D DALITZ PLOT RESULTS

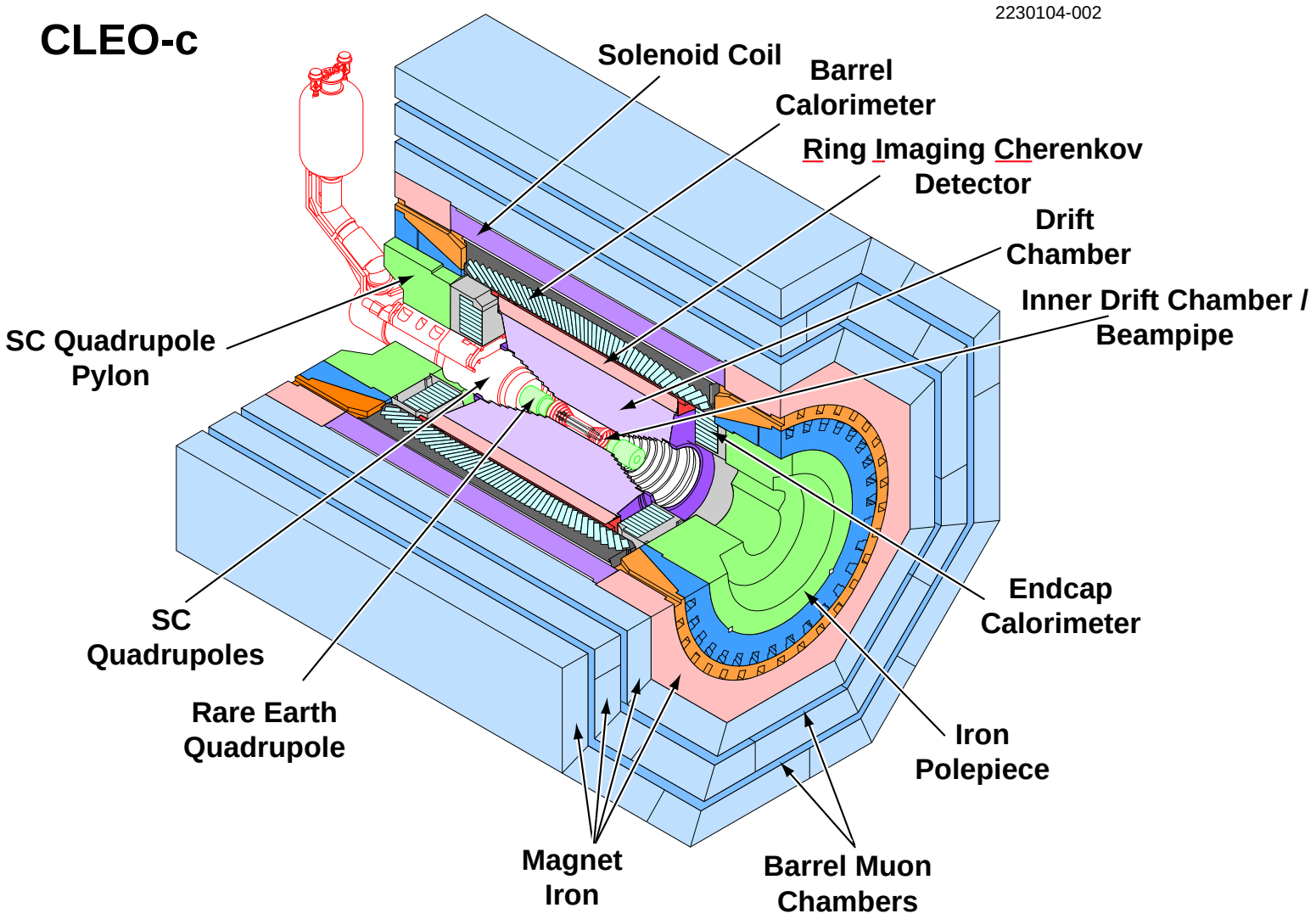
J. Rosner (U. Chicago) – CLEO – Beauty 2005 – Perugia, June 20, 2005

$B \to D_{\rm CP} K$ decays are one source of information on the weak phase γ.

For D modes such as $K_S \pi^+ \pi^-$, $\pi^+ \pi^- \pi^0$, and $K^+ K^- \pi^0$, Dalitz plots yield information on CP-eigenstate and flavor-eigenstate modes and their relative phases.

