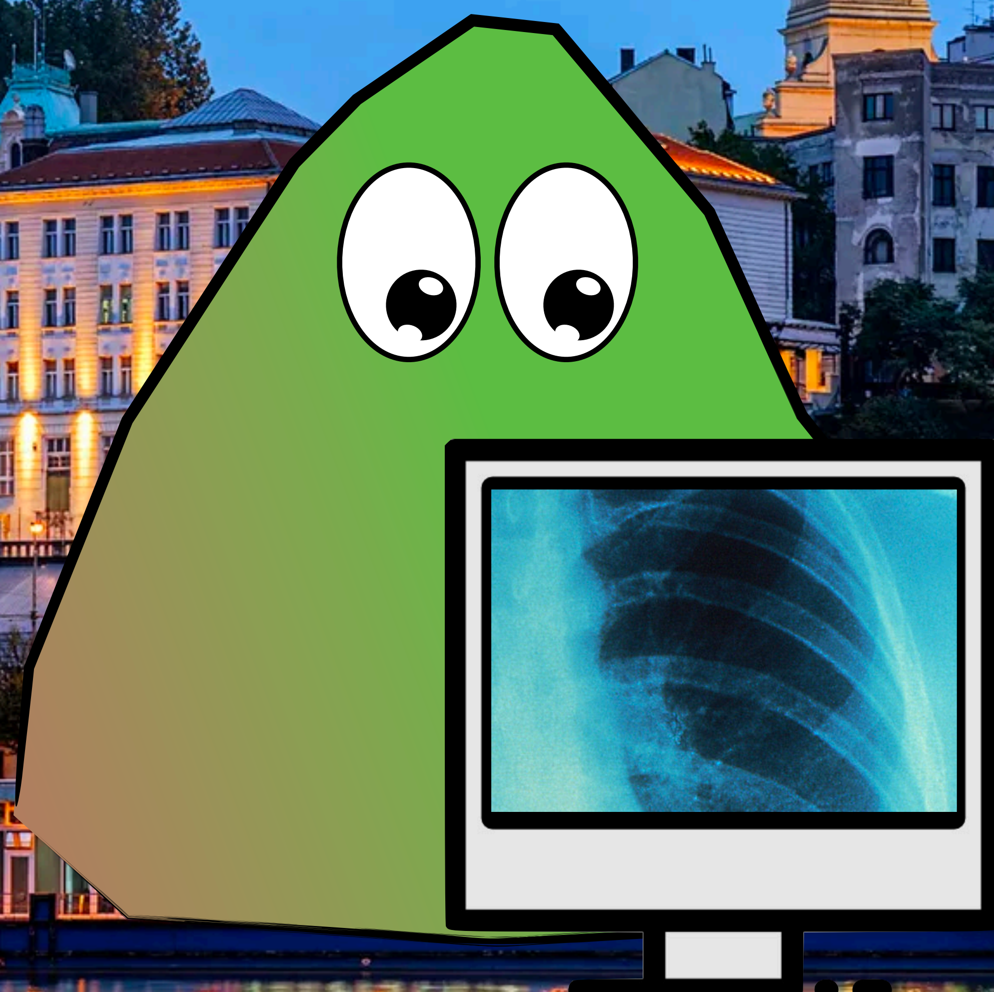
Measurements of top quark mass and properties in **ATLAS**



11th Large Hadron Collider Physics Conference, Belgrade

Jay Howarth

What is it we want to know?

- **Ideally, we want to know the quantum numbers of the quarks:**
  - ➡ **mass**
  - ➡ **spin**
  - ➡ **charge**

- **Properties of QCD** (particularly quark confinement) **makes it nearly impossible to access these directly for most quarks….**

Top Quarks

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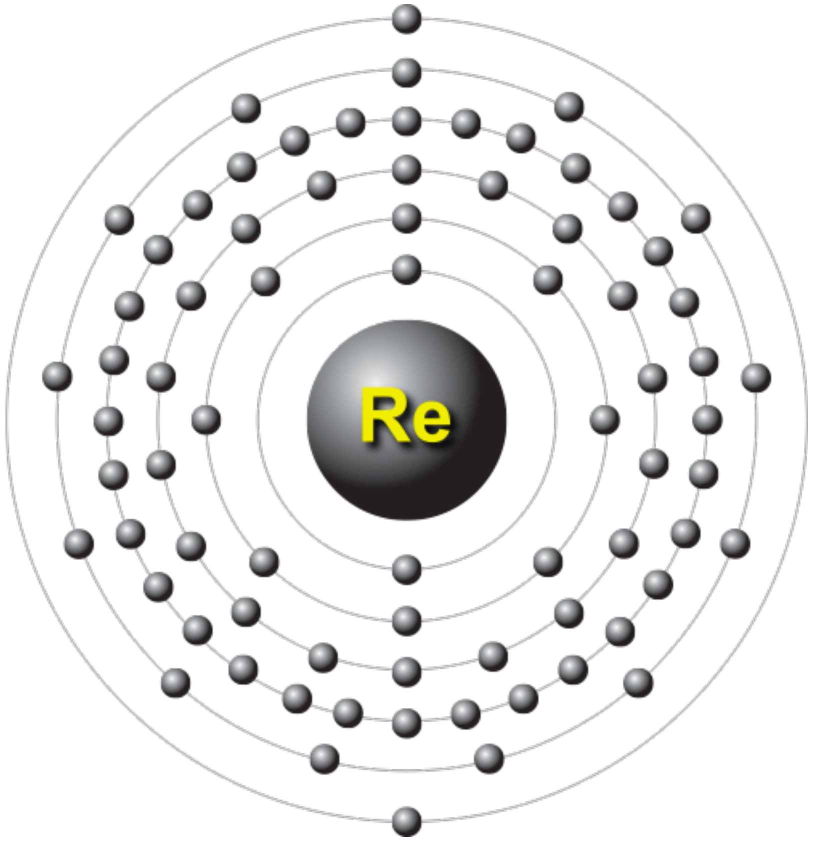
- The top quark has a special and totally unique property: it is VERY heavy!
- It has a mass of 172.5 GeV, many orders of magnitude heavier than the other quarks!
- Closest in mass to an entire Rhenium nucleus.



Top Quarks

- This phenomenally high mass leads to some unique properties:

Production		Lifetime		Hadronisation		Spin decorr.
$\frac{1}{m(t)}$	$<<$	$\frac{1}{\Gamma(t)}$	$<<$	$\frac{1}{\Lambda_{QCD}}$	$<<$	$\frac{m(t)}{\Lambda_{QCD}}$
$\sim 10^{-27}$ s		$\sim 10^{-25}$ s		$\sim 10^{-24}$ s		$\sim 10^{-22}$ s

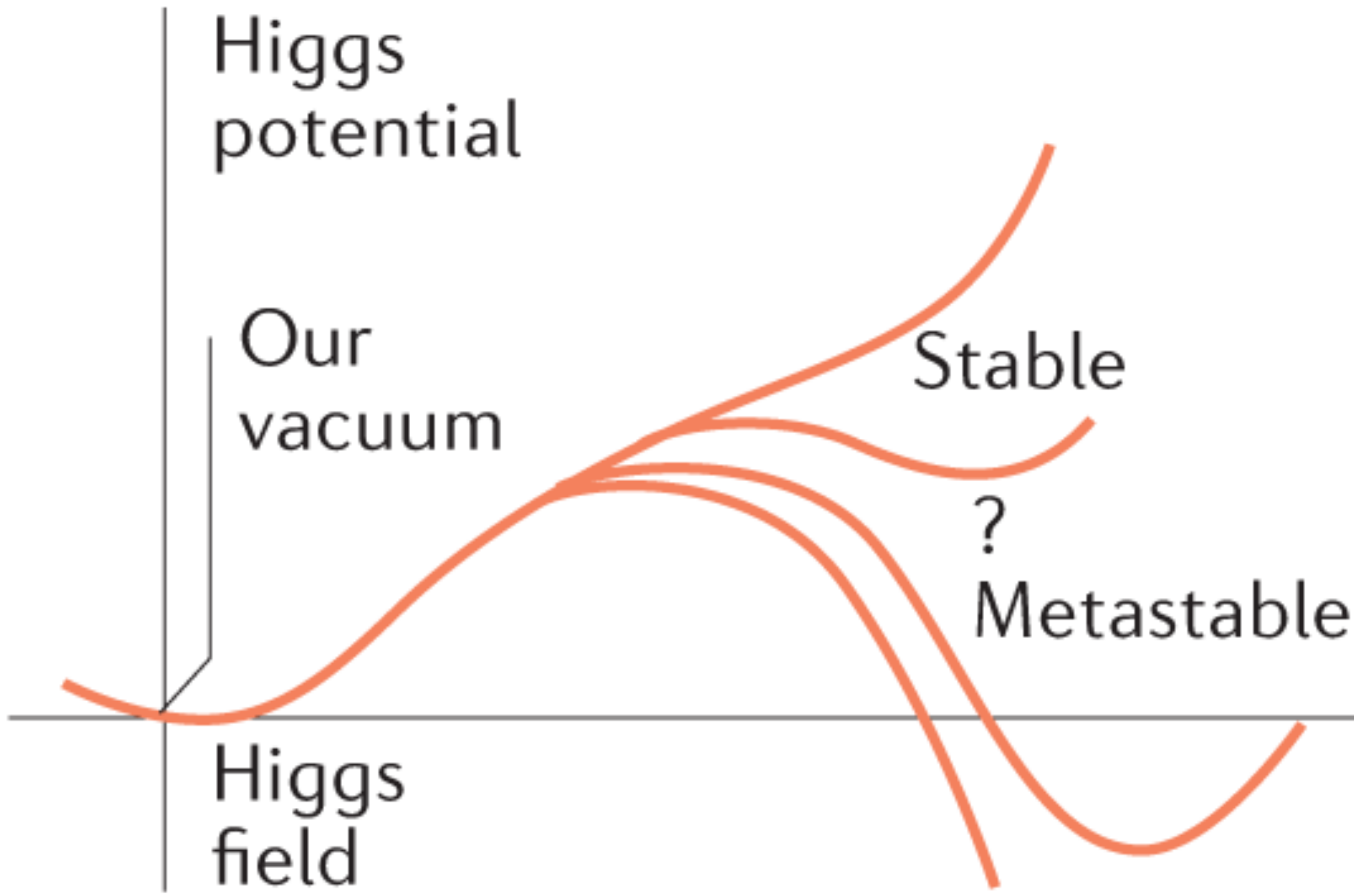
- QCD has no time to dilute its quantum numbers

- Perfect candidate to understand QCD!

