# Hadronic Event Shapes at CMS

On behalf of the CMS Collaboration

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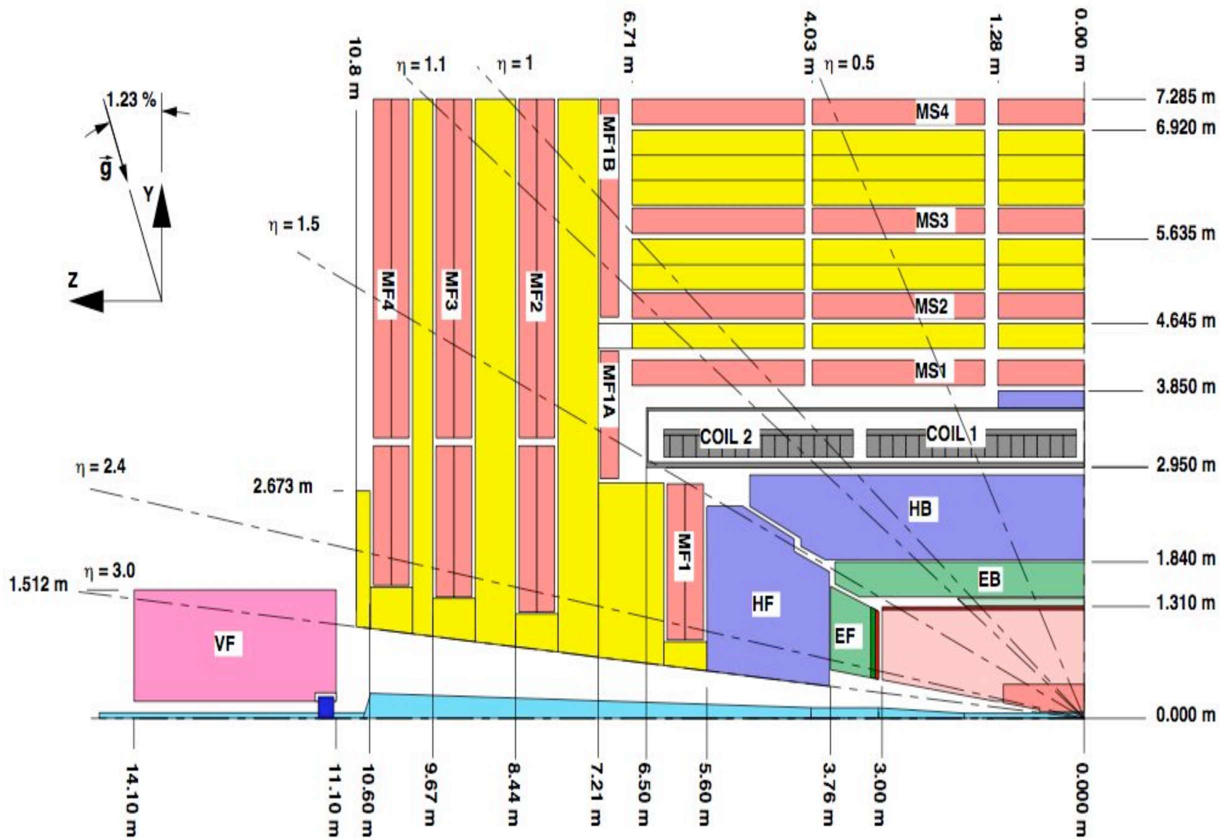
# The Compact Muon Solenoid

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: 4 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 $\alpha_S$

