Dalitz Plot Analyses at CLEO-c

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Hadron 2007

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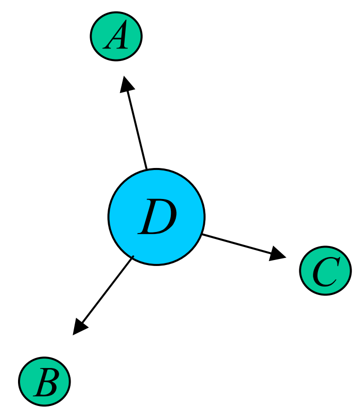
Heavy Meson Spectroscopy

Introduction

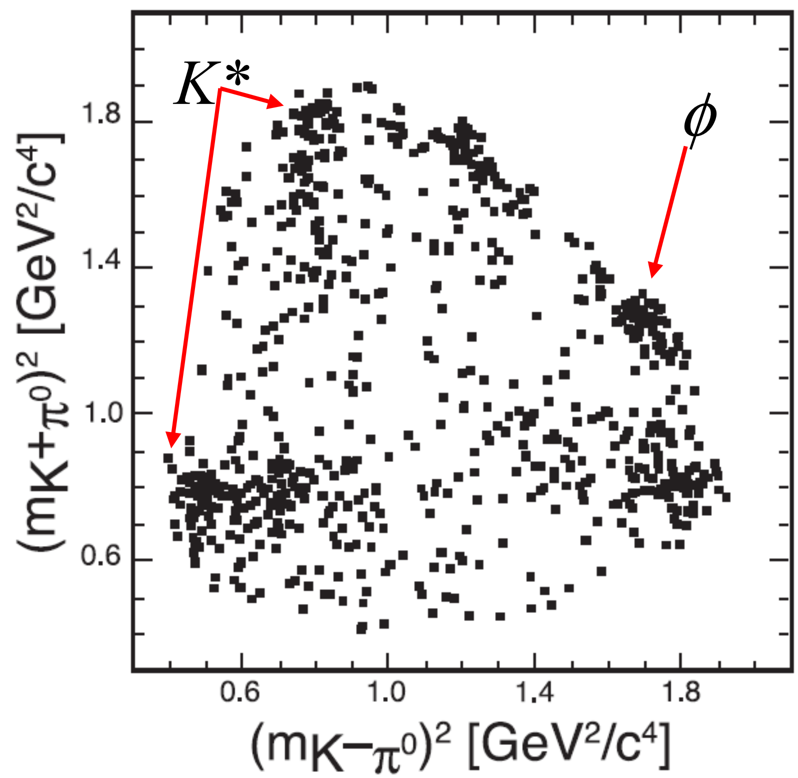
- Charm three-body analyses from several experiments summarized in PDG
- Usual analysis technique for P $\rightarrow$ 3P ($D \rightarrow ABC$) decays is the ***Dalitz plot analysis technique***
- Dalitz plot is M_{AB}^2 vs. M_{BC}^2
  - Lorentz invariant variables
  - Only two degrees of freedom for P $\rightarrow$ 3P
  - Phase space is "flat" in these variables
- Thus structure on the Dalitz plot is due to the internal dynamics of the decay



Structure

- Analyze structure on the Dalitz plot to elucidate a broad range of physics topics
  - (Doubly-)Cabibbo suppressed decays
  - CP Violation
  - Charm mixing
  - Properties of light mesons
  - Properties Kπ & ππ *S*-wave

CLEO III $D^0 \rightarrow K^+K^-\pi^0$



Studying $\pi\pi$ and $K\pi$ *S*-wave

- *S*-wave Breit-Wigner Isobars

  $\sigma(500) \to \pi^+\pi^-$

  $\kappa(800) \to K\pi$

  improve the fits for

  $D^+ \to \pi^+\pi^-\pi^+$,

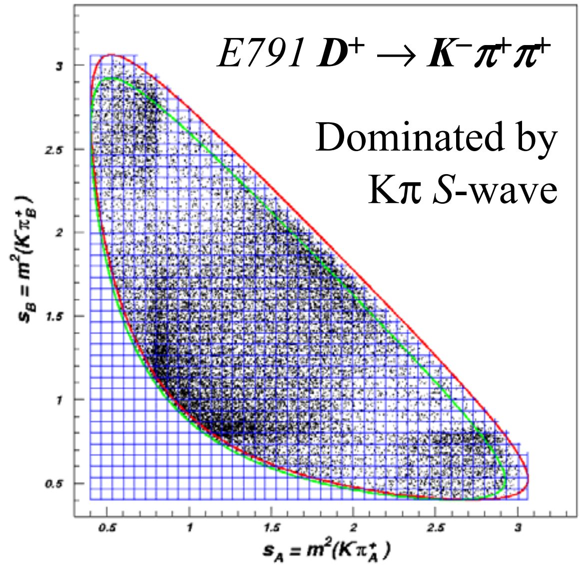
  $D^0 \to K_S\pi^+\pi^-$, and

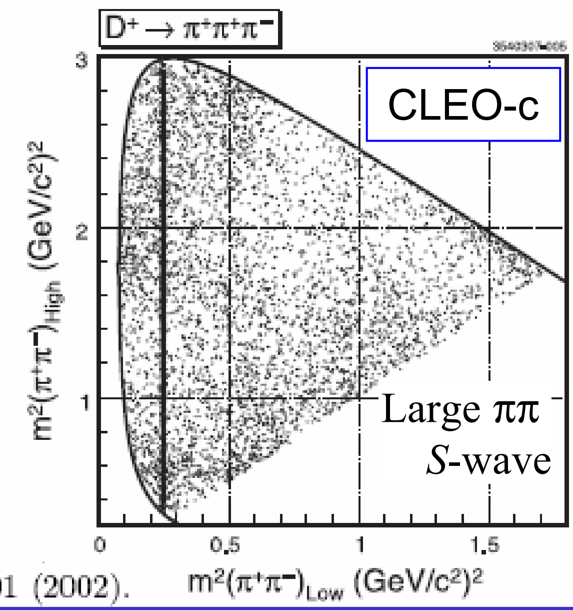
  $D^+ \to K^-\pi^+\pi^+$

  but are not required to model

  $D^0 \to K^-\pi^+\pi^0$ or

  $D^0 \to \pi^+\pi^-\pi^0$
- K-matrix Models for $D+ \to \pi^+\pi^-\pi^+$ & $D^0 \to K_S\pi^+\pi^-$ do not require $\sigma(500)$ pole
- Less model dependent approaches are desirable

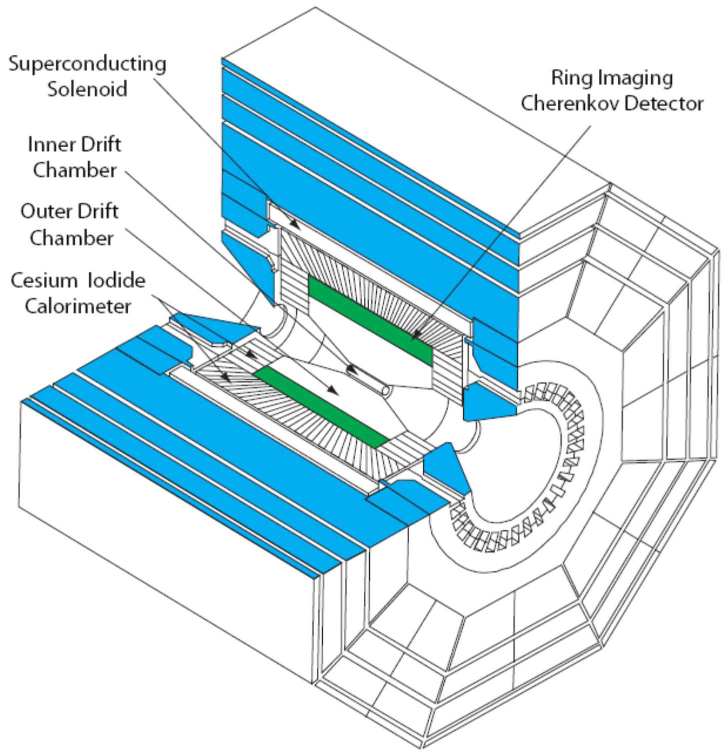




E.M. Aitala *et al.* (E791 Collaboration), Phys. Rev. Lett. 89, 121801 (2002).

About CLEO-c

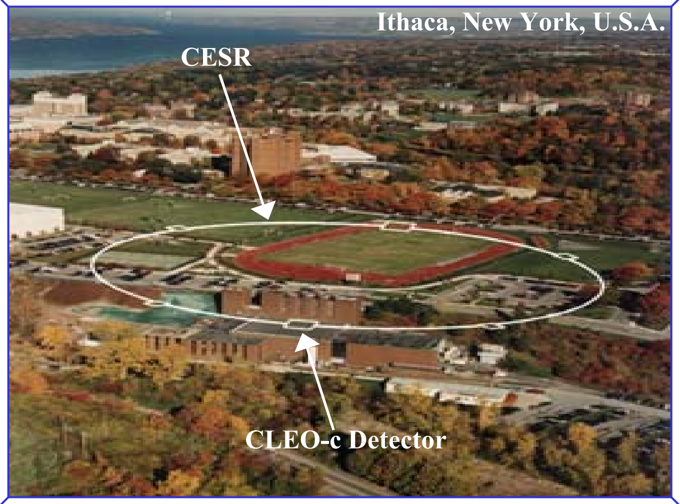
- CLEO-c is a charm facility experiment
  - Cornell Electron Storage Ring (CESR)
  - Now in the final year of data taking
  - Shutdown date: April 1, 2008
- The main focus of CLEO-c is on precision measurements of D, D_s, and $\psi(2S)$ decays
- 27 million $\psi(2S)$ events
- 572 pb^{-1} at $D\overline{D}$ threshold [$\psi(3770)$, 3770 MeV]
- 314 pb^{-1} at maximal $D_s^*\overline{D}_s$ production [4170 MeV]



CLEO-c Dalitz plot Analyses

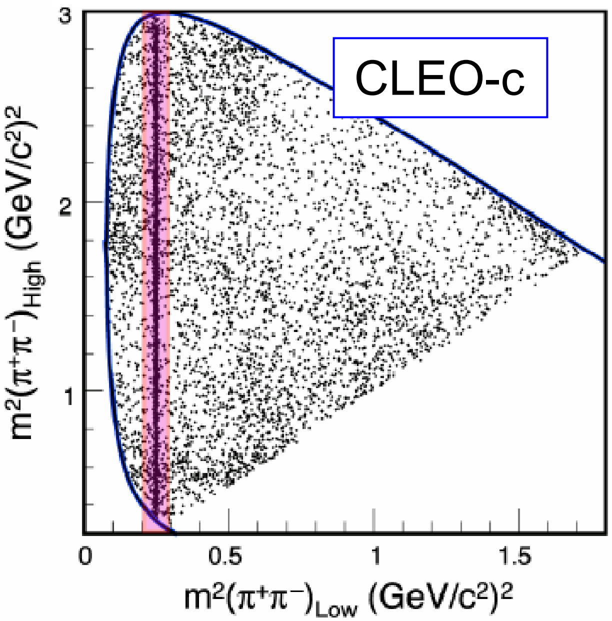
$$e^+e^- \to \psi(3770) \to D\bar{D}$$

- **$D^+ \to \pi^+ \pi^- \pi^+$** — **Phys. Rev. D 76, 012001 (2007)** — **281 pb^{-1}**
- **$D^+ \to K^- \pi^+ \pi^+$** — **EPS 2007, Preliminary results** — **281 pb^{-1}**
- **$D^+ \to K^+ K^- \pi^+$** — **NEW, Preliminary results** — **572 pb^{-1}**
- **$D^0 \to K_S \pi^0 \pi^0$** — **NEW, Preliminary results** — **281 pb^{-1}**
- **$D^0 \to K_{S,L} \pi^+ \pi^-$** — **Charm 2007, γ sensitivity study** — **281 pb^{-1}**



$D^+ \to \pi^+ \pi^- \pi^+$

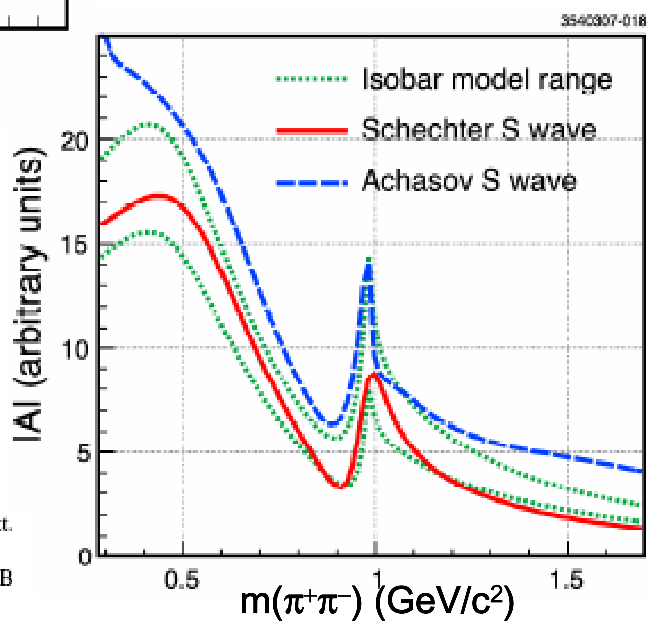
Published in Phys. Rev. D 76, 012001 (2007)



The Dalitz plot shown has been folded because of the symmetry of the two π^+.

