LESSONS FROM THE STANDARD CHARM DECAYS

★ INTRODUCTION

- AOB ON CHARM PHYSICS

  ... EXTENDED

- FLASH SOME RESULTS THAT I WON'T HAVE TIME TO TALK MORE

★★ SPECTROSCOPY

... MESONS

- D^{**}, D_s^{**}

... BARYONS

- DOUBLE CHARM [ccq]

★★★ HADRONIC DECAYS

- 3-BODY

- MORE OR LESS (3)-BODY

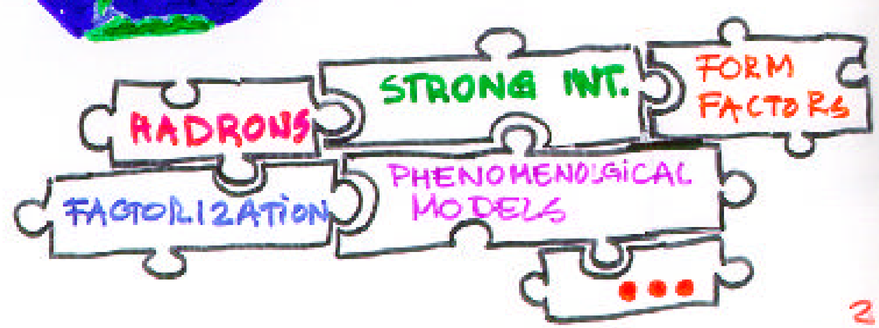
... MUCH MORE TO CHARM THAN WHAT THE BETTY BOOP FANS THOUGHT...

INTRODUCTION

- ABOUT THIS TALK
  - BAD: ONE HAVE TO CHOOSE
    (... LOTS LEFT OUT)
  - GOOD: ONE "CAN" CHOOSE
    (AND THERE ARE MANY WONDERFULL CHOICES)
  - FOCUS ON RECENT RESULTS

- WHY IS CHARM SO CHARMING ?
  - ~ 1/2 THE ANSWER IN A RECENT PART I REVIEW
    BY BIANCO, FABRI, BENSON & BIGI hep-ex 0306039

STANDARD MODEL
WEAK DECAYS
QUARKS & LEPTONS
...



- HEAVY ENOUGH FOR THE HEAVY QUARK QCD METHODOLOGY ? ?
  - ? SPECTROSCOPY ▷ HQ SYMMETRY
  - ? LIFETIMES ▷ $1/m_c$ EXPANSIONS
  - ? SEMILEPTONIC DECAYS ▷ FACTORIZATION ∴ HADRONIC COMPLEXITY ISOLATED
  - TEST TO NON PERTURBATIVE QCD ▷ HADRONIC DECAYS ◁▷ FSI
- VERY RICH DECAY PATTERN ▷ PROBE TO EXCLUSIVE HEAVY-LIGHT TRANSITIONS
  ▷ INPUT TO QCD MODELS
  ▷ SM PARAMETERS
- HIGH STATISTICS GOOD QUALITY DATA (ONLY TIME/VERTEX DETECTORS CAN DO)
  ▷ FIXED TARGET ▷ e^+e^- ▷ HADRON COLLIDER
- PLACE TO LOOK FOR NEW PHYSICS & RARE PROCESSES
- LIGHT MESON SPECTROSCOPY
- GOLDEN PRIZE TO LATTICE QCD PREDICTIONS
- LOT TO BE UNDERSTOOD

••• EVEN MORE THAN "SERVE" B PHYSICS

••• EXTENDED

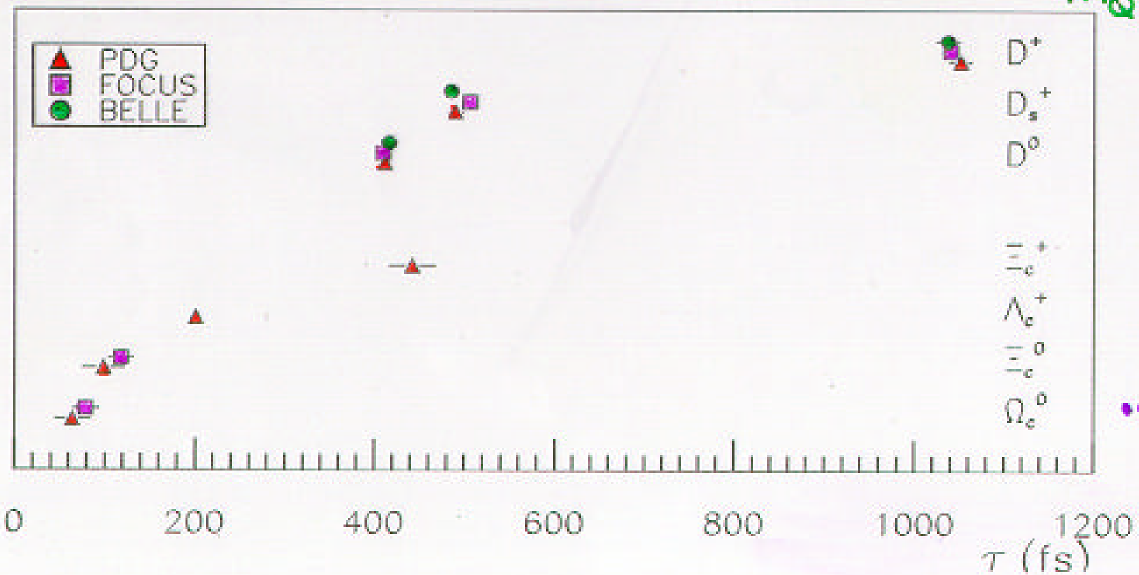
LIFETIMES MOST INCLUSIVE DECAY INFORMATION

- DECAY WIDTH → UNDERLYING DYNAMICS $\xrightarrow{\text{WEAK DECAYS}}$ STANDARD MODEL PARAMETERS (CKM, m_Q, decay constants...)

$$\Gamma_T = \sum_i \Gamma_i = \frac{\hbar}{\tau_T}$$

→ THEORETICAL PREDICTIONS

- FIXED TARGET & COLLIDER: HIGH PRECISION & SYSTEMATIC DIFFERENCES
- LIFETIME DIFFERENCES: MIXING, CP ASYMMETRIES
- CHARM LIFETIME HIERARCHY ESTABLISHED: $1/m_Q$ + QCD CORRECTIONS



... FOCUS MEASURED ALL.

... EXTENDED

SEMILEPTONIC DECAYS ... NICE & CLEAN

(PLB 535, 43 (2001))

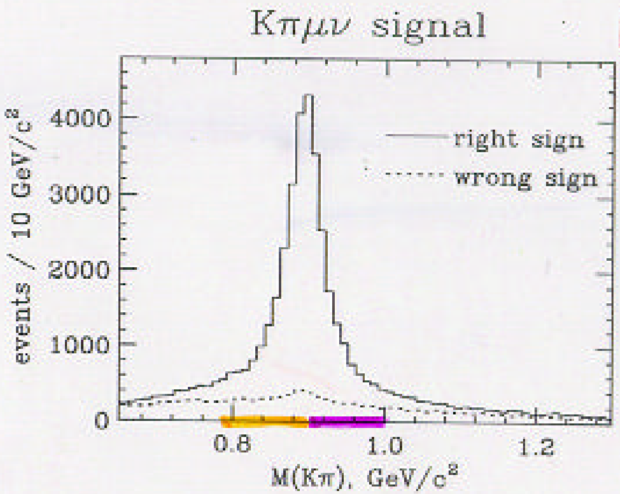
FOCUS : "EVIDENCE FOR INTERFERENCE PHENOMENA IN THE DECAY $D^+ \to \bar{K}^{*} \mu^+ \nu$"

$D^+ \to \bar{K}^{*} \mu^+ \nu$

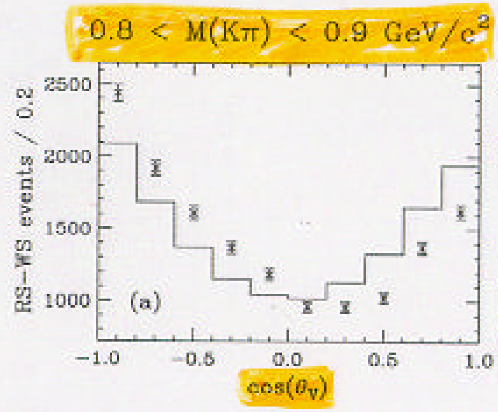
- ~ 100% FOR OVER LAST ~(20-1) YEARS
- PLACE TO MEASURE PV FORM FACTORS

5 VARIABLES

$m_{K\pi}$, $m^2_{\ell\nu}$ ($\equiv q^2$)



UNEXPECTED BACKWARD - FORWARD ASYMMETRY

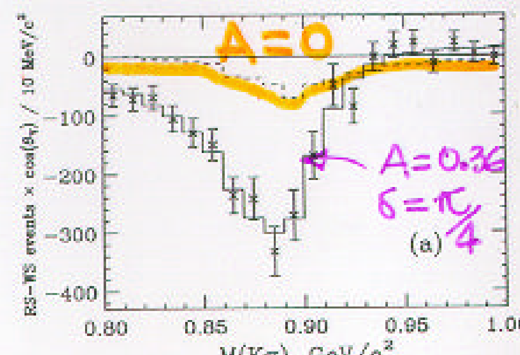


- $\cos(\theta_V)$ ~ OK FOR $0.9 < m_{K\pi} < 1.0$ GeV
- 100% $\bar{K}^{*}\mu^+\nu$ NOT ENOUGH
- NOT SO OBVIOUS IN $m_{K\pi}$

ONE SIMPLE EXPLANATION :
ADD A CONSTANT SCALAR AMP.

INTERFERENCE TERMS WILL SHOW UP ...

$$\frac{d^5\Gamma}{dm_{K\pi}\, dq^2\, d\cos\theta_V\, d\cos\theta_\ell\, d\chi} \propto Kq^2 \left| \begin{array}{l} (1+\cos\theta_\ell)\sin\theta_V e^{i\chi} B_{K^{*0}} H_+ \\ -(1-\cos\theta_\ell)\sin\theta_V e^{-i\chi} B_{K^{*0}} H_- \\ -2\sin\theta_\ell(\cos\theta_V B_{K^{*0}} + Ae^{i\delta}) H_0 \end{array} \right|^2 + \ldots$$



A, δ EXTRACTED FROM $\cos\theta_V$ WEIGHTED MASS :

$A = 0.36$ • $\delta = \pi/4$

THERE ARE OTHER POSSIBLE EXPLANATIONS ...

