# Multijet Study

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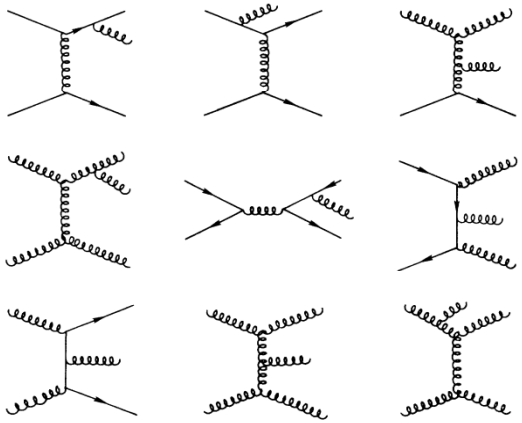
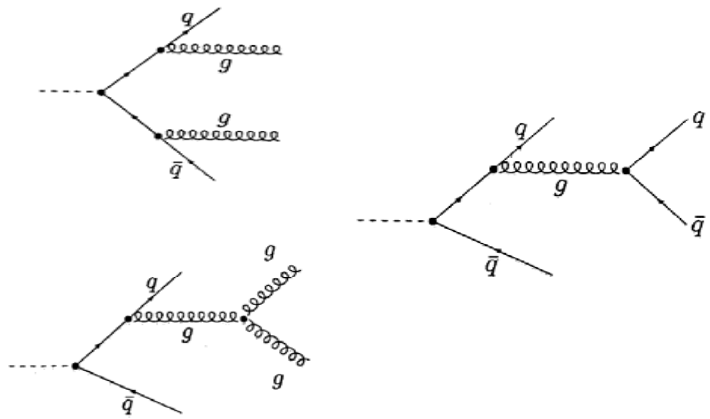
# Multijet Study

**Motivation:**

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



3-parton final states



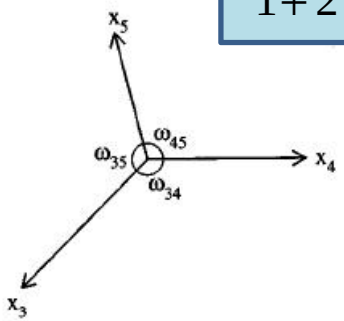

4-parton final states

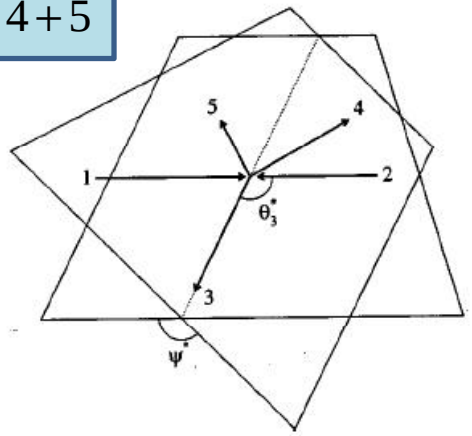
❑ Several tests of QCD which are sensitive to the gluon self-coupling have already been carried on in the earlier $e^+e^-$ and hadron collider experiments which are based on study of angular correlations in 3-jet and 4-jet events.

❑ 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 ($\varphi_3$).
- Angle between the plane containing partons 1 and 3 and the plane containing partons 4 and 5 ($\Psi^*$) 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, $\lambda$, is defined as:

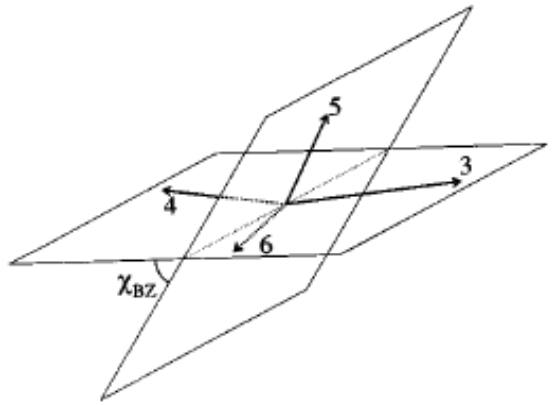
$$|\cos\lambda| = \frac{\sin\omega_{45} - \sin\omega_{53}}{\sin\omega_{34}}$$

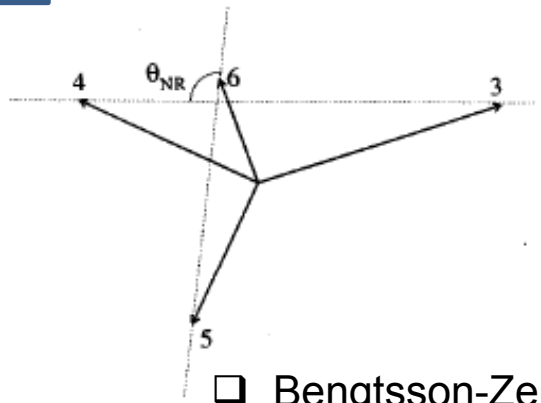
**A set of kinematic variables for 3-parton:**

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

# 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:

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

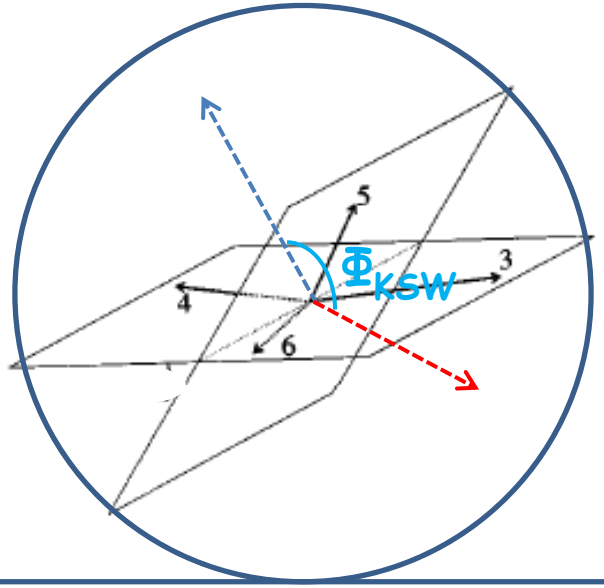
- Bengtsson-Zerwas angle :
  Angle between the plane containing the two leading jets and the plane containing the two non-leading jets.

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

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

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

# Different topological properties of 4-parton events




The variable proposed by Korner, Schierholz and Willrodt, $\Phi_{KSW}$ is defined for events for which there are two jets in both hemispheres defined by the thrust axis. $\Phi_{KSW}$ is the angle betweeen the normals to the plane containing the jets in one hemisphere and to the plane defined by the other two jets.
Gluons alignment in the splitting process $g \rightarrow gg$ favours $\Phi_{KSW} \approx \pi$
Whereas $g \rightarrow q\bar{q}$ prefers the planes to be orthogonal.

**A set of kinematic variables for 4-parton:**

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

# 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.

# Event Selection and MC data used

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

  CSA08 _QCDJetEt50_S156 sample with luminosity 10 $pb^{-1}$ .This sample has a pthat-min of 75 GeV. with 4,010,400 events being produced.
- GenJets, uncorrected and corrected Calojets are compared.
- L2L3 Corrections are applied on the calojets.
- Event selection was based on Corrected Calojets for CSA08 sample.
- Jets are selected in the $|\eta| < 3.0$ region (upto endcap).
- The Leading Jet Et threshold is kept at 80 GeV on the corrected jets.
- 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 their c.m. frame and ordered in descending order of their Energies (E) in the boosted frame.

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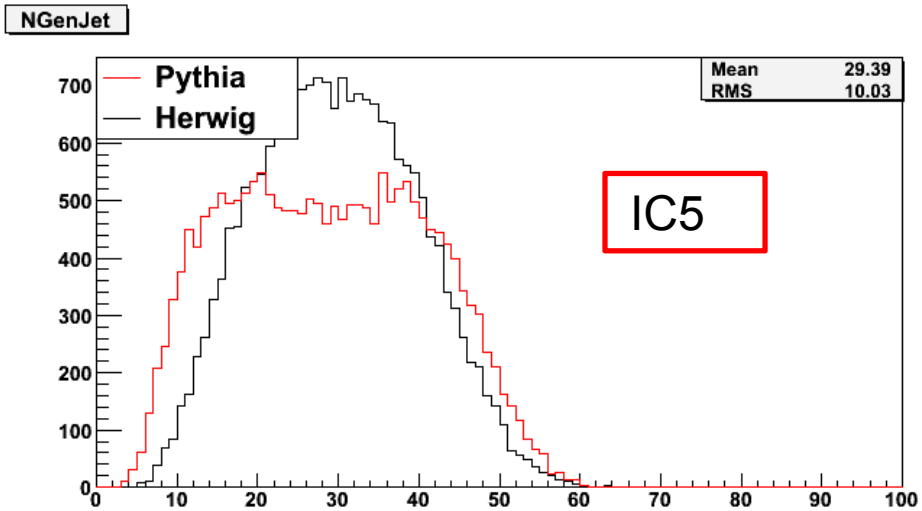
❖ In all plots for different multijet topologies in the following slides:

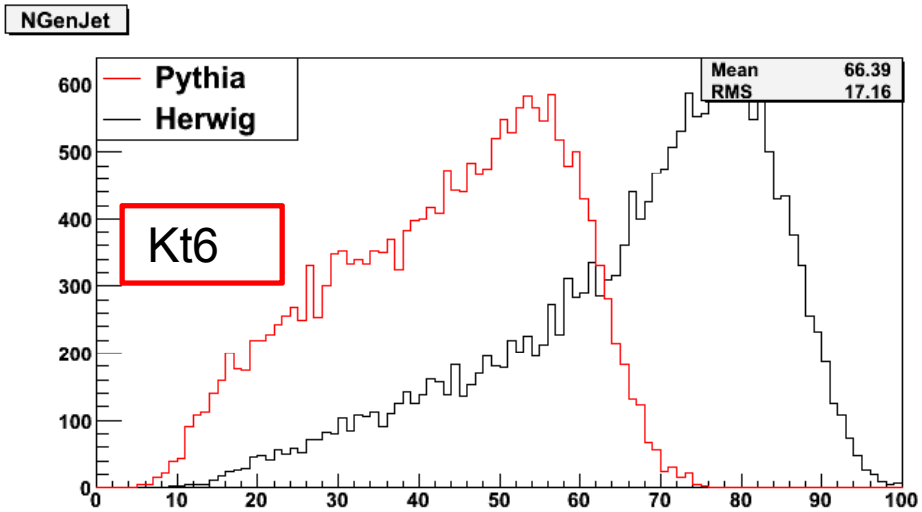
Black line for GenJet, Blue line for Calojet (uncorrected), Red line for Corrected Calojets (L2L3 correction)

