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Searching for 3rd Generation Squarks in ATLAS

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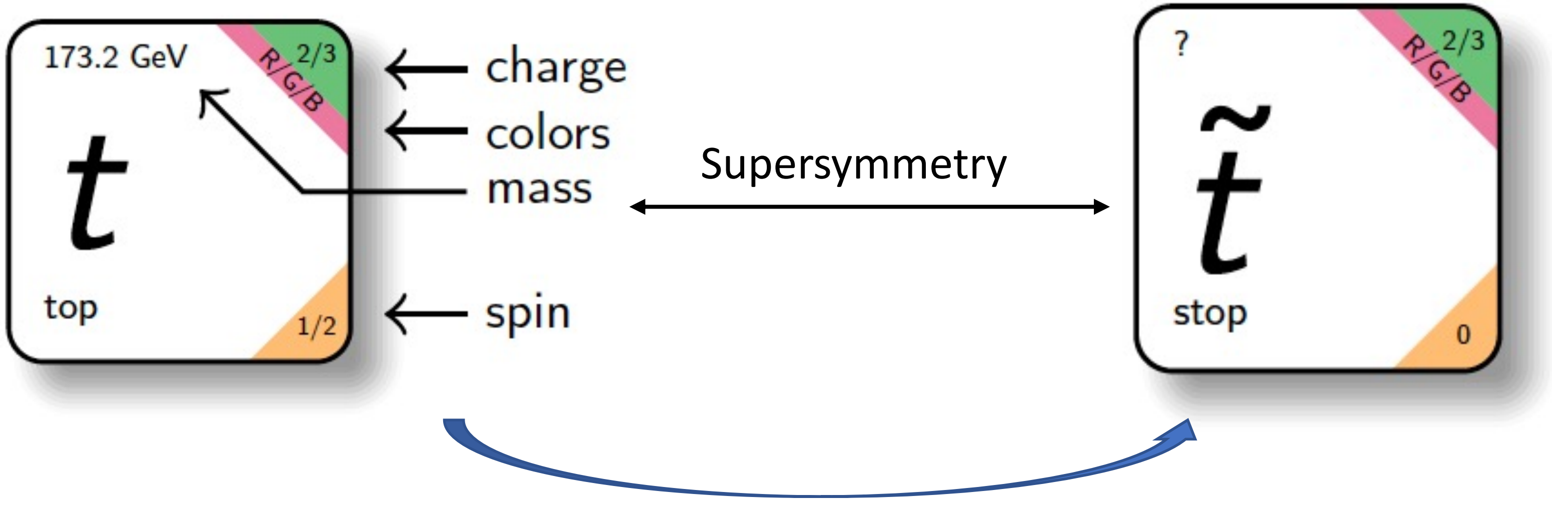
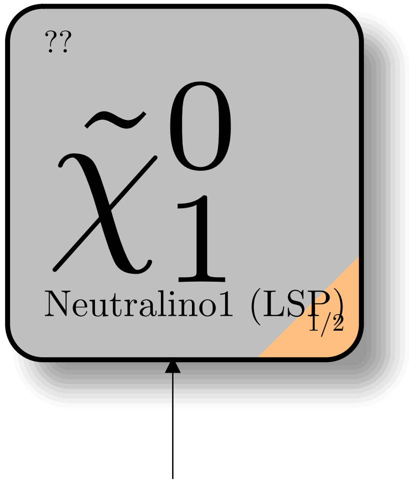
Supersymmetry (SUSY)



Bosonic SUSY superpartner



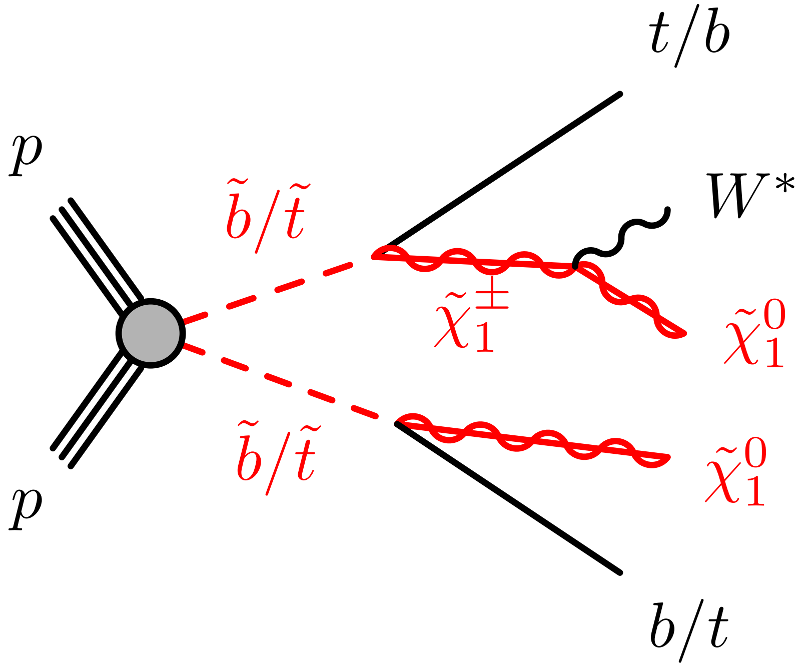
Dark matter candidate because of R-parity

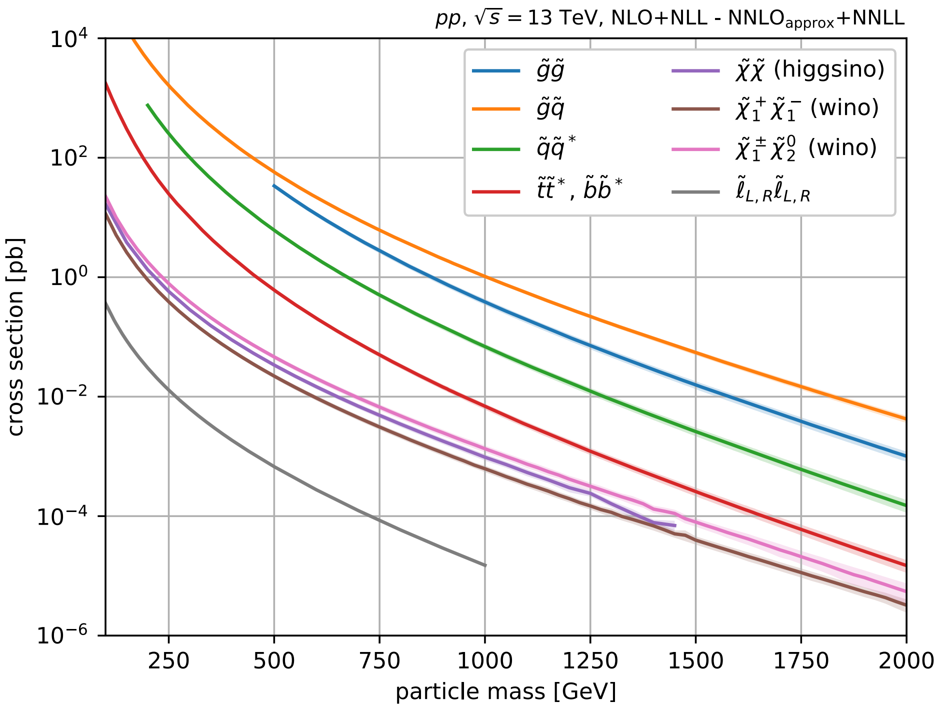
- Lightest SUSY particle (LSP) is stable and non-interacting