... FOCUS IS REFITTING $m_{K\pi}$ LINE SHAPE (SEE PANEL ...)

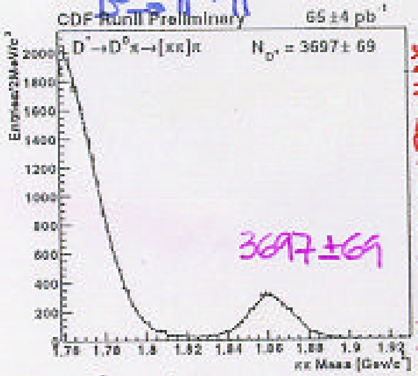
EXTENDED

NEW MEASUREMENTS OF CABIBBO-SUPPRESSED (2) DECAYS

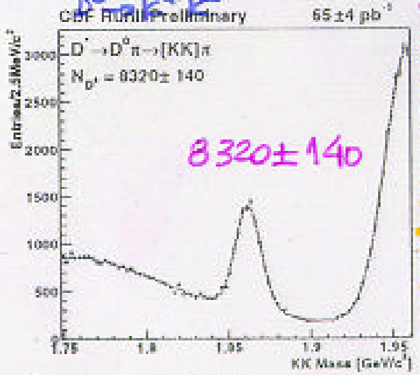
$K K \times \pi\pi \rightarrow$ FSI

SU(3)$_F$ VIOLATION ...

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



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



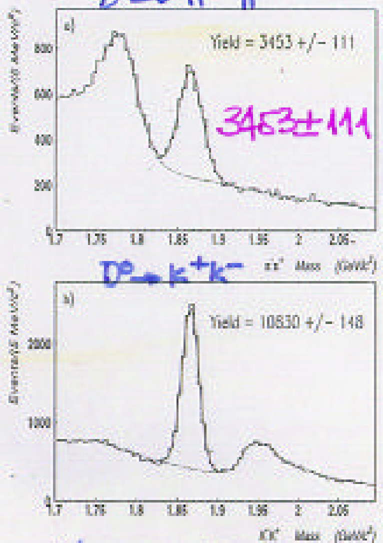
CDF (IVAN FURIC XVII RENCONTRE ... VALLE d'AOSTE 03/03)

PREL

• $N_{K\pi}$ = 93560 ± 340

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

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



FOCUS

• $N_{K\pi}$ = 105030 ± 372

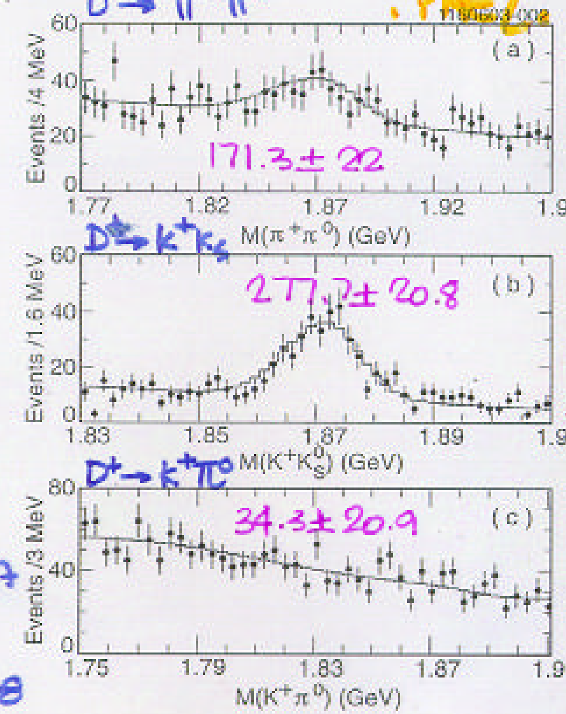
• $N_{K\pi\pi}$: 12898 ± 157

• $N_{\pi K_s}$: 1435 ± 48

$D^+ \to \pi^+\pi^0$

$D^+ \to K^+K_s$

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



PREL

CLEO

hep-ex/0212058

$\Gamma(D^0 \to [\ ])/\Gamma(D^0 \to K\pi)$ (%)	$[K^+K^-]$	$[\pi^+\pi^-]$
CDF	9.38 ± 0.18 ± 0.10	3.686 ± 0.076 ± 0.036
FOCUS	9.93 ± 0.14 ± 0.14	3.53 ± 0.12 ± 0.06
PDG	10.84 ± 0.26	3.76 ± 0.17

$\frac{\Gamma(D^+ \to [\ ])}{\Gamma(D^+ \to [\ ])}$ (%)	CLEO	PDG (CLEO!)
$[\pi^+\pi^0]$ / $[K^-\pi^+\pi^+]$	1.44 ± 0.19 ± 0.10	2.08 ± 0.6 ± 0.5
$[K^+K_s]$ / $[\pi^+K_s]$	18.74 ± 1.53 ± 0.85	26.3 ± 3.5
$[K^+\pi^0]$ / $[K^-\pi^+\pi^+]$	< 0.46 (90%CL)	

SPECTROSCOPY

●●● MESON

- SU(4) QUARK MODEL ➔ GOOD GUIDE FOR THE GROUND STATES … CHARMING PICTURES
- HEAVY QUARK SYMMETRY ➔ $m_Q \to \infty$ + QCD ➔ $[Qq]$ … EXCITED STATES

" QCD HYDROGEN ATOM "

- S_Q
- $j_q = S_q + L$

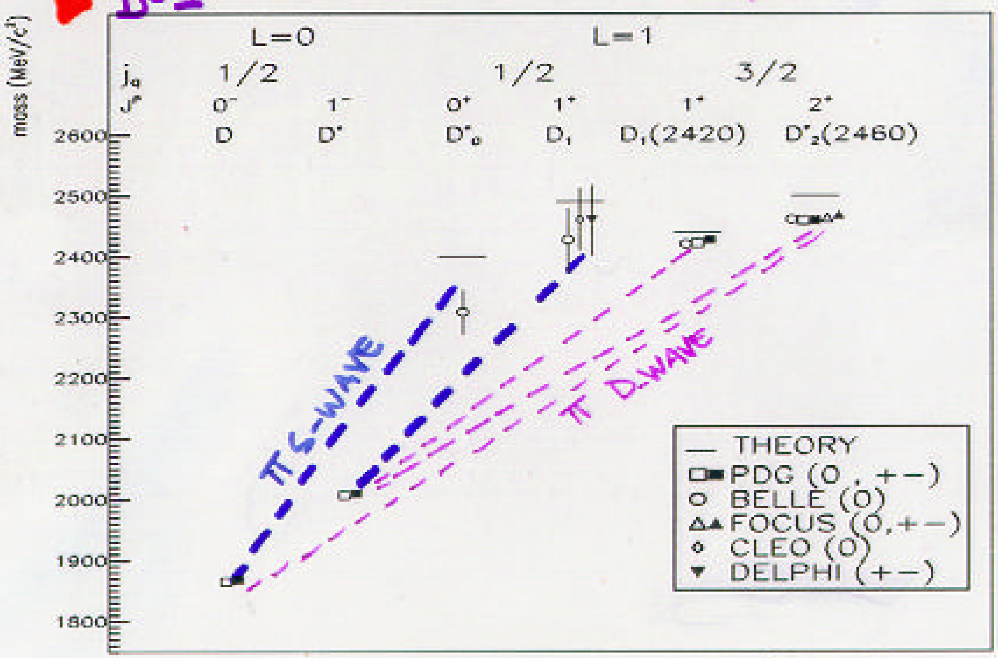
} CONSERVED

➔ $J \equiv S_Q + j_q$

➔ L=1, n=1 ➔ $D_0^*(1/2)$, $D_1(3/2)$, $D_1(1/2)$, $D_2^*(3/2)$

➔ L=0, n=2 ➔ $D^{*\prime}$, D'

➔ $D^{0\pm}$



(SEE: hep-ex 0306039 PAGE 65)

➔ TRASITIONS : ● S-WAVE WIDE
● D-WAVE NARROW

OBSERVED EXPERIMENTALY

➔ $D^{*\prime}(1/2)$ $m = 2637 \pm 7$ MeV , $\Gamma < 15$

DELPHI PLB 426 (1998)

NOT CONFIRMED OPAL, CLEO, ZEUS

●●● ALL WORKS ↪ FINE

OBS BELLE : FULL COHERENT AMPLITUDE ANALYSIS
hep ex/0307021 $B^- \to D^+\pi^{--}$ AND $B^- \to D^{*+}\pi^-\pi^-$

D_s^{**} $[c\bar{s}]$ ▷ PREDICTION : SIMILAR TO $D^{0\pm}$ + ∼ 80 MeV

MASS MeV/c² WIDTH MeV/c²	D_{s0}^* (1/2)	D_{s1} (1/2)	$D_{s1}(2536)$ (3/2)	$D_{s2}^*(2573)$(3/2)	D'(1/2)	$D^{*\prime}$ 1/2
THEORY	2480 WIDE	2570 WIDE	2530 < 1	2590 10 - 20	2670	2730
PDG (±)			2573.3 ± 6 < 2.3 90%CL	2572.4 ± 1.5 15 ± 5		
FOCUS PREL. R. KUTSCHKE . FRONTIER IN CONT. PHYS. II - VANDERBUILT U. MARCH (2001)			2535.1 ± 0.3 1.6 ± 1	2567.3 ± 1.4 28 ± 5		

▷ $D_1(2536)$: MANY OBSERVATIONS • ALL IN $\to D^{*+}K$ MODE • NOT $\to D^+K$

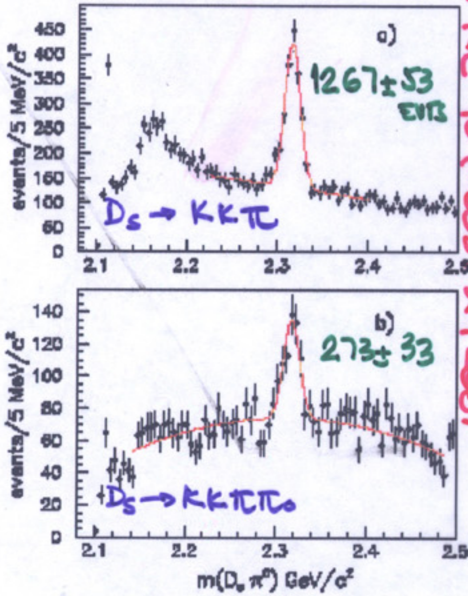
▷ $D_{sJ}^*(2573)$: (ALEPH / ARGUS / CLEO) • J^P CONSISTENT 2^+ • FOCUS $D_{s2}^* \to D^+ K_s^0$ (FIRST OBSERVATION)

