The strong coupling α_s from Transverse Energy-Energy Correlations using the ATLAS detector

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Test QCD from event-shape functions

The study of collider observables, including **event-shapes functions**, is well established to test QCD as they characterize the topology of the collisions.

Nowadays, there is still a lot of ongoing work in this field:

- Many fundamental concepts and techniques in QFT and collider physics have been naturally unified through a geometric language applied to event-shapes. [arXiv:2004.04159]
- The EEC function in e^+-e^- collisions attracts significant recent attention:
  - Analytical calculations at NLO using pQCD. [arXiv:1801.03219]
  - Numerical results at NNLL+NNLO accuracy. [arXiv:1804.09146]

Here, are the most recent measurements of event shapes by ATLAS:

- Measurement of hadronic event shapes in multijet final states at $\sqrt{s} = 13$ TeV with the ATLAS detector. [arXiv:2007.12600]
- Determination of the strong coupling constant and test of asymptotic freedom from Transverse Energy-Energy Correlations in multijet events at $\sqrt{s} = 13$ TeV with the ATLAS detector. [ATLAS-CONF-2020-025]

Transverse Energy-Energy Correlations

TEEC function: transverse energy-weighted azimuthal angular distribution of produced jet pairs in the final state,

$$\frac{1}{\sigma}\frac{\mathrm{d}\Sigma}{\mathrm{d}\cos\phi} = \frac{1}{\sigma}\sum_{i,j}^{\text{jets}}\int \mathrm{d}\sigma_{pp\to\text{jets}}\; x_{\mathrm{T}i}x_{\mathrm{T}j}\;\delta\left(\cos\Delta\varphi_{ij}-\cos\phi\right)\,.$$

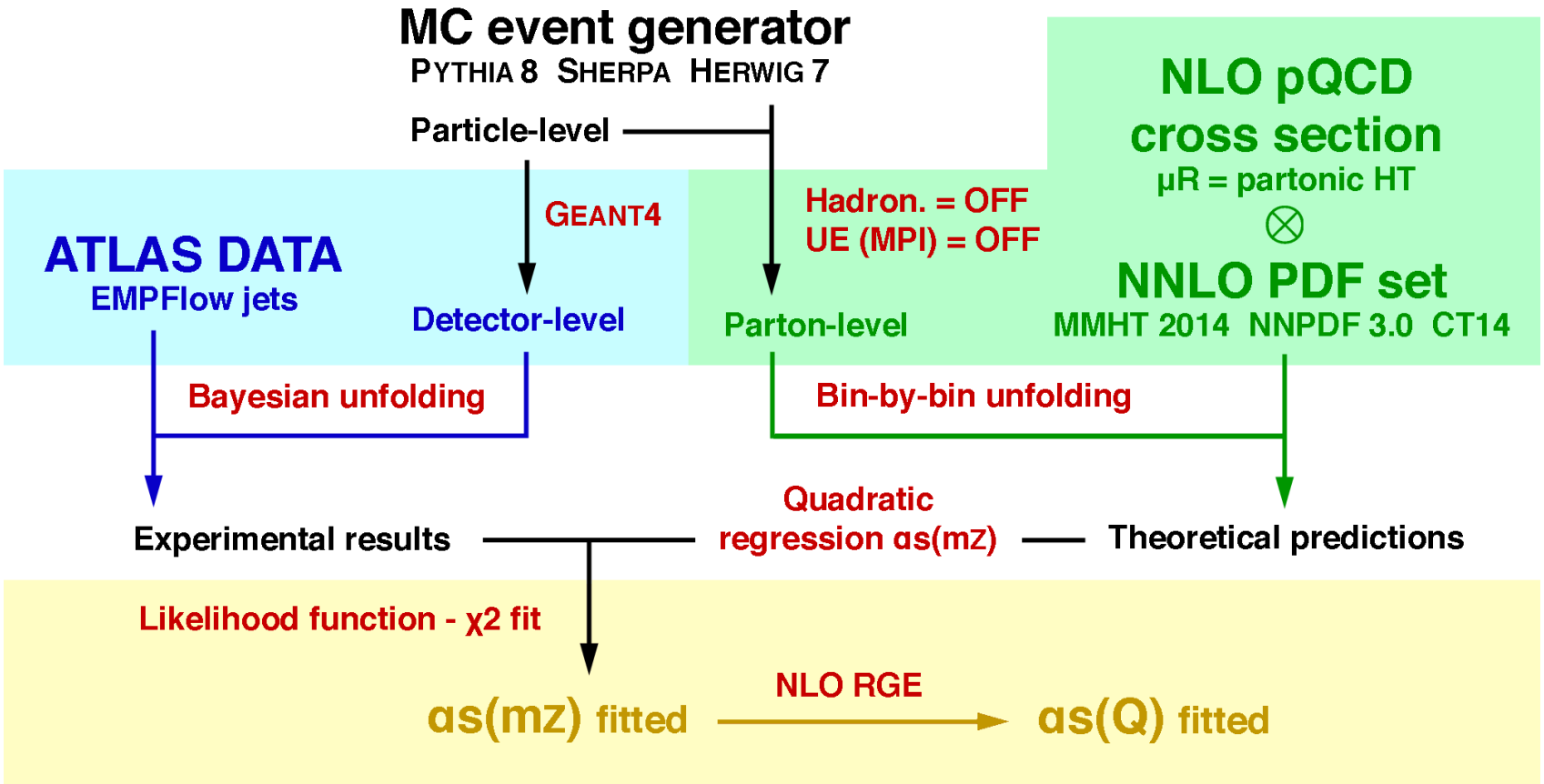
Here, $x_{\mathrm{T}i} = E_{\mathrm{T}i}/E_{\mathrm{T}}$ is the jet i normalized transverse energy and the normalization to σ ensures that the integral of the function over $\cos\phi$ is unity.

