Search for chargino and neutralino production in final states with two same-sign leptons, jets and missing transverse momentum at $\sqrt{s} = 13$ TeV with the ATLAS detector

Samuel Lo [1]

[1]The University of Hong Kong

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Introduction

Experimental Setup

Challenges

Signal Region

Backup

“N-1” plots

Introduction

Standard Model : Fundamental Particles

- Standard Model(SM) is the current mainstream theory to describe the electromagnetic force, weak force and strong force.

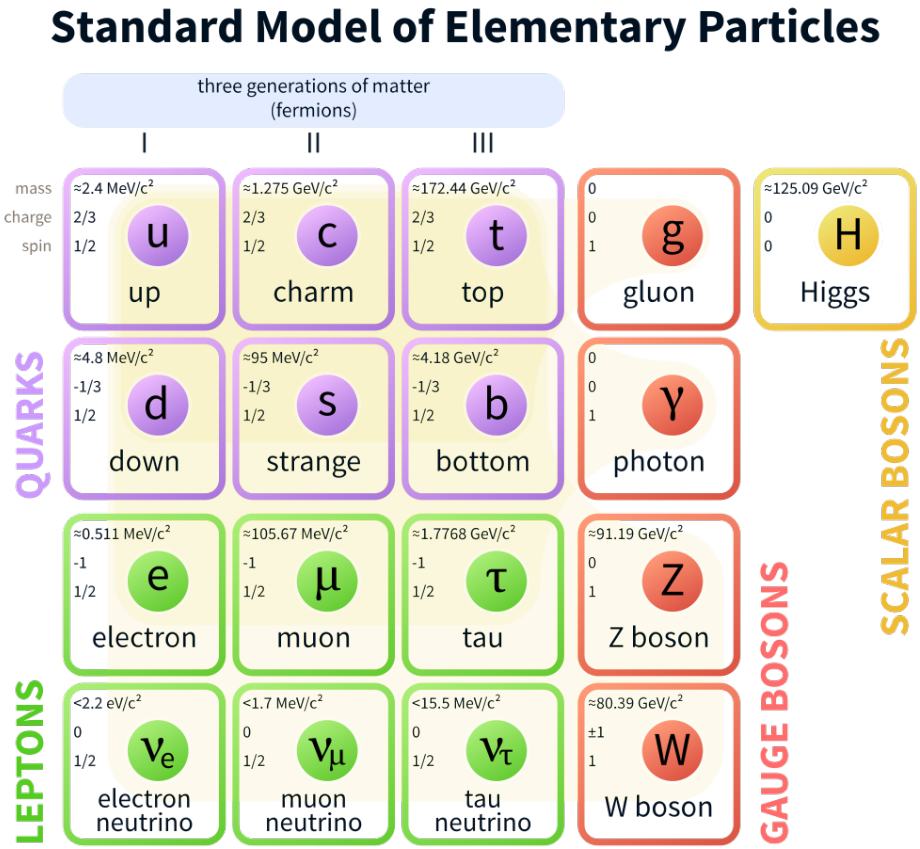


Figure: The "periodic" table for all fundamental particles in SM.

Standard Model : Fundamental Interaction

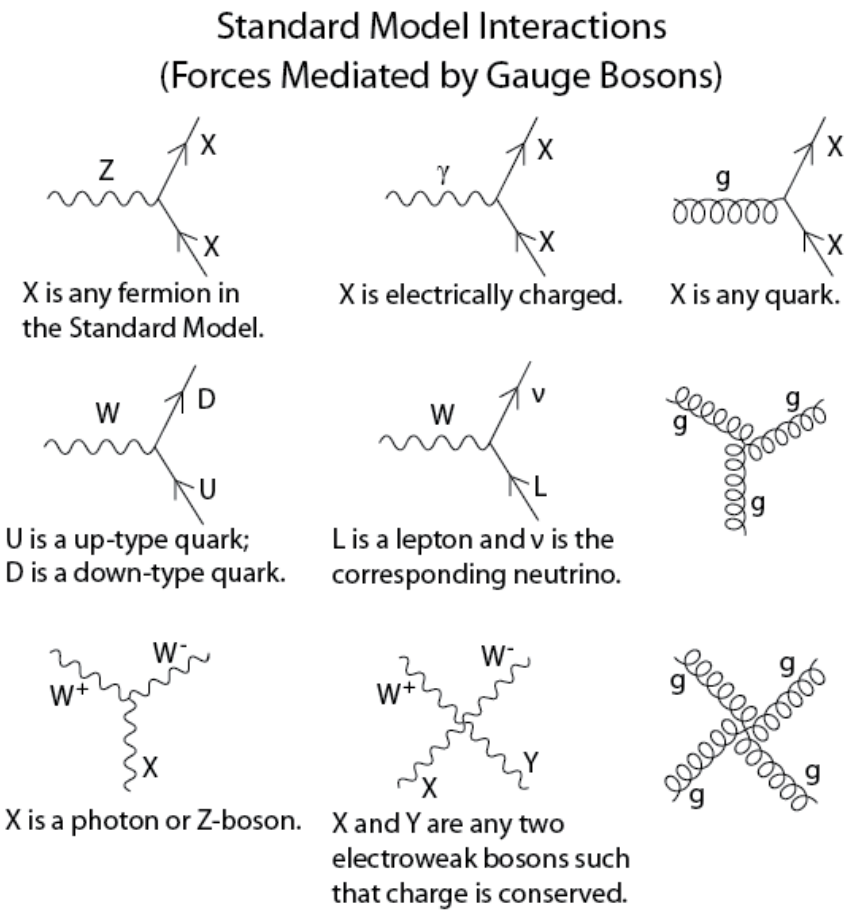


Figure: All allowed fundamental Feynman vertices in SM, except higgs-related vertices.

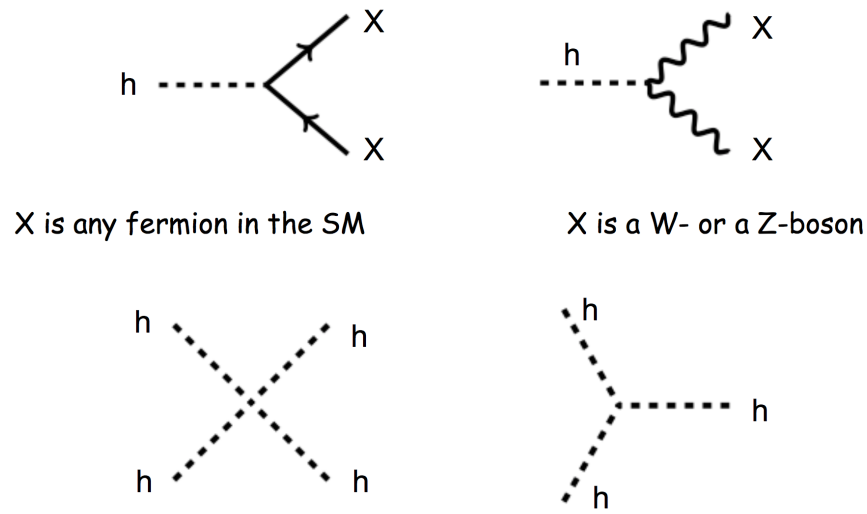


Figure: All allowed fundamental higgs-related Feynman vertices in SM.

Standard Model : Limitation

- SM cannot explain gravity.
- SM cannot explain the nature of dark matter.
- The hierarchy problem
  - Why the weak force is stronger than the gravity by 10^{24}.
  - Why the Higgs mass is much lighter than the Planck mass.
  - At very high energy scale, the Higgs boson mass is strongly sensitive to quantum corrections.

Supersymmetry

- Supersymmetry(SUSY) is a theoretical extension of the Standard Model.
- It is one of the most promising theory.
- It can solve the hierarchy problem of Higgs mass.
- It can explain the nature of dark matter.

Supersymmetry : MSSM

- Minimal Supersymmetric Standard Model(MSSM) is the simplest realization of the supersymmetry.
- It predicts that each particle in the Standard Model has its own partner particle, called the superpartner.
- The spin of the superpartner will differ from the Standard Model particle by 1/2.
- A symmetry between the fermions and bosons.

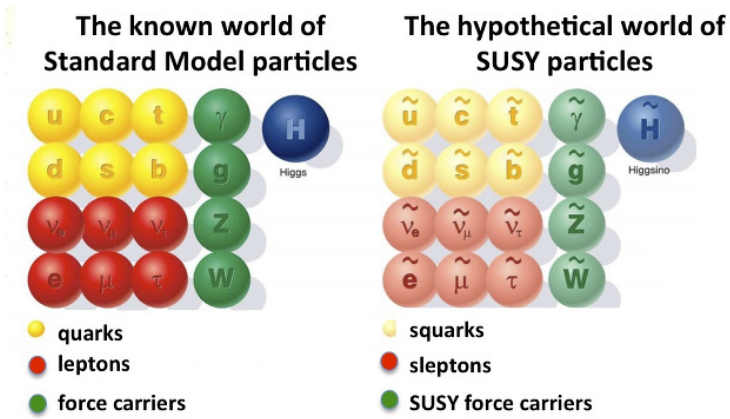


Figure: The particles in Standard Model and their corresponding superpartners and their names.

Supersymmetry : Superpartners

- In the MSSM, one more neutral Higgs filed H and two more charged Higgs fileds H^+, H^- needed to be introduced.
- In SM electro-weak bosons, there are in total 4 neutral bosons: γ, Z, h and H, and 4 charged bosons: W^+, W^-, H^+ and H^-.
- The superpartners of the 4 neutral bosons together form 4 mass eigenstates, called neutralinos: $\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$ and $\tilde{\chi}_4^0$.
- The superpartners of the 4 charged bosons together form two mass eigenstates with electric charge ± 1, called charginos: $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^\pm$.

Type	SM particle	Symbol	Spin	R-parity	Superpartner	Symbol	Spin	R-parity
Fermions	Quark	q	$\frac{1}{2}$	+1	Squark	$\tilde{q}$	0	-1
	Lepton	l	$\frac{1}{2}$	+1	Slepton	$\tilde{l}$	0	-1
Gluon	Gluon	g	1	+1	Gluino	$\tilde{g}$	$\frac{1}{2}$	-1
Neutral EW Bosons	Photon	γ	1	+1	Neutralinos	$\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\chi}_3^0$, $\tilde{\chi}_4^0$	$\frac{1}{2}$	-1
	Z Boson	Z	1	+1				
	Neutral Higgs	h,H	0	+1				
Charged EW Bosons	W Boson	W^+, W^-	1	+1	Charginos	$\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^\pm$	$\frac{1}{2}$	-1
	Charged Higgs	H^+, H^-	0	+1				

Table: The spin and R-parity for the Standard Model particles and their superpartners.

Supersymmetry : R-parity

- The baryon number B is defined by $\frac{1}{3}(n_q - n_{\bar{q}})$, where n_q is the number of quarks and $n_{\bar{q}}$ is the number of anti-quarks.
- The lepton number L is defined by $n_l - n_{\bar{l}}$, where n_l is the number of leptons and $n_{\bar{l}}$ is the number of anti-leptons.
- In SM, $(B - L)$ is conserved. But in MSSM, it is no longer conserved.
- To keep $(B - L)$ conservation and prevent the proton decay, the R-parity P_R is introduced.

$$P_R = (-1)^{3(B-L)-2s}$$

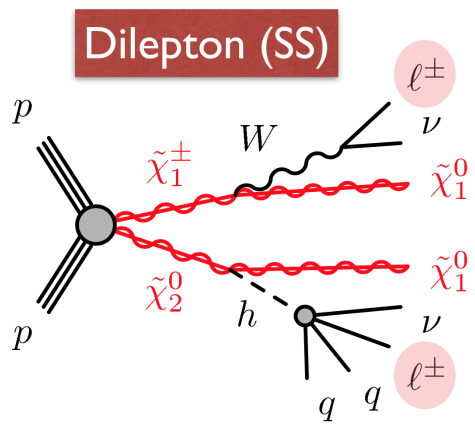
where s is the spin.

Supersymmetry : R-parity

- All SM particles have R-parity +1, while all SUSY particles have R-parity −1.
- If the R-parity is conserved, the lightest supersymmetric particle (LSP) cannot decay and is stable.
- If the LSP is electrically neutral and interacts with matter only by the weak interaction and gravity, it could be a candidate for dark matter, for example the lightest neutralinos $\tilde{\chi}_1^0$.
- In this thesis, the R-parity is assumed to be conserved, and the lightest neutralino $\tilde{\chi}_1^0$ is assumed to be the LSP.
- Due to the conservation of R-parity, the supersymmetric particles can only be pair-produced, and will eventually decay into SM particles and the lightest neutralino $\tilde{\chi}_1^0$ (i.e. LSP).

