Jet reconstruction with first data in ATLAS

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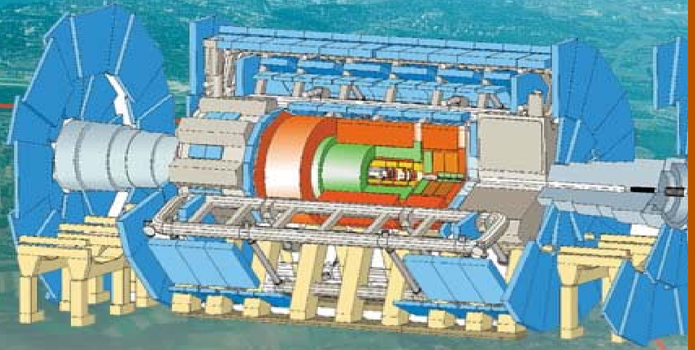
on behalf of

The ATLAS Collaboration



Physics at LHC 2008, Split, Croatia

30 September 2008

Outline

- ***Jets at LHC***
  experimental requirements (light-flavour jets)
- ***Jet algorithms in ATLAS***
  popular and alternative approaches
- ***Calibration strategy***
  main models and refined corrections
- ***Requirements for initial jet reconstruction***
  baseline/robust methods
  in-situ ("data only") calibration
- ***Conclusions***

Jets at LHC

New kinematic regime for jet physics

Jets can be much harder

- Jets get more narrow in general (kinematic effect)
- Higher energies to be contained in calorimeters

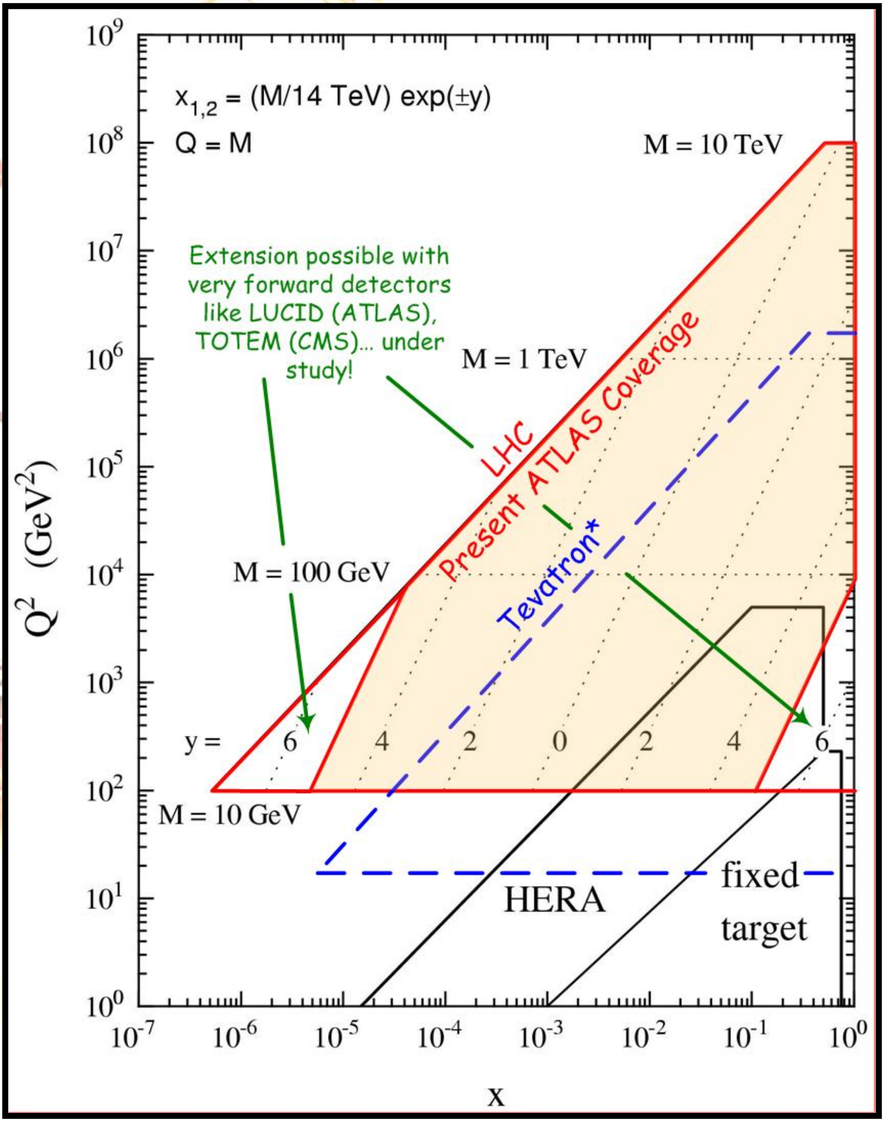
Jet reconstruction challenging

Physics requirements typically 1% jet energy scale uncertainty

- top mass measurement in ttbar
  LHC is a top factory!
- hadronic final states at the end of long decay chains in SUSY

Quality takes time

- Previous experiments needed up to 10 years of data taking to go from ~4% down to ~1%
- Cannot often be achieved for all kinds of jets and in all physics environments



W. Stirling, LHCC Workshop "Theory of LHC Processes" (1998)

Experimental Requirements for Jet Finders

Detector technology independence

- Minimal contributions to spatial and energy resolution
- Insignificant effects of detector environment
  - Noise, dead material, cracks
- Easy to calibrate (…Well…)

Environment independence

- Stability with changing luminosity
- Identify all physically interesting jets from energetic partons in pert. QCD
- High reconstruction efficiency

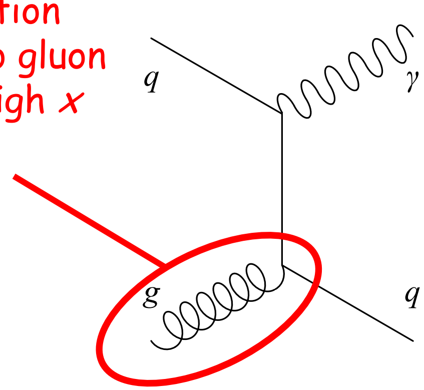
Implementation

- Fully specified
  - selections and configurations known
- Efficient use of computing sources

