SCALARS IN CHARM DECAYS

J. Rosner – University of Chicago – 2/13/08 at Scadron70

On behalf of the CLEO Collaboration; special thanks to M. Dubrovin

Three-body charmed meson and χ_c decays will yield rich information on low-mass scalar resonances once fully analyzed

Observe $f_0(980)$, $a_0(980)$; broad S-wave amplitudes in $\pi\pi$, $K\pi$; $f_0(1370) \to \pi\pi$ in some fits

Relevant CLEO data sets:

Open charm production near 10 GeV

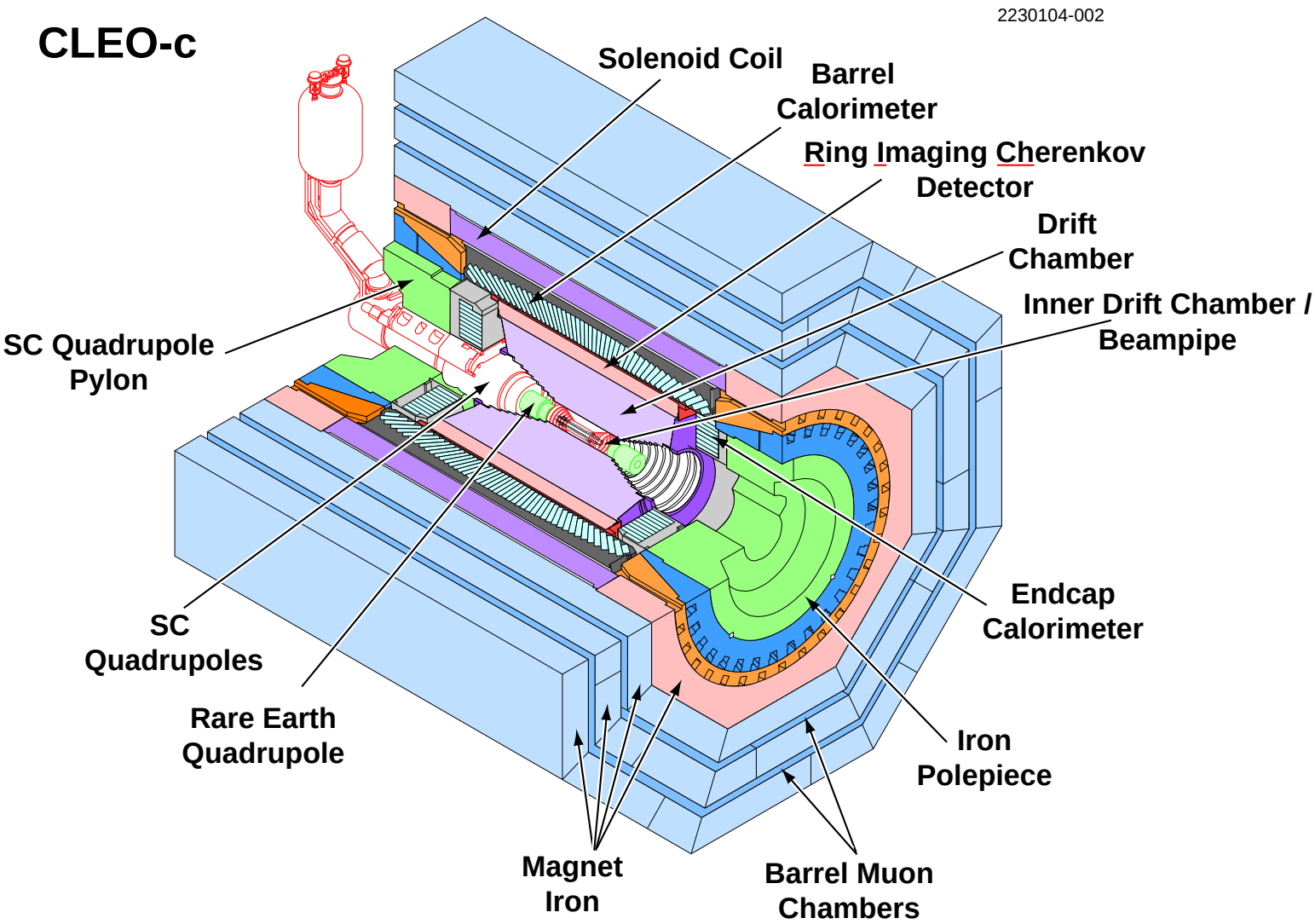
3 + 24.5 million $\psi(2S)$ as source of χ_c states, about 6 million tagged $\pi^+\pi^- J/\psi$

More than 800 pb^{-1} at $\psi(3770) \Rightarrow$ > 5 million very clean $D\bar{D}$ pairs

Anticipate ~ 600 pb^{-1} at 4170 MeV, $\Rightarrow$ ~ 570 K $D_s\bar{D}_s$ pairs

Production mechanism affects determination of resonance properties (especially for broad states)

THE CLEO-c DETECTOR



Excellent particle ID, charged/neutral momentum/energy resolution

EXAMPLES OF CHANNELS

$D^+ \to K^-\pi^+\pi^+$: κ? (CLEO 281 pb^{-1} arXiv:0707.3060; $> 4\times$ E791)

$D^0 \to K_S\pi^+\pi^-$: CLEO (9 fb^{-1} near 10 GeV) needed no σ, κ [H. Muramatsu +, PRL **89**, 251802], but BaBar [SLAC-PUB-12983], Belle [PR D 73, 112009] have $M(\sigma_1) \simeq 500$ MeV, $M(\sigma_2) \simeq 1037$ MeV

$D^0 \to \pi^0\pi^+\pi^-$: $\rho^\pm, \rho^0$ [D. Cronin-Hennessy +, PR D **72**, 031102]

$D^+ \to \pi^-\pi^+\pi^+$: scalars important [G. Bonvicini +, PR D **76**, 012001]

$D^0 \to K^+K^-\pi^0$: $K\pi$ S-wave needed [C. Cawlfield +, PR D **74**]

$D^0 \to K_S\eta\pi^0$: $a_0(980)$, $K^*(892)$ seen [P. Rubin +, PRL **93**, 111801]

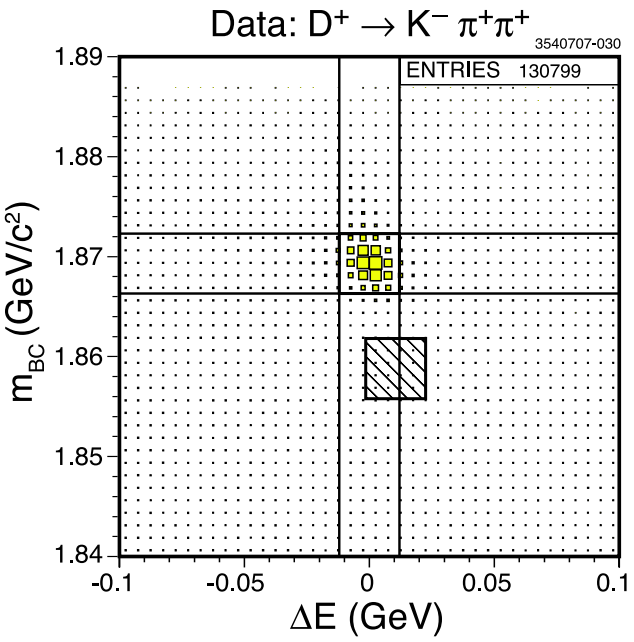
$D^+ \to K^-K^+\pi^+$: $K^-\pi^+$ S-wave [e.g., LASS amplitude] important;
$D^0 \to K_S\pi^0\pi^0$: $K^*(892)$, $f_0(980)$, $f_0(1370)$, $K^*(1680)$ [P. Naik, L. Zhang, and N. Lowrey, HADRON 07 (arXiv:0712.2266)]

