

Scalars in heavy flavor decays

Alberto Reis

CBPF, Rio de Janeiro.

Scalars and heavy flavor decays

The identification of the scalars is still challenging:

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

$K\pi$ below 1 GeV \Rightarrow The $\kappa(800)$: an $I = 1/2$ state? Pole position?

$\pi\pi/K\bar{K}$ between 1-2 GeV \Rightarrow what is the nature of the $f_0(1370)$?

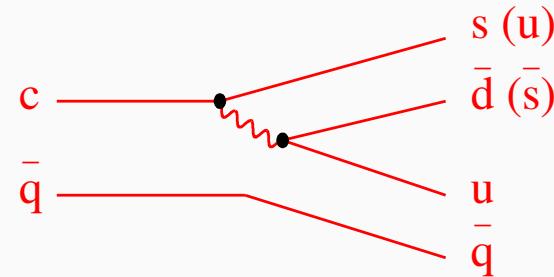
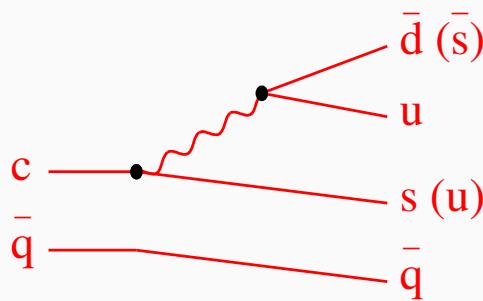
Look at answers given by heavy flavor decays:

$$B, D \rightarrow PPP; \quad D \rightarrow PPl\nu; \quad \tau \rightarrow PP\nu$$

Scalars and heavy flavor decays

Why HF → light quarks?

- mass spectrum is accessible, continuously, from threshold;
- statistics is rapidly becoming sufficiently large;
- B, D decays: resonances are constrained by 'final state' quarks;



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

Scalars and heavy flavor decays

$D \rightarrow PPl\nu, \tau \rightarrow PP\nu$: the best processes for PP S-wave at low mass.



- Simple and clean, most directly related to scattering data.
- Largely dominated by P-wave: very large samples required.
- missing neutrino(s) \Rightarrow difficult reconstruction, high background.

$D \rightarrow PPP \Rightarrow$

- easy to obtain, small NR, low background;
- much more complex: 3-body FSI.
- Relation to scattering is not direct.

Scalars and heavy flavor decays

The standard technique for $B, D \rightarrow PPP$:
an unbinned fit of the Dalitz plot (Dp),

$$\mathcal{L} = \prod_{\text{events}} [P_S(s_a, s_b) + P_B(s_a, s_b)] ,$$

$$P_S = \frac{1}{N_S} \times \text{eff} \times \left| \sum_L f_D^L \mathcal{S}^L \mathcal{A}^L \right|^2 ,$$

$$\mathcal{A}^L = \sum c_k e^{i\delta_k} A_k^L, \quad A_k^L = f_R^L \times BW_k$$

Analyses differ by the way the S-wave, \mathcal{A}^0 , is modeled.

Scalars and heavy flavor decays

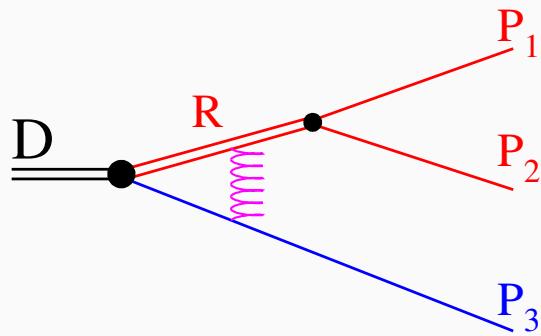
The isobar model \Rightarrow simple and intuitive.

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

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

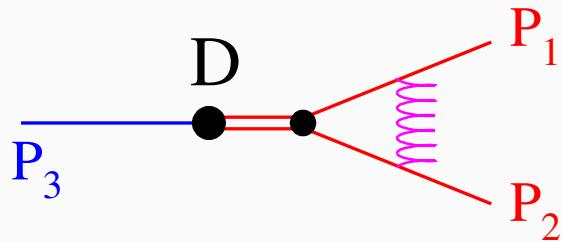
$$A_k^0(s_a, s_b) = (f_R^0) \times BW_k$$

There are well known conceptual problems with this approach.



Scalars and heavy flavor decays

The K-matrix model \Rightarrow no interaction between P_3 and $P_1 P_2$.



Dynamics of the final state is driven by the $P_1 P_2 \rightarrow$ 2-body unitarity.

No attempt to measure the S-wave: input from other reactions ($\text{HF} \leftarrow \text{LQ}$).

- Difficult to interpret: K-matrix and S-matrix poles are not the same.
- Production of $P_1 P_2$ is unknown. Production phase may also contain FSI.
- The basic assumption – absence of 3-body FSI – is far from trivial.

Scalars and heavy flavor decays

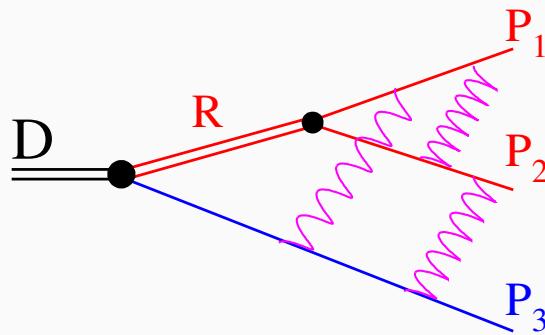
The MIPWA \Rightarrow no assumption about the nature of the S-wave.

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 bins, with 2 free parameters per bin,

$$A_0(s = s_k) = a_k e^{i\gamma_k}.$$

- 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

The data:

- $D^0 \rightarrow K^+ K^- \pi^0$ – BaBar
- $\tau^- \rightarrow \bar{K}^0 \pi^- \nu_\tau$ – Belle
- $D^+ \rightarrow K^- \pi^+ \pi^+$ – CLEOc, FOCUS

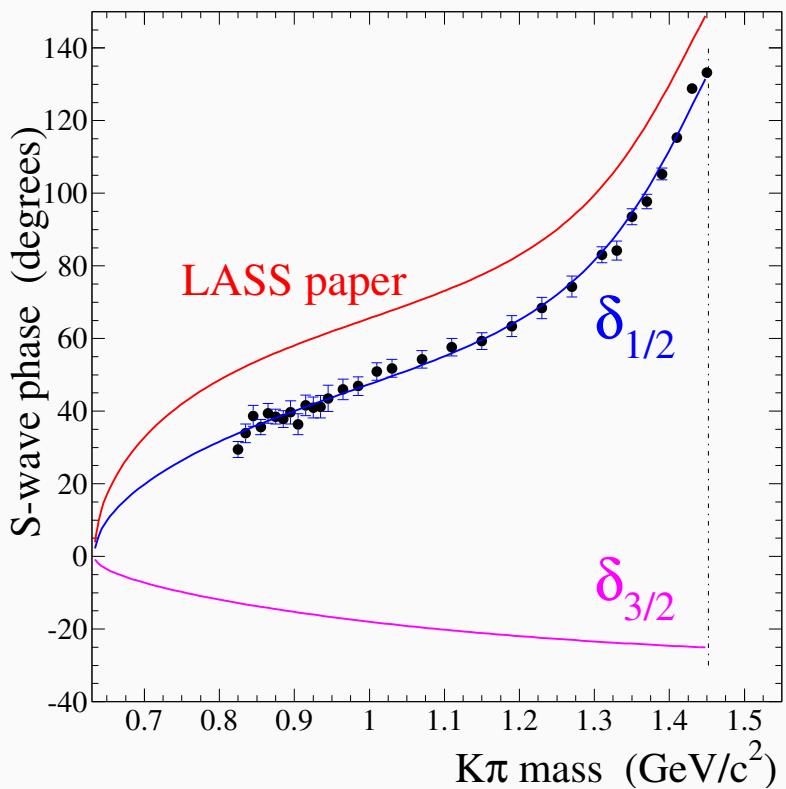
The $K\pi$ amplitude – the classic LASS experiment

$K^- p \rightarrow K^- \pi^+ n$ at 11 GeV.

151K events with $|t| \leq 0.2 \text{ GeV}/c^2$ and $m(n\pi^+) > 1.7 \text{ GeV}/c^2$

At small t , π exchange dominates : $K^- \pi^+ \rightarrow K^- \pi^+$.

Cross section is elastic up to $K\eta'$ threshold (1.454 GeV/c²).



$$\mathcal{A}_{1/2}(s) = \sin \delta_{1/2}(s) e^{i \delta_{1/2}(s)},$$

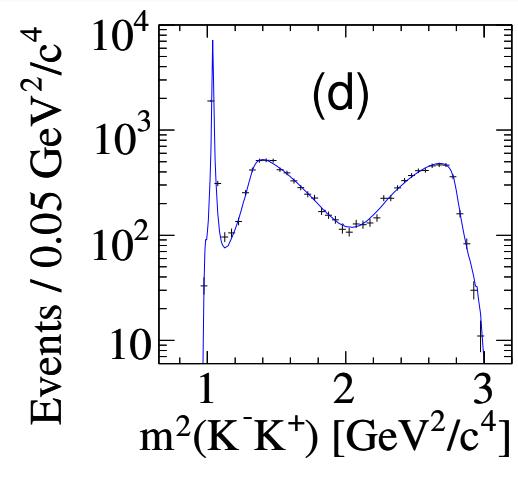
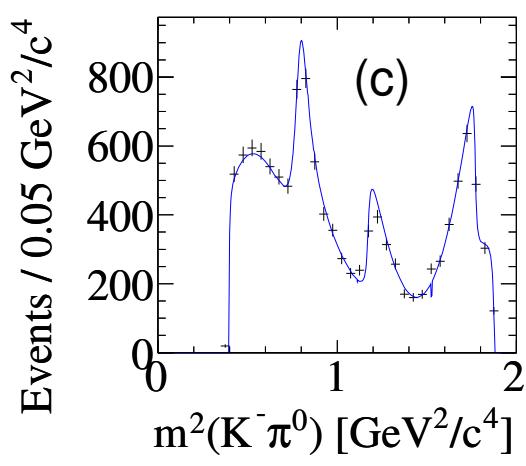
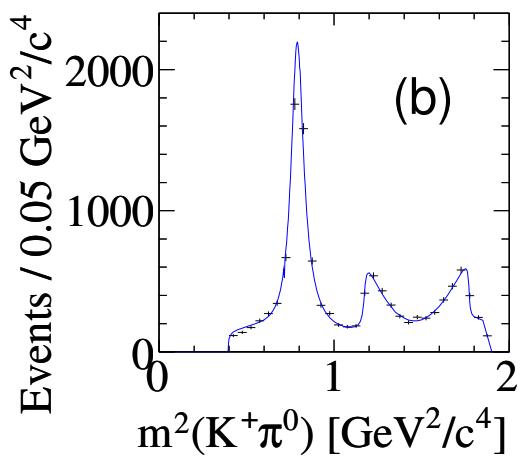
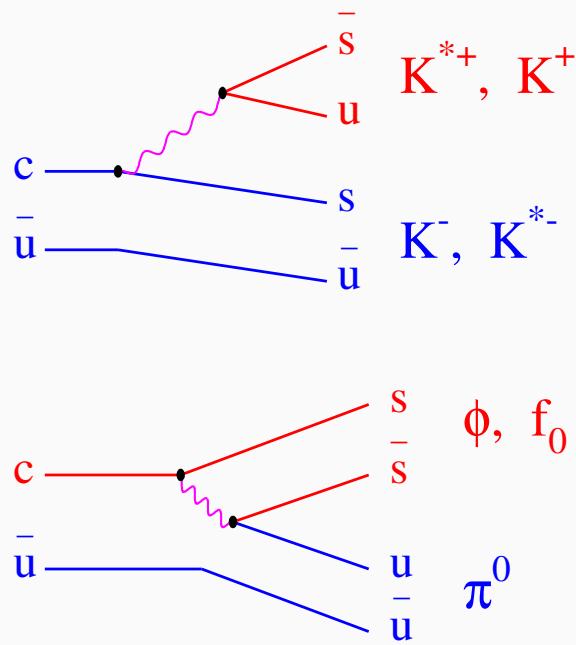
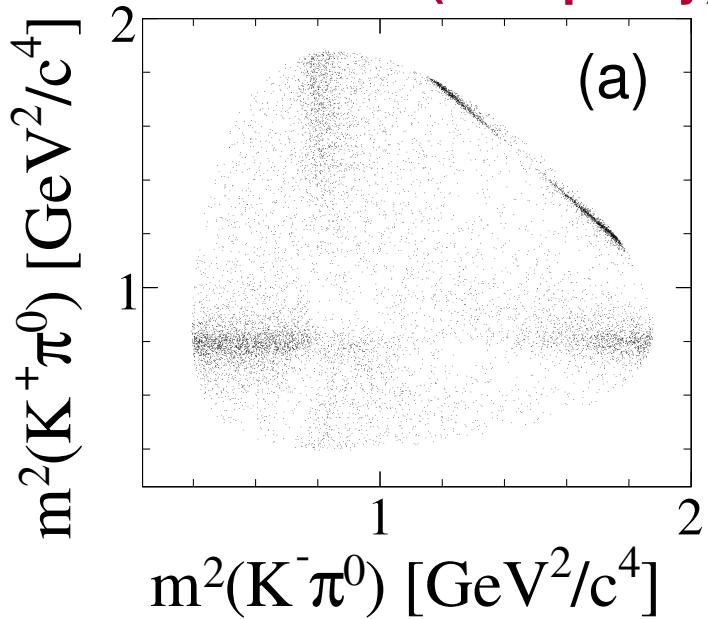
$$\delta_{1/2}(s) = \delta_{bg}(s) + \delta_R(s),$$

