Interference in $K_S^0 K_S^0$ spectrum

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Selection: reminder

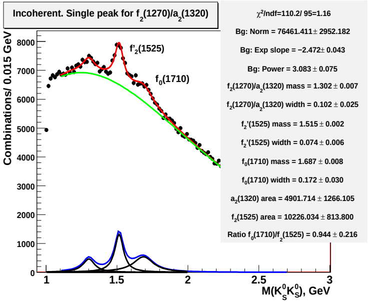
- **Data**: HERA II (04-07) inclusive
- No explicit trigger
- V0lite finder

- **Tracks**
  - Not primary
  - $p_T > 100$ MeV
  - $\geq 3SL$, start from 1st

- K_S^0
  - $\theta_{2D} < 0.12$ rad
  - $\theta_{3D} < 0.24$ rad
  - $m(p\pi) < 1.21$ GeV
  - $m(ee) > 0.05$ GeV
  - $p_T > 0.3$ GeV
  - $|\eta| < 1.75$ GeV

Model description

- Main assumption: only $f_2(1270)$, $a_2(1320)$, $f_2(1525)$, $f_0(1710)$ contribute
- Other possible: $f_0(1370)$, $a_0(1450)$, $f_0(1500)$, ... (e.g. $f_0(1500)$ was observed in $K\overline{K}$, see Ref.[2])
- Also $f_0(980)$, $a_0(980)$. Have **large** coupling to $K\overline{K}$ (e.g. Ref. [2], backup)
- Simplest background model, $Bg(m) = m^{p_0} e^{-p_1 m}$
- M, Γ of resonances are free unless otherwise stated



Check various assumptions

- Single peak for $f_2(1270)/a_2(1320)$
- Incoherent addition of $f_2(1270)$, $a_2(1320)$ and others
- Relative amplitudes and phases fixed to $\gamma\gamma$ (+5/-3/+2)
- Determine relative amplitudes and phases from the fit (maximum coherence, $\beta_{12} = \beta_{13} = \beta_{23} = 1$, see next 2 slides for definition)
- Coherence factors (β_{12}, β_{13}, β_{23}) free
- $f_2(1525)$ does not interfere ($\beta_{13} = \beta_{23} = 0$)
- $a_2(1320)$ does not interfere ($\beta_{12} = \beta_{23} = 0$)

Reminder

Interfering Breit-Wigners

- $BW_k(m) = \frac{M_k\sqrt{\Gamma_k}}{M_k^2 - m^2 - iM_k\Gamma_k} = Re_k + iIm_k$
  - M_k, Γ_k – mass and width of resonance k
  - $Re_k = \frac{M_k\sqrt{\Gamma_k}(M_k^2 - m^2)}{(M_k^2 - m^2)^2 + M_k^2\Gamma_k^2}$, $Im_k = \frac{M_k\sqrt{\Gamma_k}M_k\Gamma_k}{(M_k^2 - m^2)^2 + M_k^2\Gamma_k^2}$
  - $|BW_k|^2 = Re_k^2 + Im_k^2 = \frac{M_k^2\Gamma_k}{(m^2 - M_k^2)^2 + m_k^2\Gamma_k^2}$
- Now consider n interfering resonances, i.e. $f(m) = |\sum_{i=1}^{n} \alpha_k e^{i\delta_k} BW_k(m)|^2$
- One of the phases can be ruled out

Reminder

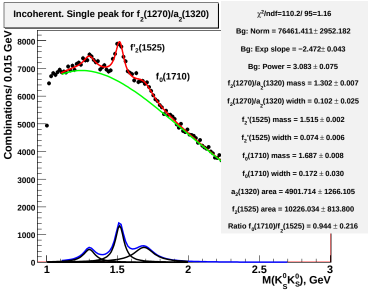
Interfering Breit-Wigners

- After some algebra:
- $f(m) = A + B$, where
- $A = \sum_{i=1}^{n} \alpha_k^2 |BW_k|^2$ – incoherent term
- $B = \sum_{k \neq l} \alpha_k \alpha_l [\cos(\delta_k - \delta_l)(Re_k Re_l + Im_k Im_l) + 2\sin(\delta_k - \delta_l) Re_k Im_l]$ – interference term
- For general treatment, introduce 'coherence factors' $\beta_{kl} \in [0, 1]$, i.e. (see e.g. [3])
  - $B = \sum_{k \neq l} \beta_{kl} \alpha_k \alpha_l [\cos(\delta_k - \delta_l)(Re_k Re_l + Im_k Im_l) + 2\sin(\delta_k - \delta_l) Re_k Im_l]$
  - $\beta_{kl} = 0$ means incoherent addition of resonances k and l
  - $\beta_{kl} = 1$ means maximum coherence

