Dalitz decays of charmed mesons.

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Summary:

- Introduction.
- Experimental techniques.
- The method of Dalitz plot analysis.
- Issues in Light meson spectroscopy.
- Experimental results.
- Conclusions.

Dalitz Analysis of Charm decays.

• The Dalitz plot analysis of three-body charm decays is the most complete way of analyzing the data.

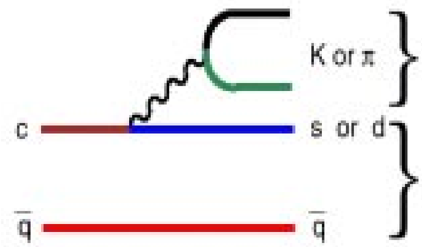
• It allows to measure decay amplitudes and phases.

• The final state is the result of the interference of all intermediate states.

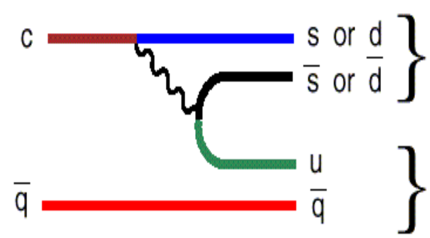
Charmed mesons decays.

• The lowest order diagrams which contribute to charm decays are:

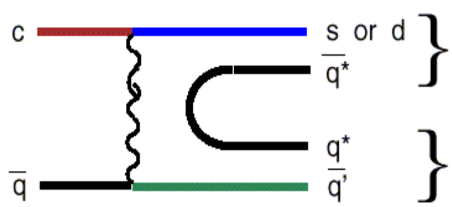
• External (a_1):



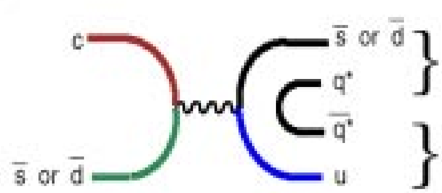
• Internal (a_2), color suppressed:



• W-exchange, helicity suppressed:



• W-annihilation, Little evidence yet:



The role of Final State Interactions.

• Factorization models assume weak amplitudes to be real.

• The fact that the observed amplitudes have a relative complex phase is a consequence of the Final State Interaction.

• The effect of color suppression can be obscured by the effects of FSI.

CP violation.

• CP violation is expected to be small in charm decays.

• Need two amplitudes with different phases:

$$Ae^{i\delta_A} + Be^{i\delta_B}$$

• In signly Cabibbo-suppressed dacays penguin terms may provide a weak phase.

• Final State Interactions provide a strong phase shift.

• Under CP the weak phases change sign but the strong ones do not.

• Any difference in the Dalitz plot, between D and $\bar{D}$ would be an evidence for CP violation.

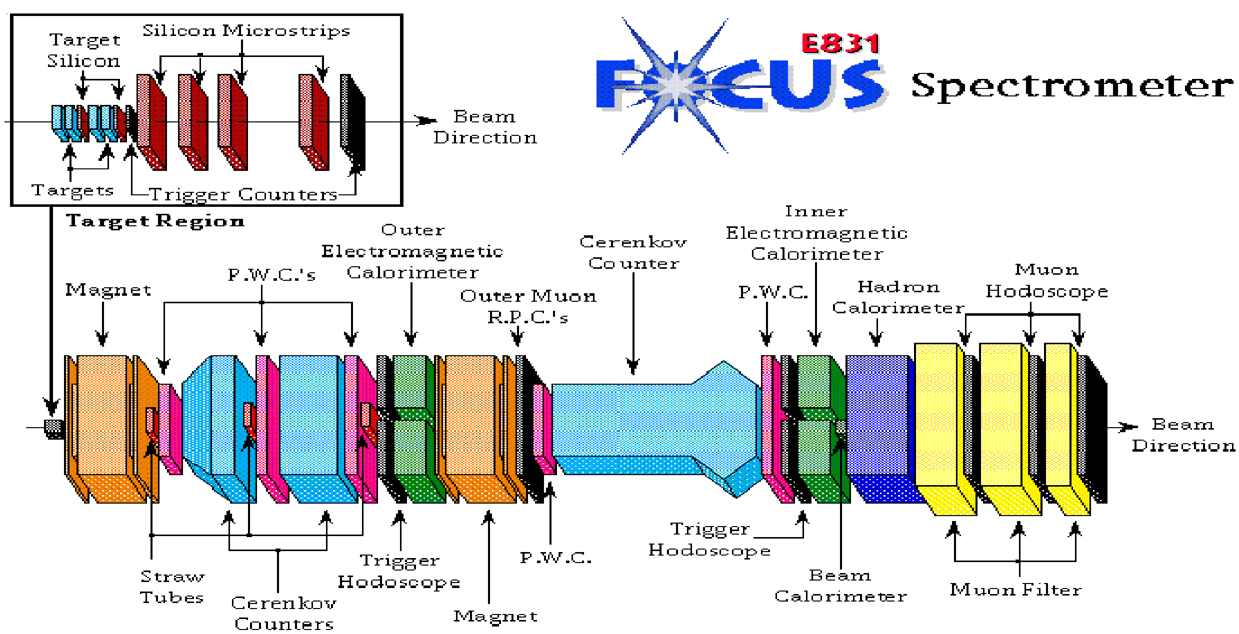
Recent experiments (fixed target).

- E791. Data taken during 1990-1991 using 500 GeV/c π^- beam at Fermilab. 2.5 $\times 10^5$ reconstructed charm.

- FOCUS. Successor to E687 which took data in 1990-1991. Data taken during 1996-1997. 170 GeV γ beam. 10^6 reconstructed charm.

- The technique employed here is to have good vertexing and good particle identification.

- Use of the Lorentz boost to separate the charm vertex.



Recent experiments (e^+e^- colliders).

e^+e^- colliders at the $\Upsilon(4S)$:

- Experiment CLEO: 9 fb^{-1}

- BaBar: 22.0 fb^{-1} at the end of 2000. Much more is coming.

- Belle.

Recent experiments (e^+e^- colliders).

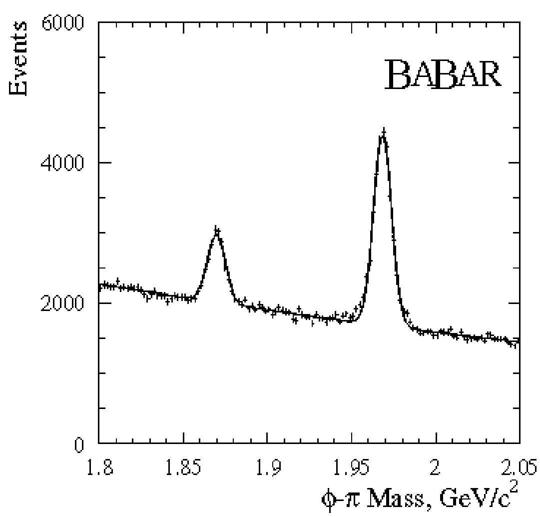
•Charmed mesons are obtained from continuum through a cut in center of mass momentum p^* and the request that they come from a D^* decay.

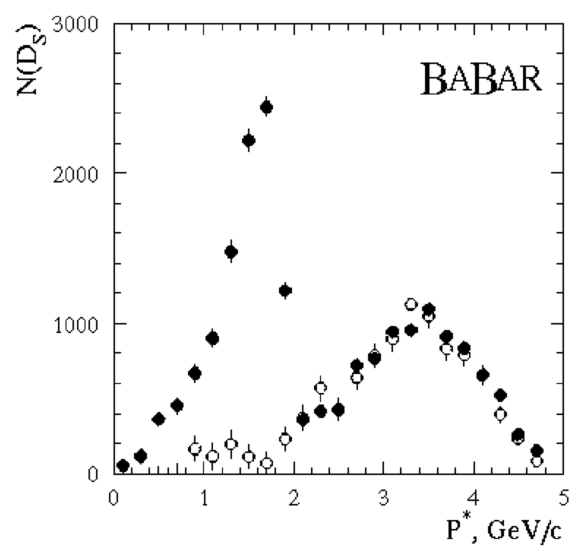
$$e^+e^- \to D^* \qquad X$$
$$\to D\pi$$

$$e^+e^- \to D_S^* \qquad X$$
$$\to D_S\gamma$$

where $\pi = \pi^{\pm}, \pi^0$

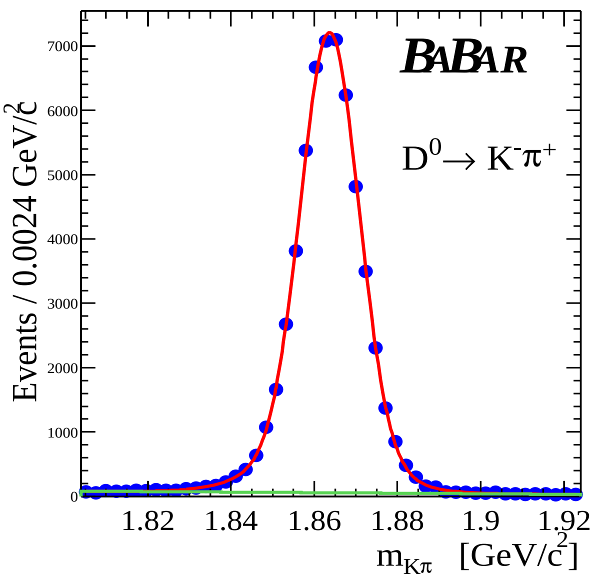
• Example from BaBar: mass distribution for $D_S \to \phi\pi$ and p^* momentum spectrum.

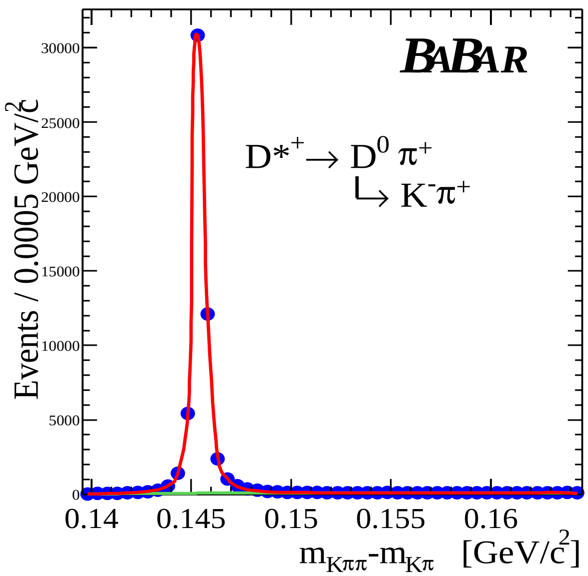




Recent experiments (e^+e^- colliders).

• Example from BaBar: Δm for $D^{*+} \rightarrow \pi^+ D^0$, $D^0 \rightarrow K^-\pi^+$.





• In the case of D^0 the charge of the slow pion gives the quantum numbers of the D^0. Example:

$$\begin{aligned} D^{*+} \rightarrow \; & D^0\pi^+ \\ & \rightarrow \bar{K}^0\pi^+\pi^- \end{aligned}$$

$$\begin{aligned} D^{*-} \rightarrow \; & \bar{D}^0\pi^- \\ & \rightarrow K^0\pi^+\pi^- \end{aligned}$$

Dalitz analysis technique.

• Nearly all charmed mesons decays proceed through intermediate resonance production.

• Dalitz plot distributions fitted with a sum of interfering amplitudes.

