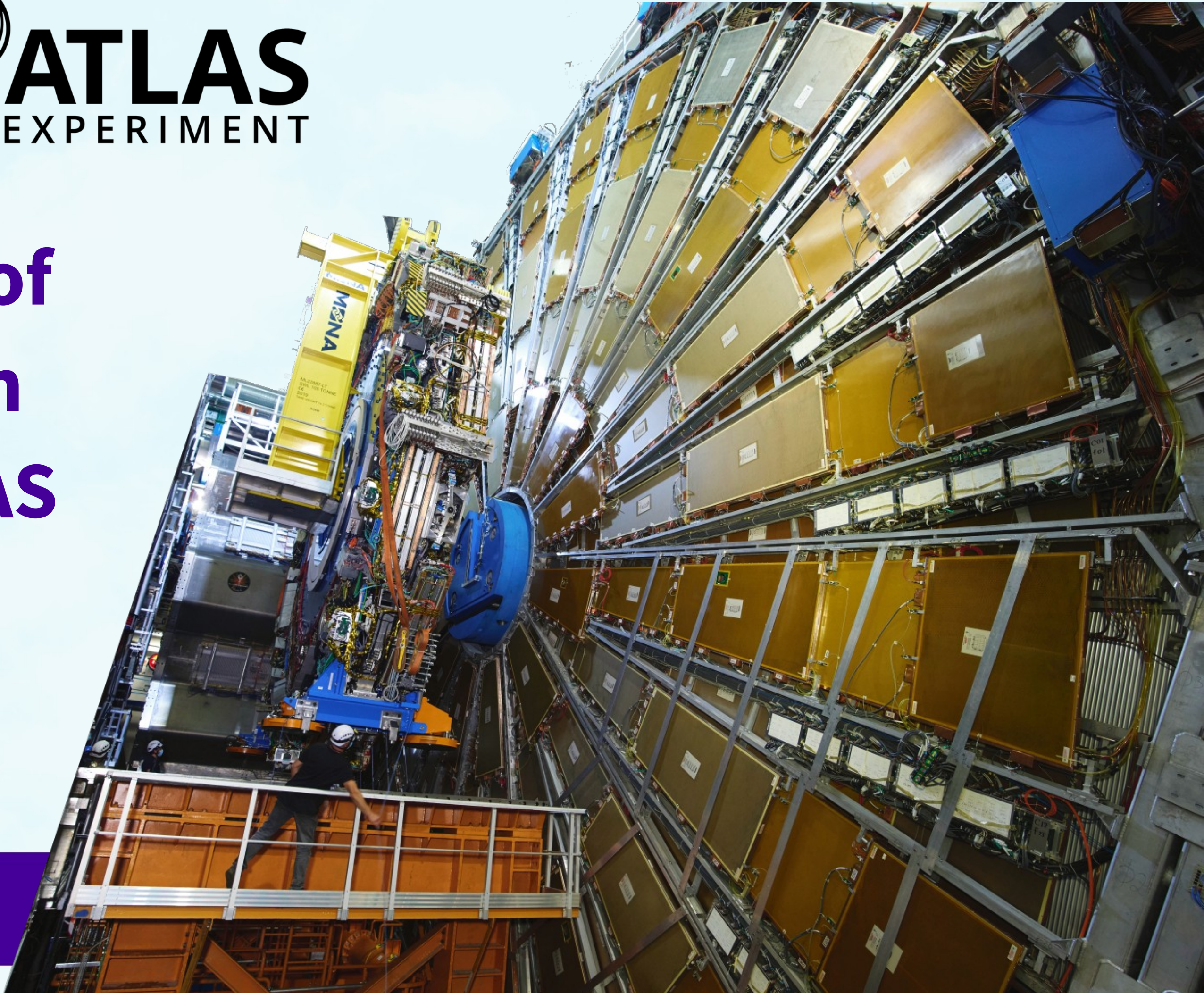
Measurements of jet cross-section ratios with ATLAS



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On behalf of the ATLAS Collaboration

