Search for Supersymmetry Weak Production in ATLAS

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Partikeldagarna 2012

Should we still be doing SUSY?

from the LHC Implication workshop: http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=173388

2. Light sleptons

In constrained frameworks, the sleptons and squarks are at the same mass scale. In more general contexts, this is unnecessary.

There are currently no model-independent limits on sleptons beyond LEP.

There are many reasons why light sleptons are motivated:

Stau coannihilation mechanism for dark matter. This forces

$$m(\tilde{\tau}) \approx m(\tilde{H})$$

SUSY contribution to muon g-2.

Stau contribution to $\Gamma(h \to \gamma\gamma)$ (Carena et al.)

M. Peskin
Light sleptons, but also compressed models, Higgsino scenarios and light stops!

HEPHY Institute of High Energy Physics — SMS classification of MSSM scenarios — OAW

Summary

- Two types of pMSSM points have been identified that have a high cross section and could nevertheless not be excluded with 7 TeV 2012 CMS data:
  → EWKino points: chargino / heavy neutralino production.
  Analyses are insensitive, and ewk sector is very often highly compressed.
  Peculiarity: chargino-LSP production. Search for boosted Ws + large MET?
  → Squark points: squark-squark production.
  Spectrum by far not as compressed.
  Many points will be covered simply with more data, some more points would benefit by going to lower mass splittings in the analyses.
- The SMS models cover very nicely missed pMSSM points.
  There is no striking inconsistency between the pMSSM scan and the SMS results. More cross validation can be done.

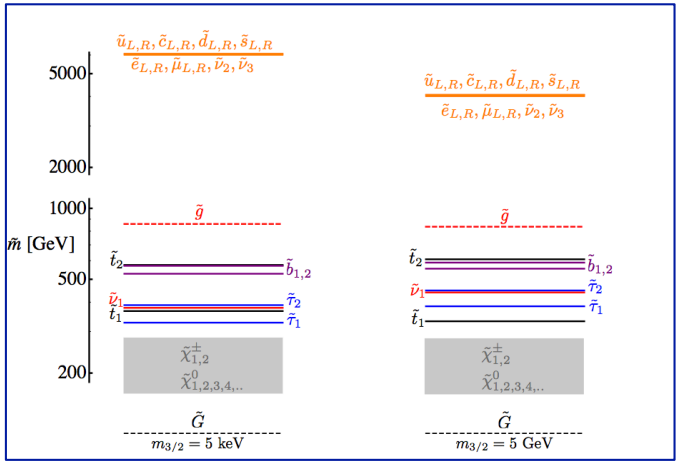
CERN, July 2012 The pMSSM team 28

W. Waltenberger et al.
"Low mass charginos / neutralinos or compressed models"

Harder but Important in 2012-13

- Low Mass, Low Cross-Section Resonances
  - Maybe only observable in associated production, or in pairs
- Broad resonances
  - Precise (or monotonically uncertain) predictions of falling distributions?
- Electroweak Production
  - Includes charginos, neutralinos, sleptons; many other possibilities
- Non-Standard Model Higgs
  - New Scalar States (possibly very low cross-section)
  - New Production Modes
  - New Decay Modes (possibly rare – recall 10^6 Higgses)
- Rare W, Z, t decays (?)
  - LHC has the most of each of these [but trigger issues]

M. Strassler: Electroweak SUSY production



Models with low mass gauginos
eg. arXiv:1203.1622, 1206.6540, 1110.6926, 1203.5539, …

Particle Content in Minimal Supersymmetric Standard Model

after EW symmetry breaking

Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$	(same)
			$\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$	(same)
			$\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	$\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$	(same)
			$\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$	(same)
			$\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	$\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	−1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$
charginos	1/2	−1	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\tilde{C}_1^\pm\ \tilde{C}_2^\pm$
gluino	1/2	−1	$\tilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)

also often denoted

$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0,$

$\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$

index: increase with mass

Looking for the production of these

The neutralinos are a mix of the neutral gauginos and Higgsinos

$$\begin{pmatrix} \tilde{\chi}^0_1 \\ \tilde{\chi}^0_2 \\ \tilde{\chi}^0_3 \\ \tilde{\chi}^0_4 \end{pmatrix} = M_{\tilde{N}} \begin{pmatrix} \tilde{B}^0 \\ \tilde{W}^0 \\ \tilde{H}^0_d \\ \tilde{H}^0_u \end{pmatrix} \qquad M_N \equiv \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'v_d & \frac{1}{2}g'v_u \\ 0 & M_2 & \frac{1}{2}gv_d & -\frac{1}{2}gv_u \\ -\frac{1}{2}g'v_d & \frac{1}{2}gv_d & 0 & -\mu \\ \frac{1}{2}g'v_u & -\frac{1}{2}gv_u & -\mu & 0 \end{pmatrix}$$

M_1, M_2, μ, $tan(\beta)$ are <u>fundamental parameters of the underlying SUSY theory</u>.
Similar to m_Z, $sin(\theta_W)$ in the EW theory.

- By searching for **SUSY weak production** we can put general limits on M_1, M_2, μ, $tan(\beta)$

$\Rightarrow$ Can for instance be input into global beyond the standard model fits.

- If we were to observe neutralinos and charginos, we could **measure** M_1, M_2, μ, relatively quickly by mapping what decay channels we see and their branching ratios.

These parameters are also central for dark matter predictions, eg.

$$f\bar{f} \leftrightarrow \chi\chi \qquad \Omega_{\mathrm{DM}} \sim \langle \sigma_A v \rangle^{-1}$$

SUSY Production at LHC

SUSY weak production could also be the way we discover SUSY.

Since November 2011 we have a dedicated sub-group in the SUSY group.

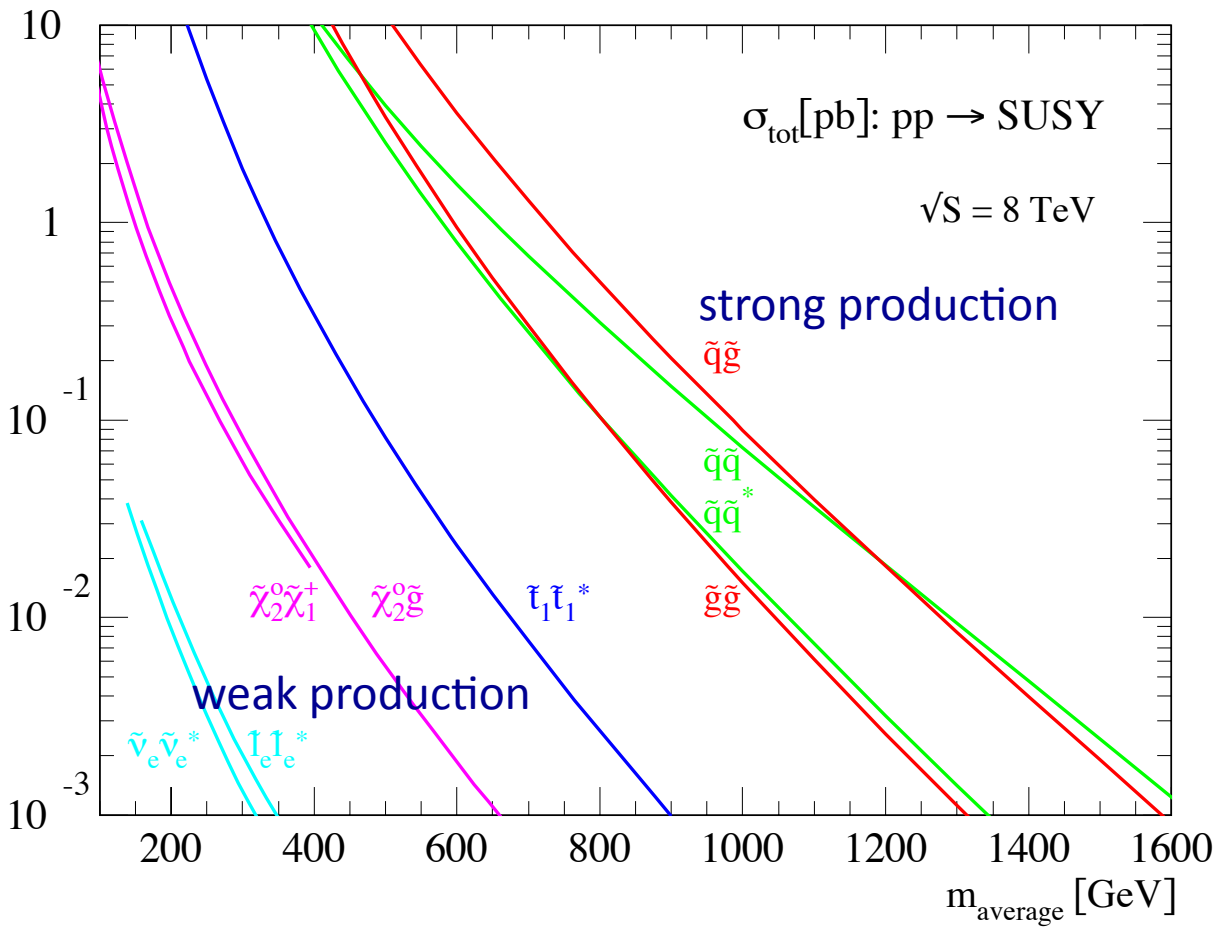
In this talk weak production with leptons.

