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# Light Quark Fragmentation and a Measurement of $A_s$*
# at the SLD

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## Abstract

We have studied the fragmentation process in $Z^0 \to$ light-flavor ($u\bar{u}$, $d\bar{d}$, $s\bar{s}$) events by measuring the differential cross sections for the production of the identified hadrons $\pi^\pm$, $K^\pm$, $p/\bar{p}$, $K^0_s$, $\Lambda^0/\bar{\Lambda}^0$, $K^{*0}/\bar{K}^{*0}$ and $\phi$, and by performing a preliminary study of correlations in rapidity between pairs of identified $\pi^\pm$, $K^\pm$, and $p/\bar{p}$. Short range charge correlations are observed between all combinations of these three hadron species. A strong long range correlation is observed for high-momentum charged kaon pairs, and weaker $\pi^+\pi^-$, $\pi^+K^-$ and $pK^-$ correlations are observed. The SLC beam polarization is used to tag the quark hemisphere in each event, allowing the first study of rapidities signed such that positive rapidity is along the quark rather than antiquark direction. Distributions of signed rapidities and of ordered differences between signed rapidities provide new insights into leading particle production and several new tests of fragmentation models. We have used these correlation studies to perform a preliminary direct measurement of the parity violating coupling of the $Z^0$ to strange quarks, $A_s$. Our result is:

$$A_s = 0.82 \pm 0.10(stat.) \pm 0.08(syst.)(preliminary).$$

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# 1. Introduction

The process by which the primary $q$ and $\bar{q}$ in the decay of the $Z^0$ boson fragment into jets of hadrons is poorly understood theoretically. A number of phenomenological models exist. Measurements of the production of identified hadrons and the study of correlations in rapidity between identified charged hadrons are important for testing the predictions of theory and models.

Efficient particle identification provided by the SLD Cherenkov Ring Imaging Detector (CRID [1]) is central to most of our studies. The SLD vertex detector [2] was used to select flavor-tagged light ($u\bar{u}$, $d\bar{d}$, $s\bar{s}$), $c\bar{c}$ and $b\bar{b}$ events. We have recently published our measurements of the production of identified $\pi^{\pm}$, $K^{\pm}$, $p/\bar{p}$, $K_s^0$, $\Lambda^0/\bar{\Lambda}^0$, $K^{*0}/\bar{K}^{*0}$ and $\phi$ in these flavor-tagged samples (details in Ref. [3]). Substantial flavor dependences are observed. These results were used to test the QCD predictions of MLLA+LPHD and the predictions of three fragmentation models (JETSET 7.4 [4], HERWIG 5.8 [5], and UCLA 4.1 [6]). We found the light-flavor data to be in better agreement with the MLLA QCD+LPHD prediction than the flavor inclusive sample. We observed a number of differences between data and simulation in the differential cross sections of the light-flavor sample that have been seen before in all-flavor events, and we can conclude that the discrepancies indicate problems with the modelling of light-flavor fragmentation. We also used the $e^-$ beam polarization to study leading particle production in a unique way. We observed a significant effect for $p/\bar{p}$, $\Lambda^0/\bar{\Lambda}^0$, $K^{\pm}$ and $K^{*0}/\bar{K}^{*0}$ at high particle momentum and found that high-momentum $K^-$ ($K^+$) and $\bar{K}^{*0}$ ($K^{*0}$) are produced predominantly in $s$ ($\bar{s}$) jets.

The fragmentation process in hadronic jets can be probed more deeply by studying correlations [7, 8, 9] in rapidity between pairs of identified charged hadrons. In this paper we discuss several correlations in rapidity between identified charged hadrons, and we conclude with an application of the correlation studies to tag $s$ and $\bar{s}$ jets in a direct measurement of the parity violating coupling of the $Z^0$ to strange quarks, $A_s$. Approximately 300,000 hadronic $Z^0$ decays, produced by the SLAC Linear Collider (SLC) and recorded by the SLC Large Detector (SLD), are used in the study of correlations in rapidity and the $A_s$ measurement. The SLC delivered an electron beam with an average polarization of 74% and an unpolarized positron beam. A description of the SLD detector, trigger, track and hadronic event selection, and Monte Carlo simulation, can be found in Ref. [10].

