The $\pi\pi$ and $K\pi$ S-wave from charm decays

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The $\pi\pi$ and $K\pi$ S-wave from charm decays

The identification of the scalars is still a big challenge:

- Many candidates: which ones are genuine $q\bar{q}$ states?
- What is the position of their poles?
- What are the couplings to specific modes?

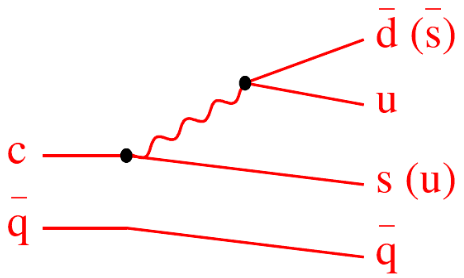
$K\pi$ bellow 1 GeV/c^2 $\Rightarrow$ The $\kappa(800)$: an $I = 1/2$ state? What is its pole position?

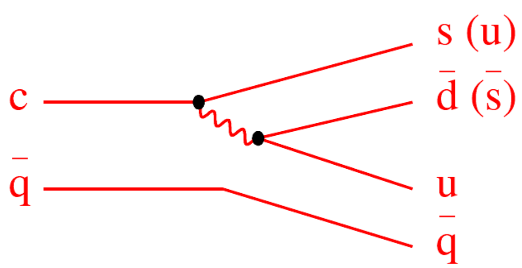
$\pi\pi$ between 1.2-1.5 GeV/c^2 $\Rightarrow$ what is the nature of the $f_0(1370)$?

The $\pi\pi$ and $K\pi$ S-wave from charm decays

Why charm is so interesting for light quark studies?

- mass spectrum is accessible, continuously, from threshold;
- very large and clean samples available;
- $D \to PPP$ decays: resonances are constrained by 'final state' quarks;





The bulk of the hadronic decay width is well described in terms of valence quark diagrams connected to known $q\bar{q}$ resonances.

- The drawback: one cannot extract the $\pi\pi/K\pi$ amplitudes in a model independent way.

The isobar model for the S-wave

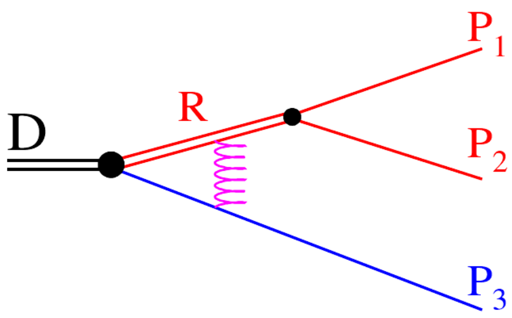
The isobar model is simple and intuitive.

$$\mathcal{A}^0(s_a, s_b) = \mathrm{NR} + \sum c_k e^{i\delta_k} A_k^0(s_a, s_b),$$

D decays $\longrightarrow$ $\mathrm{NR} = c_0 e^{i\delta_0}$; B decays $\longrightarrow$ $\mathrm{NR} = f(s_a, s_b)$

$$A_k^0(s_a, s_b) = (f_R^0) \times BW_k$$

There are well known conceptual problems with this approach.



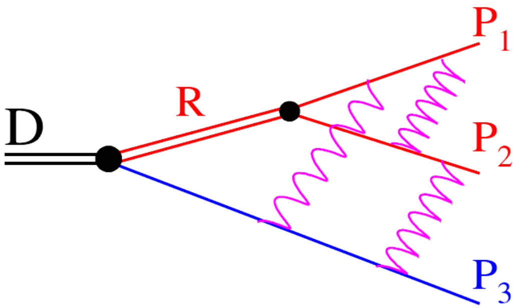
The MIPWA technique

The MIPWA $\Rightarrow$ no assumption about the nature of the S-wave.

The amplitude is a generic, complex function, $A_0(s) = a(s)e^{i\gamma(s)}$.

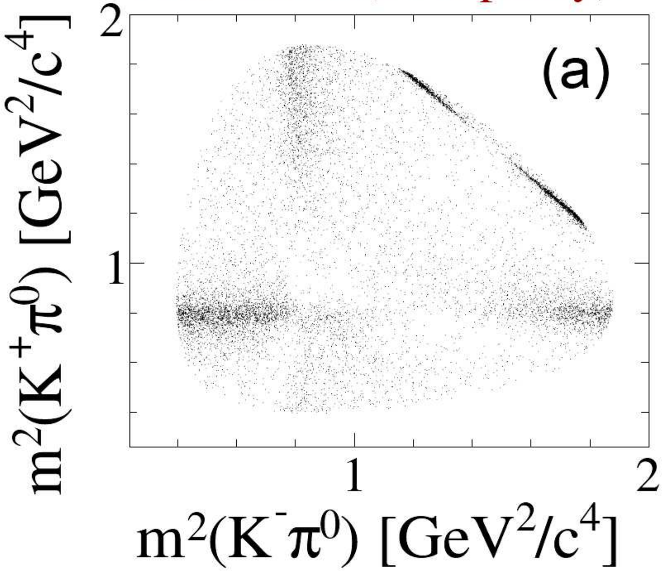
The $P_1 P_2$ spectrum is divided in slices , $A_0(s = s_k) = a_k e^{i\gamma_k}$.

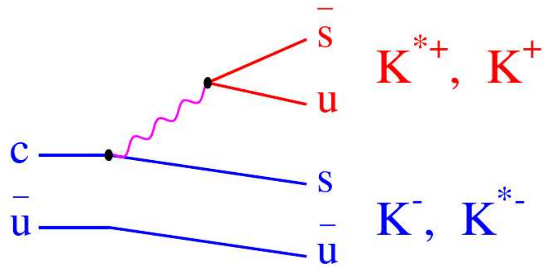
- The method rely on a precise representation of the P- and D-waves.
- Results are inclusive : full FSI, production, all isospin contributions.
- The basic problem: how to extract the pure PP amplitude?

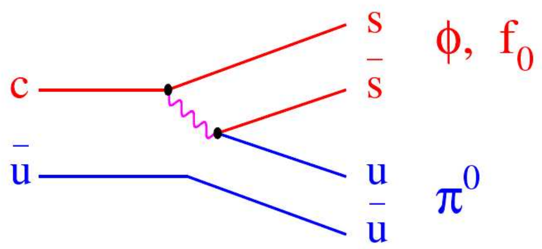


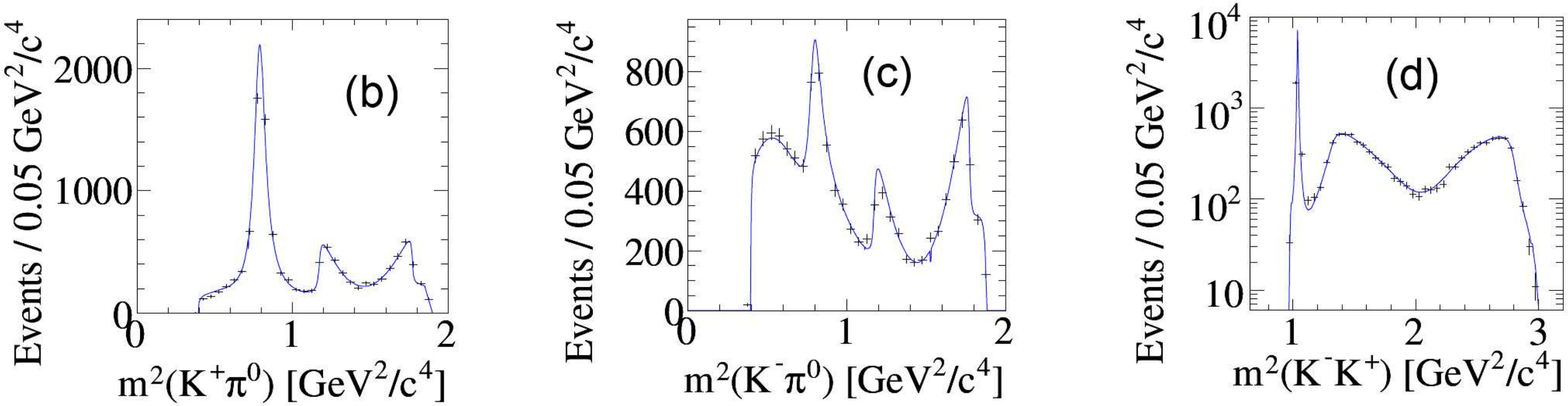
The $K\pi$ amplitude – $D^0 \to K^- K^+ \pi^0$ – BaBar

11K events (98% purity)









The $K\pi$ amplitude – $D^0 \to K^- K^+ \pi^0$ – BaBar

- The isobar model yields the worse fit: $\mathbf{prob < 5\%}$;
- The E791 MIPWA S-wave describes well the data: $\mathbf{prob = 23\%}$.
- The LASS I=1/2 S-wave provides the best fit; $\mathbf{prob = 62\%}$.