- Brief review of $B \to D_{\rm CP} K$ decays and how they determine γ
- Dalitz plot for the decay $D^0 \to K^+ K^- \pi^0$
- Dalitz plot for the decay $D^0 \to K_S \pi^+ \pi^-$
- Dalitz plot for the decay $D^0 \to \pi^+ \pi^- \pi^0$
- Remaining steps

THE CLEO-c DETECTOR



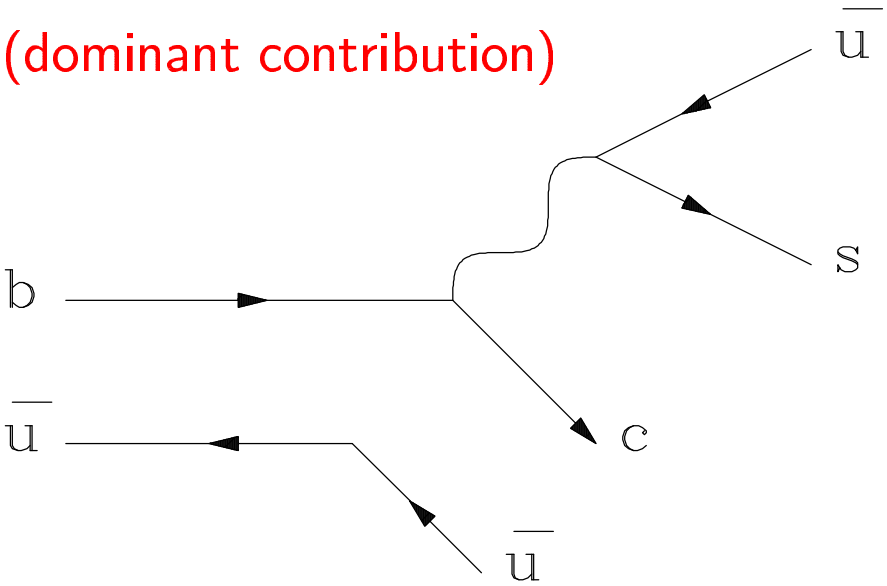
RICH for particle ID. Charged particle resolution $\Delta p/p \simeq 0.6\%$ at 1 GeV/c;
CsI calorimeter resolution 2.2% for $E_\gamma = 1$ GeV and 5% at 100 MeV.
Inner drift chamber: all stereo.

γ FROM $B \to DK$ DECAYS

Bigi-Sanda PL B **211**, 213 (1988): Interfere $b \to c\bar{u}s$ (real) and $b \to u\bar{c}s$ ($\sim e^{-i\gamma}$) subprocesses in $B^- \to D^0 K^-$ and $B^- \to \overline{D}^0 K^-$, respectively by studying common decay products of D^0 and $\overline{D}^0$. Gronau-Wyler PL B **265**, 172 (1991): neutral D CP eigenstates. Atwood-Dunietz-Soni PR D **63**, 036002 (2001): DCS modes.

$B^- \to D^0 K^-$

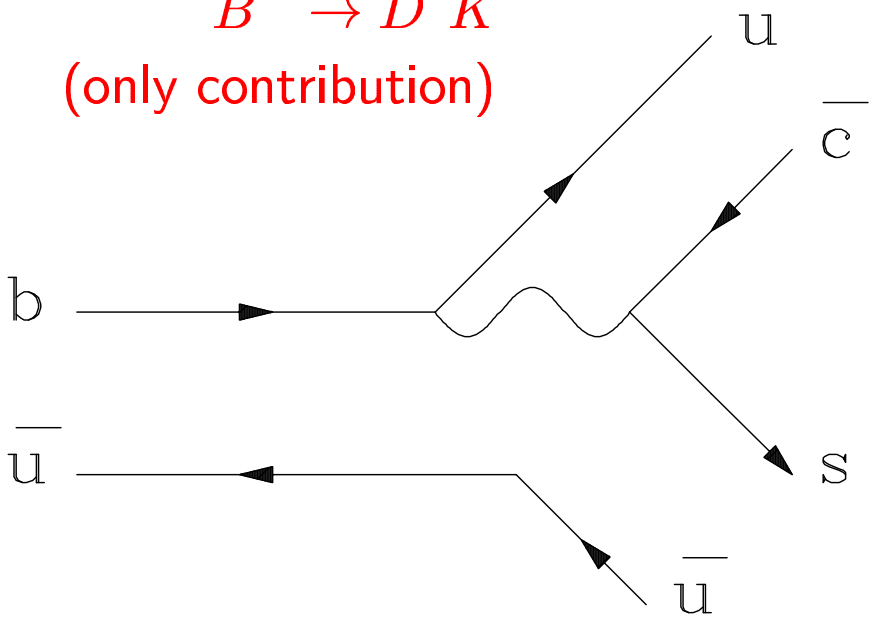
(dominant contribution)



$\sim V_{cb}V_{us}^* = A\lambda^3$

$B^- \to \overline{D}^0 K^-$

(only contribution)



$\sim V_{ub}V_{cs}^* r = A\lambda^3 e^{-i\gamma} r$

Here $r < 1$ is an amplitude ratio, small because of color and form factor suppression.

Can observe interference if final states are CP eigenstates $D_{1,2} = (D^0 \pm \overline{D}^0)/\sqrt{2}$.

