Update on Multijet Study

Outline

- Detector effects
- Systematic uncertainties
  - Trigger Bias
  - Event selection
- Comparison of PYTHIA with ALPGEN
- Comparison among different jet algorithms

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Event selection and Monte Carlo sample used

- A specific trigger sample - **CSA08 _QCDJetEt50_S156** with luminosity 10 pb^{-1} was used. **Event selection** is done in the following way:

- HLT conditions (threshold of 110 GeV on leading jet Pt) is applied.

- A MinPt threshold (50 GeV) is applied on all corrected jets.

Detector Effects

- Closer look to see the source of detector corrections:
  - Energy resolution
  - Position resolution
    - Effect on η, φ
- Resolutions on these quantities are obtained by studying the bulk properties of Monte Carlo jets using full simulation.

Jet Energy Resolution

- Effect of jet energy resolution is approximated by a gaussian distribution applied to generator level information with a resolution term consisting of a constant term, stochastic term and a noise term.
- In the barrel region (|η| <1.4)

$$\frac{\sigma(p_T)}{p_T} = \sqrt{\left(\frac{6.0}{p_T}\right)^2 + \left(\frac{1.4}{\sqrt{p_T}}\right)^2 + (0.043)^2}$$

- In the endcap region (1.4 < |η| <3.0)

$$\frac{\sigma(p_T)}{p_T} = \sqrt{\left(\frac{6.6}{p_T}\right)^2 + \left(\frac{1.1}{\sqrt{p_T}}\right)^2 + (0.044)^2}$$

the functions were derived from MC over CSA08 JetEtxx samples

https://twiki.cern.ch/twiki/bin/view/CMS/CSA08AnaJets

- Study the ratio of smeared and unsmeared quantities to see the effect of energy resolution.

Position (η/ Φ) Resolution

- The effect of position resolution is studied by applying a Gaussian distribution to the jet direction (in η and ϕ) at the generator level with resolutions again consisting of 3 terms added in quadrature.
- **For 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 region (1.4 < |η| < 3.0) and in forward region (3.0 < |η| < 5.0) region †

$$\sigma(\eta) = \sqrt{\left(\frac{1.42}{p_T}\right)^2 + \left(\frac{0.21}{\sqrt{p_T}}\right)^2 + (0.017)^2} \quad \text{and} \quad \sigma(\eta) = \sqrt{\left(\frac{1.25}{p_T}\right)^2 + (0.025)^2}$$

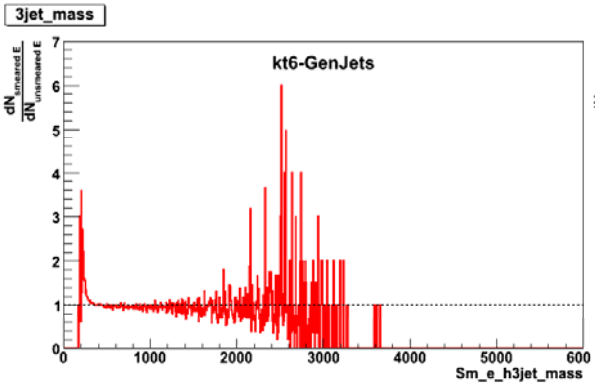
- **For ϕ:** In the barrel region (|η|<1.4) † :

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

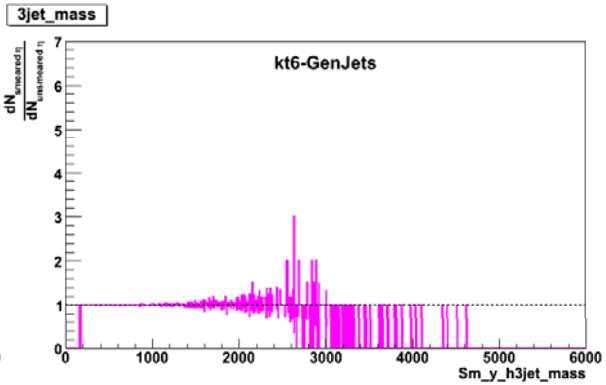
- Study the ratio of smeared and unsmeared quantities to see detector effects.
- The combined effect of energy and position resolution is studied by smearing E, η and ϕ simultaneously and this joint effect is compared to the one observed from comparison between Genjet and Calojet.

† [These functions were derived by Zhen Qi from MC over CSA07 PYTHIA QCD-samples in the Gumbo soup]

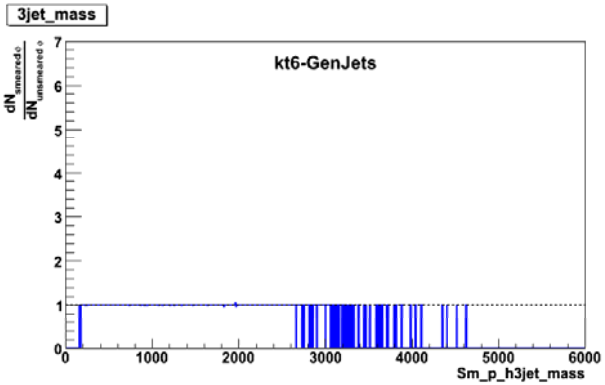
Effect on 3-jet invariant mass



Energy smearing

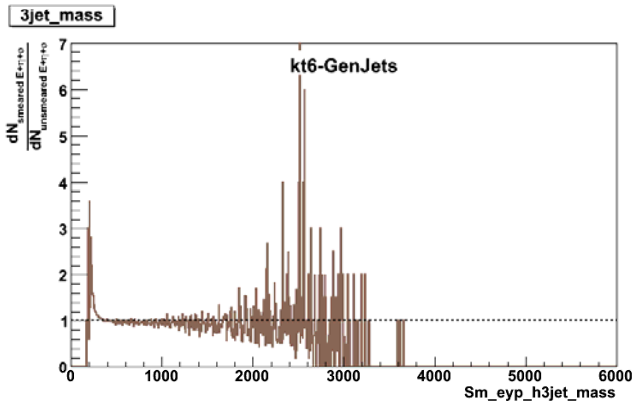


Eta smearing

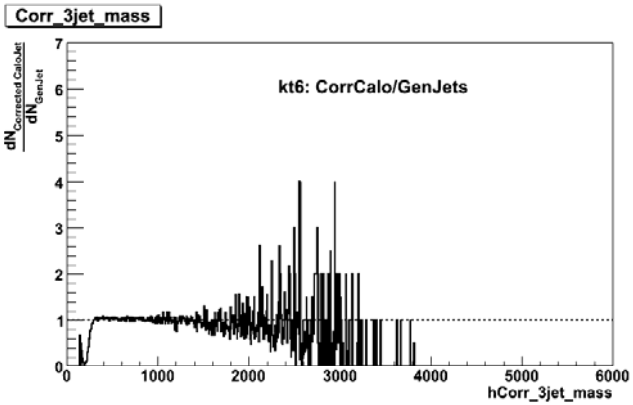


Phi smearing

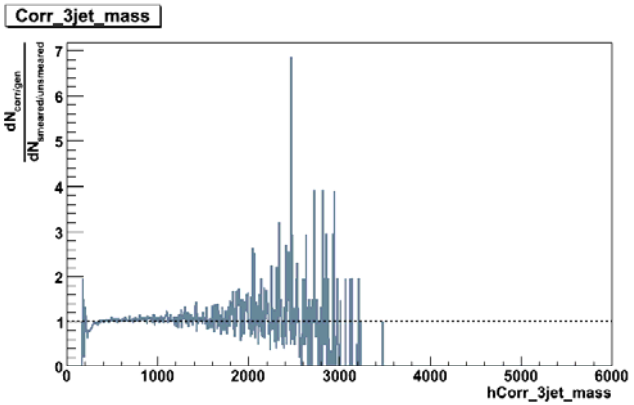
- We study the combined detector effects and compare that to the corrected/gen ratio.
- We also present the ratio of the combined detector effects (Smeared Gen*) to the corrected calorimeter jets.



Energy+Eta+Phi smearing

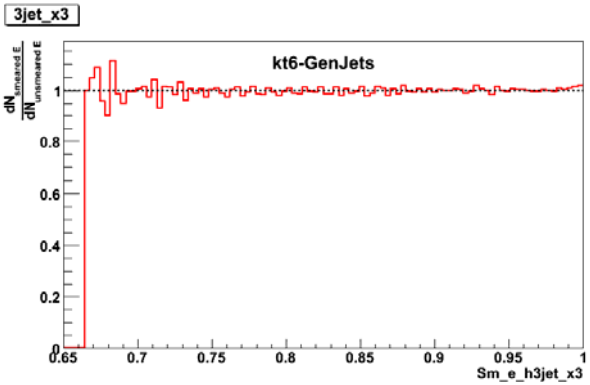


Corrected Calo/Genjet

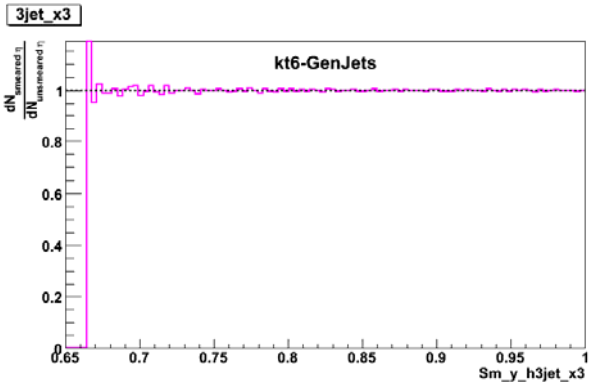


CorrCalo/SmearedGen*

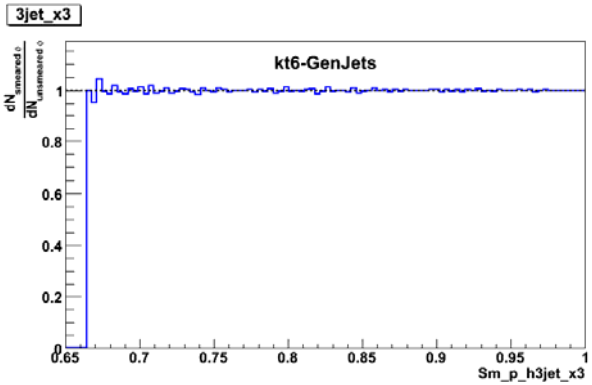
Effect on a 3-jet Scaled energy (x3)



