Measuring large-area jets with ATLAS

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In this talk: overview

ATLAS-CONF-2011-073

Large-area jets can capture the radiation from boosted object decays such as top, Higgs, exotic resonances.

- A quick look at standard ATLAS jet measurements
- Measurements of mass, filtered mass and splitting scale in large-area jets
- Detector corrections and systematic uncertainties
- The (near) future

The three kinds of jets presented here:

- Cambridge-Aachen (C-A) jets with R=1.2
- Filtered C-A jets with R=1.2
- Anti-k_T jets with R=1.0

$$d_{ij} = min(k_{t,i}^{n}, k_{t,j}^{n}) \frac{\Delta R_{ij}^{2}}{R^{2}}$$

$$d_{iB} = k_{t,i}^{n}$$

n=-2 $\rightarrow$Anti-k_t

n=0 $\rightarrow$C-A

Data, Monte-Carlo and selection cuts

Full details:

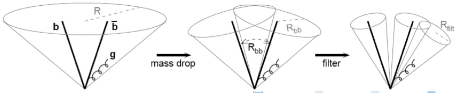
Measurement of Jet Mass and Substructure for Inclusive Jets in s = 7 TeV pp Collisions with the ATLAS Experiment
ATLAS-COM-CONF-2011-084

Basic summary:

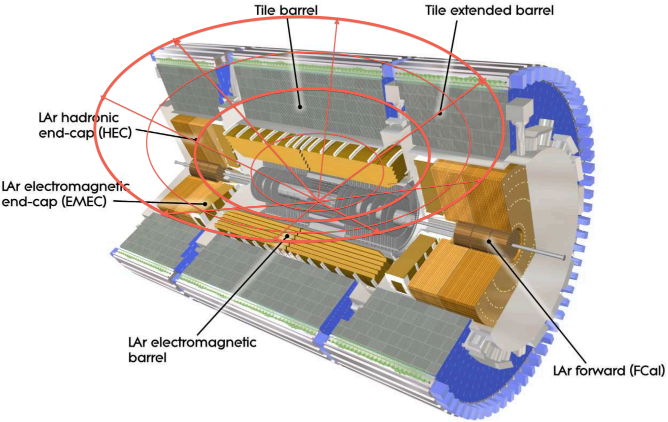
- 2010 ATLAS data, $\sim 35pb^{-1}$
- All events must have a single primary vertex (reduces dataset to $\sim 8pb^{-1}$).
- Jets are inclusive: we do not separate leading/ sub-leading.
- All jets must have $p_T > 300$GeV and $|y| < 2$.
- Measurements in data are compared with:
  - Pythia 6.423 (AMBT1 and Perugia2010 tunes)
  - Herwig 6.510
  - Herwig++ 2.4
  - Alpgen 2.13
- All MC is passed through full simulation of ATLAS based on GEANT 4

Splitting/filtering procedure implemented using:

- Minimum mass drop $\mu = 0.67$
- Maximum asymmetry $d_{12} = 0.09$
- Minimum splitting angle $R_{bb} = 0.3$



Large-area jets in ATLAS (visually)



A jet with R=1.2 subsumes much of the ATLAS detector →We cannot restrict the analysis to the central region of the detector.

Measurements of large-area jets

The results presented here are Jet mass, filtered jet mass and splitting scale.

$$m^2_{jet} = \sum_i E^2 - \sum_i \mathbf{p}^2 \quad \text{(sum over jet constituents } i\text{)}$$

Jet mass is our touchstone:

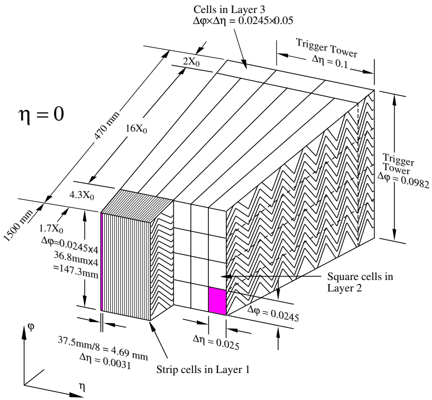
- Crucial for boosted particle searches, both in terms event selection and the final measurement.
- Generated entirely by by the energy and position measurement of the (massless) jet constituents.

