Charm Dalitz analyses

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Outline

- Theoretical motivations.
  - Extract (and exploit) strong interaction dynamics.
- *Dalitz analysis* of multibody hadronic final states
  - Results from B-factories (BaBar)
    - $D^+ \to \pi^+\pi^-\pi^+$
    - $D^0 \to K^0K^-\pi^+, K^0K^+K^-, K^0\pi^+\pi^-$.
    - $D_s \to \pi^+K^+K^-$
  - For Belle results see talk on D-mixing
  - Results from the charm threshold (CLEO-c)
    - $D^+ \to \pi^+\pi^-\pi^+$, $D^0 \to K^0K^-\pi^+$

Latest results available

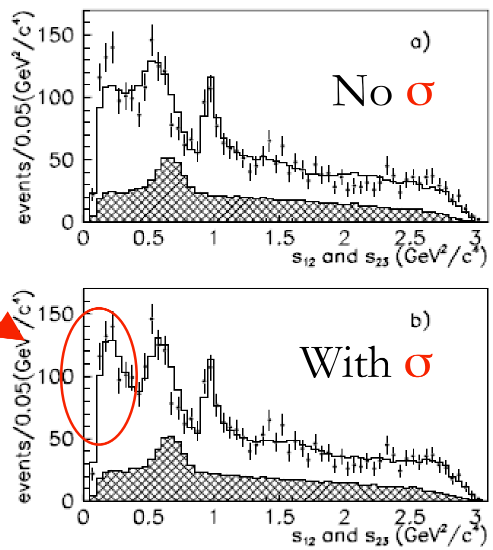
Light meson spectroscopy

- Scalar mesons, unknown beasts!

I = 1	I = ½	I=0
		$f_0(600)$[?]
$a_0(980)$	k(800)[?]	$f_0(980)$
		$f_0(1370)$
$a_0(1450)$	$K_0^*(1430)$	$f_0(1500)$
		$f_0(1710)$
		$X_0(1550)$

– Too many to fit into a single $q\bar{q}$ nonet
  » Which nature ? Multiquark ? Meson-meson buond states ?
– Large width, experimentally difficult to resolve

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



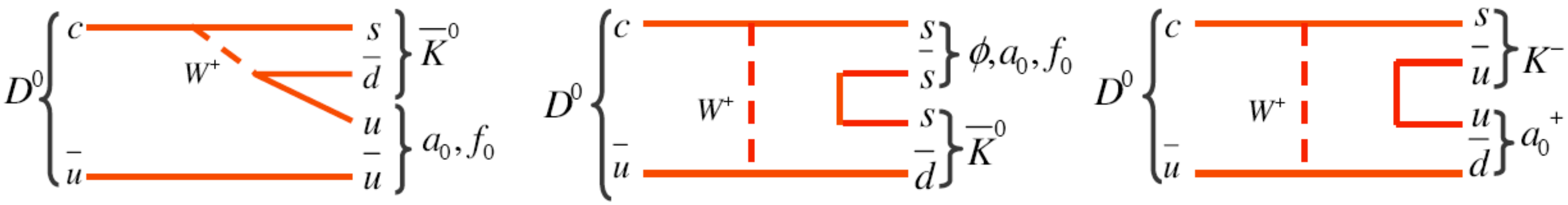
$\sigma \equiv f_0(600)$ or low mass $\pi^+\pi^-$ S-wave is required.

Different parametrization
FOCUS: K-matrix;
E791:Rel.Breit-Wigner (BW)

$a_0/f_0(980)$ mesons

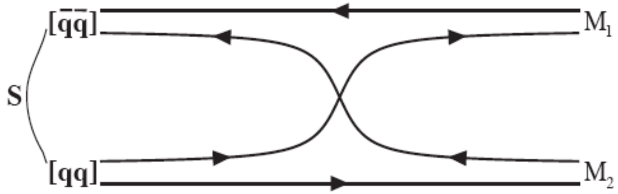
- Non-strange and strange content in $f_0(980)$ and $a_0(980)$
- They lie on the KK threshold
  - Resonance shape affected
    - » Flatte's parametrization used:
      large errors on the couplings!!

- Analysis of $D^0 \to K^+K^-\overline{K}^0$ can help!



An example: tetraquarks?

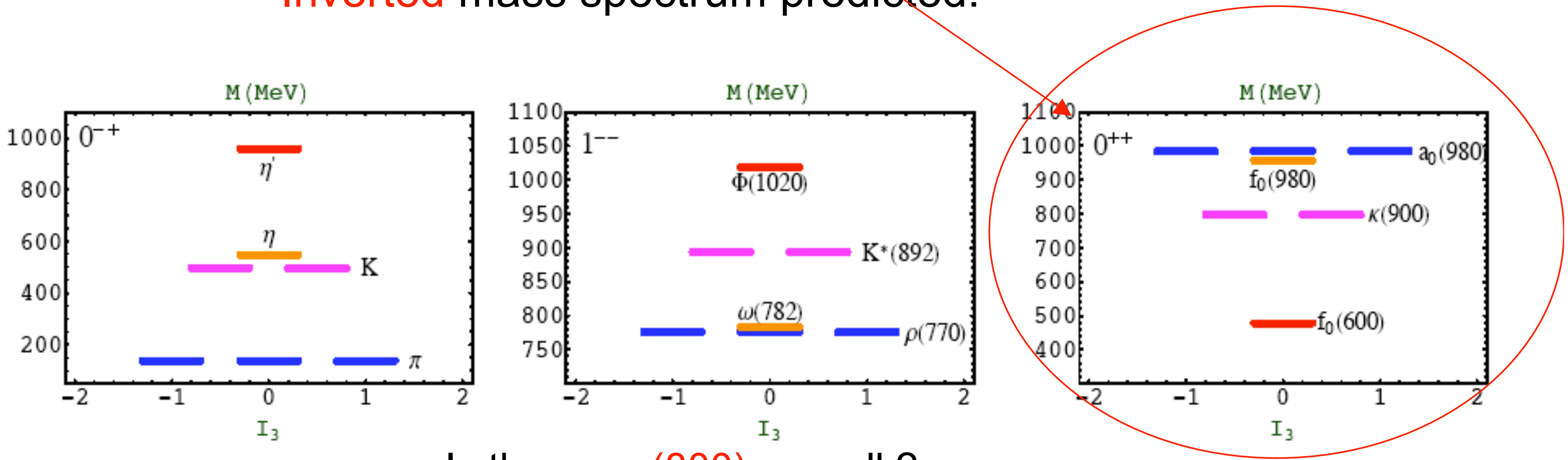
– 2 diquark bound state decay to 2 mesons



S. Nussinov, hep-ph/0307357; M. Karliner and H.J. Lipkin, hep-ph/0307243. R.L. Jaffe and F. Wilczek, Phys. Rev. Lett. **91** (2003) 232003.

L.Maiani et al., Phys.Rev.Lett. 93 (2004) 212002

- Inverted mass spectrum predicted!



» Is there a κ(800) as well ?

» What is the $K^{*0}(1430)$?

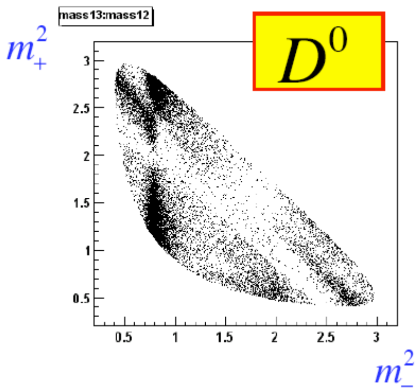
S-wave and CKM γ extraction

$D^0 \to K_s\pi^+\pi^-$ has a rich dynamics

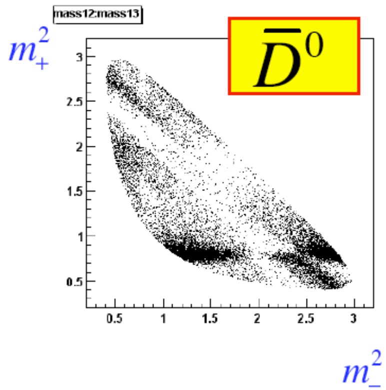
Big $K\pi$ and $\pi\pi$ S-wave

Pictorial view of decay rate of $B^- \to D^0 K^-$ with $D^0 \to K_S \pi^+\pi^-$

$|\mathcal{A}\_|^2 = \Big|$



$+ r_B e^{i(\delta_B - \gamma)}$



$\Big|^2$

$$r_B = \frac{|\mathcal{A}(B^- \to \overline{D}^0 K^-)|}{|\mathcal{A}(B^- \to D^0 K^-)|} \approx 0.1 - 0.3$$

$\delta_B =$ strong phase

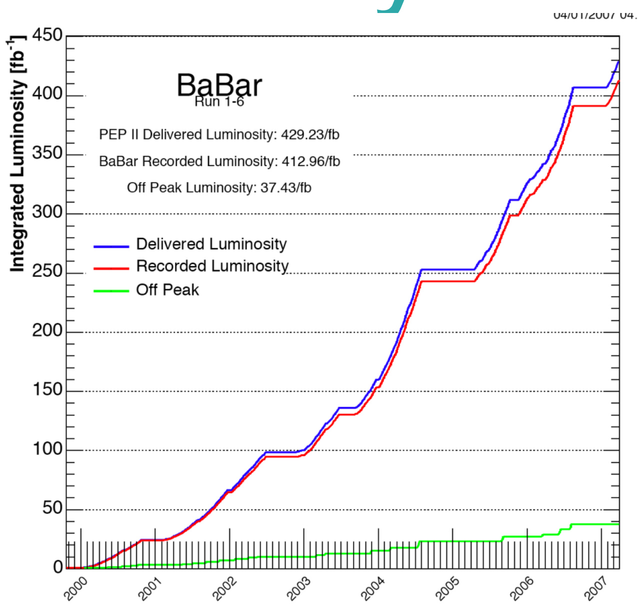
$\gamma =$ weak phase

D^0 decay amplitude is an input for B decay amplitude description

It's crucial to parametrize S-wave correctly !

B-factory and charm factory

- D meson decays
  - » Large coupling to scalar mesons
  - » Initial state always $\mathbf{J^P = 0^-}$
  - » Isospin and parity violation possible



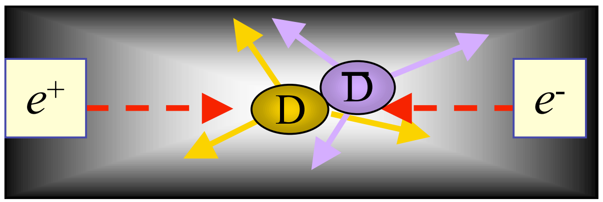
Run 1-5: more than 500M cc events

- B-factories are producing $c\bar{c}$ events too

$$\sigma_{eff}(b\bar{b}) = 1.1\ nb \qquad \sigma_{eff}\left(c\bar{c}\right) = 1.3\ nb$$

- CLEO-c
  - Run on threshold!
  - Quantum-coherence

$$\psi(3770) \rightarrow D\bar{D}$$



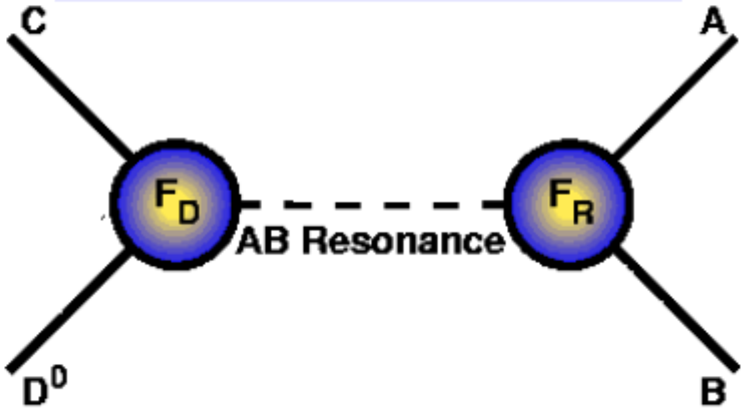
- Pure C = -1
- No additional particles
- Low multiplicity
- Clean ν recon.

