Preliminary results of KL fit to the Dalitz-plot of $\pi^0\pi^0\gamma$ final state

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Situation of the $\pi^0\pi^0\gamma$ final state:

- **status of KLOE memos**
- **preliminary results for KL on the Dalitz-plot**

KLOE PHIDEC meeting
LNF 16-Feb-2006

Kloe memo on $\pi^0\pi^0\gamma$ visible cross-section vs sqrt(s)

- We have x-checked the fits vs sqrt(s) to determine the absolute shift of the energy scale. A mistake found! The data table called "no-shift" **was indeed shifted of 150 keV**

- All tables and fit redone.

- No major changes on the results just rounding of numbers!

- However final conclusion changed: **we have to shift the energy scale of 150 keV to get the right Mϕ**

- New version of KLOE Memo done and re-submitted to referees. We are waiting for comments before changing it on KLOE doc-page

Improved KL parametrization for the $\pi^0\pi^0\gamma$

N.N.Achasov, private communication
NOW PUBLISHED HEP-PH 0512047

- Insertion of a KK phase:

$$\tan \delta_B^{K\bar{K}} = \sqrt{m^2 - 4m_{K+}^2}\, f_K(m^2) = \frac{\sqrt{m^2 - 4m_{K+}^2}}{\Lambda_K} \mathrm{atan} \frac{m_2^2 - m^2}{m_0^2}$$

Beyond to its contribution in the interference term,
IT CHANGES THE SCALAR TERM AMPLITUDE
IN THE $M_{\pi\pi} < 2M_{K^+}$ REGION

$$M_{sig} = \sqrt{\frac{1 - f_K(m^2)\sqrt{4m_{K+}^2 - m^2}}{1 + f_K(m^2)\sqrt{4m_{K+}^2 - m^2}}}\, g(m) e^{i\delta_B^{\pi\pi}} \left((\phi\epsilon) - \frac{(\phi q)(\epsilon p)}{(pq)} \right) \sum_{R,R'} g_{RK^+K^-} G_{RR'}^{-1} g_{R'\pi^0\pi^0}$$

- New parametrization of the ππ phase:

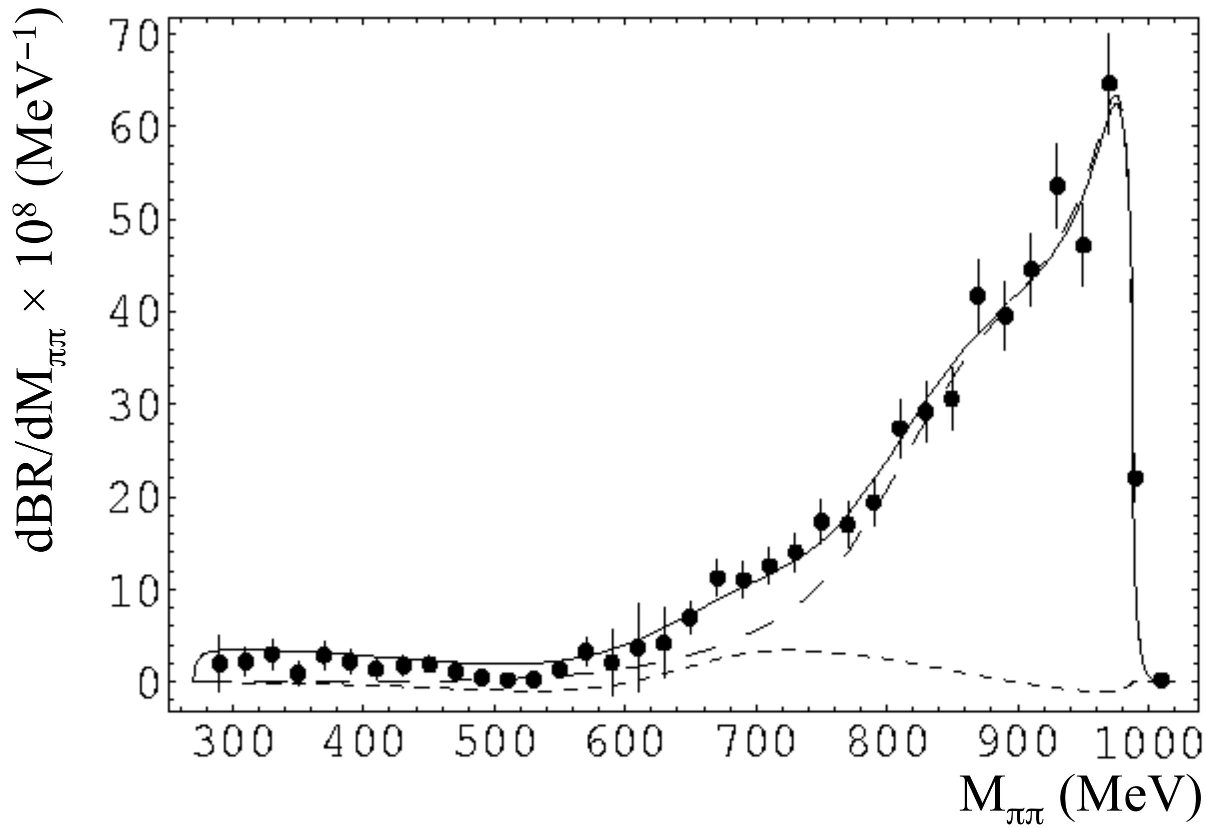
$$\tan(\delta_B^{\pi\pi}) = -\frac{p_\pi}{2m_\pi} \left(b_0 - b_1 \frac{p_\pi^2}{(2m_\pi)^2} + b_2 \frac{p_\pi^4}{(2m_\pi)^4} \right) \frac{1}{1 + p_\pi^2/\Lambda^2}$$

$$p_\pi = \sqrt{m^2 - 4m_{\pi+}^2}$$

new KL parametrization on old KLOE data (I)

