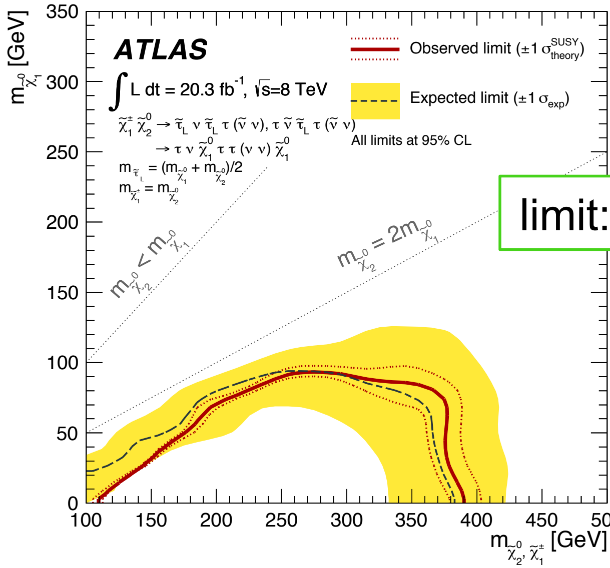


limit: 320 GeV

ATLAS

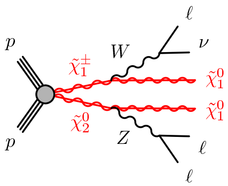


limit: 700 GeV
no τs

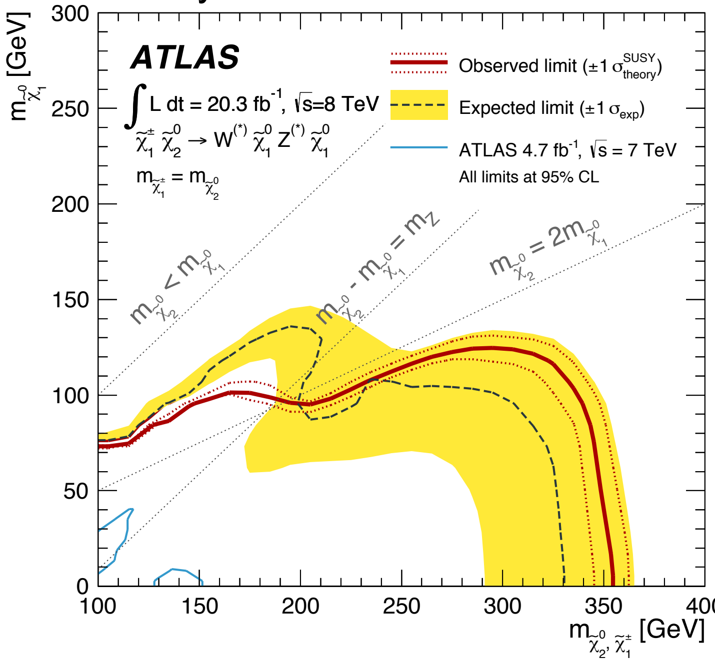


limit: 380 GeV

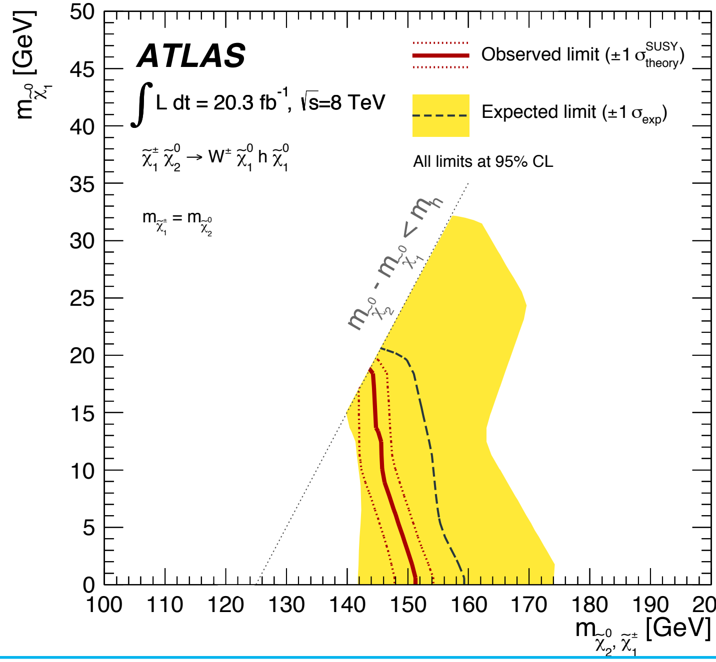
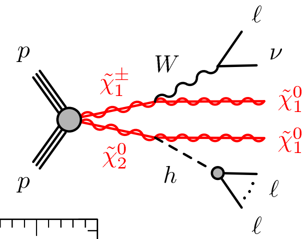
3 lepton RESULTS – WZ/ WH decays



decays via WZ



decays via Wh

•observed and expected 95% CL exclusion contours for chargino and neutralino production in WZ-mediated (left) and Wh-mediated (right) simplified models

•WZ mediated models:

N2/C1 up to 345GeV are excluded for massless LSP

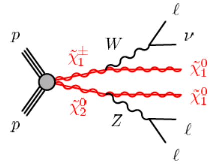
SR0 offers best exlusion limit for small N2/C1 masses, reduced sensitivity for the region m(N2)-M(N1) = m(Z) -> signal populated regions with high WZ background

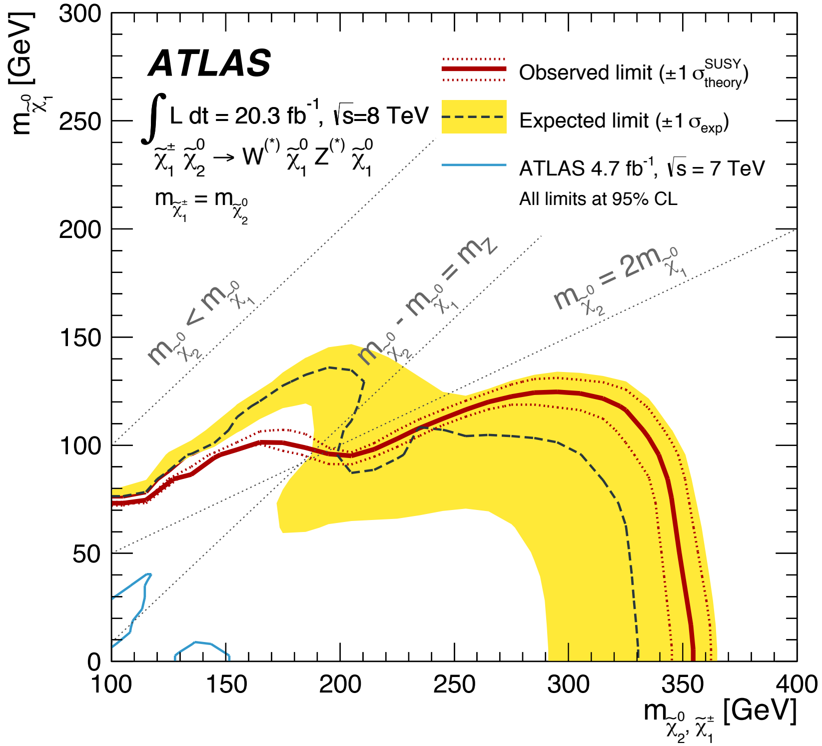
•Wh models:

N2/C1 masses up to 148 GeV are excluded; SR2a offers best limit for high N2/C1 masses

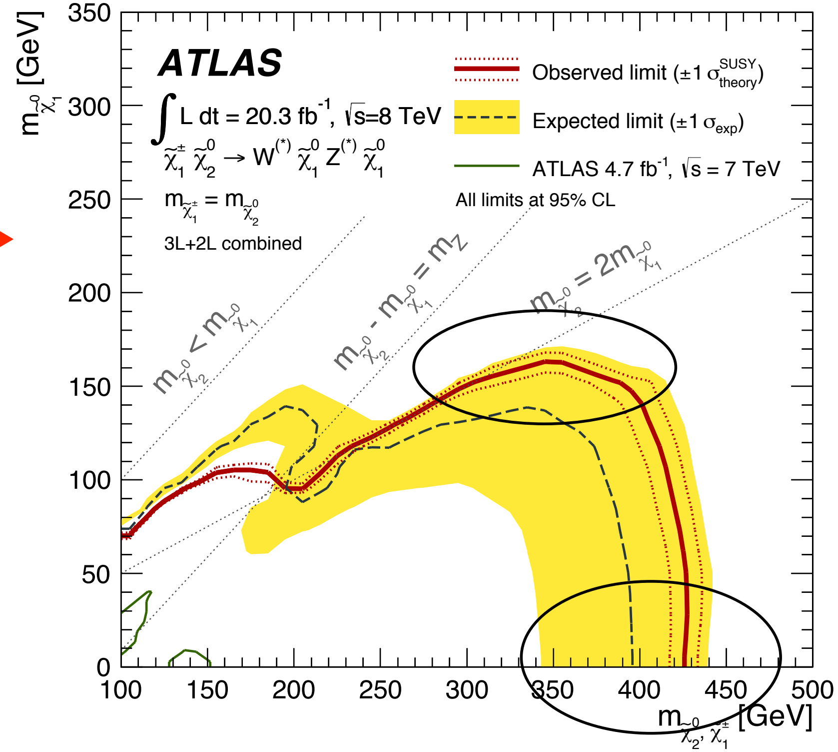
2+3 lepton – COMBINED RESULTS – WZ decays

3L only





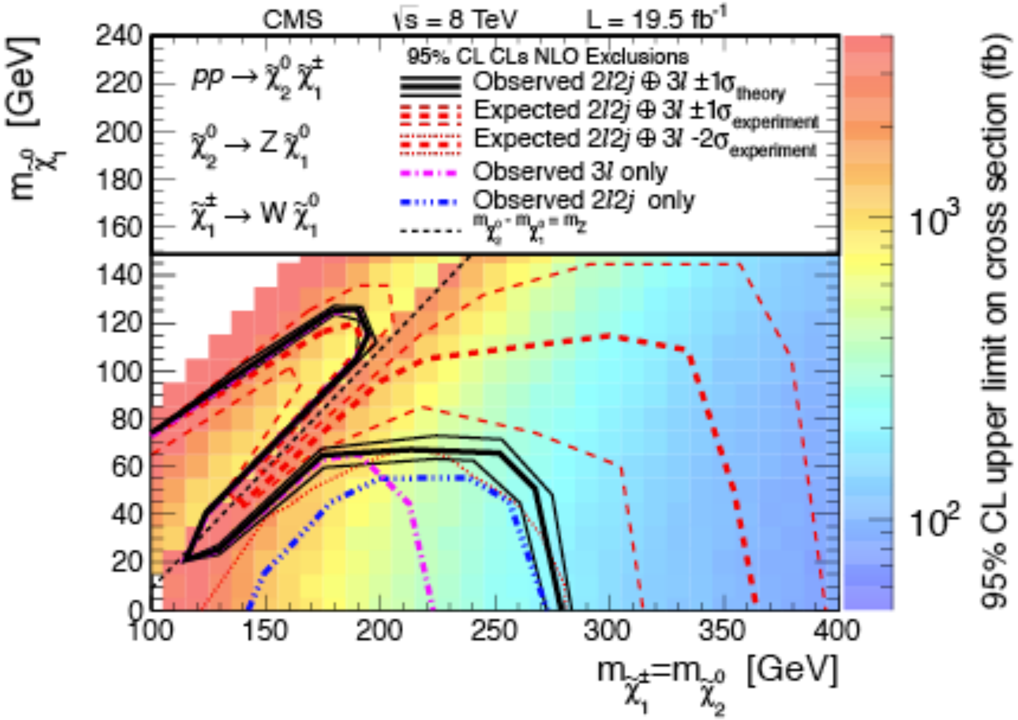
2Lep + 3Lep combination



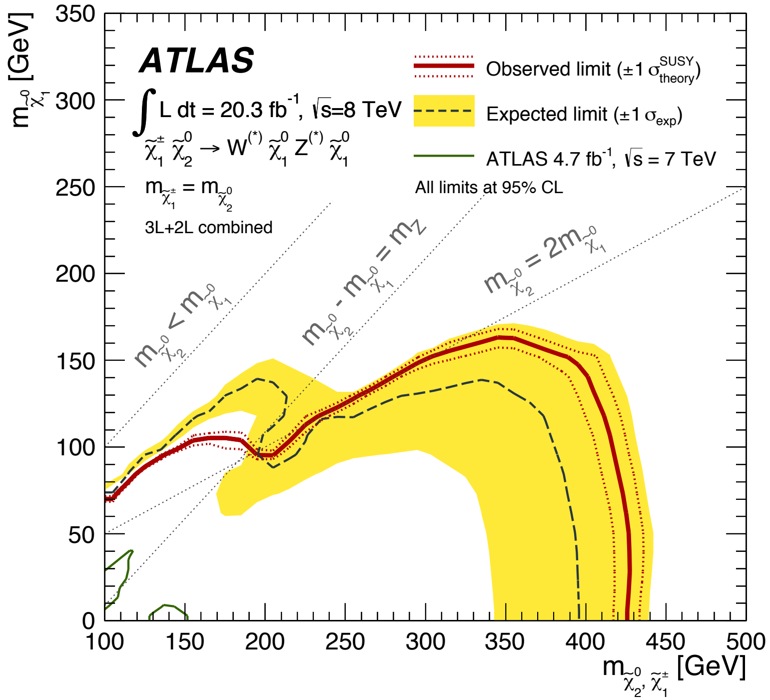
- 2l epton: for a massless LSP, models with chargino masses between 180 GeV - 355 GeV are excluded
- 2 Lep + 3 Lep combination improves limits significantly
  95% limit for massless LSP: chargino/neutralino2 masses between 100 GeV - 415 GeV

COMPARISON WITH CMS WZ decays

CMS



ATLAS



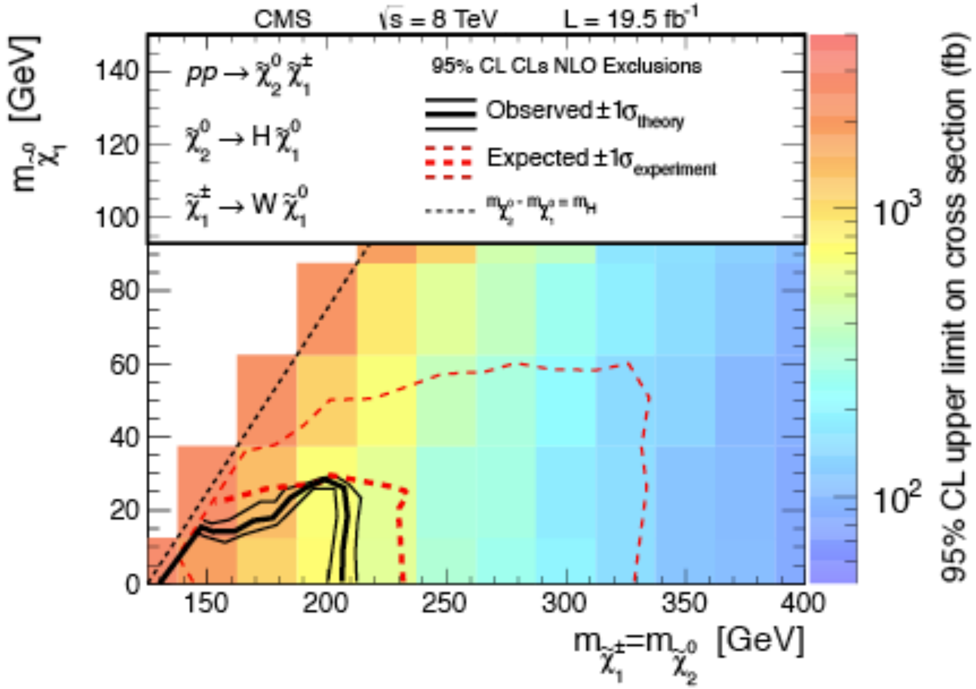
limit: 270 GeV
2l + 3l combined, incl. τs
limits at diagonal :
C1=200 GeV, N1=120 GeV

limit: ≈415 GeV
2l+3l combined, no τs
limits at the diagonal:
C1= 200 GeV, N1=110 GeV

COMPARISON WITH CMS – Wh decays

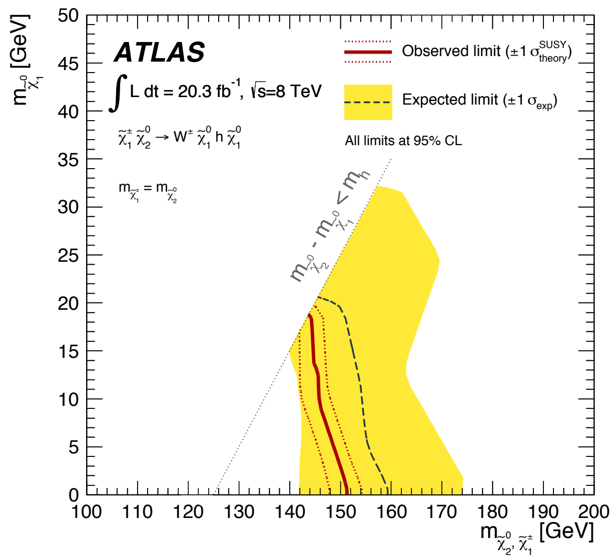
CMS

1lep +bb, 2lep, 3lep, 4lep analyses used

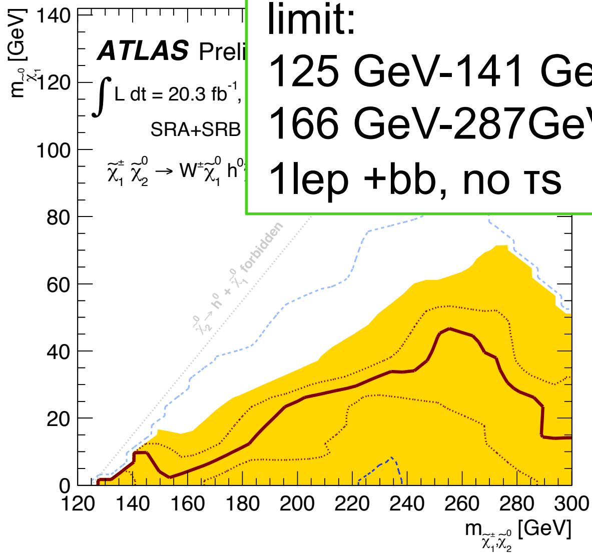


limit: 200 GeV
1lep + bb incl. τs

ATLAS

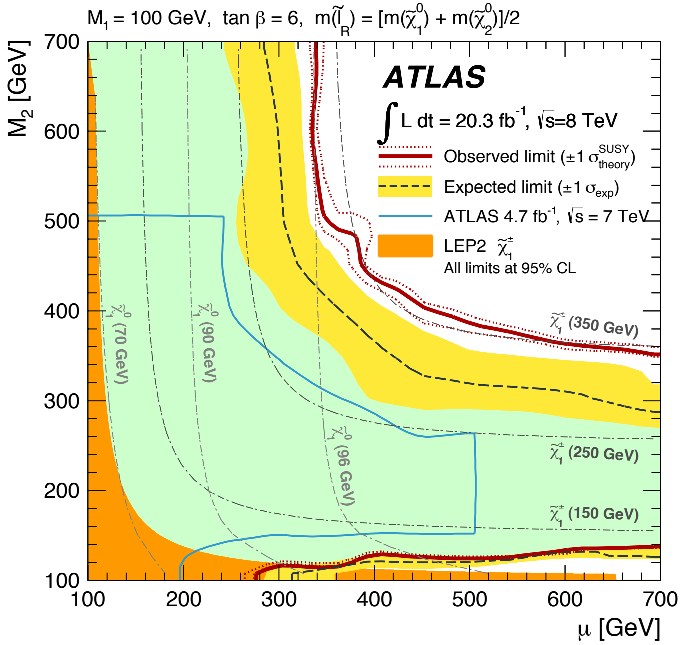


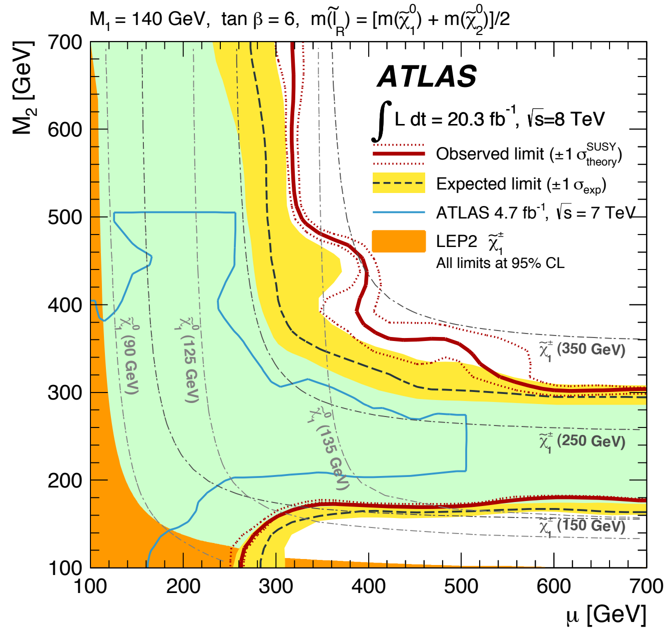
1 lepton + bb(H): [ATLAS-CONF-2013-093]

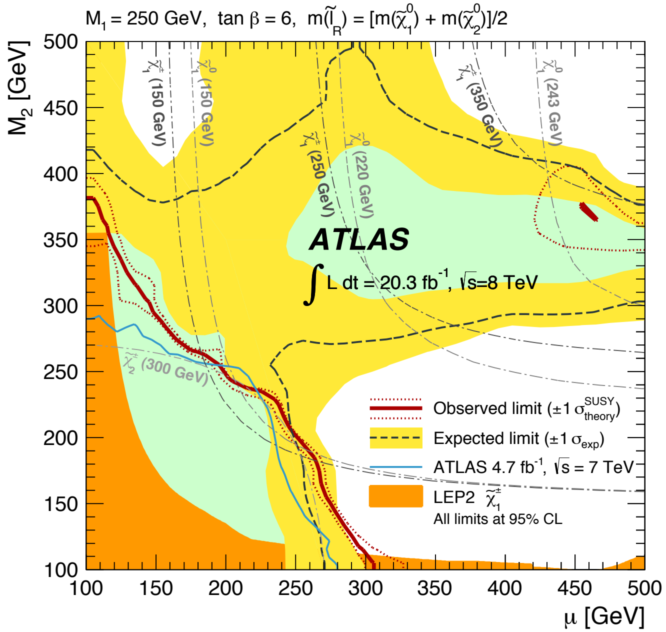


limit:
125 GeV-141 GeV,
166 GeV-287GeV
1lep +bb, no τs

3 lepton - RESULTS pMSSM grids

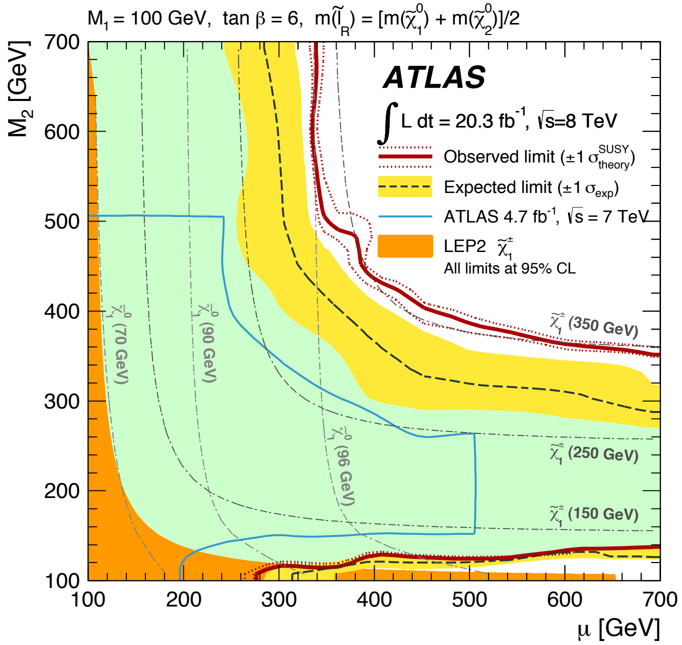


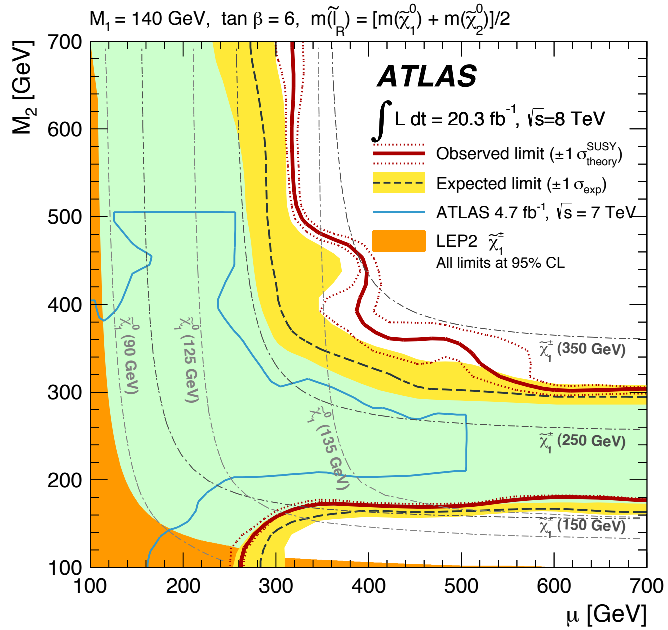


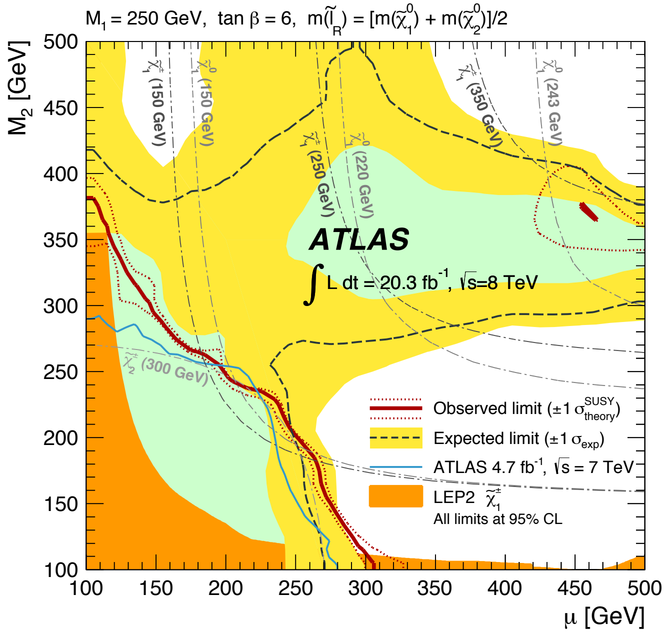


- •pMSSM slepton grids
- right-handed sleptons are degenerate in mass, with mass m(slepton)= {m(N1)+m(N2)}/2
- tan β = 6 yields comparable N2 branching ratios into each slepton generation
- to probe the sensitivity for different N1 compositions, three values of M1 are considered:
M1=100 GeV (top, left), M1=140 GeV (top right), M1=250 GeV (bottom)

3 lepton – RESULTS pMSSM grids

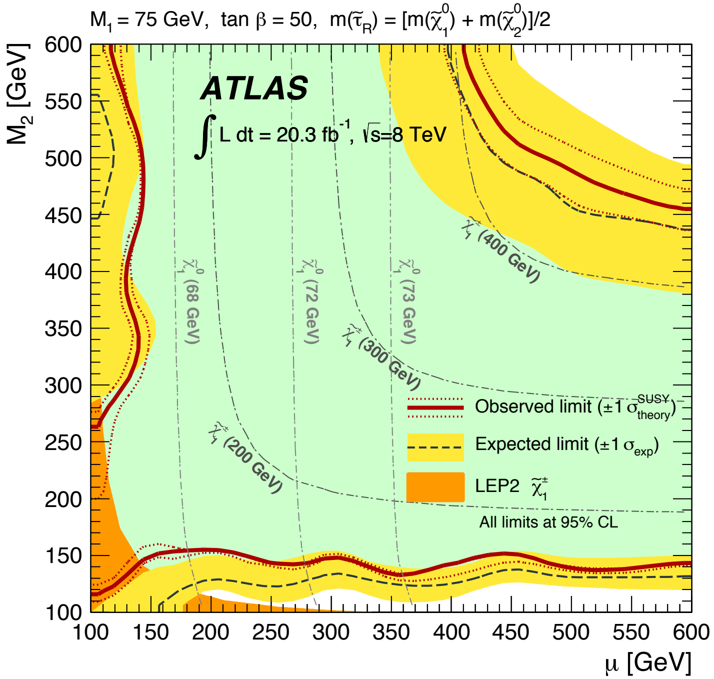


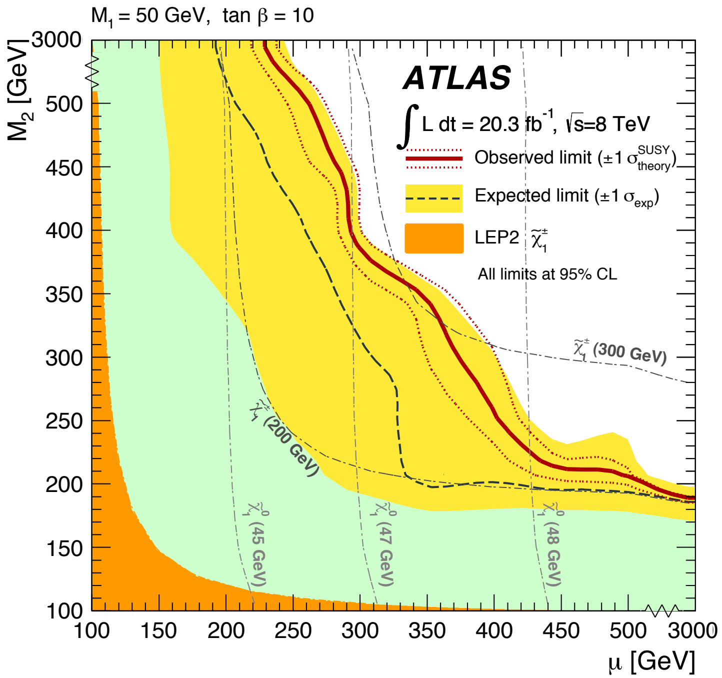




- observed and expected 95% CL exclusion contours in the pMSSM models with sleptons (no staus): M1=100 GeV (top, left), M1=140 GeV (top right), M1=250 GeV (bottom)
- SR0a, SR0b, SR1SS and SR2a are used
- due to small mass differences between N2 -N1 and C1-N1 limited sensitivity is found in the regions with M1≈M2≪μ
- For M1 =250 GeV, M2 > =250 GeV and μ >=250 GeV : characterized by small C1-N1 mass splitting
→observed limit sign. smaller than expected

3 lepton – RESULTS pMSSM grids





•observed and expected 95% CL exclusion contours in the pMSSM models with staus (left) and no sleptons (right):

•RH stau scenario:

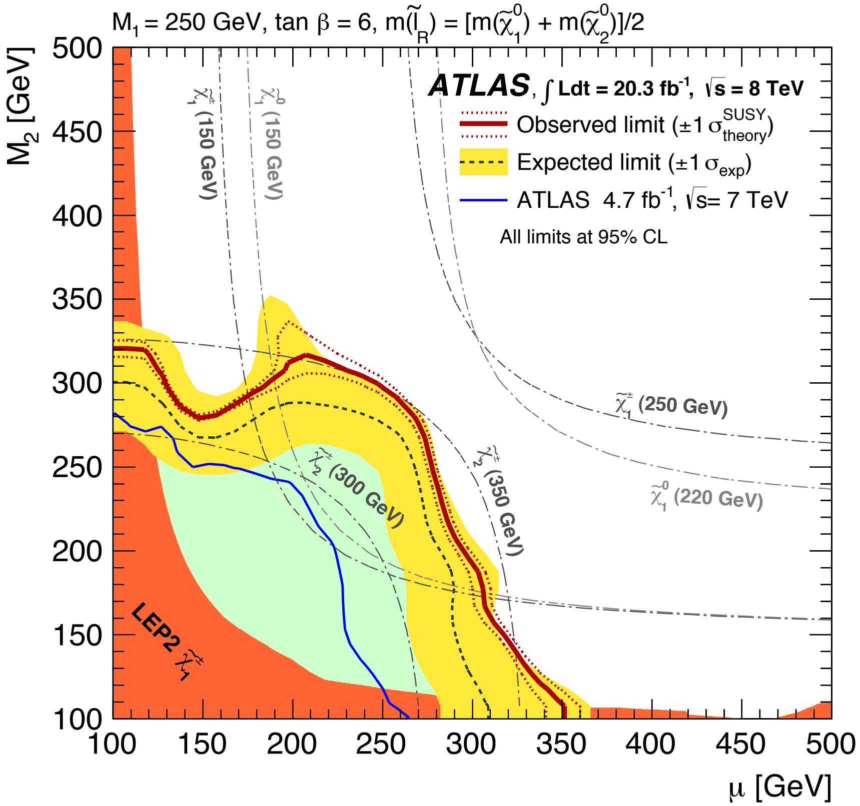
- selectrons and smuons are heavy and the RH stau mass is set to m(stau)={m(N1)+m(N2)}/2 and tanβ = 50; M1 =75 GeV resulting in a bino-like N1
- small mass splitting between N2-N1 and C1-N1 reduces sensitivity for region M1≈M2≪μ and M1≈μ ≪ M2 region

• no slepton decays:

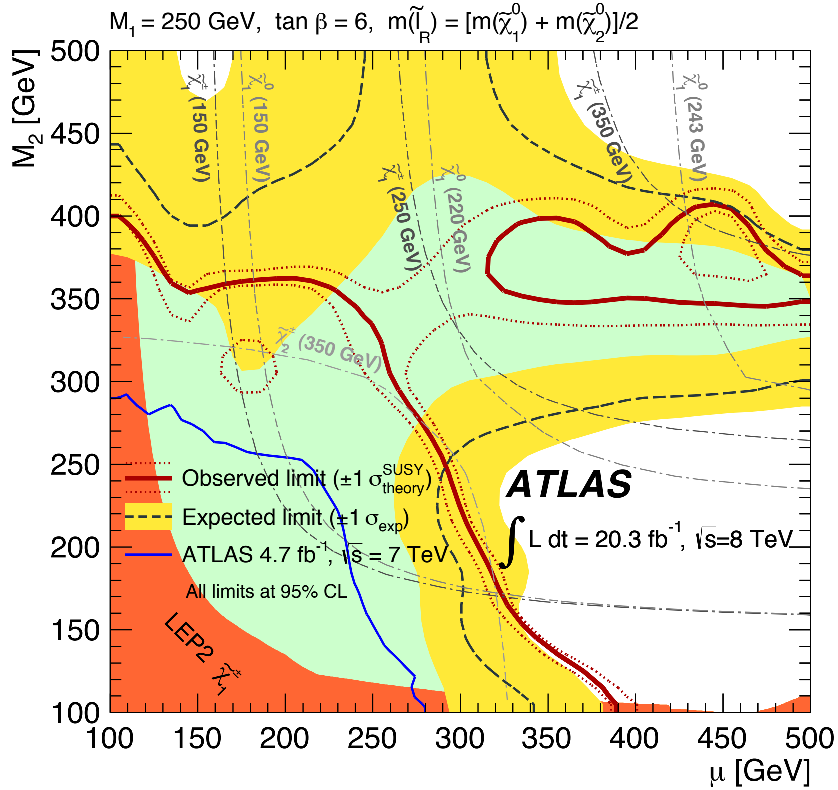
- all sleptons are heavy; decays via W, Z or Higgs bosons dominate; M1=50 GeV and tan β =10
- region with M2 >=200 GeV, μ >=200 GeV : decay mode N2-> hN1 is kinematically allowed and reduces the sensitivity

2 + 3 lepton - pMSSM grid combination

2Lep



2Lep + 3 Lep combination



4 lepton ANALYSIS

paper:

CERN-PH-EP-2014-074 (arXiv:1405.5086)

-> submitted to PRD

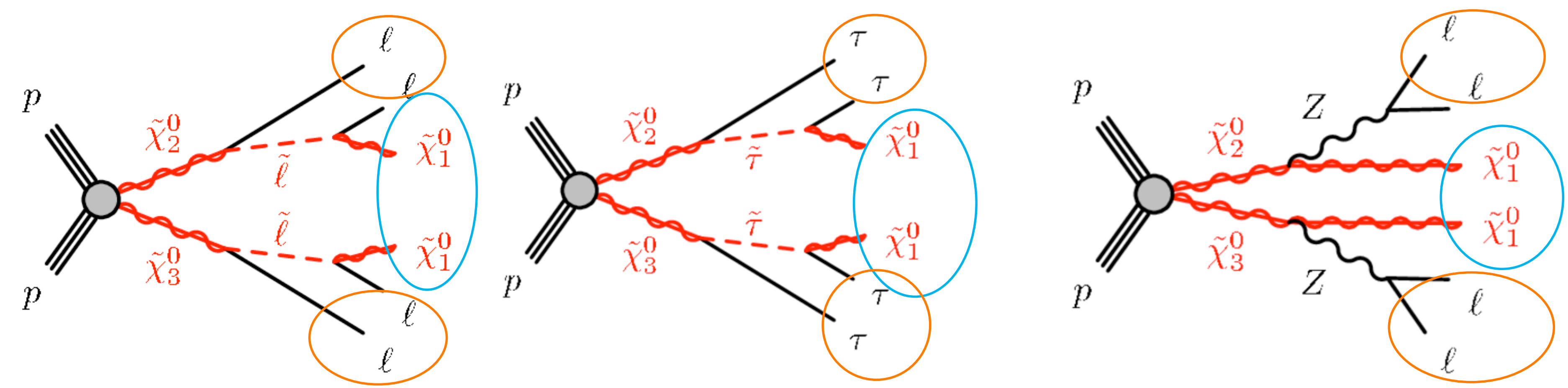
Search for supersymmetry in events with four or more leptons in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector

→in this paper RPV and RPC models are studied
→I will only discuss the RPC models today, but RPV results are in back up

4 lepton - SUSY MODELS – SIMPLIFIED MODELS

neutralino2-neutralino3 production

E_T^{miss} from neutralino1 (LSPs) + >=1 SFOS lepton pair



R-slepton $\tilde{\chi}_{2,3}^0 \to \ell^\pm \tilde{\ell}_R^\mp \to \ell^+\ell^-\tilde{\chi}_1^0$

Stau $\tilde{\chi}_{2,3}^0 \to \tau^\mp \tilde{\tau}_1^\pm \to \tau^\mp\tau^\pm\tilde{\chi}_1^0$