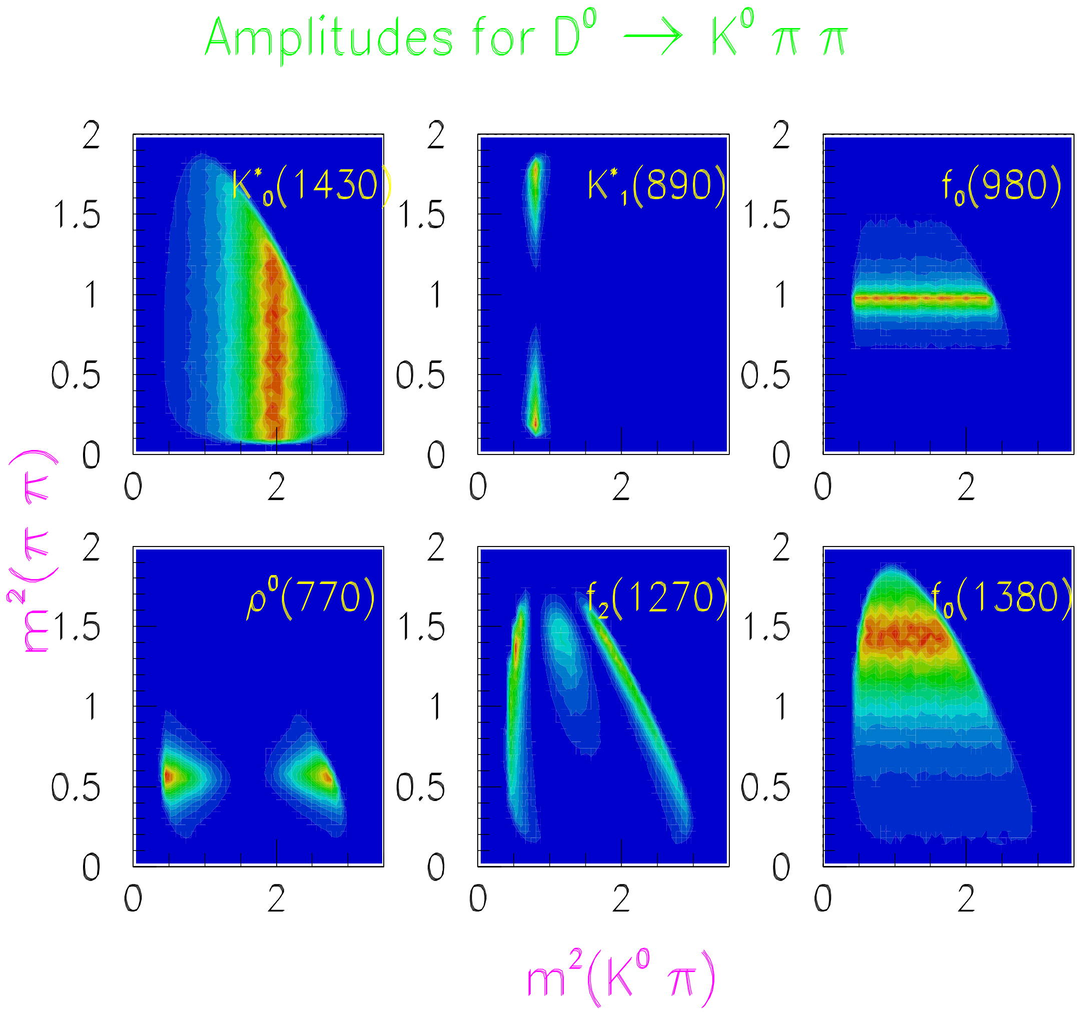
$$\sum c_i A_i e^{i\phi}$$

• Each amplitude is the product of a Breit-Wigner and a term describing the angular distributions (for example: Zemach tensors).

$$A_i = BW(m)Z(\Omega)$$

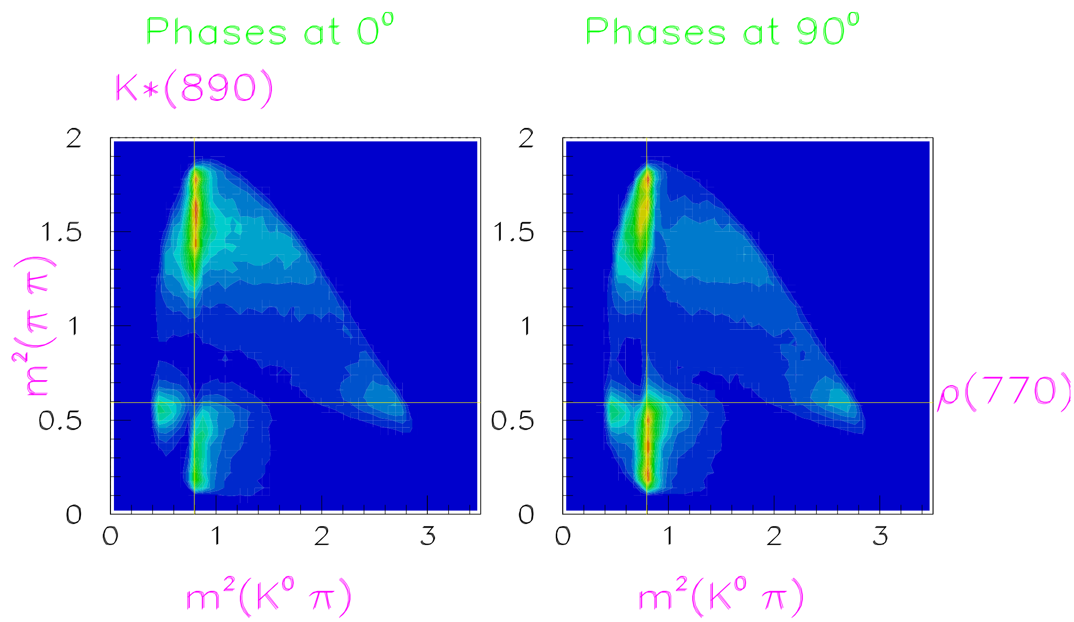
Dalitz analysis.

- Example:

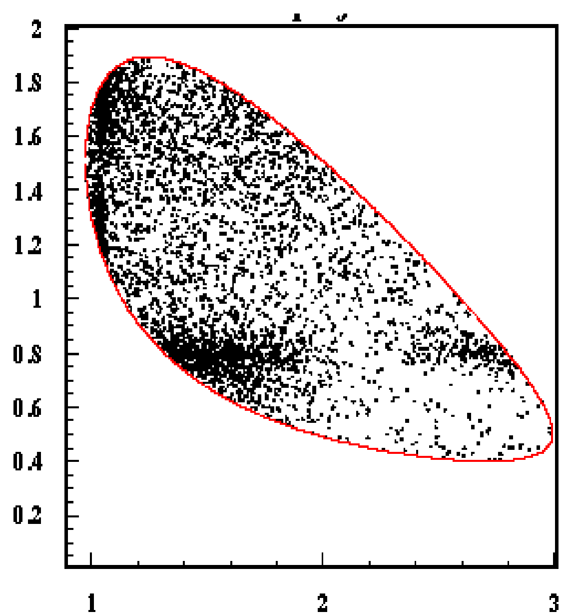


Dalitz analysis.

• Bare amplitudes are real ($\phi = 0$ or 180^0). Asymmetry can only be generated by FSI. • Monte-Carlo. Example from $D^0 \to K^0\pi^+\pi^-$. Presence of $K^(890)$, $\rho^0(770)$ and $f_0(1370)$.



• Example from $D^+ \to K^+K^-\pi^+$ from FOCUS: strong asymmetry between the two K^* lobes.

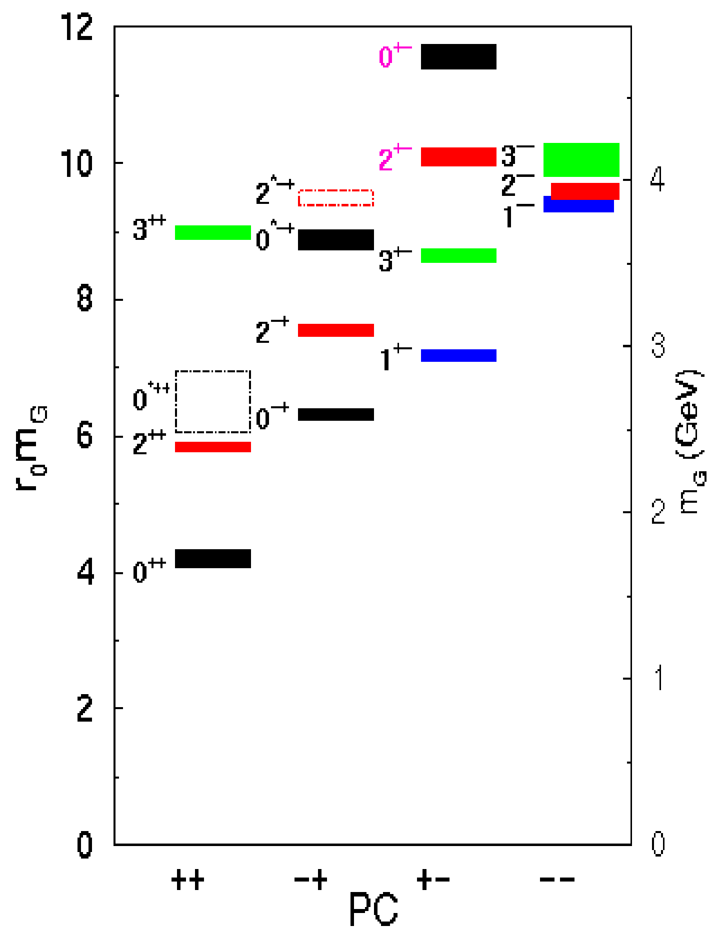


The puzzle of the scalar mesons.

• The scalar mesons are still a puzzle in Light Meson Spectroscopy.

• The question is relevant, since among the states observed up to now may hide the scalar glueball or 4-quark states.

• Lattice QCD glueballs spectrum:



• The Scalar Glueball is expected at about 1700 MeV.

The multiplet of the scalar mesons.

• We expect 9 states, in PDG we find 15 candidates:

I = 1/2	I = 1	I = 0
		$f_0(400-1200)$
	$a_0(980)$	$f_0(980)$
		$f_0(1370)$
$K_0^*(1430)$	$a_0(1490)$	$f_0(1500)$
		$f_0(1710)$

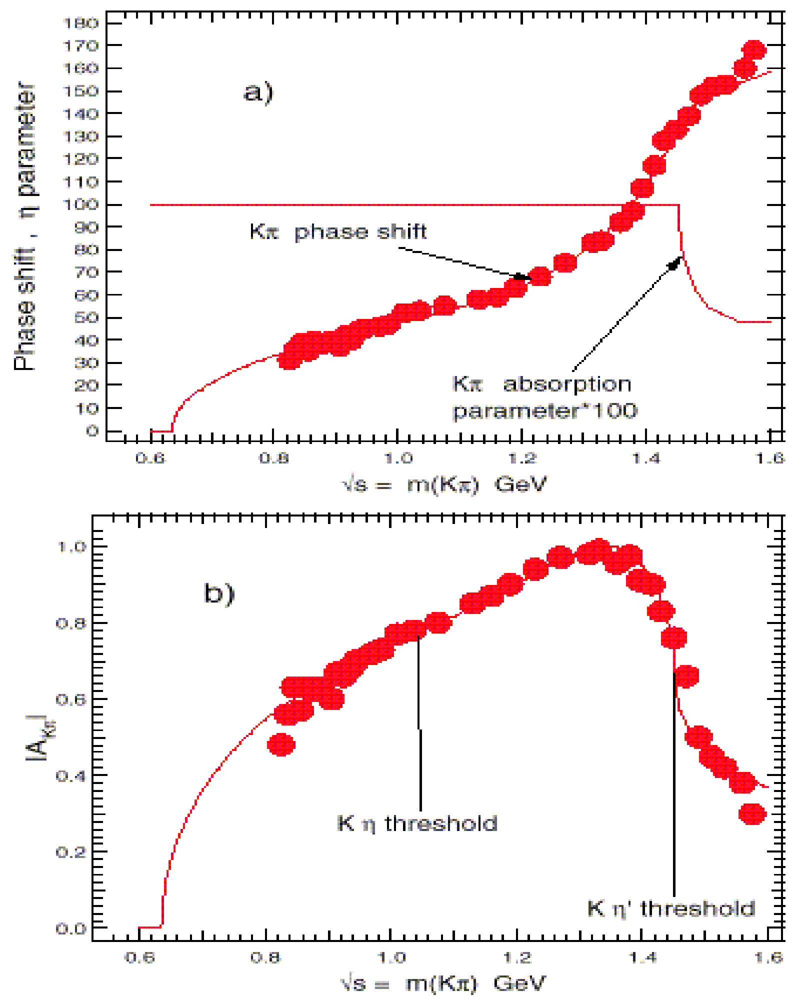
• Among these, $f_0(1710)/f_2(1710)$ appears with different spins in different experiments.