281 pb^{-1} @ $\psi(3770)$

Dalitz amplitudes

D^0 three-body decay $D^0 \to ABC$ decaying through an r=[AB] resonance

S. Kopp *et al.*, Phys.Rev.**D63**:092001,2001



D^0 three-body amplitude

$$\mathcal{A}_D(s_{12}, s_{13}) = a_0 e^{i\delta_0} + \sum_r a_r e^{i\delta_r} \mathcal{A}_r(s_{12}, s_{13})$$

NR term (direct 3 body decay)

a_0, δ_0, a_r, δ_r : Free parameters of fit

$$\mathcal{A}_r(s_{12}, s_{13}) = F_D^J F_r^J \times M_r^J \times BW_r^J$$

Relativistic Breit-Wigner

$$BW_r^J(s) = \begin{cases} \dfrac{1}{M_r^2 - s - iM_r\Gamma_r(\sqrt{s})} \\ \dfrac{1}{M_r^2 - s - iM_r(\rho_1 g_1^2 + \rho_2 g_2^2)} \end{cases}$$

$a_0(980)/f_0(980)$

Angular distribution

D and *r* Blatt-Weisskopf form factors

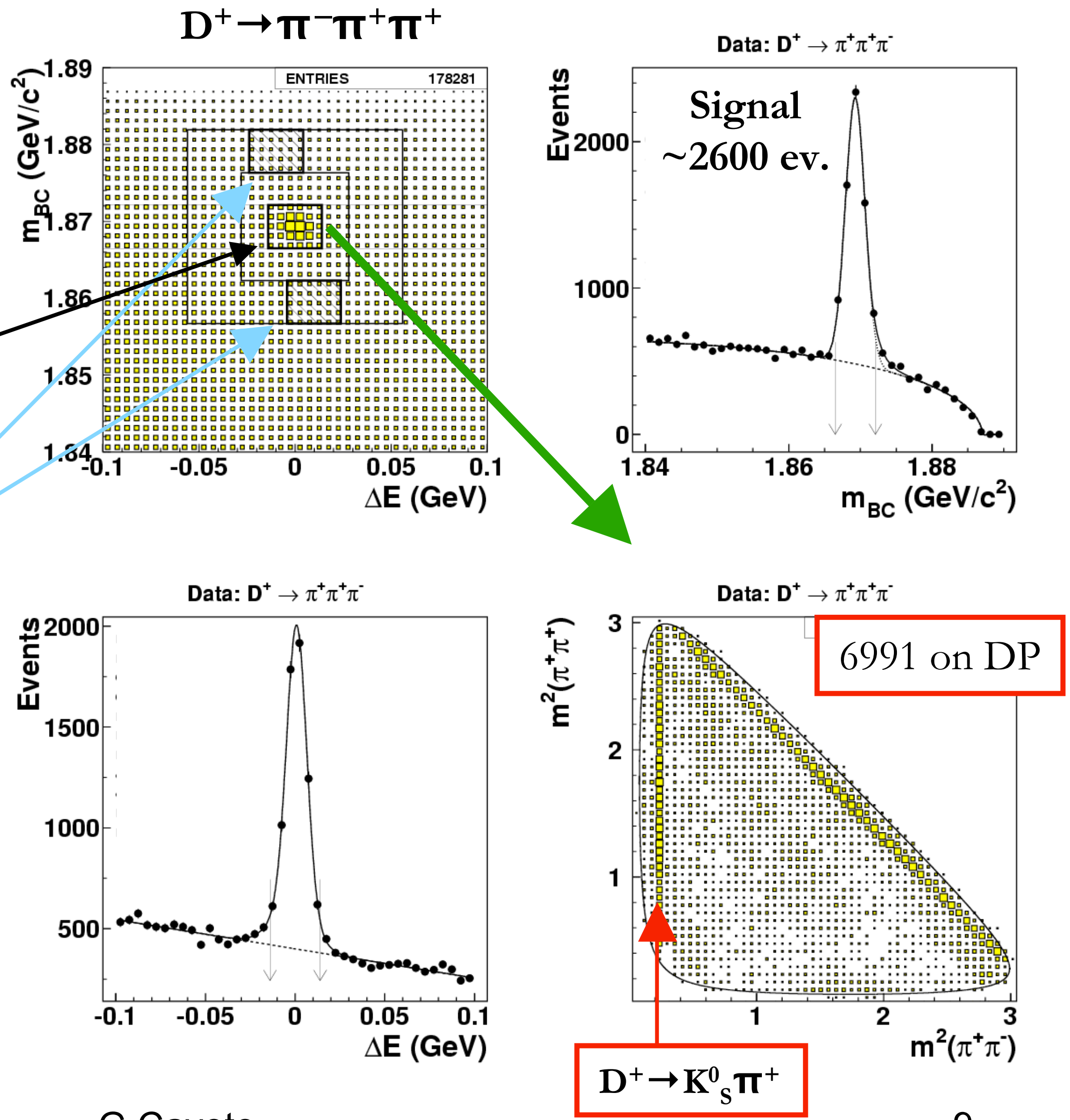
$D^+ \to \pi^+\pi^-\pi^+$ (CLEO-c)

- L=281 pb^{-1} @ $\psi(3770)$
- Untagged analysis

$$m_{BC} = \sqrt{E_{beam}^2 - p_D^2}$$

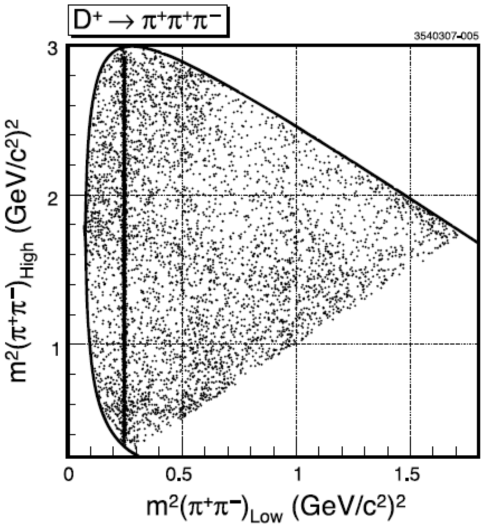
$$\Delta E = E_D - E_{beam}$$

- Signal box for DP
  - $|\Delta E|<2\sigma$
  - $|m_{BC}-m_D|< 2\sigma$
- Bkg boxes for DP
  - $|\Delta E_{\pm}|<2\sigma$
  - $5\sigma<|m_{BC}-m_D|<9\sigma$



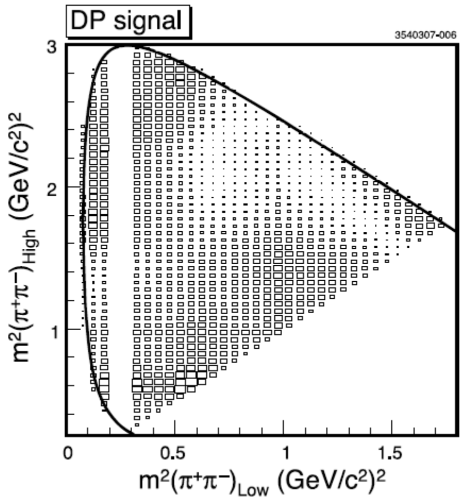
- DP Statistics:
  - $N(\pi^-\pi^+\pi^+)$ ~2600 ev.
  - $N(K_s\pi^+)$ ~2240 ev.
  - N_{back} ~ 2150 ev.

Nominal fit

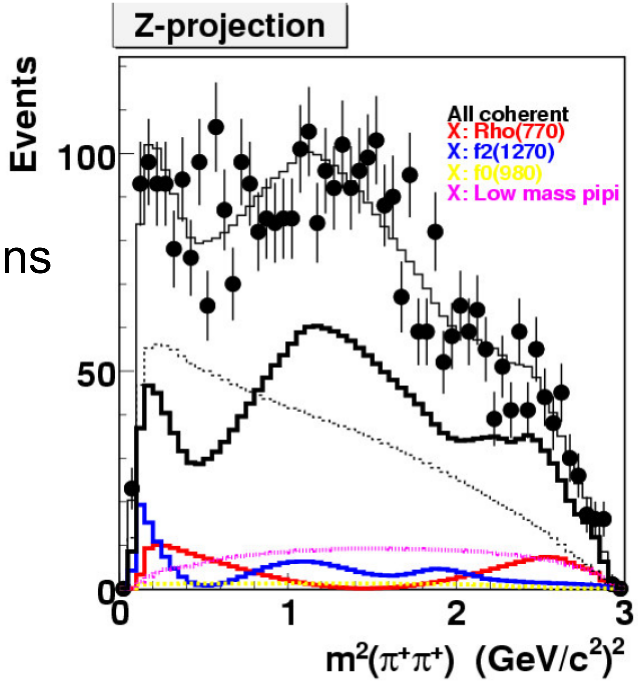


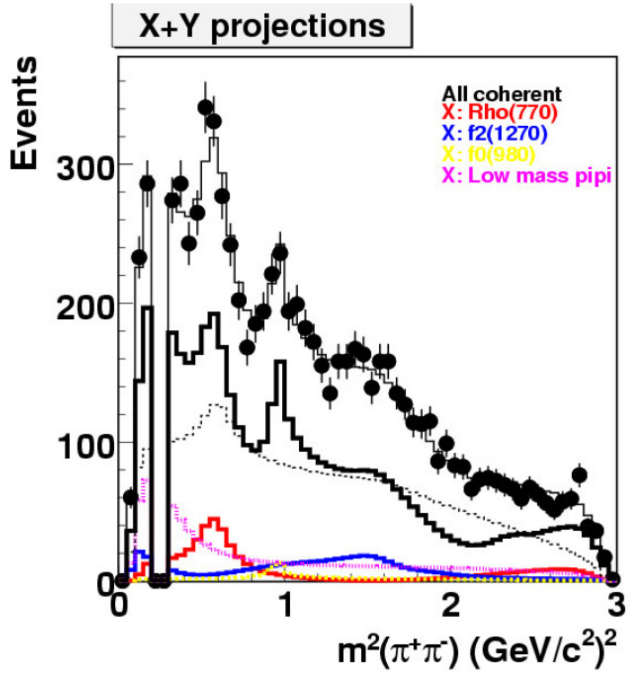
data Dalitz distribution

Signal PDF only [K_S removed]



Leading fractions shown on projections





CLEO-c $D^+ \to \pi^+\pi^-\pi^+$ Results

hep-ex/0704.3954

Mode	Fit Values		
	Relative Amplitude	Phase (degrees)	Fit Fraction (%)
$\rho(770)\pi^+$	1.0	0	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	237±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
	Limits on Other Contributing Modes		
$\rho(1450)\pi^+$	0.9±0.5	51±22	<2.4
$f_0(1710)\pi^+$	1.0±1.5	-17±90	<3.5
$f_0(1790)\pi^+$	1.0±1.1	23±58	<2.0
Non-resonant	0.17±0.14	-17±90	<3.5
I=2 $\pi^+\pi^+$ S-wave	0.17±0.14	23±58	<3.7

