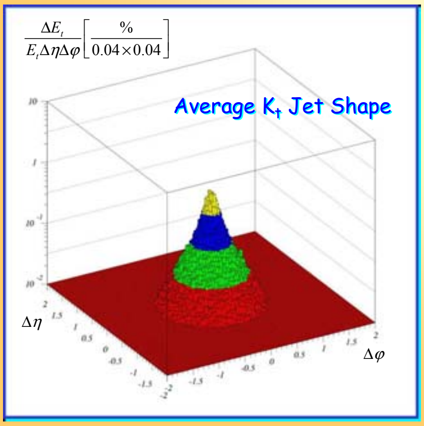
Peter Loch
University of Arizona
Tucson, Arizona 85721

Jet Reconstruction in ATLAS



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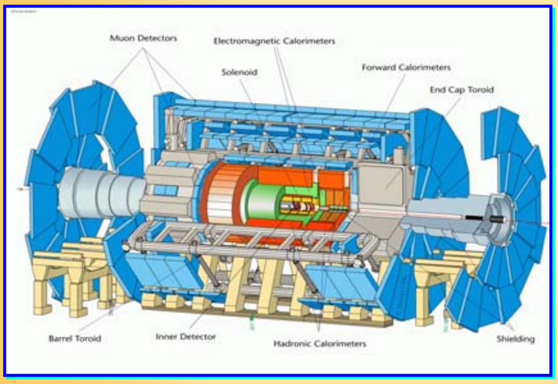
The ATLAS Detector



Length ~45 m, height ~22 m, weight ~7000 tons

- Inner Detector (2T solenoid, |η|<2.5):
  $\sigma_{p_t}/p_t \approx 0.05\%/GeV \times p_t \oplus 1\%$
- Calorimetry:
  - electromagnetic, |η|<3.2
    $\sigma_E/E \approx 10\,\%\sqrt{GeV}/\sqrt{E} \oplus 0\%$
  - hadronic (central, |η|<1.7)
    $\sigma_E/E \approx 50\,\%\sqrt{GeV}/\sqrt{E} \oplus 3\%$
  - hadronic (endcaps, 1.7<|η|<3.2)
    $\sigma_E/E \approx 60\,\%\sqrt{GeV}/\sqrt{E} \oplus 3\%$
  - hadronic (forward, 3.2<|η|<4.9)
    $\sigma_E/E \approx 100\,\%\sqrt{GeV}/\sqrt{E} \oplus 5\%$
- Muon system (~4T toroid, |η|<2.7):
  $\sigma_{p_t}/p_t \approx 10\%$ for $p_t(\mu) \approx 1\,TeV/c$

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Jet Reconstruction Guidelines in ATLAS

- Jets define the hadronic final state of any physics channel -> jet reconstruction and calibration essential for signal and background definition;
- But which jet algorithm to use ? Recommendations based on CDF & DØ experience from Tevatron Run I† very helpful;

Some "Theoretical" requirements:

- infrared safety
- collinear safety
- invariance under boost
- order independence (same jet from partons, particles, detectors)

Some "Experimental" requirements:

- detector (technology) independence
- minimal contribution to spatial and energy signal resolution (beyond effects intrinsic to the detector)
- stability with luminosity (!!, control of underlying event and pile-up effects)
- "easy" to calibrate, small algorithm bias to signal
- identify all physically interesting jets from energetic partons in pQCD (high reco efficiency!)
- efficient use of computing resources
- fully specified (pre-clustering, energy/direction definition, splitting and merging)

†G. Blazey et al., "Run II Jet Physics", hep-ex/0005012v2, 2000

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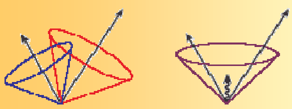
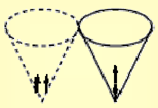
Jet Finding Algorithm Implementations (1)

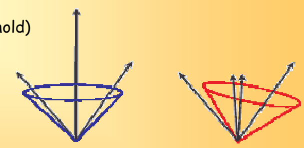
- from **guidelines + easy implementation** -> implemented K_t clustering (exploits kinematical correlations between particles) and (seeded and seedless) cone algorithm (geometrically motivated);
- **Seeded cone algorithm** (most common and fast) has problems with some theoretical and experimental requirements:



infrared sensitivity
(soft gluon radiation merges jets)



collinear sensitivity (1)
(signal split into two towers below threshold)



collinear sensitivity (2)
(sensitive to E_t ordering of seeds)

