ETH Institute for
Particle Physics

Measurement of Hadronic Event Shapes with the CMS detector at the LHC

http://arxiv.org/abs/1102.0068

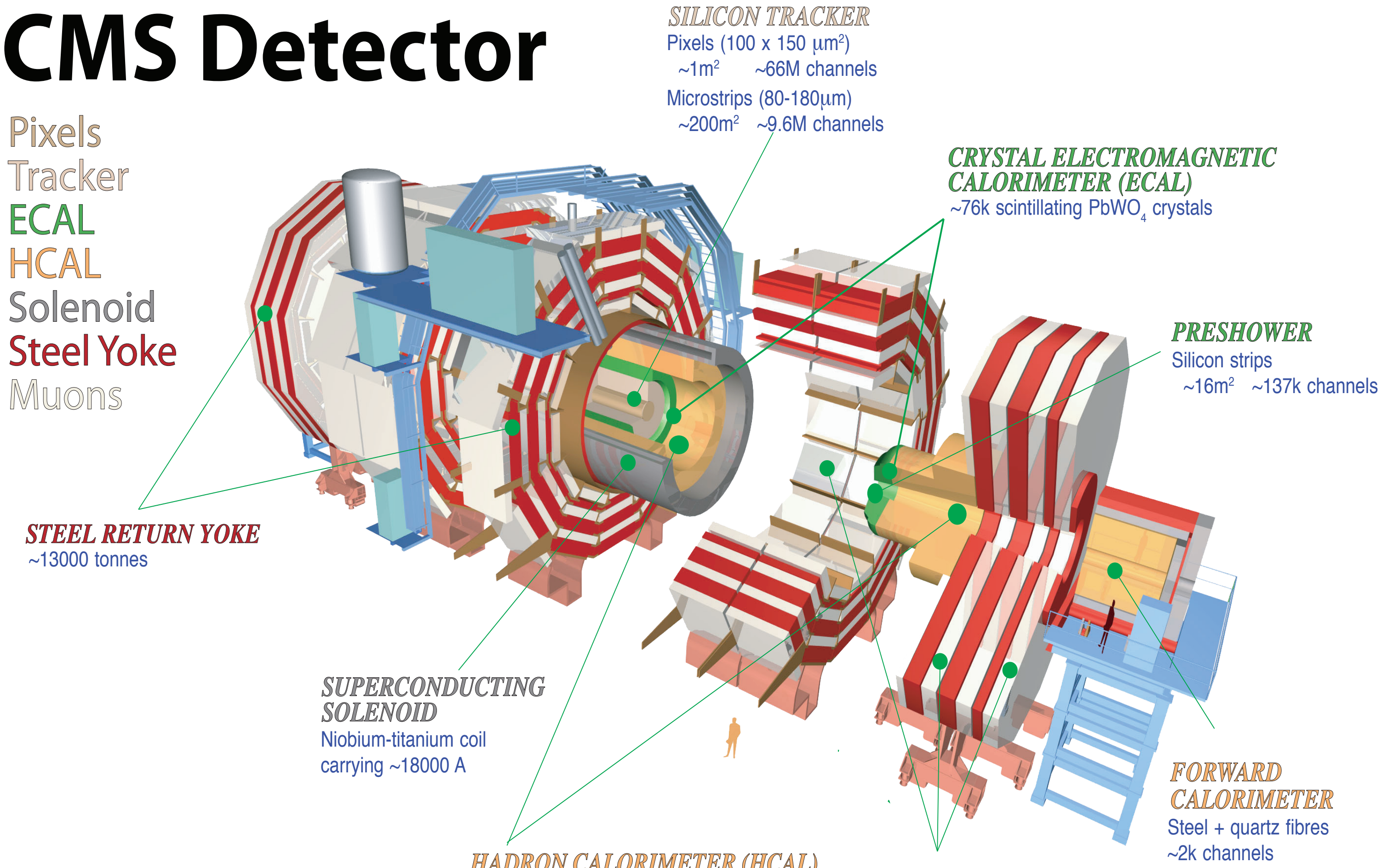
Submitted to PLB

Matthias Weber on behalf of the CMS collaboration

ETH Zurich

Winter Workshop on Recent QCD Advances at the LHC, 16 Feb 2011

The CMS detector



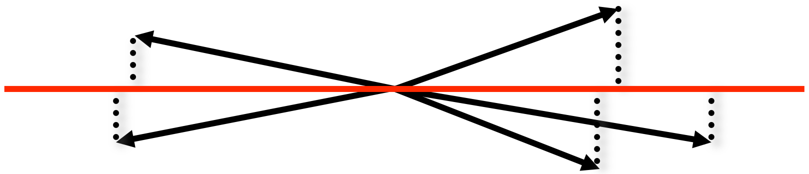
Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

Event Shape Variables

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

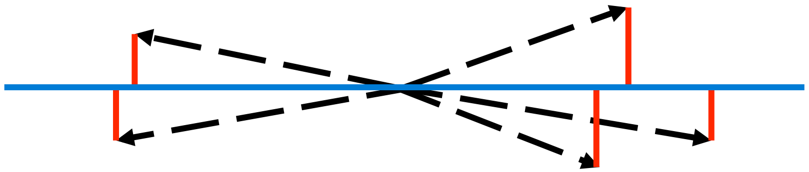
→ this is our goal for this first measurement

- **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:**



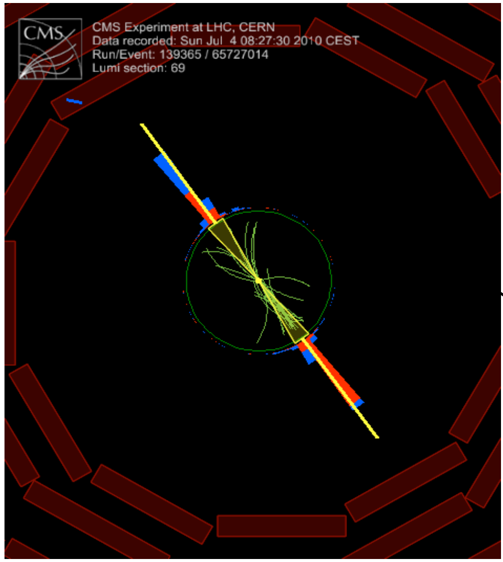
$$T_{m,\mathcal{C}} \equiv \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i} \times \vec{n}_{\mathrm{T},\mathcal{C}}|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

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

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

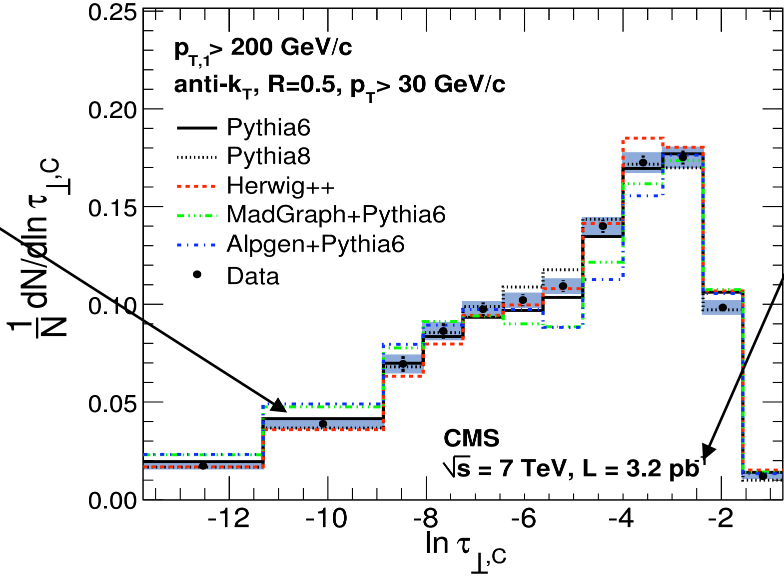
Illustration: central transverse thrust

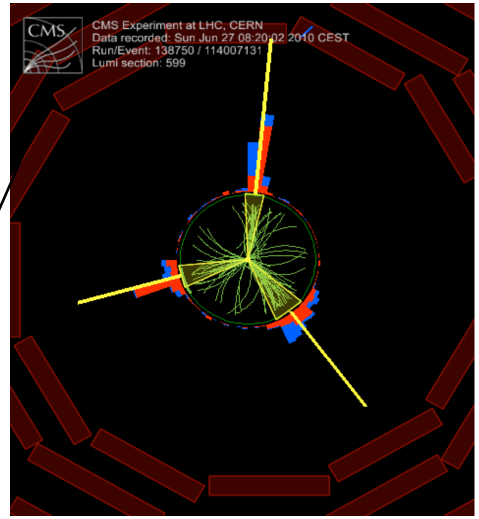
- Event shapes provide information about the properties of hadronic final states
- Normalized inclusive distribution of the central transverse thrust: plotted in the natural logarithm of $\ln \tau_{\perp,\mathcal{C}} = \ln(1 - T_{\perp,\mathcal{C}})$