$\tilde{\chi}_{2,3}^0 \to Z^{(*)}\tilde{\chi}_1^0 \to \ell^\pm\ell^\mp\tilde{\chi}_1^0$

neutralino decay via sleptons

neutralino decay via staus

neutralino decay via Z

•probe three types of simplified models with assumption: N2, N3 are higgsino-like, N1 is bino-like and decay chains with intermediate right-handed smuons and selectrons, with intermediate right-handed staus and with intermediate Z bosons

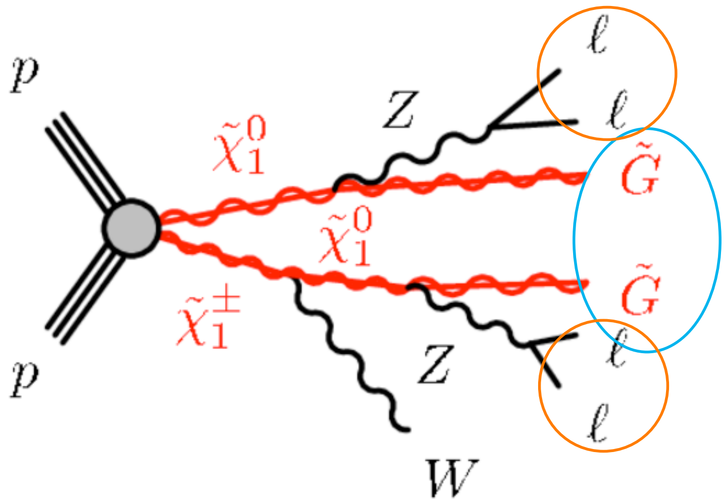
→smuons/selecton models: assume same neutralino branching fraction to selectrons and smuons (mixing among neutralino states); N2, N3 have masses between 100 GeV and 700 GeV, N1 varies between 0-20 GeV and cross sections between 1.7 pb-0.2 fb

→stau, Z models: LSP massless

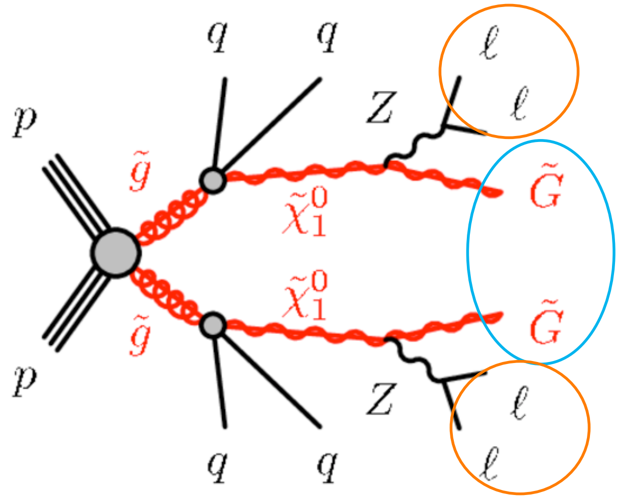
4 lepton - SUSY MODELS – GGM models

gauge mediated SUSY breaking scenarios

E_T^{miss} from gravitino (LSPs)



weak production GGM



strong production GGM

• probe two GGM SUSY scenarios: M1 (bino mass) = M2 (wino mass) = 1 TeV, cτ < 0.1 mm, tanβ= 1.5 and tanβ= 30; μ- m_g (= M3) are varied with 200 GeV < μ < m_g -10 GeV
→N1, N2, C1 are higgsino-like co-NLSPs

•model tanβ= 1.5: N1 decays to Z+gravitino (97%)
model tanβ= 30: N1 decays to Z+ gravitino or h+gravitino (m(h)=125 GeV) depending on μ
(0% for μ= 100 GeV to 40% for μ=500 GeV
• cross section between 1.2-1.9 pb (for m_g = 600 GeV) to 3.1 fb, except for μ = 200 GeV (σ < 0.6 pb)

4 lepton - SIGNAL REGIONS

•electrons and muons are collectively referred to as "light leptons"
→ includes those from leptonic tau decays
"taus" refers to hadronically decaying taus
•define 9 SRs with >= 4 leptons, classified depending on the number of light leptons (==2,==3 or ==4) and sub-divided between vetoing or presence of the Z-boson
→ Z regions target GGM and Z RPC models, SRnoZa target RPC N2N3 decays
•single or di-lepton triggers are used

	$N(\ell)$	$N(\tau)$	Z-veto	E_T^{miss} [GeV]		m_{eff} [GeV]
SR0noZa	≥ 4	≥ 0	SFOS, SFOS+ℓ, SFOS+SFOS	>50		–
SR1noZa	=3	≥ 1	SFOS, SFOS+ℓ	>50		–
SR2noZa	=2	≥ 2	SFOS	>75		–
SR0noZb	≥ 4	≥ 0	SFOS, SFOS+ℓ, SFOS+SFOS	>75	or	>600
SR1noZb	=3	≥ 1	SFOS, SFOS+ℓ	>100	or	>400
SR2noZb	=2	≥ 2	SFOS	>100	or	>600

for RPC N2N3 sleptons decays

	$N(\ell)$	$N(\tau)$	Z-requirement	E_T^{miss} [GeV]	
SR0Z	≥ 4	≥ 0	SFOS	>75	–
SR1Z	=3	≥ 1	SFOS	>100	–
SR2Z	=2	≥ 2	SFOS	>75	–

for GGM and Z RPC models

• SFOS: cuts on SFOS pairs + invariant mass of the candidate Z boson using the combinations of the 2 light leptons with an additional light lepton (SFOS+ l or SFOS+SFOS) to suppress radiative Z decays; E_T^{miss} cut to suppress Z+X SM background

4 lepton - SM BACKGROUNDS

Irreducible backgrounds with at least four prompt leptons:

ZZ/γ*, ZWW, ZZZ, tWZ, ttbar + Z/WW, higgs boson decays

- tiny contribution
- determined using MC simulation

Reducible background with at least one fake lepton/tau:

leptons from a semileptonic decay of heavy-flavour quarks,

lepton from misidentified light-flavour quark or gluon jet or

electron from photon conversion in single- and pair-

production of top quarks, WW, W+ jets, Z+jets:

main components:

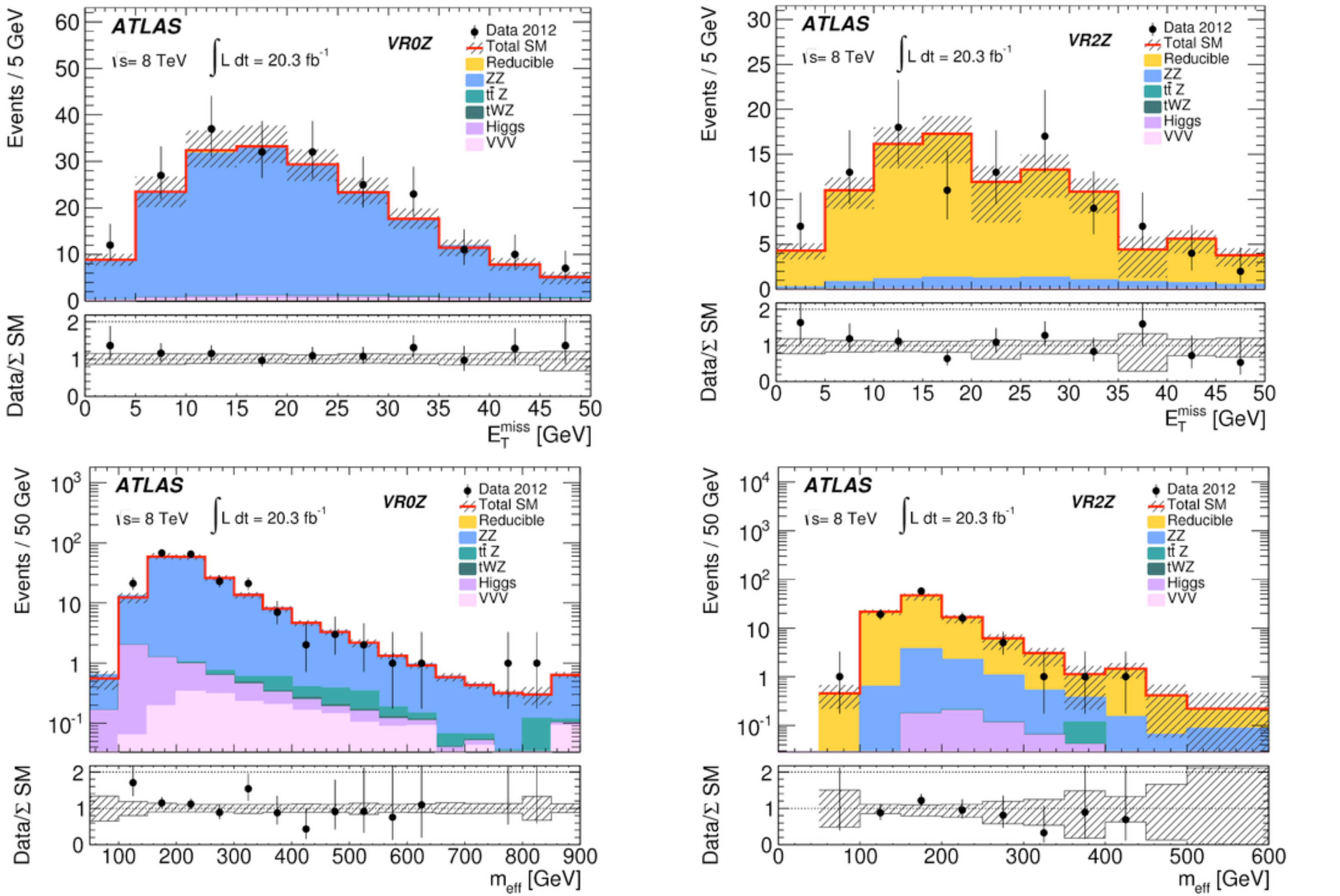
WWW, WZ/γ*, ttbar + W, Zγ* + jets, ttbar, Wt, WW

modeled with weighting method

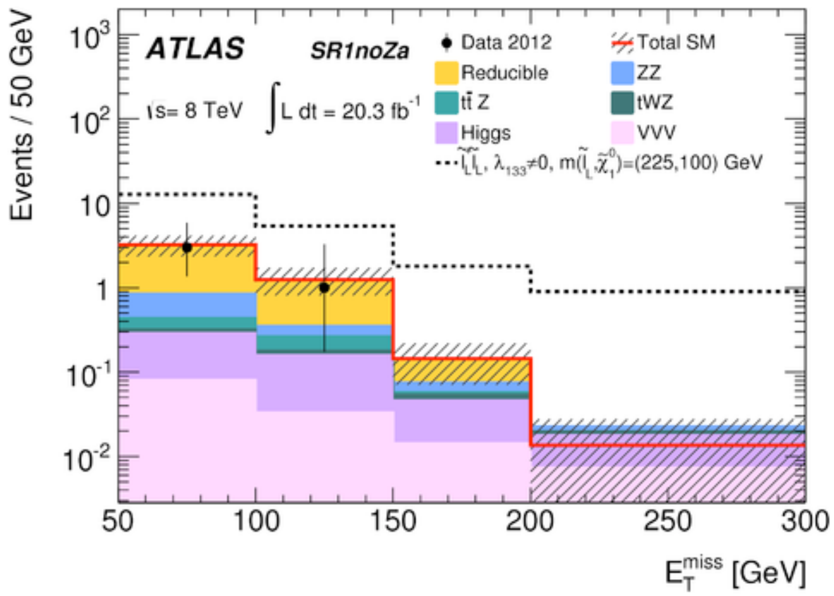
- using MC probabilities for non-prompt leptons to pass or fail signal selections in SR and CR

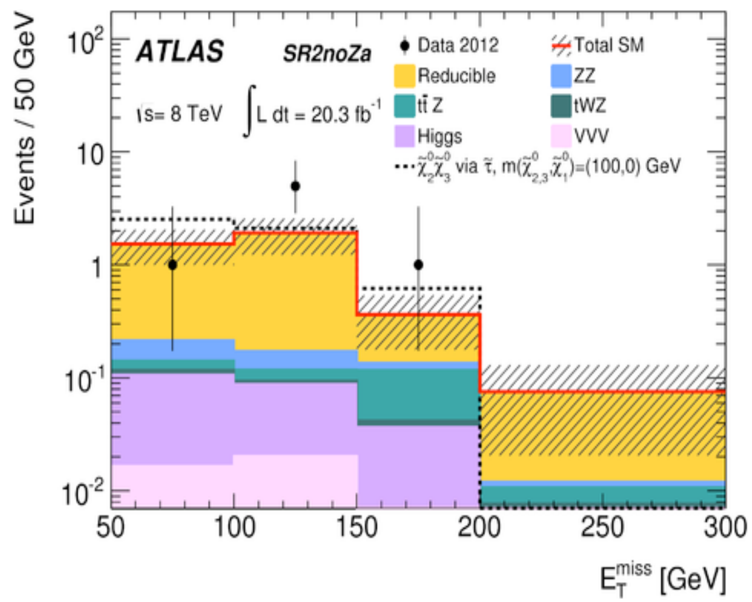
Data-MC agreement and background models are tested in six validation regions!

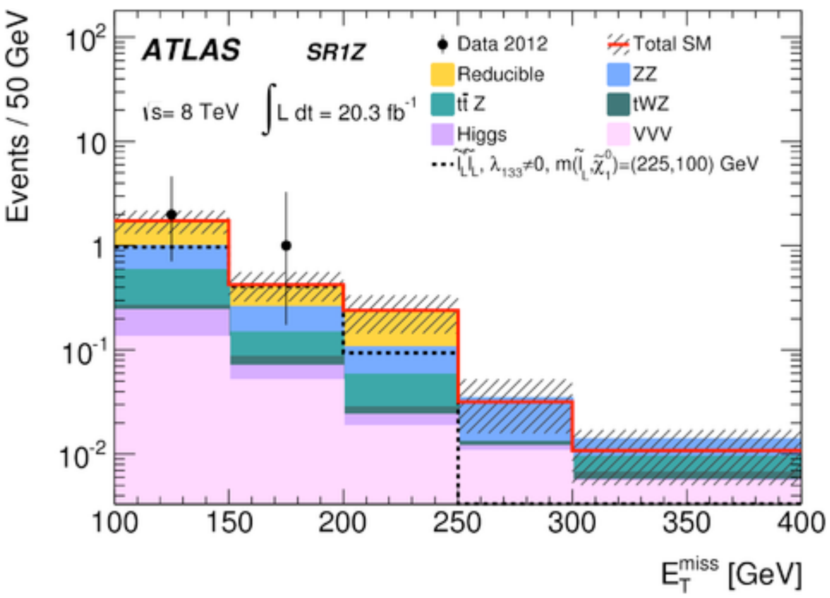
4 lepton - VALIDATION REGIONS

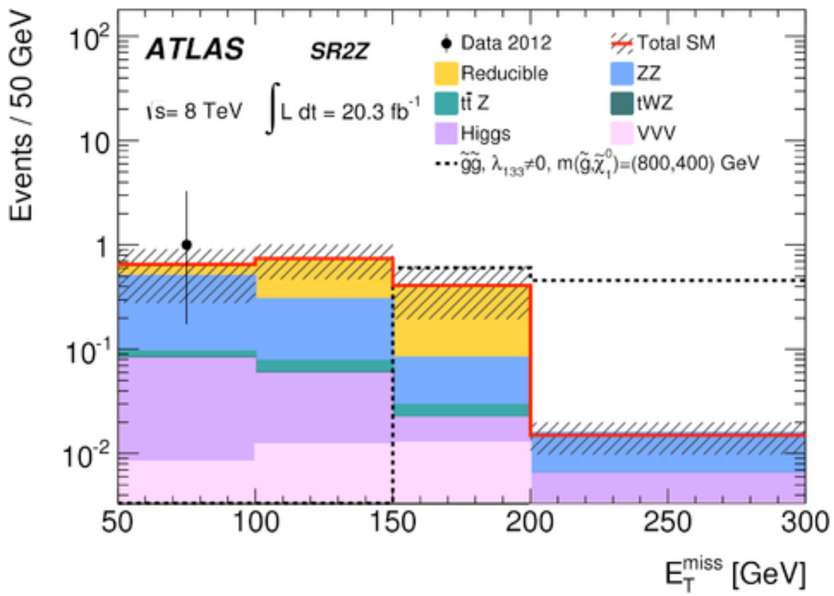


4 lepton – SIGNAL REGIONS

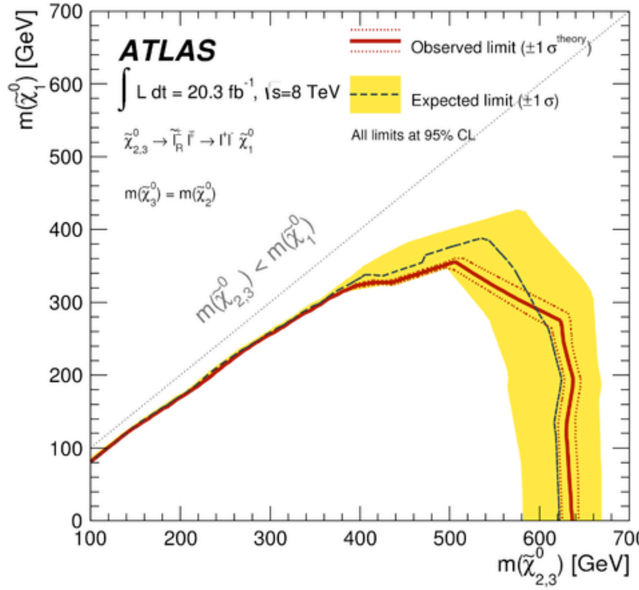


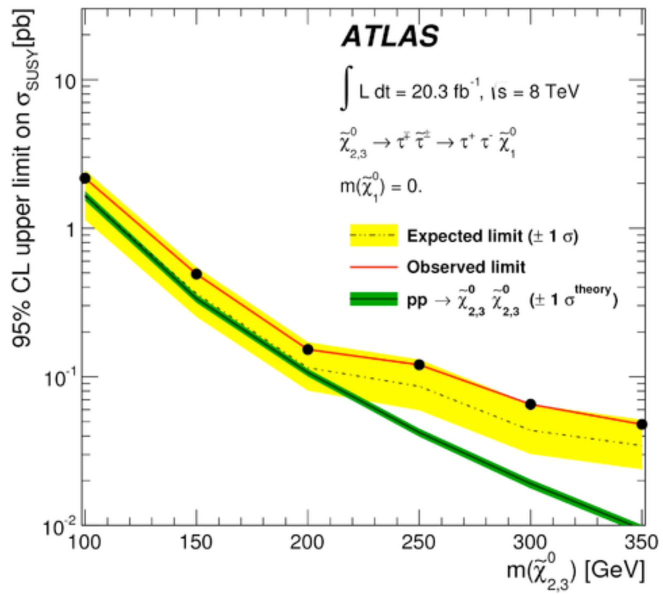


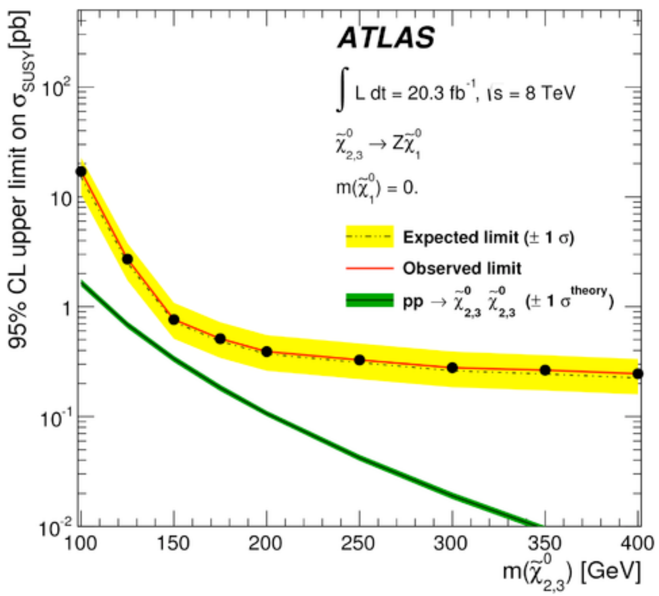




4 lepton – RESULTS







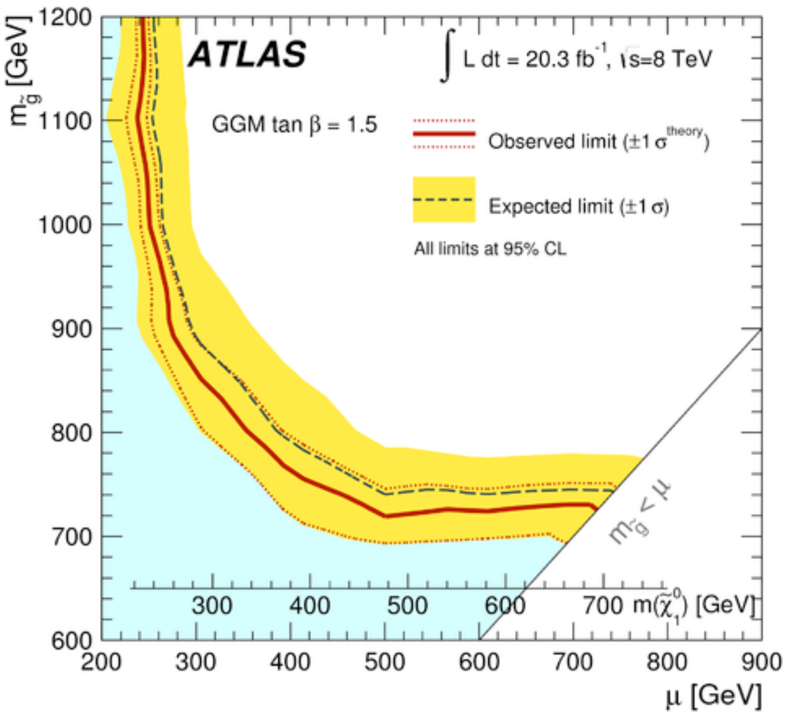
•observed and expected 95% CL limit contours for the R-slepton RPC simplified models (top left); observed and expected 95% CL limits on the production cross-section for the stau (top right) and Z RPC simplified models (bottom), respectively, assuming zero mass for the LSP

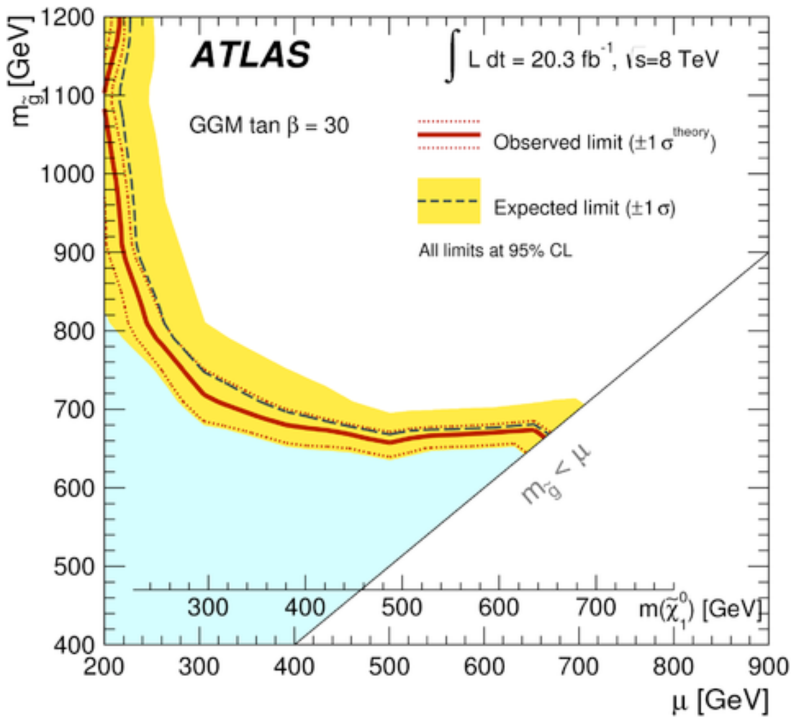
• strongest constraints for RPC models are obtained for R-slepton model: limit N2/N3 <620 GeV for massless LSP; maximum N1 mass limit is 340 GeV

• as the LSP mass increases, the leptons are less energetic, decreasing the analysis acceptance.

the region allowed by LEP (m(N2/N3) >100 GeV) no limits are set on the stau or Z models; 95% CL upper limits on the visible cross-section: 0.17 fb and 0.45 fb, depending on the final state.

4 lepton – RESULTS

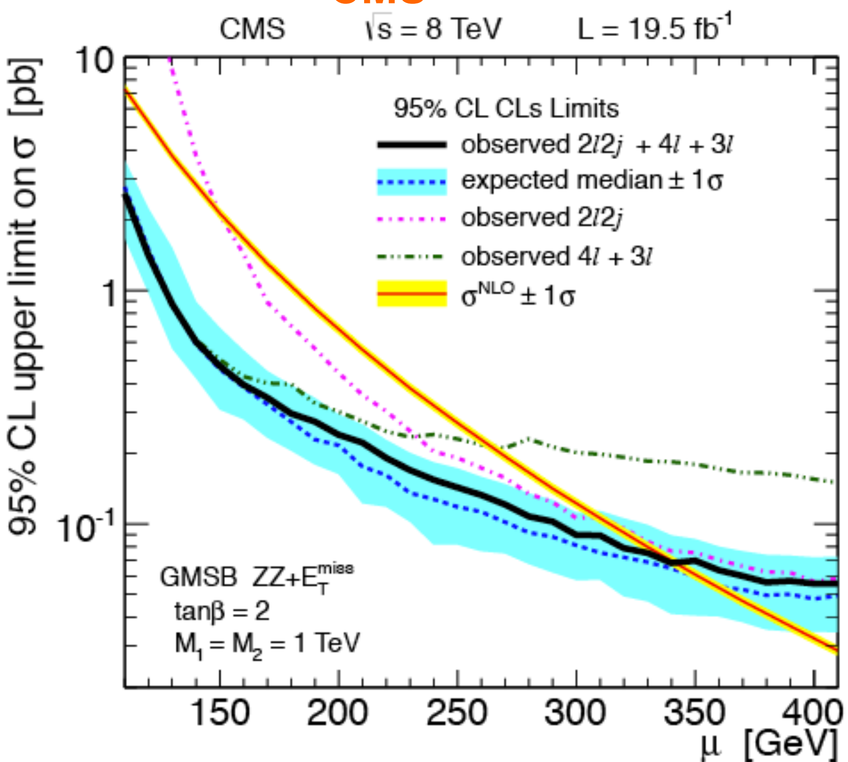




• observed and expected 95% CL limit contours for the two GGM models
• only regions with a Z boson requirement are statistically combined to extract these limits
• for tan β = 1.5:
independently of the value of μ, gluinos with m<700 GeV are excluded
for very large gluino masses: direct production of N1, C, N2 becomes dominant
→ values of μ =200 GeV - 230 GeV are excluded for any gluino mass
•for tan β = 30:
the limits are weaker; gluinos with m<640 GeV are excluded

COMPARISON WITH CMS

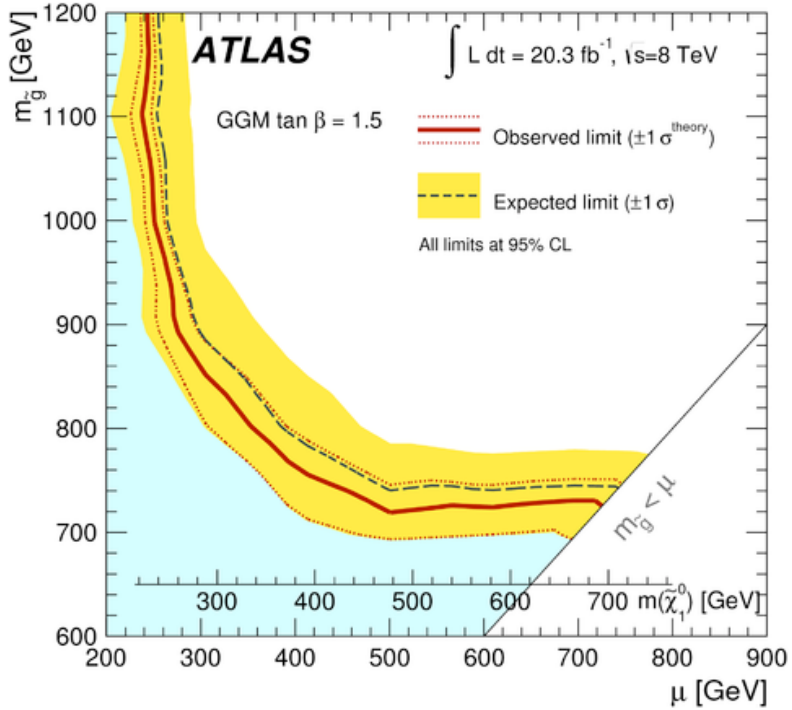
CMS



limit: 330 GeV
tanβ=2, M1=M2=1 TeV

2l, 4l, 3l combined, incl. τs

ATLAS



limit:
tanβ=1.5, M1=M2=1 TeV, M3= m_g
independently of the value of μ,
gluinos with m<700 GeV are excl.
μ =200 GeV - 230 GeV are excl. for any gluino mass

Summary

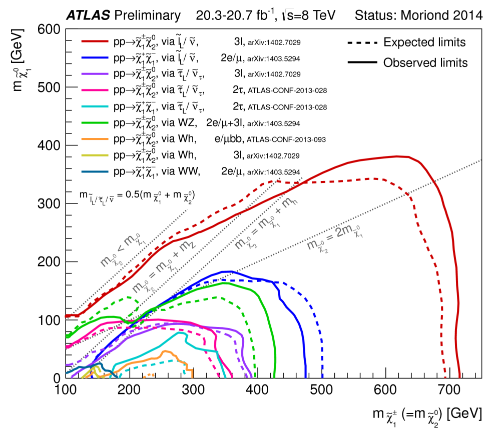
- ATLAS has developed a broad SUSY program
- detailed and thorough searches, covering wide ranges of signatures of electroweak SUSY particles
- presented today the results of the EW SUSY production 2-3 and 4 lepton paper
- no sign of SUSY found yet….

  … we could exclude already low mass chargino/neutralino/slepton models + many new (combination)-papers will be published in the next weeks/months

  BUT…

  we will start with LHC run 2 soon!
- high energy running will significantly increase our sensitivity to many of these SUSY scenarios

Looking forward to next exciting years!



BACK UP

MOTIVATION

- in SUSY scenarios with heavy squarks and gluinos while non-coloured SUSY particles are light, weak gauginos (charginos, neutralinos) and sleptons ĩ may dominate the SUSY production at the LHC

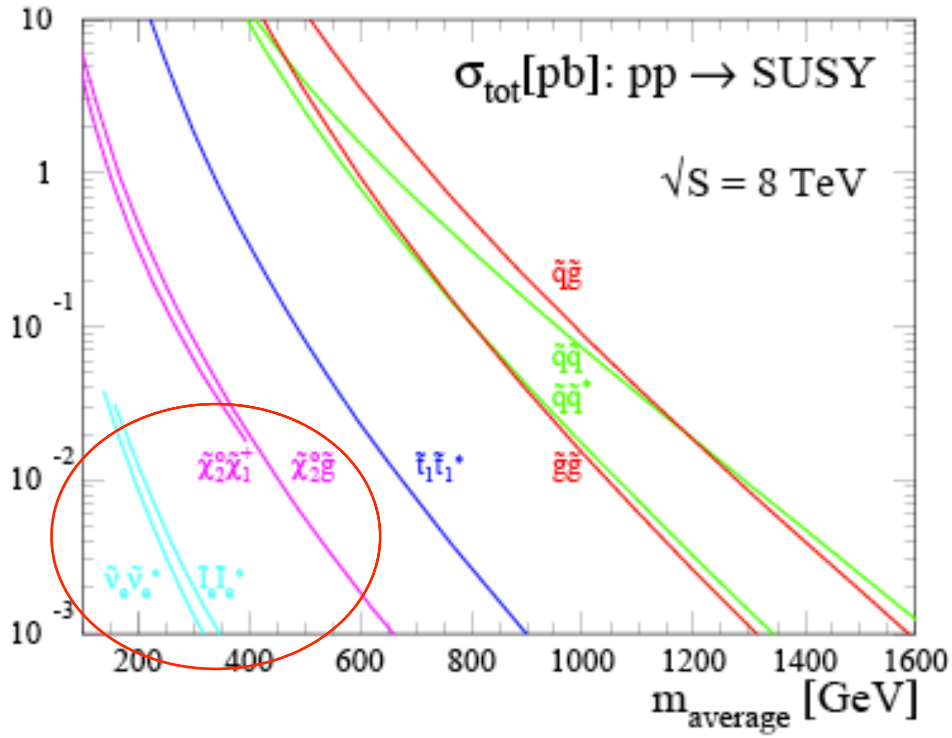
- gauginos can decay via sleptons or via

  Standard Model gauge boson

- relatively clean signature:

  - missing transverse energy E_T^{miss} from LSP
  - low hadronic activity

  → focus on final states with == 2 leptons (e, μ)



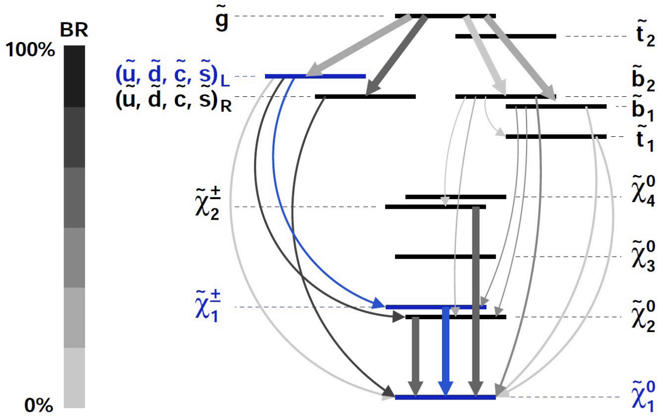
Searching for Supersymmetry

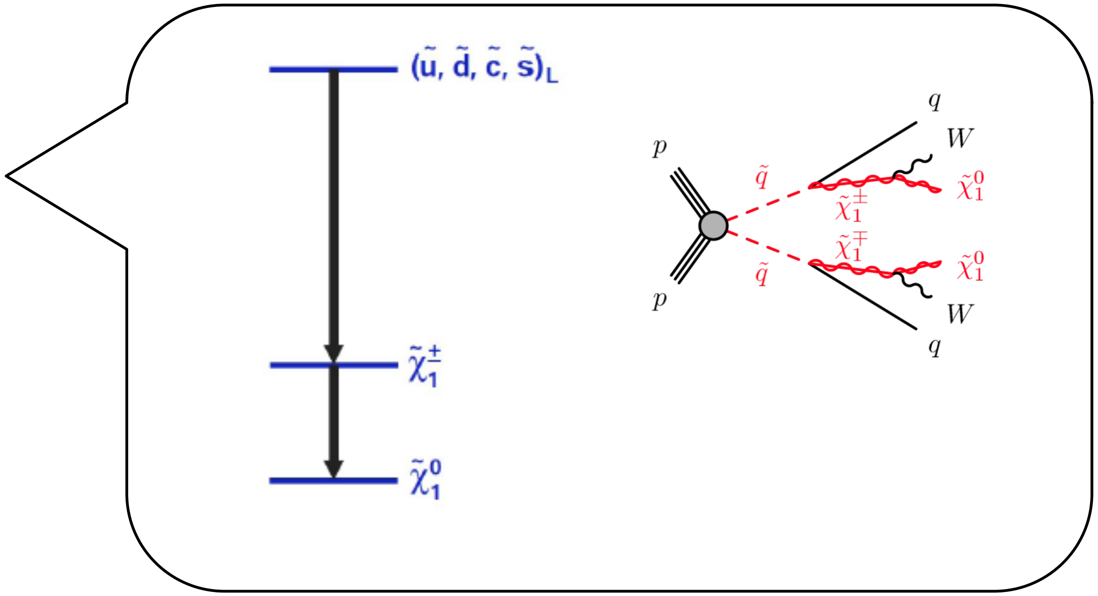
How to search for SUSY ?

✓ focus on the process of interest

✓ study a specific decay chain using simplified models

- simple and broad approach for SUSY searches
- small number of sparticles
- assumed BR usually 100%
- decay described by masses and cross sections





SUSY limits

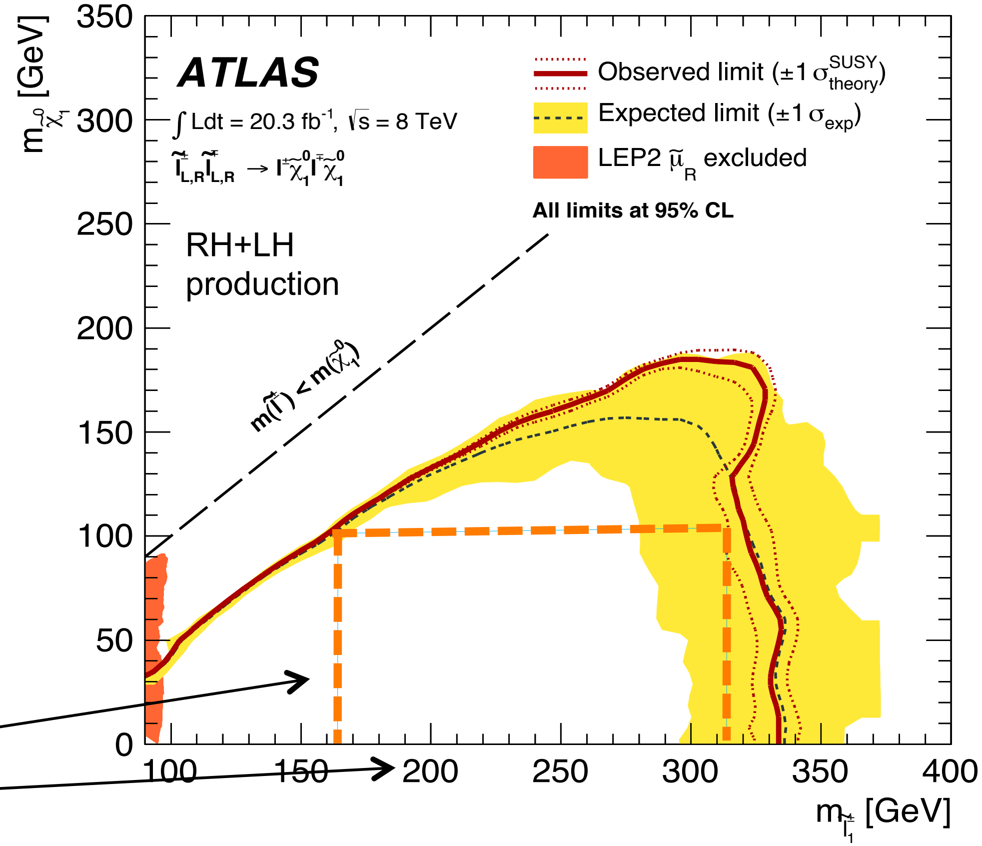
- compute the 95% CL model independent limits on $\sigma_{vis} = \sigma \times A \times \varepsilon$
- compute 95% CL model dependent exclusion curves on σ_{SUSY} and sparticle masses

expected limits
± 1 σ experimental uncertainties + ISR uncertainties on signal MC

observed limits
± 1σ signal theory uncertainties (xsection uncertainties, PDF, renor-malisation/factorisation scales)

best limits:

LSP mass ≈ 100 GeV
slepton mass ≈ 160GeV - 310 GeV



MSSM

Symbol	Description	number of parameters
$\tan\beta$	the ratio of the vacuum expectation values of the two Higgs doublets	1
M_A	the mass of the pseudoscalar Higgs boson	1
μ	the higgsino mass parameter	1
M_1	the bino mass parameter	1
M_2	the wino mass parameter	1
M_3	the gluino mass parameter	1
$m_{\tilde{q}}, m_{\tilde{u}_R}, m_{\tilde{d}_R}$	the first and second generation squark masses	3
$m_{\tilde{l}}, m_{\tilde{e}_R}$	the first and second generation slepton masses	2
$m_{\tilde{Q}}, m_{\tilde{t}_R}, m_{\tilde{b}_R}$	the third generation squark masses	3
$m_{\tilde{L}}, m_{\tilde{\tau}_R}$	the third generation slepton masses	2
A_t, A_b, A_τ	the third generation trilinear couplings	3

2 lepton OBJECTS

E_T^{miss}:

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

ΔΦ = azimutal angle between the direction of E_T^{miss} vector and the nearest lepton or central jet/b-jet

→aim: suppress events where missing transverse momentum arises from significantly mis-measured jets or leptons such that it is aligned with E_t^{miss}

- **stransverse mass m_{T2}**: $$m_{\mathrm{T2}} = \min_{\mathbf{q}_{\mathrm{T}}+\mathbf{r}_{\mathrm{T}}=\mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}} \left[\max\left(m_T(\mathbf{p}_{\mathrm{T}}^{\ell_1}, \mathbf{q}_{\mathrm{T}}), m_T(\mathbf{p}_{\mathrm{T}}^{\ell_2}, \mathbf{r}_{\mathrm{T}})\right)\right]$$

p_T^{l1}, p_T^{l2} = tranverse momenta of the two leptons

q_T = transverse vector that minimizes the larger of the two transverse masses m_T

$$m_{\mathrm{T}}(\mathbf{p}_{\mathrm{T}}, \mathbf{q}_{\mathrm{T}}) = \sqrt{2(p_{\mathrm{T}} q_{\mathrm{T}} - \mathbf{p}_{\mathrm{T}} \cdot \mathbf{q}_{\mathrm{T}})}$$

→for SM WW, ttbar with leptonic decay: m_{T2} has an upper endpoint: W-mass

OBJECTS

The stransverse mass m_{T2} is defined for pair produced particles that each decay to two particles, out of which one goes undetected.

