Jet sub-structure

Interplay with the detector

Extracted from a much longer discussion at the:

March 18 TeraScale meeting on

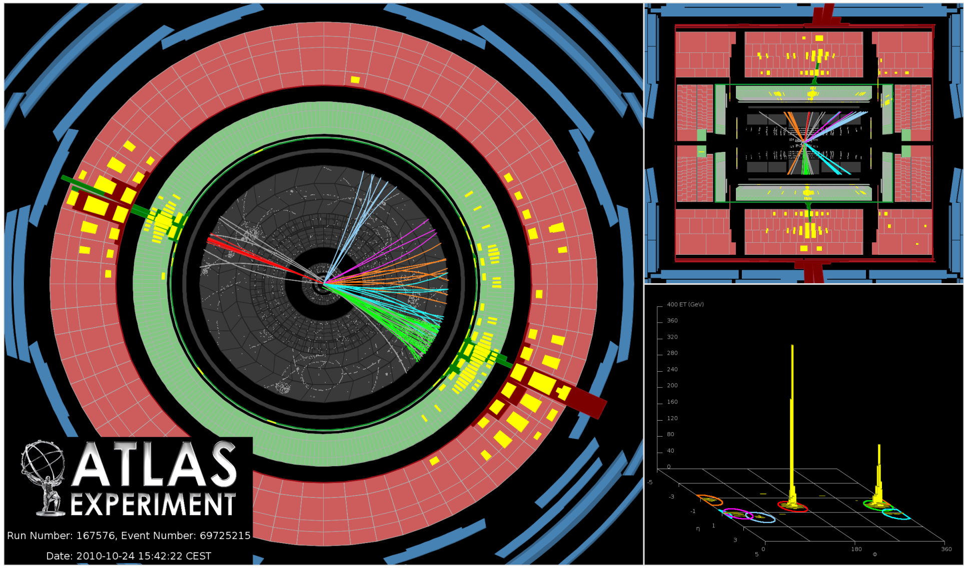
"emerging opportunities at the Linear Collider"

University of Oregon, USA

Marcel Vos (IFIC Valencia)

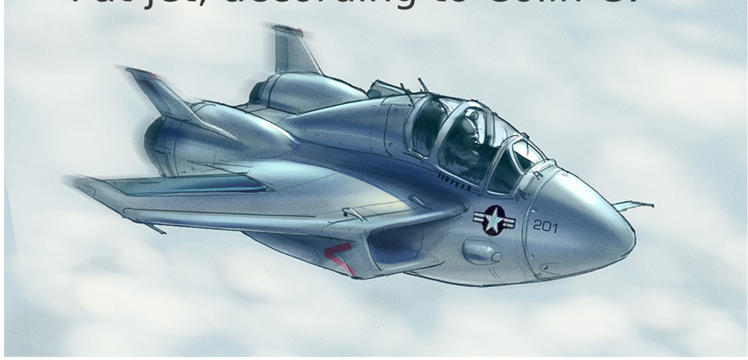
Today's menu:

Boosted objects



Detectors!

Fat jet, according to Colin G.



Fat jets

Tools & Techniques: BOOST2010 Benchmark Samples

- ✔ Many groups, many great ideas, many promising results, but … not easy to compare performance in a meaningful way
- ✔ Benchmark: created events for QCD inclusive jets and SM tt production
- ✔ Pythia and Herwig, several tunes for UE, several options for parton shower. Their use here does not imply we claim that these samples are any more "true" than others. Recent LHC work has rendered them obsolete, as expected.
- ✔ Samples provided on two "mirror" sites:
  - ➔ http://www.lpthe.jussieu.fr/esalam/projects/boost2010-events/
  - ➔ http://tev4.phys.washington.edu/TeraScale/boost2010/

HERWIG is used in conjunction with JIMMY that takes care of the underlying event generation. For this study we rely on a tune from ATLAS [ATLPHYS-PUB-2010-002]

PYTHIA 6.4, with a number of tunes for the UE description: DW, DWT and Perugia0. The parton shower model of the DW and DWT samples is Q2-ordered. Both yield identical results for the underlying event at the Tevatron. However, the two tunes extrapolate differently to the LHC, where DWT leads to a more active underlying event. The Perugia tune [Peter Zeiler Skands. Tuning Monte Carlo Generators: The Perugia Tunes. 2010.] uses a pT -ordered parton shower.

To disentangle the impact of the parton shower and that of the underlying event, we generated an additional set of samples with the UE generation switched off.

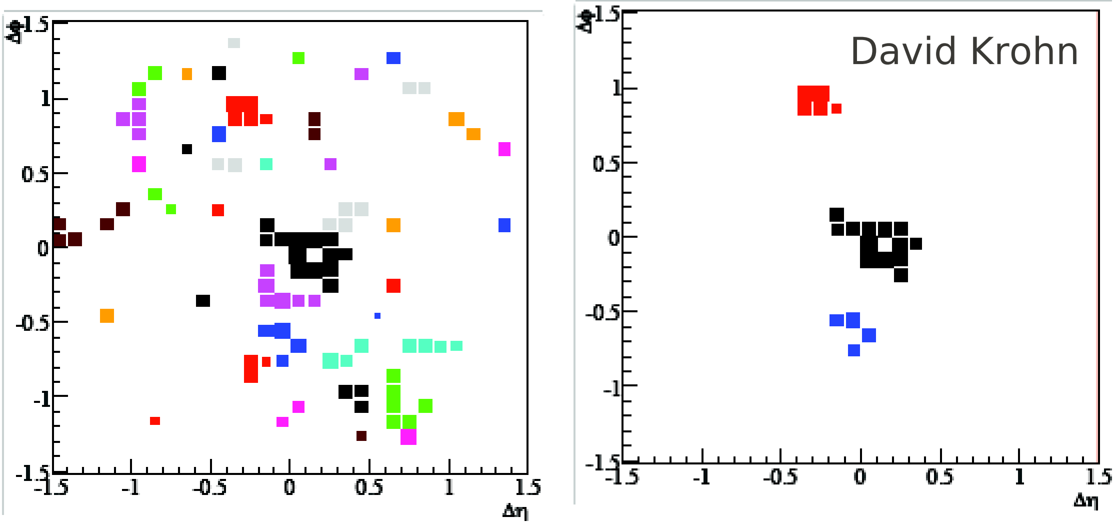
CSIC

IFIC

Tools and Techniques: grooming

Jet substructure is often hidden:

- ✔ **Soft emissions inside the jet**
- ✔ **Underlying event**
- ✔ **Pile-up***



*Pile-up is identified and (partially) corrected for by associating jets or clusters to tracks and vertices

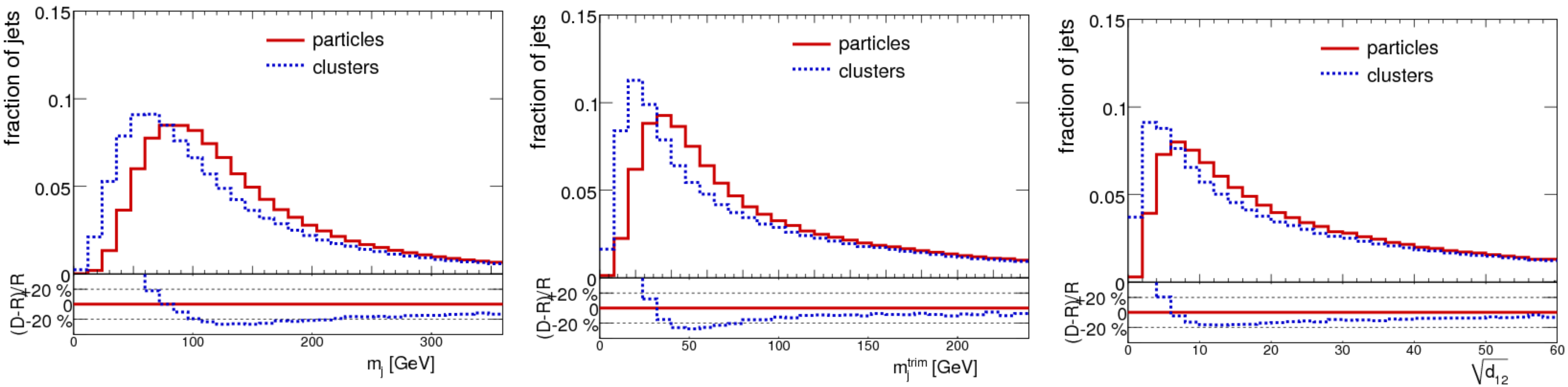
***Jet grooming techniques* to remove the "softest" parts (at large angle) of the jet:**

- ✔ **Filtering:** break jet into subjets on angular scale R_{filt} , take n_{filt} hardest subjets Butterworth, Davison, Rubin & Salam '08
- ✔ **Trimming:** break jet into subjets on angular scale R_{trim}, take all subjets with $p_{T,sub} > \varepsilon_{trim} p_{T,jjet}$ Krohn, Thaler & Wang '09
- ✔ **Pruning:** as you build up the jet, if the two subjets about to be recombined have $R > R_{prune}$ and min(pt1, pt2) < ε_{prune} ($p_{T1} + p_{T2}$), discard the softer one. Ellis, Vermilion & Walsh '09

