Determination of α_s Using ATLAS Multi-Jet Cross-Section Ratio Measurements

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on behalf of the ATLAS Collaboration

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Motivation for Determining α_S

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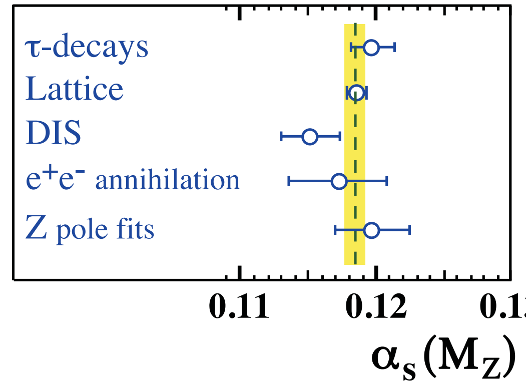
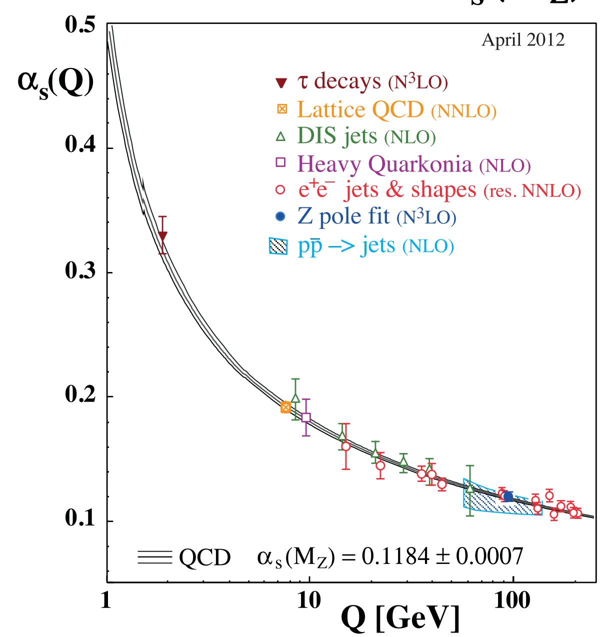


- Strong coupling strength, α_S, is the only free parameter in QCD
  - (excluding m_q)
- α_S has been determined using many experimental observables
- Compatible values demonstrate
  - QCD is a correct theory of strong interactions and only one, universal coupling is needed
- Different processes allow the running of $\alpha_S(Q^2)$ to be observed

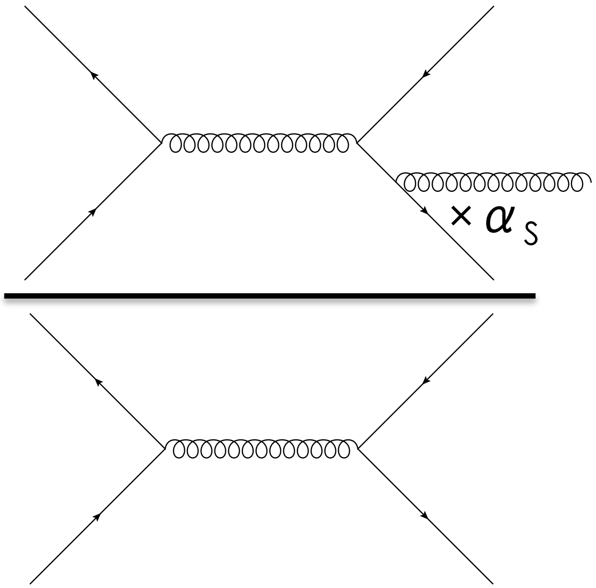


ATLAS Multi-Jet Ratio Measurements

Measure ratio of cross-sections for events with ≥ 3 jets to ≥ 2 jets

- Cancellation of systematic uncertainties
- Allows more precise test of QCD

Measure as a function of p_T to observe the running of the coupling:



$$R_{3/2}\left(p_T^{\text{lead}}\right) = \frac{d\sigma_{N_{\text{jets}}\geq 3}}{dp_T^{\text{lead}}} \Bigg/ \frac{d\sigma_{N_{\text{jets}}\geq 2}}{dp_T^{\text{lead}}}$$

Another ratio with similar α_S sensitivity is:

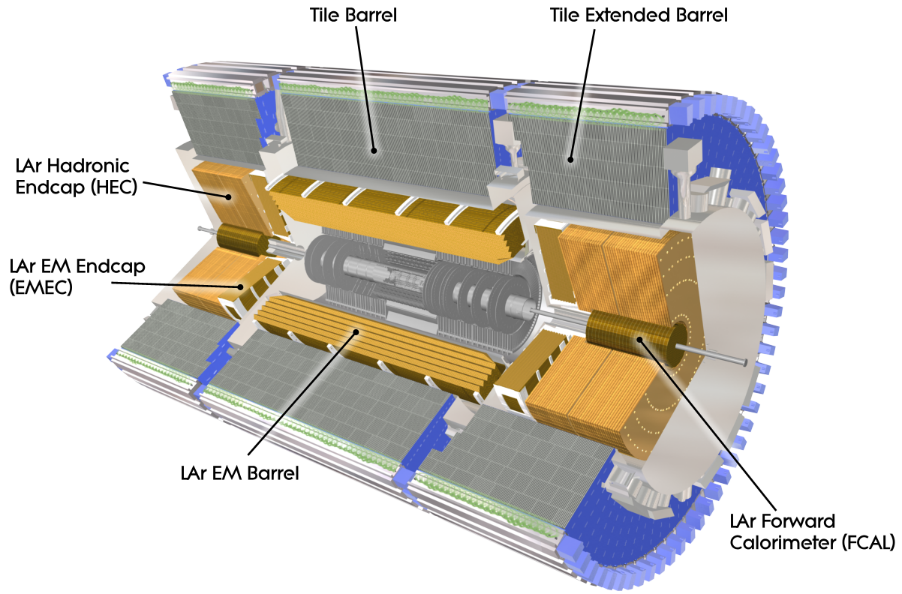
$$N_{3/2}\left(p_T^{\text{all jets}}\right) = \sum_i^{N_{\text{jets}}} \frac{d\sigma_{N_{\text{jets}}\geq 3}}{dp_{T,i}} \Bigg/ \sum_i^{N_{\text{jets}}} \frac{d\sigma_{N_{\text{jets}}\geq 2}}{dp_{T,i}}$$

