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Charm Physics Results from CLEO

The CLEO Collaboration
M.S. DUBROVIN
Department of Physics & Astronomy, Wayne State University,
Detroit, MI 48201

We present recent results in the charm sector from the CLEO Collaboration. The data used were collected by the CLEO II and III detectors at the Cornell Electron Storage Ring (CESR). Measurements of form factors and branching fractions in semileptonic decays of D-meson and charmed-baryons, searches for CP violation and rare decays, and Dalitz analyses of D-meson decays are discussed, as well as future plans for the CLEO-c experiment at CESR-c.

1 Charm physics at CLEO

Since the 1980's the primary goal of CLEO Collaboration was the study of Υ-resonances and B-meson physics. The charm sector received steady attention as well. Among ~ 350 CLEO publications about 18% were devoted to the decays of charmed mesons and about 14% to charmed baryons. At this time we continue to study all aspects of charm including semileptonic decays of mesons and baryons, Dalitz plot analysis of three-body D-meson decays, fragmentation, inclusive decay rates, doubly and singly Cabibbo suppressed decays, searches for rare and forbidden decays, CP-violation, etc.

The data using in our analyses were collected with three detector configurations [1–3],

CLEO II	*Oct*.1989 – *Apr*.1995	4.7 fb^{-1},
CLEO II.V	*Nov*.1995 – *Feb*.1999	9 fb^{-1},
CLEO III	*Jul*.2000 – *Mar*.2003	~ 16 fb^{-1},

at Cornell e^+e^- Storage Ring (CESR) with $\sqrt{s} \simeq 10$ GeV. At this time about half of the CLEO III data is available for analysis.

2 Recent results overview

2.1 First Observation of the Exclusive Decays $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$ *and* $\Lambda_c^+ \to \Lambda\omega\pi^+$

This is a first publication [4] based on CLEO III statistics, 4.1 fb^{-1} at $\Upsilon(4S)$. The goal is to search for the inclusive multi-body baryonic decay $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$. In spectator quark model this decay is equivalent to the D-meson decays observed with high rate, $D^+ \to \overline{K^0}\pi^+\pi^+\pi^-\pi^0$ ($BR = 5.4^{+3.0}_{-1.4}\%$), $D^0 \to K^-\pi^+\pi^+\pi^-\pi^0$ ($BR = 4.4 \pm 0.4\%$). In this analysis we used the power of CLEO III reconstruction capabilities including $K/p/\pi$ particle identification using RICH & dE/dx. We apply high momentum cut, $\mathbf{P}(\Lambda_c^+) > 3.5$ GeV/c, to suppress combinatoric

background. Other cuts were quite standard. A clear signal from the decay $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$ is seen in the invariant $\Lambda\pi^+\pi^+\pi^-\pi^0$ mass spectrum, Fig. 1.

A search for substructure in $\pi^+\pi^-\pi^0$ combinations shows a signal from $\Lambda_c^+ \to \Lambda\omega\pi^+$, $\omega \to \pi^+\pi^-\pi^0$ and a contribution from $\Lambda_c^+ \to \Lambda\eta\pi^+$, $\eta \to \pi^+\pi^-\pi^0$ at $\sim 3\sigma$ level. The later decay has previously been observed in the $\eta \to \gamma\gamma$ decay mode [5]. We find that the decay $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$ is saturated by the $\Lambda\omega\pi^+$ and $\Lambda\eta\pi^+$ intermediate states. We find NO evidence for $\omega\pi$ higher mass resonances. This study is limited by the allowed phase space.

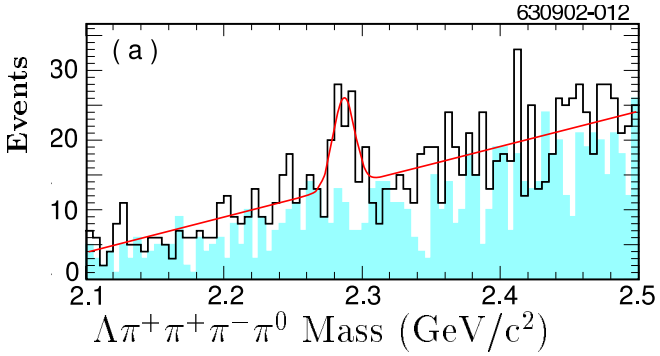

Figure 1: Invariant $\Lambda\pi^+\pi^+\pi^-\pi^0$ mass spectrum.

