Extracting top quark Yukawa coupling from tt differential cross-section in the dilepton final state

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ATLAS EXPERIMENT

Open questions in SM

Open questions in SM

→What are dark matter & dark energy?

→The Hierarchy problem

→Are neutrinos Majarona particles?

Open questions in SM

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→What are dark ma… …gy?

→… problem

→Are neutrinos Majarona particles?

Is the universe stable

Open questions in SM

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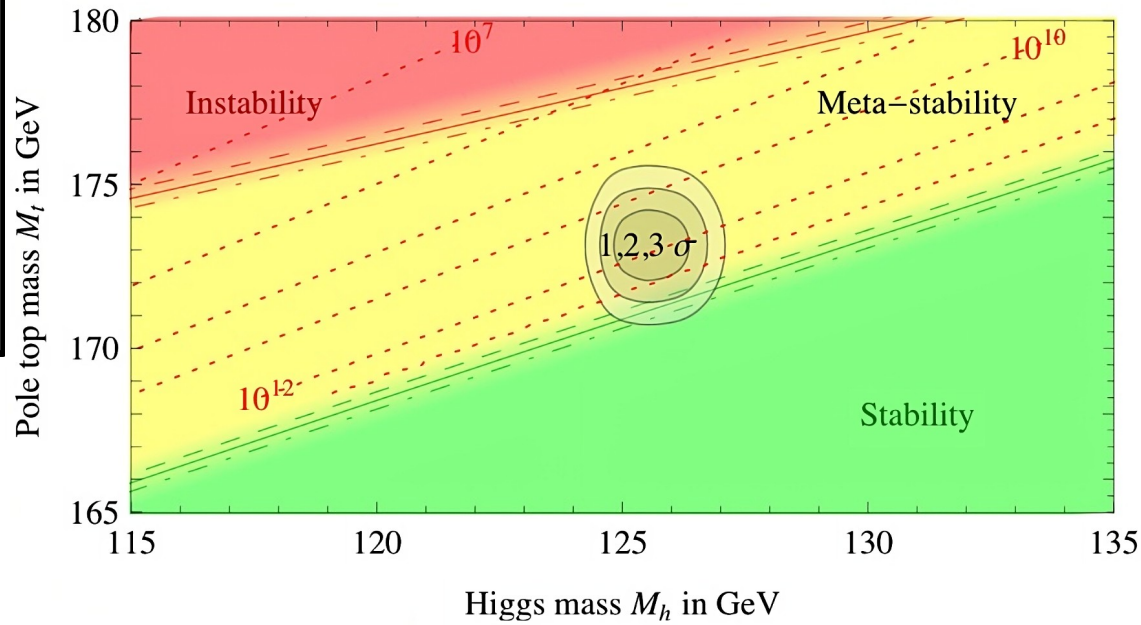
Is the universe stable

According to our best estimates the universe is meta-stable

Standard Model phase diagram showing the stability of the Higgs potential as a function of the Higgs and top masses



Yukawa coupling

Yukawa Interaction:

→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

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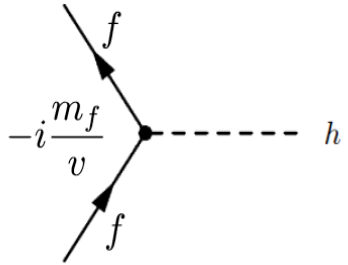
$$\mathcal{L}_{Yuk} = -\Sigma_f \left(m_f + \frac{m_f}{v} H \right) \bar{\psi}_f \psi_f + ...$$



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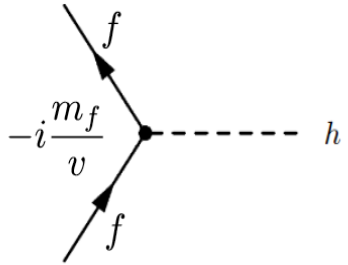


Top quark:

→Most massive particle in SM - m_t = 172.5 Gev

→Provides access to the largest Yukawa coupling ($\mathbf{Y_t}$)

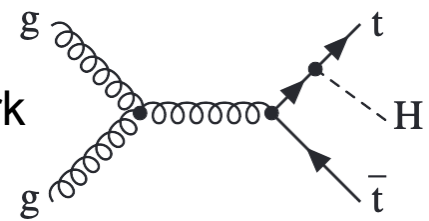
- Predicted to be close to unity

Y_t Extractions

Two methods to extract Y_t, direct & indirect

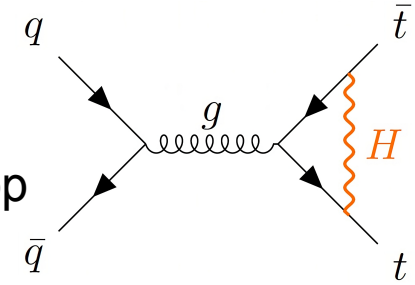
Direct:

Processes with top quark and Higgs in final state e.g. ttH & tH



Indirect:

Processes where virtual Higgs exchanged e.g. 4 top & tt cross-section



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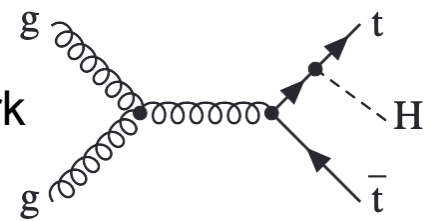

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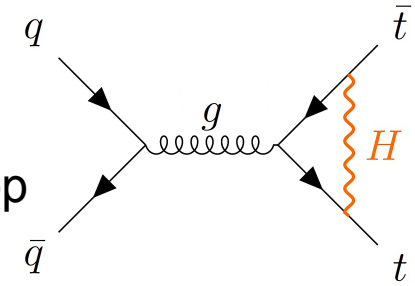


Extracting from tt cross-section

→ tt modelling sensitive to EW corrections in production threshold region

→ Several measurements from CMS and ATLAS

Production threshold for tt occurs when the centre of mass energy is ~2·m_t

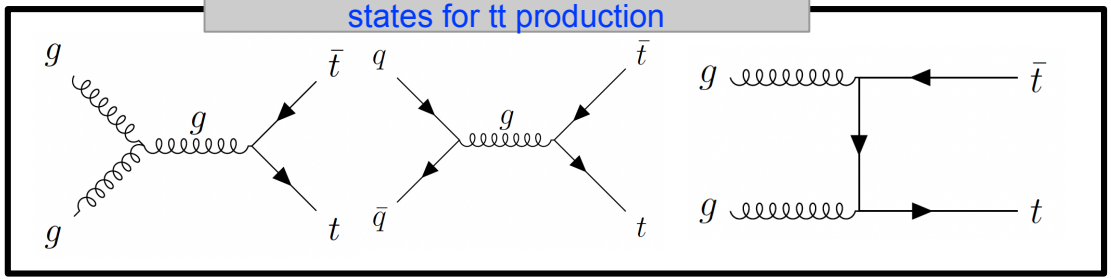
Analysis signature

Goal: Extract Y_t from dilepton tt production using ATLAS experiment at LHC

tt production:

- Produced via gg & qq initial states at LO
- Gluon production dominant at LHC
- Top quark decays to bottom quark & W^+ boson ~100%

Feynman diagrams for gg and qq initial states for tt production



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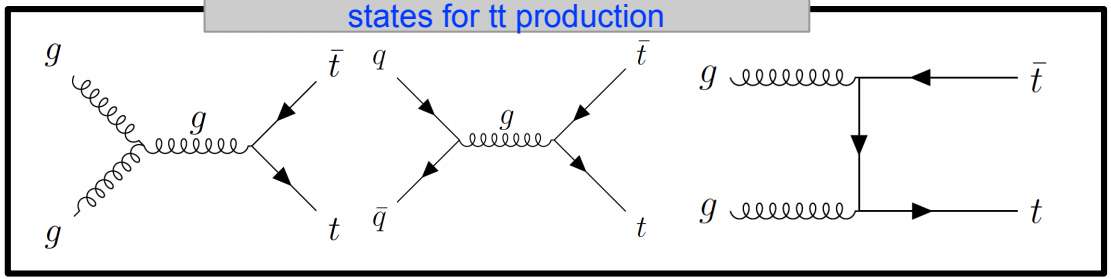
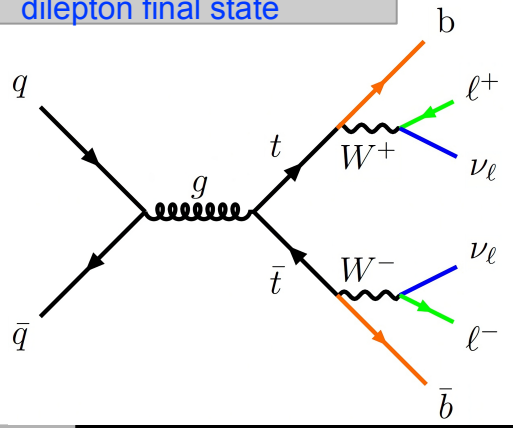


tt decay: $t\bar{t} \rightarrow bW^+\bar{b}W^- \rightarrow b\ell^+\nu_\ell\ \bar{b}\ell^-\nu_\ell$

