Studies on hadronic top decays

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Abstract

Top events in the boosted regime are studied using Pythia as Monte Carlo event generator. The topology of those events is analyzed using the ANTI-KT algorithm for jets clustering and the Soft Drop Mass mechanism for the subsequent splitting of the fat jet into subjets. Several hadron definitions are studied and their impact on parton-hadronic level resolution ($\Delta\Phi$ resolution between the top quark and the top jet candidate). The soft QCD effects (initial and final state radiation) are studied in top events, responsible for the increase (decrease) of the clustered fat jet mass.

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1 Introduction

The large number of top-antitop quark pairs produced at the LHC provides a unique opportunity to improve our understanding of $t\bar{t}$ production and to test the Standard Model at the TeV scale. The top quark is the heaviest of all known elementary particles, with a mass close to that of an atom of gold.
The top quark decays through weak interaction producing a W-boson and a down type quark. The most likely case is the decay to a bottom quark with a branching ratio of 0.91 ± 0.04. Besides the W-boson can decay into a charged lepton (e, μ, τ) and the corresponding neutrino $(\nu_e, \nu_\mu, \nu_\tau)$ with a branching ratio of 10.80 ± 0.09 for each, or to an up type quark (u, c) and a down type quark (d, s, b) with a branching ratio of 67.60 ± 0.27 [1].
The Standard Model predicts its mean lifetime to be about 5×10^{-25} s. It does not have enough time to form bound states (hadrons), giving the unique opportunity of study the properties of a bare quark which are preserved in the decay chain and transferred to its decay products. The top quark is present in the higher-order diagrams and it provides, within the electroweak theory of particle interactions, indirect constraints on the Higgs boson mass, together with the W boson mass. Top quark production also plays an important role in many scenarios in the search for new physics beyond the Standard Model. Several models predict the existence of new particles decaying to or with large couplings to the top quark. Therefore, the study of top quarks may provide hints to the presence of new physics processes. Furthermore, top quark production constitutes a large background to many of the searches for new physics processes, and it is, therefore, important to understand the properties and the characteristics of top production and decay mechanisms [2]. A precise understanding of the top signal is crucial to claiming new physics.

2 Techniques

For event generation of proton protons collisions at $\sqrt(s) = 13$ TeV PYTHIA main42 code have been used. Rivet tools were used for the analysis.

2.1 PYTHIA

PYTHIA is a standard tool for the generation of events in high energy collisions, comprising a coherent set of physics models for the evolution from a hard process to a complex multiparticle final state. The program is based on a combination of analytical results and various QCD-based models. The different steps in the simulation include the hard subprocesses, the initial and final state parton showers, the underlying events, beam remnants and finally hadronization and decays.

2.2 Rivet

The RIVET toolkit (Robust Independent Validation of Experiment and Theory) is a system for comparison of Monte Carlo event generators. It provides a large (and evergrowing) set of experimental analyses useful for comparison, as well as a convenient infrastructure for adding your own analyses. RIVET is one of the most widespread ways by which analysis code from the LHC and other high-energy collider experiments is preserved for comparison and development of future theory models. It is used by phenomenologists, MC generator developers, and experimentalists on the LHC and other facilities.

3 Analyses

3.1 Top jets topology

At high p_T the system should have a boosted topology. This means that instead of having several jets due to the products of the top decay, all can be clustered to a single jet (called fat jet). We consider as high p_T values above 400 GeV.

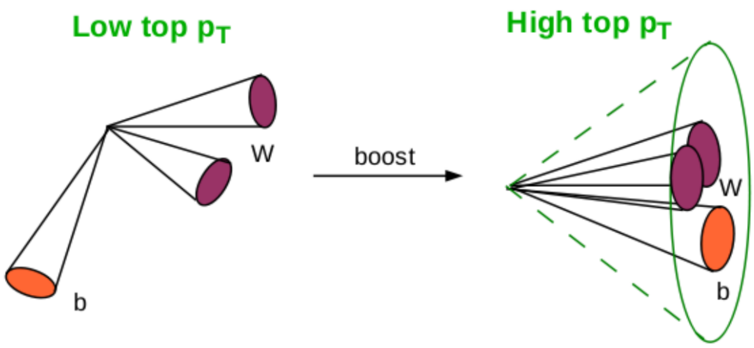


Figure 1: Boosted topology at hight p_T

3.2 Clustering algorithm

The fat jets are clustered with the ANTI-KT algorithm [3] taking $\Delta R_0 = 0.8$. The algorithm clusterizes in cone shapes of angle ΔR_0 around the hard particles[1]. If there are two hard particles inside the same cone the resulting jet is a combination of two cones. If two different cones overlap they are divided according to their energies.
It is required two jets with p_T, the leading (jet with the highest p_T) and subleading (jet with the second highest p_T) jets are considered as top candidates. The jets are selected only if there is a b-hadron[2] inside. Each fat jet is clustered into two subjets

