Charm Physics Results from CLEO

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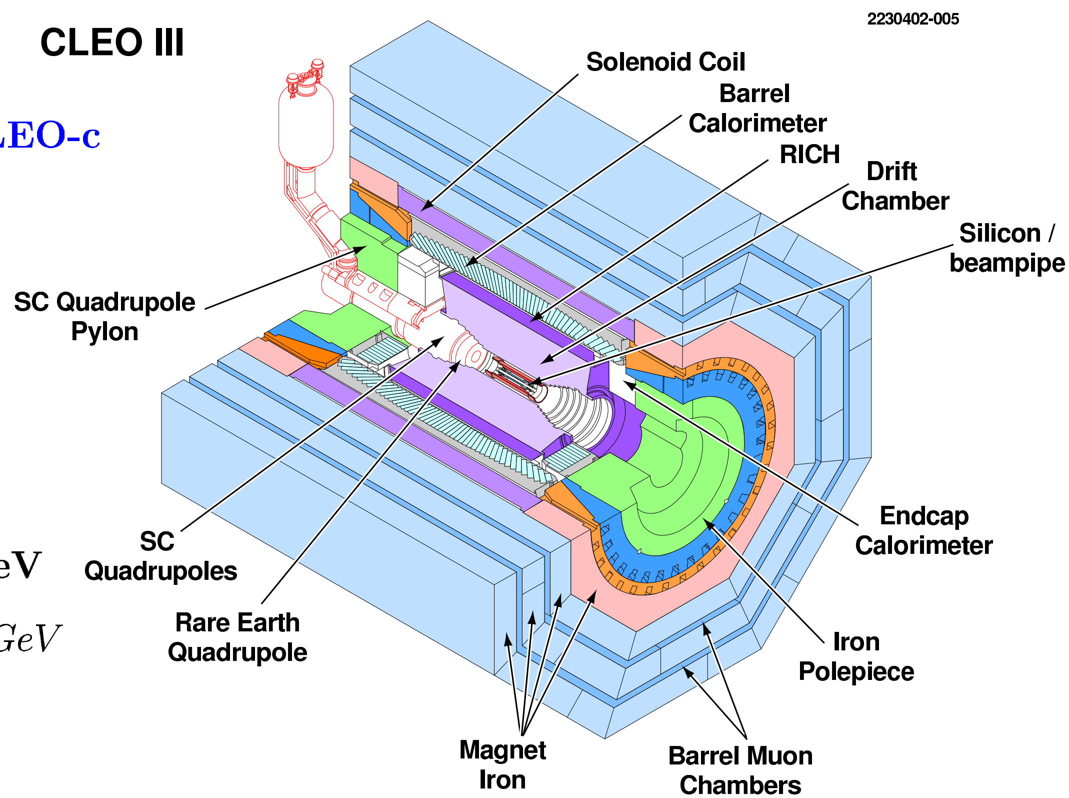
for CLEO collaboration

Outline

- Charm physics at CLEO
- Recent results overview
  - ▷ First Observation of the Exclusive Decays $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$ and $\Lambda_c^+ \to \Lambda\omega\pi^+$
  - ▷ Form Factors and Search for CPV in the Decay $\Lambda_c^+ \to \Lambda e^+\nu_e$
  - ▷ First Search for Flavor Changing Neutral Current Decay $D^0 \to \gamma\gamma$
  - ▷ Search for CPV in the Dalitz Decay $D^0 \to K_S^0\pi^+\pi^-$
  - ▷ Dalitz Analysis $D^0 \to \pi^+\pi^-\pi^0$
  - ▷ First Observation and Dalitz Analysis of the Decay $D^0 \to K_S^0\eta\pi^0$
- CLEO-c and CESR-c project news
- Summary

CLEO III @ CESR $\Longrightarrow$ CLEO-c @ CESR-c

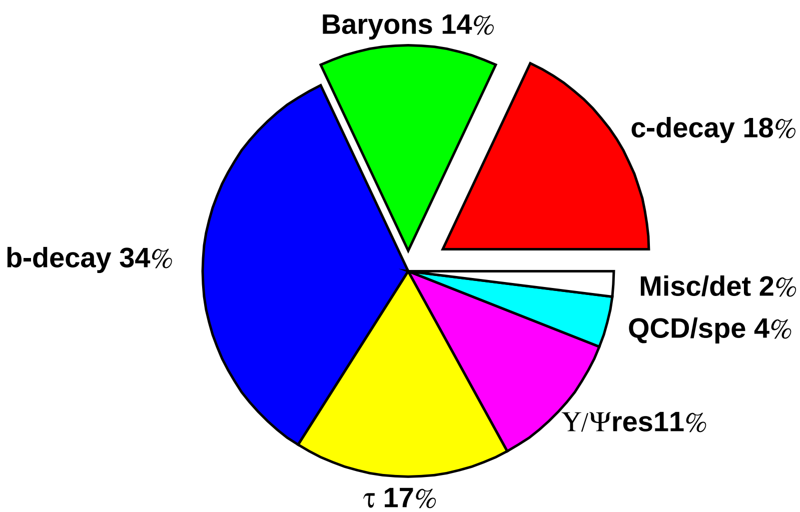
- **Tracker:**
  - ▷ **Silicon Strip Tracker** $\rightarrow$ **ZD for CLEO-c**
  - ▷ **Wire Drift Chamber**
  - ▷ **93% of** 4π, $\sigma_p/p = 0.35\%$ @ $1GeV$, dE/dx: **5.7%** π @ $min\ I$
- **CsI Calorimeter: 93% of** 4π, $\sigma_E/E = 2\%$ @ $1GeV$, 4% @ $100MeV$
- **RICH: 83% of** 4π, **87% Kaon ID with 0.2% fake @0.9GeV**
- **Muon Chambers: 85% of** 4π @ $p > 1GeV$
- **Super-conducting Solenoid: 1.5T** $\rightarrow$ **1T for CLEO-c**
- **Trigger: Tracks & Showers, Pipelined, Latency=2.5**μs
- **DAQ: Event size=25kB, Thruput<6MB/s**



Charm physics at CLEO

Publications since 1980–

- $\sim$350 papers
- diverse physics:

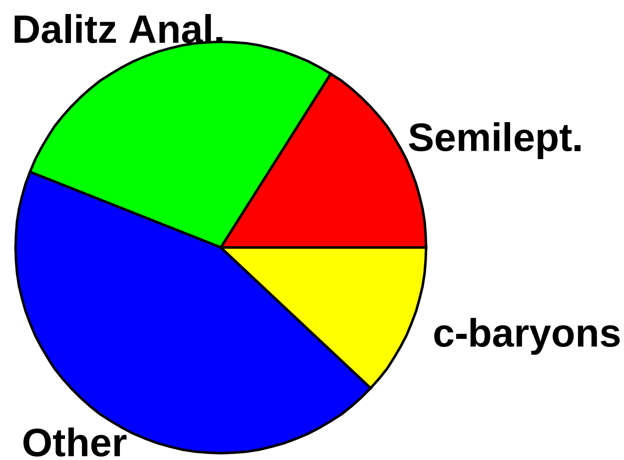


Statistics:

- 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 : $\sim$ 16 fb^{-1}

Interest in charm physics:

- Ongoing analyses:

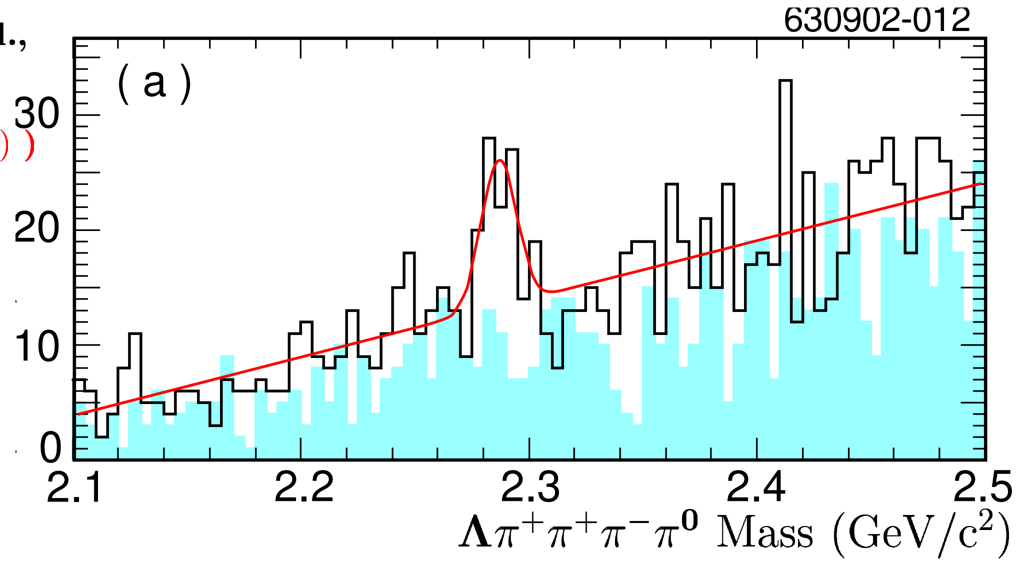


$\Downarrow$

- charm fragmentation
- rate of Cabibbo suppressed decays
- inclusive rates
- search for rare decays (SM test)
- search for CPV

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

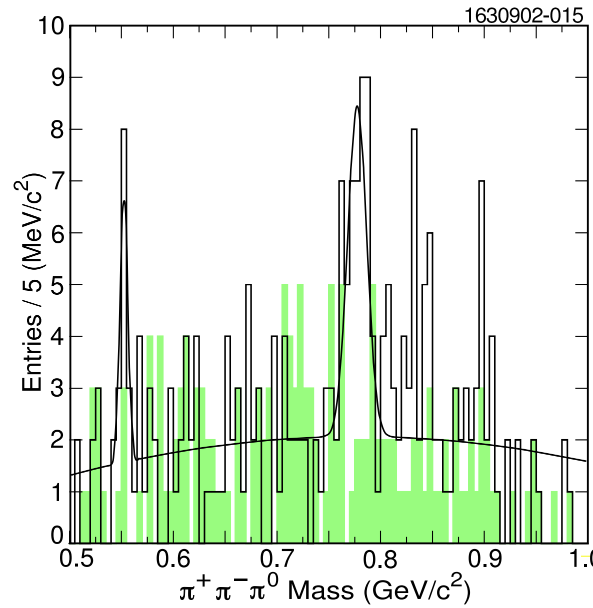
- CLEO Collaboration, D.Cronin-Hennessy et al., Phys.Rev.D67:012001,2003; hep-ex/0210048
- First CLEO III publication (4.1 fb^{-1} @ $\sim \Upsilon(4S)$)
- Search for exclusive multi-body baryonic decay equivalent to
  $D^+ \to \overline{K^0}\pi^+\pi^+\pi^-\pi^0$ (5.4$^{+3.0}_{-1.4}$%)
  $D^0 \to K^-\pi^+\pi^+\pi^-\pi^0$ (4.4±0.4%)
  recently observed @ CLEO
- Use full power of CLEO III reconstruction:
  - ▷ $K/p/\pi$ ID: RICH & dE/dx
  - ▷ other standard cuts...
  - ▷ P(Λ_c^+) > 3.5 GeV/c to suppress combinatoric background



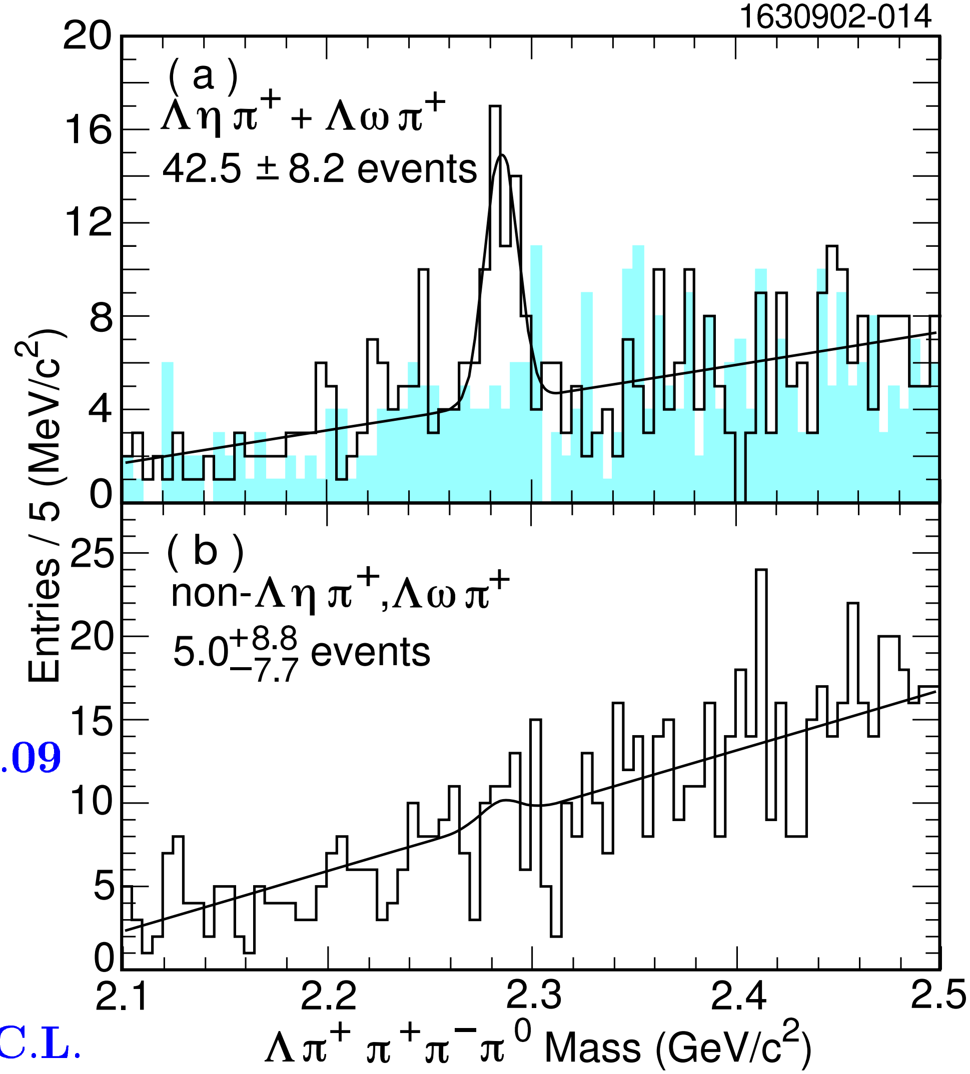
- **Clear signal from $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$ in mass spec. ⇑**
- **Search for substructure in $\pi^+\pi^-\pi^0$ combinations:**
  - ▷ $\Lambda_c^+(\Lambda\pi^+\pi^+\pi^-\pi^0)$-mass signal region — Solid-line histogram ⇒
  - ▷ $\Lambda_c^+(\Lambda\pi^+\pi^+\pi^-\pi^0)$-mass sidebands — Green histogram ⇒