The K_S band is clearly seen.

Confirm large ππ *S*-wave as seen by E791 and FOCUS



Three different models tried:

- **Isobar model**
- **Schechter S-wave**
- **Achasov S-wave**

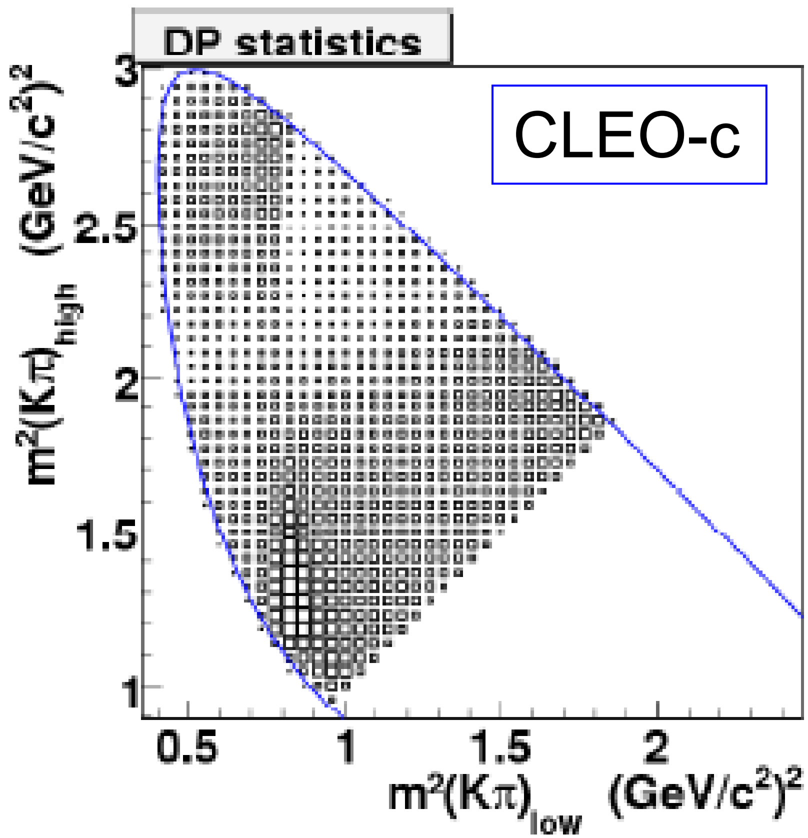
All fit the Dalitz plot well

See paper for more details

E. M. Aitala *et al.* (E791 Collaboration), Phys. Rev. Lett. 86, 770 (2001).
J. M. Link *et al.* (FOCUS Collaboration), Phys. Lett. B 585, 200 (2004).

$D^+ \rightarrow K^- \pi^+ \pi^+$

EPS' 07 conference: *hep-ex/0707.3060*



The Dalitz plot shown has been folded because of the symmetry of the two π^+.

The $K^*(892)$ band is clearly seen.

>60% Kπ *S*-wave has been seen by previous experiments.

Sets of Kπ waves interfering allow us to apply a quasi- model independent partial wave analysis (QMIPWA).

We compare fits of isobar and QMIPWA techniques in CLEO-c to the same fits done by E791.

We also expect a small I=2 ππ *S*-wave

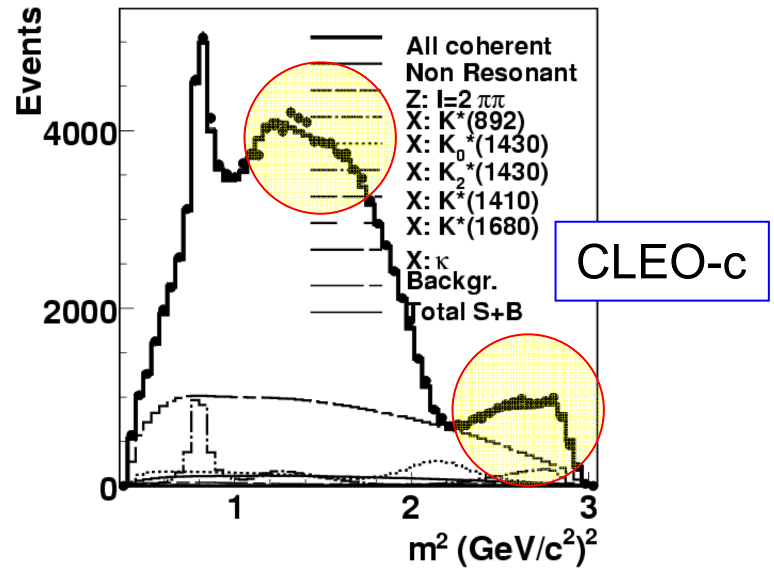
E.M. Aitala *et al.* (E791 Collaboration), Phys. Rev. Lett. 89, 121801 (2002).
E.M. Aitala *et al.* (E791 Collaboration), Phys. Rev. D73, 32004 (2006).

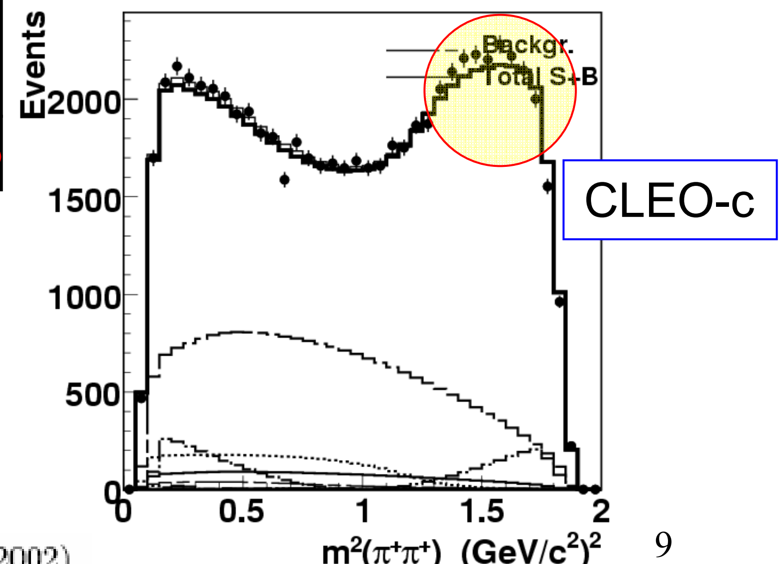
Comparison with E791, Isobar

$D^+ \to K^- \pi^+ \pi^+$

CLEO-c Preliminary

Fit Fractions		
Mode	E791	CLEO-c
NR	13.0±5.8±4.4	10.4±1.3
$K^*(892)\pi^+$	12.3±1.0±0.9	11.2±1.4
$K_0^*(1430)\pi^+$	12.5±1.4±0.5	10.5±1.3
$K_2^*(1430)\pi^+$	0.5±0.1±0.2	0.40±0.04
$K^*(1680)\pi^+$	2.5±0.7±0.3	1.36±0.16
$\kappa\pi^+$	47.8±12.1±5.3	31.2±3.6
χ^2/ν, Prob.	46/63(???)	448/388, P=2%





The CLEO-c fit probability for the E791 Isobar model is ~2% and the fit significantly underestimates the data in the range $1.3 < m^2(\pi^+\pi^+) < 1.6\ (\mathrm{GeV}/c^2)^2$

hep-ex/0707.3060

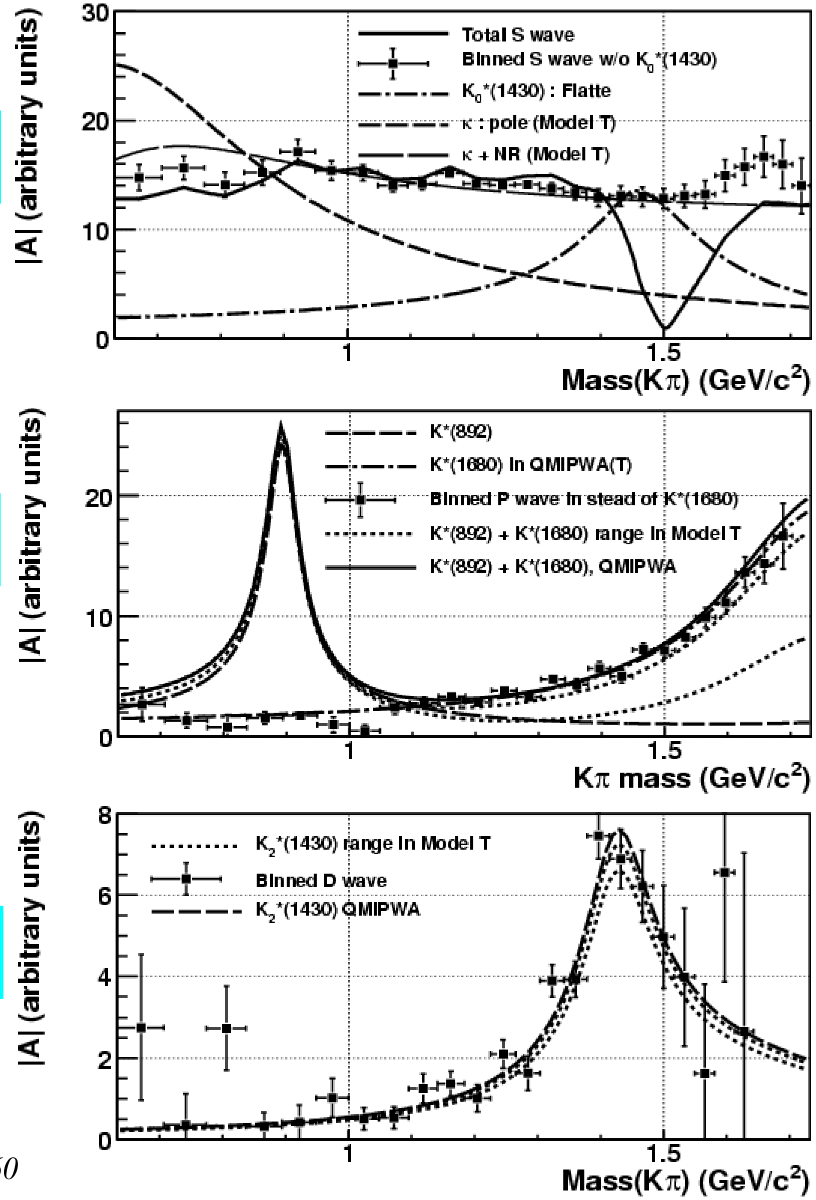
E.M. Aitala *et al.* (E791 Collaboration), Phys. Rev. Lett. 89, 121801 (2002).