If the undetected particles are massless, the two-lepton m_{T2} distribution (for $\tilde{\ell}$ pair production) has an endpoint given by

$$m_{T2}^2 = m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2 + \frac{m_{\tilde{\ell}}^2 - m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{\ell}}} \left(\sqrt{\left(\frac{m_{\tilde{\ell}}^2 + m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{\ell}}}\right)^2 - m_{\tilde{\chi}_1^0}^2} - \frac{m_{\tilde{\ell}}^2 + m_{\tilde{\chi}_1^0}^2}{2m_{\tilde{\ell}}} \right)$$

It can be shown that this equation simplifies to $\approx m_{\tilde{\ell}} - m_{\tilde{\chi}_1^0}$.

In particular, m_{T2} is a powerful tool rejecting WW background, since the WW m_{T2} distribution will end at the W mass.

J.Phys. G29 (2003) 2343-2363, Phys.Lett. B463 (1999) 99-103.

MATRIX METHOD

- takes care of fake leptons from W+jets, semi leptonic ttbar, single top t- and s-channel or multi-jets
- employs a set of linear equations relating kinematic properties of the leptons to be real (R) or fake (F)
- number of observed events with one (or two) fakes is extracted from this system of linear equations relating the number of events with 1(2) additional signal (tight T) or tagged lepton (loose L) candidates to the number of events with 1(2) additional candidates that are either real or fake candidates
- coefficients of the linear equations are functions of real-lepton id efficiencies r (obtained from MC simulation + scaled to account differences to data) and fake-object misidentification probabilities (f)

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{bmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{bmatrix} \cdot \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

- fake rate depends of the type of fake and the process that produced the fake

→ fake rates are obtained from MC simulated samples and corrected for differences between data and MC in each signal and validation region

- weighted average fake efficiency for a generic region XR: $$f^l_{XR} = \sum_{i,XR} (sf^i \times R^i_{XR} \times f^i)$$

sf^i : scaling factor for lepton fake type (HF, conversion)
R^i_{XR}: fraction of type iin region XR
f^i : fake efficiency for type i, parametrized as a function of p_T

MATRIX METHOD

Define a set of tight and loose object selection criteria.

Determine the *real efficiency* r, i.e the probability for a real, prompt lepton to pass the tight selection. This is done using real data.

Determine the *fake rate* f, i.e the probability for a fake, non-prompt lepton to pass the tight selection. This is done using MC truth.

Let N_{TT} denote the number of events with two tight leptons, N_{TL} the number of events with one tight and one loose lepton and so on.

Let N_{RR} denote the number of events with two real leptons, N_{RF} the number of events with one real and one fake lepton and so on.

The number of events with at least one fake lepton is found by inverting the matrix below. For 3-Lepton, the method is applicable under the assumption that the leading lepton is always real.

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{bmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{bmatrix} \cdot \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

MATRIX METHOD

- Use isolation to define "loose" and "tight" leptons
  - "tight" (T) are the signal leptons
  - "loose" (L) leptons have more relaxed isolation requirements
    - electrons: `medium++` and no isolation
    - muons: no isolation
- The fake rate f is the probability that a loose fake lepton passes tight
  - $f(e(p_{\mathrm{T}})) = \sum_{i \in \mathrm{QCD,\ conv}} f_i(p_{\mathrm{T}}) w_i(p_{\mathrm{T}}) s_i(p_{\mathrm{T}})$
  - f_i Measured for $E_T^{\mathrm{miss,\,rel}} < 50$ GeV, Z mass, == 2 μ, >=1 el with $m_T < 40$ GeV in MC
  - Compared with rates in fake-rich control regions $\rightarrow s_i$
  - Weighted average for each SR used in estimate $\rightarrow w_i$
- The real efficiency $r = (N_T/N_L)_{|m_{\ell\ell} - m_Z| < 5\ \mathrm{GeV}}$

$$\begin{bmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{bmatrix} = \begin{bmatrix} rr & rf & fr & ff \\ r(1-r) & r(1-f) & f(1-r) & f(1-f) \\ (1-r)r & (1-r)f & (1-f)r & (1-f)f \\ (1-r)(1-r) & (1-r)(1-f) & (1-f)(1-r) & (1-f)(1-f) \end{bmatrix} \begin{bmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{bmatrix}$$

$$N_{TT}^{RF} = r_1 f_2 N_{LL}^{RF},\ N_{TT}^{FR} = f_1 r_2 N_{LL}^{FR},\ N_{TT}^{FF} = f_1 f_2 N_{LL}^{FF}$$

MATRIX METHOD

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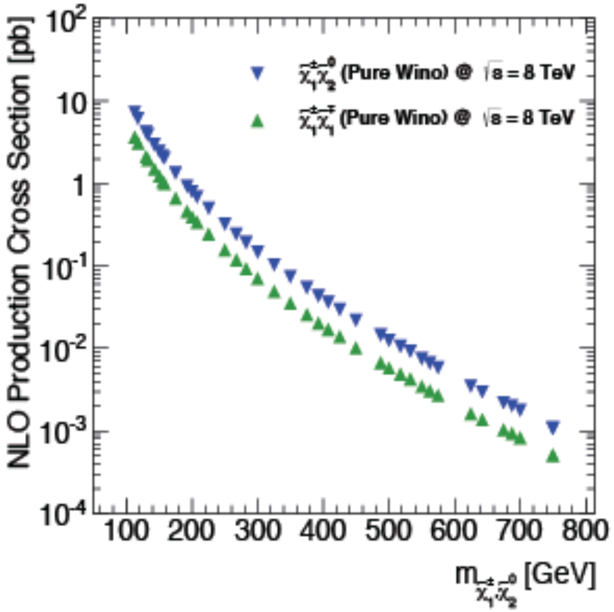
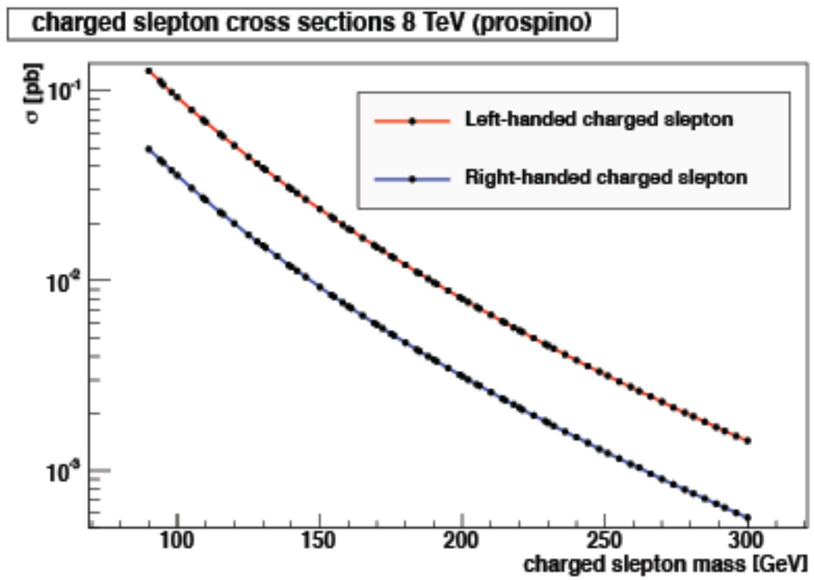
$$N_{TT}^{RF} = r_1 f_2 N_{LL}^{RF},\ N_{TT}^{FR} = f_1 r_2 N_{LL}^{FR},\ N_{TT}^{FF} = f_1 f_2 N_{LL}^{FF}$$

2 lepton

2 lepton - Motivation

- if gluinos and squarks are massive (> 1TeV), weak gauginos and slepton production will be dominant at the LHC
- signature of direct gaugino decays: multiple leptons, low jet multiplicity + missing energy





2 lepton - OBJECTS

Order	Distance	Object rejected
1	$\Delta R(e_1, e_2) < 0.05$	electron with lowest cluster E_T
2	$\Delta R(j, e) < 0.2$	jet
3	$\Delta R(\tau, e\mu) < 0.2$	tau
4	$\Delta R(j, e) < 0.4$	electron
5	$\Delta R(j, \mu) < 0.4$	muon
6	$\Delta R(e, \mu) < 0.01$	electron and muon
7	$\Delta R(\mu, \mu) < 0.05$	both muons
8	$m(ll, SFOS) < 12$ GeV	both leptons
9	$\Delta R(j, \text{signal } \tau) < 0.2$	jet

Signal jet definitions : central light jets (L20), central b-jets (B20) and forward jets (F30)

cuts	Central light jets L20	Central b-jets B20	Forward jets F30
p_T [GeV]	>20	>20	>30
$\lvert\eta_{det}\rvert$	<2.4	<2.4	[2.4,4.5]
b-tag MV1	≤0.3511	>0.3511	-
JVF	$\lvert JVF\rvert > 0$ if $p_T < 50$ GeV	-	-

2 lepton - MC samples

Category	Process	MCID	Generator	Remarks
Top	$t\bar{t}$	105200	MC@NLO	
	Wt	108346	MC@NLO	
	st, s-chan	108343-45	MC@NLO	
	st, t-chan	117360-2	ACER	
	$t\bar{t}$+ boson	119353-6, 119583	MADGRAPH (LO)	LO cross section scaled to NLO using k-factor [31]
WW	WW	126928-36	POWHEG	
	WW via g-g fusion	169471-9	gg2wwJimmy	
	W^+W^+jj	126988-9	SHERPA	
	$VV \to lvqq$	157817-9	SHERPA	
	WWW^*	167006	MADGRAPH	
	$WWjj$	147191,147193	SHERPA	
ZV	WZ	129477-94	POWHEG	
	ZZ	126937-42, 126949-51	POWHEG	
	ZZ via g-g fusion	116600-3	gg2zzJimmy	
	$VV \to llqq$	157814-16	SHERPA	
	ZWW^*	167007	MADGRAPH	
	ZZZ^*	167008	MADGRAPH	
	$WZjj$	147194-6	SHERPA	
ZX	DY ($m(ll)$ <40 GeV)	173041-6	SHERPA	41-4 are AF2, 45-6 are FullSim
	Z 40 GeV< $m(ll)$ <60 GeV	147770-2	SHERPA	
	Z ($m(ll)$ >60 GeV)	117650-5,60-5,70-5	ALPGEN(Pythia)	
	Zcc ($m(ll)$ >60 GeV)	110805-16	ALPGEN(Pythia)	
	Zbb ($m(ll)$ >60 GeV)	110817-28	ALPGEN(Pythia)	
Higgs	WH	160255,160755,161105	PYTHIA	The cross sections are obtained from [32, 33, 34].
	ZH	160305,160805,161155	PYTHIA	
	VBF	160205,160705,161055	POWHEG	
	g-g fusion	160155,160655,161005	POWHEG	
W + $jets$	$W(\to \ell\nu)$ + jet	117680-5,690-5,700-5	ALPGEN(Pythia)	For matrix method
	Wbb	110801-4	ALPGEN(Pythia)	For matrix method
	Wcc	126606-9	ALPGEN(Pythia)	For matrix method
	Wc	126601-5	ALPGEN(Pythia)	For matrix method
$W + \gamma$	$W + \gamma$	126739,42,126856	SHERPA	For matrix method
Heavy Flavor	$b\bar{b}$	129136	Pyhia8B	For matrix method
	$c\bar{c}$	147668	Pyhia8B	For matrix method

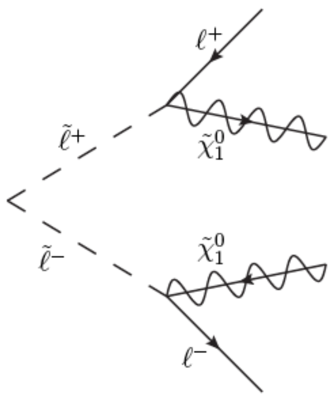
2 lepton - SUSY MODELS

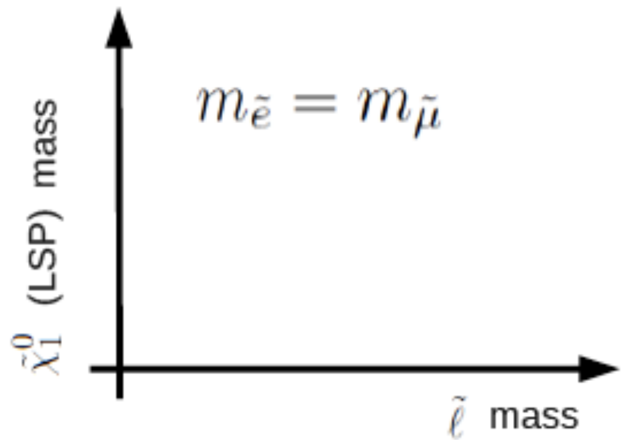
Direct slepton models

- direct production of sleptons, models based on pMSSM
- grid with left-handed and right-handed sleptons (both have same mass), no sneutrinos
- all gauginos masses – except for LSP set to 2.5 TeV
- models contain only selectrons and smuons $m_{\tilde{e}} = m_{\tilde{\mu}}$ in range 90-370 GeV step size:

$$m_{\tilde{\ell}} \geq m_{\tilde{\chi}_1^0} + 30 \text{ GeV}$$

- $\tilde{\chi}_1^0$ is bino-like (μ large) and varied by scanning M_1 in range 0-200 GeV
- σ = 127…0.5 fb for left-handed sleptons, σ = 49 to 0.2 fb for right-handed sleptons, independently of the neutralino mass as the slepton mass : 100GeV to 370 GeV





2 lepton - SUSY MODELS

Simplified models

- minimal particle content necessary to produce SUSY-like events
- parameterization in SUSY particles masses; only free parameter are:

neutralino 1 mass, slepton mass, sneutrino mass and chargino mass

- BR for decays in higgs bosons is set to 0
- Squarks are set to be very heavy
- charginos are pair produced via s-channel + exchange a virtual gauge boson
- decay modes:

- via on-shell charged left-handed sleptons – including staus and sneutrinos with equal BR:

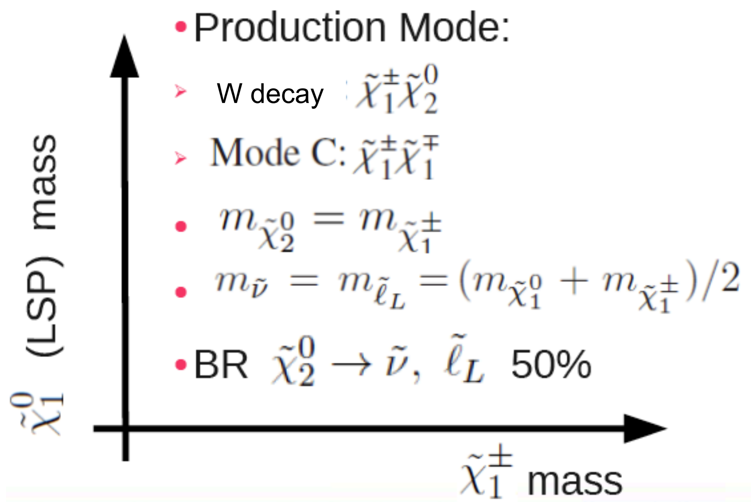
$$m_{\tilde{\nu}} = m_{\tilde{\ell}_L} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_1^\pm})/2.$$

cross section assuming chargino is about 95% wino-like

σ=5 pb (chargino mass = 100 GeV) …σ=0.35 pb

(chargino masses > 200 GeV

- via Z and W boson (W decay)



2 lepton - SUSY MODELS

chargino-to-W scenario

- mass grid in chargino-neutralino1 mass plane in 10 GeV steps from (100,0) to
  chargino mass – neutralino mass > 80 GeV
- BR assumes 100%
- Bino-like LSP, pure wino-like chargino + mass degenerated
- charged higgs very heavy→ decay only via W
- small higgsino component is allowed

pMSSM grid

- masses of the colored sparticles and CP-odd Higg boson and LH sleptons are set to very high values to allow only chargino-neutralino2 production via WZ and decays via RH sleptons, gauge boson or higgs; lightest higgs mass set to 125 GeV, $m_{\tilde{\ell}_R} = (m_{\tilde{\chi}_1^\pm} + m_{\tilde{\chi}_1^0})/2$
- mass hierarchy, composition and production cross section of charginos and neutralinos are converned by tanβ, the expectation values of the two higgs doublets, gaugino mass parameters M1, M2 and the higgs mass parameter μ; studies are done in μ-M2 plane
- preferred decays $\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell \to \tilde{\chi}_1^0 \ell\ell.$

2 lepton - DATA-MC SAMPLES | TRIGGER

- **Data**:

  full 8 TeV 2012 corresponding to 20.3 fb^{-1}

- **MC (most important ones)**:

  TOP: ttbar, Wt with MC@NLO (Powheg/Alpgen for cross checks)

  ttbar + boson with Madgraph (LO xsection scaled to NLO via k-factor)

  WW: WW w/ Powheg (Sherpa for cross checks), WW via gluon fusion w/ gg2WW

  ZV: ZW/ZZ w/ Powheg (Sherpa for cross checks), ZZ via gluon fusion w/ gg2ZZ

  VVV: WWW, WWZ and ZZZ w/ Madgraph

  Higgs: Associated production modes (WH, ZH) w/ Pythia and the VBF, ggF w/ Powheg

- **SUSY Signal:**

  all signal samples are generated w/ Herwig++, cross-sections are computed with prospino

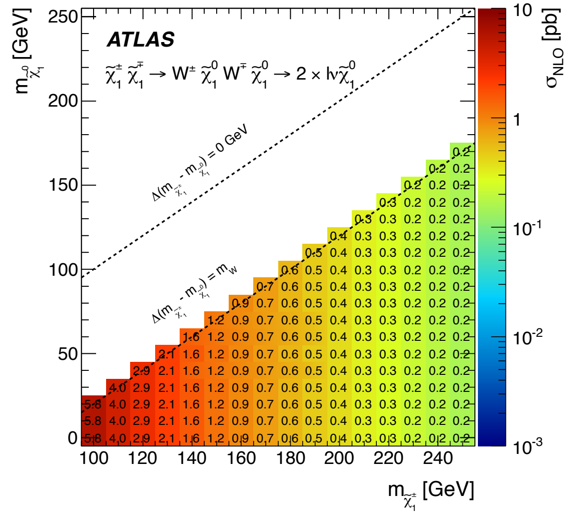
- **Trigger**:

  symmetric and asymmetric di-electron, di-muon and asymmetric electron-muon trigger

  no trigger simulation is used, trigger weights are applied to MC

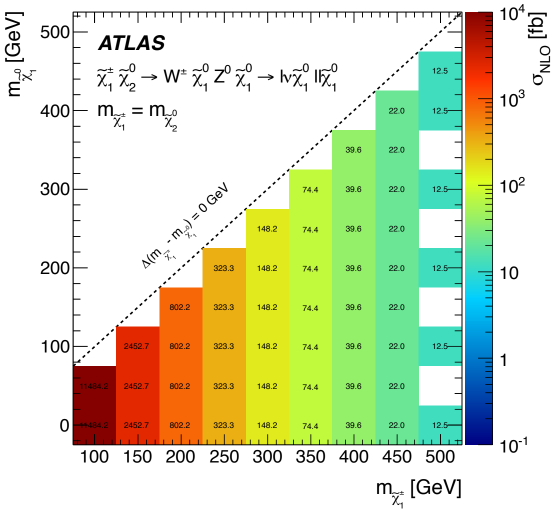
2 lepton SUSY MODELS

chargino1-chargino1 production



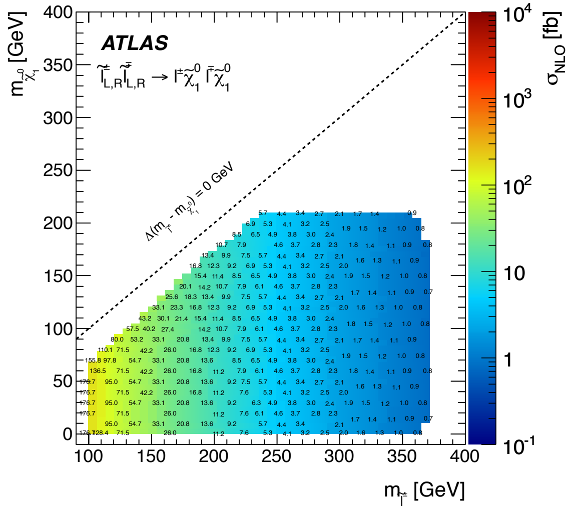
σ ≈ 6pb-10fb

chargino1-neutralino2 production

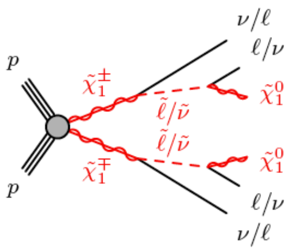


σ ≈ 12pb-40fb

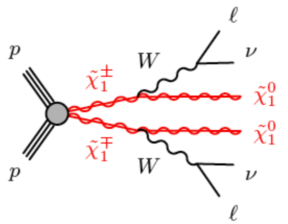
slepton pair production



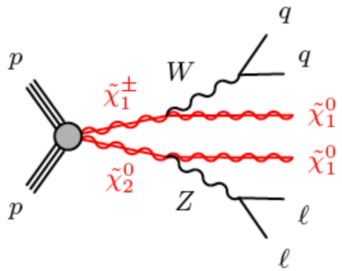
σ ≈ 127fb-0.5fb (LH)
σ ≈ 49fb-0.2fb (RH)



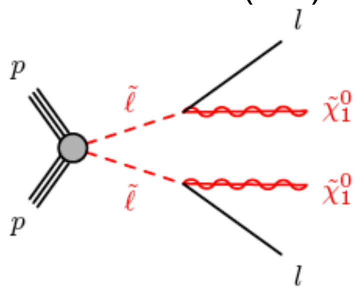
via intermediate sleptons



with on-shell W decays



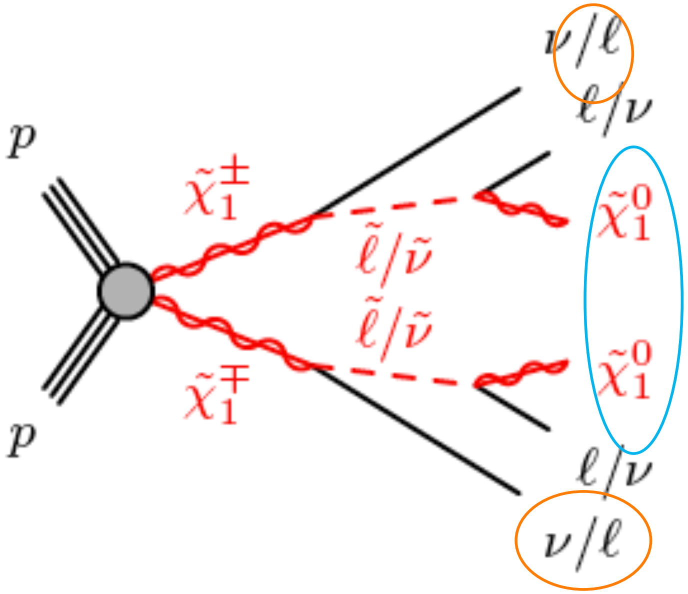
with on-shell W,Z decays



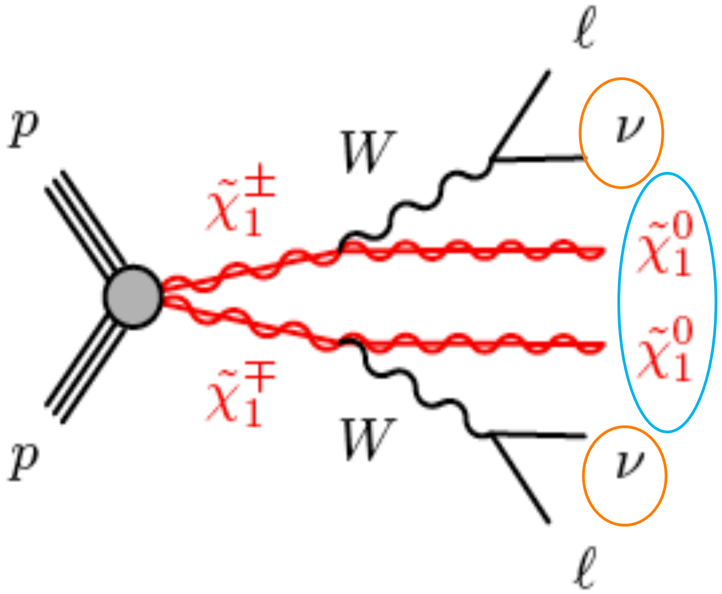
via virtual Z

2 lepton SUSY MODELS

chargino1-chargino1 production



via intermediate sleptons

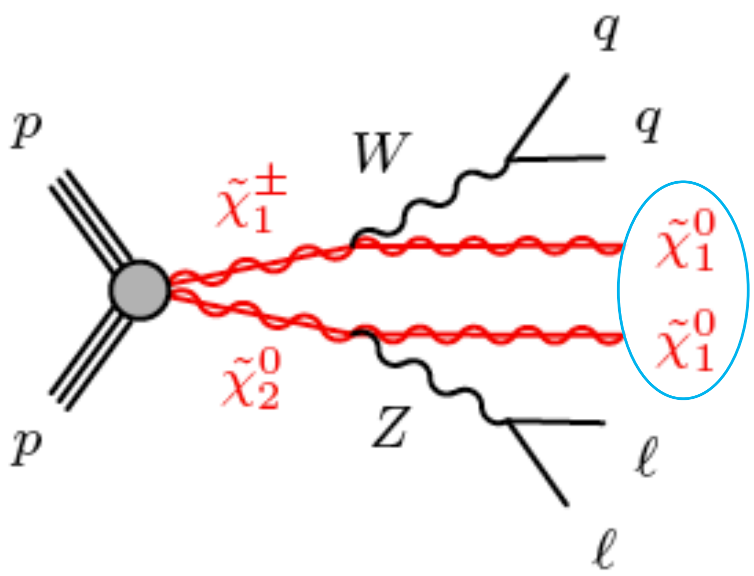


with W decays

E_T^{miss} from neutralino1 (LSPs) and neutrinos
same flavour and different flavour leptons

2 lepton SUSY MODELS

chargino1-neutralino2 production

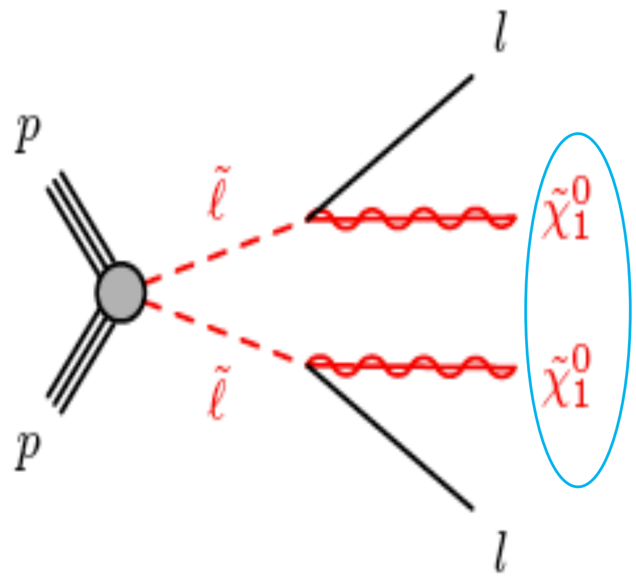


with W,Z decays

E_T^{miss} from neutralino1 (LSPs) + 2 jets in final state
ONLY same flavour leptons (ee, μμ)

2 lepton SUSY MODELS

slepton pair production

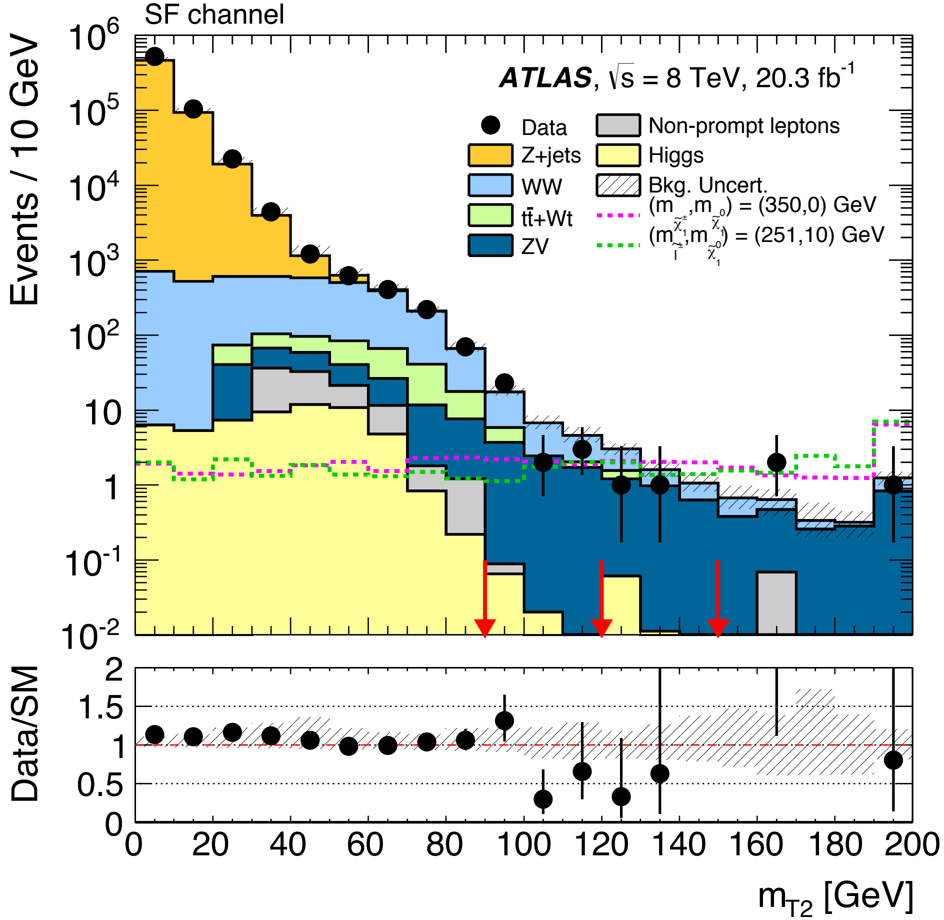


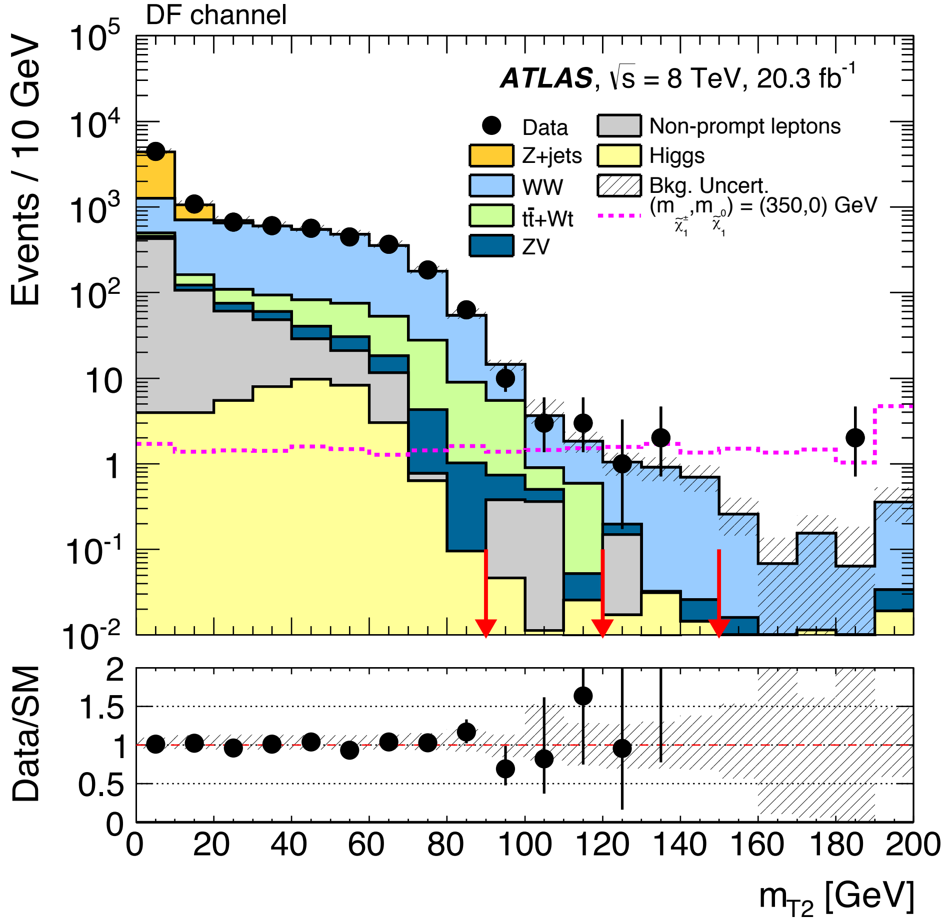
via virtual Z

E_T^{miss} from neutralino1 (LSPs)
ONLY same flavour leptons (ee, μμ)

2 lepton RESULTS SRmT2

> m_{T2} distribution before applying the final m_{T2} cuts





2 lepton - COMMENTS

- SRmT2 chargino-chargino production: studies performed with particle level MC samples show that signal acceptance in SRmT2 depends weakly on the slepton mass
- choice of $m_{\tilde{\ell}} = (m_{\tilde{\chi}_1^\pm} + m_{\tilde{\chi}_1^0})/2$ minimizes (maximizes) the acceptance for small (large) chargino-neutralino mass splitting

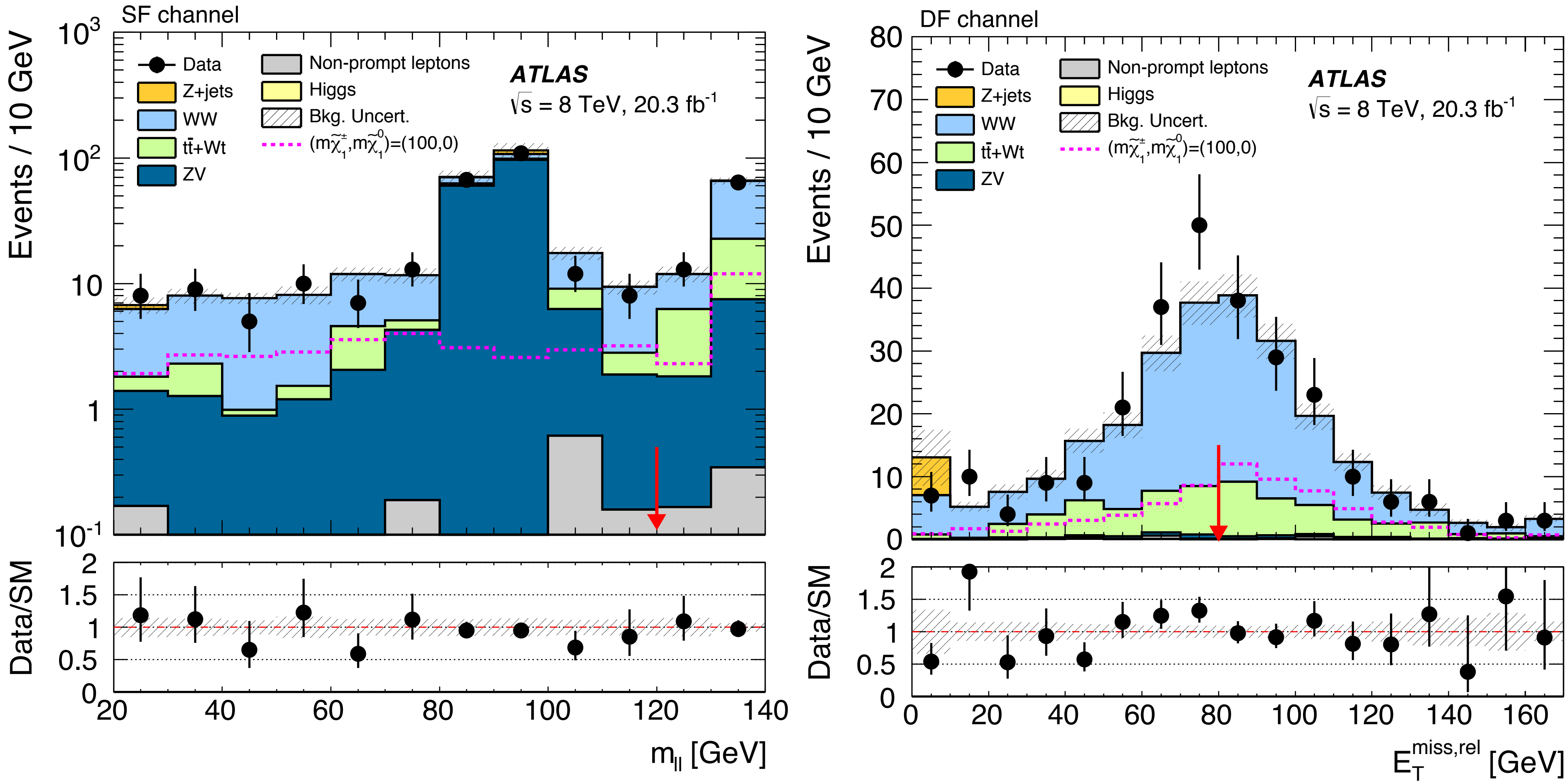
2 lepton - SYSTEMATIC UNCERTAINTIES

Table 4. Systematic uncertainties (in %) on the total background estimated in different signal regions. Because of correlations between the systematic uncertainties and the fitted backgrounds, the total uncertainty can be different from the quadratic sum of the individual uncertainties.

