Jet Production Measurements with ATLAS

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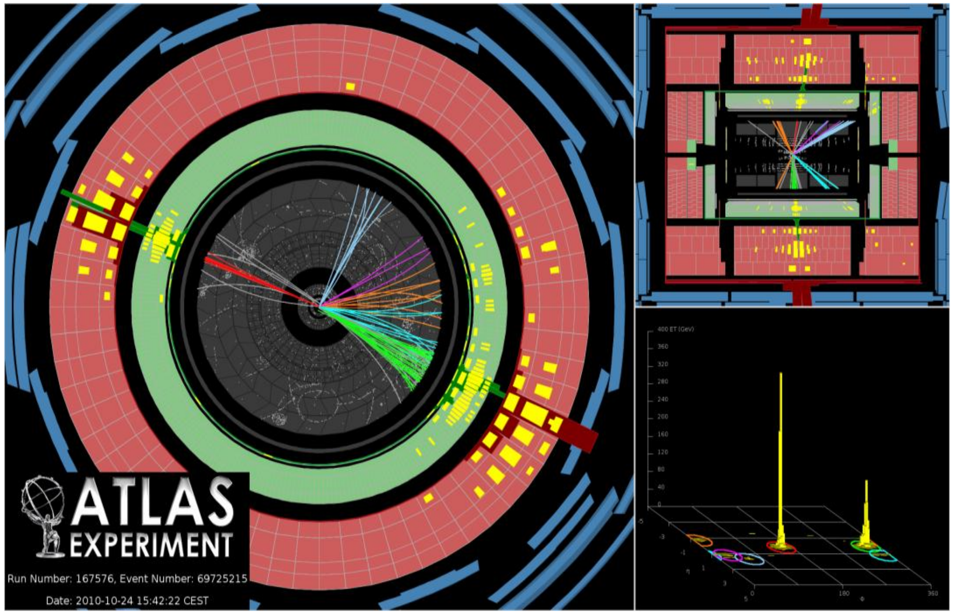
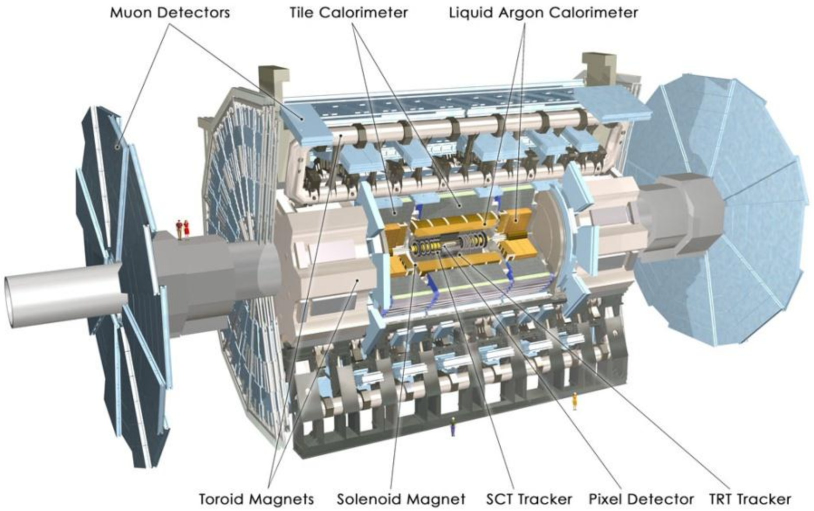
Introduction

- Jet production at LHC
    - Process with dominant cross-section
    - Test of pQCD
    - New physics searches

- Recent results on 2010 data
    - Jet substructure measurements
- 2011 data
    - Extended kinematic reach
    - High pile-up environment

High mass (2.6 TeV) dijet event





Jet Reconstruction and Calibration

Calorimeter cells
(EM-scale)

↓ Noise suppression, local hadronic /EM-scale calibration

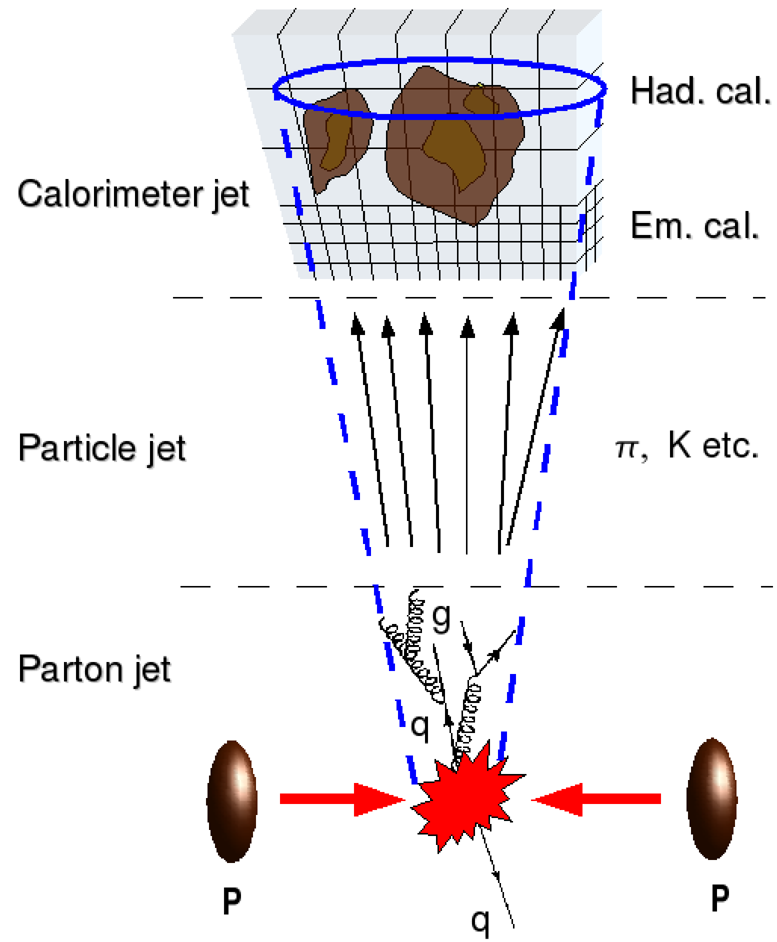
Topological clusters

↓ Anti-k_T R=0.6,1.0, Cambridge-Aachen R=1.2

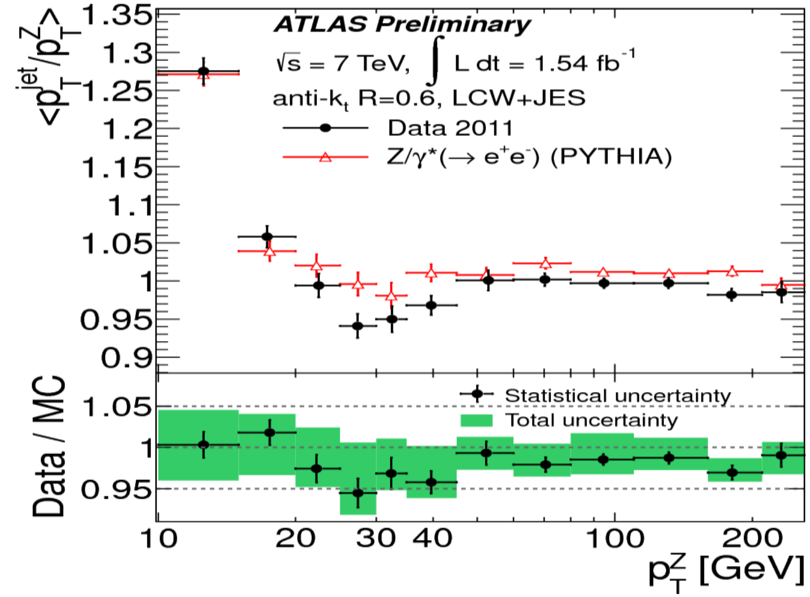
Calorimeter Jets

↓ Offset correction, MC-based energy, η calibration

Particle Jets



Jet Calibration Performance

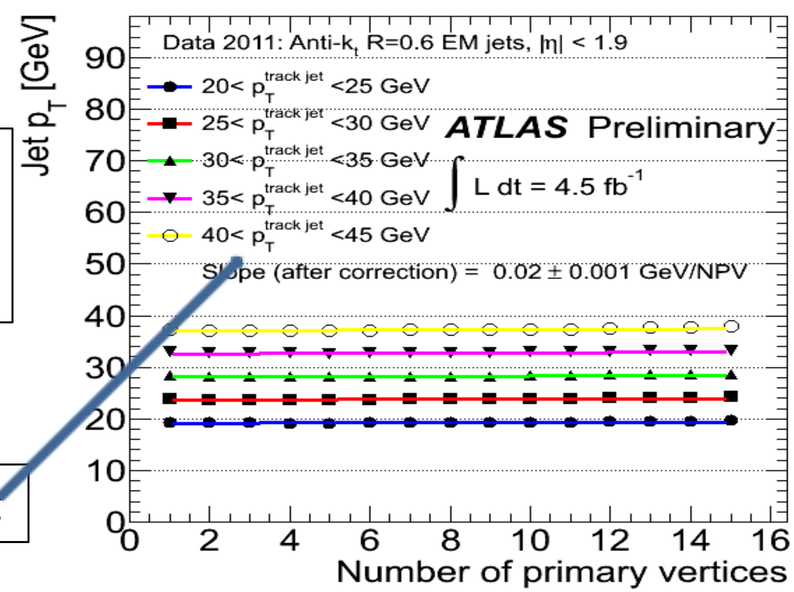


- ($P_{T,}\eta$)-dependent jet energy scale (JES) correction derived from Monte Carlo truth
  - Locally calibrated calorimeter clusters with hadronic weights
  - In-situ validation in Z/γ*+jets, dijet events
- Jet energy corrected with Monte Carlo based offset correction for effects of pile-up
  - Function of η, < μ >, N_{PV}

