Hadronic Decays of Charm Particles

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Talk Outline

I. Motivation

II. Description of E791, FOCUS, & SELEX experiments

III. New branching ratio measurements

IV. Analysis of resonant substructure in charm decays

V. Conclusions

Motivation/Background

Hadronic decays are rich in information about QCD

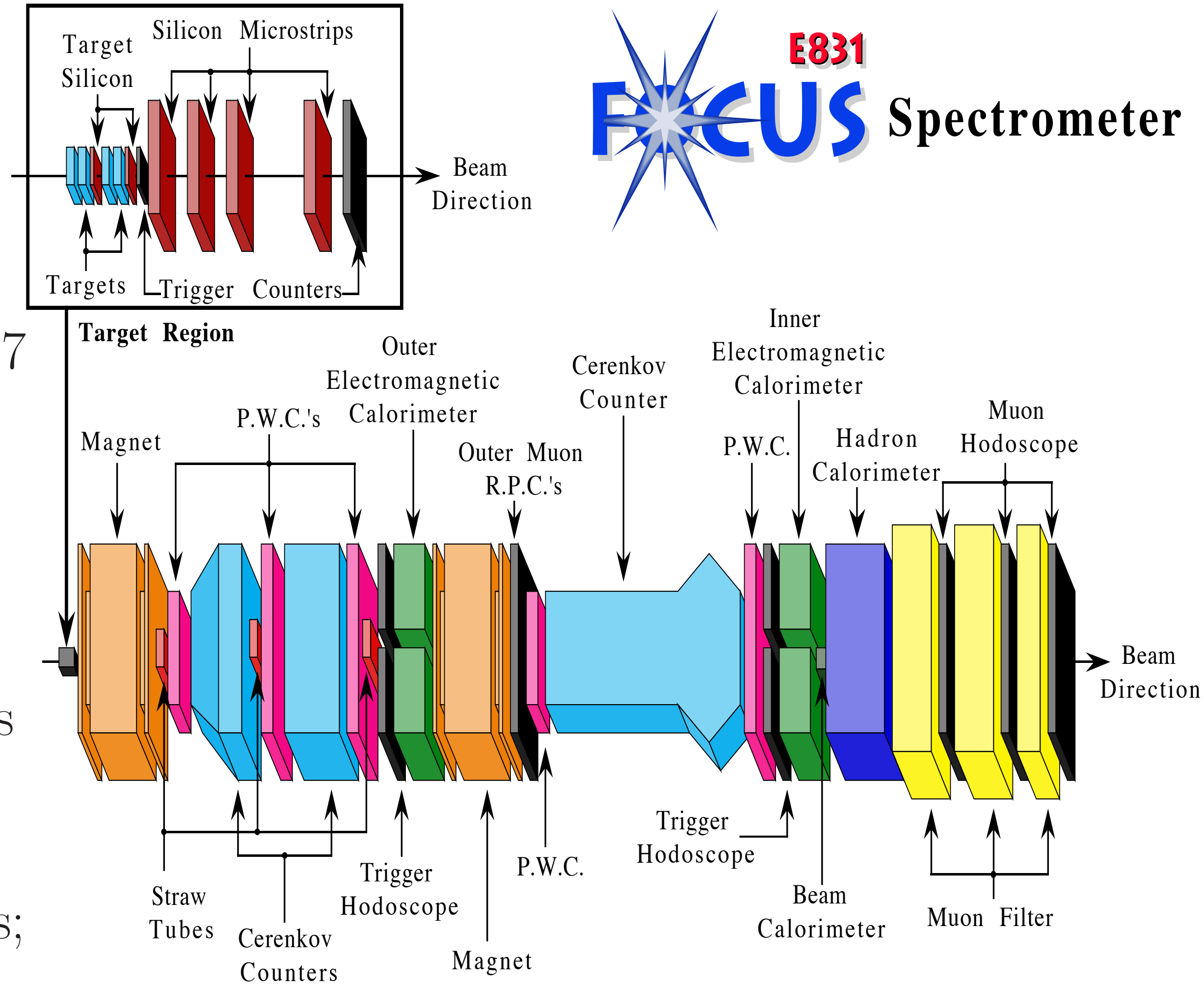
- Hadronic decays give rise to difference between D^+ and D^0 lifetimes
- Suppression of $D^0 \to \pi\pi$ to $D^0 \to KK$ proved importance of final state interactions in charm decays
- Hadronic decays can provide information on relative strengths of decay diagrams (spectator, W exchange, annihilation, etc.)
- Resonant analyses of charm decays can also provide information on light resonances
- The charm sector is rich (maybe too rich) in hadronic decay modes

Accessing information from hadronic decays can be difficult

- Branching ratios are fairly simple to measure
- Resonant analyses of multi-body final states are not so easy
  - Resonant parameters often not well known
  - Quantum mechanical interferences complicates the analysis

E791, FOCUS, & SELEX Experiments

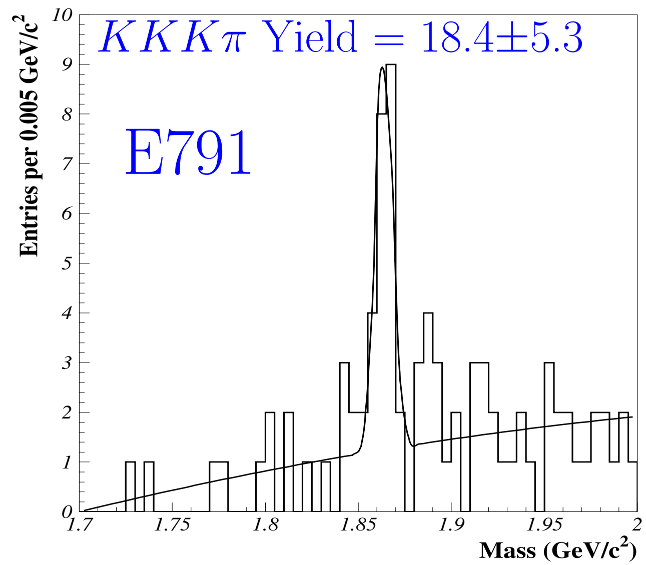
- Beams
  500 GeV π^-
  <180> GeV γ
  540–600 GeV p, Σ^- & π^-
- E791 ran in 1991/2
  SELEX & FOCUS in 1996/7
- All used segmented targets
- E791, FOCUS, & SELEX had 17, 16, & 38 Si planes for vertexing and tracking
- Wire chambers and magnets for tracking & momentum
- E791 (FOCUS) used 2(3) threshold Čerenkov counters; SELEX used a RICH

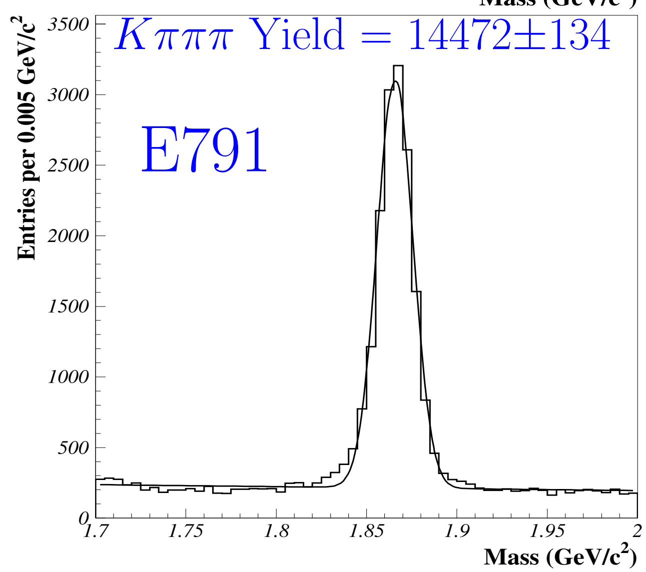


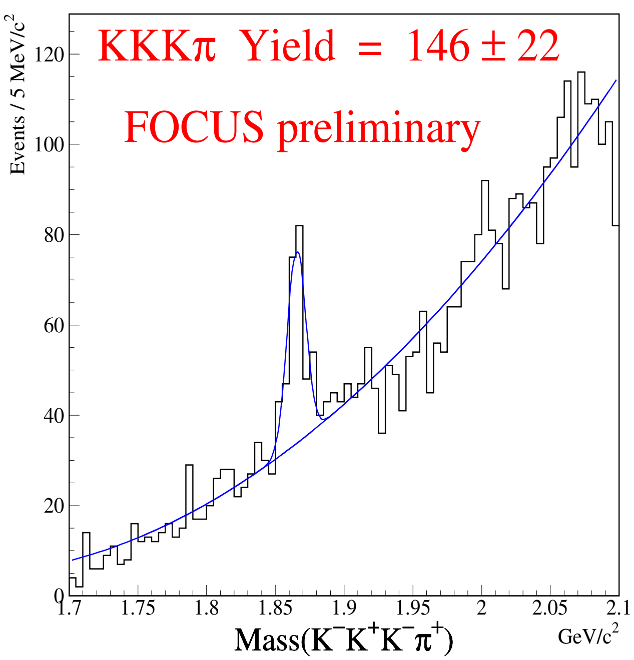
- E791 and FOCUS used EM and hadronic calorimeters to loosely trigger on hadronic events slightly enriched with charm. Goal is charm production and decays.
- SELEX used online vertex trigger based on miss distance. Goal is high-x_F baryons, especially charm-strange baryons.

