SM precision measurements at the LHC

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on behalf of the
ATLAS, CMS, LHCb Collaborations

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Introduction

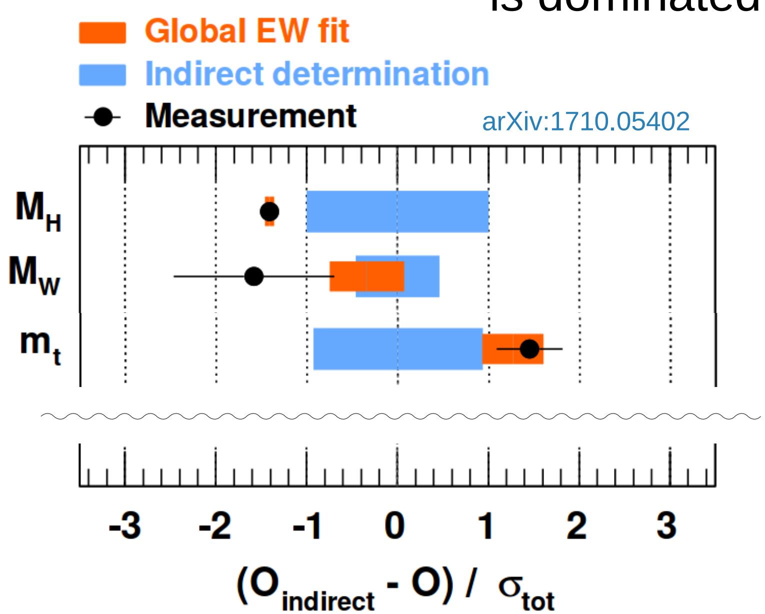
- Exceptional detector performance, new analysis methodologies, and unprecedented higher-order theoretical calculations have made SM precision measurements a flagship of the LHC physics programme

Presenting today a selection of recent SM measurements at the LHC

- ATLAS W-boson angular coefficients arXiv:2509.13759
- CMS boosted m_W SMP-24-012
- LHCb m_W from unfolded cross sections arXiv:2509.18817
- ATLAS Inclusive dijets cross sections arXiv:2512.19073
- CMS α_s from inclusive jet production PLB 868 (2025) 139651

Motivation for W measurements

The global fit of the electroweak observables is dominated by the measurement of m_W



	Measurement	SM Prediction (*)
m_H	125.1 ± 0.1	104.5 ± 21.7
m_t	172.56 ± 0.31	174.4 ± 2.1
m_W	80.369 ± 0.013	80.356 ± 0.006

(*) PDG 2025

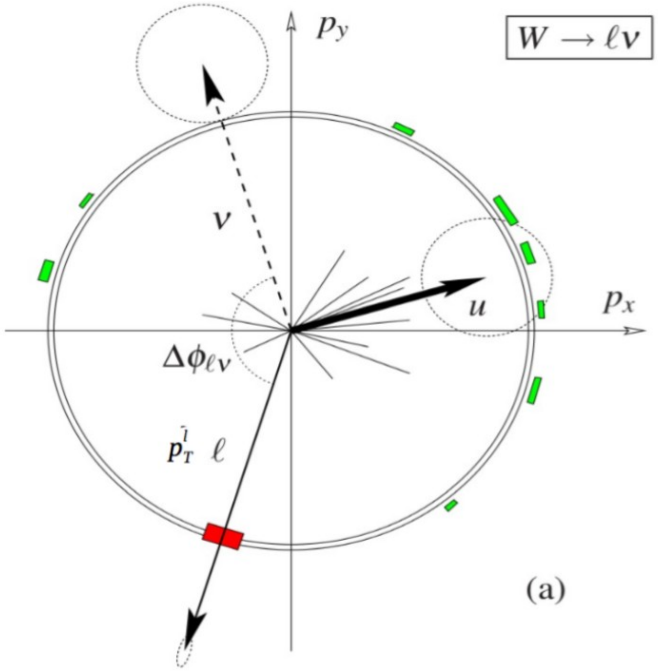
The measurements of the Higgs and top-quark masses are currently more precise than their indirect determination from the global fit of the electroweak observables → Improving precision will not increase sensitivity to new physics

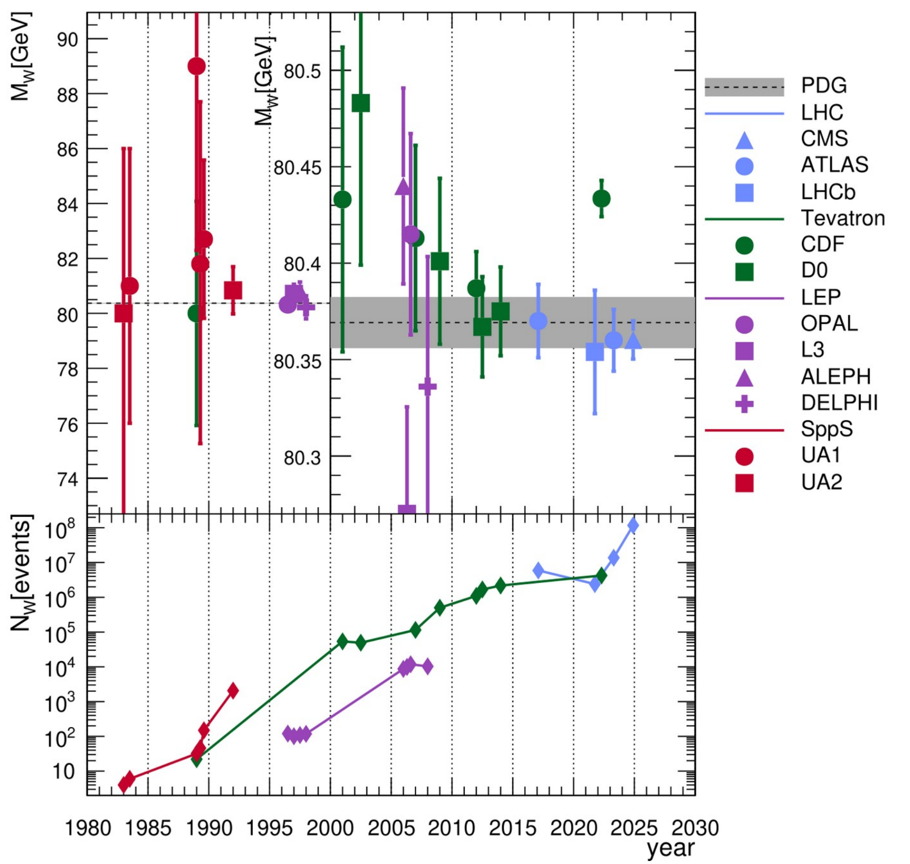
Indirect determination of m_W (±6 MeV) is more precise than the experimental measurement → Call for $\delta m_W^{exp} \sim 5$ MeV