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

CERN-PH-EP2010-072





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

Event Selection

- Dataset from jet-triggered data: integrated luminosity L=3.2 pb^{-1}
- The leading two jets should be central $|\eta_{j1,j2}|<1.30$
- Use central jets with p_T>30 GeV/c for event shape calculation. (jet algorithm: anti-k_T , R=0.5)
- Divide phase space in exclusive bins of the leading jet p_T:
  - 90 GeV/c<$p_{T,1}$<125 GeV/c (**low**),
  - 125 GeV/c<$p_{T,1}$<200 GeV/c (**medium**),
  - $p_{T,1}$>200 GeV/c (**high**)

CERN-PH-EP2010-072

- Previous results (L=78 nb^{-1}) also available, using inclusive bins
  - $p_{T,1}$>60 GeV/c
  - $p_{T,1}$>90 GeV/c

CMS-PAS-QCD-10-013

ETH Institute for Particle Physics

Jet Reconstruction Types

CMS uses four different types of jet reconstruction:

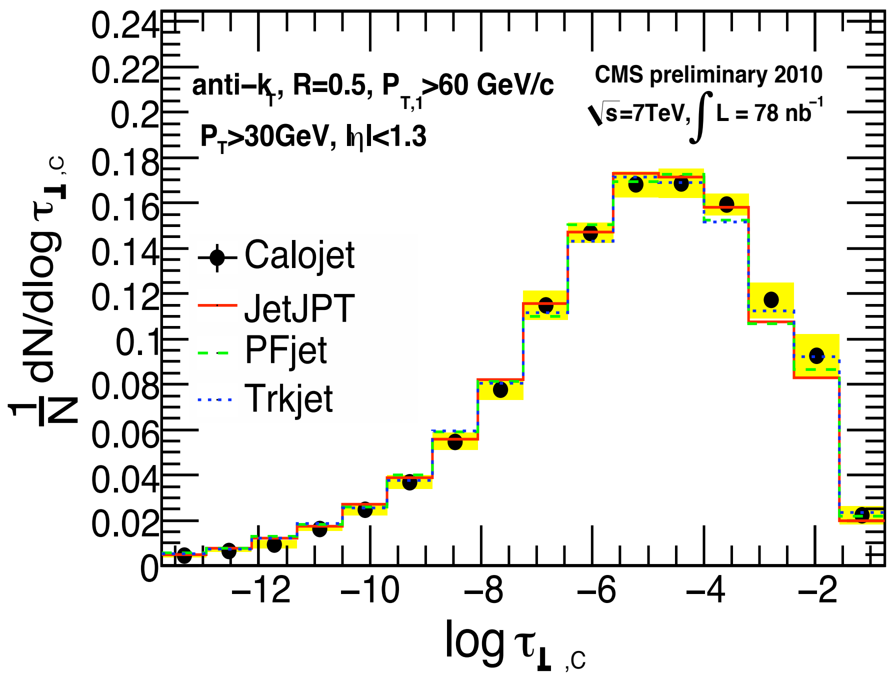
- Track jets: charged tracks are combined into jets
- Calorimeter jets (CaloJets) use energy deposits in the calorimeter
- JetPlusTrack (JPT) –Jets: calorimeter jets are modified in energy and position using associated tracks
- Particle Flow Jets (PFJets): in a first step particles are reconstructed as a combination of charged tracks and calorimeter deposits using particle flow techniques. In a second step jets are clustered out of these PFparticles.

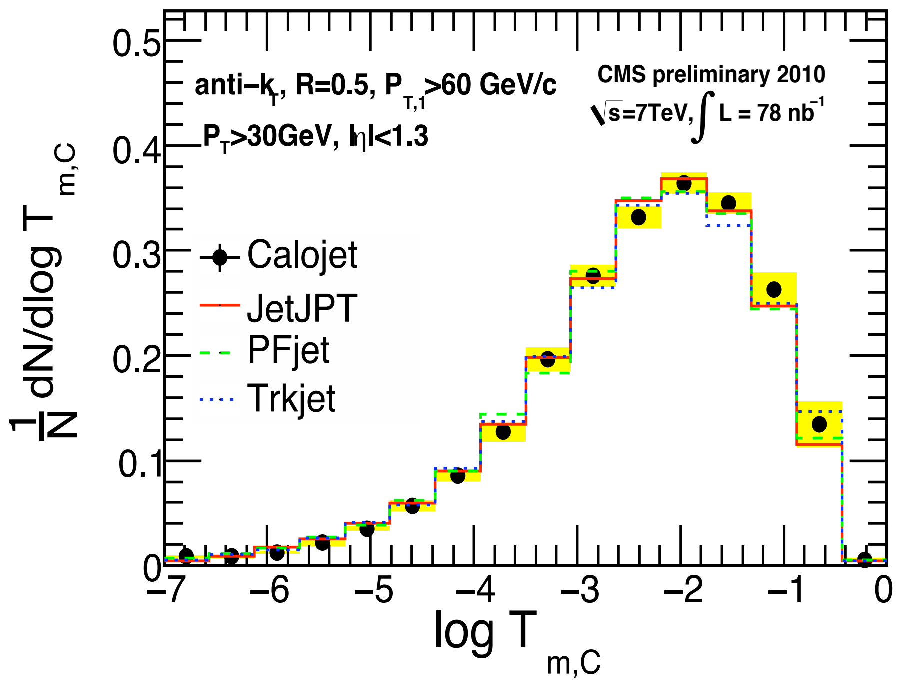
Dedicated jet-talk by Andreas Hinzmann

Comparison of different Jet Types

Compare event-shape distributions using different jet types as inputs. The distributions are not unfolded.

$p_{T,1}$>60 GeV





Distributions of all four jet reconstruction types show a nice agreement for both variables

Unfolding procedure:

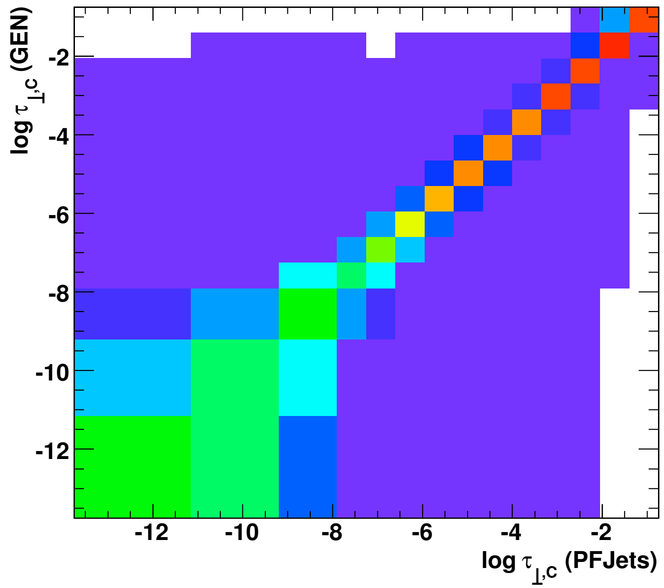
Singular Value Decomposition

SVD Unfolding

- The SVD method is based on the singular value decomposition of the response matrix.

Hoecker, Kartvelishvili, Nucl.Instrum.Methods A 312 (1996)

- The response matrix is obtained from Pythia6 D6T QCD samples.



Significant off-diagonal elements, especially for low event shape values (>30 %), elements > 0.90 only for highest event-shape values

- Choose the regularization parameter such that the chi2-value between the unfolded and the generator level distributions is minimal.

