

# Hadronic Event Shapes in pp collisions at 7 TeV

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# Definition of Event Shape

Event shape variables display the geometrical flow of the energy in any event.

Variables defined in terms of four momenta.

Only two variables are used

Banfi, Salam, Zanderighi, '08,'10

Central transverse thrust

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

Central thrust minor

$$T_{m, \mathcal{C}} \equiv \frac{\sum_{i \in \mathcal{C}} |\vec{p}_{\perp, i} \times \vec{n}_{T, \mathcal{C}}|}{\sum_{i \in \mathcal{C}} p_{\perp, i}}$$

Jet momenta are used as a input for the event shape calculation

# Motivation

**Experimentally viable** - Event-shape distributions are robust against jet energy scale uncertainties and jet energy resolution effects.

**Theoretically stable** : collinear and infra red safe, enables to compute in perturbation theory.

Event shapes can be used as a laboratory to test different models of QCD multijet production.

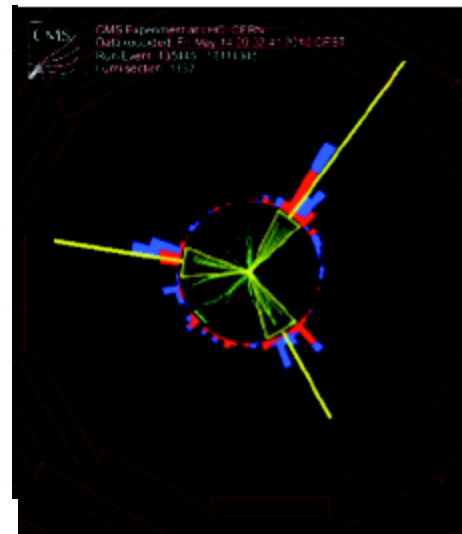
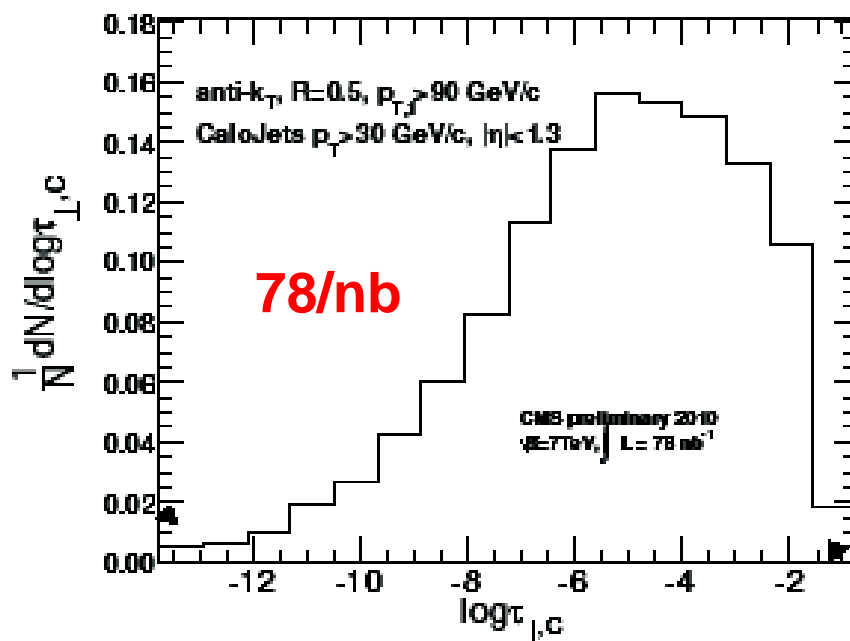
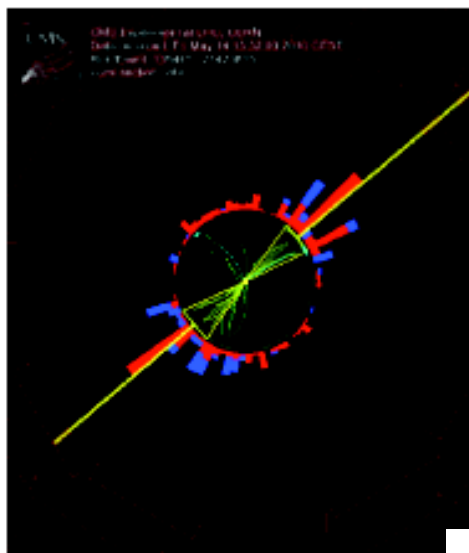
See talk by Gobinda Mazumdar