Our Signal Scenario : Motivation

- In the recent searches for the squarks ($\tilde{q}$) and gluinos ($\tilde{g}$), the masses of gluinos and the first and second generation squarks are suggested to be larger than 1 TeV, while the masses of the third generation squarks are still allowed to be below 1 TeV.
- In this case, the direct pair production of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ may be the dominant SUSY production process at the LHC, if the masses of them are below 1 TeV.
- In this thesis, their masses are assumed to be the same, and denoted by $m_{\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0}$.



Our Signal Scenario : Decay Processes

- If all the slepton ($\tilde{l}$) are heavier than $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$:
  1. $\tilde{\chi}_1^{\pm}$ will decay to W boson and $\tilde{\chi}_1^0$:
     $\tilde{\chi}_1^{\pm} \to W^{\pm} + \tilde{\chi}_1^0$
  2. $\tilde{\chi}_2^0$ will decay to the lightest MSSM Higgs boson h and $\tilde{\chi}_1^0$:
     $\tilde{\chi}_2^0 \to h + \tilde{\chi}_1^0$

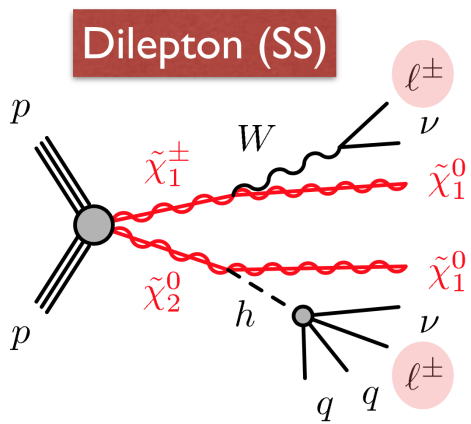
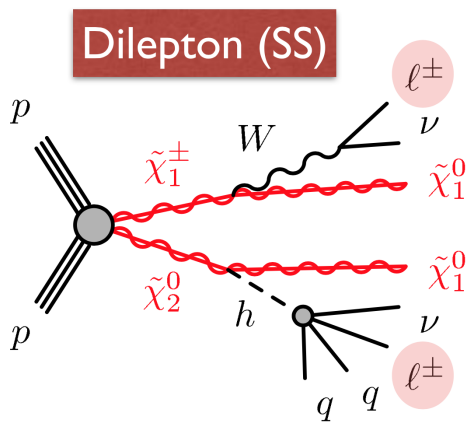


Figure: The Feynman diagram for our Wh same-sign signal scenario.

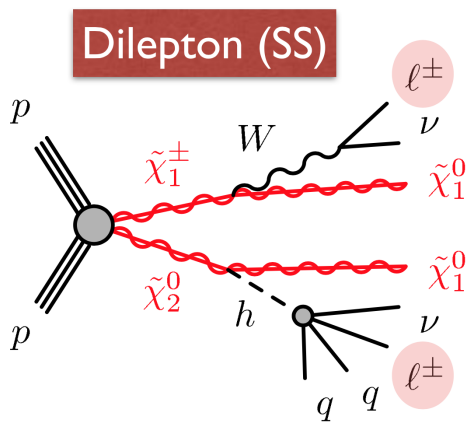
Our Signal Scenario : Decay Processes

- The W boson will further to one lepton (electron or muon) and one neutrino with the SM branching ratio :
  $W^{\pm} \to \ell^{\pm} + \nu$
- The Higgs boson h will eventually decay to one lepton (electron or muon), quarks (i.e. jets) and neutrino(s) by various decay modes with the SM branching ratios. (For example, $h \to W^{+}W^{-}$ and $h \to \tau^{+}\tau^{-}$)
- From now on, a lepton $\ell^{\pm}$ only refer to an electron or muon, but not τ lepton or neutrino.



Our Signal Scenario : Signal Signature in the Final State

- In this thesis, we only search for two same-sign(SS) leptons, in order to suppress the SM backgrounds.
- A large missing energy is expected, due to the undetected neutralinos $\tilde{\chi}_1^0$ and neutrinos ν.
- Each quark will eventually become a particle shower within a narrow cone, called a jet, by the process of hadronization.
- The mass difference between the two lightest neutralinos $(m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0})$ should be larger than the Higgs mass ($\sim$ 125 GeV).



Our Signal Scenario : Sensitive Region

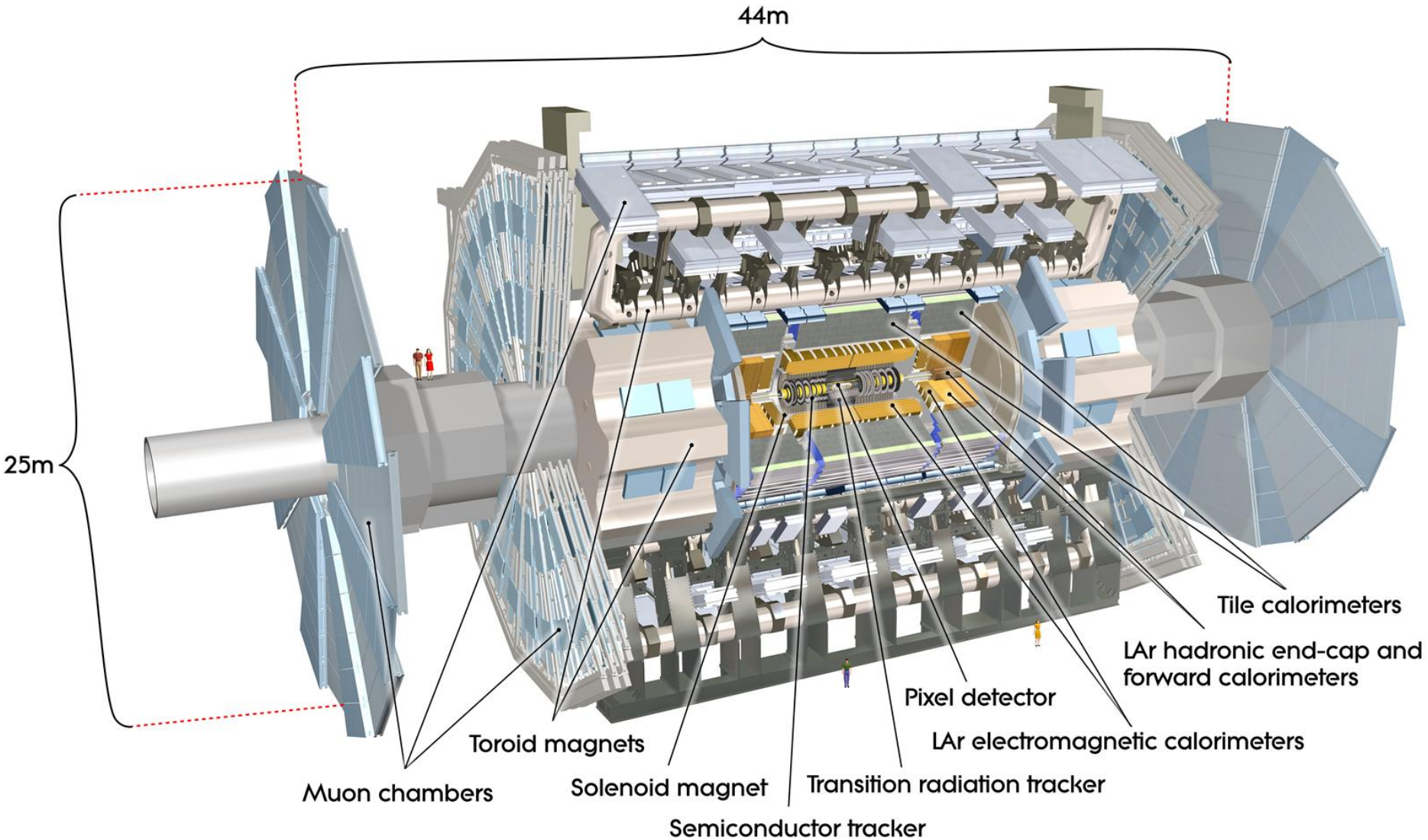
- If the mass difference $(m_{\tilde{\chi}_1^\pm,\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0})$ is slightly larger than the Higgs mass, it is called the compressed region.
- In the compressed region, one of the lepton may have low energy, due to the low momentum of the Higgs boson, and hence it may not be detected.
- In this case, there may be originally 3 leptons, but only 2 leptons are detected.
- This allows more decay modes for Higgs boson, which produce two leptons. (For example, $h \to ZZ$)
- Hence, the signal will be more sensitive in the compressed region.

Experimental Setup

Experimental Setup : LHC

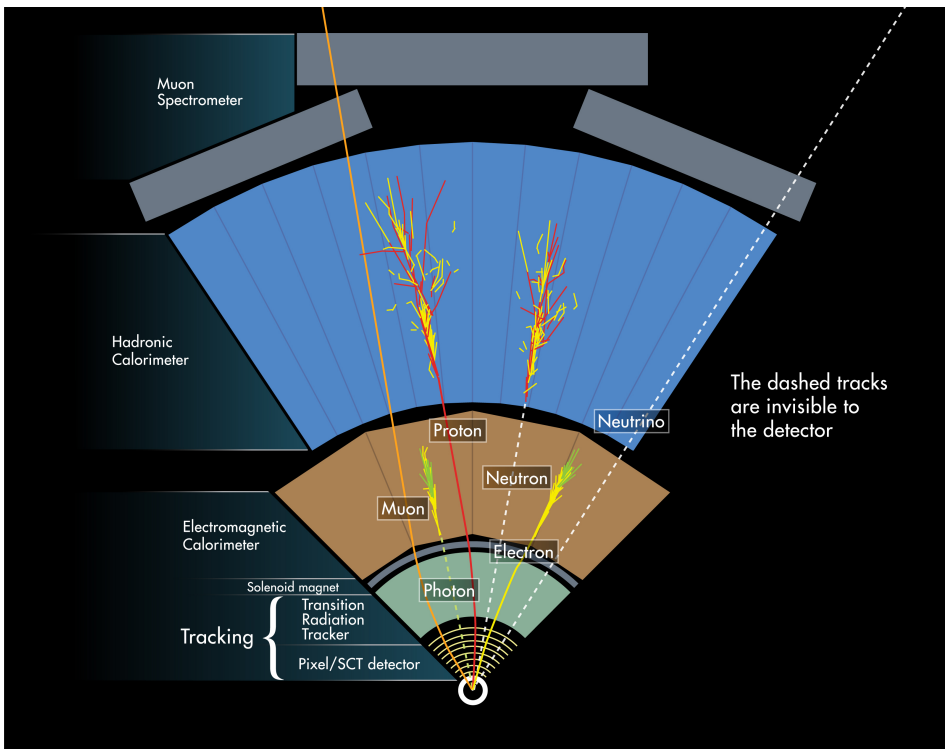
- The Large Hadron Collider (LHC) is the most powerful circular particle accelerator in the world.
- Its circumference is 27 km.
- Two beams of protons will be accelerated in opposite direction to centre-of-mass energy 13 TeV.
- They will be finally collided at the ATLAS detector.

Experimental Setup : ATLAS detector



Experimental Setup : ATLAS detector

- The ATLAS detector consists of 3 main components:
  1. Inner detector: It is a particle tracker. It measures the tracks of charged particles.
  2. Calorimeter: It measures the energy of the particle and stops the particle. It consists of electromagnetic and hadronic calorimeters.
  3. Muon spectrometer: It is a particle tracker for muons.



Challenges

Challenges

Estimation of the signal sensitivity

- Cross section for our signal ~ 0.1 pb
- Total luminosity in one year $\sim 10^4$ pb^{-1}
- Expected number of signal events in one year $\sim 10^3$
- Time interval between each collision $= 25$ ns
- Total number of events in one year $\sim 10^{15}$
- The probability to have a signal event $\sim 10^{-12}$
- Conclusion: the SUSY signal is very rare.

Strategy

In order to extract the signal, the following strategies are used.

