Observation of the Charmed Meson Decay $D^0 \rightarrow K^- \pi^+ \pi^0$

A Thesis
Presented for the
Master of Science
Degree
The University of Mississippi
Department of Physics

Qiuming Jie

May, 1997
Abstract

Observation of the Charmed Meson Decay $D^0 \rightarrow K^-\pi^+\pi^0$

Qiuming Jie

Thesis directed by Dr. Donald J. Summers.

We report the result of the first E791 observation of $D^0 \rightarrow K^-\pi^+\pi^0$ in a data subset from hadroproduction experiment E791 at Fermilab. We use the charge of pion from the strong decay $D^{*+} \rightarrow D^0\pi^+_\text{b}$ (and charge conjugate) to identify the neutral D, then find $62 \pm 11 \ D^0 \rightarrow K^-\pi^+\pi^0$ decays. By using the number of $D^0 \rightarrow K^-\pi^+$ decays, we calculate the $\pi^0$ finding efficiency to be 3.5%.
Acknowledgments

I am happy to take this opportunity to thank the many people who helped me in the past three years.

I would like to thank my advisor Dr. Donald J. Summers and Dr. Lucien M. Cremaldi for their invaluable guidance and assistance in the preparation and writing of this thesis. Without their patience and understanding, it would have been impossible to finish this work.

I would like to thank Dr. Kumar Bhatt for his participation as a member of my committee.

I would also like to thank Eric Aitala for providing the programs and teaching me how to run them, Dr. David Sanders for drawing the figures, Dr. David Craig for system support.
3.3 Definition of Discrimination Variables ........................................... 30
3.4 Eliminating the $K^-\pi^+\pi^+$ Mis-identified Vertices ..................... 32
3.5 Primary Selection of $D^0 \rightarrow K^-\pi^+\pi^0$ decay ....................... 33
3.6 Final Analysis ............................................................................. 35

4 Conclusion ...................................................................................... 60

Bibliography ..................................................................................... 61
List of Figures

1.1 The E791 Spectrometer .................................................. 3
1.2 The distribution of $\text{Mass}(K^{-}\pi^{+})$ found in the substrip. .......... 9
1.3 The distribution of $\Delta M = M(K^{-}\pi^{+}\pi_{0}^{\mp}) - M(K^{-}\pi^{+})$; (1) in mass window $1.7 \text{ GeV/c}^2 \leq M(K^{-}\pi^{+}) \leq 2.1\text{GeV/c}^2$, the shadow is wrong-side events; (2) in mass window $1.7 \text{ GeV/c}^2 \leq M(K^{-}\pi^{+}) \leq 1.82\text{GeV/c}^2$; (3) in mass window $1.83 \text{ GeV/c}^2 \leq M(K^{-}\pi^{+}) \leq 1.87\text{GeV/c}^2$; (4) in mass window $1.89 \text{ GeV/c}^2 \leq M(K^{-}\pi^{+}) \leq 2.1\text{GeV/c}^2$. ............... 10
1.4 The distribution of $\text{Mass}(K^{-}\pi^{+}\pi_{0}^{\mp})$ found in the substrip. .......... 11

2.1 Energy deposited per SLIC channel in the U, V, Y1 and Y2 views. (Real Data) .................................................. 13
2.2 Energy deposited per SLIC channel in the U, V, Y1 and Y2 views. (MC Data). .................................................. 14
2.3 Visualizing the SLIC information of one event. The numbers in the second and third columns are the energy deposited in Y view channels, and numbers in the second and third rows are the energy deposited in U and V view channels, respectively. The letters in the middle represent the locations where particles hit the SLIC. At the bottom, there is some reconstruction information. .................................. 15
2.4 The distribution of the $\text{TestB}(\gamma_1) \times \text{TestB}(\gamma_2)$ and $\text{TestC}(\gamma_1) \times \text{TestC}(\gamma_2)$ of the $\pi^0$ candidate from the $\pi^0$ list. These two variables were used as cuts. Events in the shadow area were selected. Out of 9769 photon pairs, 5854 pairs pass $\text{TestB}(\gamma_1) \times \text{TestB}(\gamma_2) \geq 0.04$ cut, and all pass $\text{TestC}(\gamma_1) \times \text{TestC}(\gamma_2) \leq 0.4$ cut. ......................... 18
3.1 Illustration of SDZ. 