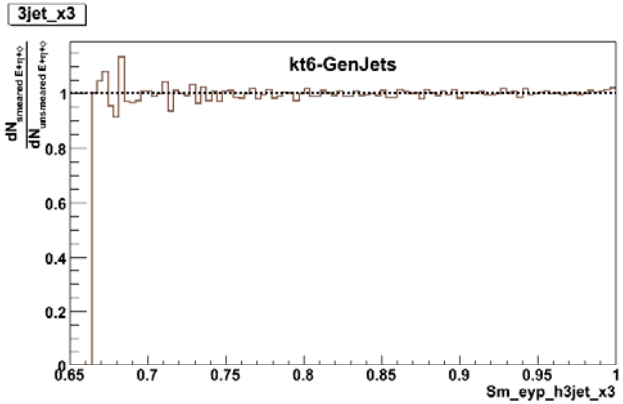
Energy smearing



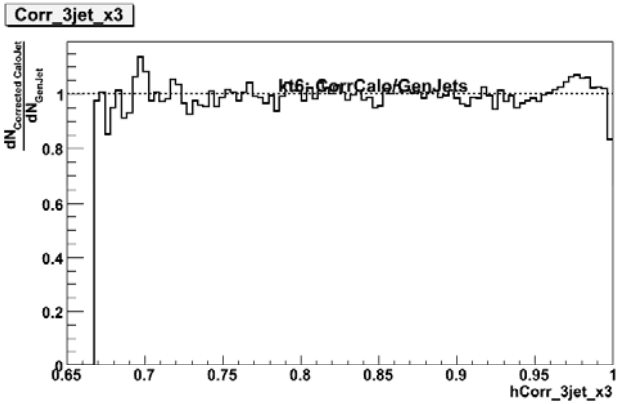
Eta smearing



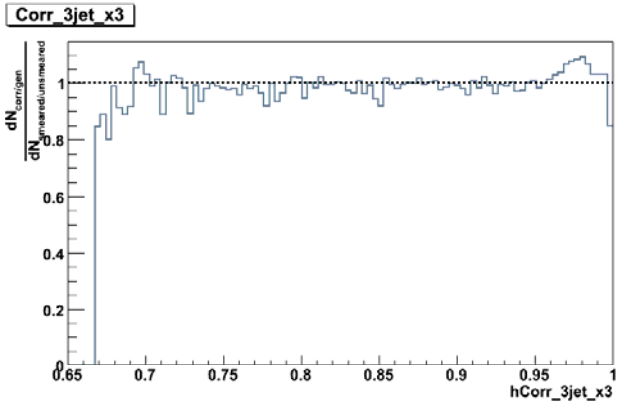
Phi smearing



Energy+Eta+Phi smearing

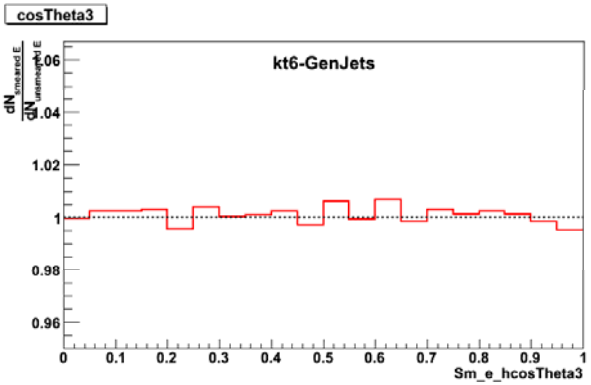


Corrected Calo/Genjet

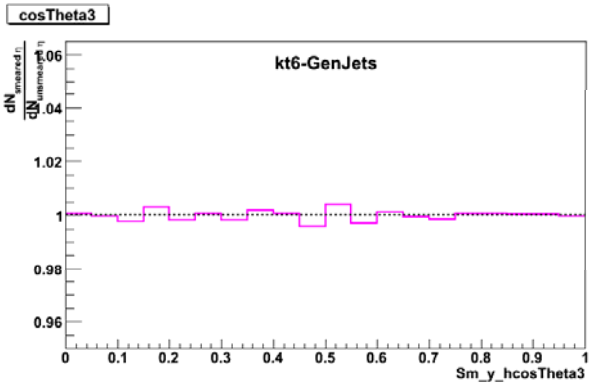


CorrCalo/SmearedGen

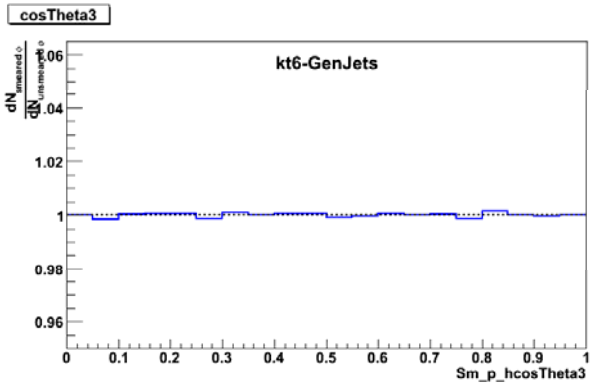
Effect on 3-jet cosθ_3



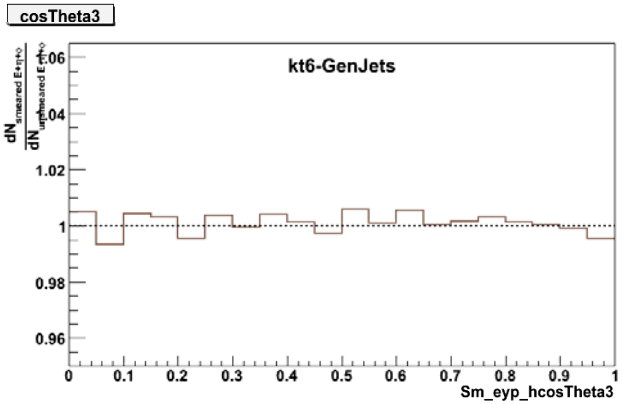
Energy smearing



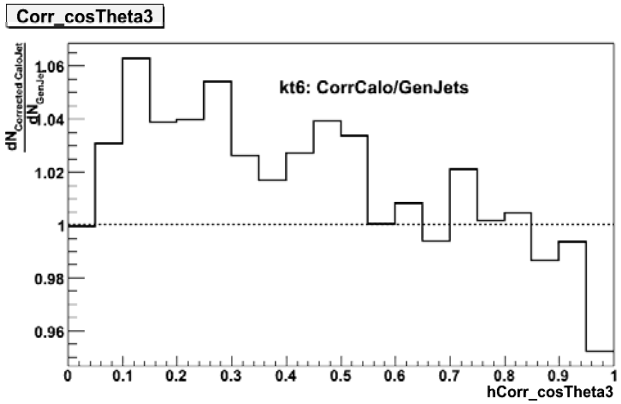
Eta smearing



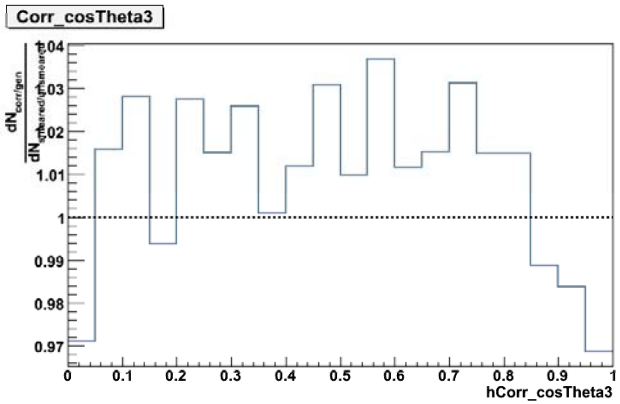
Phi smearing



Energy+Eta+Phi smearing

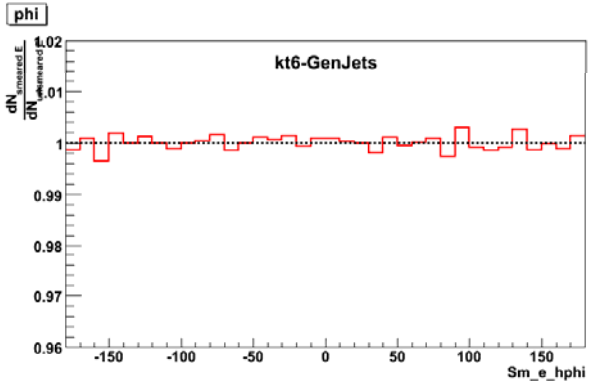


Corrected Calo/Genjet

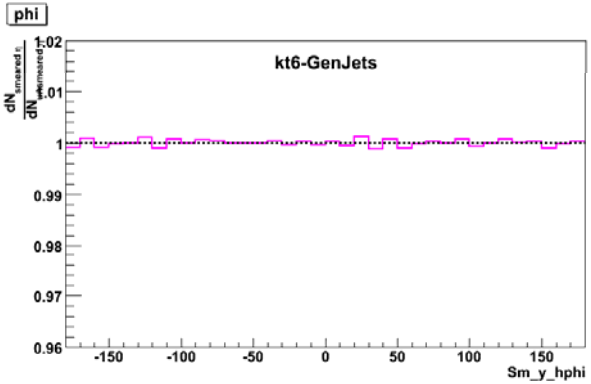


CorrCalo/SmearedGen

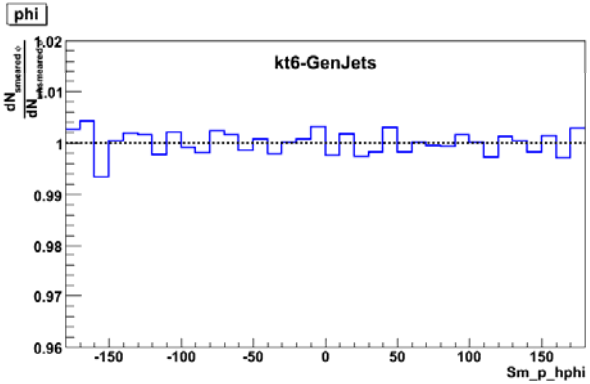
Effect on 3-jet azimuthal angle (Φ)



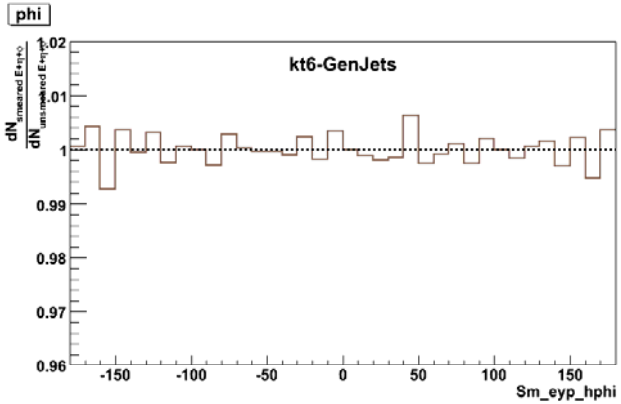
Energy smearing



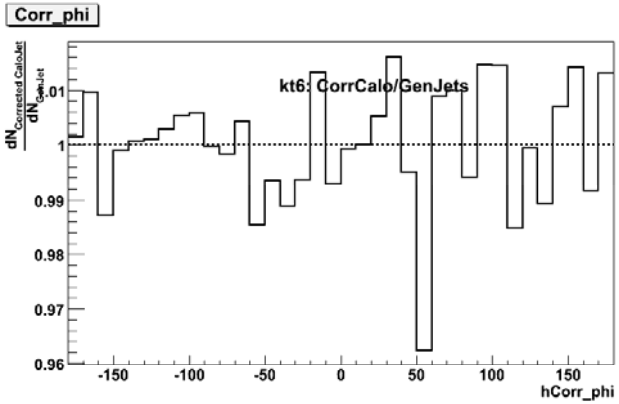
Eta smearing



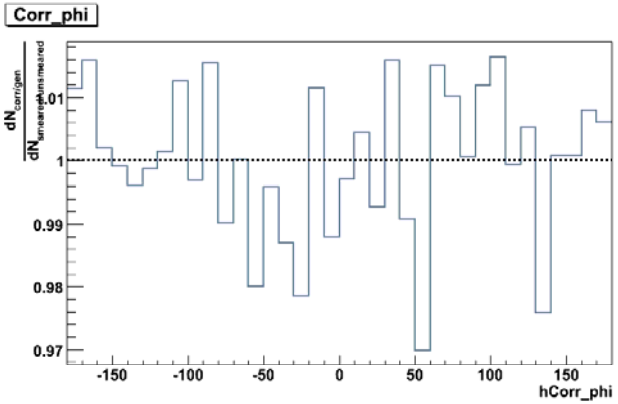
Phi smearing



Energy+Eta+Phi smearing

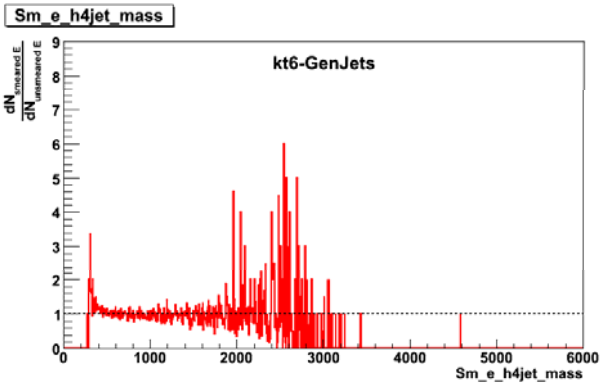


Corrected Calo/Genjet

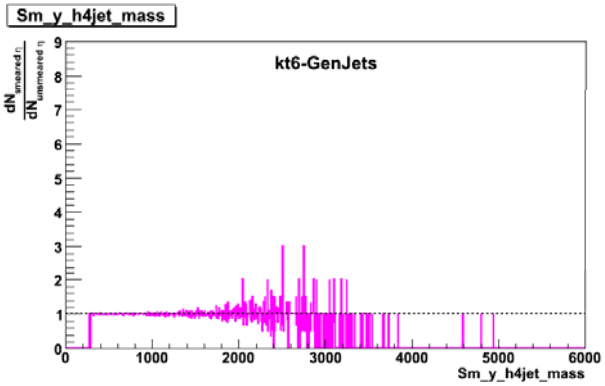


CorrCalo/SmearedGen

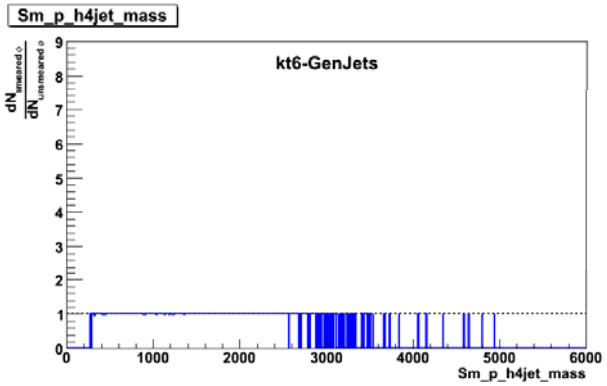
Effect on 4-jet invariant mass



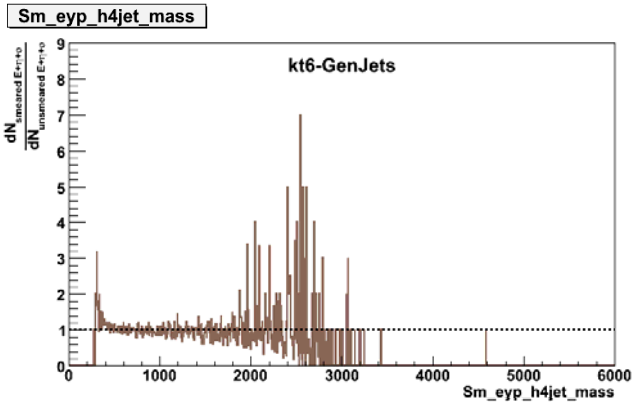
Energy smearing



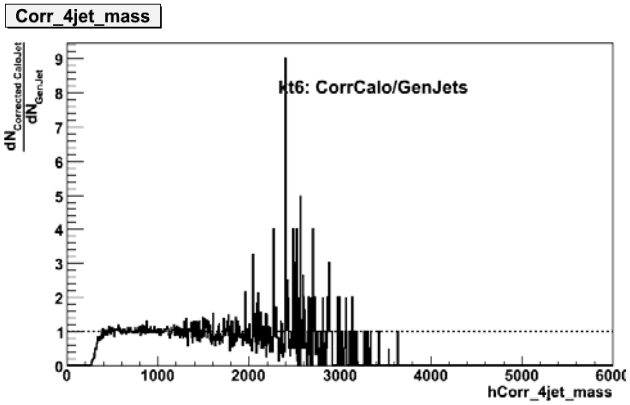
Eta smearing



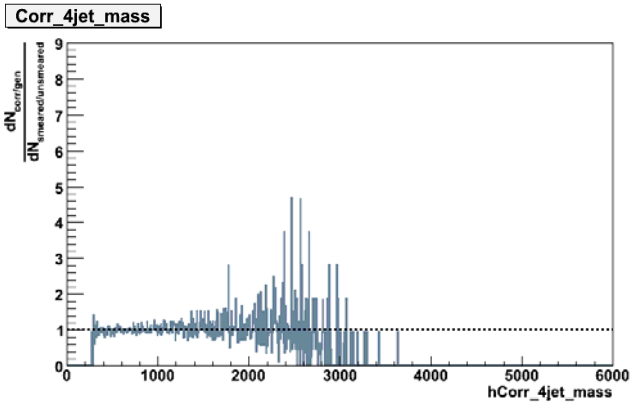
Phi smearing



Energy+Eta+Phi smearing

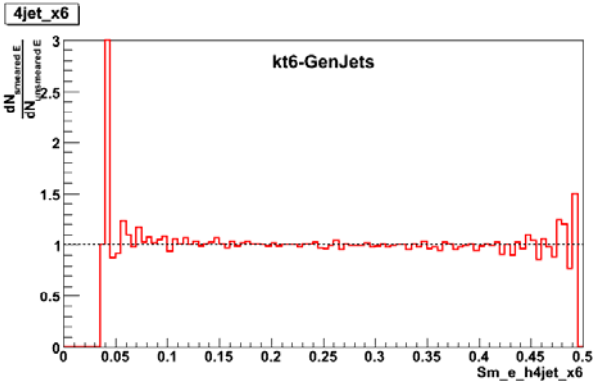


Corrected Calo/Genjet

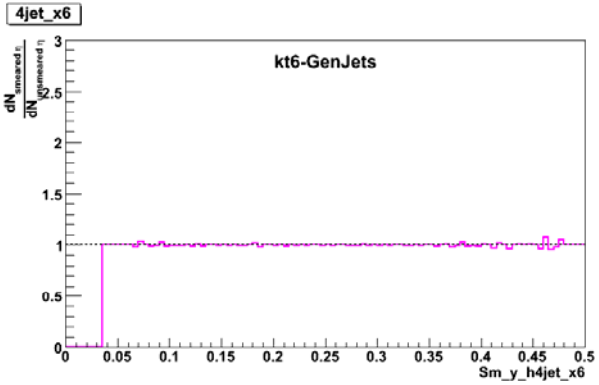


CorrCalo/SmearedGen

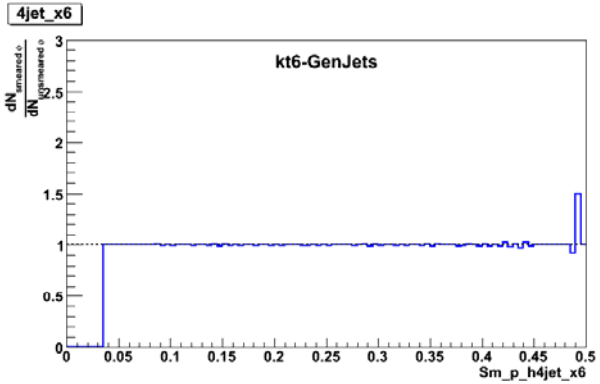
Effect on a 4-jet scaled energy (x6)



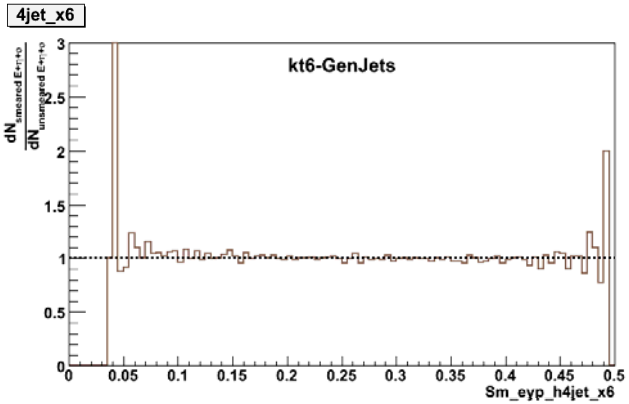
Energy smearing



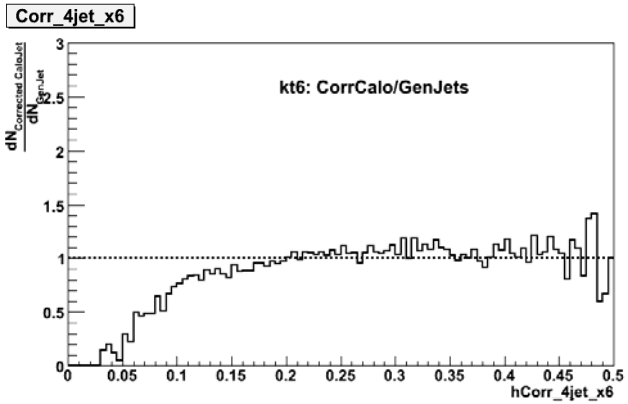
Eta smearing



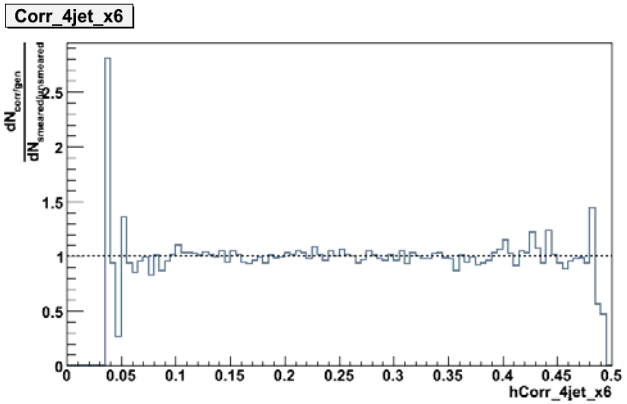
Phi smearing



Energy+Eta+Phi smearing

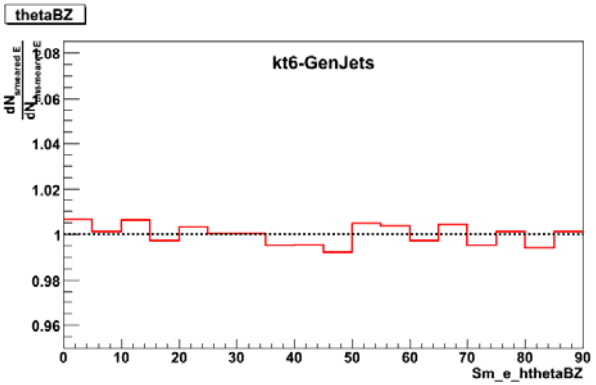


Corrected Calo/Genjet

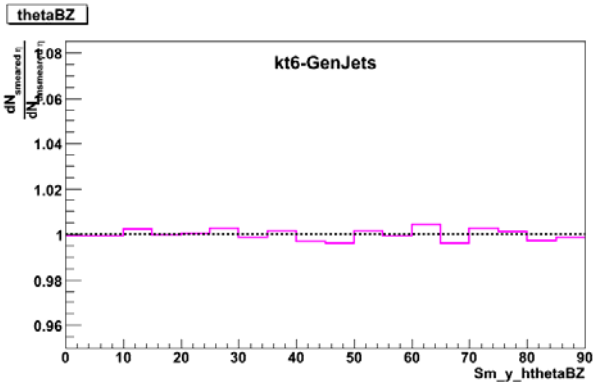


CorrCalo/SmearedGen

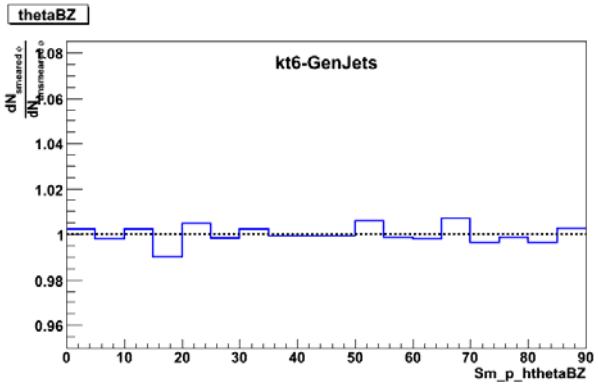
Effect on Bengtsson-Zerwas angle (4-jet)