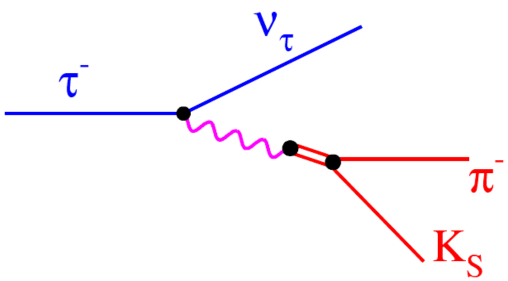
Decay fractions (%) - LASS S-wave

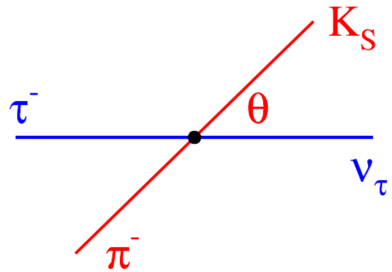
mode	model I	model II
$K^*(892)^+ K^-$	45.2 ± 0.9	44.4 ± 0.9
$K^*(1410)^+ K^-$	3.7 ± 1.5	-
$K^+ \pi^0 (S)$	16.3 ± 0.1	71.1 ± 4.2
$\phi \pi^0$	19.3 ± 0.7	19.4 ± 0.7
$f_0(980) \pi^0$	6.7 ± 1.8	10.5 ± 1.4
$K^*(892)^- K^+$	16.0 ± 0.9	15.9 ± 0.9
$K^*(1410)^- K^+$	2.7 ± 1.5	-

A larger sample will allow a direct (MIPWA) measurement of the $K\pi$ S-wave.

The $K\pi$ amplitude – $\tau^- \rightarrow \overline{K}^0\pi^-\nu_\tau$ – Belle

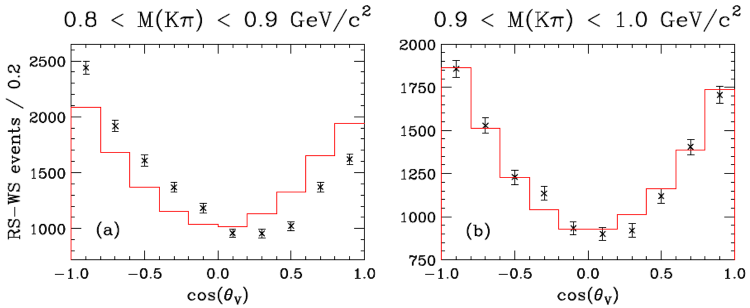
$$e^+e^- \rightarrow \tau^+\tau^-, \quad \tau^+ \rightarrow l^+\nu_\tau\nu_l, \quad \tau^- \rightarrow K_S\pi^-\nu_\tau;$$

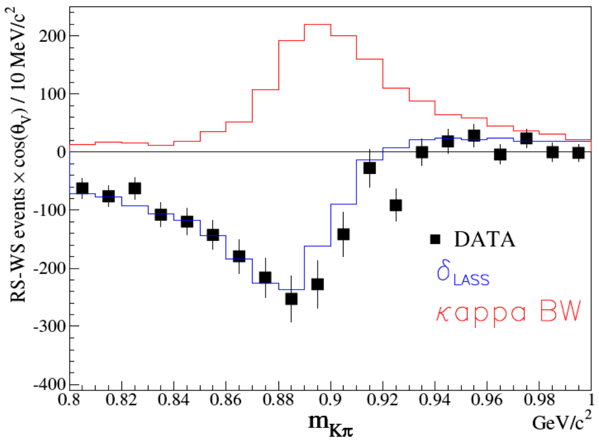




- $\overline{K}^0\pi^-$ free from FSI, but 3 missing neutrinos: no angular analysis.

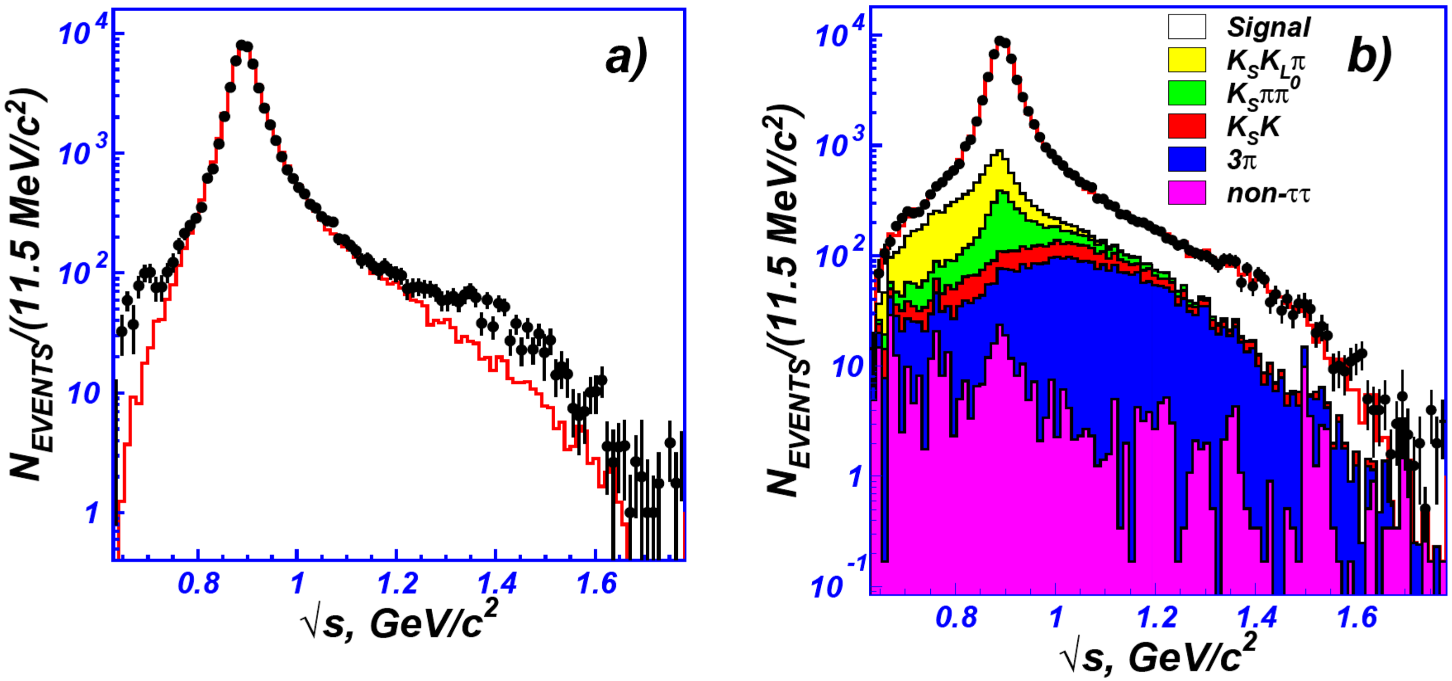
$D^+ \rightarrow K^-\pi^+\mu^+\nu$ (FOCUS)





The $K\pi$ amplitude – $\tau^- \to \overline{K}^0 \pi^- \nu_\tau$ – Belle

The $\overline{K}^0 \pi^-$ is dominantly in P-wave : $f(\overline{K}^*(892)^-) \simeq 93\%$.



