Hadronic Event Shapes at 10 TeV

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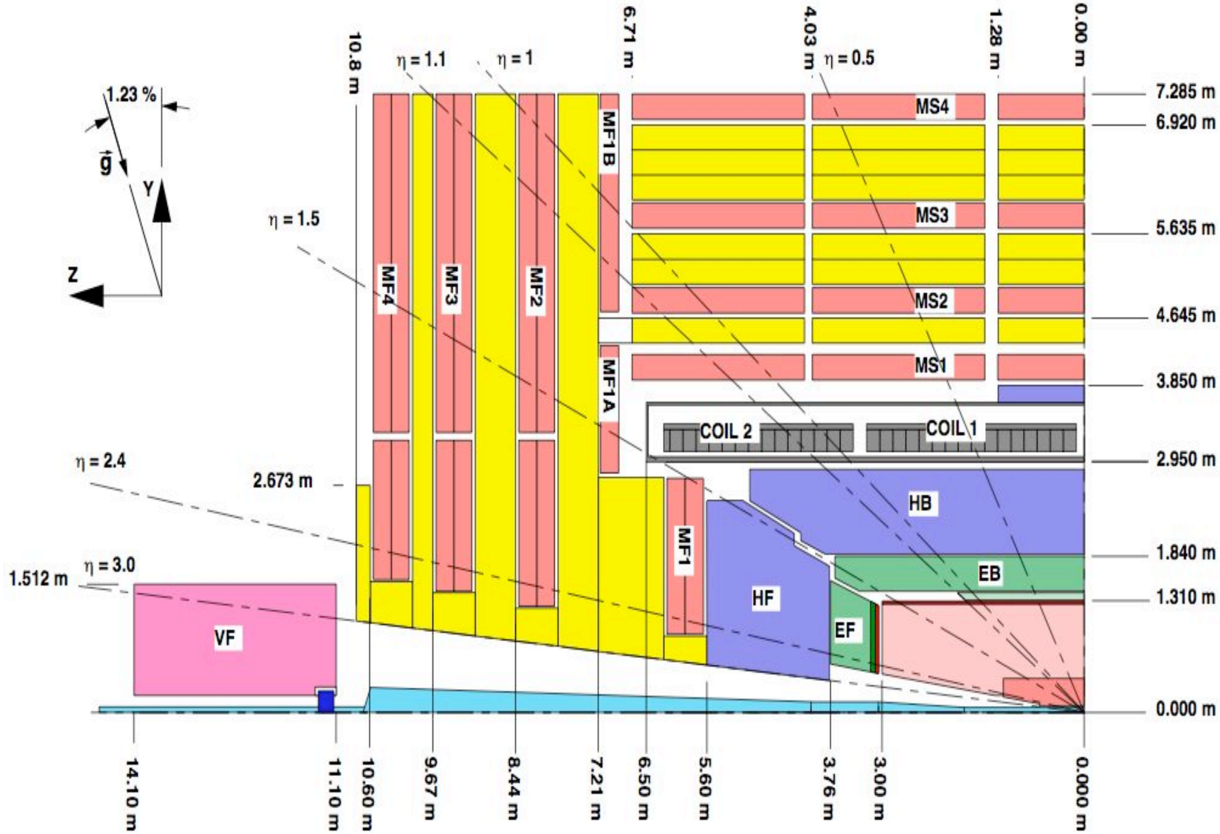
The Compact Muon Solenoid

The Compact Muon Solenoid (CMS) is a multi-purpose particle physics detector at the LHC:

- length: 21.6 m
- diameter: 14.6 m
- weight: 12500 tons
- magnetic field strength: 3.8 T
- Calorimeter coverage: barrel region |η|<1.4, endcap region: 1.4<|η|<3.0



Motivation

- **Experimental**: Normalized event-shape distributions are expected to be robust against jet energy scale uncertainties and jet energy resolution effects

  → event shapes suitable for initial data analysis, here lies our main interest

- **Theoretical**: Event Shapes are collinear and infrared safe, which enables their computation in perturbative QCD

- Event Shapes can be used to distinguish between different models of QCD multi-jet production

  → this study intends to show this

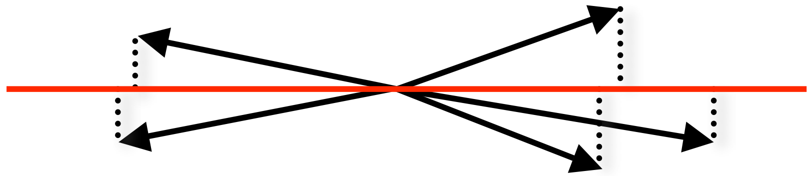
- Possibility in the future: measurements of α_S

Definition of Event Shapes

- Variables defined in terms of four momenta in the transverse plane, in analogy to the e^+e^- case

Banfi, Salam, Zanderighi, JHEP **0408** (2004) 62

- **Central transverse thrust:**



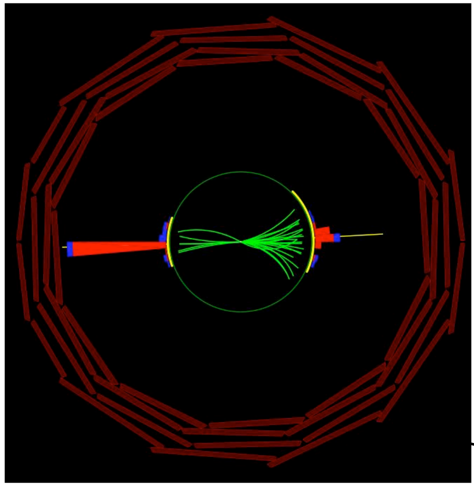
$$T_{\perp,\mathcal{C}} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in\mathcal{C}} \left|\vec{p}_{\perp,i} \cdot \vec{n}_T\right|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

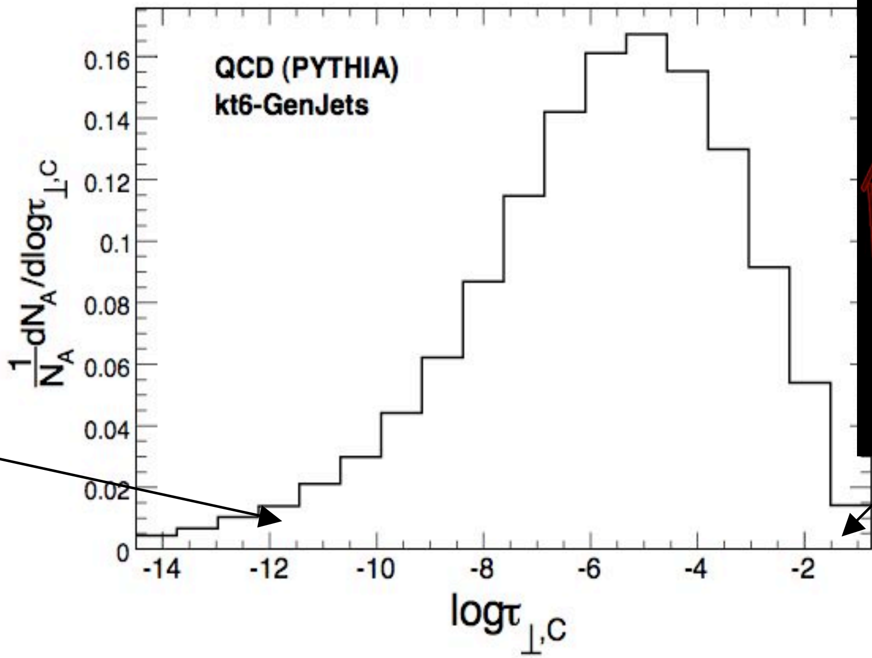
- Calorimeter Jet momenta are used as input for the event shape calculation

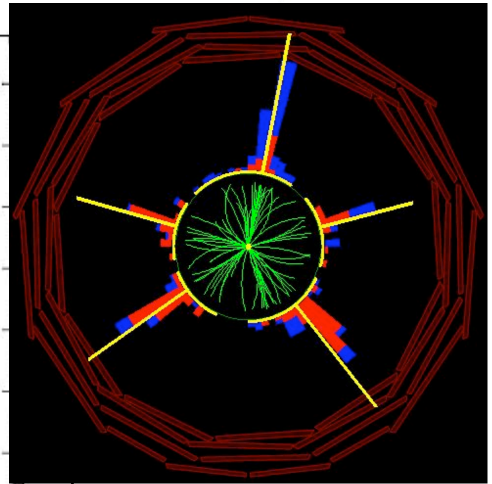
Illustration: central transverse thrust

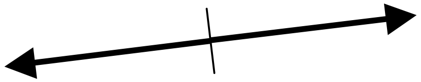
- Normalized inclusive PYTHIA generator level distribution of the central transverse thrust:

plotted in a natural logarithm of $\log \tau_{\perp,\mathcal{C}} = \log(1 - T_{\perp,\mathcal{C}})$

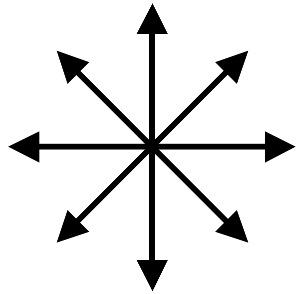








$$\tau_{\perp,\mathcal{C}} = 0$$



$$\tau_{\perp,\mathcal{C}} = 1 - \frac{2}{\pi}$$

Event-Shape Variables

Other Variables (not shown in this presentation):

- Thrust Minor
- Total jet broadening
- Wide jet broadening
- Total jet mass
- Heavy jet mass
- Three-jet resolution threshold

