A search for tWZ production in the Tetralepton channel using ATLAS Full Run 2 data

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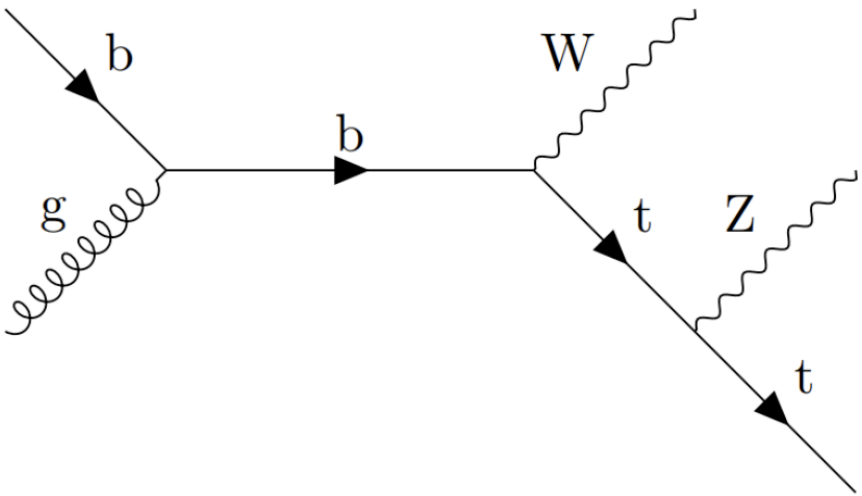
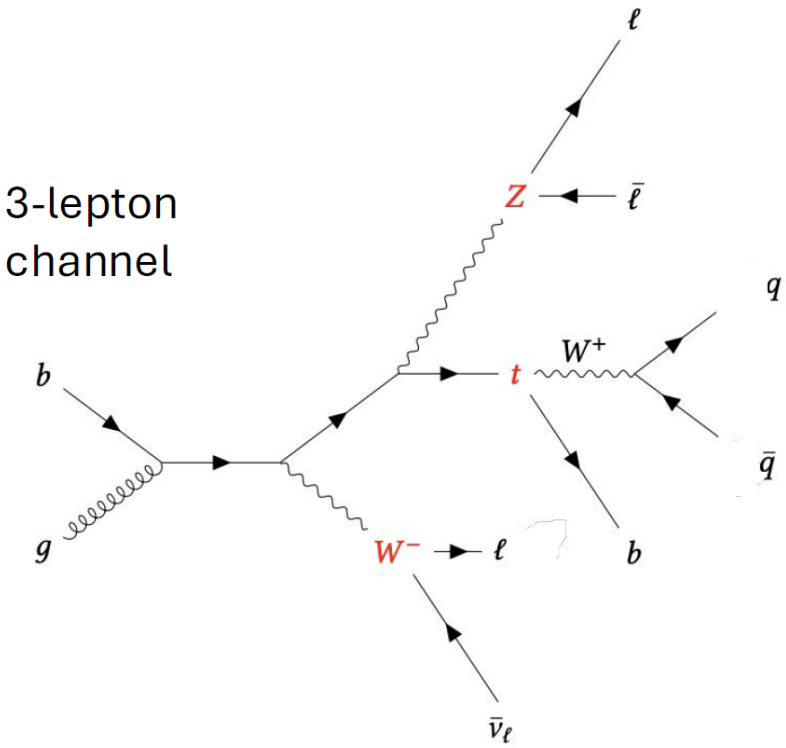
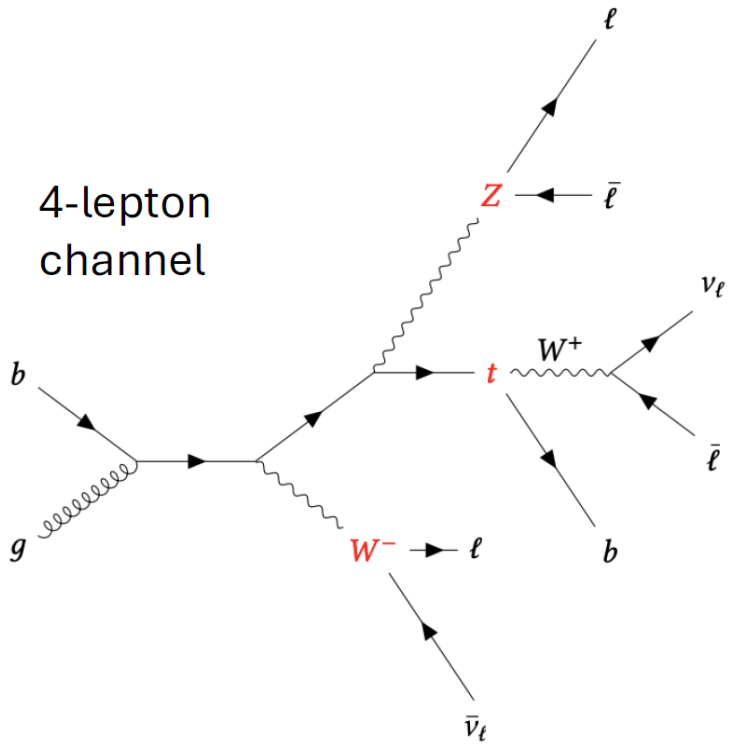
tWZ Analysis Motivation