$D^+ \to K^- \pi^+ \pi^+$: $K\pi$ partial waves Isobar model and QMIPWA

***S* wave**

***P* wave**

***D* wave**



hep-ex/0707.3060

- **We use a binned complex amplitude (100 MeV bin size)**
  - **$K\pi$ waves: 26 parameters for amplitude and 26 for phase.**
- ***S* wave**
  - **$K_0^*(1430)$ Breit-Wigner**
  - **Binned amplitude replacing non-resonant & κ in isobar model**
- **Binned *S*-wave actually used in QMIPWA fit**

P and *D*-wave binned to confirm our Breit-Wigner K*'s

CLEO-c

$D^+ \to K^- \pi^+ \pi^+$ Comparison Summary

EPS' 07 conference: *hep-ex/0707.3060*

Comparison of CLEO-c and E791.
Only statistical errors are shown for CLEO-c.
(Systematic errors should have similar magnitudes).

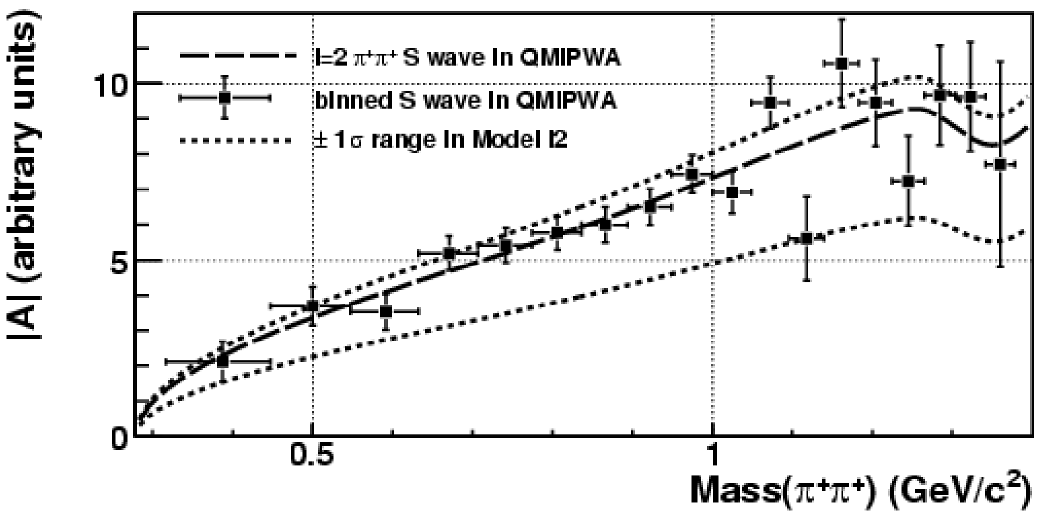
Fit Fractions				
	ISOBAR		QMIPWA	
Mode	E791 [5]	CLEO-c	E791 [6]	CLEO-c
NR	$13.0\pm5.8\pm4.4$	10.4 ± 1.3	see S wave	see S wave
$\overline{K}^*(892)\pi^+$	$12.3\pm1.0\pm0.9$	11.2 ± 1.4	$11.9\pm0.2\pm2.0$	10.0 ± 0.3
$\overline{K}_0^*(1430)\pi^+$	$12.5\pm1.4\pm0.5$	10.5 ± 1.3	see S wave	11.4 ± 3.6
$\overline{K}_2^*(1430)\pi^+$	$0.5\pm0.1\pm0.2$	0.40 ± 0.04	$0.2\pm0.1\pm0.1$	0.476 ± 0.014
$\overline{K}^*(1680)\pi^+$	$2.5\pm0.7\pm0.3$	1.36 ± 0.16	$1.2\pm0.6\pm1.2$	2.52 ± 0.08
$\kappa\pi^+$	$47.8\pm12.1\pm5.3$	31.2 ± 3.6	see S wave	see S wave
Total S wave	73 ± 15	52 ± 4	$78.6\pm1.4\pm1.8$	67.4 ± 1.3
χ^2/ν, Prob.(%)	46/63, 94%	448/388, 2%	277/277, 47.8%	368/346, 19.5%

CLEO-c Preliminary

E.M. Aitala *et al.* (E791 Collaboration), Phys. Rev. Lett. 89, 121801 (2002).
E.M. Aitala *et al.* (E791 Collaboration), Phys. Rev. D73, 32004 (2006).

$D^+ \to K^- \pi^+ \pi^+$: Adding I = 2 ππ *S*-wave Isobar model and QMIPWA

I= 2 ππ *S* wave



I = 2 ππ *S* wave has been observed in ππ scattering

We use a unitary I=2 amplitude.

We fit for the binned I=2 to confirm our unitary amplitude

Data require it
(fit probability improves)

Affects Kπ *S* wave slightly

hep-ex/0707.3060

Discussion: *S* waves in $D^+ \to K^- \pi^+ \pi^+$

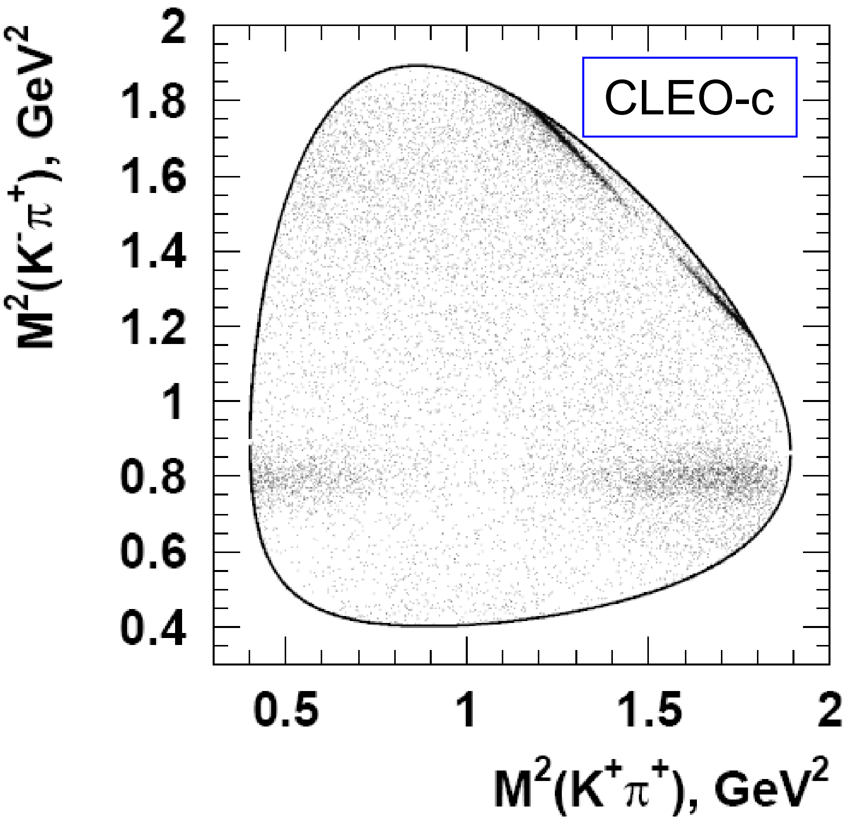
- **<u>Kπ *S* wave</u>**
  - **We do not use a form factor for *S* wave**
  - **We do not distinguish I=1/2, 3/2**
  - **Amplitude is almost constant below $K_0^*(1430)$**
  - **Binned wave shows a minor deviation from the isobar model**
  - **Phase shows slow variation from -100^o to $\sim 0^o$,**
    - **This is well described by the complex pole + $K_0^*(1430)$**
  - **I=2 <u>ππ</u> *S* wave slightly changes results for <u>Kπ</u> *S* wave**

More to come… working with 572 pb^{-1} sample now…

hep-ex/0707.3060

$D^+ \to K^+ K^- \pi^+$

New! CLEO-c Preliminary



Singly Cabibbo-suppressed decays could exhibit CP-violating asymmetry.

Expected to be < $O(10^{-3})$.

Observation > $O(10^{-3})$ may mean new physics.

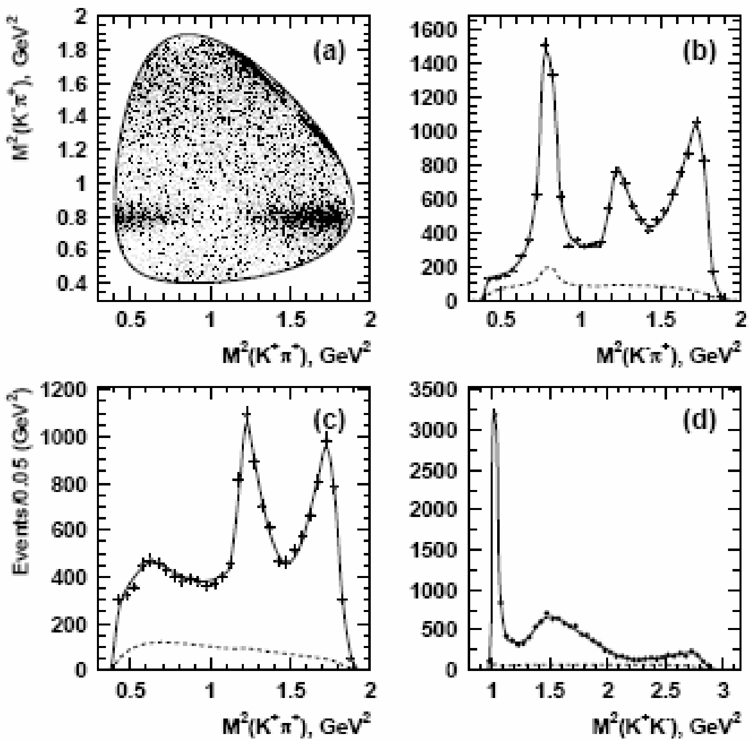
Submodes can be isolated, and we may also take CP asymmetry for submodes.

$D^+ \to K^*(892)\, K^+$
$D^+ \to K_0^*(1430)\, K^+$
$D^+ \to \phi\, \pi^+$

$$A_{CP} = \frac{N_{D+}/\epsilon_{D+} - N_{D-}/\epsilon_{D-}}{N_{D+}/\epsilon_{D+} + N_{D-}/\epsilon_{D-}}$$

$D^+ \to K^+ K^- \pi^+$

CLEO-c Preliminary



Kπ *S*-wave described by LASS model for Kπ → Kπ elastic scattering.