$$\delta_{bg} = \cot^{-1} \left[\frac{1}{aq} + \frac{bq}{2} \right],$$

$$\delta_R = \operatorname{tg}^{-1} \left[\frac{m_0 \Gamma}{m_0^2 - s} \right].$$

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

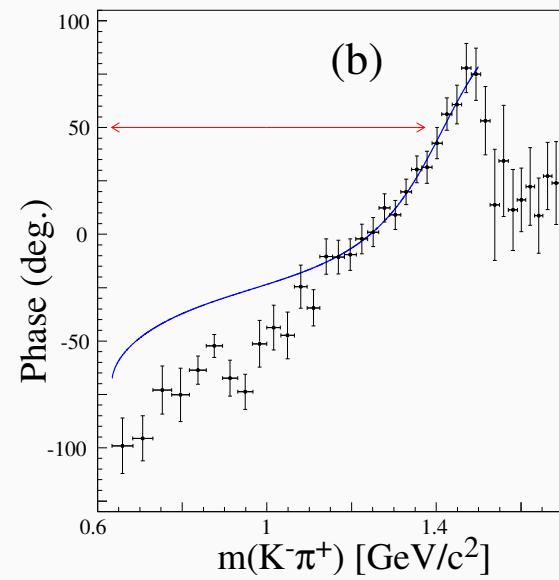
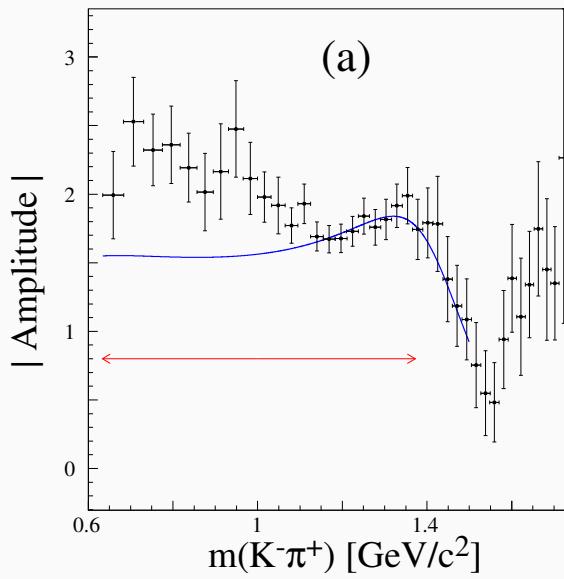
11K events (98% purity)



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

The Dp was fit with three different models for the $K^\pm\pi^0$ S-wave:

- isobar model: $NR + \kappa(800)^+ + \overline{K}^*(1430)^0$
- the E791 MIPWA S-wave
- the LASS $I = 1/2$ S-wave



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

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

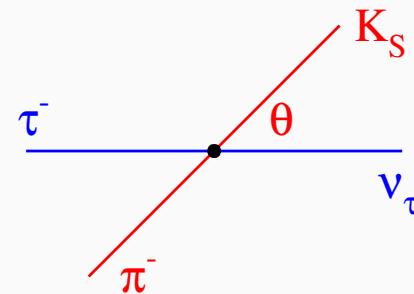
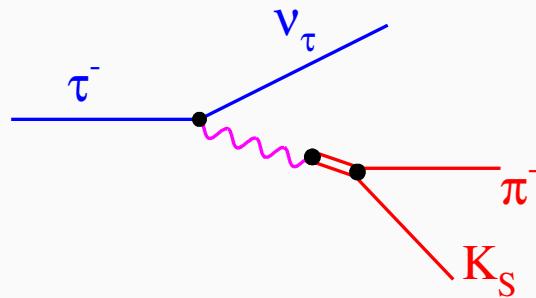
Decay fractions (%) - LASS S-wave

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 measurement of the S-wave.

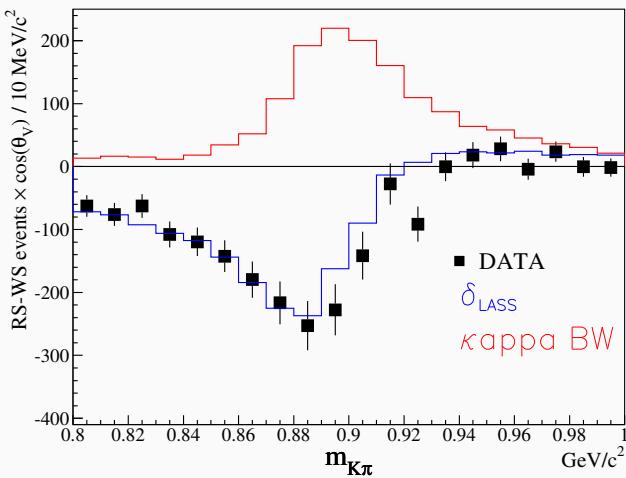
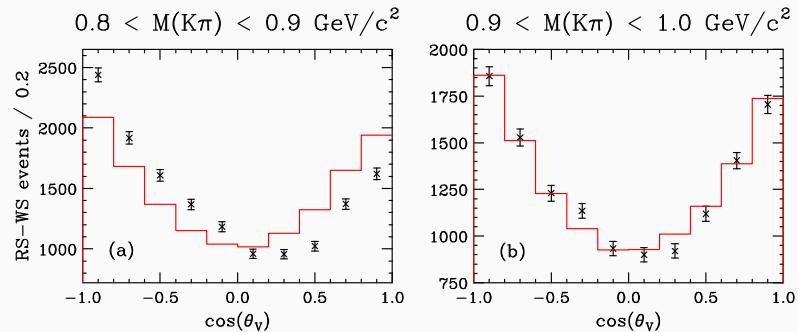
The $K\pi$ amplitude – $\tau^- \rightarrow \bar{K}^0 \pi^- \nu_\tau$ – Belle

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



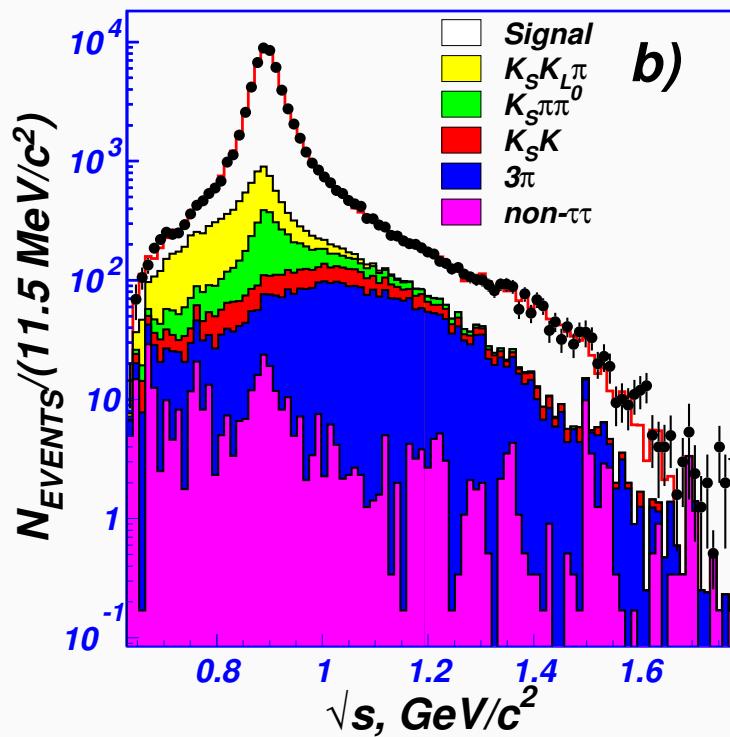
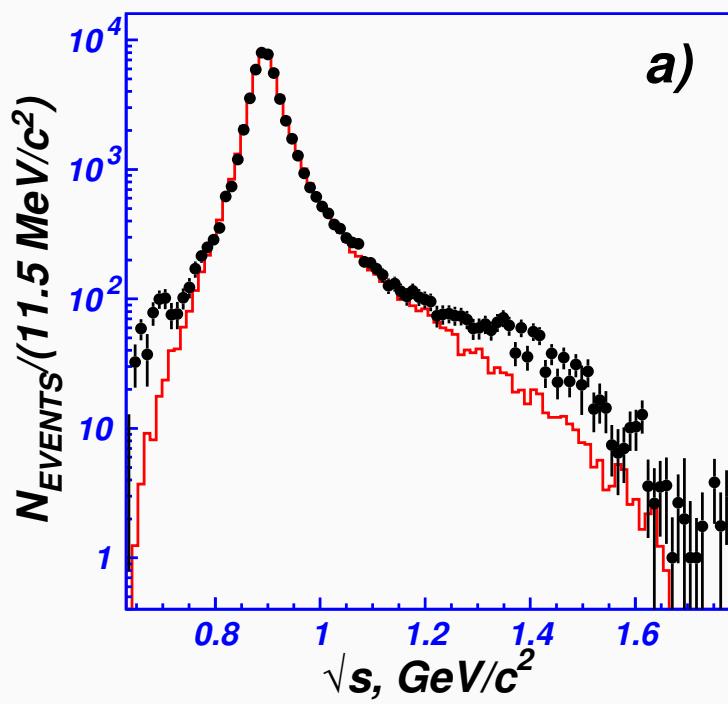
- $\bar{K}^0 \pi^-$ free from FSI, but 3 missing neutrinos: no angular analysis.

