Hadronic Event Shapes in pp collisions at 7 TeV

Sandeep Bhowmik

Visva-Bharati University, Santiniketan, India

On behalf of the CMS collaboration

CMS PAS -12-022

Abstract

Event shape variables exhibit sensitivity to the structure of QCD radiation in hadron collisions. Five infrared- and collinear-safe event shape variables, each sensitive to the different features of multi-jet production, are measured using hadronic jet data collected with the CMS detector from pp collisions at $\sqrt{s}$ = 7 TeV, corresponding to a total integrated luminosity of 5 fb^{-1}. The measurements are compared to predictions of various QCD-inspired event generators of multi-jet production.

Introduction

- Event shape variables are geometric properties of the energy flow in hadronic final states.
- Many of these are collinear- and infrared-safe, as well as robust with respect to mismeasurement of soft or close-by particles.
- They are sensitive to the details of the features of quantum chromodynamics (QCD) and used to calculate α_s in e^+e^- collider [1].
- Due to lack of knowledge in initial momentum of the partonic system in hadron collider, a large set of event shape variables measured in the transverse plane, has been proposed which are sensitive to different radiation features in proton-proton colliders [2].
- These variables are normalized to the sum of the measured transverse momentum of all reconstructed objects in the event to reduce the main systematic uncertainty due to the jet energy scale.
- These measurements have improved the understanding of the structure of QCD and have been used for the tuning and validation of various QCD inspired Monte Carlo (MC) event generators.

Event Shape Variables

Transverse Thrust

The event thrust observable in the transverse plane is defined by:

$$T_{\perp,C} \equiv \max_{\hat{n}_T} \frac{\sum_i |\vec{p}_{\perp i} \cdot \hat{n}_T|}{\sum_i p_{\perp i}}, \quad \tau_{\perp,C} \equiv 1 - T_{\perp,C}$$

where $p_{\perp i}$ represents the transverse momentum of the i-th jet, and n_T is the unit vector that maximizes the projection (transverse thrust axis).
In the limit of a perfectly balanced two-jet event, $\tau_{\perp,C}$ is zero, while in isotropic multi-jet events it is $(1 - 2/\pi)$.

Jet Broadenings

Having determined the transverse thrust axis n_T, the transverse region is separated into an upper part C_U, consisting of all jets with $p_\perp . n_T > 0$, and a lower part C_L, with $p_\perp . n_T < 0$. The pseudo-rapidities and the azimuthal angles of the axes for the upper and lower regions are defined by:

$$\eta_X = \frac{\sum_{i \in C_X} p_{\perp i}\eta_i}{\sum_{i \in C_X} p_{\perp i}}, \quad \phi_X = \frac{\sum_{i \in C_X} p_{\perp i}\phi_i}{\sum_{i \in C_X} p_{\perp i}}$$

where X refers to upper (U) or lower (L) part. The broadening in the two regions are then defined as

$$B_{X,C} \equiv \frac{1}{2P_\perp} \sum_{i \in C_X} p_{\perp i}\sqrt{(\eta_i - \eta_X)^2 + (\phi_i - \phi_X)^2},$$

where $P_\perp$ is the scalar sum of the transverse momenta of all the jets. The total jet broadening is defined as

$$B_{tot,C} \equiv B_{U,C} + B_{L,C}$$

Jet Masses

For the same definitions of upper and lower regions, the normalized squared invariant mass is defined by:

$$\rho_X \equiv \frac{1}{P^2}\left(\sum_{i \in C_X} p_i\right)^2$$

where P is the scalar sum of the momenta of all the constituents (p_i) in jets. The jet mass is defined as the sum of the masses in the upper and lower regions, $\rho_{tot,C} \equiv \rho_U + \rho_L$.

Similarly, the corresponding jet mass in the transverse plane, defined to be the two dimensional jet mass $\rho^T_{tot,C}$, is also calculated.

