

Differential cross-section measurement of $t\bar{t}t\bar{t}$

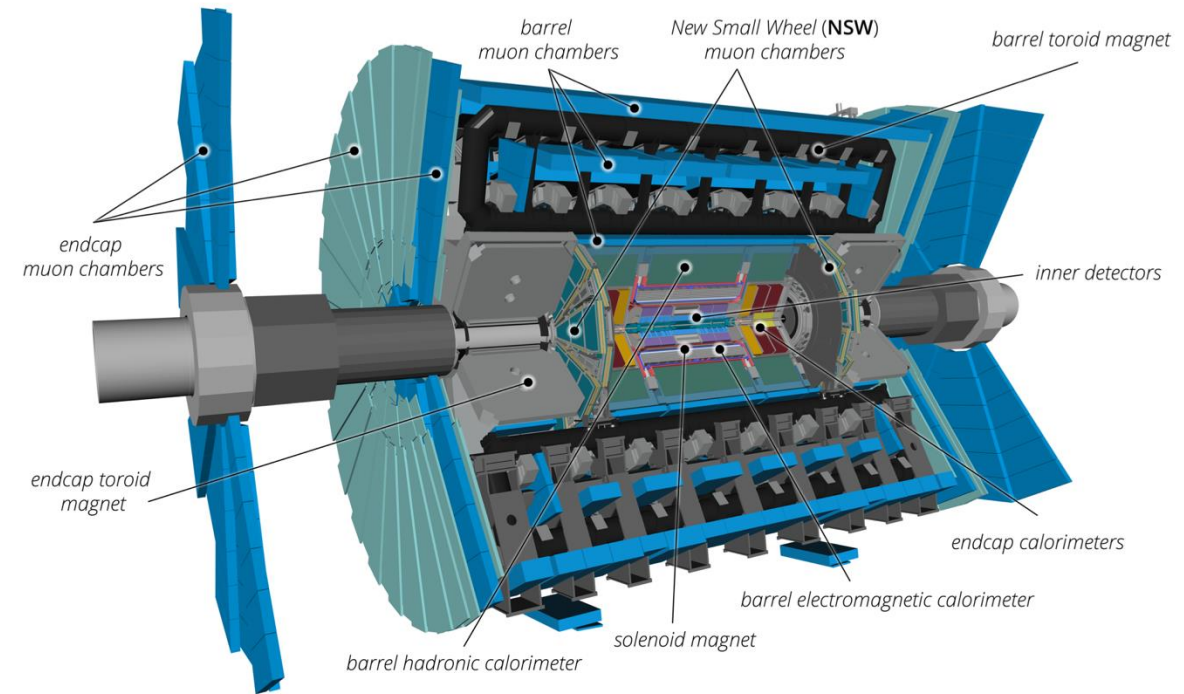
With ATLAS using 2022-2024 data

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IOP APP + HEPP Annual Conference

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$t\bar{t}t\bar{t}$ Process

$t\bar{t}t\bar{t}$ process:

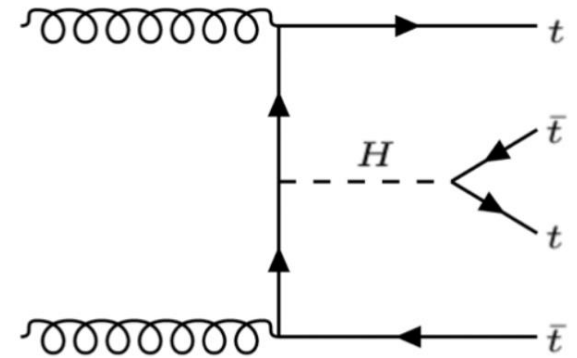
- One of the rarest processes at the LHC
- Observed by ATLAS and CMS in 2023 using data from 2015-2018
- Measured cross-section higher than SM prediction

Motivations:

- Sensitivity to many BSM scenarios
- Linked to the Top Yukawa coupling constant

Goals:

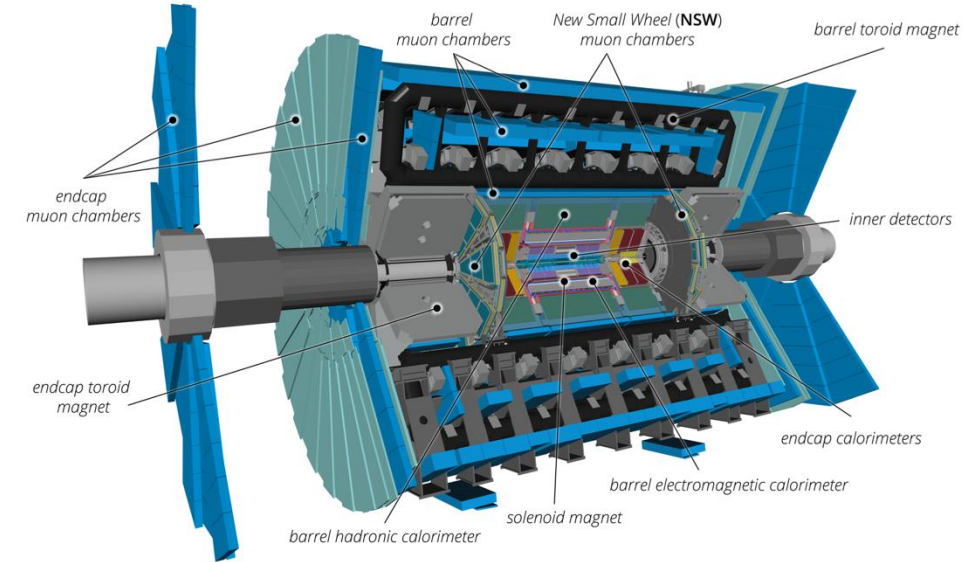
- Measure the $t\bar{t}t\bar{t}$ cross-section in Run 3
- Make a first differential cross-section measurement
- *This talk will focus on the differential cross-section study*



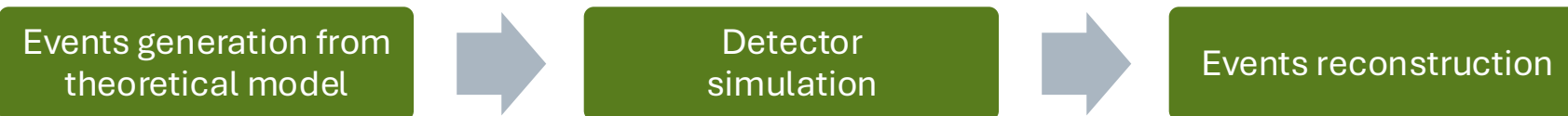
| $t\bar{t}t\bar{t}$ cross-section ($\sqrt{s} = 13\text{TeV}$) | |
|--|-------------------------------------|
| ATLAS measurement | $22.5^{+6.6}_{-5.5}$ fb |
| CMS measurement | $17.7^{+6.0}_{-5.5}$ fb |
| SM prediction (NLO) | 12.0 ± 2.4 fb |

Data

- Using partial Run 3 dataset collected with ATLAS
 - Data collected between 2022 and 2024 = 184 fb^{-1}
 - Comparison with full Run 2 dataset (used for the observation) = 147 fb^{-1}
- Centre-of-mass energy of proton-proton beams = 13.6 TeV
- Data is compared to Monte Carlo simulated events derived from the Standard Model
- This analysis is currently blinded (only using simulated events) to avoid bias

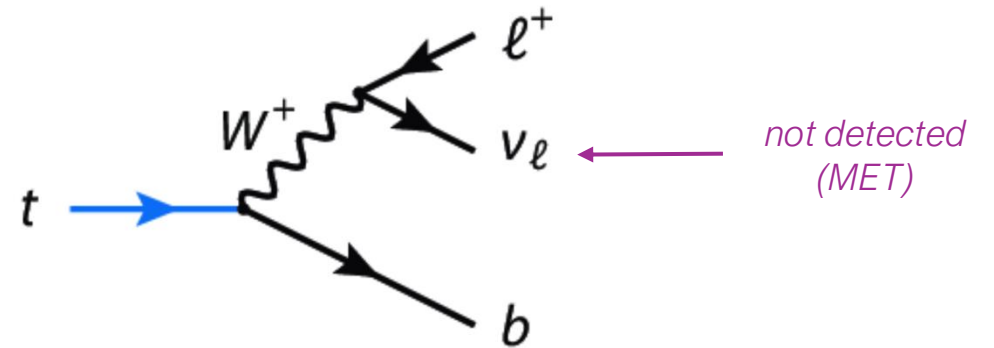
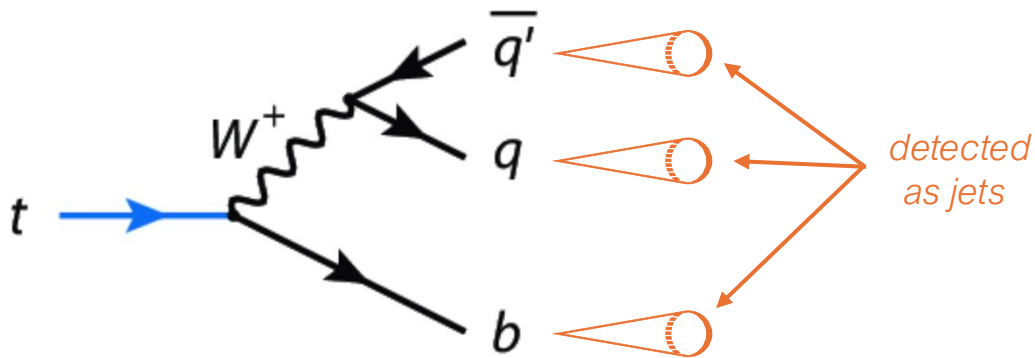