[1]Particles with high energies
[2]Product of hadronization of the b quark

(corresponding to the W subjet and the b-hadron). The clustering is made with the Soft Drop Mass algorithm [4] which removes particles in the jets that do not match the following condition:

$$\frac{\min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \left(\frac{\Delta R_{12}}{\Delta R_0} \right) \quad (1)$$

We take $z_{cut} = 0.1$ and $\beta = 0.8$ as values for the parameters.
The algorithm removes wide angle soft radiation, softening the effects of contamination from initial state radiation, underlying events and multiple collisions (pileup).

3.3 Losses in clustering

During the clustering algorithm, there are several cases in which partially or completely the jets are lost (not analyzed).

B-Hadron outside of the fat jet

In the low p_T region could the b-hadron be with ΔR value greater than 0.8, because of that it is not clustered inside the fat jet. The figure 3 shows the ΔR between the fat jet and the b-hadron. It could be estimated that in 12% of the events the b-hadron is not clustered in the fat jet.

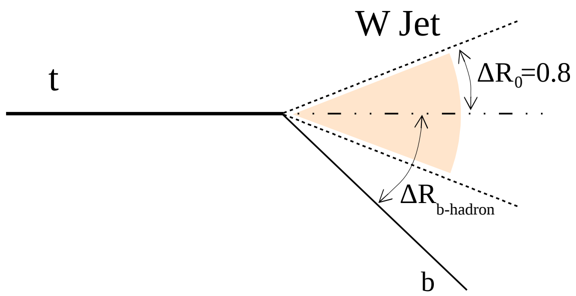


Figure 2: Scheme of b-hadron outside the fat jet

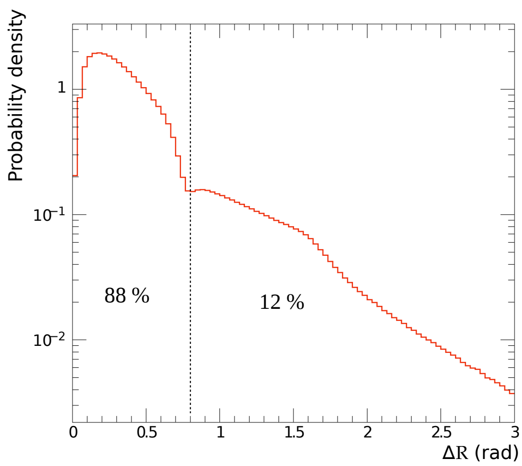
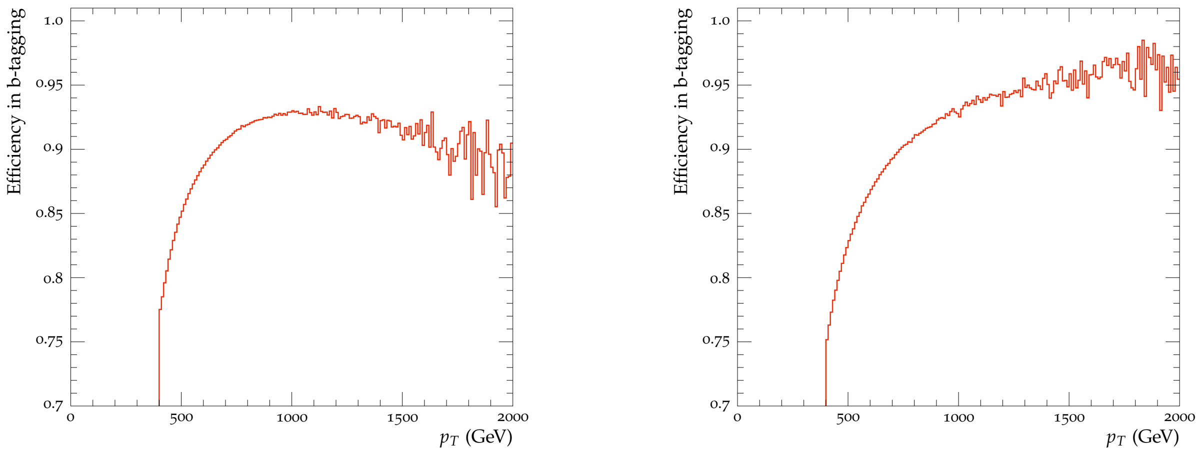


Figure 3: Angular distribution of the b-hadron respect to the jet ($p_T > 400$ GeV)

It was made a study about the fraction of events that are accepted by the b-hadron requirement. The results are shown in figure 4. As it can be seen the requirement fails mainly for p_T below 800 GeV.

