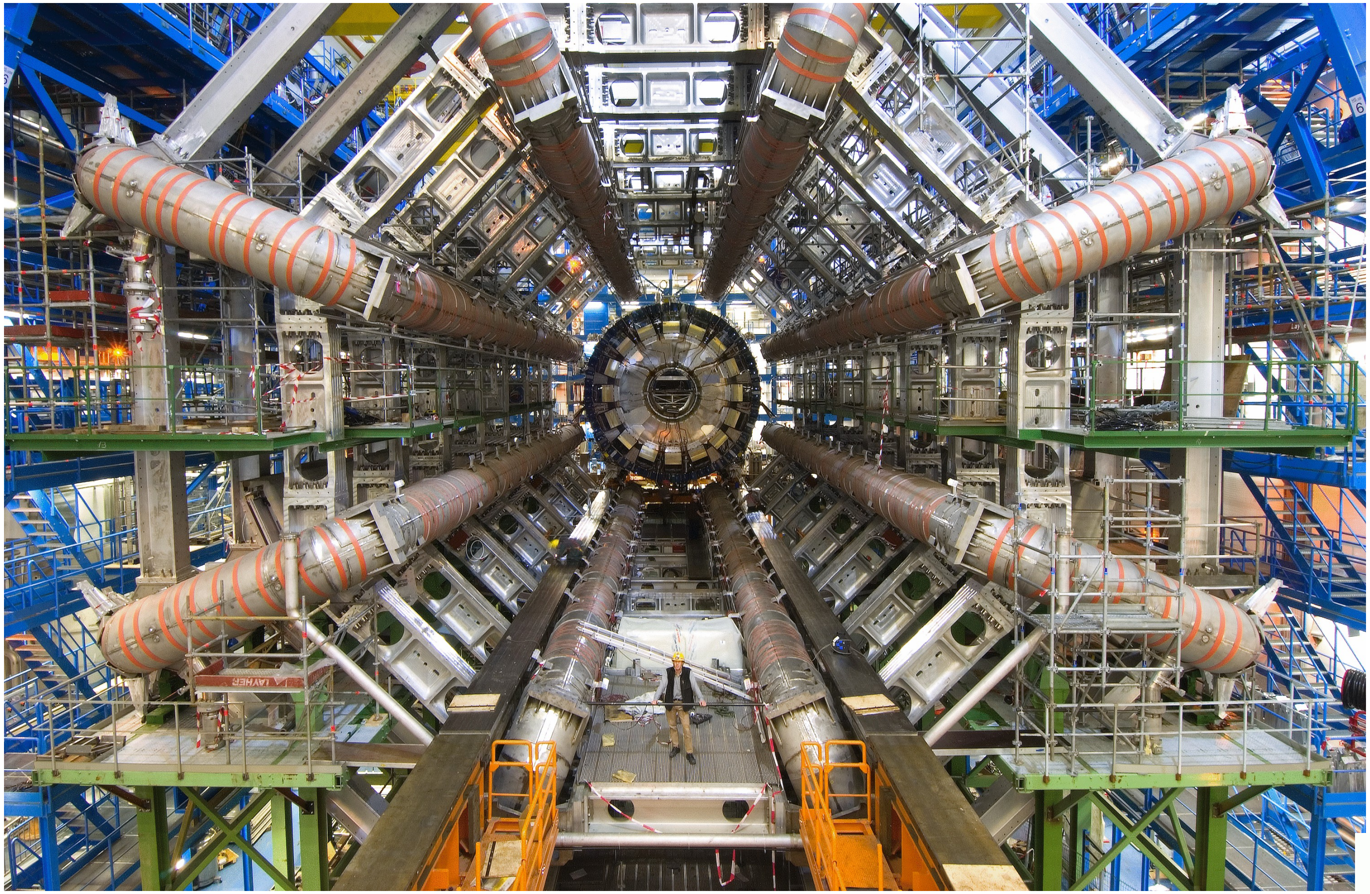
Trilepton signatures from SUSY at ATLAS



Tina Potter on behalf of the ATLAS Collaboration
28/10/08
ICPP, Istanbul

Royal Holloway
University of London

Supersymmetry Primer

- Provides answer to quadratic divergences in the loop corrections to the Higgs mass
- R-parity conservation brings proton lifetime into agreement with experimental data
- Introduces heavy new particles
- Lightest Supersymmetric Particle (LSP) is stable – *good dark matter candidate!*

SM Particle		Spin	R	Superpartner	Spin	R
fermion	l	½	+1	$\tilde{l}$	0	-1
	q	½	+1	$\tilde{q}$	0	-1
boson	$W^{\pm}, W^0$	1	+1	$\tilde{W}^{\pm}, \tilde{W}^0$	½	-1
	B	1	+1	$\tilde{B}$	½	-1
	g	1	+1	$\tilde{g}$	½	-1
	H	0	+1	$\tilde{H}^0_u, \tilde{H}^0_d$	½	-1

R-Parity

$$R=(-1)^{2(B-L)+2S}$$

S = spin
B = baryon number
L = lepton number

$$\tilde{H}_u=(\tilde{H}^+_u, \tilde{H}^0_u)$$
$$\tilde{H}_d=(\tilde{H}^0_d, \tilde{H}^-_u)$$

Standard Model

Gauge eigenstates $W^{\pm}, W^0, B$ mix to give 4 mass eigenstates W^+, W^-, Z, γ

Supersymmetry

Neutral higgsinos and gauginos $\tilde{H}^0_u, \tilde{H}^0_d, \tilde{W}^0, \tilde{B}^0$ mix to give 4 mass eigenstates called neutralinos $\tilde{\chi}^0_1, \tilde{\chi}^0_2, \tilde{\chi}^0_3, \tilde{\chi}^0_4$ (*usually the LSP*: $\tilde{\chi}^0_1$)

Charged higgsinos and gauginos $\tilde{H}^+_u, \tilde{H}^-_d, \tilde{W}^+, \tilde{W}^-$ mix to give 2 mass eigenstates called charginos $\tilde{\chi}^{\pm}_1, \tilde{\chi}^{\pm}_2$

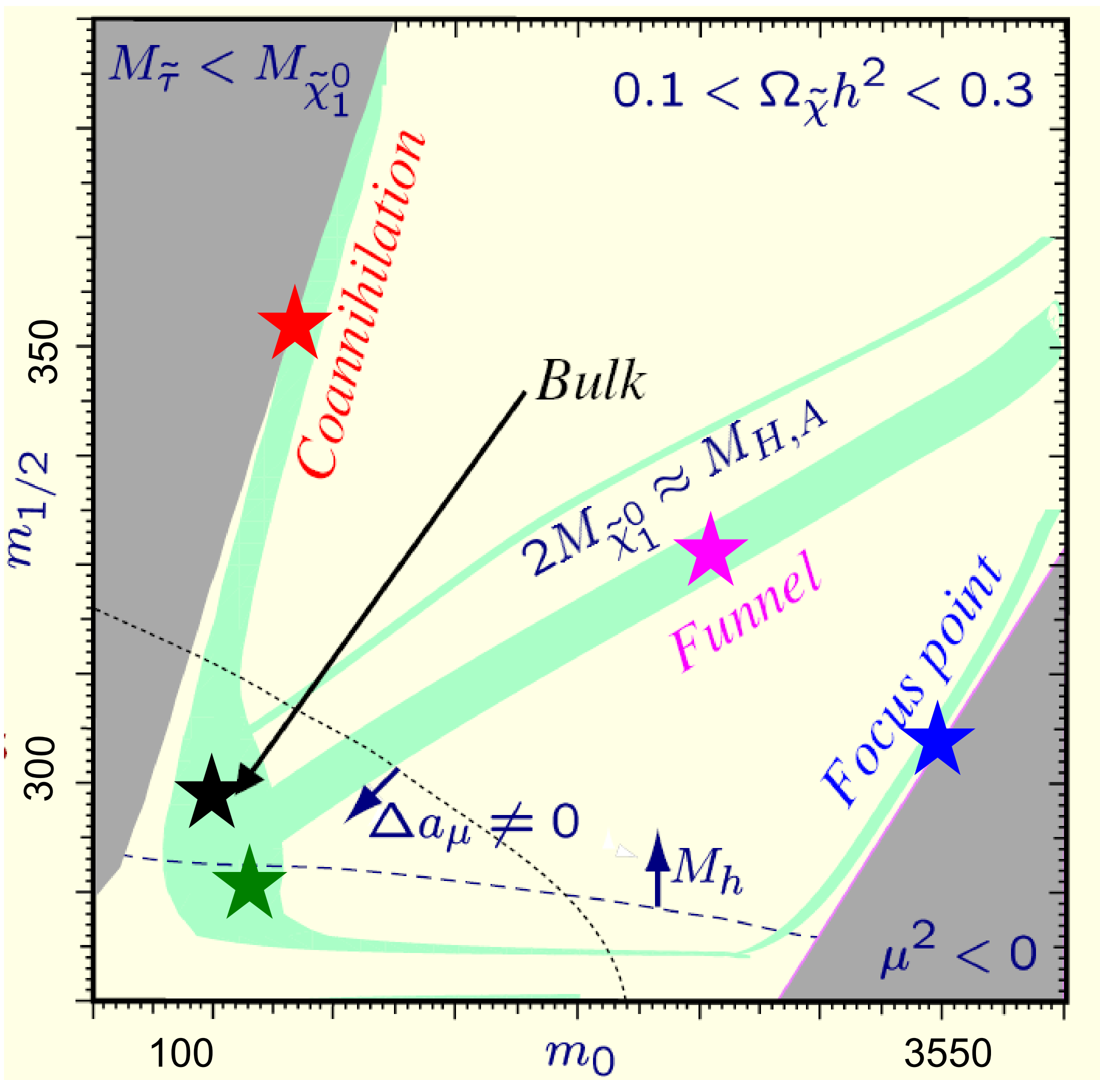
ATLAS at the LHC is dedicated to finding new physics at the TeV scale, such as SUSY

