Top-quark mass, properties and cross section in ATLAS and CMS

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on behalf of the ATLAS and CMS collaborations
Weak Interactions and Neutrinos, WIN2025
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Content

Overview of the **most recent** top-quark results by ATLAS and CMS

- $t\bar{t}$ and single top-quark cross section
- top-quark mass and other properties

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- CMS [Link]
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Here, will cover five results, all using full Run-2 dataset (13 TeV)

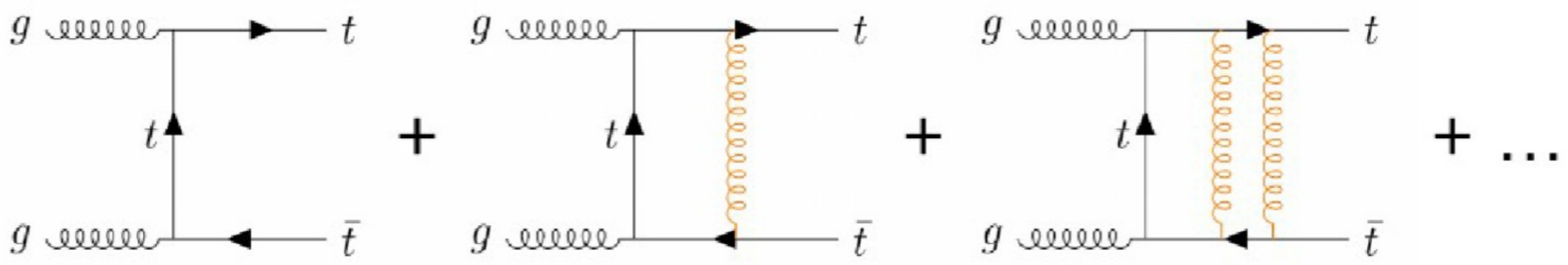
- $t\bar{t}$ production at threshold arXiv:2503.22382
- WbWb dilepton production CERN-EP-2025-094
- Top-quark mass at high transverse momentum Phys. Lett. B 867 (2025) 139608
- Quantum entanglement and magic Rep. Prog. Phys. 87 (2024) 117801 Nature 633 (2024) 542 Phys. Rev. D 110 (2024) 112016 CMS-PAS-TOP-25-001
- Test of lepton flavour universality in W decays Eur. Phys. J. 84 (2024) 993 JHEP 05 (2025) 038

$t\bar{t}$ production at threshold

arXiv:2503.22382

Top-quark bound state?

- lifetime of top-quark is too short
- still QCD predicts quasi-bound $t\bar{t}$ states below the $t\bar{t}$ threshold
- dominant component is pseudo-scalar



At threshold

- non-perturbative
- colour singlet ${}^1S_0^{[1]}$
  - attractive potential $V(r) = -\frac{4}{3}\frac{\alpha_S}{r}$ → peak
- colour octet ${}^1S_0^{[8]}$
  - repulsive potential $V(r) = \frac{1}{6}\frac{\alpha_S}{r}$
- but: no MC generator available

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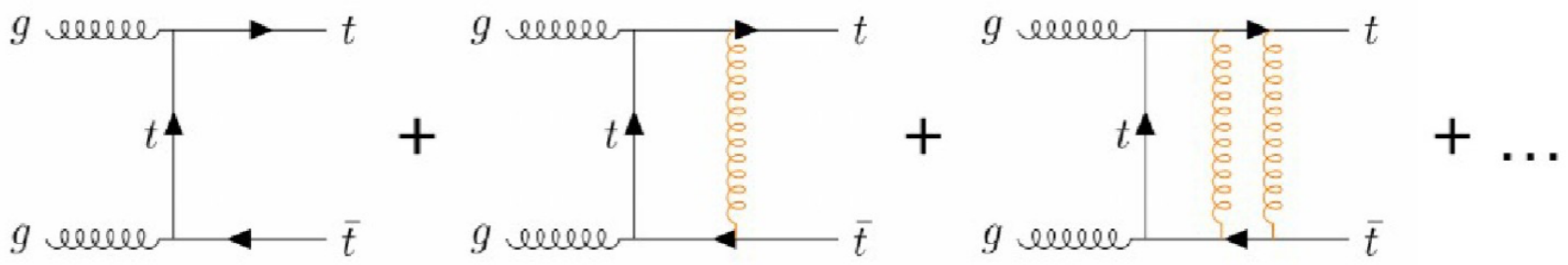

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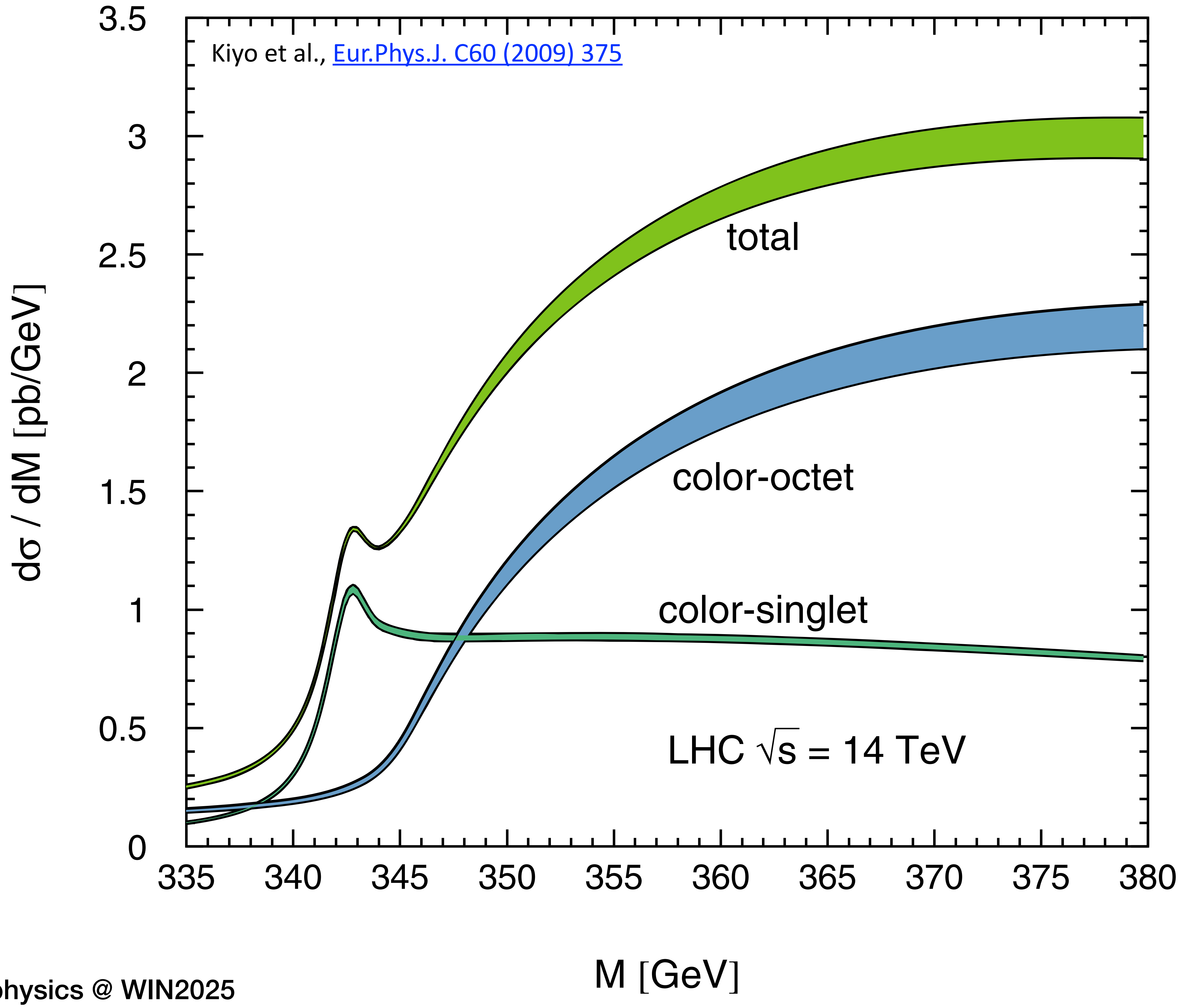

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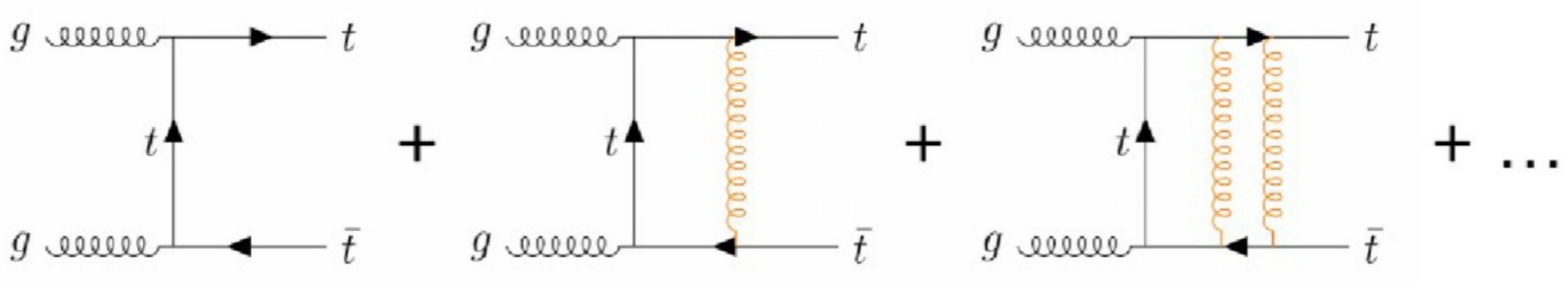
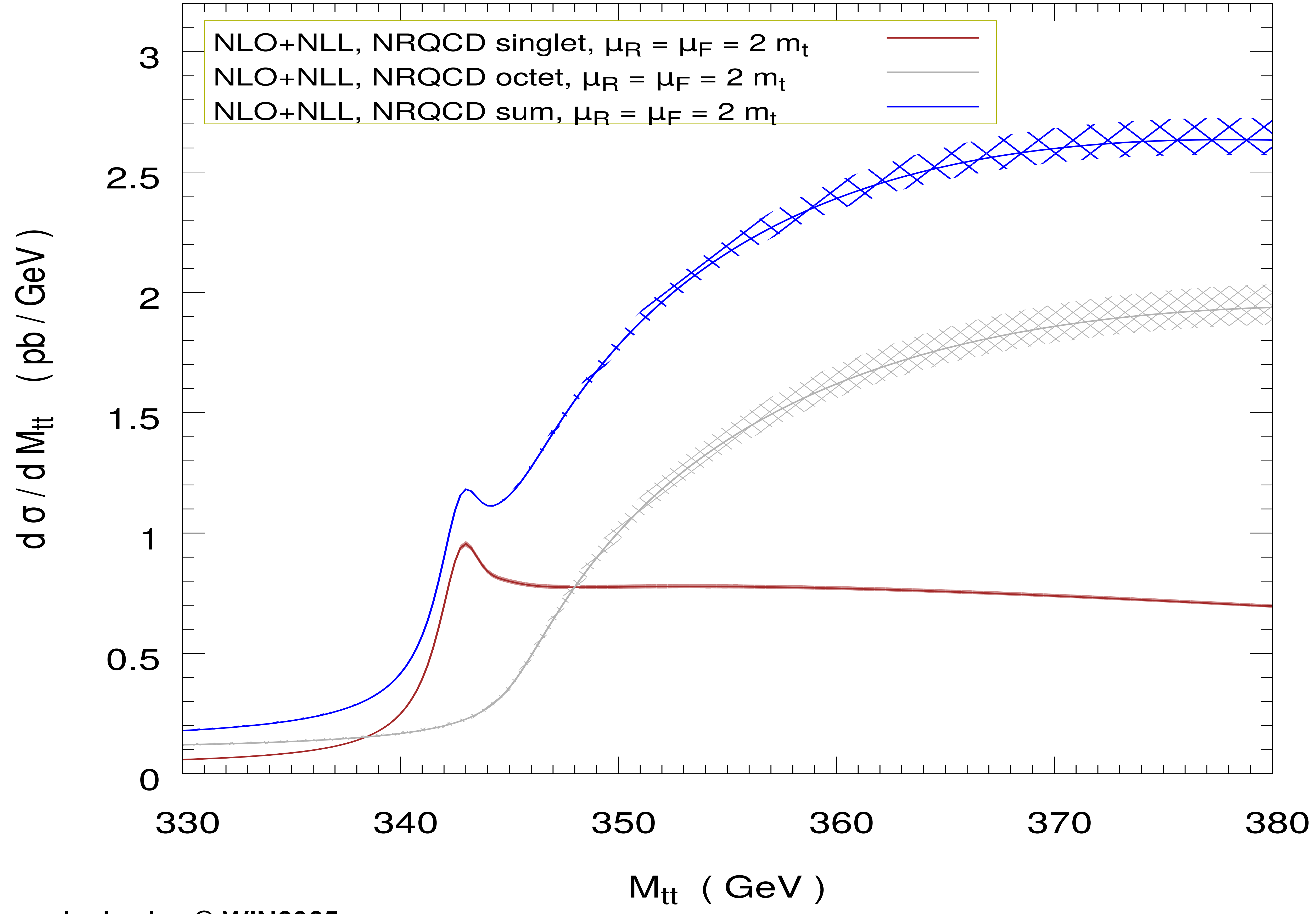


Garzelli et al. Phys.Lett.B 866 (2025) 139532 including Coulomb resummation for bound-state effects and threshold resummation for emissions of soft and collinear gluons



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$t\bar{t}$ production at threshold

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Simplified model

- pseudo-scalar simulated with m_{η_t}= 343 GeV and Γ_{η_t}= 2.8 GeV

Dilepton $t\bar{t}$ selection

- reconstruct $t\bar{t}$ system analytically, after smearing (100 times) to account for resolution

