Trilepton SUSY Studies

Tina Potter and Antonella De Santo
RHUL
10/1/08
UK ATLAS, Durham

Royal Holloway
University of London

Outline

- Object definitions

- Exclusive trilepton study

- Inclusive trilepton study

- Lepton efficiencies and fake rates

- Outlook on data driven background estimation

- Summary

Studies performed in context of CSC notes 5 & 7

Object Definitions

	Muon	Electron	Photon	Jet
Collection Key	StacoMuonCollection	ElectronCollection	PhotonCollection	Cone4TowerParticleJets
p_T cut	>10 GeV	>10 GeV	>10 GeV	>10 GeV
η cut	$\|\eta\| < 2.5$	$0 < \|\eta\| < 1.37$ or $1.52 < \|\eta\| < 2.5$	$\|\eta\| < 2.5$	$\|\eta\| < 2.5$
Calorimeter Isolation	$\|E\| < 10$ GeV in $\Delta R = 0.2$	$\|E\| < 10$ GeV in $\Delta R = 0.2$	$\|E\| < 10$ GeV in $\Delta R = 0.2$	- -
IsEM flag	-	0x3FF	0x7FF	-
Other	bestMatch combinedMuon HighPt algorithm	Egamma author only	-	-
Overlap Removal	none	none	ele-pho $\Delta R > 0.2$	ele-jet $\Delta R > 0.2$

Overlap removal

if ΔR < 0.2 between ele-jets, electron has priority

if 0.2 < ΔR < 0.4 between ele-jets, jet has priority
if ΔR < 0.4 between muon-jets, jet has priority

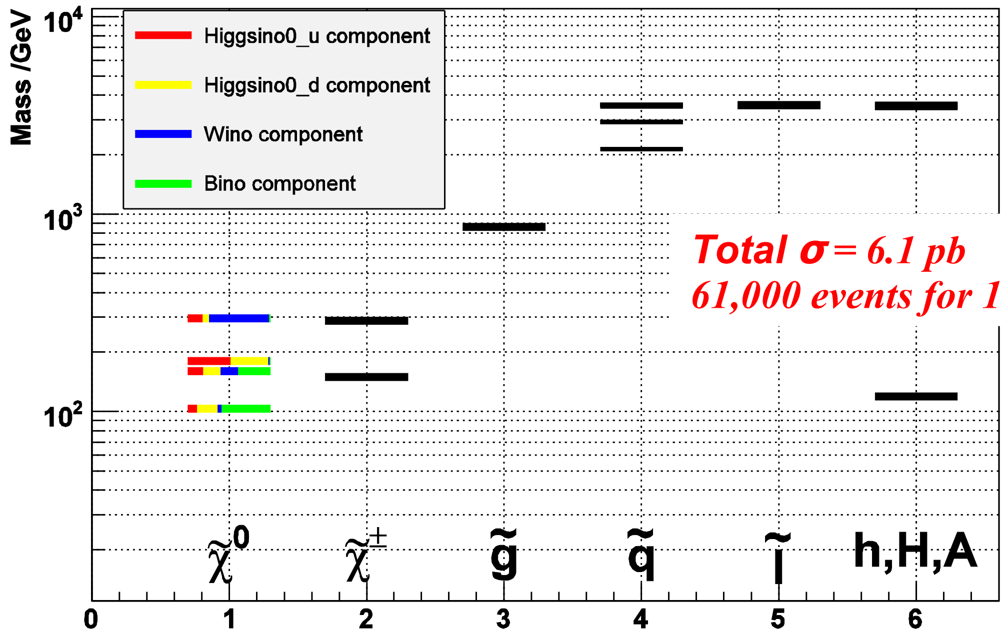
if SFOS pair found with M_{SFOS} < 20 GeV, pair is removed from event
likely to be from conversions

Object definitions and overlap removal used is in agreement with SUSY CSC 5 & 7 notes

SU2

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

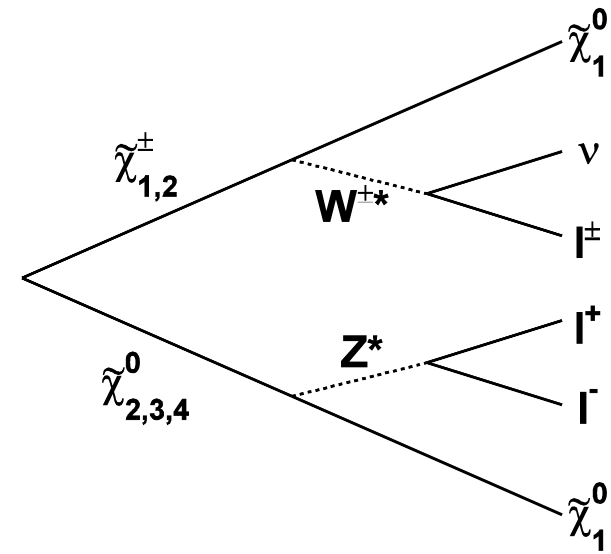
Mass spectrum of sparticles at the SU2 point



Total σ = 6.1 pb
61,000 events for 10 fb^{-1}

Heavy scalars are too massive so no decays through intermediate sleptons

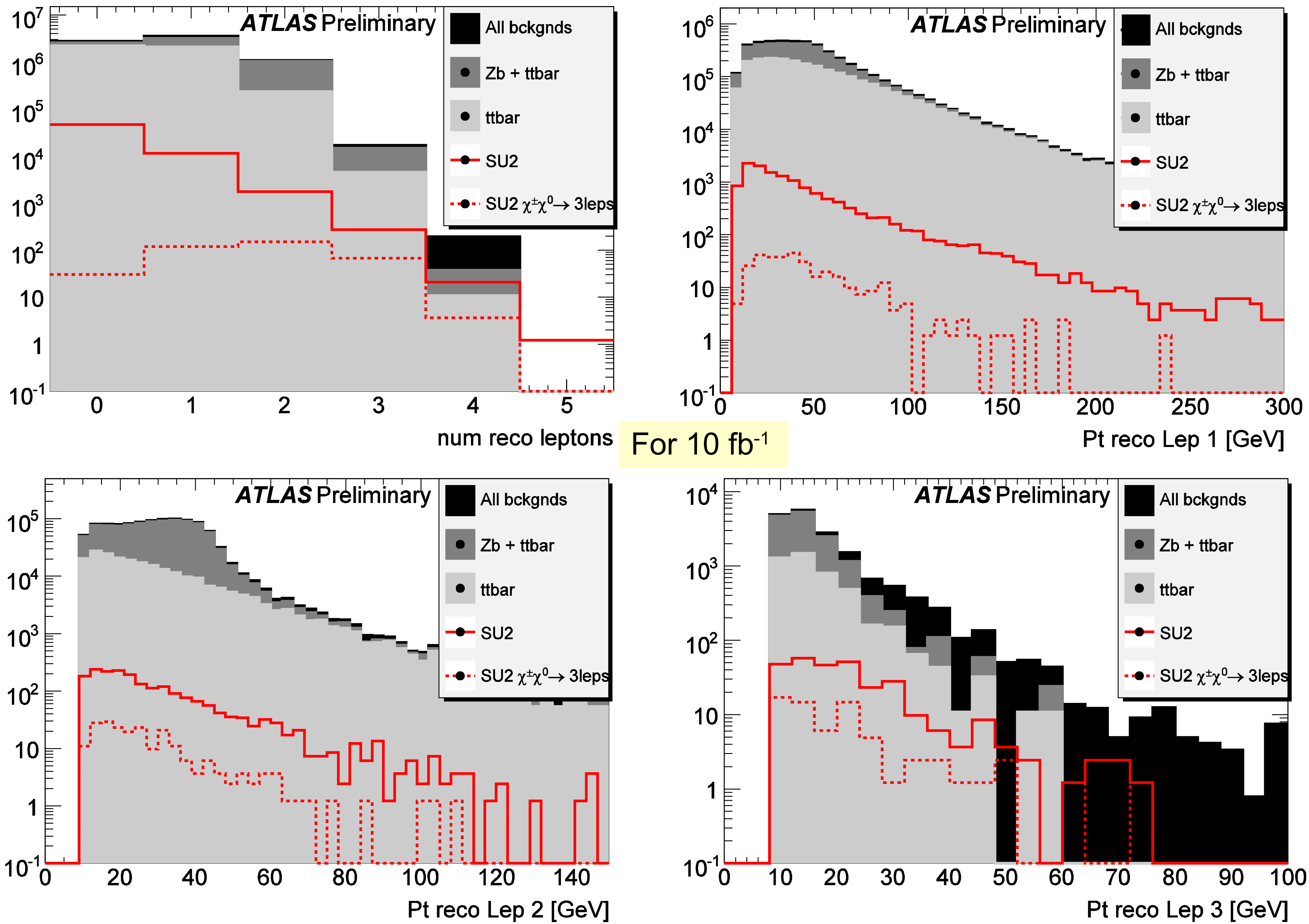
Direct chargino-neutralino production and decay to a trilepton final state