mSUGRA parameter space and benchmark points

minimal SuperGRAvity
SUSY breaking is mediated from the hidden sector to the visible sector by *gravitational* interactions

mSUGRA sparticle mass spectrum depends on 4 parameters and one sign:

m_0 *scalar mass*
$m_{1/2}$ *gaugino mass*
A_0 *trilinear coupling*
tan β *ratio of Higgs VEV*
sign μ *sign of SUSY Higgs mass term*



SU3 – Bulk Region
LSP is mostly Higgsino
Low masses, long decay chains through squarks and sleptons

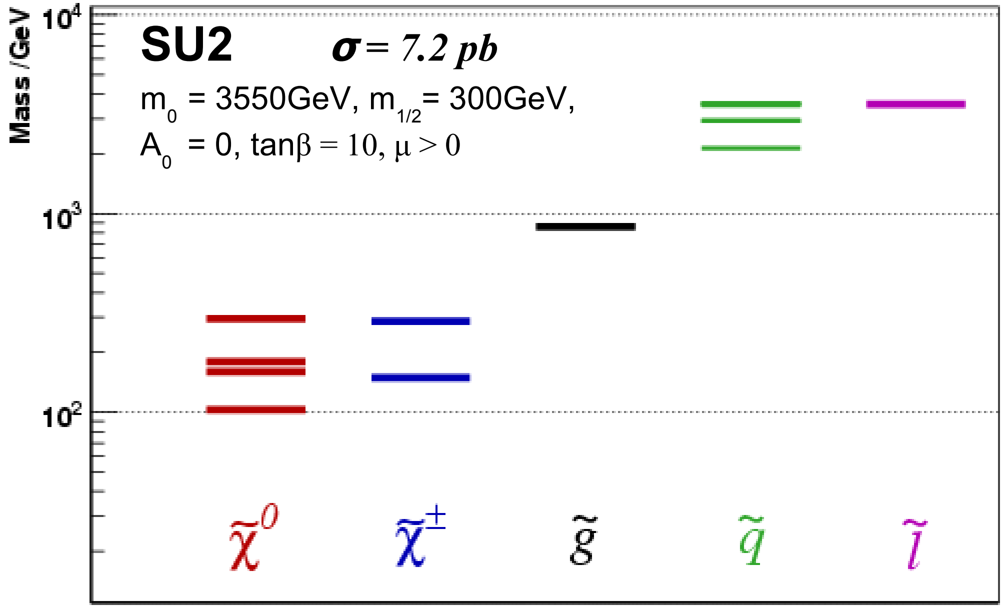
SU4 – Low Mass Region
Similar to bulk region
Close to Tevatron discovery limit

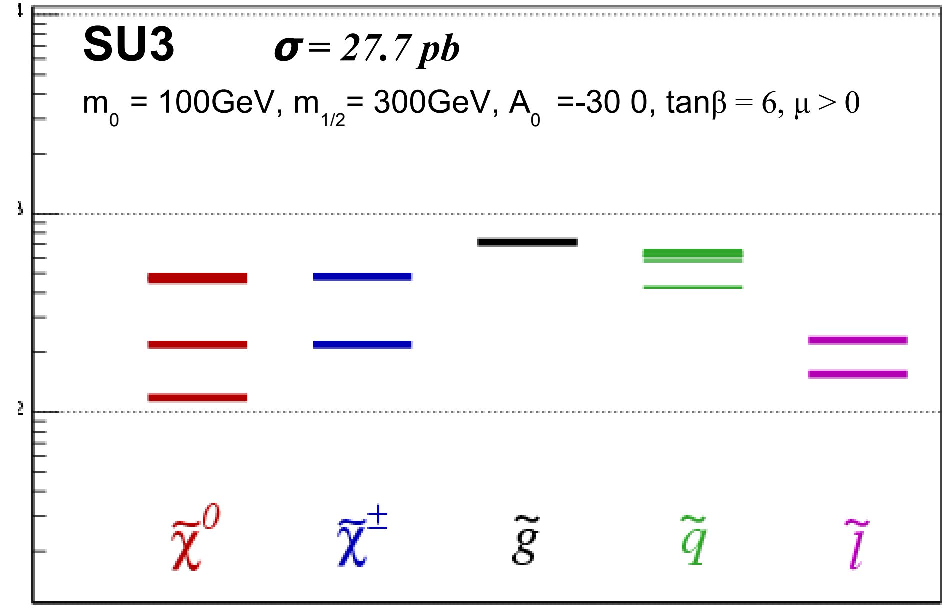
SU2 – Focus point
LSP is mostly Higgsino
Very heavy squarks and sleptons, relatively light gauginos

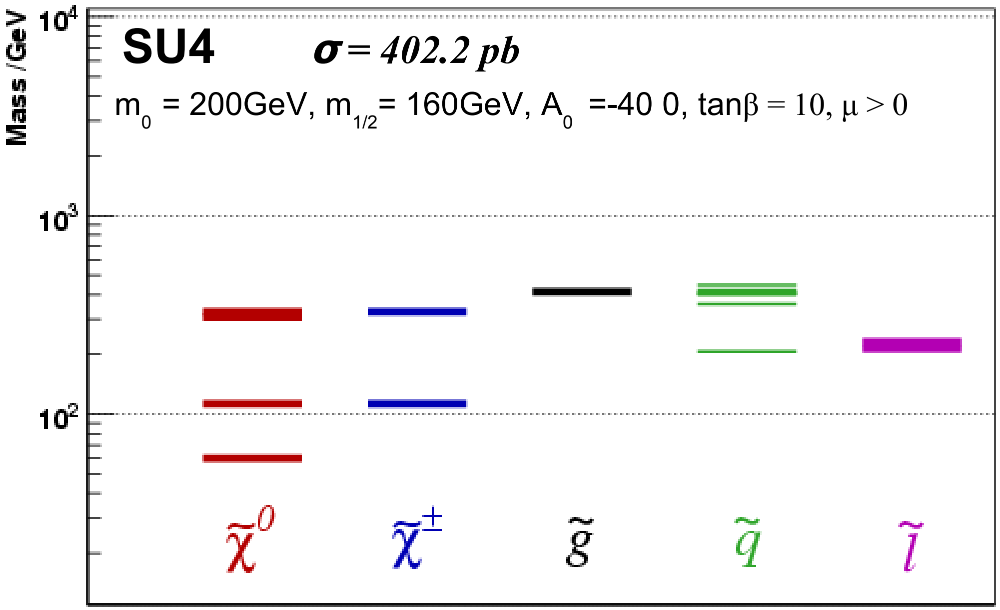
SU1 – Coannihiation Region
LSP is pure Bino.
Slepton masses close to LSP mass – soft final state leptons

SU6 – Funnel Region
Large tanβ,
Heavy Higgs resonance

n.b. SU2, SU3, SU4 just labels e.g. SU3 = SUSY benchmark 3







Leptonic final states are clean channels to search for in the messy hadronic environment of the LHC.