Top Mass

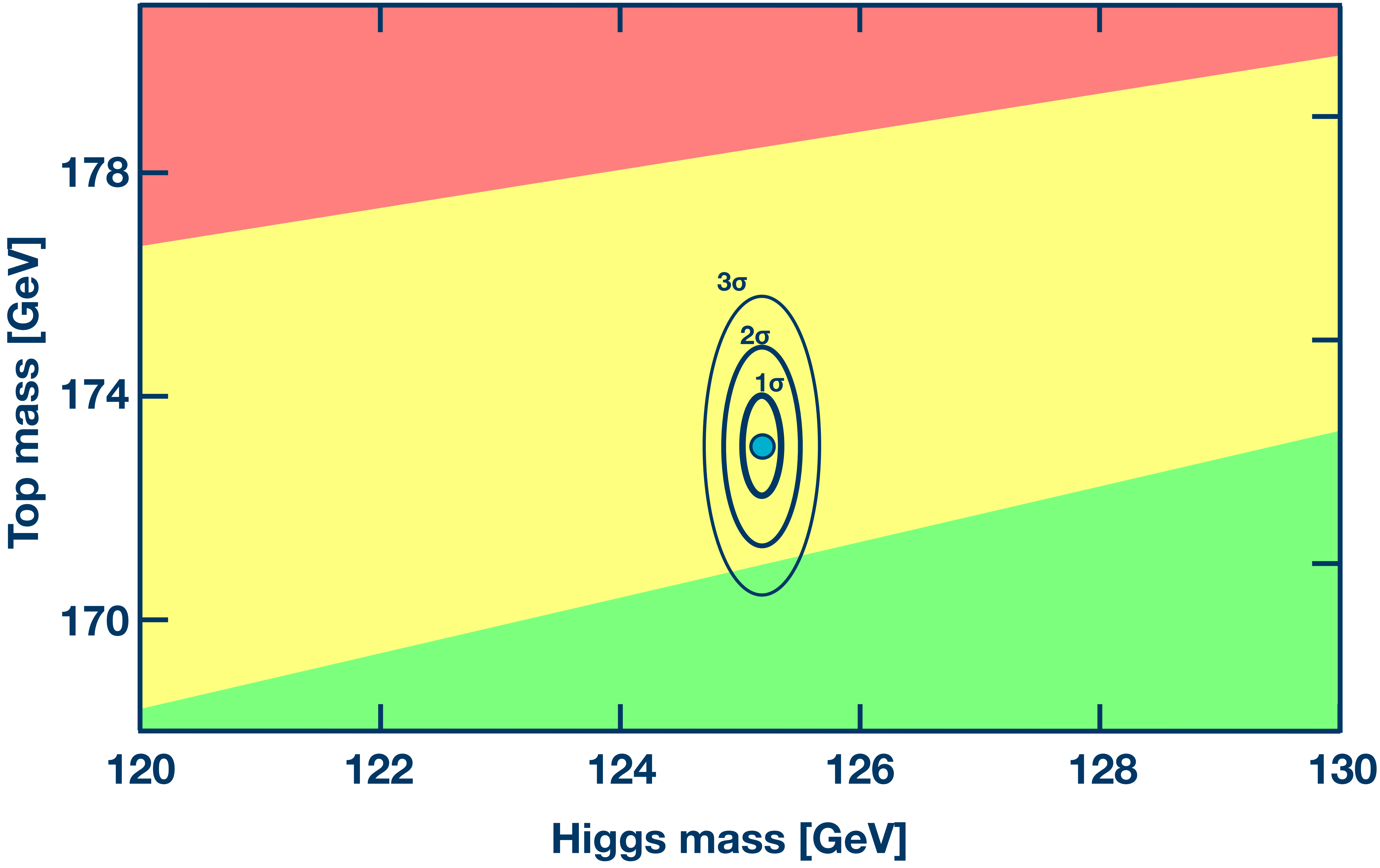
Vacuum stability

- **A simple and accessible question at the LHC is** *"are we in a local or global minima?"*.

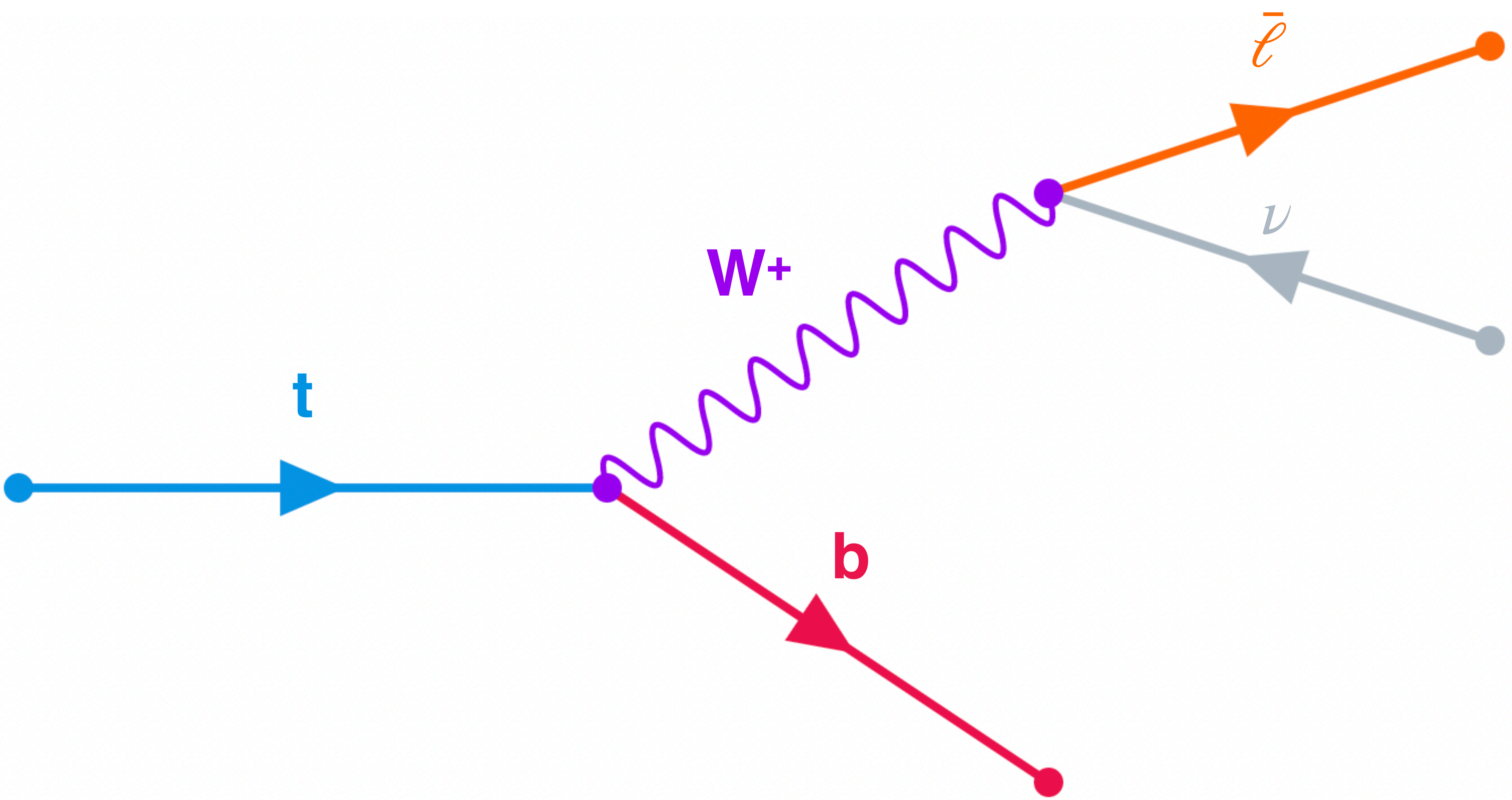


- **Measuring m_W, m_t, m_H can tell us.**

Fate of the Universe



How do we measure it?



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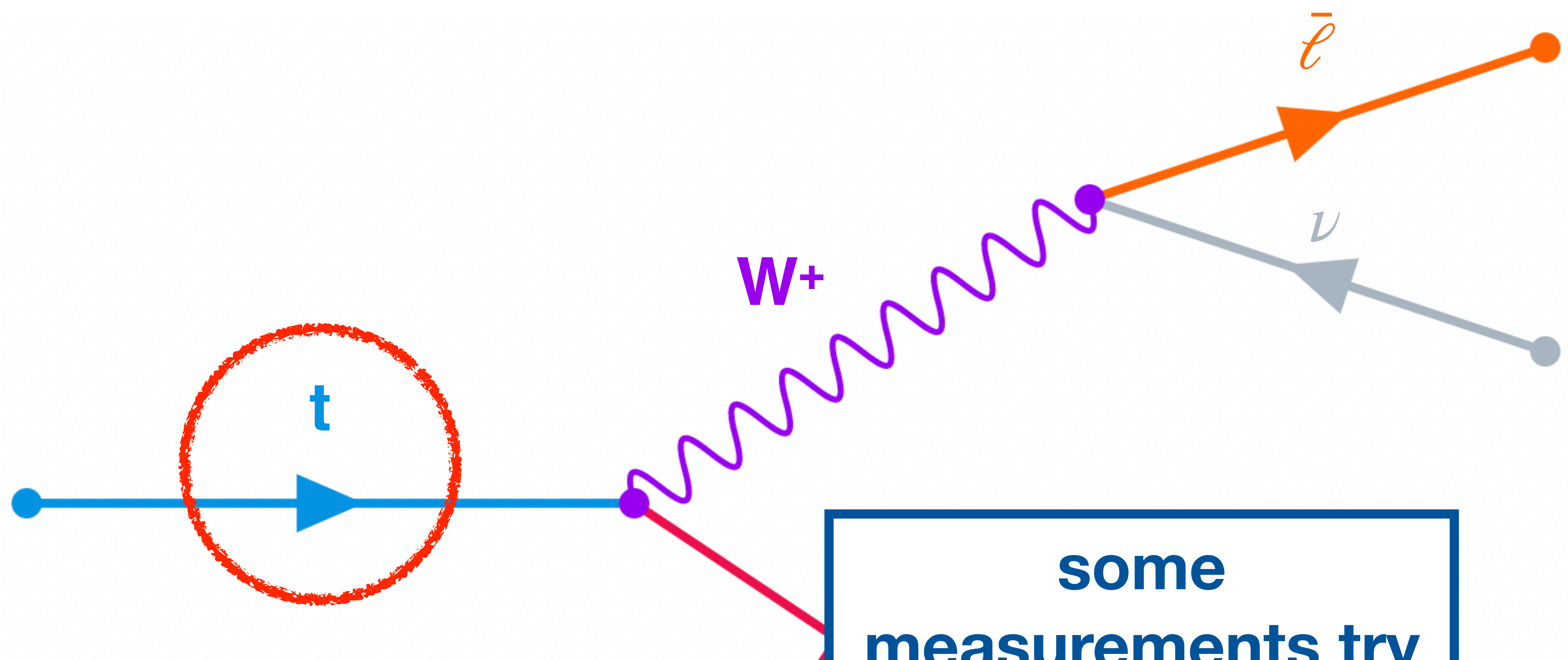
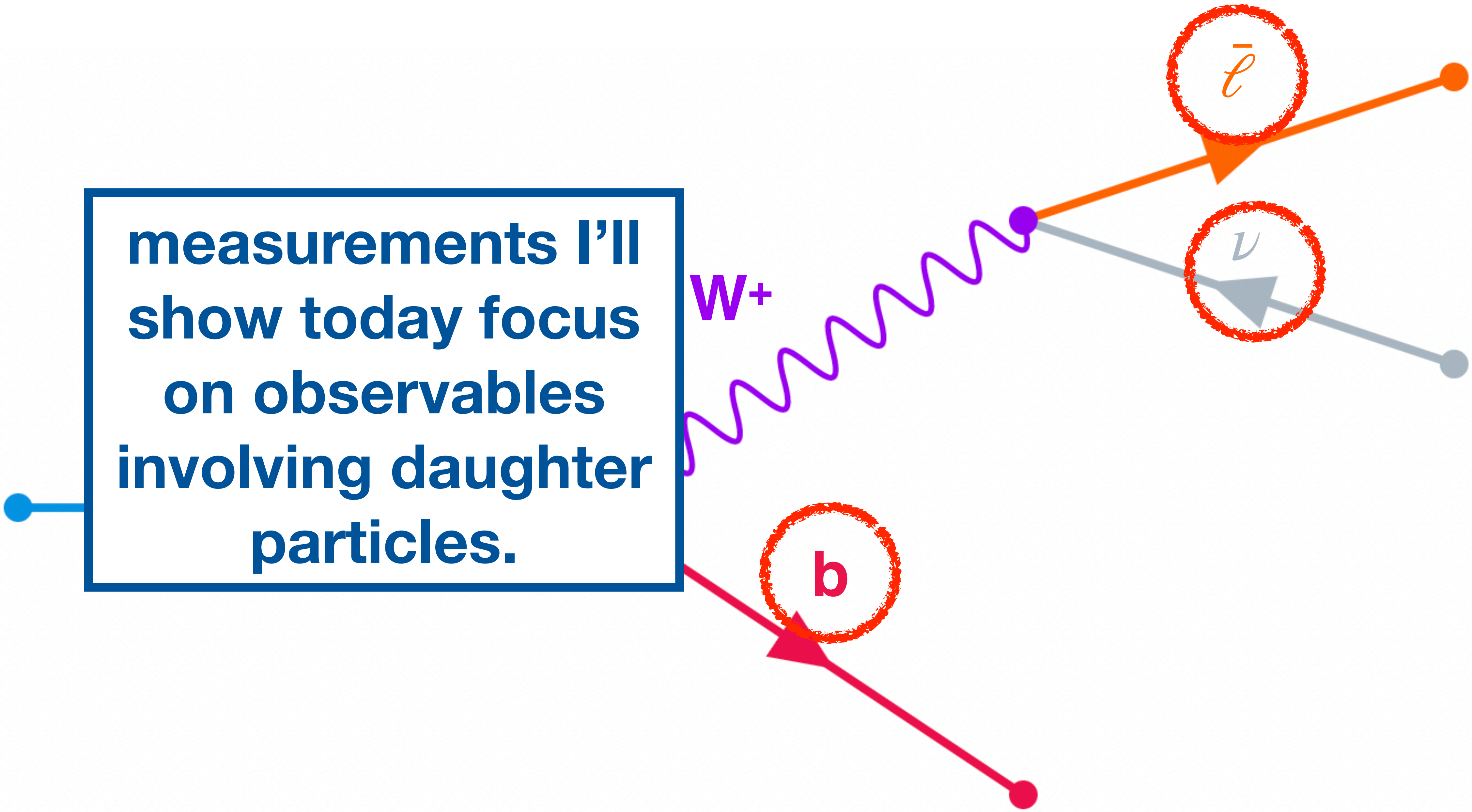