Significant fractions

Upper limits on other components

Consistency with E791

E791 BW σ Fit Fraction
(46.3±9.0±2.1)%

σ pole provides
a good description of the DP

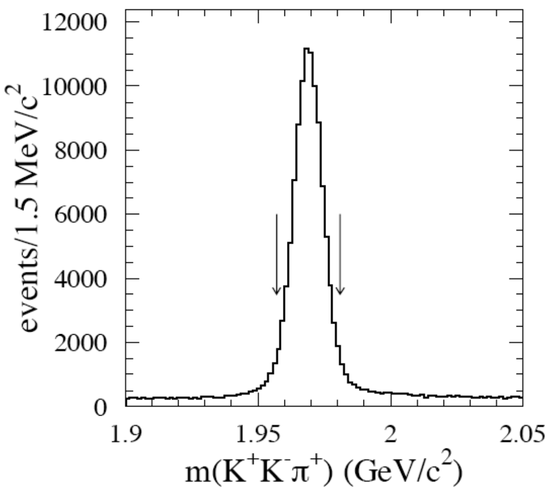
$$Pole_A(s) = \frac{1}{s - s_A},$$

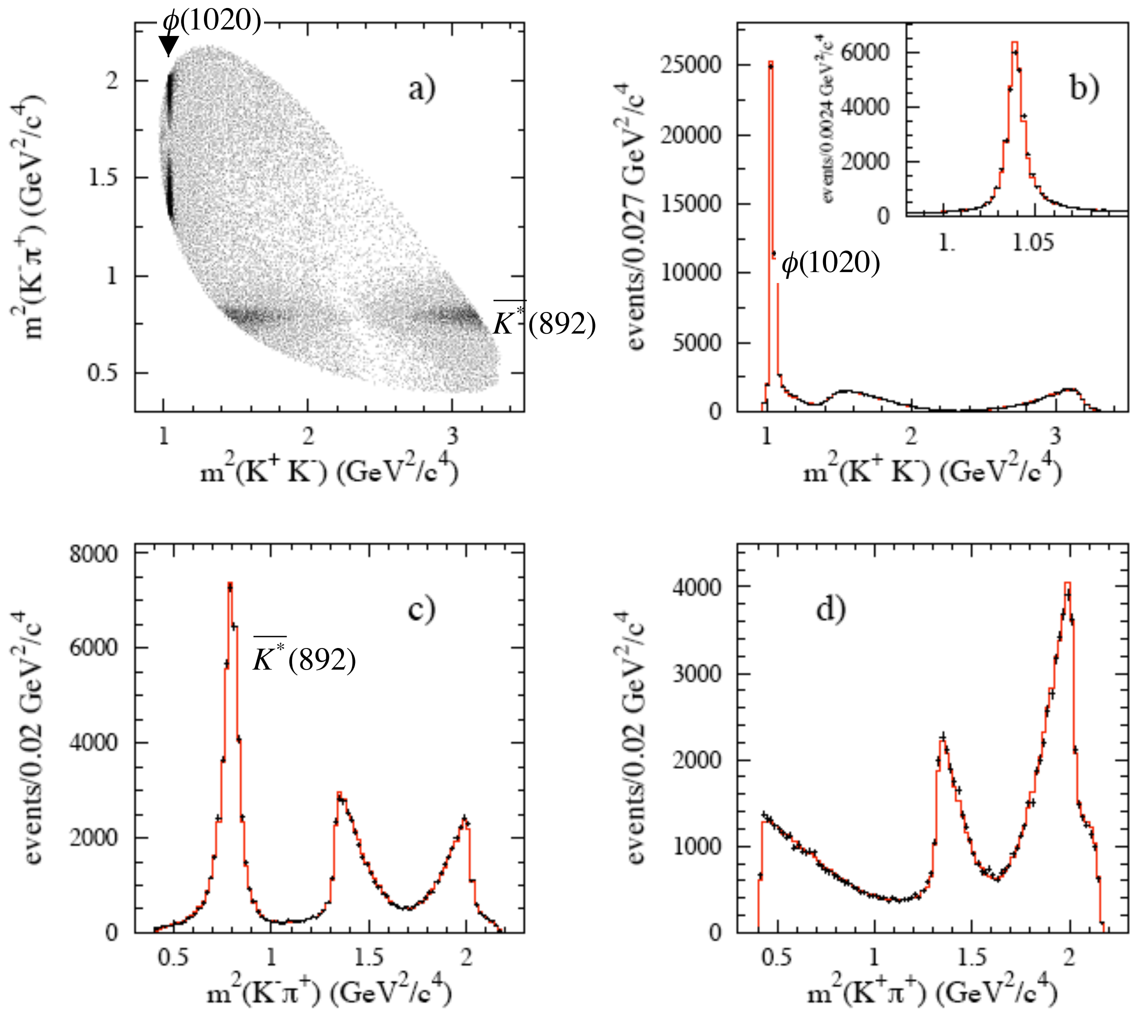
$$s_\sigma = (0.47 - i0.22)^2 GeV^2$$

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

Partial Wave analysis (S-wave extraction)
Measurement of $\phi\pi$ and K^*K fit fraction

240 fb^{-1}





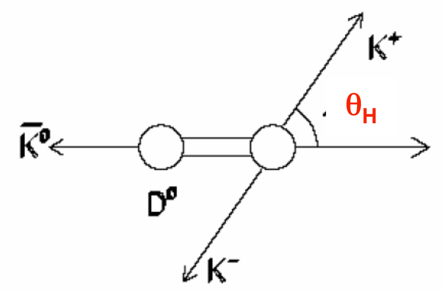
Vertex separation and p* requirements

100850 events

95% purity

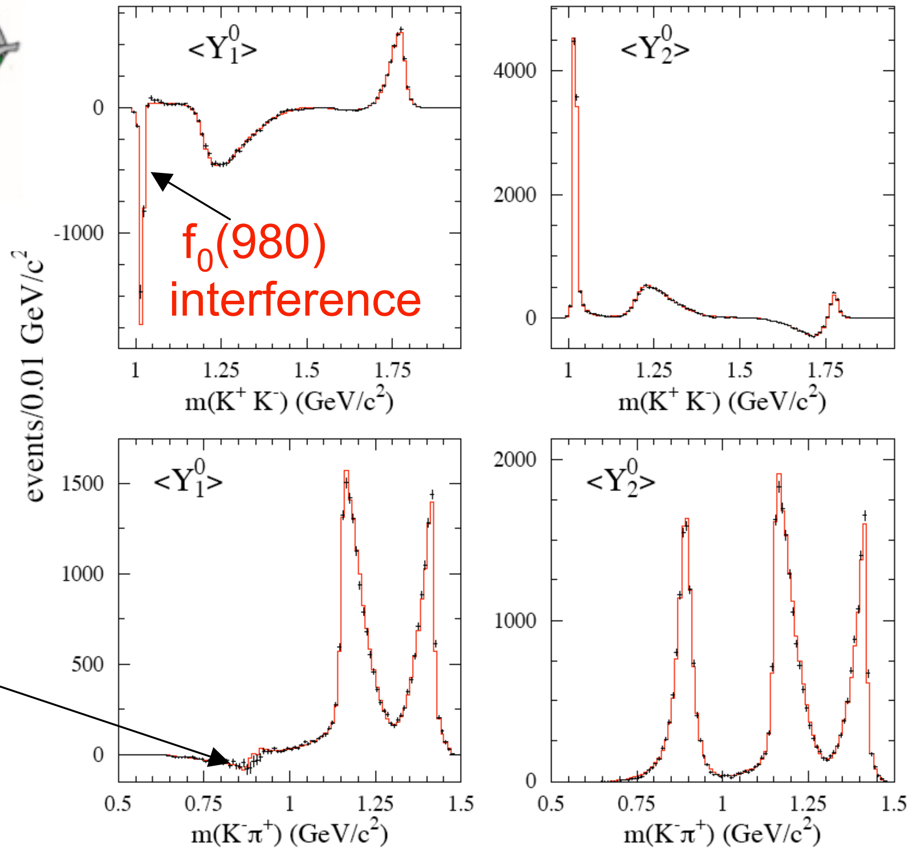
Angular moments

Helicity angle θ_H



Each event was weighted by the spherical harmonic $Y^0_L(\cos\theta_H)$ (L=0,1,2,.....).

$$\begin{cases} \sqrt{4\pi}\langle Y_0^0\rangle = S^2 + P^2 \\ \sqrt{4\pi}\langle Y_1^0\rangle = 2|S||P|\cos\phi_{SP} \\ \sqrt{4\pi}\langle Y_2^0\rangle = \frac{2}{\sqrt{5}}P^2 \end{cases}$$



Very small

S-P interference.

No κ(800) ?

$D_s \rightarrow \pi^+ K^- K^+$ Dalitz results

BaBar preliminary

Decay Mode	Decay fraction(%)	Amplitude	Phase(radians)
$\bar{K}^*(892)^0 K^+$	$48.7 \pm 0.2 \pm 1.6$	$1.(Fixed)$	$0.(Fixed)$
$\phi(1020)\pi^+$	$37.9 \pm 0.2 \pm 1.8$	$1.081 \pm 0.006 \pm 0.049$	$2.56 \pm 0.02 \pm 0.38$
$f_0(980)\pi^+$	$35 \pm 1 \pm 14$	$4.6 \pm 0.1 \pm 1.6$	$-1.04 \pm 0.04 \pm 0.48$
$\bar{K}_0^*(1430)^0 K^+$	$2.0 \pm 0.2 \pm 3.3$	$1.07 \pm 0.06 \pm 0.73$	$-1.37 \pm 0.05 \pm 0.81$
$f_0(1710)\pi^+$	$2.0 \pm 0.1 \pm 1.0$	$0.83 \pm 0.02 \pm 0.18$	$-2.11 \pm 0.05 \pm 0.42$
$f_0(1370)\pi^+$	$6.3 \pm 0.6 \pm 4.8$	$1.74 \pm 0.09 \pm 1.05$	$-2.6 \pm 0.1 \pm 1.1$
$\bar{K}_2^*(1430)^0 K^+$	$0.17 \pm 0.05 \pm 0.3$	$0.43 \pm 0.05 \pm 0.34$	$-2.5 \pm 0.1 \pm 0.3$
$f_2(1270)\pi^+$	$0.18 \pm 0.03 \pm 0.4$	$0.40 \pm 0.04 \pm 0.35$	$0.3 \pm 0.2 \pm 0.5$
Sum	$132 \pm 1.2 \pm 15.6$		
χ^2/NDF	1.5		

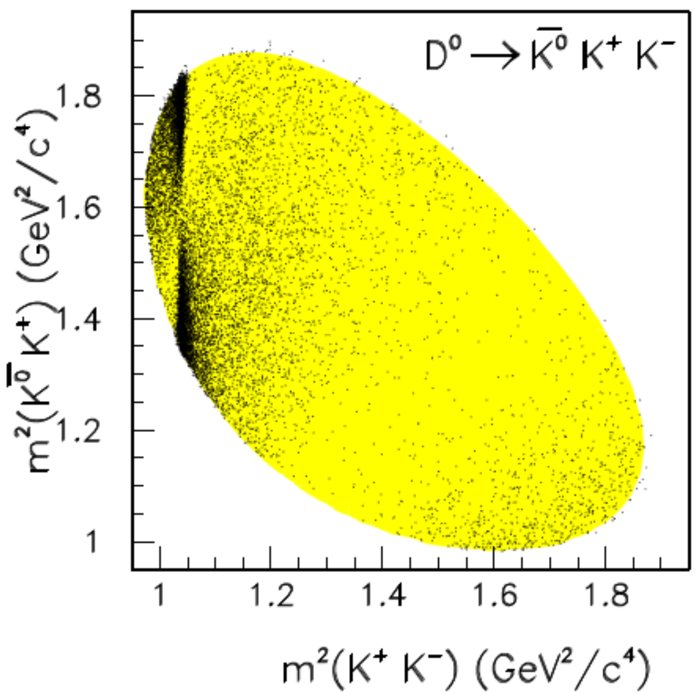
- Decay dominated by P-wave
- Large $f_0(980)$ contribution
  - But big syst. uncertainty (different model used)

