$t\bar{t}Z \rightarrow \bar{\nu}\nu$

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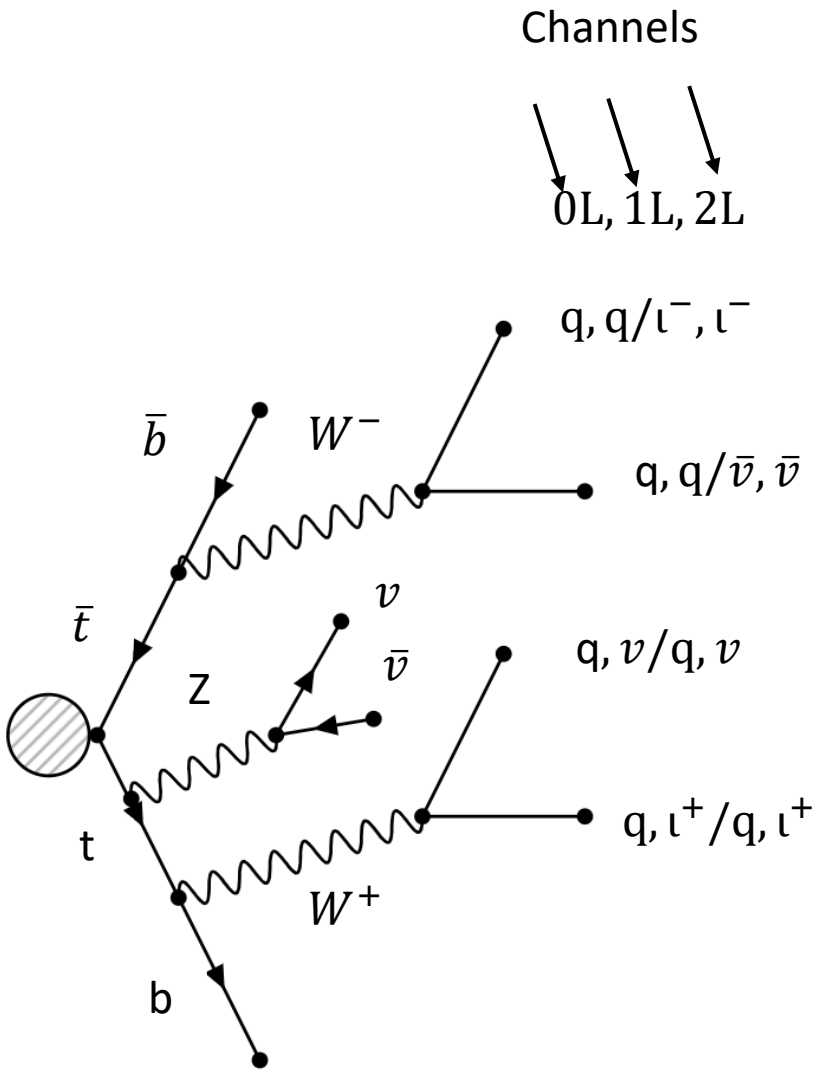
Motivation

- $t\bar{t}Z \rightarrow \bar{\nu}\nu$ is particularly sensitive to specific EFT operators as the BR of $Z \rightarrow \bar{\nu}\nu$ is much larger at 20% compared to $Z \rightarrow \bar{e}e/\bar{\mu}\mu$ at 6%. This implies more events are in the tail end of the distribution. This leads to more potential in the EFT fits
- DM+top searches for DM production in association with the top have their two main backgrounds listed as ttbar and $t\bar{t}Z \rightarrow \bar{\nu}\nu$. [1]
- However, $t\bar{t}Z \rightarrow \bar{\nu}\nu$ is difficult to measure with its high amount of background events.



Overview of Analysis

- Planning to combine 3 channels(0L, 1L, 2L) cross section measurements to search for the $t\bar{t}Z \rightarrow \bar{\nu}\nu$.

- First inclusive measurement of $t\bar{t}Z \rightarrow \bar{\nu}\nu$.