53K signal events, B/S $\sim$ 20%.

The $K\pi$ amplitude – $\tau^- \to \overline{K}^0\pi^-\nu_\tau$ – Belle

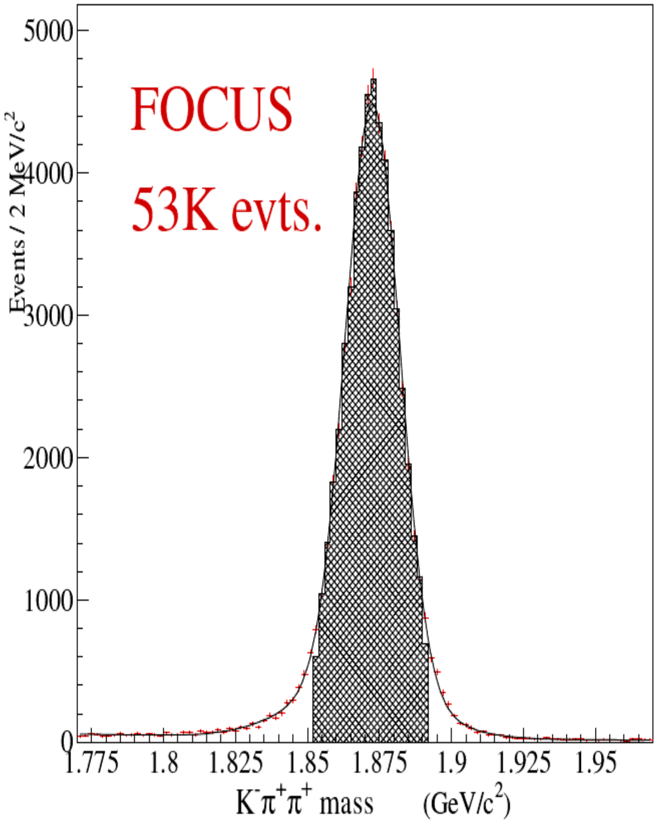
The $\overline{K}^0\pi^-$ mass spectrum is fitted with diferent models:

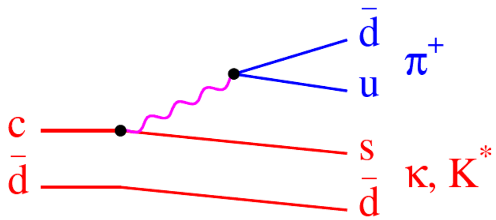
- $\overline{K}^*(892)^-$ (I)
- $\overline{K}^*(892)^- + \kappa^- + \overline{K}^*(1680)^-$ (II)
- $\overline{K}^*(892)^- + \kappa^- + \overline{K}^*(1410)^-$ (III)
- $\overline{K}^*(892)^- + \kappa^- + \overline{K}_0^*(1430)^-$ (IV)
- $\overline{K}^*(892)^- + \mathrm{LASS}\ (I = 1/2)$ (V)

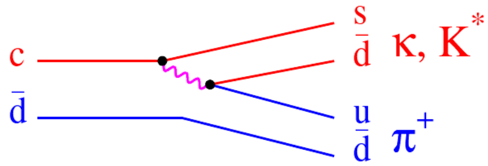
	I	II	III	IV	V
χ^2	484	107	92	87	197
C.L (%)	0	5	30	41	10^{-8}

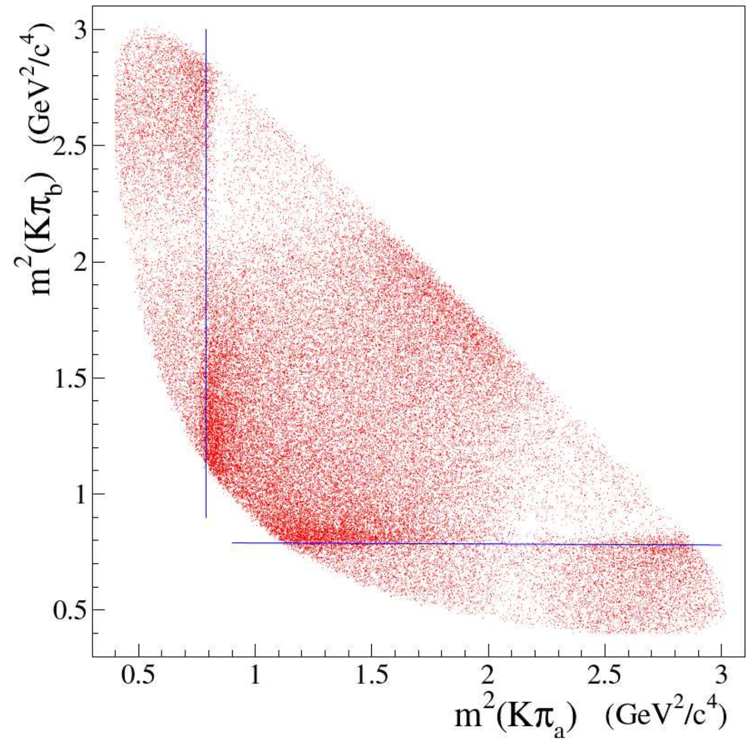
- **The S-wave model with the $\kappa^-(800)$ yields the best fit;**
- **This data is inconsistent with LASS $I = 1/2$ S-wave**

The $K\pi$ amplitude – $D^+ \to K^-\pi^+\pi^+$ – FOCUS



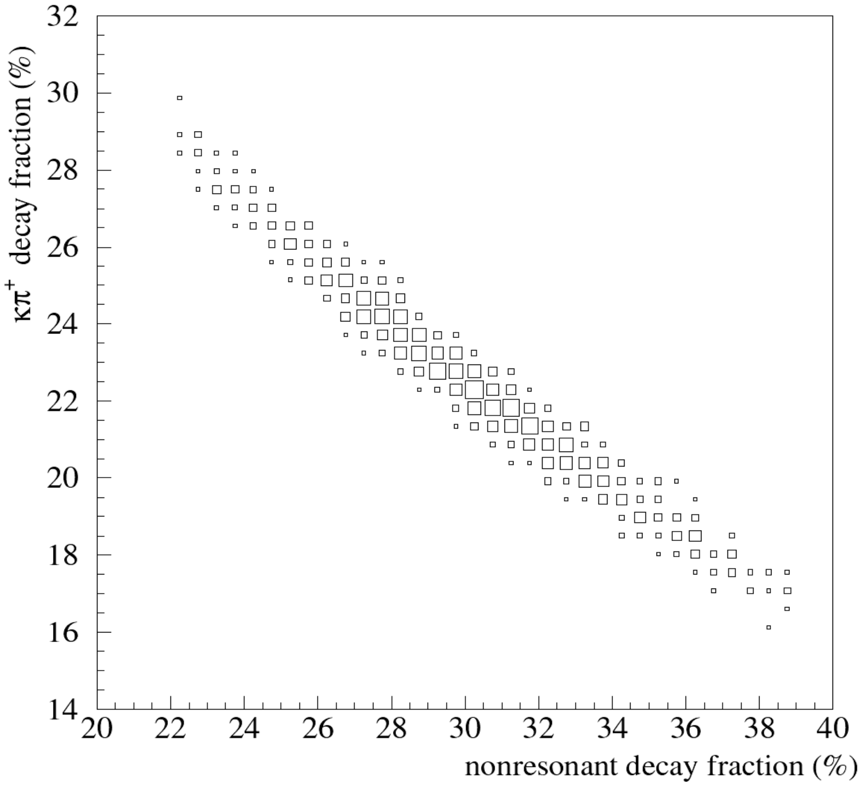






The $K\pi$ amplitude – $D^+ \to K^-\pi^+\pi^+$ – Isobar Model

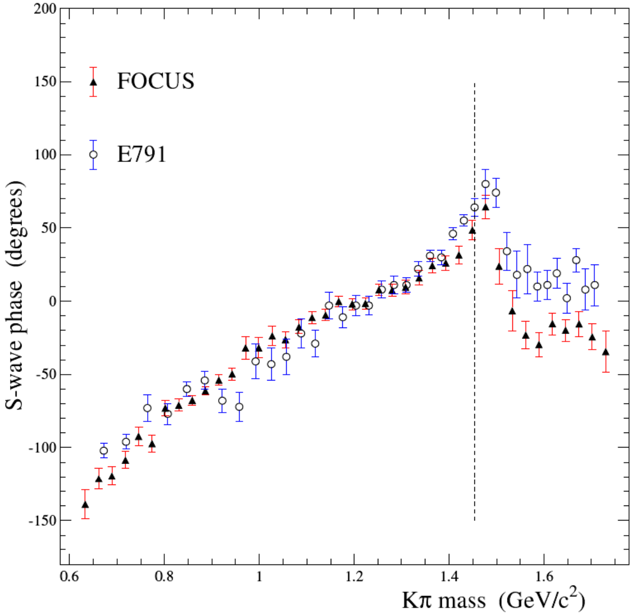
With the isobar model for the S-wave
one cannot disentangle the κ and NR decay fractions!