Out-of-time pile-up: Interactions in near-by bunch crossings

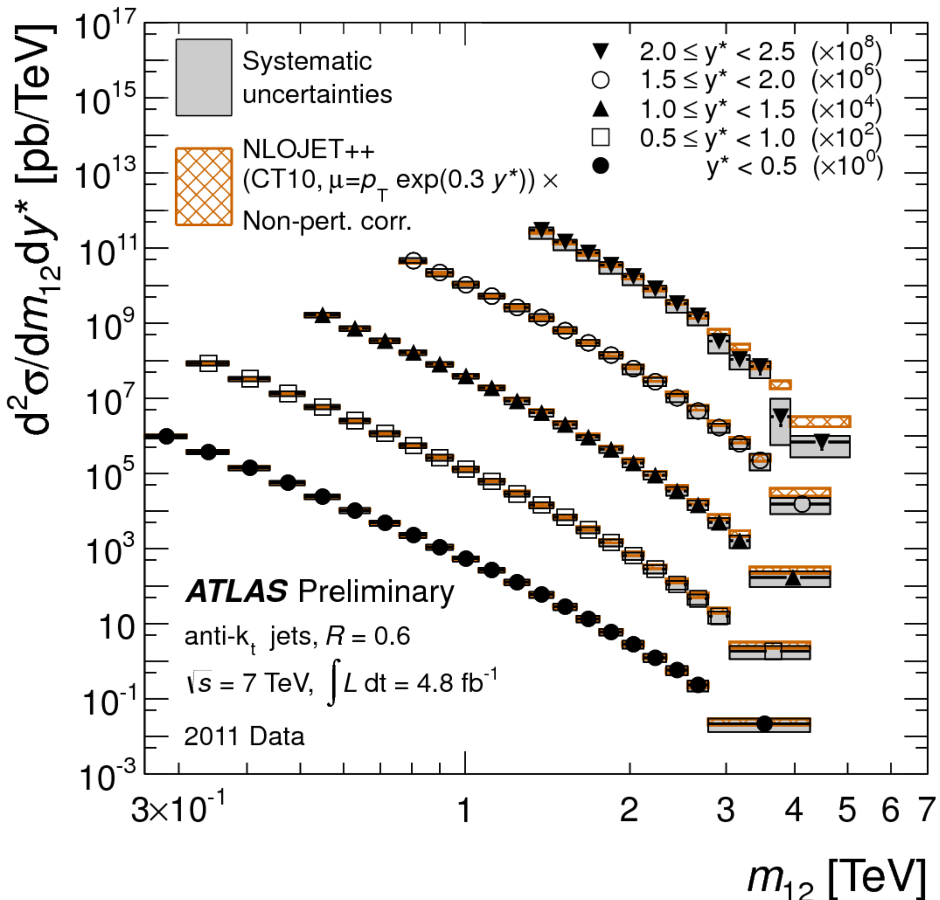
- **In-time pile-up**: Multiple interactions in same crossing

P_T of closest matched track jet



Dijet Mass Cross-section

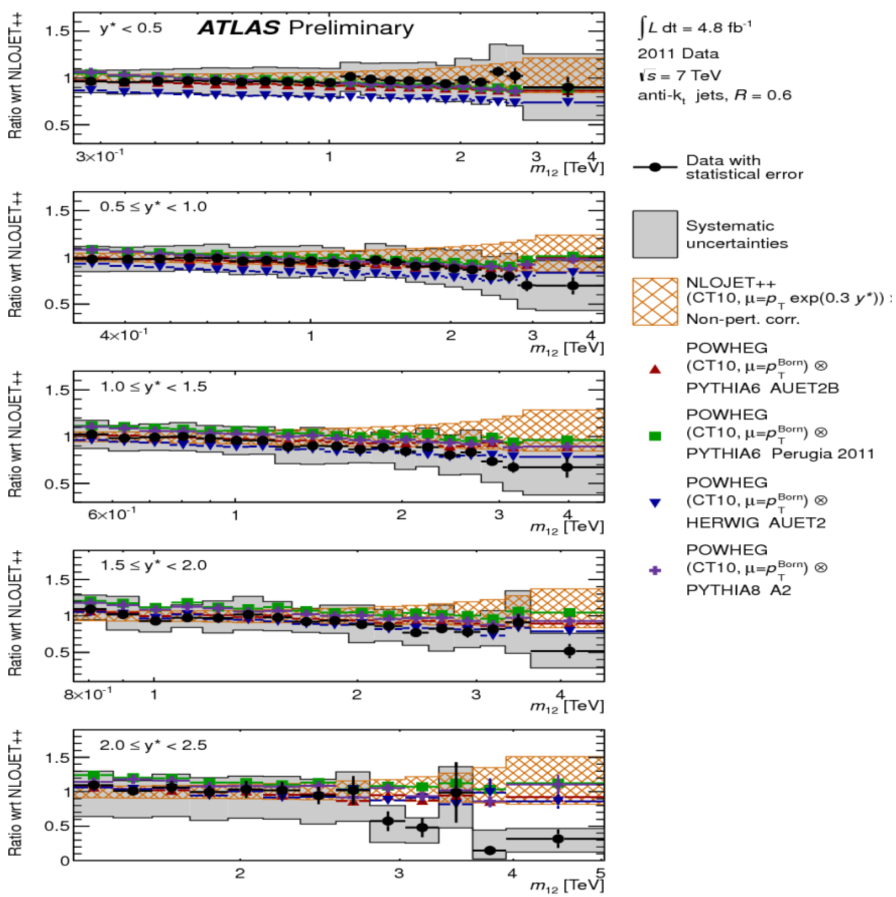
- 2011 data: $\mathscr{L}$ = 4.8 fb-1
- Cross-section binned in y* (rapidity difference in COM frame)
- Probe of NLO pQCD and PDFs
- Event selection:
  - >=1 primary vertex
  - event quality cuts
  - **$P_{T,j1}$>100 GeV, $P_{T,j2}$>50 GeV**
  - **|y|<4.4, y*<2.5**
  - jet P_T, energy corrected for pile-up
- Uncertainties:
  - JES, calorimeter resolution, reconstruction efficiency, pile-up



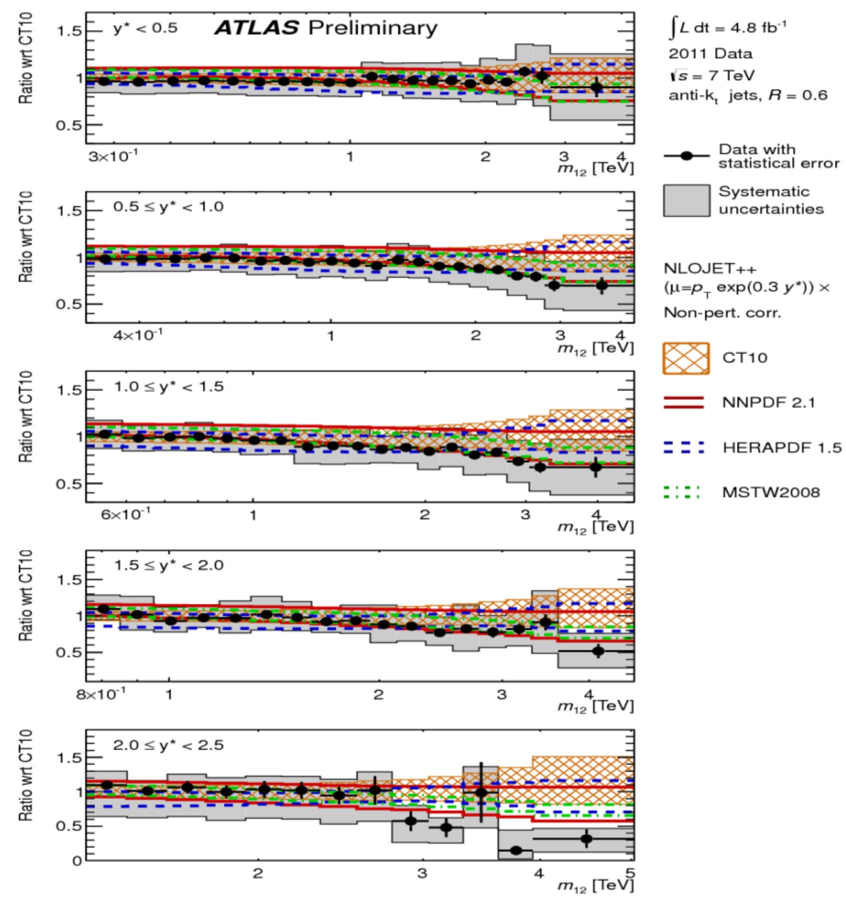
Kinematic Reach: 260 GeV < m_{12} < 4.6 TeV