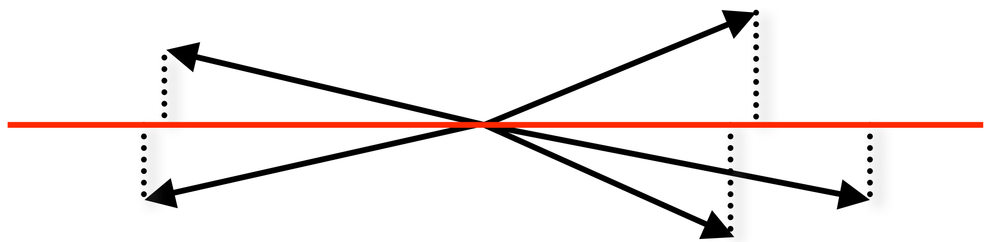
# Definition of Event Shapes

- Several event-shape 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

- **Example: Central transverse thrust:**

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

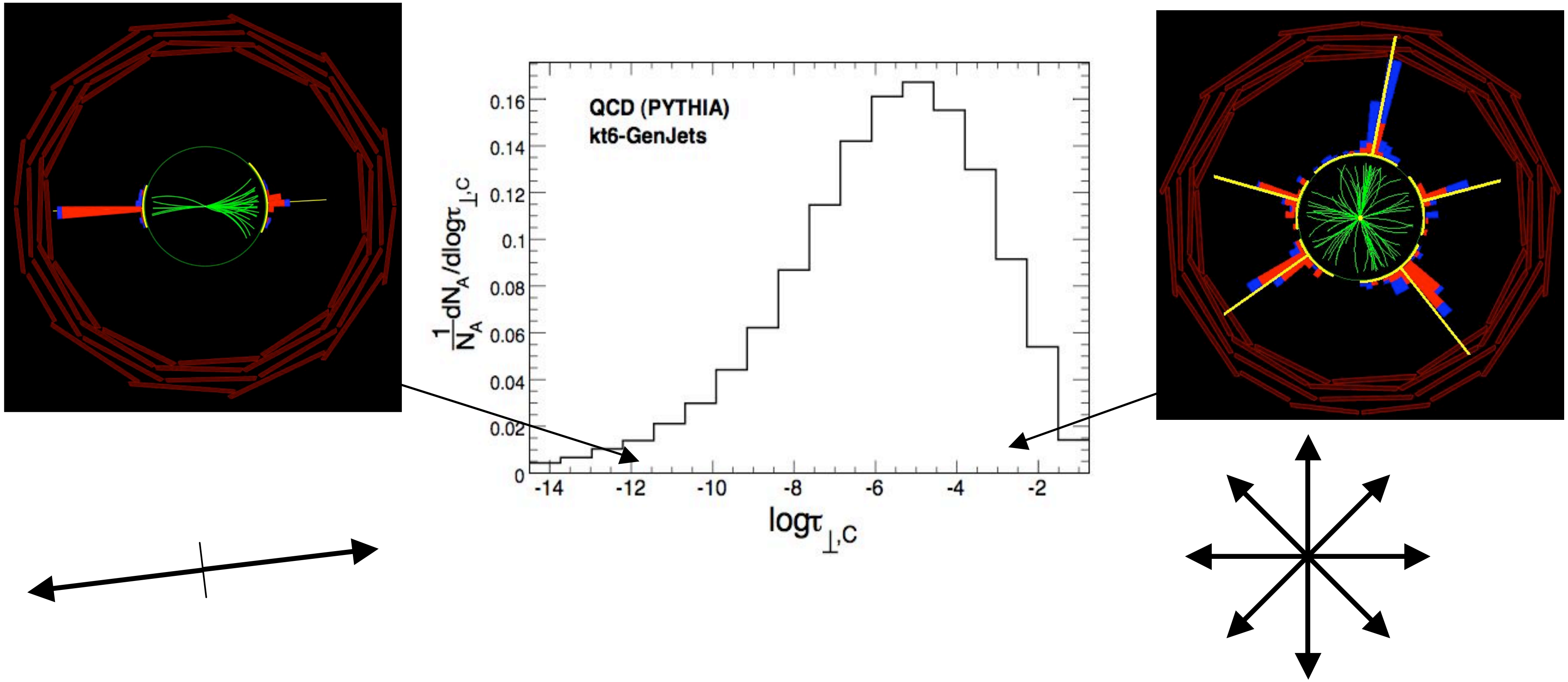


- Calorimeter jet momenta are used as input for the event shape calculation

# Illustration: central transverse thrust

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

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



# 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 $E_T > 60$ GeV (corrected calorimeter, generator level)
  - use only central jets for the event-shape calculation