3.2 Illustration of $P_t$. 

3.3 Distribution of: (1) distance of closest from the secondary vertex; and (2) the mass of combination of closest track and the tracks of vertex; (3) distance of second closest track from the secondary vertex; and (4) the mass of combination of the second closest track and the tracks of vertex. Events in the shadow area have high probability being $K^-\pi^+\pi^0$, and were rejected from further analysis.

3.4 The distribution of $\Delta M$, SDZ, $P_t(K^-\pi^+\pi^0)$ and $P_t(K^-\pi^+)$ before applying final cuts. (Monte Carlo Data).

3.5 The distribution of impact parameters of $K^-$ and $\pi^+$, $K^-$ and $\pi^+$ probability. (Monte Carlo Data).

3.6 The distribution of $\Delta M$ after applying cuts: 1) the $\pi$ and $\pi_b$ charge sign match; 2) SDZ $\geq$ 10.; 3) $P_t(K^-\pi^+\pi^0) \leq 0.35$ GeV/c; 4) $P_t(K^-\pi^+\pi^0) \leq P_t(K^-\pi^+)$. (Monte Carlo Data).

3.7 The distribution of $\Delta M$ after applying cuts: 5) the $K$ probability $\geq 0.7$; 6) impact parameter of $K \geq 0.008$ cm; 7) impact parameter of $\pi^+ \geq 0.008$ cm; 8) Mass($K^-\pi^+$) $\leq 1.8$ GeV/$c^2$. (Monte Carlo Data).

3.8 The distribution of mass($K^-\pi^+\pi^0$) after applying cuts: 1) the $\pi$ and $\pi_b$ charge sign match, $\Delta M \leq 0.15$ GeV/$c^2$; 2) SDZ $\geq$ 10.; 3) $P_t(K^-\pi^+\pi^0) \leq 0.35$ GeV/c; 4) $P_t(K^-\pi^+\pi^0) \leq P_t(K^-\pi^+)$. (Monte Carlo Data).

3.9 The distribution of mass($K^-\pi^+\pi^0$) after applying cuts: 5) the $K$ probability $\geq 0.7$; 6) impact parameter of $K \geq 0.008$ cm; 7) impact parameter of $\pi^+ \geq 0.008$ cm; 8) Mass($K^-\pi^+$) $\leq 1.8$ GeV/$c^2$. (Monte Carlo Data).

3.10 The distribution of mass($D^0\pi_b^+$) after applying cuts: 1) the $\pi$ and $\pi_b$ charge sign match, $\Delta M \leq 0.15$ GeV/$c^2$; 2) SDZ $\geq$ 10.; 3) $P_t(K^-\pi^+\pi^0) \leq 0.35$ GeV/c; 4) $P_t(K^-\pi^+\pi^0) \leq P_t(K^-\pi^+)$. (Monte Carlo Data).

3.11 The distribution of mass($D^0\pi_b^+$) after applying cuts: 5) the $K$ probability $\geq 0.7$; 6) impact parameter of $K \geq 0.008$ cm; 7) impact parameter of $\pi^+ \geq 0.008$ cm; 8) Mass($K^-\pi^+$) $\leq 1.8$ GeV/$c^2$. (Monte Carlo Data).
3.24 The distribution of Mass($K^+\pi^+\pi^0$) after applying all final cuts. (Real Data)  

3.25 The distribution of Mass($D^{*+}$) after applying all final cuts. (Real Data)
these events, E791 has reconstructed the largest sample of charmed particle decays that exist today, over 200K $D^0$, $D^+$, $D_s$, and $Λ_c$ decays. In addition it has an immense sample of hyperon decays for studies in those areas.

