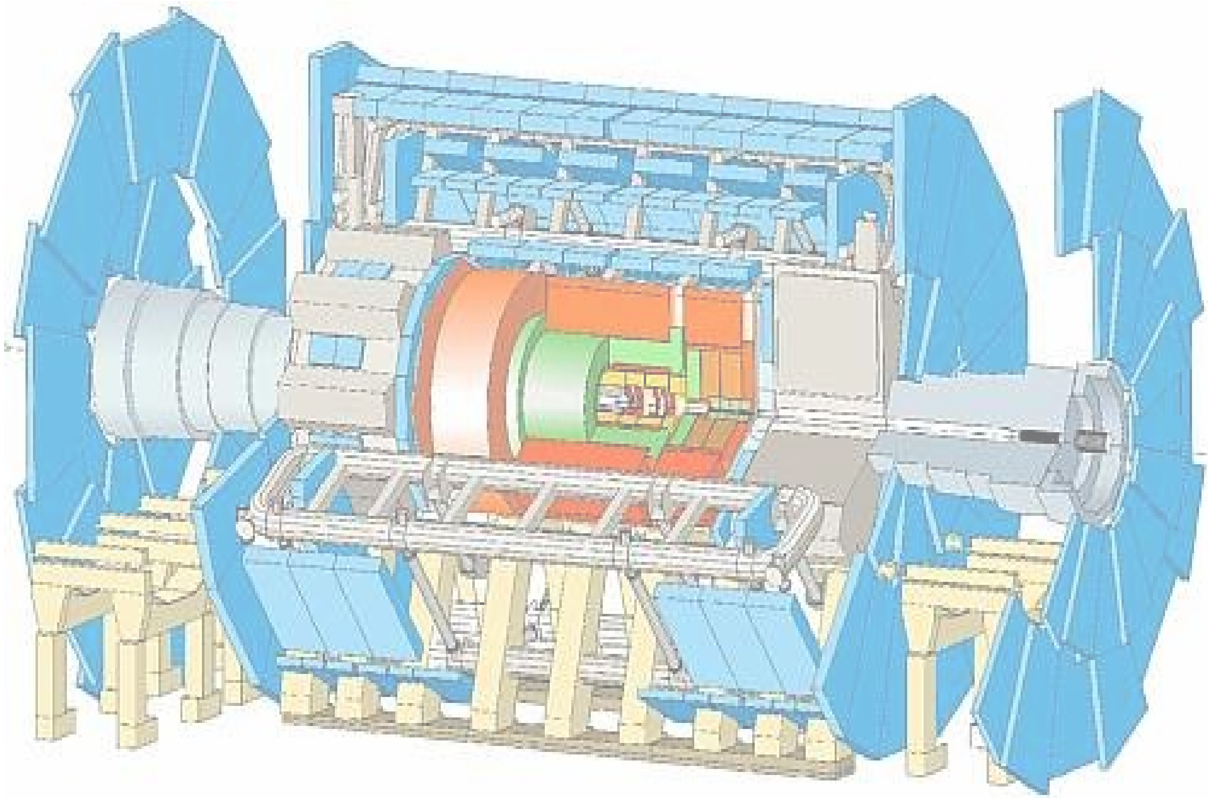
Trilepton SUSY Signatures



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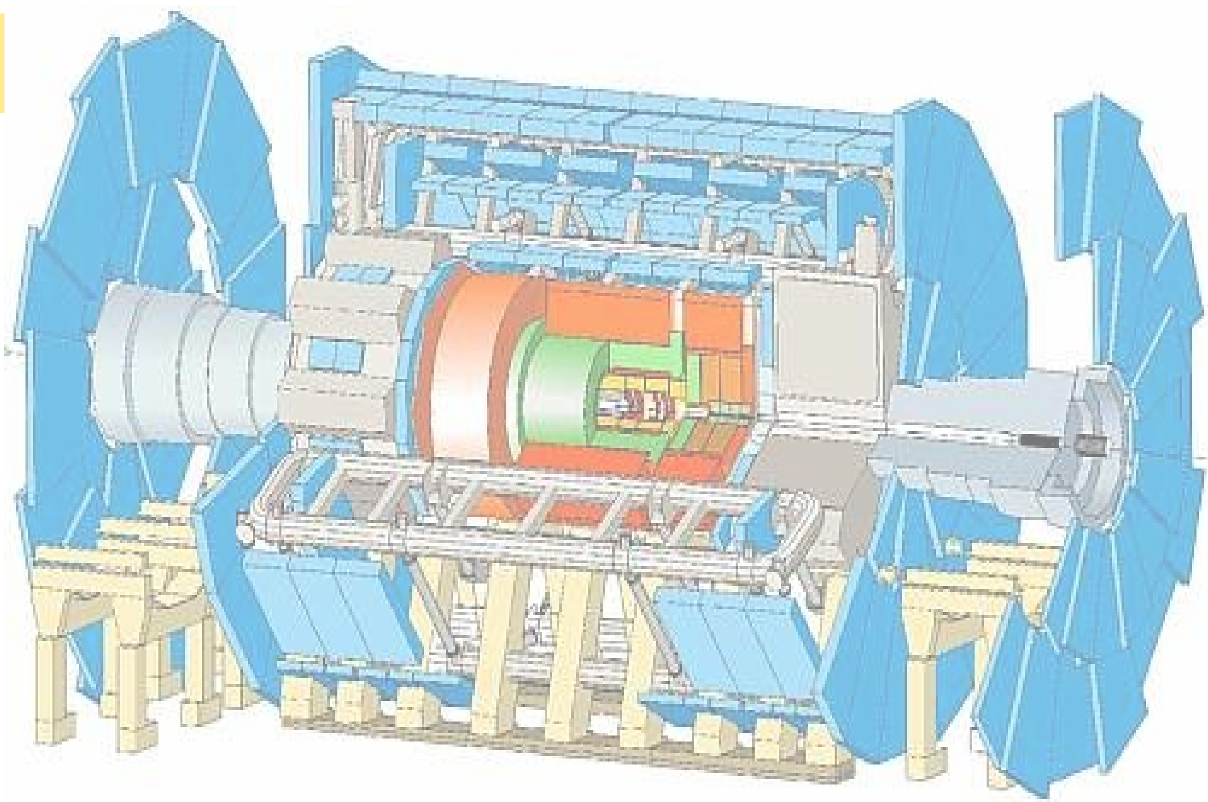
The ATLAS detector

Trilepton Analysis uses the *entire* ATLAS detector



Inner Tracker
- charged particles

Electromagnetic Calorimeter
- electrons
- photons

Hadronic Calorimeter
- jets

Magnet System
- momentum measurement

Muon Spectrometer
- muons

Not forgetting...
+ trigger
+ data acquisition
+ computing
...systems

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!

R-Parity

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

S = spin
B = baryon number
L = lepton number

SM Particle	Particle	Spin	R-Parity	Superpartner	Spin	R-Parity
Fermions	l	1/2	+1	$\tilde{\ell}$	0	-1
	q	1/2	+1	$\tilde{q}$	0	-1
Bosons	$W^{\pm}, W^0$	1	+1	$\tilde{W}^{\pm}, \tilde{W}^0$	1/2	-1
	B	1	+1	$\tilde{B}$	1/2	-1
	g	1	+1	$\tilde{g}$	1/2	-1
	H	0	+1	$\tilde{H}_u, \tilde{H}_d$	1/2	-1

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

Gauge eigenstates $W^{\pm}, W^0, B$

mix to give 4 mass eigenstates

W^+, W^-, Z, γ

Neutral higgsinos and gauginos $\tilde{H}_u^0, \tilde{H}_d^0, \tilde{W}^0, \tilde{B}^0$

mix to give 4 mass eigenstates called neutralinos $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$

usually the LSP

Charged higgsinos and gauginos $\tilde{H}_u^+, \tilde{H}_d^-, \tilde{W}^+, \tilde{W}^-$

mix to give 2 mass eigenstates called charginos $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$

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

mSUGRA parameter space and benchmark points

mSUGRA sparticle mass spectrum depends on 4 parameters m_0, $m_{1/2}$, A_0, $\tan\beta$, and one sign, μ