Dijet Mass Cross-section

Ratio wrt. NLOJET++



Ratio wrt. CT10



- **Overall agreement with NLO pQCD within errors**
- **Some tension at high m_{12} and large y* (up to 40%)**

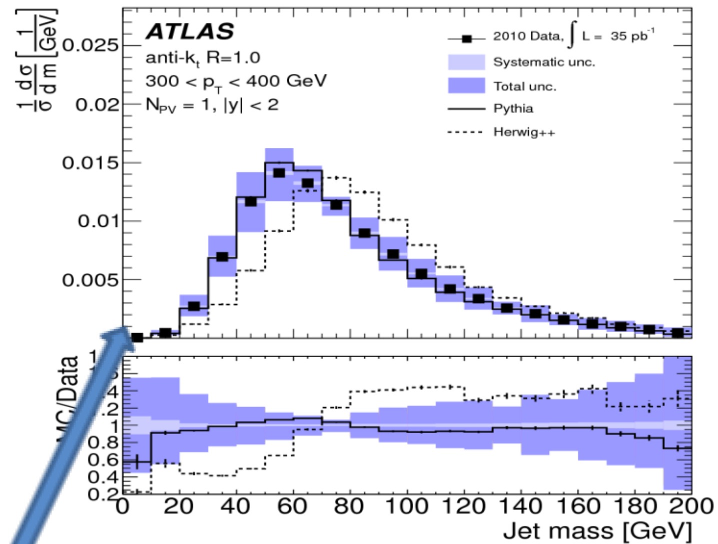
arXiv:1203.4606

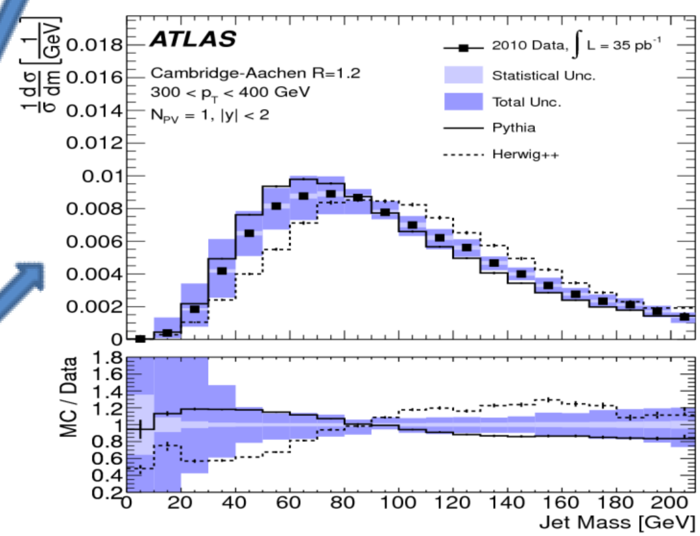
Jet Mass and Substructure

- 2010 Dataset $\mathscr{L}$ = 35 pb-1
- Jet selection
  - **Anti-k$_T$ R=1.0, Cambridge-Aachen R=1.2**
  - **P$_T$> 200 GeV, |y|<2.0**
- Event Selection
  - **exactly 1 primary vertex** (no pile-up)
  - event quality cuts – remove events with non-collision jets
- Uncertainties
  - Jet energy scale, jet mass scale, resolution
  - In-situ constraints from track-jet studies

- Comparison to QCD Monte Carlo
  - Distribution shape reproduced by Pythia
  - Jet mass overestimated by Herwig++

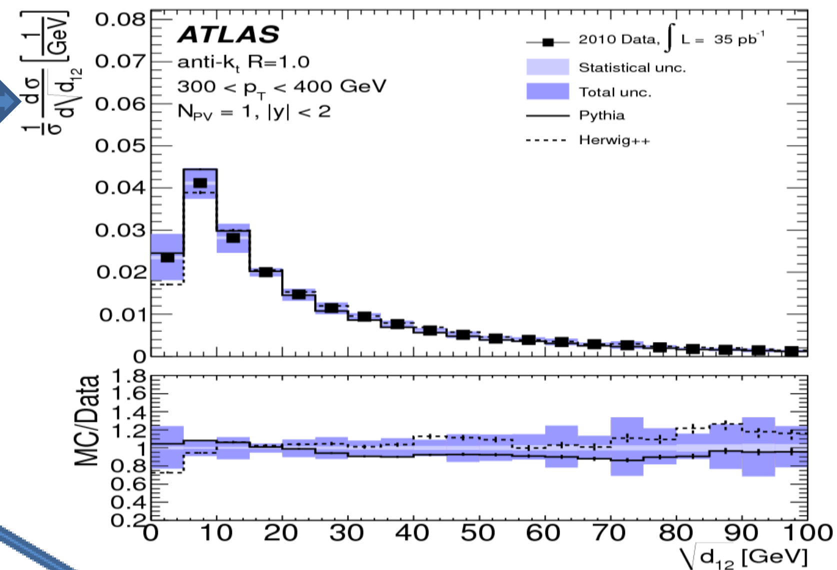
Jet Mass Measurements

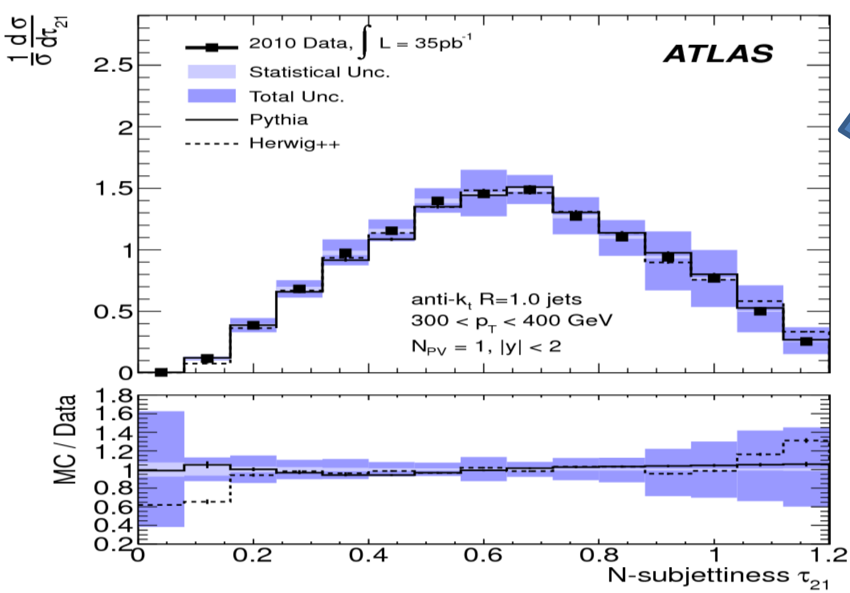


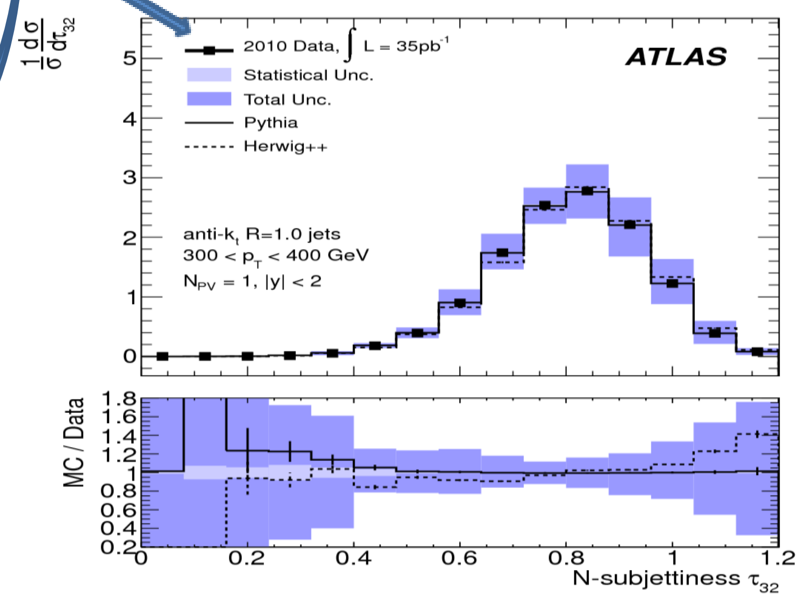


Jet Mass and Substructure

- "Shape" observables
  - **Splitting scale** - scale at which jet splits into subjets
  - **N-subjettiness** - measure of subjet multiplicity
- Discriminate QCD jets from boosted particle decays
- Overall agreement with both Pythia and Herwig++ QCD Monte Carlo