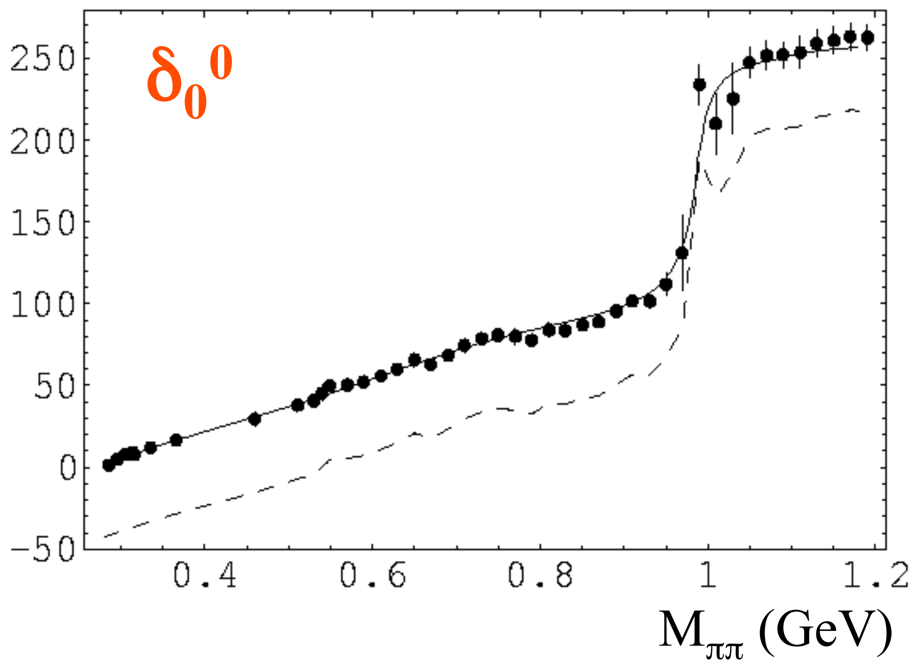
Achasov-Kiselev: combined fit to KLOE 2000 + ππ scattering data

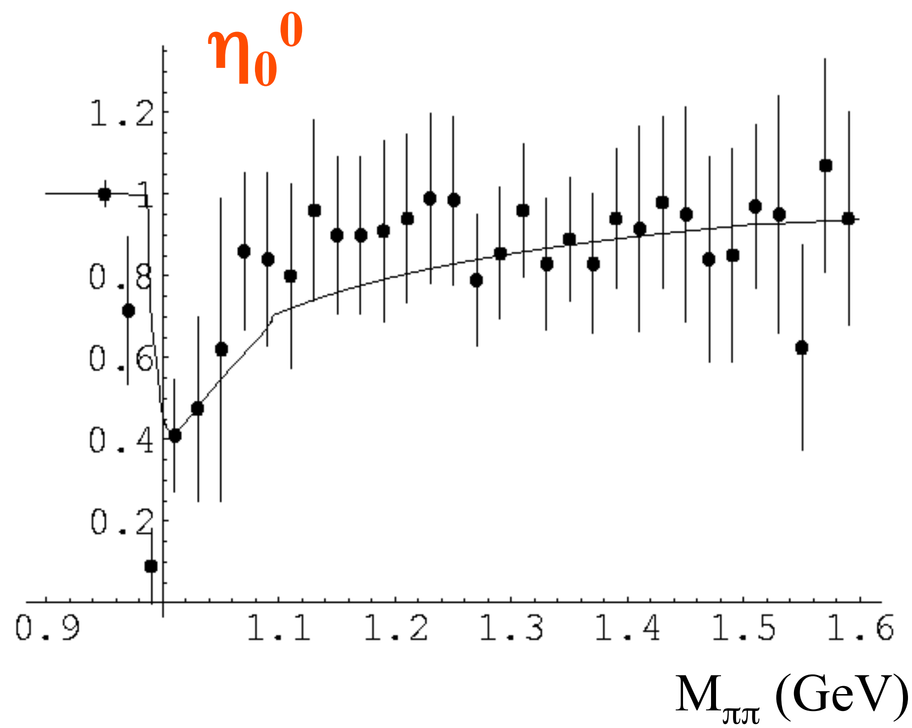
dBR/dM$_{\pi\pi}$ (KLOE 2000 data)



new KL parametrization on old KLOE data (II)

Achasov-Kiselev: combined fit to KLOE 2000 + ππ scattering data





Paper published:
Hep-ph 0512047

Theory advantages of the new parametrization

✓Able to reproduce Mass-spectrum, δ^0_0 and inelasticity

✓ Sum of overlapping resonances with the correct propagator matrix

✓ A lot of theory restrictions applied:

- The $\pi\pi$ scattering length a^0_0 fixed to the recent calculation of Colangelo
- In the $\pi\pi$ scattering amplitude the Adler zero in $T(\pi\pi \to \pi\pi)$ is granted in the region below the threshold ($0 < m^2_{\pi\pi} < 4M^2_{\pi}$)

- A $\sigma(600)$ meson is needed to obtain a good fit

K-loop fit results: f_0 + σ (600) (the six "variants")

In their paper, N. Ach. et al. used six possible variants for the fit.

- In the first two (A1,A2) they tried different coupling signs between g_σππ and g_f_0ππ. Adler zero in T(ππ–>KK) to M_π^2

- In the third and fourth fit (A3,A4) they tried different values of the inelasticity + for variety they fixed the Adler-Zero in T(ππ–>KK) to $M_\pi^2/2$.

In these first four cases the couplings of g_σKK are small but not negligible: (0.55,-0.93,0.43,-1.1) GeV respectively.