ATEEC function: its forward-backward azimuthal angular asymmetry,

$$\frac{1}{\sigma}\frac{\mathrm{d}\Sigma^{\text{asym}}}{\mathrm{d}\cos\phi} = \frac{1}{\sigma}\frac{\mathrm{d}\Sigma}{\mathrm{d}\cos\phi}\bigg|_{\phi} - \frac{1}{\sigma}\frac{\mathrm{d}\Sigma}{\mathrm{d}\cos\phi}\bigg|_{\pi-\phi}\,.$$

- Large sensitivity to QCD radiation and the strong coupling $\alpha_{\mathrm{s}}(Q^2)$.
- IR safety, they are not affected by IR divergences in e^+e^- collisions.
- Smaller sensitivity to IR divergences than other variables in pp collisions.
- Mild sensitivity to PDFs and factorization and renormalization scale variations.

Analysis workflow



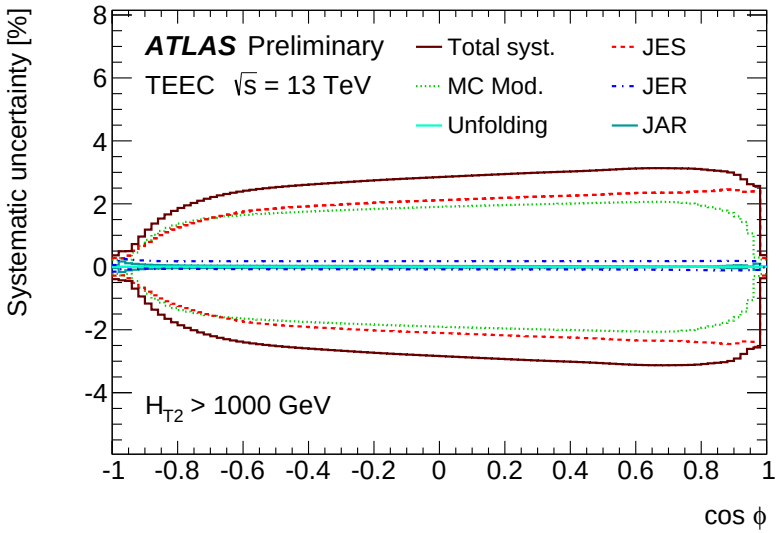
- TEEC function computed at fixed-order with a collinear cut $|\cos\phi| < 0.92$.
- Non-pQCD corrections computed with PYTHIA 8 tunes A14, AU2 and 4C.