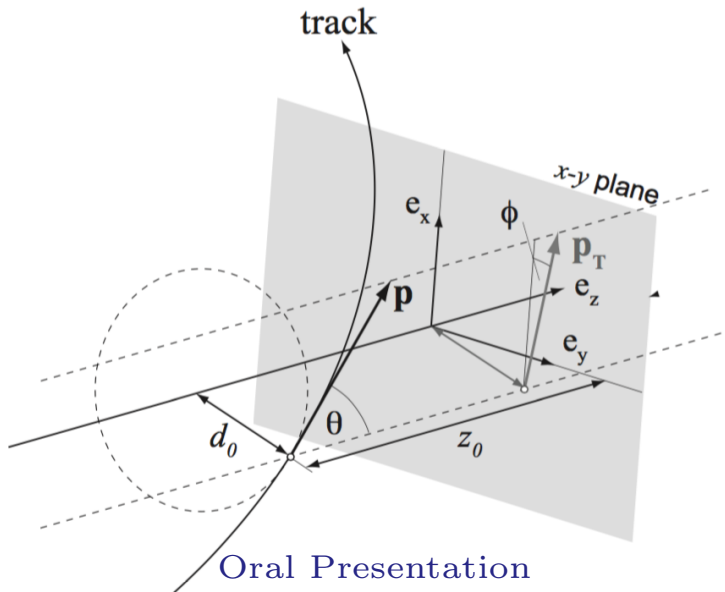
- A hardware trigger system are used when taking the data (online), to only store the interested events in the disk.
  (40 MHz $\rightarrow$ 100 kHz $\rightarrow$ 1 kHz)
- Some discriminant variables (based on the kinematic variables) are defined, to help distinguish the signal and the background (i.e. noise).
- Two dedicated signal regions are defined based on the discriminant variables, to maximize signal sensitivity (like the signal-to-noise ratio).

Signal Region

Signal Region : Basic kinematic variables

- The z-axis is in the proton beam direction.
- The direction of the momentum $\mathbf{p}$ of the particle can by specified by the azimuthal angle ϕ and the polar angle θ, as usual in the spherical coordinate system.
- The transverse momentum $\mathbf{p_T}$ is the projection of $\mathbf{p}$ onto the x-y plane. The magnitude of $\mathbf{p_T}$ is denoted by p_T

$$p_T = \sqrt{p_x^2 + p_y^2}$$



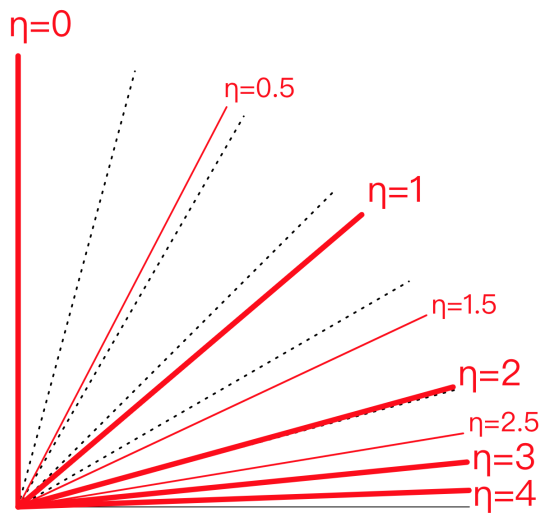
Signal Region : Basic kinematic variables

- The pseudorapidity η is defined by

$$\eta = -\ln\left(\tan\frac{\theta}{2}\right)$$

- The values of pseudorapidity η have reflective symmetry about the x-y plane. (Negetive value for $90° < \theta < 180°$)
- The angle separation ΔR of two particles is defined as:

$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} = \sqrt{(\phi_2 - \phi_1)^2 + (\eta_2 - \eta_1)^2}$$



Signal Region : discriminant variable

- The missing momentum $\mathbf{p}^{\text{miss}}$ due to undetected particle is defined by

$$\mathbf{p}^{\text{miss}} = -\sum_{\text{All detected particles}} \mathbf{p}$$

- The transverse missing erengy, denoted by E_T^{miss} or MET, is defined by

$$E_T^{\text{miss}} = |\mathbf{p}_T^{\text{miss}}| = \sqrt{(p_x^{\text{miss}})^2 + (p_y^{\text{miss}})^2}$$

- p_T^1 and p_T^2 are p_T of the two leptons, with $p_T^1 \geq p_T^2$. The lepton with larger p_T is called the leading lepton, while the lepton with smaller p_T is called the sub-leading lepton.

Signal Region : discriminant variable

- n_{jets}: Number of signal jets:
- $n_{\text{b-jets}}$: Number of b-jets (jet from b quark).
- $$\Delta\eta_{ll} = |\eta_1 - \eta_2|$$
- $$m_{\text{eff}} = p_T^1 + p_T^2 + E_T^{\text{miss}} + \sum_{\text{signal jets}} p_T$$
- m_{ll}: The invariant mass of the 4-momentum sum of the two leptons
$$(m_{ll})^2 = (p_1 + p_2)^2$$

Signal Region : discriminant variable

- m_T: It is designed to reconstruct the mass of the W boson.

$$m_T = \sqrt{2p_T^1 E_T^{\text{miss}}(1 - \cos\Delta\phi)}$$

where $\Delta\phi$ is the azimuthal angle between the leading lepton and the missing transverse momentum.

- m_{T2}: It is designed to set a lower bound on the masses of the unseen pair of charginos $\tilde{\chi}_1^{\pm}$ and neutralinos $\tilde{\chi}_2^0$.

$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^1, \mathbf{q}_T), m_T(\mathbf{p}_T^2, \mathbf{p}_T^{\text{miss}} - \mathbf{q}_T)\right)\right]$$

$$m_T(\mathbf{p}_T, \mathbf{q}_T) = \sqrt{2p_T q_T(1 - \cos\Delta\phi)}$$

Signal Region : discriminant variable

- m_{lj} or m_{ljj}: It is designed to reconstruct the mass of the Higgs boson.

$$p_{\text{jet-system}} = \begin{cases} p_{\text{jet1}} & \text{for SRjet1} \\ p_{\text{jet1}} + p_{\text{jet2}} & \text{for SRjet23} \end{cases}$$

$$p_{\text{closest-lepton}} = \begin{cases} p_{\ell 1} & \text{if } \Delta R(p_{\ell 1}, p_{\text{jet-system}}) \leq \Delta R(p_{\ell 2}, p_{\text{jet-system}}) \\ p_{\ell 2} & \text{if } \Delta R(p_{\ell 1}, p_{\text{jet-system}}) > \Delta R(p_{\ell 2}, p_{\text{jet-system}}) \end{cases}$$

$$(m_{lj(j)})^2 = (p_{\text{closest-lepton}} + p_{\text{jet-system}})^2$$

Signal Region : Pre-selection

- Signal Region(SR) is a set of cuts of the discriminant variables, such that the signal sensitivity is high.
- By trying different sets of cuts, the signal region with the highest signal sensitivity can be found. This process is called the signal region optimization. The following cuts are the pre-selection, before the signal region optimization.

Pre-selection:

- Exactly 2 leptons with $p_T > 25$ GeV.
- The two leptons are same-sign in electric charge (SS).
- $n_{\text{b-jets}} = 0$, to reduce the SM background from top quark.
- Two signal regions: SRjet1 with $n_{\text{jets}} = 1$, SRjet23 with $n_{\text{jets}} = 2$ or 3.

Signal Region : cut result

	SRjet1	SRjet23
n_{jets}	1	2 or 3
Leading lepton p_T [GeV]	≥ 25	≥ 25
Sub-leading lepton p_T [GeV]	≥ 25	≥ 25
$\lvert\Delta\eta_{ll}\rvert$	< 1.5	-
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	≥ 100	≥ 100
m_{eff} [GeV]	≥ 260	≥ 240
m_{T}^{l1} [GeV]	≥ 140	≥ 120
m_{lj}/m_{ljj} [GeV]	< 180	< 130
m_{T2} [GeV]	≥ 80	≥ 70

Backup

Pre-selection plots

Yields in pre-selection

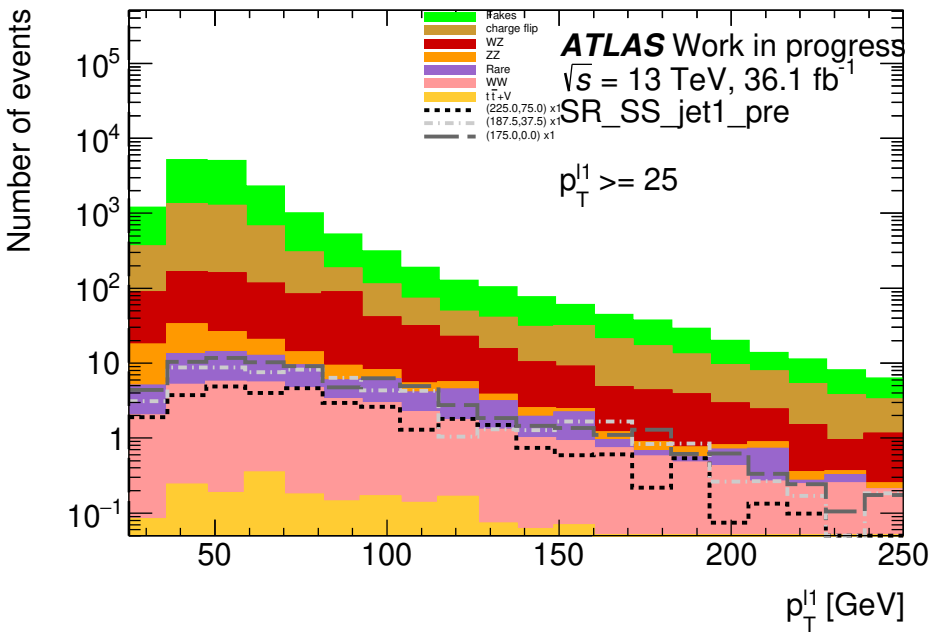
	Number of events
Fakes	11580.965417 ± 45.775452 (107219)
charge flip	3622.756937 ± 2.810481 (3375964)
WZ	691.333566 ± 34.238864 (68626)
ZZ	66.945860 ± 1.049840 (21749)
Rare	47.371873 ± 4.082859 (1662)
WW	38.128141 ± 0.388221 (15666)
$t\bar{t}+V$	1.971267 ± 0.138488 (671)
Total BG	16049.473060 ± 57.389305 (3591557)
(225.0,75.0)	33.08 ± 1.57 (676)
(187.5,37.5)	62.09 ± 3.13 (568)
(175.0,0.0)	74.30 ± 3.57 (556)

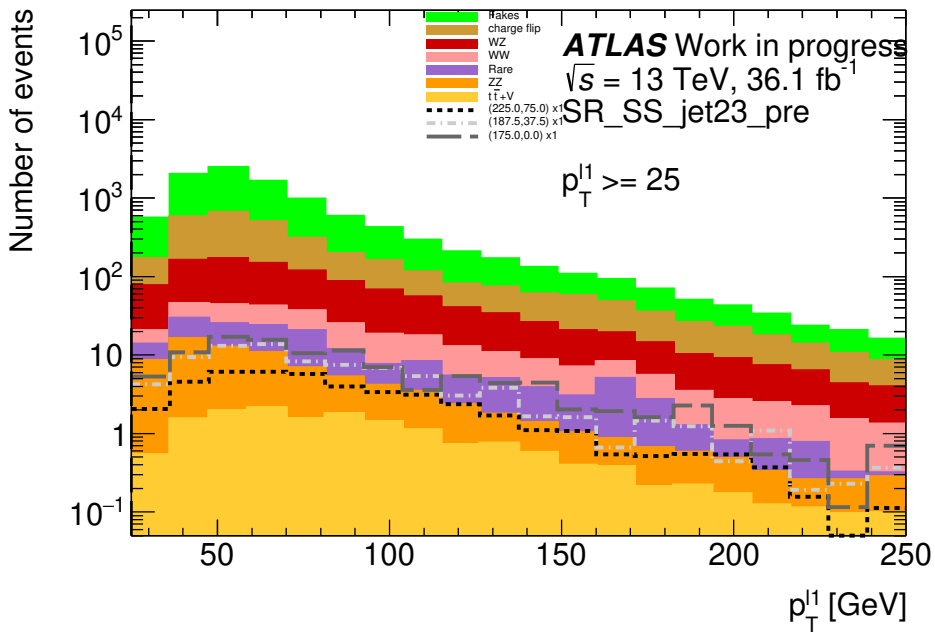
Table: Yields in SRjet1

	Number of events
Fakes	6848.284248 ± 36.074557 (66096)
charge flip	2074.427691 ± 2.680118 (1679673)
WZ	776.282836 ± 5.978666 (147413)
WW	153.455294 ± 0.679752 (72175)
Rare	92.181843 ± 6.338615 (3011)
ZZ	62.932966 ± 1.198123 (35945)
$t\bar{t}+V$	16.375388 ± 0.359456 (6082)
Total BG	10023.940266 ± 37.235816 (2010395)
(225.0,75.0)	45.01 ± 1.76 (937)
(187.5,37.5)	86.02 ± 3.84 (754)
(175.0,0.0)	107.96 ± 5.14 (743)