Event shape variables are also useful to determine  $\alpha_s$

# Example: Central Transverse Thrust

Normalized inclusive distribution of the central transverse thrust

$$\log \tau; \quad \tau = 1 - T$$



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

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

# Jets in CMS

Anti-Kt algorithm:

$$d_{ij} = \min \left( k_{T,i}^{-2}, k_{T,j}^{-2} \right) \frac{\Delta R_{ij}^2}{R^2}$$
$$\Delta R_{i,j}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

**Calo Jet:** Jets are clustered from ECAL and HCAL towers

**Jet-Plus-Track Jets(JPT):** Calorimeter jets are corrected with tracks informations. JEC is applied

**Particle Flow Jets(PF):** Particles are reconstructed from all sub-detector informations, and then clustered to form jets. Calibrated at the particle level.

**Track Jets:** Reconstructed from tracks only, completely independent from Calorimetric jet measurements.

# Jet Selection

- ❑ Jet are required to pass quality cuts to remove possible instrumental and non-collision background.
- ❑ For Calo and JPT jets,  $EMF > 0.01$ ; no. of calo cells containing energy more than 90% must be greater than one; the fraction of energy fraction in HCAL must be  $< 98\%$ .
- ❑ PF jets,  $CHF > 0$ ,  $CEF < 0.99$ .  $NEF < 0.99$ ,  $NHF < 0.99$ ,  $N > 1$
- ❑ Track jets are reconstructed, if have at least two tracks.

**Corrections on jets are used.**

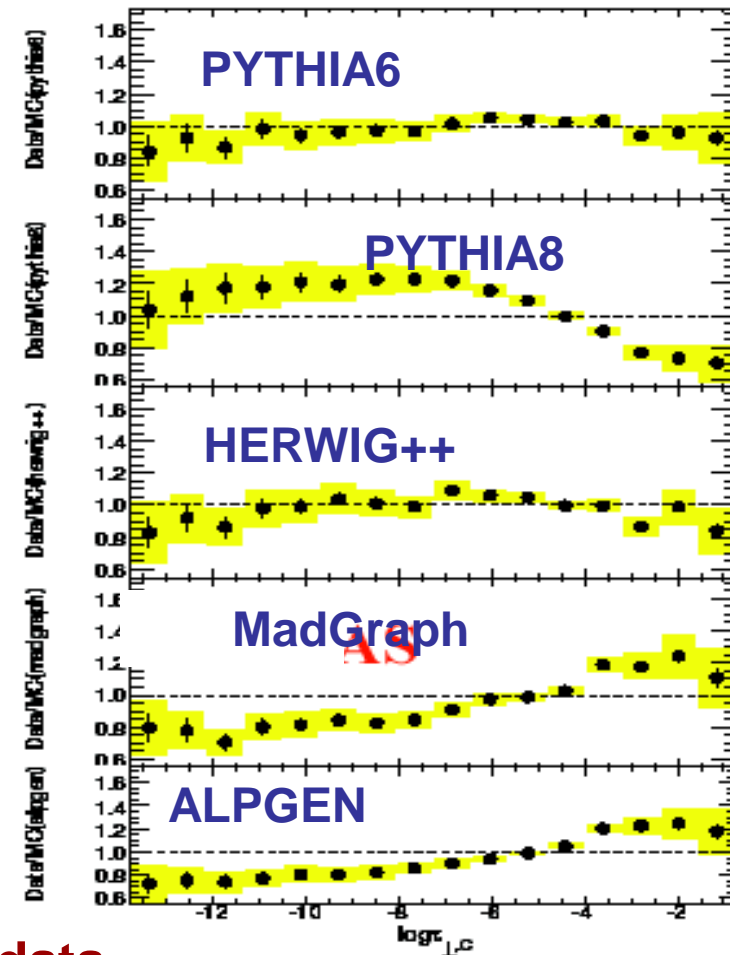
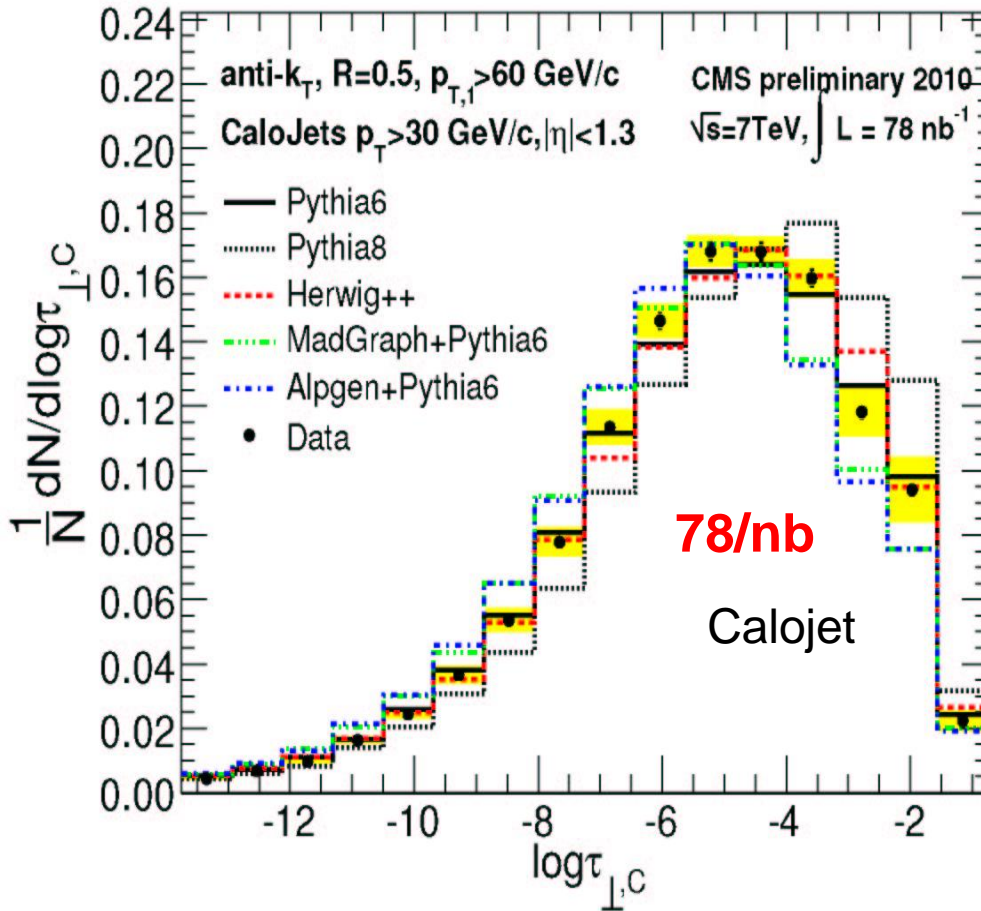
# Jet Selection(contd.)