This alternative ratio has smaller scale dependence in phase-space studied

ATLAS Detector: Measuring and Triggering Jets

2008 JINST 3 S08003

- ATLAS equipped with sampling calorimeters over $|\eta| < 4.9$
- Determination of α_S uses region $|y| < 2.8$
  - Excellent jet energy resolution: $\sigma/E \approx 0.55/\sqrt{E} + 5/E$
- Inner detector is used to reconstruct event vertices



- ATLAS trigger system is designed to select 200 events/second from the LHC bunch crossing rate of 40 MHz
  - Jets are allocated some fraction of this total recording rate
- Trigger split into three levels, only first two were used in 2010
  - L1: hardware-based, identifies jets from calorimeter towers using a sliding window algorithm
  - L2: software-based, reconstructs jets from calorimeter cells using a cone algorithm

Jets

Jets defined using the anti-k_T algorithm with distance parameter R = 0.6

- Constructed from 3D topological energy clusters
- Four-momentum recombination scheme

Dominant source of experimental uncertainty is the jet energy scale

- Jets must be corrected for dead material, unclustered energy etc.

A great deal of work has gone into reducing and quantifying these uncertainties

- Found to be between 2%-3% for this analysis
- Validated with *in situ* tests e.g. using γ+jets

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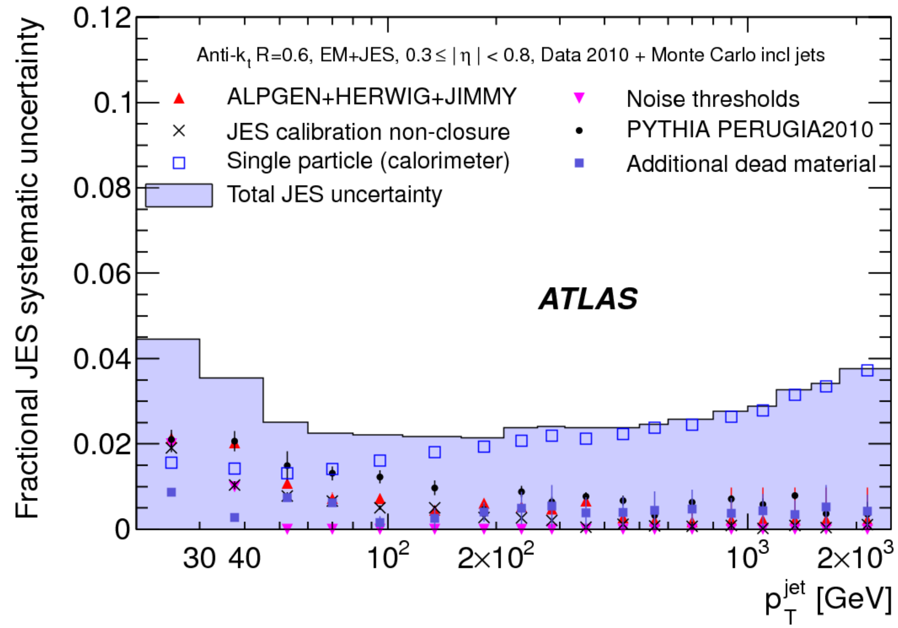
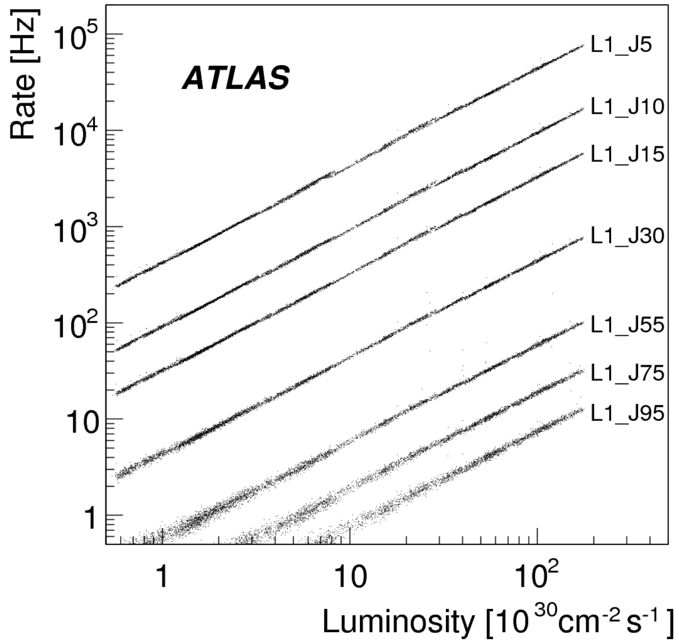
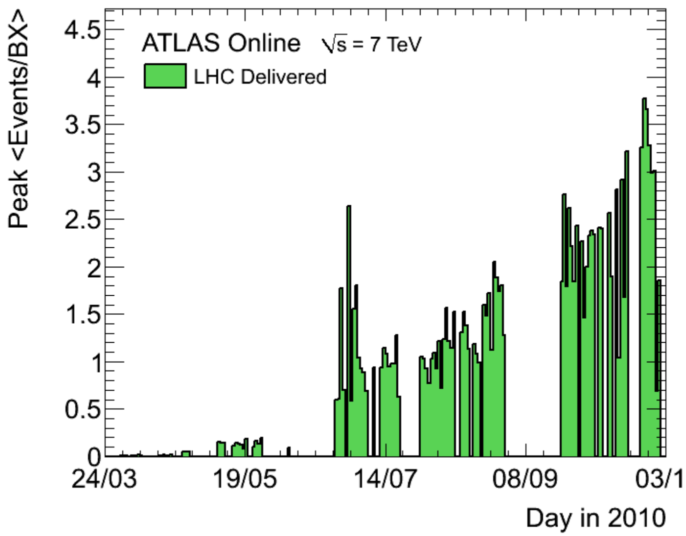