- Spacetime symmetry between bosons (integer spin) and fermions (half-integer spin).
- SUSY close to the electroweak scale (EWK), would solve open questions of the standard model
  - Hierarchy problem
  - Gauge unification

Supersymmetric signal process (tb+E^{miss}_T final states)

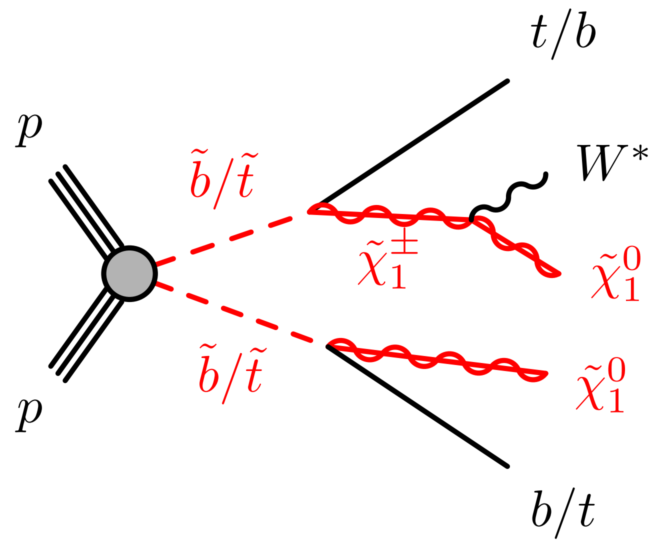
- Large Hadron Collider (LHC) can probe TeV energy scale ($\sqrt{s}$ = 13 TeV). Thus, one can access the m($\tilde{t}$) ~TeV.
  - Higher m($\tilde{t}$) , lower the cross-section
  - Higher $\sqrt{s}$, higher cross-section → needed for TeV scale m($\tilde{t}$)
- Most ATLAS searches assume symmetric decays, which if multiple decay modes are open would have weaker limits/poorer sensitivity. We are interested in the signal where multiple decay modes are open.
- This search for 3rd generation squarks are therefore unique
  - specifically optimised to target the asymmetric decay mode, which leads to a final state consisting of a top-quark (t), a bottom-quark (b) and missing transverse energy (E^{miss}_T)
  - provided that the W boson is off-shell such that m($\tilde{X}_1^{\pm}$) ~ m($\tilde{X}_1^0$).





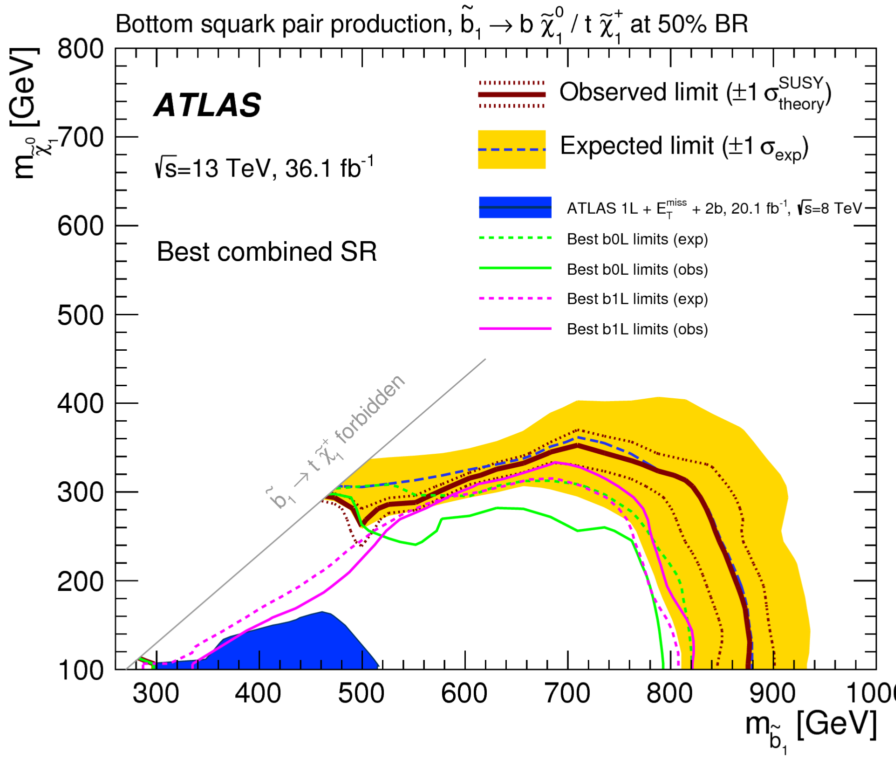
SUSY Cross-sections at $\sqrt{s}$ = 13 TeV

The tb+E^{miss}_T analysis



- tb+E^{miss}_T search has been performed using 20 fb^{-1} ATLAS Run 1 data and 36 fb^{-1} ATLAS Run 2 data.
- m($\tilde{t}$) upto 880 GeV excluded for m($\tilde{X}^0_1$) = 110 GeV (combined bb+ E^{miss}_T and tb+E^{miss}_T exclusion limits).
- Analysis is being repeated with the full 139 fb^{-1} ATLAS Run 2 data,
  - as the increased luminosity increases the signal sensitivity.

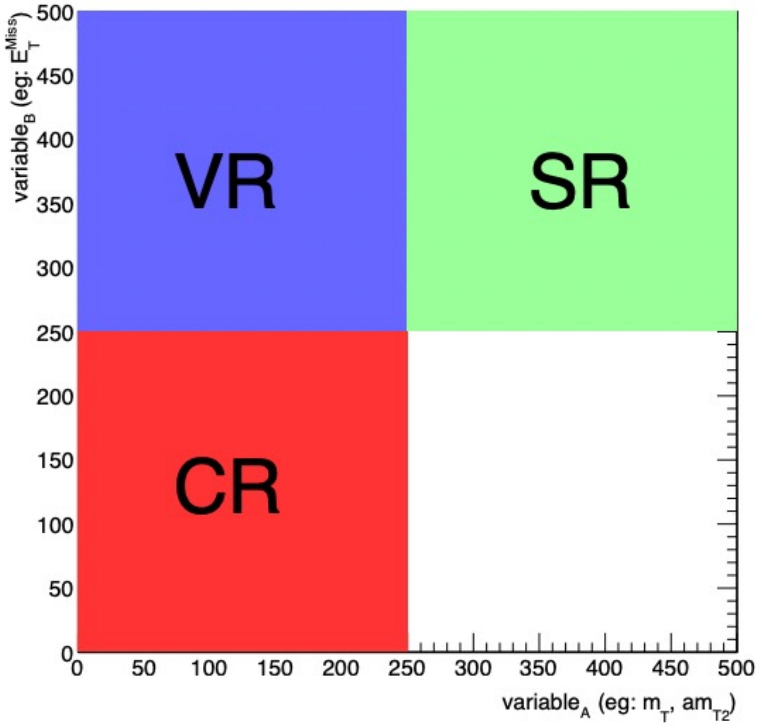
→ work in progress



SUSY Search Strategy

- Validation Regions (VR) defined to validate the backgrounds in the SR
  - Kinematically close to the SR, however orthogonal to both the SR and the CR