	m_{T2}^{90}		m_{T2}^{120}		m_{T2}^{150}		WWa		WWb		WWc		Zjets
	SF	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF	DF	SF
CR statistics	5	3	6	4	8	4	5	5	5	3	6	4	1
MC statistics	5	7	7	12	10	23	3	4	5	8	6	10	14
Jet	4	1	2	1	5	7	3	6	4	2	4	3	11
Lepton	1	2	1	1	4	1	1	3	2	3	1	8	4
Soft term	3	4	1	1	2	8	< 1	2	3	5	1	6	5
b-tagging	1	2	<1	<1	<1	<1	1	1	1	2	<1	1	2
Non-prompt lepton	<1	1	<1	<1	1	<1	1	1	1	2	<1	1	<1
Luminosity	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2
Modelling	11	13	21	31	18	40	6	6	8	10	15	19	42
Total	13	16	24	34	23	47	9	11	12	14	17	24	47

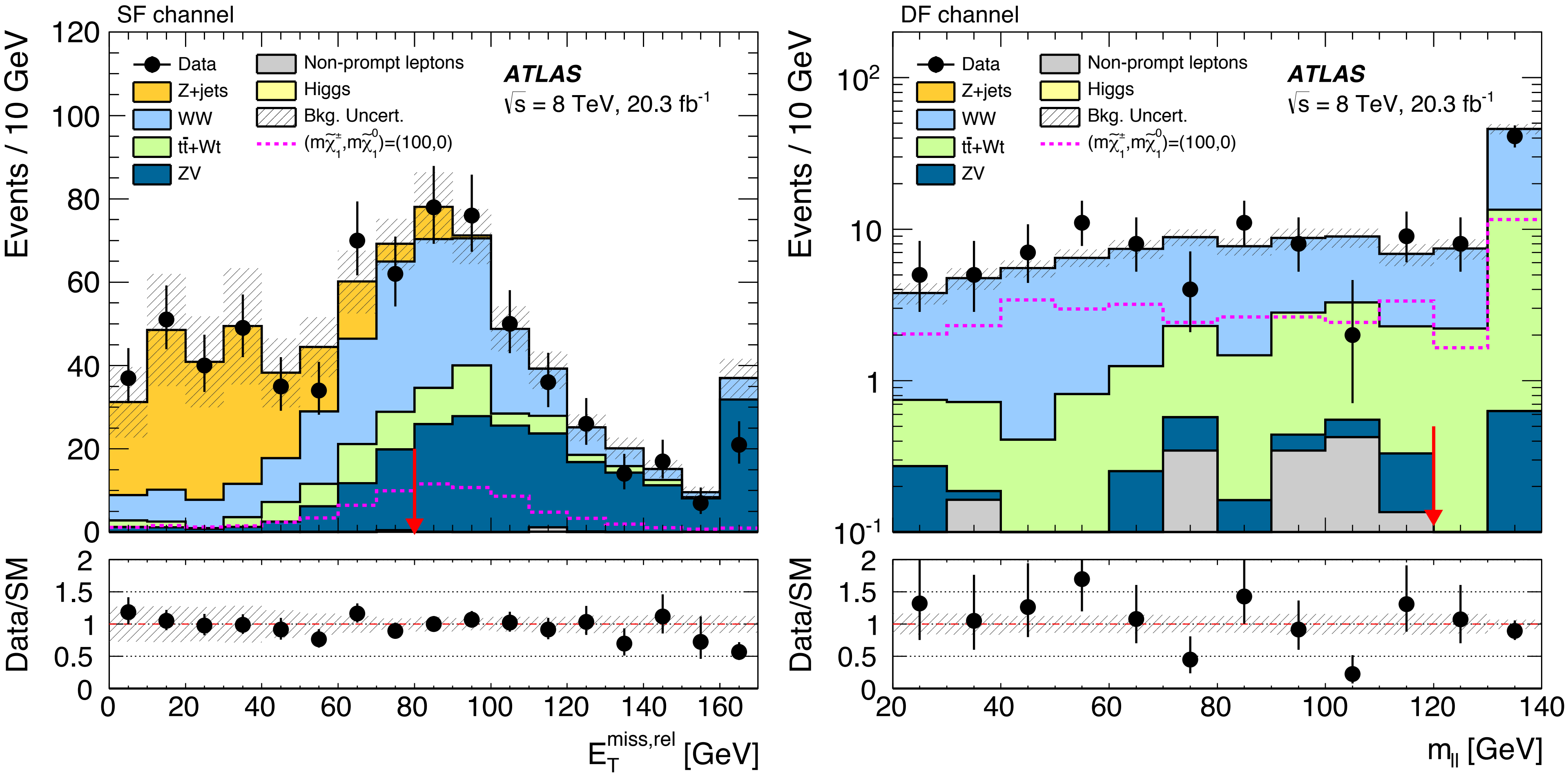
2 lepton - RESULTS SRWWa

> $m(l,l)$ and $E_T^{miss, rel}$ distribution of SR WWa before applying the final $m(l,l)$ and $E_T^{miss, rel}$ cuts

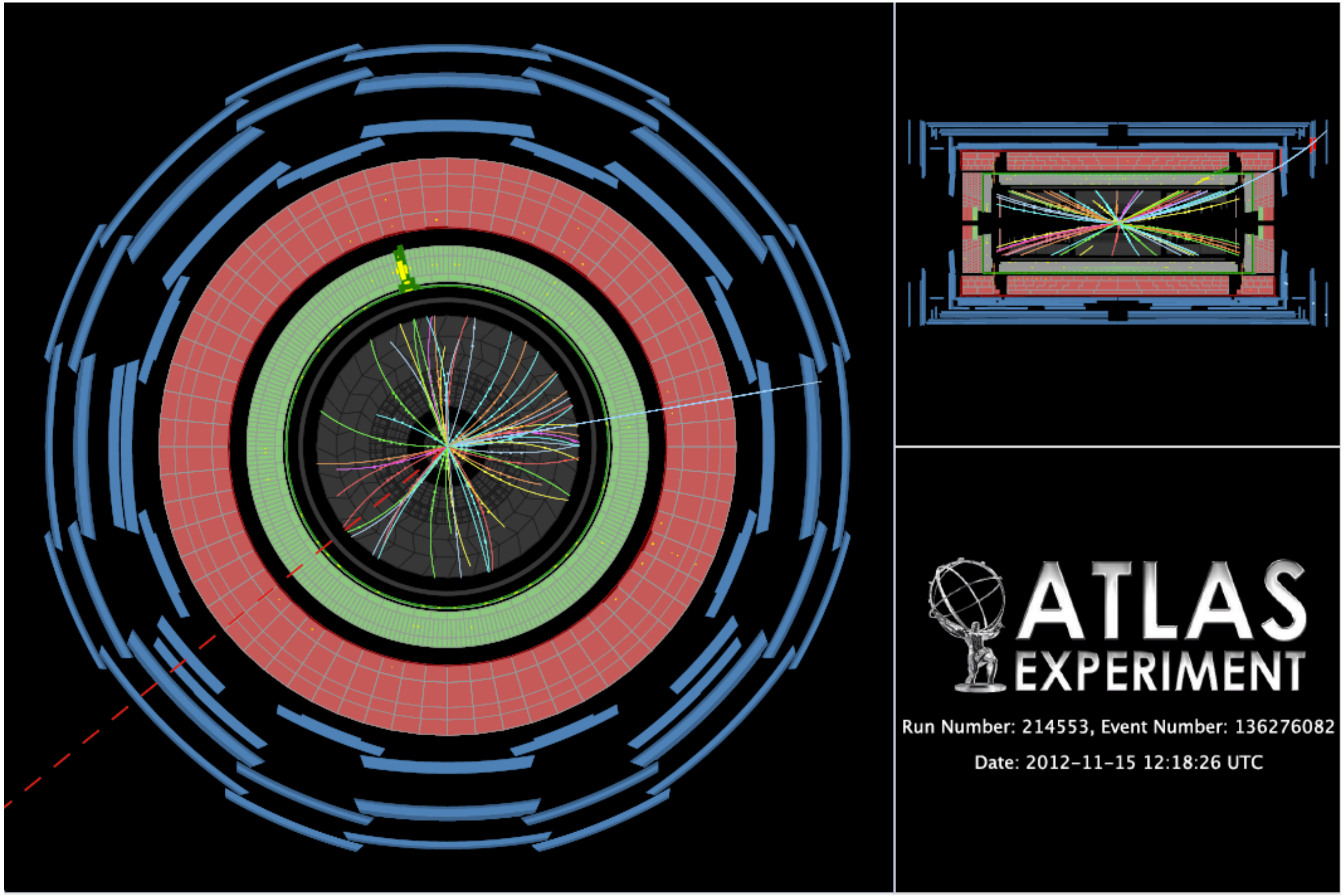


2 lepton - SR WW

- m(l,l) and $E_T^{miss, rel}$ distribution of SR WWa before applying the final m(l,l) and $E_T^{miss, rel}$ cuts

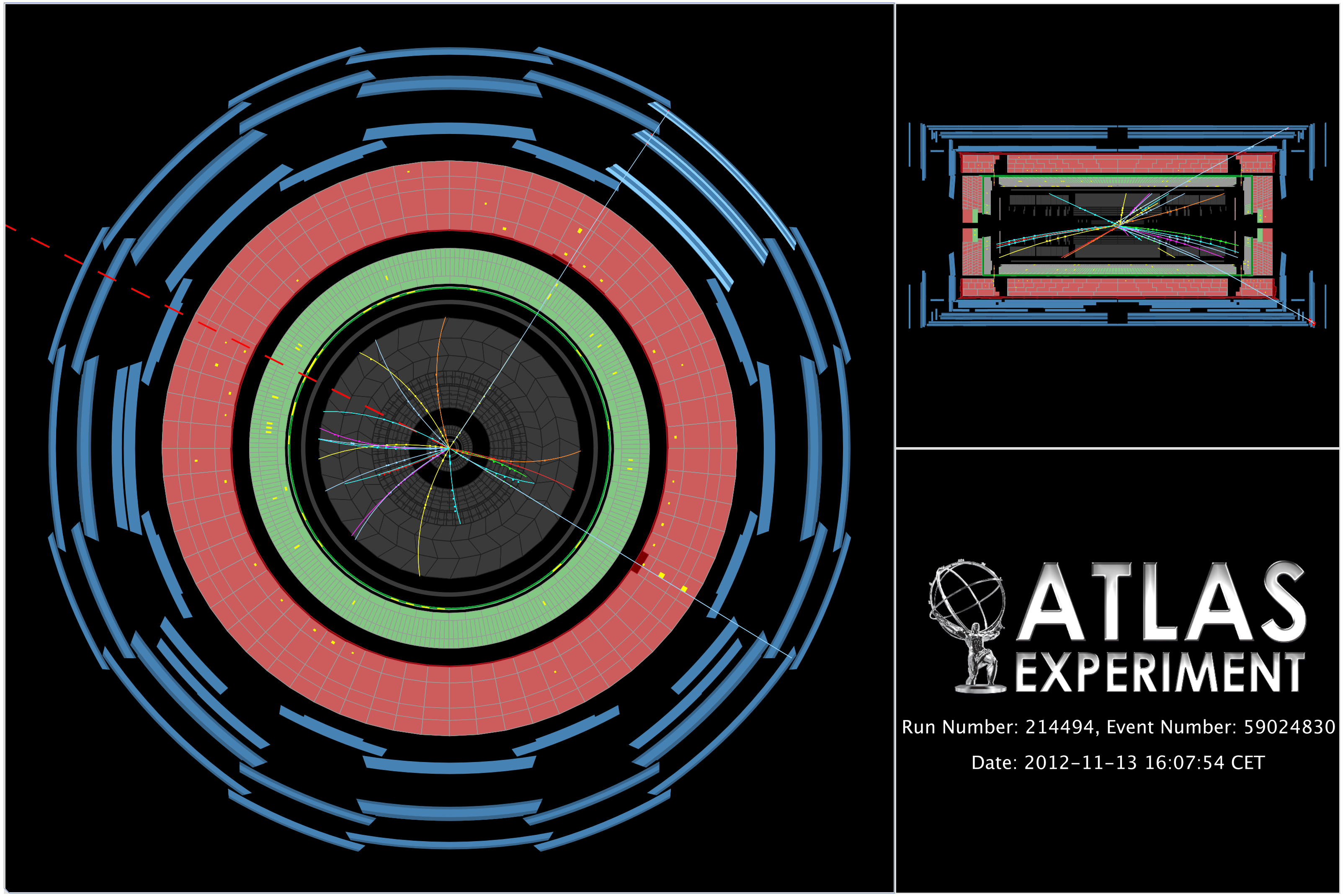


2 lepton - highest mT2 event in emu channel



highest m_{T2} event in eμ channel:
m_{T2} =184 GeV
p_T(el) = 107 GeV (green), p_T (μ) =153 GeV (blue), E_T^{miss}= 205 GeV

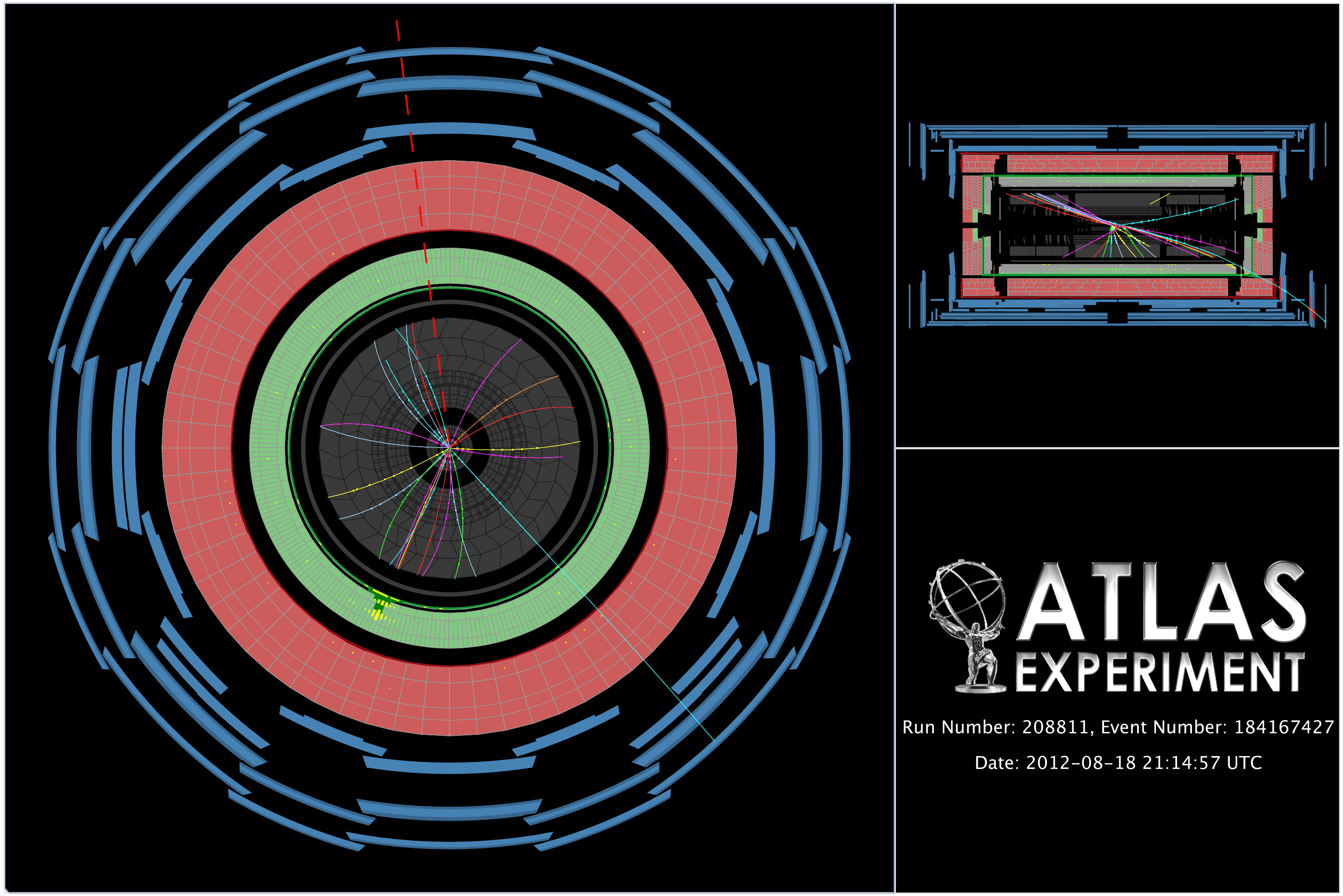
2 lepton - High mumu event in SR WW



highest $E_T^{miss, rel}$ event in $\mu^+\mu^-$ channel:

$p_T(\mu 1)$ = 174 GeV, p_T $(\mu 2)$ = 32 GeV, E_T^{miss}= 154 GeV

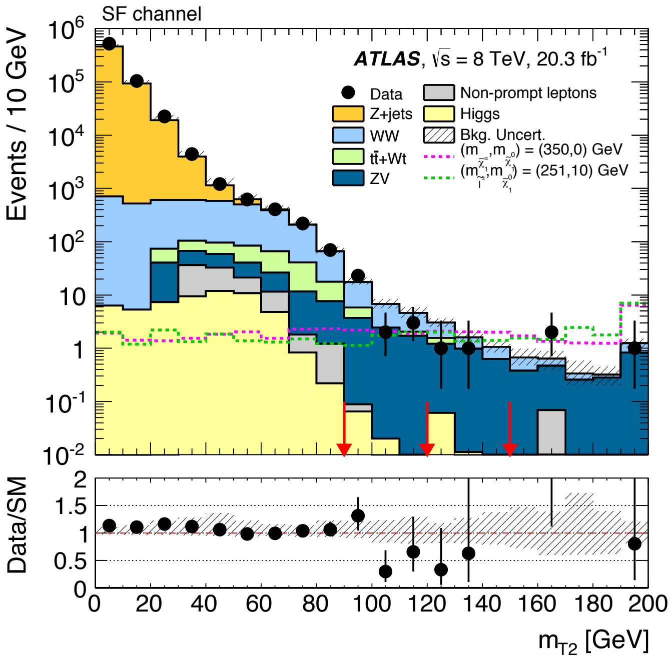
2 lepton - High emu event in SR WW

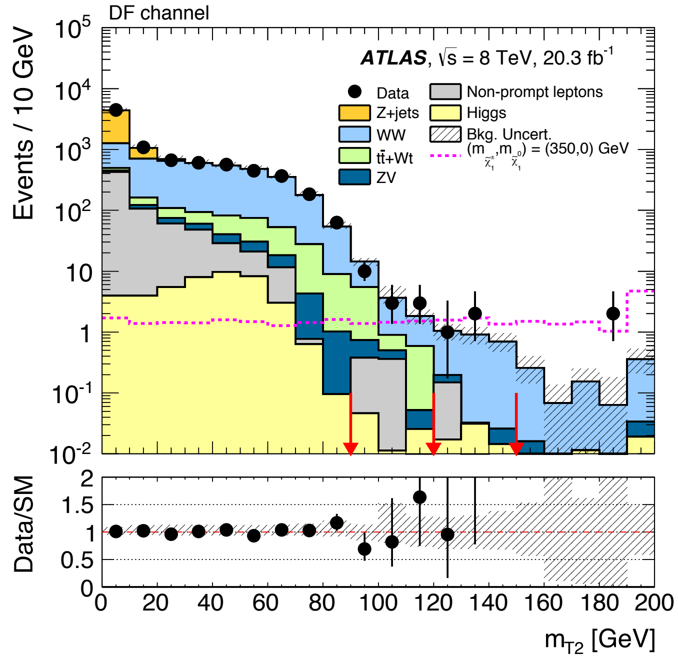


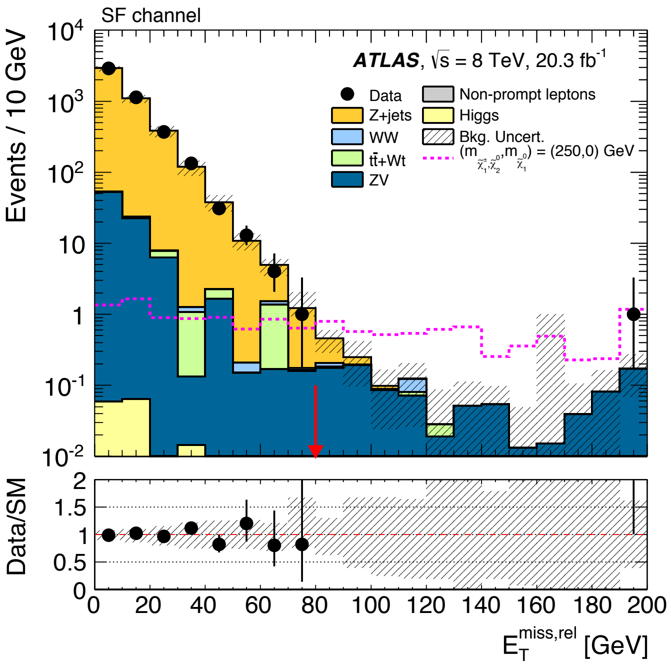
highest $E_T^{miss, rel}$ event in eμ channel:

$p_T(el) = 104$ GeV, $p_T(\mu) = 97$ GeV, $E_T^{miss} = 196$ GeV

2 lepton - SR Zjets

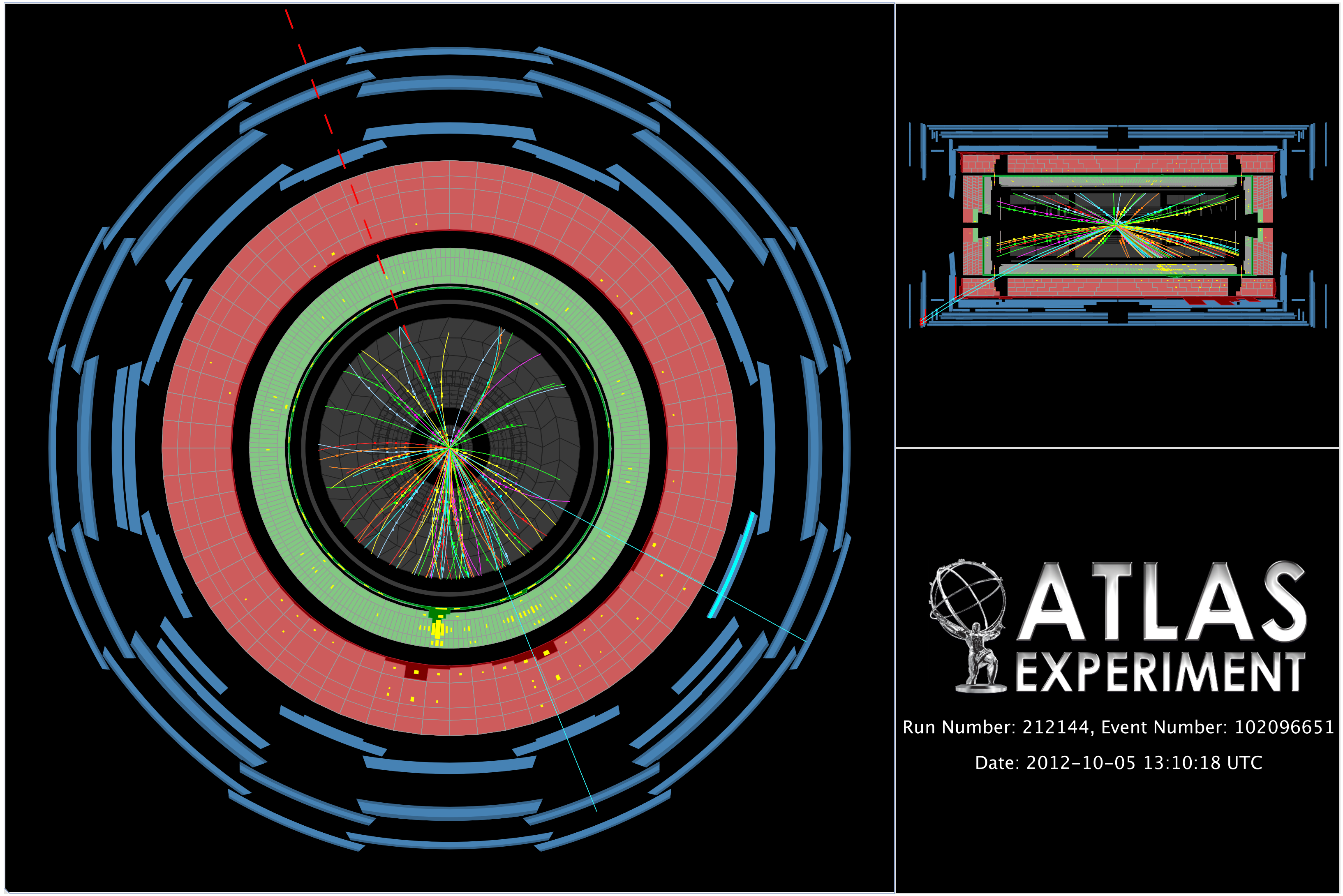






> m_{T2} and $E_T^{miss,\,rel}$ distribution before applying the final m_{T2} ($E_T^{miss,\,rel}$) cuts

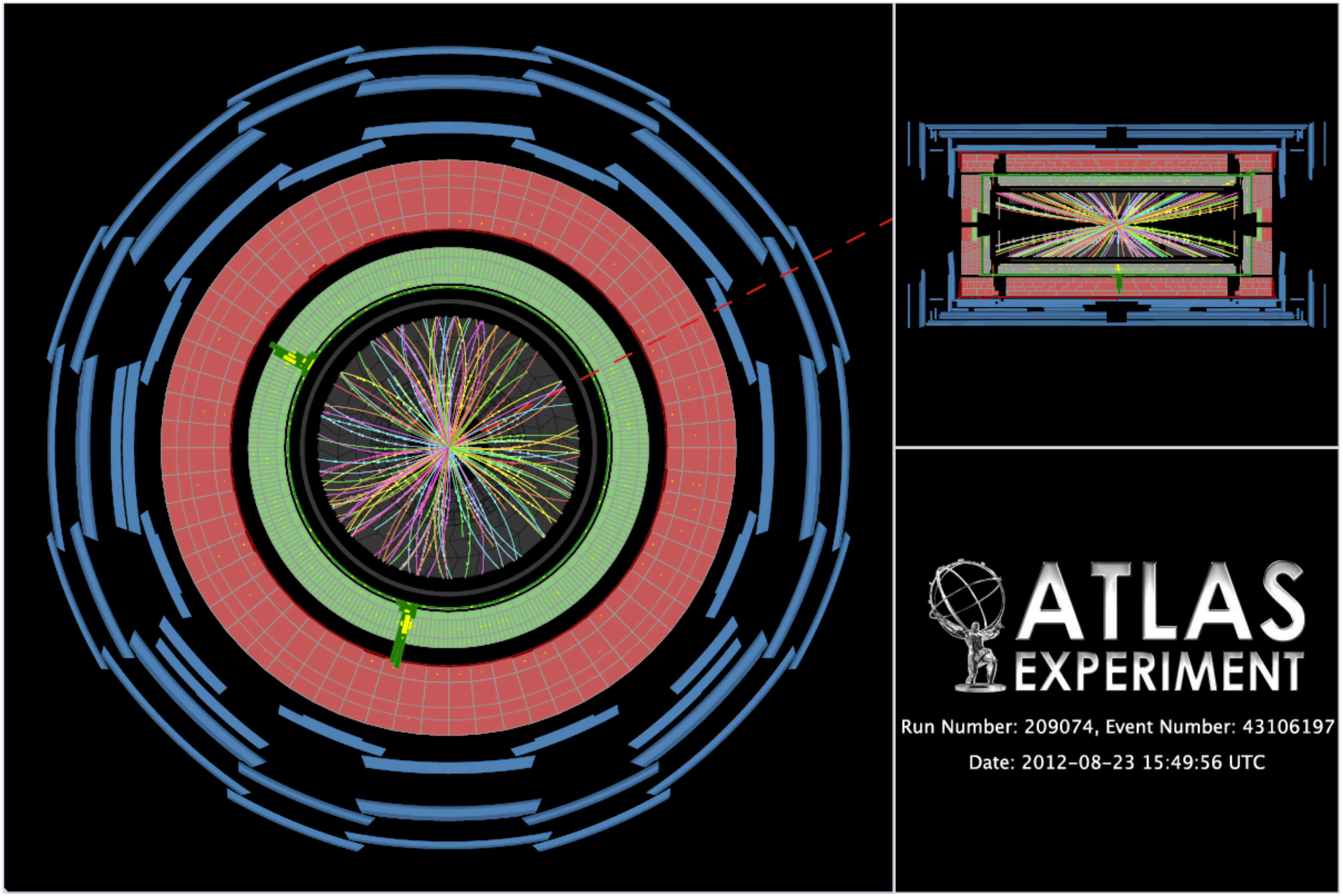
2 lepton - High mumu event in SR Z jets



highest $E_T^{miss, rel}$ event in $\mu^+\mu^-$ channel:

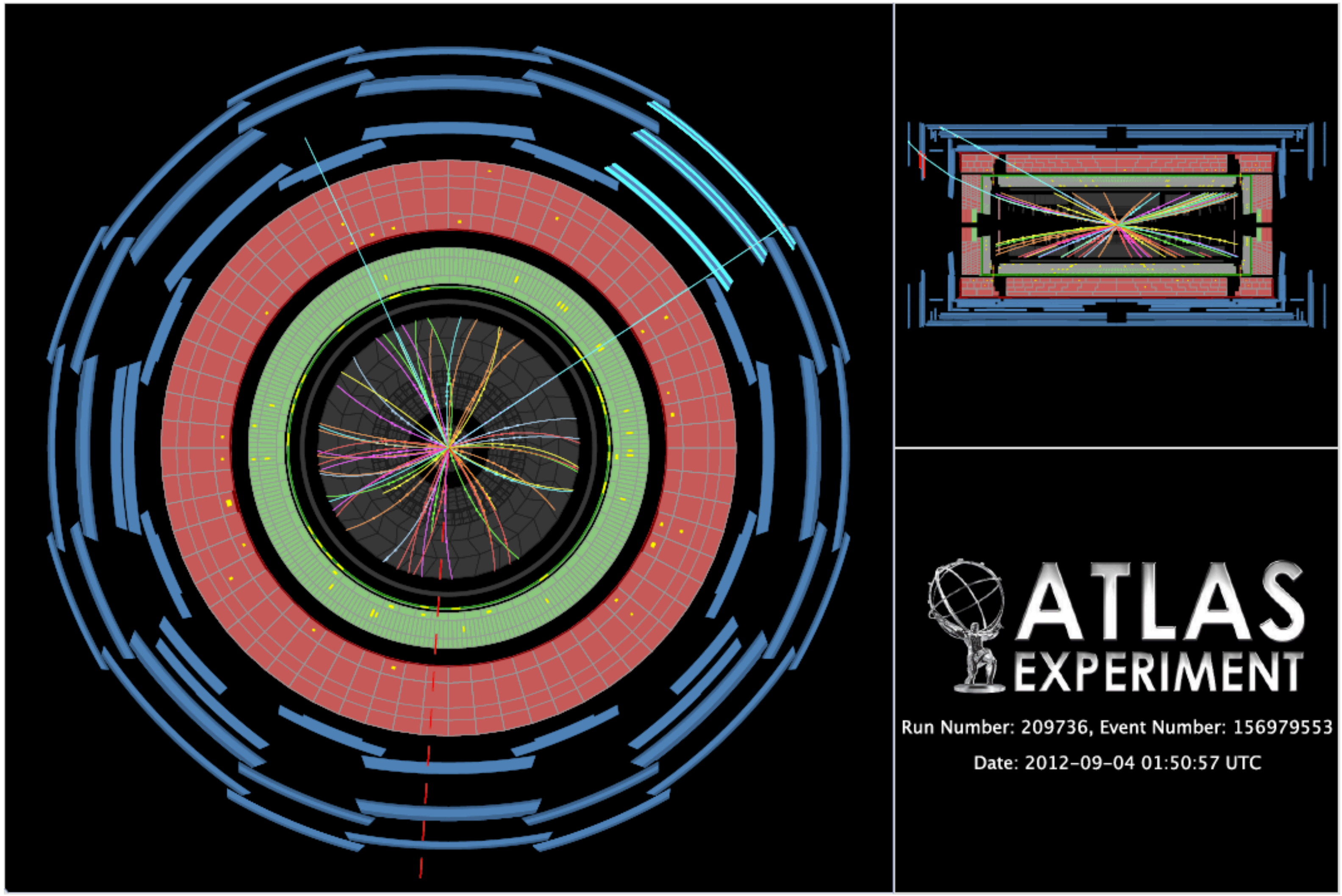
$p_T(\mu 1)$ = 169 GeV, p_T ($\mu 2$) = 106 GeV, $E_t^{miss, rel}$= 478 GeV

2 lepton - highest mT2 event in ee channel



highest m_{T2} event in e^+e^- channel:
m_{T2} =170 GeV
p_T(el1) = 153 GeV, p_T (el2) =128 GeV, E_T^{miss}= 174 GeV

2 lepton - highest mT2 event in mumu channel



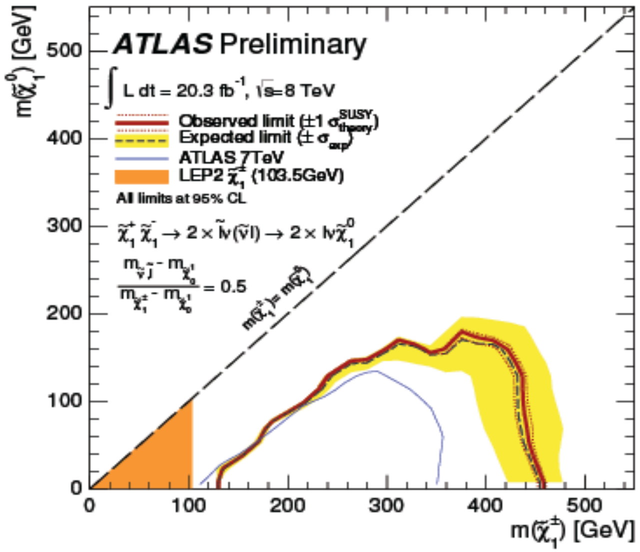
highest m_{T2} event in $\mu^{+}\mu^{-}$ channel:
m_{T2} =218 GeV
$p_T(\mu 1)$ = 168 GeV, $p_T(\mu 2)$ =133 GeV, E_T^{miss}= 213 GeV

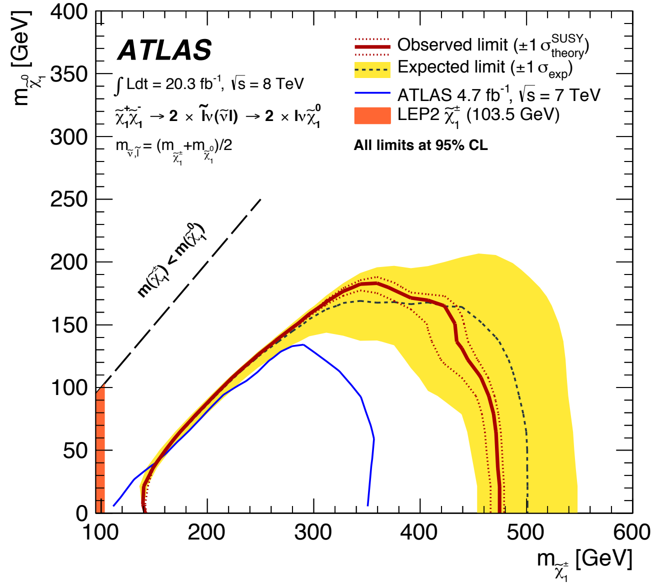
2 lepton - RESULTS – SR mT2

- results using SRmT2: chargino production with intermediate sleptons

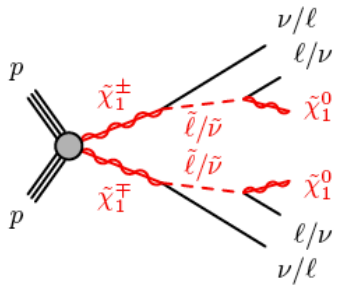
NEW

conference note

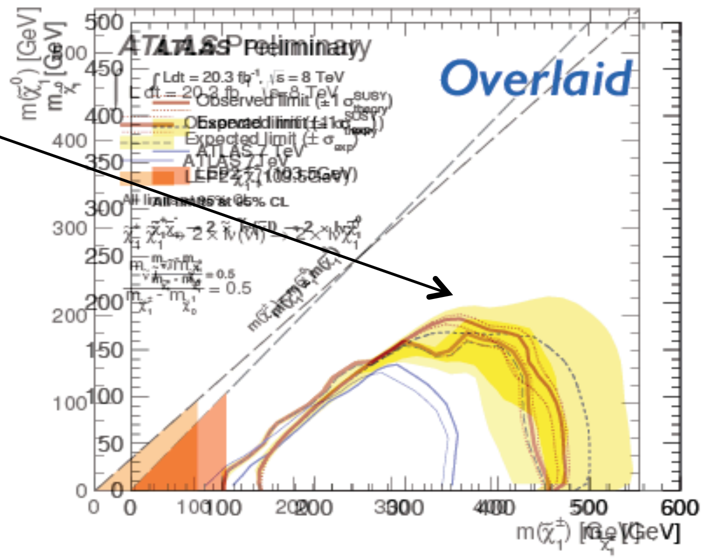




improvement of limits at high chargino masses
best limit:



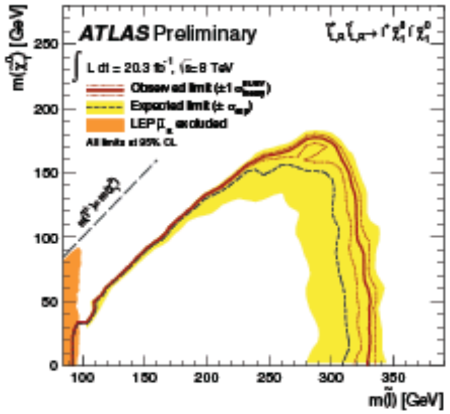
chargino masses : 130-465 GeV,
for LSP = 0 GeV



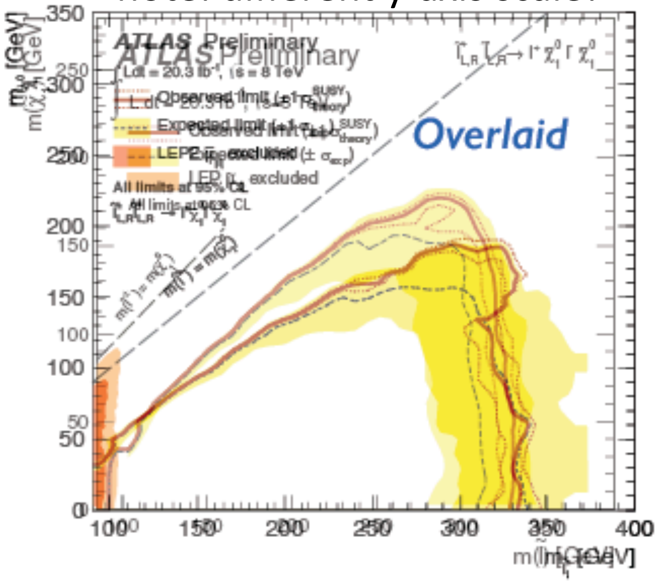
2 lepton - RESULTS – SR mT2

- results using SR mT2: direct slepton production

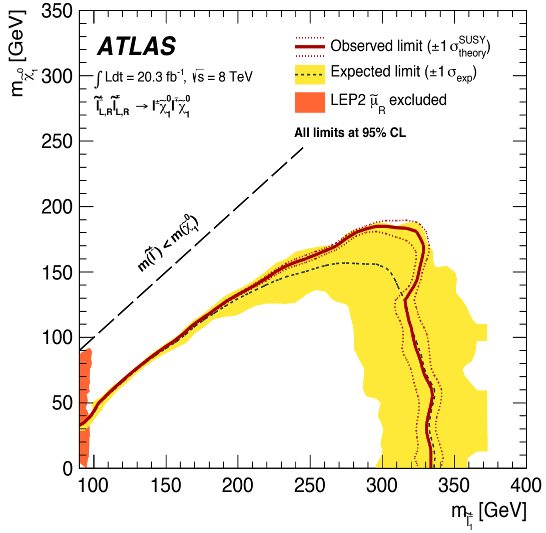
conference note



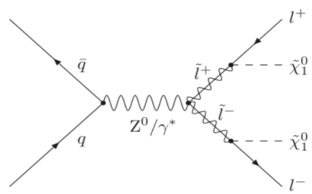
note: different y-axis scale!



