Study of the quantum interference between singly and doubly resonant top-quark production in proton-proton collisions at the LHC with the ATLAS detector

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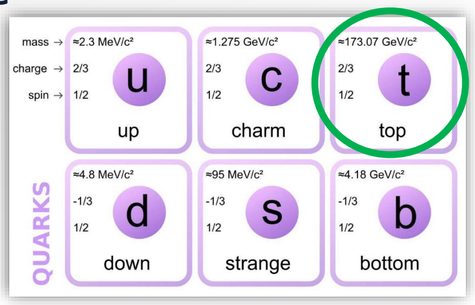
The 1s t INFN International School on Underground Physics: Theory & Experiments

Introduction

The **top quark** is the heaviest known elementary particle of the Standard Model. It allows to explore unique physics domains, inaccessible otherwise:

- One of them is the **quantum interference** between singly (NLO tW with an extra b-quark) and doubly (LO $t\bar{t}$) resonant top quark production, which can lead to identical $WbWb$ final-states [1]. In **my thesis**, the measurement of the particle-level differential cross-section of the $WbWb$ production in the dilepton channel is provided



The **measurement** is performed using the full ATLAS Run-2 dataset from proton-proton collisions at the LHC ($\sqrt{s} = 13\ \mathrm{TeV}$ and $\mathrm{L} = 139\ \mathrm{fb}^{-1}$):

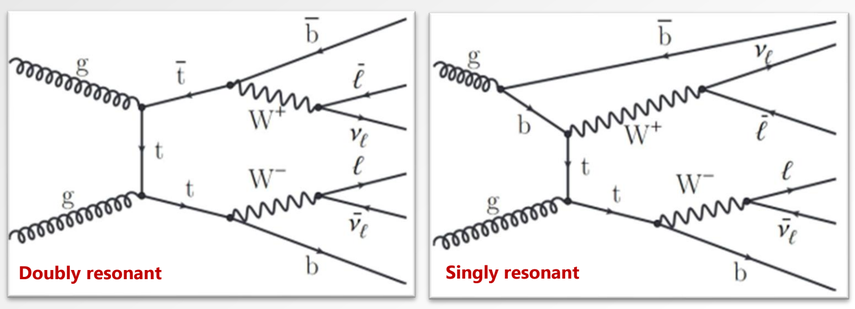
- The **single differential** cross-section has been measured as a function of two interference-sensitive variables, defined as $m_{bl}^{\mathrm{minimax}}$ and $\Delta R(b_1, b_2)$
- The **double differential** cross-section has been measured as a function of $m_{bl}^{minimax}$ in bins of $\Delta R(b_1, b_2)$.

Results have been compared to different prediction schemes: the Diagram Removal (DR) and the Diagram Subtraction (DS), that model in a different way the quantum interference description

Process production

Quantum interference between:

(LO) $gg \to t\bar{t} \to WbWb$ (NLO) $gb \to tWb \to WbWb$



$$\alpha + \beta \to t + W + b \Longrightarrow \mathcal{A}_{\alpha\beta} = \mathcal{A}_{\alpha\beta}^{(Wt)} + \mathcal{A}_{\alpha\beta}^{(t\bar{t})}$$

[2]

$$\sigma_{WbWb} \propto \left|\mathcal{A}_{\alpha\beta}\right|^2 = \left|\mathcal{A}_{\alpha\beta}^{(Wt)}\right|^2 + 2\mathcal{R}e\left\{\mathcal{A}_{\alpha\beta}^{(Wt)}\mathcal{A}_{\alpha\beta}^{(t\bar{t})}\right\} + \left|\mathcal{A}_{\alpha\beta}^{(t\bar{t})}\right|^2$$

Event selection

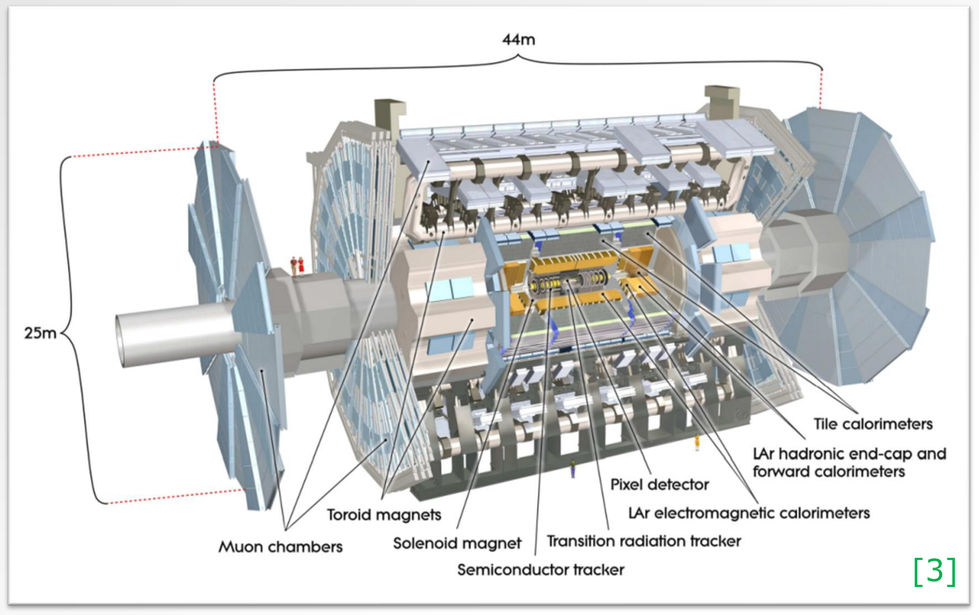
Dilepton Opposite-Sign (OS) channel (ee, $e\mu$ and $\mu\mu$):

