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Study of the quantum interference between singly- and doubly-resonant top-quark production in the *WbWb* phase space with the ATLAS detector

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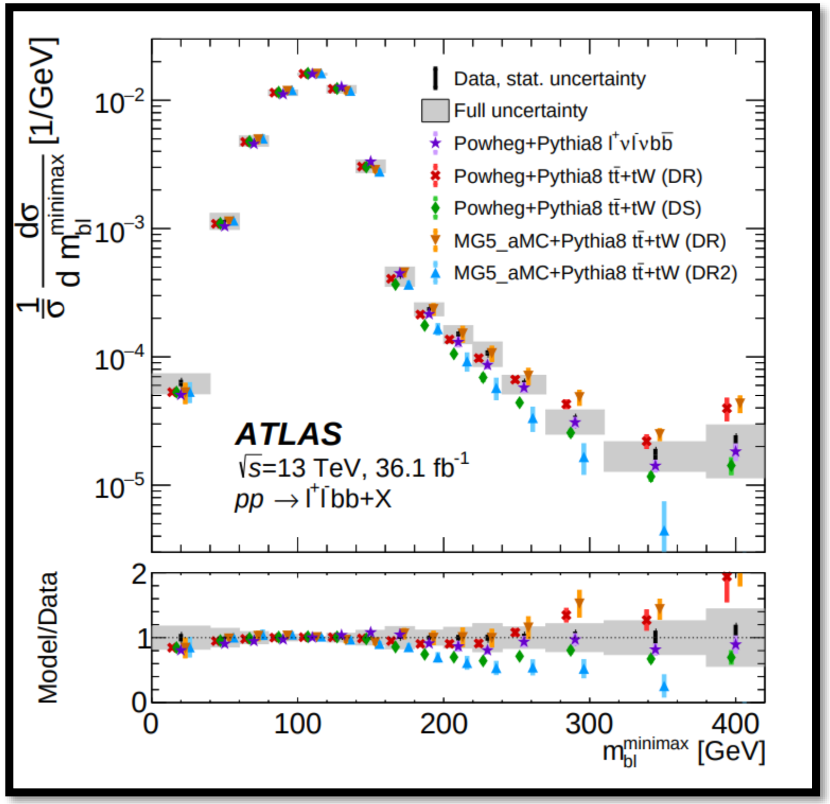
Outline of the talk

- Introduction
- The *WbWb* production
- Event selection and requirements
- Systematic uncertainties
- Differential cross-sections measurement
- Conclusions

Introduction

- Study of the quantum interference between singly- and doubly-resonant top-quark production
  - I.e: measurement of the WbWb cross-section in the dilepton channel
  - Consider variables sensitive to the interference between $t\bar{t}$ and tW: $m_{bl}^{\mathrm{minimax}}$
- ATLAS Run-2 dataset (2015-2018): $\sqrt{s} = 13$ TeV corresponding to $\mathrm{L} = 139\ \mathrm{fb}^{-1}$
- Measurement of the cross-section through the **unfolding** procedure

Previous measurement (2018)



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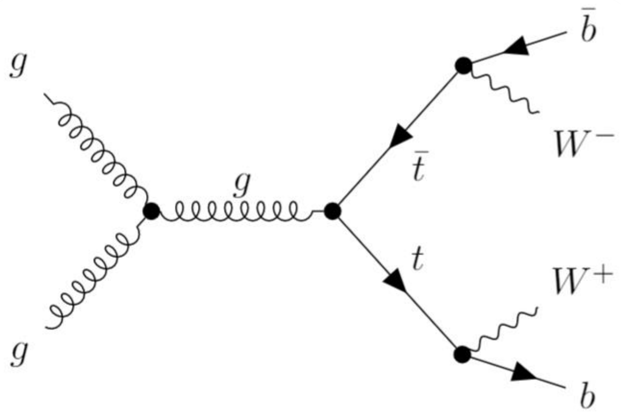
The $WbWb$ production cross-section at the NLO for tW