$\chi_{c1} \to \eta\pi^+\pi^-$: $a_0(980)$, $f_2(1270)$, $\sigma(500)$; $K^+K^-\pi^0$, $\pi^\pm K^\mp K_S$: $K^*(892)$, $K_0^*(1430)$, $K_2^*(1430)$, $a_0(980)$ [S. B. Athar +, PR D **75**]

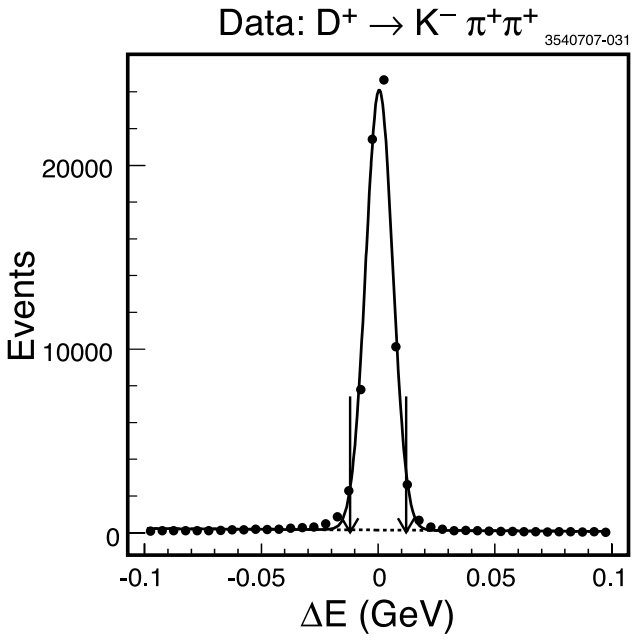
CLEAN $D^+ \to K^-\pi^+\pi^+$ SIGNAL

Select D^+ candidates in $K^-\pi^+\pi^+$ on the basis of energy conservation and beam-constrained mass: $\Delta E \equiv E_D - E_{\rm beam}$; $m_{BC} = \sqrt{E^2_{\rm beam} - P^2_D}$

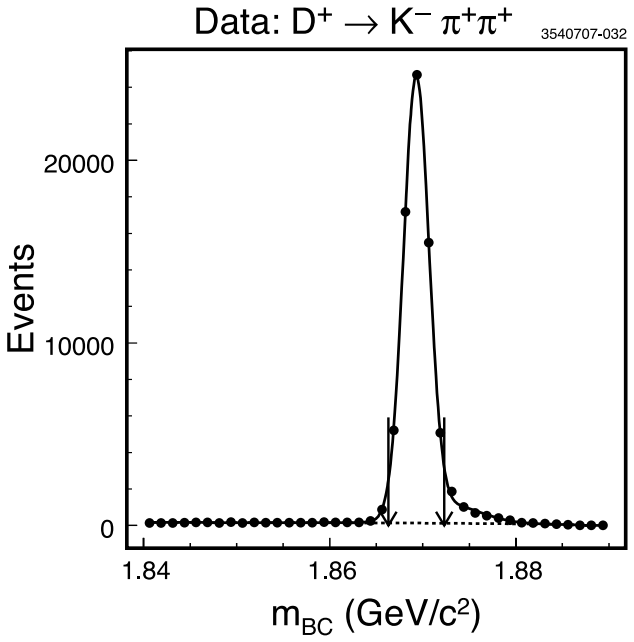
m_{BC} vs. ΔE



Signal in ΔE



Signal in m_{BC}

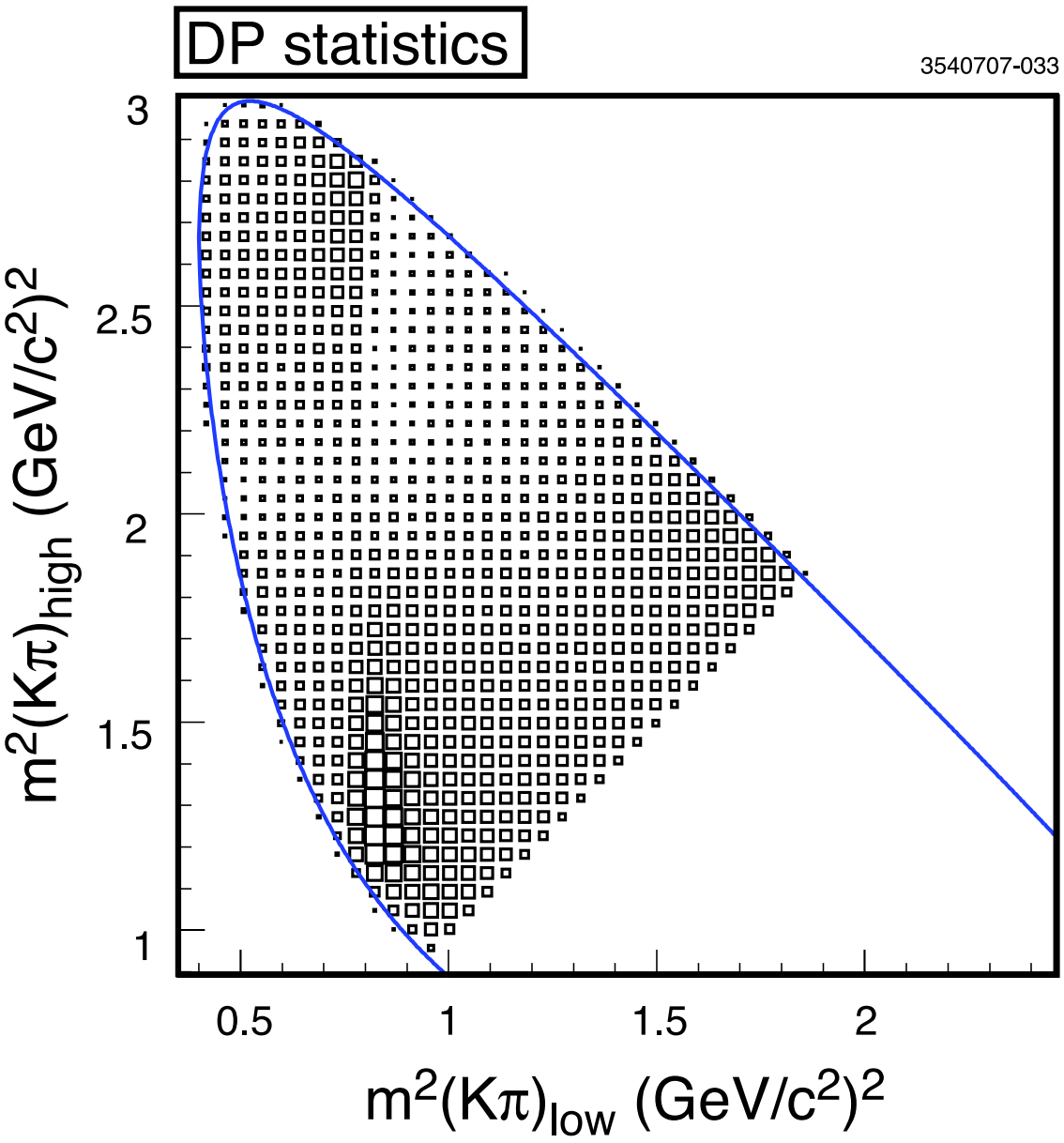


CLEO PRELIMINARY: CLEO-CONF 07-01, arXiv: 0707.3060

Colored events lie in "signal box"; diagonal shading indicates "background box"