Monte Carlo simulations



Objects

- Top quarks:
 - Top quark decays before reaching the ATLAS detector
 - Top quark decays into a W boson and b quark
 - W boson decays into either a quark-antiquark pair (67%) or a lepton-neutrino pair (33%)
- Final state particles:
 - Leptons
 - **Jets**
 - **Missing transverse energy (MET)**
- Phase space:
 - 2 same-sign leptons or 3 or 4 leptons
 - Reduced background from other sources



Unfolding

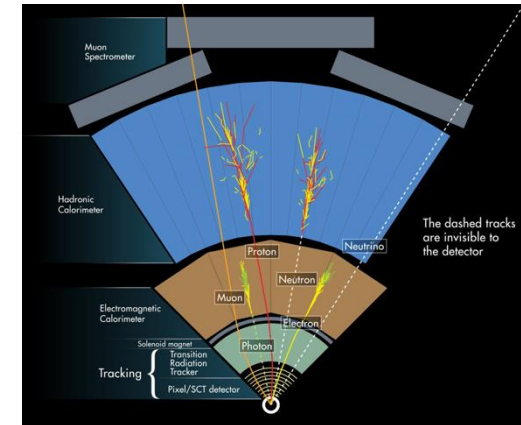
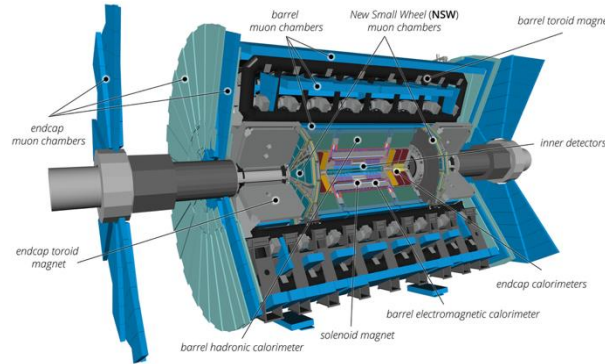
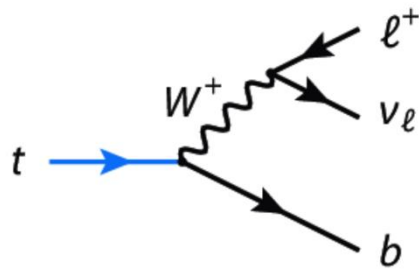
Unfolding

