A search is performed in symmetric 3-jet hadronic Z decay events for evidence of colour singlet exchange and for colour reconnection effects predicted by the Rathsman model. Asymmetries in particle flow and the angular separation of particles are found to be sensitive to such effects. 95% upper limits of 7-9% are found for the fraction of colour singlet exchange, and of 0.93% for the colour reconnection parameter $R_0$ (default value 0.1) of the Rathsman model.

1 Introduction

Events with large rapidity gaps, attributed to colour singlet exchange (CSE), have been observed at HERA\textsuperscript{1} and the TEVATRON\textsuperscript{2}. By crossing symmetry, we may expect similar gaps in three jet hadronic Z decays (figure 1). Large rapidity gaps have been observed in 1-2% and $\simeq$10% of events with two high $p_t$ jets at the TEVATRON and HERA respectively. The ‘gap survival probability’ due to overlap with particles produced in the underlying event has been estimated\textsuperscript{3} to be about 20% at the TEVATRON. An advantage of the Z decay study is the absence of this suppression factor as there is no underlying event. This study, performed by L3\textsuperscript{4}, searches

\textsuperscript{a}Talk presented at the XXXVII Rencontre de Moriond (QCD), Les Arcs, March 2002
for such gaps by exploiting differences in colour flow, in 3-jet events, between Cse and colour octet exchange (COE): in the latter colour flow is present between the qg and qg gaps and is inhibited by destructive interference in the qg gap, while in the former case colour flow occurs predominantly in the qg gap (figure 2). For this study, the Jetset Parton Shower program

![Colour Octet](image1)

![Colour Singlet](image2)

Figure 2: Colour flow in COE (left) and Cse (right) shown by dotted lines.

5 has been used to model COE. Two simple models have been used to simulate the expected colour flow in Cse: events of type qgγ with a photon effective mass as in the gluon jet mass distribution are generated, and the photon is then replaced by a boosted quark dijet (model CS0), or by a gluon fragmenting independently (model CS2). The Rathsman6 model, tuned7 to L3 hadronic Z decay data b, is also studied.

2 Methodology

![Jet 1](image3)

![Jet 2](image4)

Figure 3: Definitions of numbers of particles in inter-cone gaps (left) and angles relative to gap bisector (right).

Three jet events are selected at jet resolution parameter, 0.05, using the Jade algorithm8, with inter-jet angles within ±30° from the symmetric Mercedes topology. Particle momenta are projected onto the event plane defined by the two most energetic jets, and then all the angles (measured from most energetic jet) are rescaled so as to align jets at 0°-120°-240° for uniformity in event-to-event comparison. To quantify the inter-jet gap angle, two definitions are used: the minimum opening angle of the particles measured from the bisector in each

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5 A preliminary tuning has been performed for three different values of the colour recombination parameter: \(R_0 = 0.037, 0.1, 0.2\). The default value of 0.1 was obtained by fitting the model to H1 data on the diffractive proton structure function6.
gap, \( B_{ij} = \min(\phi_{ij}^1, \phi_{ij}^2) \), \((B\text{-angle, figure 3})\). To minimise fragmentation bias, cones of half angle 15\(^\circ\) around the jet-axis are removed in the definition of the gaps. Assigning jets 1, 2 to primary quarks, and introducing the generic variable for the gap between jets \( i, j \) as \( \theta_{ij} \) \((i, j = 1, 3)\), where \( \theta_{ij} \) may be the number of particles in the gap, \( N_{ij} \), \( B_{ij} \) (see figure 3) or \( S_{ij} \), \((S\text{-angle})\), the \textit{gap asymmetries} are defined as: \( A_{12} = (-\theta_{12} + \theta_{23} + \theta_{31})/(\theta_{12} + \theta_{23} + \theta_{31}) \), and cyclically for the other gaps. Reduced colour flow and thereby larger separation for \( C_{\text{se}} \) in gaps 23, 31 (together referred to as qg) with respect to gap 12, should thus make \( A_{12} \) peak more strongly at positive values for \( C_{\text{se}} \) than for \( C_{\text{oe}} \). The angular asymmetries, in particular that using the bisector angle, are found to be more sensitive in separating \( C_{\text{se}} \) and \( C_{\text{oe}} \) contributions than those using \( N_{ij} \).