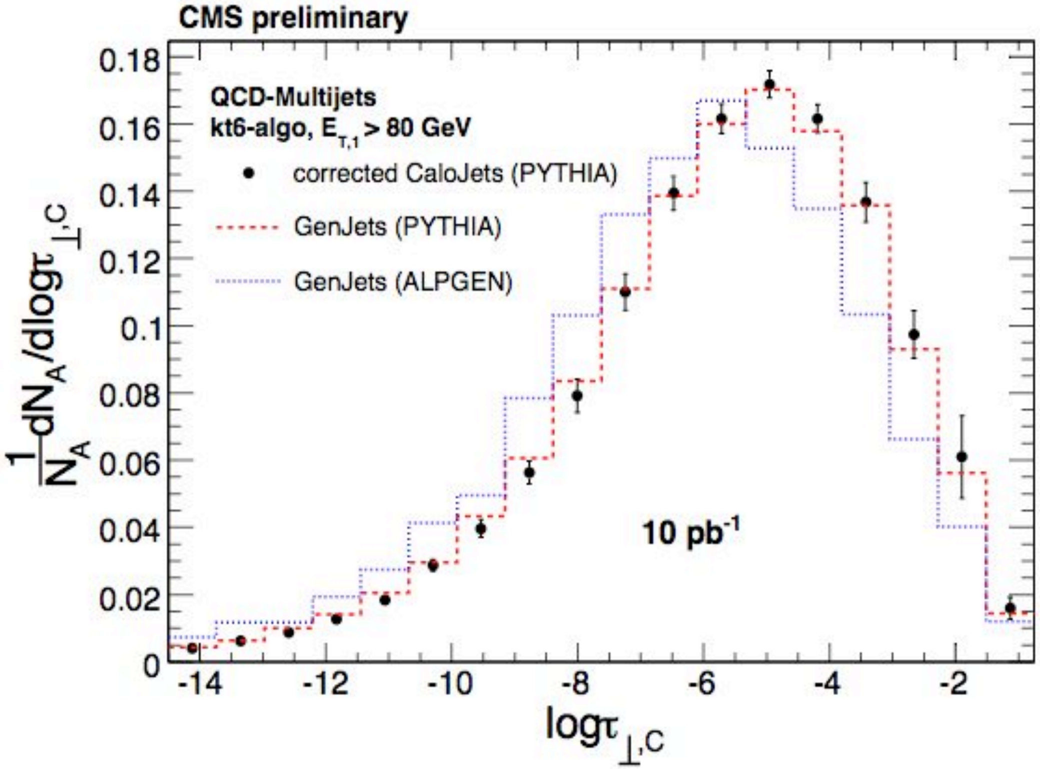
- **Samples used at $\sqrt{s}$ = 14 TeV:**
  - PYTHIA QCD samples: $2\rightarrow 2$ processes involving gluons and light quarks
  - ALPGEN QCD samples:
    Matrix element calculation: 2 jets - 6 jets with $p_T^{jets}>20$ GeV/c

# Presentation of Results

- In the following plots "data points" are evaluated from the PYTHIA sample using calorimeter jet momenta, corrected for their relative and absolute energy response
  - Jet algorithm: $k_T$, D=0.6, for the following plots
- 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 and the limited knowledge of the jet energy scale (see later)

# Results: central transverse thrust

- Compare normalized event-shape distributions (calculated from corrected jet momenta) with the corresponding generator level predictions from PYTHIA 6.409 and ALPGEN 2.1




- CaloJets: reconstructed calorimeter jet

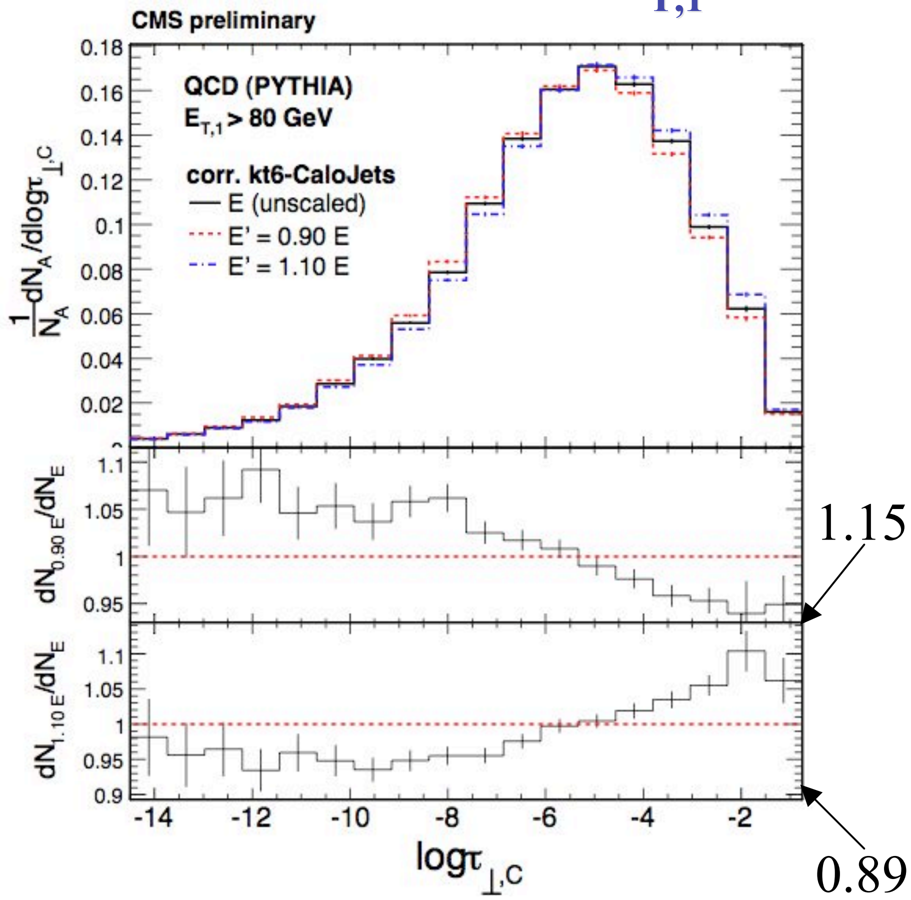
- GenJets: particle jets on generator level

