The importance of correlations of experimental uncertainties:

ATLAS jet measurements

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on behalf of the ATLAS collaboration

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Outline

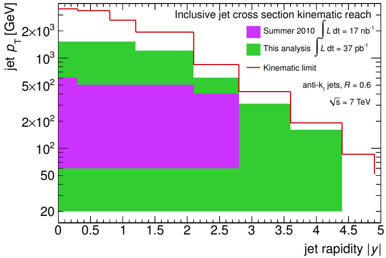
Correlations of systematic uncertainties **necessary**
for data/theory comparisons / inclusion of experimental data in PDF fits

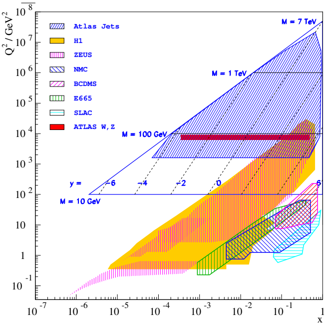
This talk: correlated uncertainties
for **updated** ATLAS 2010 inclusive jet/dijet measurement
(to be submitted to PRD)

Inclusive jet/dijet cross section measurements

Using full 2010 dataset (**37 pb**$^{-1}$)
$\rightarrow$ probe of perturbative QCD in new kinematic regime

First public presentation of **updated analysis**





20 GeV$<p_T^{jet}<$1.5 TeV
70 GeV $< m_{12} <$ 5 TeV
$|y| <$4.4

$7 \cdot 10^{-5} < x < 0.9$
$Q^2 > 2 \cdot 10^7$ GeV^2

Measurement details

Data:

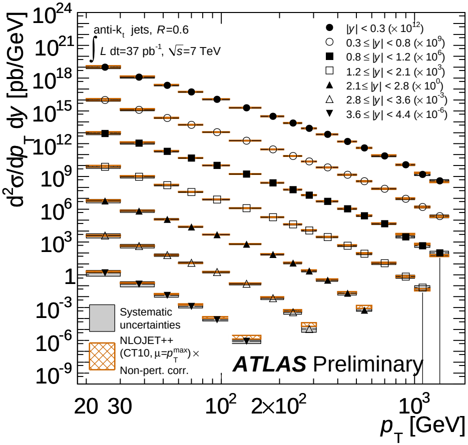
- Anti-k_T jets with R=0.4 and R=0.6, calibrated to hadron level
- **New:** Detector effects corrected for using Iterative Dynamically Stabilized (IDS) unfolding [physics.data-an/1106.3107]
- **New:** Evaluation of **correlated experimental uncertainties**

Theory comparisons:

- Fixed-order NLO QCD parton-level calculation: **NLOJET++** [hep-ph/0307268]
  - Established benchmark theory prediction for inclusive jet and dijet production
  - Interfaced to APPLGrid [hep-ex/1009.5908] for uncertainties/comparison to PDFs
  - Non-perturbative corrections from PYTHIA [hep-ph/0603175] (uncertainties: other generators/tunes)
- **Updated:** NLO ME + parton shower MC: **POWHEG** [hep-ph/1009.5594]

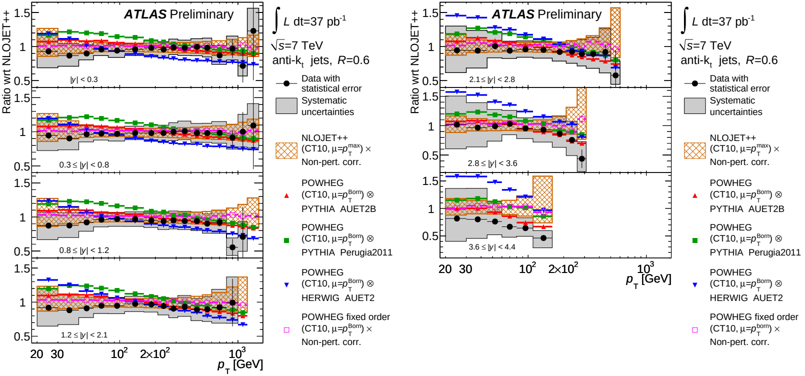
This talk: results for inclusive jet measurement, R=0.6