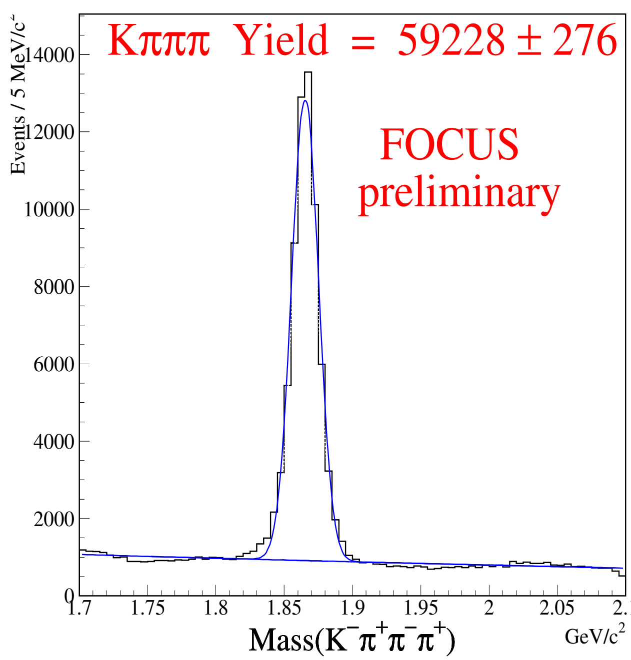
Branching Ratios (D^0)

- Deviations from naïve weak prediction give information about QCD
- Use the decay $BR\left(\frac{D^0 \to K^- K^+ K^- \pi^+}{D^0 \to K^- \pi^+ \pi^- \pi^+}\right)$ to measure $s\bar{s}$ popping penalty
- E687: $0.0028 \pm 0.0007 \pm 0.0001$
- E791: $0.0054 \pm 0.0016 \pm 0.0008$
- FOCUS preliminary: 0.00306 ± 0.00047



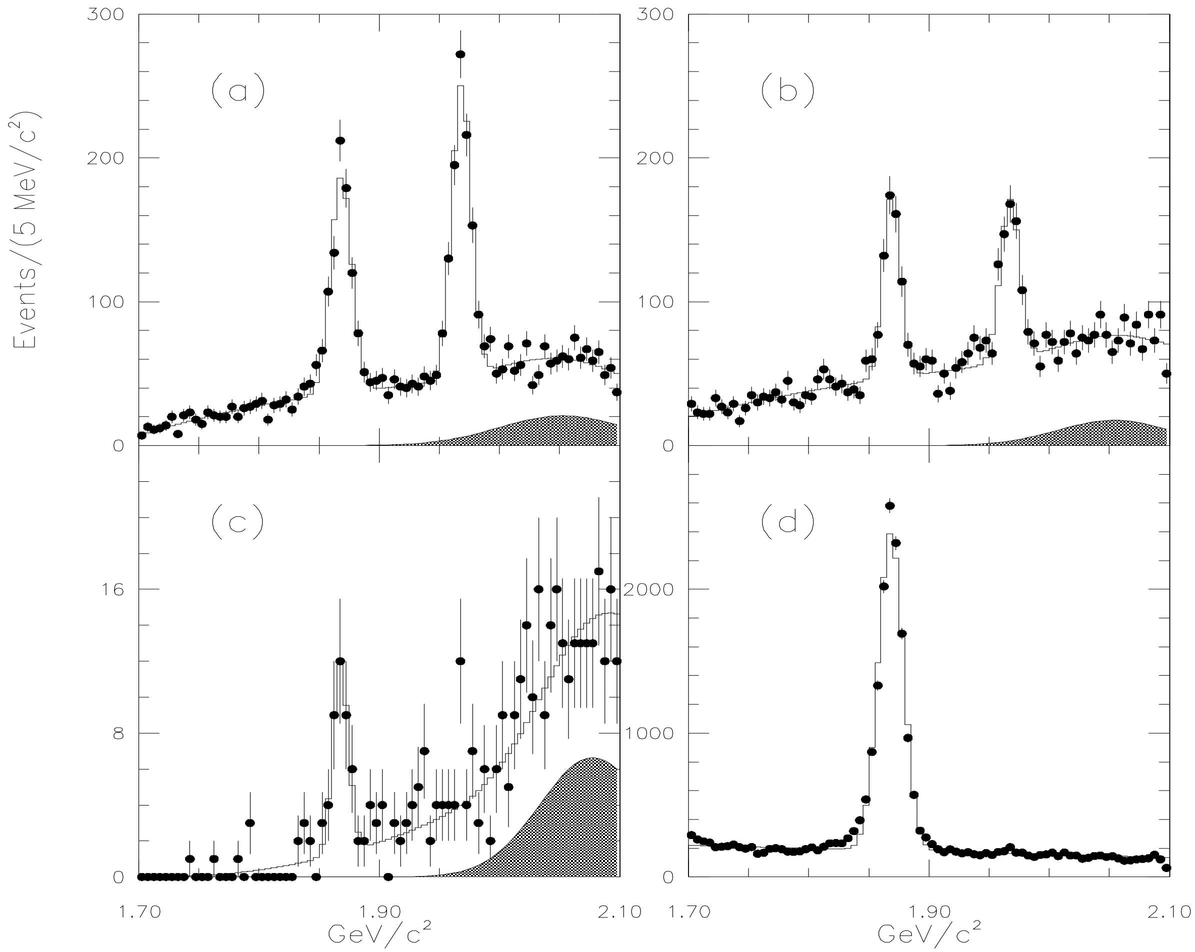






Branching Ratios ($D^+, D_s^+ \rightarrow K_s h^+ h^- h^+$)

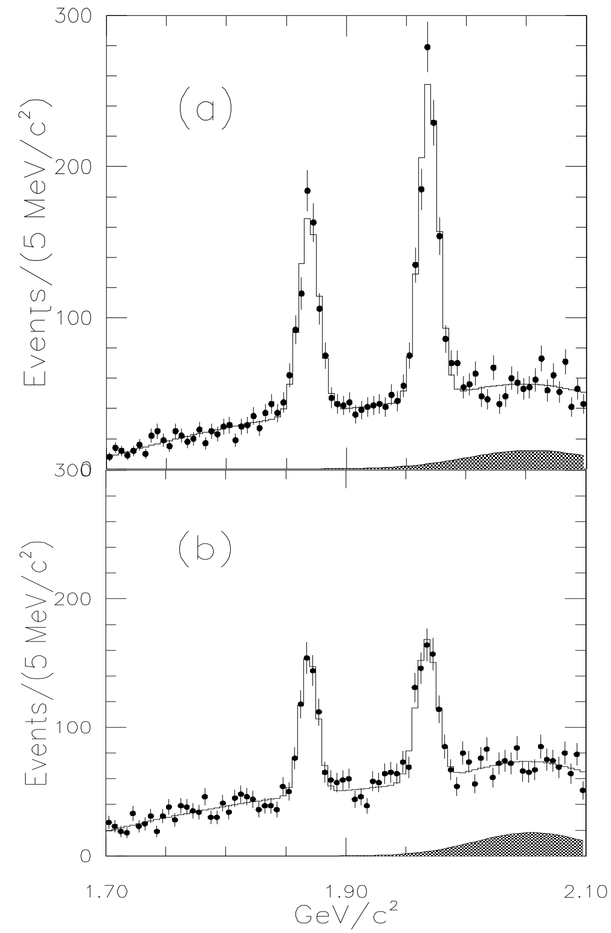
D^+ Branching Ratio	FOCUS	Previous
(a) $\Gamma(K^0 K^- \pi^+ \pi^+)$	$(0.54 \pm 0.08)\%$	$(1.0 \pm 0.6)\%$
(b) $\Gamma(\overline{K^0} K^+ \pi^- \pi^+)$	$(0.39 \pm 0.06)\%$	$< 2\%$
(c) $\Gamma(\overline{K^0} K^+ K^- \pi^+)$	$(0.054 \pm 0.014)\%$	—



(b) $\Gamma(D_s^+ \rightarrow \overline{K^0} K^+ \pi^- \pi^+)$

FOCUS: $(2.5 \pm 0.9)\%$

Previous: $< 2.8\%$



$D^+ \to K_s h^+$ – FOCUS preliminary

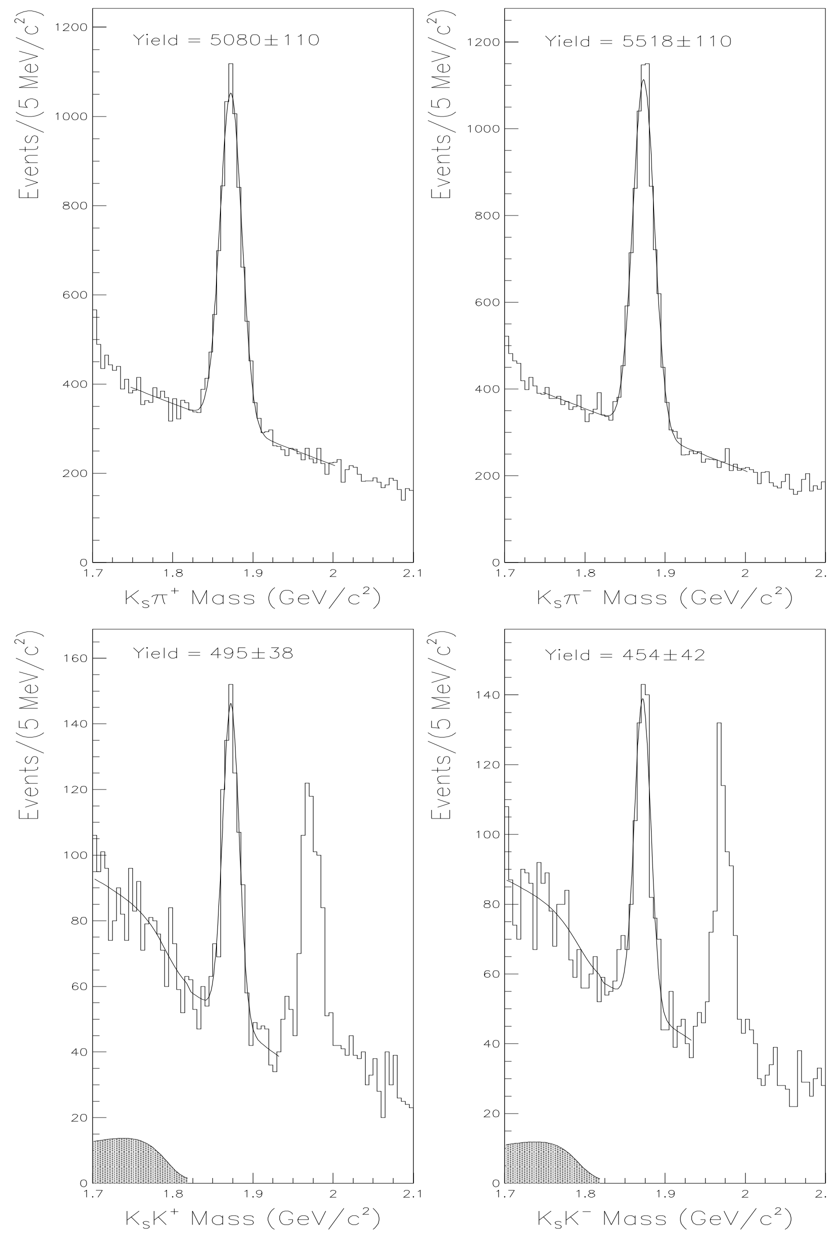
Branching Ratio Measurements:

D^+ BR	FOCUS	PDG Average
$\frac{\Gamma(\overline{K^0}\pi^+)}{\Gamma(K^-\pi^+\pi^+)}$	$(30.60\pm0.46\pm0.58)\%$	$(32.0\pm4.0)\%$
$\frac{\Gamma(\overline{K^0}K^+)}{\Gamma(K^-\pi^+\pi^+)}$	$(6.04\pm0.35\pm0.35)\%$	$(7.7\pm2.2)\%$
$\frac{\Gamma(\overline{K^0}K^+)}{\Gamma(\overline{K^0}\pi^+)}$	$(19.96\pm1.20\pm1.06)\%$	$(26.3\pm3.5)\%$

Direct *CP* Violation search:

- Measure $A_{CP} = \frac{\eta(D^+\to K_s h^+) - \eta(D^-\to K_s h^-)}{\eta(D^+\to K_s h^+) + \eta(D^-\to K_s h^-)}$
- Normalize to another mode to account for production asymmetries

CP Asymmetry	FOCUS
$A_{CP}(K_s\pi^+)$ w.r.t. $K^-\pi^+\pi^+$	$(-1.6\pm1.5\pm0.9)\%$
$A_{CP}(K_sK^+)$ w.r.t. $K^-\pi^+\pi^+$	$(6.9\pm6.0\pm1.8)\%$
$A_{CP}(K_sK^+)$ w.r.t. $K_s\pi^+$	$(7.1\pm6.1\pm1.4)\%$



Branching Ratio ($\Xi_c^+ \to pK^-\pi^+$)

- Only Cabibbo-suppressed decay of a charm-strange baryon ever seen
- First observed by SELEX; also seen by FOCUS

SELEX:

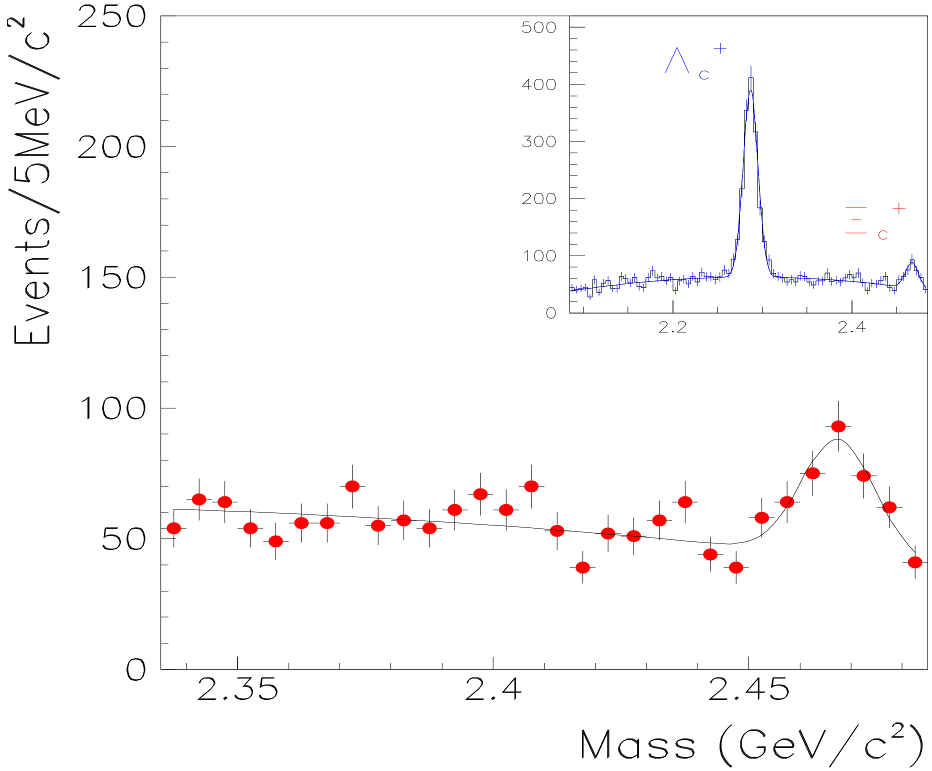
Yield ($\Xi_c^+ \to pK^-\pi^+$) $=$ 150 ± 22

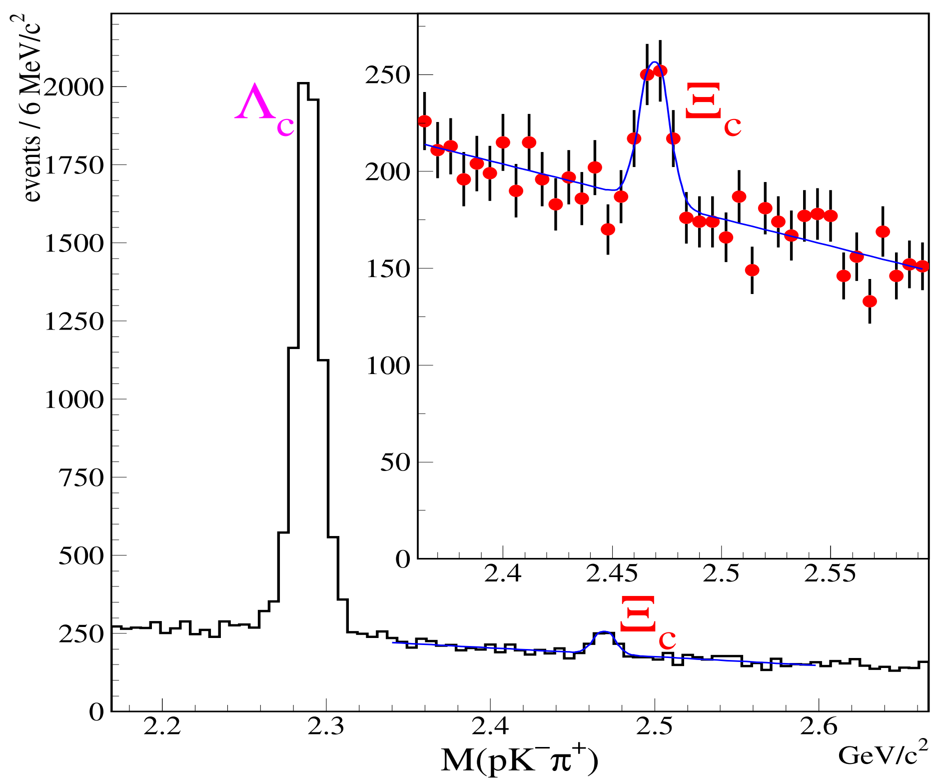
$$\frac{\Gamma(\Xi_c^+ \to pK^-\pi^+)}{\Gamma(\Xi_c^+ \to \Xi^-\pi^+\pi^+)} = (20 \pm 4 \pm 2)\%$$

FOCUS:

Yield ($\Xi_c^+ \to pK^-\pi^+$) $=$ 202 ± 35

$$\frac{\Gamma(\Xi_c^+ \to pK^-\pi^+)}{\Gamma(\Xi_c^+ \to \Xi^-\pi^+\pi^+)} = (23.4 \pm 4.7 \pm 2.2)\%$$





Resonance Analyses (Dalitz Plot)

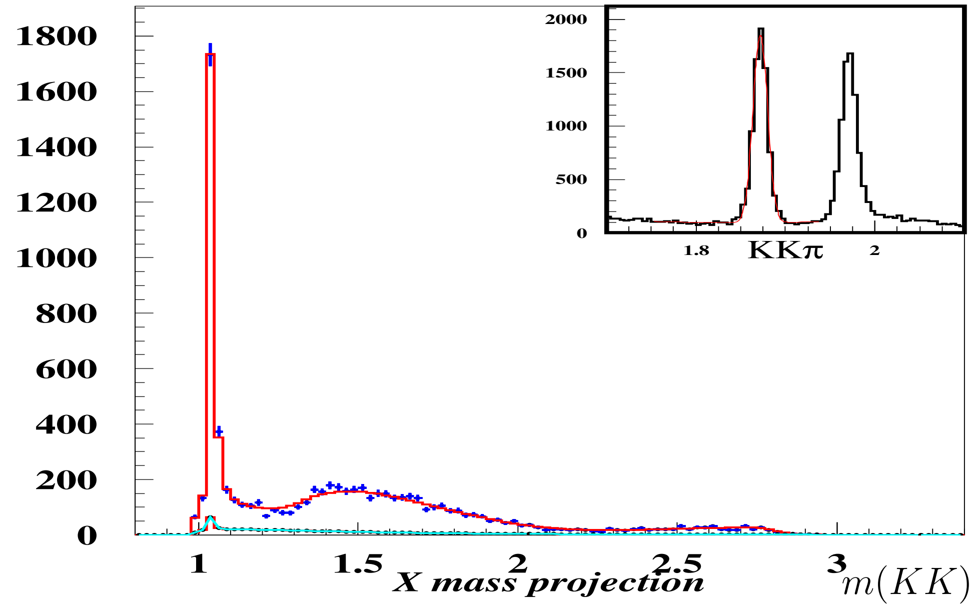
- For three-body final states, a Dalitz plot shows resonant contributions
- Fitting the Dalitz plot requires a coherent analysis allowing for interferences, different relative phases, etc.