NEW



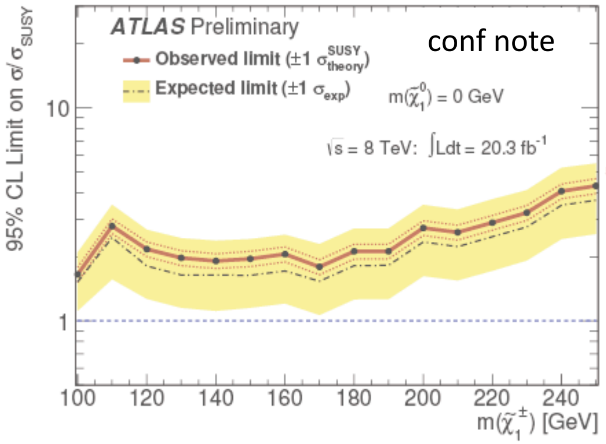
- improvement of the limits in high slepton mass region
- limits for individual selection/smuon channels are in the back up

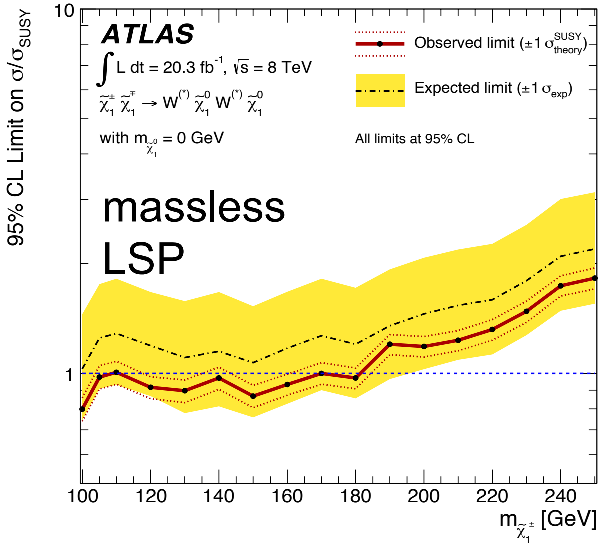


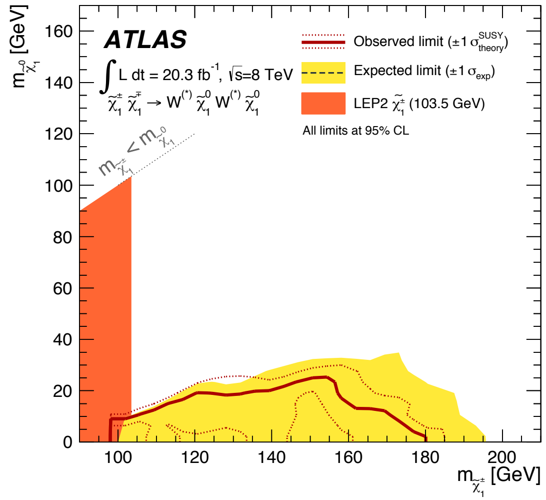
best limit:
- for massless LSP slepton (selections and smuons) mass 90- 315 GeV
- 100 GeV LSP: slepton 160-310 GeV

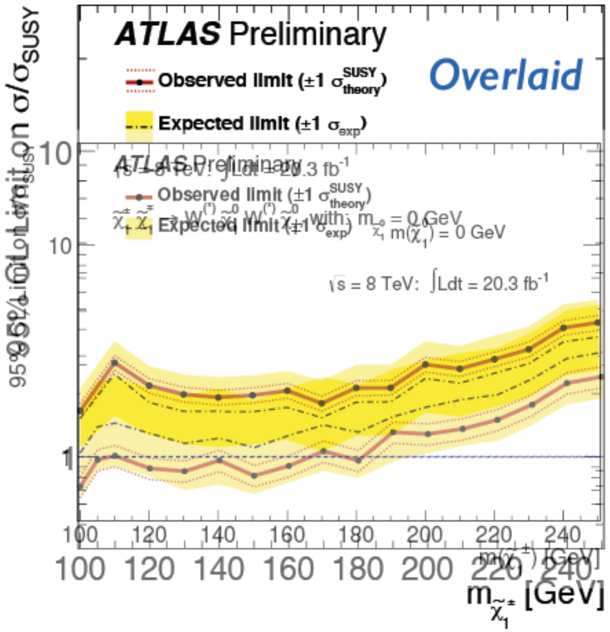
2 lepton - RESULTS – SR WW

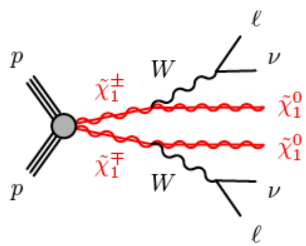
> results using SRWW: direct chargino production with intermediate W boson











95%CL exclusion limit:
massless LSP: chargino masses between 100-105 GeV, 120GeV-135 GeV and 145-160 GeV
→ First limit from this scenario obtained at a hadron collider!!!

2 lepton - RESULTS SRWW

	SR-WWa		SR-WWb		SR-WWc	
	SF	DF	SF	DF	SF	DF
Background						
WW	57.8 ± 5.5	58.2 ± 6.0	16.4 ± 2.5	12.3 ± 2.0	10.4 ± 2.7	7.3 ± 1.9
ZV	16.3 ± 3.5	1.8 ± 0.5	10.9 ± 1.9	0.6 ± 0.2	9.2 ± 2.1	0.4 ± 0.2
Top	9.2 ± 3.5	11.6 ± 4.3	2.4 ± 1.7	4.3 ± 1.6	$0.6^{+1.2}_{-0.6}$	0.9 ± 0.8
Others	3.3 ± 1.5	2.0 ± 1.1	0.5 ± 0.4	0.9 ± 0.6	$0.1^{+0.5}_{-0.1}$	0.4 ± 0.3
Total	86.5 ± 7.4	73.6 ± 7.9	30.2 ± 3.5	18.1 ± 2.6	20.3 ± 3.5	9.0 ± 2.2
Observed events	73	70	26	17	10	11
Predicted signal						
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (100, 0)$	25.6 ± 3.3	24.4 ± 2.2				
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (140, 20)$			8.3 ± 0.8	7.2 ± 0.8		
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (200, 0)$					5.2 ± 0.5	4.6 ± 0.4
p_0	0.50	0.50	0.50	0.50	0.50	0.31
Observed $\sigma^{95}_{\rm vis}$ [fb]	0.78	1.00	0.54	0.49	0.29	0.50
Expected $\sigma^{95}_{\rm vis}$ [fb]	$1.13^{+0.46}_{-0.32}$	$1.11^{+0.44}_{-0.31}$	$0.66^{+0.28}_{-0.20}$	$0.53^{+0.23}_{-0.16}$	$0.52^{+0.23}_{-0.16}$	$0.41^{+0.19}_{-0.12}$

2 lepton - RESULTS SRmT2

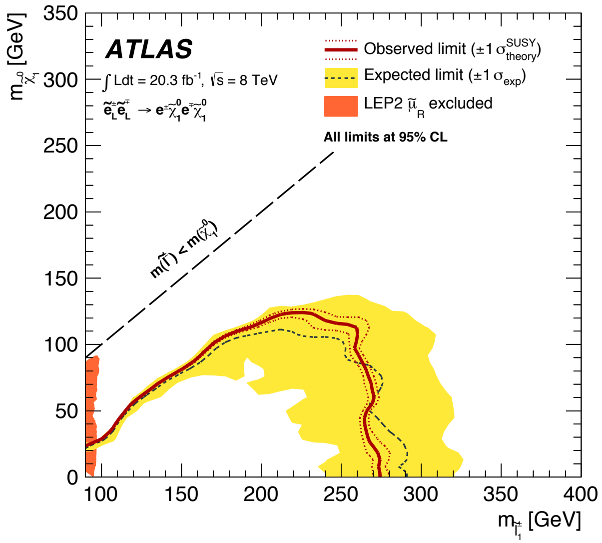
	SR-m_{T2}^{90}		SR-m_{T2}^{120}		SR-m_{T2}^{150}	
	SF	DF	SF	DF	SF	DF
Expected background						
WW	22.1 ± 4.3	16.2 ± 3.2	3.5 ± 1.3	3.3 ± 1.2	1.0 ± 0.5	0.9 ± 0.5
ZV	12.9 ± 2.2	0.8 ± 0.2	4.9 ± 1.6	0.2 ± 0.1	2.2 ± 0.5	< 0.1
Top	3.0 ± 1.8	5.5 ± 1.9	$0.3^{+0.4}_{-0.3}$	< 0.1	< 0.1	< 0.1
Others	0.3 ± 0.3	0.8 ± 0.6	$0.1^{+0.4}_{-0.1}$	0.1 ± 0.1	$0.1^{+0.4}_{-0.1}$	$0.0^{+0.4}_{-0.0}$
Total	38.2 ± 5.1	23.3 ± 3.7	8.9 ± 2.1	3.6 ± 1.2	3.2 ± 0.7	1.0 ± 0.5
Observed events	33	21	5	5	3	2
Predicted signal						
$(m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (350, 0)$	24.2 ± 2.5	19.1 ± 2.1	18.1 ± 1.8	14.7 ± 1.7	12.0 ± 1.3	10.1 ± 1.3
$(m_{\tilde{\ell}}, m_{\tilde{\chi}_1^0}) = (251, 10)$	24.0 ± 2.7	—	19.1 ± 2.5	—	14.3 ± 1.7	—
p_0	0.50	0.50	0.50	0.27	0.50	0.21
Observed $\sigma_{\mathrm{vis}}^{95}$ [fb]	0.63	0.55	0.26	0.36	0.24	0.26
Expected $\sigma_{\mathrm{vis}}^{95}$ [fb]	$0.78^{+0.32}_{-0.23}$	$0.62^{+0.26}_{-0.18}$	$0.37^{+0.17}_{-0.11}$	$0.30^{+0.13}_{-0.09}$	$0.24^{+0.13}_{-0.08}$	$0.19^{+0.10}_{-0.06}$

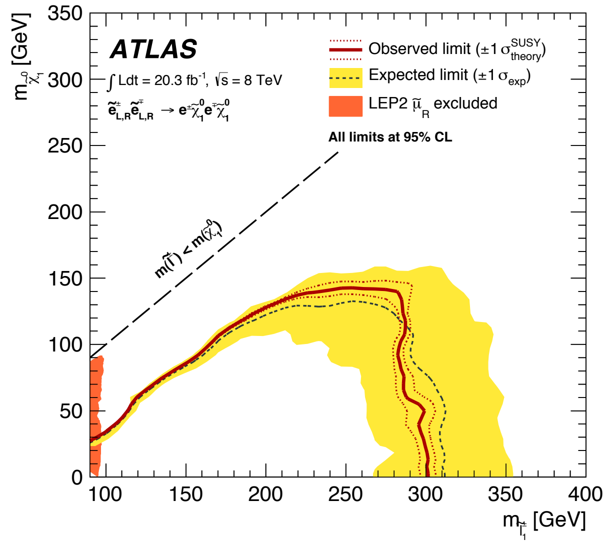
2 lepton - SR Zjets

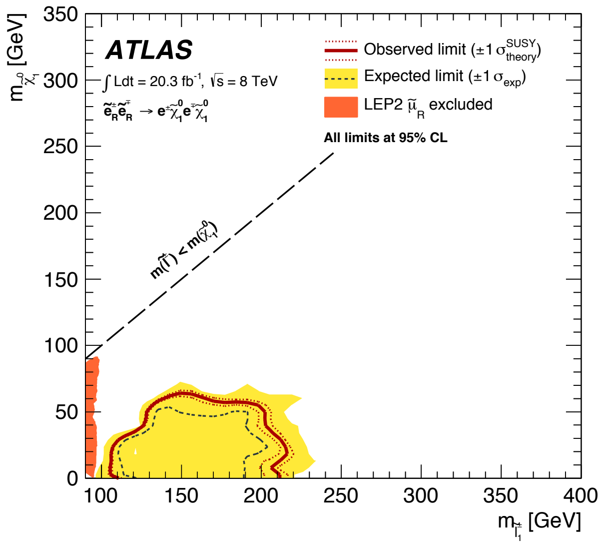
	SR-Zjets
Background	
WW	0.1 ± 0.1
ZV	1.0 ± 0.6
Top	< 0.1
Z + jets and others	0.3 ± 0.2
Total	1.4 ± 0.6
Observed events	1
Predicted signal	
$(m_{\tilde{\chi}_2^0,\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (250, 0)$	6.4 ± 0.8
$(m_{\tilde{\chi}_2^0,\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}) = (350, 50)$	3.7 ± 0.2
p_0	0.50
Observed σ_{vis}^{95} [fb]	0.17
Expected σ_{vis}^{95} [fb]	$0.19^{+0.11}_{-0.06}$

2 lepton - SRs limits

limit-selectrons

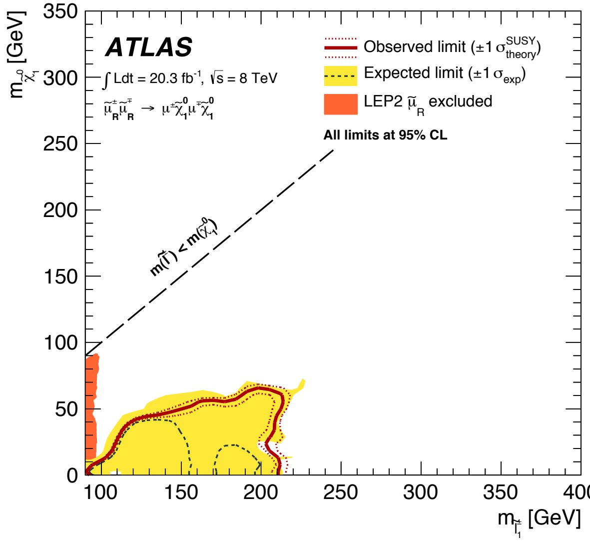


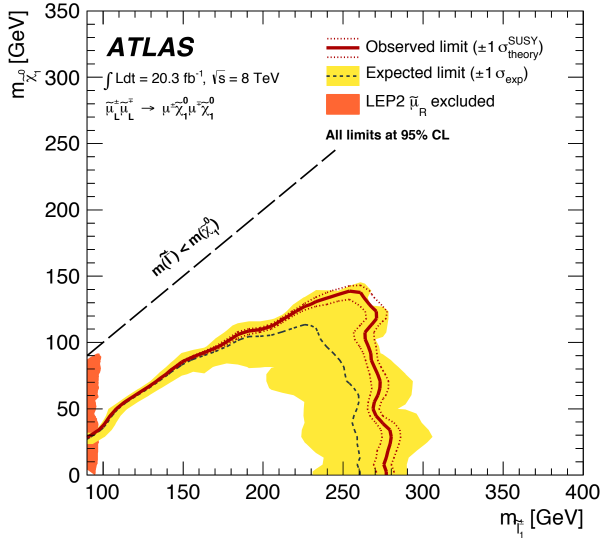


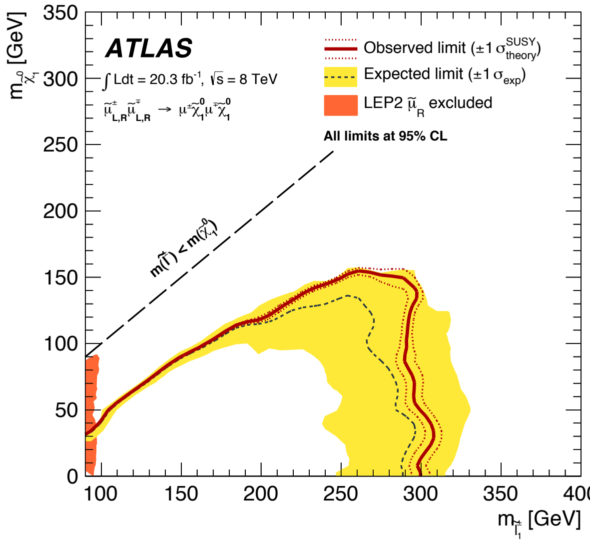


2 lepton - SRs limits

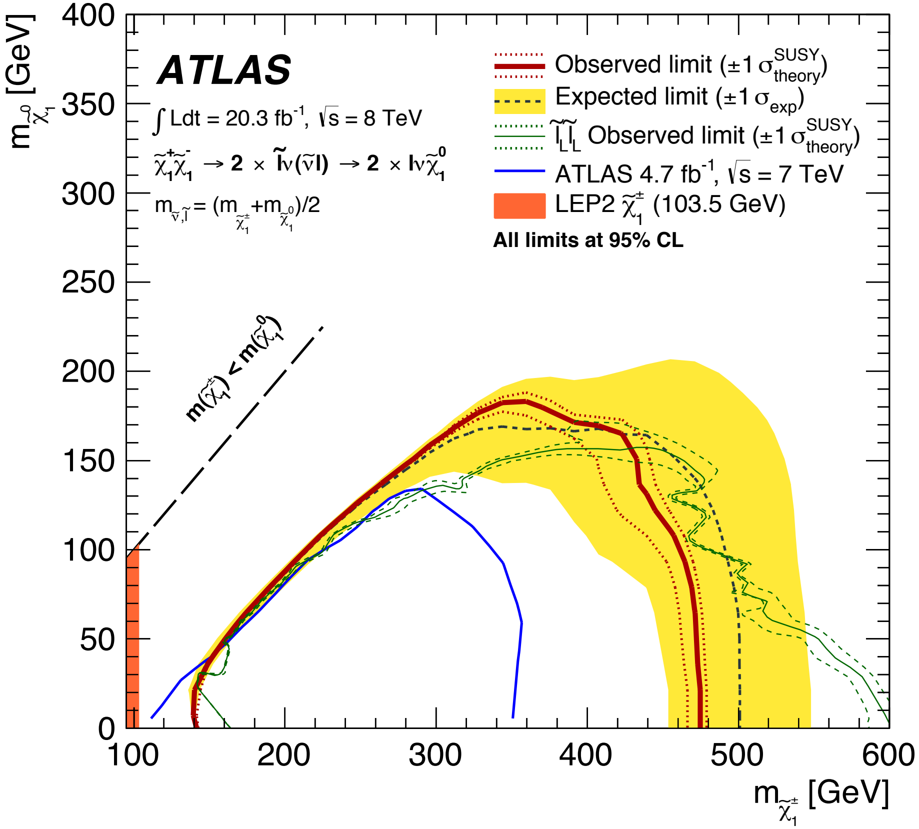
limit-smuons







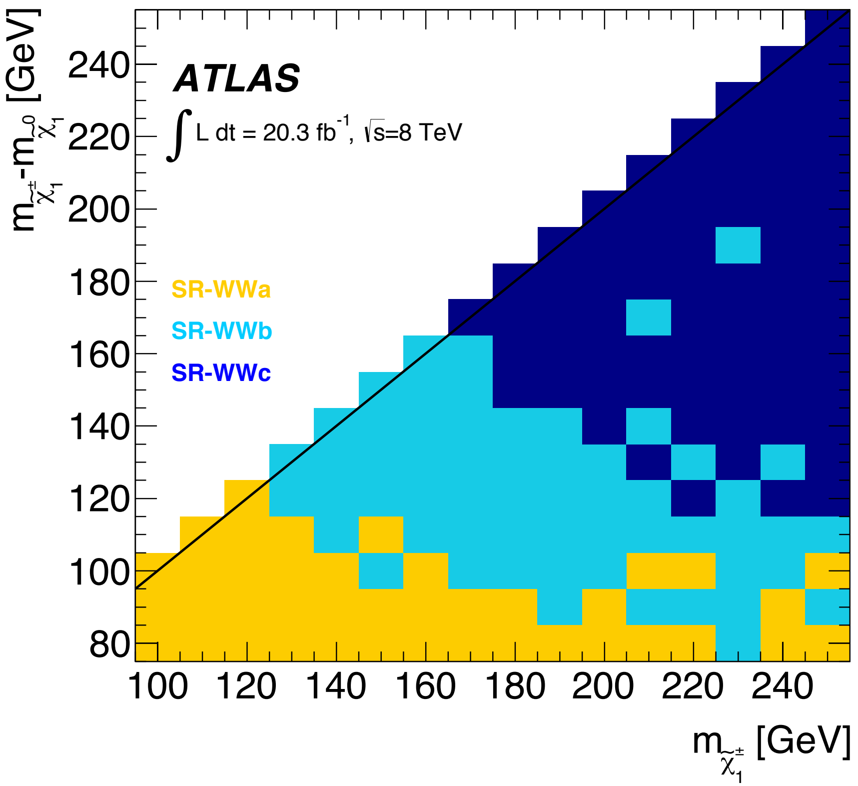
2 lepton - SRs limits

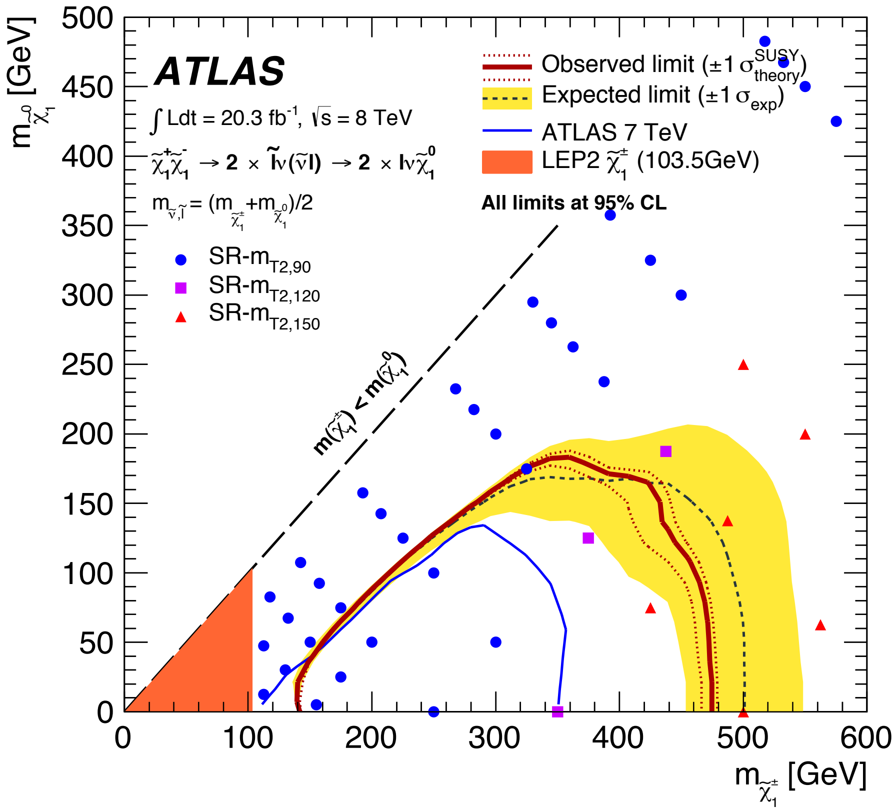


green line:left-handed slepton limit using the conversion

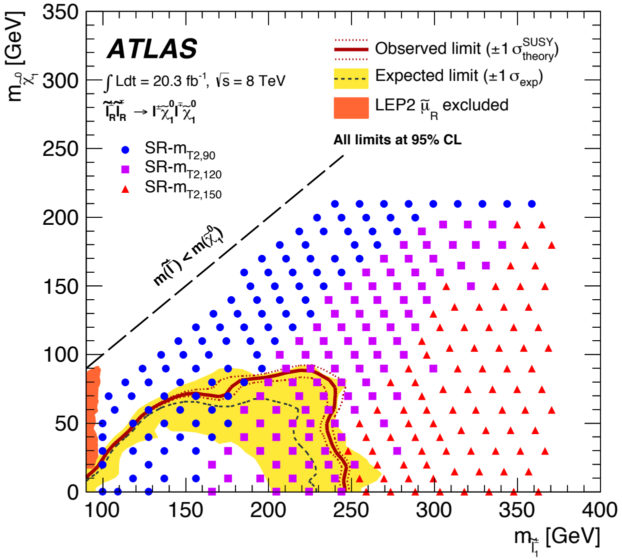
$$m_{\tilde{\ell}} = (m_{\tilde{\chi}_1^{\pm}} + m_{\tilde{\chi}_1^0})/2$$

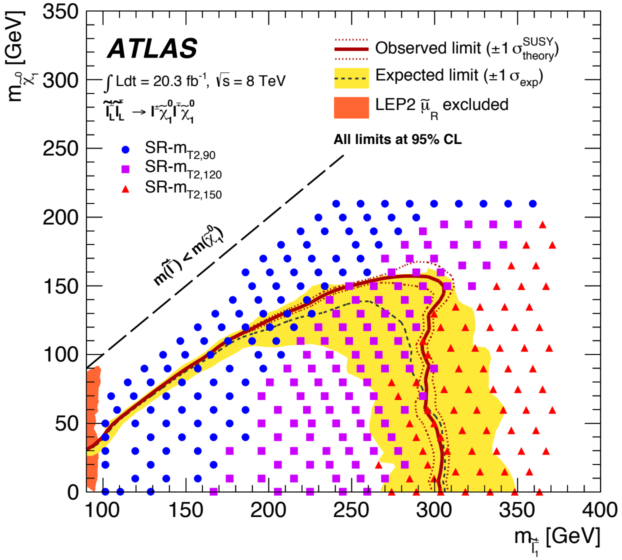
2 lepton - SRs contributions

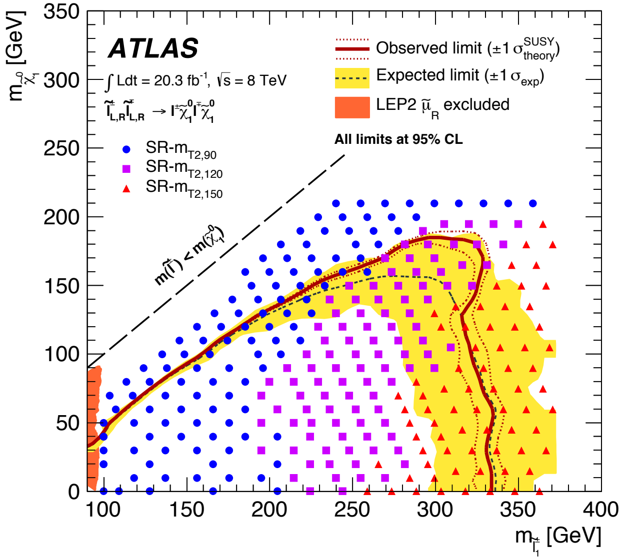




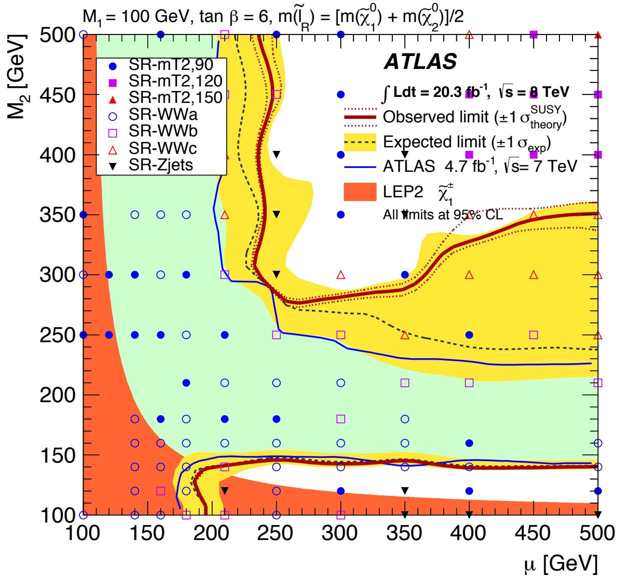
2 lepton - SRs contribution

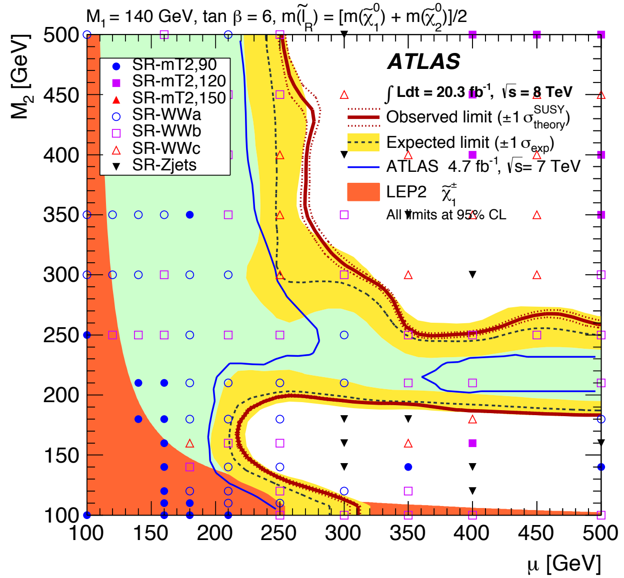


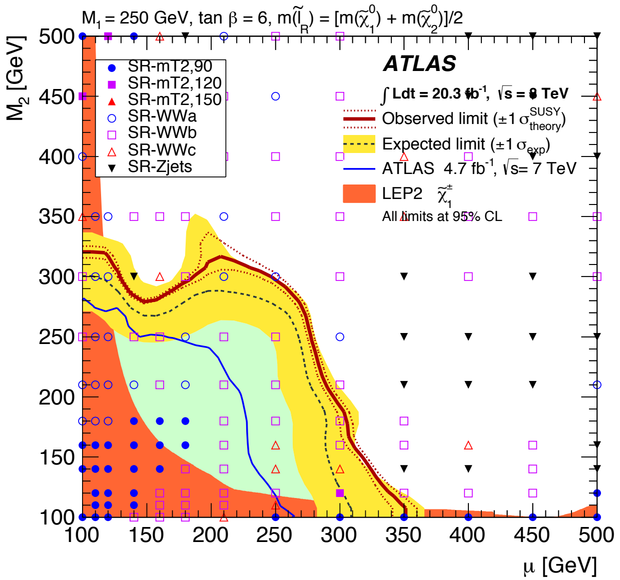


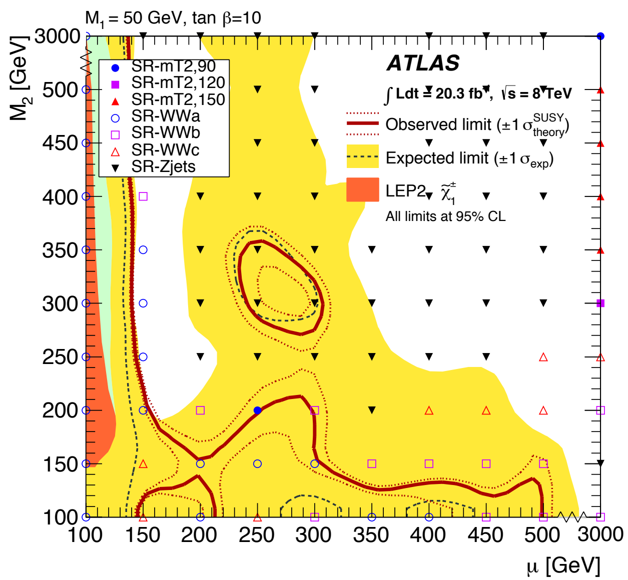


2 lepton - SRs contribution

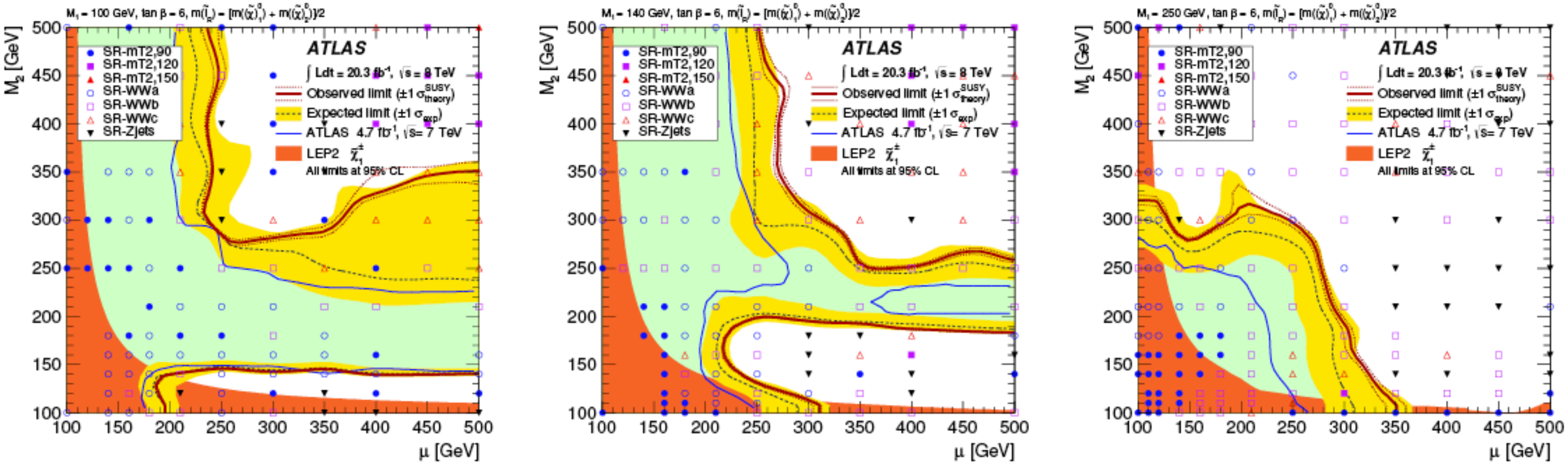








2 lepton - SR contribution



Z+MET Template

Method

Use events form a seed region (CR/SR/VR) defined from an additional METSig cut

$$E_T^{miss,significance} = \frac{E_{\mathrm{T}}^{\mathrm{miss}}}{\sqrt{\sum E_T^{miss,RefJet} + \sum E_T^{miss,SoftTerm}}}.$$

Use seed events to smear MET:

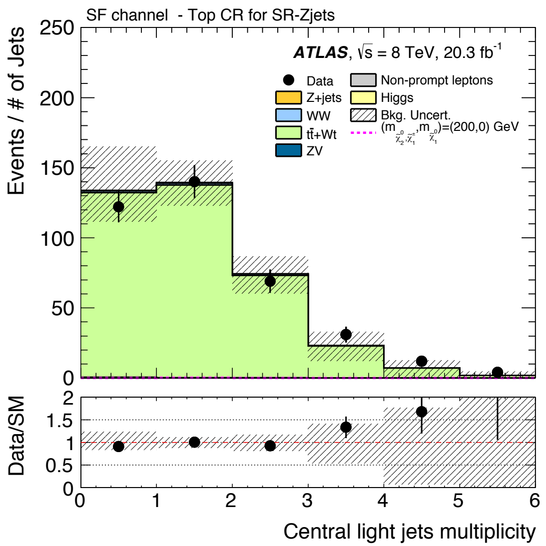
$$E_{x,y}^{miss,smeared} = E_{x,y}^{miss} - \sum p_{x,y} + \sum p_{x,y} + \Delta E_{x,y}^{SoftTerm}$$

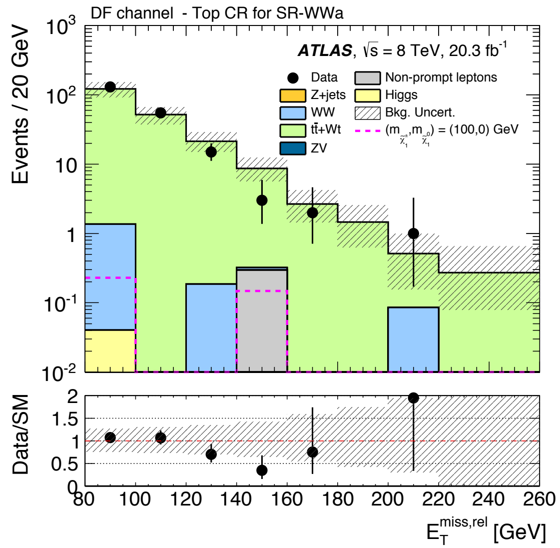
2 lepton - CONTROL REGION

Table 2. Control region definitions.