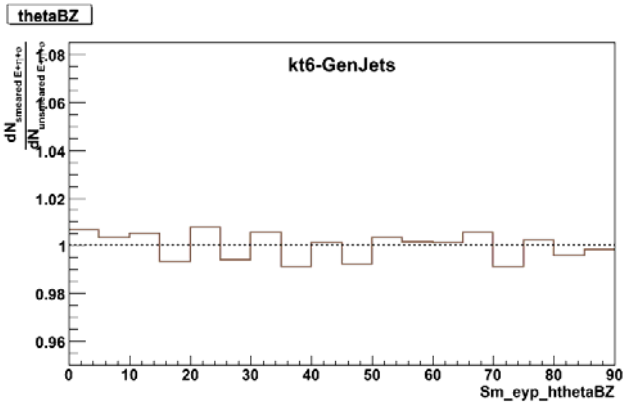
Energy smearing



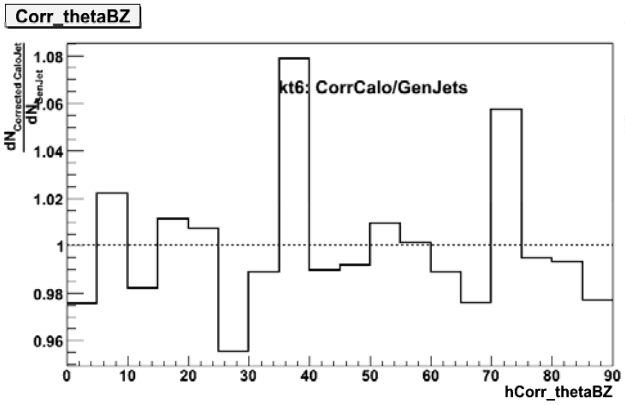
Eta smearing



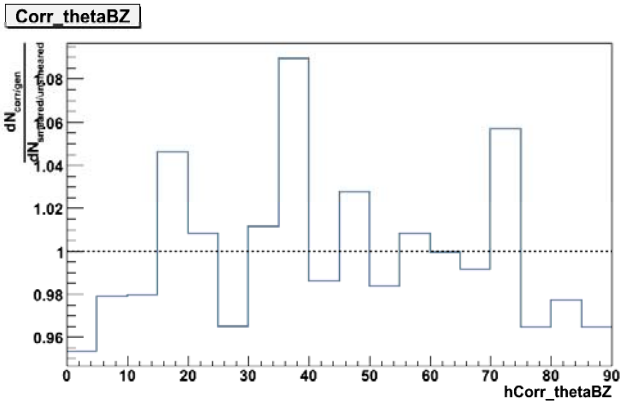
Phi smearing



Energy+Eta+Phi smearing

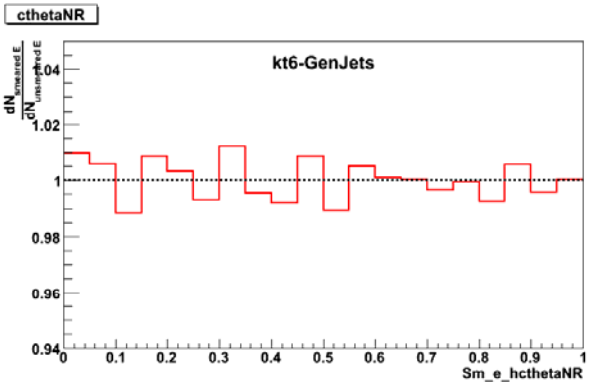


Corrected Calo/Genjet

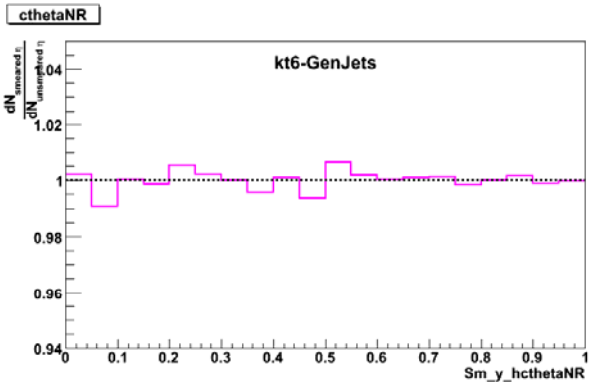


CorrCalo/SmearedGen

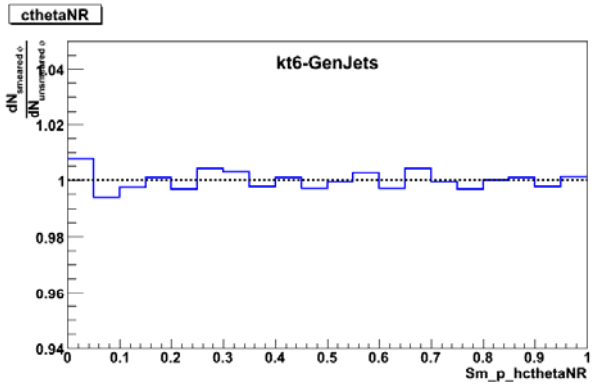
Effect on Nachtmann-Reiter angle (4-jet)



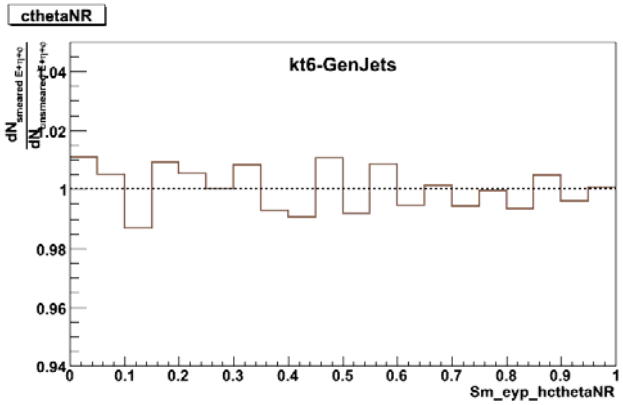
Energy smearing



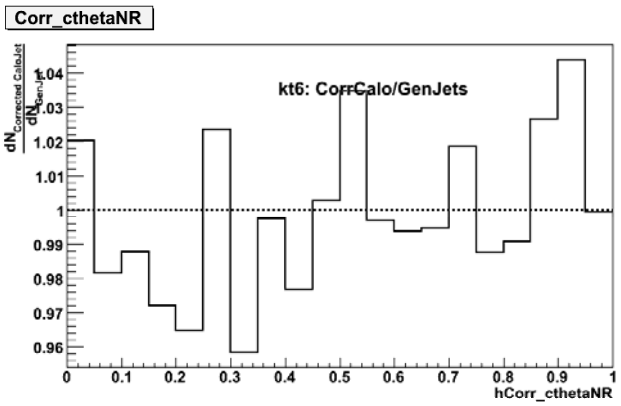
Eta smearing



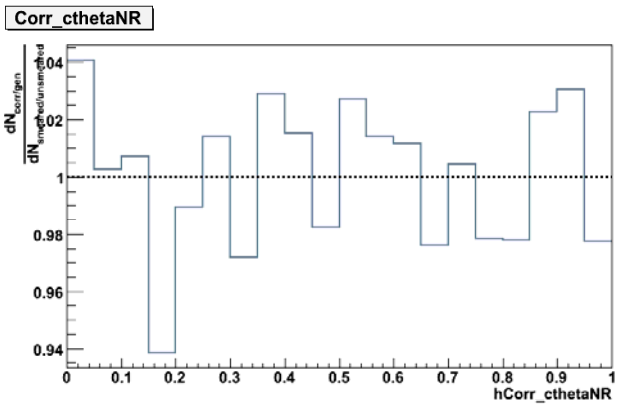
Phi smearing



Energy+Eta+Phi smearing



Corrected Calo/Genjet



CorrCalo/SmearedGen

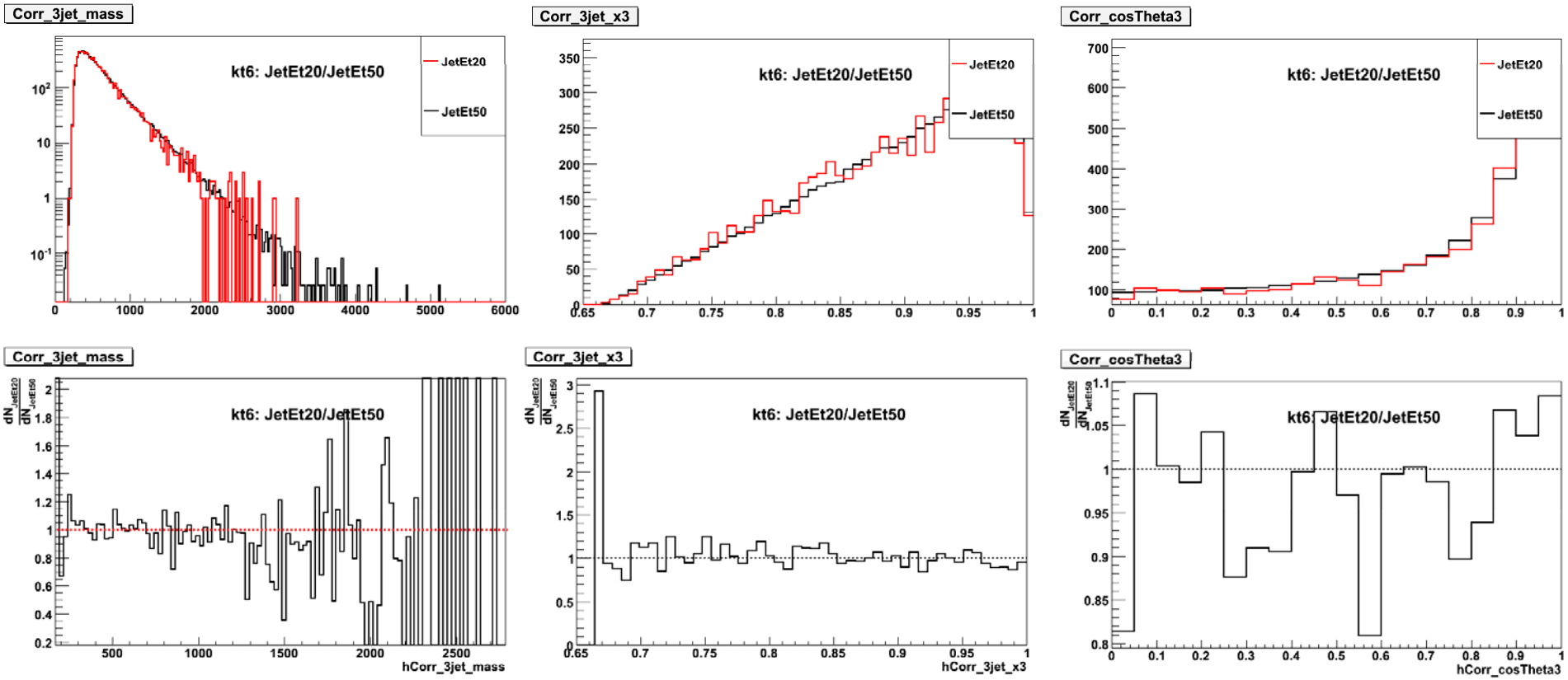
Systematic uncertainty due to Trigger Bias

- This analysis was carried out by events from a specific trigger path, by using CSA08 JetEt50 S156 samples.
- In order to see how stable our event selection conditions are we look at the ratio of the distributions for JetEt20 sample to those for JetEt50 sample.

Sample	Events	Xsec [pb]	L[pb-1]	pT min (GeV)
JetET20	3 926 600	101 600 000	0.0386	30
JetET30	4 131 600	21 550 000	0.1917	45
JetET50	4 010 400	2 484 000	1.6145	75
JetET80	2 891 200	323 700	8.9317	120
JetET110	3 980 000	88 730	44.8552	160
JetET150	4 172 400	17 120	243.7150	220

Topological properties of 3parton events – Systematic uncertainties

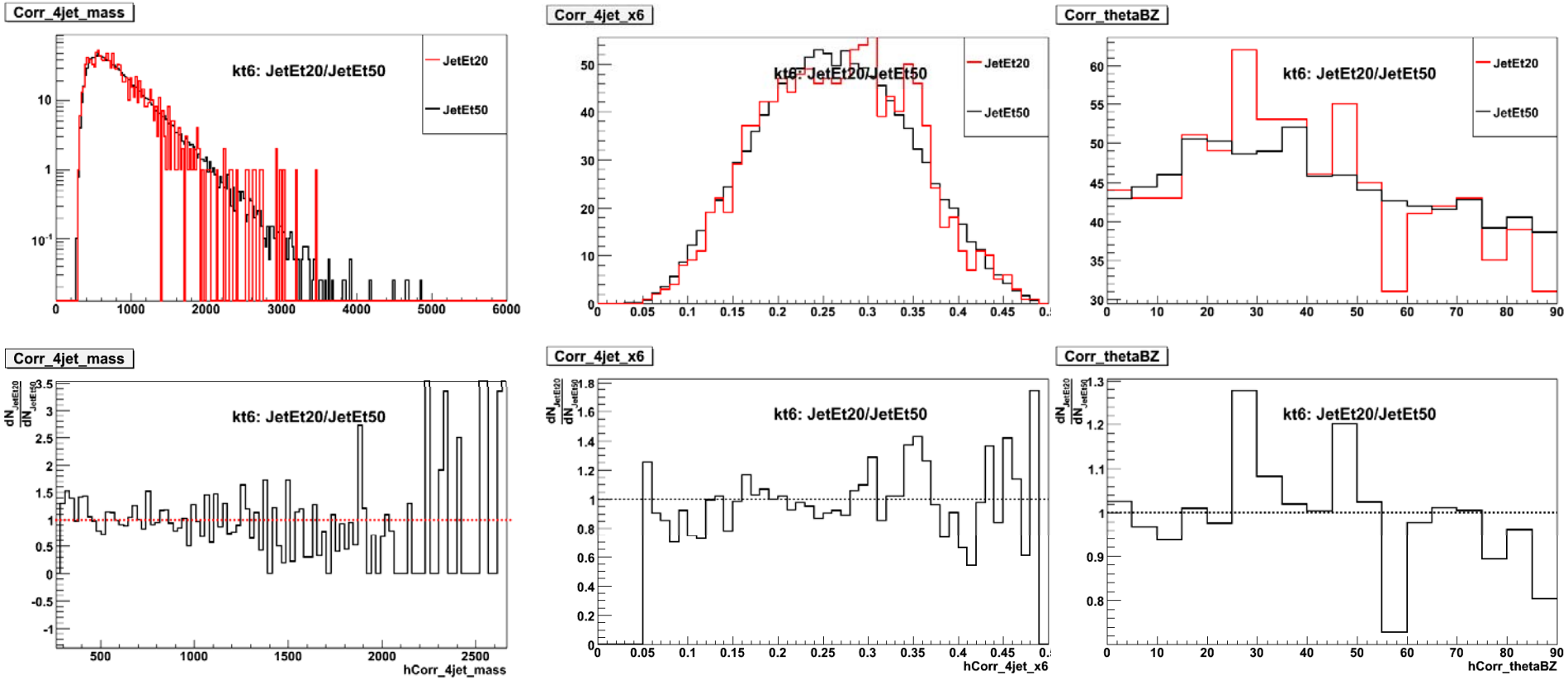
- Ratio of the JetEt20 sample with respect to the JetEt50 sample.



- We observe that the uncertainties are bigger for kinematic variables and smaller for angular variables.

Topological properties of 4parton events – Systematic uncertainties

- Ratio of the JetEt20 sample with respect to the JetEt50 sample.



- We observe that the uncertainties are comparable for kinematic variables as well as for angular variables.

Systematic uncertainty due to Selection Criteria

- In this analysis the inclusive curve was derived by events from a specific trigger path, simulated by using CSA08 JetEt50 S156 samples.

- Samples should be used, when the trigger is 100% efficient; distribution might be biased if the sample is already used when the trigger is not 100% efficient.