Will present in particular an analysis with 2 lepton final states: **arXiv:1208.2884**

Precursor of this analysis was presented last year, now in **Phys. Lett. B709 (2012) 137-157**

Combined with a 3-lepton analysis in : **arXiv:1208.3144**

SUSY Production Cross Section [pb]



SUSY Particle Masses

Prospino 2
http://www.thphys.uni-heidelberg.de/~plehn/

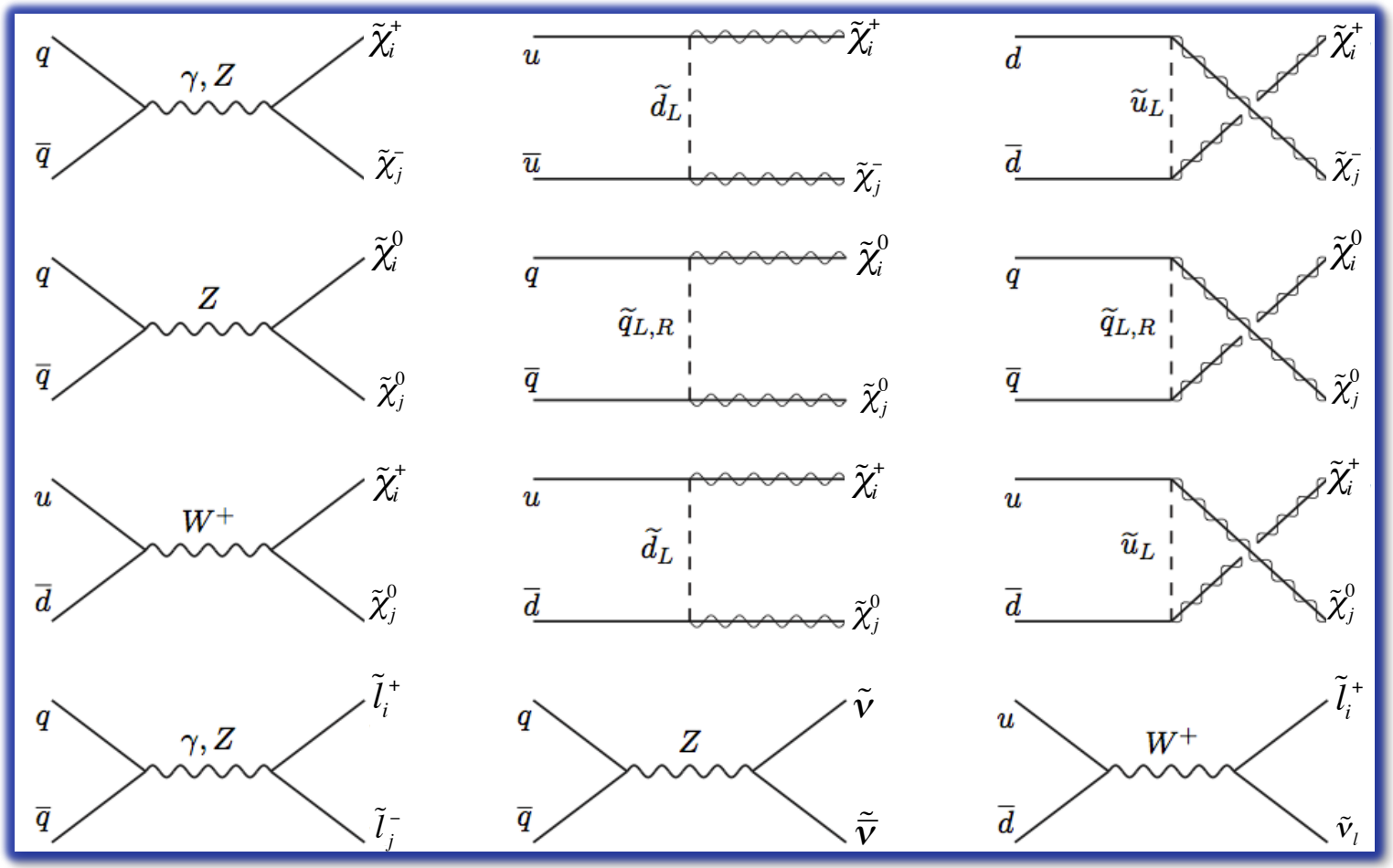
SUSY Weak Production at LHC

Chargino pair production

Neutralino pair production

Chargino-Neutralino production

Slepton pair production

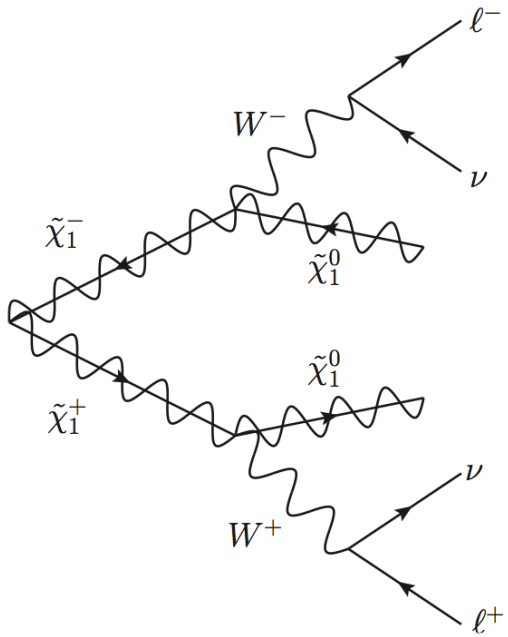


Design signal regions to address all these channels, <u>except sneutrino production</u>

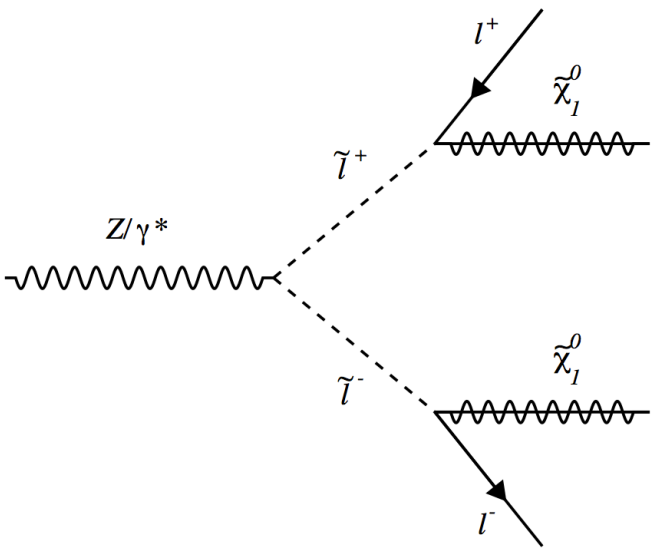
⇒ One further complication: several possible decay channels