The study of large and filtered jets in ATLAS data is completely new. With new methods we use tools that are well understood in terms of standard ATLAS jet measurements. In some cases we extend these tools.

A brief reminder of the ATLAS potential for jet physics is in the next slides..

Measuring position

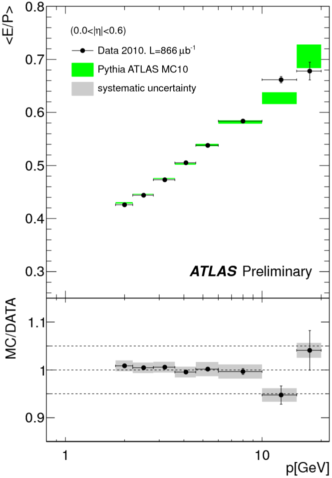
Jet mass is generated entirely by the angular separation and energy of its (massless) constituents.



- Position resolution of calorimeter clusters$\sim$ 0.05rad.
- Finest granularity in EM calorimeter is $\sim 0.025 \times 0.025$
- 'Trigger towers' are 0.1×0.1

We have the capability of measuring position precisely with the calorimeter and have the added benefit of being able to use track-matching.

The Jet Energy Scale (JES)-I



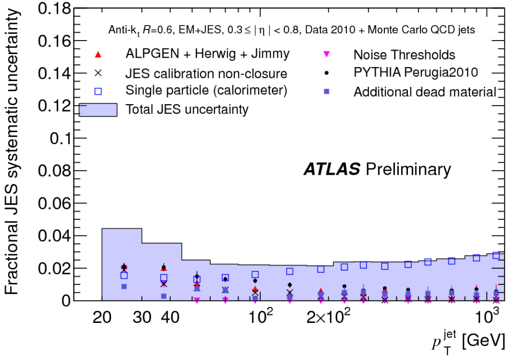
Measuring the calorimeter response E/p as a function of the track momenta:

- E(cluster)/p(track) is measured for tracks $<$ 20GeV
- Neutral particles are given 3(4)% calo uncertainty for EM(HAD)
- This uncertainty is propagated to the jet

The dominant uncertainty on energy scale measurement comes from the **calorimeter response.** This work is ongoing.

The Jet Energy Scale (JES)-II

A good understanding of the jet energy scale is vital.

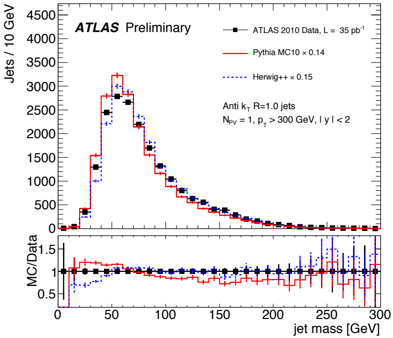


- Anti-$k_\perp$ R=0.6 jet energy scale known to $< 5\%$ in central region
- This is strongly dominated by the single particle response of the calorimeter.

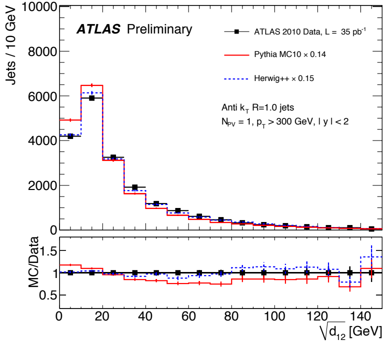
Standard jet calibration 'EtaJES' : corrections in η and energy. Custom calibration for large-area jets follows the same principle **with an additional mass correction**.