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



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

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



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

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

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

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

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

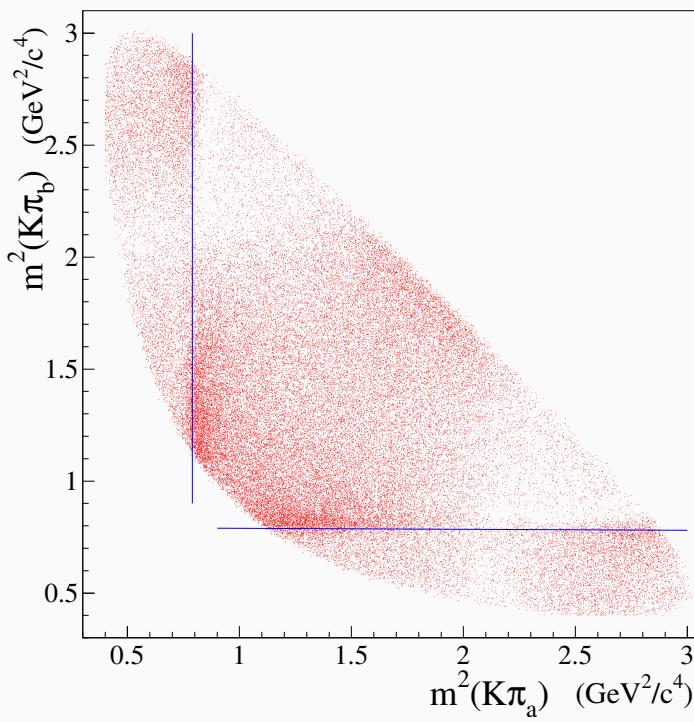
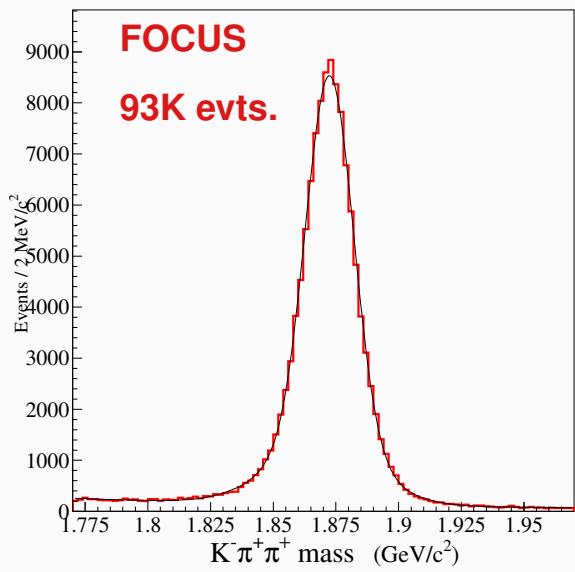
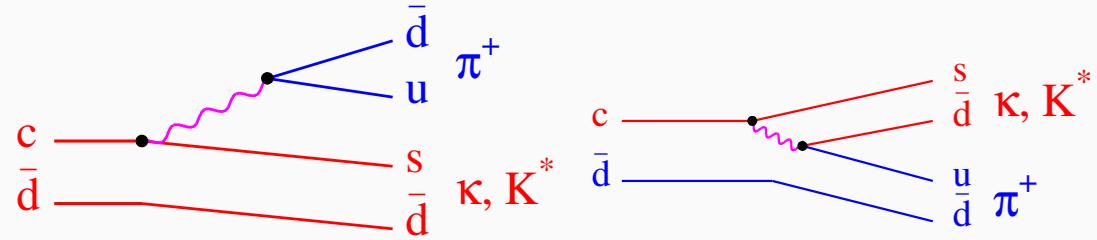
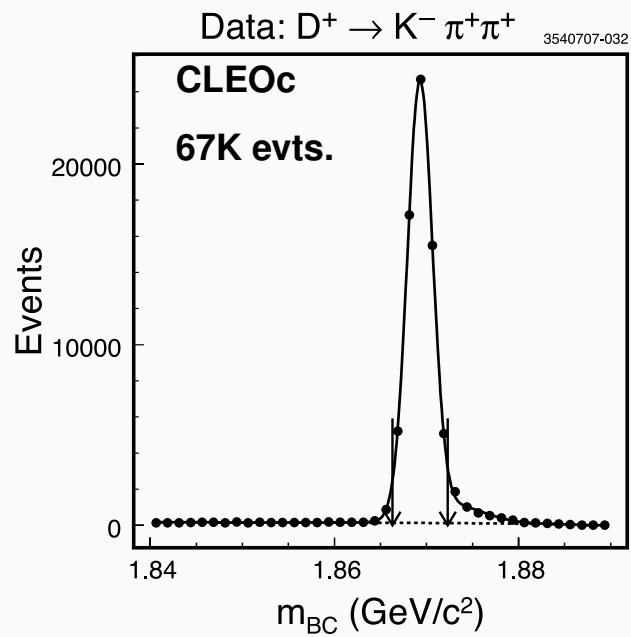
κ^- a la BES

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

- The S-wave model with the $\kappa^-(800)$ yields the best fit;
- This data is inconsistent with LASS $I = 1/2$ S-wave;
- The S-wave component is small, so a larger sample is necessary.

If the angular analysis is performed on a larger sample and if it shows a resonant behavior of the S-wave at low mass, this would be a compelling evidence of the charged $\kappa(800)$.

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



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

Results (fractions, in %) of the $D^+ \rightarrow K^-\pi^+\pi^+$ Dp fit with the isobar model for the S-wave.

mode	E791	CLEOc	FOCUS(a)	FOCUS(b)	FOCUS(c)
$\bar{K}^*(892)^0\pi^+$	12.3 ± 1.4	11.2 ± 1.4	11.3 ± 0.3	11.2 ± 0.3	11.7 ± 0.3
$\bar{K}^*(1410)^0\pi^+$	–	–	1.2 ± 0.3	1.3 ± 0.3	1.1 ± 0.3
$\bar{K}^*(1680)^0\pi^+$	2.5 ± 0.8	1.4 ± 0.2	3.3 ± 0.3	3.8 ± 0.3	2.7 ± 0.3
$\bar{K}_2^*(1430)\pi^+$	0.5 ± 0.2	0.4 ± 0.4	0.20 ± 0.05	0.20 ± 0.05	0.20 ± 0.05
$\bar{K}_0^*(1430)\pi^+$	12.5 ± 1.4	10.5 ± 1.3	16.8 ± 0.8	18.7 ± 1.2	14.3 ± 0.7
$\kappa(800)\pi^+$	47.8 ± 13.2	31.2 ± 3.6	43.5 ± 4.5	22.3 ± 3.2	71.3 ± 5.5
nonresonant	10.4 ± 1.4	13.0 ± 7.3	14.3 ± 3.0	7.5 ± 3.1	31.6 ± 4.5
<hr/>					
$\kappa(800)$ mass	797 ± 48	805 ± 11	837 ± 12	829 ± 14	867 ± 14
$\kappa(800)$ width	410 ± 97	453 ± 21	443 ± 21	433 ± 18	485 ± 27
$\bar{K}_0^*(1430)$ mass	1461 ± 3	1459 ± 5	1466 ± 4	1468 ± 4	1466 ± 4
$\bar{K}_0^*(1430)$ width	169 ± 5	175 ± 16	193 ± 7	193 ± 7	192 ± 7

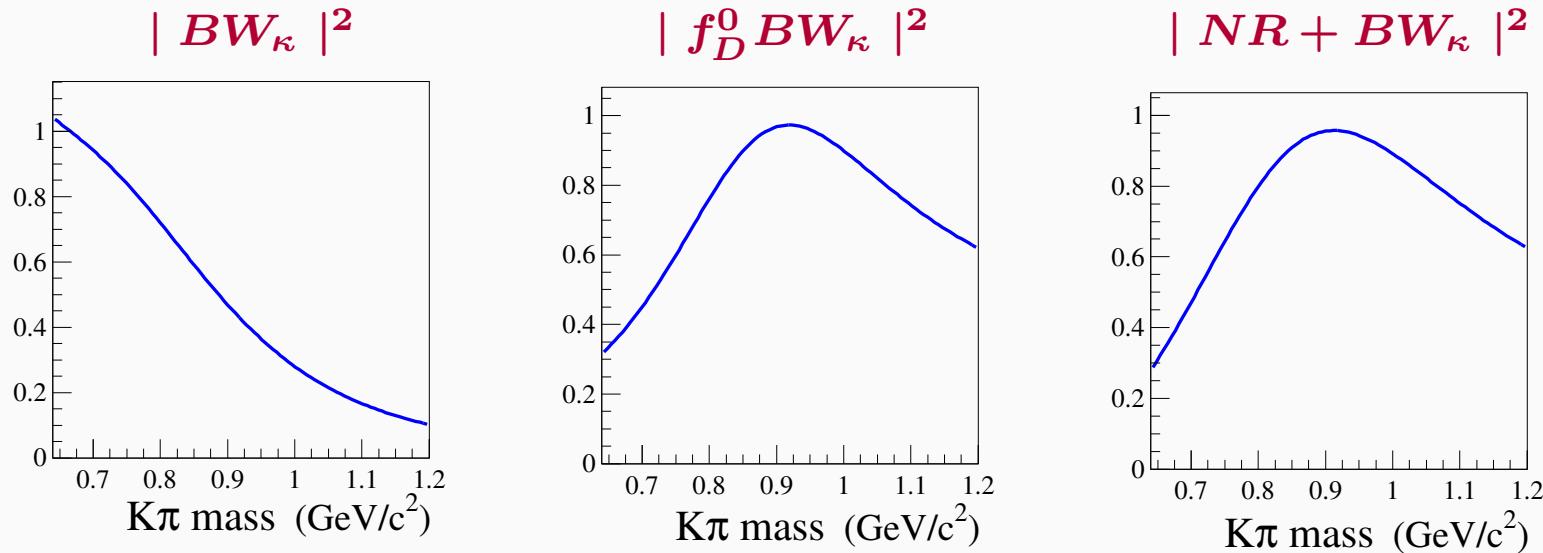
FOCUS(b) : $r_D = 6 \text{ GeV}^{-1}$ (instead of 5 GeV^{-1}) in the Gaussian form factor.

FOCUS(c) : no Gaussian form factor (or $r_D = 0$).

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

*Small variations on the S-wave model
cause drastic changes in κ/NR decay fractions!*

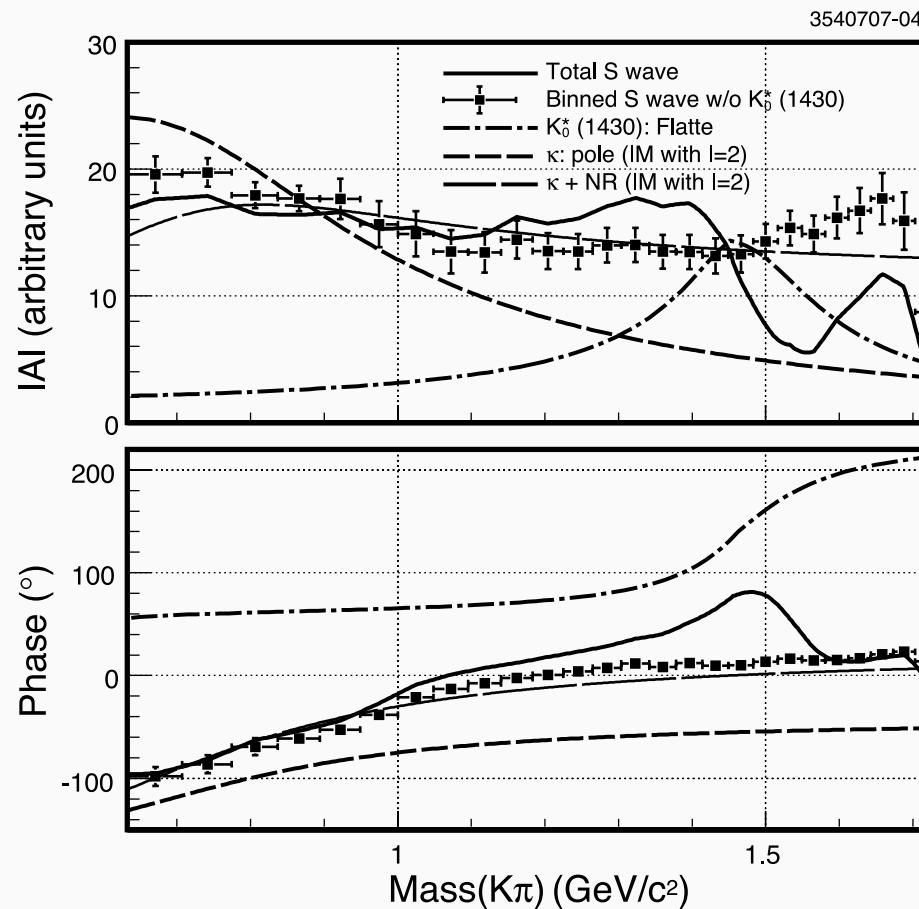
The origin: interference between the broad κ BW and the uniform NR.