- But seeded cone is easy to implement and fast -> added **split/merge step** helps with dynamics;
- alternatively use **seedless cone** (typically slow, though!);

schematics from G. Blazey et al., "Run II Jet Physics", hep-ex/0005012v2, 2000

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Jet Finding Algorithm Implementations (2)

- K_t **clustering** avoids most of the problems of cone finders, but can be very slow (CPU time increase ~n^3) -> use pre-clustering to reduce number of kinematic objects on input;
- other **common implementation** details for both algorithms: **default 4-momentum recombination** in jet clustering procedures, user-defined pre- and final selections, noise suppression based on pre-summation of calorimeter towers (i.e. suppress negative signals from pile-up and noise in calorimeters, should be handled by calorimeter clustering in the near future)…
- …and **recent hugh software design effort** (jet and detector event data models, jet algorithm implementations) to make jet finders universal or order independent: can now take tracks, calorimeter cells, -towers, -clusters, energy flow objects, and MC truth objects on input without code changes or adaptations (all in releases since ~May 2004);
- performance improvement expected from using **calorimeter clusters with hadronic calibration** applied -> more stable against noise, better comparison with truth tracks when using input filters, better energy resolution;

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Seeded Cone Jet Algorithm Configuration

- uses uncalibrated (em scale) projective calorimeter towers on a $\Delta\eta\times\Delta\varphi$ = 0.1×0.1 grid;
- starting with the highest Et tower, surrounding towers are collected within ΔR = 0.7, with immediate updates of the jet 4-vector (towers are consider massless pseudo-particles, cone "walks" a bit);
- if no more towers are within the given radius, a new cone is started with not yet clustered Et tower, if the Et of the next possible seed is above 2 GeV;
- the process is inclusive, i.e. the same tower can contribute to different jets (no check if tower already clustered);
- the final jets need at least 10 GeV Et to survive;
- the following split/merge takes the highest Et jet and checks the rest for overlap; if overlap of more than 50% is found (measured in Et of common constituents with respect to the higher Et jet), the jets are merged;
- if the overlap is < 50%, the chaired constituents are removed from the farthest jet and attached to the closer jet;
- split/merge is continued until all overlaps are resolved -> each constituent is exclusively assigned to one jet only;

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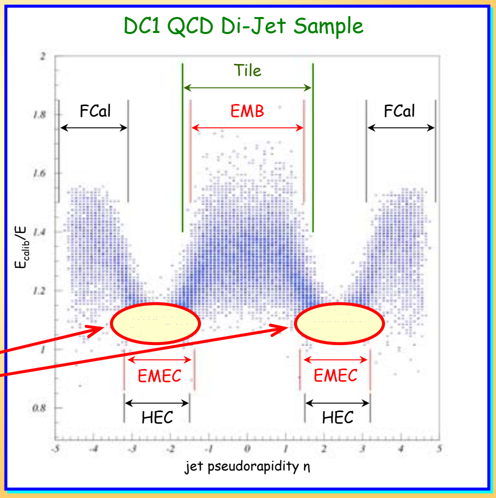
Cone/Kt Jet Calibration (1)

- cone or Kt jets (D=1) are presently not calibrated after jet formation -> uncalibrated constituents do not allow application of input selection based on signal (cannot be compared to particle level jet!);
- jet calibration is applied using an H1 motivated cell weighting method: cell signals in the jet are retrieved, and weighted according to the corresponding cell energy density -> recombination of weighted cells adjusts jet kinematic (scale & direction!);

Weights in EndCaps fixed now!