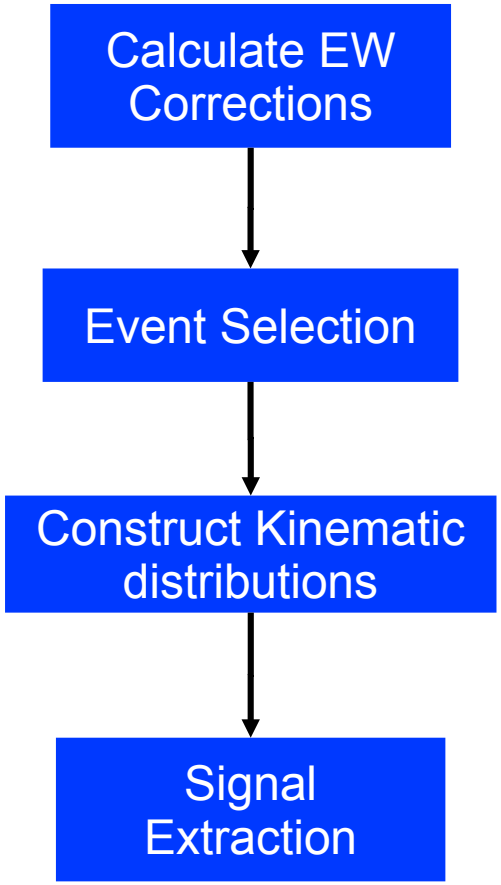
Feynman diagrams for tt dilepton final state



Final state topology:

- 2 leptons (e/μ)
- 2 b-jets
- E^t_{miss}

Analysis strategy



1. Calculate Electroweak corrections for tt
   i. Corrections applied as event weights in final histograms
2. Define a region pure in dilepton tt
3. Construct observables **sensitive to Y_t**
   i. Implemented at detector level
4. Extract Y_t using full systematic model

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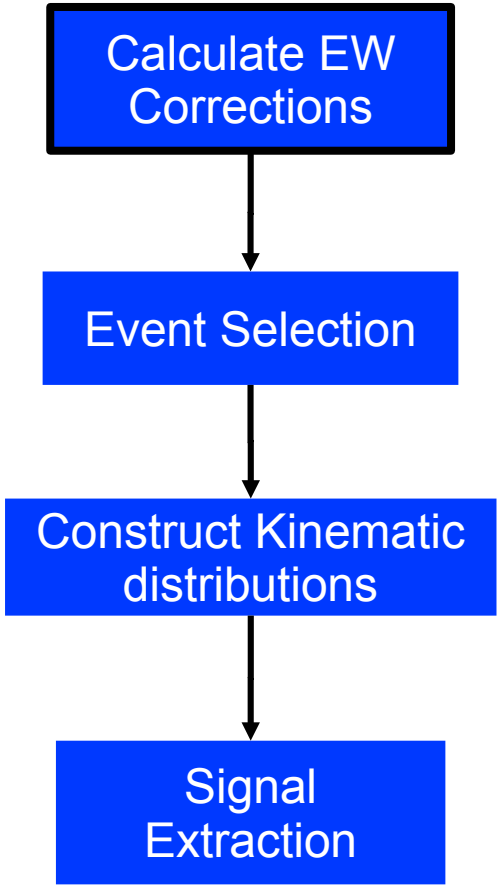

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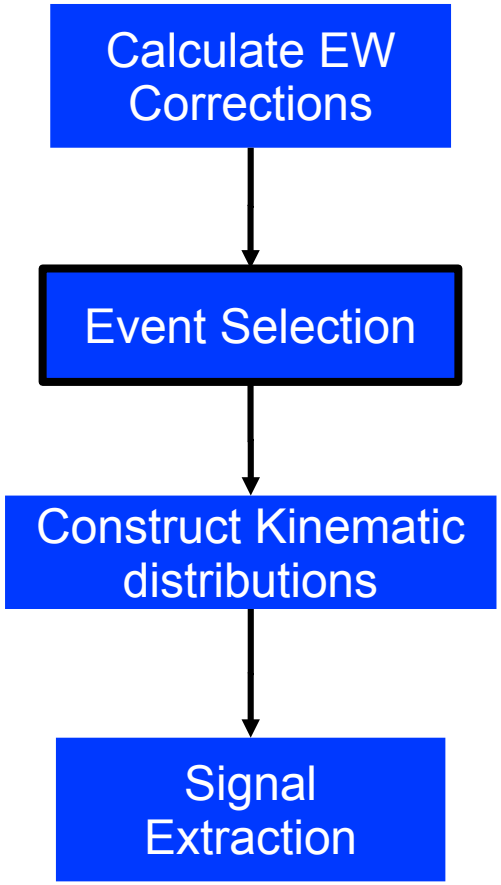