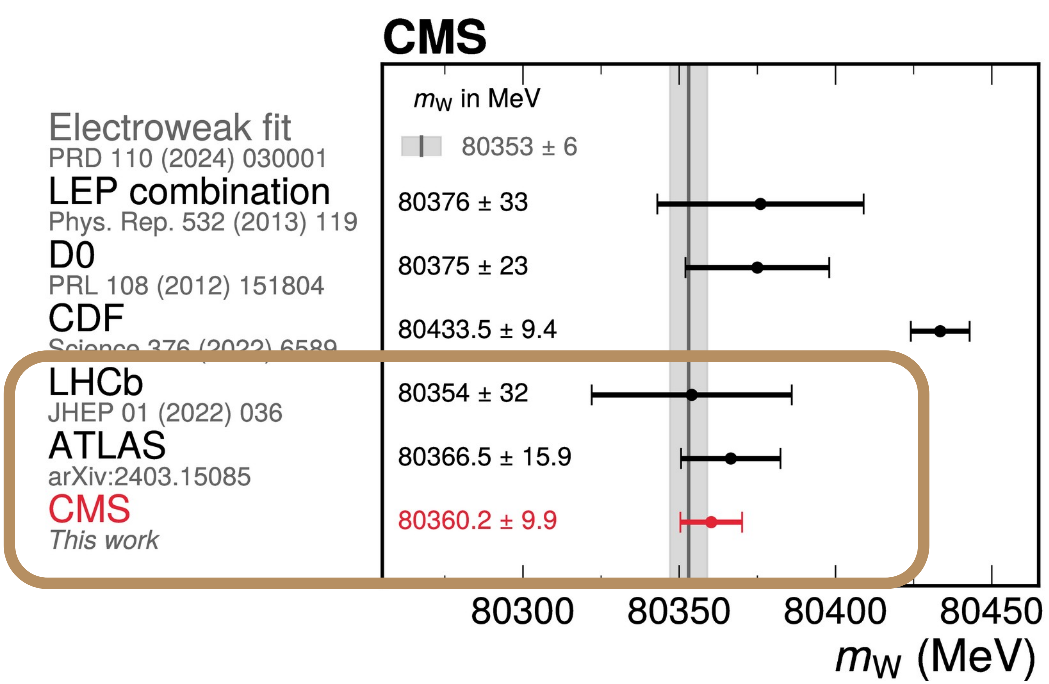
The W mass is nowadays the crucial measurement to improve the sensitivity of the global EW fits to new physics

W-boson measurements at the LHC

- Measurements of W → ℓν final states at the LHC are complicated by neutrinos which are undected. Measurements rely either on the indirect reconstruction of the neutrino p_T from momentum balance, or on the kinematic properties of the charged lepton (electron or muon)
- The measurement of the W-boson mass is a milestone of the LHC physics programme. It requires a precise modelling of the W-boson production and decay process, which benefits from auxiliary measurements of W-boson final states







W-boson angular variables

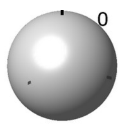
- The W $\rightarrow$ $\ell\nu$ cross section can be expressed through the factorisation of the production dynamic and the decay kinematic properties of the dilepton system

$$\frac{d^3\sigma^{U+L}}{dp_T\,dy\,dm}\left(1+\cos^2\theta+\sum_{i=0}^{7}A_i(y,p_T,m)P_i(\cos\theta,\phi)\right)$$

- Decomposition of ($\cos\theta,\phi$) into 9 helicity cross sections $\rightarrow$ basis of spherical harmonics

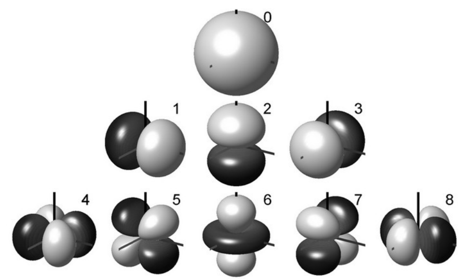
Why 9?

ℓ denotes the degree of the spherical harmonics



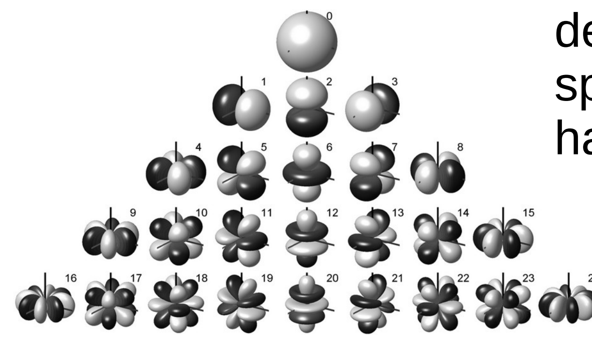
Spin 0 (Higgs)

$\ell = 0$
n = 1



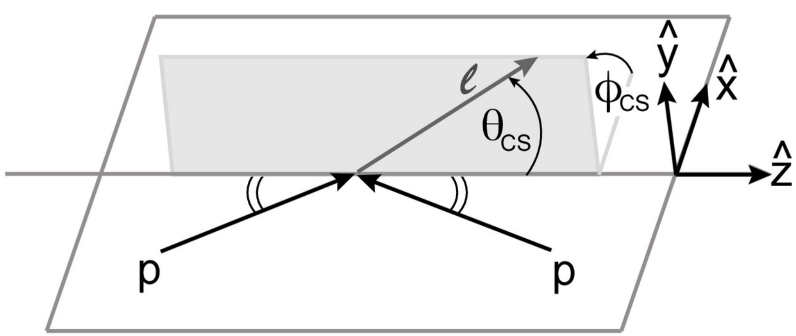
Spin 1 (W,Z,γ*)

