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A Measurement of Quark and Gluon Jet Differences at the Z^0 Resonance*

THE SLD COLLABORATION*

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ABSTRACT

We have studied differences between quark and gluon jets using 3-jet events in hadronic decays of Z^0 bosons collected by the SLD experiment at SLAC. Gluon jets were identified in symmetric 3-jet events containing one jet tagged as a heavy quark jet and compared with a mixed sample of quark and gluon jets and also with a mixed sample of light quark (u, d and s) and gluon jets. Our preliminary results show that the particle multiplicity in gluon jets is higher than that in light quark jets. These results are in qualitative agreement with QCD expectations. Differences are also observed in particle energy spectra and the jet widths, consistent with QCD expectations.

Global properties of quark and gluon jets are expected to differ in QCD since the color charges of quarks and gluons are $4/3$ and 3 respectively. The gluon self-coupling is stronger than the quark-gluon coupling, therefore the number of soft gluons emitted by a gluon is expected to be greater than that emitted by a quark. In first order QCD, the ratio of parton multiplicities of gluon and quark jets is equal to the ratio of color charges, $9/4$. According to a higher order calculation,² the parton multiplicity ratio is 1.84 ± 0.02 and the hadron multiplicity ratio is reduced to 1.38 ± 0.02 . This implies that particles in gluon jets have a softer energy spectrum and wider distribution of angles with respect to the jet axis than those in quark jets of the same energy. The purpose of this analysis is to search for differences between quark and gluon jets in these properties.

This analysis used about 60% of the data collected by the SLD¹ experiment in 1993. In total, 17,458 hadronic events were selected by criteria described elsewhere.^{3,4} We used symmetric 3-jet events defined as 3-jet events in which the angles between the highest energy jet and each of the two others were approximately the same. The highest energy jet is a quark jet with high probability, and the two lower energy jets are a quark and a gluon jet.

After selecting 3-jet events using the Durham algorithm with y_{cut} value 0.01, each jet was required to have a visible energy greater than 5 GeV and to be in the barrel region, $|\cos\theta_{jet}| < 0.7$. We also required the sum of angles between the 3 jets to exceed

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358° to reject poorly measured events. To select symmetric 3-jet events, we required the angles between the highest energy jet and each of the two others to be within 150 ± 10 degrees. The kinetic energies of the two lower energy jets, calculated from the CM energy and the angles between the jet axes, were equal with 20%. We obtained 304 symmetric 3-jet events after these cuts.

We tagged heavy quark decays using normalized impact parameters, b/σ_b , of charged tracks with respect to the IP, in the plane transverse to the beam. If one of the two lower energy jets in an event contained two or more tracks with $b/\sigma_b > 2$, it was tagged as a heavy quark jet and the remaining lower energy jet was tagged as a gluon jet. We obtained 57 gluon-tagged jets with a purity of $(82 \pm 4)\%$ estimated from a Monte Carlo study (the errors in this study are statistical only). For comparison, we considered a ‘normal mixture’ of quark and gluon jets, consisting of the two lower energy jets of all symmetric 3-jet events, and a ‘light mixture’, consisting of the two lower energy jets of symmetric 3-jet events in which no track has $b/\sigma_b > 2$. The light mixture is a subset of the normal mixture. The numbers of jets in the three samples and their flavor compositions are listed in Table 1.

The visible energy, kinetic energy and average charged multiplicities of the three samples are listed in Table 1. The samples have similar average energies, so can be directly compared. The multiplicity of the gluon-tagged jets is larger than both mixture samples, and the ratio of gluon tagged to light mixture is 1.10 ± 0.07 . Using MC information, pure charged multiplicities of light quark, heavy quark and gluon jets were calculated and listed in Table 2. The charged multiplicity ratio of gluon and light quark jets is 1.36 ± 0.24 . This is consistent with previous results.⁵ The energy spectra of charged particles in the three samples are plotted in Fig. 1(a). Figures 1(b) and (c) show the ratio of the gluon-tagged to the normal mixture and gluon tagged to light mixture respectively. Both ratios are clearly sloped, indicating a softer spectrum in gluon jets as expected. Linear fits to the ratios yield slopes of -0.60 ± 0.27 and -0.65 ± 0.27 , respectively. Distributions of the angles between the jet axis and charged tracks are plotted in Fig. 2(a). In the region between the two lower energy jets, the jets overlap and assignment of tracks can be ambiguous. To avoid this ambiguity, we exclude tracks in the region between the 2 jets. The ratios of distributions for gluon-tagged to the normal mixture (Fig. 2(b)) and for gluon-tagged to the light mixture (Fig. 2(c)) are again sloped. Fitted slopes are 0.0060 ± 0.0026 and 0.0064 ± 0.0026 , respectively. These results are consistent with QCD expectations.