▷ D_s^* (1/2) WERE EXPECTED TO HAVE ENOUGH PHASE SPACE TO DECAY TO DK (ISOSPIN CONSERVING) ▶ S-WAVE : WIDE

(F. PORTER EPS 07/2003)

$D_{sJ}^{*}(2317)^{\pm}$ $\hookrightarrow D_s^+\pi^0$

BABAR

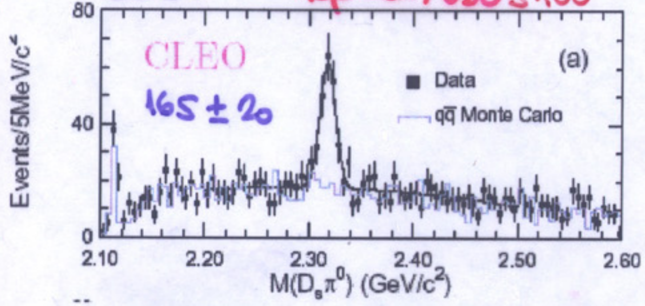


PRL 90 (2003) 242001

- FROM $D_s \to \phi\pi^+$ $\to K^{*0}K^+$
- $M = 2316.8 \pm 0.4 \pm 3$ MeV
- $\Gamma \lesssim 10$ MeV

CLEO

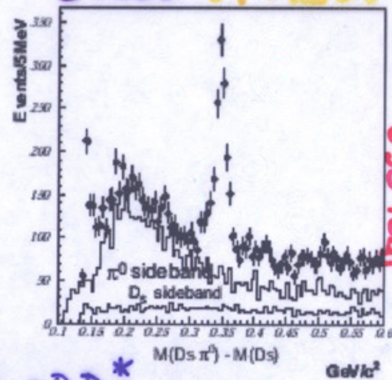
hep-ex/0305100



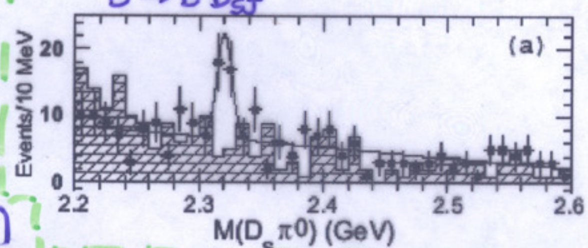
- $N(D_s\pi^0, D_s \to \phi\pi^+) = 155 \pm 23$
- $M = 2318.5 \pm 1.2 \pm 1.1$ MeV
- $\Gamma < 7$ MeV
- $BR(D_{sJ}^* \to [\,]) / BR(D_{sJ}^* \to D_s^+\pi^0)$
  - $[D_s^+\gamma] < 0.052$ (90% CL)
  - $[D^{*+}\gamma] < 0.059$
  - $[D_s^+\pi^+\pi^-] < 0.019$
  - $[D_s^{*+}\pi_0] < 0.11$

BELLE . PREL.

hep-ex 0307052 / 0307061



$B \to D D_{sJ}^*$



- YIELDS:
  - $D_s \to \phi\pi$: 761 ± 44 EVTS
  - $B^+ \to \bar{D}^0 D_{sJ}^{*+}$: $13.4^{+6.2}_{-5.4}$
  - $B^0 \to D^- D_{sJ}^{*+}$: $10.8^{+4.2}_{-3.6}$
- $M = 2317.2 \pm 0.5 \pm 0.9$
- $\Gamma \to$ RESOLUTION
- $BR(\to D_s^+\gamma)/BR(\to D_s^+\pi_0) < 0.05$ 90% CL

▷ ALL WIDTHS CONSISTENT WITH DETECTOR RESOLUTION

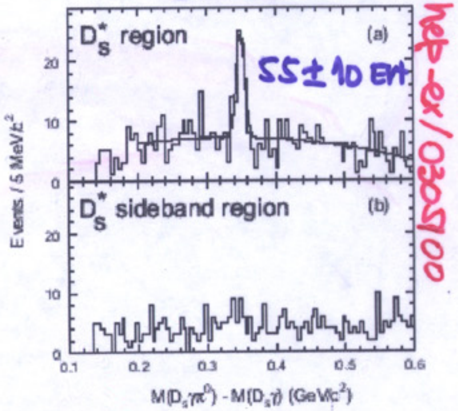
▷ FEED DOWN FROM $D_{sJ}(2460)$ (BY NEGLECTING γ IN $D_s^*(2112) \to D_s\gamma$) CONSIDERED

$D_{sJ}^{*}(2463)^{\pm}$

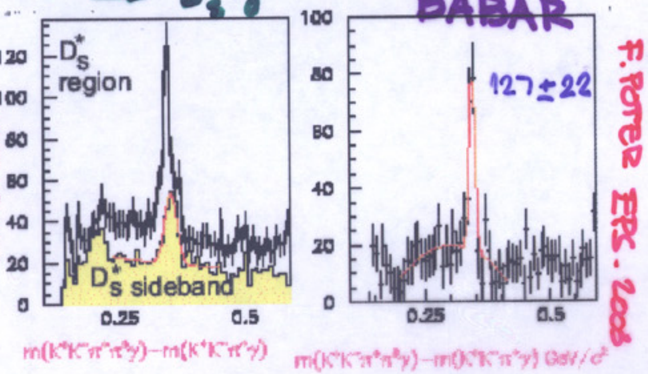
$\hookrightarrow D_s^{*+}\pi_0$

$\hookrightarrow D_s^{+}\gamma$

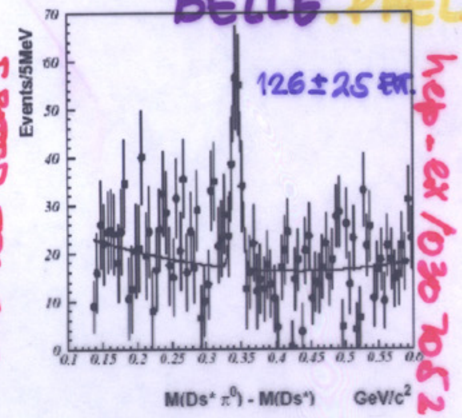
CLEO

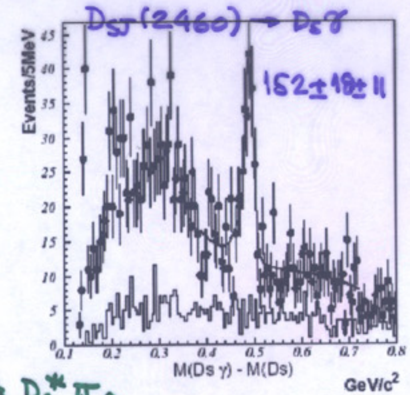


.PREL. BABAR



BELLE .PREL.





- $N(D_s^*\pi^0, D_s^* \to D_s\gamma) = 41 \pm 12$
  - $m = 2463.6 \pm 1.7 \pm 1.2$
  - $\Gamma \leq 7$

- $m = 2457.0 \pm 1.4 \pm 3$
- $\Gamma \to$ RESOLUTION

▷ FEED UP FROM $D_{sJ}(2317)$ (BY ADDING A RANDOM γ TO D_s) CONSIDERED

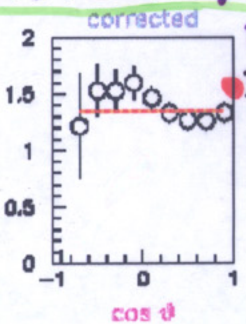
- $D_{sJ}^{*} \to D_s^{*}\pi_0$
- $m = 2456.5 \pm 1.3 \pm 1.1$ MeV
- $D_{sJ}^{*} \to D_s\gamma$
- $m = 2459.5 \pm 1.3$
- $BR(\to D_s\gamma)/BR(\to D_s^{*+}\pi_0) = 0.63 \pm .15$
- + EXCLUSIVE B DECAYS (hep-ex/0307041)

INTERPRETATION

$[c\bar{s}]$ $D^*_{s0^+}(2317)$ $D^*_{s1^+}(2463)$

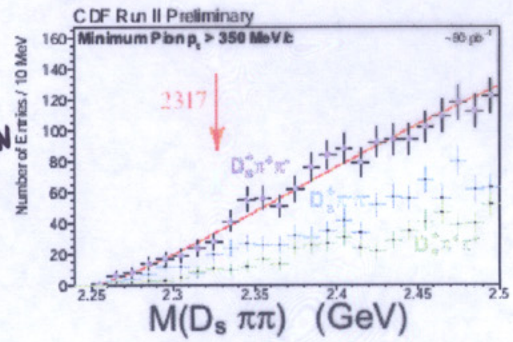
- BELOW THRESHOLD TO DK, DK^* (ISOSPIN CONSERVIO)
- ISOSPIN VIOLATING ($D_s\pi_0$, $D_s^*\pi_0$) ⟷ NARROW WIDTH
- MASS LOWER BUT DIFFERECE AS EXPETED

CONSISTENCY



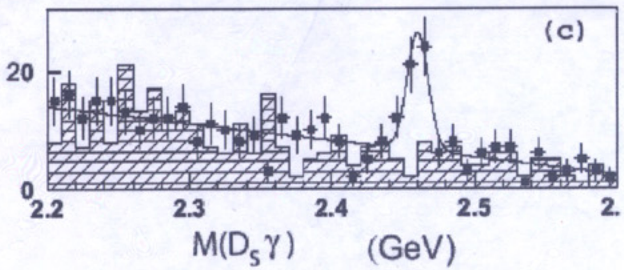
BABAR:
- $D^*_{sJ}(2317) \to D_s\pi^0$ HELICITY DISTRIBUTION UNIFORM → CONSISTENT 0^+

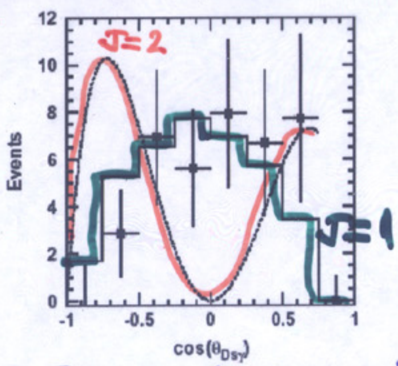
CDF



- $D_{sJ}(2317)$ NOT SEEN IN FORBIDDEN TO 0^+:
  - $\to D_s\pi^+\pi^-$
  - $\to D_s\pi_0\pi_0$
  - $\to D_s\gamma$

- $D^*_{sJ}(2463)$ SEEN IN $D_s\gamma \neq 0^+$
- BELLE: HELICITY ANGLE DISTRIBUTION FOR $D^*_{sJ}(2463)$ CONSISTENT W/ 1^+





- $B \to D\,D_{sJ}(2463)$, $\hookrightarrow D_s\gamma$
- $\theta_{D_s\gamma}$: ANGLE BETWEEN D_{sJ} (IN B REST F.) AND D_s (IN D_{sJ} REST FRAME)

THEORY: WHY SO LIGHT?