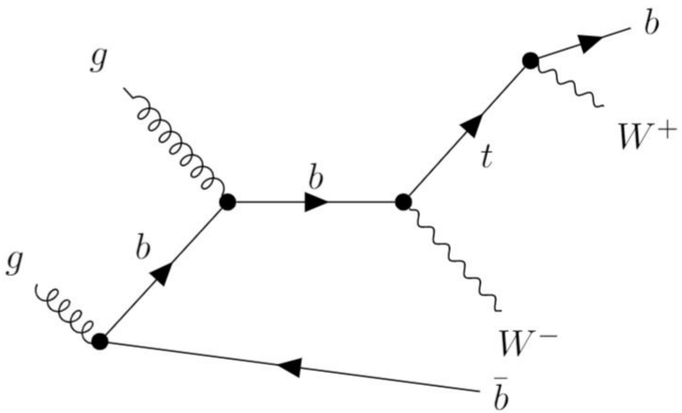
Top quark production processes at the LHC

LO:	Double t:	$gg \to t\bar{t} \to WbWb$
LO:	Single t:	$gb \to tW \to WbW$

LO:	Double t:	$gg \to t\bar{t} \to WbWb$
NLO:	Single t:	$gb \to tWb \to WbWb$



Doubly resonant (LO)



Singly resonant (NLO)

$$\alpha + \beta \to t + W + b \quad \Rightarrow \quad \mathcal{A}_{\alpha\beta} = \mathcal{A}_{\alpha\beta}^{(tW)} + \mathcal{A}_{\alpha\beta}^{(t\bar{t})}$$

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

The DR and DS schemes in tW generators

- ***Diagram Removal** (DR)* - all the doubly-resonant diagrams in the NLO tW process amplitude are removed

$$\left|\mathcal{A}_{\alpha\beta}\right|^2_{DR} = \left|\mathcal{A}^{tW}_{\alpha\beta}\right|^2$$

- ***Diagram Subtraction** (DS)* - NLO tW cross-sections are modified by implementing a subtraction term, in order to locally cancel the $t\bar{t}$ contribution:

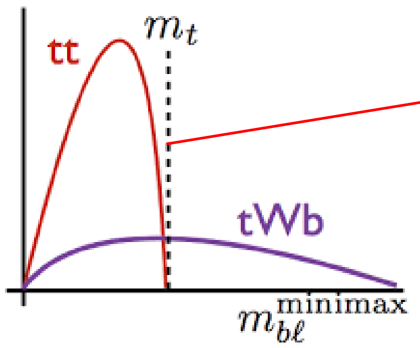
$$\left|\mathcal{A}_{\alpha\beta}\right|^2_{DS} = \left|\mathcal{A}^{tW}_{\alpha\beta} + \mathcal{A}^{t\bar{t}}_{\alpha\beta}\right|^2 - C^{SUB}$$

The m_{bl}^{minimax} variable

$pp \rightarrow WbWb \rightarrow l_1^- b_1 \nu_{l,1} l_2^+ \bar{b}_2 \bar{\nu}_{l,2}$

$$m_{bl}^{\text{minimax}} \equiv \min\{\max(m_{b_1 l_1}, m_{b_2 l_2}), \max(m_{b_1 l_2}, m_{b_2 l_1})\}$$

- bl coming from t: on-shell → two m_{bl} below the top mass bound
- bl coming from Wb: off-shell → only a single m_{bl} below the top mass bound



For $m_{bl}^{\text{minimax}} > m_{top}$
contribution of two on-shell top final-state is suppressed and interference become large

Preliminary event selection and samples

- Dilepton opposite-sign and different-flavour final state ($e\mu$, $e\tau$, $\mu\tau$) with $N_{\text{jets}} \geq 2$ and $N_{\text{bjets}} = 2$:
  - This selection reduces the $Z + jets$ background and allows comparison with the $bb4l$ prediciton

- Other requirements (kinematical cuts): $p_T^{\text{lepton}} > 28$ GeV, $p_T^{\text{jets}} > 25$ GeV and $|\eta| < 2.5$

- Samples:
  - **Signal**: $t\bar{t} + tW$ (Powheg + Pythia8 samples)
  - **Backgrounds**: $t\bar{t}V$, fake leptons, diboson production, Z + jets

Unfolding procedure

- Unfolding ➡ data corrected for:
  - Detector efficiency and finite resolution
  - Limited geometrical acceptance
- Particle-level phase space
- Iterative Bayesian unfolding:

$$\frac{d\sigma^{\mathrm{fid}}}{dX^i} \equiv \frac{1}{\mathcal{L}\cdot\Delta X^i}\cdot\frac{1}{\epsilon^i}\cdot\sum_j M^{-1}\cdot f^j_{\mathrm{acc}}\cdot\left(N^j_{\mathrm{obs}} - N^j_{\mathrm{bkg}}\right)$$

$$\frac{d\sigma^{\mathrm{norm}}}{dX^i} = \frac{1}{\sigma^{\mathrm{fid}}}\cdot\frac{d\sigma^{\mathrm{fid}}}{dX^i}$$