- In variants five and six (A5, A6) they use the "naïve" 4-quark model expectations for the sigma i.e. g_σKK –> (0.13,-0.035)GeV

- In all cases the mass of σ is between 450-700 MeV and its width very large (see Table)

KL fit results: $f_0 + \sigma$ (the six "variants") : Sγ term

FIXED $M,\Gamma\ \sigma$

Fit	M_{f_0} (MeV)	$g_{f_0 K^+K^-}$ (GeV)	$g_{f_0 \pi^+\pi^-}$ (GeV)	R_{f_0}	$M, \Gamma(\sigma)$ (MeV)	χ^2	$P(\chi^2)$
1	976.8 ± 0.3	3.76 ± 0.04	-1.43 ± 0.01	6.91 ± 0.18	462, 286	2754	0.145
2	986.2 ± 0.3	3.87 ± 0.08	-2.03 ± 0.02	3.63 ± 0.17	485, 240	2792	0.058
3	985.2 ± 0.2	4.92 ± 0.06	-1.92 ± 0.01	6.57 ± 0.17	472, 320	2809	0.036
4	987.3 ± 0.1	3.84 ± 0.11	-2.00 ± 0.02	3.69 ± 0.22	543, 290	2855	0.008
5	987.0 ± 0.2	2.61 ± 0.05	-0.95 ± 0.01	7.55 ± 0.33	709, 493	2970	5×10^{-5}
6	983.5 ± 0.4	2.52 ± 0.04	-0.82 ± 0.01	9.44 ± 0.38	693, 442	2981	3×10^{-5}

Free $M\ \sigma$

Fit	M_{f_0}	$g_{f_0 K^+K^-}$	$g_{f_0 \pi^+\pi^-}$	R_{f_0}	M_σ	χ^2	$P(\chi^2)$
1	974.8 ± 0.6	3.49 ± 0.08	-1.29 ± 0.04	7.32 ± 0.56	551 ± 15	2734	0.208
2	986.1 ± 0.2	3.75 ± 0.07	-1.99 ± 0.02	3.55 ± 0.15	527 ± 13	2786	0.066
3	984.8 ± 0.4	4.65 ± 0.12	-1.81 ± 0.03	6.60 ± 0.40	534 ± 13	2797	0.049
4	987.3 ± 0.1	4.06 ± 0.08	-2.07 ± 0.02	3.85 ± 0.17	475 ± 25	2847	0.010
5	982.7 ± 0.4	2.42 ± 0.03	-0.95 ± 0.01	6.49 ± 0.21	406 ± 15	2817	0.027
6	980.2 ± 0.4	2.45 ± 0.04	-0.89 ± 0.01	7.58 ± 0.30	403 ± 61	2788	0.062

✓We exclude the last two variants with σ(600) fixed to the "naïve" 4-q model
✓ No improvements observed when leaving the sigma mass free. Last two variants improve but Mass of sigma lowers of 300 MeV!

KL fit results: $f_0 + \sigma$ (the six "variants") : VDM term

Fit	$\alpha_{\rho\pi}$	$C_{\omega\pi}$ (GeV^{-2})	$\phi_{\omega\pi}$	$C_{\rho\pi}$ (GeV^{-2})	$\phi_{\rho\pi}$	δ_{b_ρ} (°)	M_ω (MeV)
1	0.58 ± 0.11	0.850 ± 0.010	0.46 ± 0.13	0.260 ± 0.185	3.11 ± 3.12	33.0 ± 9.7	782.52 ± 0.29
2	0.68 ± 0.03	0.832 ± 0.003	0.30 ± 0.05	0.061 ± 0.211	3.14 ± 3.08	23.6 ± 4.1	782.20 ± 0.11
3	0.66 ± 0.17	0.836 ± 0.004	0.33 ± 0.08	0.084 ± 0.056	3.14 ± 3.14	25.2 ± 6.2	782.26 ± 0.28
4	0.72 ± 0.04	0.826 ± 0.003	0.21 ± 0.06	0.062 ± 0.003	3.14 ± 0.02	15.7 ± 3.4	782.12 ± 0.11
5	0.71 ± 0.05	0.814 ± 0.003	0.22 ± 0.07	0.231 ± 0.054	0.00 ± 2.01	26.1 ± 3.7	781.91 ± 0.13
6	0.81 ± 0.03	0.813 ± 0.003	0.21 ± 0.05	0.060 ± 0.006	3.12 ± 0.43	10.4 ± 1.8	781.91 ± 0.09