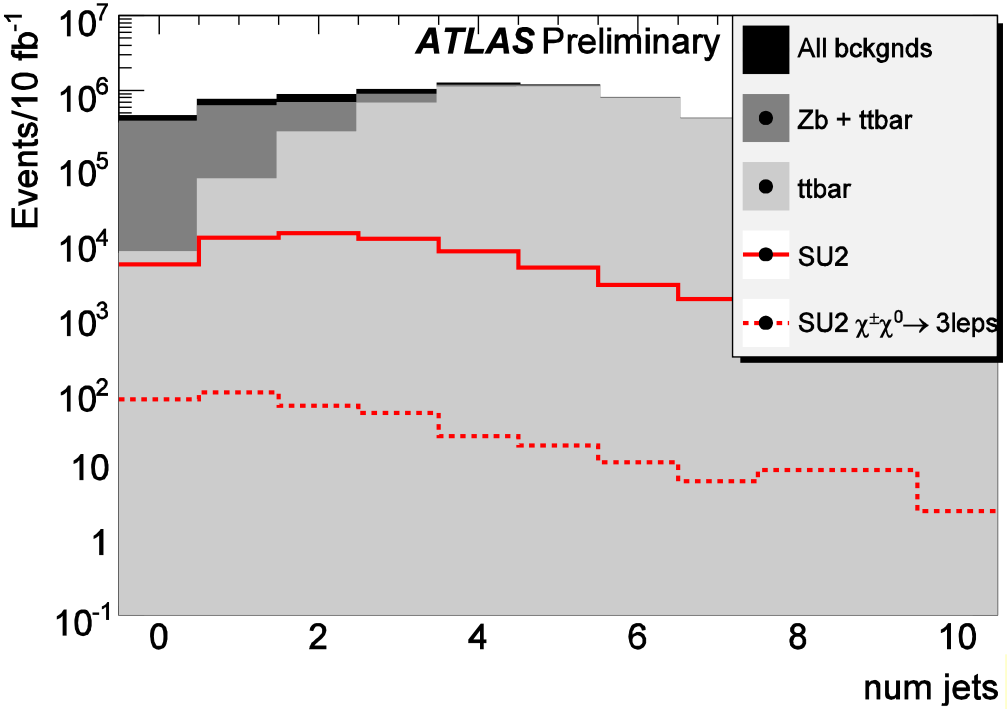


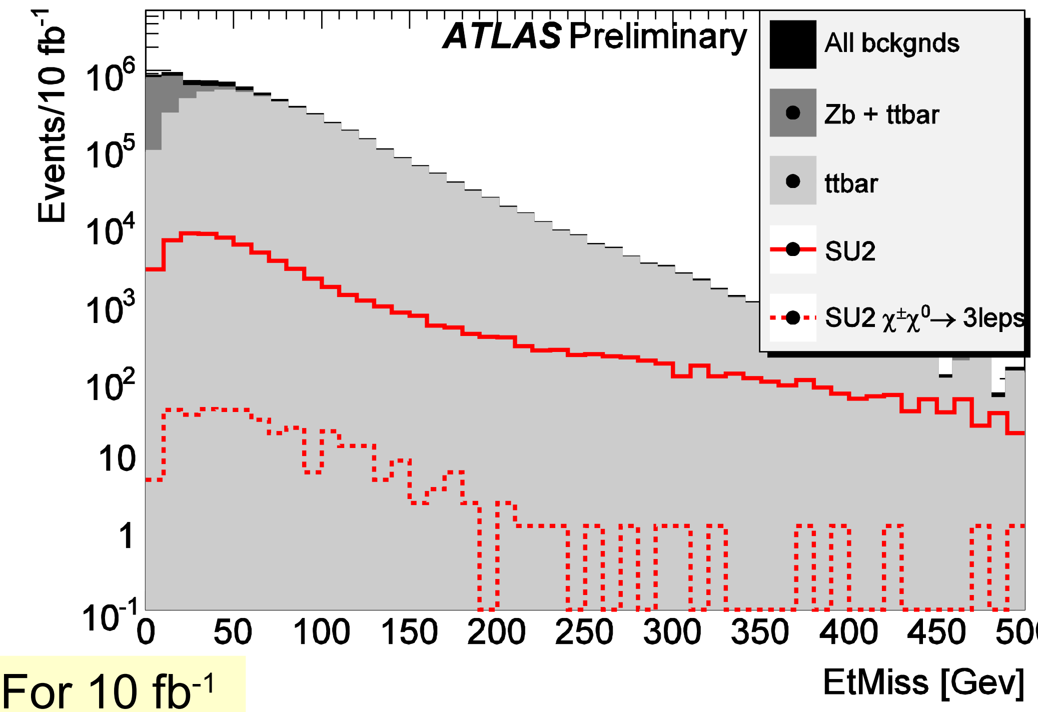
Production	σ [fb]	# events /10 fb^{-1}	# 3l events /10 fb^{-1}
$\tilde\chi_1^\pm \tilde\chi_2^0$	1138.0	11380	175
$\tilde\chi_1^\pm \tilde\chi_3^0$	679.3	6793	105
$\tilde\chi_1^\pm \tilde\chi_4^0$	51.4	514	6
$\tilde\chi_2^\pm \tilde\chi_2^0$	58.5	585	7
$\tilde\chi_2^\pm \tilde\chi_3^0$	61.6	616	7
$\tilde\chi_2^\pm \tilde\chi_4^0$	310.3	3103	26
TOTAL		22991	326

Normalised to10 fb^{-1}

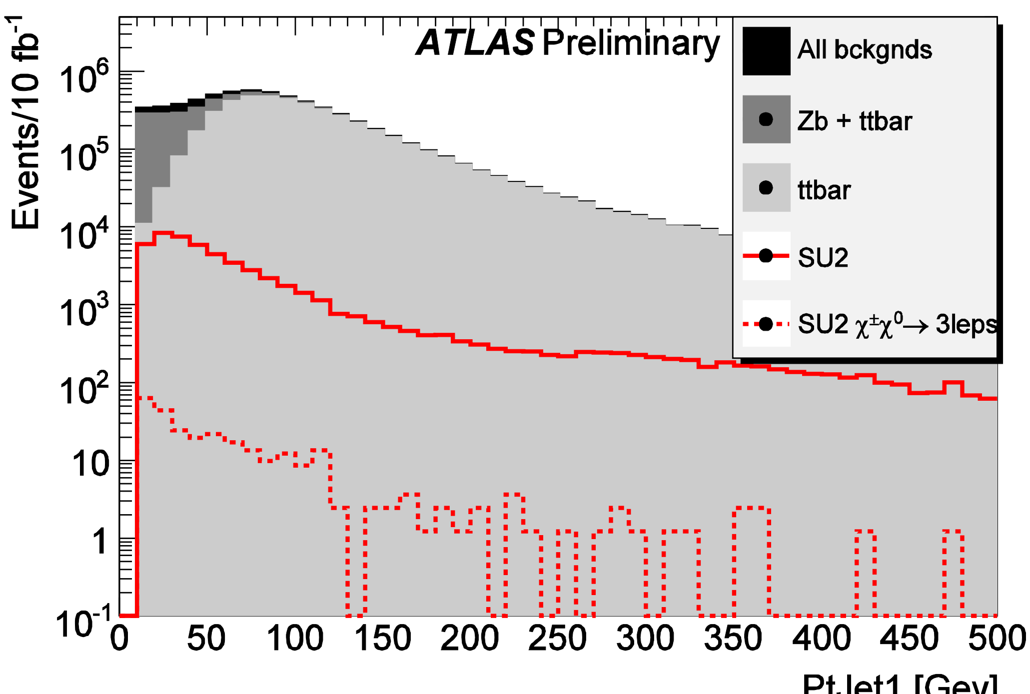
Process	Generator	σ_{NLO} [pb]	# events /10 fb^{-1}	Sample Luminosity [fb^{-1}]
$SU2$	Herwig	6.1	61000	8.2
$SU3$	Herwig	23.2	232000	20.4
$SU4$	Herwig	327.5	3275000	0.6
$t\bar t$	MC@NLO	461.0	4610000	0.9
ZZ	Herwig	3.9	39000	12.7
ZW	Herwig	16.1	161000	3.0
WW	Herwig	40.9	409000	1.2
$Z\gamma$	Pythia	3.4	34000	3.0
Zb	AcerMC	226.2	2262000	0.8

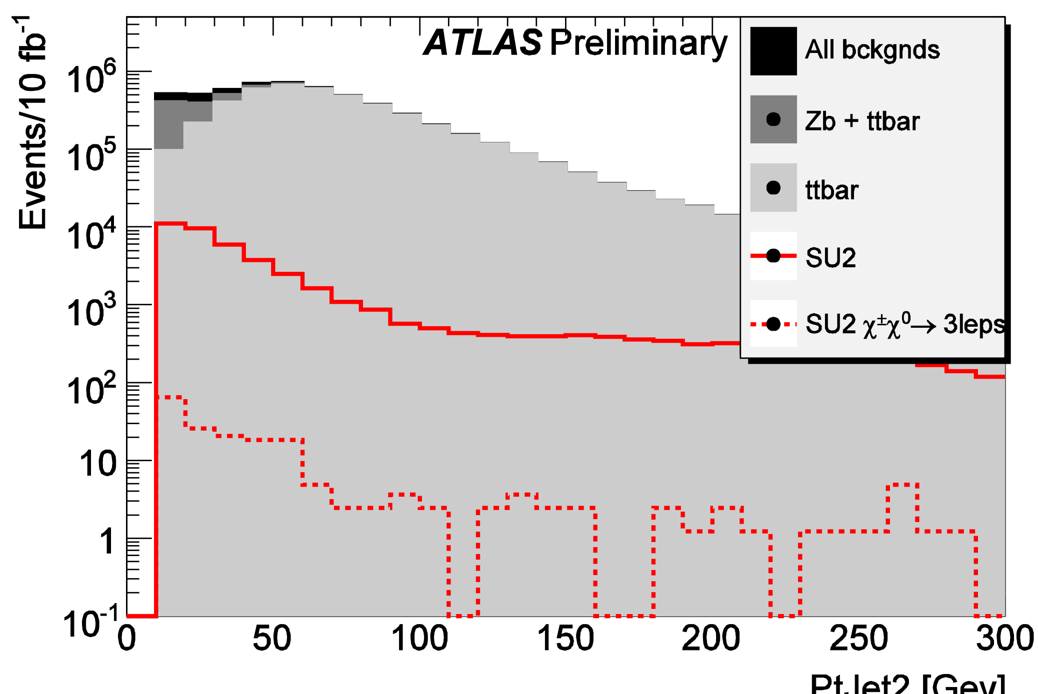

ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU2
SU2 $\chi^{\pm}\chi^{0}\rightarrow$ 3leps
num reco leptons
Pt reco Lep 1 [GeV]
Pt reco Lep 2 [GeV]
Pt reco Lep 3 [GeV]
For 10 fb^{-1}


ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU2
SU2 χ±χ0→ 3leps
Events/10 fb-1
num jets


ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU2
SU2 χ±χ0→ 3leps
Events/10 fb-1
EtMiss [Gev]

For 10 fb^{-1}


ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU2
SU2 χ±χ0→ 3leps
Events/10 fb-1
PtJet1 [Gev]


ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU2
SU2 χ±χ0→ 3leps
Events/10 fb-1
PtJet2 [Gev]

1. 2 SFOS leptons : Same Flavour Opposite Sign leptons (e^+e^- , $\mu^+\mu^-$)

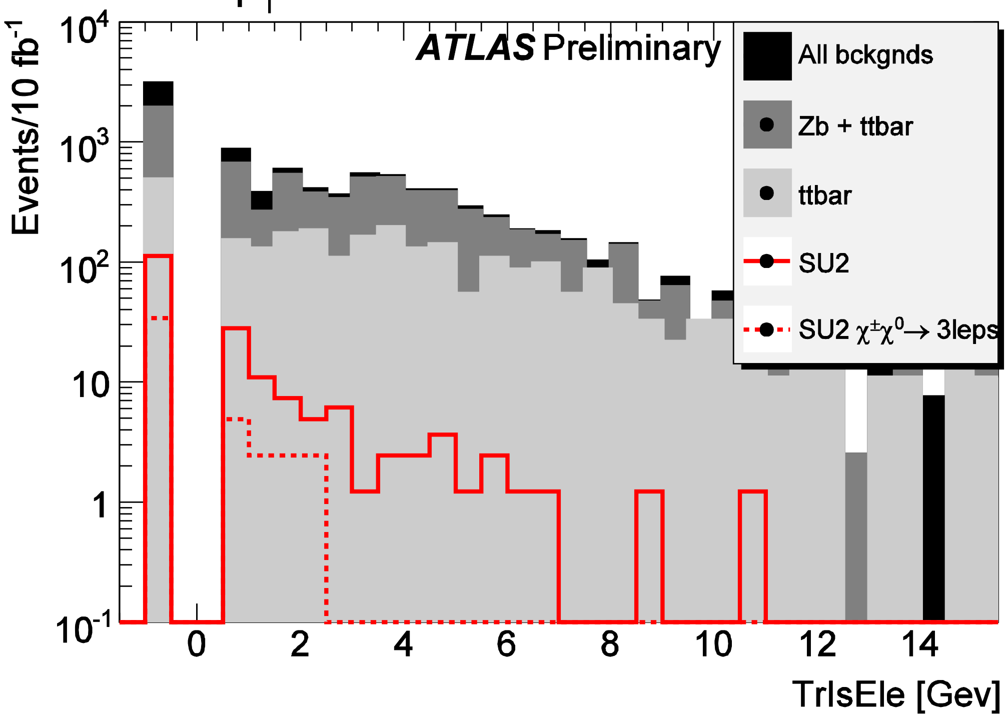
Low mass pairs (M_{SFOS}<20 GeV) already removed from event

2. $N_l >= 3$: Number of leptons (l = e,μ, $\neq \tau$)
3. Track Isolation : in $\Delta R(0.2)$, p_T^{max} <1 GeV for muons, <2 GeV for electrons.
4. 81.2 GeV < M_{SFOS} < 101.2 GeV : Invariant mass of any SFOS leptons, remove Z window
5. $\not{E}_T >$ 30 GeV : Missing transverse Energy
6. Jet Veto : no jets with p_T >20 GeV.