Boost2010 ignored the variable R option

Results: detector uncertainties

Simple "theorist's" detector with pessimistic granularity ($\Delta\eta \times \Delta\phi = 0.1 \times 0.1$), energy threshold (1 GeV)



Basic "take-away" message from BOOST2010:

Jet substructure requires a very detailed understanding of the physics AND the detector

Results on the impact of the detector: all observables receive large corrections from clustering. Detector response must be modeled precisely in MC to avoid large uncertainties on the calibration that takes the detector response back to "particle-level"

CAVEAT: this detector model is not very satisfactory. Propagate a more realistic detector model to theorists designing substructure analyses

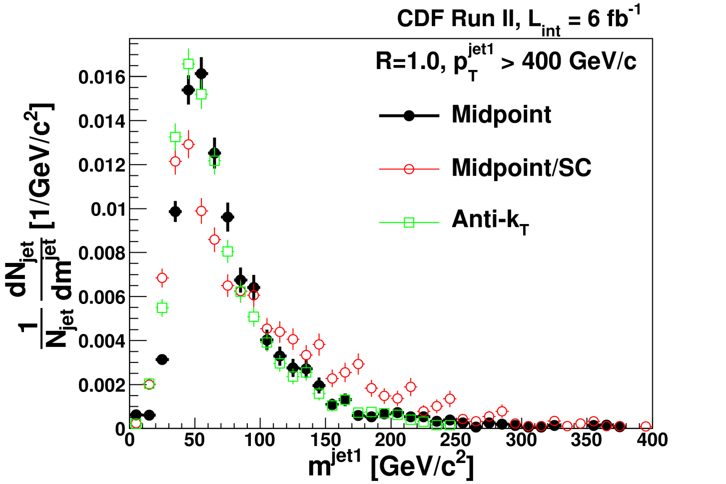
CSIC

IFIC

Experimental work

From the introduction of the hadronic WG report: "We hope that this report may be an incentive for further work and in particular for studies into the substructure of highly energetic jets in the earliest LHC data."

Experiments need to deploy new techniques and "commission" jet substructure tools. So far, no published results using filtered C/A1.2 jets. A section discusses "history", offering guidance found in Hera and Tevatron studies.



S. Chekanov et al. Measurement of subjet multiplicities in neutral current deep inelastic scattering at HERA and determination of s. Phys. Lett. B, 558:41, 2003.

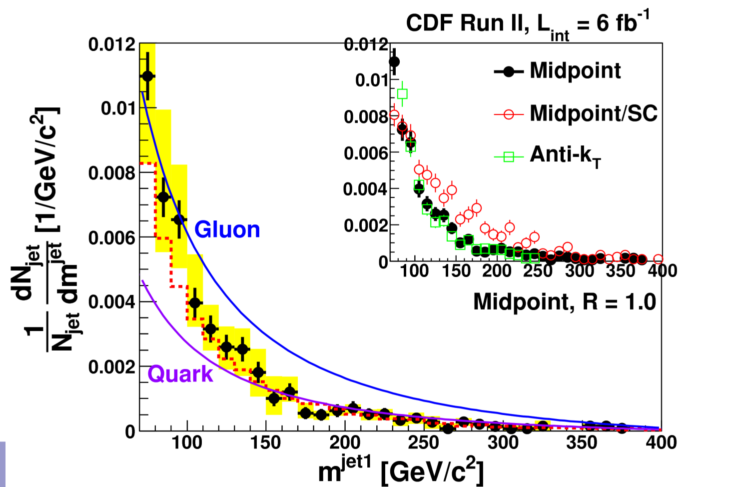
S. Chekanov et al. Substructure dependence of jet cross sections at HERA and determination of s. Nucl. Phys. B, 700:3, 2004.

S. Chekanov et al. Subjet Distributions in Deep Inelastic Scattering at HERA. Eur. Phys. J, 63:527, 2009.

V.M. Abazov et al. Subjet multiplicity of gluon and quark jets reconstructed with the kT algorithm in p¯p collisions. Phys. Rev. D, 65:052008, 2002.

D. Acosta et al. Study of Jet Shapes in Inclusive Jet Production in p¯p Collisions at ps = 1.96 TeV. Phys. Rev. D71:112002, 2005.

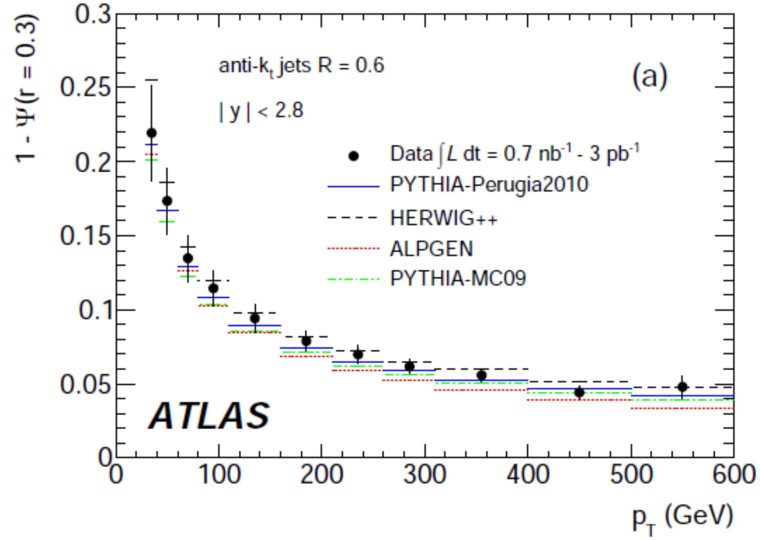
T. Aaltonen et al. The Substructure of High Transverse Momentum Jets Observed by CDF II. CDF Note, 10199, 2010.



Experimental work: outlook

Much has been learnt from the LHC. ATLAS and CMS have published jet shapes papers.

Study of Jet Shapes in Inclusive Jet Production in pp Collisions at $\sqrt{s}$ = 7 TeV using the ATLAS Detector, Phys Rev. D arXiv:1101.0070 [hep-ex],
The CMS collaboration, Jet Transverse Structure and Momentum Distribution in pp Collisions at 7 TeV, QCD-10-014-PAS, july 2010, 10 nb^{-1}, 20 < p_T < 100 GeV



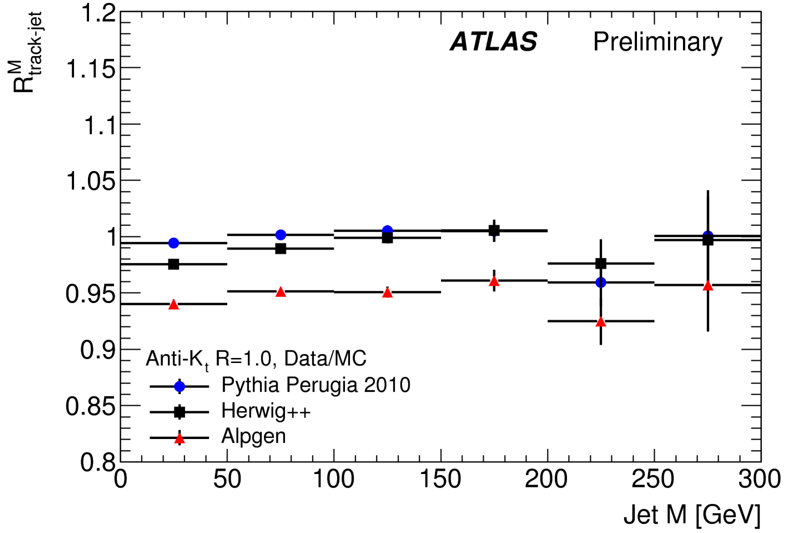
Results feeding back into tunes, strategies to deal with pile-up under development, calibrations improving. Make sure non-standard jet algorithms and observables are not forgotten (i.e. ATLAS boosted objects group, jet substructure paper)

ATLAS-CONF-2011-073

In 2010 the ATLAS “boosted objects” forum launched an effort in the Standard Model group (supported by different physics groups) to understand “fat” jet substructure in 2010 jet data.