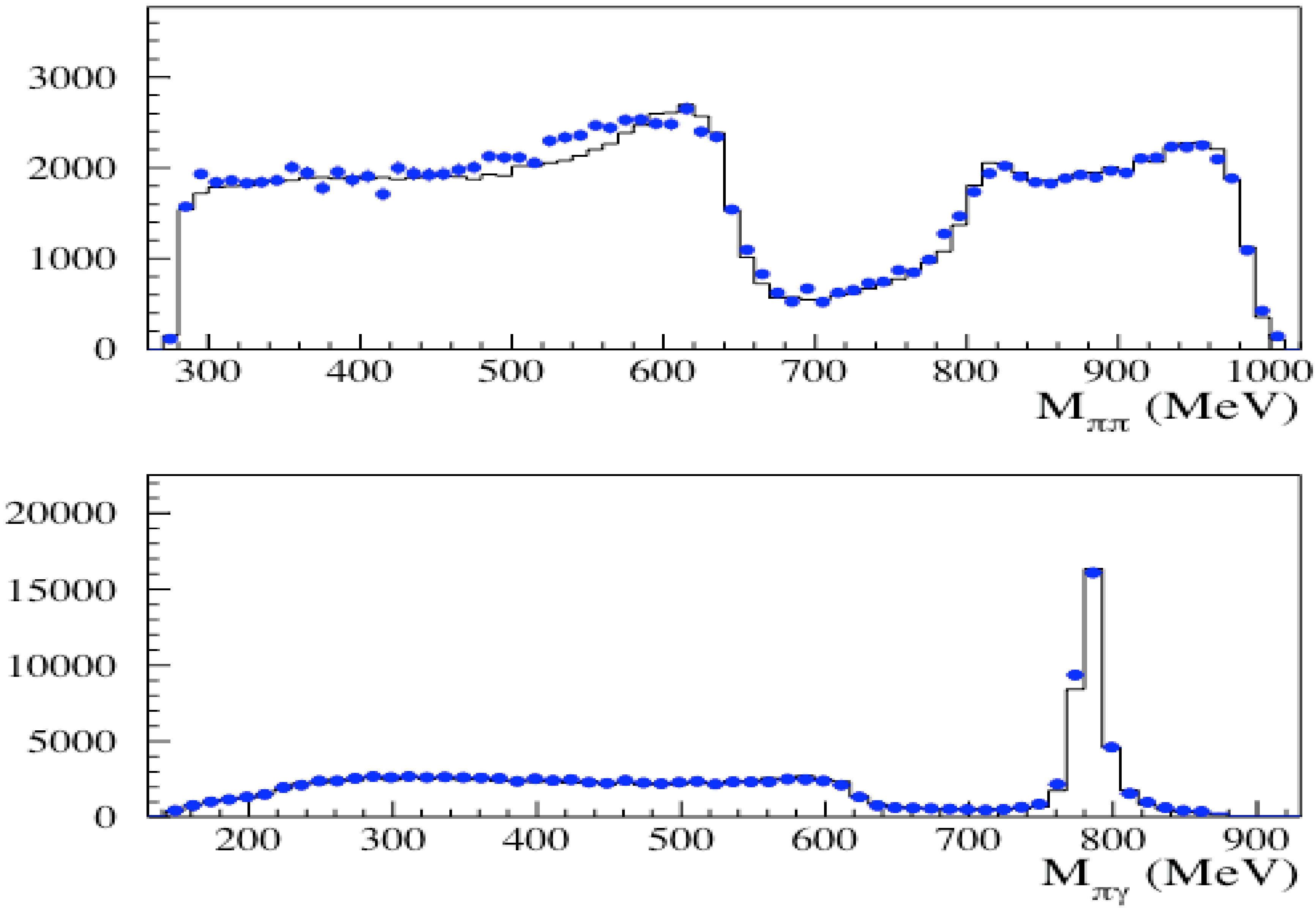
Fit	$\alpha_{\rho\pi}$	$C_{\omega\pi}$ (GeV^{-2})	$\phi_{\omega\pi}$	$C_{\rho\pi}$ (GeV^{-2})	$\phi_{\rho\pi}$	δ_{b_ρ} (°)	M_ω (MeV)
1	0.62 ± 0.05	0.852 ± 0.015	0.19 ± 0.15	0.065 ± 0.217	2.96 ± 0.61	32.8 ± 7.9	782.32 ± 0.21
2	0.73 ± 0.22	0.831 ± 0.003	0.18 ± 0.06	0.272 ± 0.123	3.14 ± 1.69	4.1 ± 3.6	782.12 ± 0.13
3	0.69 ± 0.14	0.834 ± 0.004	0.16 ± 0.06	0.069 ± 0.204	3.14 ± 2.55	15.8 ± 1.9	782.12 ± 0.24
4	0.69 ± 0.07	0.828 ± 0.006	0.40 ± 0.10	0.060 ± 0.184	3.14 ± 3.10	27.0 ± 9.1	782.20 ± 0.30
5	0.65 ± 0.05	0.829 ± 0.003	0.77 ± 0.05	0.299 ± 0.003	2.65 ± 0.24	36.1 ± 2.0	782.06 ± 0.12
6	0.62 ± 0.05	0.830 ± 0.011	0.84 ± 0.18	0.131 ± 0.201	0.69 ± 0.19	62.0 ± 8.1	782.09 ± 0.24

Stable results on the VDM side.

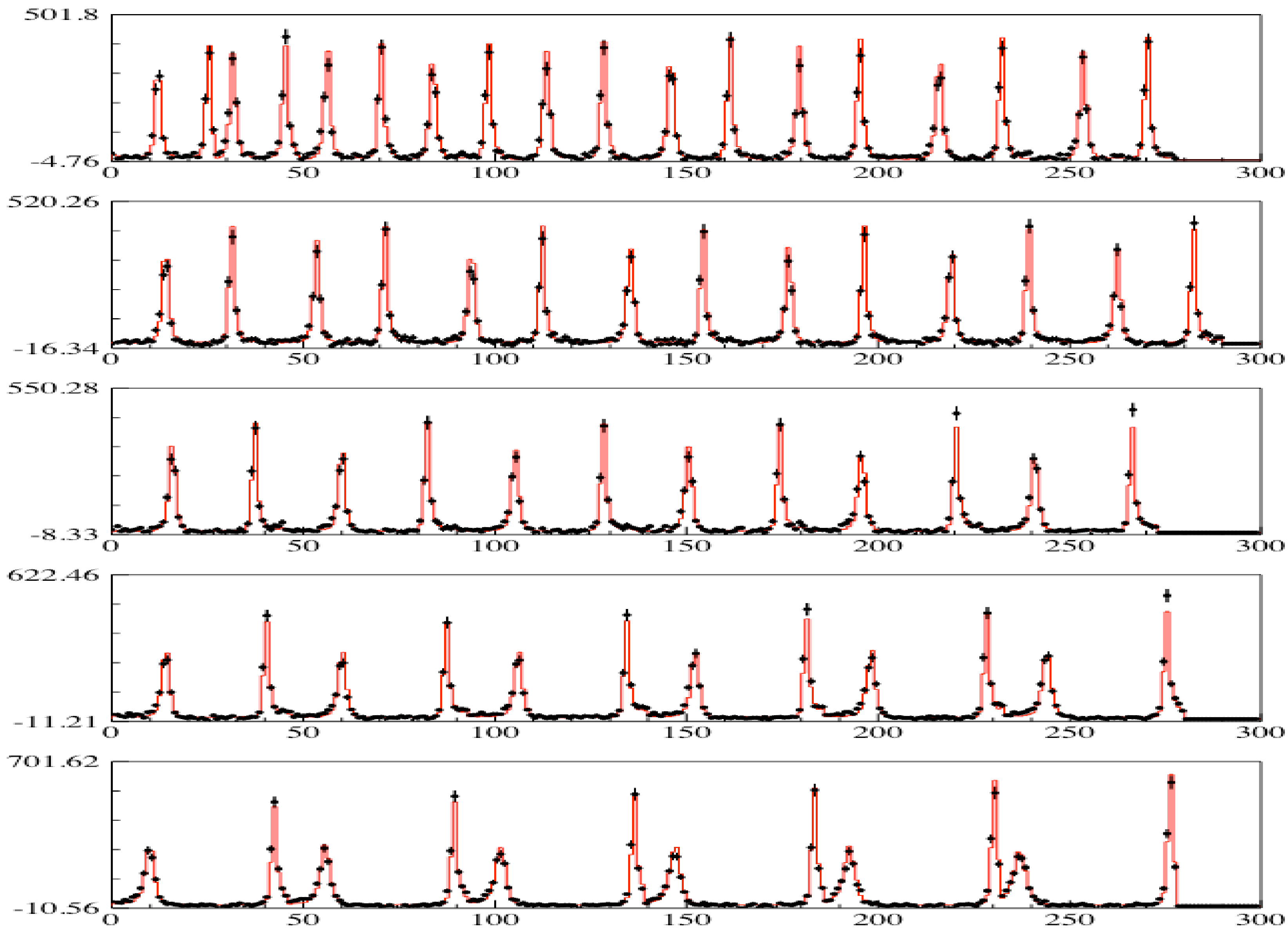
Too much jumping on δBrho when leaving Mass of s(600) free.