▷ Clear signal from ω

▷ $\sim 3\sigma$ indication on signal from η
had been seen before in $\eta \to \gamma\gamma$



$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$ and $\Lambda_c^+ \to \Lambda\omega\pi^+$ (cont.)



- The decay $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$ is saturated by $\Lambda\omega\pi^+$ and $\Lambda\eta\pi^+$ intermediate states
- We find NO evidence for $\omega\pi$ higher mass resonances
  (limited phase space in this decay)
- Normalization on $\Lambda_c^+ \to pK^-\pi^+$

- **Basic results:**

$$\left.\frac{B(\Lambda_c^+\to\Lambda\pi^+\pi^+\pi^-\pi^0)}{B(\Lambda_c^+\to pK^-\pi^+)}\right|_{Tot.} = 0.36 \pm 0.09 \pm 0.09$$

$$\frac{B(\Lambda_c^+\to\Lambda\omega\pi^+)}{B(\Lambda_c^+\to pK^-\pi^+)} = 0.24 \pm 0.06 \pm 0.06$$

$$\frac{B(\Lambda_c^+\to\Lambda\eta\pi^+)}{B(\Lambda_c^+\to pK^-\pi^+)} < 0.65 \quad @ \quad 90\%\ C.L.$$

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

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

- To be submitted to Phys. Rev. Letters
- HQET gives reliable prediction for heavy to light quark transition for Λ-type baryons

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

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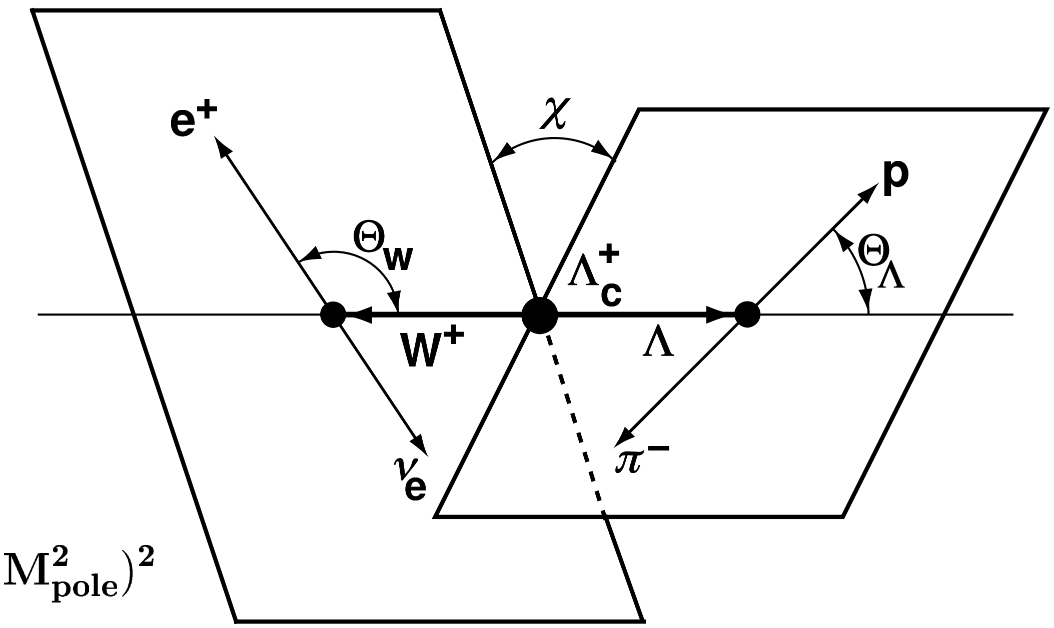


- Rate parameterization,

Körner & Krämer (KK) model:

$$R = f_2/f_1$$

$$f_i(q^2) = \frac{f_i(q^2_{max})}{(1 - q^2/M^2_{pole})^2}(1 - q^2_{max}/M^2_{pole})^2$$

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

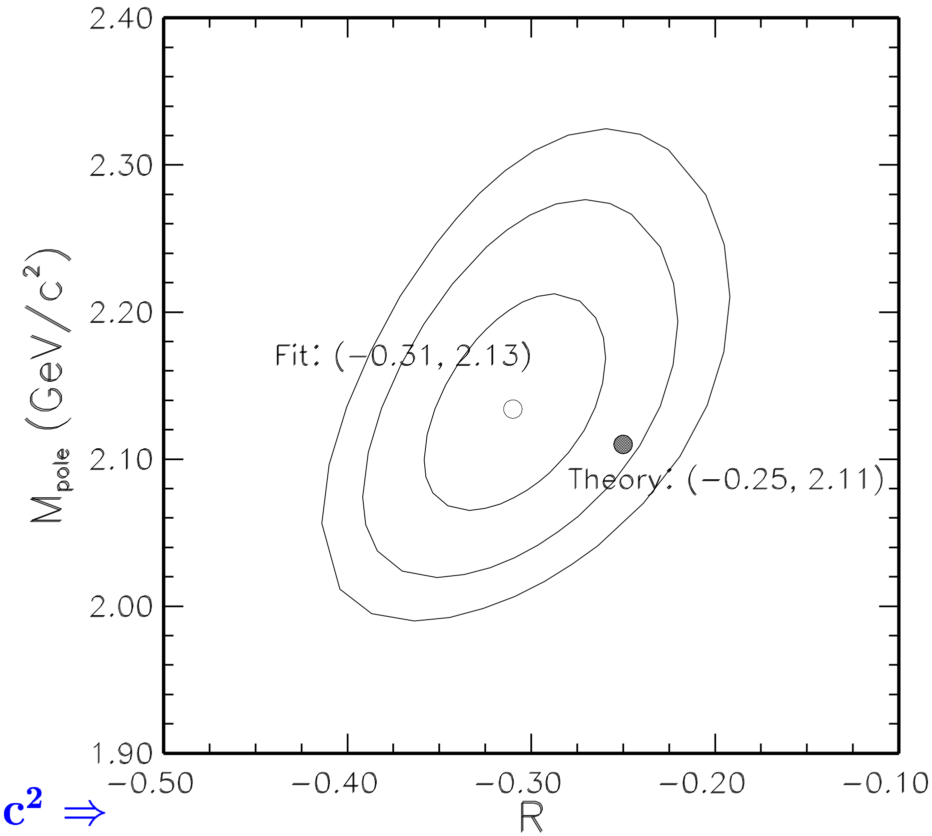
FF & Search for CPV in $\Lambda_c^+ \to \Lambda^0 e^+ \nu_e$ (cont.)

