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THE PRODUCTION OF $\pi^{\pm}, K^{\pm}, p, K^0$ and Λ^0 IN HADRONIC Z^0 DECAYS

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Abstract

We have measured production fractions and spectra for $\pi^{\pm}$, $K^{\pm}$ and p, and production spectra for K^0 and Λ^0 in both hadronic Z^0 decays and a $Z^0 \to$ light quark (uds) subset at SLD. The SLD Cherenkov Ring Imaging Detector was used to identify charged hadrons. The CCD vertex detector was used to select the enriched uds sample. For our global sample, the results are consistent with previous experiments. We observe a clear flavor dependence in production spectra, but only a small effect in hadron fractions and $\xi = ln(1/x_p)$ peak positions.

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1. Introduction

The hadronization process is the least understood portion of QCD, due to its non-perturbative nature. One model of particle production, a combination of Modified Leading Logarithm Approximation (MLLA) calculations and the hypothesis of Local Parton-Hadron Duality (LPHD)[1], has been very successful in describing the shape and energy dependence of inclusive charged and neutral particle spectra. By looking at the production characteristics for specific particle species, we hope to shed additional light on the hadronization mechanism and to test further MLLA+LPHD predictions.

Experimentally, the observed spectrum is composed of particles from hadronization as well as those from decays. At Z^0 energies, B and D hadrons are major sources of decay products. By using a signed impact-parameter tagging technique, we are able to obtain a high purity light (uds) quark sample for our analysis, thus removing the contribution from B and D hadrons. As an extra benefit, by selecting light quark events we avoid potential complications due to heavy quark fragmentation.

In this paper, we present an analysis of $\pi^{\pm}, K^{\pm}, p/\bar{p}, K^0$, and $\Lambda^0/\bar{\Lambda}^0$ production in hadronic Z^0 decays collected by the SLC Large Detector (SLD) at SLAC. The analysis is based upon the approximately 50,000 hadronic events obtained in the 1993 physics run.

2. Charged Particle and Neutral V^0 Production

The SLD Cherenkov Ring Imaging Detector (CRID) provides excellent particle identification for Z^0 physics at the SLAC Linear Collider (SLC). Through the combined use of liquid and gas fluorocarbon radiators (C_6F_{14} and C_5F_{12}, respectively), it is designed to perform π/K/p separation efficiently over a large momentum range[2]. The barrel region of the CRID ($|\cos\theta| \leq 0.7$) was fully operational for the 1993 run, and is used in this analysis.

Charged particles passing through the radiators emit Cherenkov photons, which are imaged through quartz windows into TPCs containing photosensitive gas. For each detected photoelectron, a Cherenkov angle is reconstructed. For each of the charged particle hypotheses ($\pi/K/p$ in this analysis), a likelihood is calculated based upon the number of detected photoelectrons and their measured angles, the expected numbers and angles, and the background. Particle separation is based upon the difference in the logarithms of the likelihoods for the different particle hypotheses. For this analysis, an identified particle is a particle whose log likelihood difference is greater than 5 with respect to both of the other two hypotheses.

For the charged fraction analysis, a set of hard cuts was applied to the tracks to ensure that the CRID behavior was well-modelled by the simulation. For each momentum bin, the number of observed particles of a given type is related to the true production fraction by an efficiency matrix. This analysis procedure does not require that the sum of the charged particle fractions add to unity; instead the sum was used as a consistency check and was found to be in good agreement with unity for the entire momentum range.

This matrix was determined first through detailed detector simulation and then calibrated using a high-purity sample of pions from K_s decays and the total measured identification rates. Figure 1 shows "correct" particle identification efficiencies (i.e. the diagonal matrix elements). They are above 80% over wide momentum ranges. The pion coverage is continuous from 0.5 GeV up to approximately 20 GeV. The misidentification rates (not shown) are low (peak values less than 6% and typically less than 2%). The error bars shown are conservative estimates based upon the above-mentioned calibrations.

