International Journal of Modern Physics A

Analysis of the Semileptonic Decay $D^0 \to \overline{K}^0\pi^-\mu^+\nu$

Ilaria Segoni*

Physics Department, University of Colorado at Boulder, Colorado Av.
Boulder, Colorado 80309, USA

Using data collected by the fixed target Fermilab experiment FOCUS, we present several first measurements for the semileptonic decay $D^0 \to \overline{K}^0\pi^-\mu^+\nu$. Using a model that includes a $\overline{K}^0\pi^-$ S-wave component, we measure the form factor ratios to be $r_v = 1.706 \pm 0.677 \pm 0.342$ and $r_2 = 0.912 \pm 0.370 \pm 0.104$ and the S-wave amplitude to be $A = 0.347 \pm 0.222 \pm 0.053$ GeV^{-1}. Finally, we measure the vector semileptonic branching ratio $\frac{\Gamma(D^0 \to K^*(892)^-\mu^+\nu)}{\Gamma(D^0 \to \overline{K}^0\pi^-\pi^+)} = 0.337 \pm 0.034 \pm 0.013$.

1. Measurement of r_v, r_2, and $\overline{K}^0\pi^-$ S-wave Amplitude

The data used in this analysis[1] was collected by the Fermilab fixed target experiment FOCUS. Track reconstruction is performed by two silicon systems and five stations of proportional wire chambers. The momentum of charged tracks is measured by the deflection in two magnets of opposite polarity. Charged particle identification is performed by three multi-cell threshold Čerenkov counters (for e, π, K, and p). Muons are identified by the hits left in tracking systems after penetrating approximately 21 interaction lengths of shielding material.

In reconstructing $D^0 \to \overline{K}^0\pi^-\mu^+\nu$, we select combinations of two charged tracks of opposite sign where one is identified as a pion and the other as a muon. In order to reject the decays $\pi^+/K^+ \to \mu^+\nu$, we require the muon trajectory to be consistent through the two analysis magnets. Each track must have momentum greater than 10 GeV/c. The two tracks are retained if they make a vertex with a good confidence level (C.L.>5%). The vertex must be isolated from other tracks and it must lie at least one σ outside of the target. The $\overline{K}^0$ is reconstructed as a K^0_S from the decay $K^0_S \to \pi^-\pi^+$,[2] and its invariant mass is required to be within three sigma of the nominal K^0_S mass. We require the reconstructed $K^0_S\pi^-$ mass to be within one Γ (50 MeV/c^2) of the nominal $K^*(892)^-$ mass. The invariant mass $M(K^0_S\pi^-\mu^+)$ is required to be lower than 1.8 GeV/c^2, since, from energy conservation, the signal events have $M(K^0_S\pi^-\mu^+) < M(D^0)$. Tracks reconstructed in the silicon are used to form primary vertex candidates, if they do not belong to the particles in the final state of the D^0 decay. For the primary vertex we require C.L.> 1%. The highest multiplicity vertex is retained, and ties are arbitrated by keeping the one

*On behalf of the FOCUS–E831 collaboration (see http://www-focus.fnal.gov/authors.html).

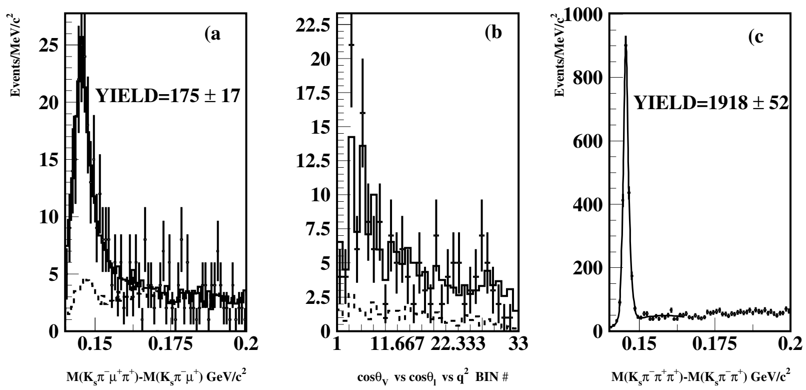

Fig. 1. a) ΔM fit and b) $\cos\theta_V$ vs. $\cos\theta_\ell$ vs. q^2 fit for the semileptonic decay. Points with error bars are data, histogram is the fit, dashed line is the background component. c) ΔM fit for the hadronic decay. The fit is to two Gaussian distributions for the signal plus a threshold function for the background.

with higher significance of separation from the secondary vertex. The significance of separation, given by the ratio of the distance between the two vertices divided by its error (ℓ/σ_ℓ) must be greater than 5. We "tag" the D^0 by requiring that it comes from the decay $D^{*+} \to D^0\pi^+$. The pion must be one of the tracks used in the primary vertex reconstruction, it must have been identified as a pion in the Čerenkov system and it must have $p > 2$ GeV$/c$. The normalization mode for the branching ratio measurement, $D^0 \to \overline{K}^0\pi^-\pi^+$, is reconstructed following the same procedure and applying the same requirements as for the semileptonic mode mode (when possible), in order to minimize bias due to possible inaccuracies in the Monte Carlo (MC) evaluation of the efficiency of the K_S^0, which is reconstructed in a very different way from ordinary tracks.