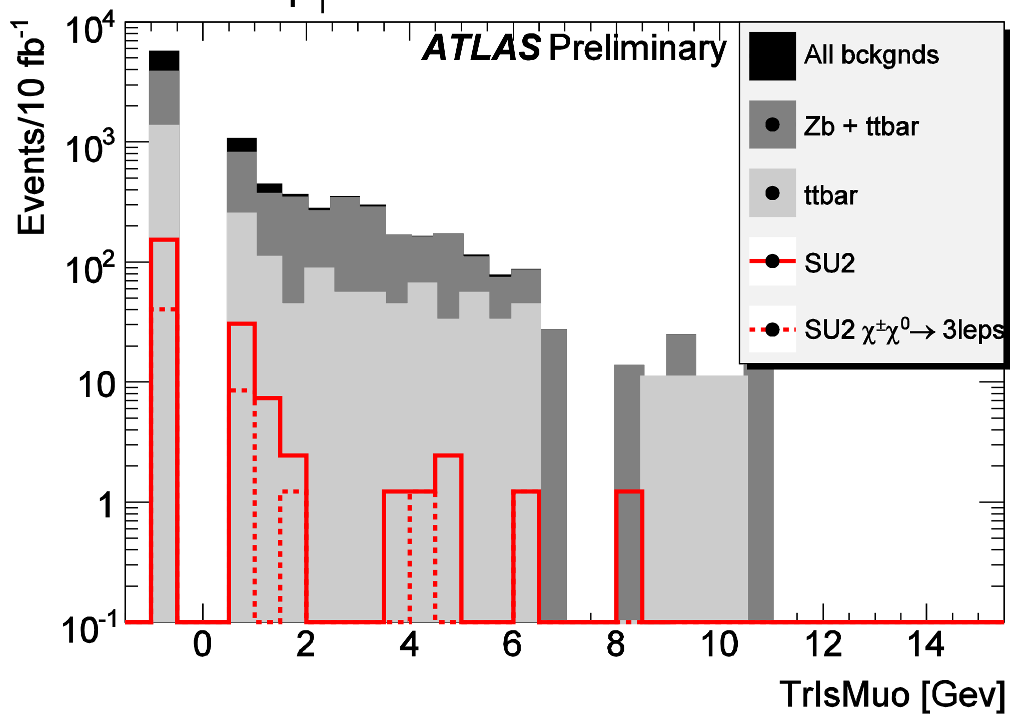
Normalised to10 fb^{-1}

Lepton track isolation:

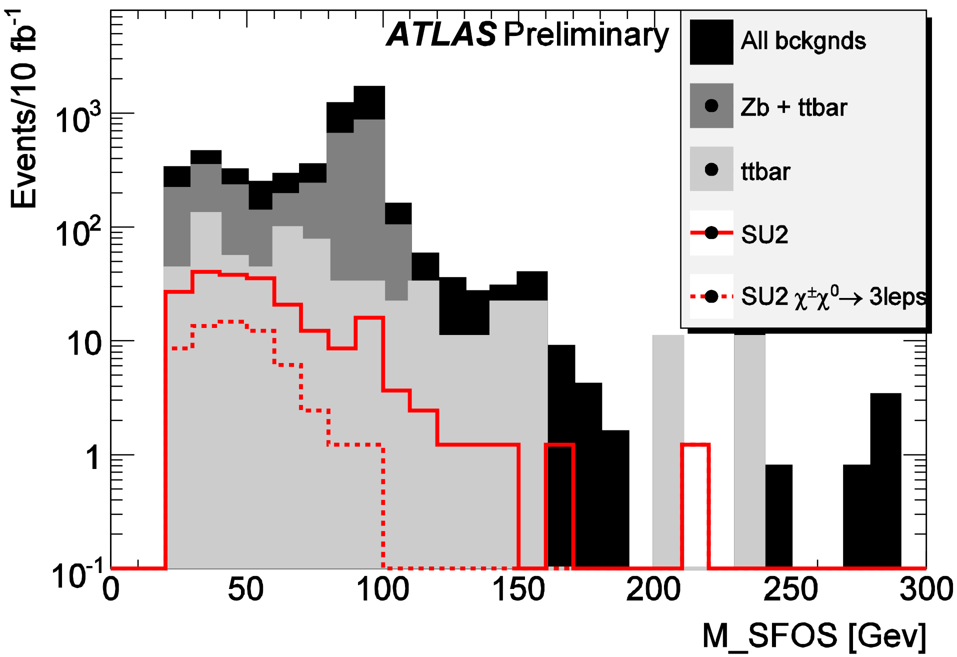
p_T^{max} < 2 GeV for electrons



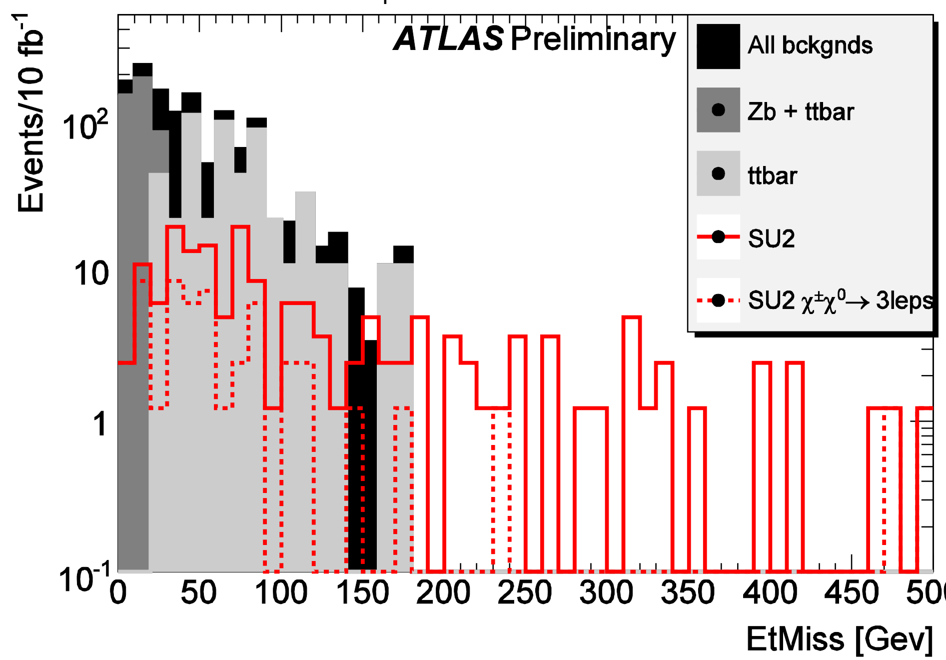
p_T^{max} < 1 GeV for muons



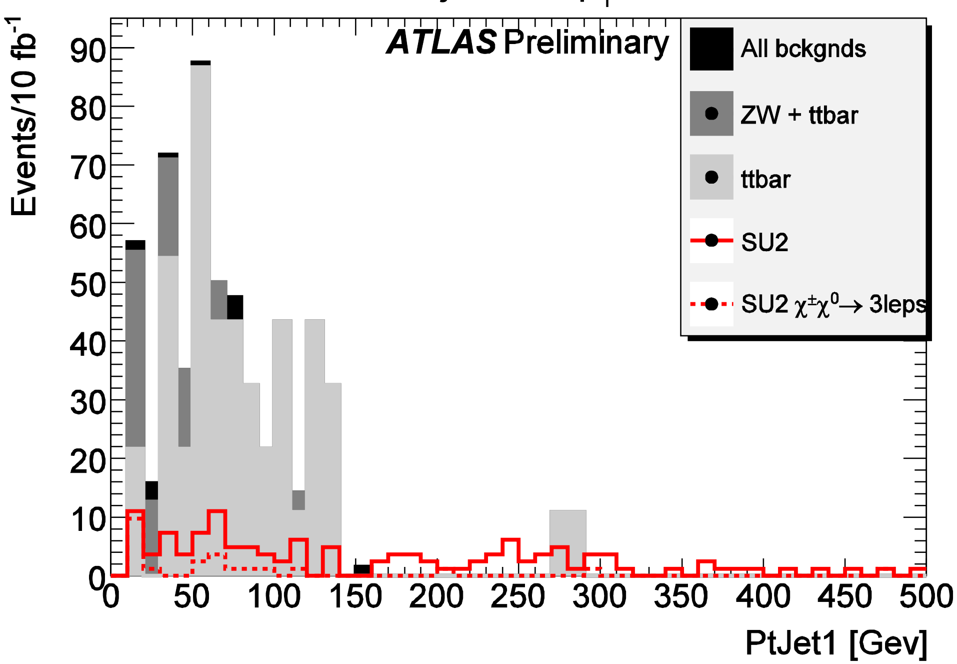
$|M_{SFOS}-M_Z| > 10$ GeV



$E_T^{miss} > 30$ GeV



Jet Veto – no jet with $p_T > 20$ GeV



Normalised to10 fb^{-1}

Normalised to10 fb^{-1}

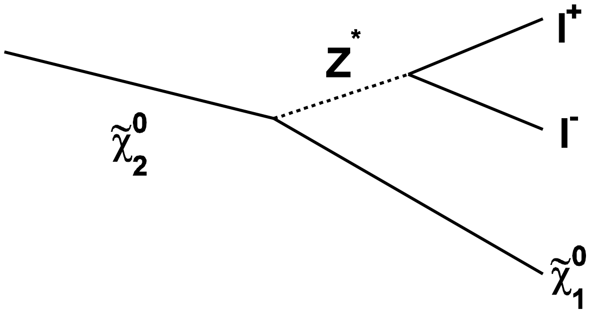
Kinematic Cut	No Cuts	$N_L >= 2$	SFOS	$N_L >= 3$	TrackIsol	ZWindow	$\not{E}_T$	JetVeto
Sample								
SU2 Signal	370	221	143	67	61	55	43	23
SU2 Bckgnd	59772	1828	1092	191	149	119	111	4
$t\bar{t}$	4516201	240494	106779	2882	650	520	488	43
ZZ	38153	10400	9971	579	475	57	13	6
ZW	157000	17255	14502	1913	1685	322	218	154
WW	400174	22688	10678	25	8	8	8	8
Z+Photon	32832	7184	6970	91	27	7	3	0
Zb	1591157	573601	559237	6523	2409	386	0	0
Case A S/sqrt(S+B)	23.07	2.19	1.47	2.33	2.84	4.52	5.18	1.74
Case B S/sqrt(S+B)	0.14	0.24	0.17	0.61	0.84	1.49	1.54	1.51

Case A : SUSY Bckgnd counted as SUSY Signal
(hard to distinguish experimentally)
S/sqrt(S+B) = 1.74
5σ discovery after 90 fb^{-1} of data