- Control Regions (CRs) defined to constrain the main SM background processes in the SR.
  - Kinematically close to the SRs, however designed such that they are orthogonal to the SR.
  - Designed to contain events with only the specific background process considered as much as possible.



- Signal Regions (SR) defined based upon kinematic differences between SUSY signal and SM background.
- Optimised by attempting to maximise the discovery or exclusion significance for the model.

- For preliminary investigations, CR and VR selections of the previous Run 2 analysis has been used.
- Selections will be specially optimised for this analysis.

Control region (CRttA) selections: $t\bar{t}$ dominant background

- CRttA selections defined to constrain the $t\bar{t}$ background in the region with intermediate to large Δm between the $\tilde{t}$ and $\tilde{X}_1^0$.

Some of the CRttA Selections:

Variable	CRttA
E_T^{miss}	> 250 GeV
$m_{b,l}^{min}$	< 170 GeV
am_{T2}	< 250 GeV

Control region (CRttA) selections: $t\bar{t}$ dominant background

- CRttA selections defined to constrain the $t\bar{t}$ background in the region with intermediate to large Δm between the $\tilde{t}$ and $\tilde{X}_1^0$.

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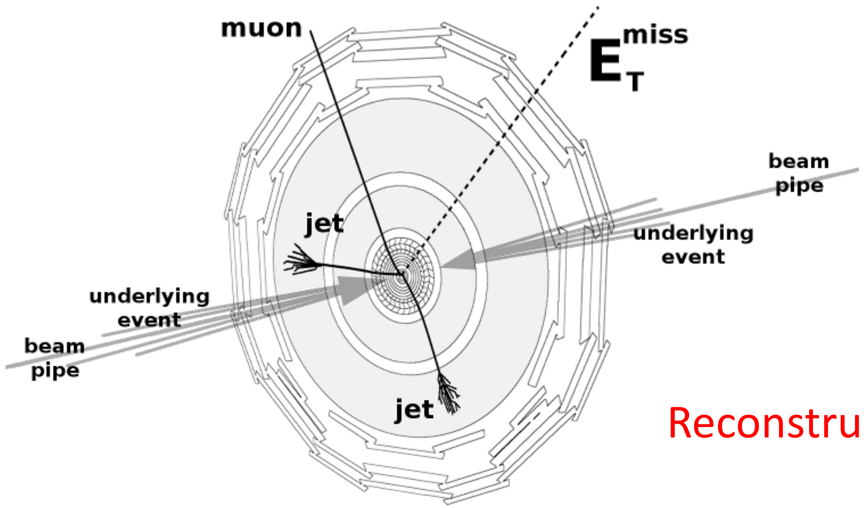
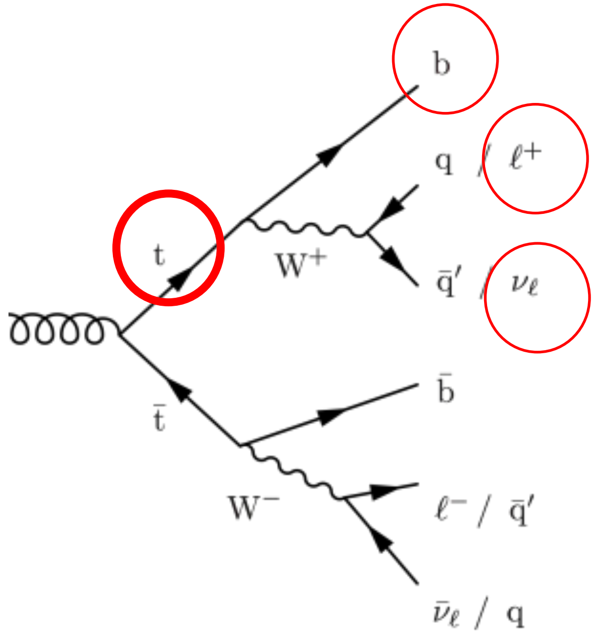


Reconstructed E^{miss}_T : $\sum_{visible} \overrightarrow{p_T} = -\sum_{visible} \overrightarrow{p_T}$

Control region (CRttA) selections: $t\bar{t}$ dominant background

- CRttA selections defined to constrain the $t\bar{t}$ background in the region with intermediate to large ∆m between the $\tilde{t}$ and $\tilde{X}_1^0$.



- Minimum invariant mass of the lepton with each of the b-jets is referred to as $m_{b,l}^{min}$.
- Consider a $t\bar{t}$ decay, and then $m_{b,l}^{min}$ is measured using 1 b-quark, 1 lepton and E_T^{miss}.
  - If $m_{b,l}^{min}$< 170 GeV, then the lepton, the b-quark and E_T^{miss} are compatible with a top-quark.

Some of the CRttA Selections:

Variable	CRttA
E_T^{miss}	> 250 GeV
$m_{b,l}^{min}$	< 170 GeV
am_{T2}	< 250 GeV

Control region (CRttA) selections: $t\bar{t}$ dominant background

- CRttA selections defined to constrain the $t\bar{t}$ background in the region with intermediate to large Δm between the $\tilde{t}$ and $\tilde{X}_1^0$.

Some of the CRttA Selections:

Variable	CRttA
E_T^{miss}	> 250 GeV
$m_{b,l}^{min}$	< 170 GeV
am_{T2}	< 250 GeV

- Asymmetric transverse mass am_{T2} is used to measure the masses of semi-invisibly decaying particles.
- In the tb+ E^{miss}_T analysis, am_{T2} is used to reject $t\bar{t}$ pair production where one top quark decays semi-leptonically.

Control region (CRttA) selections: $t\bar{t}$ dominant background

- CRttA selections defined to constrain the $t\bar{t}$ background in the region with intermediate to large ∆m between the $\tilde{t}$ and $\tilde{X}_1^0$.
- CRttA region defined to have am_{T2} < 250 GeV and $m_{b,l}^{min}$ < 170 GeV to produce a pure $t\bar{t}$ region.

