Measurement of transverse energy-energy correlations at $\sqrt{s} = 7$ TeV and determination of $\alpha_s(m_Z)$ with ATLAS

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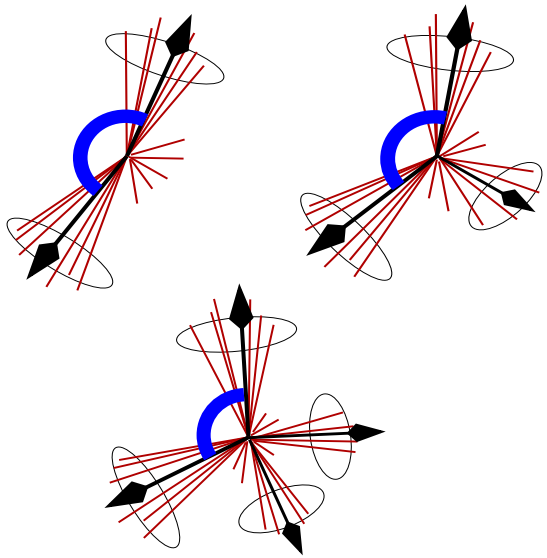
Transverse energy-energy correlations. Definition.

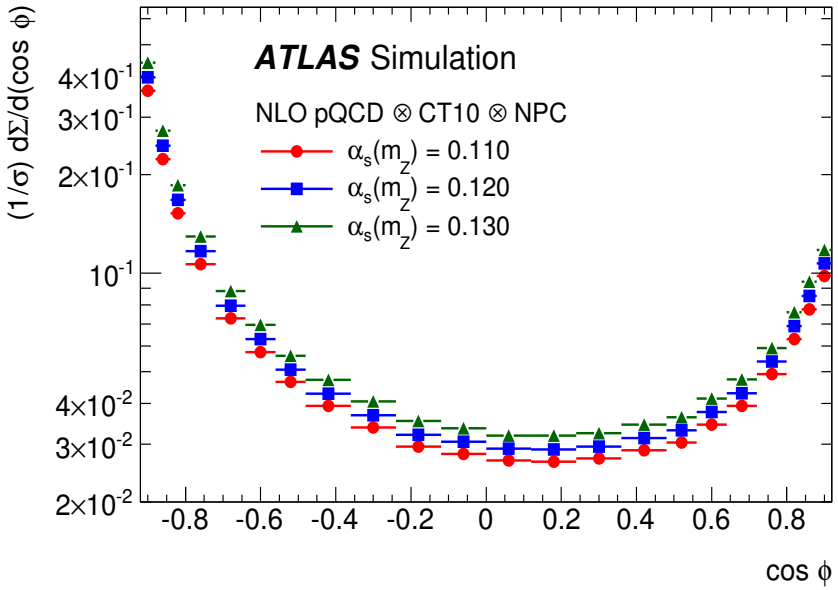
TEEC: The x_{T}-weighted distribution of differences in azimuth between jets i and j, with $x_{\mathrm{T}i} = \frac{E_{\mathrm{T}i}}{\sum_k E_{\mathrm{T}k}}$

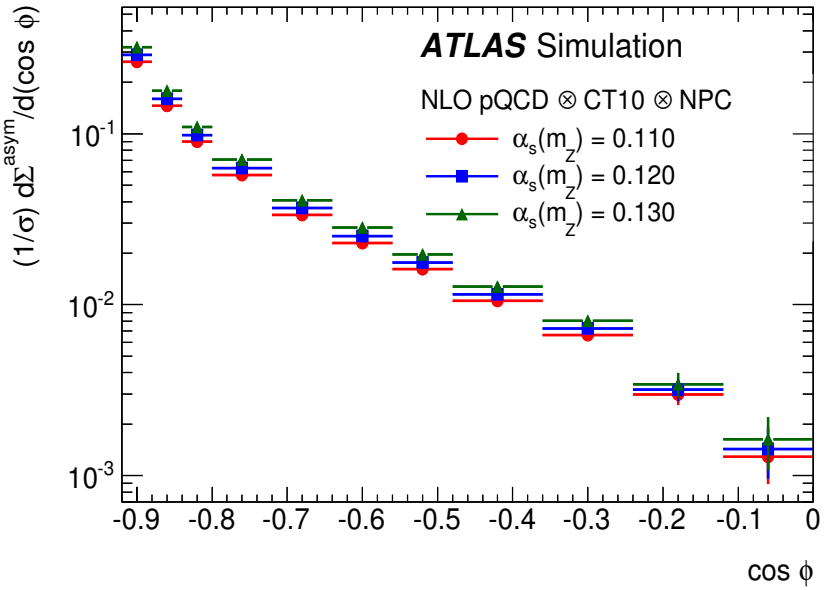
$$\frac{1}{\sigma}\frac{d\Sigma}{d(\cos\phi)} = \frac{1}{\sigma}\sum_{ij}\int \frac{d\sigma}{dx_{\mathrm{T}i}dx_{\mathrm{T}j}d(\cos\phi)} x_{\mathrm{T}i}x_{\mathrm{T}j}dx_{\mathrm{T}i}dx_{\mathrm{T}j}$$

And the azimuthal asymmetry ATEEC is defined as

$$\frac{1}{\sigma}\frac{d\Sigma^{\mathrm{asym}}}{d(\cos\phi)} \equiv \frac{1}{\sigma}\frac{d\Sigma}{d(\cos\phi)}\bigg|_{\phi} - \frac{1}{\sigma}\frac{d\Sigma}{d(\cos\phi)}\bigg|_{\pi-\phi}$$







[A. Ali, F. Barreiro, J. Llorente, W. Wang. Phys. Rev. **D86**, 114017 (2012)]

Transverse energy-energy correlations. Properties.

The TEEC and ATEEC functions exhibit several advantages:

- Theoretically:
  - Smaller sensitivity to IR divergencies than other event shape variables.
  - NLO corrections are about 10% for ATEEC.
  - Reduced sensitivity to PDFs. μ-uncertainties similar to other cross-section ratios.
- Experimentally:
  - φ^{jet} measured with a very high precision $\Rightarrow$ Migration suppression.
  - The TEEC function is highly stable w.r.t. JES and JER ($w \sim E_i E_j / E^2$).

These measurements extend those of EEC and AEEC which played significant role in determining $\alpha_s(m_Z)$ in e^+e^- colliders.