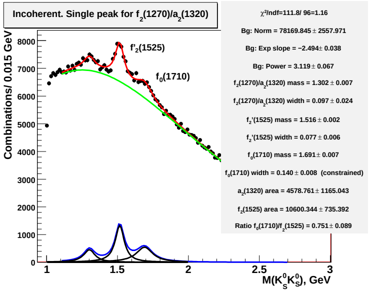
Fit-I

Incoherent addition of Breit-Wigners. Single peak for $f_2(1270)/a_2(1320)$

- Was used e.g. in [1], [2] (see backup)



$\Gamma_{f_0(1710)}$ free



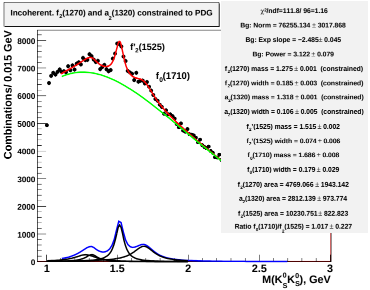
$\Gamma_{f_0(1710)}$ constrained to PDG

- Generally nice description. Dip not perfect.

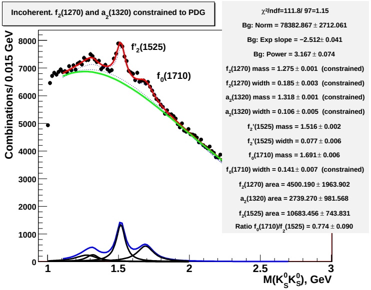
Fit-IIa

Incoherent addition of Breit-Wigners. Separate peaks for $f_2(1270)$ and $a_2(1320)$

- Masses and widths of $f_2(1270)$ and $a_2(1320)$ constrained to PDG



$\Gamma_{f_0(1710)}$ free



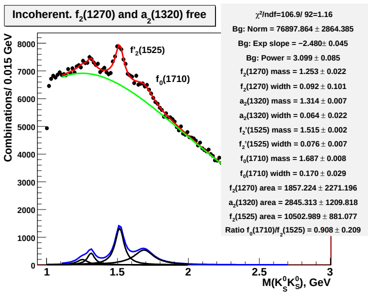
$\Gamma_{f_0(1710)}$ constrained to PDG

- χ^2 is not improved

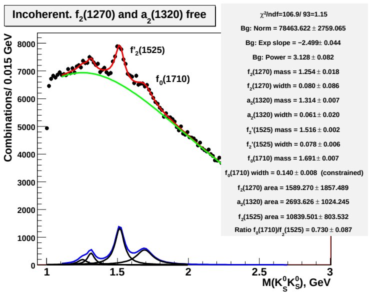
Fit-IIb

Incoherent addition of Breit-Wigners. Separate peaks for $f_2(1270)$ and $a_2(1320)$

- Masses and widths of $f_2(1270)$ and $a_2(1320)$ FREE



$\Gamma_{f_0(1710)}$ free



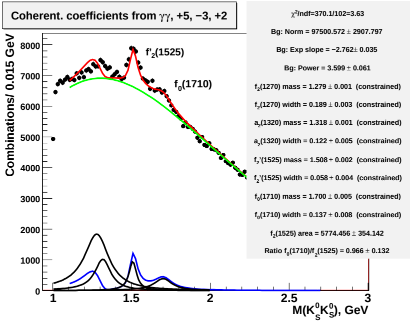
$\Gamma_{f_0(1710)}$ constrained to PDG

- χ^2 is improved a bit
- Resonance parameters reasonable ($\Gamma_{f_2(1270)}$ lower)