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

# 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: $E_{T,1}$>80GeV




→ Typical variations within 8% over a good subrange

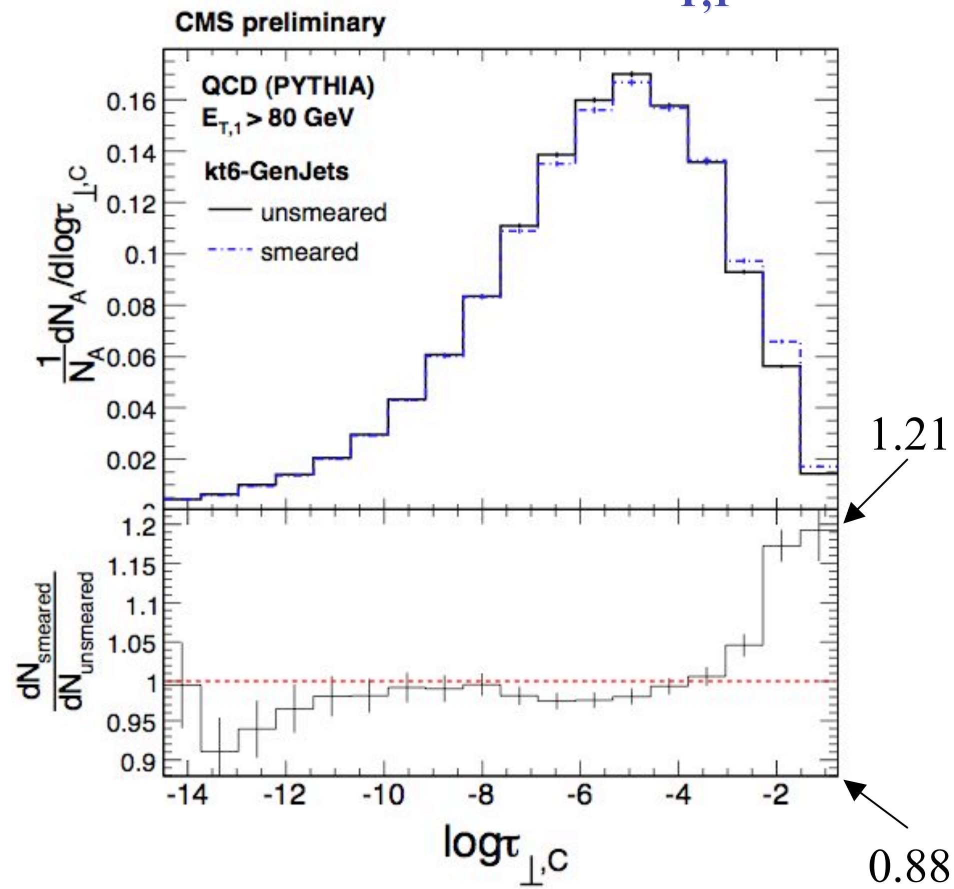
# Syst. Uncertainty: Jet Energy Resolution

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

- The jets have been reordered in $E_T$' after applying the smearing
  - threshold $E_T' > 60$ GeV

