



# TOP QUARK CROSS SECTIONS INCLUDING TTBAR, SINGLE TOP AND TOP+X IN ATLAS

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Lake Louise Winter Institute 2026

March 3, 2026

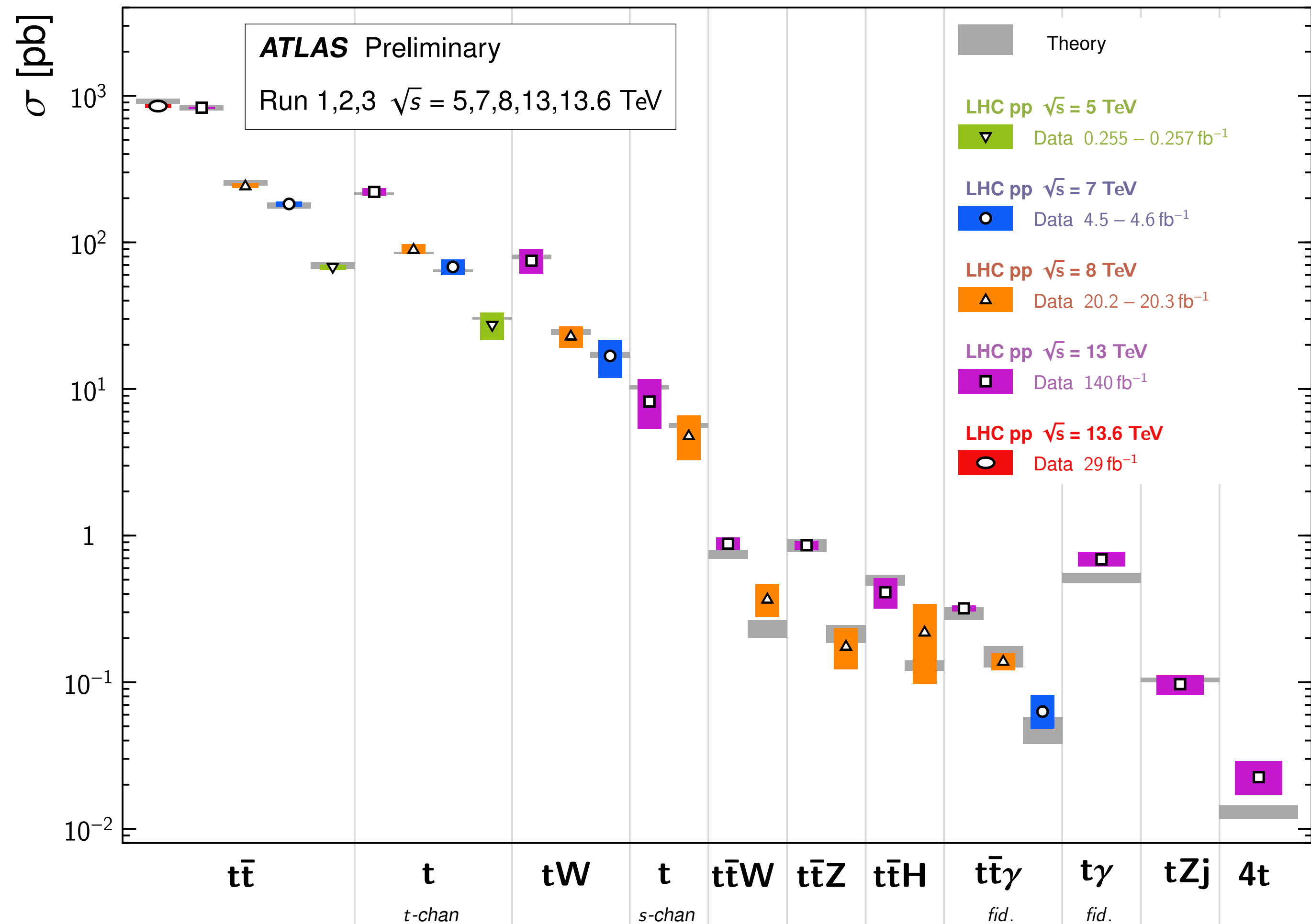
Tadej Novak, Jožef Stefan Institute  
*on behalf of the ATLAS Collaboration*



- **Top quark measurements:**
  - a cross-check of the Standard Model
  - a portal for new physics discoveries
  - a challenge for the theory calculations (NLO, NNLO, NNLL, ...)
- 5 orders of magnitude range of cross-sections probed by ATLAS.
  - Exceptional agreement with important contribution from the LHC Run 2 (140 fb<sup>-1</sup>) and Run 3 (29 fb<sup>-1</sup>) data.

**Top Quark Production Cross Section Measurements**

Status: May 2025



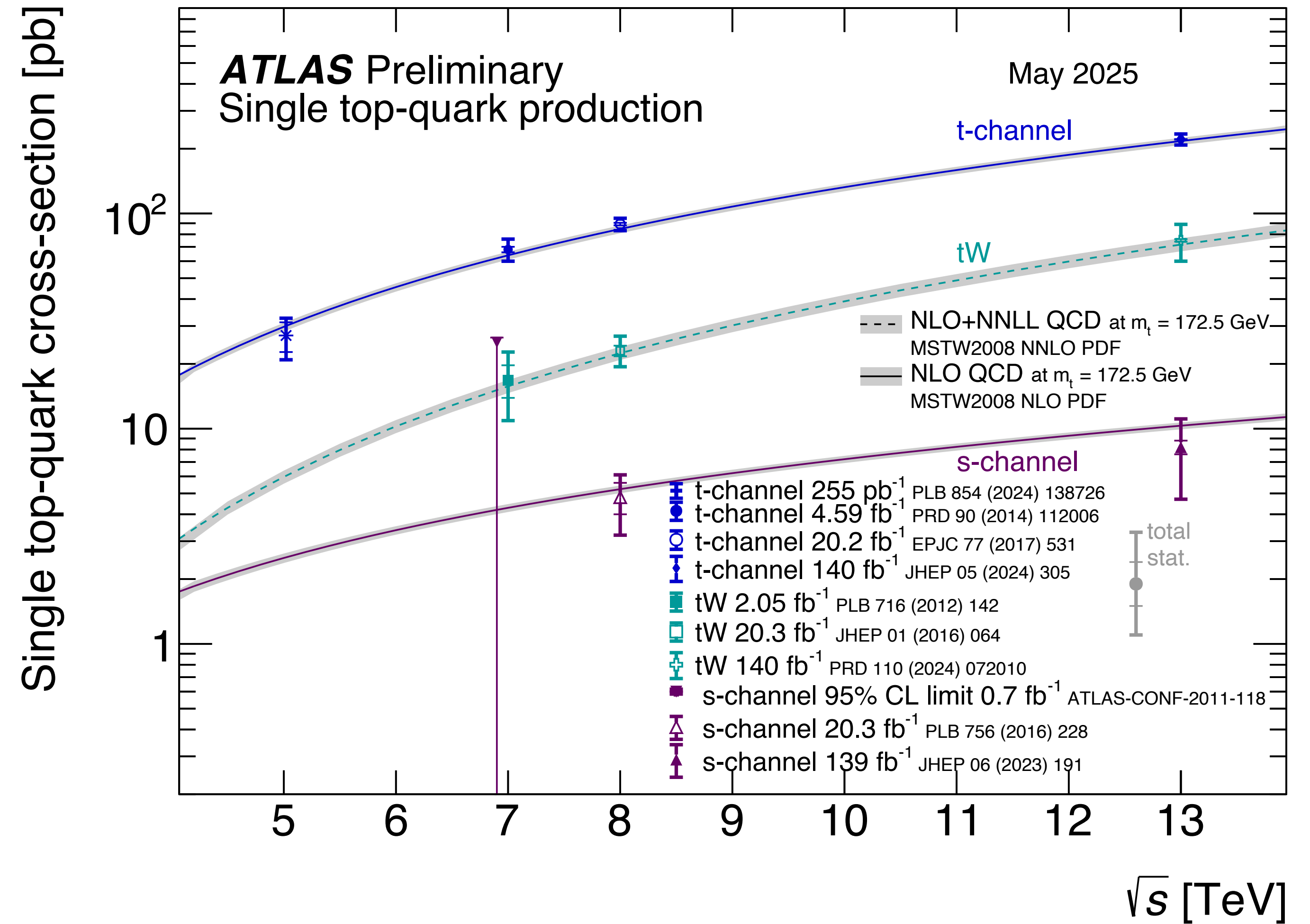
7 additional measurements not yet in the above plot!