*Good fits can be achieved with the isobar S-wave, but
it cannot provide an unambiguous physics result for this mode.*

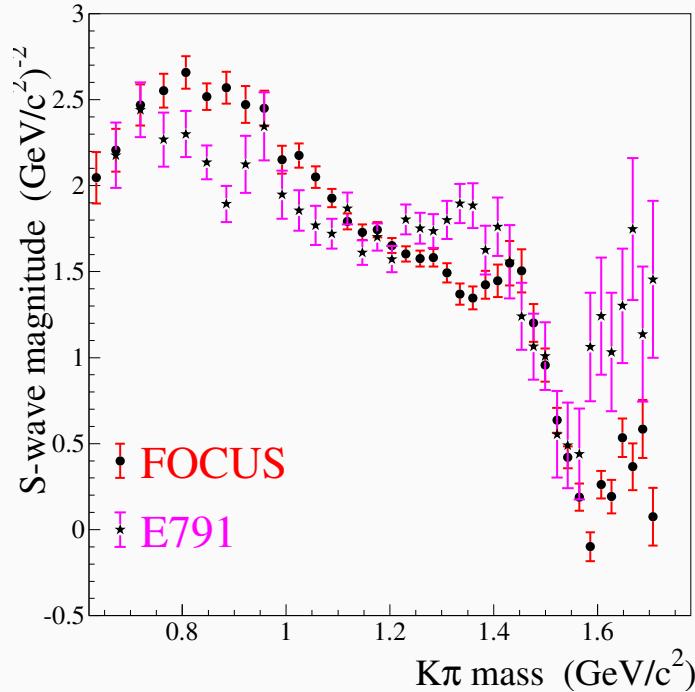
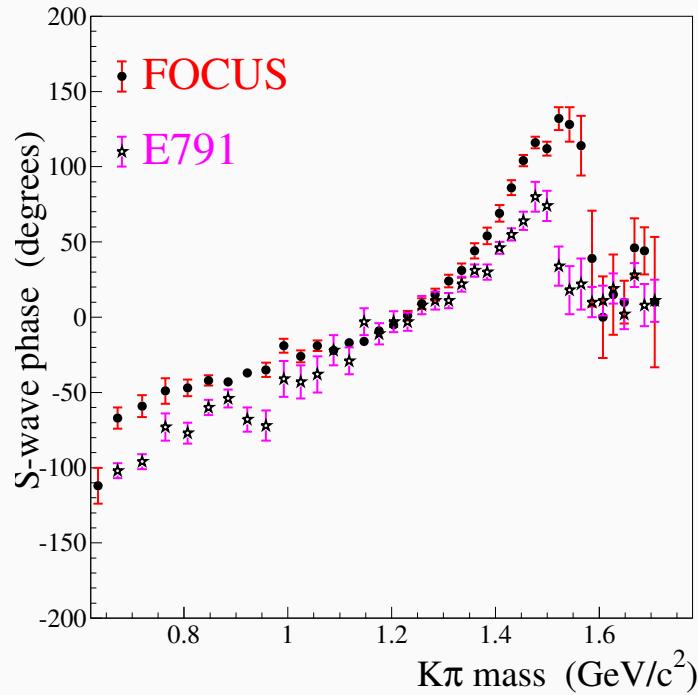
The $K\pi$ amplitude – $D^+ \rightarrow K^-\pi^+\pi^+$ – CLEOc

- S-wave is a binned amplitude plus a Flatté function for the $\bar{K}_0^*(1430)$.
- (Q)MIPWA fit includes an $I = 2 \quad \pi^+\pi^+$ amplitude.
- P-wave is a binned amplitude plus a BW for the $\bar{K}^*(892)^0$.



The $K\pi$ amplitude - $D^+ \rightarrow K^-\pi^+\pi^+$ - FOCUS

FOCUS MIPWA (preliminary):

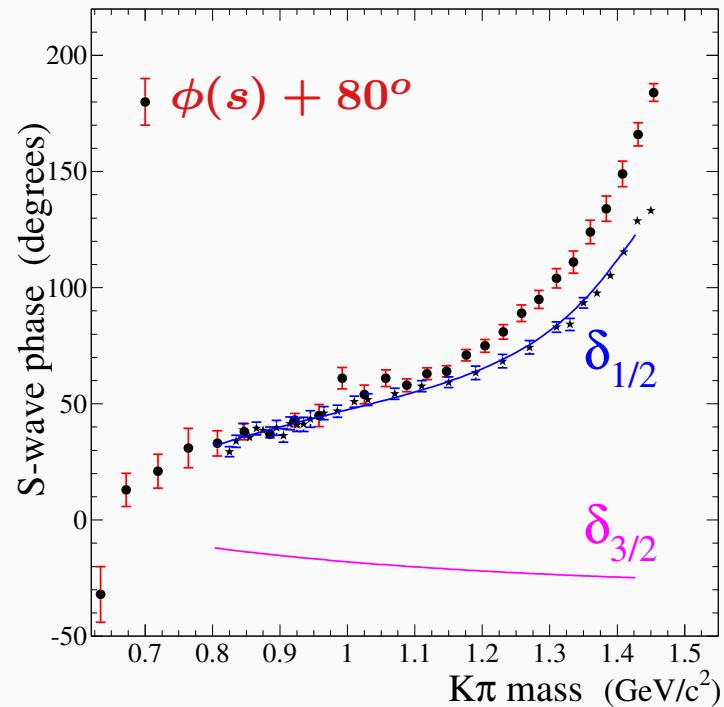
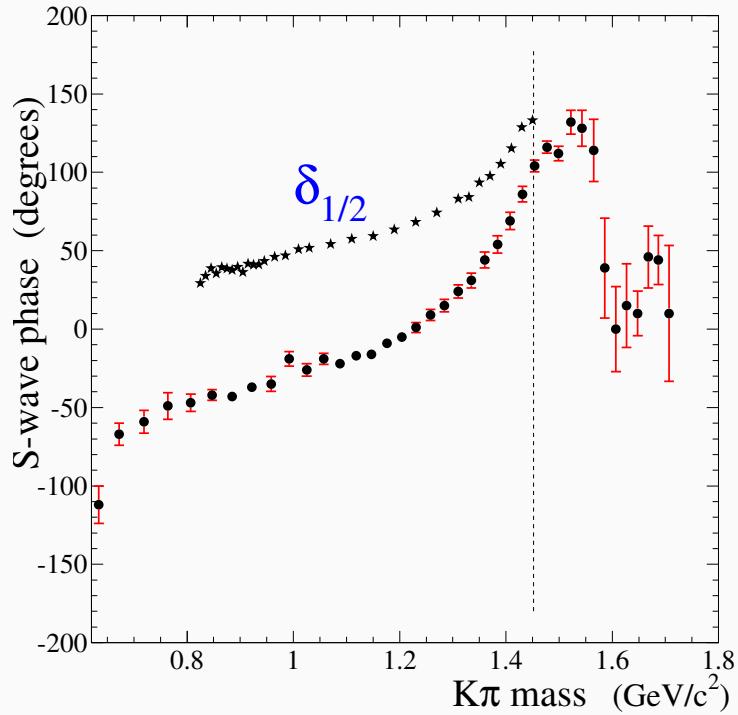


MIPWA decay fractions (%)

mode	E791	CLEOc	FOCUS
$\bar{K}^*(892)^0\pi^+$	11.9 ± 2.0	10.0 ± 0.3	10.3 ± 0.3
$\bar{K}^*(1410)\pi^+$	-	-	1.0 ± 0.4
$\bar{K}^*(1680)\pi^-$	1.2 ± 1.2	2.5 ± 0.1	2.4 ± 0.6
$\bar{K}_2^*(1430)\pi^-$	0.2 ± 0.1	0.48 ± 0.01	0.1 ± 0.1
$K^-\pi^+$ S-wave	78.6 ± 2.3	67.4 ± 1.3	77.7 ± 2.0

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

$D^+ \rightarrow K^-\pi^+\pi^+$ versus $K^-\pi^+ \rightarrow K^-\pi^+$:



- Even adding $\delta_{1/2}$ and $\delta_{3/2}$ (purely NR) there is no agreement:
$$\phi_{K\pi\pi}(s) = \delta_{\text{LASS}}(s) + \gamma(s)$$
- Additional phase $\gamma(s)$: production? 3-body FSI? Perhaps both.

The $K\pi$ amplitude – K-matrix – FOCUS

- The S-wave amplitude:

$$\mathcal{A}_0(s) = F_{1/2}(s) + F_{3/2}(s) = |\mathcal{A}_0(s)| e^{i\alpha(s)}$$

$$F_I = (1 - i \mathbf{K}_I \rho)^{-1} P_I$$

- Fit parameters are contained in the production vectors P_I .
- The P_I vectors contain also an energy dependent phase.
- The resulting S-wave phase $\alpha(s) \Rightarrow I_{1/2} + I_{3/2} + \gamma_{\text{prod}}(s)$
- The dominant component is the S-wave: $f_S = (83.2 \pm 1.5)\%$

$$f_S \rightarrow f_{1/2} = (207 \pm 28)\%,$$

$$f_{3/2} = (40 \pm 10)\%$$

The $K\pi$ amplitude – conclusions

- Is there a charged $\kappa(800)$? If not, what is the neutral $\kappa(800)$?
- The answers given by Belle and Babar are conflicting. Higher statistics and a refined analysis are necessary in both cases.
- Measuring the $I = 1/2$ $K\pi$ amplitude near threshold is necessary for a precise determination of the $\kappa(800)$ pole.
- A MIPWA of $D^+ \rightarrow K^-\pi^+\mu^+\nu$ would be the cleanest way, but a very large sample is required.
- Large and clean $D^+ \rightarrow K^-\pi^+\pi^+$ samples already exist, but extracting the $I = 1/2$ $K\pi$ amplitude is not trivial.
- Input from theory: a better understanding of the decay dynamics and of the strongly interacting 3-body system is necessary!
- Large samples will come soon from LHCb, CMS and ATLAS.

$$f_0(1370)/f_0(1500)$$

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

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

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

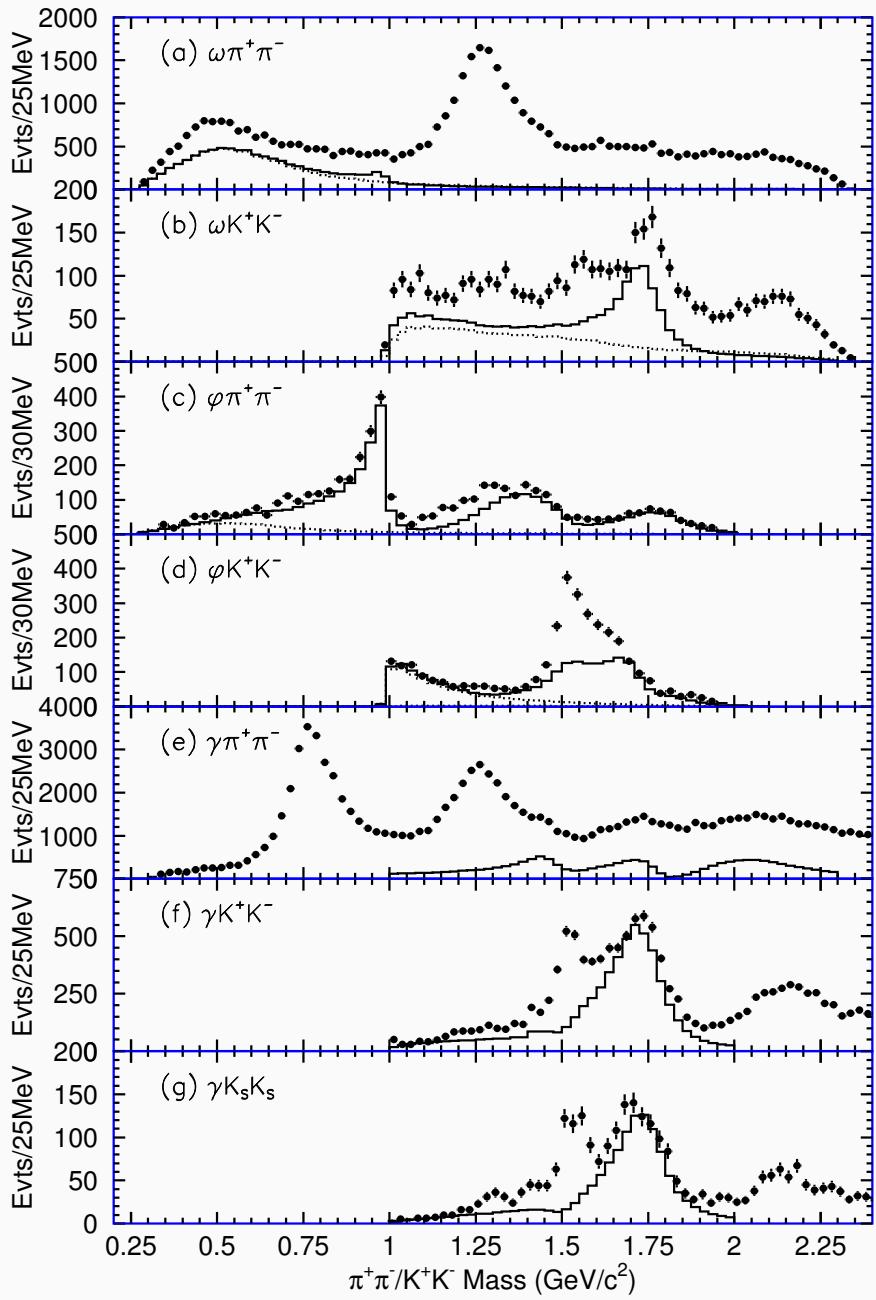
The $f_0(1370)$, however, is rather uncertain (and sometimes questioned):

