69th Annual Conference of the South African Institute of Physics

ATLAS EXPERIMENT

Measurement of the top quark Yukawa coupling from $t\bar{t}$ kinematic distributions

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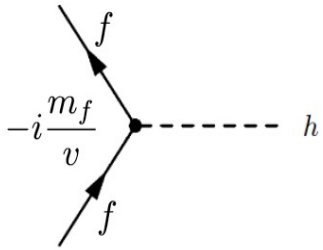
Introduction

Yukawa Interaction:

$$\mathcal{L}_{Yuk} = -\Sigma_f \left(m_f + \frac{m_f}{v} H \right) \bar{\psi}_f \psi_f + \ldots$$



→Occurs between the fundamental fermion fields and Higgs field.

→Fermion mass related to the strength of their Yukawa coupling

→Forms a unique test of the SM in a sector where one could expect New Physics to play a role

Top quark:

→Most massive particle in SM: m_{top} = 172.5 GeV

→Provides access to the largest Yukawa coupling (Y_t)

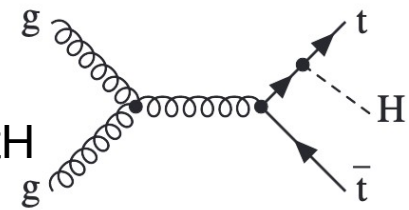
- Predicted to be close to unity

Extraction methods

Two methods to extract Y_t

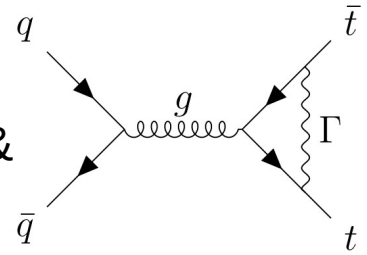
Direct:

Processes with top quark and Higgs in final state e.g. $t\bar{t}H$ & tH



Indirect:

Processes where virtual Higgs exchanged e.g. 4 top & **$t\bar{t}$ cross-section**



Extracting from tt cross-section

→ tt modelling sensitive to EW corrections in production threshold region

→Several measurements from CMS and ATLAS

CMS

Channels investigated:

- Lepton + jets — CERN-EP-2019-119
- Dilepton — CERN-EP-2020-152

ATLAS

Channels investigated:

- Lepton + jets — Ongoing
- **Dilepton** — **This Analysis**

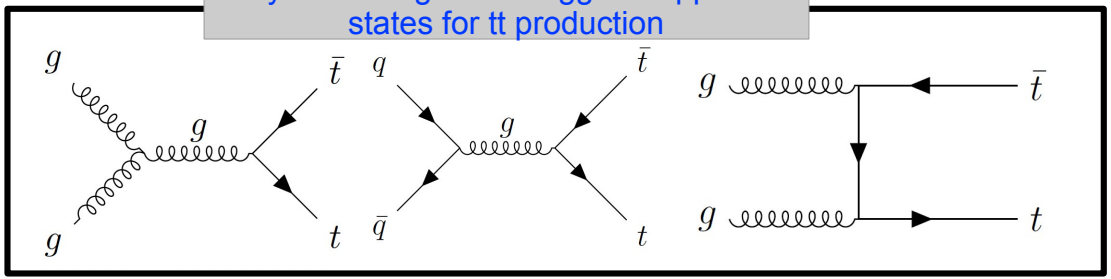
Analysis topology

Goal: Extract top quark Yukawa coupling from dilepton $t\bar{t}$ production using Run 2 data

$t\bar{t}$ production:

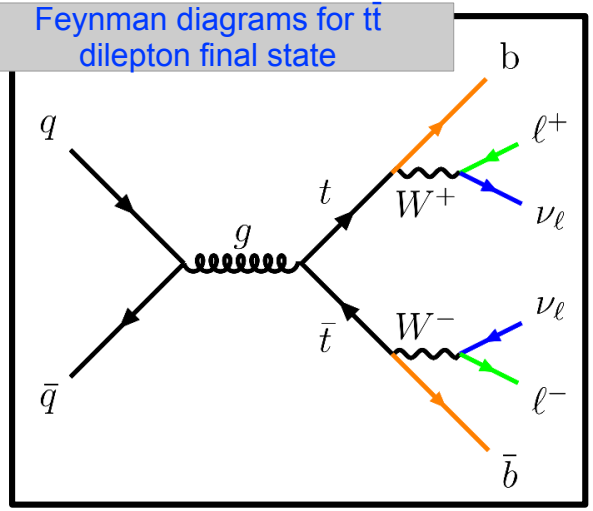
- via gg or $q\bar{q}$ production
- Gluon production dominant at LHC