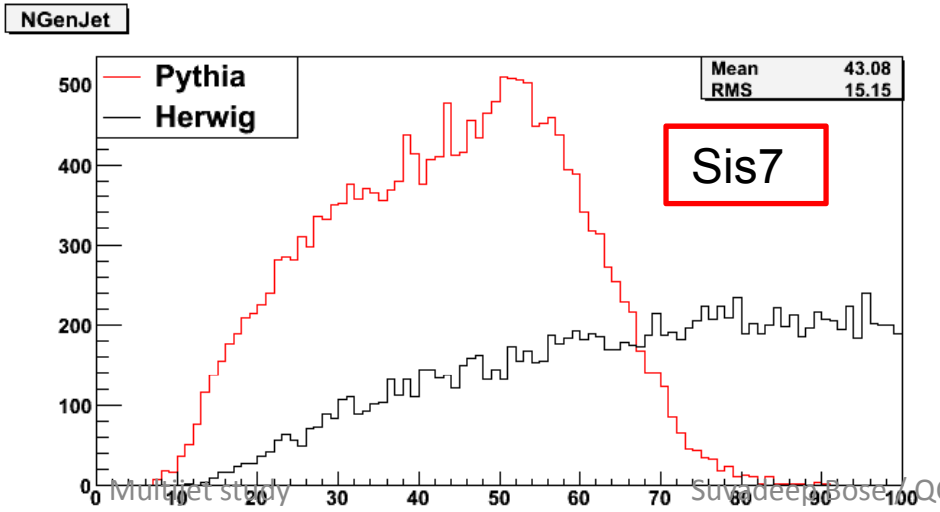
# Generator level studies

# Comparison of Pythia and Herwig

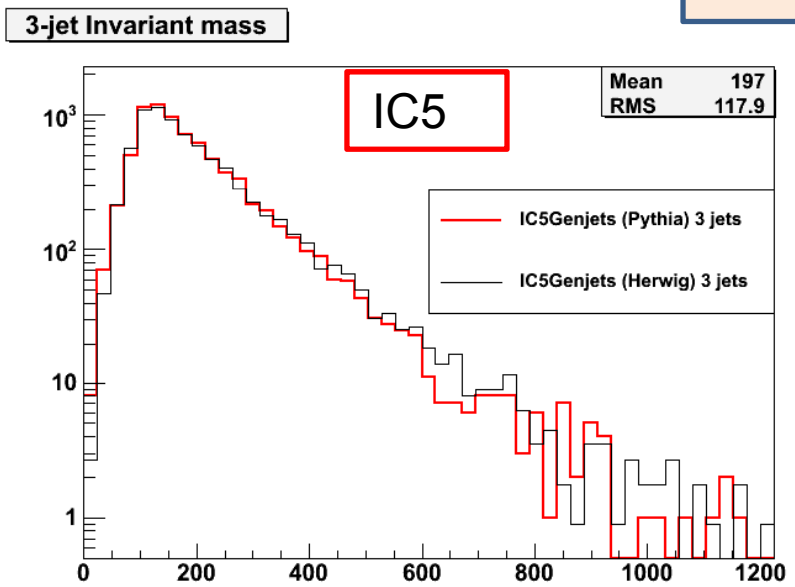
# Jet multiplicites

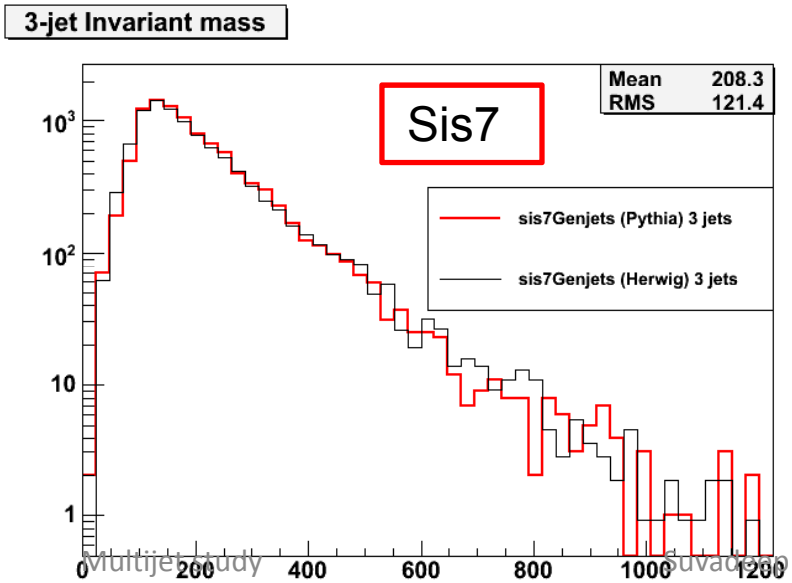


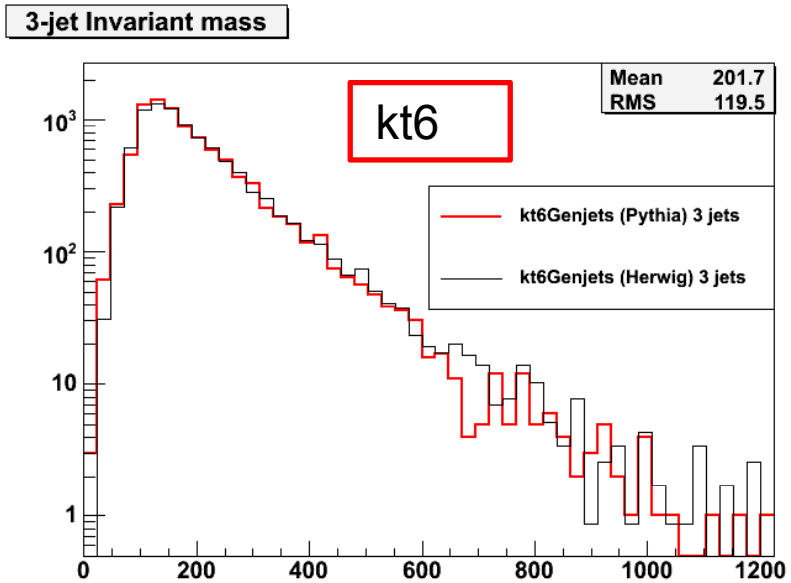



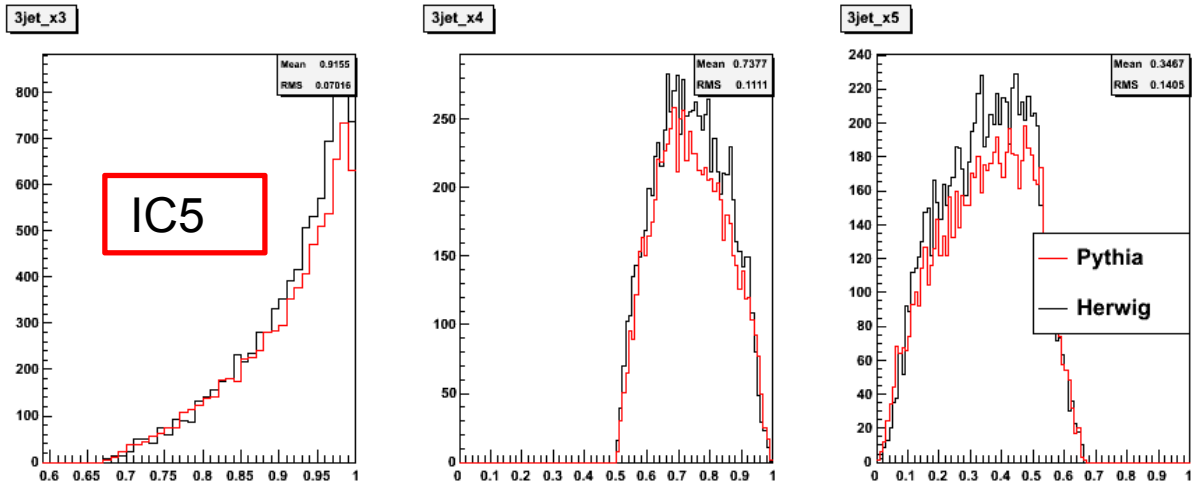
# 3-jet Invariant masses

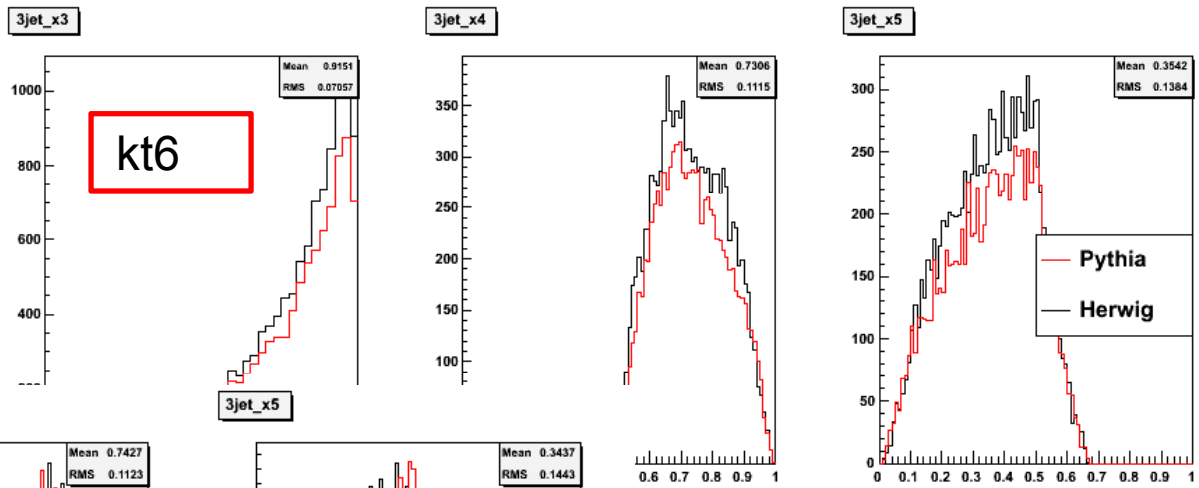


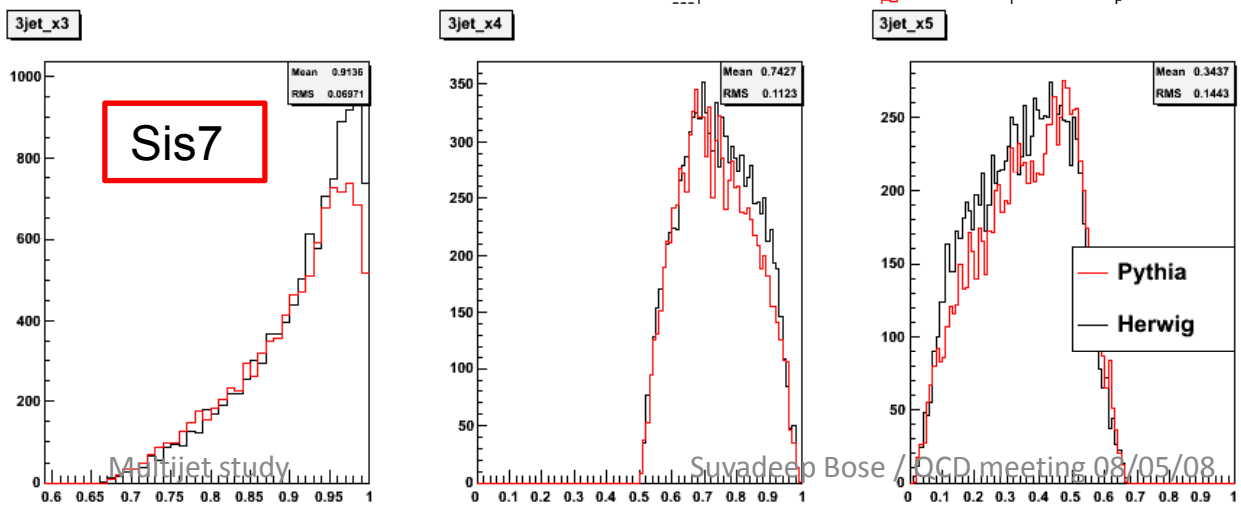



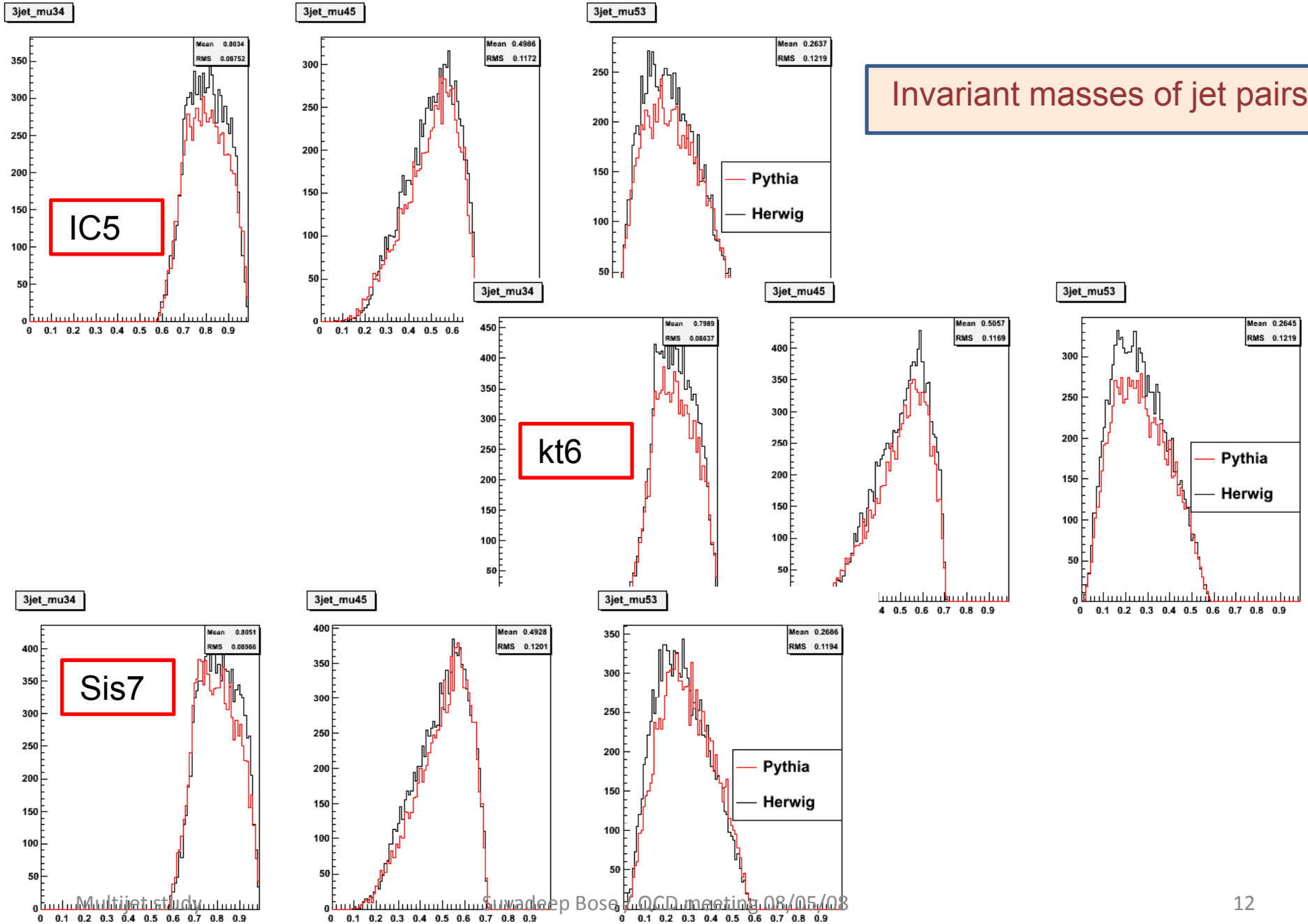
