Measurement of the cross-sections of ttW production at 13 TeV with the ATLAS detector

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Motivation

- ttW process is the dominant background in many measurements with MultiLepton final states. \bigcirc
- Significant mis-modelling observed in the 80 fb⁻¹ ttH-ML analysis: \bigcirc
 - Normalisation factors above the theoretical prediction
 - $\lambda^{2lLJ} = 1.56 \pm 0.29$, $\lambda^{2lHJ} = 1.26 \pm 0.19$ and $\lambda^{3l} = 1.68 \pm 0.29$
 - Similar excesses, $\lambda^{CMS} = 1.43$, observed in <u>ttH-ML CMS</u> analysis
- A two-step analysis strategy was decided for the **full Run 2 ttH-ML analysis**: 0
 - The first step is to measure inclusive and differential cross-sections of ttW production in $2\ell SS$ and 3ℓ channels
 - Following on ttW measurements, measure the cross-section of ttH production





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Signal Modeling

- Nominal ttW MC sample is Sherpa 2.2.10
 - ▶ QCD sample: LOI+NLOI (597 fb → 573.68 fb)
 - Include -3.9% interference effect from
 LO3+NLO2 EW diagrams
 - EW sample: NLO3 diagram (42.1 fb)
- Alternative ttW samples used for uncertainties
 - MG5_aMC@NLO FxFx: account for Matrix
 Element (ME) and Parton Shower (PS) uncertainty
 - Powheg+Pythia8/Herwig7: give additional PS uncertainty as the difference
 - Separated to QCD and EW, normalized to Sherpa cross-sections



Object and event selection

Pre-Selection

- Applying lowest pT un-prescaled Di-lepton triggers
- Leptons:
 - pT>10 GeV, $|\eta_e| < 2.47$, $|\eta_{\mu}| < 2.5$
 - veto electrons in LAr crack region
 - FCLoose isolation, Loose/ LooseLH ID for μ/e
- Jets:
 - Reconstruct with Anti-Kt PFlow w/ R=0.4
 - Pass JVT, pT>25 GeV
 - Tag b-jets with DLIr tagger

Overlap removal

- e/μ: if ΔR(e, μ) < 0.01,
 remove μ if calo-tagged, else remove e
- e/j: if ∆R(jet, e) < 0.2,
 remove jet if not b-tagged
- μ/j: if ΔR(jet, μ) < 0.4,
 remove jet if not b-tagged, < 3 tracks

Event Selection $(2\ell SS \text{ and } 3\ell)$

- ▶ Njet≥2, Nb-jet≥1
 - \geq Ib (hybrid WP, =Ib @ 60% or \geq 2 @ 77%)
- ▶ $M_{\ell\ell}$ >12 GeV in $2\ell SS$
- $M_{\ell\ell} > 12 \text{ GeV}, |M_{\ell\ell} M_Z| > 10 \text{ GeV} (SFOS), |M_{3\ell} M_Z|$ $> 10 \text{ GeV}, \text{ in } 3\ell$



Background Estimation

- Irreducible background: \bigcirc
 - ttZ,VV samples: estimated with dedicated CR and free floated when fitting
- **Reducible background:** \bigcirc
 - Charge mis-identification (Q-MisID)
 - Wrongly associate a track to an electron or measure the electron track-curvature
 - Estimated through a Data-Driven approach in the $2\ell SS$ channel
 - Suppressed with an MVA method

- Internal and Material Conversion (CO)
 - Suppressed with track invariant masses and conversion radius cuts





Background Estimation

- **Reducible background:** 0
 - Non-prompt leptons from Heavy Flavor (HF) decay
 - Rejected with Multivariate lepton isolation, called **PromptLeptonImprovedVeto** (**PLIV**) tagger
 - Defined lepton pT- dependent working points (WPs):