- **Statistics: CLEO II, II.V** @ $\sim \Upsilon(4S)$
- **Need to estimate Λ_c^+ momentum:**
  - ▷ **direction $\sim$ event trust axis;**
  - ▷ $\vec{P}^2_{\Lambda_c^+} \simeq (\vec{P}_\Lambda + \vec{P}_e + \vec{P}_\nu)^2$
  - ▷ **weights from known fragmentation of Λ_c^+**
- **To extract R and M_{pole} we use 4D maximum likelihood fit**

  D. M. Schmidt, R.J. Morrison and M.S. Witherell, NIM in Phys. Res., Sect. A **328**, *547 (1993)*

- $R = -0.31 \pm 0.05_{stat} \pm 0.04_{syst}$

  $M_{pole} = 2.13 \pm 0.07_{stat} \pm 0.10_{syst} GeV/c^2 \Rightarrow$



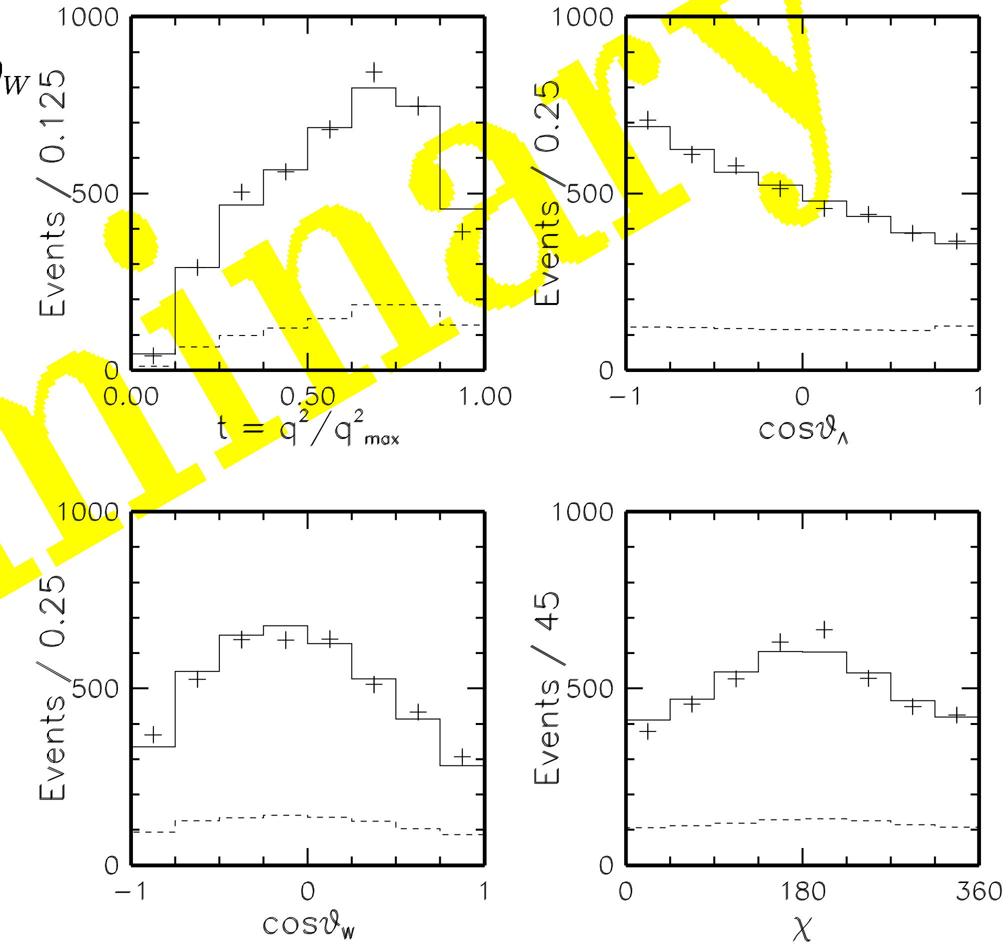
- **M_{pole} from the fit is consistent with $M_{D_s^{*+}}$!**
- **KK model predicts $R = -0.25$ at $M_{pole} = M_{D_s^{*+}} = 2.11$ GeV/c^2**

FF & Search for CPV in $\Lambda_c^+ \to \Lambda e^+ \nu_e$ (cont.)

- Distributions of four kinematic variables and (unbinned) fit projections ⇒
- Integrating the dif. rate over χ and $\cos\theta_W$

$$\frac{d\Gamma}{dq^2 d\cos\theta_\Lambda} \propto (1 + \alpha_{\Lambda_c^+}\alpha_\Lambda \cos\theta_\Lambda)$$

- Extract from the fit
  the decay asymmetry parameter:
  $\alpha_{\Lambda_c^+} = -0.85 \pm 0.03_{stat} \pm 0.02_{syst}$
  @ $< q^2 >= 0.67\ (Gev/c)^2$
  for world average $\alpha_\Lambda = 0.642 \pm 0.013$