PIC October 2024

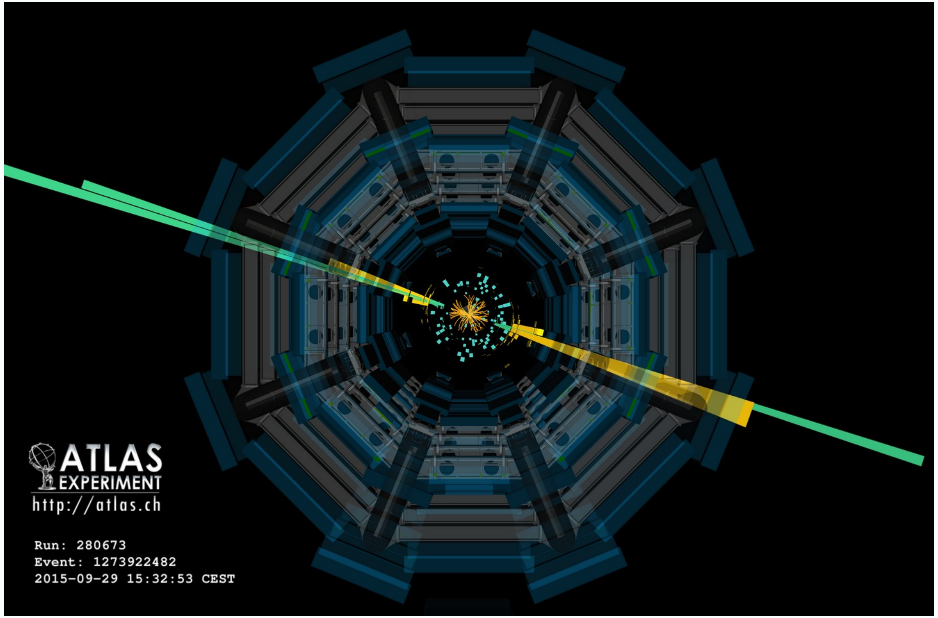
The LHC as a lab for QCD

Perturbative QCD is the underlying theory for proton-proton collisions at the LHC

Entering in **underlying event, hadronization, parton showers, α_s**

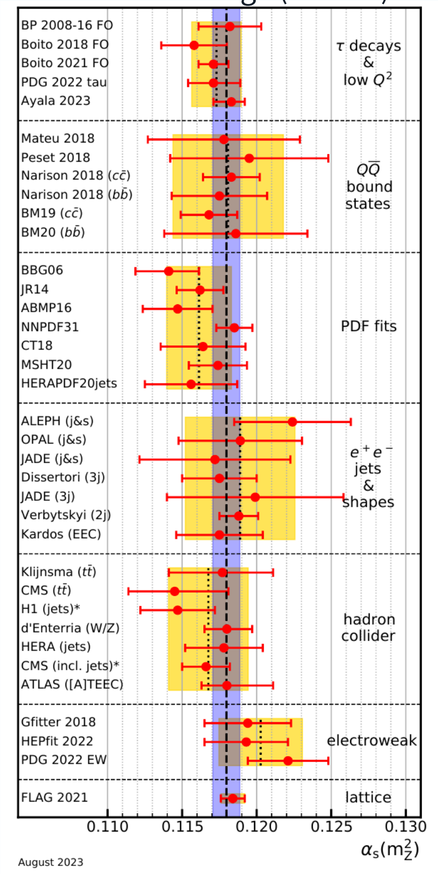
Discrepant models of QCD processes **impact the accuracy** of MC simulations

Better understanding of QCD modelling is **crucial to improve experimental precision** of LHC measurement



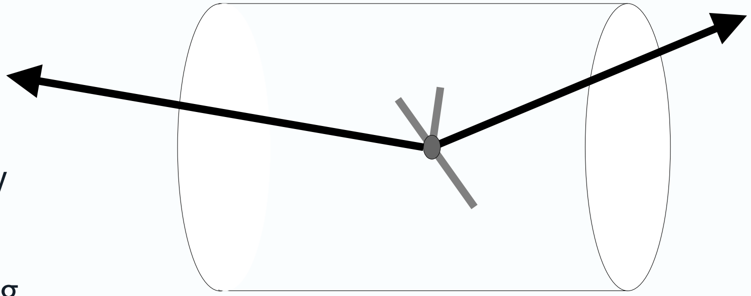
The least known coupling strength: α_s

PDG world average (NNLO+)



- Compared to the other couplings parameters, **α_s is least well known**:
- $\Delta\alpha_{EM}$~10^{-10} << ΔG_F~10^{-7} << ΔG~10^{-5} << **$\Delta\alpha_S$ ~10^{-2}**
- Uncertainty is driven by tensions within the α_S world average.
- **Becoming increasingly relevant** in predictions related to Higgs and top production, electroweak precision observables
- Targeted through observables related to energy in the event:
  - **H_{T2}:** scalar sum of two leading jets, $p_{T,1} + p_{T,2} = H_{T2}$
  - **P_T^{incl}:** Inclusive pT spectrum of two or three leading jets, p_T^{2incl} and p_{T3}^{incl}