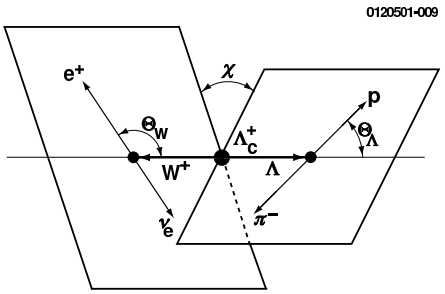

Figure 2: Definition of kinematic variables for the decay $\Lambda_c^+ \to \Lambda e^+\nu_e$.

We use the decay $\Lambda_c^+ \to pK^-\pi^+$ for systematic cross-checks and normalization, that gives the basic results for ratios of branchings

$$\left.\frac{B(\Lambda_c^+\to\Lambda\pi^+\pi^+\pi^-\pi^0)}{B(\Lambda_c^+\to pK^-\pi^+)}\right|_{Tot.} = 0.36 \pm 0.09_{stat.} \pm 0.09_{syst.}, \quad \frac{B(\Lambda_c^+\to\Lambda\omega\pi^+)}{B(\Lambda_c^+\to pK^-\pi^+)} = 0.24 \pm 0.06_{stat.} \pm 0.06_{syst.},$$

$$\left.\frac{B(\Lambda_c^+\to\Lambda\pi^+\pi^+\pi^-\pi^0)}{B(\Lambda_c^+\to pK^-\pi^+)}\right|_{N.R.} < 0.13 \;\; @ \;\; 90\%\; C.L., \qquad \frac{B(\Lambda_c^+\to\Lambda\eta\pi^+)}{B(\Lambda_c^+\to pK^-\pi^+)} < 0.65 \;\; @ \;\; 90\%\; C.L.$$

2.2 Form Factors and Search for CP Violation in the Decay $\Lambda_c^+ \to \Lambda e^+\nu_e$

The Heavy Quark Effective Theory (HQET) gives a reliable prediction on heavy to light quark transition for Λ-type baryons using the $V+A$ hadronic current,

$$< \Lambda_2|J_\mu^{V+A}|\Lambda_1 >= \bar{u}_2[f_1(q^2)\gamma_\mu(1-\gamma_5) + f_2(q^2)\;\not{v}_1\gamma_\mu(1-\gamma_5)]u_1,$$

parameterized in the frame of *Körner & Krämer* (KK) model [6]. Thus the 4-fold differential rate of the decay $\Lambda_c^+ \to \Lambda e^+\nu_e$,

$$\frac{d\Gamma}{dq^2 d\cos\theta_\Lambda d\cos\theta_W d\chi} \propto G_F^2|V_{cs}|^2\frac{q^2 P_\Lambda}{M_{\Lambda_c}^2}\cdot F(q^2,\cos\theta_\Lambda,\cos\theta_W,\chi \mid R, M_{pole}),$$

can be expressed as a function of four kinematic variables, q^2, $\cos\theta_\Lambda$, $\cos\theta_W$, χ (see Fig. 2 for explanation), and two parameters, pole mass, M_{pole}, and formfactors ratio, $R = f_2(q^2)/f_1(q^2)$, where $f_i(q^2) = \frac{f_i(q^2_{max})}{(1-q^2/M^2_{pole})^2}(1 - q^2_{max}/M^2_{pole})^2$ is taken in dipole form.

To estimate the Λ_c^+ momentum we use three sources of information: (i) direction of the event trust axis, (ii) the momentum balance equation $\vec{P}^2_{\Lambda_c^+} \simeq (\vec{P}_\Lambda + \vec{P}_e + \vec{P}_\nu)^2$, (iii) weights from known fragmentation of Λ_c^+.