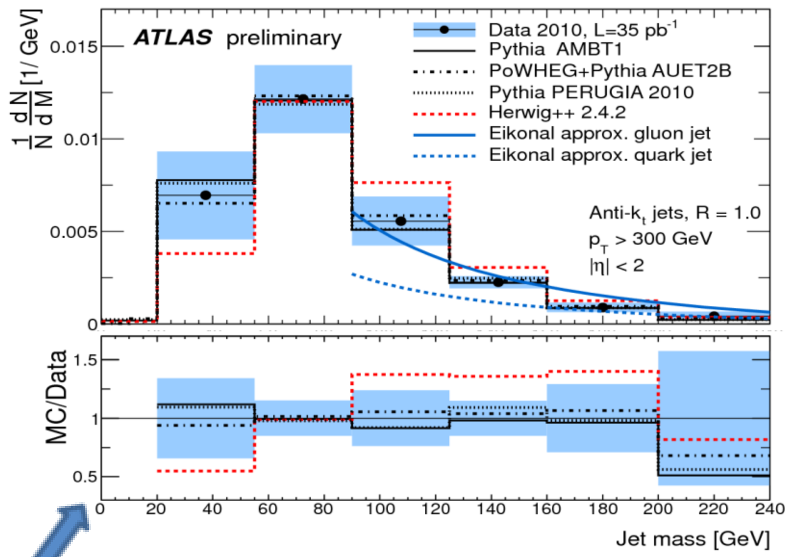




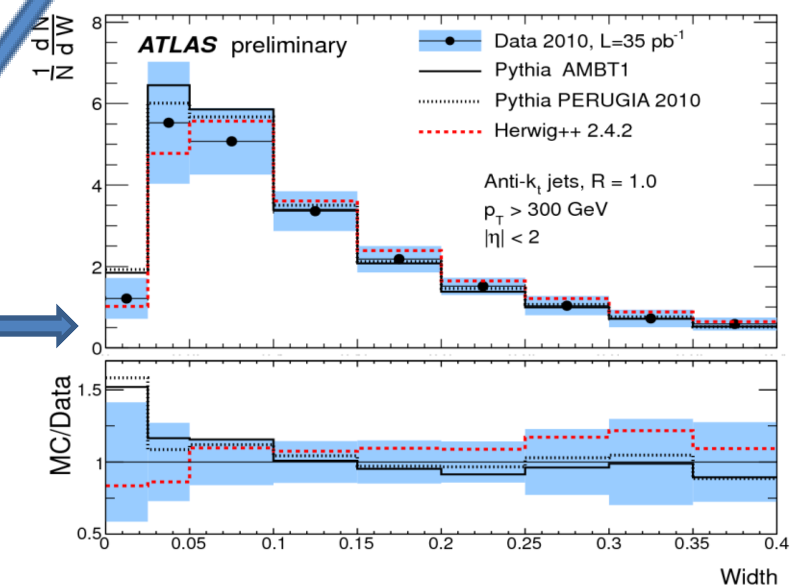


More Jet Substructure

- Full 2010 Dataset $\mathcal{L}$ = 35 pb-1
  - >=1 primary vertex
  - leading jet P_T> 300 GeV, |η|<2.0
- Data-driven pile-up corrections for observables
- Uncertainties
  - calorimeter response, resolution, unfolding

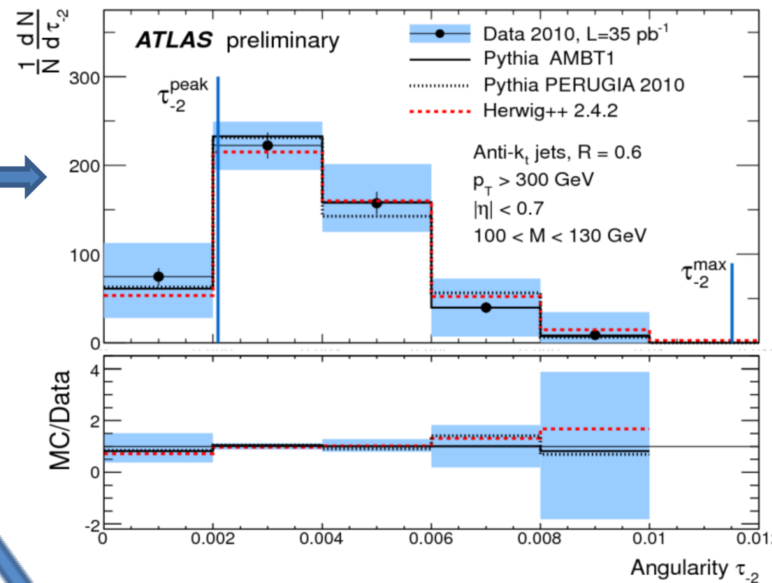


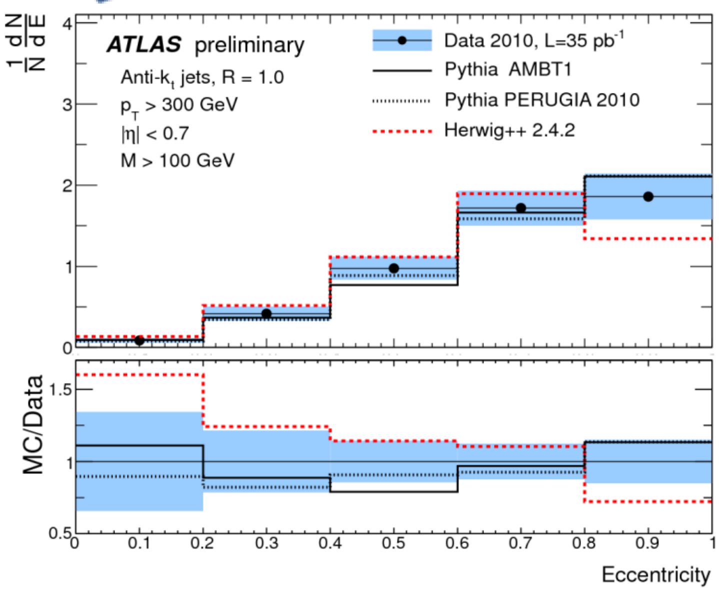
- **Jet mass**
  - Compared to QCD Monte Carlo and analytic NLO pQCD approximations
- **Jet width**
  - Strongly correlated to jet mass

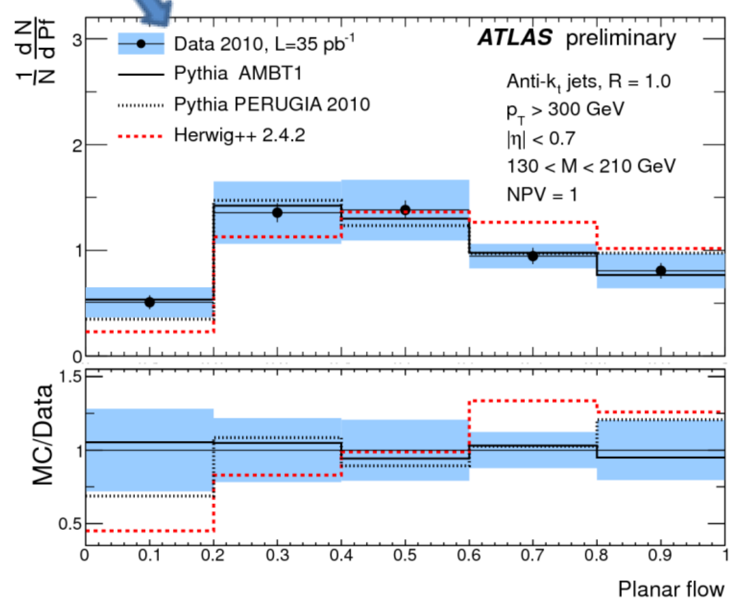


More Jet Substructure

- 2-body structure in high-mass QCD jets tested by:
  - **Angularity**
    - Approximate min. and max. distribution range predicted for QCD (from 2-body assumption)
  - **Planar flow** – discriminates 2-body configurations from >=3-body ones
  - **Eccentricity** – strong anti-correlation to planar flow







