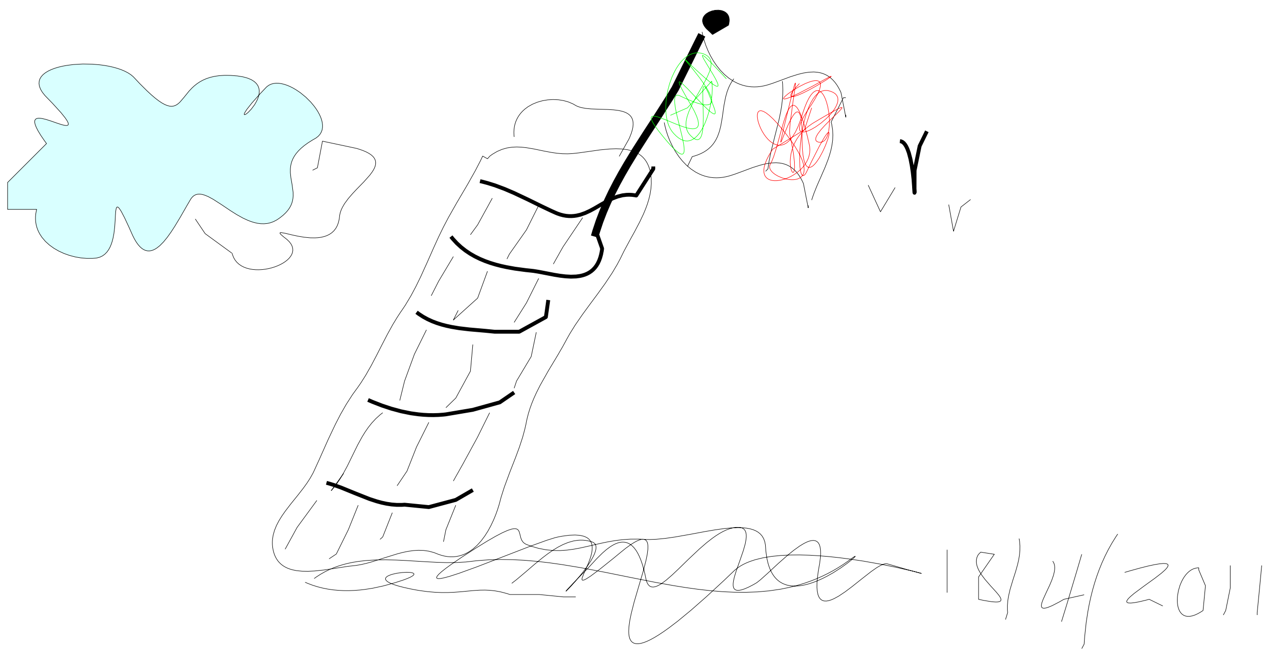
PisaJet2011
Jet Reconstruction and Spectroscopy at Hadron Colliders



Measurement of multi-jet cross sections in proton-proton collisions at 7 TeV center-of-mass energy

link

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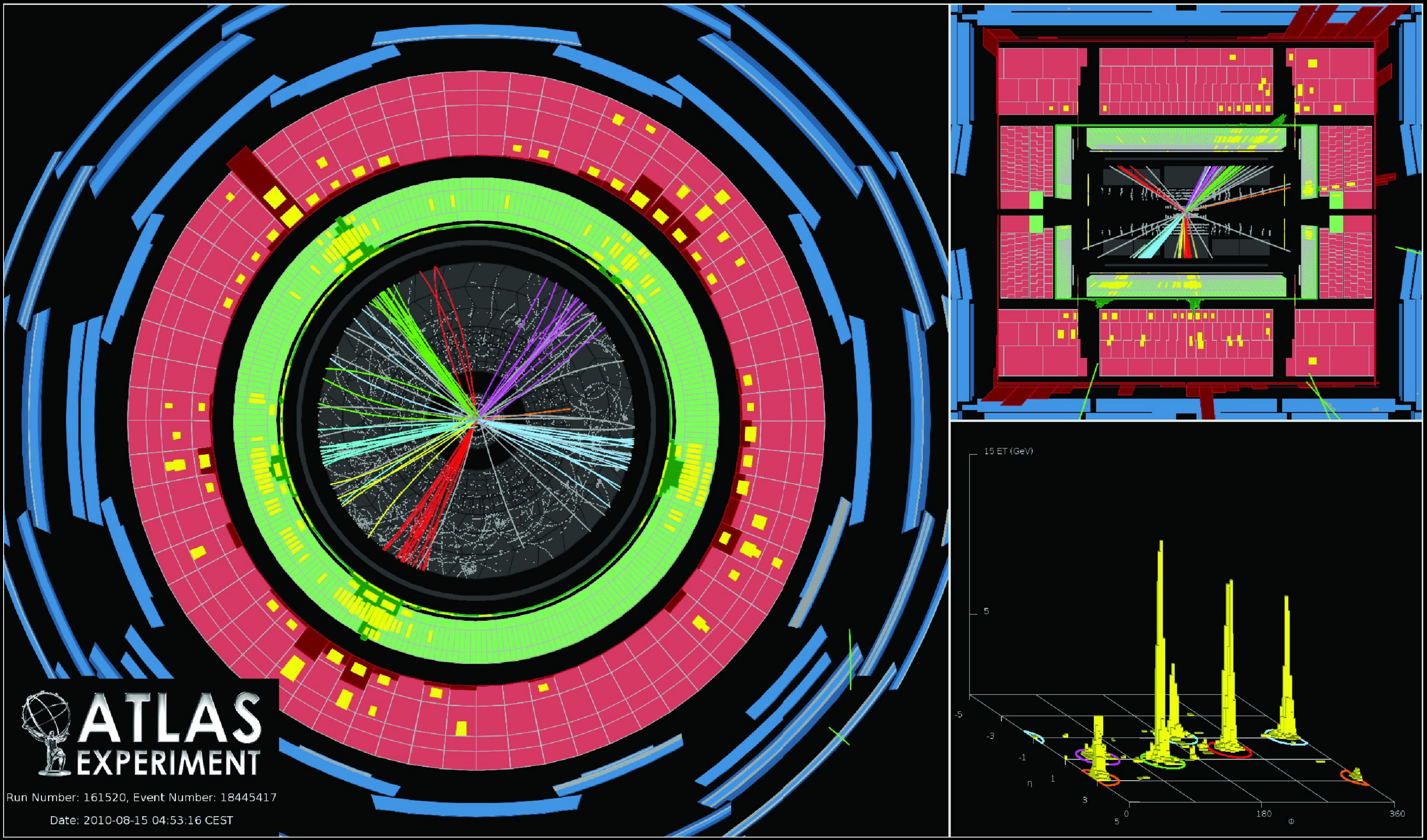
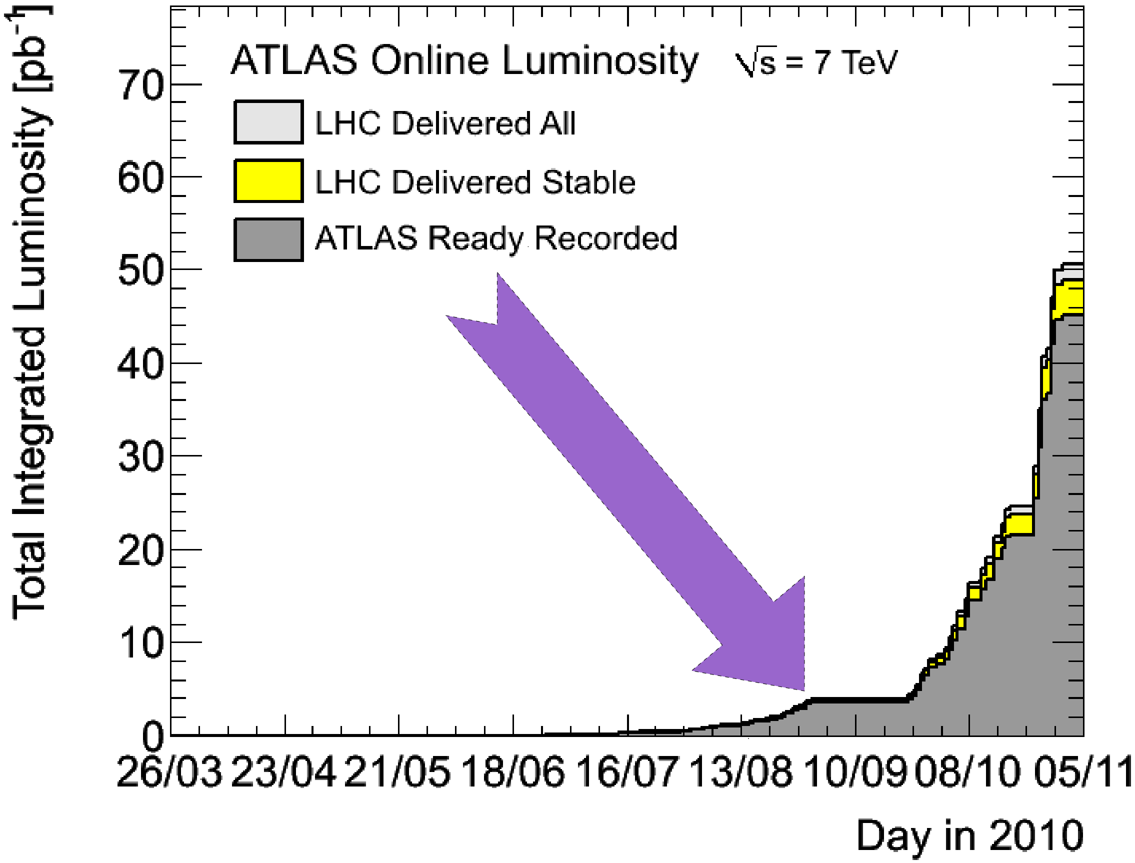


Event display of a **six-jet** event, reconstructed with the anti-k_t 0.4 algorithm, satisfying the multi-jet analysis requirements. The yellow towers represent the transverse energy deposited in the calorimeter projected on a grid of η and φ

Introduction



Multi-jet studies

- ☆ ATLAS detector
- ☆ LHC pp collisions at $\sqrt{s}$ = 7 TeV
- ☆ data sample collected between April 10 - August 30 of 2010
- ☆ total integrated luminosity of 2.43 pb^{-1}
- ☆ ~0.5M events with at least 2 jets in the final state after selection cuts