• What new information is coming from the analysis of charm decays?

The resonance $K_0^*(1430)$

• The actual parameters in PDG are from LASS experiment at SLAC using 11 GeV/c incident K.

$$K^- p \to K^- \pi^+ n$$



• Wide resonance, therefore parameters difficult to extract. Presence of an S-wave elastic background.

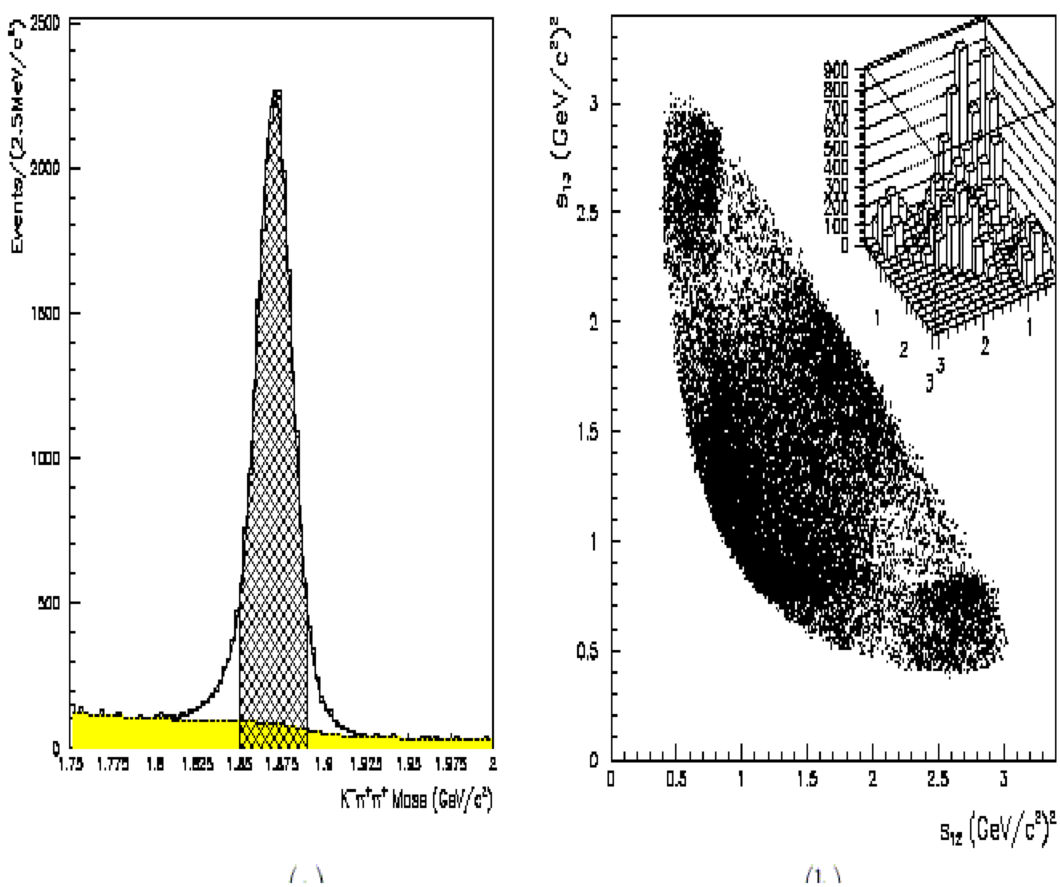
$$m = 1.412 GeV \qquad \Gamma = 294 MeV$$

Study of $D^+ \to K^-\pi^+\pi^+$ (E791)

• This Dalitz plot analyzed by several other experiments (E691, E687).

• In contrast to all other charmed mesons decays, a large Non Resonant contribution.

• Data from E791, $\approx$ 23 000 events



• Strong interferences. Channel dominated by $K^*(890)$ (13 %) and $K_0^*(1430)$ (34 %).

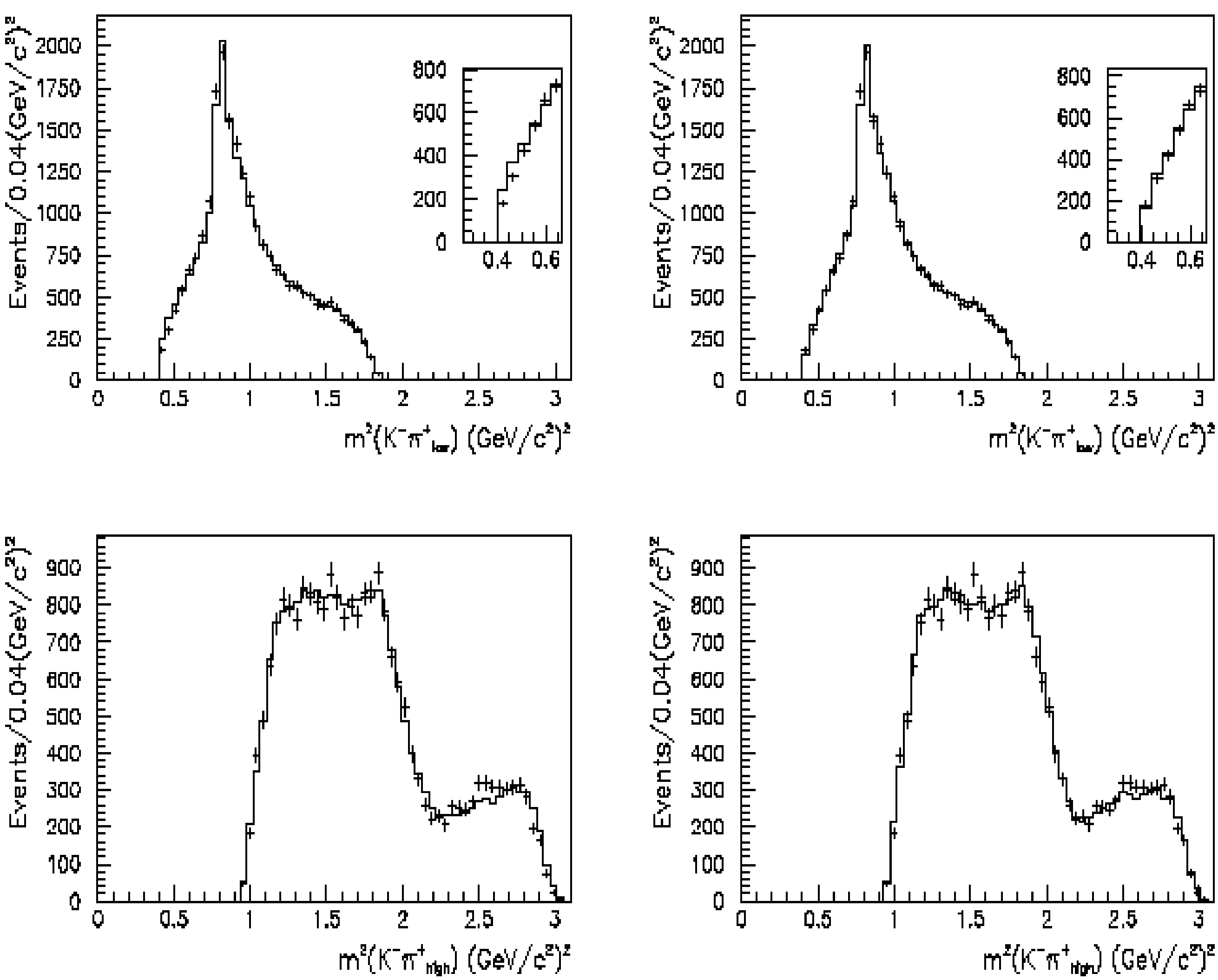
• Need a large Non Resonant contribution (104 %).

Study of $D^+ \to K^-\pi^+\pi^+$ (E791)

- Data not fitted well. Need to include a new scalar $\kappa(800)$:

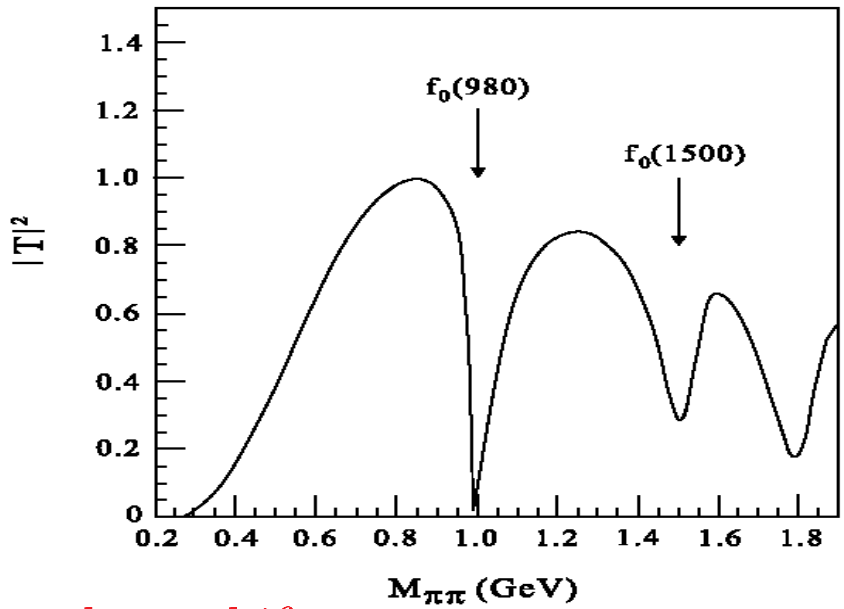
$$m = 815 \pm 30 MeV, \qquad \Gamma = 560 \pm 116 MeV$$

- In this scenario the Non Resonant contribution goes to (52 %) and that of κ to 21 % with 180^0 relative phase.