Feynman diagrams for gg and qq initial states for tt production



$t\bar{t}$ decay: $t\bar{t} \rightarrow bW^+\bar{b}W^- \rightarrow b\ell^+\nu_\ell\ \bar{b}\ell^-\nu_\ell$

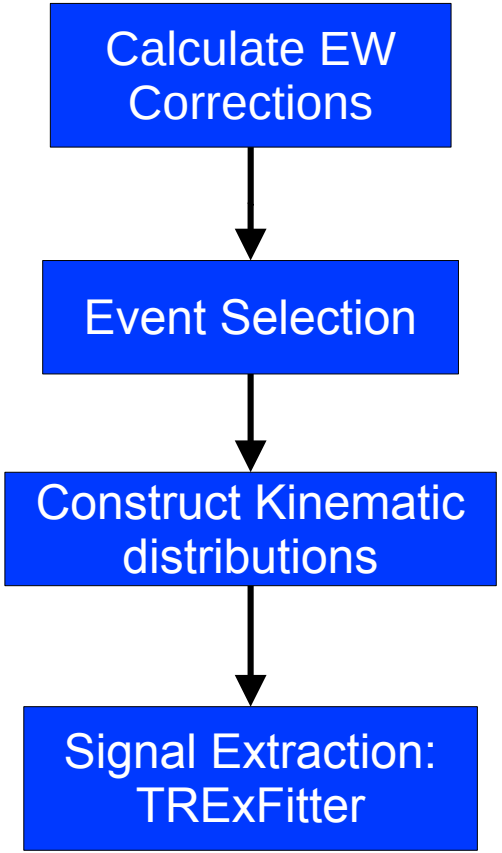
Feynman diagrams for $t\bar{t}$ dilepton final state



Final state topology:

- 2 leptons (e/μ)
- 2+ Jets
- 2 b-jets
- MET

Analysis strategy



→Implemented using HATHOR 2.1-b3

- Hathor generated weights calculated at parton level
- Detector level distributions obtained by re-weighting simulation

→Construct observables **sensitive to Y_t**

- Implemented at detector level

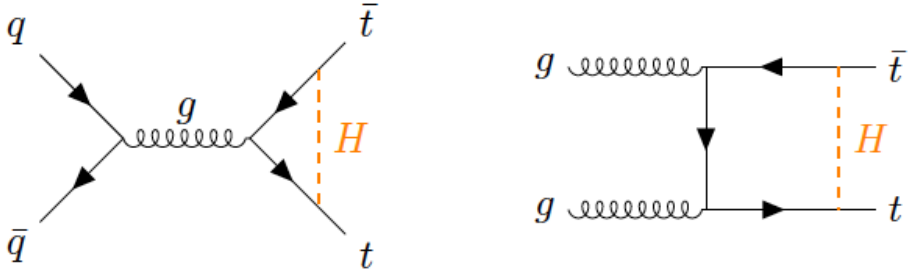
→Implemented using template morphing

- Complete set of systematic uncertainties

Electroweak corrections

At $t\bar{t}$ production threshold:

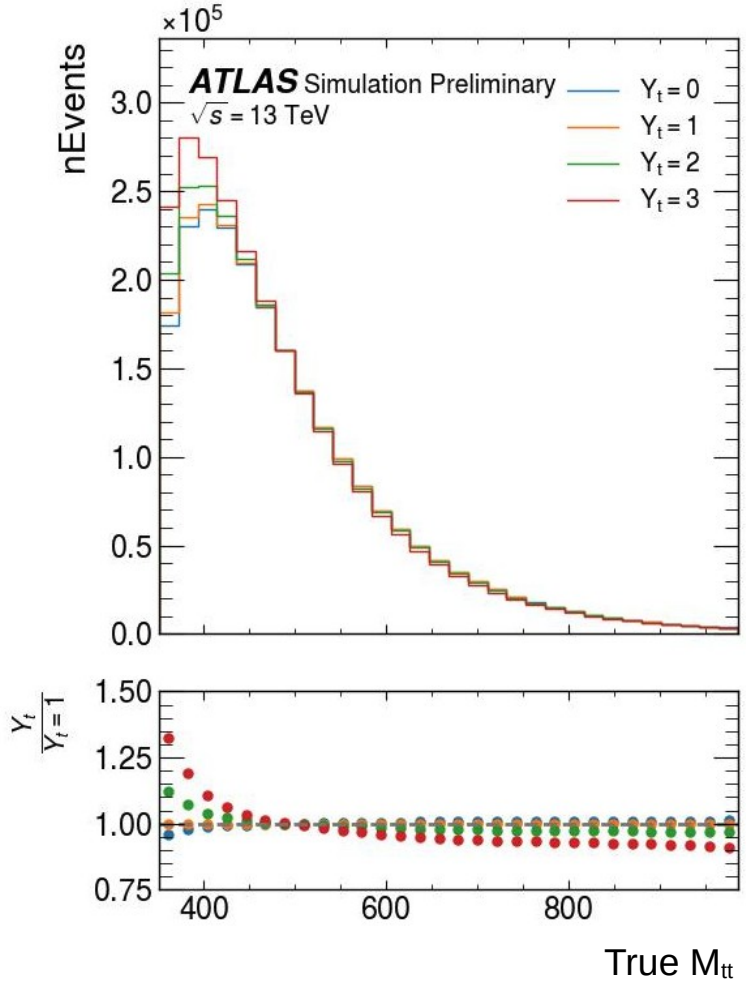
- $t\bar{t}$ cross-section sensitive to Y_t
- Exchange of virtual Higgs



→EW corrections simulated using Hathor

- Calculated for gg & $q\bar{q}$, respectively

→Most Y_t sensitive regions are low M_{tt} & small $\cos^{*}\theta$



Event selection

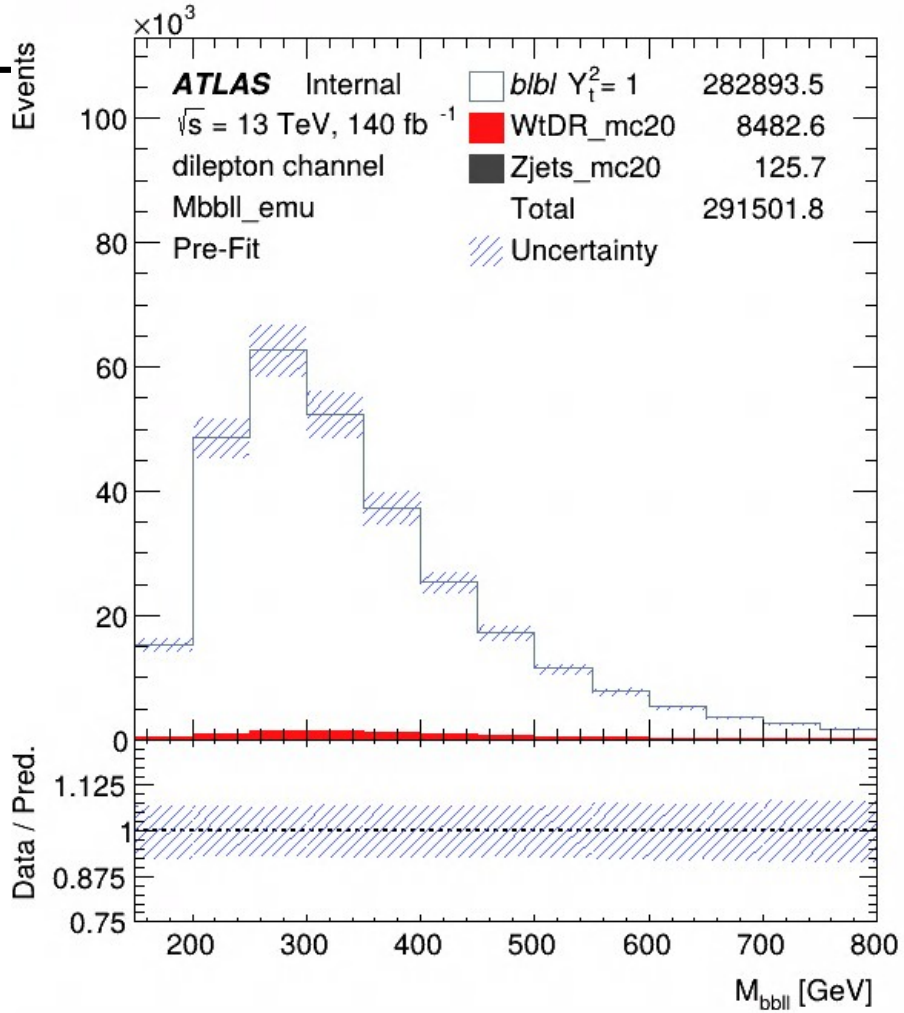
→Using full Run 2 dataset [140 fb^{-1}]