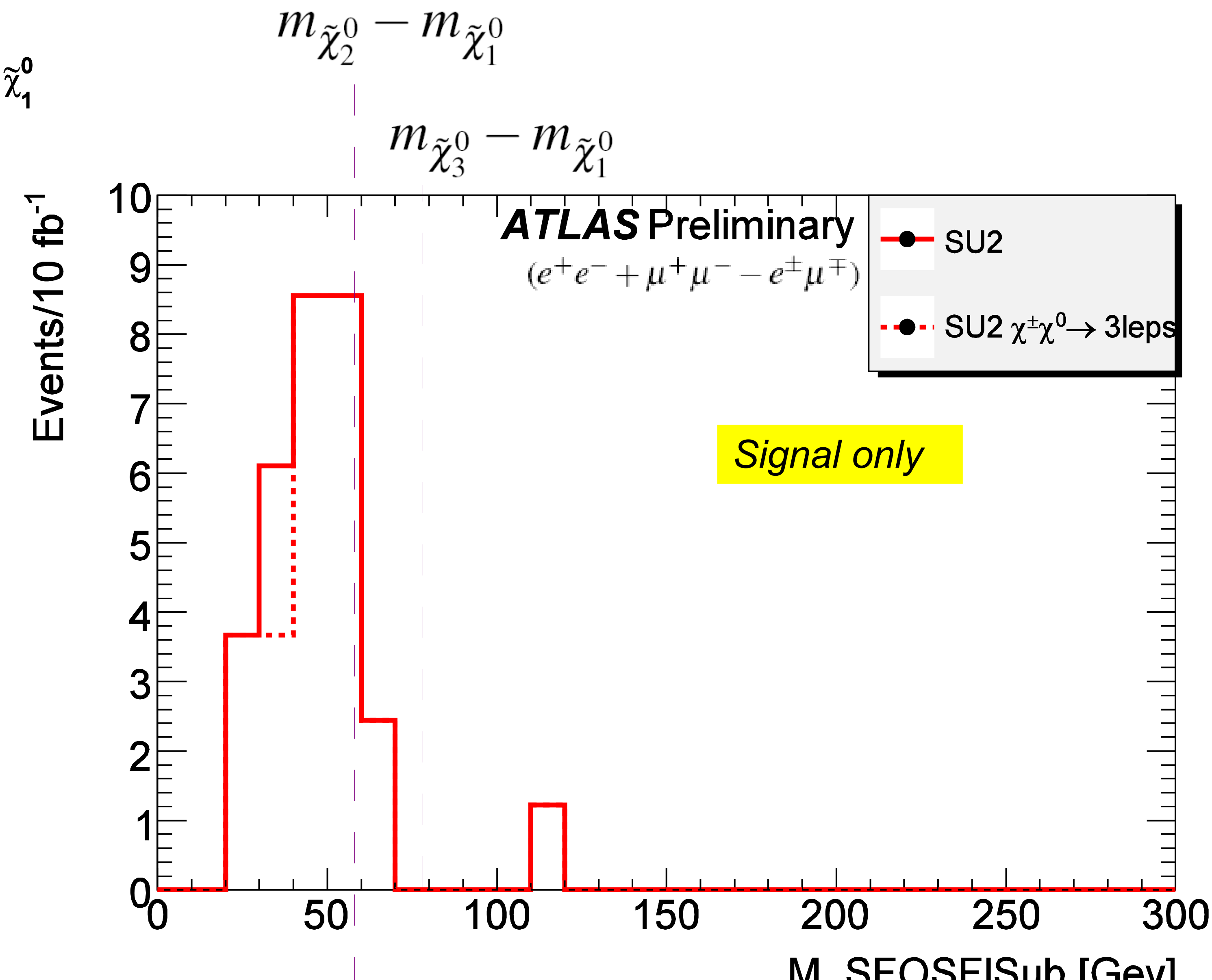
Case B : SUSY Bckgnd = 0
(only direct gaugino production)
S/sqrt(S+B) = 1.51
5σ discovery after 120 fb^{-1} of data

N-1 table

S/sqrt(S+B)	Case A	Case B
With All Cuts	1.74	1.51
Remove SFOS	1.79	1.49
Remove 3leps	1.74	0.55
Remove Track Isolation	1.39	1.16
Remove ZWindow	0.97	0.85
Remove $\not{E}_T$	1.63	1.42



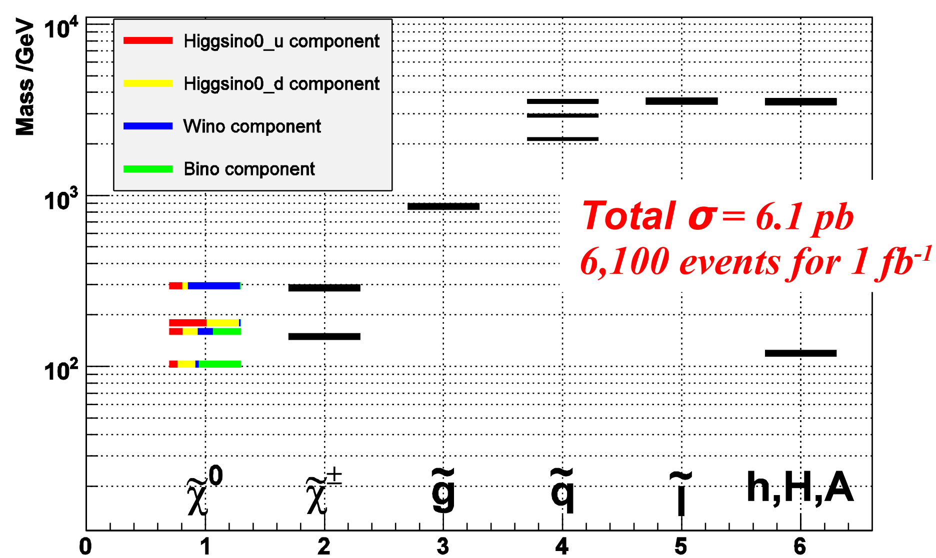
Normalised to10 fb^{-1}



SU2

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

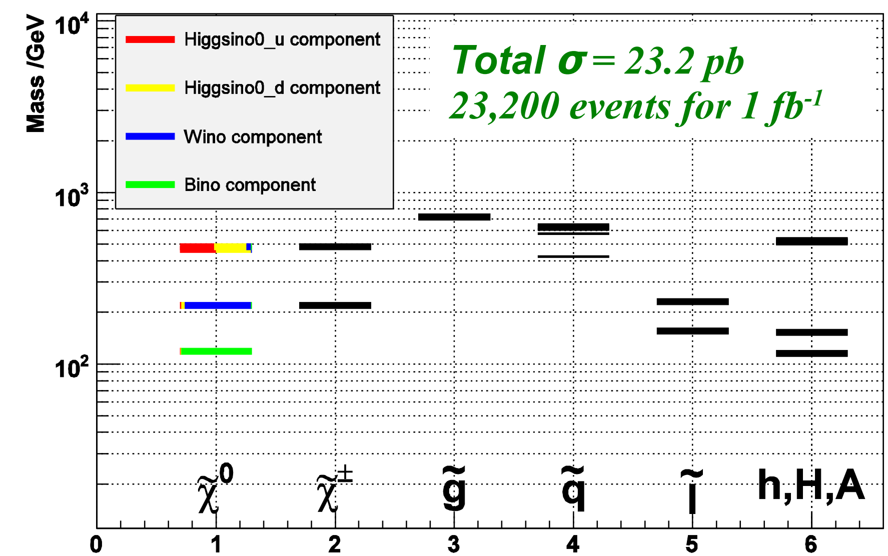
Mass spectrum of sparticles at the SU2 point



SU3

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

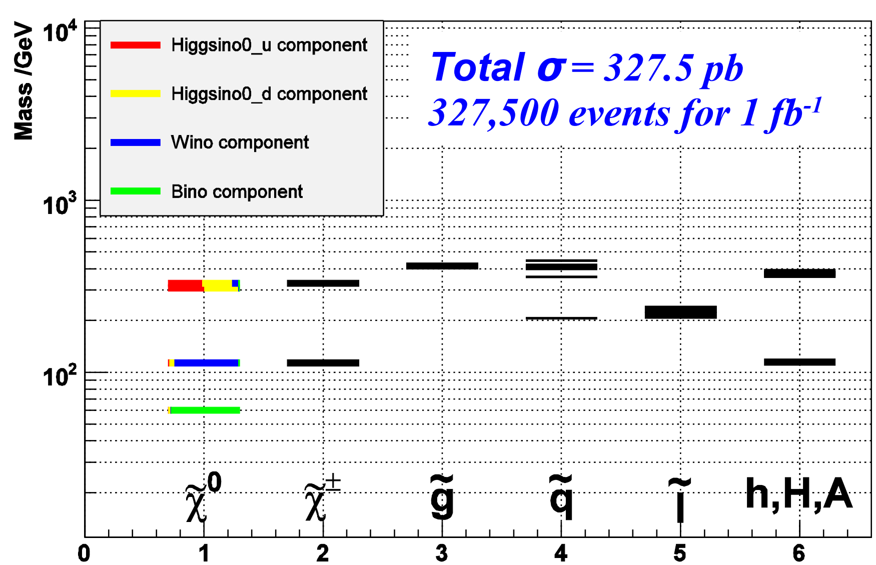
Mass spectrum of sparticles at the SU3 point



SU4

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

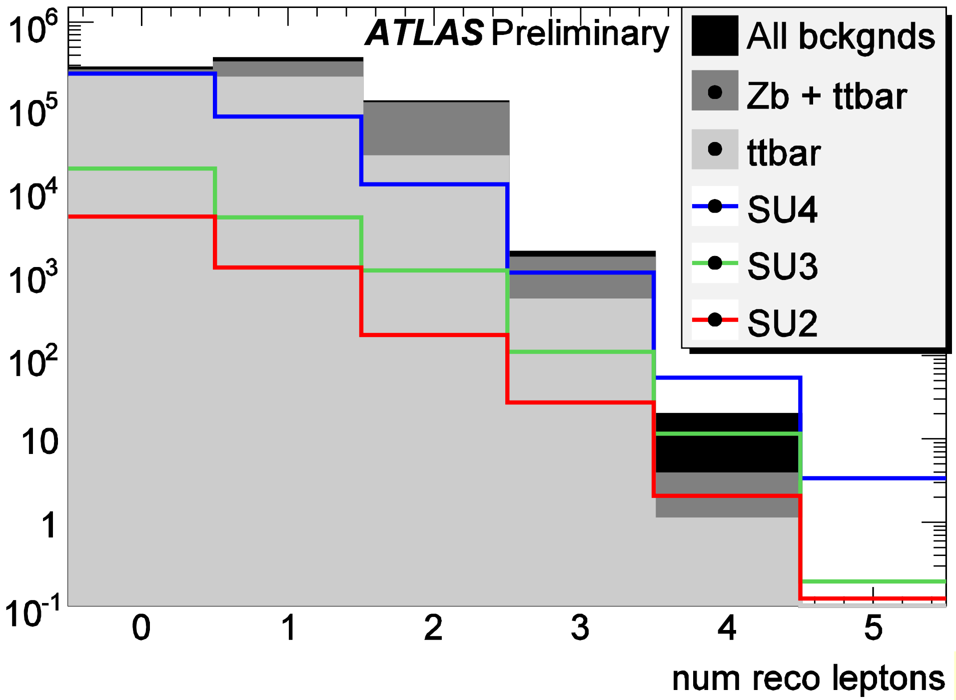
Mass spectrum of sparticles at the SU4 point