$\ell \leq 2$
n = 1+3+5 = 9



Spin 2

$\ell \leq 4$
n = 1+3+5+7+9 = 25



- Coefficients defined in the Collins-Soper frame

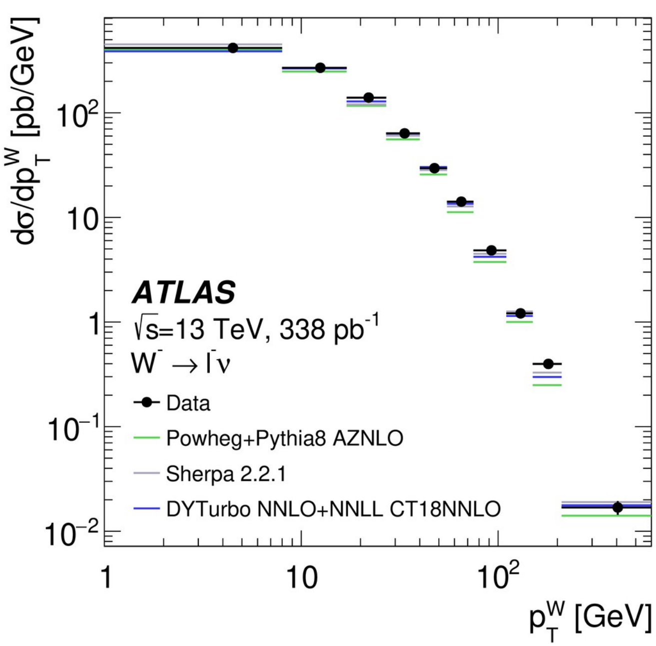
W-boson angular coefficients

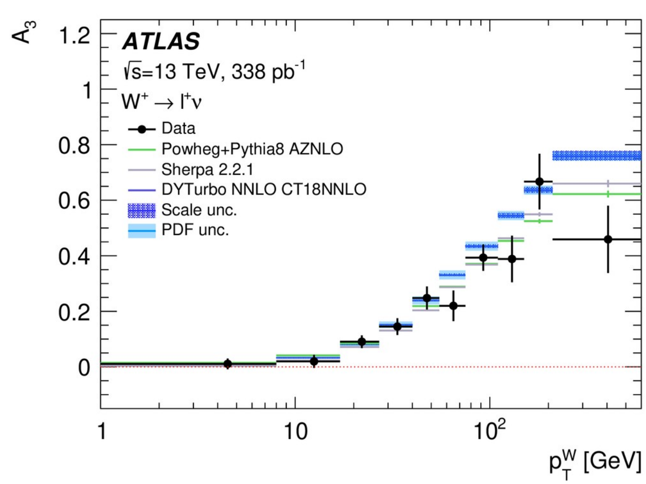
- 0.3 fb^{-1} of low pile-up data for better recoil resolution
- Exploit the angular variables decomposition to perform a simultaneous p_T measurement of
  - Angular coefficients
  - Unpolarised full-lepton phase space cross sections

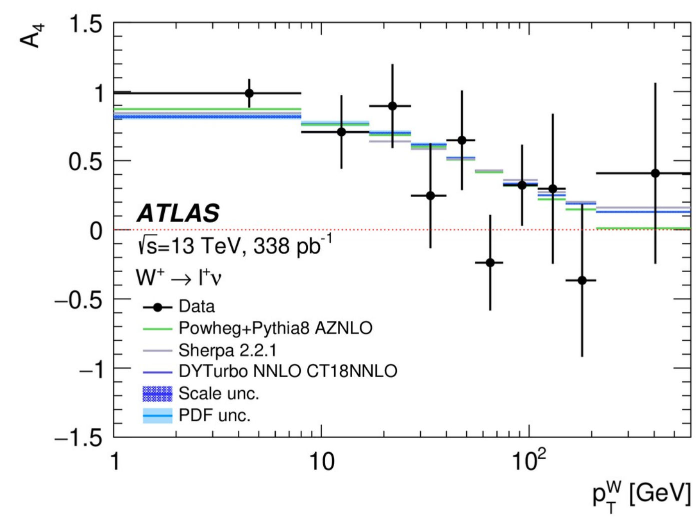
$$\frac{d^2\sigma}{dp_T dy}\left(1+\cos^2\theta+\sum A_i(p_T,y)P_i(\cos\theta,\phi)\right)$$

$$\begin{aligned}
P_0(\cos\theta,\phi) &= \frac{1}{2}(1-3\cos^2\theta)\\
P_1(\cos\theta,\phi) &= \sin 2\theta\cos\phi\\
P_2(\cos\theta,\phi) &= \frac{1}{2}\sin^2\theta\cos 2\phi\\
P_3(\cos\theta,\phi) &= \sin\theta\cos\phi\\
P_4(\cos\theta,\phi) &= \cos\theta\\
P_5(\cos\theta,\phi) &= \sin^2\theta\sin 2\phi\\
P_6(\cos\theta,\phi) &= \sin 2\theta\sin\phi\\
P_7(\cos\theta,\phi) &= \sin\theta\sin\phi
\end{aligned}$$

- Transverse momentum spectrum and polar-angle asymmetries A3, A4 are crucial ingredients for the modelling of W production needed for the m_W measurement







W-boson T-odd asymmetries

- $A_{5,6,7}$ coefficients are naive T-odd because ϕ flips sign under naive time reversal
- Sizeable non zero T-odd asymmetries in W production predicted by QCD starting at $O(\alpha_s^2)$ PRL 52 (1984) 1076,arXiv:1407.1016
- Could be used to probe dimension-8 SMEFT arXiv:2511.19617
- Interesting hint of positive A7 coefficient motivates further dedicated measurements