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

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

coannihilation region

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

SU3

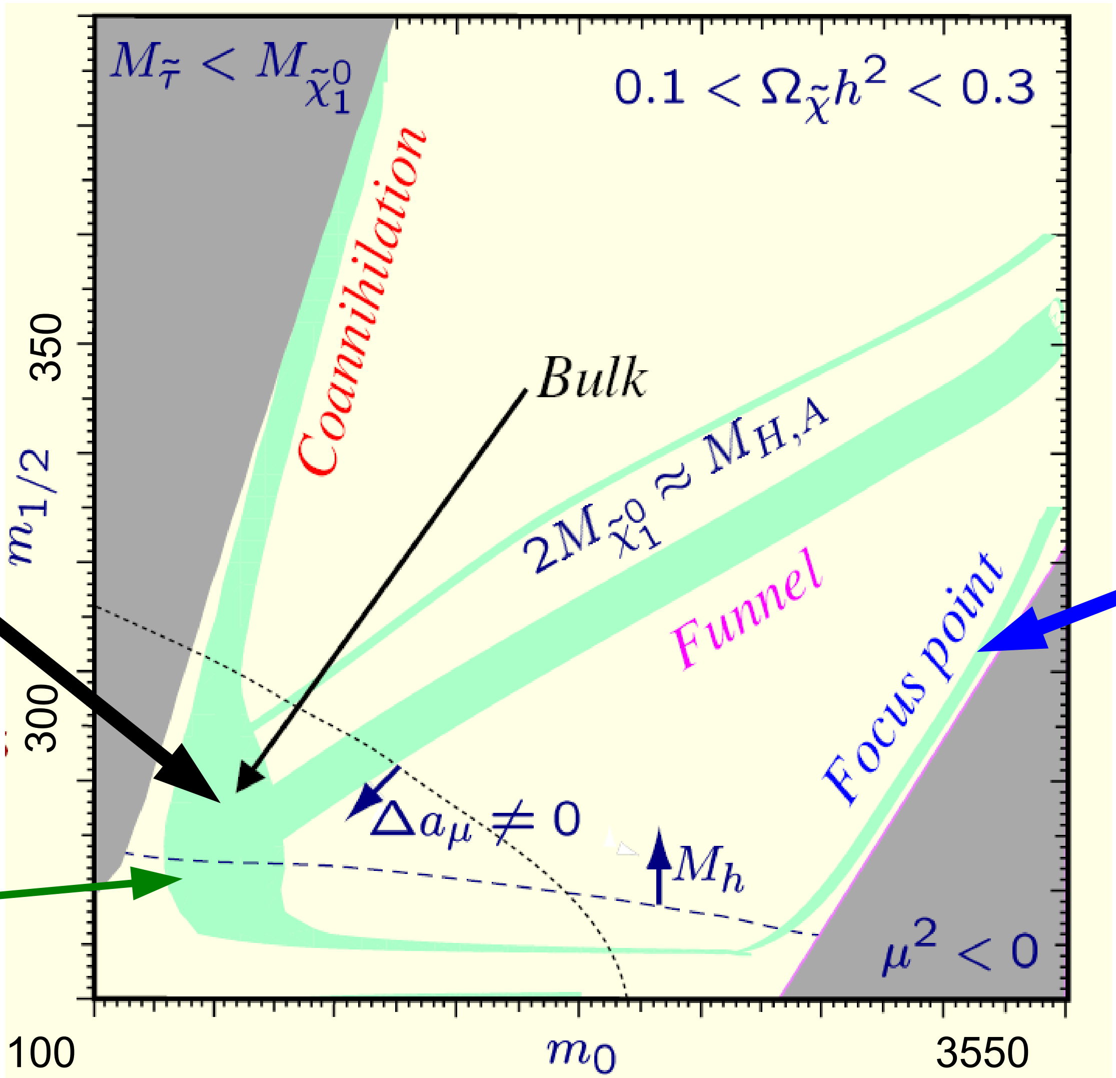
bulk region

LSP is mostly Higgsino
Low masses, long decay chains through squarks and sleptons

SU4

low mass region

Similar to bulk region



funnel region

Large $\tan\beta$,
Heavy Higgs resonance

SU2

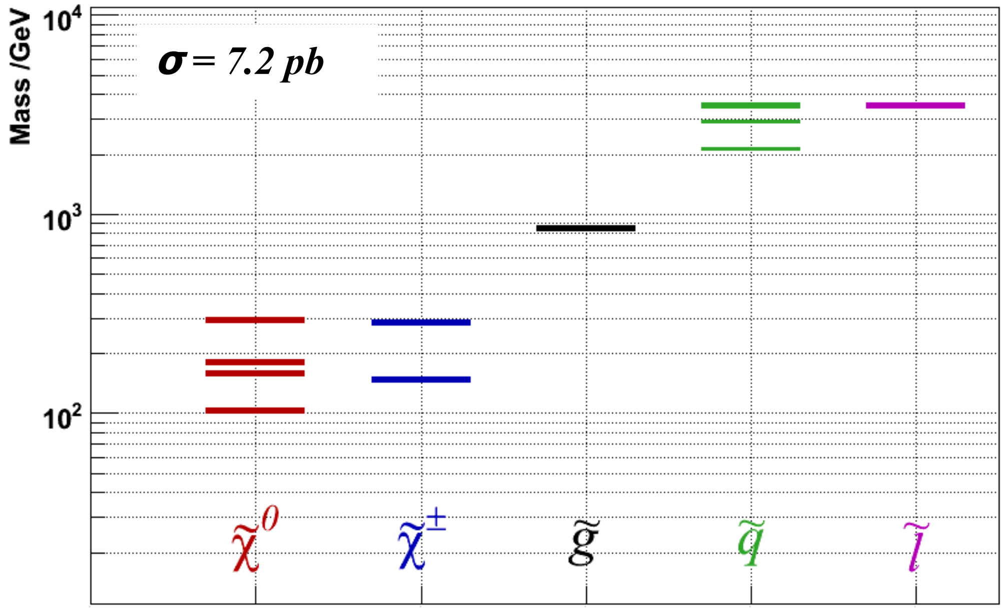
Focus point

LSP is mostly Higgsino
Very heavy squarks and sleptons , relatively light gauginos

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

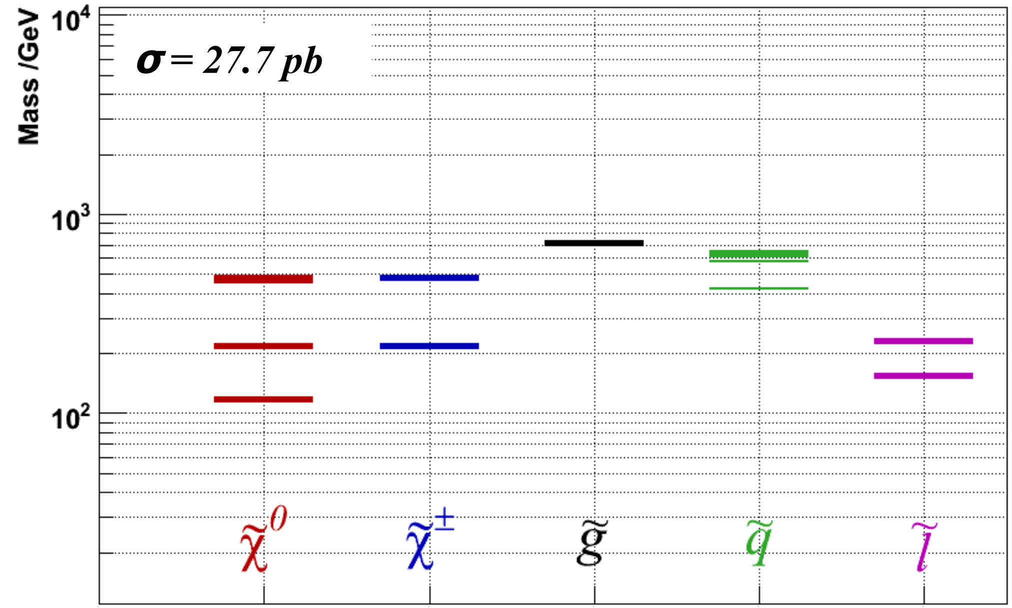
SU2

m_0 = 3550GeV, $m_{1/2}$= 300GeV, A_0 = 0, $\tan\beta = 10$, $\mu > 0$



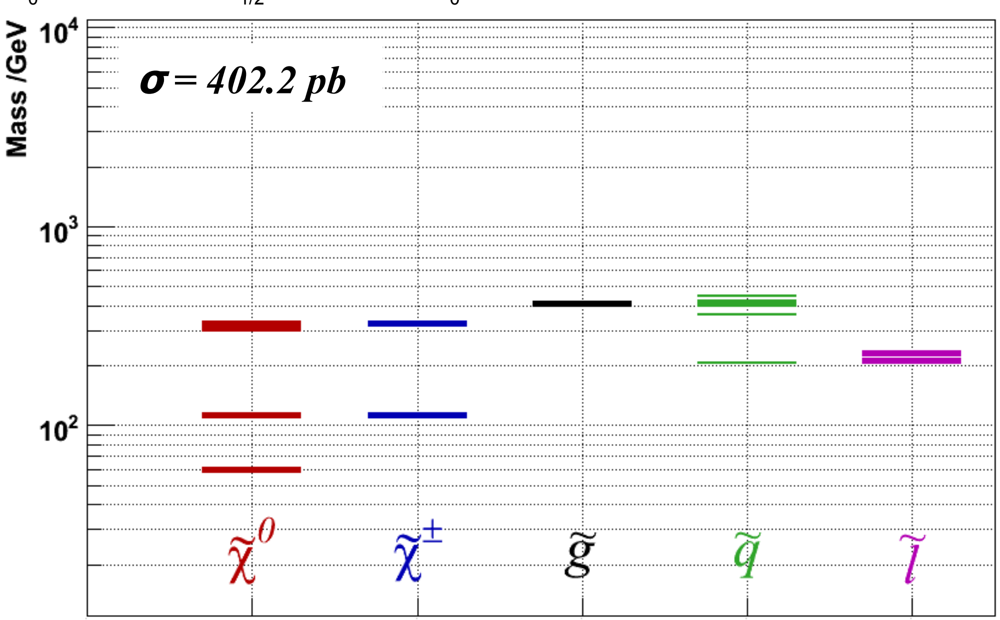
SU3

m_0 = 100GeV, $m_{1/2}$= 300GeV, A_0 =-30 0, $\tan\beta = 6$, $\mu > 0$



SU4

m_0 = 200GeV, $m_{1/2}$= 160GeV, A_0 =-40 0, $\tan\beta = 10$, $\mu > 0$



Normalised to1 fb^{-1}

some leptonic modes...

