Differential ttZ cross section measurements with ATLAS

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Outline

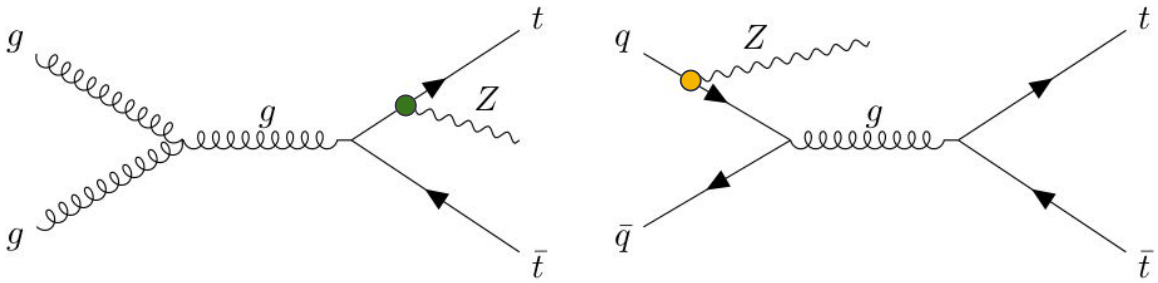
- **Introduction:**
  → associated production of a top quark pair and a Z boson.
- **Selections:**
  → final states of the ttZ system.
- **First differential ttZ measurements:**
  → iterative Bayesian unfolding,
  → results.
- **Refining the ttZ measurements:**
  → profile likelihood unfolding,
  → work-in-progress results.

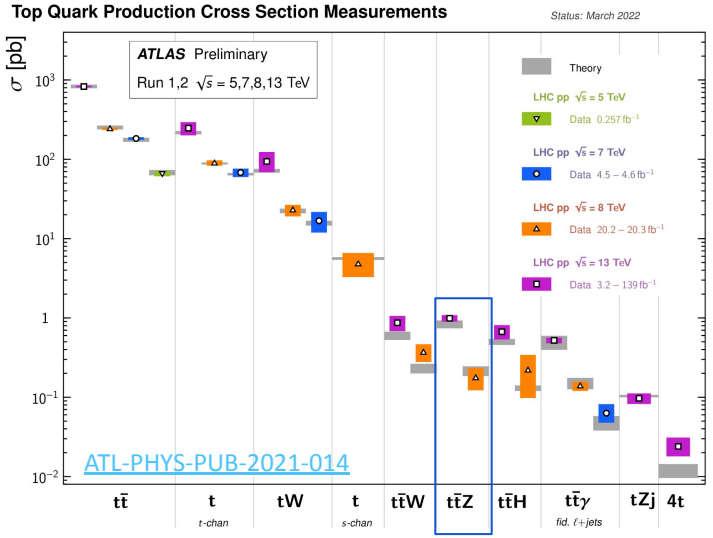
Top quarks + Z boson

The top-quark couplings play an important role in the Standard Model.

Top-quark pair + Z boson:

- A **rare SM process**.
- A direct probe of the **top-quark coupling to the Z boson**.
- An **irreducible background** in searches and measurements with multi-lepton final states, e.g. ttH.

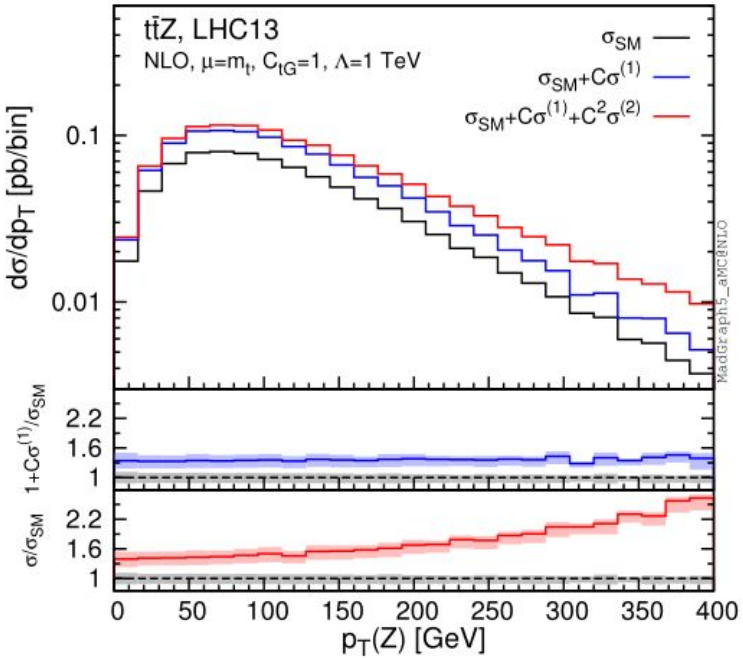




Motivation of differential measurements

New physics effects from Beyond the Standard Model theories are expected at a higher energy scale.