Data Selection

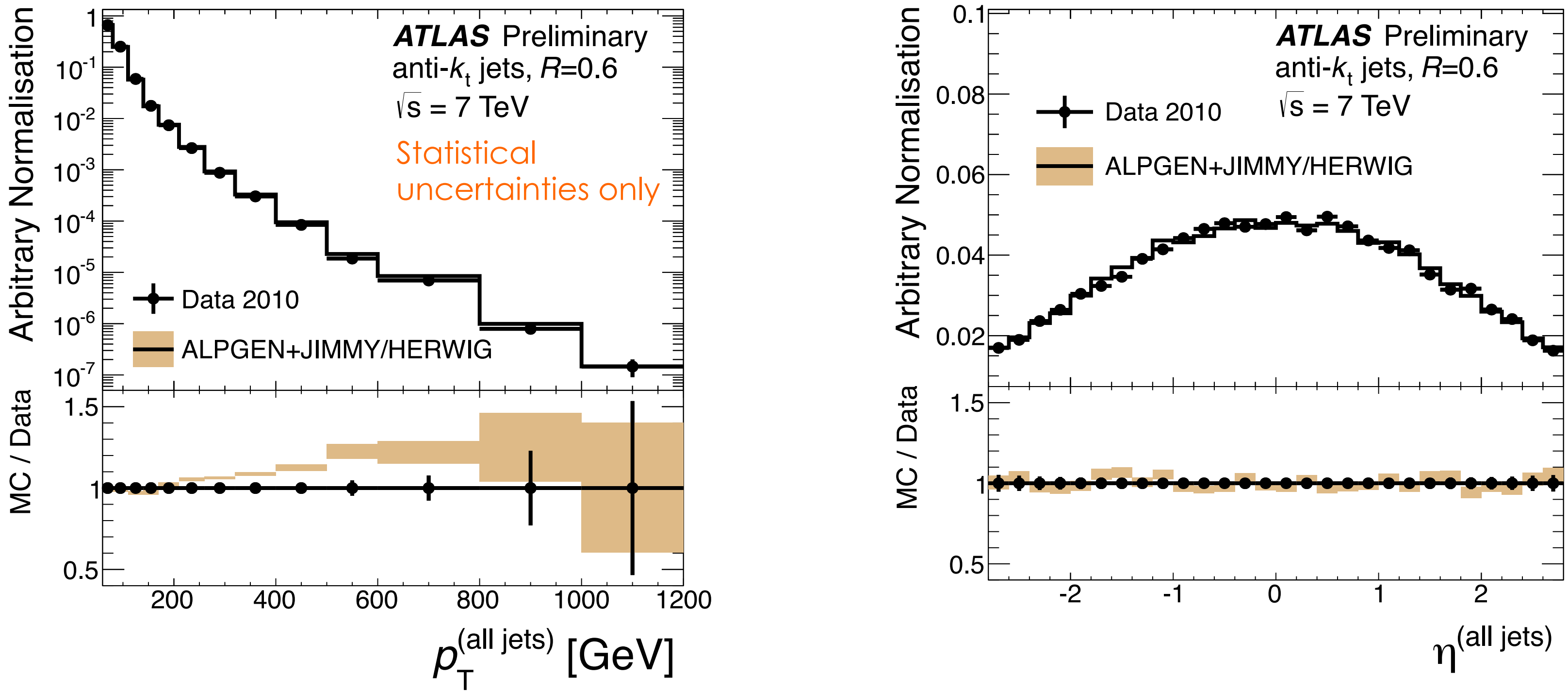
- 2010 $\sqrt{s}$ = 7 TeV pp dataset corresponding to $\int L dt$ = 36 pb^{-1}
- Appropriate trigger chain is used for each jet p_T bin to maximise effective luminosity
  - Triggers used are fully efficient for that p_T bin
  - Triggers with low jet p_T thresholds were prescaled because of high rates
- Events must have ≥ 2 jets
  - p_T > 40 GeV, $|y|$ < 2.8
- Highest p_T jet
  - p_T > 60 GeV
  - Ensures lowest trigger threshold is >99% efficient
- Events must have exactly 1 reconstructed primary vertex
  - Reduces possible contribution of jets from other pp interactions





Jets Passing Selection and Unfolding

Kinematic distributions of jets as reconstructed:



Detector inefficiencies and resolution effects are corrected for using bin-by-bin multiplicative correction factors

- Obtained using ALPGEN+HERWIG/JIMMY events passed through full GEANT-4 simulation of ATLAS detector

Theoretical Predictions

NLO pQCD jet p_T distributions have been generated for events with ≥ 2,3 jets using NLOJet++

MSTW2008 NLO PDF sets used

- Provides PDFs with $0.110 < \alpha_S (M_Z^2) < 0.130$ (steps of 0.001)

Predictions for $R_{3/2}$ and $N_{3/2}$ obtained by dividing differential cross-section distributions, e.g.

$$R_{3/2}\left(p_T^{\text{lead}}\right) = \frac{d\sigma_{N_{\text{jets}}\geq 3}}{dp_T^{\text{lead}}} \Bigg/ \frac{d\sigma_{N_{\text{jets}}\geq 2}}{dp_T^{\text{lead}}}$$

NLOJet makes parton-level predictions which must be corrected for non-perturbative effects, such as hadronisation and underlying event

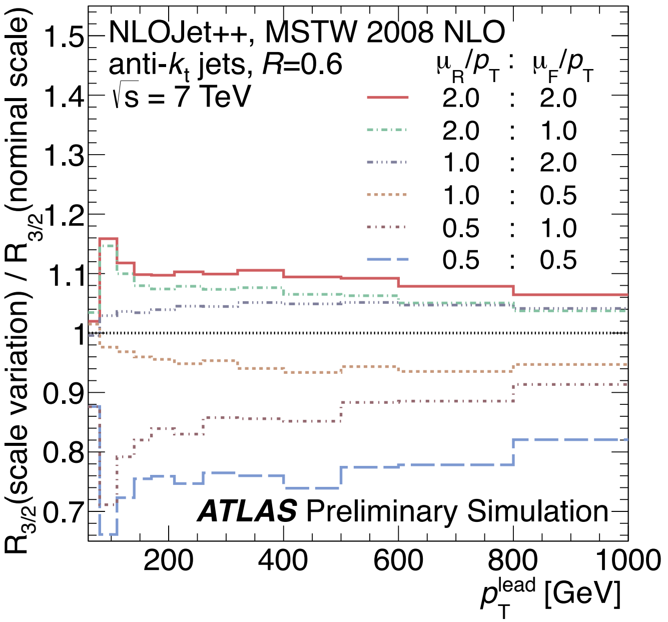
- Corrections from PYTHIA (AMBT1 tune) with MRST LO* PDFs
- <1% for p_T > 200 GeV, ~10% in 60 GeV < p_T < 80 GeV bin
- Other generators used to estimate systematic uncertainty (<2%)