- Define observed differences as systematic uncertainties

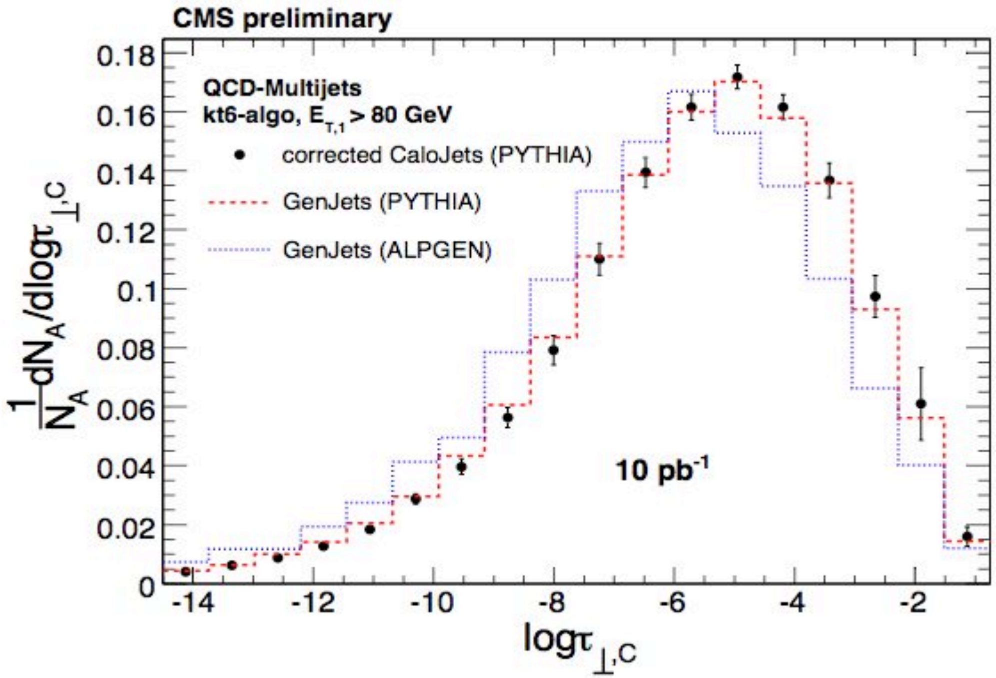
- central transverse thrust: $E_{T,1}$>80 GeV




→ Variations within 7 - 8% over large range

# 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




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

# Backup

# Analysis Procedure

- PYTHIA uses LO matrix elements plus parton shower to generate QCD multijet events by initial and final state radiation in the $2 \rightarrow 2$ process (DWT tune for UE, PDF-set: CTEQ5L)

- ALPGEN combines multi-leg tree-level matrix elements with the parton shower matched by the MLM scheme to generate QCD-multijet events

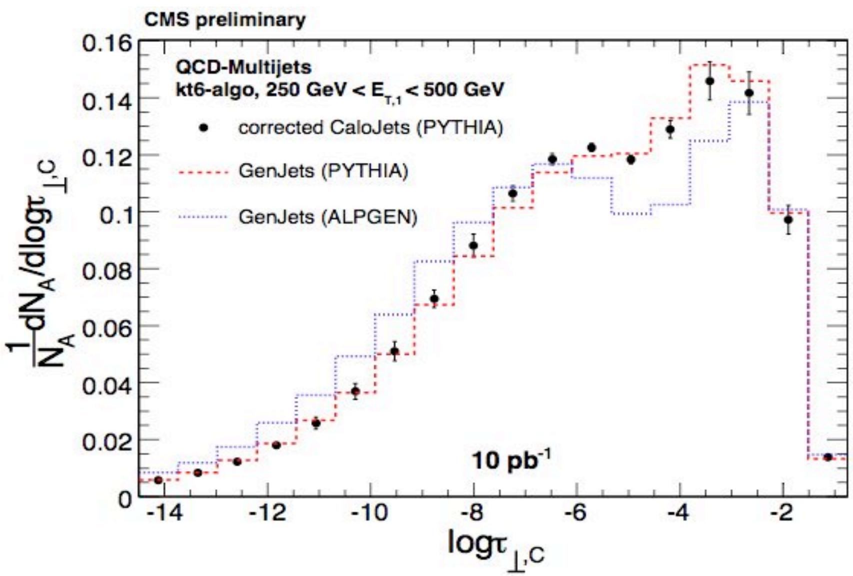
- ALPGEN production at CMS:
  - ME calculation: 2 jets - 6 jets with $p_T^{jets}$>20 GeV/c
  - jet matching cone of $\Delta R_{min} = 0.7$
  - jets are calculated up to $|\eta| = 5.0$

- The phase space is divided into three regions according to the corrected transverse energy of the leading jet
  - inclusive: $E_{T,1} > 80$ GeV
  - medium energy: 250 GeV $< E_{T,1} <$ 500 GeV
  - high energy: $E_{T,1} > 500$ GeV