Largest previous sample is from Fermilab E791 ($\sim 15,000$ events): E. M. Aitala *et al.*, PRL **89**, 121801 (2002); PR D **73**, 032004 (2006); **74**, 059901(E) (2006)

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



Note enhancements on opposite sides of $K^*(892)$ for high and low $M^2(K\pi)_{\rm high}$

These indicate interference with an amplitude of opposite parity to $K^*(892)$ (likely S-wave)

Several fits all have prominent low-$M(K\pi)$ S-wave amplitude

Quasi-model-independent partial wave analysis (QMIPWA; cf. E791) has κ-like behavior, overall phase displacement

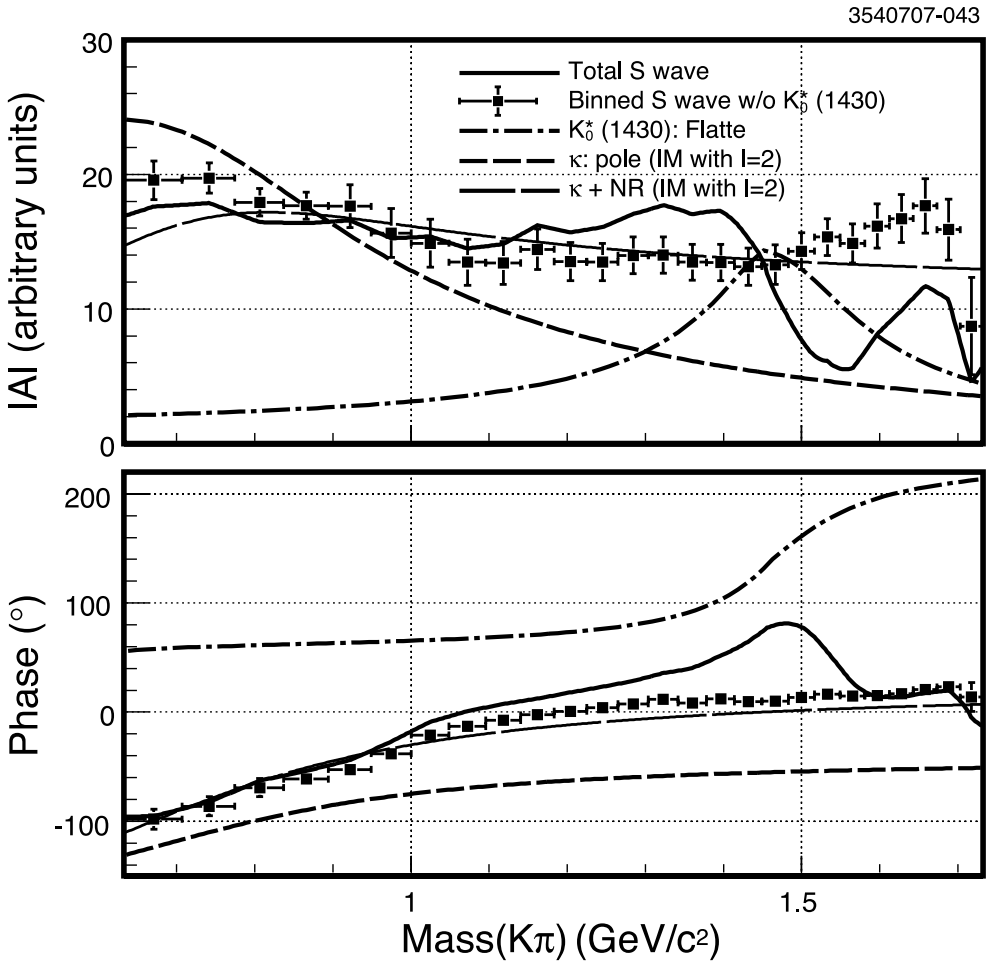
Plot shows 281 pb^{-1} of data at $\psi(3770)$; new analysis based on 572 pb^{-1} appearing soon

$K^*(892)$ $\Uparrow$ CLEO PRELIMINARY: CLEO-CONF 07-01, arXiv: 0707.3060

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

This is from arXiv:0707.3060 (281 pb^{-1}); 572 pb^{-1} similar

67086 candidate events; 1.1% background fraction; $> 2\times$ soon



κ pole position depends on Breit-Wigner width Γ: energy-dependent or fixed

QMIPWA: 26 $M^2(K\pi)$ bins (0.4–3.0 GeV^2) each for S-wave amplitude and phase

Resembles κ + NR amplitude

Contribution from $I_{\pi\pi} = 2$ amplitude ($\pi^+\pi^+ \to \rho^+\rho^+$?) required for good fit

S-wave phase does not go through 90° exactly at $M(\kappa)$

With κ (complex pole), $\kappa\pi^+$ fit fraction is $\sim 20\%$ CLEO PRELIMINARY

$K\eta'$ THRESHOLD

Scalar strange resonances couple much more strongly to $K\eta'$ than to $K\eta$: Lipkin, PRL **46**, 1307 (1981); PL B **254**, 247 (1991)

Approximate mixing: $\eta \simeq (u\bar{u}+d\bar{d}-s\bar{s})/\sqrt{3}$; $\eta' \simeq (u\bar{u}+d\bar{d}+2s\bar{s})/\sqrt{6}$

In this limit, contributions of strange and nonstrange quarks in η cancel exactly in $K_0^* \to K\eta$ while they add constructively in $K_0^* \to K\eta'$

This is the same physics that favors $B \to K\eta'$ over $B \to K\eta$

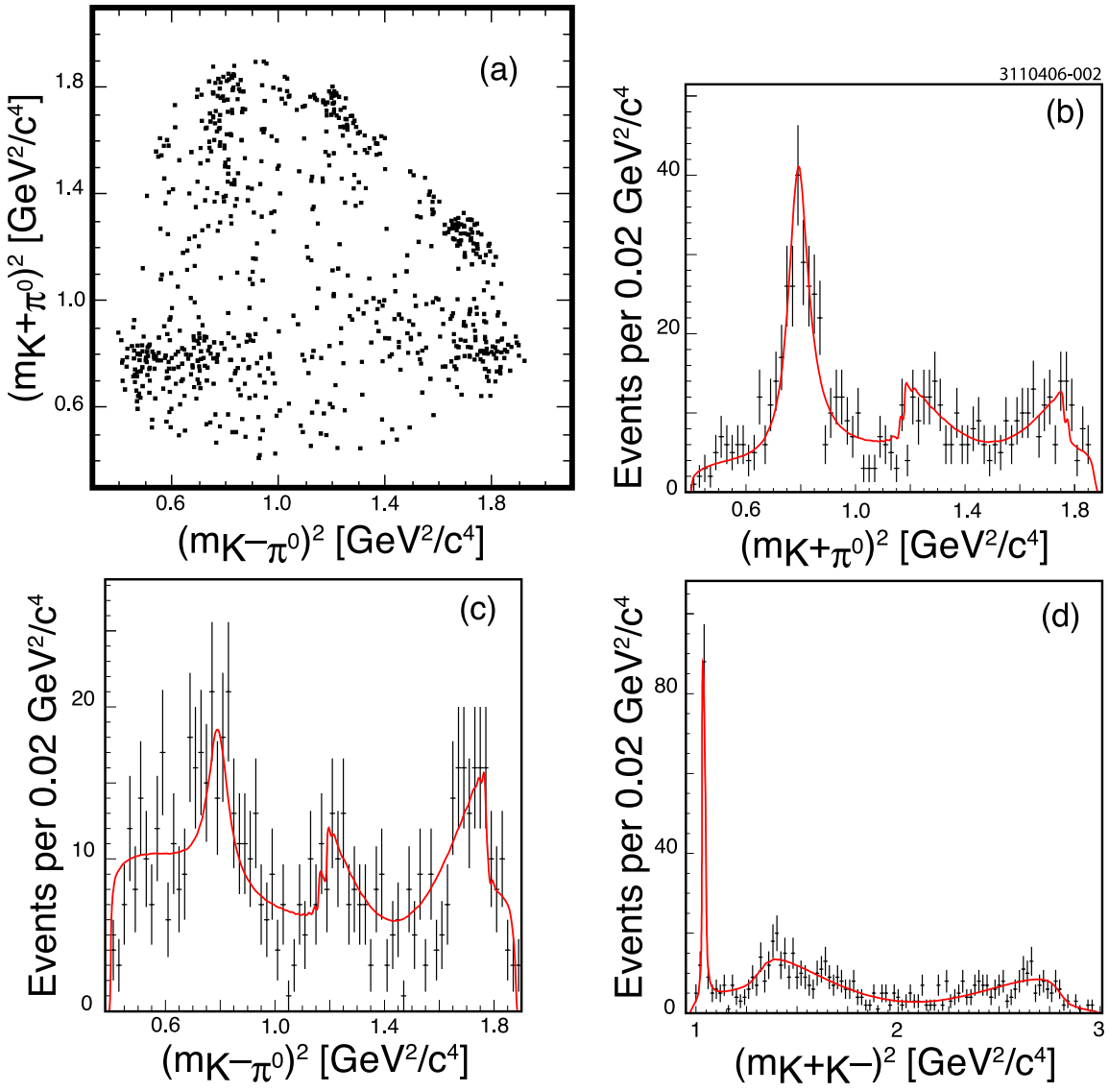
The pattern would be reversed for vector strange resonances

