MC comparison of inclusive 3-jet and 4-jet event at 7 TeV in pp collisions at the LHC

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Abstract

A Monte Carlo comparison of inclusive 3-jet and 4-jet event at 7 TeV in pp collisions at the LHC have been done between PYTHIA8_4C and the article Eur. Phys. J. C 75 (2015) 302. Also we have included a calculation with Final State Radiation off (FSR= off) in order to study the influence or FSR.

Contents

1 Introduction

In proton-proton collisions, interactions take place between the partons of the colliding protons. For hard scattering processes, the scattered partons hadronize into highly collimated bunches of particles measured as high transverse momentum (p_T) jets. Events with more than two jets in the final state include contribution from high order Quantum Chromo Dynamics (QCD). The topology of the multijet events and kinematics of the outgoing partons are studied to test higher order QCD and to get a deeper insight to the underlying physics. Since the patron scattering is practically an elementary QCD process, the jet distributions can be calculated from the first principles, provided that reasonable hadronization modeling is available. Therefore, the high p_T jets serve as a direct test of perturbative QCD (pQCD). Multijet variables are sensitive to the treatment of higher order processes and approximations used in their treatment. Thus a good agreement between the measurements and Monte Carlo prediction will establish the validity of the treatment of higher order effects and any large deviation thereof will lead to large systematic uncertainties on searches of new physics. In this note, a study of the multijet observables is presented which is based on hadronic events from 7 TeV pp collision data with the CMS detector. The kinematic and angular properties of these variables are computed from the four-vectors of the jets. Topological and kinematical variables are measured for 3-jet and 4-jet events .Has been compared Phythia8_4C with results obtained from the article Study of Inclusive Three- and Four-jet Events in pp Collision at 7 TeV [1]. A comparison with Final State Radiation off (FSR=off) has also been included.

2 Analysis

In this work the Anti-k_T algorithm [2] has been used for jet reconstruction with jet resolution parameter R=0.5. The leading jet p_T is supposed to lie in range 190-300 GeV or more than 500 GeV decided according to the data used. Non-leading jets are required to have p_T greater than 50 GeV. All the jets are required to have absolute rapidity less than 2.5. Initially we have made the study with Initial and Final State Radiaton (ISR and FSR on) on, then in order to have an idea of the influence of FSR we have put it off. For this analysis a new rivet routine CMS_2015_I1345159 has been developed.

3 Variables Under Study

3.1 Three-Jet Variables

The topological variables used in this work are defined in the centre of mass system (CM). The topological properties of the three-parton final state in the centre of mass system of the 3 partons can be described with the scaled energies and the invariant mass of the system.

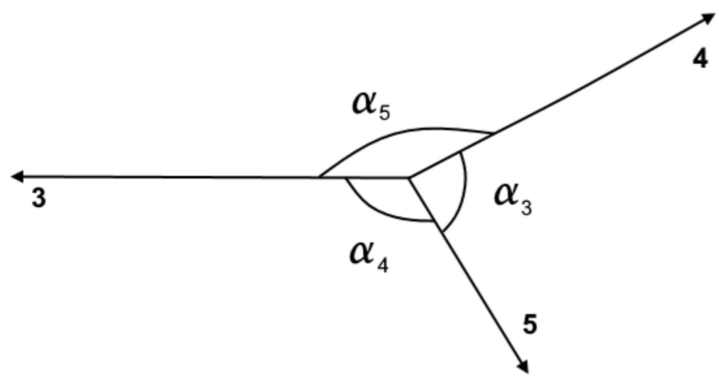


Figure 1: *Illustrations shows three-jet configuration where the scaled energies can be determined from the angles among the jets.*

It is convenient to use the notation 1+2→ 3+4+5 for the three parton process, here 1 and 2 refers to incoming partons while 3, 4, and 5 label the outgoing partons, ordered in descending energies in the centre of mass frame $E_3 > E_4 > E_5$. The invariant mass of the system is simply invariant mass of the three jet system (**Fig. 1**).

The Scaled Energies $(x_3\ , x_4)$ of the jets are ordered with respect to energies in the centre of mass frame.

$$x_i = \frac{2E_i}{\sqrt{s}}, x_3 + x_4 + x_5 = 2$$

$$x_i = \frac{\sin \alpha_i}{\sum \sin \alpha_i}$$

Here $\sqrt{s}$ is the centre of mass energy of the hard scattering process. For definition, the sum over all scaled energies is 2 as is shown in the equations, this can be also measured with the angles between the jets (α_i).

3.1 Four-Jet Variables

The four partons are ordered in descending energy in the centre of mass frame from 3 to 6 similar to in three jet system. In this case we only measure the invariant mas of the system and two new angles defined for this four-jet system.

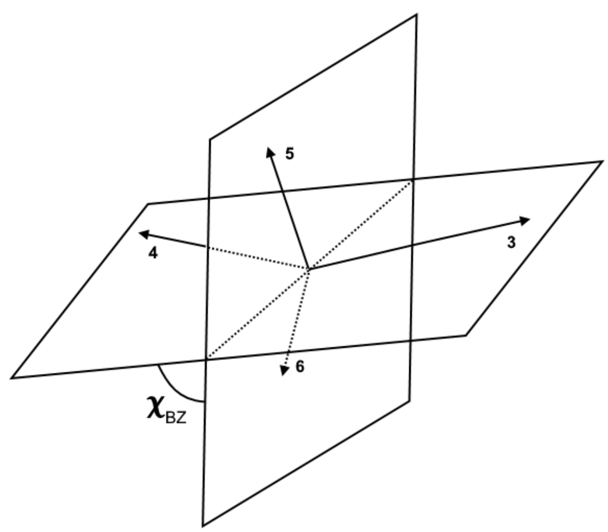


Figure 2: *Bengtsson-Zerwas angle (χ_{BZ}) definition for the four jet event.*

- **Bengtsson-Zerwas Angle**: Angle between the planes containing the two leading jets and the two non-leading jets (**Fig. 2**).

