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Measurement of the inclusive production cross section of a top-quark pair in association with a Z boson at $\sqrt{s} = 13\,\text{TeV}$ in final states with three leptons using deep neural nets with the ATLAS detector

Steffen Korn, Arnulf Quadt, Elizaveta Shabalina

14th Annual Meeting "Physics at the Terascale" - Top physics

II. Physikalisches Institut Georg-August-Universität Göttingen

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

24 November 2021

ATLAS EXPERIMENT

KONRAD ADENAUER STIFTUNG

A $t\bar{t}Z$ motivation

The SM-like coupling of the Z^0 boson (+ possible BSM contributions):

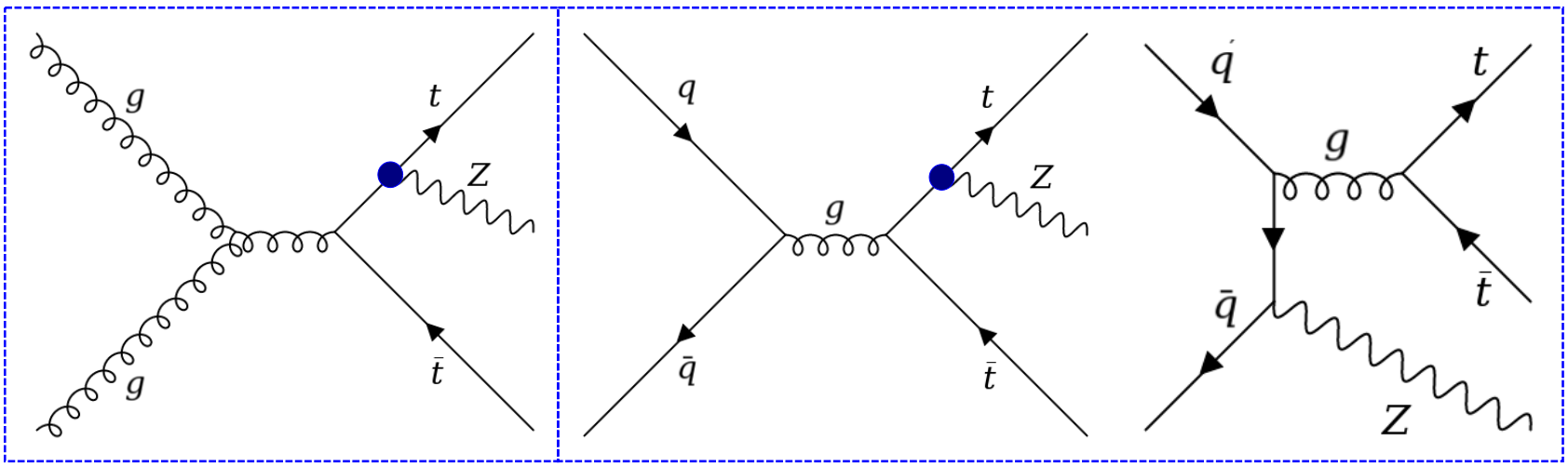
$$\Gamma_Z = -i\frac{1}{2}g_z\gamma^\mu(c_V - c_A\gamma^5 + \text{BSM Contributions}).$$

SM prediction: $c_A = T_3, \quad c_V = T_3 - 2Q\sin^2(\theta_W).$

T_3: third component of the weak isospin
θ_W: the Weinberg angle.