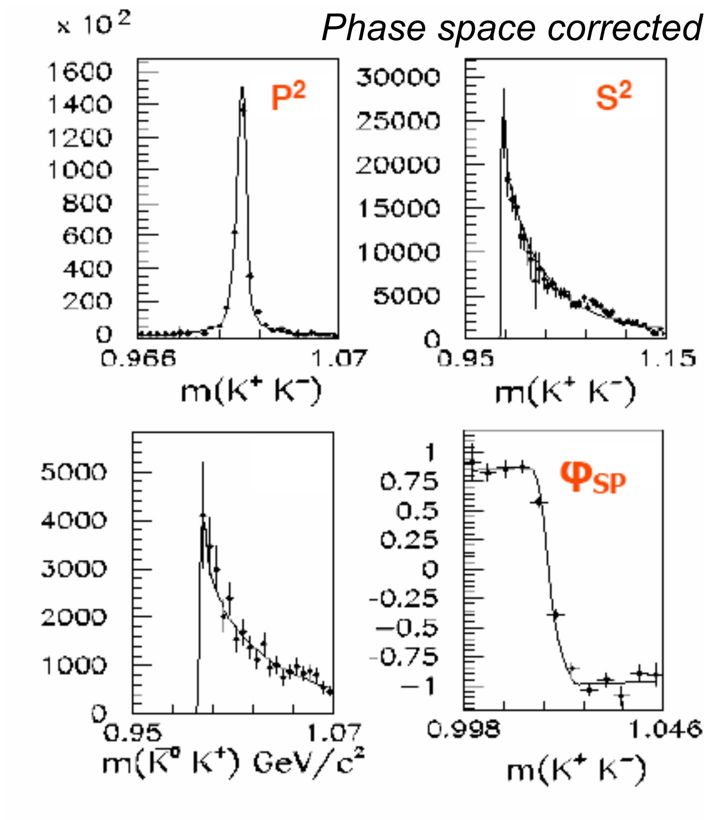
Partial Wave Analysis $D^0 \to \overline{K}^0 K^+ K^-$

Sample = 12540 Events

Purity = 97.3%

@ 91.5 fb^{-1}





– In low K^+K^- mass (no interference with a_0^+)

a_0(980) KK coupling: **g_{kk}= 464 ±29(stat.) (MeV)$^{1/2}$**

Full Dalitz $D^0 \rightarrow \overline{K}^0 K^+ K^-$ results

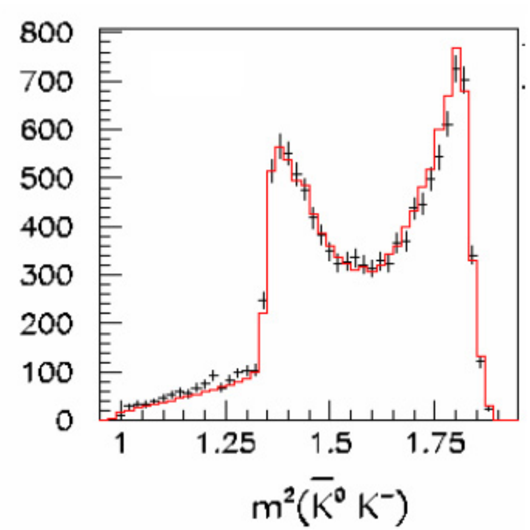
Final State	Amplitude	Phase(radians)	Fraction(%)
$\overline{K}^0 a_0(980)^0$	1.(fixed)	0.(fixed)	66.4±1.6±7.0
$\overline{K}^0 \Phi(1020)$	0.437±0.006±0.060	1.91±0.02±0.10	45.9±0.7±0.7
$K^- a_0(980)^+$	0.460±0.017±0.056	3.59±0.05±0.20	13.4±1.1±3.7
$\overline{K}^0 f_0(1400)$	0.435±0.033±0.162	-2.63±0.10±0.71	3.8±0.7±2.3
Sum			130.7±2.2±8.4

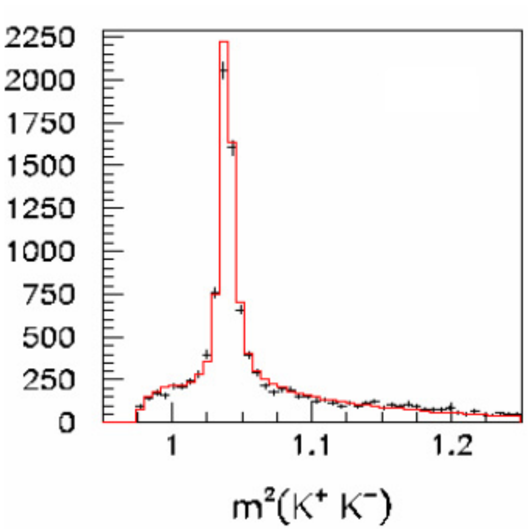
$f_0(980)$ parameters →M. Ablikim *et al.*, Phys.Lett.B607:243-253,2005

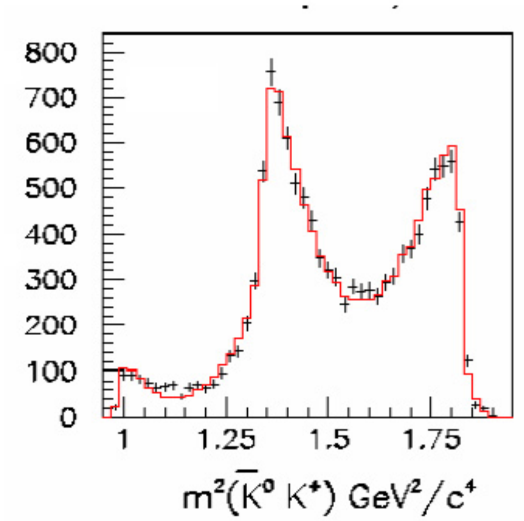
- Big contribution of $a_0(980)$ neutral and charged
- DCS and $f_0(980)$ consistent with zero

$a_0(980)$ KK coupling:

g_{kk}= 473 ±29(stat.) ±40(syst.) $(MeV)^{1/2}$



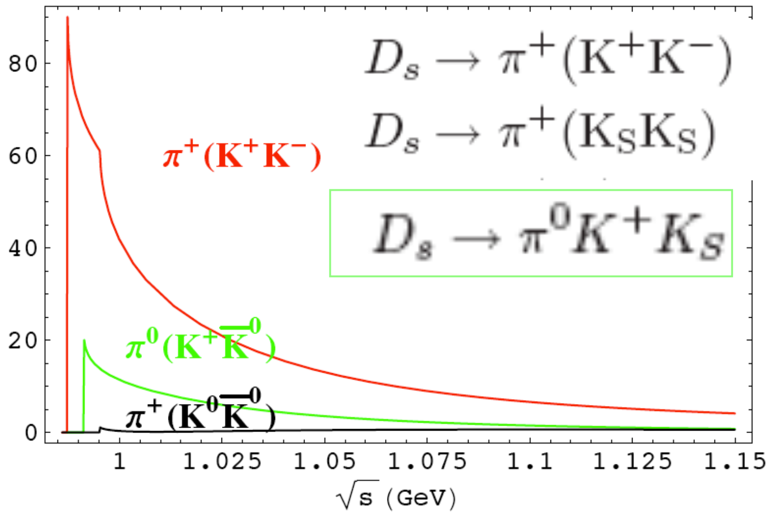




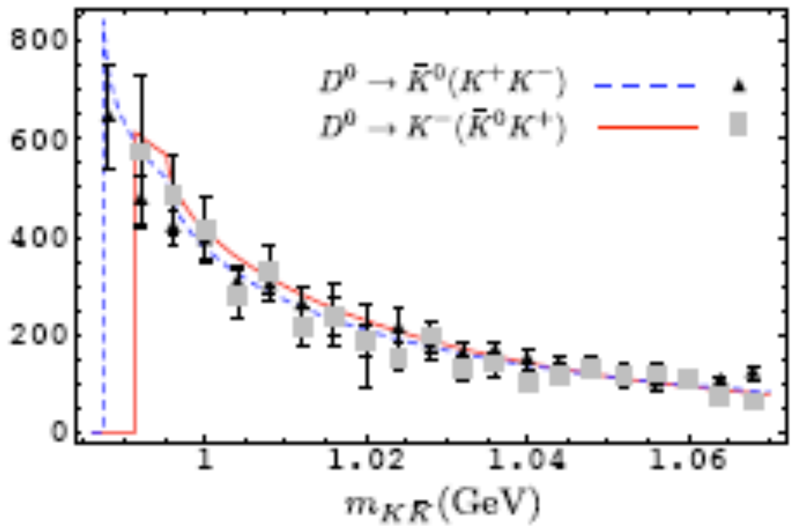
A possible interpretation.

L.Maiani et al. hep-ph/0703272

- $f_0(980)$ as 2 di-quark bound states
  - **Coupling to K_SK_S would vanish!**
    - Decay ratio would be 1/2 for $q\bar{q}$ interpretation



Prediction for rate of
S-wave in $D_s \to \pi^0 K^+K_S$



BaBar data

Prediction for rate of
S-wave in $\mathbf{D^0} \to K_SK_SK_S$

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

1) *Critical for CKM γ extraction in B decay: ADS method*

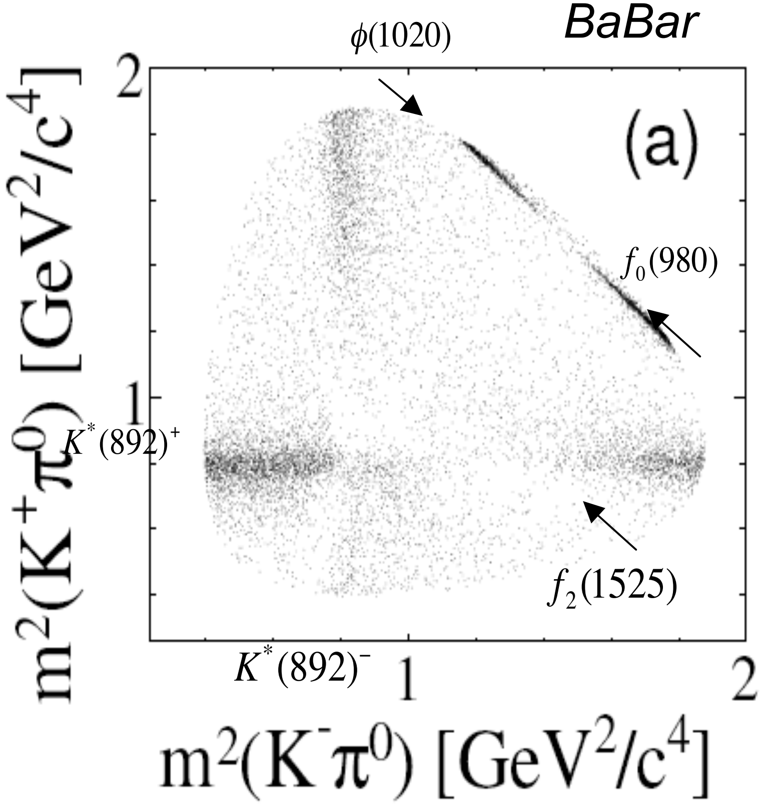
$$\mathcal{A}_{ADS} \equiv \frac{\Gamma[K^+\pi^-]K^-) - \Gamma([K^-\pi^+]K^+)}{\Gamma[K^+\pi^-]K^-) + \Gamma([K^-\pi^+]K^+)} = \frac{2\, r_B r_D \sin(\delta_B + \delta_D)\, s}{\mathcal{R}_{ADS}}$$

$$\frac{A(\overline{D^0} \rightarrow K^{*+}K^-)}{A(D^0 \rightarrow K^{*+}K^-)} = r_D e^{i\delta_D}$$

$$r_D e^{i\delta_D} = \left[\frac{a_{K^*K^+}}{a_{K^*K^-}}\right] e^{\left[i\left(\delta_{K^*K^+} - \delta_{K^*K^-}\right)\right]}$$