ATLAS
data

Physics collisions

Detector
interaction

Events reconstruction



Monte Carlo
simulation

Events generation from
theoretical model

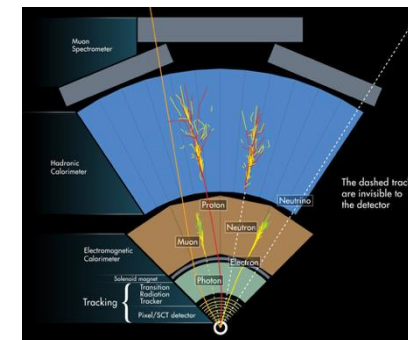
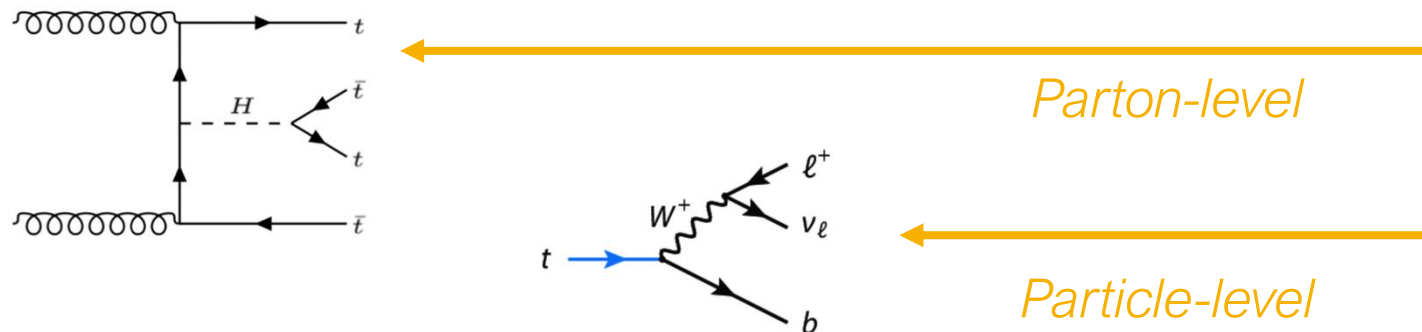
Detector
simulation

Events reconstruction

Unfolding for $t\bar{t}t\bar{t}$

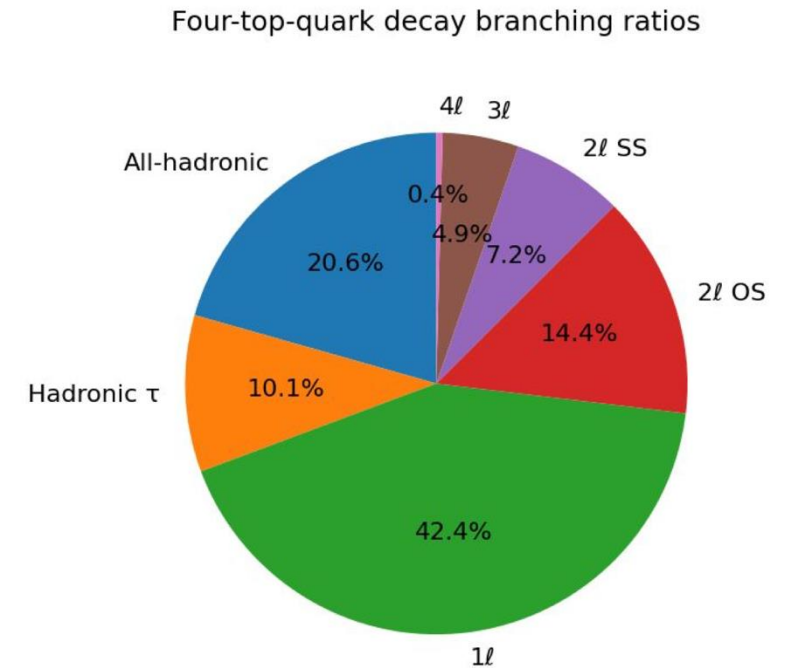


- Unfolding consists of **removing the effects of the detector** on both data and MC simulated events
- Motivations:
 - To compare results with other experiments
 - To test various theoretical models
 - To easily perform reinterpretation of the results
- Two definitions of cross-section investigated
 - Full phase-space parton-level:
 - Measure underlying kinematics of the $t\bar{t}t\bar{t}$ system (eg. $M_{t\bar{t}t\bar{t}}$)
 - Maximise sensitivity to new physics
 - Fiducial phase-space particle-level:
 - Measure kinematics of top quark decay products (eg. Lepton p_T)
 - Minimise model dependence in unfolding