# 2. Rapidity Correlations

First we selected light-flavor events. For each track identified as $\pi^{\pm}$, $K^{\pm}$ or $p/\bar{p}$, we define the rapidity $y = 0.5\ln(\frac{E+p_{\|}}{E-p_{\|}})$ using the measured momentum, its projection $p_{\|}$ along the thrust axis, and the appropriate hadron mass. The absolute value of the difference between the rapidities of each pair of identified particles, $|\Delta y| = |y_1 - y_2|$, is a suitable scale-independent variable for probing the fragmentation process, and its distribution is shown in Figure 1 for each of the six pairs of identified hadron types. A significant excess of opposite charge pairs over same charge pairs at small values of $|\Delta y|$ is observed for each hadron pair. For $KK$ and $pp$ pairs, this confirms local conservation of strangeness and baryon number, respectively. Excesses are seen in $\pi K$, $Kp$ and $\pi p$ for the first time and suggest charge ordering for all types of pairs in the fragmentation process. We have studied the range of this correlation as a function of momentum for all six pair combinations. We find that, within the context of the JETSET model, the range is independent of momentum for a given hadron pair type.

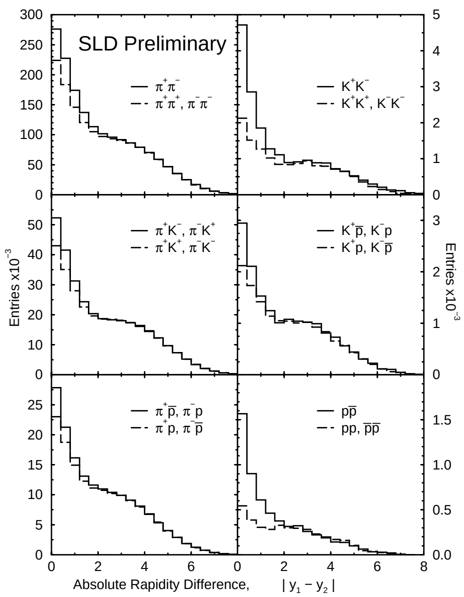


Figure 1: Rapidity difference distributions for opposite charge pairs (solid) and same charge pairs (dashed) of identified $\pi^{\pm}$, $K^{\pm}$ and $p/\bar{p}$.

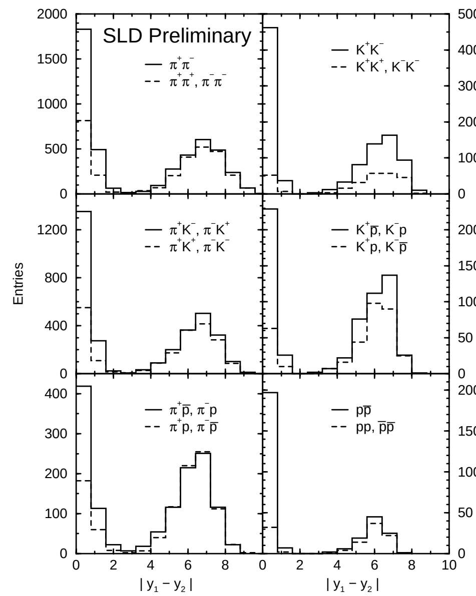


Figure 2: $|\Delta y|$ distributions for opposite charge pairs (solid) and same charge pairs (dashed) of identified $\pi^{\pm}$, $K^{\pm}$ and $p/\bar{p}$ with $p > 9$ GeV/c.