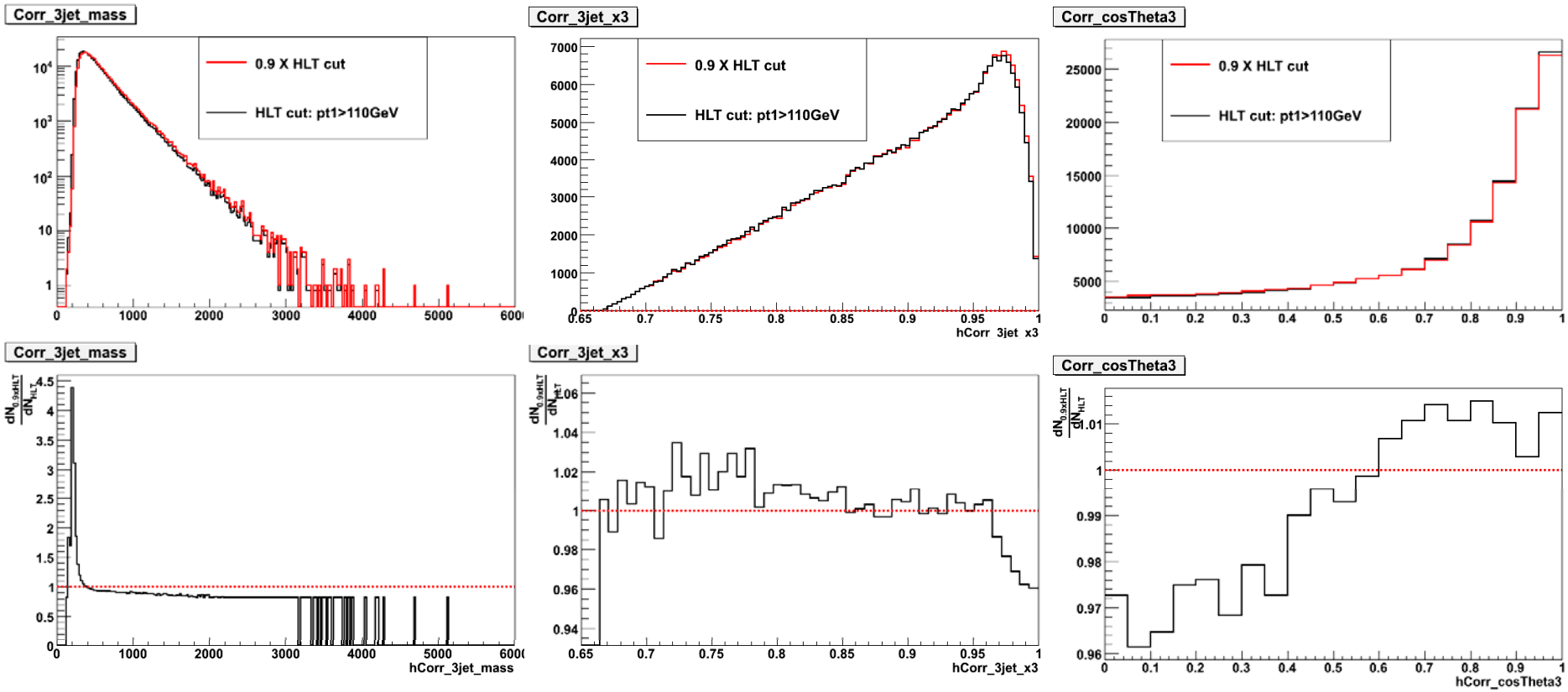
- We vary the HLT threshold by a factor of 0.9.

- Determine the sensitivity of multi-jet distributions to this effect:

Sample	$pt1_{110}$	$0.90 \times pt1_{110}$
JetEt50	110	99

Topological properties of 3parton events – Systematic uncertainties

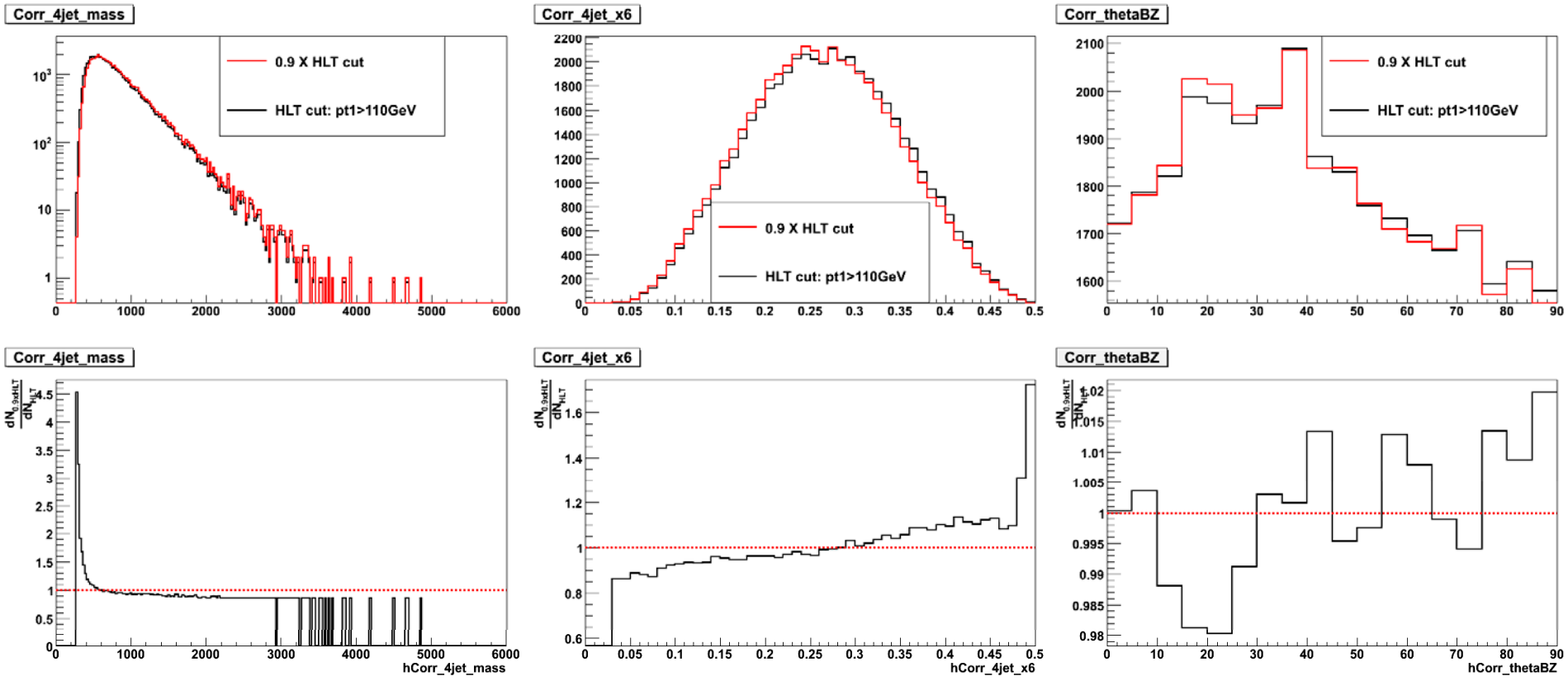
- Effect of the systematic uncertainty due to HLT selection.



- We observe that the uncertainties are small for both kinematic variables and angular variables.

Topological properties of 4parton events – Systematic uncertainties

- Effect of the systematic uncertainty due to HLT selection.



- We observe that the uncertainties are bigger for kinematic variables and smaller for angular variables (~ 3%).

Comparison of PYTHIA with ALPGEN (+PYTHIA)

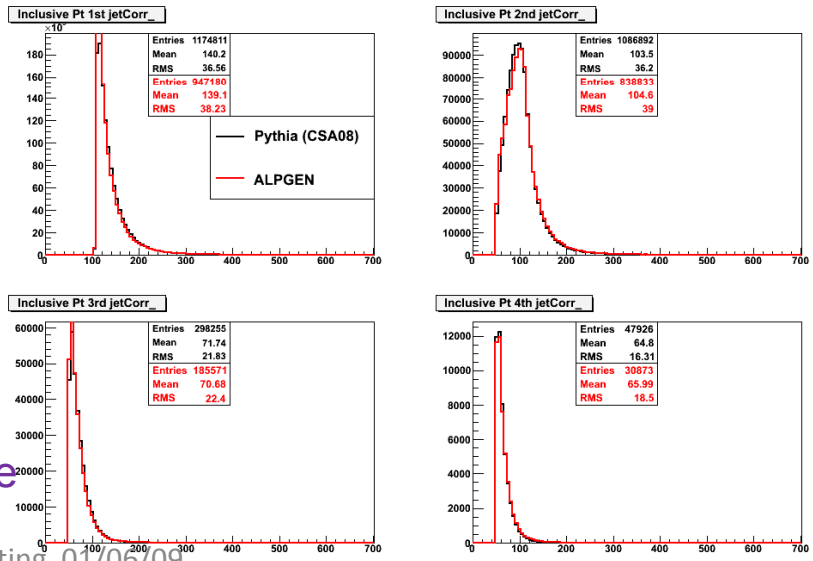
ALPGEN Njets samples are generated in two steps:.

- Matrix element generation on N partons with ALPGEN, P_T > 20 GeV
  - Samples with 2,3,4,5, ≥6 final state partons.
- Parton showering by PYTHIA
  - Showering by PYTHIA
  - Combine different samples with their corresponding cross-sections and number of events.

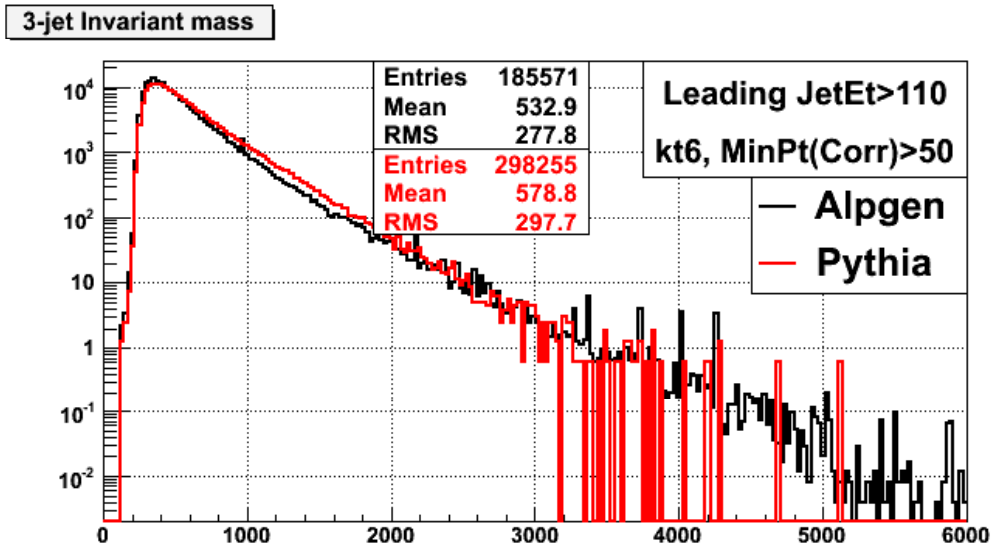
❖ We used the Summer07 production samples – ALPGEN njets produced with CMSSW_1_6_7.

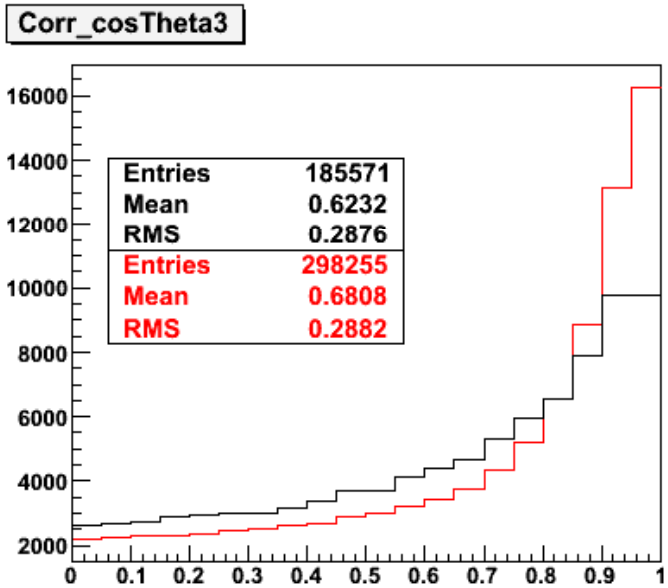
➢ Here is a set of comparison plots for PYTHIA (CSA08) and ALPGEN. Shown here are the pT distributions of the first four calorimeter jets with event selections as were used before.

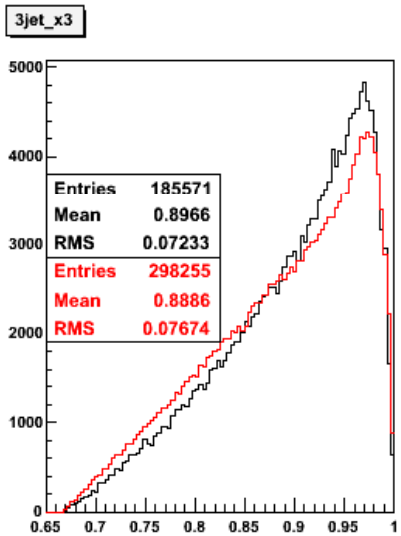
✓ We notice PYTHIA and ALPGEN for these distributions match very well.

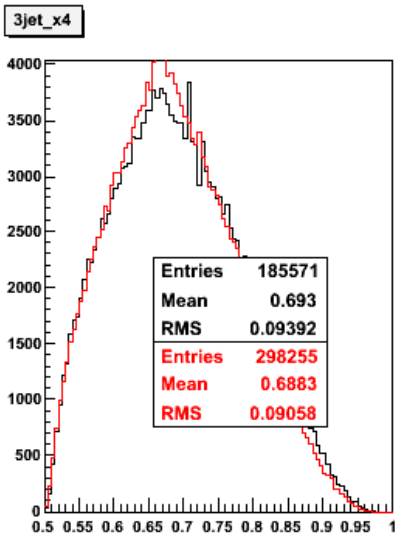


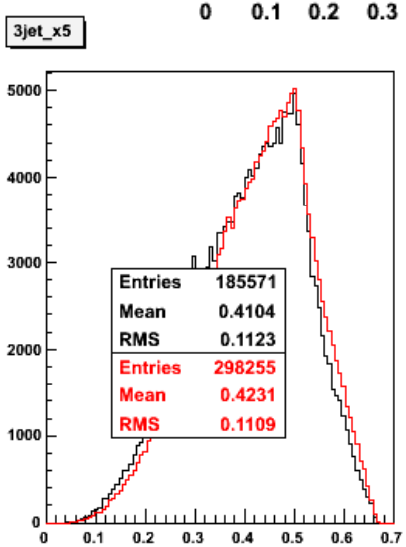
Comparison of PYTHIA with ALPGEN for 3parton events





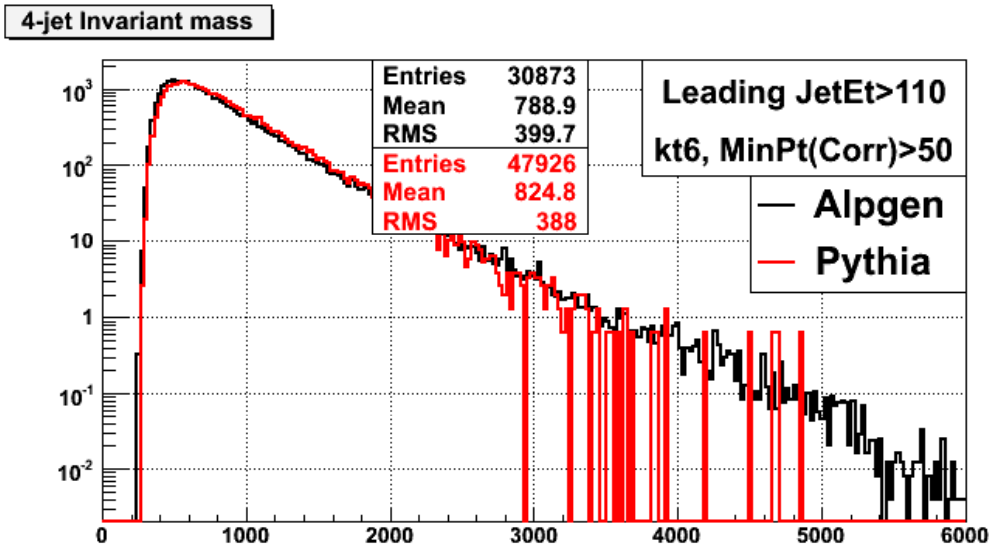


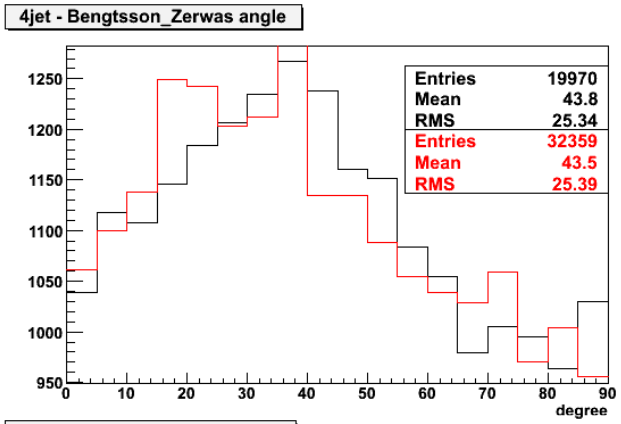


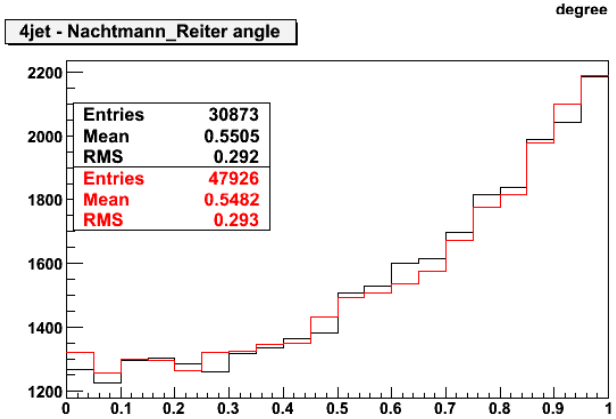


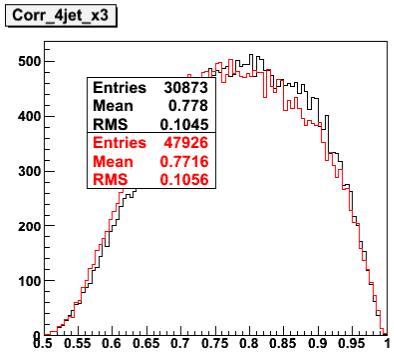
- There are mismatches between PYTHIA and ALPGEN which are more visible for the harder jets.
- The angular variable ($\cos\theta_3$) also shows differences between PYTHIA and ALPGEN.