$$\tilde\chi_1^\pm \to \tilde\chi_1^0 W^{\pm(*)} \to \tilde\chi_1^0 l^\pm \nu_l$$

$$\tilde\chi_2^0 \to \tilde\chi_1^0 Z^* \to \tilde\chi_1^0 l^+ l^-$$

$$\tilde\chi_2^0 \to \tilde l_R^\pm l^\mp \to \tilde\chi_1^0 l^+ l^-$$

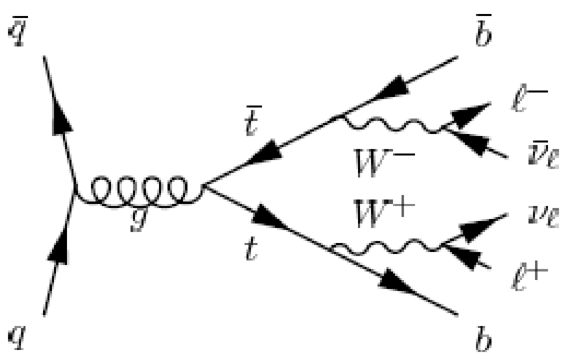
$$\tilde\chi_1^\pm \to \tilde\tau_1^\pm \nu_\tau \to \tilde\chi_1^0 \tau^\pm \nu_\tau$$

$$\tilde\chi_2^0 \to \tilde\tau_1^\pm \tau^\mp \to \tilde\chi_1^0 \tau^+ \tau^-$$

	SU2	SU3	SU4
σ_{TOT} [pb]	7.18	27.68	402.19
σ_{3lep} [pb]	0.07	0.30	2.49
# 3 lepton events	~ 70	~ 300	~ 2500

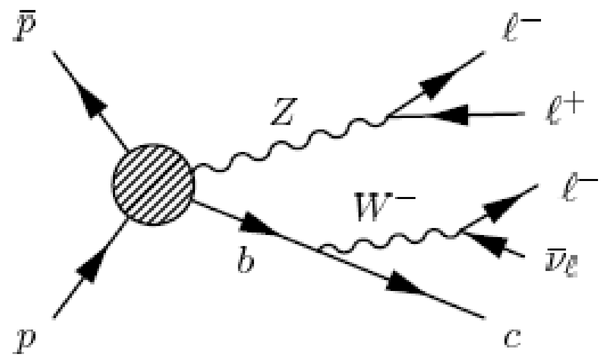
Standard Model Backgrounds

σ = 450 pb



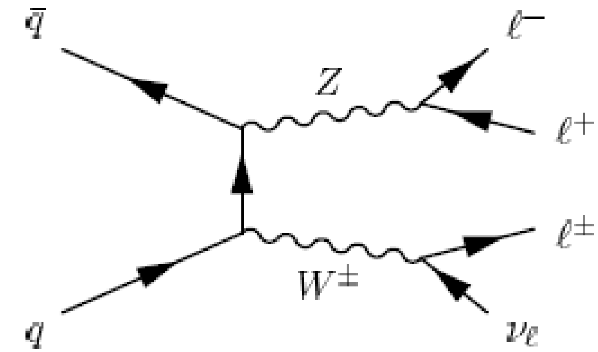
$t\bar{t}$

σ = 164 pb



Zb

σ = 16 pb

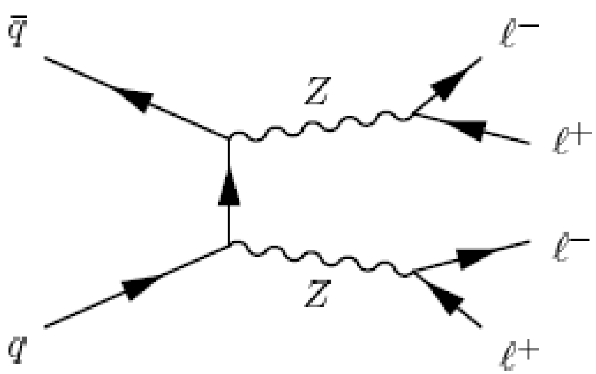


ZW

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

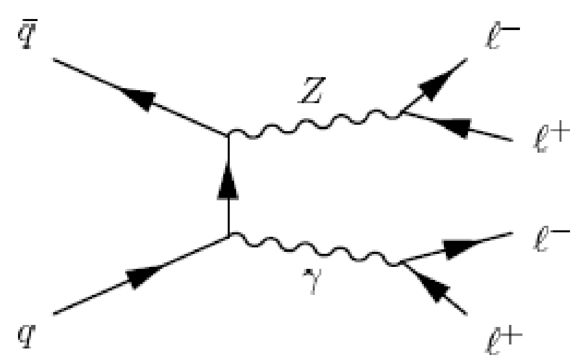
3 good leptons
+ E_T^{miss} from neutrino