1.2 Spectrometer

The Tagged Photon Spectrometer, illustrated in Figure 1.1, is a series of detectors used to track, measure the momentum of, and identify particles produced in high energy collisions of a pion beam and nuclear target. The tracking systems consist of 8 1mm proportional wire chambers (PWCs) beam planes including two beam stations spaced widely apart. They project into 6 25µm planes of silicon microstrip detector (SMD) just in front of a Pt-C-C-C-C-C segmented target, (one 0.5 mm thick platinum foil followed by four 1.6 mm thick diamond foils with approximately 15 mm center-to-center separations). These detectors are used to precisely track the transverse position and slope of the incoming $π^-$ meson, which interacts in our target. The interaction point is identified with over 95% efficiency. A 17 plane silicon strip detector placed just after the target, tracks secondaries from the interaction. The longitudinal and transverse vertex resolution of this system is about 350µm and 711µm respectively, allowing efficient tagging of charm secondary vertices. Tracks proceed into a 35 plane drift chamber system interspersed around and between two horizontally bending dipoles. The mass resolution for a typical D meson decay is 8-11 MeV/c depending on the multiplicity of the decay. Two large multicell Čerenkov counters have good $π$, K, p identification capabilities between 6 and 100 GeV/c. The average efficiency for identifying kaons is 65-70% over the full momentum range and quite suited to charm decays. A electromagnetic and hadronic calorimeter gives energy measurements of electrons, photons, and hadrons. Finally muons are identified behind a 1 meter long steel filter with two sets of scintillator paddles.

A $π^-$ -N interaction event was recorded by the experiment if the following criteria were met:

1) Only one $π^-$ beam particle detected in a scintillation counter upstream of the target;
2) At least four charged tracks detected in a scintillation counter downstream of the target;
3) and a minimum of approximately 4 GeV of energy deposited transverse to the beam line in the electromagnetic and hadronic calorimeters. Heavy quark decays lead to a higher average transverse energy.

Data was recorded at a rate of 4000 events/second with a fast data acquisition system capable of recording 10MB/second to 8mm tape. 50 TBytes of data were recorded. This raw data had to be reconstructed and reduced to a manageable size before any physics analysis could be done.

This operation was performed on four large UNIX computer farms set up at the University of Mississippi, Kansas State University, Fermilab, and CBPF in Brazil. 24,000 raw data tapes were reconstructed between 1992 and 1994. From this raw data, 8000 Data Summary Tapes (DSTs) were produced. These DSTs were further stripped for subsequent physics channels.

1.3 Event Reconstruction and Stripping Selection

The reconstruction of an event from raw data included tracking and vertex reconstruction algorithms, Čerenkov particle identification, neutral and charged particle calorimetry, and finally muon identification. For each reconstructed track a momentum four-vector was determined. Below we briefly describe this process.

1.3.1 Track Reconstruction

Track reconstruction began with SMD hit information. The SMD tracking algorithm first finds straight line segments in each view using a minimum $\chi^2$ fit. Then one dimensional tracks from the three views are combined to form three dimensional straight line tracks. The drift chamber (DC) hit information is used to find the possible positions (triplets) of the actual hit on each drift chamber group. The SMD tracks were then extended to the drift chamber and fit to the triplets along the track.
the light collected by each photocell unit to the number of photoelectrons each particle
would generate at the given momentum. This calculation is performed separately for
electrons, muons, pions, kaons, and protons. A probability or likelihood $CPRB2$ is
assigned to each hypothesis, ranging from 0 to 1.

1.3.4 Calorimetry

Calorimetry information is used to identify neutral particles, photons and neutral
hadrons, and to measure their energy. This process will be described in more detail
in the next chapter.