ATL-PHYS-PUB-2025-024

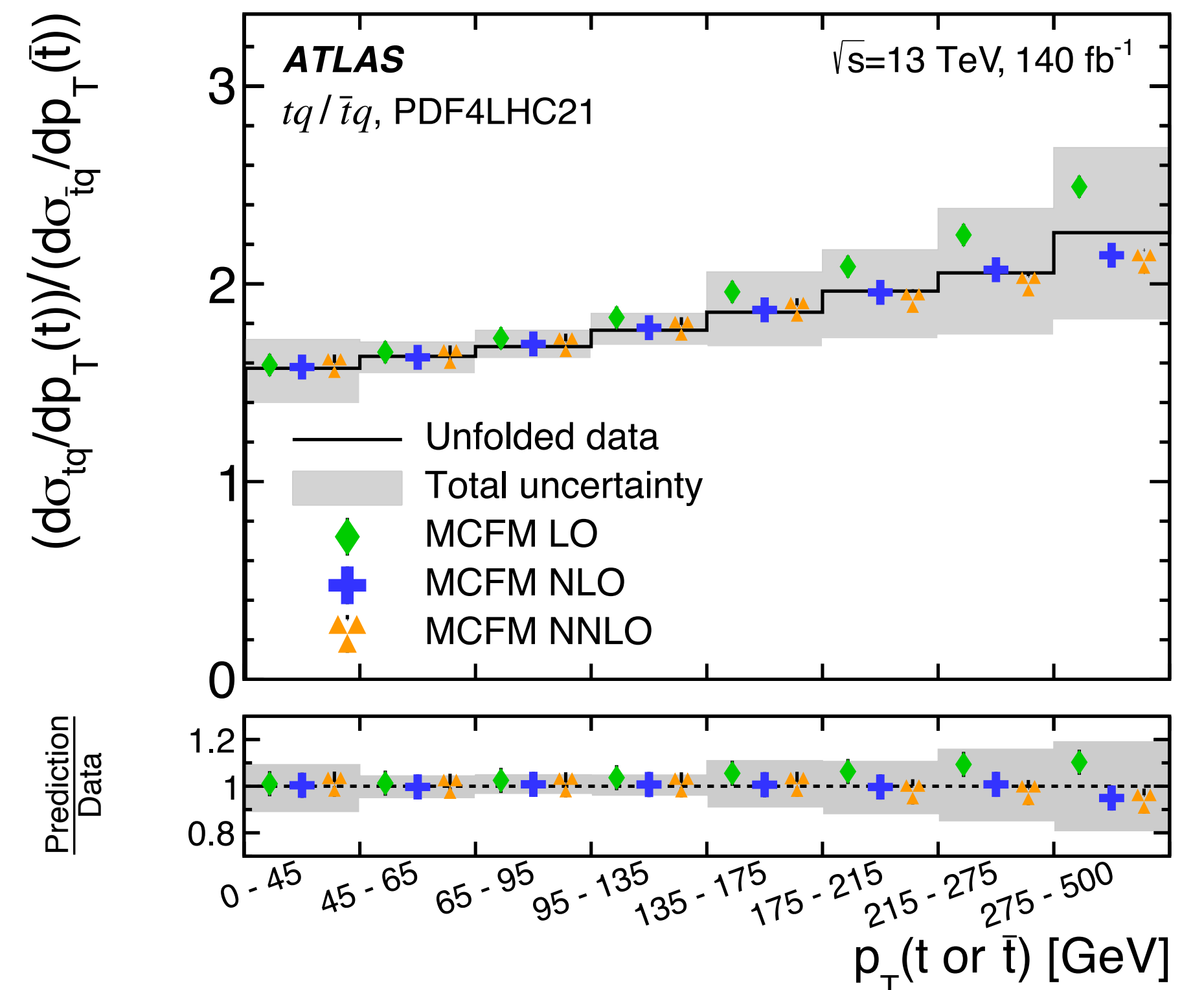
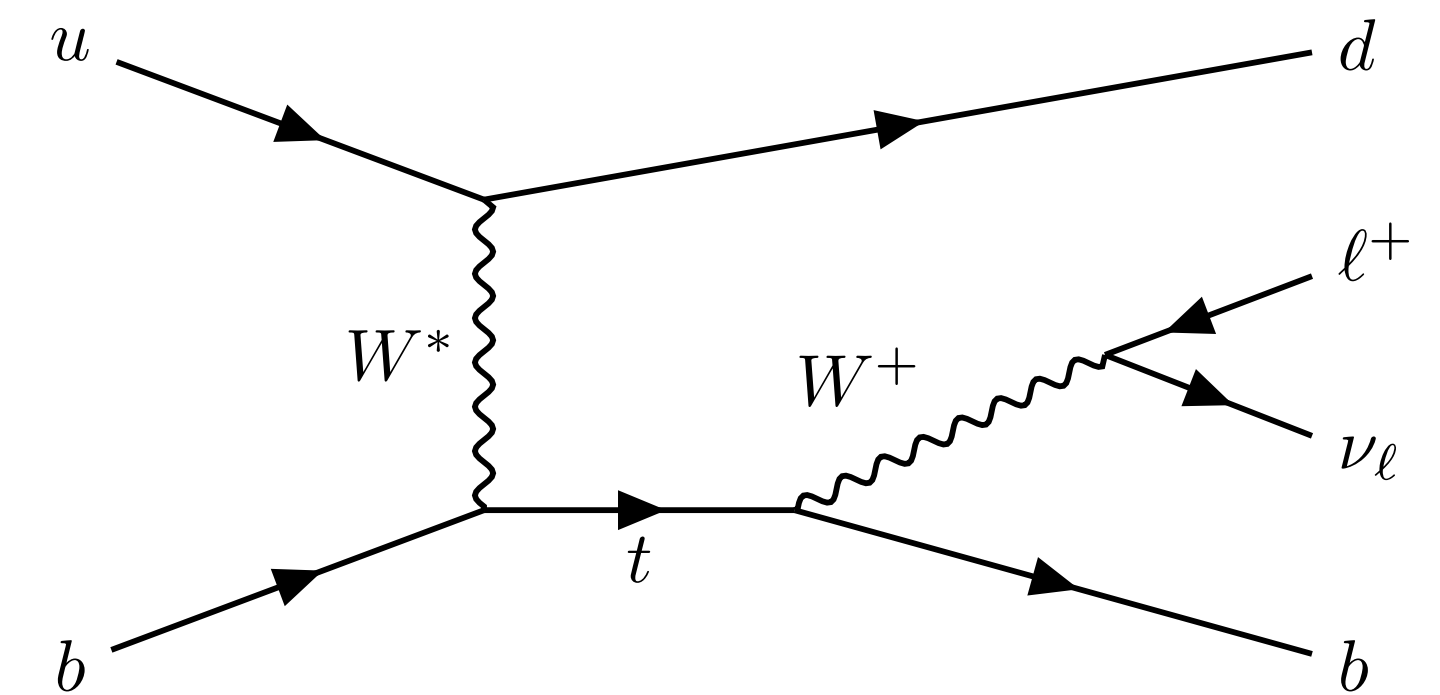
- All three single top quark production channels measured by ATLAS with full Run 2 data (140 fb<sup>-1</sup>):
  - s-channel ([JHEP 06 \(2023\) 191](#))
  - tW production ([Phys. Rev. D 110 \(2024\) 072010](#))
  - t-channel ([JHEP 05 \(2024\) 305](#) and [arXiv:2601.04938](#))



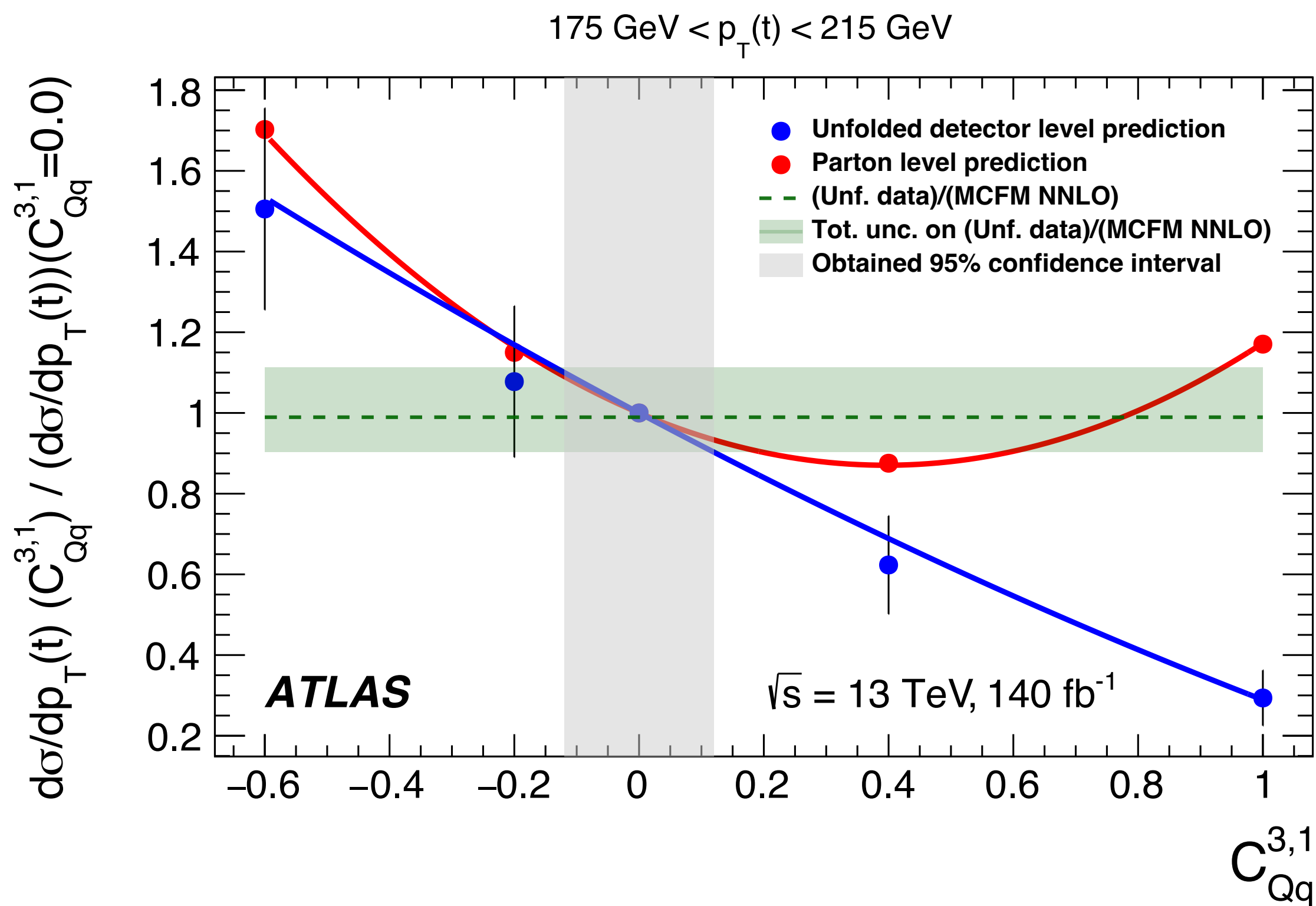
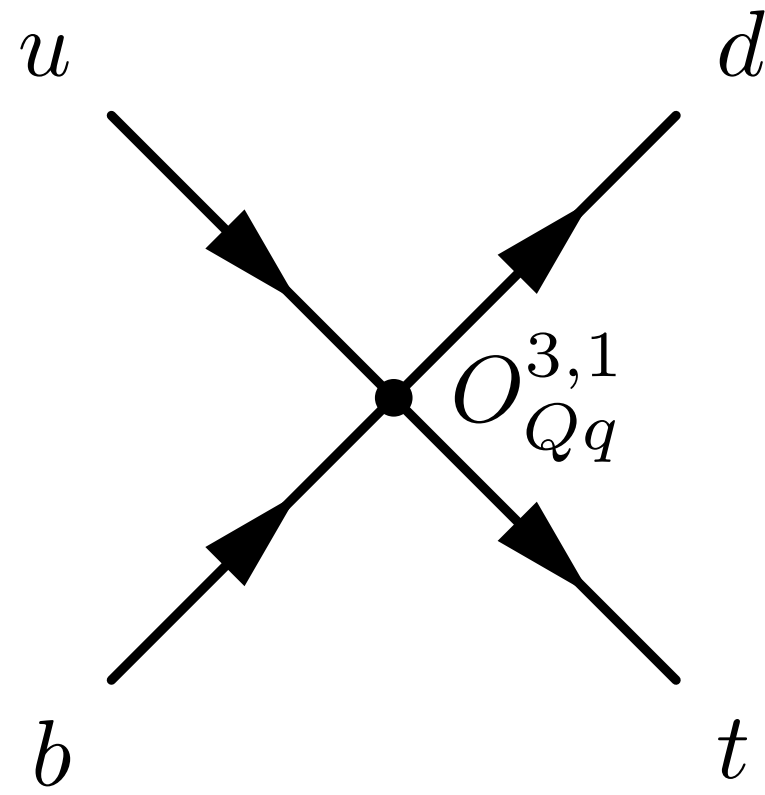