- Aiming to do a differential cross section measurement across MET using all 3 channels.

Content

- Will overview strategy for all 3 channels
- Focus on the 0L channel DNN techniques.
- Results of the 3 channels

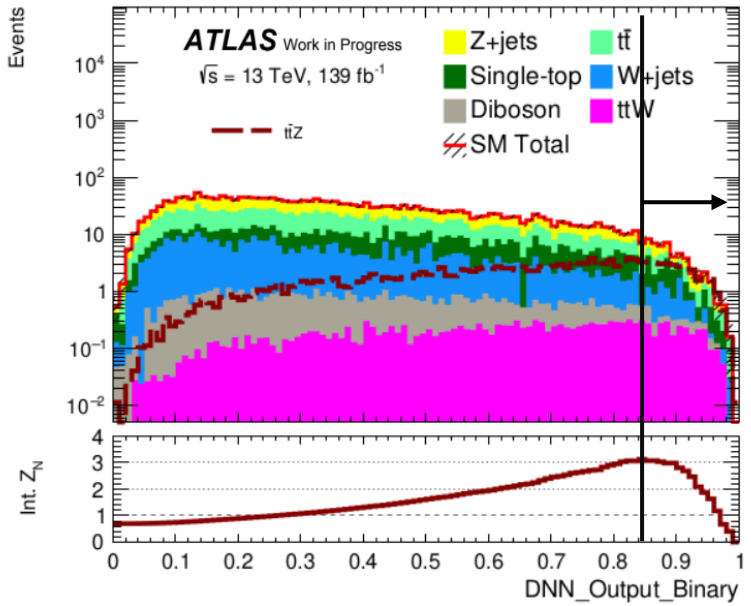
Analysis strategy

- The 3 channels take inspiration from analyses targeting $t\bar{t}$ + missing energy in ATLAS SUSY searches. All 3 channels use variables from these analyses. The cuts used by these analyses also inspired various SR
- **0L** Channel is closely related to the $t\bar{t}$ + missing energy 0L SUSY search Eur. Phys. J. C 80, 08 (2020) 737 but using additional selections (including defining a NN) to target $t\bar{t}Z$
- **1L** Channel takes inspiration from the $t\bar{t}$ + missing energy 1L SUSY search JHEP 04 (2021) 174, but with an NN built to target $t\bar{t}Z$
- **2L** Channel is built from the $t\bar{t}$ + missing energy 2L SUSY search JHEP 04 (2021) 165, already contains a very well-defined $t\bar{t}Z$ region so only minor optimisation was needed.

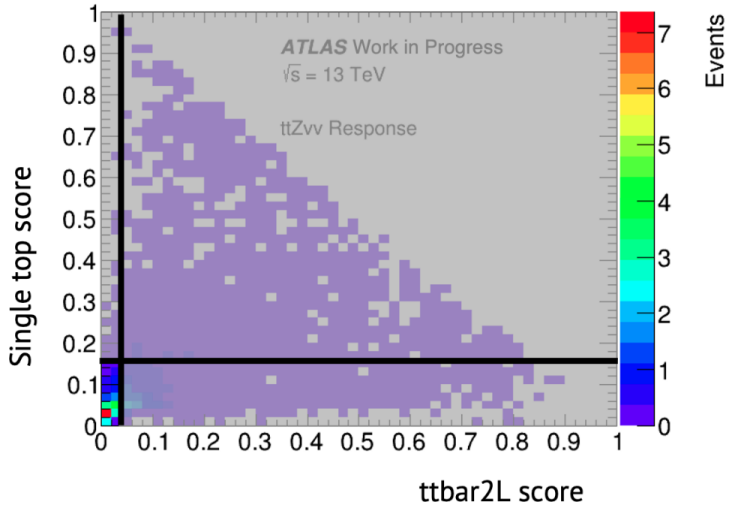
Channel strategies(0L,1L,2L)

- **0L** used binary classifier to train on SUSY variables. During training, the DNN learns from the disruptions of these variables how to separate signal from background to produce a master variable with the best possible separation.
- **1L** used a DNN tagger to tag the $t\bar{t}Z \rightarrow \bar{\nu}\nu$ and main 2 backgrounds(single top and ttbar2L) then used the background scores to define SRs and CRs.
- **2L** used optimisations to already well-defined $t\bar{t}Z$ regions for SR.