Understand jet mass scale, calibrate using MC, determine uncertainties:

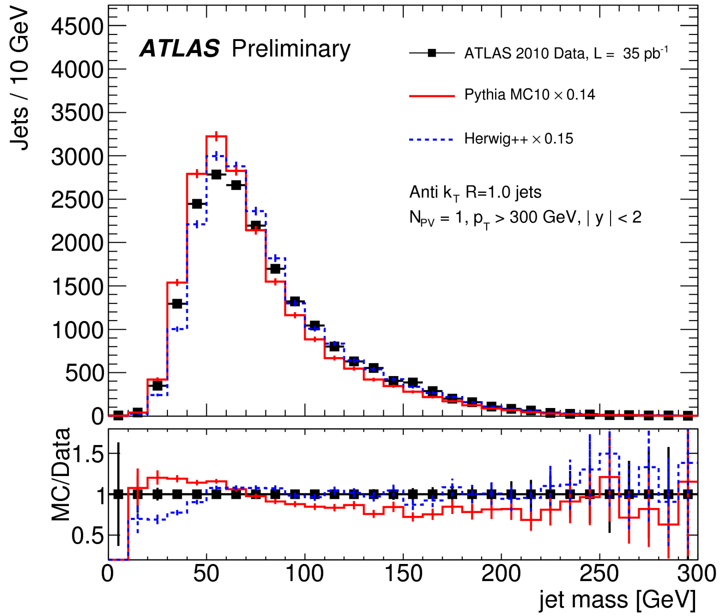
- MC-derived calibration for jet mass
- Study pile-up (but ignore for measurement)
- Jet mass and splitting scale systematics understood using “in situ” methods
- Uncertainties on resolution/extrapolation beyond tracker coverage from MC a la ICHEP2010

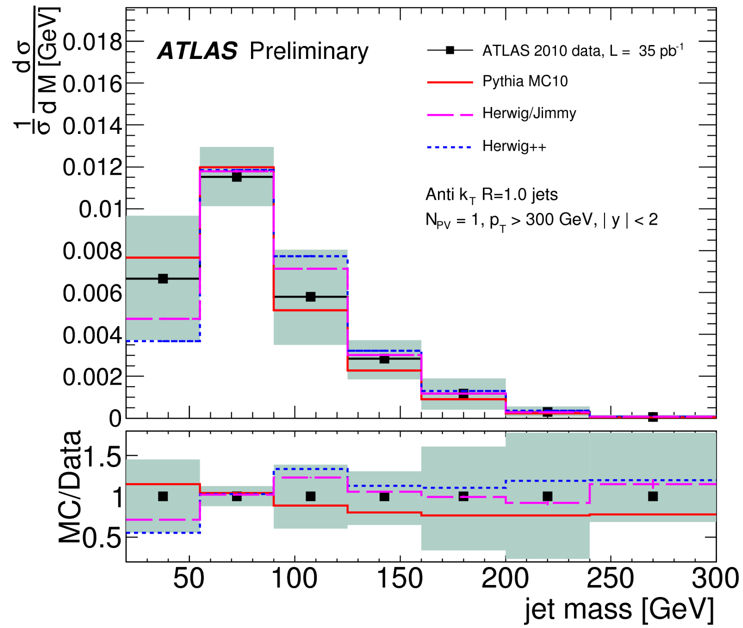


JES, JER, JMS and JMR available for AntiKt10, C/A1.2 and filtered C/A1.2

Some features of substructure response are understood. No attempts yet to improve the performance (using tracks, revisiting clustering,...). It would be interesting to see what CMS comes up with...

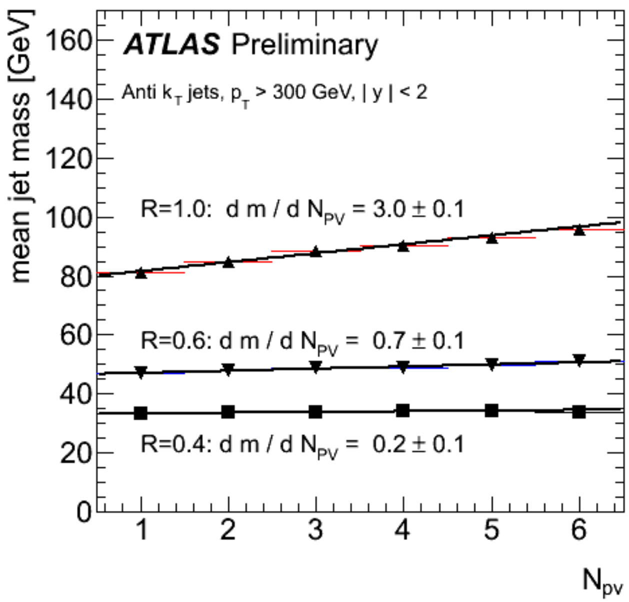
Unfold the measurement

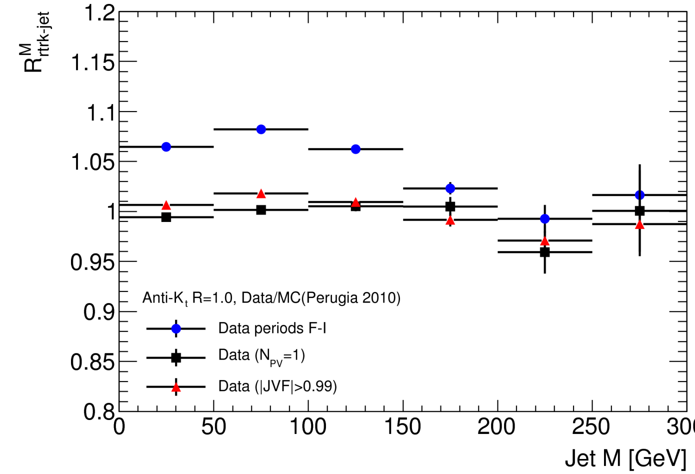




Improving on this preliminary result in three ways for the paper:
- add one more substructure observable (n-subjettiness, David Miller)
- slightly more aggressive systematics (limiting MC set to generators that are compatible with data)
- unfold using full true → reco matrix will allow smaller bin size

Pile-up



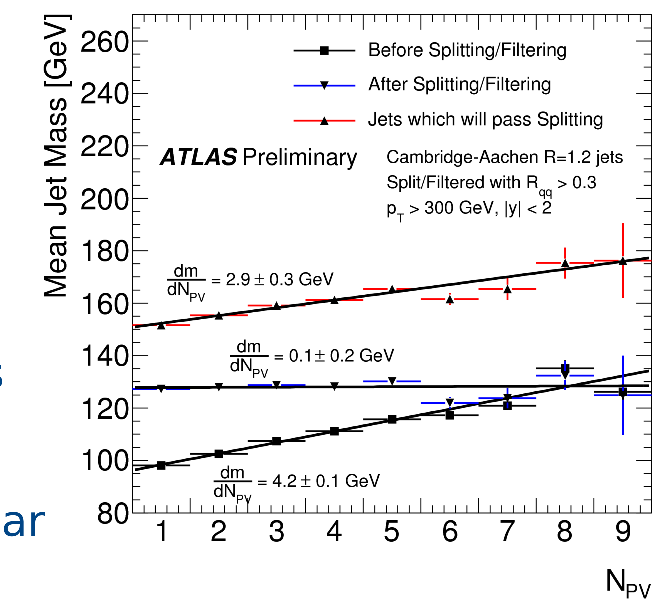


Pile-up is a major issue

R=1 jets gain weight at a rate of ~3 GeV/additional vertex

No solution is quite ready yet:

- cutting on N_{pvx} is impossible
- JVF cut restores the scale at large acceptance loss
- cluster-level correction seems hard/impossible
- jet-level correction not available for “fat” jets
- groomed “fat” jet collection expected later this year



Interplay jet substructure and detector

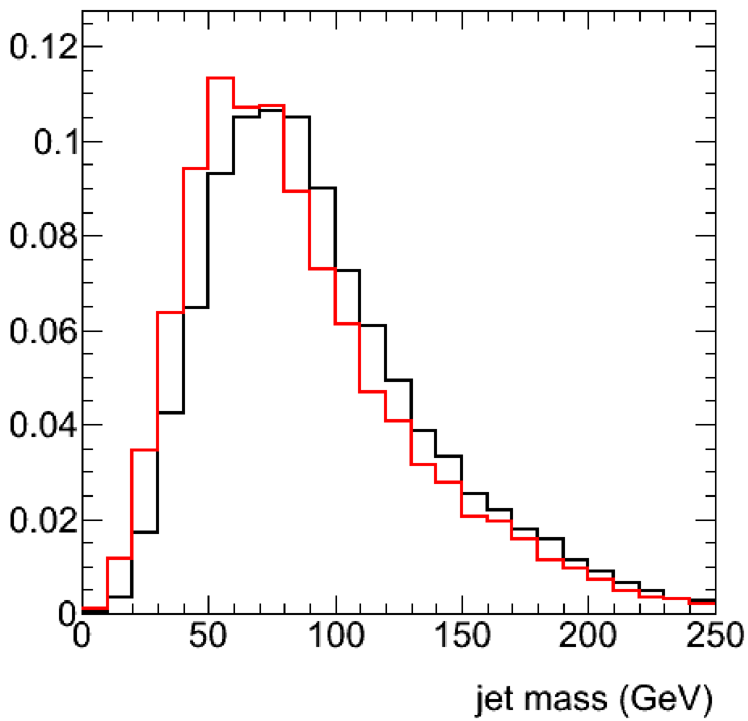
- ATLAS has studied substructure response in great detail
  - Know what's important and what's not
- In the remainder of this talk I'll discuss the interplay of detector and jet substructure using a toy model
  - Building on work by Chris Vermillion and Steve Ellis
  - Hope to bring this to maturity in the next months, with detector experts (P. Loch, M. Thomson)
  - A stress test for jet substructure tools (definitely not a competitor for full simulation)
  - If successful provide this as a FastJet tool