Some leptonic modes...

$$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W^{\pm(*)} \to \tilde{\chi}_1^0 l^\pm \nu_l \qquad \tilde{\chi}_1^\pm \to \tilde{\tau}_1^\pm \nu_\tau \to \tilde{\chi}_1^0 \tau^\pm \nu_\tau$$

$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^* \to \tilde{\chi}_1^0 l^+ l^- \qquad \tilde{\chi}_2^0 \to \tilde{\tau}_1^\pm \tau^\mp \to \tilde{\chi}_1^0 \tau^+ \tau^-$$

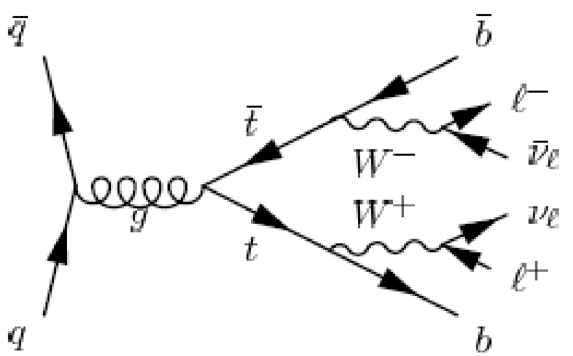
$$\tilde{\chi}_2^0 \to \tilde{l}_R^\pm l^\mp \to \tilde{\chi}_1^0 l^+ l^-$$

	SU2	SU3	SU4
σ_{TOT} [pb] $\sigma_{3\ lep}$ [pb]	7.18 0.07	27.68 0.30	402.19 2.49
# 3 lep events for 1 fb^{-1}	~70	~300	~2500

σ quoted are for √s = 14 TeV

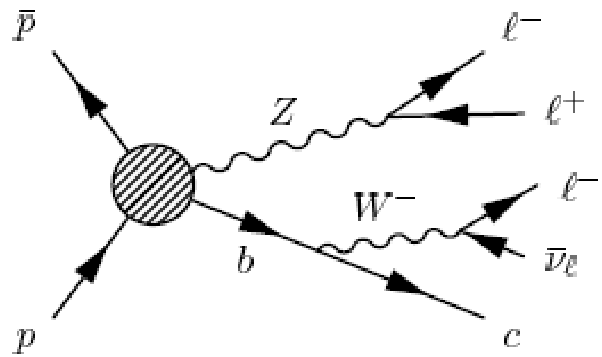
Standard Model Backgrounds

σ = 450 pb



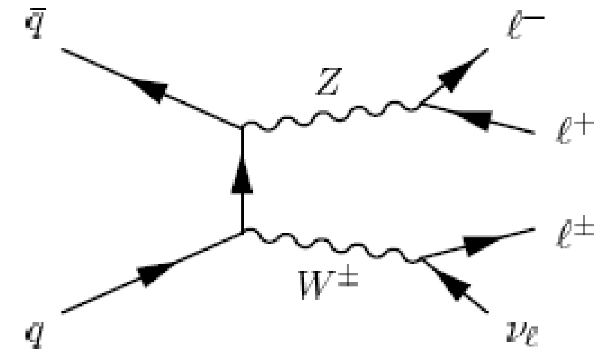
$t\bar{t}$

σ = 164 pb



Zb

σ = 16 pb

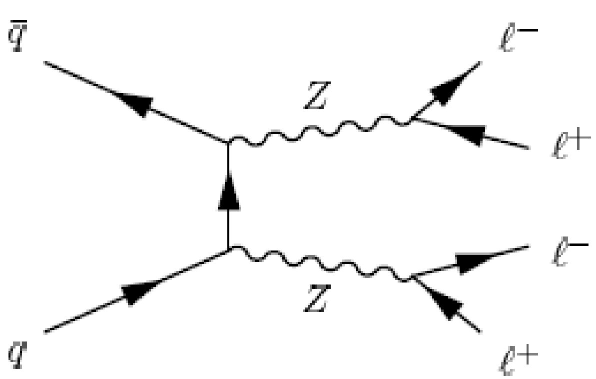


ZW

3rd lepton is from b decay or lepton-jet misidentification

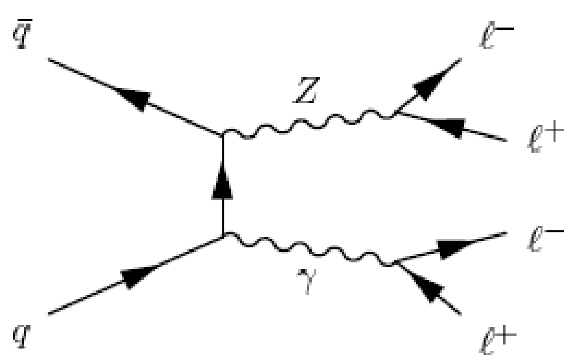
3 good leptons
+ E_T^{miss} from neutrino