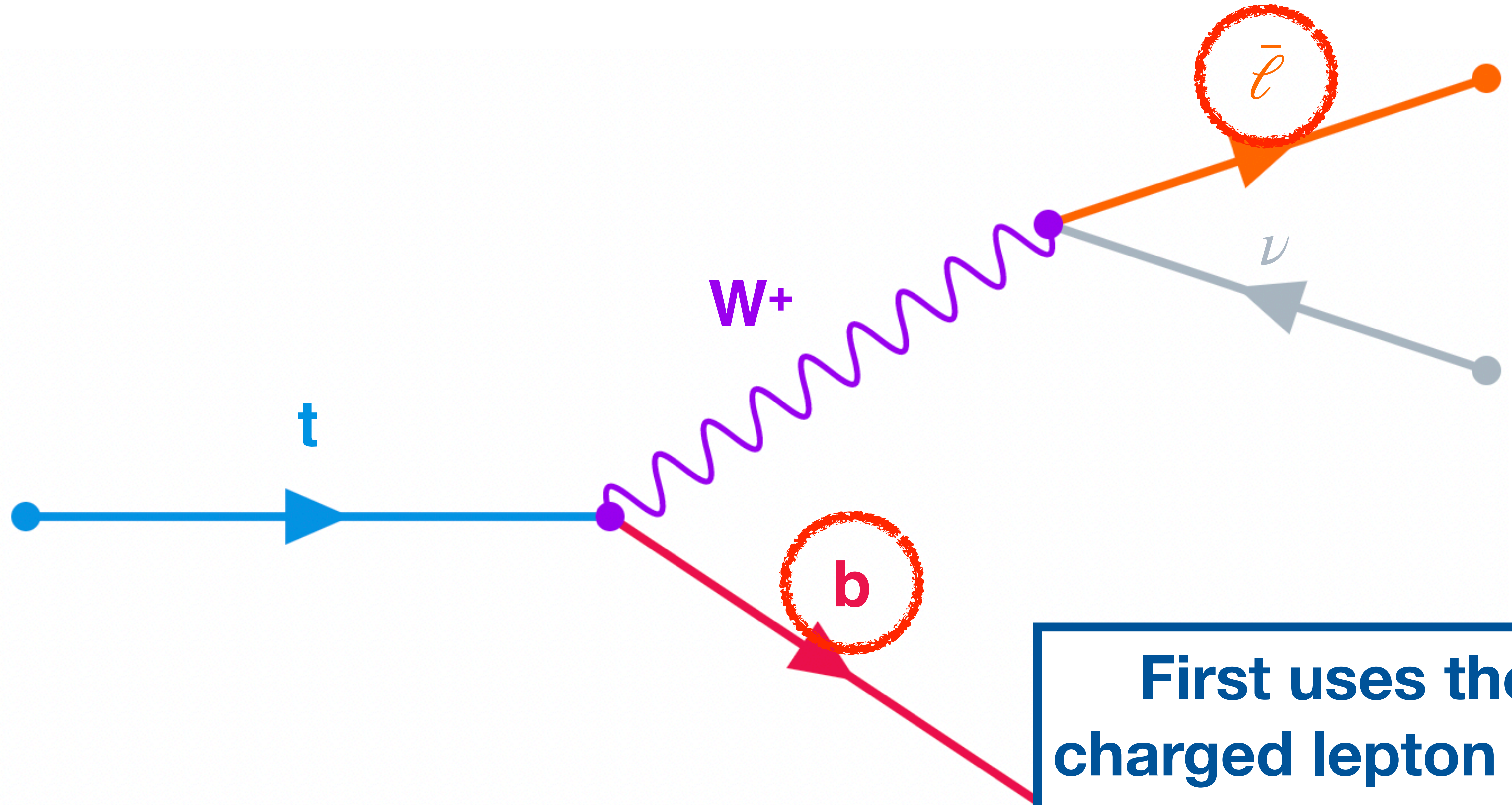
some measurements try to reconstruct the top itself and measure it's mass

How do we measure it?



measurements I'll show today focus on observables involving daughter particles.

How do we measure it?



First uses the charged lepton and b as a proxy for the top.

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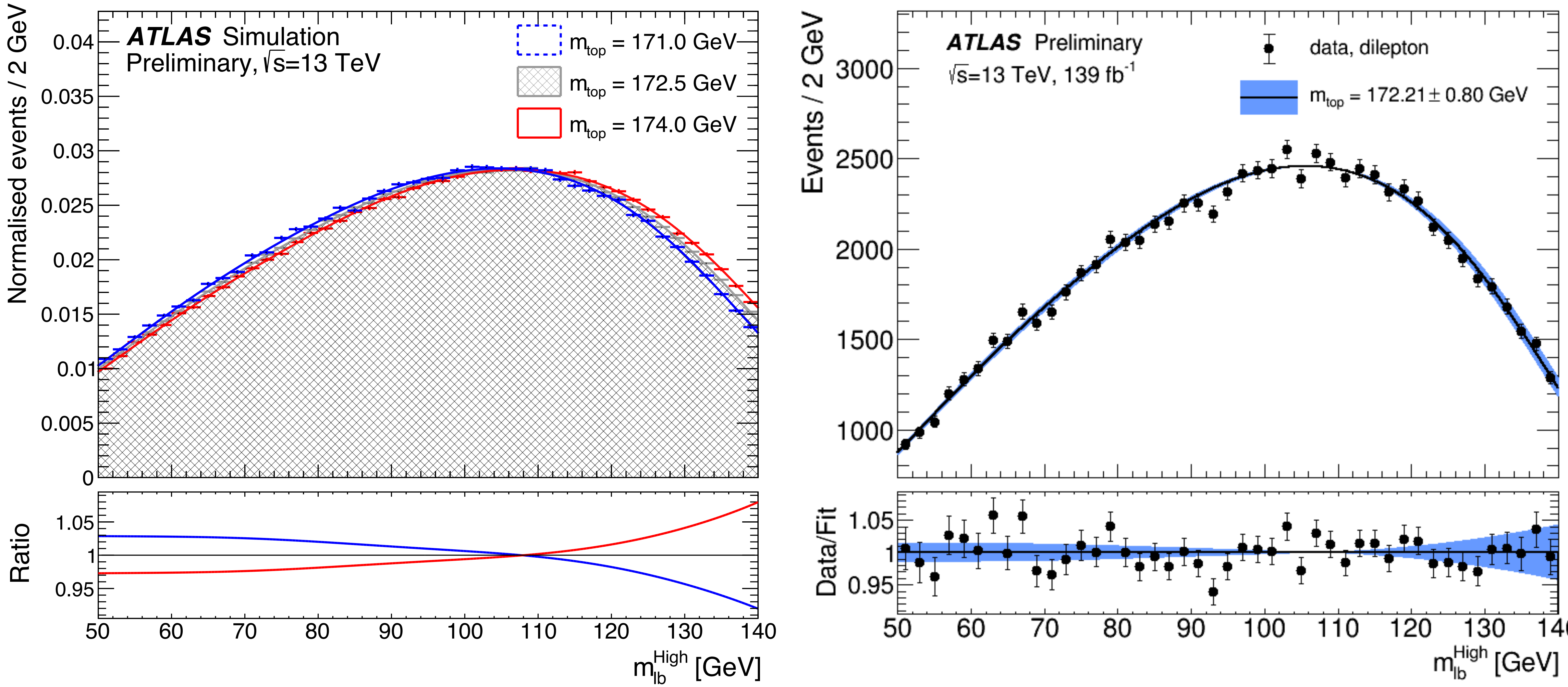

- **Top mass measured in proxy observable** (m_{lb}) **using template fit.**
- **Templates functions constructed from different mass hypotheses and fit to data** (unbinned max likelihood fit).