Fit-IIIa

Coefficients from $\gamma\gamma$

- $f(m) = |5BW(1270) - 3BW(1320) + 2BW(1525)|^2$



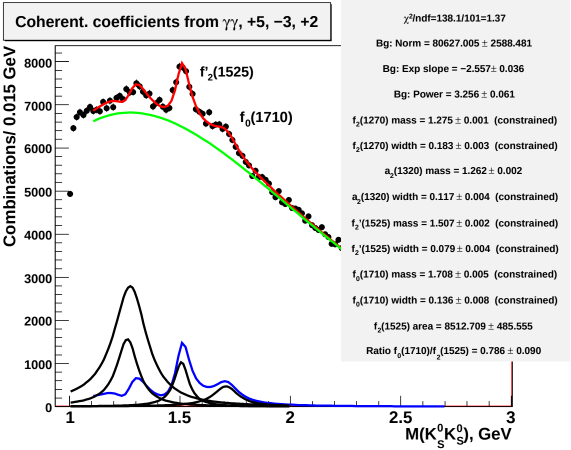
m, Γ of $f_2(1270)$ and $a_2(1320)$ constrained to PDG

- Peak position for $f_2(1270)/a_2(1320)$ is shifted to ~ 1250 MeV
- This is observed in $\gamma\gamma$ [2] but **contradicts with our data** (~ 1305 MeV)

Fit-IIIb

Coefficients from $\gamma\gamma$

- Mass of $a_2(1320)$ FREE

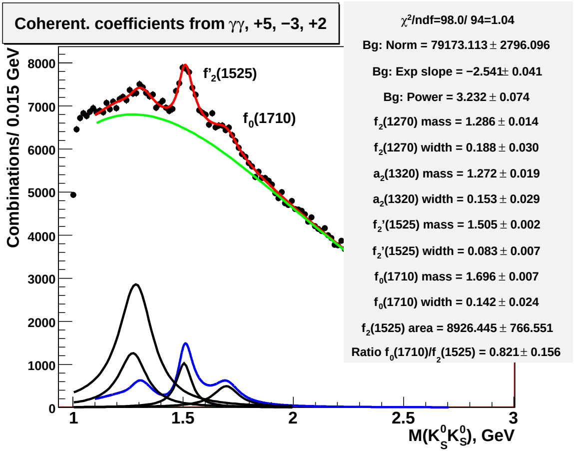


- Roughly similar to ZEUS paper (DESY 08-068): $a_2(1320)$ has lower mass and produces another peak

Fit-IIIc

Coefficients from $\gamma\gamma$

- ALL masses and widths free



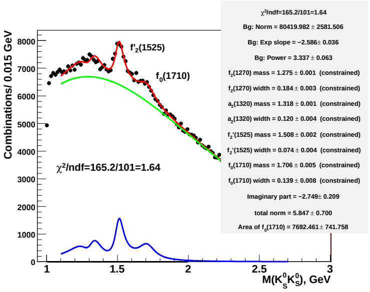
- Reasonable fit can be obtained, good χ^2, dip
- However m and Γ of $a_2(1320)$ still disagree with PDG

Adding 'incoherent part'

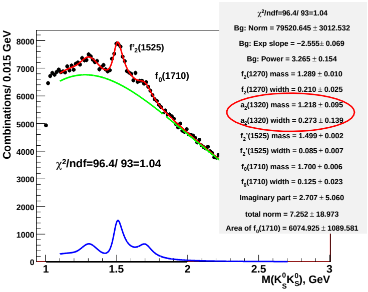
- generalize previous function by adding 'incoherent term', same for all 2^{++} (following from SU(3) symmetry) (H. Lipkin)
- $f(m) = |(5+x)\cdot BW(1270)+(-3+x)\cdot BW(1320)+(2+x)\cdot BW(1525)|^2$
- x is complex, should be corrected for phase space

Adding 'incoherent part'

- Unfortunately does not help much



ALL masses, widths constrained



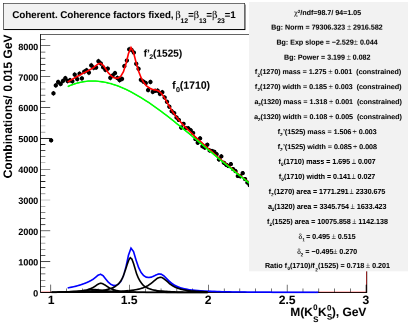
ALL masses, widths free

- m, Γ constrained: bad description
- m, Γ free: $a_2(1320)$ far from PDG

Fit-IV

Coherent sum of 2^{++} Breit-Wigners. Separate peaks for $f_2(1270)$ and $a_2(1320)$