In order to extract R and M_{pole} we use 4-D maximum likelihood fit [7] and get $R = -0.31 \pm 0.05_{stat} \pm 0.04_{syst}$ and $M_{pole} = 2.13 \pm 0.07_{stat} \pm 0.10_{syst} GeV/c^2$. Note, that M_{pole} from the fit is consistent with $M_{D_s^{*+}}$ value used as a parameter of KK model. The KK model predicts $R = -0.25$ at $M_{pole} = M_{D_s^{*+}} = 2.11\ GeV/c^2$.

We also measure the *decay asymmetry parameter*, $\alpha_{\Lambda_c^+}$, which appears in parameterization of the differential rate after integration over χ and $\cos\theta_W$ that gives $\frac{d\Gamma}{dq^2 d\cos\theta_\Lambda} \propto (1+\alpha_{\Lambda_c^+}\alpha_\Lambda \cos\theta_\Lambda)$, where α_Λ is a similar decay asymmetry parameter for Λ. We obtain from the fit $\alpha_{\Lambda_c^+} = -0.85 \pm 0.03_{stat} \pm 0.02_{syst}$ @ $< q^2 >= 0.67\ (GeV/c)^2$ for world average $\alpha_\Lambda = 0.642 \pm 0.013$.

The decay asymmetry can be obtained for two charge conjugate states separately, $\alpha_{\Lambda_c^+}\alpha_\Lambda = -0.561 \pm 0.026_{stat}$, $\alpha_{\Lambda_c^-}\alpha_{\bar{\Lambda}} = -0.535 \pm 0.024_{stat}$. These two values allow us to estimate a CP violation in this decay, $A_{\Lambda_c^+} = \frac{\alpha_{\Lambda_c^+} + \alpha_{\Lambda_c^-}}{\alpha_{\Lambda_c^+} - \alpha_{\Lambda_c^-}} = 0.01 \pm 0.03_{stat} \pm 0.01_{syst} \pm 0.02_{A_\Lambda}$. We find no evidence of CP violation in terms of the decay asymmetry parameter.

2.3 First Search for Flavor Changing Neutral Current Decay $D^0 \to \gamma\gamma$

Standard Model (SM) predicts the rate for the $D^0 \to \gamma\gamma$ decay of $\sim 10^{-8}$ or less. Non SM extension, i.e. gluino exchange in SUSY, might enhance this rate by two orders of magnitude. A measurement of this rate is a good test of new physics beyond the SM.

For this analysis [8] we use statistics of CLEO II & II.V. Combinatoric background is suppressed by the tagging process $D^{*+} \to D^0\pi^+$ using the energy release variable $Q = M(D^{*+}) - M(D^0) - m_{\pi^+}$, Fig. 3b. The decay $D^0 \to \pi^0\pi^0$ with measured rate is used for systematic cross-checks and normalization, Fig. 3a. The ratio of efficiency is determined from Monte Carlo. $\varepsilon(\gamma\gamma)/\varepsilon(\pi^0\pi^0) = 1.59 \pm 0.05$. We found 19.2 ± 9.3 signal events from the fit, and set an upper limit

$$B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 0.033, \quad B(D^0 \to \gamma\gamma) < 2.9 \times 10^{-5} \ \ @ \ \ 90\% C.L.$$

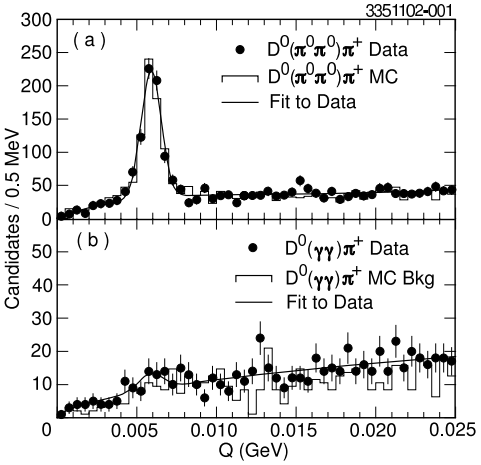

Figure 3: Energy release in the decay $D^{*+} \to D^0\pi+$ for (a) $D^0 \to \pi^0\pi^0$; (b) $D^0 \to \gamma\gamma$.