- The total cross-sections are measured  
 $\sigma(tq) = 137 \pm 8 \text{ pb (5.9\%)}$      $\sigma(\bar{t}q) = 84 \pm 6 \text{ pb (6.6\%)}$   
 $\sigma(tq + \bar{t}q) = 221 \pm 13 \text{ pb (6.1\%)}$
- Good background separation reached using a **neural network**.
- First separate measurement** of differential  $tq$  and  $\bar{t}q$  cross-sections at 13 TeV with the full Run-2 dataset.
  - Also first measurement of the differential  $tq/\bar{t}q$  cross-section ratio.
- Good agreement is observed with theoretical predictions.
  - For most measured distributions, the sensitivity to differences between the predictions is **limited by the systematic uncertainties**.

[JHEP 05 \(2024\) 305](#)  
[arXiv:2601.04938 \(submitted to JHEP\)](#)



# DIFFERENTIAL T-CHANNEL SINGLE TOP PRODUCTION CROSS-SECTIONS

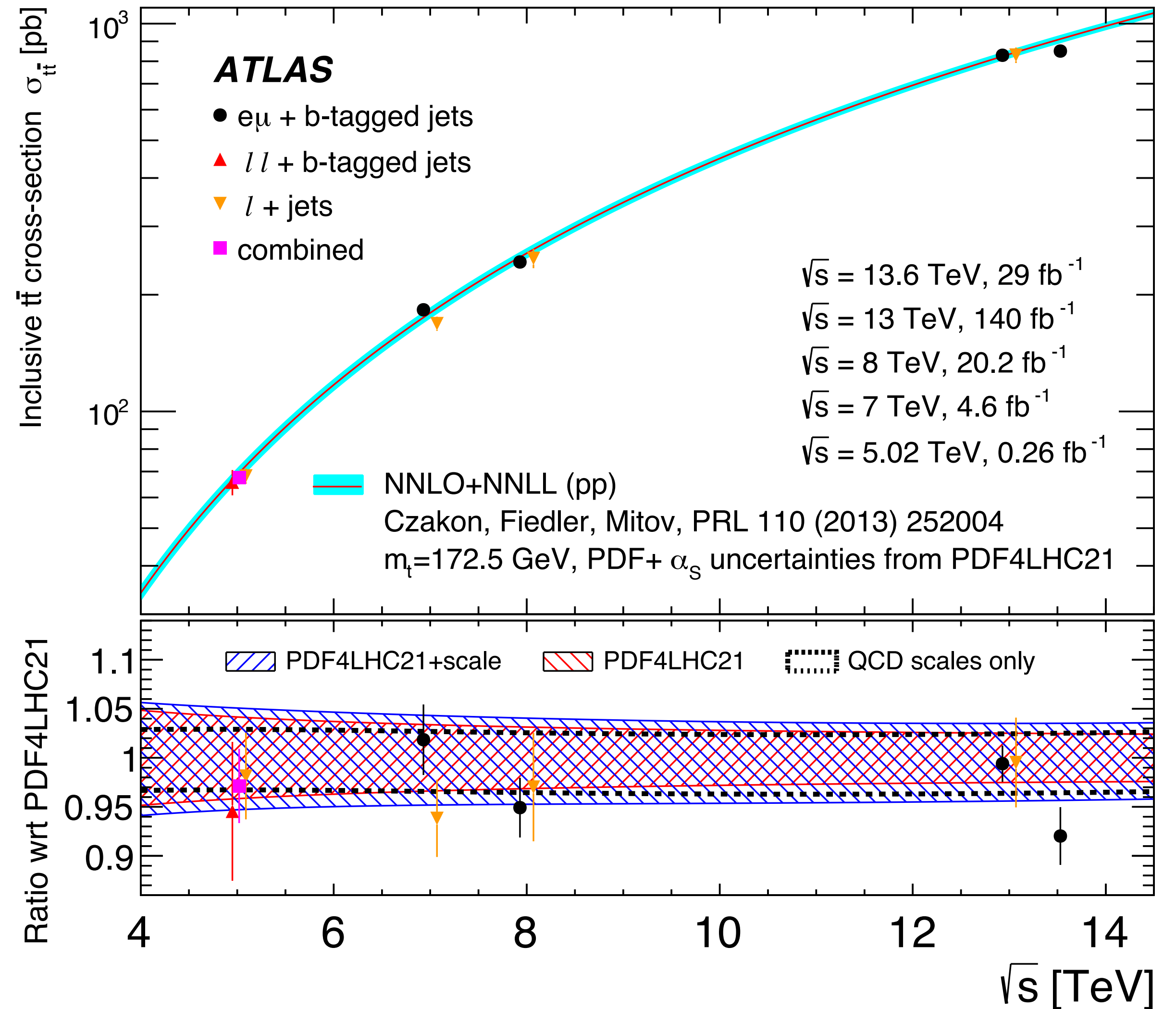


- The measured differential distributions are also interpreted in an EFT approach to constrain the Wilson-Coefficient  $C_{Qq}^{3,1}$  associated with a four-quark operator.
- High absolute values of  $C_{Qq}^{3,1} / \Lambda^2$  would increase the number of (anti)top quarks produced at higher transverse momenta.
  - Selection efficiency is altered significantly by non-zero  $C_{Qq}^{3,1}$  contributions.
- The 95% confidence level is measured to be  $|C_{Qq}^{3,1} / \Lambda^2| < 0.12 \text{ TeV}^{-2}$ .



- Many full Run 2 (140 fb<sup>-1</sup>) measurements performed:
  - $t\bar{t}$ +jets, including dedicated ones with heavy-flavour jets ([JHEP 01 \(2025\) 068](#), [JHEP 08 \(2024\) 182](#), [Phys. Lett. B 860 \(2025\) 139177](#), [JHEP 11 \(2024\) 101](#), [arXiv:2509.15066](#))
  - Same charge  $tt$  or  $\bar{t}\bar{t}$  search ([JHEP 02 \(2025\) 084](#))
  - Inclusive  $WWbb$  final state ([JHEP 02 \(2026\) 153](#), [arXiv:2510.26476](#))
- Also first measurement available for Run 3 together with the ratio to the Z boson production cross-section ([Phys. Lett. B 848 \(2024\) 138376](#)).