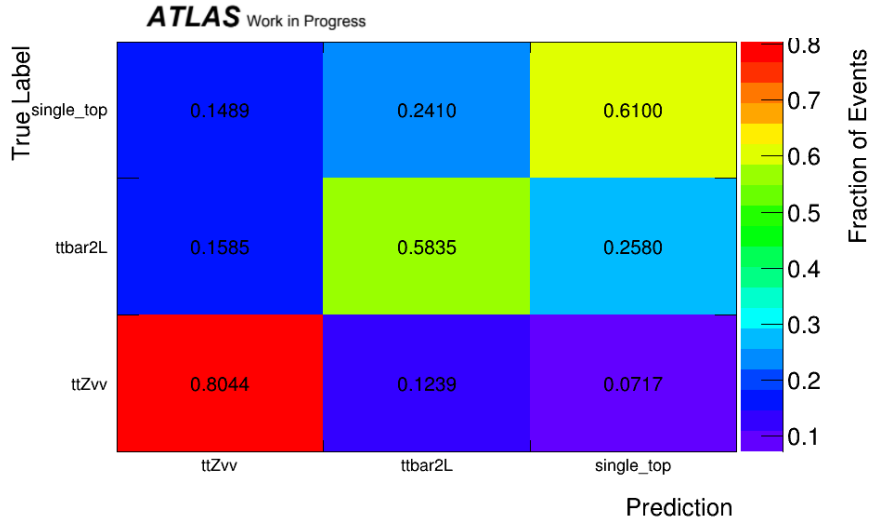
0L



1L



1L



Channel signal region Definitions

- mtbmin and mtbmax cuts in zero lepton remove most of the $t\bar{t}$ background allowing the DNN output Binary to then define the signal region.

0L

variable	cut
pre-selection 0L cuts	applied
mtbmin	> 200
mtbmax	> 200
met aligned jet cleaning	$== 1$
DNN output Binary	> 0.84

- The 1L uses low background DNN scores to define a single SR

1L

variable	cut
$pre - selection\_1L$	applied
ttbar2L_Score	< 0.05
single_top_Score	< 0.16
nTau	$== 0$

- Using MT2 the 2L channel was able to produce 4 highly pure but low stat signal regions