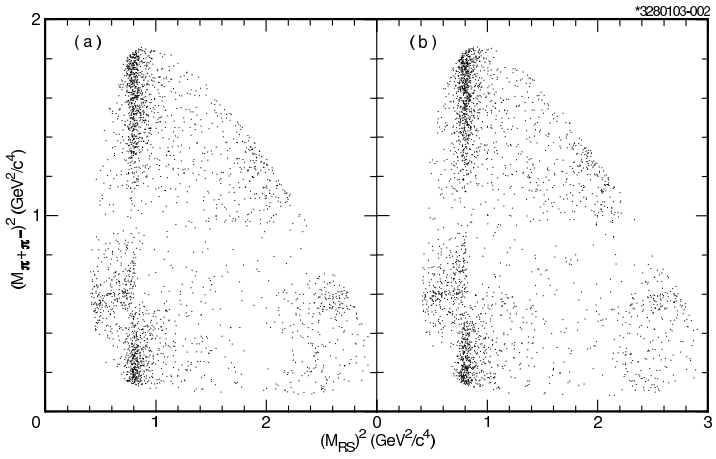

Figure 4: Dalitz plots for the decay $D^0 \to K^0_S\pi^+\pi^-$ for (a) D^0, $M_{RS} = M(K^0_S\pi^-)$; (b) $\overline{D^0}$, $M_{RS} = M(K^0_S\pi^+)$.

2.4 Dalitz Plot Analyses of the Decays $D \to PPP$ at CLEO

The Dalitz plot analyses of D-meson decays in to three pseudoscalars, $D \to PPP$, are interesting for many reasons.

- The Dalitz plot clearly shows the intermediate states and their interference.
- These sorts of decays accounts for a large fraction of the total D meson decay rate.
- It is a good place to study scalars, $f_0(980)$, $a_0(980)$.
- In these decays there are indications on the not well established light scalar mesons, $\sigma(500)$, $\kappa(400-600)$ (see E791, FOCUS, CLEO recent results).

- An opportunity to search for CP violation in amplitudes and phases, that may be more visible than rate asymmetries.

For the Dalitz plot analyses discussed here we use the CLEO II.V 9 fb^{-1} data sample, the large sample which has well understood resolutions and systematics. We also use a "generic" (all known decays included) and signal Monte-Carlo simulation in order to estimate an efficiency variation across the Dalitz plot.

We exploit $D^* \to D\pi_{slow}$ tagging process in order to suppress background and to define an initial flavor of D^0 or $\overline{D^0}$-meson. We use other standard for CLEO event selection algorithms, and $\sim 2-3\sigma$ cuts on energy release variable, $Q = M(D^*) - M(D) - M_\pi$, and invariant D-meson mass, $M(D)$.

The Dalitz plot is a scatter plot of two (of three) invariant masses squared, i.e. m^2_{23} versus m^2_{12}. A general formalism of the *matrix element parameterization* and *unbinned maximum likelihood fit* is published in detail in Ref. [9]. Thus for the matrix element we use a sum of amplitudes of non-resonant and all possible resonant terms,

$$\mathcal{M} = a_{nr}e^{i\varphi_{nr}} + \sum_{resonances} a_r e^{i\varphi_r}\mathcal{A}_J(123|r),$$

where $a_r e^{i\varphi_r}$ are the complex parameters (fit parameters) and $\mathcal{A}_J(123|r)$ is a spin dependent Breit -Wigner amplitude for appropriate intermediate resonance, r.

Based on parameters extracted from the fit one may define for each resonance a $Fit\ Fraction = \frac{\oint_{PS}|a_r\mathcal{A}_J(123|r)|^2 d\mathcal{D}P}{\oint_{PS}|\mathcal{M}|^2 d\mathcal{D}P}$, and an *Integrated CP Asymmetry*, $\mathcal{A}_{CP} = \oint_{PS}\frac{|\mathcal{M}_{D^0}|^2 - |\mathcal{M}_{\bar{D}^0}|^2}{|\mathcal{M}_{D^0}|^2 + |\mathcal{M}_{\bar{D}^0}|^2} d\mathcal{D}P \Big/ \oint_{PS} d\mathcal{D}P$. The modified complex parameters can be also used in order to search for CP violation in terms of amplitudes and phases, $a_r e^{i\varphi_r} \longrightarrow a_r e^{i\delta_r}\left(1 \pm \frac{b_r}{a_r}e^{\pm i\phi_r}\right)$, where a_r and δ_r - CP conserving parameters; b_r and ϕ_r - CP violating parameters, showing the difference in amplitude and phase between D^0 and $\overline{D^0}$.