Process		σ (nb)	Evts/year (Λ=10 fb^{-1})
$W \to e\nu$		15	~10^8
$Z \to e^+ e^-$		1.5	~10^7
$t\bar{t}$		0.8	~10^7
Inclusive Jet Production	p_t > 200 GeV	100	~10^9
	p_t > 1 TeV	0.1	~10^6
	p_t > 2 TeV	10^{-4}	~10^3
	p_t > 3 TeV	1.3×10^{-6}	~10

- Expectations:
  - Jet energy scale error very quickly systematically dominated
    - Large statistics in unexplored kinematic range already at low luminosity
  - Calibration channels quickly accessible
    - Especially for γ+jet(s), W->jj, etc.

Dominant direct photon production gives access to gluon structure at high x (~0.0001-0.2)



Popular Jet Algorithms in ATLAS

Seeded cone

- p_T (seed) > 1 GeV

Alternative applications:

- CDF mid-point, anti-k_T, Cambridge/Aachen recursive recombination (0th order kT), “optimal jet finder” (event shape fit)

- More options: **FastJet** libraries

easier comparison with CMS, theory

No universal configuration or jet finder

- Narrow jets

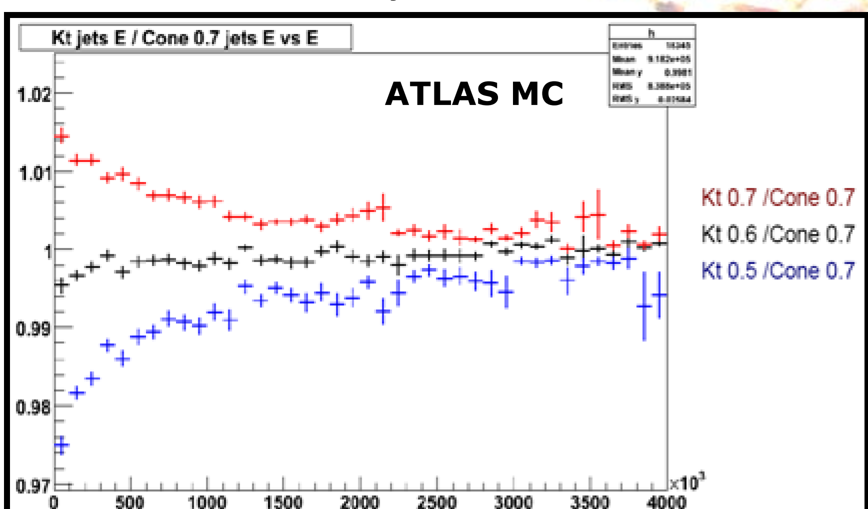
W->jj in ttbar, some SUSY

- Wider jets

Inclusive jet cross-section, QCD

Recursive recombination (k_T)

Algorithm	R_{cone}	D	Clients
Seeded Cone Et (seed) = 1 GeV, $f_{S/M}$ = 0.5	*0.4*		W mass spectroscopy, top physics, SUSY
Kt (FastKt)		*0.4*	
Seeded Cone Et (Seed = 1 GeV), $f_{S/M}$ = 0.5	*0.7*		QCD, jet cross-sections
Kt (FastKt)		*0.6*	