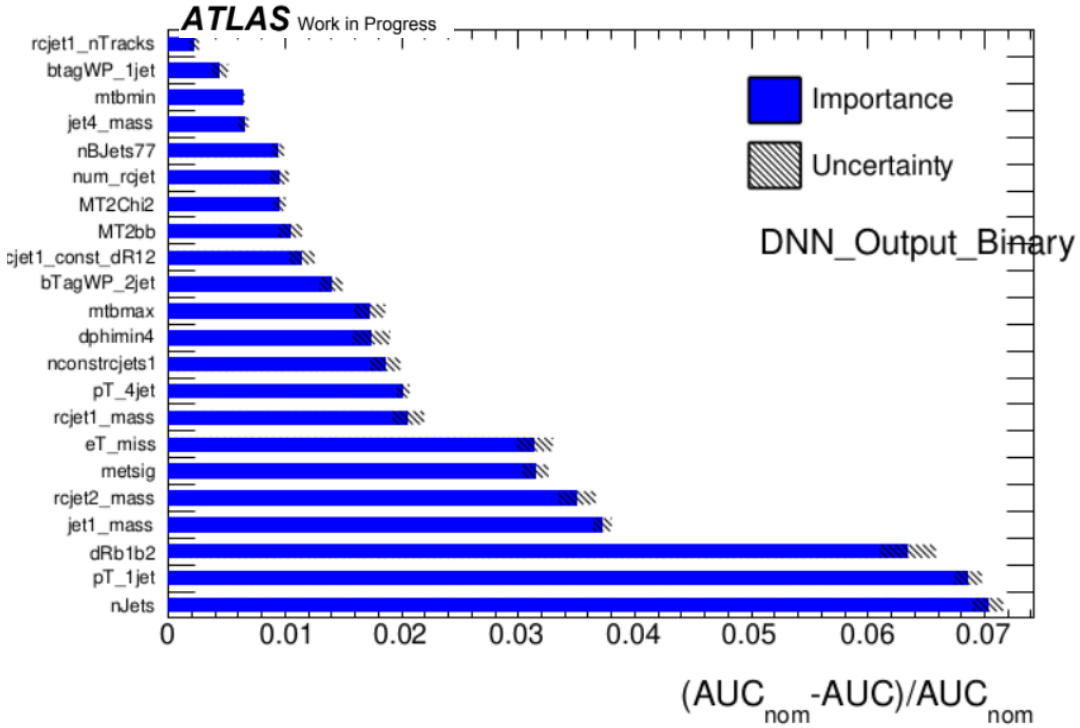
2L

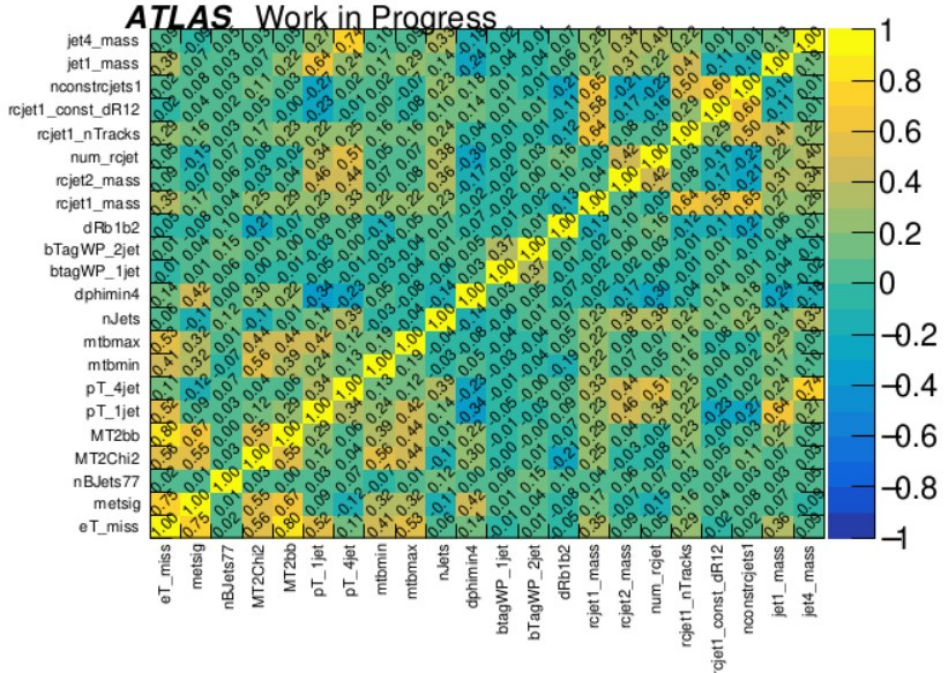
variable	cut
metsig	> 14
MT2ll	> 110
pT_Boost	> 1.5
MT2(SR1)	$110 - 120$
MT2(SR2)	$120 - 130$
MT2(SR3)	$130 - 140$
MT2(SR4)	> 140

$$m_{\mathrm{T2}}(\boldsymbol{p}_{\mathsf{T}}^{\alpha}, \boldsymbol{p}_{T}^{\beta}, \boldsymbol{p}_{\mathsf{T}}^{\mathsf{miss}}) = \min_{\boldsymbol{q}_{\mathsf{T}}^{1}+\boldsymbol{q}_{\mathsf{T}}^{2}=\boldsymbol{p}_{\mathsf{T}}^{\mathsf{miss}}} \max(m_{\mathsf{T}}^{2}(\boldsymbol{p}_{\mathsf{T}}^{\alpha}, \boldsymbol{q}_{\mathsf{T}}^{1}), m_{\mathsf{T}}^{2}(\boldsymbol{p}_{\mathsf{T}}^{\beta}, \boldsymbol{q}_{T}^{2}))$$