- Rare, unobserved process ($\sigma_{tWZ}^{SM} \approx 136$ fb) and CMS observed PAS Link.
- Sensitive to the electroweak couplings of the top quark
  - affected by 13 EFT operators, see more from this paper.
  - important input to *global* EFT fit(s).
- Challenging background to ttZ
- Overlaps with $t\bar{t}Z$ at NLO
  - Sensitive to diagram removal and interference modelling

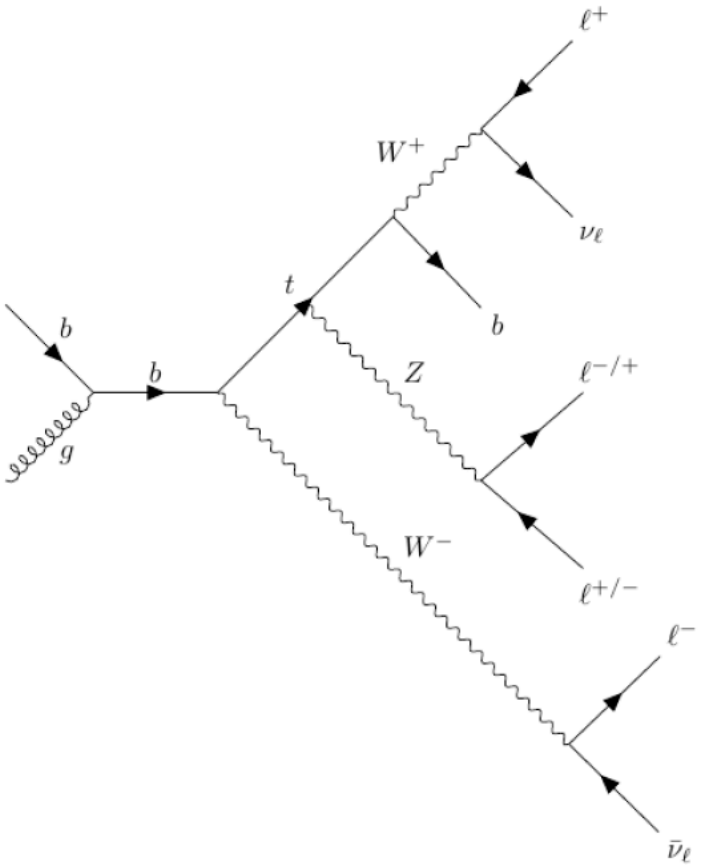
tWZ Decay Channels





- The W decays hadronically about 67% of the time and only decay leptonically about 33% of the time.
- We focus on the tetralepton channel despite its low event count because not many processes have 4-lepton final states.

