Open Problem on Light Meson Spectroscopy
or
Experimental Problems of Low Mass Scalar Mesons

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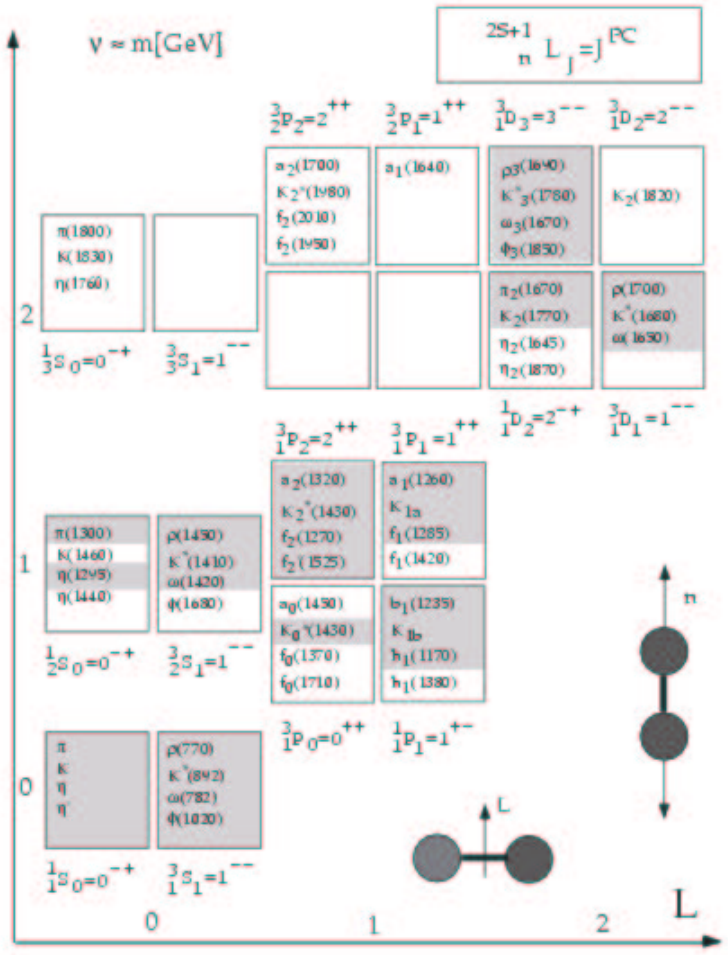
Daphne2004 - Physics at Meson Factories

Light Mesons Spectra

Amsler and Törnqvist quark-antiquark mass spectrum, according SU(3)

Physics Report 389 (2004), 61



$\nu = n + L - 1 \approx Mass$ Versus L

(n is the radial excitation)

Does not work in this schema the low mass scalar mesons $\sigma(500)$, $f_0(980)$, $a_0(980)$ and $\kappa(800)$

Problems of Low Mass Scalar Mesons

- **Theoretical point of view**

Are They a

- **SU(3) Multiplet?**
- **Quark-Antiquark state?**
- **Four-quark state ?**
- **Molecule state?**
- **Dyson state?**

- **Experimental point of view**

Is the $\sigma(500)$ a true resonance?

Does the $\kappa(800)$ exist?

$f_0(980)$ and $a_0(980)$: the $g_K/g_{\pi(\eta\pi)}$ Problem

Light Scalar Vs Vector Mesons in Charm Decay

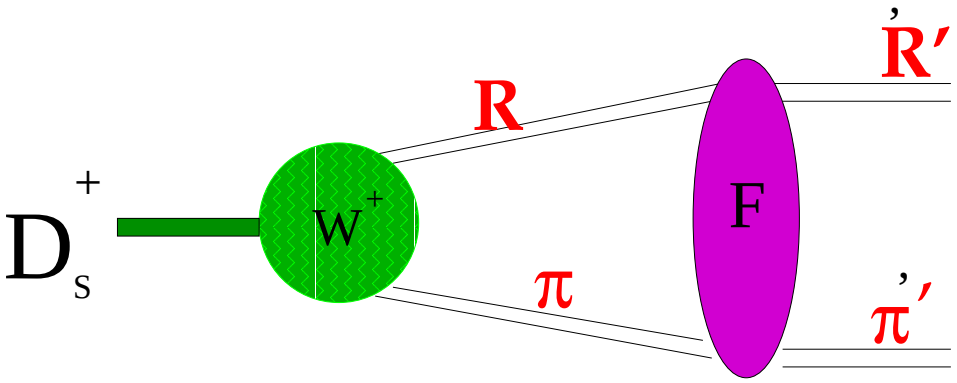
Amplitude Analysis Formalism

- **Resonant individual amplitude**

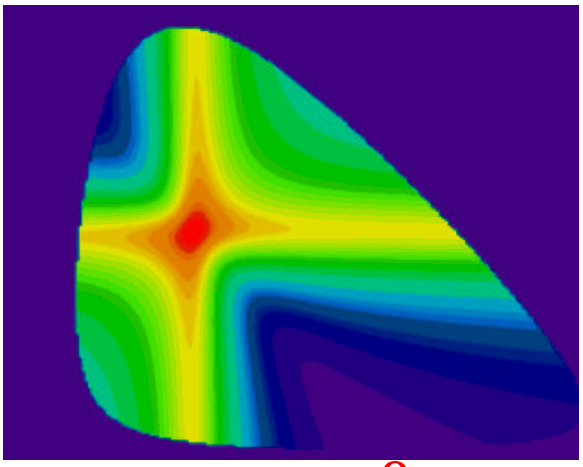
$$\mathcal{A}_i = F_D \times F_{R_i} \times BW_i \times \mathcal{M}_i^J \times e^{i\gamma_i}$$

- **Total Amplitude: coherent sum of individual amplitudes**

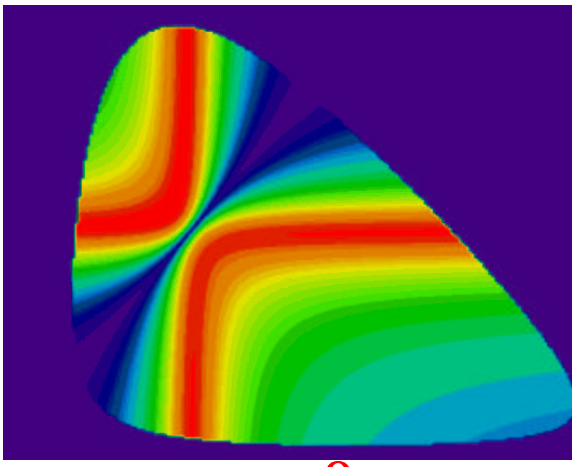
$$\mathcal{A} = a_{nr} e^{i\gamma_{nr}} + \sum_j a_j \mathcal{A}_j$$