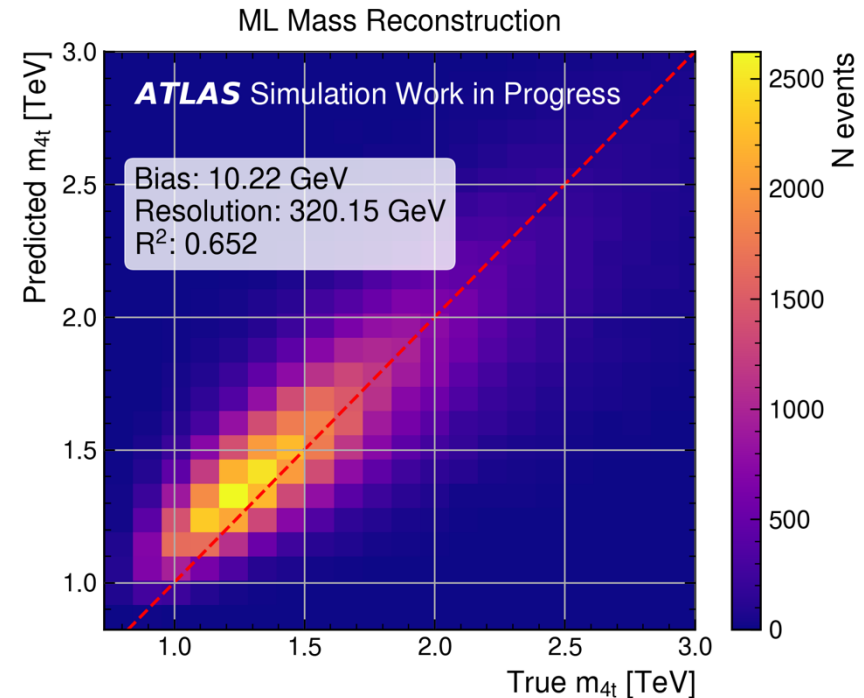
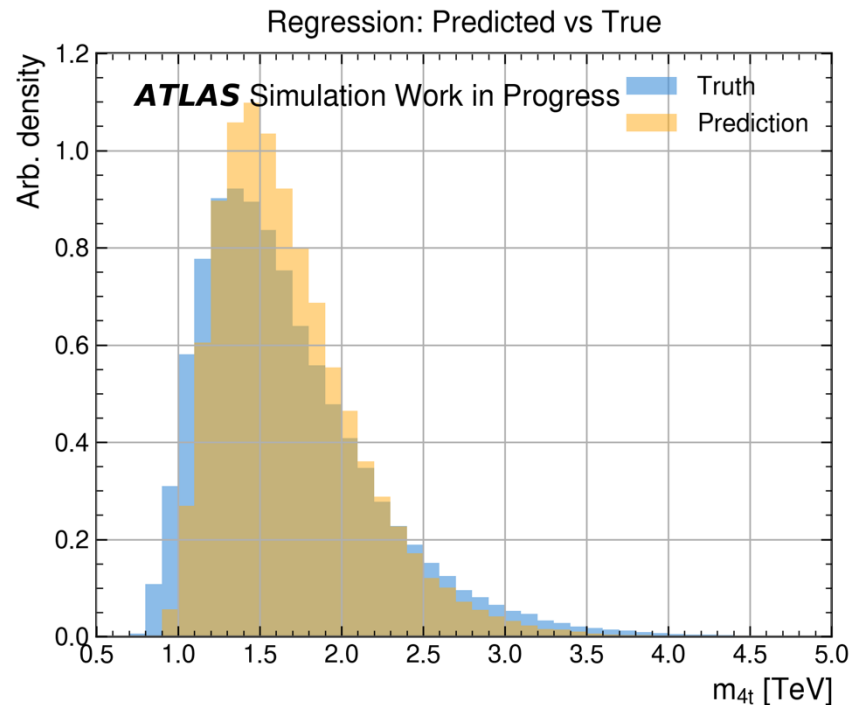
Unfolding for $t\bar{t}t\bar{t}$

- Signal regions are defined as regions of the phase-space that are enriched in $t\bar{t}t\bar{t}$ events
- Event selection:
 - 2 same-sign leptons or 3 leptons or 4 leptons
 - Min 6 jets
 - Min 4 b-jets
 - Min 500 GeV of scalar sum of transverse momenta
- Main backgrounds:
 - $t\bar{t}W$
 - $t\bar{t}Z$
 - $t\bar{t}H$
- Limited statistics likely allow for ~ 3 bins per variable
- Method: Profile Likelihood Unfolding (with [TREx Fitter](#))
- The fit extracts the cross-section in each bin