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

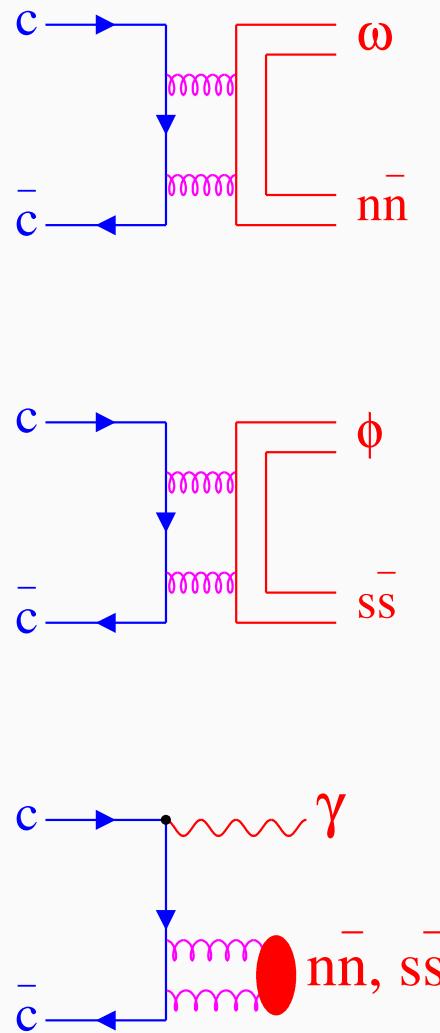
What HF decays can tell about the $f_0(1370)$ mass, width and couplings?

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

$f_0(1370)/f_0(1500)$: J/ψ decays – BES.

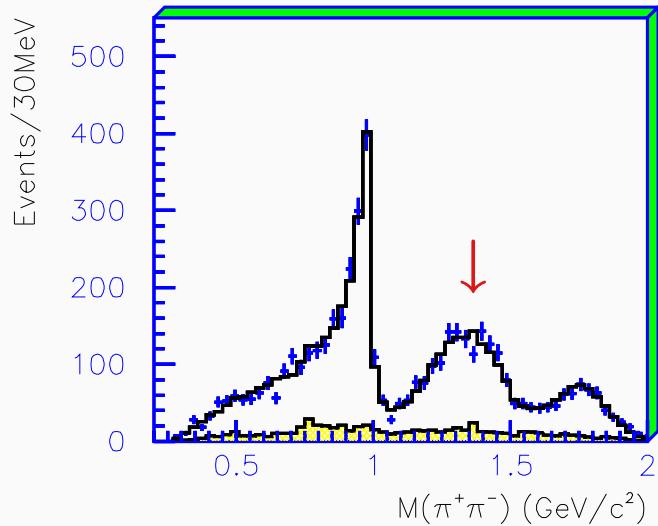


$$J/\psi \rightarrow VPP$$

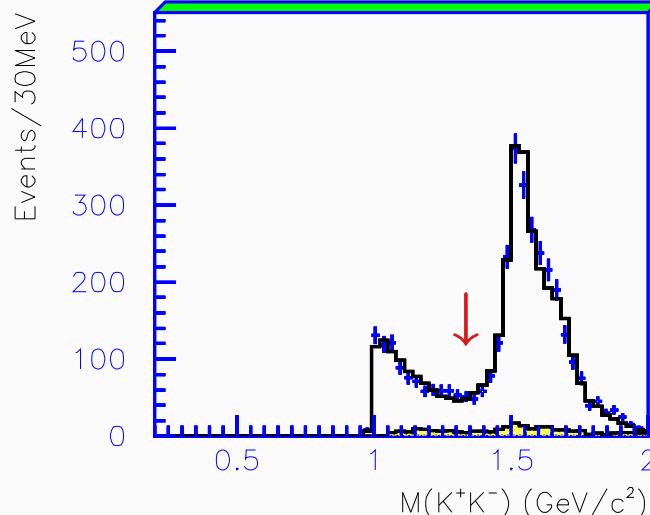


$f_0(1370)/f_0(1500)$: J/ψ decays – BES.

BES $\Rightarrow J/\psi \rightarrow \phi\pi^+\pi^-$



$J/\psi \rightarrow \phi K^+K^-$

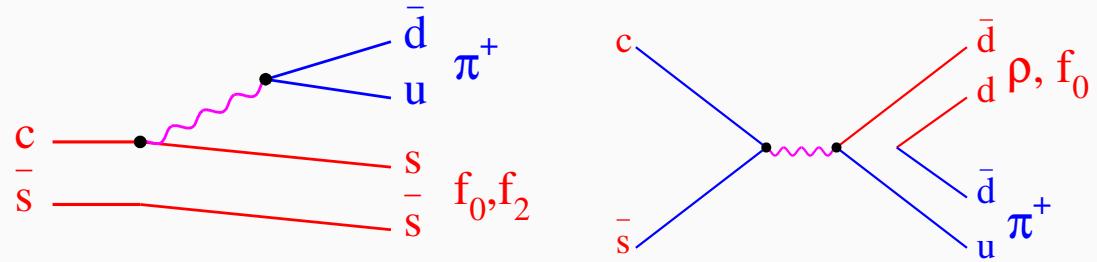
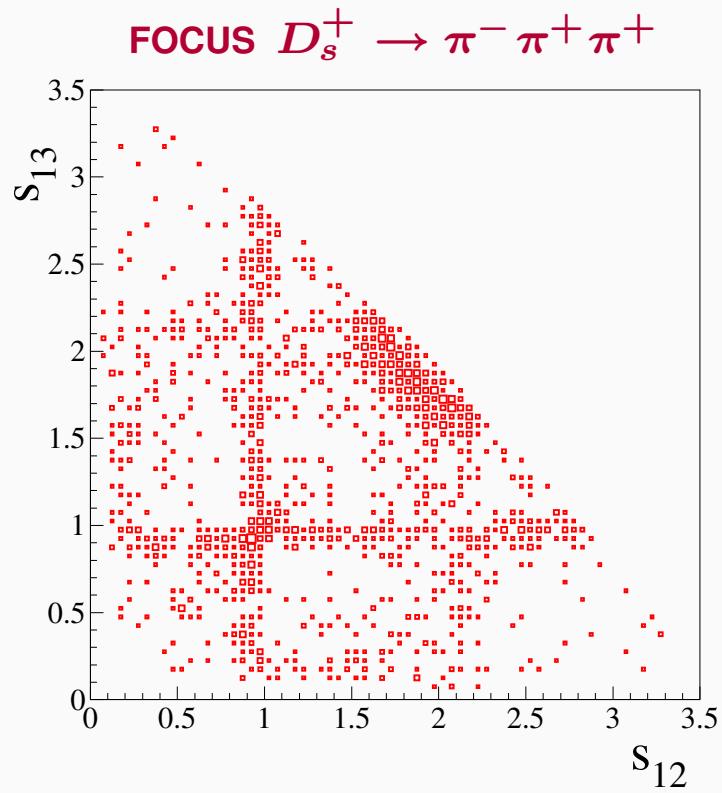


- $J/\psi \rightarrow \phi\pi\pi$: dominant $f_0(1370)$ interfering with a small $f_0(1500)$.
- $J/\psi \rightarrow \phi KK$: no indication of $f_0(1370)$.
- $J/\psi \rightarrow \gamma\pi\pi/\gamma KK$: no indication of $f_0(1370)$ either.

$f_0(1370)$ Breit-Wigner parameters

$m_0(MeV)$	$\Gamma_0(MeV)$	$\Gamma_{K\bar{K}}/\Gamma_{\pi\pi}$
1350 ± 50	265 ± 40	0.08 ± 0.08

$$f_0(1370)/f_0(1500) : D_s^+ \rightarrow \pi^- \pi^+ \pi^+$$



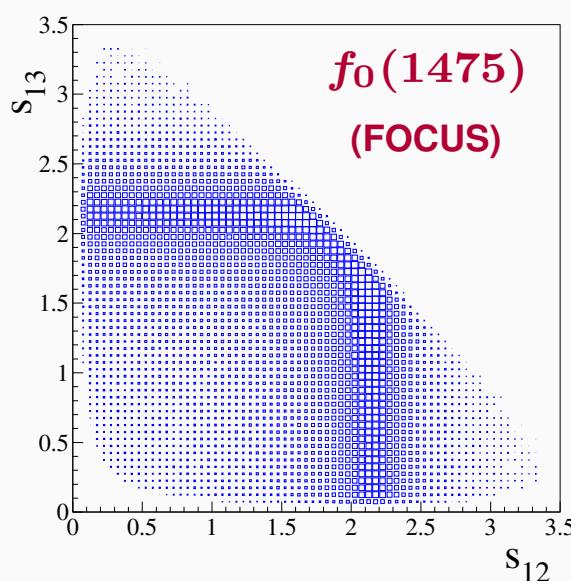
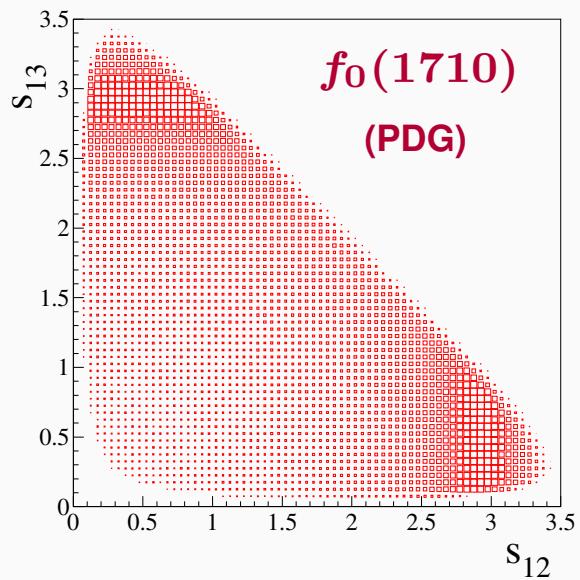
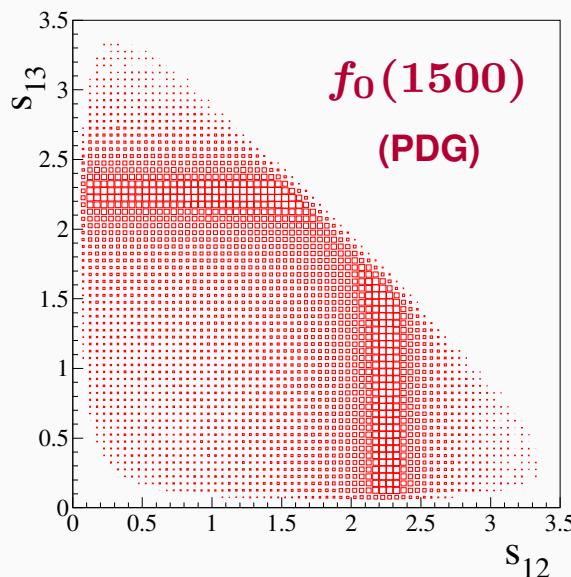
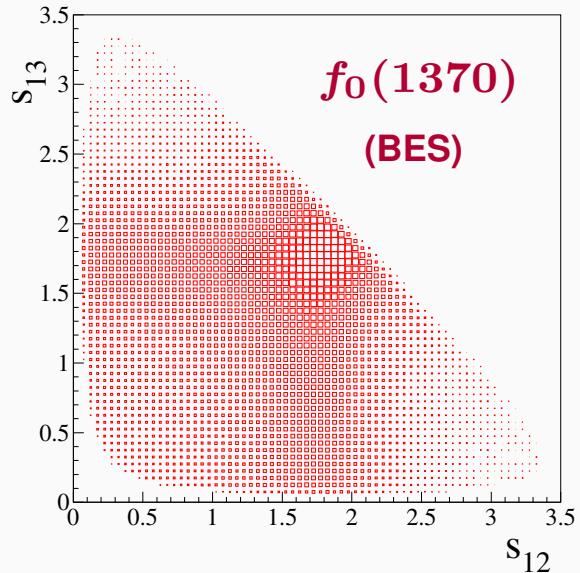
Decay fractions (%)