2) *What's the nature of the $K\pi$ S-wave below 1.4 GeV ?*

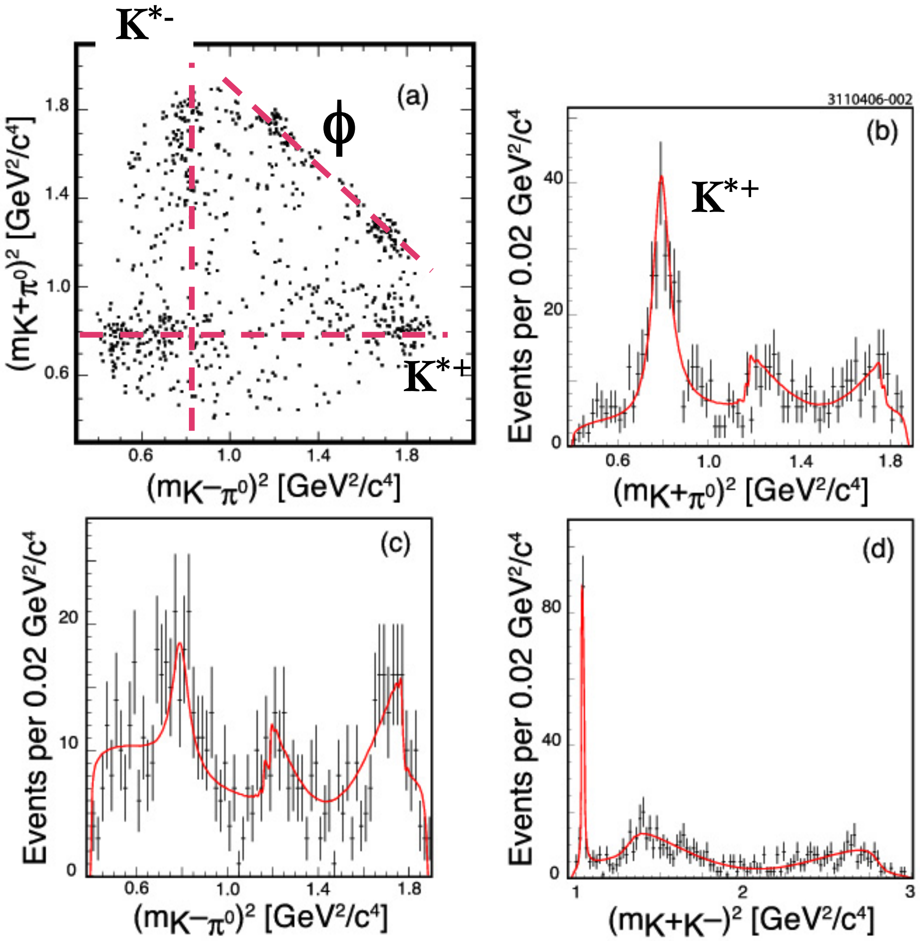
BaBar



$K\pi$ scattering: LASS parametrization Nucl. Phys. B296, 493 (1988); W. Dunwoodie, web notes.

CLEO-c $D^0 \to K^-K^+\pi^0$ result

Phys. Rev. D **74**, 031108(R) (2006)



Mode	Fit Values		
	Relative Amplitude	Phase (degrees)	Fit Fraction (%)
$K^{*+}K^-$	1.0	0	46.1±3.1
$K^{*-}K^+$	0.52±0.05±0.04	332±8±11	12.3±2.2
$\phi\pi^+$	0.64 ±0.04	326±9	14.9±1.6
NR	5.62±0.45	220±5	36.0±3.7

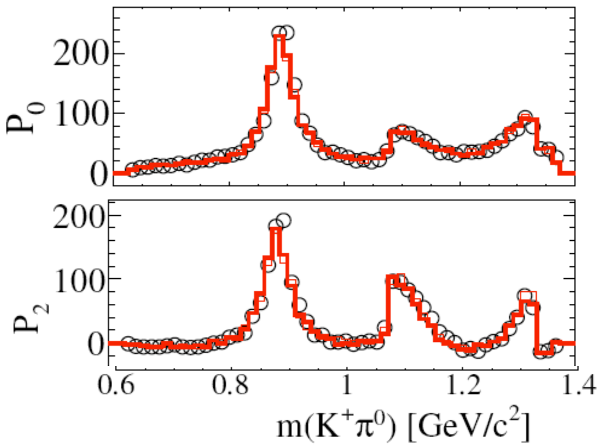
Read off the values from the DP fit

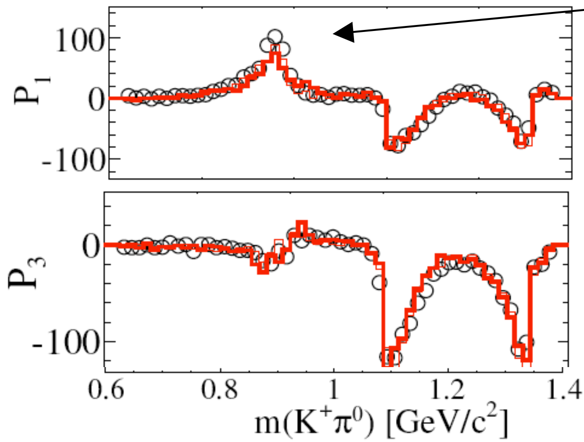
$r_D = 0.52 \pm 0.05 \pm 0.04$
$\delta_D = (332 \pm 8 \pm 11)^o$

- First measurement of δ_D.
- Significant improvement on r_D over previous value using K*K BF's

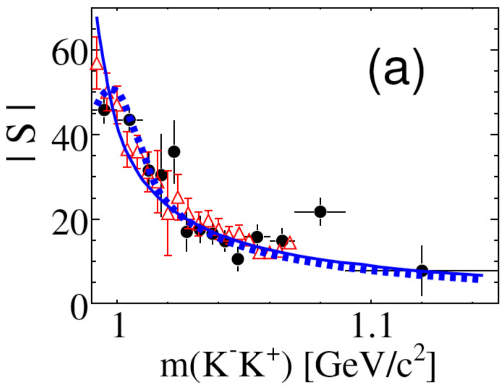
Analysis of angular moments

$$P_0 = \frac{|S|^2 + |P|^2}{\sqrt{2}}, \quad P_1 = \sqrt{2}|S||P| \cos\theta_{SP}, \quad P_2 = \sqrt{\frac{2}{5}}\ |P|^2$$



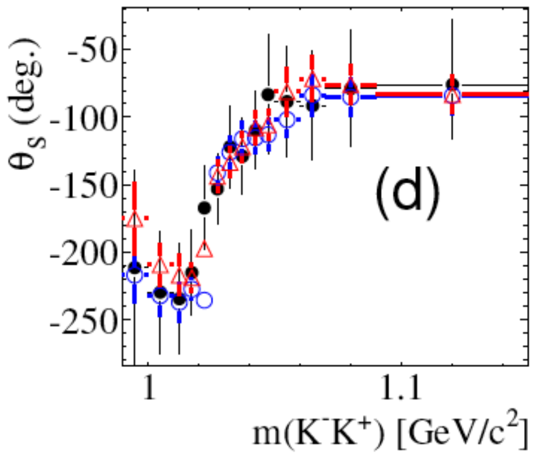


Significantly large interference between S and P waves.



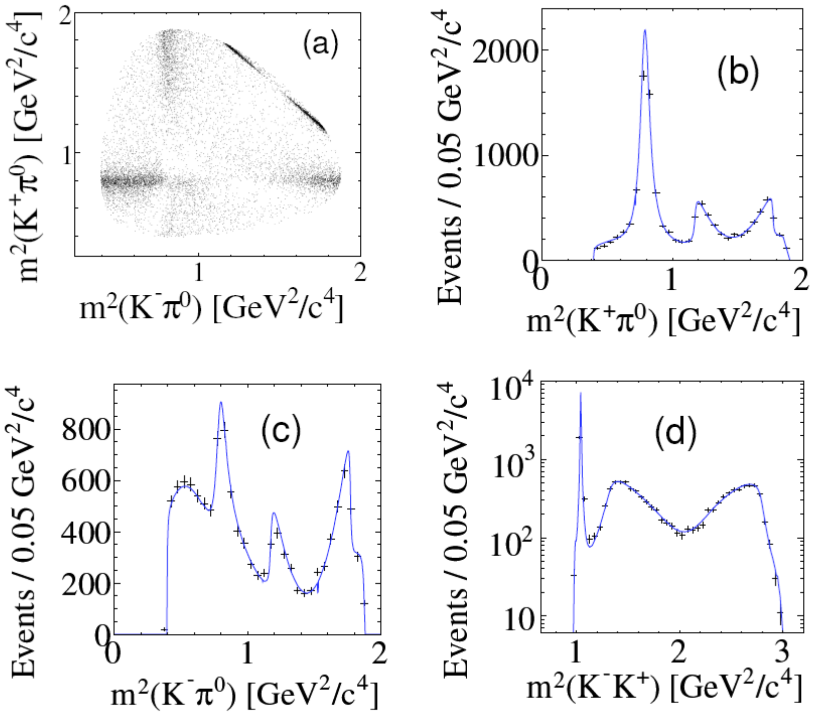
S-wave shape in agreement with

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



BaBar $D^0 \to K^+K^-\pi^0$ results

hep-ex/0704.3593 (sub.to PRD)



State	Amplitude, a_r	Phase, ϕ_r (°)	Fraction, f_r (%)
$K^*(892)^+$	1.0 (fixed)	0.0 (fixed)	45.2±0.8±0.6
$K^*(1410)^+$	2.29±0.37±0.20	86.7±12.0±9.6	3.7±1.1±1.1
$K^+\pi^0(S)$	1.76±0.36±0.18	-179.8±21.3±12.3	16.3±3.4±2.1
$\phi(1020)$	0.69±0.01±0.02	-20.7±13.6±9.3	19.3±0.6±0.4
$f_0(980)$	0.51±0.07±0.04	-177.5±13.7±8.6	6.7±1.4±1.2
$[a_0(980)^0]$	[0.48±0.08±0.04]	[-154.0±14.1±8.6]	[6.0±1.8±1.2]
$f_2'(1525)$	1.11±0.38±0.28	-18.7±19.3±13.6	0.08±0.04±0.05
$K^*(892)^-$	0.601±0.011±0.011	-37.0±1.9±2.2	16.0±0.8±0.6
$K^*(1410)^-$	2.63±0.51±0.47	-172.0±6.6±6.2	4.8±1.8±1.2
$K^-\pi^0(S)$	0.70±0.27±0.24	133.2±22.5±25.2	2.7±1.4±0.8

Using LASS parametrization for **Kπ** S-wave

Kπ S-wave from E791 as systematics

Model with charged κ

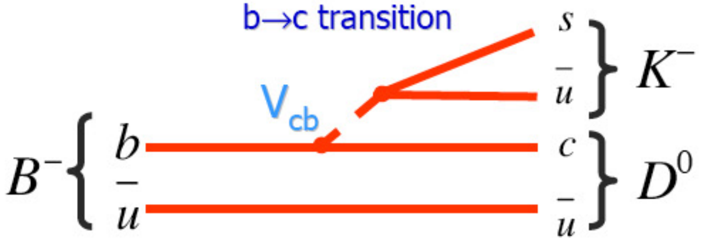
m=(870±30)MeV/c² Γ=(150±20)MeV/c²

not favoured by data (and parameter different from neutral scalar κ)