$\alpha_{\rho\pi}$ ≈0.6, Cρπ unstable but determined with large error. Precise Mω!.

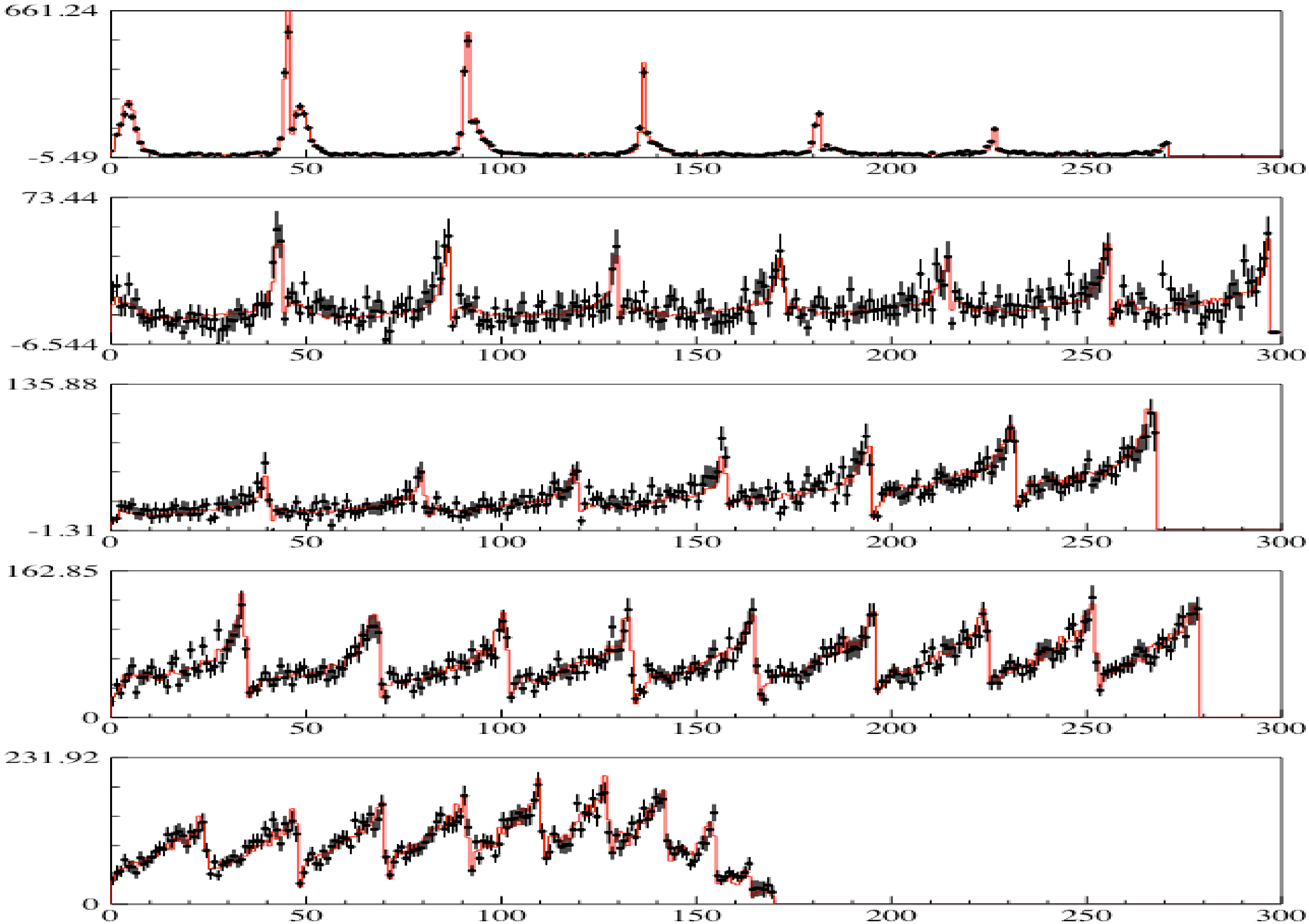
KL fit A1: $f_0 + \sigma$ (MASSES) @ $\sqrt{s}$=1019.6 MeV