VeryTight and Tight



Use custom PLIV WPs to build CRs enriched in non-prompt

HF leptons and to enhance ttW

- Tight [T]: VeryTight PLIV WP
- Medium [Mexcl]: Tight-not-VeryTight PLIV WP

Non-prompt/Fake leptons Estimation: Template Fit

IO control regions: 6 for HF fakes, 1 for VV, I \bigcirc

for $t\bar{t}Z$ and 2 for internal and material CO

Use custom PLIV WPs to define CR

6 fit normalisation factors: HFe + HFu + 0

internalCO + materialCO + VV + $t\bar{t}Z$

0

	Linc	L	Minc	М	Т
FCLoose isolation			Yes		
Non-prompt lepton BDT	No	PLIV < 0 and	Tight	Tight-not-	VeryTight
(PLIV)		not-Tight		VeryTight	

Fake Estimation (Alternative): Matrix Method

- Estimate the non-prompt lepton background with the matrix method (data-driven)
- Define CR, in which measure the efficiencies for the real and fake leptons from Loose selection to Tight selection:
- Apply the efficiencies in the SR to calculate the total number of fake events (where at least one of the leptons is fake)

$$\begin{pmatrix} N^{TT} \\ N^{T\bar{T}} \\ N^{\bar{T}\bar{T}} \\ N^{\bar{T}\bar{T}} \\ N^{\bar{T}\bar{T}} \end{pmatrix} = \begin{pmatrix} \epsilon_{r,1}\epsilon_{r,2} & \epsilon_{r,1}\epsilon_{f,2} & \epsilon_{f,1}\epsilon_{r,2} & \epsilon_{f,1}\epsilon_{f,2} \\ \epsilon_{r,1}\bar{\epsilon}_{r,2} & \epsilon_{r,1}\bar{\epsilon}_{f,2} & \epsilon_{f,1}\bar{\epsilon}_{r,2} & \epsilon_{f,1}\bar{\epsilon}_{f,2} \\ \bar{\epsilon}_{r,1}\bar{\epsilon}_{r,2} & \bar{\epsilon}_{r,1}\epsilon_{f,2} & \bar{\epsilon}_{f,1}\epsilon_{r,2} & \bar{\epsilon}_{f,1}\epsilon_{f,2} \end{pmatrix} \begin{pmatrix} N^{rr} \\ N^{rf} \\ N^{fr} \\ N^{fr} \end{pmatrix}$$

 $N_{TT}^f = N_{TT}^{rf} + N_{TT}^{fr} + N_{TT}^{ff} = \epsilon_{r,1}\epsilon_{f,2}N^{rf} + \epsilon_{r,2}\epsilon_{f,1}N^{fr} + \epsilon_{f,1}\epsilon_{f,2}N^{ff}$

Matrix Method:

• Defined 5 regions for fit test, injected $\mu_{ttW} = 1.7$:

2ISS: subleading lepton Pt in CR and SR,

▶ 3l: 3rd leading lepton Pt SR, VV CR and ttZ CR

 $2\ell SS, P_{T,subleading lep}$

 3ℓ , N_{b-jets} / $P_{T,subleading lep}$

Fake Estimation (Alternative): Matrix Method

ttZ Xsec and VV Xsec are constrained.

No significant pull is observed.