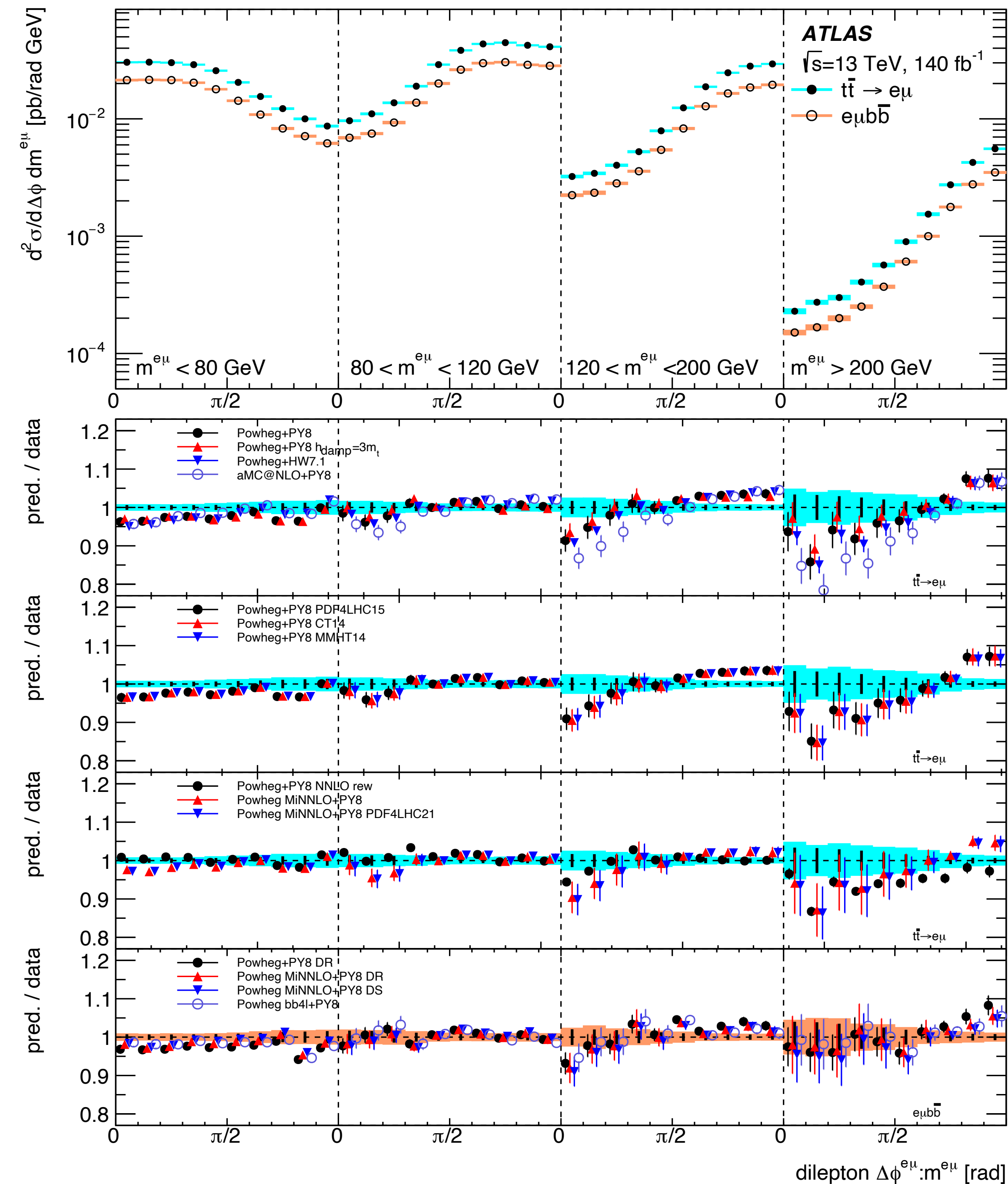
ATL-PHYS-PUB-2025-024



# ELECTRON-MUON DILEPTON DIFFERENTIAL TOP PAIR CROSS-SECTION



[arXiv:2509.15066](https://arxiv.org/abs/2509.15066) (submitted to EPJC)



- Inclusive cross-section measurement in the  $e^\pm\mu^\mp$  channel using the full Run 2 dataset:

$$\sigma(t\bar{t}) = 829.3 \pm 11.1 \text{ pb}, \quad \Delta\sigma/\sigma = 1.3\% \quad !!!$$

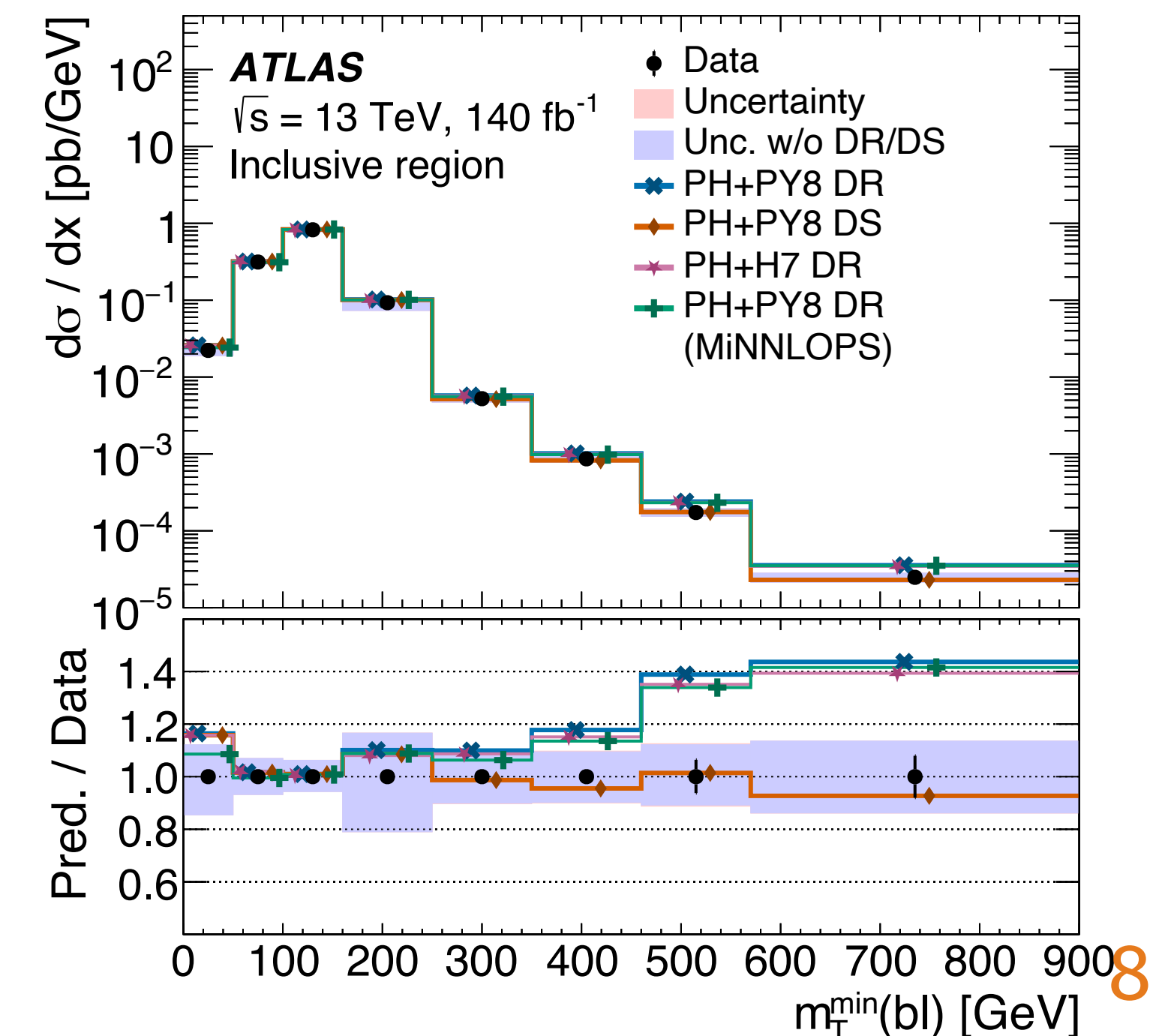
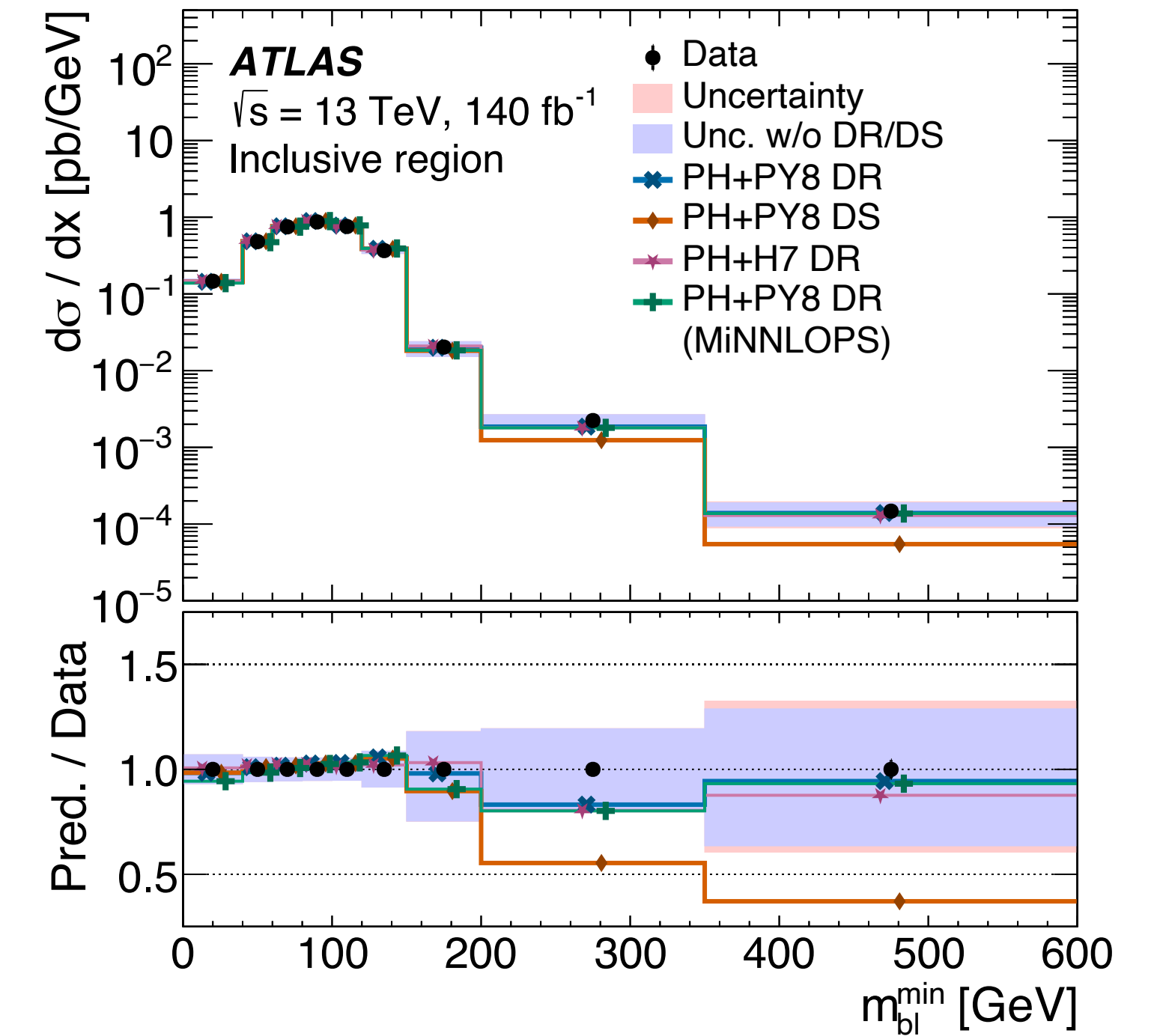
- Absolute and normalised single and double differential cross-sections for the  $t\bar{t} \rightarrow e^\pm\mu^\mp\nu\bar{\nu}b\bar{b}$  process as a function of single-lepton and dilepton kinematic variables.
- Complementary measurement treating both  $t\bar{t}$  and  $tW$  events as signal.
- State-of-the-art generators Powheg MiNNLO & Powheg  $bb4l$  describe the data better than Powheg  $h\nu q$  (the usual LHC workhorse).