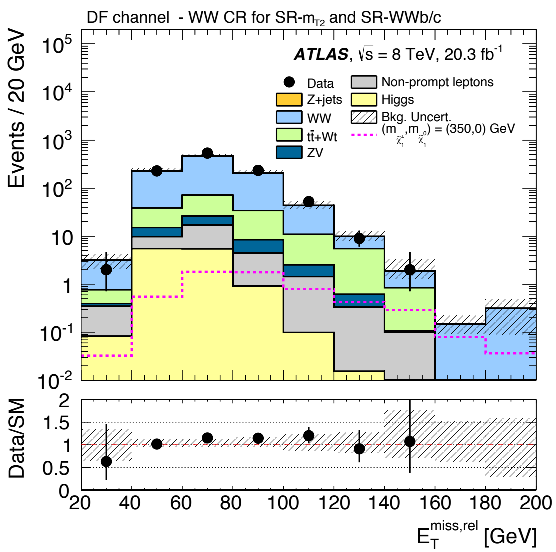
SR	m_{T2} and WWb/c			WWa			Zjets
CR	WW	Top	ZV	WW	Top	ZV	Top
lepton flavour	DF	DF	SF	DF	DF	SF	SF
central light jets	0	0	0	0	0	0	0
central b-jets	0	≥ 1	0	0	≥ 1	0	≥ 1
forward jets	0	0	0	0	0	0	0
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	—	—	< 10	—	—	< 10	> 10
$m_{\ell\ell}$ [GeV]	—	—	—	< 120	< 120	—	—
$E_{\mathrm{T}}^{\mathrm{miss,rel}}$ [GeV]	—	—	—	$[60, 80]$	> 80	> 80	> 80
$p_{\mathrm{T},\ell\ell}$ [GeV]	—	—	—	> 40	> 80	> 80	> 80
m_{T2} [GeV]	$[50, 90]$	> 70	> 90	—	—	—	—
$\Delta R_{\ell\ell}$	—	—	—	—	—	—	$[0.3, 1.5]$

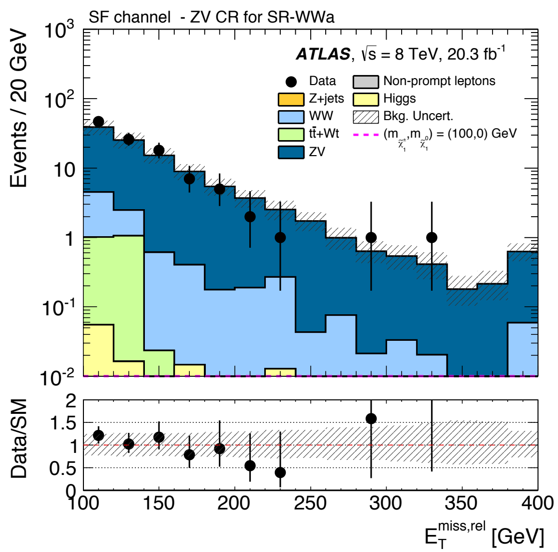
2 lepton - CONTROL REGIONS



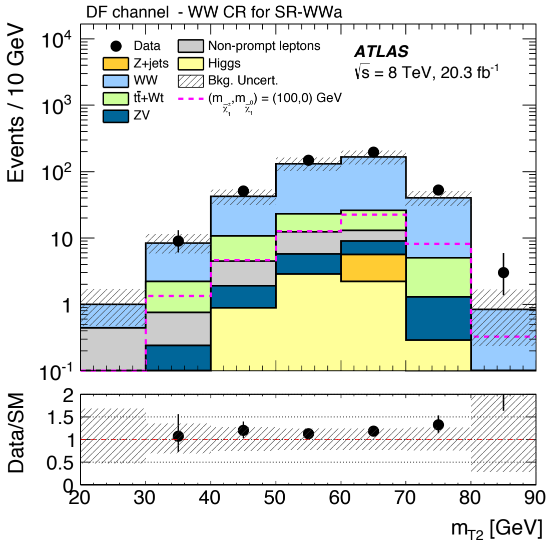


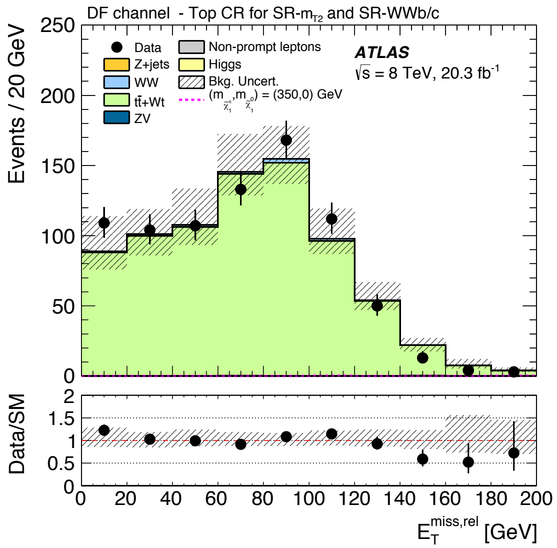
- •no data-normalization factor is applied
- •hashed regions= total systematic uncertainties



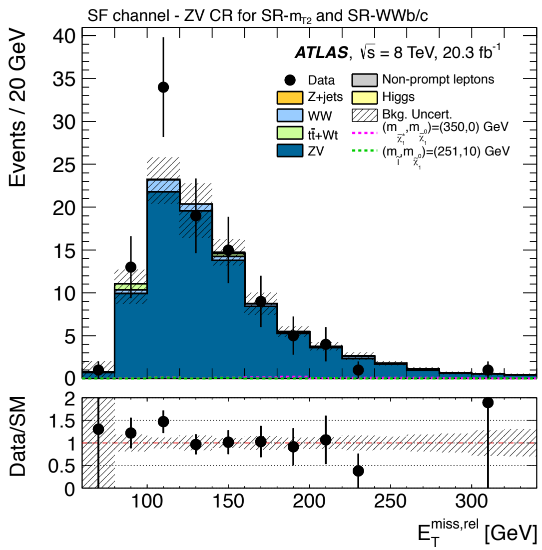


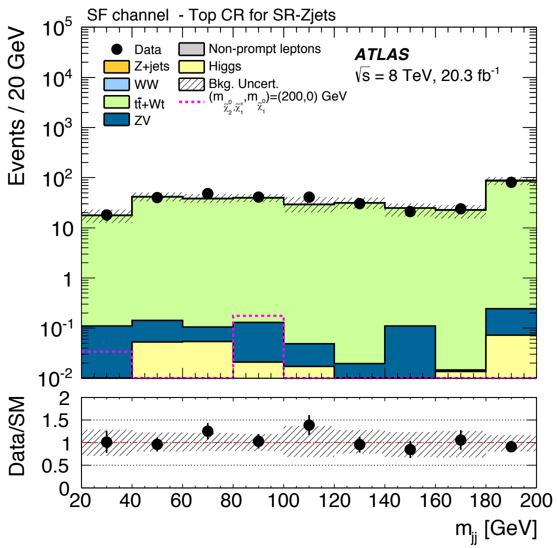
2 lepton - CONTROL REGION





- no data-normalization factor is applied
- hashed regions= total systematic uncertainties





2 lepton - RESULTS CRs

> number of observed and predicted events in the CRs, data/MC normalization factor and composition in the CRs obtained from the fit

SR	m_{T2} and WWb/c			WWa			Zjets
CR	WW	Top	ZV	WW	Top	ZV	Top
Observed events	1061	804	94	472	209	175	395
MC prediction	947	789	91	385	215	162	399
Normalization	1.14	1.02	1.08	1.12	0.97	1.04	0.99
Statistical error	0.05	0.04	0.12	0.08	0.08	0.12	0.06
Composition							
WW	84.6%	1.4%	5.0%	86.8%	1.7%	10.5%	1.3%
Top	10.4%	98.5%	<0.1%	7.3%	98.1%	2.8%	98.0%
ZV	2.0%	0.1%	94.9%	1.9%	<0.1%	82.9%	0.3%
Non-prompt lepton	1.9%	<0.1%	<0.1%	2.7%	<0.1%	<0.1%	<0.1%
Other	1.1%	<0.1%	0.1%	1.3%	<0.1%	3.7%	0.3%

3 lepton

3 lepton – EVENT SELECTION

Electrons

Baseline
- medium quality
- pT > 10 GeV
- |eta|<2.47
- author 1 or 3

Signal
- tight quality
- ptcone30/pT < 0.16
- etcone30/pT < 0.18
- $|z0*\sin\theta| < 0.4$
- d0 significance < 0.5

Muons

Baseline
- STACO loose
- combined or segment-tagged
- pT > 10 GeV
- |eta| < 2.4

Signal
- ptcone30/pT < 0.12
- $|z0*\sin\theta| < 1.0$
- d0 significance < 0.3

Taus

Baseline
- pT > 20 GeV
- |eta| < 2.5
- 1 or 3 tracks, |charge| = 1

Signal
- EleBDTLoose==0
- MuonVeto==0
- JetBDTSigMedium==1

MET

- Egamma10NoTau

Jets

Baseline
- Anti-kt 4 LC topo
- pT > 20 GeV
- |eta| < 4.5

Signal
- JVF > 0.5 (pT > 50 GeV)
- |eta| < 2.5

Overlap Removal

- Discard softer e if dR(e1,e2) <0.05
- Discard jet if dR(e,jet) <0.2
- **Discard tau if dR(tau,e/μ) <0.2**
- Discard electron if dR(e,jet) <0.4
- Discard muon if dR(μ,jet) <0.4
- Discard electron and muon if dR(e,μ) <0.01
- Discard muons if dR(μ,μ) <0.05
- Discard SFOS pair with Mll <12 GeV
- **Discard jet if dR(jet,signal tau) <0.2**

Trigger scheme

- Single isolated e/μ triggers
- di-lepton ee/$\mu\mu$/eμ triggers

3 lepton – MC samples

Z incl. virtual γ

Table 1. For the MC samples used in this paper for background estimates, the generator type, the order of cross-section calculations used for yield normalisation, names of parameter tunes used for the underlying event generation and PDF sets.

Process	Generator + fragmentation/hadronisation	Cross-section	Tune	PDF set
Dibosons				
WW, WZ, ZZ	POWHEG-r2129 [34, 35] + PYTHIA-8.165 [38]	NLO QCD with MCFM-6.2 [39, 40]	AU2 [36]	CT10 [37]
* WZ, ZZ	aMC@NLO-2.0.0.beta3 [41] + HERWIG-6.520 [42] (or + PYTHIA-6.426)	NLO QCD with MCFM-6.2	AU2	CT10
ZZ via gluon fusion (*not incl. in* POWHEG)	gg2VV [43] + HERWIG-6.520	NLO	AUET2B [44]	CT10
$W\gamma$, $Z\gamma$	SHERPA-1.4.1 [45]	NLO	(internal)	CT10
Tribosons				
WWW, ZWW	MADGRAPH-5.0 [46] + PYTHIA-6.426	NLO [47]	AUET2B	CTEQ6L1 [48]
Higgs				
via gluon fusion	POWHEG-r2092 + PYTHIA-8.165	NNLL QCD, NLO EW [49]	AU2	CT10
via vector-boson-fusion	POWHEG-r2092 + PYTHIA-8.165	NNLO QCD, NLO EW [49]	AU2	CT10
associated W/Z production	PYTHIA-8.165	NNLO QCD, NLO EW [49]	AU2	CTEQ6L1
associated $t\bar{t}$-production	PYTHIA-8.165	NNLO QCD [49]	AU2	CTEQ6L1
Top+Boson				
$t\bar{t}W$, $t\bar{t}Z$	ALPGEN-2.14 [50] + HERWIG-6.520	NLO [51, 52]	AUET2B	CTEQ6L1
* $t\bar{t}W$, $t\bar{t}Z$	MADGRAPH-5.0 + PYTHIA-6.426	NLO	AUET2B	CTEQ6L1
$t\bar{t}WW$	MADGRAPH-5.0 + PYTHIA-6.426	NLO [52]	AUET2B	CTEQ6L1
tZ	MADGRAPH-5.0 + PYTHIA-6.426	NLO [53]	AUET2B	CTEQ6L1
$t\bar{t}$	POWHEG-r2129 + PYTHIA-6.426	NNLO+NNLL [54–59]	PERUGIA2011C	CT10
Single top				
t-channel	ACERMC-38 [60] + PYTHIA-6.426	NNLO+NNLL [61]	AUET2B	CTEQ6L1
s-channel, Wt	MC@NLO-4.06 [62, 63] + HERWIG-6.520	NNLO+NNLL [64, 65]	AUET2B	CT10
W+jets, Z+jets	ALPGEN-2.14 + PYTHIA-6.426 (or + HERWIG-6.520)	DYNNLO-1.1 [66] with MSTW2008 NNLO [67]	PERUGIA2011C	CTEQ6L1

SUSY signal: Herwig ++ (2.5.2), w. CTEQ6L1 PDF set

3 lepton – SIGNAL REGIONS - TRIGGER

Trigger	p_T threshold [GeV]
Single Isolated e	25
Single Isolated μ	25
Double e	14,14 25,10
Double μ	14,14 18,10
Combined $e\mu$	14(e),10(μ) 18(μ),10(e)

SR0τa bin	m_{SFOS}	m_T	E_T^{miss}	3ℓ Z veto
1	12–40	0–80	50–90	no
2	12–40	0–80	>90	no
3	12–40	>80	50–75	no
4	12–40	>80	>75	no
5	40–60	0–80	50–75	yes
6	40–60	0–80	>75	no
7	40–60	>80	50–135	no
8	40–60	>80	>135	no
9	60–81.2	0–80	50–75	yes
10	60–81.2	>80	50–75	no
11	60–81.2	0–110	>75	no
12	60–81.2	>110	>75	no
13	81.2–101.2	0–110	50–90	yes
14	81.2–101.2	0–110	>90	no
15	81.2–101.2	>110	50–135	no
16	81.2–101.2	>110	>135	no
17	>101.2	0–180	50–210	no
18	>101.2	>180	50–210	no
19	>101.2	0–120	>210	no
20	>101.2	>120	>210	no

3 lepton - SM BACKGROUNDS

Region name	N(ℓ)	N(τ)	Flavour/sign	Z boson	E_T^{miss}	N(b-tagged jets)	Target process
VR0τnoZa	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	m_{SFOS} & $m_{3\ell}$ veto	35–50	–	WZ^*, Z^*Z^*, Z^*+jets
VR0τZa	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	request	35–50	–	WZ, Z+jets
VR0τnoZb	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	m_{SFOS} & $m_{3\ell}$ veto	> 50	1	$t\bar{t}$
VR0τZb	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	request	> 50	1	WZ
VR0τb	3	0	$\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$	binned	binned	1	WZ, $t\bar{t}$
VR1τa	2	1	$\tau^\pm\ell^\mp\ell^\mp$, $\tau^\pm\ell^\mp\ell'^\mp$	–	35–50	–	WZ, Z+jets
VR1τb	2	1	$\tau^\pm\ell^\mp\ell^\mp$, $\tau^\pm\ell^\mp\ell'^\mp$	–	> 50	1	$t\bar{t}$
VR2τa	1	2	$\tau\tau\ell$	–	35–50	–	W+jets, Z+jets
VR2τb	1	2	$\tau\tau\ell$	–	> 50	1	$t\bar{t}$

Sample	VR0τnoZa	VR0τZa	VR0τnoZb	VR0τZb	VR1τa	VR1τb	VR2τa	VR2τb
WZ	91 ± 12	471 ± 47	$10.5^{+1.8}_{-2.0}$	58 ± 7	14.6 ± 1.9	1.99 ± 0.35	$14.3^{+2.4}_{-2.5}$	1.9 ± 0.4
ZZ	19 ± 4	48 ± 7	0.62 ± 0.12	2.6 ± 0.4	$1.76^{+0.29}_{-0.28}$	0.138 ± 0.028	1.8 ± 0.4	0.12 ± 0.04
$t\bar{t}V + tZ$	3.2 ± 1.0	$10.1^{+2.3}_{-2.2}$	9.5 ± 3.1	18 ± 4	0.9 ± 0.9	2.8 ± 1.3	1.0 ± 0.7	1.7 ± 0.7
VVV	1.9 ± 1.9	0.7 ± 0.7	$0.35^{+0.36}_{-0.35}$	0.18 ± 0.18	0.4 ± 0.4	0.08 ± 0.08	0.12 ± 0.12	$0.06^{+0.07}_{-0.06}$
Higgs	2.7 ± 1.3	2.7 ± 1.5	1.5 ± 1.0	0.71 ± 0.29	0.57 ± 0.34	0.5 ± 0.5	0.6 ± 0.4	0.5 ± 0.5
Reducible	73^{+20}_{-17}	261 ± 70	47^{+15}_{-13}	19 ± 5	71 ± 9	22.7 ± 2.8	630^{+9}_{-12}	162^{+6}_{-8}
Total SM	191^{+24}_{-22}	794 ± 86	69^{+15}_{-14}	98 ± 10	89^{+10}_{-9}	28.2 ± 3.2	648^{+10}_{-13}	166^{+6}_{-8}
Data	228	792	79	110	82	26	656	158
CL$_b$	0.90	0.49	0.72	0.79	0.30	0.37	0.61	0.30

3 lepton – SYSTEMATIC UNCERTAINTIES

Table 9. Summary of the dominant systematic uncertainties in the background estimates for each signal region. Uncertainties are quoted relative to the total expected background. For the 20 bins of the SR0τa the range of the uncertainties is provided.

	SR0τa	SR0τb	SR1τ	SR2τa	SR2τb
Cross-section	4–25%	37%	9%	3.1%	3.0%
Generator	3.2–35%	11%	3.1%	6%	< 1%
Statistics on irreducible background	0.8–26%	8%	5%	5%	3.1%
Statistics on reducible background	0.4–29%	14%	8%	13%	12%
Electron misidentification probability	0.3–10%	1.3%	< 1%	–	–
Muon misidentification probability	0.1–24%	2.2%	< 1%	–	–
τ misidentification probability	–	–	8%	4%	5%

theoretical xsection uncertainties:

30% ttV
50% tZ
5% ZZ
7% WZ
100% VVV

3 lepton - RESULTS

Table 8. Expected numbers of SM background events and observed numbers of data events in the signal regions SR0τa-bin13–bin20, SR0τb, SR1τ, SR2τa and SR2τb for 20.3 fb^{-1}. Statistical and systematic uncertainties are included as described in section 7.3. Also shown are the one-sided p_0-values and the upper limits at 95% CL on the expected and observed number of beyond-the-SM events (N^{95}_{exp} and N^{95}_{obs}) for each signal region, calculated using pseudo-experiments and the CL$_s$ prescription. For p_0-values below 0.5, the observed number of standard deviations, σ, is also shown in parentheses.

Sample	SR0τa-bin13	SR0τa-bin14	SR0τa-bin15	SR0τa-bin16	SR0τa-bin17	SR0τa-bin18
WZ	613 ± 65	207^{+33}_{-32}	58^{+12}_{-13}	$3.9^{+1.6}_{-1.4}$	50^{+7}_{-6}	2.3 ± 1.3
ZZ	29 ± 4	5.5 ± 1.5	$3.5^{+1.1}_{-1.0}$	$0.12^{+0.08}_{-0.07}$	$2.4^{+0.7}_{-0.6}$	0.08 ± 0.04
$t\bar{t}V + tZ$	$2.9^{+0.7}_{-0.6}$	$2.0^{+0.7}_{-0.6}$	$0.67^{+0.29}_{-0.28}$	$0.08^{+0.10}_{-0.08}$	0.8 ± 0.5	$0.15^{+0.16}_{-0.15}$
VVV	1.3 ± 1.3	0.8 ± 0.8	1.0 ± 1.0	0.33 ± 0.33	3.2 ± 3.2	0.5 ± 0.5
Higgs	2.2 ± 0.7	0.98 ± 0.20	0.31 ± 0.11	0.033 ± 0.018	0.95 ± 0.29	0.05 ± 0.04
Reducible	68^{+21}_{-19}	$2.2^{+1.9}_{-2.0}$	1.2 ± 0.6	$0.14^{+0.25}_{-0.14}$	$11.3^{+3.5}_{-3.2}$	0.27 ± 0.20
Total SM	715 ± 70	219 ± 33	65 ± 13	$4.6^{+1.7}_{-1.5}$	69^{+9}_{-8}	3.4 ± 1.4
Data	714	214	63	3	60	1
p_0 (σ)	0.50	0.50	0.50	0.50	0.50	0.50
N^{95}_{exp}	133^{+46}_{-36}	66^{+24}_{-18}	$28.6^{+10.1}_{-7.2}$	$5.9^{+2.6}_{-1.5}$	$21.4^{+8.2}_{-5.6}$	$4.8^{+2.0}_{-1.1}$
N^{95}_{obs}	133	65	27.6	5.2	18.8	3.7

3 lepton - pMSSM grid

Simplify general MSSM to 19 free parameters via the following assumptions

- CP conservation
- minimal flavour violation
- negligible tri-linear couplings
- degenerate 1st and 2nd generation sfermion masses.

Additional assumptions Higgs vev ratio $\tan\beta$=6/10/50, higgs mass is tuned to $\sim$ 125 GeV using stop mixing sector and slepton masses $m_{\tilde{\ell}_R} = (m_{\tilde{\chi}_1^0} + m_{\tilde{\chi}_2^0})/2$ reduce free parameters down to 3:

U(1) gaugino mass **M1**, SU(2) gaugino mass **M2**, higgsino mass μ

We probe three phenomenological MSSM models,

decays via sleptonR

Low $\tan\beta$=6,
M1=100/140/250 GeV.

decays via W/Z/h

Low $\tan\beta$=10,
M1=50 GeV.

decays via stauR

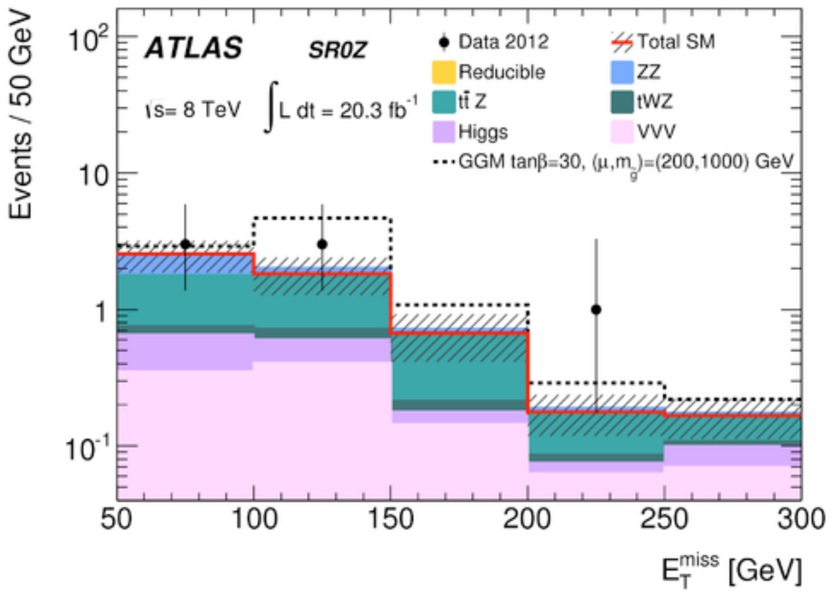
High $\tan\beta$=50,
$\rightarrow$ high BR to staus
M1=50 GeV (fixed $m_{\tilde{\tau}_R}$).
M1=75 GeV ($m_{\tilde{\tau}_R} = (m_{\tilde{\chi}_2^0} + m_{\tilde{\chi}_1^0})/2$).

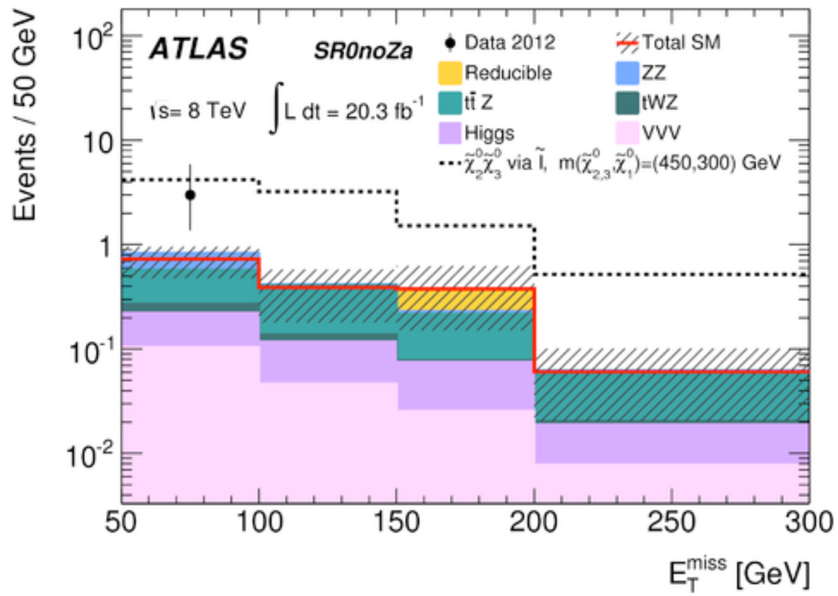
3 lepton - pMSSM grids

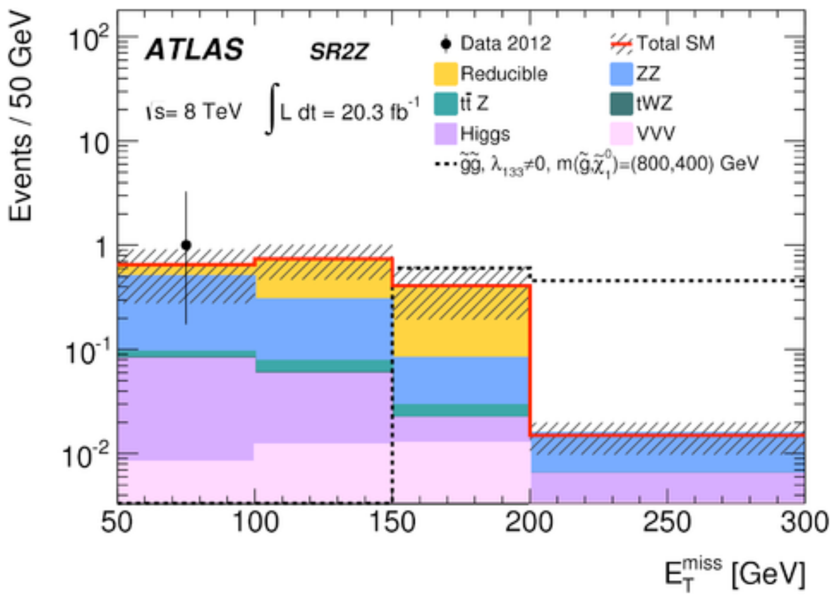
- for a given value of M1 : sensitivity for high values of M2 and μ, and therefore for high values of chargino and heavy neutralino masses, is driven by the decrease of the production cross-section
- the masses of the coloured sparticles, of the CP-odd Higgs boson, and of the left-handed sleptons are set to high values

  →allow only the direct production of charginos and neutralinos via W/Z bosons and their decay via right-handed sleptons, gauge bosons and Higgs bosons
- by tuning the mixing in the top-squark sector, the value of the lightest mass hierarchy, composition and production cross-sections of the electroweakinos are governed by the ratio of the expectation values of the two Higgs doublets tanβ, the gaugino mass parameters M1 and M2, and the higgsino mass parameter μ
- for the hierarchy M1 <M2 <μ (M1 <μ<M2), the N1 is bino-like, the N2, C1 are wino-like (higgsino-like) and the dominant electroweakino production process leading to a final state with three leptons is pp-> C1N2 (pp-> C1N2, pp->C1N3)
- if M2 <M1 <μ (μ<M1 <M2), the N1 (N1, N2) and C1 are wino-like (higgsino-like) with similar masses and the dominant process leading to a final state with three high transverse momentum leptons is the pair-production of the higgsino-like (wino-like) C2 and the bino-like N2 (N3)
- pMSSM scenarios under study are parametrised in the μ–M2 plane and are classified based on the masses of the right-handed sleptons into three groups,