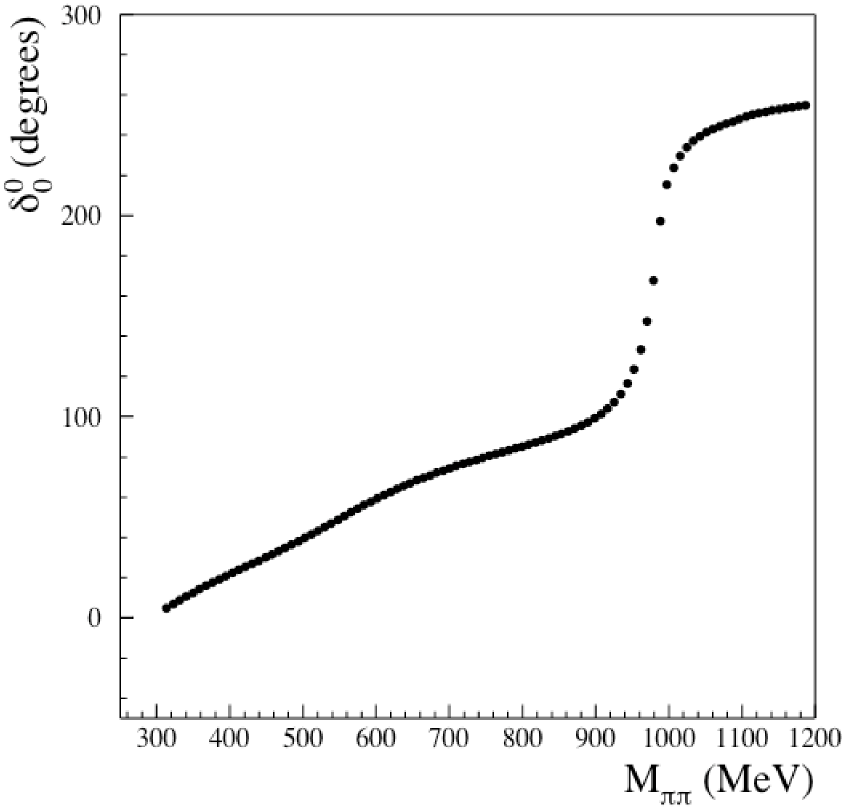
KL fit A1: $f_0 + \sigma$ (dalitz-slices) @ $\sqrt{s}$=1019.6 MeV