1.3.5 Filtering of Data

The filtering of data was performed as the events were reconstructed by the farm.
Only those events likely to contain charm particle decays or a clear neutral kaon or
hyperon decay were saved. An event having a primary vertex would be accepted by
the filter if one of the following three criteria were met:

1. presence of a secondary vertex with good separation;

2. presence of a $K_s$ or a $\Lambda$ from ESTR vertex reconstruction;

3. presence of a $\phi$ from two SESTR tracks.

The filtering retained about 17% of the original data sample. After filtering, all
reconstructed physical parameters (tracks, vertices, etc.) and raw data were written
to output data summary tapes (DSTs) for further processing.

1.3.6 Stripping

After the data was reconstructed and filtered data was written to DST, it was further
split into two streams, A and B, by E791 stripping software. Stream A saved all events
we expected to reconstruct about 50 $K^-\pi^+\pi^0$ decays.

$$N_{K^-\pi^+\pi^0} = \epsilon_{\pi^0} \times N_{K^-\pi^+} \times \frac{BR(D^0 \to K^-\pi^+\pi^0)}{BR(D^0 \to K^-\pi^+)} \approx 50$$

Both $D^0$ come from $D^{*+} \to D^0\pi^0$, the ratio of branching ratios (BR) for the two modes is about 3.6, and we used a $\pi^0$ finding efficiency of 3% for the calculation.

From Figures 1.2, 1.3 and 1.4, we determined the number of $D^0 \to K^-\pi^+$ in this substrip to be 487 ± 24. The cuts used for $D^0 \to K^-\pi^+$ are in the Table 1.2. Charm quarks are Cabibbo favored to decay into strange quarks in a few picoseconds. The cuts are designed to look for secondary vertices with a strange meson. No particular mass is favored over another. The small phase space for the $D^{*+}$ decay is exploited.

<table>
<thead>
<tr>
<th>Cut Name</th>
<th>Cut Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDZ</td>
<td>$\geq 10$</td>
</tr>
<tr>
<td>C(K)</td>
<td>$\geq 0.6$</td>
</tr>
<tr>
<td>C($\pi$)</td>
<td>$\geq 0.2$</td>
</tr>
<tr>
<td>PRA</td>
<td>$\geq 0.75$</td>
</tr>
<tr>
<td>Tau</td>
<td>$\leq 2.0$ ps</td>
</tr>
<tr>
<td>$\Delta M$</td>
<td>$\Delta M &lt; 0.15$ GeV/c$^2$</td>
</tr>
<tr>
<td>PTB</td>
<td>$P_t(K^-\pi^+) \leq 0.35$ GeV/c</td>
</tr>
</tbody>
</table>

Table 1.2: Cuts for $D^0 \to K^-\pi^+$ decay. Definitions are in Section 3.3.

By measuring the number of $K^-\pi^+\pi^0$ decays we can directly estimate $\epsilon_{\pi^0}$.

A number of $\pi^0$ reconstruction algorithms were tested to find the $\pi^0$'s within the $D^0 \to K^-\pi^+\pi^0$ decays, as described in the next sections.
Figure 1.3: The distribution of $\Delta M = M(K^-\pi^+\pi^+_b) - M(K^-\pi^+)$; (1) in mass window $1.7 \text{ GeV}/c^2 \leq M(K^-\pi^+) \leq 2.1 \text{ GeV}/c^2$, the shadow is wrong-side events; (2) in mass window $1.7 \text{ GeV}/c^2 \leq M(K^-\pi^+) \leq 1.82 \text{ GeV}/c^2$; (3) in mass window $1.83 \text{ GeV}/c^2 \leq M(K^-\pi^+) \leq 1.87 \text{ GeV}/c^2$; (4) in mass window $1.89 \text{ GeV}/c^2 \leq M(K^-\pi^+) \leq 2.1 \text{ GeV}/c^2$. 
Chapter 2

Reconstruction of $\pi^0$'s

2.1 Introduction

In $D^0 \rightarrow K^-\pi^+\pi^0$, one of the main difficulties is to detect $\pi^0 \rightarrow \gamma\gamma$. The lifetime of the $\pi^0$ is very short ($10^{-16}$s), and it immediately decays into two $\gamma$ rays. If the $\gamma$ rays hit the Segmented Liquid Ionization Calorimeter (SLIC) [19,20], they create two electromagnetic showers. After identifying the position centroid of these showers in the SLIC, the two photons energies and positions are determined.