2.5 Search for CP Violation in the Decay $D^0 \to K^0_S\pi^+\pi^-$

The results of the Dalitz plot analysis of $D^0 \to K^0_S\pi^+\pi^-$ were published [10] for clearly observed and measured 10 modes, $K^{*-}(892)\pi^+$, $K^*_0(1430)^-\pi^+$, $K^*_2(1430)^-\pi^+$, $K^*(1680)^-\pi^+$, $K^0_S\rho$, $K^0_S\omega$, $K^0_S f_0(980)$, $K^0_S f_2(1270)$, $K^0_S f_0(1370)$, and the "wrong sign" $K^{*+}(892)\pi^-$.

In present consideration we use the same clean sample of 5299±73 signal events with $\sim 2\%$ of background to search for CP violation (see Fig. 4). The SM predicts for this decay a CP violation in rate at the level of $\sim 10^{-6}$ due to the $K^0 - \overline{K^0}$ mixing. Hence, an observation of CP violation in $D^0 \to K^0_S\pi^+\pi^-$ would be a strong evidence for non-SM processes.

The results will be published soon in terms of parameters, a_r, δ_r, b_r/a_r, ϕ_r, *Fit Fraction* and *Interference Contribution* for 10 intermediate states and non-resonant amplitude. Preliminarily, we find NO indication to CP asymmetry in integrated parameter, $\mathcal{A}_{CP} = -0.39 \pm 0.34$, and in all other types of CP asymmetries.

2.6 Dalitz Plot Analysis of the Decay $D^0 \to \pi^+\pi^-\pi^0$

The decay $D^0 \to \pi^+\pi^-\pi^0$ is interesting for a couple of reasons:

- SM predicts a large CP violation in rate $\sim 10^{-3}$ that is close to our sensitivity;
- E791 found in $D^+ \to \pi^+\pi^+\pi^-$ decay strong evidence for $\sigma(500) \to \pi^+\pi^-$ in the intermediate state. We would expect to observe this state or its charged isospin partner in $D^0 \to \pi^+\pi^-\pi^0$.

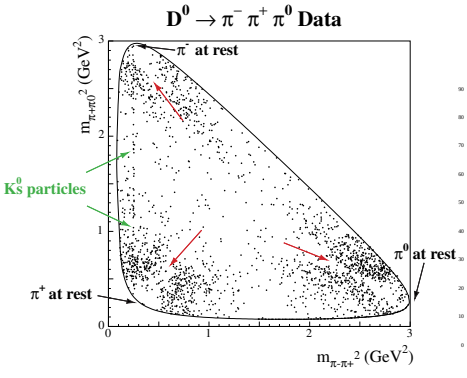

Figure 5: The Dalitz plot for $D^0 \to \pi^+\pi^-\pi^0$ decay.

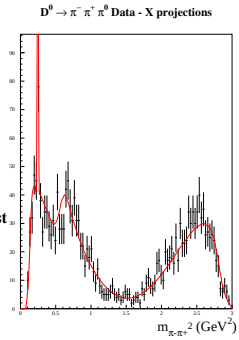

Figure 6: The $m^2_{\pi^-\pi^+}$ projection.

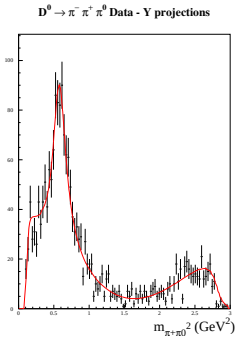

Figure 7: The $m^2_{\pi^+\pi^0}$ projection.