$D \to KK^*$ AND USE IN B DECAYS

Grossman, Ligeti, Soffer PR D **67**, 071301(R) (2003): Measure the four rates $B^\pm \to K^\pm(K^{*+}K^-)_D$ and $B^\pm \to K^\pm(K^{*-}K^+)_D$. Provides information on γ if relative (strong) phase between $D^0 \to K^{*+}K^-$ and $D^0 \to K^{*-}K^+$ is known.

D. Suprun and J. Rosner PR D **68**, 054010 (2003): Learn this relative phase from the study of $D^0 \to K^+K^-\pi^0$, where both final states occur and interfere with one another in the region where K^{*+} and K^{*-} bands cross on the Dalitz plot.

CLEO has a sample of $D^0 \to K^+K^-\pi^0$ decays which shows this interference clearly.

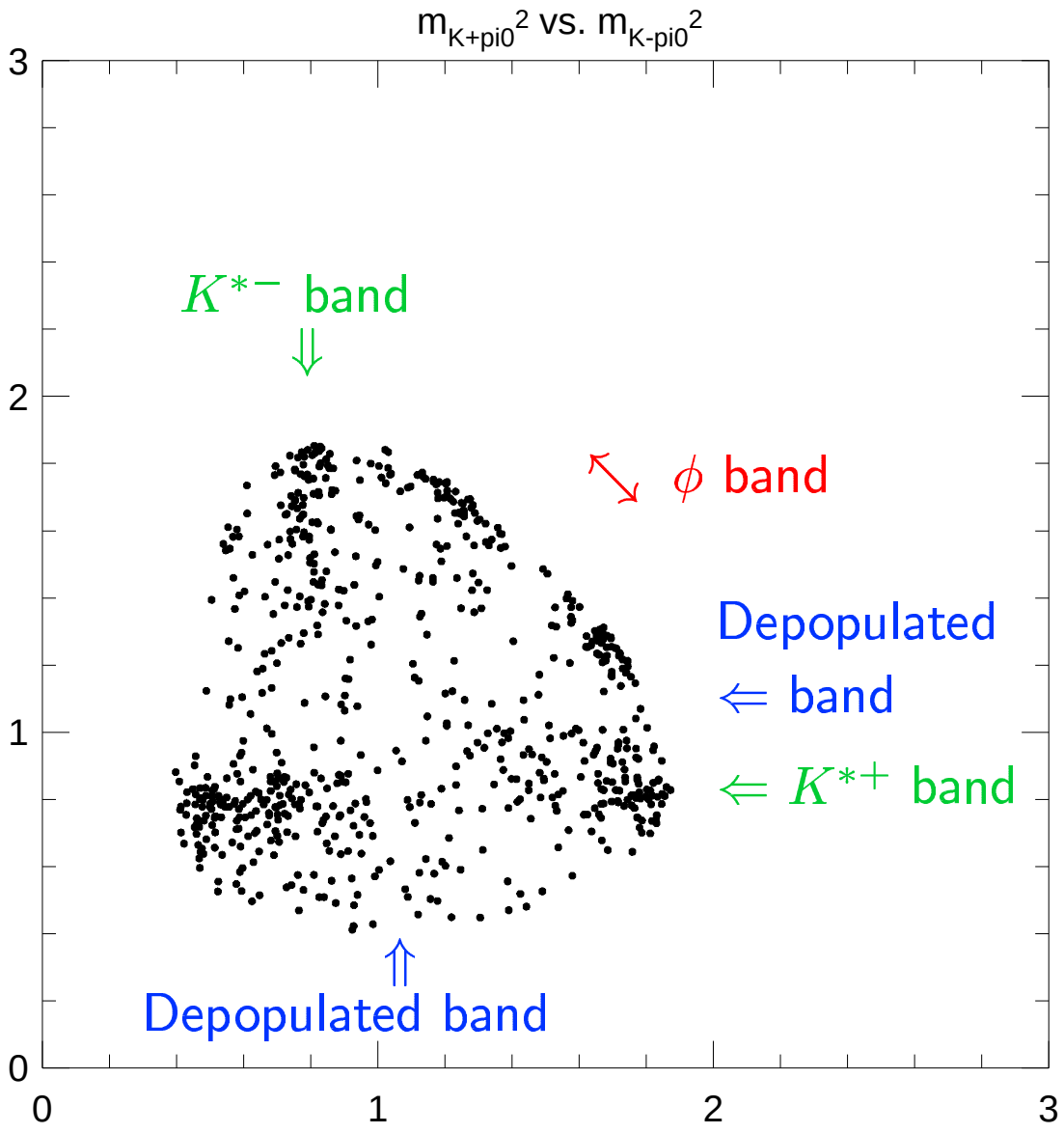
Paras Naik, Spring 2005 APS Meeting, Tampa: 9 fb^{-1} accumulated at CLEO III (predecessor to CLEO-c with inner silicon vertex detector instead of inner drift chamber).

K^{*+} and K^{*-} bands found to interfere destructively where they cross. Also can see effects of interference with S-wave $K\pi$.

See deficit in $M(K\pi)$ projection above $M[K^*(892)]$ which is hard to fit using known resonances.