Preselection

- **Event Preselection**:
  - the two hardest jets are central $|\eta|<\eta_C=1.3$
  - two or more jets with $p_T > 50$ GeV/c (corrected calorimeter, generator level)
  - use only central jets for the event-shape calculation

- **Samples used at $\sqrt{s}$ = 10 TeV:**
  - PYTHIA & HERWIG++ QCD samples:
    2→2 processes involving gluons and light quarks, different Underlying Event & Hadronization Models
  - MADGRAPH QCD samples:
    Matrix element calculation: 2 jets - 4 jets with p_T^{jets}>20 GeV/c

Presentation of Results

- The "data points" are evaluated from the MADGRAPH sample using calorimeter jet momenta, corrected for their relative and absolute energy response
  - Jet algo : k_T, D=0.6
- The statistical uncertainty corresponds to an integrated luminosity of 10 pb^{-1}
- The error bars of the data points include the systematic errors due to jet energy resolution, η and ϕ position resolution and the limited knowledge of the jet energy scale
- The phase space is divided into two regions according to the corrected transverse energy of the leading jet

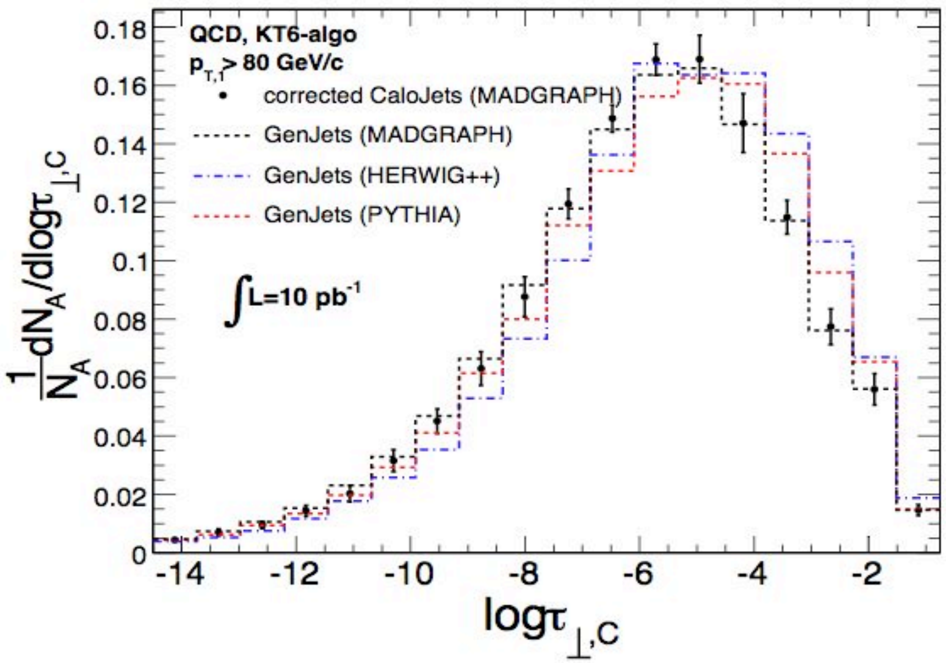
  - inclusive: $p_{T,1} > 80$ GeV

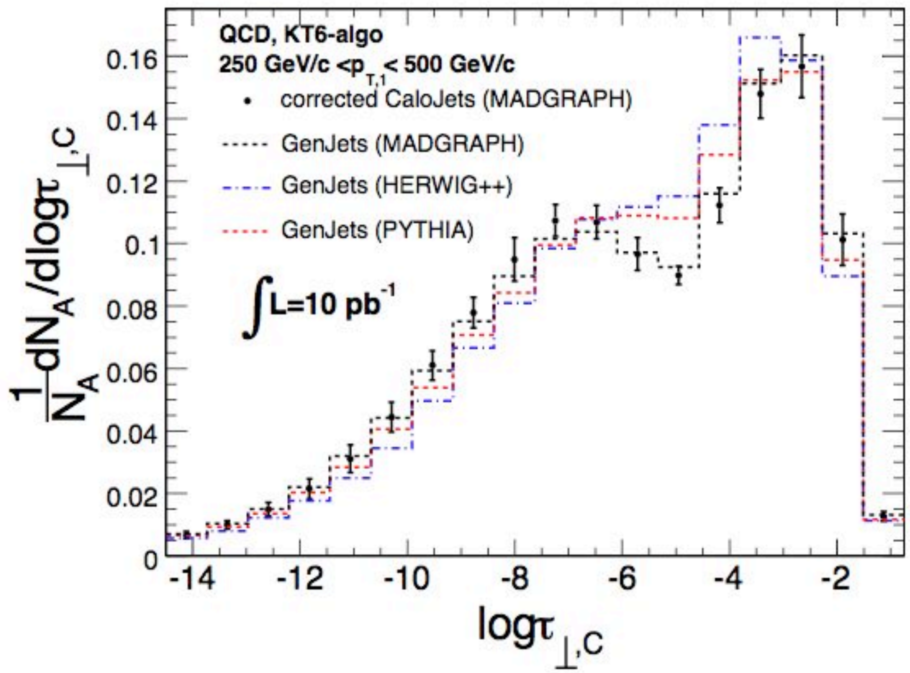
  - medium energy: 250 GeV $< p_{T,1} <$ 500 GeV

Results: central transverse thrust

- Compare the normalized event-shape distributions (calculated from corrected jet momenta) with the corresponding generator level predictions from MADGRAPH, PYTHIA and HERWIG++ QCD samples

inclusive **medium**





- Already in early measurements differences between data and modelling of QCD-multijets in Monte Carlo generators can be studied.

Systematic Uncertainties

- Jet Energy Scale
- Jet Energy Resolution
- Jet Position Resolution

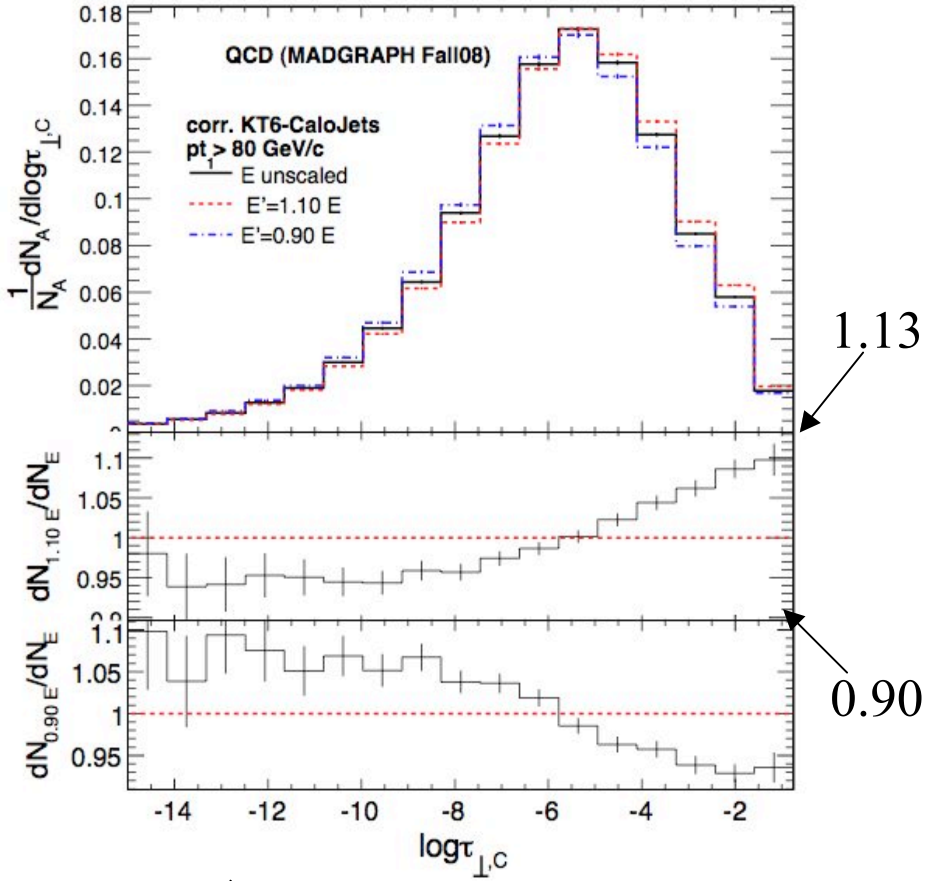
Systematic Uncertainty: Jet Energy Scale

- A global 10% uncertainty on the jet energy scale is assumed at startup (flat in pseudo-rapidity)

- Event-Shape variables are expected to be robust against jet energy scale variations, simply by their definition.