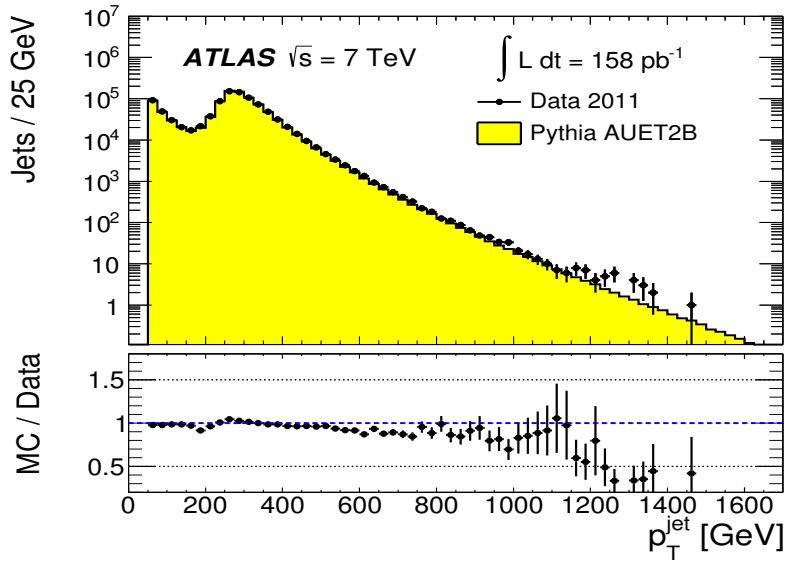
Event selection

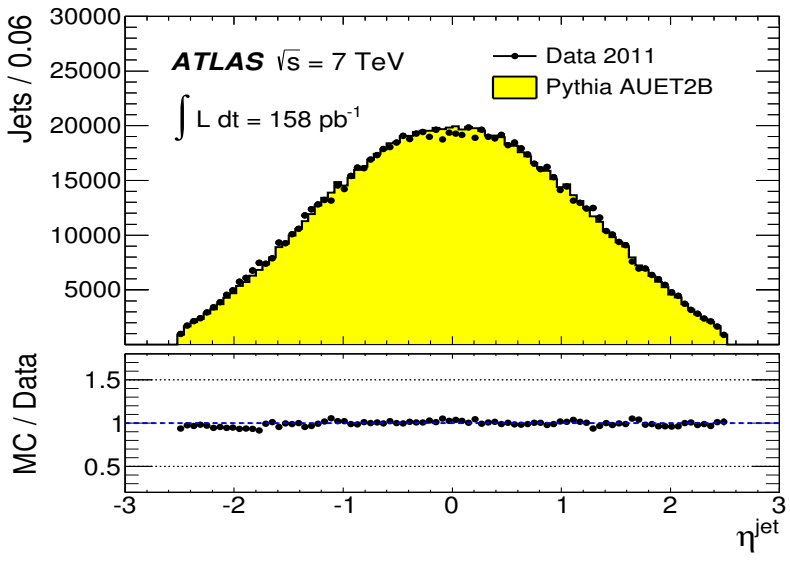
For this measurement, we have selected inclusive multi-jet events in 4.6 fb^{-1} of 2011 data with the following cuts:

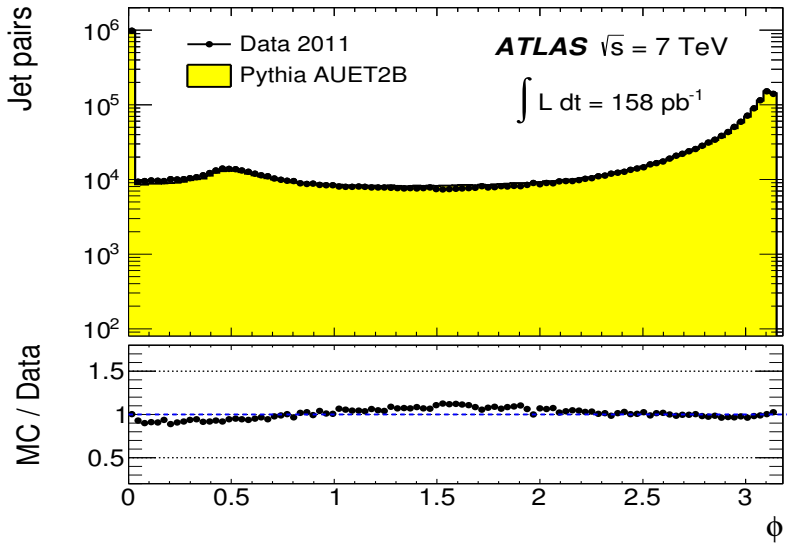
- Trigger: EF_j135_a4tc_EFFS.
- Trigger prescale factor of ~ 30 ($\mathcal{L}_{\text{eff}} = 158\ \text{pb}^{-1}$).
- At least one primary vertex with 5 or more tracks with $p_T > 400$ MeV.
- Jet selection: anti-k_T ($R = 0.4$) jets with LC+JES calibration.
- Jet cleaning: Bad and Ugly jets are removed.
- $p_T > 50$ GeV, $|\eta| < 2.5$ and $|\text{JVF}| > 0.75$ for each jet.
- The two leading jets have to fulfill $p_{T1} + p_{T2} > 500$ GeV.

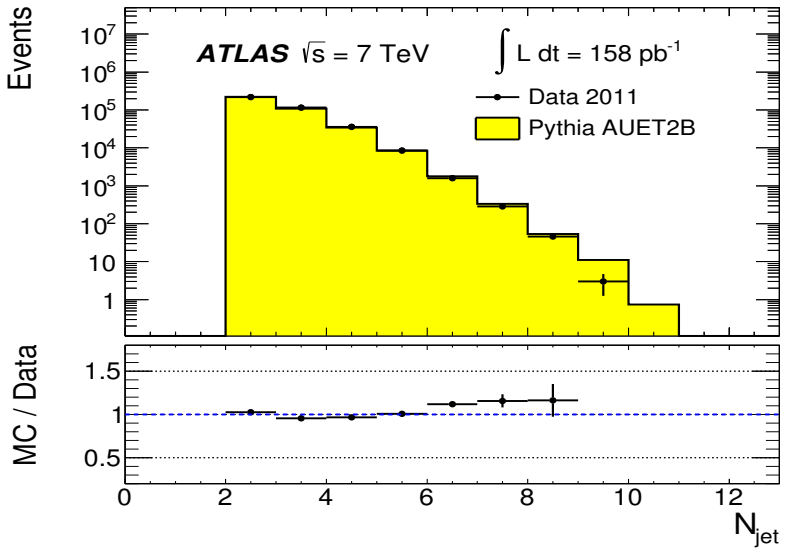
Control plots

The plots show control distributions for the selected jets, compared to expectations by PYTHIA AUET2B