# DIFFERENTIAL CROSS-SECTION MEASUREMENTS OF $WBWB$ EVENTS (1)

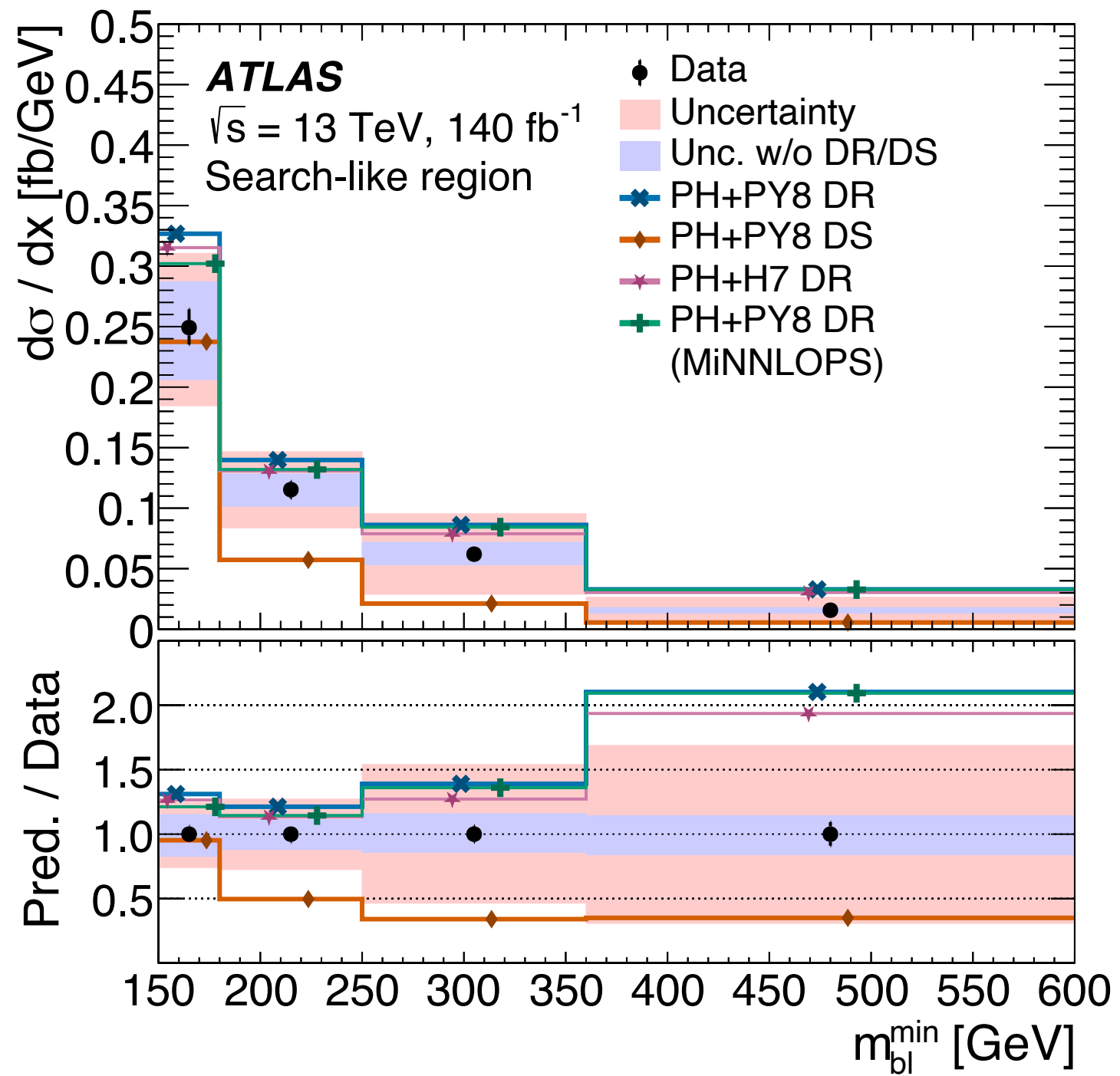


- Two dedicated measurements of coherent production of singly and doubly resonant top-quark in  $W^+W^-b\bar{b}$  events performed, with **one lepton and two leptons in the final state**.
- Focusing on the  $m_{b\ell}$  as the proxy for the interference between  $t\bar{t}$  and  $tW$  events.
  - The combination yielding the lowest mass in the single-lepton channel.
  - The “minimax” variable in the dilepton channel:
 
$$m_{b\ell}^{\text{minimax}} = \min \left( \max(m_{b_1\ell_1}, m_{b_2\ell_2}), \max(m_{b_1\ell_2}, m_{b_2\ell_1}) \right)$$
- **None of the models describe the tails of the distributions well.**
  - Different models describe different distributions better.
  - Even the new  $bb4l$  model (tested in the dilepton channel) fails to describe the minimax variable well.

[JHEP 02 \(2026\) 153](#)  
[arXiv:2510.26476](#)  
 (submitted to JHEP)