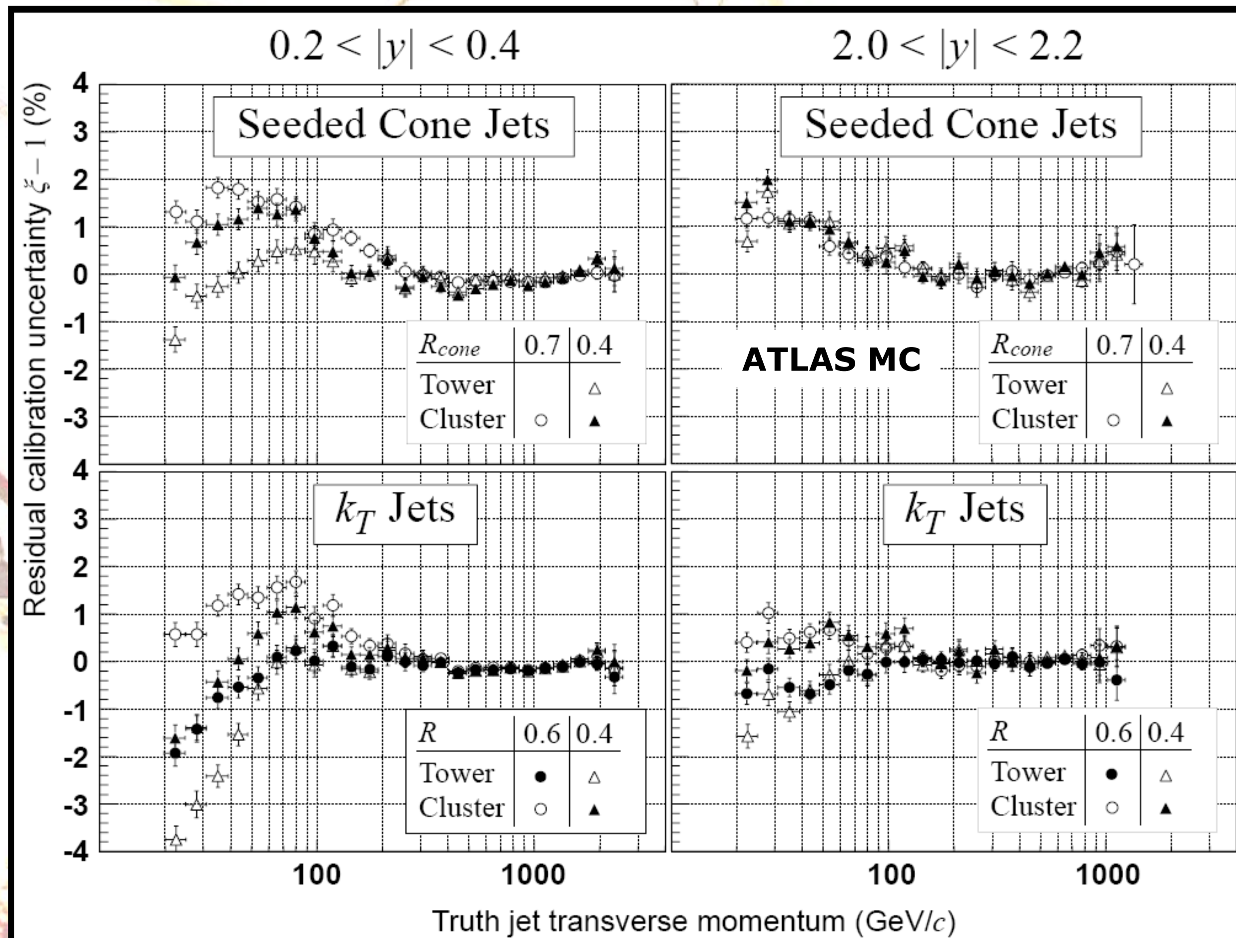


Deviations of Signal Linearity

Estimated effect of a distorted detector

$$\xi = \frac{\left(E_{jet}^{calo} / E_{jet}^{truth}\right)_{alt}}{\left(E_{jet}^{calo} / E_{jet}^{truth}\right)_{ref}}$$

ξ can be viewed as a measure of residual calibration uncertainty (distorted detector) with respect to the best calibrated jet reco configuration => estimation of systematic error in the general jet reco

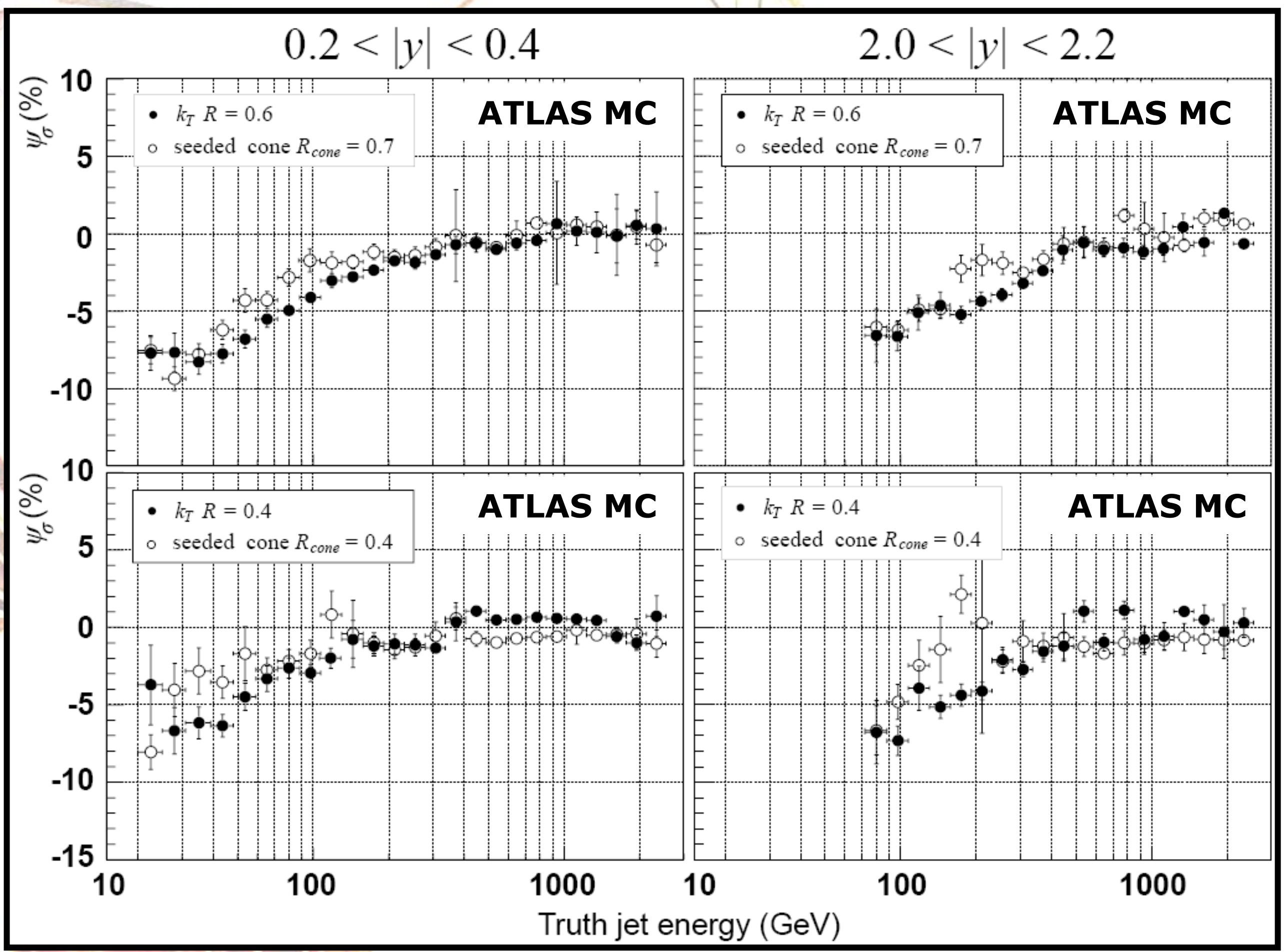


Effect of detector distortion depends on jet size, calorimeter signal choice, and kinematic domain:

~ 2% for cone jets, up to ~4% for central (narrow) kT jets!