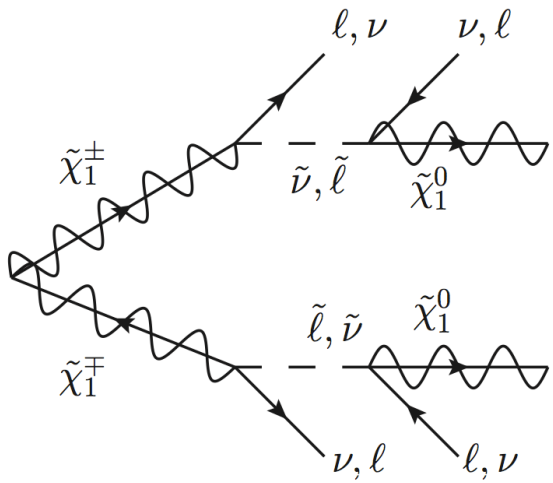
Signal Regions

- 2 OS leptons + NO Jets **SR-m_{T2}**
  - **jet veto**
  - $|m_{ll} - m_Z|>10$ GeV (Z-veto)
  - $E_T^{miss}(rel)>40$ GeV
  - $m_{T2}> 90$ GeV



$$\tilde{l}^+ + \tilde{l}^- \rightarrow \tilde{\chi}_1^0 l^+ + \tilde{\chi}_1^0 l^-$$

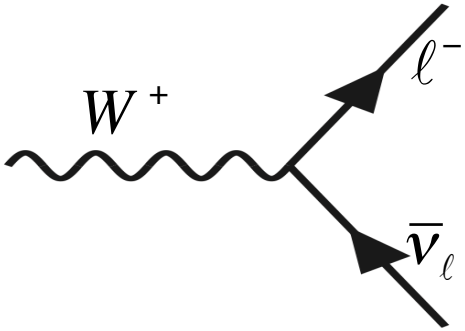




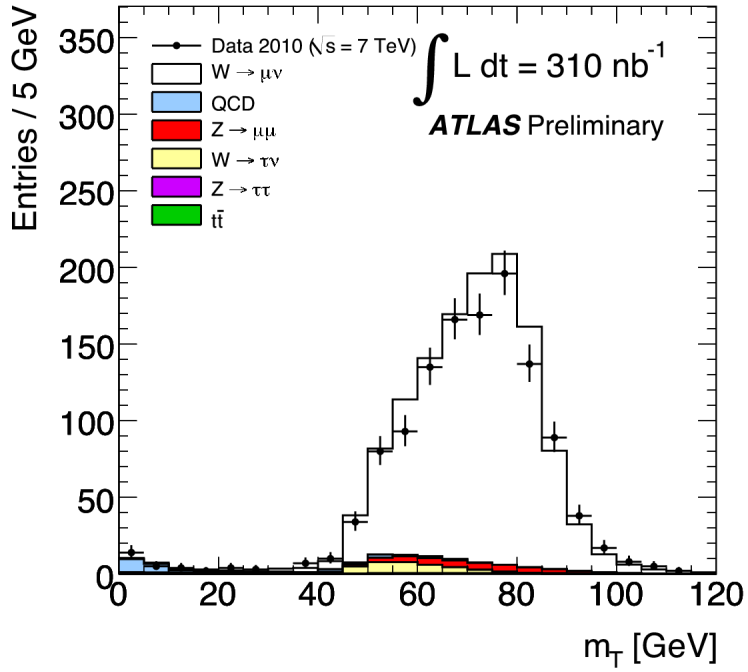
$$\tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow (l^+ \nu \tilde{\chi}_1^0) + (l^- \nu \tilde{\chi}_1^0)$$

m_T and M_{T2}

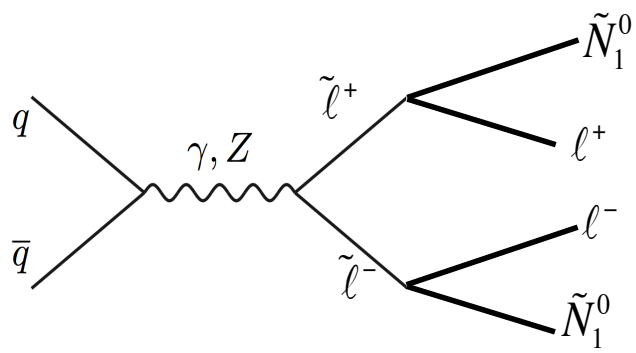
The transverse mass variable m_T was introduced in earlier lectures.



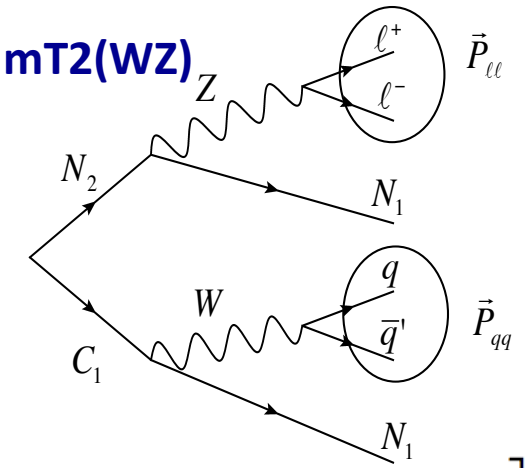
$$m_T = p_T^\ell p_T^\nu \quad (1-\cos\phi_{\ell\nu})$$
$$= p_T^\ell E_T^{miss}(1-\cos\phi_{\ell,E_T^{miss}})$$

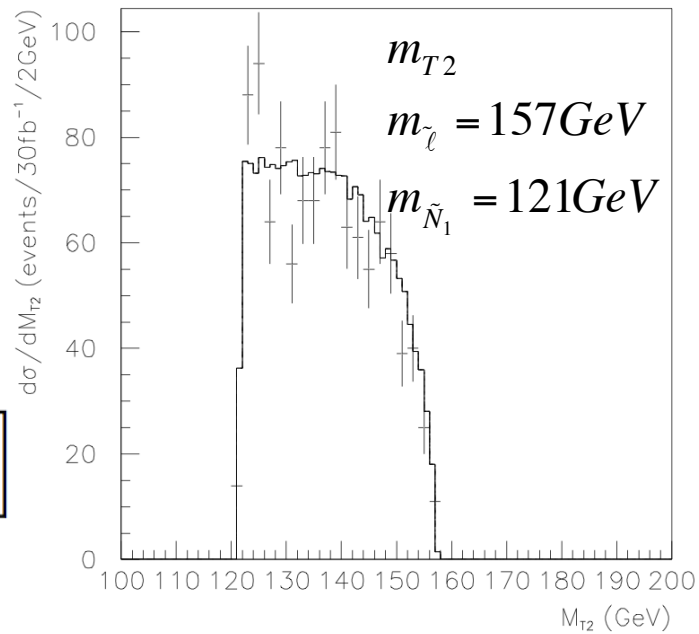


Now consider the slepton production and decay, there are now **two invisible particles**



mT2(WZ)



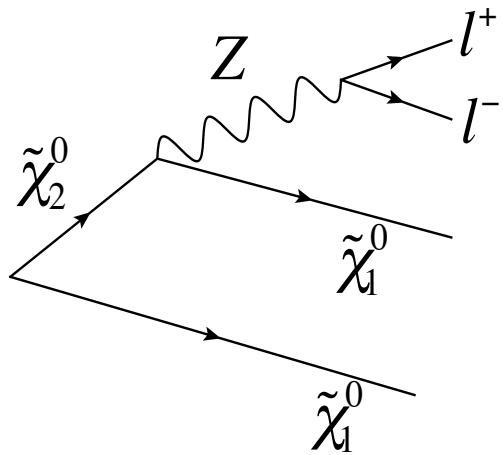


$$M_{T2}^2 \equiv \min_{\not{p}_1+\not{p}_2=\not{p}_T}\left[\max\left\{m_T^2(\mathbf{p}_{Tl^-},\not{p}_1), m_T^2(\mathbf{p}_{Tl^+},\not{p}_2)\right\}\right]$$