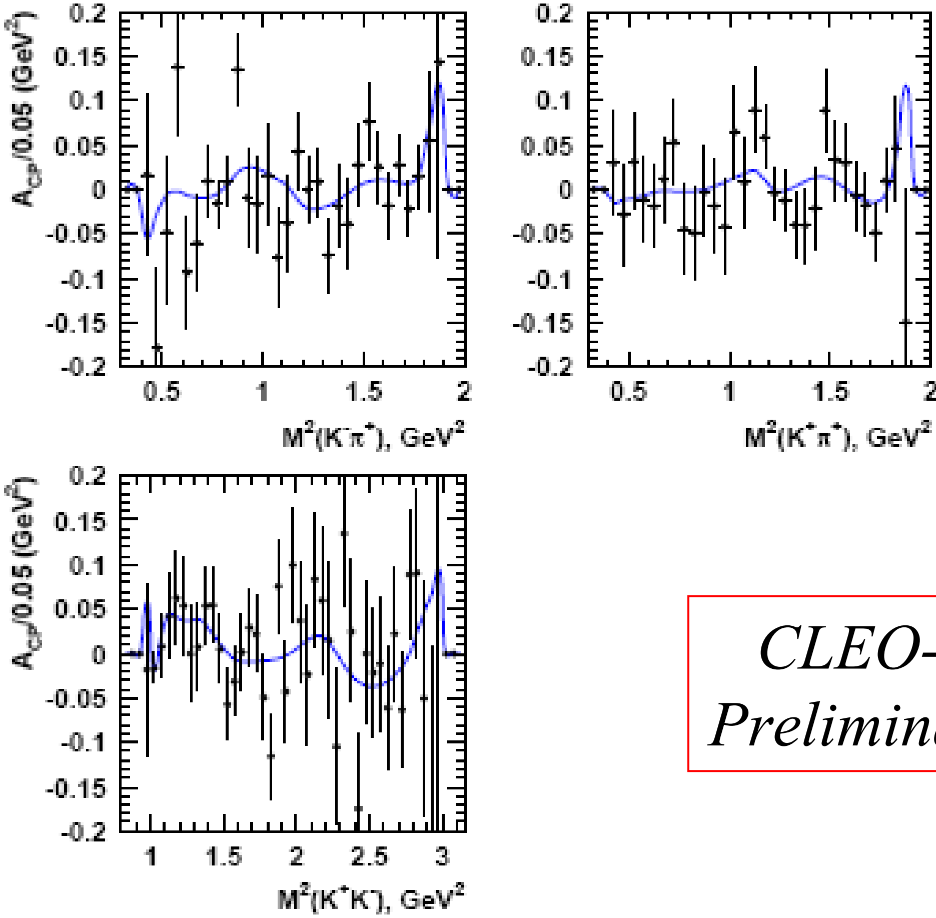
D. Aston *et al.* (LASS Collaboration), Nucl. Phys. B **296**, 493 (1988)

component	Amplitude	Phase (deg)	Fit Fraction (%)
$\overline{K}^*(892)^0 K^+$	1(fixed)	0(fixed)	$23.9 \pm 0.6^{+0.1+0.9}_{-0.3-0.4}$
$K^-\pi^+(S)K^+$	$4.53 \pm 0.16^{+0.22+0.31}_{-0.01-0.23}$	$21 \pm 3^{+0+7}_{-6-2}$	$53 \pm 3^{+5+8}_{-0-5}$
$a_0(980)\pi^+$	$0.74 \pm 0.09^{+0.03+0.16}_{-0.01-0.39}$	$96 \pm 7^{+0+4}_{-4-15}$	$1.7 \pm 0.4^{+0.1+1.3}_{-0.0-0.6}$
$\phi(1020)\pi^+$	$1.23 \pm 0.02^{+0.00+0.01}_{-0.00-0.02}$	$-148 \pm 3^{+1+5}_{-1-3}$	$28.0 \pm 0.5^{+0.0}_{-0.4} \pm 0.5$
$f_2(1270)\pi^+$	$0.91 \pm 0.13^{+0.03+0.11}_{-0.01-0.24}$	$20 \pm 6^{+5+9}_{-0-11}$	$0.9 \pm 0.2^{+0.1}_{-0.0} \pm 0.2$
$a_0(1450)\pi^+$	$1.36 \pm 0.10^{+0.20+0.45}_{-0.01-0.25}$	$116 \pm 5^{+1+13}_{-5-10}$	$3.4 \pm 0.5^{+1.0+2.5}_{-0.0-1.2}$
$\phi(1680)\pi^+$	$2.6 \pm 0.3^{+0.2+0.6}_{-0.0-0.7}$	$-96 \pm 10^{+0+17}_{-16-12}$	$0.89 \pm 0.18^{+0.15+0.3}_{-0.02-0.2}$
$\overline{K}^*_2(1430)^0 K^+$	$3.5 \pm 1.0^{+1.6+1.6}_{-0.0-2.6}$	$-156 \pm 6^{+1+30}_{-0-8}$	$2.1 \pm 1.2^{+2.4+2.2}_{-0.0-1.3}$

NR + $K_0^*(1430)$ gives a very similar fit.

$D^+ \rightarrow K^+ K^- \pi^+$

D^+ and D^- asymmetry



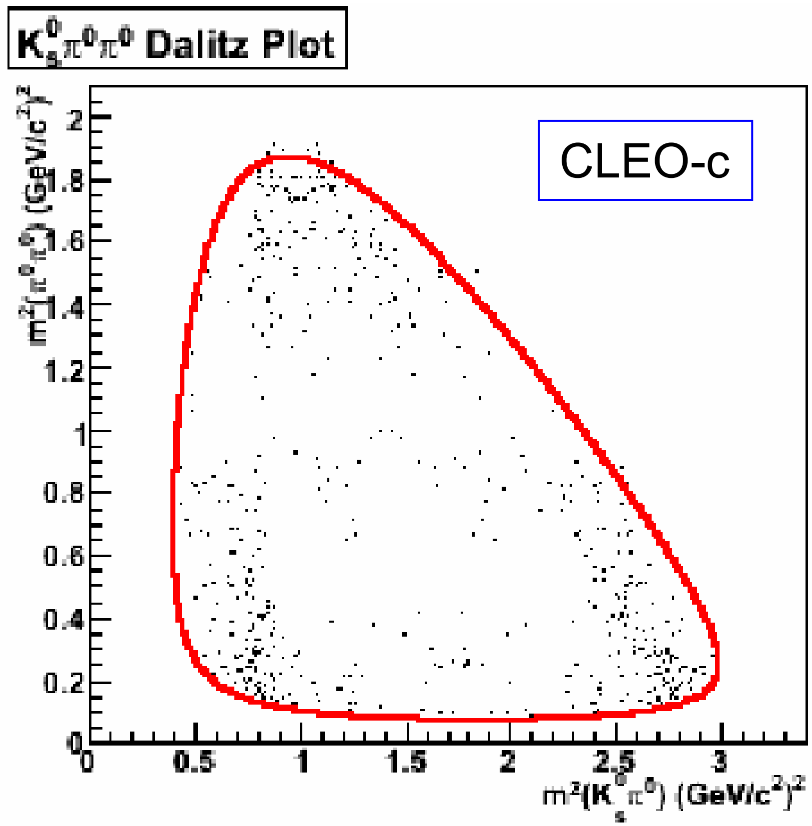
$$A_{CP} = \frac{N_{D+}/\epsilon_{D+} - N_{D-}/\epsilon_{D-}}{N_{D+}/\epsilon_{D+} + N_{D-}/\epsilon_{D-}}$$

Component	A_{CP}(fraction) (%)
$\overline{K}^*(892)^0K^+$	$0.2 \pm 2.7^{+2.3+0.7}_{-0.4-0.4}$
$K^-\pi^+(S)K^+$	$-1 \pm 5^{+1+6}_{-2-4}$
$a_0(980)\pi^+$	$-18 \pm 23^{+4+24}_{-9-6}$
$\phi(1020)\pi^+$	$-3.7 \pm 1.9^{+0.1+0.2}_{-0.2-0.3}$
$f_2(1270)\pi^+$	$5 \pm 26^{+3+22}_{-4-46}$
$a_0(1450)\pi^+$	$-20 \pm 13^{+0+16}_{-8-9}$
$\phi(1680)\pi^+$	$-6 \pm 21^{+22+7}_{-4-3}$
$\overline{K}_2^*(1430)^0K^+$	$59 \pm 41^{+1+8}_{-28-41}$

CLEO-c Preliminary

$D^0 \rightarrow K_S \pi^0 \pi^0$

New! CLEO-c Preliminary



No resonant substructure in PDG
First DP analysis with two π^0 particles.

The Dalitz plot shown has been created symmetrically, swapping the identical π^0 particle for each event.
This appears as two entries for each event.

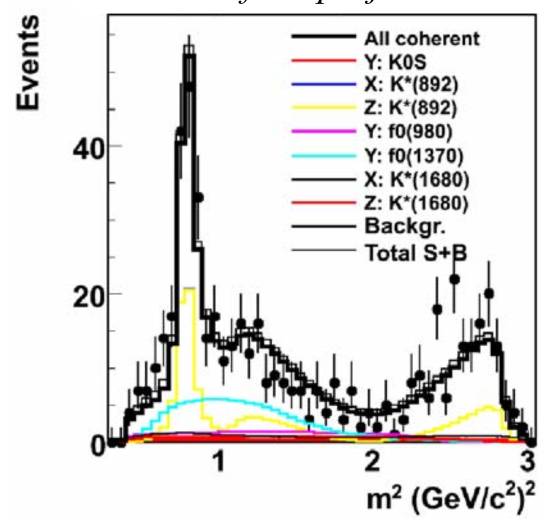
$K^*(892)$ bands are visible.

Interesting opportunity to look for $\pi\pi$ S-wave since there is no ρ^0 resonance (like in $K_S \pi^+ \pi^-$).

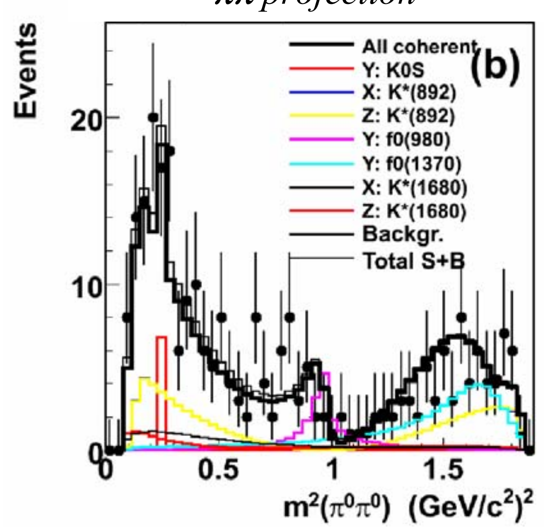
One neutral D decays to $K_S \pi^0 \pi^0$.
The other D decays to "flavor-tag" modes $D^0 \rightarrow \{K^- \pi^+, K^- \pi^+ \pi^0, K^- \pi^+ \pi^+ \pi^-\}$.

$D^0 \rightarrow K_S \pi^0 \pi^0$

Sum of $K\pi$ projections



$\pi\pi$ projection



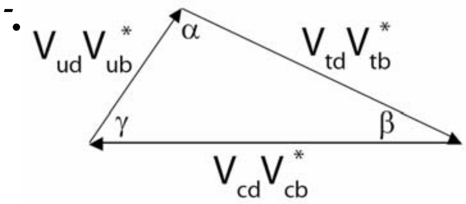
CLEO-c Preliminary

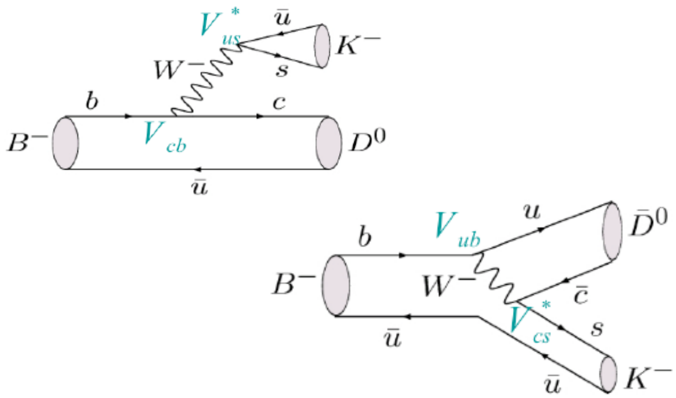
resonance	double tag
K^0_S	
Fit Fraction	$0.026 \pm 0.023 \pm 0.003 \pm 0.001$
Amplitude	$0.101 \pm 0.029 \pm 0.009 \pm 0.004$
Eff. Width	$0.0046 \pm 0.0011 \pm 0.0001 \pm 0.0001$
$K^*(892)$	
Fit Fraction	$0.542 \pm 0.054 \pm 0.030 \pm 0.053$
Amplitude	1 (fixed)
Phase	0 (fixed)
$f_0(980)$	
Fit Fraction	$0.090 \pm 0.032 \pm 0.009 \pm 0.027$
Amplitude	$1.50 \pm 0.27 \pm 0.10 \pm 0.20$
Phase	$12 \pm 17 \pm 14 \pm 8$
$f_0(1370)$	
Fit Fraction	$\boxed{0.238 \pm 0.071 \pm 0.047 \pm 0.086}$
Amplitude	$2.77 \pm 0.45 \pm 0.30 \pm 0.66$
Phase	$344 \pm 10 \pm 10 \pm 18$
$K^*(1680)$	
Fit Fraction	$0.114 \pm 0.027 \pm 0.021 \pm 0.032$
Amplitude	$4.55 \pm 0.68 \pm 0.49 \pm 0.59$
Phase	$97 \pm 20 \pm 17 \pm 13$