Thus $K_0^*(1430)$ should be strongly associated with nearby $K\eta'$ threshold; $K\pi$ S wave should become inelastic only above this

Expect a zero (Ramsauer-Townsend effect!) in scalar $I = 1/2$ $K\pi$ amplitude below $K_0^*(1430)$ if a low-mass κ exists

CLEO, E791 $K_0^*(1430)$ heavier ($M \simeq 1460$ MeV), narrower ($\Gamma \simeq 175$ MeV) than PDG 2006 (1414±6 MeV, 290±21 MeV, based mainly on elastic $K\pi$ [LASS]). BES [PR D **72**, 092002, $\chi_{c0} \to \pi^+\pi^-K^+K^-$]: 1455±20±15 MeV, $270\pm45^{+35}_{-30}$ MeV

$D^0 \to K^+K^-\pi^0$ (CLEO PR D 74, 031108)



Opposite sign of interference between $K^{*\pm}$ and large S wave (fit fraction 20–40%) visible in Dalitz plot

This sample was based on 9.0 fb^{-1} at 10.58 GeV (CLEO III); 735 $D^0 \to K^+K^-\pi^0$ cands.

Opposite relative phase for $D^0 \to (K^{*+}K^-,\ K^{*-}K^+)$

$K\pi$ S wave appreciable but could not tell if resonant

Could dip in $M(K\pi)$ around 1 GeV be a Ramsauer-Townsend zero between a κ and $K_0^*(1430)$?

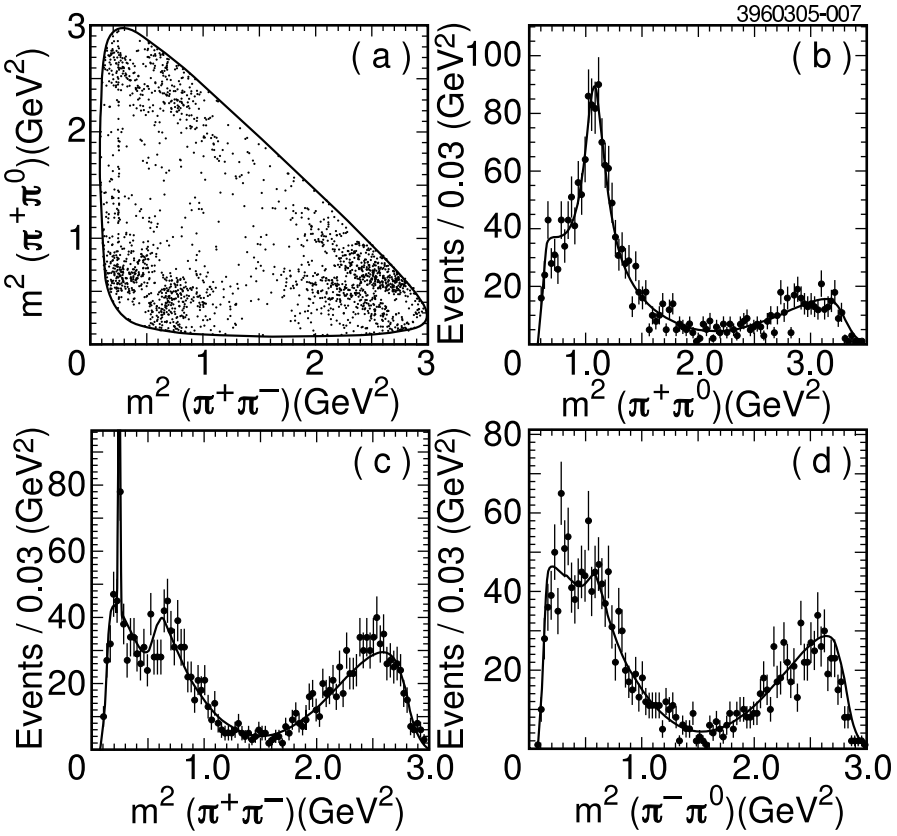
Never did $\Uparrow$ fit a curious dip in $M(K\pi)$

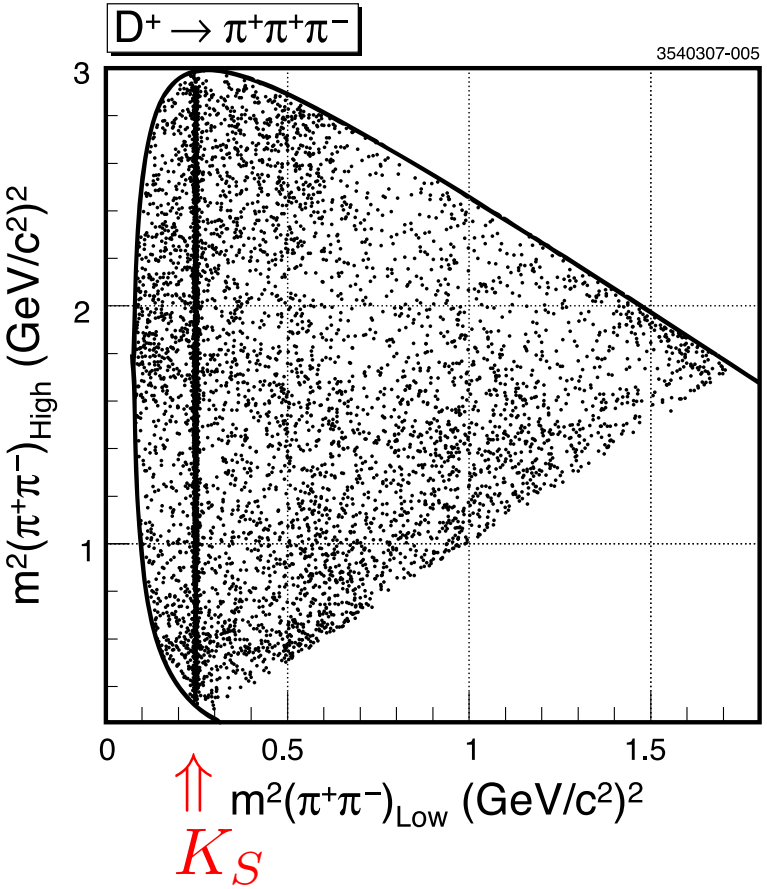
BaBar has $> 11,000$ events for 385 fb^{-1}: PR D **76**, 011102(R) (2007) (no dip)