$$
\begin{aligned}
P_0(\cos\theta,\phi) &= \frac{1}{2}(1-3\cos^2\theta) \\
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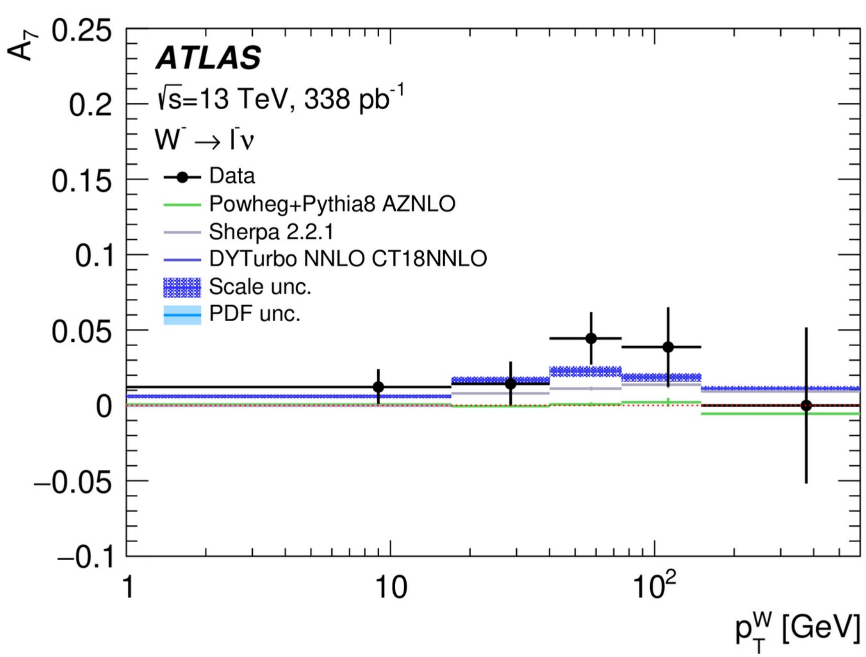
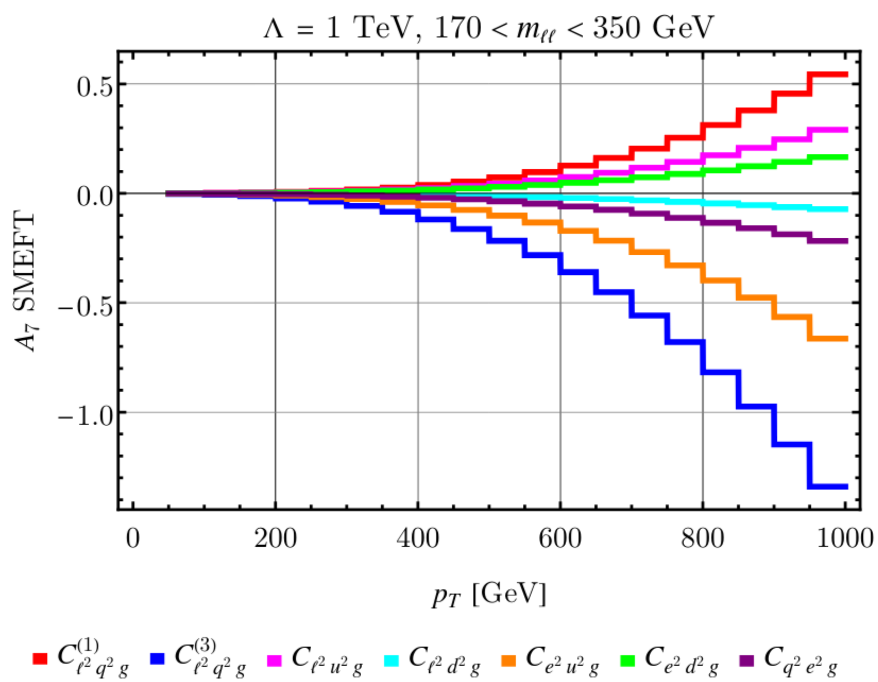
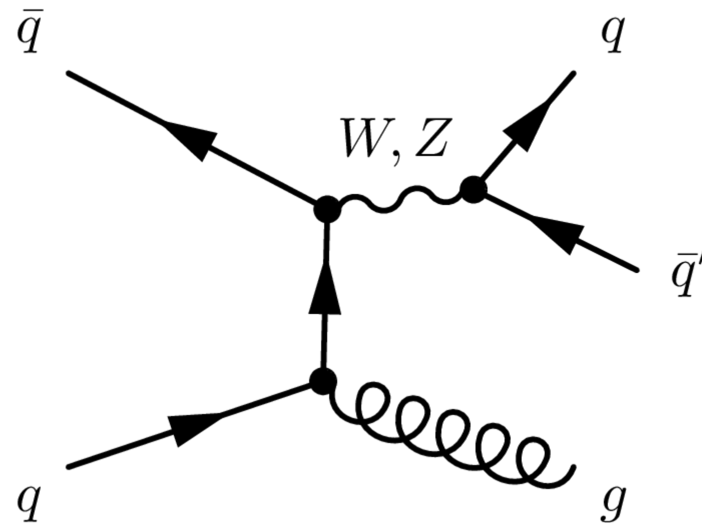
\end{aligned}
$$

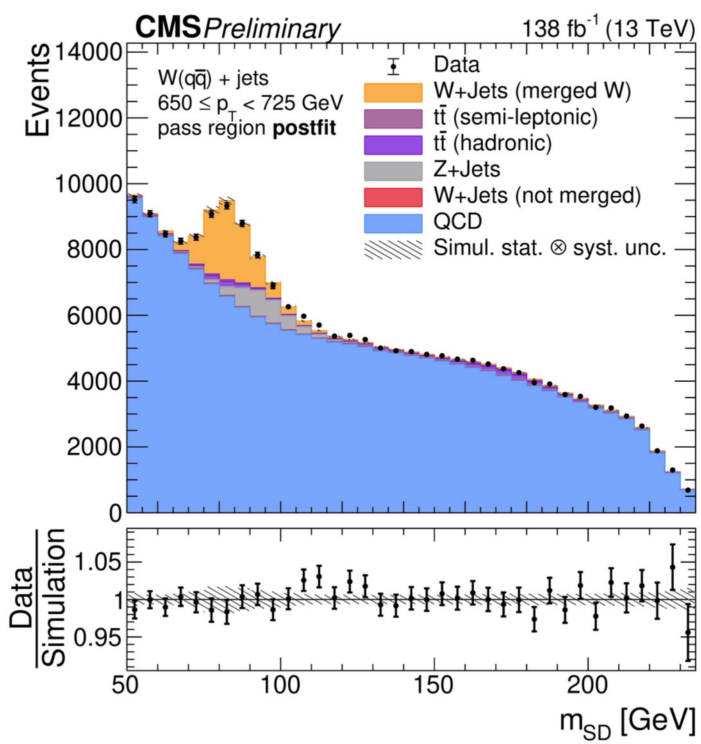


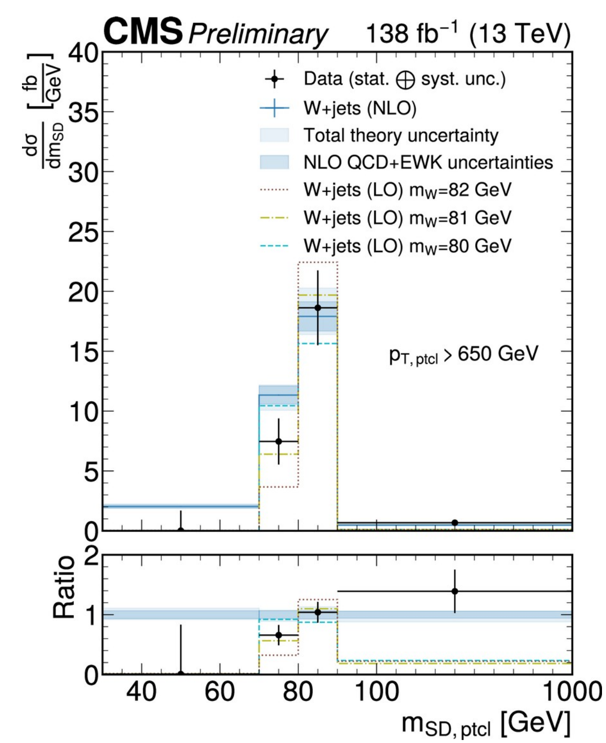


Boosted m_W

- Exploit hadronic decay of the W-boson to fully reconstruct the invariant mass
- Highly boosted W bosons, reconstructed as a large-radius jet, jet mass measured using the soft drop algorithm
- Challenge: Large background and worse energy resolution of jets compared to electrons and muons
- m_W = 80.77 ± 0.57 GeV