Jet Resolution Parameter

The third-jet resolution parameter is defined as

$$Y_{23,C} \equiv \frac{min(R^2 \times p^2_{\perp,3},\ min(p_{\perp,i}, p_{\perp,j})^2 \times \Delta R^2_{ij})}{P^2_{12}}$$

where $\Delta R^2_{ij} = (\eta_i - \eta_j)^2 + (\phi_i - \phi_j)^2$, $p_{\perp,3}$ is the transverse momentum of the third jet in the event, $p_{\perp,i(j)}$, $\eta_{i(j)}$, and $\varphi_{i(j)}$ are the transverse momentum, pseudo-rapidity and azimuthal angle of the i(j)-th jet respectively. To compute P_{12}, three jets are merged into two using the k_T-algorithm[3,4] with a cone-size of R (= 0.6); P_{12} is then defined as the sum of two remaining jets' transverse momenta. If there are more than three jets in the event, they are iteratively merged using the same procedure as above in order to form two jets.

Event Selection and Monte Carlo Samples

This analysis uses events collected with single-jet triggers, where the $p_\perp$ of at least one jet is above a certain threshold. Events are divided into five bins of $p_{\perp,1}$ and each bin utilizes data from one trigger path. The choice of ranges of $p_{\perp,1}$ has been determined by the trigger criteria.

Range of $p_{\perp,1}$ (GeV/c)	Luminosity (pb^{-1})	Number of events	Fraction of events (%) $N_{jet} = 2$	$N_{jet} = 3$	$N_{jet} = 4$	$N_{jet} > 4$
110 - 170	0.403	96833	57.9	32.6	7.8	1.7
170 - 250	7.15	228854	43.0	37.7	14.6	4.7
250 - 320	153	601554	34.8	37.8	19.1	8.3
320 - 390	521	497827	31.0	37.0	21.2	10.9
> 390	5 fb^{-1}	2234304	28.4	35.6	22.5	13.5

Jet selection criteria

- Remove events with noisy jet
- Event shapes are calculated with all jets within $|\eta| < 2.4$ and $p_\perp > 30 Gev/c$
- At least one jet in both hemisphere

Monte Carlo Samples

MC Generator	Tune	Description
Pythia6.426	D6T PERUGIA-P0 Z2	virtuality-ordered parton showering (PS) and based on Tevatron data. $p_\perp$-ordered PS based on LEP and Tevatron data. $p_\perp$-ordered PS based on CMS data.
Pythia8.153	TUNE4C	$p_\perp$-ordered PS and an UE description based on the multiple parton interaction (MPI) model of PYTHIA6 interleaved with initial and final state radiation.
Herwig++ 2.5.0	TUNE23	PS evolution is based on angular ordering, and an eikonal MPI model is used to generate the UE.
Madgraph 5.1.5.7		It employs matrix element (ME) calculations to generate events and PYTHIA6-TUNEZ2 to generate the PS and UE.