- Define observed differences as systematic uncertainties

- central transverse thrust: $p_{T,1}$>80GeV/c



→ Typical variations within 8% over a good subrange

Syst. Uncertainty: Jet Energy Resolution

- A gaussian smearing is applied on the generator level momenta to evaluate the effect of the jet energy resolution:

- In the barrel region $|\eta| < 1.4$:

$$\frac{\sigma(p_{\mathrm{T}})}{p_{\mathrm{T}}} = \sqrt{\left(\frac{4.03}{p_{\mathrm{T}}}\right)^2 + \left(\frac{1.32}{\sqrt{p_{\mathrm{T}}}}\right)^2 + (0.03)^2}$$

- In endcap $1.4 < |\eta| < 2.6$:

$$\frac{\sigma(p_{\mathrm{T}})}{p_{\mathrm{T}}} = \sqrt{\left(\frac{5.0}{p_{\mathrm{T}}}\right)^2 + \left(\frac{0.98}{\sqrt{p_{\mathrm{T}}}}\right)^2 + (0.00)^2}$$

and transition region $2.6 < |\eta| < 3.0$:

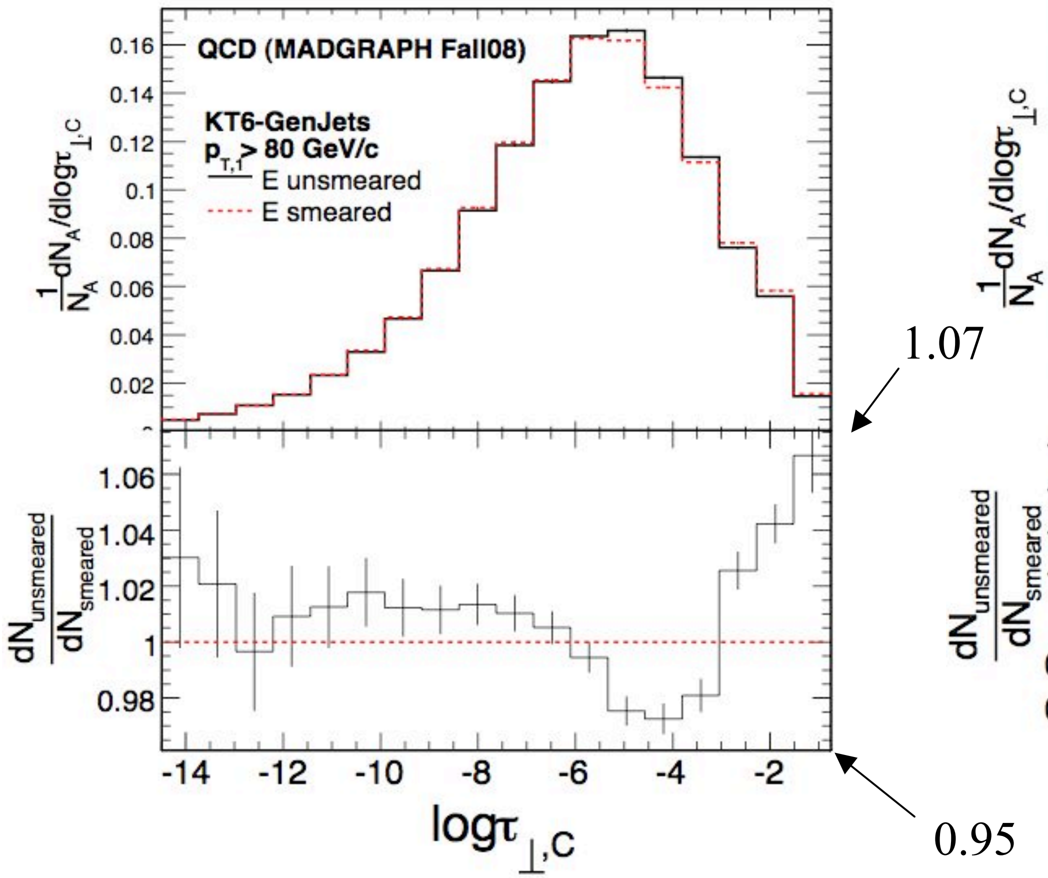
$$\frac{\sigma(p_{\mathrm{T}})}{p_{\mathrm{T}}} = \sqrt{\left(\frac{5.47}{p_{\mathrm{T}}}\right)^2 + \left(\frac{0.18}{\sqrt{p_{\mathrm{T}}}}\right)^2 + (0.06)^2}$$

the functions were derived from MC over the PYTHIA QCD samples

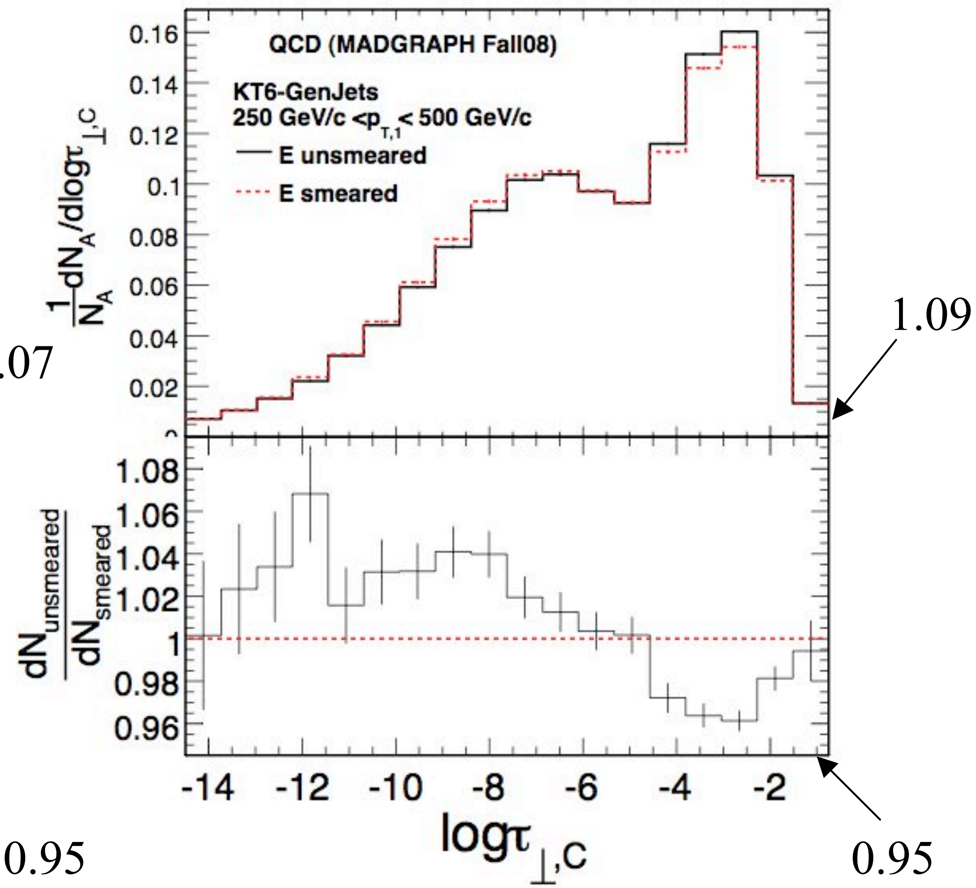
- Define observed differences as systematic uncertainties

Systematics: Jet Energy Resolution

central transverse thrust: **inclusive**



central transverse thrust: **medium**



➡ Variations within 6% over large range

Syst. Uncertainty: Jet Φ Resolution

- A gaussian smearing is applied on the generator level momenta to evaluate the effect of the jet phi resolution:

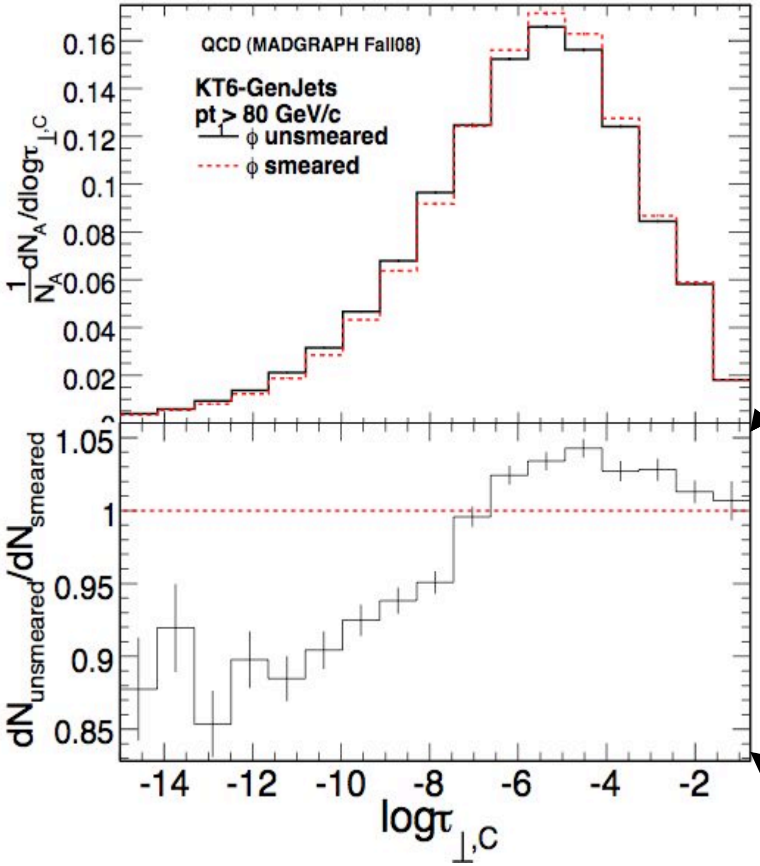
- In the barrel region $|\eta| < 1.4$

$$\sigma(\phi) = \sqrt{\left(\frac{2.72}{p_{\mathrm{T}}}\right)^2 + \left(\frac{0.23}{\sqrt{p_{\mathrm{T}}}}\right)^2 + (0.004)^2}$$