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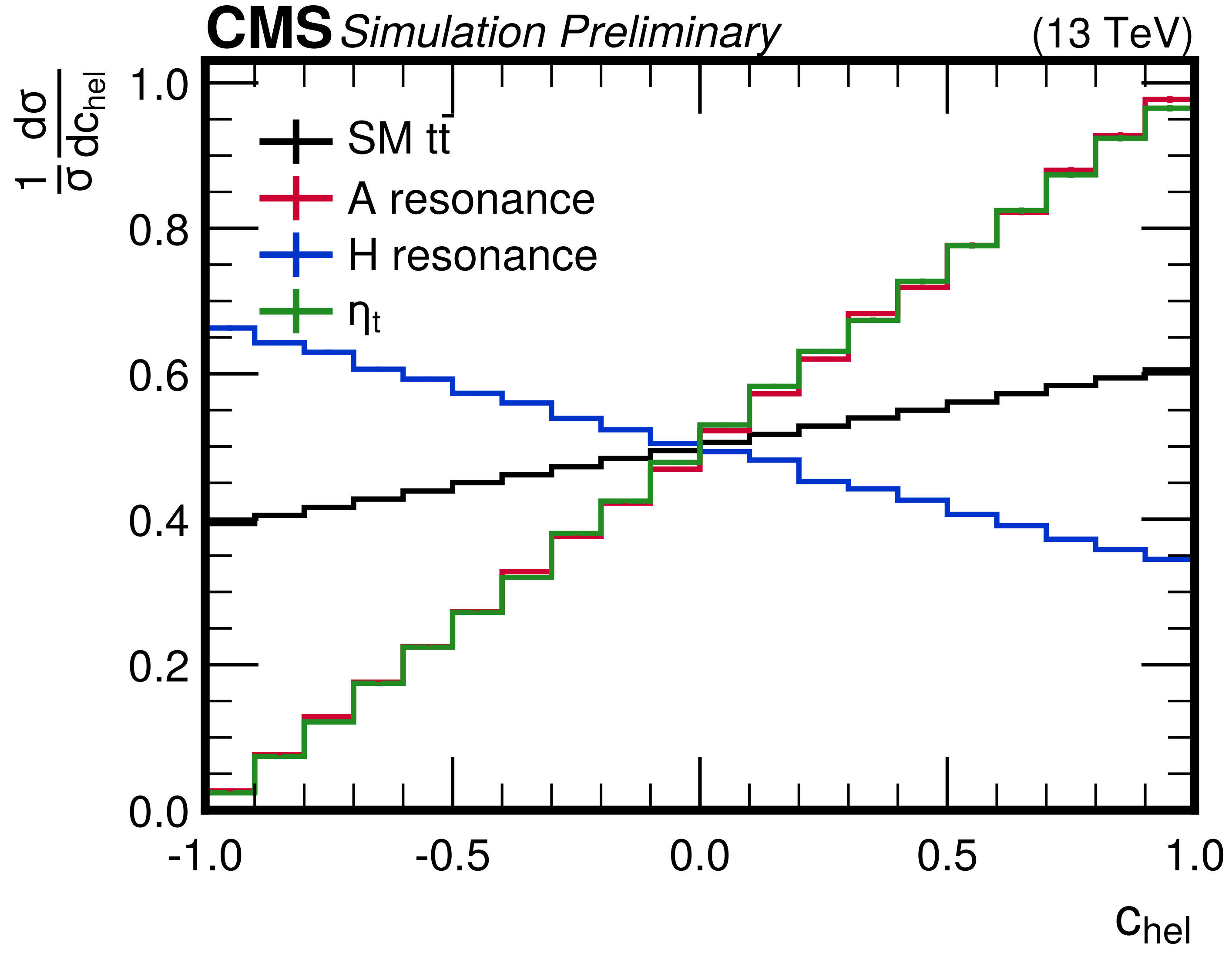
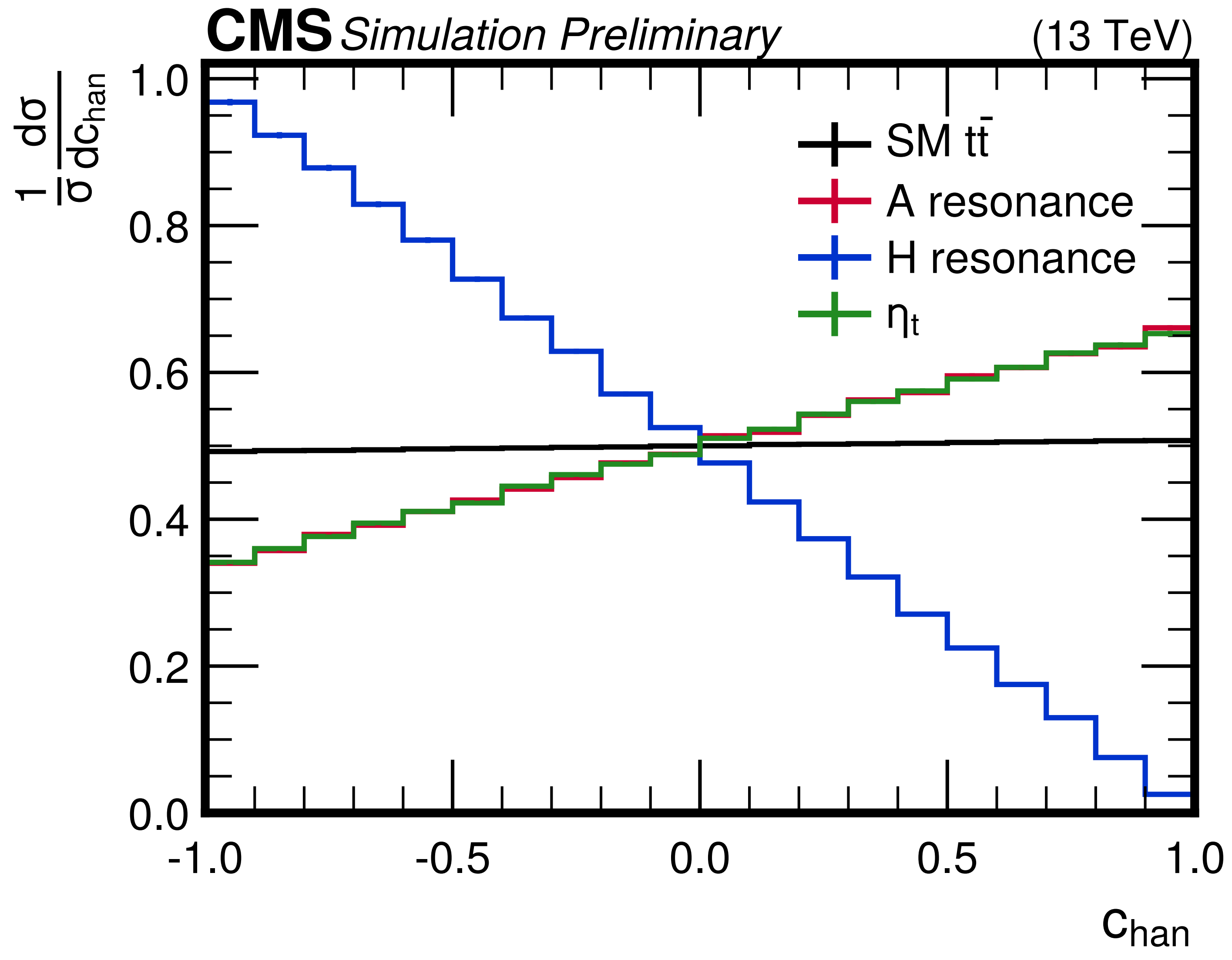
Observables

- $m_{t\bar{t}}$, $c_{\text{hel}} = \hat{\ell}_t^+ \cdot \hat{\ell}_{\bar{t}}^-$, and c_{han} (flip one ℓ in top direction)
- can distinguish between η/A (pseudo-scalar) and H (scalar)





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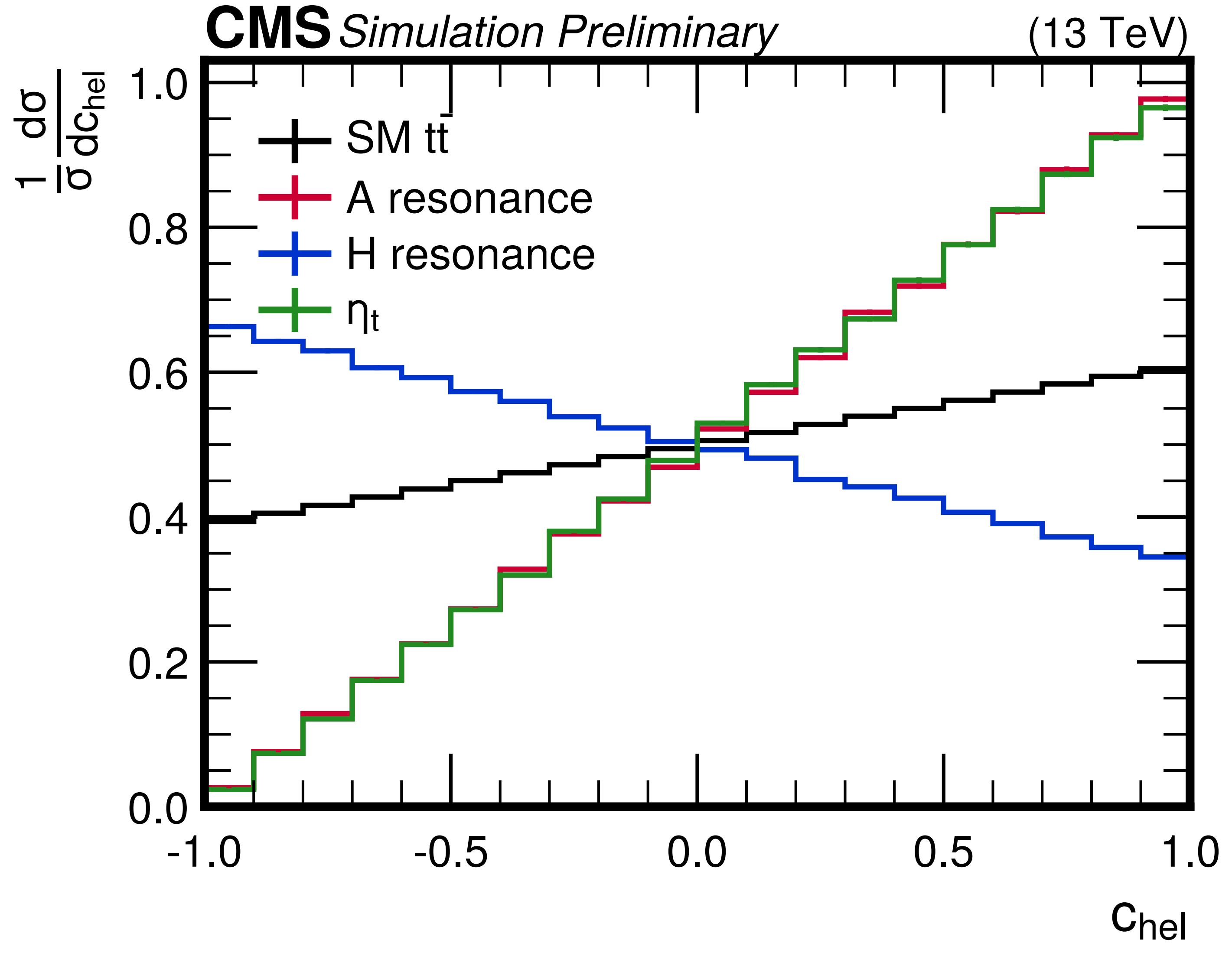
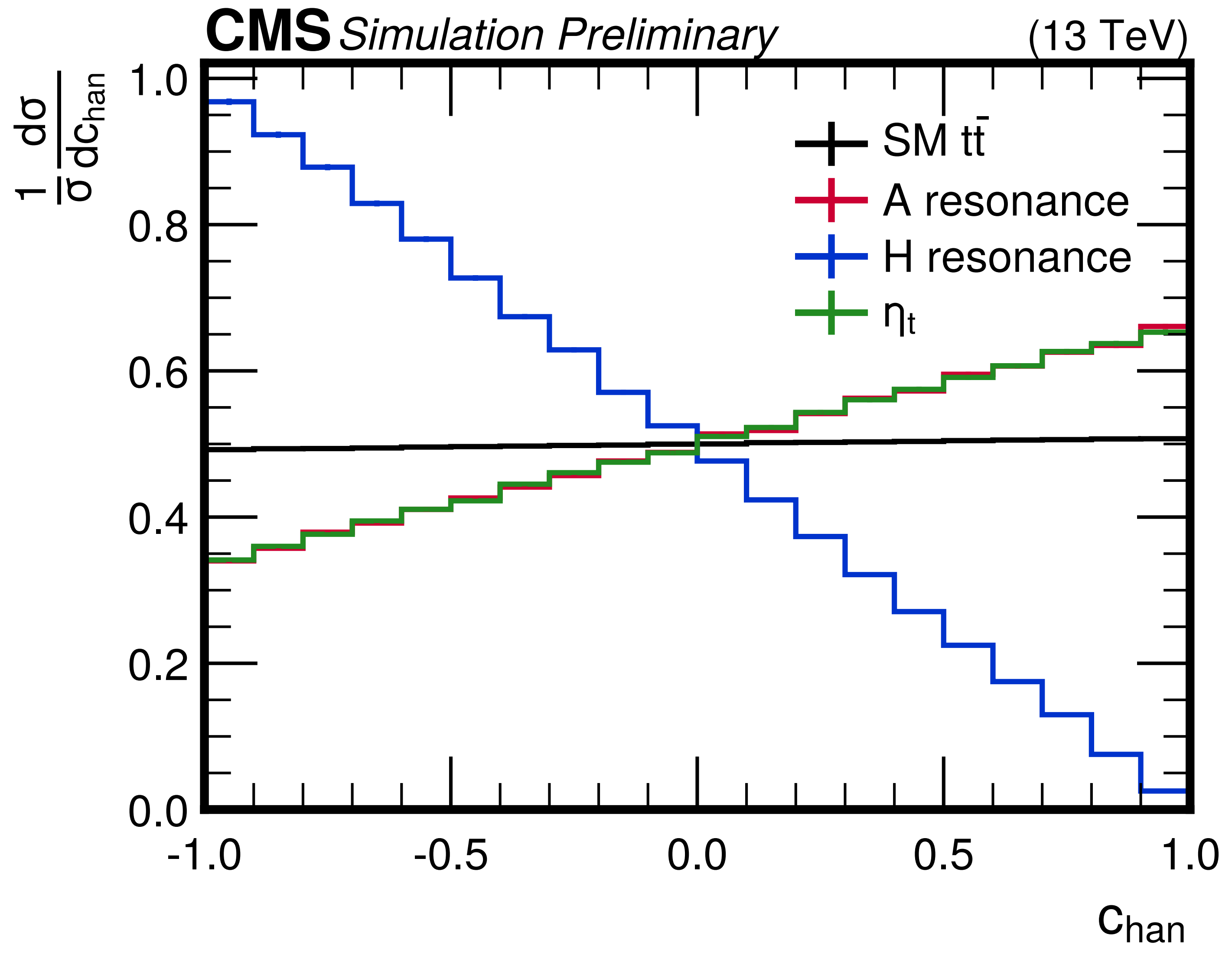
Modeling

- $t\bar{t}$ with Powheg+Pythia
- corrected to NNLO QCD, NLO EW by reweighting in bins of $m_{t\bar{t}}$ and cos θ*
- normalised to NNLO+NNLL cross section





Observation of pseudo-scalar excess

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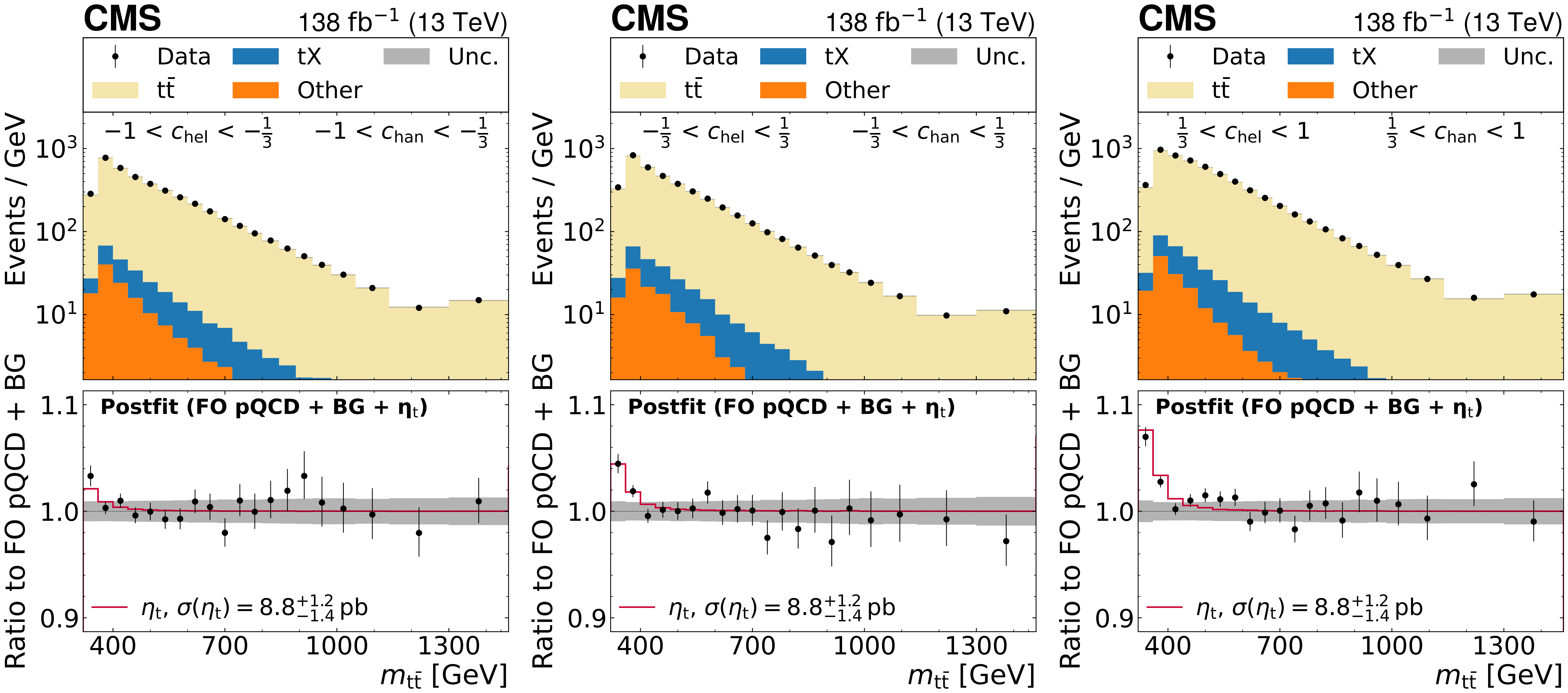
Simultaneous profile-likelihood fit to $m_{t\bar{t}}$, c_{hel}, c_{han}