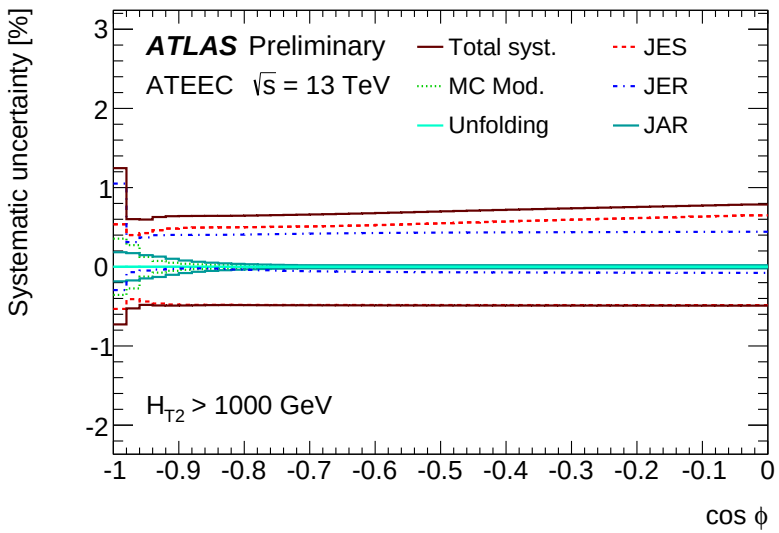
Event selection and experimental uncertainties

The data sample corresponds to the full dataset recorded during the LHC p-p Run 2 at $\sqrt{s} = 13$ TeV. The available integrated luminosity is 139 fb^{-1}.

- PFlow anti-k_T R=0.4 reconstructed jets with $p_T > 60$ GeV and $|\eta| < 2.4$.
- Multi-jet events $H_{T2} = p_{T1} + p_{T2} > 1$ TeV using the HLT_j460 single-jet trigger.

The dominant uncertainties arise from knowledge of the jet energy scale and resolution and the modelling of the strong interaction in the unfolding.