See C.G. Lester and D.J. Summers
http://arxiv.org/abs/hep-ph/9906349v1

Signal Regions (2)

- 2 OS leptons +Jets Veto **SR-OSjveto**
  - Jet-veto
  - $|m_{ll} - m_Z|>10$ GeV (Z-veto)
  - $E_T^{miss}(rel) > 100$ GeV



Same channels as before as well as $\tilde{\chi}_2^0\tilde{\chi}_1^0 \rightarrow l^{\pm}l^{\mp}\tilde{\chi}_1^0\tilde{\chi}_1^0$

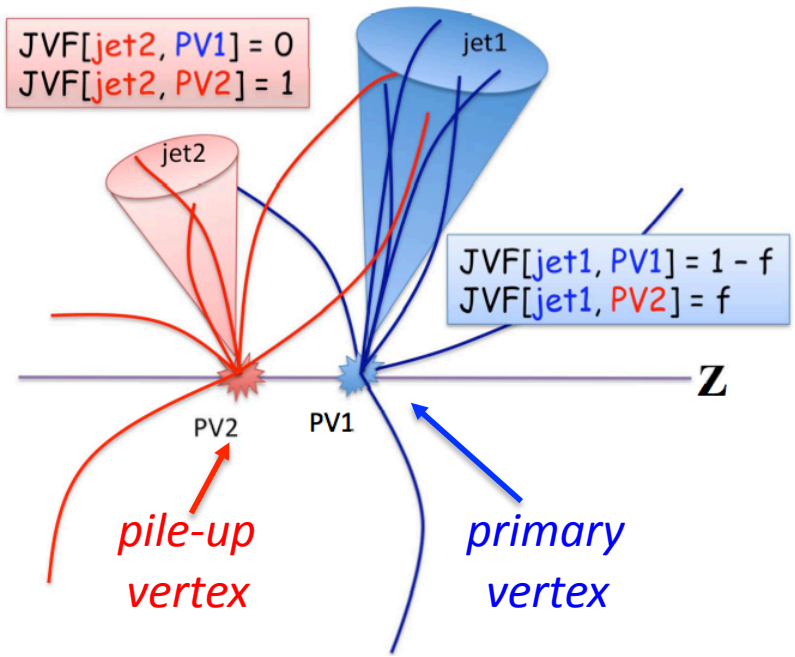
Both Regions use Special <u>Jet-Veto</u>

Pile-up leads to hadronic jets arising from "parasitic" proton-proton collisions.

We do not want to veto SUSY signal events containing "pile-up" jets.

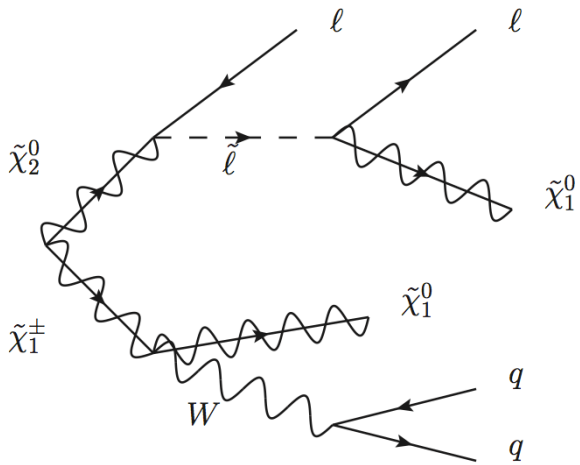
Veto jets with pT>30 GeV and high JVF.

$$JVF(\mathrm{jet}_i, \mathrm{vtx}_j) = \frac{\sum_k p_T(\mathrm{trk}_k^{\mathrm{jet}_i}, \mathrm{vtx}_j)}{\sum_n \sum_l p_T(\mathrm{trk}_l^{\mathrm{jet}_i}, \mathrm{vtx}_n)}$$



Signal Regions (3)

- 2 OS leptons + Jets **SR-2jets**
  - 2 or more jets
  - $|m_{ll} - m_Z|>10$ GeV (Z-veto)
  - Same flavour leptons
  - top tag veto
  - b-jet veto
  - $E_T^{miss}(rel) > 50$ GeV



2 jets

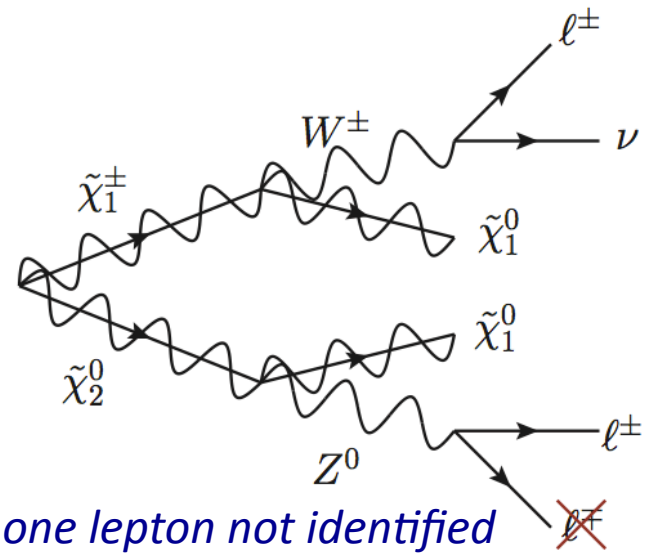
Also any process like: $\tilde{\chi}_2^0\tilde{\chi}_i^{0,\pm} \rightarrow (l^\pm l^\mp \tilde{\chi}_1^0) + (q\bar{q}\tilde{\chi}_1^0)$

- 2 same sign leptons +No Jets **SR-SSjveto**
  - Jet-Veto
  - $E_T^{miss}(rel) > 50$ GeV

  This region is designed to be complementary to a tri-lepton analysis:

  $$\tilde{\chi}_2^0\tilde{\chi}_1^\pm \rightarrow (l^+l^-\tilde{\chi}_1^0) + (l^\pm\nu\tilde{\chi}_1^0)$$

  not presented here.



one lepton not identified

Background Composition in Opposite Sign

Opposite sign dilepton pairs

SR-m_{T2}					
	e^+e^-	$e^\pm\mu^\mp$	$\mu^+\mu^-$	all	SF
Z+X	$3.2 \pm 1.1 \pm 1.7$	$0.3 \pm 0.1 \pm 0.2$	$3.6 \pm 1.3 \pm 1.7$	$7.1 \pm 1.7 \pm 2.1$	$6.8 \pm 1.7 \pm 2.1$
WW	$2.3 \pm 0.3 \pm 0.4$	$4.8 \pm 0.4 \pm 0.7$	$3.5 \pm 0.3 \pm 0.5$	$10.6 \pm 0.6 \pm 1.5$	$5.8 \pm 0.4 \pm 0.9$
$t\bar{t}$, single top	$2.6 \pm 1.2 \pm 1.3$	$6.2 \pm 1.6 \pm 2.9$	$4.1 \pm 1.3 \pm 1.6$	$12.9 \pm 2.4 \pm 4.6$	$6.8 \pm 1.8 \pm 2.3$
Fake leptons	$1.0 \pm 0.6 \pm 0.6$	$1.1 \pm 0.6 \pm 0.8$	$-0.02 \pm 0.01 \pm 0.05$	$2.2 \pm 0.9 \pm 1.4$	$1.0 \pm 0.6 \pm 0.6$
Total	$9.2 \pm 1.8 \pm 2.5$	$12.4 \pm 1.7 \pm 3.1$	$11.2 \pm 1.9 \pm 3.0$	$32.8 \pm 3.2 \pm 6.3$	$20.4 \pm 2.6 \pm 3.9$
Data	7	9	8	24	15
$\sigma_{\rm vis}^{\rm obs(exp)}$ (fb)	1.5 (1.8)	1.6 (2.0)	1.6 (1.9)	2.5 (3.3)	1.9 (2.5)

Z+X = Z+jets, $WZ^{(*)}$, $ZZ^{(*)}$, $Z\gamma^{(*)}$

Fake leptons

"fake muon" = muon for light in-flight hadron decay or semi-leptonic heavy flavour

"fake electron" = electron for light in-flight hadron decay or semi-leptonic heavy flavour or photon conversion.