# Scaled energies of 3-parton



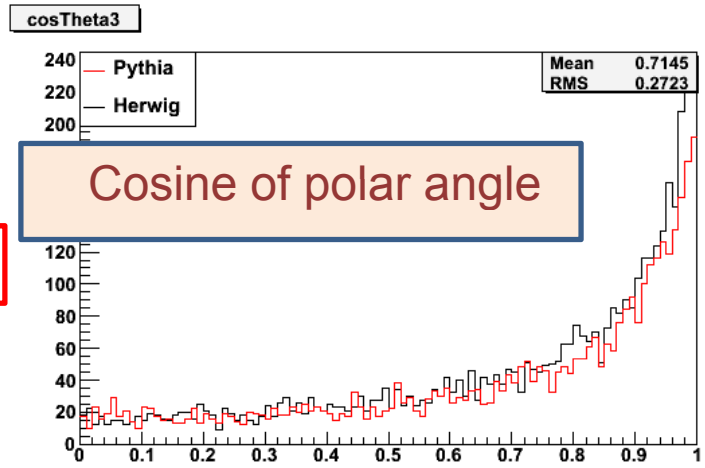



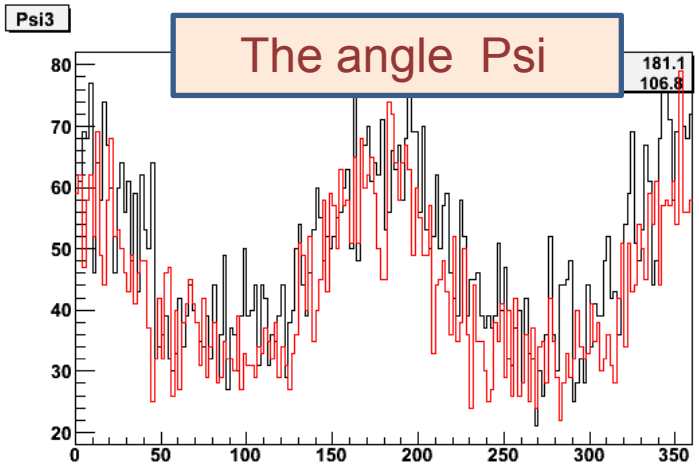
# Invariant masses of jet pairs



IC5

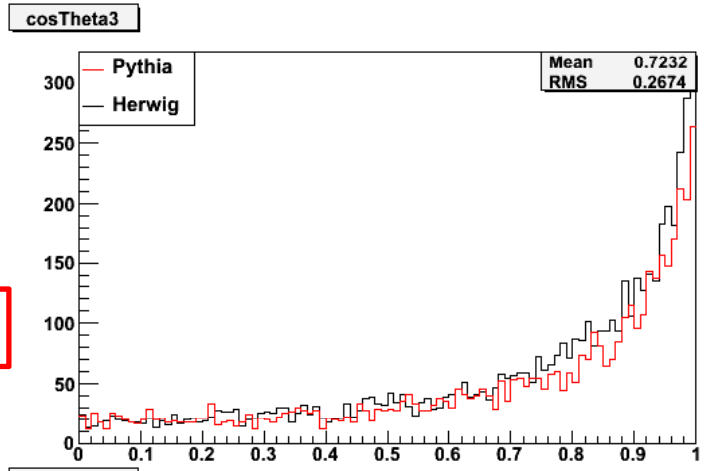


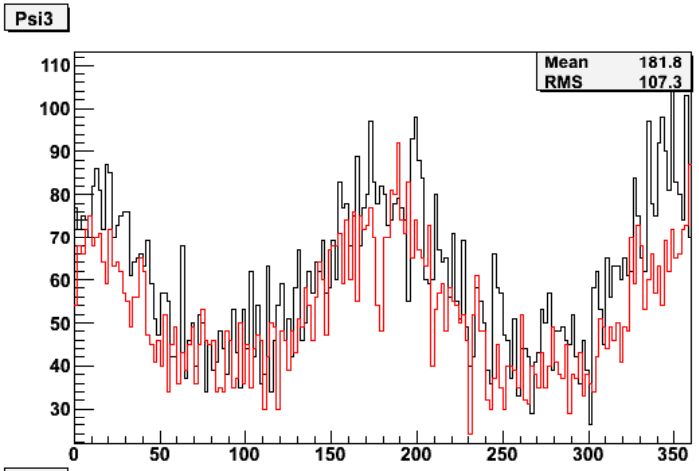

Cosine of polar angle



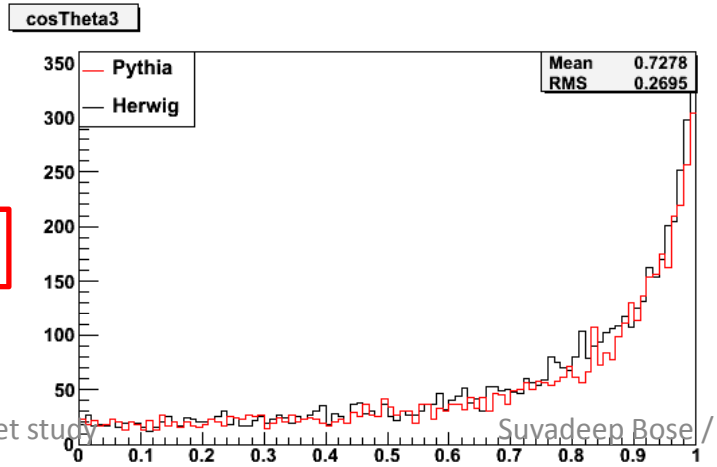

The angle Psi

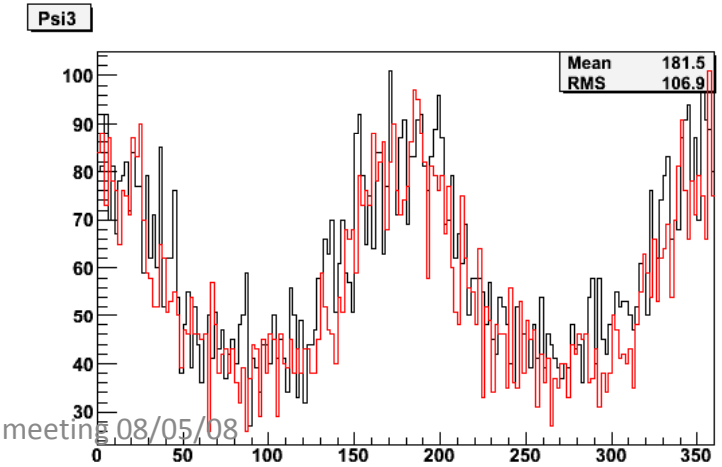
kt6



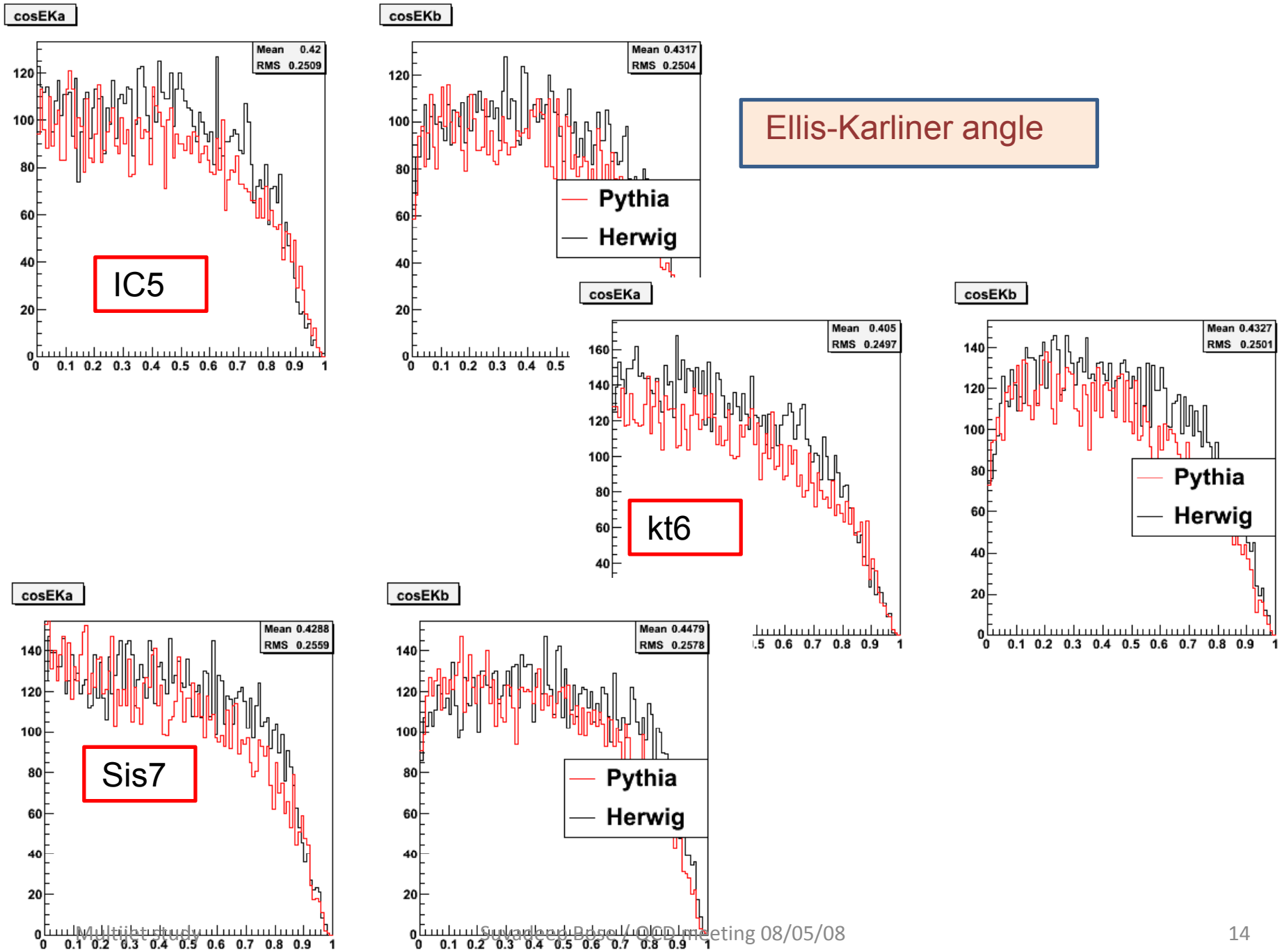




Sis7

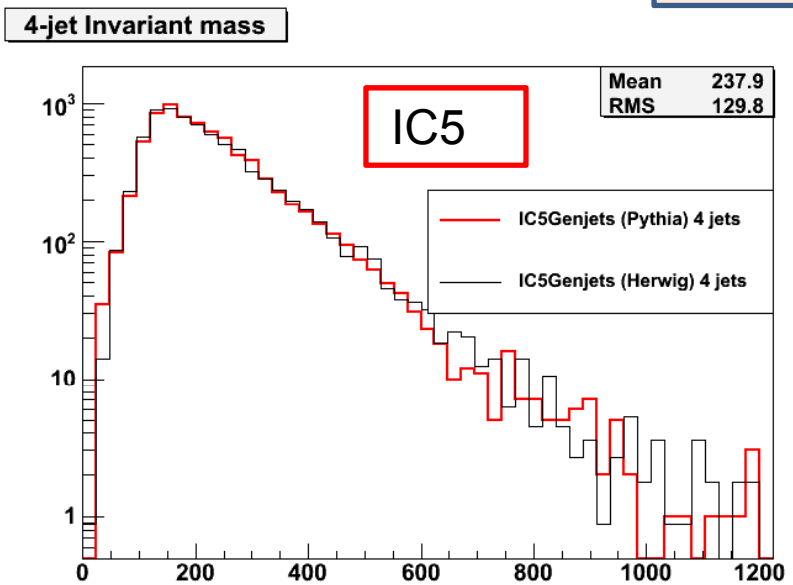