MANY POSSIBLE EXPLANATIONS.

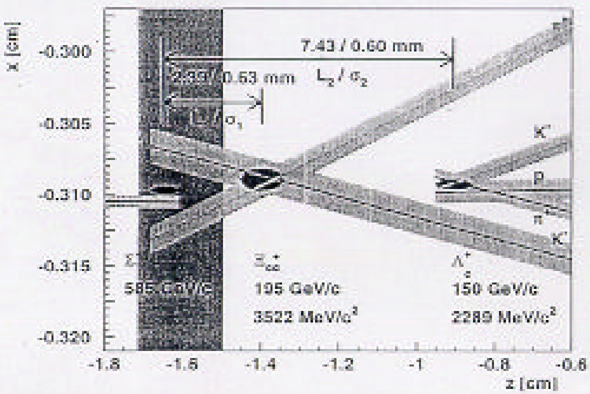
VERY RICH SPECTROSCOPY ••• BARYONS

SU(4) MULTIPLETS HELP IDENTIFY ($\sim$ NO J^P MEASUREMENTS)

- GROUND STATES : ONLY Ω_{cc}^{*} ($J^P = 3/2^+$) NOT SEEN

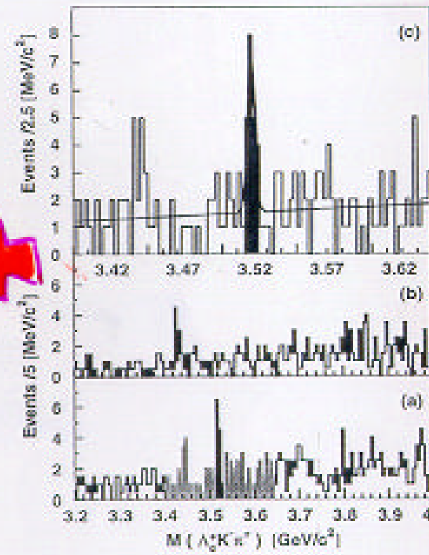
C = 1 • HQS • [Qqq] "... THERE ARE 22 CHARMED BARYONS FOUND..." J. Yelton hep-ex/0206088

FIRST OBSERVATION OF THE DOUBLY CHARMED BARYON Ξ_{cc}^{+} SELEX PRL 89 (2003) 112001

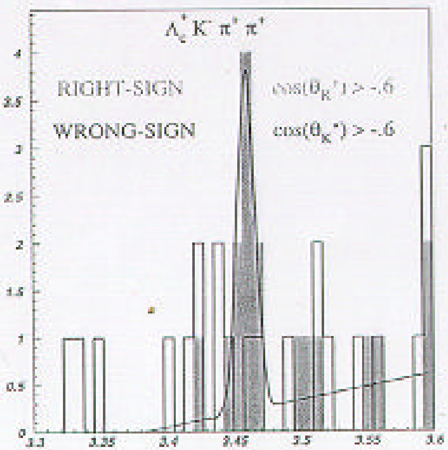


- 600 GeV Λ BEAM
- 1630 $\Lambda_c \to pK\pi$
- RICH DETECTOR

- SIGNAL 15.9 EVTS
- BKG 6.1 ± 0.5 EVTS
  6.3 σ
- MASS 3519 ± 1 MeV/c²



SELEX SEP/2002 • OLD • PREL. hep-ex/0209075



+ π & HELICITY CUT

$\Lambda_c K^- \pi^+ \pi^- \Rightarrow \Xi_{cc}^{++}$

- 9 EVENTS 1 BKG EXPECTED
- MASS 3460 MeV/c²

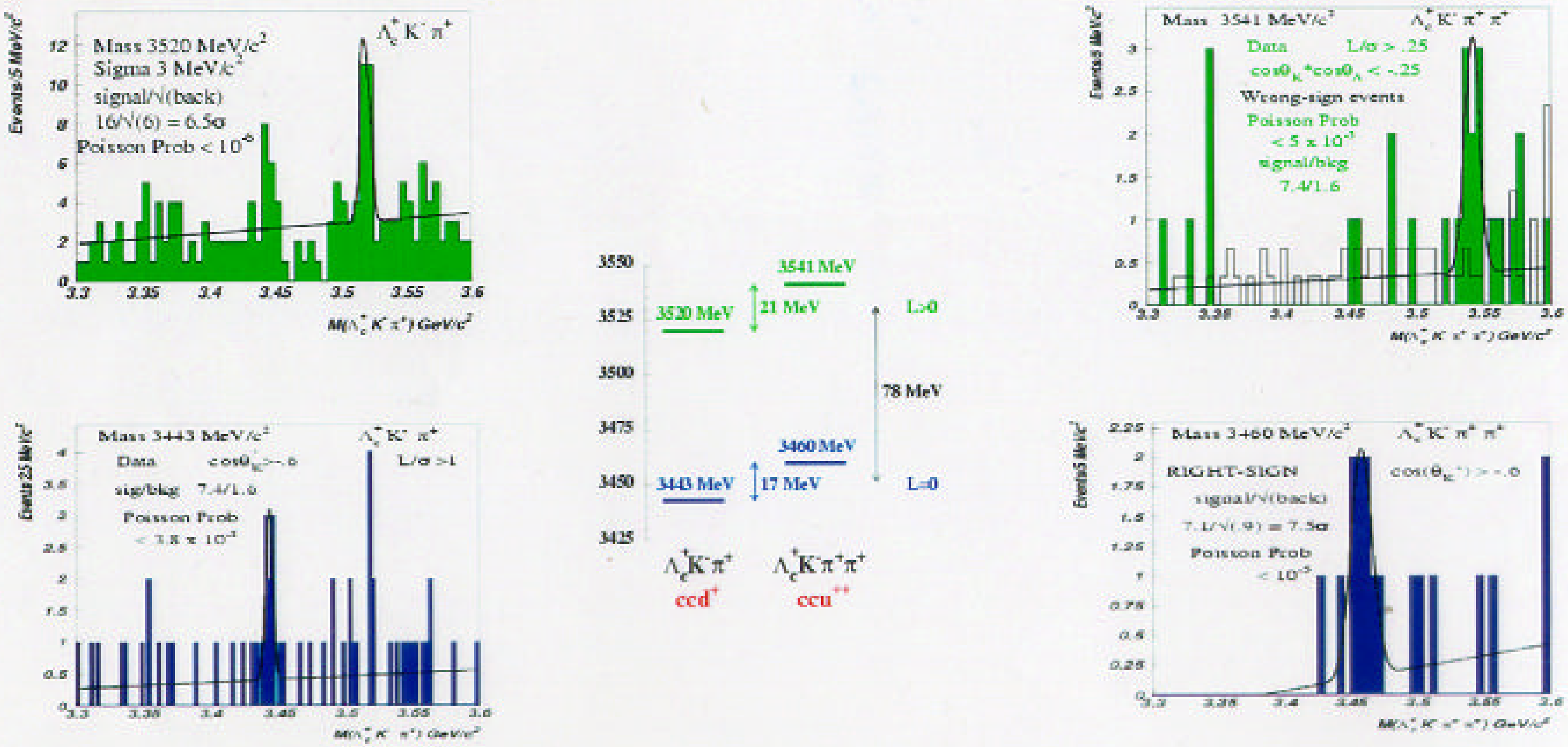
$\Delta m = m_{ccd^+} - m_{ccu^{++}} \sim 60$ MeV/c !

DOUBLE CHARM • SELEX • 2003 • PREL. • (WINE & CHEES – FRMILAB 13/6/03) CIPANPO3

ARE $(3520)^{+}$ AND $(3460)^{++}$ REALLY ISODOUBLETS ?

• NO, THEY BEHAVE DIFFERENTLY WRT HELICITY CUT •

GO BACK & REANALYSE BOTH + AND ++



SELEX Double Charm — Wine and Cheese 6/13/03

NEED CONFIRMATION (EXP.) EXPLANATION (THE)

FOCUS: PHOTO PRODUCTION • 19444 ± 262 Λ_c SAMPLE (∽ 12 x SELEX)

SEARCHED ALL OVER (21 MODES) AND DID NOT FIND [ccq]

P. SHELDON. FRONTIER SCIENCE 2002)

★★★ CHARM HADRONIC DECAYS

- $\Gamma_{SL} \ll \Gamma_{TOTAL}$ + COMPARABLE SL WIDTHS ⊳ HADRONIC DECAYS ARE IN THE ORIGIN OF THE LARGE LT DIFFERENCES
- DECAY MECHANISMS • RICH RESONAT SUBSTRUCTURE • FINAL STATE INTERACTION

  ... 3 BODY : BEST OFFER !
- $P \to P_1 P_2 P_3$ (EVEN BETTER OFFER ...)
  - DYNAMICS $|M_0(\underbrace{m_{12}^2, m_{23}^2}_{\text{ONLY TWO VARIABLES}})|^2 \propto$ DALITZ PLOT
  - RELATIVE INTERMEDIATE STATE CONTRIBUTION (a_i) • FSI (δ_i) • RESONANCE PARAMETERS $(\vec{\alpha}_i)$

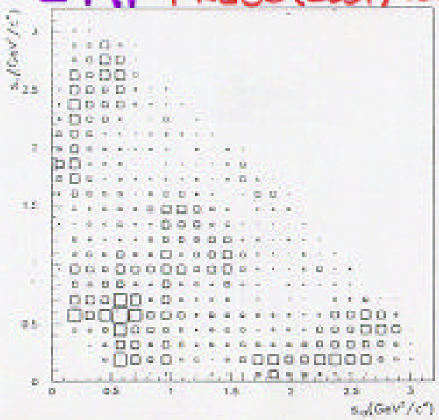
$$M_0 = \sum a_i A_i(m_{12}^2, m_{23}^2, \vec{\alpha}_i)\, e^{i\delta_i}$$

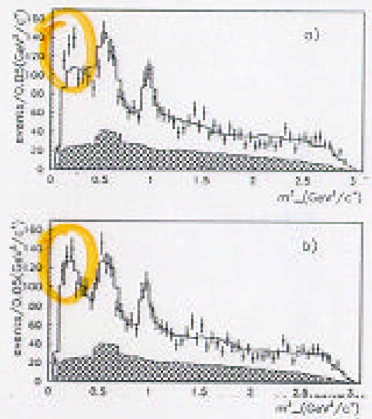
  - NEED A "MODEL" FOR THE RESONANT AMPLITUDES ⊳ USUALLY BREIT-WIGNERS SOMETIMES CAN MEASURE $\vec{\alpha}_i = (m_0, \Gamma_0)$
  - DEAL WITH QUANTUM INTERFERENCE (ALWAYS A PLEASURE ...)
  - STUDY SCALAR RESONANCES (THAT SEEM TO BE FAVOURED ...)
  - WELL DEFINED INITIAL STATE
  - INVESTIGATE ~~CP~~ (YET ANOTHER PLACE ...)