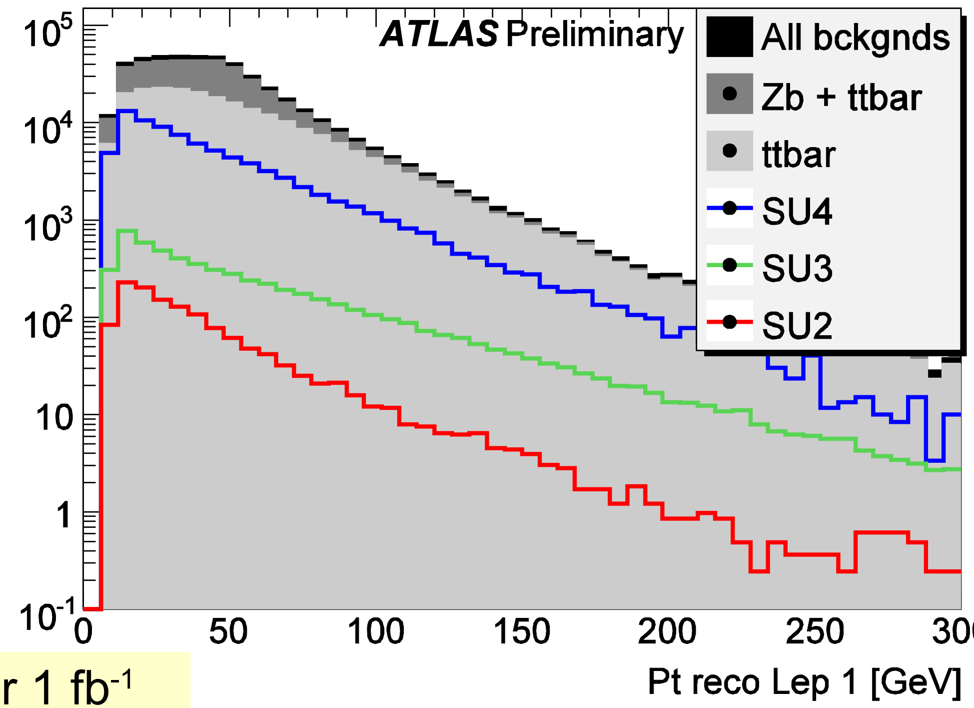


Normalised to1 fb^{-1}

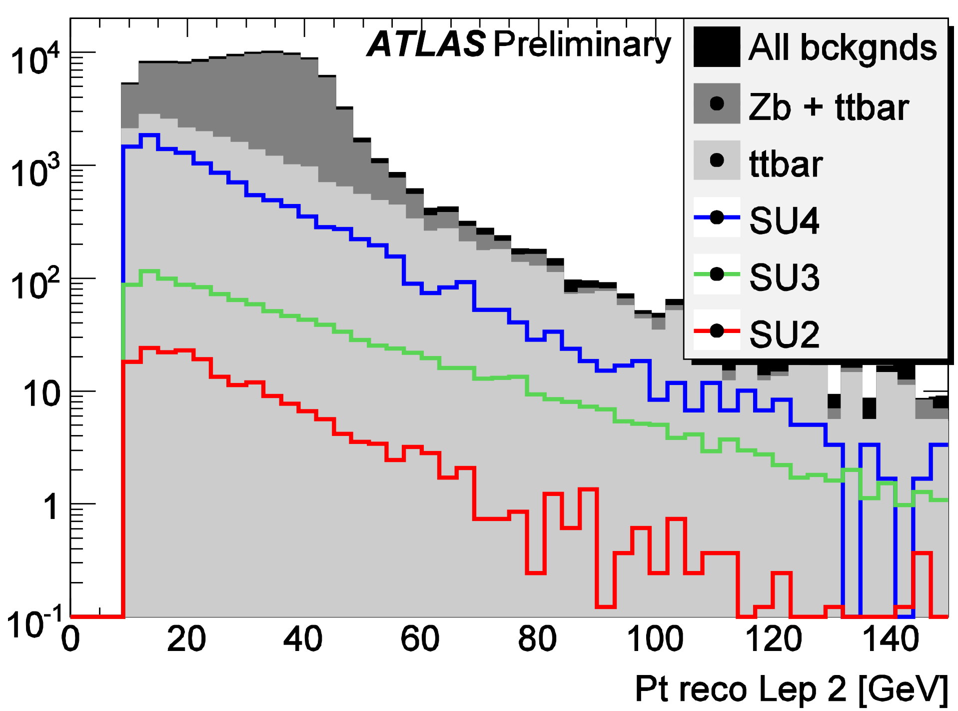
	SU2	SU3	SU4
σ_{TOT} [pb]	6.08	23.24	327.50
σ_{3lep} [pb]	0.06	0.25	2.03
Total events	6075	23238	327500
3 lepton events	60	250	2027

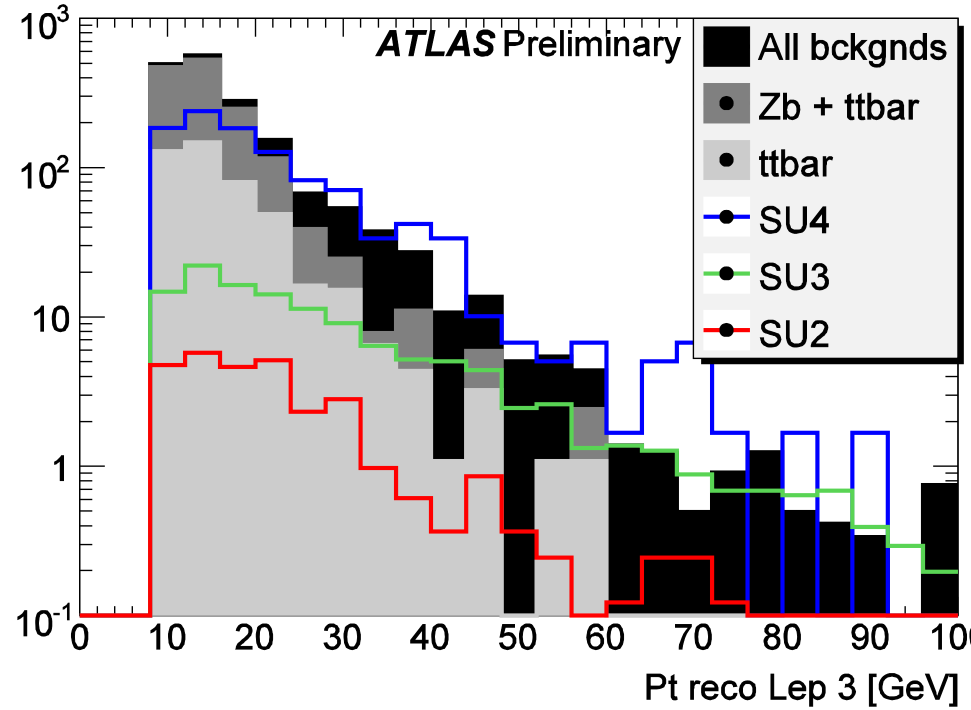
Process	Generator	σ_{NLO} [pb]	# events /1 fb^{-1}	Sample Luminosity [fb^{-1}]
$SU2$	Herwig	6.1	6100	8.2
$SU3$	Herwig	23.2	23200	20.4
$SU4$	Herwig	327.5	327500	0.6
$t\bar{t}$	MC@NLO	461.0	461000	0.9
ZZ	Herwig	3.9	3900	12.7
ZW	Herwig	16.1	16100	3.0
WW	Herwig	40.9	40900	1.2
$Z\gamma$	Pythia	3.4	3400	3.0
Zb	AcerMC	226.2	226200	0.8

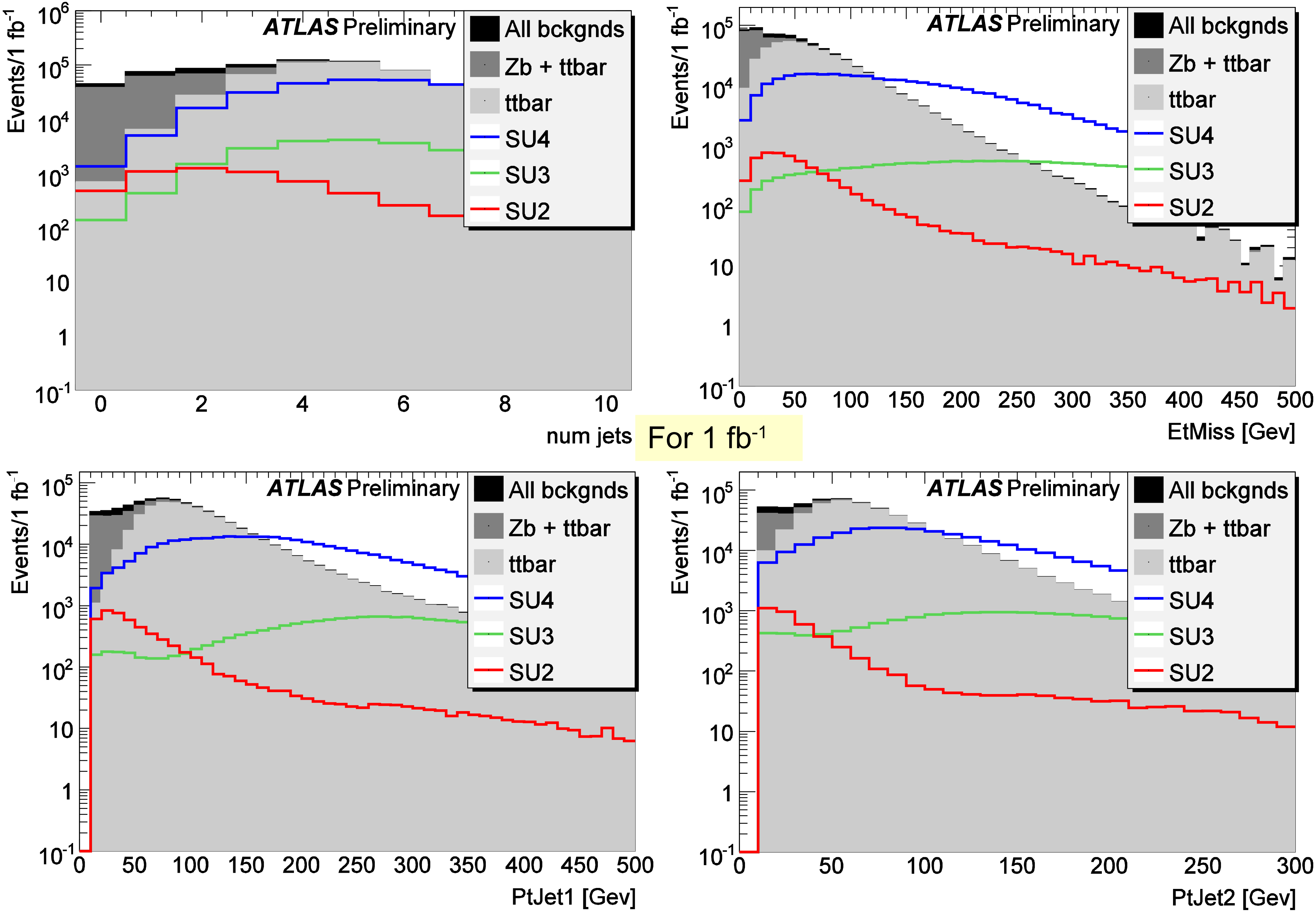

ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU4
SU3
SU2
num reco leptons


ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU4
SU3
SU2
Pt reco Lep 1 [GeV]

For 1 fb^{-1}


ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU4
SU3
SU2
Pt reco Lep 2 [GeV]


ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU4
SU3
SU2
Pt reco Lep 3 [GeV]


ATLAS Preliminary
All bckgnds
Zb + ttbar
ttbar
SU4
SU3
SU2
Events/1 fb-1
num jets
EtMiss [Gev]
PtJet1 [Gev]
PtJet2 [Gev]
For 1 fb-1

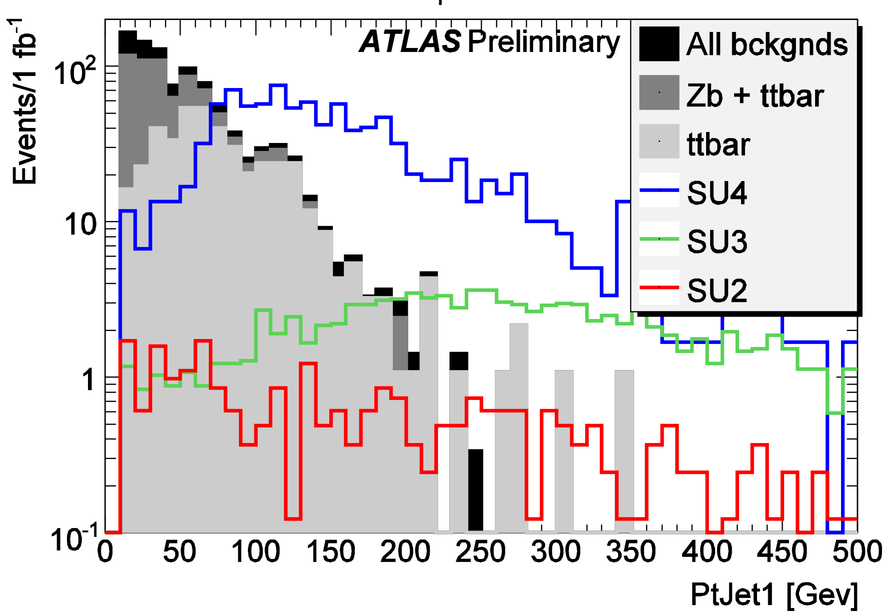
Normalised to1 fb^{-1}

1. $N_l >= 3$: Number of leptons ($l = e, \mu, \neq \tau$)