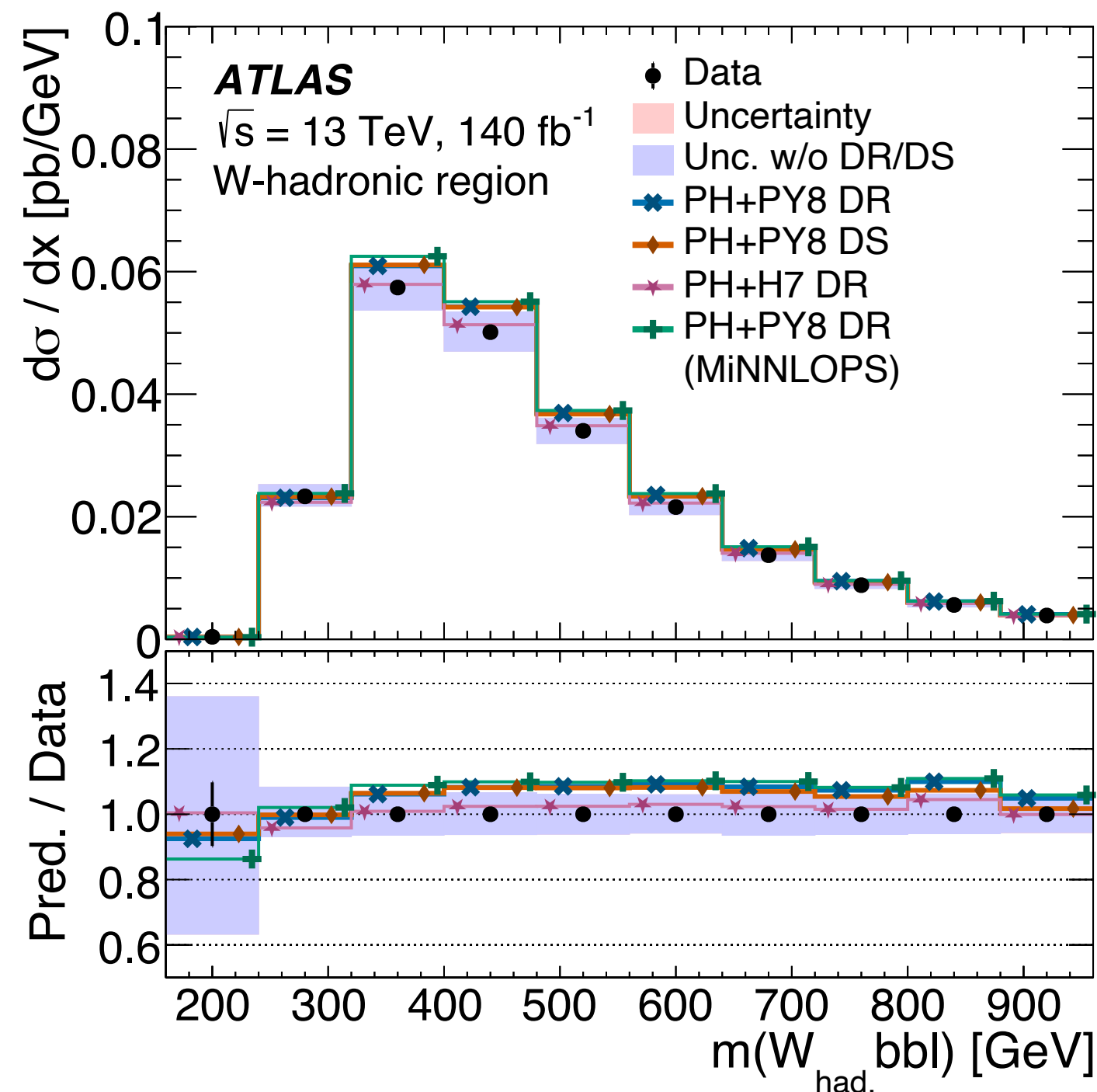
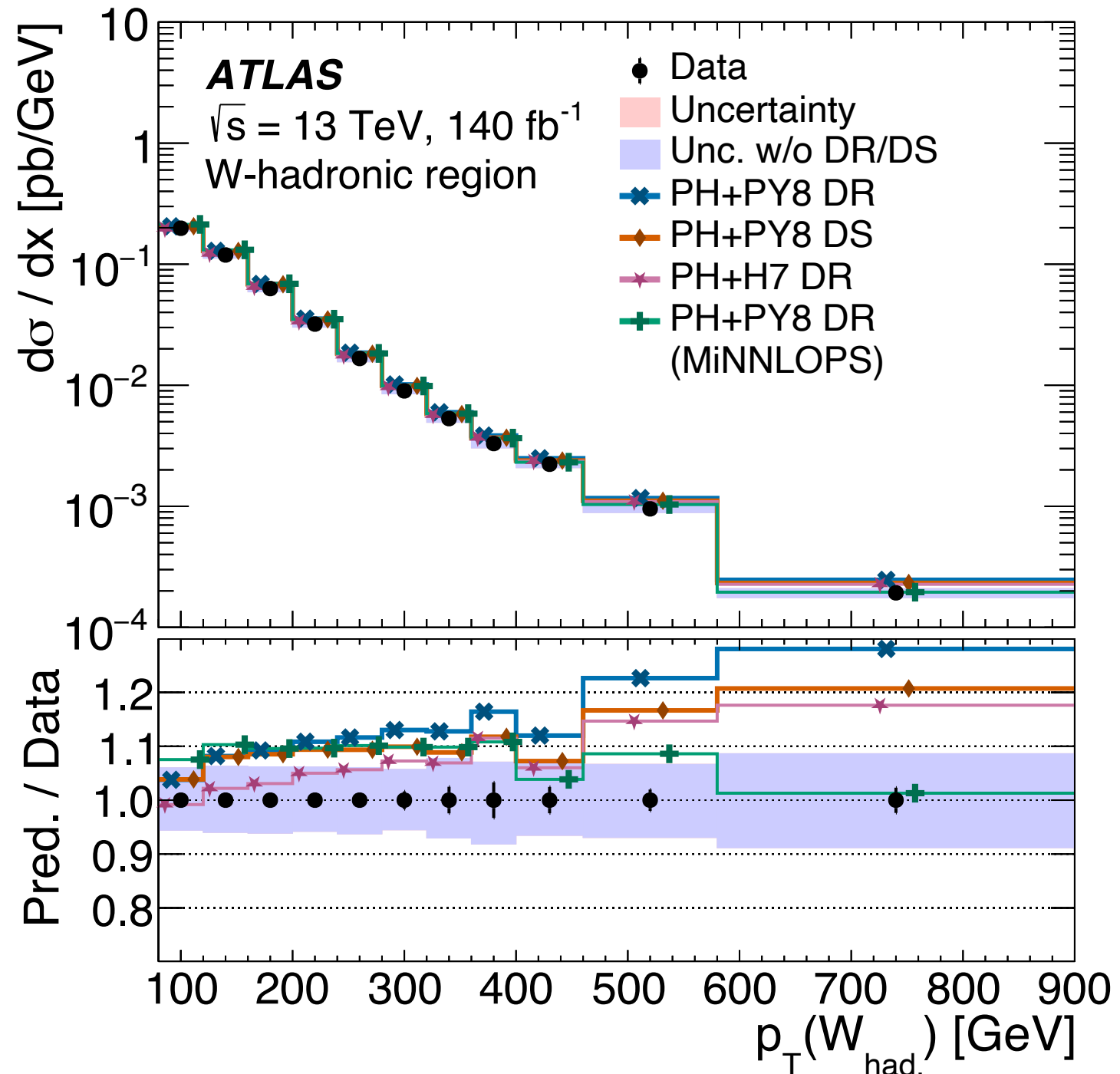


# DIFFERENTIAL CROSS-SECTION MEASUREMENTS OF $WBWB$ EVENTS (2)



- Specialised selections defined in the single-lepton channel:

- Search-like region — high  $m_{bl}^{\min}$
- W-hadronic region — focusing on the hadronic W boson reconstruction and related observables
- Search-like region very sensitive to the interference — high DR/DS modelling uncertainty.
- All predictions envelope the data.

