Precise Measurement of Inclusive Dijet Production with the ATLAS Detector

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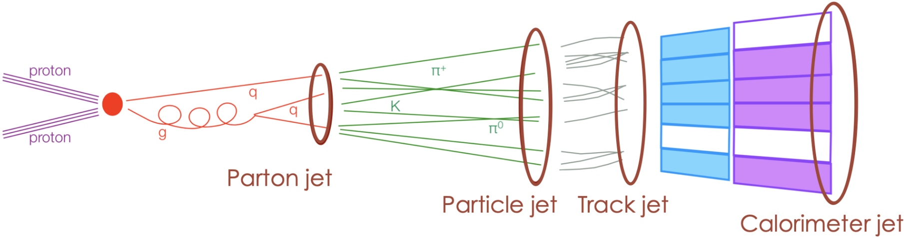
ATLAS EXPERIMENT

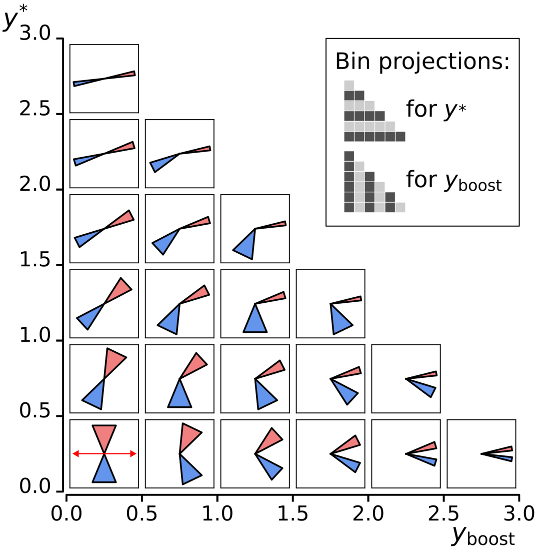
Jet Reconstruction at ATLAS

- **ATLAS detector**
  - Multi-purpose detector at LHC
  - Various specialised sub-detectors
    - For jet measurements, mainly calorimeters and inner detector (ID)
- **Jets**
  - *pp* collision → partons → hadronisation → collimated hadron shower
  - Observed as energy deposited in calorimeters and tracks of charged hadrons in ID
- **Jet reconstruction at ATLAS**
  - Topological jets: energy deposited in calorimeters
  - Particle flow jets: calorimeter energy + tracks of charged hadrons in ID
    - Improved resolution and reconstruction efficiency, especially at lower p_T



Dijet Observables and Motivation

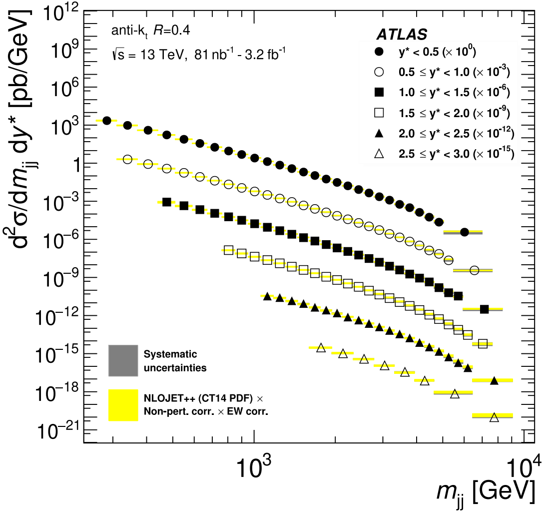
- Events with at least **2 jets in final state**
  - $p + p \to \text{jet}_1 + \text{jet}_2 + X$
- **Dijet observables**
  - $m_{jj} = \sqrt{(p_1 + p_2)^2}$
  - $y^* = |y_1 - y_2|/2$
  - $y_{\text{boost}} = |y_1 + y_2|/2$
- **Motivation**
  - QCD tests at high energy scale
  - Possible α_S and PDF extraction
    - PDF = description of proton structure
    - PDFs and α_S inputs to MC simulation