Z+X, WW and top are comparable in size

Background Composition in Same Sign

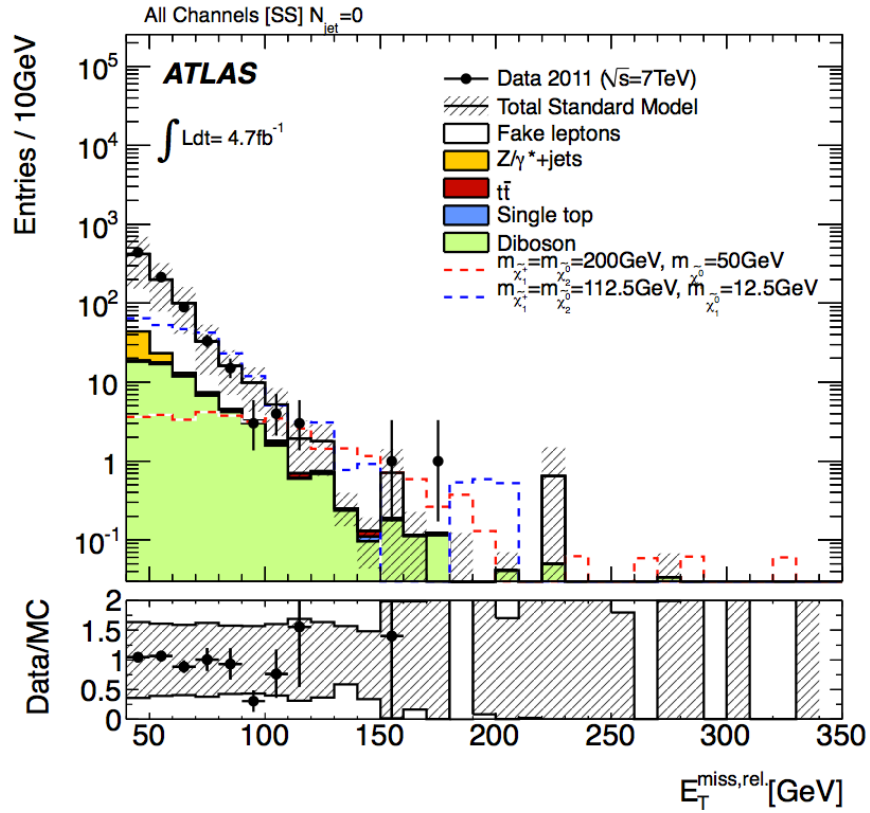
Same sign dilepton pairs

SR-SSjveto				
	$e^{\pm}e^{\pm}$	$e^{\pm}\mu^{\pm}$	$\mu^{\pm}\mu^{\pm}$	all
Charge flip	$0.49 \pm 0.03 \pm 0.17$	$0.34 \pm 0.02 \pm 0.11$	—	$0.83 \pm 0.04 \pm 0.18$
Dibosons	$0.62 \pm 0.13 \pm 0.18$	$1.93 \pm 0.23 \pm 0.36$	$0.94 \pm 0.16 \pm 0.26$	$3.50 \pm 0.31 \pm 0.54$
Fake leptons	$3.2 \pm 0.9 \pm 1.7$	$2.9 \pm 0.9 \pm 1.9$	$0.6 \pm 0.6 \pm 0.3$	$6.6 \pm 1.4 \pm 3.8$
Total	$4.3 \pm 0.9 \pm 1.7$	$5.1 \pm 1.0 \pm 1.9$	$1.5 \pm 0.6 \pm 0.4$	$11.0 \pm 1.5 \pm 3.9$
Data	1	5	3	9
$\sigma_{\rm vis}^{\rm obs(exp)}$ (fb)	0.7 (1.1)	1.6 (1.6)	1.3 (0.9)	1.9 (2.1)

Dominant backgrounds

- Fake leptons
- Diboson mostly
- Charge flip

  Z –> ee where one of the electrons emits an early brem photon (data driven)



Backgrounds

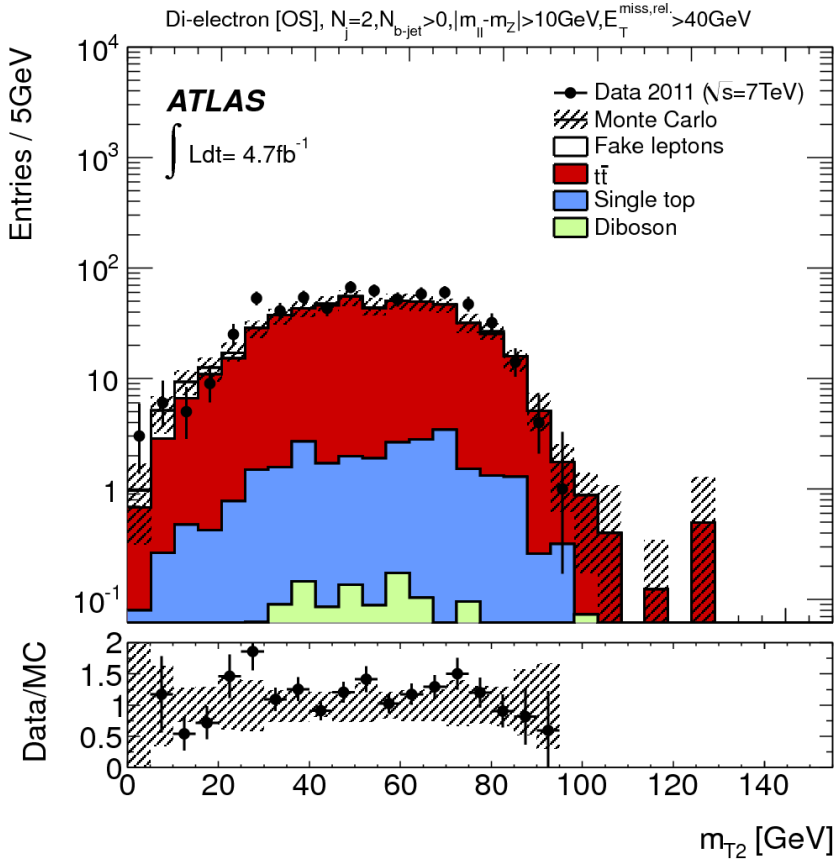
Signal Regions	WW	Top (pair + Wt)	Z+jets, $WZ^{(*)}$, $ZZ^{(*)}$, $Z\gamma^{(*)}$	fakes
SR-m_{T2}	Simulation	Data TOP control region	Data Z+X control region	Data fake lepton control region
SR-jveto	Data WW control region	Data TOP control region	Data Z+X control region	Data fake lepton control region
SR-2jets	Simulation	Data TOP control region	Data Z+X control region	Data fake lepton control region
SR-SSjveto	Simulation Charge flip from data	Simulation Charge flip from data	Simulation Charge flip from data	Data fake lepton control region