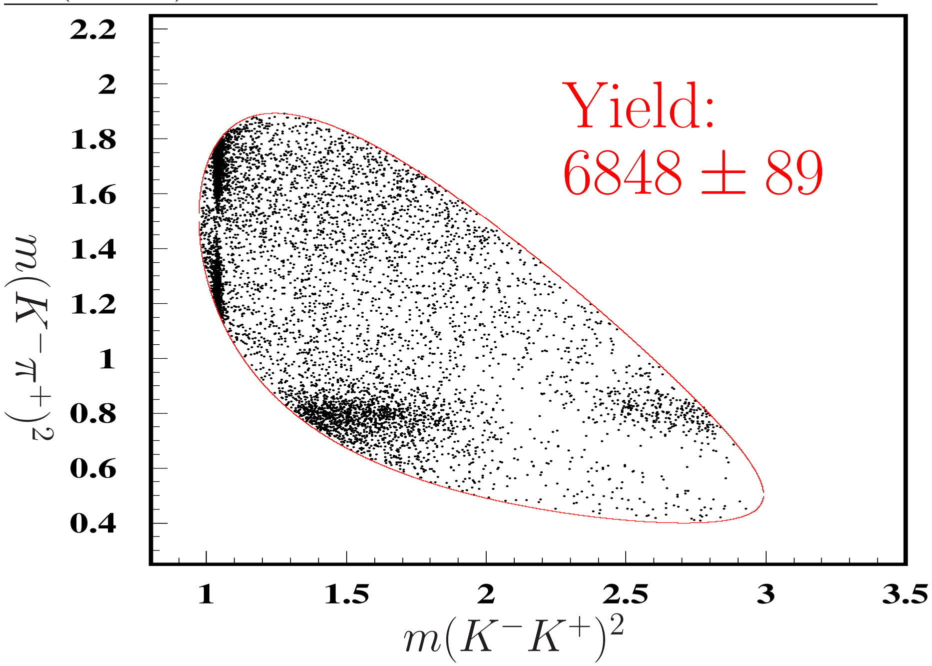
Dalitz plot analyses shown:

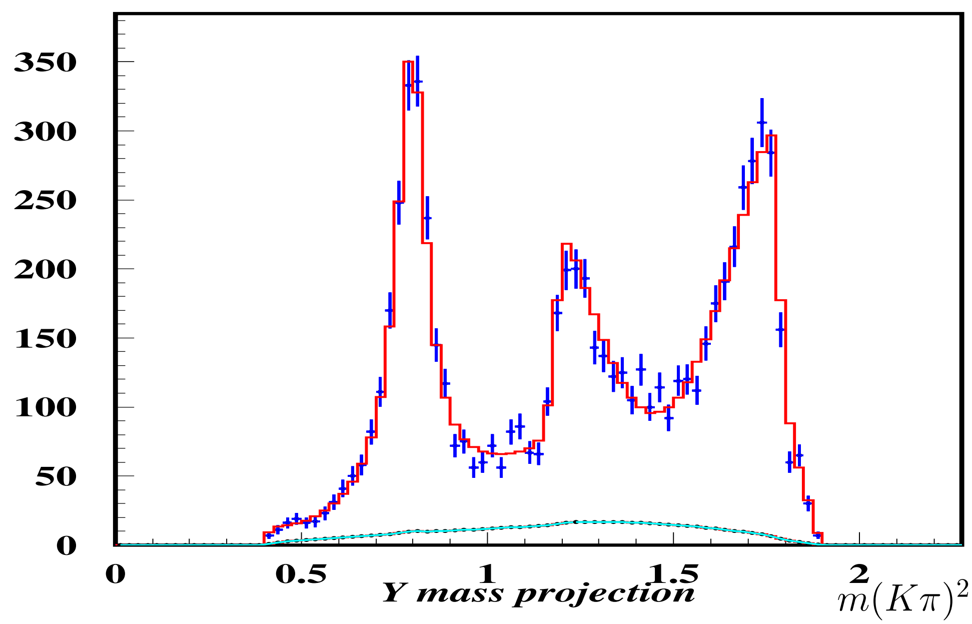
- $D^+ \to K^+K^-\pi^+$ (FOCUS)
- $D_s^+ \to \pi^+\pi^-\pi^+$ (E791 & FOCUS)
- $D^+ \to \pi^+\pi^-\pi^+$ (E791)
- $D^+ \to K^-\pi^+\pi^+$ (E791)
- $D^+ \to K^+\pi^-\pi^+$ (FOCUS)
- $D_s^+ \to K^+\pi^-\pi^+$ (FOCUS)

FOCUS $D^+ \to K^- K^+ \pi^+$ preliminary analysis

Mode	Fraction (%)	Phase (°)
$K^*(892)K^+$	22.0 ± 1.1	0 (fixed)
$a_0(980)\pi^+$	27.8 ± 4.8	146 ± 5
$\phi(1020)\pi^+$	27.8 ± 0.9	244 ± 6
$f_2(1270)\pi^+$	0.7 ± 0.2	12 ± 7
$f_0(1370)\pi^+$	5.9 ± 1.2	60 ± 6
$K^*(1410)K^+$	8.8 ± 1.9	135 ± 6
$K_0^*(1430)K^+$	69.3 ± 6.3	63 ± 4
$\phi(1680)\pi^+$	1.5 ± 0.5	-70 ± 9







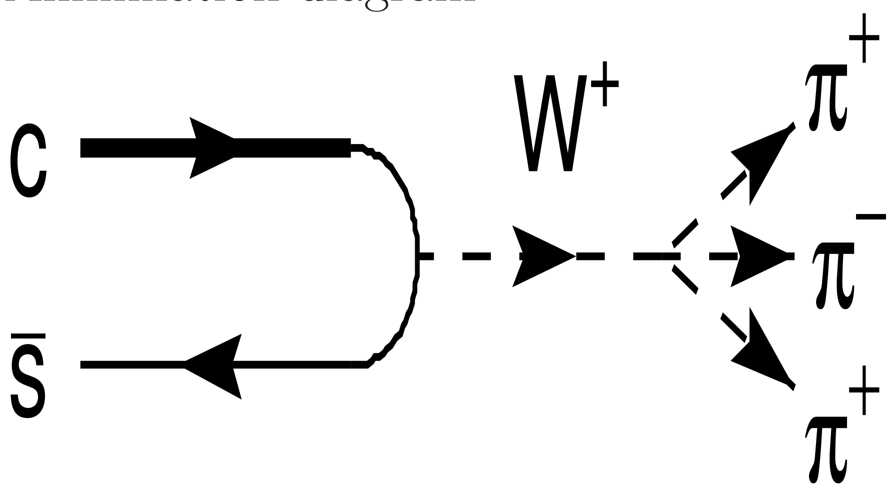
- Will look for direct CP violation by comparing D^+ & D^- Dalitz plots

$D_s^+ \to \pi^-\pi^+\pi^+$ Dalitz plot analysis

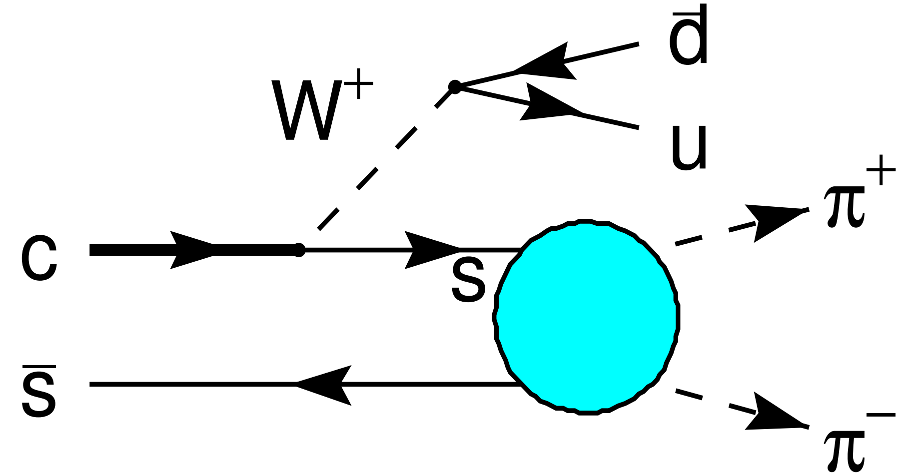
Cabibbo favored but 2 strange quarks disappear??