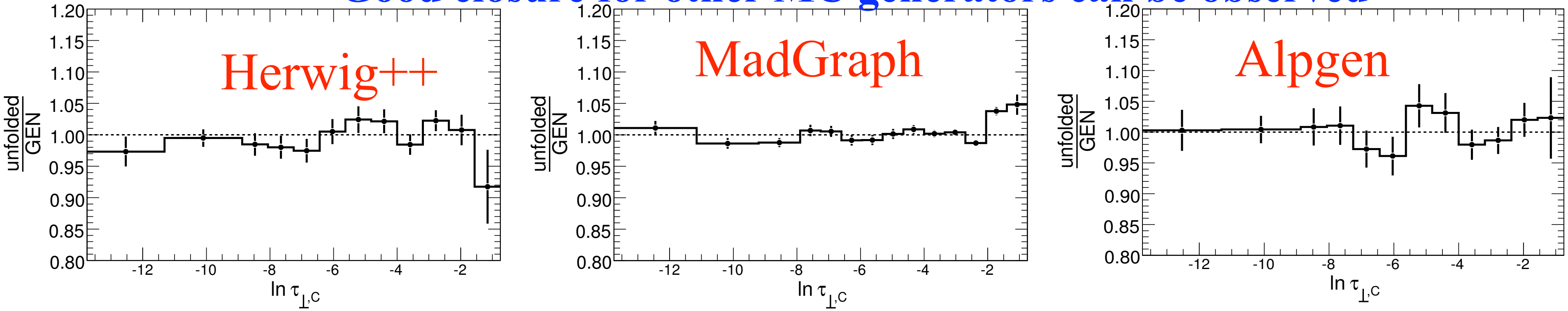
Closure Tests

- Check if using the Pythia6 response matrix introduces a bias for other generators
- For illustration:

  Smear jets in energy, η, φ. Calculate transverse thrust out of these smeared jets

  -> pseudodata distribution
- Check the closure between the unfolded pseudo-data distribution and the generator hadron level distribution, using the Pythia6 D6T response matrix.

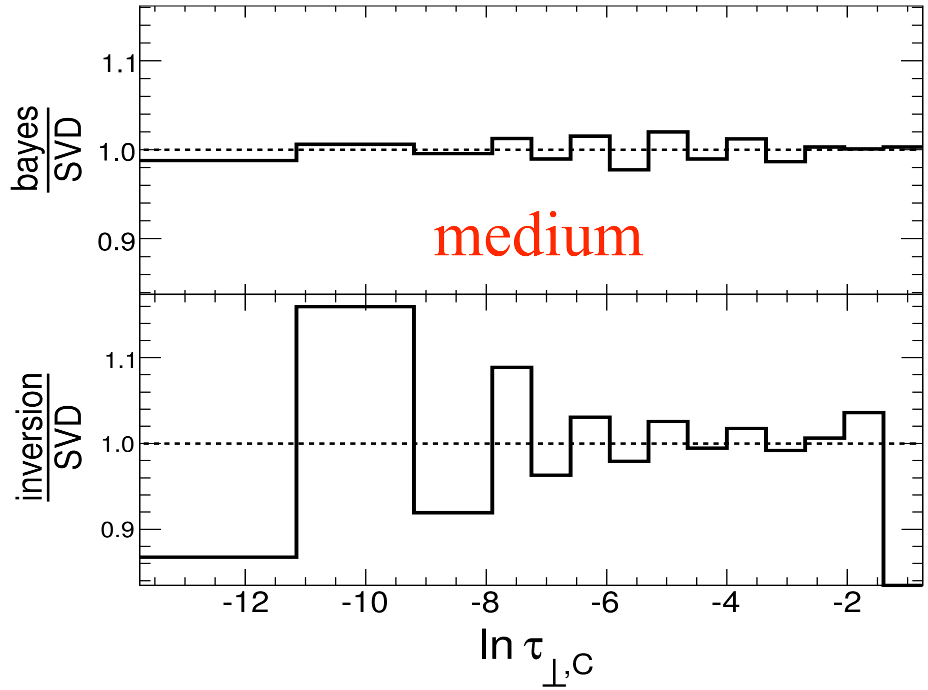
Good closure for other MC generators can be observed



- Further test: check compatibility of statistical chi2 between pre-unfolded data and fully simulated samples, and between unfolded data and generated samples

Cross check: compare different unfolding procedures

Compare different unfolding procedures:
SVD unfolding, iterative bayesian unfolding (d'Agostini method) and the *inversion* of the response matrix



Bayes and SVD unfolded data distributions very close (differences within 1 % for most bins). The matrix inversion leads to similar results for high event shape values, oscillations for lower values.

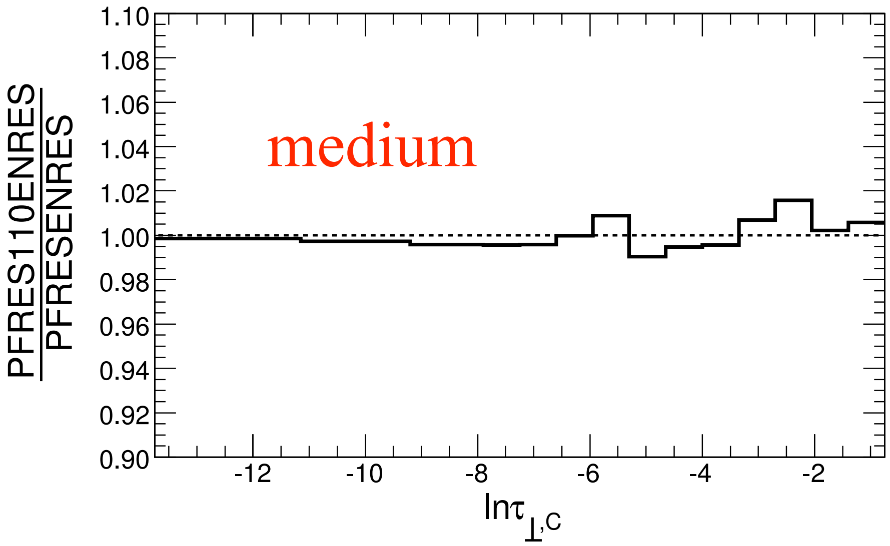
Systematics:

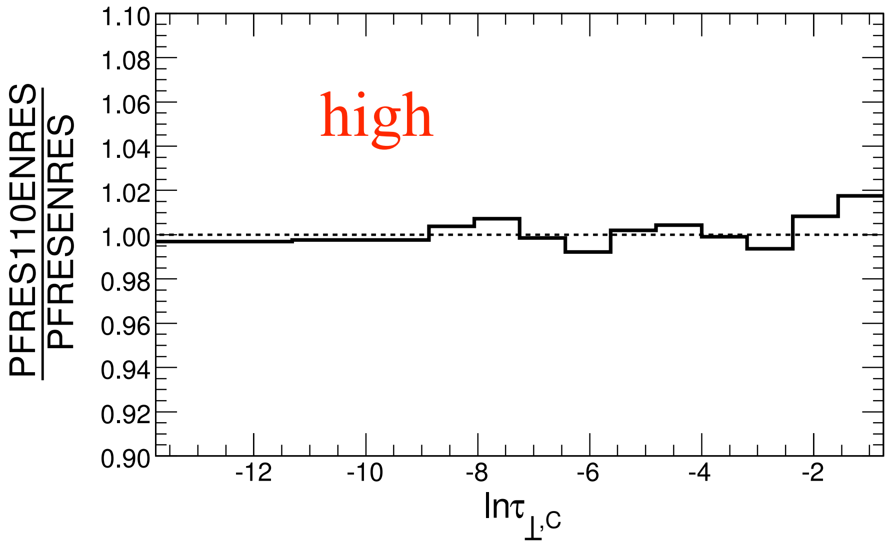
Jet Energy Scale

Jet Energy Resolution

Jet Energy Resolution uncertainty

- First energy resolution measurements indicate a up to 10% worse jet energy resolution than predicted by Pythia6
- Smear genjets in position and energy and calculate the thrust out of these
- Repeat procedure with a 10% increase in the jet energy resolution



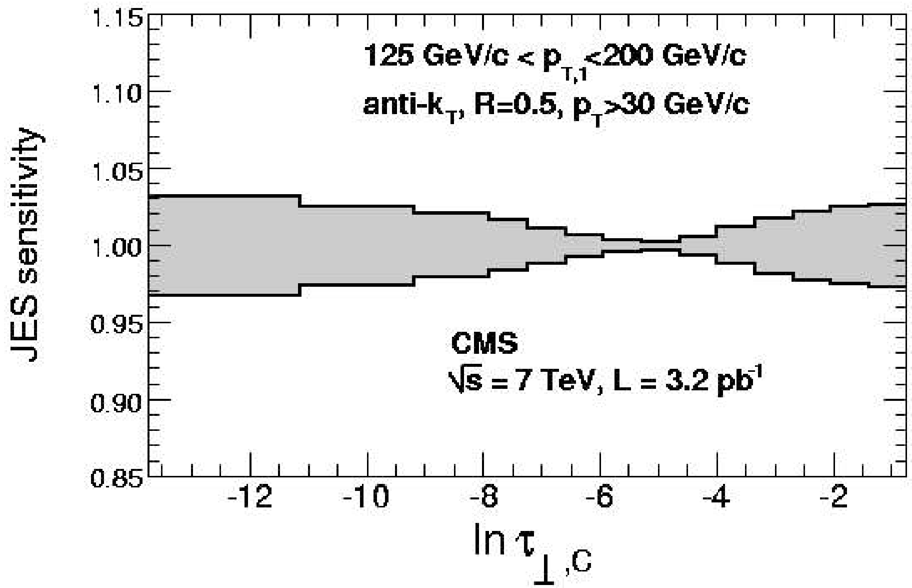


→ Deviations are well within 1% for most bins.