→Focus on dilepton **eμ channel**

→Backgrounds included:

- tW, Z+jets

Selection Criteria	
Lepton p_T	$\ell \geq 25$ GeV (ℓ = e or μ)
Jet p_T	jet $p_T \geq 20$ GeV
B-tag WP	DL1d = 77%
No. b-jets	$N_b \geq 2$
$m_{\ell\ell}^{OS}$	$m_{\ell\ell}^{OS} \geq 10$ GeV



Kinematic distributions

→EW corrections are calculated at parton level

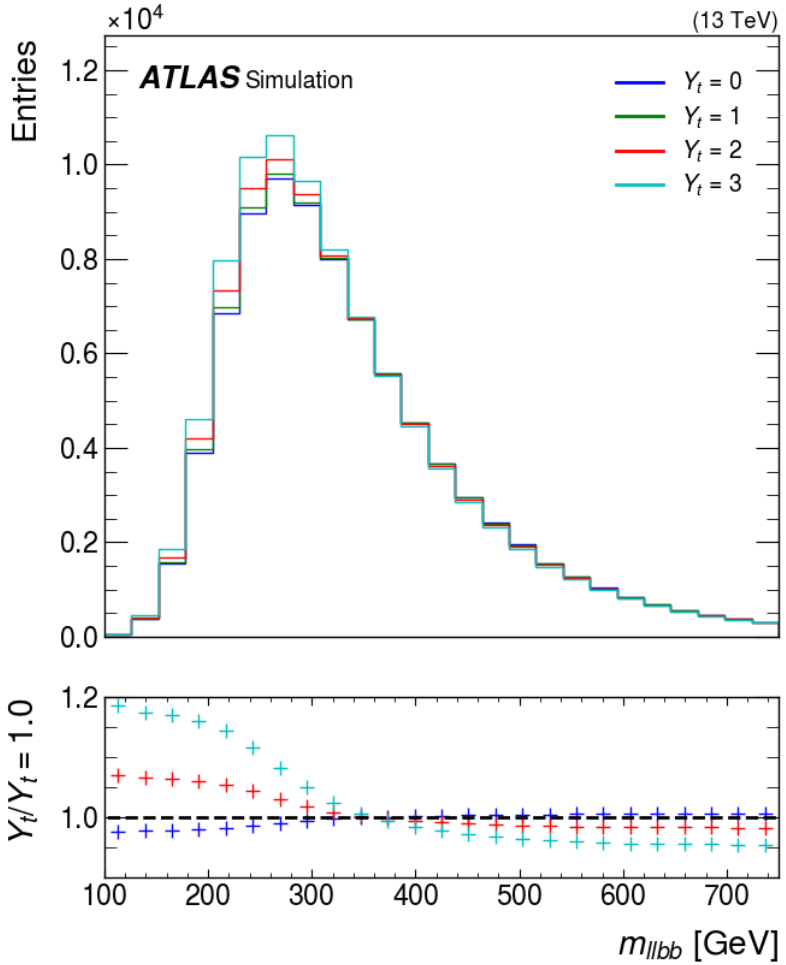
→Need to obtain observables at **detector level**

Constructed observables:
→Use measured decay products of tt pair
→Serve as proxy for M_{tt} & Δy_{tt}
→At detector level:
- M_{llbb}
- $\cos^{*}\theta_{lb}$

Are there more sensitive observables?

→Reconstruct the true M_{tt} from detector level objects?