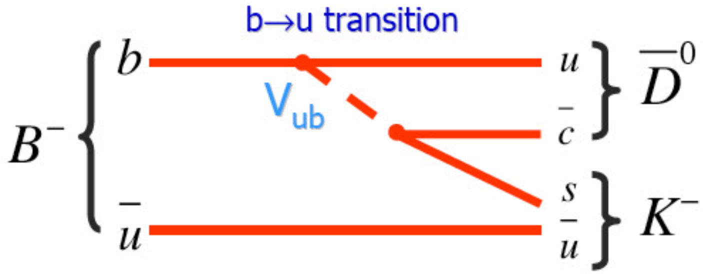
$$\delta_D = -35.5^\circ \pm 1.9^\circ \text{ (stat) } \pm 2.2^\circ \text{ (syst)}$$
$$r_D = 0.599 \pm 0.01 \text{ (stat) } \pm 0.011 \text{ (syst)}$$

Towards CKM γ: $D^0 \rightarrow K_S\pi^+\pi^-$

$B^- \rightarrow D^{0(*)}K^-$ with $D^0 \rightarrow K_S\pi^+\pi^-$



$$e^{i\delta_B}\, e^{-i\gamma}$$



Interference occurs when some final state is accessible by both D^0 and $\overline{D}^0$

Giri-Grossman-Soffer-Zupan: PRD68, 054018 (2003): Final state = $K_s^0\pi^+\pi^-$ $\Rightarrow$ Dalitz Plot Analysis

$$B^-: \quad \mathcal{A}_-(m_-^2, m_+^2) = \left|A(B^- \rightarrow D^0 K^-)\right|\left[f(m_-^2, m_+^2) + r_B e^{i\delta_B} e^{-i\gamma} f(m_+^2, m_-^2)\right]$$

$$B^+: \quad \mathcal{A}_+(m_-^2, m_+^2) = \left|A(B^+ \rightarrow \overline{D}^0 K^+)\right|\left[f(m_+^2, m_-^2) + r_B e^{i\delta_B} e^{+i\gamma} f(m_-^2, m_+^2)\right]$$

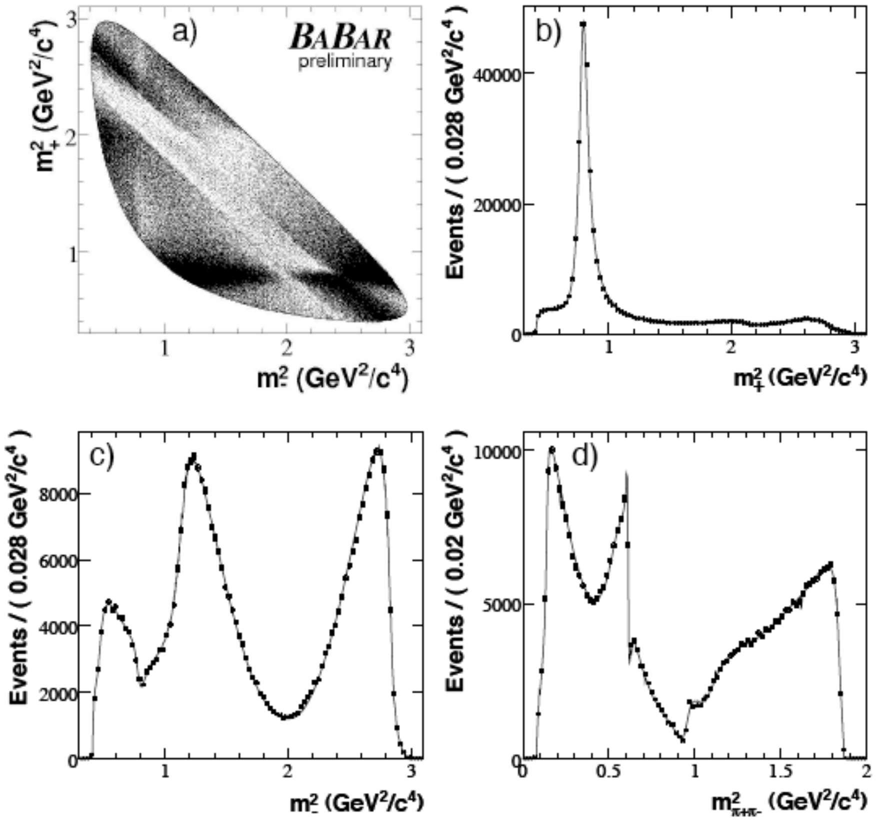
$$f(m_+^2, m_-^2)$$

→ Input from Dalitz analysis

(assumption on the model: systematic error on γ)

Dalitz analysis $D^0 \rightarrow K_S\pi^+\pi^-$

Isobar model resonance + Non resonant terrm



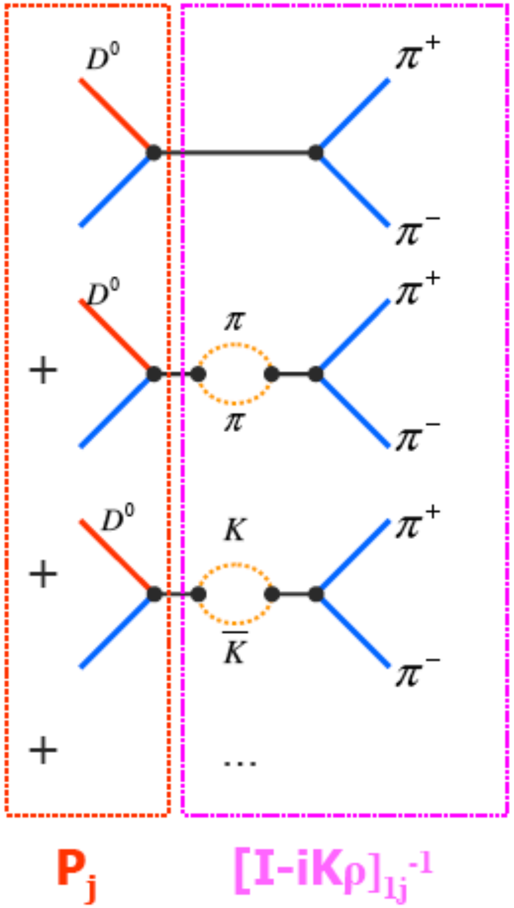
Component	$Re\{a_r e^{i\phi_r}\}$	$Im\{a_r e^{i\phi_r}\}$	Fit fraction (%)
$K^*(892)^-$	-1.223 ± 0.011	1.3461 ± 0.0096	58.1
$K_0^*(1430)^-$	-1.698 ± 0.022	-0.576 ± 0.024	6.7
$K_2^*(1430)^-$	-0.834 ± 0.021	0.931 ± 0.022	3.6
$K^*(1410)^-$	-0.248 ± 0.038	-0.108 ± 0.031	0.1
$K^*(1680)^-$	-1.285 ± 0.014	0.205 ± 0.013	0.6
$K^*(892)^+$	0.0997 ± 0.0036	-0.1271 ± 0.0034	0.5
$K_0^*(1430)^+$	-0.027 ± 0.016	-0.076 ± 0.017	0.0
$K_2^*(1430)^+$	0.019 ± 0.017	0.177 ± 0.018	0.1
$\rho(770)$	1	0	21.6
$\omega(782)$	-0.02194 ± 0.00099	0.03942 ± 0.00066	0.7
$f_2(1270)$	-0.699 ± 0.018	0.387 ± 0.018	2.1
$\rho(1450)$	0.253 ± 0.038	0.036 ± 0.055	0.1
Non-resonant	-0.99 ± 0.19	3.82 ± 0.13	8.5
$f_0(980)$	0.4465 ± 0.0057	0.2572 ± 0.0081	6.4
$f_0(1370)$	0.95 ± 0.11	-1.619 ± 0.011	2.0
σ	1.28 ± 0.02	0.273 ± 0.024	7.6
σ'	0.290 ± 0.010	-0.0655 ± 0.0098	0.9

Total 119.5%

$\pi\pi$ S-wave contains σ and σ'

- σ: m=(490±6)MeV/c² Γ=(406±11)MeV/c²
- σ': m=(1024±4)MeV/c² Γ=(89±7)MeV/c²

K-matrix for $\pi\pi$



K-Matrix formalism overcomes the main limitation of the BW model to parameterize large and overlapping *S*-wave $\pi\pi$ resonances.

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

$$\mathcal{A}_D(s_{12}, s_{13}) = \underbrace{F_1}_{\pi\pi\ S-wave} + \underbrace{\sum_r a_r e^{i\delta_r} A_r(s_{12}, s_{13})}_{\substack{\pi\pi\ P,D-waves \\ K\pi\ S,P,D-waves}}$$

$$F_1 = \sum_j \underbrace{[\mathrm{I} - i\mathbf{K}\boldsymbol{\rho}]_{1j}^{-1}}\ \mathbf{P}_j$$

I.J.R. Aitchison, Nucl. Phys. **A189**, 417 (1972)

$\mathbf{P}_j$ → Initial production vector

$[\mathrm{I} - i\mathbf{K}\boldsymbol{\rho}]_{1j}^{-1}$ → Provided by scattering experiment

5 channels: **1**=$\pi\pi$ **2**=KK **3**=multi-meson **4**= $\eta\eta$ **5**= $\eta\eta'$
V.V. Anisovitch, A.V Sarantev Eur. Phys. Jour. **A16**, 229 (2003)

K-matrix fit

ππ S-wave
with K-matrix
parametrization

BaBar hep-ex/0607104

	Component	$\mathrm{Re}\{a_r e^{i\Phi_r}\}$	$\mathrm{Im}\{a_r e^{i\Phi_r}\}$	Fit fraction (%)
Cabibbo Allowed modes	$K^*(892)^-$	-1.159 ± 0.022	1.361 ± 0.020	58.9
	$K_0^*(1430)^-$	2.482 ± 0.075	-0.653 ± 0.073	9.1
	$K_2^*(1430)^-$	0.852 ± 0.042	-0.729 ± 0.051	3.1
	$K^*(1410)^-$	-0.402 ± 0.076	0.050 ± 0.072	0.2
	$K^*(1680)^-$	-1.00 ± 0.29	1.69 ± 0.28	1.4
Doubly Cabibbo Suppressed modes	$K^*(892)^+$	0.133 ± 0.008	-0.132 ± 0.007	0.7
	$K_0^*(1430)^+$	0.375 ± 0.060	-0.143 ± 0.066	0.2
	$K_2^*(1430)^+$	0.088 ± 0.037	-0.057 ± 0.038	0.0
	$\rho(770)$	1 (fixed)	0 (fixed)	22.3
	$\omega(782)$	-0.0182 ± 0.0019	0.0367 ± 0.0014	0.6
	$f_2(1270)$	0.787 ± 0.039	-0.397 ± 0.049	2.7
	$\rho(1450)$	0.405 ± 0.079	-0.458 ± 0.116	0.3
ππ S-wave	β_1	-3.78 ± 0.13	1.23 ± 0.16	–
	β_2	9.55 ± 0.20	3.43 ± 0.40	–
	β_4	12.97 ± 0.67	1.27 ± 0.66	–
	f_{11}^{prod}	-10.22 ± 0.32	-6.35 ± 0.39	–
	sum of $\pi^+\pi^-$ S-wave			16.2

Total fit fraction 116%

Value of χ^2 compatible with nominal model
since it is dominate by the P-wave components,
which are identical between the two model