Bylund, O.B., Maltoni, F., Tsinikos, I. et al



Signatures of ttZ

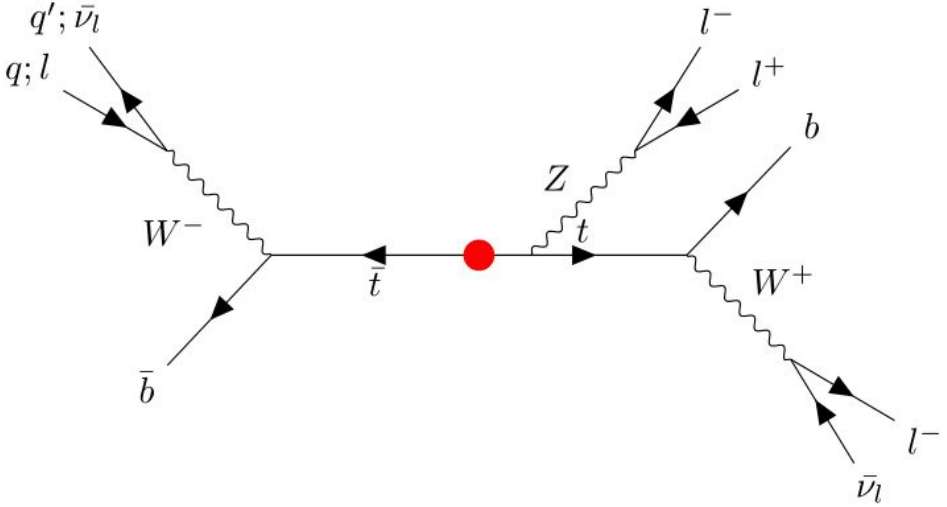
Final states with three (3ℓ) or four (4ℓ) isolated leptons (e or μ) are most sensitive.

3ℓ channel:

- 3 isolated leptons,
- jets and b-jets.

4ℓ channel:

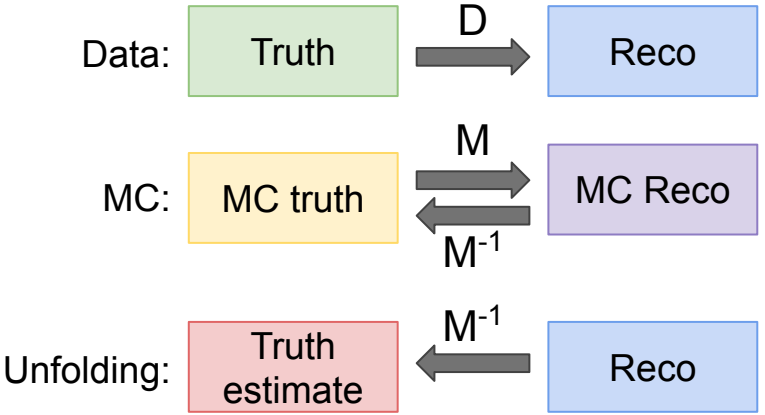
- 4 isolated leptons,
- jets and b-jets,
- MET.



Iterative Bayesian Unfolding

The unfolding problem is solved using the Improved Iterative Bayesian Unfolding by G. D'Agostini.