Reconstructed spectrum ($\vec{R}$), True spectrum ($\vec{T}$), Response matrix ($\boldsymbol{R}$):

$$\vec{R} = \boldsymbol{R}\cdot\vec{T}$$

Correction factors:

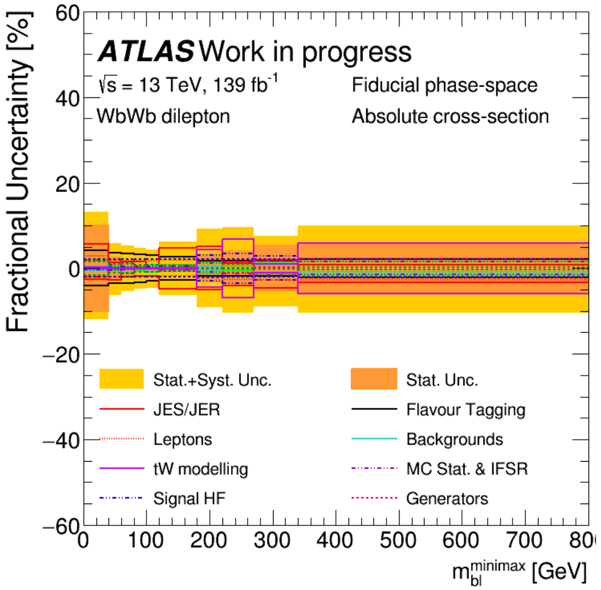
- f^j_{acc}= acceptance factor
- ϵ^i= inefficiency factor

Systematic uncertainties

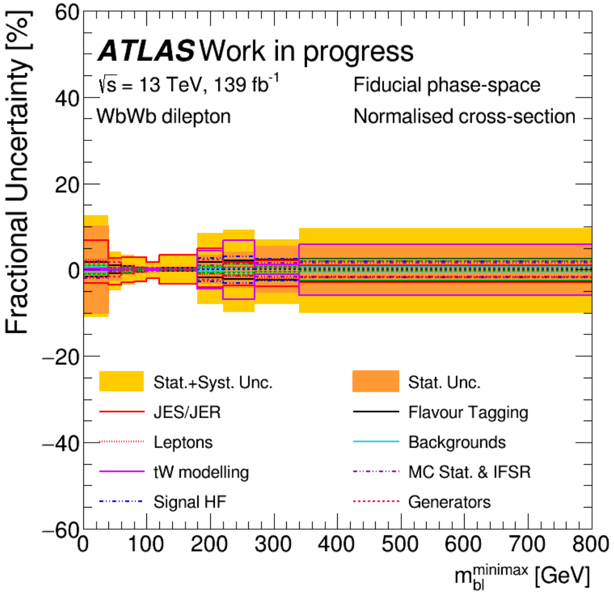
- Evaluated by:
  1. Unfolding the varied MC detector-level spectra with nominal corrections
  2. Compare the unfolded result with the particle-level distribution of the generator

- Detector-related systematics:
  - Lepton and jet reconstruction efficiency, b-tagging, pileup reweighting, luminosity, etc…
- Signal modelling systematics:
  - Choice of removal scheme, finite sample statistics of MC generators, etc…
- Background modelling systematics:
  - Related to background processes