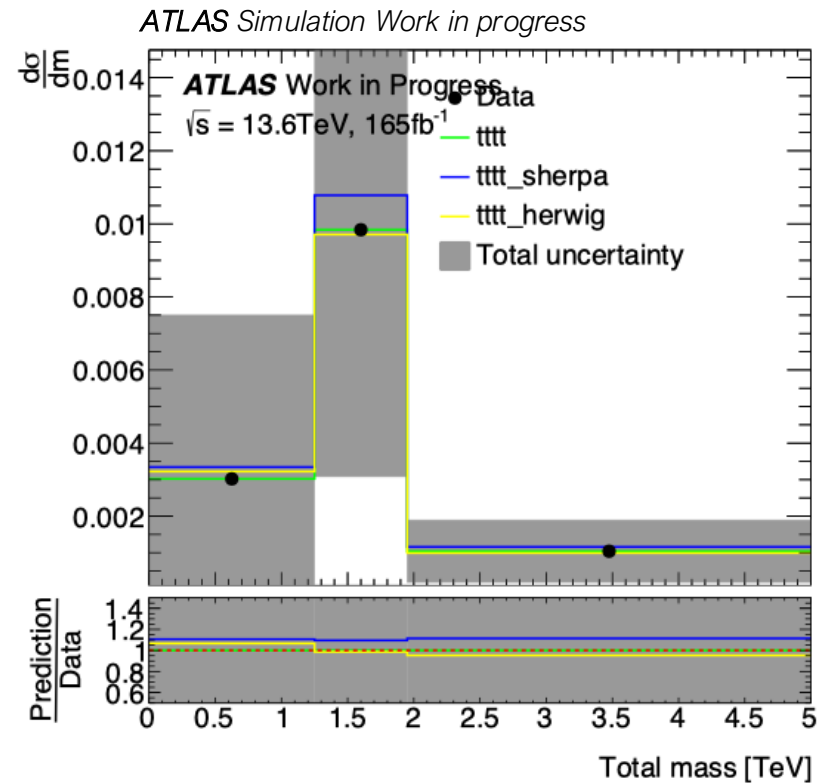
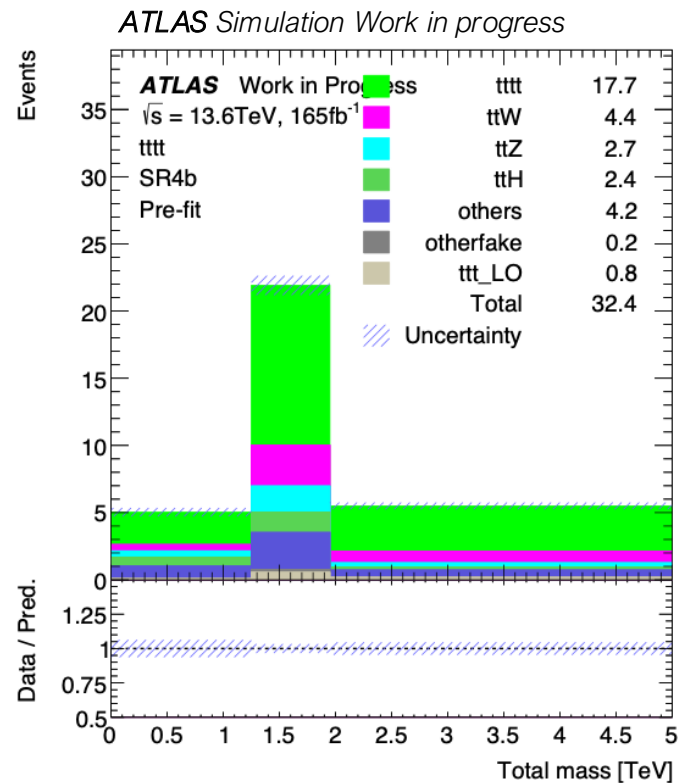
Machine Learning

- Use a [Deep Sets](#) ML method to estimate the true invariant mass of the $t\bar{t}t\bar{t}$
- Input variables:
 - Lepton: pT , η , ϕ , E
 - Jet: pT , η , ϕ , E & b-tag information
 - Event level: HT , MET & object multiplicities