Jet algorithm

- anti-k_T5 PFJet for all study

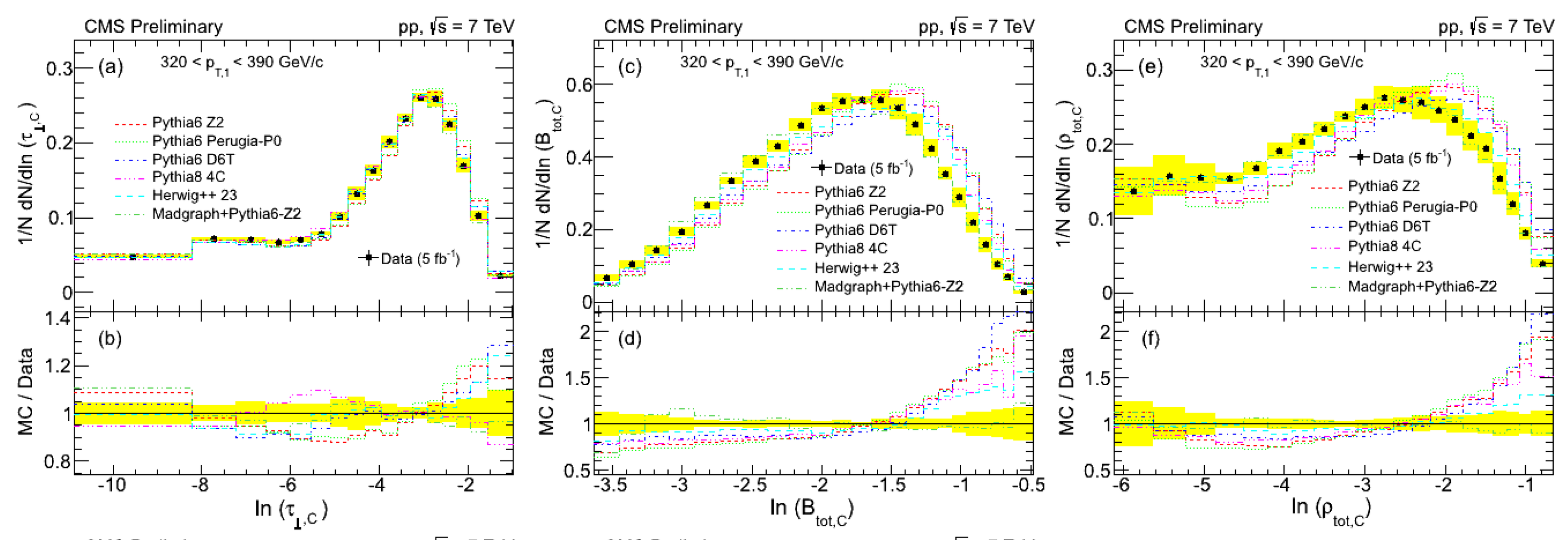
Unfolding and systematic Uncertainties

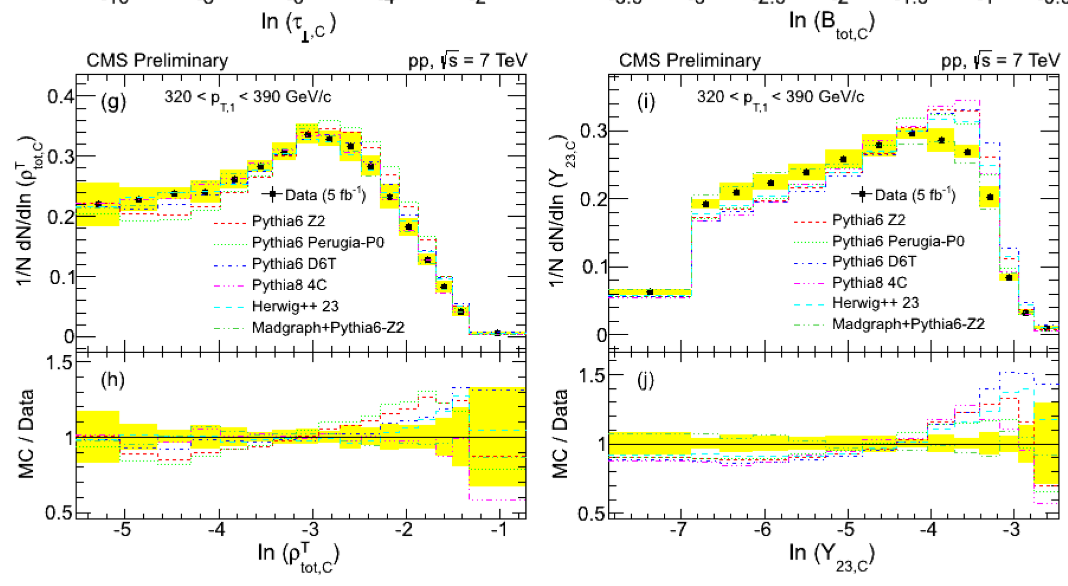
In order to unfold the measured distributions from the detector level to the generator level, a response matrix is formed using simulated events. The D'Agostini method [5] is used to unfold the collision data, using the response matrix obtained from the fully simulated sample of events with PYTHIA6 generator with tune Z2

