Charm and Strange Quark Asymmetry at the Z^0 Pole in DELPHI

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Abstract

A measurement of the c and s quark forward-backward asymmetry is presented, based on the multihadronic events collected by the DELPHI detector at LEP during 1991 and 1992. The initial quark is tagged by the presence of a D^{*+} in the case of c and a high momentum Λ or K^0_L in the case of s. The experimental results are $A^c_{FB} = 0.066 \pm 0.026$ (stat) ± 0.009 (syst) and $A^s_{FB} = 0.129 \pm 0.056$ (stat) ± 0.038 (syst).

1 Introduction

At the Z^0 pole the forward-backward asymmetries in the differential cross section $d\sigma/d\cos\theta$ for the process $e^+e^- \to f\bar{f}$ result from the interference of vector and axial vector couplings of the initial and final state fermions to the Z^0 boson. In the framework of the Standard Model the integrated Born asymmetry is given by:

$$A_{FB}^f(M_Z^2) \approx \frac{3}{4}\frac{2v_e a_e}{v_e^2 + a_e^2} \cdot \frac{2v_f a_f}{v_f^2 + a_f^2} . \quad (1)$$

The vector and axial vector couplings of the fermions are defined by $v_f = I_3^f - 2 \cdot Q_f \cdot \sin^2\theta_W$ and $a_f = I_3^f$, where Q_f and I_3^f denote the charge and weak isospin of the fermions. The indices e and f refer to the initial electron and final fermion, respectively.

A tagging of the primary quark flavour, direction and charge is needed in an experimental measurement of the quark asymmetries in the Z^0 multihadronic events. This can be done either by using global features of the multihadronic event or by reconstructing a characteristic particle in the event. This contribution presents a precise measurement of the charm quark asymmetry and a first measurement of the strange quark asymmetry at the Z^0 pole. Techniques to separate events with different primary $q\bar{q}$ pairs are discussed.

2 Charm asymmetry

The forward-backward asymmetries for the processes $e^+e^- \to c\bar{c}$ and $e^+e^- \to b\bar{b}$ at $\sqrt{s} = m_Z$ can be measured from the polar angle ($\cos\theta$) distribution of charged D^* mesons. The charge of the $D^{*\pm}$ is directly correlated to the primary quark. A D^{*+} is identified through its decay into $D^\circ\pi^+$, where the D° is reconstructed in the decay modes $K^-\pi^+$, $K^-\pi^+\pi^\circ$ and $K^-\pi^+\pi^-\pi^+$. Particle identification provided by the DELPHI Ring Imaging Cherenkov Counter (RICH) and the Time Projection Chamber (TPC) is used to veto the kaon candidates against pion hypothesis. The D^0 decay length is obtained from the measured decay vertex using the DELPHI Micro Vertex Detector (VD). No π° reconstruction is performed for the $K^-\pi^+\pi^\circ$ decay mode, where the satellite peak at 1.62 GeV/c^2 is used to identify the D° candidates.

In 905,000 selected hadronic events, taken in 1991 and 1992 with the DELPHI detector at LEP, 4828 $D^{*+} \to D^\circ\pi^+$ decays at a scaled energy $X_E = E/E_{beam}$ above 0.2 are reconstructed. Only events at $\sqrt{s} = m_Z$ enter the analysis because of the strong energy dependence of the forward-backward asymmetry expected in the standard model. For the measurement partially reconstructed D^{*+} mesons and reflections from other decay modes (see figure 1) have to be considered as signal to avoid charge correlations in the background. This leads to a significant increase of the sample, especially in the $K^-\pi^+\pi^\circ$ distribution.