σ = 4 pb



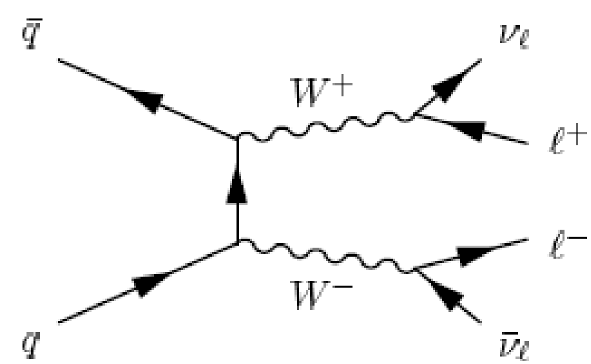
ZZ

σ = 3 pb



$Z\gamma$

σ = 41 pb



WW

4 good leptons but no E_T^{miss}

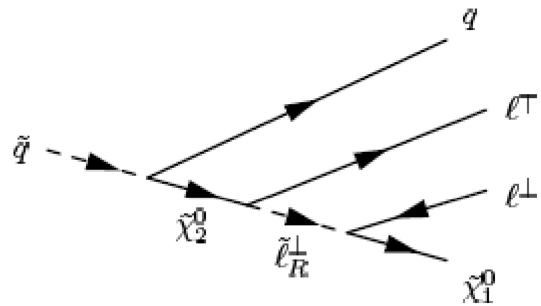
jets may fake leptons

Normalised to1 fb^{-1}

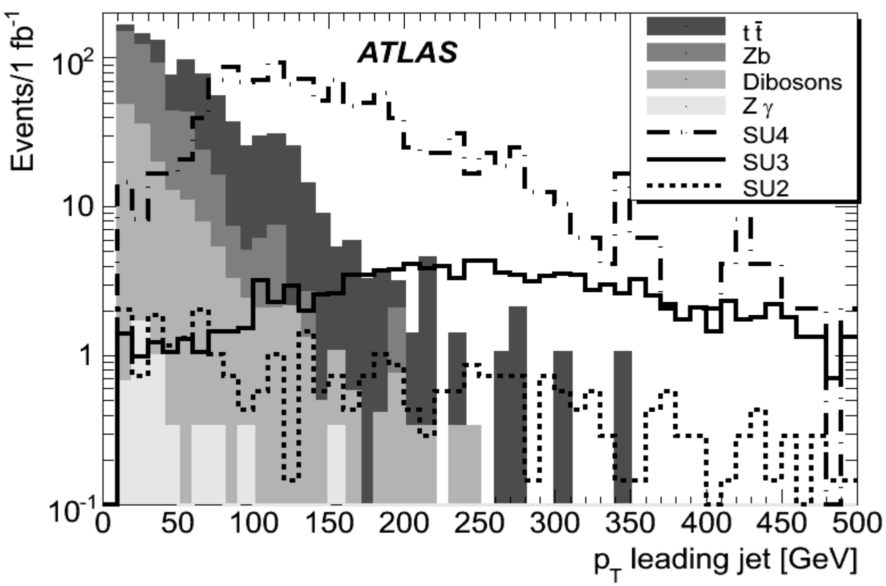
Simple and powerful analysis

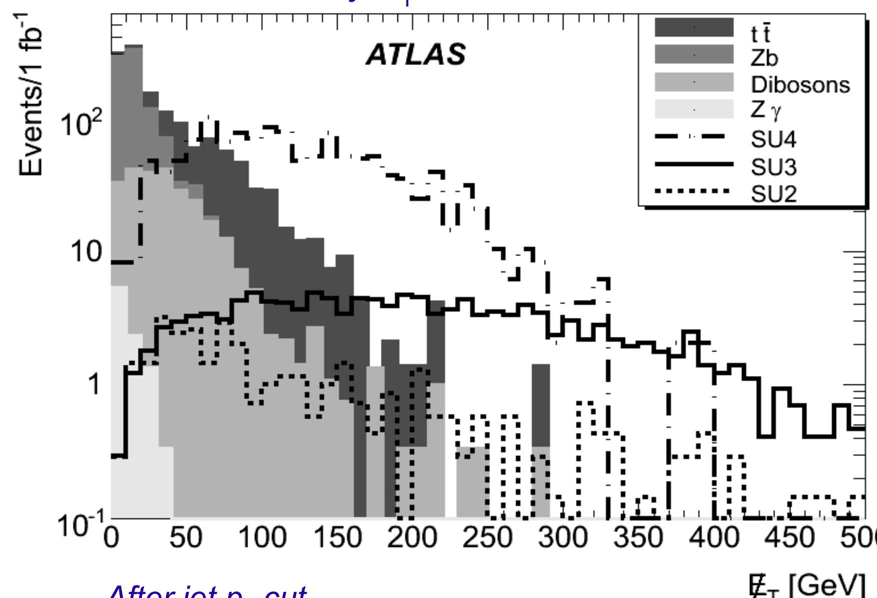
1. $N_{leps} \geq 3$

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

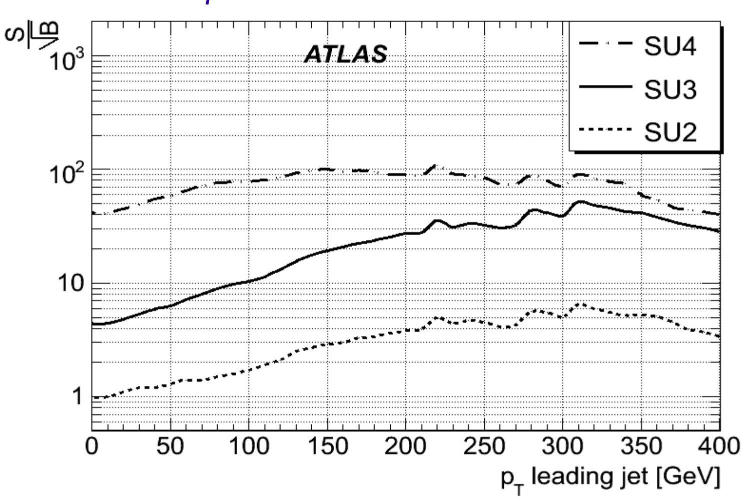


Possibly $E_T^{miss} > 150$ GeV

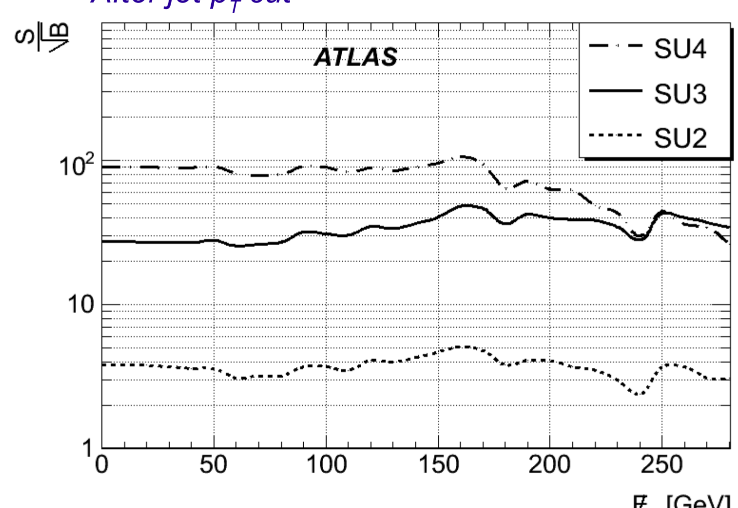




After 3lep cut



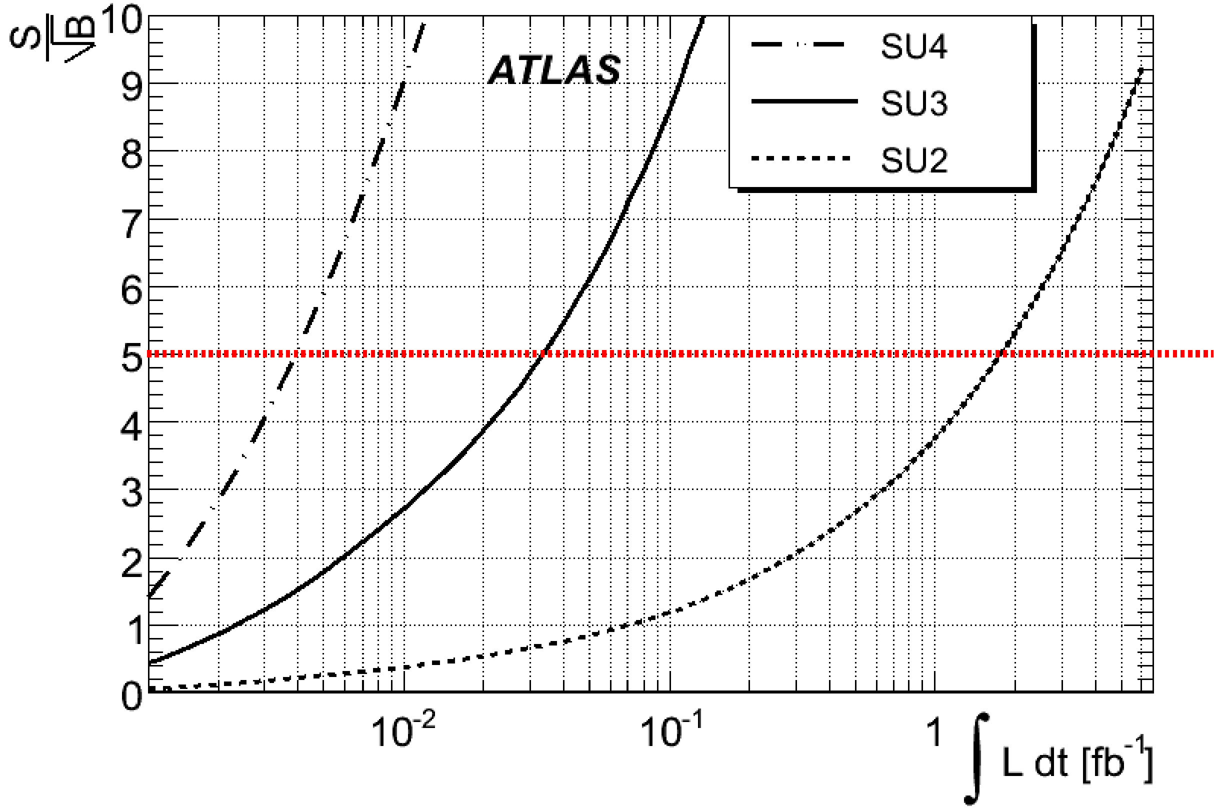
After jet p_T cut



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	$\frac{S}{\sqrt{B}}$	3.8	27.3
SU4	$\frac{S}{\sqrt{B}}$	34.7	90.3
SU2	$\frac{S}{B}$	0.0	1.1
SU3	$\frac{S}{B}$	0.1	7.9
SU4	$\frac{S}{B}$	0.9	26.2

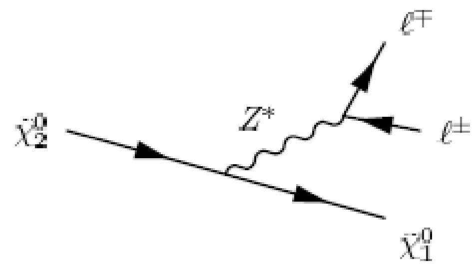
Early SUSY discovery channel??



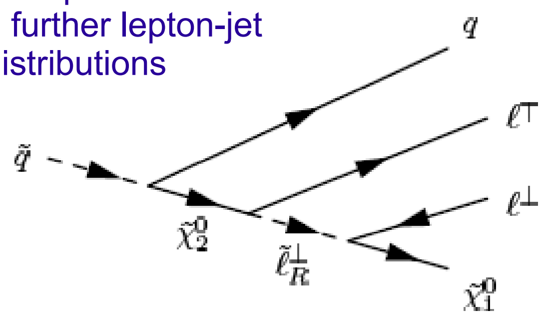
n.b. not using E_T^{miss}, so search is good for very early data when E_T^{miss} systematics may not be fully understood.