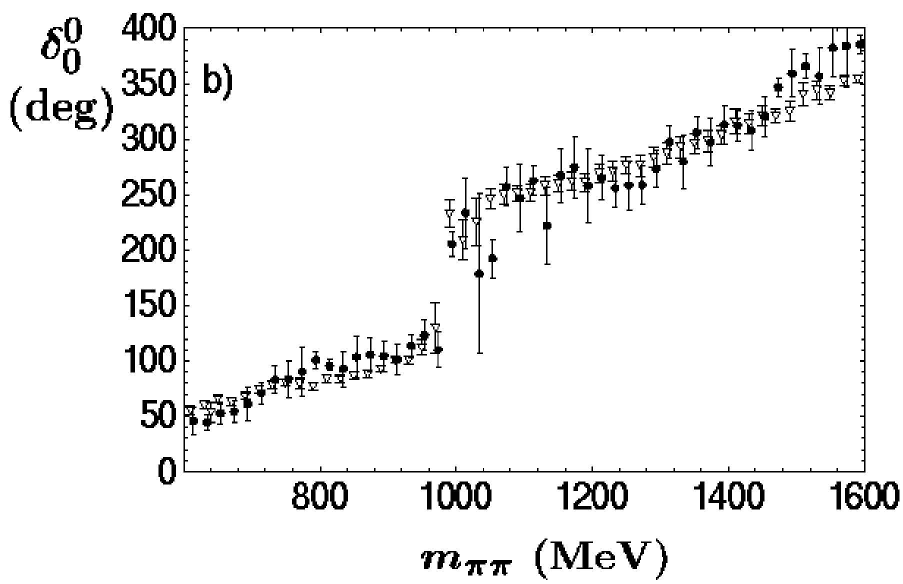


The resonance $\sigma/f_0(400-1200)$

• Sketch of the S-wave amplitude from different experiments.



• The $\pi\pi$ phase shift.

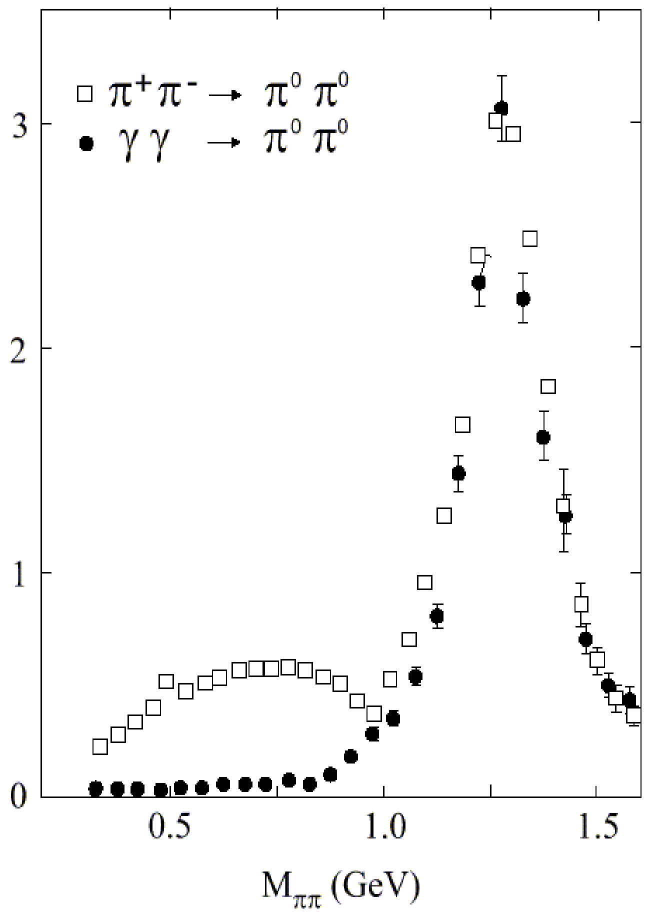


• Slowly moving phase and a wide structure: the σ

• Two other scalar mesons interfering with the background scalar amplitude: $f_0(980)$ and $f_0(1500)$

The resonance $\sigma/f_0(400-1200)$

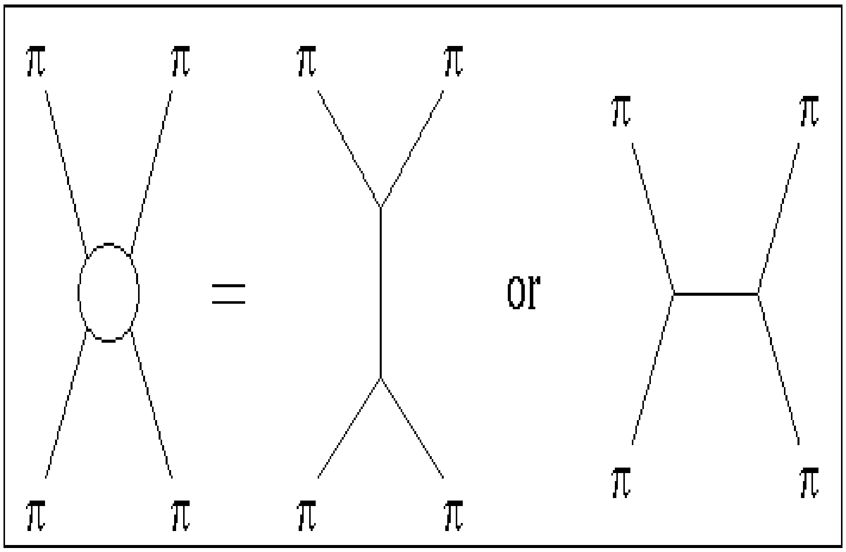
- Strong suppression of σ production in $\gamma\gamma$ collisions.



- Minkowski and Ochs: σ is the scalar glueball (the *Red Dragon*)

The resonance $\sigma/f_0(400-1200)$

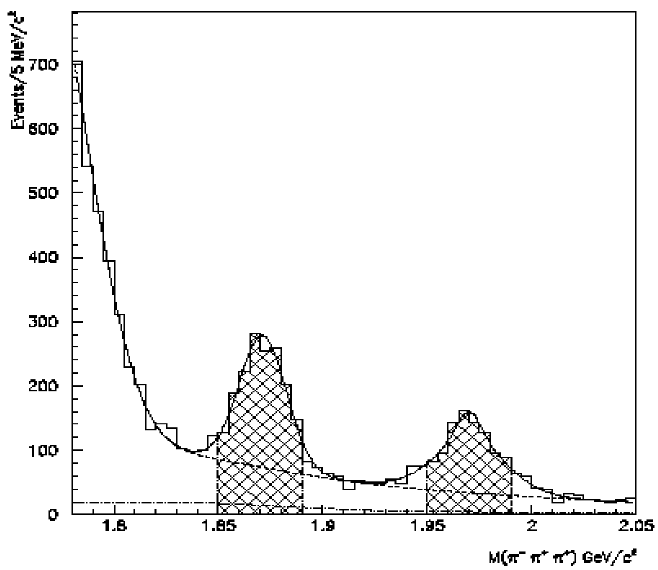
- Klempt and Pennington: the σ is a pole in the t-channel.



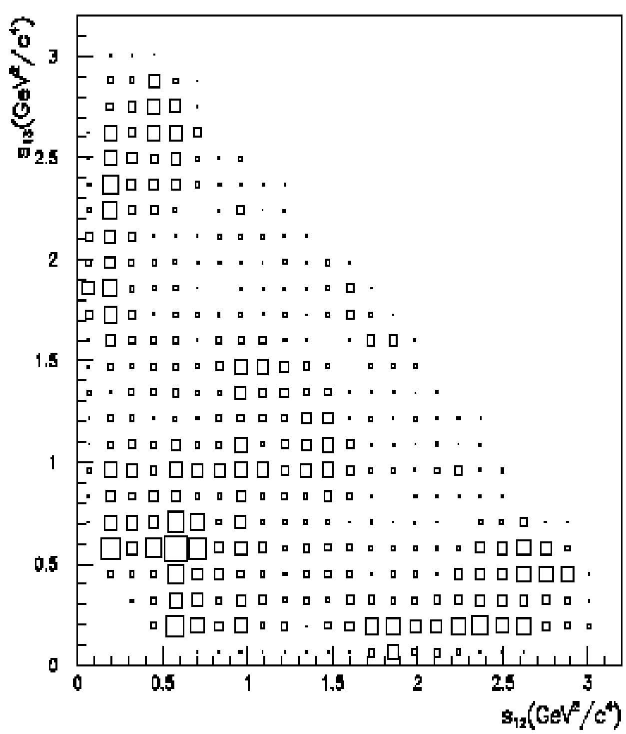
- A pole in the S channel does not depend on the reaction.
- A pole in the t channel gives rise to shapes which are strongly dependent from the physical process.

Study of $D^+ \to \pi^-\pi^+\pi^+$ (E791)

- $\pi^+\pi^+\pi^-$ mass spectrum from E791. (1686 events in D^+ and 937 in D_S^+.) Signal/Background 2/1.

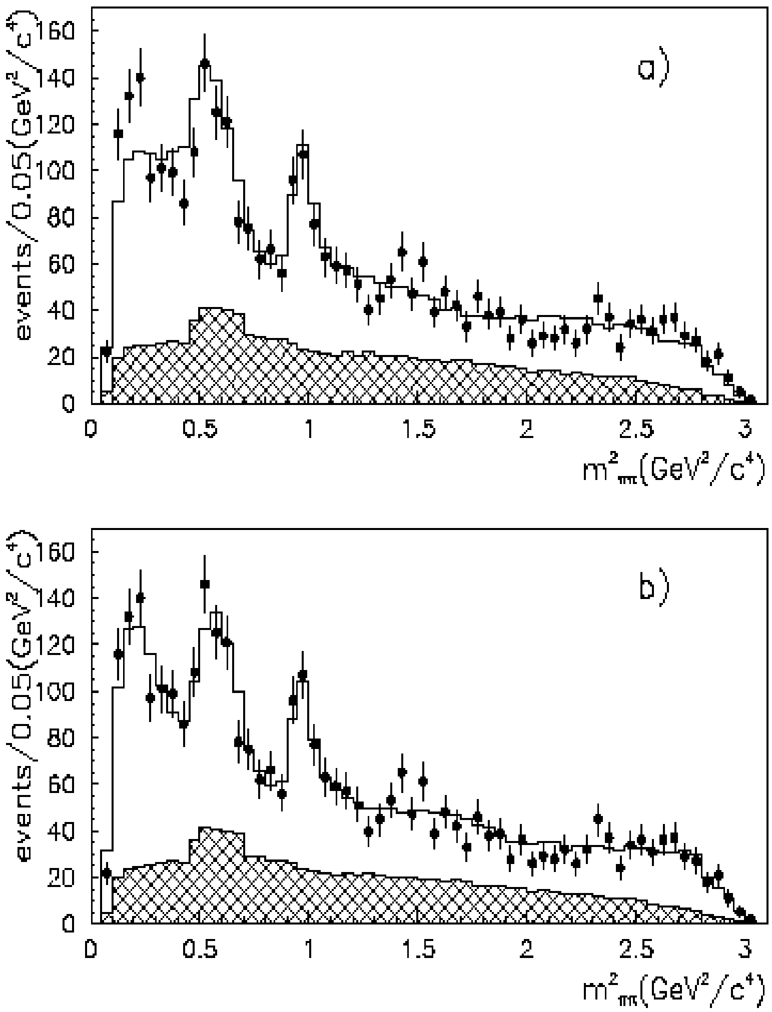


- D^+ Dalitz plot (symmetrized).



Study of $D^+ \to \pi^-\pi^+\pi^+$ (E791)

- $\pi^+\pi^-$ projection. Evidence for $\rho(770)$ and $f_0(980)$.



- Need of an extra scalar resonance $\sigma(500)$ to fit the data.