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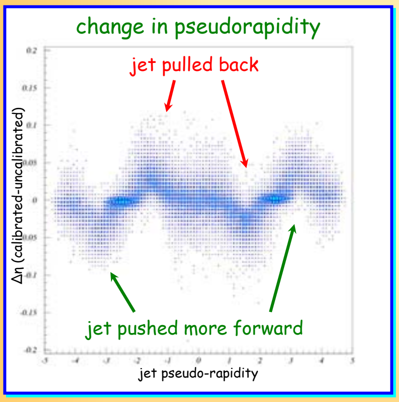
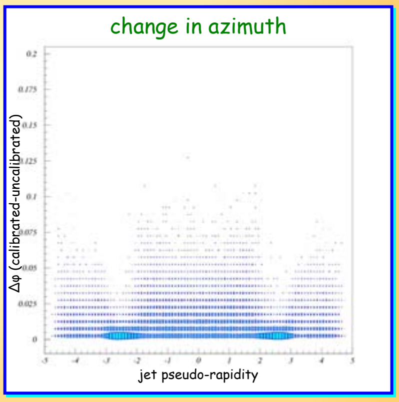
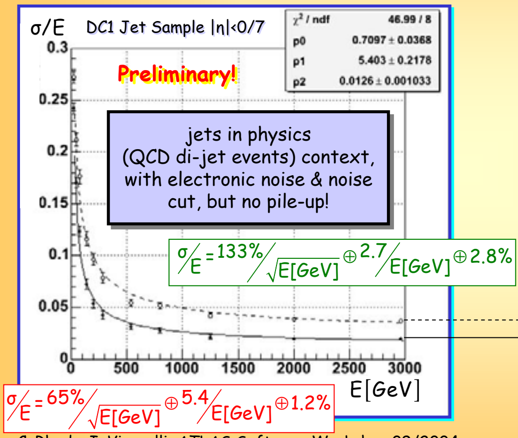
Cone/Kt Jet Calibration (2)





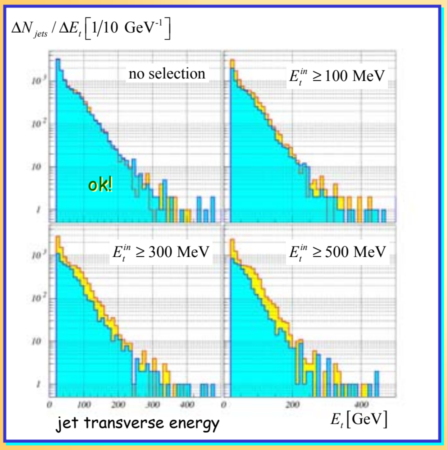
Cone/Kt Jet Calibration (3)

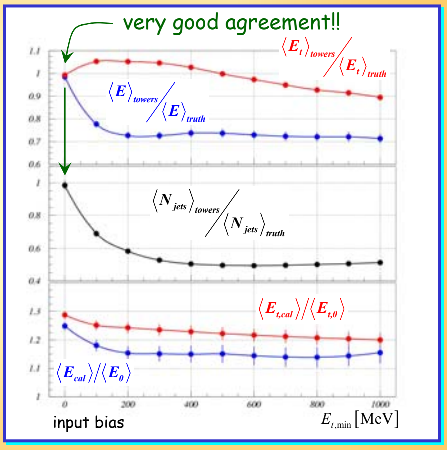


C. Rhoda, I. Vivarelli, ATLAS Software Workshop 09/2004

- calibration makes jet response flat within +/-2% up to 3 TeV;
- improvement in resolution indicates significant compensation effect;
- effect of pile-up not completely understood -> spring 2005: new simulations (millions of QCD di-jets + pile-up);

Input Biasing in Kt Jets: Jet Signals





MC truth   Tower jets

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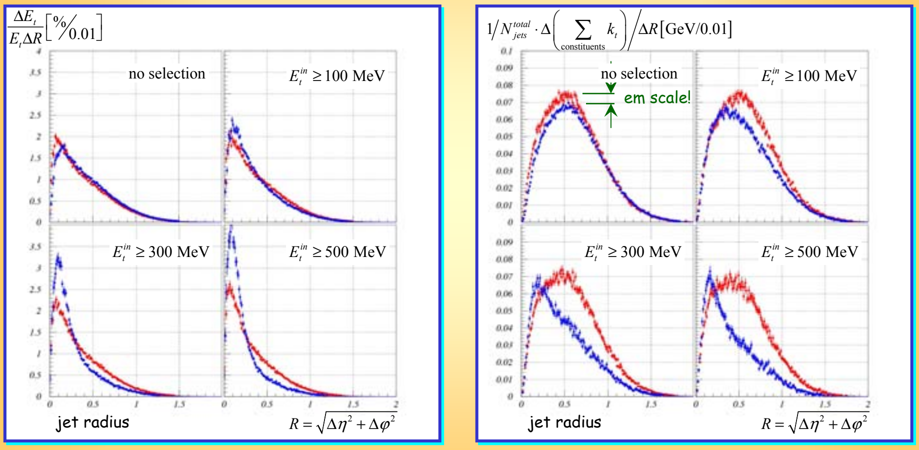
University of Arizona
Tucson, Arizona 85721