- Define observed differences as systematic uncertainties

Systematics: Jet Φ Resolution

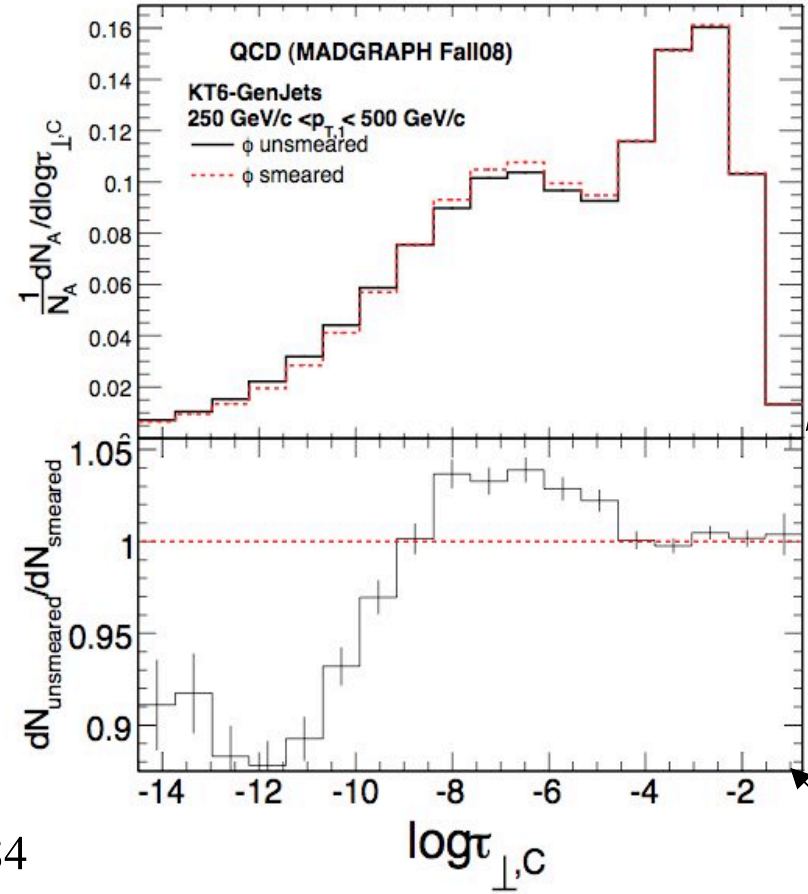
central transverse thrust: **inclusive**



1.06

0.84

central transverse thrust: **medium**



1.05

0.88

➡ Variations within 5-15% over large range

Syst. Uncertainty: η Resolution

- A gaussian smearing is applied on the jet position resolution in η

- in the barrel region |η| <1.4:

$$\sigma(\eta) = \sqrt{\left(\frac{1.31}{p_T}\right)^2 + \left(\frac{0.25}{\sqrt{p_T}}\right)^2 + (0.026)^2}$$

- In the endcap 1.4 < |η| < 3.0 and HF 3.0 < |η| < 5.0 regions

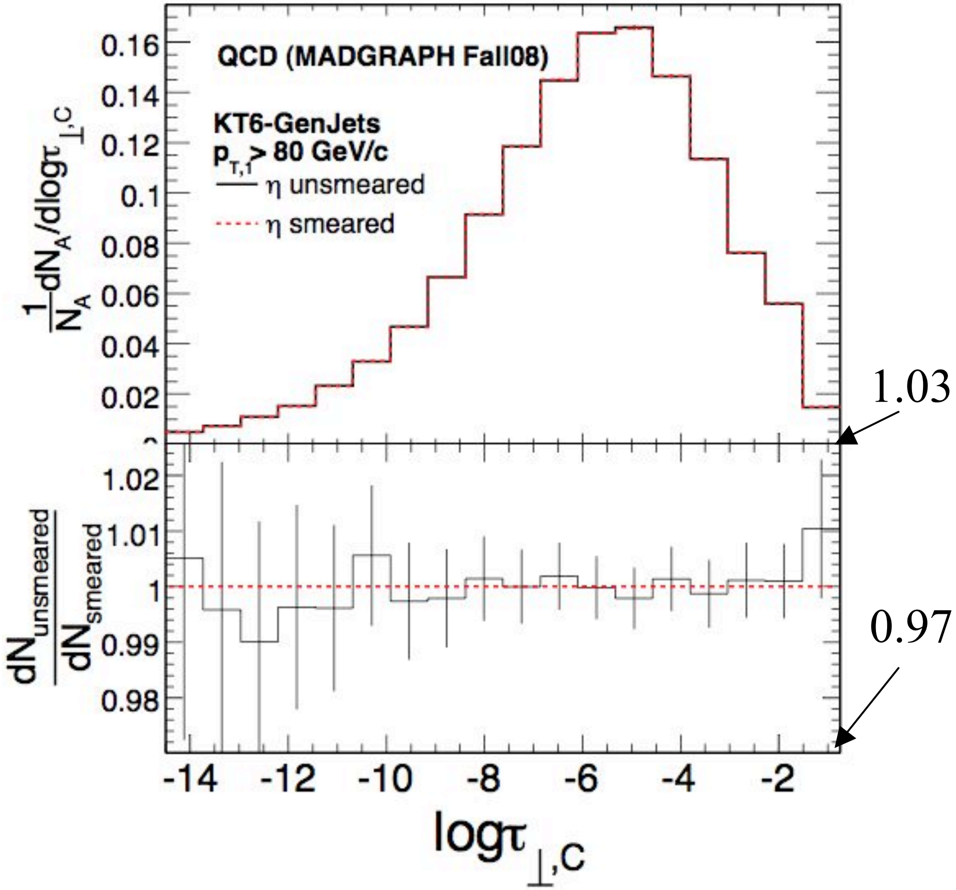
$$\sigma(\eta) = \sqrt{\left(\frac{1.42}{p_T}\right)^2 + \left(\frac{0.21}{\sqrt{p_T}}\right)^2 + (0.017)^2}$$

$$\sigma(\eta) = \sqrt{\left(\frac{1.25}{p_T}\right)^2 + (0.025)^2}$$

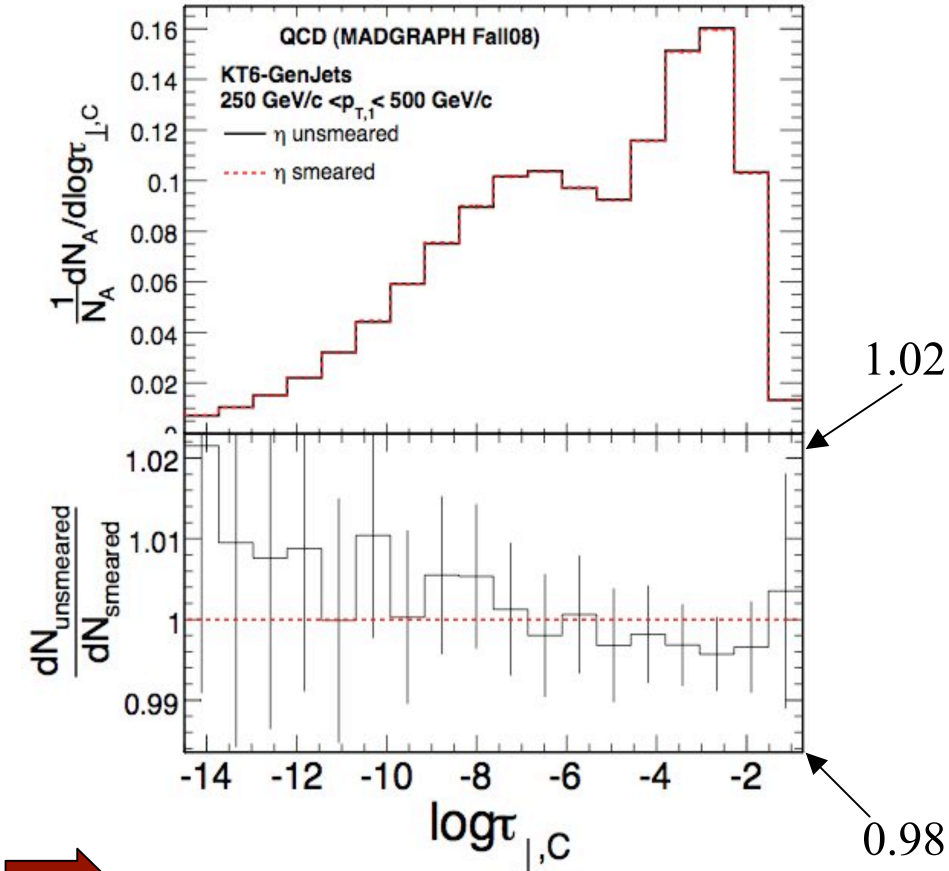
- Define observed differences as systematic uncertainties

Systematics: Jet η Resolution

central transverse thrust: **inclusive**



central transverse thrust: **medium**



Variations are well within 1% over the whole range

Trigger Studies

- In data analysis the inclusive curve will be derived by combining events from several trigger paths based on the transverse momentum of the leading jet.

- Samples should be used, when the trigger more than 99 % efficient; distribution might be biased if the sample is already used before.