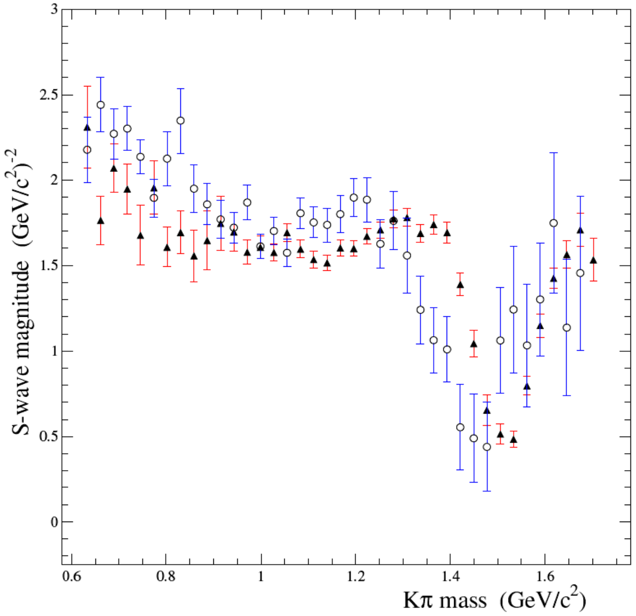


The κ and NR decay fractions
from 2000 miniMC samples generated
according to the isobar fit result.

The $K\pi$ amplitude – $D^+ \rightarrow K^-\pi^+\pi^+$ – MIPWA

FOCUS preliminary





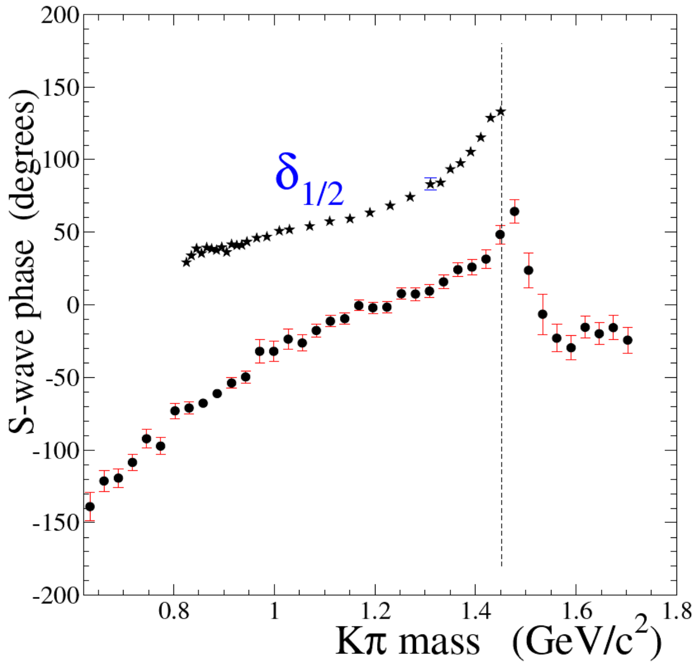
MIPWA decay fractions (%)

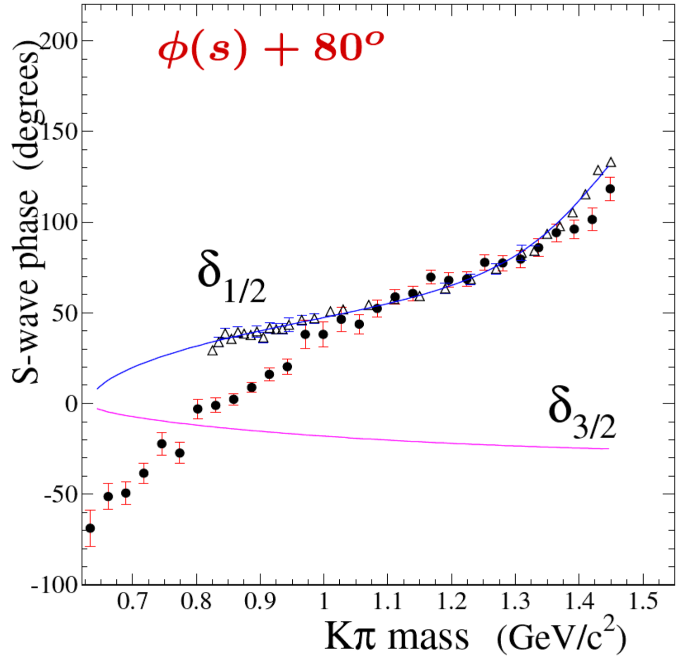
mode	E791	CLEOc	FOCUS
$\overline{K}^*(892)^0\pi^+$	11.9 ± 2.0	9.9 ± 0.5	12.3 ± 0.4
$\overline{K}^*(1680)\pi^-$	1.2 ± 1.2	2.0 ± 0.1	1.8 ± 0.7
$\overline{K}_2^*(1430)\pi-$	0.2 ± 0.1	0.48 ± 0.01	0.1 ± 0.1
$K^-\pi^+$ S-wave	78.6 ± 2.3	83.8 ± 3.8*	80.2 ± 1.4

* only the binned amplitude. The $\overline{K}_0^*(1430)\pi-$ adds $13.3 \pm 0.6\%$

The $K\pi$ amplitude – $D^+ \to K^-\pi^+\pi^+$ – FOCUS

$D^+ \to K^-\pi^+\pi^+$ *versus* $K^-\pi^+ \to K^-\pi^+$:





No combination of $\delta_{1/2}$ and $\delta_{3/2}$ can reproduce $\phi(s)$.

$$\phi(s) = \delta_{\mathbf{LASS}}(s) + \gamma(s)$$

An additional phase $\gamma(s)$ is required, probably due to 3-body FSI.

The $K\pi$ amplitude – conclusions

- *Is there a charged κ ? The answers given by BaBar and Belle are inconclusive.*
- *The* $\tau^- \rightarrow \overline{K}^0 \pi^- \nu_\tau$ *decay is promising, but high statistics and angular analysis are required.*

- *The* $\boldsymbol{D^+ \rightarrow K^- \pi^+ \pi^-}$ *decay can fill the existing gap between LASS data and the* $K^- \pi^+$ *thershold.*
- *Extracting the Kπ I=1/2 amplitude is not a trivial task. One has to deal with the 3-body final state interaction. Systematics is also a problem.*

- *The* $\boldsymbol{D \rightarrow K\pi\mu\nu}$ *decay provides a cleaner environment, but very high statistics is necessary.*
- *Input from theory is urgently needed in order to quantify the effect of FSI.*

The $\pi\pi$ S-wave between 1.2-1.5 GeV^2 - $f_0(1370)$

The $f_0(1500)$ is a narrow, well stablished state (pp, $p\bar{p}$, J/ψ data):

$m_0(MeV)$	$\Gamma_0(MeV)$
1505 ± 6	109 ± 7

$\Gamma_{\pi\pi}/\Gamma_0$	$\Gamma_{4\pi}/\Gamma_0$	$\Gamma_{K\bar{K}}/\Gamma_0$	$\Gamma_{\eta\eta}/\Gamma_0$
$(34.9 \pm 2.3)\%$	$(49.5 \pm 3.3)\%$	$(8.6 \pm 1.0)\%$	$(5.1 \pm 0.9)\%$