- ❑ Jet with  $p_T > 30$  GeV and  $|\eta| < 2.6$  are selected;  
Two leading jet should pass quality cuts.
- ❑ Two leading jets are required to be in the central region of the detector  $|\eta| < 1.3$ .
- ❑ To maximise the trigger eff., the leading jet  $p_T > 60(90)$  GeV cut for low(high) data sample.
- ❑ If the event is selected, then all jets with  $p_T > 30$  GeV and  $|\eta| < 1.3$  is used in calculation.

# Central Transverse Thrust

Band is the effect of systematic and statistical error,  
While black arrow is for statistical error only.

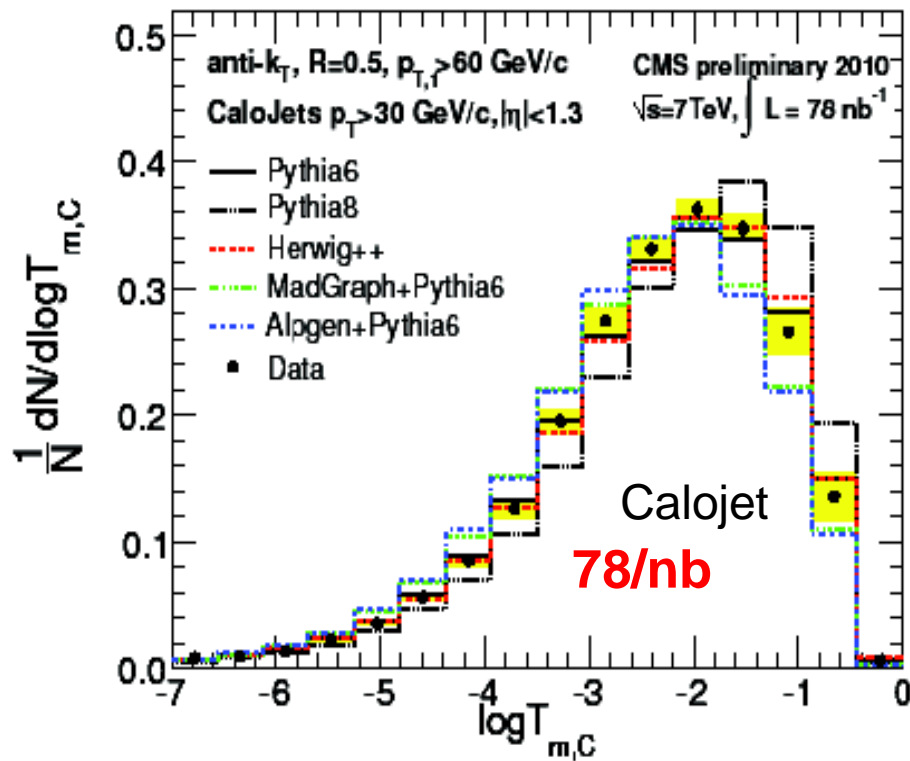
DATA/MC



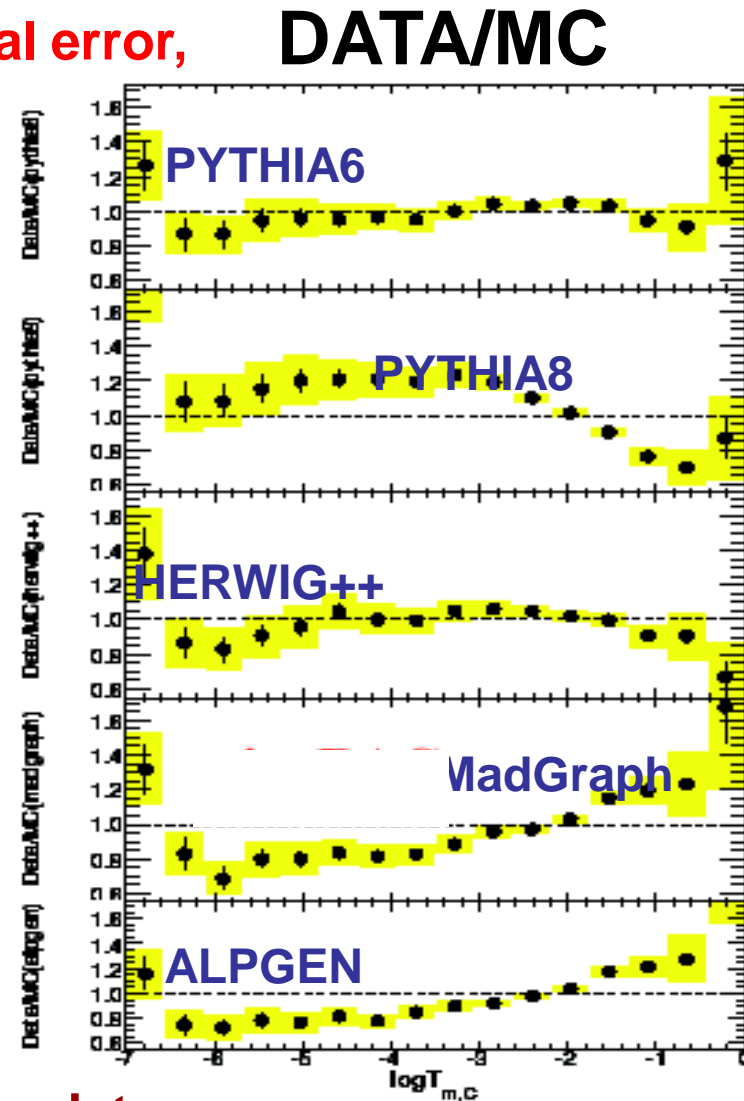
Pythia6 and Herwig++ agree better with data,  
Alpgen, Madgraph and Pythia8 are away from data.