Two primary motivations

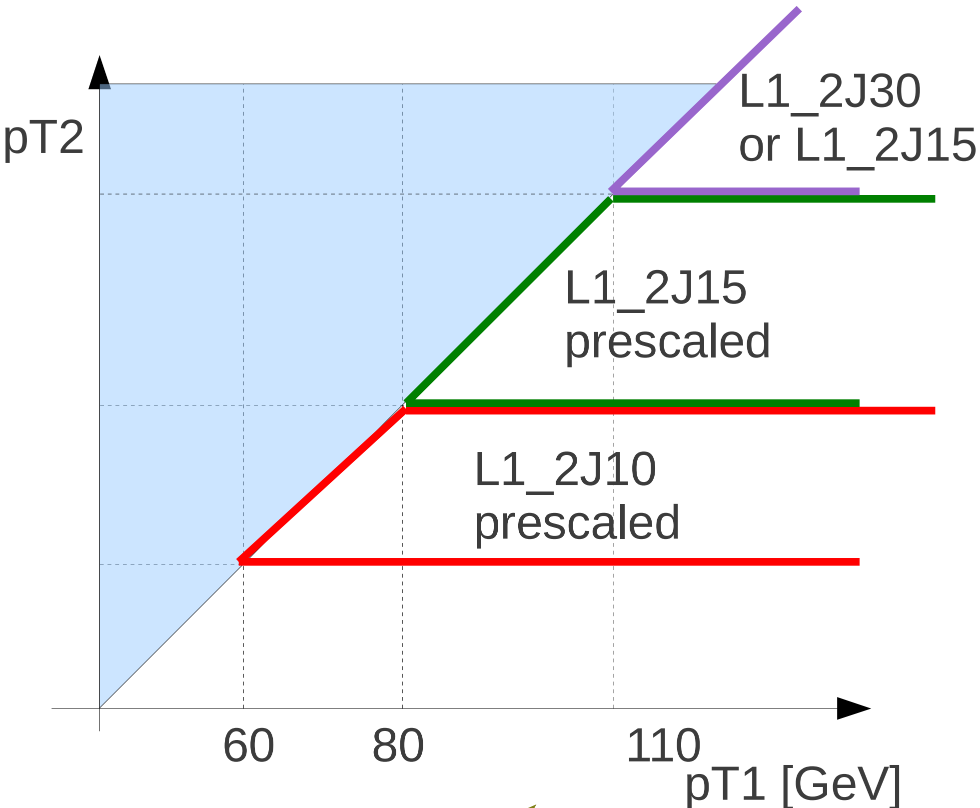
- ☆ evaluate how robust leading-order (LO) QCD calculations are in representing the high jet multiplicity events
- ☆ test next-to-leading-order (NLO) perturbative QCD (pQCD) calculations

Also, important for α_s fit studies, as background for many physics channels and new searches, ...

SALVACHUA Belen's talk

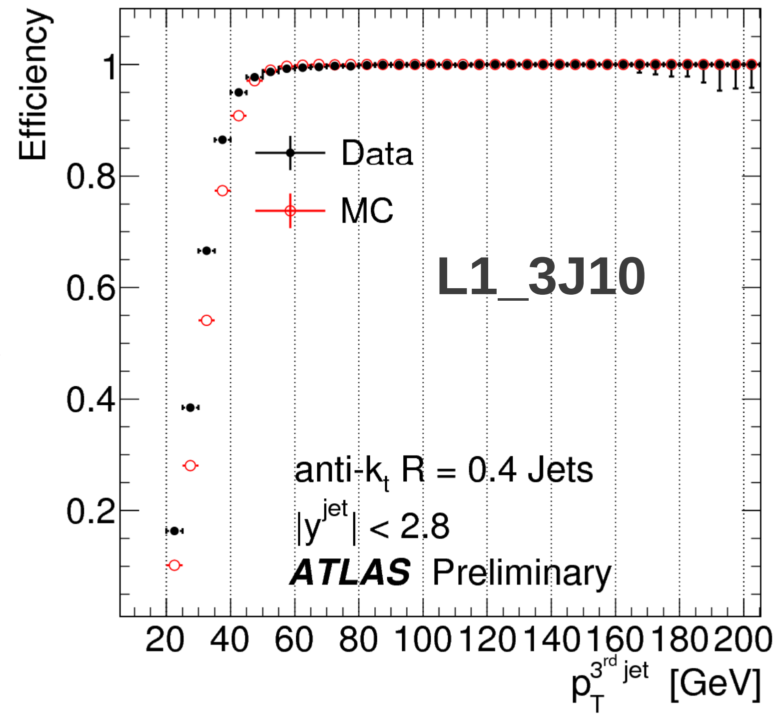
- ► For the **LO comparisons**, events with up to 6 jets in the final state are studied
- ► For the **NLO perturbative QCD study**, the focus is on 3-jet events and comparisons to 2-jet events

Trigger Strategy

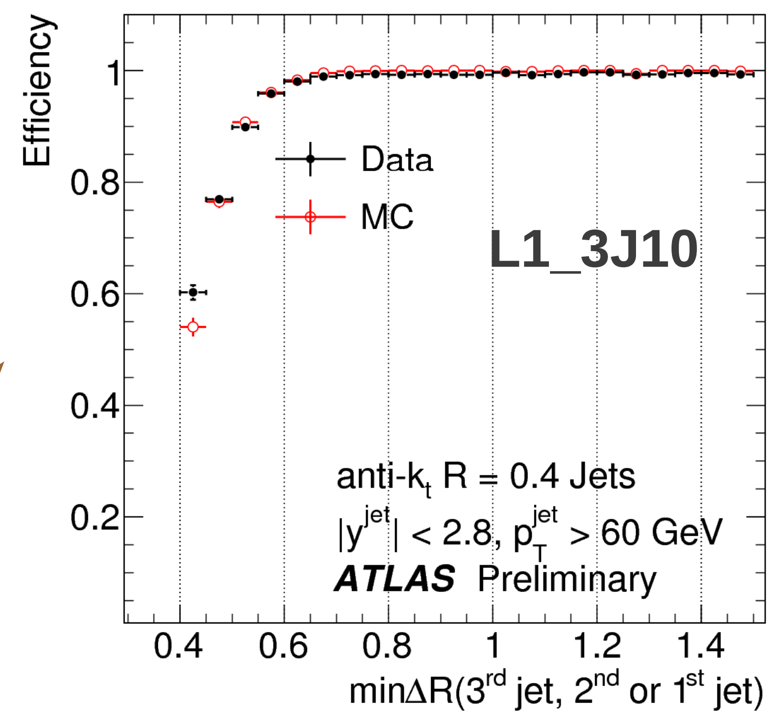


Exclusive combination of di-jet triggers according to the 2nd jet pT

Trigger turn-on efficiency Vs 3rd jet pT



Topological inefficiency of the 3-jet trigger observed for anti-k_t 0.4 jets due to Close-by jet activity



Analysis Skeleton

Vertex Reconstruction

- At least one Primary Vertex (PV) with at least 5 associated tracks
- No cut on the PV *z*-position is applied
- Event vertex from which jets are considered to originate, has the largest ΣpT^{tracks} of the compatible tracks

Jet Reconstruction

Gregory Soyez's talk

- Topological calorimeter clusters evaluated at the EM scale as inputs to the jet algorithm
- Anti-k_t R=0.4, 0.6 with full 4-momentum recombination used to reconstruct jets from clusters

Jet Energy Calibration

SCHOUTEN Doug's talk

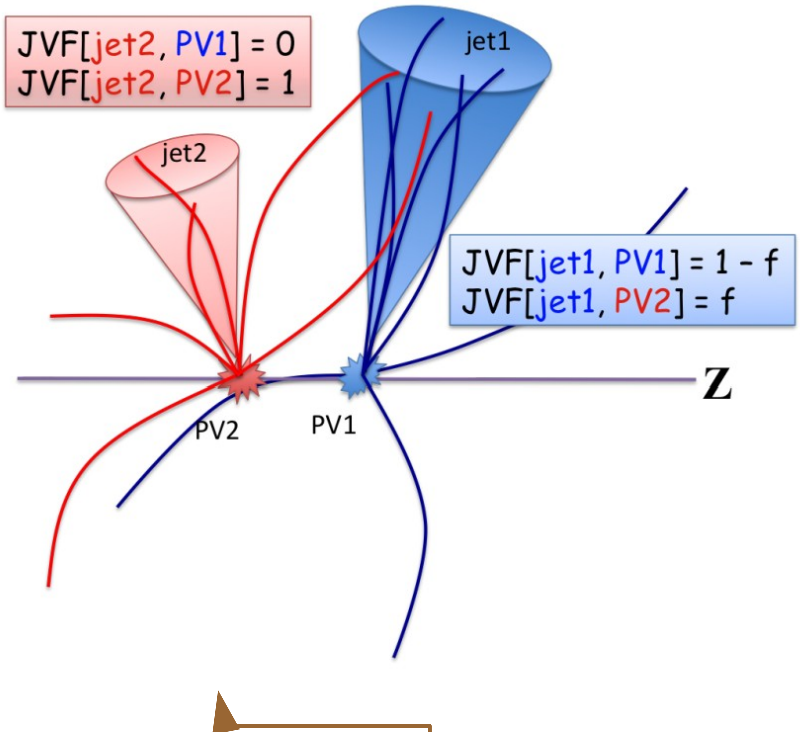
- A MC-based calibration scheme sets the jet energy to the true hadron level
- The JES calibration was also cross-checked on data

