STUDY OF HADRONIC DECAYS OF THE Z BOSON AT LEP

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This report summarizes four recent papers on the characteristics of the hadronic decays of the Z by the LEP collaborations ALEPH, DELPHI and OPAL.

1 Introduction

Each of the four LEP experiments has recorded around 4 million hadronic Z decays, mostly in the period between 1990 and 1995. The analysis of the main physics topics on this subject has been essentially completed, but a few specific points are still under investigation, especially in the QCD sector.

This report summarizes four recent papers on the characteristics of the hadronic decays of the Z, submitted to this conference by the LEP collaborations OPAL, ALEPH and DELPHI.

2 Charged multiplicities in Z decays into u, d, and s quarks

Flavour independence is a fundamental property of QCD: a breaking of the flavour symmetry should only occur due to (calculable) mass effects. An observable for testing flavour independence is the multiplicity of charged hadrons in jets originating from quarks of a specific flavour. For the light (u, d, and s) quarks the mass effects are expected to be negligible at LEP energies. OPAL presents a new, high statistics investigation of the flavour dependence of the strong interaction based on the mean charged multiplicity determined separately for events of primary u, d, s quarks and the type of the hadron carrying the largest momentum. Three different selections are based on $K_0^0$, $K^\pm$ and highly energetic charged particles. Leading $K_0^0$ and $K^\pm$ are likely to contain a primary s quark from the Z decay. To a lesser extent, due to the requirement of $s\bar{s}$ quark pair creation during hadronization, leading $K_0^0$ and $K^\pm$ should also emerge from primary d and u quarks, respectively. In a sample with large momentum (non identified) charged particles, events of primary u, d and s quarks are expected to be found in approximately equal proportions.

By requiring a $K_0^0$ with momentum fraction $x_p = p/p_{beam}$ larger than 0.4, 19,359 events are selected with $58\%$ Z $\rightarrow s\bar{s}$ and $16\%$ Z $\rightarrow d\bar{d}$. By requiring a $K^\pm$ with $x_p > 0.5$, 18,979 events are selected with $54\%$ Z $\rightarrow s\bar{s}$ and $22\%$ Z $\rightarrow u\bar{u}$. By requiring a charged particle with $x_p > 0.7$, 27,909 events are selected almost equally populated in $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$, but with only $4\%$ heavy quarks.

The presence of a large momentum particle biases the multiplicity. To reduce this bias, the multiplicity measurement was performed in the hemisphere opposite to the one containing the particle used for the tagging. The final corrected multiplicities are

\[
< n >_{u\bar{u}} = 17.77 \pm 0.52(stat)^{+0.86}_{-1.20}(sys)
\]

\[
< n >_{d\bar{d}} = 21.44 \pm 0.69(stat)^{+1.46}_{-1.17}(sys)
\]

\[
< n >_{d\bar{s}} = 20.02 \pm 0.14(stat)^{+0.39}_{-0.37}(sys),
\]

where the $u\bar{u}$ and $d\bar{d}$ multiplicities are statistically anticorrelated (about $-89\%$). The systematic error is dominated by uncertainties on the fragmentation. The multiplicities...
are consistent in 1.8σ for the \(ud\) case, in 1.5σ for \(us\), and in 0.9σ for \(ds\). The world average of the charge multiplicity (for all flavours) is 21.07 ± 0.11.

The multiplicities were transformed into \(\alpha_S\) ratios using a NLLA calculation. Ratios of \(\alpha_S\) for the light quark flavours were found consistent with 1 at a precision of 5 to 9%, superior to earlier investigations.

### 3 Results on identified hadrons

The description of the hadronization process in QCD is connected with confinement and requires nonperturbative methods which are not available. Measurements of identified hadron spectra in \(e^+e^-\) improve the understanding of hadronization, and allow tuning the free parameters in the QCD inspired Monte Carlo models. Being closer to the main event, vectors and higher order resonances are of particular interest.

More insights into the hadronization process may be obtained from the analysis of quark and gluon jets separately.

#### 3.1 Production of \(\omega(782)\)

ALEPH presents a measurement of the inclusive momentum distributions of the \(\omega(782)\) meson. The \(\omega\) cross section is extracted using the invariant mass distribution of \(\pi^+\pi^-\pi^0\) triplets.

The average \(\omega\) rate per event is

\[
< \omega > = 0.996 \pm 0.032 (stat) \pm 0.056 (sys),
\]

below the predictions of JETSET 7.4 (1.31) and HERWIG 6.1 (1.17) over the full momentum spectrum. This measurement improves substantially the world average of 1.08 ± 0.09.