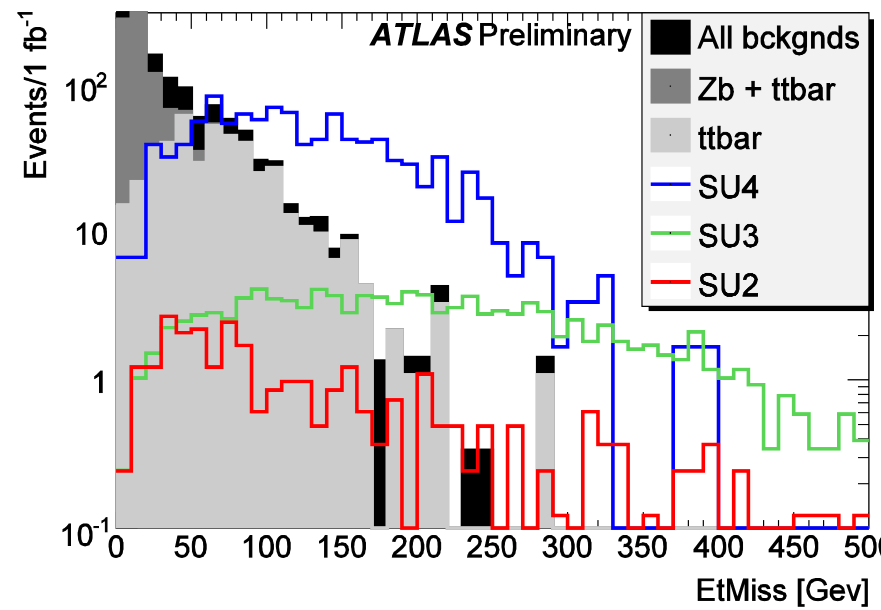
2. At least 1 jet $p_T^{jet1} > 200$ GeV : transverse momentum of leading jet

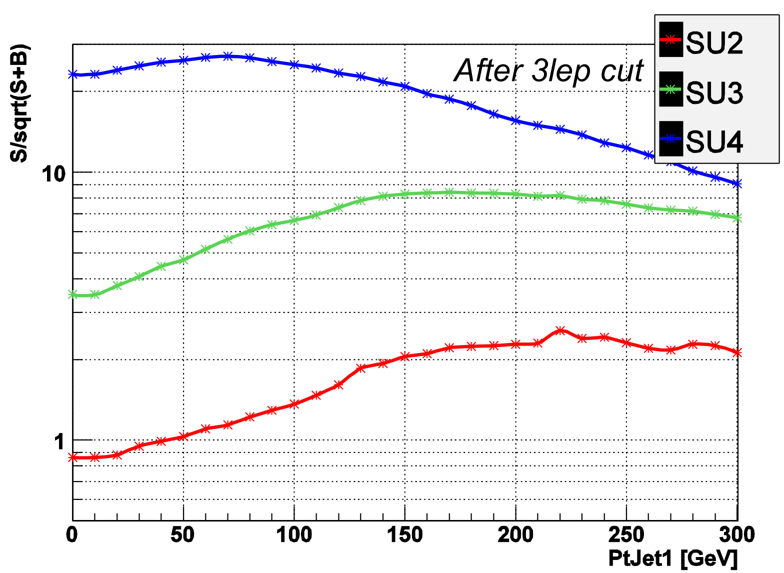
Simple and powerful analysis

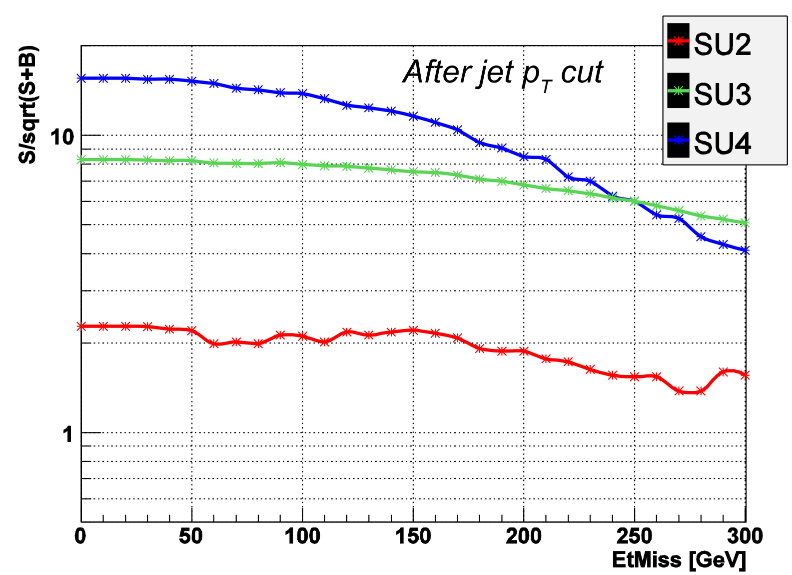
At least 1 jet with $p_T > 200$ GeV



Possibly $E_T^{miss} > 150$ GeV







Normalised to1 fb^{-1}

Kinematic Cut	No Cuts	N_l	p_T^{jets}
Sample			
SU2	6014	30	11
SU3	22949	117	79
SU4	322826	1045	254
$t\bar{t}$	451620	455	11
ZZ	3815	59	0
ZW	15700	193	1
WW	40017	3	0
Z+Photon	3283	9	0
Zb	159116	656	0
SU2 : S/sqrt(S+B)	7.3	0.8	2.3
SU3 : S/sqrt(S+B)	27.5	3.0	8.3
SU4 : S/sqrt(S+B)	323.4	21.2	15.6

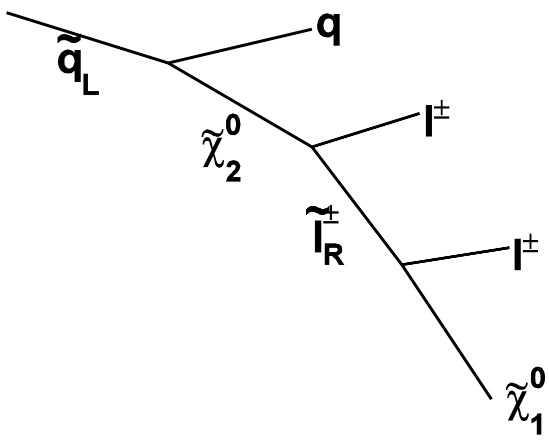
SU2
S/sqrt(S+B) = 2.3
5σ discovery after 5 fb^{-1} of data

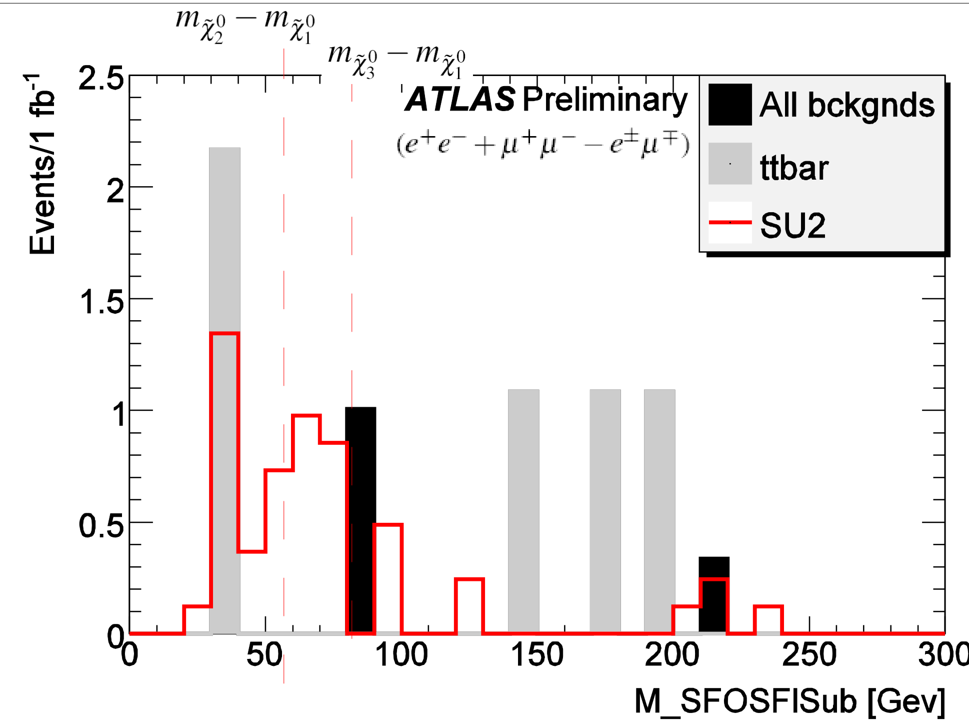
SU3
S/sqrt(S+B) = 8.3
5σ discovery after 400 pb^{-1} of data

SU4
S/sqrt(S+B) = 15.6
5σ discovery after 150 pb^{-1} of data

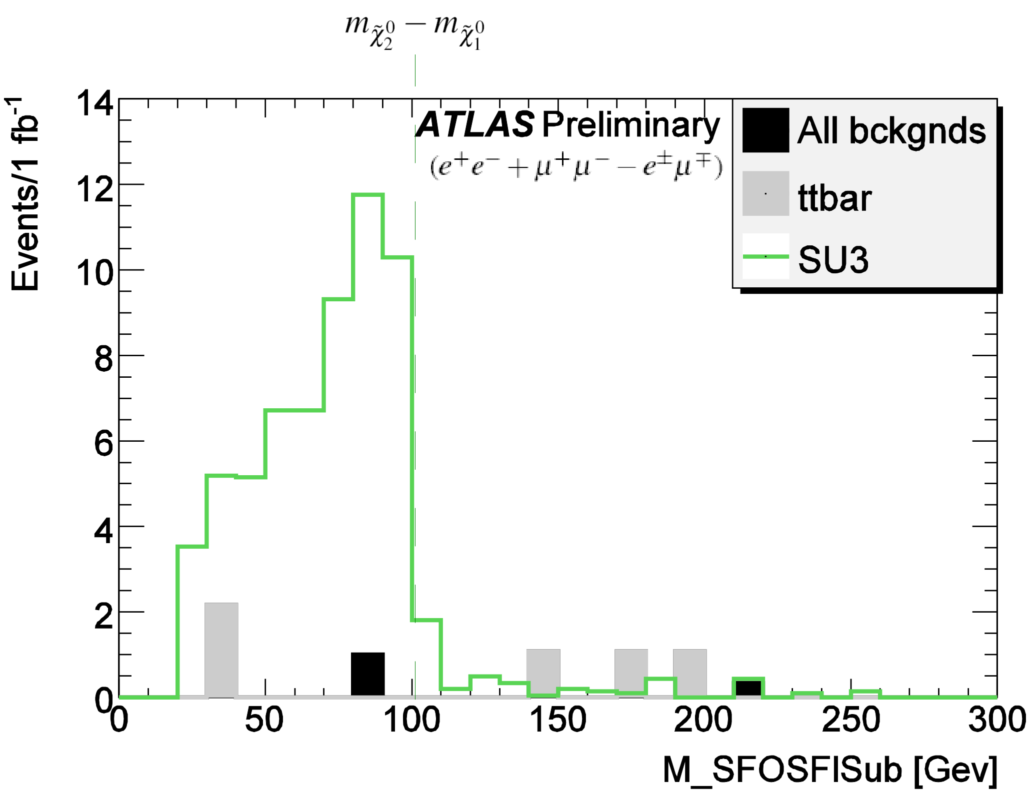
Possible combinations of jet p_T, E_t^{miss} and track isolation cuts