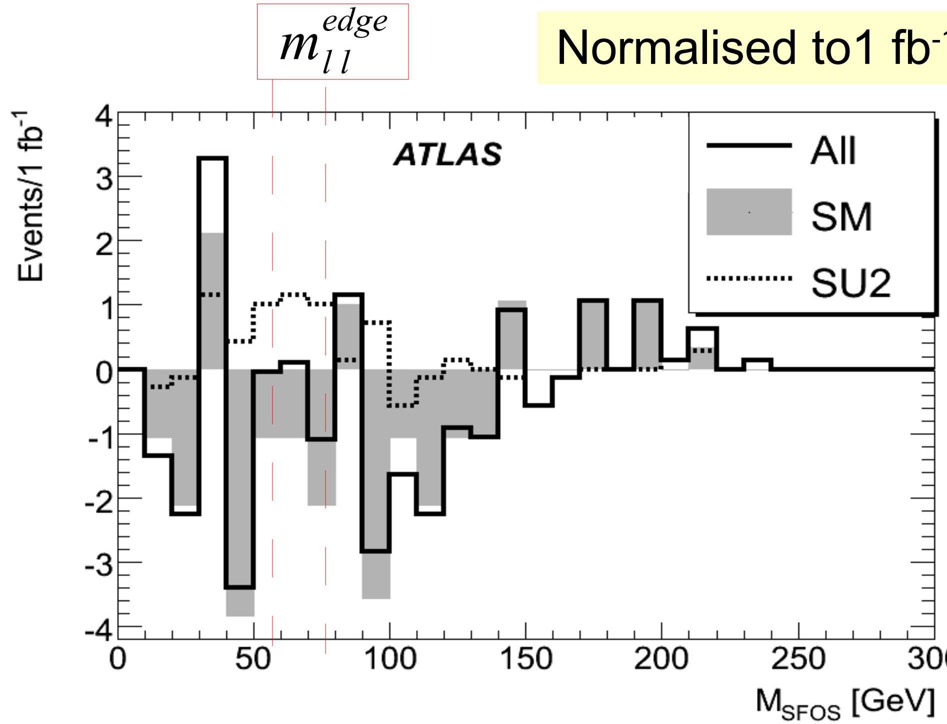
Normalised to1 fb^{-1}

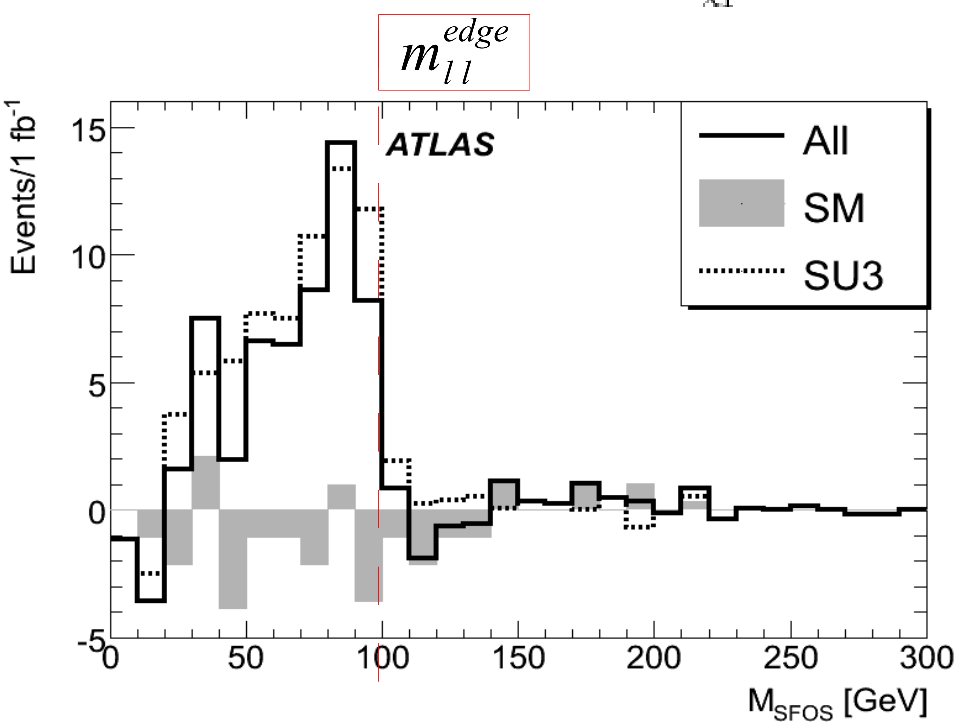
SFOS – OFOS is plotted to remove combinatorics i.e. $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$

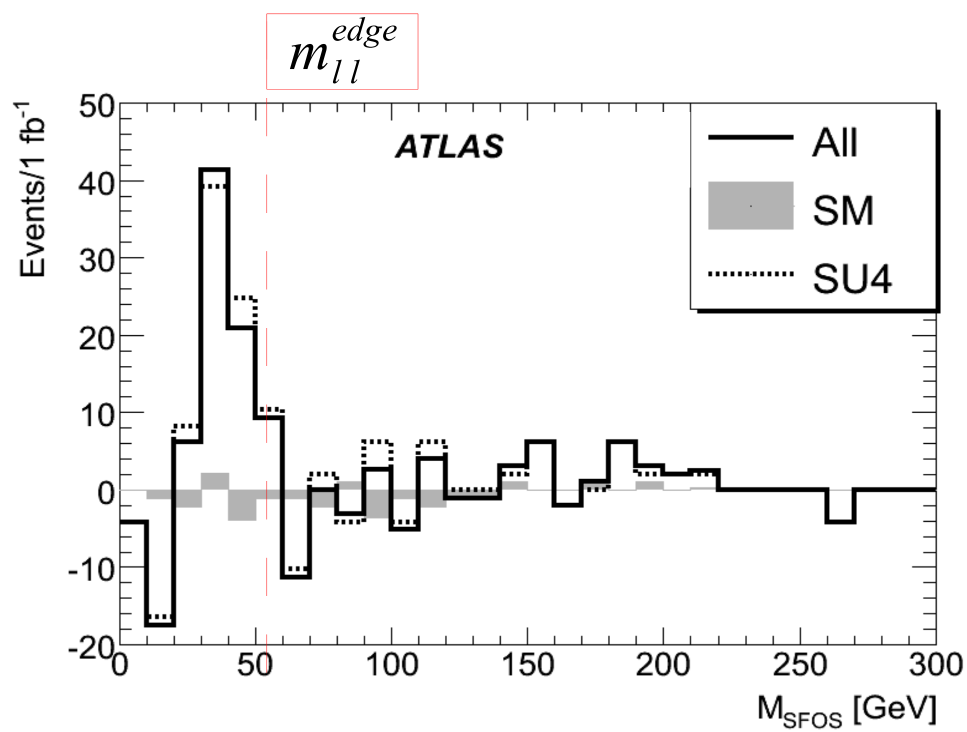


Entire SUSY mass spectrum could be revealed with further lepton-jet invariant mass distributions