Interaction can proceed in two ways:

Annihilation diagram



Via resonance which couples to $K\overline{K}$ & $\pi\pi$



- $f_0(980)$ is an example of a resonance which couples to $K\overline{K}$ and $\pi\pi$
- Significant $\rho(770)$ would indicate annihilation diagram contributions

FOCUS $D_s^+ \to \pi^-\pi^+\pi^+$ preliminary analysis

Mode	Fraction (%)	Phase (°)
$f_0(980)\pi^+$	94.4 ± 2.5	0 (fixed)
NR	25.5 ± 4.4	246 ± 4
$f_2(1270)\pi^+$	9.8 ± 1.2	140 ± 6
$\rho(1450)\pi^+$	4.1 ± 0.7	188 ± 14
$S_0(1475)\pi^+$	17.4 ± 2.2	250 ± 4

Use data to measure parameters:

$S_0(1475)$

$$M_{S_0(1475)} = 1473 \pm 8\ \mathrm{MeV}/c^2$$

$$\Gamma_{S_0(1475)} = 112 \pm 17\ \mathrm{MeV}/c^2$$

$f_0(980)$ in K-matrix formalism

$$M_{f_0(980)} = 963 \pm 6\ \mathrm{MeV}/c^2$$

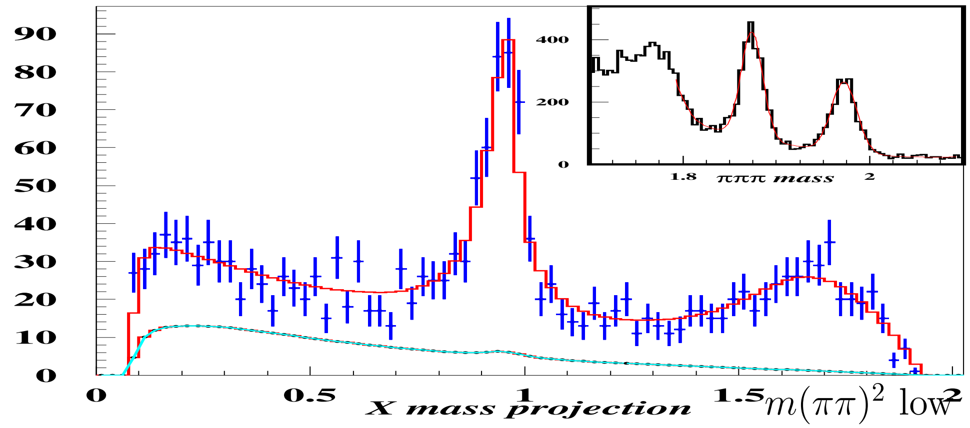
$$\Gamma_{f_0(980)} = 297 \pm 92\ \mathrm{MeV}/c^2$$

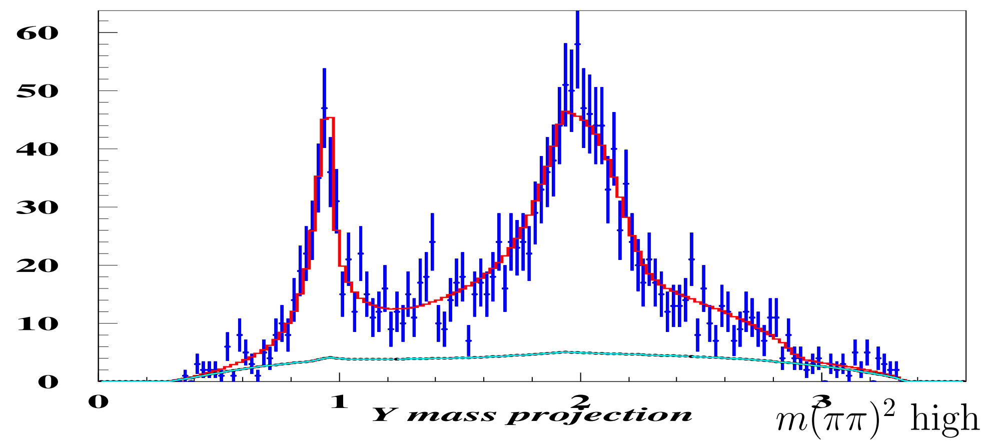
$$\gamma^2_{KK}/\gamma^2_{\pi\pi} = 2.09 \pm 0.53$$

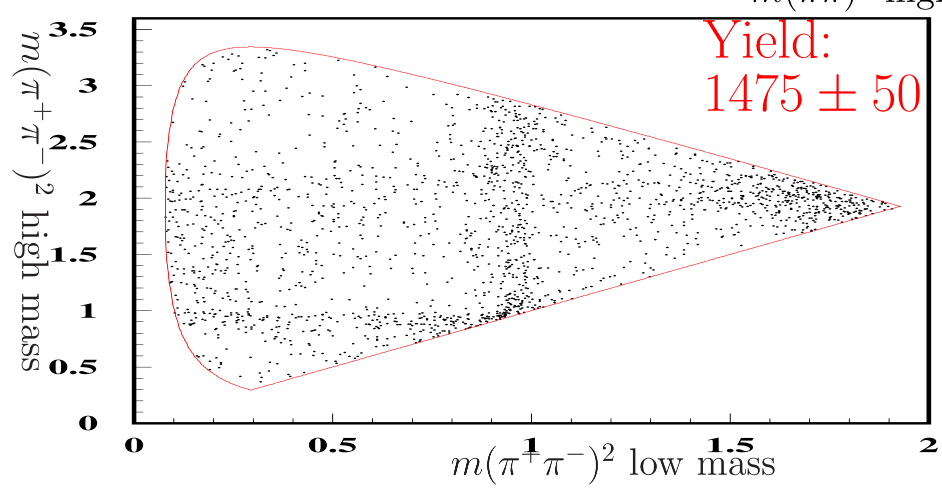
$f_0(980)$ converted to standard Breit-Wigner

$$M_{f_0(980)} = 982\ \mathrm{MeV}/c^2$$

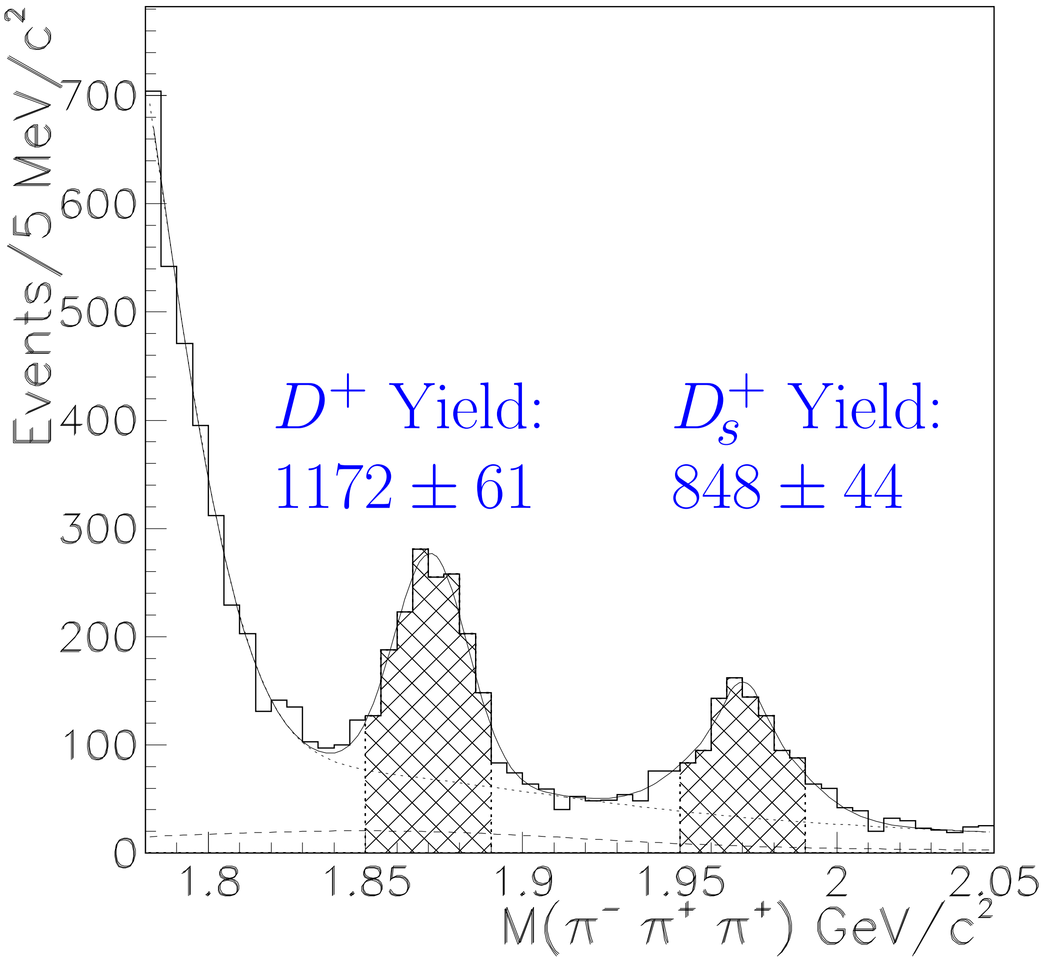
$$\Gamma_{f_0(980)} = 89\ \mathrm{MeV}/c^2$$