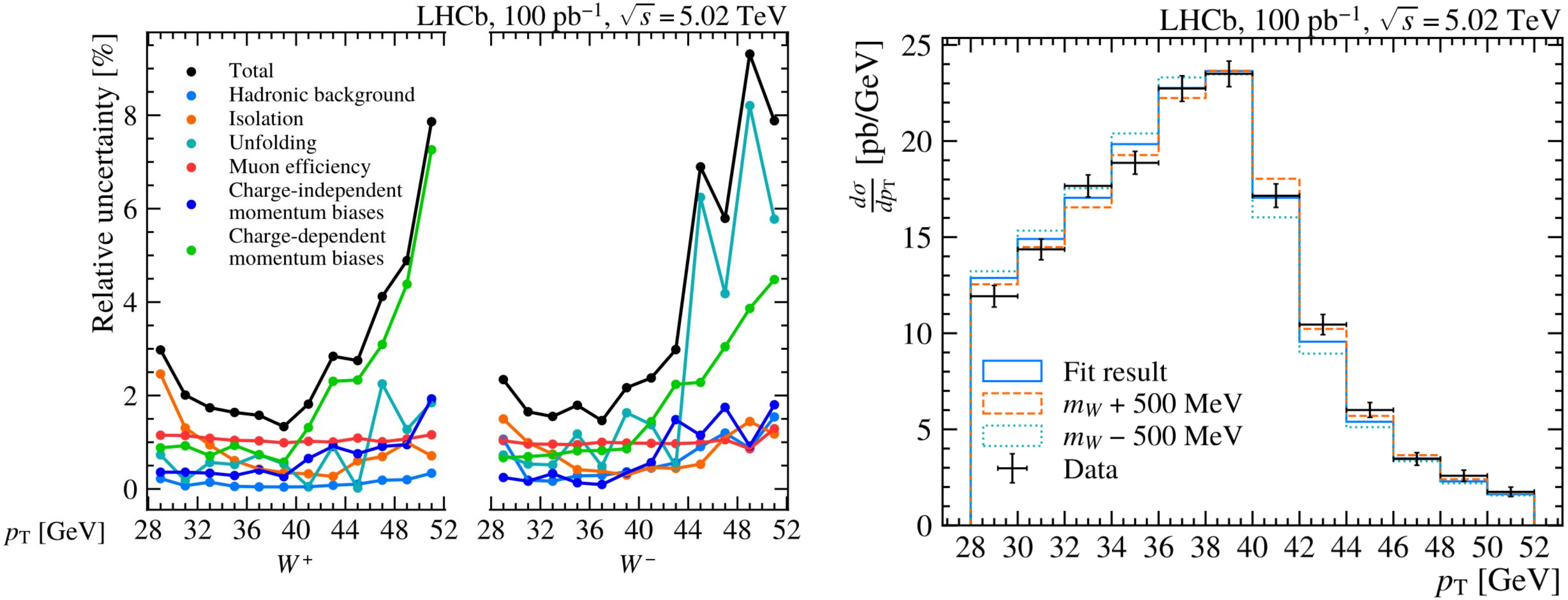






m_W from unfolded cross sections

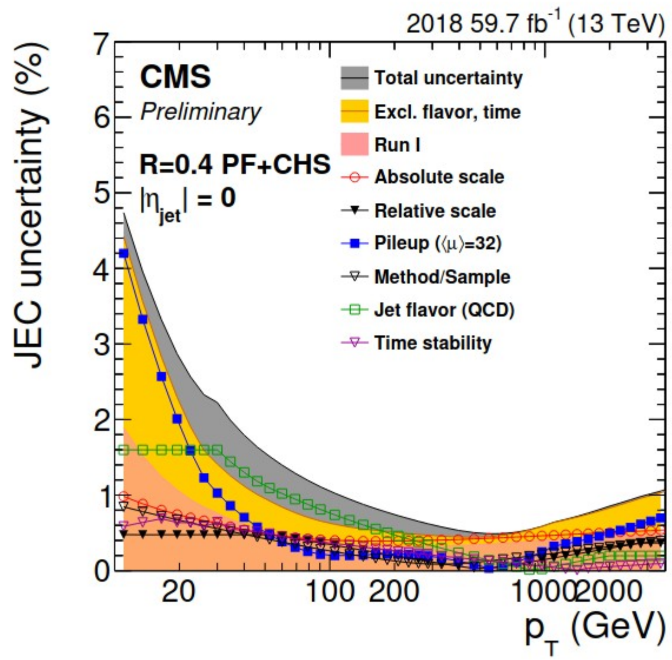
- LHCb measurement of m_W in the forward region from unfolded p_T muon cross section
- Performed on a statistically limited dataset as a proof of principle
- M_W = 80.369 ± 0.130(exp.) ± 0.33(th.) GeV
- Interesting new technique, will allow improving existing measurements of m_W when more accurate theory predictions become available