Tetralepton Overview



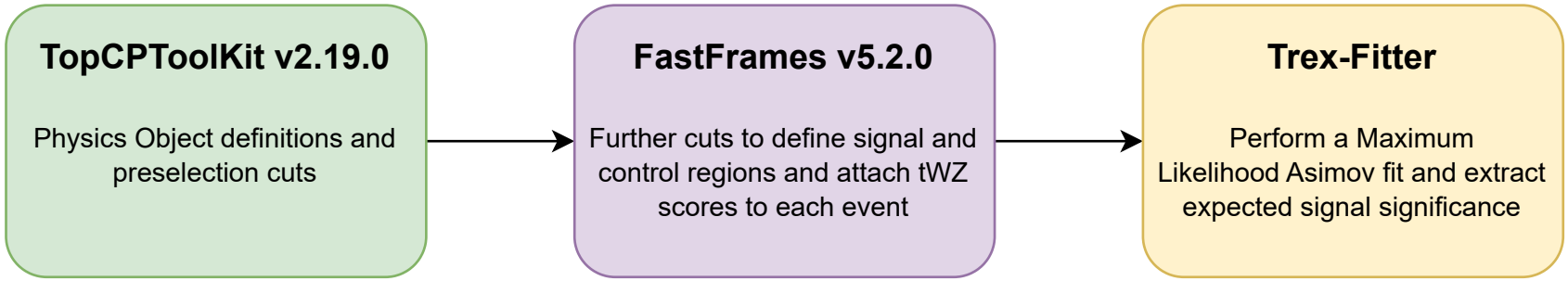
Characteristics

- Smaller branching ratio events in full run 2.
- Smaller backgrounds: $t\bar{t}Z$ & ZZ

Approach

- ML S/B discriminator
  - tWZ vs major backgrounds – $t\bar{t}Z$ & ZZ
  - Currently: Training a DNN to increase signal sensitivity.

Analysis Pipeline



Ntuple setup & Object Selection

- Latest Ntuple production based on:
  - AnalysisBase 25.2.52, TopCPToolKit v2.19.0 and FastFrames v5.2.0.
- Ntuple pre-selection:
  - 4 leptons(electrons and muons) $p_t > 10$ GeV
  - corrections applied for modelling of: pileup, jet/lepton ID, flavour tagging, trigger efficiency, beamspot

Lepton definitions

	Pre-selected electrons	Pre-selected muons
Acceptance	$p_T > 10$GeV, $\lvert\eta^{clust}\rvert < 2.47$	$p_T > 10$GeV, $\lvert\eta\rvert < 2.5$
Identification WP/Quality	LooseBLayerLH & TightLH	Medium
Overlap removal	AnaElectrons.loose	AnaMuons.loose
	Electrons	Muons
Identification WP/Quality	LooseBLayerLH & TightLH	Medium
Isolation WP	Tight_VarRad & NonIso	Tight_VarRad & NonIso

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Jet definitions

All jets	
Collection WP	AntiKt4EMPFlowJets
Acceptance	$p_T > 20$ GeV, $\|\eta\| < 4.5$
Overlap removal	AnaJets.baselineJvt
b-tagged jets	
Acceptance	$p_T > 20$ GeV, $\|\eta\| < 4.5$
b-tagging algorithm	GN2v01
b-tagging WP	FixedCutBEff_77 & Continuous

Tetralepton - Baseline selections and regions

Baseline selections

$$N_\ell = 4$$
$$p_T(\ell_1, \ell_2, \ell_3, \ell_4) > (28, 18, 10, 10)\ \text{GeV}$$
$$p_T(\text{jet}) > 20\,\text{GeV},\ |\eta(\text{jet})| < 4.5$$
$$|\eta(\ell_e)| < 2.47$$
$$|\eta(\ell_\mu)| < 2.5$$
$$\sum_{i=1}^{4} \text{charge}(\ell_i) = 0$$