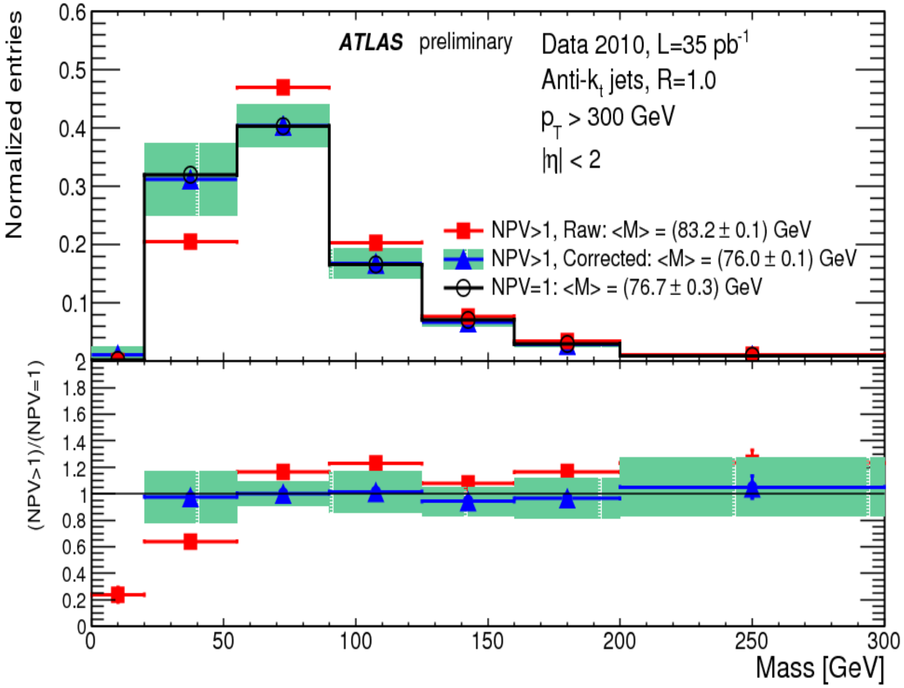
Pile-up Corrections for Jet Substructure

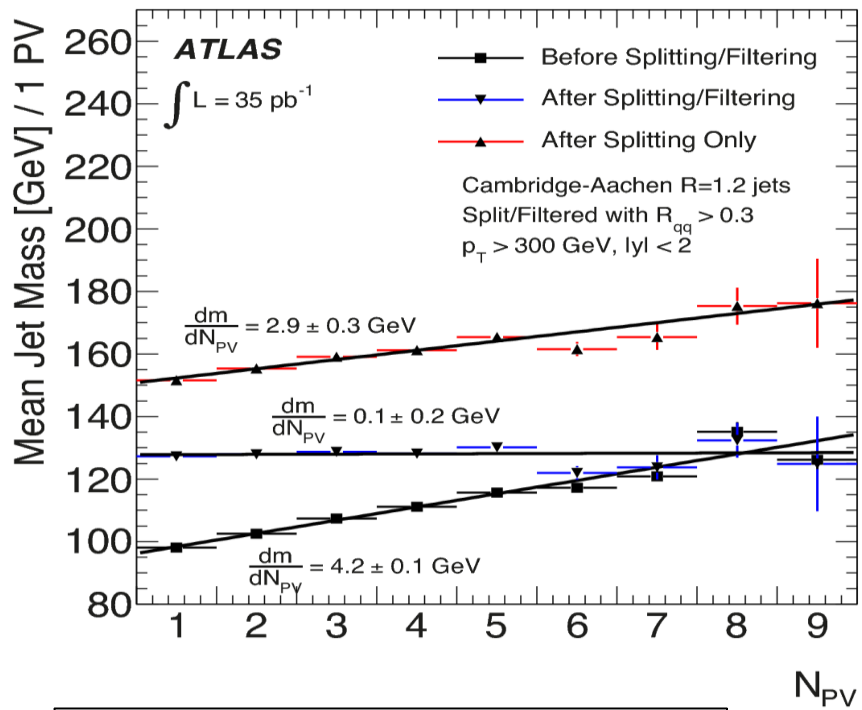
ATLAS-CONF-2012-044

arXiv:1203.4606

• Data-driven "**complementary cone**" corrections for individual observables (arXiv:1101.3002)

• Jet grooming by "**Splitting and Filtering**" (Phys. Rev. Lett. 100, 242001 (2008))





• Closure : Agreement with single-vertex events.

• Largely eliminates dependence of jet mass on N_{PV}

Published Results with 2010 Data

- Inclusive jet and dijet production cross-sections
  - **arXiv:1112.6297**
- B-jet and bbbar-dijet production cross sections
  - **Eur. Phys. J. C71 (2011) 1846**
- Measurement of charm meson production
  - **Phys. Rev. D85 (2012) 052005**
- Properties of jets measured from tracks
  - **Phys. Rev. D84 (2011) 054001**
- Dijet azimuthal decorrelation
  - **Phys. Rev. Lett. 106 (2011) 172002**
- Study of jet shapes
  - **Phys. Rev. D83 (2011) 052003**
- Multi-jet production cross section
  - **Eur. Phys. J. C71 (2011) 1763**

Conclusions

- Presented measurements of
  - Jet production cross-section
  - Jet substructure
- New kinematic reaches explored in 2011 data
  - Challenging running conditions, high pile-up
- 2010 data was used for first measurement of many substructure observables
  - Test of QCD
  - Useful for boosted particle searches in 2011 and 2012 data

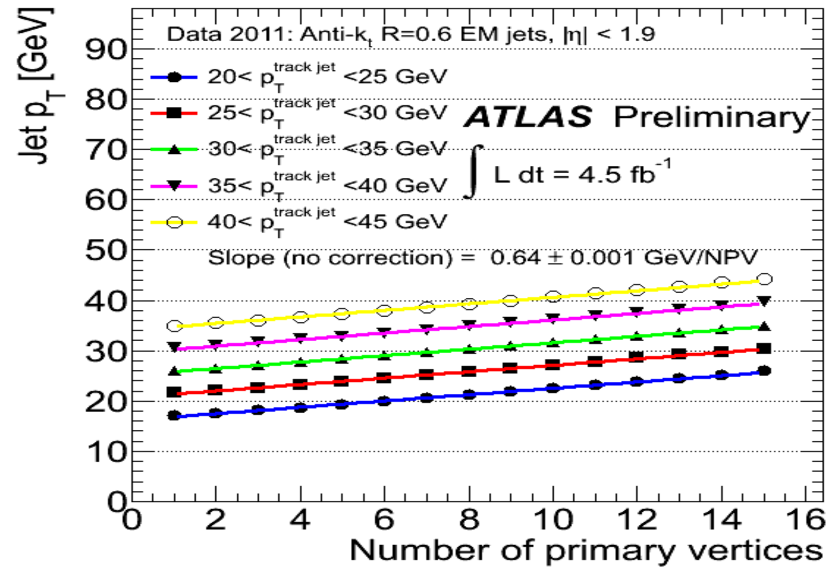
Additional Material

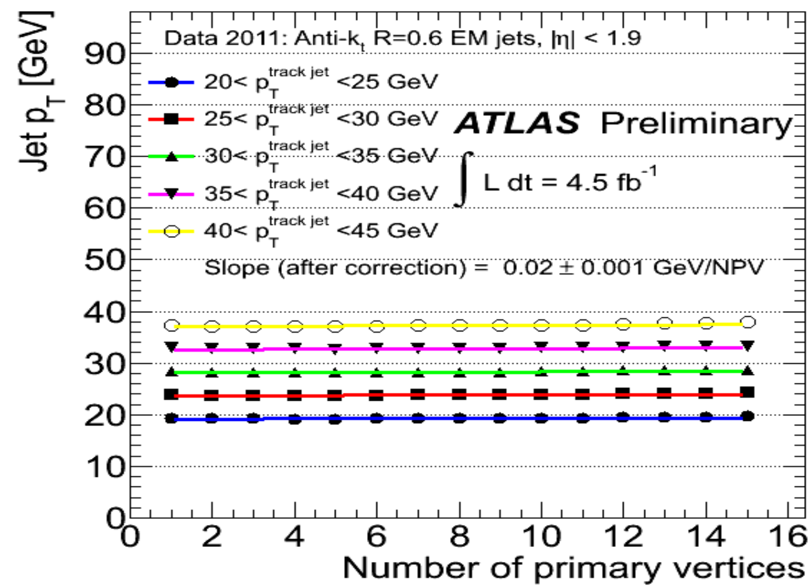
Jets in the Presence of Pile-up (I)

- **In-time pile-up**: multiple interactions in same bunch crossing
- **Out-of-time pile-up**: interactions in near-by bunch crossings
- Jet energy corrected with Monte Carlo based offset correction
    - Function of η, < μ >, N_{PV}