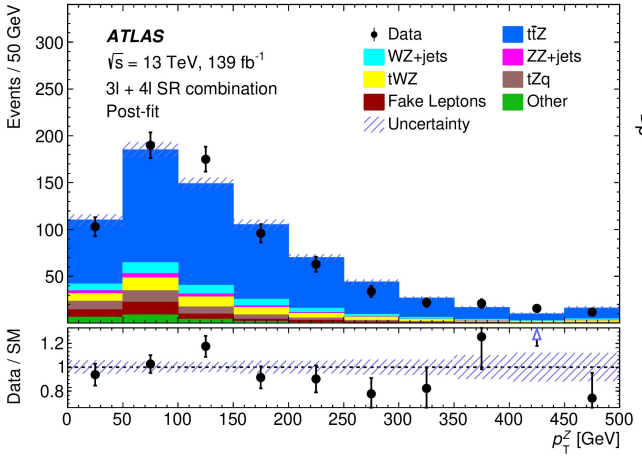
- M := P($x \in$ *Bin i* | $y \in$ *Bin j*).
- **Matrix inversion is avoided.**
- Stop after N iterations:
  → **χ^2 between the prior and posterior is small enough.**



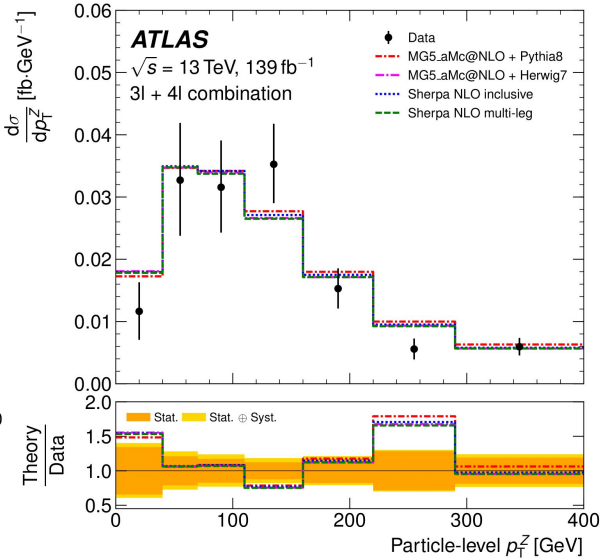
$$\hat{\mu}_j = \frac{1}{f^j_{acc}} \cdot \sum_{i}^{bins} \widetilde{M}_{i,j} \cdot \epsilon^i_{eff} \cdot (N^i_{obs} - N^i_{bkg})$$

IBU Result: Eur. Phys. J. C 81 (2021) 737

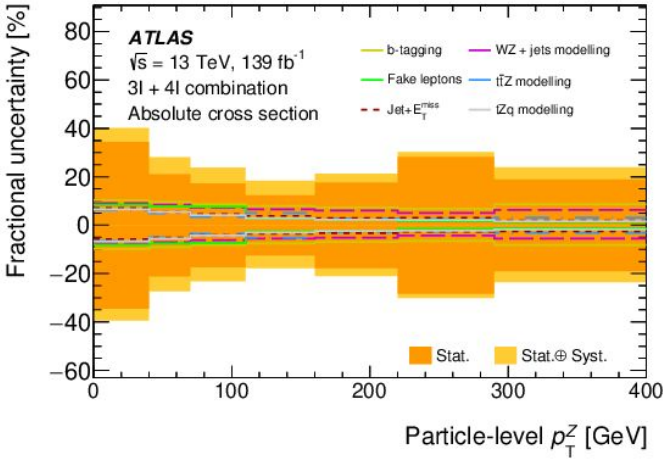
Combine 3L and 4L regions into one:



Unfolded pT(Z) distribution:



Breakdown of uncertainties:



Dominant sources of uncertainty:

1. **Statistical uncertainty,**
2. **Signal modelling,**
3. **Jet flavour-tagging.**

Refine the measurements

The profile likelihood unfolding aims to improve three main areas of the ttZ differential measurements with IBU.

- The previous ttZ analysis was **dominated by the statistical uncertainty**:
  - Straightforward to use multiple signal regions.
- Combination of the **two channels**, 3L and 4L:
  - Fully exploit the different purities of the two channels.
- Our **signal is not pure**:
  - Direct use of control regions.