- Full coherence assumed
- M, Γ of $f_2(1270)$ and $a_2(1320)$ constrained to PDG
- Relative amplitudes (areas) and phases (δ_1, δ_2) are determined



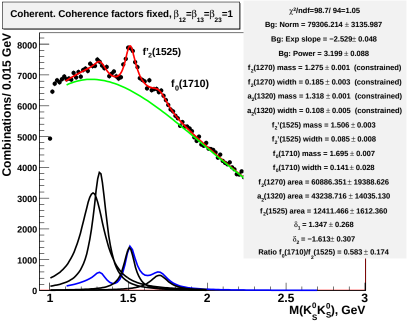
$\Gamma_{f_0(1710)}$ free

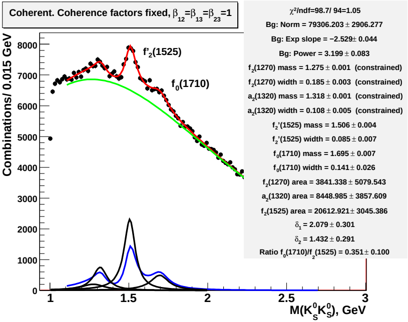
- Good χ^2, dip

Ambiguity

Coherent addition of 2^{++} Breit-Wigners. Separate peaks for $f_2(1270)$ and $a_2(1320)$

- However fit is ambiguous



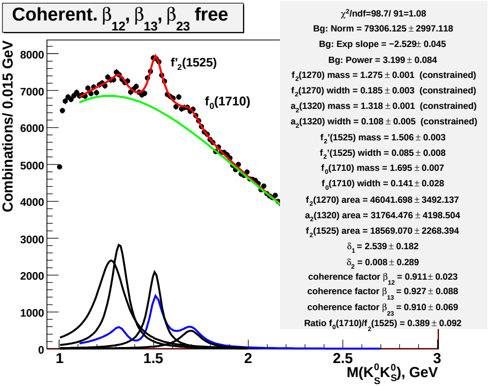


- χ^2 is the same
  - Ambiguity in $f_2(1525)$ area is due to the possibility of large negative interference of it with $f_2(1270)$ and/or $a_2(1320)$
- Prior knowledge of relative amplitudes and phases could help

Fit-V

Coherent addition of 2^{++} Breit-Wigners. Separate peaks for $f_2(1270)$ and $a_2(1320)$

- Coherence factors free

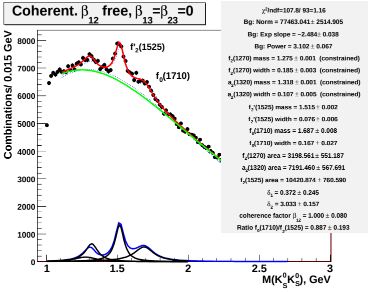


- χ^2 remains the same
- rather large coherence prefered from the fit
- Obviously (even more) ambiguous

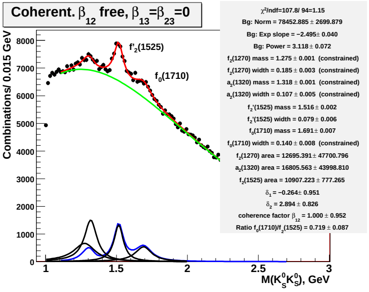
Fit-VI

Only $f_2(1270)$ and $a_2(1320)$ interfere

- Was used in (very) old analyses



$\Gamma_{f_0(1710)}$ free



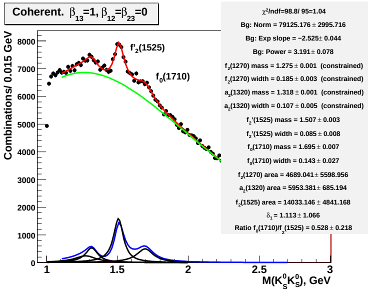
$\Gamma_{f_0(1710)}$ constrained to PDG

- χ^2 slightly worse, interference of isoscalar mesons is expected,
- maybe this scenario can be ruled out

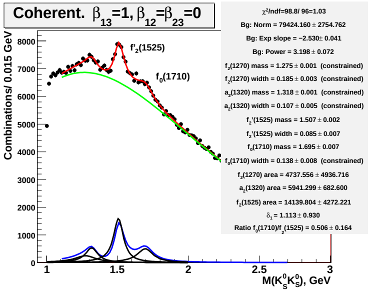
Fit-VII

Only $f_2(1270)$ and $f_2(1525)$ interfere. $a_2(1320)$ added incoherently

- One can argue that *isovector* $a_2(1320)$ might not interfere with *isoscalars* $f_2(1270)$ and $f_2(1525)$ in inclusive reactions (?)