gluon-gluon fusion

quark-anti-quark annihilation



A $t\bar{t}Z$ introduction

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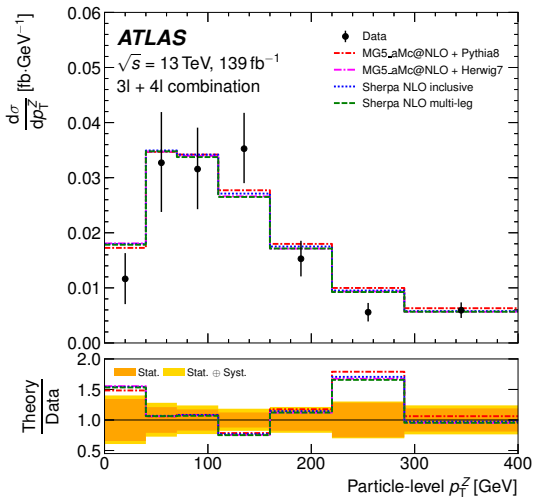
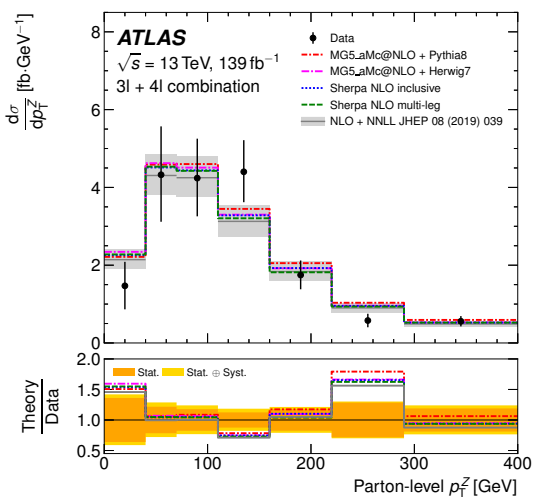
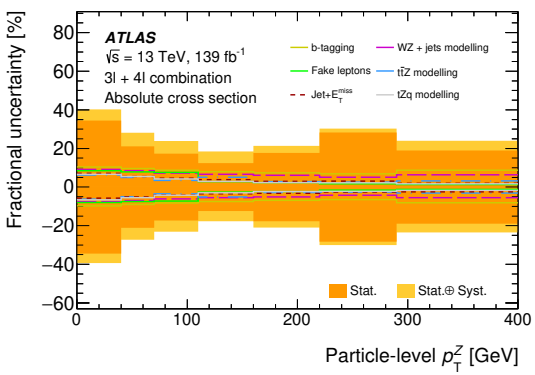
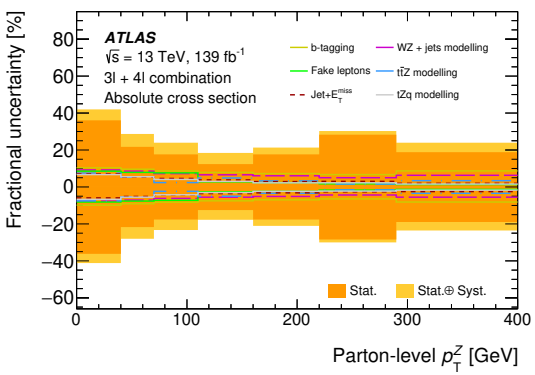
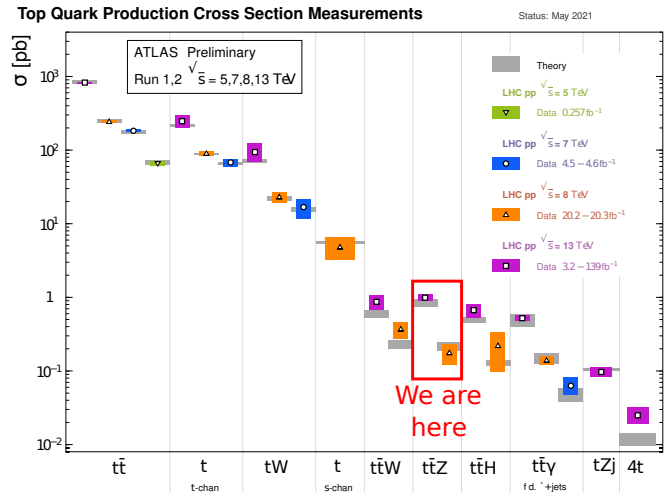
Building on previous $t\bar{t}Z$ full run-2 analysis, Eur.Phys.J.C 81 (2021) 737











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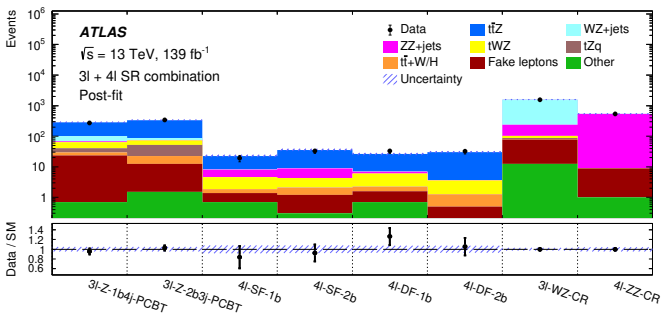