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- **Final selection also uses DNN to resolve lepton-jet pairing ambiguity.**

	m_{top} [GeV]
Result	172.21
Statistics	0.20
Matrix-element matching	0.40
Colour reconnection	0.27
Recoil effect	0.39
Jet energy scale	0.37
Other uncertainities	0.29
Total uncertainty	0.80

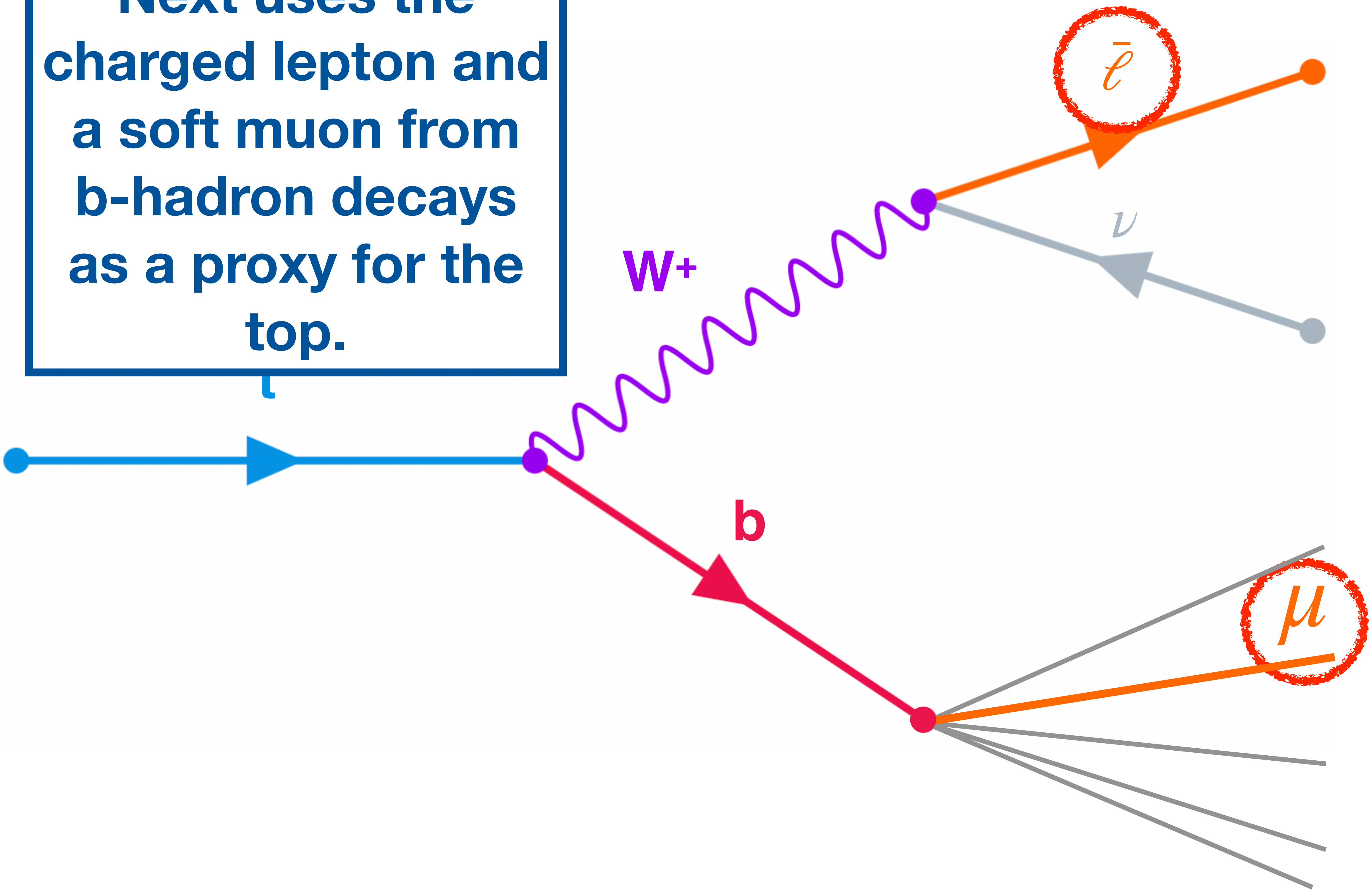
*full table in backup

$$m_{top}^{dilepton} = 172.21 \pm 0.20\,(\text{stat}) \pm 0.67\,(\text{syst}) \pm 0.39\,(\text{recoil})\ \text{GeV}.$$

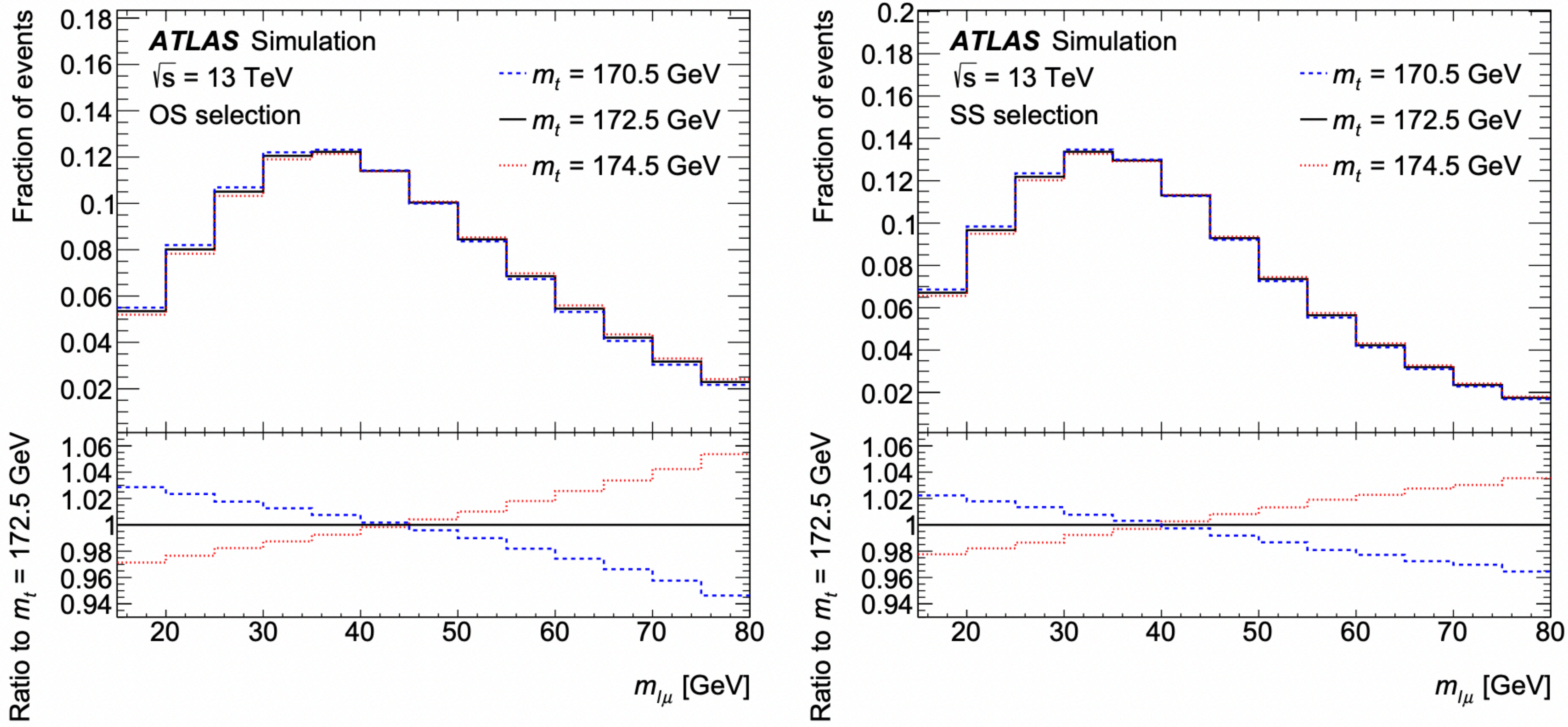
- **Uncertainty dominated by MC modelling and Jet energy scale uncertainties.**

How do we measure it?

Next uses the charged lepton and a soft muon from b-hadron decays as a proxy for the top.