$D^0 \to \pi^+\pi^-\pi^0$ **VS** $D^+ \to \pi^-\pi^+\pi^+$

CLEO $D^0 \to \pi^+\pi^-\pi^0$ (PR D **72**, 031102, 9 fb^{-1} nr 10 GeV)

CLEO $D^+ \to \pi^-\pi^+\pi^+$ (PR D **76**, 012001, 281 pb^{-1})



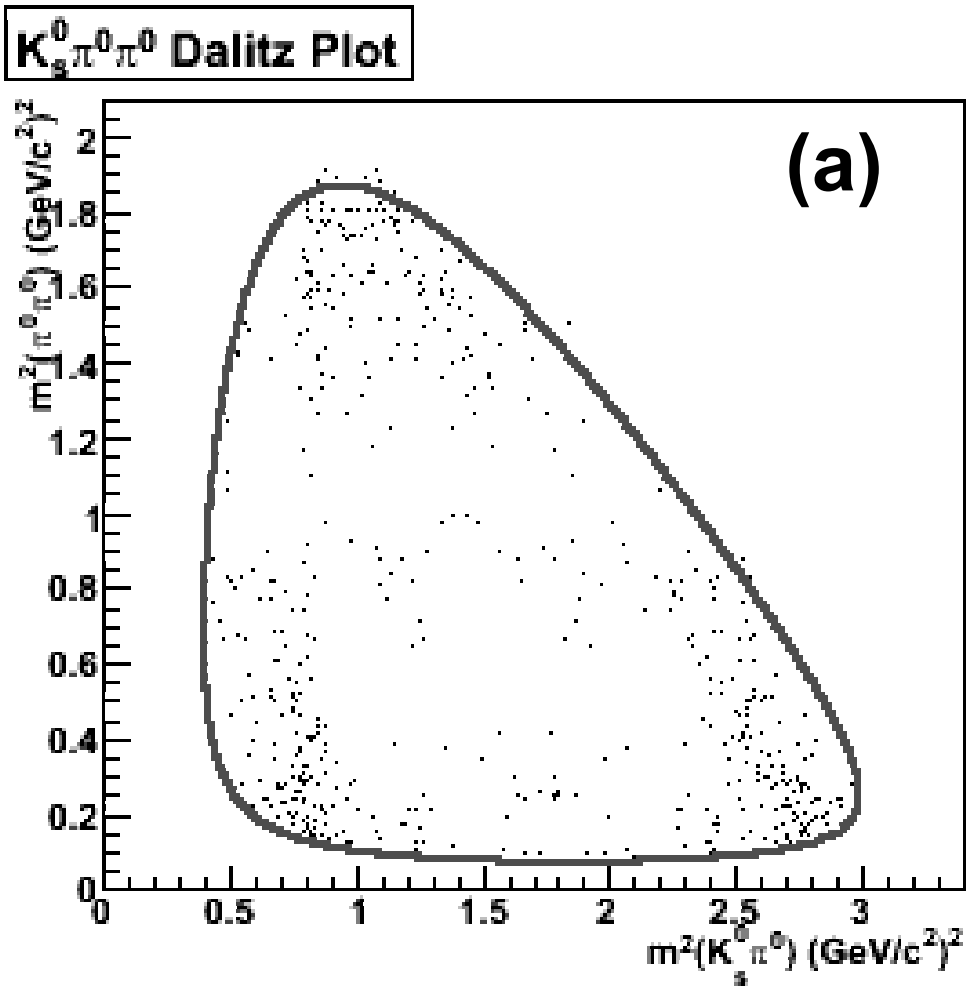


$D^0 \to \pi^+\pi^-\pi^0$ dominated by $\rho^\pm, \rho^0$ intermediate states while $D^+ \to \pi^-\pi^+\pi^+$ can have only ρ^0, not produced by charged weak current

Scalar fit fraction for D^0 decay is $< 4\%$; for D^+ it is 40–80%

$D^0 \to K_S\pi^0\pi^0$

CLEO PRELIMINARY: HADRON 07 (arXiv:0712:2266)



$m^2(\pi^0\pi^0)$ vs. $m^2(K_S\pi^0)$ (GeV^2)

Data sample of 281 pb^{-1} taken at $\psi(3770)$

Final sample will be $3\times$ this

Components of Dalitz plot fit (with Fit Fractions:)

$K^*(892)$: 0.542$\pm$0.054$\pm$0.030$\pm$0.053

$f_0(980)$: 0.090$\pm$0.032$\pm$0.009$\pm$0.027

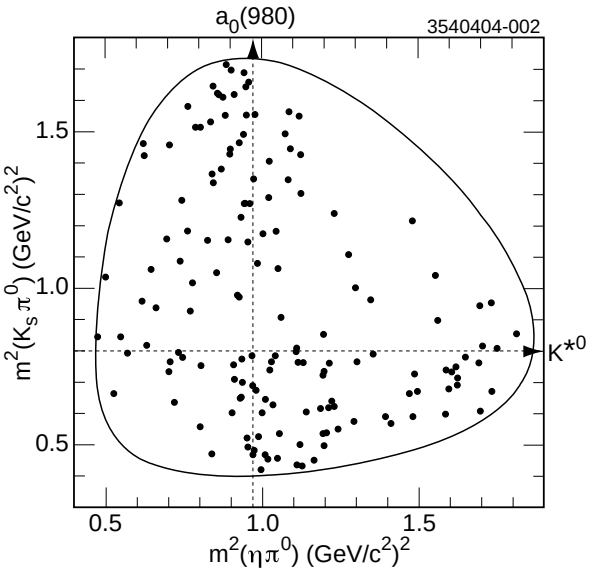
$f_0(1370)$: 0.238$\pm$0.071$\pm$0.047$\pm$0.086

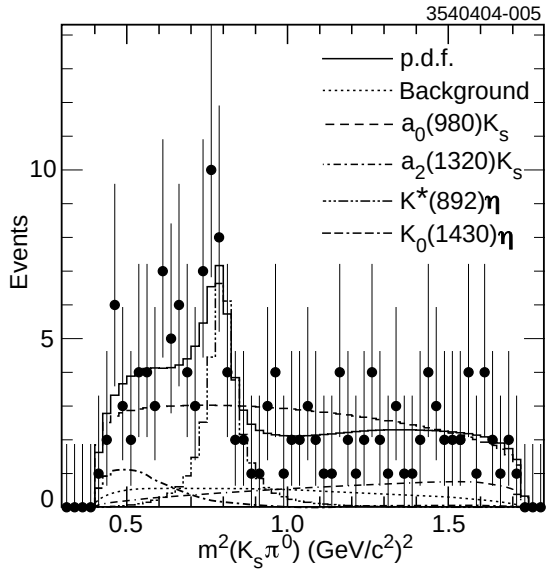
$K^*(1680)$: 0.114$\pm$0.027$\pm$0.021$\pm$0.032