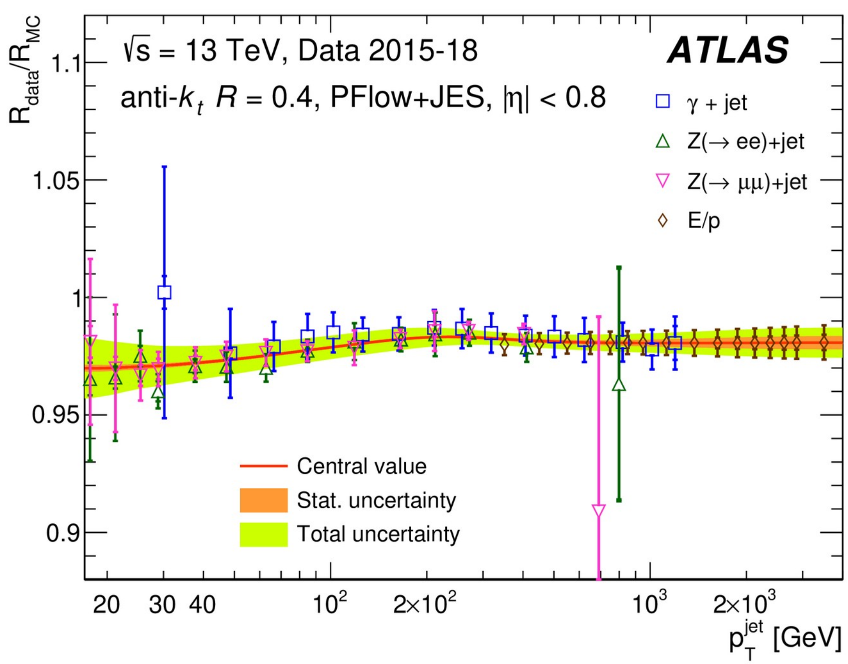


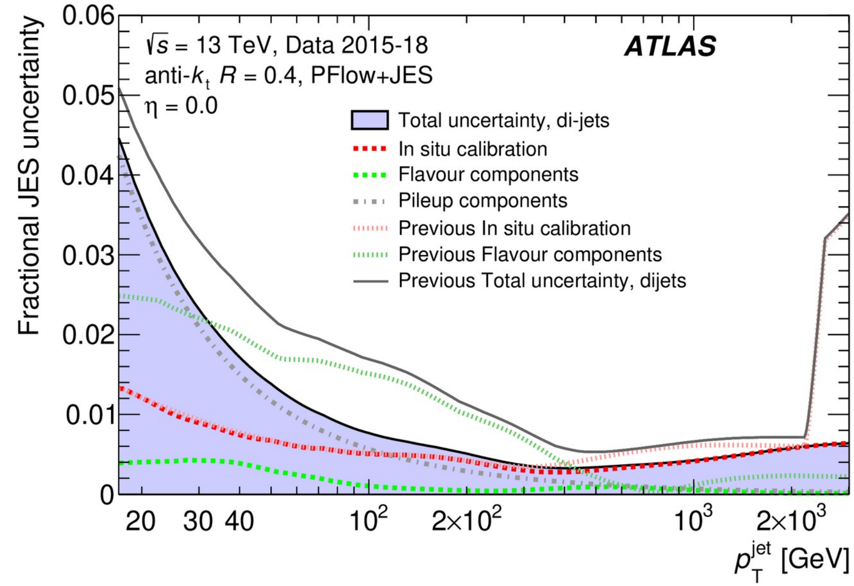
Jet energy scale

- ATLAS and CMS have very precise jet energy scale calibrations
- ATLAS recently made a step forward combining single-particle response and Z/γ + jet p_T balance, reaching 0.3% at 300 GeV and 0.6% at 4 TeV

