Simultaneous cross section measurements of high-p_T electron-muon final state processes from proton-proton collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector

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Introduction

- The cross-sections for the production of $t\bar{t}$, W^+W^-, and $Z/\gamma^* \to \tau\tau$ at the LHC are predicted to high precision within the standard model.
- In this analysis, a simultaneous measurement of these cross-sections is performed in the final state including an oppositely charged **electron** and **muon** pair.
- These processes are naturally well separated in a two-dimensional parameter space of missing transverse momentum ($\not{E}_T$) and jet multiplicity (N_{jets}) (see Figure 1).
- A likelihood function is constructed to fit the data to the expected distributions (templates) of the processes and **simultaneously extract** their cross-sections.

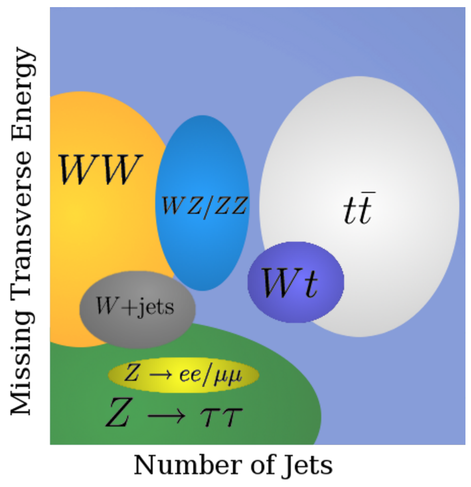

Figure 1: 2D parameter space of electron-muon final state processes

- This analysis allows for a broader test of the standard model.
- In particular, these measurements offer a new window on the parton distribution functions (PDFs) through the **correlations** between pairs of cross-sections.

Data and Monte Carlo Samples

- This study analyzes the 7 TeV **pp** collision data collected by the ATLAS detector at the LHC corresponding to an integrated luminosity of 4.6 fb^{-1}. The data selected for the analysis are collected using single high-energy lepton (**e** or μ) triggers.
- To simulate the Standard Model processes, Monte Carlo events are generated by various generators: MC@NLO ($t\bar{t}$, W^+W^-, and **Wt**), SHERPA ($Z/\gamma^* \to \tau\tau$), and ALPGEN (**WZ**, **ZZ**). The events are then processed through a detector simulation based on GEANT4. Some alternative samples are used for systematic variations, such as POWHEG $t\bar{t}$ and W^+W^-.

Object and Event selection

- Electron candidates: E_T (transverse energy) > 25 GeV, $|\eta|$ (pseudo-rapidity) < 2.47 (veto $1.37 < |\eta| < 1.52$)
- Muon candidates: p_T (transverse momentum) > 20 GeV, $|\eta| < 2.5$
- Jets: $E_T > 30$ GeV, $|\eta| < 2.5$
- Event selection: exactly one **e** and one μ of opposite charge. The selected events are mostly $t\bar{t}$, W^+W^-, and $Z/\gamma^* \to \tau\tau$.

Fit Method

- The 2D parameter space is divided into 2 bins of jet multiplicity, $N_{jets} = 0$ and $N_{jets} \geq 1$, and 20 bins of $\not{E}_T$ between 0 and 200 GeV.
- The fiducial volume is defined as one electron of $E_T > 25$ GeV and $|\eta| < 2.47$ (veto $1.37 < |\eta| < 1.52$), and one muon of $p_T > 20$ GeV and $|\eta| < 2.5$.
- 2D $\not{E}_T$ vs N_{jets} templates are produced for signals ($t\bar{t}$, W^+W^-, $Z/\gamma^* \to \tau\tau$) and backgrounds (**Wt**, **WZ**, **ZZ**, fake/non-prompt).
- The template for the fake/non-prompt lepton background is derived from data. Other templates are from Monte Calro simulation.
- The normalizations of the $t\bar{t}$, W^+W^-, and $Z/\gamma^* \to \tau\tau$ templates are treated as free parameters in the fit, whereas the normalizations of the background templates are constrained to their expected values.
- Fitted yields are used to extract fiducial and full cross-sections, which are defined as:

$$\sigma_{\mathrm{fid}} = \frac{\mathcal{N}}{\mathcal{C} \cdot \mathcal{L}}, \tag{1}$$

$$\sigma_{\mathrm{tot}} = \frac{\mathcal{N}}{\mathcal{A} \cdot \mathcal{C} \cdot \mathcal{B} \cdot \mathcal{L}} \tag{2}$$

where
  - $\mathcal{L}$ is the integrated luminosity
  - $\mathcal{A}$ is the ratio of the number of events in the fiducial volume to the number of events in the full phase space
  - $\mathcal{C}$ is the ratio of the number of events passing the full event selection to the number of events in the fiducial volume
  - $\mathcal{N}$ is the number of events attributed to the specified process by the fit
  - $\mathcal{B}$ is the branching fraction to inclusive $e\mu$ final states

Uncertainties

- The uncertainties are estimated by examining their modification of the nominal templates.
- The dominant experimental uncertainties come from
  - electron reconstruction/identification
  - soft terms for $\not{E}_T$ computation

Results

- This analysis is the first simultaneous measurement of the $t\bar{t}$, W^+W^-, and $Z/\gamma^* \to \tau\tau$ cross-sections at $\sqrt{s} = 7$ TeV, as shown in Table 1. The measurements presented here are compared with previous dedicated ATLAS measurements and the latest theoretical predictions to NNLO in QCD for $t\bar{t}$ and $Z/\gamma^* \to \tau\tau$ and to NLO in QCD for W^+W^-.

Process	Source	σ_{full} [pb]	Uncertainties Stat.	Syst.	Lumi.	Beam	Total	$\int \mathcal{L}\,dt$ [fb^{-1}]
$t\bar{t}$	Simultaneous	182	3	10	3	3	11	4.6
	Dedicated	177	7	15	8		18	0.7
	NNLO QCD	177					11	
WW	Simultaneous	53.5	2.7	7.7	1.0	0.5	8.5	4.6
	Dedicated	51.9	2.0	3.9	2.0		4.9	4.6
	NLO QCD	49.2					2.3	
$Z/\gamma^* \to \tau\tau$	Simultaneous	1174	24	80	21	9	87	4.6
	Dedicated ($e\mu$)	1066	33	100	44		170	1.5
	NNLO QCD	1070					54	

Table 1: Measured cross sections compared with theory and dedicated measurements

- Comparisons between data and predictions before and after the fitting procedure are shown in Figure 2. Better agreement is observed after the fitting procedure.

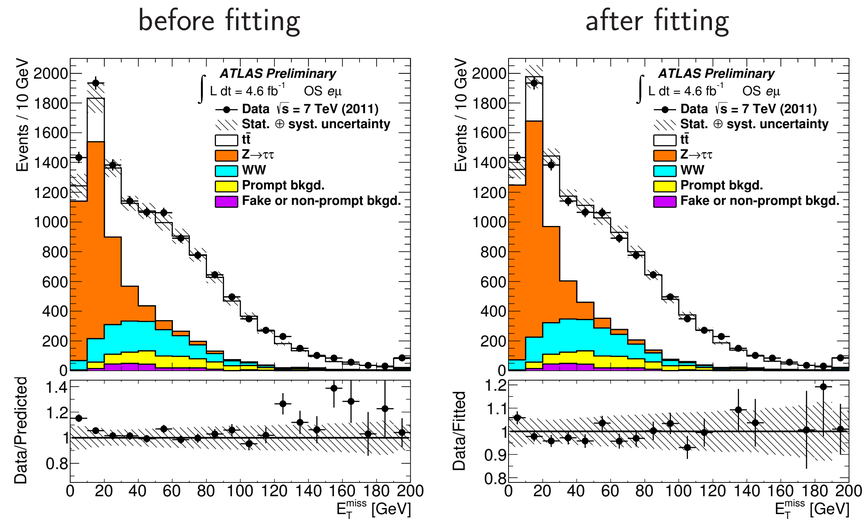

Figure 2: Comparisons between data and predictions before and after the fitting procedure. The signal predictions are from Monte Carlo (MC@NLO and SHERPA), and normalized with theoretical cross sections (before fitting) or measured cross sections (after fitting).