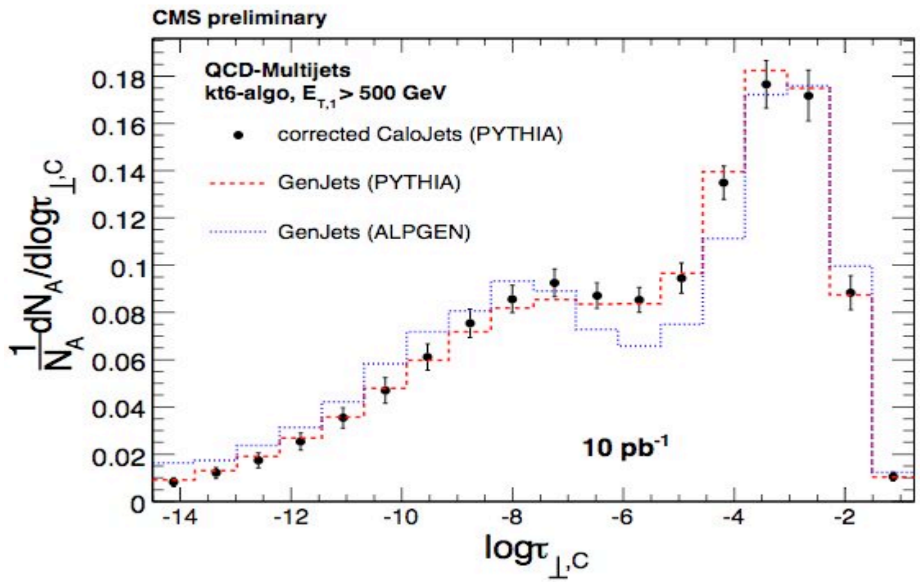
# Results: central transverse thrust

- Already in early measurements differences between data and QCD multi-jet modelling in Monte Carlo Generators can be studied for medium and high energetic events.

**medium**




**high**



# Sensitivity to Jet Energy Corrections

- **Goal** : compare event-shape distributions computed with
  - Generator level jets
  - Uncorrected calo level jets
  - Corrected calo level jets

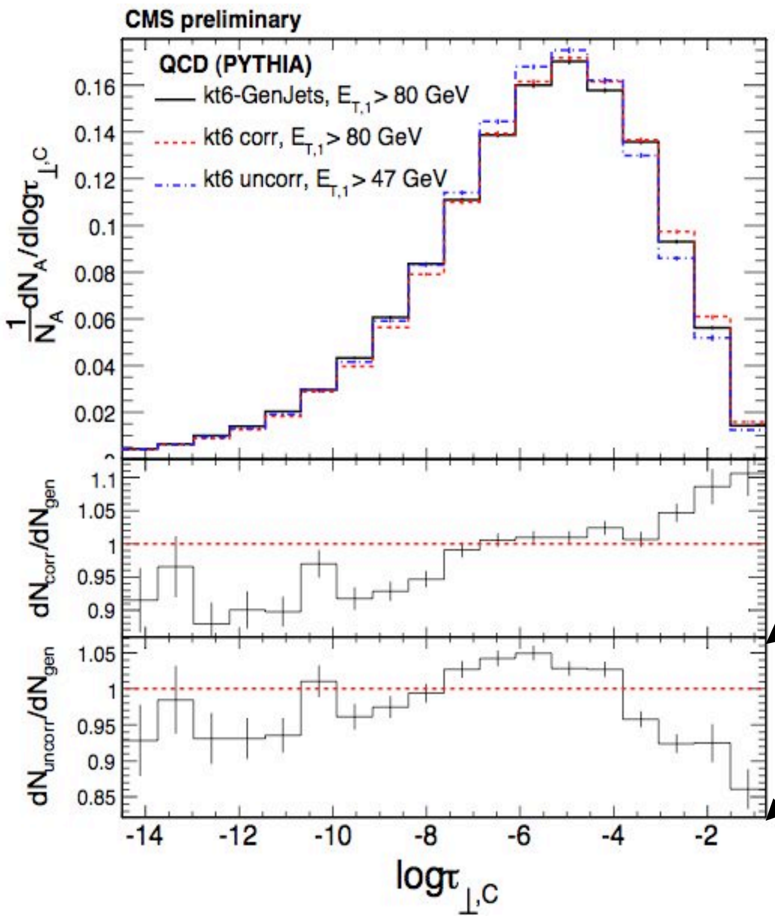
- **Beware** : thresholds !
  - For meaningful comparison have to select similar samples

- For all uncorrected calorimeter level jets: threshold of $E_T$ = 30 GeV

- For the uncorrected leading jets:
  threshold is set according to the response of generated level jets,
  additionally requiring that the number of selected events agree within 3 %:
  - low threshold: $E_{T,1}$ > 47 GeV (uncorrected)
  - medium threshold: $E_{T,1}$ > 190 GeV (uncorrected)