Convergence of calculations: VBF/VBS



- Vector Boson Scattering (VBS) and Vector Boson Fusion (VBF) topologies produce high-energy forward jets with little activity inbetween
- Measuring VBF/VBS probes Higgs-Gauge-Boson couplings and self-couplings of gauge bosons – it's still one of the primary goals of the LHC to study these processes
- Large uncertainties in these measurements from QCD modelling
- Due to poor convergence of conventional MC calculations due to large logarithms
- Can test the same logarithmic structure in multijet events, targeted through observables related to angular distributions in the event:
  - **m_{jj} and $m_{jj,max}$:** invariant mass of leading dijets or maximum m_{jj} in event
  - **Δy_{jj} and $\Delta y_{jj,max}$:** rapidity difference of leading dijets or maximum in event

New ATLAS measurements with Jets

Using Run-2 data at $\sqrt{s}$ = 13 TeV

- 2015-2018
- $\mathscr{L} = 140\ \text{fb}^{-1}$
- Luminosity uncertainty is 0.83%

Improved jet uncertainty model

- Improved jet-flavor response uncertainties
- **Reduction of factor 3** in jet energy uncertainty **at high jet p_T** due to extrapolation of single-hadron response measurements ($W \to \tau\nu$ *insitu* determination replaces prior test beam result)

Reconstruction

- Anti-kt jets with radius parameter $R = 0.4$
- Built from Particle flow (PFlow) objects combining measurements from the ATLAS inner detector and calorimeters
- Calibrated such that jet energy scale (JES) matches particle-level jets

Selection

- p_T > 60 GeV and $|y| < 4.5$
- At least 2 jets
- $H_{T2} \geq 250$ GeV

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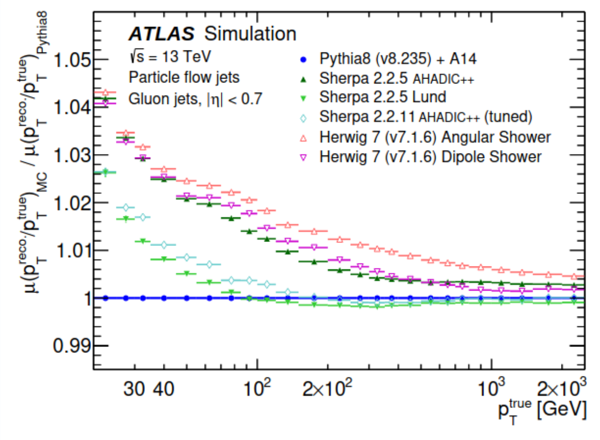
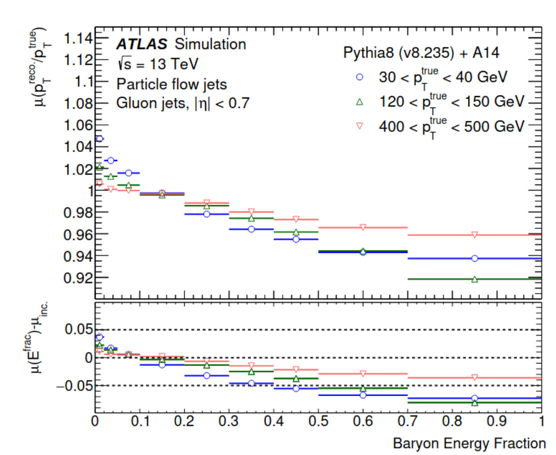
Measurements of jet cross-section ratios in 13 TeV proton–proton collisions with ATLAS
arXiv:2405.20206, submitted to PRD, Auxiliary figures: STDM-2020-04

Jet flavour response



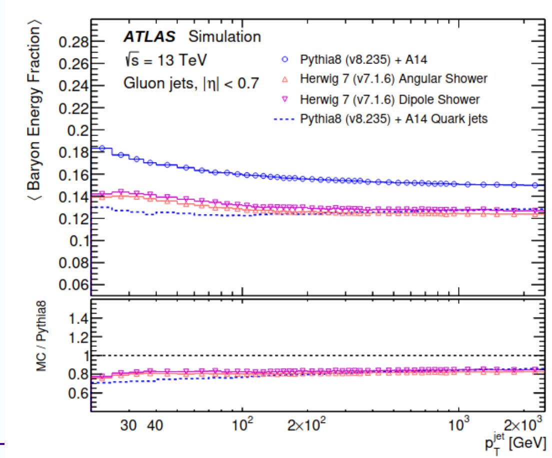
Insitu jet energy corrections are dominated by quark-initiated jets → need to add uncertainty due to jet flavour from MC studies