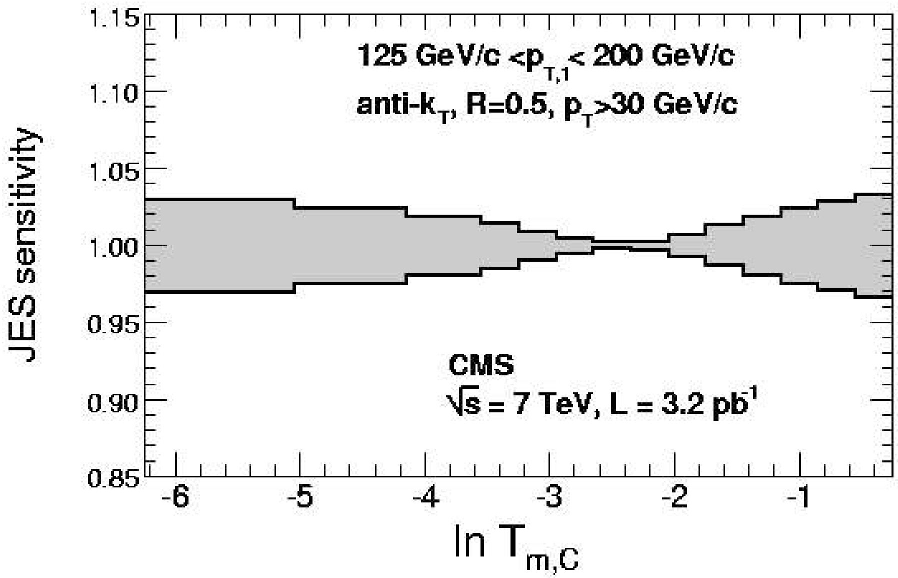
Jet Energy Scale Uncertainty

Use η and p_T - dependent jet correction uncertainties. Compare the distributions using scaled jet momenta after unfolding

Medium bin



thrust



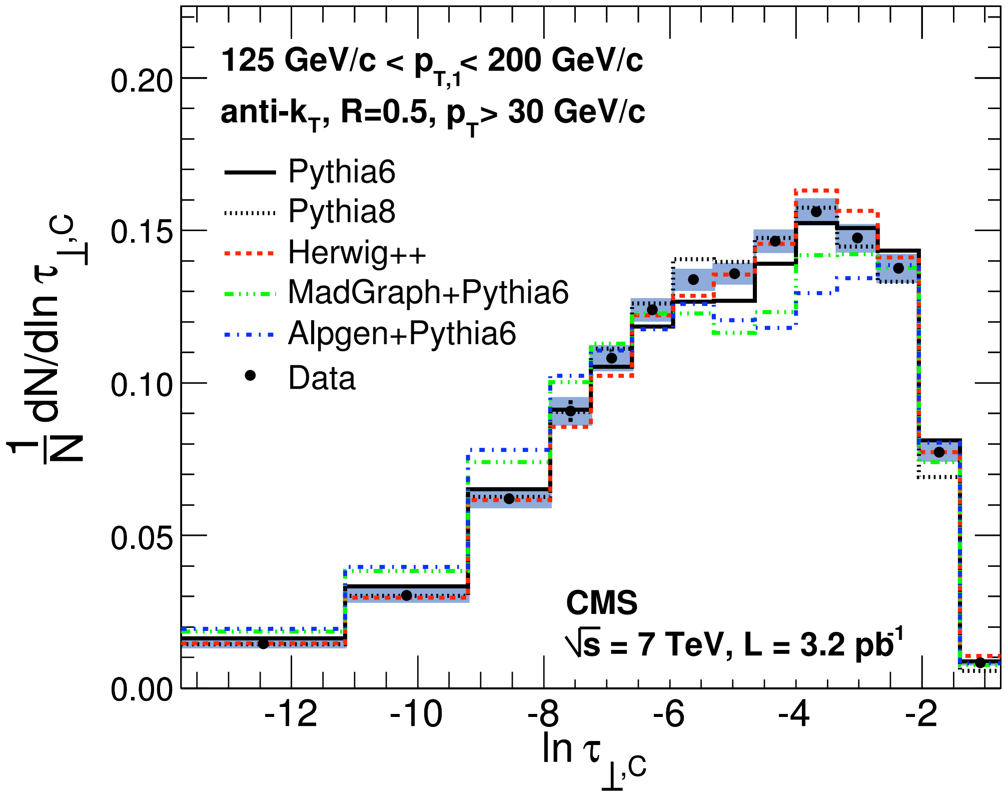
Thrust minor

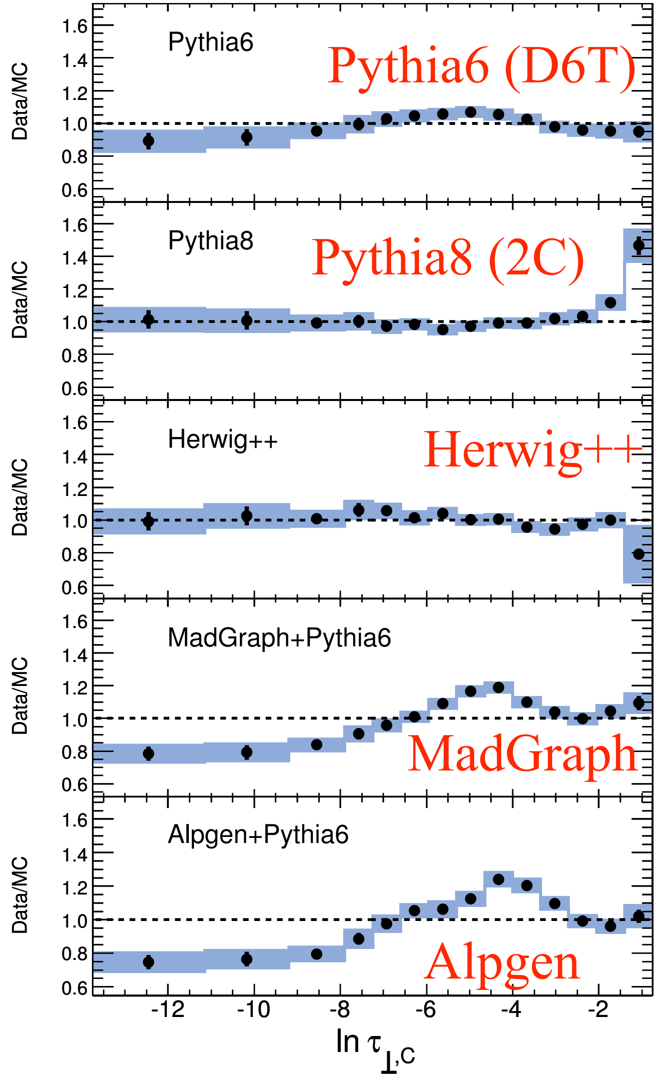
The jet energy scale uncertainty leads to deviations within 3% on the distributions

RESULTS

Central transverse thrust, medium bin

Black error bar = statistical error
Blue error band = systematic + statistical errors