Dijet event topology illustration,
⟷ = axis of colliding beams

ATLAS Dijet Measurements at 13 TeV

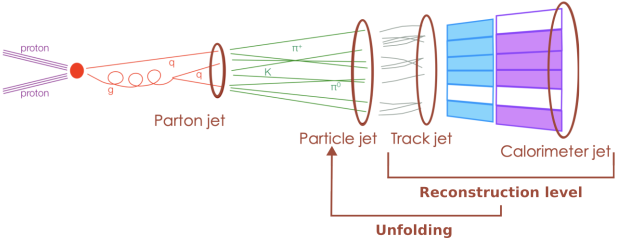
- **Recent ATLAS dijet measurements**
  - 13 TeV pp collisions
  - anti-k_t jets, $R = 0.4$
  - $p_{\mathrm{T},i} > 75$ GeV, $|y_i| < 3.0$
  - $H_\mathrm{T} = p_{\mathrm{T},1} + p_{\mathrm{T},2} > 200$ GeV
- **JHEP 05 (2018) 195** [1]
  - 2015 data (3.2 fb^{-1})
  - $\frac{\mathrm{d}^2\sigma}{\mathrm{d}m_{\mathrm{jj}}\mathrm{d}y^*}$
  - Topological jets
  - NLO leading-colour theory prediction
- **Latest measurement** [2]
  - 2015–2018 data (140 fb^{-1})
  - $\frac{\mathrm{d}^2\sigma}{\mathrm{d}m_{\mathrm{jj}}\mathrm{d}y^*}$ and $\frac{\mathrm{d}^2\sigma}{\mathrm{d}m_{\mathrm{jj}}\mathrm{d}y_{\mathrm{boost}}}$
  - Particle flow jets
  - NNLO full-colour theory prediction

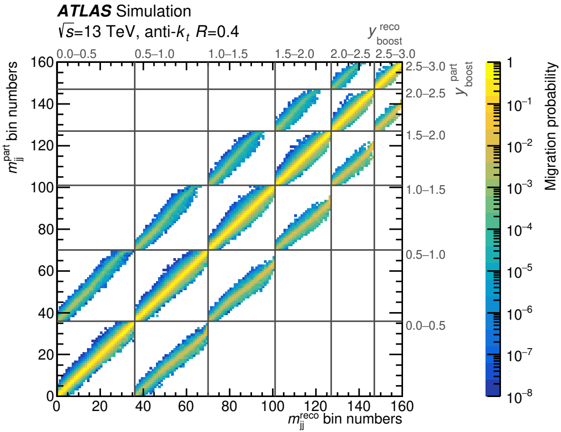


Dijet cross-section [1]

Data Unfolding

- **Reconstructed data corrected** for detector effects to particle level
  - Finite resolution, inefficiencies
- Using **unfolding technique**
  - Simulation-based – reconstruction & particle level jets in MC samples
  - Response matrix describing detector response → migrations between bins
  - Purity/efficiency corrections