# Sensitivity to Jet Energy Corrections (2)

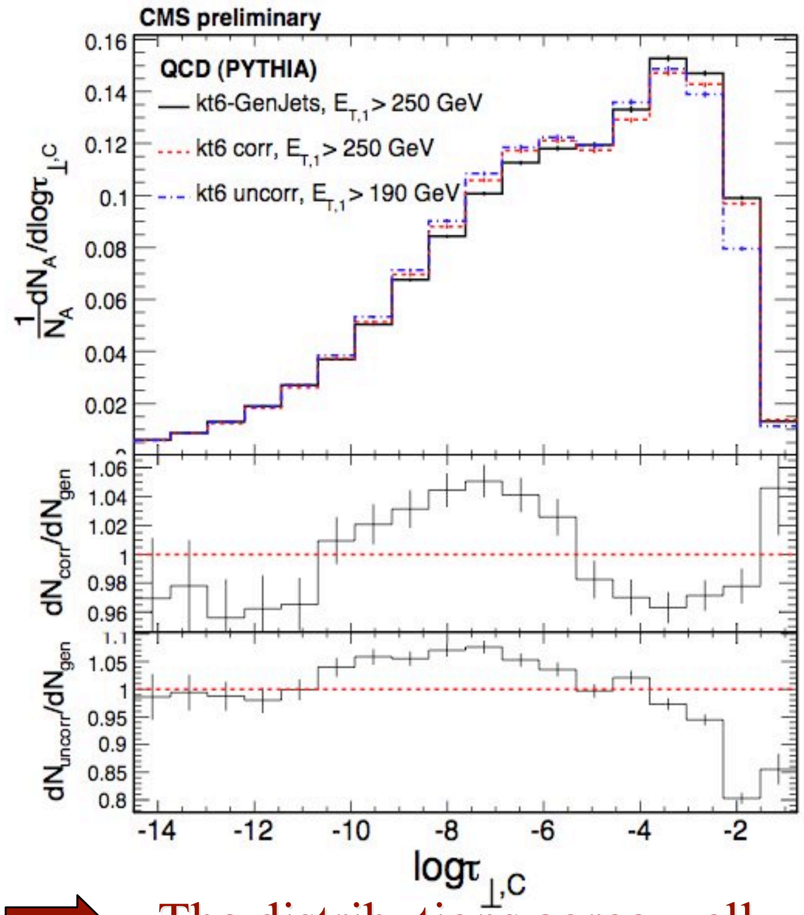
central transverse thrust: **inclusive**




1.07

0.82

central transverse thrust: **medium**




1.10

0.79

The distributions agree well within 7-10% 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:

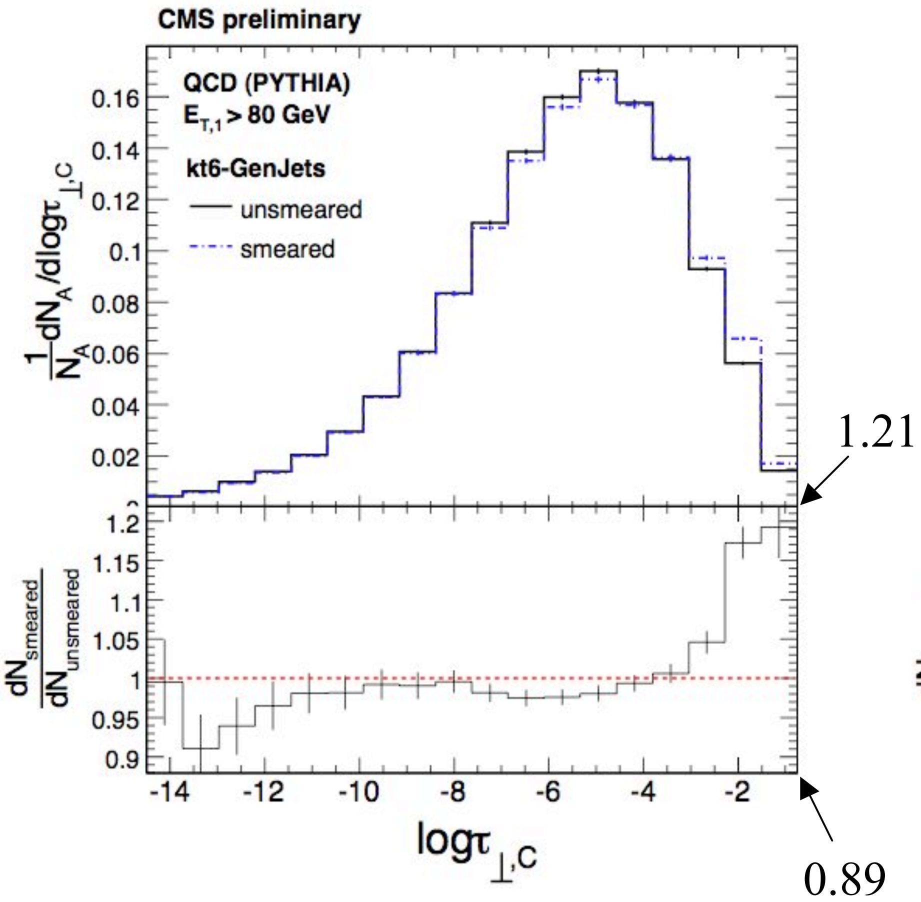
$$\frac{\sigma(p_{\mathrm{T}})}{p_{\mathrm{T}}} = \sqrt{\left(\frac{5.2}{p_{\mathrm{T}}[\mathrm{GeV}]}\right)^2 + \left(\frac{1.2}{\sqrt{p_{\mathrm{T}}[\mathrm{GeV}]}}\right)^2 + (0.043)^2}$$