$D^0 \to K^+K^-\pi^0$ DALITZ PLOT

Paras Naik, Spring 2005 APS Meeting, Tampa: CLEO III, 689 events (9.0 fb^{-1})



Data at or near $\Upsilon(4S)$

Flavor tagged by $D^{*+} \to \pi^+ D^0$

K^{*+} band $\simeq$ 3–4 $\times$ K^{*-} band
(reflects $f_{K^*} > f_K$ in part)

Diagonal band at upper right:
ϕ (fit fraction $\simeq 10\%$)

Note opposite signs of interference with background on low sides of K^{*+} and K^{*-} bands

Fits with Breit-Wigner and K-matrix forms are in progress

$D^0 \to K^0_S\pi^+\pi^-$ AND B DECAYS

Giri, Grossman, Soffer, Zupan PR D bf 68, 054018 (2003): Determine γ using $B^\pm \to DK^\pm$ followed by (e.g.) $D \to K_S\pi^+\pi^-$, $K_SK^+K^-$, $K_S\pi^+\pi^-\pi^0$.

Uses interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$ subprocesses.

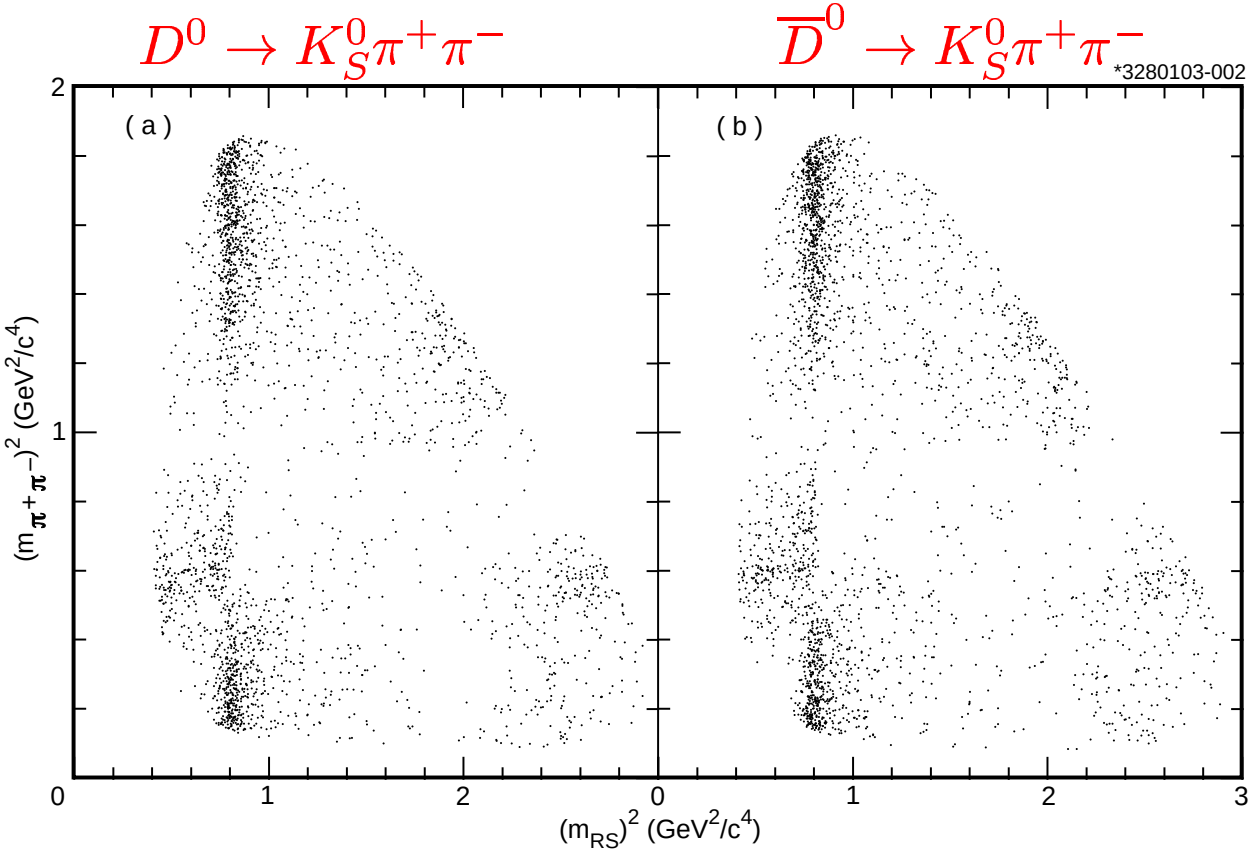
Advantages:

- Resonances $\Rightarrow$ large strong phases, useful for direct CP asymmetries.
- Use only Cabibbo-favored D decay modes.
- Can consider final states involving only charged particles (e.g., $K_S\pi^+\pi^-$).