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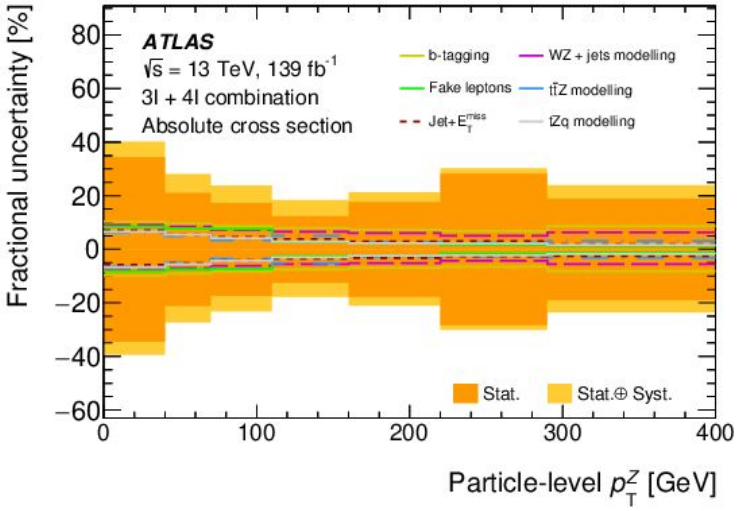
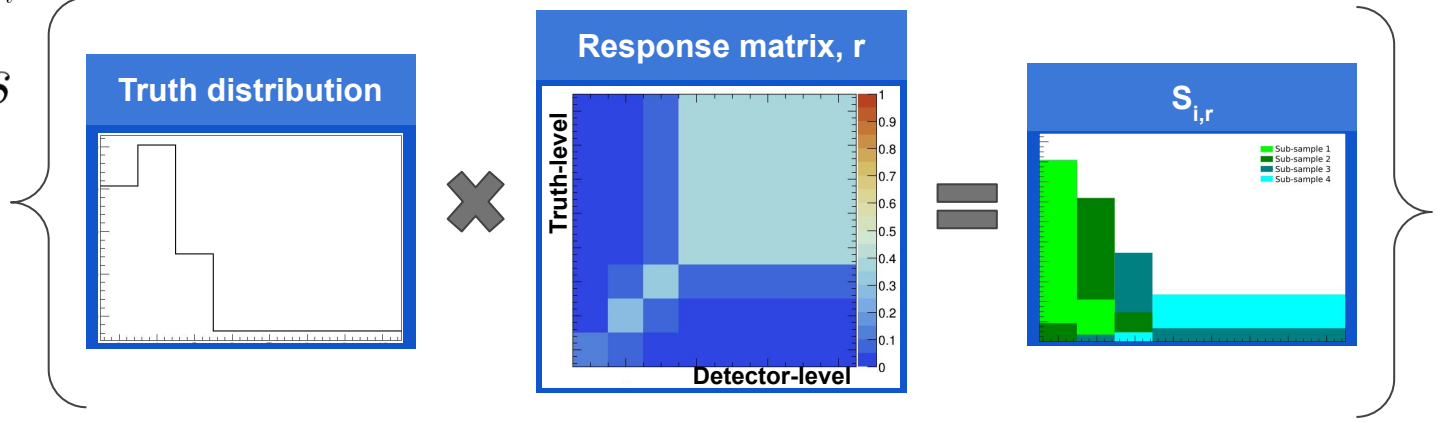


Profile Likelihood Unfolding

The unfolding problem is transformed into a maximum likelihood fit.

$$\mathcal{L}\left(\vec{n}|\mu,\vec{\theta},\vec{k}\right) = \prod_{r}^{regions}\prod_{i}^{bins}\mathcal{P}\left(n_{i,r}|\vec{\mu}\cdot\vec{S}_{i,r}\left(\vec{\theta}\right)+B_{i,r}\left(\vec{\theta},\vec{k}\right)\right)$$