Absolute differential

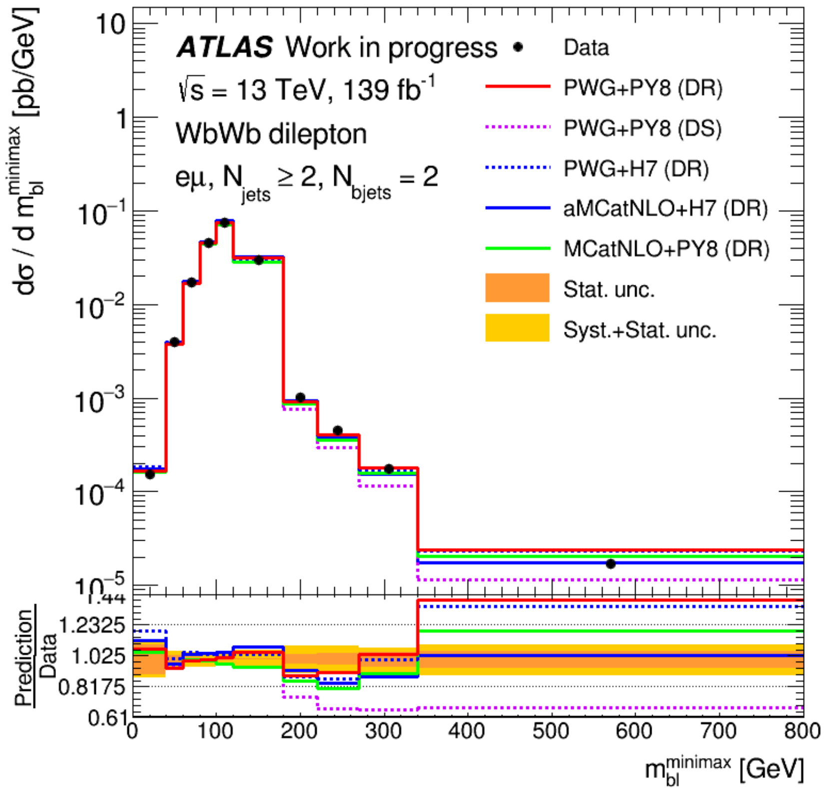


Normalized

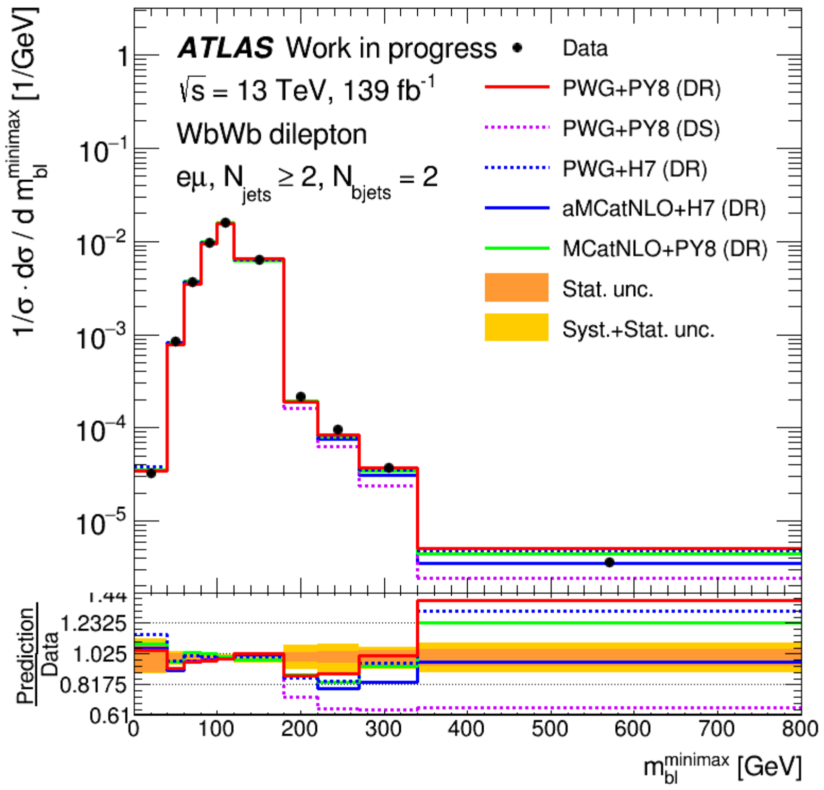


Differential cross-sections

Absolute differential xsec



Normalized differential xsec



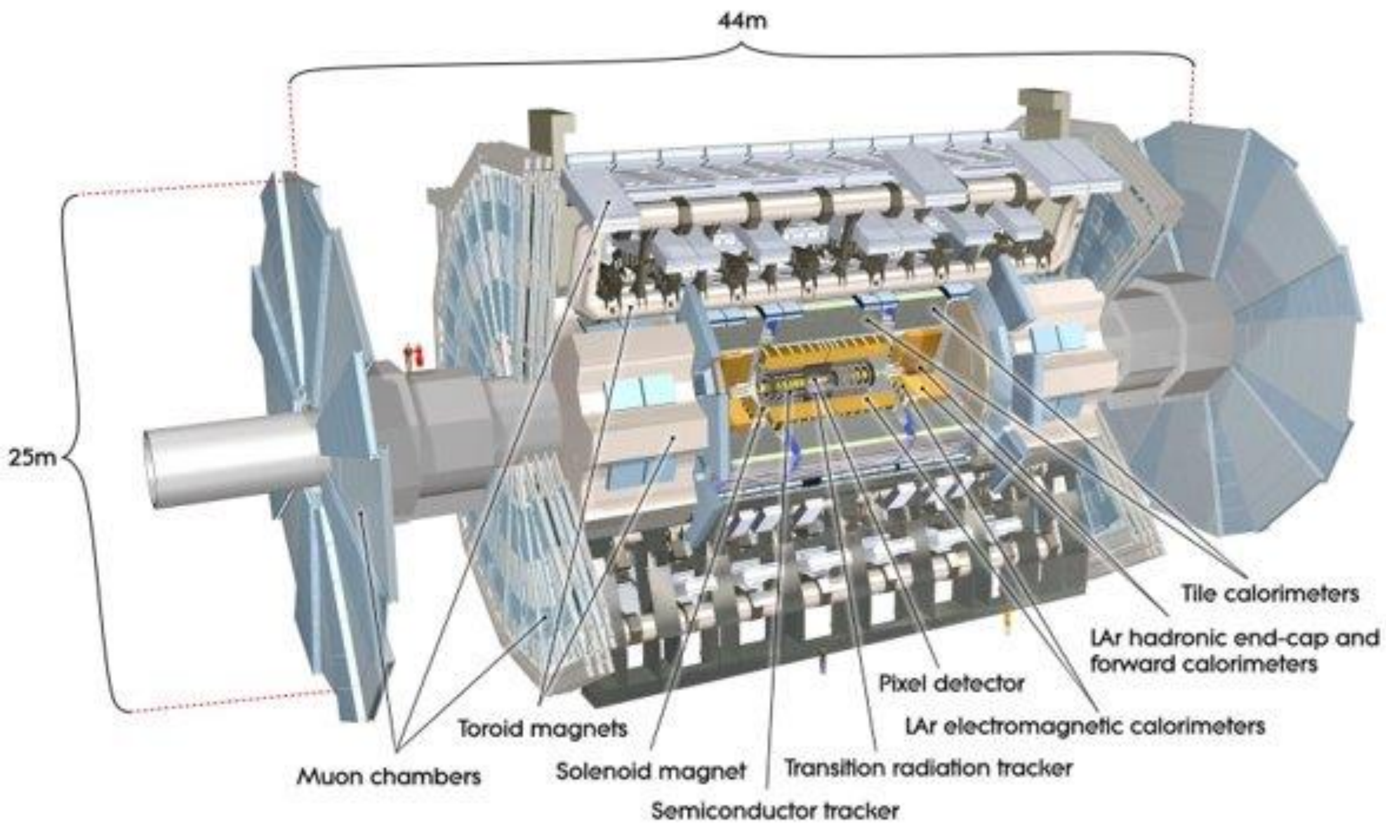
Conclusions

- Preliminary results:
  - We are aiming for a measurement of the $WbWb$ cross-section with the full Run-2 data with half the uncertainty with respect to previous measurement
  - This measurement could be compared to many predictions and can be used to define a better uncertainty linked to interference
  - In general, DR predictions seem to better describe the interference region
  - Other interference-sensitive variables than $m_{bl}^{\mathrm{minimax}}$ have been excluded

- Future improvements:
  - We need to optimize the selection
  - Search for possible signals of toponium-resonance formation in $WbWb$ phase-space