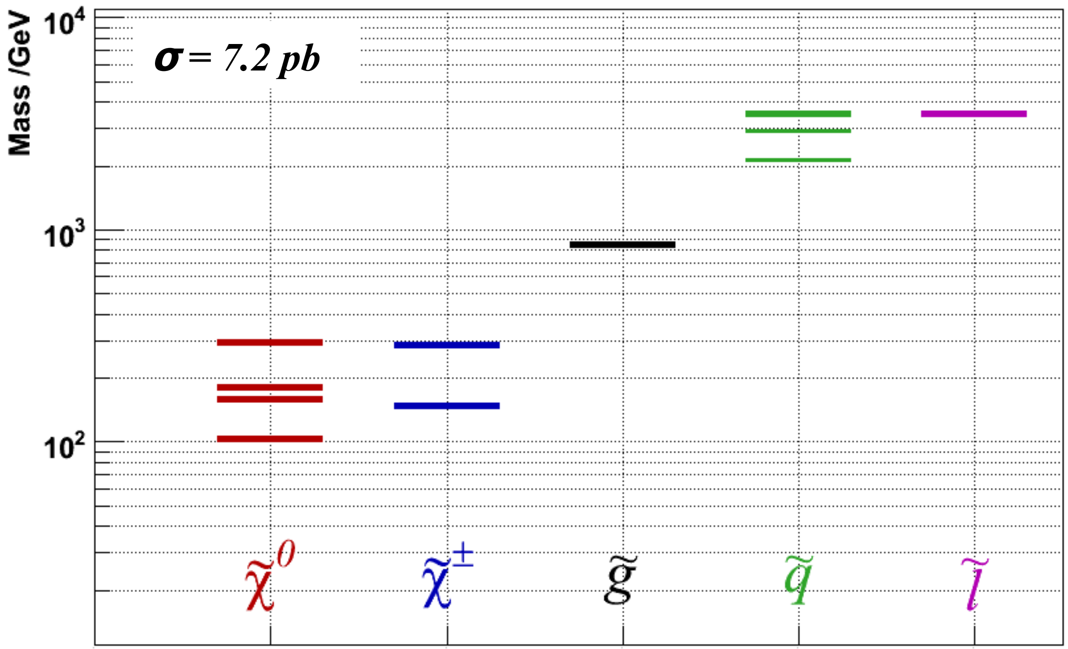






SU2

m_0 = 3550GeV, $m_{1/2}$= 300GeV, A_0 = 0, $\tan\beta = 10$, $\mu > 0$



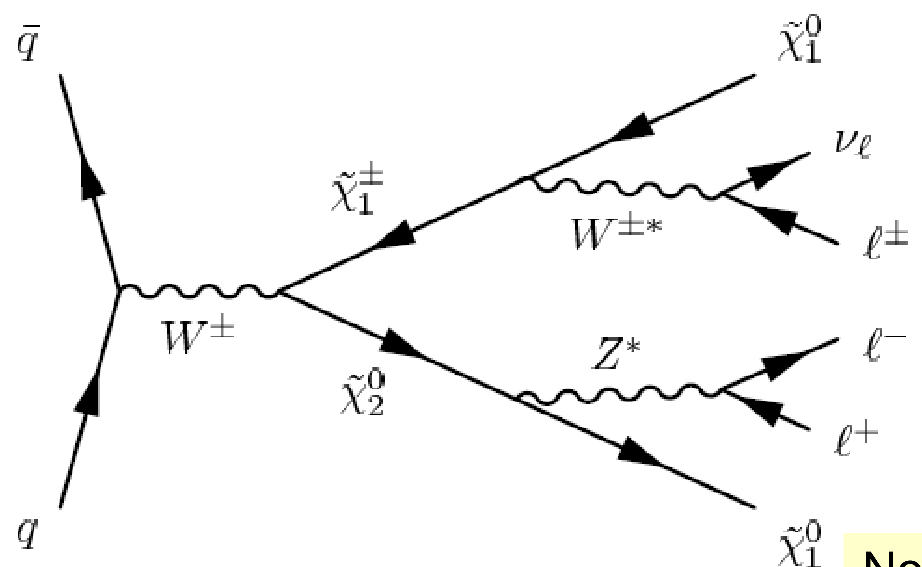
Heavy scalars are too massive so no decays through intermediate sleptons

Production	σ_{NLO} [fb]	# 3ℓ events /10 fb^{-1}
$\tilde{\chi}_2^0\tilde{\chi}_3^0$	114.3	5
$\tilde{\chi}_3^0\tilde{\chi}_4^0$	22.8	8
$\tilde{\chi}_2^\pm\tilde{\chi}_2^\pm$	217.1	40
$\tilde{\chi}_1^\pm\tilde{\chi}_2^\pm$	74.0	7
$\tilde{\chi}_2^0\tilde{\chi}_1^\pm$	1449.7	212
$\tilde{\chi}_3^0\tilde{\chi}_1^\pm$	897.2	127
$\tilde{\chi}_4^0\tilde{\chi}_1^\pm$	69.0	10
$\tilde{\chi}_2^0\tilde{\chi}_2^\pm$	84.8	10
$\tilde{\chi}_3^0\tilde{\chi}_2^\pm$	78.0	12
$\tilde{\chi}_4^0\tilde{\chi}_2^\pm$	408.3	96
TOTAL		528

Direct gaugino production and decay to a trilepton final state

3 leptons + E_T^{miss}

a "golden" SUSY channel



Normalised to10 fb^{-1}

1. $N_{leps} \geq 3$
2. 2 SFOS leptons (e^+e^-, $\mu^+\mu^-$)
3. p_T^{max} < 2 GeV for electrons, p_T^{max} < 1GeV for muons in a ΔR = 0.2 cone
4. $| M_{SFOS} - M_z |$ > 10 GeV
5. E_T^{miss} > 30 GeV
6. p_T^{jet1} < 100 GeV
7. IP^{norm} < 6

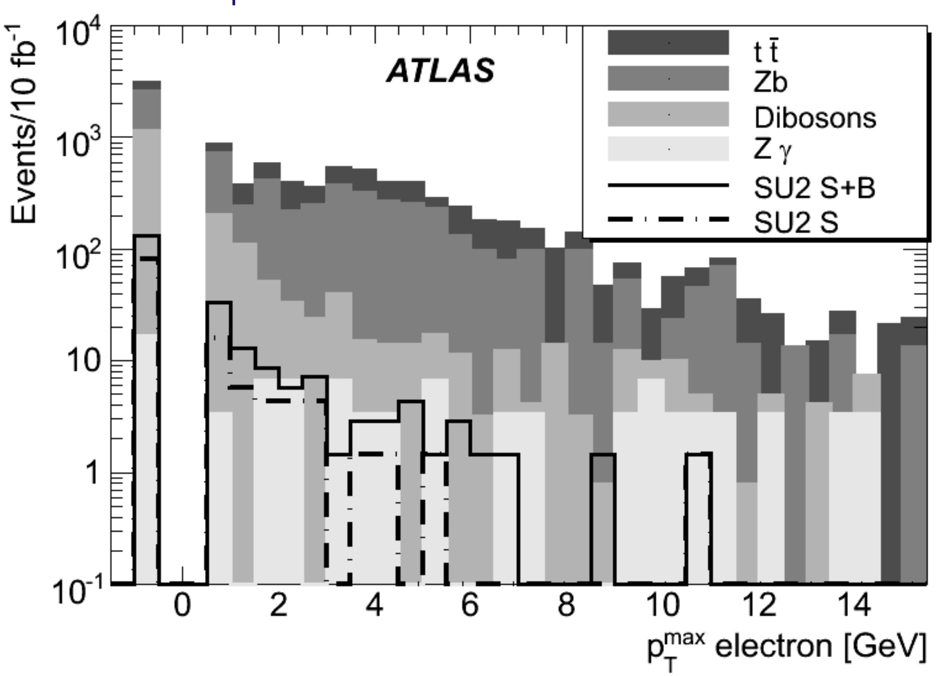
Normalised to10 fb^{-1}

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

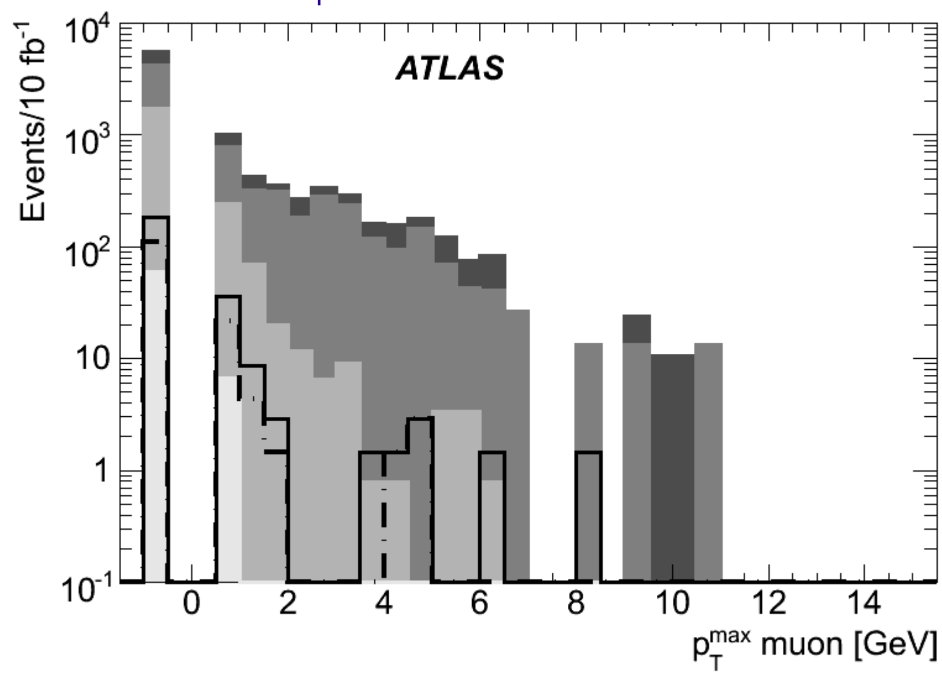
a cone in η-φ space

Lepton track isolation:

p_T^{max} < 2 GeV for electrons

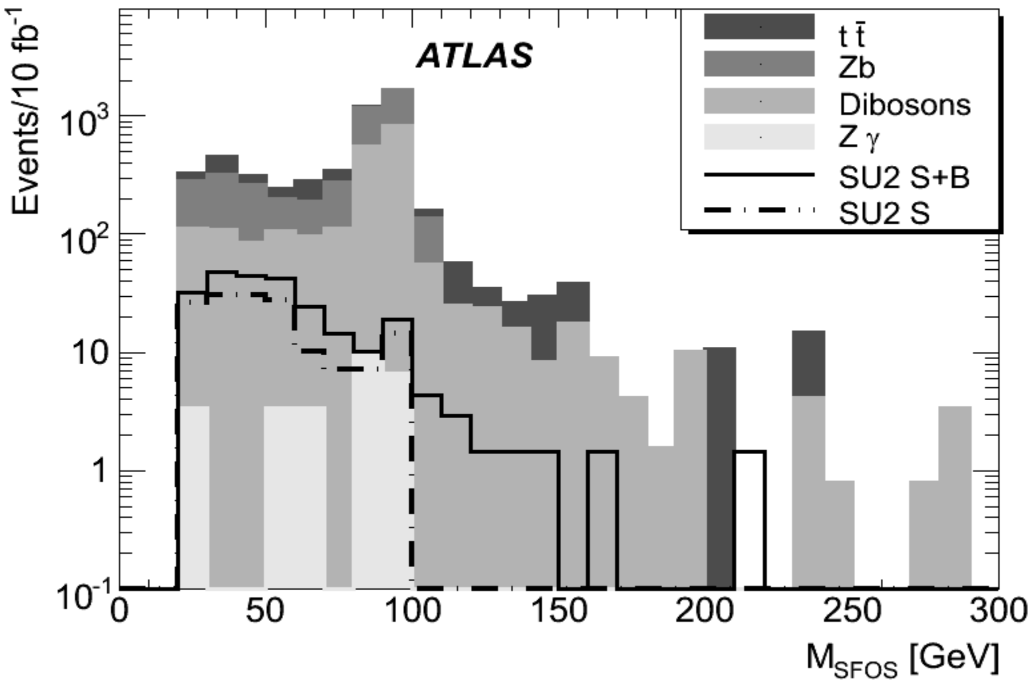


p_T^{max} < 1 GeV for muons

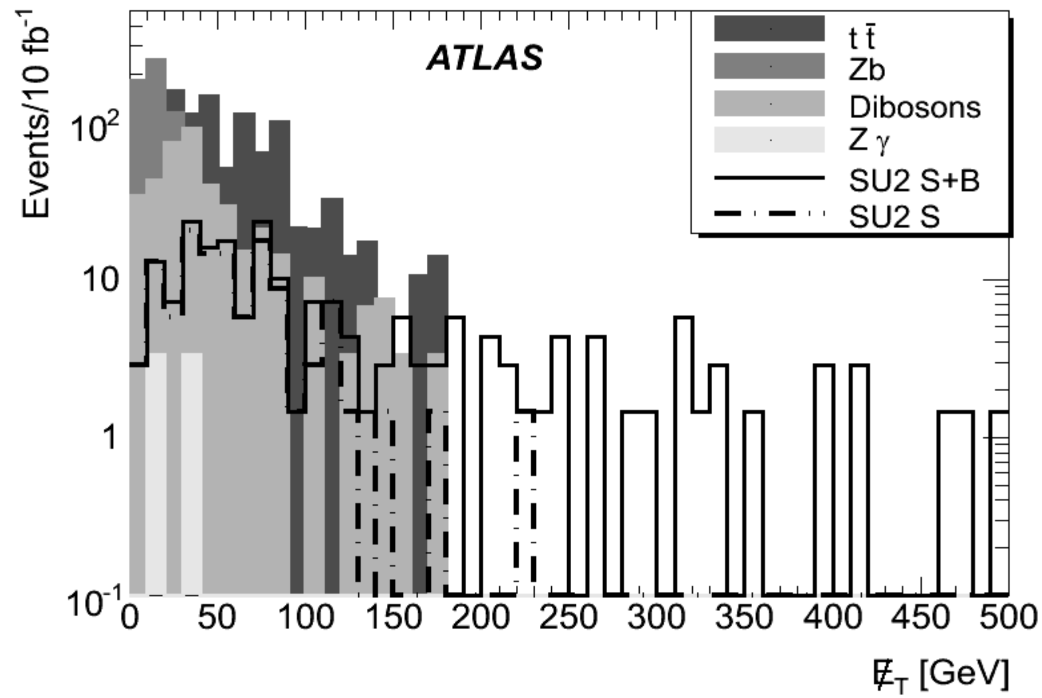


Normalised to10 fb^{-1}

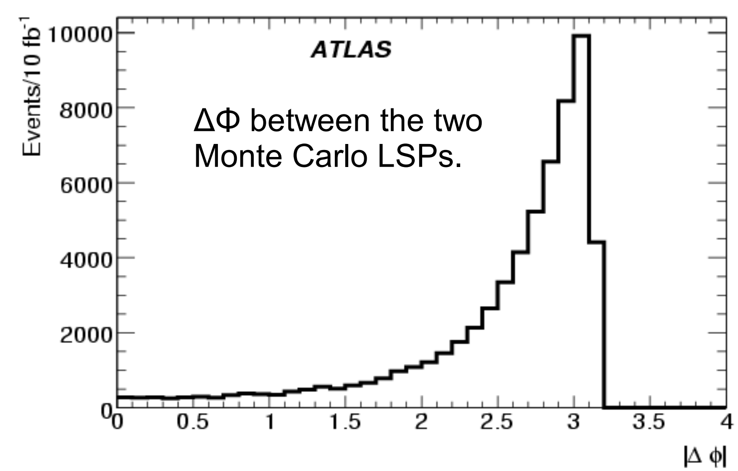
$|M_{SFOS}-M_Z| > 10$ GeV



$E_T^{miss} > 30$ GeV

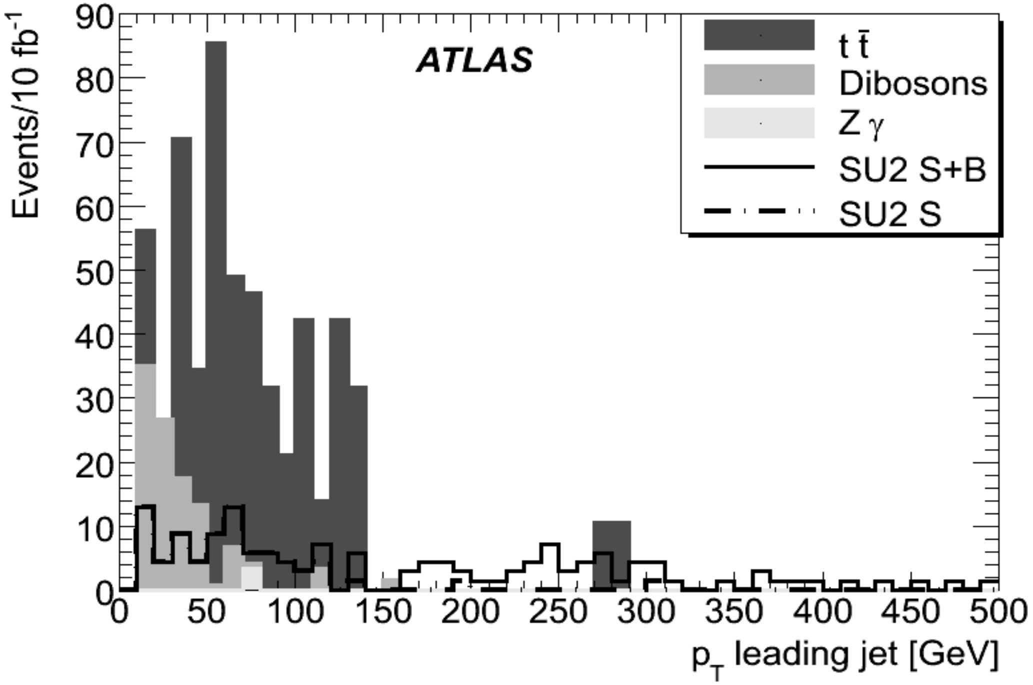


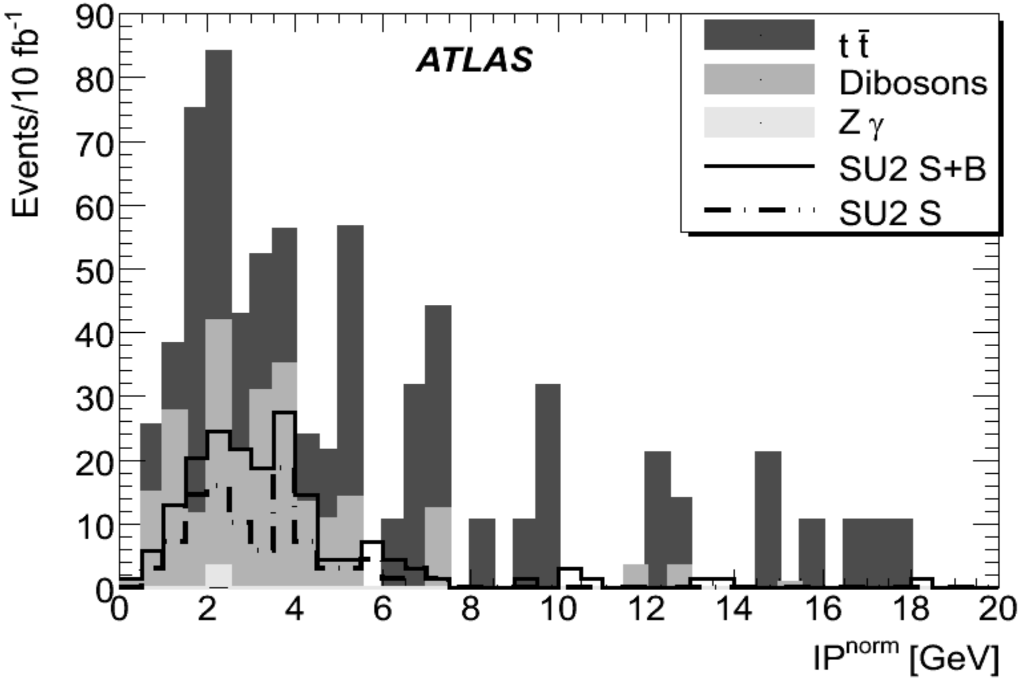
LSPs are "back-to-back"