$\Gamma_{f_0(1710)}$ free



$\Gamma_{f_0(1710)}$ constrained to PDG

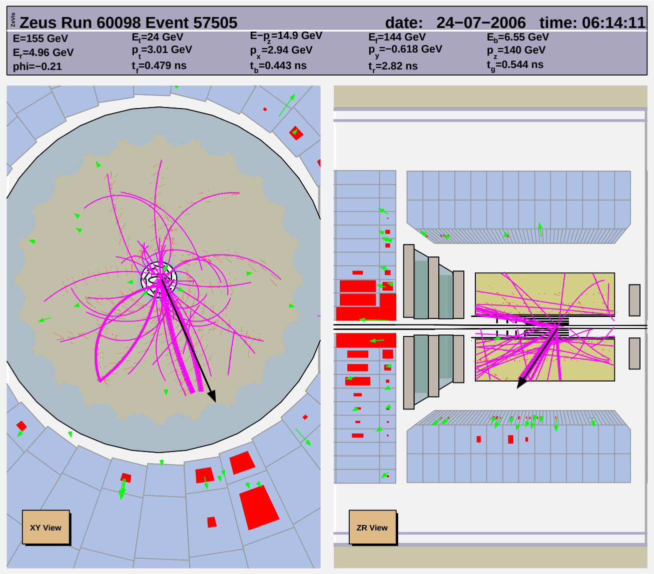
- χ^2 ok, fit more stable.
- *Enough freedom to describe spectrum*
- More complicated parametrisation (e.g. Fit-IV) introduce ambiguity.

Results summary

Fit	Comments	χ^2 / n.d.o.f.	Ratio $\frac{f_0(1710)}{f_2(1525)}$	χ^2 / n.d.o.f.	Ratio $\frac{f_0(1710)}{f_2(1525)}$
		$\Gamma_{f_0(1710)}$ free		$\Gamma_{f_0(1710)}$ constrained	
I	incoh., 1 peak	110.2/95=1.16	0.94 ± 0.22	111.8/96=1.16	0.75 ± 0.09
IIa	incoh., sep. peak	111.8/96=1.16	1.02 ± 0.2	111.8/97=1.15	0.77 ± 0.09
IIb	IIa+M,Γ free	106.9/92=1.16	1.02 ± 0.2	106.9/93=1.15	0.73 ± 0.09
IIIa	2^{++} constrained			370.1/102=3.63	0.97 ± 0.13
IIIb	$m^{a_2(1320)}$ free			138.1/101=1.37	0.79 ± 0.09
IIIc	2^{++} free	98.0/94=1.04	0.82 ± 0.16		
IV	$\delta_1 = 0.5 \pm 0.5$, $\delta_2 = -0.5 \pm 0.3$	98.7/94=1.05	0.72 ± 0.2		
	$\delta_1 = 2.1 \pm 0.3$, $\delta_2 = 1.4 \pm 0.3$	98.7/94=1.05	0.35 ± 0.1		
VI		107.8/93=1.16	0.89 ± 0.2	107.8/93=1.16	0.72 ± 0.09
VII		98.8/95=1.04	0.53 ± 0.2	98.8/96=1.03	0.51 ± 0.16

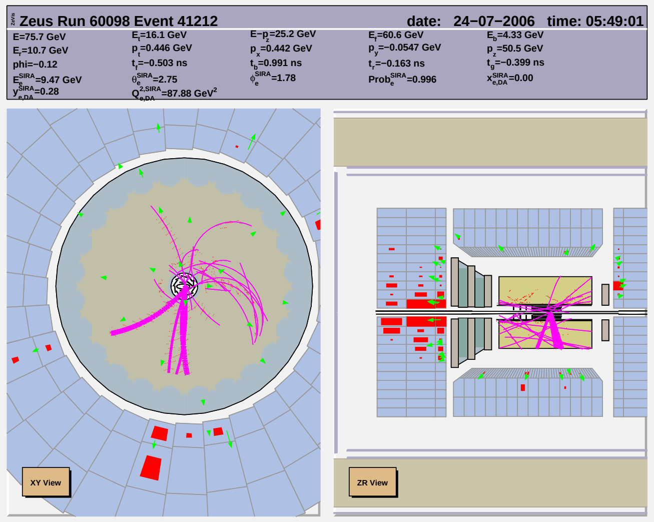
How our events look like?