⊳⊳ AS # OF STATES ↑ NOT ALWAYS EASY INTERPRETATION

$D^+ \to \pi^+ \pi^- \pi^+$ ▷ "OLD" CHARM RESULT STILL ON THE SPOT ...

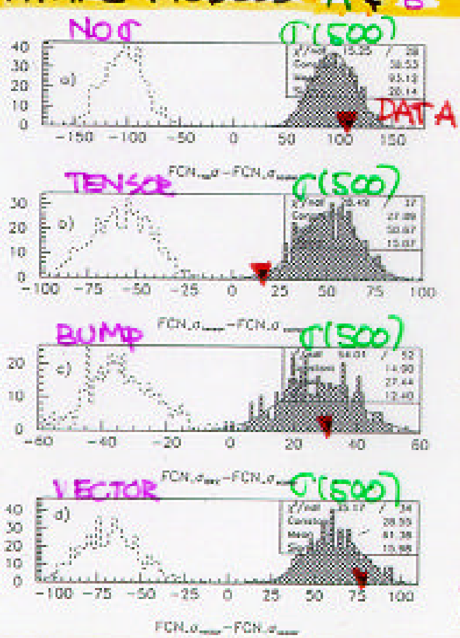
E791 PRL86 (2001) 700





	Fit Frac. (%)	Fit Frac. (%)
$\rho^0(770)\pi^+$	20.8 ± 2.4	$33.6 \pm 3.2 \pm 2.2$
$f_0(980)\pi^+$	7.4 ± 1.4	$6.2 \pm 1.3 \pm 0.4$
$f_2(1270)\pi^+$	6.3 ± 1.9	$19.4 \pm 2.5 \pm 0.4$
$f_0(1370)\pi^+$	10.7 ± 3.1	$2.3 \pm 1.5 \pm 0.8$
$\rho^0(1450)\pi^+$	22.6 ± 3.7	$0.7 \pm 0.7 \pm 0.3$
Non-res	38.6 ± 9.7	$7.8 \pm 6.0 \pm 2.7$
$\sigma\pi^+$		$46.3 \pm 9.0 \pm 2.1$
χ^2	254/162	138/162

▷ CONSISTENCY TEST TO COMPARE MODELS A & B



▷ $\sigma(500)$: $m = 478^{+24}_{-23} \pm 17$ MeV/c^2

$\Gamma = 324^{+42}_{-40} \pm 21$ MeV/c^2

▷ NON RESONANT ⟷ σ INTERPLAY

CRITICISM : THE USE OF A WIDE BREIT-WIGNER NEAR THRESHOLD

NOT SEEN IN $\pi\pi$ SCATTERING

DIFFERENT ENVIRONMENT

- CREATE MC ENSAMBLES A, B
- CALCULATE : $\Delta w_{AB} \equiv -2(\ln \mathcal{L}_A - \ln \mathcal{L}_B)$

▷ GREAT DISCRIMINATING POWER

AMPLITUDE DIFFERENCE ... DOES THE STORY ENDS ?

PLB 550, 135 (2002)

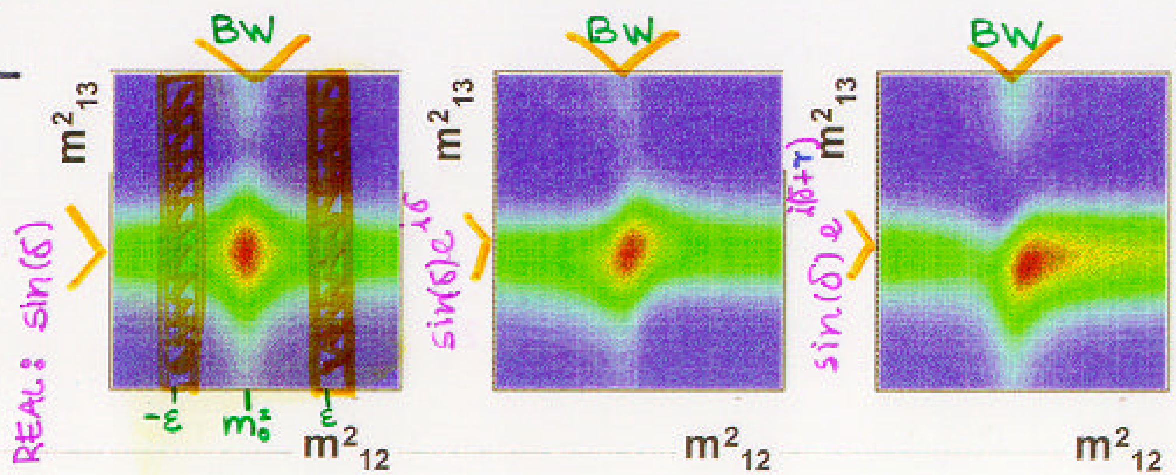
- USE A LIMITED REGION OF THE PHASE SPACE WHERE A WELL KNOWN RESONANCE $BW(m_{12}^2, m_0, \Gamma_0)$ CROSSES WITH A GENERIC AMPLITUDE $a \sin(\delta(m_{13}^2))\, e^{i\delta(m_{13}^2)}$ (ONLY!)

$$\bullet \; A_0(m_{12}^2, m_{13}^2) \sim a_R\, BW(m_{12}^2) + a \sin(\delta(m_{13}^2))\, e^{i(\delta(m_{13}^2)+\gamma)}$$

$$\bullet\bullet\bullet \; \boxed{|\Delta A_0^2| \equiv |A(m_0^2+\varepsilon, m_{13}^2)|^2 - |A(m_0-\varepsilon, m_{13}^2)|^2 \sim -c\,(\sin(2\delta(m_{13}^2)+\gamma) - \sin\gamma)}$$

- THE INTRINSIC RESONANCE PHASES AND THE FSI PHASE ARE RESPONSIBLE FOR THE OBSERVED PATTERN

• Ex:



- $|\Delta A_0^2|$: • $\delta(m_{13}^2)$ • γ • c
- MODEL-INDEPENDENT
- LIMITED APLICABILITY

AMPLITUDE DIFFERENCE @ REAL : E791 . PREL. (hep-ex/0307008)

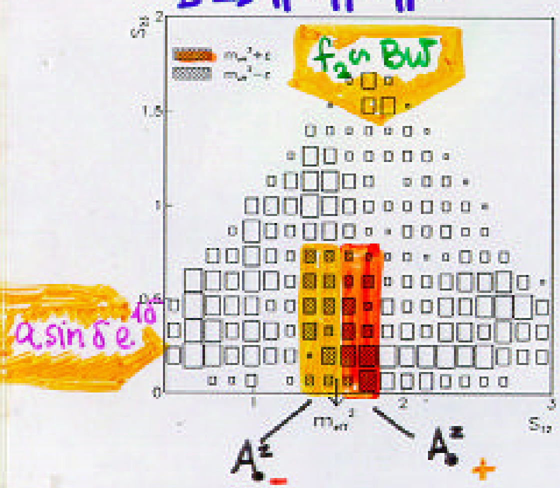
- MEASURE THE PHASE MOTION @ LOW $\pi^+\pi^-$ MASS IN A MODEL INDEPENDENT FASHION

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

- NEED A "CLEAN" DALITZ PLOT REGION : ~~$\rho(770)$~~ , ~~$f_0(980)$~~ , $f_2(1270)$

  • • • COMPLICATION DUE TO THE ANGULAR DISTRIBUTION OF f_2

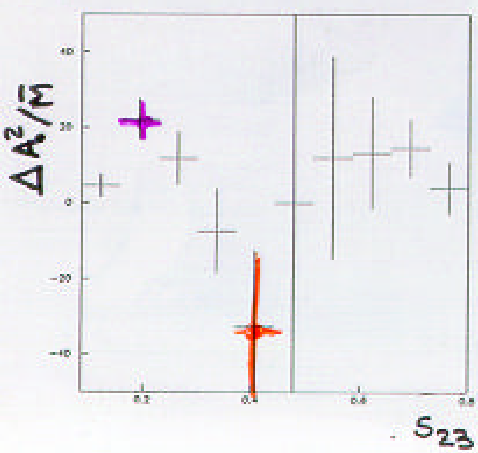
$D^+ \to \pi^+\pi^-\pi^+$



$$\begin{cases} f_2(s_{12}) : \mathrm{BW}(s_{12}, m_0, \Gamma_0)\, \overbrace{M(s_{12}, s_{23})}^{\text{ANGULAR DISTRIBUTION}} / \overbrace{p^*/\sqrt{s_{23}}}^{\text{P.S FACTOR}} \sim m^2_{eff} ; \bar{M} \\ \text{LOW}(s_{23}) : a \sin(\delta(s_{23}))\, e^{i\delta(s_{23})} \end{cases}$$

$$A^2_+ - A^2_- / \bar{M} \equiv \Delta A^2/\bar{M} \propto -c\left(\sin(2\delta(s_{23}) + \gamma) - \sin(\gamma)\right)$$

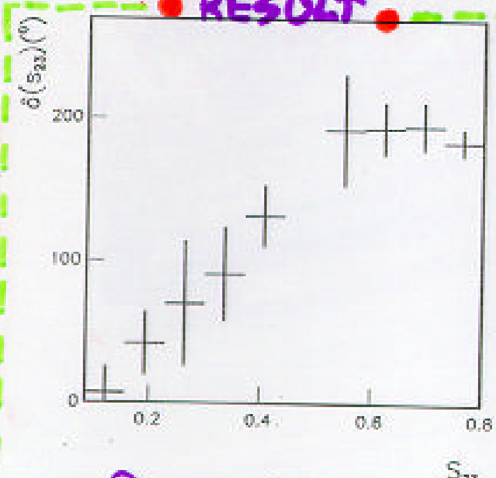
- $\boxed{\text{VARIATION } \Delta A^2/\bar{M}} \Leftrightarrow \boxed{\text{VARIATION } \delta(s_{23})}$