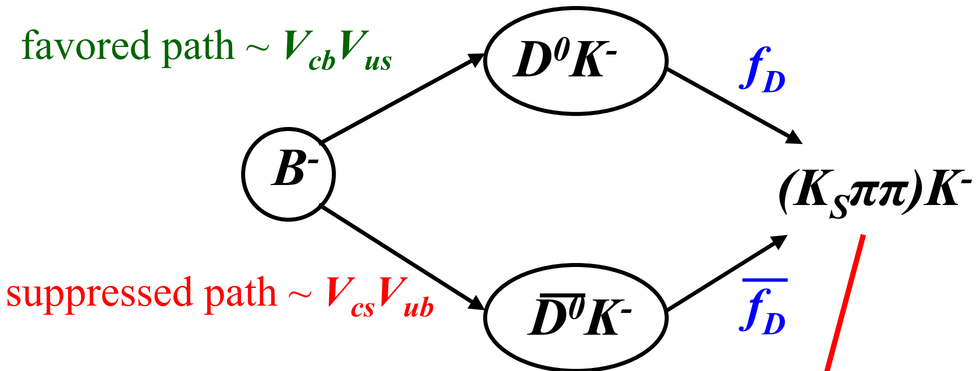
ππ *S*-wave (σ) and Kπ *S*-wave (κ) describe our statistics equally well.

$D^0 \to K_{S,L}\,\pi^+\pi^-$ and measuring γ/φ_3

- Use $B^\pm \to DK^\pm$ decays, followed by Dalitz plot analysis of $D \to K_{S,L}\pi^+\pi^-$.
- Developed by Giri, Grossman, Soffer, Zupan (GGSZ)[1] / Belle [2]
  -- exploit interference between D^0 and $\overline{D^0}$ channels





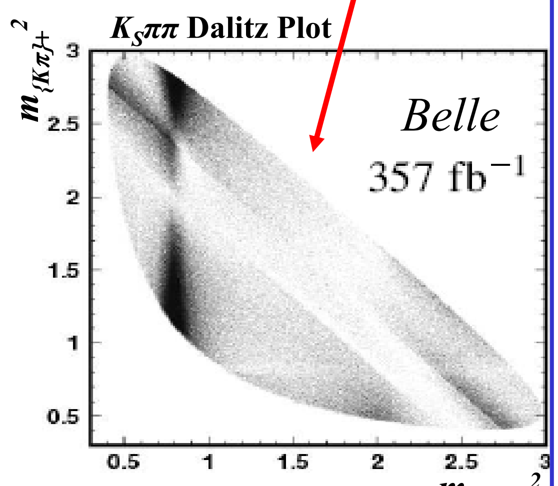


We need to know decay amplitudes and these parameters to get γ:

$$r_B e^{i(\delta_B \mp \gamma)} = \frac{A(B^\mp \to \overline{D^0}K^\mp)}{A(B^\mp \to D^0K^\mp)} \xrightarrow{r_B,\ \delta_B} \text{Measure at B-factory}$$

δ_D (as a function of Dalitz plot variables)

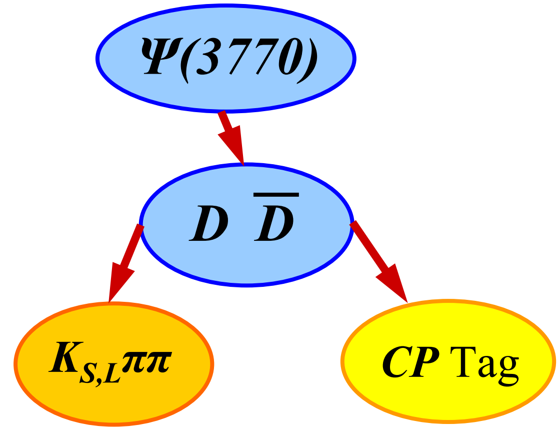
$$\delta_D = \arg\frac{A(D^0 \to K_S\pi^+\pi^-)}{|A(D^0 \to K_S\pi^+\pi^-)|} \longrightarrow \boxed{\text{Measure at CLEO-c}}$$



Giri et al. Phys. Rev. D 68, 054018 (2003)
A. Poluektov et al. (Belle Collaboration), Phys. Rev. D 73, 112009 (2006).

Measuring c_i with *CP*-tagged Dalitz Plots

$D^0 \to K_{S,L}\, \pi^+ \pi^-$



Correlated $D\overline{D}$ pairs ($C = -1$) are produced at CLEO-c

We **tag** the $K_S\pi\pi$ sample by reconstructing $D \to CP\pm$ eigenstates

$$\boxed{D_{CP\pm} = \frac{D^0 \pm \overline{D^0}}{\sqrt{2}}}$$

For ***CP***-tagged Dalitz plots, number of events in Dalitz plot is

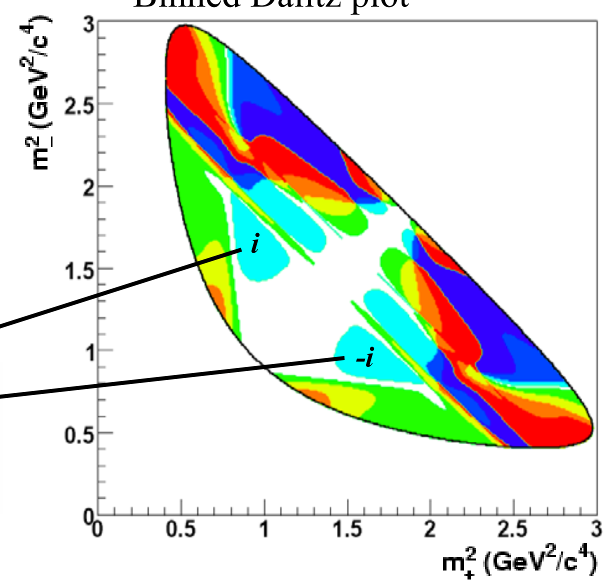
$$M \sim |f_D|^2 + |\overline{f_D}|^2 \pm 2|f_D||\overline{f_D}|\cos(\delta_D)$$

Divide the $(K_S\pi\pi)D$ Dalitz plot into bins based on model-inspired binning, symmetric under interchange of $\pi^+ \leftrightarrow \pi^-$ interchange.

$$\boxed{\text{Define} \;\to\; c_i = \langle\cos(\delta_D)\rangle_i}$$

c_i can be determined by counting ***CP***-tagged bins

Binned Dalitz plot



M_i = Number of events in CP-tagged bin i

K_i = Number of events in flavor-tagged bin i

$$c_i = \frac{1}{2}\frac{(\overset{\text{CP-}}{\overline{M}_i^-} - \overset{\text{CP+}}{\overline{M}_i^+})}{(\overline{M}_i^- + \overline{M}_i^+)}\frac{(K_i + K_{-i})}{\sqrt{K_i K_{-i}}}$$

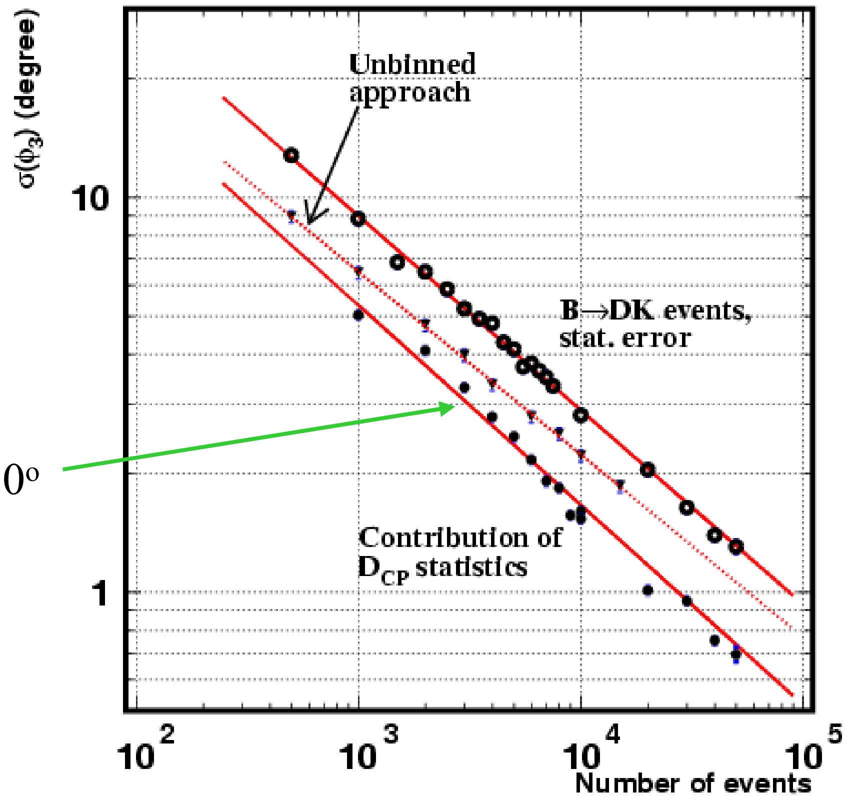
CP-tagged flavor-tagged

Bondar, Poluektov hep-ph/0703267v1 (2007)

CLEO-c Sensitivity to c_i in $D^0 \rightarrow K_{S,L}\, \pi^+ \pi^-$

- We combine $K_L\pi\pi$, $K_S\pi\pi$ Dalitz plots into an improved overall measurement of c_i
- Scale statistical uncertainty up to 750 pb^{-1}
- Combine with $K_L\pi\pi$ systematic uncertainty to determine overall expected sensitivity from CLEO-c measurement
- CLEO-c can reduce model uncertainty from ±10° down to ± 4° in γ/φ_3 measurement