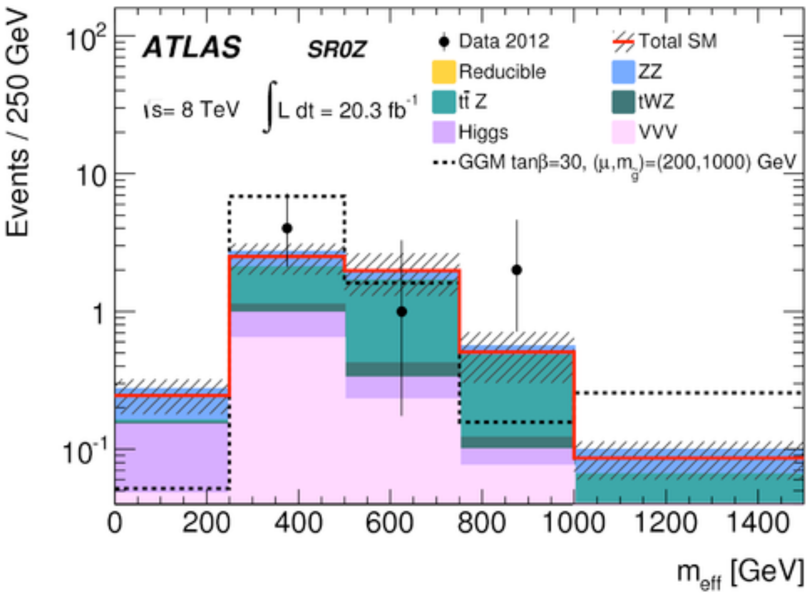
4 lepton – SIGNAL REGIONS

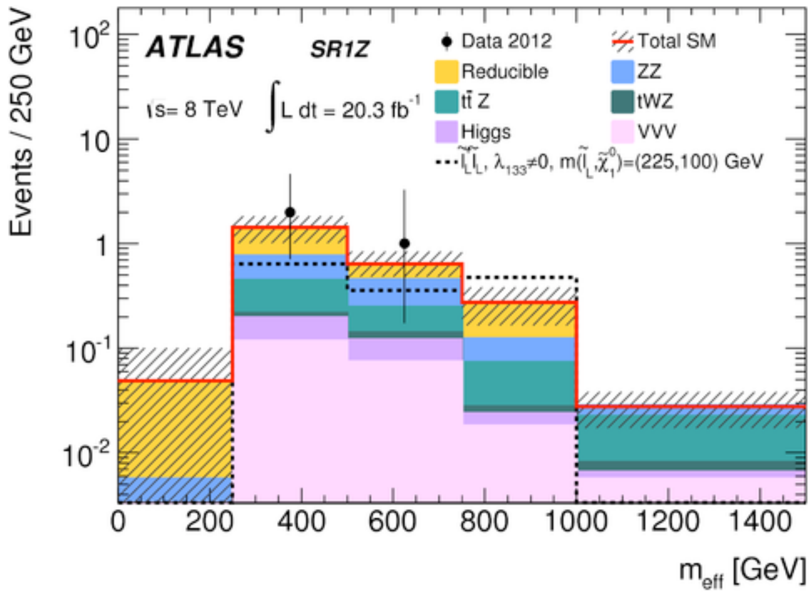


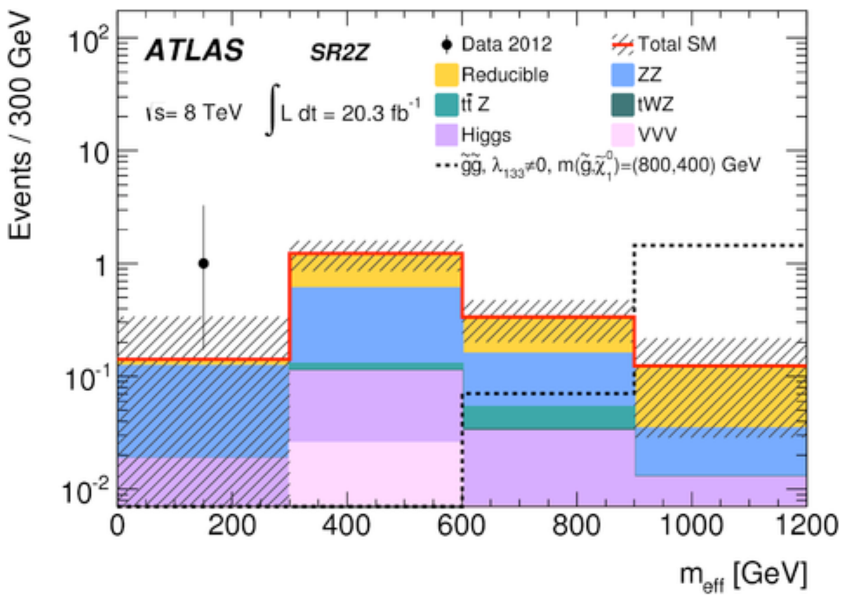




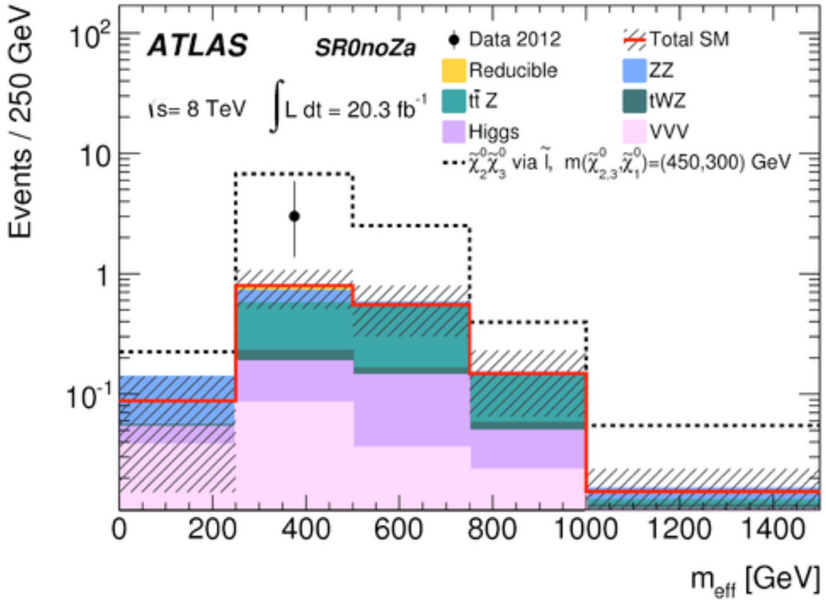
4 lepton – SIGNAL REGIONS - SRZ

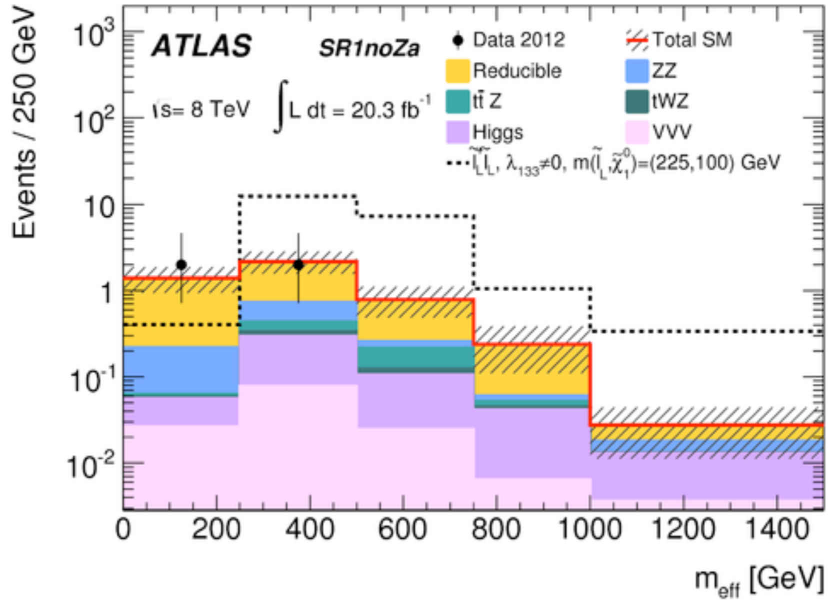


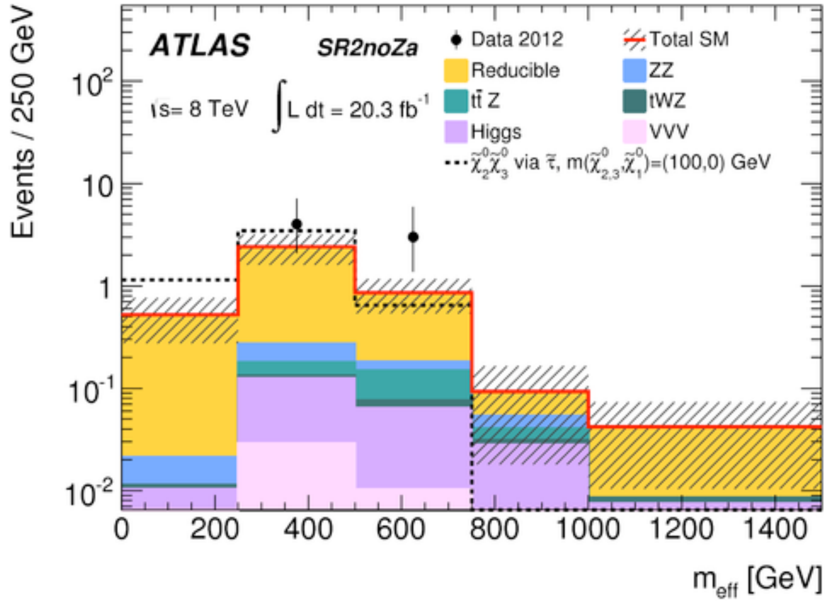




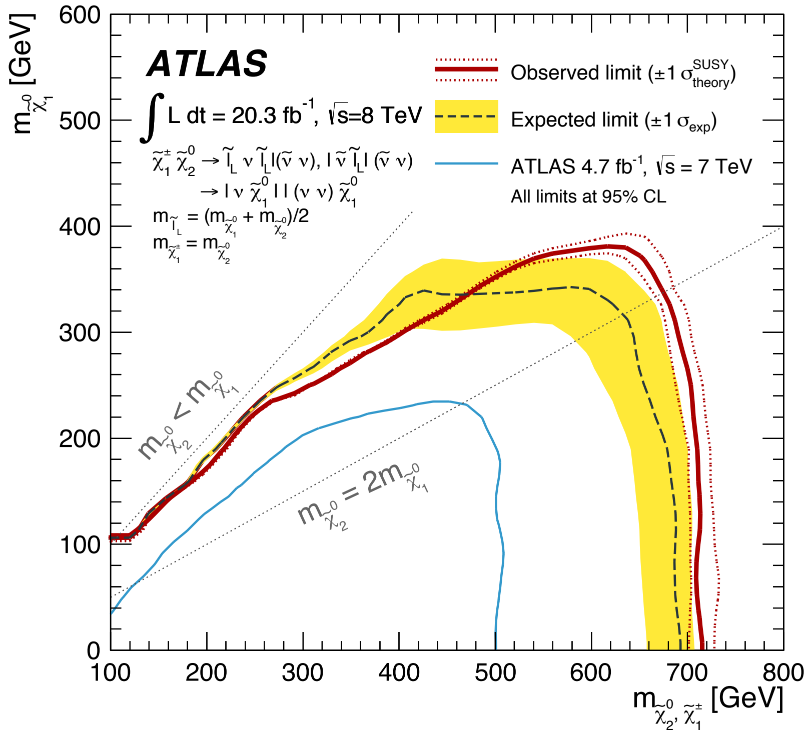
4 lepton – SIGNAL REGIONS – SR0Z

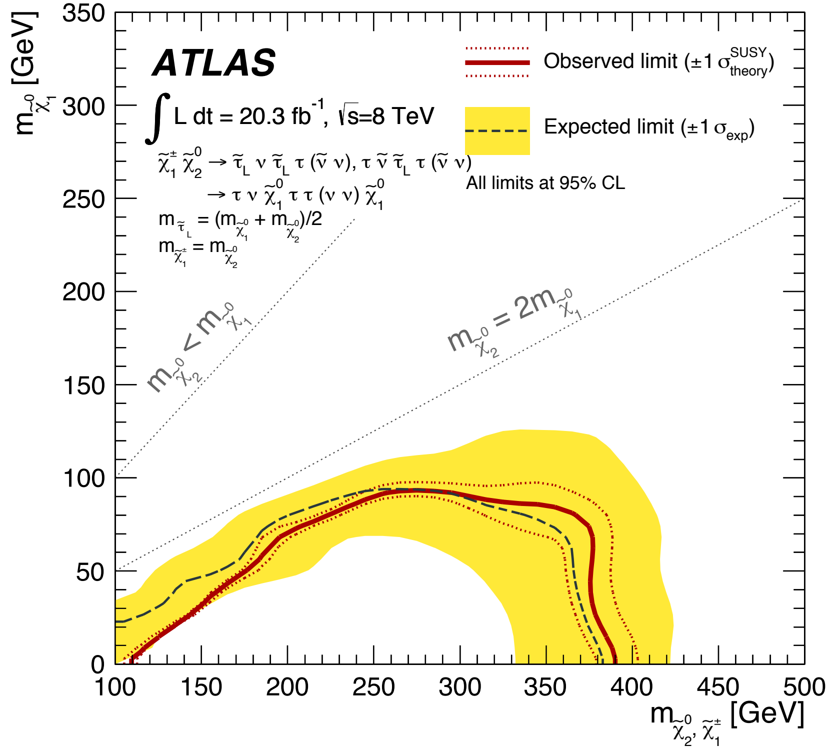






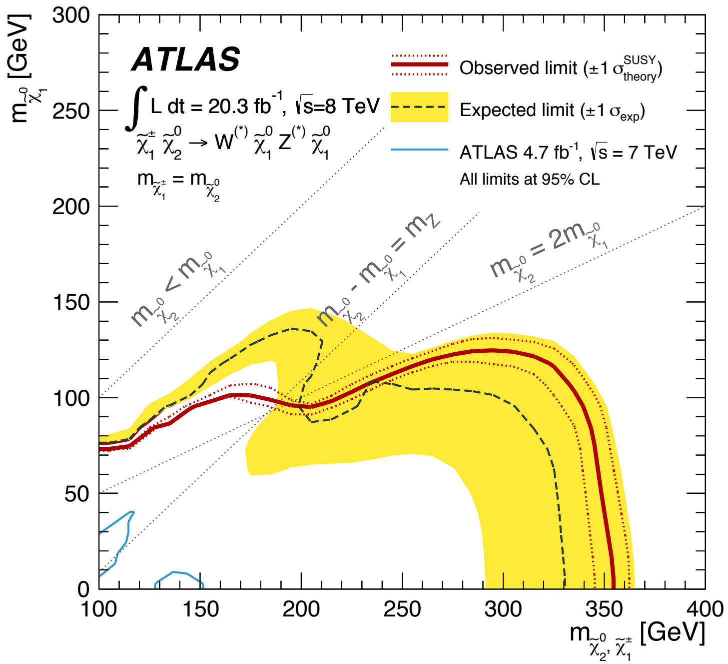
3 lepton - RESULTS

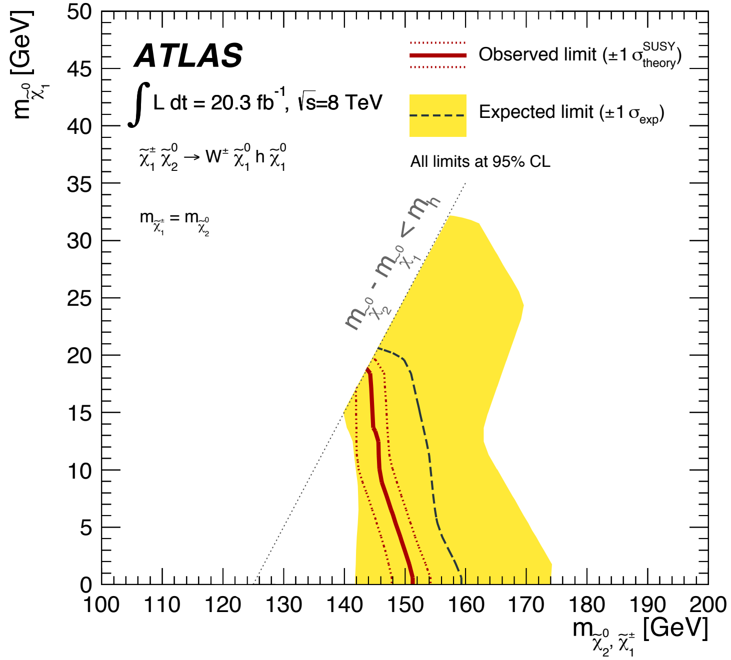




SR0a, SR0b, SR1SS, SR2a are all used and statistically combined:
- experimental uncertainties: treated as correlated between regions and processes
- experimental uncertainties on the reducible background: treated as correlated between regions only
- theoretical uncertainties: on the irreducible background and signal are treated as correlated between regions
- statistical uncertainties: treated as uncorrelated between regions and processes
- total systematic uncertainty on all SUSY signal processes: 10–20% range, with ~7% originates from the uncertainty on the signal cross-section
- uncertainty due to changes in signal acceptance from varying the PDFs and the amount of initial-state radiation is found to be negligible compared to the total systematic uncertainty for the signal scenarios under consideration

3 lepton - RESULTS



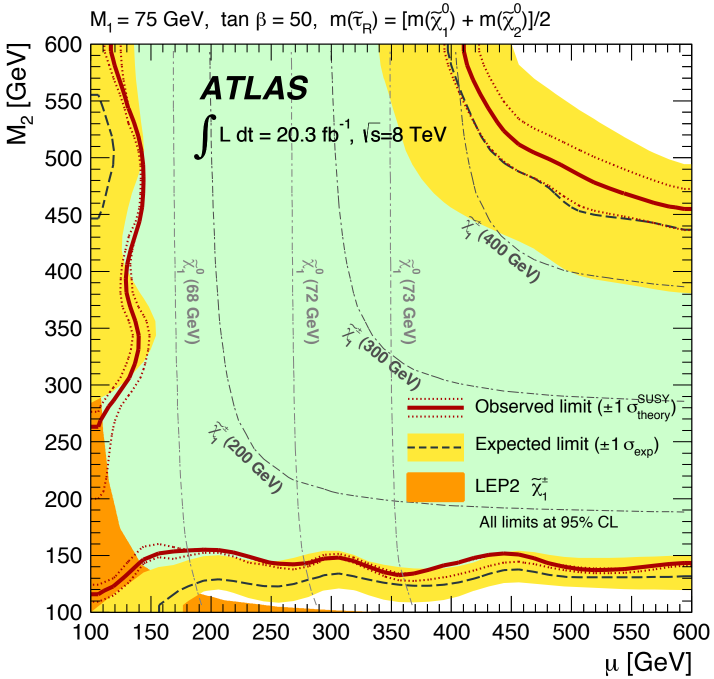


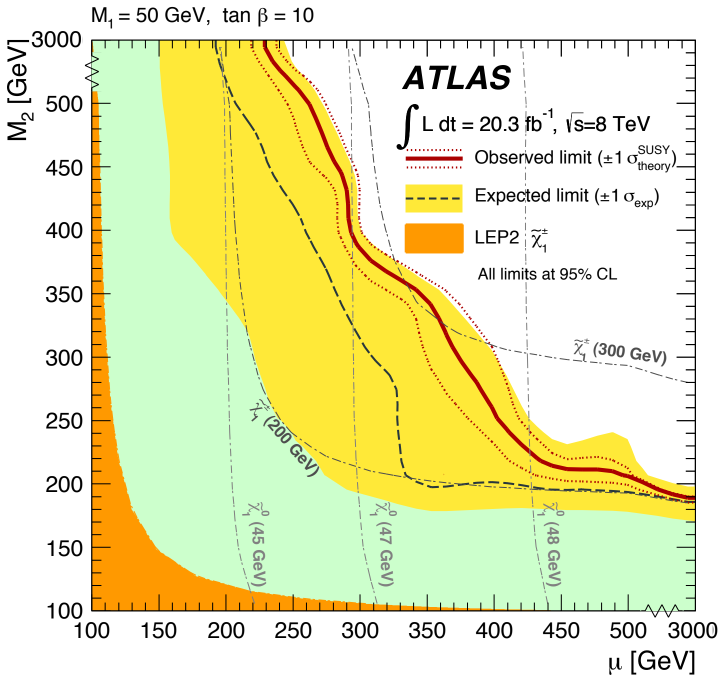
•observed and expected 95% CL exclusion contours for chargino and neutralino production in WZ-mediated (left) and Wh-mediated (right) simplified models

•Wh models:

regions SR0a, SR0b, SR1SS and SR2b offer the best sensitivity when statistically combined results in some SR0a bins and SR1 are responsible for the observed exclusion being slightly weaker than expected

3 lepton - RESULTS



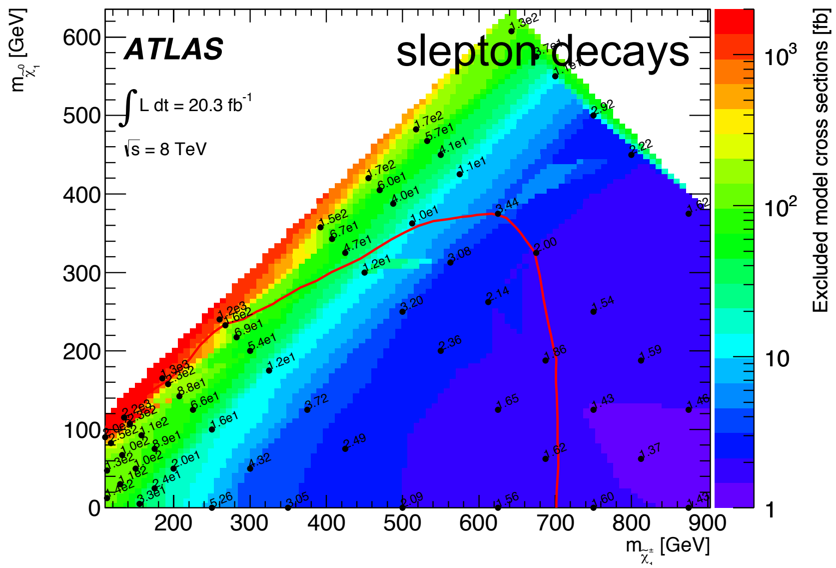


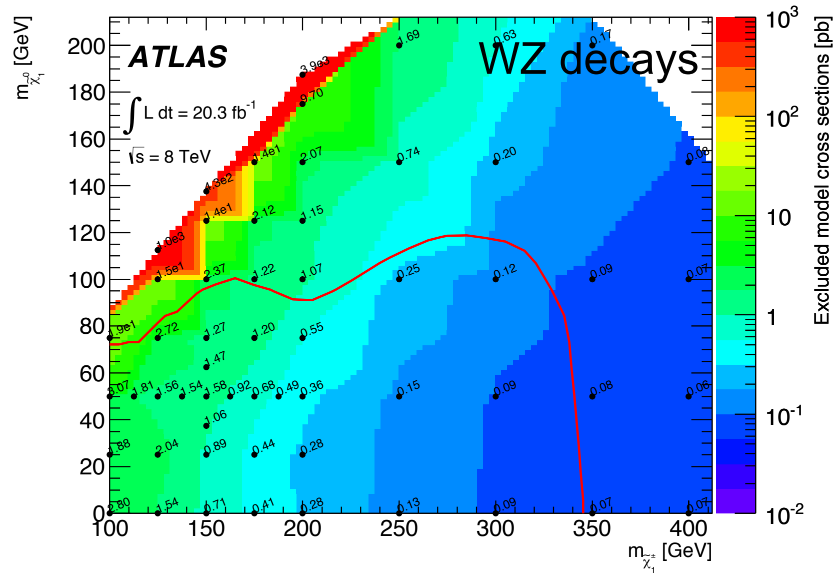
•observed and expected 95% CL exclusion contours in the pMSSM models with staus (left) and no sleptons (right):

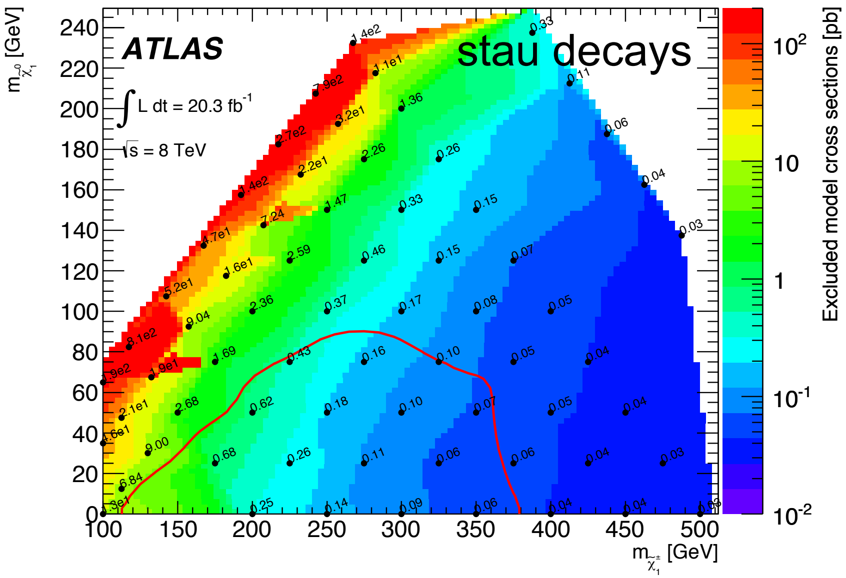
•RH stau scenario:
- selectrons and smuons are heavy and the RH stau mass is set to m(stau)={m(N1)+m(N2)}/2 and tanβ = 50
- M1 =75 GeV resulting in a bino-like N1
- small mass splitting between N2-N1 and C1-N1 reduces the sensitivity in the region M1≈M2≪μ and M1≈μ ≪ M2 region

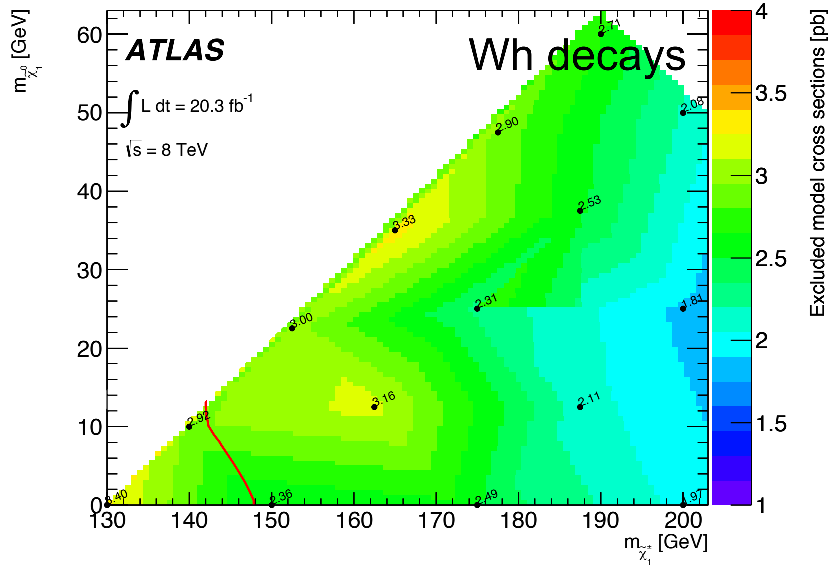
• no slepton decays:
- all sleptons are heavy; decays via W, Z or Higgs bosons dominate
- remaining parameters are M1 =50 GeV and tan β =10; higgs branching fractions are SM-like across much of the parameter space considered; but h-> N1N1 branching fraction rises to ~20% (~70%) when μ decreases to 200 (100) GeV, suppressing other decay modes -> does not affect the mass limits significantly
-region with M2 >=200 GeV, μ >=200 GeV : decay mode N2-> hN1 is kinematically allowed and reduces the sensitivity

3 lepton - RESULTS - 95% CL exclusion contours

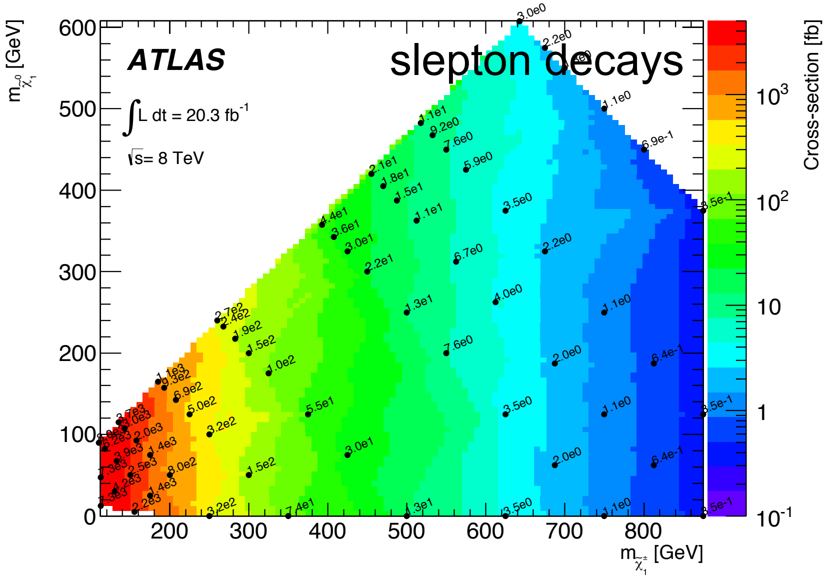


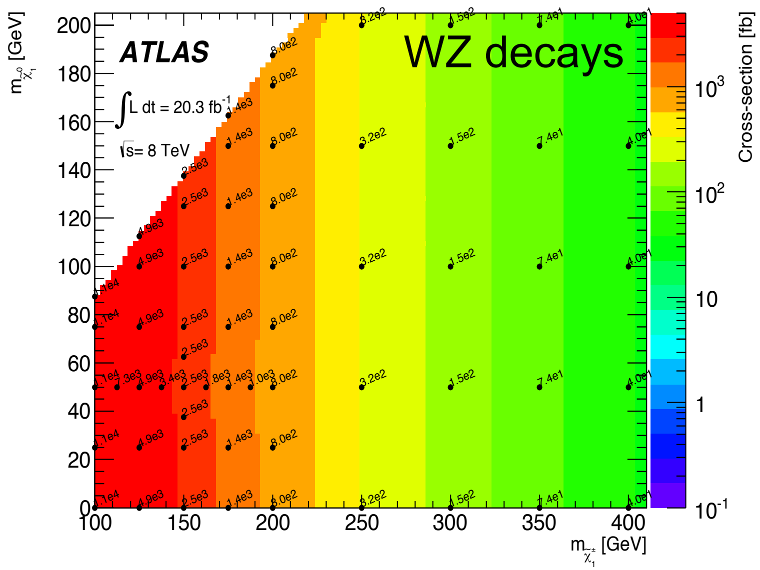


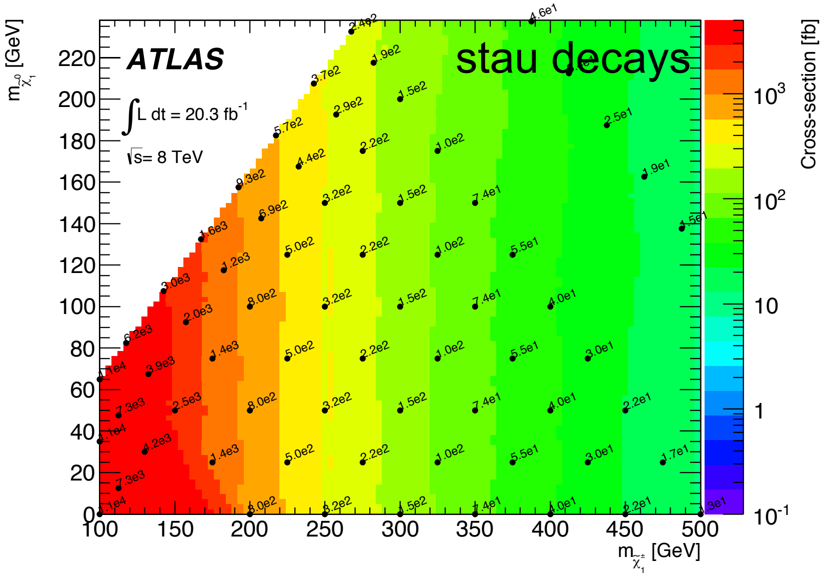


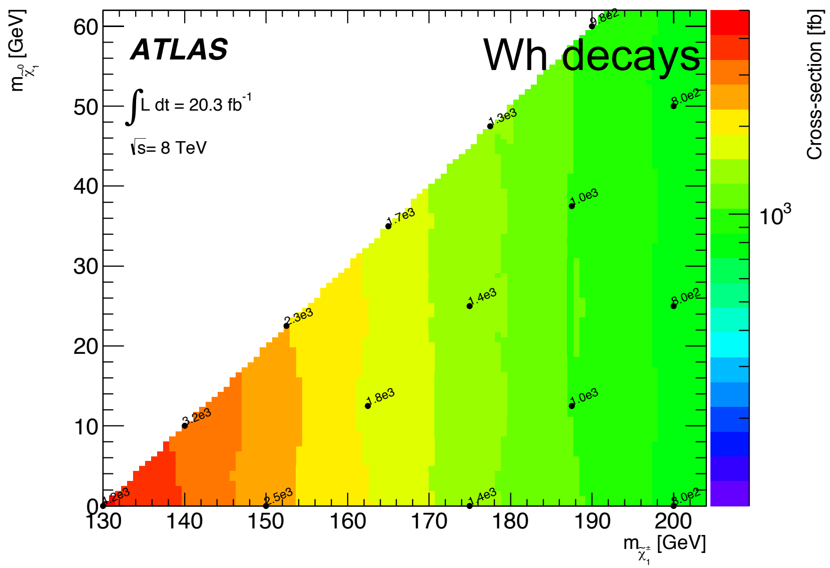


3 lepton - RESULTS cross sections





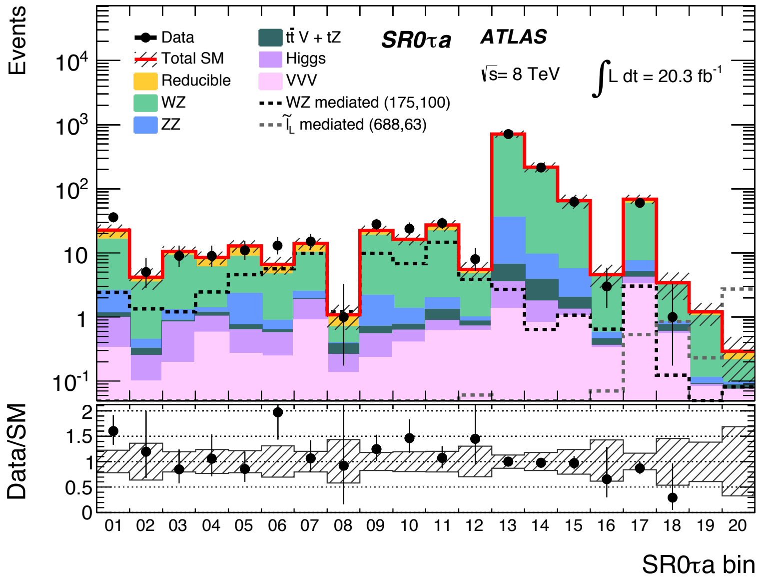


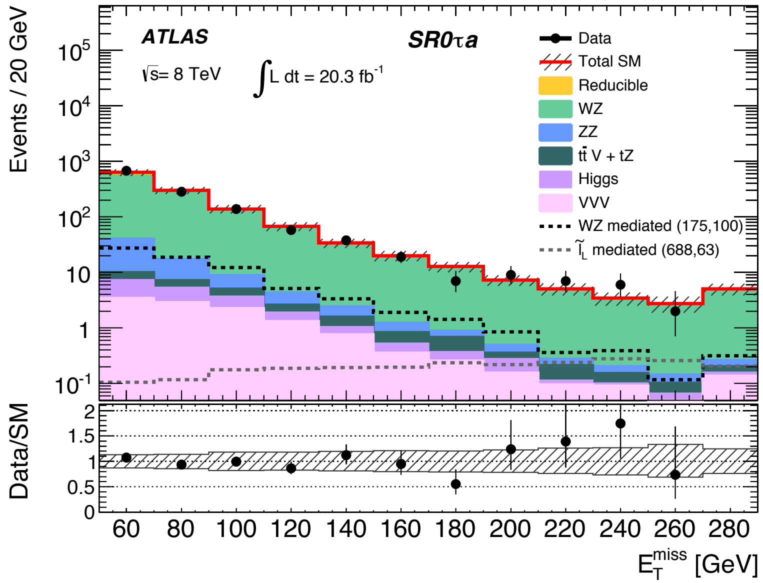


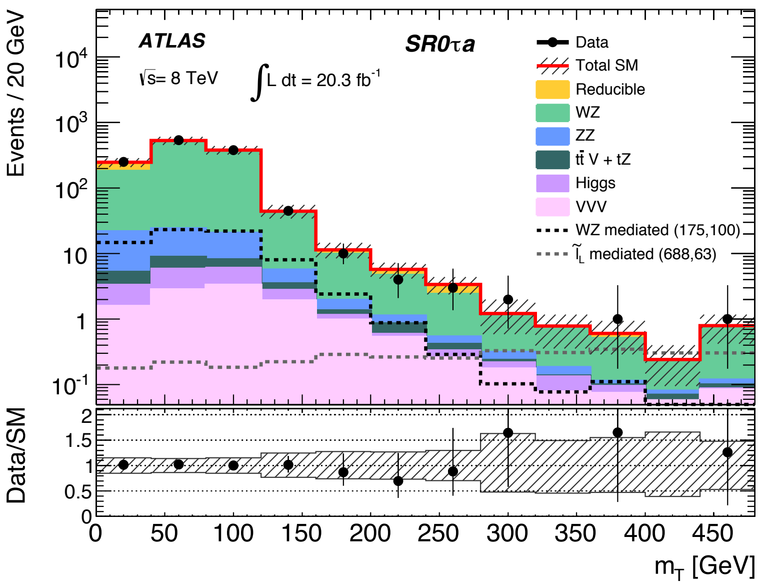
3 lepton - RESULTS

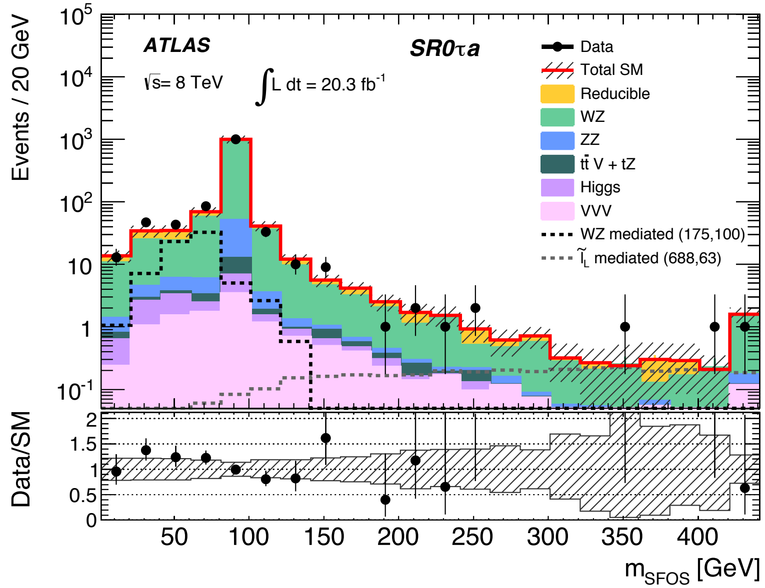
Sample	SR0τa-bin19	SR0τa-bin20	SR0τb	SR1τ	SR2τa	SR2τb
WZ	0.9 ± 0.4	0.12 ± 0.11	0.68 ± 0.20	4.6 ± 0.6	$1.51^{+0.35}_{-0.33}$	$2.09^{+0.30}_{-0.31}$
ZZ	0.021 ± 0.019	0.009 ± 0.009	0.028 ± 0.009	0.36 ± 0.08	$0.049^{+0.016}_{-0.014}$	0.135 ± 0.025
$t\bar{t}V + tZ$	$0.0023^{+0.0032}_{-0.0019}$	$0.012^{+0.016}_{-0.012}$	$0.17^{+0.32}_{-0.17}$	$0.16^{+0.18}_{-0.16}$	$0.21^{+0.27}_{-0.21}$	$0.023^{+0.015}_{-0.018}$
VVV	0.08 ± 0.08	$0.07^{+0.08}_{-0.07}$	1.0 ± 1.0	0.5 ± 0.5	0.09 ± 0.09	0.031 ± 0.033
Higgs	0.007 ± 0.006	0.0009 ± 0.0004	0.49 ± 0.17	0.28 ± 0.12	0.021 ± 0.010	0.08 ± 0.04
Reducible	$0.17^{+0.16}_{-0.15}$	$0.08^{+0.11}_{-0.08}$	1.5 ± 0.4	4.3 ± 0.8	5.1 ± 0.7	4.9 ± 0.7
Total SM	1.2 ± 0.4	$0.29^{+0.18}_{-0.17}$	3.8 ± 1.2	10.3 ± 1.2	6.9 ± 0.8	$7.2^{+0.7}_{-0.8}$
Data	0	0	3	13	6	5
p_0 (σ)	0.50	0.50	0.50	0.19 (0.86)	0.50	0.50
N^{95}_{exp}	$3.7^{+1.4}_{-0.7}$	$3.0^{+0.8}_{-0.0}$	$5.6^{+2.2}_{-1.4}$	$8.1^{+3.2}_{-2.2}$	$6.8^{+2.7}_{-1.9}$	$6.7^{+2.8}_{-1.8}$
N^{95}_{obs}	3.0	3.0	5.4	10.9	6.0	5.2

3 lepton - SIGNAL REGION

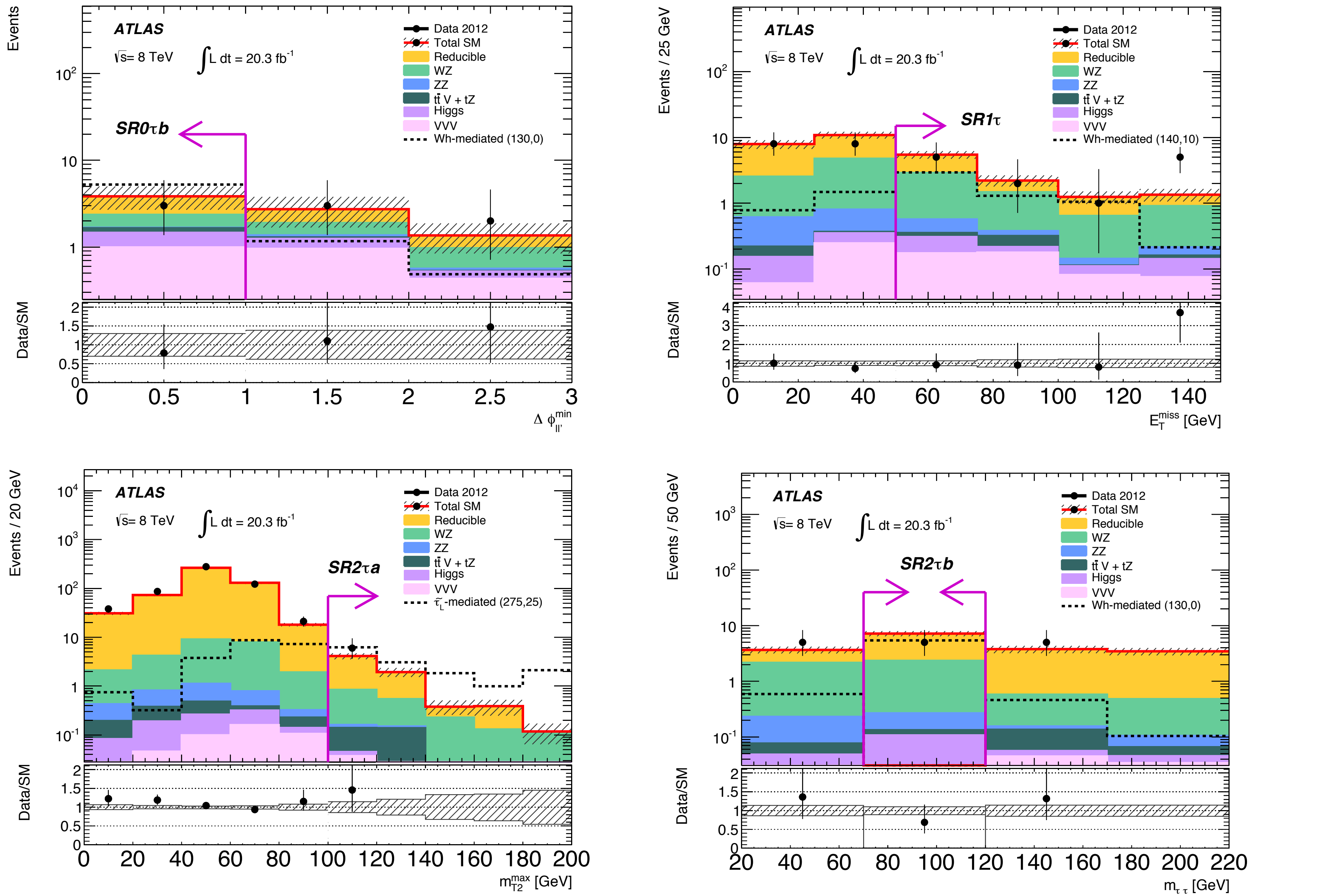




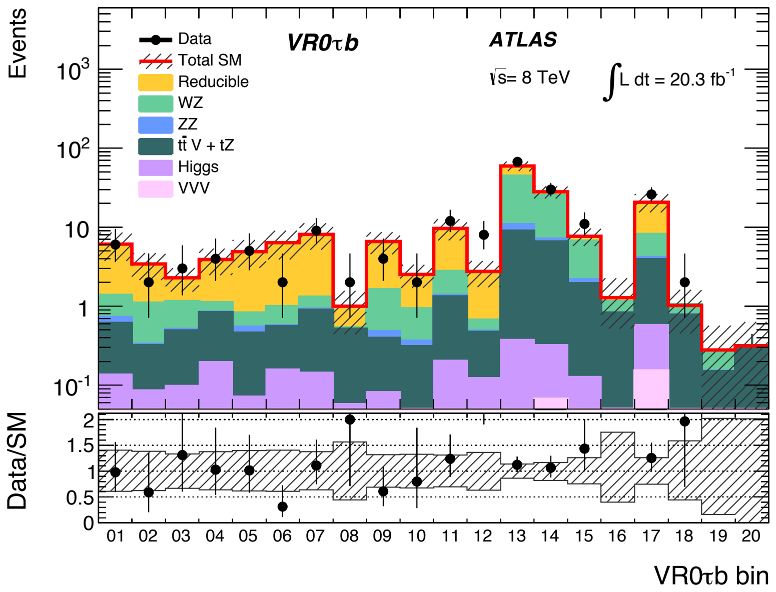


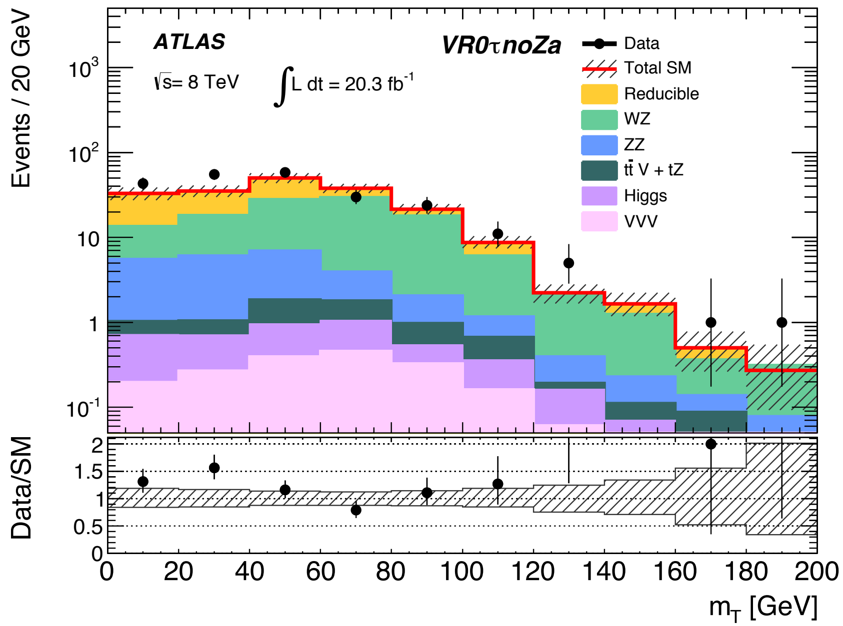


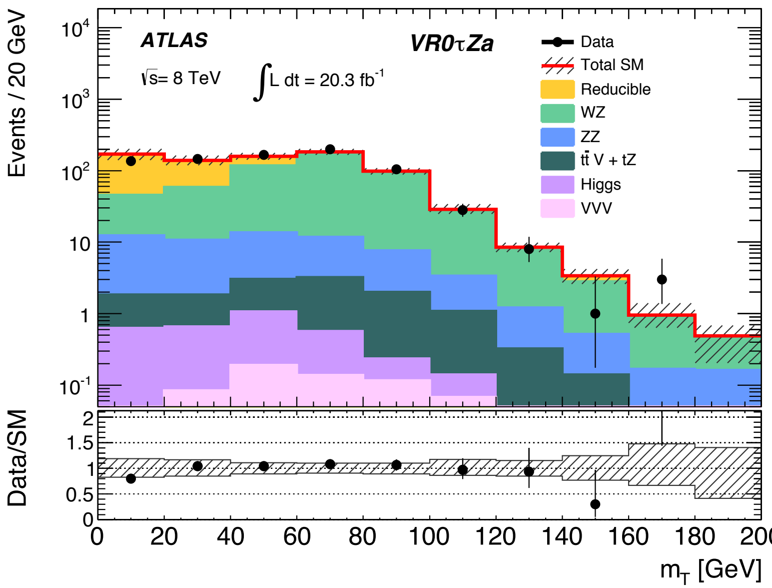
3 lepton - SIGNAL REGION



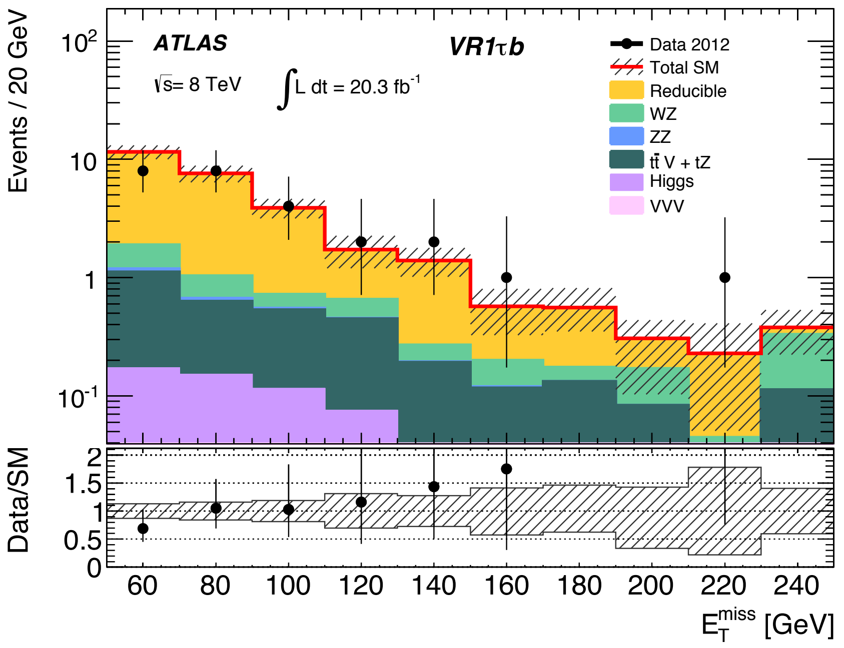
3 lepton – VALIDATION REGIONS

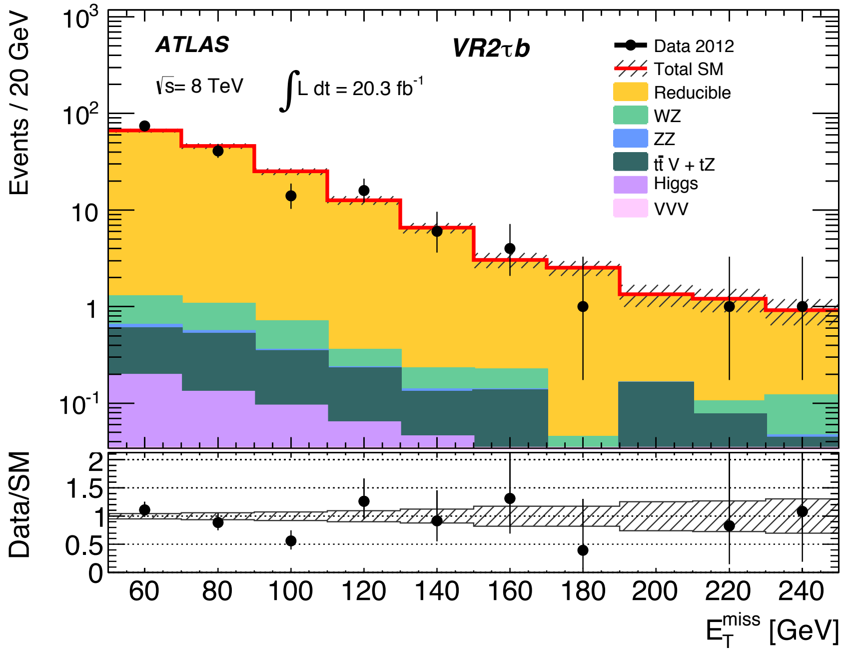






3 lepton – VALIDATION regions





high-E_T^{miss}+ b-tagged jet validation regions

4 lepton

4 lepton - OBJECT SELECTION

Baseline Muons
pT > 10 GeV, |η| < 2.5
STACO loose
MCP cuts

Signal Muons
Isolation (track)
d0 significance, z0sinθ

Lepton isolation
Subtract tracks or clusters from e/μ within cone
(Subtracted leptons must pass signal cuts, except for isolation)