Yield: #events that pass the selection

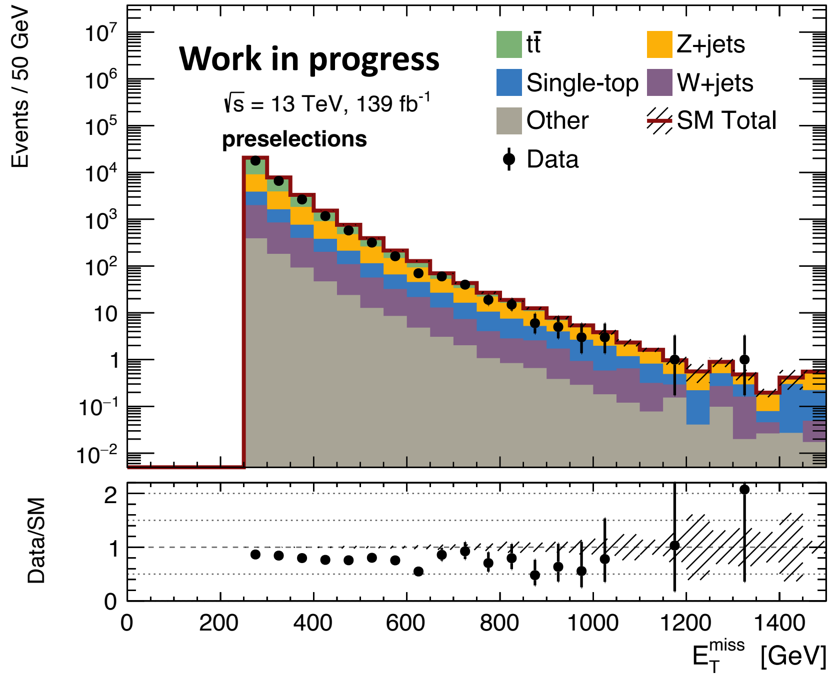
Contribution/Selection	CRttA
Data	125.0±11.18
ttbar	115.01±2.99
Single top	7.07±1.03
W+jets	1.96±0.63
Z+jets	0.35±0.18
Other	4.64±0.29
SM	129.04±3.25

Some of the CRttA Selections:

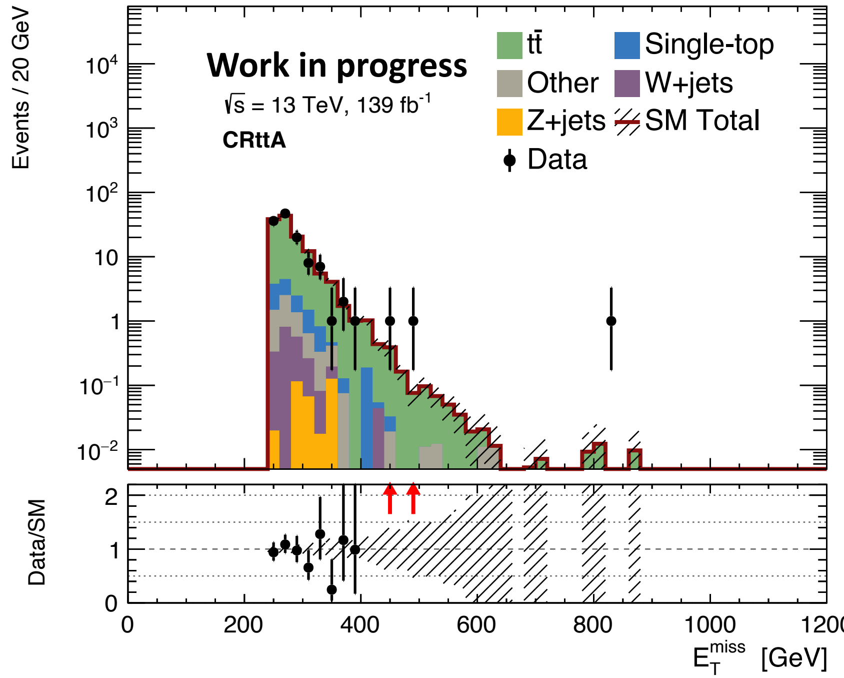
Variable	CRttA
E_T^{miss}	> 250 GeV
$m_{b,l}^{min}$	< 170 GeV
am_{T2}	< 250 GeV

Performance of Control Region (CRttA): E^{miss}_{T}

Before applying selections



After applying selections

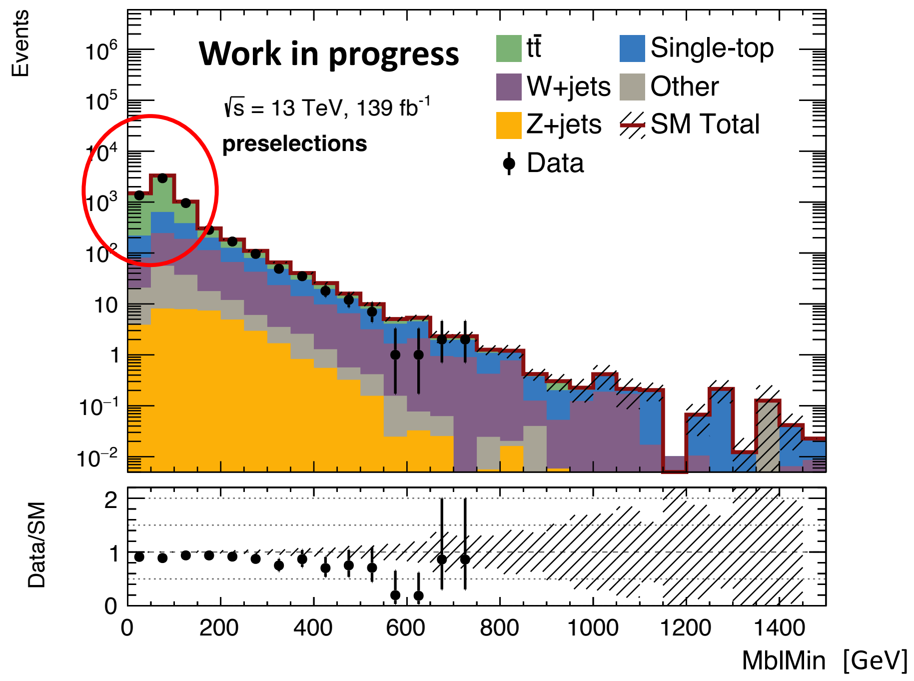


- As our expected signal includes a top quark, a bottom, quark and E^{miss}_{T} in the form of $\tilde{X}^0_1$, we will use a E^{miss}_{T} trigger.
- Efficiency of E^{miss}_{T} trigger is ~100% at $E^{miss}_{T} > 250$ GeV.
- MC files generated with a selection of $E^{miss}_{T} > 250$ GeV

- The no. of events that pass the CRttA selections is considerably lower in comparison to pre-CRttA selections.