$$\prod_{r}^{regions}$$



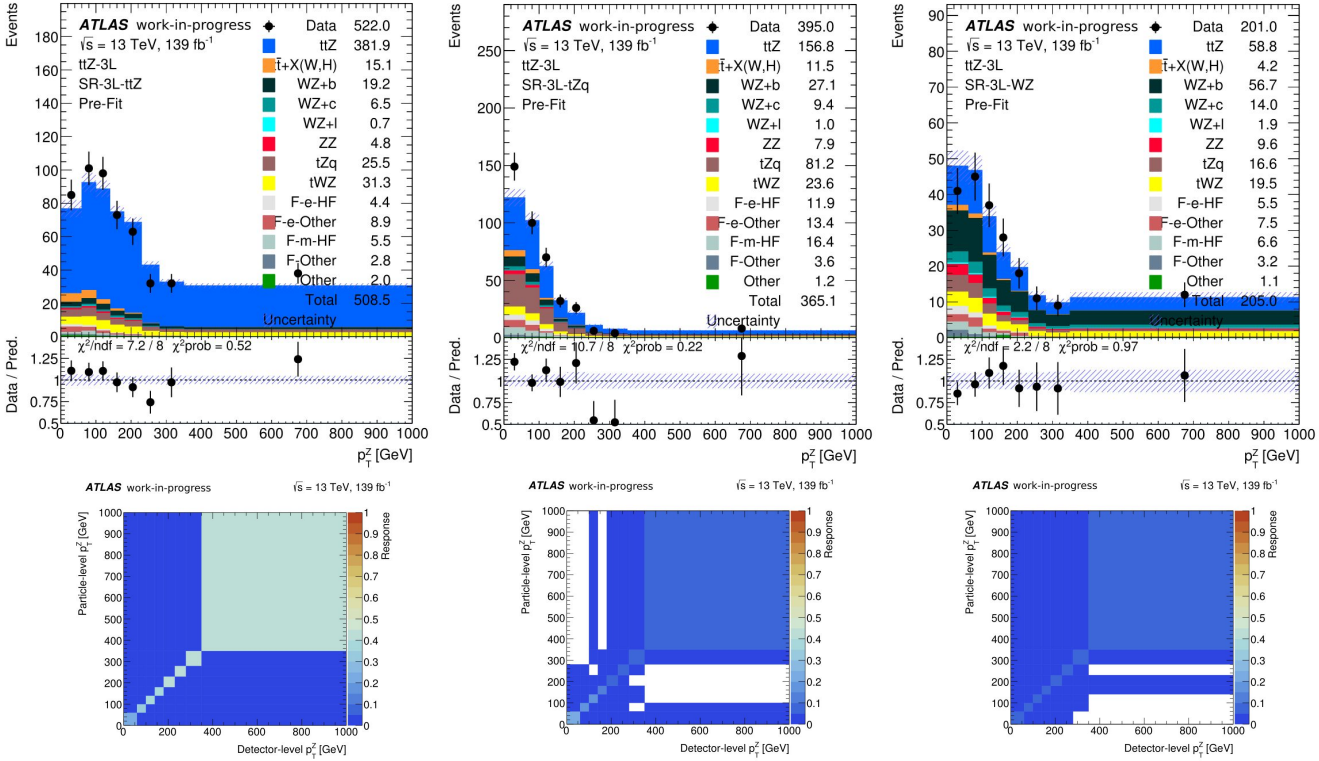
- **Fold the truth-level distribution bin-by-bin via a response matrix**:
  → one "sub-sample" for each truth bin, $S_{i,r}$ → **one Parameter of Interest, POI, per truth bin**.
- **Add background reco distributions**.
- **Fit the sum of the folded distributions**:
  → normalisation of each POI.

$$\mathrm{POI}(\text{truth-bin } i) = \frac{\sigma^{t\bar{t}Z}}{\sigma^{t\bar{t}Z}_{\mathrm{SM},i}}$$

Signal regions

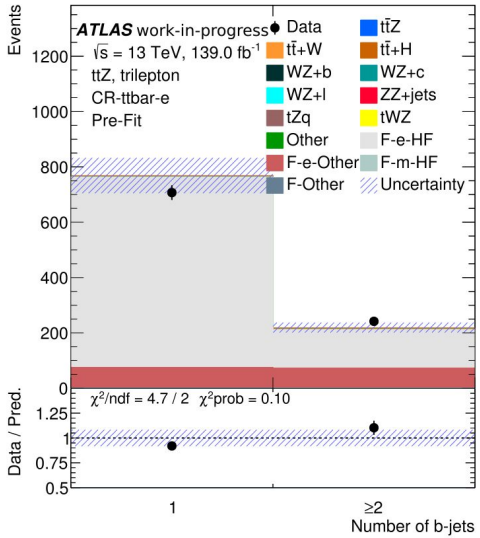
Signal regions are defined using Deep Neural Network cuts

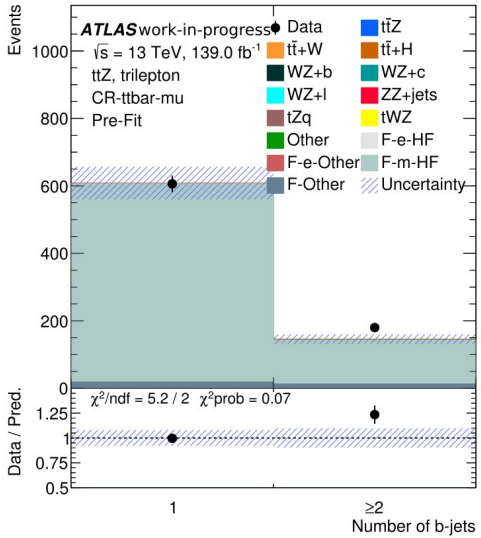
→ Improved acceptance.