For a measurement of $A_{FB}^{c\bar{c}}$ and $A_{FB}^{b\bar{b}}$ it is necessary to separate D^{*+} from c and b primary quarks and from combinatorial background. Expecting the c and b asymmetry to be of comparable size and to have the same relative sign, the statistical precision of the measurement is limited by the negative correlation between the two asymmetries. A good separation, leading to a relatively small correlation, is obtained using the scaled energy distribution X_E of the D^{*+} candidates and the D° decay distance to distinguish between the different classes (see figure 2) in an unbinned maximum likelihood fit to the D^{*+} samples. A further constraint on the background is obtained from the sidebands in the mass difference distribution, assuming the background to be flat in the signal region. Due to the acceptance for D^{*+} mesons and background being different at small and large polar angles, the fit method has to account for the $|\cos\theta|$ distribution of the classes.

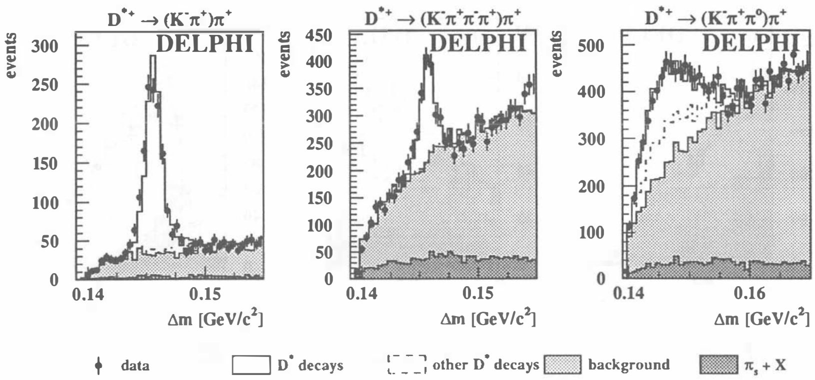

Figure 1: *Mass spectra of* D^* *decay modes,* $X_E > 0.2$

The asymmetry for a fixed polar angle determines the contribution to the log likelihood according to the three classes:

$$\mathcal{L} = -ln \prod_{j=1}^{N_{Data}} \sum_{class=1}^{3} P_{class,j}\frac{1}{2}\left(1+\frac{8}{3}A_{FB}^{class}\frac{\cos\theta}{1+\cos^2\theta}\right) . \quad (2)$$

The probability P_{class} for being c, b or background is calculated from the density of Monte Carlo events around each data event in the space given by the mass difference, energy, polar angle and D° decay distance distributions. The effective D^{*+} asymmetry observed in bottom events has to be corrected for mixing of neutral B mesons. Since the D° decay length is used to separate charm and bottom events, the time dependence of the $B_d^\circ - \bar{B}_d^\circ$ oscillation effect, needs to be taken into account:

$$A_{FB}^{b\bar{b},mix} = (1-2\chi)\cdot A_{FB}^{b\bar{b}} \quad \text{with} \quad \chi(\Delta L) = \frac{1}{2}\left\{1-\cos\left(\frac{\Delta m}{\Gamma}\cdot\frac{\tau}{\tau_{B_d^\circ}}\right)\right\} . \quad (3)$$

The individual contributions to the D^{*+} production from different B decays are obtained from the Lund model predictions implemented in the JETSET 7.3 Parton Shower Monte Carlo program [1] (JETSET PS in the following) by taking into account the production of mesons with angular momentum $L = 1$. A three parameter fit to the data yields [2]:

$$A_{FB}^{c\bar{c}} = 0.082 \pm 0.029\,(\text{stat}) \pm 0.012\,(\text{syst}) \text{ and } A_{FB}^{b\bar{b}} = 0.035 \pm 0.058\,(\text{stat}) \pm 0.023\,(\text{syst}) , \quad (4)$$

with a statistical correlation of −38%. The background asymmetry is found to be $A_{FB}^{back} = 0.000 \pm 0.009$ (stat). The main contributions to the systematic error are given by the uncertainty due to the fit method and the correction for the lifetime oscillation of neutral B mesons. The influence on the charm asymmetry due to the error of $A_{FB}^{b\bar{b}}$ is reduced by constraining the b asymmetry to the value measurement using semileptonic decays [3]. This asymmetry $A_{FB}^{b\bar{b}} = 0.075 + 0.096 \cdot A_{FB}^{c\bar{c}}$ is corrected for the effective mixing at LEP using the average value $\chi_{eff}^{l} = 0.115 \pm 0.009 \pm 0.006$ [4]. Then the effective D^* asymmetry is calculated taking the oscillation of neutral B mesons into account. A fit to the data yields [2]:

$$A_{FB}^{c\bar{c}} = 0.066 \pm 0.026\,(\text{stat}) \pm 0.009\,(\text{syst}) . \quad (5)$$

This result is in good agreement with other measurements [5, 6].