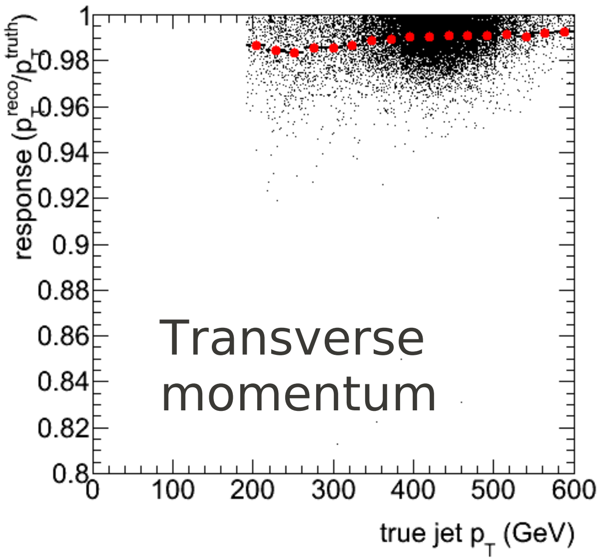
CSIC

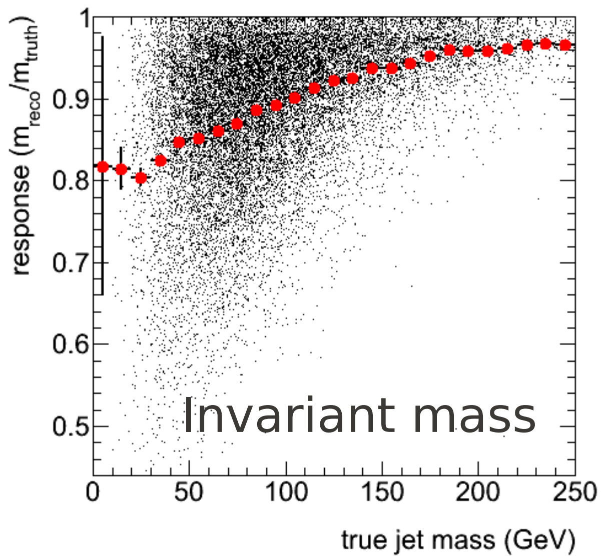
IFIC

Simple detector effects

Threshold: particles with E < 1 GeV are simply discarded





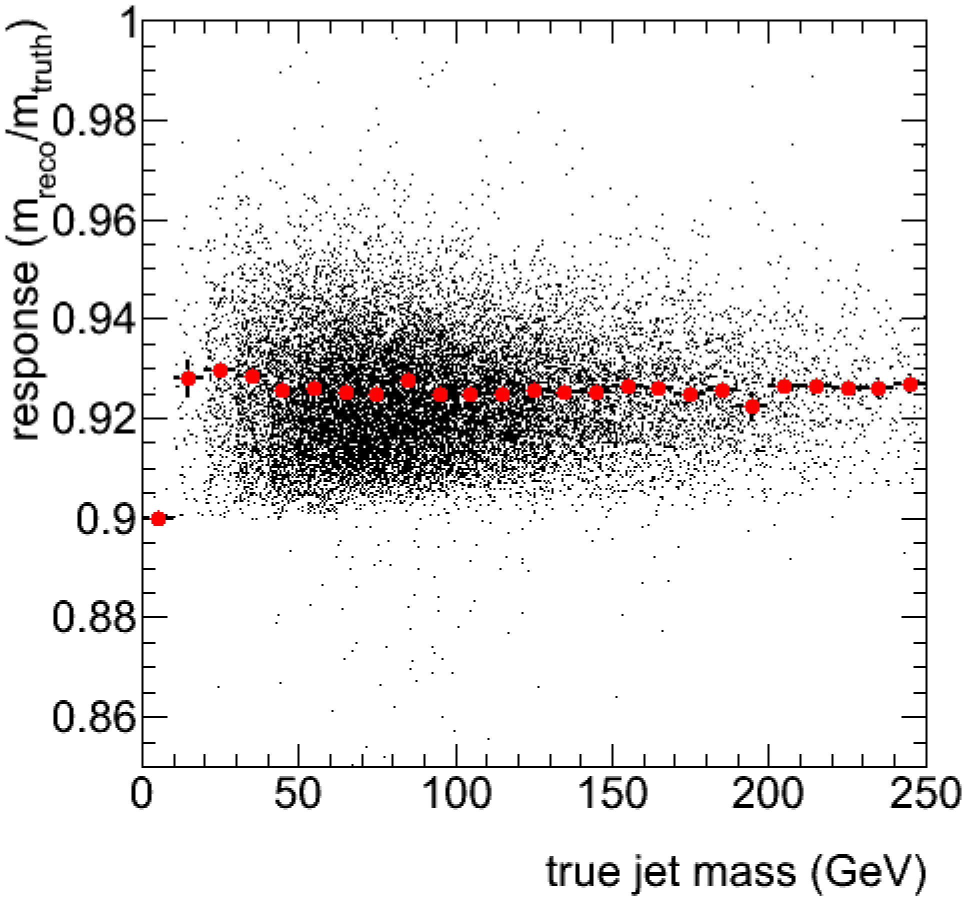


- ✔ Transverse momentum measurement relatively stable
  - ➔ Response hardly affected: average ~ 99 %
  - ➔ Resolution effect small: RMS < 1 %
- ✔ Strong impact on jet invariant mass measurement
  - ➔ Mass response drops by 10s of % for low mass jets
  - ➔ Resolution 6 % overall

Simple detector effects

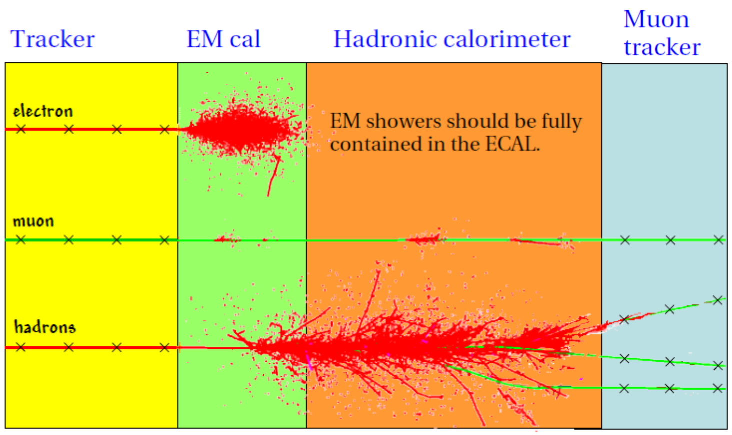
Hadronic scale off by 10 %

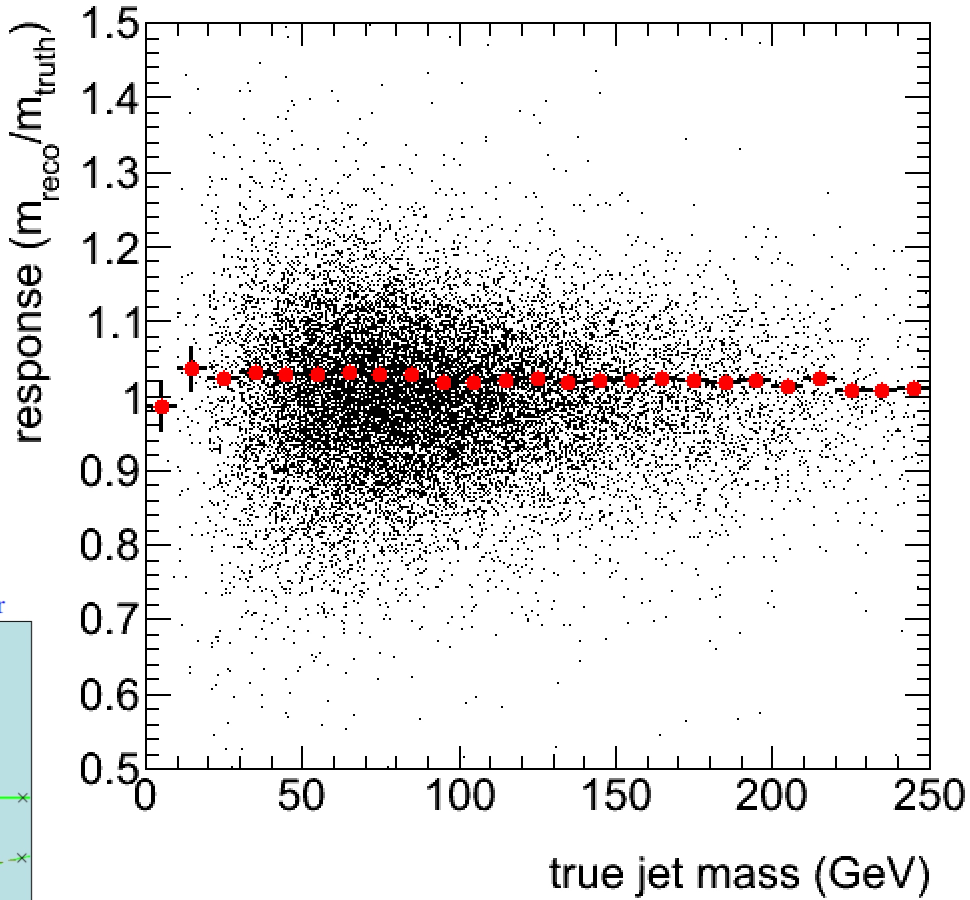
- ✔ difference between QGSP and QGSP_BERT
- ✔ Overall effect on scale is compensate' even by blind calibration
- ✔ Calibration that distinguishes EM/hadronic scales needed to remov residual resolution effect