- The best-fit values and likelihood contours obtained from the simultaneous fit, after scaling to cross-section values, are overlayed together with theoretical cross-section predictions as shown in Figure 3.

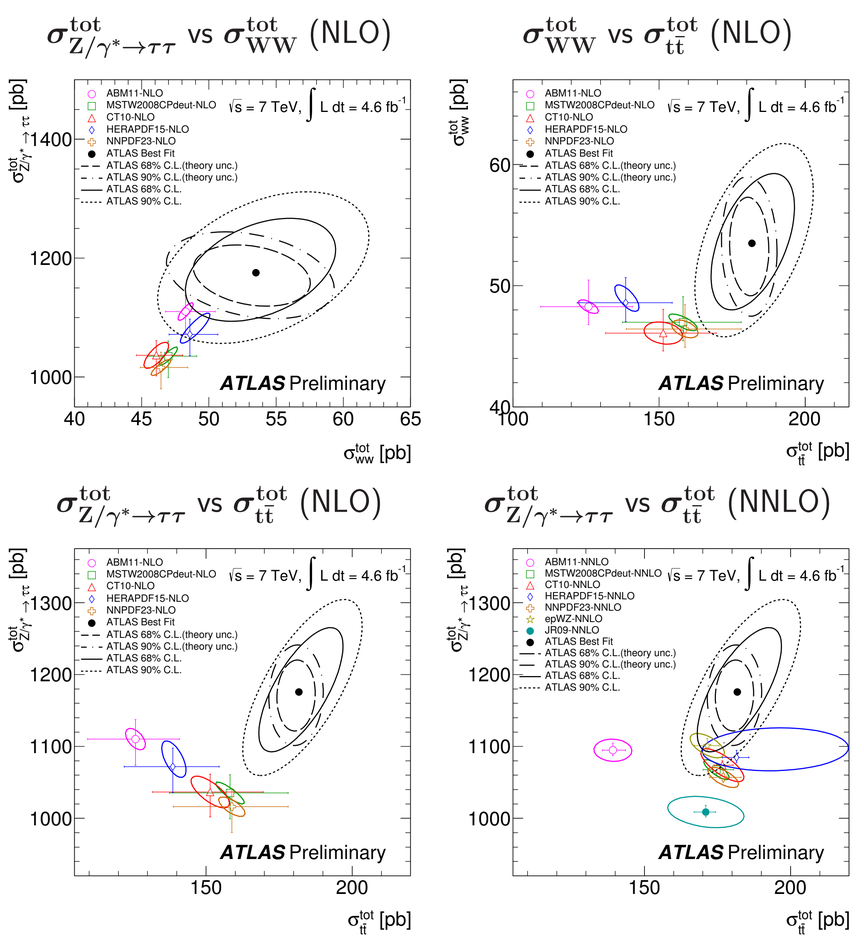

Figure 3: Contours of the profile likelihood as a function of pairs of production cross-sections, representing the 68% C.L. (full line) and 90% C.L. (dashed line) areas accounting for all systematic uncertainties. The theoretical cross-section predictions are shown at NLO or NNLO in QCD for different PDF sets (open symbols) with the contours corresponding to the 68% C.L. uncertainties on each PDF set.

Conclusion

- The simultaneous measurements of the $t\bar{t}$, W^+W^-, and $Z/\gamma^* \to \tau\tau$ production cross sections are **consistent** with the individual ATLAS cross-section measurements and with the predicted theoretical cross-sections within uncertainty.
- The uncertainty bands of the measured cross-sections of $t\bar{t}$ and $Z/\gamma^* \to \tau\tau$ indicate that the **NLO** predictions significantly underestimate the data, while comparisons to **NNLO** calculations indicate that MSTW2008, CT10, HERAPDF, NNPDF, and ATLASPDF describe the data well.