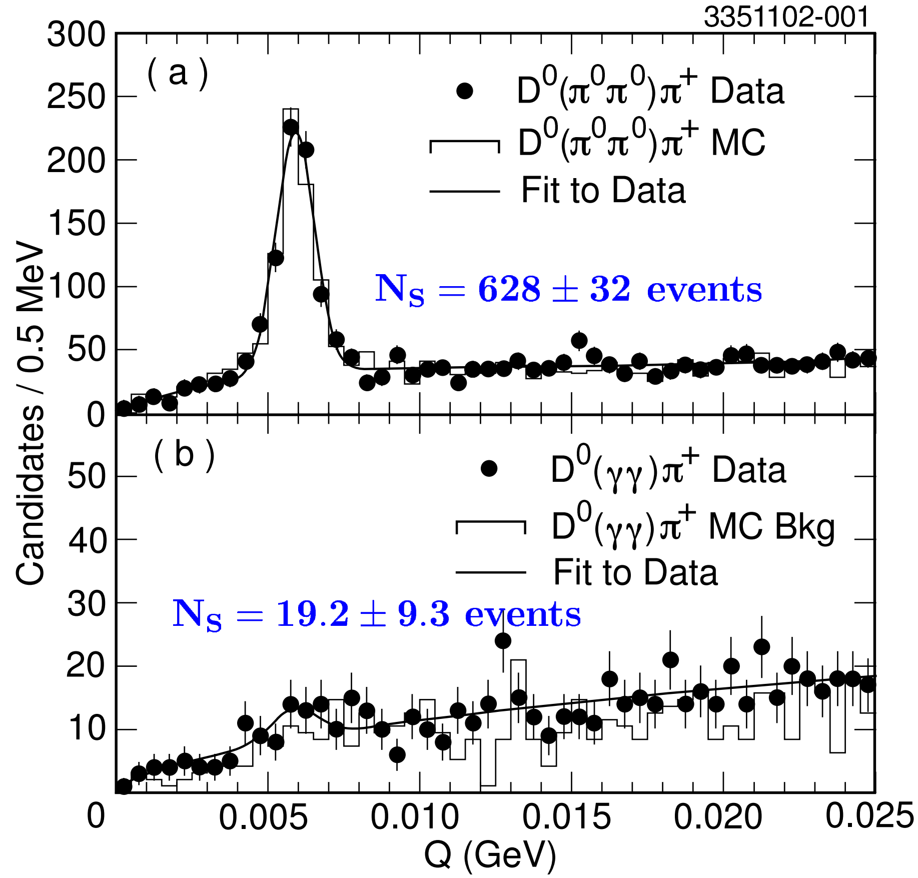
Search for CPV

- Split statistics for two charge conjugate states:
  $\alpha_{\Lambda_c^+}\alpha_\Lambda = -0.561 \pm 0.026_{stat}$
  $\alpha_{\Lambda_c^-}\alpha_{\bar\Lambda} = -0.535 \pm 0.024_{stat}$
- CP asymmetry:

$$A_{\Lambda_c^+} = \frac{\alpha_{\Lambda_c^+} + \alpha_{\Lambda_c^-}}{\alpha_{\Lambda_c^+} - \alpha_{\Lambda_c^-}} = 0.01 \pm 0.03_{stat} \pm 0.01_{syst} \pm 0.02_{A_\Lambda}$$

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

- CLEO Collaboration, T.E.Coan, et al., Phys. Rev. Lett. 90, 101801 (2003); hep-ex/0212045
- SM predicts the rate $\sim 10^{-8}$ or less
- Gluino exchange in SUSY might enhance the SM rate by two orders of magnitude
- Good test of new physics beyond SM
- Statistics: CLEO II, II.V
- Combinatoric background is suppressed by tagging proc. $D^{*+} \to D^0\pi^+$, $Q = M(D^{*+}) - M(D^0) - M_{\pi^+} \Rightarrow$
- Normalization on $D^0 \to \pi^0\pi^0$
- M.C.: $\varepsilon(\gamma\gamma)/\varepsilon(\pi^0\pi^0) = 1.59 \pm 0.05$



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

Dalitz Analyses of Decays $D \to PPP$ in CLEO

▷ Why Dalitz analyses of $D \to PPP$ are interesting:

- Dalitz plot clearly shows the intermediate states and their interference
- Significant part of D meson fragmentation
- Good place to study scalars, $f_0(980)$, $a_0(980)$
- Indication on light scalars, $\sigma(500)$, $\kappa(400-600)$??? (E791, FOCUS, CLEO recent results)
- Search for CPV at amplitude and phase level (and rate as well)

▷ General approach:

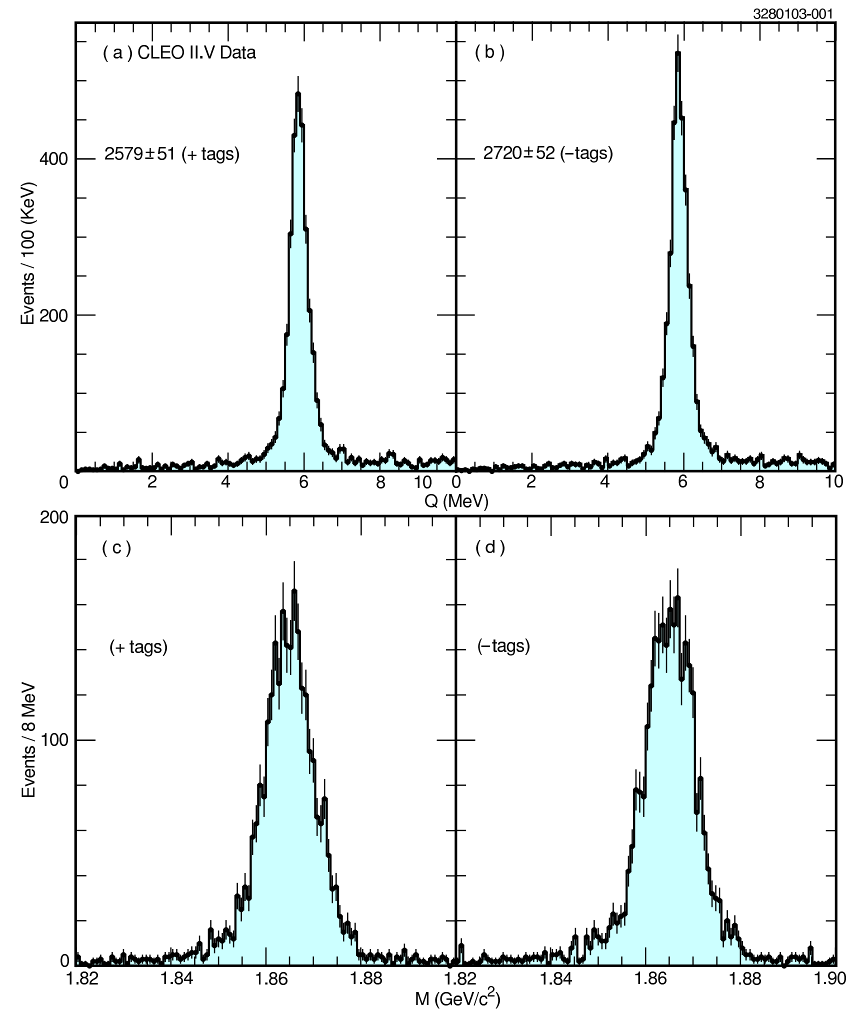
- Statistics: 9 fb^{-1} of CLEO II.V data; "generic" and signal M.C.
- We use $D^* \to D\pi_{slow}$ tagging process
  - ◇ to suppress background
  - ◇ to define a flavor of $D/\overline{D}$ @ $t = 0$
- Standard event selection, $2-3\sigma$ cuts on $Q = M(D^*) - M(D) - M_\pi$ and $M(D)$
- **Dalitz plot: m^2_{23} versus m^2_{12}**
- Matrix element parameterization and unbinned maximum likelihood fit:

  S.Kopp et al., CLEO Collaboration, Phys. Rev. D63, 092001 (2001)

