EXPERIMENTAL IDENTIFICATION OF QUARK AND GLUON JETS*

Sona Pochybova

Institute for Particle and Nuclear Physics, Wigner RCP, HAS
1121 Budapest, XII. Konkoly Thege Miklós út 29–33, Hungary

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With increasing luminosities at the LHC, the jet-studies become more accessible. With rising statistics and excellent detector capabilities, possibility emerges to identify jets as quarks or gluons to study and understand how differences in their fragmentation properties influence final particle spectra. We propose a method to separate jets into quark-like and gluon-like samples which can be performed directly on data without the necessity to rely on Monte Carlo. We study the fragmentation of the selected jets and compare to reference samples of quarks and gluons.

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1. Introduction

At recent luminosity of the LHC accelerator, large number of high energy jets have been detected in both pp and heavy-ion collisions and are becoming the focus of research activities. General jet properties as well as jet reconstruction methods have been studied extensively [1]. With increasing luminosity jet shape, fragmentation processes and wide classes of correlations become accessible. Identification of the source of the shower, namely if it has been a quark or a gluon, becomes crucial as it influences the final particle spectra we observe experimentally.

There is a difference between how quark and gluon jets fragment. These differences are theoretically embraced in the QCD Casimir factors (also known as color factors), which are proportional to the probability a parton radiating a soft gluon. Gluon's color factor (C_A) is more than twice bigger than that of a quark (C_F) [2]

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$$\frac{C_A}{C_F} = \frac{3}{4/3} = 2.25\,. \tag{1}$$

This means that gluons are expected to form higher multiplicity jets with softer fragmentation function and larger cone size.

Experimentally, the differences between quark and gluon jets were tested extensively at LEP in e^+e^- collisions [3] and later at the Tevatron in $p\bar{p}$ collisions [4]. In both experiments, the above expectations have been fulfilled. Furthermore, at LEP the C_A, C_F factors have been measured to be $C_A = 2.89 + -0.01(\text{stat.}) + -0.21(\text{syst.})$ and $C_F = 1.30 + -0.01(\text{stat.}) + -0.09(\text{syst.})$. These are consistent with the QCD prediction [5].

At the LHC, we have a unique opportunity to further extend our knowledge and understanding of the jet-fragmentation phenomena, especially baryon production. For this, however, we need a method that will help us to separate jets into quark and gluon samples. The method we propose is described in the following sections.

2. Quark and gluon jet selection method

In this section, we describe the proposed method to distinguish quark and gluon jets. This method is based on a jet-shape variable denoted as R_{90}, which is the jet-size containing 90% of jet's energy. In order to obtain the cut to distinguish the jets based on this variable, first we have to study its dependency on the origin of the jet. In an experiment, we have the possibility to identify events which are source to quarks or gluons, namely γ–jet and three-jet events, respectively. By studying the properties of jets in these selected events, we are able to calibrate cuts to be applied to jets in other events, were the origin of observed particle showers is unclear.

In order to perform such study, we simulated 1 milion of γ–jet events and 10 milion of jet–jet events in pp collisions at $\sqrt{s} = 7\,\text{TeV}$ using Pythia 6.4 MC generator with Perugia-0 tune [7]. The jets were reconstructed using *anti–*k_T algorithm with $R = 0.4$ [8]. From γ–jet events, we then selected a quark–jet sample and from three-jet events we selected the lowest momentum jets as gluons.

In Fig.1, the average jet-shape $\langle R_{90} \rangle$ is plotted as the function of jet's transverse momentum for gluon jets (three-jet sample), all jets (jet–jet sample) and quark jets (γ–jet sample). We observe, that on average, the quark jets have a smaller R_{90} than gluons, as expected from QCD (see Introduction). Further, it is apparent that the mixed sample is very close to the distribution for gluons. This demonstrates the gluon dominance in the overall jet production.