Channel	$\mu_{t\bar{t}Z}$
3ℓ	$1.17 \pm 0.07(\text{stat.})^{+0.12}_{-0.11}(\text{syst.})$
4ℓ	$1.21 \pm 0.15(\text{stat.})^{+0.11}_{-0.10}(\text{syst.})$
$3\ell + 4\ell$	$1.17 \pm 0.06(\text{stat.}) \pm 0.10(\text{syst.})$
$\sigma(pp \to t\bar{t}Z)$	$0.99 \pm 0.05(\text{stat.}) \pm 0.08(\text{syst.})$ pb
Total rel. unc.	9.5%

The perfect time for ttZ

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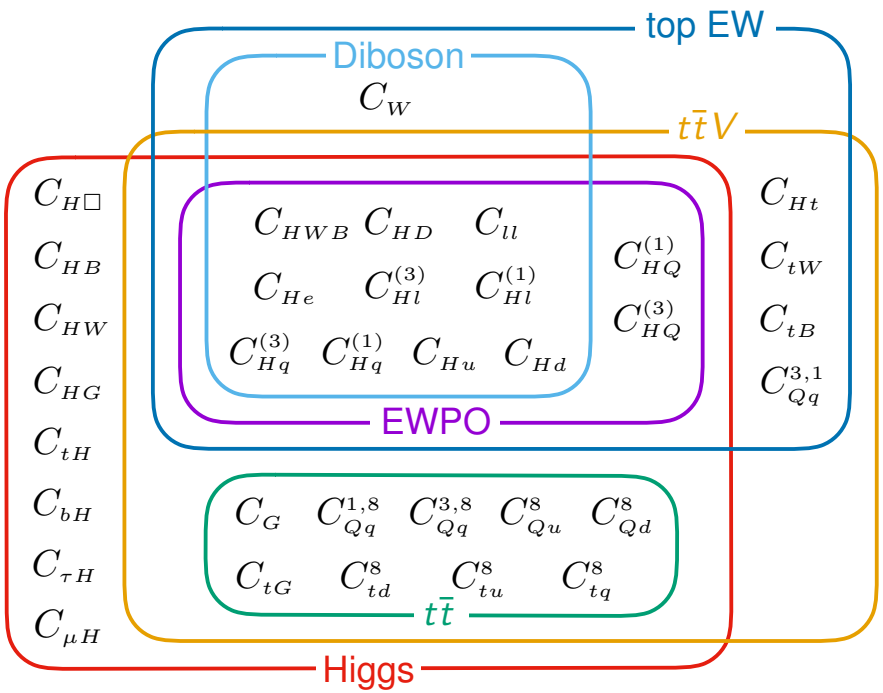
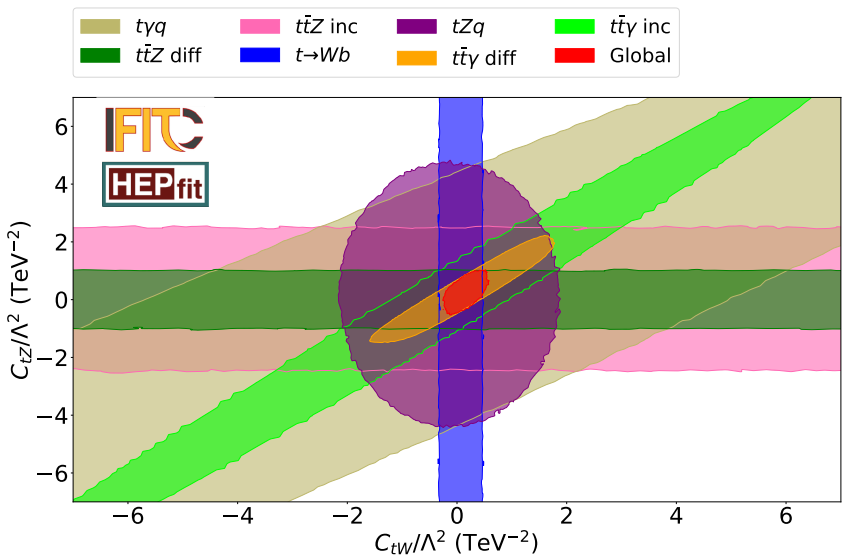
Goal: Improve on prev. analysis (9.5% unc.)