The SLIC reconstruction only determined where the photons hit the SLIC, and not where the photons originated. Unlike a charged track, neutrals can’t be pointed back to tell which vertex they came from. I first briefly introduce calorimetry reconstruction, then give the method which we used to reconstruct $\pi^0 \rightarrow \gamma\gamma$ decays.

2.2 Calorimeter

The SLIC of E791 is a 2.44 m by 4.88 m electromagnetic calorimeter with 334 counters divided between three views (U and V strips at $\pm 20.5^\circ$ to the vertical, plus horizontal Y strips)[19,20]. Fig 2.1 shows the energy deposited on the detectors for some typical events. Fig 2.2 is Monte Carlo (MC) data. Comparing the two figures, we see that photomultiplier tube pulse height to energy calibrations are good but not perfect. One would expect smoothly decreasing curves for perfect calibration.
Figure 2.2: Energy deposited per SLIC channel in the U, V, Y1 and Y2 views. (MC Data).
2.3 Shower Reconstruction

The first part of reconstruction algorithm found electromagnetic shower energy groupings (sectors) in each view (U, V and Y views). A stepwise regression fit to the counter energies was used to find energies in sectors. The one dimensional views were then combined together to find the X and Y positions of particles, as well as their energies. After finding clusters of energy in each of the three views, associated triplets of clusters with charged tracks or neutral shower candidates were considered. Again a stepwise regression was used to find the optimal set of candidate shower energies. More specifically, the following quantity is minimized:

\[ \chi^2 = \sum_{\text{cluster } i} \left( e_i - \sum_{\text{candidate } j} \alpha_{ij} \varepsilon_j \right)^2 \omega_i \quad (2.1) \]

where \( e_i \) is the energy measured in cluster \( i \); \( \omega_i \) is the weight for the energy measurement \( e_i \) (\( \omega_i = 1/\sigma_i^2 \)); \( \varepsilon_j \) is the energy candidate \( j \) would deposit in the SLIC (\( \varepsilon_j \) are the parameters to be determined by the fit); and \( \alpha_{ij} \) is a position-dependent energy correction factor which includes an optical attenuation factor and corrections for physical and optical shower leakage between the right and left Y views. The goal is to find the set of candidates with energy \( \varepsilon_j \) which minimizes the above \( \chi^2 \). Reference [21] describes the algorithm in detail. Fig 2.3 visualizes the SLIC information, including the reconstruction information, of a typical event.

2.4 \( \pi^0 \) Reconstruction from the DST

After shower reconstruction, the pertinent individual photon data was stored in the neutral particle calorimeter hit banks. Standard E791 library routines paired these photons to find \( \pi^0 \to \gamma\gamma \) candidates from the information of shower reconstruction. This software created two cutting variables, TestB and TestC. TestB was a variable which described the likelihood of a neutral being a real photon. TestC described how close the candidate fit a \( \pi^0 \) mass hypothesis. Combining the definition of momentum for photons, \( p = E/c \), and assuming the photons origin is the secondary vertex, one can get a full 4-momentum. Thus, the \( \pi^0 \)s were reconstructed. After reconstruction,
Figure 2.4: The distribution of the TestB(γ1) × TestB(γ2) and TestC(γ1) × TestC(γ2) of the π⁰ candidate from the π⁰ list. These two variables were used as cuts. Events in the shadow area were selected. Out of 9769 photon pairs, 5854 pairs pass TestB(γ1) × TestB(γ2) ≥ 0.04 cut, and all pass TestC(γ1) × TestC(γ2) ≤ 0.4 cut.
Figure 2.6: The mass distribution of $\pi^0$ candidates, the $\pi^0$s in the shadow area were selected to find the $D^0 \rightarrow K^-\pi^+\pi^0$ events. The two photons were selected from the photon pair index of the $\pi^0$ list.
Figure 2.8: The distribution of $\text{TestB}(\gamma_1) \times \text{TestB}(\gamma_2)$, this variable was used as a cut, the events in shadow area were selected. 79656 out of 266458 pairs passed the cut. The two photons were randomly selected.
Figure 2.10: The distribution of $\text{TestC}(\gamma_1) \times \text{TestC}(\gamma_2)$ before and after the distance and energy cuts. The two photons were randomly selected.
Figure 2.12: Using the TestP(γ1)×TestP(γ2) ≥ 0.8 cut on the π⁰ candidates of the previous figure.
Figure 2.13: Distribution of $\text{TestP}(\gamma_1) \times \text{TestP}(\gamma_2)$. The two photons were randomly selected.
3.2 PAW Analysis Tool