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

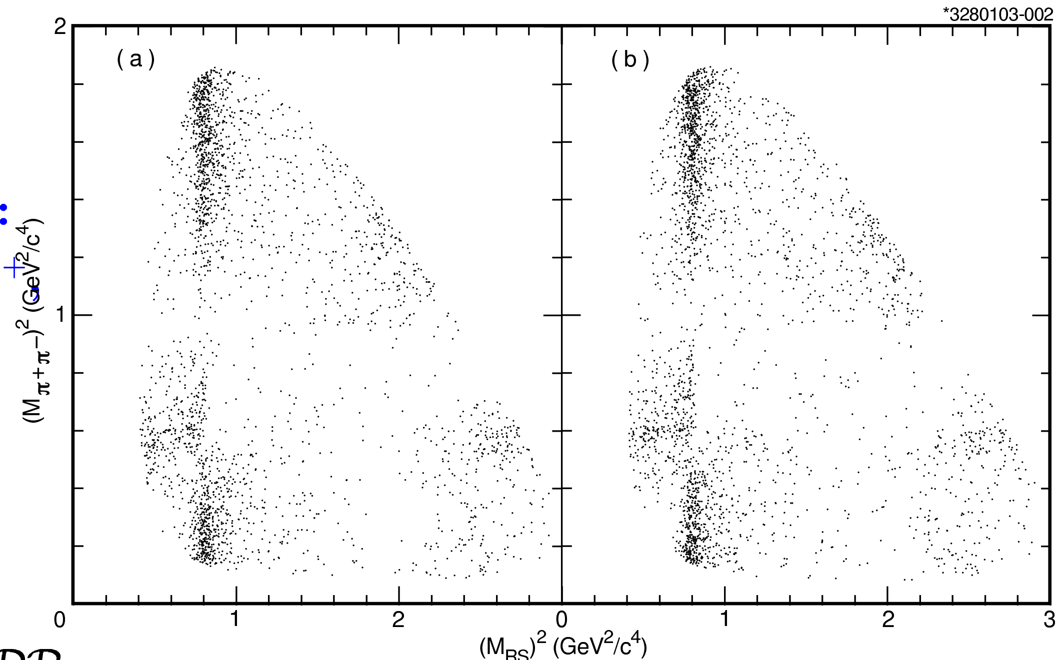
Search for CPV in the Dalitz Decay $D^0 \to K^0_S\pi^+\pi^-$

- Dalitz Analysis of $D^0 \to K^0_S\pi^+\pi^-$ was published, CLEO Collaboration, H. Muramatsu et al., Phys.Rev.Lett.89:251802,2002, hep-ex/0207067
- This search for CPV to be submitted to Phys. Rev. Letters
- SM predicts CPV$\sim 10^{-6}$ due to $K^0 - \overline{K^0}$ mixing
- Observation of CPV in $D^0 \to K^0_S\pi^+\pi^-$ would be strong evidence for non-SM processes
- We use $\pi^\pm_{slow}$ sign tag ($D^{*+} \to D^0\pi^+_{slow}$) to split events for $D^0/\overline{D^0}$ flavors
- $Q = M(D^*) - M(D) - M_\pi$ and $M(D) \Longrightarrow$ shows a clean sample of 5299±73 signal events with $\sim 2\%$ of background



Search for CPV in the Dalitz Decay $D^0 \to K^0_S\pi^+\pi^-$

- **Dalitz plots for**
  a) D^0, $M_{RS} = M(K^0_S\pi^-)$;
  b) $\overline{D^0}$, $M_{RS} = M(K^0_S\pi^+)$



- **Clearly observed the 10 modes:**
  $K^{*-}\pi^+$, $K_0^*(1430)^-\pi^+$, $K_2^*(1430)^-\pi^+$, $K^*(1680)^-\pi^+$, $K^0_S\rho$, $K^0_S\omega$, $K^0_S f_0(980)$, $K^0_S f_2(1270)$

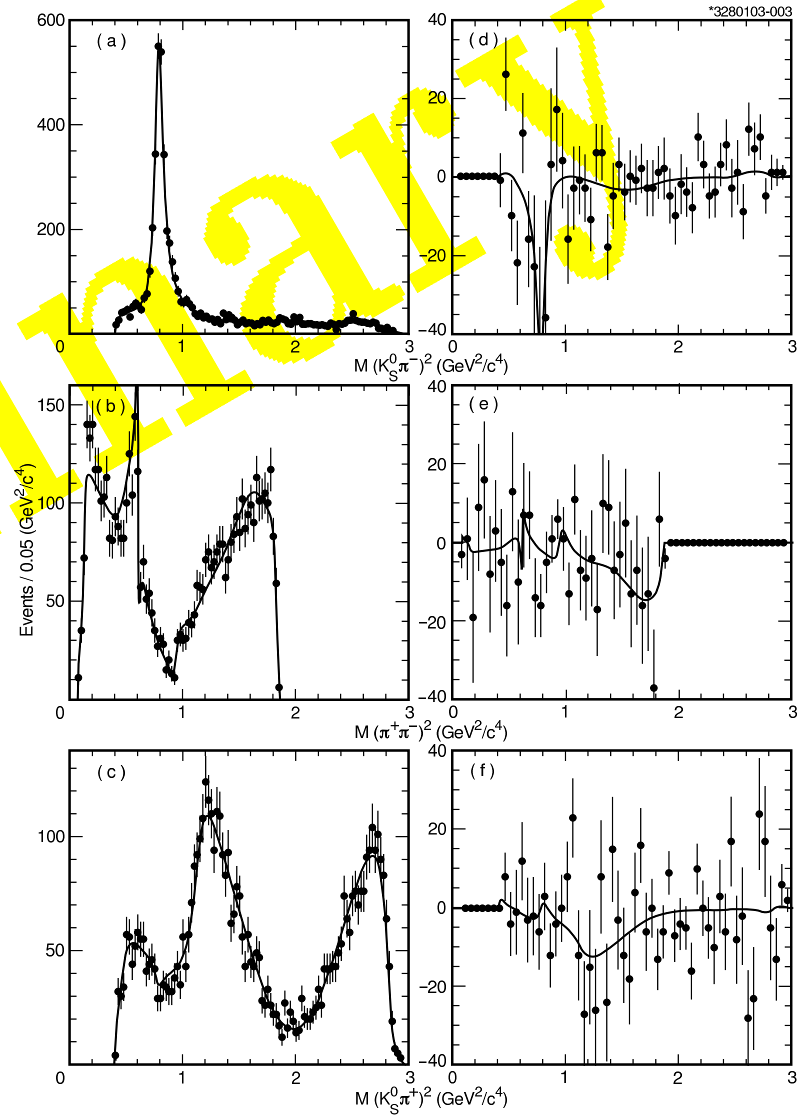
- $Fit\ Fraction = \frac{\oint_{PS} |a_r \mathcal{A}_J(123|r)|^2 d\mathcal{DP}}{\oint_{PS} |\mathcal{M}|^2 d\mathcal{DP}}$,

- **Integrated CP asymmetry**
  $\mathcal{A}_{CP} = \oint_{PS} \frac{|\mathcal{M}_{D^0}|^2 - |\mathcal{M}_{\bar{D}^0}|^2}{|\mathcal{M}_{D^0}|^2 + |\mathcal{M}_{\bar{D}^0}|^2} d\mathcal{DP} \Big/ \oint_{PS} d\mathcal{DP}$

- **CPV in amplitude:**
  $a_r e^{i\varphi_r} \longrightarrow a_r e^{i\delta_r}\left(1 \pm \frac{b_r}{a_r} e^{\pm i\phi_r}\right)$, **where**
  a_r **and** δ_r **- CP conserving parameters;**
  b_r **and** ϕ_r **- CP violating parameters,**
  difference in amplitude between D^0 and $\overline{D^0}$