0L channel Analysis

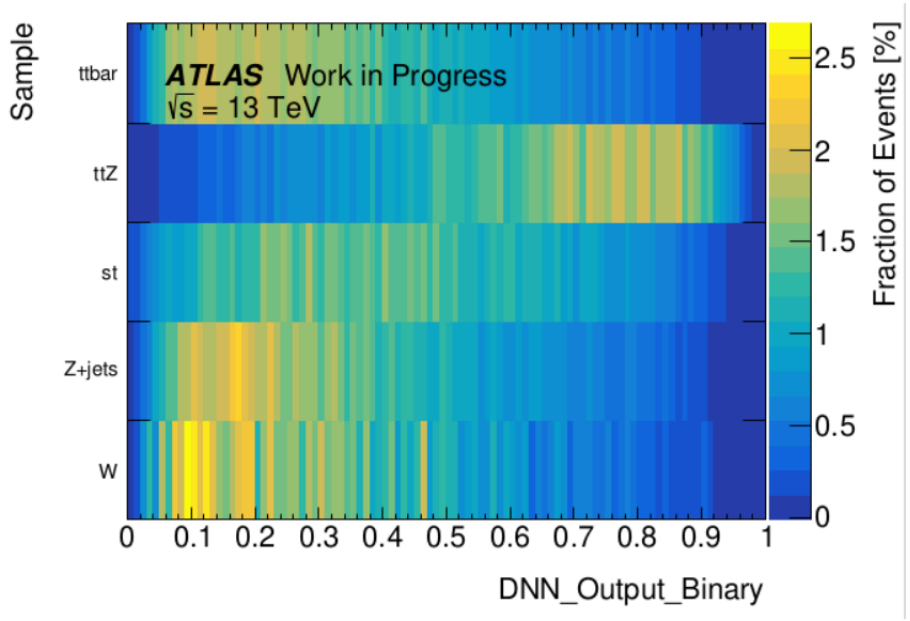
- Use Area Under the Receiver Operating Characteristic Curve (AUC) to calculate variable importance from many SUSY variables.
- Variables which were highly correlated and ranked low on importance were removed to improve training
- DNN was trained in the 0L with the mbtmin and mtbmax cuts from the previous slide applied
- Low impacting backgrounds like ttW and diboson were not included in the training