Out-of-time pile-up

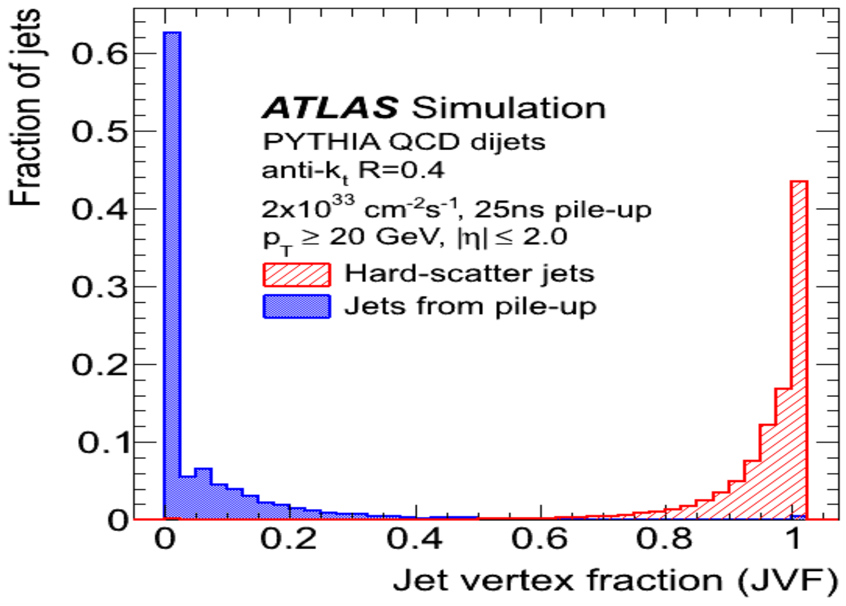
- **In-time pile-up**

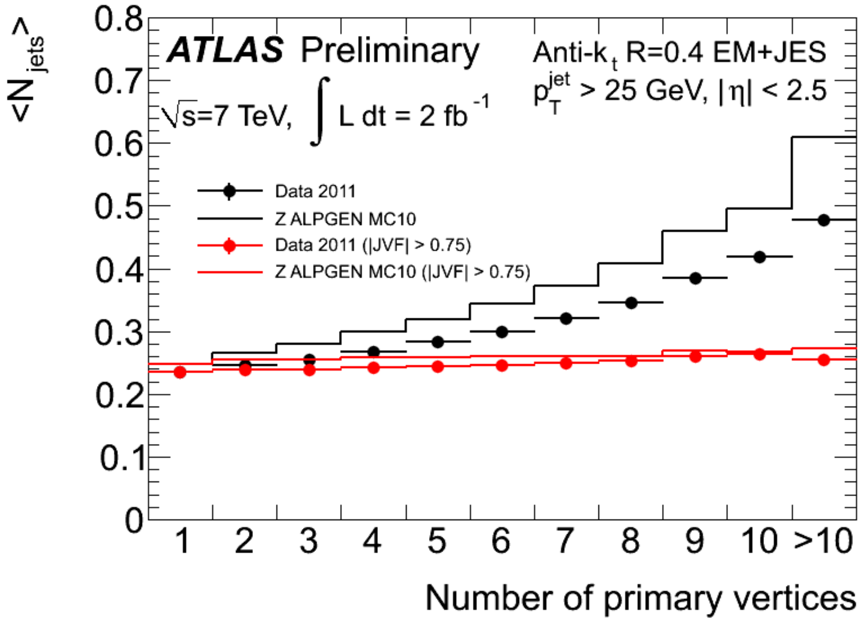




Jets in the Presence of Pile-up (II)

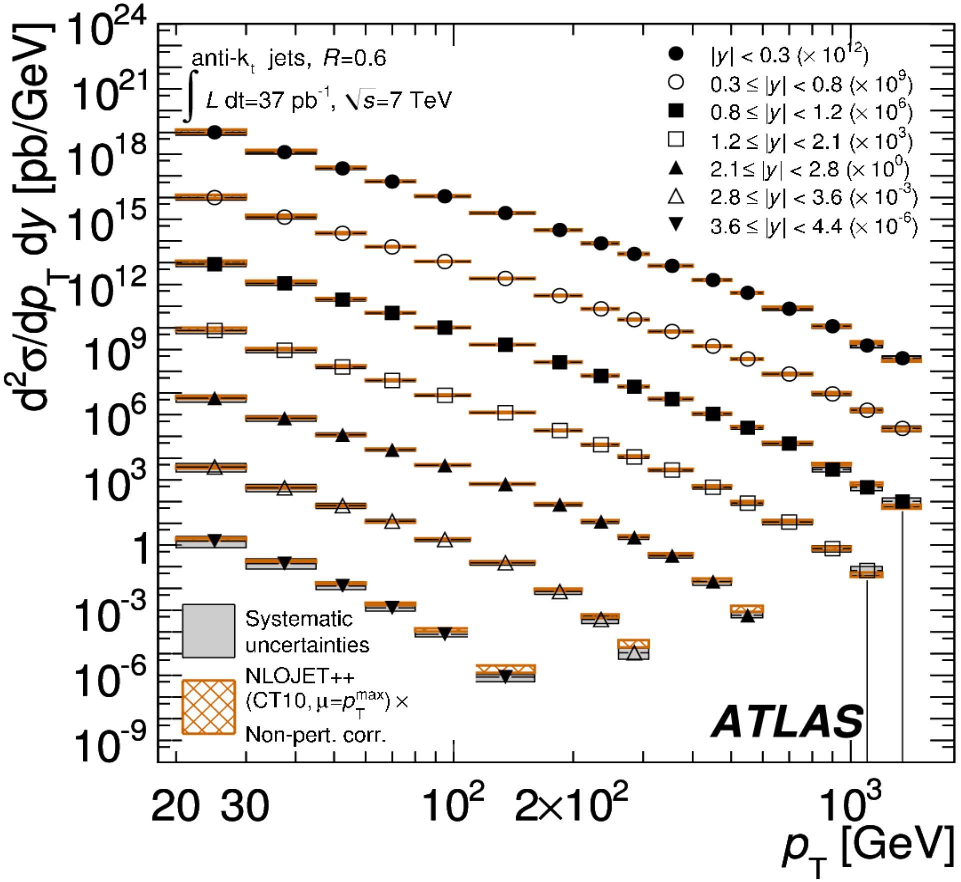
- **Jet Vertex Fraction**
  - Measure of energy fraction in jet from hard interaction





Inclusive Jet Production Cross-section

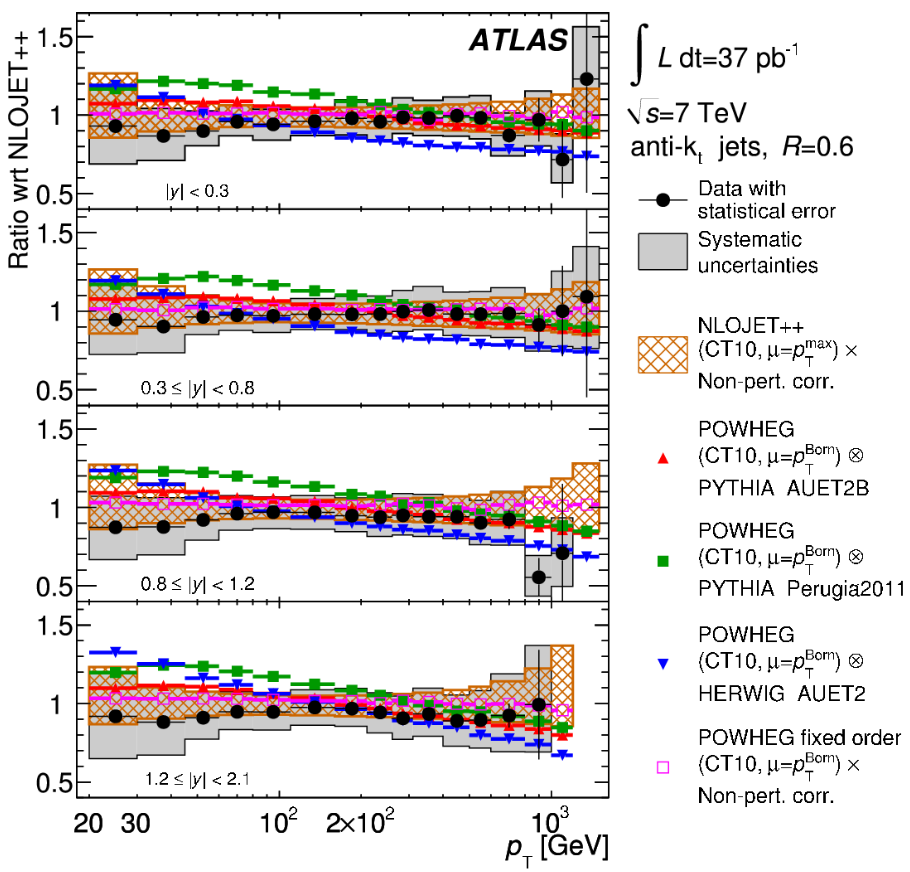
- 2010 data: $\mathscr{L}$ = 37 pb-1
- Cross-section binned in jet rapidity y
- Probe of NLO pQCD and PDFs
- Event selection:
    - >=1 primary vertex
    - event quality cuts
    - At least one jet with **P_T>20 GeV**
    - **|y|<4.4**
- Uncertainties:
    - JES, calorimeter resolution, reconstruction efficiency, pile-up