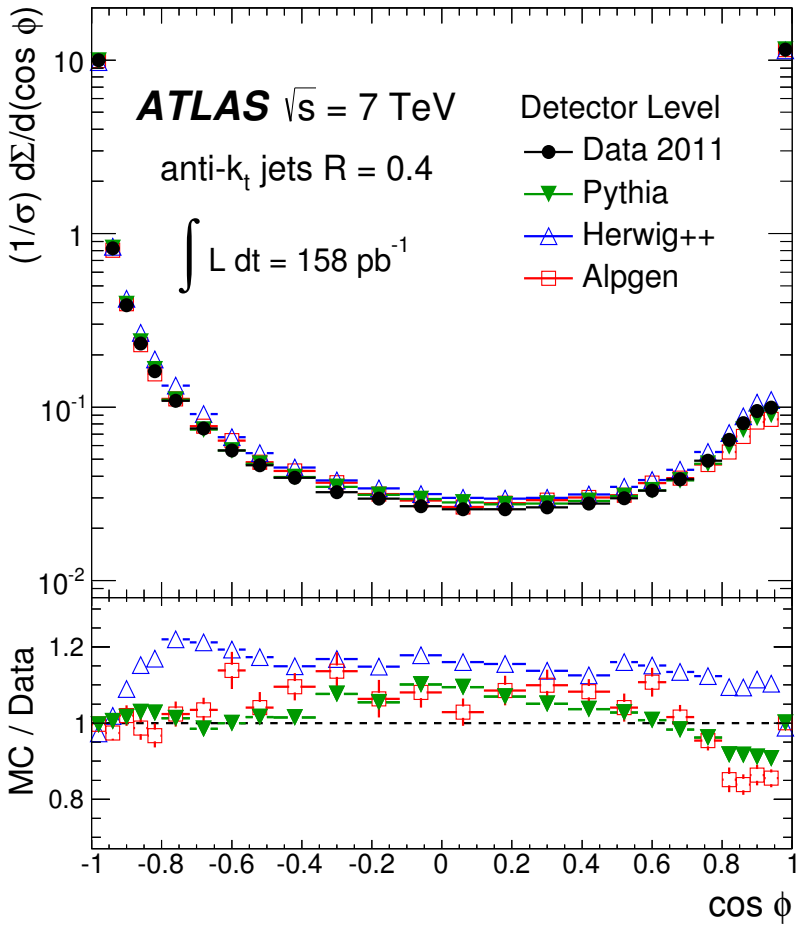


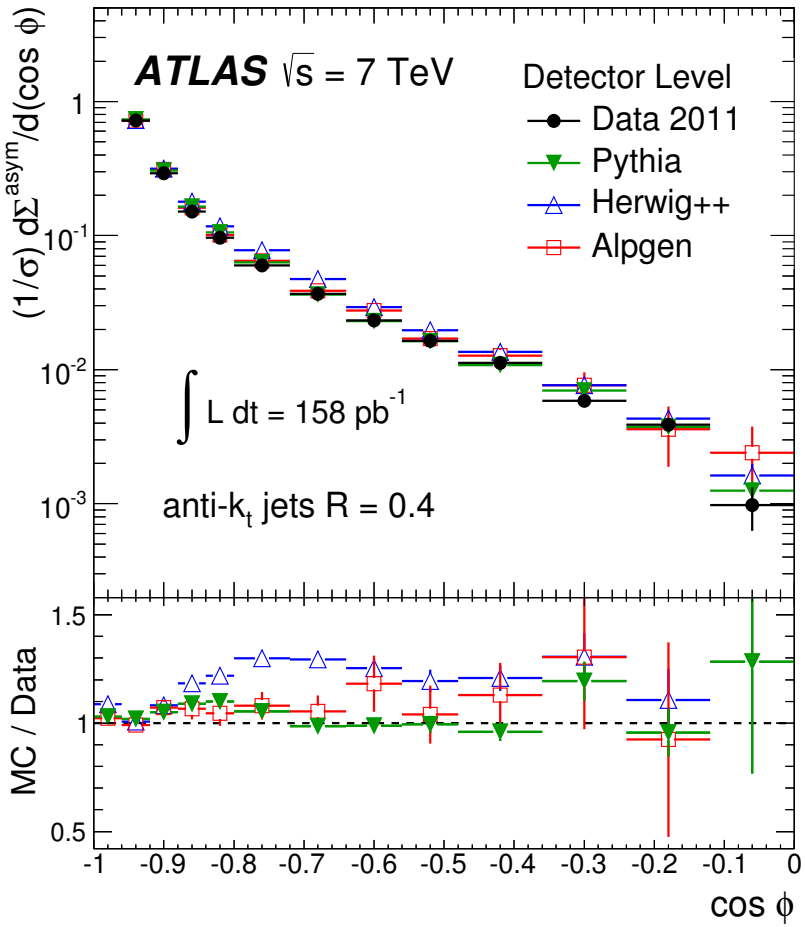




Results at the Detector Level

The plots below show the TEEC and ATEEC functions along with several MC expectations. The error bars in data include statistical uncertainties only.

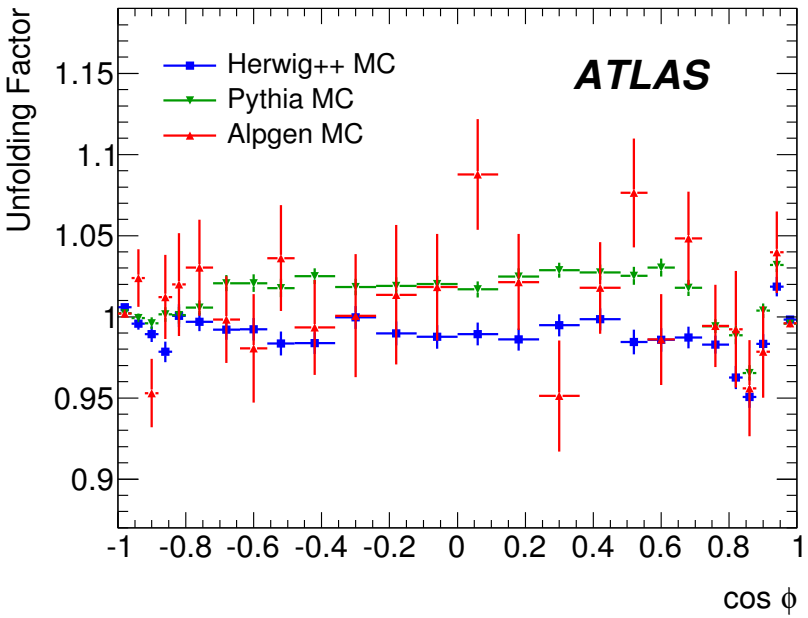


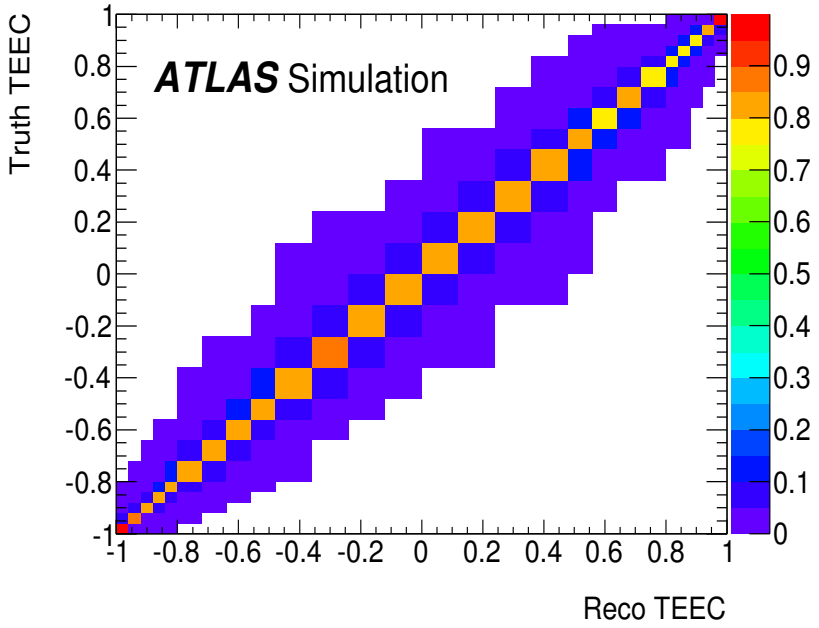


Pythia and Alpgen describe the gross features of the data.

Unfolding

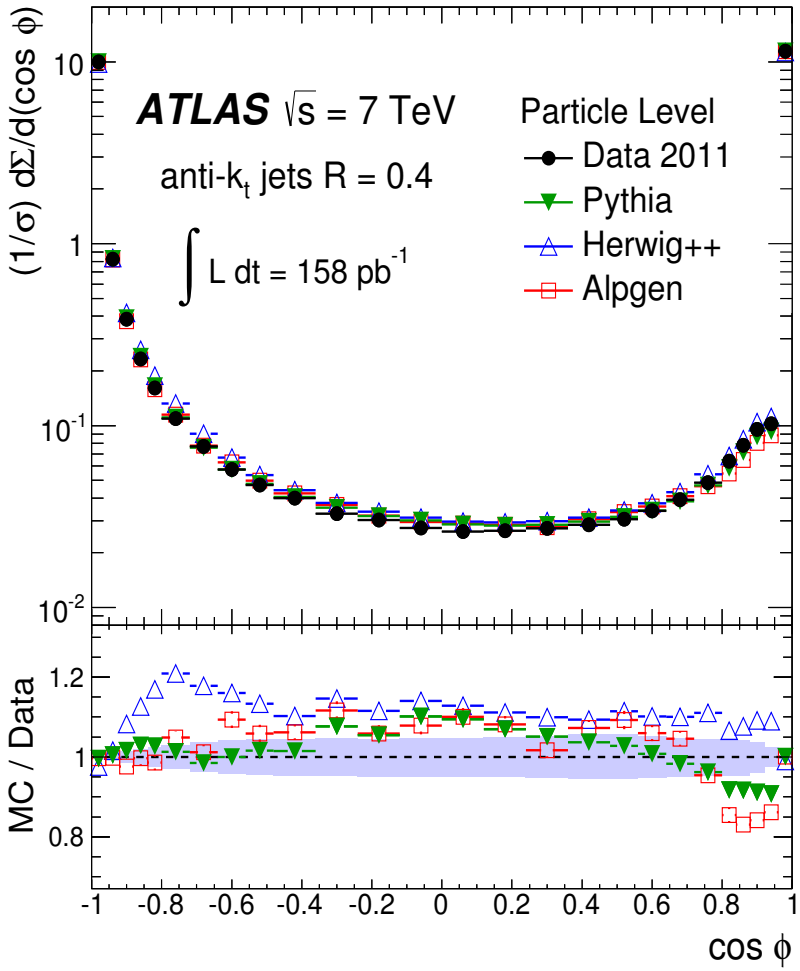
To correct our data for detector effects, we perform a bin by bin unfolding based on the Pythia samples. The unfolding is cross-checked using a matricial approach based on Bayes' theorem.