σ = 4 pb



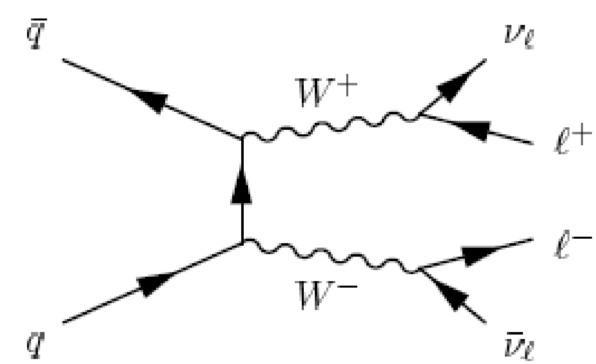
ZZ

σ = 3 pb



$Z\gamma$

σ = 41 pb



WW

4 good leptons but no E_T^{miss}

jets may fake leptons

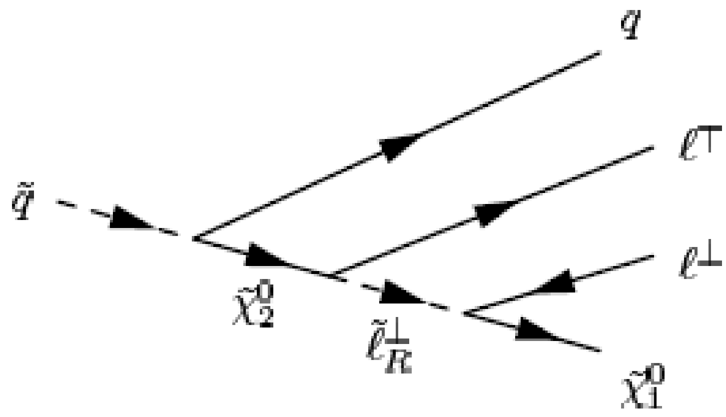
σ quoted are for √s = 14 TeV

Normalised to1 fb^{-1}

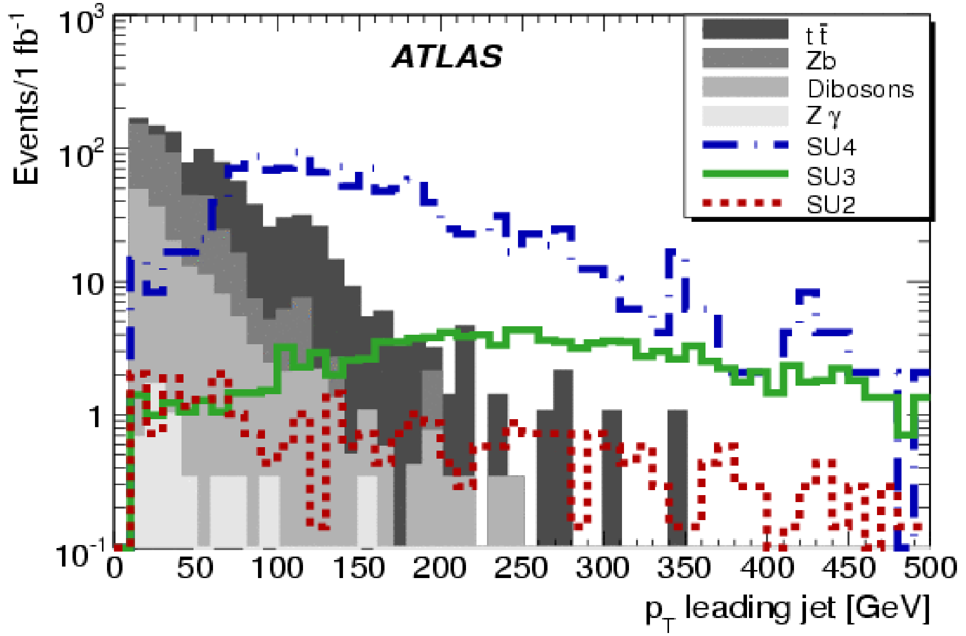
Simple and powerful analysis

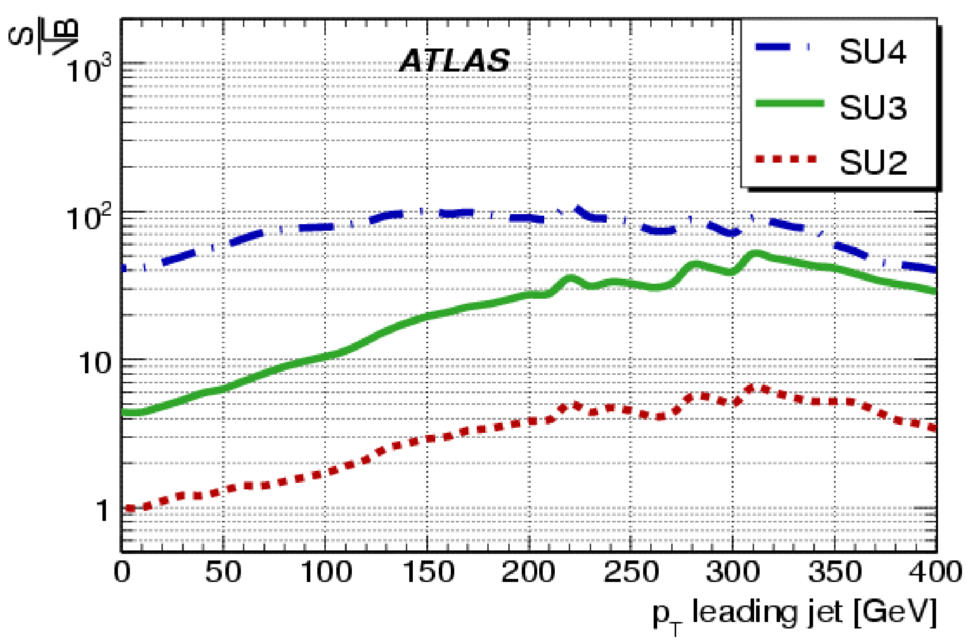
1. $N_{leps} \geq 3$
2. $N_{jets} \geq 1$ & $p_T^{jet1} > 200$ GeV

Cut values optimised using S/√B



After 3lep cut



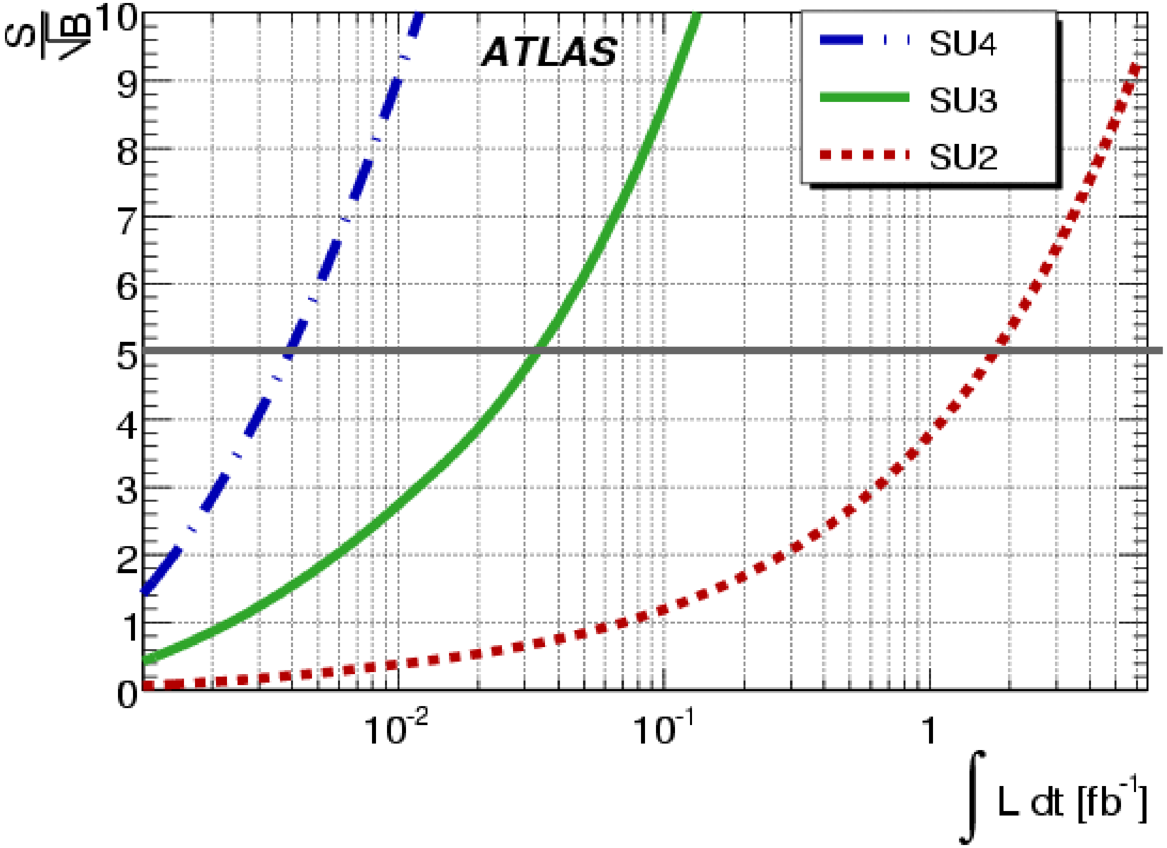


Requiring $p_T^{jet\,1} > 200$ GeV is a compromise between increasing the signal significance to its maximum value and still applying a common cut to each SUSY scenario.

Normalised to1 fb^{-1}

No. events	None	N_ℓ	p_T^{jet1}
SU2	7112	35	13
SU3	27304	139	94
SU4	396445	1284	312
$t\bar{t}$	440658	444	11
Zb	159116	662	0
ZW	15672	193	1
ZZ	3820	59	0
WW	40052	3	0
$Z\gamma$	3283	9	0
SU2	$\frac{S}{\sqrt{B}}$	0.9	3.8
SU3		3.8	27.3
SU4		34.7	90.3
SU2	$\frac{S}{B}$	0.0	1.1
SU3		0.1	7.9
SU4		0.9	26.2

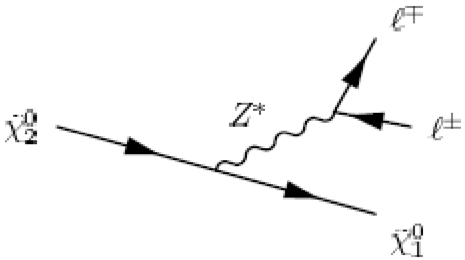
Early SUSY discovery channel??

