A MONTE CARLO STUDY ON THE IDENTIFICATION OF QUARK AND GLUON JETS *

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Abstract

Three jets events in the e^+e^- collisions at 91.2 GeV are investigated using both HERWIG and JETSET Monte Carlo generators. The angles between the three jets are used to identify the quark and gluon jets. The analysis at parton level is done to ensure the reasonableness of this method and an angular cut is utilized to improve the purity of this identification. The multiplicity inside the identified quark or gluon jets agree with the QCD predictions qualitatively.

In the theory of QCD, unobserved quarks and gluons are confined by color force. They eventually hadronize into observed final state jets, which in a sense inherit the information about original partons. In order to study the difference of nonpertubative hadronization processes between quarks and gluons, it is important to identify whether a final state jet is originated from a quark or gluon. Many works have been done on this topic, see for example 1 2 3. Recently mostly used way are the so called b-tagged events in which b (and anti-b) quarks are well tagged and the rest jet is certainly a gluon jet 4 5 6. This method, apart from its high accuracy, is restricted in quark flavour and is inapplicable to the gluon jets produced together with the light-quark jets.

In this paper we analyse the events of e^+e^- annihilations at 91.2 GeV generated by HERWIG 5.9 7 and JETSET 7.4 8 to find a method for the identification of quark and gluon jets without flavour restriction. Durham jet algorithm 9 is used to form jets both at parton level and at hadron level. R_2 and R_3 are two and three jets fraction, respectively. Distributions of R_2, R_3 at parton level and hadron level, are obtained by varying y_cut value from 10^{-4} to 10^{-1}, cf. Fig.1, in which there exists a y_cut value (log (y_cut) = -2.5), where R_3 both at parton level and at hadron level get to the maximum. We choose this y_cut for all the later analysis.

We assume that the three jets in one event are coming from quark, antiquark and radiated gluon, respectively. Because of energy-momentum conservation, the three jets in one event must lie in a plan. These three jets are ordered according to the angles between two neighbouring jets. Jet-1 is

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*This work is supported in part by the NSFC under project 19975018
defined as the jet opposite to the smallest angle $\theta_1$ and jet-3 is opposite to the largest angle $\theta_3$. A three-jet event topology is depicted in Fig.2.

In QCD, the gluon radiated from one of the parent quark is expected to have relatively small energy and close to its parent quark, so in the above jet plan jet-1 might be a quark jet and jet-3 a gluon jet. At parton level quark and gluon can be precisely identified. We select three jets events by requiring two jets in one event contain opposite flavor $q$ and $\bar{q}$ seperately and the other one contains only gluon or $q\bar{q}$ pairs.

The distributions of ordered three angles at parton level are shown in figure 3, in which the smallest angle $\theta_1$ are well seperated from the largest one $\theta_3$, which means that one of the quark jets are unambiguos defined, but the large overlap of $\theta_2$ and $\theta_3$ might cause wrong identification between the gluon jet and the other quark jet. The efficiency of quark or gluon jet identification at parton level as a function of $\theta_3 - \theta_2$ of each event is calculated by comparing the type of jets determined from the angular rule, i.e. assuming that gluon jet is always opposite to the largest angle, to the original parton type. The results are in Fig.4, which shows that the larger the angular difference, the higher the efficiency.

In case of final state hadrons, events with $|\theta_1 + \theta_2 + \theta_3 - 360^\circ| < 1^\circ$ are selected to satisfy the planar request. This cut elimilates about 26% events.

In the application of the angular rule to final state hadrons, the direction of hadron jets might not be exactly the direction of the original partons since the effect of hadronization will change the angles between jets. The events with three jets both at parton level and at hadron level are selected to estimate the deviation. Of each event, hadron level ordered jet $i$ is matched to parton level ordered jet $i$ and the distribution of the angular differences

\[ \text{parton } \theta_i - \text{hadron } \theta_i \quad (i = 1, 2, 3) \]
are shown in Fig. 5.

In these plots the largest angle $\theta_3$ which is supposed to opposite to gluon jet is the most stable one. It indicates that the effects of hadronization on the relative direction of two quarks are small, while the fluctuation on the direction of radiated gluon is much larger. On the average, the angle deviation between parton level and hadron level is less than 3$^\circ$.

Based on the efficiency and angle deviation analyses given above, we require an angular cut $\theta_{\text{cut}} = 20^\circ$ for $\theta_3 - \theta_2$ in hadron jet analysis and retain only the events with $\theta_3 - \theta_2 > \theta_{\text{cut}}$. This cut rejects about 50% events. Within the selected hadron events, we study the purity of angular rule. Firstly, ap-
ply angular rule to hadrons to get quark and gluon jets sample. Secondly, partons are forced into three jets and jets type is defined as the efficiency study. Thirdly, associate each hadron jet with a parton jet by finding the combination which minimizes the sum of the angular difference between them and define pure events by requiring hadron jet has the same jet type as its associated parton jet. Purity which is defined as the number of pure events over the number of all selected hadron events is 63.8% for Herwig 5.9 and 83.2% for Jetset 7.4.

Jets from two jets events are taken as quark jets which are compared with the three ordered jets from three jets events. Because of the higher color charge of the gluon, it is expected that gluon jets are of higher multiplicity than quark jets of the same energy. In this paper, the multiplicity $n$ of the charged particles inside jet are investigated. Jet energy is defined as the total energy of all the charged particles in the jet. The mean multiplicity $\langle n \rangle$ of jet as a function of jet energy are shown in Fig. 6 for HERWIG 5.9 and JETSET 7.4 respectively. Jet-1 and jet-2 which are identified as quark jet have the same behavior as quark jets of two jets events, jet-3 which is expected to be a gluon jet is well separated from the other three samples and has higher mean multiplicity.

In conclusion, based on the idea that the radiated gluon jet is close to its parent quark and from the idea of Parton-Hadron-Duality that the direction of hadron jet is the same as parton jet, we use the angles between final state hadron jets to identify quark or gluon jet. Two angular cuts are applied. The
first one is planary cut, rejecting the events with $|\theta_1 + \theta_2 + \theta_3 - 360^\circ| > 1^\circ$. The second one is the angular-difference cut, requiring $\theta_3 - \theta_2 > \theta_{cut}$ with $\theta_{cut} = 20^\circ$. After these cuts the jet opposite to the largest angle $\theta_3$ is taken as the gluon jet. The property of the gluon and quark jet obtained in this way show obvious differences. The higher mean multiplicity of gluon jet sample agrees with QCD prediction, indicating that this angular method of jet identification is capable of distinguishing gluon jet from quark jet. In addition, there is no restriction on quark flavor and no requirement on the jets in one event to have similar energy. So it is relatively easy to carry out in experiment with high statistics.

Acknowledgements

The authors thank Professor Sijbrand de Jong for helpful discussion.

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