Inclusive jet cross section: results



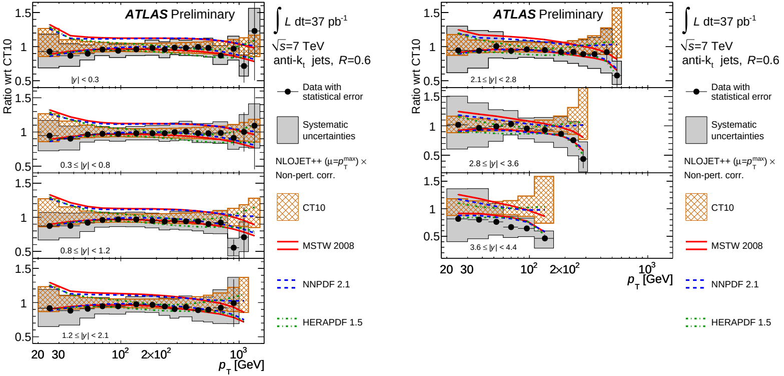
Agreement with pQCD in wide kinematic range

Comparison to POWHEG



Good agreement between NLOJET++ and POWHEG fixed order calculations
Significant deviations at low/high p_T when POWHEG interfaced to parton shower MC (PYTHIA/HERWIG)

Comparison to different PDF sets

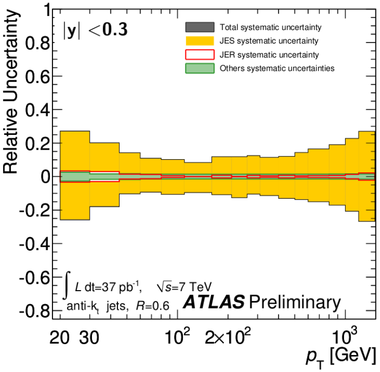


Data **below** NLOJET++ at high pT (forward region)
⇒ for more quantitative comparisons and for PDF fits need estimate of **uncertainty correlations**

Experimental systematic uncertainties for inclusive jet cross section

Sources of systematic uncertainties:

jet energy scale, jet energy resolution, luminosity (3.4 %, not shown below) , unfolding, jet matching, jet angular resolution, reconstruction efficiency, pile-up, trigger, jet ID



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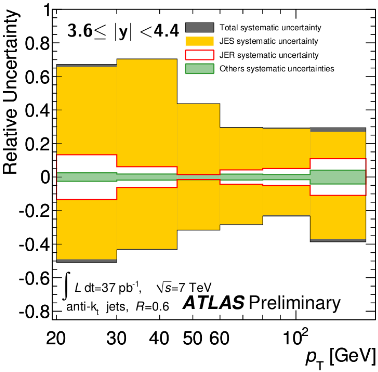


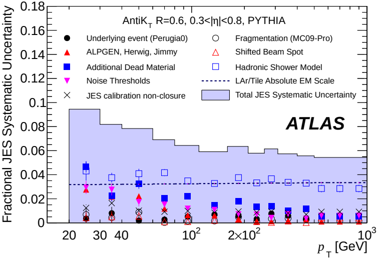
Jet energy scale uncertainty in ATLAS

Estimate of JES uncertainty based on:

- isolated hadron response uncertainties (in-situ/test beam)
- Monte Carlo samples with systematic variations (e.g. distorted geometry)
- p_T balance in dijet events for $|\eta|>0.8$
- in-situ measurements in case of pile-up, corrected for in calibration
  (added separately as f(N_{PV}), on average <3% for low p_T central jets)

Before collisions:

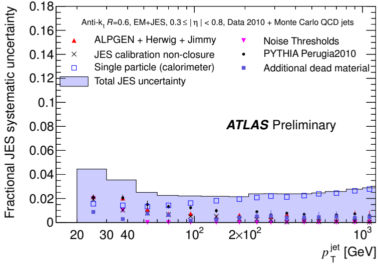
<7% for for jets with $|\eta|<0.8$, p_T=100 GeV
<10% for endcap jets



[ATLAS-CONF-2010-056 , [hep-ex/1009.5908]]

After analysis of 2010 collision data:

<2.5% for jets with $|\eta|<0.8$, p_T =100 GeV
<9 (14)% for jets with $|\eta|<2.8$ (4.4)



[ATLAS-CONF-2011-032]

JES uncertainty due to calorimeter response

Propagate single isolated hadron uncertainties to jets
to obtain estimate of **calorimeter** Δ_{JES}
$\Rightarrow$ uncertainty constrained by in-situ measurements

Data used to evaluate calorimeter uncertainties:

- Isolated tracks matched to calorimeter clusters (E/p): $0.5 < p < 20$ GeV
  - Average hadronic response in calorimeters described by MC within 2-5% [ATLAS-CONF-2011-028]
  - Use of resonances for particle identification [ATLAS-CONF-2011-019]
- Combined ATLAS test-beam: $20 < p < 350$ GeV [ATL-TILECAL-PUB-2009-007]