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

This angle can take values between 0 and π. In this work we have redefined the cosine of these angle using its absolute value. We are going to measure these angle in the range between 0 and $\frac{\pi}{2}$.

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

- **Nachtmann-Reiter Angle**: Angle between the momentum vector difference of the two leading jets and the two non-leading jets (**Fig. 3**).

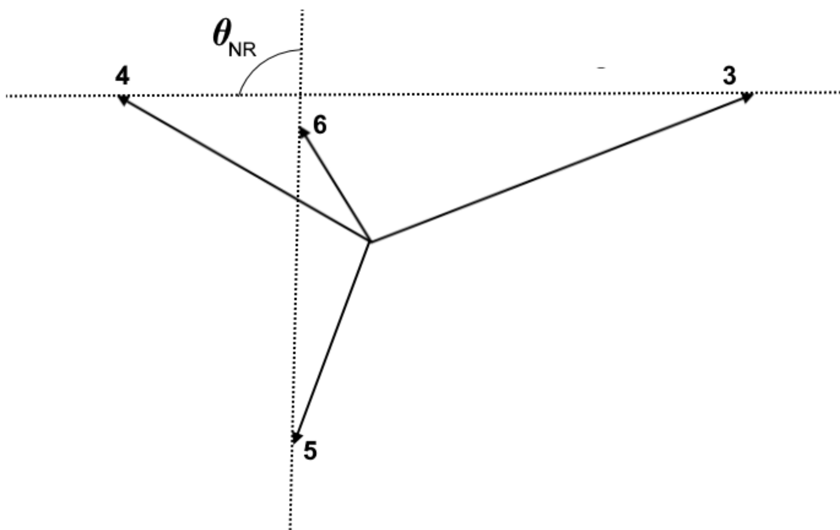


Figure 3: *Nachtmann-Reiter angle (θ_{NR}) definition for the four jet event.*

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

As in the definition for the Bengtsson-Zerwas angle we are going to redefine this angle:

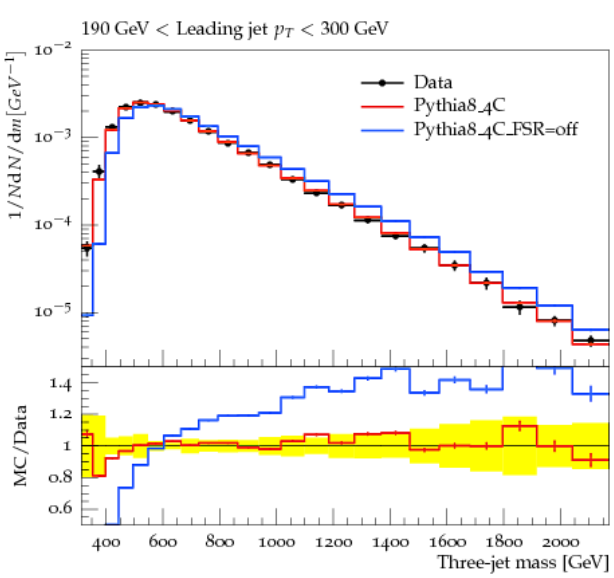
$$\cos\theta_{NR} = \frac{|(\vec{p}_3 - \vec{p}_4)\cdot(\vec{p}_5 - \vec{p}_6)|}{|\vec{p}_3 - \vec{p}_4||\vec{p}_5 - \vec{p}_6|}$$