- An event with jet



How our events look like?

- Clean DIS event



Conclusions

- Fits with interference under various assumptions were tried
- +5, -3, +2
  - m, Γ of $f_2(1270)$, $a_2(1320)$ constrained to PDG - fit unresonable
  - m, Γ of $f_2(1270)$, $a_2(1320)$ free - fit reasonable but $a_2(1320)$ parameters far from PDG
- incoherent addition of isovector $a_2(1320)$ - reasonable and stable fit
- introducing more parameters leads to ambiguity
- Other possibilities
  - measure ratio of $f_0(1710)$ to observable contribution of 2^{++} mesons which is stable ?

To do

- choose fit assumption
- fit in bins of z variable (redefine? jets?)

References

- [1] "$K_S^0 K_S^0$ final state **in two-photon collisions** and implications for glueballs", L3 Coll., Phys. Lett. B 501 (2001) 173-182

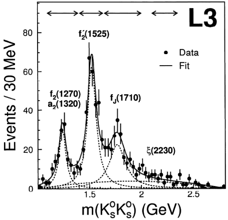
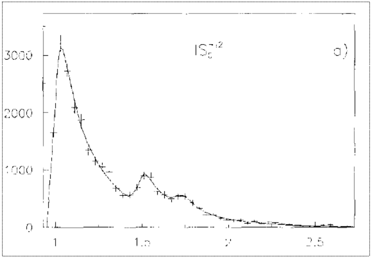


Table 1
The parameters of the three Breit–Wigner functions and the parabolic background from the fit on the $K_S^0K_S^0$ mass spectrum

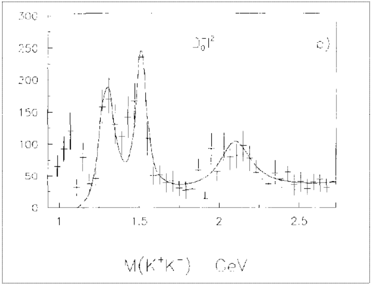
Mass region	$f_2(1270)$–$a_2(1320)$	$f_2'(1525)$	$f_J(1710)$	Background
Mass (MeV)	1239 ± 6	1523 ± 6	1767 ± 14	–
Width (MeV)	78 ± 19	100 ± 15	187 ± 60	–
Integral (Events)	123 ± 22	331 ± 37	221 ± 55	149 ± 21

References

- [2] “A partial wave analysis of the centrally produced K^+K^- and $K^0_S K^0_S$ systems **in pp interactions**... ”, WA102 Coll., Phys. Lett. B 453 (1999) 305-315



$f_0(980)$	$M = 985$	$\pm$	10 MeV,	$\Gamma = 65$	$\pm$	20 MeV
$f_0(1500)$	$M = 1497$	$\pm$	10 MeV,	$\Gamma = 104$	$\pm$	25 MeV
$f_0(1710)$	$M = 1730$	$\pm$	15 MeV,	$\Gamma = 100$	$\pm$	25 MeV



$f_2(1270)/a_2(1320)$	$M = 1305$	$\pm$	20 MeV,	$\Gamma = 132$	$\pm$	25 MeV
$f_2'(1525)$	$M = 1515$	$\pm$	15 MeV,	$\Gamma = 70$	$\pm$	25 MeV
$f_2(2150)$	$M = 2130$	$\pm$	35 MeV,	$\Gamma = 270$	$\pm$	50 MeV

References

- [3] "$f^0 - A_2^0$ Interference and the $f^0 \to K\overline{K}$ Branching Ratio", N.N. Biswas *et.al*, Phys. Rev. D5 (1972) 1564-1569
- [4] "$K\overline{K}$ system in $\pi^- p \to K^- K^+ n$ at 6 GeV/c ", A.J. Pawlicki *et.al*, Phys. Rev. D12 (1975) 631-637"

In these works interference of $f_2(1270)$ and $a_2(1320)$ only is considered. The relative amplitudes, relative phase and coherence factors are determined from the fit.