Mean Multiplicity of Quark and Gluon Jets as a Function of Opening Angle in $e^+e^- \to b\bar{b}g$ Events

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Abstract

A comparison of the properties of quark and gluon jets has been made by Monte Carlo simulation of the reaction $Z \to b\bar{b}g$. The jet energy is held fixed for every 5 GeV between 15–30 GeV energies and the mean multiplicity of b-quark and gluon jets are obtained as function of the angle between them. It is seen that the jet properties not only depend on the jet energies but also on the angle between the jets.

Key Words: Jets; Quarks; Gluon; Jet energy.

1.   Theory

Quarks and gluons have different coupling strengths to an additional gluon. They have different colour charge and because of this one can expect to observe some differences in the properties of quark-induced and gluon-induced jets. According to QCD the colour charge of a gluon is C_A/C_F=9/4 larger than the colour charge of a quark. This implies that gluon jets are more likely to radiate than quark jets. For quark and gluon jets of similar energy, QCD therefore predicts that the gluon particle multiplicity should be higher, that the gluon jet should be wider and that it should have softer particle energy spectrum than quark jets [1]. However, the ratio C_A/C_F=9/4 is calculated at the parton level for pairs of collinear gg and $q\bar{q}$ jets at infinite (asymptotic) energy and leading order. A large non-leading and finite energy correction of order $\sqrt{\alpha_s}$, heavy quark effects, and 2nd order calculations significantly reduce the magnitude of gluon-quark jets multiplicity differences at present energy[2]. This current study uses Monte Carlo events to demonstrate that particle multiplicities in jets depend on the jet type (quark or gluon), the jet energy, and also the angle between jets.

2.   Event Generation and Jet Construction

To make a comparison between quark- and gluon-induced jets, 3-jet events are selected; in this topology two jets are quark-induced and one jet is gluon-induced. When studying real data, gluon and quark jets can be distinguish with a high purity by tagging b-quarks in heavy favour events [3]; and so that the current Monte-Carlo study can be compared to studies in real data, the present study uses only b-favour events.

Monte Carlo events were generated using JETSET 7.4 [4], modified with DYMU3 [5] for electromagnetic radiative effects and improved bottom and charm decay tables. b-flavour events are selected and clustered with the DURHAM jet finding algorithm with a resolution parameter of y_{cut}=0.01 in the 'E' recombination scheme [6, 7, 8, 9]; events containing three distict jets are selected. Charged tracks plus neutral objects are

used as input to this algorithm. The event plane is determined from the normalized jet momentum tensor and the 4-vectors projected on to the event plane.

3.   Mean Multiplicity as a Function of Opening Angle

The mean charged and charged-plus-neutral particle multiplicity of gluon and quark jets (jet2 and jet3) are obtained as a function of the opening angle between the two least energetic jets, jet2 and jet3 at fixed jet energy. An illustration of the definition of the jet angles used in this analysis is shown in Figure 1. The angles θ_{12}, θ_{23}, and θ_{32} represent the plane angles, e.g. θ_{12} is the angle between the projections of jet1 and jet2 in the event plane. The jet energies are divided into sub-samples between 15 and 30 GeV for every 5 GeV. Figures 2 and 3 show the mean particle multiplicities as a function of the opening angle at fixed jet energy for quark and gluon jets respectively. Their ratio is plotted in Figure 4. Both charged plus neutral particles and charged particles only are considered.

4.   Results and Conclusion

In Figures 2 and 3 it is seen that particle multiplicities in both quark and gloun jets increase with jet energy and with the angle between the two jets. The dependence of the angle between jets is more profound for gluon jets, for this can be seen in Figure 4 where the ratio of gluon to quark multiplicities are shown; and relative to the quark jet, the particle multiplicities increase more for the gluon jet as the angle increases.