  EPJC 85 (2025) 9, 927

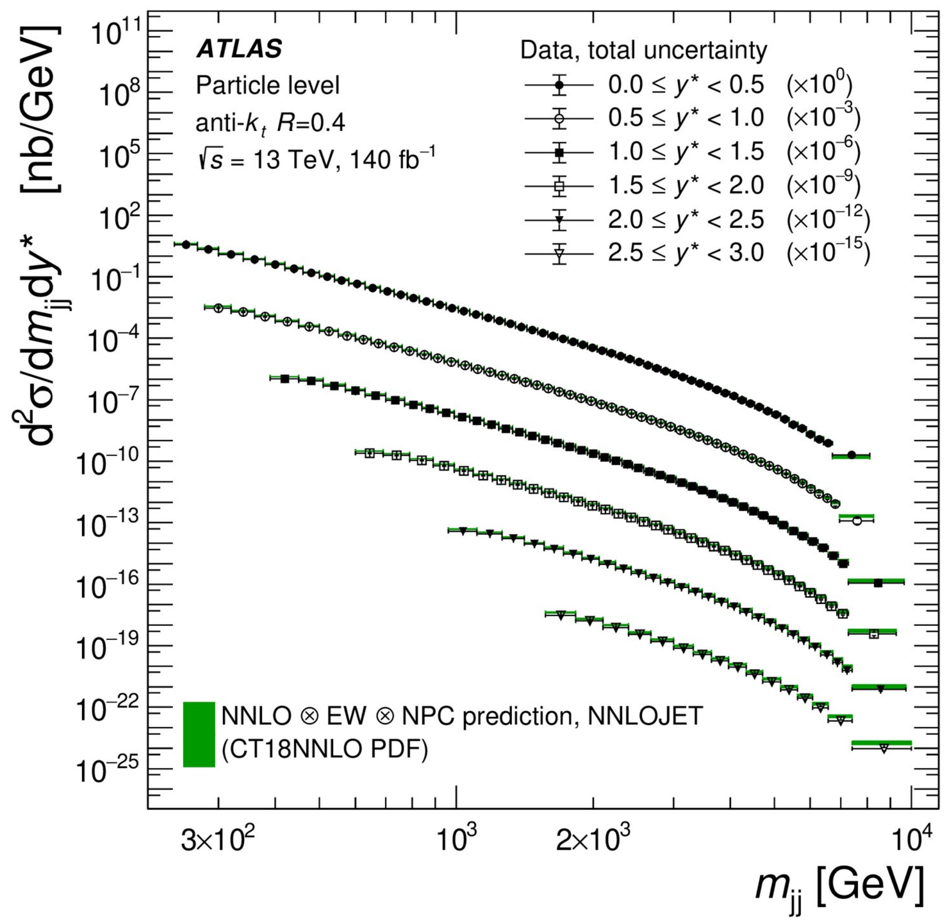


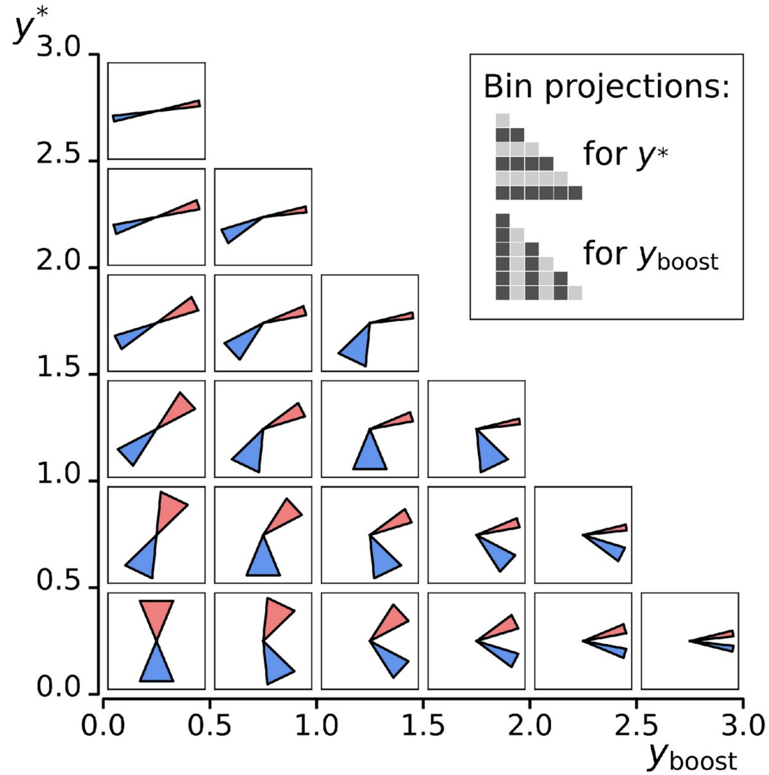


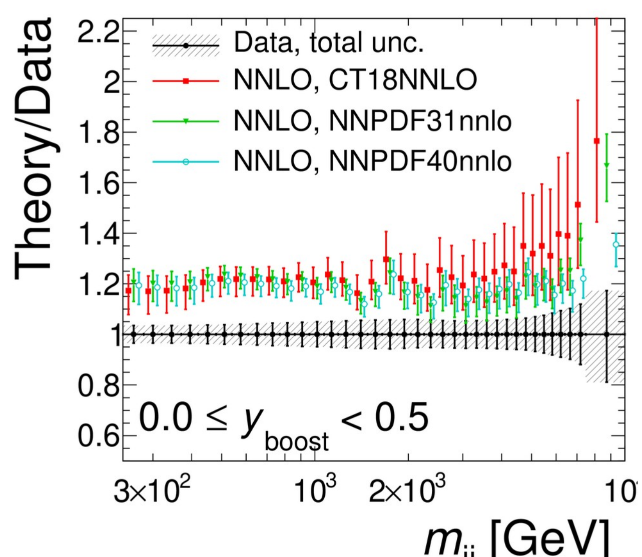


ATLAS inclusive dijets

- Measurement of inclusive dijets cross sections as functions of m_{jj}, y*, yboost
- Rely on very precise JES calibration
- Provide constraints on PDFs, and can be used for determination of the strong coupling