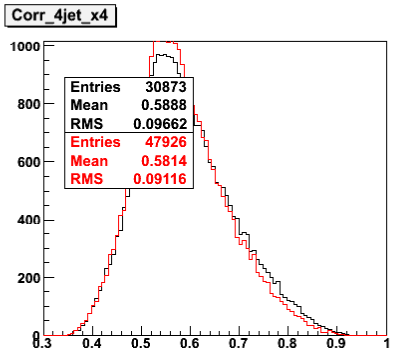
Comparison of PYTHIA with ALPGEN for 4parton events

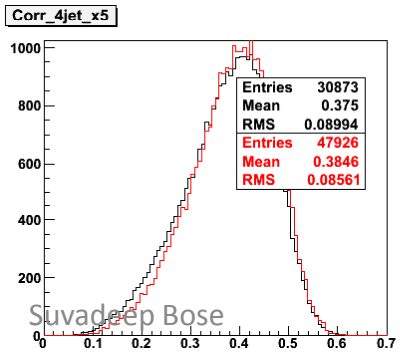


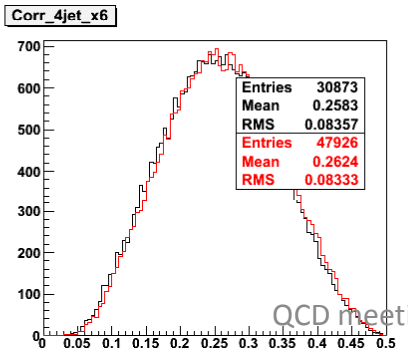








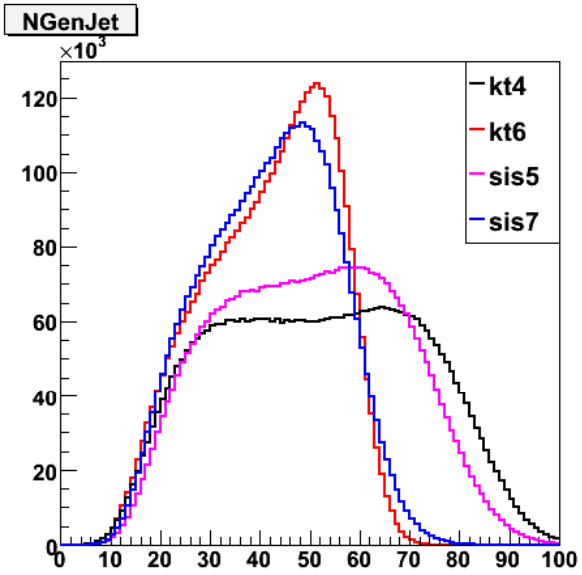


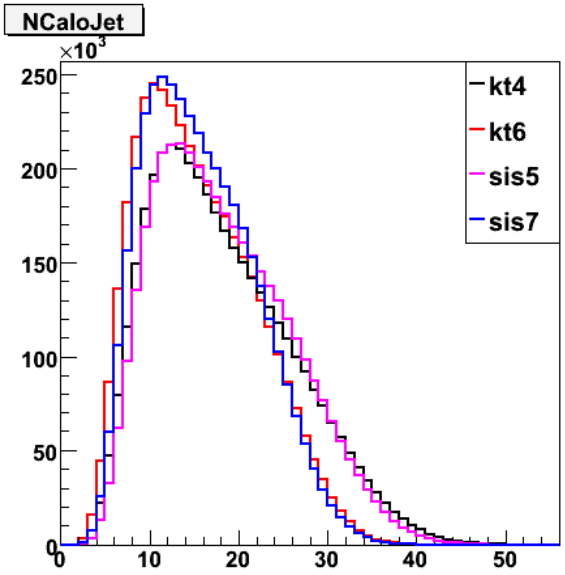


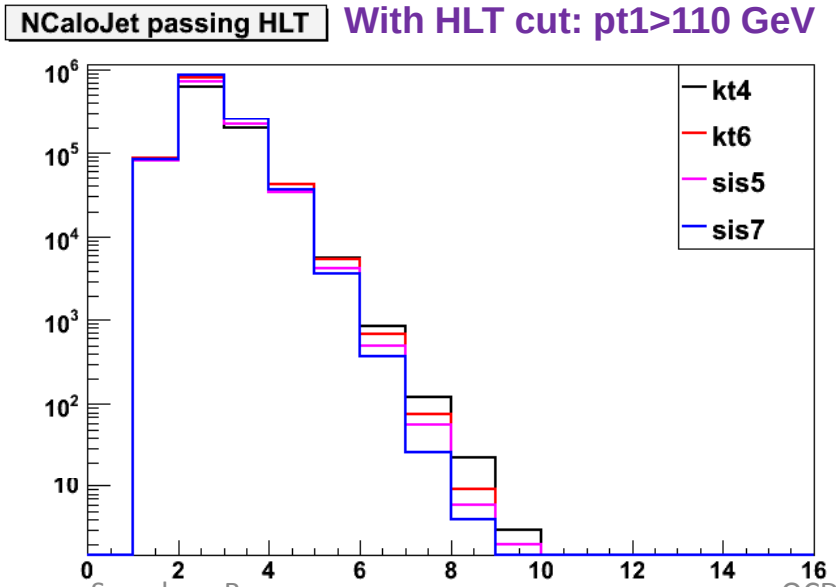
- There are mismatches between PYTHIA and ALPGEN which are more visible for the harder jets.
- The angular variables also show differences between PYTHIA and ALPGEN.

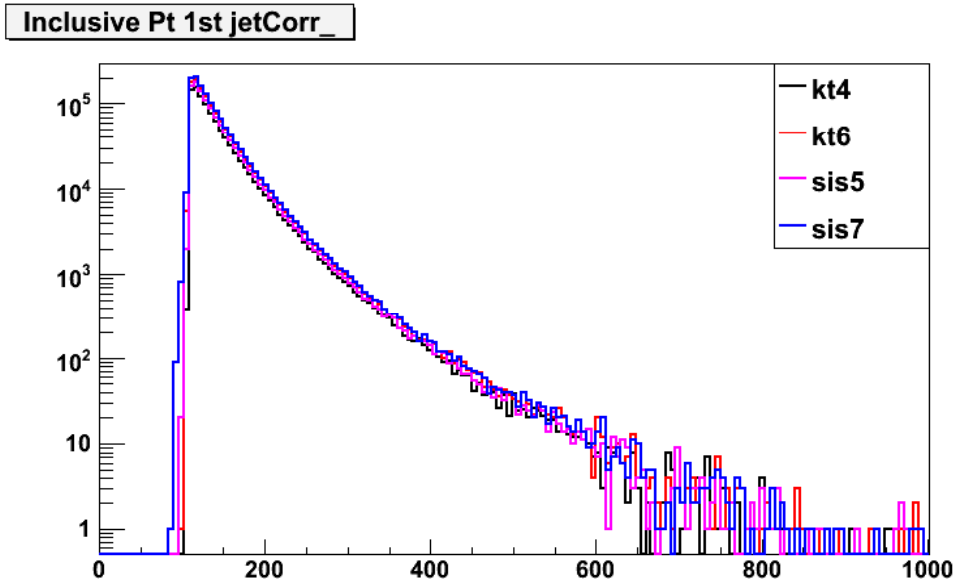
Different Jet Algorithms : Jet Multiplicities and Leading Jet Pt

- SisCone5
- SisCone7
- Kt4
- Kt6

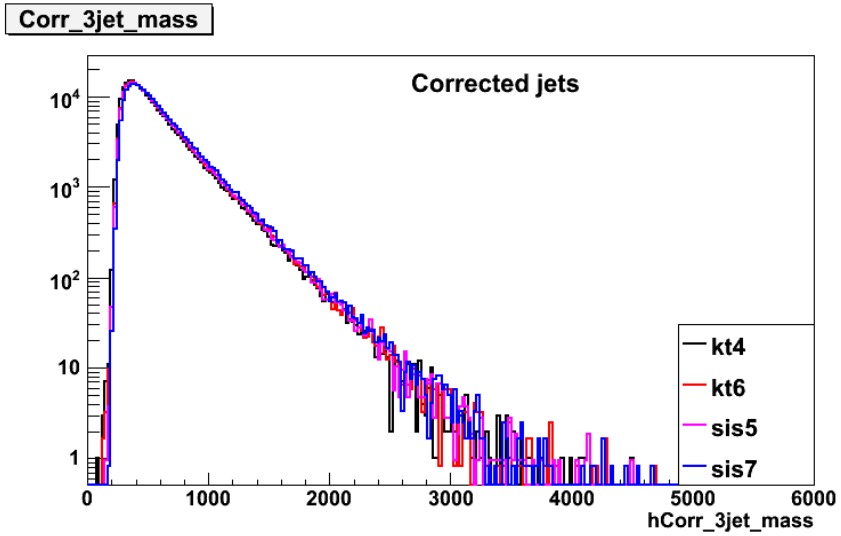


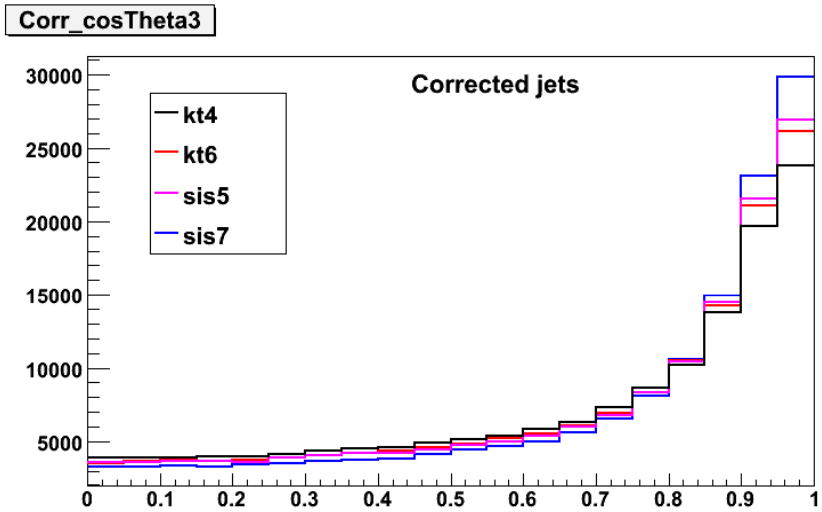


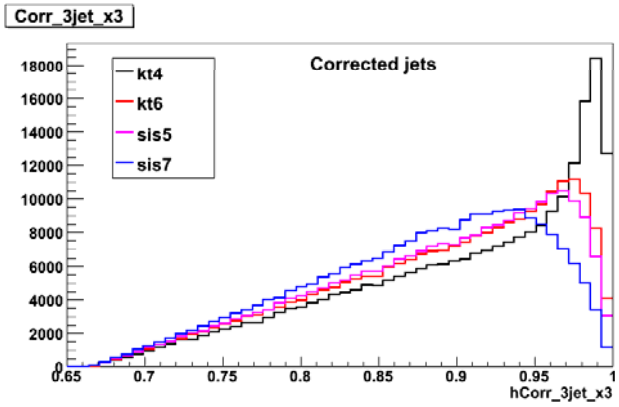


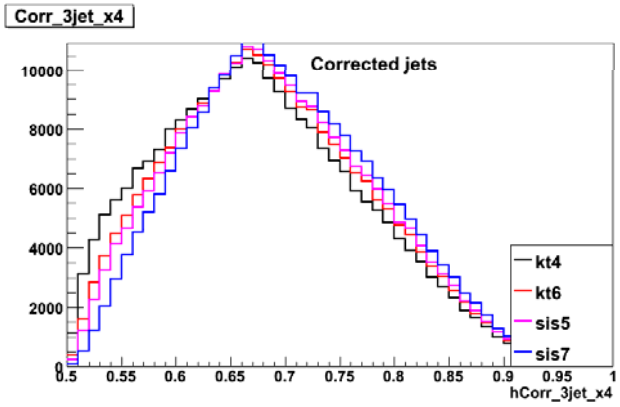


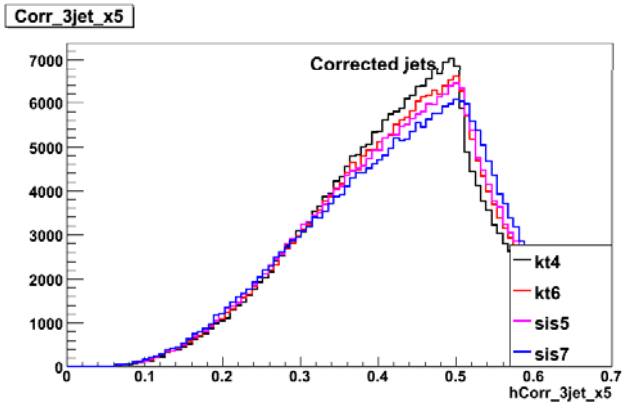
Topological properties of 3parton events for different jet algorithms





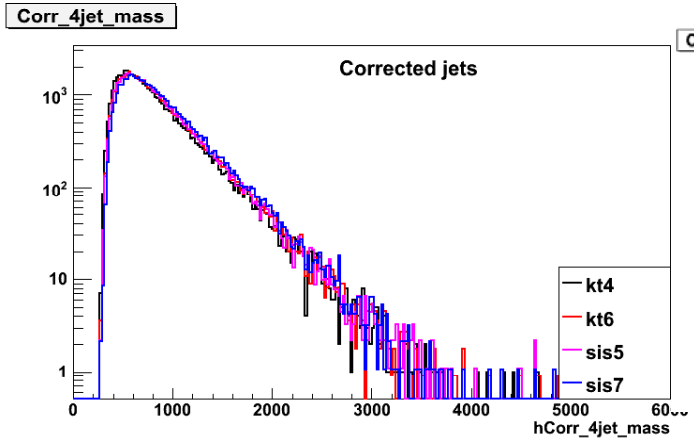


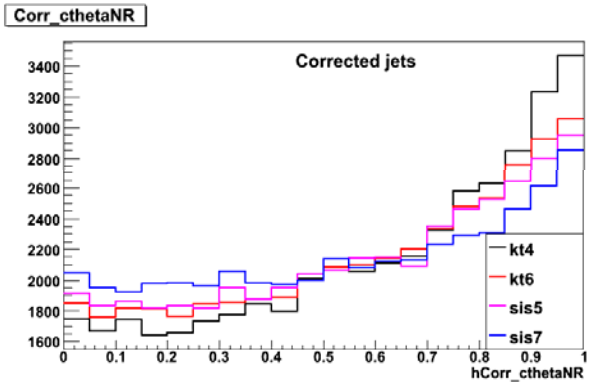


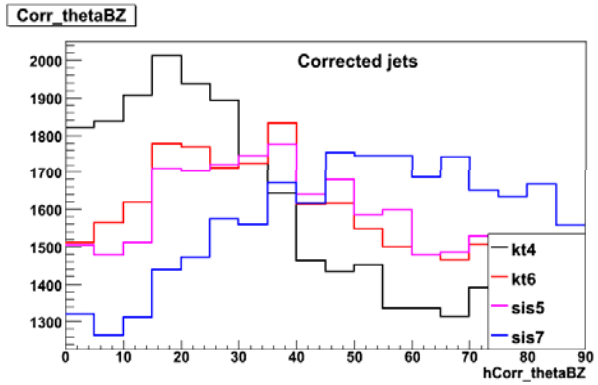


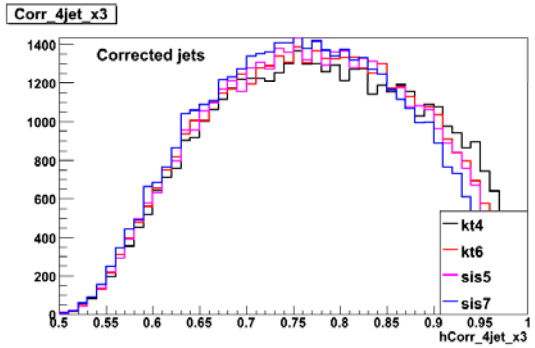
- We observe differences between different jet algortihms. Differences are more for harder jets, less for softer jets.