In conclusion, these results are consistent with the expectations from theoretical considerations. Jets of higher energy are generally higher in multiplicity. Due to their greater colour charge, gluons radiate more than quarks and so gluon jets have a greater particle multiplicity. An additional effect is that we see particle multiplicities increasing in both quark and gluon jets when the angle between the quark and gluon jet increases; this effect is more profound for gluon jets.
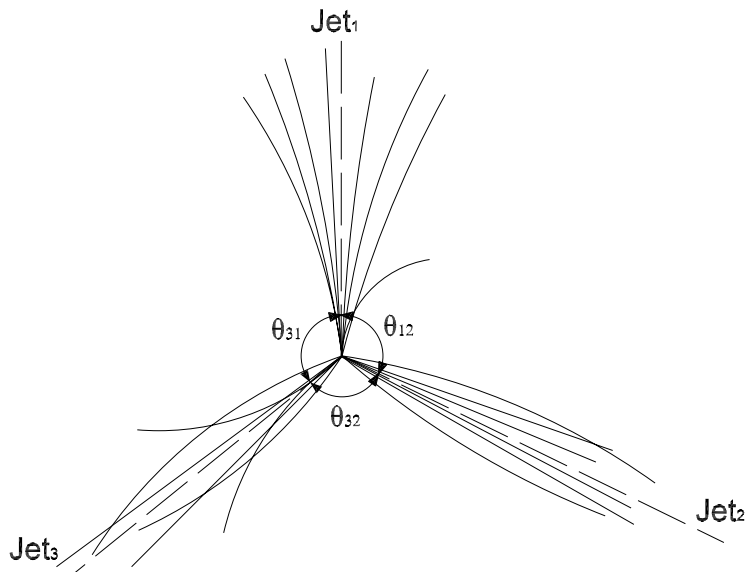

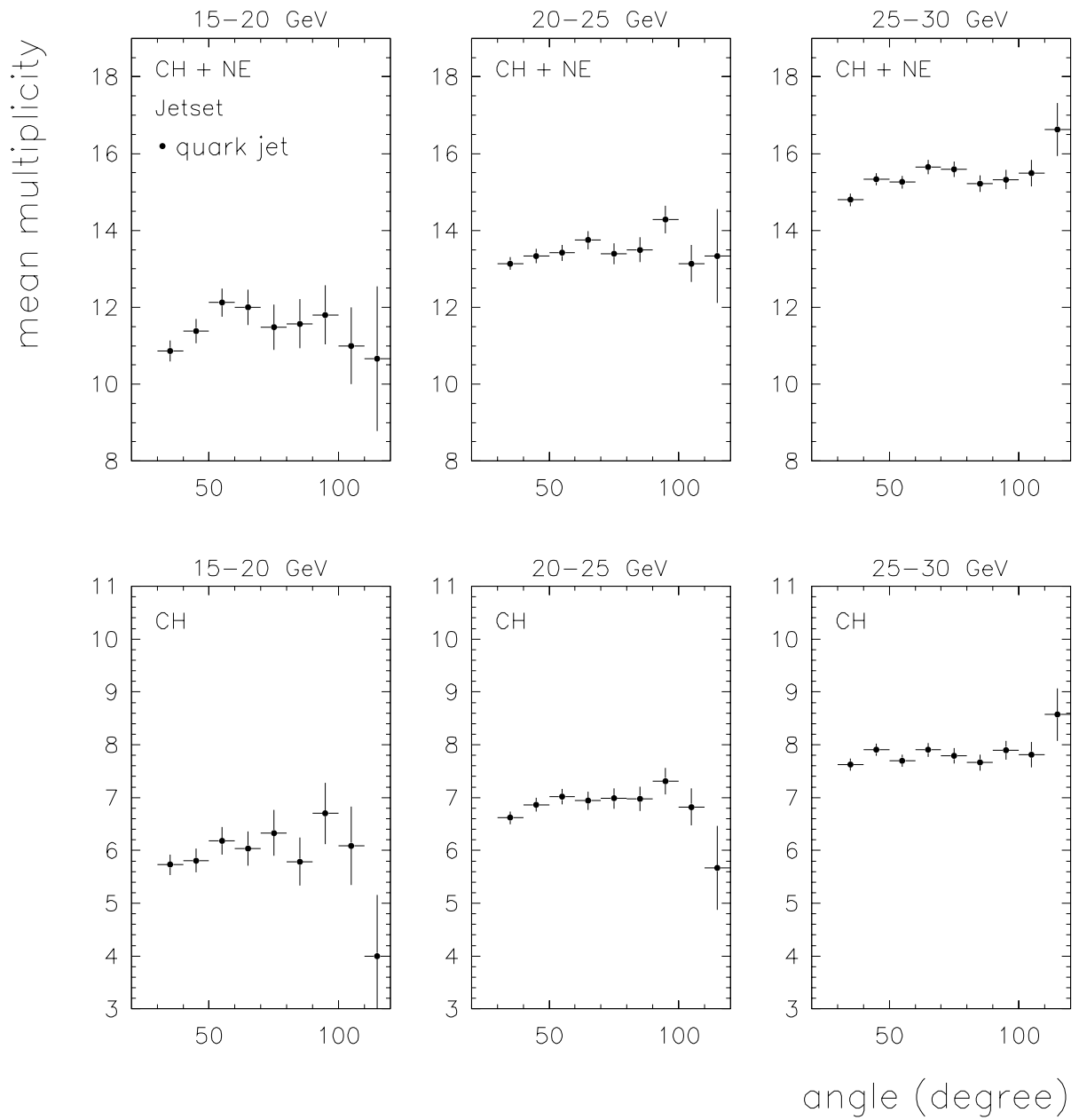**Figure 1.** An illustration of the definition of the 3 jets event shape used in this analysis.