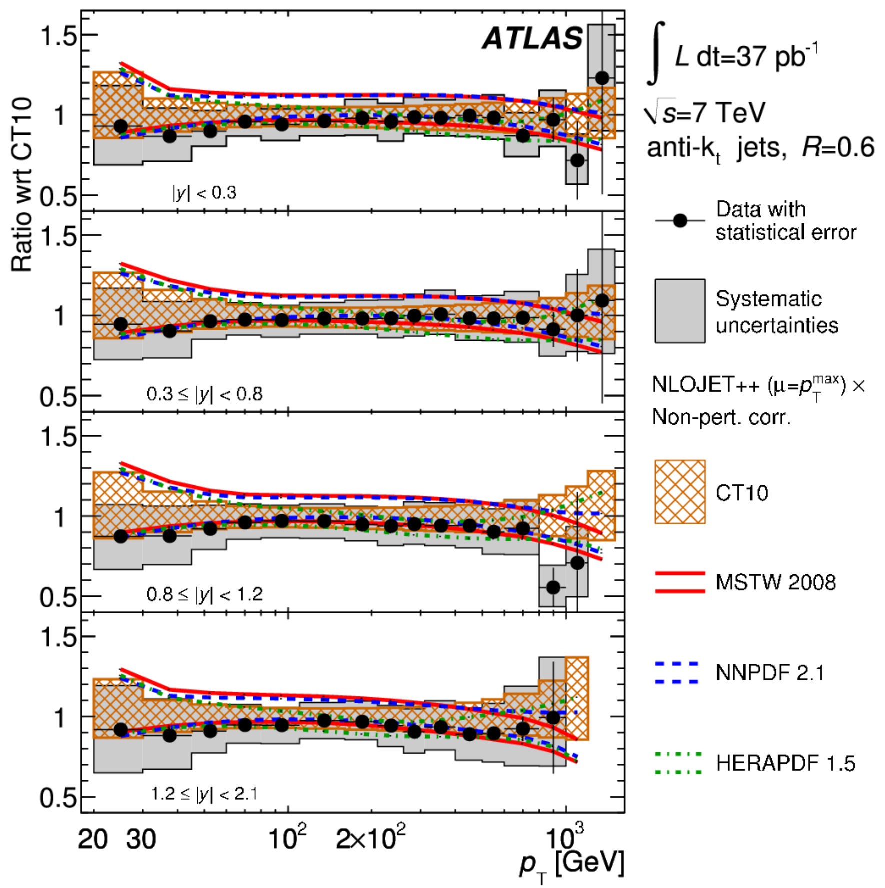
Kinematic Reach: 20 GeV < P_T < 1.5 TeV

Inclusive Jet Production Cross-section

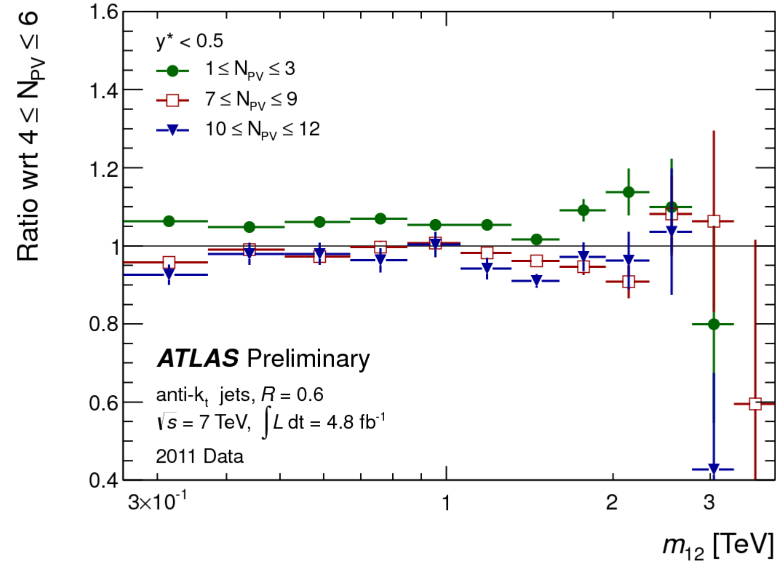
Ratio wrt. NLOJET++



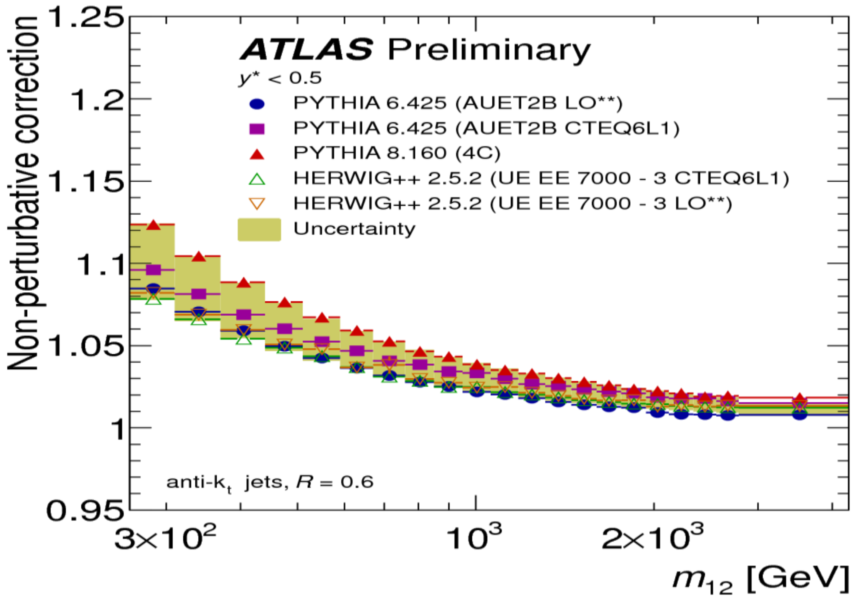
Ratio wrt. CT10



Dijet Mass Cross-section



- Variation of cross-section with level of pile-up within ~7%



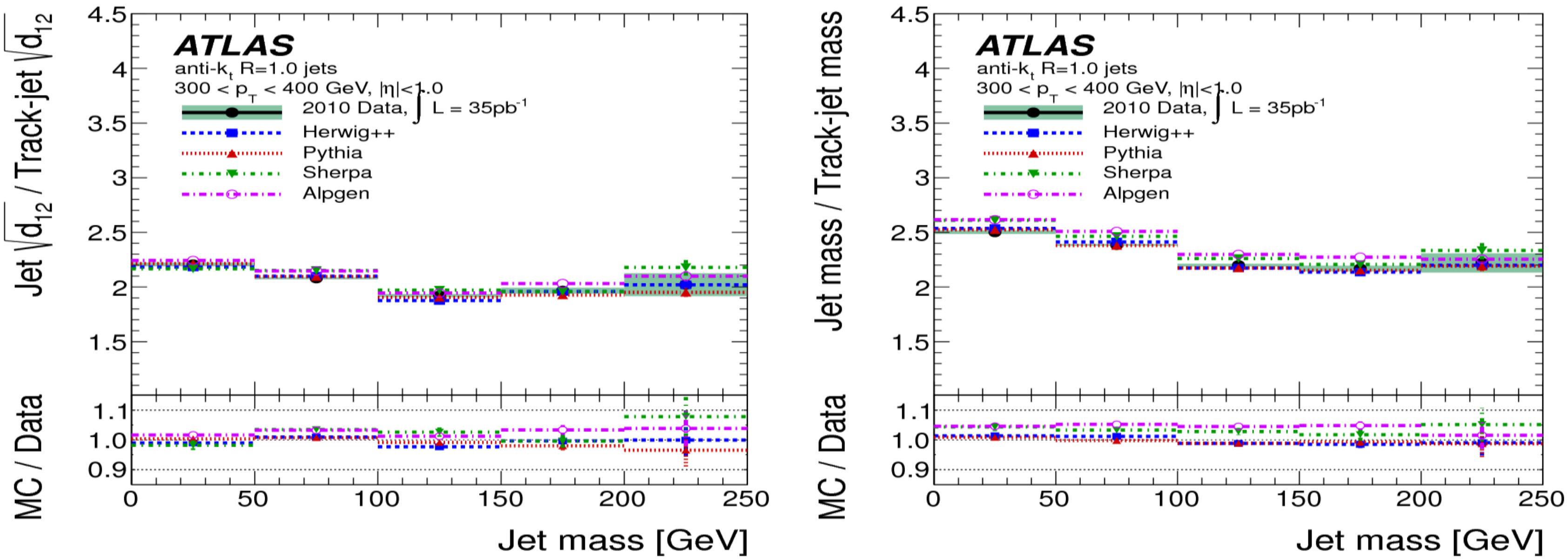
- Correction factor for non-perturbative effects of hadronisation and UE modeling
- Close to unity for high dijet mass