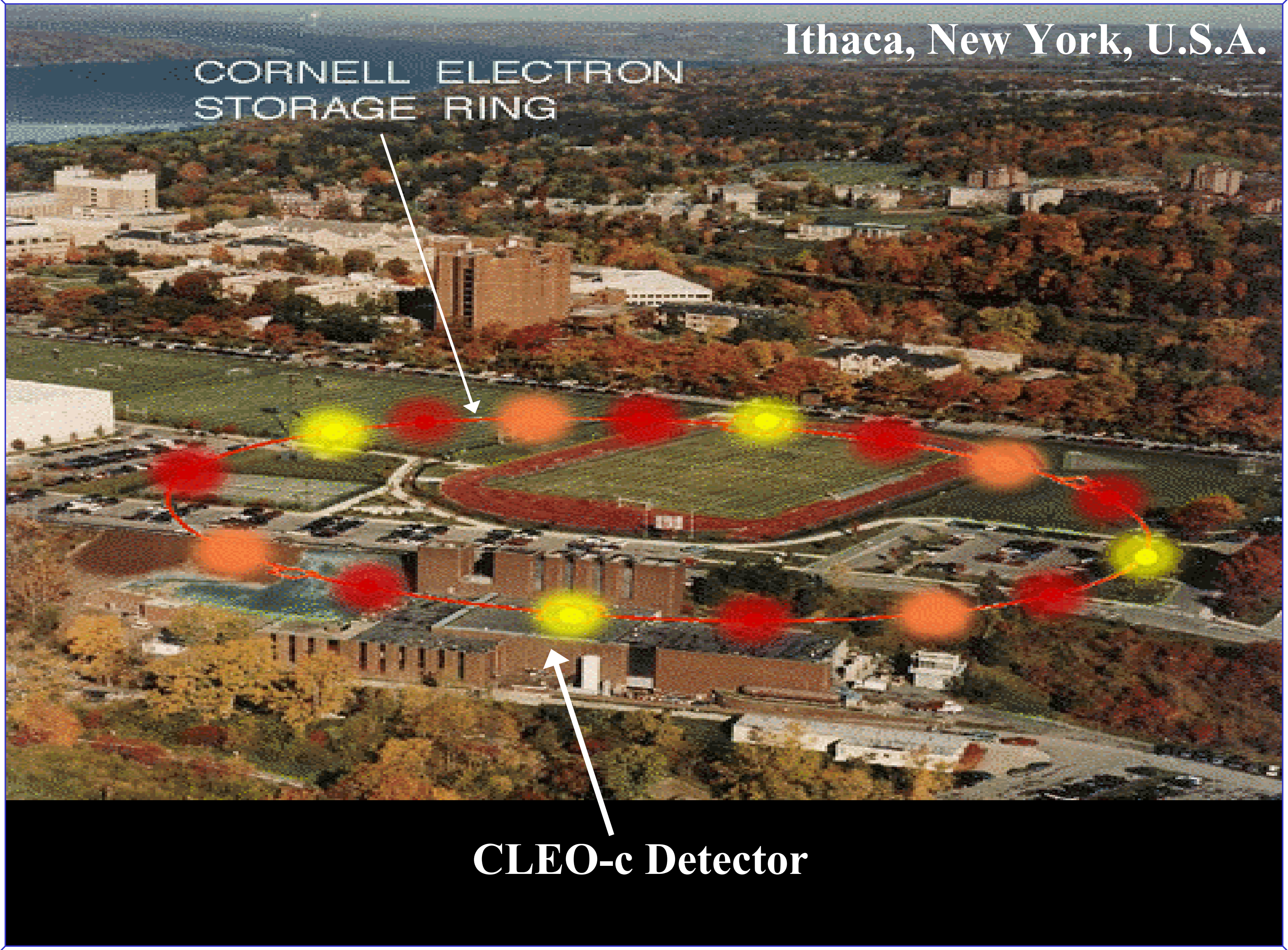
[1] Bondar, Poluektov [hep-ph/0510246]



Conclusion

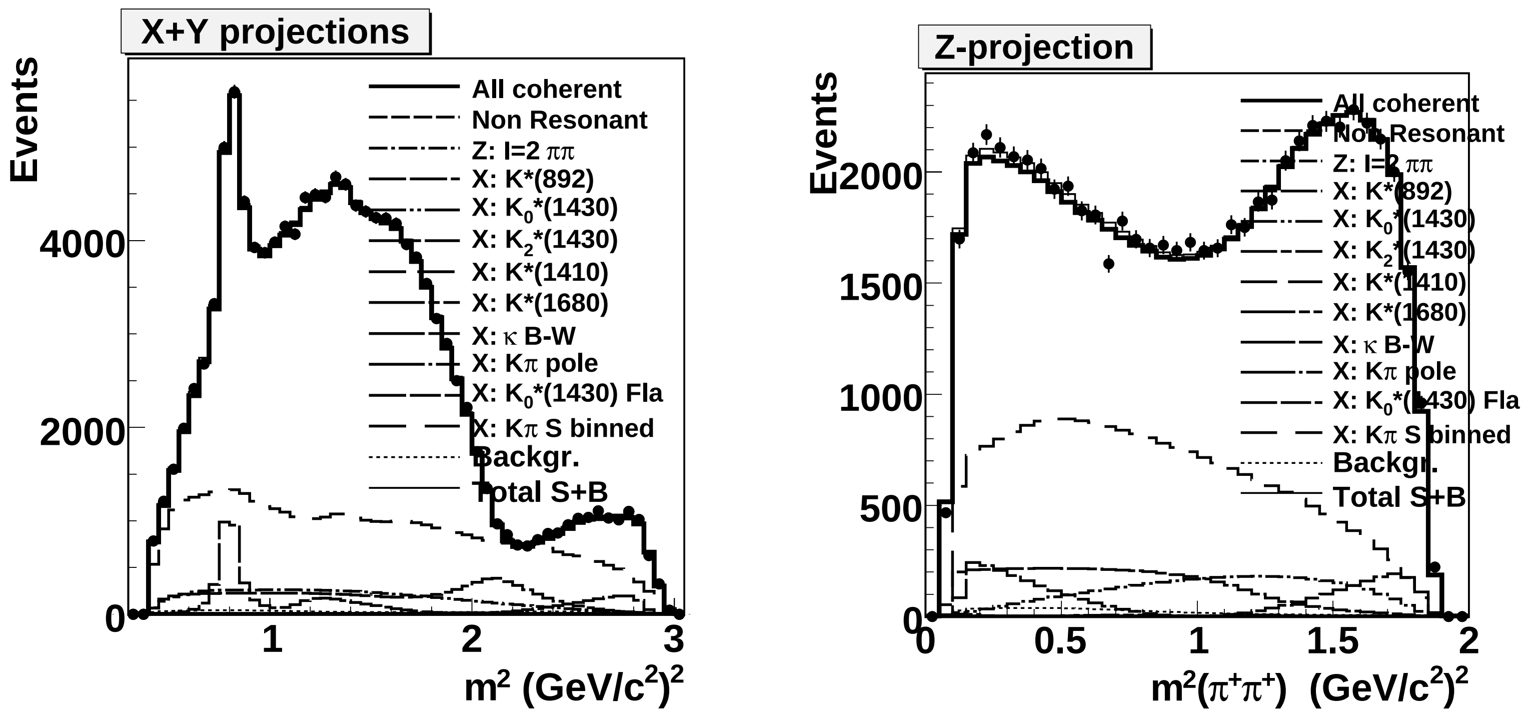
- CLEO-c is making a strong contribution to
  - our understanding of Kπ and ππ *S*-waves
  - our understanding of strong phases
  - narrowing the *D* model error on measurement of CKM model γ
- More to come…
  - Double Dalitz plot analyses
    - ($K_S \pi^+ \pi^-$ vs. $K_S \pi^+ \pi^-$, $K_L \pi^+ \pi^-$)
  - D_S Dalitz plots
- More data being taken
  - 800 pb^{-1} at $\psi(3770)$ will be available soon!
  - 630 pb^{-1} near 4170 MeV by end of CLEO-c run

BACKUP SLIDES


Ithaca, New York, U.S.A.
CORNELL ELECTRON STORAGE RING
CLEO-c Detector

QMIPWA Invariant mass projections

$D^+ \to K^- \pi^+ \pi^+$



CLEO-c

Dalitz plot Analysis Technique

- Internal dynamics of $\boldsymbol{D^0 \rightarrow ABC}$ (P → 3P)
- Daughter 4-momenta: 12 parameters
  - Conservation of 4-momentum: 4 constraints
  - Masses of Decay products: 3 constraints
  - ***D*** is spin-0 : 3 orientations uninteresting
- Decay described by 2 degrees of freedom
  - 3 Lorentz invariants $(M_{AB})^2$, $(M_{AC})^2$, $(M_{BC})^2$, related by: $(M_D)^2 + (M_A)^2 + (M_B)^2 + (M_C)^2 = (M_{AB})^2 + (M_{AC})^2 + (M_{BC})^2$
- Dalitz plot is $(M_{AB})^2$ vs $(M_{BC})^2$
  - Phase space is "flat" in these variables

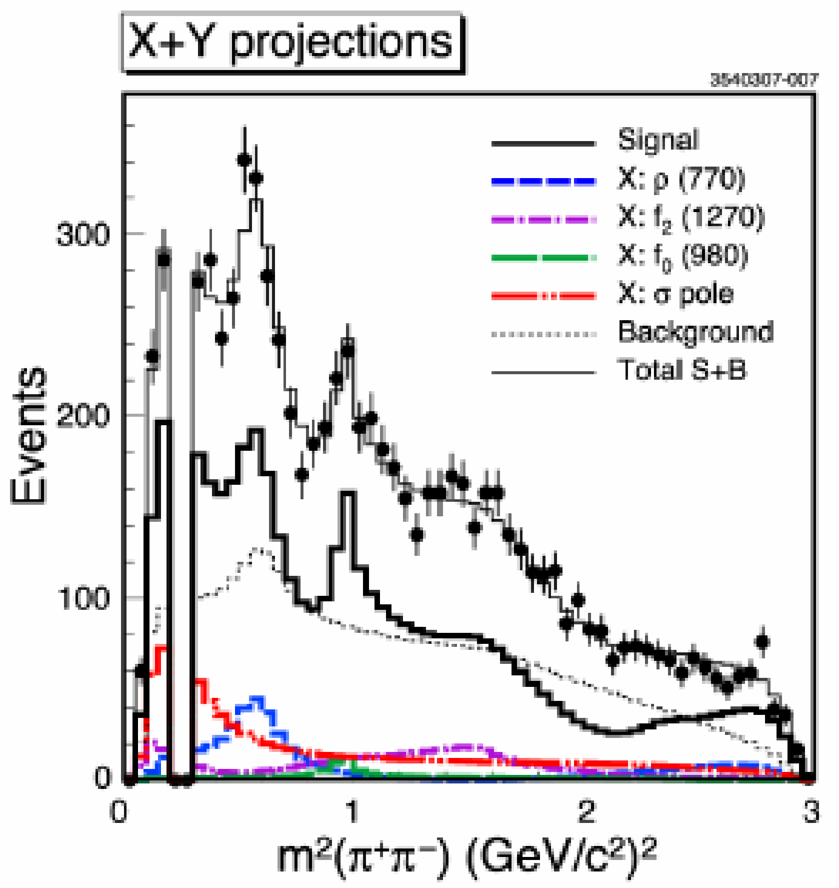
Isobar model results

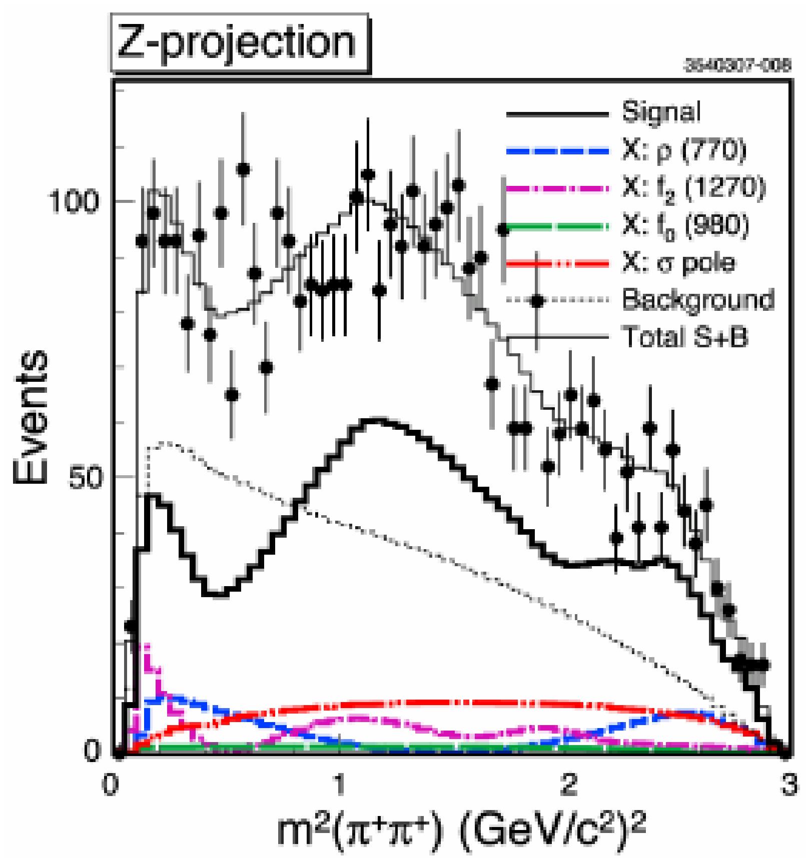
Starting from the dominant contributions clearly seen in the data, additional resonances are added or removed one by one to improve the fit. A contribution is kept if the amplitude is significant at more than 3 standard deviations and the phase uncertainty is less than 30°.