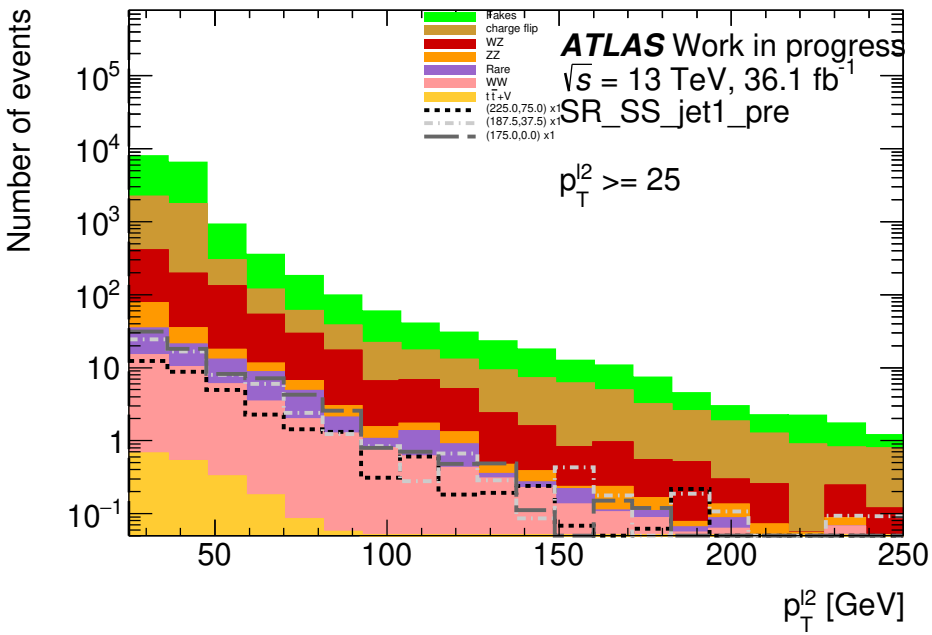
Table: Yields in SRjet23

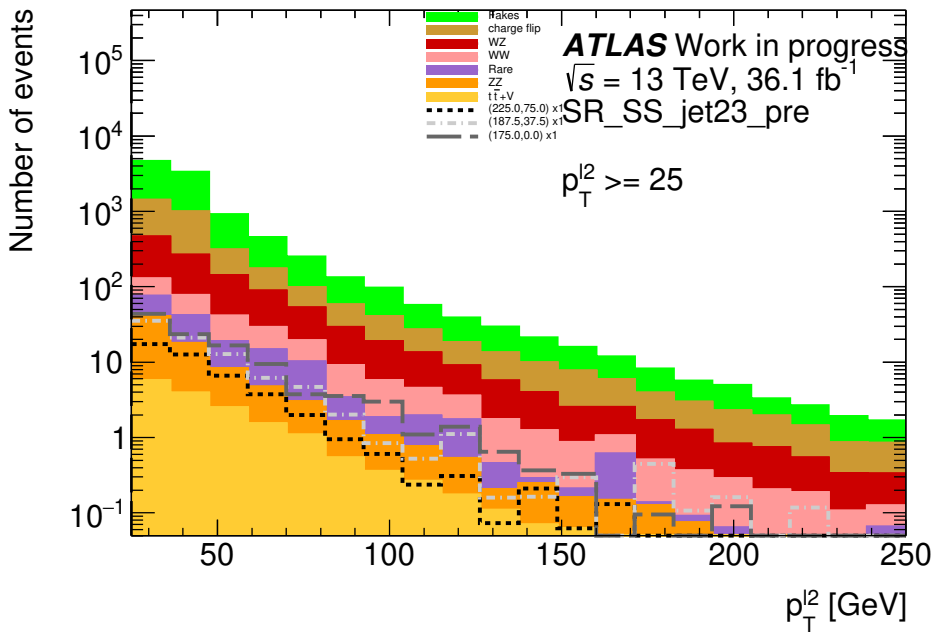
p_T^{l1}


fakes
charge flip
WZ
ZZ
Rare
WW
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet1_pre
p_T^{l1} >= 25
Number of events
p_T^{l1} [GeV]


fakes
charge flip
WZ
WW
Rare
ZZ
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet23_pre
p_T^{l1} >= 25
Number of events
p_T^{l1} [GeV]

p_T^{l2}


fakes
charge flip
WZ
ZZ
Rare
WW
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet1_pre
p_T^{l2} >= 25
Number of events
p_T^{l2} [GeV]


fakes
charge flip
WZ
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(225.0,75.0) x1
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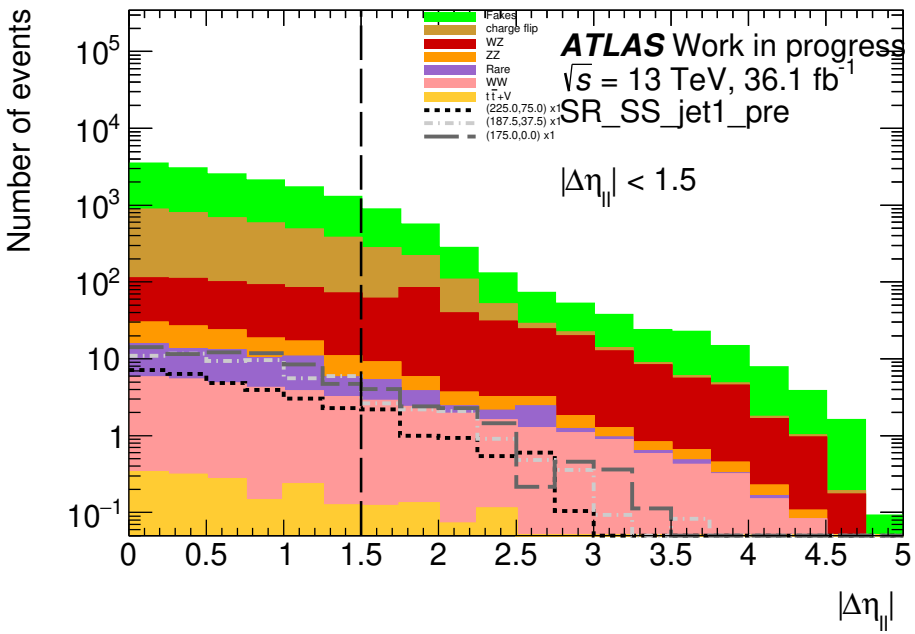
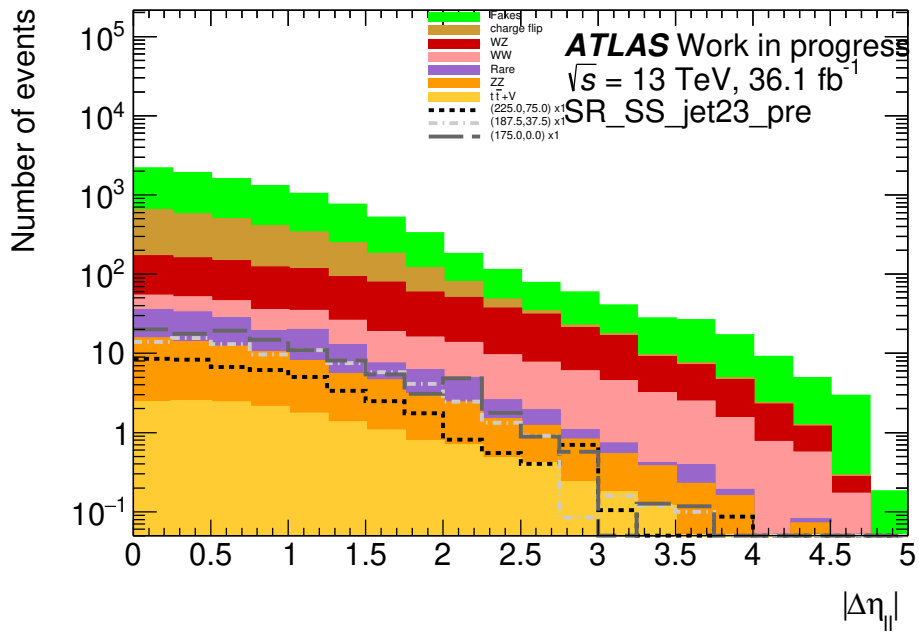
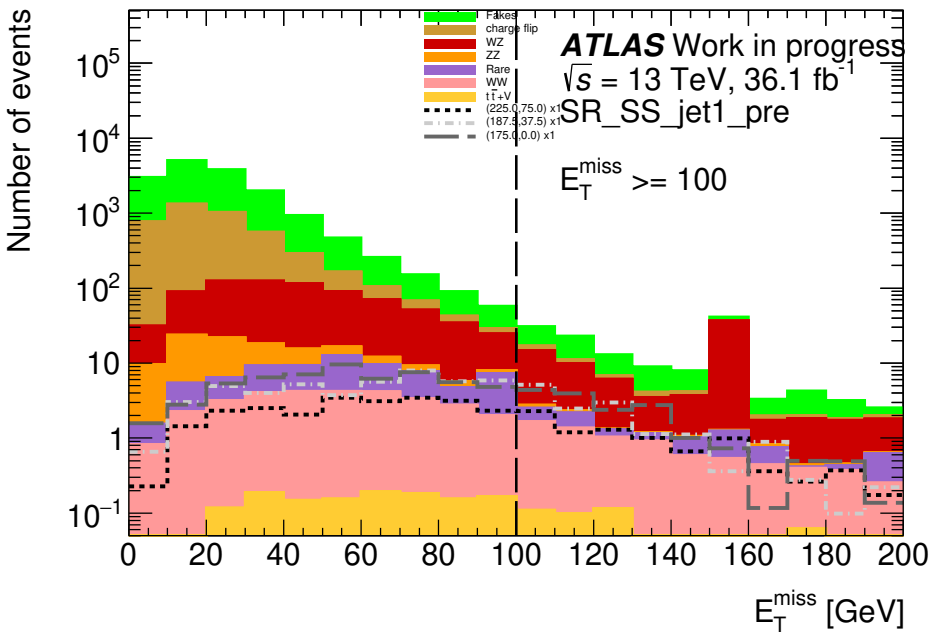
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet23_pre
p_T^{l2} >= 25
Number of events
p_T^{l2} [GeV]

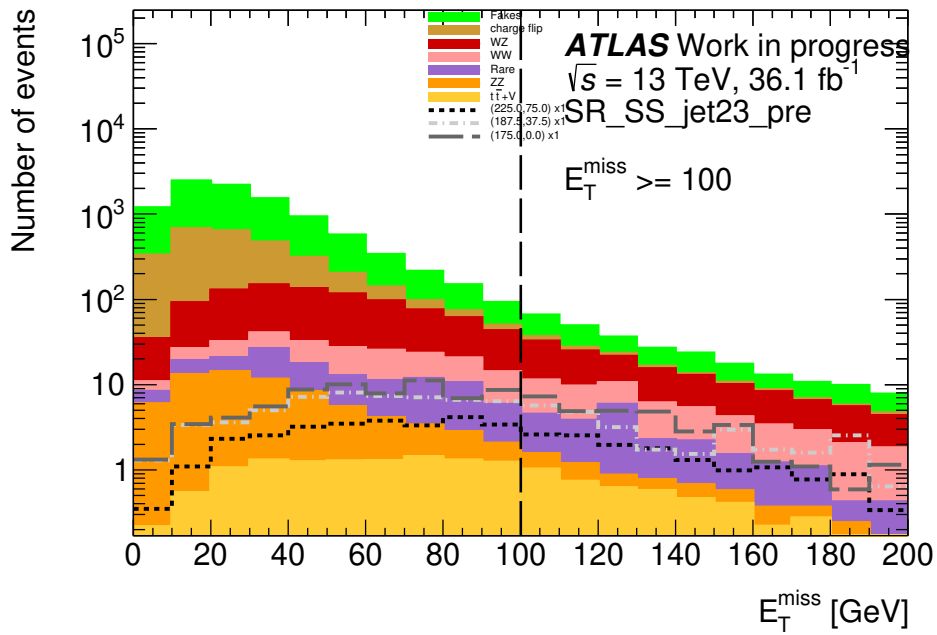
$|\Delta\eta_{ll}|$


Number of events
Fakes
charge flip
WZ
ZZ
Rare
WW
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet1_pre
$|\Delta\eta_{ll}| < 1.5$
$|\Delta\eta_{ll}|$