Peter Loch's talk

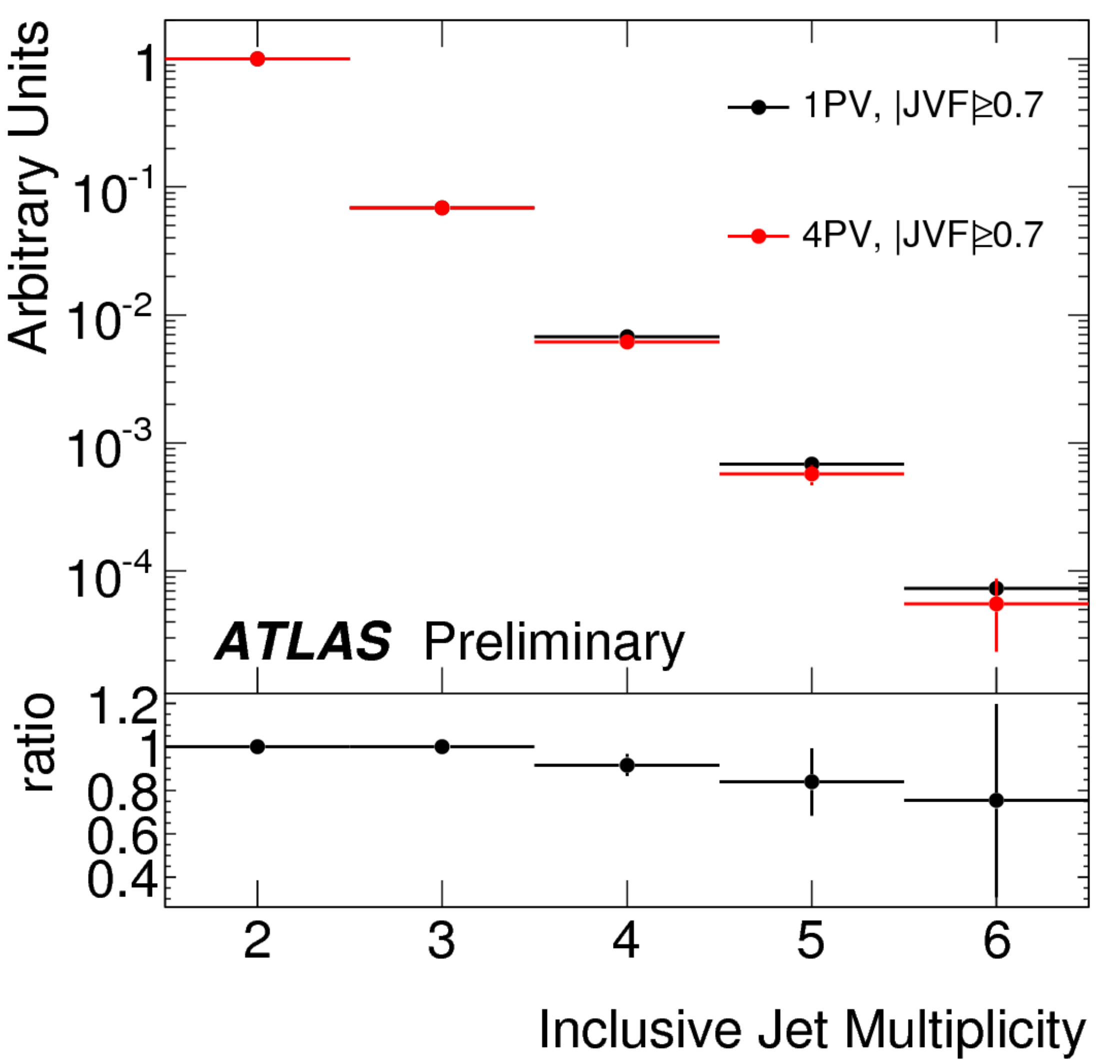
Jet Selection Criteria

- $|y|<2.8$, $pT > 60$ GeV/c and $pT^{lead}>80$ GeV/c
- Jet cleaning cuts (reject spurious jets, suppress beam & non-collision backgrounds)
- Jet accepted if >70% of the associated charged particle *pT* comes for the event vertex (Jet Vertex Fraction cut)

Impact and Treatment of Pile-Up

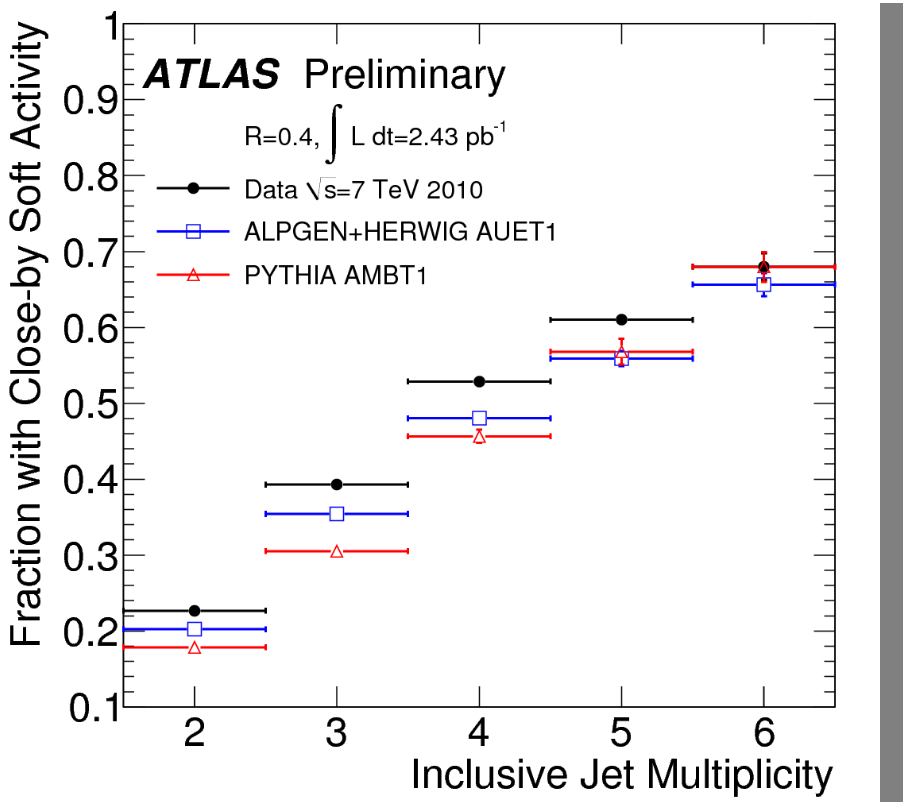


Inclusive jet multiplicity distribution for events containing 1 and 4 primary vertices after the JVF cut



- ~40% of the selected events have N ≥ 2 PVs
- The Jet Vertex Fraction discriminant helps to reject jets coming from secondary soft interactions

Systematics & Unfolding



Systematic Uncertainties

Jet energy scale!

Differences in light-quarks/gluon jet response in the calorimeter

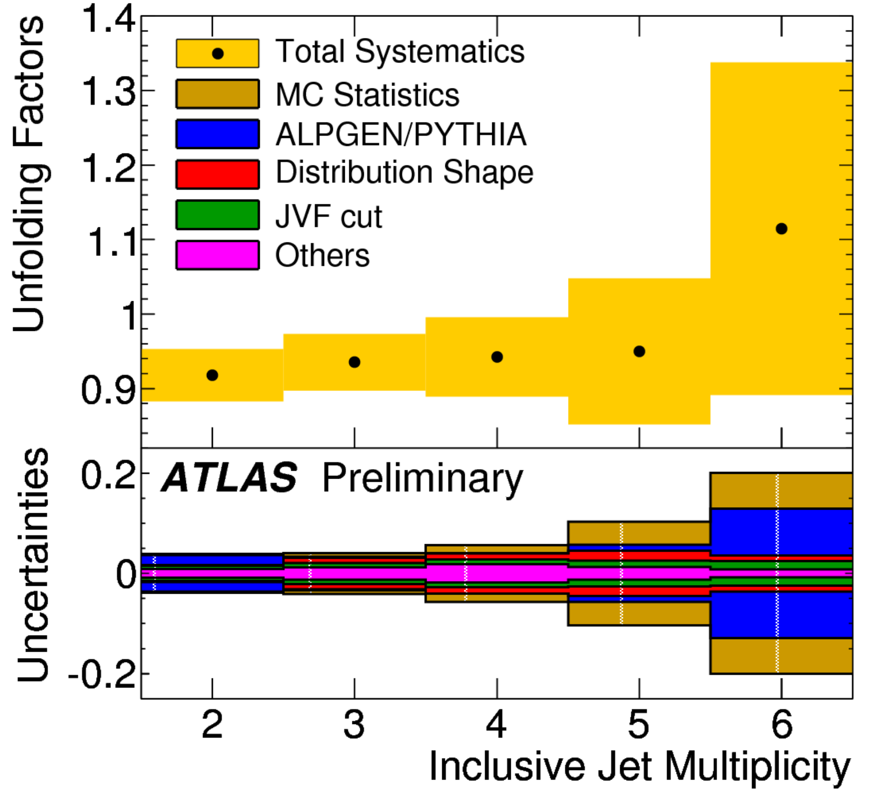
Close-by jet activity

Overlapping pp interactions and events with more than one interaction point

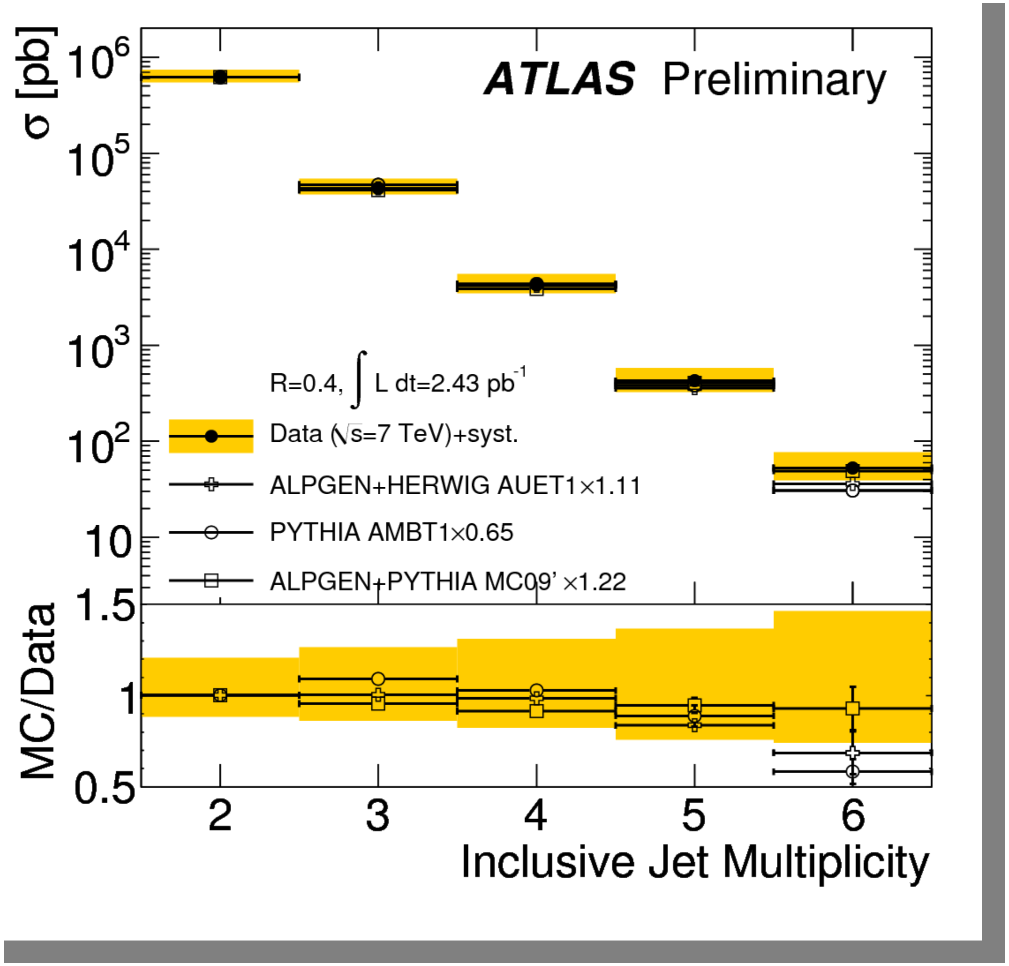
Luminosity calculation (cancels-out in ratios)