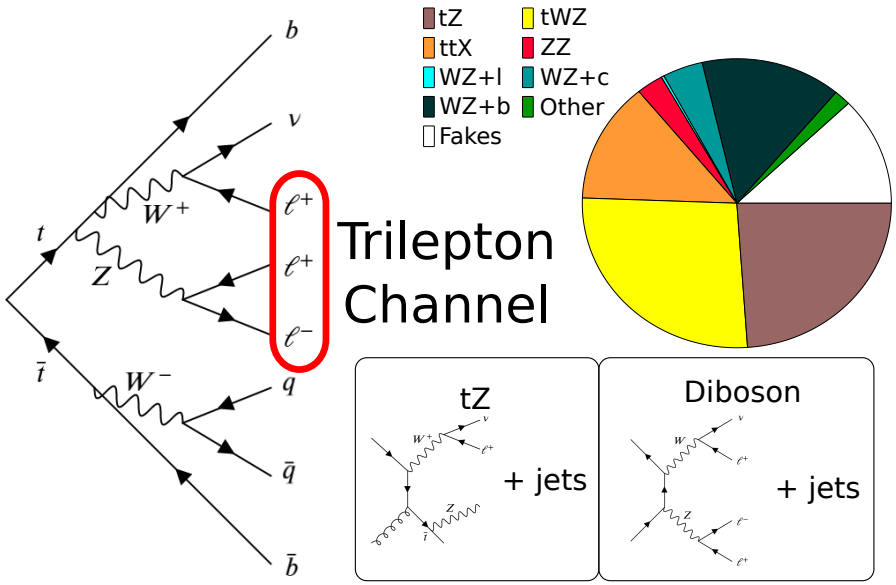
- Currently 3 ongoing refined full run 2 analyses with tentative summer 2022 aims:
  - $t\bar{t}Z$ 2/3/4 leptons + jets, plans for EFT interpretation
  - $t\bar{t}\gamma$ 1/2 leptons + 1 photon + jets, plans for EFT interpretation
  - tZq 3 leptons + jets
- $t\bar{t}Z$, $t\bar{t}\gamma$ and tZq are included in several recent global fits
- Complementarity between analyses can be seen → combinations provide great opportuntity to constrain EFT parameters, 2107.13917 & JHEP04(2021)279





The 3L final state

Trilepton channel "golden $t\bar{t}Z$ channel" (w.r.t. S/B, stats.)
$\rightarrow$ Inclusive measurement drives several decisions



Variable	3L Preselection
Leptons	=3, OSSF
	$\lvert m_{\ell\ell} - m_Z \rvert < 10$ GeV
Lepton p_T (ℓ_1, ℓ_2, ℓ_3)	>27 GeV, >20GeV, >15GeV
$n_{b\text{-jets}}$	≥ 1 @85%
n_{jets}	≥ 3

Backgrounds:

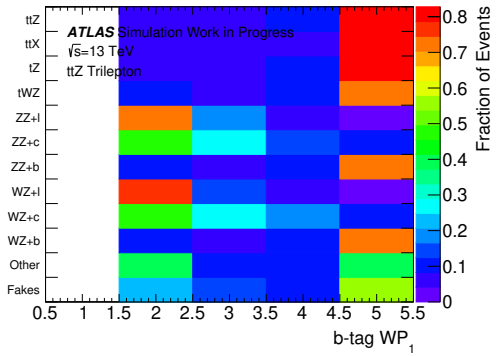
- Processes with tops: tZq, tWZ, $t\bar{t}X(H, W)$
- Diboson processes: WZ & ZZ
- Processes with fake leptons

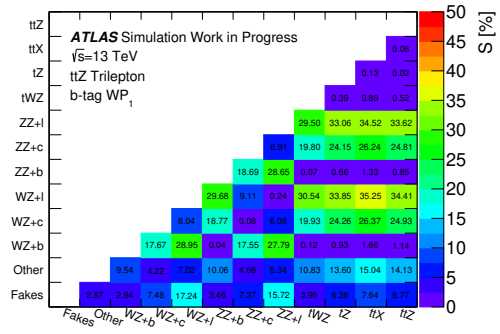
Training Goal:

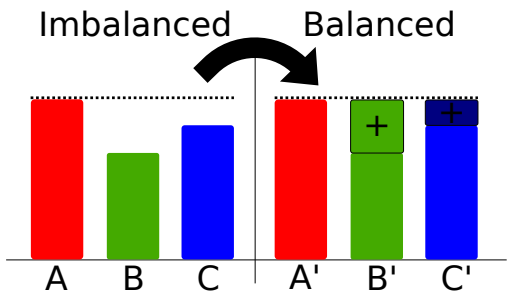
- Separating $t\bar{t}Z$ from main backgrounds, tZ and $WZ + b$ using a multi-class NN
- Open up acceptance and recover purity with NN
  $\rightarrow$ looser cuts w.r.t. previous analysis

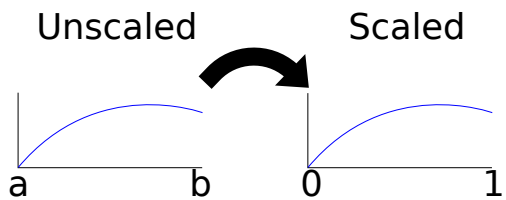
3L NN setup

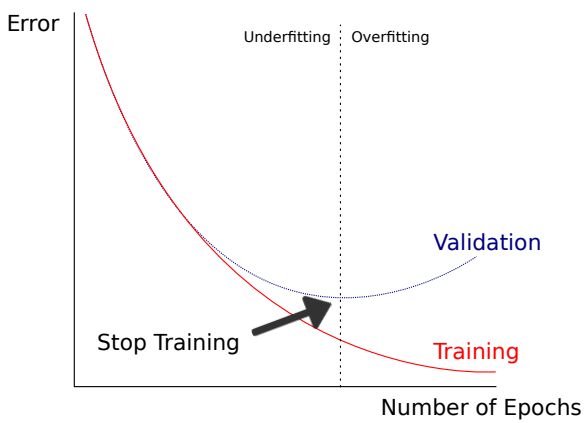
- Building 3-class neural network, separating $t\bar{t}Z$, tZq (class 1) and WZ (class 2) events
- Common NN-Framework (used in $t\bar{t}H$, $t\bar{t}\gamma$, $t\bar{t}Z$, 4-tops)
- Define inputs based on separation power studies $\rightarrow$ kinematic variabes, b-tagging variables, reconstructed top mass, ...
- Reweight classes $\rightarrow$ integral over each classes weights is identical
- Rescale event variables $\rightarrow \in [0, 1]$ to prevent large NN weights
- Perform K-folding using early stopping

