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Rare and Forbidden Charm Meson Decays in FOCUS

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The abundant data from Fermilab's FOCUS experiment is being searched for rare and forbidden decays of charm mesons. An example of the search methodology in the preliminary analysis of $D^0 \rightarrow \mu^+\mu^-$ is presented. The blind analysis uses the data in the sidebands and a simulation of the signal to optimize the selection cuts based on a determination of the sensitivity for discovery at the 90% confidence level.

1. Introduction

The discovery of processes which are predicted to be non-existent by the Standard Model would be a clear signal of new physics. So would rates that are higher than expected for rare processes. The former include lepton number violating (LNV) and family lepton number violating (FLNV) decays. Flavor-changing neutral currents (FCNC) are an example of the latter. The charm sector is a good place to search for FCNC effects since the predicted rates are very low; thus there is a large "window of opportunity". Limits established for s and b quark decays do not necessarily apply to c decays since the couplings to new physics may be different.

In the Standard Model, short-distance contributions to FCNC decays are suppressed by the GIM mechanism. Long-distance effects (LDE) are typically much larger. As an example, for $D^0 \rightarrow \mu^+\mu^-$ a one-loop calculation obtains a branching ratio of order 10^{-19}.[1] LDE increase the branching ratio by four orders of magnitude. For other FCNC charm decays, calculations of branching ratios (including LDE) are typically of order 10^{-8} to 10^{-6}.[2] Current experimental limits are several orders of magnitude above the theoretical predictions in most cases.[3] For $D^0 \rightarrow \mu^+\mu^-$ the limit is 4.1×10^{-6}.[4]

FOCUS' main goal was a tenfold increase in the number of charm events detected by an upgraded E687 spectrometer.[5] This goal was exceeded with the reconstruction of more than 10^6 charm particle decays from a sample of 6.3×10^9 triggers collected during Fermilab's 1996-97 fixed target run.

2. Methodology

Important criteria used in the search are the particle identification and the vertexing requirements (well-determined and spatially-separated primary and secondary vertices). Vertexing variables include the confidence levels of the primary and secondary vertices as well as the detachment variable l/σ. Others are the multiplicity of the primary vertex and the isolation variables which are designed to reduce backgrounds from cases where the wrong tracks are assigned to the primary or secondary vertex. For muon id there is a requirement of a minimum number of hits consistent with the track and independent confidence level cuts are applied to the inner muon detector and the outer.

The $D^0 \to K^-\pi^+$ channel is used as the normalization mode in this analysis. Those events are selected with the same requirements as the signal except, of course, for the particle id. We are carrying out a blind analysis using the sensitivity to optimize the cuts. This is calculated as the average 90% confidence limit for the branching ratio for an infinite ensemble of experiments each having zero signal and an average background level equal to that observed in the sidebands. We use the confidence limits for the number of signal events determined by Lopez and Rolke [6] who extend the Cousins and Feldman limit calculation [7] to the case where the background level is not known with absolute precision as is our case. The relative efficiency of detection is found with a full Monte Carlo simulation. The total number of D^0s produced in the target (1.0×10^8) is determined by doing a fit to the $D^0 \to K^-\pi^+$ invariant mass histogram.

3. Preliminary Sensitivity Results

Our preliminary results are presented in Table 1. The lowest sensitivity is at the level of 1.5×10^{-6} which is almost a factor of three lower than the current limit. The relevant invariant mass histograms for data and Monte Carlo are presented in Fig. 1. Final cut values will depend on the results of ongoing background studies. The signal region will only be looked at when cuts have been finalized.

The preliminary analysis of other rare and forbidden decays in FOCUS (D^+ or $D_s^+ \to h\mu\mu$) yields sensitivities in the 5×10^{-6} range which is roughly an order of magnitude below existing limits.

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Table 1. Cuts and sensitivity results for the four cut combinations with the best sensitivities.

	Cut Combination			
	1	2	3	4
— Cuts —	—	—	—	—
L/σ $(>)$	**7.0**	7.0	7.0	7.0
Primary isolation $(<)$	$\mathbf{10^{-4}}$	10^{-4}	10^{-4}	10^{-4}
Secondary isolation $(<)$	$\mathbf{10^{-2}}$	10^{-2}	10^{-2}	10^{-2}
Secondary CL $(>)$	**0.01**	0.05	0.01	0.01
$(\mid z\ \ prim. - z\ \ target\ edge \mid)/\ \sigma$ $(\leq)$	**0.0**	2.0	0.0	0.0
Number of Muon Planes Hit $(\geq)$	**4**	4	4	4
Inner Muon CL $(>)$	**0.01**	0.01	0.01	0.01
Outer Muon CL $(>)$	**0.01**	0.01	0.03	0.01
Kaonicity $(<)$	**8.0**	8.0	8.0	5.0
— Results —	—	—	—	—
Background Rate in Sidebands	**1.0**	1.0	1.0	1.0
$D^0 \to \mu^+\mu^-$ *efficiency* (%)	**2.271**	2.256	2.255	2.243
Sensitivity (10^{-6})	**1.493**	1.502	1.503	1.512

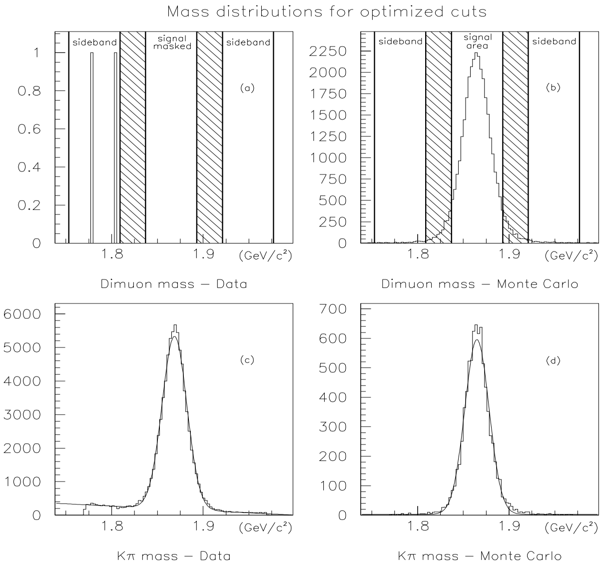

Fig. 1. Invariant mass histograms with optimum cuts. Dimuon invariant mass for (a) data and (b) Monte Carlo. The D^0 signal region is masked in the data. $K\pi$ invariant mass for the normalizing mode in (c) data and (d) Monte Carlo.