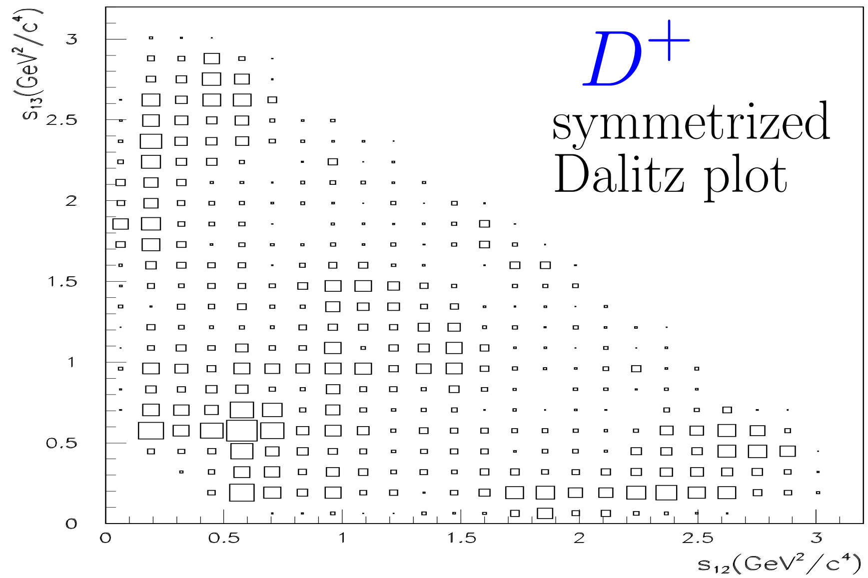


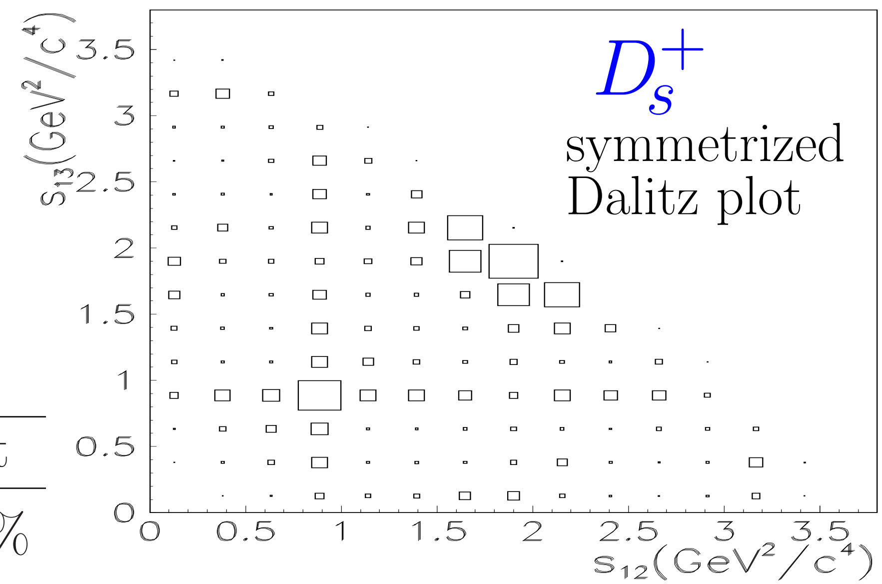




E791 $D^+, D_s^+ \to \pi^-\pi^+\pi^+$ analysis







BR	E791	PDG2K Fit
$\Gamma\left(\frac{D^+\to\pi^-\pi^+\pi^+}{D^+\to K^-\pi^+\pi^+}\right)$	$(3.11\pm0.18^{+0.16}_{-0.26})\%$	$(4.06\pm0.34)\%$
$\Gamma\left(\frac{D_s^+\to\pi^-\pi^+\pi^+}{D_s^+\to\phi\pi^+}\right)$	$(24.5\pm2.8^{+1.9}_{-1.2})\%$	$(28\pm6)\%$

E791 $D_s^+ \to \pi^-\pi^+\pi^+$ resonant analysis

- Fit for resonant amplitudes and phases
- Large errors on $f_0(980)$ and $f_0(1370)$ parameters $\Rightarrow$ fit for these parameters

$f_0(1370)$ parameters

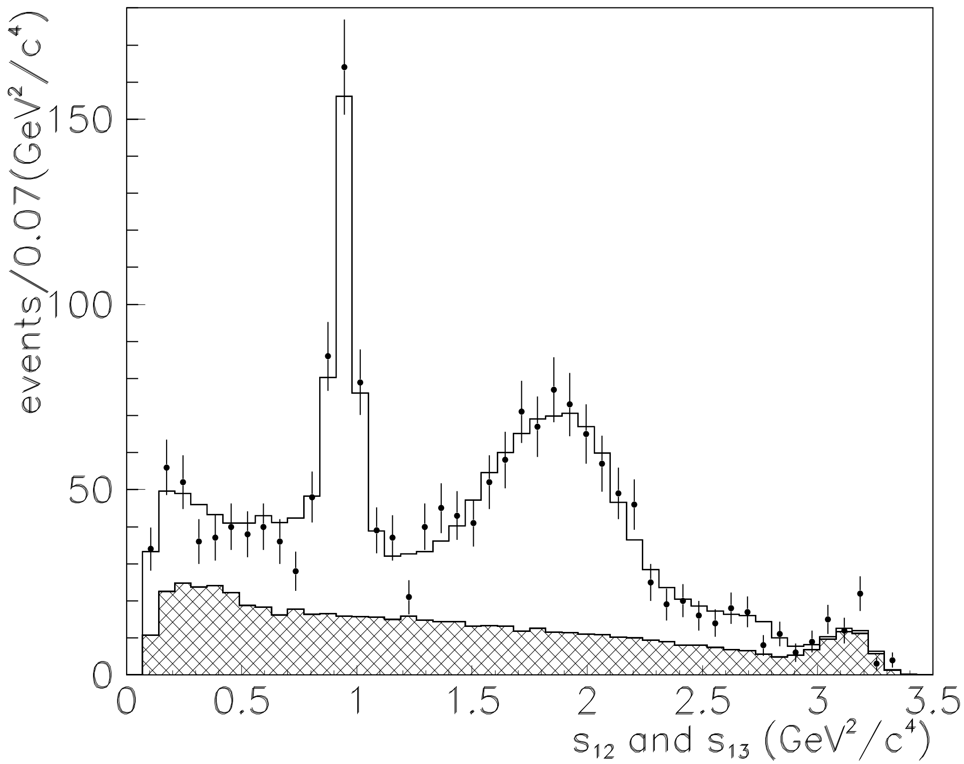
$$M_{f_0(1370)} = 1434 \pm 18 \pm 9 \text{ MeV}/c^2$$
$$\Gamma_{f_0(1370)} = 172 \pm 32 \pm 6 \text{ MeV}/c^2$$

$f_0(980)$ parameters
(coupled channel Breit Wigner)

$$M_{f_0(980)} = 977\pm3\pm2 \text{ MeV}/c^2$$
$$g_\pi = 0.09 \pm 0.01 \pm 0.01$$
$$g_K = 0.02 \pm 0.04 \pm 0.03$$

$f_0(980)$ parameters
(standard Breit Wigner)

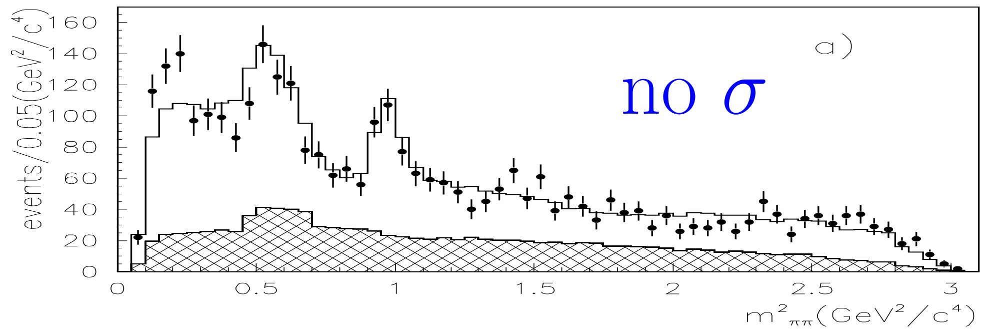
$$M_{f_0(980)} = 975\pm3\pm2 \text{ MeV}/c^2$$
$$\Gamma_{f_0(980)} = 44 \pm 2 \pm 2 \text{ MeV}/c^2$$



Mode	Fraction (%)	Phase (°)
$f_0(980)\pi^+$	56.5±4.3±4.7	0 (fixed)
NR	0.5±1.4±1.7	181±94±51
$\rho(770)\pi^+$	5.8±2.3±3.7	109±24±5
$f_2(1270)\pi^+$	19.7±3.3±0.6	133±13±28
$f_0(1370)\pi^+$	32.4±7.7±1.9	198±19±27
$\rho(1450)\pi^+$	4.4±2.1±0.2	162±26±17

E791 $D^+ \to \pi^-\pi^+\pi^+$ resonant analysis

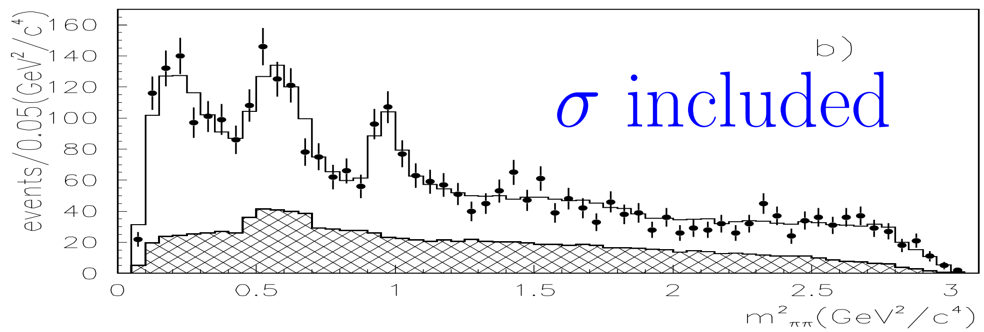
a) No σ in model (CL $= 10^{-5}$)



b) σ in model (CL $= 75\%$)

$$M_\sigma = 478^{+24}_{-23} \pm 17 \text{ MeV}/c^2$$

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



(a)

Mode	Fraction(%)	Phase (°)
$\rho(770)\pi^+$	20.8±2.4	0 (fixed)
NR	38.6±9.7	150±12
$f_0(980)\pi^+$	7.4±1.4	152±16
$f_2(1270)\pi^+$	6.3±1.9	103±16
$f_0(1370)\pi^+$	10.7±3.1	143±10
$\rho(1450)\pi^+$	22.6±3.7	46±15

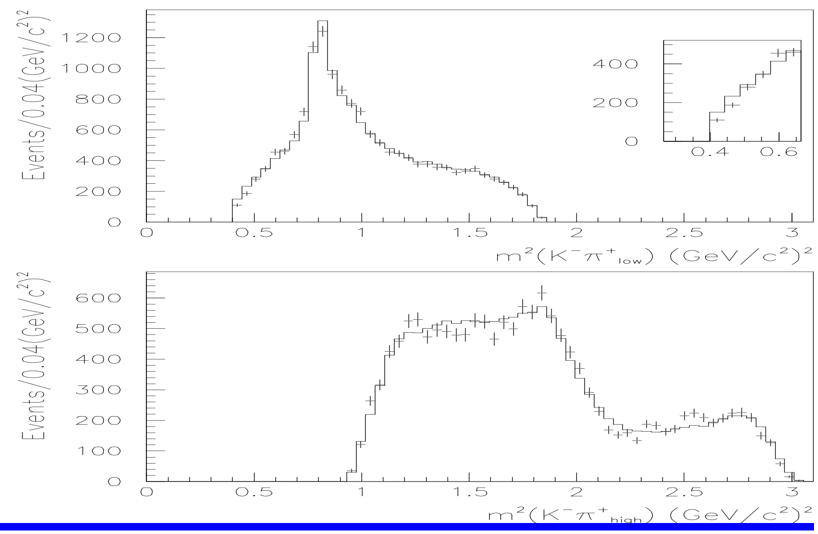
(b)