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
$f_0(1475)\pi^+$	23.3 ± 0.5	32.4 ± 7.9
<i>NR</i>	13.2 ± 5.7	1 ± 2

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

- $f_0(1475)$ (MeV/c²) →

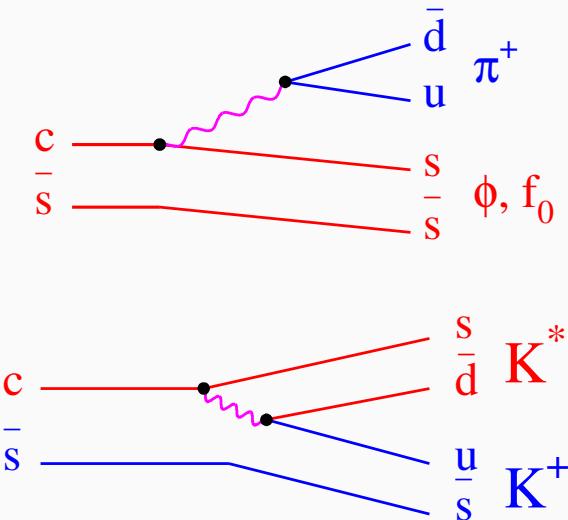
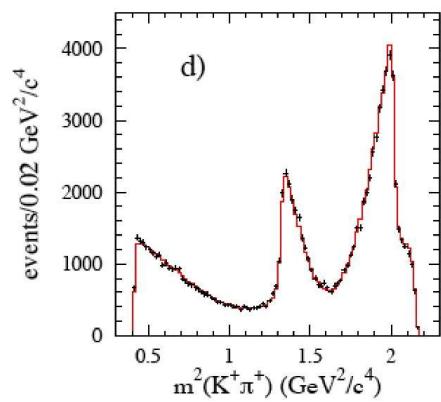
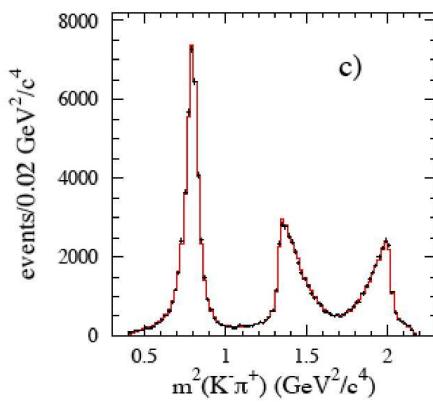
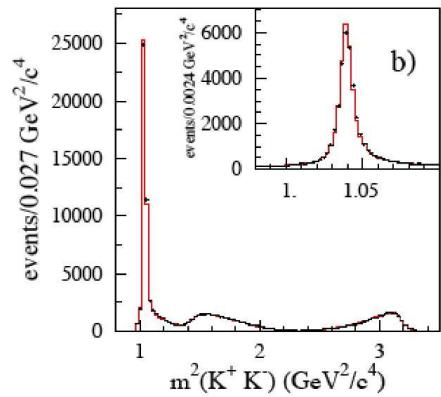
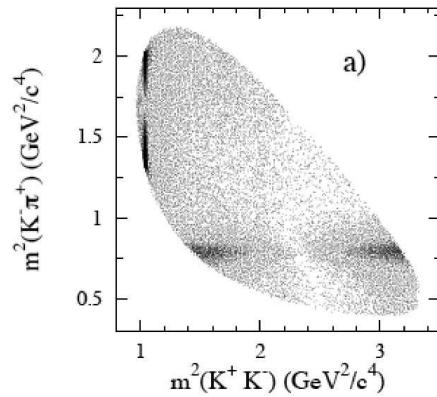
$$f_0(1370)/f_0(1500) : D_s^+ \rightarrow \pi^- \pi^+ \pi^+$$



MC simulation of
 $D_s^+ \rightarrow f_0(X)\pi^+$,
 $f_0(X) \rightarrow \pi^-\pi^+$.

Scalar state in
 $D_s^+ \rightarrow \pi^-\pi^+\pi^+$
consistent with
 $f_0(1500)$.

$$f_0(1370)/f_0(1500) : D_s^+ \rightarrow K^- K^+ \pi^+ - \text{BaBar}$$



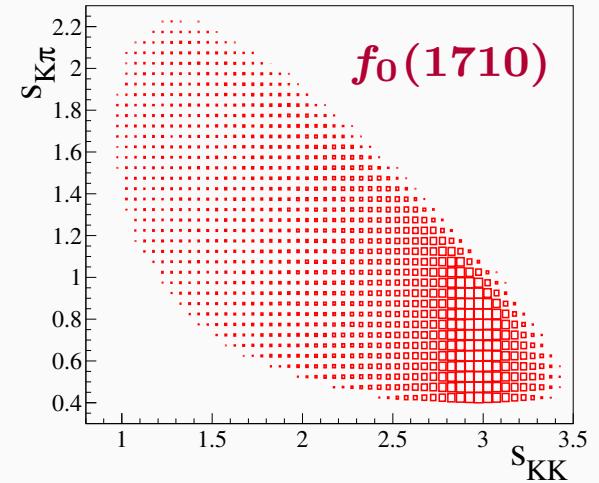
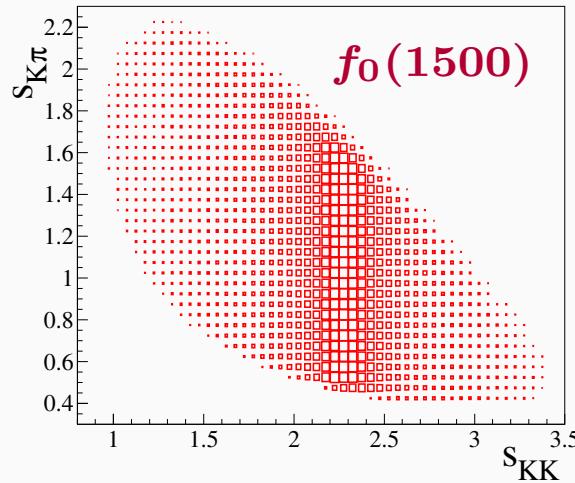
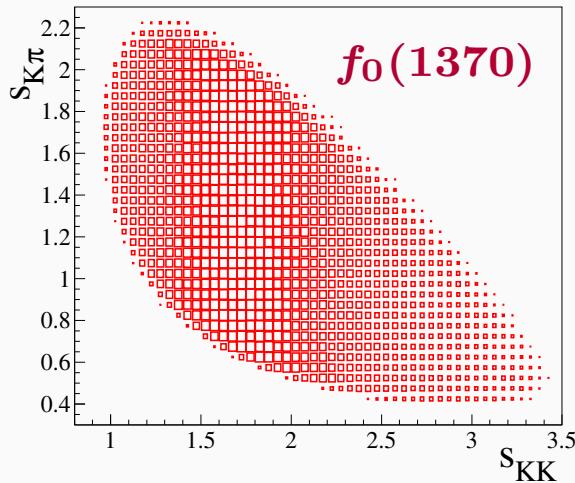
mode	fraction (%)
$K^*(892)^0 K^+$	48.7 ± 1.6
$\phi(1020)\pi^+$	37.9 ± 1.8
$f_0(980)\pi^+$	35 ± 14
$f_0(1370)K^+$	6.3 ± 4.8
$f_0(1710)K^+$	2.0 ± 1.0