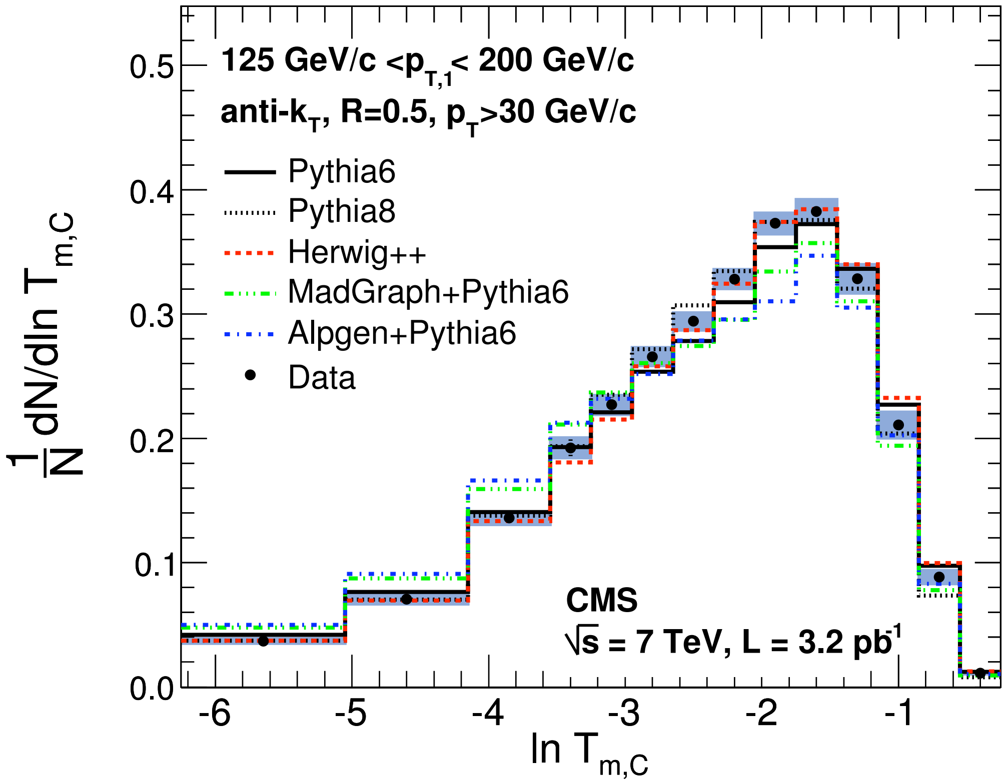


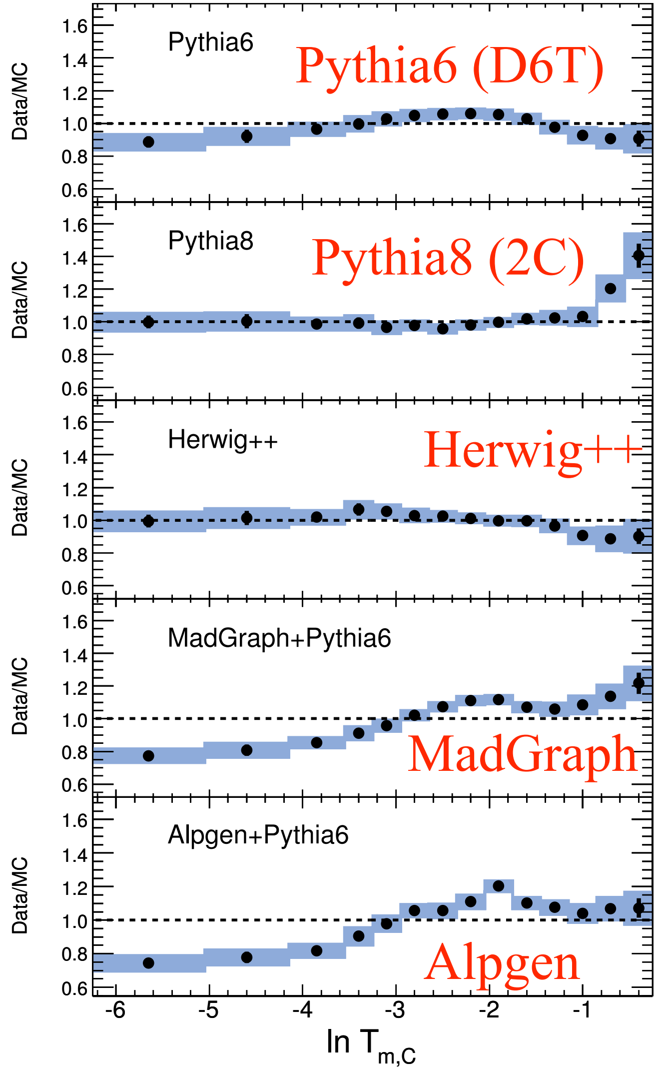
Pythia6, Pythia8 and Herwig++ are close to the data,
Alpgen, MadGraph show discrepancies

Central thrust minor, medium bin

Black error bar = statistical error

Blue error band = systematic + statistical errors



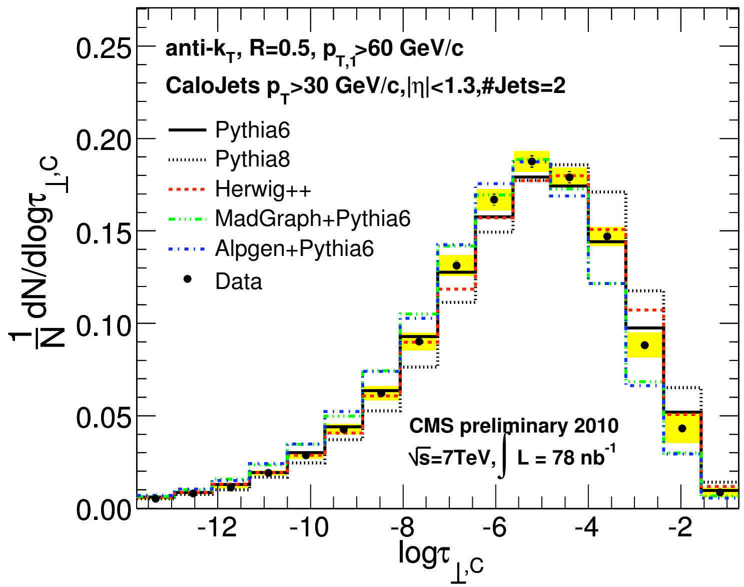


Pythia6, Pythia8 and Herwig++ are close to the data, Alpgen, MadGraph show discrepancies

ETH Institute for Particle Physics

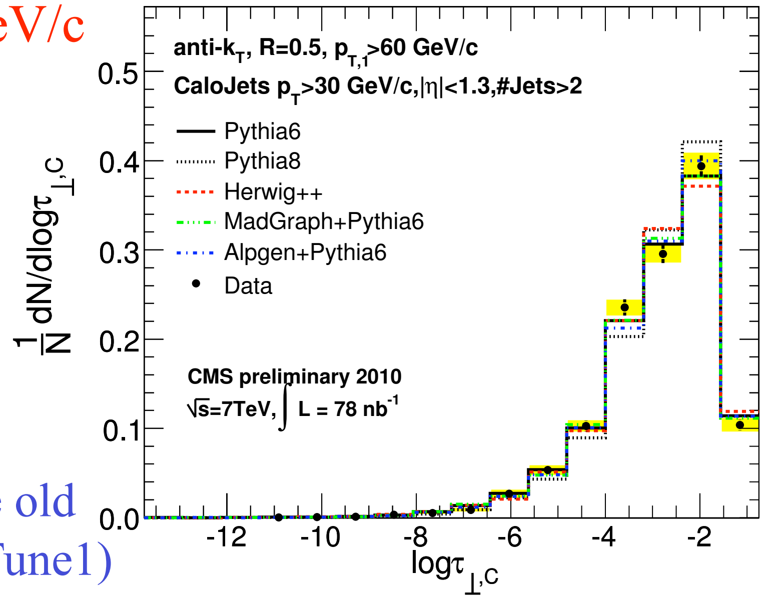
Discrepancy MC vs Data

- From previous plots:
  - good agreement of data with Pythia6 and Herwig++, Pythia8
  - discrepancies with Alpgen and MadGraph predictions
- Similar discrepancy for Alpgen as for MadGraph
- Discrepancy mainly in region of 2 central jets. Good agreement between data and all MCs in region of 3 and more central jets



p_T>60 GeV/c

Note: here old Pythia8 (Tune1)



Summary & Outlook

- **We provided the first unfolded measurement of hadronic event shapes with the CMS detector, using particle flow jets as input**
- SVD unfolding method shows good closure with generator level distributions for all generators
- Study of systematic uncertainties:

  - p_T and eta-dependent Jet Energy Scale leads to deviations well within 3%

  - closure of the unfolding (within 1-2%)

  - increase of jet energy resolution by 10% has no significant impact (<1%)
- Comparison with predictions of our main MC event generators:

  - good agreement with Pythia6, Pythia8 and Herwig++

  - discrepancies with Alpgen and MadGraph
- Outlook: provide the results in RIVET format