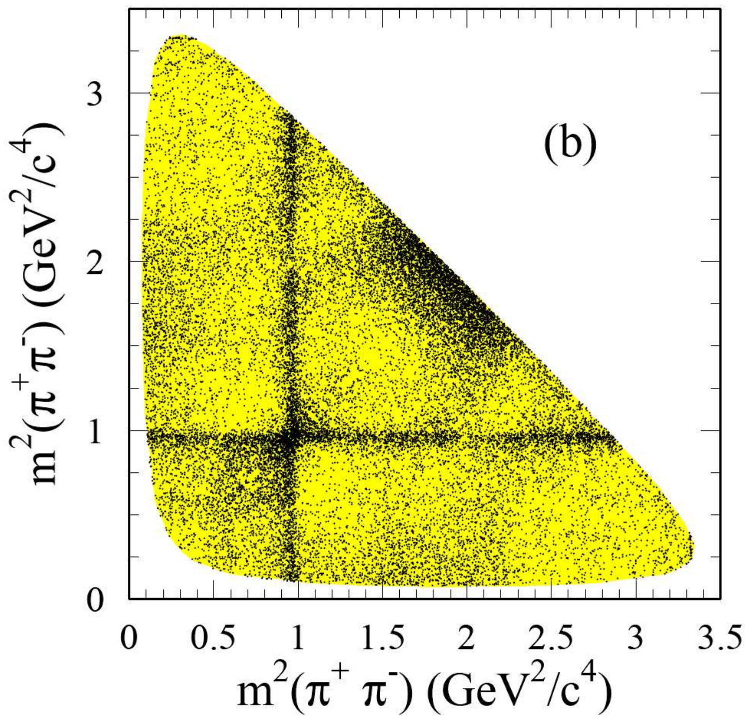
The $f_0(1370)$, however, is not well stablished:

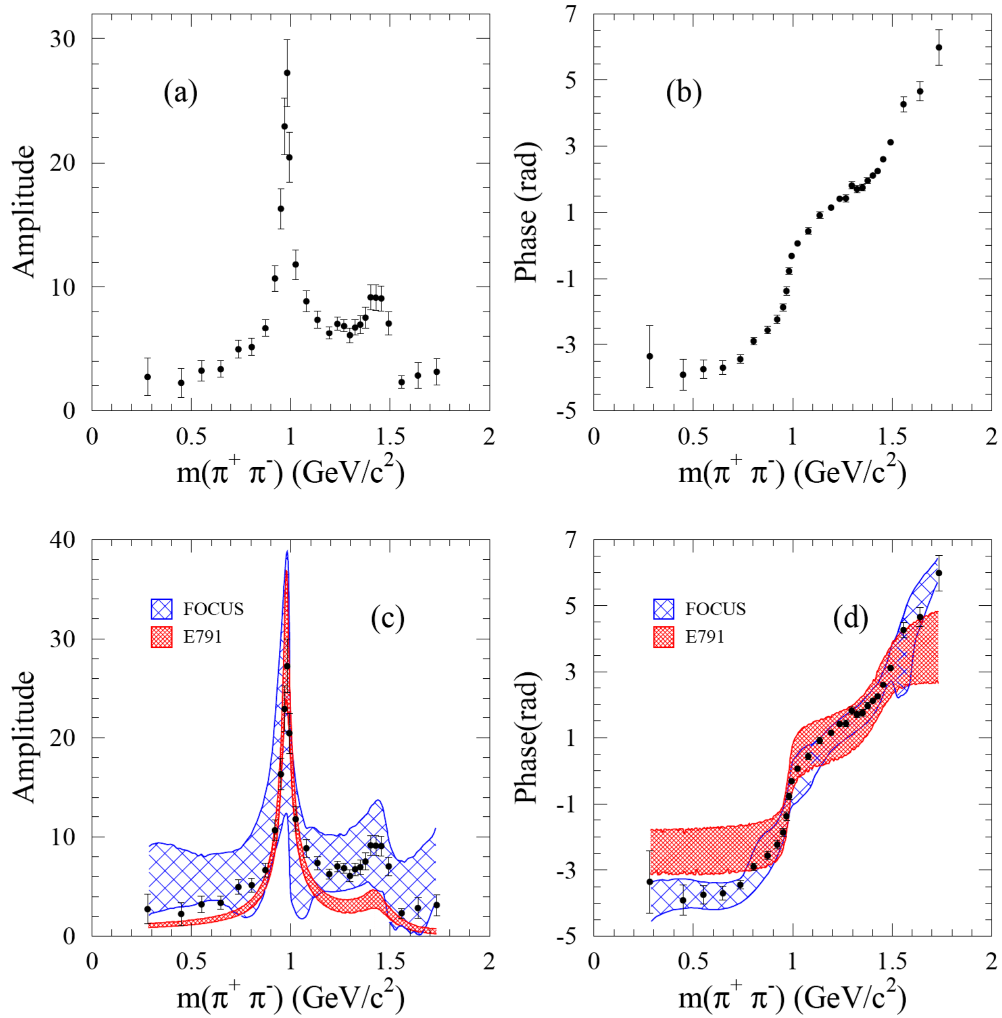
$m_0(MeV)$	$\Gamma_0(MeV)$
$1200 - 1500$	$200 - 500$

What HF decays can tell about the $f_0(1370)$ mass, width and couplings?

Are both $f_0(1370)$ and $f_0(1500)$ observed in B and D decays?

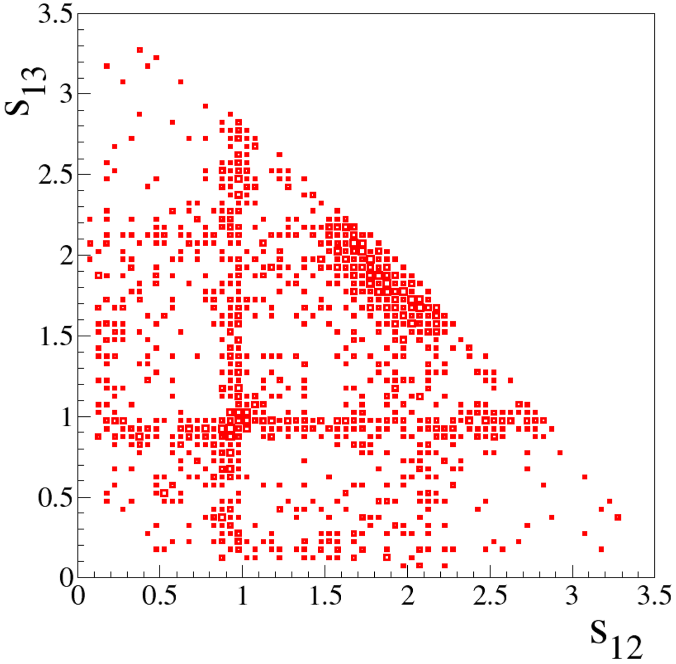
$f_0(1370)$: $D_s^+ \to \pi^-\pi^+\pi^+$ – BaBar

