Dalitz analyses at CLEO-c

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Abstract. Using about 60 pb^{-1} of integrated e^+e^- luminosity collected in the CLEO-c pilot run in the $\psi(3770)$ mass range we assess the yield and quality of 3-body hadronic D meson decays for Dalitz plot analyses.

1. Introduction

CESR-c and CLEO-c are in the beginning of the first year of an ambitious experimental program [1]. Over the next three years we plan to collect an integrated luminosity of a few fb^{-1} of $\psi(3770) \to D\bar{D}$, $D_s\bar{D}_s$ at threshold, and J/ψ decays. With this data we plan extensive Dalitz plot analyses of D, D_s, and J/ψ decays. From October 2003 to April 2004 CESR-c was running with six (of twelve in the final design) wigglers at a collision energy close to the mass of $\psi(3770)$. During this pilot run CLEO-c integrated e^+e^- luminosity of 60 pb^{-1}. At this meeting I present the results of this pilot run for Dalitz analyses of D meson hadronic decays showing what can be done with the full CLEO-c data set.

Three body K and π combinations represent a significant fraction of D meson decays. Not all of them are studied well (Table 1). For D meson decays Dalitz plots show a rich set of intermediate states. With high statistics we may improve parameters of well established intermediate resonances. These decays present a clean conditions to study in coupled channels scalar mesons $f_0(980)$, $a_0(980)$, which have low production rate and are strongly contaminated by background in other processes. We may also check with high statistics a resent results on light scalars $f_0(600)$, κ from E791 [3],[4] and FOCUS [5] experiments. The $D-\overline{D}$ mixing and CP violation in charm decays are highly suppressed in the Standard Model. An observation of a rate of $\sim 10^{-3}$ for CP forbidden decays will be an indication on new physics. However, there is a room for CP asymmetry in Standard Model, which is predicted at the level of $A_{CP} \sim 10^{-3}$ for some singly Cabibbo suppressed decays due to "Tree–Penguin" diagram interference in $D^0 \to \pi^+\pi^-\pi^0$ and $D^+ \to K^+K^-\pi^+$ decays for example.

2. Advantage of CLEO-c

Comparing with CLEO III, BaBar, Belle, and other high energy and fixed target experiments CLEO-c (as well as BES) has a significant advantage in D mesons production mechanism. At the energy range close to the $D\overline{D}$ pairs mass threshold the D mesons are produced almost at rest without accompanying particles. These events have lower multiplicity, are cleaner and allow a specific CP tagging since one of D mesons can be used to tag the production of another one for study. Due to the quantum coherence [6] tagging allows us to select D mesons with particular CP parity, i.e. in the processes: $\psi(3770) \to D\bar{D}$, $C(D\bar{D}) = -1$, opposite CP D-s;

$e^+e^- \to \pi^0 D\bar{D}$, $C(D\bar{D}) = -1$, opposite CP D-s; and $\psi(4140) \to \gamma D\bar{D}$, $C(D\bar{D}) = +1$, the same CP D-s.

3. Considered Modes

In our preliminary study we estimate the yield of three body hadronic D-meson decays which can be used for Dalitz plot analyses. We consider all possible three body K, π combinations and few $K\eta\pi$ combinations listed in Table 1 for Cabibbo favorite or singly suppressed decays only.

4. Particle & Event selection

To select events we use a dedicated software package developed at CLEO-c for D mesons tagging, producing the so called "DTag skim" [7] of events. The particle processing algorithms include

- K/π track selection with momentum in the range 50 MeV/c $\leq$ p $\leq$ 2000 MeV/c, "good" track fit quality, track origin is consistent with interaction point (excluding π tracks for K^0_S vertices), $|\cos\theta| < 0.93$.
- Particle ID: combined RICH and dE/dx probability depending on track momentum and $\cos\theta$.
- $\pi^0 \to \gamma\gamma$ and $\eta \to \gamma\gamma$ selection: $E_\gamma > 30$ MeV, isolated shower using E_9/E_{25} energy depositions in the crystal calorimeter, "good" $m_{\gamma\gamma}$ fit quality, $|m_{\gamma\gamma} - m_{\pi^0(\eta)}| < 3\sigma_{\gamma\gamma}$.