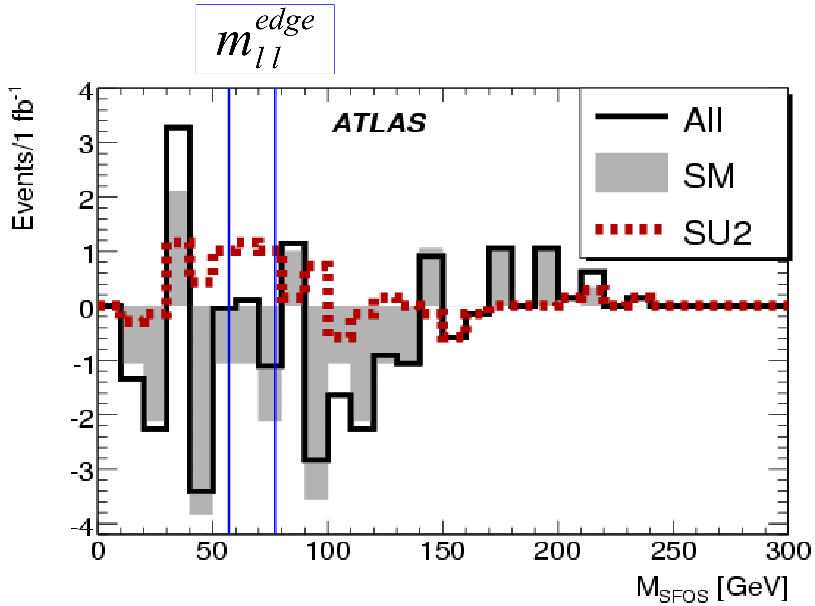


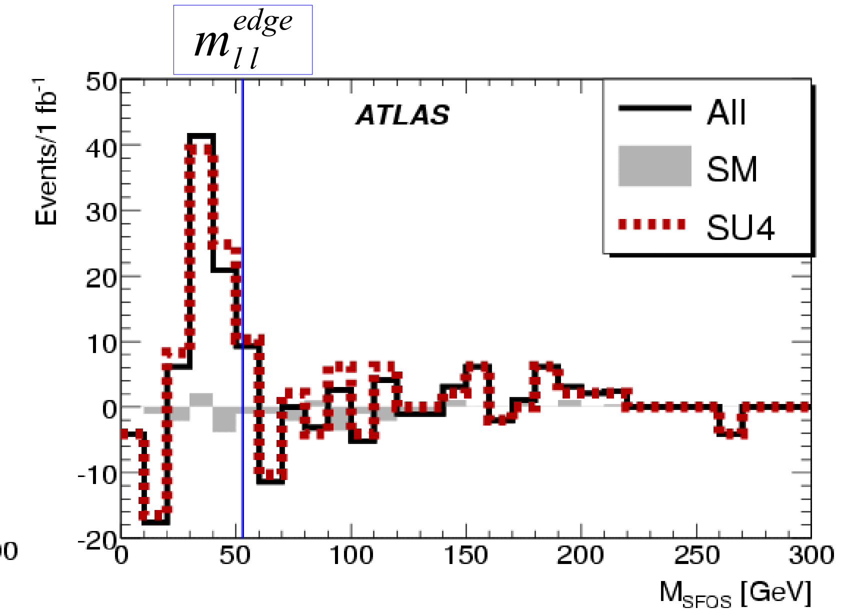
n.b. not using E_T^{miss},
so search is good for very early data when E_T^{miss} systematics may not be fully understood.

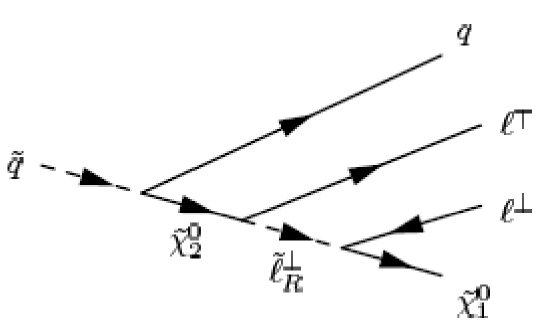
SFOS – OFOS is plotted to remove combinatorics i.e. $(e^+e^- + \mu^+\mu^-) - (e^+\mu^- + e^-\mu^+)$

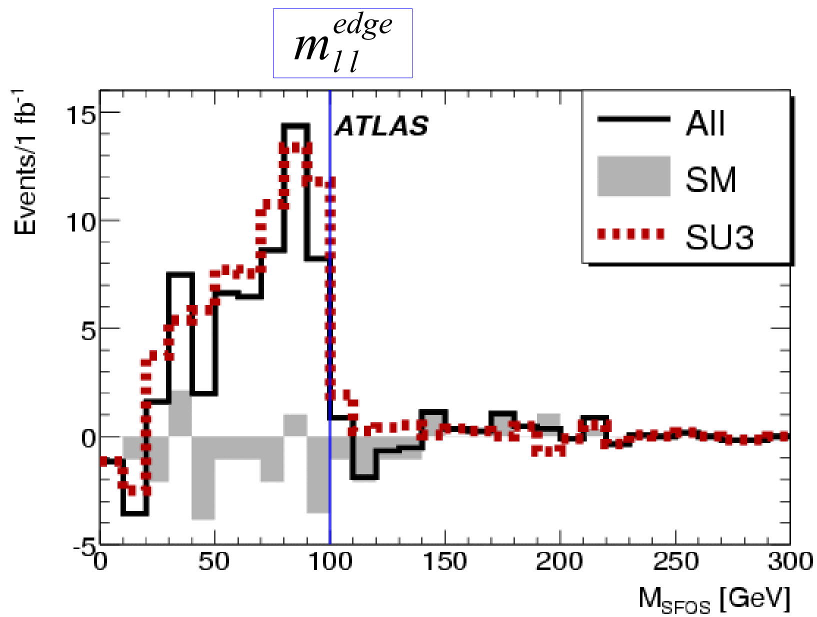
Normalised to1 fb^{-1}





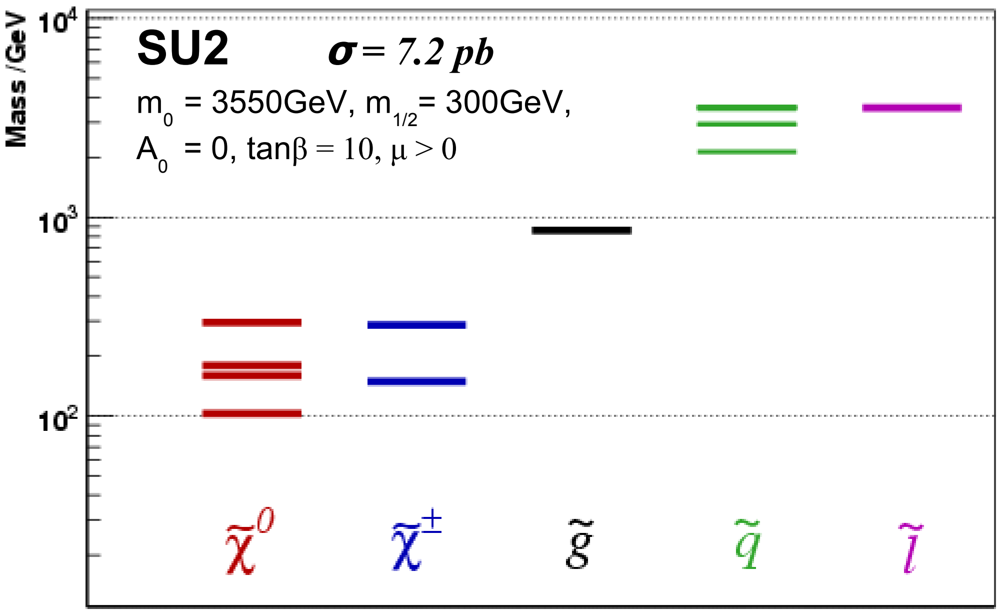






Entire SUSY mass spectrum could be revealed with further lepton-jet invariant mass distributions

Normalised to10 fb^{-1}

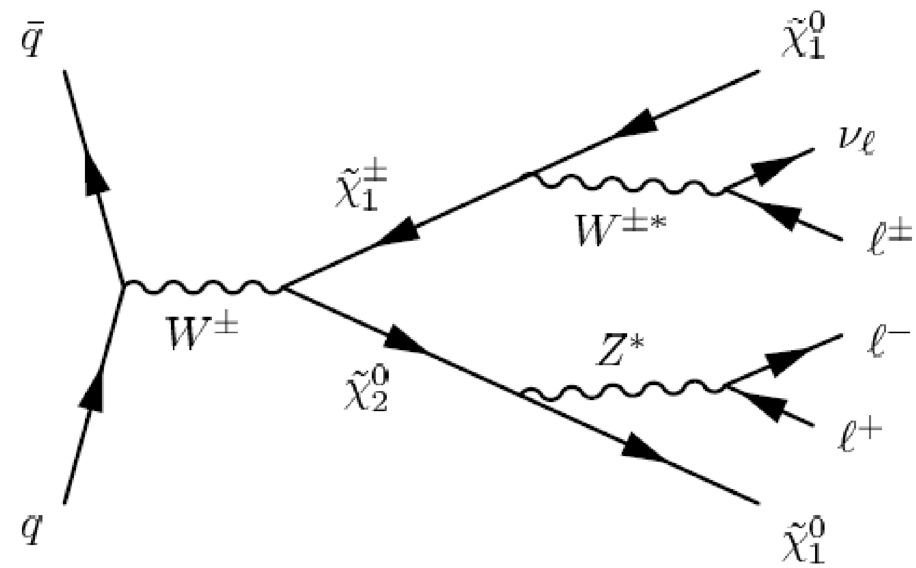


Process	σ_{NLO} [fb]	No. 3-lep evts [/10 fb^{-1}]
$\tilde{\chi}_2^0\tilde{\chi}_3^0$	191.0	5
$\tilde{\chi}_3^0\tilde{\chi}_4^0$	26.4	5
$\tilde{\chi}_2^{\pm}\tilde{\chi}_2^{\pm}$	200.4	40
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{\pm}$	46.9	5
$\tilde{\chi}_2^0\tilde{\chi}_1^{\pm}$	1278.7	197
$\tilde{\chi}_3^0\tilde{\chi}_1^{\pm}$	770.7	119
$\tilde{\chi}_4^0\tilde{\chi}_1^{\pm}$	43.0	6
$\tilde{\chi}_2^0\tilde{\chi}_2^{\pm}$	54.3	8
$\tilde{\chi}_3^0\tilde{\chi}_2^{\pm}$	56.5	9
$\tilde{\chi}_4^0\tilde{\chi}_2^{\pm}$	373.2	95
TOTAL		489