# Central Transverse minor

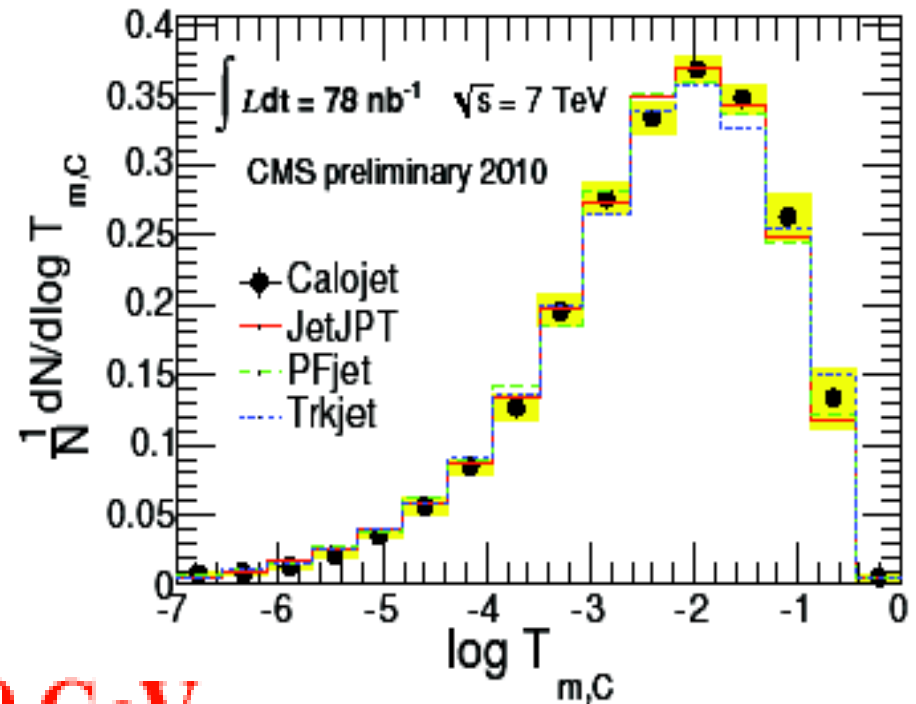
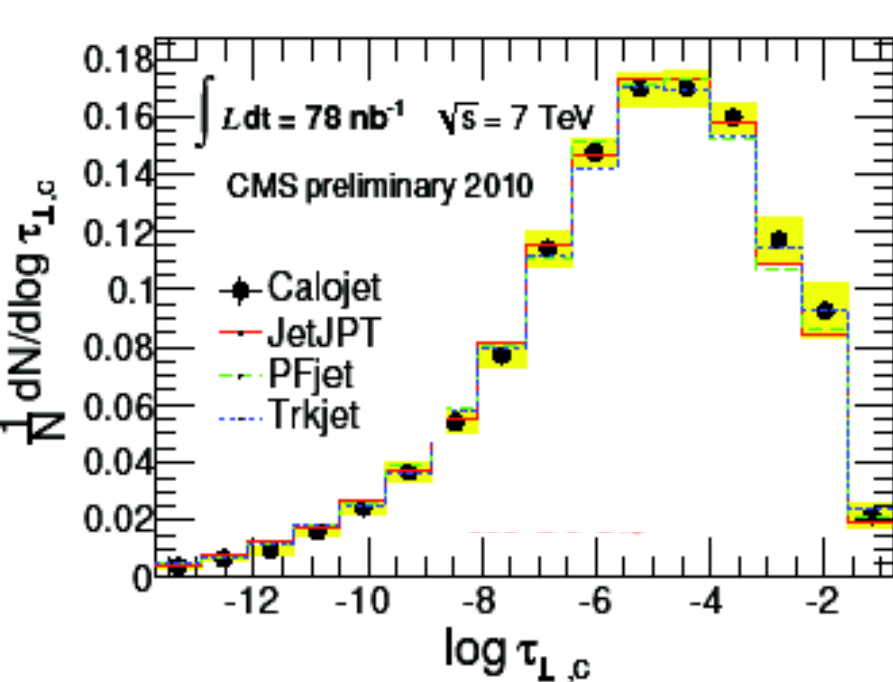
Band is the effect of systematic and statistical error, DATA/MC  
While black arrow is for statistical error only.



Pythia6 and Herwig++ agree better with data,  
Alpgen, Madgraph and Pythia8 are away from data.



# Comparison between different jet types



$p_{T,1} > 60 \text{ GeV}$

Distributions of all four types of jet show a very good consistency.



Final results are based on CaloJets only, a conservative Choice,  
Updated results with PF jets(yet to publish with high lumi) .