- CLEAR $\Delta A^2/\bar{M}\big|_{MAX}$ & $\big|_{MIN}$

  ►► $c, \gamma, \delta(s_{23})$

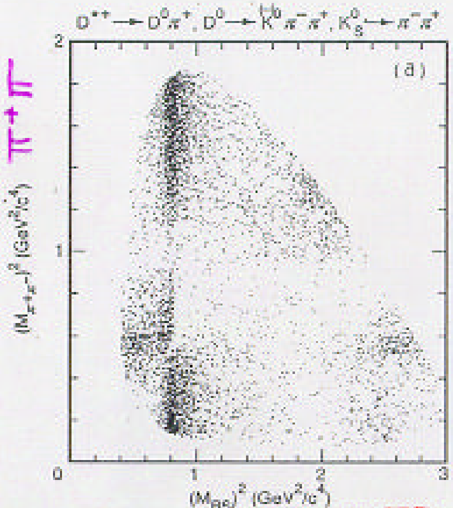
• RESULT •



• $\gamma = 2.78 \pm .33$

($\gamma_{DALITZ} = 2.59 \pm 0.19$)

$D^0 \to K_s \pi^- \pi^+$ • CLEO • PRL 89 (2002) 251802



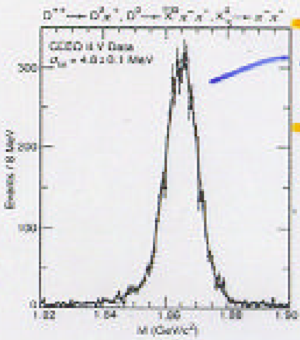
$\pi^+\pi^-$

$K_s\pi^-$

▷ D^* TAG : $D^{*+} \to D^0 \pi^+$

↳ $\bar{K}_0 \pi^- \pi^+$ (FAVORED)

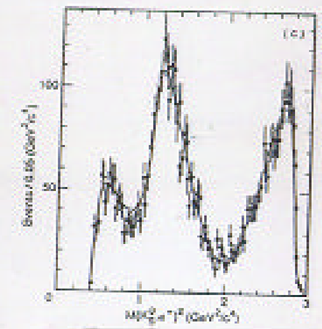
↳ $K_0 \pi^+ \pi^+$ (DCS OR MIXING)

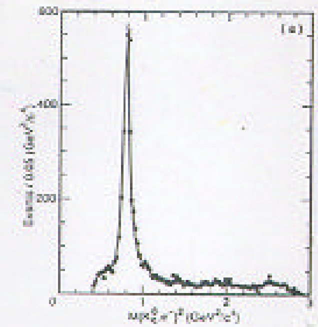


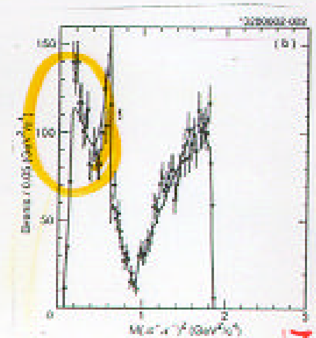
$S \sim 5300$
$B \sim 2\%$

• RESULT •

mode	fraction(%)
$K^*(890)^+$	0.34±0.13
$\rho(770)$	26.4±0.9
w	0.72±0.18
$K^*(890)^-$	65.7±1.3
$f_0(908)$	4.3±0.5
$f_2(1270)$	0.27±0.15
$f_0(1370)$	9.9±1.1
$K_0^*(1430)$	7.3±0.7
$K_2^*(1430)$	1.1±0.2
$K^*(1680)$	2.2±0.4
NR	0.9 ±0.4







▷ MODES : NR • 7 $[K_s\pi^-]$ • 10 $[\pi^+\pi^-]$ • 2 $[K_s\pi^+]$

▷ IF $\sigma(500)$ ▷ $m_\sigma = 513 \pm 32$ $\Gamma_\sigma = 335 \pm 67$
$f_\sigma = 0.57 \pm 13$ $\delta_\sigma = 214 \pm 11°$

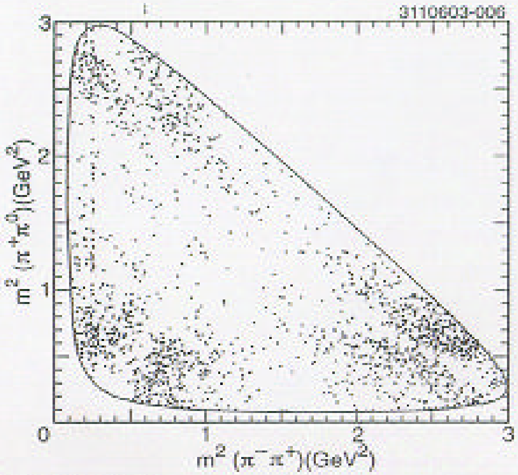
• NOT INCLUDED IN FINAL FIT !

▷ $K^{*+}\pi^-$: 5.5σ • $\dfrac{BR(D^0 \to K^{*+}\pi^-)}{BR(D^0 \to K^{*-}\pi^+)} = (0.5 \pm 0.2 \pm \ldots)\%$ •

▷ D^0 & $\bar{D}^0$: NO $\cancel{CP}$

- FIT QUALITY IS NOT DISCUSSED...
- ARE THERE OTHER POSSIBLE SOLUTIONS ?

$D^0 \to \pi^-\pi^+\pi^0$ • CLEO • PREL. (hep-ex/0306048)



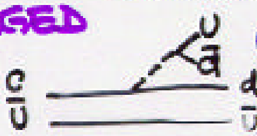
- $D^{*+} \to D^0\pi^+$
  $\hookrightarrow \pi^+\pi^-\pi^0$
  $\hookrightarrow \gamma\gamma$

- $S \sim 1100$
  $B \sim 18\%$

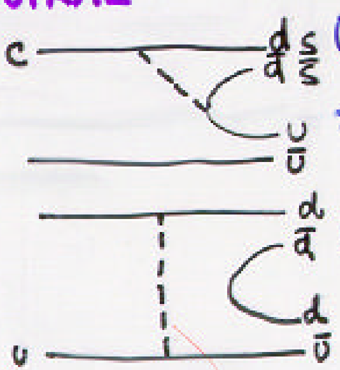
mode	phase(^{o})	fraction(%)
ρ^+	0.0	77.5±1.8±4.8
ρ^0	$10 \pm 3 \pm 3$	23.9±1.8±4.6
ρ^-	$-4 \pm 3 \pm 4$	32.3±2.1±2.2
NR	$77 \pm 8 \pm 11$	2.7±0.9±1.7

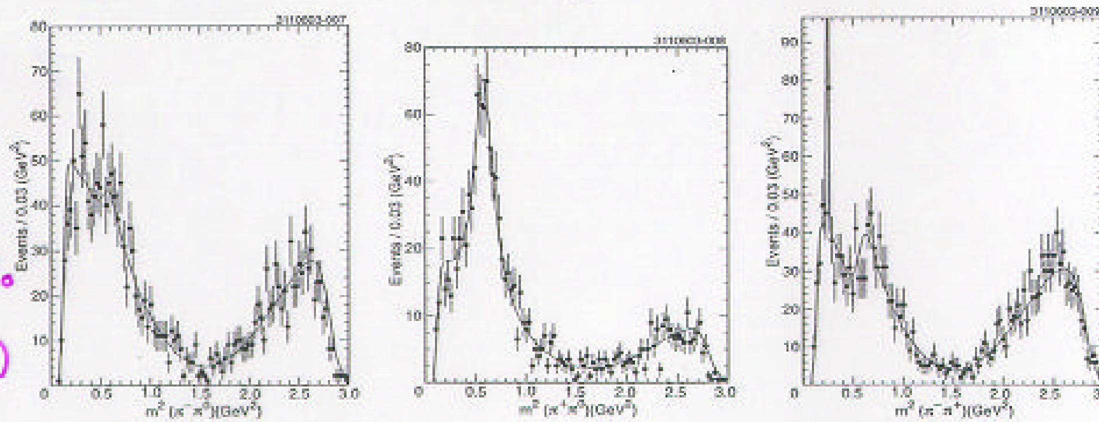
- NO SIGNIFICANT SCALAR $\sigma(500)$ OR $f_0(980)$ CONTRIBUTIONS

• CHARGED



• NEUTRAL



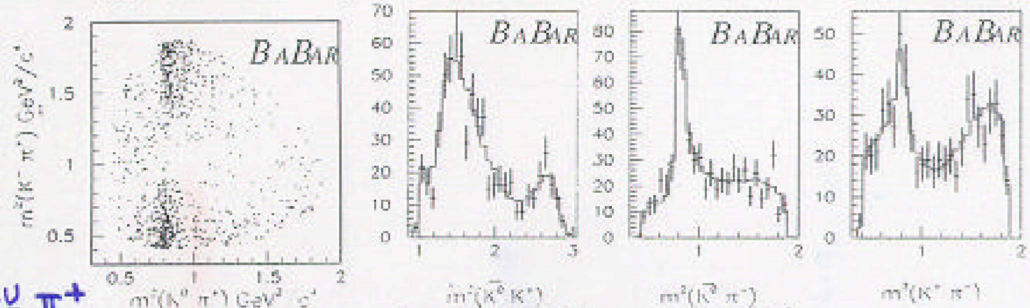


- D^0 & $\bar{D}^0$: NO ~~CP~~

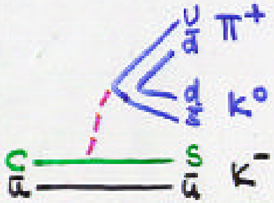
• FIT QUALITY ?