To extract D decay signals we use two variables the energy difference between the reconstructed D candidate and the beam energy,

$$\mathbf{\Delta}E = E_{cand} - E_{beam},$$

and the beam constrained mass,

$$\mathbf{m}_{BC} = \sqrt{E_{beam}^2 - p_{cand}^2}.$$

As expected a signal is seen as a concentration of events in the middle of the 2-dimensional plot for m_{BC} vs ΔE shown in Figure 1. We count a number of signal events using two orthogonal slices of this 2-dimensional histogram, selected by requirements $|m_{BC} - m_D| < 5$ MeV/c^2, shown in Figure 2, and $|\Delta E| < 20$ MeV, shown in Figure 3. Though the widths of m_{BC} and ΔE signal spectra vary for different decay modes, for now we use fixed cuts for yield estimate. The m_{BC} spectrum is fitted by a single Gaussian for signal and ARGUS function for the background. The ΔE distribution is fitted by a single Gaussian for signal and linear function for background. The yields obtained from two spectra are statistically consistent. In Table 1 we show the signal yield obtained from m_{BC} spectrum. Even with currently available pilot run statistics we may carry out about ten competitive Dalitz plot analyses.

5. Data quality

We have tested the resolution of invariant mass for two track combinations in $D^+ \to K^-\pi^+\pi^+$ decay. The error on the invariant mass is propagated from the track fit error matrices. We find that 95% of invariant masses have errors below 5 MeV/c^2 with a mean resolution ~2.5 MeV/c^2.

A direct comparison of D^+ mass resolution is done for $D^+ \to K^-K^+\pi^+$ mass spectrum. We have compared CLEO-c data with spectra presented in resent publications from BaBar(hep-ex/0408136) and FOCUS(E831)(hep-ex/0407014). Our sample is smaller, but CLEO-c not only has about four times better mass resolution m_{BC}, but also lower background. This is the advantage arising from clean events and kinematics of low momentum D meson production at threshold.

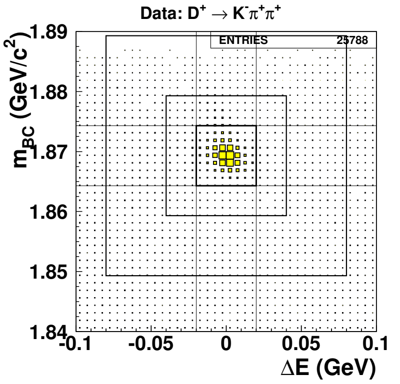

Figure 1. Scatter plot of m_{BC} versus ΔE.

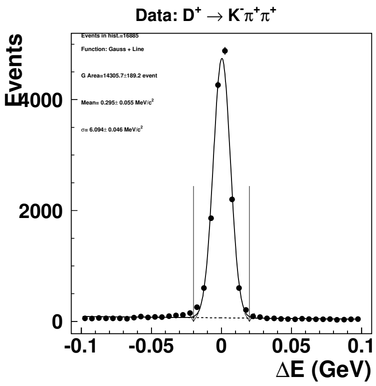

Figure 2. ΔE distribution.

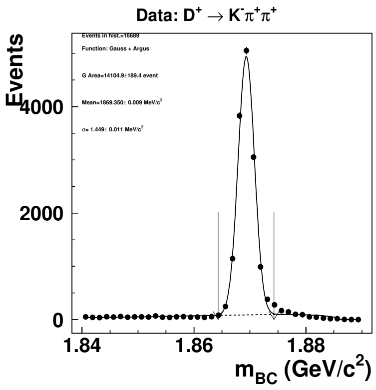

Figure 3. m_{BC} distribution.

Table 1. Considered 3-body modes, the branching ratios(BR) from PDG [2], and observed yield for luminosity $\mathcal{L} \simeq 60$ pb^{-1}.

	D^0			D^+		
Mode	Final State	BR,%	Yield	Final State	BR,%	Yield
$\pi\pi\pi$	$\pi^0\pi^0\pi^0$	N/A	95	$\pi^+\pi^0\pi^0$	N/A	189
	$\pi^+\pi^-\pi^0$	0.73(5)	1937	$\pi^+\pi^+\pi^-$	0.31(4)	714
$K\pi\pi$	$K_S\pi^0\pi^0$	~1.8/2	537	$K_S\pi^+\pi^0$	9.7(3.0)/2	4134
	$K_S\pi^+\pi^-$	5.97(35)/2	4755	$K^-\pi^+\pi^+$	9.2(6)	14105
	$K^-\pi^+\pi^0$	13.0(8)	15887			
$KK\pi$	$K_SK\pi$	~1/2	1174	$K_SK_S\pi^+$	~2/4	398
	$K^-K^+\pi^0$	0.124(35)	258	$K_SK^+\pi^0$	N/A	151
	$K_SK_S\pi^0$	<0.059	228	$K^-K^+\pi^+$	0.89(8)	1162
KKK	$K_SK^+K^-$	1.03(10)/2	358	$K_SK_SK^+$	1.8(8)/4	66
	$K_SK_SK_S$	0.092(16)	32	$K^-K^+K^+$	N/A	~0
$K\eta\pi$	$K^0_S\eta\pi^0$	~0.5	94	$K^0_S\eta\pi^+$	N/A	89
	$K^-\eta\pi^+$	~1	281			