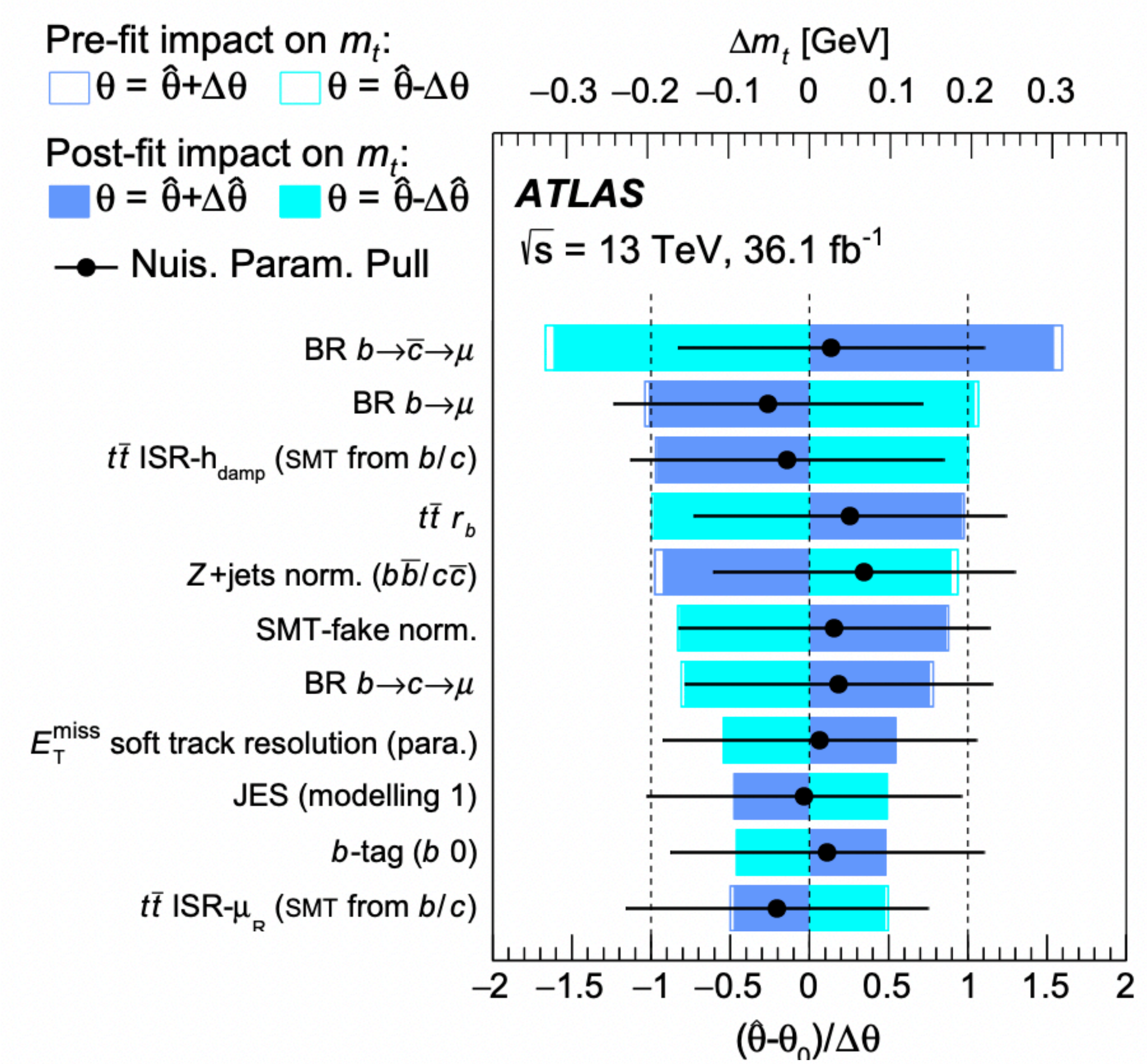


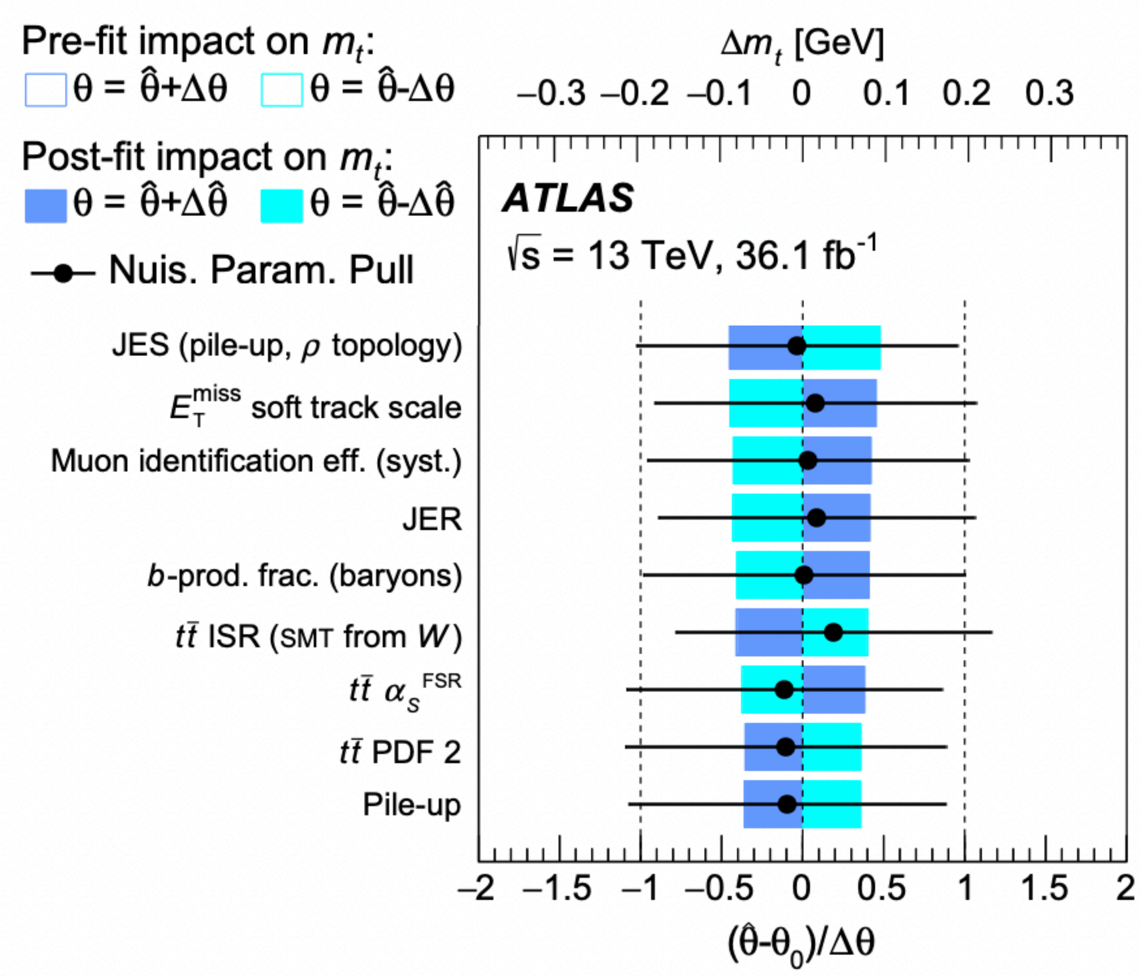
2209.00583 (Accepted by JHEP)



- **Similar to previous method but uses soft muon in b jet** ($m_{\mu l}$)**; leptons measured more precisely than jets.**
- **Additional complication is μ and l can be same sign.**
- **Requires precise knowledge of b-fragmentation.**

- **Mass extracted using binned maximum likelihood fit.**

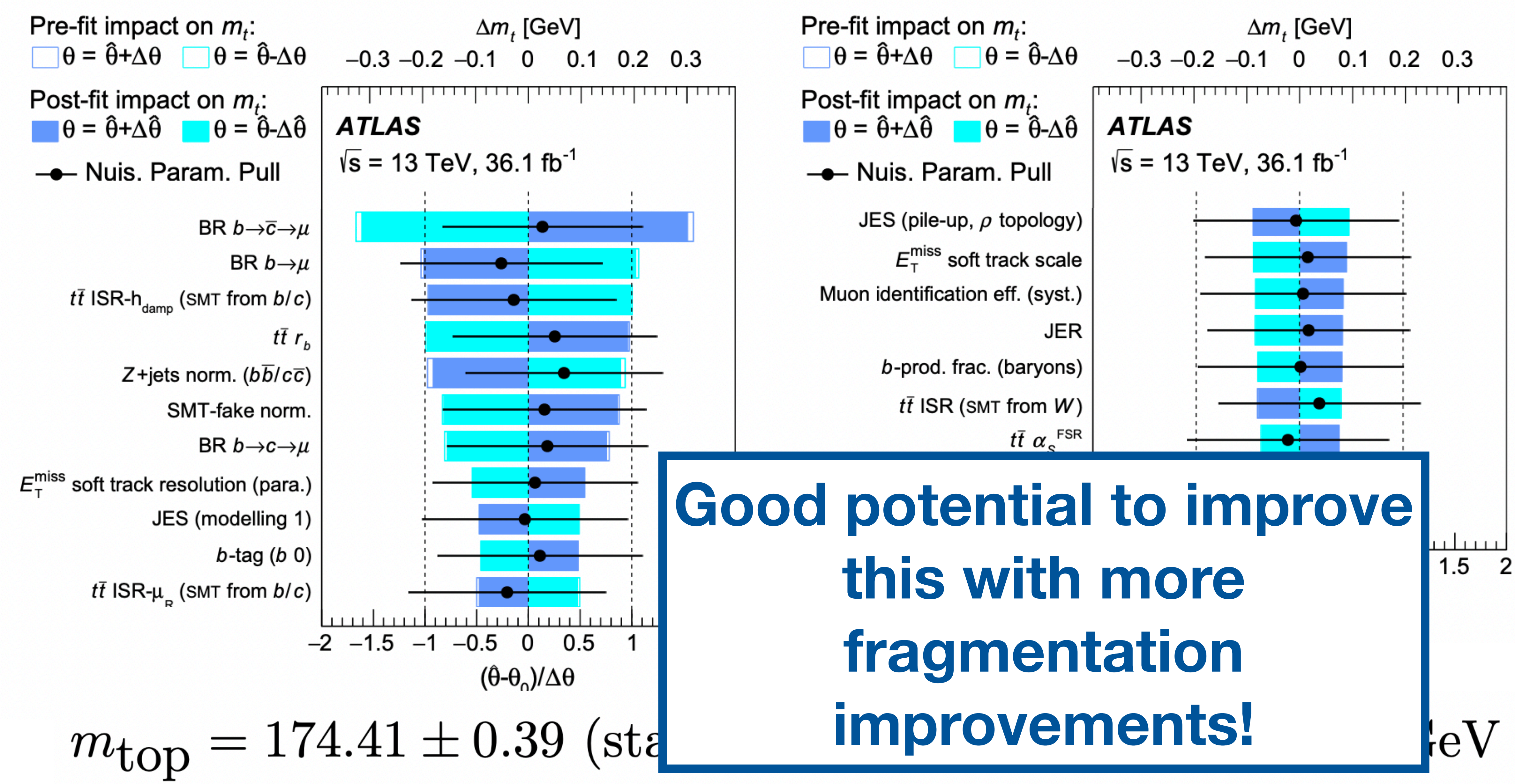




$$m_{\rm top} = 174.41 \pm 0.39\ ({\rm stat.}) \pm 0.66\ ({\rm syst.}) \pm 0.25\ ({\rm recoil})\ {\rm GeV}$$

- **Measurement dominated by uncertainties on the b-fragmentation and decay.**

- **Mass extracted using binned maximum likelihood fit.**

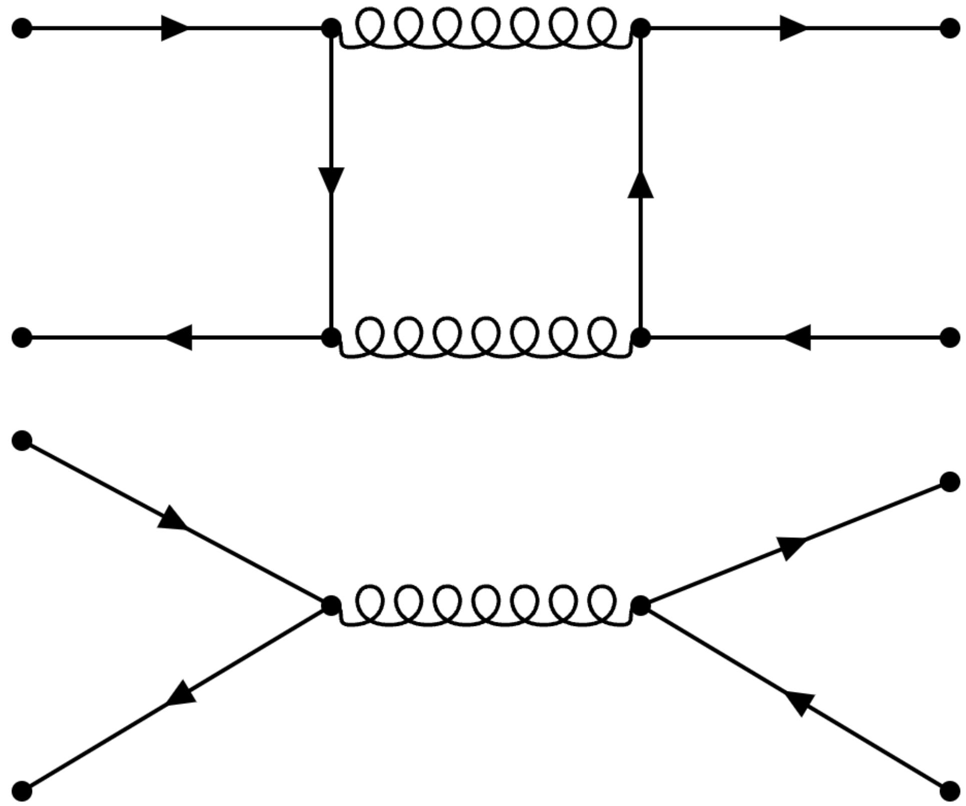


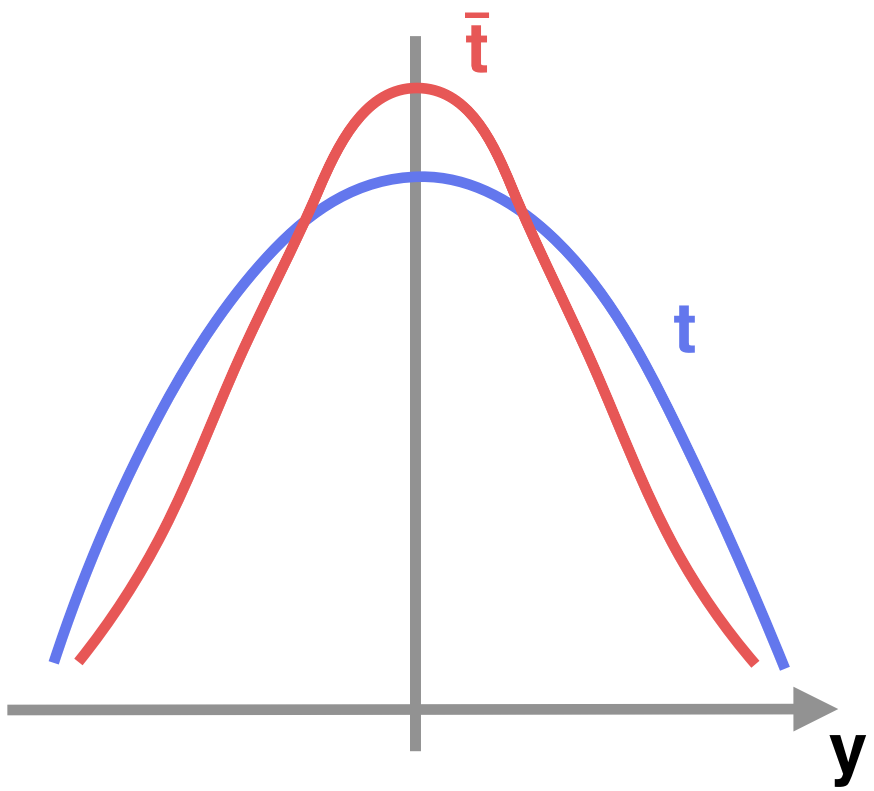
Good potential to improve this with more fragmentation improvements!