Constant Phase γ: Final State Interaction



$\gamma = 0^0$



$\gamma = 90^0$

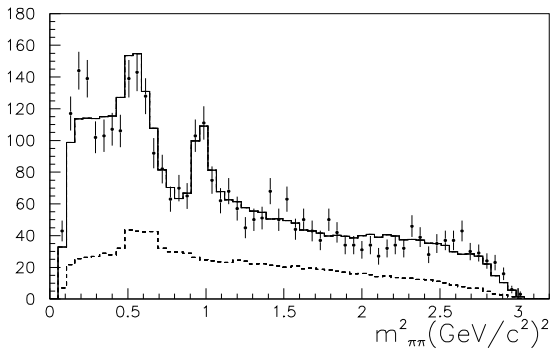
Is the $\sigma(500)$ a true resonance?

Experimental Evidence for a Light and Broad Scalar Resonance in $D^+ \to \pi^-\pi^+\pi^+$ Decay (E791 Collaboration PRL 86, 770 (2001))

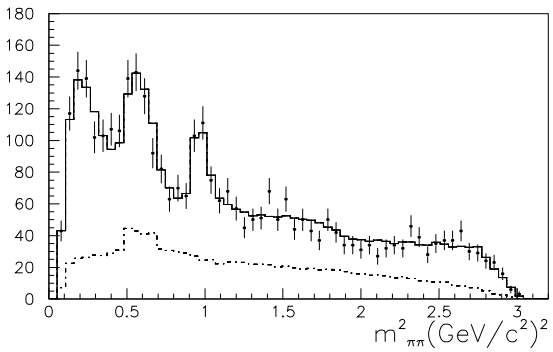
- Started fitting including all known dipion resonances.
- The result presented a bad fit quality $CL = 10^{-5}$
- New scalar amplitude, with a free mass and width

$M_\sigma = 478^{+24}_{-23} \pm 17$ MeV/c^2 $\quad$ $\Gamma_\sigma = 324^{+42}_{-40} \pm 21$ MeV/c^2

- The fit quality become good $CL = 76\%$
- Scalar $\sigma\pi^+$ is responsible for 50 % of the total decay rate
- Vector $\rho(770)\pi^+$ is responsible for 30 %



Without σ



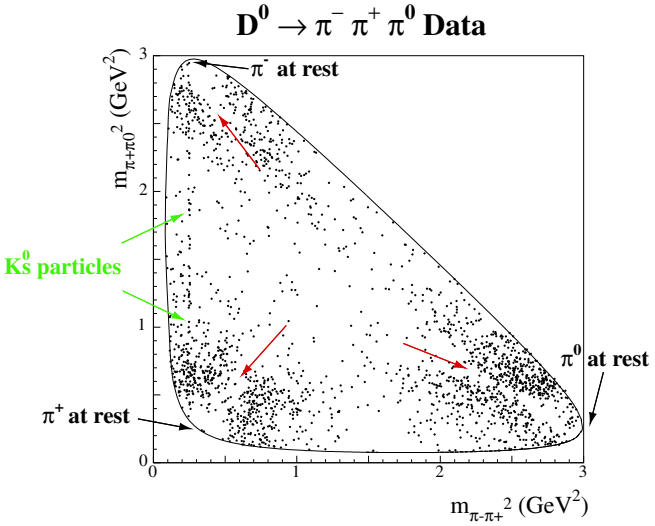
With σ

Criticism:

- *A priori* Breit-Wigner Assumption.
- Not directly "seen" in $\pi\pi$ scattering.

More $\sigma(500)$ in Charm Decay

- $D^0 \to \pi^0\pi^+\pi^-$ Decay
  - **CLEO Collaboration** (Preliminary hep-ex/0306048)



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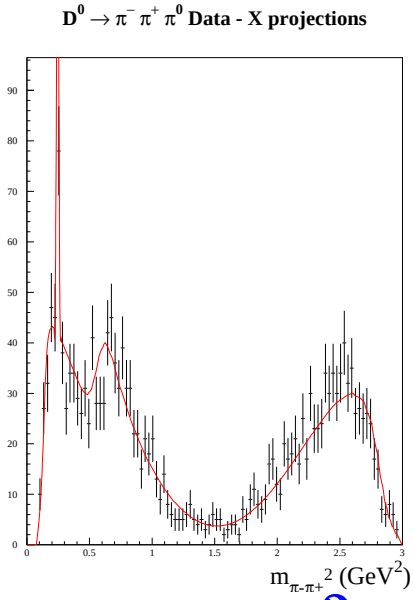


$M^2_{\pi^+\pi^-}$

Interm. state	Amplitude	Phase (^{o})	Fit Fraction (%)
$\rho^+\pi^-$	1 (fixed)	0 (fixed)	76.5±1.8±4.8
$\rho^0\pi^0$	0.56±0.02±0.07	10±3±3	23.9±1.8±4.6
$\rho^-\pi^+$	0.65±0.03±0.04	-4±3±4	32.3±2.1±2.2
Non resonant	1.03±0.17±0.31	77±8±11	2.7±0.9±1.7

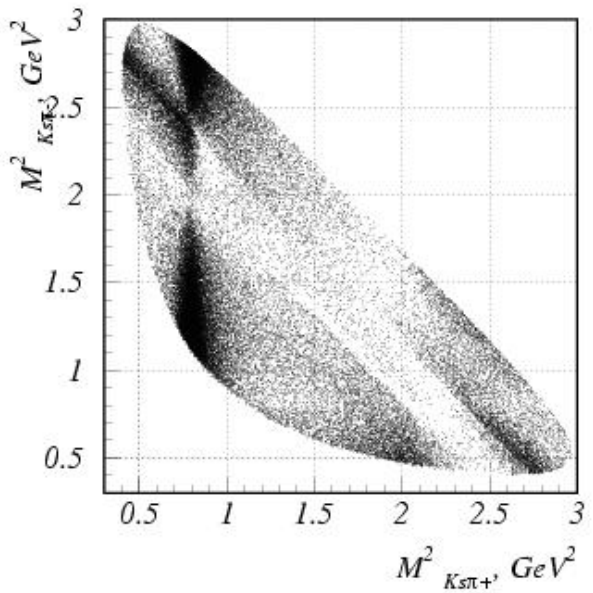
- **Vector $\rho(770)$ Dominance**
- **No scalar $\sigma(500)$ above 1%**
- **No scalar $f_0(980)$**