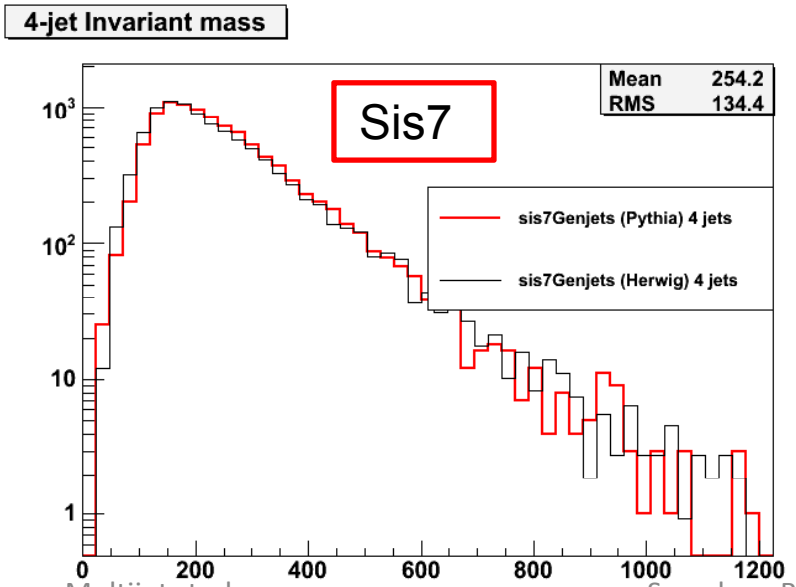



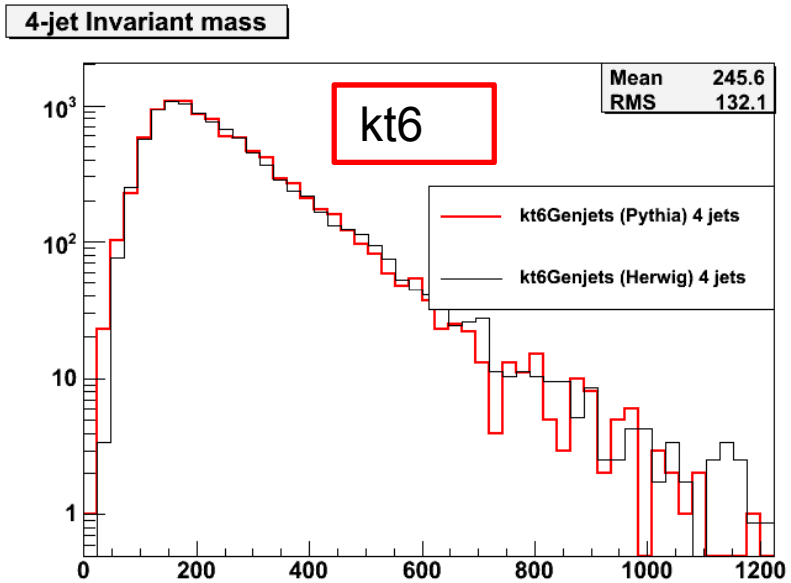
# Ellis-Karliner angle



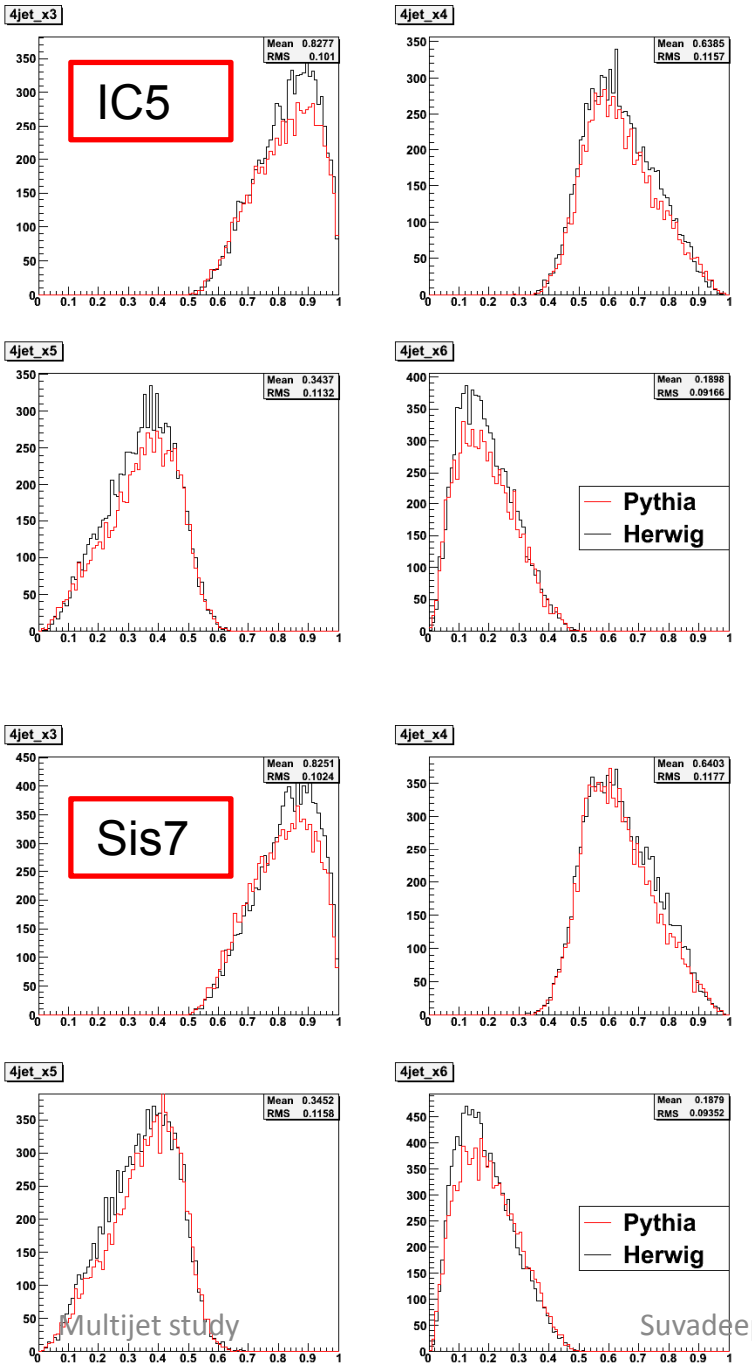
# 4-jet Invariant masses

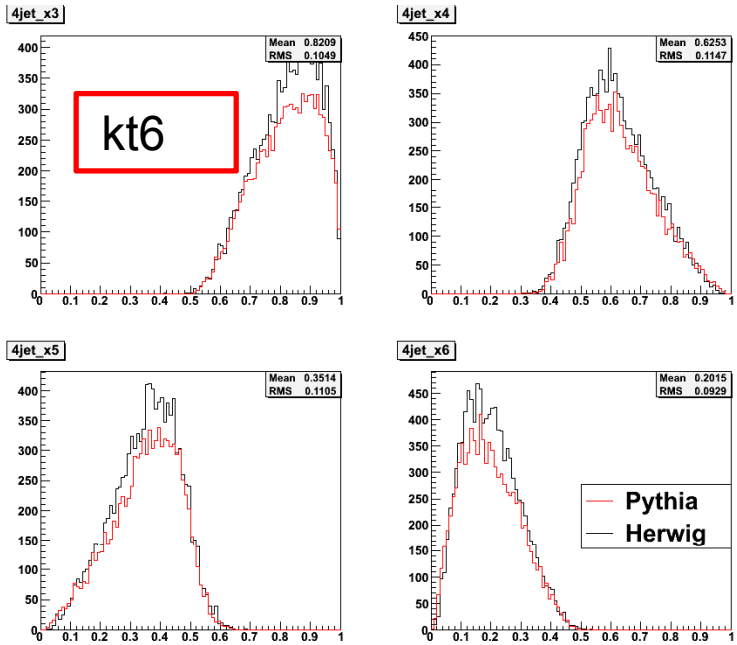


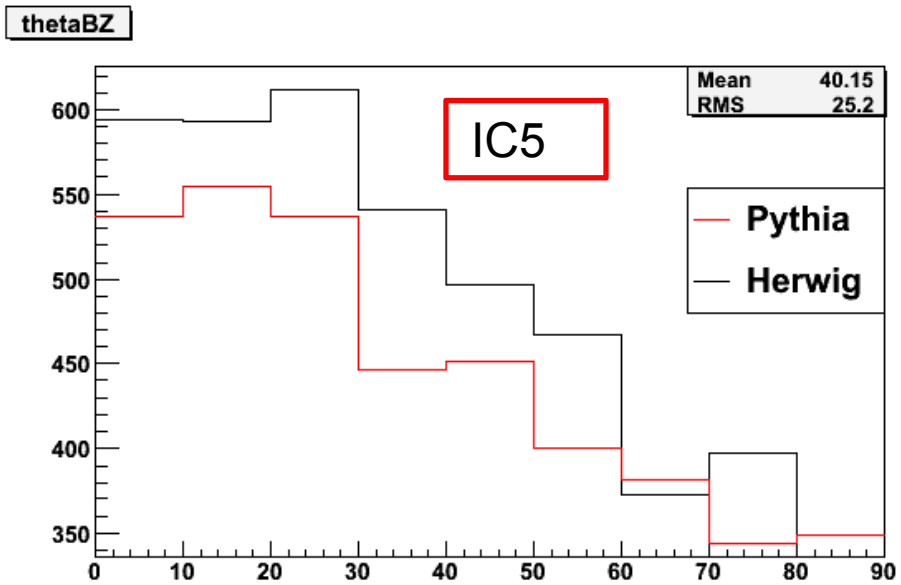



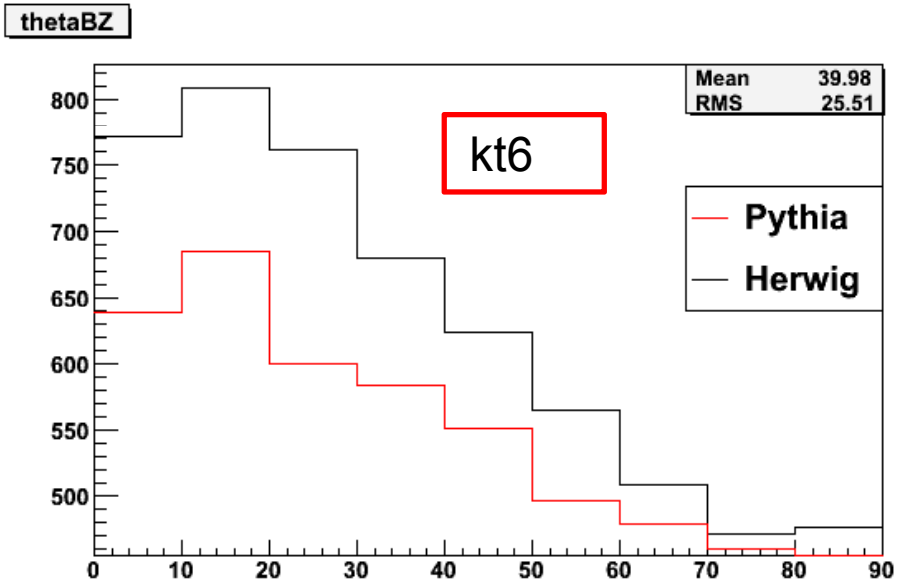
# 4-parton scaled energies

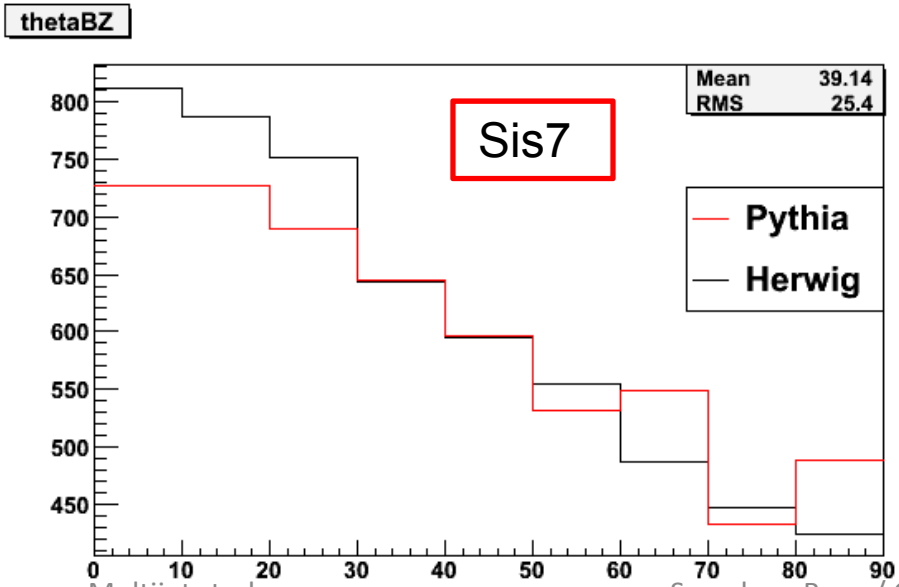


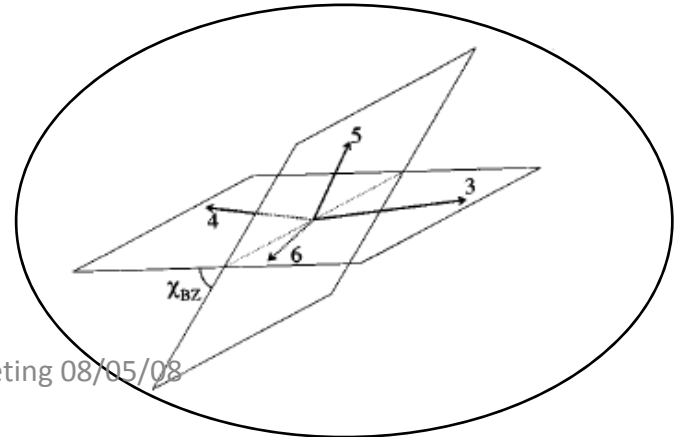