All OSSF lepton pairs require $m_{\text{OSSF}} > 10\,\text{GeV}$

Regions

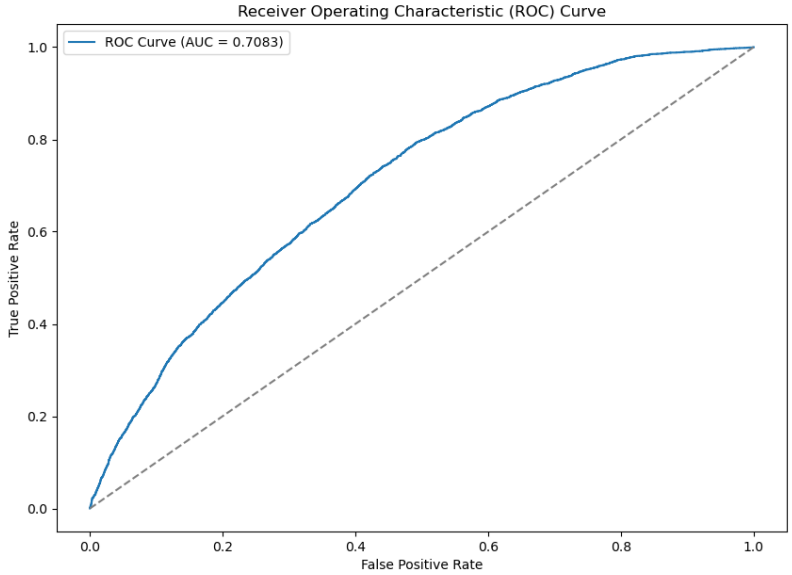
tWZ OF SR	tWZ SF SR	$t\bar{t}Z$ CR	ZZb CR	tWZ Loose SR
$N_\ell(\text{tight}) = 4$	$N_\ell(\text{tight}) = 4$	$N_\ell(\text{tight}) = 4$	$N_\ell(\text{tight}) = 4$	$N_\ell(\text{tight}) = 3$ $N_\ell(\text{loose \& not tight}) = 1$
$N_{\text{Z candidate}} = 1$	$N_{\text{Z candidate}} = 1$	$N_{\text{Z candidate}} = 1$	$N_{\text{Z candidate}} = 2$	$N_{\text{Z candidate}} = 1$
$N_{\text{jet}} \geq 1$	$N_{\text{jet}} \geq 1$	$N_{\text{jet}} \geq 2$	$N_{\text{jet}} \geq 1$	$N_{\text{jet}} \geq 1$
$N_{\text{b-jet}} = 1$	$N_{\text{b-jet}} = 1$	$N_{\text{b-jet}} \geq 1$ $N_{\text{b-jet}} = 2$	$N_{\text{b-jet}} = 1$	$N_{\text{b-jet}} = 1$
Opp. Flavour Non-Z leptons	Same Flavour Non-Z leptons			

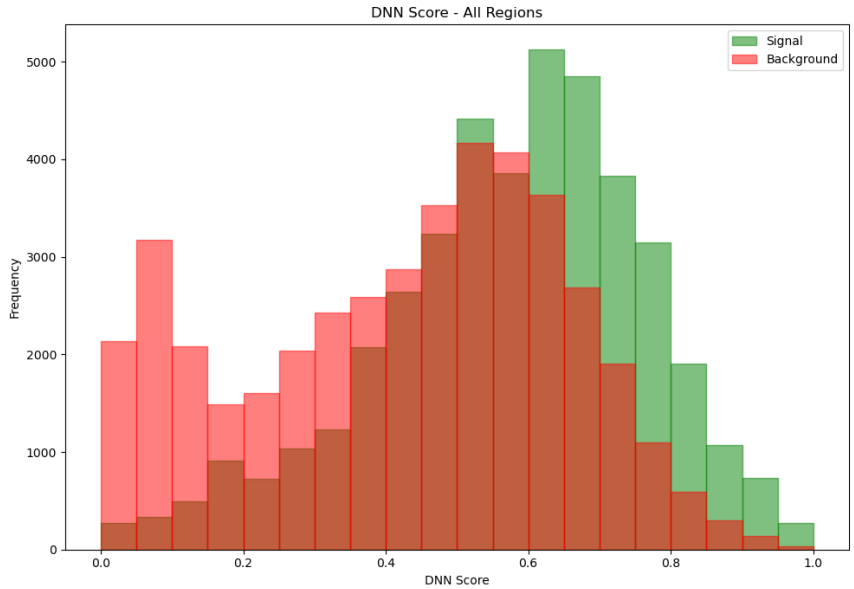
Sample List:

- Only using Run 2 data and MC for now
  - 2015 – 2018

Process	DSID	Sample	Simulation
tWZ	525955	aMCPy8EG	Fast
ttll	700309	Sherpa2211	Full
ZZ	700600, 700587	Sherpa222	Full
WZ	700588, 700601	Sherpa222	Full
tllq	545027, 545028	aMCPy8EG	Full
tt	410472	PhPy8EG	Full
ttW	700205	Sherpa2210	Full
ttH	364345	PhPy8EG	Full
ttWW	410081	MGPy8EG	Full
ZH	364310	PhPy8EG	Full

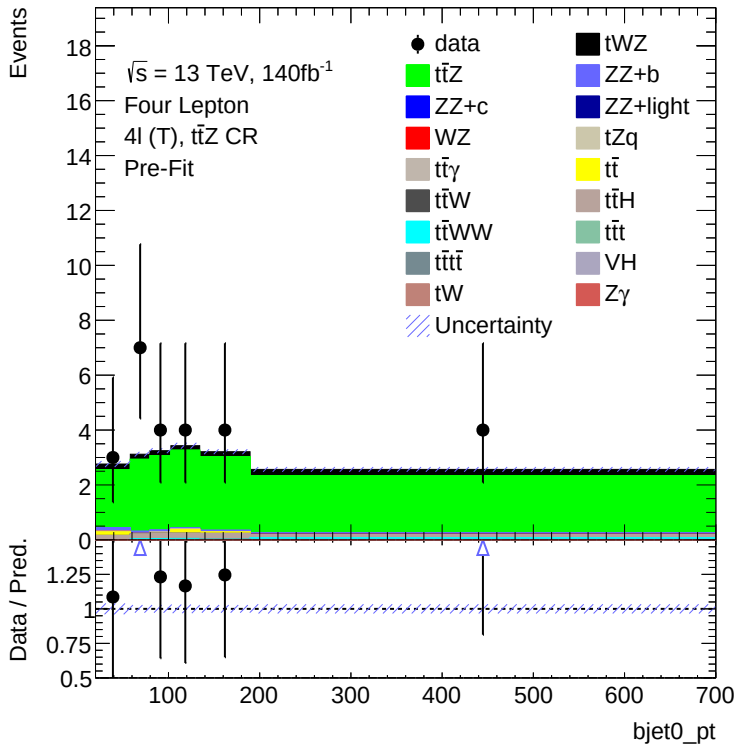
DNN Training Results