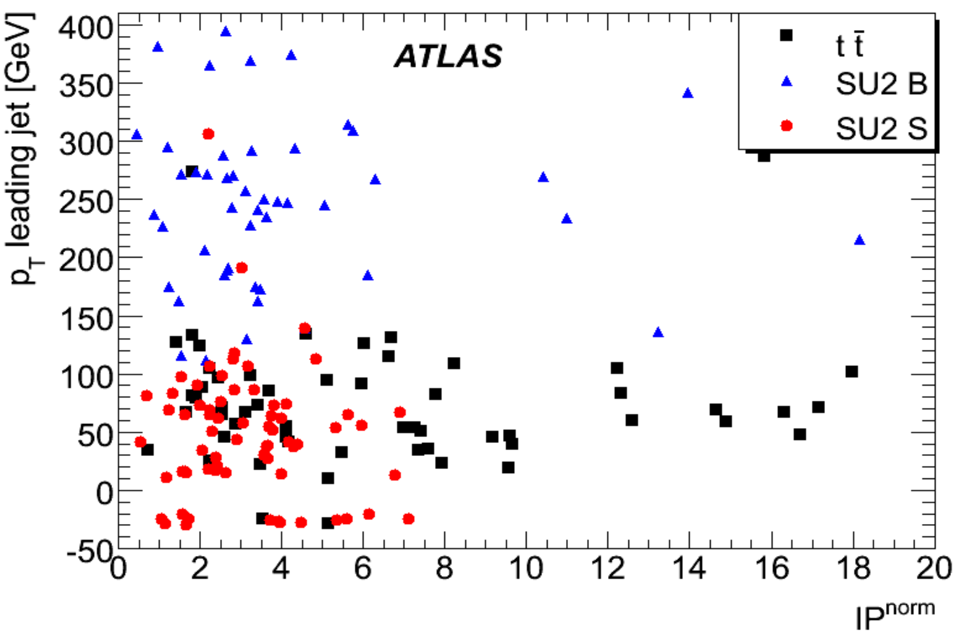


Jet Veto and IP

Normalised to10 fb^{-1}

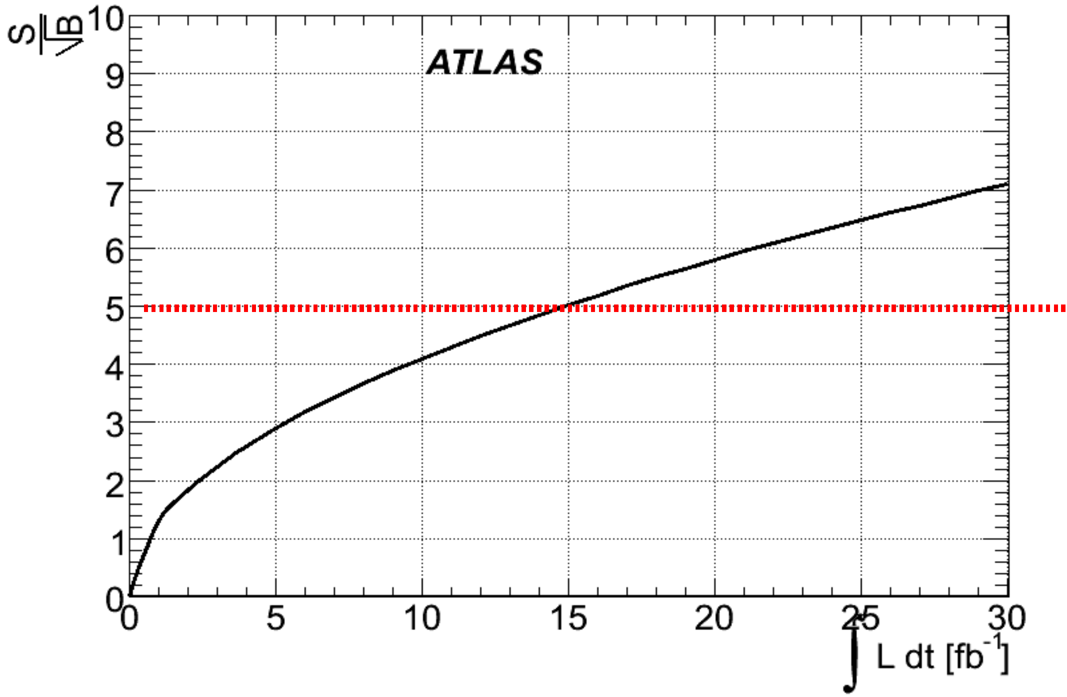






Normalised to10 fb^{-1}

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



Outlook on Data Driven Background Estimations

Most dangerous backgrounds are ttbar and ZW

ttbar

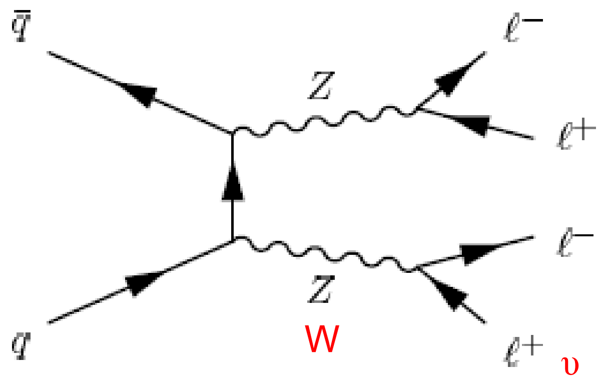
use lepton flavour and sign combinations of trilepton events.

SUSY incompatible no SFOS pair	SUSY compatible SFOS pair
$e^+e^+\mu^+$	$e^+e^-\mu^+$
$e^+e^+\mu^-$	$e^+e^-\mu^-$
$e^-e^-\mu^+$	
$e^-e^-\mu^-$	$\mu^+\mu^-e^+$
	$\mu^+\mu^-e^-$
$\mu^+\mu^+e^+$	
$\mu^+\mu^+e^-$	$e^+e^-e^+$
$\mu^-\mu^-e^+$	$e^+e^-e^-$
$\mu^-\mu^-e^-$	$\mu^+\mu^-\mu^+$
	$\mu^+\mu^-\mu^-$
$e^+e^+e^+$	
$e^-e^-e^-$	
$\mu^+\mu^+\mu^+$	
$\mu^-\mu^-\mu^-$	

The number of non-compatible combinations can be used to estimate the numbers of SUSY compatible combinations and thus the ttbar background to SUSY trilepton signal

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

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

Gaugino only SUSY discovery possible with trilepton channel

ZW and ttbar are the most dangerous backgrounds.
Controlled by lepton track isolation and Z mass window removal but moderate amounts still remain.
Background estimations not yet performed for trilepton analysis but ideas are already in place

Backup slide

Samples used

Sample	Generator	σ_{LO} [pb]	$\sigma_{LO} \times EF$	k	$\sigma_{NLO} \times EF$ [pb]	Sample $\mathcal{L}$ [fb^{-1}]
SU2	Herwig	4.9	4.9	1.5	7.2	6.9
SU3	Herwig	18.6	18.6	1.5	27.7	17.1
SU4	Herwig	262.0	262.0	1.5	402.2	0.5
$t\bar{t}$	MC@NLO	833.0	449.8	1.0	449.8	1.0
ZZ	Herwig	11.0	2.1	1.9	3.9	12.7
ZW	Herwig	27.0	7.8	2.1	16.1	3.0
WW	Herwig	70.0	24.5	1.7	40.9	1.2
$Z\gamma$	Pythia	3.8	2.6	1.3	3.4	3.0
Zb	AcerMC	205.0	153.8	1.0	163.9	0.8

Direct gaugino selection: N-1 table

$N_L >= 3$	SFOS	TrackIsol	ZWindow	$\not{E}_T$	Jet Veto	IP^{norm}	$\frac{S}{\sqrt{B}}$
$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	4.1
$\times$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	2.0
$\surd$	$\times$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	3.8
$\surd$	$\surd$	$\times$	$\surd$	$\surd$	$\surd$	$\surd$	2.9
$\surd$	$\surd$	$\surd$	$\times$	$\surd$	$\surd$	$\surd$	2.5
$\surd$	$\surd$	$\surd$	$\surd$	$\times$	$\surd$	$\surd$	3.4
$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\times$	$\surd$	4.0
$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$\times$	3.6