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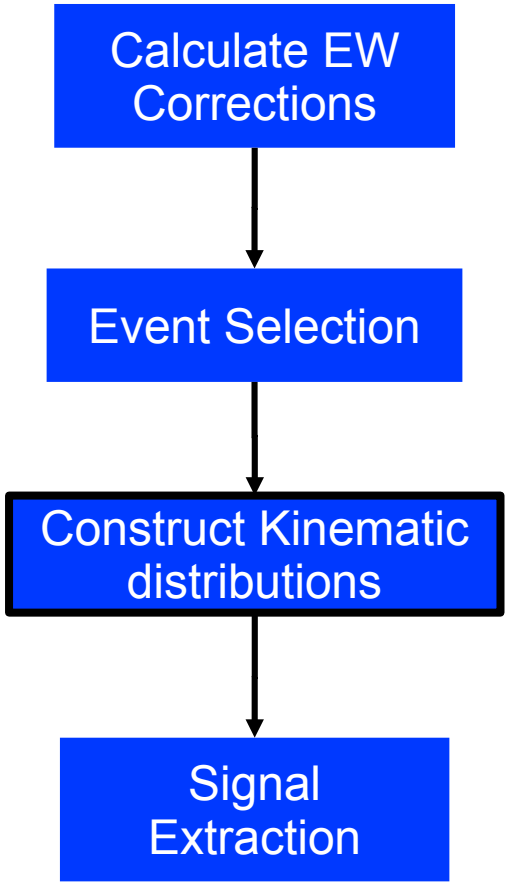

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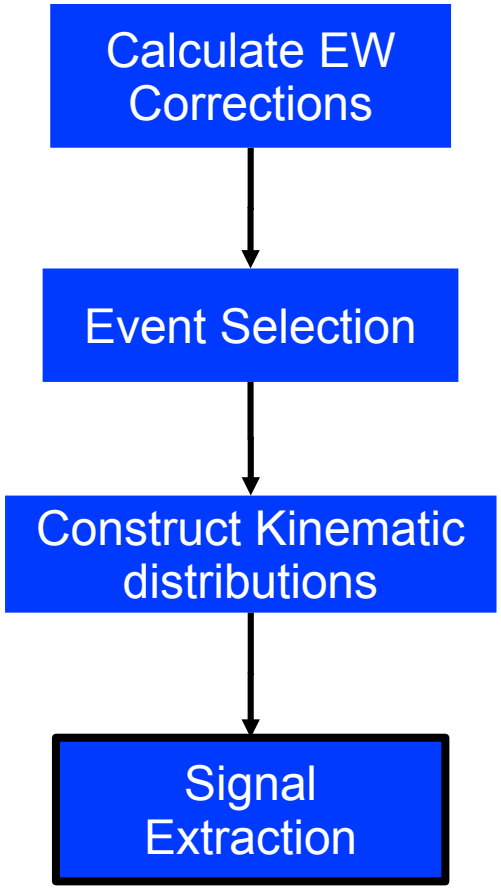

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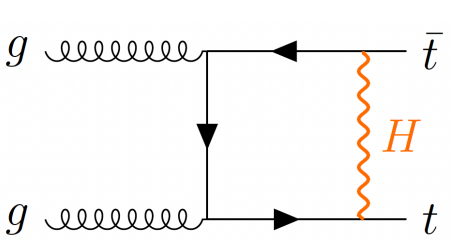
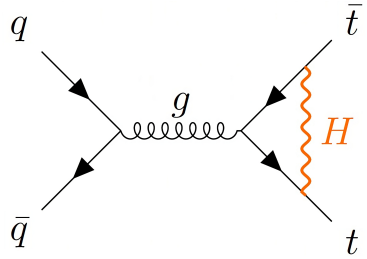
Electro-Weak corrections

At tt production threshold:

→ tt cross-section sensitive to Y_t

- Exchange of virtual Higgs





→EW corrections simulated using Hathor

- Calculated for gg & qq, respectively

→Most Y_t sensitive region is at low M_{tt}

Weak force starts entering the cross-section at loop-induced order, α_{weak}, i.e., Y_t^2 (from Higgs contribution)