Scale Dependence of pQCD Calculations

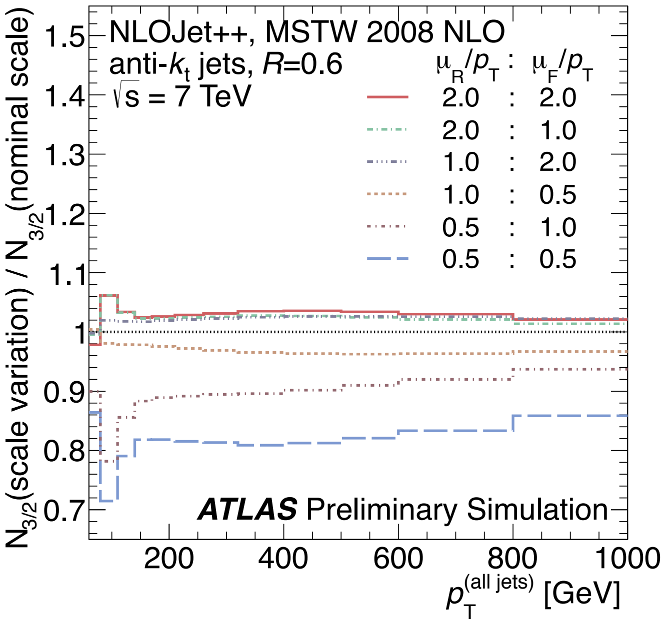
$R_{3/2}$ predictions use renormalisation and factorisation scales set to the leading jet p_T ($\mu_R = \mu_F = p_T^{lead}$)

For $N_{3/2,}$ the scales are set to the p_T of each jet

Scale dependence of $R_{3/2}$



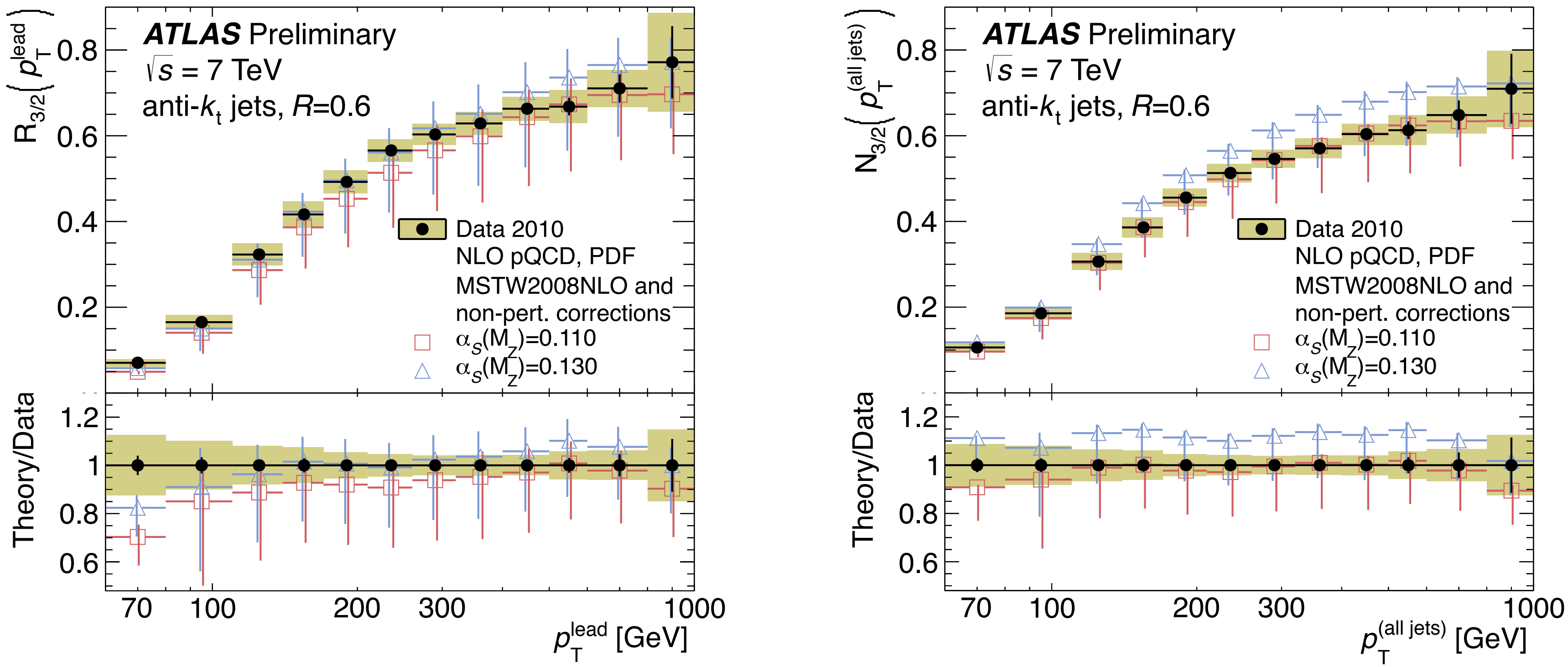
Scale dependence of $N_{3/2}$



$N_{3/2}$ is more stable against the choice of scale

⇒use for α_S extraction

Results $R_{3/2}$ and $N_{3/2}$



Total experimental uncertainty shown in yellow band

Theoretical error bars include scale, PDF and non-perturbative correction uncertainties

Two ratio measurements are sensitive to different event kinematics

Extraction of α_S

$\alpha_S(M_Z)$ is extracted by comparison to NLOJet++ predictions made with different values of $\alpha_S(M_Z)$