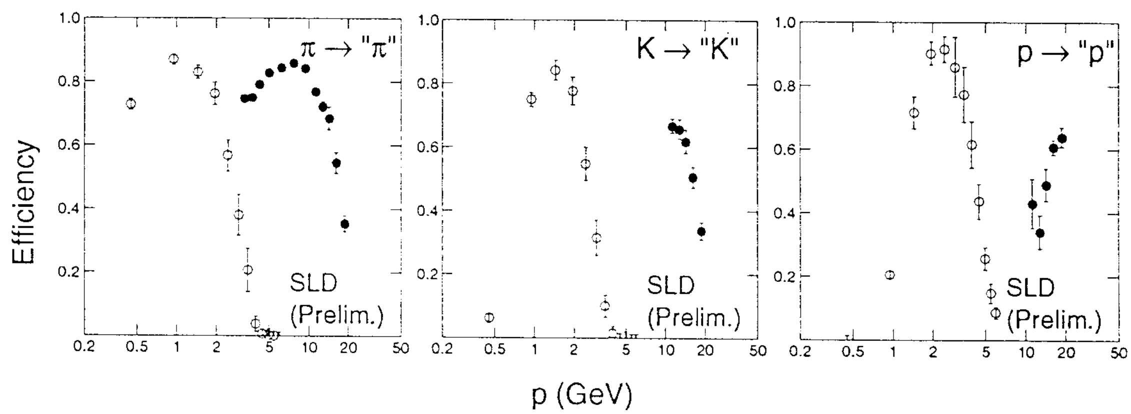

Figure 1: Identification efficiencies for charged $\pi^{\pm}, K^{\pm}$, and $p/\bar{p}$ for the SLD CRID, with systematic errors. The open circles are for the liquid radiators; the closed circles are the gas.

The measured charged particle fractions for Z^0 hadronic decays are shown in Fig. 2. We observe that the pion fraction is dominant at low momentum, that the kaon fraction increases with momentum, and that the proton fraction seems to plateau at high momentum. Where the coverage overlaps, these measured fractions were found to be in good agreement with other measurements [3, 4, 5]. Additionally, these measurements fill in the gaps in coverage inherent in dE/dX measurements.

To measure the production of Λ^0's and K^0's, oppositely charged tracks were combined to form V^0 candidates. Candidate pairs were required to point back toward the primary vertex and to have secondary vertices separated from the primary by at least 5σ in flight length. Potential gamma conversions were rejected by requiring the e^+e^- invariant mass of the charged track pair to be greater than 70 MeV. Candidates were rejected if their vertex was located outside of the SLD CCD vertex detector (VXD) but included a track with multiple vertex detector hits. Kinematically-overlapped K_s were rejected from the Λ^0 sample by rejecting all V^0's whose invariant mass was within ± 30 MeV of the K_s mass. Λ^0's were removed from the K_s sample by cuts on the angle of the positively charged track in the pion-pion rest frame.