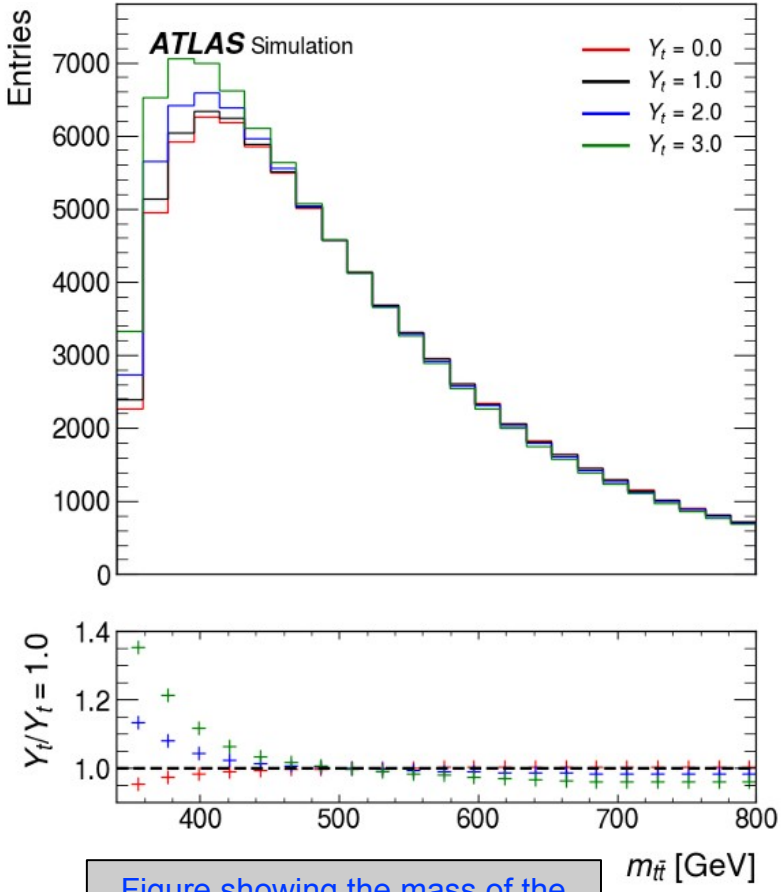


Figure showing the mass of the simulated tt system for different values of Y_t

Electro-Weak corrections

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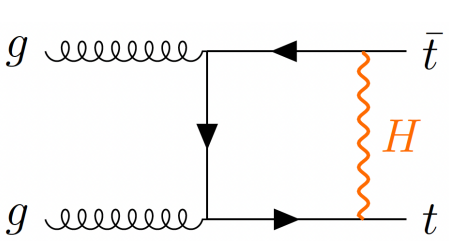

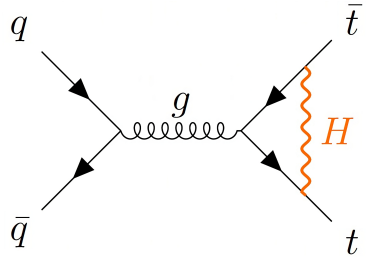

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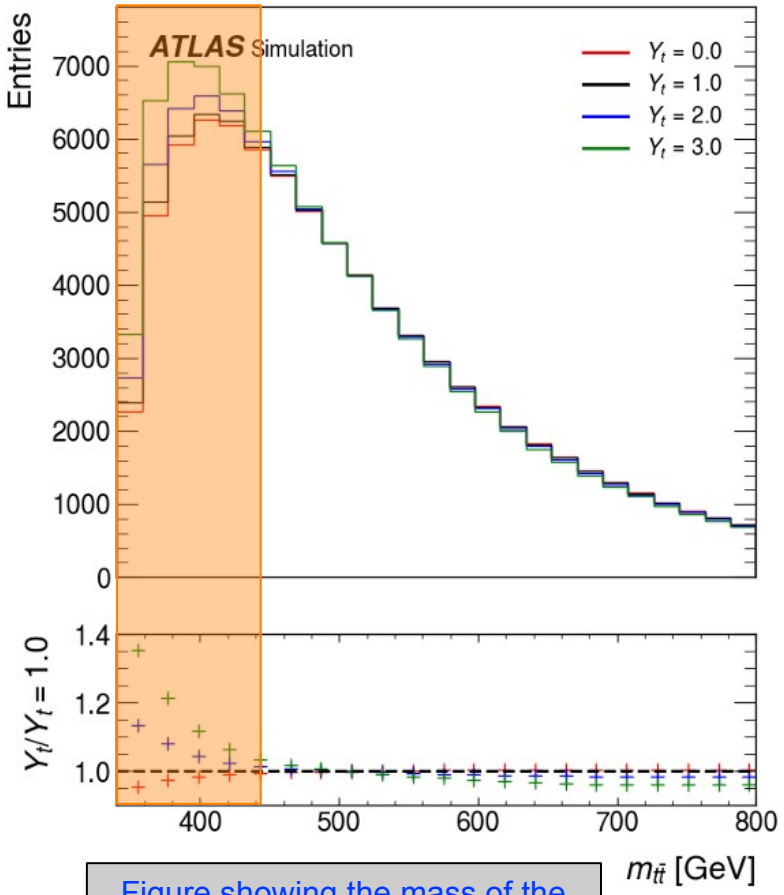

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Event Selection

Leptons:

→Electron: $p_T \geq 25$ GeV

→Muon: $p_T > 25$ GeV

→Exactly 2 leptons (e/μ)

- Regions split into ee, eμ & μμ

OSSF cuts:

→ Z veto: $|m_{ll} - 91| > 10$ GeV

→ $M_{ll} \geq 50$ GeV

→ $E^t_{miss} \geq 30$ GeV

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

→Currently using tt and tW samples

→Moving forward:

- Include more backgrounds (Z+jets)
- Include jet systematics

Jets:

→No. of Jets ≥ 2

- Jet p_T: $p_T \geq 20$GeV

→No. of b-jets = 2 [DL1r]

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}

→At detector level:

- M_{llbb}

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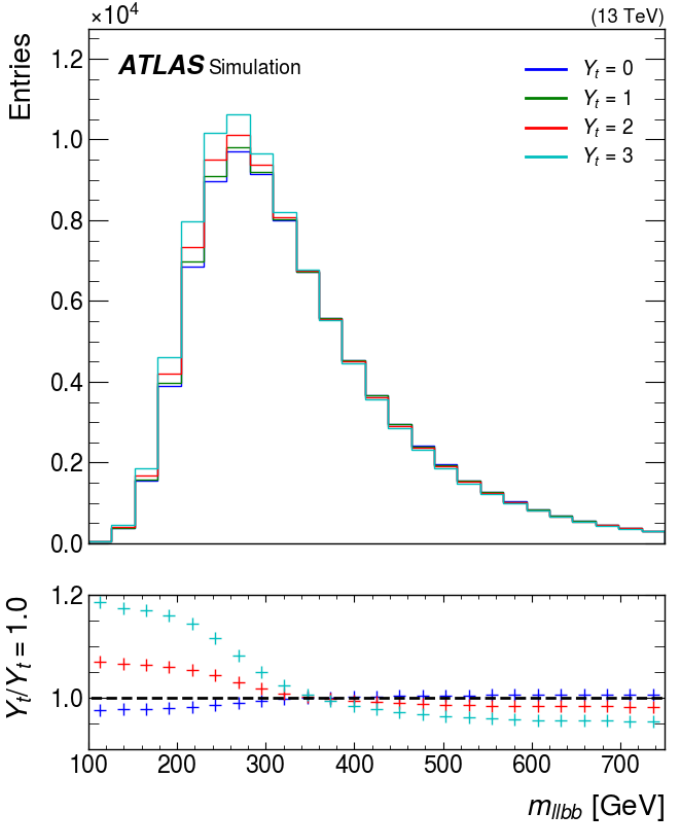

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Are there more sensitive observables?

→Room for improvement using top reconstruction

More on this in James' talk tomorrow

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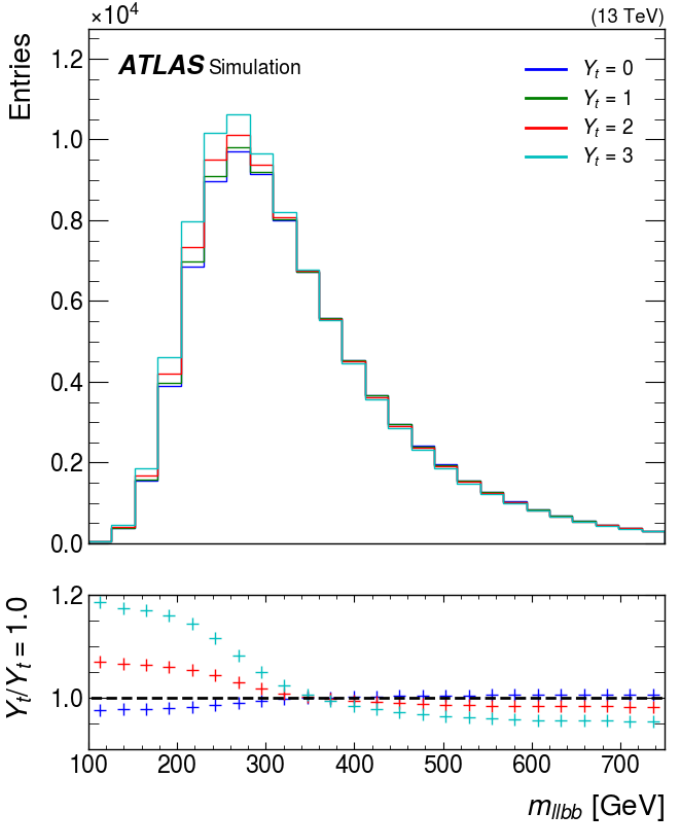

Technical information:

→A binned profile likelihood fit is used

→Extraction implemented using template morphing

- Templates are created using EW corrections for Y_t = 0,1,2 & 3
- Linearly interpolating between templates