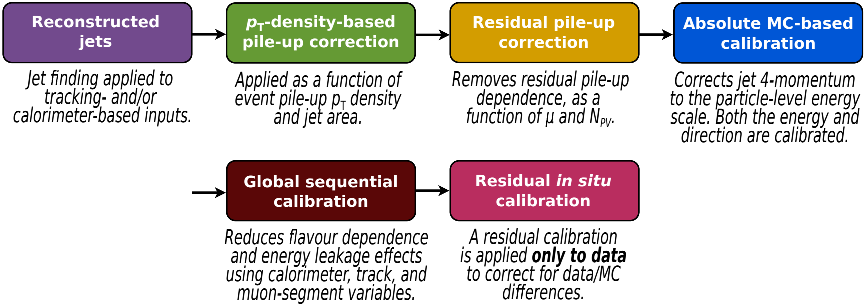


Response matrix

Experimental Uncertainties and Jet Calibration

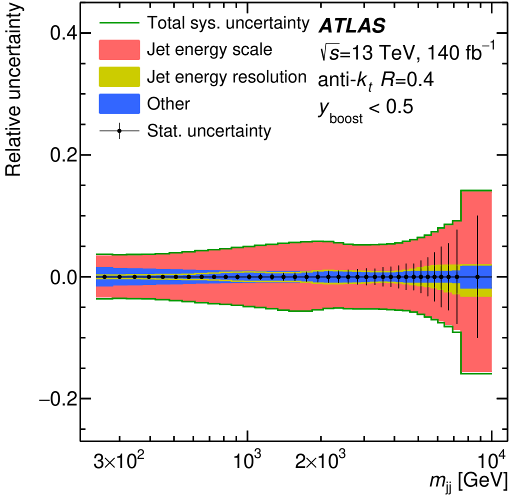
- **Systematic uncertainty** sources
  - Jet energy scale (JES) unc.
    - Dominant source
    - Full set of 1172 components
  - Jet energy resolution (JER) unc.
  - Other sources
    - Luminosity, unfolding bias, ...

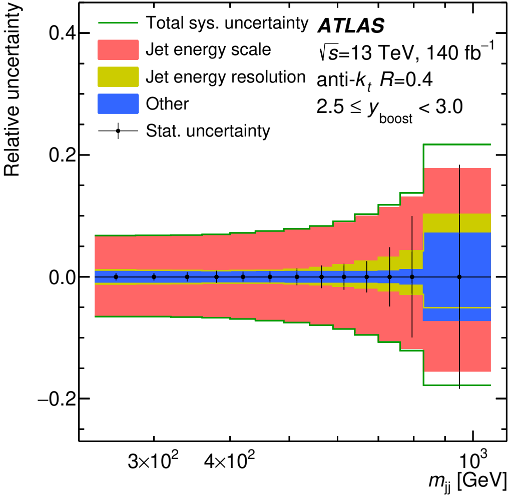
- **Jet calibration** – multiple steps and methods (connected with JES uncertainty) [3]
  - Pileup corrections
  - MC-based calibrations
  - Residual *in situ* calibrations (MC vs Data)
    - Various methods of comparing jets to well-calibrated objects (e.g. forward vs central jets, jets vs gamma or Z, E/p)



Total Experimental Uncertainty

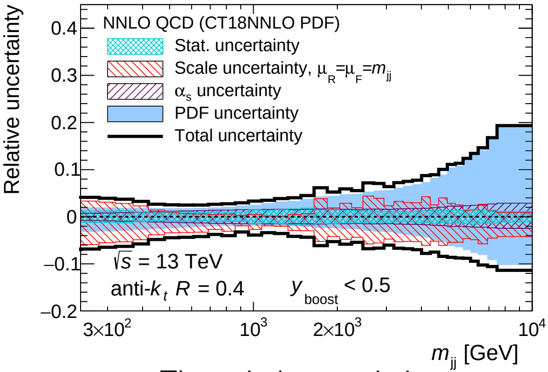
- **Total systematic and statistical uncertainties** of the dijet cross-sections
  - Systematic – mostly at level of 5–10%; up to ∼15–20% in last m_{jj} bins
  - Statistical – mostly $< 1\%$; up to ∼10–20% in last m_{jj} bins





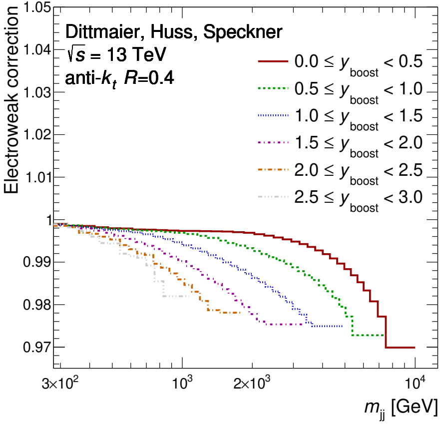
Theoretical Predictions and Electroweak Corrections

- **Theoretical calculations**
  - pQCD – NNLO matrix element, full colour
    - Renormalisation & factorisation scales $\mu_R = \mu_F = m_{jj}$
    - Various PDF sets
    - Uncertainty sources – stat., scale, α_S, PDF