$D^0 \to K^0 K^- \pi^+$ • $D^0 \to \bar{K}^0 K^+ \pi^-$ • BABAR • PREL. hep.ex/0207089

$D^0 \to K^0 K^- \pi^+$ (D^* TAG)

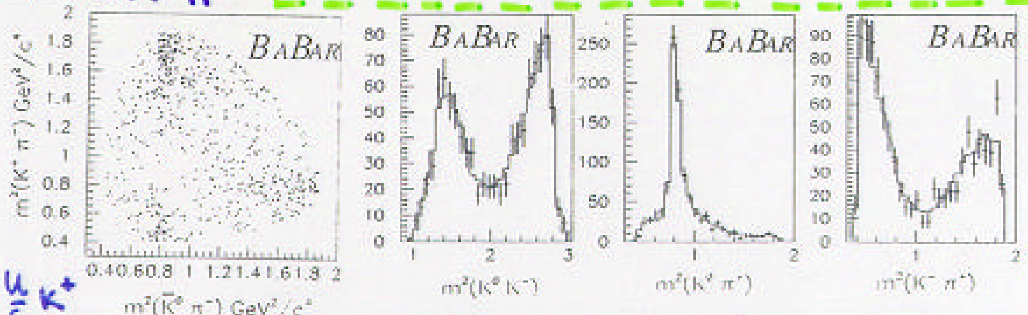


Final state	Fraction (%)	Phase (degrees)
$\overline{K}_0^{*0}(1430)K^0$	$4.8 \pm 1.4 \pm 1.6$	52 ± 27
$\overline{K}_1^{*0}(892)K^0$	$0.8 \pm 0.5 \pm 0.1$	175 ± 22
$\overline{K}_1^{*0}(1680)K^0$	$6.9 \pm 1.2 \pm 1.0$	-169 ± 16
$\overline{K}_2^{*0}(1430)K^0$	$2.0 \pm 0.6 \pm 0.1$	51 ± 18
$K_0^{*+}(1430)K^-$	$13.3 \pm 3.5 \pm 3.9$	-41 ± 25
$K_1^{*+}(892)K^-$	$63.6 \pm 5.1 \pm 2.6$	0
$K_1^{*+}(1680)K^-$	$15.6 \pm 3.0 \pm 1.4$	-178 ± 10
$K_2^{*+}(1430)K^-$	$13.8 \pm 2.6 \pm 7.9$	-52 ± 7
$a_0^-(980)\pi^+$	$2.9 \pm 2.3 \pm 0.7$	-100 ± 13
$a_0^-(1450)\pi^+$	$3.1 \pm 1.9 \pm 0.9$	31 ± 16
$a_2^-(1310)\pi^+$	$0.7 \pm 0.4 \pm 0.1$	-149 ± 27
N.R.	$2.3 \pm 0.5 \pm 5.6$	-136 ± 23
Sum	$\boxed{130 \pm 8}$	

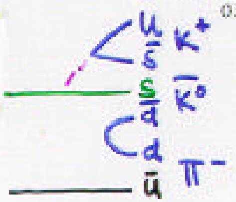


- SAMPLE 1008 EVTS • S ~ 96%
- IF $\not{k}$ ⇨ $f_{\not{k}} = (15 \pm 12)\%$ • NO IMPROVE
- $\chi^2/\mathrm{DOF} = 46/44$

$D^0 \to \bar{K}^0 K^+ \pi^-$



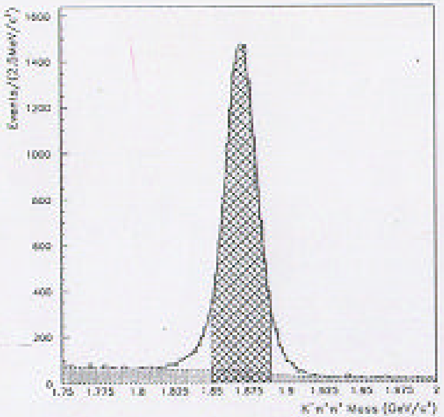
Final state	Fraction (%)	Phase (degrees)
$K_0^{*0}(1430)\overline{K}^0$	$26.0 \pm 16.1 \pm 3.3$	-38 ± 22
$K_1^{*0}(892)\overline{K}^0$	$2.8 \pm 1.4 \pm 0.5$	-126 ± 19
$K_1^{*0}(1680)\overline{K}^0$	$15.2 \pm 11.9 \pm 0.5$	161 ± 9
$K_2^{*0}(1430)\overline{K}^0$	$1.7 \pm 2.5 \pm 0.2$	53 ± 38
$K_0^{*-}(1430)K^+$	$2.4 \pm 8.2 \pm 1.0$	-142 ± 115
$K_1^{*-}(892)K^+$	$35.6 \pm 7.7 \pm 2.3$	0
$K_1^{*-}(1680)K^+$	$5.1 \pm 5.7 \pm 1.1$	124 ± 27
$K_2^{*-}(1430)K^+$	$1.0 \pm 1.0 \pm 0.2$	-26 ± 38
$a_0^+(980)\pi^-$	$15.1 \pm 12.5 \pm 0.6$	-160 ± 42
$a_0^+(1450)\pi^-$	$2.2 \pm 2.7 \pm 1.2$	148 ± 25
N.R.	$36.6 \pm 25.8 \pm 2.7$	-172 ± 13
Sum	$\boxed{144 \pm 37}$	

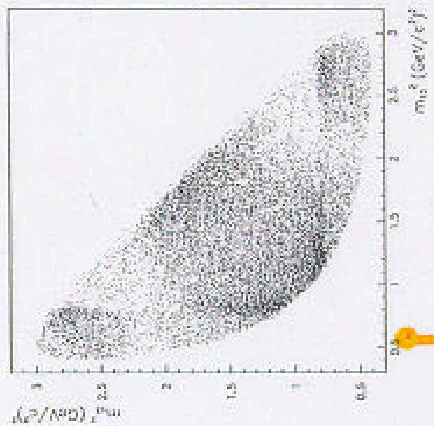


- SAMPLE 659 EVTS • S ~ 96%
- LARGE NR • IF ~~NR~~ : ~ SAME FIT QUALITY
- ~~NR~~ : K_0^{*-} ⇧ ~ 26% • $a_0^+(980)$ ⇩ ~ 5%
- $\chi^2/\mathrm{DOF} = 25/29$

- ARE THESE THE ONLY PHYSICAL SOLUTIONS ?

$D^+ \to K^-\pi^+\pi^+$ • E791 • PRL 89 (2002), 121801





- VERY LARGE / CLEAN SAMPLE : ~ 15000 EVTS • $\sim 6\%$ BKG
- NEED NEW $K\pi$ SCALAR κ TO 'SOLVE' THE FIT
  - • $m_\kappa = 797 \pm 19 \pm 43$ • $\Gamma_\kappa = 410 \pm 43 \pm 87$ •
  - 'SOLVE' $\equiv$ $\chi^2/_{63} = 2.7 \rightarrow 0.73$ + EXTENSIVE QUALITY / CONSISTENCY TESTS

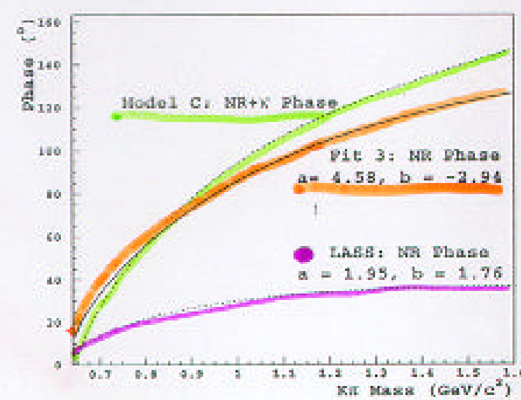
Decay Mode	Model A: No κ Fraction (%)	Model A: No κ Phase	Model C: With κ Fraction (%)	Model C: With κ Phase
NR	90.9 ± 2.6	$0°$ (fixed)	$13.0 \pm 5.8 \pm 4.4$	$(-11 \pm 14 \pm 8)°$
$\kappa\pi^+$	–	–	$47.8 \pm 12.1 \pm 5.3$	$(187 \pm 8 \pm 18)°$
$\bar{K}^*(892)\pi^+$	13.8 ± 0.5	$(54 \pm 2)°$	$12.3 \pm 1.0 \pm 0.9$	$0°$ (fixed)
$\bar{K}_0^*(1430)\pi^+$	30.6 ± 1.6	$(54 \pm 2)°$	$12.5 \pm 1.4 \pm 0.5$	$(48 \pm 7 \pm 10)°$
$\bar{K}_2^*(1430)\pi^+$	0.4 ± 0.1	$(33 \pm 8)°$	$0.5 \pm 0.1 \pm 0.2$	$(-54 \pm 8 \pm 7)°$
$\bar{K}^*(1680)\pi^+$	3.2 ± 0.3	$(66 \pm 3)°$	$2.5 \pm 0.7 \pm 0.3$	$(28 \pm 13 \pm 15)°$

- PHYSICS SOLUTION CHANGES DRAMATICALLY

FURTHER EXAMINING THE LOW $K^-\pi^+$ MASS REGION ...
(hep-ex/0307003)

- HOW DO THE κ RESONANT BEHAVOUR OBSERVED IN $D^+ \to K^-\pi^+\pi^+$ COMPARES TO THE $K\pi$ SCATTERING? LASS (NP B296 (1988) 493)

$$A_S \sim \frac{M_{12}}{p^*_{12}} \sin\delta_B \, e^{i\delta_B} + [K_0^*(1430)] \quad \bullet \quad \cot\delta_B = \frac{1}{a p^*} + \frac{1}{2} b p^*$$



• SHOULD $K\pi_{SCAT} \sim K\pi_{CHARM}$?

CHARM 3-BODY REMARKS / CHALLENGES

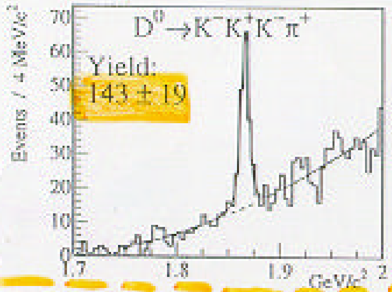
...

- CLEAR / EFFICIENT QUALITY CRITERIA ... SET
- BEWARE OF • QUALITY AND PHYSICS PREJUDICES
  ... PREJUDICES WHO HAVE THEM ???
- HARMONY WITH SCATTERING RESULTS ... UNDERSTAND THE $\neq$'s
- BETTER REPRESENTATION OF THE RESONANCES
  ... WE KNOW THE LIMITATIONS
- CAN WE SAY MORE ABOUT THE FSI
  ... HOW TO COMPARE PHASES
- CHALLENGE OF CHALLENGES • UNDERSTAND THE OVERALL PICTURE
  - QUASI TWO BODY ...SMALL
  - VECTOR DOMINATES SOME DECAYS
  - LARGE SCALAR CONTRIBUTIONS IN SOME DECAYS

... THEN SOME OF US CAN RETIRE

4 – BODY • FOCUS • PREL • (Γ : K. STENSON APS/DPF 2003 AMPLITUDE ANALYSIS : @ STYLISTICS REVIEW)

▶ $D^0 \to K^- K^+ K^- \pi^+$: CABIBBO FAVOURED • PHASE SPACE & $s\bar{s}$ SUPPRESSED •



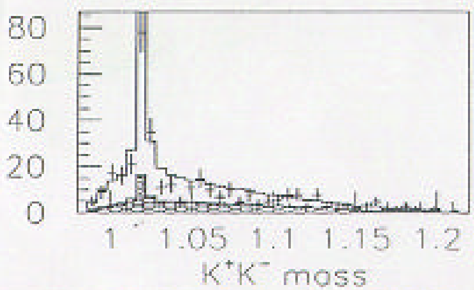
• $\dfrac{\Gamma(D^0 \to K^- K^+ K^- \pi^+)}{\Gamma(D^0 \to K^- \pi^+ \pi^- \pi^+)} = (0.257 \pm 0.034 \pm 0.023)\%$ • $(0.32 \pm 0.09)\%$ PDG •

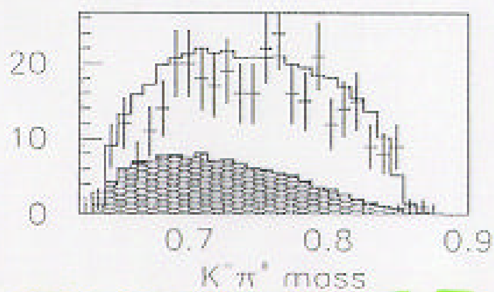
▶ FULL COHERENT AMPLITUDE ANALYSIS (5 DOF's)

S = 139 evts
B = 65 evts.