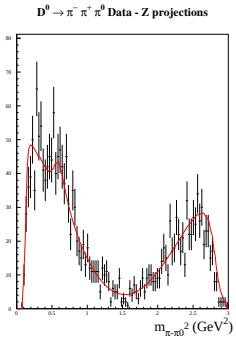

Figure 8: The $m^2_{\pi^-\pi^0}$ projection.

Table 1: Results of the Fit for the decay $D^0 \to \pi^+\pi^-\pi^0$. Statistical and systematic errors are shown respectively.

Interm. state	Amplitude	Phase (^{o})	Fit Fraction (%)
$\rho^+\pi^-$	1 (fixed)	0 (fixed)	76.5±1.8±4.8
$\rho^0\pi^0$	0.56±0.02±0.07	10±3±3	23.9±1.8±4.6
$\rho^-\pi^+$	0.65±0.03±0.04	-4±3±4	32.3±2.1±2.2
Non resonant	1.03±0.17±0.31	77±8±11	2.7±0.9±1.7

Distributions of Q and $M(D)$ shows $\sim$ 1100 signal events with $\sim 18 \pm 3\%$ of background. The Dalitz plot and three projections are shown in Figs 5–8. The observed $K^0_S\pi^0$ contribution is consistent with previous measurements and is not allowed to interferee with the other contributions to the Dalitz plot. Preliminary results of the fit parameters are listed in Table 1. Our conclusions: $A_{CP} = 0.01^{+0.09}_{-0.07}(stat) \pm 0.09(syst)$ and there is NO CP asymmetry in A_{CP} at the level of our sensitivity; there is NO statistically significant difference *in amplitude and phase* between $D^0/\overline{D^0} \to \pi^+\pi^-\pi^0$; non-resonant contribution is small; there is NO indication on $\sigma(500)$ fit fraction at the level of $\sim$1%.

2.7 First Observation and Dalitz Plot Analysis of the Decay $D^0 \to K^0_S\eta\pi^0$

In the decay of $D^0 \to K^0_S\eta\pi^0$ one would expect a strong manifestation of $D^0 \to K^0_S a_0(980)$, if the scalar resonance $a_0(980)$ indeed contributes to the complementary $D^0 \to K^0_S(K^+K^-)$ decay along with $f_0(980)$. There is no result in PDG for $D^0 \to K^0_S\eta\pi^0$ yet.

To study this decay we use the mode: $K^0_S \to \pi^+\pi^-$, $\eta \to \gamma\gamma$, $\pi^0 \to \gamma\gamma$. The decay $D^0 \to K^0_S\pi^0$ is used for systematic cross-checks and normalization. We observe a clean signal in Q (Fig. 9) and $M(K^0_S\eta\pi^0)$ (Fig. 10) distributions and have preliminary measured the ratio of branchings

$$R = \frac{BR(D^0 \to K^0_S\eta\pi^0)}{BR(D^0 \to K^0_S\pi^0)} = 0.38 \pm 0.07_{stat.} \pm 0.05_{syst.}.$$

In spite of large background $\sim$ 30% we are going to perform a Dalitz plot analysis for the decay $D^0 \to K^0_S\eta\pi^0$ (see Fig. 11). Our preliminary observations confirms that the $K^0_S a_0(980)$ is a dominant intermediate state, the $K^*(892)\eta$ is seen with a significant interference term. To get a good fit to the observed data another contribution, such as non-resonant or high mass states, is needed. We are working on completing this analysis.

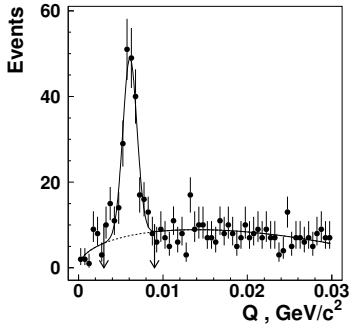

Figure 9: The Q distribution for the decay $D^{*+} \to D^0(K^0_S\eta\pi^0)\pi^+$.