Derive the backgrounds as much as possible from data control regions

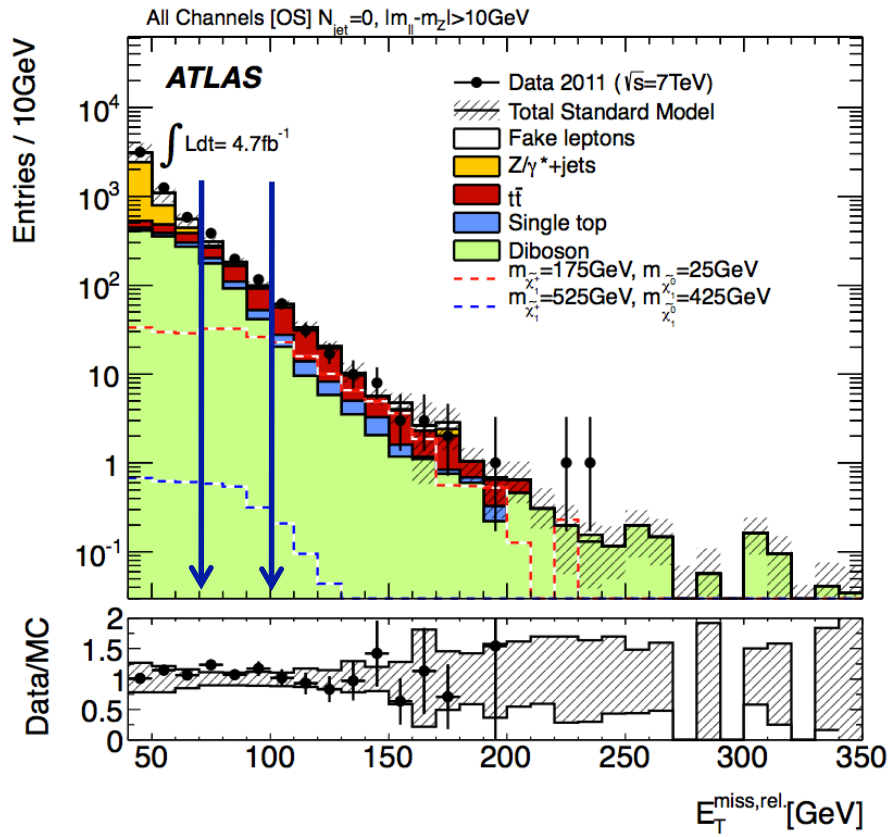
control region definitions

	top	WW	$Z+X$
$m_{\ell\ell}$	Z-veto	Z-veto	Z-window
signal jets	≥ 2	$=0$	$=0, \geq 2, \geq 0$
signal b-jets	≥ 1	$=0$	$\geq 0, =0, \geq 0$
$E_{\mathrm{T}}^{\mathrm{miss,rel.}}$	$> 100, 50, 40$	70–100	$> 100, 50, 40$
other	-	-	-, m_{CT}-veto, -

(Some) Background Control Regions



m_{T2} in top control region



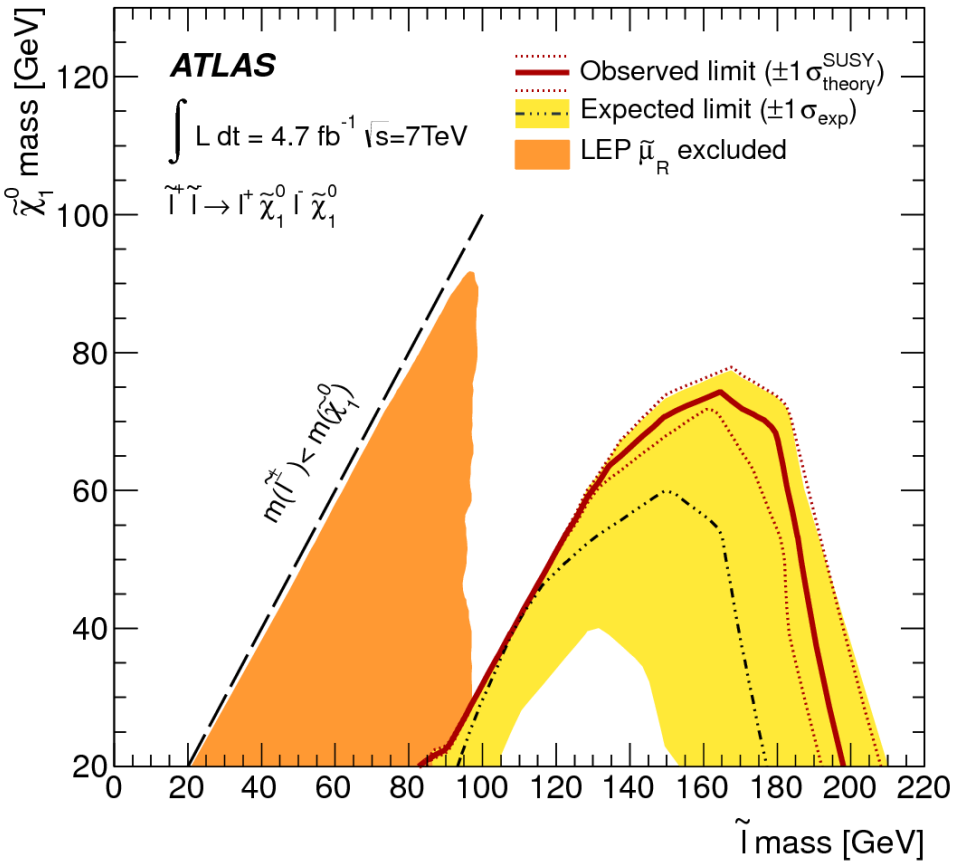
E_T^{miss}(rel) after Z-veto , jet-veto the 70 – 100 GeV range with additional b-veto is the WW control region.

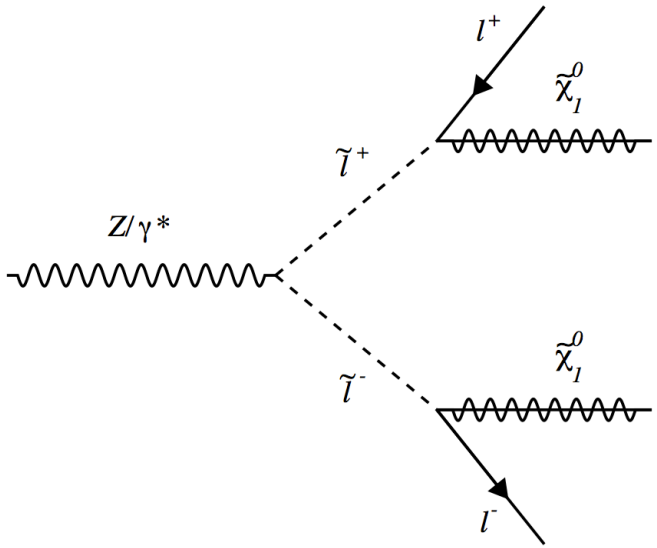
Systematics

SR-	m_{T2}	OSjveto	SSjveto	2jets
Total statistical	9	4	13	6
Total systematic	19	19	35	49
Jet uncertainties	9	8	3	5
Lepton uncertainties	14	1	1	5
b-tagging efficiency	1	1	0	14
MC modelling	7	17	4	45
Fake leptons	5	5	35	4

Table 4: Systematic uncertainties (%) on the total background estimated in each SR for all flavours combined. The total statistical uncertainty includes limited MC event numbers in the CR and SR. Jet systematic uncertainties include: JES, JER and E_T^{miss} cluster and pile-up uncertainties. Lepton systematic uncertainties include: all lepton scales and resolutions, reconstruction and trigger efficiencies. MC modelling uncertainties include choice of generator, ISR/FSR and modelling of the Z/γ^*+jets line-shape.