Backup

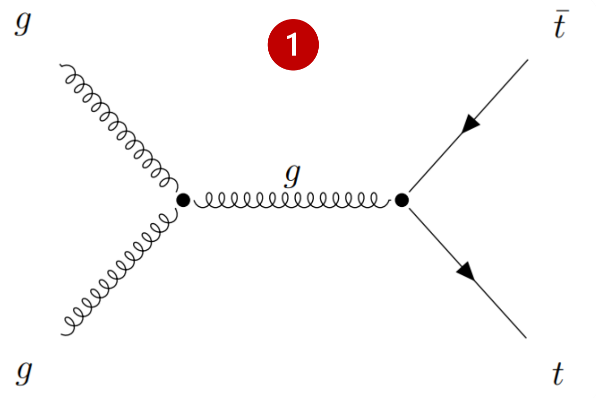
The ATLAS detector

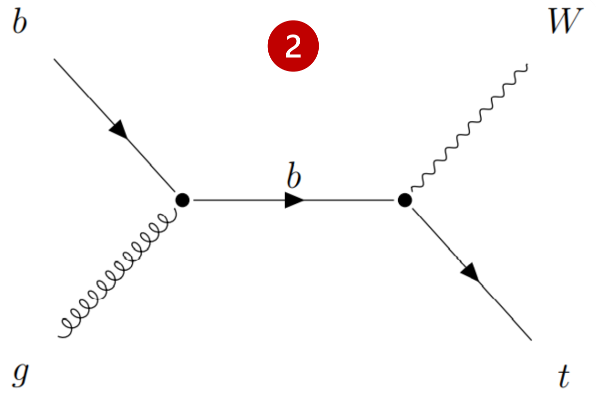


Top quark production processes at the LHC

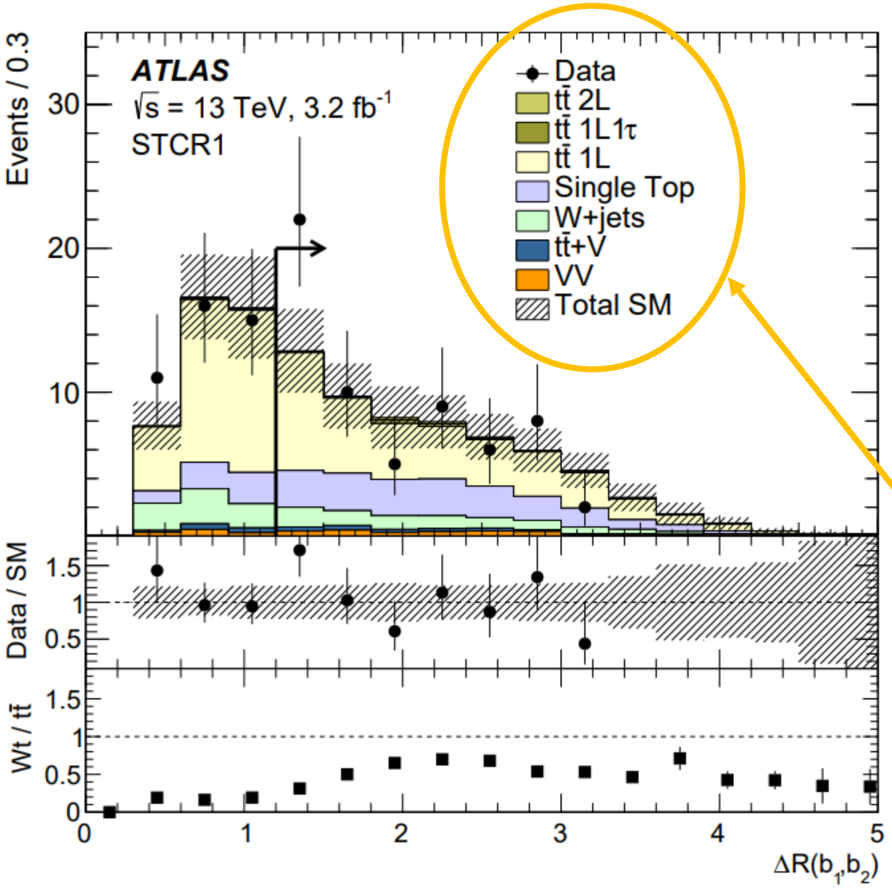
- Top quark production processes at the LO
  - $\boldsymbol{t\bar{t}}$ **pair** production (Fig. 1): $gg \rightarrow t\bar{t} \rightarrow WbWb$ (dominant)
  - **Single-top** production (Fig. 2): $gb \rightarrow tW \rightarrow WbW$ (subdominant)

At LO $t\bar{t}$ and tW don't interfere (different final-states)





Impact of interference in BSM processes



[PRD 94 (2016) 052009](#)

Background processes given by $t\bar{t}$ and Wt

Toponium resonance in WbWb phase-space

- Recent studies (ATLAS 2020): deviations between data and predictions in $t\bar{t} \to WbWb \to ll$ productions:
  - Possibility of a signal in toponium-resonance η_t formation at $\Delta\phi_{ll} < \frac{\pi}{5}$ and $m_{ll} < 50\ \text{GeV}$

Excess of data could be explained by the existance of the η_t state

- $WbWb$ cross-section improvements would lead to a complete investigation of this process in $WbWb$ phase-space

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