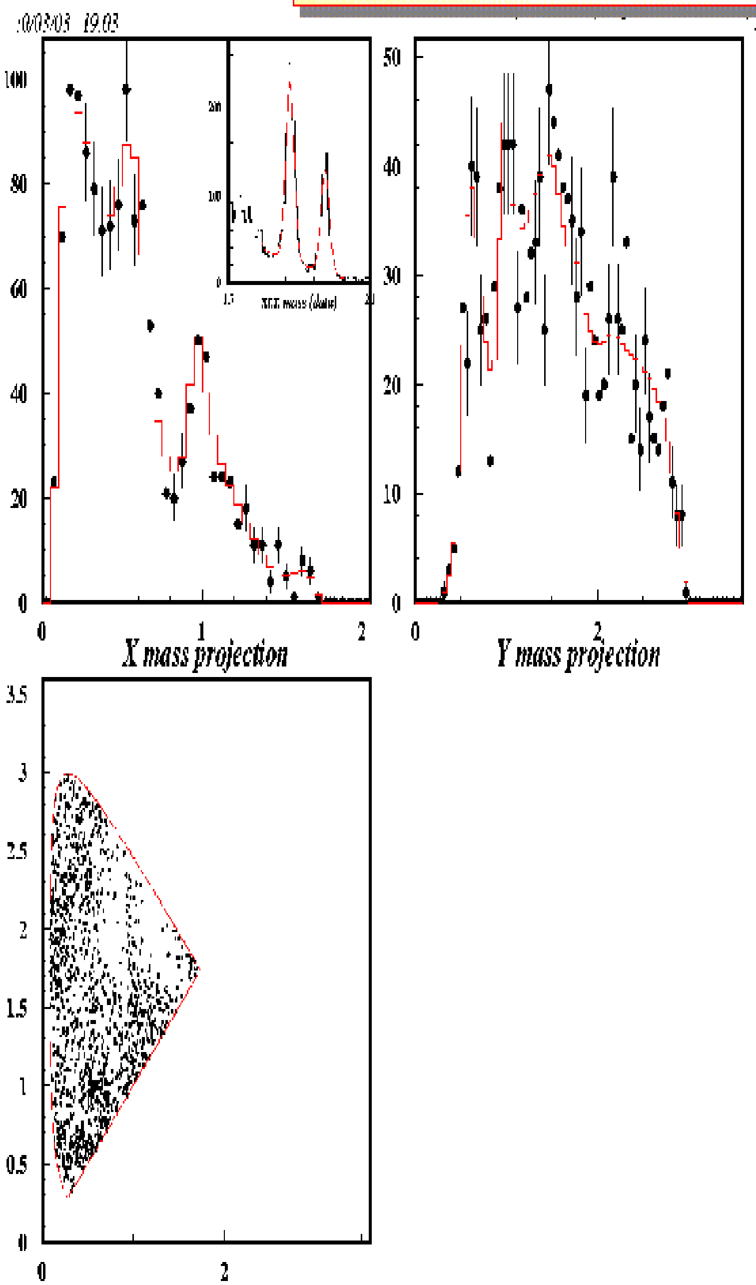
$$m = 478 \pm 24, \qquad \Gamma = 324 \pm 41 \qquad MeV$$

- In this hypothesis the dacay $\sigma\pi$ accounts for nearly half (46 %) of D^+ decay.
- In this scenario the $f_0(1370)$ contribution vanishes.

Study of $D^+ \to \pi^-\pi^+\pi^+$ (FOCUS)

- Similar results obtained by FOCUS.

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



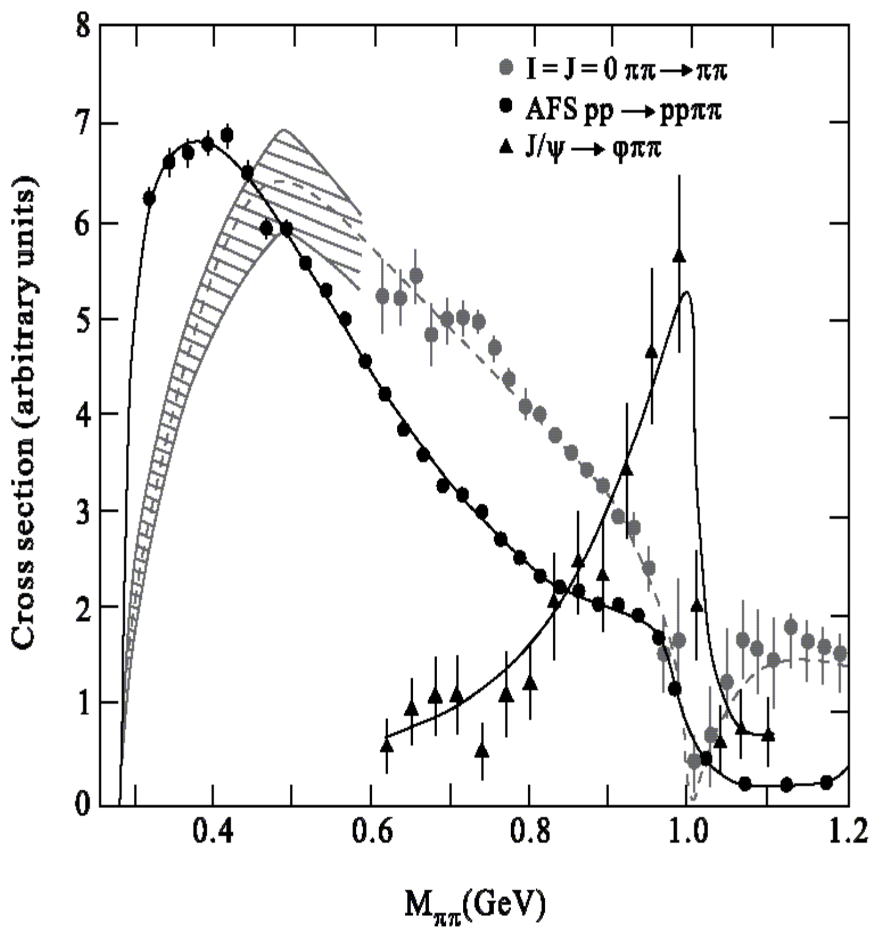
Fit results

	Fit frac.	Phase
NR	0.10 ± 0.08	0 (fixed)
ρ (770)	0.34 ± 0.04	84 ± 14
f_2 (1270)	0.11 ± 0.02	171 ± 15
f_0 (980)	0.06 ± 0.02	238 ± 21
S_0 (1475)	0.01 ± 0.01	273 ± 34
ρ (1450)	0.04 ± 0.01	0 ± 30
f_0 (400)	0.26 ± 0.01	-64 ± 16
f_0 (1300)	0.01 ± 0.01	-19 ± 80

K-matrix f_0

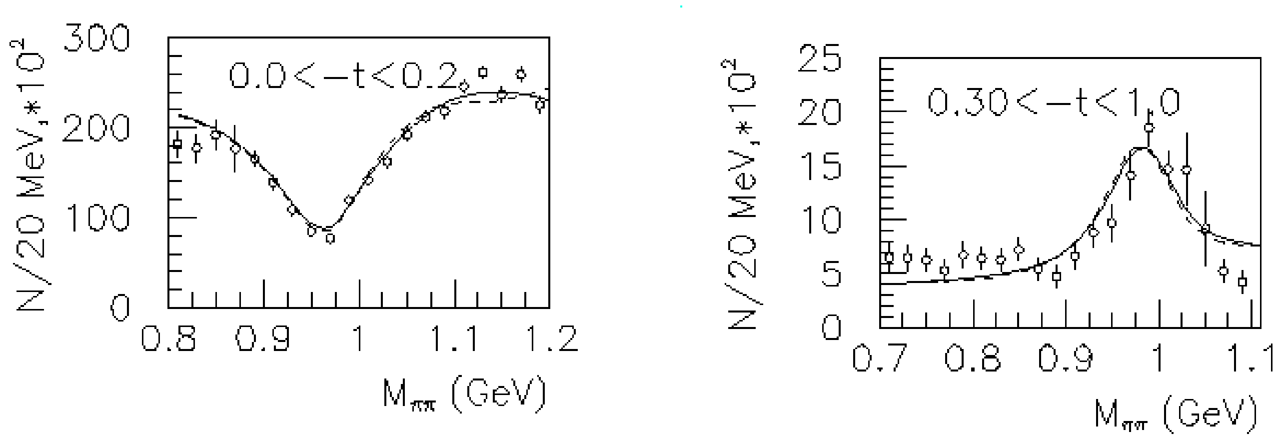
The problem of $f_0(980)$ and $a_0(980)$

- Both Considered as candidates for being 4-quark states due to their proximity to $\bar{K}K$ threshold.
- $f_0(980)$ appears as a peak or as a hole in different reactions.
- As a sharp drop in central production.
- As a peak in $J/\psi \to \phi\pi\pi$



The problem of $f_0(980)$ and $a_0(980)$

- In the same experiment it changes as a function of the 4-momentum transfer.
- $\pi^- p \to \pi^0 \pi^0 n$ at 40 GeV/c (GAMS).



- Most likely explanation: $f_0(980)$ interferes with other scalars such as $f_0(1370)$ or σ. When these other scalars are suppressed $f_0(980)$ appears as a peak.

The $f_0(980)$.

• The $f_0(980)$ parameters are usually described by a coupled channel Breit-Wigner to $\pi^+\pi^-$, K^+K^- and $K^0_S K^0_S$ final states:

$$BW_{ch}(f_0)(m) = \frac{F_r}{m_0^2 - m^2 - i m_0(\Gamma_\pi + \Gamma_K)}$$

where:

$$\Gamma_\pi = g_\pi (m^2/4 - m_\pi^2)^{1/2}$$

$$\Gamma_K = \frac{g_K}{2}[(m^2/4 - m_{K^+}^2)^{1/2} + (m^2/4 - m_{K^0}^2)^{1/2}]$$

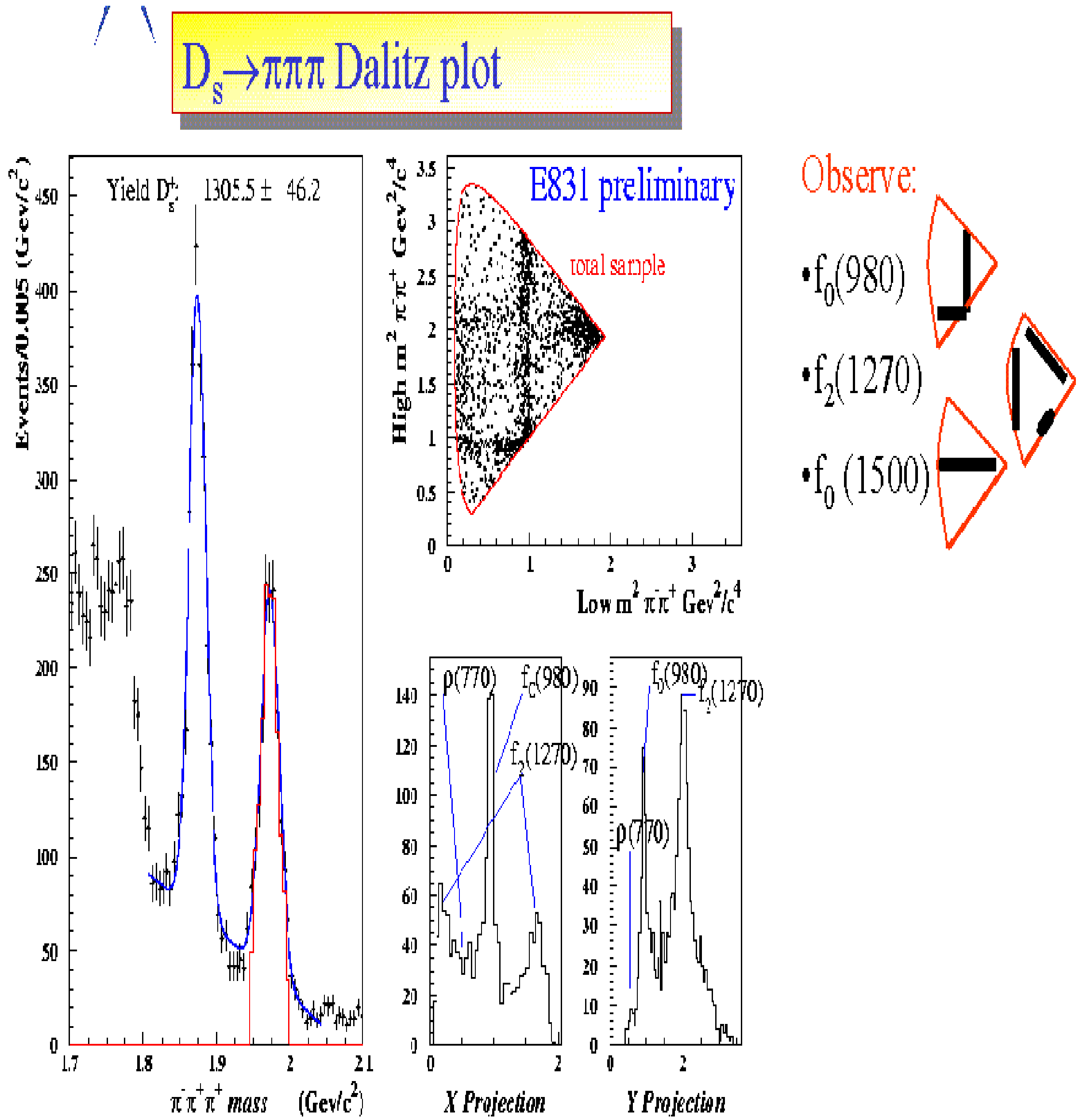
• The f_0 parameters have been measured by CERN/WA76 experiment studying the centrally produced $\pi^+\pi^-$ system.