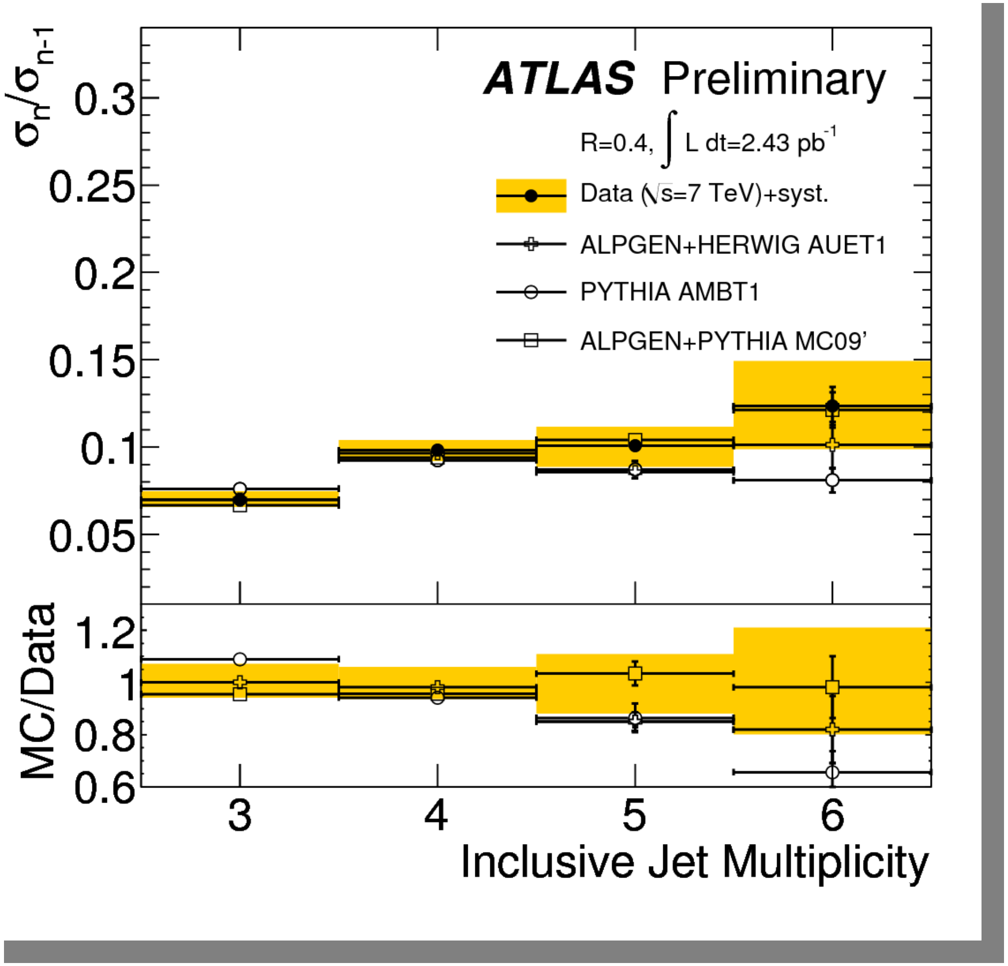
Unfolding of Detector Effects: Classic bin-by-bin correction

- Jet pT, η and φ resolution
- Variation of the input distribution shapes
- Impact of JVF on different observables
- Vertex distributions dependence on the trigger choice
- ALPGEN/PYTHIA differences in jet shapes and PS evolution



Inclusive Jet Multiplicity



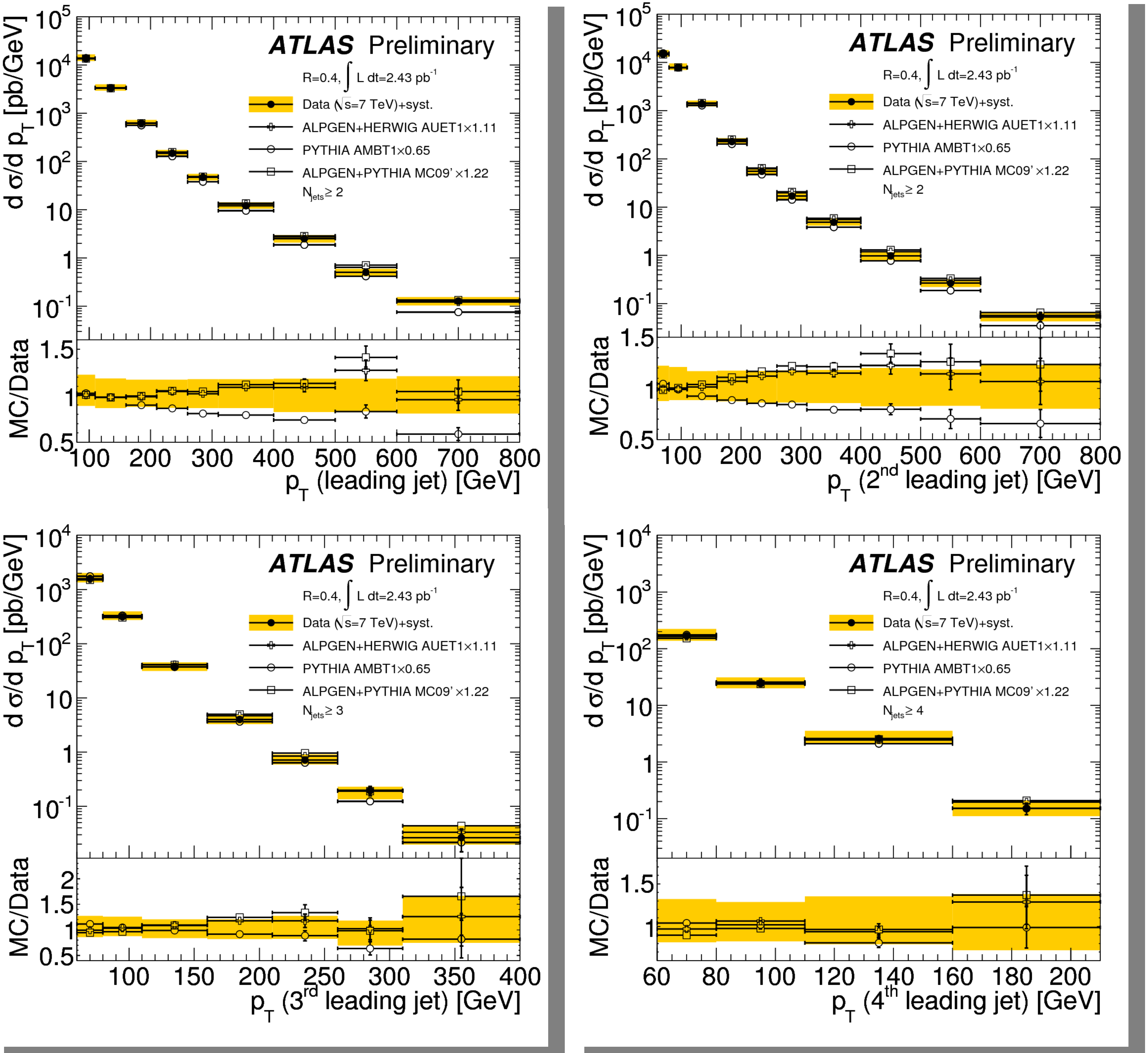


Measurement systematics go from 10-20% at low multiplicities to 30-40% at higher ones

3-to-2: Reduced systematic uncertainties ✔

◊ Good description of data by LO QCD 2→**2** ME theoretical models
◊ Better agreement between data and LO QCD 2→**6** ME MC generators ✔

Differential Cross-Section Vs Jet pT



Measurement uncertainty is ~10-20% across *pT* and increasing up to 30% for the pT^{4th}

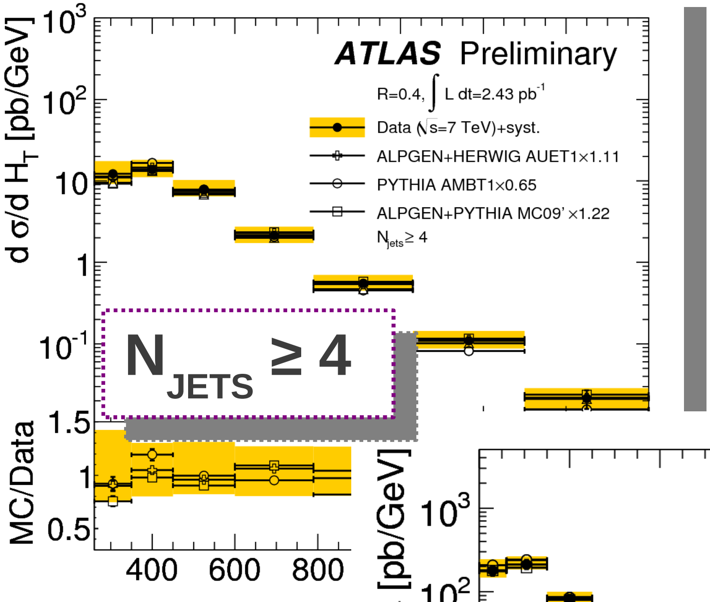
The JES uncertainty remains the dominant uncertainty in the measurement

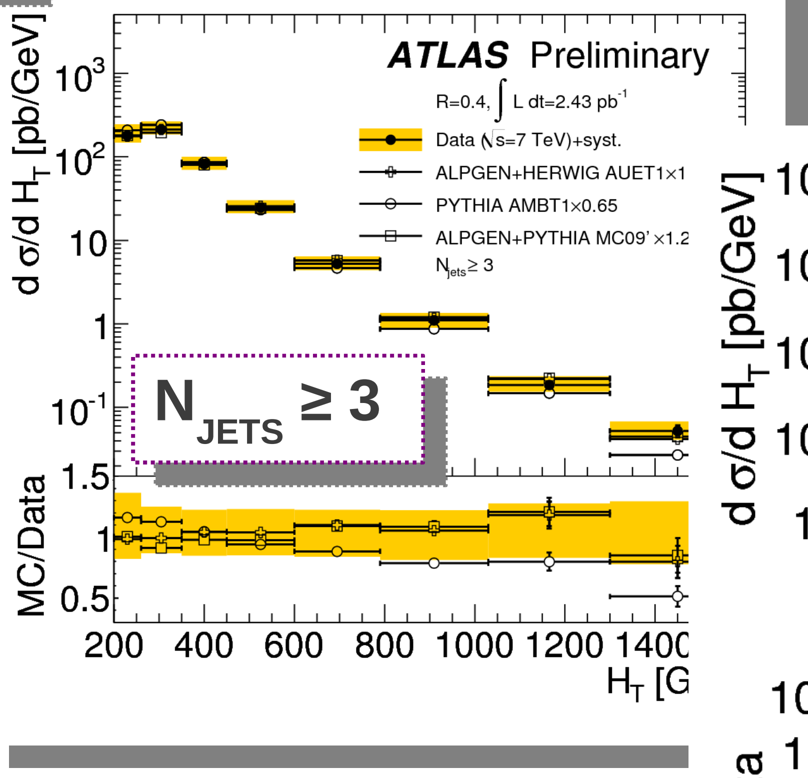
Good agreement between data and ALPGEN (all tunes) within the systematics ✔