$$pp \to WbWb \to l^+\nu_l l^-\ \bar{\nu}_l b\bar{b}$$

Requirements

- Selection provided by e/μ triggers
- $p_T^{\mathrm{lepton}} > 28\ GeV$, $p_T^{\mathrm{jets}} > 25\ \mathrm{GeV}$ and $|\eta| < 2.5$
- 2 b-tagged jets at 60% efficiency with veto on 3° b-tagged jet at 85% efficiency
- Interference taken into account with DR and DS schemes
- Comparison of data with NLO + PS predictions.

The ATLAS detector

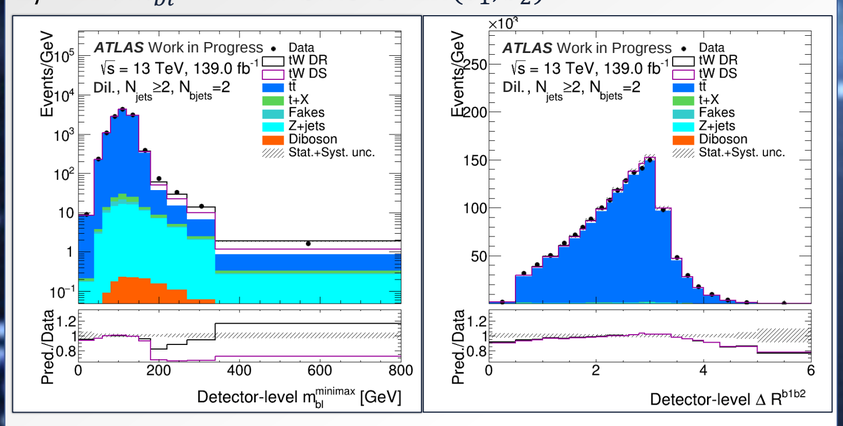


[3]

Observables of interest

Cross-section extraction as a function of:

1) 1D: $m_{bl}^{\mathrm{minimax}}$ and $\Delta R(b_1, b_2)$
2) 2D: $m_{bl}^{\mathrm{minimax}}$ in bins of $\Delta R(b_1, b_2)$



Detector-level distributions (1D)

Event yields

	Sample	Total events
Signal	$t\bar{t}$	264000 ± 6000
	tW (DR)	8200 ± 180
Bkg	$t\bar{t}V$	734 ± 3
	Fakes	375 ± 7
	Diboson	44.8 ± 0.9
	Z+jets	2420 ± 33
	Expected	276000 ± 6000
	Observed	278333