Large differences in response to gluon-initiated jets now better understood and treated



De-convolution of response to gluon jets and fragmentation model (i.e. particle spectra and the particle content of a jet) lead to overall smaller uncertainty:

- Flavor generator
- Flavor hadronization
- Flavor shower



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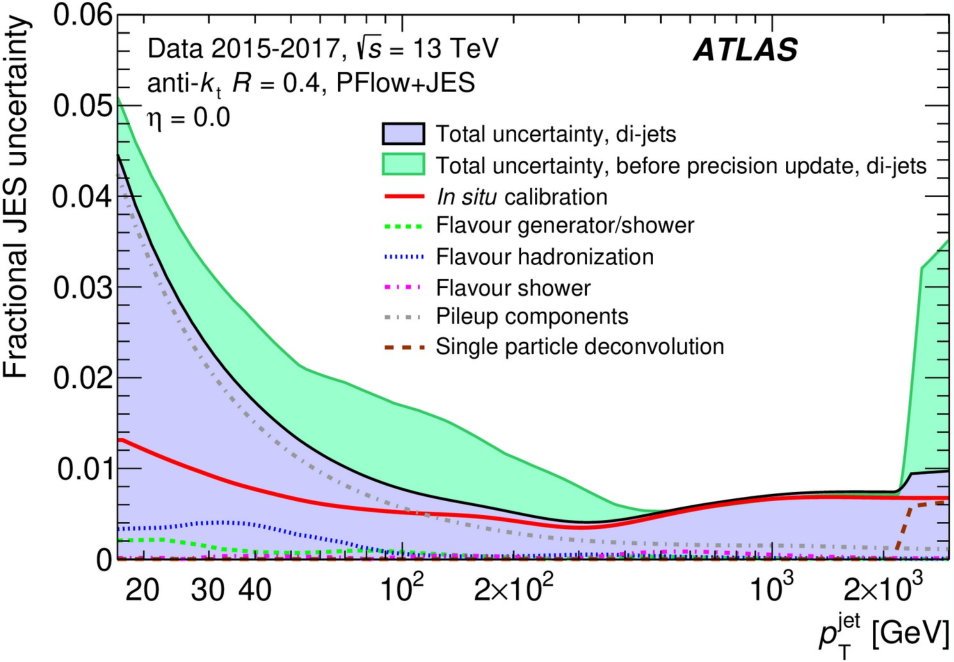
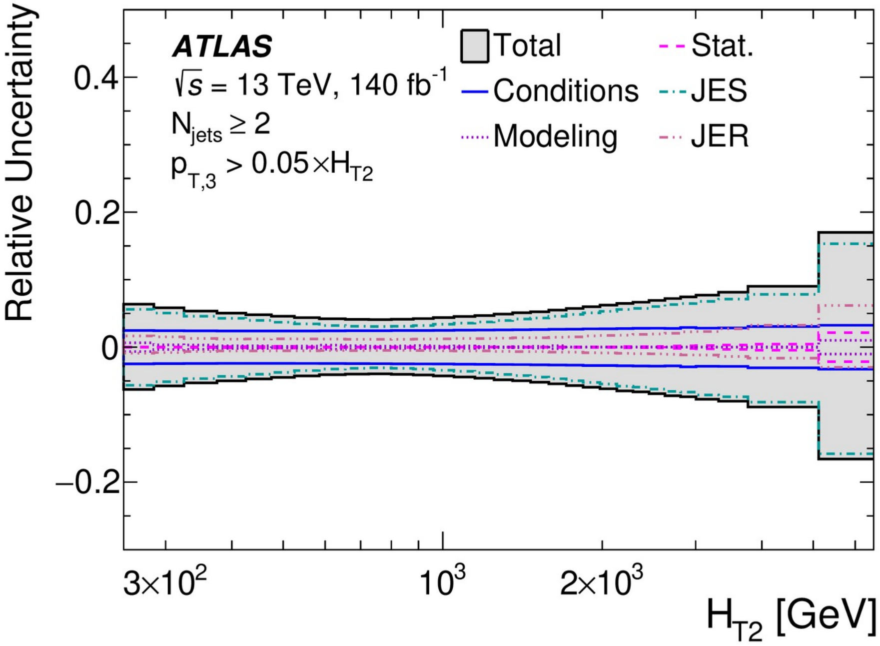
Jet flavour response