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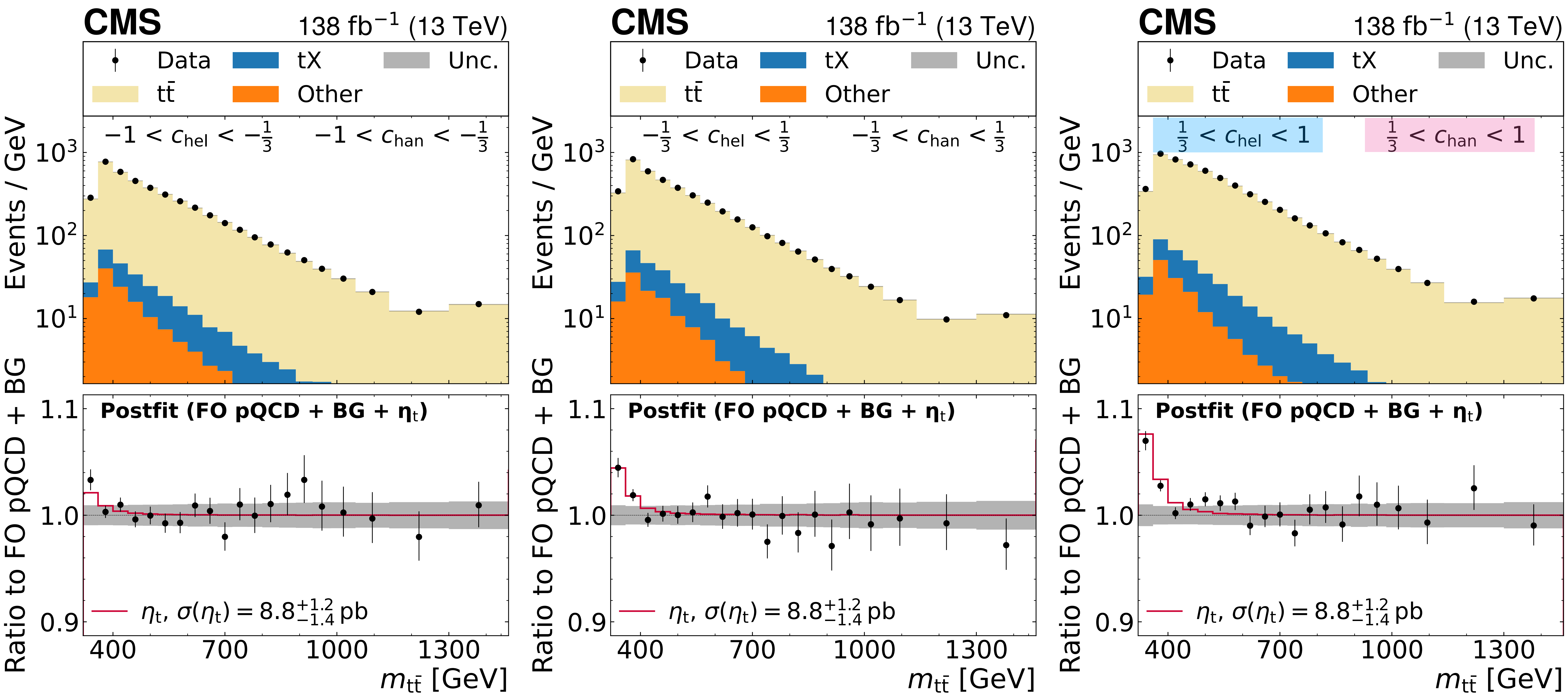

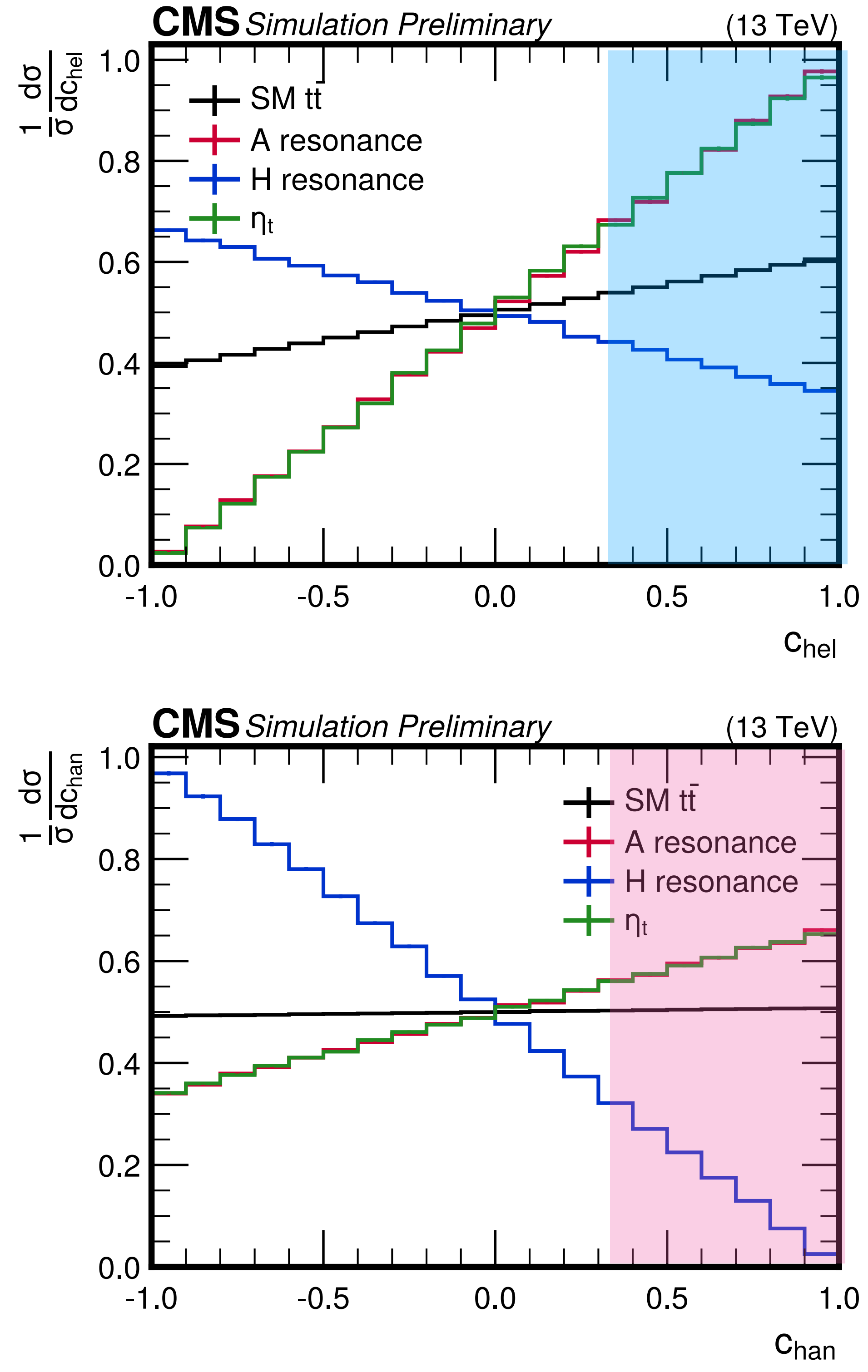

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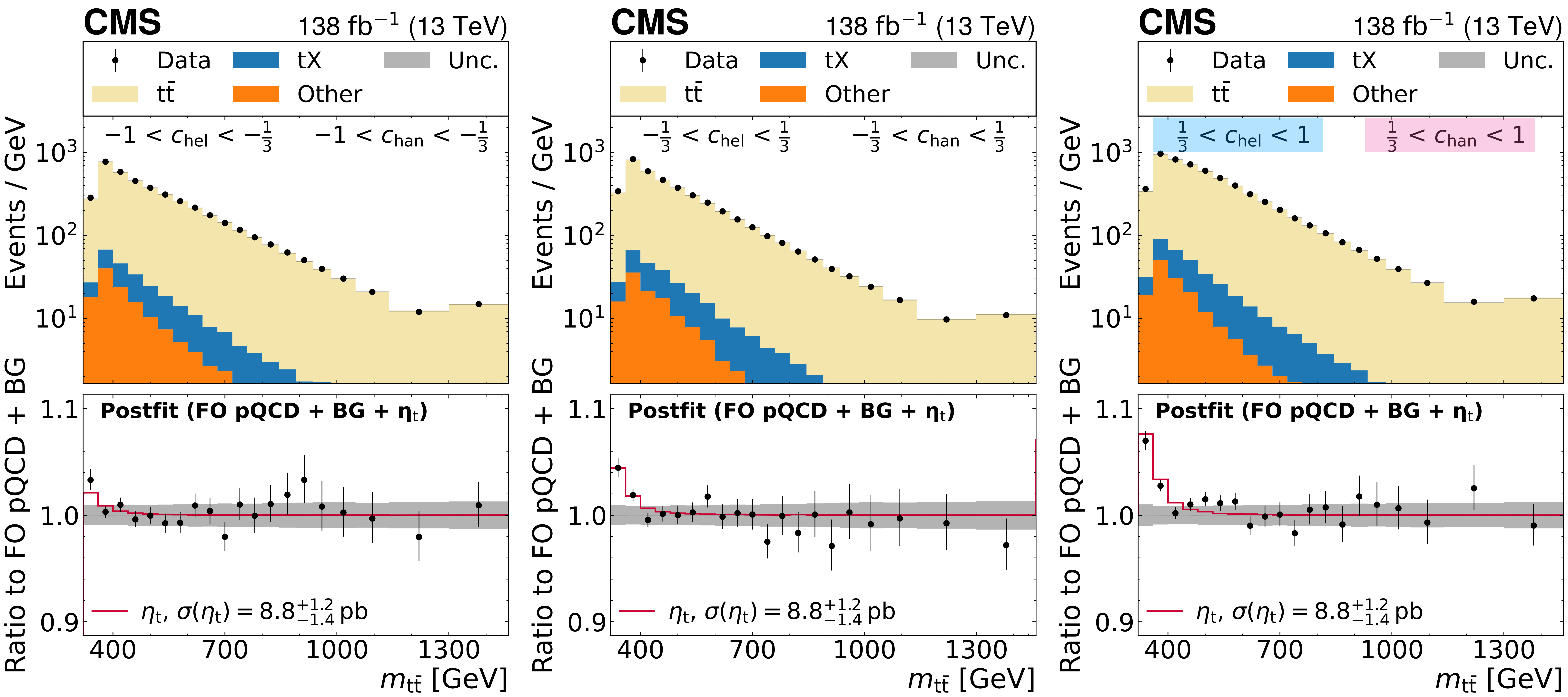
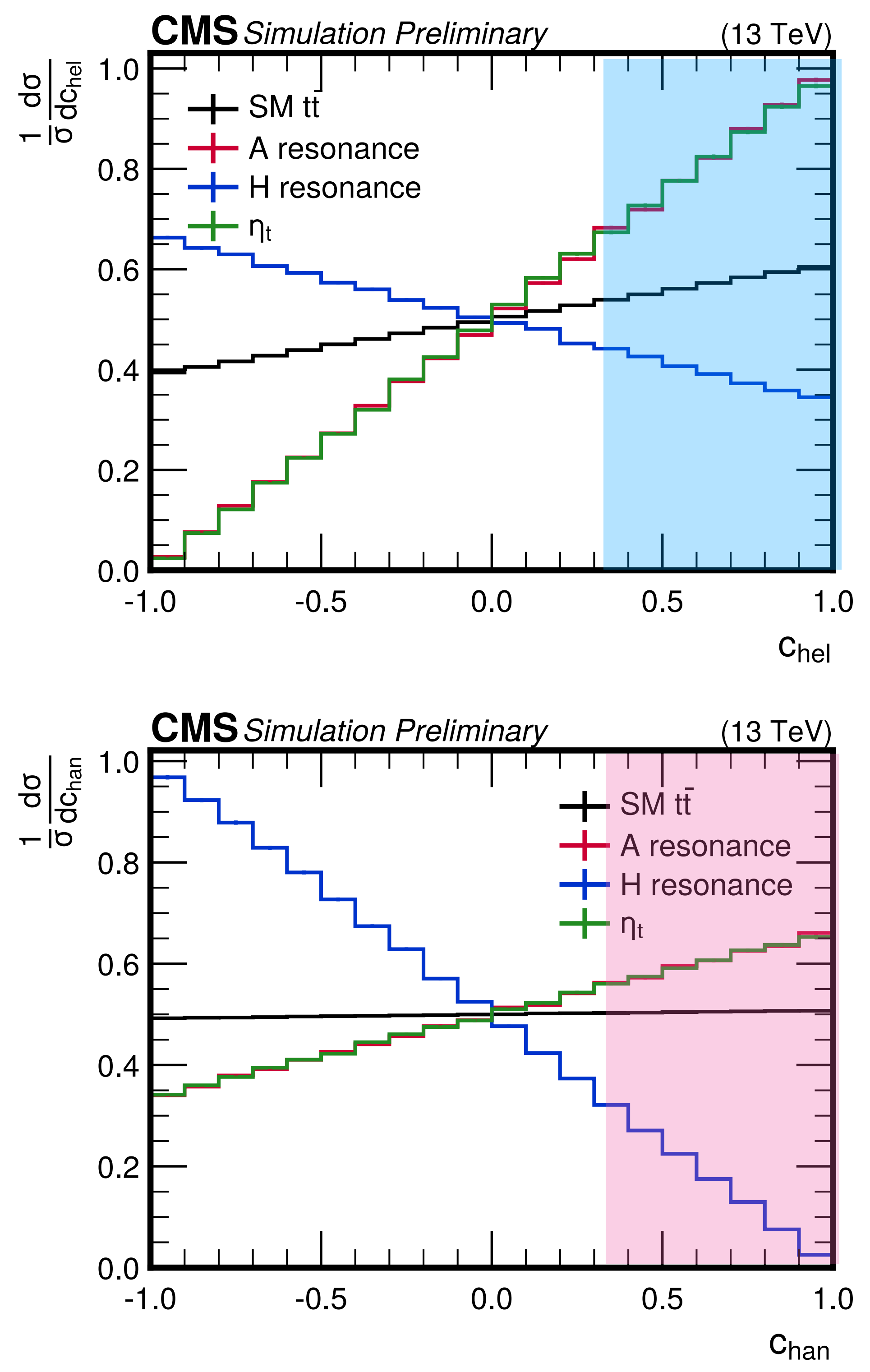




Clear excess in low $m_{t\bar{t}}$ and most pronounced in high c_{hel} → $\sigma_{\eta_t} = 8.8 \pm 0.5\,(\text{stat.})\,^{+1.2}_{-1.4}\,(\text{syst.})$

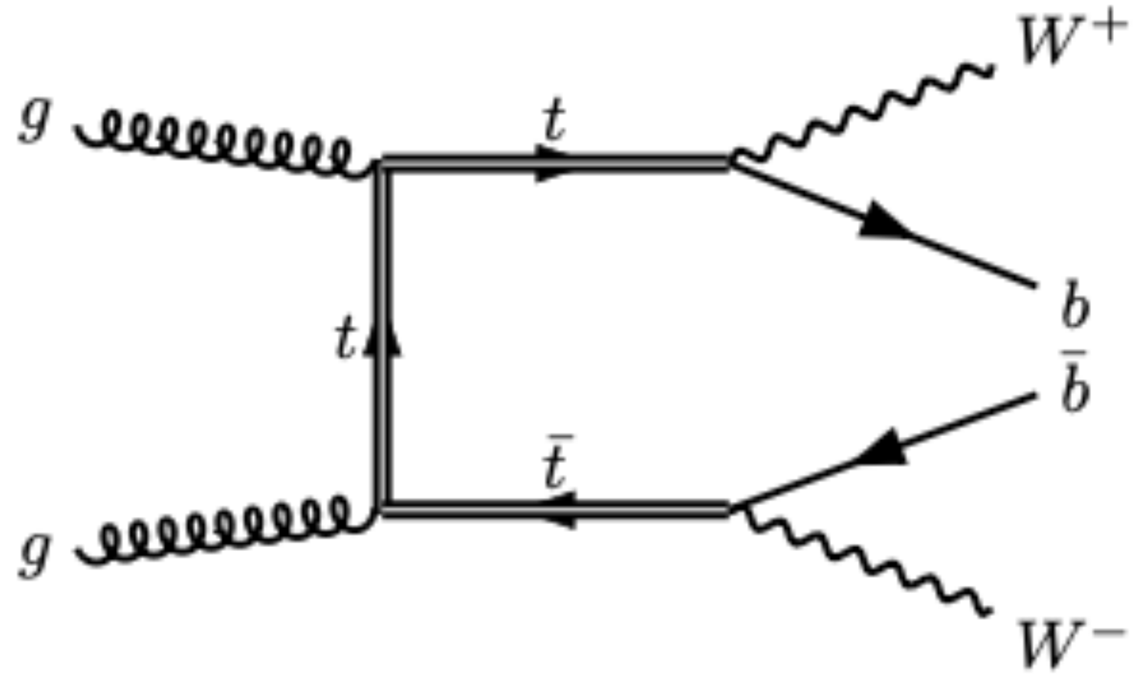
Caveat: $t\bar{t}$ threshold difficult to model; can't distinguish η_t from generic pseudo-scalar A