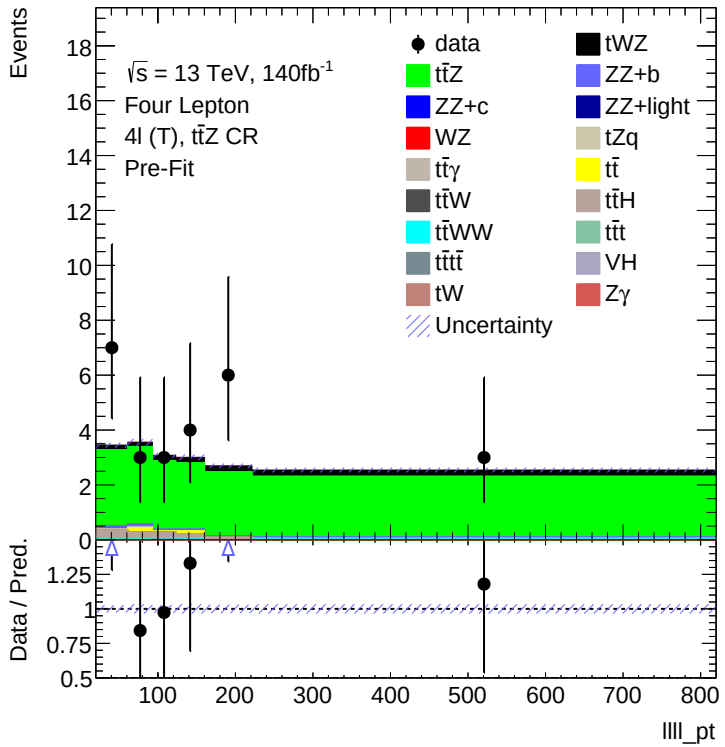




- The left plot shows the current ROC curve for the DNN with an AUC = 0.7083.
- The right plot shows the normalised DNN score distribution of both signal and background.

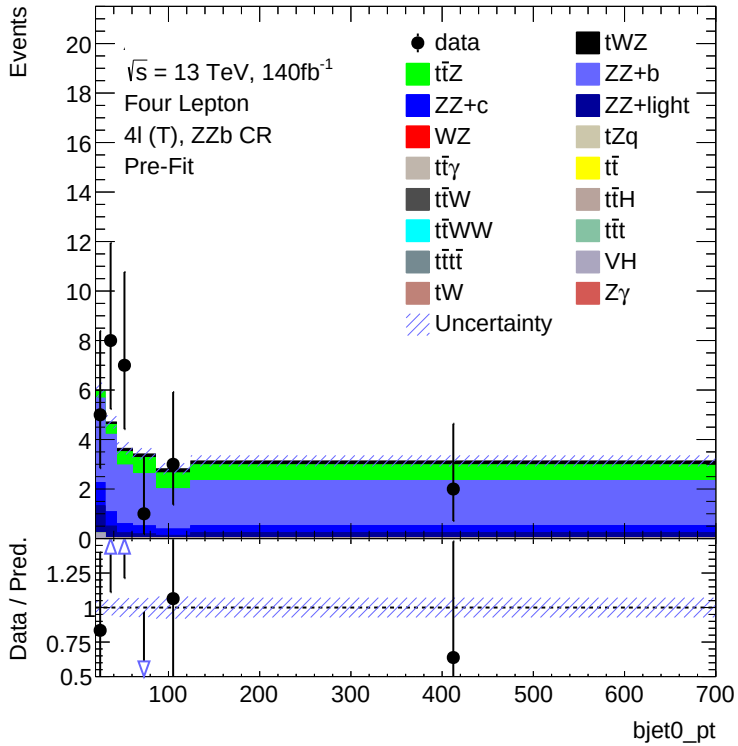
$t\bar{t}Z$ CR Control Plots

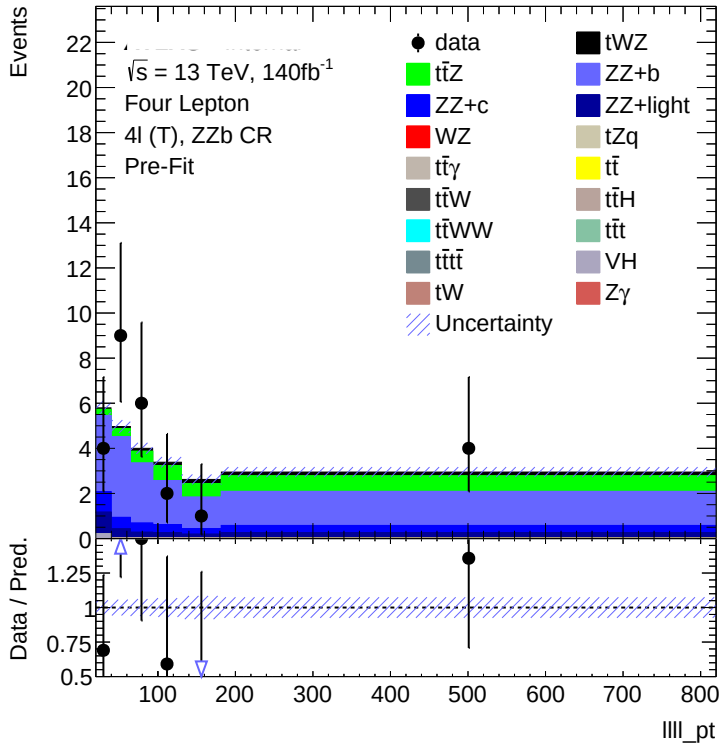




- Reasonable agreement in the leading b-jet pt distribution and a visible discrepancy in the 4 lep pt distribution.