- **Measurement dominated by uncertainties on the b-fragmentation and decay.**

Other Properties

Charge Asymmetry [Accepted by JHEP]





- **Interference between born and box diagrams induces an asymmetry in the direction of tops vs. anti-tops.**

- **Extremely subtle precent-level** (0.6%) **effect.**
  (one of the most precise SM tests in top physics)**.**

Charge Asymmetry [Accepted by JHEP]

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- **This measurement selected dileptonic and semi-leptonic** (resolved and boosted) **$t\bar{t}$ events and uses builds two asymmetries:**

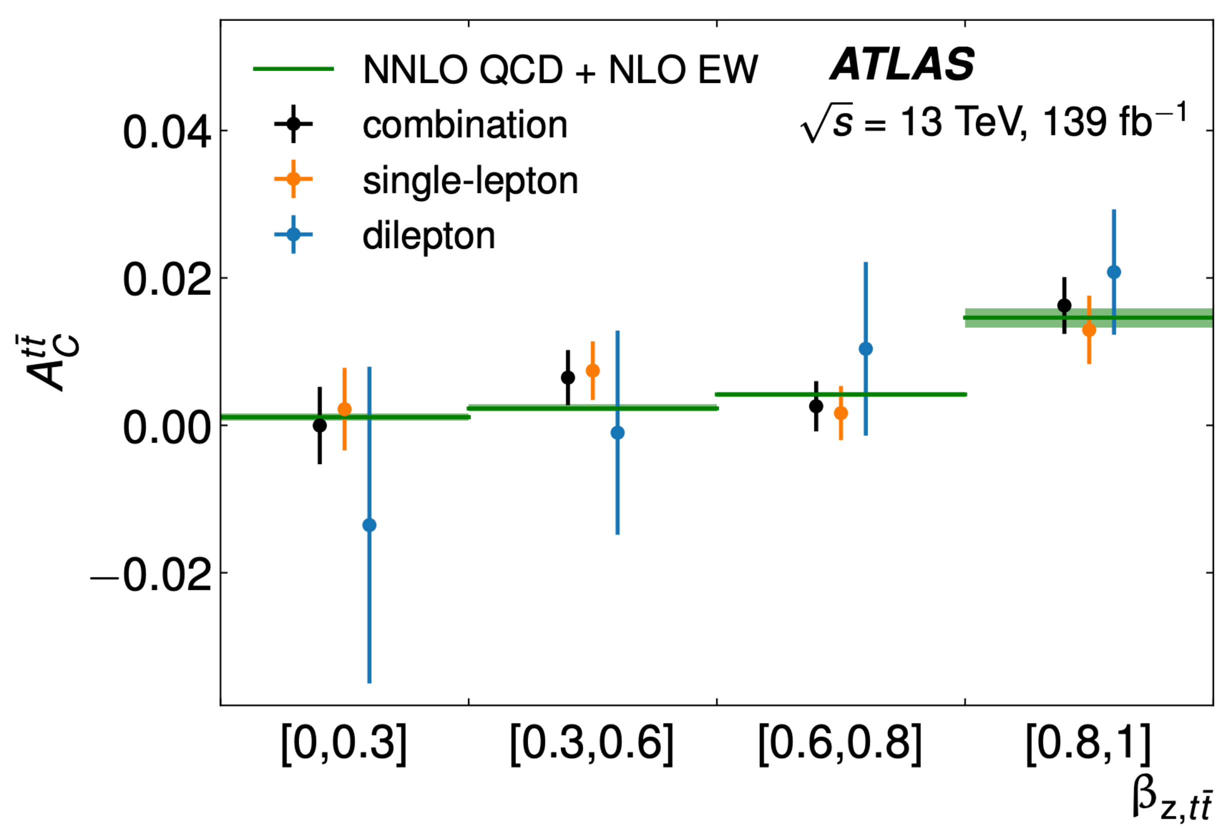
$$A_C^{t\bar{t}} = \frac{N(\Delta|y_{t\bar{t}}| > 0) - N(\Delta|y_{t\bar{t}}| < 0)}{N(\Delta|y_{t\bar{t}}| > 0) + N(\Delta|y_{t\bar{t}}| < 0)} \qquad \Delta|y_{t\bar{t}}| = |y_t| - |y_{\bar{t}}|$$

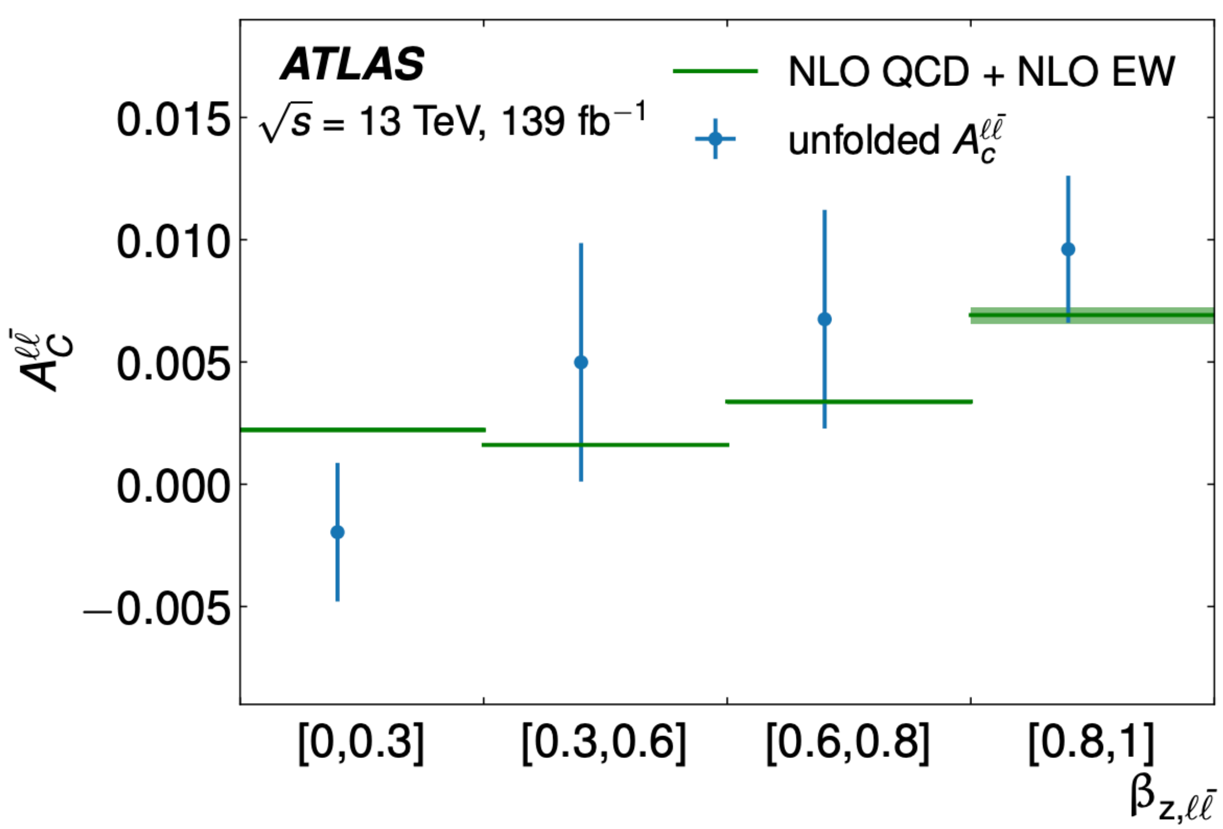
$$A_C^{\ell\bar{\ell}} = \frac{N(\Delta|\eta_{\ell\bar{\ell}}| > 0) - N(\Delta|\eta_{\ell\bar{\ell}}| < 0)}{N(\Delta|\eta_{\ell\bar{\ell}}| > 0) + N(\Delta|\eta_{\ell\bar{\ell}}| < 0)} \qquad \Delta|\eta_{\ell\bar{\ell}}| = |\eta_{\bar{\ell}}| - |\eta_{\ell}|$$

- **Observables are corrected for detector effects using a Fully Bayesian Unfolding.**

- **Systematic uncertainties are marginalised and can be constrained by the data.**

Charge Asymmetry [Accepted by JHEP]





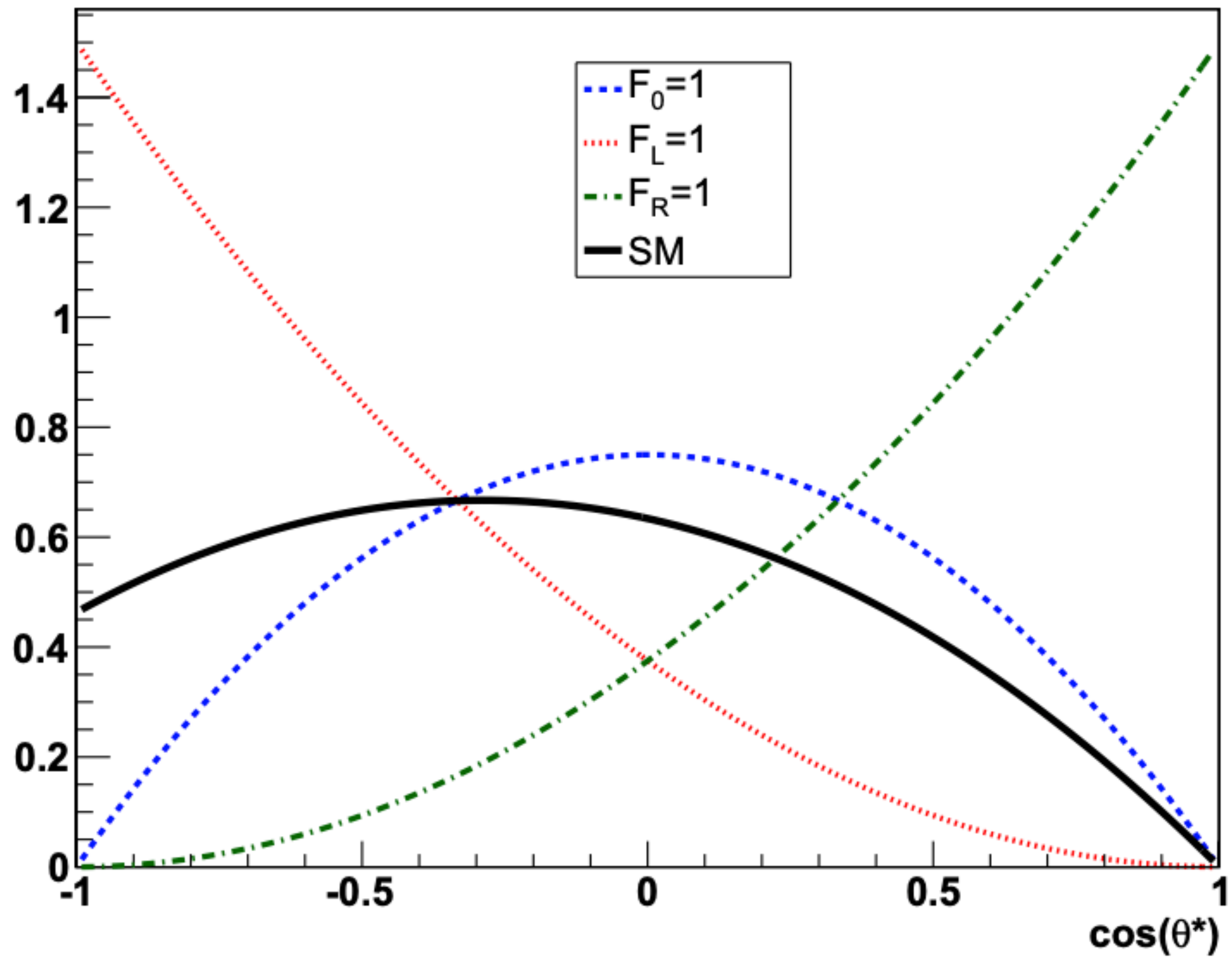
- **Measured inclusive asymmetries are:**