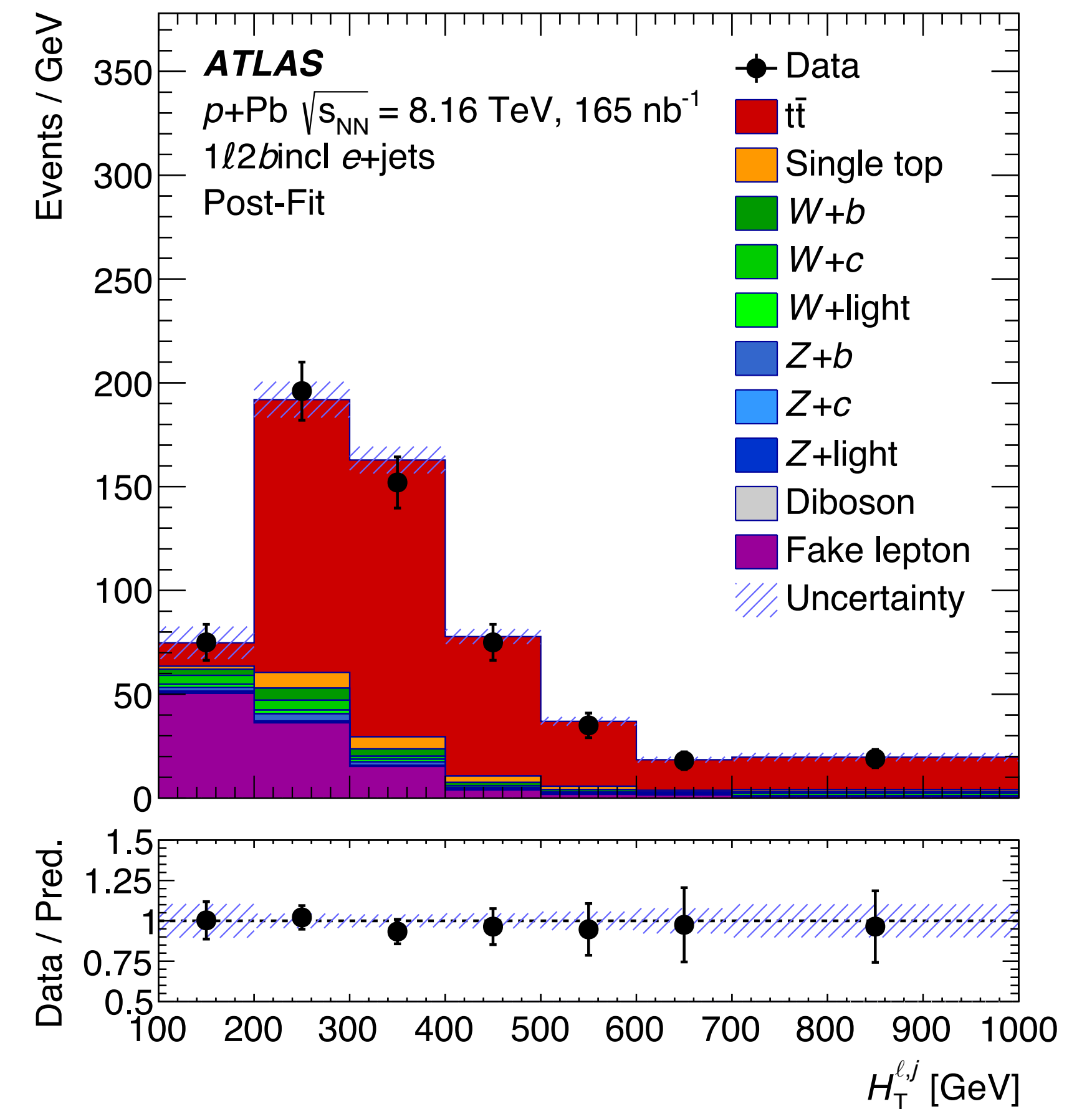
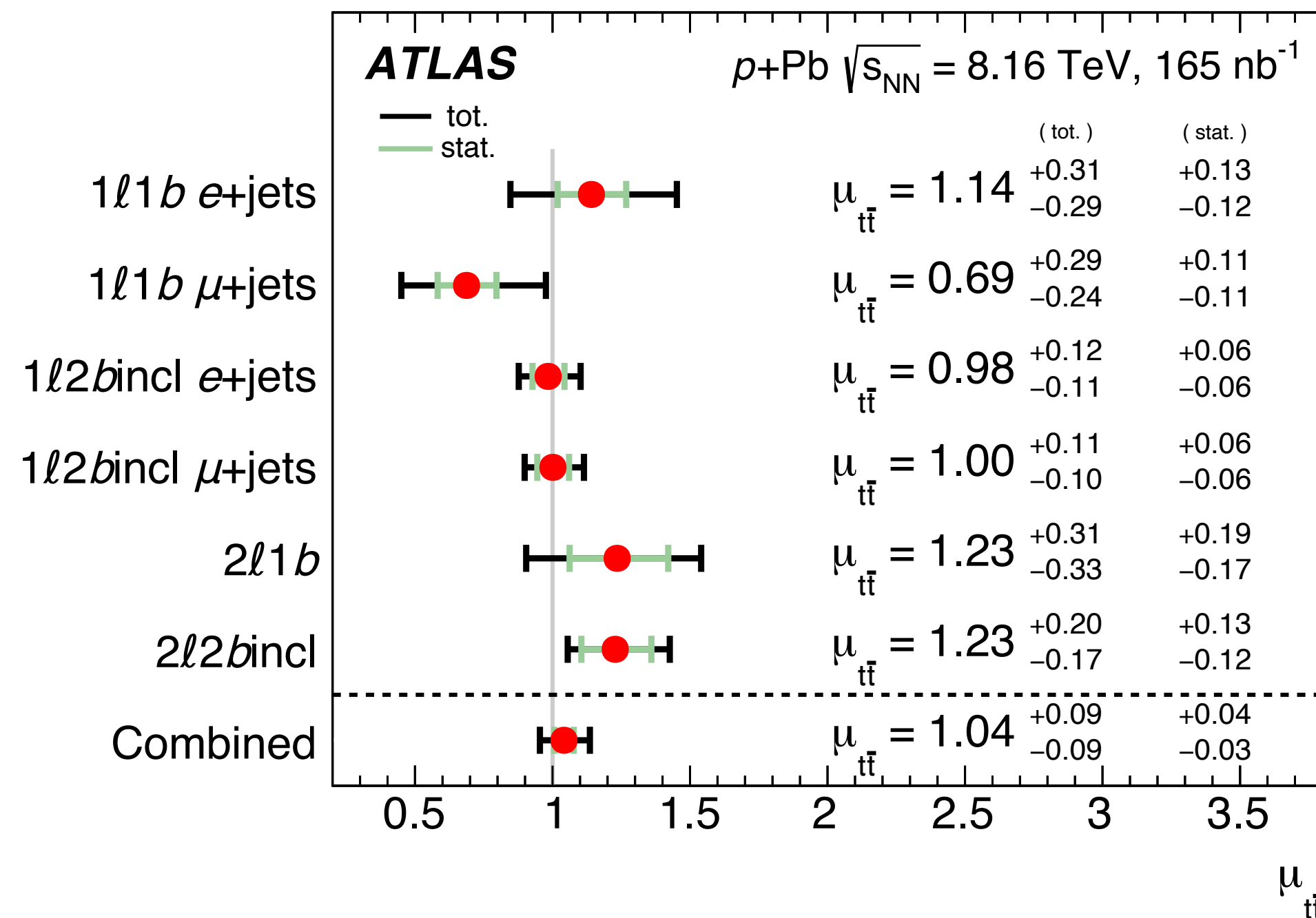


- W-hadronic measurement less sensitive to the interference — lower uncertainties.
- Showering with Herwig7 and the MiNNLOPS model agree with the data the best.



- The measurement is performed using  $165 \text{ nb}^{-1}$  of  $p+\text{Pb}$  data collected by ATLAS at  $\sqrt{s_{\text{NN}}} = 8.16 \text{ TeV}$  in 2016.
- Top-quark pair production is observed with a significance over  $5\sigma$  in each channel.
- $\sigma(t\bar{t}) = 58.1_{-4.9}^{+5.2} \text{ nb}$ ,  $\Delta\sigma/\sigma = 9\%$
- The nuclear modification factor also measured

$$R_{pA} = \frac{\sigma_{t\bar{t}}^{p+\text{Pb}}}{A_{\text{Pb}} \cdot \sigma_{t\bar{t}}^{pp}} = 1.090 \pm 0.100, \Delta R/R = 9\%$$



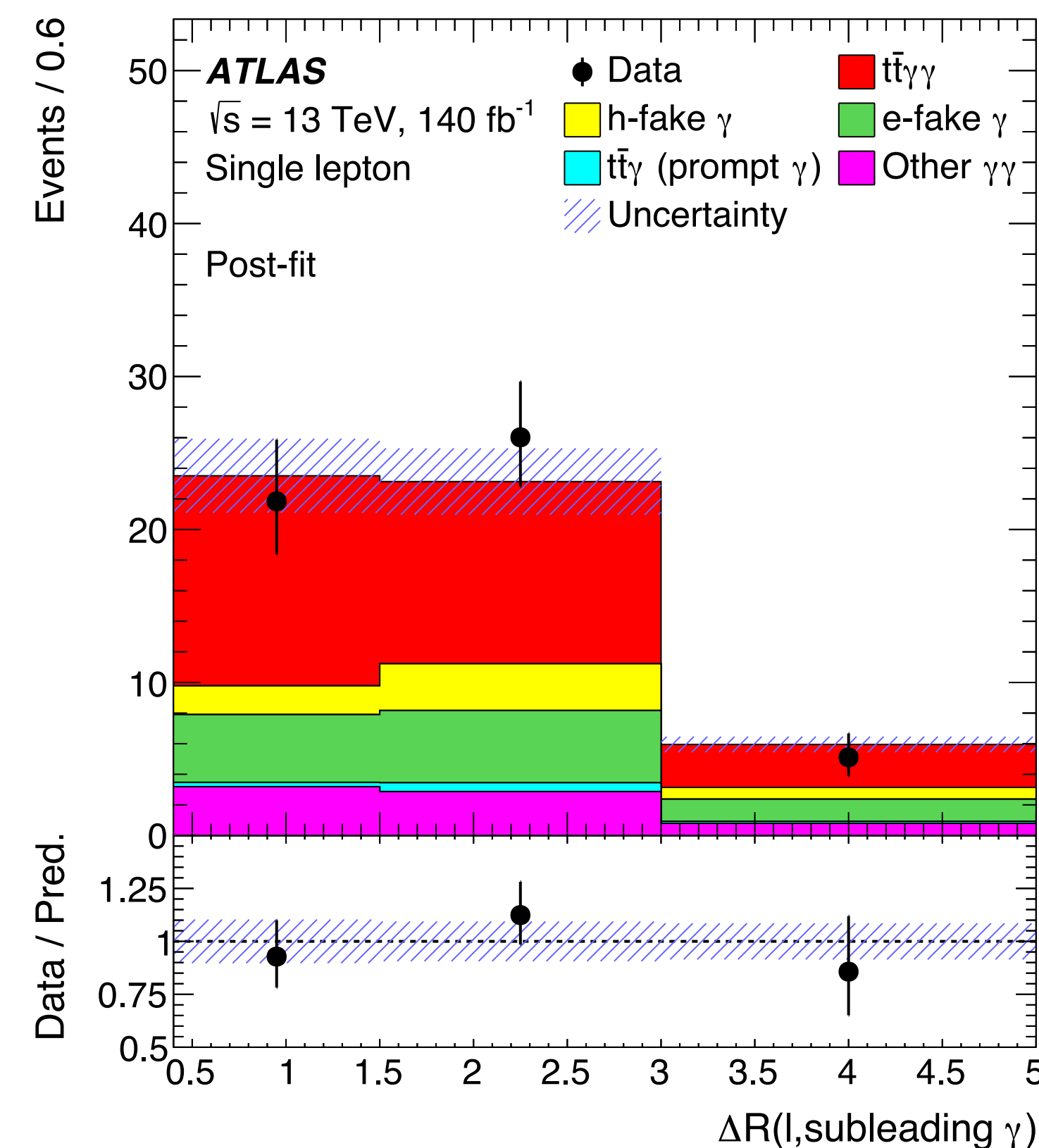
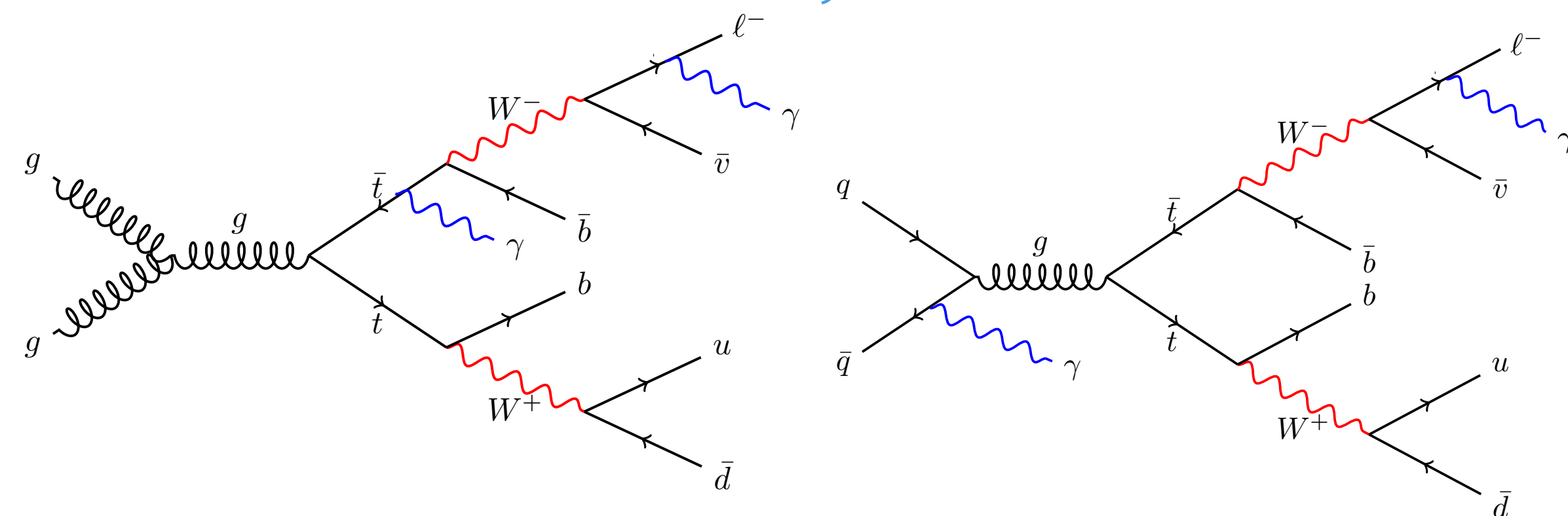