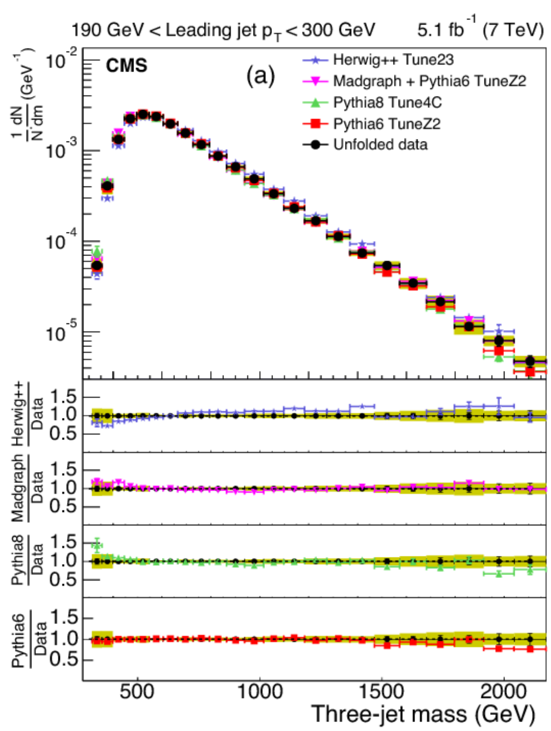
4 Results

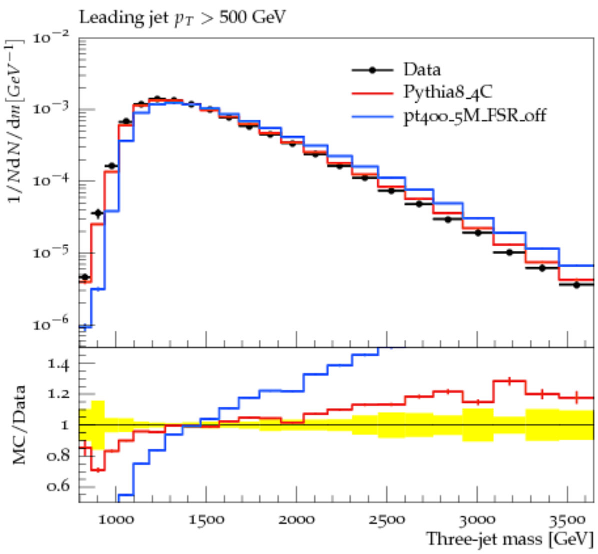
Predictions coming from Phythia8_4C (on the left) are compared with data and results obtained from the article Eur. Phys. J. C 75 (2015) 302 (on the right). Are also included predictions when Final State Radiation is off (FSR=off) in the following figures.

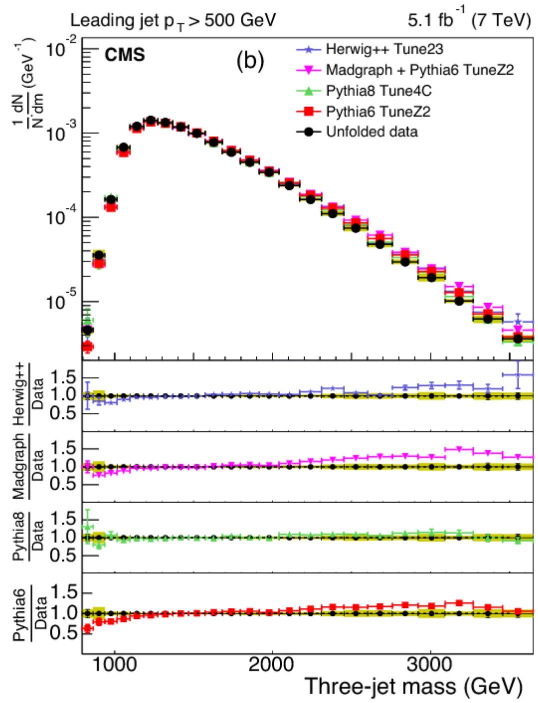
4.1 Three-Jet Results

- ❑ Three-Jet Mass

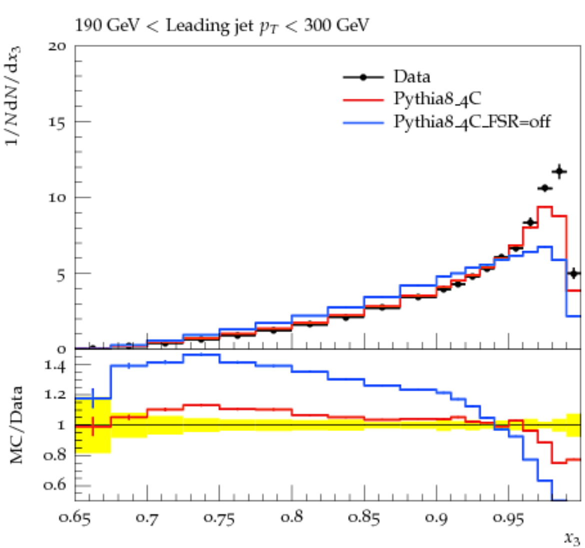


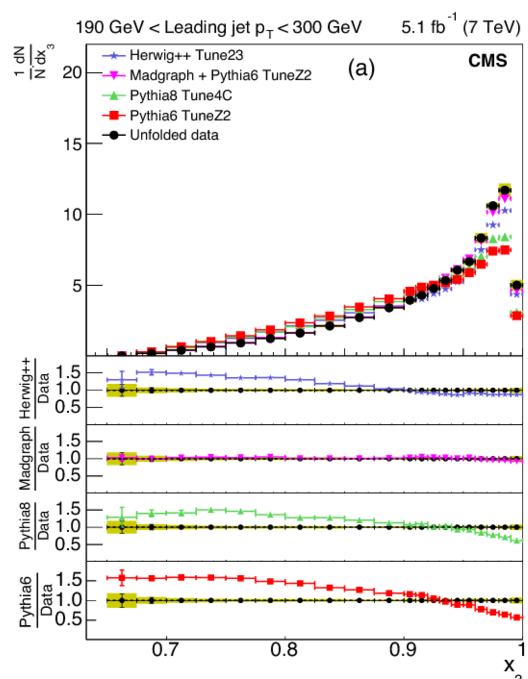


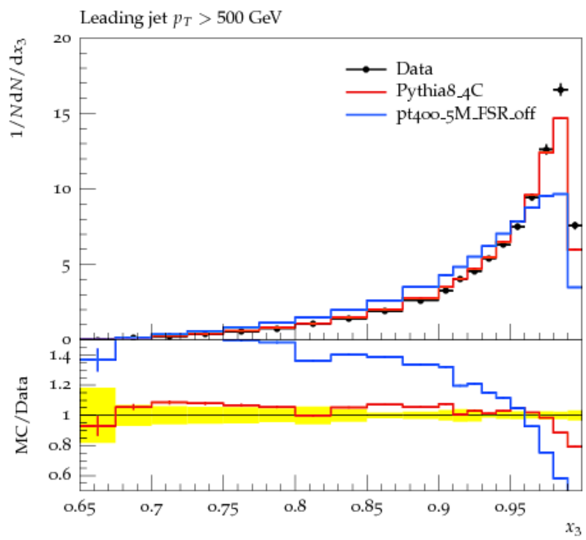

Leading jet $p_T > 500$ GeV
Data
Pythia8_4C
pt400_5M_FSR_off
$1/N dN/dm [GeV^{-1}]$
MC/Data
Three-jet mass [GeV]