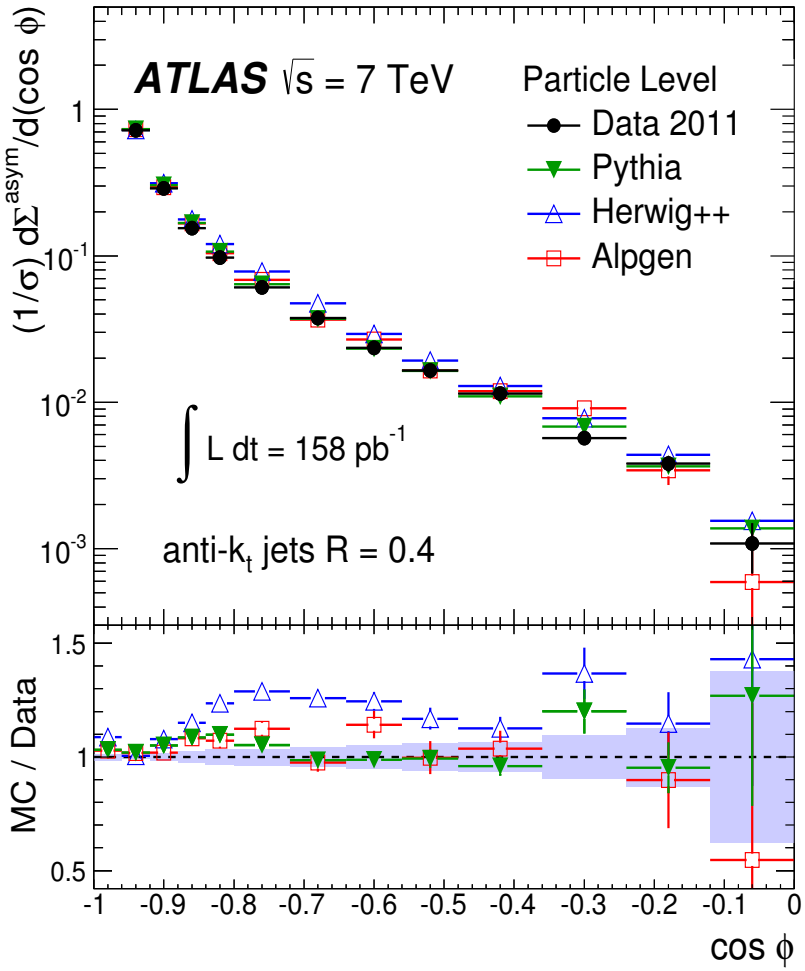




Unfolding: Corrected data

The plots below show the TEEC and ATEEC distributions, corrected for detector effects, compared to the truth level information from various Monte Carlos.





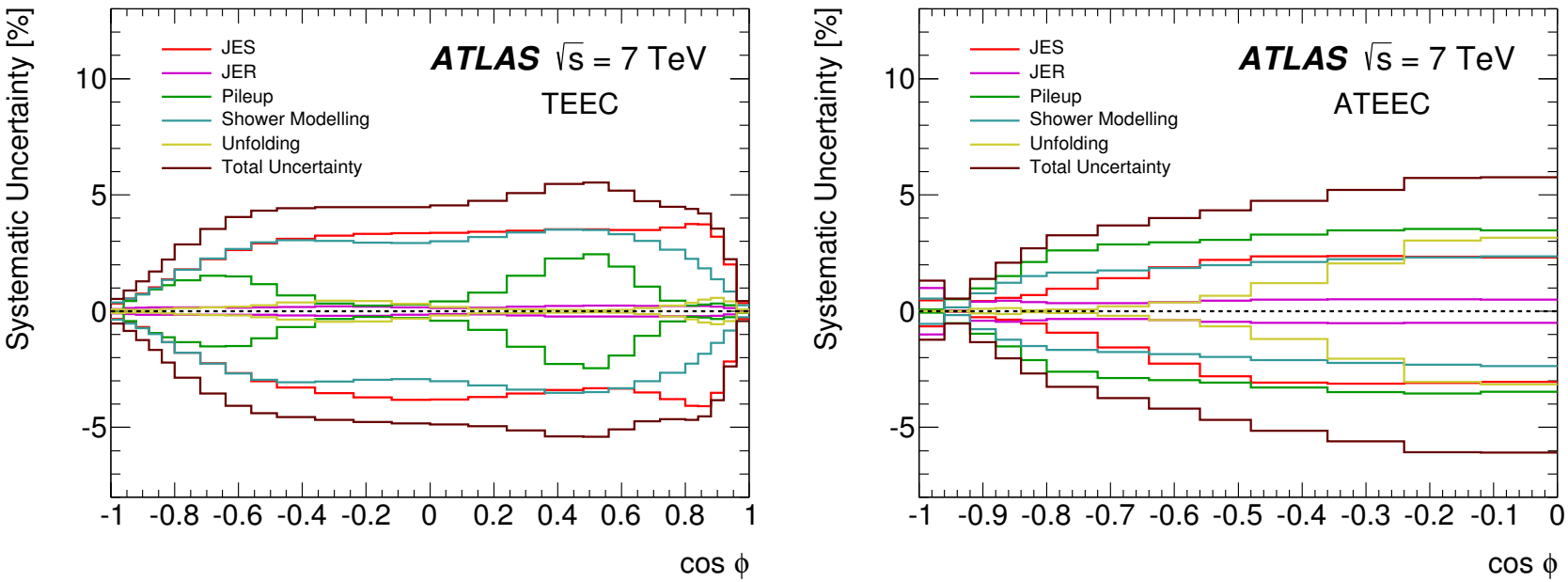
Systematic uncertainties

The main systematic uncertainties are:

- Jet energy scale: Uncertainty on the jet calibration in 61 nuisance parameters. Evaluated by scaling up and down the jet energy and momentum.
- Jet energy resolution: Evaluated by smearing the jet energy and momentum by a smearing factor accounting for finite resolution.
- Shower modelling: The parton shower model in the Monte Carlo used for the unfolding.
- Pileup: How the MC describes the pileup dependence of the observable.
- Unfolding: Effects of the misdescription of the data by the MC model used for unfolding.

Systematic uncertainties

The plots below show the relative systematic uncertainties for the TEEC (left) and ATEEC (right).



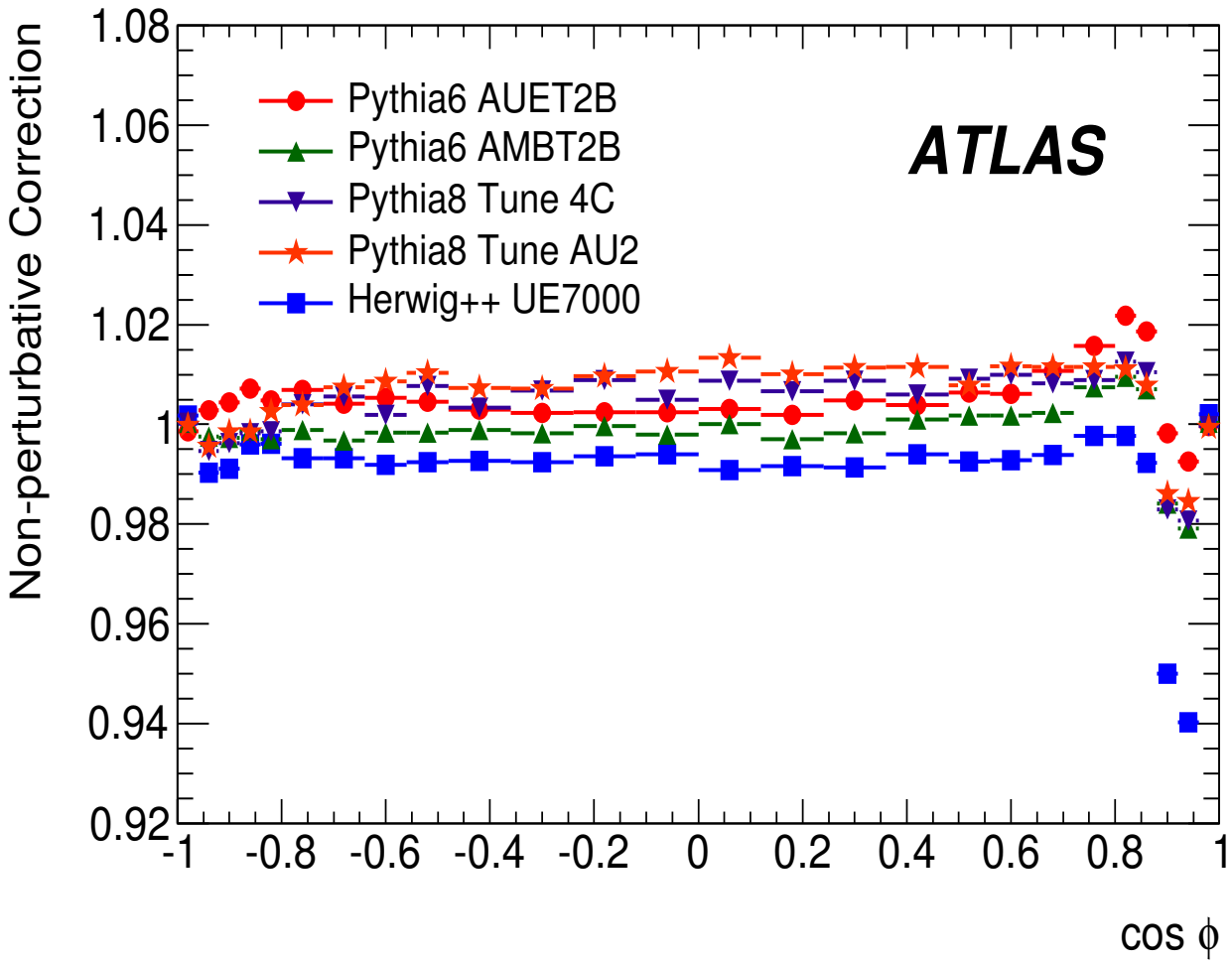
All numbers (including the 61-dimensional breakdown for JES uncertainty) in