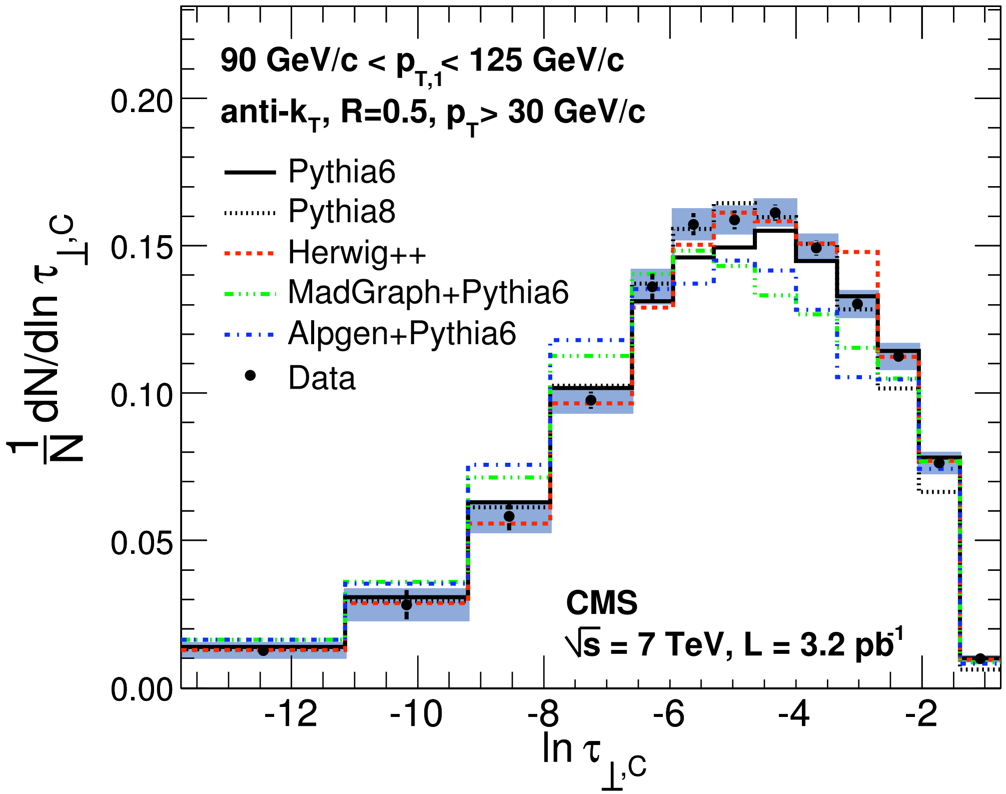
BACKUP

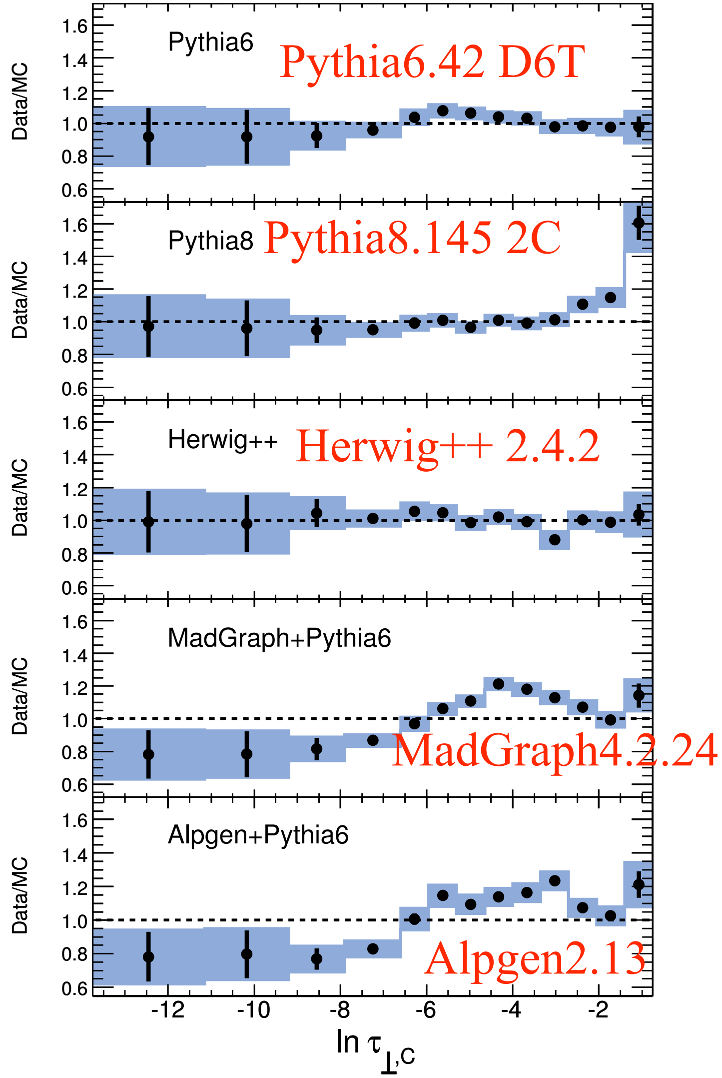
ETH Institute for Particle Physics

Central transverse thrust, low bin

Black error bar = statistical error

Blue error band = systematic + statistical errors



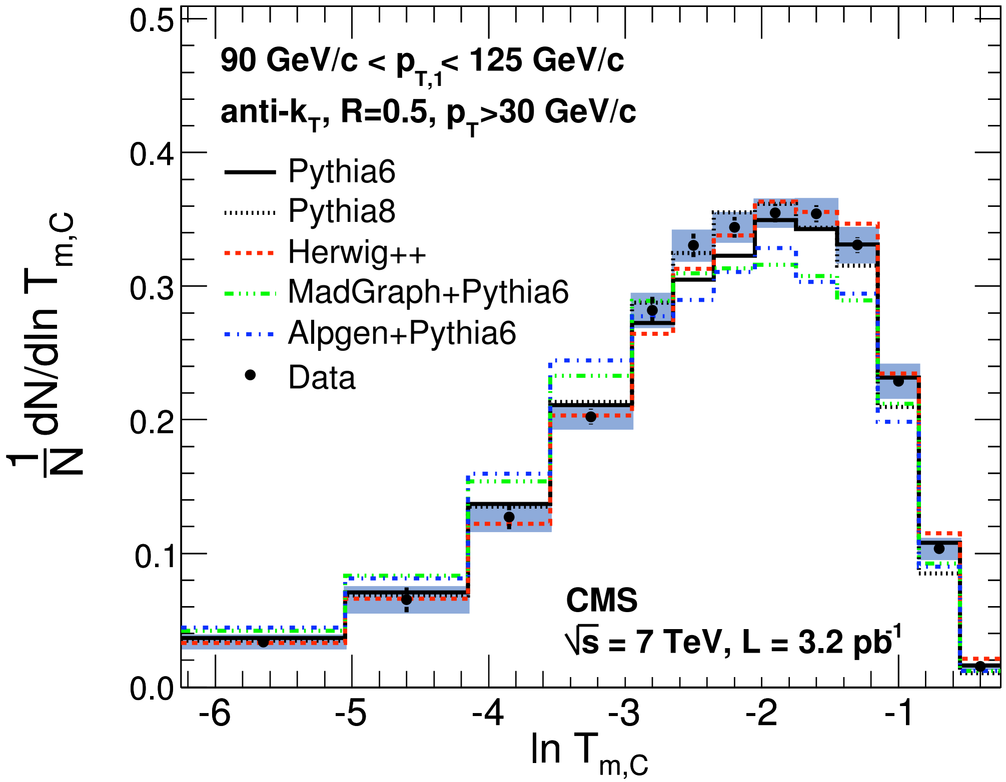


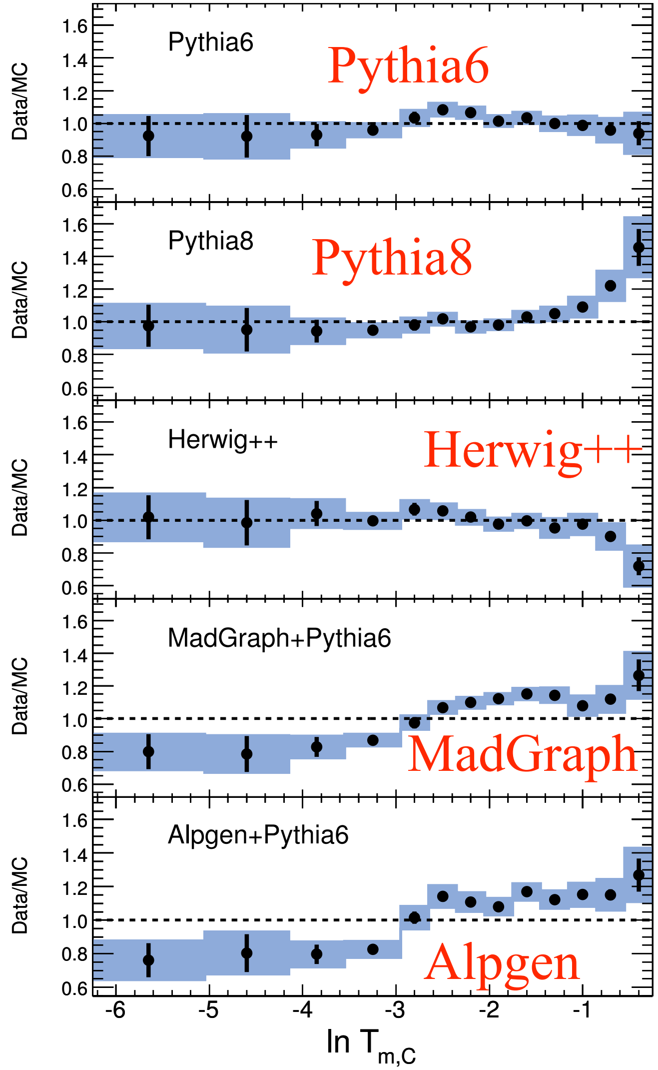
Pythia6, Pythia8 and Herwig++ are close to the data,
Alpgen, MadGraph show discrepancies