Systematic uncertainty:

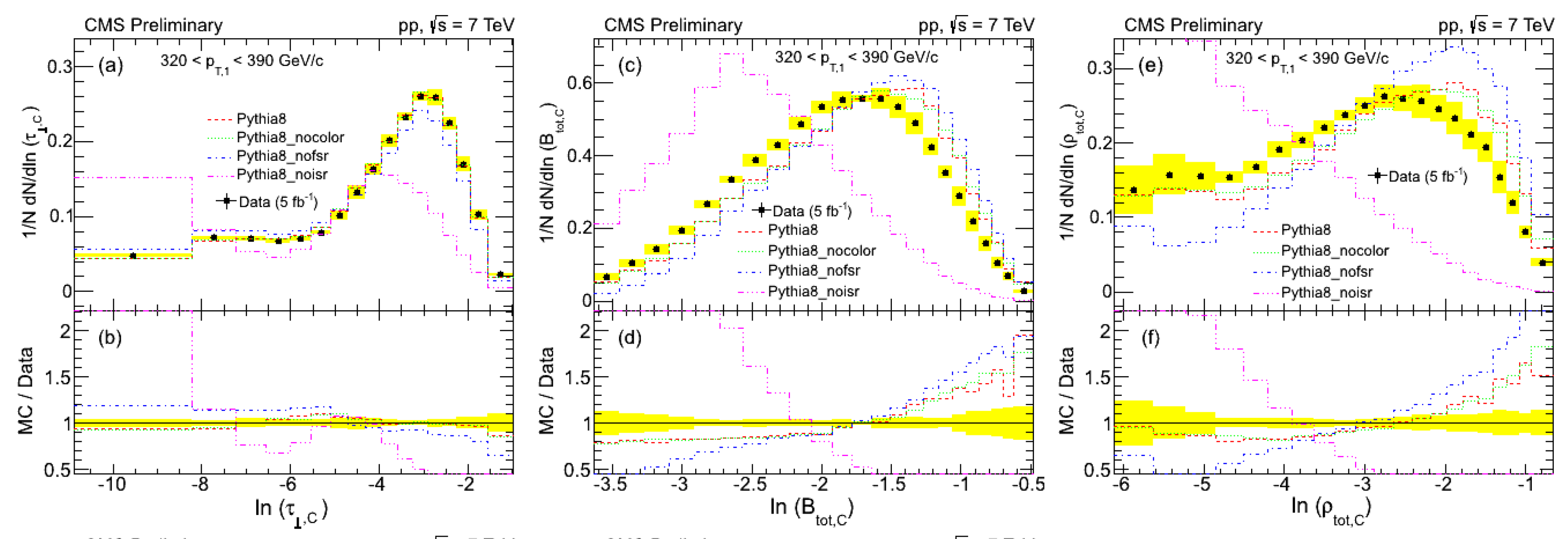
Unfolding	< 6%
Jet Energy Scale	< 3%
Jet Energy and Position Resolution	< 5%