$$m_0 = 0.979 GeV, \qquad g_\pi = 0.28, \qquad g_K = 0.56$$

• However there was no constraint from $\bar{K}K$ data. Coupling to $\bar{K}K$ poorly known.

Study of $D_S^+ \to \pi^-\pi^+\pi^+$ (FOCUS)

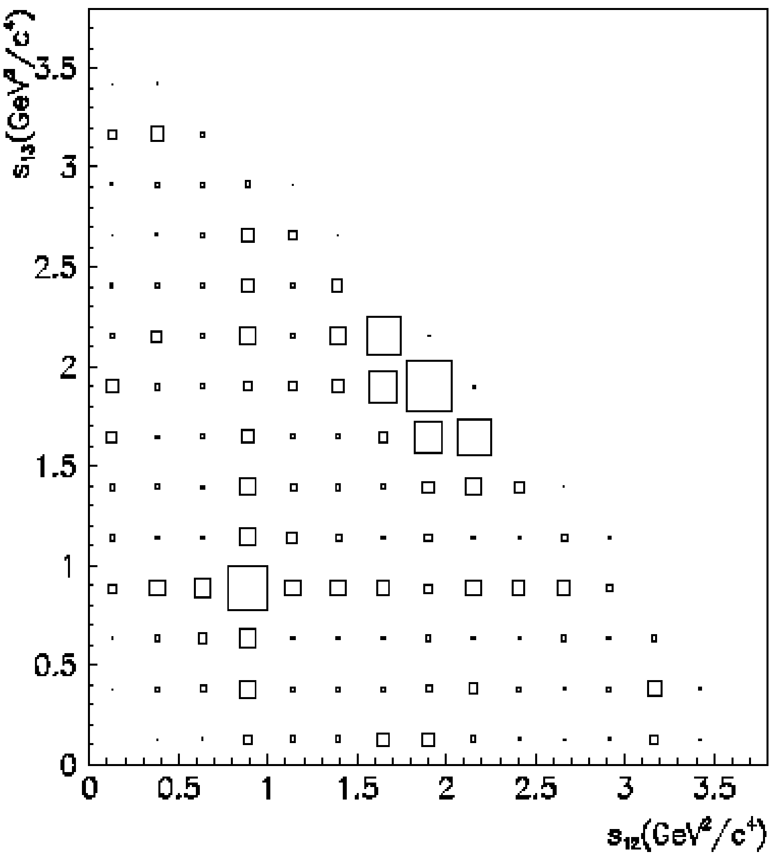
- 1300 events



- Strong $f_0(980)$ appearing as a narrow peak.

Study of $D_S^+ \to \pi^-\pi^+\pi^+$ (E791)

- 850 events



- $f_0(980)$ parameters insensitive to the $\bar{K}K$ coupling.

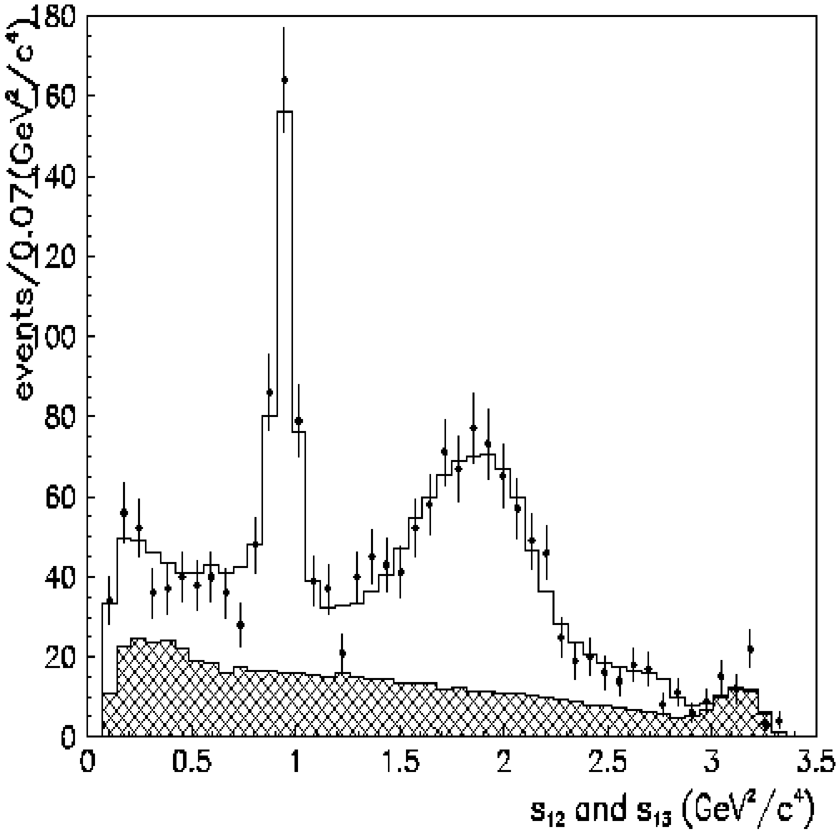
Study of $D_S^+ \to \pi^-\pi^+\pi^+$ (E791)

- Fitting with a standard BW, they obtain:

$$m = 975 \pm 3 \quad MeV \qquad \Gamma = 44 \pm 2 \quad MeV$$

- Large $f_0(980)$ contribution: 57 %. $\bar{s}s$ meson?.

- The fit requires the presence of an $f_0(1370)$ 32 %, a $\bar{u}u + \bar{d}d$ state. W-annihilation or rescattering?

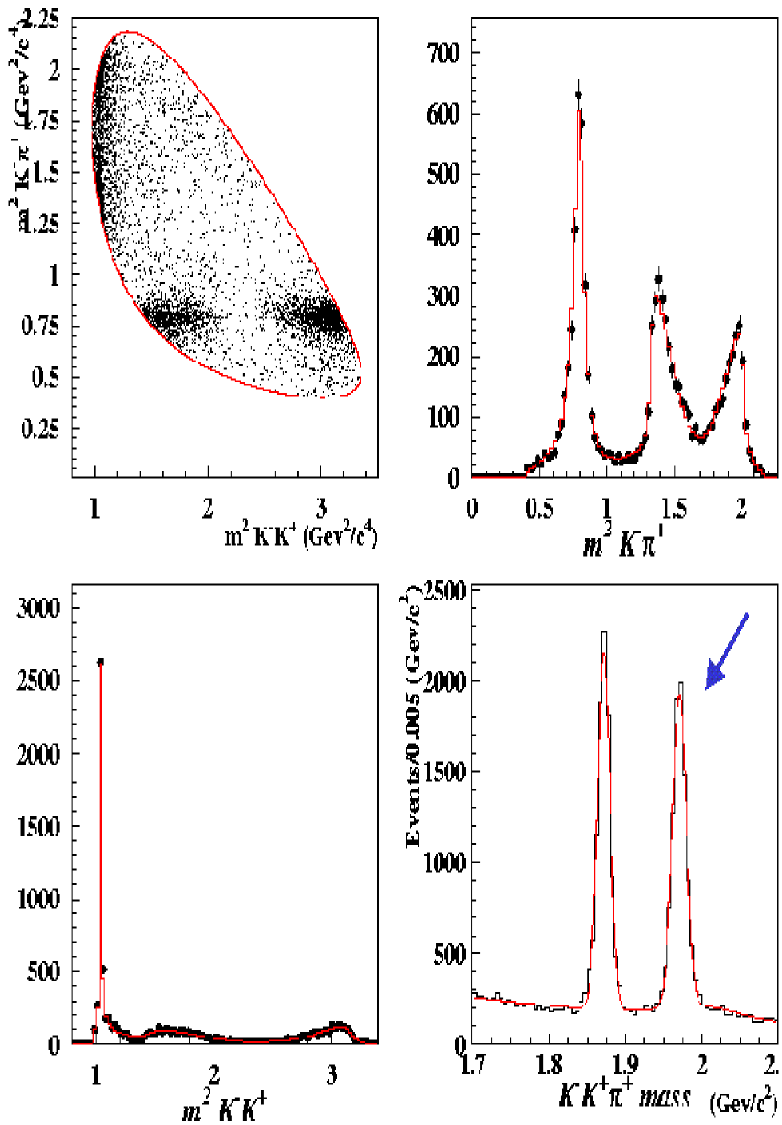


Study of $D_S^+ \to K^- K^+ \pi^+$ (FOCUS)

- The study of the decay of $D_S^+ \to K^- K^+ \pi^+$ requires a relatively broad scalar meson in the threshold region.

- Presence of both $f_0(980)$ and $a_0(970)$?