Simple detector effects

- ✔ Resolution
- ✔ Hadronic;: 50%/sqrt(E) + 3 %
- ✔ EM: 20 %/sqrt(E) + 1 %



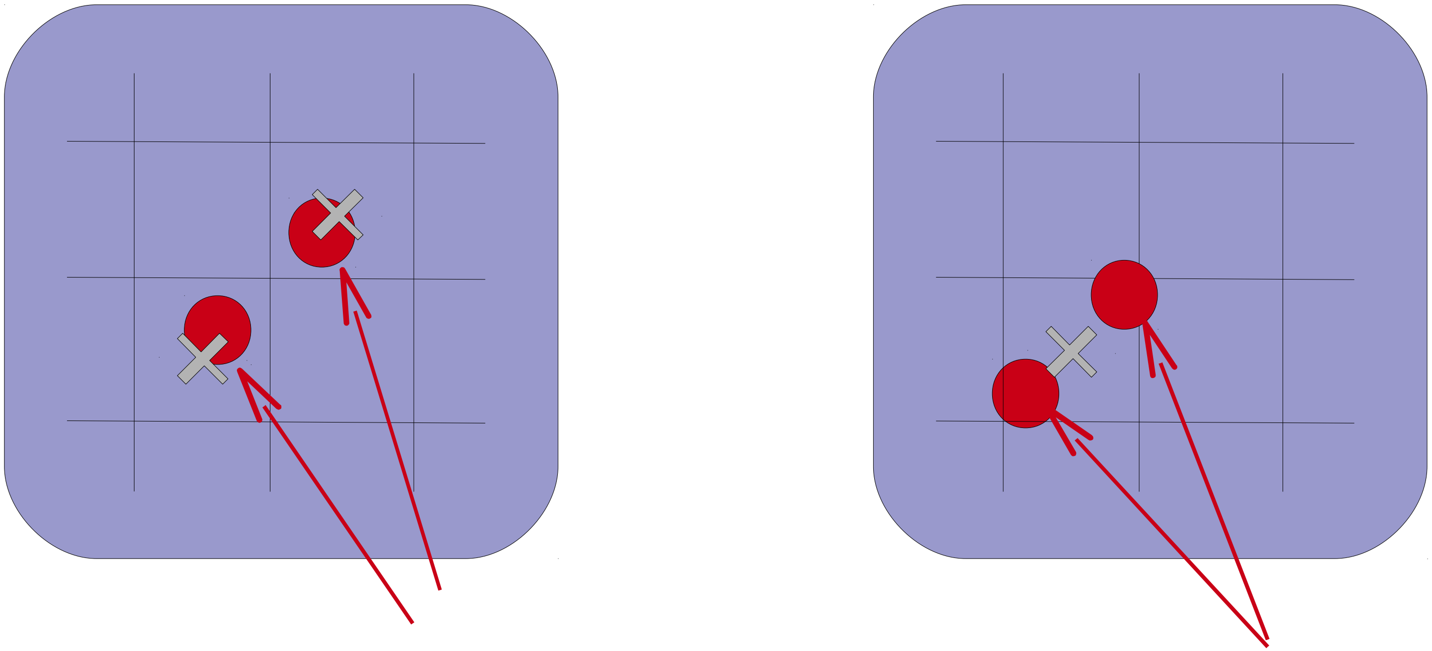


Mass destruction

A toy clustering model. Shoot two 50 GeV pions with $\Delta R = 0.1$.

Cluster on a $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ grid

Compare $m_{\pi\pi}$ (= 5 GeV) with "measured" mass



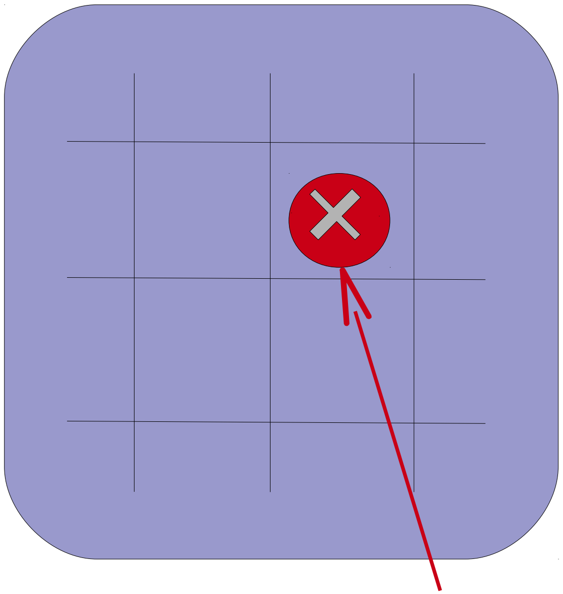
Two clusters. Invariant mass ~correct

One mass-less cluster

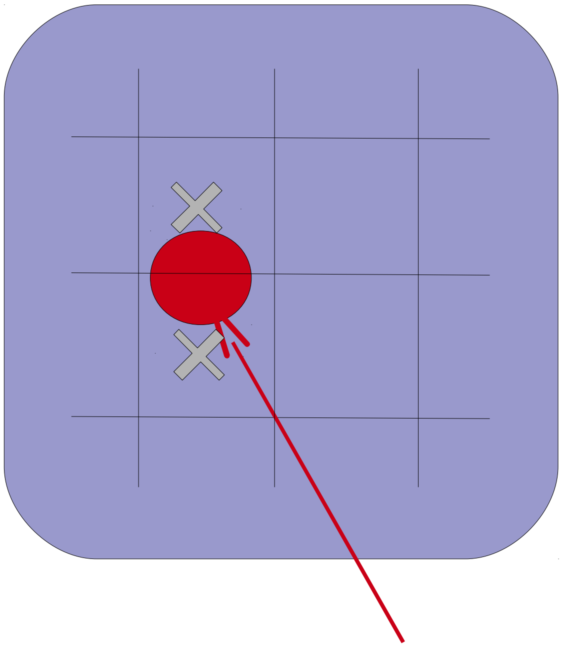
Mass generation

A toy clustering model. Shoot a single 100 GeV pionCluster on a $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ grid

Compare $m_{\pi\pi}$ (~ 0 GeV) with “measured” mass



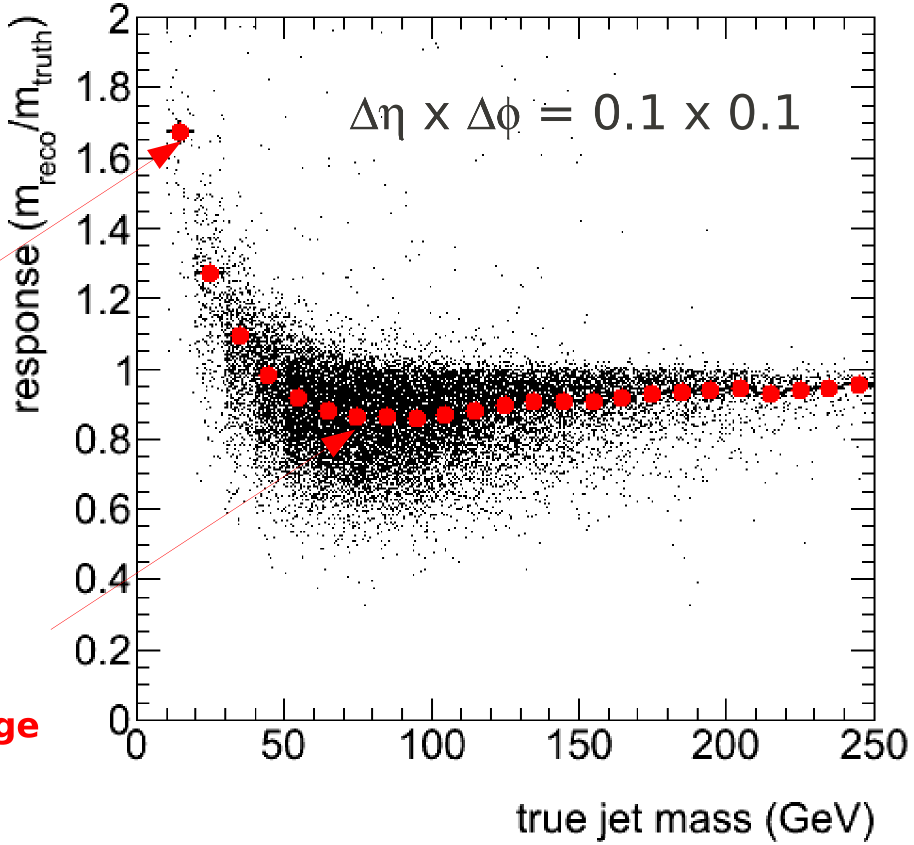
One cluster. Invariant mass = 0



Two clusters
Invariant mass ~ 5 GeV

Impact of detector granularity on response

These and the following slides:
Herwig di-jet samples for 7 TeV LHC.
400 < pT < 500 GeV