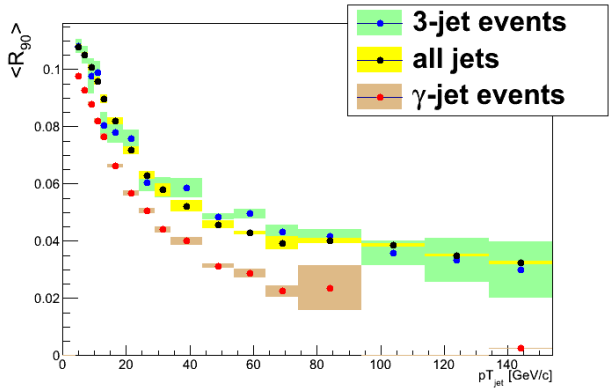


Fig. 1. The average value of R_{90}, denoted as $\langle R_{90}\rangle$, as a function of jet's momentum pT_{jet}. From three-jet events, we select only the least energetic jet to obtain a gluon–jet sample. The sample of all jets is a mix of quark and gluon jets and serves as a reference for further calibration of the cut. The γ–jet events are the source for quarks.

In the following, we will focus on a narrow momentum interval $pT_{\text{jet}} = (34; 44)\,\text{GeV}/c$. To determine a proper cut based on the R_{90} variable, first we must understand how the gluon jets from three-jet events and the quark jets from γ–jet events contribute to the $\langle R_{90}\rangle$ for all jets. To do this, we calculate $\Delta R = R_{90q/g} - \langle R_{90}\rangle$ for each gluon and quark jet. The obtained distribution of ΔR is displayed in Fig. 2. We see that the distributions are overlapping, however, we can identify regions were gluons dominate over the quarks and *vice versa*. The specific fractions of quark and gluon jets in different ΔR bins are plotted in Fig. 3. Figure 3 clearly shows that gluons

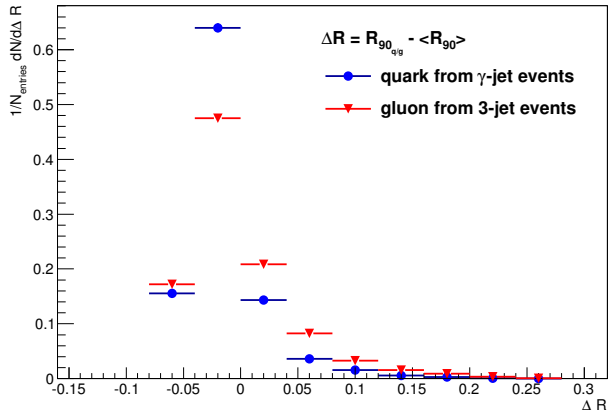


Fig. 2. The extracted ΔR distribution, where $\Delta R = R_{90} - \langle R_{90}\rangle$.

dominate the positive region of the plot and their fraction is increasing with ΔR, whereas quarks dominate region $\Delta R = (-0.08; 0)$. Unfortunately, the maximum of quark fraction is only 55% and the sample of selected quark jets will be highly contaminated by gluons (45%). This fact has to be taken into consideration later.

To perform our analysis, in the following, we select the quark sample to be containing jets with $\Delta R = (-0.04; 0)$ and gluon sample to be containing jets with $\Delta R = (0.; 0.04)$. In the next section, we validate our selection criterion by comparing the selected jets to MC quarks and gluons.

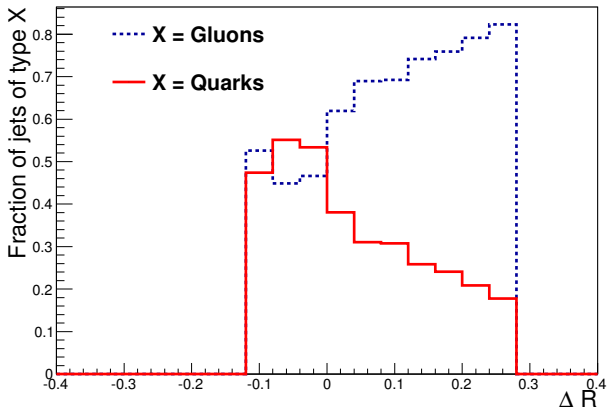


Fig. 3. Fraction of quark and gluon jets from selected events in different ΔR bins.