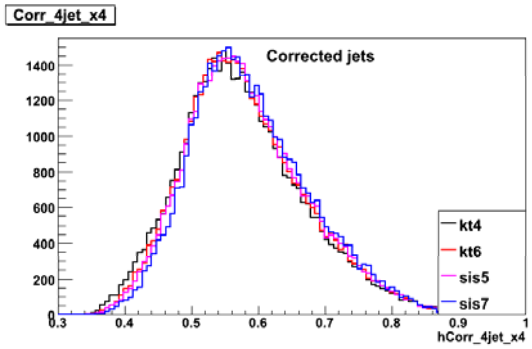
Topological properties of 4parton events for different jet algorithms

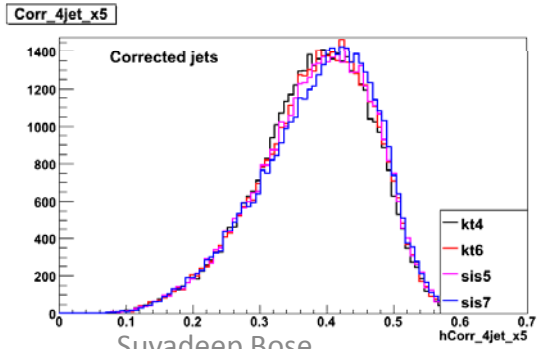


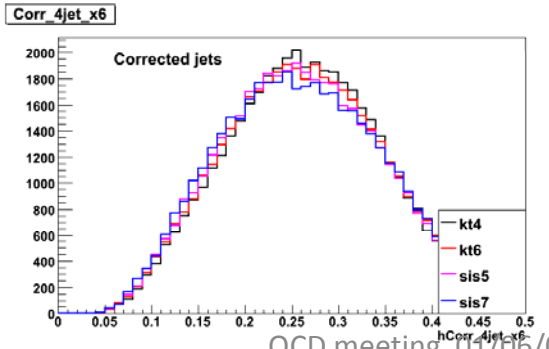






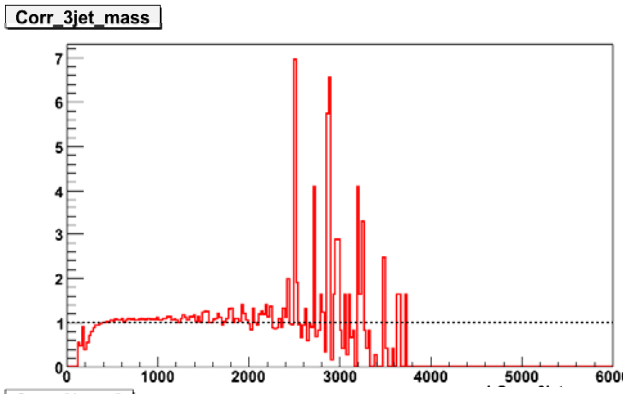


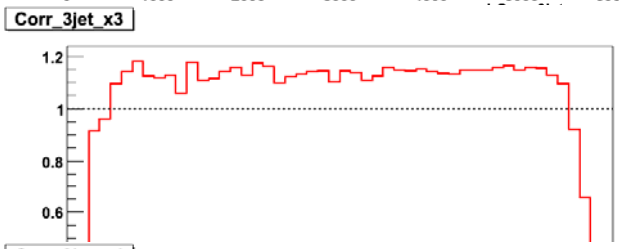


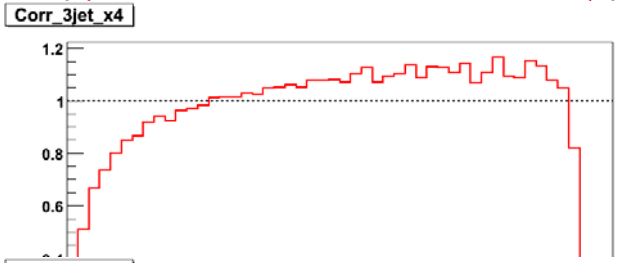


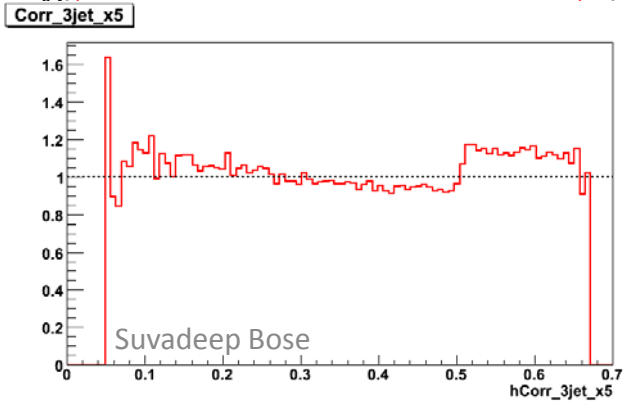
- We observe small differences between different jet algorithms for kinematic variables.
- Differences are seen for 4-jet angular variables as well.
- We see kt6 and siscone5 match closer than the rest of the algorithms.
- Distributions among same algorithms for narrow/broad jets eg. (kt4 and kt6) and (sis5 and sis7) are significantly different for angular distributions.

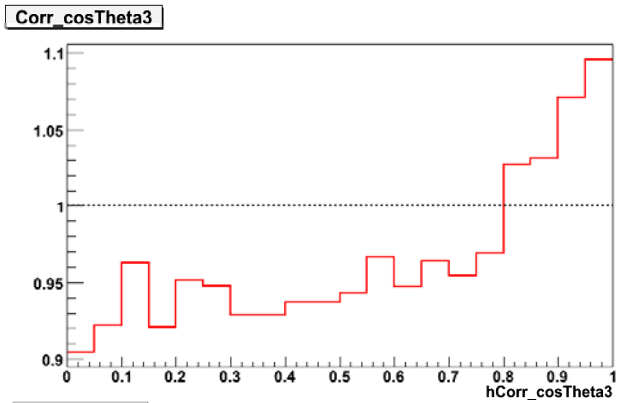
Distributions for multi-jet variables : kt4/kt6

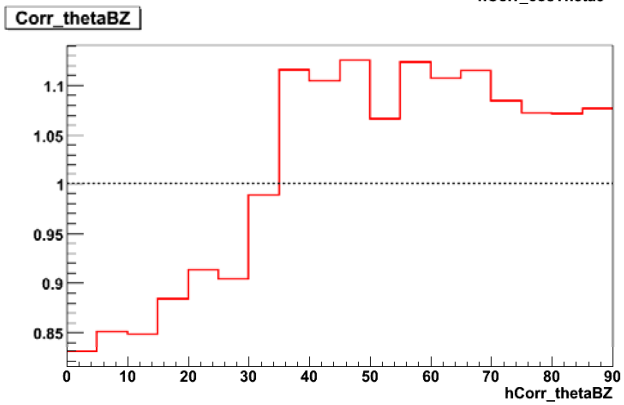


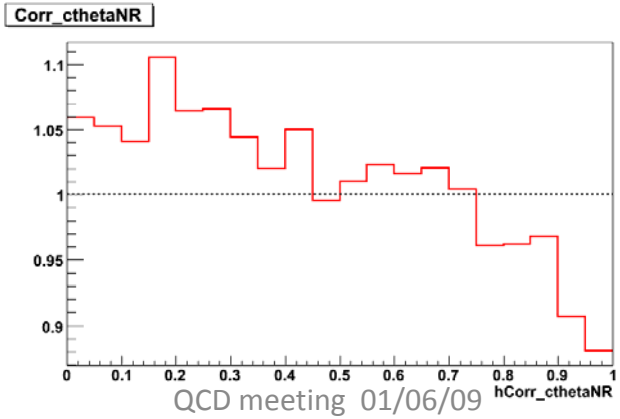


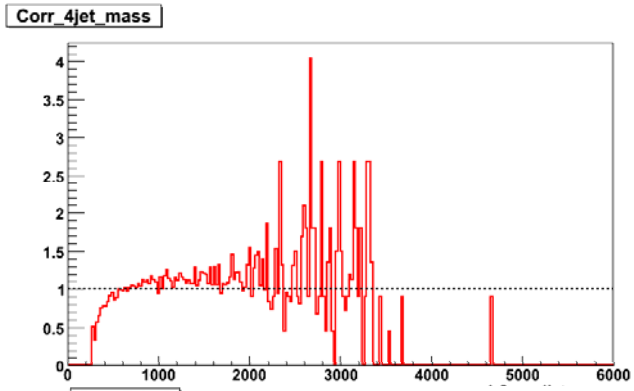


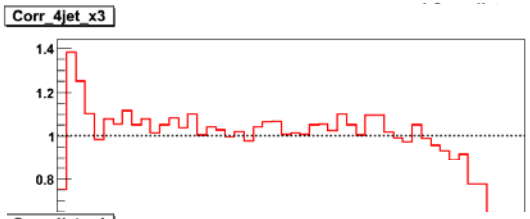


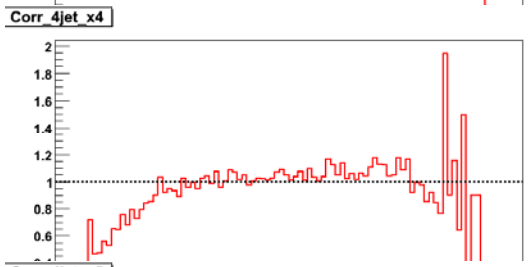


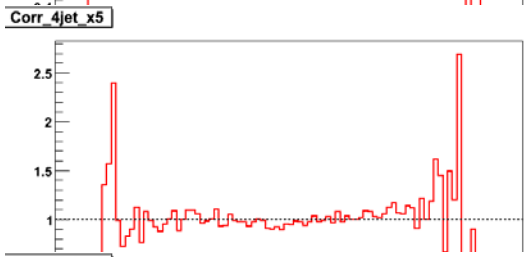


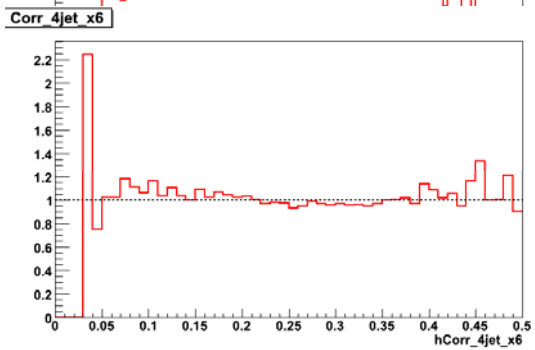




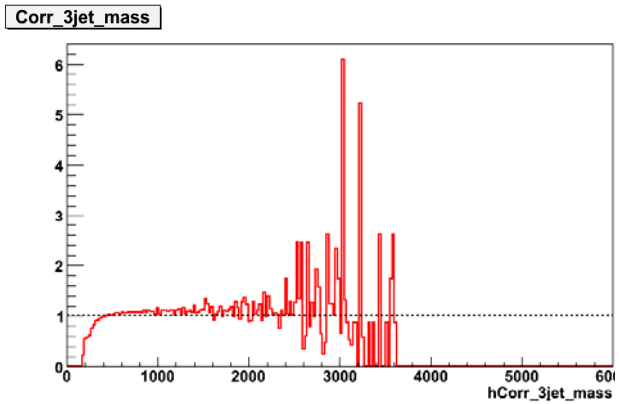


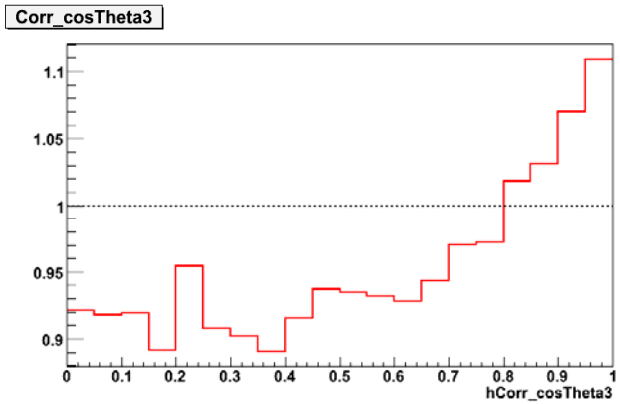


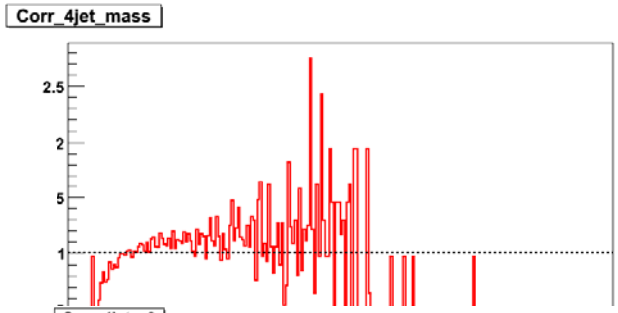


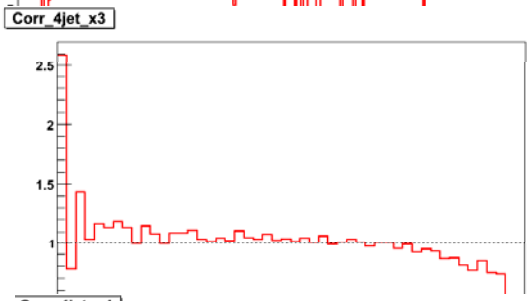


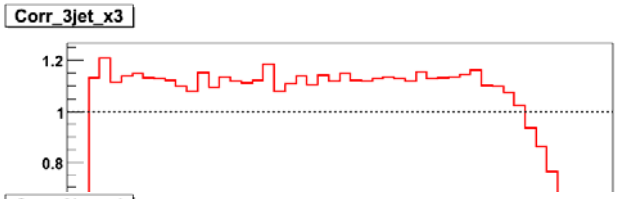
Distributions for multi-jet variables : sis5/sis7

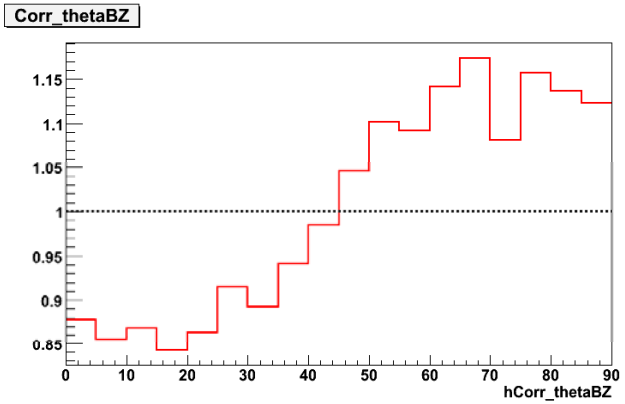


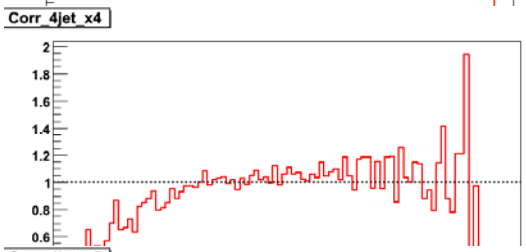


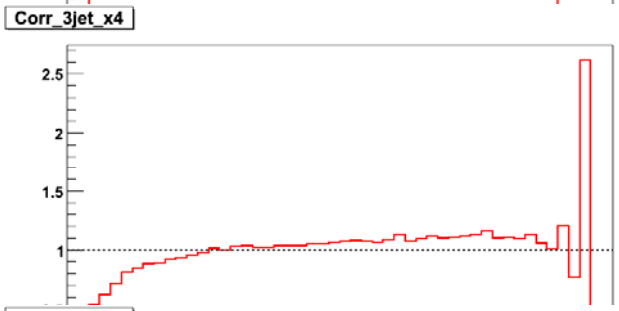


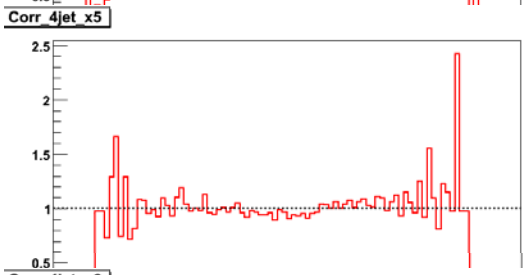


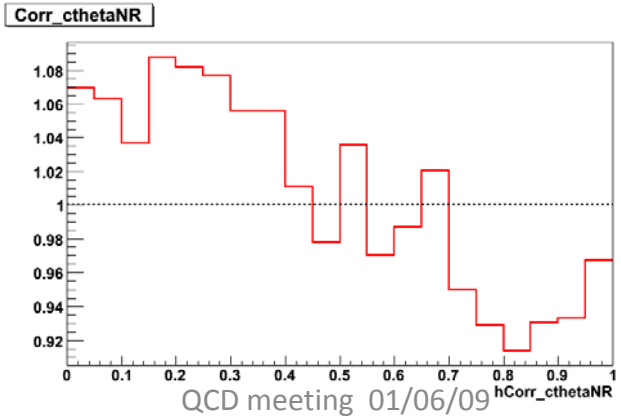


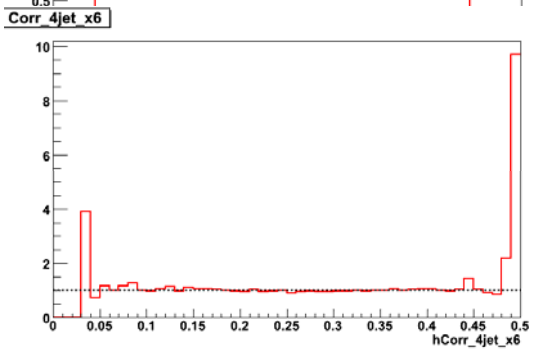


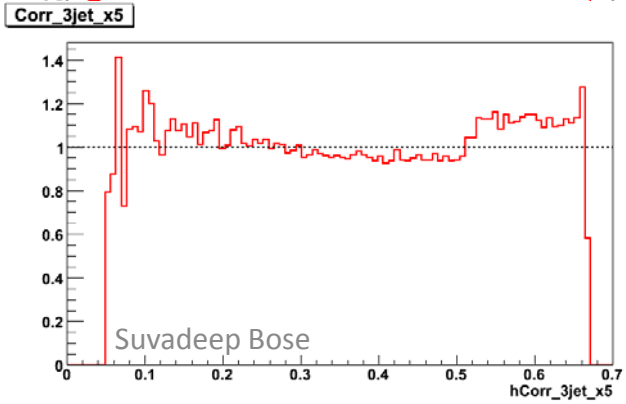












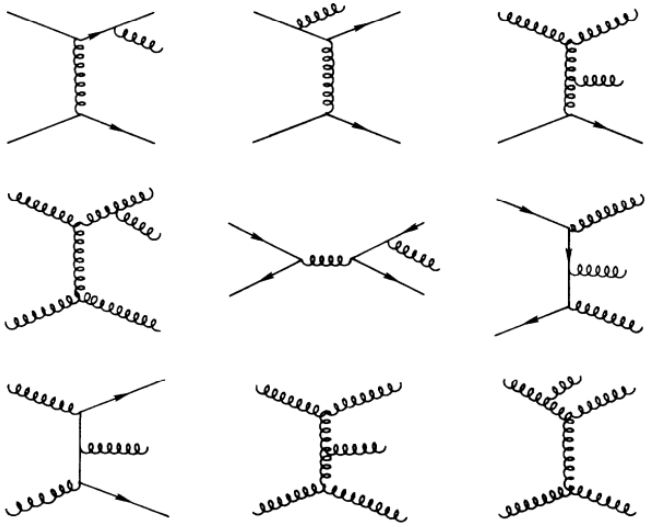
Summary

- We studied the detector effects. Effect of position resolution is not significant in all the variables, even less for scaled energies. Effect of energy resolution is small for angular variables but significant for scaled energies or masses.
- The simple *Gaussian smearing model* does not reproduce the net effect of detector correction.
- Systematic uncertainties due to trigger bias was studied. The uncertainties are small.
- We studied the systematic uncertainty due to event selection criteria. We see that the effect is small (less than 5%).
- The PYTHIA Monte Carlo samples were compared to Matrix Element calculations (ALPGEN). We observe differences more in the angular variables. Among kinematic variables differences are more visible for harder jets than softer jets.
- We studied the distributions for different jet algorithms. We notice different jet algorithms give differences in the kinematic and topological distributions. The distributions for Kt6 and SisCone5 algorithms look closer.