Rise due to particles torn apart in clustering
→ promotion of low-mass jets

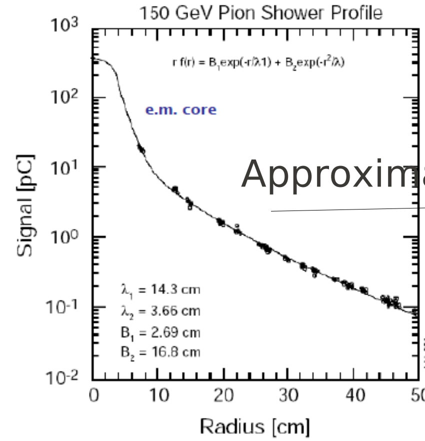
Dip due to merged particles
→ underestimate intermediate mass range

Trivial detector model leads to non-trivial and sizeable effects

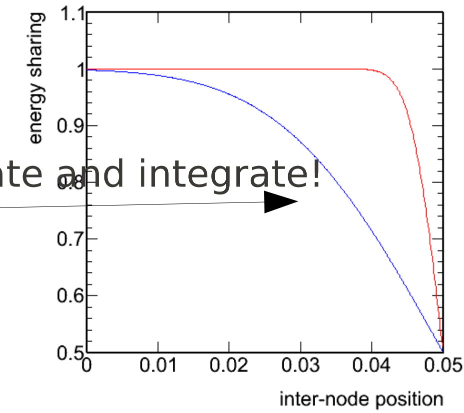
- Substructure is removed by clustering massive systems into a mass-less object
- Significant fake substructure is created by splitting mass-less objects (tearing them apart)

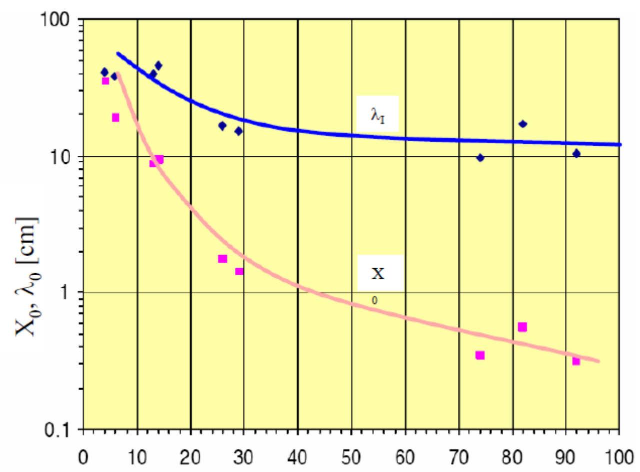
Granularity - Caveat

Assumptions on shower shape lead to strong differences in the observed response

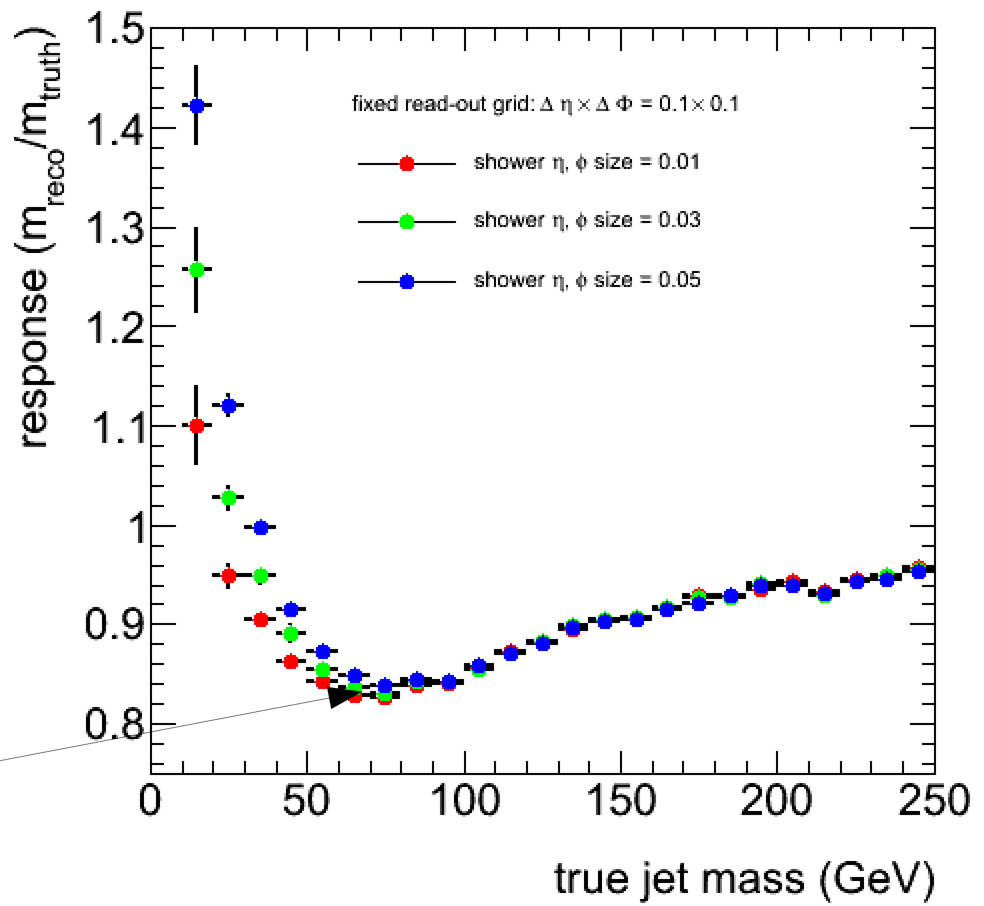


Approximate and integrate!



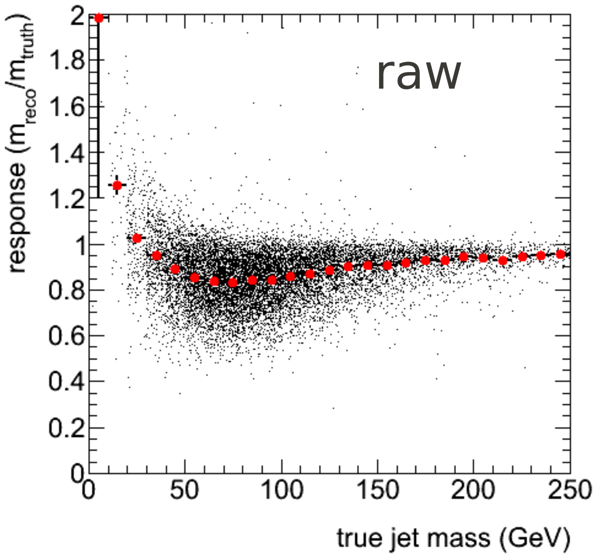


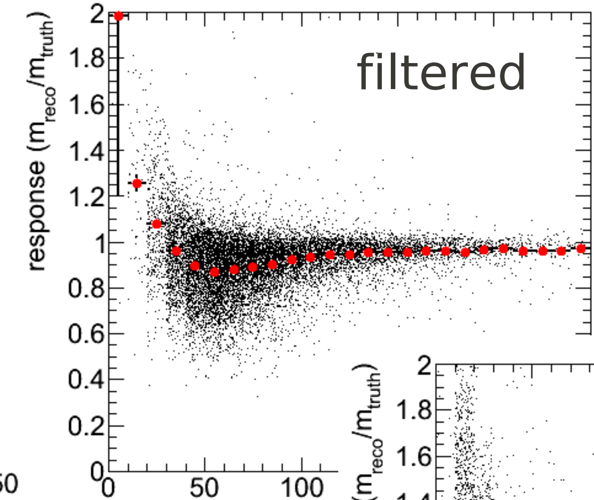
Real shower size depends on material and detector size