Large reduction of uncertainties compared with previous JES uncertainty
Measurements still **dominated by JES**, followed by conditions.
For rapidity-related mesaurements, modelling uncertainties become also important

Theoretical predictions

Fixed-order predictions

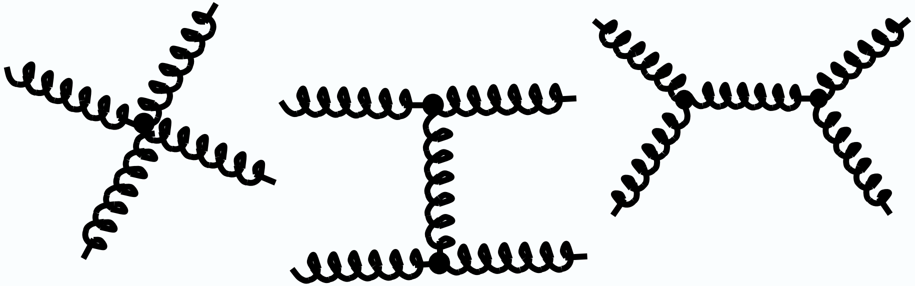
- **NLOJet++ program** with NNLO PDFs ($NF = 5$ scheme) and $\alpha s\ (mZ) = 0.118$, scale set to H_T (scalar sum of partons)
- **NNLO [Czakon et al.]** with MRST NNLO PDF, H_T scale and $\alpha s\ (mZ) = 0.118$
- Both with **non-perturbative corrections** relating parton-level calculation to hadron-level

Resummed calculation

- **High Energy Jets (HEJ) framework** includes leading logarithmic QCD corrections in $\hat{s}/p_T^2$ to all orders in αs and matching to fixed-order accuracy
- Relevant in regions of phase space with large m_{jj} or Δy_{jj}

Selection

- Anti-kt jets with radius parameter $R = 0.4$
- Built from stable particle with $c\tau > 10$ mm, except neutrinos and muons
- $P_T > 60$ GeV
- At least 2 jets with $H_{T2} > 250$ GeV
  → robust selection without interplay with logarithmic perturbative contributions