Slepton Results L=5fb^{-1}

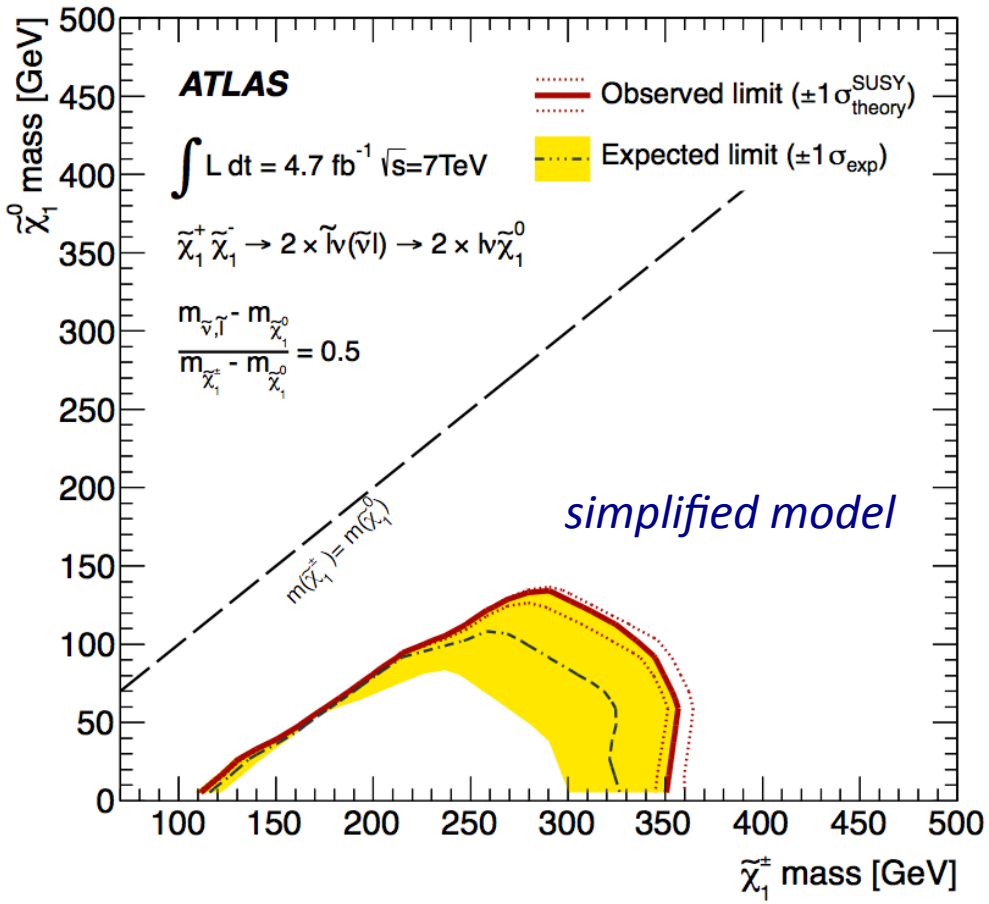


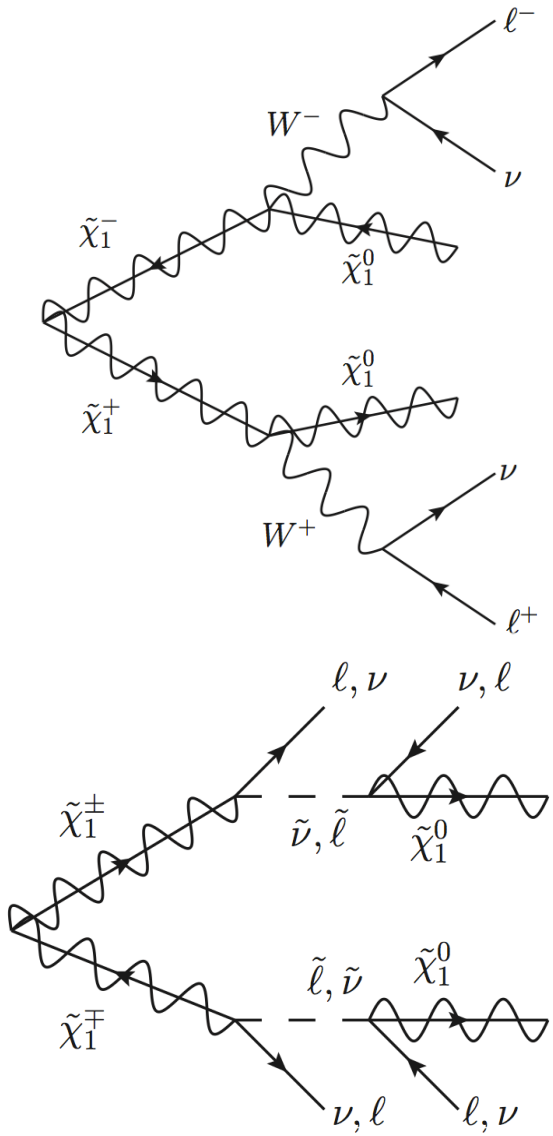


First limits on direct slepton production since LEP

pMSSM framework Left-handed sleptons

Chargino Pair Production Results L=5fb^{-1}

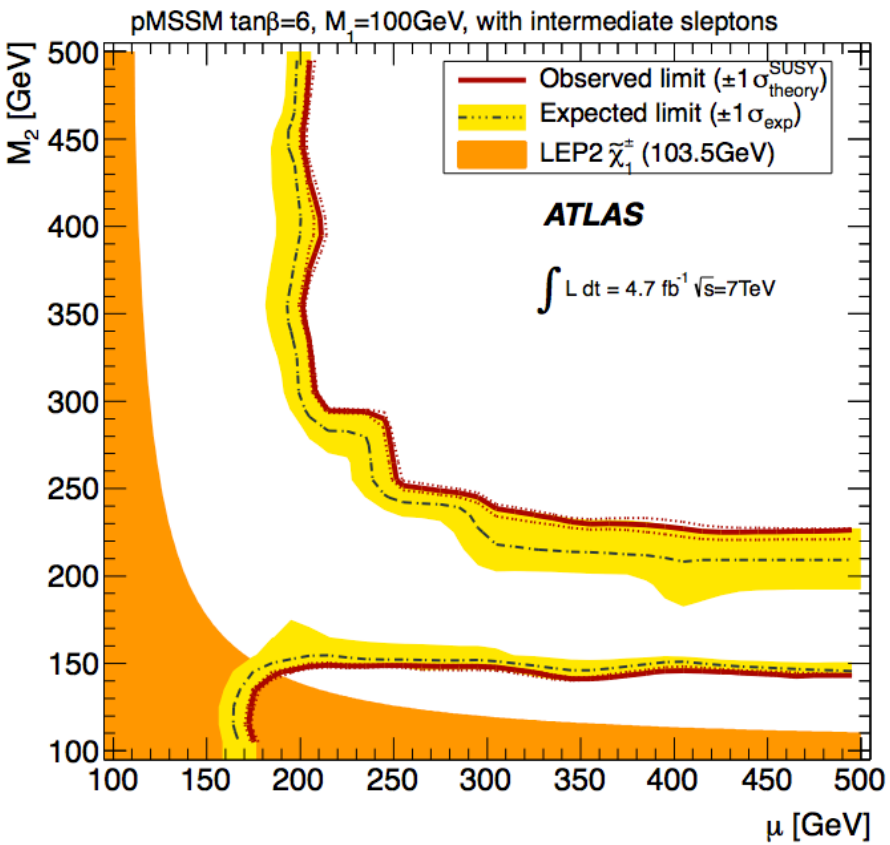




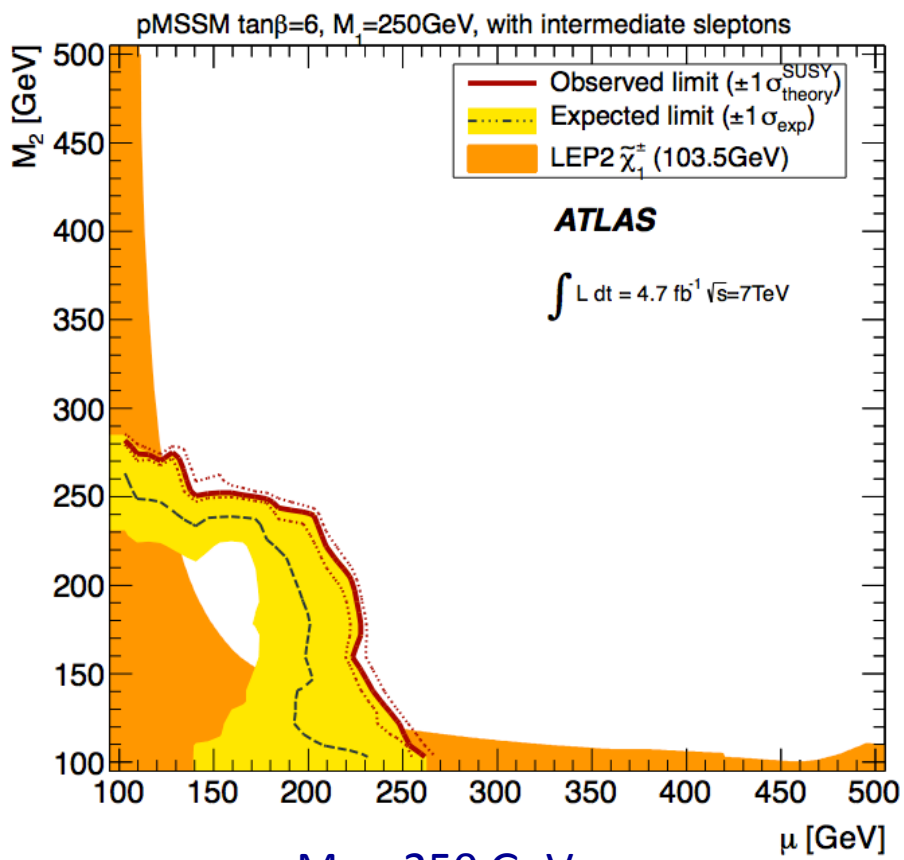
First LHC limits on dirct chargino pair production.
Does not rely on mass assumptions between C1 and N2

$$\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow (l^+\nu\tilde{\chi}_1^0) + (l^-\nu\tilde{\chi}_1^0)$$

Interpretation in pMSSM M_1, M_2, μ space



M_1 = 100 GeV

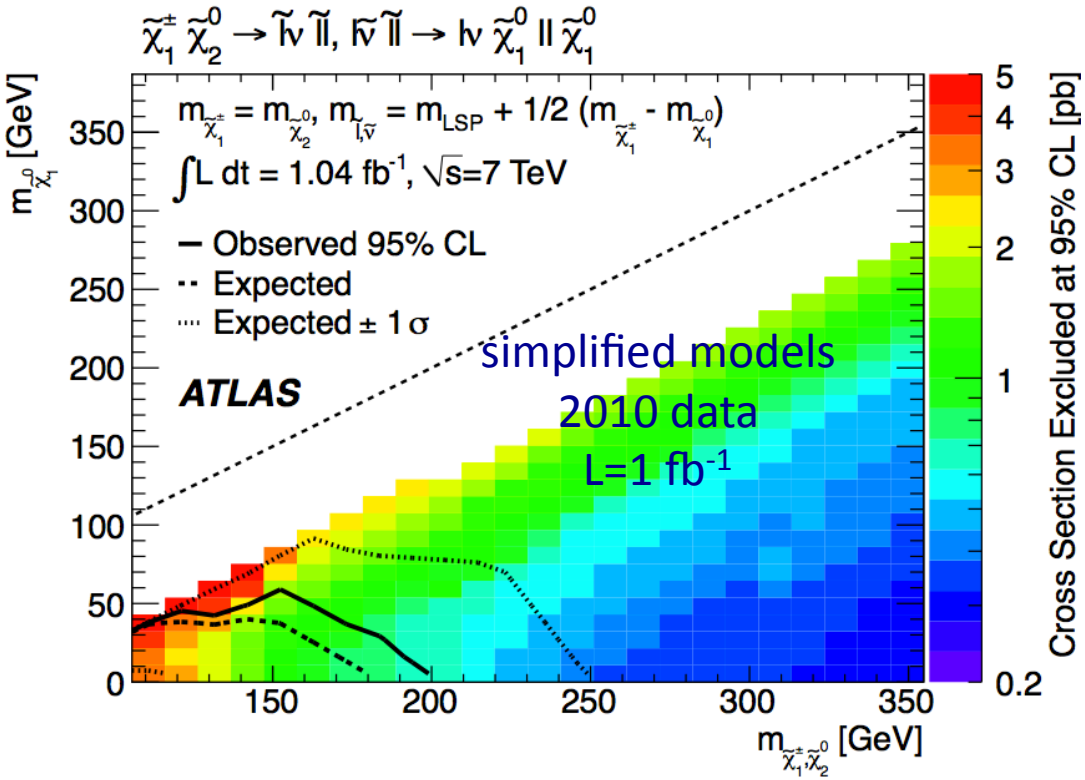


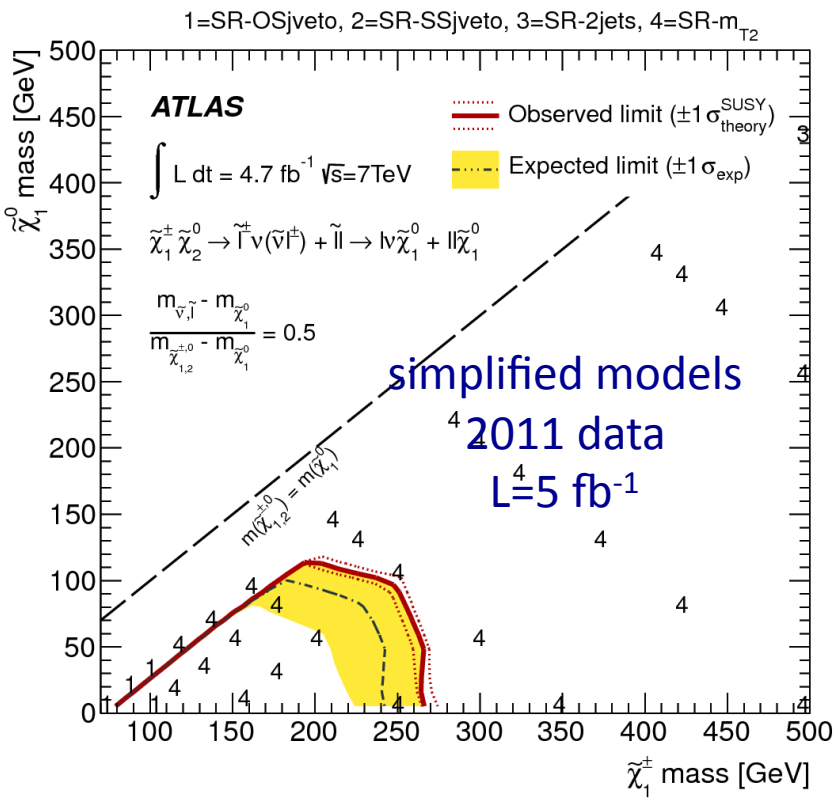
M_2 = 250 GeV

Limits combined with the 3-lepton search see:
arXiv:1208.3144

Assuming here that the gaugino decays proceed via intermediate sleptons

Comparison with previous gaugino search





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Preliminary version showed last year

ATLAS conference note:
ATLAS-CONF-2012-076

Significant improvement from 1 to 5fb-1 analysis
Further reaching limits, many new signal regions (only one in the L=1 fb^{-1} analysis)

Conclusions

- Search for weak production of SUSY particles is crucial to
  Discover or kill SUSY …

- We have search for weakly produced SUSY particles (gauginos and sleptons)
  - Negative search
  - New limits that can be used by theorists

- Analysis of ~20 fb^{-1} of 2012 data is well underway, results to be expected by
  Moriond conference 2013

- Other models can and should be searched for with the presented final states
  - Complete set of gaugino decays (Higgs, tau leptons,…)
  - Compressed SUSY spectra
  - Universal extra dimension models

- This is what we will do during the LHC shutdown