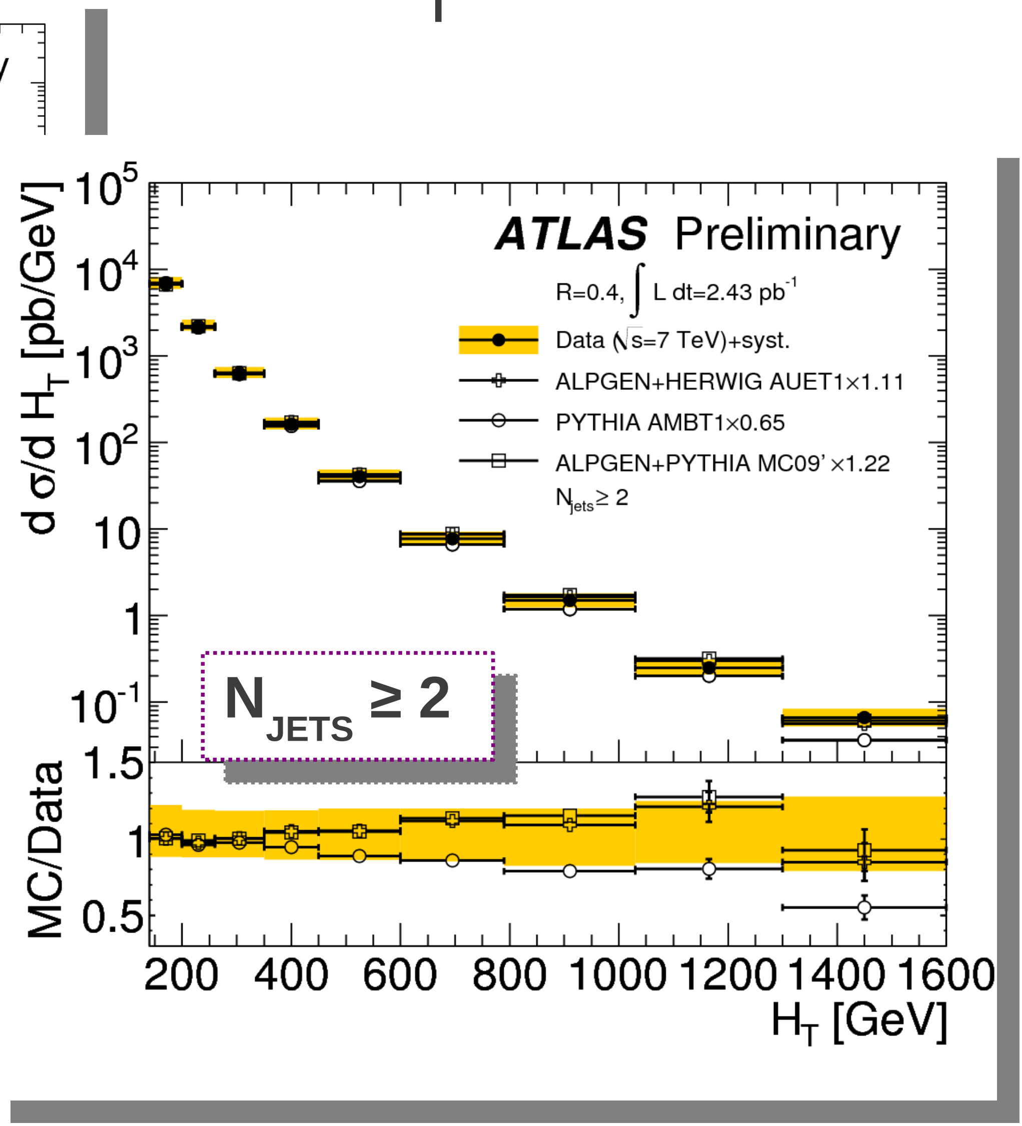
Steeper shape of PYTHIA than that of the data

PYTHIA undershoots the multi-jet cross-section

Differential Cross-Section Vs $H_T = \sum |pT^{jet}|$





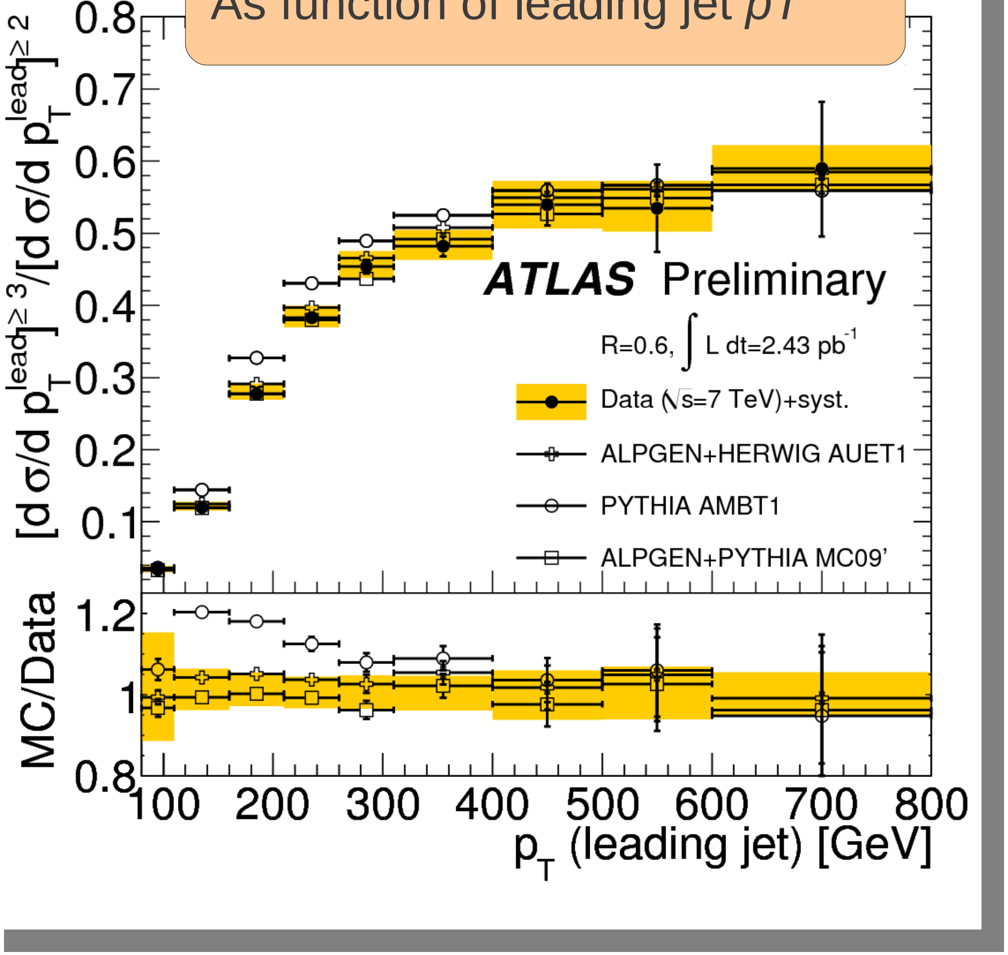


- ☑ Important to characterize the phase-space of QCD
- ☑ Interesting for searches with complex hadronic activity like $t\,\bar{t}$

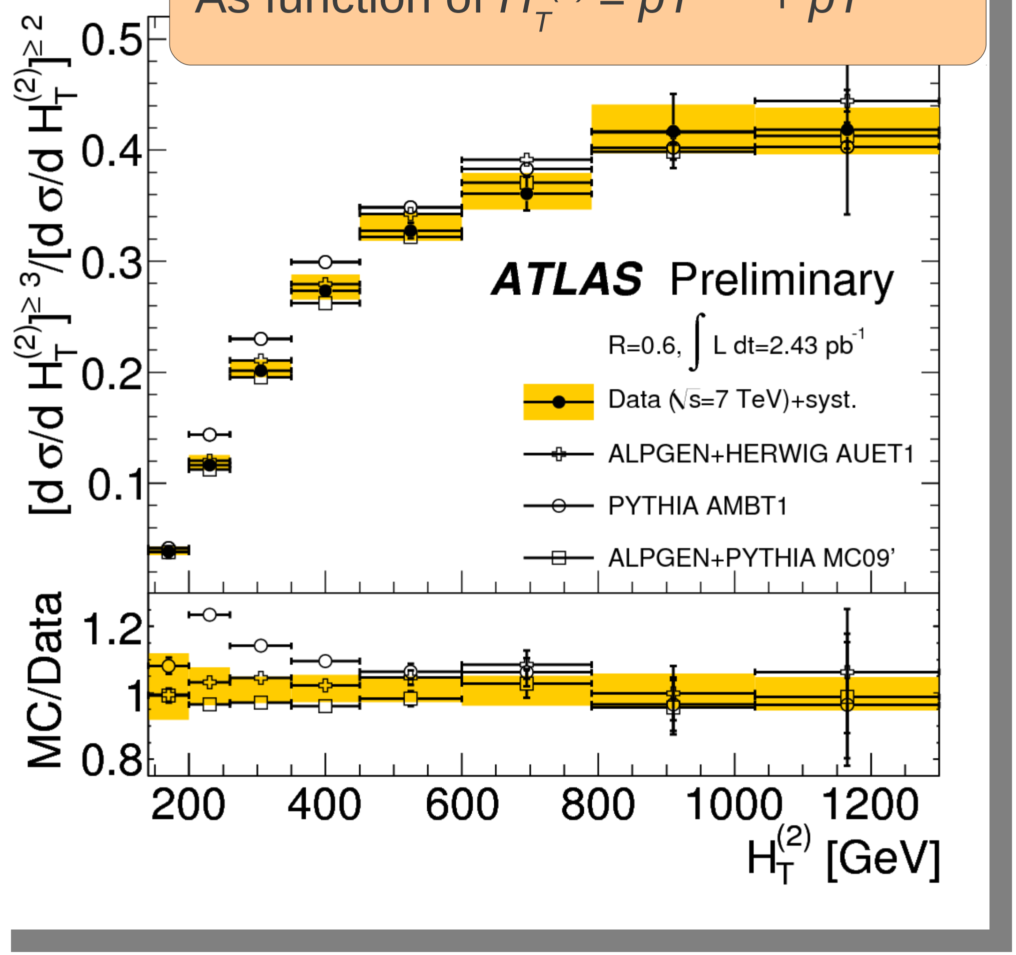
3-to-2 jet Differential Cross-section Ratios