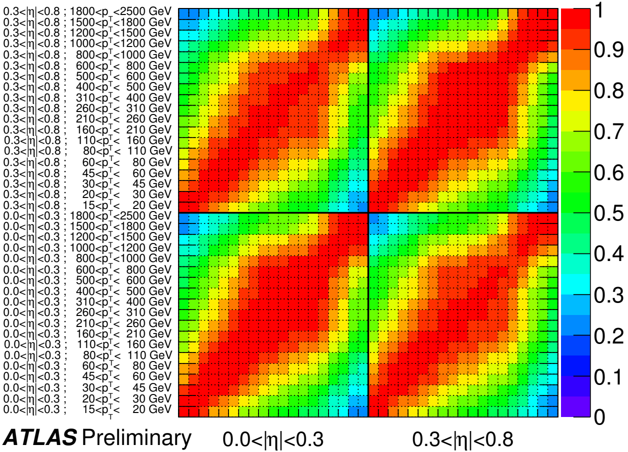
Decomposition of calorimeter JES uncertainty:

7 separate sources of single hadron uncertainties:
E/p data/MC difference, calorimeter acceptance, combined test beam,
neutral particles, high momentum particles,
absolute EM energy scale for EM/HAD calorimeters

Total contribution to JES uncertainty: **1.5-4%**

Calorimeter response uncertainty correlations

Pseudo-experiment approach for propagation of single particle uncertainties to JES uncertainty → full **bin-to-bin correlation matrix** available



Relevant correlations for jets close in p_T, limited for low vs high p_T jets

Decomposition of calorimeter uncertainty

Simplified approach to reproduce correlation matrix:

Full calorimeter uncertainty correlation matrix

$\Rightarrow$ **regroup** calorimeter uncertainty sources into **nuisance parameters**

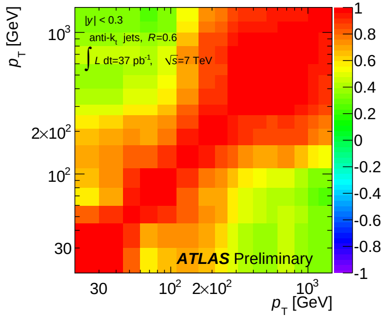
every nuisance parameter uncorrelated to each other, but fully correlated across bins

- Split calorimeter uncertainty subcomponents using covariance matrix (c_{ij}):
  1. Derive first source $\sigma^{(n)}, n = 1$ taking bin k of covariance matrix as reference:
  $$\sigma_i^{(1)} = c_{ik}/\sqrt{c_{kk}}$$
  2. Use new covariance matrix to generate the other sources:
  $$c_{ij}^{(n)} = c_{ij}^{(n-1)} - \sigma_i^{(n-1)}\sigma_j^{(n-1)}$$
  $$\sigma_i^{(n)} = c_{ik'}^{(n)}/\sqrt{c_{k'k'}^{(n)}}$$
  3. Iterate two steps above until no significant decorrelations in modified covariance matrix
  4. Build the last source $\sigma^{(n)}, n = N$:
  $$\sigma_i^{(N)} = \sqrt{c_{ii}} - \sum_{n=1}^{N-1} (\sigma_i^{(n)})^2$$
- Combine calorimeter sources with similar p_T shape into a single subcomponent

New covariance/correlation matrix **validated** by comparison with original

Correlation of uncertainties for inclusive jet cross section

Bin-to-bin correlation matrix for systematic uncertainties, central region $(0 \leq |\eta| < 0.3)$



(uncertainties symmetrised for display only)

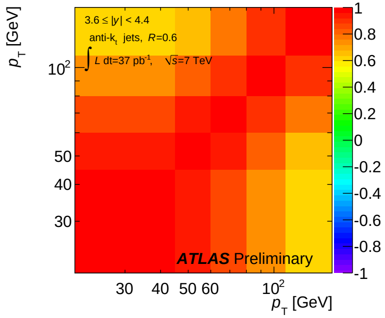
Decomposition of experimental systematic uncertainties into **nuisance parameters**:

- **Most uncertainties** treated as correlated across p_T, decorrelations for central/forward y (different detector technologies)
- **JES uncertainty - calorimeter**: decomposition as in previous slides;
- **JES uncertainty - MC variations**: fully correlated in p_T, y (smooth variations);
- **JES uncertainty - forward JES/dijet balance**: fully correlated in p_T, y (dominated by differences between MC models);
- **Luminosity, unfolding**: fully correlated (p_T, y);
- **Pile-up**: completely uncorrelated (pile-up corrected for during JES calibration, uncertainty on correction)

Correlation matrix for statistical uncertainties available as well
statistical uncertainties $\ll$ systematic uncertainties in most bins