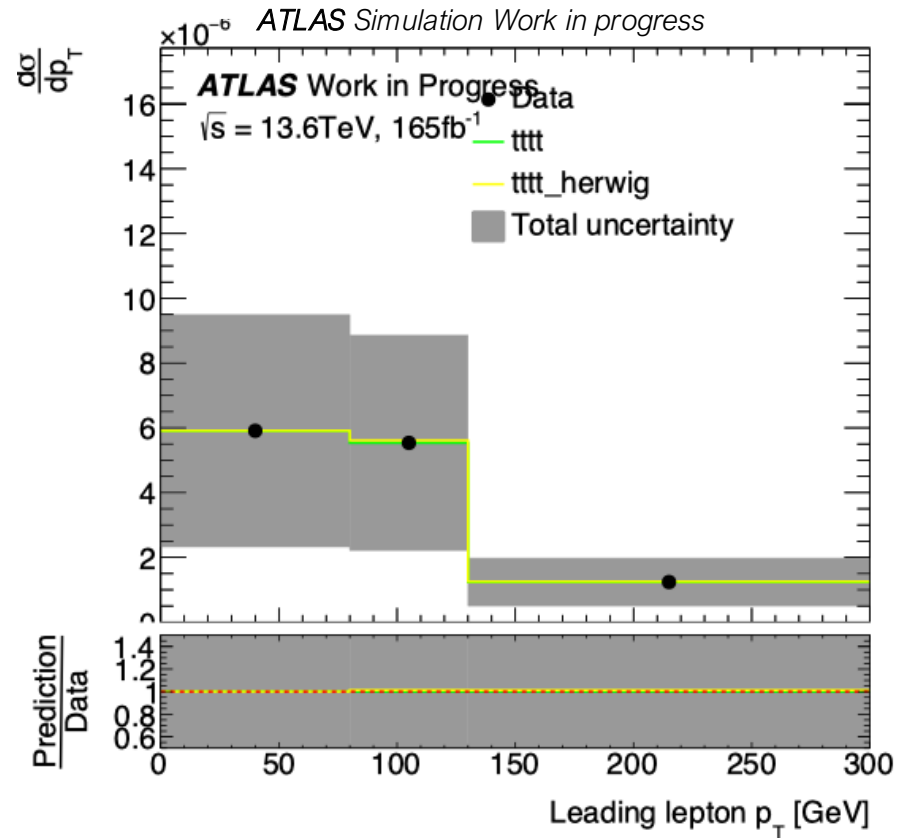
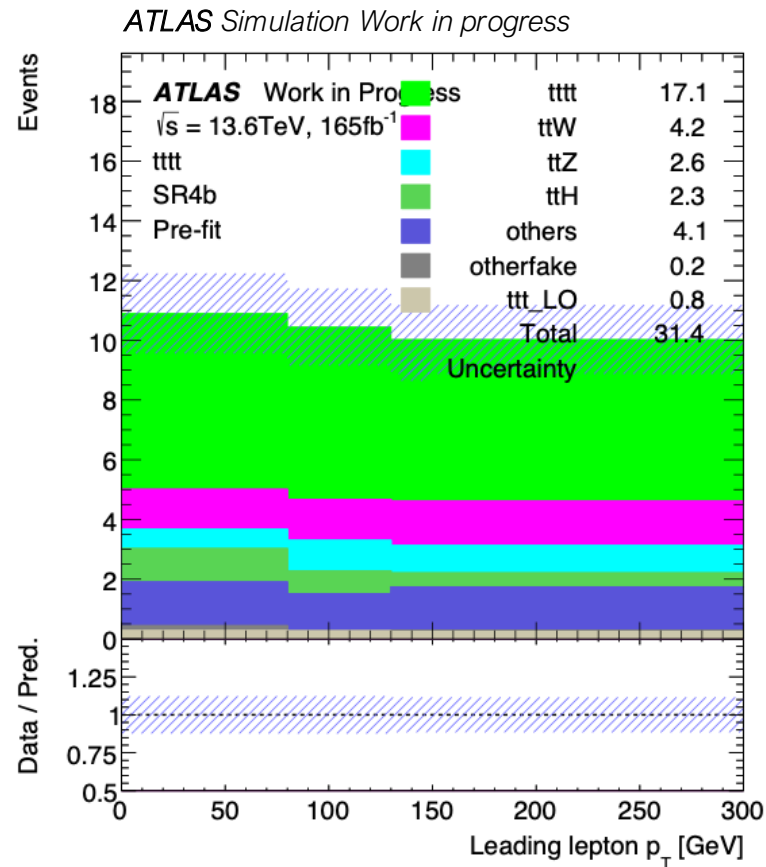
Unfolding at parton-level

- Using the $t\bar{t}t\bar{t}$ invariant mass to unfold
- In this signal region, $\sim 50\%$ of signal ($t\bar{t}t\bar{t}$) events
- No systematics for now