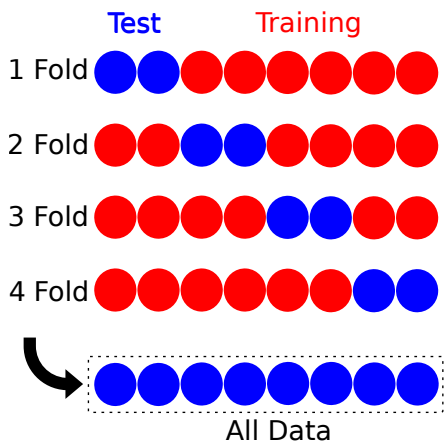




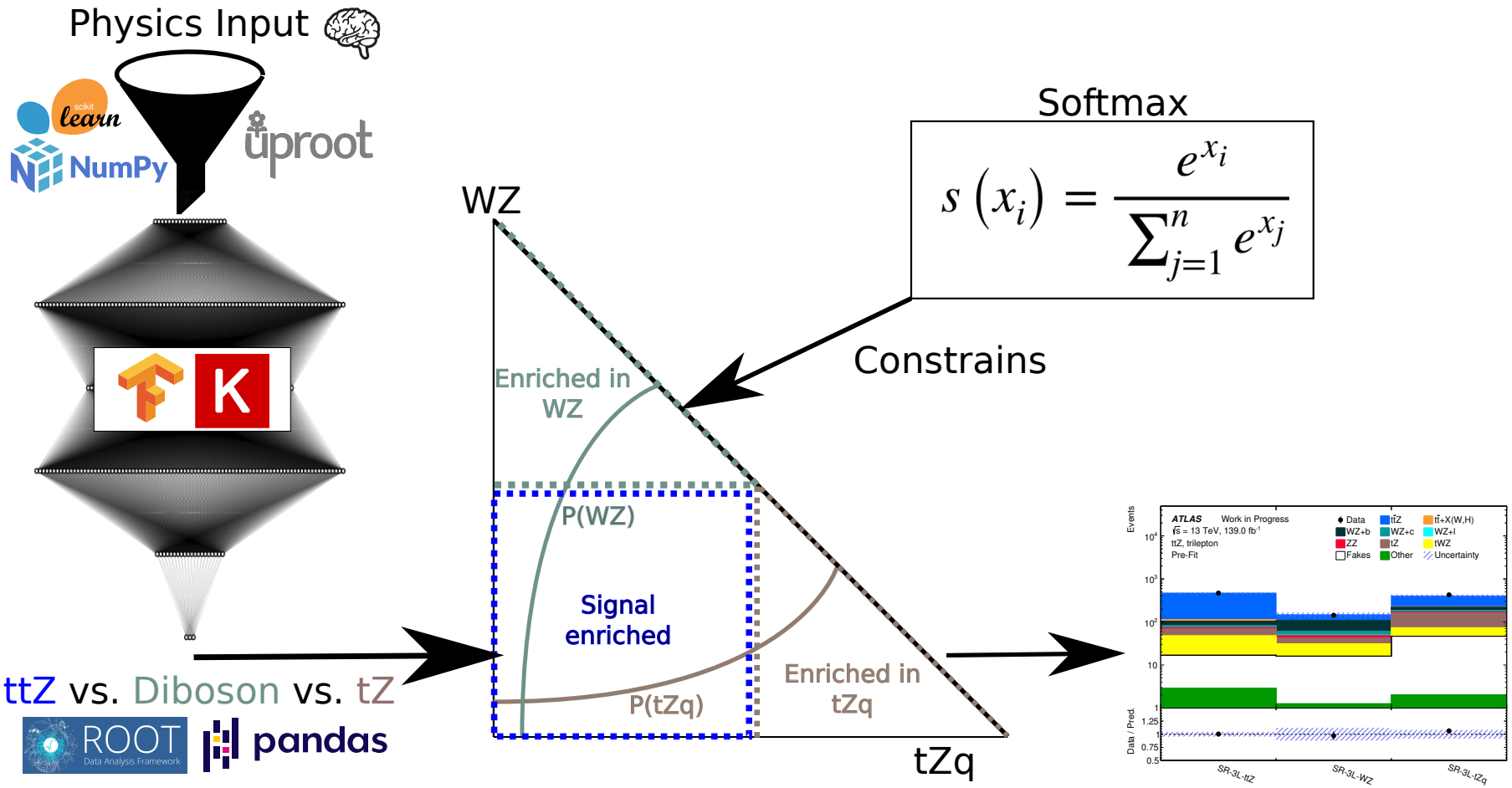








Neural Network Approach



- Concept for the 3ℓ channel: Use physics input in 3-class NN $\rightarrow$ define regions based on cuts $\rightarrow$ fit these regions $\rightarrow$ extract $\mu_{t\bar{t}Z}$ and $\mathcal{N}_{WZ+b}$
- Full analysis pipeline based on NN conversion/training/optimisation, region definition, TRExFitter fits