Mode	Fraction (%)	Phase (°)
$\sigma\pi^+$	46.3±9.0±2.1	206±8±5
$\rho(770)\pi^+$	33.6±3.2±2.2	0 (fixed)
NR	7.8±6.0±2.7	57±20±6
$f_0(980)\pi^+$	6.2±1.3±0.4	165±11±3
$f_2(1270)\pi^+$	19.4±2.5±0.4	57±8±3
$f_0(1370)\pi^+$	2.3±1.5±0.8	105±18±1
$\rho(1450)\pi^+$	0.7±0.7±0.3	319±39±11

E791 $D^+ \to K^-\pi^+\pi^+$ preliminary analysis

Standard fit, known resonances: CL $= 10^{-11}$

Mode	Fraction (%)	Phase (°)
NR	90.9 ± 2.6	0 (fixed)
$K^*(892)\pi^+$	13.8 ± 0.5	54 ± 2
$K_0^*(1430)\pi^+$	30.6 ± 1.6	54 ± 2
$K_2^*(1430)\pi^+$	0.4 ± 0.1	33 ± 8
$K^*(1680)\pi^+$	3.2 ± 0.3	66 ± 3



Fit with κ and free K_0^* parameters: CL $= 95\%$

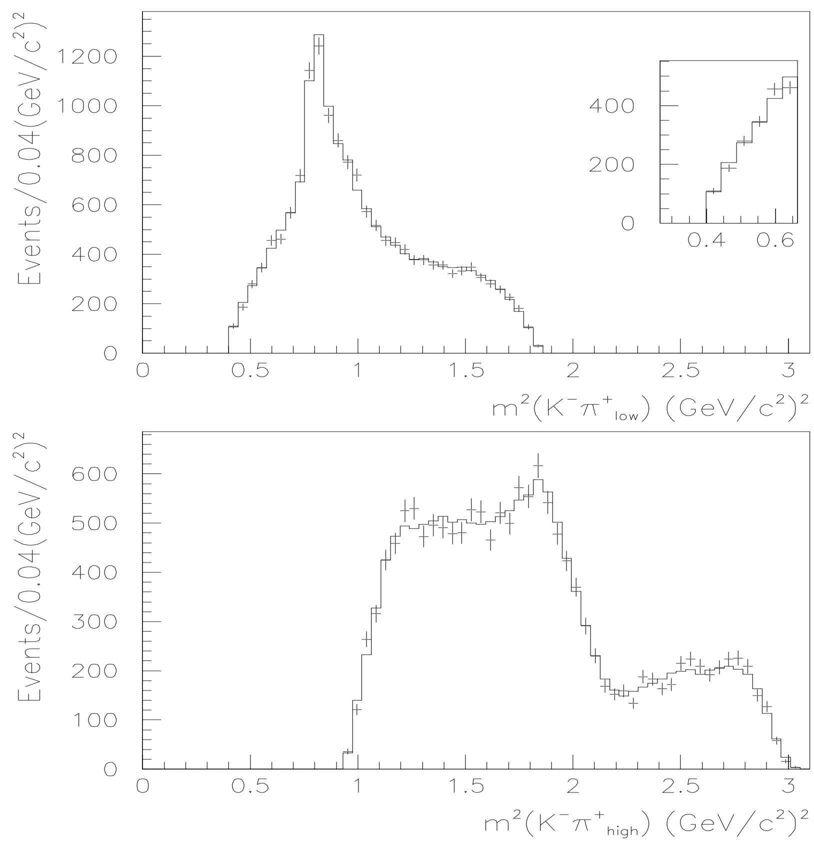
$M_\kappa = 797 \pm 19 \pm 42$ MeV/c^2

$\Gamma_\kappa = 410 \pm 43 \pm 85$ MeV/c^2

$M_{K_0^*(1430)} = 1459 \pm 7 \pm 6$ MeV/c^2 (PDG $= 1412 \pm 6$)

$\Gamma_{K_0^*(1430)} = 175 \pm 12 \pm 12$ MeV/c^2 (PDG $= 294 \pm 23$)

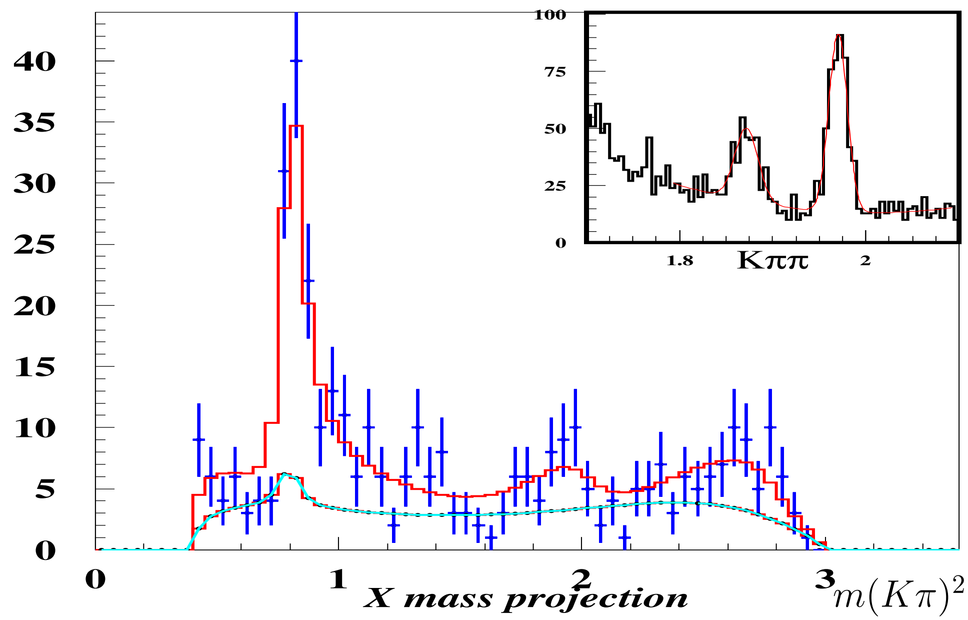
Mode	Fraction (%)	Phase (°)
$\kappa\pi^+$	$47.8 \pm 12.1 \pm 3.7$	$187 \pm 8 \pm 17$
NR	$13.0 \pm 5.8 \pm 2.6$	$349 \pm 14 \pm 8$
$K^*(892)\pi^+$	$12.3 \pm 1.0 \pm 0.9$	0 (fixed)
$K_0^*(1430)\pi^+$	$12.5 \pm 1.4 \pm 0.4$	$48 \pm 7 \pm 10$
$K_2^*(1430)\pi^+$	$0.5 \pm 0.1 \pm 0.2$	$306 \pm 8 \pm 6$
$K^*(1680)\pi^+$	$2.5 \pm 0.7 \pm 0.2$	$28 \pm 13 \pm 15$