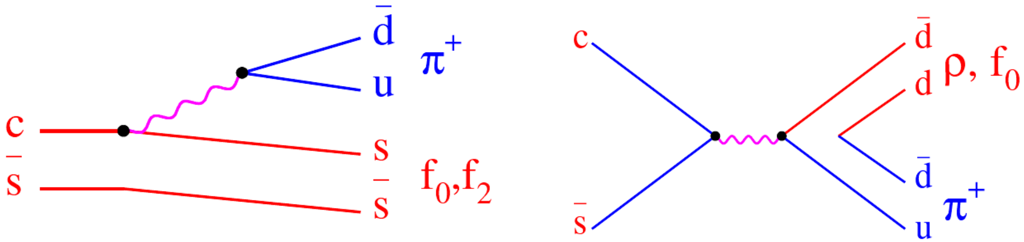




$f_0(1370)$: $D_s^+ \to \pi^-\pi^+\pi^+$ – FOCUS and E791

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





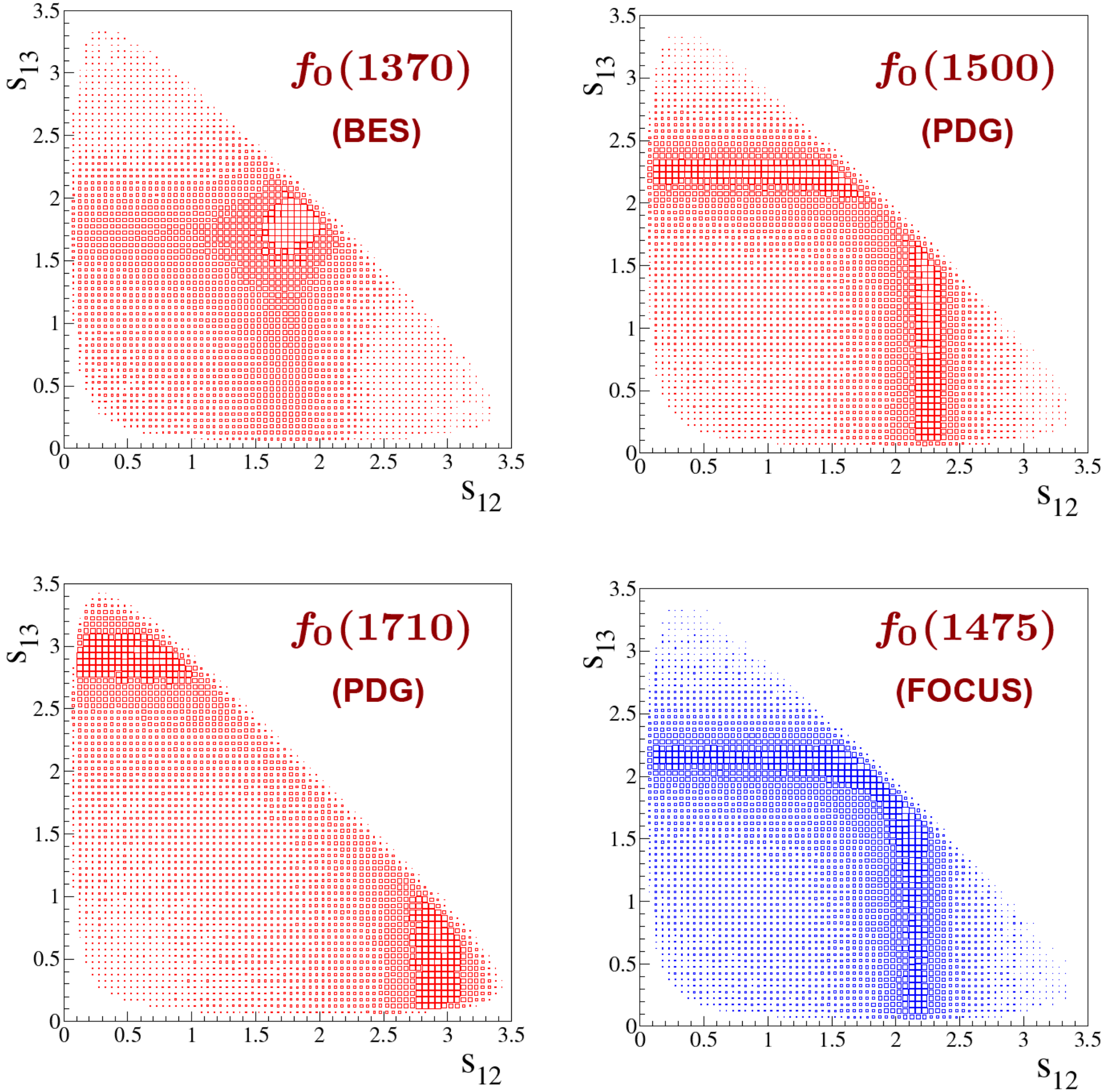
Decay fractions (%)

mode	FOCUS	E791
$f_0(980)\pi^+$	76.9 ± 4.9	56.5 ± 5.9
$f_2(1270)\pi^+$	9.7 ± 1.4	19.7 ± 3.4
$\rho(770)^0\pi^+$	1.2 ± 0.1	5.8 ± 4.4
$\rho(1450)^0\pi^+$	4.0 ± 1.0	4.4 ± 2.1
$f_0(X)\pi^+$	23.3 ± 0.5	32.4 ± 7.9
NR	13.2 ± 5.7	1 ± 2

- $f_0(X)$ (MeV/c^2) $\to$

	FOCUS	E791
m_0	1476 ± 5.7	1434 ± 18
Γ_0	119 ± 18	173 ± 32

$f_0(1370)$: $D_s^+ \to \pi^-\pi^+\pi^+$



MC simulation of

$D_s^+ \to f_0(X)\pi^+$,

$f_0(X) \to \pi^-\pi^+$.

Scalar state in

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

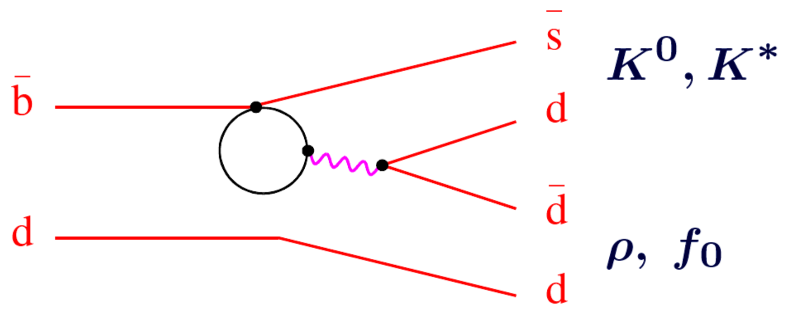
consistent with

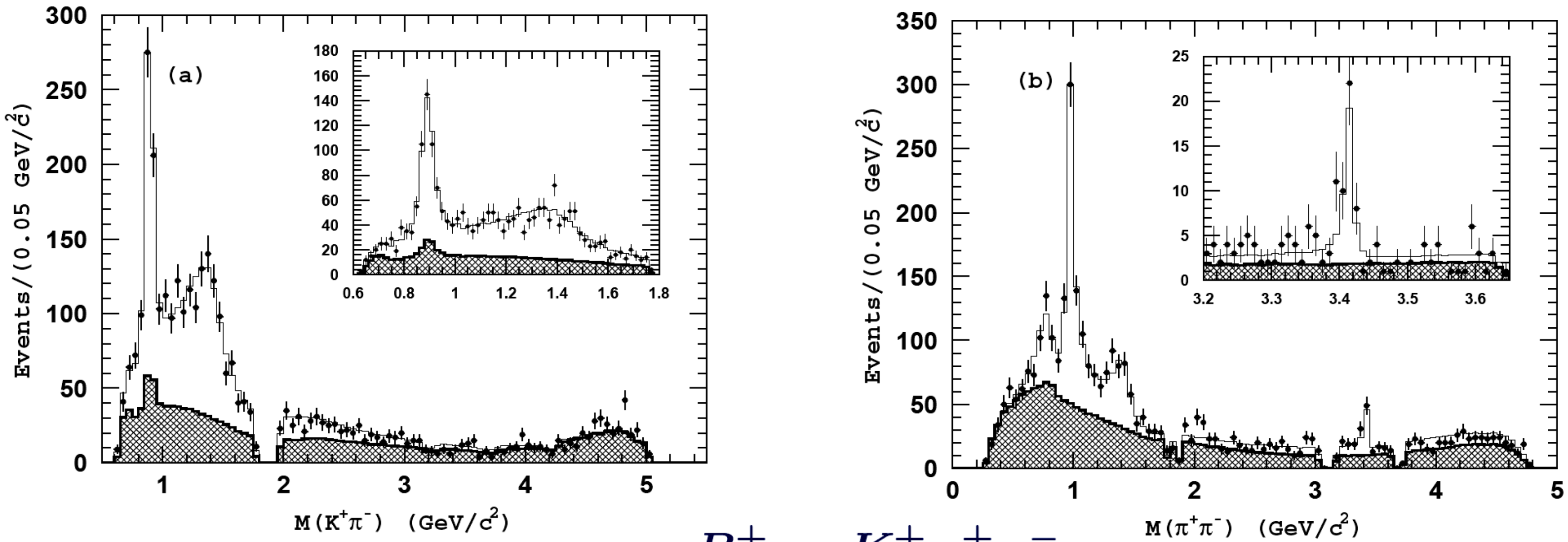
$f_0(1500)$.