# Bengtsson-Zerwas angle ($\chi_{BZ}$)

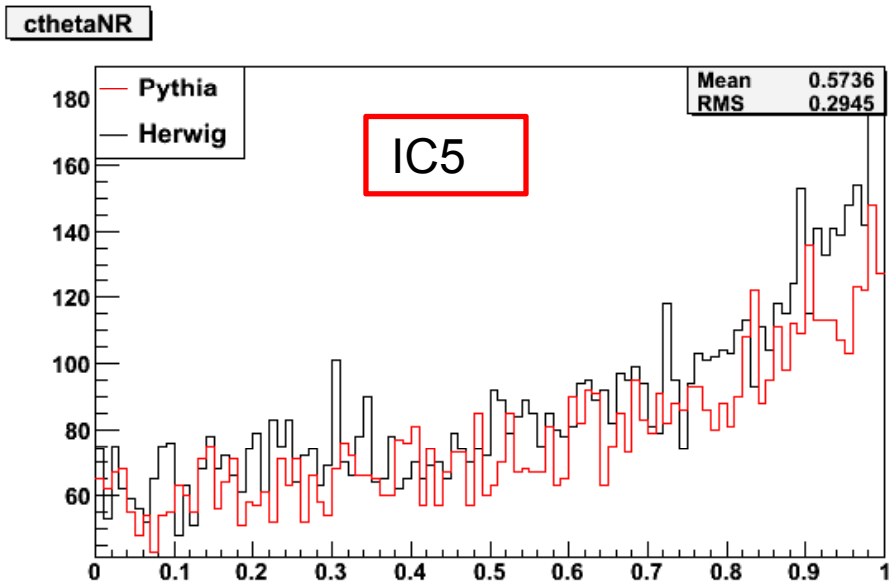


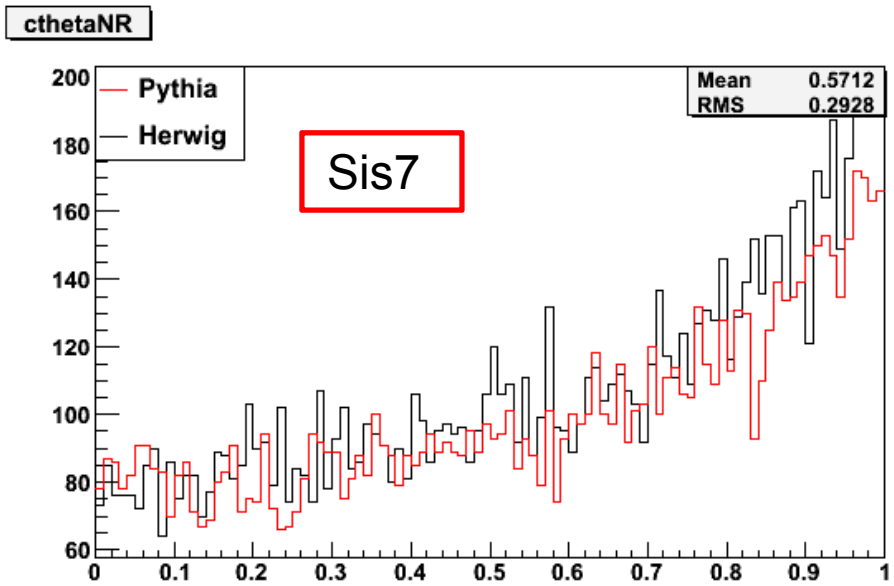



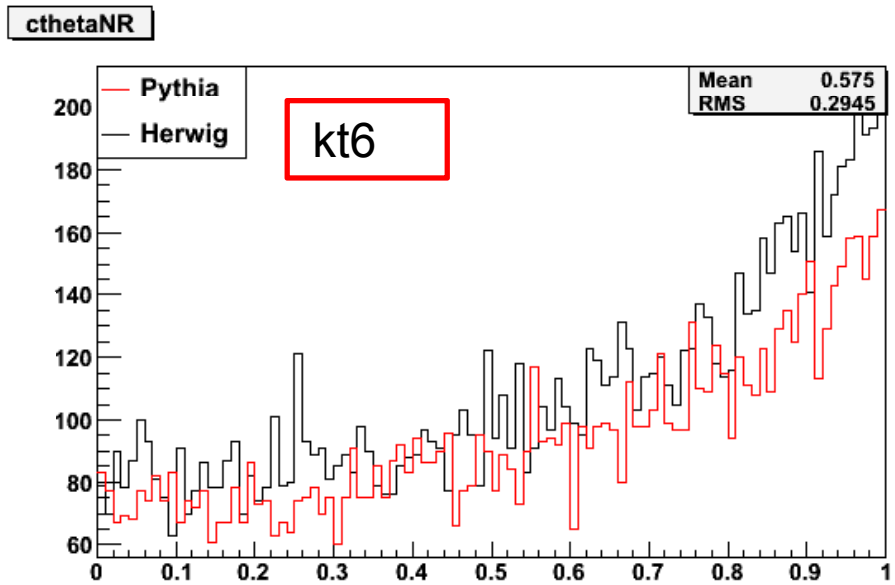



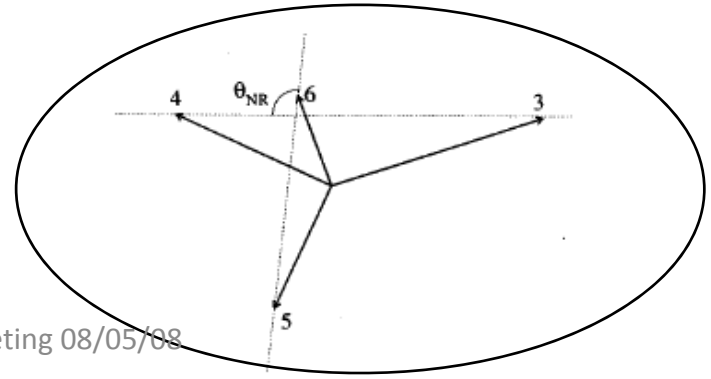



# Nachtmann-Reiter angle ($\cos\theta_{NR}$)



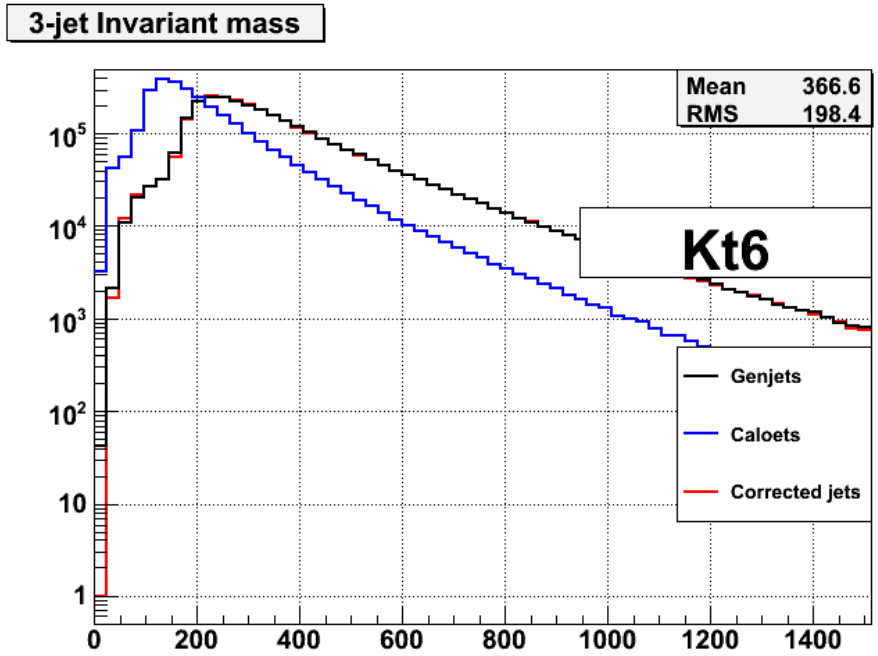



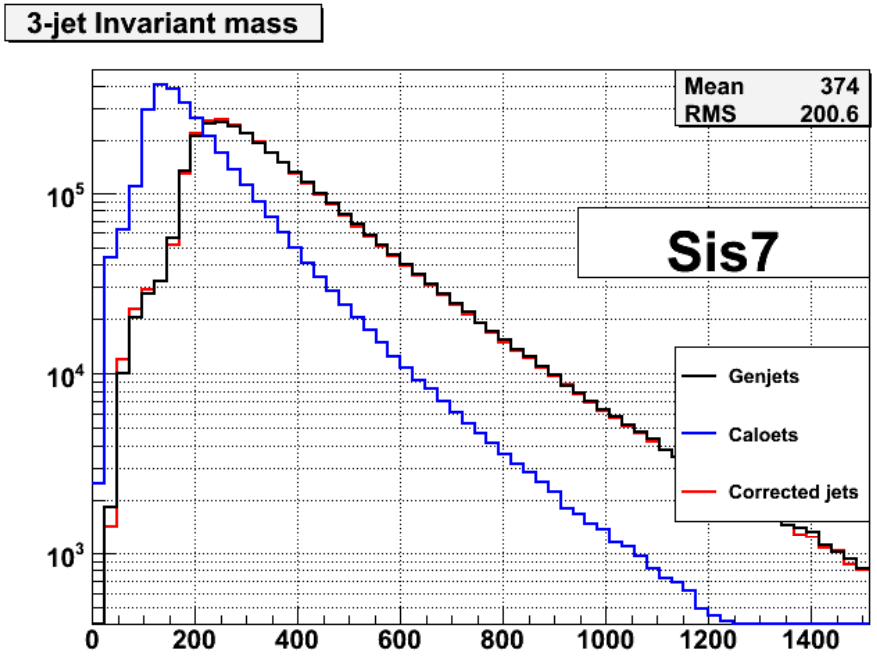



# CSA08 MC sample Analysis

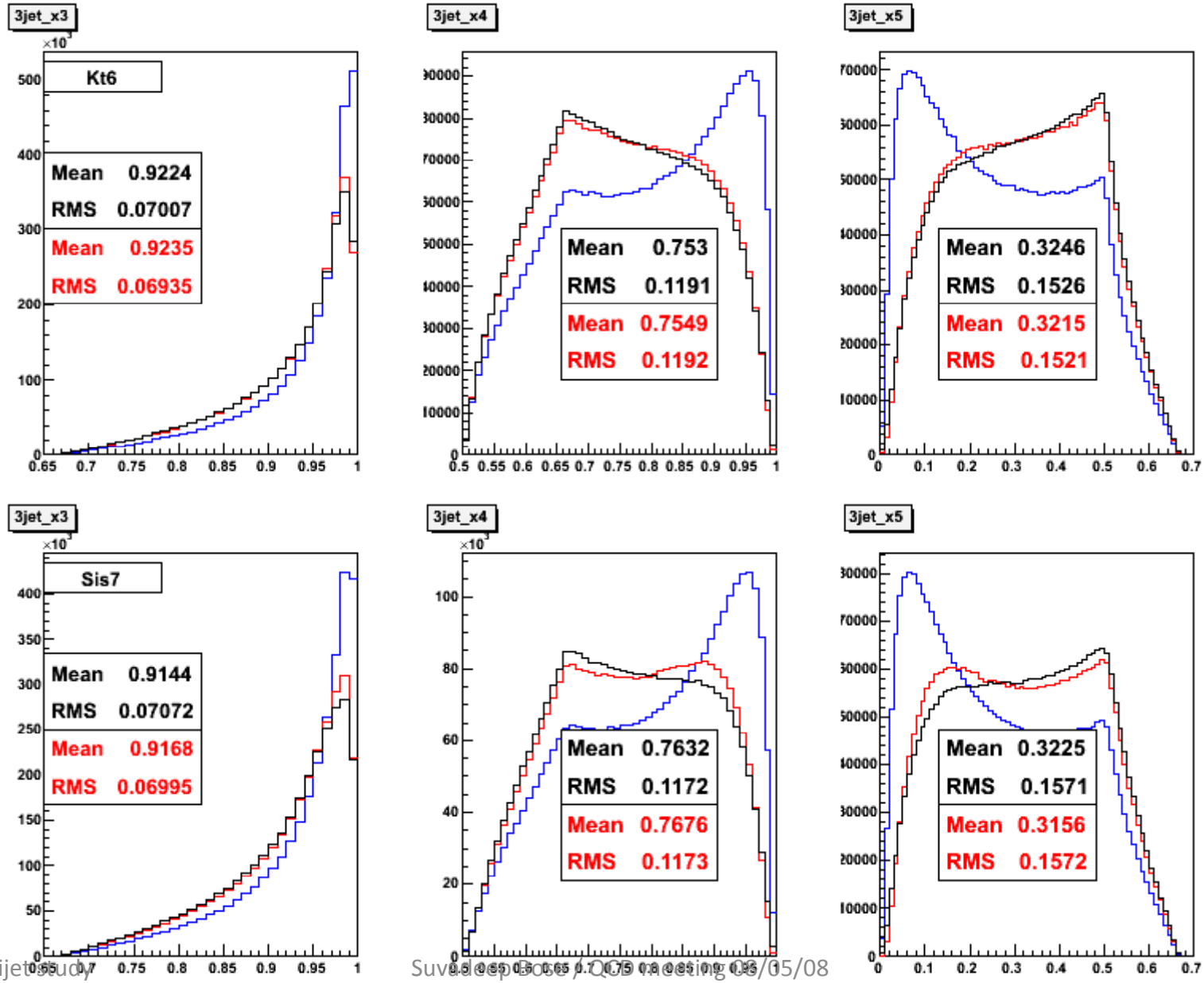
## Comparison between Genjet and Corrected jets