Mode	Amplitude, a.u.	Phase, (°)	Fit Fraction, %
$\rho(770)\pi^+$	1(fixed)	0(fixed)	20.0±2.3±0.9
$f_0(980)\pi^+$	1.4±0.2±0.2	12±10±5	4.1±0.9±0.3
$f_2(1270)\pi^+$	2.1±0.2±0.1	−123±6±3	18.2±2.6±0.7
$f_0(1370)\pi^+$	1.3±0.4±0.2	−21±15±14	2.6±1.8±0.6
$f_0(1500)\pi^+$	1.1±0.3±0.2	−44±13±16	3.4±1.0±0.8
σ pole	3.7±0.3±0.2	−3±4±2	41.8±1.4±2.5
$\sum_i FF_i$, %			90.2

Mode	Upper Limit on Fit Fraction, %
$\rho(1450)\pi^+$	<2.4
N.R.	<3.5
I=2 $\pi^+\pi^+$ S-Wave	<3.7
$f_0(1710)\pi^+$	<1.6
$f_0(1790)\pi^+$	<2

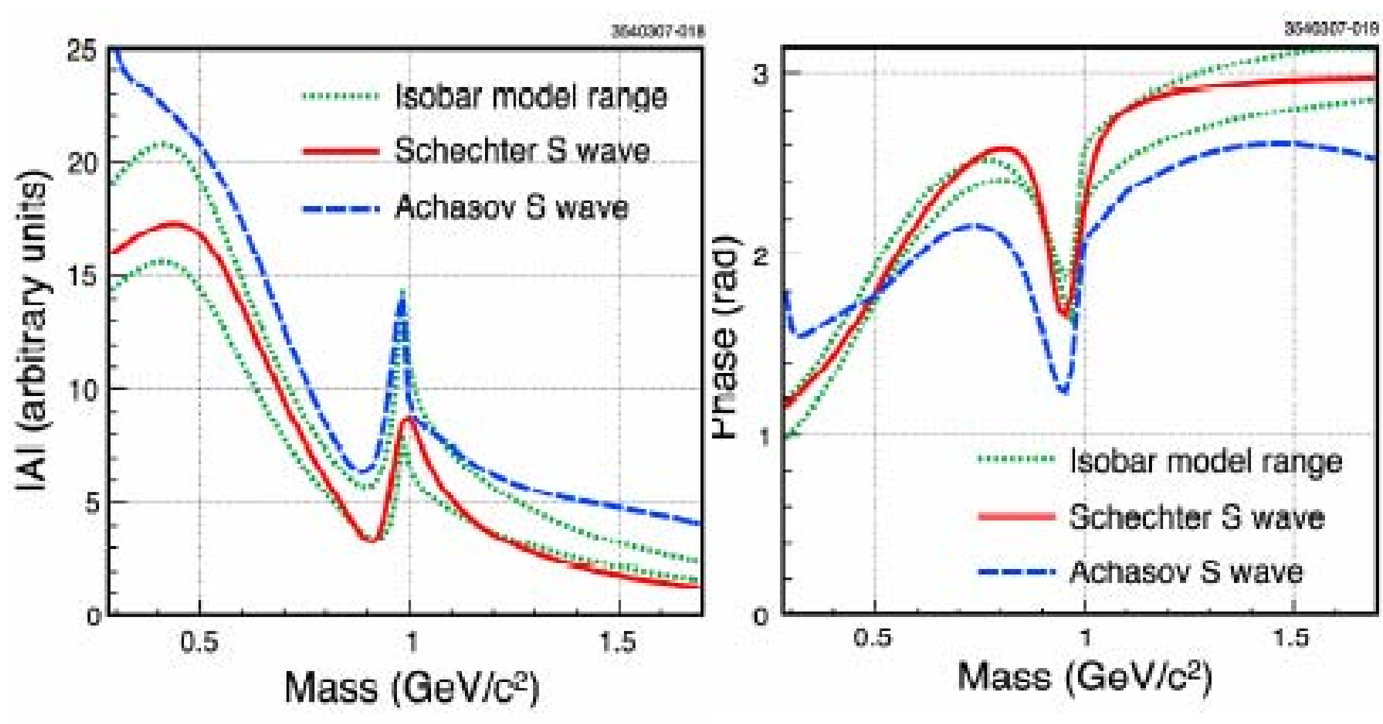
Fits to the Mass projections





Comparison of amplitudes and phases

The two models used to extend the isobar model give amplitudes and phases which are close to the isobar results but are a better physical description of the *S* wave component

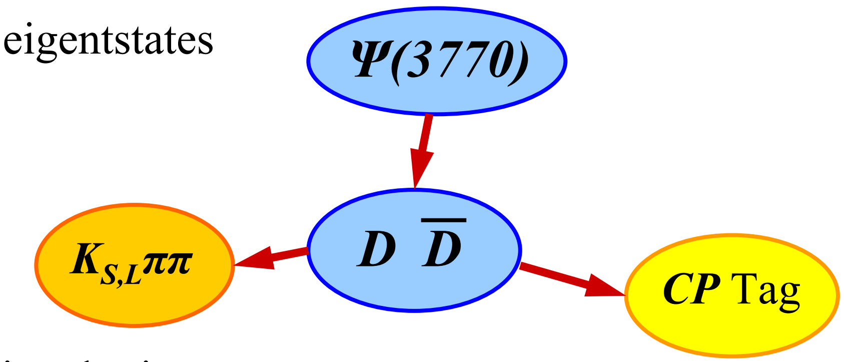


Measuring c_i with *CP*-tagged Dalitz Plots

$D^0 \rightarrow K_{S,L}\, \pi^+ \pi^-$

Correlated $D\overline{D}$ pairs ($C = -1$) are produced at CLEO-c
We **tag** the $K_S\pi\pi$ sample by reconstructing $D \rightarrow CP\pm$ eigentstates

$$\boxed{D_{CP\pm} = \frac{D^0 \pm \overline{D^0}}{\sqrt{2}}}$$



For *CP*-tagged Dalitz plots, number of events in Dalitz plot is

$$M \sim |f_D|^2 + |\overline{f_D}|^2 \pm 2|f_D||\overline{f_D}| \cos(\delta_D)$$

Divide the $(K_S\pi\pi)D$ Dalitz plot in to bins, symmetric under interchange of $\pi^+ \leftrightarrow \pi^-$ interchange.

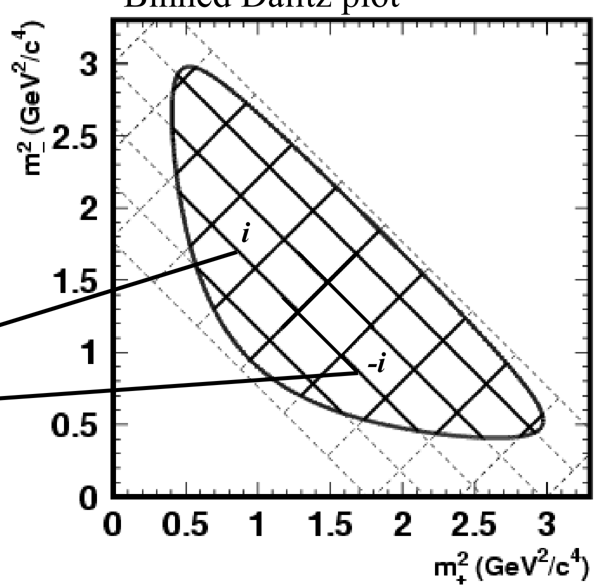
$$\boxed{\text{Define } \rightarrow c_i = \langle\cos(\delta_D)\rangle_i}$$

c_i can be determined by counting *CP*-tagged bins

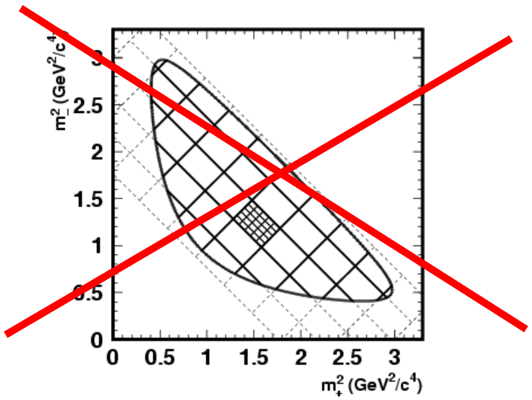
$$c_i = \frac{1}{2}\frac{(\overline{M}_i^- - \overline{M}_i^+)}{(\overline{M}_i^- + \overline{M}_i^+)}\frac{(K_i + K_{-i})}{\sqrt{K_i K_{-i}}}$$

CP-tagged flavor-tagged

Binned Dalitz plot



$D^0 \to K_S\, \pi^+ \pi^-$ Binned Analysis



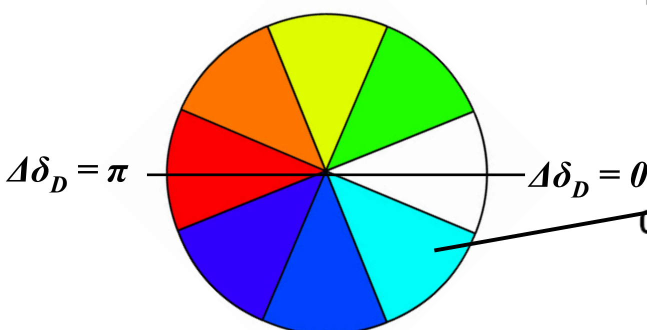
$\boldsymbol{s_i}$ can be determined from $\boldsymbol{c_i} \rightarrow \quad \boldsymbol{s_i} = \pm\sqrt{1 - \boldsymbol{c_i}^2}$

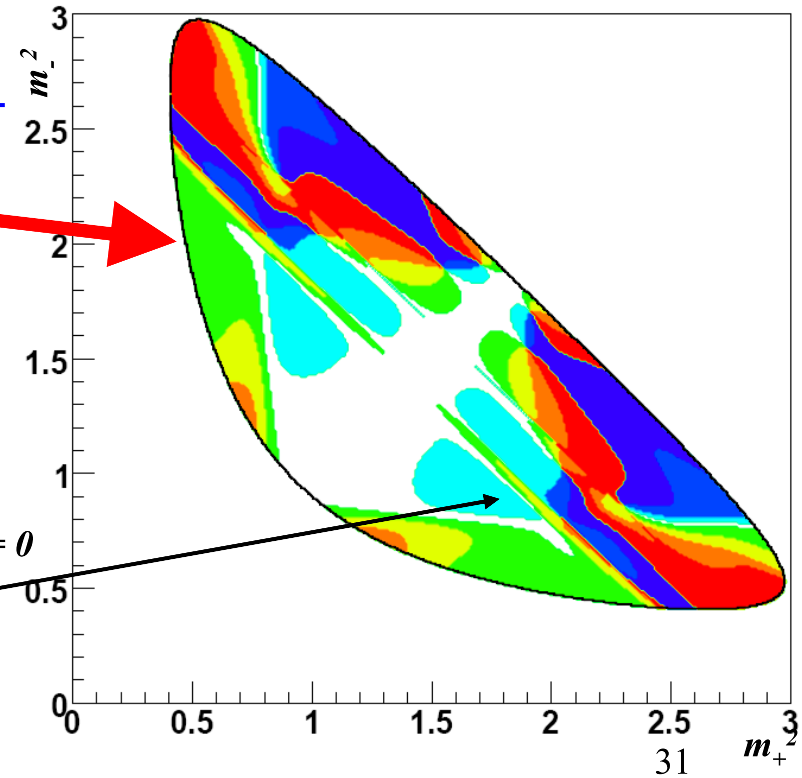
Provided fluctuations of phase difference $\boldsymbol{\delta_D}$ across bins are small