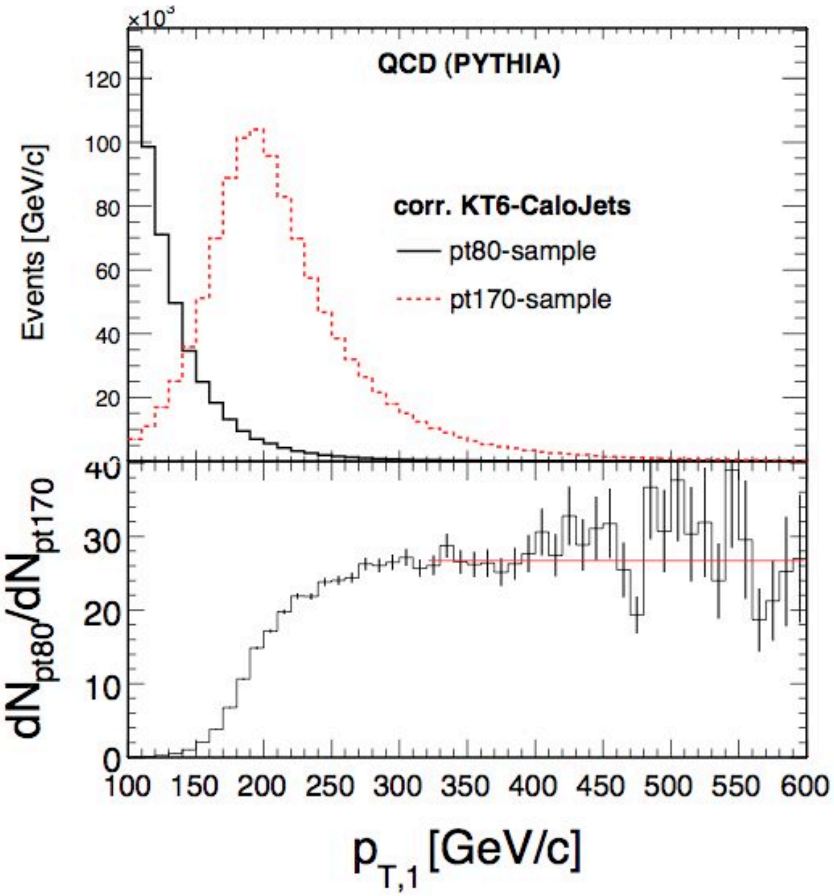
Trigger Name	HLT_Jet50	HLT_Jet80	HLT_Jet110
100% efficient in $p_{T,1}$ [GeV/c]	<80	110	130
Prescale for L=8.0e+29 $cm^{-2}s^{-1}$	5	1	1

- The prescale of a trigger is determined by using the overlap between the subsequent trigger samples (e.g overlap between HLT_Jet50 and HLT_Jet80)

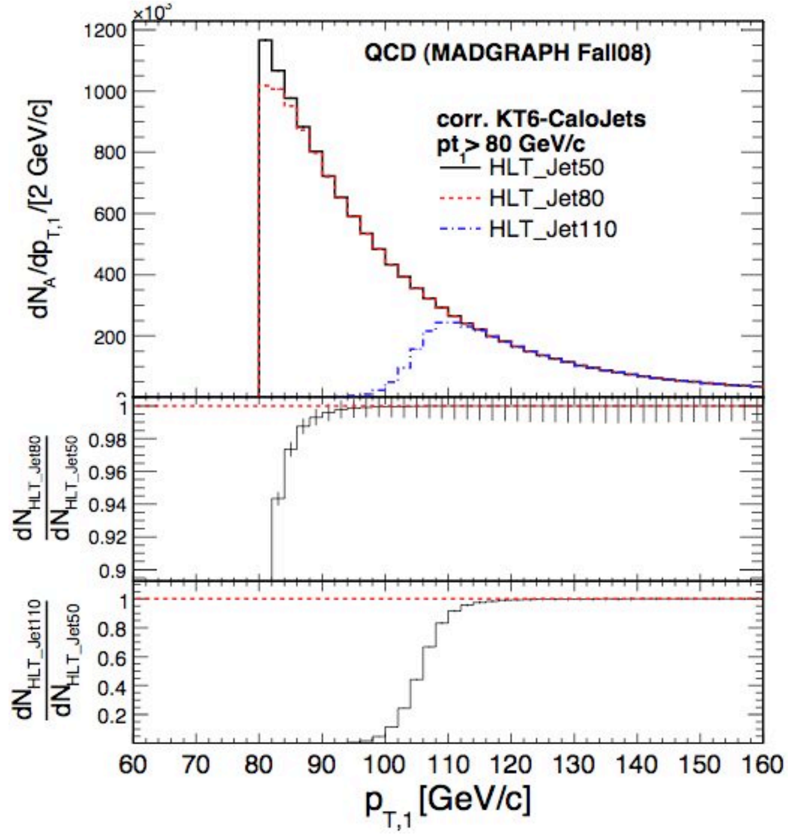
  ➡ Simulated by using the overlap between the PYTHIA QCD samples.

Trigger Studies (1)

- Prescale between **"Trigger Samples"**



- Trigger turn on curve



HLT_JET80 100% efficient for $p_{T,1}$>110 GeV/c

Cleaning Cuts

- In order to be save against beam halo/gas, effects of cosmics crossing the detector and noise effects in the calorimeter, the following cleaning cuts are used:

  a cut on $MET/Et_{sum} < 0.3$

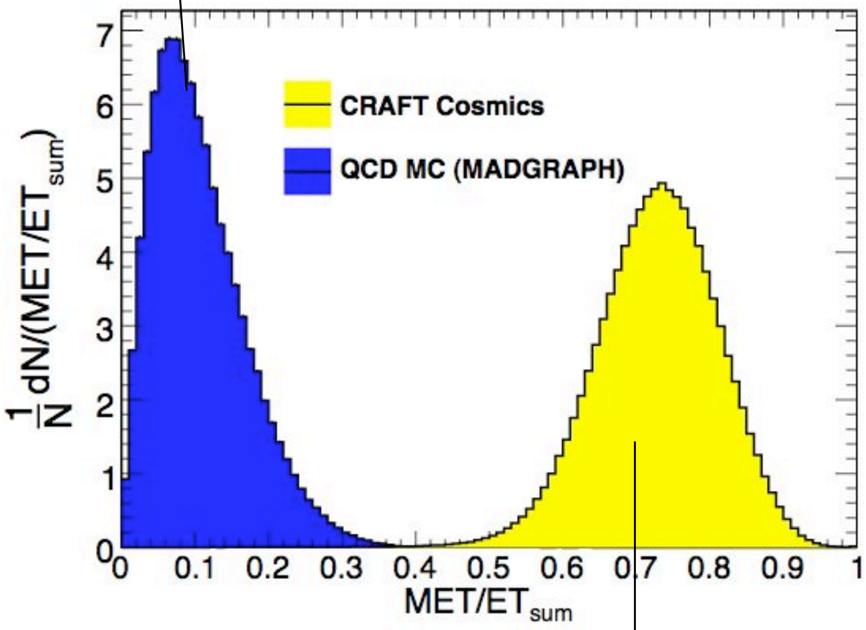
- Jet ID cuts on the electromagnetic fraction (EMF) of a jet:
  EMF>0.01

- If an event doesn't fulfill the first cut it is rejected.

- If a central jet ($|\eta|<1.3$) with $p_T > 50$ GeV/c doesn't fulfill the JetID criteria, the event is rejected.

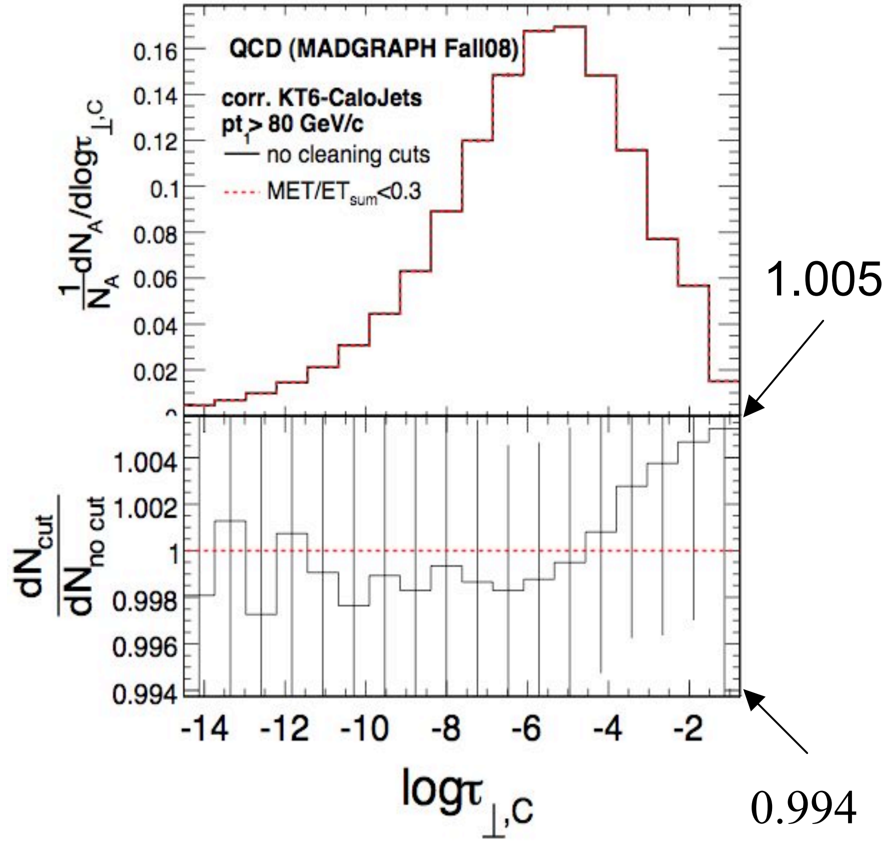
Cleaning Cuts (1)

- MET/Et_{sum} distribution over the **inclusive** QCD sample



CMS cosmic data

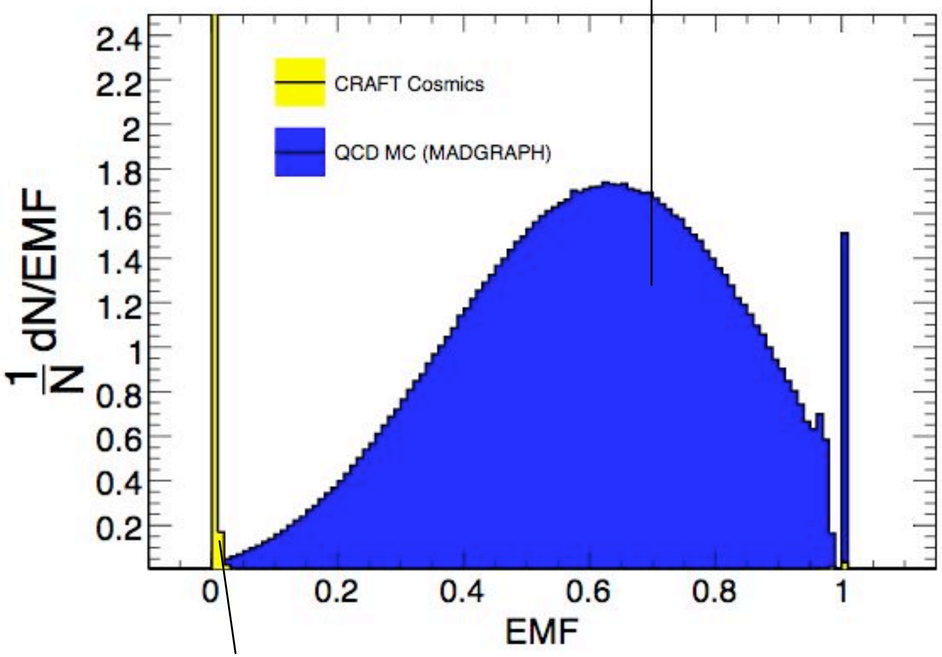
- Central transverse thrust **inclusive**