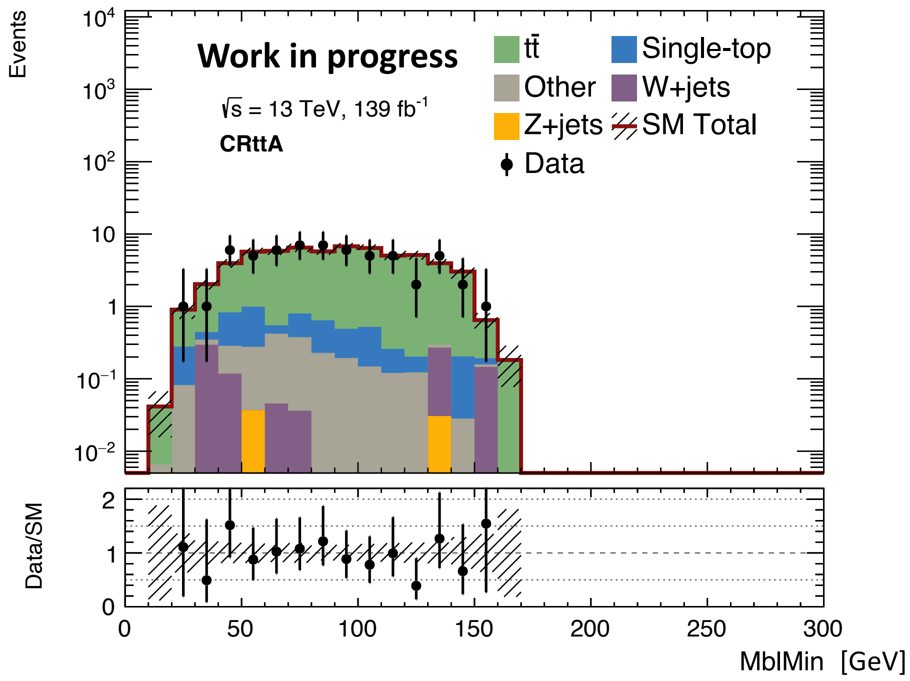
Performance of Control Region (CRttA): $m_{b,l}^{min}$

Before applying selections



- Low values of $m_{b,l}^{min}$ specifically picks up top quark events.

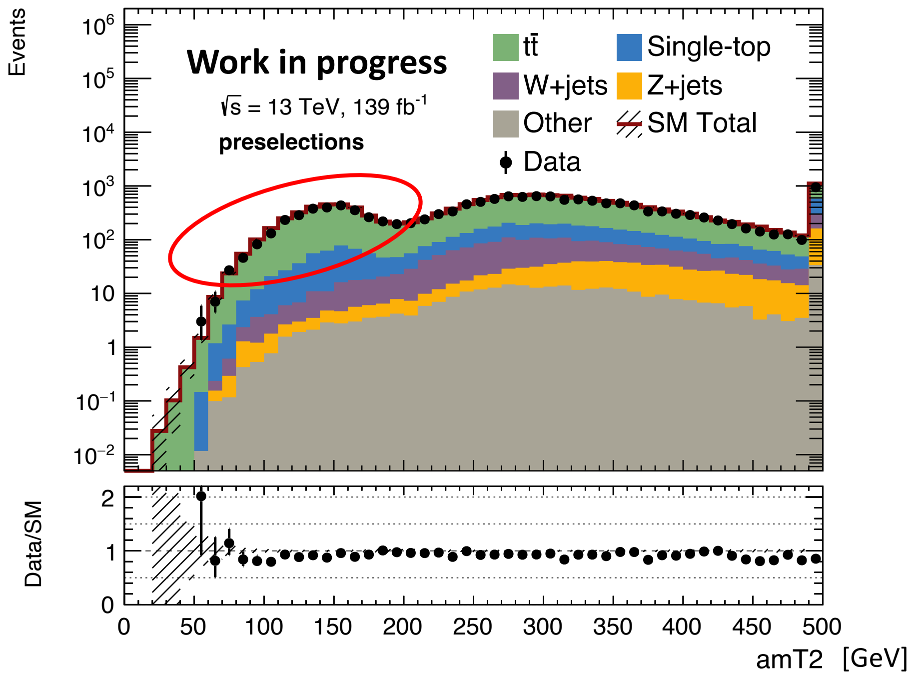
After applying selections



- $t\bar{t}$ background isolated applying $m_{b,l}^{min}$ < 170 GeV selection.

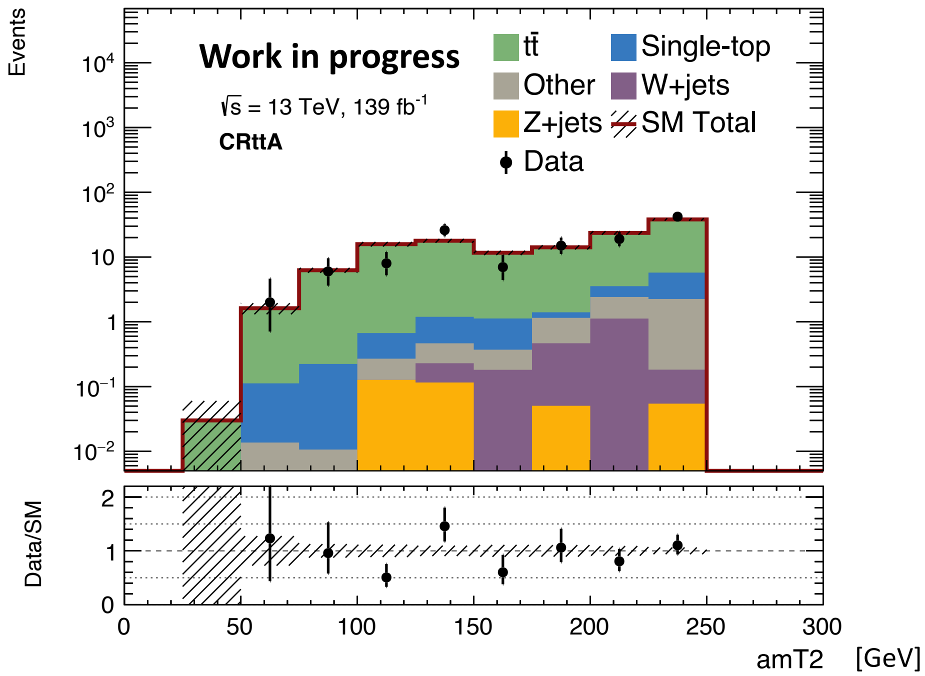
Performance of Control Region (CRttA): am_{T2}

Before applying selections



- The lower region of the variable is dominated by $t\bar{t}$.

After applying selections



- Dominated by $t\bar{t}$ background after applying am_{T2} selection < 250 GeV.