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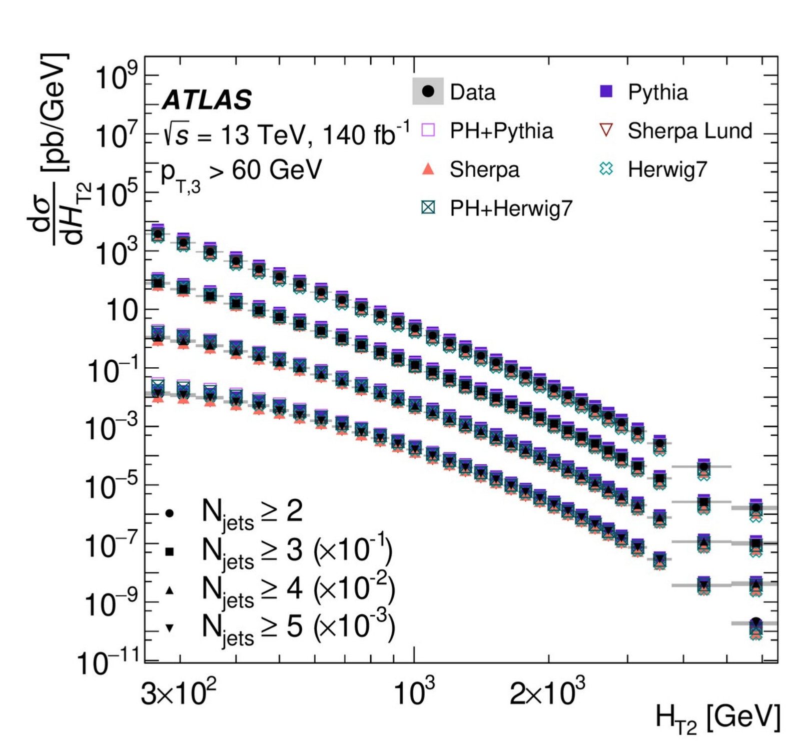
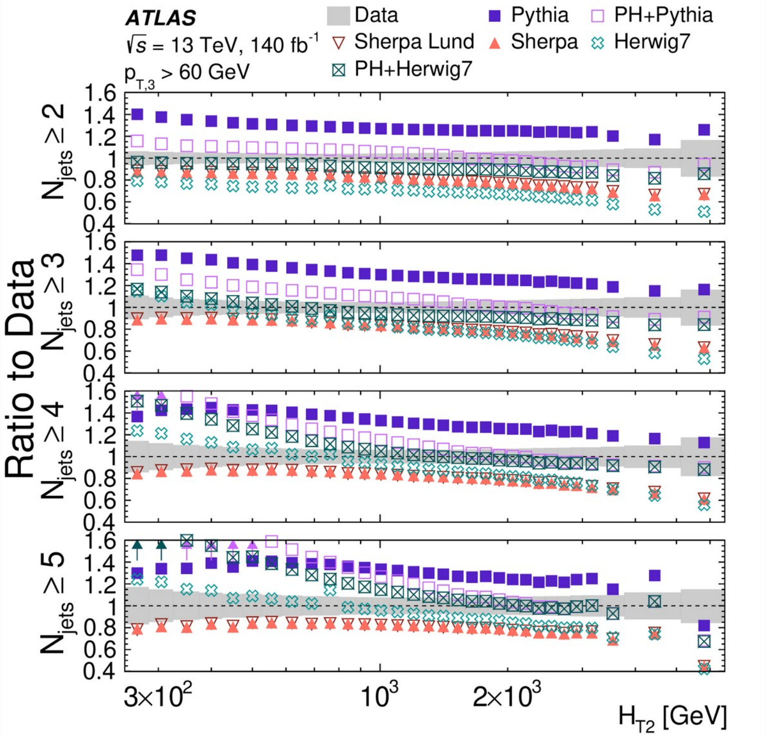
Results: Energy-related observables

- No single MC prediction is able to describe the data across all H_{T2} and multiplicity bins.





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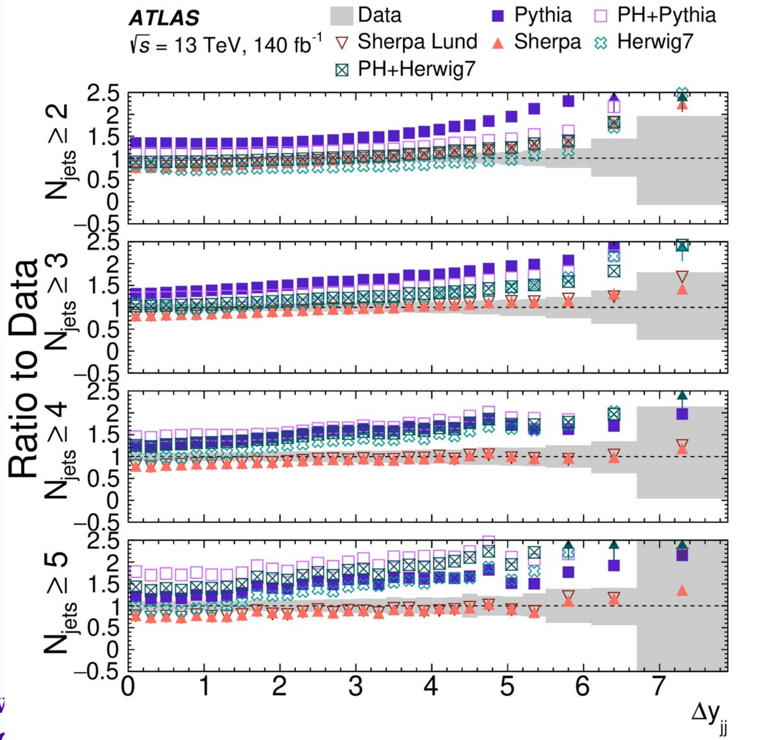
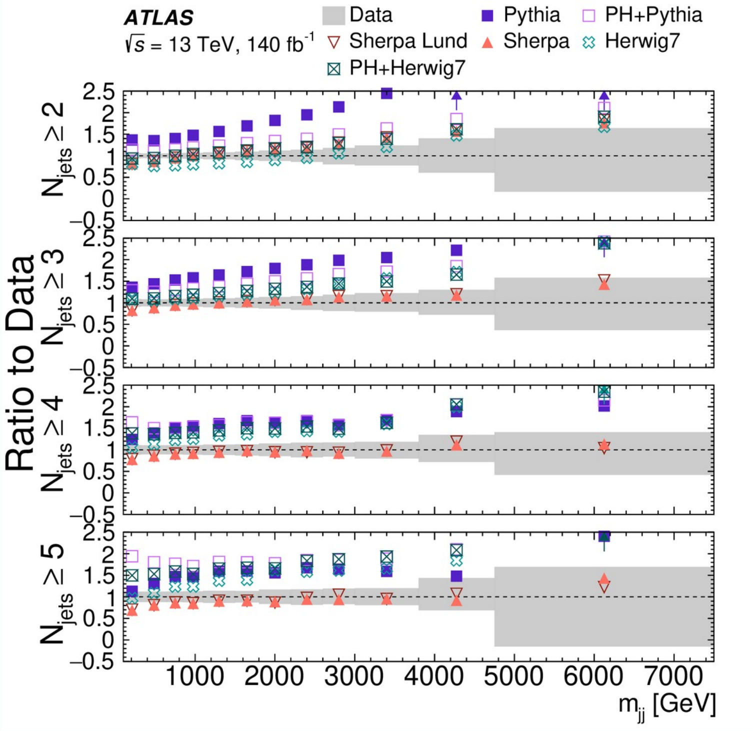
Results: Angle-related observables