- Several measurements of top quark pair production with additional bosons were performed with full Run 2 data:
  - $t\bar{t}\gamma$  ([JHEP 10 \(2024\) 191](#))
  - $t\bar{t}Z$  ([JHEP 07 \(2024\) 163](#))
  - $t\bar{t}W$  ([JHEP 05 \(2024\) 131](#))
  - High-mass  $t\bar{t}\ell^+\ell^-$  ([Eur. Phys. J. C 85 \(2025\) 1434](#))
  - $t\bar{t}\gamma\gamma$  ([Phys. Lett. B 874 \(2026\) 140195](#))
  - $t\bar{t}Wj$  ([arXiv:2509.19038](#))



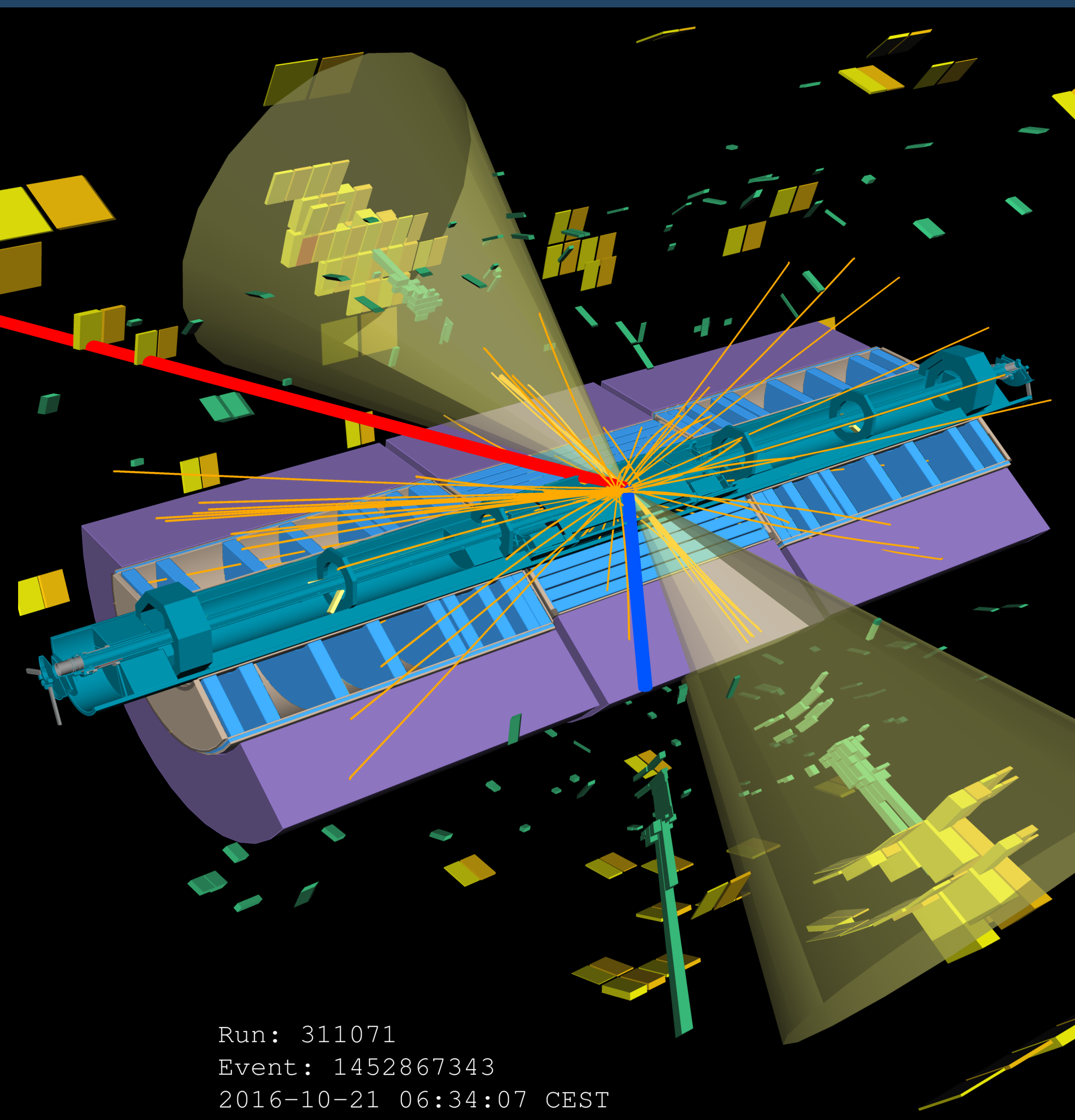
[Phys. Lett. B 874 \(2026\) 140195](#)

- Event selection:
  - exactly 2 isolated photons
  - exactly one isolated electron or muon
  - $e\gamma$  Z-veto
  - at least 4 jets, of which at least one tagged as a  $b$ -jet
- Fiducial cross-section measured
 
$$\sigma_{t\bar{t}\gamma\gamma} = 2.42 \pm 0.58, \quad \Delta\sigma/\sigma = 23\%$$
- Ratio to the  $t\bar{t}\gamma$  cross-section also measured
 
$$R_{t\bar{t}\gamma\gamma/t\bar{t}\gamma} = (3.30 \pm 0.70) \times 10^{-3}, \quad \Delta R/R = 20\%$$
- Observed significance of  $5.2\sigma$ .

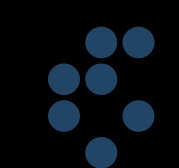


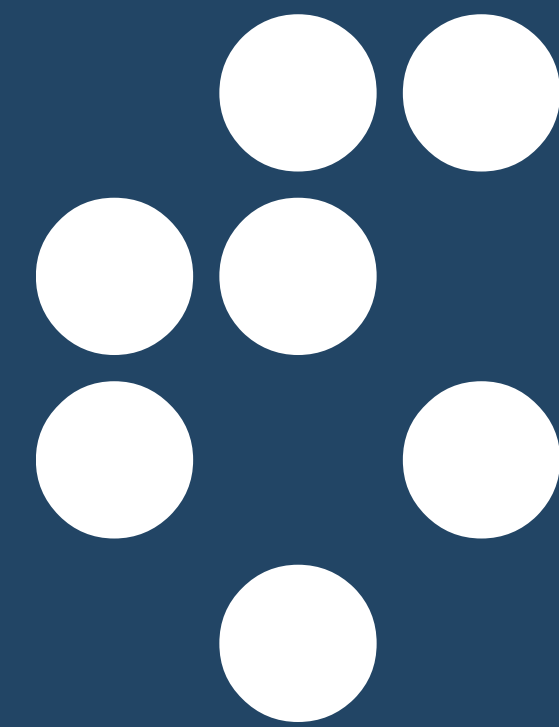


- ATLAS managed to achieve extraordinary top quark measurement precision using full Run 2 data.
  - Many measurements limited by systematic uncertainties.
- Run 3 still ongoing.
  - About  $415 \text{ fb}^{-1}$  already available together with Run 2 — 3x increase.
- MC predictions more precise than NLO are needed for future measurements — presented results may help to achieve that.



Run: 311071  
Event: 1452867343  
2016-10-21 06:34:07 CEST





# DIFFERENTIAL CROSS-SECTION MEASUREMENTS OF $WbWb$ EVENTS (3)