Validation region (VRA_amT2) selections

Some of the VRA_amT2 Selections:

Variable	CRttA
E_T^{miss}	> 250 GeV
am_{T2}	> 250 GeV
$m_{b,l}^{min}$	< 170 GeV

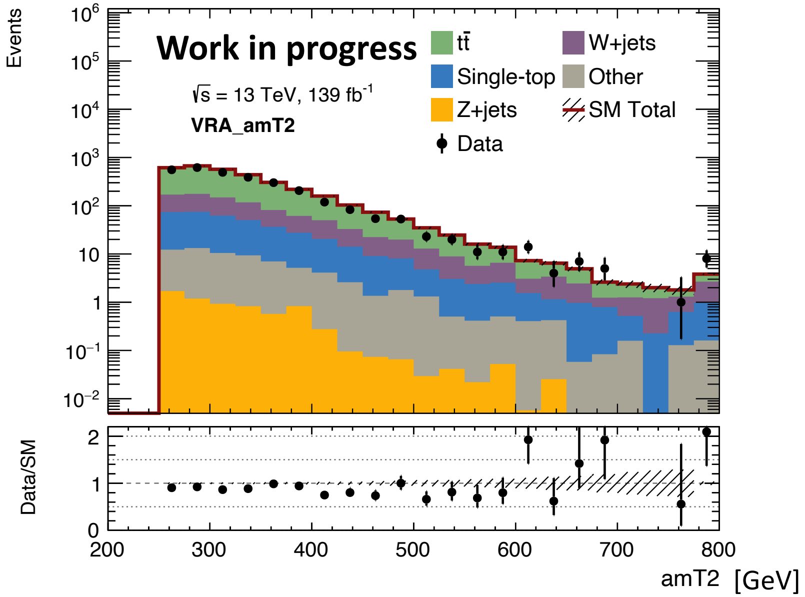
- VRA_am_{T2} aims to validate the modelling of am_{T2} in the region with intermediate to large Δm between the $\tilde{t}$ and $\tilde{X}_1^0$ by using the SR am_{T2} selection (am_{T2} is orthogonal to the corresponding CR selection).

Yield: #events that pass the selection

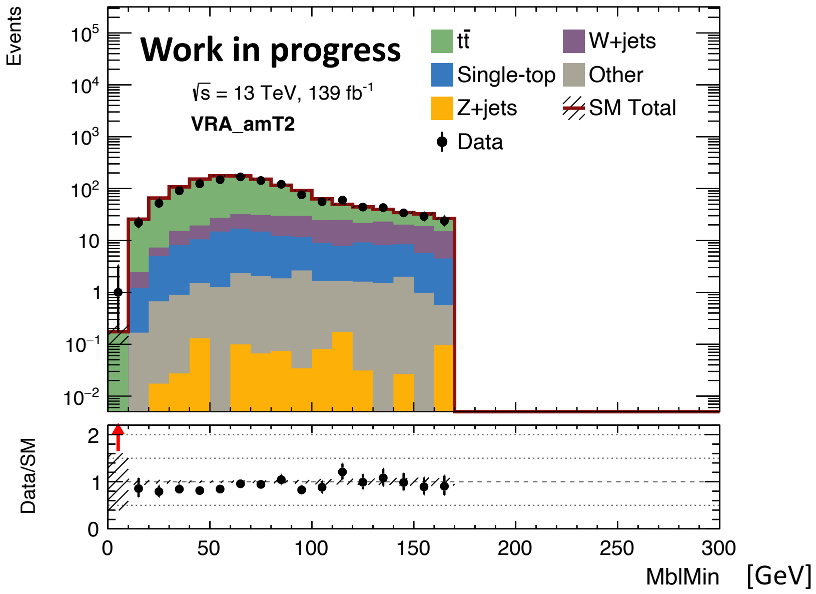
Contribution/Selection	VRA_amT2
Data	2976.0±54.55
ttbar	2396.12±10.80
Single top	326.07±5.96
W+jets	534.56±8.59
Z+jets	6.74±0.68
Other	64.82±2.39
SM	3328.31±15.23

Performance of Validation Region (VRA_amT2)