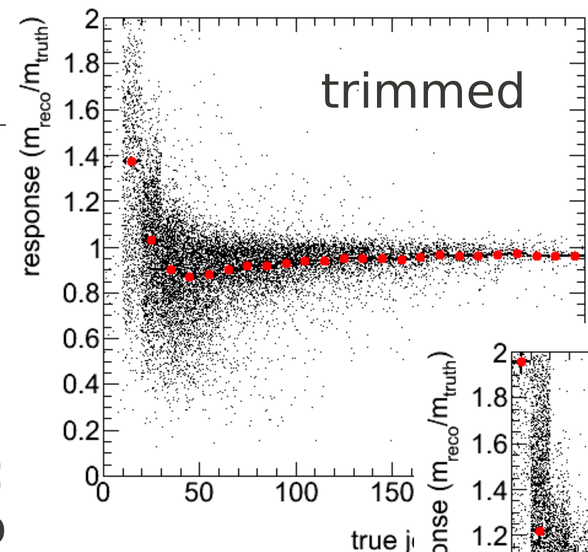
Dip +/- constant

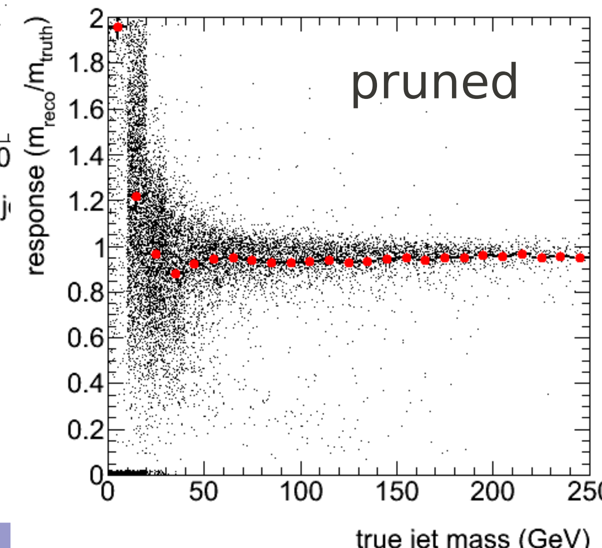
Grooming





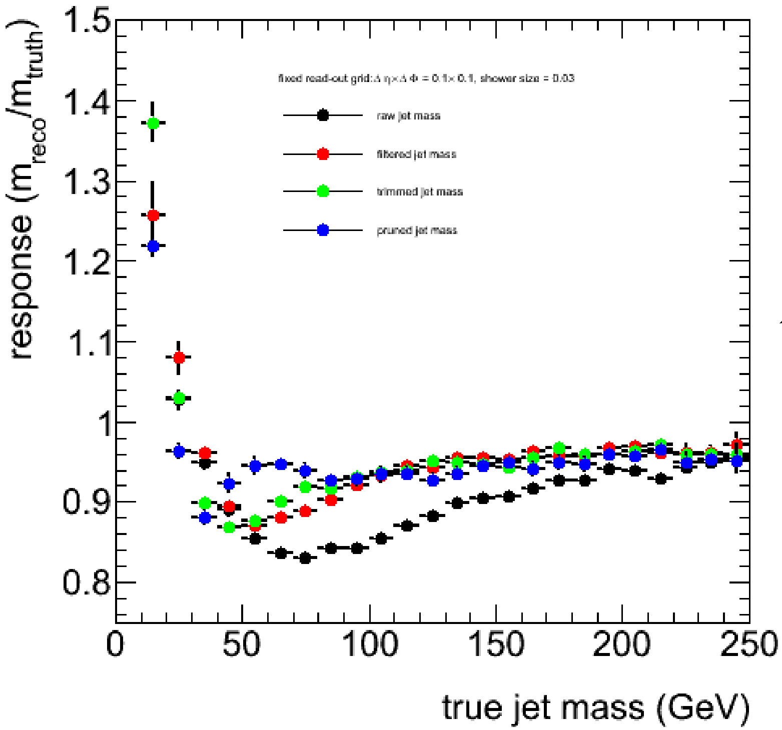
$\Delta\eta \times \Delta\phi = 0.1 \times 0.1$
shower size = 0.03





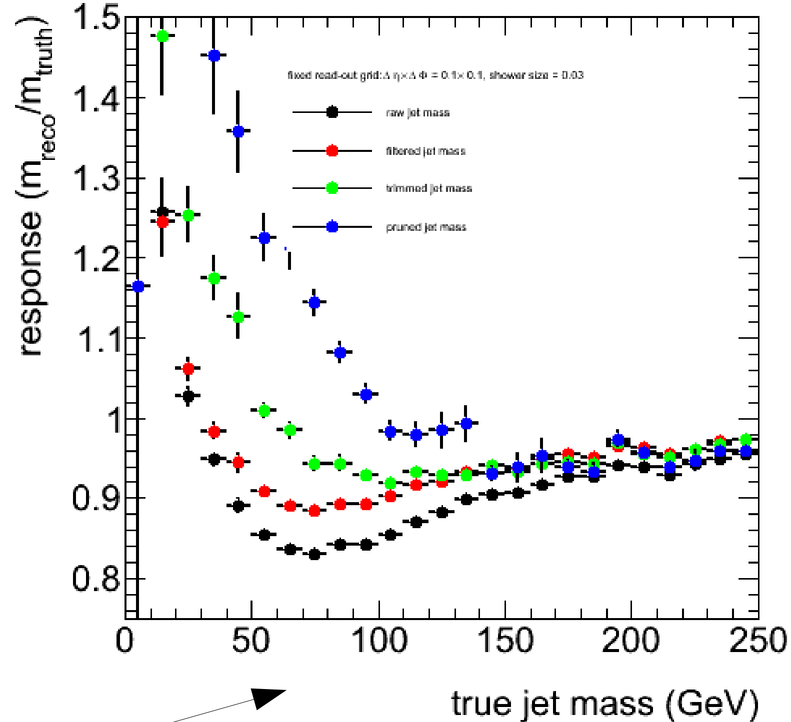
Try different grooming methods: in this setup pruning is known to act most aggressively, followed by trimming

Grooming



$\Delta\eta$ x $\Delta\phi$ = 0.1 x 0.1
shower size = 0.03

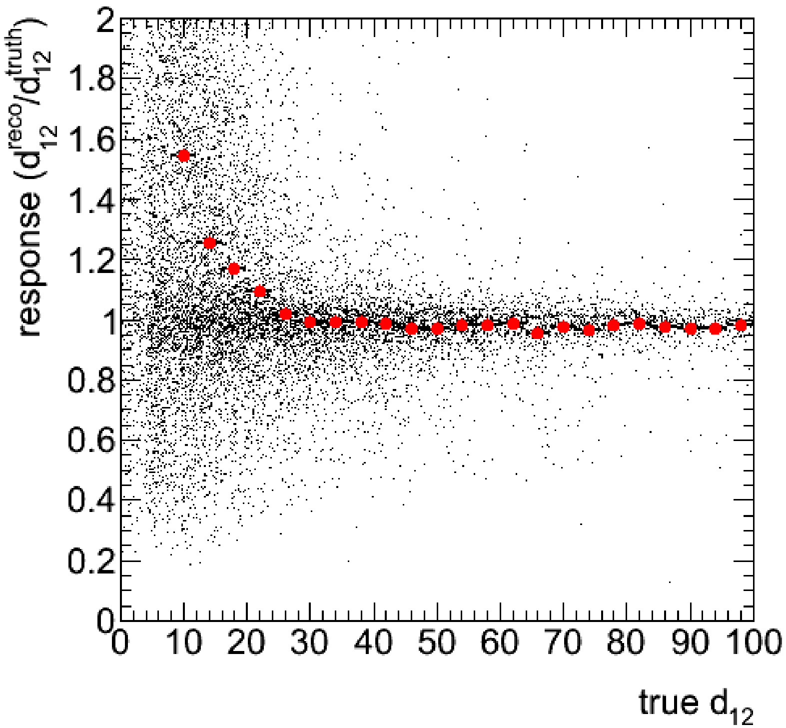
Denominator = groomed jet mass

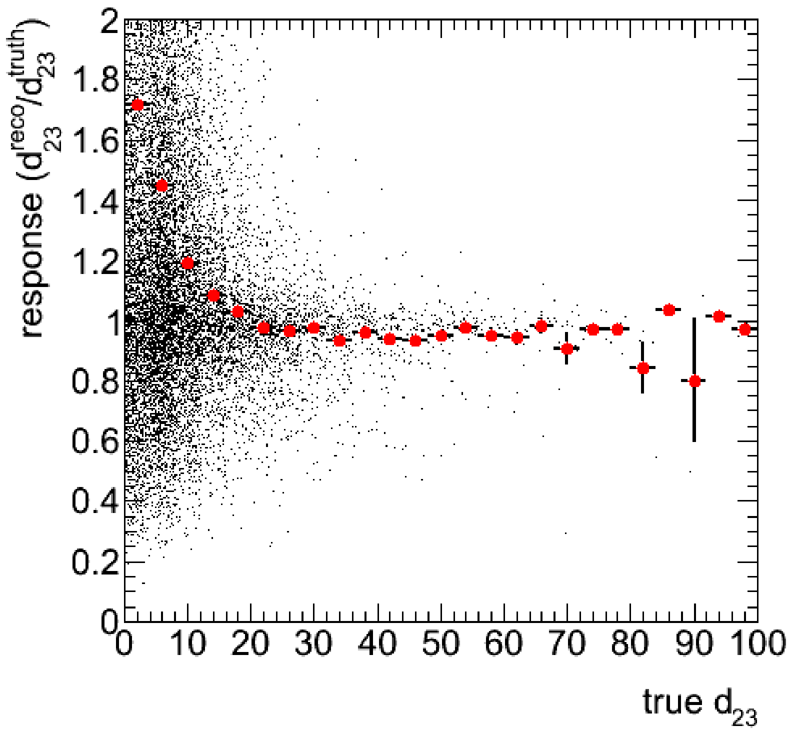


Grooming moves the response problems to lower true (groomed) mass!