Input Biasing in Kt Jets: Jet Shapes



Truth jets Tower jets Truth jets Tower jets

TeV4 LHC Workshop
February 3-5, 2005 at Brookhaven National Laboratory
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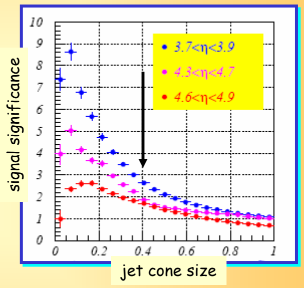
Jet Physics Considerations

- little activity on theoretical issues right now -> we compare to the (closest) particle jet as a reference for reconstruction quality (also # of jets etc.);
- Kt jet resolution is worse than cone (small signals with large fluctuations explicitely pulled in by algorithm) -> we need to understand/stabilize the input (calorimeter signals) better;
- we also like to connect more to QCD related issues: realistic evaluation of the kinematic regimes accessible using reconstructed jet events -> effect of non-linear jet energy calibration based on calorimeter cells (!) on error on x, Q^2; jet finding efficiencies at the boundaries (sensitivity study, basically), effects of detector acceptance…(quite some work going on wrt theoretical uncertainities of PDFs -> experimental limitations really straight forward/understood ?) ;
- "small" jets in pile-up under signal event -> suppression strategy ? Can we learn something for soft QCD ? Special triggers ?
- forward jet calibration in the presence of low/high lumi pileup… (no tracking, insignificant Pt contribution -> Et miss normalization ??);

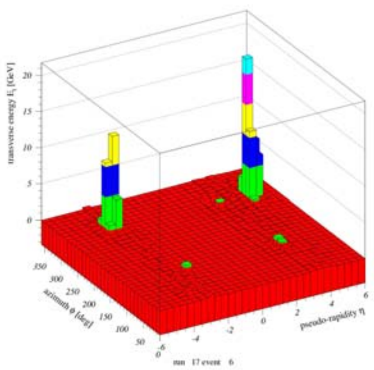
Forward Jet Reconstruction

- certainly a valid question: how well can forward jet kinematics be reconstructed in the presence of pile-up (here at 10^{34});
- studied signal significance (= signal/RMS pile-up) for "tag jets" in WW scattering vs jet cone size;
- not at all easy – cone size optimization needs to include many aspects: pile-up fluctuations take over around $\Delta R \approx 0.4$, below that out of cone (big hadronic showers compared to cone size), signal linearity etc.;
- maybe specialized jet algorithm needed in this region -> much more work needed, especially transition to less "violent" signal regimes in the endcaps;



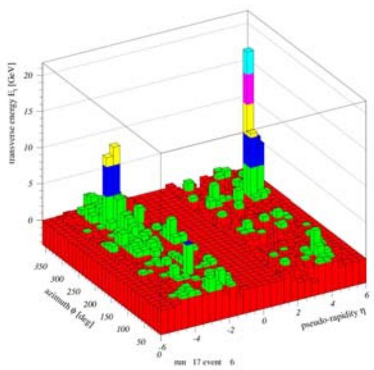
qqWW->qqH->qq+X

no pile-up



ATLAS Forward Direction Only!

pile-up @ 10^{34}



ATLAS Forward Direction Only!

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Conclusions

- ATLAS has easily configurable jet reconstruction algorithms available;
- Default jet finder is seeded cone using calorimeter towers (full calibration available for cone size 0.7);
- Typical scale error today 5-10%, including using cone based calibration on Kt jets -> not quite where we want to be, but not too bad either;
- Need to understand pile-up contributions before getting too fancy with calibration -> fear that pile-up (positive signal bias!) suppression capability will ultimatively determine jet reconstruction quality, not so much e/h compensation (gut feeling only!);
- Simple Et cut on jet finder input to suppress noise unacceptable, as expected -> better strategies will become available with calibrated cluster input (summer 2005, hopefully);