Theoretical uncertainties

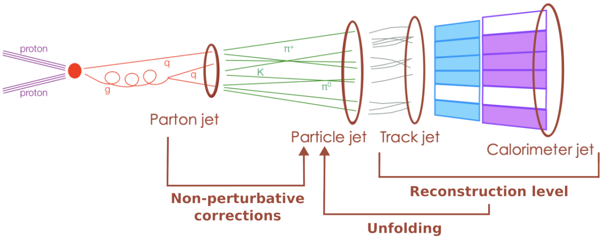
- Electroweak corrections up to NLO
  - Contributions to dijet production via γ, Z, $W^\pm$
  - Tree and 1-loop corrections

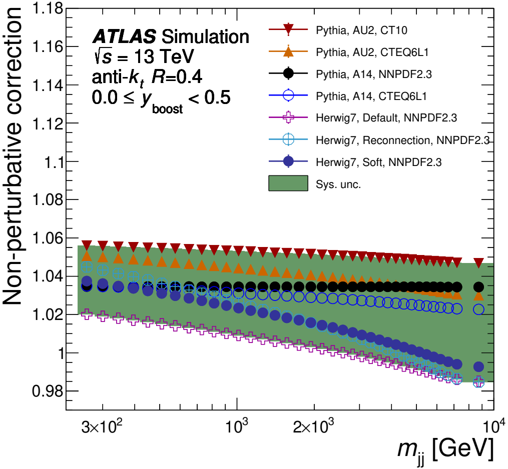


Electroweak corrections

Non-Perturbative Corrections to Theoretical Predictions

- **Theoretical predictions at parton level**
  - Corrected to particle level via non-perturbative corrections (NPC)
  - **NPC** = effects of hadronisation, and multi-parton interactions
    - Studied using different MC generators, tunes, and PDF sets
    - Central value = correction
    - Envelope = systematic uncertainty