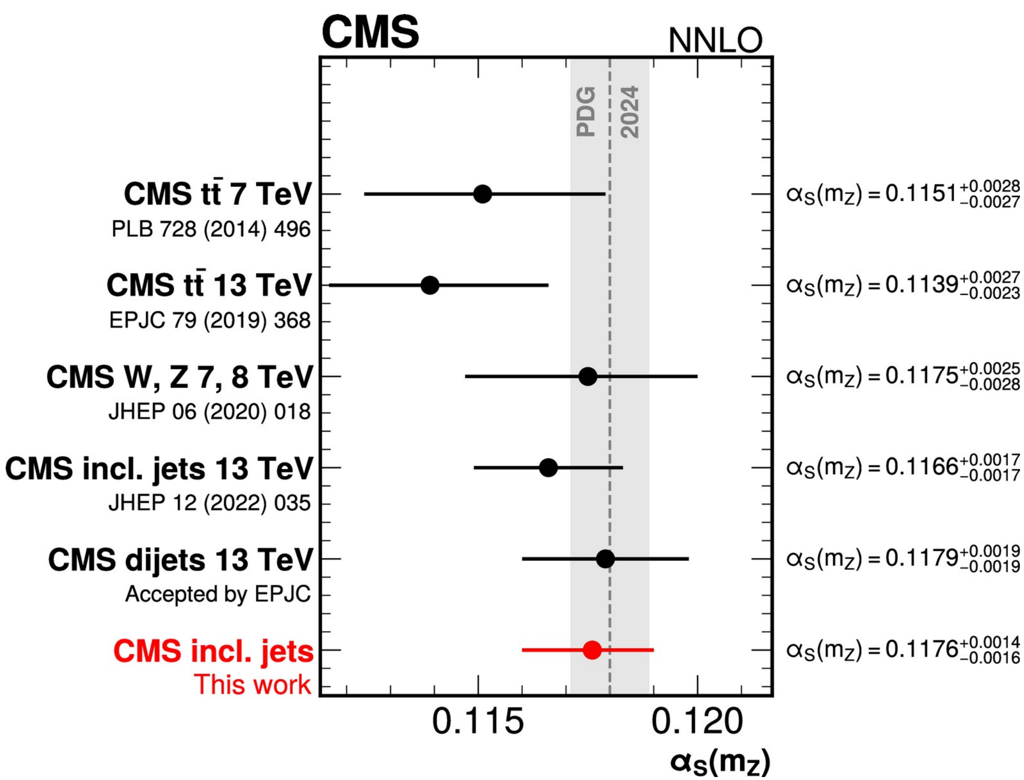


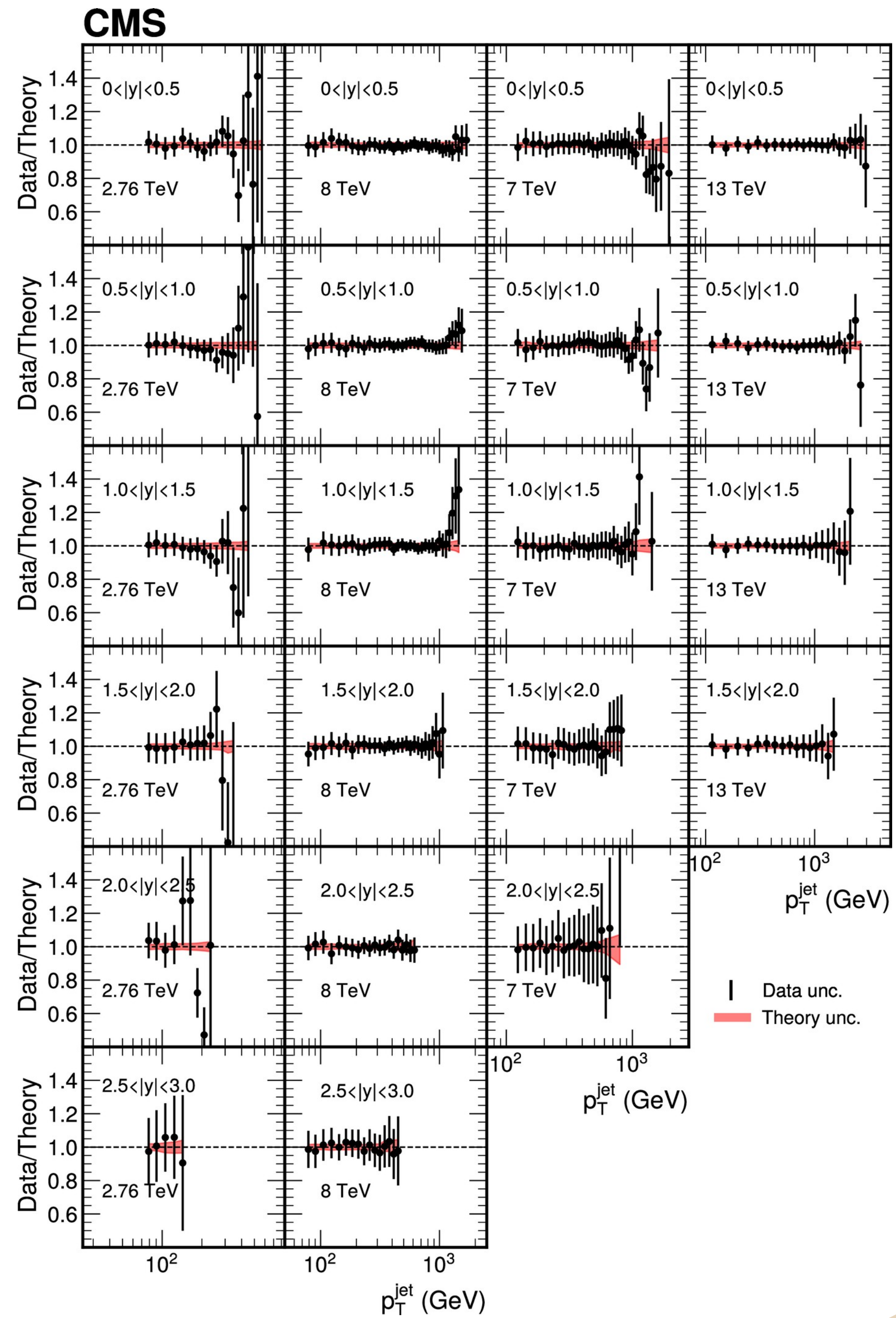




CMS $\alpha_s(m_Z)$ from jet production

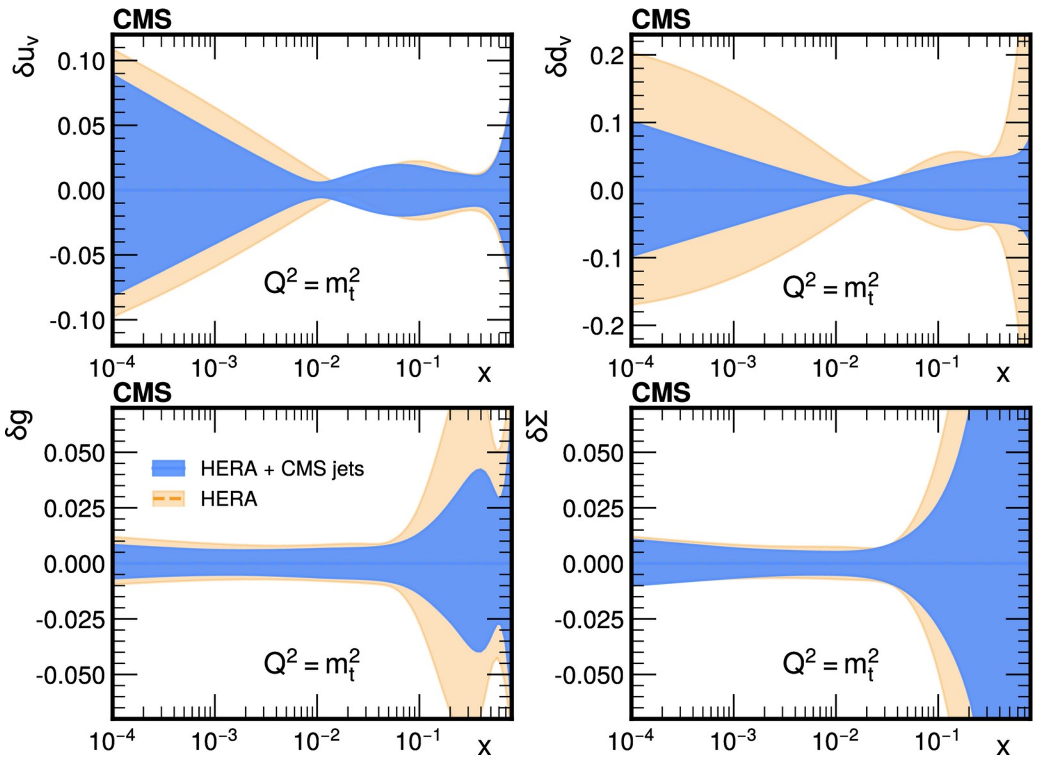
- Combined QCD analysis of inclusive jet cross sections at 2.76, 7, 8, 13 TeV and HERA DIS data at NNLO
- $\alpha_s(m_Z) = 0.1176 \pm 0.0015$

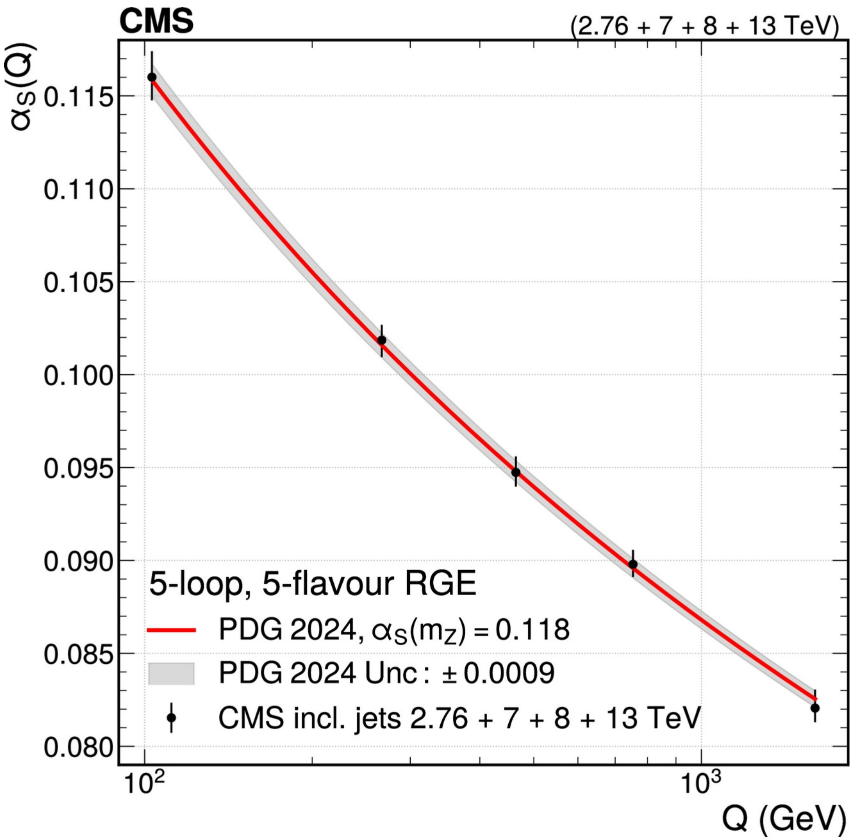




CMS $\alpha_s(m_Z)$ from jet production

- Significant reduction of the gluon PDF uncertainty at high x
- Tested RGE running of α_s up to the TeV scale





Summary

- SM precision measurements at the LHC are enabled by a tremendous advance of experimental techniques, physics performance, and development of theory tools beyond expectation
- They provide stringent tests of the consistency of the SM, and offer validation and improvement of theory predictions, which is crucial to increase the sensitivity of BSM searches