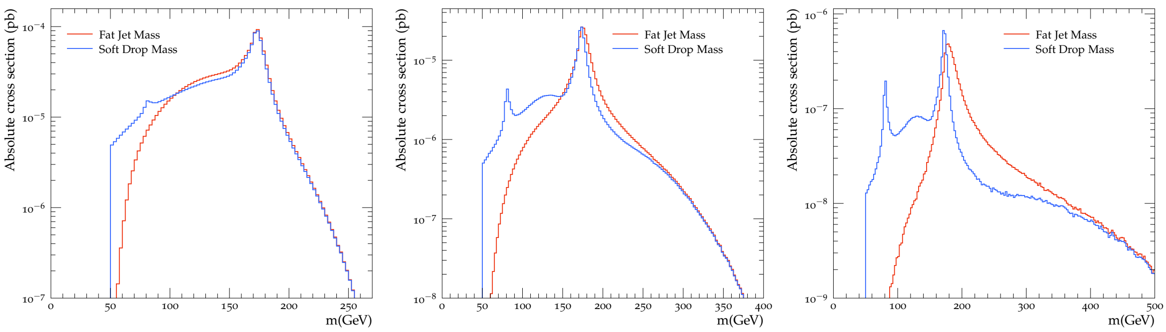


(a) (b)

Figure 4: Fraction of events having a b-Hadron in: (a) leading jet, (b) subleading jet

B-Hadron is removed by the Soft Drop Mass algorithm

Sometimes the p_T of the b-hadron is too low compared to the p_T of the W jet and the Soft Drop Mass algorithm removes it from the jet (even though that there is a b-hadron inside and the event was already accepted). The figure 5 shows the jet mass; besides the top peak ($\sim$ 172 GeV) there is also a peak in the W mass (80 GeV) after applying the Soft Drop Mass algorithm. This happens mainly in the high p_T region because at that energies the W could have higher p_T.



(a) 400GeV $< p_T <$ 500GeV (b) 600GeV $< p_T <$ 800GeV (c) 1000GeV $< p_T <$ 1500GeV

Figure 5: Mass of the fat jets before and after applying the Soft Drop Mass

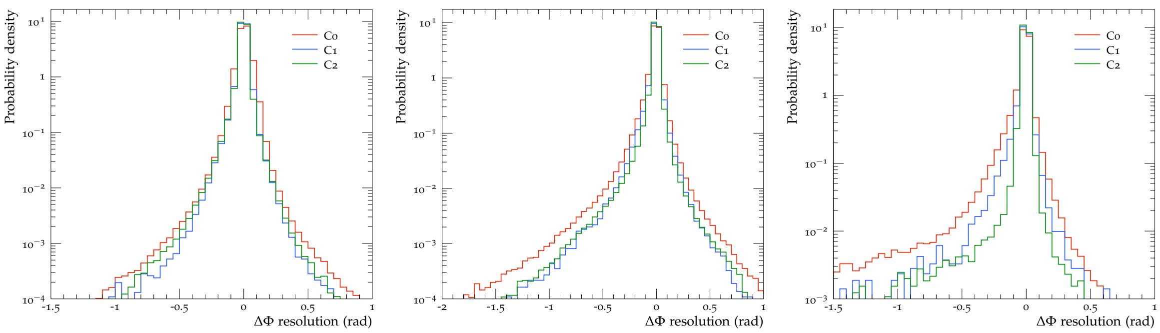
3.4 Comparison between different criteria for selection of events

Several criteria for the hadron definition of top jets were tested, as an attempt to discard the events were the hadron-b is removed by the Soft Drop Mass and to minimize the tails.