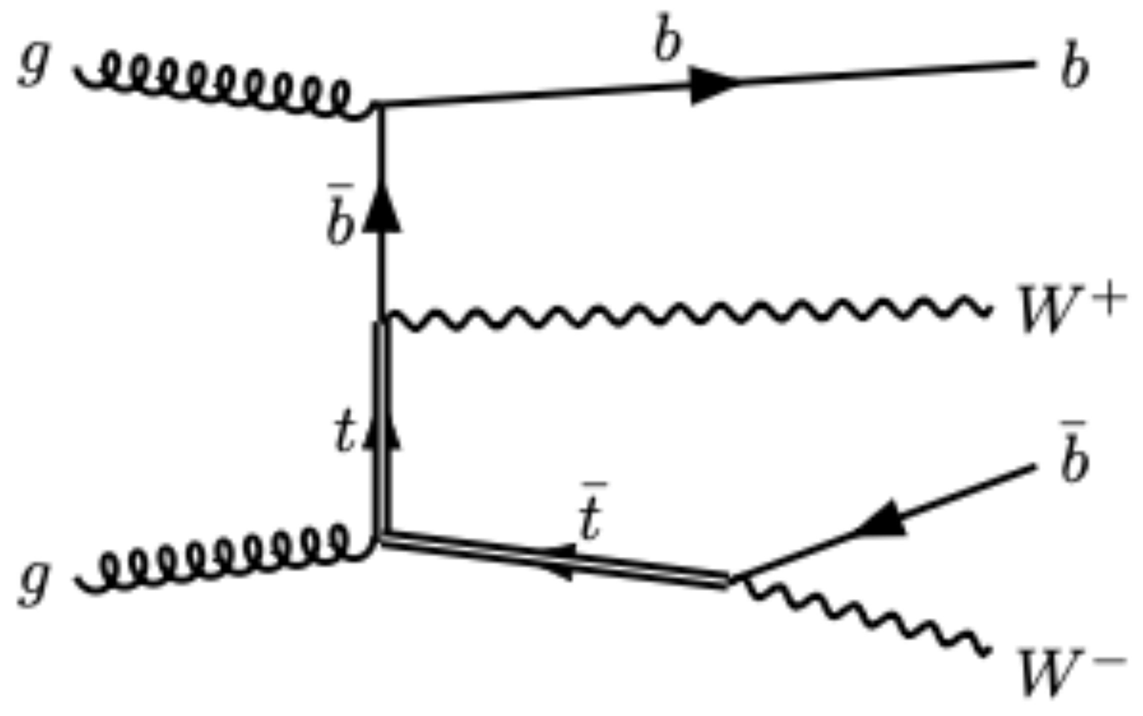
WbWb production

CERN-EP-2025-094

Scope:

- **Tackle the $t\bar{t}$/tWb interference**: differential cross section for one variable and in a region with enhanced sensitivity
- **Help WbWb modelling**: differential cross sections for several kinematic variables in a more inclusive phase space





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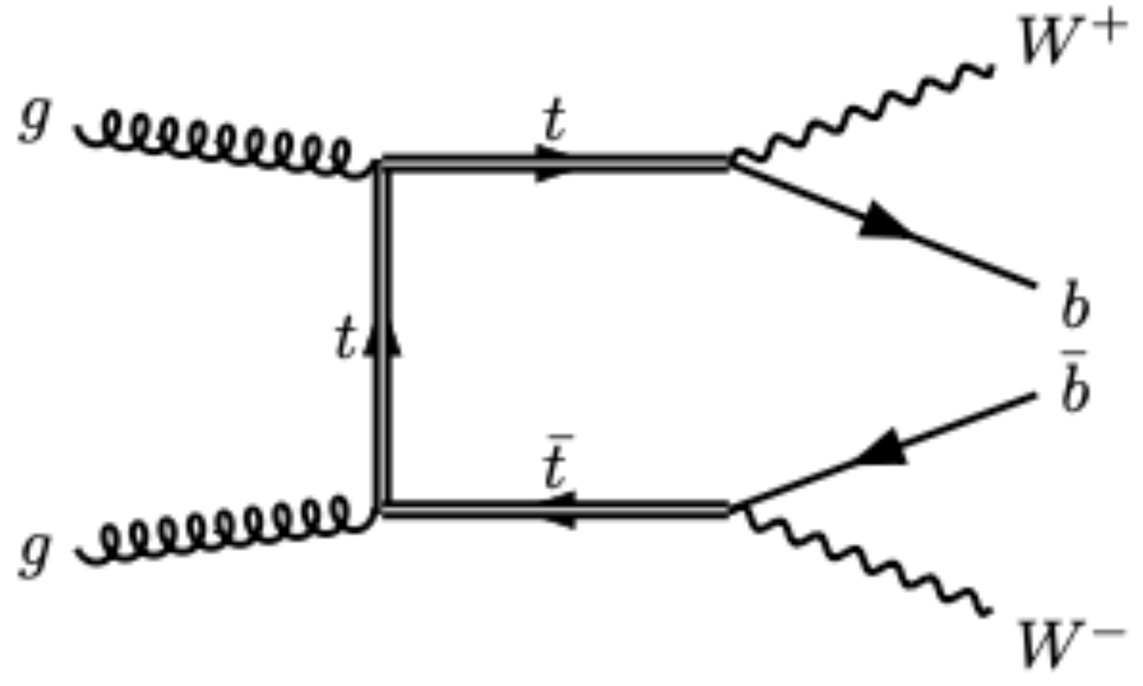
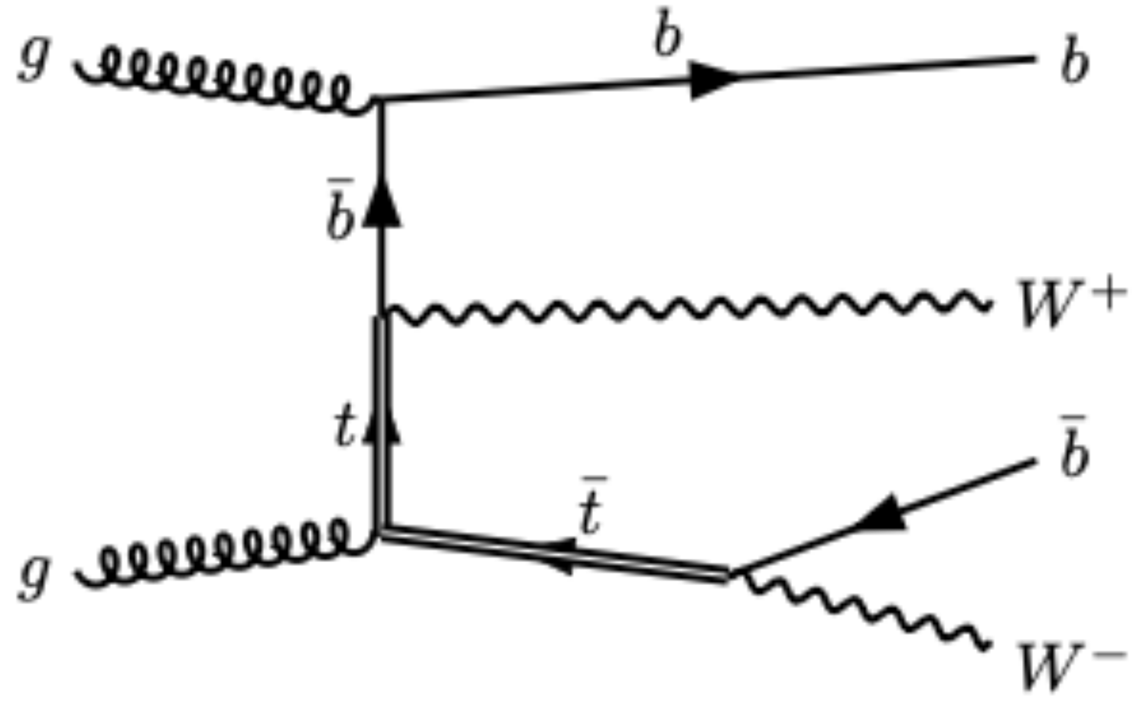


Strategy: cut → count → unfold

- fiducial phase-space with 2b and opposite sign eμ
- unfolded at particle level (iterative Bayesian unfolding)
- compare to NLO+PS predictions



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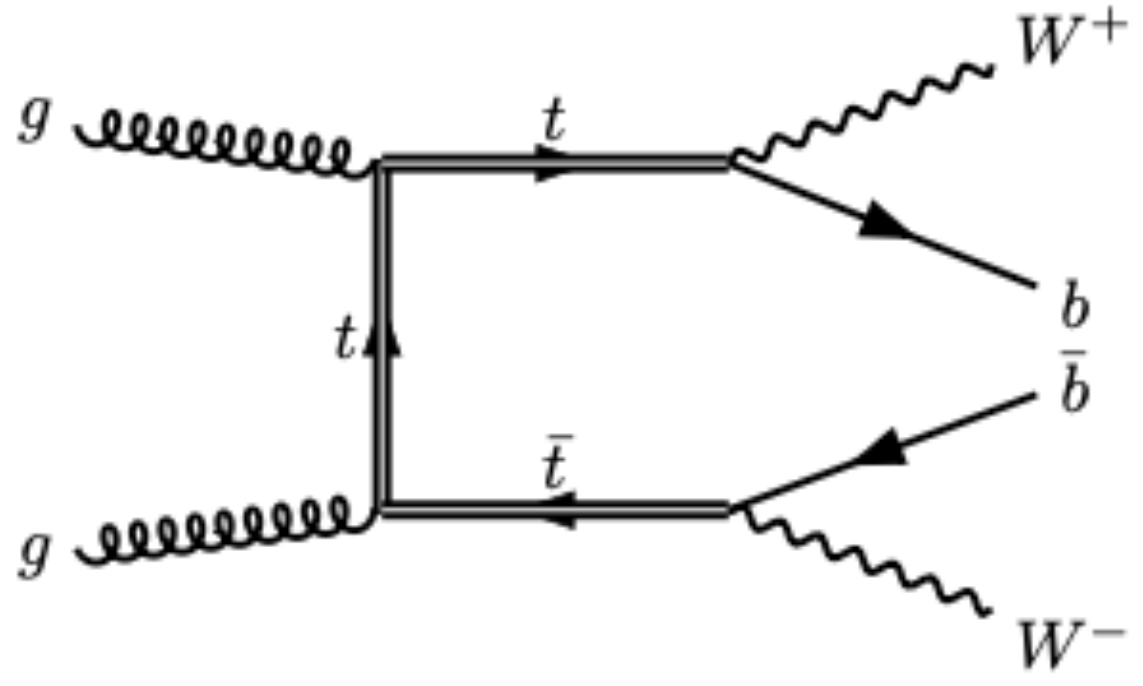

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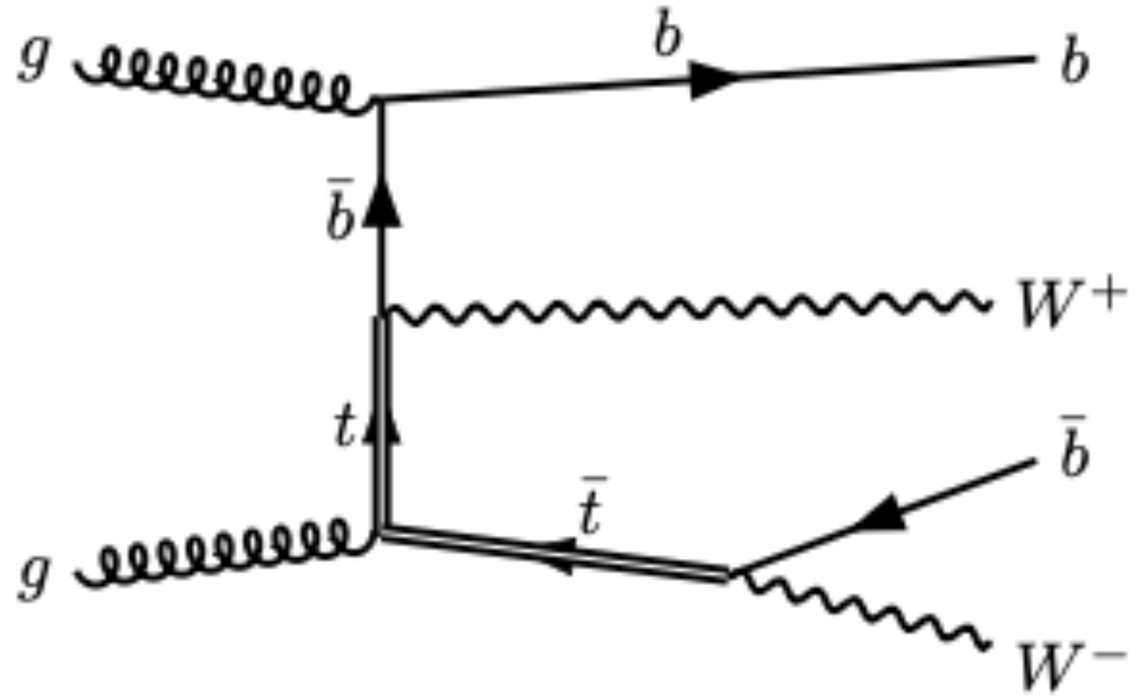

Modelling of WbWb and interference between doubly and singly resonant production

$$m^{bl}_{\text{minimax}} \equiv \min\left\{\max\left(m^{b_1 l_1}, m^{b_2 l_2}\right), \max\left(m^{b_1 l_2}, m^{b_2 l_1}\right)\right\}$$

WbWb production

CERN-EP-2025-094

Measured distributions at particle level

- p_T of jets, ℓ, 2b systems
- p_T and m_T of $2b2\ell$ and $2b2\ell2\nu$ systems
- n_{jets}

WbWb production

CERN-EP-2025-094

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Integrated cross section

- fiducial 2b-exclusive and 2b-inclusive
- systemaic uncertainty dominated by flavour tagging and generator modelling

2b-exclusive region $\sigma_{fid} = 5.77 \pm 0.01\,(\text{stat.})\,^{+0.27}_{-0.29}\,(\text{syst.}) \pm 0.05\,(\text{lumi.})$ pb

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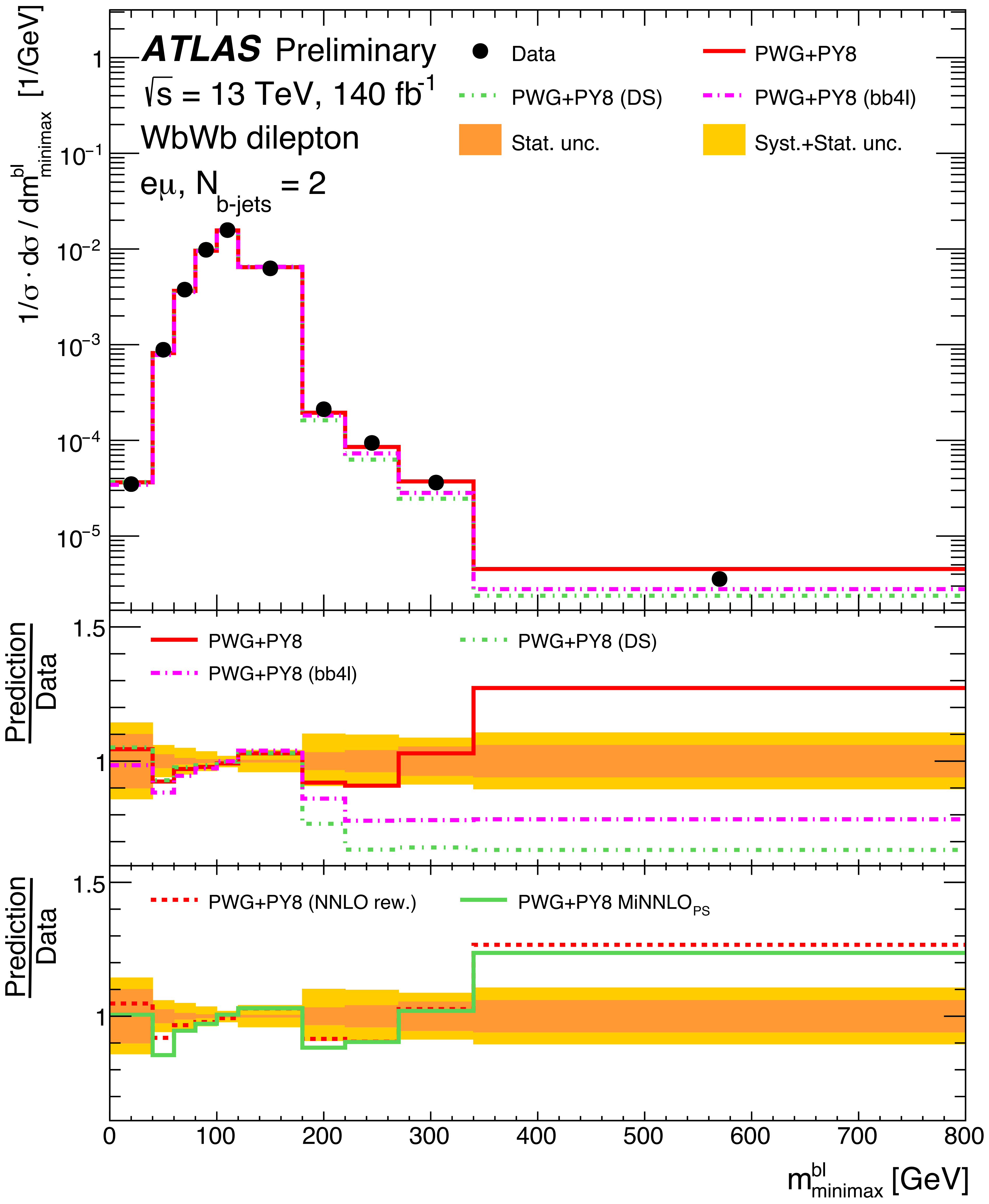