  $Ac^{t\bar{t}} = 0.068 \pm 0.015$ (stat. + syst.)

  $Ac^{ll} = 0.054 \pm 0.026$ (stat. + syst.)

- **4.7 sigma disagreement with 0: very strong evidence!**

W Boson Helicity [Accepted by PLB]

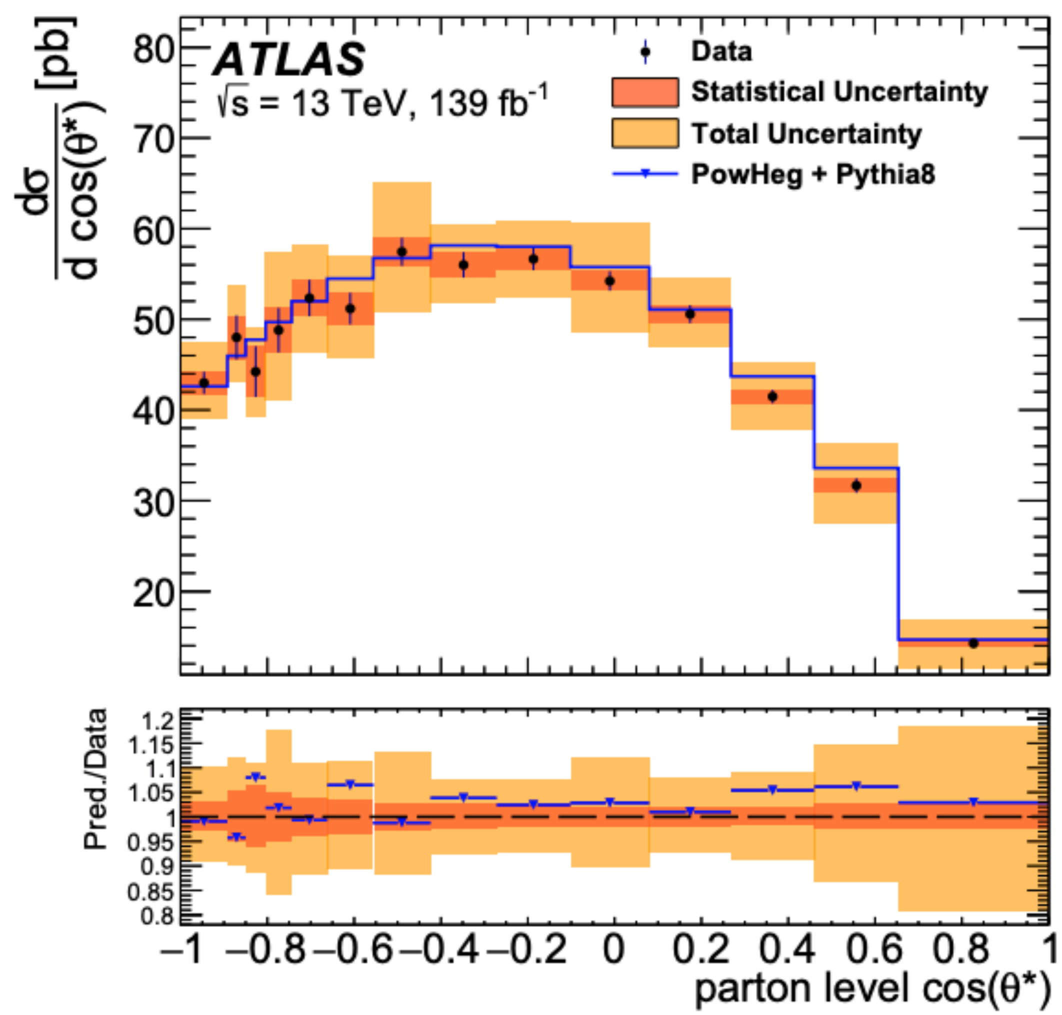


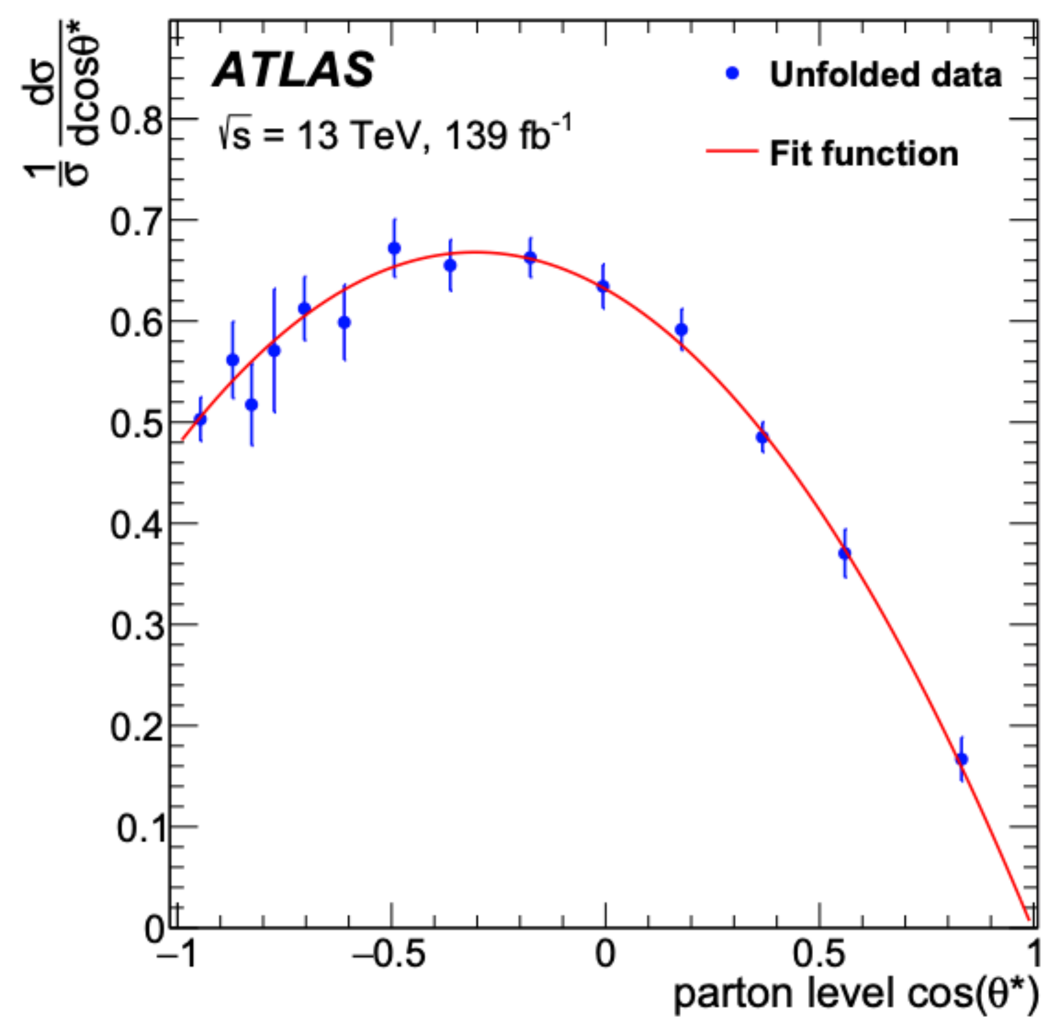
- **W bosons can be polarised longitudinally** (F_0) **or left-handed** (F_L)**, but not right-handed** (F_R) **in the SM.**
- **Sensitive to anomalous Wtb couplings** (any significant F_R = new physics!)**.**

W Boson Helicity [Accepted by PLB]

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)f_0 + \frac{3}{8}(1-\cos\theta^*)^2 f_L + \frac{3}{8}(1+\cos\theta^*)^2 f_R.$$

- Measured by unfolding using angular distribution of charged lepton decay from the W.