- The jets have been reordered in $E_T$' after applying the smearing
  - Again : threshold $E_T$' > 60 GeV

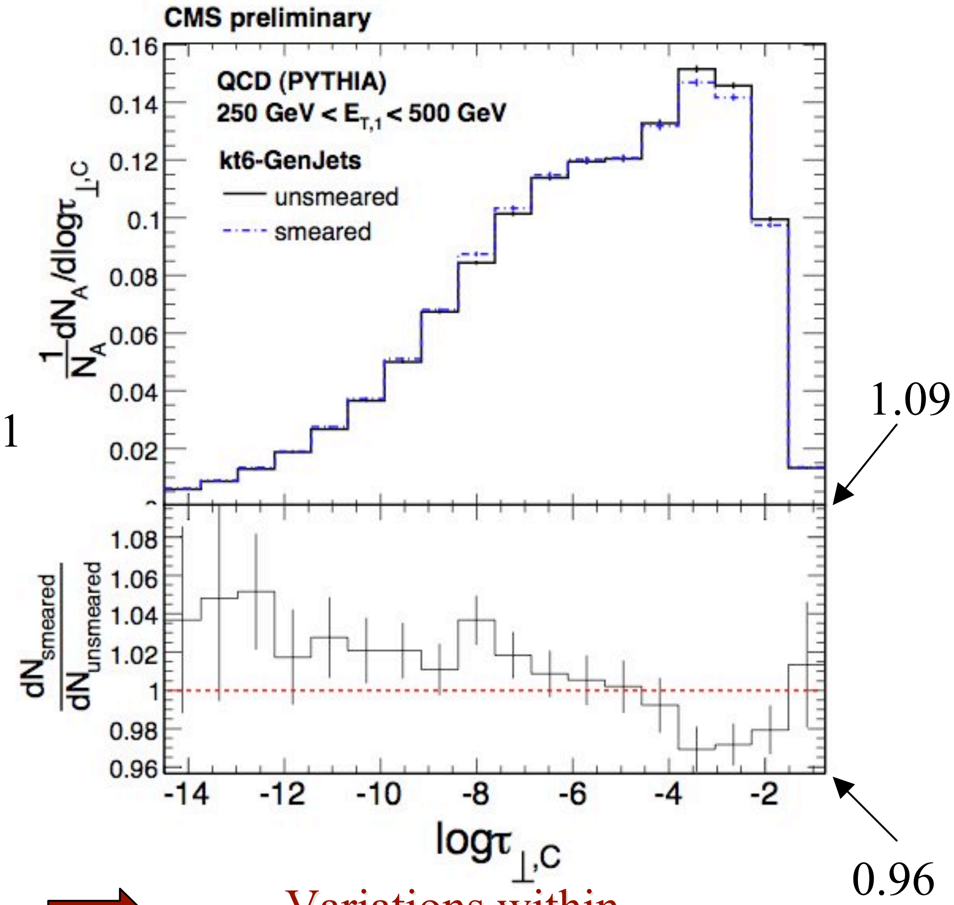
- Define observed differences as systematic uncertainties

# Systematics: Jet Energy Resolution (1)

central transverse thrust: **inclusive**




central transverse thrust: **medium**




Variations within
7 - 8% over a large range

# Systematics: Jet Energy Resolution (2)

- For high values of the central transverse thrust distribution (inclusive sample, ie. $E_{T,1}$>80) the deviations are around 20%.

- **Illustration**:
  events, where a hard jet is balanced by two jets closely below (above) the threshold of 60 GeV.
  Only one jet jumps above the threshold after the smearing is applied (drops below the threshold).