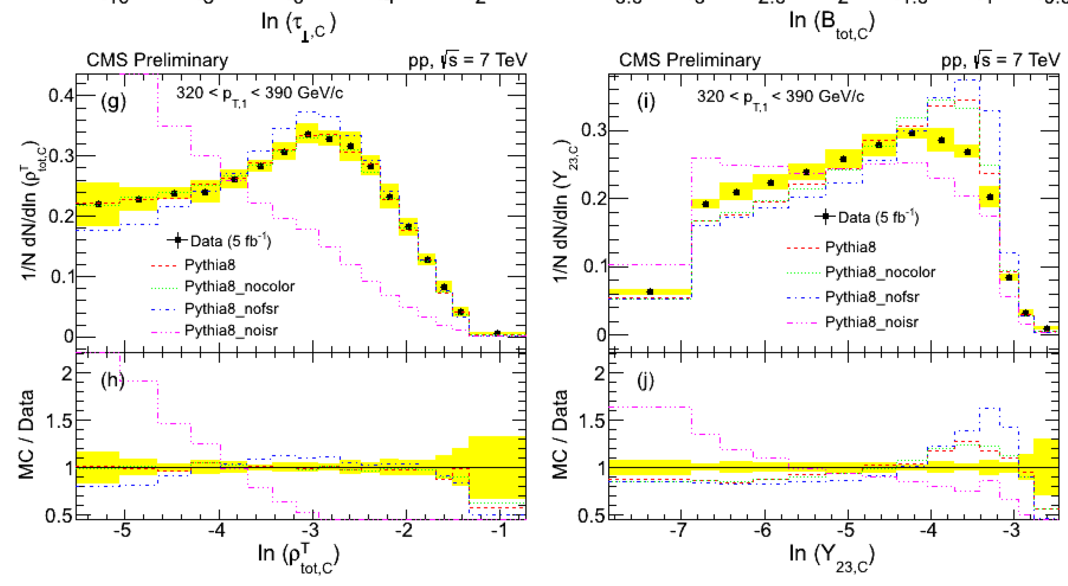
Results





Comparison between data and various Monte Carlo models, in events with $320 < p_\perp < 390$ GeV/c for the leading jet





Comparison between data and Pythia8 with effect of ISR, FSR and color connection, in events with $320 < p_\perp < 390$ GeV/c for the leading jet

Summary

- An extended set of event shape variables in multi-jet events: $\tau_{\perp,C}$, $B_{tot,C}$, $\rho_{tot,C}$, $\rho^T_{tot,C}$ and $Y_{23,C}$, have been studied in detail and compared to simulated events using several different event generators.
- For the central thrust, all generators show an overall agreement with data to within 10%, with PYTHIA8 and HERWIG++ exhibiting a better agreement than the others.
- Variables which are sensitive to longitudinal energy flow in the event show a larger disagreement between data and theory, with the predictions of PYTHIA6 showing the worst agreement.
- The predictions of the virtual-ordered PS generator PYTHIA6 tune D6T show better agreement with data for the event shape variables that make use only of the jet $p_\perp$, but has worse agreement for $Y_{23,C}$ compared to other tunes of PYTHIA6.
- The predictions from MADGRAPH agree well with the data.
- Modeling of color connection between soft scatters and beam remnants, ISR, and FSR are the major sources of the discrepancies between the data and the various QCD event generators.

Next steps

Continue this work with 8 TeV data and Measurements of α_s

References

(1) M. Dasgupta and G. P. Salam, "Event shapes in $e^+ e^-$ annihilation and deep inelastic 262 scattering", J.Phys. G30 (2004) R143,
(2) A. Banfi, G. P. Salam, and G. Zanderighi, "Phenomenology of event shapes at hadron colliders", JHEP 1006 (2010) 038,
(3) S. Catani, Y. L. Dokshitzer, M. Seymour, and B.Webber, "Longitudinally invariant Kt clustering algorithms for hadron hadron collisions", Nucl.Phys. B406 (1993) 187
(4) S. D. Ellis and D. E. Soper, "Successive combination jet algorithm for hadron collisions", Phys.Rev. D48 (1993) 3160
(5) G. D'Agostini, "A Multidimensional unfolding method based on Bayes' theorem",Nucl.Instrum.Meth. A362 (1995) 487
(6) "Measurement of color coherence effects in pp collisions at $\sqrt{s}$ = 7 TeV", Technical Report CMS-PAS-SMP-12-010, 2013

LHCC Poster Session, 5 March 2014, at CERN, Geneva, Switzerland