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



WA76 parametrization for f_0

Fit results

	Fit frac.	Phase (Deg)
K^{*0} (892)	0.44 ± 0.01	0.0 (fixed)
K^*_0 (1430)	0.06 ± 0.01	114 ± 5
ϕ (1020)	0.45 ± 0.01	148 ± 4
f_0 (980)	0.16 ± 0.01	135 ± 4
f_j (1710)	0.04 ± 0.01	106 ± 8

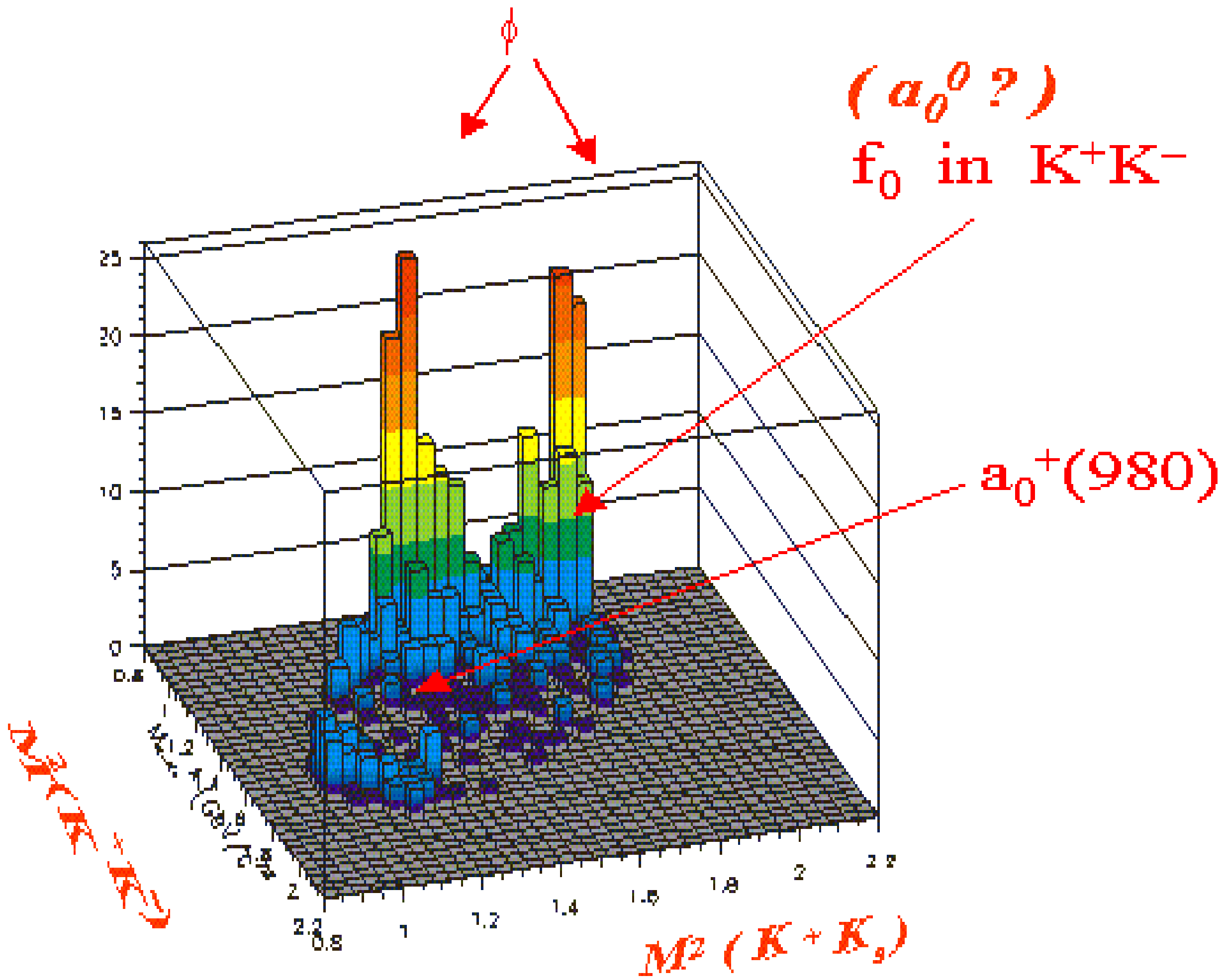
E687 published result

	Fit frac.	Phase (Deg)
K^{*0} (892)	0.48 ± 0.05	0.0 (fixed)
K^*_0 (1430)	0.09 ± 0.03	152 ± 40
ϕ (1020)	0.40 ± 0.03	178 ± 20
f_0 (980)	0.11 ± 0.04	159 ± 22
f_j (1710)	0.03 ± 0.02	110 ± 20

- No evidence for $f_0(1370)$.

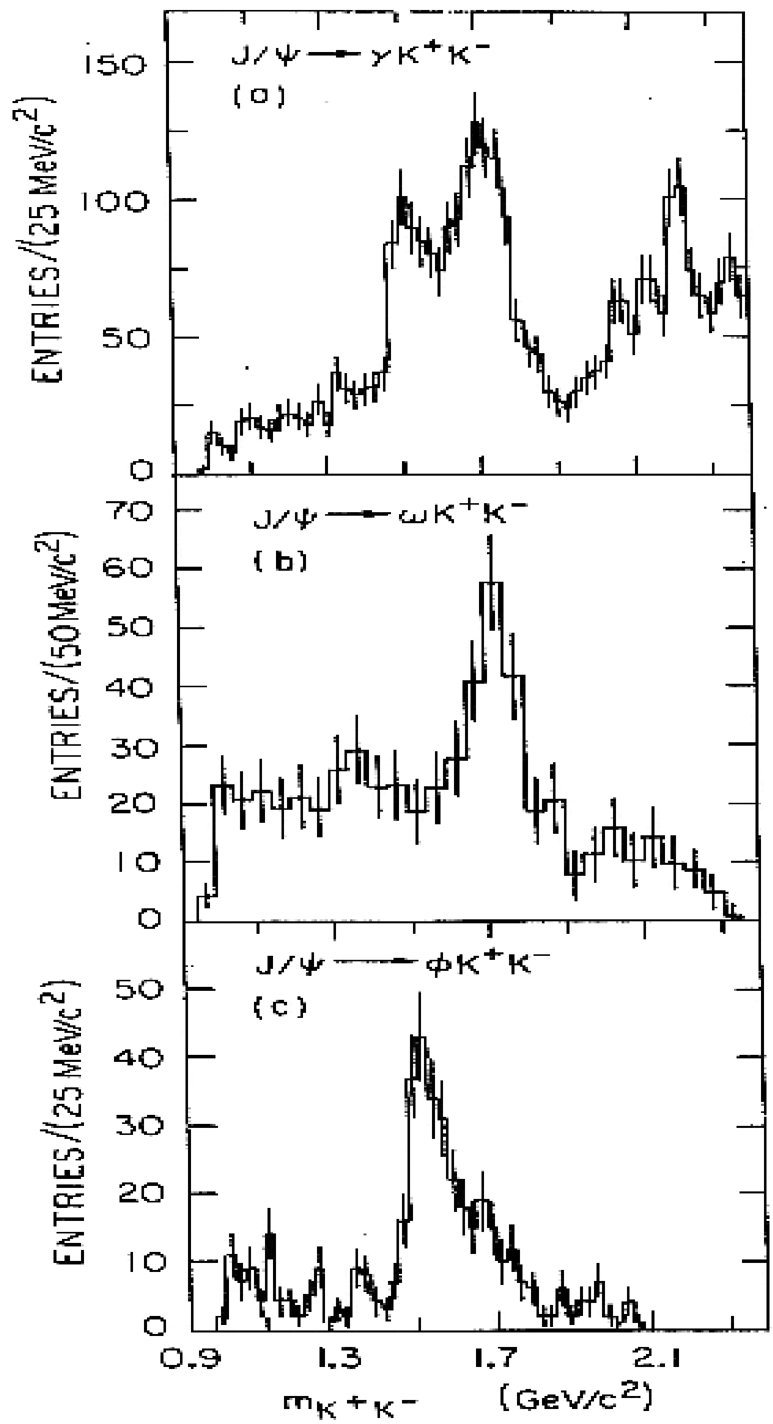
Study of $D^0 \to K_S^0 K^- K^+$ (FOCUS)

- Evidence for $D^0 \to K^- a_0^+$.
- Presence of both $K^0 f_0(980)$ and $K^0 a_0(980)$?



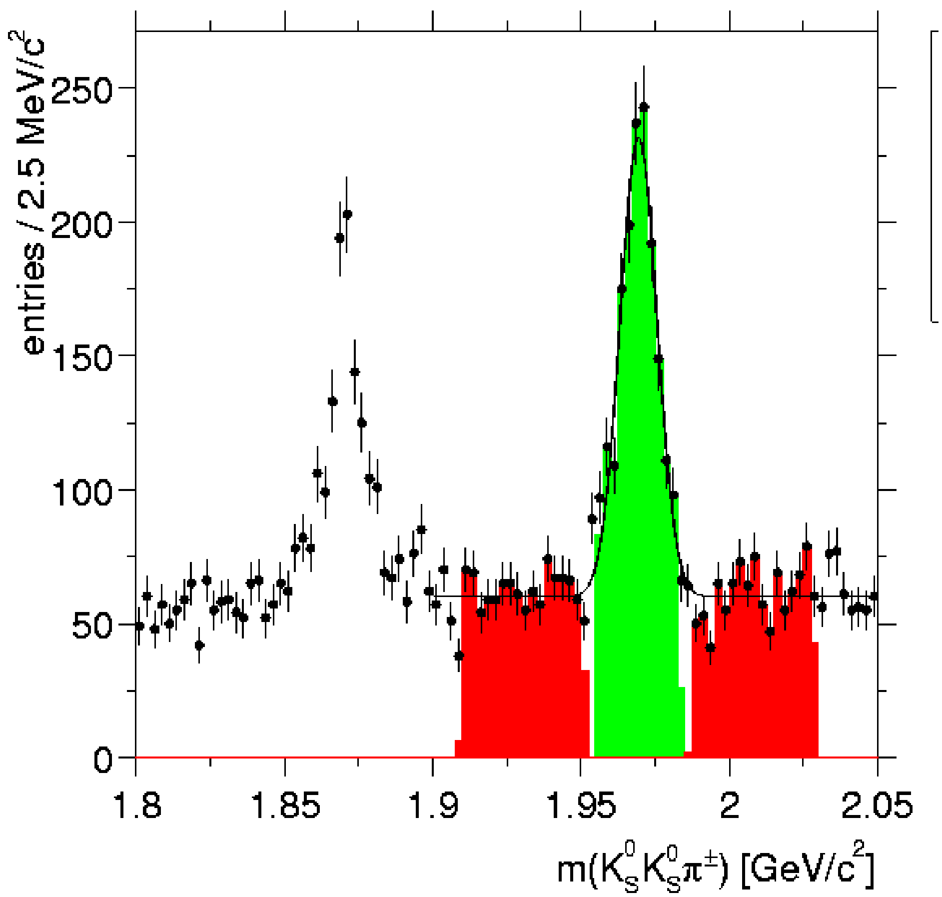
The question of the spin of the $\theta / f_j(1710)$

- This state measured with spin 0 or 2 in different experiments.
- Candidate for being the tensor or scalar glueball.
- Observed in J/ψ decay and central production.