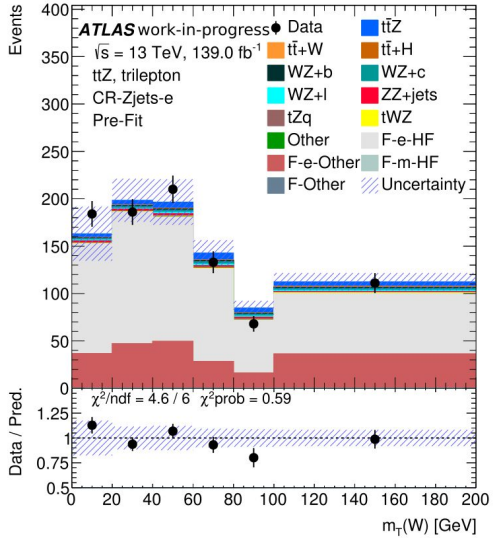


Control regions

Significant contribution of fake leptons in the signal regions:
→ Estimate using the semi-data-driven Fake Factor method.



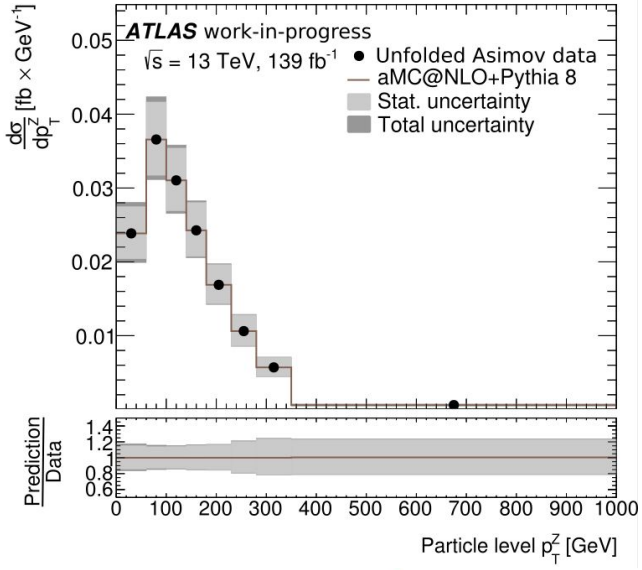


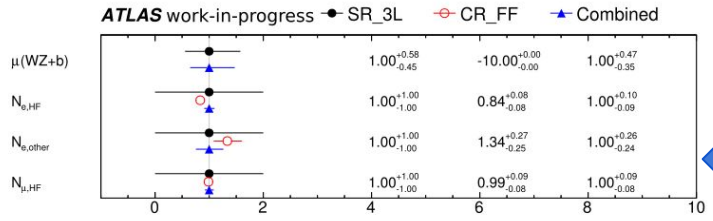


$N_{e,HF}$ $N_{e,other}$ $N_{\mu,HF}$

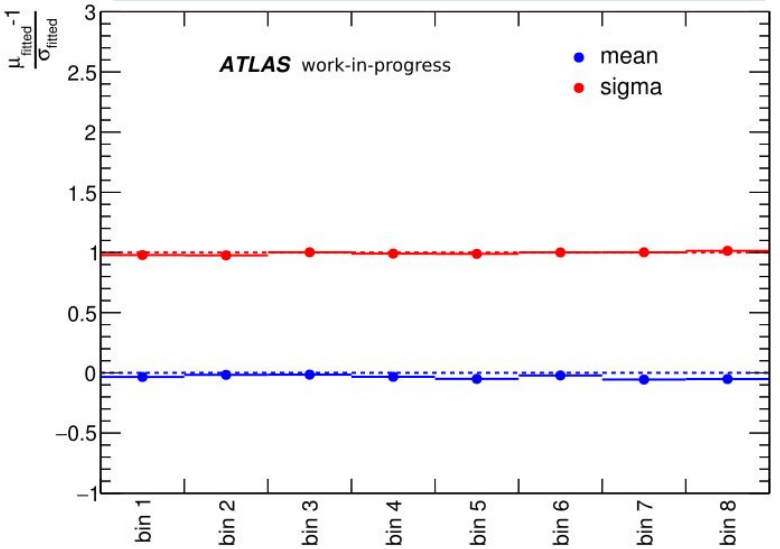
PLU results

The unfolding method passes validation tests and shows promising results.