We expect long range correlations from leading particle production to be more important at high momentum. Figure 2 shows a clear separation between pairs in the same jet ($|\Delta y| < 2.5$) and those in opposite jets ($|\Delta y| > 4$) after requiring $p > 9$ GeV/c for both tracks. The large excess of opposite charge pairs for all pair types at small $|\Delta y|$ confirms that locality holds even at the highest momenta. A strong long range correlation is observed for $KK$, and a weaker one for $\pi\pi$, $\pi K$ and $Kp$. For $|\Delta y| > 4$, the predictions of the JETSET model are generally consistent with the data, except that the simulation predicts much smaller $\pi K$ and $Kp$ correlations and a larger $\pi p$ correlation than are observed in the data.

The SLC electron beam polarization allows the quark (vs. antiquark) direction to be tagged in each hadronic event, exploiting the large forward-backward quark production asymmetry in $Z^0$ decays. If the beam was left-(right-)handed, the forward (backward) thrust hemisphere was taken as quark jet. After removing events with $|\cos\theta_{thrust}| < 0.15$, the probability to tag the quark direction correctly is 73%. The resulting signed rapidity and the ordered differences between signed rapidities provide new insights into leading particle production and several new test of fragmentation models. The signed rapidity distributions of $\pi^{\pm}$, $K^{\pm}$ and $p/\bar{p}$ with $p > 9$ GeV/c confirm strong leading $K^{\pm}$ and $p/\bar{p}$ production and show evidence for leading $\pi^{\pm}$ production. For particle-antiparticle pairs, we define $\Delta y^{+-} = y_{+} - y_{-}$ as the difference between the signed rapidities of the positively and negatively charged particle. Figure 3 gives the distribution of $\Delta y^{+-}$ for $\pi^{+}\pi^{-}$, $K^{+}K^{-}$ and $p\bar{p}$. Asymmetries (also shown) in these distributions indicate ordering along the fragmentation chain. For $K^{+}K^{-}$ pairs, the negative difference at high $|\Delta y^{+-}|$ can be attributed to leading $K^{\pm}$ being produced predominantly in $s\bar{s}$ events. For the $p\bar{p}$ pairs, the positive difference at low $|\Delta y^{+-}|$ indicates that the $p$ in an associated $p\bar{p}$ pair follows the quark direction more closely than the $\bar{p}$. This could be due to leading baryon production and/or to baryon number ordering along the fragmentation chain. The simulation is consistent with the data.

# 3. Strange Quark Asymmetry

We have performed a direct measurement of the strange quark asymmetry [11], $A_s$. Each thrust hemisphere of a light-flavor tagged event was required to contain at least one identified strange particle ($K^{\pm}$, $K_s^0$ or $\Lambda^0/\bar{\Lambda}^0$), and the strange particle of highest momentum was used to tag the strangeness of the hemisphere. We required at least one of the two hemispheres to have definite strangeness (i.e. to contain a $K^{\pm}$ or $\Lambda^0/\bar{\Lambda}^0$), and the other to have indefinite or opposite strangeness (e.g. $K^{+}K^{-}$). This procedure resulted in an overall $s\bar{s}$ purity of 69% for the selected sample. The initial $s$ quark direction is approximated by the thrust axis of the event, signed to point in the direction of negative strangeness. Figure 4 shows the polar angle distributions of the tagged strange quark for left-handed ($P_e < 0$) and right-handed ($P_e > 0$) electron beams. The expected production asymmetries, of opposite sign for the left-handed and the right-handed beams, are clearly visible. $A_s$ was extracted from these distributions by a binned maximum likelihood fit. Also shown in the figure are our estimates of the non-$s\bar{s}$ backgrounds. The cross-hatched histograms indicate $c\bar{c} + b\bar{b}$ backgrounds, showing asymmetries of the same sign and similar slope to the total distribution. These backgrounds are understood experimentally and were evaluated using a detailed Monte Carlo simulation. Standard systematic variations of the simulation [10] were considered. The hatched histograms indicate $u\bar{u} + d\bar{d}$ backgrounds, showing asymmetries of the opposite sign. The size and slope of this background, as well as the analyzing power in $s\bar{s}$ events, are not well understood experimentally.