Study of $D_S^+ \to K_S^0 K_S^0 \pi^+$ (BaBar)

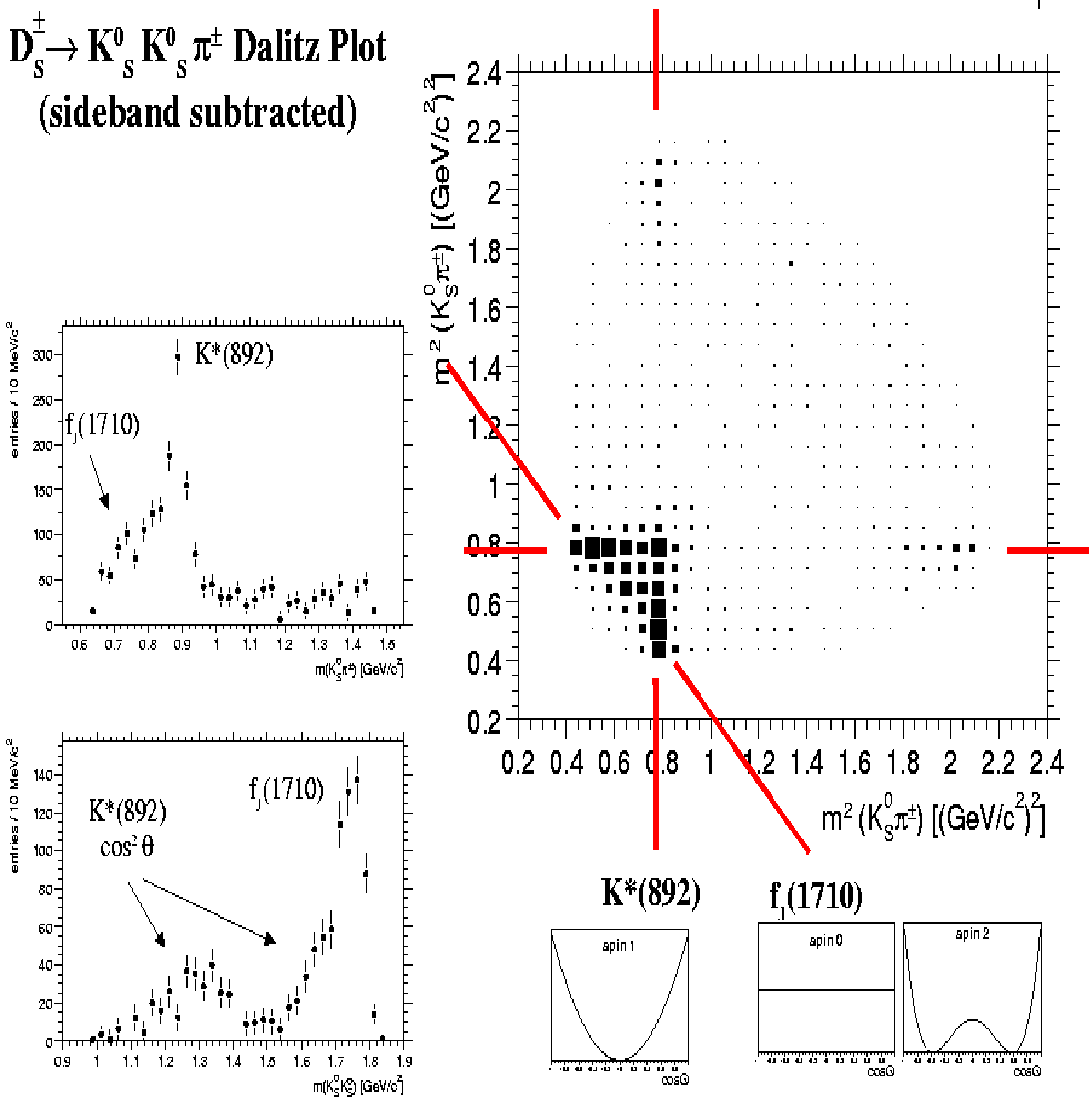
- Channel isolated using $D_S^* \to D_S \gamma$ and p^* cuts.



- Evidence for the decay $D_S \to f_j(1700)\pi$

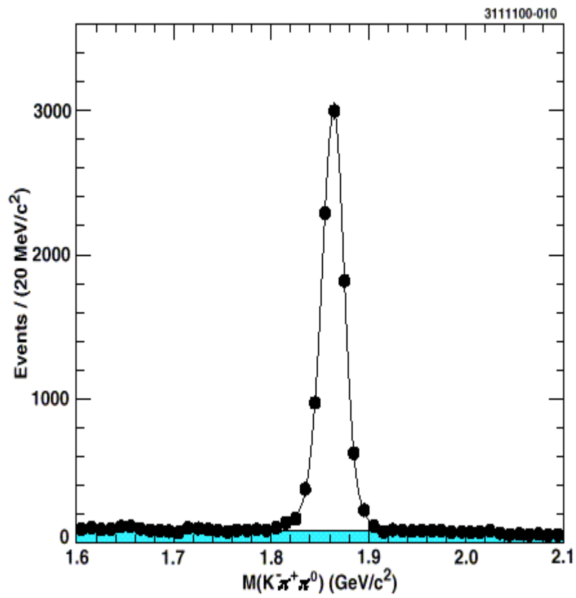
Study of $D_S^+ \to K_S^0 K_S^0 \pi^+$ (BaBar)

- Dalitz plot analysis in progress.

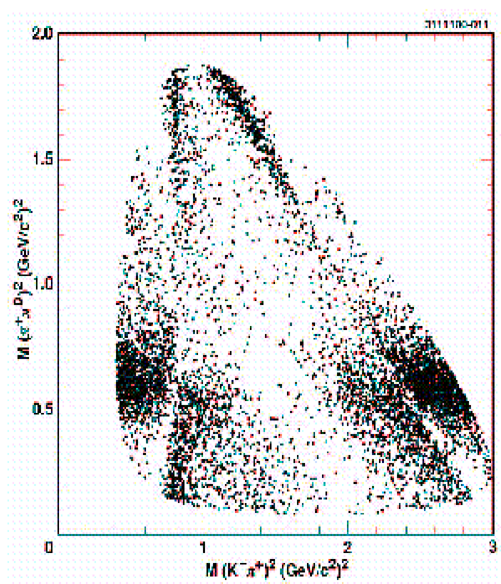


Study of $D^0 \to K^-\pi^+\pi^0$ (CLEO)

- 7000 events.

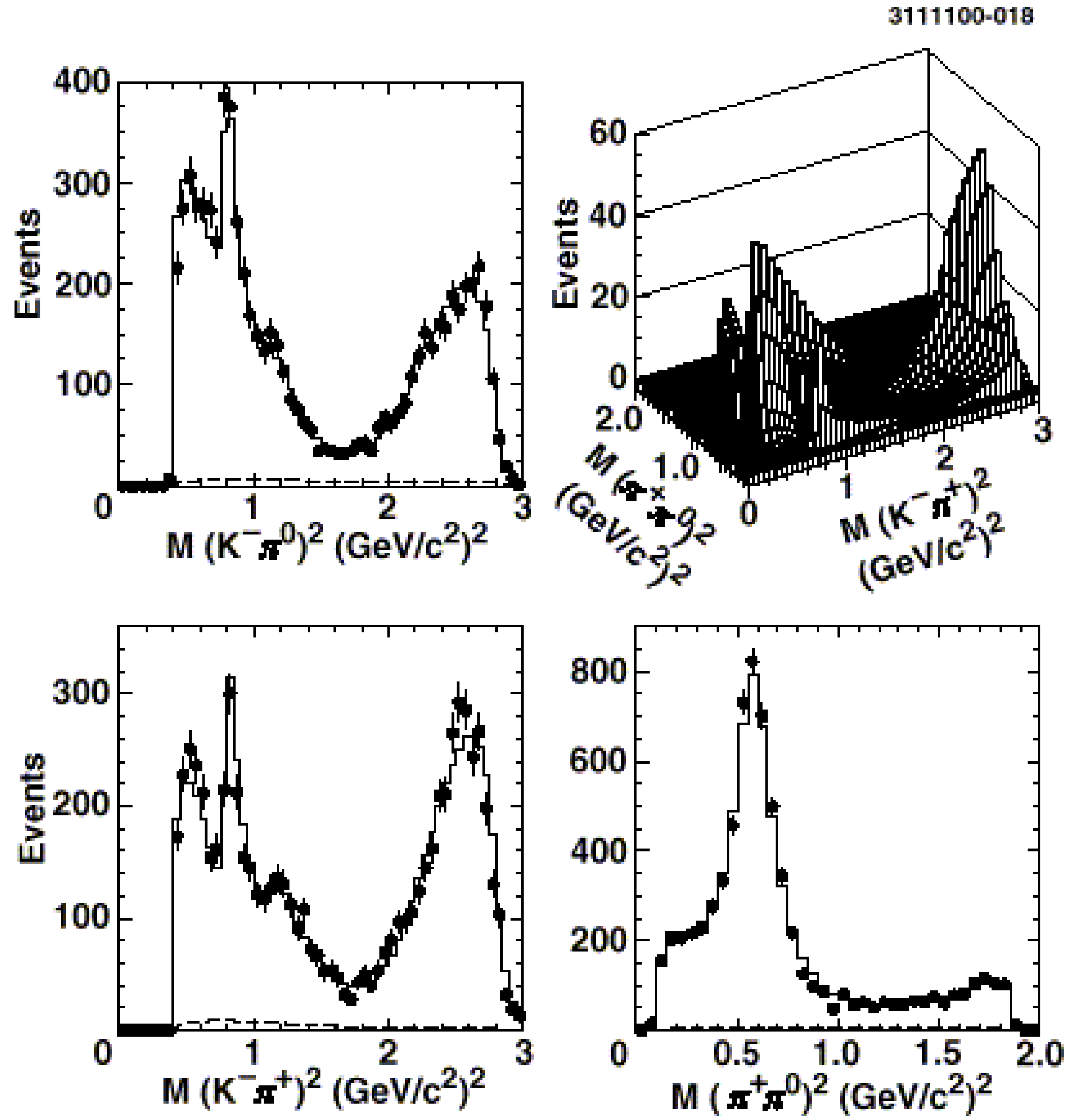


- Dalitz plot.



Study of $D^0 \to K^-\pi^+\pi^0$ (CLEO)

- The Dalitz analysis shows strong $\rho^0(770)$ (79 %) production and $K^*(890)$ (29 %). No evidence for κ.



- Dalitz plot asymmetry:

$$A_{CP} = -0.031 \pm 0.086$$

Conclusions.

• A new chapter in physics has been open: the hight statistics Dalitz analysis of charmed mesons decays.

These studies will give information on:

• The different diagrams which originate charm decays.

• Possible signs of CP violation in the charm sector.

• Possibly solve several questions left open in light meson spectroscopy.

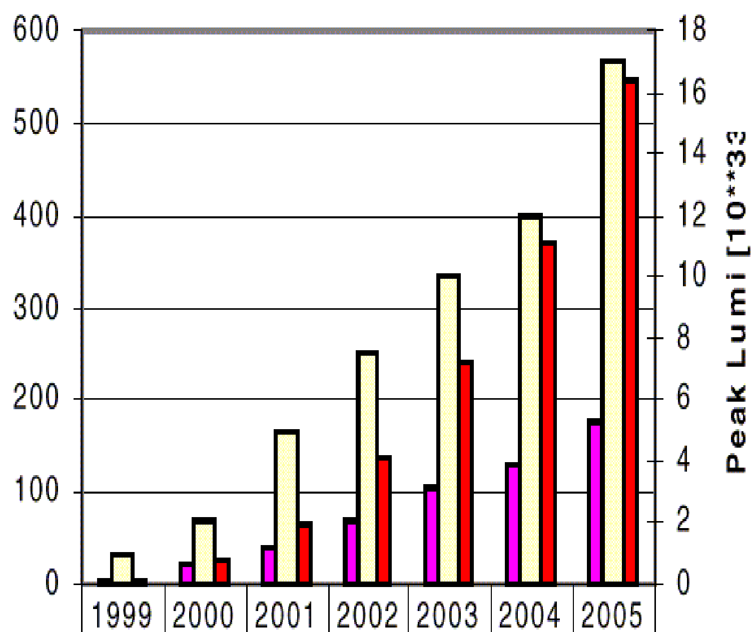
Conclusions.

Near Future will be dominated by B-factories.

Present available data on Dalitz decays from fixed target and B-factories:

- Cabibbo allowed 1-5 $\times 10^4$ events
- Cabibbo suppressed 1-10 $\times 10^3$ events.
- Doubly Cabibbo suppressed 50 - 300 events.

Expected integrated luminosity from BaBar.



	1999	2000	2001	2002	2003	2004	2005
Yearly Lumi	2	23	40	70	105	130	175
Cumulative Lumi	2	25	65	135	240	370	545
Peak Lumi	1	2	5	7.5	10	12	17

Year

- In the next few years we expect an increase of these yields by a factor 20.