![Figure 4: Minimum bisector angle gap asymmetries for gaps 12 and qg.](image)

### Results

The analysis is performed with 2 million hadronic Z decay events recorded by the L3 detector during 1994-95. In order to distinguish quark jets from gluon or colour singlet jets, quark jets are tagged by demanding that the b-tag discriminants\(^{\text{c}}\) of jets 1 and 2 are above a certain cut-off \((B_1 = 1.25)\) and that of jet 3 is below a second cut-off \((B_2 = 1.5)\). This optimised selection tags 2668 events with a gluon purity of 78\%. The asymmetries are calculated using calorimetric clusters with at least 100 MeV in the electromagnetic calorimeter and either at least two crystals hit or at least 900 MeV in the hadron calorimeter, or, no energy deposit in the electromagnetic calorimeter, and more than 1800 MeV in the hadron calorimeter. As a cross-check, the analysis was repeated using only charged tracks with \( p_t > 100 \) MeV. The \( B_{ij} \) asymmetry distributions, corrected for detector effects as well as flavour composition, are compared to different models, all normalized to unit area, in figure 4. The bin-by-bin correction factor typically lies in the range of \( \pm 20\% \). The fractional bin-by-bin systematic errors were estimated by using the \textsc{Durham} \((k_{\perp})\)

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\(^{\text{c}}\)The jet b-tag discriminant is defined as: \( B_{\text{jet}} = -\log_{10} P \) where \( P = P_i^n \sum_{j=0}^{n-1} (-\ln P_i)^j/j! \) and \( P_i^n = \prod_{i=0}^n P_i \). Here, \( P_i \) is the probability that the \( i \)-th particle in the jet originates at the primary vertex.
algorithm$^9$ with $y_{\text{cut}} = 0.01, 0.02$ instead of the JADE one, giving $\sim 4\% - 7\%$, and by changing the b-tag cuts so that the gluon purity varies by $\pm 10\%$ resulting in an error of $\sim 3\%-8\%$. These errors are added in quadature. Changing the jet cone angle from $15^\circ$ to $20^\circ$ is found to have no effect on the angular asymmetries. The data are consistent with COE as modelled by JETSET. The probability for having a $\chi^2$ greater than the observed value between data and the RATHSMAN model with the default colour reconnection parameter value $R_0 = 0.1$ is $\mathcal{O}(10^{-6})$. Fits to data with admixture of a fraction of CSE to COE are consistent with zero admixture. Making a combined fit to the asymmetries between gaps 12 and $qg$, the upper limit of the fraction of CSE present in data, obtained with the CS0 or CS2 models, is estimated to be between $7\%$ and $9\%$ at $95\%$ confidence level. A similar fit for the parameter $R_0$ of the Rathsmann model, using the $B_{ij}$ asymmetries, yields a $95\%$ confidence level upper limit on the former of 0.0093. This implies a very small mass shift for the W due to colour reconnection effects, in this model, of a few MeV. For the default value, $R_0 = 0.1$, the mass shift for decay of W-pairs into four jets is about 65 MeV$^6$. It is clearly then of interest to perform a similar analysis using other colour reconnection models (for example ARIADNE$^{10}$) applicable both to Z and W-pair decays. Since the fraction of colour singlet exchange expected, on the basis of the TEVATRON measurements, is only 5-10\%, after allowing for the effect of gap survival probability, the present analysis is not sufficiently sensitive to confirm or exclude a similar effect in hadronic Z-decays. A LEP combination, and/or an analysis with higher statistics using asymmetric 3-jet events is then desirable.

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References

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