3. Method performance

In this section, we show extracted leading particle fragmentation functions and compare them to the ones coming from the MC model. The leading particle fragmentation functions for quarks and gluons are shown in Fig. 4. We see small discrepancy between the MC jet-fragmentation and fragmentation of selected jets which is at the level of 20% in the middle-z region (0.3–0.7). At extreme values of z we find larger discrepancies. This indicates that our selection is biased towards middle-z region and by applying the cut we are cutting out jets with extreme fragmentation properties.

For the selected quarks, the small discrepancy is surprising since the contamination of the quarks by gluons in our ΔR selection area is as high as 45% (see Fig. 3). This result indicates that we are selecting rather a quark-like sample as compared to identifying jets on jet-by-jet basis. Furthermore, this result suggests that we are able to study the behavior of quark jets by selecting jets that are "quark-like". This raises the question to what extent the fragmentation is determined by the original parton-type and what other factors determine jet's behavior.

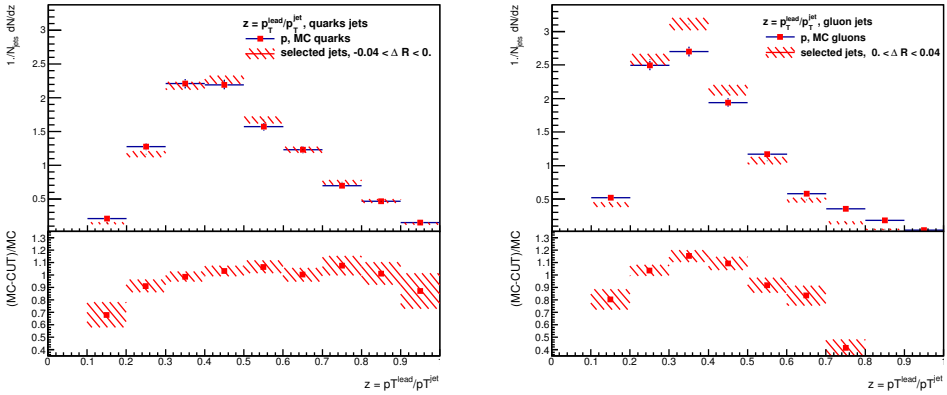


Fig. 4. Top: Leading particle fragmentation functions of jets selected based on cut (hatched histogram) compared to MC quark and gluon jets (full symbol histogram). The fragmentation is calculated as $z = pT^{\mathrm{lead}}/pT^{\mathrm{jet}}$. Bottom: Performance of the method quantified by (Cut-MC)/MC.

For the gluons, the well-behaving region of z is smaller than for quarks (0.2–0.6) and the fragmentation function is different, peaking at smaller values than for quarks. Similarly to previous arguments we can claim, that we have selected a sample of "gluon-like" jets.

4. Conclusion

In the previous sections, we proposed a method for the selection of quark and gluon jets, which is based on the observation of differences between such jets in three-jet and γ–jet events. We identify these events as sources of gluons and quarks, respectively. Observing the differences of their R_{90} variable and how this contributes to the overall jet $\langle R_{90} \rangle$, we calibrated the cut used for identifying the jets. Applying this cut to the MC jets, we were able to reproduce the leading particle fragmentation function of MC quarks and gluons, thus validating our selection. Specifically, we were able to separate the sample into "quark-like" and "gluon-like" jets, making it possible to investigate the physical properties of such jets.

Further studies targeting the internal structure of jets could be very valuable. Use of reference samples from γ–jet and three-jet events remains essential to cross-check the behavior of our selection. All of these analyses were based on MC. It is an interesting question what a similar analysis will show when done on data. Such an analysis will be the topic of a forthcoming paper, here we wanted to present and discuss the method.

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