- $D^0 \to K^0_s \pi^+ \pi^-$ **Decay**
  - **CLEO Collaboration,** 5299± 73 Events (prl 89, 251802, 2002)

Assuming the $D^0 \to K^0_s \sigma(500)$ amplitude they found:

  - mass = 513± 32 and $\Gamma = 335 \pm 67$
  - Little but significant contribution

  - **BaBar Collaboration,** 57800 Events (hep-ex/0308043)
  - mass = 536 ± 6 and $\Gamma = 460 \pm 15$



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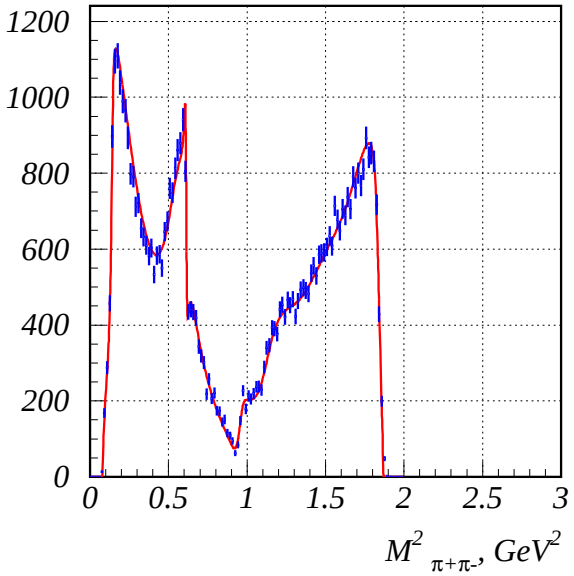


$M^2_{\pi+\pi-}$

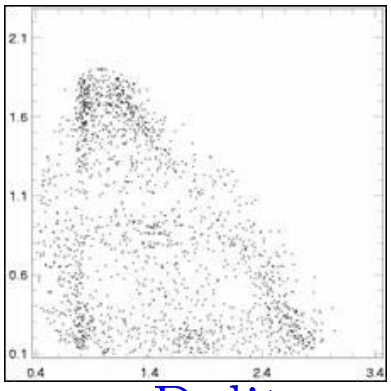
  - $D^0 \to K^0_s \sigma(500)$ **Amplitude** 1.66 ± 0.09

(18 Standard Deviations)

• $D^0 \to K^0_s \pi^0 \pi^0$ Decay

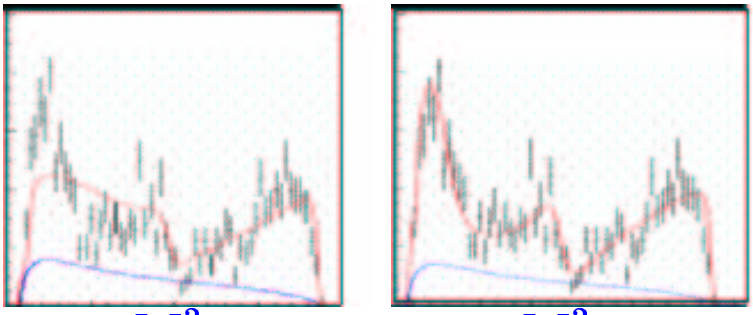
- CLEO Collaboration 770 Events (Very Preliminary)

- Good place to search low mass $\pi\pi$ spectrum.
  Since $\rho(770) \not\to \pi^0\pi^0$, there is no this contribution



Dalitz

Without $\sigma(500)$ With $\sigma(500)$



$M^2_{\pi^0\pi^0}$ $M^2_{\pi^0\pi^0}$

- **Fit seems to prefer $\sigma(500)$**

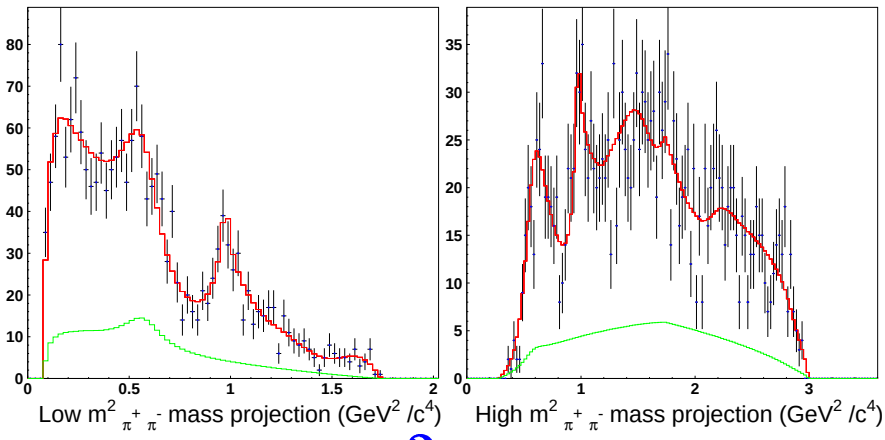
Back to $D^+ \to \pi^-\pi^+\pi^+$ with Different Approach

- **K-Matrix Formalism**
  - **FOCUS Collaboration** (Phys.Lett.B585, 200,2004)
  - Two body original formalism, extended to three body D decay, assuming a two body system isolated.