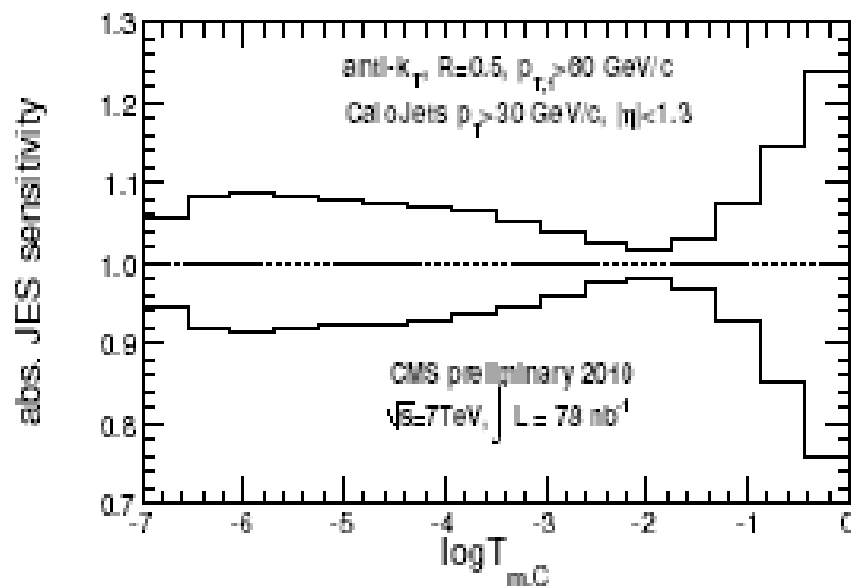
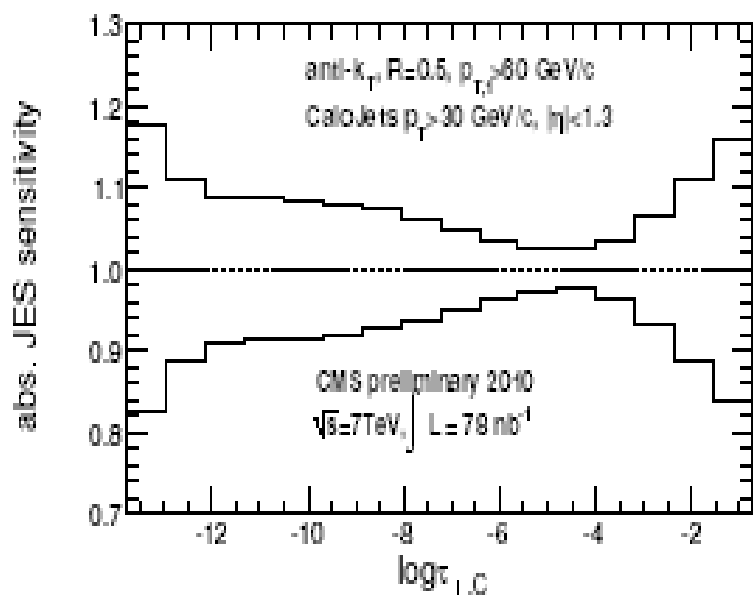
# Systematic Uncertainties: JES