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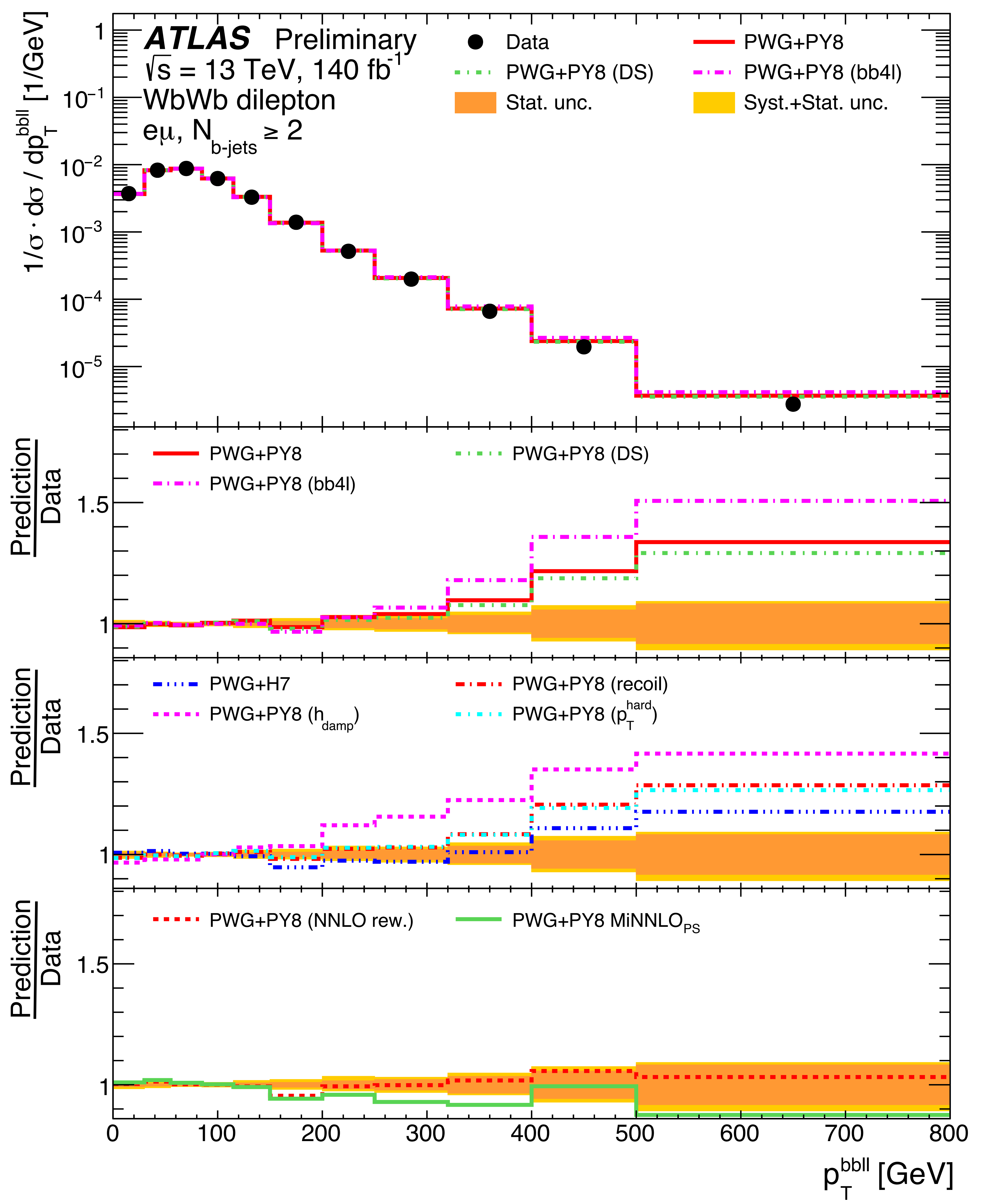

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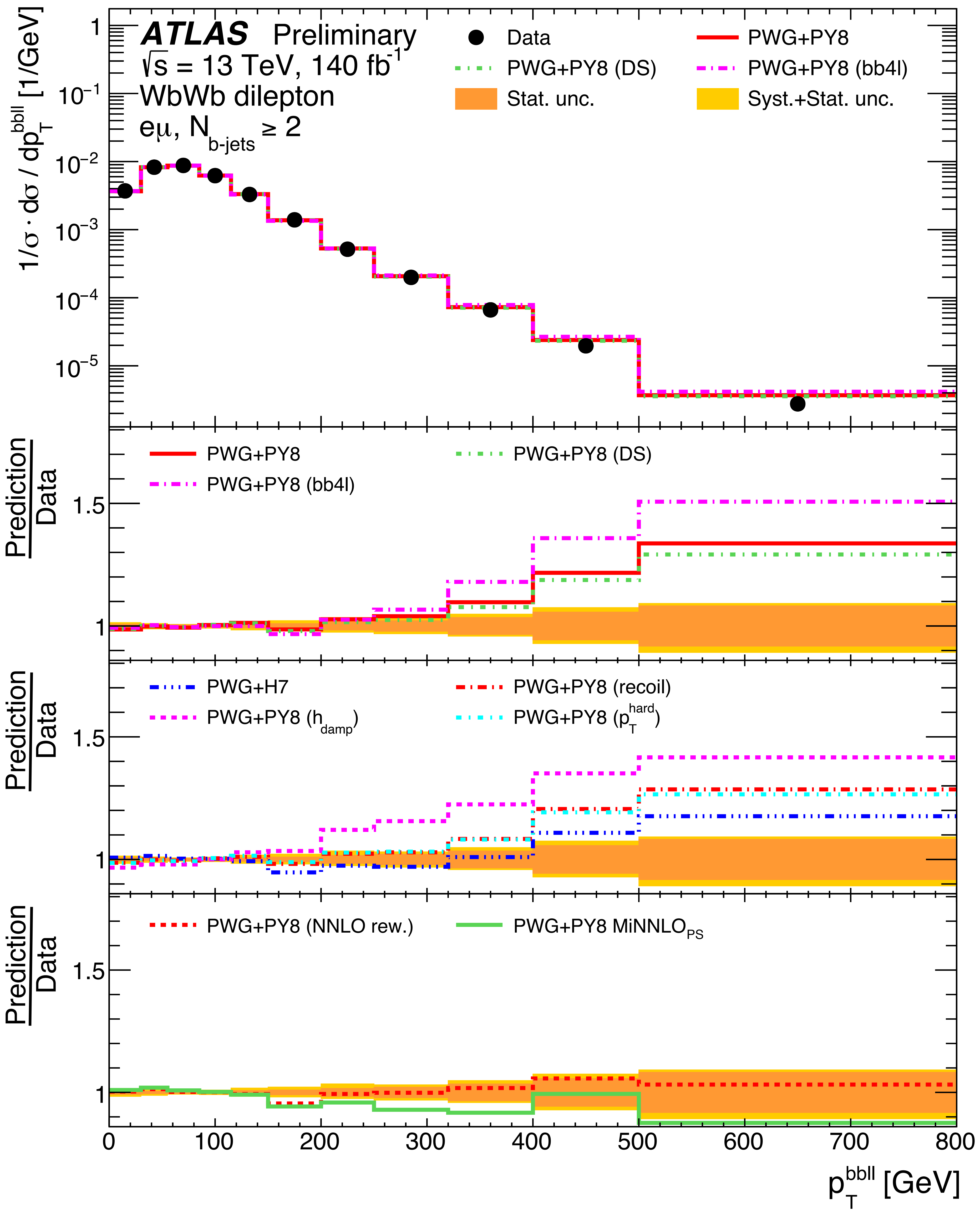
Bottom line

- best agreeing after NNLO reweighting
- interference handling: DR better than DS



m_{top} at high transverse momentum

Boosted top-quark decay products are collimated

- can be reconstructed as a single large-radius jet
- simplifies the reconstruction compared to inclusive phase space
- expected to reduce the systematic uncertainties

Three observables = three handles

- average top-jet mass: sensitive to m_{top}

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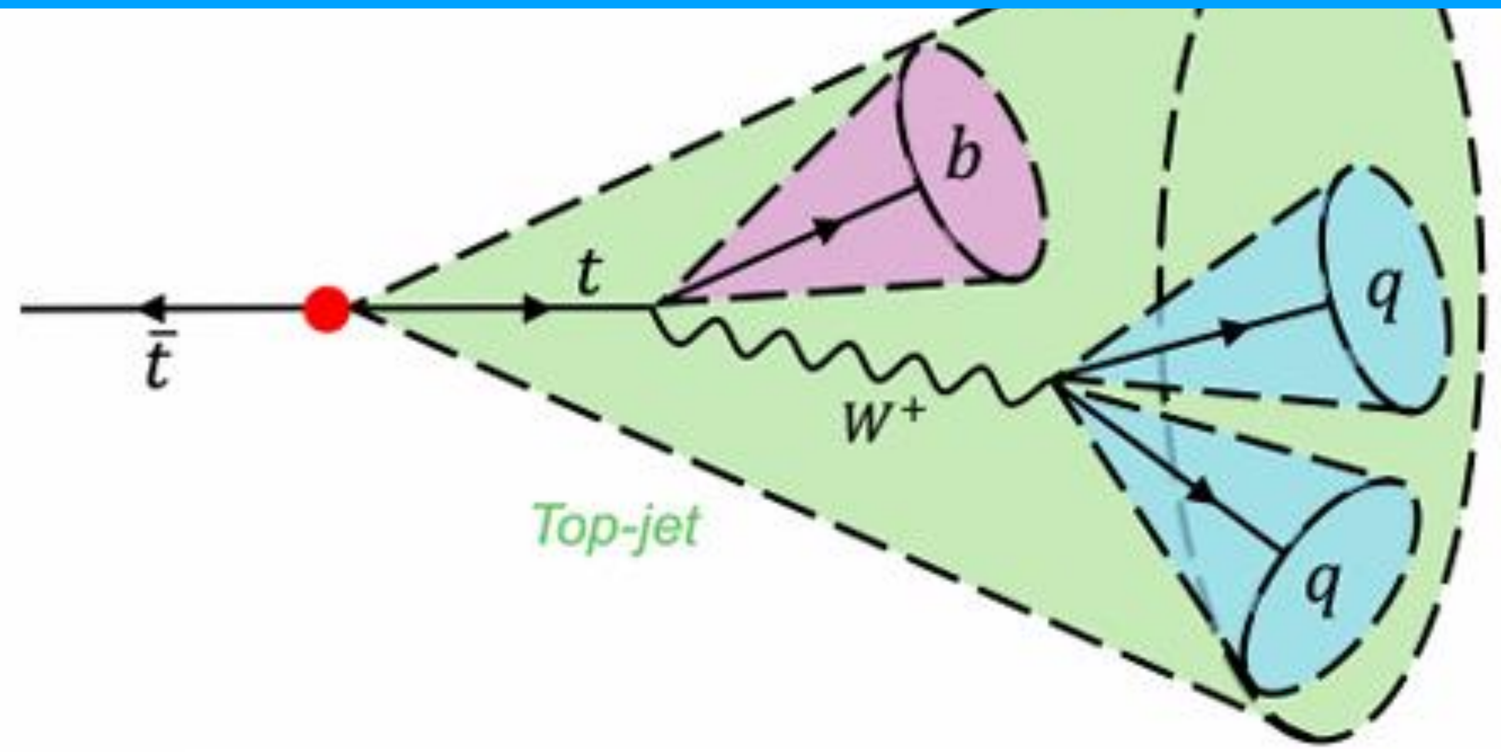

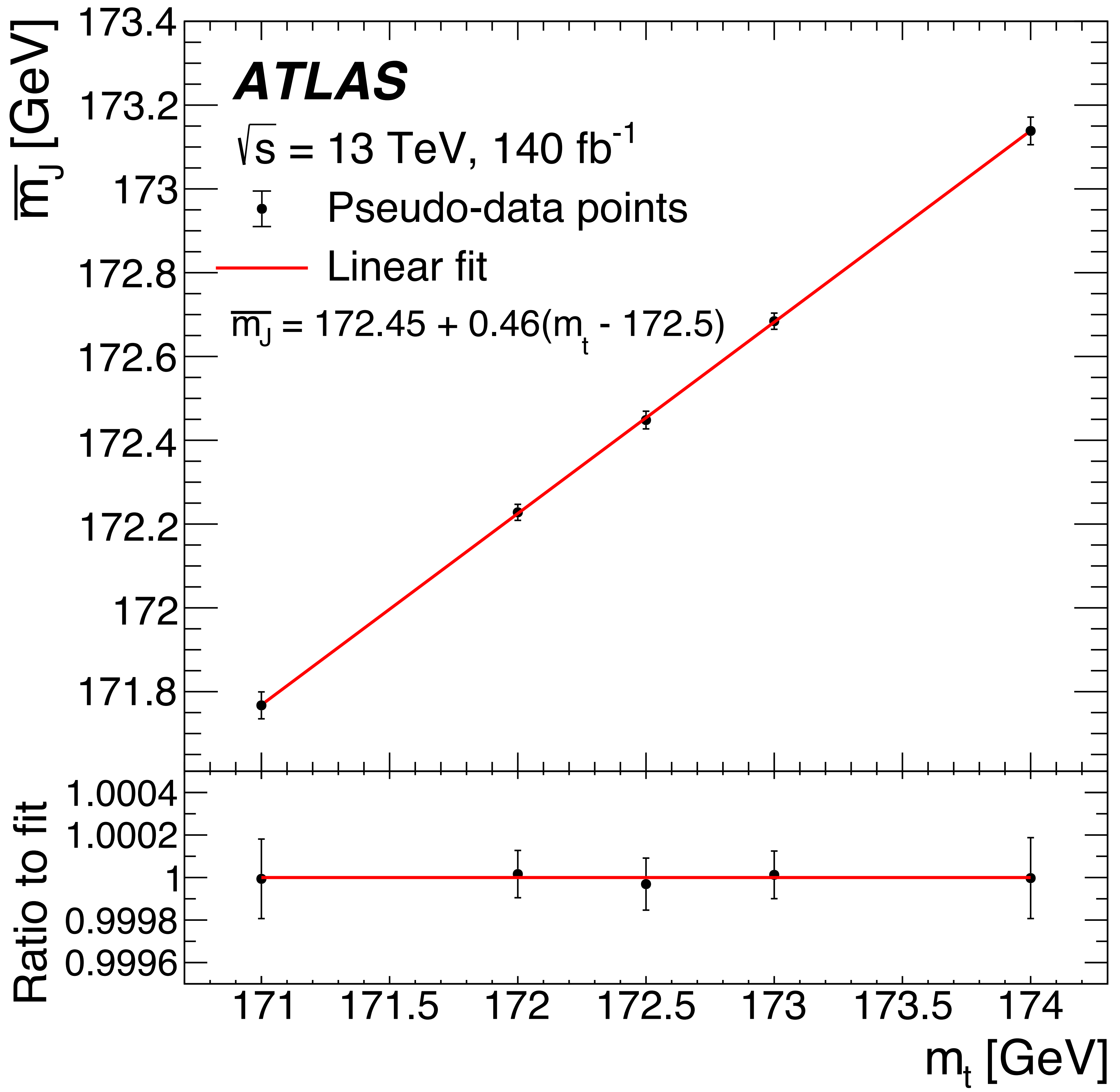

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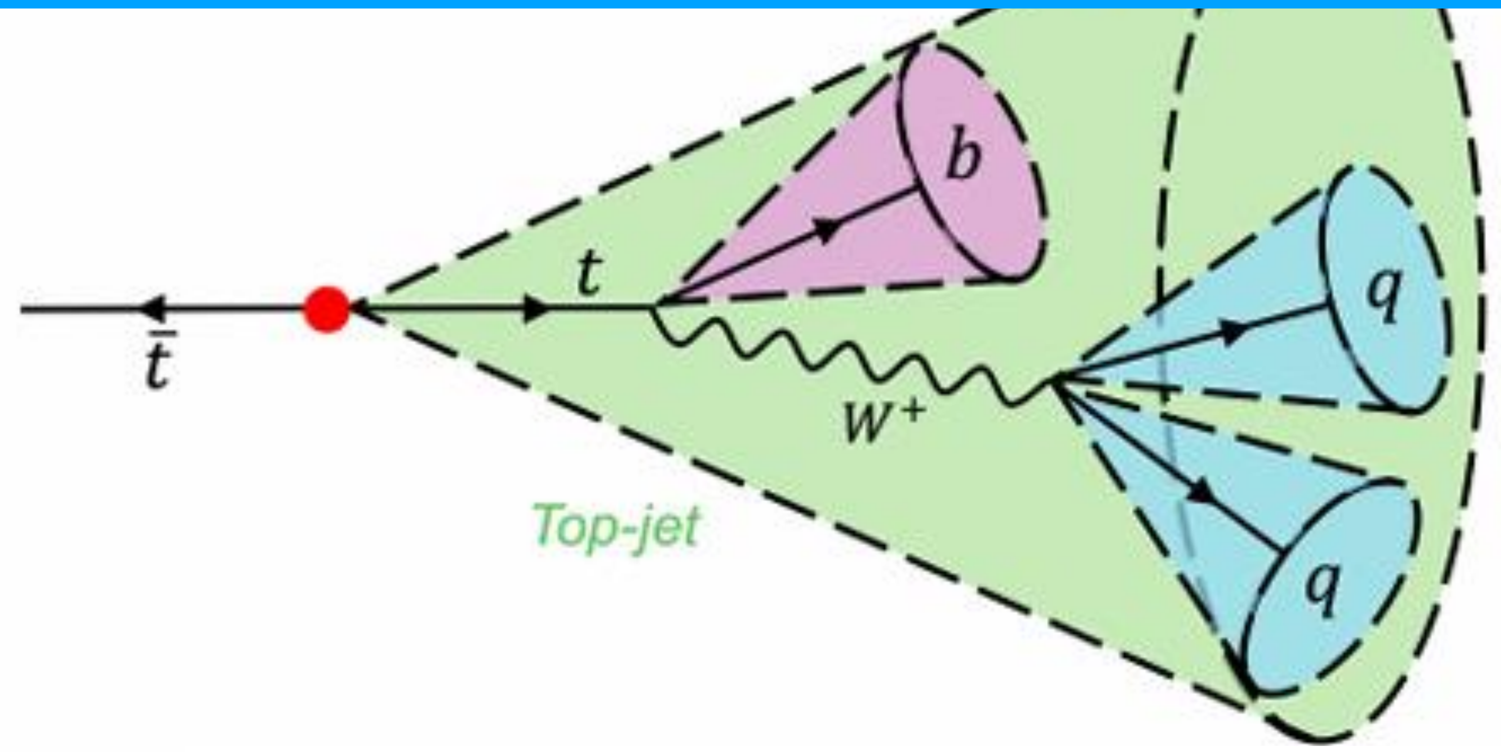