$B^- \to D^{0(*)} K^-$ model error on γ

BaBar hep-ex/0607104

Evaluating model uncertainty

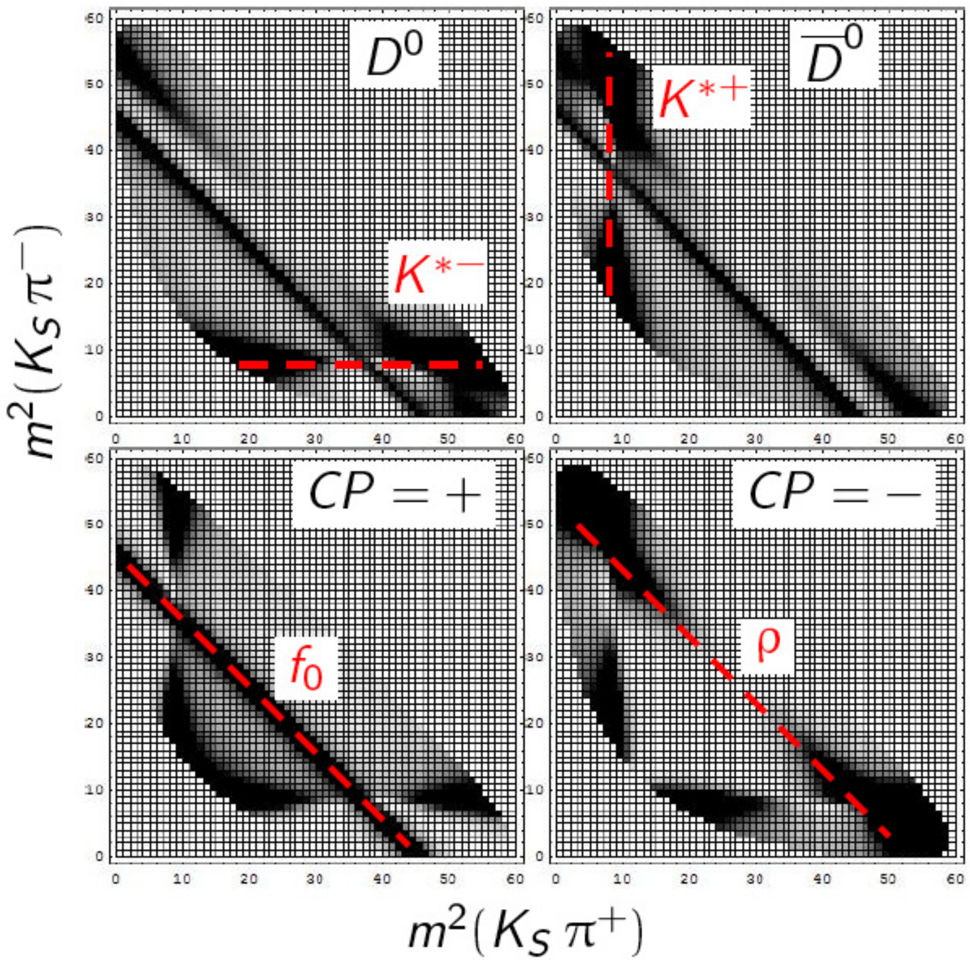
- Alternative parametrization for $\pi\pi$ S-wave (BW model and K-matrix model)
- Alternative parametrization for $K\pi$ S-wave (BW E791 and LASS parametrization)

$$\gamma = (92 \pm 41(stat) \pm 11(syst) \pm 12(\mathrm{mod}el)$$

$\pi\pi$ and $K\pi$ S-wave the most critical

CP-tagged Dalitz $D^0 \rightarrow K_S\pi^+\pi^-$ plots

The ψ(3770) has positive CP
Daughter D^0 mesons have opposite CP (P-wave decay)



Dalitz plots for toy MC with $K^*\pi$, $K_S\,\rho$, $K_S\,f_0$ components

Clear difference in flavor-tagged (top) and *CP*-tagged (bottom) plots

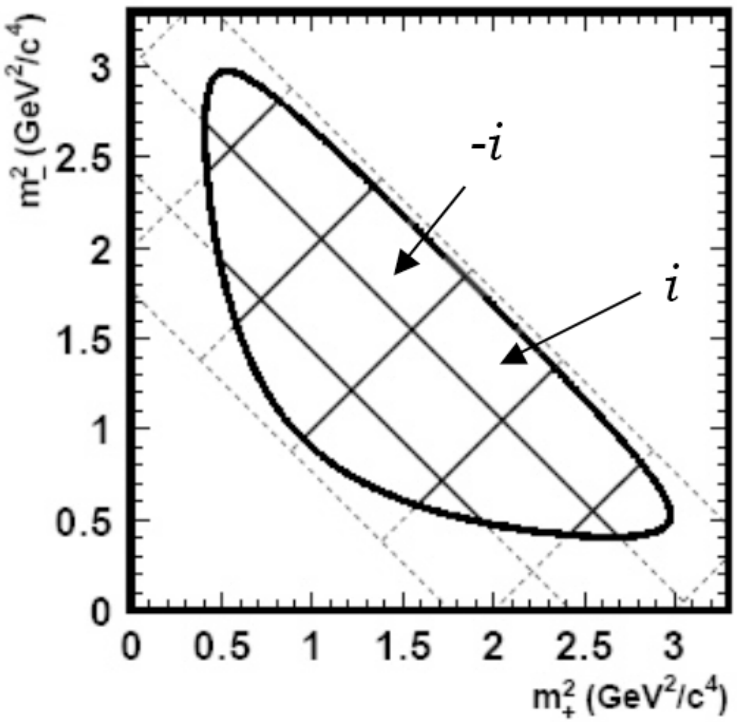
Model independence

Measure c_i to reduce model systematic on γ

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

K_i - flavor tag yield in bin i
$M_i^{\pm}$ - CP± yield in bin i

CLEO-c will detemine c_i by counting yields in bin i for flavor and CP tags



Impact of CLEO-c

D.Asner talk at Flavour at LHC WS

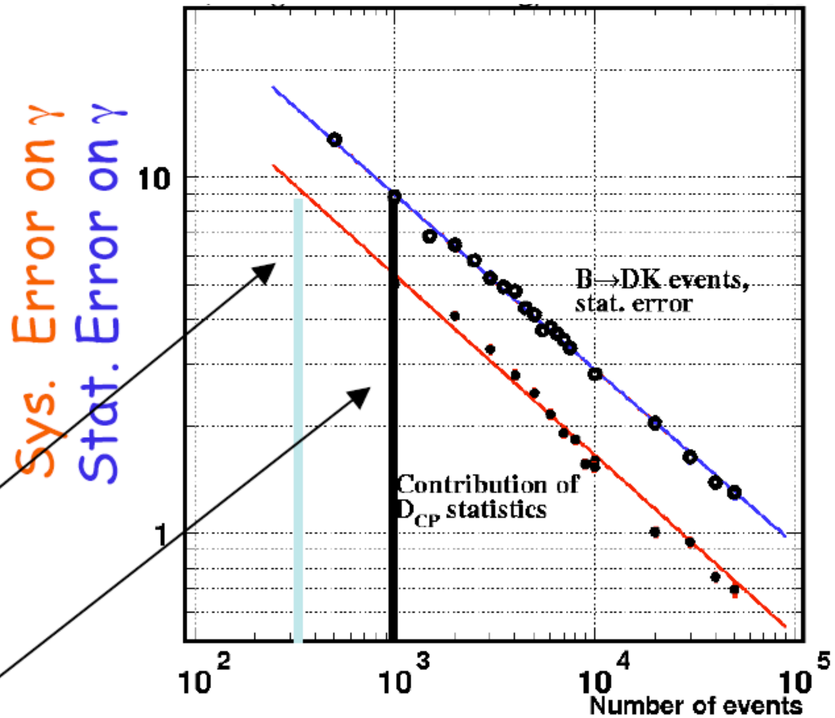
# of events (CLEO-c)	$K_S\pi+\pi-$		$K_L\pi+\pi-$	
	281 pb-1	750 pb-1	281 pb-1	750 pb-1
KK	66	175	134	350
ππ	27	75	62	150
$K_S\pi^0$	95	250	103	275
$K_L\pi^0$	93	250	-	-
$K_S\pi+\pi-$	180	500	457	1200

570 CP tags in 281 pb^{-1} → 6-7° sys. err.

~1500 CP tags expected in 750 pb^{-1} → ~4° sys. err.

~1700 "double" Dalitz tags expected in 750 pb^{-1}

γ error vs. D_{CP} statistics



# of B+→DK+ , D→$K_S\pi+\pi-$

# of CP tagged D→$K_S\pi+\pi-$

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

Conclusion & Outlook

- Charm multi-body decays crucial to determine strong interaction bound states
  - Nature of light mesons resonances still uncertain
- More information from comparison of several channels
  - Multi-channel analyses can be the way to go.
- Interplay with B physics
  - Determine strong phase variation useful to extract CKM angle γ
  - Quantum-coherent states crucial to reduce model error on phase variation
    (DD sample at threshold - CP-tagged Dalitz plot)

Current statistical WA error on γ (1ab^{-1} stat.) : ±19°

SuperB-factory → 25 ab^{-1} : stat. error ±4°

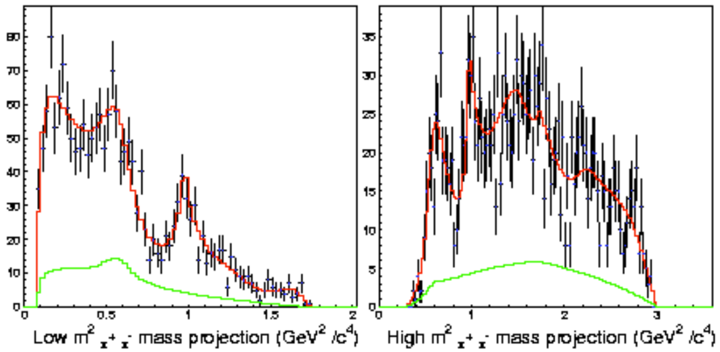
BES-III → 20 fb^{-1} : syst. error ±1°

A super-flavour factory the way to go !!!

Back-up

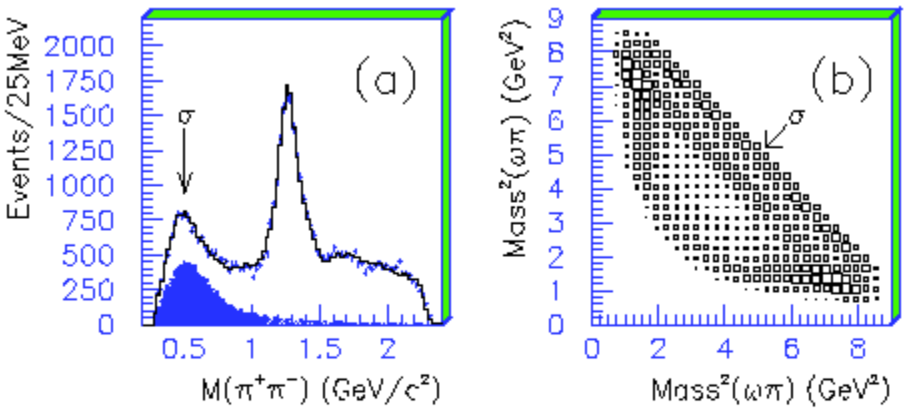
Different parametrizations

FOCUS: K-matrix approach
- No need for a σ, employed a (ππ) S-wave to describe data



Although not entirely clear this is correct:
"… *the K-matix approach employed in Ref [5] does not meet the chiral requirements of a soft expansion for low energies…*"
[J. Oller, PRD71 054030]

BESII- J/ψ→ωπ⁺π⁻

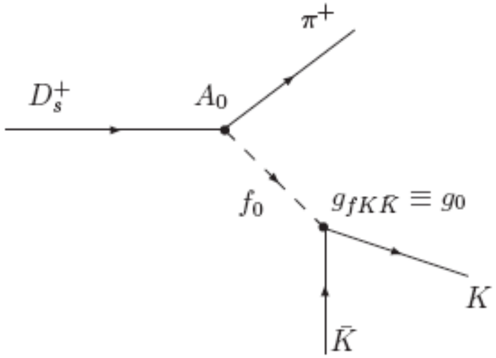


Described via a complex pole

Understand S-wave in (relatively) clear enviroment
Extend parametrization to more involved decays