LO pQCD Theory

As function of leading jet *pT*



As function of $H_T^{(2)} = pT^{lead} + pT^{sec}$

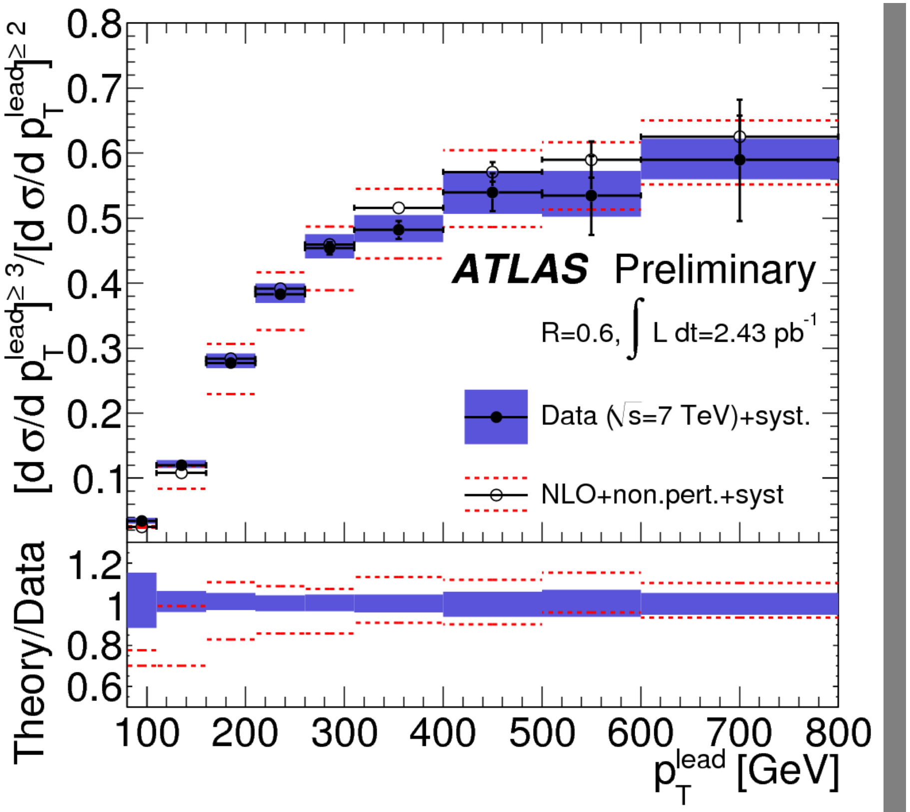


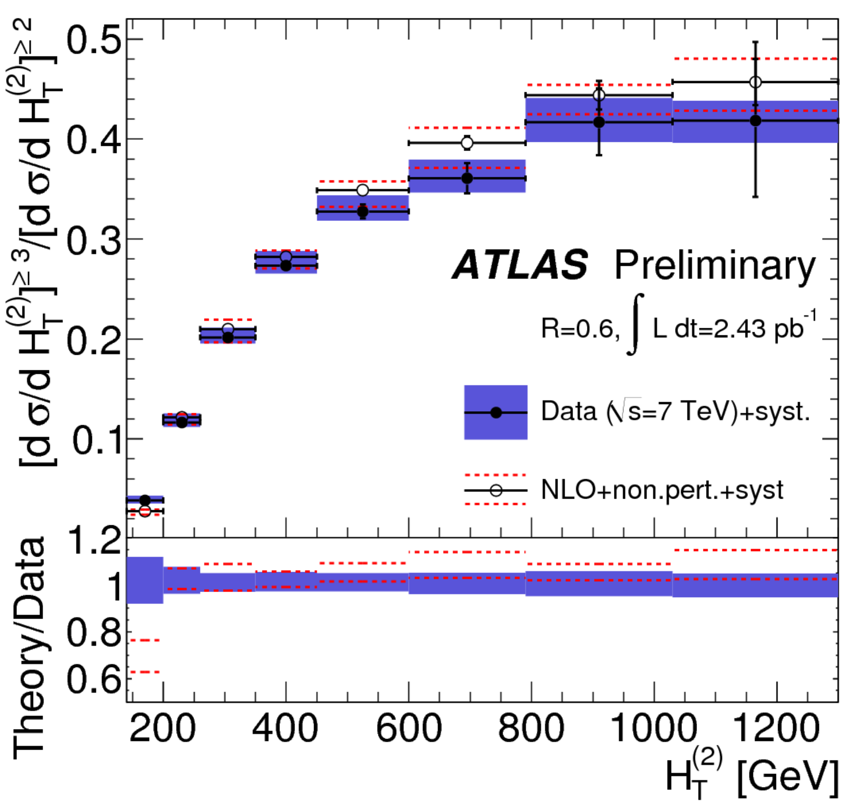
- The cross-section ratio vs pT^{lead} is of interest for tuning the Final State Radiation
- $H_T^{(2)}$ presents a stability under variations of the renormalization scale in the NLO prediction ✔

3-to-2 jet Differential Cross-section Ratios

NLO pQCD Theory

Experimental results compared to NLO pQCD calculations with the MSTW2008nlo PDF set





Anti-k_t 0.6 jets:

less sensitive to theoretical scale uncertainties

→ Data measurement uncertainties ~5%

→ Theory prediction uncertainties ~5%

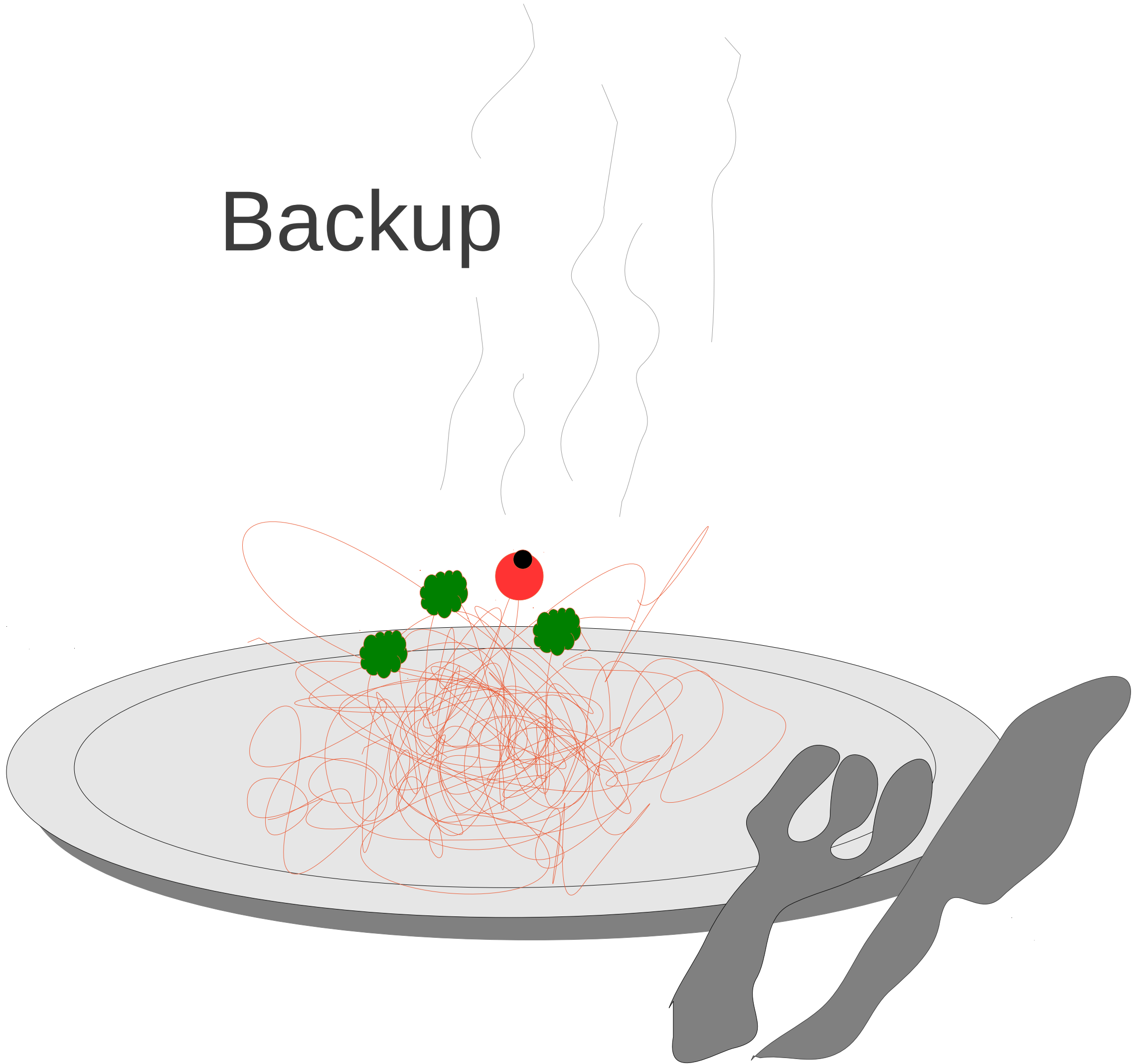
Reduced experimental uncertainties ✔

A possible good candidate for the α_s fit ✔

Synopsis

- Good characterization of the multi-jet topologies
  - with multiplicity up to **6 jets**
  - for jet ***pT***s up to **800 GeV/c**
  - for event H_T up to **1.6 TeV**
- Good description of data by LO ME+PS Monte-Carlo simulations
  - Better description of shapes and cross-sections estimations by ALPGEN+HERWIG/JIMMY bravo! than PYTHIA
- **3-to-2** cross-section ratios have reduced measurement uncertainties and comparable to the uncertainties of the **LO** and **NLO** theoretical predictions