The muonic branching fraction of the \(\omega(782)\) is measured for the first time:

\[
BR(\omega \rightarrow \mu^+\mu^-) = (9.8 \pm 2.9 \pm 1.1) \times 10^{-5}.
\]

#### 3.2 Production of \(\pi^0, \eta, \eta'(958), K_S^0\) and \(\Lambda\) in 2- and 3-jet events

For isoscalar mesons (\(\eta, \eta'(958), \omega(782), \phi(1020)\)), some theoretical models predict a special enhancement in gluon jets compared to quark jets. L3 found that the measured momentum spectrum in gluon jets is harder than in HERWIG and JETSET.

In a new analysis, ALEPH measures the production rates of \(\pi^0, \eta, \eta'(958), K_S^0\) and \(\Lambda\) in hadronic events, two-jet events and each jet of three-jet events.

Jets are clustered using Durham with \(y_{cut} = 0.01\); this classifies 31% of the events as 3-jet. The lowest energy jet originates from a gluon with 71% probability.

The \(\pi^0\) and \(\eta\) mesons are analyzed using the \(\gamma\gamma\) decay channel, and the \(\eta'\) using \(\eta' \rightarrow \eta\pi^+\pi^-\). \(K_S^0\) are reconstructed from their decay into \(\pi^+\pi^-\), and \(\Lambda\) into \(p\pi^-\).

The spectra for \(\pi^0\) are reasonably reproduced by JETSET and HERWIG. \(\eta\) and \(\eta'(958)\) are well reproduced by JETSET for quark jets and gluon jets. Therefore, the JETSET description of gluon fragmentation into isoscalar mesons is in agreement with the experiment. HERWIG shows a too steep dependence on \(x_P\) for \(\eta\) spectra in two-jet events and each jet of three-jet events.

The spectra for \(K_S^0\) and \(\Lambda\) are well reproduced by JETSET and ARIADNE, while HERWIG fails.

### 4 Rapidity-rank structure of \(p\bar{p}\)

The baryon sector is not well modeled by current QCD-inspired Monte Carlos; only the string fragmentation model JETSET can reproduce the octet and decuplet rates.

In JETSET hadrons results from breaks in the string stretched between the primary quarks. Baryons are formed when diquark-antidiquark pairs are created, and couple to an adjacent (anti)quark. A mechanism to attenuate the strict rapidity ordering coming from this mechanism is the so-called pop-
corn: a meson “pops up” inside a diquark–antidiquark pair.

To study the relative occurrence of popcorn, DELPHI proposes a novel method based on the rapidity–rank structure of \( p\bar{p} \) pairs, where rapidity is defined with respect to the thrust axis.

Proton identification is provided by Cherenkov angle measurement from the RICH and ionization energy loss in the TPC. The number of events with one \( p \) and one \( \bar{p} \) in each hemisphere is 27.6 thousand. The background to this event sample can be determined from the number of events that have two \( p \)'s or two \( \bar{p} \)'s in a given hemisphere. These events, 10.1 thousand, result mainly from misidentifications, but also from non-correlated baryon pairs, and they are subtracted from the signal.

The charged particles in each event are ordered in rapidity. Two types of rapidity–rank configurations for \( p\bar{p} \) pairs are considered: (a) when the \( p \) and \( \bar{p} \) are adjacent in rapidity; (b) when the \( p \) and \( \bar{p} \) have one or more mesons between them. The ratio \( R = N(pM\bar{p})/(N(p\bar{p}) + N(pM\bar{p})) \) is calculated, where \( N(p\bar{p}) \) and \( N(pM\bar{p}) \) represent the number of rapidity–rank configurations of each type in the data sample, and are implicitly a function of the minimum distance \( \Delta y_{\text{min}} \) between a baryon in the pair and a meson. The probability that a given rapidity configuration will represent the actual rank order on the string is enhanced as \( \Delta y_{\text{min}} \) is made larger.

The ratio \( R(\Delta y_{\text{min}}) \) for data is plotted in Figure 1 and compared to the predictions in the cases of no popcorn and 100% popcorn. The data are consistent with no contribution from \( pM\bar{p} \) configurations. An upper limit contribution of 15% is determined at 90% confidence level.

Previous studies of the \( \Lambda\bar{\Lambda} \) rapidity difference have claimed evidence for popcorn. This might indicate the importance of dynamical effects not incorporated in JETSET or simply the inadequacy of the popcorn model, although no firm conclusion can be drawn yet.

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