Correlation of uncertainties for inclusive jet cross section

Bin-to-bin correlation matrix for systematic uncertainties, forward region ($3.6 \leq |\eta| < 4.4$)



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Final correlated uncertainties for ATLAS jet measurements

Correlation treatment results in 87 nuisance parameters:

ATLAS Preliminary

	$\|y\|$-bins						
Uncertainty Source	0-0.3	0.3-0.8	0.8-1.2	1.2-2.1	2.1-2.8	2.8-3.6	3.6-4.4
JES 1: Noise threshold	1	1	2	3	4	5	6
JES 2: Theory UE	7	7	8	9	10	11	12
JES 3: Theory Showering	13	13	14	15	16	17	18
JES 4: Non-closure	19	19	20	21	22	23	24
JES 5: Dead material	25	25	26	27	28	29	30
JES 6: Forward JES	31	31	31	31	31	31	31
JES 7: E/p response	32	32	33	34	35	36	37
JES 8: E/p selection	38	38	39	40	41	42	43
JES 9: EM+neutrals	44	44	45	46	47	48	49
JES 10: HAD E-scale	50	50	51	52	53	54	55
JES 11: High p_{T}	56	56	57	58	59	60	61
JES 12: E/p bias	62	62	63	64	65	66	67
JES 13: Test-beam bias	68	68	69	70	71	72	73
Unfolding	74	74	74	74	74	74	74
Jet matching	75	75	75	75	75	75	75
Jet energy resolution	76	76	77	78	79	80	81
y-resolution	82	82	82	82	82	82	82
Jet reconstruction eff.	83	83	83	83	84	85	86
Luminosity	87	87	87	87	87	87	87
JES 14: Pile-up (u_1)	u	u	u	u	u	u	u
Trigger (u_2)	u	u	u	u	u	u	u
Jet identification (u_3)	u	u	u	u	u	u	u

- Each number ⇔ separate nuisance parameter (fully correlated across p_T^{jet})
  e.g. **76: JER in central region, 87: luminosity...**
- Uncertainties marked as u are treated as completely uncorrelated

Correlated systematic errors: tests in PDF fits

Inclusion of correlated errors in χ^2 comparisons / PDF fits

(see also [hep-ph/0110123], [hep-ph/0201195])

$$\chi^2(\mathbf{p},\mathbf{r}) = \sum_{i=1}^{N} \frac{1}{\sigma^2_{i,stat} + \sigma^2_{i,uncorr}} [(D_i - T_i(\mathbf{p}) - \sum_{k=1}^{K} r_k \beta_{ik})^2] + \sum_{k=1}^{K} r_k^2 \quad (1)$$

β_k: correlated systematic uncertainty sources, r: Gaussian shifts

Results of *proof of principle* PDF fitting tests [C.D., thesis under review]:

- Using HERAPDF fitting code (NLOJET++/APPLGrid, QCDNUM)
- HERA 1.5 data as baseline [PoS, ICHEP2010]
- Include all p_T, y bins of ATLAS inclusive jet data

All uncertainties considered as **uncorrelated** :
$\chi^2 \approx$ **20 / 90** data points
All systematic uncertainty components considered as **fully correlated** (p_T, y):
$\chi^2 \approx$ **1000 / 90** data points
Splitting of correlated uncertainties as shown in previous slide:
$\chi^2 \approx$ **50 / 90** data points

Conclusions

Updated 2010 ATLAS inclusive jet/dijet measurement:

- 2 orders of magnitude in jet pT and dijet mass
  10 orders of magnitude in cross-section
- Experimental (systematic) uncertainties approach theoretical uncertainties:
  e.g. central jets, p_T=100 GeV: syst. unc. (JES) ≈ 10%, theo. unc. ≈ 5%
- Paper to be submitted to PRD → data will be available on `HEPData`

Treatment of correlated experimental uncertainties:

- Allows quantitative theory comparisons, meaningful inclusion in PDF fits
- Strategy: use nuisance parameters (asymm uncertainties)
  - JES (calorimeter): reproduce information on correlation matrix using further decomposition of sources
  - Other uncertainties: assess bin-to-bin (p_T, y) correlations
- Nuisance parameters will be published/delivered through `HEPData`

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Material for discussion: how to present systematic uncertainties on data

Treatment of correlated uncertainties

- Nuisance parameters vs covariance/correlation matrix?
- Simple methods to obtain nuisance parameters for LHC experiments?
- How to publish results and methodology of estimate of correlations

Comparison and combination of measurements from different experiments

- Identification of common sources of systematic uncertainties (e.g. JES in presence of different calibration procedures?)
- Common theory uncertainties (e.g. non-perturbative corrections)