A Study of the Charge of Leading Hadrons in Gluon and Quark Fragmentation

Martin Siebel
Fachbereich C, Bergische Universität Wuppertal,
42097 Wuppertal, Germany

In this study the electric charges of leading systems in quark and gluon jets from hadronic three-jet events in $e^+e^-$-annihilation measured with the DELPHI-experiment are examined. Leading systems are defined by a rapidity gap between the leading system of a jet and the rest of the event. The measured charge distributions are compared with results from Monte-Carlo simulations which do not contain colour-octet neutralisation processes. In the data an enhanced production of neutral leading systems compared to Monte-Carlo predictions is found in gluon jets, which is compatible with the expectations from colour-octet neutralisation. The quark jet sample is found in agreement with the simulation.

1 Introduction

The existence of hadrons which contain gluons as valence particles is one of the possible features of QCD which has not yet been experimentally verified. The production of these particles requires a process in which colour charges are balanced via colour-octet charges of gluons. This process should especially occur in gluon rich environments as e.g. in gluon jets from hadronic three-jet events in $e^+e^-$-annihilation. However, this colour-octet neutralisation process is expected to be obscured by higher order colour-triplet neutralisation processes. It has been suggested to investigate jets with a large gap in rapidity between the leading system and the bulk of the jet. The presence of a rapidity gap is a signature of an early colour decoupling of the leading system from the rest of the event. Due to the early decoupling, higher order triplet processes are suppressed and the effects of colour-octet neutralisation are expected to be observable.

Current fragmentation models only consider the neutralisation of colour charges via the production of quark-antiquark pairs, i.e. colour triplet neutralisation. Due to the production of different quark flavours, the leading system is allowed to have charges of +1, 0 and -1 in lowest order. Colour octet neutralisation on the other hand only allows for neutral leading systems, as gluons do not carry an electric charge. The expected signature of colour-octet neutralisation
is therefore a higher fraction of neutral leading systems in gluon jets than it is predicted by Monte-Carlo models which only account for colour-triplet neutralisation.

2 Data Analysis

The data analysed for this study\textsuperscript{2} have been recorded with the DELPHI-experiment at LEP in the years 1994-95 with a center-of-mass energy of $\sqrt{s} = 91.2$ GeV. After applying cuts to select well-measured hadronic events, three-jet events have been selected using the Durham-algorithm\textsuperscript{3} with $y_{\text{cut}} = 0.015$. Additional cuts to provide clearly separated jets leave 314000 selected events.

Gluon and quark jets are identified in an implicit way assuming that the most energetic jet of an event (jet 1) is a quark jet and the least energetic jet (jet 3) is the gluon jet. This method provides purities $\geq 90\%$ for the quark jet sample and $\sim 70\%$ for the gluon jet sample. Alternatively, gluon jets are identified for cross-check reasons using a tagging technique in events with initial $b$-quarks raising the gluon jet purity to 88%. Details about the tagging procedure and the applied cuts are given elsewhere\textsuperscript{4}. The leading system of a jet is defined by the requirement that all charged particles of the jet have a rapidity larger than a given cut-value $\Delta y$. For central results $\Delta y = 1.5$ is chosen. The inclusion of neutral particles in the rapidity gap definition does not affect the results of this analysis.

The production of rapidity gaps is suppressed more strongly in the fragmentation of gluons than in the fragmentation of quarks. This leads to a depletion of the gluon jet contribution to a given jet sample when a rapidity gap is demanded. The purity of the gluon jet sample in dependence of the size of the rapidity gap has been obtained from Monte-Carlo simulation. Additionally, the gluon jet purity has been deduced from the reduction rate of the three explicitly tagged jet samples (gluon jets, $b$-jets, untagged) when a rapidity gap is demanded. The gluon jet purity with a rapidity gap of $\Delta y = 1.5$ taken from Monte-Carlo (calculated from the reduction rate) is 47.2\% (47.4\%) for the gluon jet sample defined by energy ordering and 82.0\% (80.4\%) for the explicitly tagged gluon jet sample. The purities obtained with both methods are in good agreement.

The data are compared to three different Monte-Carlo models: \textsc{Jetset}\textsuperscript{5} with and without simulated Bose-Einstein correlation (BEC) and \textsc{Ariadne}\textsuperscript{6} without BEC. Mesons of the same charge are pulled closer together due to the Bose-Einstein correlation. This can affect the charge distribution of the leading systems. As the magnitude of this disturbance is not known, the Monte-Carlo model with BEC is taken into account to study systematic effects. Differences in the deviation from the Monte-Carlo models are included in the systematic error of this study.