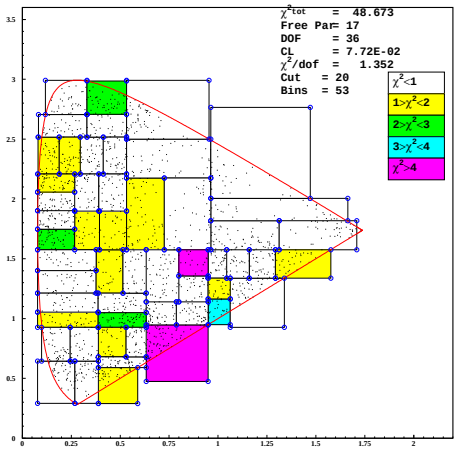
(Vector and tensor's amplitude $\Rightarrow$ usual formalism)

$$A(D \to (\pi^+\pi^-)_{00^{++}}\pi^+) = (I - iK\rho)^{-1}_{1j} \times \left\{ \sum_\alpha \frac{\beta_\alpha g_j^{(\alpha)}}{m_\alpha^2 - m^2} + f_{1j}^{\rm prod} \frac{1\,{\rm GeV}^2 - s_0^{\rm prod}}{s - s_0^{\rm prod}} \right\} \times \frac{s - s_A/2m_\pi^2}{(s - s_{A0})(1 - s_{A0})}.$$

- K Matrix parameters, extracted from $\pi\pi$ scattering without $\sigma(500)$ (Anisovich and Sarantsev, Eur. Phy. J. A16, 229, 2003)



$M^2_{\pi^+\pi^-}$



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- The fit quality is good CL = 7.7%

Phase Motion

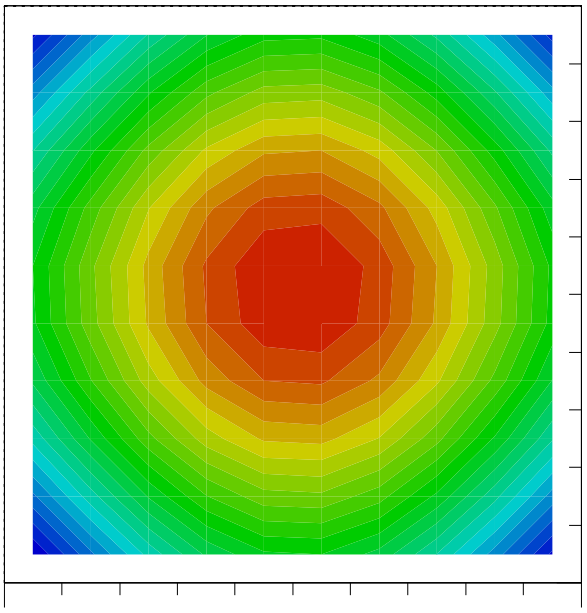
I.B and Jussara Miranda (Phys.Lett.B550, 135,2002 and hep-ex/0405019)

Measure the $\delta(s)$ phase of an under study state in s_{13} through its interference with a well established resonance in s_{12}

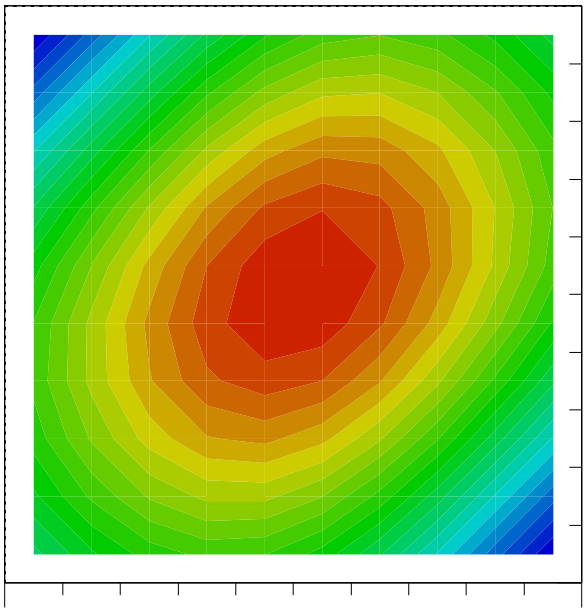
$$\mathcal{A}(s_{12}, s_{13}) = a_R \mathcal{BW}(s_{12}) + a_s/(p^*/\sqrt{s}_{13}) sin\delta(s_{13}) e^{i(\delta(s_{13})+\gamma)}$$

One-resonance crossing

with a Non-Resonance



Crossing two Resonances

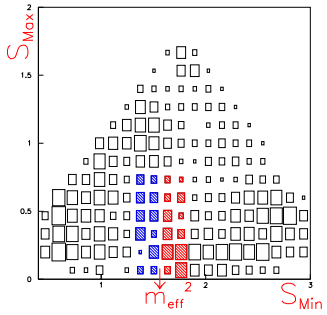


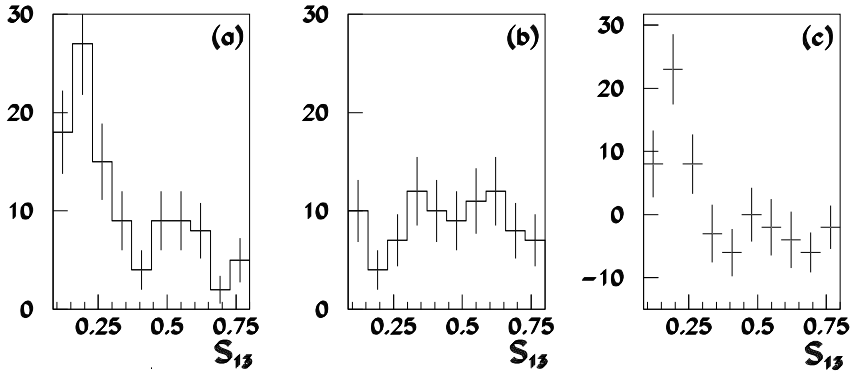
The difference of the amplitudes square

$$|\mathcal{A}(m_0^2+\epsilon, s_{13})|^2 - |\mathcal{A}(m_0^2-\epsilon, s_{13})|^2 =$$

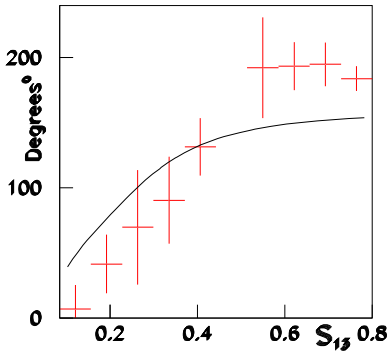
$$\frac{-4a_s a_R/(p^*/\sqrt{s}_{13})\epsilon m_0\Gamma_0}{\epsilon^2+m_0^2\Gamma_0^2}(sin(2\delta(s_{13})+\gamma)-sin\gamma)$$

- Using the same $D^+ \to \pi^-\pi^+\pi^+$ events used by the E791 data and $f_2(1270)$ resonance





After angular distribution corrections:



- Good agreement between E791 γ and in this analysis.
- Phase variation $\Delta\delta(s_{13}) \sim 180^0$, stronger than CHPT $\Delta\delta(s_{13}) \sim 100^0$
- Should $\pi\pi_{scatt} \sim \pi\pi_{decay}$?