# 3-jet Invariant masses

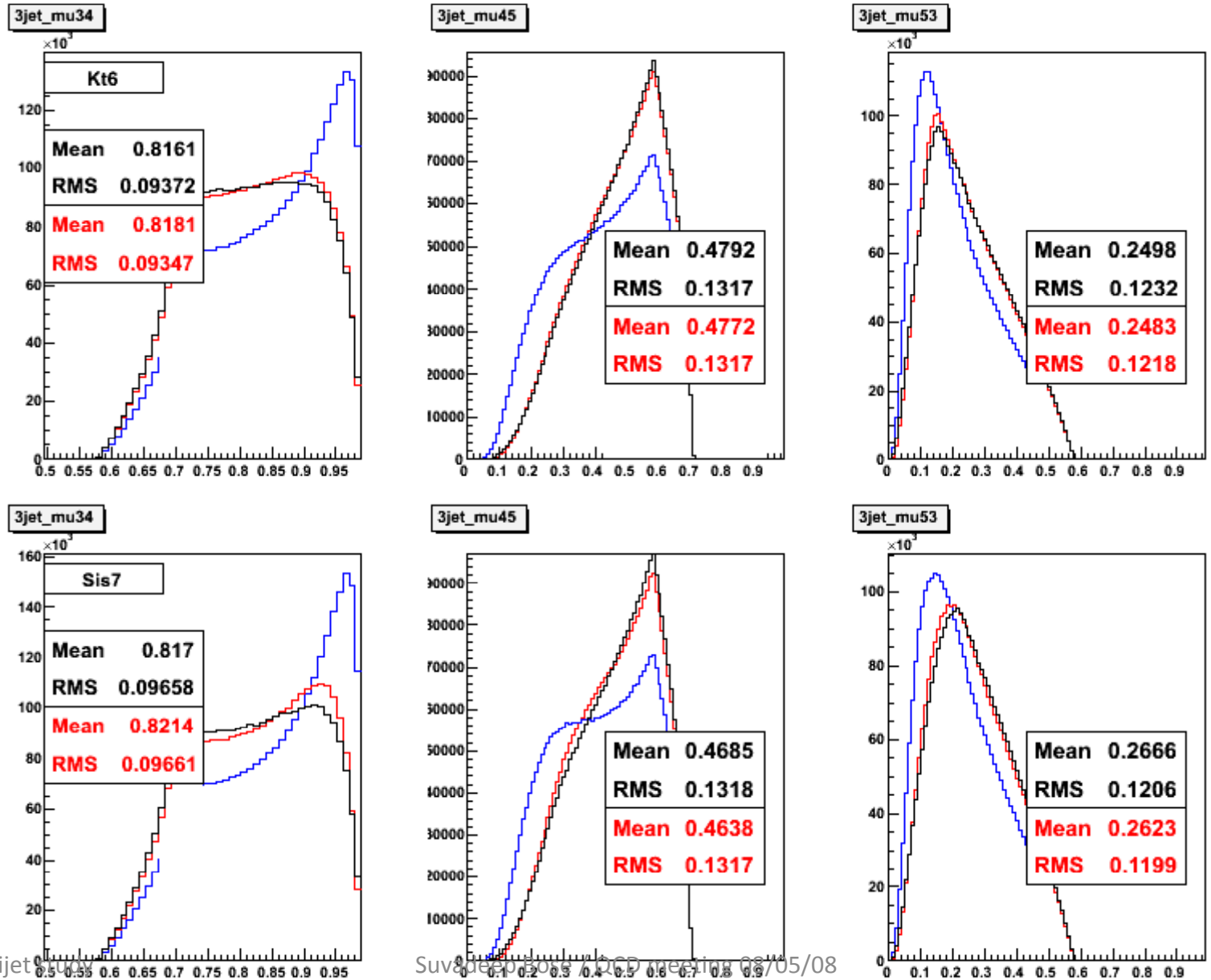


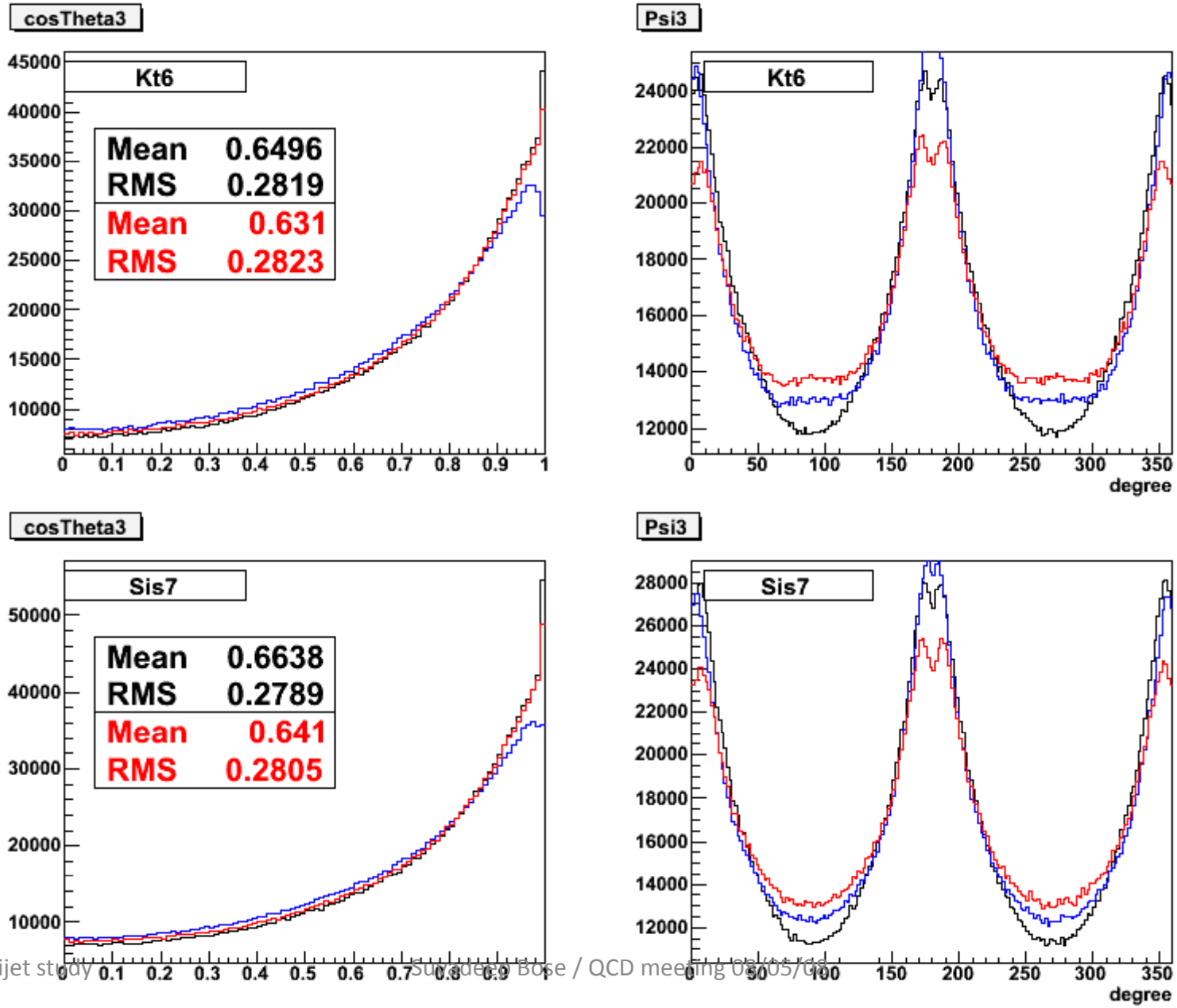
# Scaled energies of 3-parton



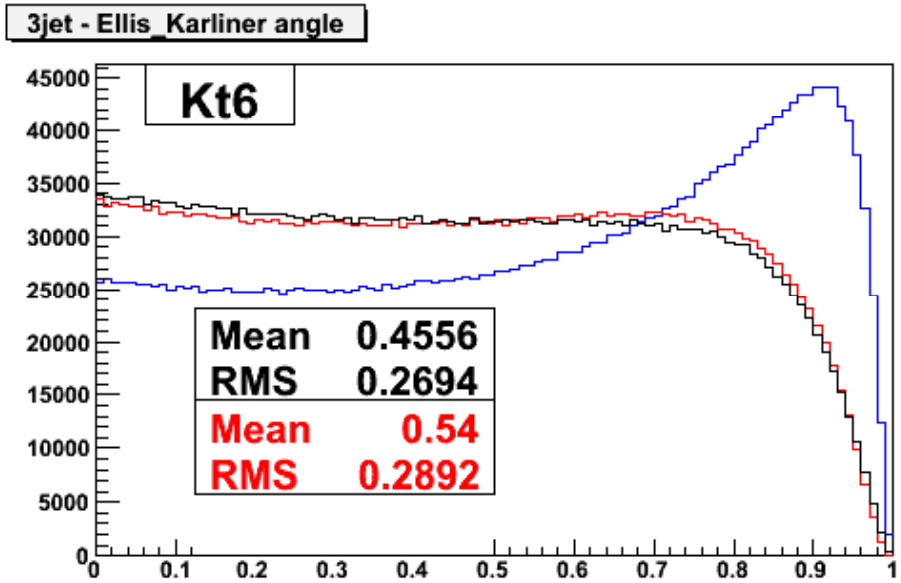
# Invariant masses for jet pairs – 3-parton case

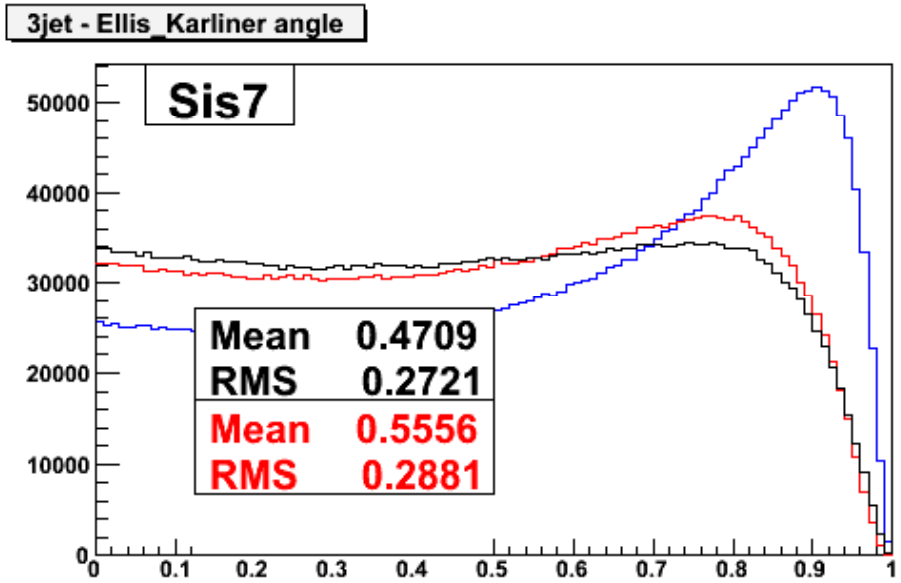


# Cosine of polar angle & the Psi angle – 3-parton case

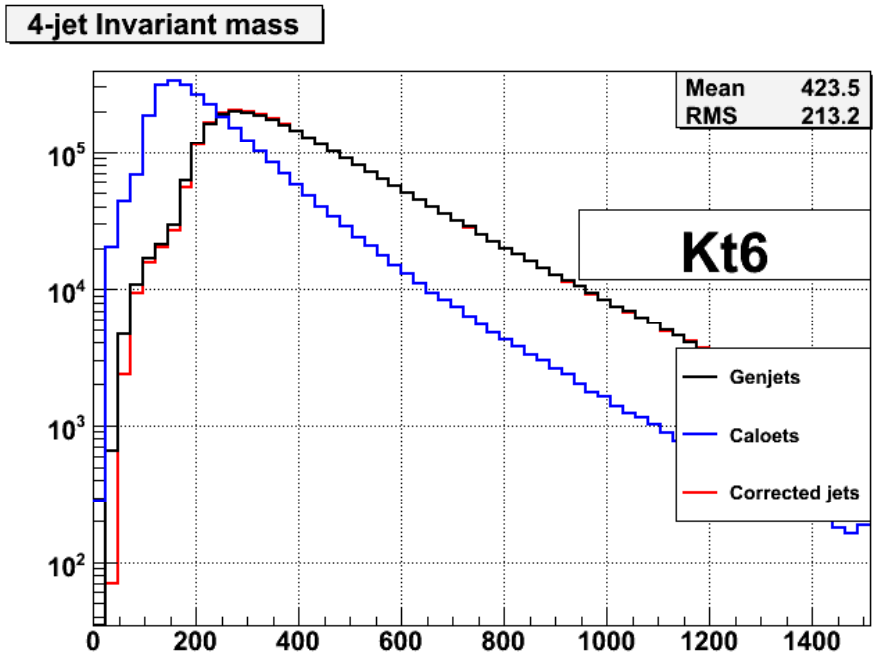


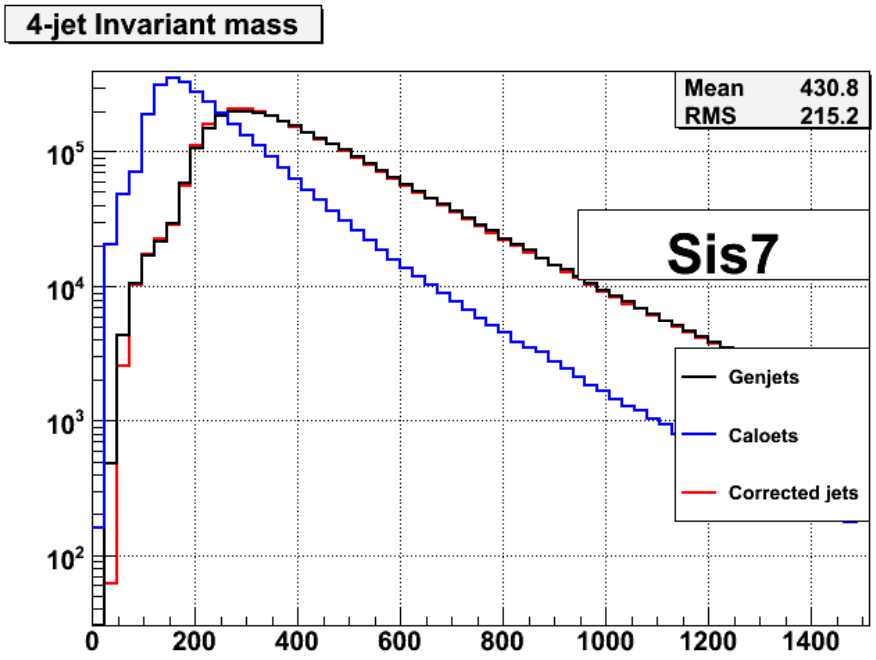
# Ellis-Karliner angle for a 3-parton case



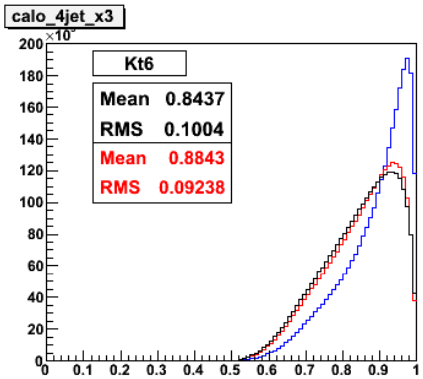



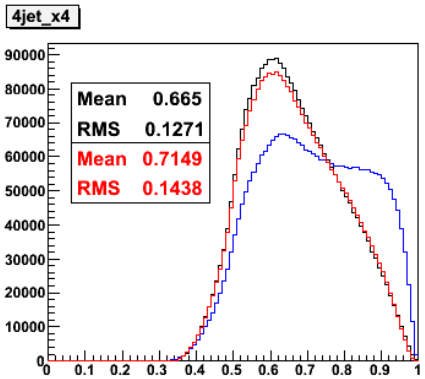
# 4-jet Invariant masses

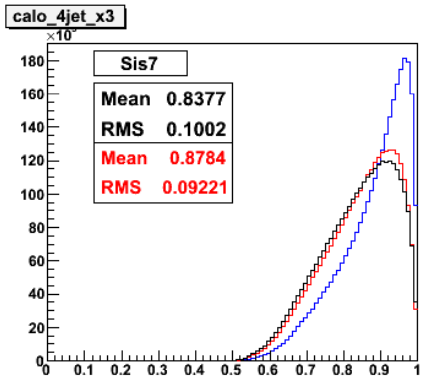


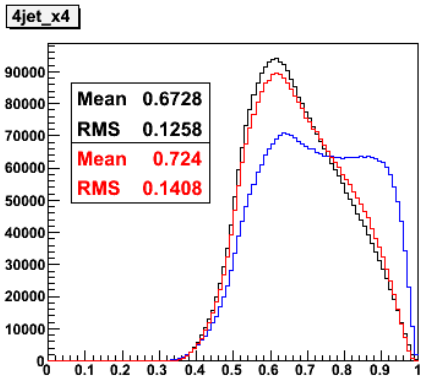



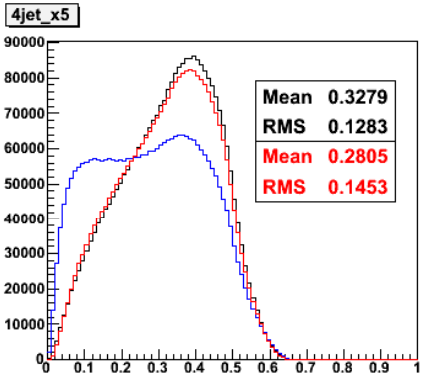
# Scaled energies of 4-parton : x3, x4, x5, x6