http://hepdata.cedar.ac.uk/view/ins1387176

Non-perturbative effects

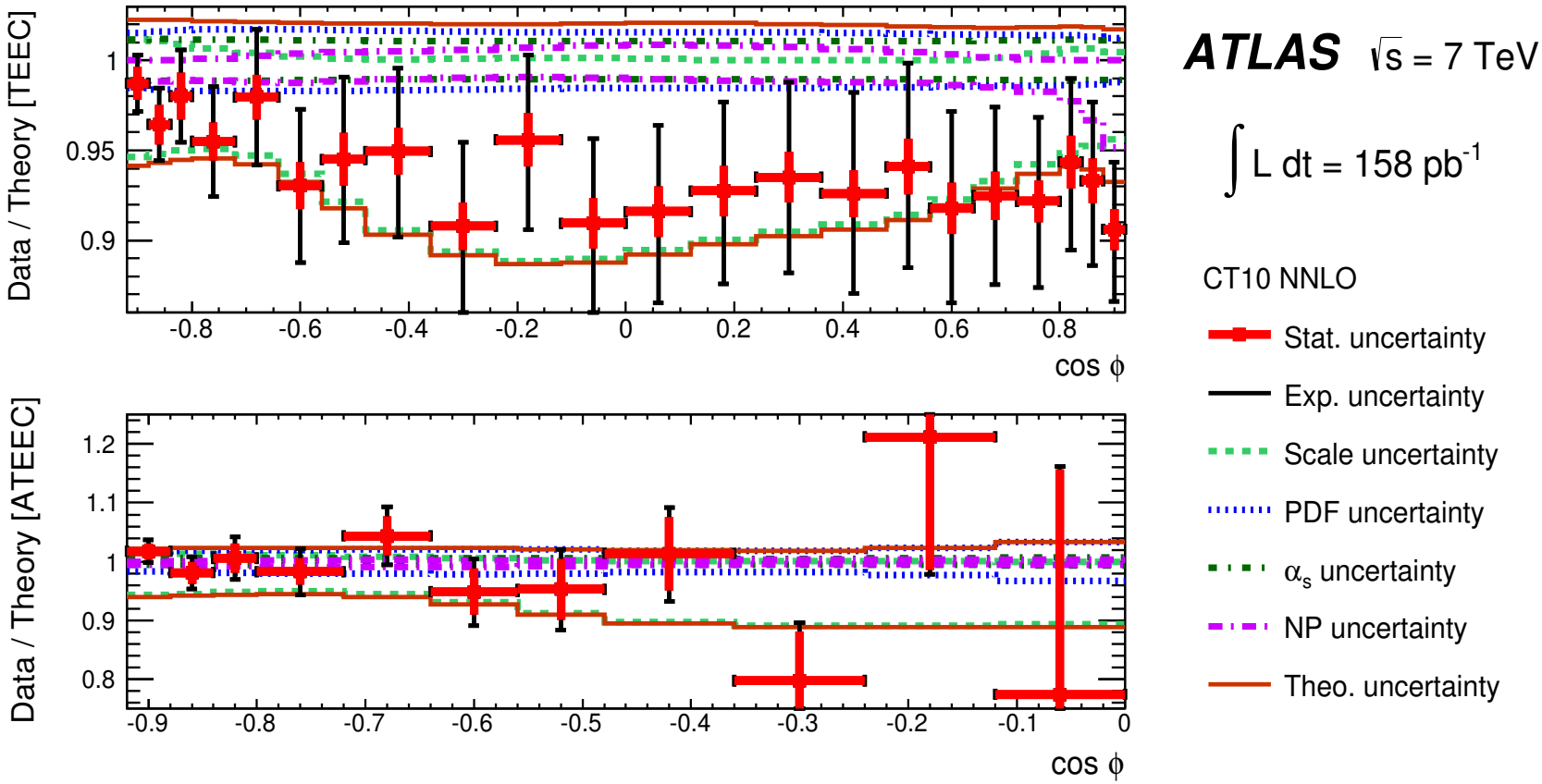
The plot below shows the total non-perturbative correction

$$\mathcal{F} = \frac{\mathrm{TEEC}(\mathrm{Had} = \mathrm{ON}, \mathrm{UE} = \mathrm{ON})}{\mathrm{TEEC}(\mathrm{Had} = \mathrm{OFF}, \mathrm{UE} = \mathrm{OFF})}$$



Comparison Data / Theory

- The agreement data / prediction is good within uncertainties.
- Theoretical uncertainties dominated by μ_R, μ_F.



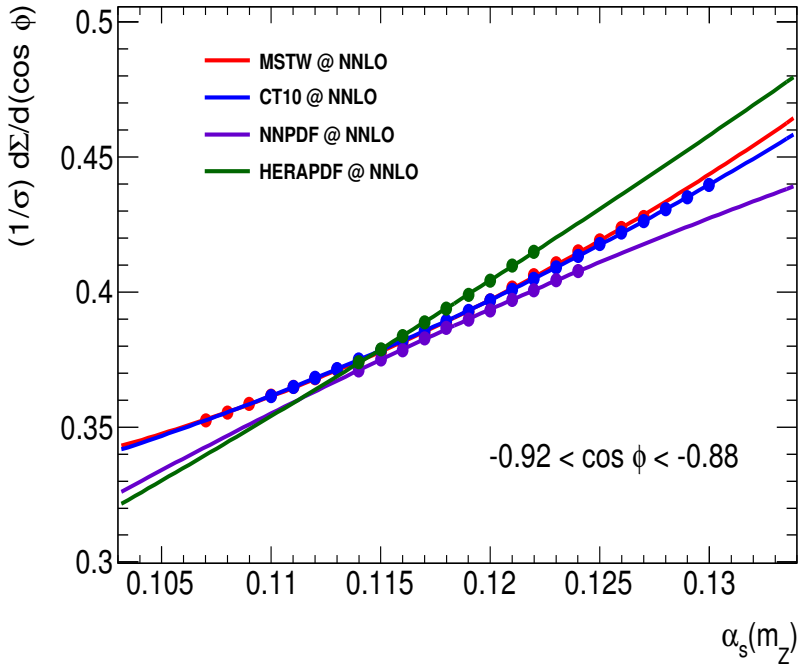
Determination of the strong coupling constant