Method has been utilized by Belle [PR D **70**, 072003 (2004), hep-ex/0406067; hep-ex/0411049; hep-ex/0504013: combined modes] $\Rightarrow \phi_3[=\gamma] = (68^{+14}_{-15} \pm 13 \pm 11)^\circ$ based on 275 M $B\bar{B}$ and by BaBar [hep-ex/0408088] $\Rightarrow \gamma = (70 \pm 26 \pm 10 \pm 10)^\circ$ based on 227 M $B\bar{B}$. Last error: D decay modeling. CLEO can help.

CLEO $D^0 \to K^0_S\pi^+\pi^-$ DALITZ PLOT

CLEO D. M. Asner *et al.*, PR D **70**, 091101(R) (2004): 9.0 fb^{-1} at CLEO II.V



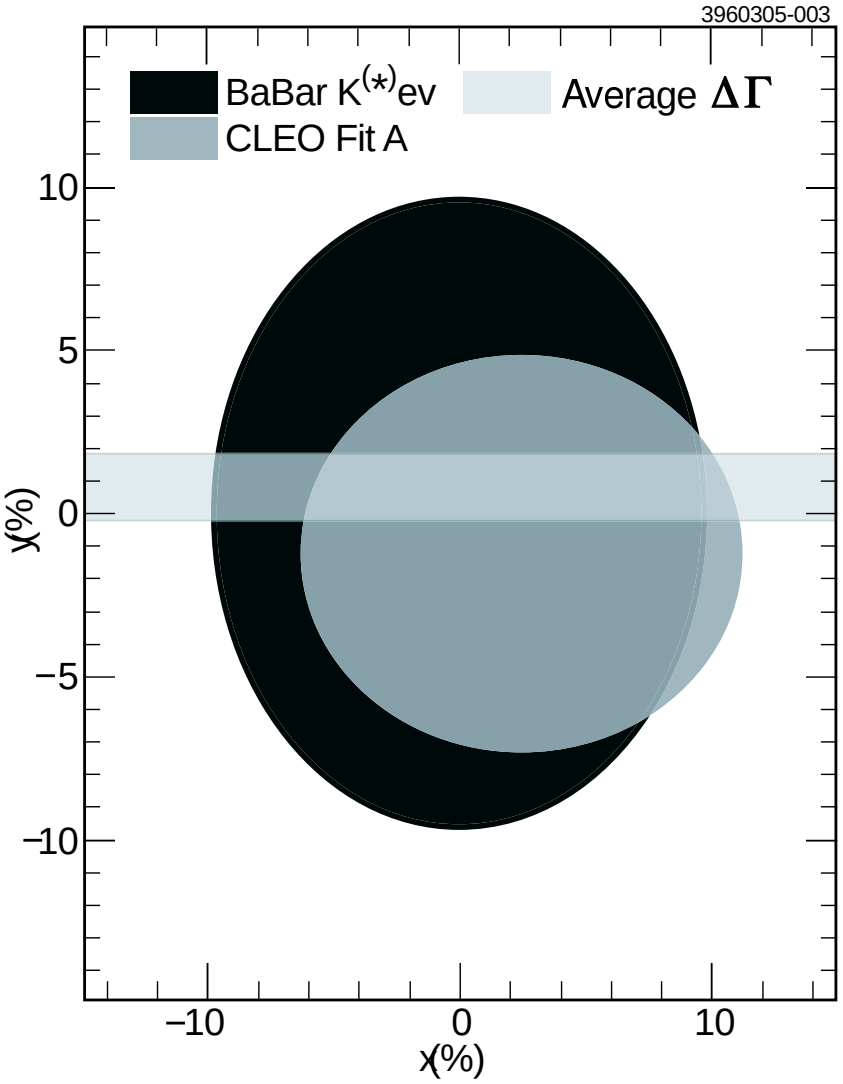
Doubly-Cabibbo-suppressed $D^0 \to K^{*+}\pi^-$ mode visible through destructive interference with Cabibbo-favored $D^0 \to K^{*-}\pi^+$ (right-sign or "RS").

Dominant fit fractions $K^{*-}(892)\pi^+$ ($\sim 2/3$), $\overline{K}^0\rho^0$ ($\sim 27\%$). Latter is CP-odd for $\overline{K}^0$ detected as K^0_S. CP-even modes $K^0_S f_2(1270)$, $K^0_S f_0(980, 1370)$ total $\sim 1/3$.

$D^0 \to K^0_S\pi^+\pi^-$ AND MIXING

CLEO D. M. Asner *et al.*, CLNS 05/1908, hep-ex/0503045: $\surd$ PRD.

Search for D^0–$\overline{D}^0$ mixing in Dalitz plot analysis of $D^0 \to K^0_S\pi^+\pi^-$.