ATLAS work in progress

Instrumental TTLAS_lumi

	ivietnoa			ATLAS_TRIG_MU_SYST ATLAS_TRIG_MU_STAT ATLAS_TRIG_EL ATLAS_PRW_DATASF ATLAS_MU_SF_TTVA_Syst ATLAS_MU_SF_TTVA_Stat ATLAS_MU_SF_ISO_Syst ATLAS_MU_SF_ISO_Stat ATLAS_MU_SF_ID_Syst ATLAS_MU_SF_ID_Stat
<i></i>	Theory			
•	ttZ varRF			ATLAS_MU_SAGITTA_RESBIAS
•	ttZ modeling (A14 variations)			ATLAS_MU_ID_SYST_LOWPT
	ttZ modeling (Shower)			ATLAS_MU_ID
1	ttw varKF			ATLAS_MET_SoftScale ATLAS_MET_SoftBesPerp
	ttW PDF Alternate		• • • • •	ATLAS_MET_SoftScale
	ttWW ror a _s			ATLAS_JVT ATLAS JES SinglePart
	ttH varBE			ATLAS_JES_PU_Rho
	ttH modeling (parton shower)			ATLAS_JES_PU_PtTerm ATLAS_JES_PU_OffsetNPV
<u> </u>	ttH modeling (generator)			ATLAS_JES_PU_OffsetMu
<u> </u>	three top x-section			ATLAS_JES_NP_Stat6 ATLAS_JES_NP_Stat5
<u> </u>	tZ x-section		• • • • • • • • • • • • • • • • • • •	ATLAS_JES_NP_Stat4
÷	singleTop x-section			ATLAS_JES_NP_Stat3 ATLAS_JES_NP_Stat2
÷	four top x-section			ATLAS_JES_NP_Stat1
•	WtZ x-section			ATLAS_JES_NP_M004 ATLAS_JES_NP_Mod3
•	VV varRF			ATLAS_JES_NP_Mod2
•	VVV x-section			ATLAS_JES_NP_Mix3
•	VH x-section			ATLAS_JES_NP_Mix2
• • • • • • • • • • • • • • • • • • •	QMisID x-section			ATLAS_JES_NP_Det2
0 1 2				ATLAS_JES_NP_Det1 ATLAS_JES_Elayor_Besp
A)/AA				ATLAS_JES_Flavor_Comp
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,				ATLAS_JES_EtaInter_Stat ATLAS_JES_EtaInter_NonClosure
				ATLAS_JES_EtaInter_NonClosure
progress	Muon			ATLAS_JES_EtaInter_NonClosure
	DLIV Muon Statistical		• • • • • • • • • • • • • • • • • • •	AATLAS_JES_BJES
	PLIV Muon Statistical			ATLAS_JER_Eff9 ATLAS_JER_Eff8
	PLIV Muon QCD Template		• • • • • • • • • • • • • • • • • • •	ATLAS_JER_Eff7
	PLIV Muon M., Window			ATLAS_JER_Eff5
	PLIV Muon Sherpa vs. Powł	neq		ATLAS_JER_Eff4
0 1	2	5		ATLAS_JER_Eff2
(Â - A)/AA	_			ATLAS_JER_Eff12
(0 00)/ 20		I		ATLAS_JER_Eff10
				ATLAS_JER_Eff1
				ATLAS_FTAG_L9
				ATLAS_FTAG_C9 ATLAS_FTAG_C19
				ATLAS_FTAG_B9
				ATLAS_FTAG_B19 ATLAS_EL_SF_RECO
				ATLAS_EL_SF_ISO
				ATLAS_EL_SF_ID ATLAS_EG_SCALE
				ATLAS_EG_RES
		-	-2 –1 0 1 (θ̂-θ ₀)/Δθ	2
			v	

surePosEta osureNegEta osure2018Data

Fake Estimation Comparison: TF vs MM

Overall, the shapes agree quite well between the two estimates within their uncertainties \bigcirc

• MM seems to be predicting a higher estimate than the TF (1.6 to 2 times higher)

Inclusive Fit studies

- Measures both inclusive and differential cross-sections based on the template fit method
- Inclusive and fiducial cross section measurements: 0
 - Inclusive fit: hybrid fit, Asimov data in SR and real data in CR
 - Charge ratio fit: $R_{+} = \frac{\sigma_{ttW-}}{\sigma_{ttW+}}, R_{-} = \frac{\sigma_{ttW+}}{\sigma_{ttW-}}$
 - Fiducial fit uses the same fiducial phase space in the differential fit
- Granted approval for unblinding, reviewing the fit results with data! 0

mu_ttW split into the stat and syst components $\mu(ttW) = 1.03^{+0.07}_{-0.07}(Stat.)^{+0.10}_{-0.08}(Syst.)$

ATLAS work in progress

Conclusion

- The ttW analysis has been significantly developed with the full Run 2 dataset 0
 - Estimated the challenging fake lepton background
 - Measured the inclusive and differential cross-sections
 - Reviewing the unblinded results.
 - Planning the publication end of this year.
- In the meantime, measurement of the cross-section of ttH production began this spring. 0

Thank you for your attention!