Splitting in anti-k_t R=1.0 jets

Anti-k_t R=1.0 mass:



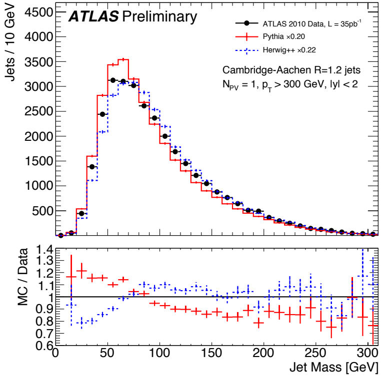
Anti-k_t R=1.0 splitting scale:



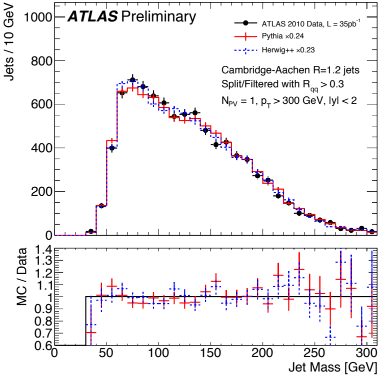
Agreement within 30% between **detector-level** data and Monte Carlo is fair at this point for both the mass and the splitting scale $\sqrt{d_{12}} = min(p_{Ta}, p_{Tb}) \times \delta R_{a,b}$.

Filtering in C-A R=1.2 jets

Cambridge-Aachen R=1.2 jet mass:



C-A R=1.2 filtered jet mass:



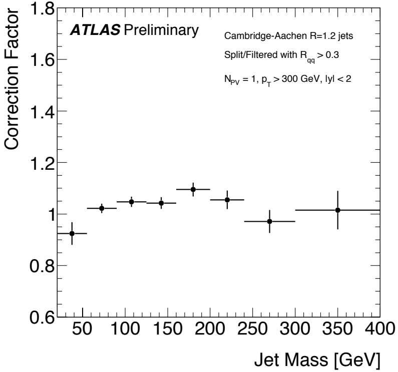
Note the lower statistics after splitting and filtering: we throw away jets in which the minimum splitting angle $R_{bb} < 0.3$.

Bin-by-bin corrections are determined by comparing the jet mass at particle and detector level.

Define three bin-by-bin correction factors:

1. Determine $C_{MC} = \frac{A_{part,MC}}{A_{det,MC}}$
2. Determine $C_{RW} = \frac{A_{data}}{A_{part,MC}}$
3. Re-weight the MC: $A_{RW} = C_{RW} \times A_{MC}$
4. Find $C_{MCRW} = \frac{A_{part,MCRW}}{A_{det,MCRW}}$

- Pythia and Herwig++ are MC.
- The largest difference is taken as systematic uncertainty on unfolding.

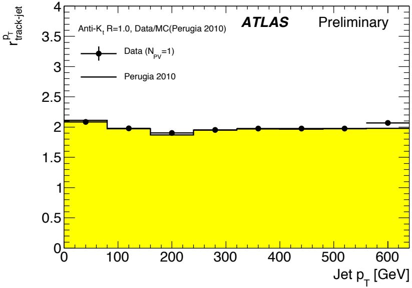


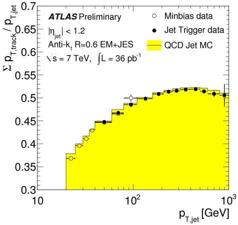
Uncertainties in energy (JES) and mass (JMS)-I

The largest systematic uncertainty on the jet mass measurement is in the JES/JMS. We use the same procedure as for standard jets to determine the magnitude of this.