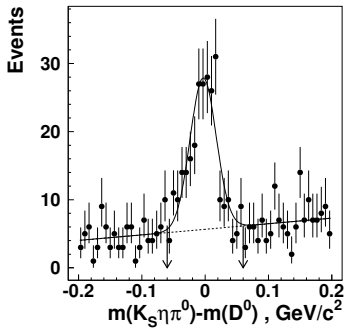

Figure 10: The $M(K^0_S\eta\pi^0) - M_{D^0}$ mass difference distribution.

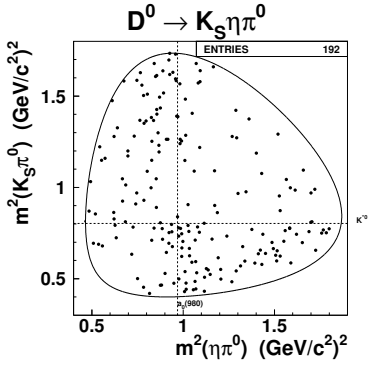

Figure 11: Dalitz plot for the decay $D^0 \to K^0_S\eta\pi^0$.

3 CLEO-c and CESR-c project news

The NSF has approved a five year program of charm physics called CLEO-c and CESR-c[11]. The first year of this program has been successfully completed. Since October 2002 to March 2003 the crucial part of this project a single super-conducting (SC) wiggler had been successfully tested at CESR and five other wigglers have been assembled and prepared for installation. During a current shutdown since March 3 to July 2, 2003 the 6 SC wigglers will be installed in CESR. CLEO III will be upgraded to CLEO-c by replacing the silicon vertex detector (SVX) with a 6-layers drift chamber with large stereo angle (ZD).

The program of CLEO-c scans can be briefly listed as follow:

- 2003 Act I: $\psi(3770)$ — 3 fb^{-1}; 30M events, 6M *tagged* D (310 times MARK III).
- 2004 Act II: $\sqrt{s} \sim 4100\ MeV$ — 3 fb^{-1}; 1.5M $D_s\bar{D}_s$, 0.3M *tagged* D_s (480 $\times$ MARK III).
- 2005 Act III: $\psi(3100)$ — 1 fb^{-1}; 1 Billion J/ψ (170 times MARK III, 20 times BES II).

This statistics is required for precise measurement of branching ratios, decay constants and other SM parameters in charm sector.

4 Summary and Acknowledgments

The CLEO Collaboration continues to produce results in charm physics using CLEO II, II.V, III statistics. We have a broad charm-physics dedicated program and are looking forward to CLEO-c/CESR-c data. We gratefully acknowledge the effort of the CESR staff in providing us with excellent luminosity and running conditions. This work was supported by the National Science Foundation, the U.S. Department of Energy, the Research Corporation, and the Texas Advanced Research Program.

References

1. CLEO Collaboration, Y. Kubota *et al.*, *Nucl. Instrum. Methods* A **320**, 66 (1992).
2. T. Hill, *Nucl. Instrum. Methods* A **418**, 32 (1998).
3. G. Viehhauser, *CLEO III Operation*, *Nucl. Instrum. Methods* A **462**, 146 (2001).
4. CLEO Collaboration, D.Cronin-Hennessy *et al*, *Phys. Rev.* D **67**, 012001 (2003); hep-ex/0210048.
5. CLEO Collaboration, R.Ammar *et al*, *Phys. Rev. Lett.* **74**, 3534 (1994).
6. J. G. Körner and M. Krämer, *Phys. Lett.* B **275**, 495 (1992).
7. D. M. Schmidt, R.J. Morrison and M.S. Witherell, *Nucl. Instrum. Methods* A **328**, 547 (1993).

8. CLEO Collaboration, T.E.Coan, *et al*, *Phys. Rev. Lett.* **90**, 101801 (2003); hep-ex/0212045.
9. S. Kopp *et al*, CLEO Collaboration, *Phys. Rev.* D **63**, 092001 (2001).
10. H. Muramatsu *et al*, CLEO Collaboration, *Phys. Rev. Lett.* **89**, 251802 (2002), hep-ex/0207067.
11. CLEO-c and CESR-c: A New Frontier of Weak and Strong Interactions, CLNS-01/1742.