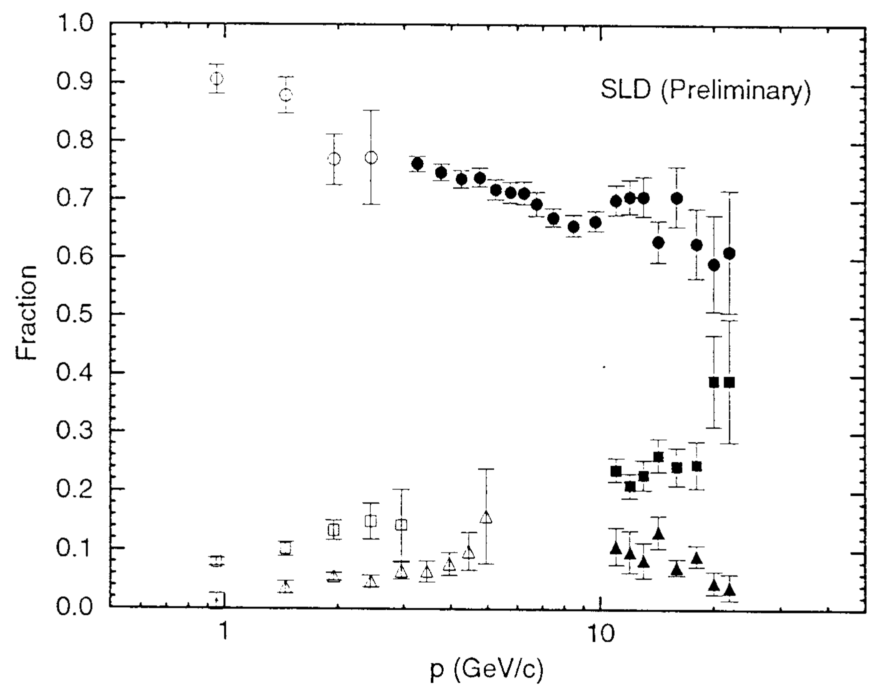

Figure 2: Charged hadron fractions measured by SLD. Circles are $\pi^\pm$, squares are $K^\pm$, and triangles are $p/\bar{p}$. Open symbols are for the liquid radiator; solid symbols are for the gas.

For comparison with MLLA+LPHD predictions, the production cross sections for the charged and neutral particles were plotted as a function of $\xi = \ln(1/x_p)$. The resulting spectra were then fitted by gaussian approximations of the MLLA prediction (see Figure 3). Table 1 lists the peak positions for the 5 species along with errors due to statistical and systematic uncertainties of the fits. The spectra for the charged and neutral kaons are consistent, and those for p and Λ^0 are similiar in shape. The pions peak at higher ξ (lower momentum) as expected by MLLA + LPHD; however, we do not see a substantial peak shift between the kaons and the baryons. The measured peak positions are in good agreement with previous measurements[3].

3. Flavor Tagging

The analysis was repeated on high-purity *uds* and *b* quark samples (86% and 89% purity, respectively) obtained using impact parameters measured in the SLD CCD vertex detector[6]. There was increased production of both charged and neutral kaons in the heavy quark sample, and it appeared the particle production cut off more quickly with increasing momentum (decreasing ξ) for all of the particles in the heavy quark sample. When comparing the *uds* sample to the full hadronic sample (*udscb*), we see that there is little change in the spectra peak positions (table 1), indicating that peak shifts due to heavy quark decay products are small.

Particle type	$Z^0 \rightarrow all$ (ξ^*)	$Z^0 \rightarrow uds$ (ξ^*)
$\pi^\pm$	3.69±0.03	3.78±0.04
$K^\pm$	2.85±0.11	2.98±0.17
$p/\bar{p}$	2.56±0.13	2.57±0.13
K^0	2.71±0.16	2.81±0.05
$\Lambda^0/\bar{\Lambda}^0$	2.63±0.10	2.68±0.10

Table 1. Spectra peak positions (ξ^*) for the full hadronic and *uds* samples.

4. Summary

Using the SLD CRID we have made a preliminary measurement of charged hadron fractions in hadronic Z^0 decays over a large momentum range, complementing previous measurements using ionization energy loss. The production of neutral K^0 and Λ^0 was also studied. Spectrum shapes were found to be adequately described by the gaussian approximation to the MLLA+LPHD prediction. The peak positions and fractions are in agreement with previous measurements. By isolating a high purity *uds* sample, it was shown that spectrum shapes were strongly affected by heavy quark fragmentation and decays, but that the effect on the peak positions was small.

References

[1] T.I. Azimov, Y.L. Dokshitzer, V.A. Khoze and S.I. Troyan, Z. Phys. **C27** (1985) 65.

[2] SLD Design Report, SLAC-REPORT 273, (1984).

[3] DELPHI Collab., P. Abreu *et al.*, CERN-PPE-95/28, submitted to Nucl. Phys. B.

[4] OPAL Collab., P.D. Acton *et al.*, *Z. Phys.* **C63** (1994) 181.

[5] ALEPH Collab., D. Decamp *et al.*, CERN-PPE-94/201, submitted to Z. Phys. C.

[6] SLD Collab.,K. Abe *et al.*, SLAC-PUB-6687, submitted to Phys. Rev. Lett.