→ Variations are less than 1% using the MET/Et_{sum} cut

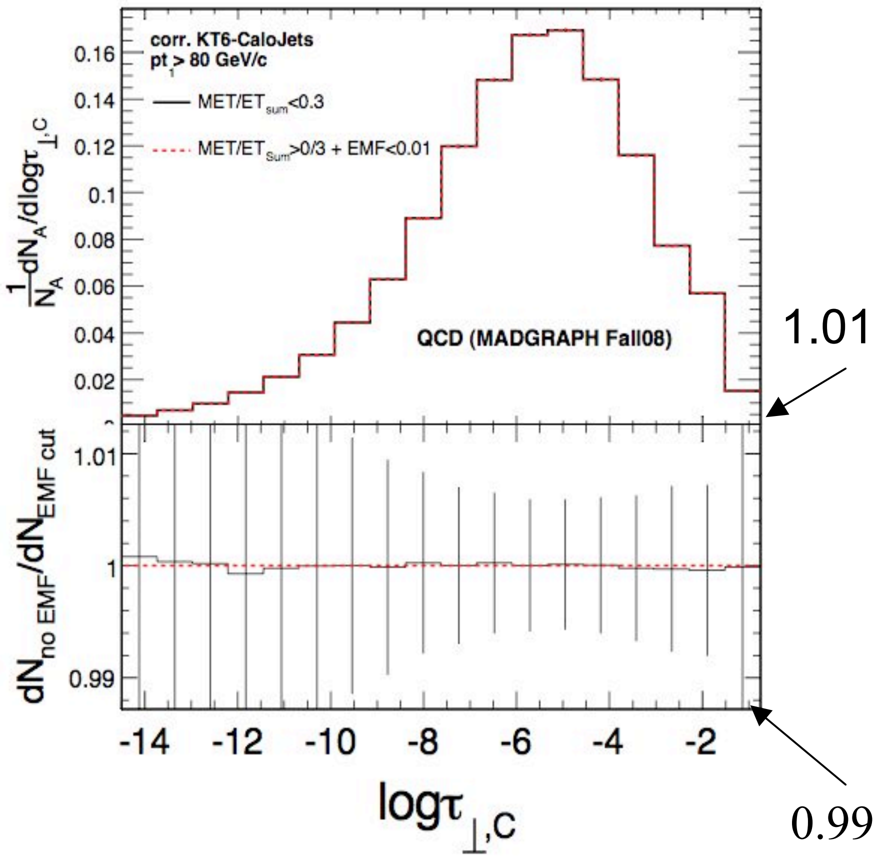
Cleaning Cuts (2)

- distribution of the electromagnetic energy fraction (EMF) of KT6 barrel CaloJets with $p_T > 50$ GeV/c in QCD MC



Kt6 barrel Calojets with $p_{T,raw}$>25 GeV/c
In CMS cosmic data

- Central transverse thrust **inclusive**



→ Variations are less than 1% using the additional EMF cut

Summary

- Systematic uncertainties expected at startup, from jet energy resolution effects and the limited knowledge of the jet energy scale, are small

  - within 8% for both effects
- Systematic uncertainties from the jet position resolutions in η and ϕ are small

  - within 1% respectively 5-8 % for both effects.

- A first study on cleaning cuts shows, that effects are within 1% over most of the event-shape distribution

- An early measurement of event-shape variables allows already to study differences in the modelling of multi-jet production

Backup

Sensitivity Studies

- Choice of Jet Algorithm
- Choice of Jet Algorithm Parameters

Sensitivity to the Jet Algorithm

- **Goal** : study dependence of event shape on choice of jet algorithm

- The following algorithms were compared:

  - seedless infrared safe cone algorithm with radius R = 0.5 (**SC5**)

  - iterative cone algorithm with radius R = 0.5 (**IC5**)

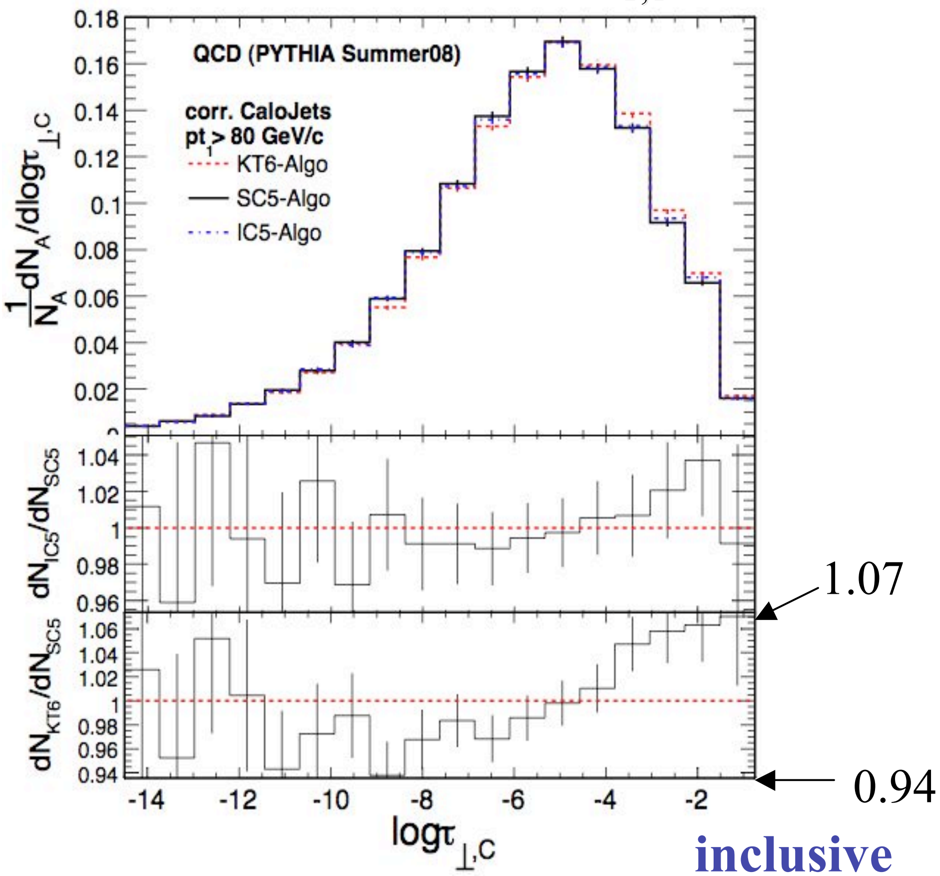
  - k_T-algorithm with D-parameter D = 0.6 (**KT6**)

- The calorimeter jets have been corrected for their relative and absolute energy response

- The pythia6 Summer08 V9 samples are used in this test

Sensitivity to the Jet Algorithm (2)

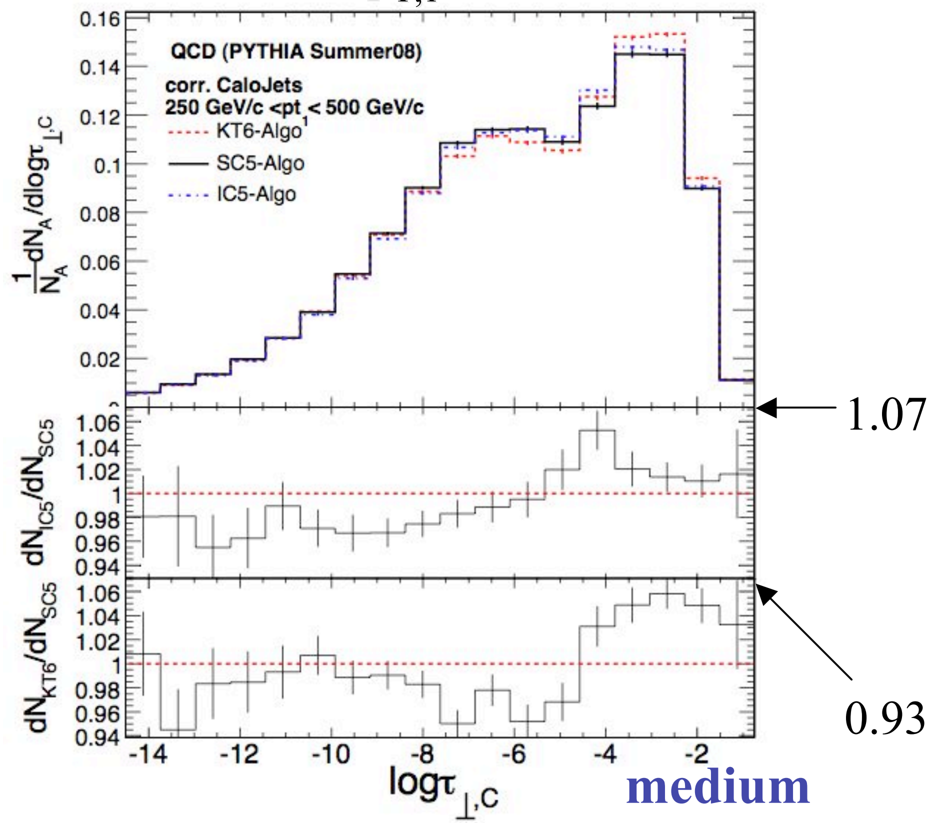
central transverse thrust: $p_{T,1}$>80 GeV/c



inclusive

central transverse thrust:

250 GeV/c<$p_{T,1}$< 500 GeV/c

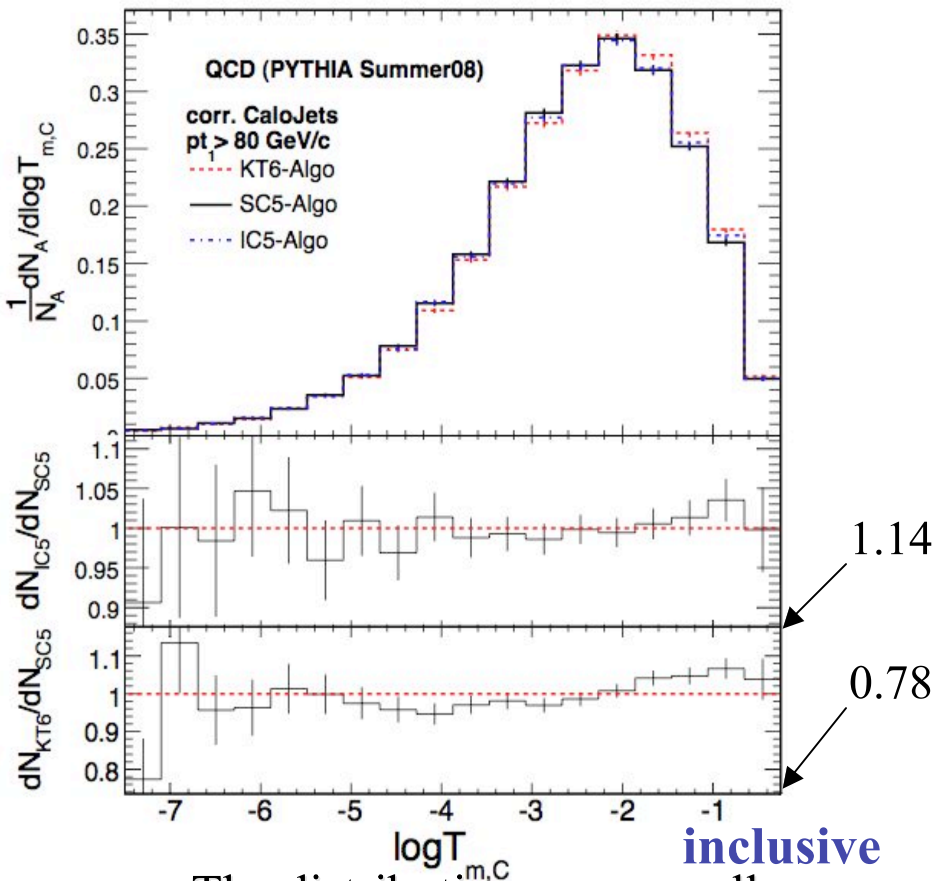


medium

- The distributions agree well within 7% - reference distr: SC5
- The distributions agree well within 7%

Sensitivity to the Jet Algorithm (3)

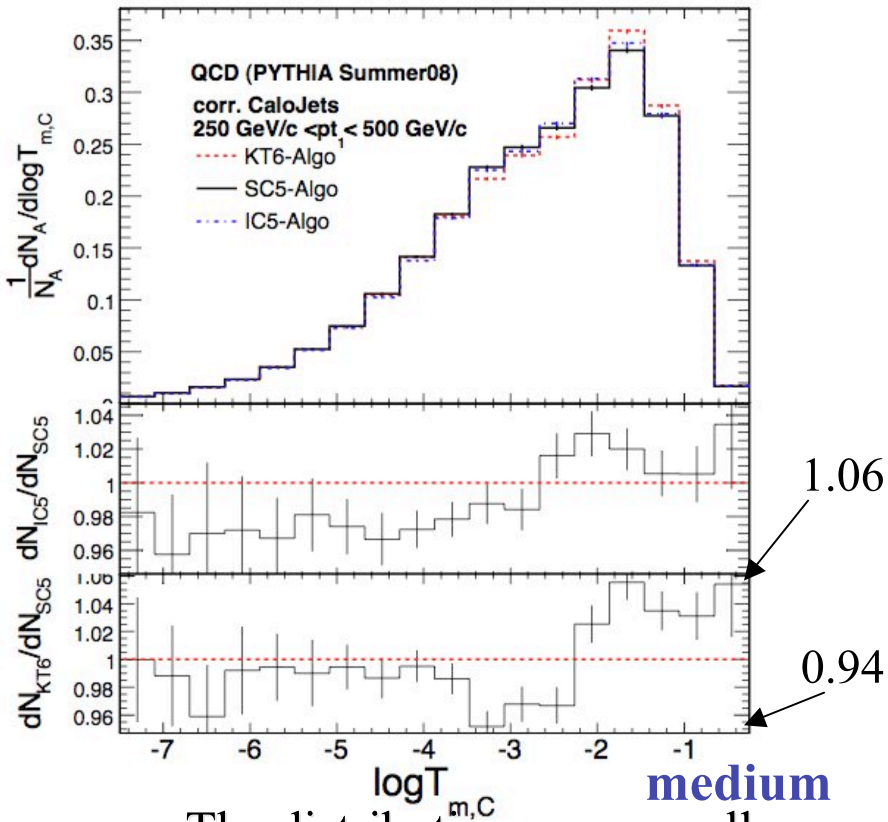
central thrust minor: $p_{T,1}$>80 GeV



inclusive

→ The distributions agree well (within 5-10%)

central thrust minor:
250 GeV/c < $p_{T,1}$< 500 GeV/c



medium

→ The distributions agree well (within 7%)

Sensitivity to Jet Parameters

- **Goal** : study dependence of event shape on choice of jet algorithm parameters

- The following algorithms parameters are compared:

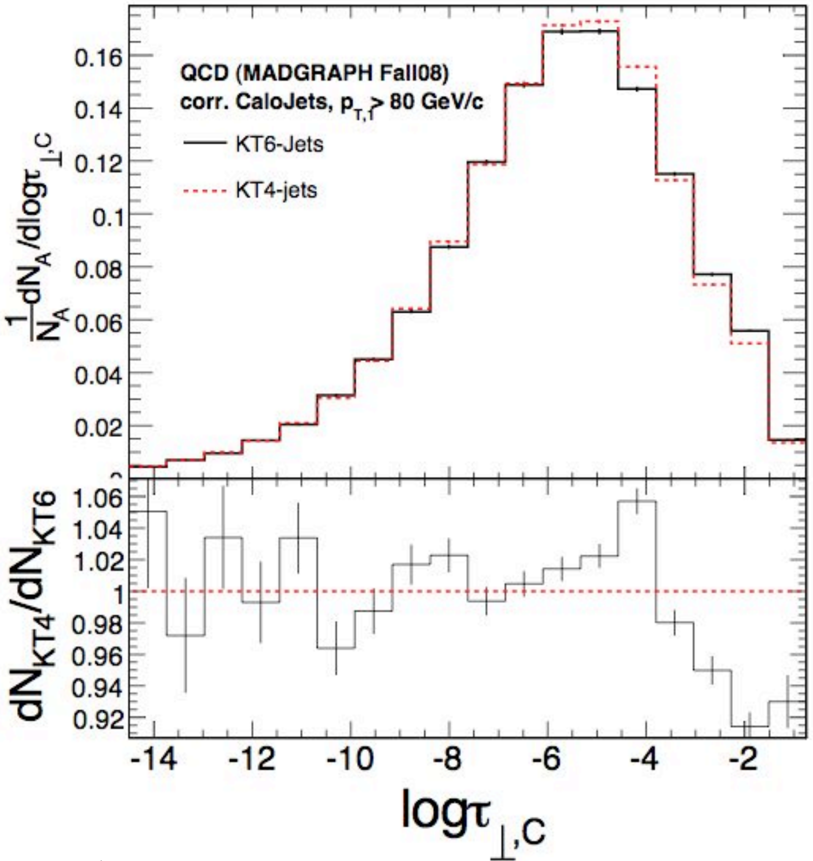
  - sisCone-algorithm: radius R = 0.5 and radius R = 0.7

  - k_T-algorithm: D-parameter D = 0.6 and D = 0.4

- All Fall08 Madgraph Samples are used in this test

Sensitivity to Jet Parameters (1)