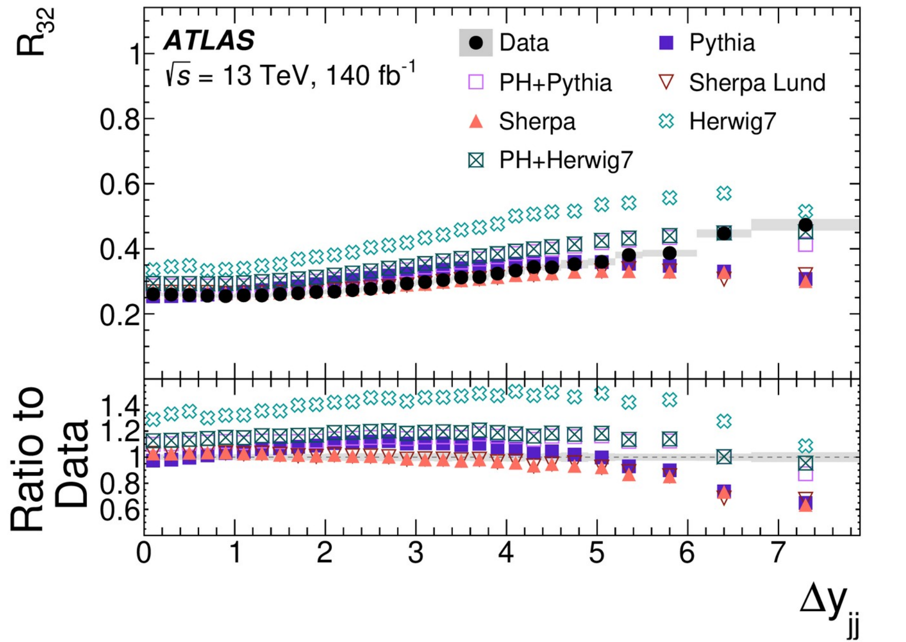
- Discrepancy with data increases for the more VBF/VBS-like phase-space