Due to linear interpolation we extract Y^2_t

Extracting Y_t

→The full run 2 dataset used [140 fb^{-1}]

→Analysis is fully blinded

→Reduced set of systematics:

- tt & tW normalisations

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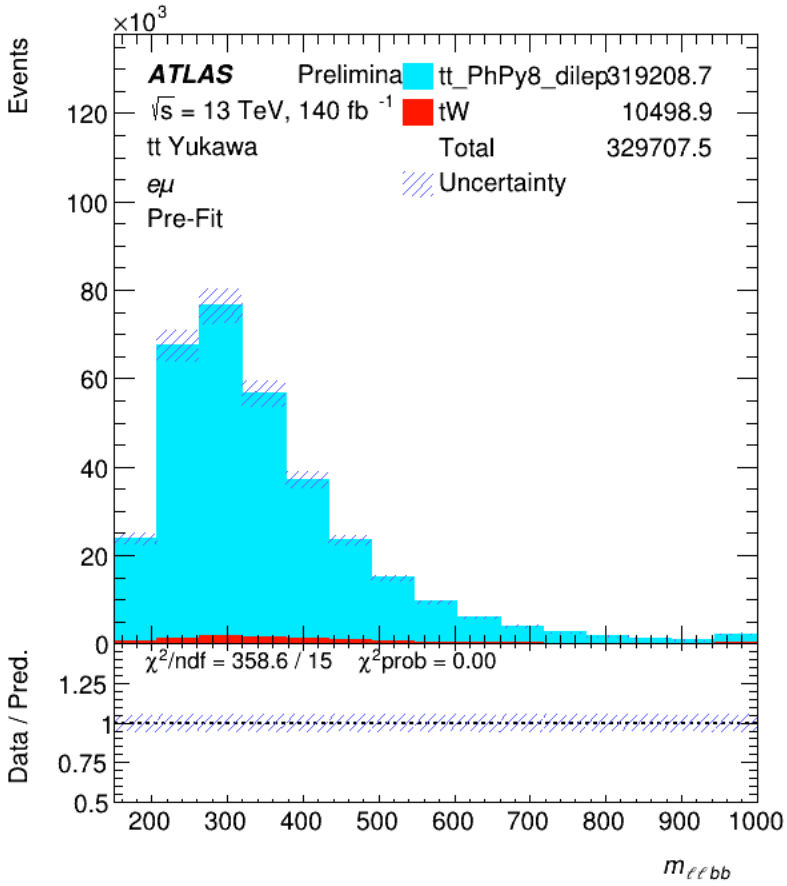
Figure showing the prefit mass of the measured decay products using Asimov data



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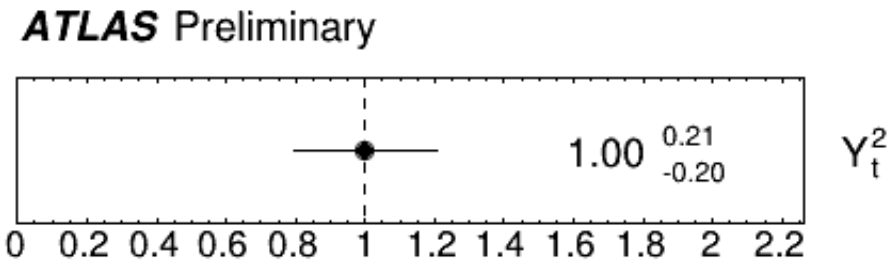
Extracted value:



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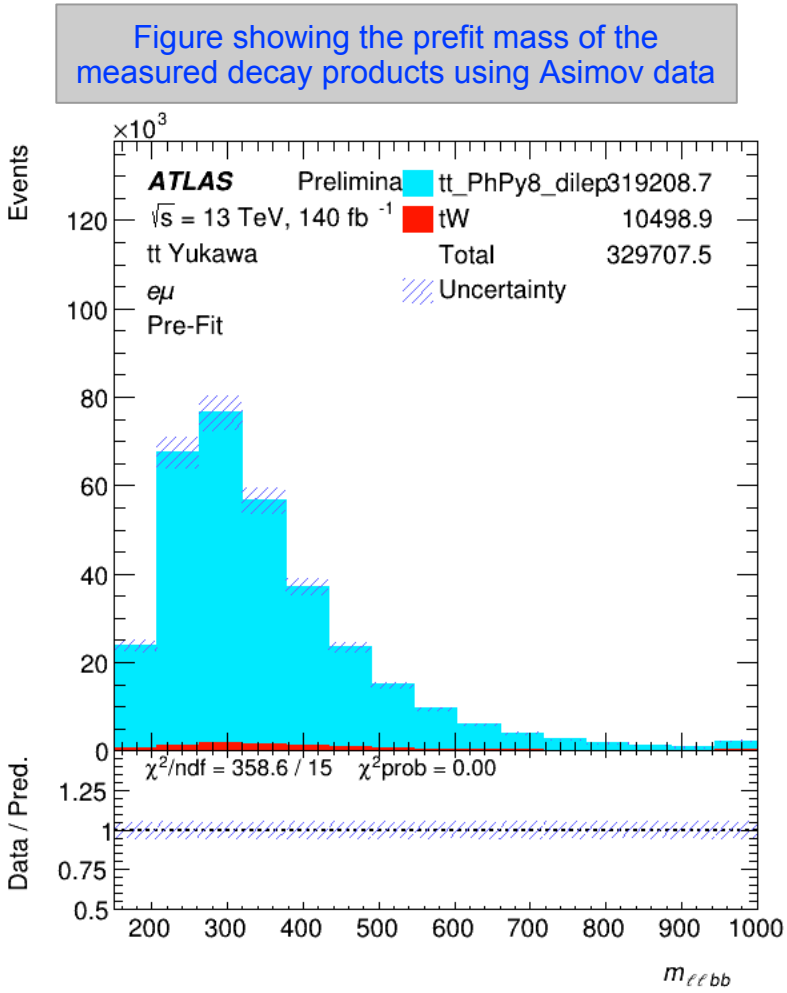


Conclusion

→ Electroweak corrections calculated for tt and applied as event weights

→ Event selection in place to select for dilepton tt

→ Constructed kinematic variables sensitive to Y_t

- Using mass of measured decay products of tt (M_{llbb})
- Potential to implement top reconstruction

→ Extraction implemented using a reduced set of systematics

→ Using Asimov data extracted a best fit value of

- $Y^2_t = 1.00 \pm 0.21$

Thank you for your time

Any Questions?

Backup

Extracting Y_t

→To test the extraction a signal injection test was performed using **custom Asimov data**

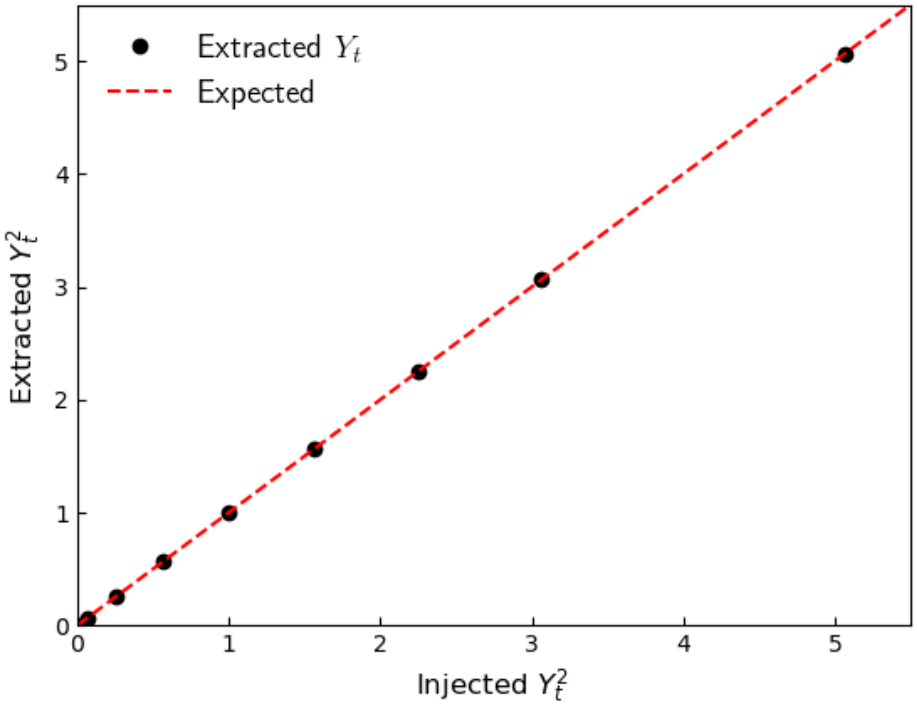
→ Using 36 fb^{-1} data while testing

Strategy

→Create custom Asimov dataset for multiple values of Yt

→Fit simulation & extract best fit value for Y_t

→Should return injected Y_t



Looking Forward

Top quark reconstruction:

→Estimate 4 vector of top quarks

→Increase sensitivity to Y_t

Imaginary part of Y_t:

→Sensitivity at high masses to imaginary part of Y_t

Beyond SM:

→ Y_t expected to be sensitive to BSM theories

→ Interpret results using SM Effective Field Theory

Toponium:

→Theoretical bound state of top quarks

→ Predicted to form in the production threshold region