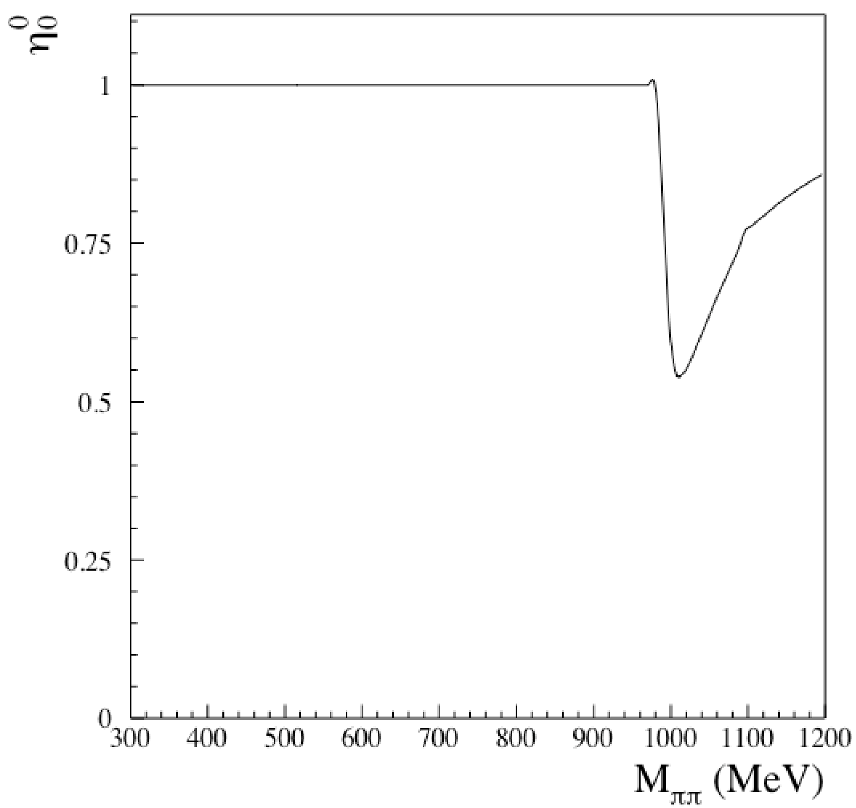


KL fit A1: $f_0 + \sigma$ (dalitz-slices) @ $\sqrt{s}$=1019.6 MeV

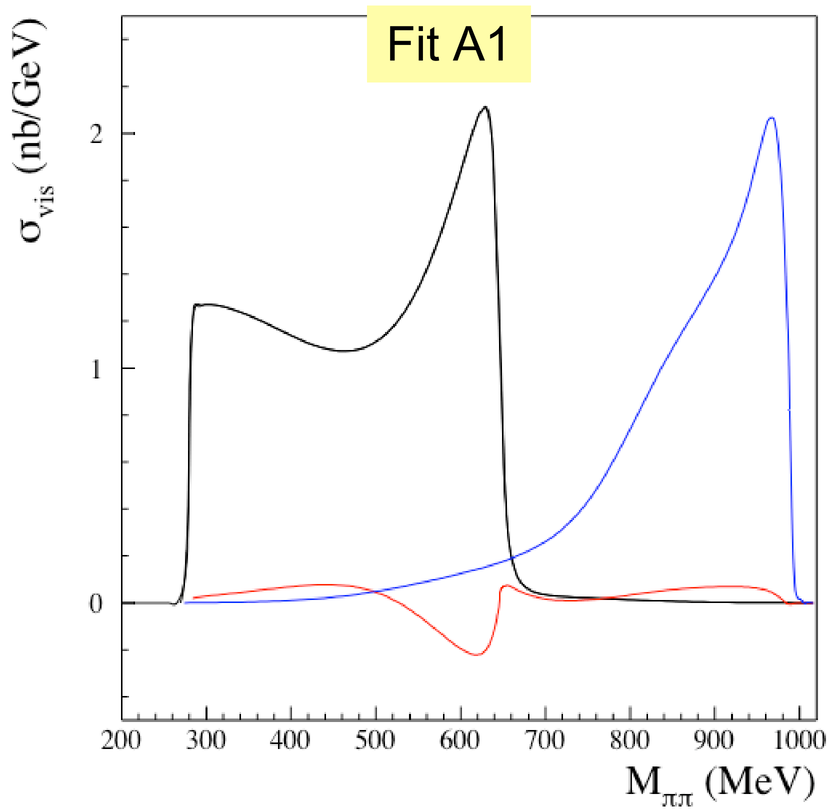


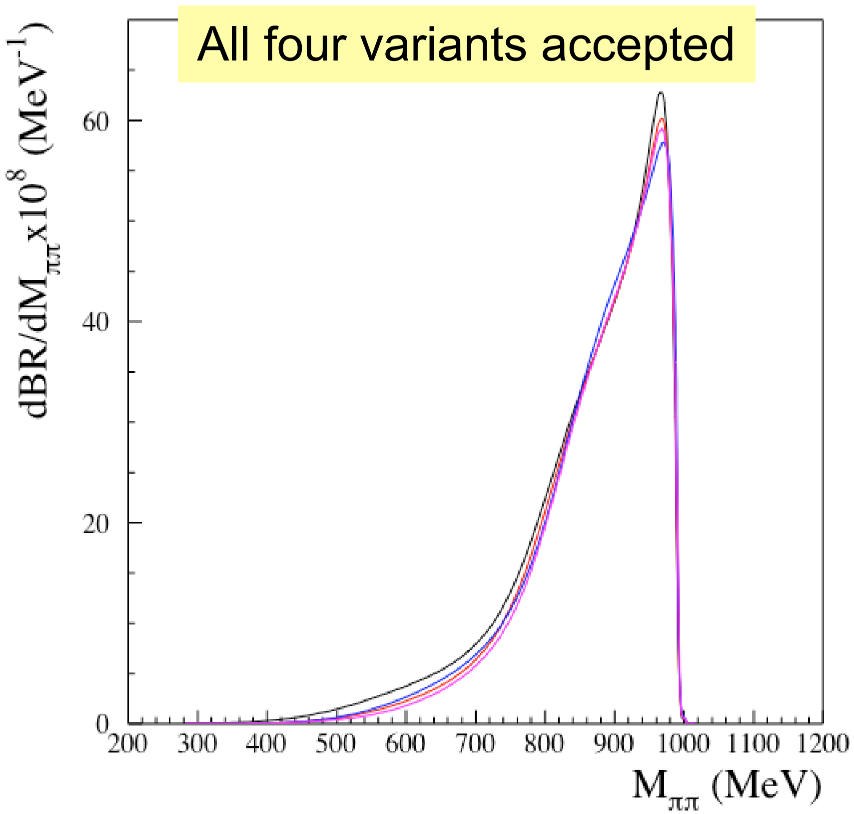
KL fit A1: $f_0 + \sigma$ (phases + inelasticity)





KL fit A1: $f_0 + \sigma$ (VDM/Sγ compositions)

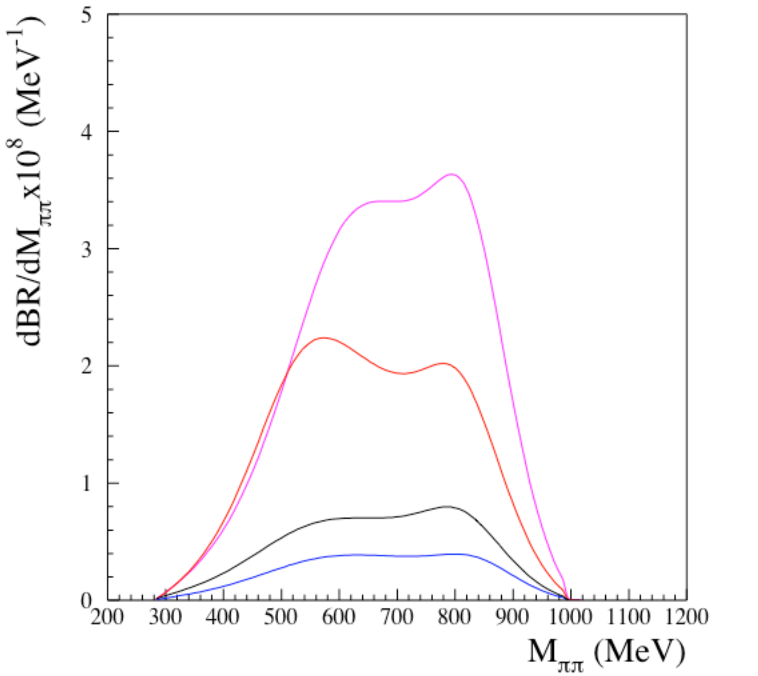


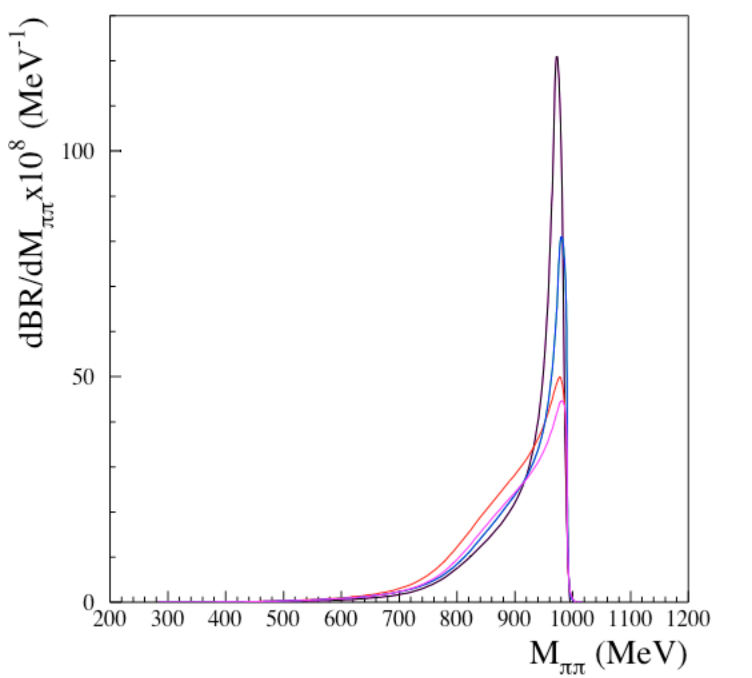


BR($\phi \to S\gamma \to \pi^0\pi^0\gamma$) of around 1.1 X10^{-4} for fit A1

Max variation with other 3 models of 8 %

KL fit results: $f_0 + \sigma$ ($f_0+\sigma$ composition)