Central thrust minor, low bin

Black error bar = statistical error

Blue error band = systematic + statistical errors

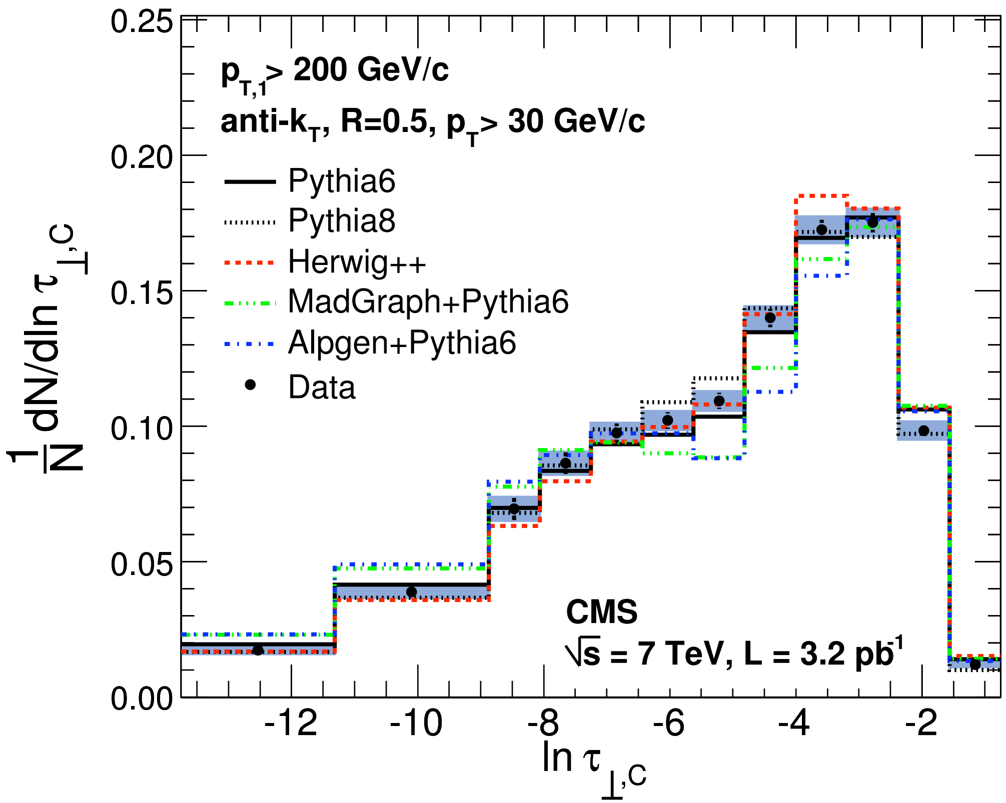


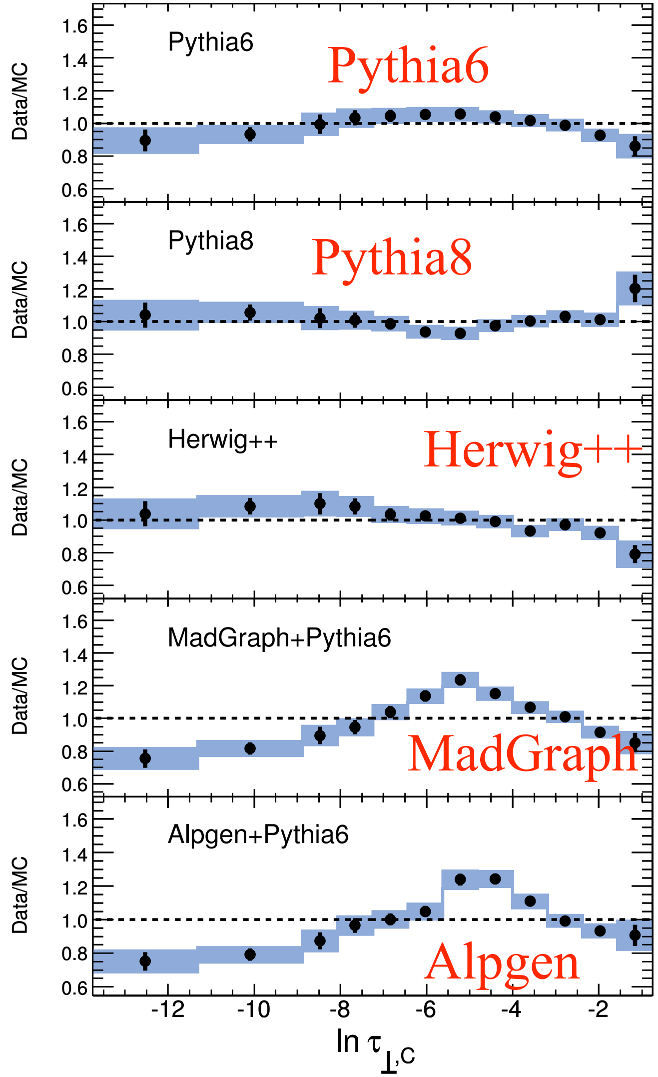


Pythia6, Pythia8 and Herwig++ are close to the data, Alpgen, MadGraph show discrepancies

Central transverse thrust, high bin

Black error bar = statistical error
Blue error band = systematic + statistical errors