- Compare track-jets to calorimeter jets in p_T(shown), splitting scale and mass.

$$r^{p_T}_{\text{track-jet}} = \frac{p_T^{\text{jet}}}{p_T^{\text{track-jet}}}$$



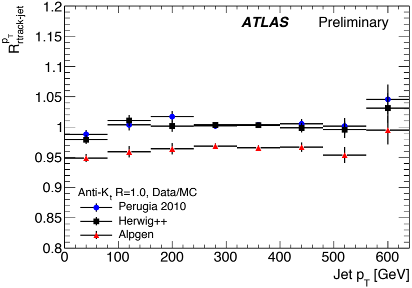


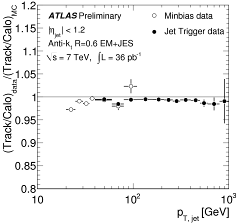
We see agreement between the results for anti-k_T R=1.0 (above) and R=0.6 (right) jets using the (inverse of) the same method.

Comparing track-jet to cluster-jet in both data and MC: construct a **double ratio**:

- Double ratio cancels effects from hard process (to first order).

$$R^{p_T}_{r\text{track-jet}} = \frac{r^{p_T,\text{data}}_{\text{track-jet}}}{r^{p_T,\text{MC}}_{\text{track-jet}}}$$

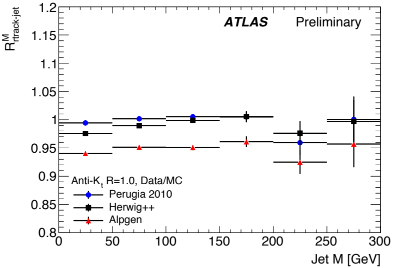




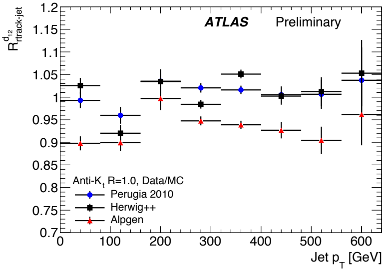
Agreement* between the double-ratio results for anti-k_T R=1.0 (above) and R=0.6 (right) jets using the (inverse of) the same method. *Alpgen discrepancy is under investigation.

Double ratios also constructed for mass and splitting scale:

Mass:



$\sqrt{d_{12}} = min(p_{Ta}, p_{Tb}) \times \delta R_{a,b}$:



We establish JES, JMS for three different algorithms:

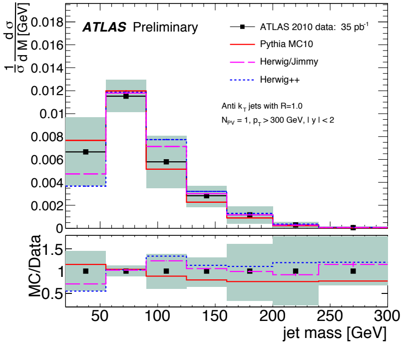
Jet Algorithm	JES	JMS	JER	JMR
anti-k_t $R = 1.0$	5%	7%	20%	30%
Cambridge-Aachen $R = 1.2$	5%	6%	20%	30%
Cambridge-Aachen Filtered $R = 1.2$	6%	7%	20%	30%

	Scale	Resolution
$\sqrt{d_{12}}$	15%	30%

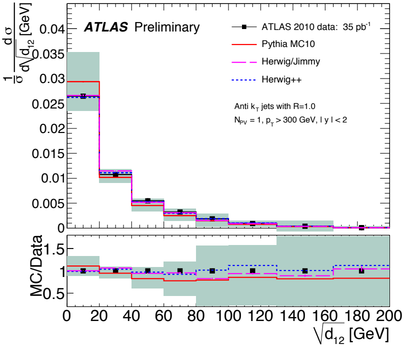
JMR/JER: Jet mass/energy resolution.