We measure the D^0 semileptonic form factor ratios (r_v and r_2), and the S-wave amplitude (A) using a model that includes a $\overline{K}^0\pi^-$ S-wave component[3] that interferes with the dominant $K^*(892)^-$. We use a combined fit of the mass difference $\Delta M = M(D^*) - M(D)$ and the three dimensional distribution $\cos\theta_V$ vs. $\cos\theta_\ell$ vs. q^2(where θ_V is the angle between the π^- and the D in the K^* rest frame, θ_ℓ is the angle between the ν and the D in the W rest frame, and $q^2 = (P_\mu + P_\nu)^2$). The ΔM distribution allows for us to evaluate the background level. For the events plot in the $\cos\theta_V$ vs. $\cos\theta_\ell$ vs. q^2 distribution we require $\Delta M < 0.15$ GeV$/c^2$. We use a binned maximum likelihood where the fit parameters are the signal and background yields, r_v, r_2, and A. Non-charm backgrounds are essentially removed by the requirements on ℓ/σ_ℓ, on the muon, and on the decay vertex being at least one σ out of the target. The charm background distribution is taken from a MC which simulates all known charm decays other than our signal mode. The signal distribution is taken from a MC where we generate our signal decay. While for ΔM we use the shape of the reconstructed events, the signal distribution for $\cos\theta_V$ vs. $\cos\theta_\ell$ vs. q^2 is determined using a MC event weighting method based on Reference.[5] The number of expected signal events in each $\cos\theta_V$ vs. $\cos\theta_\ell$ vs. q^2 bin is given by the amplitude evaluated with this weighting method multiplied by the bin efficiency. We first fit for r_v and r_2, fixing A and the S-wave phase, δ, to the values measured by FOCUS for the isospin conjugate decay $D^+ \to K^-\pi^+\mu^+\nu$ ($A = 0.330$, $\delta = 0.68$[4]). Then we fix r_v and r_2 to the values we measure and we fit for A. Fig. 1 *a* and *b* show the ΔM and the $\cos\theta_V$ vs. $\cos\theta_\ell$ vs. q^2 fits.

The branching ratio is measured by dividing the efficiency corrected yields of the semileptonic and the hadronic modes. For the semileptonic mode we correct for the amount of K^* in the $\overline{K}^0\pi^-$ system. For the hadronic mode the fit is to two Gaussian distributions plus a threshold function for the background (see Fig. 1 *c*).

We carefully considered and evaluated many possible sources of systematic uncertainty in our results. For the r_v, r_2, and A measurements the systematic uncertainty derives from the fitting choices. For the branching ratio measurement the systematic uncertainty derives from fitting choices and input model in MC ($\overline{K}^0\pi^-\pi^+$ resonant structure, input r_v, r_2, and S-wave parameters, hadron calorimeter simulation).

None of the measurements presented has ever been performed before. The results, which are shown in Table 1, are in excellent agreement with theoretical expectations, with estimates based on isospin symmetry, and with results for the semielectronic decay $D^0 \to K^*(892)^-e\nu$.[1]

Table 1.

Measurements for the decay	$D^0 \to \overline{K}^0\pi^-\mu^+\nu$
r_v	$1.706 \pm 0.677 \pm 0.342$
r_2	$0.912 \pm 0.370 \pm 0.104$
$A(\text{GeV}^{-1})$	$0.347 \pm 0.222 \pm 0.053$
$\frac{\Gamma(D^0\to K^*(892)^-\mu^+\nu)}{\Gamma(D^0\to\overline{K}^0\pi^-\pi^+)}$	$0.337 \pm 0.034 \pm 0.013$

References

1. J. M. Link [the FOCUS Collaboration], arXiv:hep-ex/0410067.
2. J. M. Link *et al.* [FOCUS Collaboration], Nucl. Instrum. Meth. A **484** (2002) 174.
3. J. M. Link *et al.* [FOCUS Collaboration], Phys. Lett. B **535** (2002) 43.
4. J. M. Link *et al.* [FOCUS Collaboration], Phys. Lett. B **544** (2002) 89.
5. D. M. Schmidt, R. J. Morrison and M. S. Witherell, Nucl. Instrum. Meth. A **328** (1993) 547.