ATLAS work-in-progress

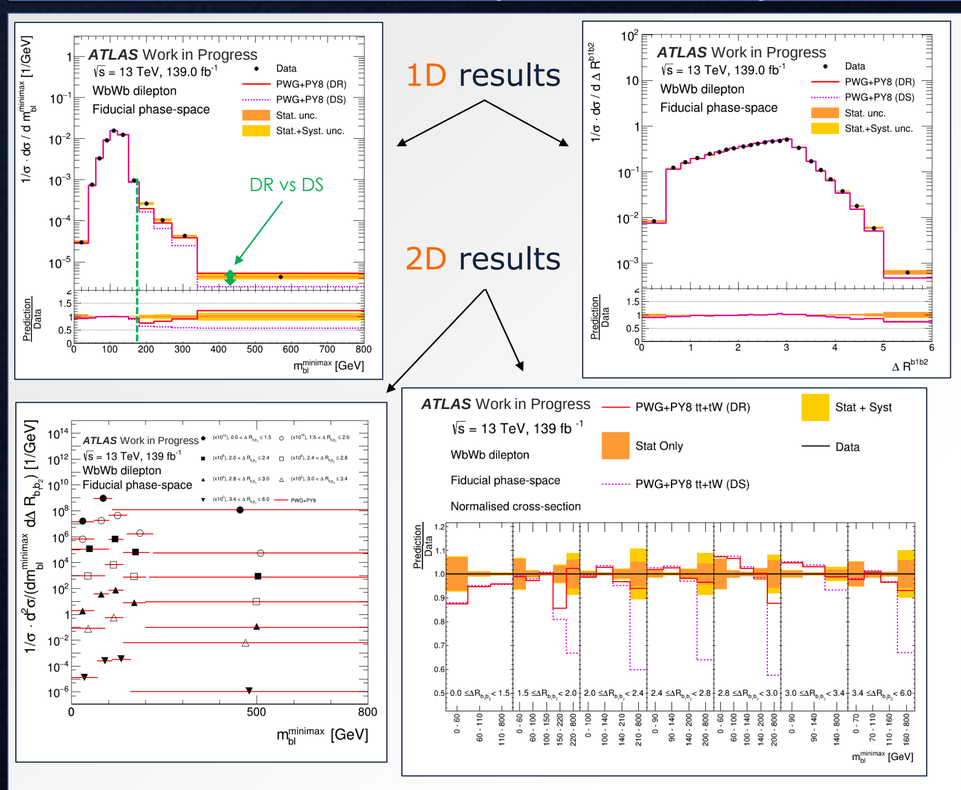
Unfolding procedure

Unfolding is used to correct data for finite resolution and limited geometrical acceptance of the detector. It can be applied to several analyses for cross-section extractions. Final cross-sections are extracted through an **iterative Bayesian unfolding** method, using this equation [4]:

$$\frac{d\sigma^{\mathrm{fid}}}{dX^i} \equiv \frac{1}{\mathcal{L}\cdot\Delta X^i}\cdot\frac{1}{\epsilon^i}\cdot\sum_j M^{-1}\cdot f_{\mathrm{acc}}^j\cdot\left(N_{\mathrm{obs}}^j - N_{\mathrm{bkg}}^j\right) \Longrightarrow \frac{d\sigma^{\mathrm{norm}}}{dX^i} = \frac{1}{\sigma^{\mathrm{fid}}}\cdot\frac{d\sigma^{\mathrm{fid}}}{dX^i}$$

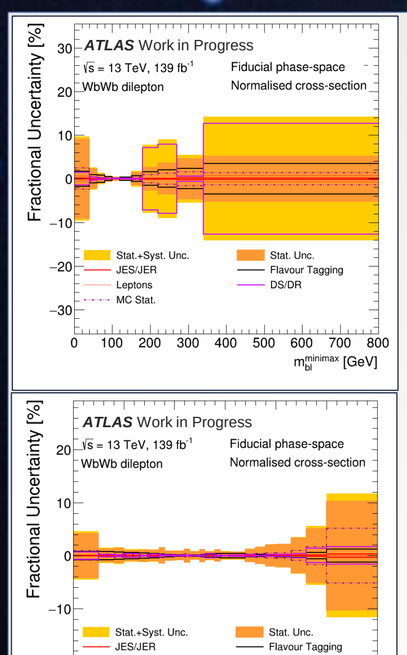
Binning has been provided through **binning optimization** procedures (with additional resolution studies) and **closure tests** to ensure their stability

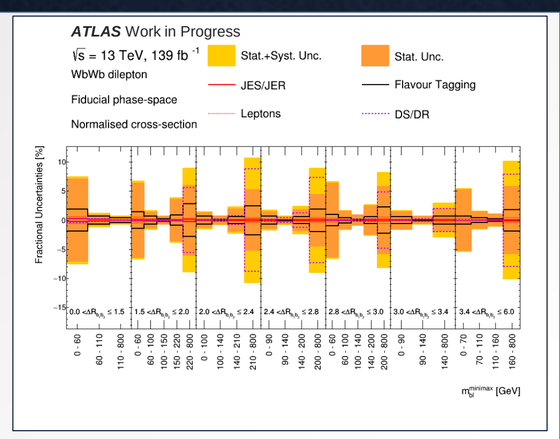
Final Results (1D and 2D)



1. $m_{bl}^{\mathrm{minimax}}$ distribution: better described by DR than DR
2. $\Delta R(b_1, b_2)$ distribution: no evident discrimination between DR and DS schemes

Systematic uncertainties (1D and 2D)





List of considered systematics:

1. Detector-level: lepton reconstruction efficiency, JVT, b-tagging, pileup reweighting and luminosity
2. Signal modelling: choice of removal scheme and finite sample statistics of MC generators

Fiducial σ

Total fiducial cross-section:

Sample	Fiducial cross-section [pb]
Data	7.49±0.22
$t\bar{t} + tWb$ (Powheg+Pythia8, DS)	7.4671±0.0017
$t\bar{t} + tWb$ (Powheg+Pythia8, DR)	7.4907±0.0015

ATLAS work-in-progress

Uncertainties are related to the previous paragraph (see on the left panel).

Bibliography

[1] Morad Aaboud et al. In: *Phys. Rev. Lett.* 121.15 (2018), p.152002.

[2] Stefano Frixione et al. In: *Journal of High Energy Physics (*2008), p. 029.

[3] The ATLAS collaboration. In: *JINST* **3** S08003 (2008).

[4] Biondi, Silvia. In: *EPJ Web Conf.* 137 (2017), p. 11002.

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