NEW RESULTS FROM THE FOCUS/E831 EXPERIMENT

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The E831/FOCUS experiment at Fermilab is a photoproduction experiment which generated high quality charm particles. During its run, we obtained a large data set, including more than 1 million charm mesons in the $K\pi/K2\pi/K3\pi$ mode decays. The current analysis efforts by the collaboration members are quite active and diverse. I will summarize the recent papers published by the FOCUS group on topics of semileptonic decays of charm mesons.

1 Introduction

In this paper, we will summarize three recent papers1, 2, 3 published by the FOCUS/E831 collaboration on topics of semileptonic decays of charm mesons.

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1.1 Semileptonic Decays of Charm Particles

Traditionally, the semileptonic decays of heavy flavored particles are accessible to both collider and fixed target experiments with ease. The decays have clean and distinguishable signatures, and the Cabibbo-allowed decay channels like $D^0 \to K^- l^+ \nu_l$, $D^+ \to \overline{K}^0 (K^- \pi^+) l^+ \nu_l$, $D^+_s \to \phi (K^- K^+) l^+ \nu_l$ have large branching ratios. Their fully explicit decay rates can be calculated from first principles, for example, theoretical tools like Feynman diagrams. Involving a lepton in the final decay stage implies that we do not have to worry about the usual final state interaction between hadrons. The possible complications coming from the QCD portion of the decay process are contained in form factors. The form factors can be calculated by various methods, LGT and quark models. The angular distributions and invariant masses among the decay products would determine the form factors ratios while the branching ratio measurements and information from the CKM matrix would give the absolute scale for the form factors.

1.2 The FOCUS Spectrometer

The FOCUS/E831 spectrometer is an upgraded version of the E687 fixed target spectrometer located in the Fermilab proton beam area. It is designed to study charm particles produced by average 180 GeV photon beams and BeO target segments. The spectrometer consists of a precise silicon micro vertex system, proportional wire chambers with two dipole magnets, threshold Cerenkov systems, electromagnetic and hadronic calorimeters, and muon identification systems. During the 1996-1997 fixed target run, a huge data set was obtained including more than 1 million charm mesons in the $K\pi/K2\pi/K3\pi$ decay modes. The members of the E831 group are from diverse countries, USA (and Puerto Rico), Italy, Brazil, Mexico and Korea.

2 The New S-wave Interference in $D^+ \to K^- \pi^+ \mu^+ \nu$ Decays

For last 20 years, people regarded the $D^+ \to K^- \pi^+ \mu^+ \nu$ decays as 100% $D^+ \to \overline{K}^0 (K^- \pi^+) \mu^+ \nu$ events. The E687 and E691 groups set an upper limit for the possible scalar contributions in the $D^+ \to K^- \pi^+ l^+ \nu_l$ decays$^{15}$, but they could not provide clear evidence of decay paths other than the dominant P-wave $D^+ \to \overline{K}^0 (K^- \pi^+) l^+ \nu_l$ channel. The situation was changed when the next generation sample from the FOCUS spectrometer was analyzed to get form factors of the $D^+ \to K^- \pi^+ \mu^+ \nu$ decays.$^{11}$

After the selection cuts involving vertex confidence levels and particle identification requirements, we obtained 31,254 $D^+ \to K^- \pi^+ \mu^+ \nu$ and its charge conjugate decays.$^{6}$ During the form factor analysis, we checked the angular distribution of Kaon in the $K\pi$ rest frame ($\cos \theta_V$) and found that it showed a huge forward-backward asymmetry below the $K^*(892)$ pole mass while almost no asymmetry above the pole. Since the $K^*$ is a P-wave, pure $K^* \to K\pi$ decays would have shown only a symmetric forward-backward $\cos \theta_V$ distribution over the entire $K\pi$ invariant mass range. This suggests a possible quantum mechanics interference effect.

A simple approach to emulate the interference effect is adding a spin zero amplitude in the matrix elements of the $D^+ \to K^- \pi^+ \mu^+ \nu$ decays. We tried a constant amplitude with a phase, $A \exp(i\delta)$, in the place where the $K^*$ couples to the spin zero component of the $W^+$ particle. We made the simplest assumption that the $q^2$ dependence of this anomaly S-wave coupling would be the same as that of the $K^*$.

The $D^+ \to K^- \pi^+ \mu^+ \nu$ event is a 4-body decay, which is represented by 5 kinematic variables, two invariant masses and three angular variables. For each of these variables, we extracted interference effects by using various weighting schemes and studied if our measured $A = 0.36$

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$^6$ In this paper we assume that a decay and its charge conjugate decay go through the same physical process.
and $\delta = \pi/4$ are working properly in reproducing the effects for Monte Carlo (MC) events. As shown in Fig. 1 where the invariant mass of the $K\pi$ particles are weighted by $\cos \theta_V$, the interference effect is reproduced with satisfaction. Our measured phase of $\pi/4$ relative to the $K^*(892)$ is consistent with the one found by LASS collaboration for isosinglet s-wave around the $K^*$ pole from a $K\pi$ phase shift analysis. Our data is consistent with a broad resonance interpretation as well, but the pole of the resonance would be located above the $K^*$ pole in absence of any FSI re-phasing. We tried a $\kappa(800)$ resonance hypothesis. It turned out that to produce the interference effect, a 100 degree phase shift is needed between the $\kappa$ and the $K^*$. One interesting side effect of the S-wave interference is that it breaks the $\chi \leftrightarrow -\chi$ symmetry of the distribution of the azimuthal angle ($\chi$) between the $K\pi$ and the $W^+\pi^+$ decay planes in the $D^+$ rest frame. The proper definition of $\chi$ requires that it should change sign between $D^+ \to K^-\pi^+\mu^+\nu$ and its charge conjugate decays. Without the proper sign convention, we would see a false CP violation between the charge conjugate decays in the $\chi$ distribution.