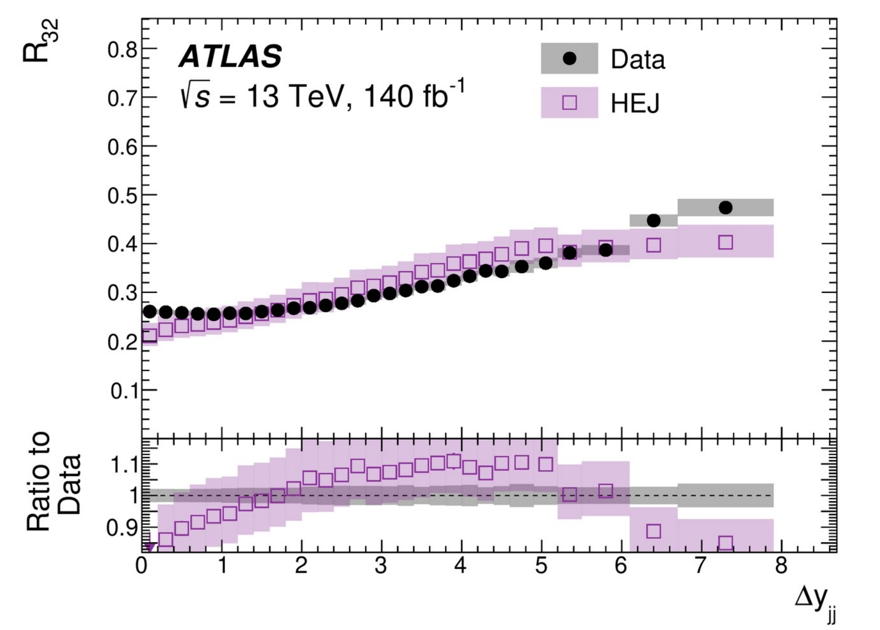




Results: Angle-related jet ratios

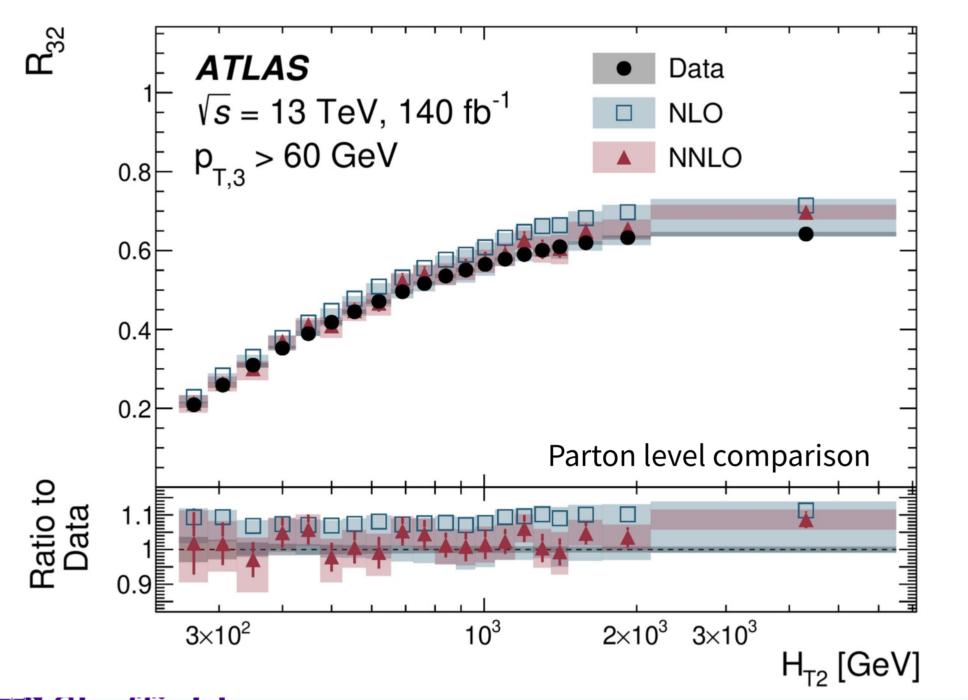
- In general, agreement between the data and predictions worsens as the third jet's p_T cut is increased
- Ratios are calculated not only for R32 (3-jet over 2-jet cross section but up to R54)
- R43 and R54 ratios tend to be better modeled than the R32 and R42 ratios
- HEJ framework with much better agreement as expected (note the scale)





Results: NLO vs NNLO for Jet ratios

- Improvement seen when moving to NNLO, however larger statistical uncertainties



	$\chi^2/d.o.f.$	
	NLO	NNLO
$p_{T,3} > 60$ GeV	0.48	0.36
$p_{T,3} > 0.05 \times H_{T2}$	0.55	0.32
$p_{T,3} > 0.10 \times H_{T2}$	1.05	0.24
$p_{T,3} > 0.20 \times H_{T2}$	1.11	0.30
$p_{T,3} > 0.30 \times H_{T2}$	9.24	5.49

Conclusions

- New Run-2 jet energy scale uncertainty systematic improve significantly jet measurements at ATLAS
- Presented measurements with sensitivity to α_s and VBF/VBS topologies
  - Cross-sections and ratio of 3/2, 4/3, 5/4 jet multiplicities distributions
  - As function of energy-related observables (H_{T2}) and angle-related observables (Δy)
- Generally difficulties of MC to describe data in all regions of phase space
- The data is uploaded on HEP Data and the selection code will be made available in Rivet soon

Backup

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