Least Squares fit to data, minimising χ^2 w.r.t. $\alpha_S(M_Z)$

- Over 6 p_T bins $\in$ [210, 800 GeV] simultaneously

Correlated systematic uncertainties included as nuisance parameters

Theoretical uncertainties estimated by altering theoretical predictions and refitting

The strong coupling is determined to be:

$$\alpha_S(M_Z) = 0.111 \pm 0.006(\mathrm{exp.})^{+0.016}_{-0.003}(\mathrm{theory})$$

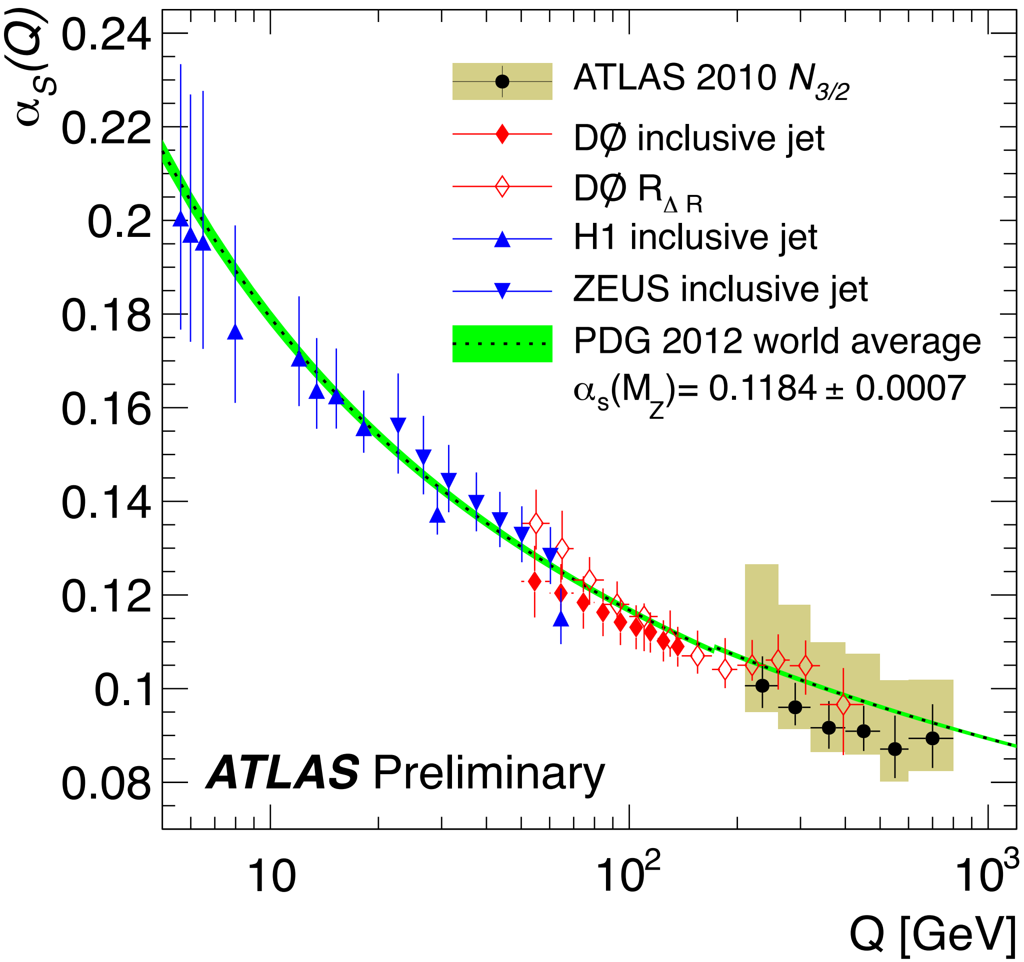
In agreement with

- PDG value $\alpha_S(M_Z) = 0.1184 \pm 0.0007$
- D0 value $\alpha_S(M_Z) = 0.1191^{+0.0048}_{-0.0071}$
- CDF value $\alpha_S(M_Z) = 0.1178 \pm 0.0001(\mathrm{exp.})^{+0.0081}_{-0.0095}(\mathrm{syst.})$

Theoretical uncertainties dominated by scale uncertainty

The Running of α_S

- $\alpha_S(Q)$ is determined by extracting $\alpha_S(M_Z)$ from each p_T bin individually
- These $\alpha_S(M_Z)$ are transformed to $\alpha_S(Q)$ using 2-loop approximate RGE solution
  - Q = average jet p_T for that bin
- Scale probed is extended beyond previous measurements to Q = 800 GeV



Conclusion

ATLAS has made its first determination of α_S, using ratio measurements for events with ≥ 3 jets to ≥ 2 jets

- $N_{3/2}$ is a new observable found to have reduced scale dependence in kinematic phase space studied

$$\alpha_S(M_Z) = 0.111 \pm 0.006(\text{exp.})^{+0.016}_{-0.003}(\text{theory})$$

Running of $\alpha_S(Q)$ was observed up to Q= 800 GeV

Both results are consistent with world averages

Improvements are possible on experimental aspects of the determination of α_S

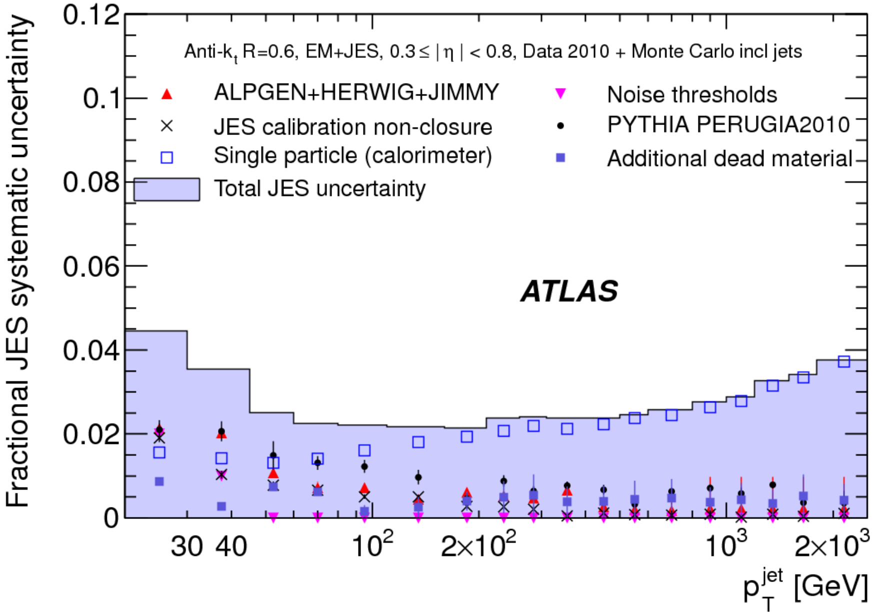
- Results using a different physical observable and the full 2012 dataset are coming soon from ATLAS