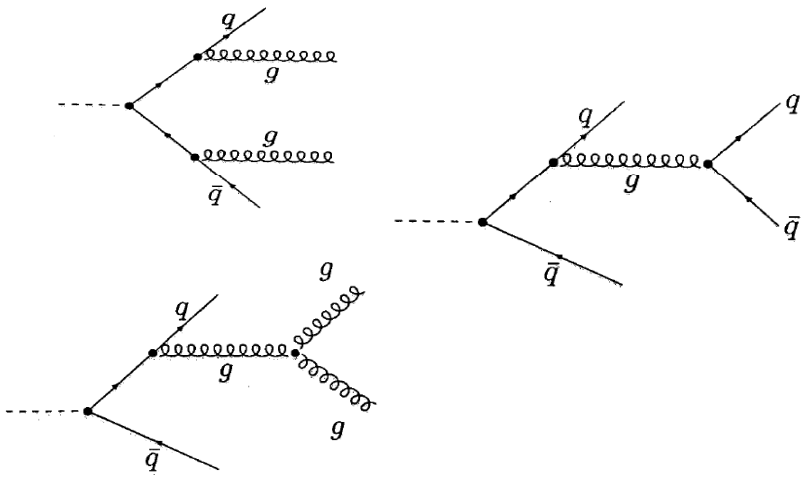
Back up slides

Multijet Study : Motivation

❑ The essential features of QCD are provided by the vector nature of gluon and gluon self coupling. These reflect on the so called colour factors which appear in various vertices.



3-parton final states



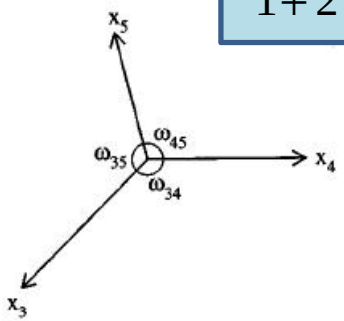
4-parton final states

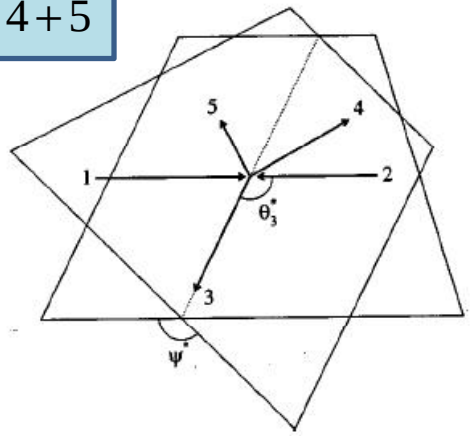
❑ Several tests of QCD sensitive to the spin and the self-coupling of gluons have already been carried out in the earlier e^+e^- and hadron collider experiments based on study of angular correlations in 3-jet and 4-jet events.

❑ Study of thee and four jet events allows a test of the validity of the QCD calculations to higher order and a probe of the underlying QCD dynamics. The topological distributions of these multijet events provide sensitive tests of the QCD matrix element calculations.

Different topological properties of 3-parton events

$$1+2 \rightarrow 3+4+5$$





3-jet

- Scaled energies: ordered in their c.m. frame:

$x_i = 2E_i / \sqrt{\hat{s}}$ where $x_3 + x_4 + x_5 = 2$

Alternately, $$x_i = \frac{2\sin\omega_{jk}}{\sin\omega_{34} + \sin\omega_{45} + \sin\omega_{53}}$$

- Scaled invariant masses of jet pairs:

$$\mu_{ij} = m_{ij} / \sqrt{\hat{s}} : i, j = 3,4,5; i \neq j$$

- Angles that fix the event orientation
Cosine of angle w.r.t beam ($\cos\theta_3$)
of parton 3.

- Azimuthal angle of parton 3 (φ_3).

- Angle between the plane containing partons 1 and 3 and the plane containing partons 4 and 5 (ψ^*) defined by

$$\cos\psi^* = \frac{(\vec{p}_1 \times \vec{p}_3)\cdot(\vec{p}_4 \times \vec{p}_5)}{|\vec{p}_1 \times \vec{p}_3||\vec{p}_4 \times \vec{p}_5|}$$

- The Ellis-Karliner angle, λ, is defined as:

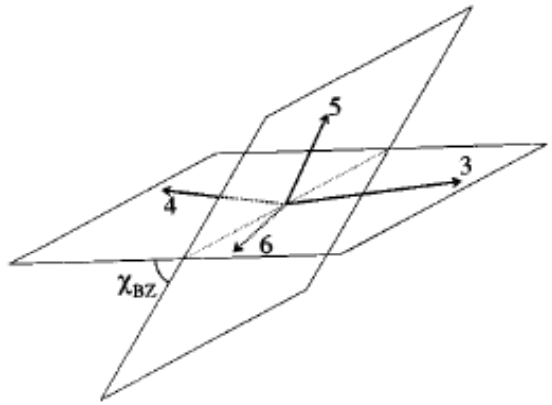
$$|\cos\lambda| = \frac{\sin\omega_{45} - \sin\omega_{53}}{\sin\omega_{34}}$$

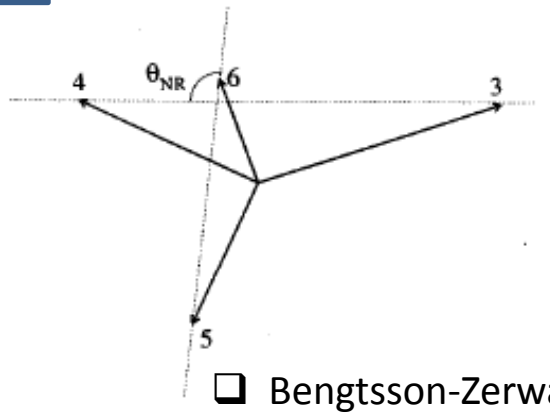
A set of kinematic variables for 3-parton:

$$x_3, x_5, \cos\theta_3, \psi^*, \cos\lambda$$

Different topological properties of 4-parton events

$$1+2 \rightarrow 3+4+5+6$$





- Scaled energies: ordered in their c.o.m. frame:

$$x_i = 2E_i / \sqrt{\hat{s}}$$

- Cosines of the polar angles :

$$\cos\theta_i, i = 3,4,5,6$$

- Cosines of their opening angles :

$$\cos\omega_{ij} : i, j = 3,4,5,6; i \neq j$$

- Scaled masses:

$$\mu_{ij} = m_{ij} / \sqrt{\hat{s}} : i, j = 3,4,5,6; i \neq j$$

$$x_i, \cos\theta_i, \omega_{jk}, \cos\chi_{BZ}, \cos\theta_{NR}$$

- Bengtsson-Zerwas angle :
  Angle between the plane containing the two leading jets and the plane containing the two non-leading jets.

$$\cos\chi_{BZ} = \frac{(\vec{p}_3 \times \vec{p}_4)\cdot(\vec{p}_5 \times \vec{p}_6)}{|\vec{p}_3 \times \vec{p}_4||\vec{p}_5 \times \vec{p}_6|}$$

- Nachtmann-Reiter angle:
  Angle between the momentum vector differences of the leading jets and the two non-leading jets:

$$\cos\theta_{NR} = \frac{(\vec{p}_3 - \vec{p}_4)\cdot(\vec{p}_5 - \vec{p}_6)}{|\vec{p}_3 - \vec{p}_4||\vec{p}_5 - \vec{p}_6|}$$

Data set obtained from CSA 08 (S156) with cross-sections

Sample	Events	Xsec [pb]	L[pb-1]
JetET20	3 926 600	101 600 000	0.0386
JetET30	4 131 600	21 550 000	0.1917
JetET50	4 010 400	2 484 000	1.6145
JetET80	2 891 200	323 700	8.9317
JetET110	3 980 000	88 730	44.8552
JetET150	4 172 400	17 120	243.7150

- **Each individual JetETxx sample is treated like a primary dataset based on a single jet trigger.**

❑ **As these datasets are highly biased by construction we have decided to take one MC sample and apply HLT cuts to decide the kinematic range where the sample is fully efficient.**

L1(Corrected) Gev	Prescale	HLT (Corrected) GeV	Rate Hz
15	10^5	30	0.3
30	10^4	60	0.3
70	100	110	2.5
100	10	150	3.5
150	1	200	9.6

Sample	p_T Min (GeV)	Events
JetET20	30	3.926.600
JetET30	45	4.131.600
JetET50	75	4.010.400
JetET80	120	2.891.200
JetET110	160	3.980.000
JetET150	220	4.171.600

Generator level MC production – Pythia and Herwig

- Generator level Pythia and Herwig samples produced privately in CMSSW_2_0_11.

PYTHIA datacard:

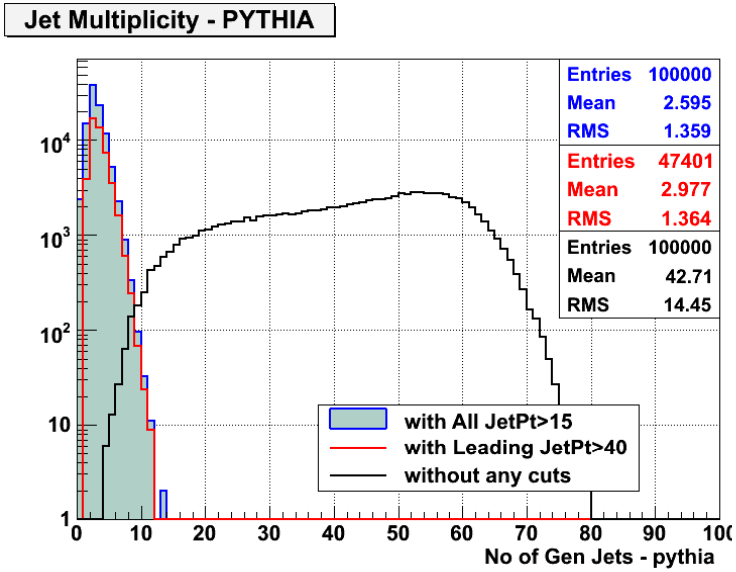
```
MSEL=0          ! User defined processes,
MSUB(11)=1      ! Min bias process: ff->ff
MSUB(12)=1      ! Min bias process: ffbar->ffbar
MSUB(13)=1      ! Min bias process: ffbar->gg
MSUB(28)=1      ! Min bias process: fg->fg
MSUB(53)=1      ! Min bias process: gg->ffbar
MSUB(68)=1      ! Min bias process: gg->gg
CKIN(3)=30.     ! minimum pt hat for hard interactions
```

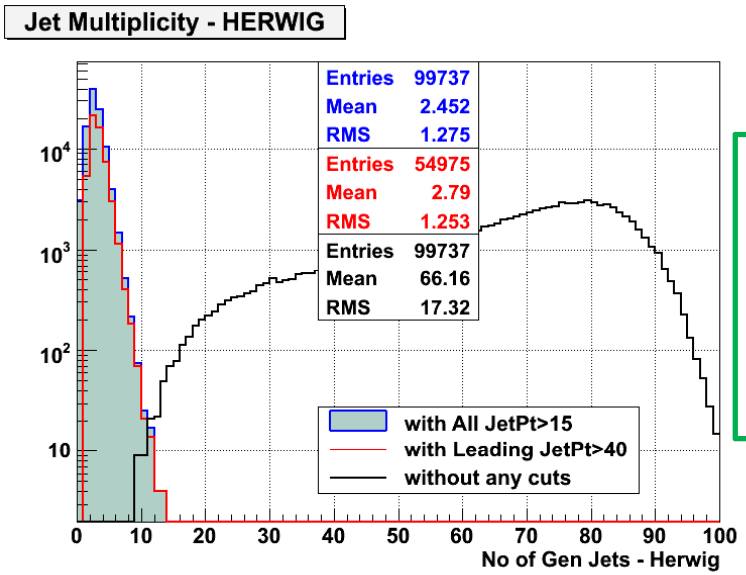
HERWIG datacard:

```
IPROC    = 1500     ! Process QCD 2->2
PTMIN    = 30.0
```

- Event selection was based on GenJet information.
- A Min p_T threshold of 15 GeV on all jets and
- A threshold of 40 GeV on leading jet on top of the Min p_T threshold.

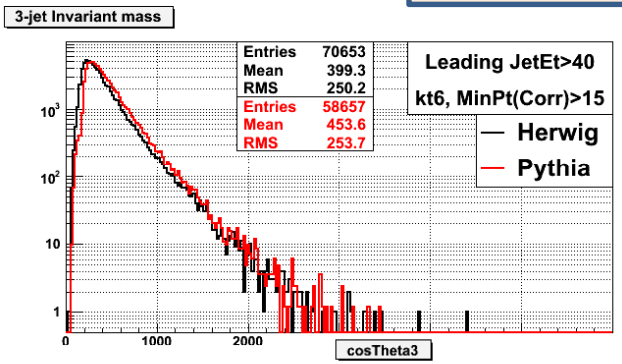
Jet Multiplicities for PYTHIA and HERWIG at Generator level

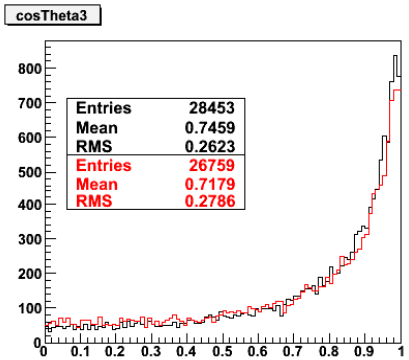


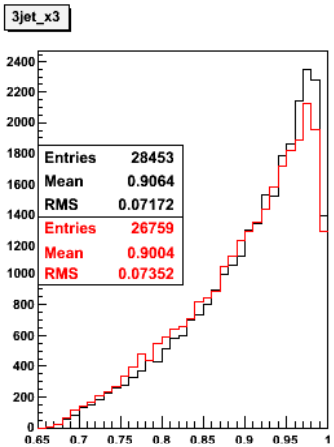


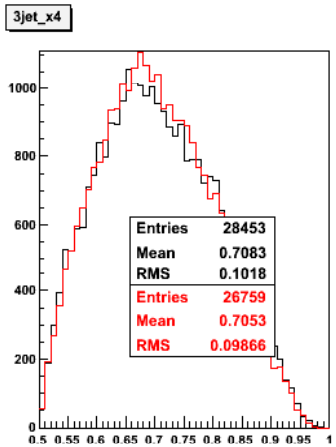
Clearly we have very few jets passing the conditions as seen from the mean of multiplicity Indicating mostly dijet events.