3L SR regions

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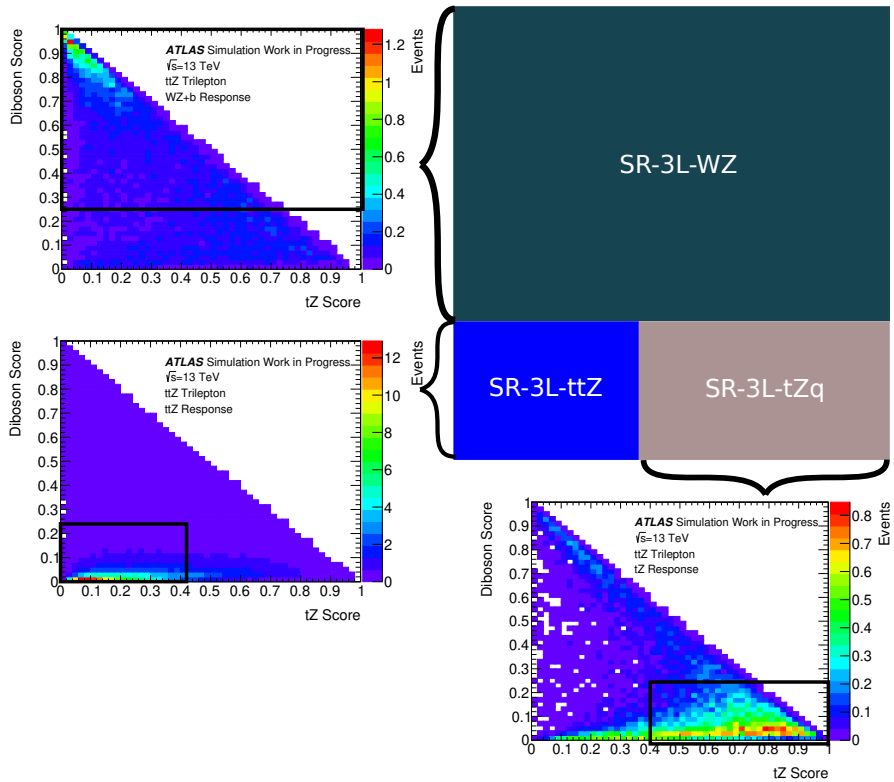
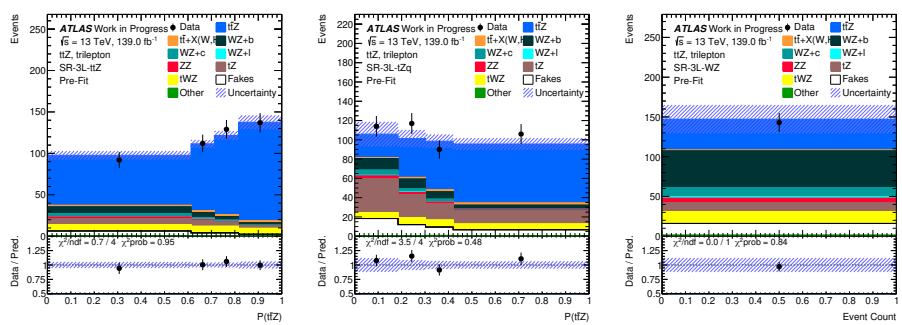
Optimise region definitions (i.e. cuts on NN discriminants) based on

1. best S/B in region(s)
2. best signal yields in region(s)
3. best result in asimov fit

- Resulting regions shown below.
- Use TRExFitter auto-binning for SR-3L-ttZ/tZq on P($t\bar{t}Z$)
- One bin in SR-3L-WZ for WZ+b normalisation
- 60% b-tagging cut rejects WZ+l almost completely → great improvement w.r.t. previous analysis (measured WZ+LF and extrapolated to WZ+HF) - now we **measure WZ+HF directly**

	SR-3L-ttZ	SR-3L-tZq	SR-3L-WZ
DNN-tZ Output	<0.4	≥0.4	-
DNN-diboson Output	<0.26	<0.26	≥0.26
$N_{b\text{-jets}}$	-	-	≥ 1@60%