Figure showing the mass of the measured decay products at detector level for $t\bar{t}$



Reconstructing m_{tt}

Aim: Improve sensitivity by reconstructing the mass of the $t\bar{t}$ system using ML

Training:

→Implemented simple DNN using Keras

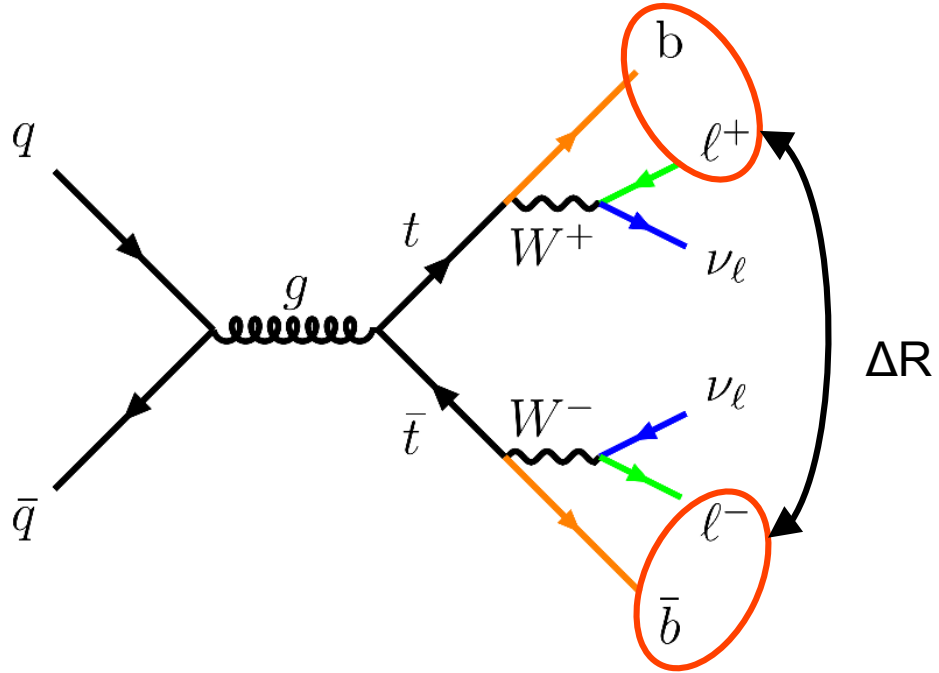
→Architecture:

- 3 hidden Layers
- Nodes: 24, 12, 6, 1 output

Input variables:

→M_{lb} combinations, E^{T}_{miss}

→ΔR between lb systems



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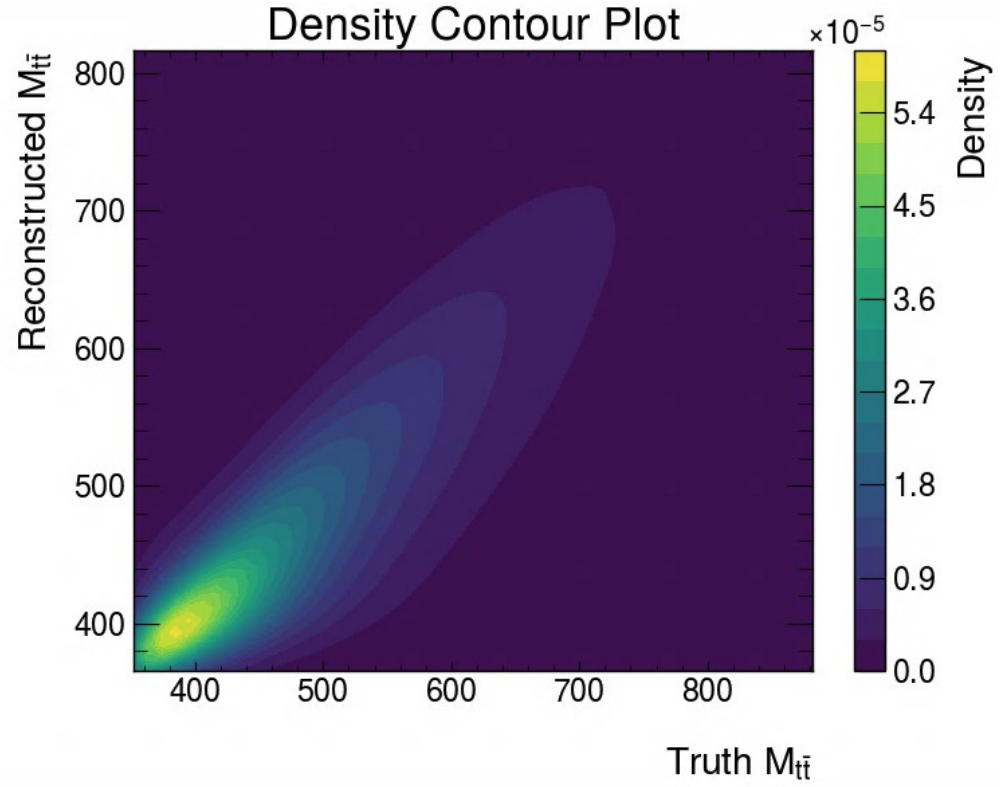
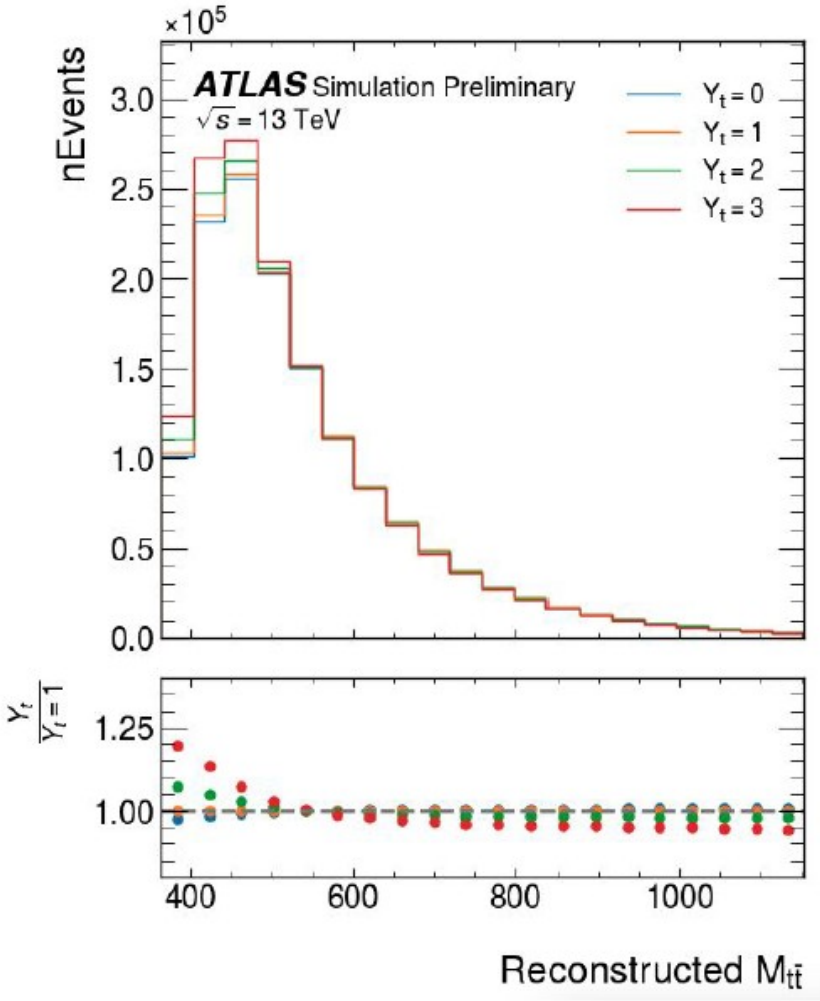
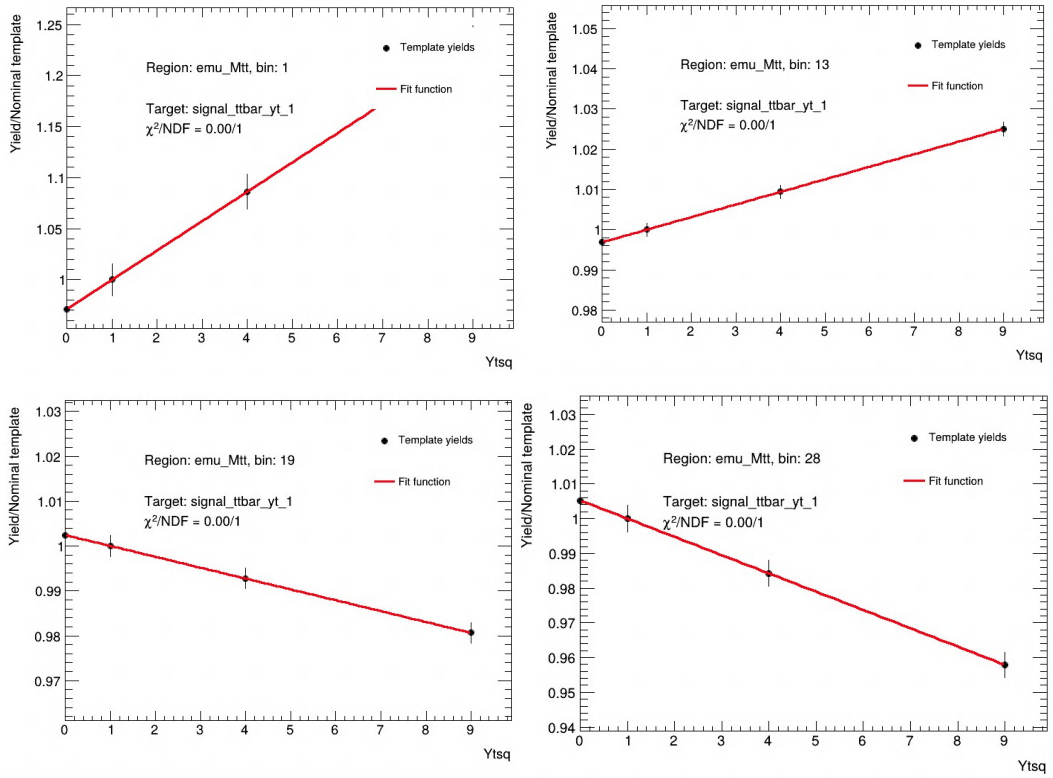