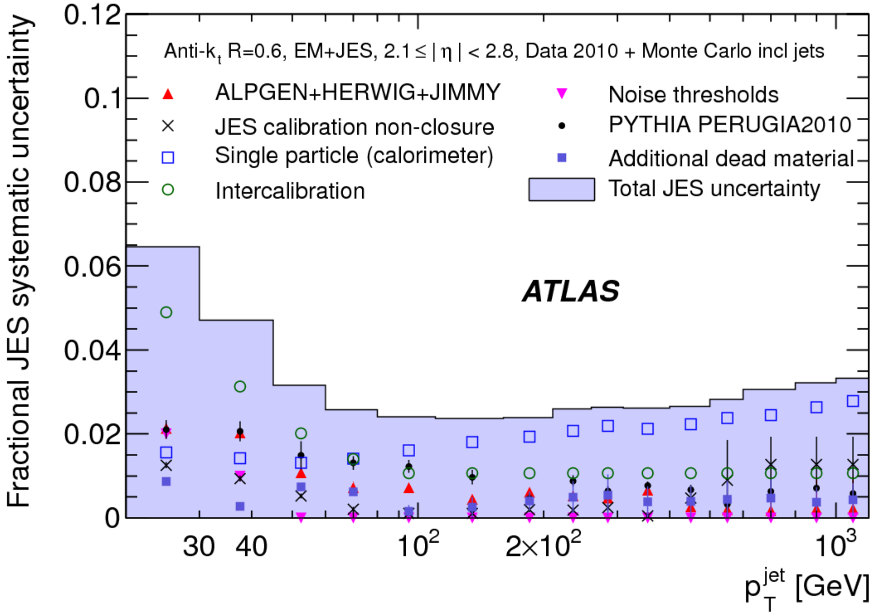
Largest uncertainty came from theory

- NNLO predictions would be extremely welcome!