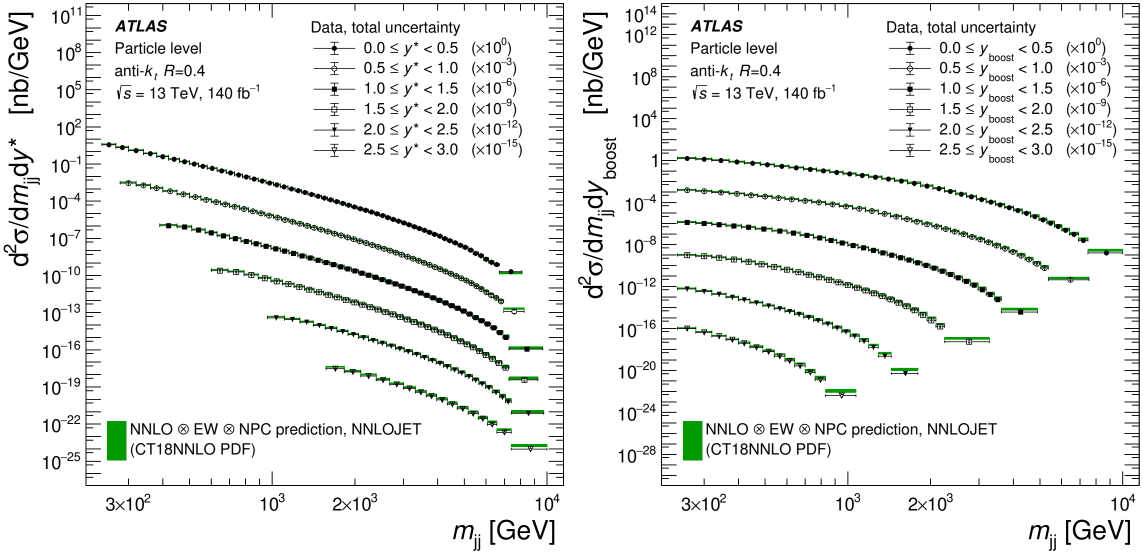




Non-perturbative corrections

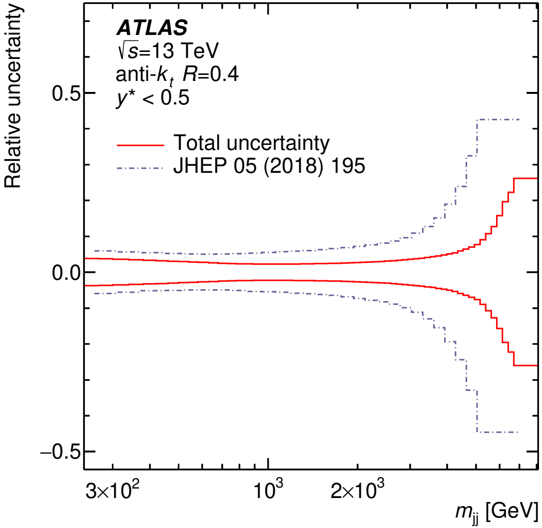
Results – Cross-Sections

- Two **double-differential dijet cross-sections** on particle level – m_{jj} 240 GeV to 10 TeV



Results – Comparison with Previous Dijet Measurement at ATLAS

- **Comparison with JHEP 05 (2018) 195**
  - Cross-sections compatible within experimental uncertainties
  - Uncertainties significantly reduced by a factor up to three
    - Statistical uncertainty – 40× larger dataset → finer binning, smaller uncertainty
    - Systematic uncertainty – improvements in jet calibration [4]



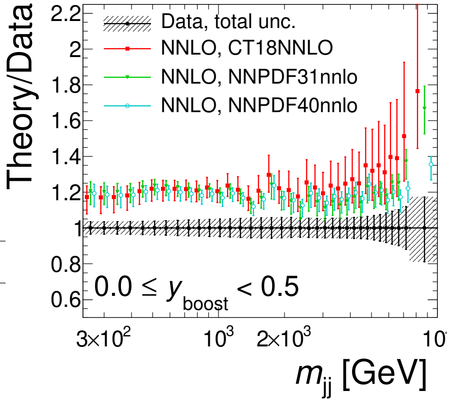
Total uncertainty comparison

Results – Theory-to-Data Comparison

- **Theory-to-data comparison** on particle level
  - For NNLO and NLO
    - NNLO improves prediction in some regions
  - For various PDF sets
    - Best qualitative agreement – NNPDF4.0
    - Best quantitative agreement – ATLASpdf21
  - Theory systematically overestimates data
    - Dependence on μ_R, μ_F, jet radius, ...

	χ^2/ndf				
	CT18NNLO	NNPDF3.1NNLO	NNPDF4.0NNLO	MSHT2020NNLO	ATLASpdf21T3
$y_{boost} < 0.5$	33/36	48/36	37/36	43/36	44/36
$0.5 \leq y_{boost} < 1.0$	51/34	55/34	53/34	55/34	54/34
$1.0 \leq y_{boost} < 1.5$	41/31	40/31	39/31	47/31	47/31
$1.5 \leq y_{boost} < 2.0$	26/26	27/26	26/26	31/26	35/26
$2.0 \leq y_{boost} < 2.5$	24/20	24/20	21/20	28/20	31/20
$2.5 \leq y_{boost} < 3.0$	15/13	15/13	14/13	20/13	16/13
$0.0 \leq y_{boost} < 3.0$	183/160	178/160	185/160	195/160	166/160

Theory-to-data χ^2 studies



Theory-to-data comparison for different PDF sets

Summary

- **Latest dijet cross-section measurement at ATLAS recently published** [2]
- **Multitude of improvements** with respect to the previous ATLAS measurement
  - Larger dataset → finer binning and reduced statistical uncertainties
  - Reduced systematic uncertainties
  - Additional observable y_{boost} → improved sensitivity to theory
  - NNLO theoretical predictions with full colour
- **Can and will be used for extraction of of α_S and PDF**

[1] ATLAS Collaboration, *Measurement of inclusive jet and dijet cross-sections in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, JHEP **05** (2018) 195.

[2] ATLAS Collaboration, *Measurement of inclusive dijet cross-sections in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, `arXiv:2512.19073[hep-ex]`.

[3] ATLAS Collaboration, *Jet energy scale and resolution measured in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Eur. Phys. J. C **81** (2021) 689.

[4] ATLAS Collaboration, *A precise measurement of the jet energy scale derived from single-particle measurements and in situ techniques in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Eur. Phys. J. C **85** (2025) 927.