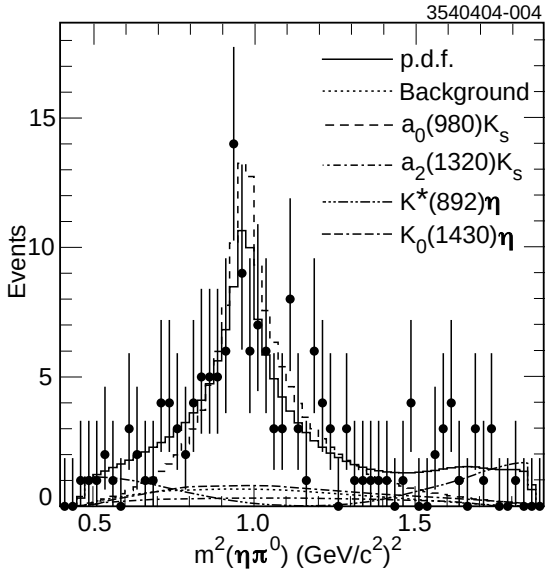
No apparent low-mass σ

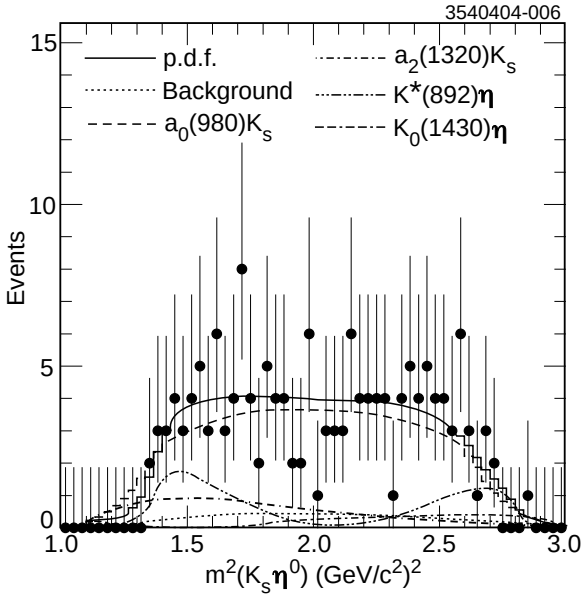
Potential source of information on $I_{\pi\pi} = 0$ resonances

$D^0 \to K_S\eta\pi^0$









Using 9.0 fb^{-1} near $\Upsilon(4S)$

Signal yield 155 ± 22 events

$a_0(980)K_S$ fit fraction $\mathcal{O}(1)$

$K^*(892)\eta$ f.f.$\simeq 30\%$

Would be interesting to compare $D^0 \to K_S a_0^0$ with $D^0 \to K^- a_0^+$, $D^+ \to K_S a_0^+$

Related processes might be $D^0 \to \bar{\kappa}^0\pi^0$, $D^0 \to \kappa^-\pi^+$, $D^+ \to \bar{\kappa}^0\pi^+$ if κ and a_0 in same SU(3) multiplet

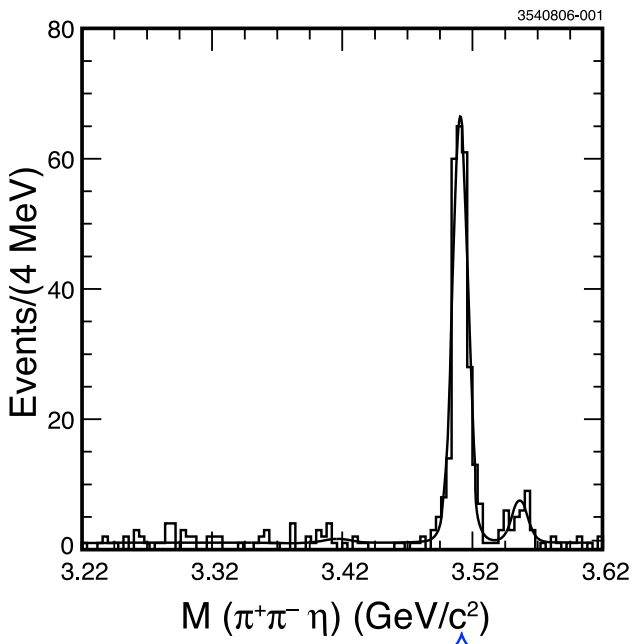
Full $\psi(3770)$ data: 1200 $K_S\pi^0\eta$, 8000 $K^-\pi^+\eta$, 5000 $K_S\pi^+\eta$ events

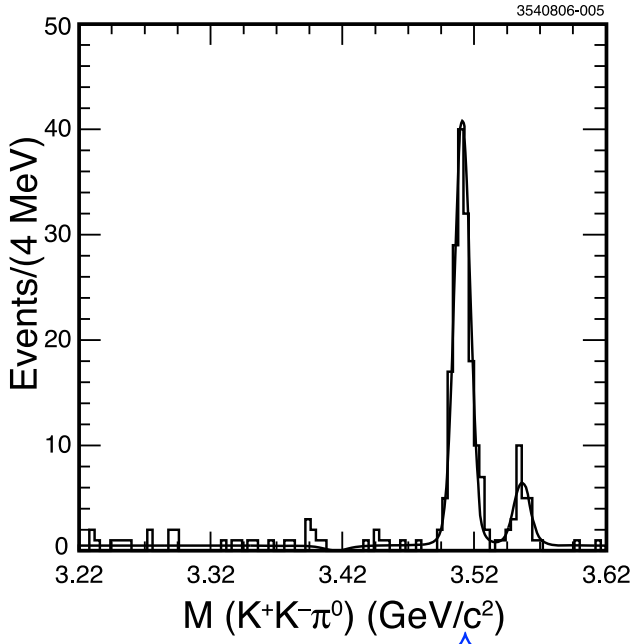
P. Rubin *et al.* [CLEO], PRL **93**, 111801 (2004)