Extraction method

- →Binned profile likelihood fit
- →Extraction implemented using template morphing
  - Templates are created using EW corrections for Y_t = 0,1,2 & 3
  - Linearly interpolating between templates
  - Parameter of interest: Y^2_t
- →Complete set of systematics



Results

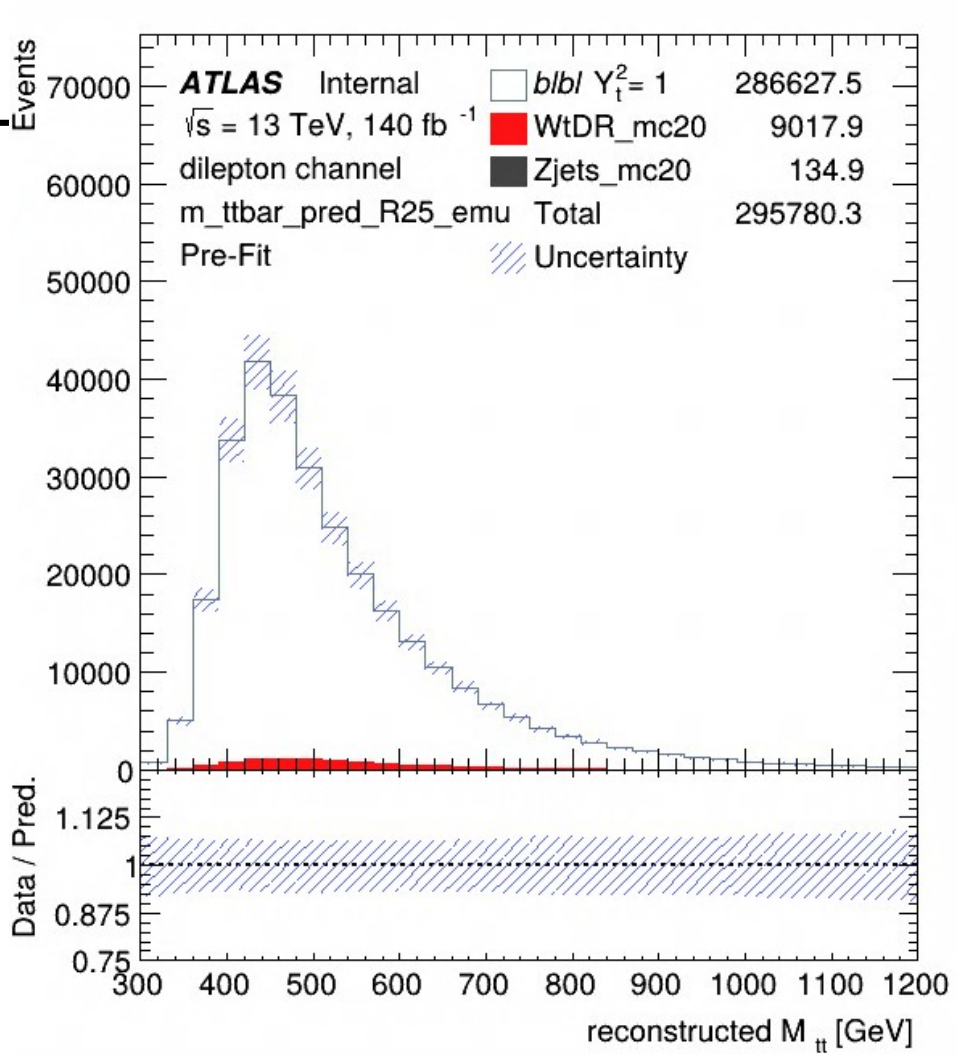
→Results shown are blinded

→Dominant uncertainties due to

- $t\bar{t}$ modelling
- B-tagging

→Reduced uncertainties from m_{tt} reconstruction

Variable	Extracted Y_t
$m_{\ell\ell bb}$	$1.00^{+1.73}_{-1.70}$
reconstructed m_{tt}	$1.00^{+1.56}_{-1.50}$



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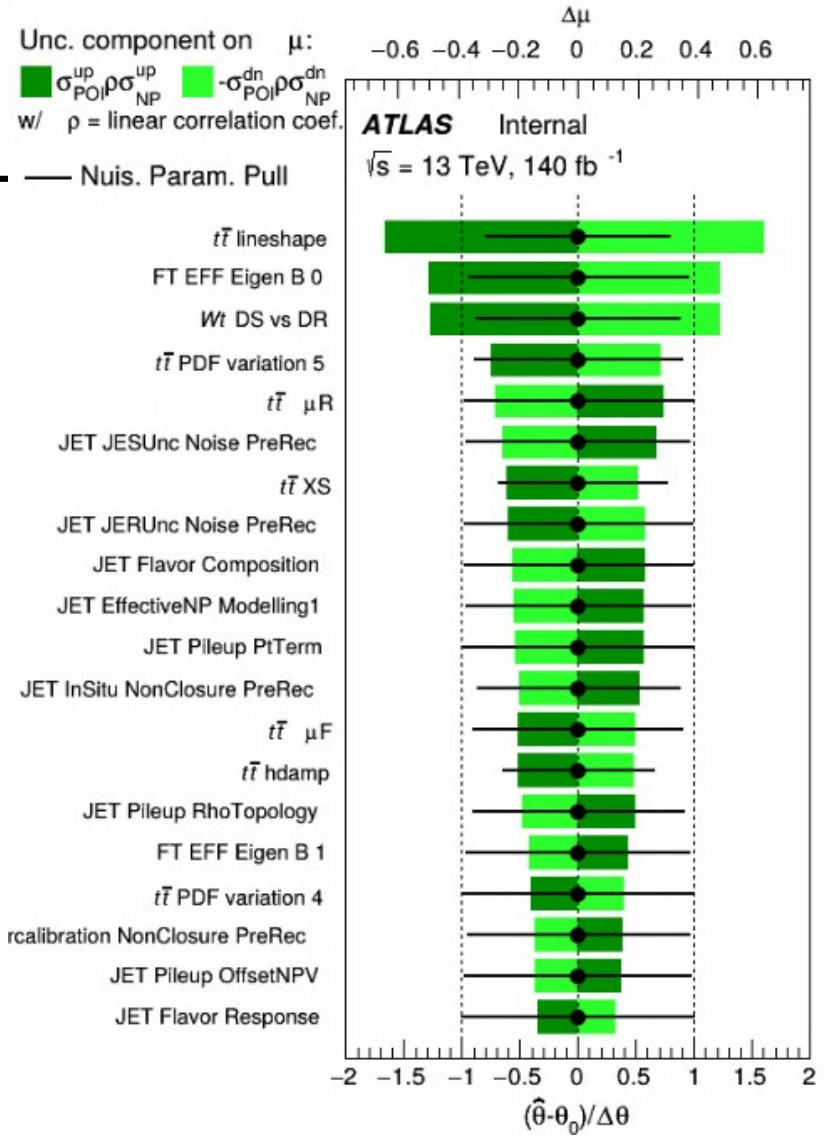

Conclusion

→Indirect measurement of top quark Yukawa coupling in dilepton channel

→Electroweak corrections implemented using Hathor

→Constructed variables sensitive to variations in Y_t

- Implemented reconstruction of m_{tt} using ML

→Blinded extraction of Y_t using binned profile likelihood fit

→Dominant uncertainties due to:

- $t\bar{t}$ modelling
- B-tagging

Thank you for your time

Any Questions?

Reconstructing m_{tt}