In the following analysis process, we use the PAW (physical analysis workstation) software package developed at CERN. Ntuples are data structures within PAW that are large multi-dimensional arrays, which can be considered as event files. PAW stores them in a data base format so they can be easily manipulated. Ntuples can be accessed as a whole or single columns, or even single components. A rather complete set of operators is available to deal with Ntuples – these include capabilities to apply cuts or selection criteria to Ntuple data.

After our final $D^0 \rightarrow K^+\pi^+\pi^0$ event selection relevant information about the decay was stored in an Ntuple. Both real data and Monte Carlo events were treated and saved in Ntuple format. Then the operators were used to manipulate these information to optimize the cuts. This selection mechanism is describe next.

3.3 Definition of Discrimination Variables

To choose a clean sample of $D^0 \rightarrow K^-\pi^+\pi^0$ events, a series of selection criteria had to be applied to filtered DST data. Cuts were applied on following parameters at the primary selection and the analysis stage.

SDZ ($\geq$) The significance of the $Z$ separation of the primary and the secondary
C(K) (≥) Čerenkov identification probability of kaons. Kaons had an *apriori* probability of 0.125. A Čerenkov probability of being a kaon above this value gave a positive indication of the particle's being a kaon.

C(π) (≥) Čerenkov identification probability of pion.

PRA(≤) decay asymmetry \( PRA = \frac{P_1 - P_2}{P_1 + P_2} \) where \( P_1, P_2 \) are the momenta of the two particles, this cut only used for \( D^0 \rightarrow K^-\pi^+ \) decay.

TAU(≤) proper lifetime cut for particle.

P(≥) Track momentum restricting the momentum of the track makes the Čerenkov identification more effective.

### 3.4 Eliminating the \( K^-\pi^+\pi^+ \) Mis-identified Vertices

Some charm decay modes are three prongs, such as \( D^+ \rightarrow K^-\pi^+\pi^+ \). If one track is mis-vertexed or lost from the secondary vertex, especially the \( \pi^+ \), a two-prong vertex will result. This kind of "false-two-prong" vertex has similar properties as \( D^0 \rightarrow K^-\pi^+\pi^0 \)'s two prong vertex, and can contaminate the the sample, lowering the S/N ratio. Because the general \( P_t \) balance cut is not able to completely eliminate this kind of background, we inserted a subprogram to achieve this goal.

The subprogram rejected fake two-prong vertex candidates by the following algorithm:

1) It located the closest and the second closest track to the two-prong vertex in question;
Figure 3.3: Distribution of: (1) distance of closest from the secondary vertex; and (2) the mass of combination of closest track and the tracks of vertex; (3) distance of second closest track from the secondary vertex; and (4) the mass of combination of the second closest track and the tracks of vertex. Events in the shadow area have high probability being $K^-\pi^+\pi^+$, and were rejected from further analysis.
reduced the background in the real data. But in the real data background came from both sources mentioned above, seen in the distribution of \( M(D^0) \) and \( M(D^{*+}) \). Figures 3.18 to 3.21. There were still many fake \( D^0 \)s passing through the primary selection and final cuts, but a clear signal over background is evident in Figure 3.24.