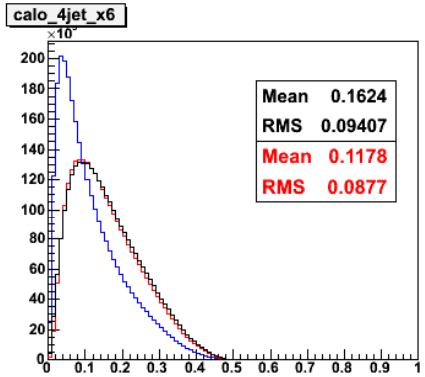


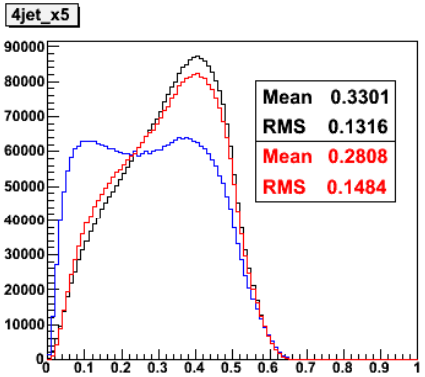



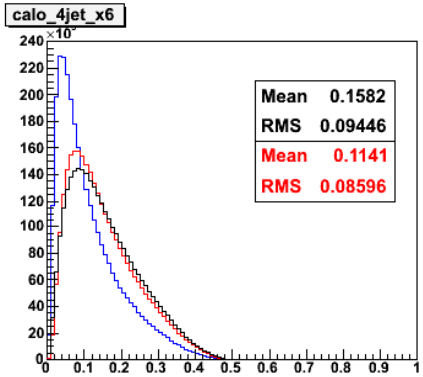



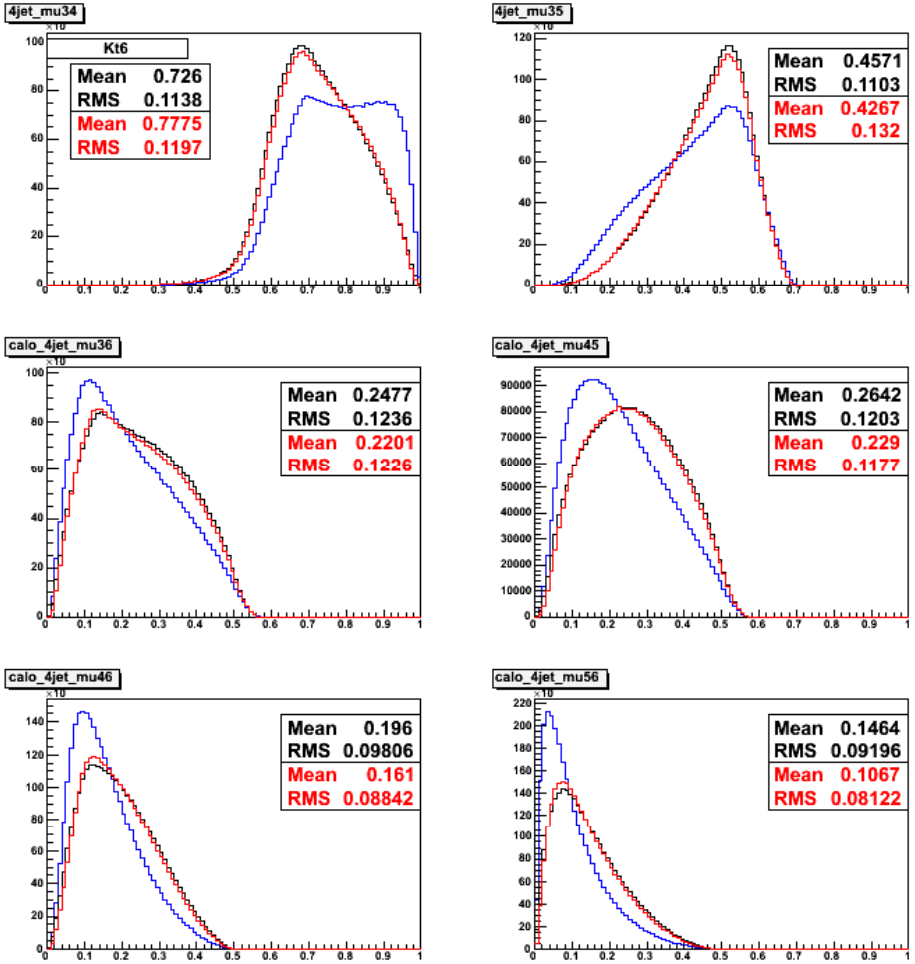



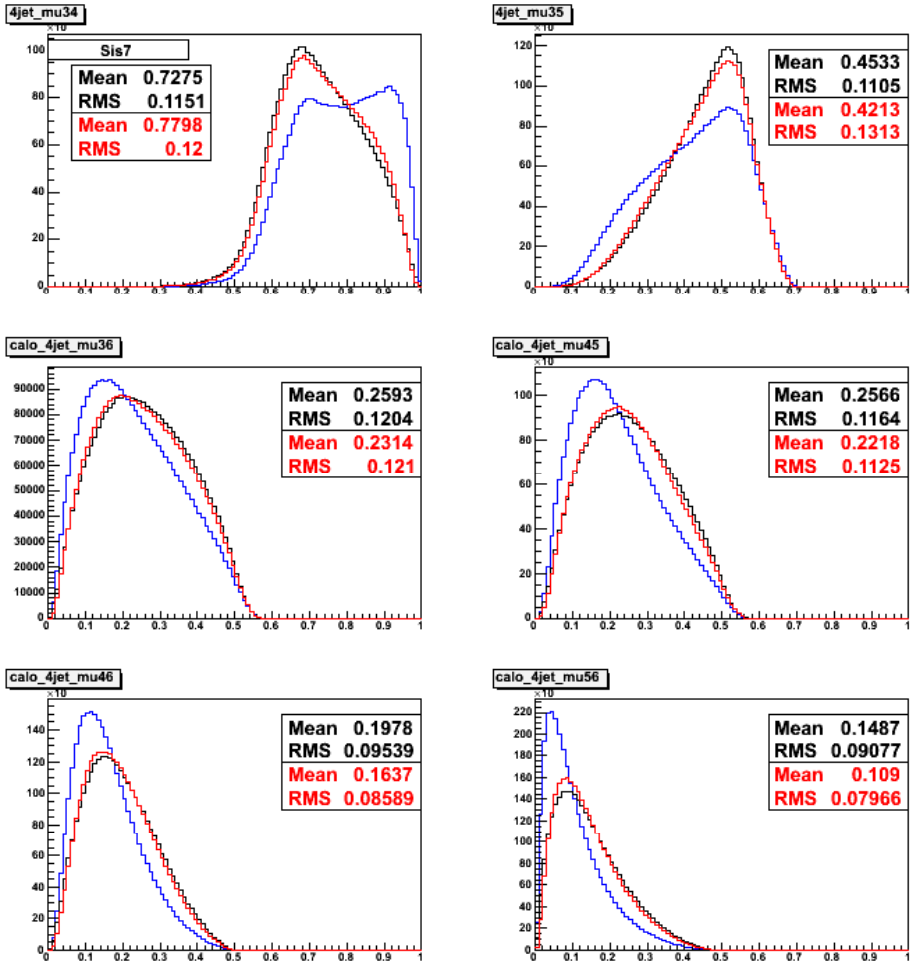



# Invariant masses of jet pairs – 4-parton case

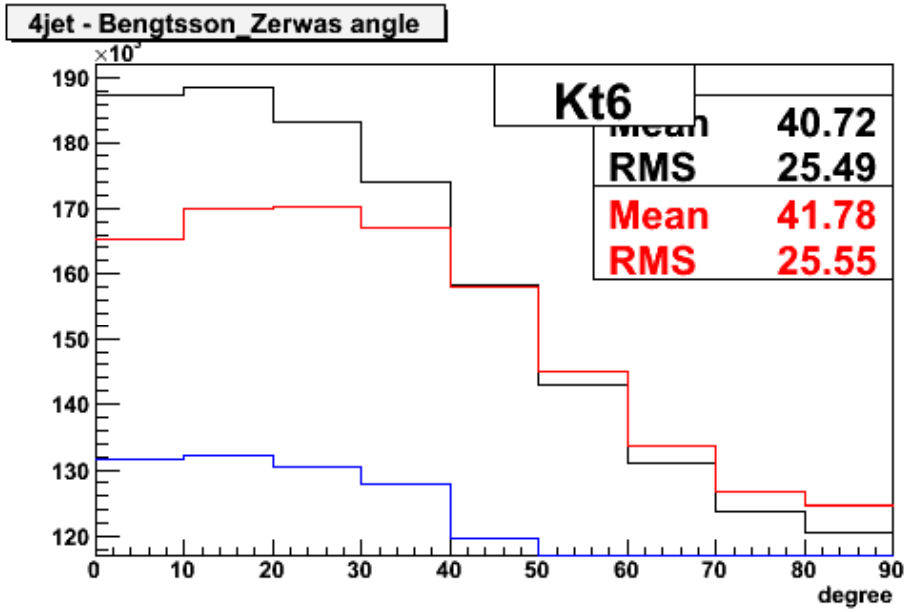


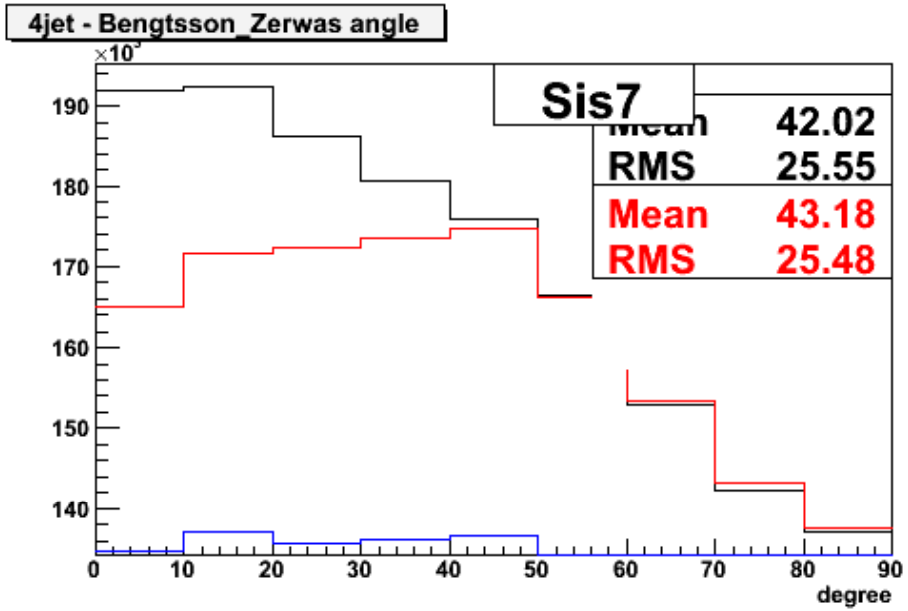

kt6



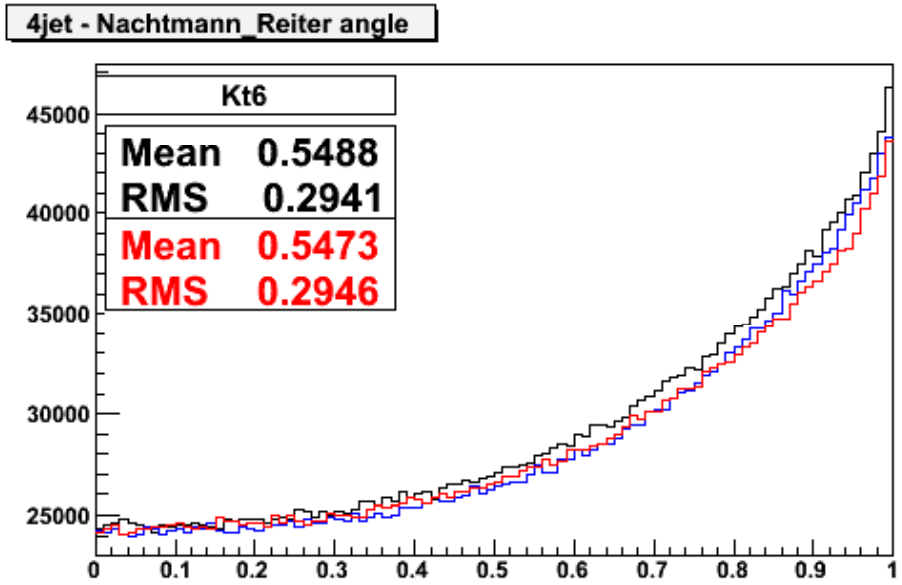

SisCone7

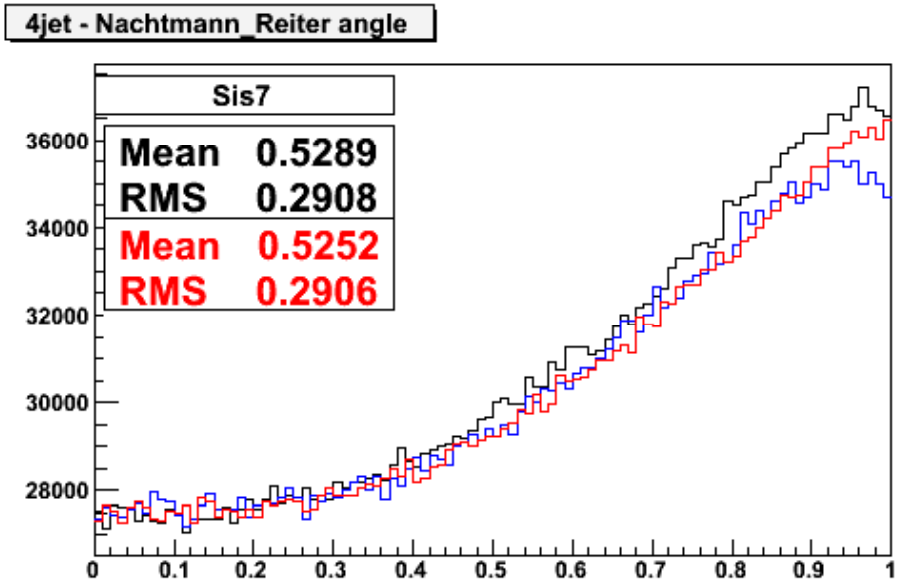
# The Bengtsson_Zerwas angle for 4-parton case