$f_0(1370)$: $B \to K\pi\pi$ – Belle

Charmless 3-body B decays – Belle $B \to K\pi\pi$

- $B^0 \to K^0\pi^+\pi^-$
- $B^+ \to K^+\pi^+\pi^-$





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

$f_0(1370)$: $B \longrightarrow K\pi\pi$ – Belle

The peak at 1.4 GeV/c^2 $(\pi^+\pi^-)$ is better described by a single scalar state.

$B^+ \longrightarrow K^+\pi^+\pi^-$

mode	fraction (%)
$K^*(892)^-\pi^+$	13.0 ± 1.0
$K_0^*(1430)^-\pi^+$	65.5 ± 4.5
$\rho(770)^0K^+$	7.9 ± 1.0
$f_0(980)K^+$	17.7 ± 3.6
$f_0(X)K^+$	4.1 ± 0.9
NR	34 ± 2.7

$B^0 \longrightarrow K^0\pi^+\pi^-$

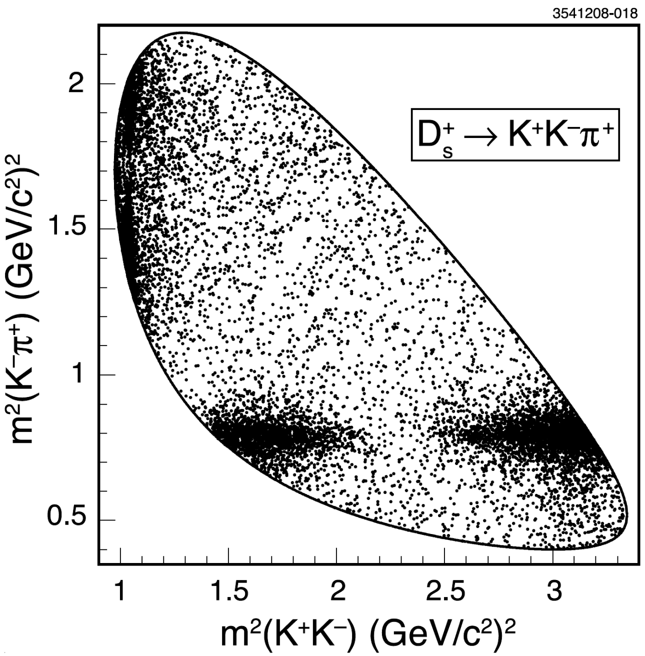
mode	fraction (%)
$K^*(892)^+\pi^-$	11.8 ± 1.7
$K_0^*(1430)^+\pi^-$	64.8 ± 7.8
$\rho(770)^0K^0$	12.9 ± 20
$f_0(980)K^0$	16.0 ± 4.2
$f_0(X)K^0$	3.7 ± 2.4
NR	41.9 ± 5.5

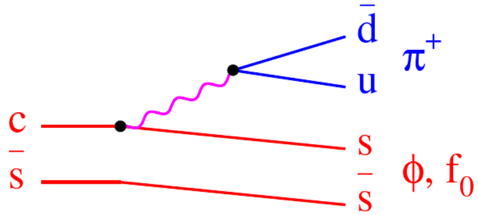
$f_0(X)$ parameters (GeV/c^2): $m_0 = 1.449 \pm 0.013$,

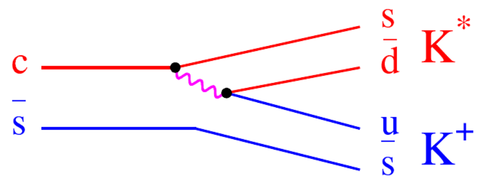
$\Gamma_0 = 0.126 \pm 0.025$

- Small $\pi\pi$ NR component; $\pi\pi$ S-wave apparently under control.
- Large interference between $K\pi$ NR and $K_0^*(1430)^+\pi^-$.
- Need to understand broad structures in Dalitz plot of B decays.

$f_0(1370)$: $D_s^+ \to K^- K^+ \pi^+$ – CLEO-c







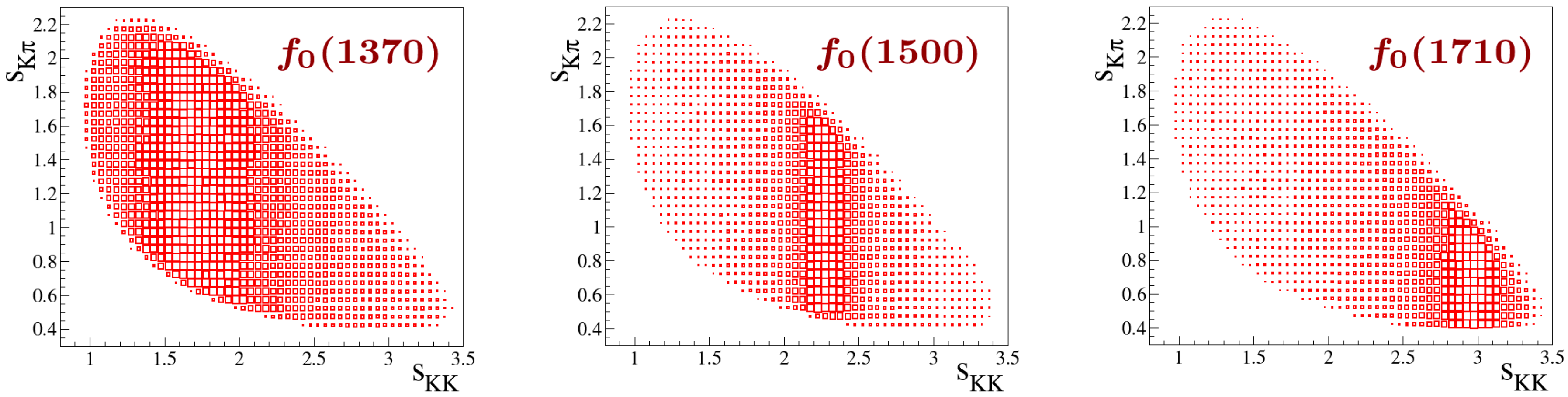
mode	CLEO-c	BaBar
$K^*(892)^0 K^+$	47.4 ± 1.5	48.7 ± 1.6
$\phi(1020)\pi^+$	42.2 ± 1.6	37.9 ± 1.8
$f_0(980)\pi^+$	28.2 ± 1.9	35 ± 14
$f_0(1370)K^+$	4.3 ± 0.6	6.3 ± 4.8
$f_0(1710)K^+$	3.4 ± 0.5	2.0 ± 1.0

$f_0(1370) \Rightarrow m_0 = 1.315 \pm 34$ GeV/c^2, $\Gamma_0 = 0.276 \pm 39$ GeV/c^2 (CLEO-c)

$m_0 = 1.313 \pm 10 \pm 114$ GeV/c^2, $\Gamma_0 = 0.395 \pm 8 \pm 133$ GeV/c^2 (BaBar)