Figure 2. Mean b-quark jet multiplicity as a function of angle, θ_{32}, for 3 jet energy bins between 15 and 30 GeV, for JETSET Monte Carlo data. Both charged plus neutral particles (upper plots) and charged particles (lower plots) only are considered.
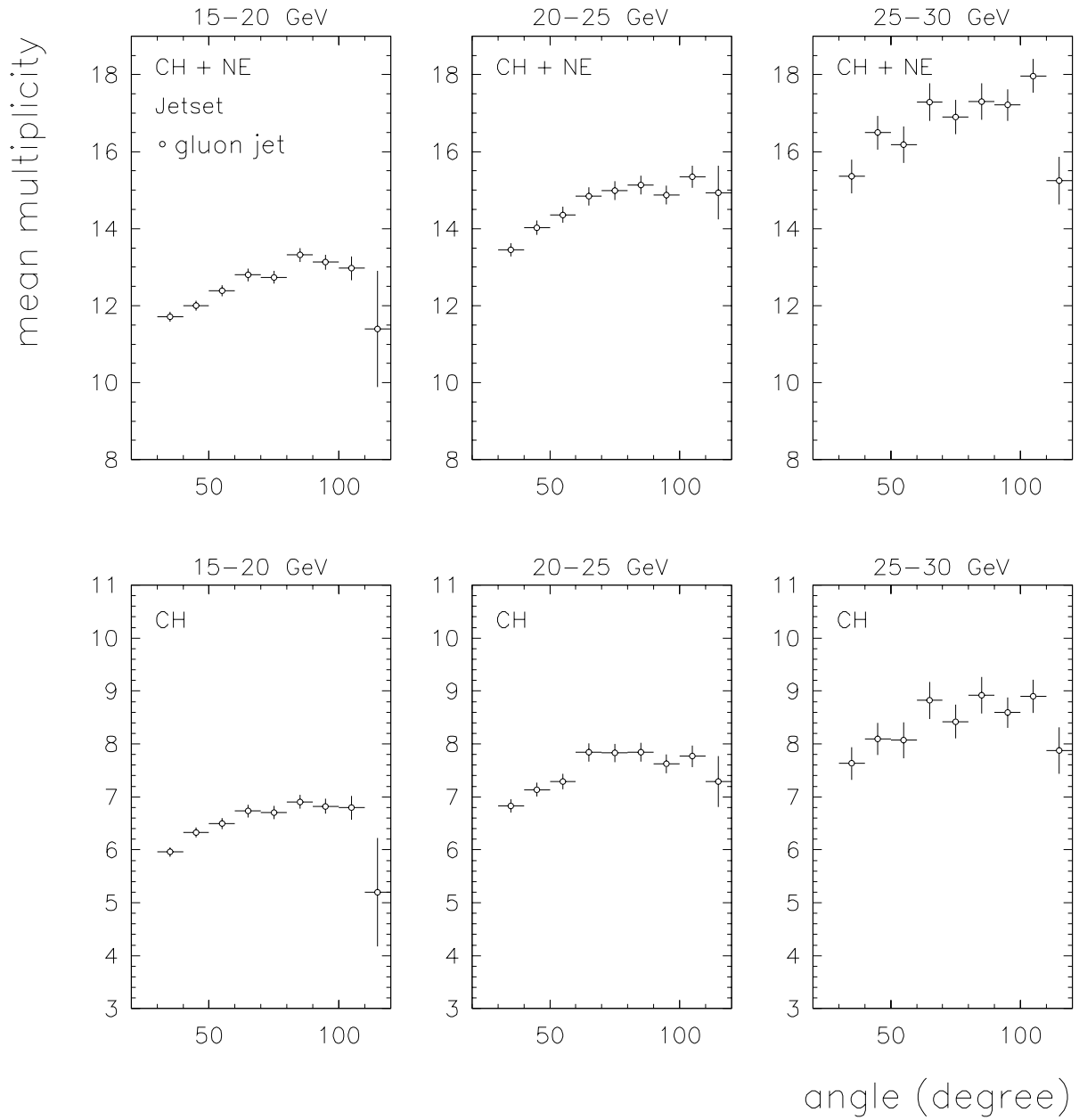
Figure 3. Mean gluon jet multiplicity as a function of angle, θ_{32}, for 3 jet energy bins between 