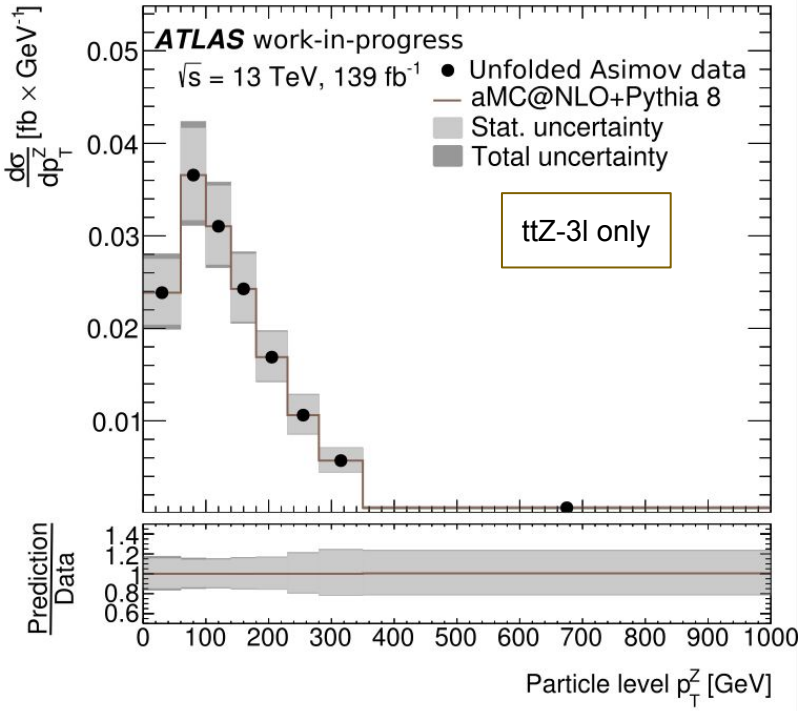
5,000 pseudo-experiments.



Combine an **unblinded** **Fake Factor fit** with **blinded** **unfolding fit**.

Comparison of measurements

Reasonable improvements are expected in the refined measurements.