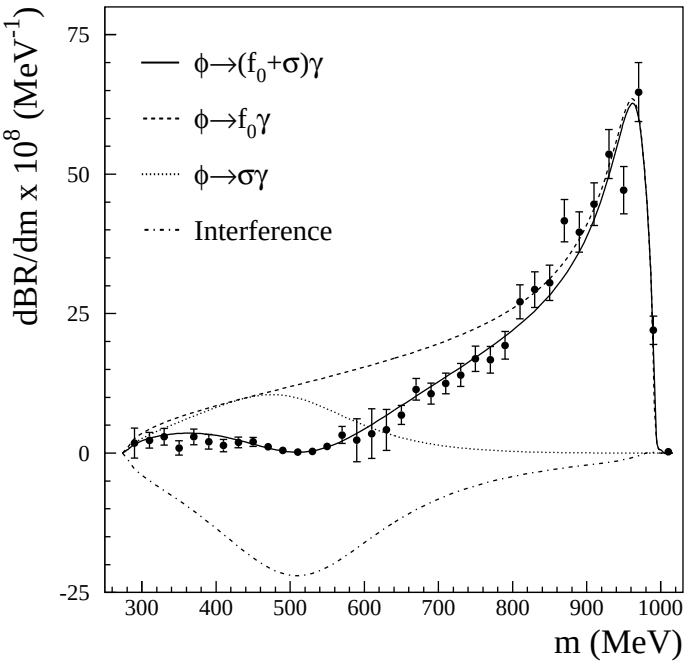
$\sigma(500)$ in non Open Charm Decays

- **Radiative $\phi \to \gamma\pi^0\pi^0$ Decay**
  - **KLOE Collaboration** (Phys.Lett.B537, 21,2002)
  - **Contributions for the $\pi^0\pi^0$ spectrum comming from $f_0(980)\gamma$, $\sigma(500)\gamma$ and $\rho(770)\pi^0$ ($\rho(770) \to \pi^0\gamma$).**

Fit the data with mass spectrum function

$f(m) = f_{S\gamma}(m) + f_{\rho\pi}(m) + f_{\rm int}(m)$

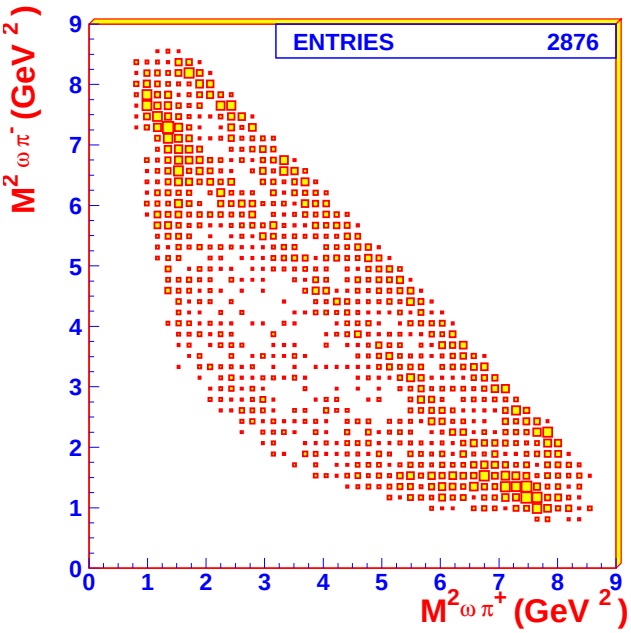
$$f_{S\gamma}(m) = \frac{2\,m^2}{\pi}\,\frac{\Gamma_{\phi S\gamma}\Gamma_{S\pi^0\pi^0}}{|D_S|^2}\,\frac{1}{\Gamma_\phi}. \qquad (1)$$



- **BR $(\phi \to \sigma\gamma \to \pi^o\pi^o\gamma) = 0.28 \pm 0.04 \quad 10^{-4}$**
- **BR $(\phi \to f_0(980)\gamma \to \pi^o\pi^o\gamma) = 1.49 \pm 0.07 \quad 10^{-4}$**

(BR $(\phi \to f_0(980)\gamma = 4.47 \pm 0.21 \quad 10^{-4})$.

- $J/\Psi \to \omega\pi^+\pi^-$ **Decay**
  - **BES Collaboration** (hep-ex/0404016)



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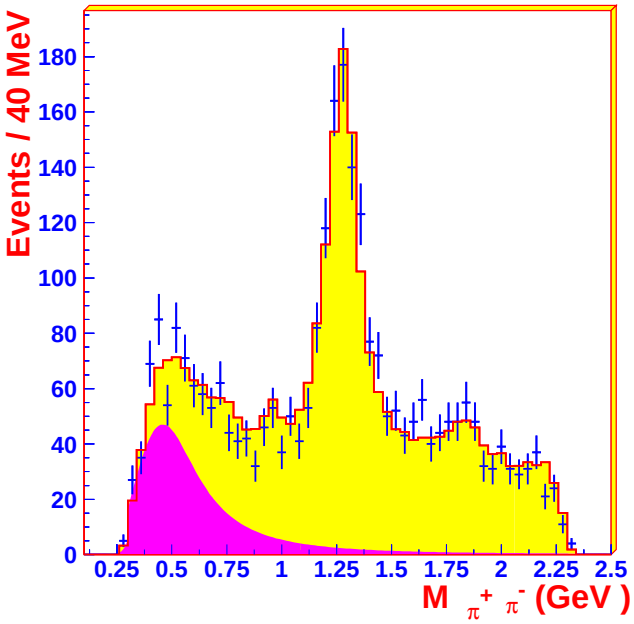


$M_{\pi^+\pi^-}$

- **Spectra similar to the MARK-III and DM2**
- **PWA analysis method**

(Ning Wu and Tu-Nan Ruan, Commun. Theor. Phys. (Beijing, China) 35 (2001))