In conclusion, we observed differences in global properties between quark and gluon jets using symmetric 3-jet events. The charged multiplicity ratio of light quark and gluon jets at 24 GeV is 1.36 ± 0.24 . We found that gluon jets have a softer energy spectrum and a wider angle distribution than quark jets. These results are in agreement with QCD expectations.

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Sample	Gluon Tag.	Light Mix.	Normal Mix.
Number of jets	57	354	608
Components(%)			
Light Quark(u, d, s)	15	42	30
Heavy Quark(c, b)	3	9	21
Gluon	82	49	49
Average Visible Energy(GeV)	13.78 ± 0.63	14.20 ± 0.30	14.10 ± 0.19
Average Kinetic Energy(GeV)	24.21 ± 0.42	24.26 ± 0.19	24.29 ± 0.12
Average Charged multiplicity	7.97 ± 0.43	7.24 ± 0.19	7.31 ± 0.12

Table 1. Summary of the three samples.

Jet type	Gluon	Light Quark	Heavy Quark
Charged multiplicity	8.34 ± 0.65	6.11 ± 0.98	6.63 ± 1.05

Table 2. Corrected Charged multiplicities

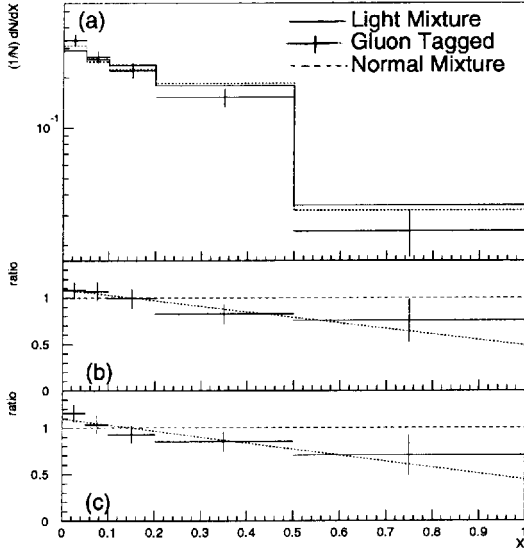


Fig. 1. a) Distributions of scaled energy $X = E/E_{jet}$ for the three samples. b) Ratio of the gluon-tagged and the normal mixture. c) Ratio of the gluon-tagged and the light mixture.

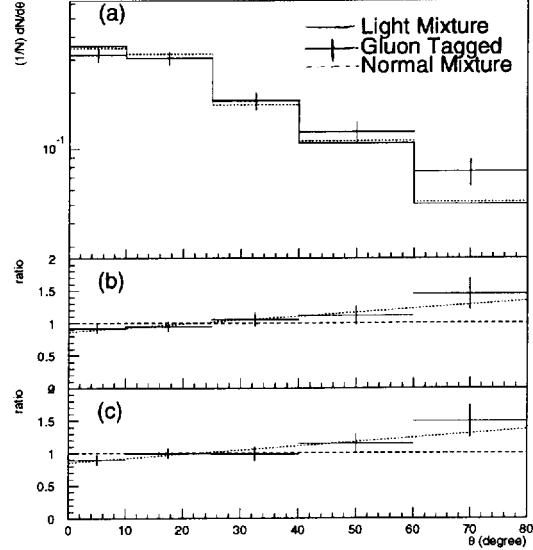


Fig. 2. a) Distributions of angles between the jet axis and charged tracks for the three samples. b) Ratio of the gluon-tagged and the normal mixture. c) Ratio of the gluon-tagged and the light mixture.

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