Flatte's formula

$$A(D_s \to \pi^+ K\bar{K}) = \langle K\bar{K};\mathrm{out}| \left(\sum_{I=0}^{1} |S_I\rangle BW_I(s) \langle S_I| \right) |A\rangle$$



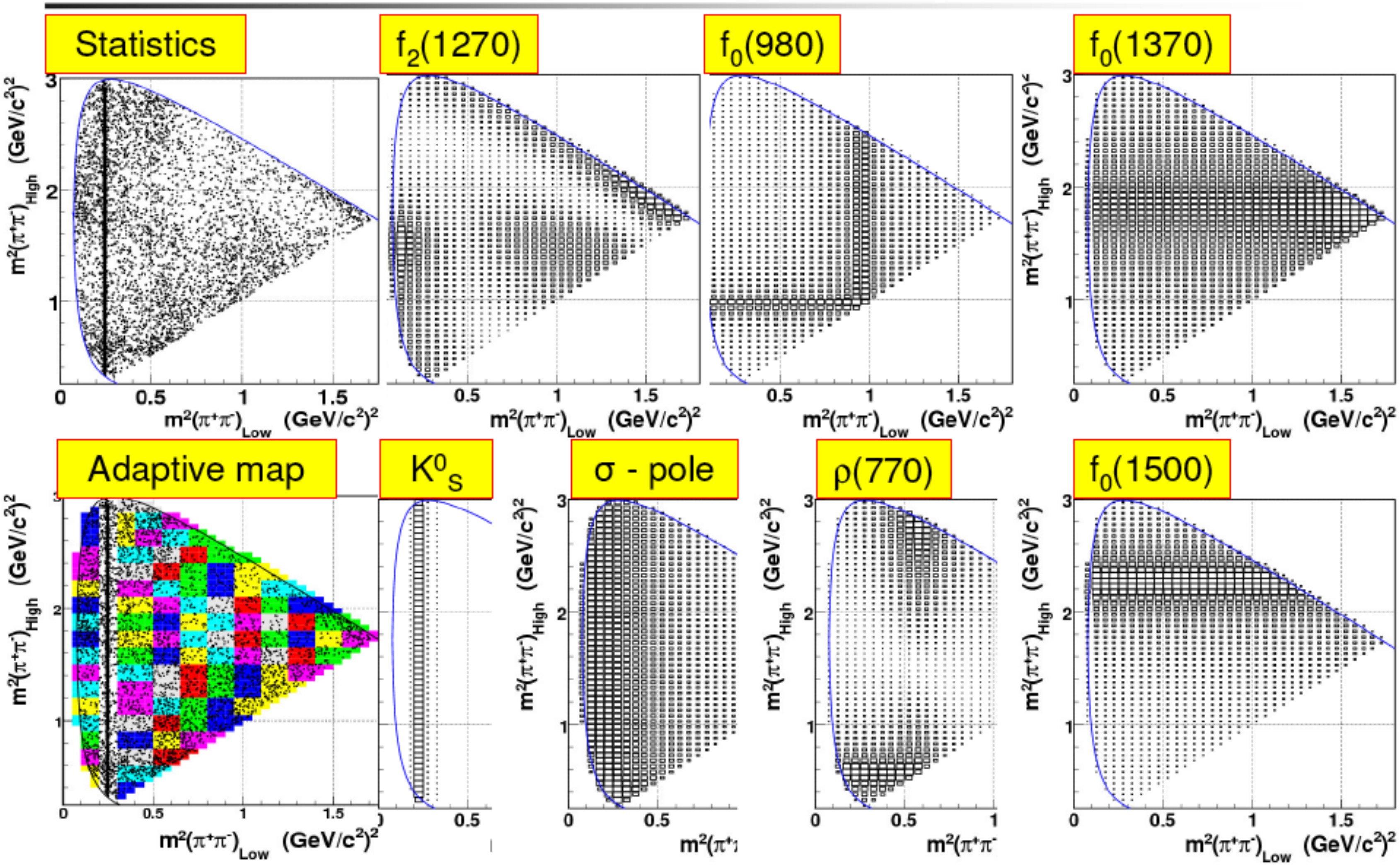
$$g_I = \langle K\bar{K};\mathrm{out}|S_I\rangle$$
$$A_I = \langle S_I|A\rangle$$

$$BW_f = \frac{1}{s - M_f^2 + iM\Gamma_f(s)}$$

$$\Gamma_{f_0} = \frac{3}{2}\, g_\pi^2 \frac{2\, p_\pi(s)}{\sqrt{s}} + g_0^2 \frac{2}{\sqrt{s}}\, (p_{\mathrm{ch}} + p_{\mathrm{neu}})$$
$$\Gamma_{a_0^0} = \Gamma_1 + g_1^2\, \frac{2}{\sqrt{s}} (p_{\mathrm{ch}} + p_{\mathrm{neu}})$$
$$\Gamma_{a_0^\pm} = \Gamma_1 + 2g_1^2\, \frac{2\, p_{01}(s)}{\sqrt{s}}.$$

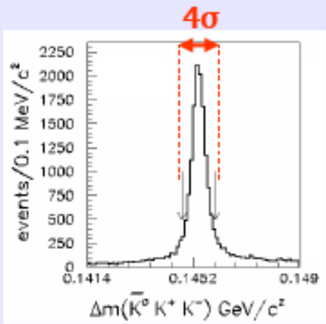
M_a (MeV) [9]	$(g_1)_{CB}$ (MeV) [9]	$(g_2^2/g_1^2)_{CB}$ [9]	$(g_2)_{CB}$ (MeV) [2]
999 ± 2	324 ± 15	1.03 ± 0.14	$473 \pm 29 \pm 40$

Contributing resonances



D^0 selection and flavour tagging

D^* tagging procedure is two-fold useful:



Event selection uses:

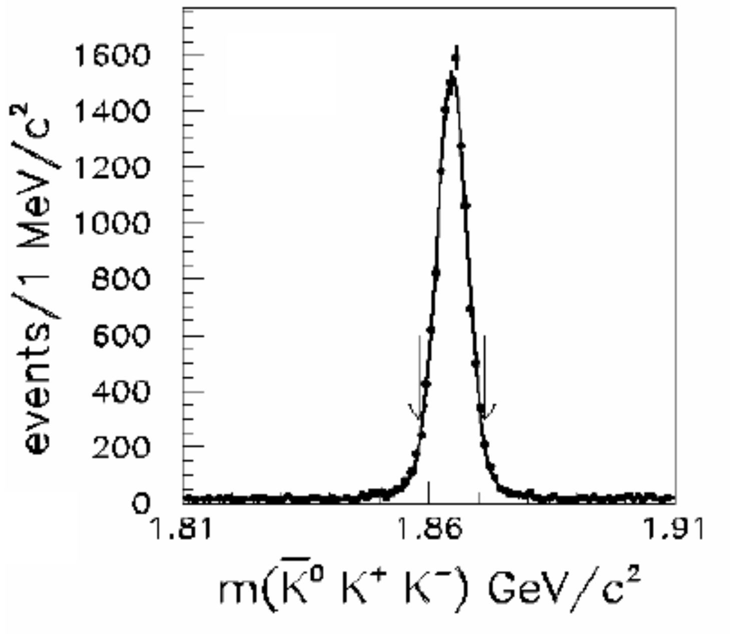
$$\Delta m(\overline{K}^0 K^+ K^-) = m(\overline{K}^0 K^+ K^- \pi_s^+) - m(\overline{K}^0 K^+ K^-)$$

1. **Selection of high purity sample**
2. **D^0 and $\overline{K}^0$ flavour set by the charge of the slow pion π_s^+**

$$e^+e^- \to D^{*+} + X$$
$$\hookrightarrow D^0 \pi_s^+$$
$$\hookrightarrow \overline{K}^0 K^+ K^-$$

$$\overline{K}^0 \to K_s^0 \to \pi^+\pi^-$$

Presence of Doubly Cabibbo Suppressed contribution may lead to misidentification of $\overline{K}^0$ flavour.



Sample = 12540 Events

Purity = 97.3%

@ 91.5 fb^{-1}

$D^0 \to K^0 K^+ K^-$: fit to PW

- **K^+K^- system: $\Phi(1020)$ and $a_0(980)^0$**

[No evidence of $f_0(980)$ (I=0) comparing $\overline{K}^0K^+$ and K^+K^- (normalized) S-waves]

$$\underbrace{c_{a_0} BW_{a_0}}_{S-wave} + \underbrace{c_\phi BW_\phi e^{i\alpha}}_{P-wave}$$

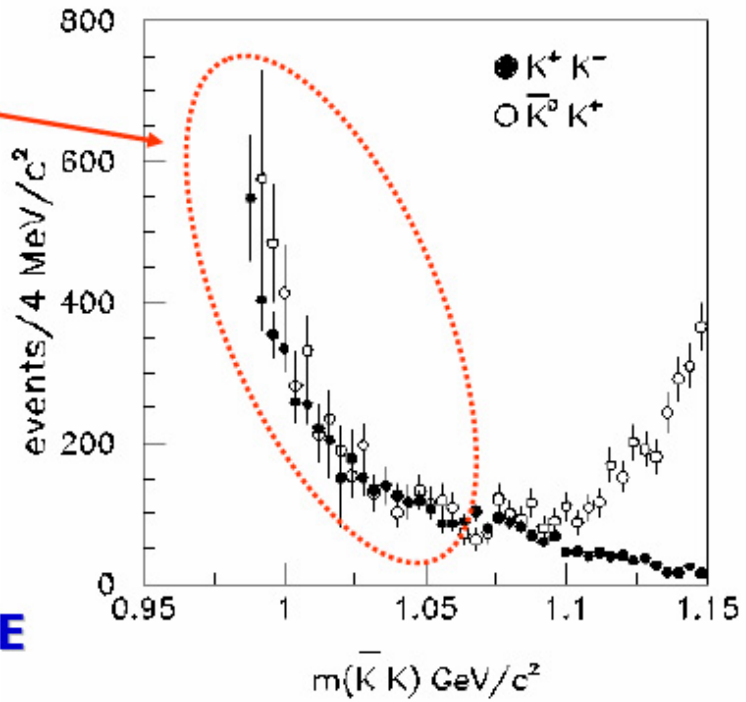
- **$\overline{K}^0K^+$ system: $a_0(980)^+$**

$$BW_\phi = \frac{1}{m_\phi^2 - m_{K^+K^-}^2 - i m_\phi \Gamma_\phi}$$

$$BW_{a_0} = \frac{1}{m_{a_0}^2 - m_{KK}^2 - i m_{a_0} (\rho_{\eta\pi} g_{\eta\pi}^2 + \rho_{KK} g_{KK}^2)}$$

FREE

Fixed to Crystal Barrel measurement
A. Abele et al., Phys. Rev. **D57**, 3860(1998)



I=1/2 Kπ S-wave

Kπ S-wave in mass range 0.6–1.4 GeV/c^2 is not well-understood. A possible κ state ~ 800 MeV/c^2 has been conjectured, but this has only been reported in the neutral state.

– For the $K^+\pi^0$ and $K^-\pi^0$ S-wave amplitudes, we try three models:
  - Amplitude obtained from LASS $K^-\pi^+ \to K^-\pi^+$ scattering.

    Nucl. Phys. B296, 493 (1988); W. Dunwoodie, web notes.

  - $K^-\pi^+$ amplitude extracted from a model-independent partial-wave analysis of $D^+ \to K^-\pi^+\pi^+$ decay by the E791 collaboration. Phys. Rev. D73, 032004 (2006)
  - [coherent sum of κ(800) + uniform NR + $K^*_0(1430)$]. { No evidence in Kπ elastic scattering. }

Normalized to arbitrary scale for m(Kπ)>1.1 Gev/c^2 for easy comparison.