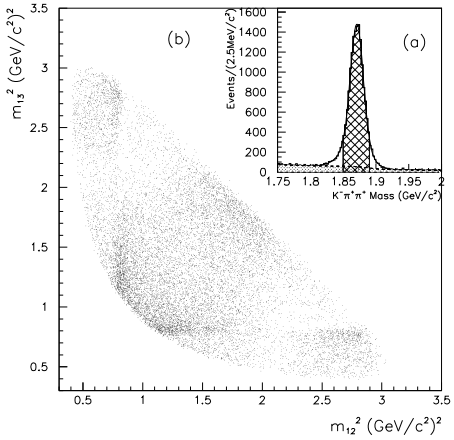
- **Used four different Breit-Wigner.**
- **With the $BW = \frac{m_0\Gamma_0}{m_0^2 - s - im_0\Gamma_0}$, Γ_0 constant.**
- **Mass and width got using scan:**

Mass $= 384 \pm 66$ and $\Gamma = 458 \pm 100$

- **Was not observed at $J/\Psi \to \phi\pi^+\pi^-$**

Does the $\kappa(800)$ exist?

Indication of a low-mass scalar $K\pi$ resonance in $D^+ \to K^-\pi^+\pi^+$ Decay (E791 Collaboration PRL 89, 121801-1 (2002))



- The same procedure used $D^+ \to \pi^-\pi^+\pi^+$
  - Parameters compatible with $\kappa(800)$

$$M_\kappa = 797 \pm 19 \pm 43 \ \ MeV/c^2$$
$$\Gamma_\sigma = 410 \pm 43 \pm 87 \ \ MeV/c^2$$

- **The fit quality become good and the scalar $\kappa(800)\pi^+$ amplitude is responsible for 50 % of the total decay rate**

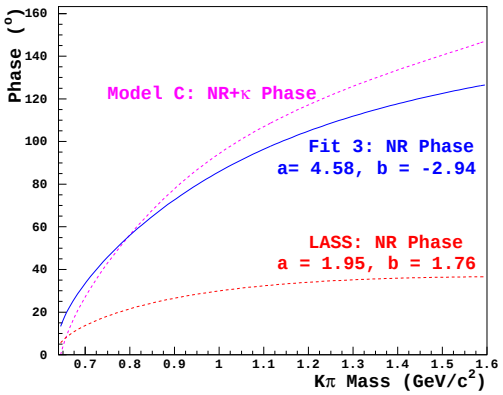
Further Studies

(Carla Göbel hep-ex/0307003)

Fit of the Kπ Phase Variation $D^+ \to K^-\pi^+\pi^+$ Versus $K\pi$ elastic scattering

$$\cot\delta_{NR} = \frac{1}{a\,p^*} + \frac{1}{2}b\,p^*$$

LASS Collaboration N.P. B296, 493 (1988)



- **Strongest in $D^+ \to K^-\pi^+\pi^+$ than $K\pi$ elastic scattering**

- **Should $K\pi_{scatt} \sim K\pi_{decay}$?**

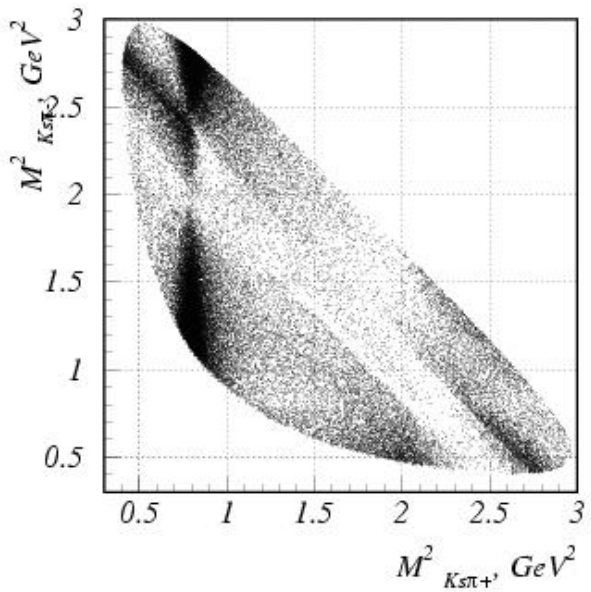
More $\kappa(800)$ in Charm Decay

$D^0 \to K^0_s \pi^+ \pi^-$ Decay

- **CLEO Collaboration, 5299± 73 Events**
  (prl 89, 251802, 2002)

No $\kappa(800)$ Contribution

- **BaBar Collaboration, 57800 Events** **(hep-ex/0308043)**



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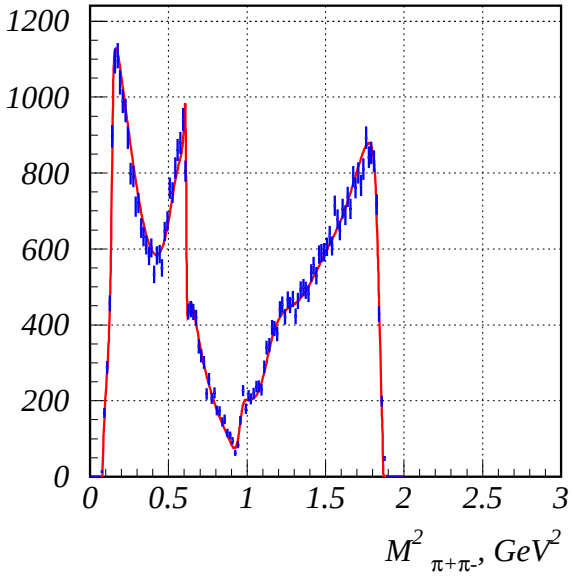
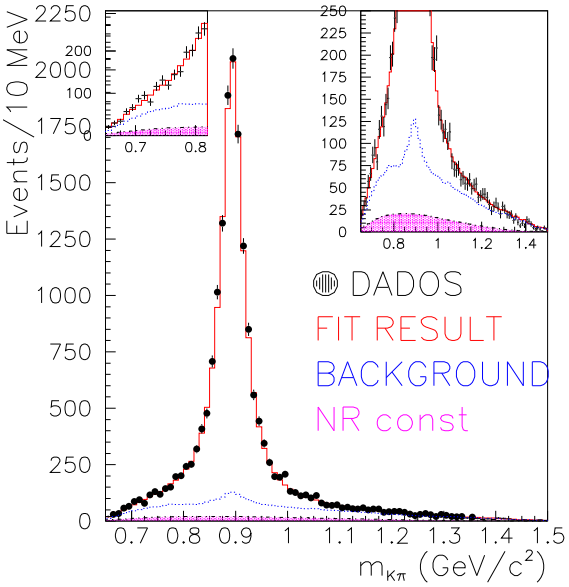