Jet Substructure Definitions

- **k_t splitting scale**
  - Recluster constituents with k_t algorithm
  - $\sqrt{d_{12}} = \min(P_{T,j1}, P_{T,j2}) \times \delta R_{j1,j2}$
- **N-subjettiness**
  - Recluster constituents with k_t algorithm requiring N subjets
  - $\tau_N = (1/d_0)\ \Sigma_k P_{T,k} \times \min(\delta R_{1,k}, \delta R_{2,k}, \ldots, \delta R_{N,k})$
  - $d0 = \Sigma_k P_{T,k} R$
- **Mass**
  - Invariant mass of jet constituents
  - $M^2 = \Sigma_i (E_i)^2 - \Sigma_i (p_i)^2$
- **Width**
  - $W = (\Sigma_i P_{T,i} R_i)/(\Sigma_i P_{T,i})$
  - $P_{T,i} = P_T$ of i^{th} constituent relative to beam axis
- **Angularity**
  - $\tau_a = (1/M) \times \Sigma_i E_i \sin^a\theta i\ (1-\cos\theta_i)^{1-a}$
  - θ_i=angle of i^{th} constituent relative to jet axis
- **Planar Flow**
  - $I_E^{kl} = (1/M) \times \Sigma_i E_i (P_{i,k}/E_i)(P_{i,l}/E_i)$
  - $Pf = 4 \times \det(I_E)/Tr(I_E)^2$
  - $P_{i,k} = k^{th}$ component of constituent transverse momentum relative to jet axis
- **Eccentricity**
  - $\mathcal{E} = 1 - \nu_{min}/\nu_{max}$
  - $\nu_{min}(\nu_{max})$ = minimum (maximum) energy-weighted variance of constituent positions along principal axes

Jet Substructure

- Systematic uncertainties on each observable
  - Constrained with track jets
  - Combined with systematic uncertainty on track jet



More Jet Substructure

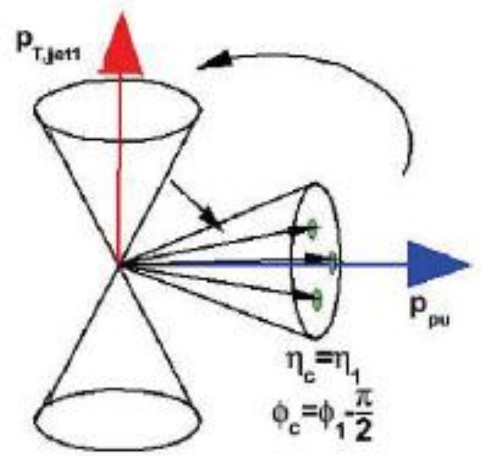
- Breakdown of systematic uncertainties on highest populated bin of each observable

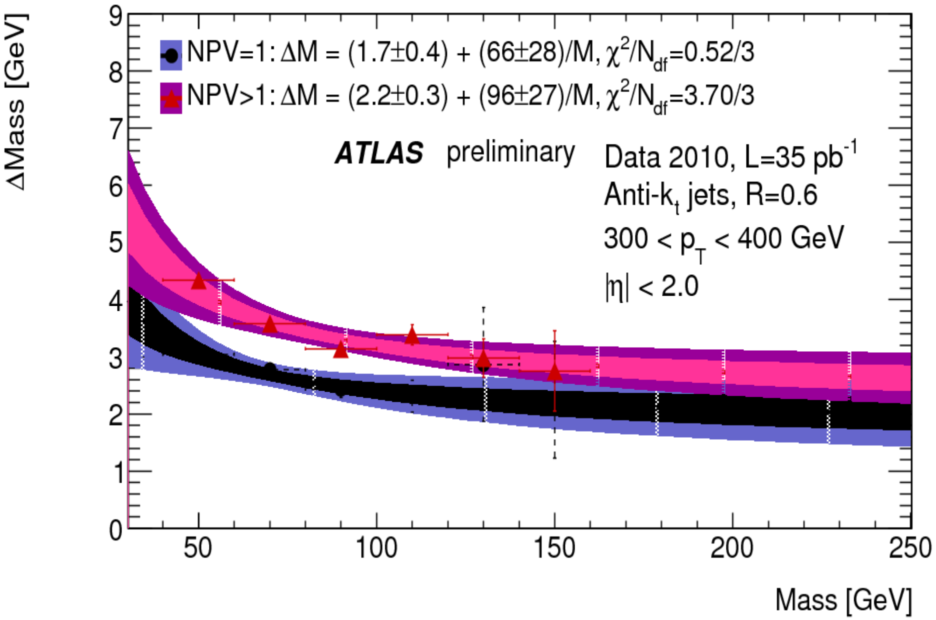
Observable	Monte Carlo			Detector effects					Pileup corrections		
	PER	H++	RW	η_{pos}	ϕ_{pos}	CES^+	CES^-	Dead M.	$Fit_{+1\sigma}$	$Fit_{-1\sigma}$	Scale
$Anti-k_t$ R = **0.6 : % contributions**											
Mass	2.3	**15.0**	-1.3	-1.4	-1.4	3.7	-4.5	-1.5	-0.6	-2.2	—
Width	**10.6**	-0.4	4.7	4.7	4.7	**5.8**	4.7	4.8	4.5	**5.0**	—
Eccentricity	0.6	-4.4	-0.9	-1.0	-0.9	0.6	-3.6	-1.5	-1.0	-0.4	—
Angularity	-2.4	**8.7**	-2.5	-2.7	-2.4	-2.7	0.5	-1.5	—	—	—
$Anti-k_t$ R = **1.0 : % contributions**											
Mass	-4.4	**-6.5**	-2.8	**-6.2**	**6.1**	1.7	**-6.0**	-4.2	-3.0	-2.7	-1.0
Width	**5.7**	**8.8**	3.4	3.2	3.4	**6.3**	0.2	3.5	3.2	3.7	3.9
Eccentricity	**7.8**	**-9.7**	1.1	2.3	2.4	-0.5	4.3	2.2	-2.2	4.2	-3.3
Planar flow	**-7.2**	-3.9	**6.2**	**5.7**	**5.9**	**6.1**	2.6	4.1	—	—	—

Pile-up Corrections for Jet Substructure

ATLAS-CONF-2012-044

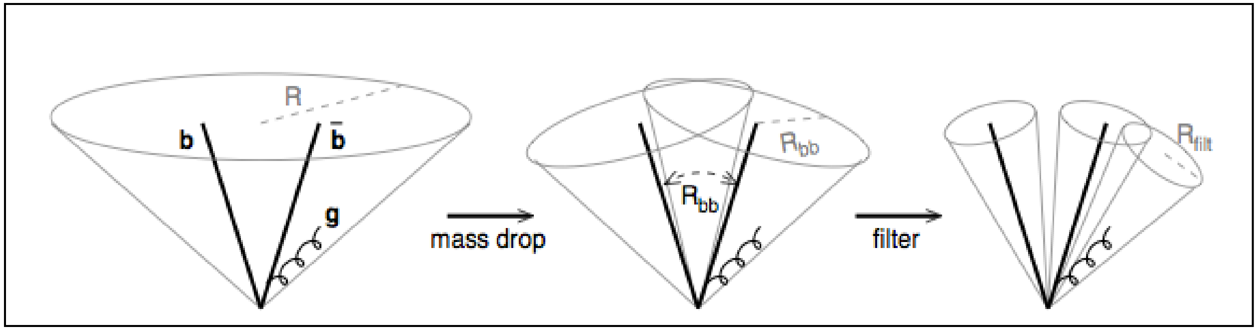
- Data-driven "**complementary cone**" corrections
  - Clusters in transverse cone in dijet events added to leading jet
  - Shift in jet observable calculated and parametrised as function of the observable
  - Binned in mass and P_T of jet
  - Corrections can be scaled according to jet area





arXiv:1203.4606

Jet Grooming



- Jets groomed by "**splitting and filtering**"
  - Preserve only hard, symmetric splittings inside the jet
  - Recluster constituents with R-parameter R_{filt} = 0.3 to find n new subjets
  - Redefine jet as sum of subjet four-momenta
- Aims to retain jet constituents associated with heavy particle decay
- Reduced sensitivity to underlying event and pile-up