MET
Egamma10NoTau

Triggers
Unprescaled single/double e/μ triggers

Baseline Electrons
pT > 10 GeV, |η| < 2.47
Author 1or 3
Medium++
Cleaning

Signal Electrons
Tight++
Isolation (calo+track)
d0 significance, z0sinθ

Baseline Jets
pT > 20 GeV, |η| < 4.5
AntiKt4LCTopo
B-jets: MV1>0.3511 (ε=80%)

Signal (B-)Jets
Baseline cuts
JVF > 0.5 if pT < 50 GeV
|η| < 2.5

Baseline Taus
pT > 20 GeV, |η| < 2.5
1- or 3-prong
|q| = 1

Signal Taus
Jet BDT Medium
Muon veto
Ele BDT Loose (1-prong)

Overlap removal
Applied at baseline level (except *)
ΔR(e,e) < 0.05: discard lowest ET
ΔR(e,j) < 0.2: discard jet
ΔR(τ,l) < 0.2: discard tau
ΔR(l,j) < 0.4: discard lepton
ΔR(e,μ) < 0.01: discard both
ΔR(μ,μ) < 0.05: discard both
m(l+l-) < 12 GeV: discard both
*ΔR(signal τ,j) < 0.2: discard jet

4 lepton - MC SAMPLES

TABLE III. The MC-simulated samples used in this paper. The generators and the parton shower they are interfaced to, cross-section predictions used for yield normalization, tunes used for the underlying event (UE) and parton density function (PDF) sets are shown. Where two PDF sets are given, the second refers to the generator used for fragmentation and hadronization. Samples preceeded by (S) are used for systematic studies only, and "HF" refers to heavy-flavour jet production. Cross-sections are calculated at leading-order (LO), next-to-LO (NLO), next-to-next-to-LO (NNLO) and next-to-next-to-leading-logarithm (NNLL) QCD precision. Certain samples include NLO electroweak (EW) corrections in the calculation. See text for further details of the event generation and simulation.

Process	Generator + fragmentation/hadronization	Cross-section calculation	UE tune	PDF set
Dibosons				
WW, WZ/γ^*, ZZ/γ^*	POWHEG-BOX-1.0 [45–48] + PYTHIA-8.165 [61]	NLO with MCFM-6.2 [62, 63]	AU2 [59]	CT10 [60]
(S) ZZ/γ^*	aMC@NLO-4.03 [64]	MCFM-6.2 [62, 63]	AUET2B [65]	CT10
ZZ/γ^* via gluon fusion	gg2ZZ [66] + HERWIG-6.520 [40]	NLO	AUET2B	CT10/CTEQ6L1
Tribosons				
WWW, ZWW, ZZZ	MadGraph-5.0 [67] + PYTHIA-6.426 [58]	NLO [68]	AUET2B	CTEQ6L1 [69]
VV+ 2 jets	SHERPA-1.4.0 [70]	LO	SHERPA default	CT10
Higgs				
via gluon fusion	POWHEG-BOX-1.0 [71] + PYTHIA-8.165	NNLL QCD, NLO EW [72]	AU2	CT10
via vector boson fusion	POWHEG-BOX-1.0 [73] + PYTHIA-8.165	NNLO QCD, NLO EW [72]	AU2	CT10
associated W/Z	PYTHIA-8.165	NNLO QCD, NLO EW [72]	AU2	CTEQ6L1
associated $t\bar{t}$	PYTHIA-8.165	NLO [72]	AU2	CTEQ6L1
Top+Boson				
$t\bar{t}+W$, $t\bar{t}+Z$	ALPGEN-2.14 [74] + HERWIG-6.520	NLO [75, 76]	AUET2B	CTEQ6L1
(S) $t\bar{t}+Z$	MadGraph-5.0 + PYTHIA-6.426	NLO [75]	AUET2B	CTEQ6L1
$t\bar{t}+WW$, tZ, tWZ	MadGraph-5.0 + PYTHIA-6.426	LO	AUET2B	CTEQ6L1
$t\bar{t}$	POWHEG-BOX-1.0 [77] + PYTHIA-6.426	NNLO+NNLL [78–83]	Perugia 2011C [84]	CT10/CTEQ6L1
Single top				
t-channel	AcerMC-38 [85]	NNLO+NNLL [86]	AUET2B	CTEQ6L1
s-channel, Wt	MC@NLO-4.03 [87]	NNLO+NNLL [88, 89]	AUET2B	CT10
W+jets, Z/γ^*+jets				
$M_{\ell\ell} >$ 40 GeV (30 GeV HF)	ALPGEN-2.14 + PYTHIA-6.426	with DYNNLO-1.1 [90]	Perugia 2011C	CTEQ6L1
10 GeV $< M_{\ell\ell} <$ 40 GeV	ALPGEN-2.14 + HERWIG-6.520	with MSTW2008 NNLO [91]	AUET2B	CTEQ6L1
Multijet	PYTHIA-8.165	LO	AU2	CTEQ6L1
SUSY signal				
RPV simplified models	HERWIG++ 2.5.2 [92]	See text	UE-EE-3 [93]	CTEQ6L1
RPC simplified models	MadGraph-5.0 + PYTHIA-6.426	NLO, see text	AUET2B	CTEQ6L1
GGM	PYTHIA-6.426	NLO, see text	AUET2B	CTEQ6L1

4 lepton - SYSTEMATIC UNCERTAINTIES

Experimental		Theoretical	
Jet energy scale	2.4%	σ: $t\bar{t}+Z/WW$ [75, 76]	30%
Jet energy resolution	5.5%	$A\epsilon$: $t\bar{t}+Z$	30–40%
		σ: ZZ/γ^*	5%
e efficiency	3.5%	$A\epsilon$: ZZ/γ^*	5–20%
τ efficiency	3.3%	σ: VVV/tWZ	50%
$E_{\mathrm{T}}^{\mathrm{miss}}$ energy scale	2.7%	$\sigma A\epsilon$: Vh/VBF [72]	20%
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution	2.7%	$\sigma A\epsilon$: ggF/$t\bar{t}h$ [72]	100%
Luminosity	2.8%	**Reducible**	
Trigger	5%	$\geq 0\tau$ SRs	$\sim$ 100%
MC sample size	$\lesssim$ 30%	$\geq 1\tau/2\tau$ SRs	30–50%

4 lepton - weighting method

Using a simplified matrix method, the weighting method

$$N_{red}^{XR} = [N_{data}^{XRCR1} - N_{MCirr}^{XRCR1}] \times F - [N_{data}^{XRCR2} - N_{MCirr}^{XRCR2}] \times F_1 \times F_2$$

Counts in CR1,
3 tight 1 loose lepton

Counts in CR2,
2 tight 2 loose lepton,
to remove double counting in first term

$$F = \frac{p(T)}{p(L)}$$

=> fake ratio

p(T) (p(L)) is the probability a fake lepton is identified as a tight (loose) lepton

L: loose lepton: pass baseline + overlap removal. Fails signal lepton requirements

T: tight lepton: pass baseline + overlap removal. Passes signal lepton requirements

4 lepton - weighting method

- Use weighted average fake ratios:

$$F_{XR}^{\ell} = \sum_{i,j} \left(R_{XR}^{ij} \times sf^{i} F^{ij} \right)$$

- Where:
  - R = process fraction, measure in signal, validation regions
  - sf = scale factor
  - F = fake rate
  - i = fake type (light, heavy flavor, conversion)
  - j = process

Process fractions:

$$R_{XR}^{ij} = \frac{N_{ij}^{XR}}{\sum_{kl} N_{kl}^{XR}} = \frac{N_{ij}\epsilon_j}{\sum_{kl} N_{kl}\epsilon_l}$$

Where:
- N is contribution from the process without the final cuts applied
- ϵ_j is the efficiency of the final cuts

N's are calculated from 3tight+1loose events for 1fake processes and a 2tight+2loose selection for 2fake events multiplied by an appropriate fake ratio

4 lepton - VALIDATION REGIONS

	N(ℓ)	N(τ)	Z-veto	E_T^{miss} [GeV]	m_{eff} [GeV]
VR0noZ	≥4	≥0	SFOS, SFOS+ℓ, SFOS+SFOS	<50	<400
VR1noZ	=3	≥1	SFOS, SFOS+ℓ	<50	<400
VR2noZ	=2	≥2	SFOS	<50	<400
	N(ℓ)	N(τ)	Z-requirement	E_T^{miss} [GeV]	
VR0Z	≥4	≥0	SFOS	<50	–
VR1Z	=3	≥1	SFOS	<50	–
VR2Z	=2	≥2	SFOS	<50	–

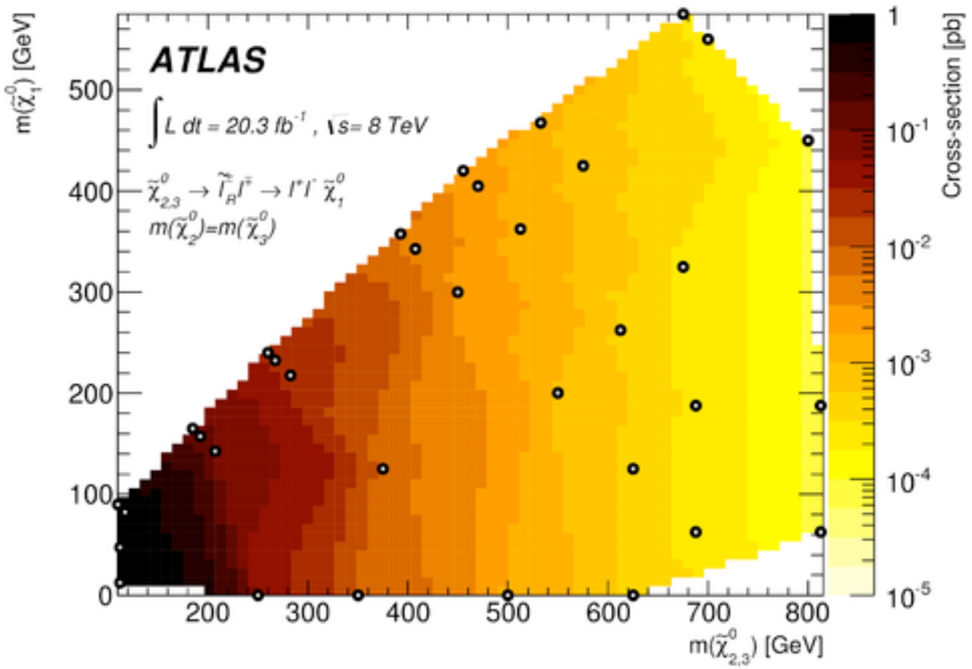
	ZZ/γ^*	tWZ	$t\bar{t}+Z$	VVV	Higgs	Reducible	Σ SM	Data	CL_b
VR0noZ	3.6 ± 0.7	0.017 ± 0.010	$0.034^{+0.036}_{-0.033}$	$0.090^{+0.032}_{-0.033}$	0.18 ± 0.13	$0.5^{+0.4}_{-0.5}$	4.4 ± 0.9	3	0.29
VR1noZ	1.43 ± 0.27	0.010 ± 0.006	0.033 ± 0.022	0.071 ± 0.029	0.28 ± 0.19	$7.1^{+1.8}_{-1.7}$	$8.9^{+1.8}_{-1.7}$	7	0.31
VR2noZ	$1.53^{+0.18}_{-0.17}$	0.007 ± 0.004	$0.025^{+0.031}_{-0.025}$	0.051 ± 0.020	0.29 ± 0.13	$33.2^{+3.3}_{-7.3}$	$35.1^{+3.4}_{-7.4}$	32	0.37
VR0Z	184^{+20}_{-19}	0.13 ± 0.07	1.2 ± 0.6	2.13 ± 0.33	4.7 ± 3.4	$0.5^{+3.1}_{-0.5}$	193^{+21}_{-19}	216	0.81
VR1Z	8.8 ± 0.9	0.039 ± 0.021	0.28 ± 0.11	0.19 ± 0.08	0.63 ± 0.16	21 ± 4	31 ± 4	32	0.55
VR2Z	$8.2^{+1.0}_{-1.0}$	0.0027 ± 0.0021	$0.09^{+0.12}_{-0.09}$	0.069 ± 0.013	0.61 ± 0.14	90^{+8}_{-22}	99^{+8}_{-22}	101	0.54

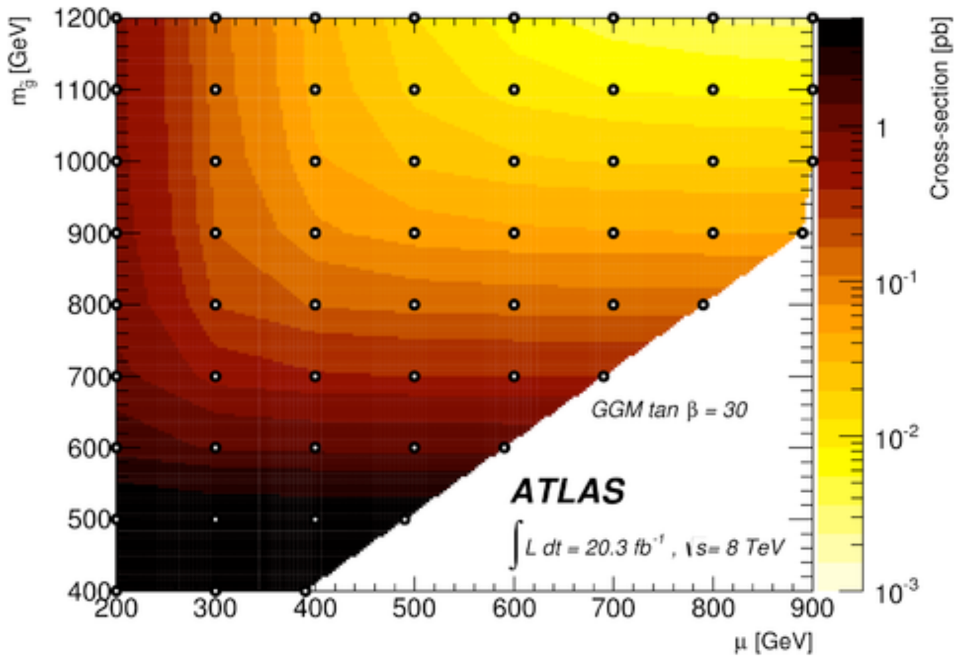
4 lepton – RESULTS

	ZZ/γ^*	tWZ	$t\bar{t}+Z$	VVV	Higgs	Reducible	Σ SM	Data
SR0noZa	0.29 ± 0.08	0.067 ± 0.033	0.8 ± 0.4	0.19 ± 0.09	0.27 ± 0.23	$0.006^{+0.164}_{-0.006}$	1.6 ± 0.5	3
SR1noZa	0.52 ± 0.07	0.054 ± 0.028	0.21 ± 0.08	0.14 ± 0.07	0.40 ± 0.33	$3.3^{+1.3}_{-1.1}$	$4.6^{+1.3}_{-1.2}$	4
SR2noZa	0.15 ± 0.04	0.023 ± 0.012	0.13 ± 0.10	0.051 ± 0.024	0.20 ± 0.16	3.4 ± 1.2	$4.0^{+1.2}_{-1.3}$	7
SR0noZb	0.19 ± 0.05	0.049 ± 0.024	0.68 ± 0.34	0.18 ± 0.07	0.22 ± 0.20	$0.06^{+0.15}_{-0.06}$	1.4 ± 0.4	1
SR1noZb	$0.219^{+0.036}_{-0.035}$	0.050 ± 0.026	0.17 ± 0.07	0.09 ± 0.04	0.30 ± 0.26	$2.1^{+1.0}_{-0.9}$	$2.9^{+1.0}_{-0.9}$	1
SR2noZb	$0.112^{+0.025}_{-0.024}$	0.016 ± 0.009	$0.27^{+0.28}_{-0.27}$	0.040 ± 0.018	0.13 ± 0.12	$2.5^{+0.9}_{-1.0}$	3.0 ± 1.0	6
SR0Z	$1.09^{+0.26}_{-0.21}$	0.25 ± 0.13	2.6 ± 1.2	1.0 ± 0.5	$0.60^{+0.22}_{-0.21}$	$0.00^{+0.09}_{-0.00}$	5.6 ± 1.4	7
SR1Z	$0.59^{+0.11}_{-0.10}$	0.042 ± 0.022	0.41 ± 0.19	0.22 ± 0.11	0.14 ± 0.05	1.0 ± 0.5	2.5 ± 0.6	3
SR2Z	$0.70^{+0.12}_{-0.11}$	0.0018 ± 0.0015	0.035 ± 0.024	0.039 ± 0.014	$0.14^{+0.04}_{-0.05}$	0.9 ± 0.5	1.8 ± 0.5	1

	Σ SM	Data	N^{obs}_{BSM}	N^{exp}_{BSM}	σ^{obs}_{vis}[fb] (asym.)	σ^{exp}_{vis}[fb] (asym.)	p_0	N_σ
SR0noZa	1.6 ± 0.5	3	5.9	$4.4^{+1.6}_{-1.0}$	0.29 (0.29)	$0.22^{+0.08}_{-0.05}$ $(0.21^{+0.12}_{-0.07})$	0.15	1.02
SR1noZa	$4.6^{+1.3}_{-1.2}$	4	5.7	$5.9^{+2.5}_{-1.5}$	0.28 (0.27)	$0.29^{+0.12}_{-0.07}$ $(0.30^{+0.15}_{-0.09})$	0.50	–
SR2noZa	$4.0^{+1.2}_{-1.3}$	7	9.2	$6.1^{+2.5}_{-1.4}$	0.45 (0.45)	$0.30^{+0.12}_{-0.07}$ $(0.31^{+0.15}_{-0.09})$	0.13	1.14
SR0noZb	1.4 ± 0.4	1	3.7	3.9 ± 1.4	0.18 (0.17)	0.19 ± 0.07 $(0.19^{+0.11}_{-0.07})$	0.50	–
SR1noZb	$2.9^{+1.0}_{-0.9}$	1	3.5	$4.7^{+1.9}_{-1.2}$	0.17 (0.17)	$0.23^{+0.09}_{-0.06}$ $(0.24^{+0.13}_{-0.08})$	0.50	–
SR2noZb	3.0 ± 1.0	6	8.7	$5.6^{+2.3}_{-1.3}$	0.43 (0.43)	$0.28^{+0.11}_{-0.06}$ $(0.28^{+0.14}_{-0.09})$	0.10	1.30
SR0Z	5.6 ± 1.4	7	8.1	$6.7^{+2.7}_{-1.6}$	0.40 (0.40)	$0.33^{+0.13}_{-0.08}$ $(0.34^{+0.16}_{-0.10})$	0.29	0.55
SR1Z	2.5 ± 0.6	3	5.3	$4.7^{+1.9}_{-1.1}$	0.26 (0.26)	$0.23^{+0.09}_{-0.05}$ $(0.23^{+0.13}_{-0.08})$	0.34	0.40
SR2Z	1.8 ± 0.5	1	3.5	$4.1^{+1.7}_{-0.8}$	0.17 (0.17)	$0.20^{+0.08}_{-0.04}$ $(0.21^{+0.12}_{-0.07})$	0.50	–

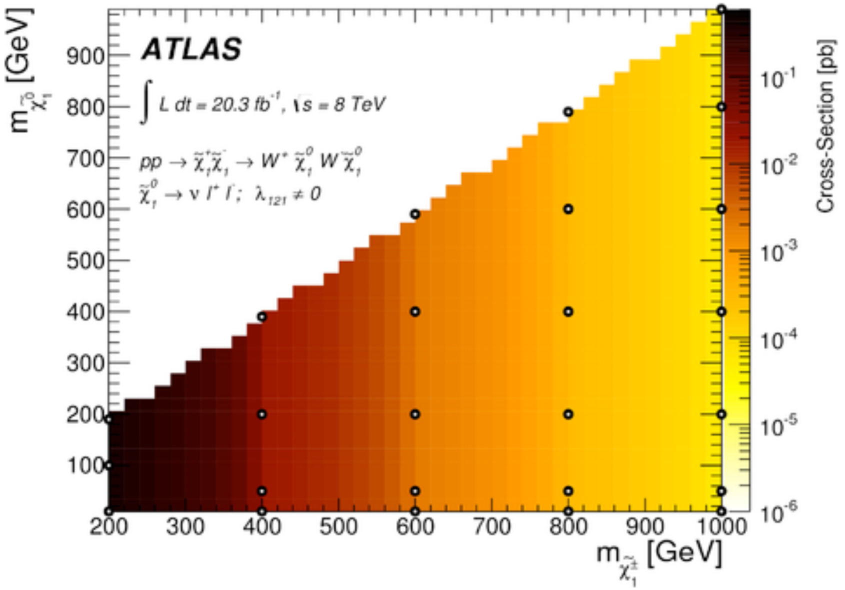
4 lepton – RESULTS

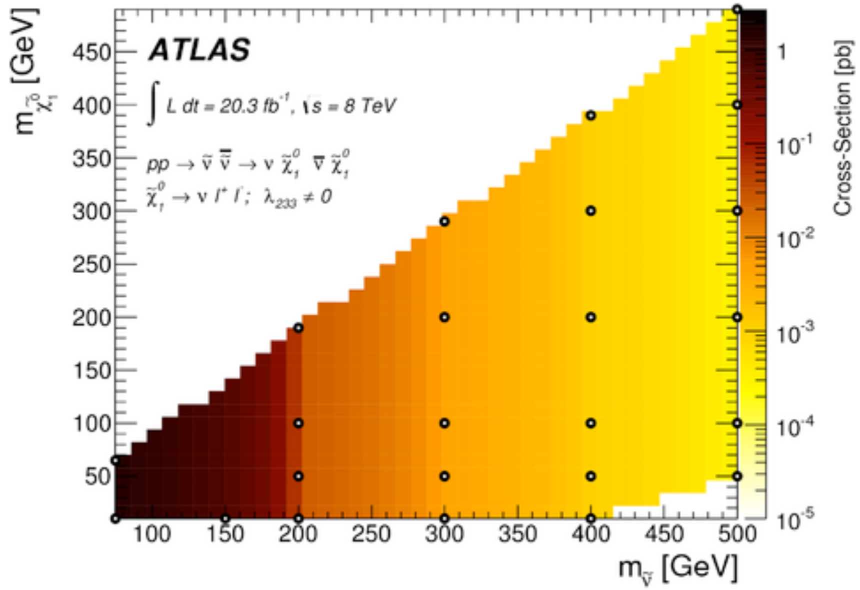


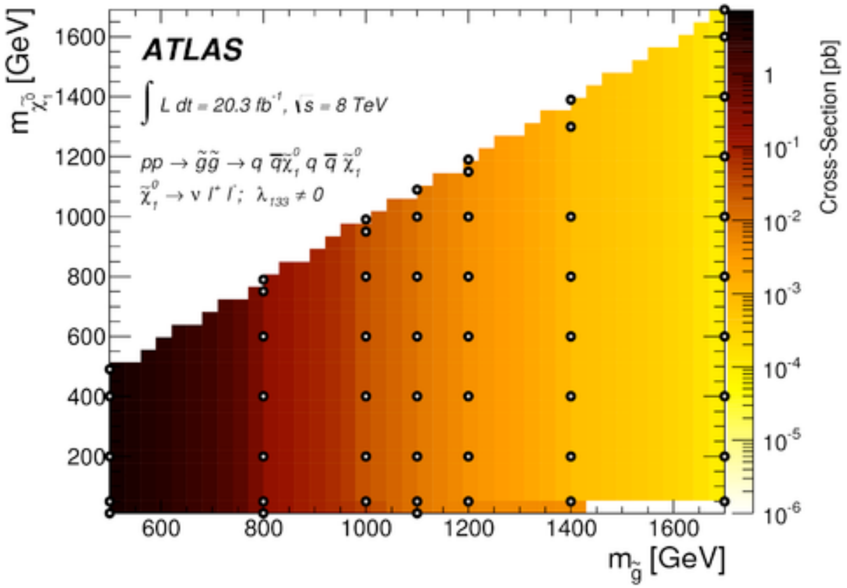


total production cross-section for a selection of models used in this analysis:
RPC R-slepton (left), GGM, tanβ = 30 (right)

4 lepton – RESULTS

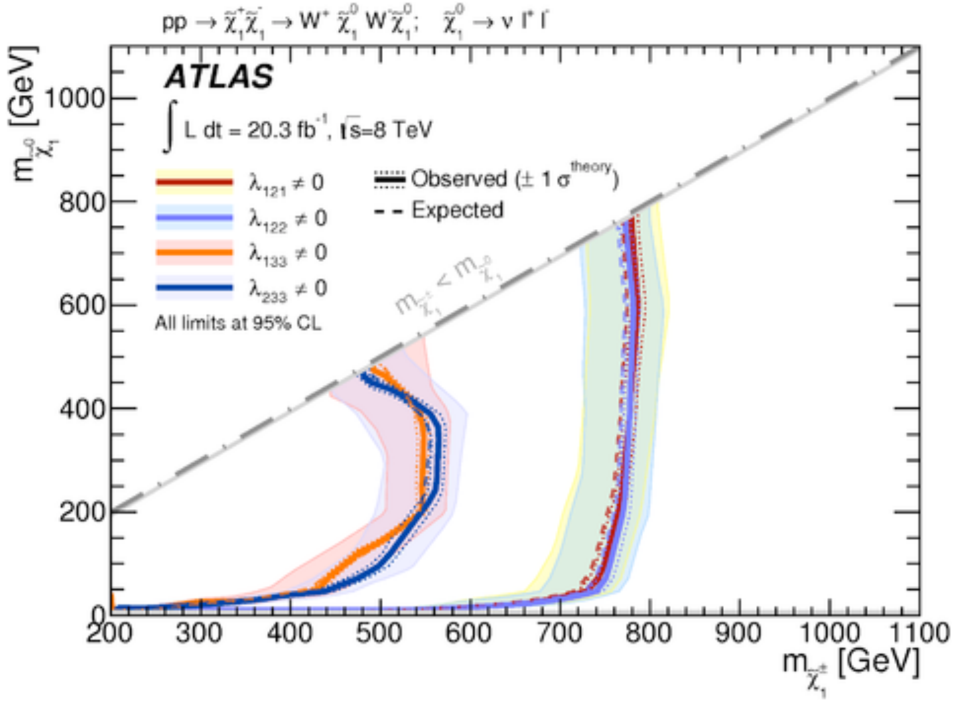


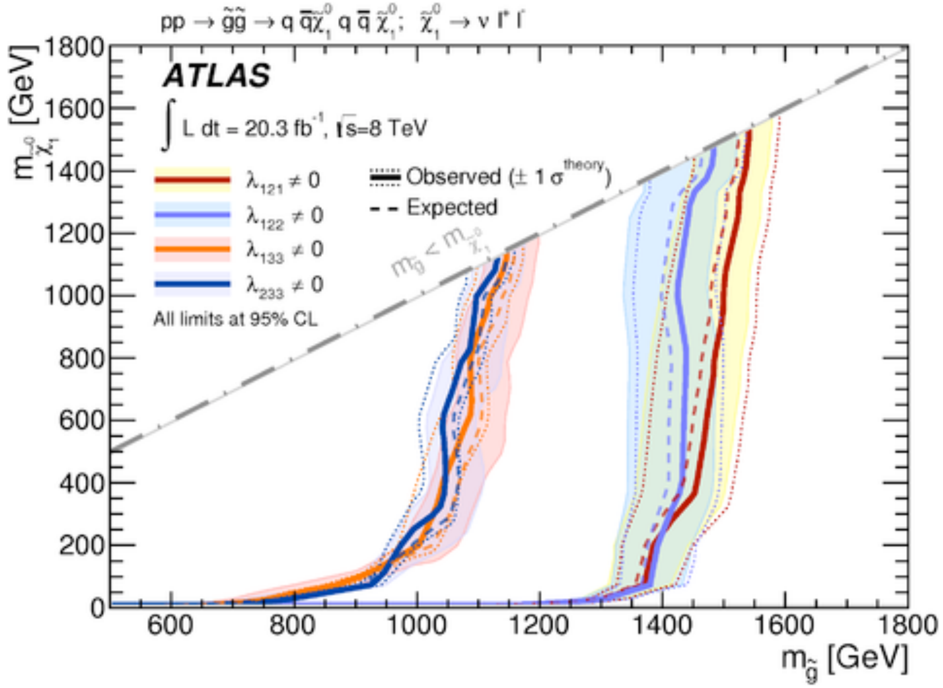




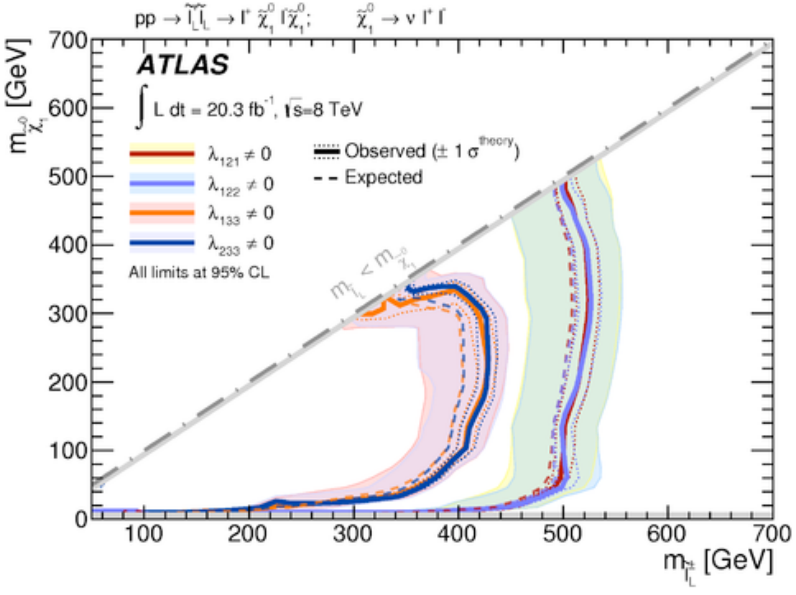
total production cross-section for a selection of models used in this analysis: RPV chargino NLSP $\lambda_{121} \neq 0$ (top left), RPV sneutrino NLSP $\lambda_{233} \neq 0$ (top right), RPV gluino NLSP $\lambda_{133} \neq 0$ (bottom)

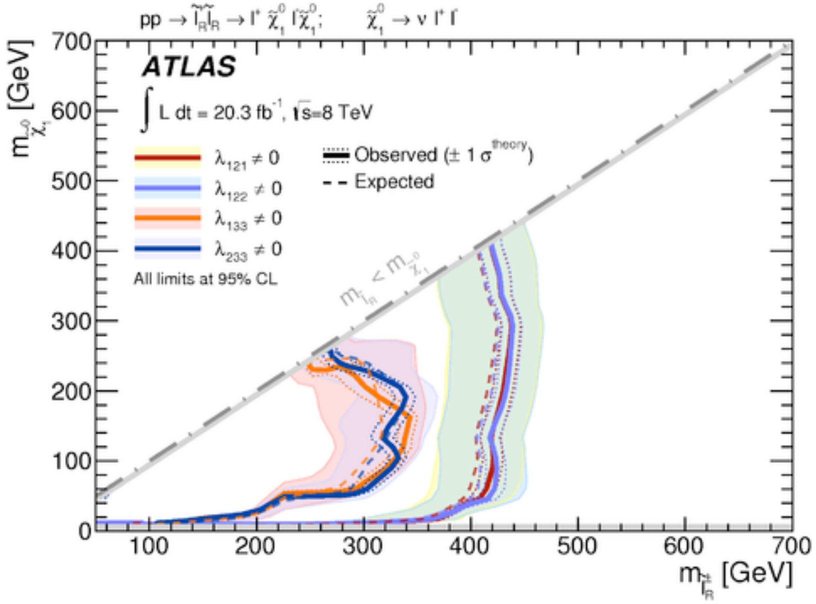
4 lepton – RESULTS

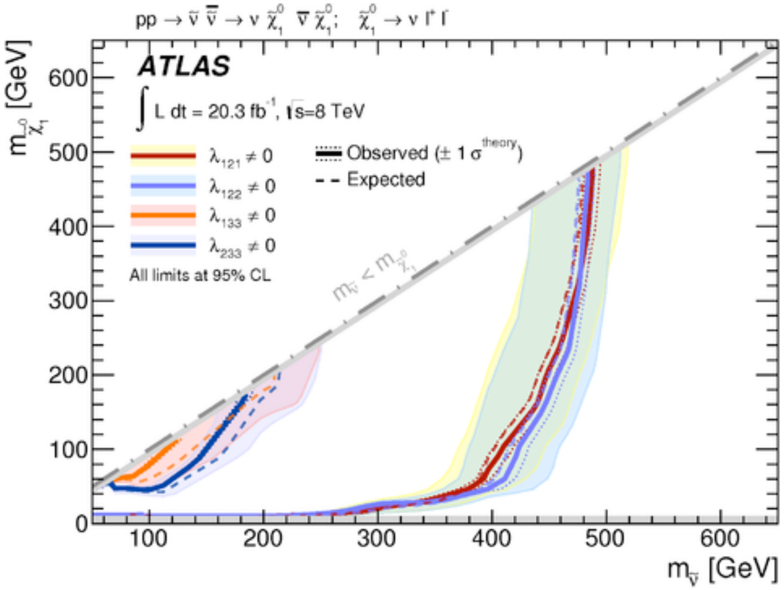




- different choices of λ parameters correspond to differently colored bands
- observed and expected 95% CL limit contours for RPV models with chargino NLSP (left) and gluino NLSP (right), assuming a promptly decaying LSP
- in RPV models where the LSP decays only to electrons and muons, the 95% CL lower mass limits are: 1350 GeV for the gluino, 750 GeV for wino-like charginos







- the 95% CL exclusion limit contours for the RPV L-slepton NLSP (top left) , (R-slepton NLSP (top right) and sneutrino NLSP (bottom) simplified models, assuming a promptly decaying LSP
- for decays only to electrons and muons, the 95% CL lower mass limits are: 490 (410) GeV for L(R)-sleptons and 400 GeV for sneutrinos
- less stringent limits are placed for RPV models with tau-rich decays
- for slepton and stau decays: mass of the LSP is assumed to be at least as large as 20% of the NLSP mass