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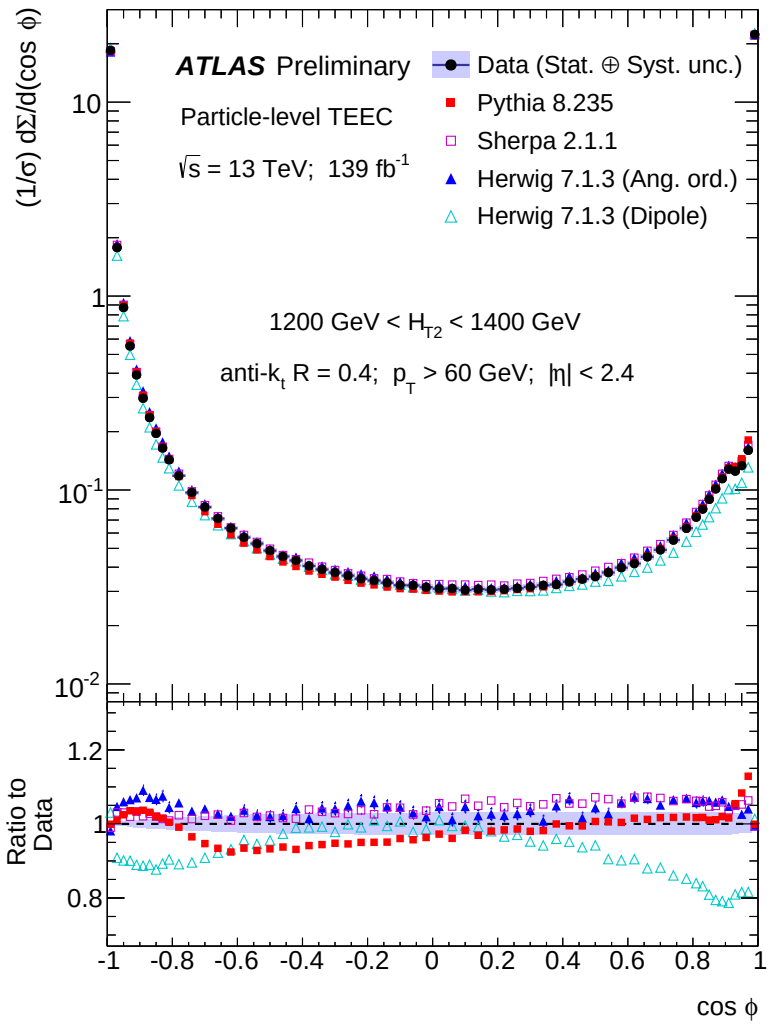
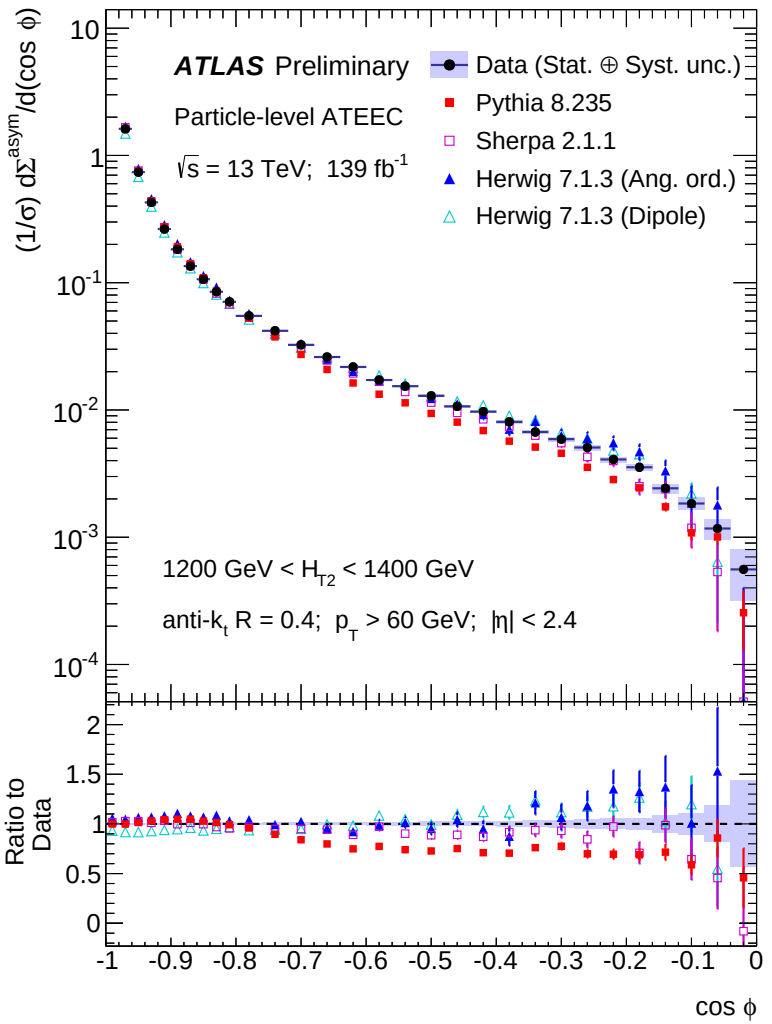
TEEC and ATEEC unfolded results