Unfolding at particle-level

- Using the leading lepton p_T to unfold
- With most systematics



Conclusion

- $t\bar{t}t\bar{t}$ is one of the rarest processes at the LHC
- $t\bar{t}t\bar{t}$ observed by ATLAS and CMS in Run 2, with a cross-section slightly higher than the Standard Model prediction
- Aiming to measure the $t\bar{t}t\bar{t}$ cross-section in Run 3 and do a first differential cross-section measurement
- Using Profile Likelihood method to unfold at parton- and particle-levels
- Using ML to estimate the true $t\bar{t}t\bar{t}$ invariant mass
- Various tests ongoing to verify the unfolded fit is not biased

BACKUPS

Profile Likelihood Unfolding

This method maximises the likelihood getting the observed number of events, in each bin, given the signal strength, the nuisance parameters and background normalisation factors.

$$L(\vec{n}|\vec{\mu}, \vec{\theta}, \vec{k}) = \prod_r^R \prod_i^N \text{Pois}(n_{i,r} | \nu_{i,r}(\vec{\mu}, \vec{\theta}, \vec{k})) \times \prod_j^{\text{NPs}} \text{Gaus}(\theta_j).$$

To make the numerical method easier, the fit finds the minimum of the negative logarithmic likelihood.

For more information on profile likelihood:

[Asymptotic formulae for likelihood-based tests of new physics](#)

Machine Learning – Deep Sets

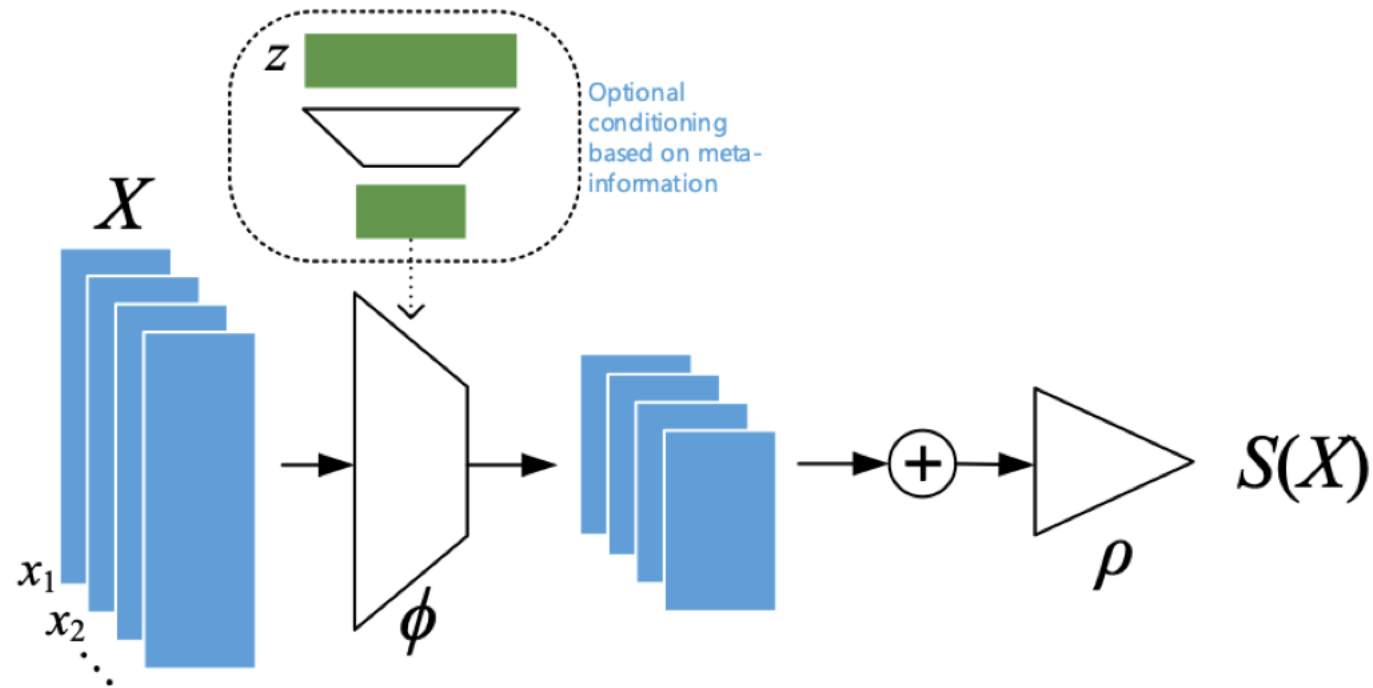


Image: Deep Sets architecture [4]