15 and 30 GeV, for JETSET Monte Carlo data. Both charged plus neutral particles (upper plots) and charged particles (lower plots) only are considered.
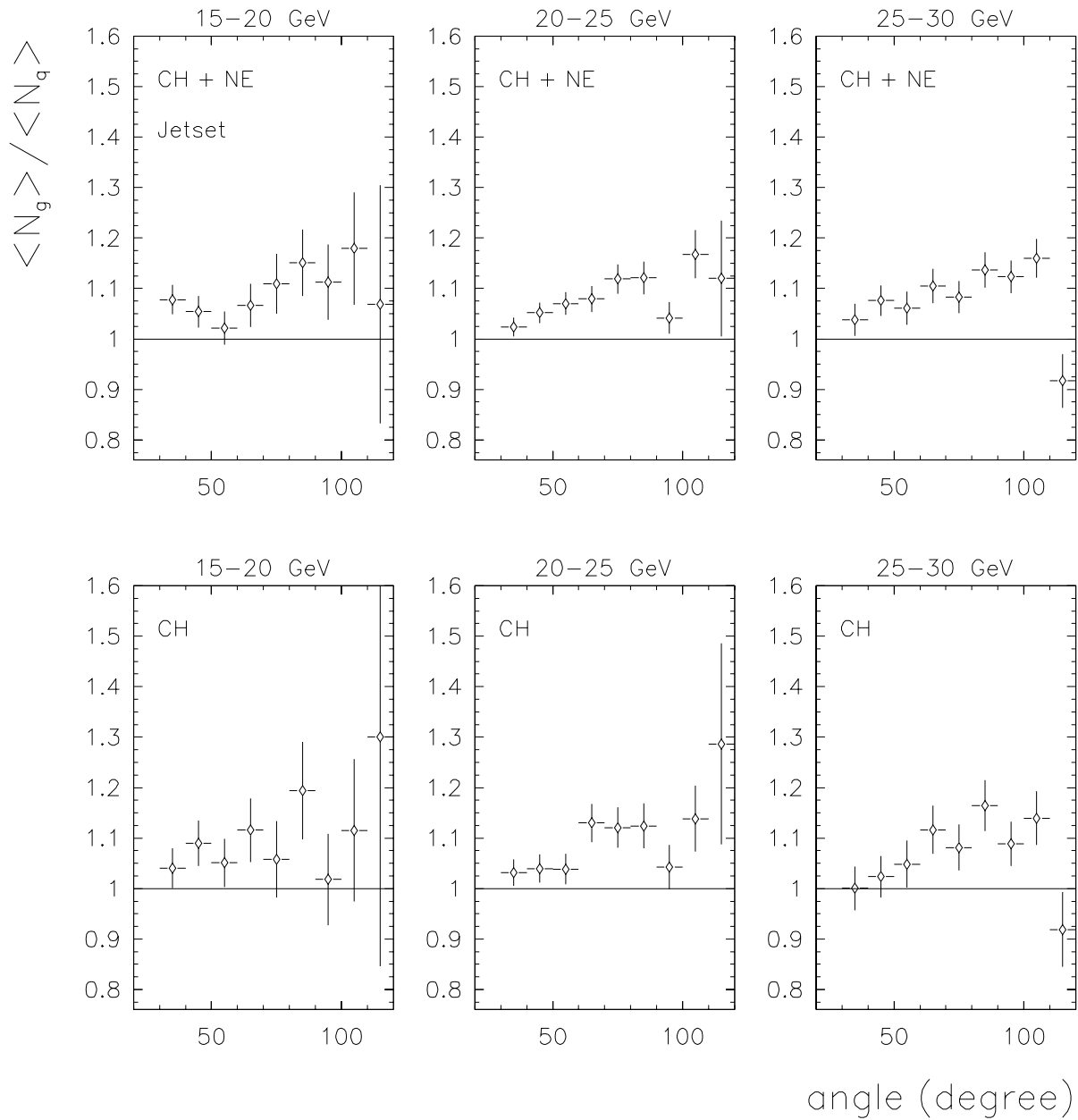
Figure 4. The mean multiplicity ratio of gluon to *b*-quark jet. Upper plots: charged plus neutral particles; lower plots: charged particles only.

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