Backup



MC Generators

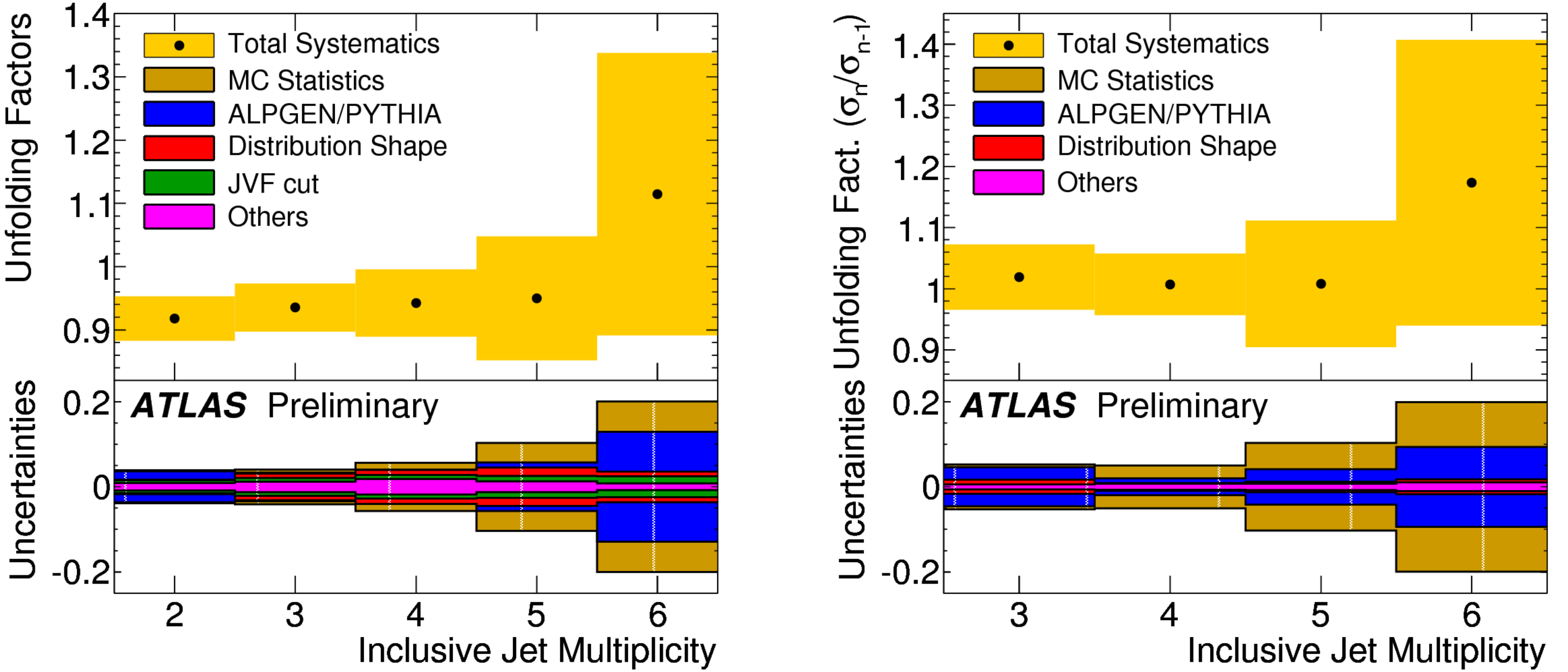
- PYTHIA
  - LO pQCD matrix element calculation for $2 \rightarrow 2$
  - Parton shower (PS)
  - Underlying event model (UE)
  - Multiple parton interactions (MPI)
  - Lund string model for hadronization and fragmentation (HAD)
  - AMBT1 tune with MRST2007 modified LO PDF
- ALPGEN
  - Generate MS with up to 6 partons in the final state
  - AUET1 tune with CTEQ6L1 PDF
  - Interfaced to PYTHIA for PS, HAD and UE
  - Interfaced to HERWIG for PS, HAD and UE and to JIMMY for MPI
  - Factorization and renormalization scale Q varies as $Q^2 = \sum_{partons} p_T^2$
- NLOJet++
  - NLO ME calculation program at parton level
  - Lacks PS, UE and HAD modeling and does not account for all non-perturbative QCD effects
  - Compare to particle-level claculations of other MC at LO and apply a multiplicative correctionto any observable O as: $C_{\text{non-pert.QCD}} = O_{\text{UE+HAD}}^{\text{particle}} / O_{\text{noUE+HAD}}^{\text{parton}}$

MC Tunes

Generator	pdf	tune	purpose
ALPGEN+HERWIG/JIMMY	CTEQ6L1 [10]	AUET1 [18]	central value*
ALPGEN+HERWIG/JIMMY	CTEQ6L1 [10]	MC09 [17]	UE studies*
ALPGEN+PYTHIA	CTEQ6L1 [10]	MC09′ [17]	PS studies
ALPGEN+PYTHIA	CTEQ6L1 [10]	D6	UE/PS studies
ALPGEN+PYTHIA	CTEQ6L1 [10]	Perugia 6 [20]	UE/PS studies
PYTHIA	MRST2007 LOmod [21, 22]	AMBT1 [19]	UE/PS studies*
PYTHIA	CTEQ5L [23]	Perugia2010 [20]	UE/PS studies

- Different Monte Carlo generators and tunes used for the LO multi-jet analysis
- The asterisk indicates the samples used to determine the uncertainties on the non-perturbative QCD corrections to the NLO calculation

Unfolding



Unfolding factors for

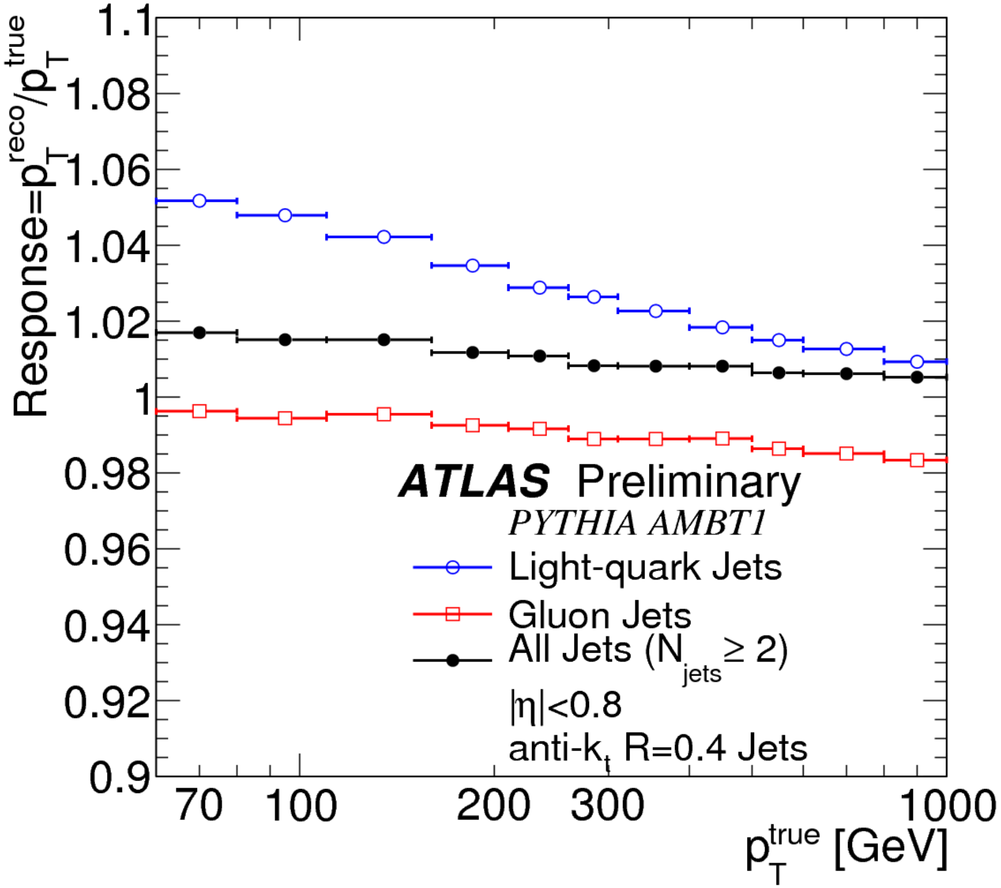
(a) the cross sections

(b) for the n to n-1 cross section ratios

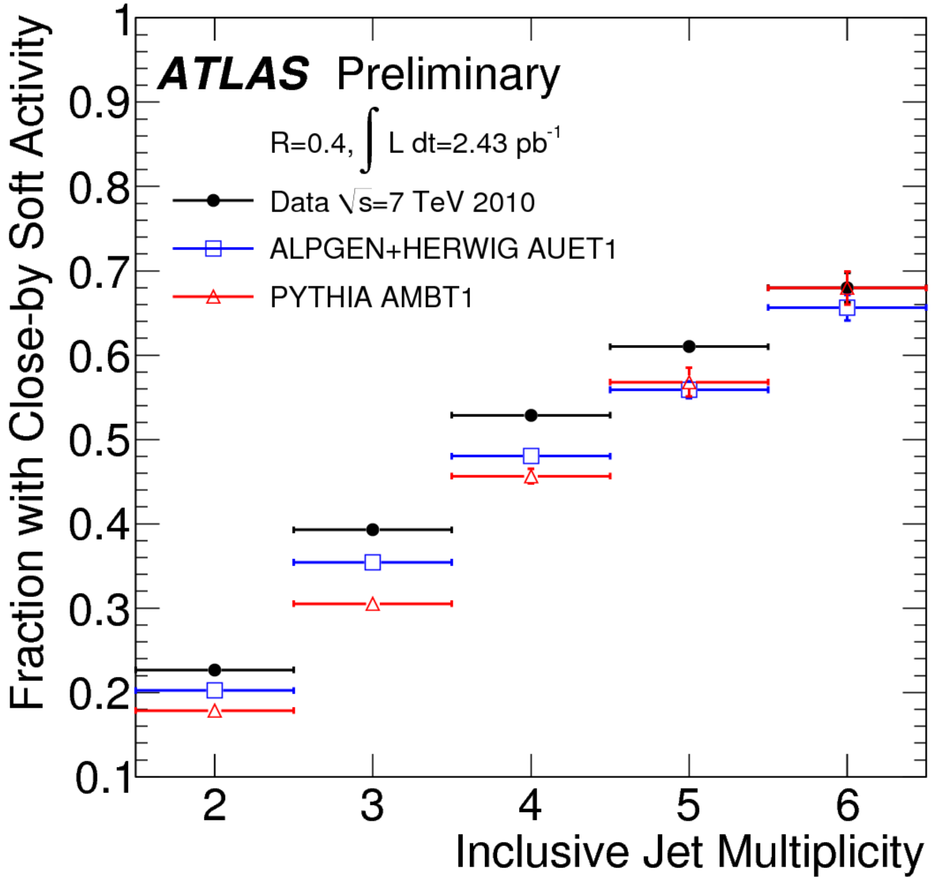
as a function of the inclusive jet multiplicity.