3 Branching Ratio Measurements

We measured the relative branching ratio between $D^+ \to \overline{K}^{*0}\mu^+\nu$ and $D^+ \to K^-\pi^+\pi^+$ decays. With a tighter selection than the one used in the interference analysis, we selected 11,698 $D^+ \to K^-\pi^+\mu^+\nu$ and its charge conjugate decays. With a selection cut set designed to be similar to the one applied upon the $D^+ \to K^-\pi^+\mu^+\nu$ decays, we obtained 65,421 $D^+ \to K^-\pi^+\pi^+$ and its charge conjugate decays. From a MC study, we determined that the pure $D^+ \to \overline{K}^{*0}\mu^+\nu$ events are 94.5% of the selected events. When this correction factor is applied, we obtained

$$\frac{\Gamma(D^+ \to \overline{K}^{*0}\mu^+\nu)}{\Gamma(D^+ \to K^-\pi^+\pi^+)} = 0.602 \pm 0.010\text{(stat)} \pm 0.021\text{(sys)}$$

(1)

When comparing this muon decay channel result with electron decay channel results from other experiments, a correction factor 1.05 should be applied. Our number, the only one considered an S-wave interference explicitly, is 1.6 $\sigma$ lower than the recent CLEO II result from the electronic decay channel and 2.1 $\sigma$ higher than the E691 measurement. Including our result, the new world average of $\Gamma(K^*\mu\nu)/\Gamma(K\pi\pi)$ is $0.62 \pm 0.02$ each experiment's statistical and systematic errors were added in quadrature prior to making the weighted average.

We also measured the relative branching ratio between $D_s^+ \to \phi(K^-K^+)\mu^+\nu$ and $D_s^+ \to \phi(K^-K^+)\pi^+$ decays. Our selection yields 793 $D_s^+ \to \phi(K^-K^+)\mu^+\nu$ and its charge conjugate
decays, and $2,192 \ D^+_s \rightarrow \phi (K^−K^+)\pi^+$ and its charge conjugate decays. The result is

$$\frac{\Gamma(D^+_s \rightarrow \phi (K^−K^+)\mu^+\nu)}{\Gamma(D^+_s \rightarrow \phi (K^−K^+)\pi^+)} = 0.540 \pm 0.033 (\text{stat}) \pm 0.048 (\text{sys})$$

(2)

Our number is comparable with all the other measurements in this channel, and the new world average of $\Gamma(\phi \mu \nu)/\Gamma(\phi \pi)$ is $0.540 \pm 0.040$.

4 The Form Factor Ratios of $D^+ \rightarrow \overline{K}^*0 \mu^+\nu$

We measured the form factor ratios of $D^+ \rightarrow \overline{K}^*0 \mu^+\nu$ and its charge conjugate decays with consideration on the S-wave contribution. Our study shows that the effect of S-wave on the measurement is minimal while the effect of charm background is significant. The new FOCUS results are as follows;

$$R_V = 1.504 \pm 0.057 \pm 0.039$$

$$R_2 = 0.875 \pm 0.049 \pm 0.064$$

(3)

(4)

Our $R_V$ value is 2.9 $\sigma$ below the E791 measurements, but consistent with others. Our $R_2$ value is consistent with other measurements. The new world averages are $1.66 \pm 0.060$ and $0.827 \pm 0.055$ for $R_V$ and $R_2$, respectively.

5 Summary and Future Plan

The FOCUS experiment found new S-wave interference phenomena in the $D^+ \rightarrow K^−\pi^+\mu^+\nu$ decays. Considering this effect in further analyses, we measured the branching ratio $\Gamma(D^+ \rightarrow K^*\mu\nu)/\Gamma(D^+ \rightarrow K\pi\pi)$ and the form factor ratios of $D^+ \rightarrow K^-\pi^+\mu^+\nu$ decays with improved statistical errors. We also measured the branching ratio $\Gamma(D_s \rightarrow \phi \mu\nu)/\Gamma(D_s \rightarrow \phi \pi)$. The analyses in other semileptonic decay modes are actively going on and we expect new results soon.

Acknowledgments

We wish to acknowledge the assistance of the staffs of Fermi National Accelerator Laboratory, the INFN of Italy, and the physics departments of the collaborating institutions. This research was supported in part by the U. S. National Science Foundation, the U. S. Department of Energy, the Italian Istituto Nazionale di Fisica Nucleare and Ministero della Istruzione Università e Ricerca, the Brazilian Conselho Nacional de Desenvolvimento Científico e Tecnológico, CONACyT-México, and the Korea Research Foundation of the Korean Ministry of Education.

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