$M^2_{\pi^+\pi^-}$

No $\kappa(800)$ Contribution

Semi-Leptonic $D^+ \to K^-\pi^+\mu^+\nu$ Decay



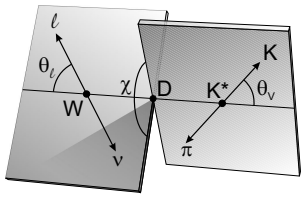
- $K\pi$ Mass Spectrum Fit

FOCUS Collaboration, Massafferri PhD Thesis CBPF 2004

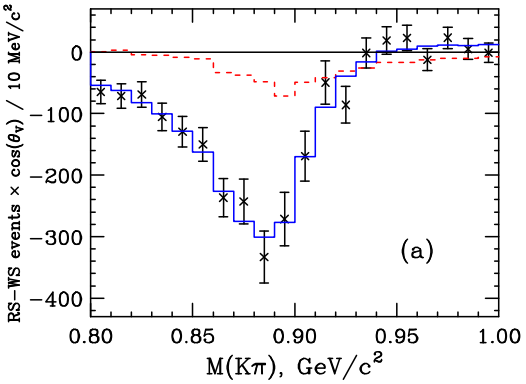
- **13455 ± 119** events
- Scalar contribution ~ **8%**
- Non-Resonant or $\kappa(800)$????

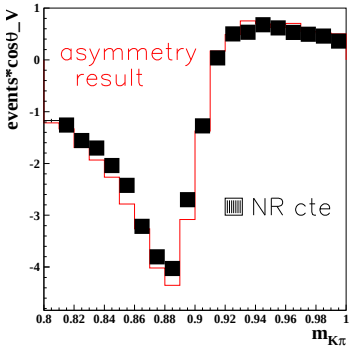
Angular Distribution Analysis

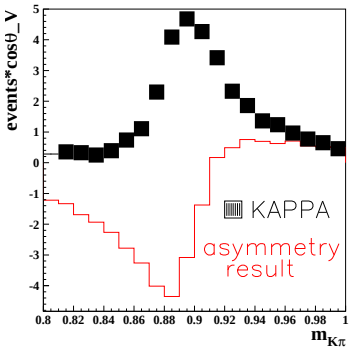
FOCUS Collaboration Phys. Lett. B535, 43,2002



- $K\pi$ mass distribution weighted by COS(Θ_V)







No $\kappa(800)$ Contribution

$f_0(980)$ and $a_0(980)$: the g_K/g_π Problem

Very well-established resonances

$f_0(980)$ mass $= 980 \pm 10$MeV and $a_0(980)$ mass $= 984.7 \pm 1.2$MeV

Bad width determination, (the $f_0(980)$ 20 to 200 MeV)

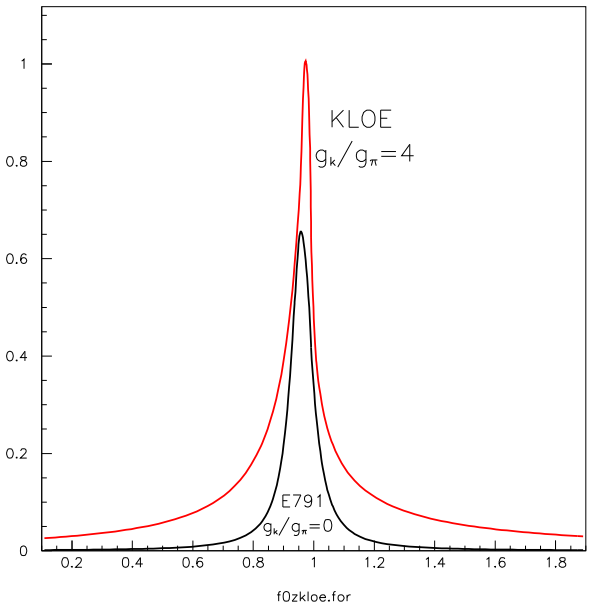
Comming from the possible decay

$$f_0(980)/a_0(980) \to KK$$

Flatté parametrization:

$$\mathcal{BW} = \frac{\Gamma m_0}{m^2 - m_0^2 + i m_0(\Gamma_\pi(m) + \Gamma_K(m))}$$

$$\Gamma_\pi(m) = g_\pi \sqrt{m_{\pi\pi}^2/4 - m_\pi^2} \qquad \Gamma_K(m) = g_K \sqrt{m_{\pi\pi}^2/4 - m_K^2}$$



$\pi\pi$ Invariant Mass

Allow to get the Γ_K through the dominant decays

$f_0(980) \to \pi\pi$ and $a_0(980) \to \eta\pi$

Three Recent g_K/g_π Results for the $f_0(980)$

About 50% of total rate

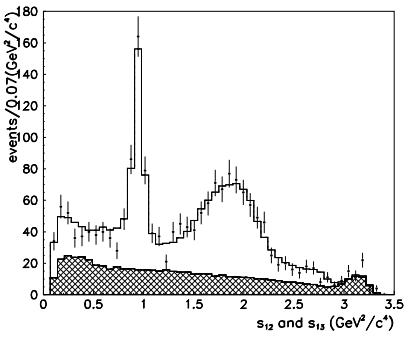
of $D_s^+ \to \pi^-\pi^+\pi^+$ decay

comming from the $f_0(980) \to \pi^+\pi^-$

$g_\pi = 0.09 \pm 0.01 \pm 0.01$

$g_K = 0.02 \pm 0.04 \pm 0.03$

E791 Collaboration Phy.Rev.Lett 86, 765 (2001)