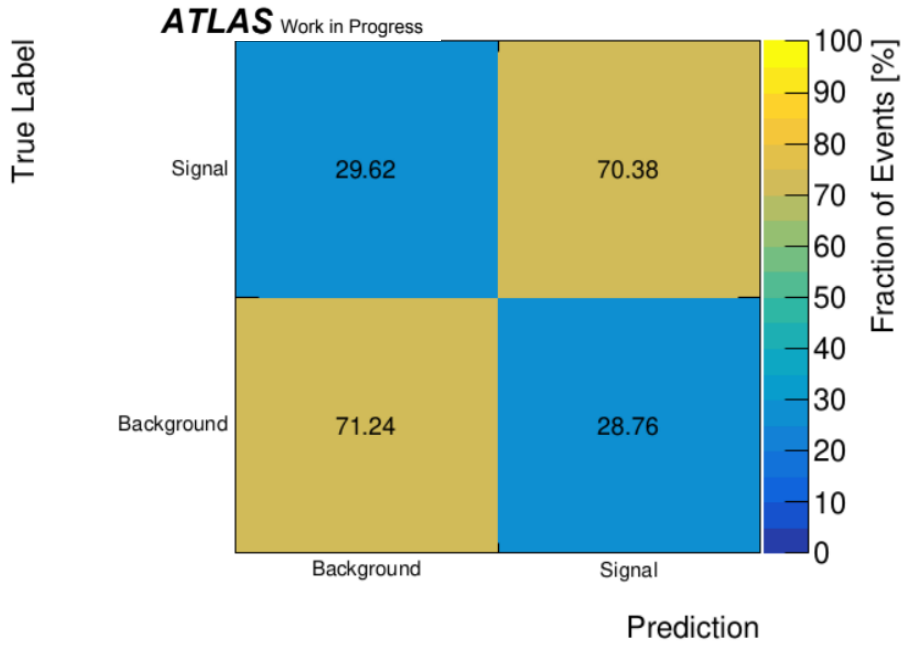




0L channel Analysis

- The DNN has around 30% mislabelling between signal and background.
- Single top is the most stubborn background to remove, peaking later than the other backgrounds.
- Control and validation regions were built using the DNN's sample distributions





Expectations

- SRs defined for all 3 channels, initial signal significance for individual channels looks promising.
- **0L** has 3CR for its 3 main backgrounds(ttbar,Z+jets,single top) defined. Assumes 10% systematics in SR
- **1L** has 2 CR(ttbar2L,single top) defined.
- **2L** has 2 CR and 2 VR(ttbar,diboson) defined. Assumes 20% systematics in SR.
- Systematics are being processed.

ATLAS Work in Progress

channel	Expected σ	Signal/Background
0L	3.05	0.58
1L	2.5-3	0.35
2L	2.75	0.86

0L

variable	Events
$t\bar{t}Z$	32.86 ± 0.94
Z+jets	18.98 ± 1.02
singletop	14.53 ± 1.47
$t\bar{t}$	12.98 ± 1.36
W+jets	5.83 ± 1.17
ttW	2.78 ± 0.16
diboson	1.44 ± 0.16
Background	56.55 ± 2.55

All MC

1L

variable	Events
$t\bar{t}2L$	58.8839 ± 2.34582
$t\bar{t}Z$	29.6201 ± 0.837355
singletop	15.2314 ± 1.42052
W+jets	7.597 ± 1.3
multiboson	2.55076 ± 0.177756
$t\bar{t}Z(qq/ll)$	0.937544 ± 0.150339
Z+jets	0.346 ± 0.095
total	115.167 ± 3.16324

2L

	SR1	SR2	SR3	SR4
ttbar2L	3.82 ± 0.83	2.23 ± 0.49	0.78 ± 0.18	1.11 ± 0.23
Z+jets	0 ± 0	0 ± 0	0 ± 0	0 ± 0
multiboson	0.113 ± 0.070	0.169 ± 0.060	0.025 ± 0.029	1.73 ± 0.36
ttX	0.340 ± 0.098	0.392 ± 0.097	0.44 ± 0.10	2.56 ± 0.53
singletop	0.356 ± 0.071	$4e-06 \pm 0.046$	$4e-06 \pm 0.028$	0.527 ± 0.083
ttZ(qq/ll)	0.067 ± 0.065	0.043 ± 0.046	0.062 ± 0.029	0.681 ± 0.068
ttZ(νν)	1.39 ± 0.12	1.51 ± 0.13	1.37 ± 0.13	9.14 ± 0.37
Total	6.08 ± 1.05	4.35 ± 0.72	2.68 ± 0.40	15.88 ± 1.31

Conclusion

- Have discussed the importance of $t\bar{t}Z \rightarrow \bar{\nu}\nu$ in ATLAS's BSM searches and completeness of the Standard model.
- Have shown the Analysis techniques used by the 3 Channels using 2 different types of DNNs and one optimised region.
- We Have shown the process of optimising the 0L DNN.
- We have shown the promising expectations of the 3 channels.
- Further processing of systematic uncertainties are needed before we can begin measuring the cross section.