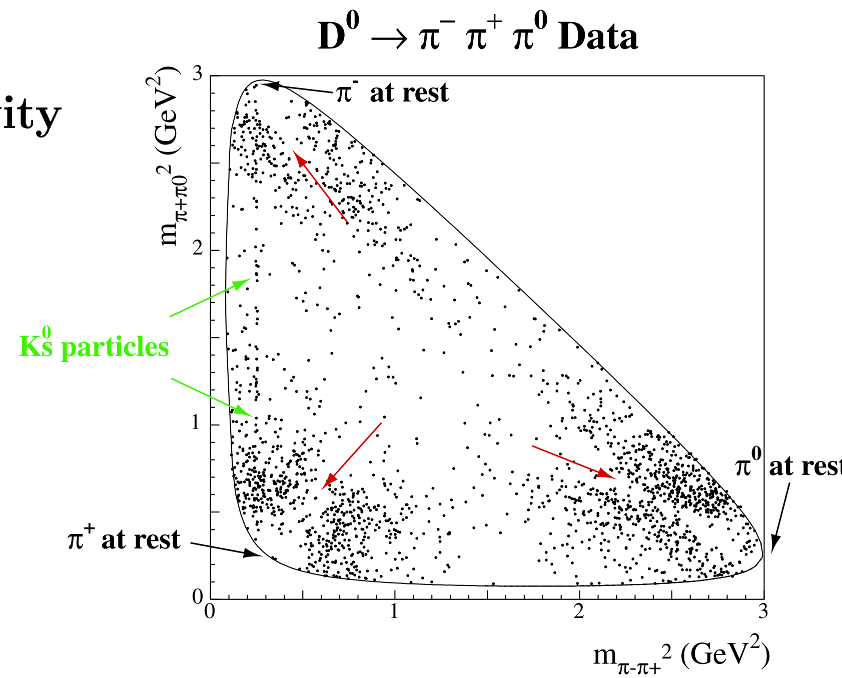
Search for CPV in the Dalitz Decay $D^0 \to K^0_S\pi^+\pi^-$

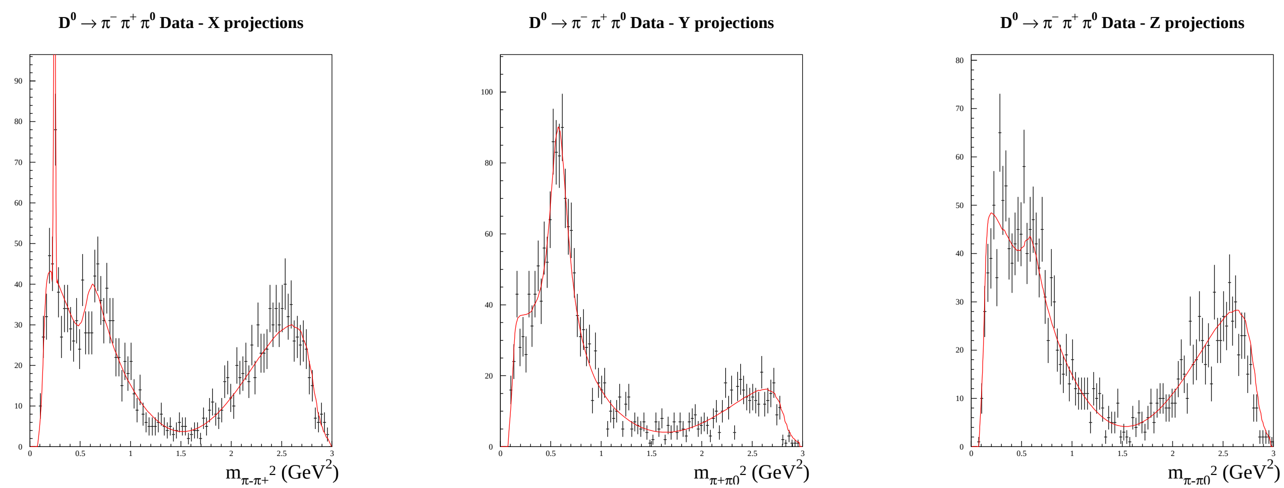
- **Results of the fits will be presented as a table of** a_r, δ_r, b_r/a_r, ϕ_r, *Fit Fraction* **and** *Interference Contribution* **for 10 intermediate states and non-resonant amplitude**
- $\mathcal{A}_{CP} = -0.39 \pm 0.34$



Dalitz Analysis $D^0 \to \pi^+\pi^-\pi^0$

- SM predicts CPV in rate $\sim 10^{-3}$!!!
  that is not so far away from our sensitivity
- E791 found in $D^+ \to \pi^+\pi^+\pi^-$
  a strong evidence for $\sigma(500) \to \pi^+\pi^-$
- What about $D^0 \to \pi^+\pi^-\pi^0$?
- Q and M(D) shows ~ 1100 signal
  events with $\sim 18 \pm 3\%$ of background
- $\pi^{\pm}_{slow}$ sign tag ...





Dalitz Analysis $D^0 \to \pi^+\pi^-\pi^0$ (cont.)

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

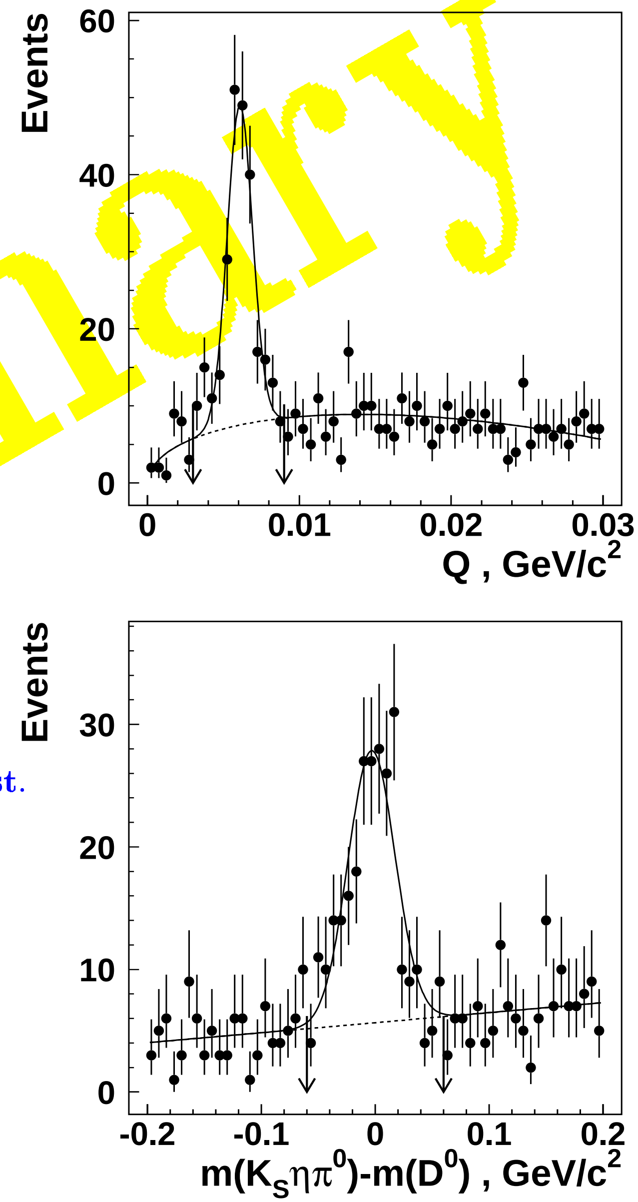
$$A_{CP} = 0.01^{+0.09}_{-0.07}(\text{stat}) \pm 0.09(\text{syst})$$