Denominator = raw jet mass

Other substructure observables





✔ Splitting scales are very sensitive to limited granularity, especially for jets with little substructure

Now to highly granular calorimetry

Transvserse read-out granularity increased by order(s) of magnitude

+ very finely segmented ongitudinally!

However, shower size comparable*

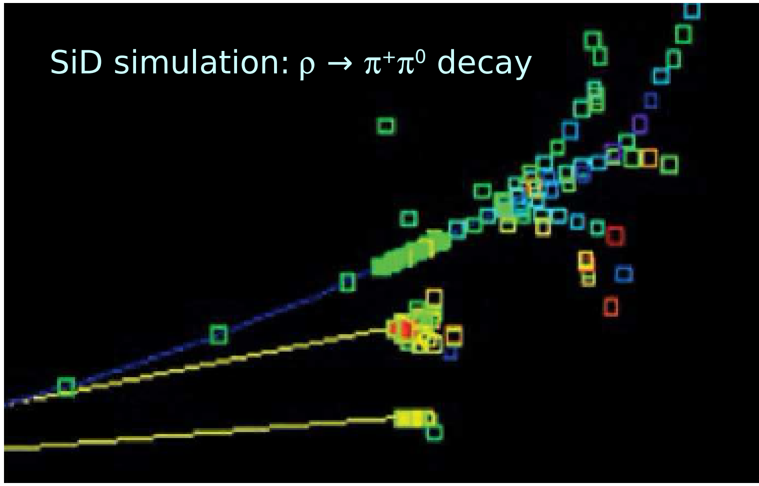
Spatial resolution on isolated particle:.

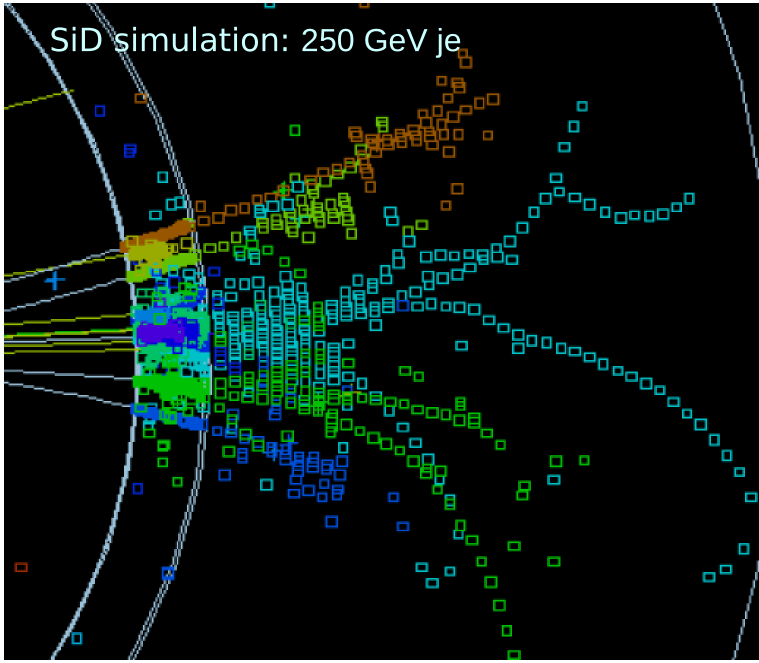
- ➔Assume: σ/sqrt(N_samples) → perfect

Two-particle resolution (minimal separation to cleanly disentangle two hadronic showers

- ➔Naively: σ

(*) remember Tungsten yields factor 2. larger detectors are not a very cost-effective way of dealing with this



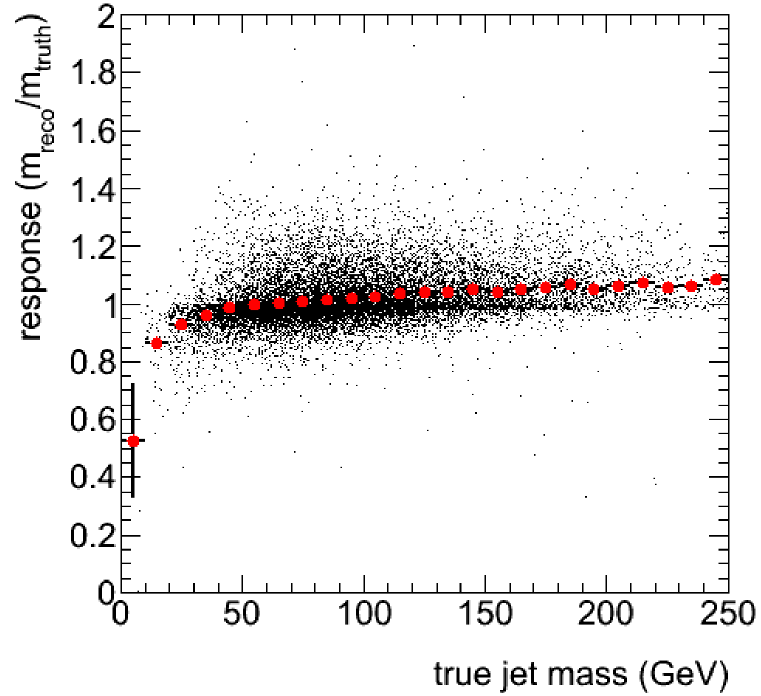


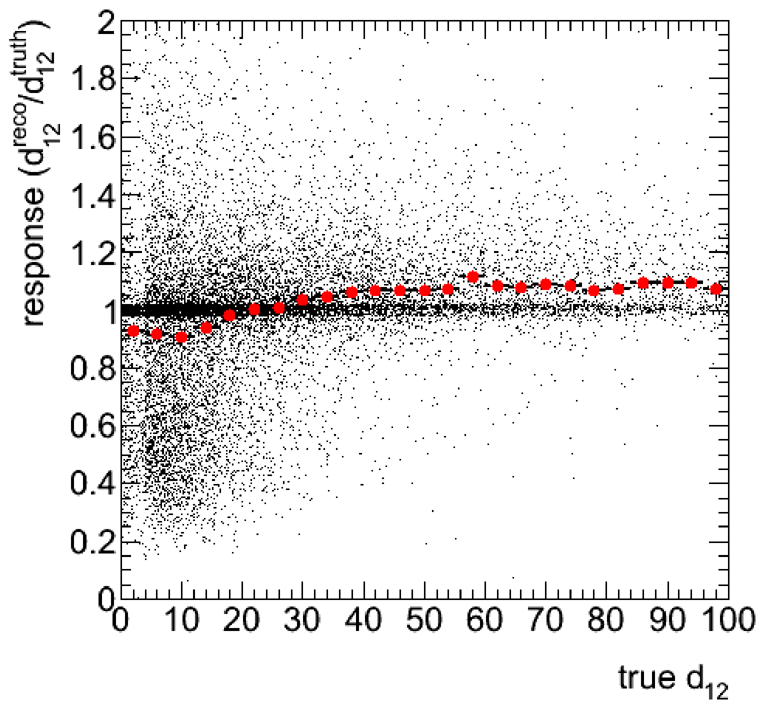
Highly granular calorimetry

- ✔ Hadronic energy deposits within $\Delta R < 0.1$ are merged into a single mass-less cluster
- ✔ Even with shower size of 0.1.. the response is extremely flat...
- ✔ Granularity term to resolution is smaller
- ✔ And nasty promotion of low-mass jets is gone!

- ✔ Validate this maybe-too-optimistic view with Pandora on full simulation

- ✔ Note I haven't used particle flow; the track information can be used to restore the mass of the merged clusters!!





IFIC
CSIC

Summary

- ✔ Simple set of tools to characterize and understand detector impact on substructure observables can help find “good” observables that show reduced sensitivity.
- ✔ Define benchmark set of “distortions (detector effects and pile-up).
- ✔ Understand in detail what can be groomed away (pile-up) and what cannot (some detector effects)
- ✔ Submit all proposed substructure observables to a common stress test. See which ones are least affected.

CSIC

IFIC