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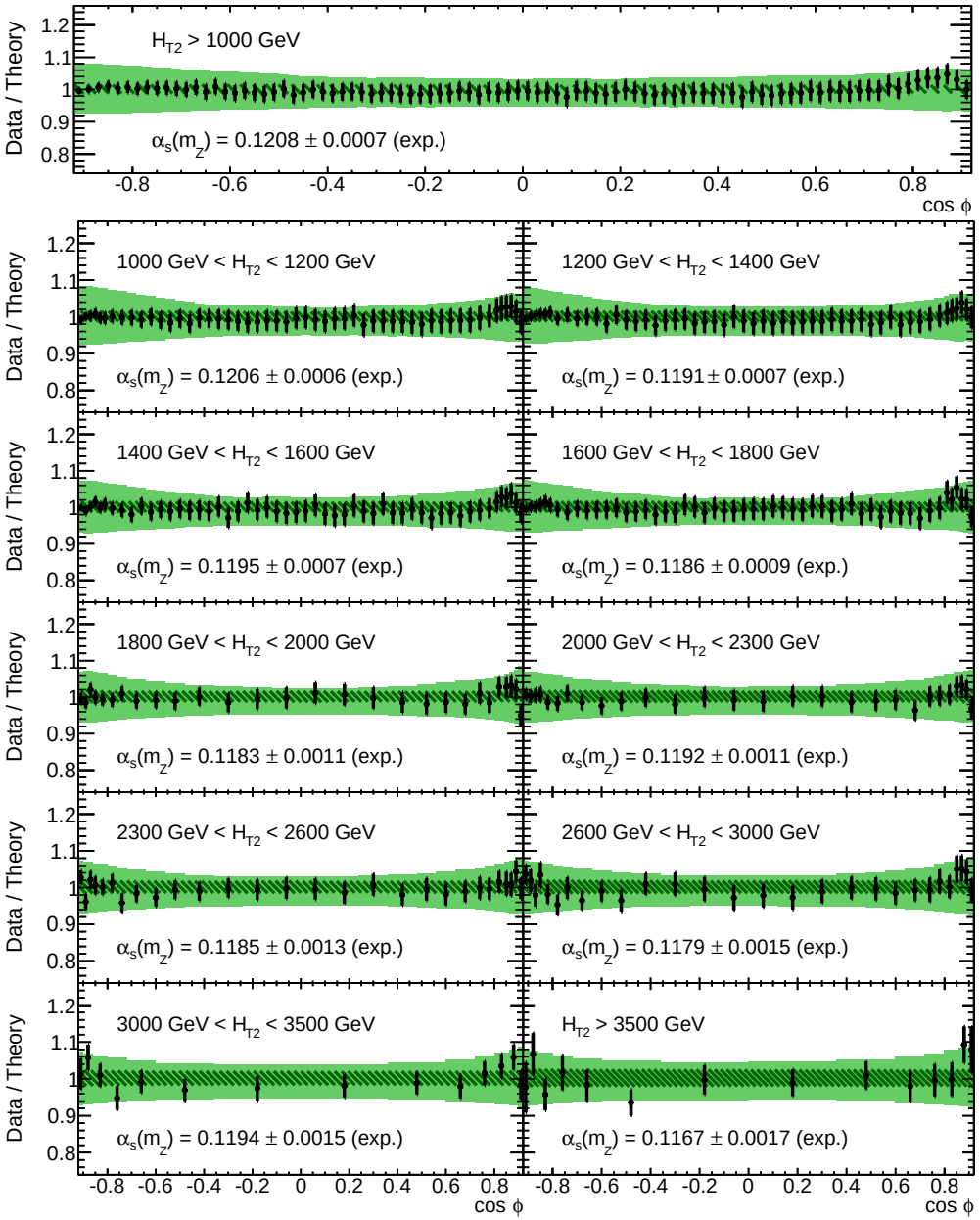
- SHERPA and HERWIG7 (Ang. ord.) give similar overall good description of data.
- The $\alpha_s(Q^2)$ values are extracted from fits of the pQCD calculations to the data.

Determination of the strong coupling from TEECs



ATLAS Preliminary

Particle-level TEEC

$\sqrt{s}$ = 13 TeV; 139 fb^{-1}

NLO pQCD

MMHT 2014 (NNLO)

Exp. unc.

Non-scale unc.

Theo. unc.