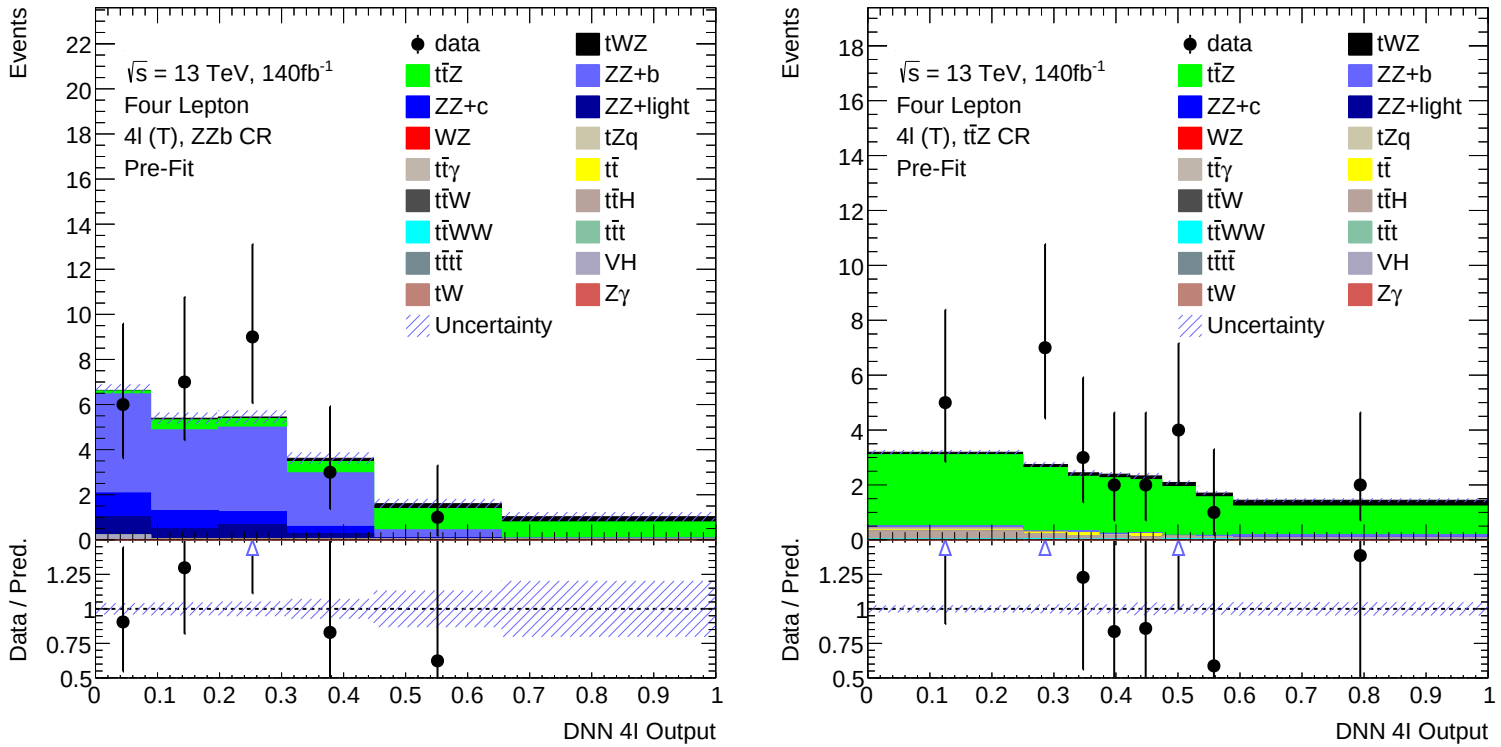
ZZb CR Control Plots





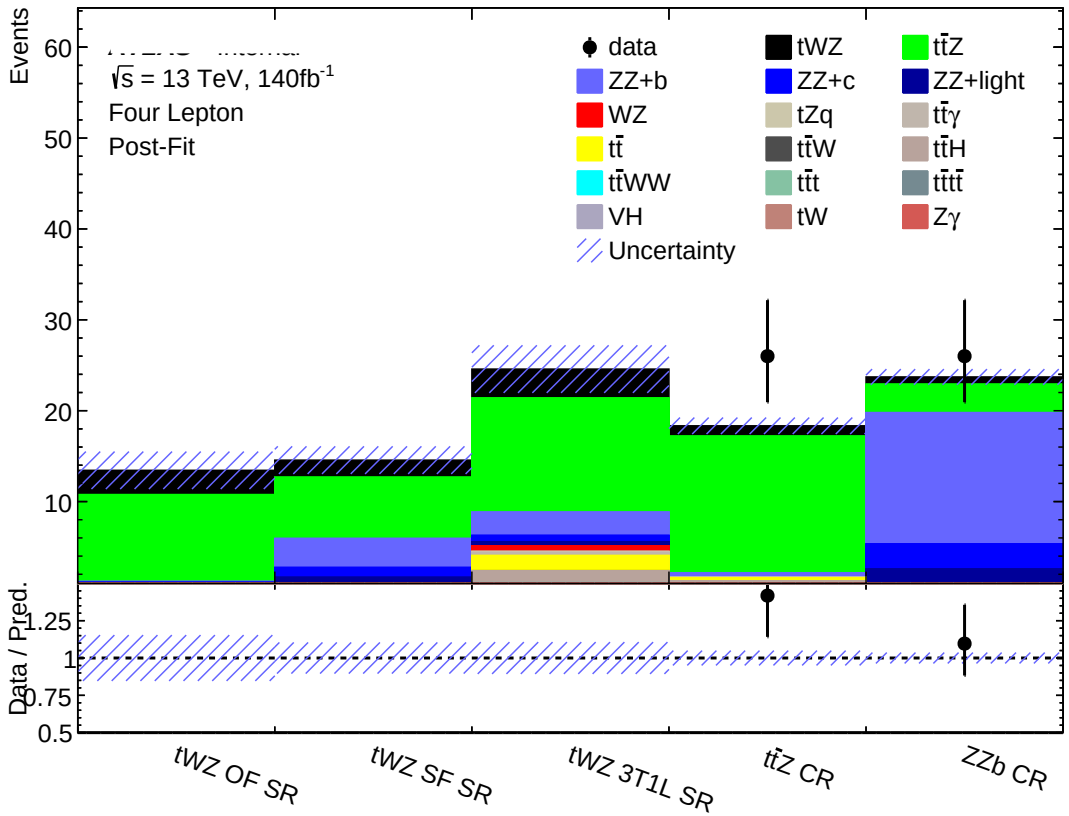
- reasonable agreement in both the leading b-jet pt and the 4 lep pt distributions.

DNN distribution Control Plots



- There's reasonable agreement between data and MC in both control regions for the DNN score distribution.

Postfit Region Summary Plot



Postfit summary plot for the three SRs and two CRs for the DNN score distribution. Fakes are included in $t\bar{t}Z$ for now and ZZ is separated by flavour. The expected signal significance is found to be $\mu_{tWZ}^{exp} = 1.4406$.

Summary

- Performed a search for tWZ production in the tetralepton channel using ATLAS Run 2 data.
- Motivated by its rarity, EFT sensitivity, and role as a background in other processes.
- Applied strict object selection and baseline cuts to define signal and control regions.
- Initial control region comparisons show reasonable agreement with some discrepancies.
- The expected signal significance was extracted as $\mu_{tWZ}^{exp} = 1.4406$.

Next Steps

- Include all systematic uncertainties in the analysis pipeline.
- Refining and retraining the DNN using the updated and recommended ntuples.