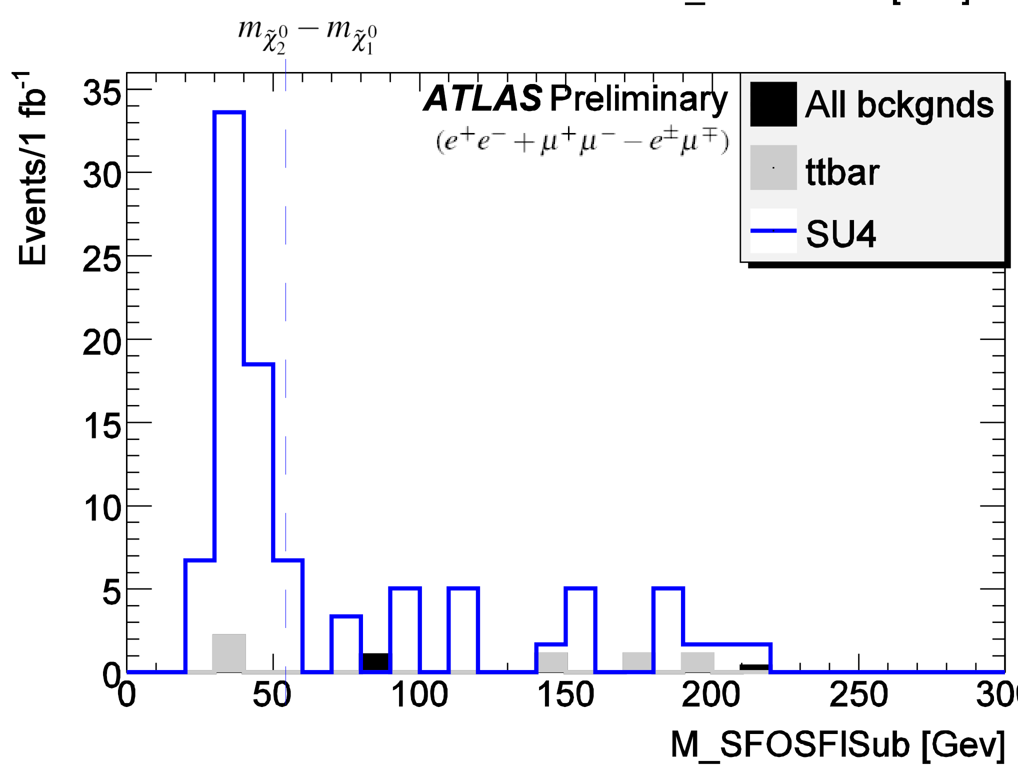
	$p_T^{jet\,1} > 200$ GeV	$\not{E}_T > 150$ GeV	Track Isolation	$S/\sqrt{S+B}$		
				SU2	SU3	SU4
Set 1	✓	✗	✗	2.3	8.3	15.6
Set 2	✗	✓	✗	1.6	7.5	17.7
Set 3	✗	✗	✓	1.0	3.6	19.7
Set 4	✗	✓	✓	1.7	7.0	14.5
Set 5	✓	✓	✗	2.2	7.6	11.6
Set 6	✓	✗	✓	2.3	7.6	13.2
Set 7	✓	✓	✓	1.9	6.7	9.5





Normalised to1 fb^{-1}





Performance

Efficiencies and Fake Rates

with p_T > 12 GeV, $|\eta|$ < 2.5, $E_T(0.2)$ < 10 GeV, from heavy decay (W,Z,τ,SUSY)

$$\text{Eff} = \frac{\#\ \text{truth}\ e(\mu)\ \text{with}\ \Delta R<0.02\ \text{match to reco}\ e(\mu)}{\#\ \text{truth}\ e(\mu)}$$

with p_T > 8 GeV, $|\eta|$ < 2.5, $E_T(0.2)$ < 10 GeV, from heavy decay (W,Z,τ,SUSY)

$$\text{Fake Rate} = \frac{\#\ \text{reco}\ e(\mu)\ \text{with no}\ \Delta R<0.02\ \text{match to truth}\ e(\mu)}{\#\ \text{truth jets}}$$

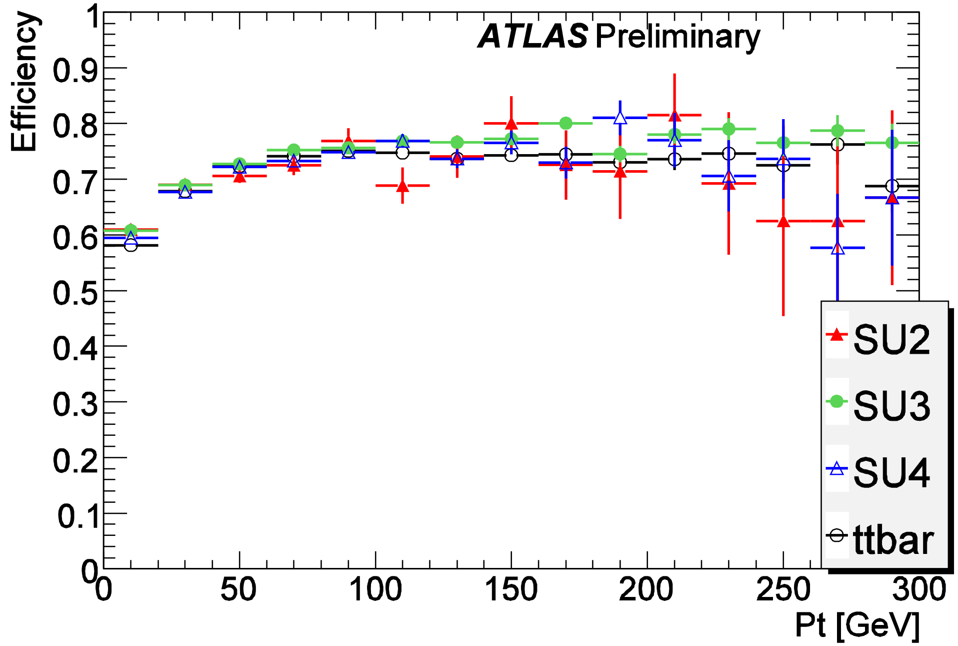
with p_T > 10 GeV, $|\eta|$ < 2.5

	Efficiency %		Fake Rate ($\times 10^{-3}$)	
	Electrons	Muons	Electrons	Muons
II : From Heavy Decays				
SU2	68.1±0.5	76.7±0.5	2.48±0.11	0.56±0.05
SU3	70.5±0.2	71.8±0.1	2.54±0.03	0.30±0.01
SU4	68.4±0.2	72.1±0.2	3.48±0.05	0.95±0.03
$t\bar{t}$	69.8±0.1	74.2±0.1	4.92±0.04	1.66±0.02