$|\eta|$ < 2.4

p_T > 60 GeV

anti-k_t R = 0.4

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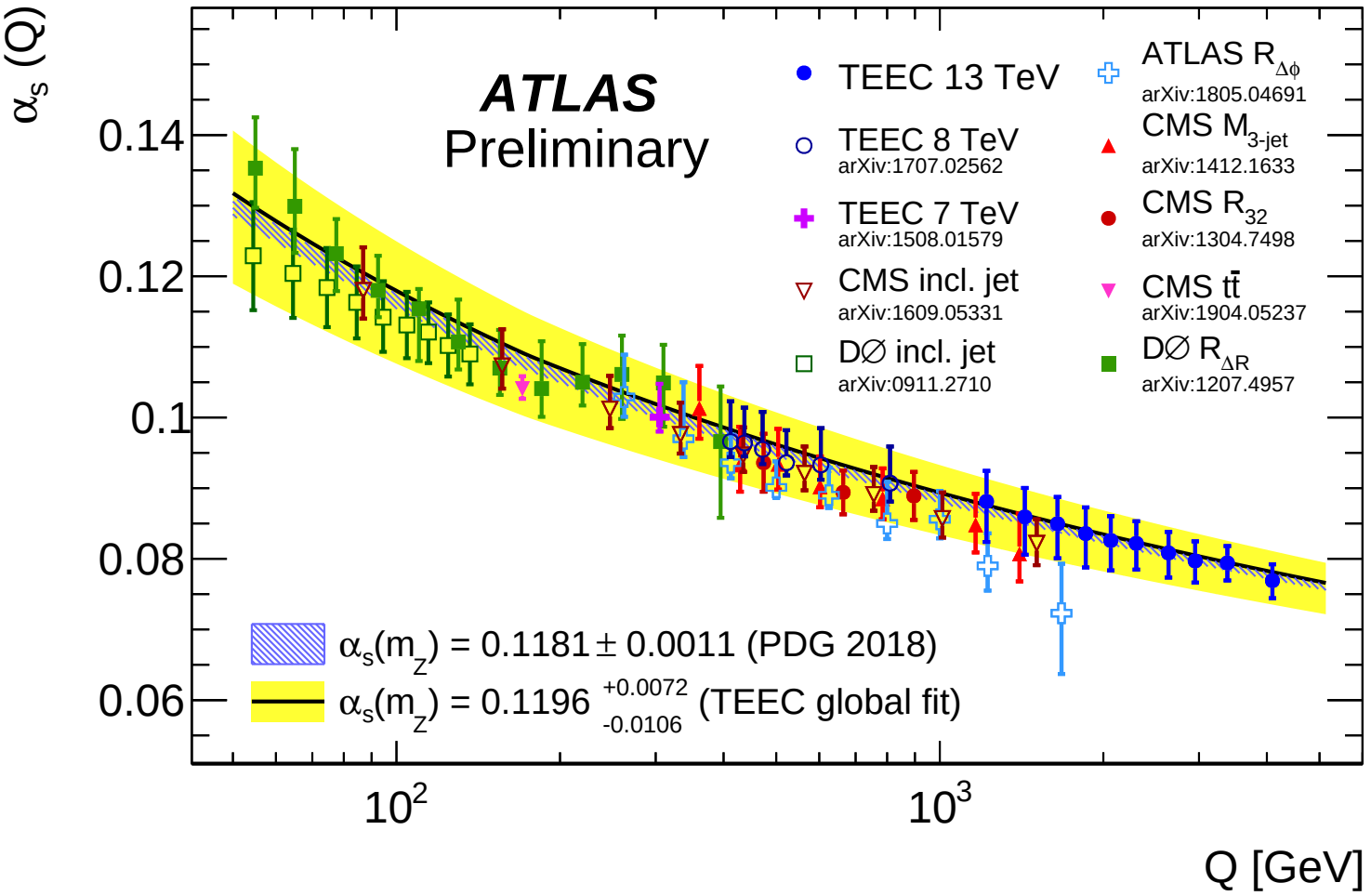
Test of asymptotic freedom from TEECs



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- The $\alpha_s(m_Z)$ values are evolved to μ_R using the NLO solution of the RGE.
- These data can be used also as a test for new physics at large scales. [arXiv:1807.00894]

Conclusions

This analysis tests asymptotic freedom beyond TeV scale at NLO accuracy.

$$\alpha_s(m_Z) = 0.1196 \pm 0.0004\ (\text{exp.})^{+0.0072}_{-0.0105}\ (\text{theo.}) \quad \text{[TEEC global fit]}$$

$$\alpha_s(m_Z) = 0.1195 \pm 0.0006\ (\text{exp.})^{+0.0084}_{-0.0107}\ (\text{theo.}) \quad \text{[ATEEC global fit]}$$

- Data results can be used to validate multi-jet production from MC event generators and to test new physics at large scale regimes.
- The agreement between data and theoretical predictions at NLO in pQCD is excellent at large momentum transfers.
- The strong coupling α_s is determined in ten intervals, testing asymptotic freedom beyond the TeV scale.
- The extracted values are in good agreement with the current world average and with previous determinations.
- Theoretical predictions at NNLO in pQCD are expected in the near future!