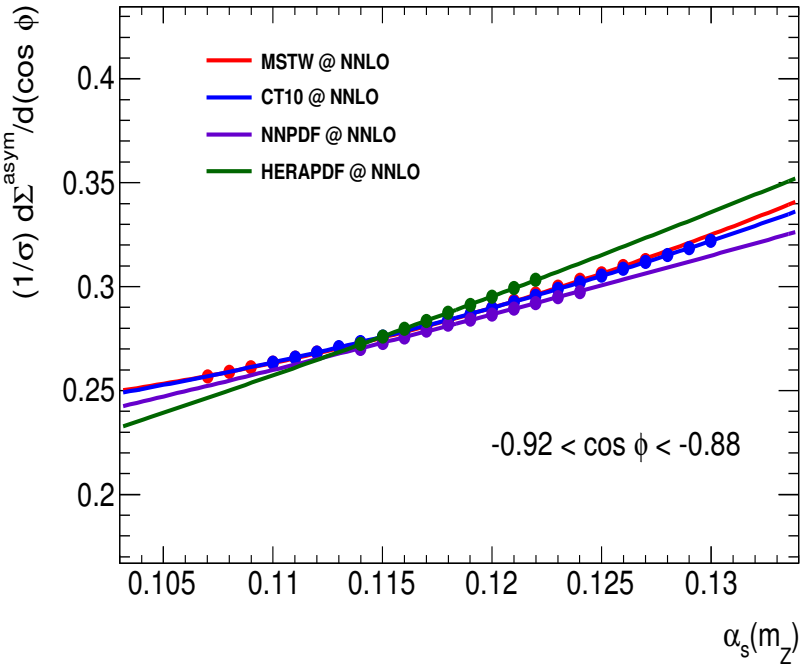
A standard χ^2 with correlations between uncertainties is used.

$$\chi^2(\alpha_s;\vec{\lambda}) = \sum_k \frac{(x_k - F_k(\alpha_s;\vec{\lambda}))^2}{\Delta x_k^2 + \Delta \tau_k^2} + \sum_i \lambda_i^2$$

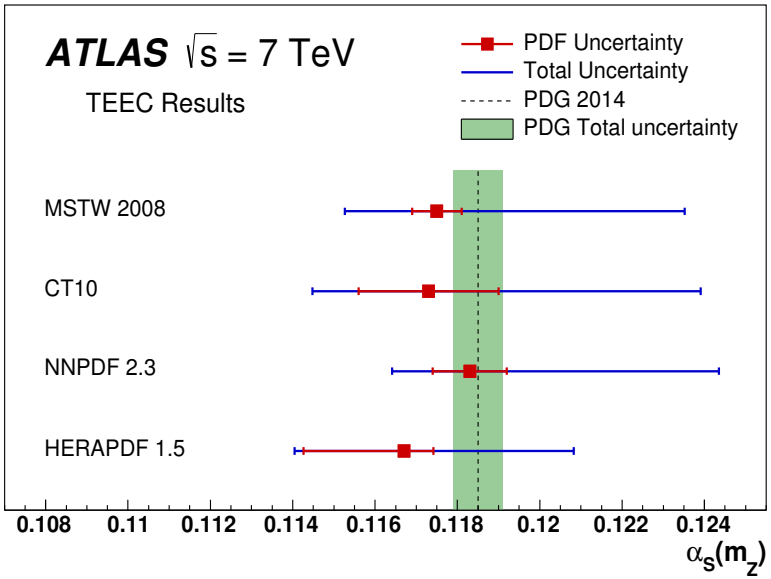
$$F_k(\alpha_s;\vec{\lambda}) = \phi_k(\alpha_s)\left(1 + \sum_i \lambda_i \sigma_{ik}\right)$$

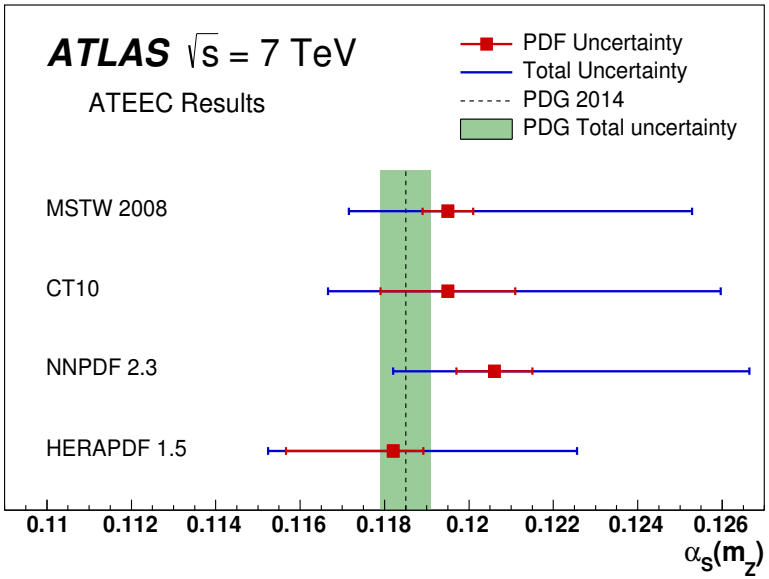
The functions $\phi_k(\alpha_s)$ are parameterised using second order polynomials.