SU2 NLO cross-sections (from Prospino 2.0.6, BR from Isajet v7.71)

Heavy scalars are too massive so no decays through intermediate sleptons

Direct gaugino production and decay to a trilepton final state



3 leptons + E_T^{miss}

a "golden" SUSY channel

σ quoted are for √s = 14 TeV

Normalised to10 fb^{-1}

1. $N_{leps} \geq 3$
2. 2 SFOS leptons (e^+e^-, $\mu^+\mu^-$)
3. Lepton Track Isolation: p_T^{max} < 2 GeV for electrons, p_T^{max} < 1GeV for muons in a $\Delta R = 0.2$ cone
4. $| M_{SFOS} - M_z | > 10$ GeV
5. $E_T^{miss} > 30$ GeV
6. Jet Veto: $p_T^{jet\ 1} < 100$ GeV
7. Lepton Impact Parameter: $IP^{norm} < 6$

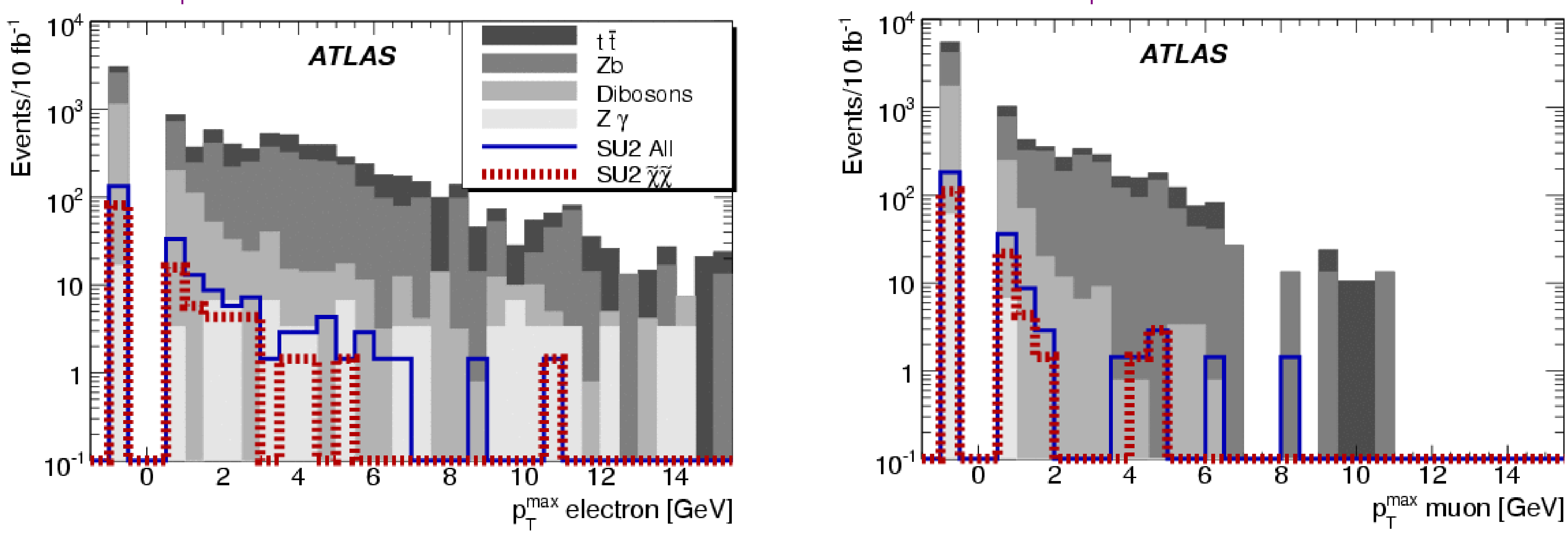
$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

a cone in η-φ space

Cut values optimised using S/√B

Lepton track isolation

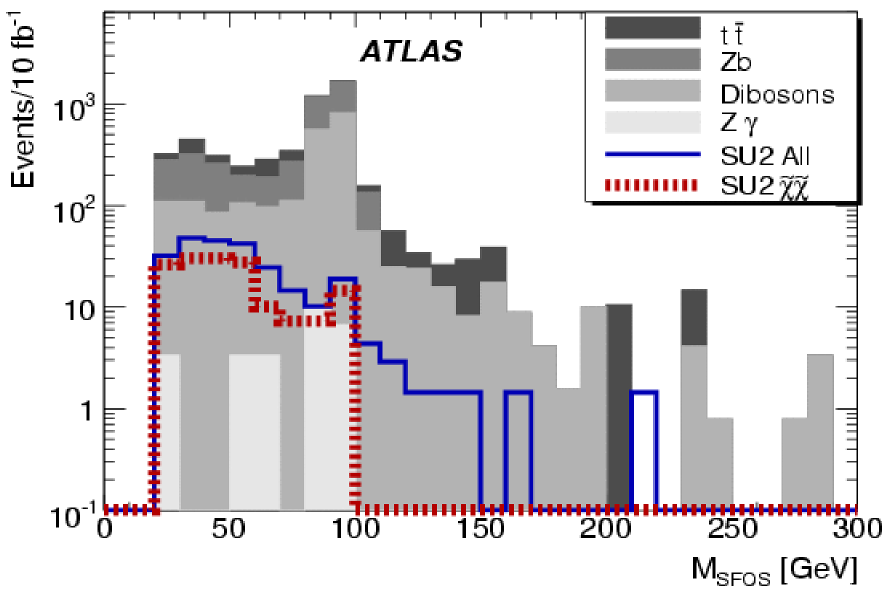
p_T^{max} < 2 GeV for electrons p_T^{max} < 1 GeV for muons



Electron tracks are less isolated due to bremsstrahlung, hadron/photon conversions.
Large reduction in ttbar and Zb backgrounds.

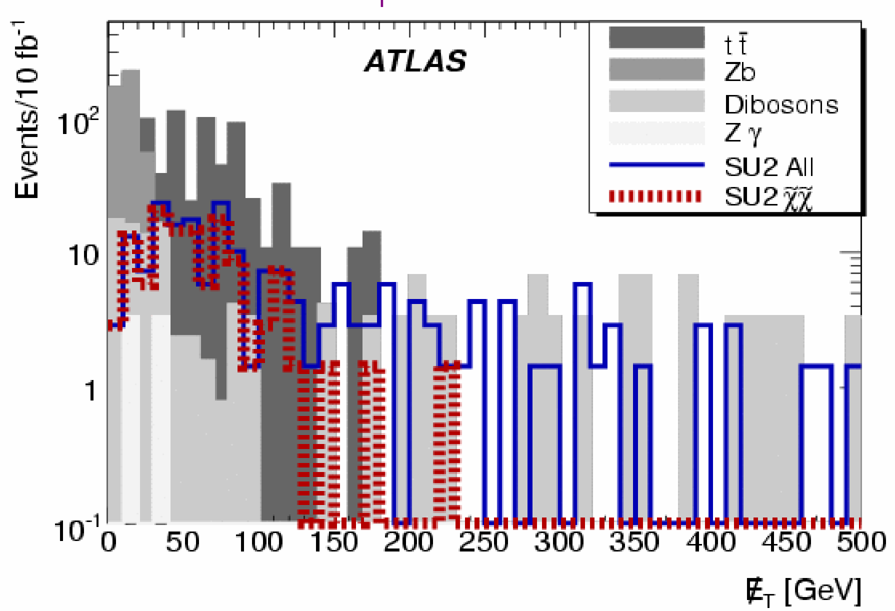
Normalised to10 fb^{-1}

$|M_{SFOS}-M_Z| > 10$ GeV



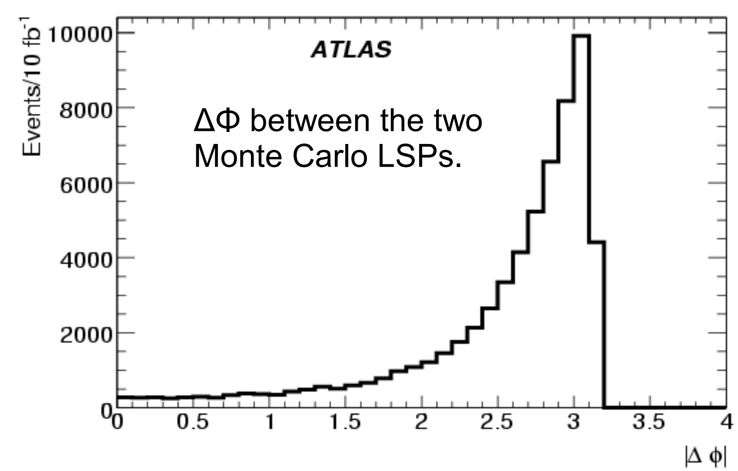
Veto events with a SFOS pair within 10 GeV of the Z mass.
Large reduction in Z SM backgrounds.