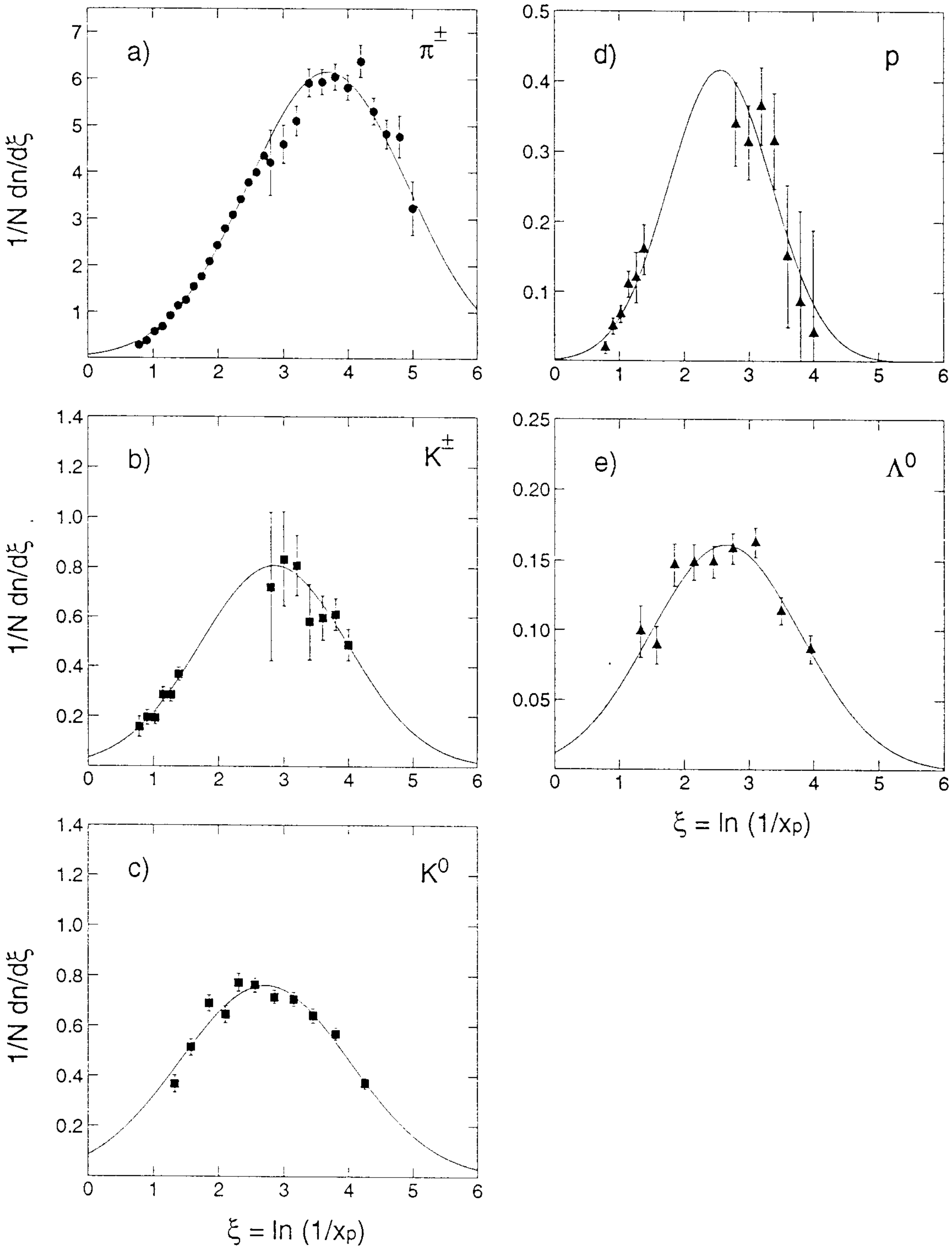

Figure 3: The production spectra for $\pi^{\pm}, K^{\pm}, K^0, p$, and Λ^0 in hadronic Z^0 decays.

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