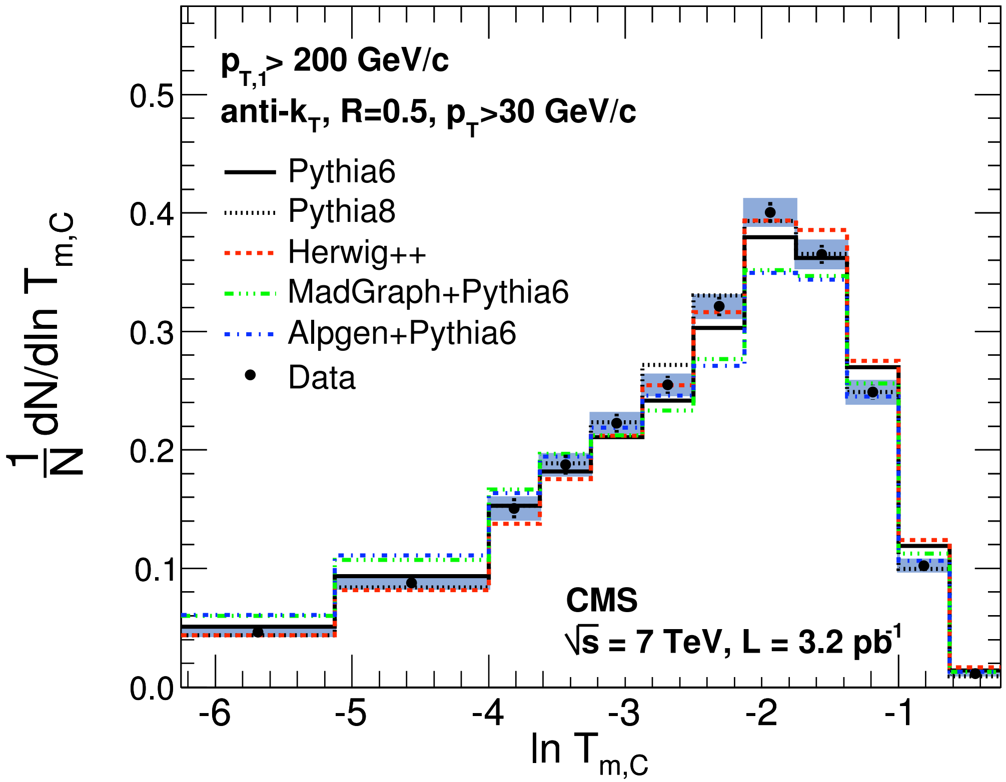


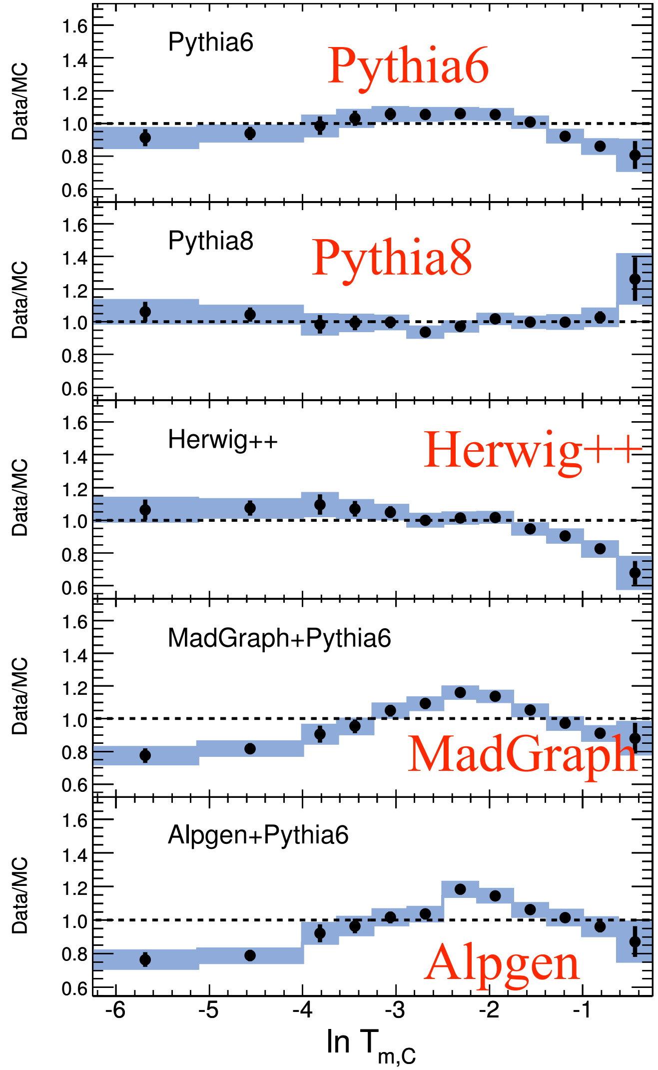
Pythia6, Pythia8 and Herwig++ are close to the data,
Alpgen, MadGraph show discrepancies

Central thrust minor, high bin

Black error bar = statistical error

Blue error band = systematic + statistical errors



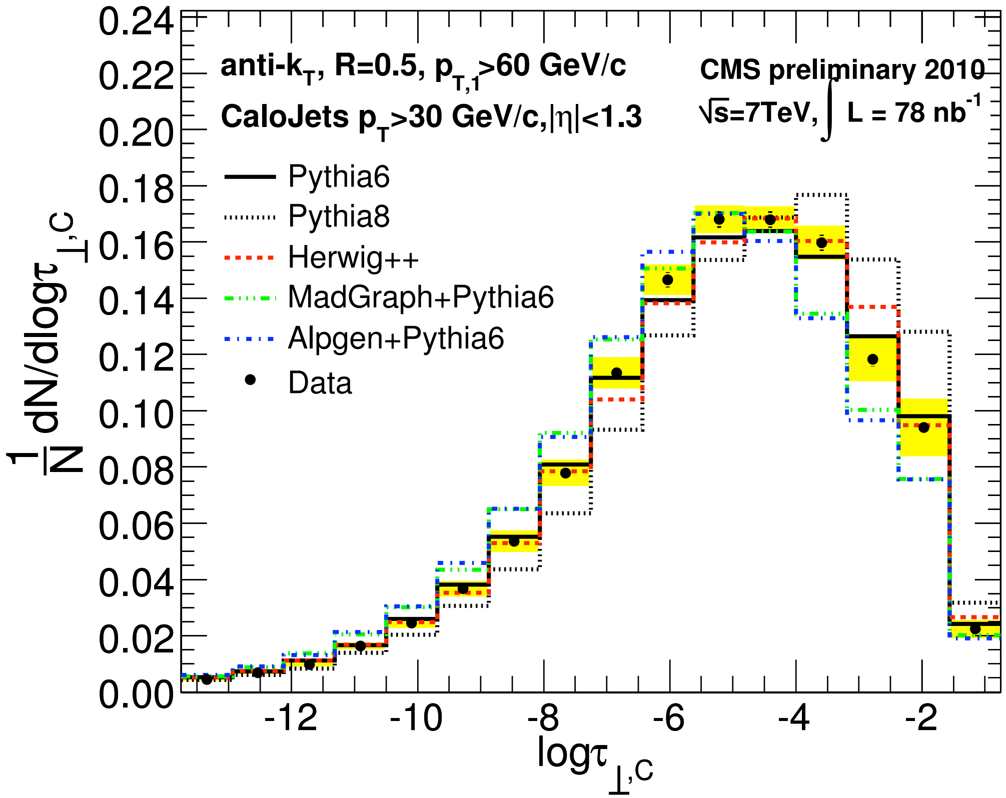


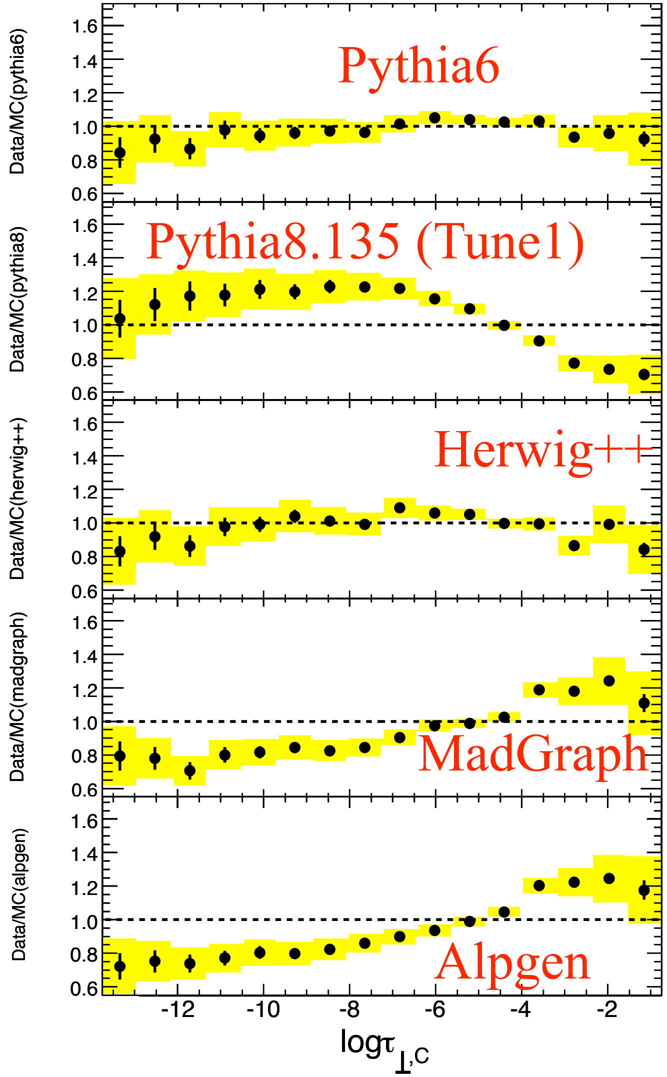
Pythia6, Pythia8 and Herwig++ are close to the data, Alpgen, MadGraph show discrepancies

Central transverse thrust, p_T>60 GeV/c

Black error bar = statistical error

Yellow band= systematic + statistical errors





Comparison prior to unfolding, MC after full Simulation

Pythia8.135 (Tune1) shows also discrepancies