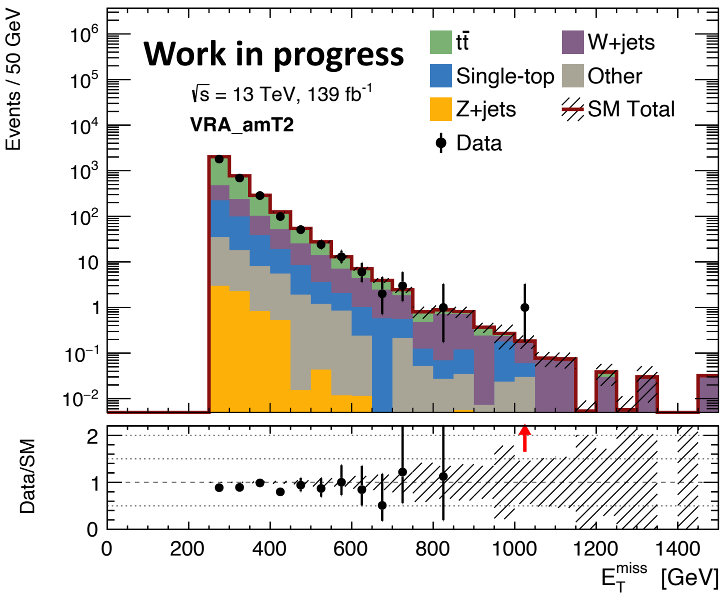
am_{T2}



$m_{b,l}^{min}$

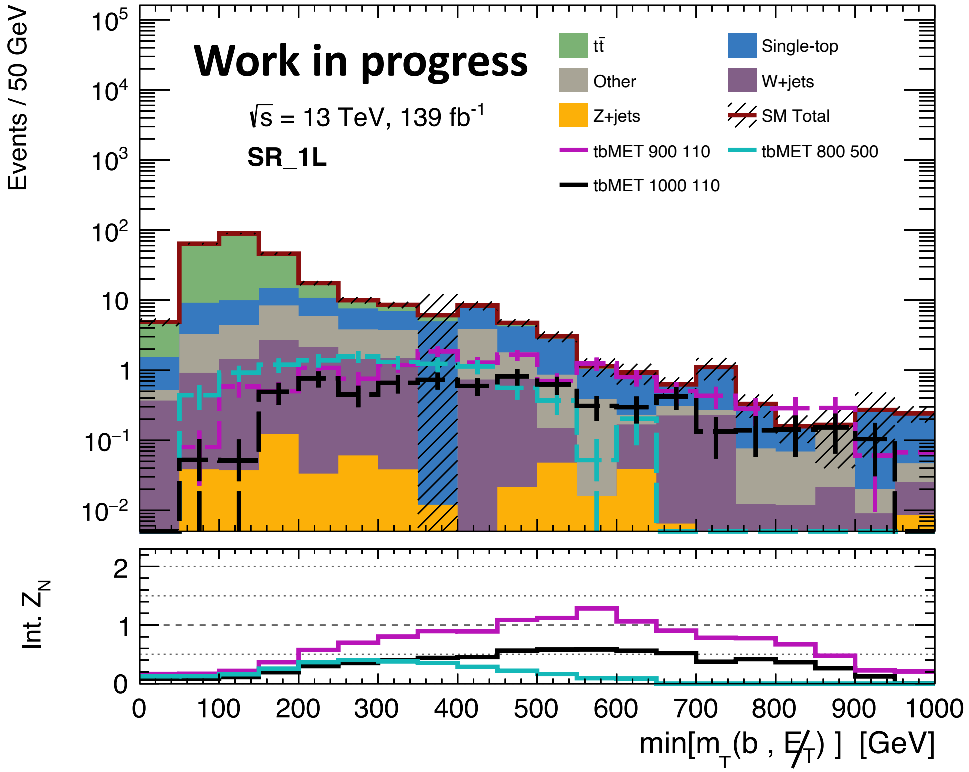


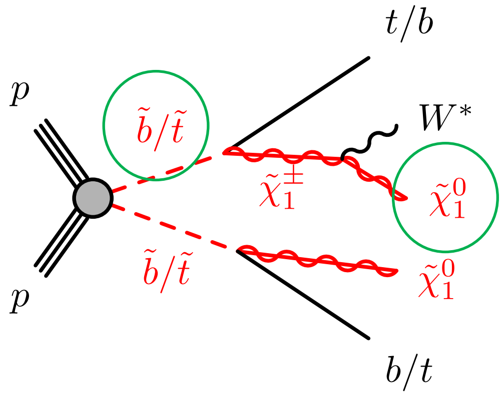
E^{miss}_{T}



- Dominated by $t\bar{t}$ in a region that is closer to our SR, and we can check the modelling.

Signal significance studies





- 3 representative points from 3 different mass regions of the m($\tilde{t}$) and m($\tilde{X}_1^0$):
  - m($\tilde{t}$) = 900 GeV, m($\tilde{X}_1^0$) = 110 GeV
  - m($\tilde{t}$) = 800 GeV, m($\tilde{X}_1^0$) = 500 GeV
  - m($\tilde{t}$) = 1000 GeV, m($\tilde{X}_1^0$) = 110 GeV

aid in optimising the signal over background ratio, referred to as the significance, demonstrated by the lower plot.

Here, $m_T(b, {}^{E}/_{T})$ is the transverse mass variable reconstruction using a b-jet and E^{miss}_T as final states.

$$m_T(b, {}^{E}/_{T}) = \sqrt{2\left(p_T(b-jet)E_T^{miss} - \vec{p_T}(b-jet).E_T^{miss}\right)}$$

Conclusions

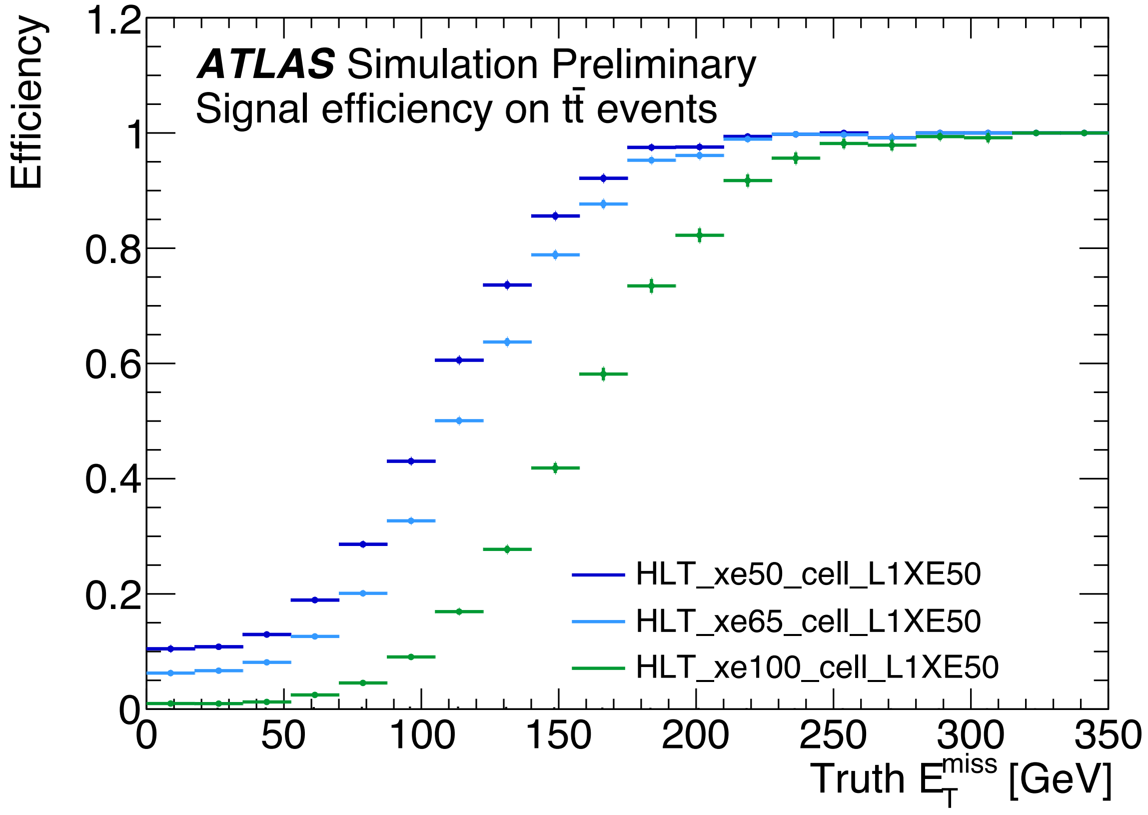
- Preliminary control and validation regions for the analysis using the previous selections shows that the key backgrounds (for e.g., $t\bar{t}$ shown here in plots, single top, W+jets) are well modelled.
- The Control, Validation and Signal regions will be further optimised for the higher luminosity of 139 fb^{-1}.

THANK YOU!

Back-up

E^{miss}_T (MET) trigger

- As our expected signal is a top quark, a bottom, quark and E^{miss}_T in the form of neutralinos we will use a E^{miss}_T trigger.
- The efficiency of E^{miss}_T trigger is ~100% at $E^{miss}_T > 250$ GeV.
- Then we if we use the MET trigger we must apply a MET filter of 250 GeV so that uninteresting events with $E^{miss}_T < 250$ GeV are not produced.
- The MET filter is applied at a E^{miss}_T lower than the analysis selection in this case MET trigger efficiency at 250 GeV, to make sure that events close to the filter are not removed.