<table>
<thead>
<tr>
<th>Cut Name</th>
<th>Cut Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDZ</td>
<td>( \geq 10 )</td>
</tr>
<tr>
<td>C(K)</td>
<td>( \geq 0.6 )</td>
</tr>
<tr>
<td>IP(K)</td>
<td>( \geq 0.008 \text{ cm} )</td>
</tr>
<tr>
<td>IP(( \pi ))</td>
<td>( \geq 0.008 \text{ cm} )</td>
</tr>
<tr>
<td>( \Delta M )</td>
<td>( \Delta M &lt; 0.15 \text{ GeV}/c^2 )</td>
</tr>
<tr>
<td>PTB</td>
<td>( P_l(K^+\pi^-\pi^0) \leq 0.35 \text{ GeV}/c )</td>
</tr>
<tr>
<td></td>
<td>( P_r(K^+\pi^-\pi^0) &lt; P_r(K^-\pi^+) )</td>
</tr>
</tbody>
</table>

Table 3.1: Cuts for \( D^0 \rightarrow K^-\pi^+\pi^0 \) analysis.

The width of the \( D^{*+} \) signal in the \( \Delta M \)-value plot was estimated from Monte Carlo events to be about 3 \( \text{MeV}/c^2 \). We used this value in the actual fit of the signal events.

The signal events in the Monte Carlo formed a Gaussian centered about 0.1457 \( \text{GeV}/c^2 \). The number of fitted events in the were \( 42.7 \pm 7.2 \). This results in a \( K^-\pi^+\pi^0 \) finding efficiency of

\[
\epsilon_{K^-\pi^+\pi^0} = \frac{N_{MC}^{K^-\pi^+\pi^0}}{N_{total}^{MC} \times \text{Fraction}(D^{*+} \rightarrow D^0\pi^+) \times \epsilon_{\pi^+}} \approx \frac{42.7 \pm 7.2}{118,000 \times 1/3 \times 70\%} \approx 1/7\%
\]

The fraction that \( D^0 \) comes from \( D^{*+} \) is around 1/3, and the efficiency of finding \( \pi^+_L \) is around 70%.

The same fit on real data resulted in a Gaussian mass peak at 0.1449 \( \text{GeV}/c^2 \), and the number of fitted events were \( 62 \pm 11.2 \) events. Now we can determine \( \pi^0 \) finding efficiency:

36
Figure 3.4: The distribution of $\Delta M$, SDZ, $P_t(K^+\pi^0)$ and $P_t(K^+\pi)$ before applying final cuts. (Monte Carlo Data).
Figure 3.6: The distribution of $\Delta M$ after applying cuts: 1) the $\pi$ and $\pi_b$ charge sign match; 2) SDZ $\geq 10$; 3) $P_t(K^-\pi^+\pi^0) \leq 0.35$ GeV/c; 4) $P_t(K^-\pi^+\pi^0) \leq P_t(K^-\pi^+)$. (Monte Carlo Data).
Figure 3.8: The distribution of mass($K^{-}\pi^{+}\pi^{0}$) after applying cuts: 1) the $\pi$ and $\pi_{b}$ charge sign match, $\Delta M \leq 0.15$ GeV/$c^2$; 2) SDZ$\geq 10$; 3) $P_{t}(K^{-}\pi^{+}\pi^{0}) \leq 0.35$ GeV/$c$; 4) $P_{t}(K^{-}\pi^{+}\pi^{0}) \leq P_{t}(K^{-}\pi^{+})$. (Monte Carlo Data).
Figure 3.10: The distribution of mass($D^0\pi^+_\ell\pi^-\pi^0$) after applying cuts: 1) the $\pi$ and $\pi_\ell$ charge sign match, $\Delta M \leq 0.15$ GeV/$c^2; 2) SDZ $\geq 10; 3) P_t(K^-\pi^+\pi^0) \leq 0.35$ GeV/$c; 4) $P_t(K^-\pi^+\pi^0) \leq P_t(K^-\pi^+)$. (Monte Carlo Data).
Figure 3.12: The distribution of $\Delta M$ after applying cuts: SDZ, impact parameters of $K^-$ and $\pi^+$, PTB, C(K). (Monte Carlo Data).
Figure 3.14: The distribution of Mass($D^{*+}$) after applying all final cuts. (Monte Carlo Data).
Figure 3.16: The distribution of impact parameters of $K^-$ and $\pi^+$; and $K^-$ and $\pi^+$ probability. (Real Data).
Figure 3.18: The distribution of $\Delta M$ after applying cuts: 5) the $K$ probability $\geq 0.7$; 6) impact parameter of $K \geq 0.008$ cm; 7) impact parameter of $\pi^+ \geq 0.008$ cm; 8) $\text{Mass}(K^-\pi^+) \leq 1.8$ GeV/$c^2$. (Real Data).
Figure 3.20: The distribution of mass($K^-\pi^+\pi^0$) after applying cuts: 5) the $K$ probability $\geq 0.7$; 6) impact parameter of $K \geq 0.008$ cm; 7) impact parameter of $\pi^+ \geq 0.008$ cm; 8) Mass($K^-\pi^+$) $\leq 1.8$ GeV/$c^2$. (Real Data).
Figure 3.22: The distribution of Mass($D_0^{*+}$) after applying cuts: 5) the $K$ probability $\geq 0.7$; 6) impact parameter of $K \geq 0.008$ cm; 7) impact parameter of $\pi^+ \geq 0.008$ cm; 8) Mass($K^-\pi^+$) $\leq 1.8$ GeV/c². (Real Data).
Figure 3.24: The distribution of Mass($K^-\pi^+\pi^0$) after applying all final cuts. (Real Data).
Chapter 4

Conclusion

Using the list of $\pi^0$ candidates from the standard E791 DST reconstruction code, we were able to find $62 \pm 11 \ D^0 \rightarrow K^-\pi^+\pi^0$ decays for the first time in the E791 data sample. There are $487 \pm 24 \ D^0 \rightarrow K^-\pi^+$ in this substrip, so the $\pi^0$ finding efficiency is 3.5% or about $1/30$. Note that $\text{BR}(D^0 \rightarrow K^-\pi^+\pi^0)/\text{BR}(D^0 \rightarrow K^-\pi^+) = 3.6$. From this number we estimate that about 2,000 $D^0 \rightarrow K^-\pi^+\pi^0$ can be found in our E791 data sample. This is $1/10$ the number of $D^0 \rightarrow K^-\pi^+$ decays that we see coming from a $D^{*+}$.

Our measurement of the $D^{*+}$ mass is $2024 \pm 6 \text{ MeV}/c^2$ and the $D^0$ mass is $1878 \pm 6 \text{ MeV}/c^2$, is in agreement with the values from the Particle Data Guide (PDG) [31] of the $D^{*+}$ mass $2010.0 \pm 0.5 \text{ MeV}/c^2$ and the $D^0$ mass $1864.5 \pm 0.5 \text{ MeV}/c^2$, respectively. Our $\Delta M = 144.9 \pm 0.2 \text{ MeV}/c^2$ compares to $\Delta M = 145.42 \pm 0.05 \text{ MeV}/c^2$ in the PDG.


34. D.J. Summers et al. (E516), Study of the Decay \( D^0 \to K^-\pi^+\pi^0 \) in High-Energy Photoproduction, Physical Review Letters 52 (1984) 410.

35. Donald Joseph Summers, A Study of the Decay \( D^0 \to K^-\pi^+\pi^0 \) in High Energy Photoproduction, Ph.D. Dissertation, University of California, Santa Barbara (March 1984).