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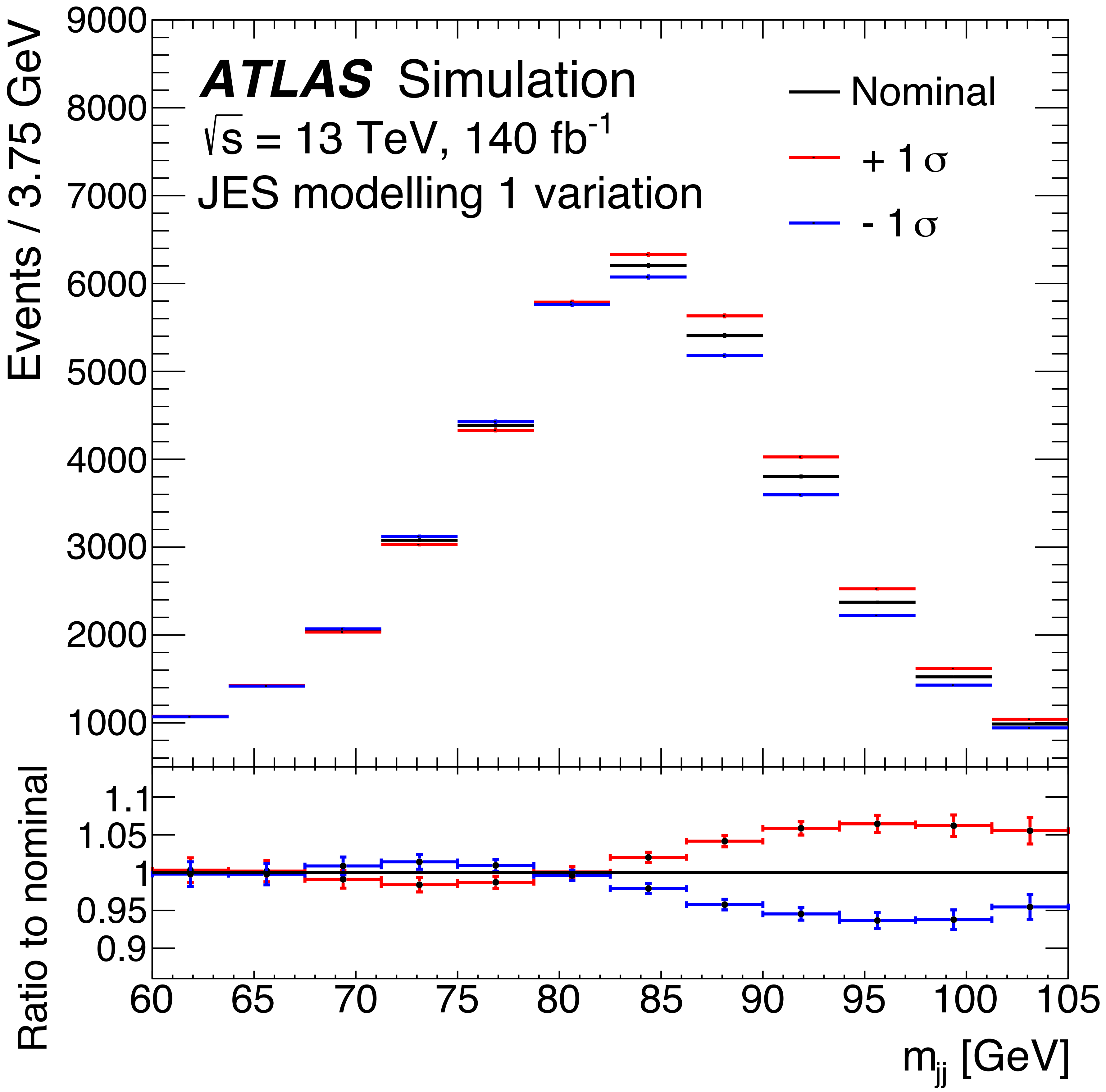

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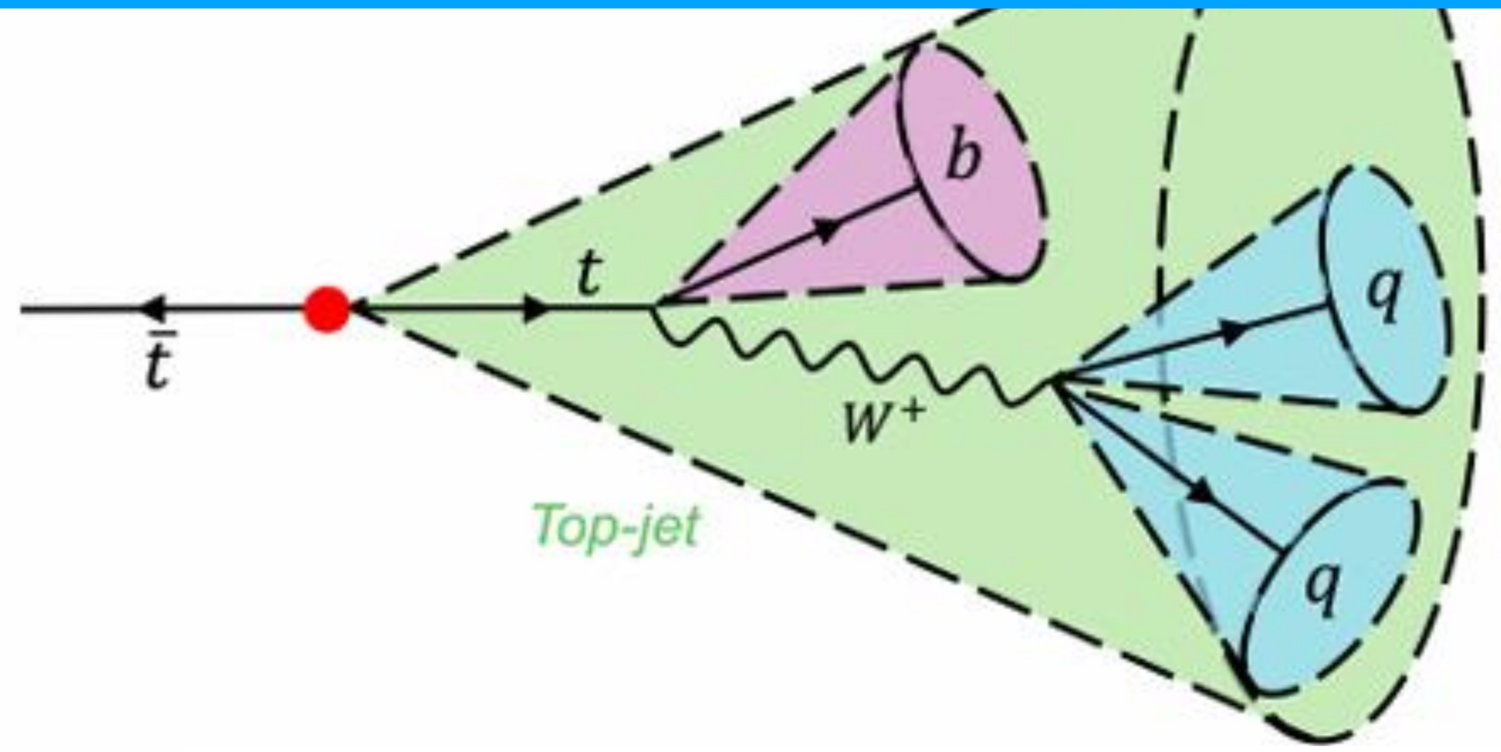

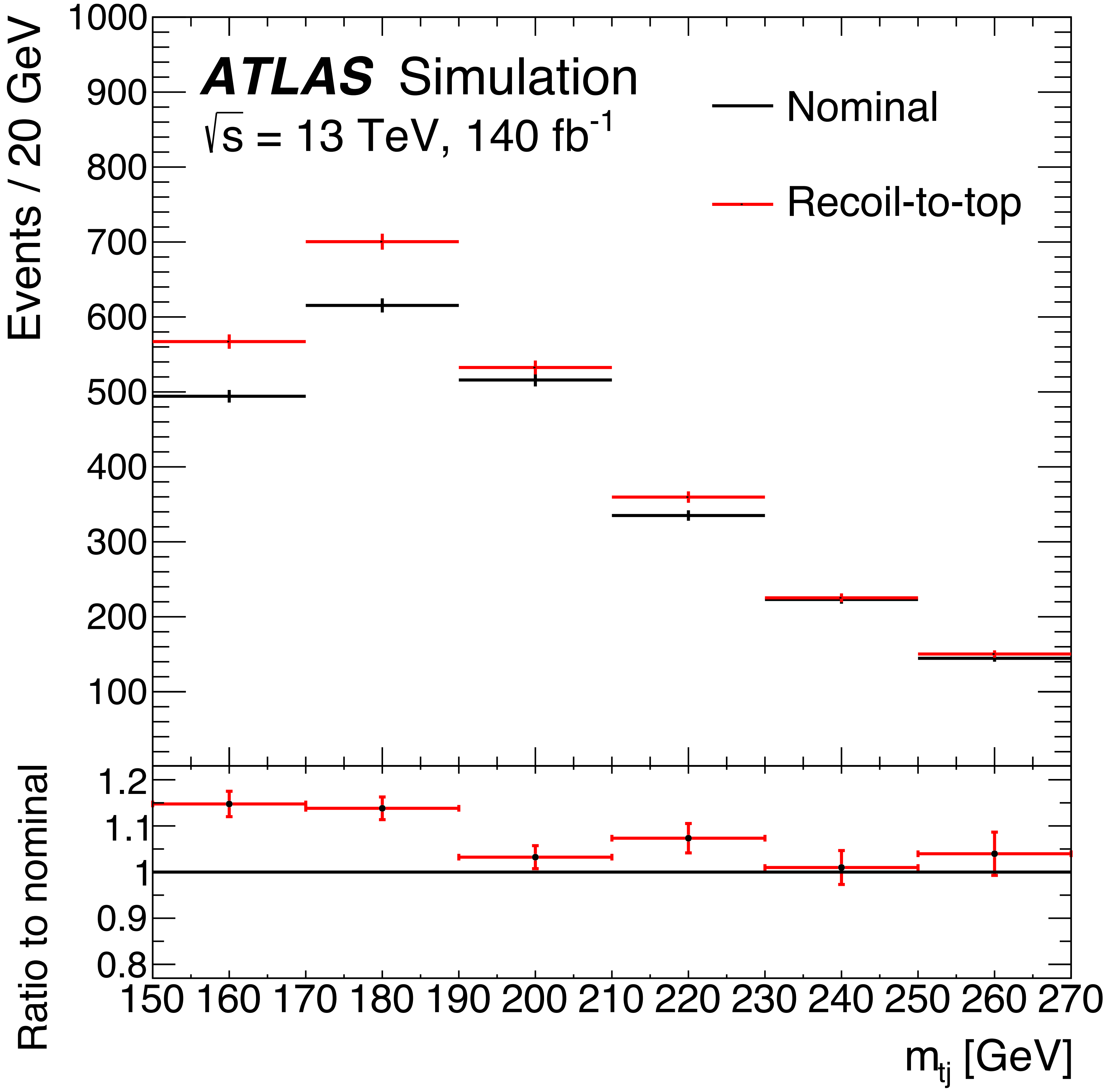

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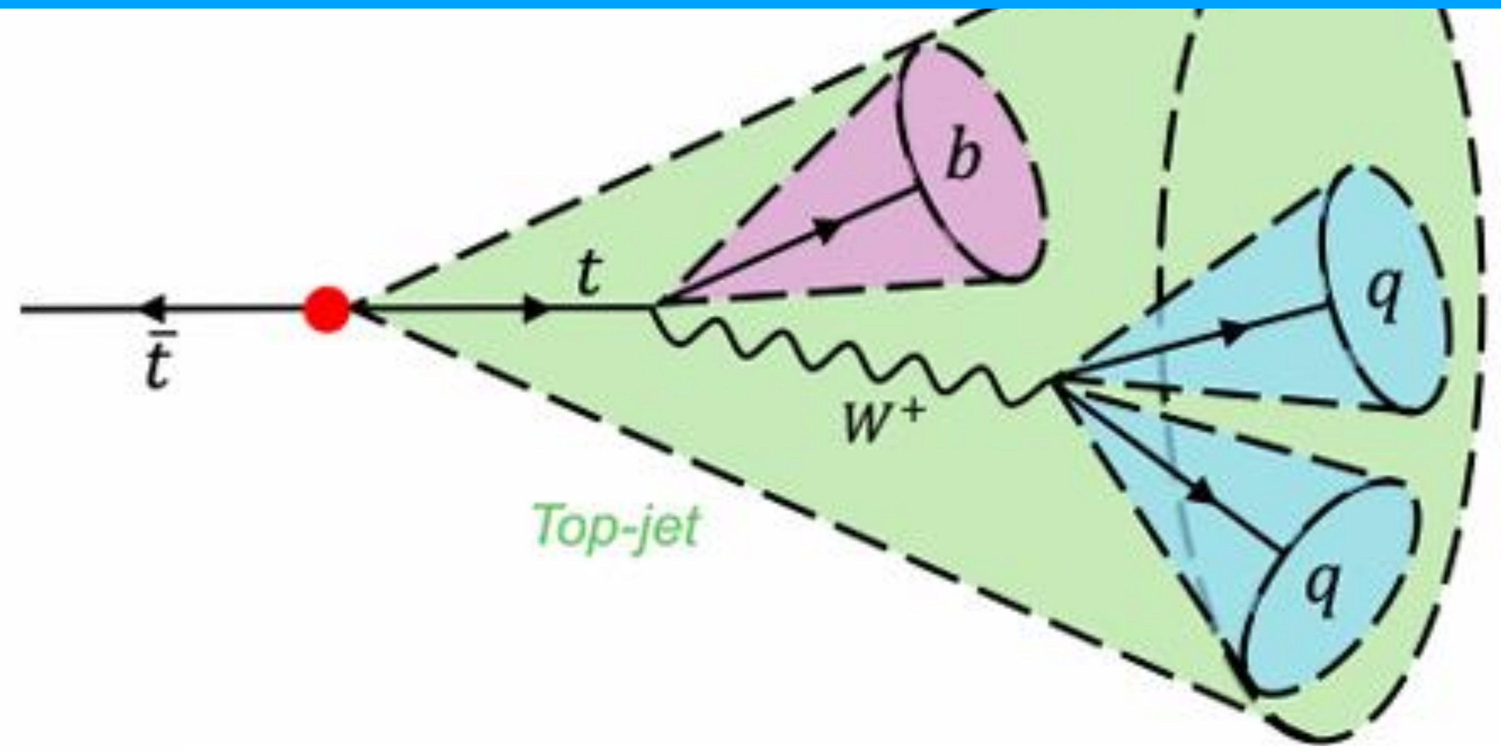