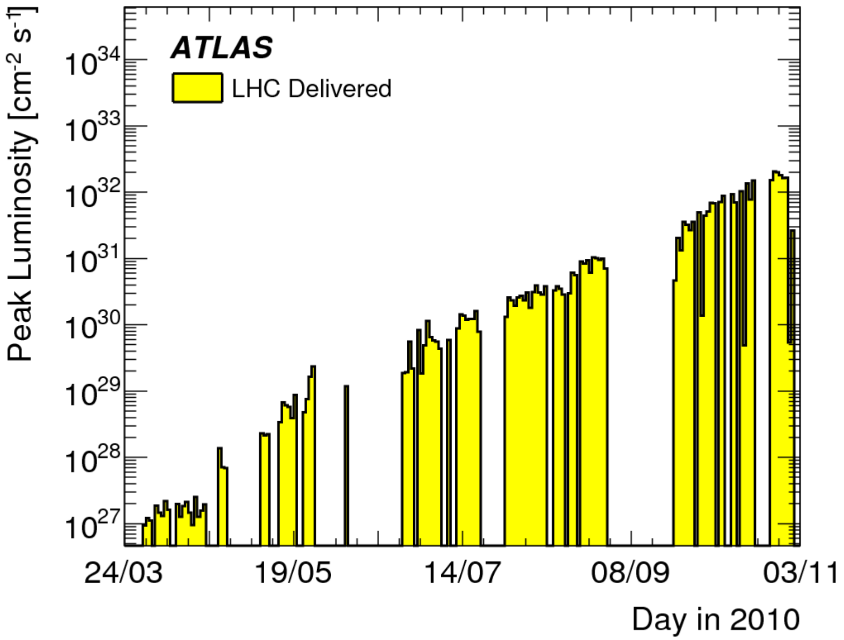
ADDITIONAL SLIDES

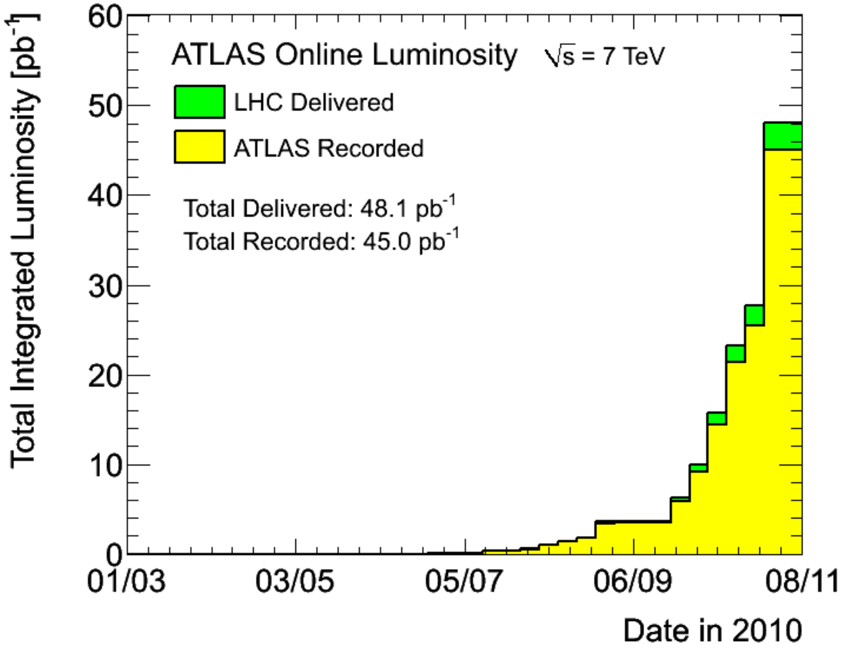
Jet Energy Scale Uncertainty





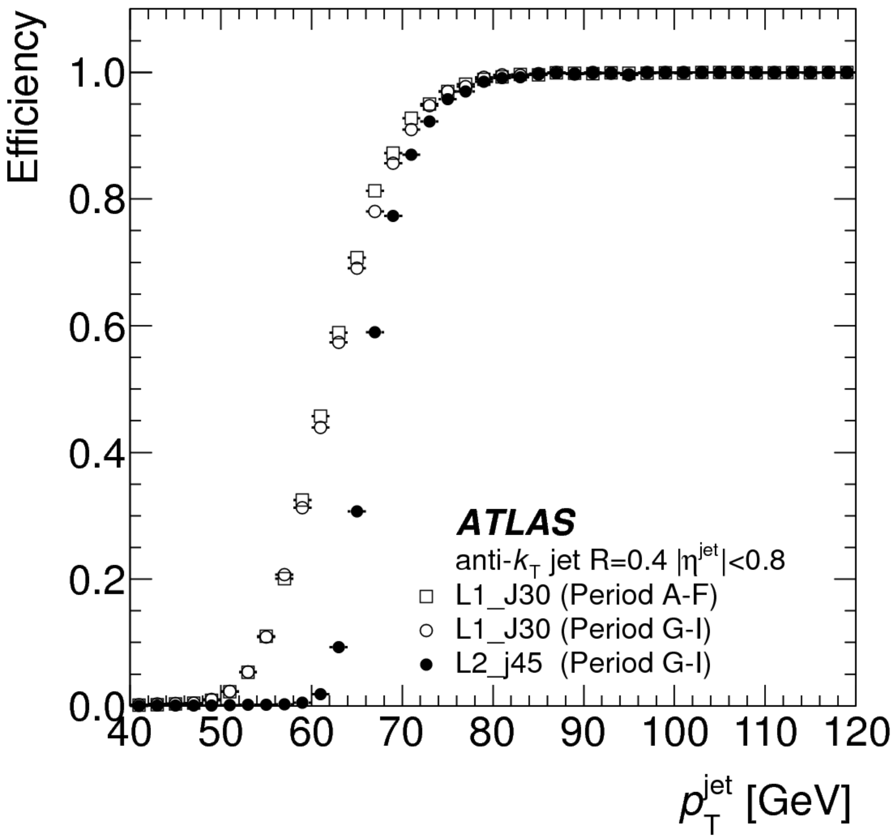
Luminosity in 2010

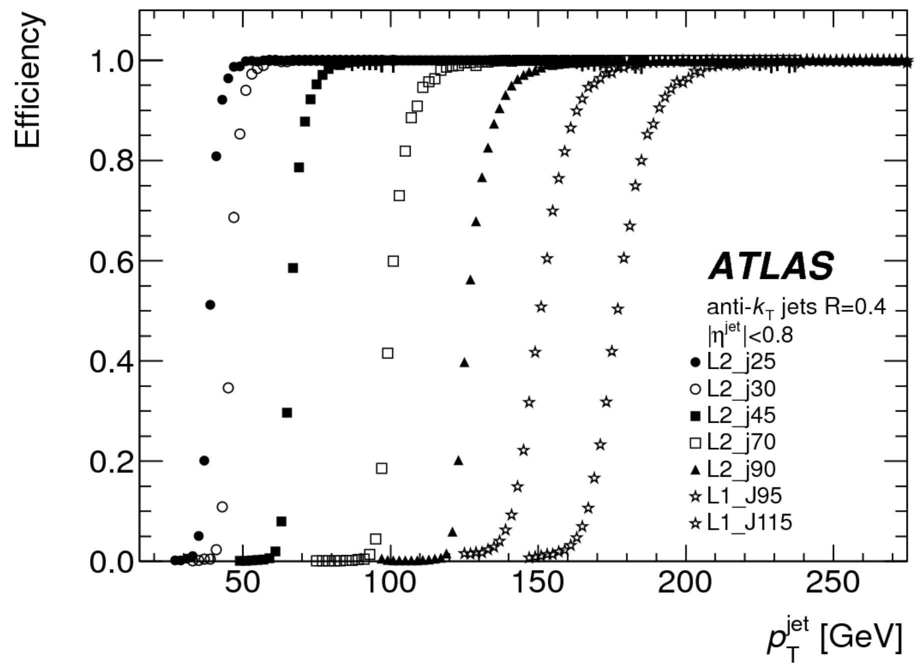




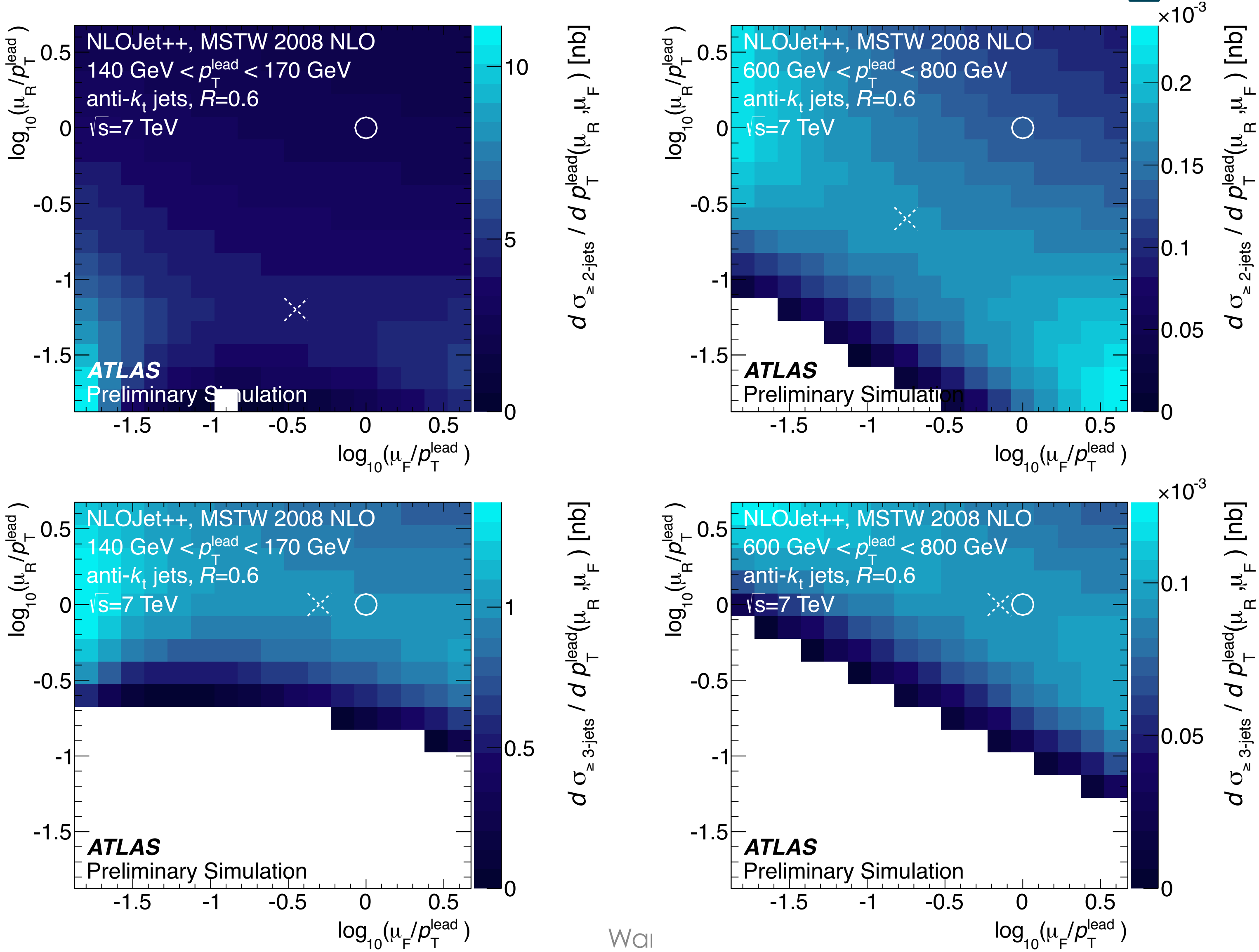
Trigger Efficiencies

Eur.Phys.J. C72 (2012) 1849

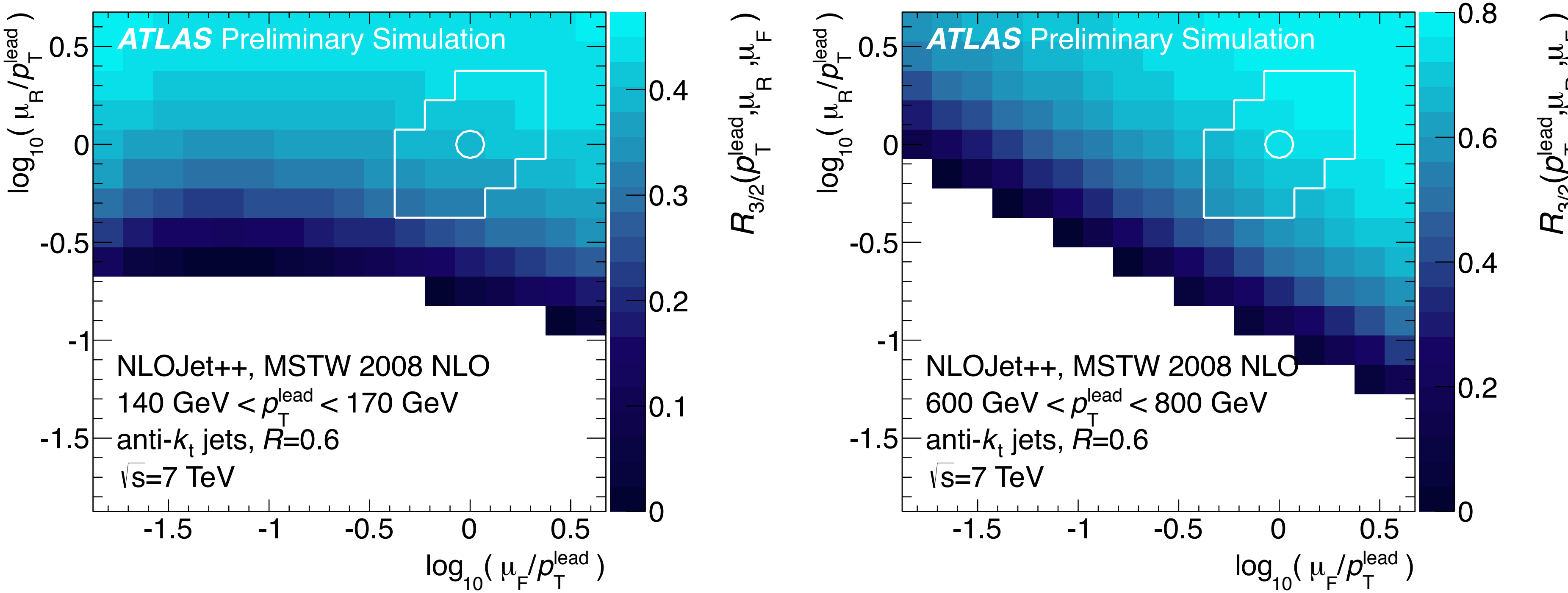




Scale Variations – Cross-Section Changes



Scale Variations – $R_{3/2}$ Changes



- Downward shifts in μ_R or μ_F from chosen nominal value result in a larger change in $R_{3/2}$ than upwards shifts
  - This is manifest as the asymmetric theoretical uncertainty on the final result

PDF Uncertainties

PDF uncertainties are estimated following the prescription in Rept. Prog. Phys. 70 (2007) 89

As an additional cross-check, the extraction is carried out using the following PDFs:

PDF	$\alpha_s(M_Z)$
MSTW08	0.111 ± 0.006
CT10	0.109 ± 0.006
HERAPDF 1.5	0.114 ± 0.005
ABM11	0.116 ± 0.005
NNPDF 2.3	0.112 ± 0.005

(Uncertainties quoted are experimental uncertainties alone)