The unfolding factors for the ALPGEN+HERWIG/JIMMY AUET1 sample are shown with the systematic uncertainty as an orange band around the points.

Systematics

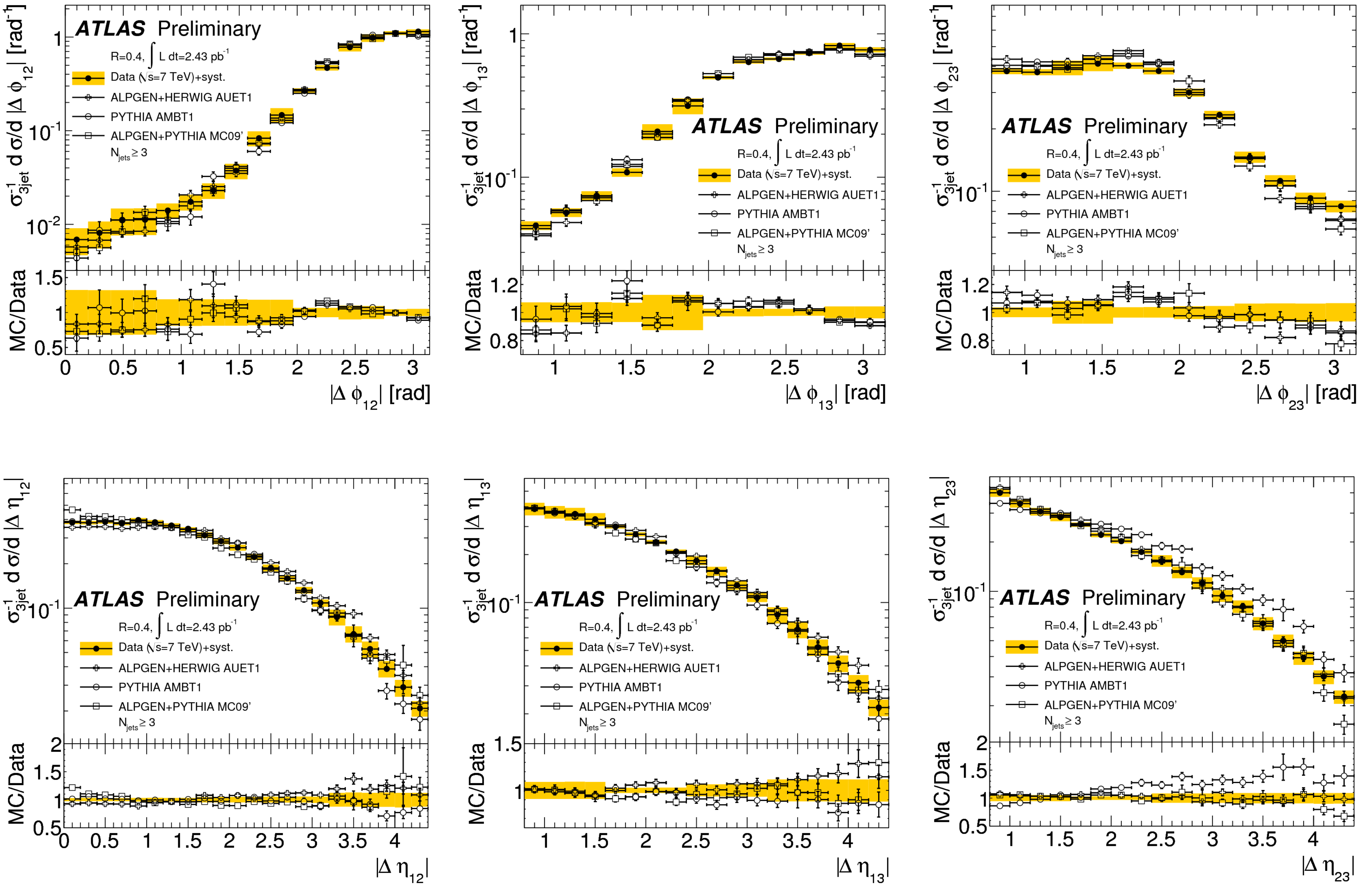


Jet response (mean reconstructed jet pT over true jet pT) as a function of the true pT for jets tagged as originating from a light quark or a gluon. The jet response in a sample with two jets of pT>=60 GeV. The anti-k_t R=0.4 algorithm is used.

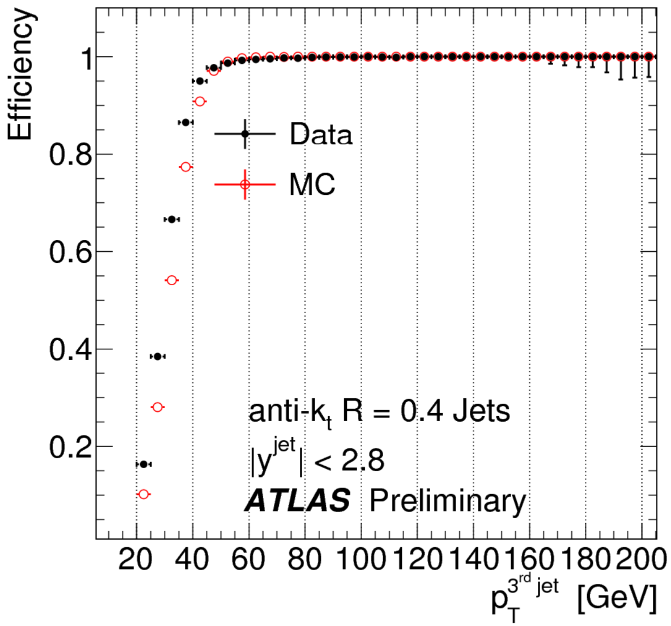


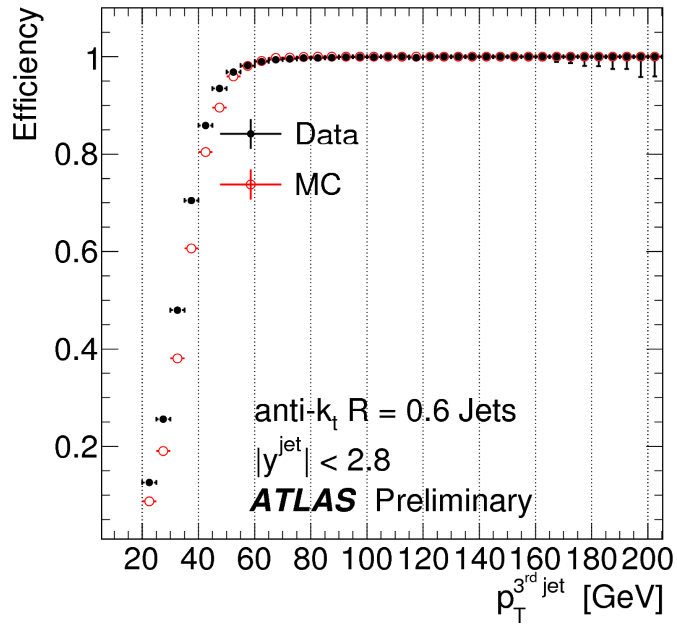
Probability of a selected jet occurring next to (within ΔR = 1.0) a reconstructed jet of uncalibrated jet pT > 7 GeV as a function of inclusive jet multiplicity. It increases with jet multiplicity, and the ALPGEN+HERWIG/JIMMY AUET1 simulation agrees best with data. Differences of up to 10% are observed in PYTHIA AMBT1

Angular Distributions

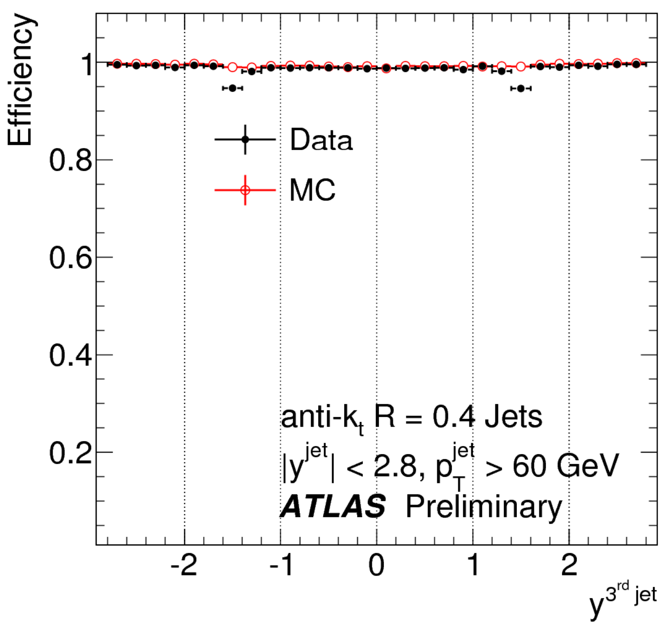


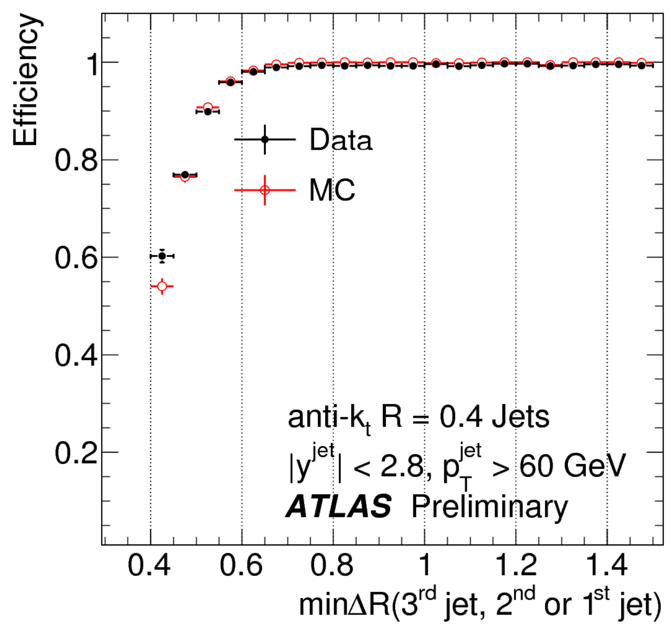
Trigger Performance





L1_3J10 trigger





Trigger efficiencies calculated as a function of jet *pT* and *y*

Studied 2-jet and 3-jet triggers bootstrapping from low multiplicity triggers

The 3-jet trigger result indicates an inefficiency for events where 2 jets are **near-by** and becomes weaker at larger jet distances

Topological inefficiency of the 3-jet trigger observed only for anti-k_t 0.4 jets

MC simulation describes well all topological dependences in the trigger the CONF

Small inefficiencies revealed in the data *pT* plateau at the *y* cracks