Effect of Calorimeter Signal Choice on Jet Energy Resolution

Typical relative energy resolution (without particular corrections for distorted detector) has a stochastic term of $60\%/\sqrt{E(GeV)}$ and a high energy limit of 3%



Difference in resolution between tower and cluster jets can be estimated with test variable ψ_σ (below)

Negative values for ψ_σ indicates a better resolution for cluster jets at low energies (better noise treatment…)

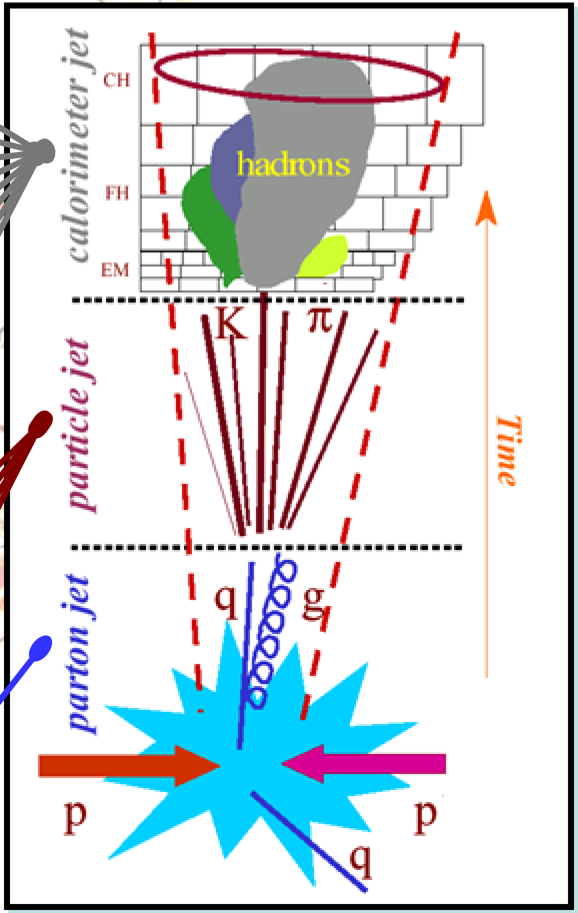
$$\psi_\sigma = \begin{cases} \sqrt{\Delta\sigma_{rel}} & \Delta\sigma_{rel} > 0 \\ -\sqrt{-\Delta\sigma_{rel}} & \Delta\sigma_{rel} < 0 \end{cases}, \Delta\sigma_{rel} = \left(\frac{\sigma(E_{cluster})}{E_{cluster}}\right)^2 - \left(\frac{\sigma(E_{tower})}{E_{tower}}\right)^2$$

Experimenter's View on Jets

longitudinal energy leakage
detector signal inefficiencies (dead channels, HV…)
pile-up noise from (off- and in-time) bunch crossings
electronic noise
calo signal definition (clustering, noise suppression ,…)
dead material losses (front, cracks, transitions…)
detector response characteristics (e/h ≠ 1)
jet reconstruction algorithm efficiency

jet reconstruction algorithm efficiency
added tracks from in-time (same trigger) pile-up event
added tracks from underlying event
lost soft tracks due to magnetic field

physics reaction of interest (interaction or parton level)



Desirable to factorize the calibration and corrections dealing with these effects as much as possible!

Jet Calibration Strategies

Essentially, there is no universal model for jet calibration

- Immediate consequence from the fact that there is no universal jet finder (or jet finder configuration) appropriate for all physics reconstruction/analysis
- But there two general strategies

Publications often refer to jets corrected to parton level

- Maybe not well-defined concept in pp, more useful in e^+e^- or deep inelastic scatt.

At LHC/ATLAS jets are foremost calibrated to the particle (hadron) level

- First aim to reconstruct the energy carried by particles into the detector (calorimeter)
  - Needs detailed and most accurate detector signal simulations for test-beams and physics processes
- Link to interaction physics needs full modeling of collision processes
  - Needs all particles, not only hard scatter fragments

Factorize jet calibration as much as possible

- Better control of systematics
  - Can even use hadron test-beams to a point

Most of all: every experiment needs its own model in the end!

Two models (explored in ATLAS):

Model I: Calibration in jet context

First find jet, then calibrate, then correct if needed

Model II: Calibration in cluster context

Calibrate calorimeter signals, then find jet, then correct (likely needed)

Local hadronic calibration plugs in here!

Best calibration likely a combination of both models

Full Calibration in Jet Context

Find the jet using basic (electromagnetic) energy scale signals in the calorimeter

- Assumes that all elementary signal corrections (electronics etc.) are taken care of
- Relative mis-calibration between input to jet finder can O(30%) or more in non-compensating calorimeters
  - Can be a problem especially for kT
- Best for compensating calorimeters, as basic energy scale is ~hadronic scale

Then calibrate it

- Complex signal weights applied to cell signals in jet (default "H1-style")
- Lower level of factorization of jet reconstruction
  - Many corrections absorbed in a few numbers
- Feedback of calibrations to basic signals (jet constituents) for missing ET calculations etc.