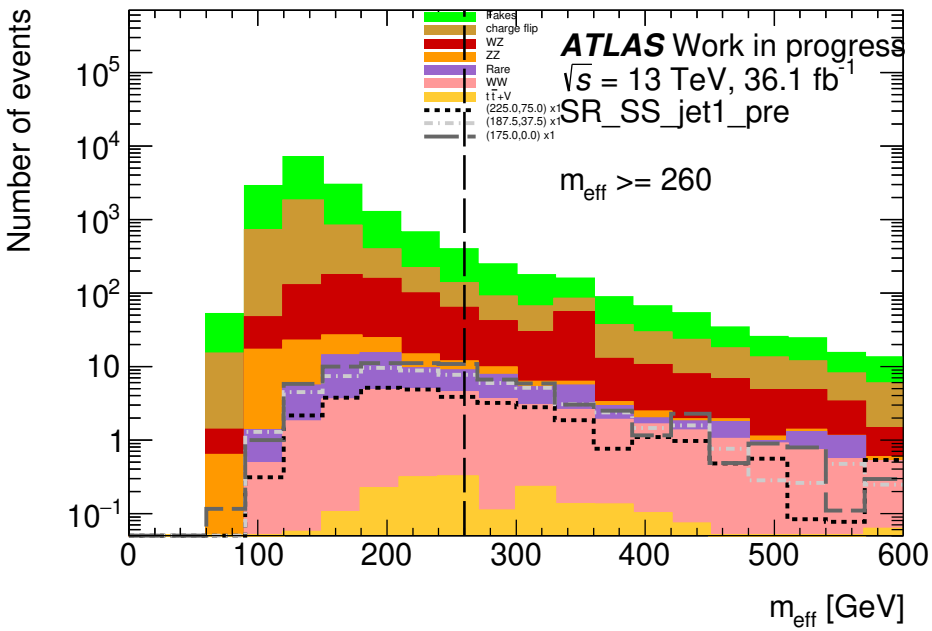

Number of events
Fakes
charge flip
WZ
WW
Rare
ZZ
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet23_pre
$|\Delta\eta_{ll}|$

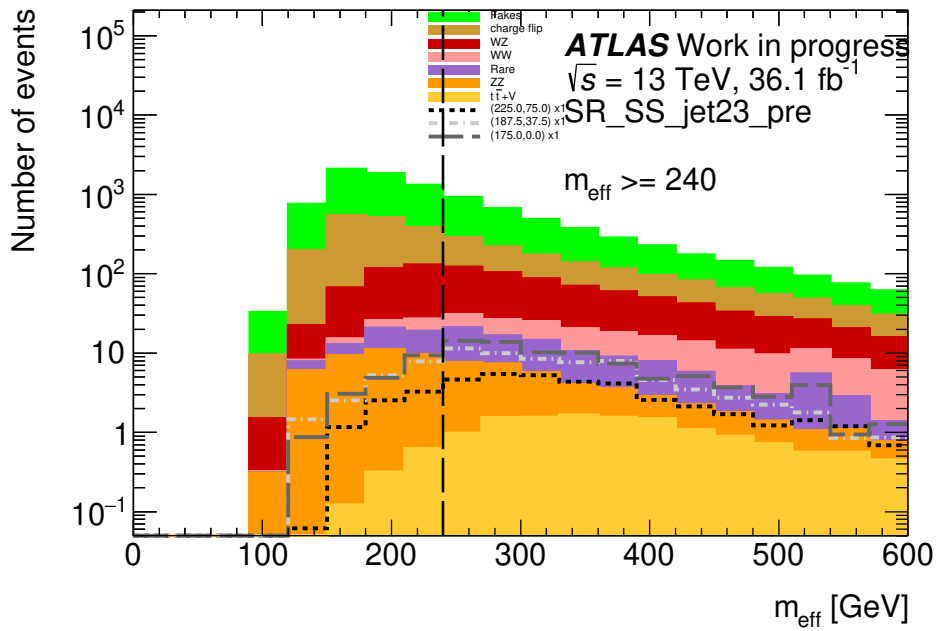
$E_{\mathrm{T}}^{\mathrm{miss}}$



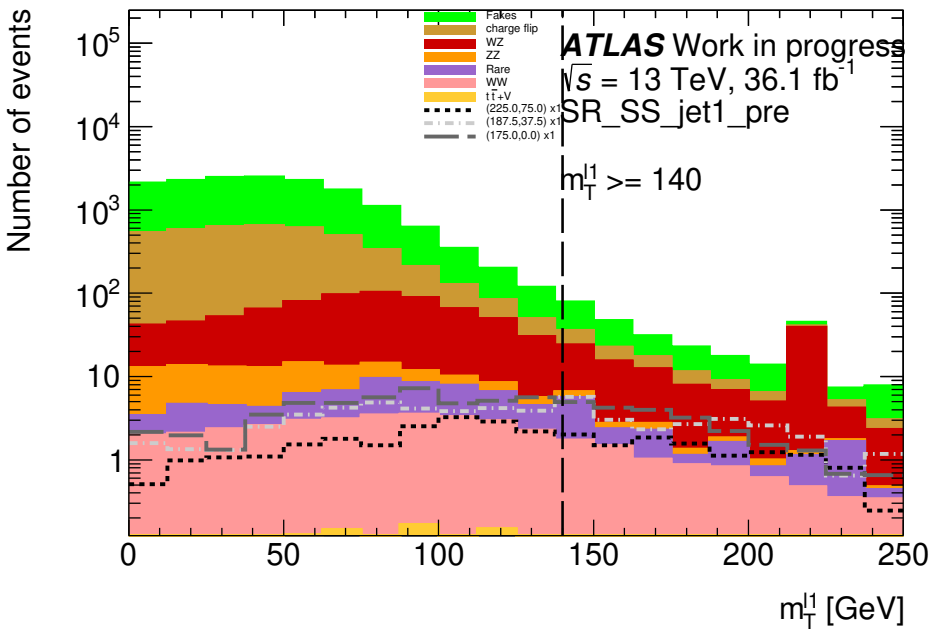


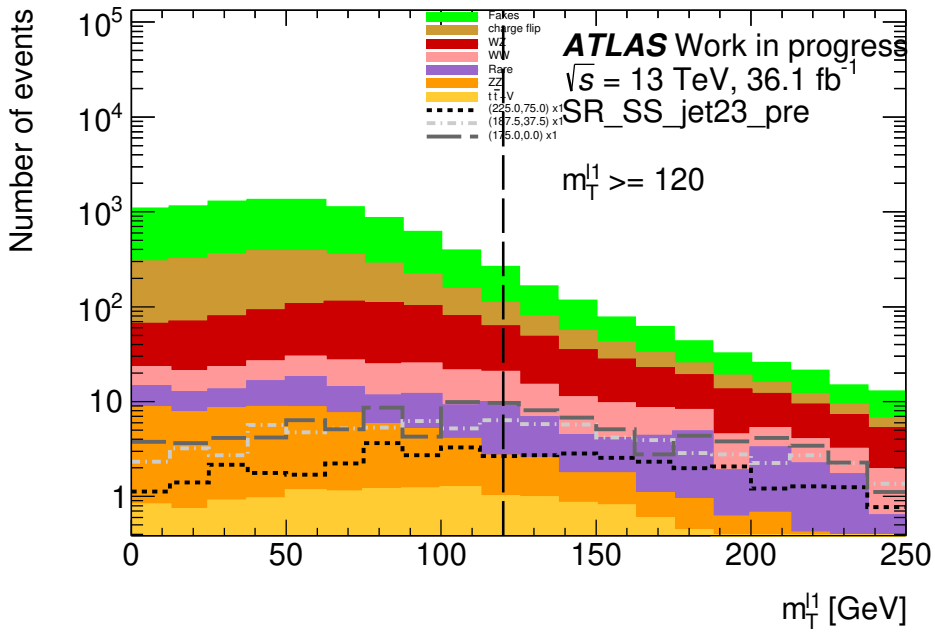
m_{eff}


Number of events
fakes
charge flip
WZ
ZZ
Rare
WW
t t̄+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet1_pre
m_eff >= 260
m_eff [GeV]

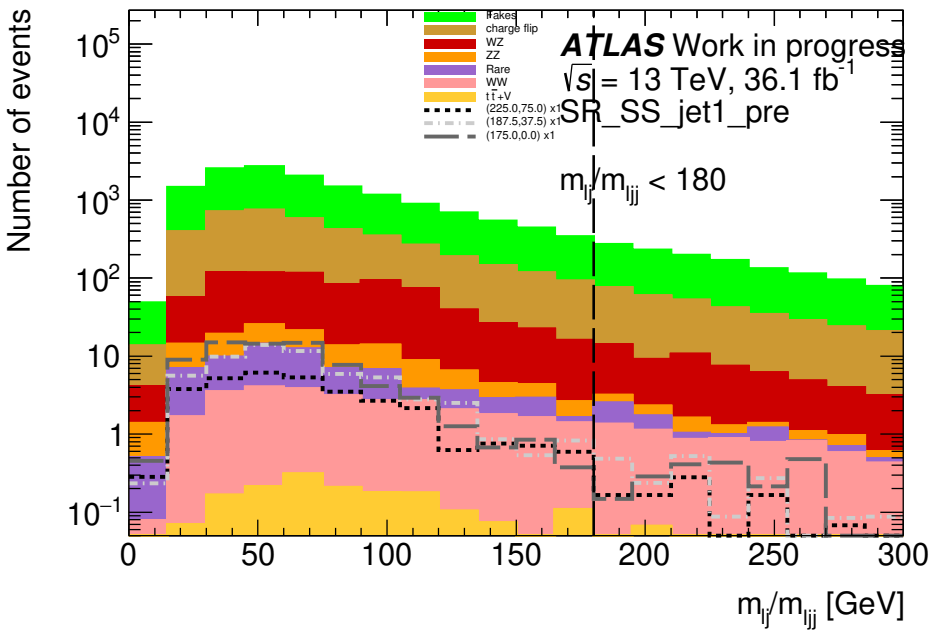

Number of events
fakes
charge flip
WZ
WW
Rare
ZZ
t t̄+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet23_pre
m_eff >= 240
m_eff [GeV]

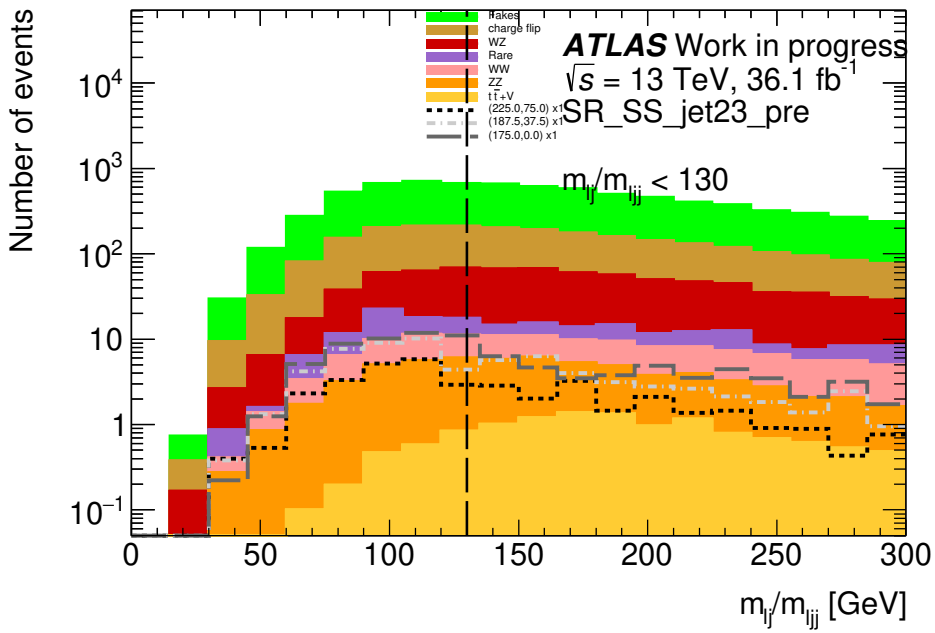
m_{T}^{l1}


Fakes
charge flip
WZ
ZZ
Rare
WW
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet1_pre
m_{T}^{l1} >= 140
Number of events
m_{T}^{l1} [GeV]

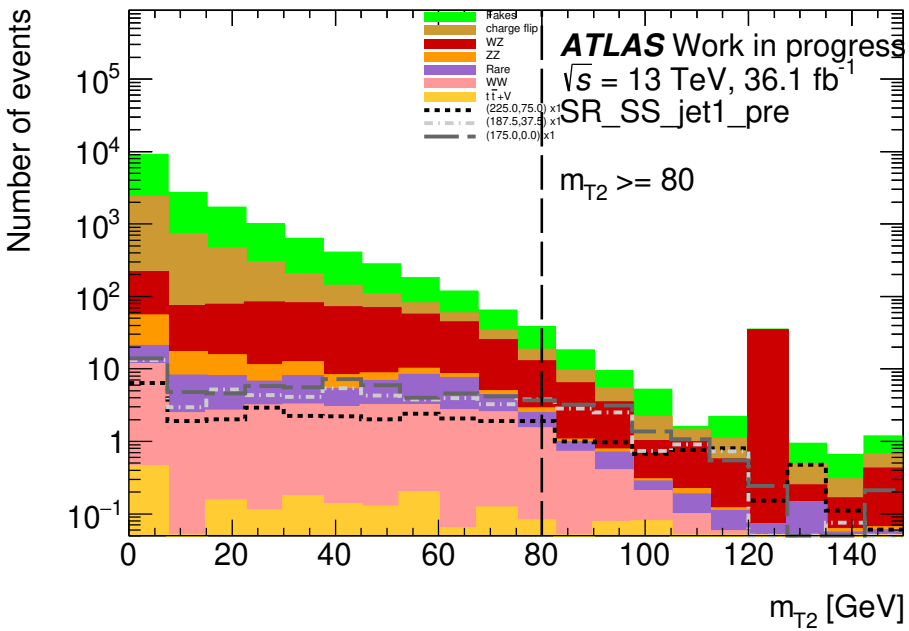

Fakes
charge flip
WZ
WW
Rare
ZZ
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet23_pre
m_{T}^{l1} >= 120
Number of events
m_{T}^{l1} [GeV]