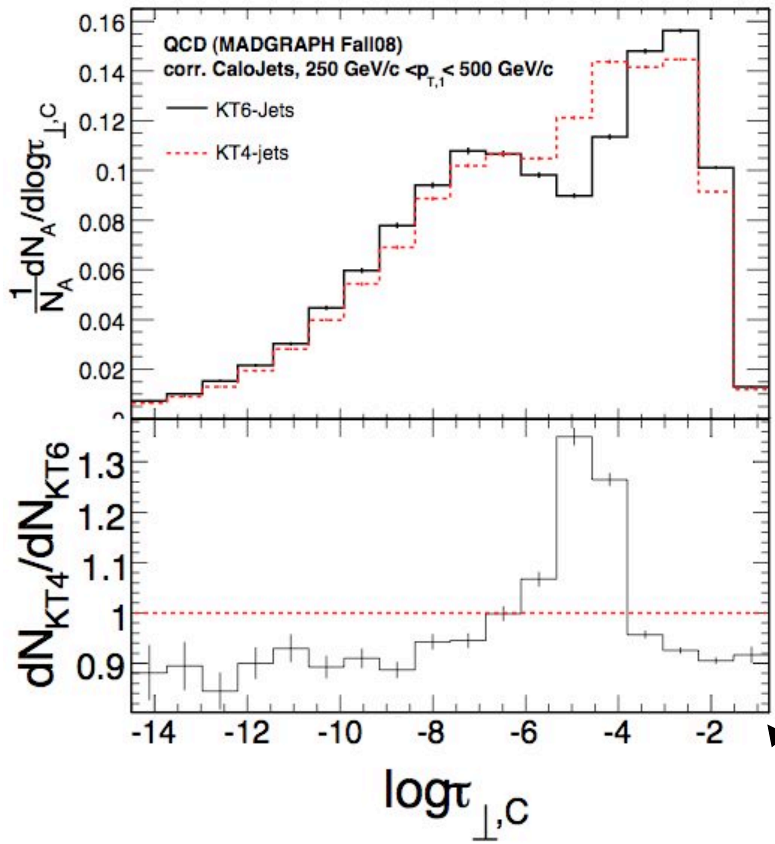
central transverse thrust: **inclusive**



1.07

0.90

central transverse thrust: **medium**



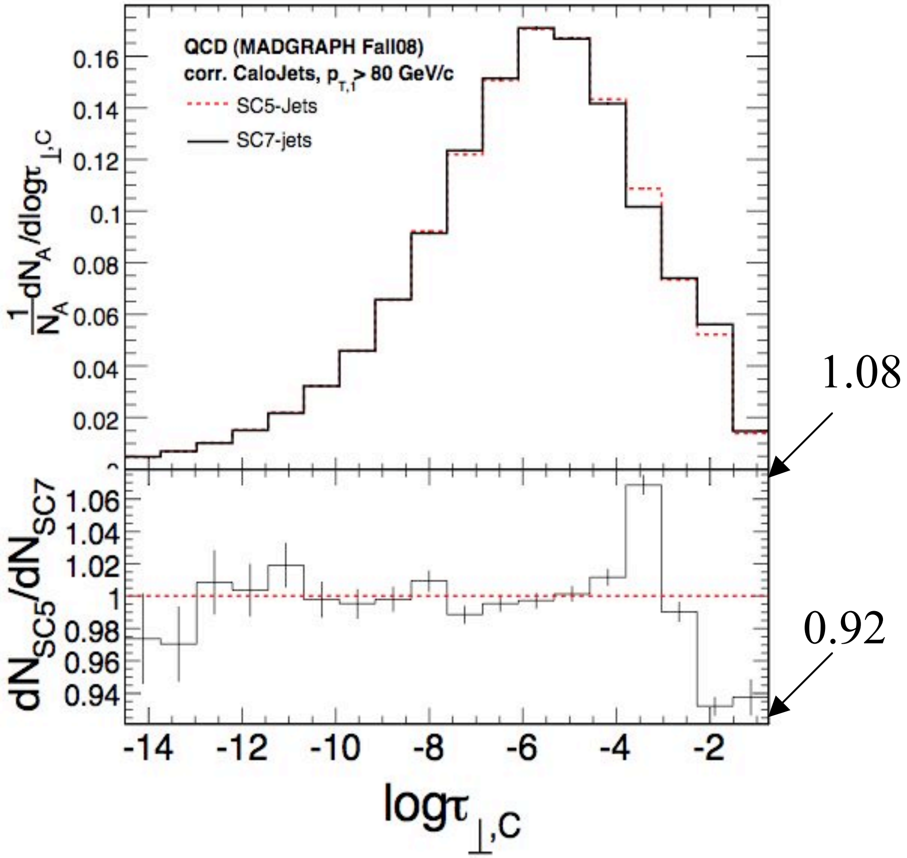
1.40

0.80

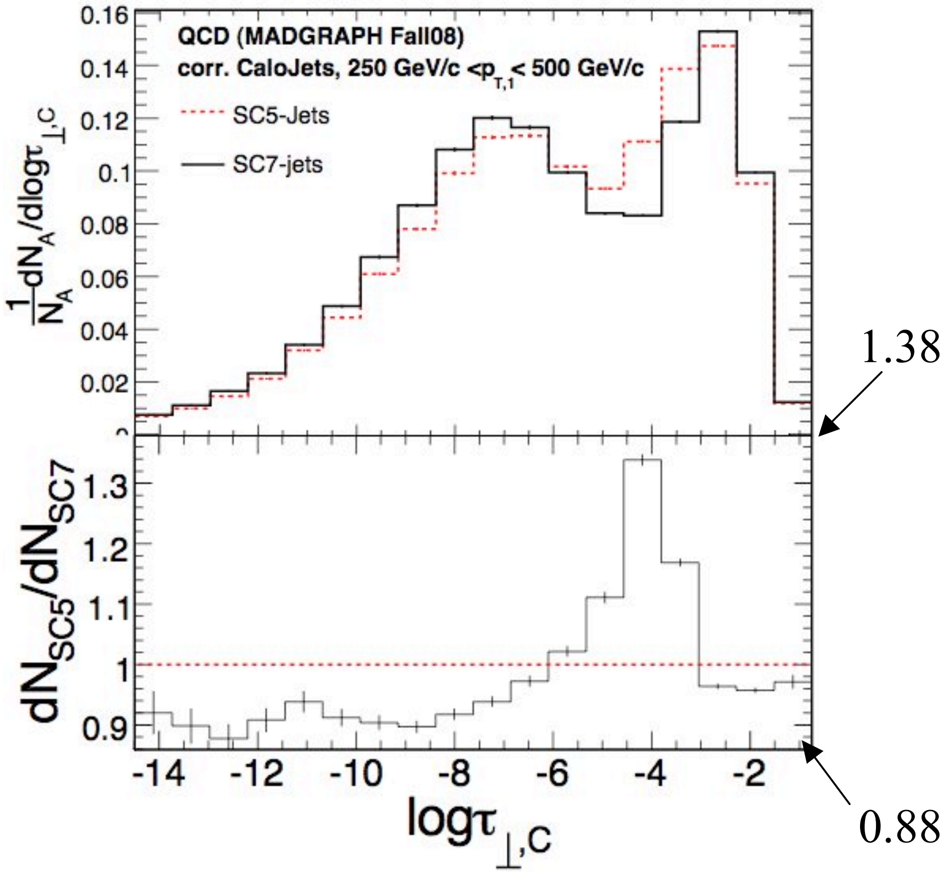
- The distributions agree well within 10% over a good subrange
- The kt4 distribution shows a shift from the dijet to the multijet region

Sensitivity to Jet Parameters (2)

central transverse thrust : **inclusive**



central transverse thrust: **medium**

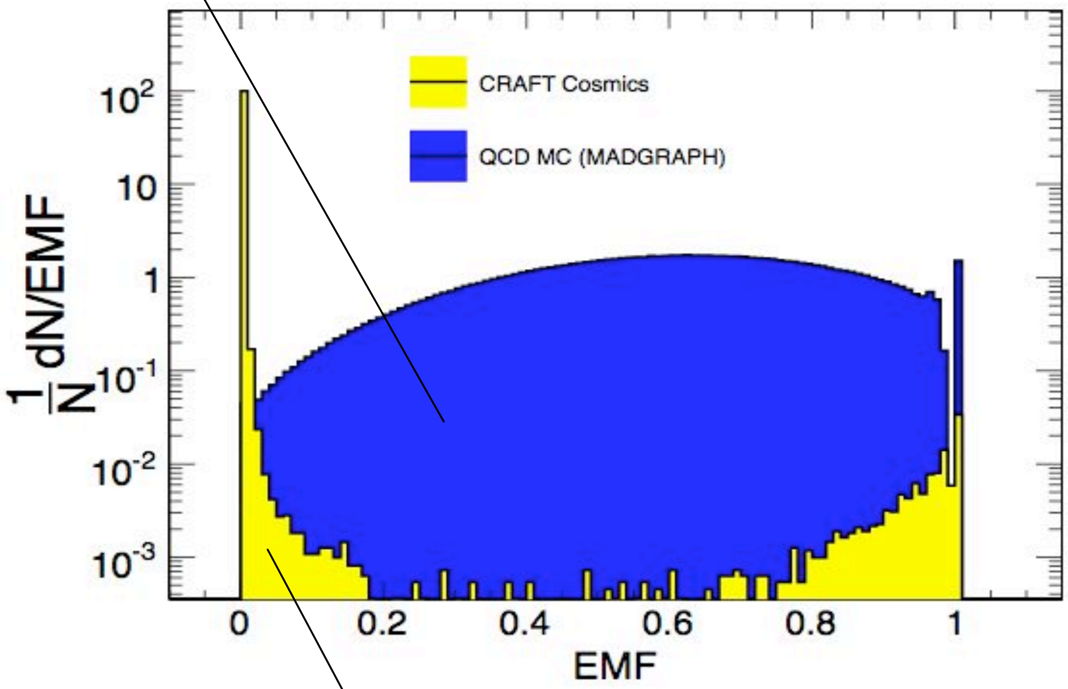


➡ The distributions agree well within 8% over a good subrange

➡ The SC5 distribution shows a shift from the dijet to the multijet region

EMF fraction

- distribution of the electromagnetic energy fraction (EMF) of KT6 barrel CaloJets with $p_T > 50$ GeV/c in QCD MC



distribution of the electromagnetic energy fraction (EMF) of KT6 barrel CaloJets with $p_{T,raw} > 25$ GeV/c in CMS cosmic data