$E_T^{miss} > 30$ GeV



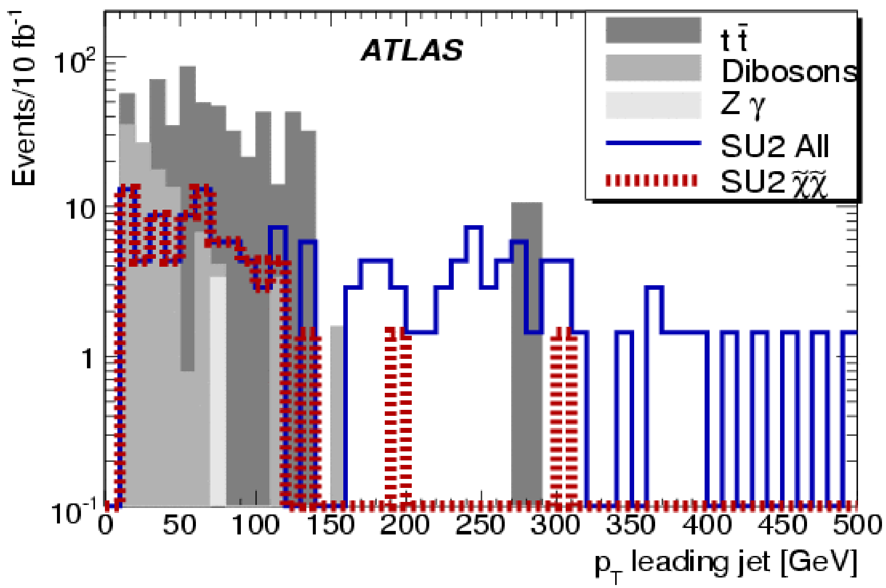
Require a small amount of E_T^{miss}
Reduction in SM backgrounds with no sizable E_T^{miss}

LSPs are "back-to-back"

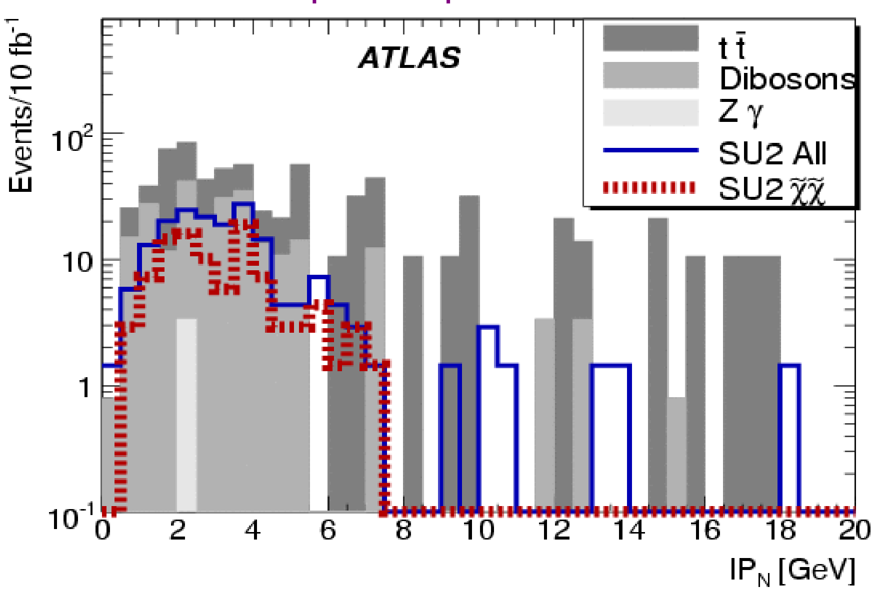


Normalised to10 fb^{-1}

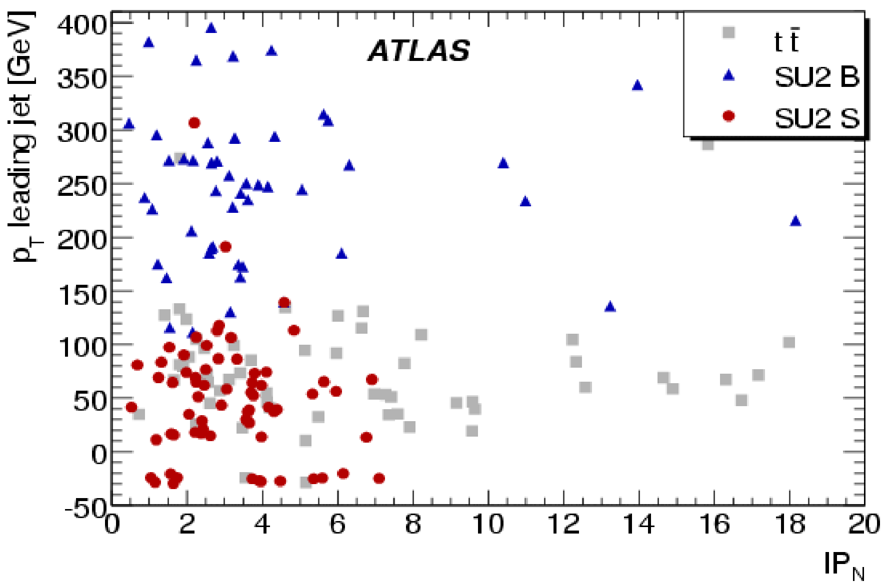
Jet Veto



Lepton Impact Parameter



$p_T^{jet\ 1}$ vs IP_N



A 2D selection is made :
$p_T^{jet\ 1} < 100$ GeV with $IP_N < 6$

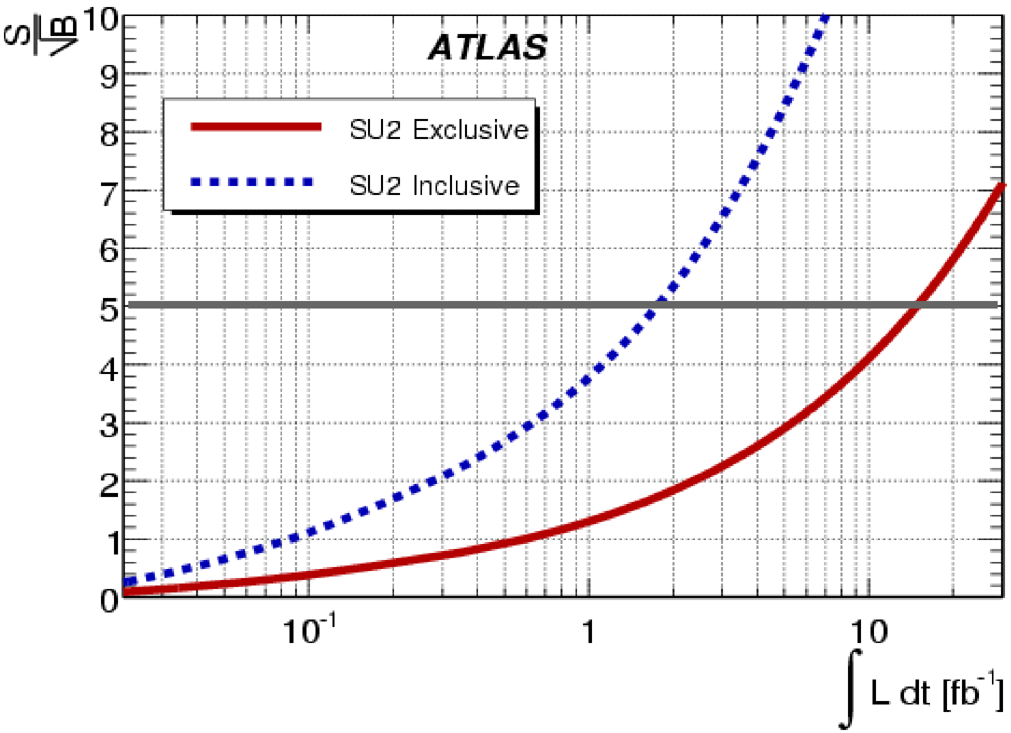
Reduction in SUSY background and remaining ttbar.