$$f_0(1370) \Rightarrow m_0 = 1.313 \pm 10 \pm 114 \text{ GeV}/c^2$$

$$\Gamma_0 = 0.395 \pm 8 \pm 133 \text{ GeV}/c^2$$

$$f_0(1370)/f_0(1500) : D_s^+ \rightarrow K^- K^+ \pi^+ - \text{BaBar}$$

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

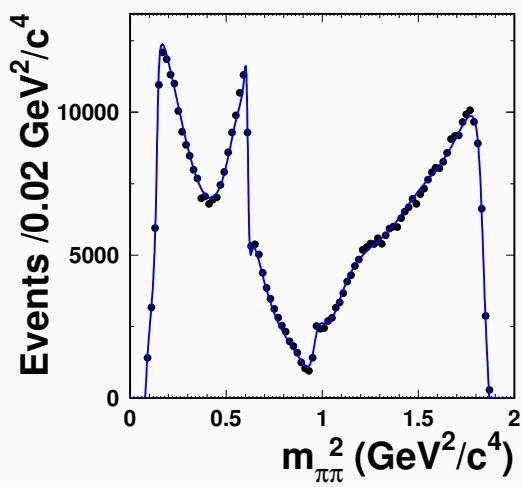
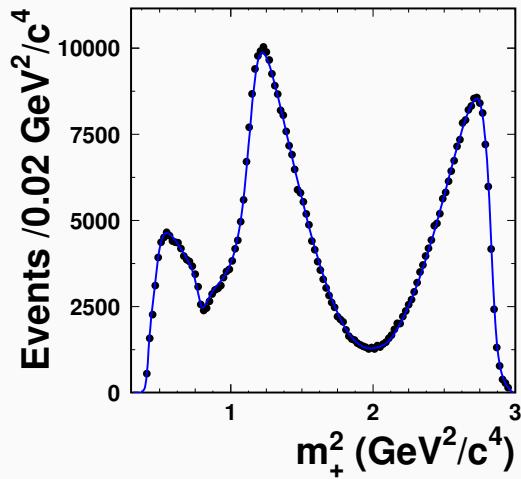
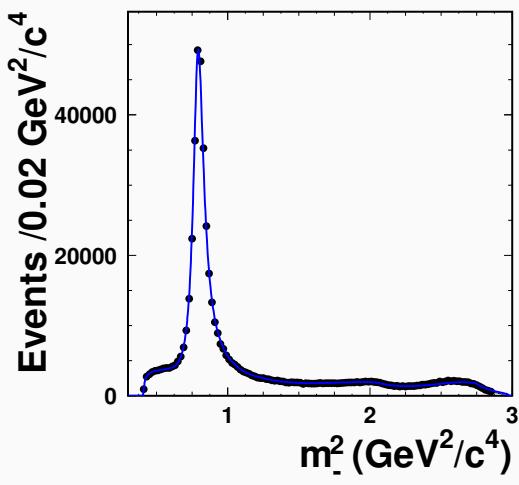
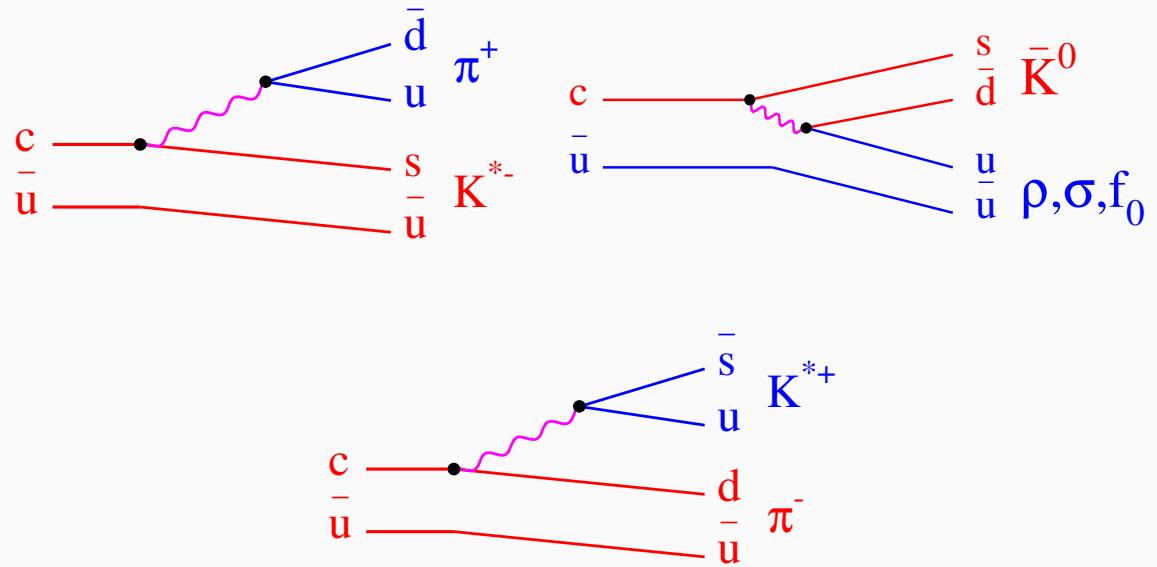
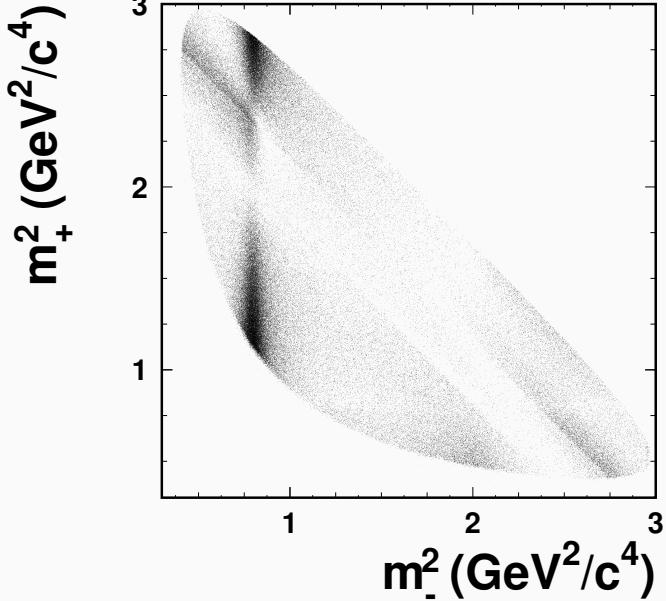


- No evidence of $f_0(1500)$, small contribution from $f_0(1710)$.
- The KK S-wave spectrum near threshold is very complex: contributions from $f_0(980)$, $a_0(980)$ and $f_0(1370)$.

Final results of this analysis are about to come.

$f_0(1370)/f_0(1500) - D^0 \rightarrow \bar{K}^0\pi^+\pi^-$ – Belle

When high statistics is not enough...



$f_0(1370)/f_0(1500)$ – $D^0 \rightarrow \overline{K}^0 \pi^+ \pi^-$ – Belle

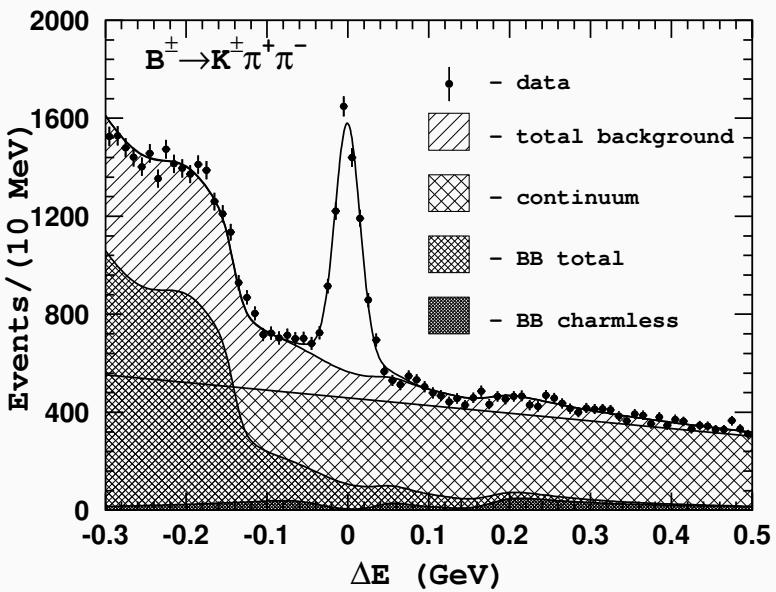
Resonance	fraction (%)
$K^*(892)^-$	62.3
$K^*(1410)^-$	0.5
$K^*(1680)^-$	0.02
$K_0^*(1430)^-$	7.2
$K_2^*(1430)^-$	1.3
$K^*(892)^+$	0.5
$K^*(1410)^+$	0.1
$K^*(1680)^+$	0.04
$K_0^*(1430)^+$	0.5
$K_2^*(1430)^+$	0.1
$\rho(770)$	21.1
$\omega(782)$	0.6
$\rho(1450)$	0.2
σ	9.1
$f_0(980)$	4.5
NR	6.2
$f_0(1370)$	1.6
σ_2	0.9
$f_2(1270)$	1.8

- 534410 ± 830 signal events!
- $f_0(1370)$ taken from E791:
 $m_0 = 1.434 \text{ GeV}/c^2$
 $\Gamma_0 = 0.173 \text{ GeV}/c^2$
- DP fit (isobar model) is poor, even with an additional scalar, σ_2 :
 $m_0 = 1.059 \pm 6 \text{ GeV}/c^2$
 $\Gamma_0 = 0.059 \pm 10 \text{ GeV}/c^2$
- $\pi\pi$ S-wave not well understood.
- Statistics is large enough ($\sim 15\%$) for a direct measurement of the S-wave.

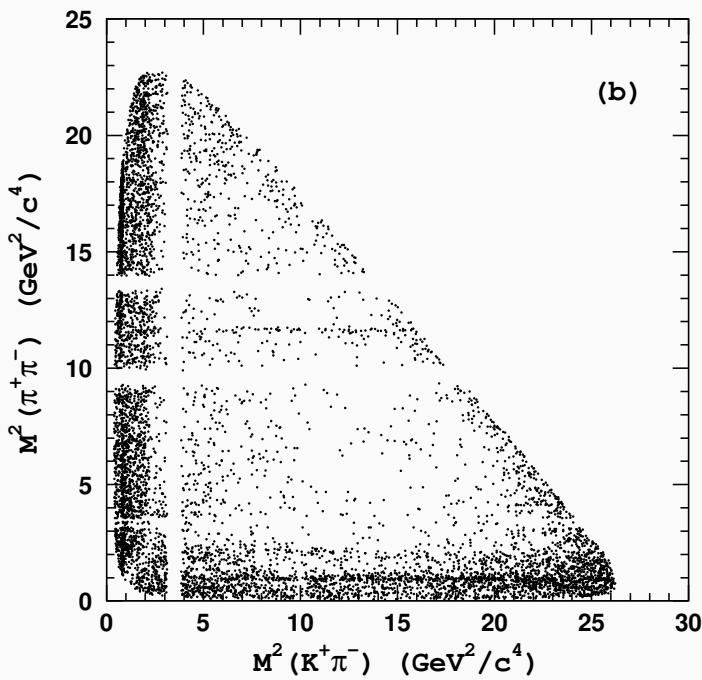
$f_0(1370)/f_0(1500)$: charmless 3-body B decays

Charmless 3-body B decays: a promising tool (still a way to go...)

- Large mass of B mesons: no phase space limitation as in D decays;
- Statistics is still small (~ 4000 events), high background ($S/B \sim 1$);
- DP analysis \rightarrow larger and non-uniform NR amplitude.



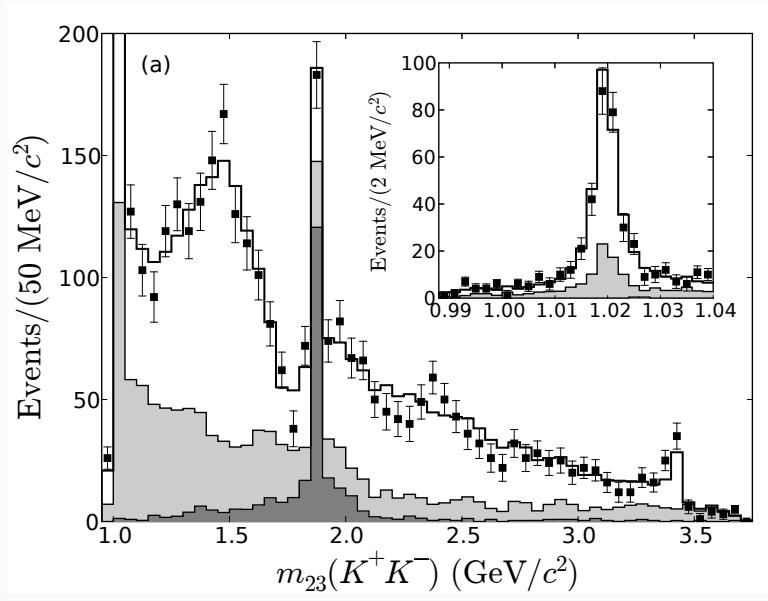
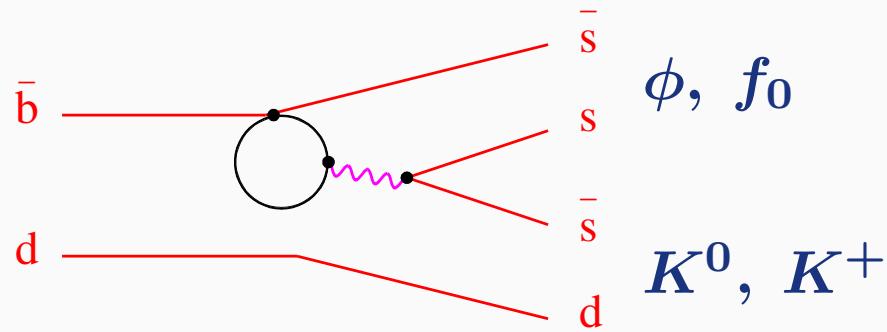
Belle $B^+ \rightarrow K^+ \pi^+ \pi^-$



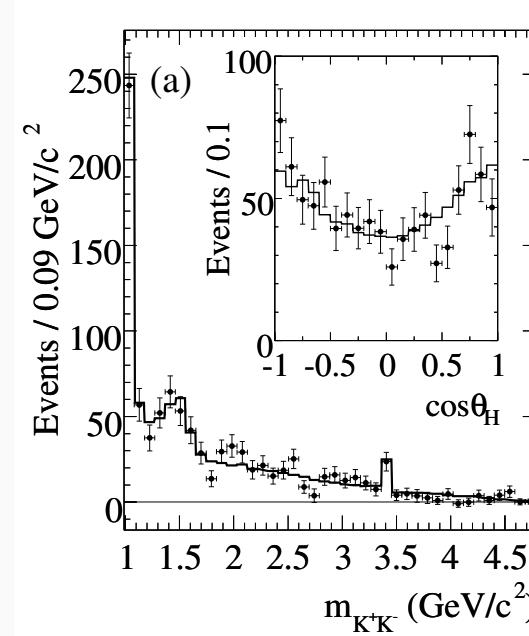
$f_0(1370)/f_0(1500)$: $B \rightarrow KKK$ – BaBar