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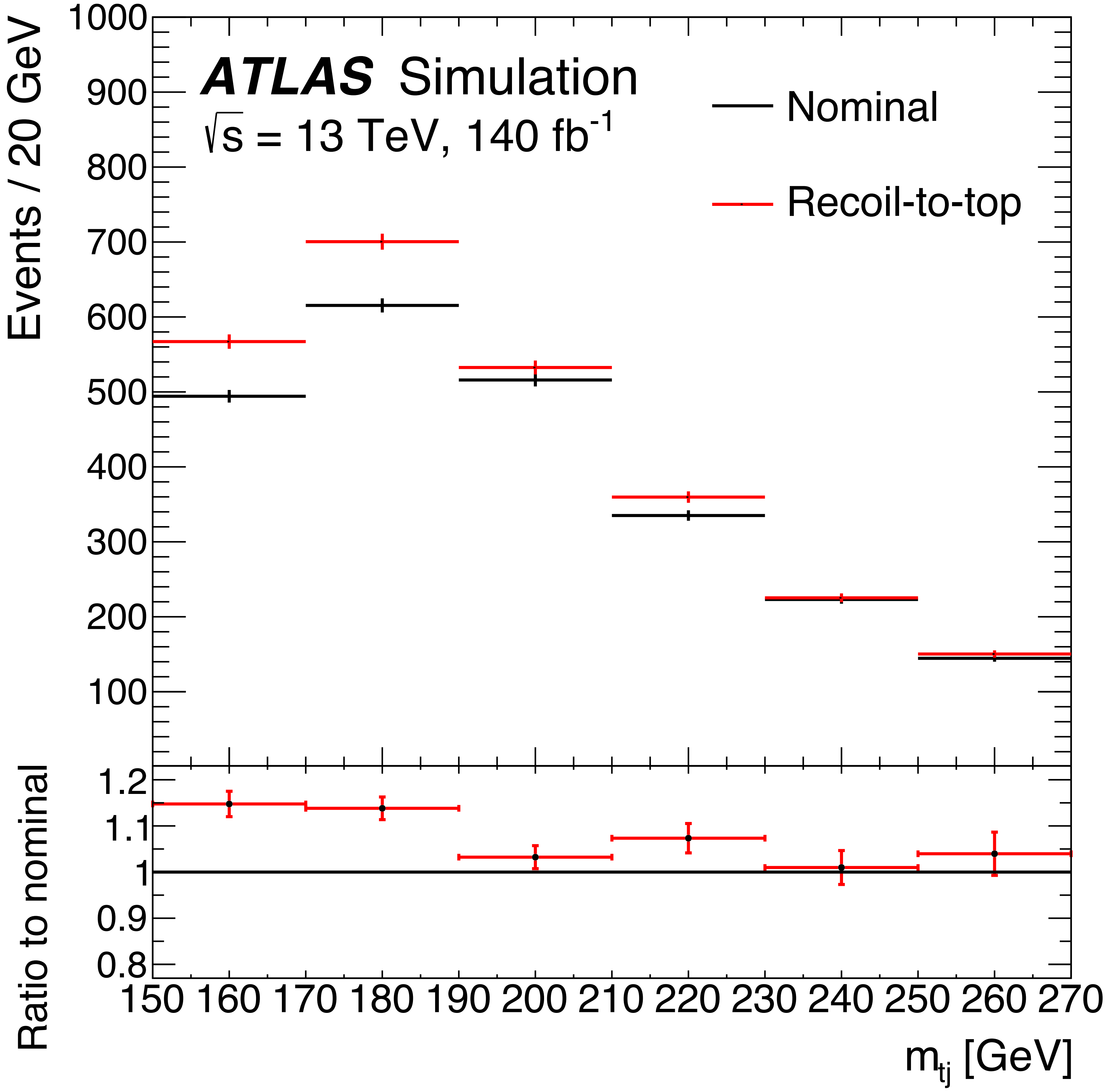

Simultaneous profile likelihood fit to the three observables

- reducing uncert. due to JES and recoil by ~80%

m_{top} at high transverse momentum

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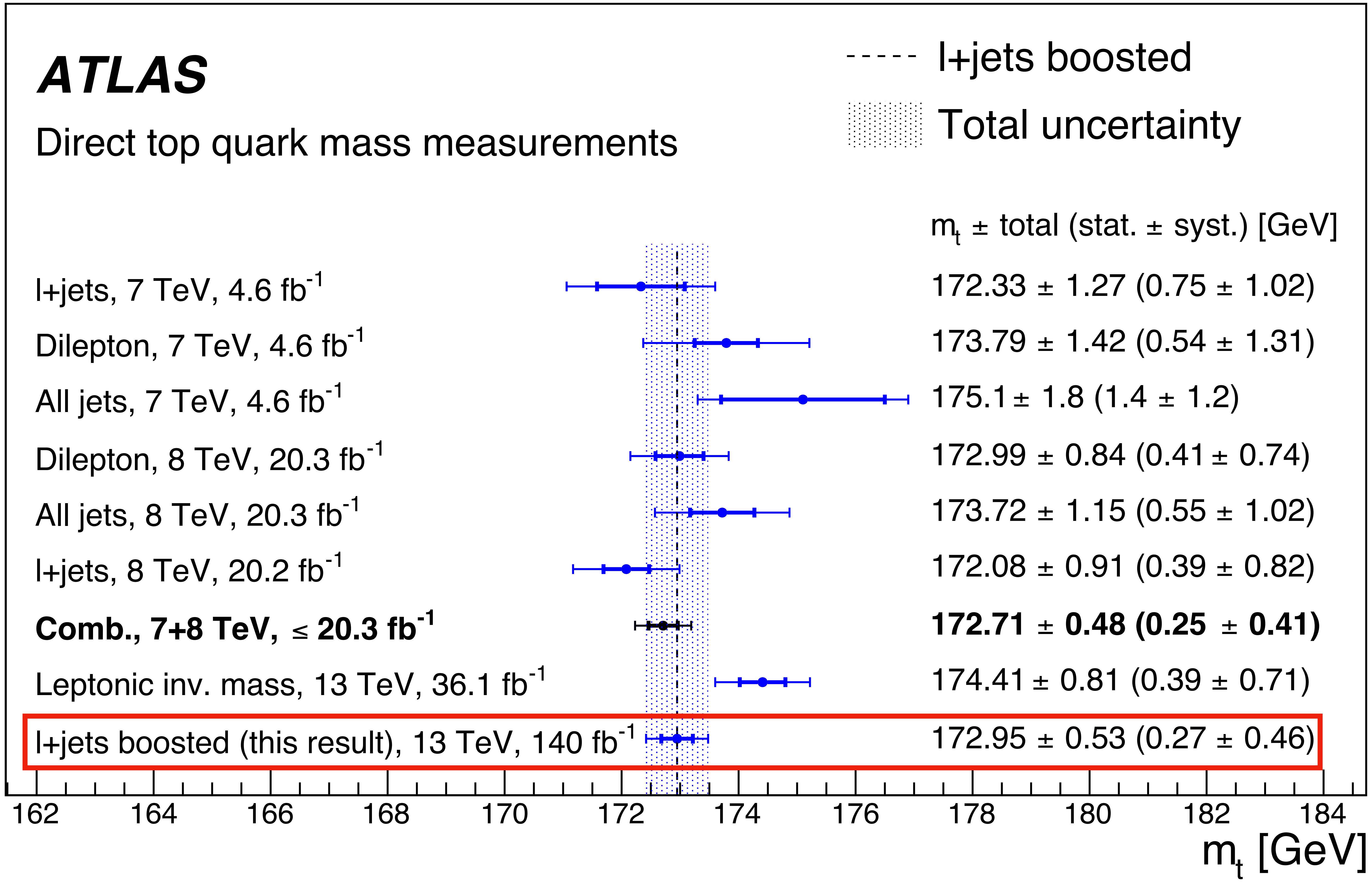
Result: m_{top} = 172.95 ± 0.53 GeV

→ most precise ATLAS m_{top} measurement in a single channel

Source	Uncertainty [GeV]
JES	± 0.29
Radiation (ISR and FSR)	± 0.17
Colour reconnection (CR1 and CR2)	± 0.15
JES heavy flavour	± 0.14
Parton shower and hadronisation model	± 0.14
JER	± 0.10
MC statistics	± 0.08
Underlying event	± 0.08
Recoil	± 0.07
Fit closure	± 0.07
Background modelling	± 0.05
Matrix element matching ($p_T^{hard} = 1$)	± 0.04
b-tagging	± 0.04
Higher-order corrections	± 0.02
E_T^{miss}	± 0.02
Pileup	± 0.01
JVT	± 0.01
PDF	± 0.01
Leptons	± 0.01
Luminosity	< 0.01
Total statistical	± 0.27
Total systematic	± 0.46
Total	± 0.53



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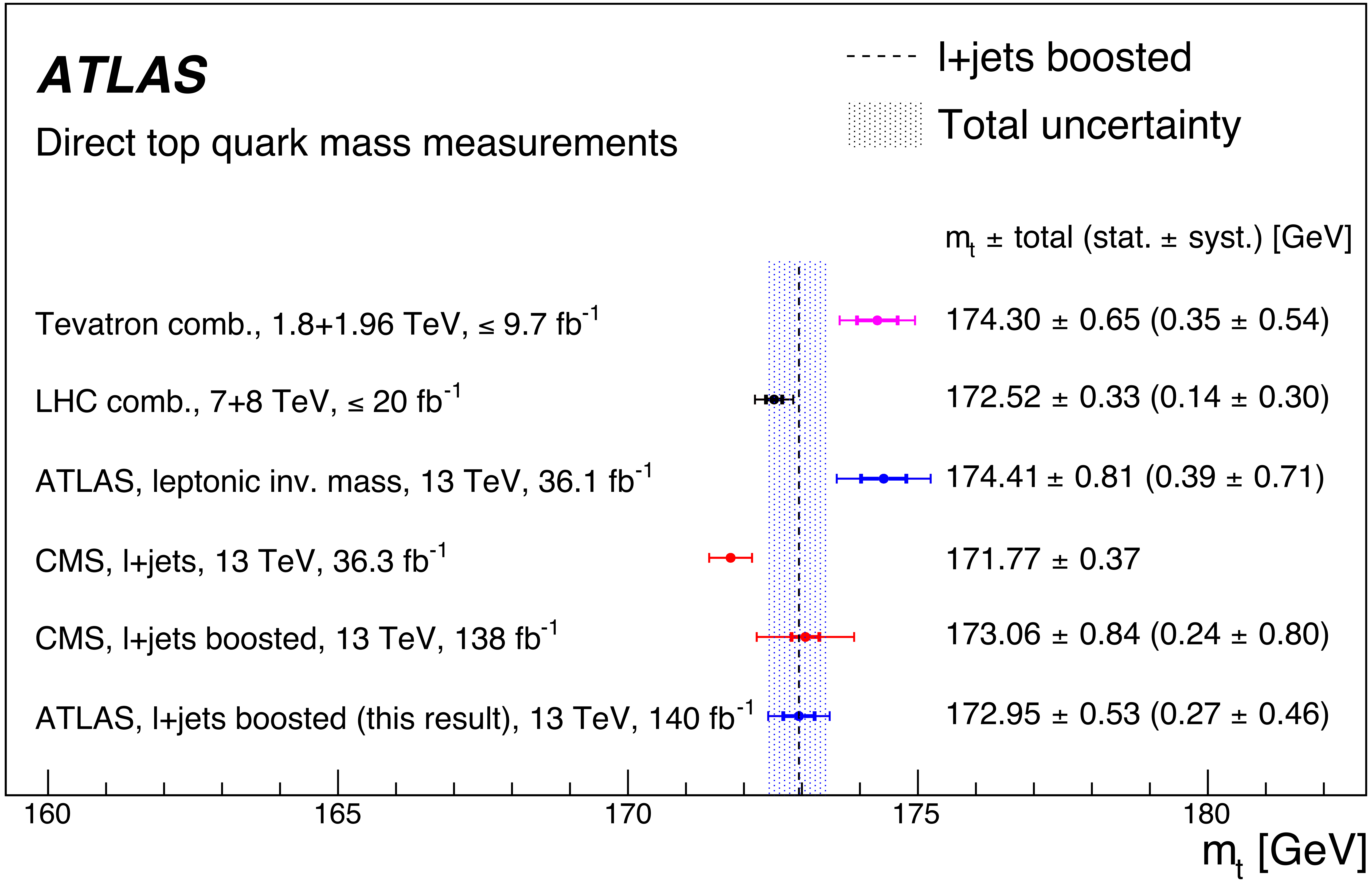

Quantum entanglement and magic

Top-quark entanglement observed

- in dilepton events by CMS Rep. Prog. Phys. 87 (2024) 117801 and ATLAS Nature 633 (2024) 542
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Here: consider "magic" $\tilde{M}_2$

- reflects how far a quantum state is from being efficiently simulated by classical systems
- for $t\bar{t}$ system use magic defined in helicity basis {n,k,r}, see White&White Phys. Rev. D 110 (2024) 116016

$$\tilde{M}_2 = -\log_2 \left(\frac{1 + \sum_{i \in n,k,r} [(P_i^4 + \bar{P}_i^4)] + \sum_{i,j \in n,k,r} C_{ij}^4}{1 + \sum_{i \in n,k,r} [(P_i^2 + \bar{P}_i^2)] + \sum_{i,j \in n,k,r} C_{ij}^2} \right)$$