Results for $\alpha_s(m_Z)$



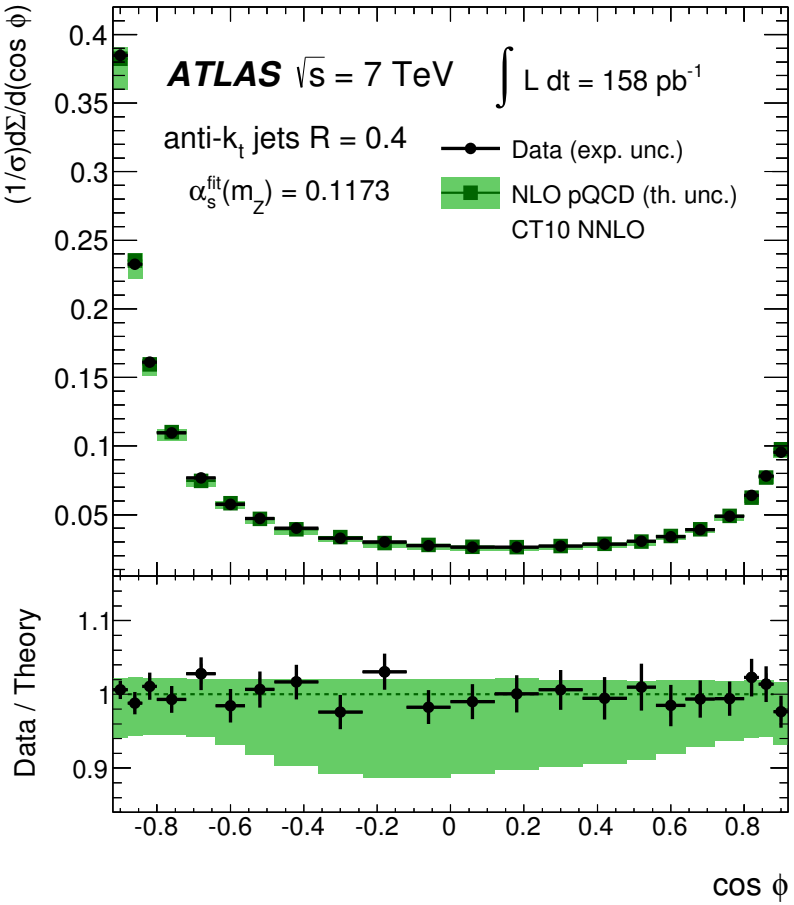


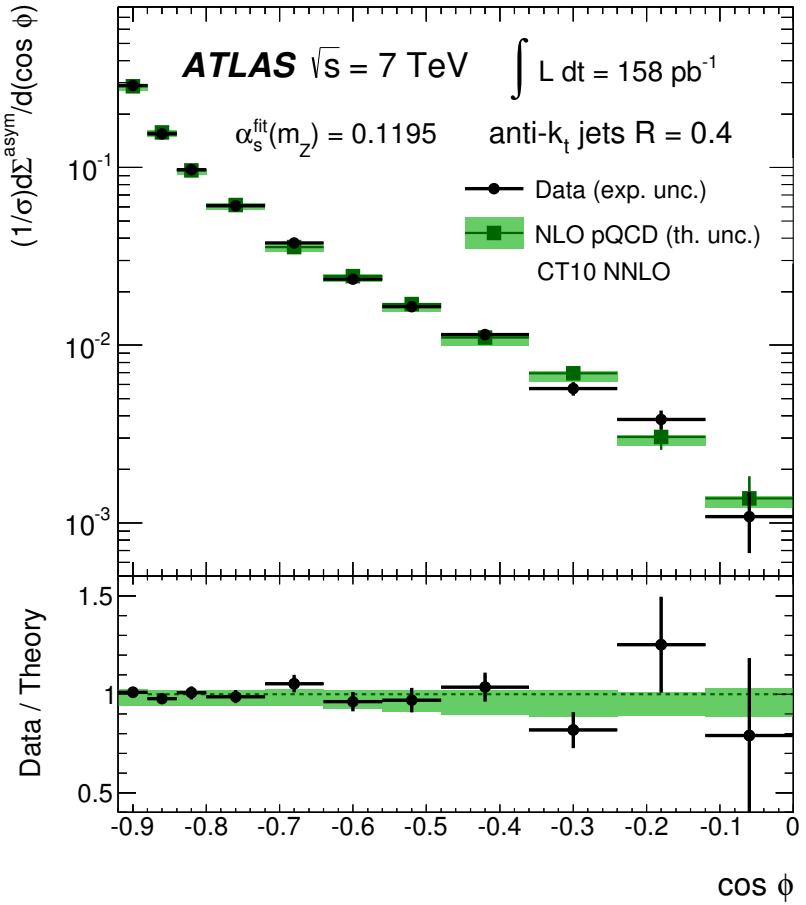
PDF	$\alpha_s(m_Z)$ value (TEEC fit)	χ^2/N_{dof}
MSTW 2008	0.1175 ± 0.0010 (exp.) $^{+0.0059}_{-0.0019}$ (scale) ± 0.0006 (PDF) ± 0.0002 (NPC)	29.0 / 21
CT10	0.1173 ± 0.0010 (exp.) $^{+0.0063}_{-0.0020}$ (scale) ± 0.0017 (PDF) ± 0.0002 (NPC)	28.4 / 21
NNPDF 2.3	0.1183 ± 0.0010 (exp.) $^{+0.0059}_{-0.0013}$ (scale) ± 0.0009 (PDF) ± 0.0002 (NPC)	29.3 / 21
HERAPDF 1.5	0.1167 ± 0.0007 (exp.) $^{+0.0040}_{-0.0008}$ (scale) $^{+0.0007}_{-0.0024}$ (PDF) ± 0.0001 (NPC)	28.7 / 21

PDF	$\alpha_s(m_Z)$ value (ATEEC fit)	χ^2/N_{dof}
MSTW 2008	0.1195 ± 0.0017 (exp.) $^{+0.0055}_{-0.0015}$ (scale) ± 0.0006 (PDF)	12.7 / 10
CT10	0.1195 ± 0.0018 (exp.) $^{+0.0060}_{-0.0015}$ (scale) ± 0.0016 (PDF)	12.6 / 10
NNPDF 2.3	0.1206 ± 0.0018 (exp.) $^{+0.0057}_{-0.0013}$ (scale) ± 0.0009 (PDF)	12.2 / 10
HERAPDF 1.5	0.1182 ± 0.0013 (exp.) $^{+0.0041}_{-0.0008}$ (scale) $^{+0.0007}_{-0.0025}$ (PDF)	12.1 / 10

Fit results

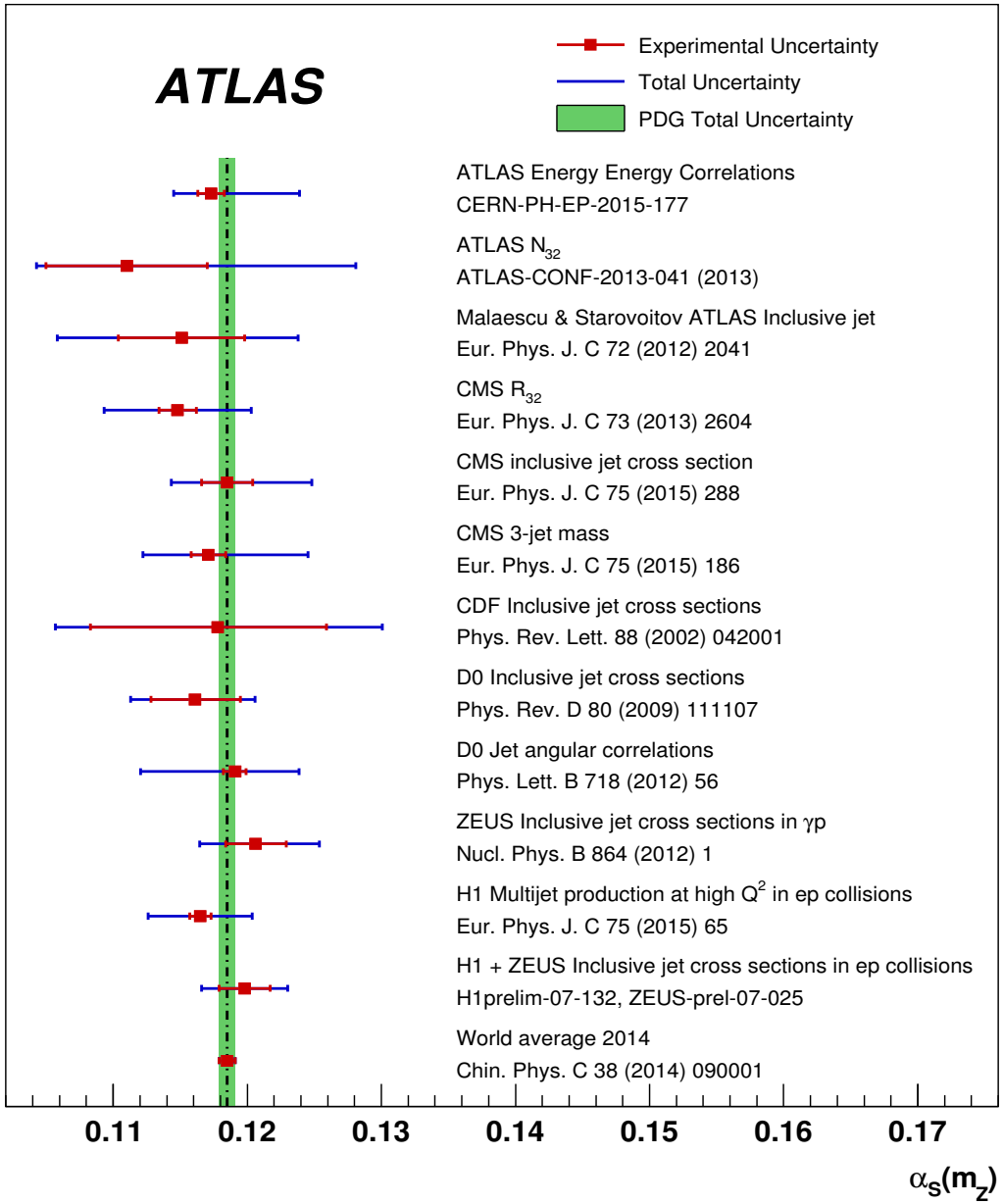
The plots below show the measured TEEC and ATEEC distributions, compared to the results of the fit





For bin k: $(\Delta x_k)^2 = \sum_{ij} C_{ij}\sigma_i^{(k)}\sigma_j^{(k)}$ with C_{ij} the uncertainty correlation matrix.