- VERY LIMITATED PS • FEW RESONANT CONTRIBUTIONS
- $\phi K^- \pi^+$ • ONLY RESONANCE WITH m_0 WITHIN PS
- $\bar{K}^{*0}(1430) K^- K^+$ • WIDE , UNDISTINGUISHABLE FROM NR
- $\phi \bar{K}^{*0}(890)$, $\bar{K}^{*0}(890) K^- K^+$ • ANGULAR DISTRIBUTION CHARACTERISTICS

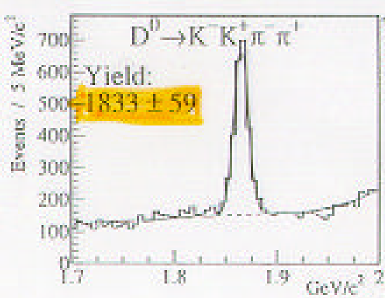
$D^0 \to K^- 3\pi \to 64516 \pm 360$

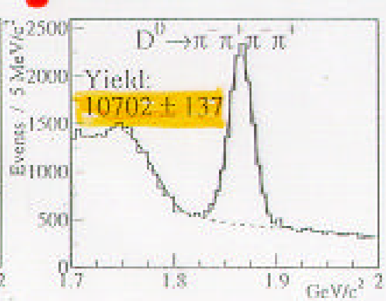




MODE	FRACTION %
$\phi K^{*0}(890)$	$48 \pm 6 \pm 1$
$\phi K^- \pi^+$	$18 \pm 6 \pm 3$
$\bar{K}^{*0}(890) K^+ K^-$	$20 \pm 7 \pm 2$
NR	$15 \pm 6 \pm 2$

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

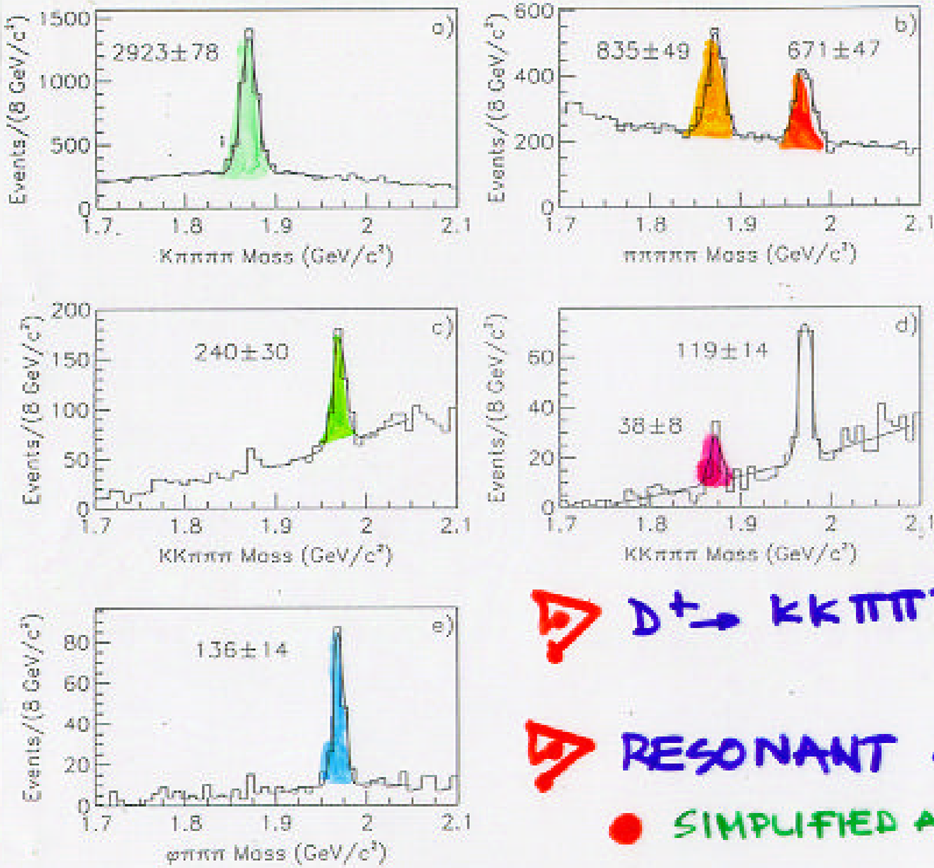




	FOCUS	PDG
$\dfrac{\Gamma(D^0 \to K^+ K^- \pi^+ \pi^-)}{\Gamma(D^0 \to K^- \pi^+ \pi^+ \pi^-)}$	$2.97 \pm 0.10\%$	$3.34 \pm 0.28\%$
$\dfrac{\Gamma(D^0 \to \pi^- \pi^+ \pi^+ \pi^-)}{\Gamma(D^0 \to K^- \pi^+ \pi^- \pi^+)}$	$8.66 \pm 0.12\%$	$9.8 \pm 0.6\%$

• • • AMPLITUDE ANALYSIS ON THE WAY

5-BODY • FOCUS • (PLB 561 (2003) 225)



Decay Mode	FOCUS
$\frac{\Gamma(D^+\to K^-\pi^+\pi^+\pi^+\pi^-)}{\Gamma(D^+\to K^-\pi^+\pi^+)}$	$0.058\pm0.002\pm0.006$
$\frac{\Gamma(D^+\to \pi^+\pi^+\pi^+\pi^-\pi^-)}{\Gamma(D^+\to K^-\pi^+\pi^+\pi^+\pi^-)}$	$0.290\pm0.017\pm0.011$
$\frac{\Gamma(D_s^+\to \pi^+\pi^+\pi^+\pi^-\pi^-)}{\Gamma(D_s^+\to K^-K^+\pi^+)}$	$0.145\pm0.011\pm0.010$
$\frac{\Gamma(D_s^+\to K^+K^-\pi^+\pi^+\pi^-)}{\Gamma(D_s^+\to K^-K^+\pi^+)}$	$0.150\pm0.019\pm0.025$
$\frac{\Gamma(D_s^+\to \phi\pi^+\pi^+\pi^-)}{\Gamma(D_s^+\to \phi\pi^+)}$	$0.249\pm0.024\pm0.021$
$\frac{\Gamma(D^+\to K^+K^-\pi^+\pi^+\pi^-)}{\Gamma(D^+\to K^-\pi^+\pi^+\pi^+\pi^-)}$	$0.040\pm0.009\pm0.019$

▷ $D^+ \to KK\pi\pi\pi$: FIRST OBSERVATION

▷ RESONANT STRUCTURE :

- SIMPLIFIED APPROACH ▷ FINAL STATE IS A INCOHERENT SUPERPOSITION OF VECTOR RESONANCES

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

Subresonant Mode	Fraction of $K4\pi$
$(K^-\pi^+\pi^+\pi^+\pi^-)_{NR}$	$0.07\pm0.05\pm0.01$
$\overline{K^{*0}}\pi^-\pi^+\pi^+$	$0.21\pm0.04\pm0.06$
$K^-\rho^0\pi^+\pi^+$	$0.30\pm0.04\pm0.01$
$\overline{K^{*0}}\rho^0\pi^+$	$0.40\pm0.03\pm0.06$

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

Subresonant Mode	Fraction of $2K3\pi$
$(K^+K^-\pi^+\pi^+\pi^-)_{NR}$	$0.10\pm0.06\pm0.05$
$\phi\pi^-\pi^+\pi^+$	$0.21\pm0.05\pm0.06$
$K^+K^-\rho^0\pi^+$	<0.03 (90% C.L.)
$\phi\rho^0\pi^+$	$0.75\pm0.06\pm0.04$

2-BODY ▷ ISOSPIN ANALYSIS • $D^0 \to KK$ • $D^0 \to \pi\pi$

FOCUS hep-ex 0212058
CLEO CLEO CONF 03-02 EPS-371 • PREL.

$D \to \pi\pi$: $D^+ \to \pi^+\pi^0$ • $D^0 \to \pi^+\pi^-$ • $D^0 \to \pi^0\pi^0$

	$\lvert A_2\rvert / \lvert A_0\rvert$	$\delta_2 - \delta_0$	
FOCUS	0.65 ± 0.14	$(83.6 \pm 10.0)^\circ$	(NEW $D^0 \to \pi^+\pi^-$ + PDG)
CLEO NEW	0.421 ± 0.040	$(87.6 \pm 4.6)^\circ$	(NEW $D^+ \to \pi^+\pi^0$ + PDG)
CLEO OLD (PRL 71 (1993), 1973)	$0.72 \pm 0.13 \pm 0.11$	$(82.0 \pm 7.5 \pm 5.2)^\circ$	

$D \to KK$: $D^+ \to K^+\bar{K}_0$ $D^0 \to K^+K^-$ $D^0 \to K_0\bar{K}_0$

	$\lvert A_0\rvert / \lvert A_1\rvert$	$\delta_1 - \delta_0$	
FOCUS	0.56 ± 0.04	$(37.1 \pm 7.5)^\circ$	NEW K^+K^-, OLD $K^+\bar{K}_0$ (PRL 88 (2002) 091602) + PDG.
CLEO OLD PRL 79 (1997) 3261	$0.61^{+0.11}_{-0.10}$	$(28.4^{+12.1}_{-9.7})^\circ$	

▷ LARGE PHASE DIFFERENCE ⟺ IMPORTANT FSI

★ CONCLUSION ★

- 1/2 HOUR NOT ENOUGH ... APOLOGIZE FOR WHAT WAS LEFT OUT
- CHARM PHYSICS REACHES MATURITY @ BEST OF WORLDS:
  - FULL OF MOTIVATION, SURPRISES ... REASONS TO LIVE
  - FULL OF GOOD NEW DADA ... ALL THAT GIFT

★ THANKS ★