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

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



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



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

$f_0(1370)/f_0(1500)$: $B \rightarrow KKK$ – BaBar

The peak at 1.5 GeV/c² (K^+K^-) is better described by a single scalar state.

$$B^+ \rightarrow K^+ K^+ K^-$$

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
<i>NR</i>	141 ± 17

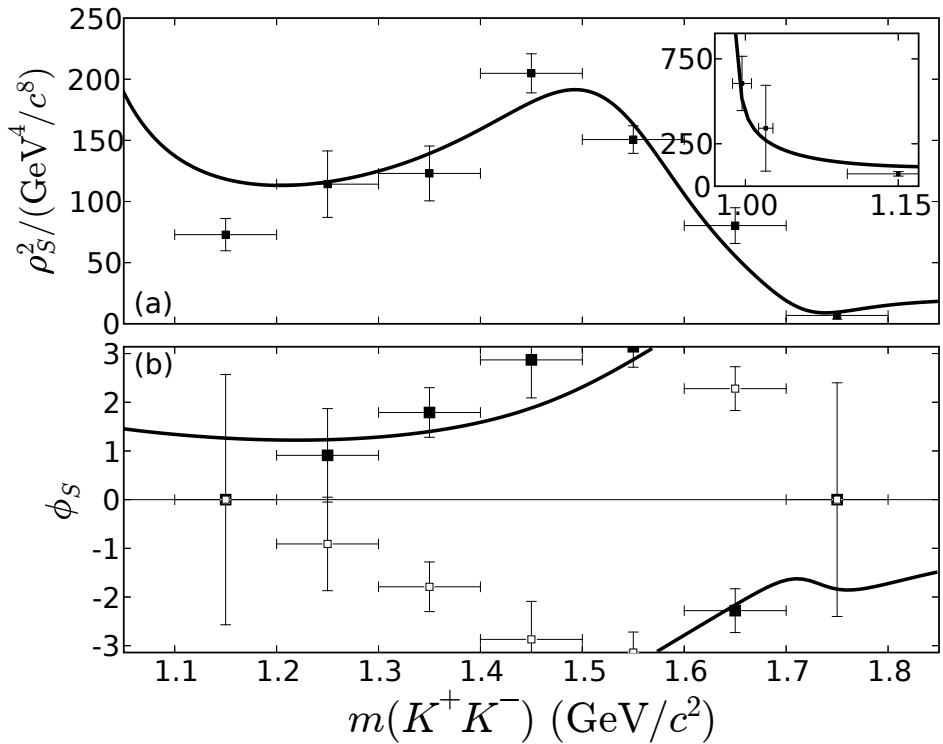
$$B^0 \rightarrow K^0 K^+ K^-$$

mode	fraction (%)
$\phi(1020)K^0$	12.5 ± 1.3
$f_0(980)K^0$	40.2 ± 9.6
$X_0(1550)K^0$	4.1 ± 1.3
$f_0(1710)K^0$	-
<i>NR</i>	112 ± 15

X_0 parameters (GeV/c²): $m_0 = 1.539 \pm 0.020$,
 $\Gamma_0 = 0.257 \pm 0.033$

- 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.

$f_0(1370)/f_0(1500)$: $B \rightarrow K K K$ – BaBar

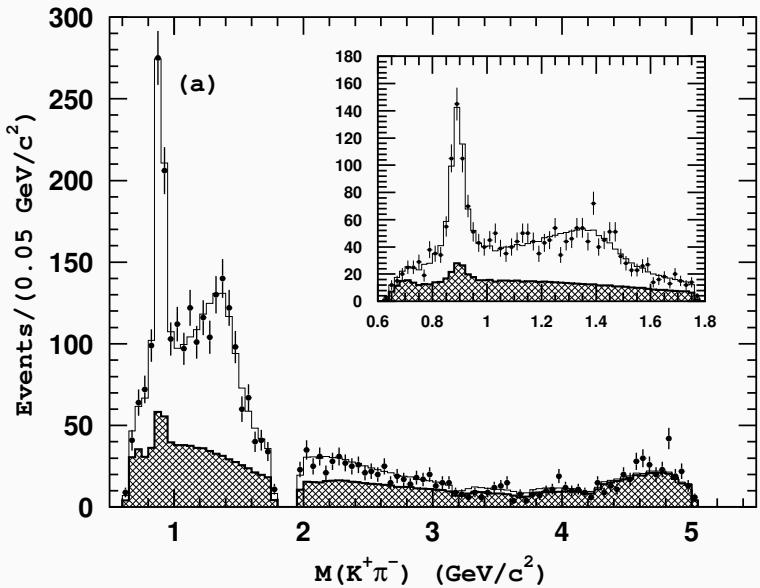
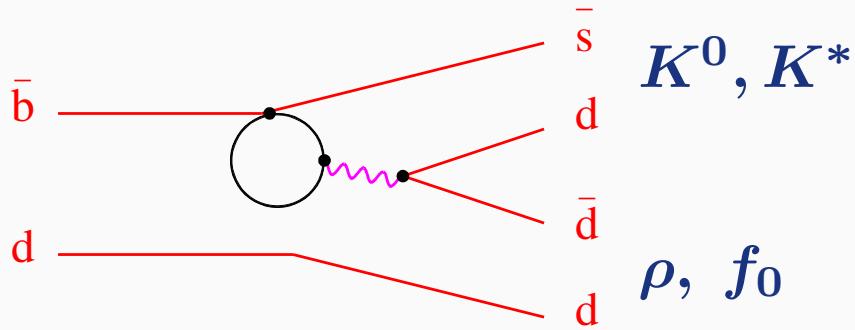


A PWA of the K^+K^- S-wave
on a limited region of the DP
show a rapid change in the
phase at $m_{KK} \sim 1.55 \text{ GeV}/\text{c}^2$

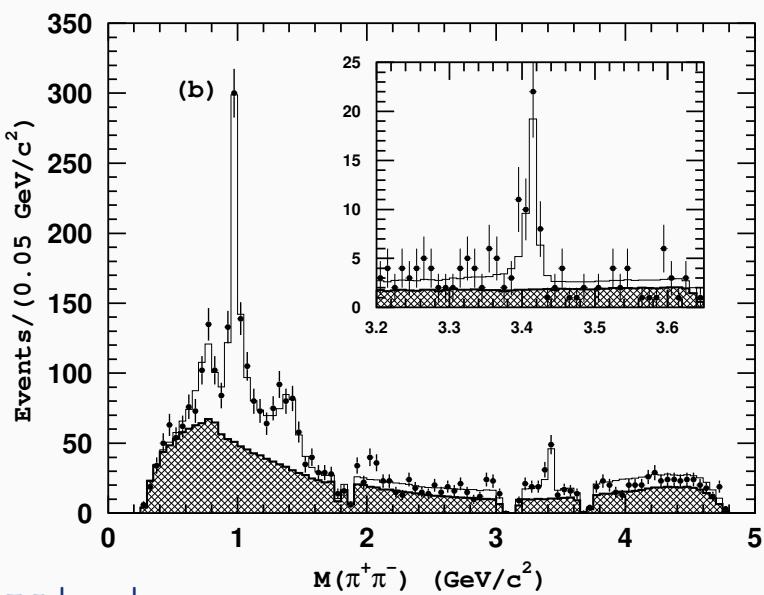
$f_0(1370)/f_0(1500)$: $B \rightarrow K\pi\pi$ – Belle

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

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



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



$f_0(1370)/f_0(1500)$: $B \rightarrow K\pi\pi$ – Belle

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

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

mode	fraction (%)
$K^*(892)^-\pi^+$	13.0 ± 1.0
$K_0^*(1430)^-\pi^+$	65.5 ± 4.5
$\rho(770)^0 K^+$	7.9 ± 1.0
$f_0(980)K^+$	17.7 ± 3.6
$f_X(1300)K^+$	4.1 ± 0.9
<i>NR</i>	34 ± 2.7

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

mode	fraction (%)
$K^*(892)^+\pi^-$	11.8 ± 1.7
$K_0^*(1430)^+\pi^-$	64.8 ± 7.8
$\rho(770)^0 K^0$	12.9 ± 2.0
$f_0(980)K^0$	16.0 ± 4.2
$f_X(1300)K^0$	3.7 ± 2.4
<i>NR</i>	41.9 ± 5.5

f_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 DP of B decays.

$f_0(1370)/f_0(1500)$: conclusions.

- A strong S-wave dominance is observed in final states having identical particles: $D^+ \rightarrow K^-\pi^+\pi^+$; $D^+, D_s^+ \rightarrow \pi^-\pi^+\pi^+$.
- 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 closer, but not quite the same as the $f_0(1500)$.
- The only indication of the $f_0(1370)$ comes from $D_s^+ \rightarrow K^+K^-\pi^+$.
- 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 $D \rightarrow PPP$ decays. An analysis focused on the physics of the scalar mesons is in order.
- A MIPWA analysis of $D_s^+ \rightarrow \pi^-\pi^+\pi^+$ (BaBar) is to appear soon.

Summary

- $HF \rightarrow LQ$: a very special key to scalar mesons studies, with unique features and constraints to be explored.
- Studies with semi-leptonic D and τ decays are still limited by statistics.
- The B-factories have enough data on $D \rightarrow \pi\pi\pi$, $D \rightarrow K\pi\pi$ and $D \rightarrow KK\pi$ for a systematic study (MIPWA) of the $\pi\pi$ and $K\pi$ S-wave.
- B decays are a very promising tool, but 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...

References

- LASS – NPB**296**, 493 (1988); W.Dunwoodie, private communication.
- BaBar $D^0 \rightarrow K^- K^+ \pi^0$ – PRD**76**, 011102 (2007).
- E791 $D^+ \rightarrow K^- \pi^+ \pi^+$ (MIPWA) – PRD**73**, 032004 (2006).
- Belle $\tau^- \rightarrow \overline{K}^0 \pi^- \nu_\tau$ – arXiv:0706.2231.
- FOCUS $D^+ \rightarrow K^- \pi^+ \mu^+ \nu_\mu$ – PLB**621**, 72 (2005).
- BES $J/\psi \rightarrow \overline{K}^*(892)^0 K^+ \pi^-$ – hep-ex/0304001.
- CLEOc $D^+ \rightarrow K^- \pi^+ \pi^+$ – arXiv:0707.3060.
- FOCUS $D^+ \rightarrow K^- \pi^+ \pi^+$ (K-matrix) – arXiv:0705.2248.
- FOCUS $D^+ \rightarrow K^- \pi^+ \pi^+$ (MIPWA) – in preparation.
- E791 $D^+ \rightarrow K^- \pi^+ \pi^+$ – PRL**89**, 121801 (2002).
- BES $J/\psi \rightarrow \phi \pi \pi$ – PLB**607**, 243 (2005).
- BES $J/\psi \rightarrow \gamma \pi \pi$ – PLB**642**, 441 (2005).

References (cont.)

- E791 $D_s^+ \rightarrow \pi^- \pi^+ \pi^+$ – PRL**86**, 765 (2001).
- FOCUS $D_s^+ \rightarrow \pi^- \pi^+ \pi^+$ – internal note, unpublished.
- BaBar $D_s^+ \rightarrow K^- K^+ \pi^+$ – arXiv:0707.1242.
- Belle $D^0 \rightarrow \bar{K}^0 \pi^- \pi^+$ – arXiv:0704.1000.
- Babar $B^+ \rightarrow K^+ K^+ K^-$ – PRD**74**, 032003 (2006).
- Babar $B^0 \rightarrow K^0 K^+ K^-$ – arXiv:0706.3885
- Belle $B^0 \rightarrow K^+ \pi^+ \pi^-$ – PRL**96**, 251803 (2006).
- Belle $B^0 \rightarrow K^0 \pi^+ \pi^-$ – PRD**75**, 012006 (2007).
- $B^0 \rightarrow K^0 \pi^+ \pi^-$ NR – arXiv:07090075.