$\Gamma \equiv \frac{\Gamma_1+\Gamma_2}{2}$, $x \equiv \frac{m_1-m_2}{\Gamma}$, $y \equiv \frac{\Gamma_1-\Gamma_2}{2}$

Mass eigenstates evolve in time as

$|D_{1,2}(t)\rangle = |D_{1,2}(0)\rangle e^{[-i(m_{1,2}-\frac{i\Gamma_{1,2}}{2})t]}$

Tag $D^0(t=0)$ flavor: $D^{*+} \to \pi^+ D^0$

Time-dependent fit to Dalitz plot sensitive to D^0–$\overline{D}^0$ mixing

CLEO 95% c.l.: moon-shaped region

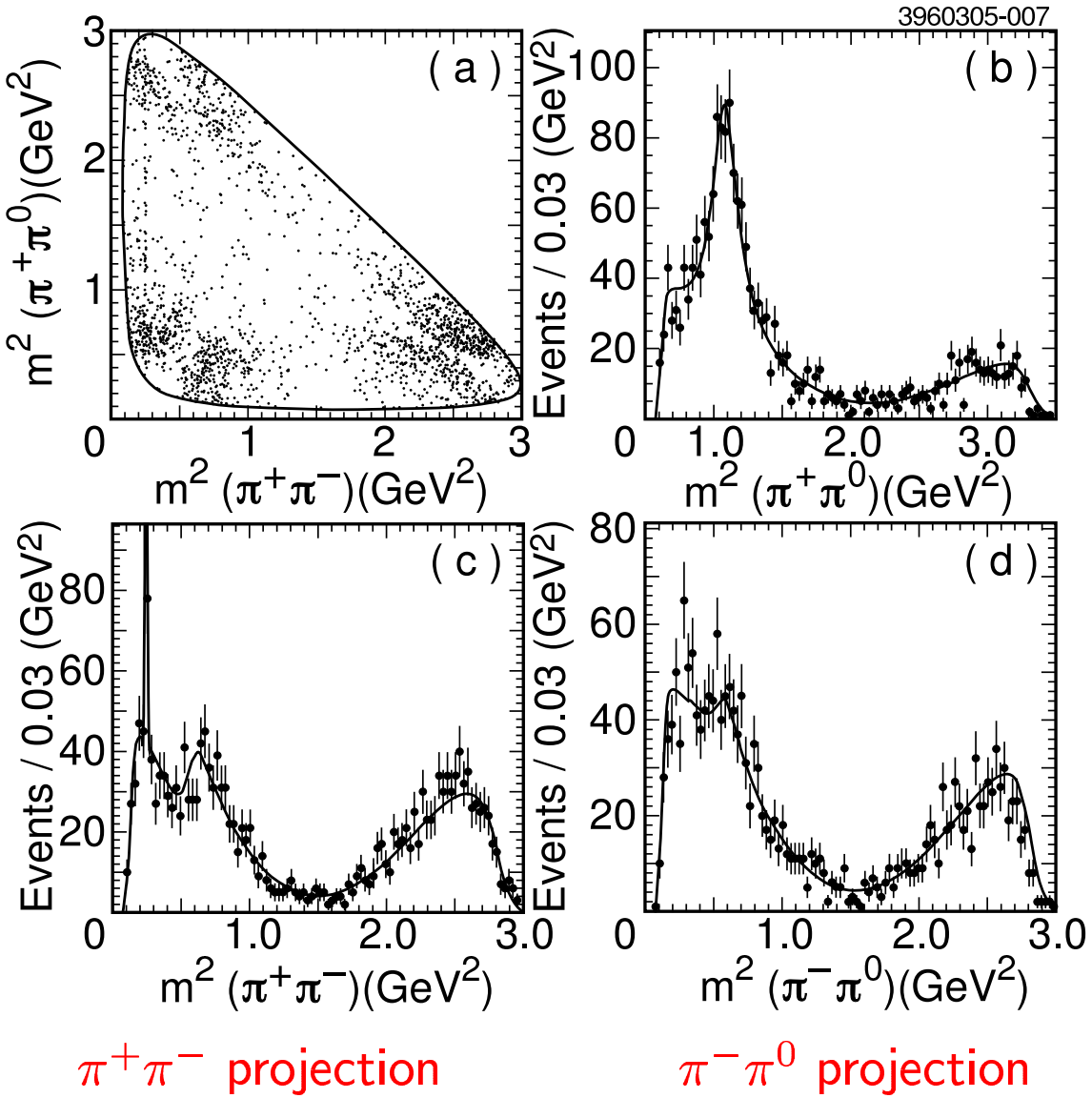
"Fit A": No CP conservation assumed

CLEO $D^0 \to \pi^+\pi^-\pi^0$ DALITZ PLOT

CLEO CLNS 05/1916, hep-ex/0503052 $\Rightarrow$ PRL: CP violation, $\pi\pi$ S-wave search

$\pi^+\pi^-\pi^0$ Dalitz plot

$\pi^+\pi^0$ projection



$\pi^+\pi^-$ projection

$\pi^-\pi^0$ projection

(b)–(d): Points: data
Curves: K-matrix fit
describing S-wave.