6. Event selection for Dalitz plot

Currently we observe ten modes of D^0 and D^+ 3-body hadronic decays with statistics exceeding 300 events. As an example we consider the decay $D^+ \to K^-\pi^+\pi^+$.

To improve the signal to background ratio on the Dalitz plot we select events with $|m_{BC} - m_D| < 2\sigma(m_{BC})$ and $|\Delta E| < 2\sigma(\Delta E)$. The selected events are shown in Fig. 4 as $m^2(\pi^+\pi^+)$ vs $m^2_{Low}(K^-\pi^+)$ scatter plot. The lowest of two possible $K^-\pi^+$ invariant mass squared is used in order to fold all events on half of the Dalitz plot. A shape for the background is estimated using events from a m_{BC} vs ΔE distribution sideband. The sideband is less than eight and more than four standard deviations from the central values in both $|m_{BC} - m_D|$ and $|\Delta E|$. These selections are graphically shown by rectangles in Figure 1. We find that the background density is not uniform, but its fraction is small, ~1.4%. To estimate the efficiency variation across the Dalitz plot we use a phase space Monte Carlo simulation of this decay. We find the efficiency is almost uniform across the Dalitz plot.

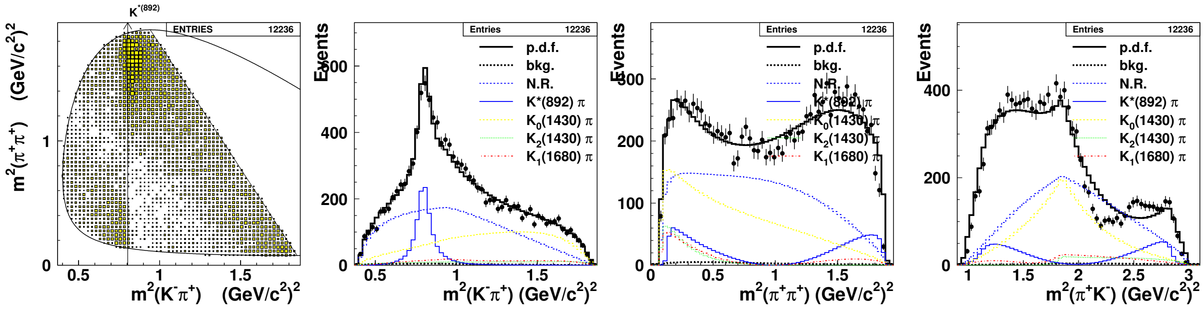

Figure 4. Dalitz plot for $D^+ \to K^-\pi^+\pi^+$ and its projection for three variables. Two $m^2(K^-\pi^+)$ projections are shown for low and high invariant $K^-\pi^+$ mass respectively.

7. Fit to the Dalitz plot

We use an unbinned maximum likelihood fit developed for earlier analyses of CLEO-II.V data [8] in order to describe the event density on the Dalitz plot. Currently, as in our previous analyses, we work within the frame of the *isobar model*. All well known $K\pi$ resonances and non-resonant fraction are included in the fit shown in projection plots of Fig 4. Our first goal is to get a consistent description of our $D^+ \to K^-\pi^+\pi^+$ data which is agrees with previous results from the E791 experiment [4].

In addition to the isobar model we are considering other models of three body D decay such as the K-matrix formalism recently used by FOCUS [5], the field theory motivated approach [9], CMB nuclear physics model [10], and others.

8. Summary

CESR-c/CLEO-c are successfully operating in the beginning of the first year of our experimental program. Using CLEO-c data we plan extensive Dalitz plot analyses of D, D_s, and J/ψ decays. We have made a preliminary Dalitz analyses of some D meson three body hadronic decays with the small integrated luminosity of our pilot run. The initial results are very encouraging, and we are working on Dalitz analyses. We expect much improved results when the full statistics of our sample is available in the next year or two.

Acknowledgments

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