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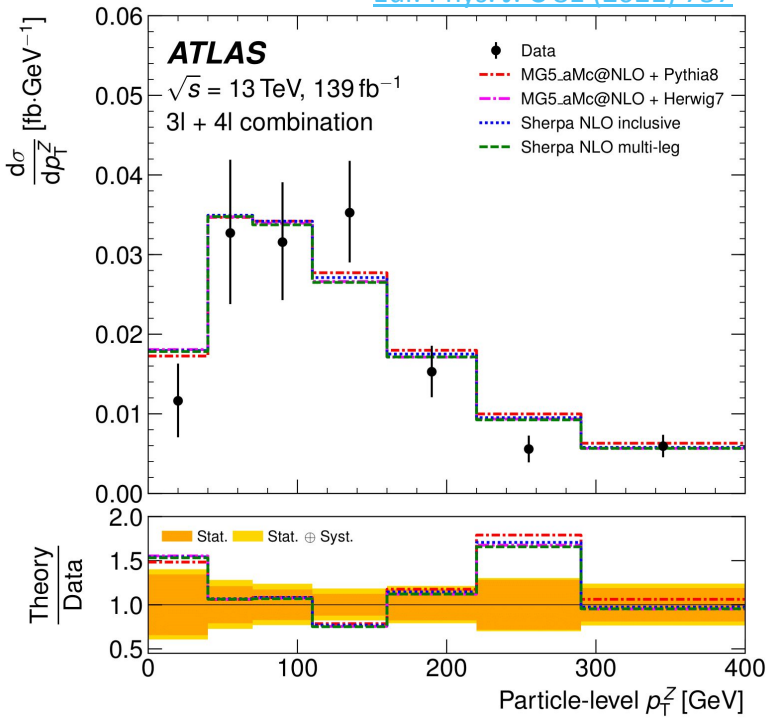
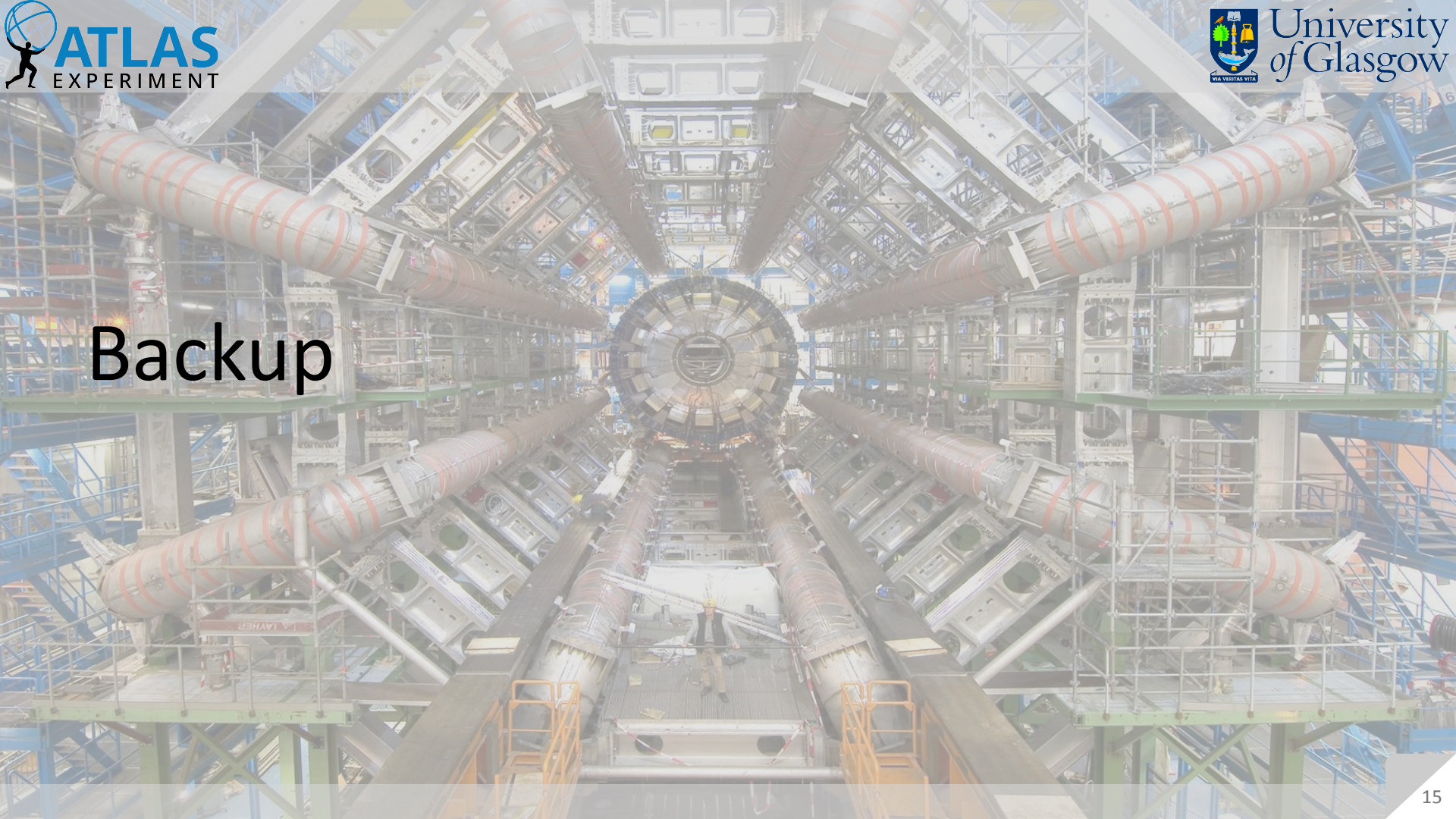


Summary

Refined measurements of the differential ttZ cross sections with ATLAS are underway → improvements are expected.

- **Reduced statistical uncertainty**:
  - DNN cuts improve the event selection,
  - Profile likelihood unfolding allows multiple signal regions.
- **Control regions are directly included**:
  - Fake lepton backgrounds are estimated using a semi-data-driven method,
  - WZ+b background is estimated from data.
- **Straightforward combination of the 3L and 4L channels**:
  - Fully exploit the different purities of the two channels.



Backup