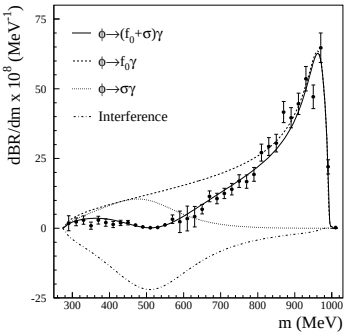
About 80 % of the total rate

$\phi \to \gamma\pi^0\pi^0$ decay

$g_\pi = 0.7 \pm 0.01$

$g_K = 2.79 \pm 0.12$

KLOE Collaboration (Phys.Lett.B537, 21,2002)



Couple Channel Analysis

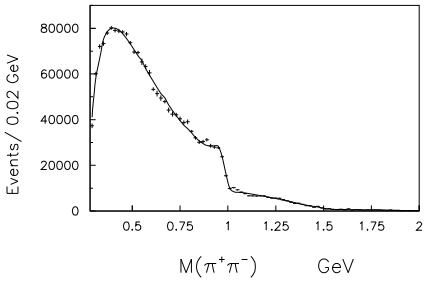
$pp \to p\pi\pi p$ interaction

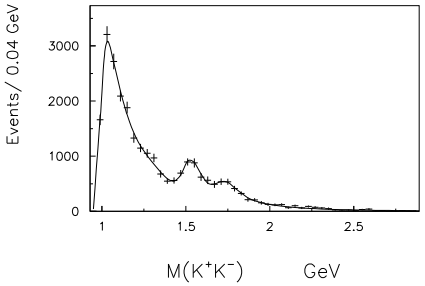
$pp \to pKKp$ interaction

$g_\pi = 0.24 \pm 0.04 \pm 0.05$

$g_K = 0.39 \pm 0.04 \pm 0.04$

Wa102 Collaboration (Phys.Lett.B462, 462,1999)





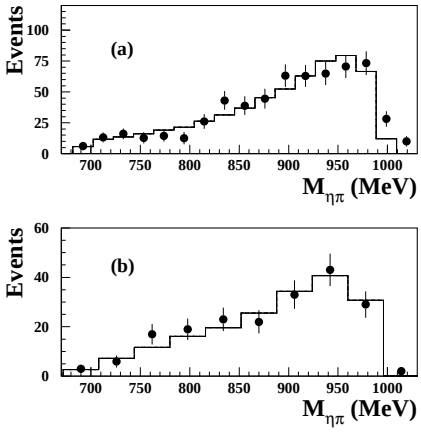
Three Recent $g_K/g_{\eta\pi}$ Results for the $a_0(980)$

$\phi \to \gamma\eta\pi^0$ decay

$g_{\eta\pi} = 0.54 \pm 0.05$

$g_K = 0.4 \pm 0.04$

KLOE Collaboration (Phys.Lett.B536,209, 2002)

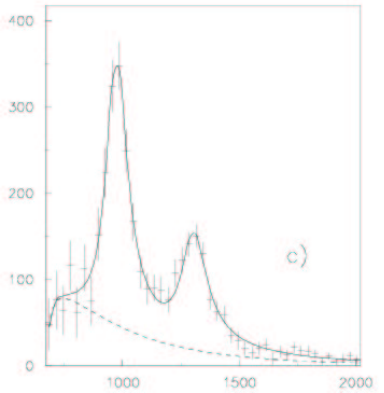


$pp \to p\eta\pi p$ interaction

$\Gamma(a_0(980) \to KK)/\Gamma(a_0(980) \to \eta\pi) =$

$0.166 \pm 0.01 \pm 0.008$

WA102 Collaboration (Phys.Lett.B488,225,2000



Mass $\eta\pi^0$

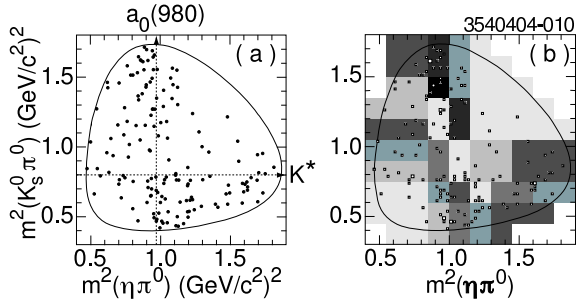
Dominant contribution of

$D^0 \to K^0_s\eta\pi^0$ decay

comming from $a_0(980) \to \eta\pi^0$

$g_K/g_{\eta\pi^0} = 0.76 \pm 0.3$

CLEO Collaboration hep-ex/0405011



Scalar Vs Vector Mesons in Charm Decay

$D \to P_1 P_2 P_3$ Can Produce $\to$

- Non-Ressonant 3 body
- Vector + Pseudoscalar
- Scalar + Pseudoscalar
- Tensor + Pseudoscalar

Proportion between Scalar and Vector S/V

$D \to P_1 P_2 P_3$ Channel	S/V
$D^0 \to K^0 \pi^+ \pi^-$	< 0.1
$D^0 \to K^- \pi^+ \pi^0$	< 0.1
$D^0 \to \pi^- \pi^+ \pi^0$	< 0.1
$D^+ \to K^0 \pi^+ \pi^0$	< 0.1
$D^+ \to K^- \pi^+ \pi^+$	> 5.0
$D^+ \to \pi^- \pi^+ \pi^+$	> 2.0
$D^+ \to K^- K^+ \pi^+$	< 0.1
$D_s^+ \to K^- K^+ \pi^+$	< 0.1
$D_s^+ \to \pi^- \pi^+ \pi^+$	> 5.0
$D_s^+ \to K^- K^+ \pi^+$	< 0.1

Scalar Dominance for Identical Particles Decays!!!

Kind of Bose-Einstein Correlation?

Vector Suppression ?

Remarks

- Is the $\sigma(500)$ a true resonance?

  Yes, however we have to find a good way to represent a broad resonance, close to thereshold

- Does the $\kappa(800)$ exist?

  We still have only strong evidences in $D^+ \to K^-\pi^+\pi^+$ decay. We are waiting for new evidences presented by BES Collaboration, for the decay $J\Psi \to K^*(890)K^+\pi^-$

- $f_0(980)$ and $a_0(980)$: the $g_K/g_{\pi(\eta\pi)}$ Problem

  Seems that we are arriving to a consensus results for the $g_K/g_{\eta\pi}$ for $a_0(980)$ decay. However the g_K/g_π from $f_0(980)$ decay is far from being understood with the recent results

- Light Scalar Vs Vector Mesons in Charm Decay

  Decays with identical particles, seems a good place to study the light scalar mesons