Based on 9.0 fb^{-1}
taken with CLEO II.V

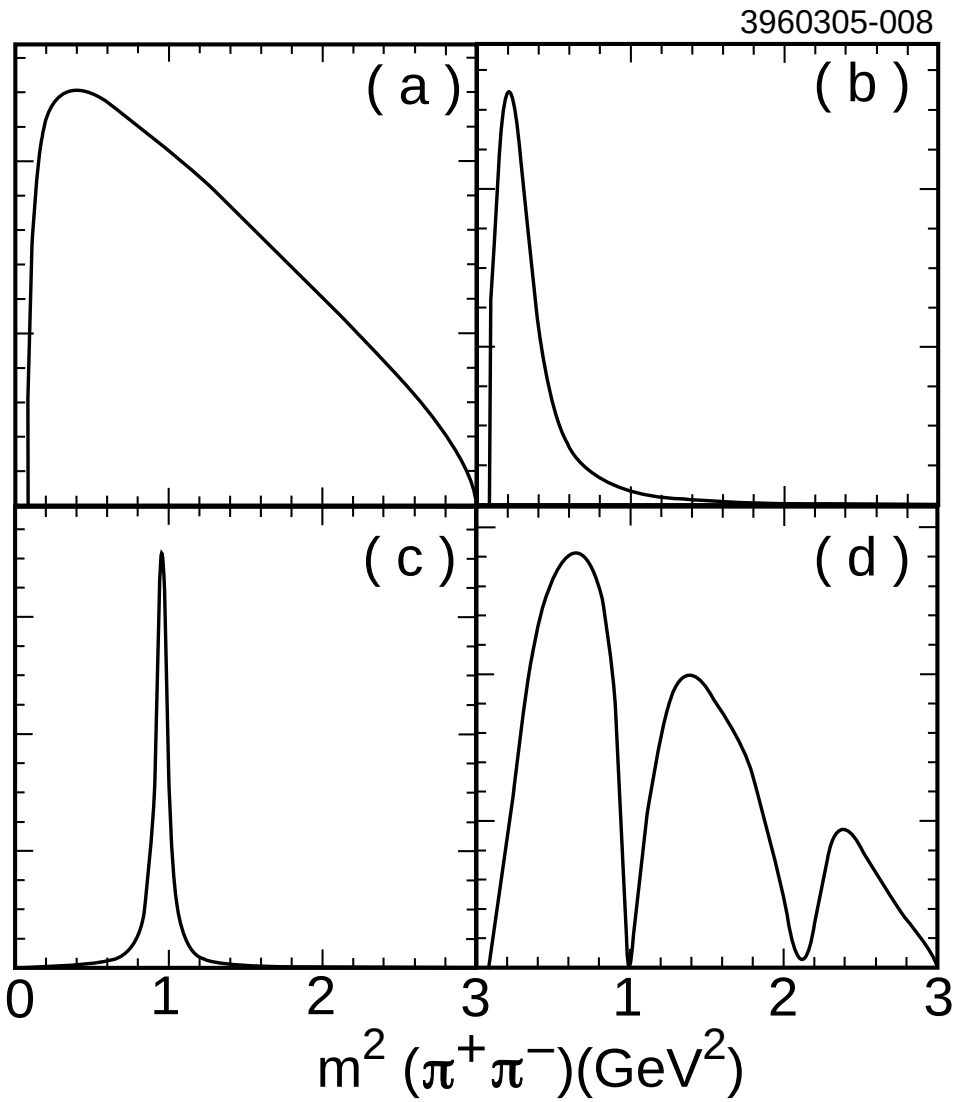
CP asymmetry as defined
in PR D **70**, 091101 is
$\mathcal{A}_{\rm CP} = 0.01^{+0.09}_{-0.07} \pm 0.05$

$B^- \to D_{\pi^+\pi^-\pi^0} K^-$ seen
(BaBar, hep-ex/05050840):
133 evts in 229 M $B\bar{B}$

$\mathcal{B} = (5.5 \pm 1.0 \pm 0.7) \times 10^{-6}$;
decay asymmetry
$A = 0.02 \pm 0.16 \pm 0.03$

S-WAVE PROJECTIONS: FITS

Flat non-resonant Breit-Wigner $\sigma(500)$



Breit-Wigner $f_0(980)$ K-matrix

All fits dominated by $\rho^{\pm}, \rho^0$

No need for S-wave;
FOCUS find a large S-wave
in $D^+ \to \pi^+\pi^+\pi^-$

Different decay processes?

Dominant tree contribution
to $D^0 \to \pi^+\pi^-\pi^0$ involves
$D^0 \to \rho^+\pi^-$ (fit fraction 75–80%)

Dominant tree contribution
to $D^+ \to \pi^+\pi^+\pi^-$ involves
$D^+ \to \pi^+ d\bar{d}$, where $d\bar{d}$ can
fragment into an S-wave

Corresponding $D^0 \to \pi^0 u\bar{u}$ or $\pi^0 d\bar{d}$
decay is color-suppressed

THE CLEO-c PROGRAM

CESR has completed a run just above charm threshold, accumulating 281 pb^{-1} at the center-of-mass energy of $\psi''(3770)$.