$f_0(1370)$: $D_s^+ \to K^- K^+ \pi^+$ – CLEO-c

MC simulation of $D_s^+ \to f_0(X)\pi^+, \quad f_0(X) \to K^+K^-$

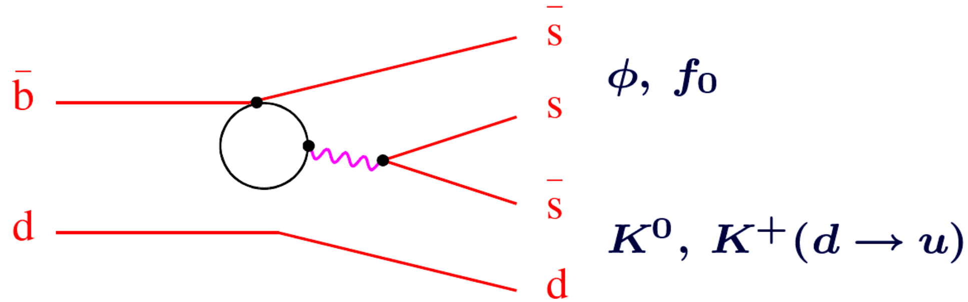


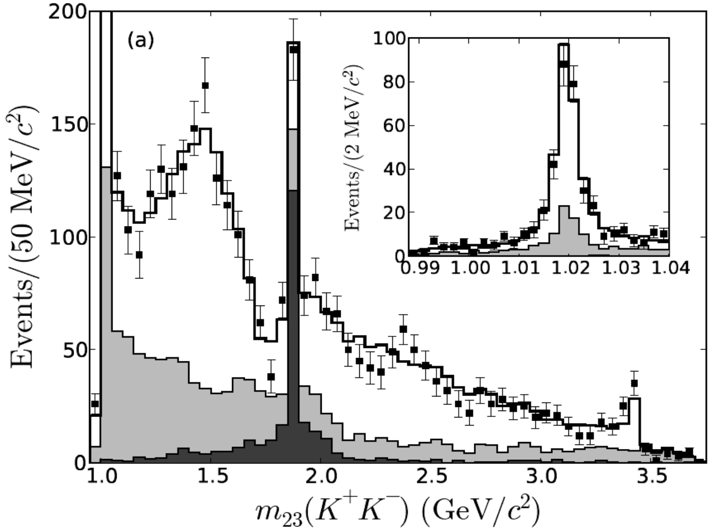
- No evidence of $f_0(1500)$, small contribution from $f_0(1710)$.
- A tough analysis: the KK spectrum near threshold is very complex, with contributions from $f_0(980)$, $a_0(980)$ and ϕ.
- CLEO-c and BaBar agree on the $f_0(1370)$ mass, but widths are very different.

$f_0(1370)$: $B \to KKK$ – BaBar

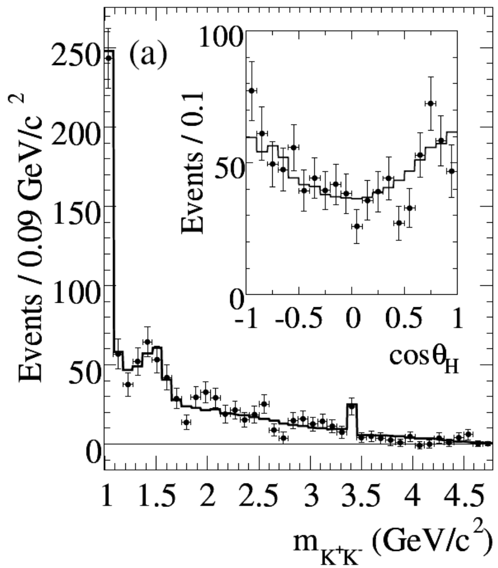
Charmless 3-body B decays – BaBar $B \to KKK$

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



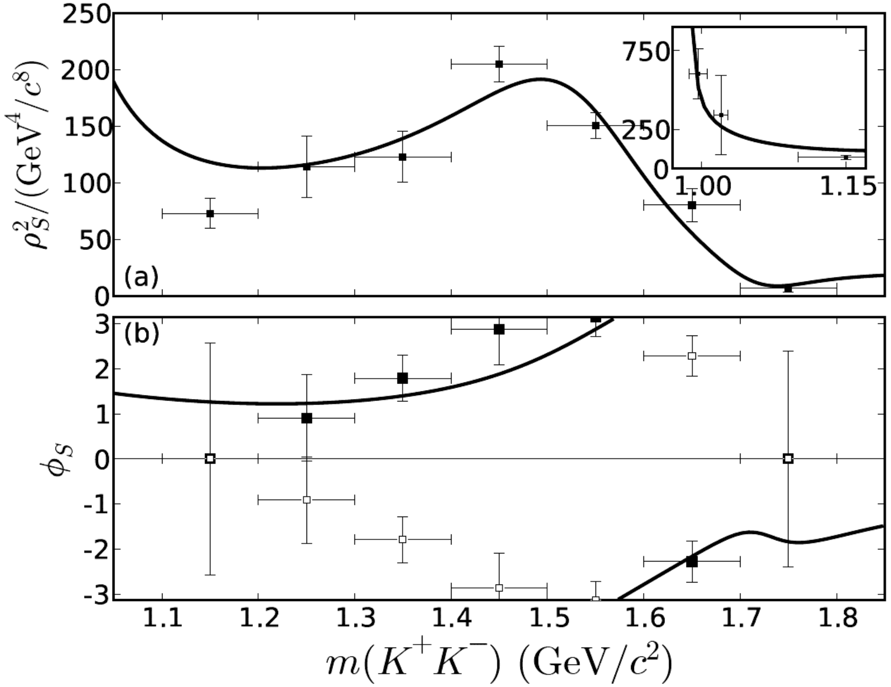


$B^0 \to K^+ K^+ K^-$



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

$f_0(1370)$: $B \to KKK$ – BaBar



A PWA of the K^+K^- S-wave on a limited region of the DP show a rapid change in the phase at $m_{KK} \sim 1.55$ GeV/c^2

$f_0(1370)$: $B \longrightarrow KKK$ – BaBar

The peak at 1.5 GeV/c^2 (K^+K^-) is better described by a single scalar state.

$B^+ \longrightarrow K^+K^+K^-$

mode	fraction (%)
$\phi(1020)K^+$	11.8 ± 1.2
$f_0(980)K^+$	19 ± 8
$X_0(1550)K^+$	121 ± 20
$f_0(1710)K^+$	4.8 ± 2.9
NR	141 ± 17

$B^0 \longrightarrow K^0K^+K^-$

mode	fraction (%)
$\phi(1020)K^0$	12.6 ± 1.0
$f_0(980)K^0$	27.8 ± 7.1
$X_0(1550)K^0$	5.7 ± 1.7
$f_0(1710)K^0$	-
NR	112 ± 15

X_0 parameters (GeV/c^2): $m_0 = 1.539 \pm 0.020$, $\Gamma_0 = 0.257 \pm 0.033$

- Very large destructive interference in the K^+K^- S-wave.
- Very different decay fractions in B^0 and B^+.
- K^+K^- spectrum is not really well understood.

$f_0(1370)$: conclusions

- A strong S-wave dominance is observed in final states having identical particles: $D^+ \to K^-\pi^+\pi^+$; $D^+, D_s^+ \to \pi^-\pi^+\pi^+$ are golden modes.

- D and B decays can be described with only one high mass scalar. Analysis of the $K\pi\pi$ and $\pi\pi\pi$ final states shows that this state is consistent (but not quite the same) with $f_0(1500)$.

- This state is not seen in final states with K^+K^-. In $D_s^+ \to K^+K^-\pi^+$ there is an indication of a broader state with lower mass ($f_0(1370)$?) .

- These results suggest that the $f_0(1500)$ may be mostly a $q\bar{q}$ object, whereas the nature of $f_0(1370)$ remains uncertain.

- Belle and Babar already have very large samples of $D \to PPP$ decays. At this point we are limted by systematics. An analysis focused on the physics of the scalar mesons is in order.

Summary

- $HF \to LQ$ is a very special key to scalar mesons, with unique features and constraints.
- Studies with semi-leptonic D and τ decays are still limited by statistics.
- The B-factories have enough data on $D \to \pi\pi\pi$, $D \to K\pi\pi$ and $D \to KK\pi$ for a systematic study (MIPWA) of the $\pi\pi$ and $K\pi$ S-wave.
- B decays are a very promising tool. Larger statistics (LHCb) and a better understanding of the NR component are necessary.
- In order to explore the full potential of heavy flavor decays, input from theory is necessary: 3-body FSI, decay dynamics, form-factors, lineshapes...

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