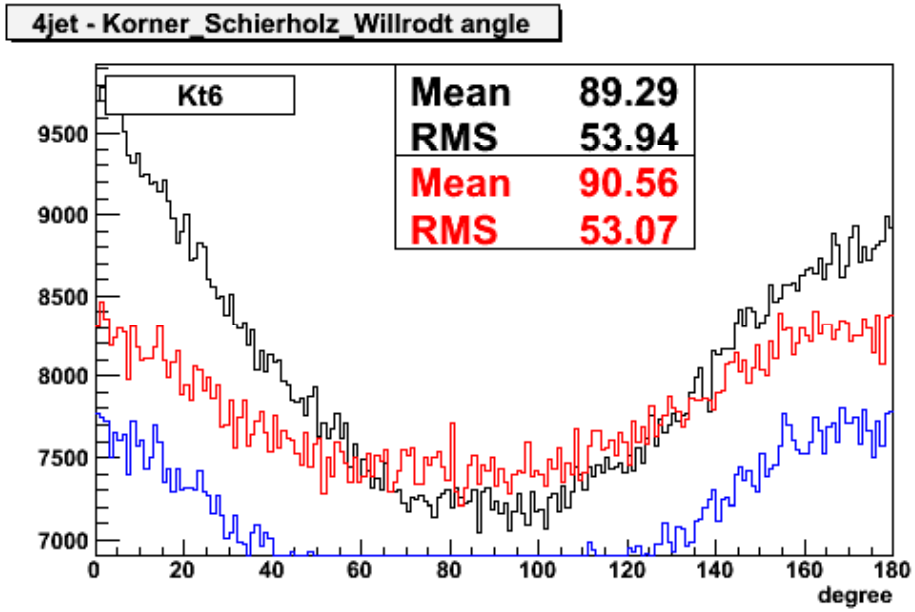



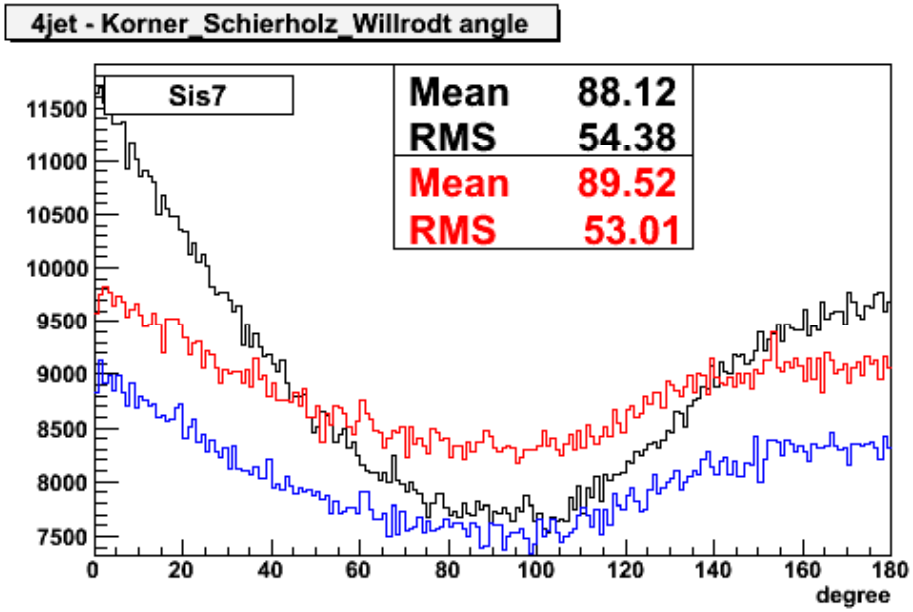
# The Nachtmann-Reiter angle for 4-parton case



# The Korner-Schierholz-Willrodt angle for 4-parton



# Summary

1. In case of *three jet events* – the topological variables such as the energy fractions carried by the two leading jets, cosine of the leading jet polar angle, the angle between the plane containing the leading jet and the beam line, the plane containing the two non leading jets, and the scaled invariant masses of the jet pairs, are studied.
2. In case *four jet events* – the energy fractions, and the cosine of the polar angles of all four jets, the six opening angles, scaled invariant masses of jet pairs, and the angles between jet planes, are studied.
3. At Generator level Pythia and Herwig samples were compared. We looked at 3 jet algorithms (IC5, Kt6, Sis7) and they are roughly similar. There is no strong dependence on jet algorithm).
4. There is difference in Pythia/Herwig for soft jets. For hard jets and 3/4 jet variables the difference is little.
5. In CSA08 one specific trigger sample (JetEt50) two jet algorithms (kt6 and SisCone7) are compared. There is a difference between GenJets and uncorrected CaloJets, but after L2L3 correction the differences are significantly reduced.

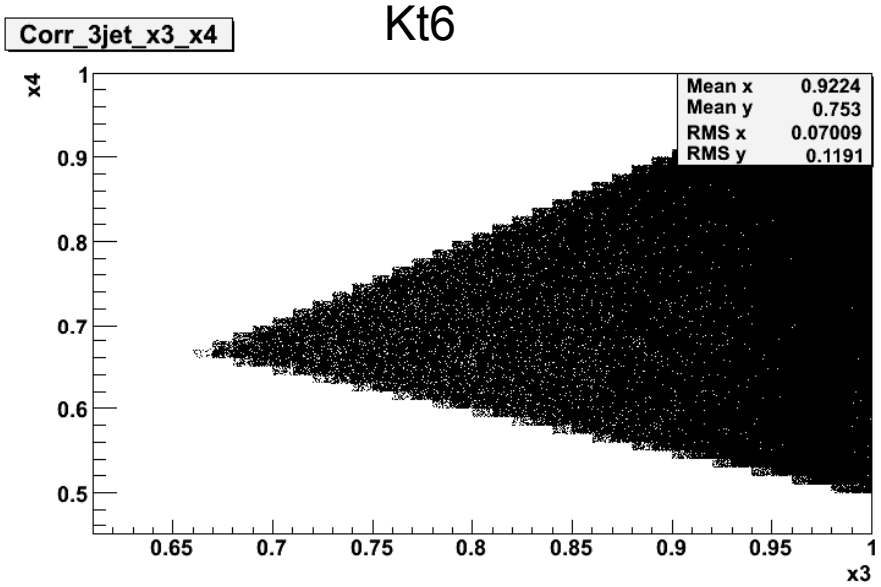
# Future plans

1. To study the effect of jet trigger and cuts on leading jet Et on the multijet angular distributions.
2. To try different trigger sample from CSA08 for similar multijet studies.
3. To try varying acceptance cuts on jets and ET thresholds of non-leading jets. Other cuts like isolation of jets are also to be studied.
4. To try different QCD models (like Phase Space, switch off triple gluon vertex, change gluon spin, alternate to inside generator).
5. To study the effect of hadronization (like Herwig vs Pythia) or different set of hadronization parameters.
6. To understand the behaviour of various angular distributions better.

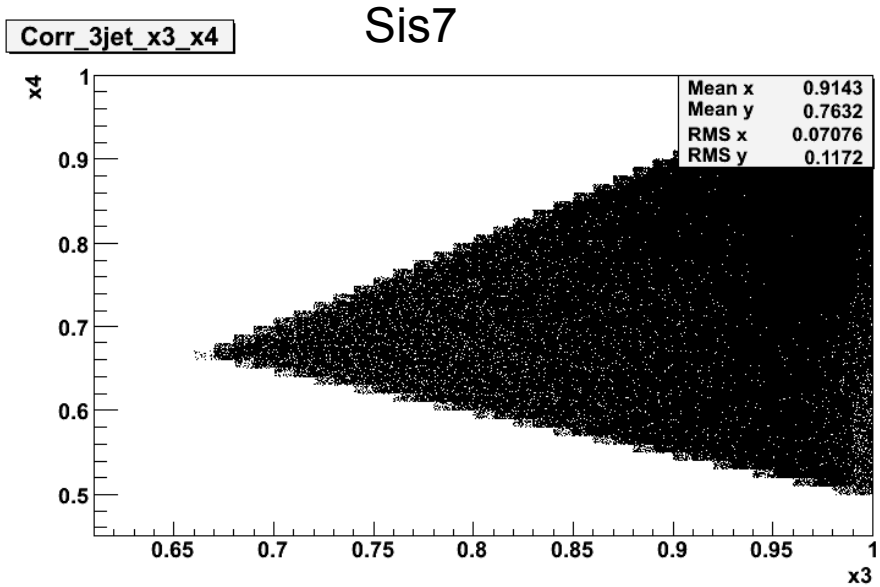
# Back up slides

# Dalitz plots for Scaled energies of 3-parton : x3 vs. x4

Kt6

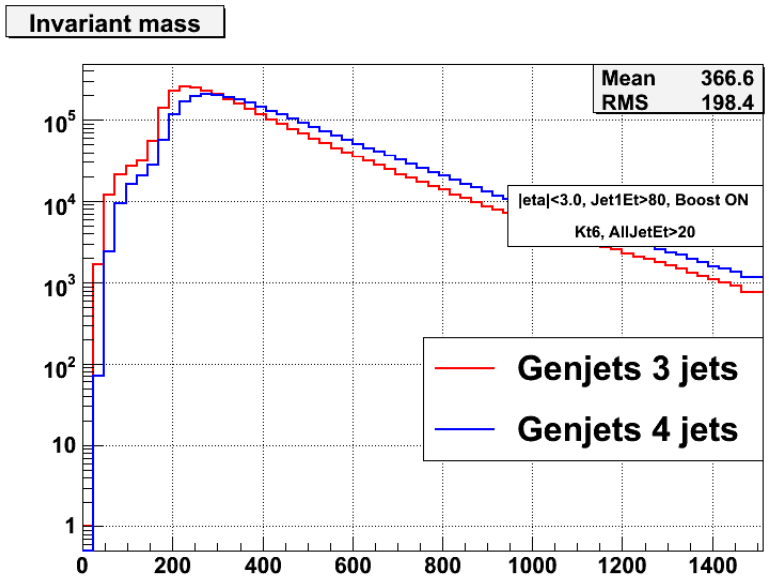



Sis7

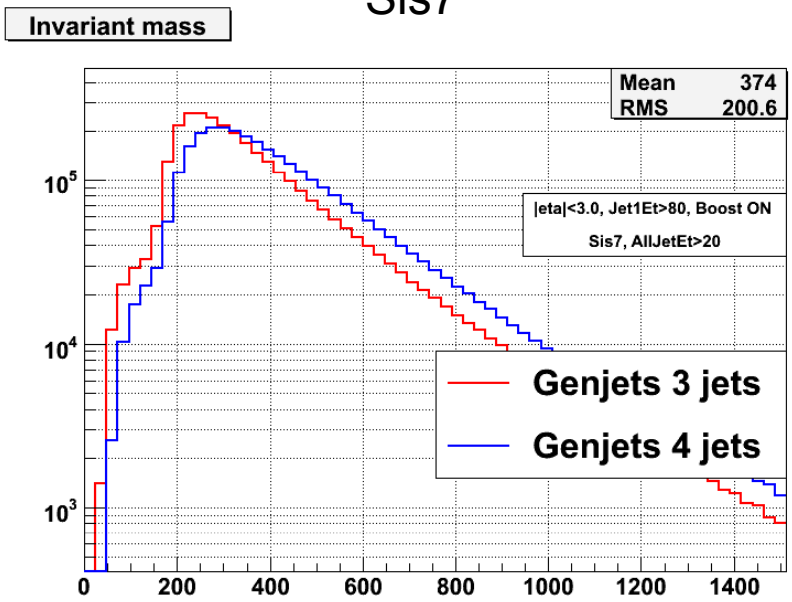


# Invariant masses

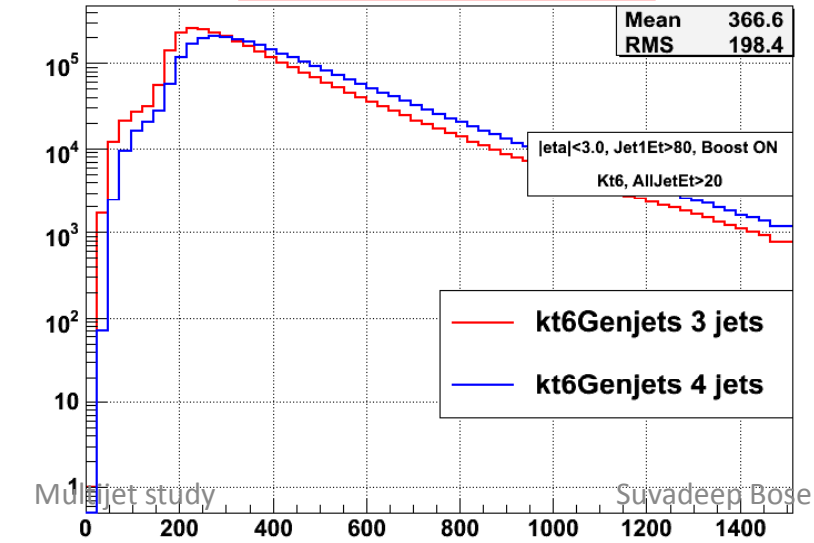
Kt6

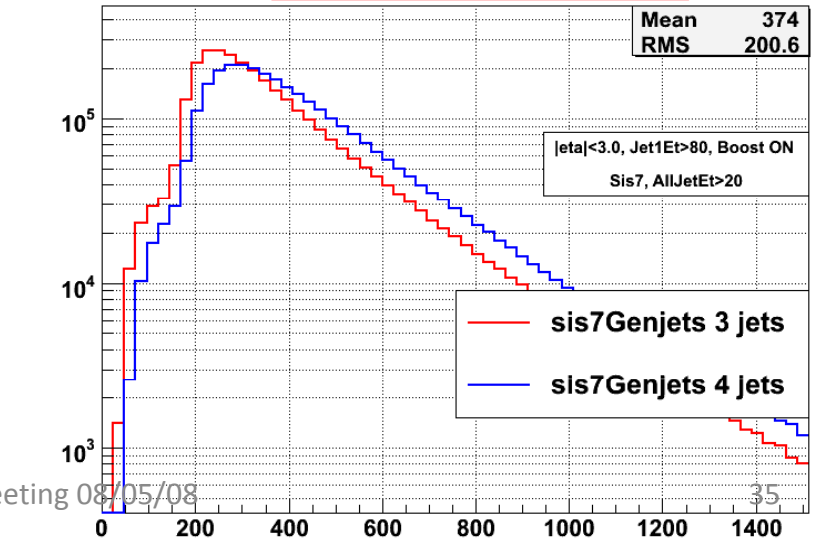



Sis7




With AllJetEt>20

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