Variation of $\boldsymbol{\delta_D}$ phase can be minimized by choosing a more intelligent, model-inspired binning:

$$2\pi(i - 1/2)/\mathcal{N} < \Delta\delta_D(m_+^2, m_-^2) < 2\pi(i + 1/2)/\mathcal{N}$$

We use $\boldsymbol{N = 8}$ bins in this analysis





Bondar, Poluektov hep-ph/0703267v1 (2007)

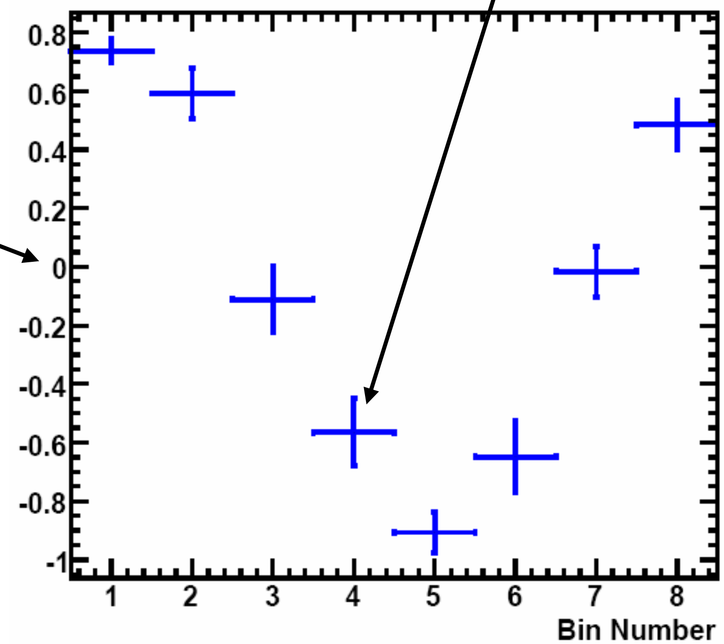
Belle Collaboration, A. Poluektov *et al*. Phys. Rev. **D73**, 112009 (2006)

CLEO-c Sensitivity to c_i in $D^0 \rightarrow K_{S,L}\, \pi^+ \pi^-$

- We combine $K_L\pi\pi$, $K_S\pi\pi$ Dalitz plots into an improved overall measurement of c_i
- Scale statistical uncertainty up to full 750 pb^{-1}
- Combine with $K_L\pi\pi$ systematic uncertainty to determine overall expected sensitivity from CLEO-c measurement
- CLEO-c can reduce model uncertainty from $\pm 10^o$ down to $\pm 4^o$ in γ/φ_3 measurement

Error bars represent <u>expected</u> uncertainty, as projected from current data sample

c_i calculated from model



- **$\pi\pi$ waves: 18 parameters for amplitude and 18 for phase.**

- *P* wave
    - $K^*(892)$ Breit-Wigner
    - Binned amplitude replacing $K^*(1680)$ in isobar model
- *D* wave
    - Binned amplitude replacing $K_2^*(1430)$ in the isobar model
- Other, narrow resonances parameterized by Breit-Wigners.

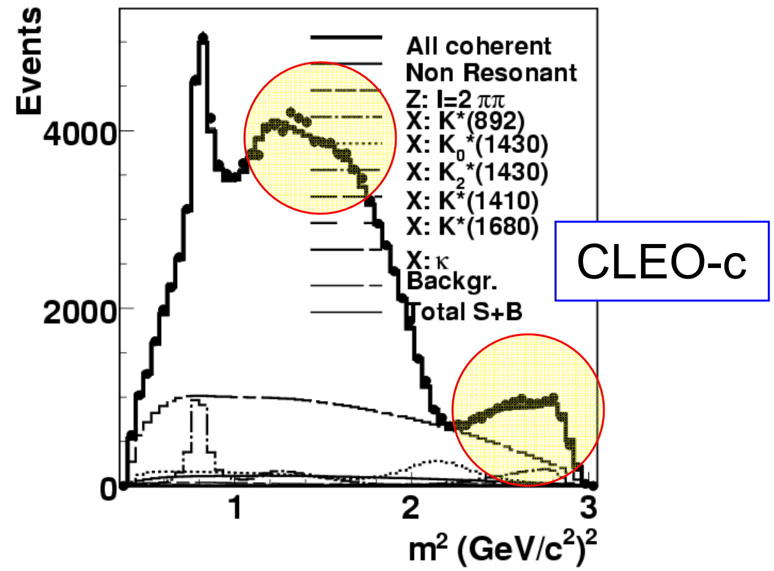
- **Parameters of the *S*, *P*, and *D* waves float one wave at a time**

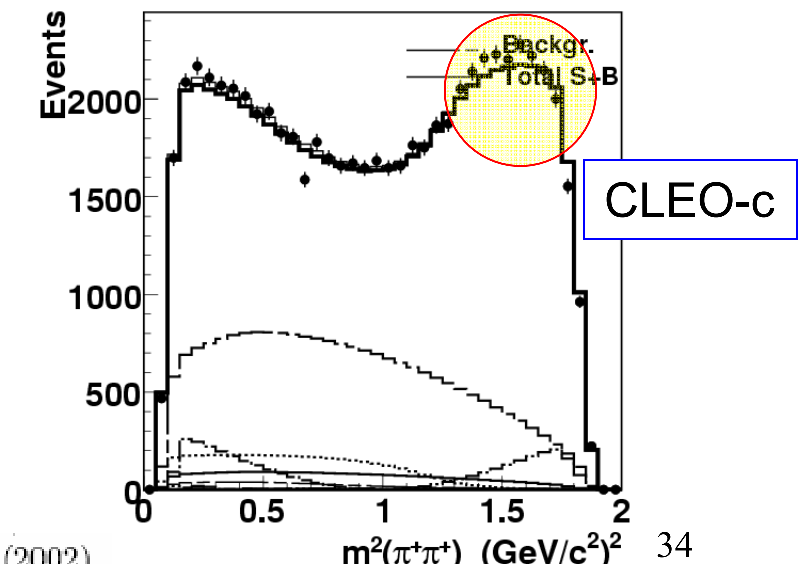
Comparison with E791, Isobar

CLEO-c Preliminary

$D^+ \to K^- \pi^+ \pi^+$

Mode	Parameter	E791	CLEO-c
NR	a (a.u.)	1.03±0.30±0.16	8.0±1.0
	ϕ (°)	−11±14±8	−19±9
	FF (%)	13.0±5.8±4.4	10.4±1.3
$\overline{K}^*(892)\pi^+$	a (a.u.)	1 (fixed)	1 (fixed)
	ϕ (°)	0 (fixed)	0 (fixed)
	FF (%)	12.3±1.0±0.9	11.2±1.4
$\overline{K}_0^*(1430)\pi^+$	a (a.u.)	1.01±0.10±0.08	3.1±0.1
	ϕ (°)	48±7±10	48±3
	FF (%)	12.5±1.4±0.5	10.5±1.3
	m (MeV/c²)	1459±7±12	1461±3
	Γ (MeV/c²)	175±12±12	169±5
$\overline{K}_2^*(1430)\pi^+$	a (a.u.)	0.20±0.05±0.04	0.98±0.04
	ϕ (°)	−54±8±7	−29±4
	FF (%)	0.5±0.1±0.2	0.40±0.04
$\overline{K}^*(1680)\pi^+$	a (a.u.)	0.45±0.16±0.02	6.7±0.5
	ϕ (°)	28±13±15	29±4
	FF (%)	2.5±0.7±0.3	1.36±0.16
$\kappa\pi^+$	a (a.u.)	1.97±0.35±0.11	4.8±0.3
	ϕ (°)	−173±8±18	−165±5
	FF (%)	47.8±12.1±5.3	31.2±3.6
Breit-Wigner	m (MeV/c²)	797±19±43	805±11
	Γ (MeV/c²)	410±43±87	453±21
Formfactor	r_κ(GeV^{-1})	1.6±1.3	1.5(fixed)
	r_D(GeV^{-1})	5.0±0.5	5 (fixed)
Other $R \to K\pi$	r_R(GeV^{-1})	1.5(fixed)	1.5(fixed)
Goodness	χ^2/ν, Prob.	46/63(???)	448/388 P=2%





The CLEO-c fit probability for the E791 Isobar model is ~2% and the fit significantly underestimates the data in the range $1.3 < m^2(\pi^+\pi^+) < 1.6$ (GeV/c²)²

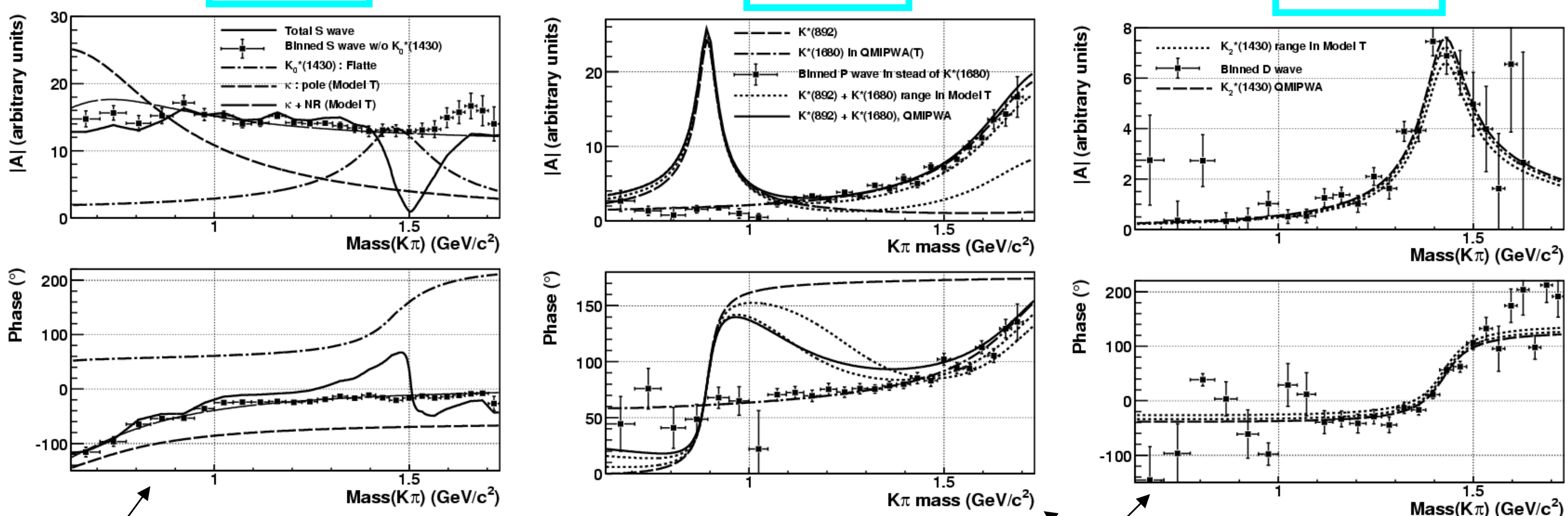
E.M. Aitala *et al.* (E791 Collaboration), Phys. Rev. Lett. 89, 121801 (2002).

$D^+ \to K^- \pi^+ \pi^+$: $K\pi$ partial waves Isobar model and QMIPWA

CLEO-c

- We use a binned complex amplitude (100 MeV bin size)
  - $K\pi$ waves: 26 parameters for amplitude and 26 for phase.
- *S* wave
  - $K_0^*(1430)$ Breit-Wigner
  - Binned amplitude replacing κ & non-resonant in isobar model

***S* wave** | ***P* wave** | ***D* wave**



Binned *S*-wave actually used in QMIPWA fit

Binned to confirm our Breit-Wigner K*'s