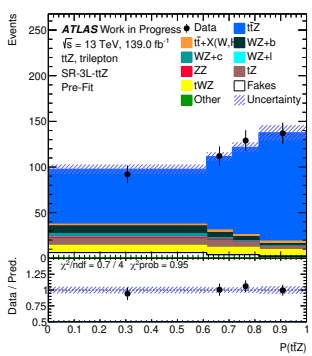


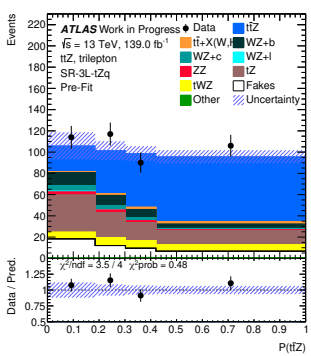


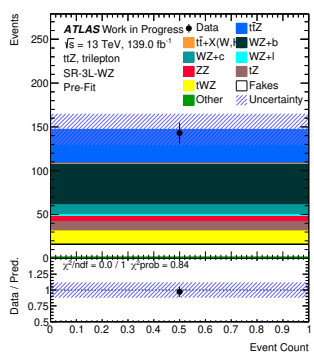
3L Event yields and fit results

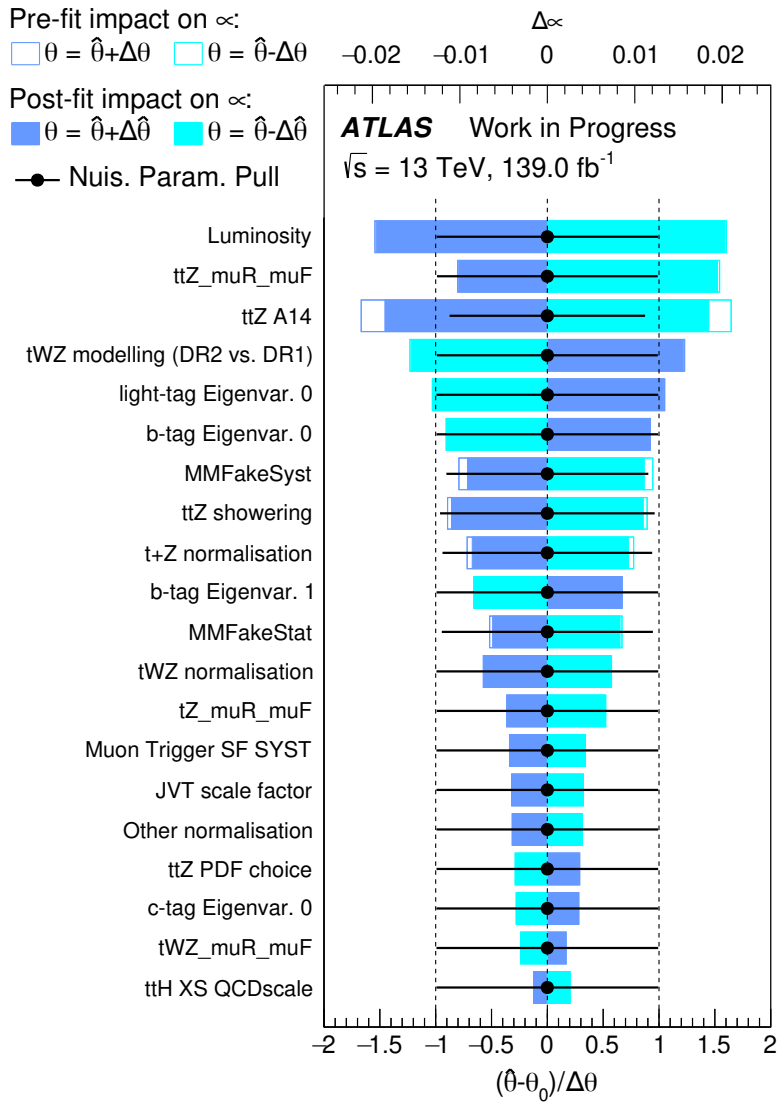
- Simultaneous fit using all three regions (incl. most syst.)
- Signal strength, $\mu_{t\bar{t}Z}$, $WZ+b$ normalisation, $\mathcal{N}_{WZ+b}$ $\rightarrow$free floating
- Able to cut syst. unc. in half (excl. jet uncertainties atm.)
- Increasing precision of analysis by $\sim 35\%$ w.r.t. previous analysis
- Good purity for unfolding $\rightarrow$ expect performance improv. there too (WIP)

Method	$\mu_{t\bar{t}Z}$	$\mathcal{N}_{WZ+b}$
NN-Based	$1 \pm 0.06(\text{stat.}) \pm 0.05(\text{syst.})$	$1 \pm 0.46(\text{tot.})$
Cut & Count	$1 \pm 0.06(\text{stat.}) \pm 0.11(\text{syst.})$	50% norm. unc. (WZ+LF extrapolation)









Summary

- Trilepton part of analysis in very good shape - Cutting syst. unc. in half w.r.t. to previous analysis, improving $\sim 35\%$ w.r.t. cut & count approach
- Multi-class NN-based regions provide great basis for unfolding and EFT studies
- Moving forward towards EFT studies $\rightarrow$ interesting physics in the pipeline

Summary

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Thank you!