Distributions unfolded to particle level

Anti-k_T R=1.0 jet mass:



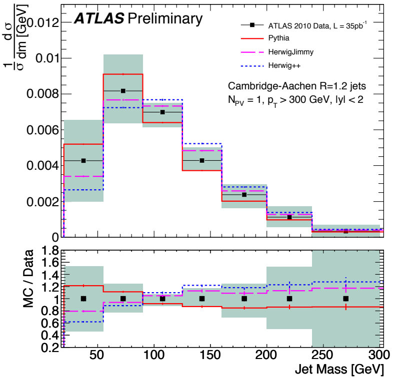
Anti-k_T R=1.0 jet splitting scale:



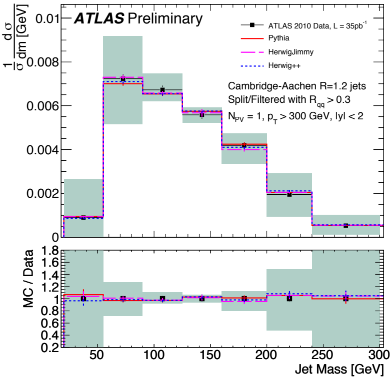
Within conservative errors, data is in quite good agreement with MC.

Distributions unfolded to particle level

C-A R=1.2 jet mass:



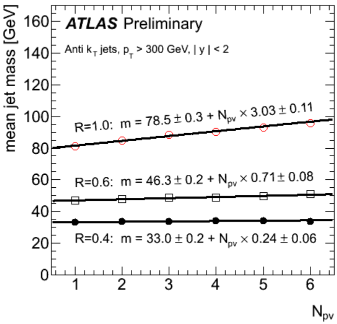
C-A R=1.2 filtered jet mass:

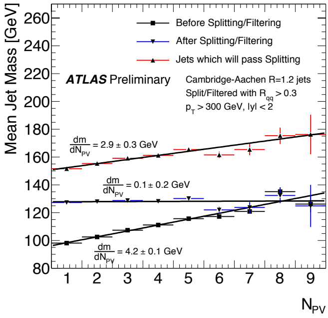


Again, MC and data agree quite well.

Pileup: the great challenge for 2011

If we select events with a single primary vertex in 2011 data, we will have 0 events.*



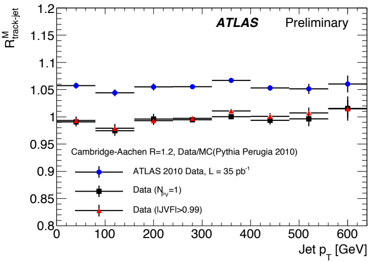


- Mass offset *will* be a problem for larger jets. But..
- ..filtering comes to the rescue here: dependence on NPV reduced to 0.

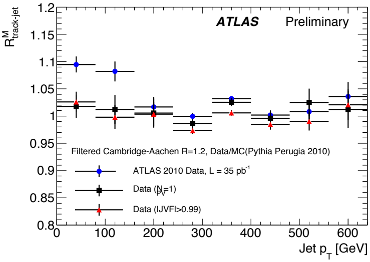
*2011 data have 15 interactions per bunch crossing.

Pileup: the great challenge for 2011

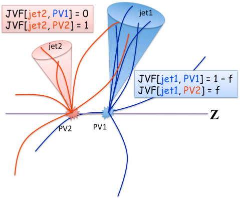
Cambridge-Aachen R=1.2:



Filtered C-A R=1.2:



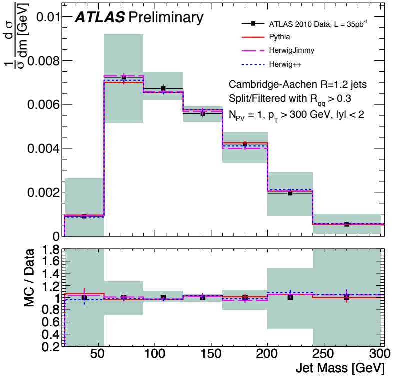
- The double ratio in mass is similar for NPV=1 ($\sim$ 20%) and JVF>0.99 ($\sim$ 50%)
- Filtering is a powerful weapon against systematic uncertainty due to pileup.
- Expect changes 2010 $\rightarrow$ 2011 data.