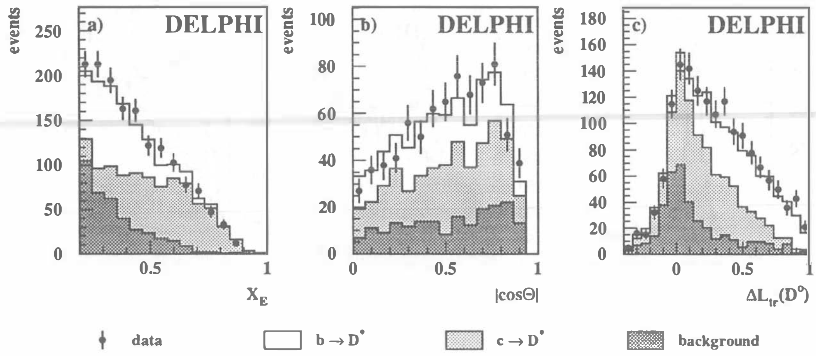

Figure 2: *The energy (a), polar angle (b) and decay length (c) distribution of the three classes of events for the* $D^{*+} \rightarrow (K^-\pi^+)\pi^+$ *decay mode*

3 Strange asymmetry

The measurement of the s asymmetry is performed using two different techniques:

- The first technique uses the presence of high momentum $\Lambda(\bar{\Lambda})$ baryons to tag a primary branching of the Z^0 into $s\bar{s}$ pairs. The baryon number of the Λ is related to the primary quark or anti-quark.
- The second analysis technique uses the presence of a high energy K_L^0 or neutron in the DELPHI Hadron Calorimeter (HCAL) as a signature of a Z^0 decay into $s\bar{s}$ or into $d\bar{d}$. This analysis method utilize the leading particle effect and the statistical correlation between the charge of the initial quark and the resulting jet. Since in this method it is impossible to separate the s from the d contribution, the measured asymmetry is a weighted mean of s and d asymmetries.

Both methods require to study the fraction of Λ and K_L^0 coming from a primary s quark. This is estimated by using JETSET PS.

3.1 Λ asymmetry

The Λ baryons are detected by their decay in flight into $p\pi^-$. Secondary vertices of the Λ decay are well separated from the primary vertex of the Z^0 decay due to the long Λ lifetime.

A total of 1540±88 (stat)±40 (syst) Λ's are found with momentum fraction $x_p = p_\Lambda/p_{beam}$ in the range [0.25,0.5] from the multihadronic events collected during 1992. A fit of the measured $|\cos\theta|$ distribution to the expression:

$$A_{FB}^s(\theta) = \frac{8}{3}A_{FB}^s\frac{\cos\theta}{1+\cos^2\theta} \tag{6}$$

yields [8] $A_{FB}^\Lambda = 0.085 \pm 0.035$ (stat) $\pm$ 0.018 (syst). The systematic error, evaluated from the data sample itself, accounts for x_p range sensitivity, fitting procedure of the invariant mass $p\pi^-$ distribution and selection cuts.

The method used in the calculation of the s quark asymmetry from the Λ asymmetry, relies on the LUND model to describe the hadronization process. The fraction of Λ's from primary s quarks contributing to the measured asymmetry is estimated to be $41.4 \pm 0.5\%$ with $95.5 \pm 0.1\%$ efficiency to tag the charge of primary s quark.