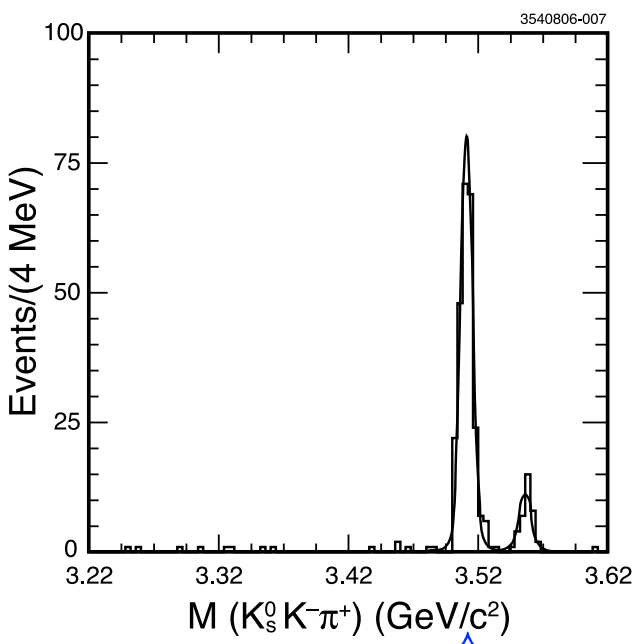
THREE-BODY χ_c DECAYS

S. B. Athar + [CLEO], PR D **75**, 032002 (2007): 3 M $\psi(2S) \to \gamma\chi_c$

Reconstruct exclusive final states; 24.5 M more $\psi(2S)$ under analysis







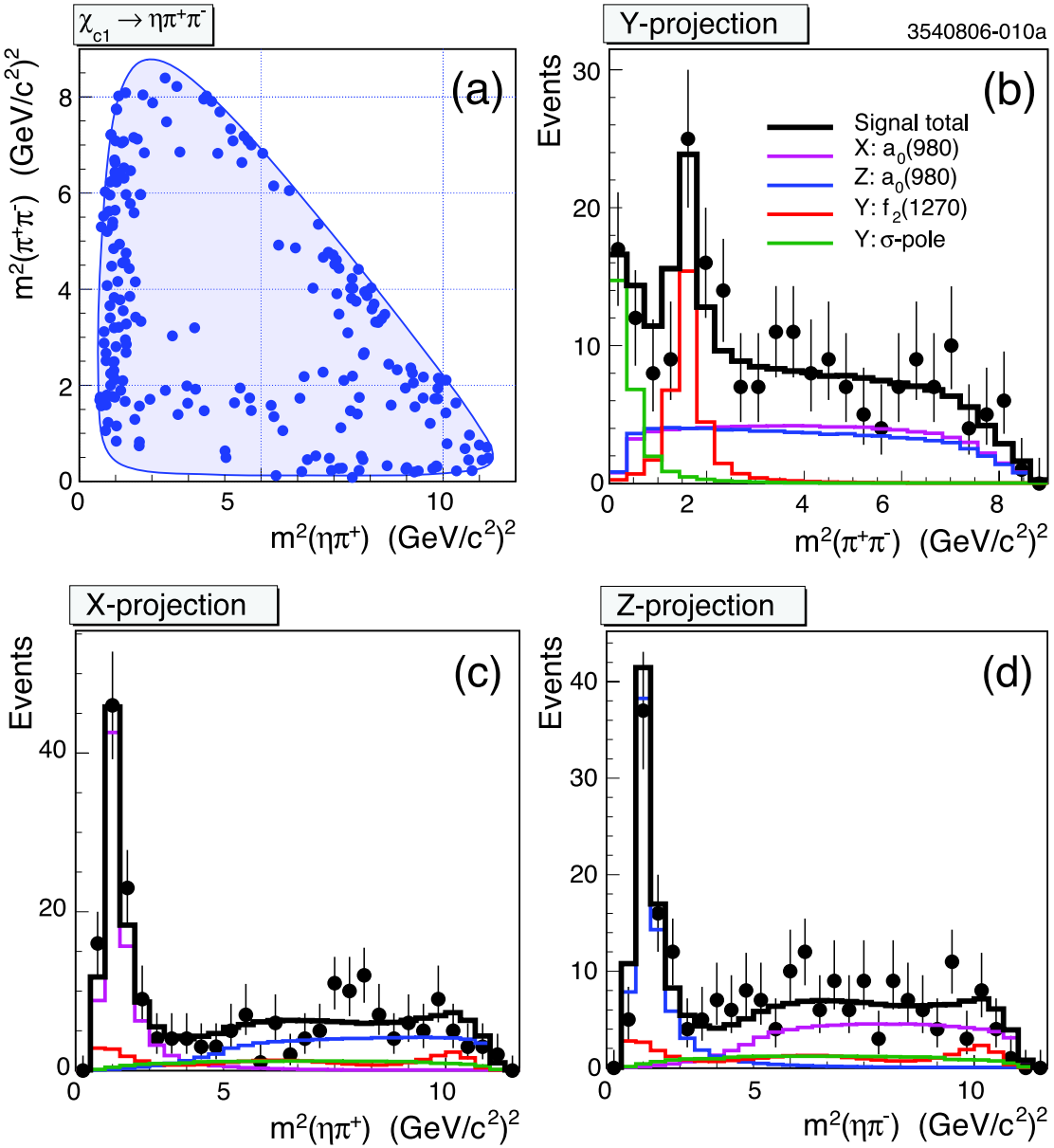
χ_{c1}: 255^{+17}_{-16} 157 ± 13 249 ± 16

Enough χ_{c1} in these channels for Dalitz plot analyses

$I_{\pi\pi} = 0$ in $\eta\pi^+\pi^-$; $I_{K\bar{K}} = 1$ in $K\bar{K}\pi$ modes

No χ_{c1} polarization or interference between resonances considered

$\chi_{c1} \to \eta\pi^+\pi^-$



Fit fractions (%):

$a_0(980)^{\pm}\pi^{\mp}$: 75.1±3.5±4.3

$f_2(1270)\eta$: 14.4±3.1±1.9

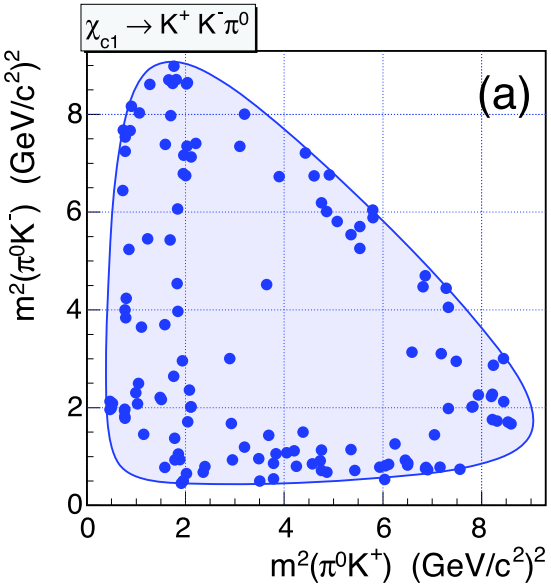
$\sigma\eta$: 10.5±2.4±1.2

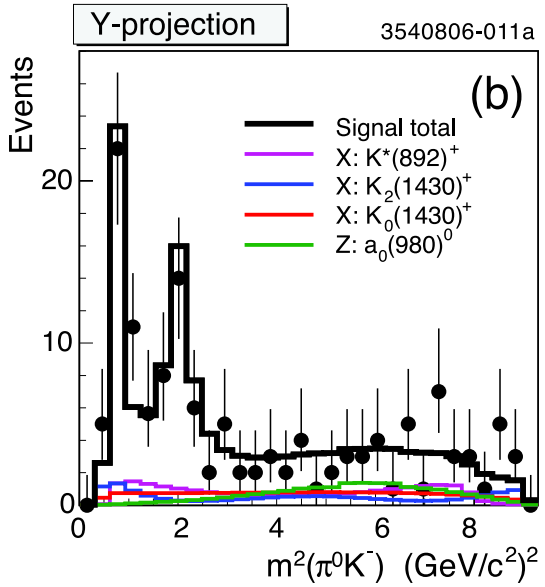
σ parametrized by complex pole at (511±28–i102±50) MeV

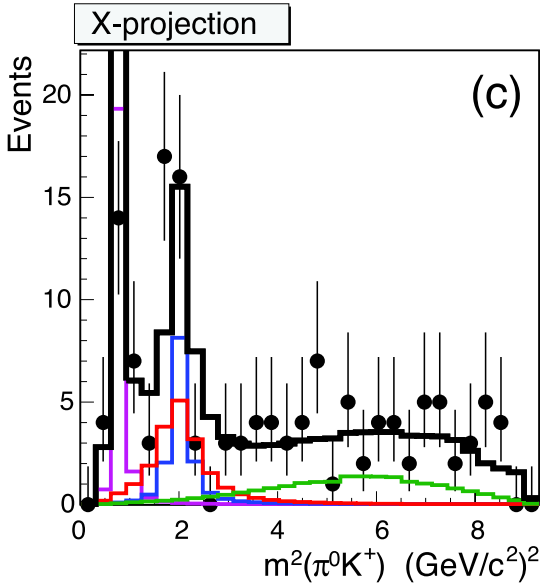
Low-mass $\pi\pi$ enhancement visible in Dalitz plot and $m^2(\pi^+\pi^-)$ projection