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/MissingEtTriggerPublicResults

Preselections

All events are required to pass the Run 2 Event Cleaning to ensure good quality data. →

Variable	Selection
Event cleaning selections	✓
Trigger	Passed either of the single lepton (e,μ) triggers, or the E^{miss}_T trigger
$n_{b\text{-jets}}$	2
n_{jets}	2,3,4
$p_T\ (j_1)$, $p_T\ (j_2)$	> 50 GeV
$p_T\ (j_4)$	< 50 GeV (or n_{jets} = 2,3)
$\min\Delta\varphi\left(j, E_T^{miss}\right)$	> 0.4
E_T^{miss} / m_{eff}	> 0.25
E_T^{miss}	> 250 GeV

Preselections

As we have a relatively high expected E_T^{miss} it is possible that we can solely use the E_T^{miss} triggers, instead of the single-lepton triggers, but this is being investigated. → Trigger

Variable	Selection
Event cleaning selections	✓
Trigger	Passed either of the single lepton (e,μ) triggers, or the E^{miss}_T trigger
$n_{b\text{-jets}}$	2
n_{jets}	2,3,4
$p_T(j_1)$, $p_T(j_2)$	> 50 GeV
$p_T(j_4)$	< 50 GeV (or n_{jets} = 2,3)
$\min\Delta\varphi\left(j, E_T^{miss}\right)$	> 0.4
E_T^{miss}/m_{eff}	> 0.25
E_T^{miss}	> 250 GeV

Preselections

No. of b-jets in the final states.

No. of jets in the final states.

Transverse momentum of the leading jets.

Missing transverse energy (MET trigger fully efficient ~ 250 GeV also we expect high MET from our signal process).

Variable	Selection
Event cleaning selections	✓
Trigger	Passed either of the single lepton (e,μ) triggers, or the E^{miss}_T trigger
$n_{b\text{-jets}}$	2
n_{jets}	2,3,4
p_T (j_1), p_T (j_2)	> 50 GeV
p_T (j_4)	< 50 GeV (or n_{jets} = 2,3)
$\min\Delta\varphi(j, E_T^{miss})$	> 0.4
E_T^{miss}/m_{eff}	> 0.25
E_T^{miss}	> 250 GeV

Preselections

Minimum azimuthal distance between the jets and the E^{miss}_T is a useful variable to discriminate between multi-jet backgrounds with a large amount of E^{miss}_T due to mismeasured jets. →

Variable	Selection
Event cleaning selections	✓
Trigger	Passed either of the single lepton (e,μ) triggers, or the E^{miss}_T trigger
$n_{b\text{-jets}}$	2
n_{jets}	2,3,4
$p_T(j_1)$, $p_T(j_2)$	> 50 GeV
$p_T(j_4)$	< 50 GeV (or n_{jets} = 2,3)
$\min\Delta\varphi(j, E_T^{miss})$	> 0.4
E_T^{miss}/m_{eff}	> 0.25
E_T^{miss}	> 250 GeV

Preselections

Ratio of E^{miss}_T to m_{eff} is also used to reject multi-jet background where m_{eff}, is taken to be the scalar p_T sum of the hadronic activity in the detector and the E^{miss}_T .

Variable	Selection
Event cleaning selections	✓
Trigger	Passed either of the single lepton (e,μ) triggers, or the E^{miss}_T trigger
$n_{b\text{-jets}}$	2
n_{jets}	2,3,4
p_T (j_1), p_T (j_2)	> 50 GeV
p_T (j_4)	< 50 GeV (or n_{jets} = 2,3)
$\min\Delta\varphi(j, E_T^{miss})$	> 0.4
E_T^{miss} / m_{eff}	> 0.25
E_T^{miss}	> 250 GeV

Control region (CRttA) selections: $t\bar{t}$ dominant background

Variable	CRttA
Preselections	✓
$n_{Leptons}$ (e,μ)	1
$p_T(l)$	> 27 GeV
$n_{b\text{-}jets}$	2
E_T^{miss}	> 250 GeV
$\min\Delta\varphi(j, E_T^{miss})$	> 0.4
$m_{b,l}^{min}$	< 170 GeV
m_{CT}	< 250 GeV
m_{bb}	< 200 GeV
m_{eff}	> 300 GeV
E_T^{miss} significance	> 8 $GeV^{1/2}$
am_{T2}	< 250 GeV
m_T	> 140 GeV
n_{jets}	> 2
p_T (j_1)	> 35
p_T (j_2)	> 35
p_T (j_4)	> 35 (or n_{jets} < 4)

Minimum invariant mass of the lepton with each of the b-jets is calculated, referred to as $m_{b,l}$. If $m_{b,l}$ < 170 GeV, then the lepton and the b-jet are compatible with a top quark. → $m_{b,l}^{min}$

Asymmetric transverse mass am_{T2} (generalisation of m_T), is used to measure the masses of semi-invisibly decaying particles. The am_{T2} is used in the tb+ E^{miss}_T analysis to reject $t\bar{t}$ pair production where one top quark decays semi-leptonically. → am_{T2}

m_{CT} → Contransverse mass m_{CT} is a mass like property calculated using Lorentz invariance in case of 2 particles boosted by equal magnitude but in opposite directions such the reference frame is different and a parity operator is required to maintain the invariance. In case of ttbar production, the maximum m_{CT} is calculated to be 135 GeV and as such this cuts on this variable helps reduce ttbar background. And this ttbar pair further decays into b jets and W bosons which further can either decay to lepton and anti-neutrino or jets from quark anti-quark. Since we know we have b-jets in the final states, placing cuts on the mctbb is more useful.

m_T → Transverse mass m_T is used to reconstruct the mass of a particle that undergoes a decay, to a detectable particle, usually a lepton (pT(l)), and an invisible particle (E^{miss}_T). Usually, a selection is placed on m_T > 90-120 GeV to remove the W+jets background, considering detector resolution effects.

Control region (CRttA) selections: $t\bar{t}$ dominant background

Variable	CRttA
Preselections	✓
$n_{Leptons}$ (e,μ)	1
$p_T(l)$	> 27 GeV
$n_{b\text{-}jets}$	2
E_T^{miss}	> 250 GeV
$\min\Delta\varphi(j, E_T^{miss})$	> 0.4
$m_{b,l}^{min}$	< 170 GeV
m_{CT}	< 250 GeV
m_{bb}	< 200 GeV
m_{eff}	> 300 GeV
E_T^{miss} significance	> 8 $GeV^{1/2}$
am_{T2}	< 250 GeV
m_T	> 140 GeV
n_{jets}	> 2
$p_T(j_1)$	> 35
$p_T(j_2)$	> 35
$p_T(j_4)$	> 35 (or n_{jets} < 4)

The invariant mass of the two b-quarks from the $t\bar{t}$ decay generally peaks at around 200 GeV as in this case the b-quarks are each coming from a top-quark produced at rest. (Important when considering searches that produce 3rd generation squarks, commonly either top- or bottom-quarks are produced in the decay chain. Therefore, a standard background for most 3rd generation analyses is $t\bar{t}$ pair production.) → m_{bb}

→ E^{miss}_T significance is a measure of the contribution of the E^{miss}_T to the total activity in an event. A selection on EmissT significance is effective at removing the multi-jet background with fake E^{miss}_T.