Apply final Jet Energy Scale (JES) corrections

- Correct for different algorithm, jet size, calorimeter signal definition

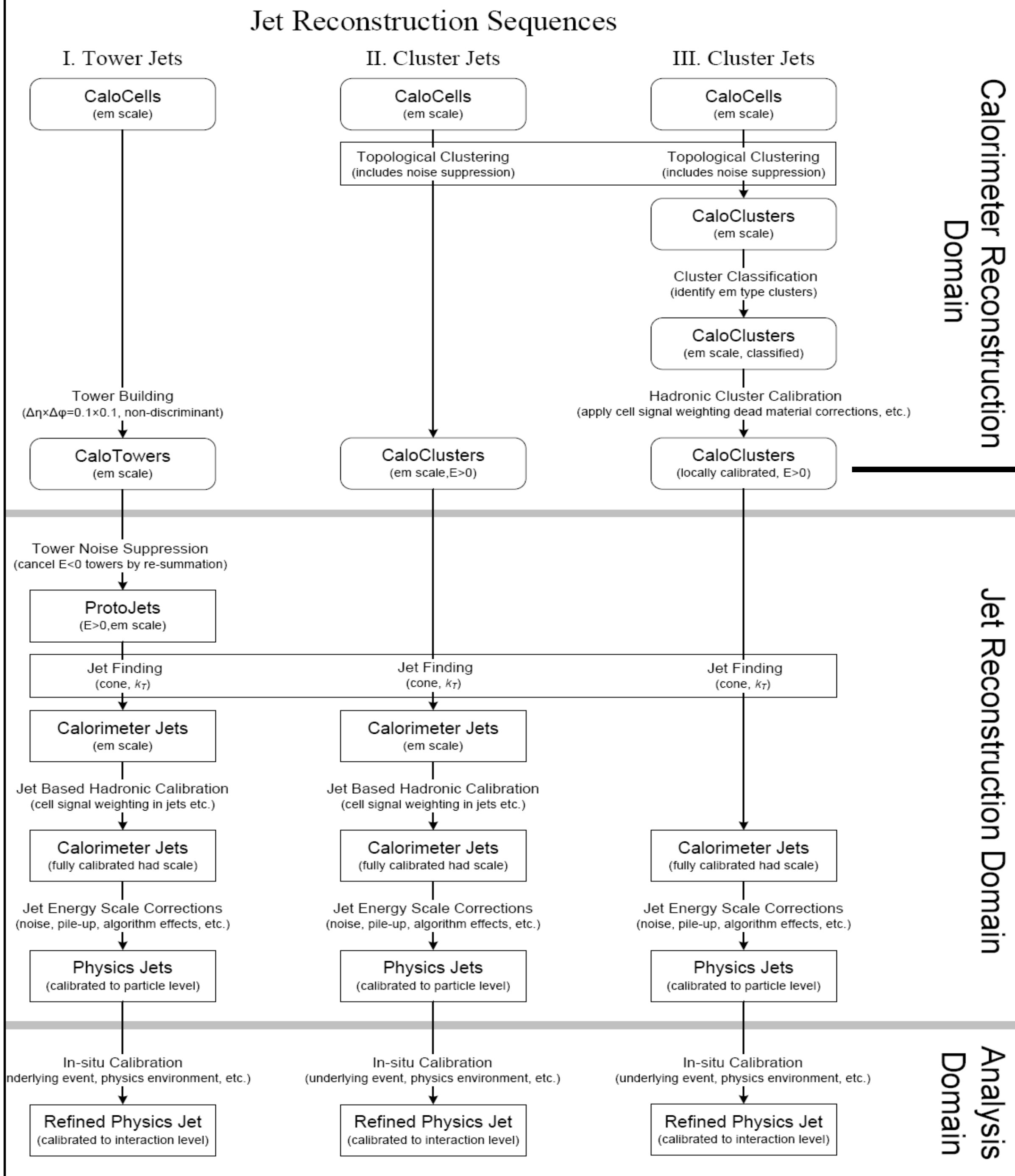
Cluster Context Jet Calibration

Calibrate calorimeter signals first as much as possible, then find jets

- Detector motivated (use measured signal shapes)
  - Applies calibration in the context of a specific calorimeter signal definition (topological clusters in ATLAS)
    - No jet context needed
  - Provides calibrated input to jet finding
    - Better for kT
- Needs final jet energy scale corrections
  - Calibration derived from single particles
  - Feedback of final corrections for missing ET calculations etc.
- High level of factorization,
  - better control of systematics (?)
  - To be fully investigated

