Quantifying the performance of jet algorithms at LHC

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In the present contribution we introduce a strategy to quantify the performance of modern infrared and collinear safe jet clustering algorithms in processes which involve the reconstruction of heavy object decays. We determine optimal choices for fictional narrow $Z' \to q\bar{q}$ and $H \to gg$ over a range of masses, providing examples of simple quark-jet and gluon-jet samples respectively. We show also that our estimates are robust against the presence of high-luminosity pileup.

Introduction

There has been sizable progress in jet algorithms in the recent years [2–7]. However, less work has been devoted with modern tools to determine the optimal jet algorithm (and associated parameters like $R$) for different physics processes at the LHC. This contribution reports on ongoing studies in collaboration with M. Cacciari, G. Soyez and G. Salam, to quantify the performance of modern jet algorithms and related background subtraction strategies in the LHC environment in the case in which masses of heavy particles are being reconstructed [9].

General strategy

We should recall that when studying the performance of jet algorithms, one should avoid figures of merit based on ambiguous concepts like parton momenta and direction (ill-defined in pQCD) or which assume a given distribution for the reconstructed mass spectra (like a Gaussian shape). Instead, we shall use figures of merit related to the maximisation of the signal over background ratio (more precisely, $S/\sqrt{B}$).

The first figure of merit is denoted by $Q_{f=z}^w(R)$, the width of the smallest mass window that contains a fraction $f = z$ of the generated massive objects,

$$f = \left( \frac{\# \text{reconstructed, massive objects in window of width } w}{\text{Total } \# \text{ generated massive objects}} \right).$$

(1)

A jet definition that is more effective in reconstructing the majority of massive objects within a narrow mass peak gives a lower value for $Q_{f=z}^w(R)$, and is therefore a “better” definition.

The second figure of merit is denoted by $Q_{w=x\sqrt{M}}^f(R)$. To compute this quality measure, we displace over the mass distribution a window of fixed width given by $w = x\sqrt{M}$, where $M$ is the nominal heavy object mass that is being reconstructed, and we find the maximum number of events of the mass distribution contained in it. In this situation we define this figure of merit as

$$Q_{w=x\sqrt{M}}^f(R) \equiv \left( \frac{\text{Max } \# \text{reconstructed massive objects in window of width } w = x\sqrt{M}}{\text{Total } \# \text{ generated massive objects}} \right)^{-1}.$$

(2)

*aInitial results have been presented in the Les Houches 2007 workshop proceedings [8].

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Figure 1: The figure of merit $Q_{f=z}(R)$ for the quark jet samples from $Z'$ corresponding to $M = 100$ GeV (left plot) and $M = 2$ TeV (right plot).

To obtain a more physical interpretation, the ratio of quality measures can be mapped to variations in effective luminosity needed to achieve constant signal-over-background ratio for the mass peak reconstruction. We assume that the background is flat and constant, and unaffected by the jet clustering. We define the effective power to discriminate signal over background $\Sigma^{\text{eff}}$ for a given jet definition $(JA, R)$ as $\Sigma^{\text{eff}}(JA, R) \equiv N_{\text{signal}}/\sqrt{N_{\text{back}}}$. Then, for example in the case of $Q_{f=z}(R)$, if we define

$$r_w \equiv \frac{Q_{f=z}^{(JA_2, R_2)}}{Q_{f=z}^{(JA_1, R_1)}} = \frac{N_{\text{back}}(JA_2, R_2)}{N_{\text{back}}(JA_1, R_1)},$$

at equal luminosity the discriminating power for $(JA_1, R_1)$ will differ by a factor $\Sigma^{\text{eff}}(JA_1, R_1) / \Sigma^{\text{eff}}(JA_2, R_2) = \sqrt{r_w}$ with respect $(JA_2, R_2)$. Equivalently the same discriminating power as $(JA_2, R_2)$ can be obtained with a different luminosity $\mathcal{L}_1 = \rho \mathcal{L}_2$, where $\rho = 1/r_w$.

