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Abstract

Flavour-changing neutral current decays are forbidden in lowest order in the Standard Model. We present results of a search for the charm changing neutral current decay $D^+ \to \pi^+\mu^+\mu^-$ based on the analysis of one third of the data from Fermilab experiment E791, accumulated during the 1991-92 fixed target run with a 500 GeV negative pion beam incident on a segmented target. Assuming that the decay kinematics are the same as for $D^+ \to K^-\pi^+\pi^+$, we set an upper limit on the branching ratio for this channel, $B(D^+ \to \pi^+\mu^+\mu^-) < 4.6 \times 10^{-5}$ at the 90% confidence level.

Fermilab E791 is a high statistics heavy quark experiment with excellent sensitivity for rare charm decays. With a 500 GeV/c π^- beam in the 1991-1992 fixed-target run, the world's largest sample of charm decays was recorded. We have searched one third of this large sample of charm decays for the flavour-changing neutral current (FCNC) decay $D^+ \to \pi^+\mu^+\mu^-$.

The E791 spectrometer is an upgraded version of the apparatus used in Fermilab experiments E516, E691, and E769 [1]. Twenty three planes of silicon microstrip detectors provided information for efficient track and vertex reconstruction. Muon identification was based on two planes of scintillation counters located behind shielding with a thickness equivalent to 2.5 meters of steel.

The strategy of the experiment was to collect data with an open trigger and then select interesting events offline. During the 1991-1992 run the data acquisition system accepted 10^4 events/sec during a typical beam spill and wrote a total of 2×10^{10} interactions onto 24,000 8 mm tapes [2]. The number of fully reconstructable charm decays on tape is estimated to be 2.5×10^5.

Our search for the flavour-changing neutral current decay $D^+ \to \pi^+\mu^+\mu^-$, making the same assumptions as the current best limit [3], results in an improvement by nearly two orders of magnitude. The important common assumption is that the $\pi\mu\mu$ and the $K\pi\pi$ decay modes have the same decay kinematic distributions. However, the FCNC process, if it exists, is new physics, with unknown properties. There is no a priori reason to say that the decay kinematics are identical.

Our search uses one third of the E791 data set and requires pairs of oppositely-charged muons from a three-prong secondary vertex significantly detached from the primary vertex. The muon identification efficiency is 97% within our geometric acceptance, and the pion misidentification probability varies between 5% and 10%, depending on track momentum.

We require secondary tracks and vertices to be of good quality. The decay vertex is required to be well separated from material in the target foils. Decay tracks are required to have a significant impact parameter relative to the primary vertex. To ensure that no tracks are missing from the secondary vertex and, in particular to eliminate muons from charm semileptonic decays, the excess momentum transverse to the candidate D^+ line of flight must be less than 250 MeV/c.

Candidate dimuon decays are those selected secondary vertices which contain two oppositely charged tracks identified as muons and whose $\pi\mu\mu$ invariant mass is in the D^+ mass region. As shown in figure 1, we find 5 such candidate vertices with $\pi\mu\mu$ mass between 1.85 and 1.89 GeV/c^2.

We calculate the number of our background events as a product of two terms, $N_{bg} = N_0 \times R$, where the normalization $N_0 = 419$ is the number of selected three-prong candidates, prior to any muon identification, with $\pi\mu\mu$ mass between 1.85 and 1.89 GeV/c^2, and $R = (1.1 \pm 0.1)\%$ is the rate at which pairs of oppositely-charged tracks are misidentified as muons. We measure R using the background-subtracted rate of such events in our sample of $D^+ \to K^-\pi^+\pi^+$ decays with identical vertex cuts. The resultant background estimate is $N_{bg} = 4.6 \pm 0.5$ events.

To obtain an upper limit for the decay $D^+ \to \pi^+\mu^+\mu^-$ we normalize to the well established decay mode $D^+ \to K^-\pi^+\pi^+$. Using event selection criteria identical to those employed for the FCNC search but without the muon tags, we find a total of $N = 9692 \pm 105$ events in the $D^+ \to K^-\pi^+\pi^+$ channel.

Assuming that $\pi\mu\mu$ and $K\pi\pi$ decays are kinematically identical, we compute the upper limit as

$$B(D^+ \to \pi^+\mu^+\mu^-) = \frac{U(\pi^+\mu^+\mu^-)}{N(K^-\pi^+\pi^+)}\frac{1}{\epsilon^2}B(D^+ \to K^-\pi^+\pi^+)$$

where $U = 5.35$ is the 90%-confidence-level upper limit for an observation of 5 events when a background of 4.6 is expected. We determine the muon identification efficiency to be $\epsilon = (97 \pm 1)\%$ within our geometrical acceptance. B, the Particle Data Group value for the hadronic branching ratio, is $B(D^+ \to K^-\pi^+\pi^+) = (8.0^{+0.8}_{-0.7})\%$ [4]. The resulting upper limit on the branching ratio is $B(D^+ \to \pi^+\mu^+\mu^-) = 4.6 \times 10^{-5}$ at the 90% confidence level. We investigated possible degradations of this limit due to the uncertainty in our background and found such effects to be negligible.

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Figure 1: Invariant mass distributions for the search channel, $M_{\pi\mu\mu}$ (solid histogram), and for the normalization channel, $M_{K\pi\pi}$ (diamonds), scaled by down by a factor of 100.