The generated events are processed with a full simulation of the DELPHI-detector and the analysis chain described above before they are compared to the data.

3 Results

In Fig.\textsuperscript{1} the distributions of the sum of charges ($SQ$) in the leading systems in gluon jets (left) and quark jets (right) with a rapidity gap of $\Delta y = 1.5$ are shown. The jets are identified by energy ordering. The solid histograms indicate the distributions obtained from the \textsc{Ariadne} Monte-Carlo simulation. The distribution for quark jets is well described by the Monte-Carlo simulation while for gluon jets the occurrence of neutral leading systems is underestimated by the simulation. This is the expected behaviour, if colour-octet neutralisation is present in the data. In the two lower plots of Fig.\textsuperscript{1} the difference between the $SQ$-distributions from data and Monte-Carlo are shown. The surplus of neutral leading systems in gluon jets is an effect of $\sim 3\sigma$, while the difference seen in the quark jet sample is compatible with zero.

In order to study the dependence of the effect on the chosen rapidity gap size, the relative deviation $R(\Delta y) = (P_{\text{data}}(SQ = 0) - P_{\text{MC}}(SQ = 0))/P_{\text{MC}}(SQ = 0)$ between data and simulation
Figure 1: **Top:** The distributions of the charges of leading systems in gluon (left) and quark (right) jets compared to the predictions of the Ariadne Monte-Carlo model (solid lines). **Bottom:** The difference between data and Monte-Carlo.

Figure 2: The dependence of the relative difference between data and Monte-Carlo simulation in gluon jets (left) and quark jets (right) as a function of $\Delta y$ for the three Monte-Carlo models Jetset with BEC (model 1), Jetset without BEC (model 2) and Ariadne without BEC (model 3).
is studied for several values of $\Delta y$. In Fig. 2, $R(\Delta y)$ is shown for all three used simulations using jets identified by energy ordering. A nearly linear increase of $R$ with $\Delta y$ can be observed for gluon jets while $R$ stays constant and compatible with zero for quark jets. However, the Monte-Carlo model including BEC shows a non-vanishing value for $R$ in gluon jets also for $\Delta y = 0$. The slope of $R(\Delta y)$ is roughly the same for all three models studied. The discrepancy introduced due to BEC seems therefore to be independent of of the rapidity gap size. In order to eliminate this influence of the BEC on this study, the variable $R'(\Delta y) = R(\Delta y) - R(0)$ is studied, where the difference obtained with a given simulation at $\Delta y = 0$ is subtracted from the $R$-values obtained with this simulation. The $R'$ values obtained for all three simulations are in good agreement for a given $\Delta y$, remaining differences are added to the systematic error.

The results obtained with the explicitly tagged gluon jet sample are consistent with the observations described above. Due to the higher gluon purity, the effect is roughly two times the size of the effect in the energy ordered gluon jet sample as it is expected from colour-octet neutralisation. However, due to the limited statistics of tagged gluon jets, the statistical error increases, leaving the effect less significant in this sample than in the gluon jet sample obtained by energy ordering. Using the gluon jet sample purities obtained as described in Sect. 2, the size of the effect in a pure gluon jet sample can be calculated. The differences of $R'$ values and estimated gluon purities between the 3 models are included in the systematic error giving

$$R'(\Delta y = 1.5) = 0.10 \pm 0.02_{\text{stat}} \pm 0.03_{\text{syst}}$$

(1)

for a pure gluon jet sample. While a variation of the event reconstruction quality and the track finding efficiency have no significant effect on the result, a variation of the parameters of the Monte-Carlo simulation, where different sets of tuned parameters have been used, leads to an uncertainty of $\pm 0.025$ on $R'$, which is included in the given systematic uncertainty. In order to check, if the good agreement between data and Monte-Carlo found in the energy ordered quark jet sample is mainly due to very hard tracks in the leading jet, only tracks with $p \leq 30$ GeV have been taken into account with no effect on the observed agreement.

The overproduction of neutral leading systems is only observed in gluon jets, the effect increases with higher gluon jet purity and with increasing rapidity gap size. All findings are in agreement with the expectations for colour-octet neutralisation in gluon jets.

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