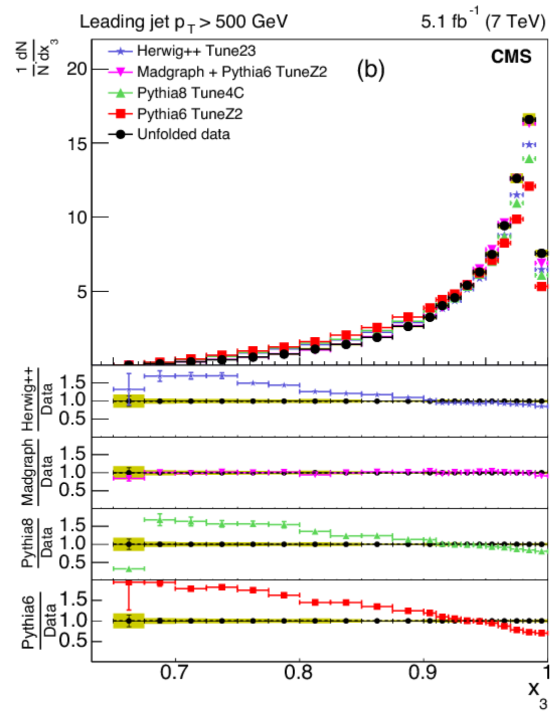

Leading jet $p_T > 500$ GeV
5.1 fb^{-1} (7 TeV)
CMS
(b)
Herwig++ Tune23
Madgraph + Pythia6 TuneZ2
Pythia8 Tune4C
Pythia6 TuneZ2
Unfolded data
$\frac{1}{N}\frac{dN}{dm}$ (GeV^{-1})
Herwig++ / Data
Madgraph / Data
Pythia8 / Data
Pythia6 / Data
Three-jet mass (GeV)

❑ X_3

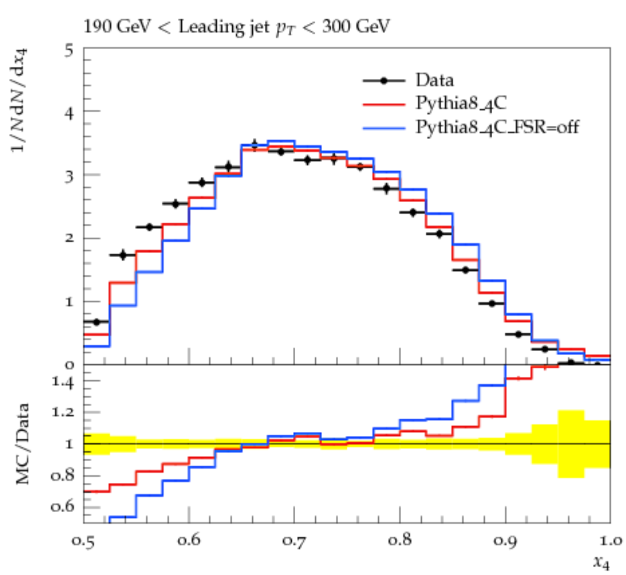

190 GeV < Leading jet p_T < 300 GeV
Data
Pythia8_4C
Pythia8_4C_FSR=off
$1/N dN/dx_3$
MC/Data
x_3

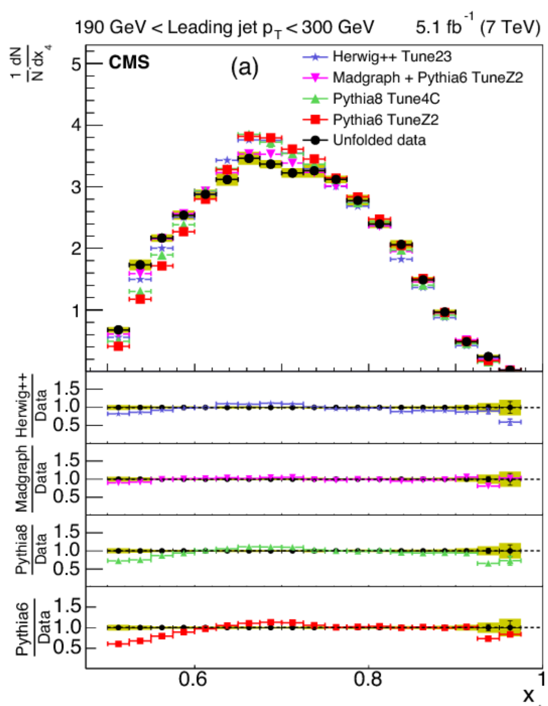

190 GeV < Leading jet p_T < 300 GeV
5.1 fb^{-1} (7 TeV)
CMS
(a)
Herwig++ Tune23
Madgraph + Pythia6 TuneZ2
Pythia8 Tune4C
Pythia6 TuneZ2
Unfolded data
$\frac{1}{N}\frac{dN}{dx_3}$
Herwig++ / Data
Madgraph / Data
Pythia8 / Data
Pythia6 / Data
x_3