- with polarisations P_i and spin correlation coefficients C_{ij}

Observation of entanglement and magic

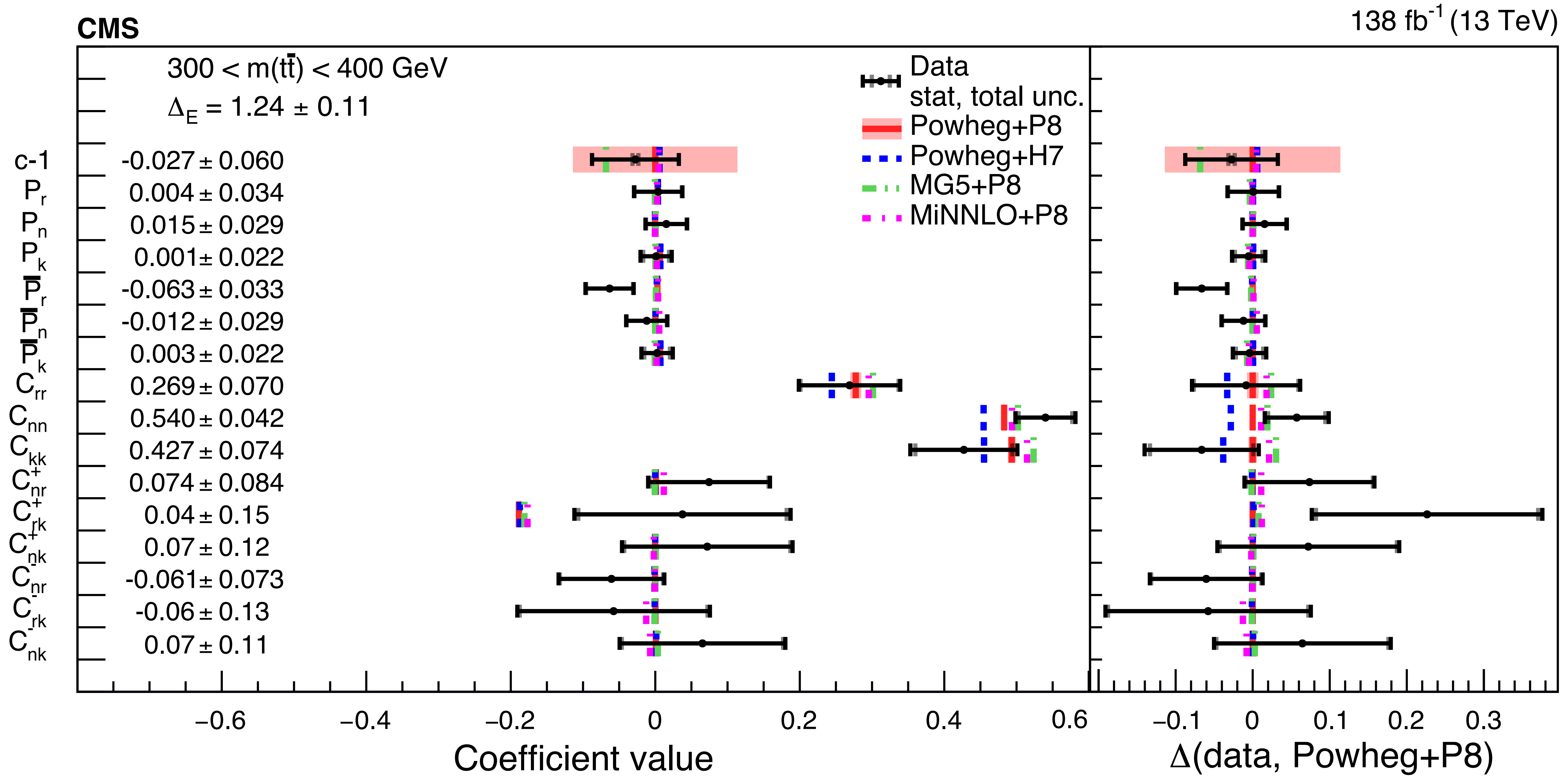
Phys. Rev. D 110 (2024) 112016

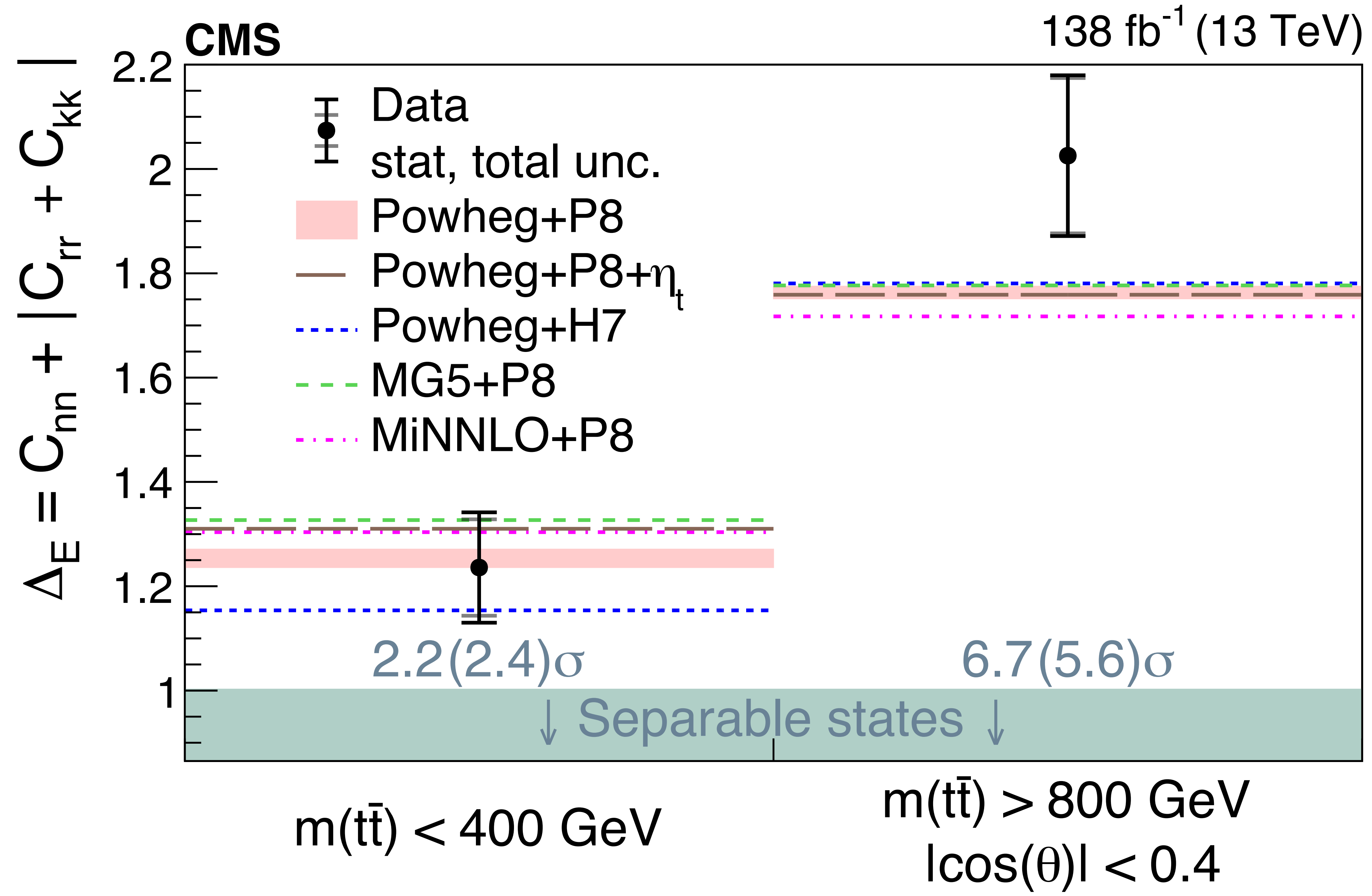
$t\bar{t}$ ℓ+jets channel

- events reconstructed using a neural network
- events divided into categories via lepton flavour, number of b-tagged jets, and NN score

Full angular information of two decay products to measure P and C

- e.g. a lepton and a down-type quark
- using templates to fit the effect of one non-zero coefficient at a time (reweighting)





Observation of magic in $t\bar{t}$

CMS-PAS-TOP-25-001

$\tilde{M}_2 > 0$ → observation

Agrees well with SM prediction

First experimental measurement of magic at the TeV scale

Test of lepton flavour universality

JHEP 05 (2025) 038

SM assumes equal couplings of e, μ, and τ to the W boson

Top-quark pairs provide a substantial dataset

- $t\bar{t} \rightarrow WbWb \rightarrow \ell\nu b\ \ell\nu b$, pure sample

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- τ is selected using $\tau \rightarrow e\nu\bar{\nu}$ decays to reduce uncertainty
- Differences in electron p_{T} and $|d_0|$ help separate $W \rightarrow \tau \rightarrow e$ and $W \rightarrow e$

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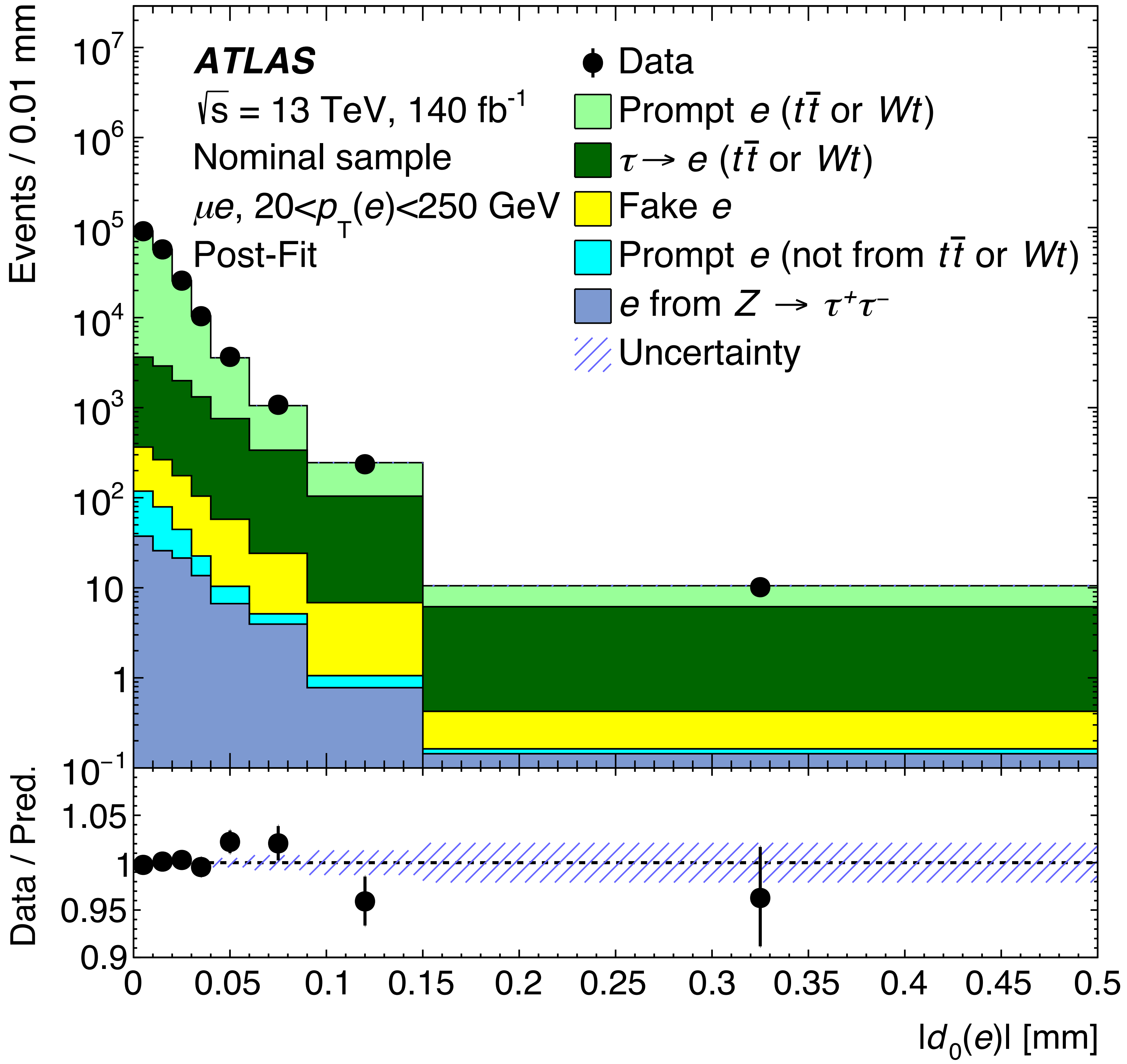

$R^W_{\tau/e}$ obtained from simultaneous fit of electron p_T and $|d_0|$ distributions

Test of lepton flavour universality

$$R^{W}_{\tau/e} = 0.975 \pm 0.012_{\text{stat.}} \pm 0.020_{\text{syst.}}$$

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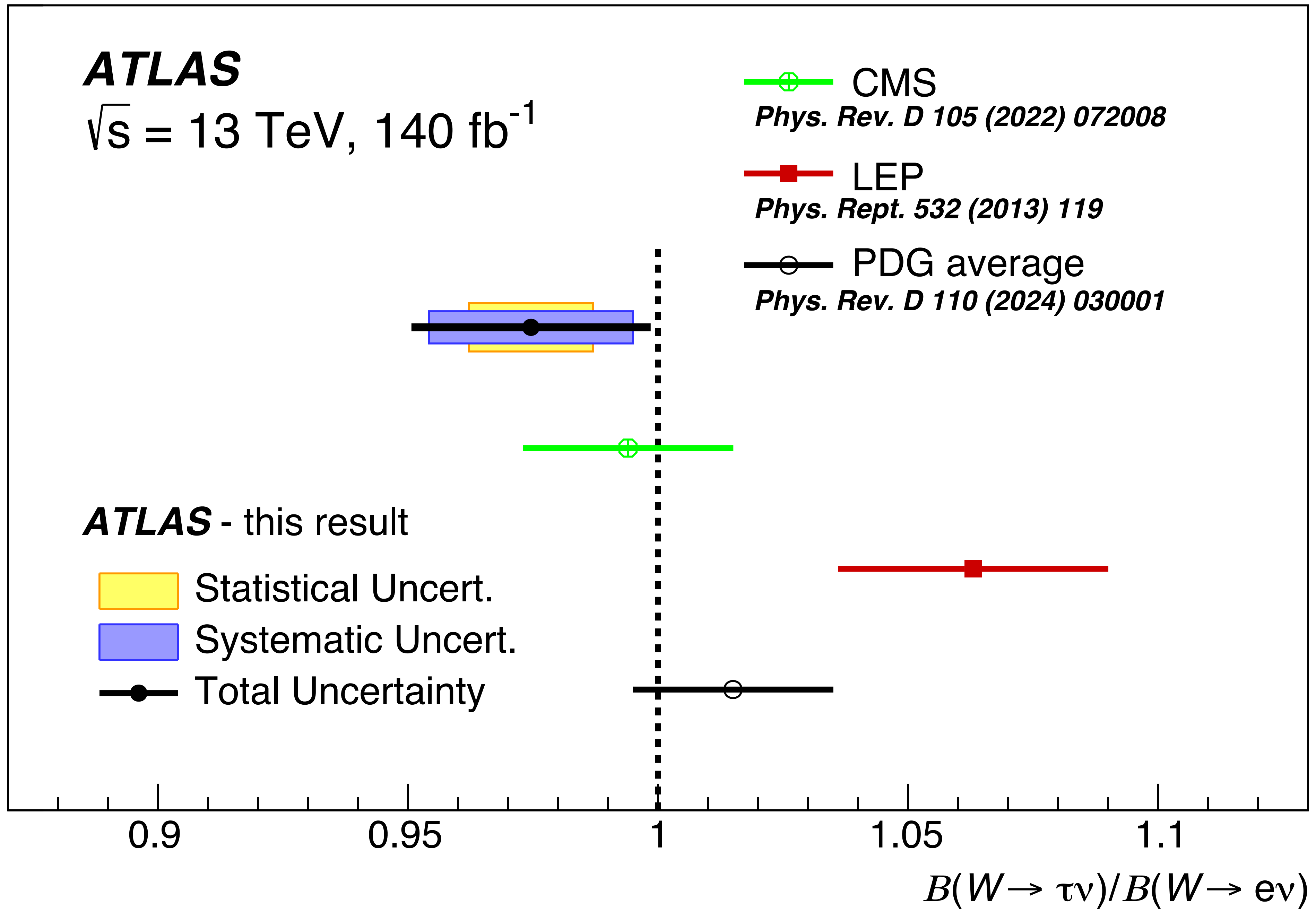

$$R^{W}_{\mu/e} = 0.9995 \pm 0.0044$$

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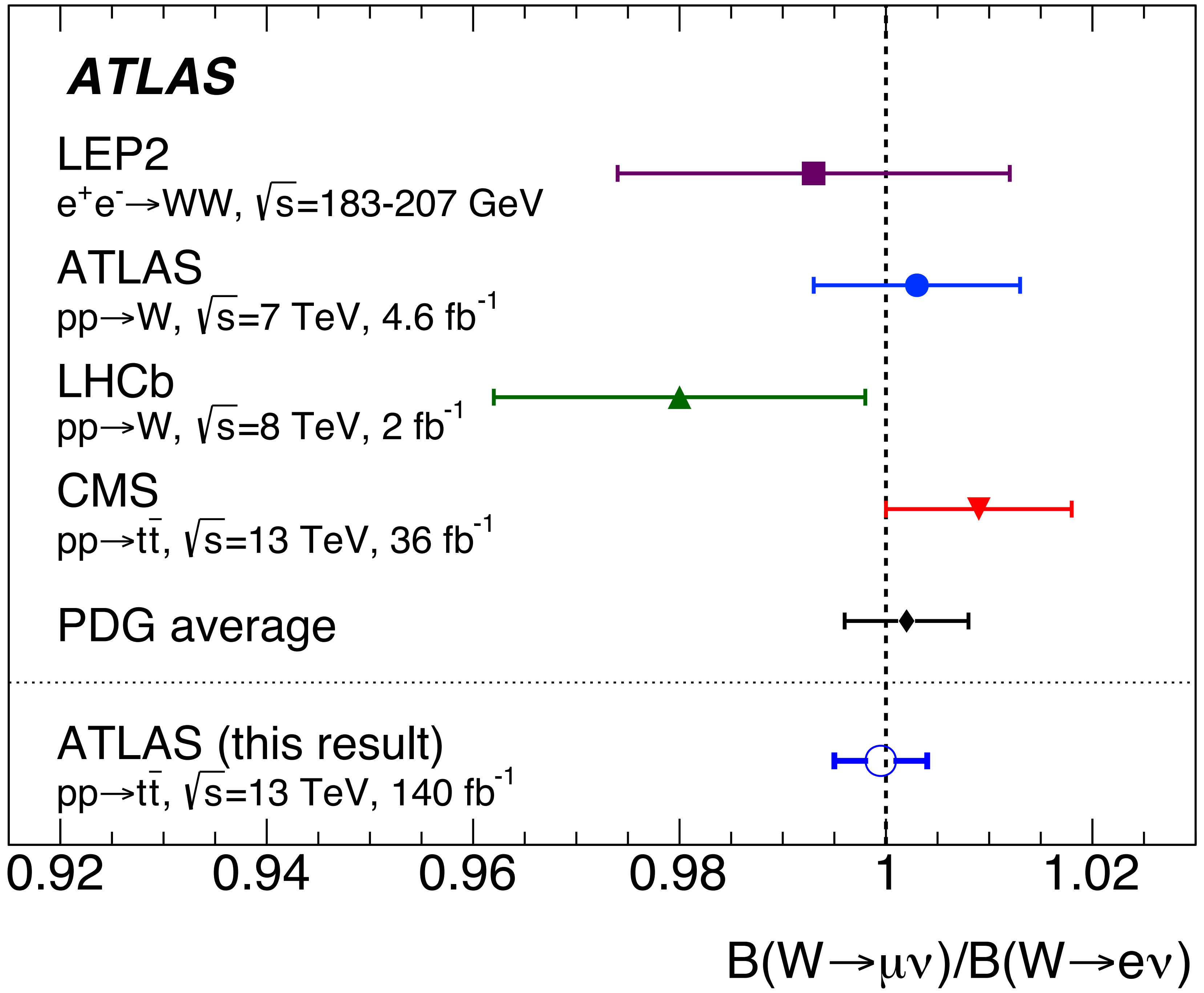

$R^{W}_{\mu/e}$ is the most precise measurement

Measurements agree well with SM prediction

No sign of lepton flavour violation

Summary

Several new top-quark results with Run-2 data of LHC by ATLAS & CMS

Cross-section

- Observation of a pseudo-scalar excess near $t\bar{t}$ production threshold
- WbWb dilepton production

Mass

- Top-quark mass at high transverse momentum

Other properties

- Quantum entanglement and magic
- Test of lepton flavour universality in W boson decays

Top-quark sector still very attractive for precision measurements, search for new physics and (new!) for quantum information studies