Main systematic uncertainties come from JES

10% flat for Calojets

$|\eta|$  dependent 2% X  $\eta$

$p_{T,1} > 60$  GeV

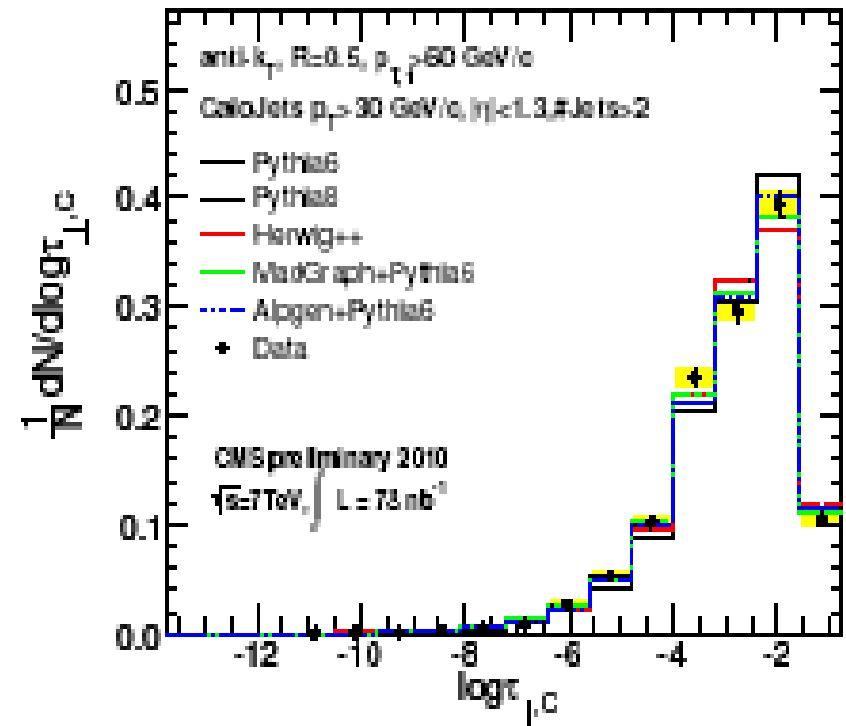
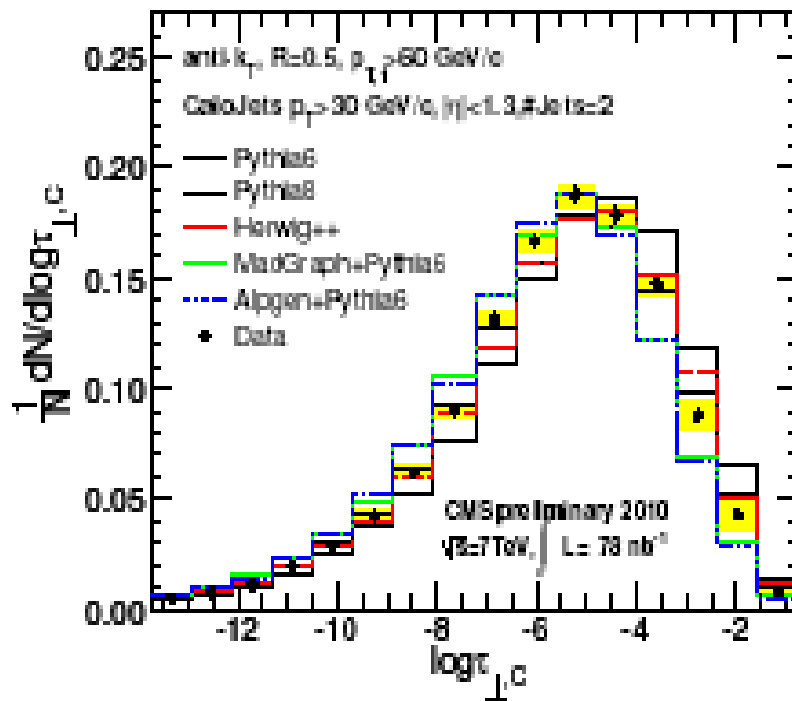


For Calojets, the JES uncertainty leads to deviations within 10%, the dominant effect.

Systematic error due to the imperfect modelling of jet energy and position resolution, It adds  $\sim 5\%$  error on the transverse thrust and thrust minor.

# Tr Thrust in multiplicity bins

**Band is effect of systematic and statistical error, while Black arrow is for statistical error only.**



**MadGraph and ALPGEN show a good agreement with the data in phase Space of three hard well separated jets, difference mainly come from ratio di-jets/3-jets.**

# Unfolding

- ❑ **Event shape distributions are invariant under a shift in jet energy scale, but JES does change the number of jets in the event, which effects the event shape distribution.**
- ❑ **Observed events shape variables are not same as predicted(theoretical) using generator level information, because of the detector smearing.**
- ❑ **To compare it correctly one needs to unfold the observab distribution based on data to generator level information.**
- ❑ **The maximum bin-by-bin difference between the original distributions and the two shifted distributions, after unfolding, is then assigned as a systematic error due to jet JES.**

# Conclusion

- ✓ **First measurement of hadronic events shape in CMS with collision data at 7 TeV, accumulated by the CMS detector during the first months(April-Aug) of 2010 with luminosity 78 /nb.**
- ✓ **Event shapes are seen to be robust against the choice of jet reconstruction object, and uncertainties in JES and expt. resolution,**
- ✓ **Comparison of data with the predictions of different event generators is performed. Good agreement with PYTHIA6 and HERWIG++ is observed. Not so good agreement with ALPGEN, MadGraph, PYTHIA8; ALPGEN and MadGraph are consistent.**

**Updated results with high luminosity is coming up**