Conclusions

We have made the first measurements of large-area jet mass, filtered mass and splitting scale.

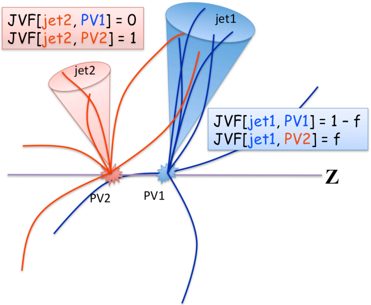
- Systematic uncertainties are very conservative here.
- **Work is ongoing to e.g. reduce the mass bin sizes to 'discovery' width.**
- We are not yet in a position to exclude any MC.
- **Pileup will be a major challenge for 2011 data. We have promising handles on this.**
- A good understanding of correlations between substructure variables will be vital for future direction.



Thanks for listening.

Backup

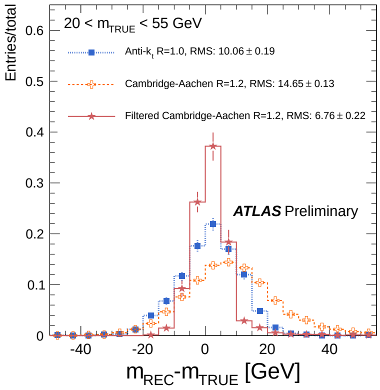
The Jet Vertex Fraction



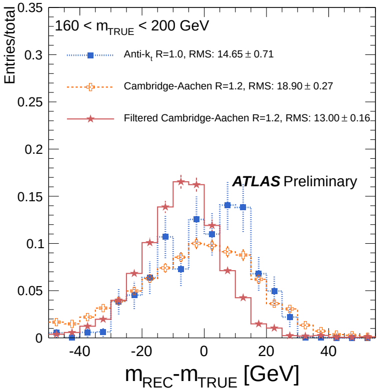
See David Miller!

Unfolding to particle level: mass resolution and binning

Low mass jets (20-55 GeV):



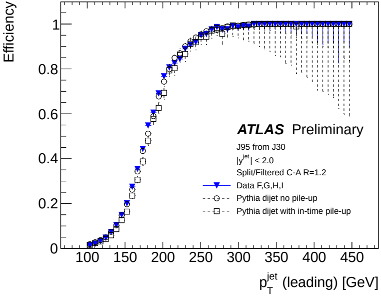
High mass jets (160-200 GeV):

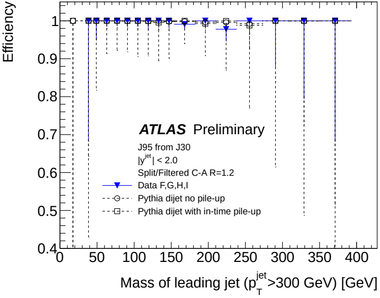


- Demand bin purity$>$ 50% $\rightarrow$ large ($\geq$ 35 GeV) mass bins.
- P_T resolution (not shown) is comparable to anti-k_T R=0.6 (15-17.5 GeV)
- Mass resolution improves resolution from 8.1% $\rightarrow$ 6.7% in low mass jets.

What we can get from the trigger

ATLAS triggers on 0.1 $\times$ 0.1 'trigger towers' at level 1. These figures show the efficiency of the first level ATLAS (hardware) $E_{raw} > 95$ GeV trigger for CA jets with R=1.2 after splitting/filtering.





We can work with this confidently for R=1.0,1.2 jets above a p_T threshold of 300 GeV.

Variables, variables

Many variables have been suggested. All use E_i and θ_i, with varying definitions of i (cluster, jet, subjet, pseudojet).

- mass
- $\sqrt{d_{12}}$
- width/ girth
- planar flow
- eccentricity
- angularity
- N-subjettiness
- subjet multiplicity
- dipolarity
- so many more.....

Correlations will help us with a necessary cull.