- 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 ~1%

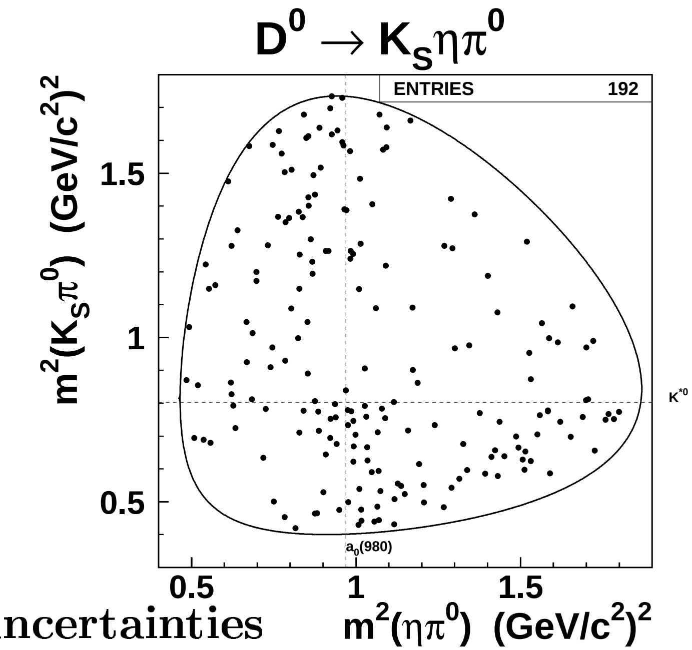
Branching ratio for the decay $D^0 \to K^0_S \eta \pi^0$

- **Why $D^0 \to K^0_S \eta \pi^0$?**
  In this decay one would expect
  a strong manifestation of $D^0 \to K^0_S a_0(980)$,
  if $a_0(980)$ contributes to $D^0 \to K^0_S(K^+K^-)$
  There is no result in PDG for $D^0 \to K^0_S \eta \pi^0$
- **We use mode:** $K^0_S \to \pi^+\pi^-$, $\eta \to \gamma\gamma$, $\pi^0 \to \gamma\gamma$
- **Normalization on** $D^0 \to K^0_S \pi^0$
  with $BR = \frac{1}{2}(2.28 \pm 0.22)\%$

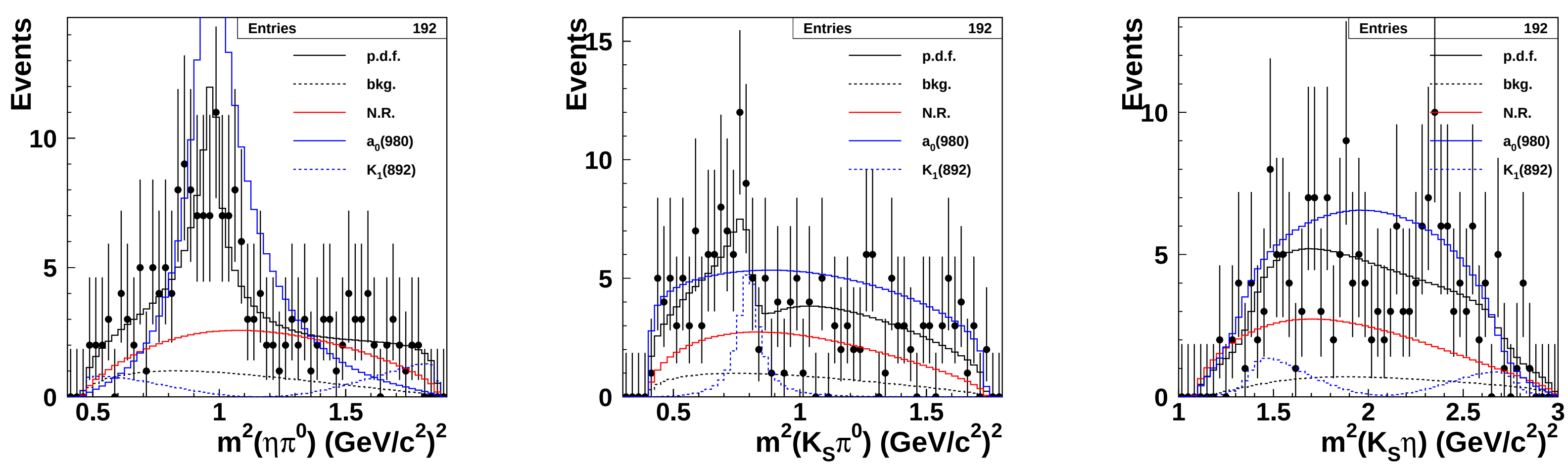
$$R = \frac{BR(D^0 \to K^0_S \eta \pi^0)}{BR(D^0 \to K^0_S \pi^0)} = 0.38 \pm 0.07_{stat.} \pm 0.05_{syst.}$$



Dalitz analysis for the decay $D^0 \to K^0_S \eta \pi^0$



- $K^0_S a_0(980)^0$ is dominant, $K^*(892)\eta$ is seen
- Something else is required for higher C.L., i.e. non-resonant or combination of $a_2(1320)K^0_S$, $a_0(1450)K^0_S$, $\kappa\eta$, $K_1(1410)\eta$, $K_0(1430)\eta$, $K_2(1430)\eta$, $K_1(1680)\eta$
- Interference is significant
- Statistics is small
- We are working on estimation of systematic uncertainties



CLEO-c and CESR-c Project News

- **2002 Prologue:** Upsilons $\sim 1-2\ fb^{-1}$ each. $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, $\Upsilon(5S)$ spectroscopy, matrix elements, Γ_{ee}, 10-20 times existing world's data. **It is successfully completed.**
- Fri, 07 Feb 2003 News: "National Science Board, the governing board of the NSF, has approved the 5 year proposals of both LEPP and CHESS."
- October 2002 — March 2003: single SC wiggler had been successfully tested at CESR
- March 3 — July 2, 2003 Shutdown for installation of 6 SC wigglers, ...
  upgrade CESR/CLEO III $\Longrightarrow$ CESR-c/CLEO-c.

Nearest future for CLEO-c

- **2003 Act I:** $\psi(3770)$ — 3 fb^{-1}; 30M events, 6M *tagged* D decays
  (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 decays
  (480 times MARK III)
- **2005 Act III:** $\psi(3100)$ — 1 fb^{-1}; 1 Billion J/ψ decays
  (170 times MARK III, 20 times BES II)

Summary

- **CLEO Collaboration continue 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 for CLEO-c/CESR-c data**