Jet algorithms We study the performance of available IRC safe jet algorithms: $k_T$ [10], Cambridge/Aachen [11, 12], anti-$k_T$ [6] and SISCone [4]. On top of these, we will examine also the performance of the filtering jet finding strategy, first introduced in [13], with $R_{\text{filt}} = R/2$ and $n_{sj} = 2$ (labeled as C/A(filt) in the various plots).

Processes investigated This general strategy has been applied to both fictitious narrow $H \rightarrow gg$ and $Z' \rightarrow q\bar{q}$ decays, which provide examples of physical gluon and quark jet samples respectively. We consider a wide range of the heavy particle masses\(^b\). Also multijet events from hadronic $t\bar{t}$ have been studied [8].

\(^b\)Some of them already excluded by measurements or indirect constraints, however in the present work we use them as a source of mono-energetic jets only.
Results

We show in Figs. 1 and 2 the quality measure $Q_{Fz}^w(R)$ for all five algorithms considered, both for quark jets and gluon jets. We observe in each case minima which define the optimal value of the radius parameter $R_{\text{best}}$. Note that the sources of quality difference do stem either from the choice of jet algorithm (specially for gluon jets) as well as from the value for $R$ adopted. Note that the results obtained with the two quality measures are consistent.

In Fig. 3 we summarize the results for $R_{\text{best}}$ for all jet algorithms for gluon jets. We observe an approximately scaling $R_{\text{best}} \sim \ln M_H (\rho_T^{\text{jet}} \sim M_H/2)$, which can be understood due to the contribution from QCD perturbative radiation [14]. The values found satisfy $R_{\text{best}} \geq 0.7 (0.9)$ for $p_T \geq 250$ GeV quark(gluon) jets.

Let us examine less favored choices for the jet definitions in the $M_H = 2$ TeV case: if we use SISCone, but with $R_{100 \text{ GeV}}^{\text{best}} = 0.6$ instead of $R_{2 \text{ TeV}}^{\text{best}} = 1.1$, we find $\rho_L \sim 0.55$. If on the other hand we use $R_{2 \text{ TeV}}^{\text{best}}$, but choose $k_T$ and instead of SISCone then $\rho_L \sim 0.6$. So we observe that almost half of the effective discriminating power $\Sigma_{\text{eff}}$ is lost with these choices.

We have studied as well how robust are our results with respect to the presence of Pile-Up (PU). To this purpose, we generated minimum bias samples with Pythia Tune DWT for LHC at high luminosity, $L_{\text{high}} = 0.25$ mb$^{-1}$ per bunch crossing. PU is subtracted based on the jet area method [3]. Our analysis shows that even at high luminosity the preferred values of $R$ are rather close to their original values without PU, as can be seen in Fig. 3.

Summary

We have presented a general strategy to quantify the performance of jet algorithms in the case in which a heavy particle mass is reconstructed. We have shown that the optimal jet definition, both the jet algorithm and its parameters like $R$, depend on both the kinematics of the process and the mass scales involved. In the case of the dijet samples studies, we find that larger $M$ implies larger $R_{\text{best}}$ to maintain jet resolution.

We have also checked that our quantitative estimates for $R_{\text{best}}$ are robust in the presence of high luminosity PU after subtraction.

Let us finally emphasize again that these results have been obtained with the assumption

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Figure 3: Left plot: the best value of the jet radius $R_{\text{best}}$ as determined for gluon jets as a function of the relevant mass scale. Right plot: comparison of the optimal $R_{\text{best}}$ for the SISCone and $k_T$ algorithms for gluon jets in without PU case and in the high-lumi PU case with subtraction that the background is flat and unaffected by jet clustering. Although our analysis cannot in any case replace a proper $S/\sqrt{B}$ study, it is indicative of the potential relevance of such variations in more realistic studies, and emphasizes the importance of flexibility for jet finding at the LHC.

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