1. Mass of the first sub-jet (the one corresponding to the W jet) in the W mass window (70 - 90 GeV).

2. Mass of the of the fat jets after applying the Soft Drop Mass in the top mass window (150 - 200 GeV).

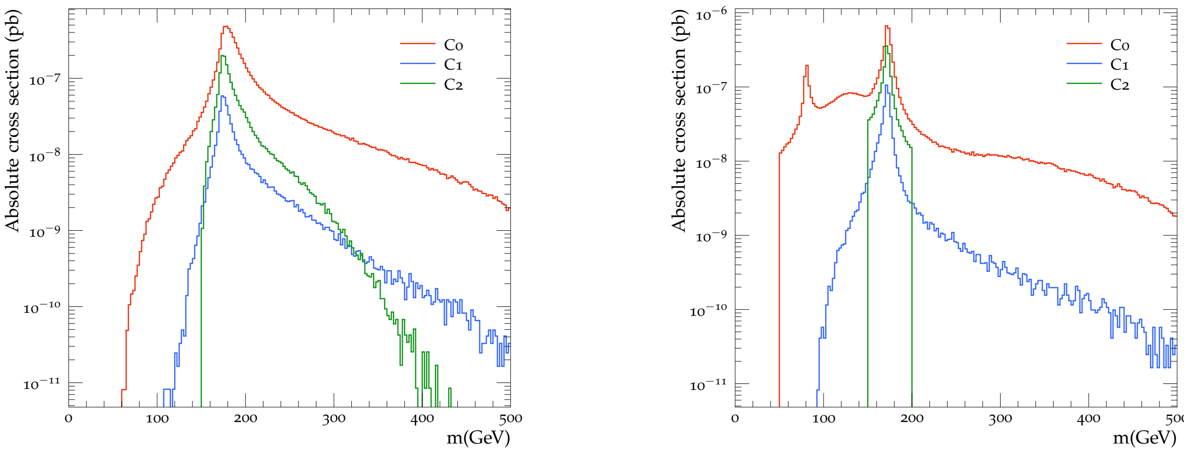
Each of this criteria has the additional requirement of the existence of the b-hadron in the fat jet.
The resolution in $\Delta\Phi$ (difference between the angle of the $t\bar{t}$ system and the leading and subleading jets) is plotted in several region of p_T (figure 6). These values give an idea of how well are reconstructed the fat jets (in the ideal case the $\Delta\Phi$ resolution is 0).



(a) 400GeV $< p_T <$ 500GeV (b) 600GeV $< p_T <$ 800GeV (c) 1000GeV $< p_T <$ 1500GeV

Figure 6: Resolution in $\Delta\Phi$ by only requiring the b-hadron (C_0) and using criteria 1 (C_1) and 2 (C_2)

By applying extra requirements it can be seen (figure 7) that the top mass peak is more clear (the soft QCD radiation affecting the top mass distribution is removed). Figure 7b illustrate the hadron definition scenarios and how the cross section decreases by this requirements.

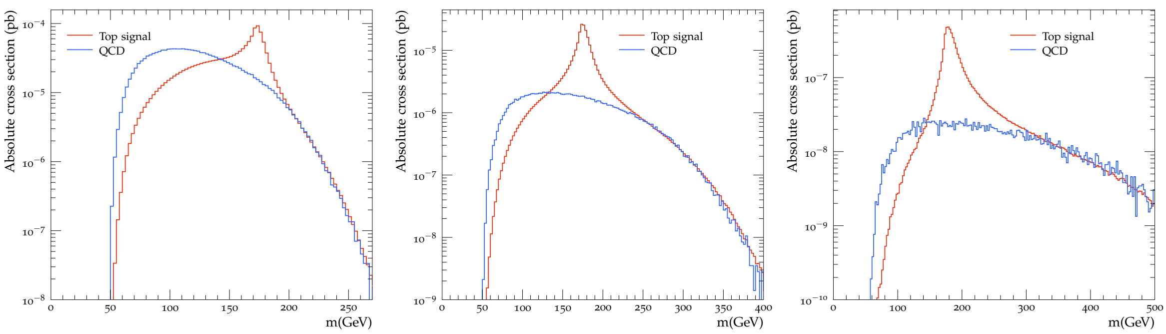


(a) Jet mass before Soft Drop (b) Jet mass after Soft Drop

Figure 7: Mass of the jets by only requiring the b-hadron (C_0) and using criteria 1 (C_1) and 2 (C_2) for p_T in the range (1000 - 1500) GeV

3.5 Studies on QCD in $t\bar{t}$ events

The same previous studies were made by only considering QCD processes. In this case, we do not obtain the top peak in the histogram for the jet mass but the large tails are well reproduced (figure 8).



(a) 400GeV $< p_T <$ 500GeV (b) 600GeV $< p_T <$ 800GeV (c) 1000GeV $< p_T <$ 1500GeV

Figure 8: Jet masses obtained in the previous analyses compared with the obtained by only considering QCD processes. The QCD plot is scaled by hand to fit the tails

4 Conclusion

There was studied the hadron definition for top signal. There were tested different definitions for the selected events. With this an improvement in the $\Delta\Phi$ resolution was obtained, the W peak in the soft drop mass histograms was removed and the resolution of the top mass peak was enhanced.
The presence of QCD effects (initial and final state radiation) in $t\bar{t}$ events were also studied. It was shown how QCD describes the large tails in the mass histograms.

References

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