Here we make use of the correlations for high-momentum charged kaons described above (Figure 2). Our Monte Carlo simulation was used to evaluate the parameters used in the fit, but was calibrated using the data. Since an $s$ jet can produce one $K$, whereas a $u$ jet or $d$ jet must produce $K\bar{K}$, the short range correlation is sensitive to the $u\bar{u} + d\bar{d}$ background. Similarly, long range same sign $K$ pairs are enriched in $u\bar{u} + d\bar{d}$, but contaminated by $s \to K\bar{K}K$. Thus we count the number of hemispheres containing an identified $K^+K^-$ pair or an identified $K^\pm K^0$ pair, and the number of events that were tagged with charged kaons of the same sign in both hemispheres, to constrain the $u\bar{u}+d\bar{d}$ background. We counted the number of hemispheres with three identified kaons to calibrate the analyzing power in $s\bar{s}$ events. The uncertainties on the measured data/MC ratios of these quantities were taken as systematic variations. We obtain:

$$A_s = 0.82 \pm 0.10(stat.) \pm 0.08(syst.)(preliminary).$$

This result is consistent with the Standard Model expectation for $A_s$. Two LEP experiments have published forward-backward asymmetries from which $A_s$ can be derived. Using $A_e = 0.1499$ [12], the DELPHI measurements [13] translate into $A_s = 1.165 \pm 0.332$ and $A_{d,s} = 0.996 \pm 0.554$. Similarly, the OPAL measurement [14] yields $A_{d,s} = 0.605 \pm 0.326$. Our measurement is consistent with these and represents a substantial improvement in precision.

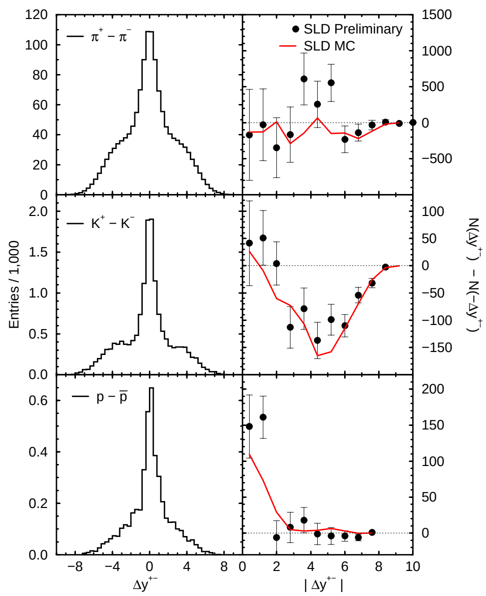


Figure 3: Distributions (left) of $\Delta y^{+-}$ for positively and negatively charged identified hadrons of the same type. The differences (right) between the right and left sides of the distributions, compared with the prediction of the simulation.

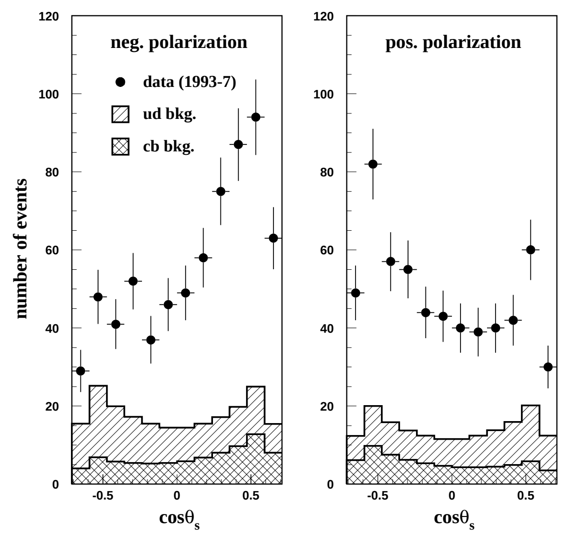


Figure 4: Polar angle distributions of the tagged strange quark, for negative (left) and positive (right) beam polarization. The dots show data, and our estimates of the non-$s\bar{s}$ backgrounds are indicated by the hatched histograms.

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