Summary of α_s determinations



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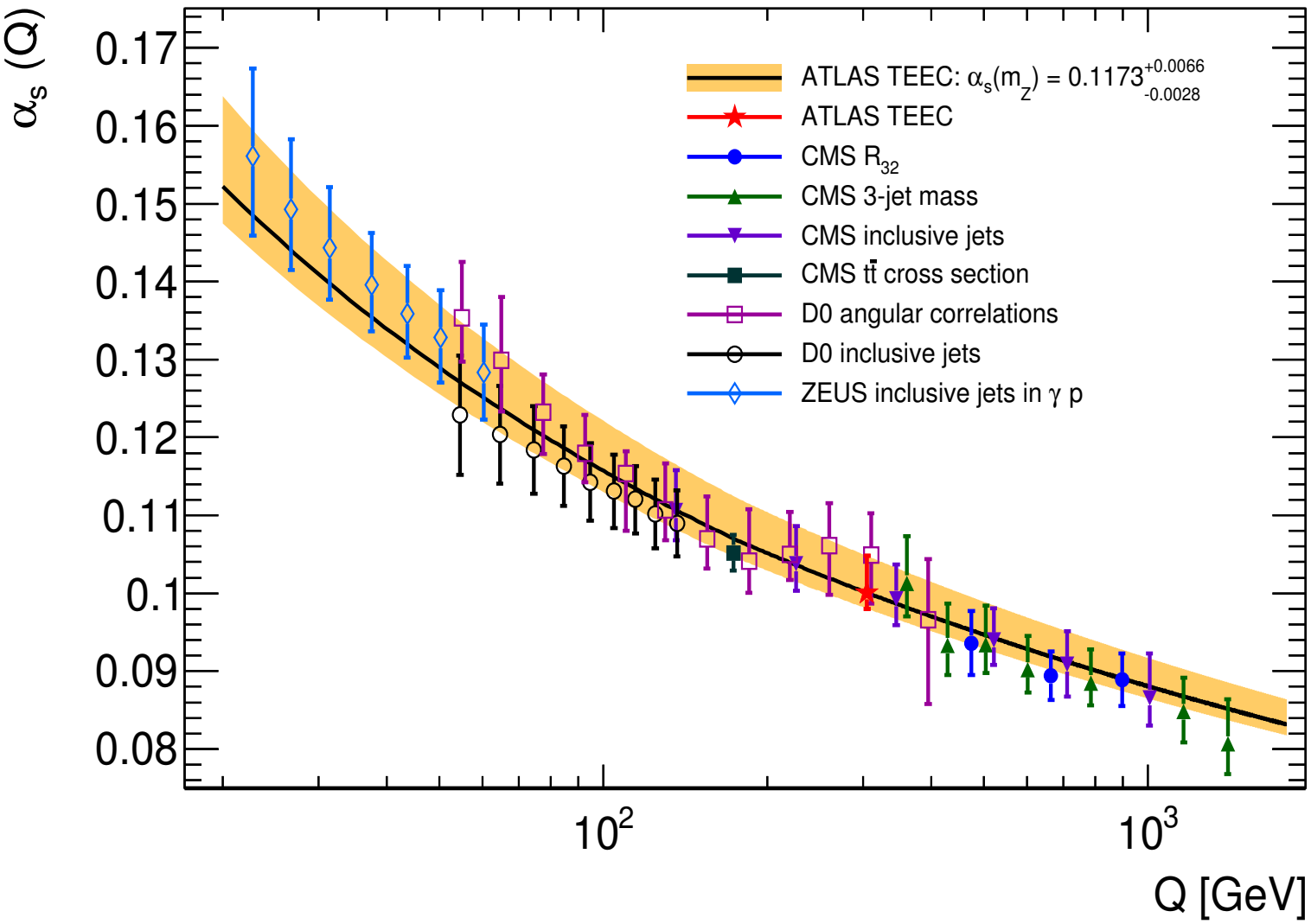


Conclusions

- First measurement of the jet-based transverse energy-energy correlations and its asymmetry at a hadron collider.
- The TEEC and ATEEC at large angles ($|\cos\phi| < 0.92$) provide a stringent test of fixed order pQCD.
- For $\cos\phi \sim \pm 1$, TEEC measurement is sensitive to higher order corrections.
- The TEEC and ATEEC are very sensitive to the value of α_s and show reduced sensitivity to the PDFs.
- The fits to the TEEC and ATEEC distributions determine values of $\alpha_s(m_Z)$ which are compatible between them and with the current world average.
- The extracted value is $\alpha_s(m_Z) = 0.1173 \pm 0.0010\ (\text{exp.})\ {}^{+0.0065}_{-0.0026}\ (\text{theo.})$
- The TEEC measurement is limited by the theoretical scale uncertainties.

All the stuff (and more) in:

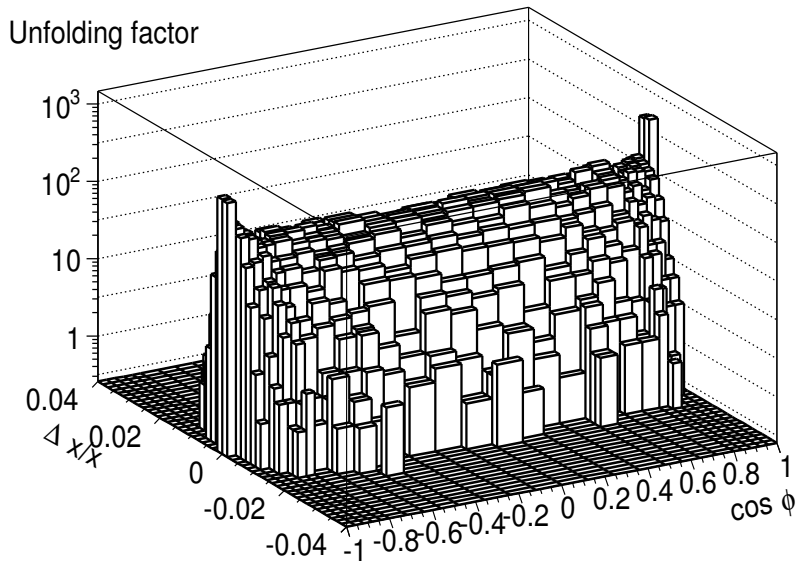
[The ATLAS Collaboration, Phys. Lett. B **750**, 427 (2015)]

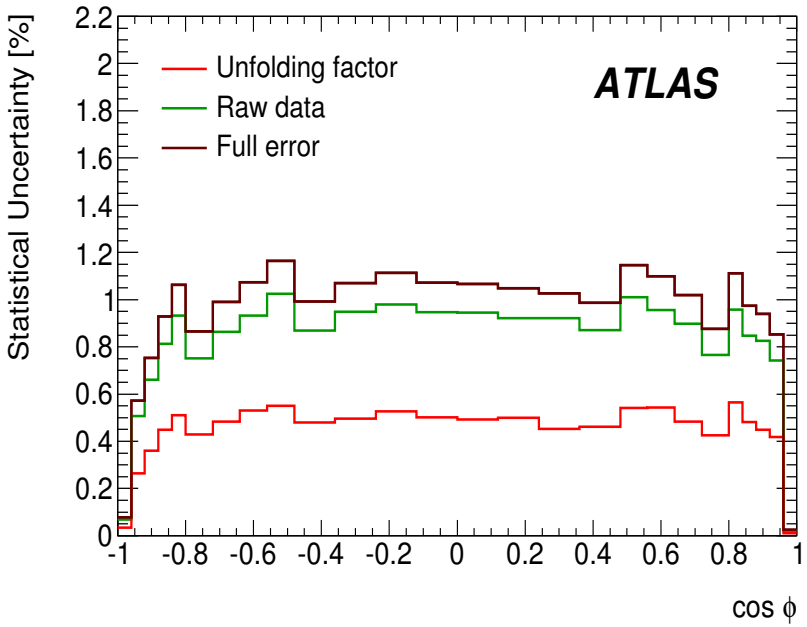
A Rivet routine is available in https://rivet.hepforge.org/analyses

Backup Slides

Unfolding: Statistical error

The statistical uncertainty is derived using the bootstrap method. The bootstrap samples for the unfolding factor are shown on the left, while the composition of the statistical error is shown on the right.





α_s fit results. Nuisance parameters.

Nuisance parameters for TEEC (top) and ATEEC (bottom) and their correlation matrices.