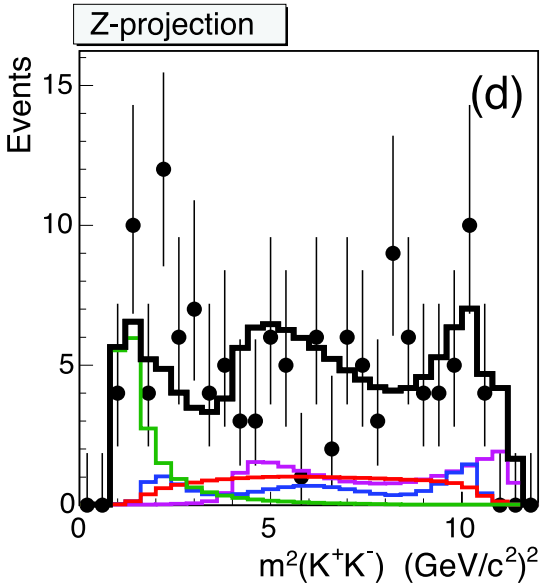
Flavor SU(3) would imply that $\chi_{c1} \to \kappa\bar{K}$ should be visible if $\chi_{c1} \to a_0\pi$ is so prominent

$\chi_{c1} \to K^+K^-\pi^0$









Fit fractions (%):

$K^*(892)\bar{K}$: 31.2±2.2±1.7

$K_0^*(1430)\bar{K}$: 30.4±3.5±3.7

$K_2^*(1430)\bar{K}$: 23.1±3.4±7.1

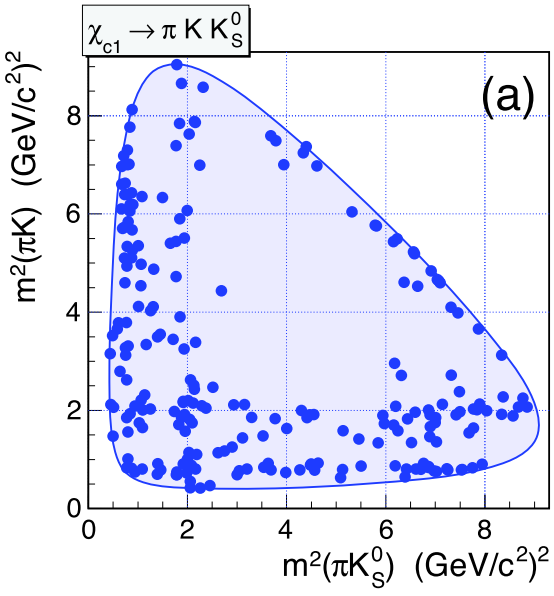
$a_0(980)\pi$: 15.1±2.7±1.5

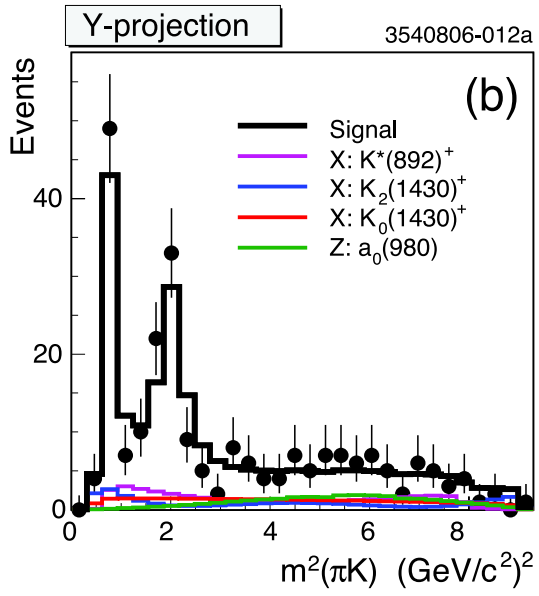
$K^+K^-\pi^0$, $K_SK^\pm\pi^\mp$ channels are related by isospin and have been combined

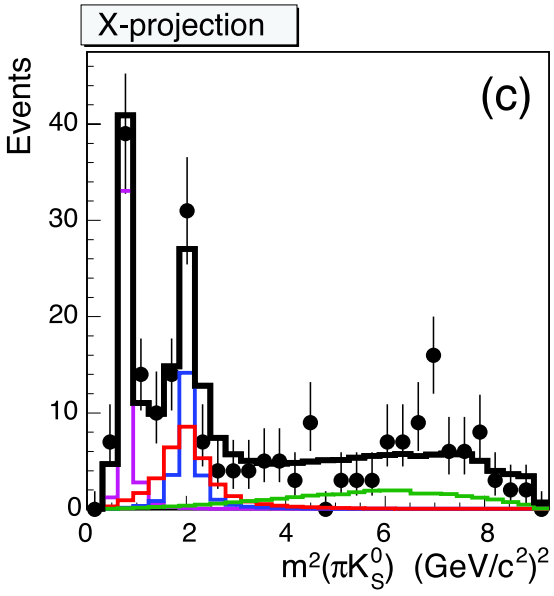
κ or nonresonant $K\pi$ S-wave doesn't improve fit quality

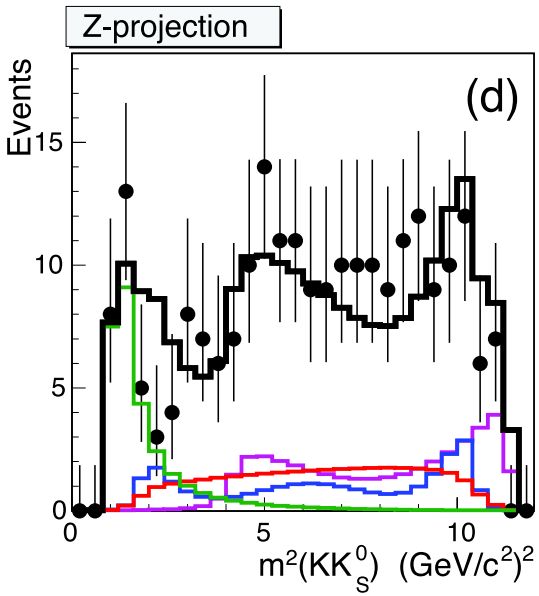
Interference might show low-mass $K\pi$ S wave as in $D^+ \to K^-\pi^+e^+\nu_e$ (CLEO, PR D **74**, 052004 (2006)

$\chi_{c1} \to K_S K^{\pm}\pi^{\mp}$









Expect twice as many events as in $K^+K^-\pi^0$ (neglecting efficiency differences)

Complete analysis of full $\psi(2S)$ data set should account for χ_{c1} polarization, interference between resonances

Expect ~ 2000 $\chi_{c1} \to \eta\pi^+\pi^-$; should permit good determination of "σ" properties

Many other three-body χ_{cJ} final states reconstructed in full $\psi(2S)$ radiative decay sample

CONCLUSIONS

Charmed meson and charmonium decays can be a rich source of information on scalar resonances between pairs of pseudoscalar mesons

Data from the CLEO III (with silicon) and CLEO-c (with inner drift chamber) detectors show the potential of these channels

The $a_0(980)$ and $f_0(980)$ are without question in CLEO data; $\kappa(800)$ and $\sigma(600)$ make sporadic appearances

σ, κ inferred M, Γ depend on production channels, line shape models

Bose statistics make σ $(I_{\pi\pi} = 0)$ easier to isolate than κ $(I_{K\pi} = 1/2)$

CLEO needs a σ in describing $\tau \to \pi\pi^0\pi^0\nu$: PR D **61**, 012002

Tests of whether the $a_0(980)$ and $f_0(980)$ belong to a nonet with $\kappa(800)$ and $\sigma(600)$ are available in charmonium (e.g., χ_{c1}) decays