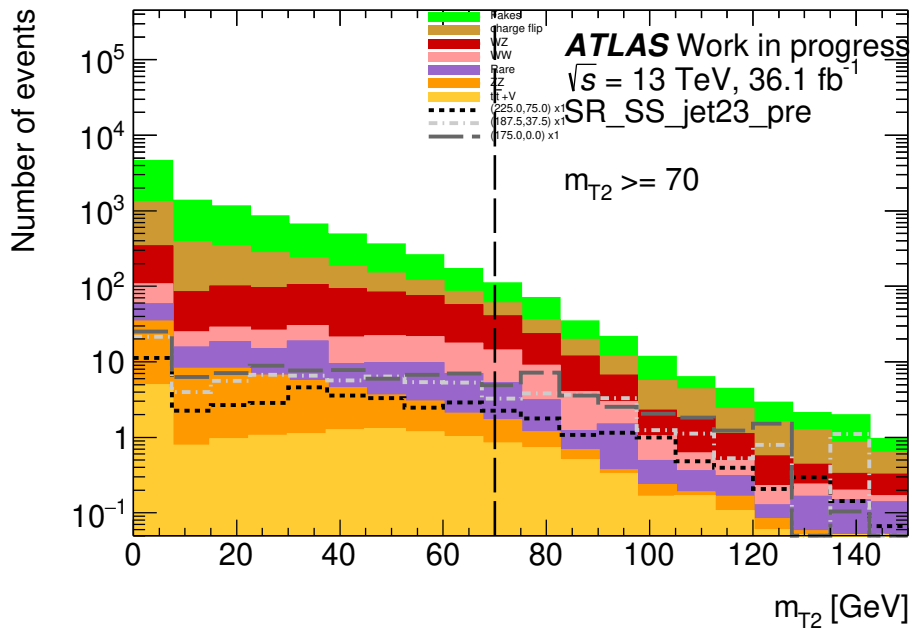
m_{lj}/m_{ljj}


Number of events
Fakes
charge flip
WZ
ZZ
Rare
WW
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet1_pre
m_{lj}/m_{ljj} < 180
m_{lj}/m_{ljj} [GeV]


Number of events
Fakes
charge flip
WZ
Rare
WW
ZZ
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet23_pre
m_{lj}/m_{ljj} < 130
m_{lj}/m_{ljj} [GeV]

m_{T2}


Fakes
charge flip
WZ
ZZ
Rare
WW
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet1_pre
m_{T2} >= 80
Number of events
m_{T2} [GeV]


Fakes
charge flip
WZ
WW
Rare
ZZ
t$\bar{t}$+V
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
SR_SS_jet23_pre
m_{T2} >= 70
Number of events
m_{T2} [GeV]

N-1 plots

Yields in SR

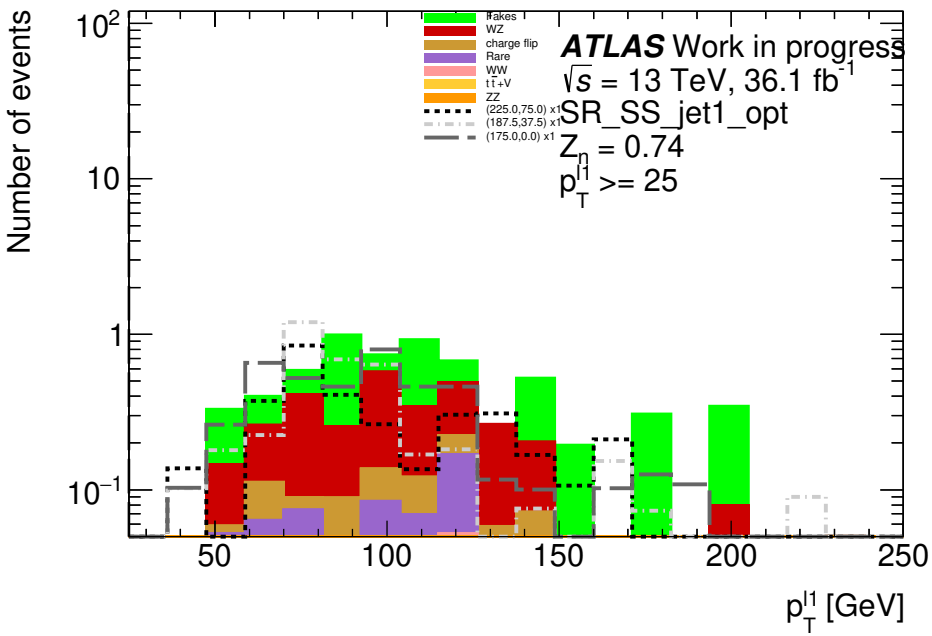
	Number of events	Significance
Fakes	3.295434 ± 0.819175 (24)	
WZ	2.176292 ± 0.397871 (257)	
charge flip	0.472185 ± 0.052737 (265)	
Rare	0.443536 ± 0.111301 (56)	
WW	0.165504 ± 0.023455 (67)	
$t\bar{t} + V$	0.124898 ± 0.046227 (36)	
ZZ	0.055330 ± 0.027713 (31)	
Total BG	6.733178 ± 0.920855 (736)	
(225.0,75.0)	3.33 ± 0.60 (60)	**0.74**
(187.5,37.5)	3.77 ± 0.95 (31)	0.86
(175.0,0.0)	4.29 ± 0.73 (36)	0.98

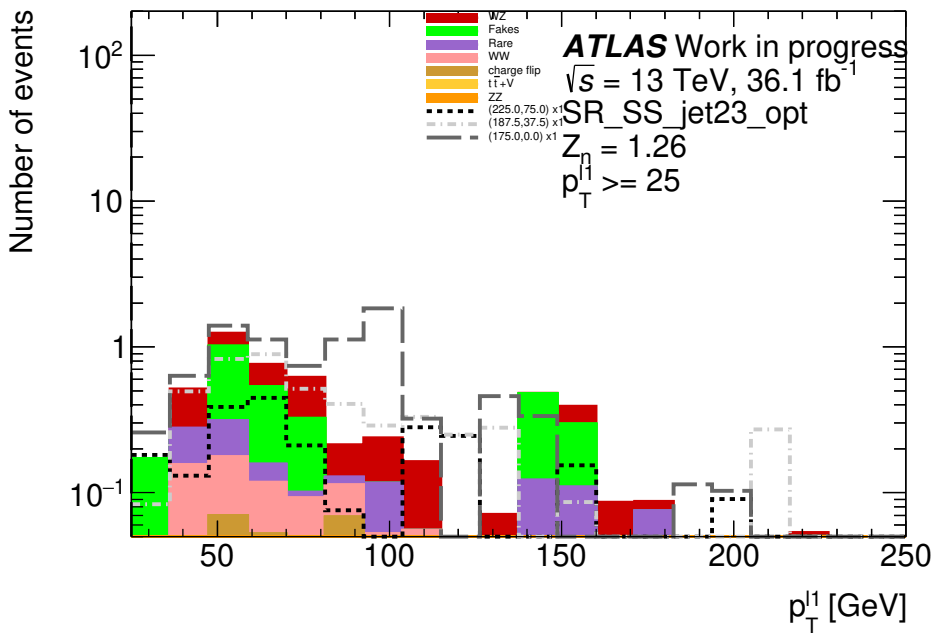
Table: Yields in SRjet1

	Number of events	Significance
WZ	1.848838 ± 0.273025 (319)	
Fakes	1.764693 ± 0.709215 (20)	
Rare	0.731015 ± 0.195114 (48)	
WW	0.514488 ± 0.036878 (235)	
charge flip	0.267485 ± 0.029086 (274)	
$t\bar{t} + V$	0.141679 ± 0.030772 (67)	
ZZ	0.067226 ± 0.024995 (24)	
Total BG	5.335425 ± 0.787005 (987)	
(225.0,75.0)	2.35 ± 0.34 (58)	0.57
(187.5,37.5)	4.72 ± 0.74 (47)	**1.26**
(175.0,0.0)	8.60 ± 1.51 (58)	2.24

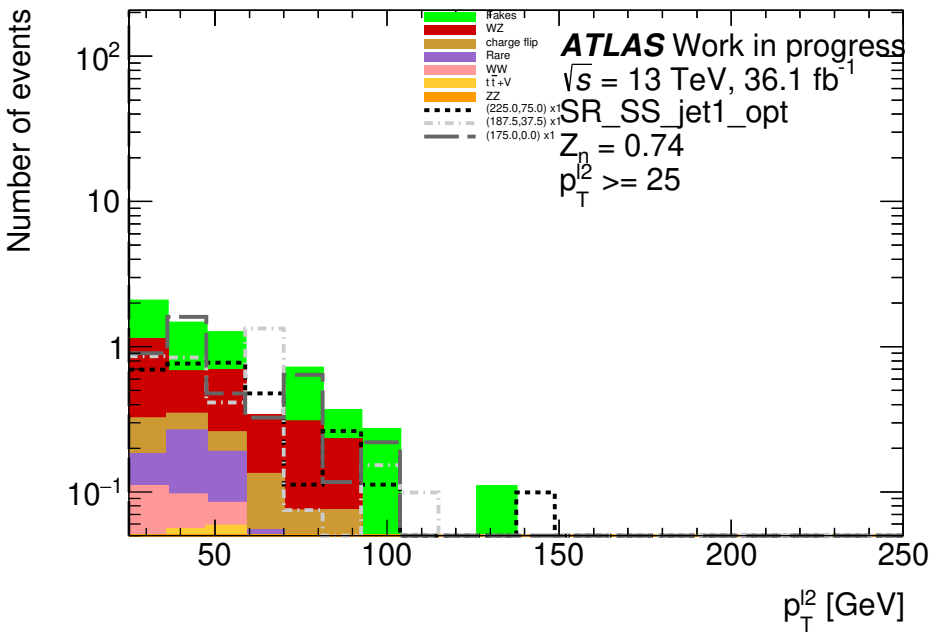
Table: Yields in SRjet23

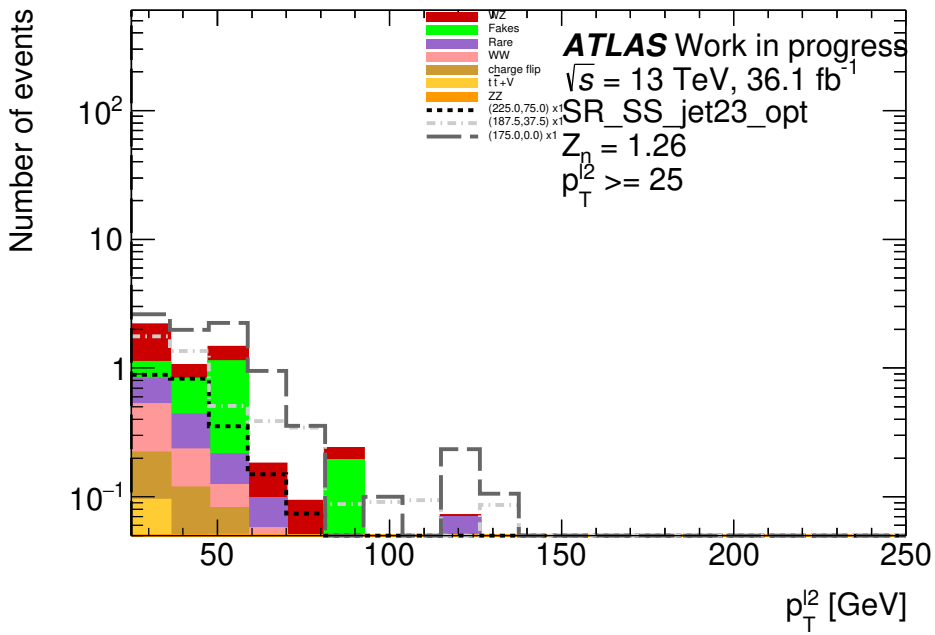
p_T^{l1}


Fakes
WZ
charge flip
Rare
WW
t t̄+V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet1_opt
Zη = 0.74
p_T^l1 >= 25
Number of events
p_T^l1 [GeV]