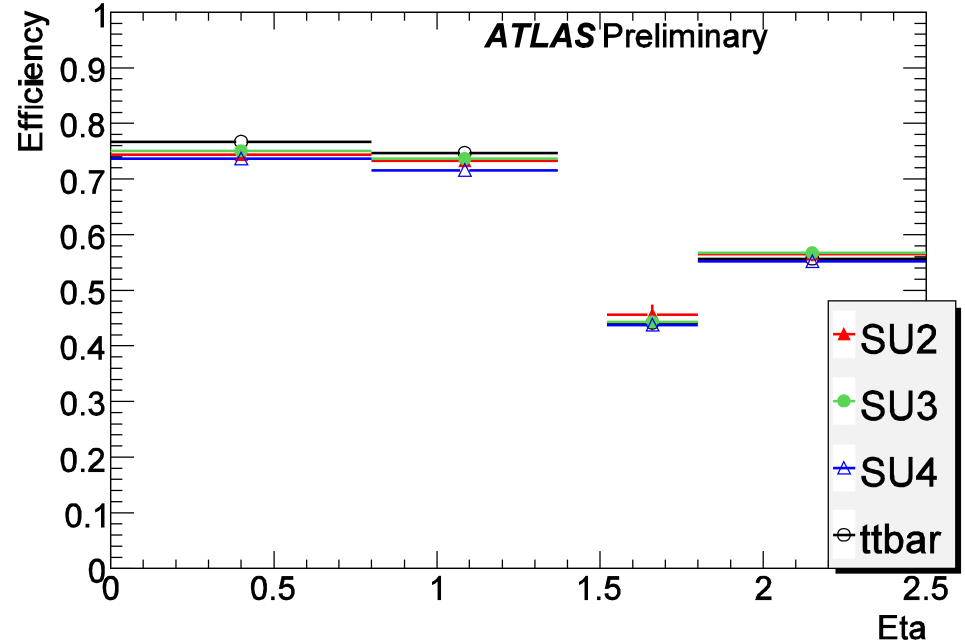
Efficiencies and Fake Rates

Electrons

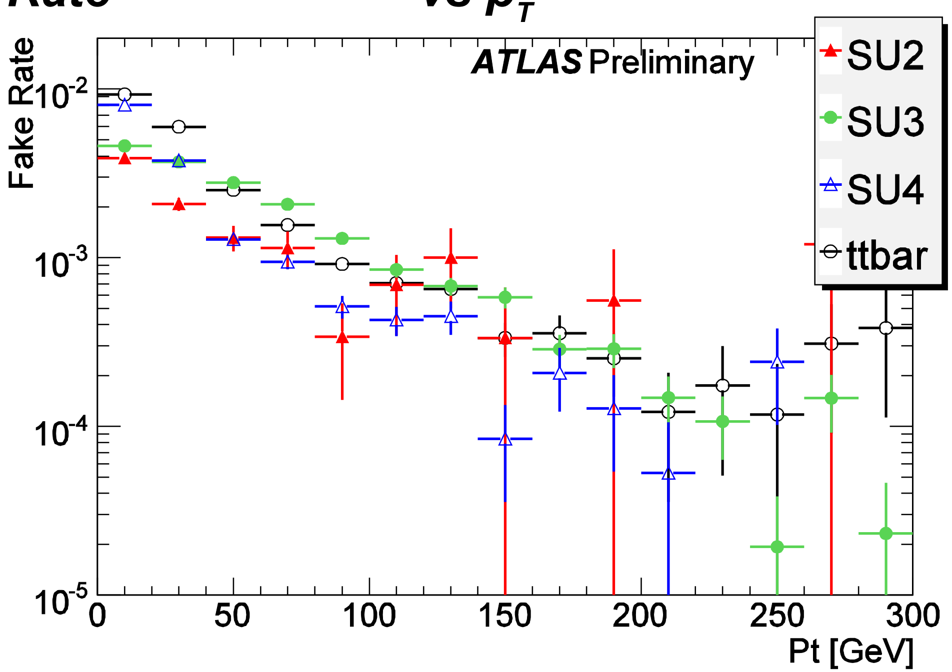
Efficiency — *vs p_T*



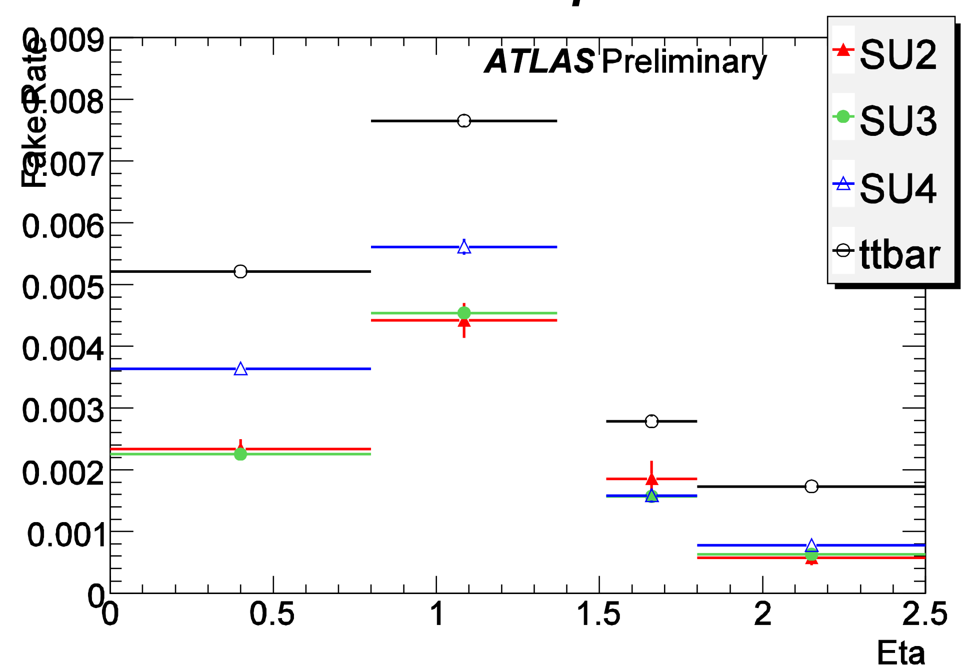
vs η



Fake Rate — *vs p_T*

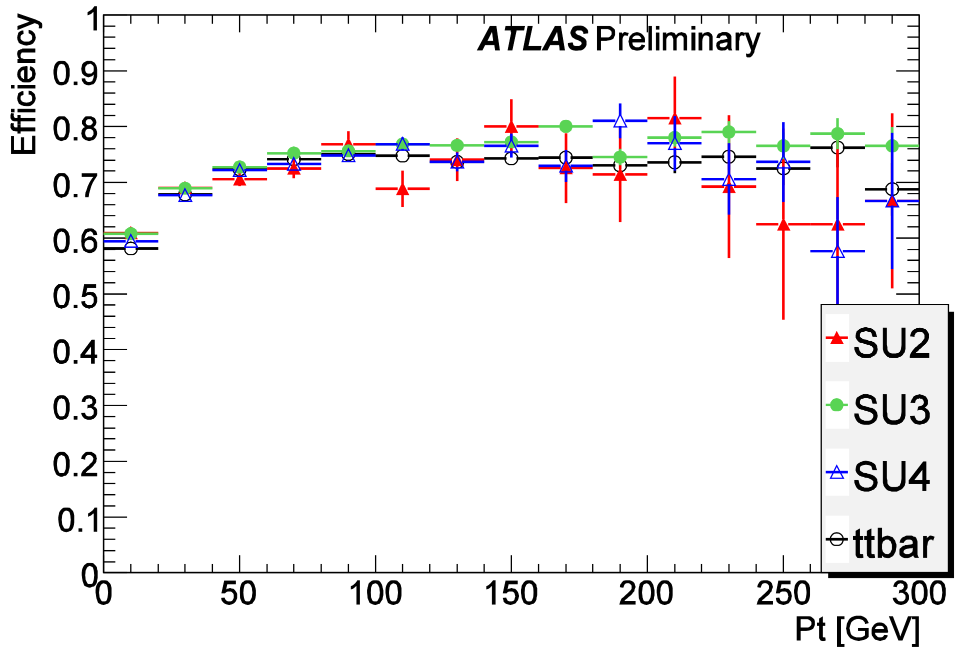


vs η

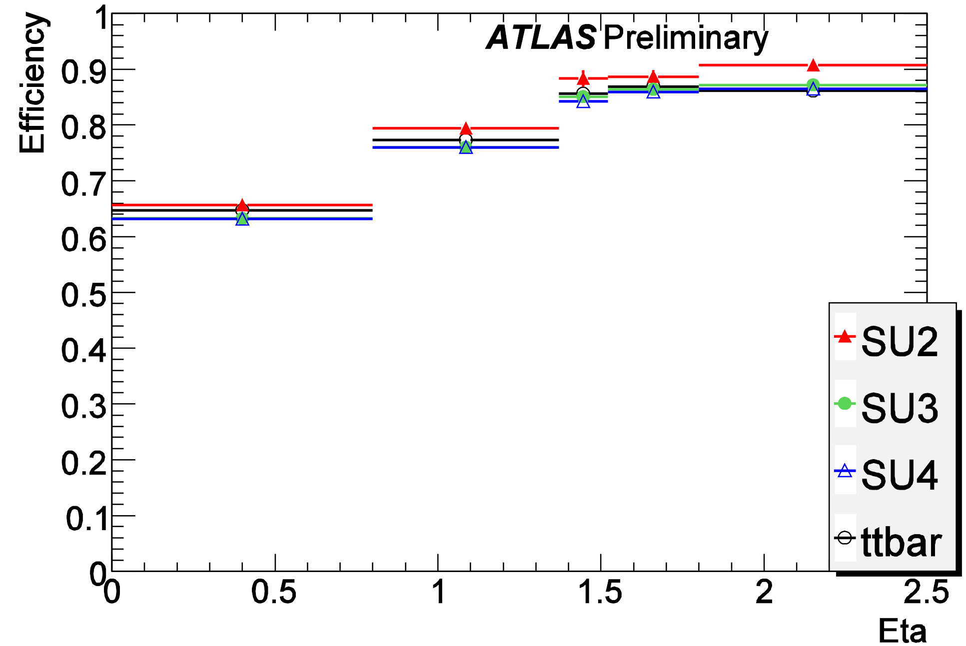


Efficiency

vs p_T

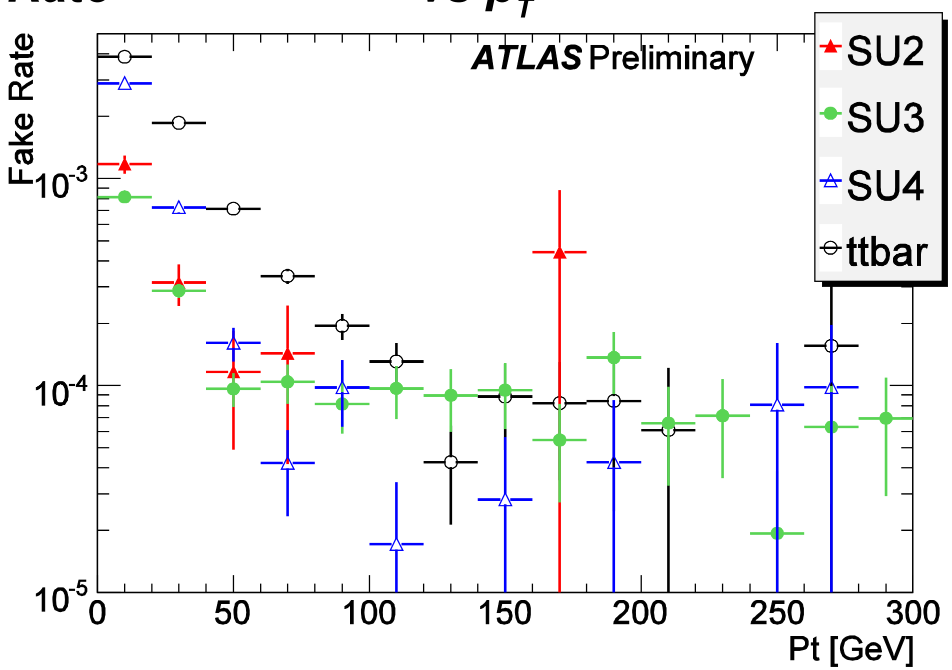


vs η

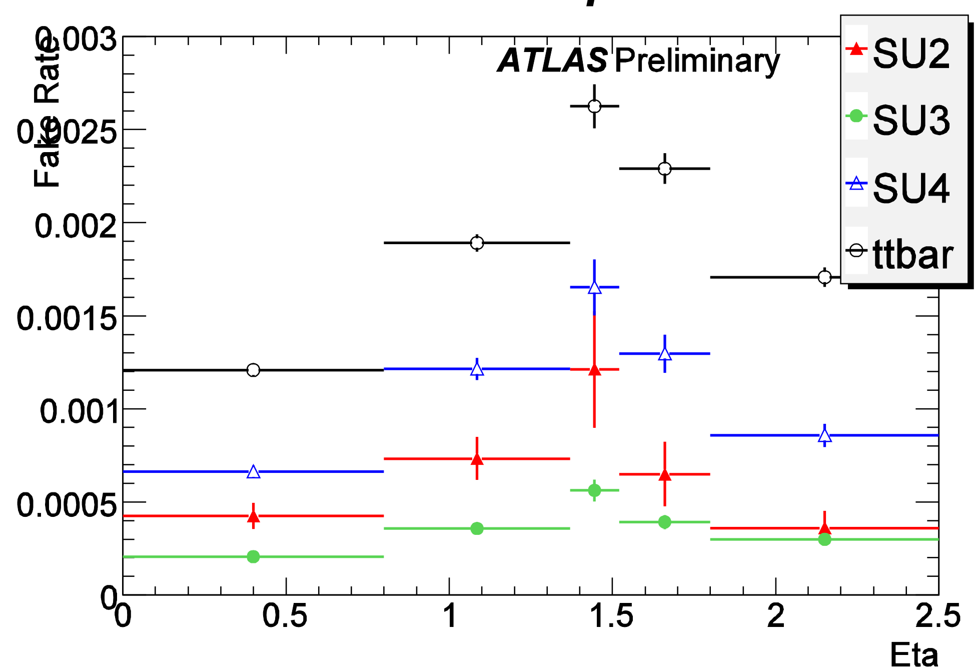


Fake Rate

vs p_T



vs η



Most dangerous backgrounds are ttbar and ZW

ttbar

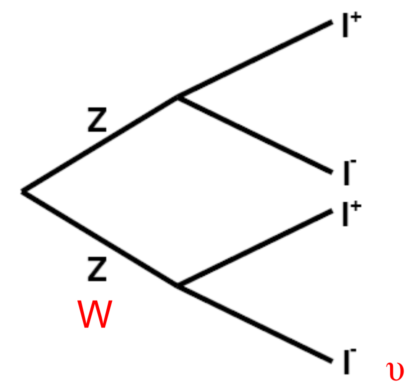
use lepton flavour and sign combinations of trilepton events.

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

Exclusive trilepton signal
Stringent cuts on lepton track isolation and a harsh jet veto
S/sqrt(S+B)= 1.74 after 10 fb^{-1} of data Case A, direct gaugino production + SUSY bckgnd
= 1.51 after 10 fb^{-1} of data Case B, direct gaugino production only
5σ discovery after 90 fb^{-1} for Case A, 120 fb^{-1} for Case B.

Inclusive trilepton signal
Simple and powerful analysis, only require 3 leptons and one high p_T jet.
SU2 : S/sqrt(S+B) = 2.3 for 1 fb^{-1} of data. 5σ discovery after 5 fb^{-1} of data
SU3 : S/sqrt(S+B) = 8.3 for 1 fb^{-1} of data. 5σ discovery after 400 pb^{-1} of data
SU4 : S/sqrt(S+B) = 15.6 for 1 fb^{-1} of data. 5σ discovery after 150 pb^{-1} of data

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.

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