Normalised to10 fb^{-1}

No. events	None	N_ℓ	SFOS	TrackIsol	ZWindow	$\not{E}_T$	Jet Veto	IP^{norm}
SU2 Signal	64037	186	178	153	120	98	87	81
SU2 Bckgnd	7081	163	127	95	85	84	0	0
$t\bar{t}$	4406579	4440	2812	634	507	476	328	180
Zb	1591157	6616	6563	2423	386	0	0	0
ZW	156720	1927	1910	1682	322	218	214	204
ZZ	38202	589	580	476	57	13	12	11
WW	400517	33	25	8	8	8	8	0
$Z\gamma$	32832	94	91	27	7	3	3	3
	$\frac{S}{\sqrt{B}}$	1.6	1.6	2.1	3.2	3.5	3.6	4.1
	$\frac{S}{B}$	0.0	0.0	0.0	0.1	0.1	0.2	0.2

Luminosity needed for discovery is an order of magnitude higher than for SU2 Inclusive trilepton analysis.

However, if gluino is also too heavy for the LHC, direct gaugino production and decay to three leptons could be a possible discovery channel.



Most dangerous backgrounds are ttbar and ZW

ttbar

For Exclusive trilepton channel:
use lepton flavour and sign combinations of trilepton events.

Control Region *no SFOS pair*		Signal Region *with SFOS pair*
$e^+e^+\mu^-$	→ *Replace e with μ or μ with e as necessary.*	$e^+e^-\mu^+$
$e^-e^-\mu^+$		$e^+e^-\mu^-$
$\mu^+\mu^+e^-$		$\mu^+\mu^-e^+$
$\mu^-\mu^-e^+$		$\mu^+\mu^-e^-$
		$e^+e^-e^+$
		$e^+e^-e^-$
		$\mu^+\mu^-\mu^+$
		$\mu^+\mu^-\mu^-$

The number of No SFOS combinations can be used to estimate the numbers of SFOS combinations and thus the ttbar background to SUSY trilepton signal.

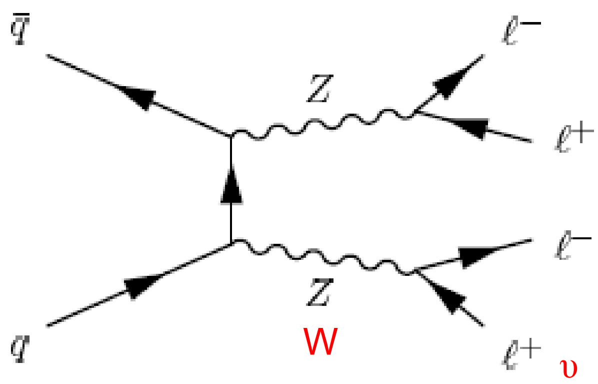
Results so far are promising!

For Inclusive trilepton channel:
Top box method? – involves reconstructing the two tops.
4-box method? - use variables (E_T^{miss} and p_T^{jet} ?) to define sideband and signal regions with independent variable (M_T ?) to normalise between the two.

Method in progress....

ZW

measure ZZ cross-section



replace a lepton with a neutrino and correct for differences in cross-sections.

Summary

Inclusive trilepton signal

Simple and powerful analysis, only require 3 leptons and one high p_T jet.
SU2 : $S/\sqrt{B}$ = 3.8 for 1 fb^{-1} of data
SU3 : $S/\sqrt{B}$ = 27.3 for 1 fb^{-1} of data
SU4 : $S/\sqrt{B}$ = 90.3 for 1 fb^{-1} of data

Early SUSY discovery channel??

Invariant mass distribution of flavor subtracted M_{SFOS} yields mass difference of lightest two neutralinos.
The entire SUSY mass spectrum can be obtained from further measurements of jet-lepton invariant mass plots.

Trileptons from direct gaugino production

"Gaugino only" SUSY discovery is possible with trilepton channel

Stringent cuts on lepton track isolation and a jet veto
$S/\sqrt{B}$= 4.1 after 10 fb^{-1} of data

ZW and ttbar are the most dangerous backgrounds.

Controlled by lepton track isolation and Z mass window removal but moderate amounts still remain.

Background estimation of ttbar to Exclusive trilepton signal shows promising results.
Background estimation of ttbar to Inclusive trilepton signal currently in progress.

More details on these analyses can be found in
ATLAS Collaboration,*"Expected Performance of the ATLAS Experiment, Detector,Trigger and Physics",* CERN-OPEN-2008-020, Geneva, 2008, to appear

Backup slides

Varying the Inclusive event selection

Set	p_T^{jet1}	$\not{E}_T$	Trk Isol.	Z_1 SU2	Z_1 SU3	Z_1 SU4	Z_2 SU2	Z_2 SU3	Z_2 SU4
1	√	×	×	3.8	27.3	90.3	3.3	16.6	38.9
2		√	×	2.3	17.7	81.0	2.1	13.0	40.7
3	×	×	√	1.2	4.6	36.4	1.2	4.4	30.4
4		√	√	2.6	21.2	82.7	2.3	13.5	36.1
5		√	×	4.7	40.4	95.8	3.6	18.2	32.3
6	√	×	√	4.5	35.9	107.1	3.6	17.5	36.6
7		√	√	4.2	38.6	79.0	3.2	16.5	26.5

$Z_1 = S/\sqrt{B}$

$Z_2 = \sqrt{[2(S+B)\ln(1+(S/B)) - S]}$

Varying the Exclusive event selection

	Set	SFOS	TrackIsol	ZWindow	$\not{E}_T$	Jet Veto	IP_N	Z_1	Z_2
	A1	√	√	√	√	√	√	4.1	3.9
	A2	×	√	√	√			3.8	3.7
Jet Veto + IP_N	A3	√	×	√	√	√	√	2.9	2.8
	A4	√	√	×	√			2.5	2.5
	A5	√	√	√	×			3.4	3.3
	B1	√	√	√	√			3.6	3.6
	B2	×	√	√	√			3.4	3.4
Jet Veto + No IP_N	B3	√	×	√	√	√	×	2.4	2.4
	B4	√	√	×	√			2.3	2.3
	B5	√	√	√	×			3.2	3.1
	C1	√	√	√	√			4.0	3.9
	C2	×	√	√	√			3.8	3.7
No Jet Veto + IP_N	C3	√	×	√	√	×	√	2.9	2.9
	C4	√	√	×	√			3.0	3.0
	C5	√	√	√	×			3.5	3.5
	D1	√	√	√	√			3.5	3.4
	D2	×	√	√	√			3.4	3.3
No Jet Veto + No IP_N	D3	√	×	√	√	×	×	2.4	2.3
	D4	√	√	×	√			2.8	2.8
	D5	√	√	√	×			3.2	3.2

Backup slides

Samples used

Process	Sample Id.	Generator	σ_{LO} [pb]	$\sigma_{LO} \times \varepsilon_F$	k-fact.	$\sigma_{NLO} \times \varepsilon_F$ [pb]	$\int \mathscr{L} dt$ [fb^{-1}]
SU2	5402	Herwig	5.2	5.2	1.39	7.2	6.9
SU3	5403	Herwig	20.9	20.9	1.33	27.7	17.1
SU4	5404	Herwig	294.5	294.5	1.37	402.2	0.5
$t\bar{t}$	5200	MC@NLO	833.0	449.8	1.0	449.8	1.0
Zb	5178	AcerMC	205.0	153.8	1.0	163.9	0.8
ZZ	5987	Herwig	11.0	2.1	1.9	3.9	12.7
ZW	5986	Herwig	27.0	7.8	2.1	16.1	3.0
WW	5985	Herwig	70.0	24.5	1.7	40.9	1.2
$Z\gamma$	5900	Pythia	3.8	2.6	1.3	3.4	3.0

trig1_misal1_csc11.005402.SU2_jimmy_susy.merge.AOD.v12000605
trig1_misal1_csc11.005403.SU3_jimmy_susy.merge.AOD.v12000605
trig1_misal1_csc11.006400.SU4_jimmy_susy.merge.AOD.v12000605
trig1_misal1_mc12.005200.T1_McAtNlo_Jimmy.recon.AOD.v12000604
trig1_misal1_mc12.005178.Zb_acer_pythia.recon.AOD.v12000605
trig1_misal1_csc11.005985.WW_Herwig.merge.AOD.v12000605
trig1_misal1_csc11.005986.ZZ_Herwig.merge.AOD.v12000605
trig1_misal1_csc11.005987.WZ_Herwig.merge.AOD.v12000605
trig1_misal1_csc11.005900.PythiaZPhoton25.merge.AOD.v12000604