The Λ asymmetry is to corrected globally for the effect of the Λ coming from the fragmentation of other quarks and decay processes, mainly of charmed and b baryons, to estimate the s quark asymmetry. In this method a correction factor, calculated with JETSET PS, is used, and the measured Λ asymmetry is corrected differentially in x_p taking into account the observed momentum distribution. We obtain:

$$A^{s}_{FB} = 0.129 \pm 0.056 \text{ (stat)} \pm 0.038 \text{ (syst)} \tag{7}$$

where the total systematic error is computed from the contributions listed in Table 1.

Source	syst.err.
Λ experimental systematics	± 0.027
Λ momentum spectrum	± 0.001
Other quarks asymmetry	± 0.024
LUND parameterization of the fragmentation	$^{+0.003}_{-0.019}$
TOTAL	± 0.038

Table 1: *Contributions of different sources to the systematic error on the measurement of s asymmetry from Λ asymmetry. For u and d asymmetries the measured values of c and b respectively are assumed [7], assigning 100% error. Fragmentation error includes also the uncertainty due to the branching ratios of Λ's coming from charmed and beauty baryons.*

3.2 Neutral hadron asymmetry

K^0_L and $n(\bar{n})$ are the only neutral hadrons which can create a high energetic shower in HCAL. By selecting events with a HCAL shower that is not associated to any charged particle it is possible to enrich a sample of $s\bar{s}$ and $d\bar{d}$ events. The production of neutrons from initial $u\bar{u}$ state is suppressed due to the isospin suppression of dd diquark. Due to tails of the energy resolution of the hadron calorimeter, also a considerable amount of non leading particles created in the fragmentation process is selected. Finally heavy meson decays into K^0_L and $n(\bar{n})$ enter the sample, resulting in contamination from $b\bar{b}$ and $c\bar{c}$ events. A total sample of 9565 hadronic events are retained from the 1992 data with a deposited energy of the neutral HCAL shower larger than 15 GeV.

The basic idea of measuring quark asymmetries by a momentum weighted charge sum is to make use of the statistical correlation between the quark charge and the jet charge [9]. The *sign* of the charge flow Q_{flow} can be used to estimate the flight direction of the quark. The charge flow is defined as $Q_{flow} = Q_1 - Q_2$, where Q_1 is the momentum weighted charge of the hemisphere defined by the direction of the neutral HCAL hit and Q_2 is the same variable for the opposite hemisphere. If Q_{flow} is positive (negative) it statistically implies that the neutral HCAL shower is created by a neutral hadron containing the initial positively (negatively) charged quark. This method also defines the charge of the initial quark in the case where the neutral hadron is not the leading particle.

The measured asymmetry is related to quark asymmetries A^f_{FB} by:

$$A^{MEAS}_{FB} = \sum_f \delta_f \alpha_f (2\epsilon_f - 1) A^f_{FB} \ , \qquad \delta_f = \begin{cases} +1 \text{ for } d,s,b \\ -1 \text{ for } u,c \end{cases} \tag{8}$$

where α_f is the weight of quark flavour f in the selected sample, and ϵ_f is the probability of the to assign the correct direction of flight for the primary quark on the HCAL axis. In the analysis the coefficients $\alpha_f$and ϵ_f are estimated using JETSET PS with the full detector simulation included. The fraction of s and d events was found to be 69$\pm$1%, with $\epsilon_{d_s} = 67\pm1\%$.

A fit to the efficiency corrected $\cos\theta$ distribution yields $A^{MEAS}_{FB} = 0.021 \pm 0.007$(stat). Using the LEP measurements for A^b_{FB} and A^c_{FB} [7] and putting $A^u_{FB} = A^c_{FB}$ and $A^{sd}_{FB} = A^s_{FB} = A^d_{FB}$, from equation (8) one obtains:

$$A^{sd}_{FB} = 0.110 \pm 0.031 \text{ (stat)}^{+0.065}_{-0.015} \text{ (exp.syst)}^{+0.030}_{-0.004} \text{ (frag)} \ . \tag{9}$$

The experimental systematic error accounts for different event axis choices and weighting modes in Q_{flow}, together with the effect of the uncertainties of $A^{b,c,u}_{FB}$, and estimation of the sensitivity on the HCAL energy cut.

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