More data at $\psi''(3770)$ will provide clean sample of $D^0\bar{D}^0$ and D^+D^- (tagging on one side $\Rightarrow$ flavor or CP eigenvalue on the other)

In $e^+e^- \to D^0\overline{D}^0$, if one D is CP-even ($D_1 \to K^+K^-, \pi^+\pi^-, \ldots$) the other must be CP-odd ($D_2 \to K_S\pi^0, \ldots$).

CP-odd three-body D^0 modes: $K_S\rho$, $K_S\omega$, $K_S\phi$.

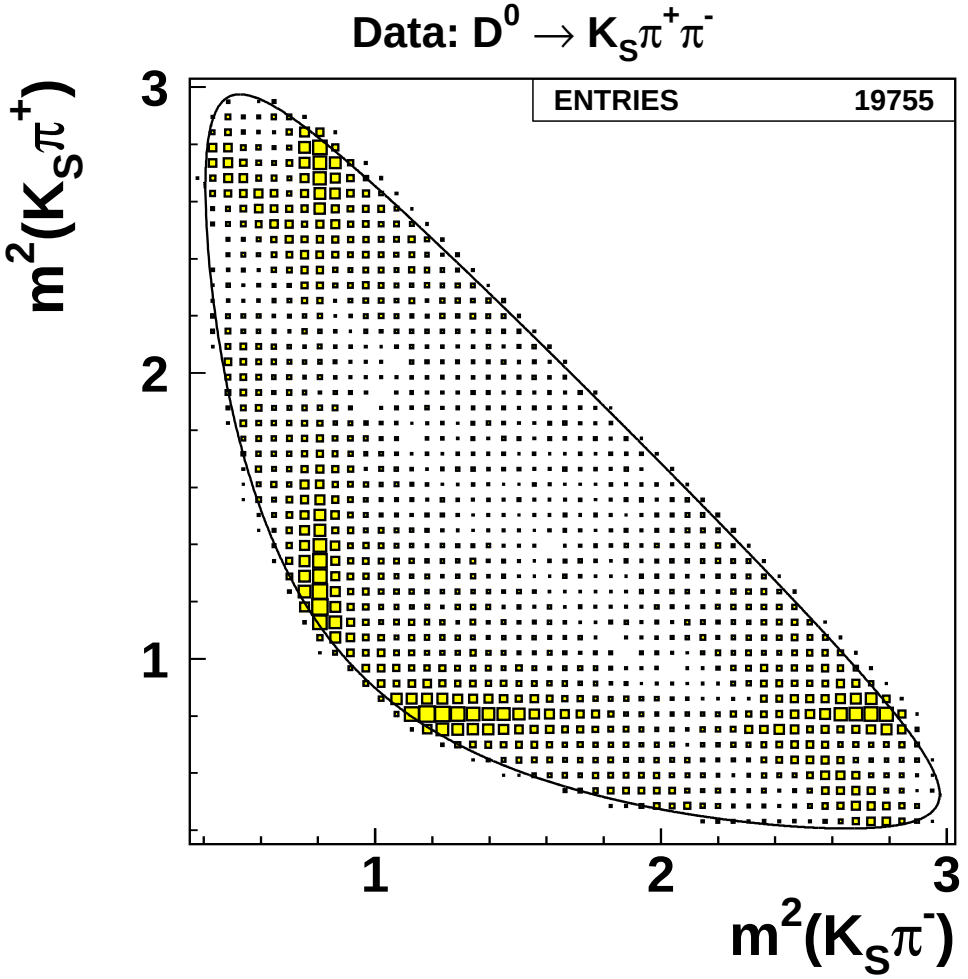
CP-even three-body D^0 modes: $K_Sf_0(980)$, $K_Sf_2(1270)$, $K_Sf_0(1370)$

Subsequent year: run at optimized energy for D_s production. Optimization studies to take place when CLEO running resumes in August.

Then: a year's worth of J/ψ, with the goal of studying light-quark and glue states that can be produced in its decay.

REMAINING STEPS

Use approximate relative phase of π between $K^{*+}K^-$ and $K^{*-}K^+$ in $D^0 \to K^+K^-\pi^0$ to obtain γ from $B^- \to D^0K^-$ à la Grossman, Ligeti, and Soffer.



CLEO-c $D \to K_S\pi^+\pi^-$ (281 pb^{-1})
$\Leftarrow$ currently under analysis

Reduce Dalitz plot modeling error in obtaining γ from $B^\pm \to DK^\pm$ followed by $D^0 \to K_S\pi^+\pi^-$.
Currently $\pm 10°$; CLEO-c's 281 pb^{-1} $\Rightarrow \pm 7°$

Expect $\gtrsim 100$ CP +, CP – tags in present sample

Eventually: $10\times$ that.