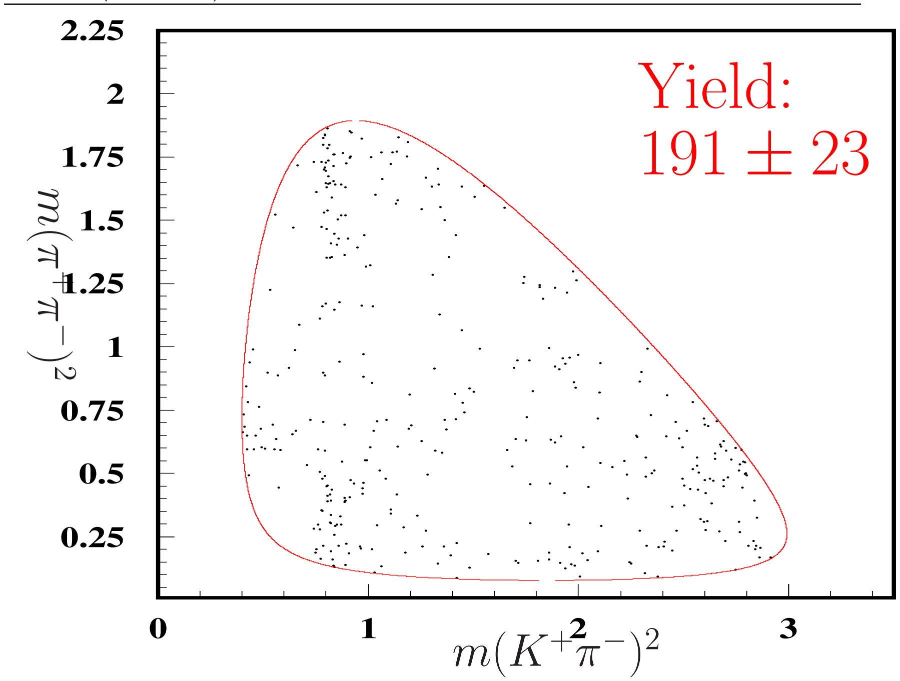


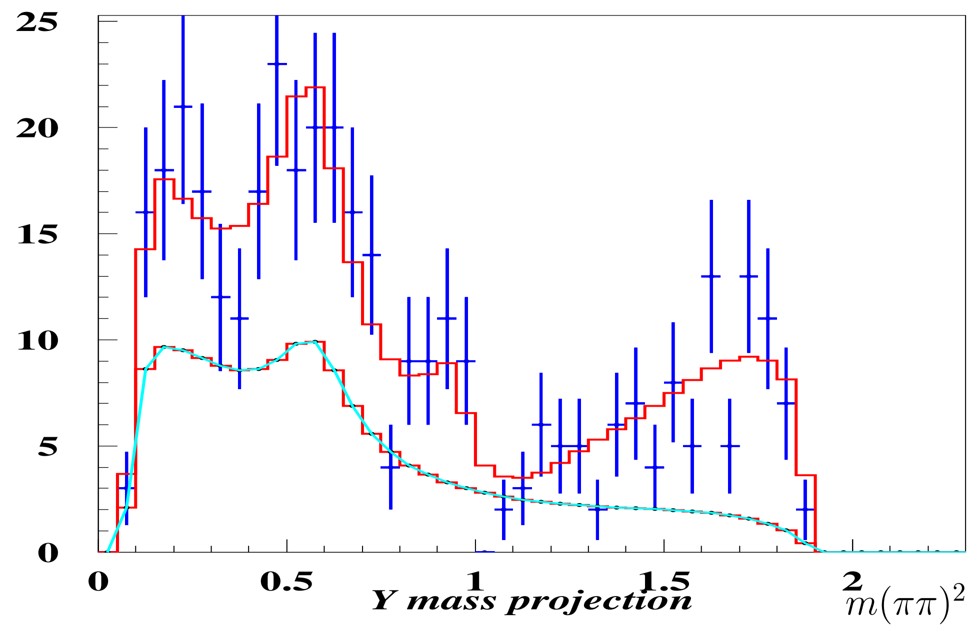
FOCUS $D^+ \to K^+\pi^-\pi^+$ preliminary analysis

Doubly Cabbibo suppressed decay

Mode	Fraction (%)	Phase (°)
$\rho(770)K^+$	51 ± 10	0 (fixed)
NR	9 ± 5	-6 ± 16
$K^*(892)\pi^+$	43 ± 7	208 ± 16
$f_0(980)K^+$	9 ± 5	73 ± 31
$K^*(1410)\pi^+$	12 ± 8	133 ± 23
$K_2^*(1430)\pi^+$	6 ± 3	48 ± 27
$\rho(1450)K^+$	10 ± 5	247 ± 15
$K^*(1680)\pi^+$	22 ± 10	2 ± 20



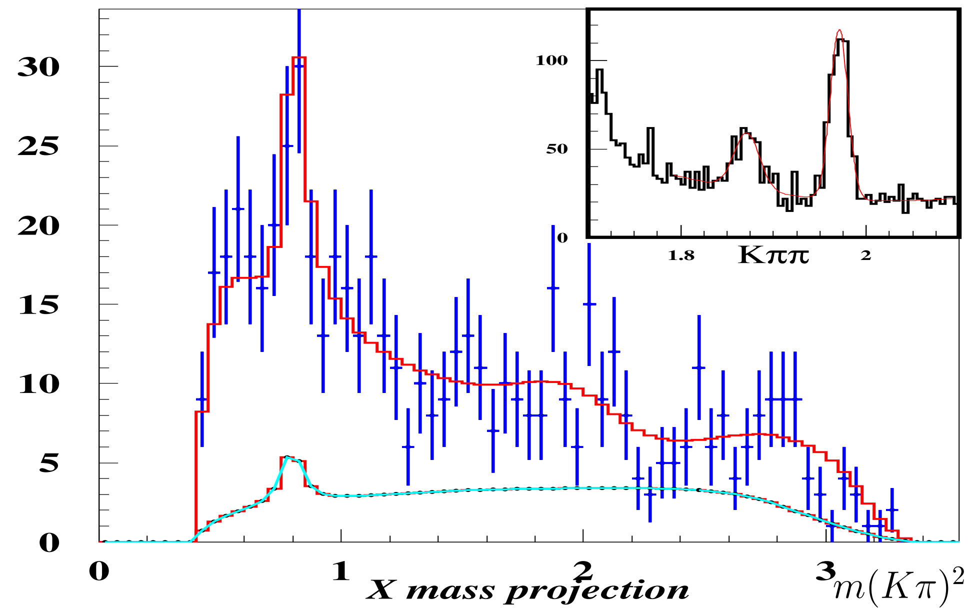


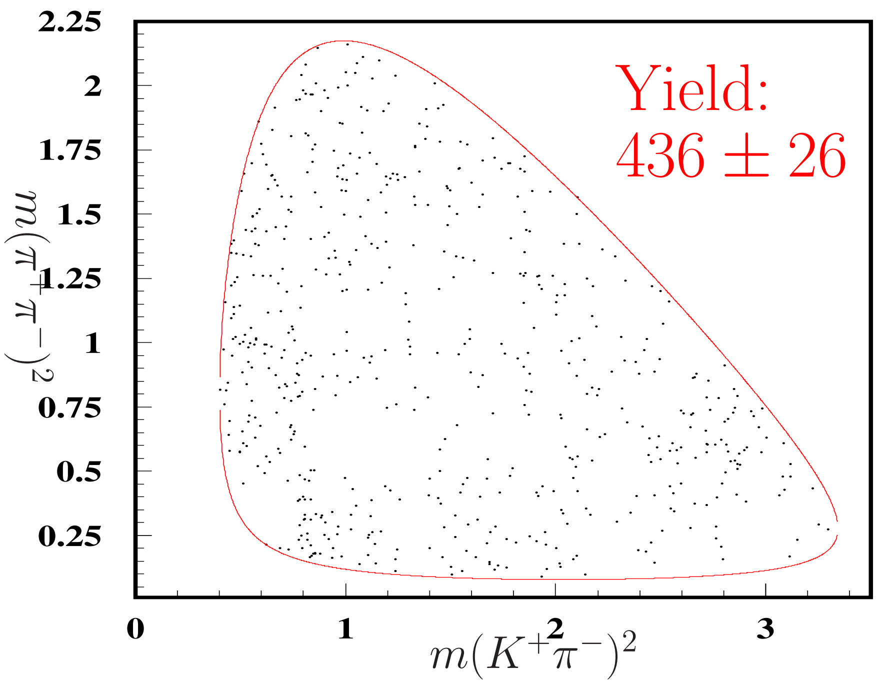


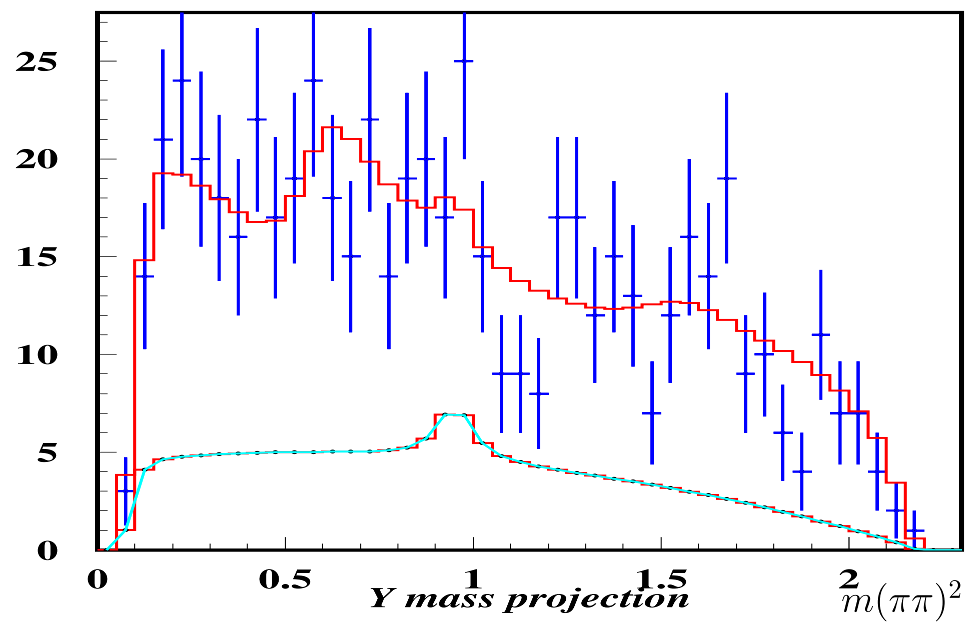
FOCUS $D_s^+ \to K^+\pi^-\pi^+$ preliminary analysis

Singly Cabbibo suppressed decay

Mode	Fraction (%)	Phase (°)
$\rho(770)K^+$	40 ± 4	0 (fixed)
NR	18 ± 4	34 ± 7
$K^*(892)\pi^+$	22 ± 3	163 ± 7
$f_2(1270)K^+$	2 ± 1	33 ± 21
$K^*(1410)\pi^+$	14 ± 5	-10 ± 7
$K_0^*(1430)\pi^+$	14 ± 6	68 ± 7
$\rho(1450)K^+$	8 ± 2	219 ± 14







Conclusions

- You can never have enough statistics in charm hadronic decays
- Charm hadronic decays can be used to investigate light resonances:

	E791		FOCUS	
Resonance	M (MeV/c^2)	Γ (MeV/c^2)	M (MeV/c^2)	Γ (MeV/c^2)
σ	$478^{+24}_{-23}\pm17$	$324^{+42}_{-40}\pm21$		
κ	$797\pm19\pm42$	$410\pm43\pm85$		
$f_0(980)$	$975\pm3\pm2$	$44\pm2\pm2$	982	89
$f_0(1370)/S_0(1475)$	$1434\pm18\pm9$	$172\pm32\pm6$	1473 ± 8	112 ± 17
$K_0^*(1430)$	$1459\pm7\pm6$	$175\pm12\pm12$		

- Exploring the nature of final-state interactions is ongoing
- Evidence for W-annihilation contributions seems to be lacking so far
- Resonant analysis will allow direct CP violation searches of multi-body decay modes
- FOCUS will have its hands full analyzing many decay modes
- Hopefully the e^+e^- experiments will also contribute