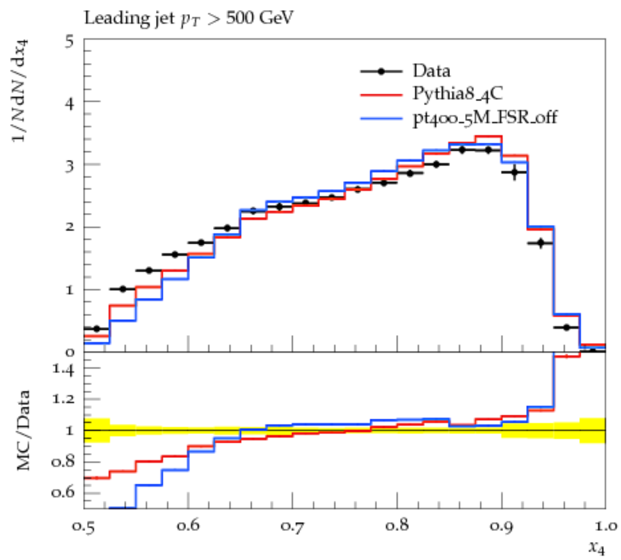

Leading jet p_T > 500 GeV
1/N dN/dx3
Data
Pythia8_4C
pt400_5M_FSR_off
MC/Data
x3

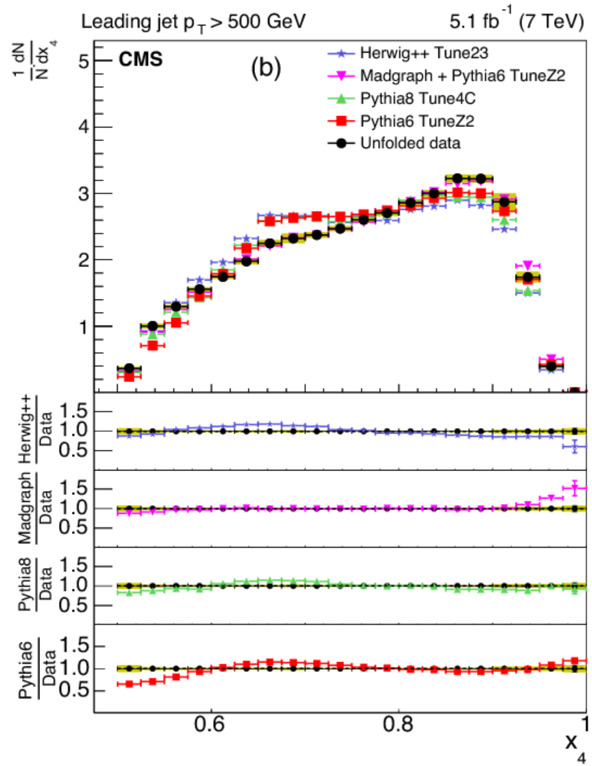

Leading jet p_T > 500 GeV
5.1 fb^-1 (7 TeV)
(b)
CMS
Herwig++ Tune23
Madgraph + Pythia6 TuneZ2
Pythia8 Tune4C
Pythia6 TuneZ2
Unfolded data
Herwig++/Data
Madgraph/Data
Pythia8/Data
Pythia6/Data
x3

❑ X_4


190 GeV < Leading jet p_T < 300 GeV
1/N dN/dx4
Data
Pythia8_4C
Pythia8_4C_FSR=off
MC/Data
x4

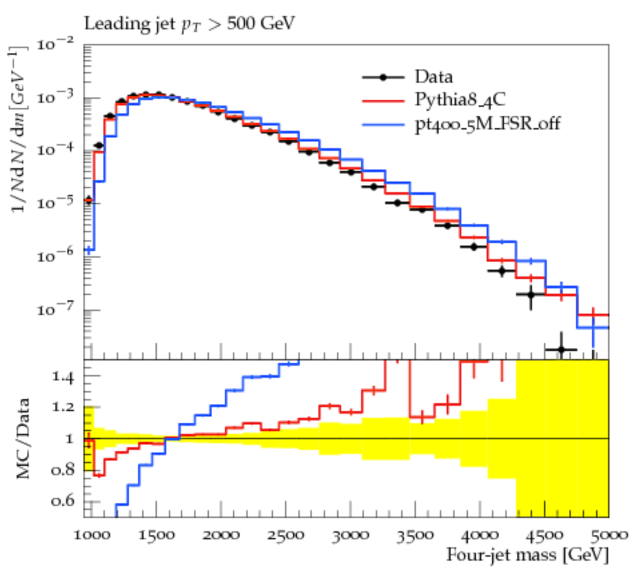

190 GeV < Leading jet p_T < 300 GeV
5.1 fb^-1 (7 TeV)
CMS
(a)
Herwig++ Tune23
Madgraph + Pythia6 TuneZ2
Pythia8 Tune4C
Pythia6 TuneZ2
Unfolded data
Herwig++/Data
Madgraph/Data
Pythia8/Data
Pythia6/Data
x4