Provides hadronic calibration outside of jet context

Local Hadronic Calibration in ATLAS



Full jet reconstruction sequence in ATLAS

Jets are made from calo-towers, uncalibrated and calibrated topological clusters

Reconstruction (software) domains are also indicated

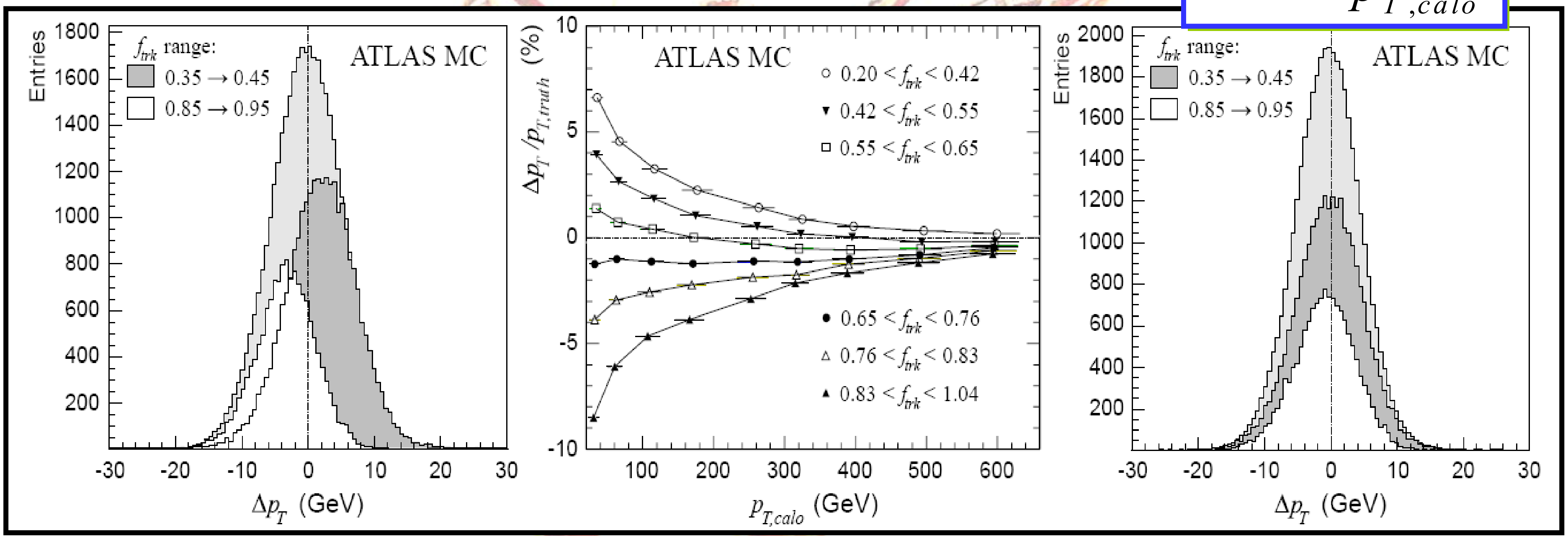
Refined JES Corrections

Further jet-by-jet corrections improving the relative energy resolution

- e.g. jet shapes in calorimeters
  - Energy density in narrow jets, for example
- Use of reconstructed tracks from the inner detector (example below)
- Can be applied after any kind of calibration
- Need to study factorization/overlap in corrections from various detectors
  - Avoid double counting
  - Establish common basic energy scale

$$f_{trk} = \frac{p_{T,track}}{p_{T,calo}}$$

Jets with $|\eta| < 0.7$ and $40 < p_T < 60$ GeV



Requirements For Initial Jet Reconstruction

Need flat jet response quickly

- Allows physics groups to start serious work
  - Non-optimal resolution initially
- Allows to show jet response publicly rather soon
  - Just be honest about the errors
    - Will improve with increasing understanding of the detector anyway
- Helps evaluating the detector performance in general
  - Larger "signal integration" volume in jet context has diagnostics power beyond detector (calorimeter) signal objects

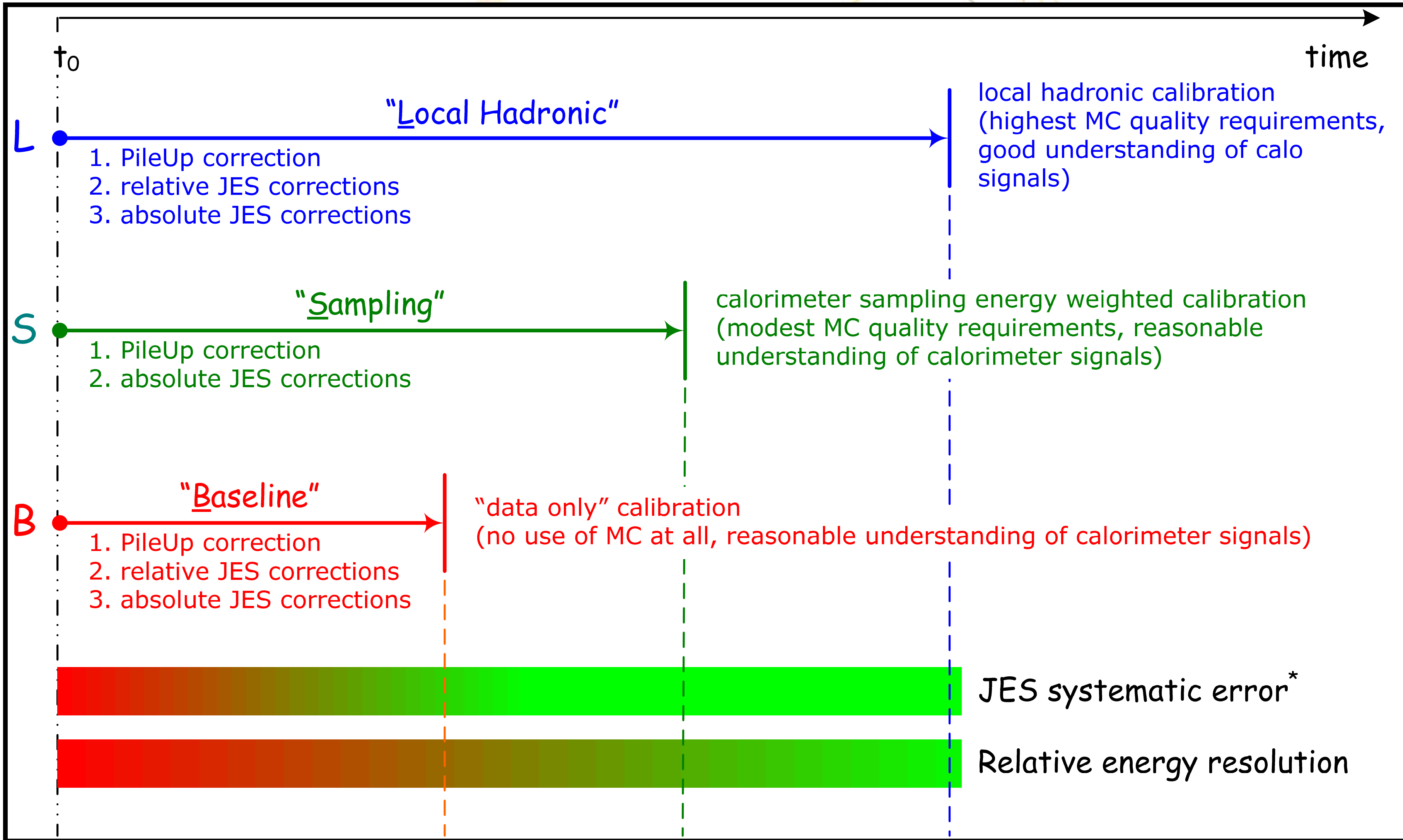
Corresponding calibration should not be MC based

- Understandings simulated response will take time
  - Physics models
    - Theoretical understanding of hard scattering at LHC energies
    - Fragmentation
    - Soft physics behind UE/pile up
  - Detector/calorimeter response simulation
    - Adequateness of models
    - Detector status in initial run (dead cells, etc.)
    - Understanding of noise (electronics and pile-up) in initial run conditions