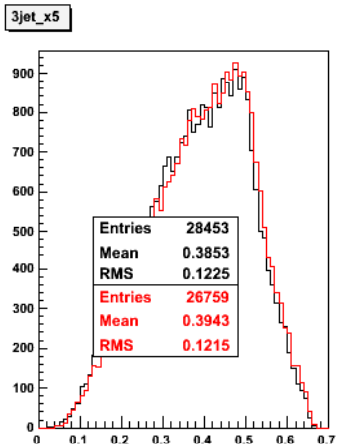
Topological properties of 3-parton events



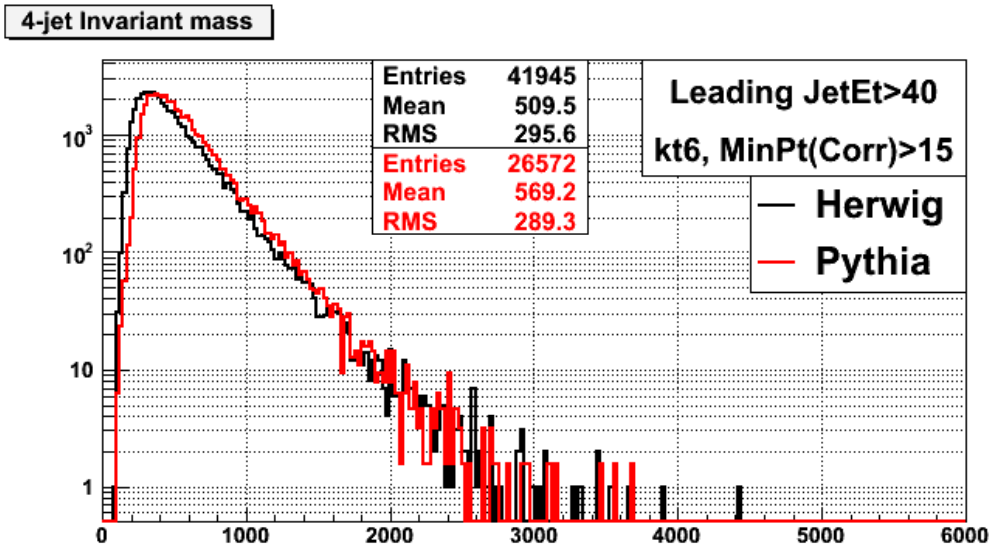


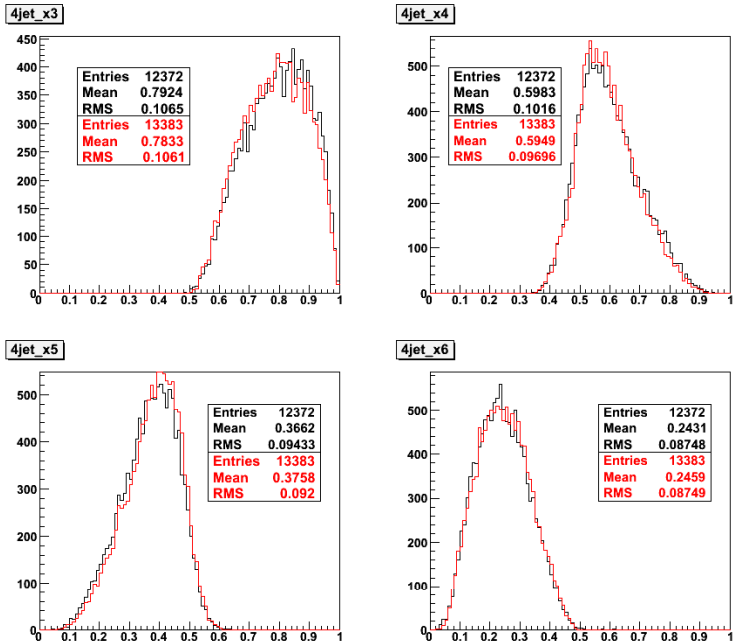


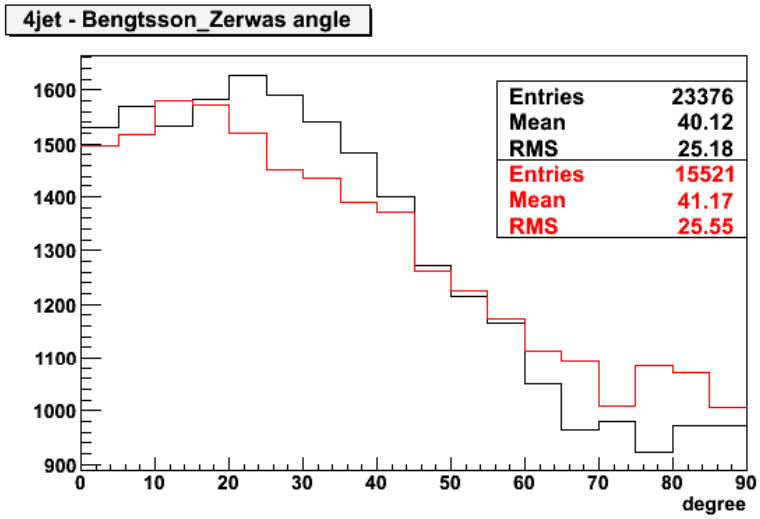


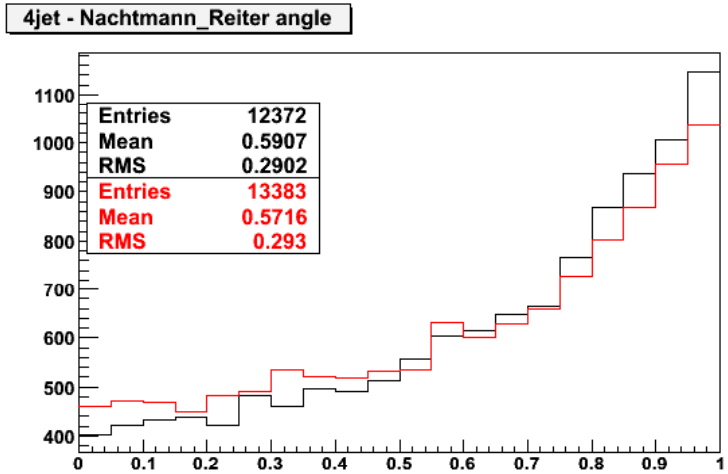


Topological properties of 4-parton events









❖ The two Monte Carlo predict very similar distributions for scaled energies but angular distributions differ by ~2%

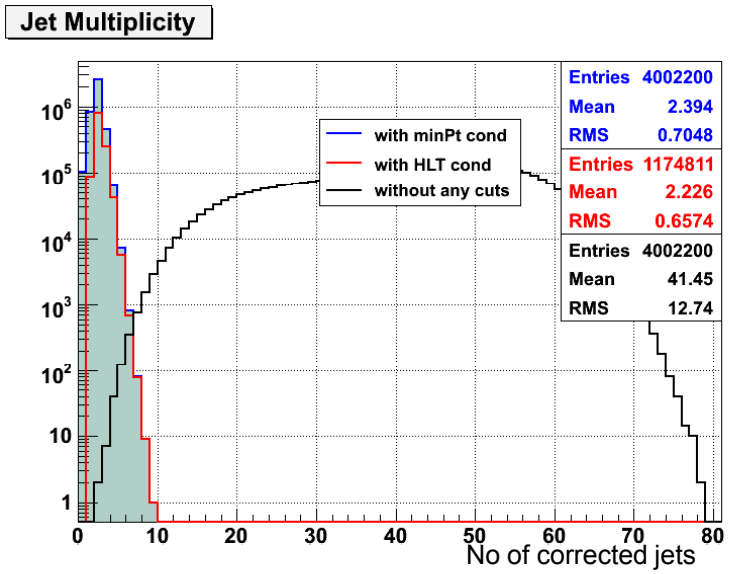
Event Selection and MC data used

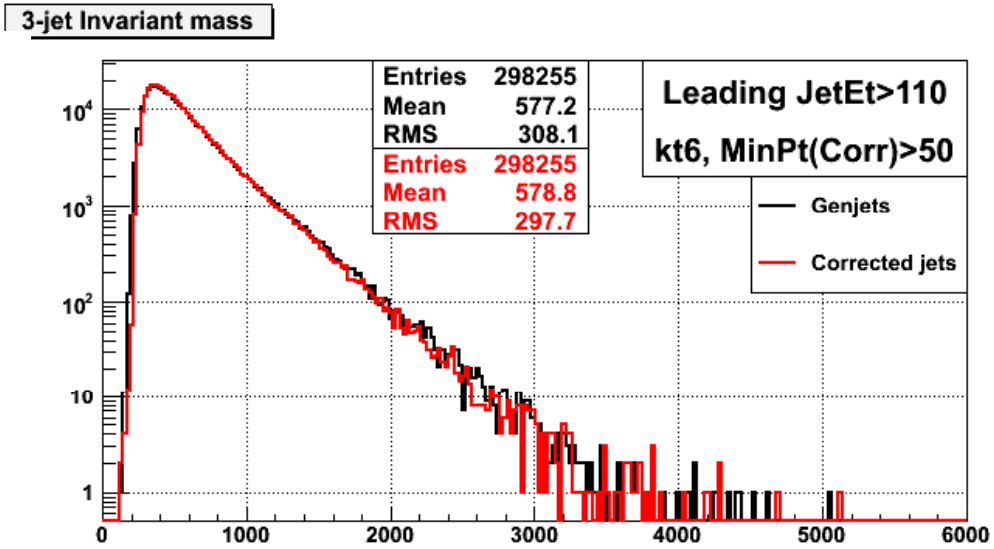
- CMSSW_2_0_7 is used for this analysis.
- One specific trigger jet sample is used for this anlysis:

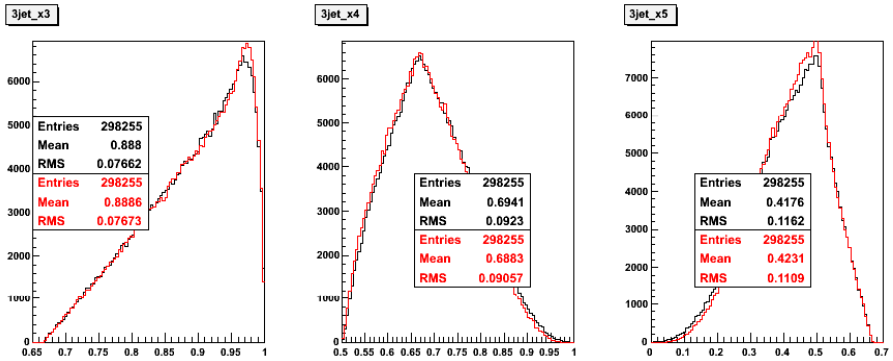
  CSA08 _QCDJetEt50_S156 sample with luminosity 10 pb^{-1} . *This sample has an equivalent pthat-min of 75 GeV. with 4,010,400 events being produced*.
- GenJets and Corrected (L2L3 correction) Calojets are compared.
- Event selection is based on Corrected Calojets for CSA08 sample.
- Jets are selected in the $|\eta| < 3.0$ region (upto endcap).
- Two jet algorithms are used for this analysis: SiSCone (R=0.7) and Kt (D=0.6).
- For 3(4) jet studies the most energetic jets are considered, the jets being ordered in their transverse energy (Et).
- The jets are boosted to the 3(4) jet centre of mass frame and ordered in descending order of their Energies (E) in the boosted frame.

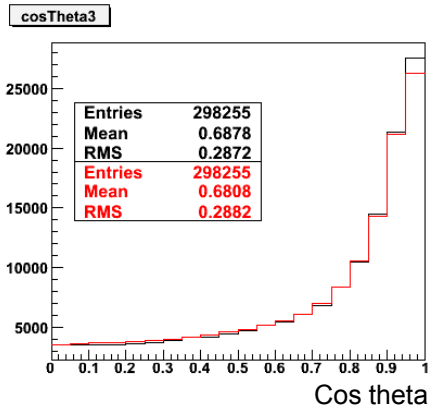
- **Event selection** is done in the following way:
  1. **HLT conditions (threshold of 110 GeV on leading jet Pt) is applied.**
  2. **A threshold (50 GeV) is applied on all corrected jets.**
  3. **Inclusive 3 jet and 4 jet events are selected.**

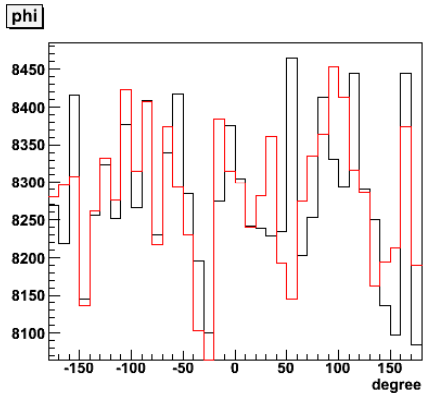
Topological properties of 3-parton events











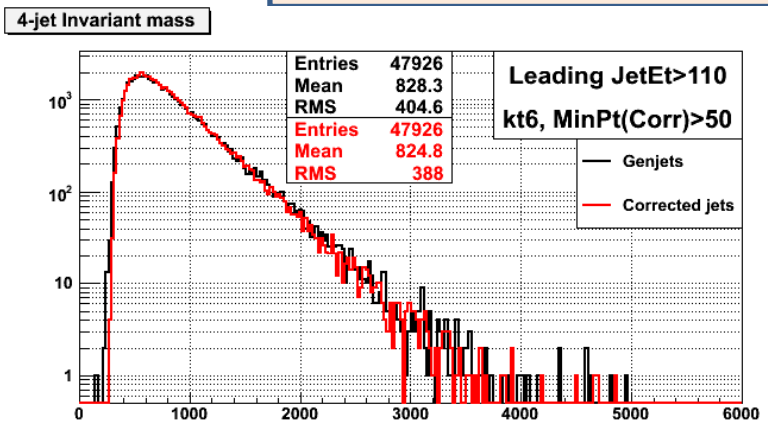
Scaled energies: ordered in their c.m. frame

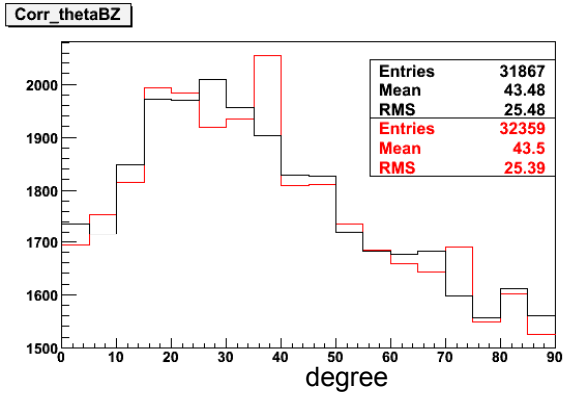
$$x_i = 2E_i / \sqrt{\hat{s}} \qquad x_3 + x_4 + x_5 = 2$$

- Cosine of angle w.r.t beam ($\cos\theta_3$) of parton 3.
- Azimuthal angle (Φ)

✓ **No significant difference between generator level jets (▬) corrected Calorimeter jets (▬).**

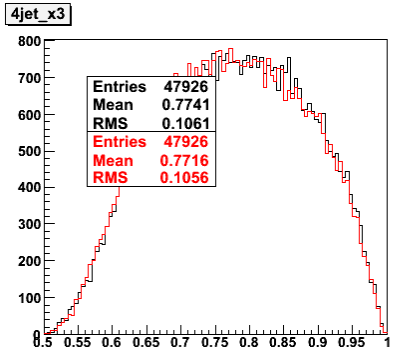
Topological properties of 4-parton events

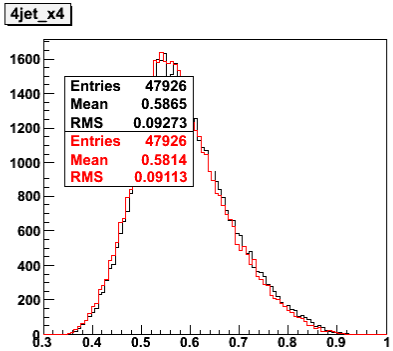


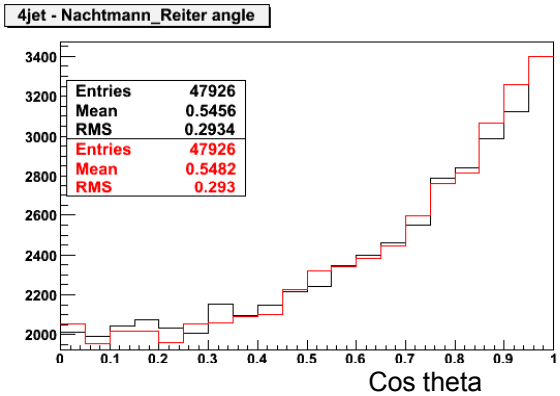


Bengtsson-Zerwas angle

$$\cos\chi_{BZ} = \frac{(\vec{p}_3 \times \vec{p}_4)\cdot(\vec{p}_5 \times \vec{p}_6)}{|\vec{p}_3 \times \vec{p}_4||\vec{p}_5 \times \vec{p}_6|}$$

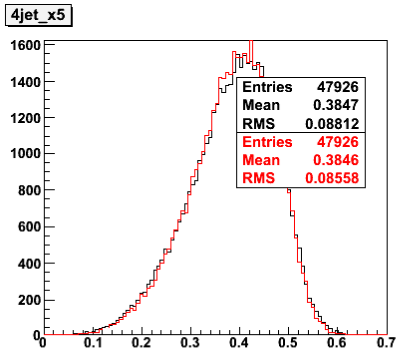


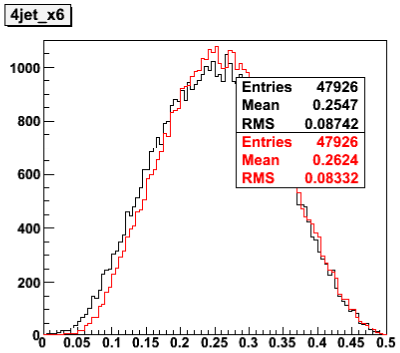




Nachtmann-Reiter angle

$$\cos\theta_{NR} = \frac{(\vec{p}_3 - \vec{p}_4)\cdot(\vec{p}_5 - \vec{p}_6)}{|\vec{p}_3 - \vec{p}_4||\vec{p}_5 - \vec{p}_6|}$$





Scaled energies: ordered in their c.m. frame: $x_i = 2E_i / \sqrt{s}$

✓ **No significant difference between generator level jets (▬) corrected Calorimeter jets (▬).**