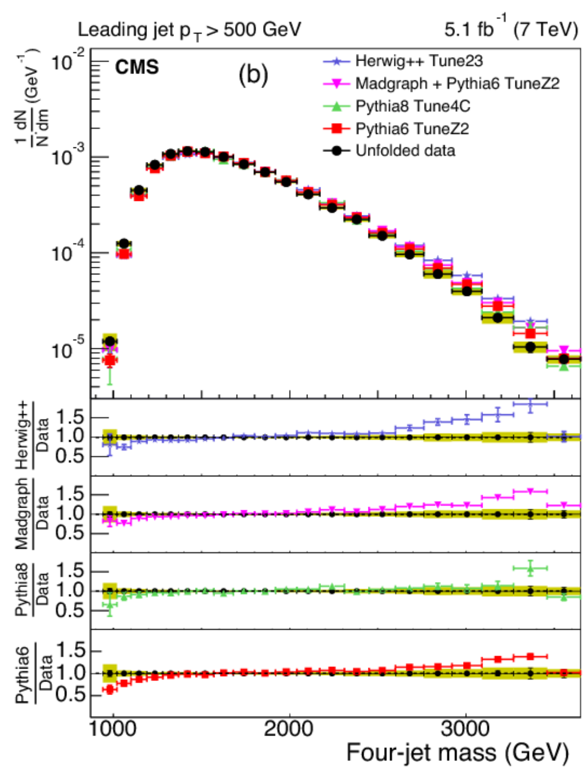


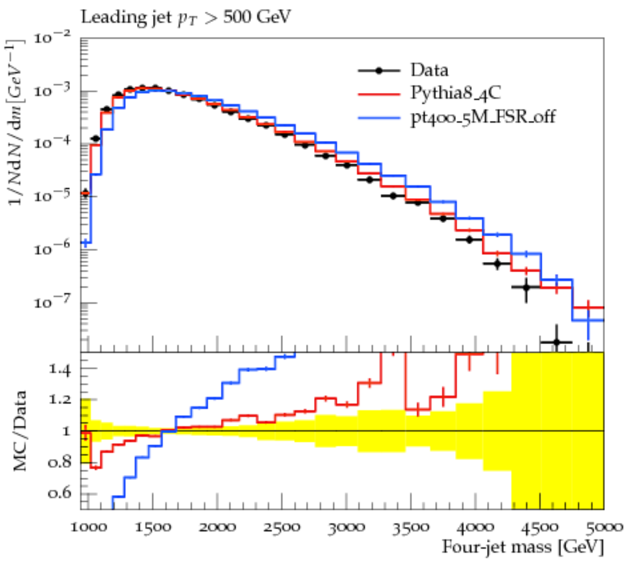


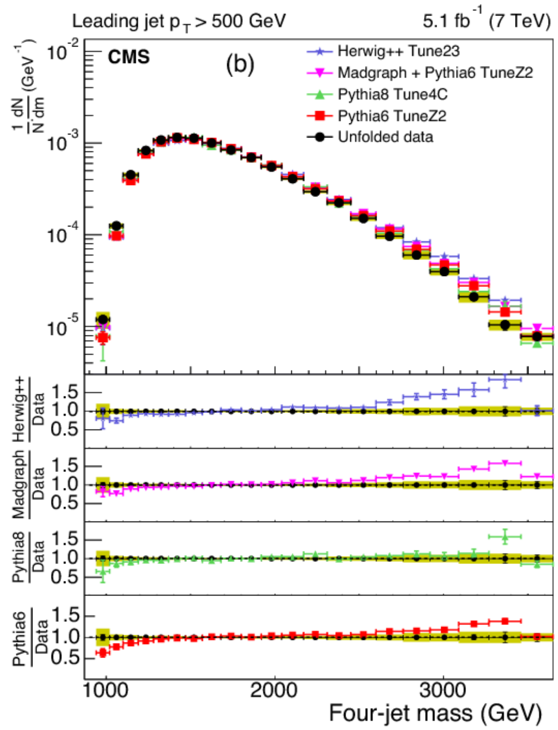
4.1 Four-Jet Results

- Four-Jet Mass

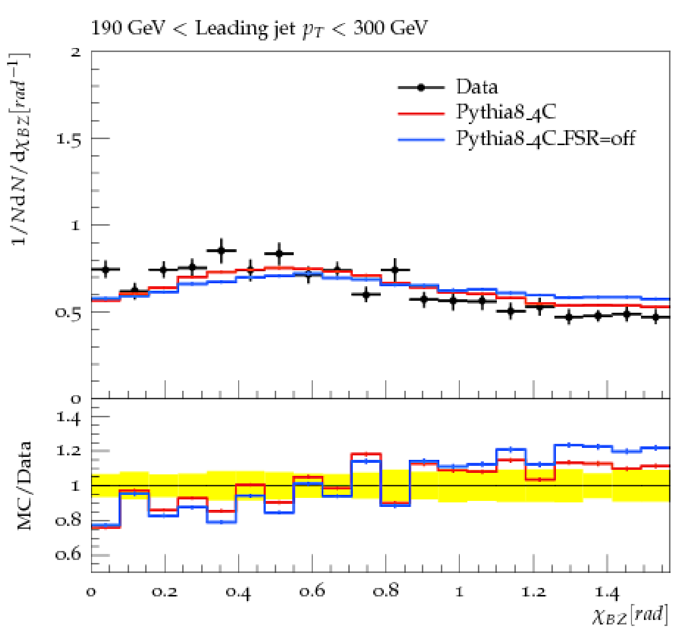


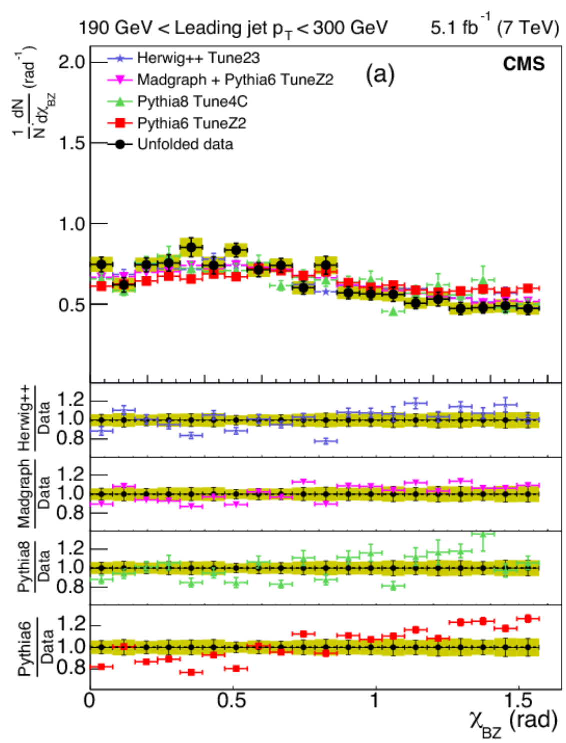


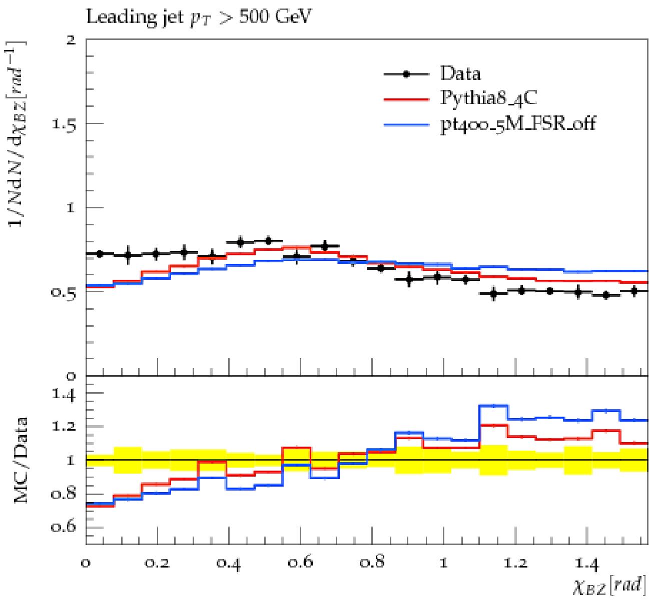


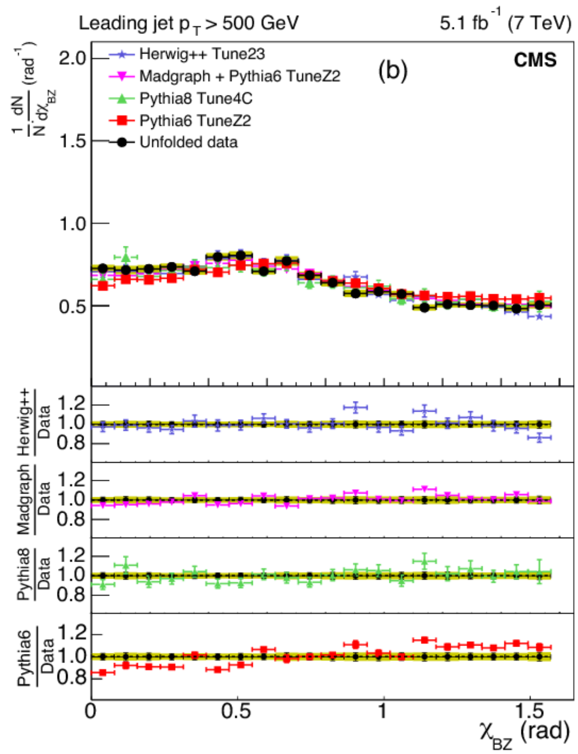


❑ Bengtsson-Zerwas Angle

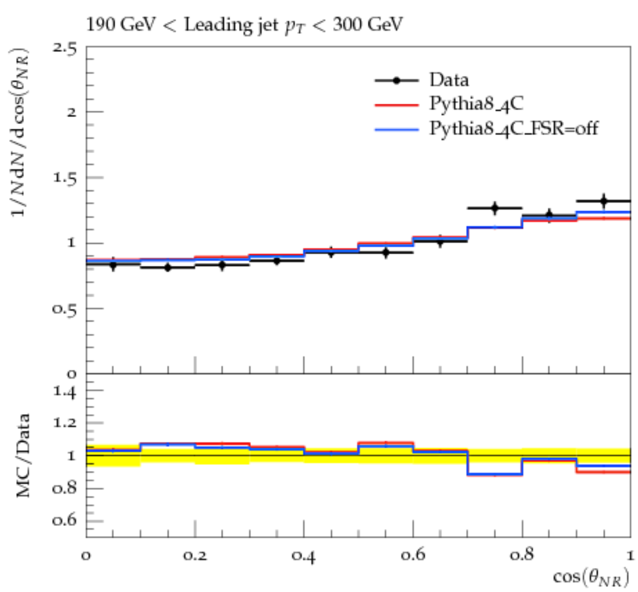


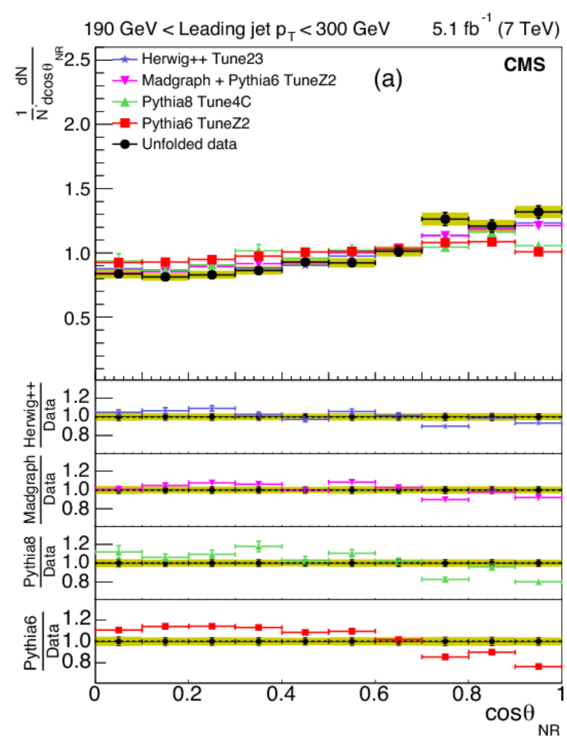


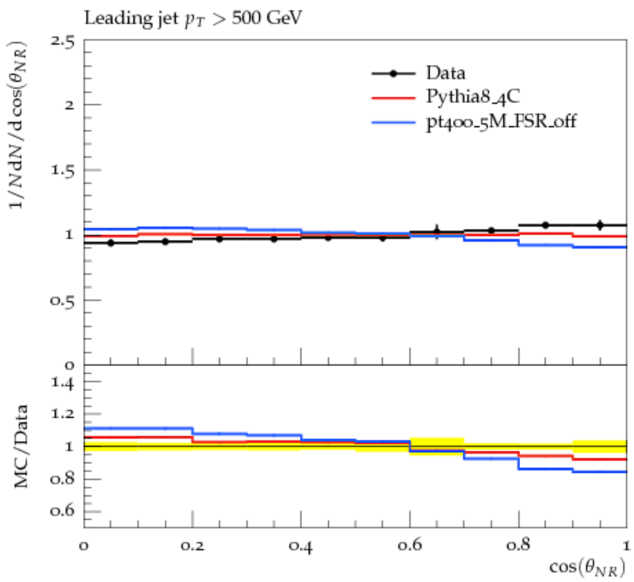


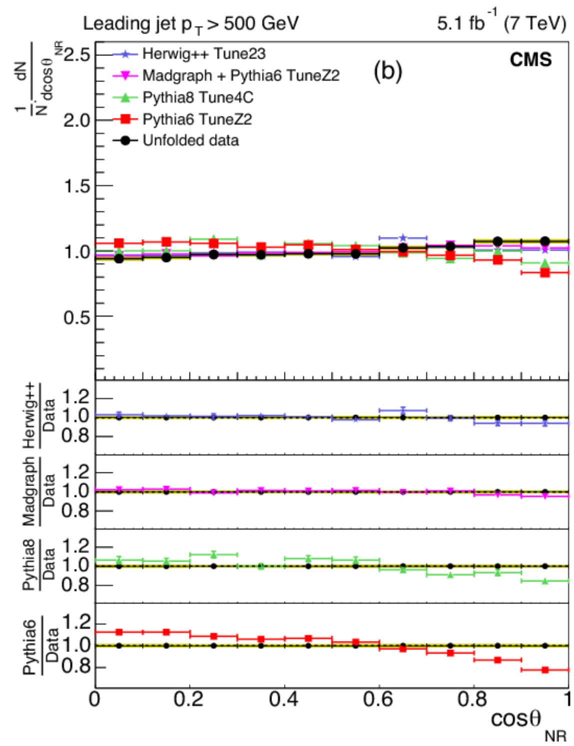


❑ Natchman-Reiter Angle









5 Conclusions

Summarizing, in this study, we have carried out a comparison between PYTHIA 8_4C predictions and the results obtained in the cited paper [1]. A new rivet routine CMS_2015_I1345159 has been developed redefining the two angles studies in order to be in agreement with [1]. We have investigated the influence of FSR in all the variables.

5 Acknowledgements

I would like to thank the QCD DESY-CMS group, especially to Hannes Jung for all his support during this period and also to Armando Bermudez for being an excellent supervisor. I would like to thank also to the organizers of the program that gave me a great opportunity to learn and work at DESY. Finally, I also thank to my professors in Higher Institute of Technology and Applied Sciences (InSTEC) for my previous education as a scientist.

References

[1] CMS Collaboration. *Study of Inclusive Three- and Four-jet Events in pp Collision at 7 TeV, Eur. Phys. J. C 75 (2015) 302*.

[2] Matteo Cacciari, Gavin P. Salam, Gregory Soyez . *The anti-kt jet clustering algorithm, arXiv:0802.1189v2 (2008) 12.*