Summary of KL fit results at $\sqrt{s}$ = 1019.6 MeV:

	$f_0 + \sigma$ (M_σ fixed)	$f_0 + \sigma$ (M_σ free)	$f_0 \rightarrow \pi^+\pi^-$
M_{f0} (MeV)	976.8 ± 0.3 + 10.5	974.8 ± 0.6 + 12.5	980 – 987
$g_{fK^+K^-}$ (GeV)	3.76 ± 0.04 +1.16	3.49 ± 0.08 + 0.57	3.9 – 6.5
$g_{f\pi^+\pi^-}$ (GeV)	–1.43 ± 0.01 + 0.60	–1.29 ± 0.04 +.77	2.8 – 3.8
M_σ (MeV)	**461-543**	**551 ± 15 - 76**	
$\alpha_{\rho\pi}(\phi)$	0.58 ± 0.11 + 0.14	0.62 ± 0.05 + 0.09	
$C_{\omega\pi}$ (GeV^{-2})	0.850 ± 0.010 - 0.24	0.852 ± 0.015 - 0.24	
$\phi_{\omega\pi}$	0.46 ± 0.13 - 0.25	0.19 ± 0.15 +0.21	
$C_{\rho\pi}$ (GeV^{-2})	0.260 ± 0.185 - 0.200	0.065 ± 0.217 +0.207	
$\phi_{\rho\pi}$	3.11 ± 3.12 + 0.03	2.96 ±0.61 +0.18	
M_ω (MeV)	**782.5 ± 0.3 - 0.4**	**782.3 ± 0.2 -0.2**	
δ_{b_ρ} (degree)	33.0 ± 9.7 - 15	32.8 ± 7.9 -28.7	
χ^2/ndf	2753/ 2676	2734 / 2675	
$P(\chi^2)$	14.5 %	**20.8 %**	

Central values are from the best fit A1.
The first error is the statistical error from the fit, the second one reflects the changes related to
A different model which still provides an acceptable fit (theory model error).

Conclusions and perspectives

We consider the KL fit concluded!

We require these results to be blessed as "preliminary" for 2 reasons:

(1) we are writing the KLOE memo to explain the fit detail & report the results to our referees and KLOE all.

(2) we are adding the fit systematics by repeating the best fit (A1+NS) with the following tests:

- Change of normalization scale **(L + Γ_{ee})**
- Change of beam energy scale **(-150 keV)**
- Change of cluster efficiency curve **(MC vs Tom)**
- Change of smearing matrix
- Change of background content **by fitting data with $\chi^2 < 3$**

We will conclude the memo on the fit by comparing with $\pi^+\pi^-\gamma$
For publication purposes we ask C.Bini to test our best fit over the $\pi^+\pi^-\gamma$ sample and G.Venanzoni to add this on EVA to test the effect on the asymmetry.

Fit function: the Achasov parametrization

$$\frac{d\sigma(e^+e^-\to\pi^0\pi^0\gamma)}{dm\,dm_{\pi\gamma}} = \frac{\alpha m_{\pi\gamma} m}{3(4\pi)^2 s^3}\Big\{ |A_{scalar}|^2 +$$

$f_0\gamma$

Model dependent term

$\alpha_{\rho\pi}(\phi)$

$$\frac{1}{16}F_1(m^2,m_{\pi\gamma}^2)\left|\left(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\right)\frac{e^{i\delta_{b_\rho}}}{D_\rho(m_{\pi\gamma}^2)}+\frac{C_{\omega\pi^0}}{D_\omega(m_{\pi\gamma}^2)}\right|^2+$$

$$\frac{1}{16}F_1(m^2,\tilde m_{\pi\gamma}^2)\left|\left(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\right)\frac{e^{i\delta_{b_\rho}}}{D_\rho(\tilde m_{\pi\gamma}^2)}+\frac{C_{\omega\pi^0}}{D_\omega(\tilde m_{\pi\gamma}^2)}\right|^2+$$

$$\frac{1}{8}F_2(m^2,m_{\pi\gamma}^2)Re\Big[\Big(\Big(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\Big)\frac{e^{i\delta_{b_\rho}}}{D_\rho(m_{\pi\gamma}^2)}+\frac{C_{\omega\pi^0}}{D_\omega(m_{\pi\gamma}^2)}\Big)\times$$

$$\Big(\Big(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\Big)\frac{e^{i\delta_{b_\rho}}}{D_\rho(\tilde m_{\pi\gamma}^2)}+\frac{C_{\omega\pi^0}}{D_\omega(\tilde m_{\pi\gamma}^2)}\Big)^*\Big]\mp$$

$\omega\pi/\rho\pi$

Set to +1

$$\frac{1}{\sqrt{2}}Re\Big[A_{scalar}\Big($$

$$F_3(m^2,m_{\pi\gamma}^2)\Big(\Big(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\Big)\frac{e^{i\delta_{b_\rho}}}{D_\rho(m_{\pi\gamma}^2)}+\frac{C_{\omega\pi^0}}{D_\omega(m_{\pi\gamma}^2)}\Big)^*+$$

$$F_3(m^2,\tilde m_{\pi\gamma}^2)\Big(\Big(\frac{e^{i\phi_{\omega\phi}(m_\phi^2)}g_{\phi\gamma}g_{\phi\rho\pi}g_{\rho\pi\gamma}}{D_\phi(s)}+C_{\rho\pi}\Big)\frac{e^{i\delta_{b_\rho}}}{D_\rho(\tilde m_{\pi\gamma}^2)}+\frac{C_{\omega\pi^0}}{D_\omega(\tilde m_{\pi\gamma}^2)}\Big)^*\Big)\Big]\Big\},$$

$f_0\gamma$/VP interf

[N.N.Achasov, A.V.Kiselev, private communication]

- ✓ **VDM free parameters: C_{VP}, $\delta_{b\rho}$, $\alpha_{\rho\pi}(\phi)$, M_ω**
- ✓ **M_σ free or fixed to BES value** (541 MeV)