Something straight forward and fast is needed

This does not mean that one gives up on MC based calibrations…

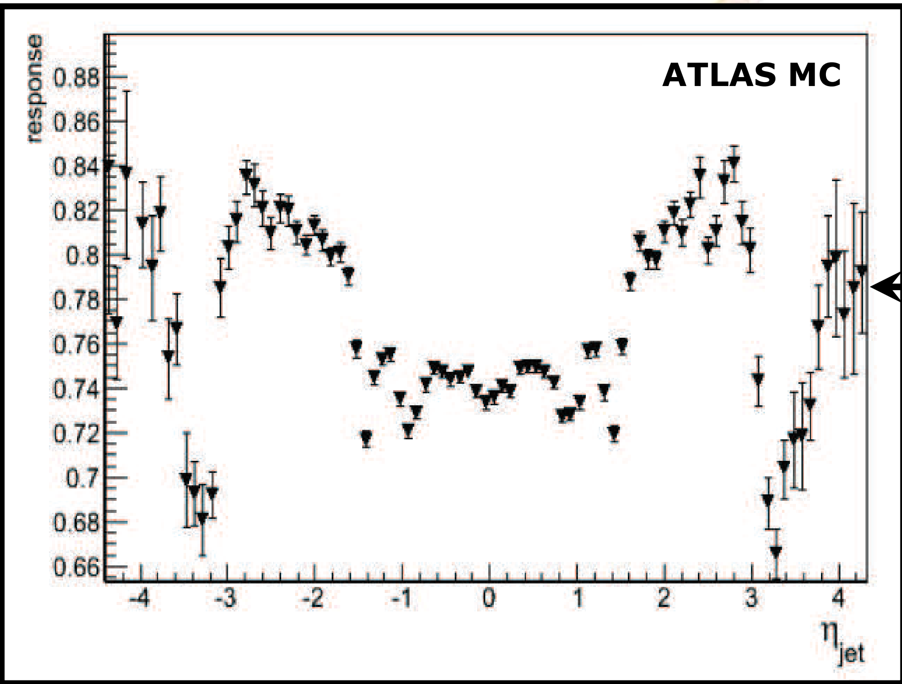
Jet Calibration For First Data



Baseline "Data Only" Jet Calibration

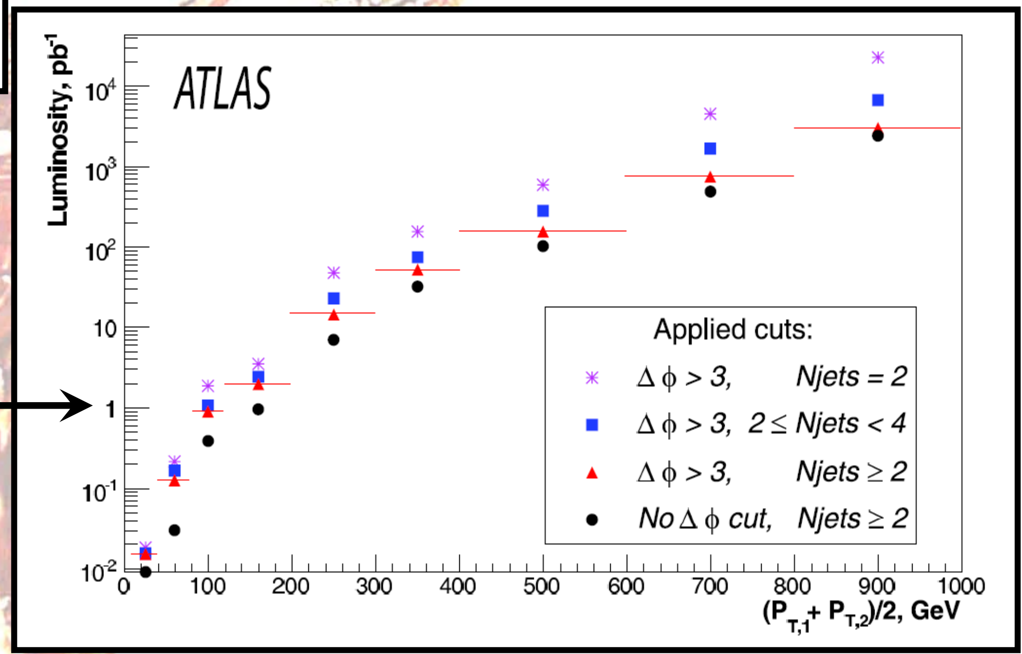
	Task	JetEnergyScale (JES)	Tool
1	**PileUp Subtraction**	$E_{bc}^{jet}(\eta_{jet},\varphi_{jet}) = E_{0}^{jet}(\eta_{jet},\varphi_{jet}) - \bar{\rho}_{0}^{mb}(N_{vtx},\eta_{jet},\varphi_{jet}) \cdot A_{\eta\varphi}^{jet}$	**minbias events** (determine E/Et density in pile-up as function of # vertices)
2	**Relative response corrections (η,φ)**	$E_{rel}^{jet} = \bar{f}(\eta_{jet},\varphi_{jet}) \cdot E_{bc}^{jet}(\eta_{jet},\varphi_{jet})$	**di-jet p_T balance** (equalize jet response of calorimeter system with respect to central region in slices of φ)
3	**Absolute energy scale corrections**	$E_{rec}^{jet} = \bar{C}(p_{t,rel}^{jet},\ldots) \otimes E_{rel}^{jet}$	**γ/Z-jet p_T balance in direct photon production** (correct JES from p_T balance with γ/**Z**, as function of jet pT etc.)