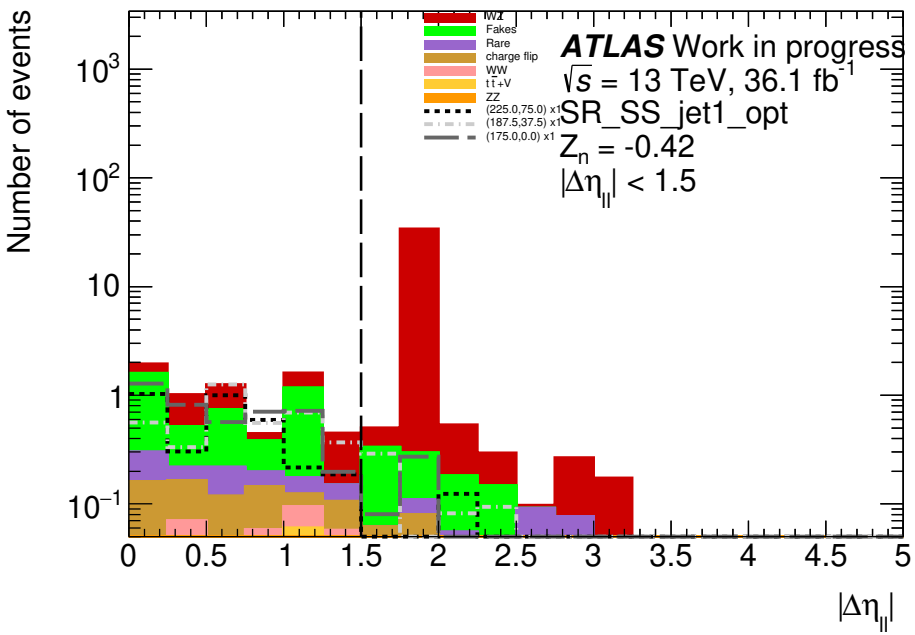

WZ
Fakes
Rare
WW
charge flip
t t̄+V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet23_opt
Zη = 1.26
p_T^l1 >= 25
Number of events
p_T^l1 [GeV]

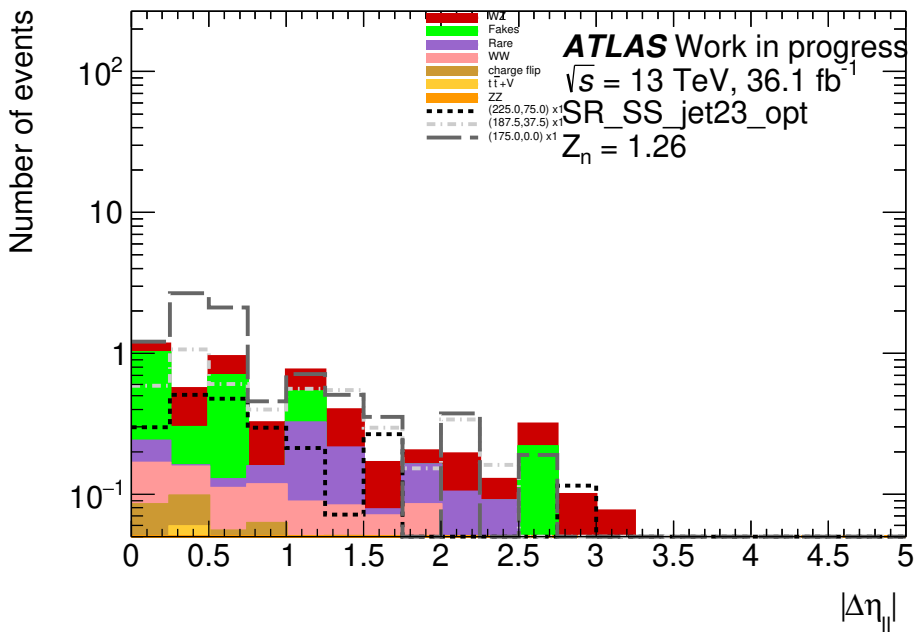
p_T^{l2}


Fakes
WZ
charge flip
Rare
WW
t t̄+V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet1_opt
Zn = 0.74
pl2T >= 25
Number of events
pl2T [GeV]

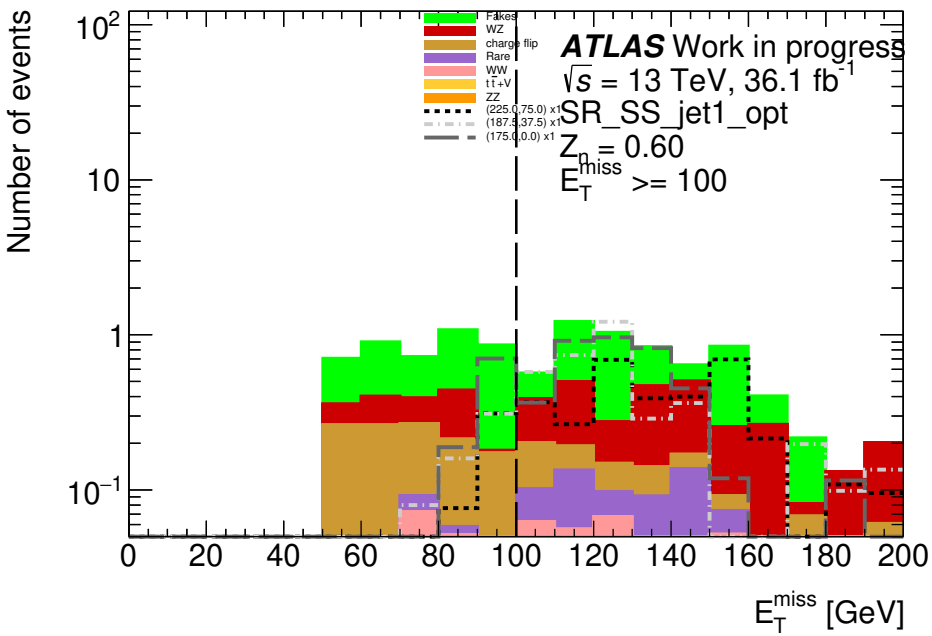

WZ
Fakes
Rare
WW
charge flip
t t̄+V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet23_opt
Zn = 1.26
pl2T >= 25
Number of events
pl2T [GeV]

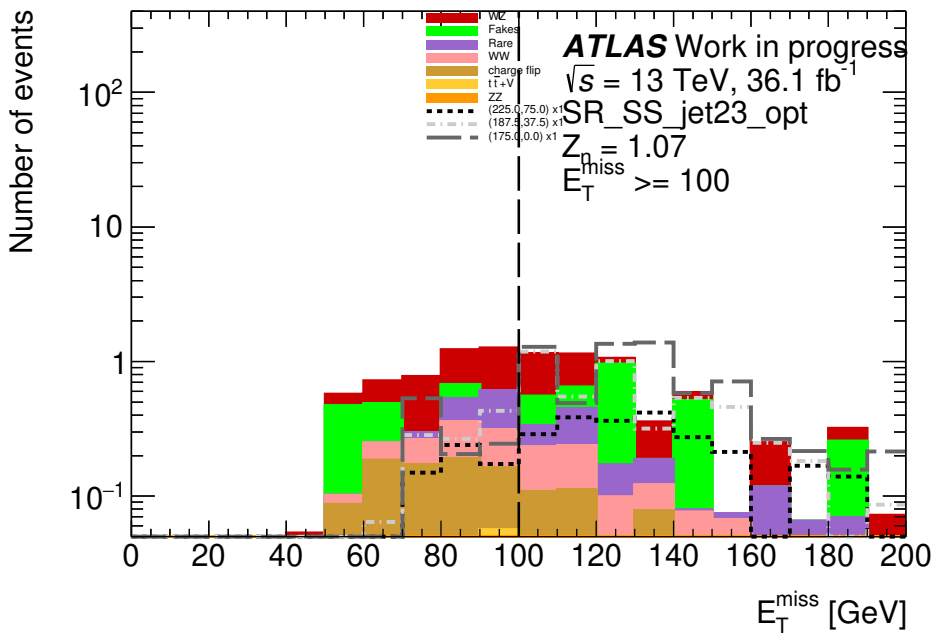
$|\Delta\eta_{ll}|$


WZ
Fakes
Rare
charge flip
WW
t t̄+V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet1_opt
Zn = -0.42
|Δηll| < 1.5
Number of events
|Δηll|

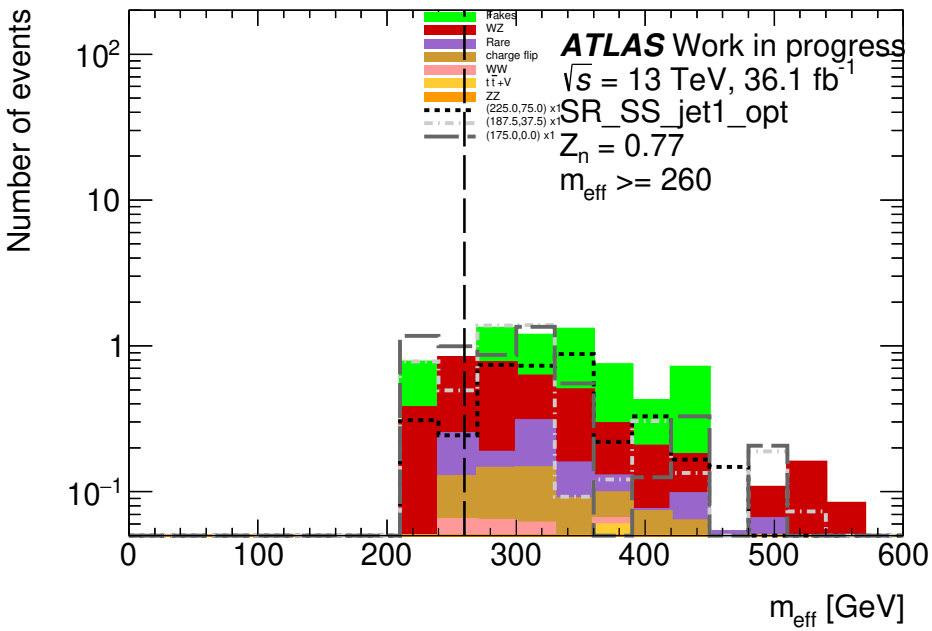

WZ
Fakes
Rare
WW
charge flip
t t̄+V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet23_opt
Zn = 1.26
Number of events
|Δηll|