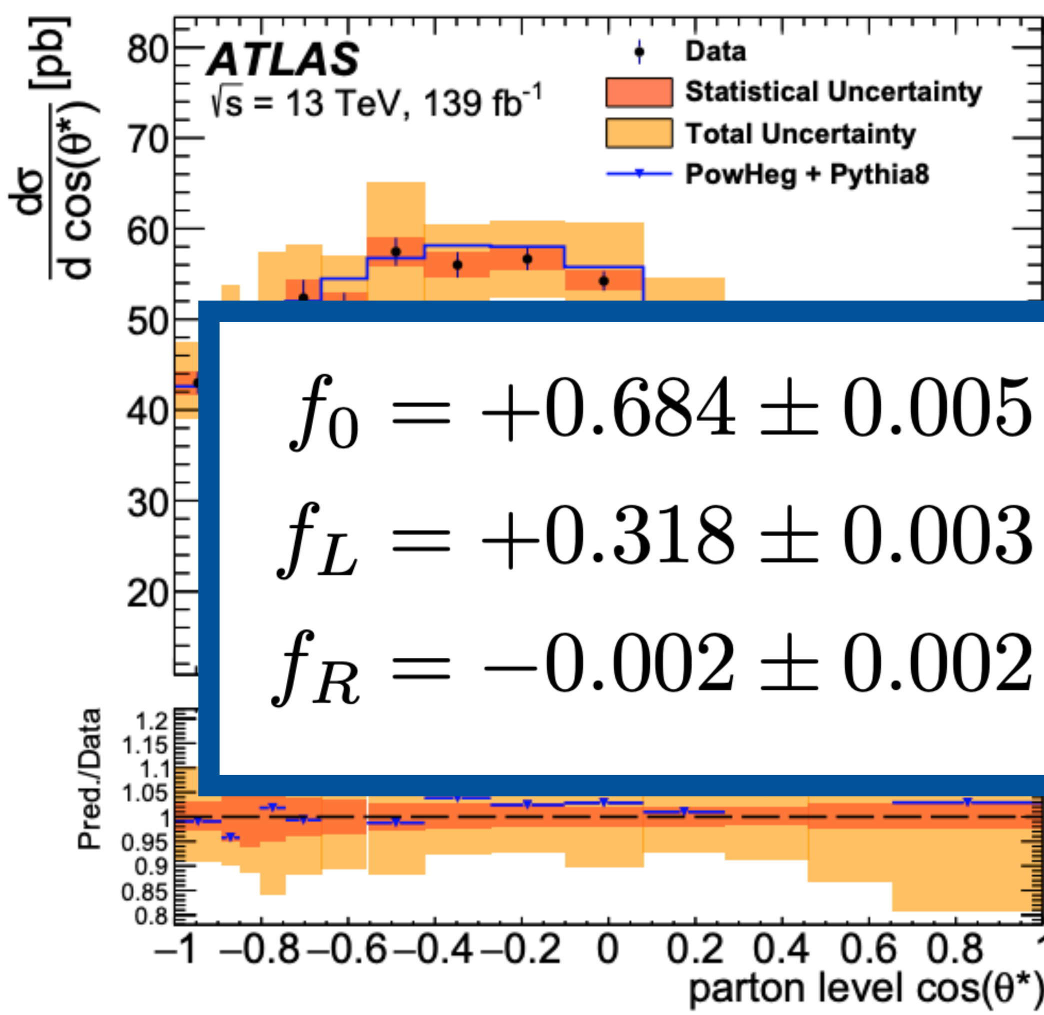


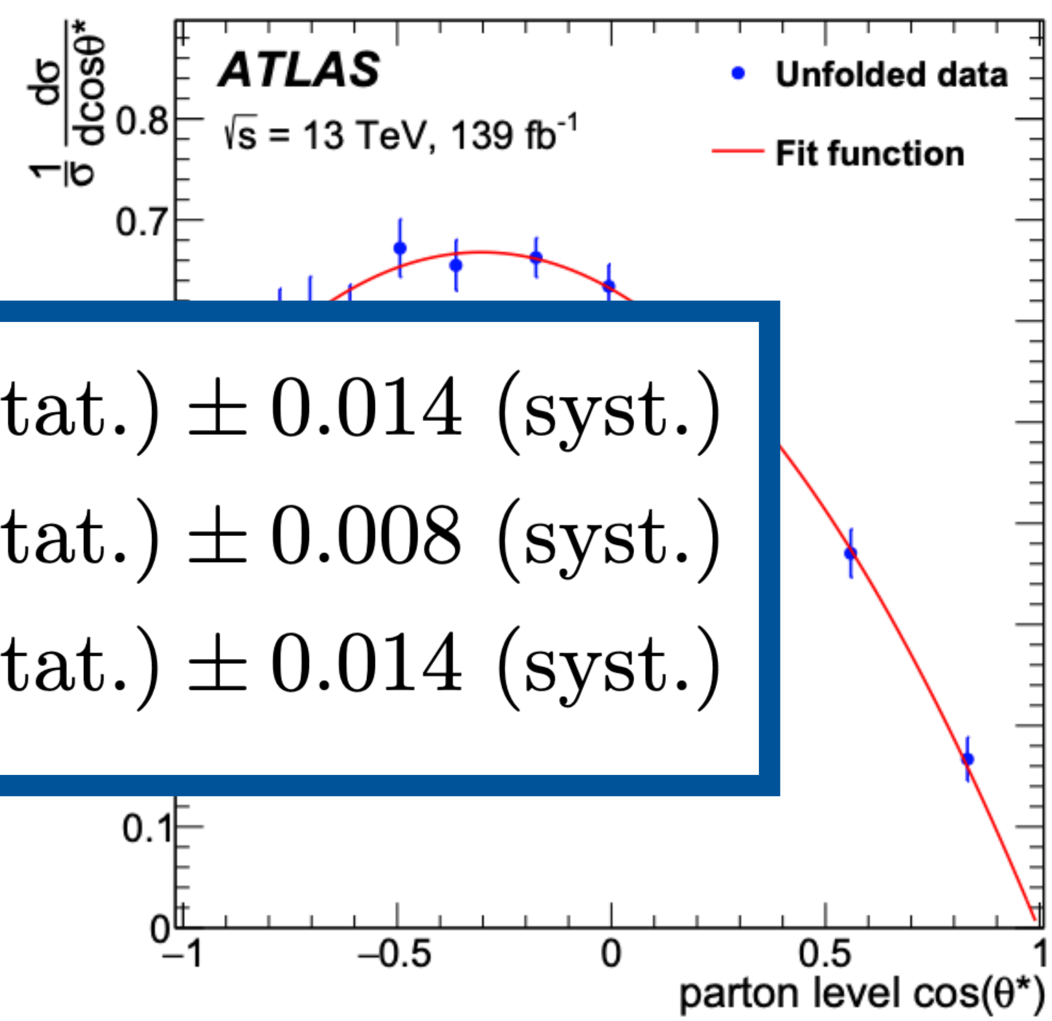


W Boson Helicity [Accepted by PLB]

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)f_0 + \frac{3}{8}(1-\cos\theta^*)^2 f_{\mathrm{L}} + \frac{3}{8}(1+\cos\theta^*)^2 f_{\mathrm{R}}.$$

- **Measured by unfolding using angular distribution of charged lepton decay from the W.**





$$f_0 = +0.684 \pm 0.005\ (\text{stat.}) \pm 0.014\ (\text{syst.})$$
$$f_L = +0.318 \pm 0.003\ (\text{stat.}) \pm 0.008\ (\text{syst.})$$
$$f_R = -0.002 \pm 0.002\ (\text{stat.}) \pm 0.014\ (\text{syst.})$$

Conclusions

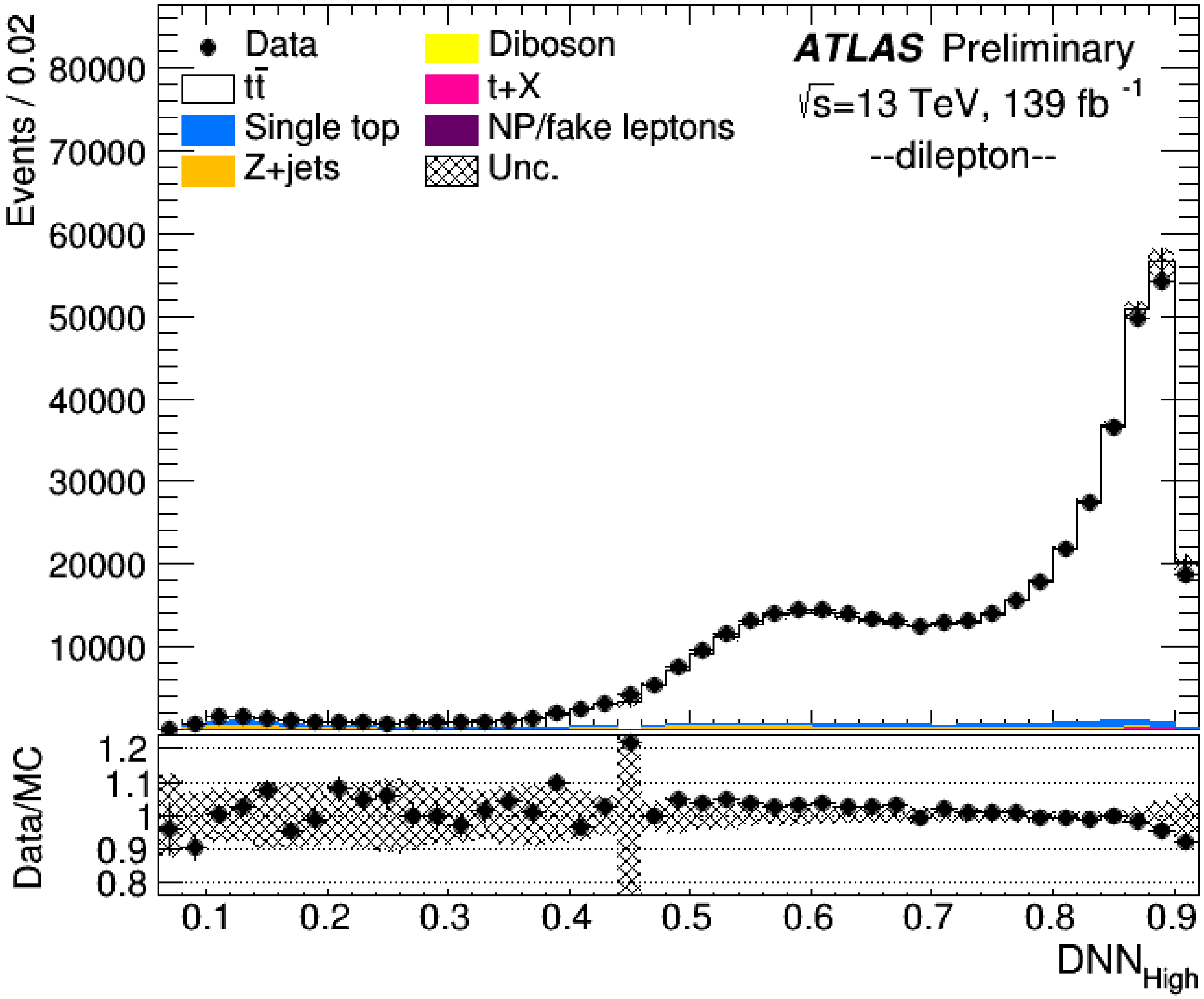
- First ATLAS Run2 top mass measurements starting to appear.
- Current sensitivity is ~1 GeV, but this will decrease as more analyses mature.
- Precision tests of top-properties already well established in Run2, now approaching ultra-precise measurements.
- Still some clear statistical benefits from upcoming Run3 data in these analyses.

Backup

Paper/CONF references

- **$t\bar{t}\gamma$ charge asymmetry: Accepted by PLB**
- **W Boson polarisation: Accepted by PLB**
- **top mass** (SMT)**: Accepted by JHEP**
- **top mass** (template)**: ATLAS-CONF-2022-058**

ATLAS-CONF-2022-058



- **Deep Neural Net used to optimise lepton-b pairings.**

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	m_{top} [GeV]
Result	172.21
Statistics	0.20
Method	0.05 ± 0.04
Matrix-element matching	0.40 ± 0.06
Parton shower and hadronisation	0.05 ± 0.05
Initial- and final-state QCD radiation	0.17 ± 0.02
Underlying event	0.02 ± 0.10
Colour reconnection	0.27 ± 0.07
Parton distribution function	0.03 ± 0.00
Single top modelling	0.01 ± 0.01
Background normalisation	0.03 ± 0.02
Jet energy scale	0.37 ± 0.02
b-jet energy scale	0.12 ± 0.02
Jet energy resolution	0.13 ± 0.02
Jet vertex tagging	0.01 ± 0.01
b-tagging	0.04 ± 0.01
Leptons	0.11 ± 0.02
Pile-up	0.06 ± 0.01
Recoil effect	0.39 ± 0.09
Total systematic uncertainty (without recoil)	0.67 ± 0.05
Total systematic uncertainty (with recoil)	0.77 ± 0.06
Total uncertainty (without recoil)	0.70 ± 0.05
Total uncertainty (with recoil)	0.80 ± 0.06