In-situ studies using QCD jet events

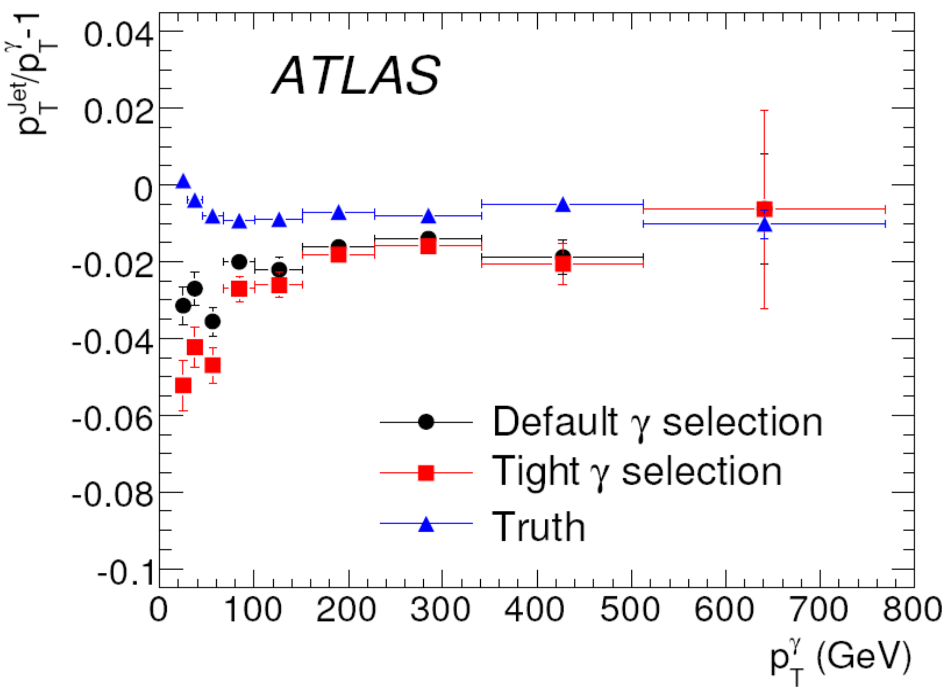


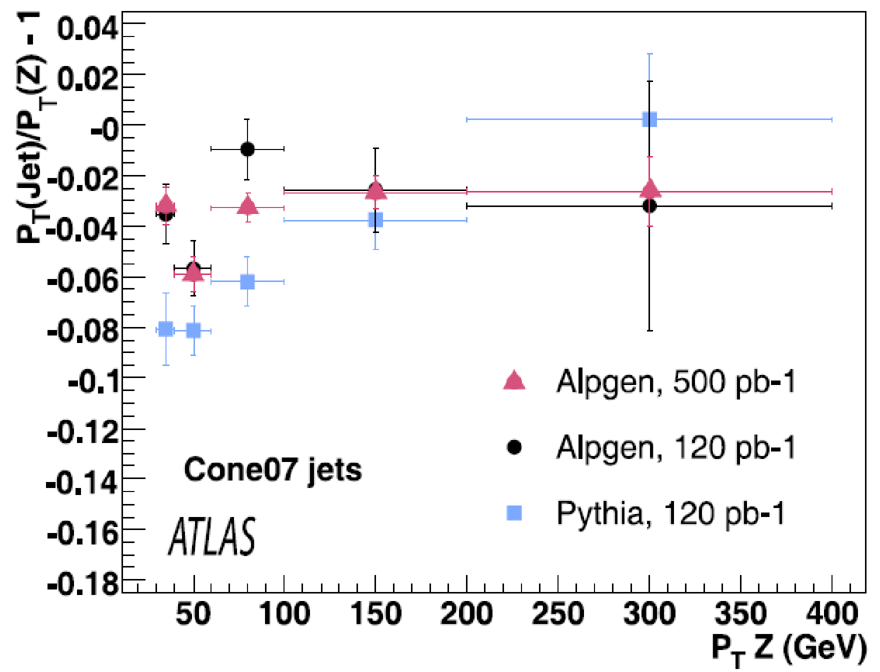
Calorimeter response p_T(reco)/p_T(truth) for jets at EM scale reveals significant variations with η_{jet} (cracks and dead-material regions…)

Integrated luminosity required to reach 0.5% precision (p_T balance fit mean) for various p_T ranges in the region $0.7<\eta<0.8$ with different selection cuts



In-situ studies using γ/Z-jet events





p_T low edge	Bin width	Fitted balance	Integrated luminosity, pb^{-1}	Error for 10 pb^{-1}
20 GeV	10 GeV	-0.052 ± 0.007	0.67	0.2%
30 GeV	15 GeV	-0.042 ± 0.005	0.67	0.2%
45 GeV	22.5 GeV	-0.047 ± 0.005	9.1	0.4%
67.5 GeV	33.5 GeV	-0.027 ± 0.003	9.1	0.4%
101 GeV	51 GeV	-0.026 ± 0.003	47	0.7%
152 GeV	76 GeV	-0.018 ± 0.002	47	0.4%
228 GeV	114 GeV	-0.016 ± 0.002	535	1.7%
342 GeV	171 GeV	-0.021 ± 0.005	535	4%
513 GeV	256 GeV	-0.006 ± 0.026	535	19%

- γ-jet p_T balance above 80 GeV flattens at the level of -0.02
- In Z-jet events differences between two generators can be tested with ~ 100 pb^{-1} of data for p_T < 100 GeV

Missing Et Projection Fraction (MPF) has been explored, as well

- Pioneered by DØ collaboration

Conclusions

- ***Rich program of jet physics at LHC***
- ***Various jet algorithms considered in ATLAS***
  - popular choices (seeded cone and k_T recombination)
- ***Two principal models of hadronic calibration***
  - jet context with several implementations ("H1 style" cell signal weights, sampling layer weights)
  - Local hadronic calibration in cluster content
  - activity in refined jet-by-jet corrections (e.g. with tracks)
- ***Jet reconstruction performance evaluation with LHC data coming***
  - Quite a few handles
  - robust/data-driven (coarse) calibration at the beginning

Many Thanks to all members of the ATLAS jet working group