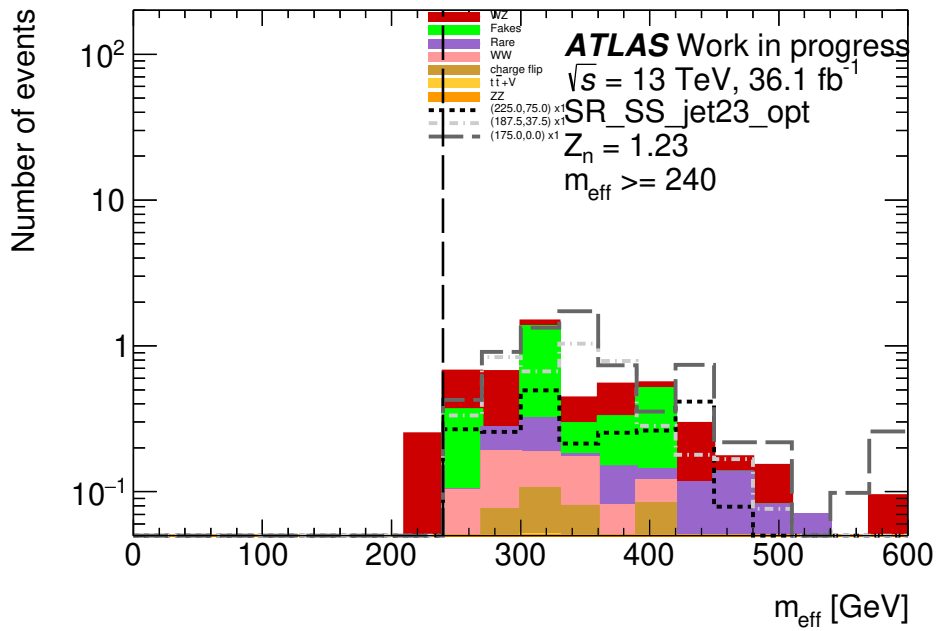
$E_{\mathrm{T}}^{\mathrm{miss}}$



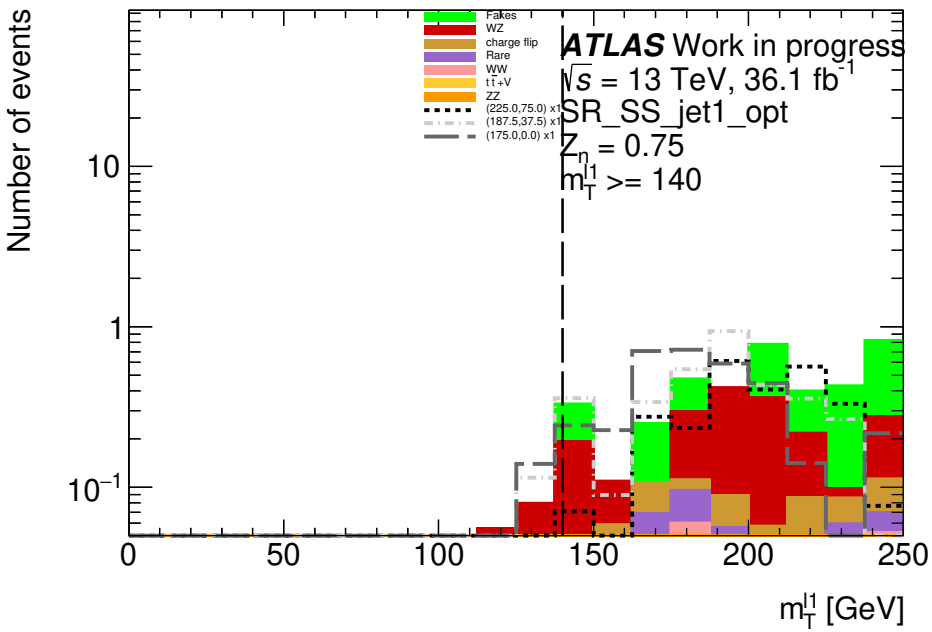


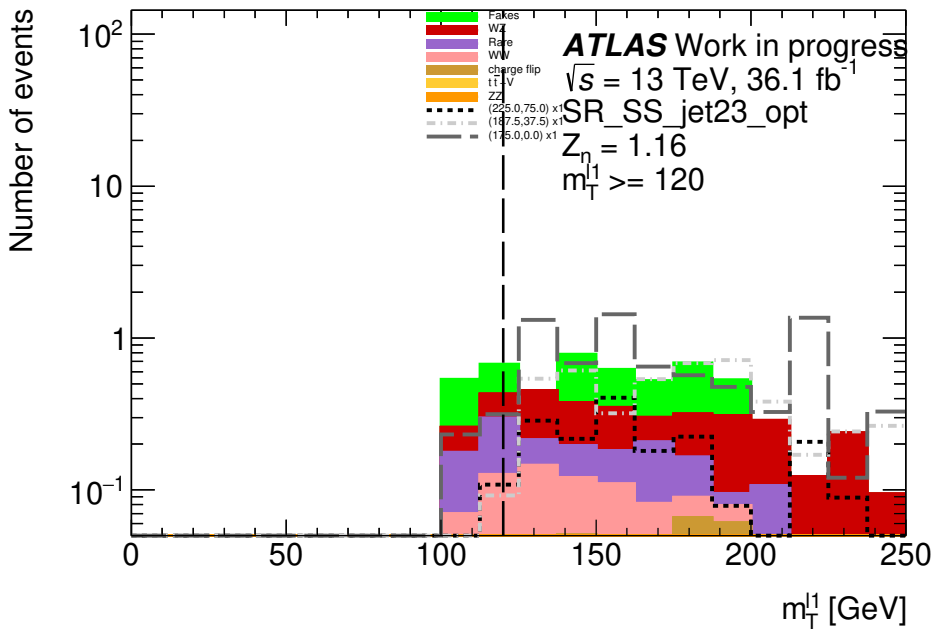
m_{eff}


Number of events
Fakes
WZ
Rare
charge flip
WW
t t̄ +V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet1_opt
Zn = 0.77
meff >= 260
meff [GeV]

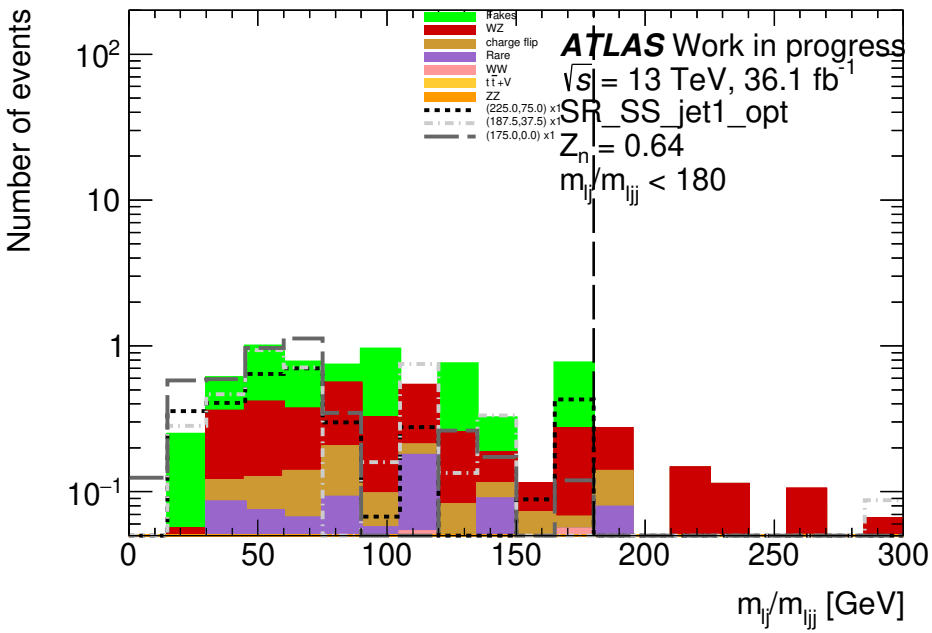

Number of events
WZ
Fakes
Rare
WW
charge flip
t t̄ +V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet23_opt
Zn = 1.23
meff >= 240
meff [GeV]

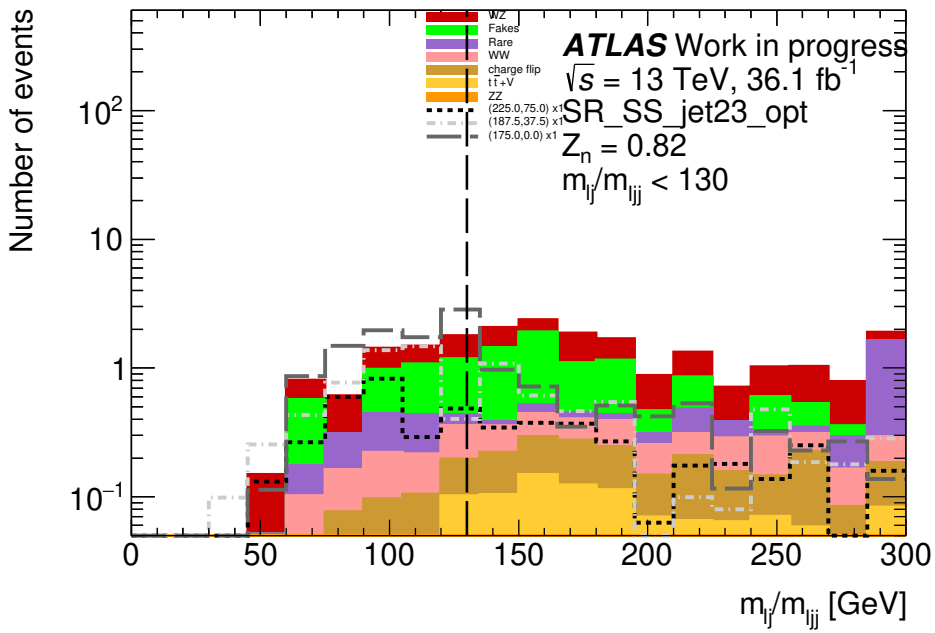
m_{T}^{l1}


Fakes
WZ
charge flip
Rare
WW
t t̄ +V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet1_opt
Zη = 0.75
m_T^l1 >= 140
Number of events
m_T^l1 [GeV]

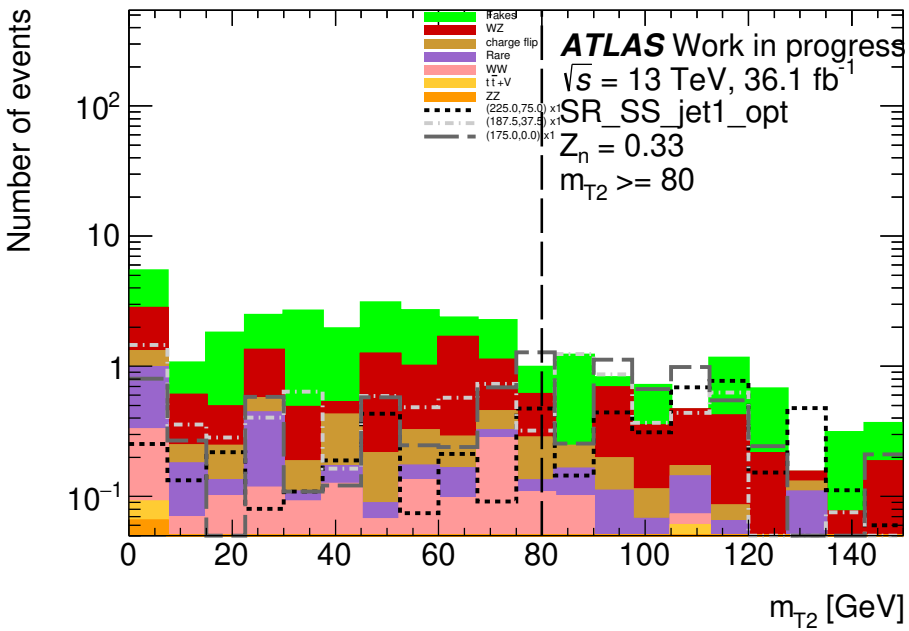

Fakes
WZ
Rare
WW
charge flip
t t̄ +V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet23_opt
Zη = 1.16
m_T^l1 >= 120
Number of events
m_T^l1 [GeV]

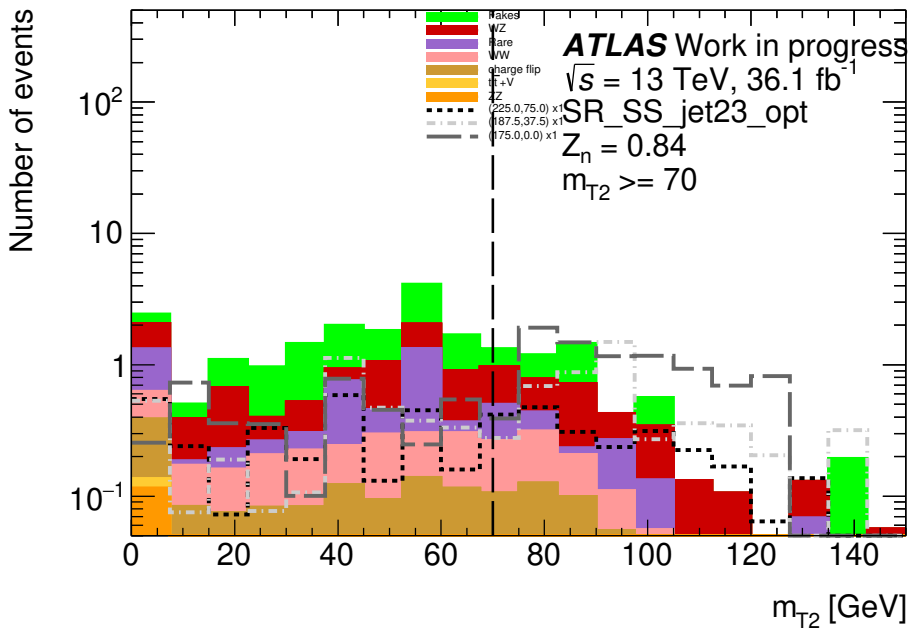
m_{lj}/m_{ljj}


Fakes
WZ
charge flip
Rare
WW
t t̄+V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet1_opt
Zn = 0.64
mlj/mljj < 180
Number of events
mlj/mljj [GeV]


WZ
Fakes
Rare
WW
charge flip
t t̄+V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet23_opt
Zn = 0.82
mlj/mljj < 130
Number of events
mlj/mljj [GeV]

m_{T2}


Number of events
Fakes
WZ
charge flip
Rare
WW
t t̄ +V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet1_opt
Zn = 0.33
mT2 >= 80
mT2 [GeV]


Number of events
Fakes
WZ
Rare
WW
charge flip
t t̄ +V
ZZ
(225.0,75.0) x1
(187.5,37.5) x1
(175.0,0.0) x1
ATLAS Work in progress
√s = 13 TeV, 36.1 fb-1
SR_SS_jet23_opt
Zn = 0.84
mT2 >= 70
mT2 [GeV]