Progress report on $\pi^0 \pi^0 \gamma$ analysis

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- **Final fits to the $\sqrt{s}$-dependence of visible cross sections**
- **Status of KLOE memos …**
- **Plans for the fitting of the Dalitz-plot**

ϕ decays meeting – 22 Nov 2005

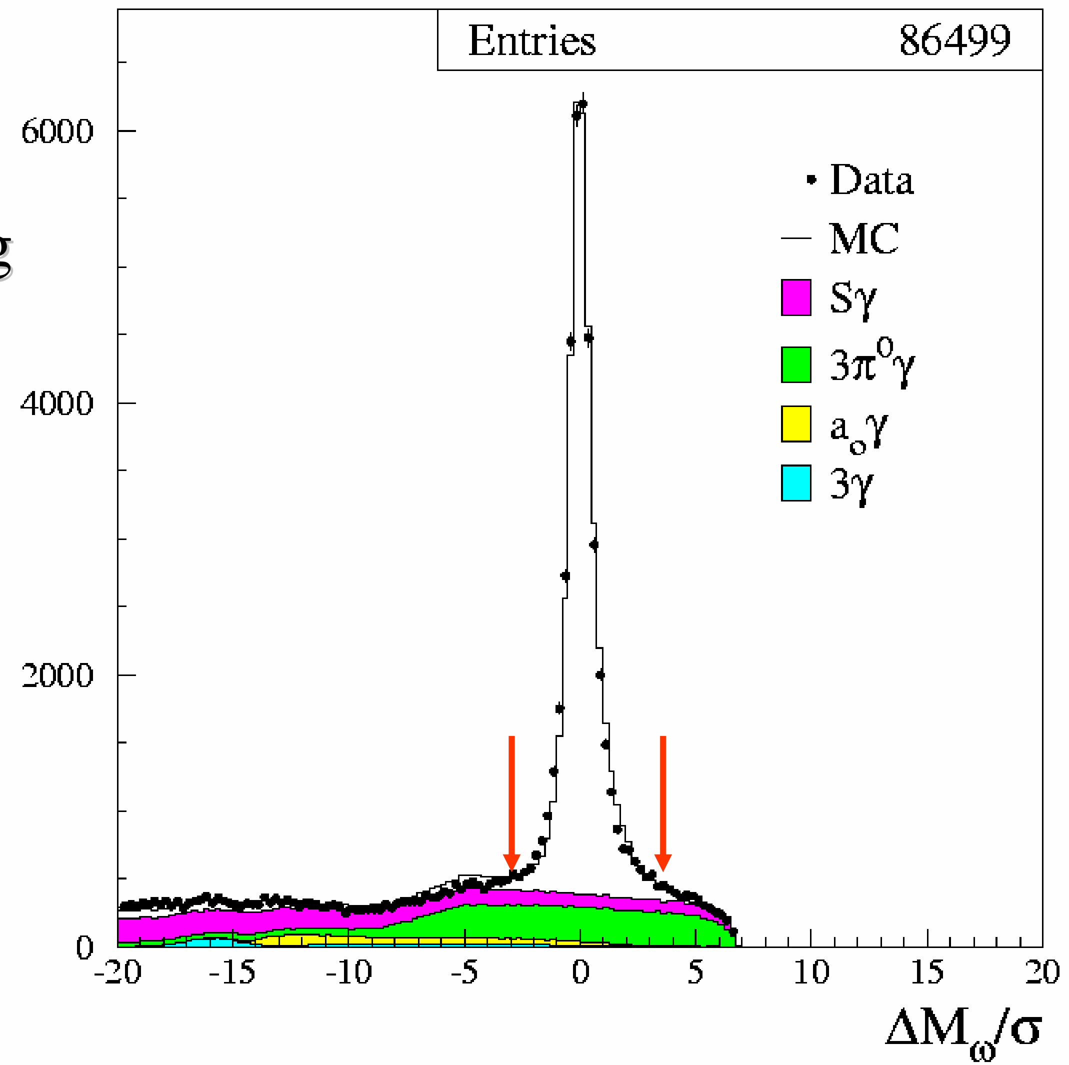
Status and plan

- As shown in the July phidec meeting, we have reached a stable conclusive result for the data analysis while we are completing the fit on the dalitz-plot.
- Today we show the results of the fits to the $\pi\pi\gamma$ visible cross section obtained by repeating the analysis "as in 2001" i.e. **neglecting any interference between VDM and scalar terms .**
- From these fits we will extract the parameters describing the $e^+e^- \rightarrow \omega\pi^0$ and the BR($\phi \rightarrow \pi\pi\gamma$).
- To understand how well we do all of this (+ for checking the normalization of our main background) we have also analized a large sample of $\varphi\rightarrow\eta\gamma$ decays in 7 photons (prescaling 1/50 while running our 5-photon selection).

ωπ vs Sγ events (Masses)

- With our new, process independent, photon pairing procedure, we build the best omega mass.

- As in 2001, we then count as :
  - ωπ events the ones in within 3 sigma from Mω
  - Sγ all the others



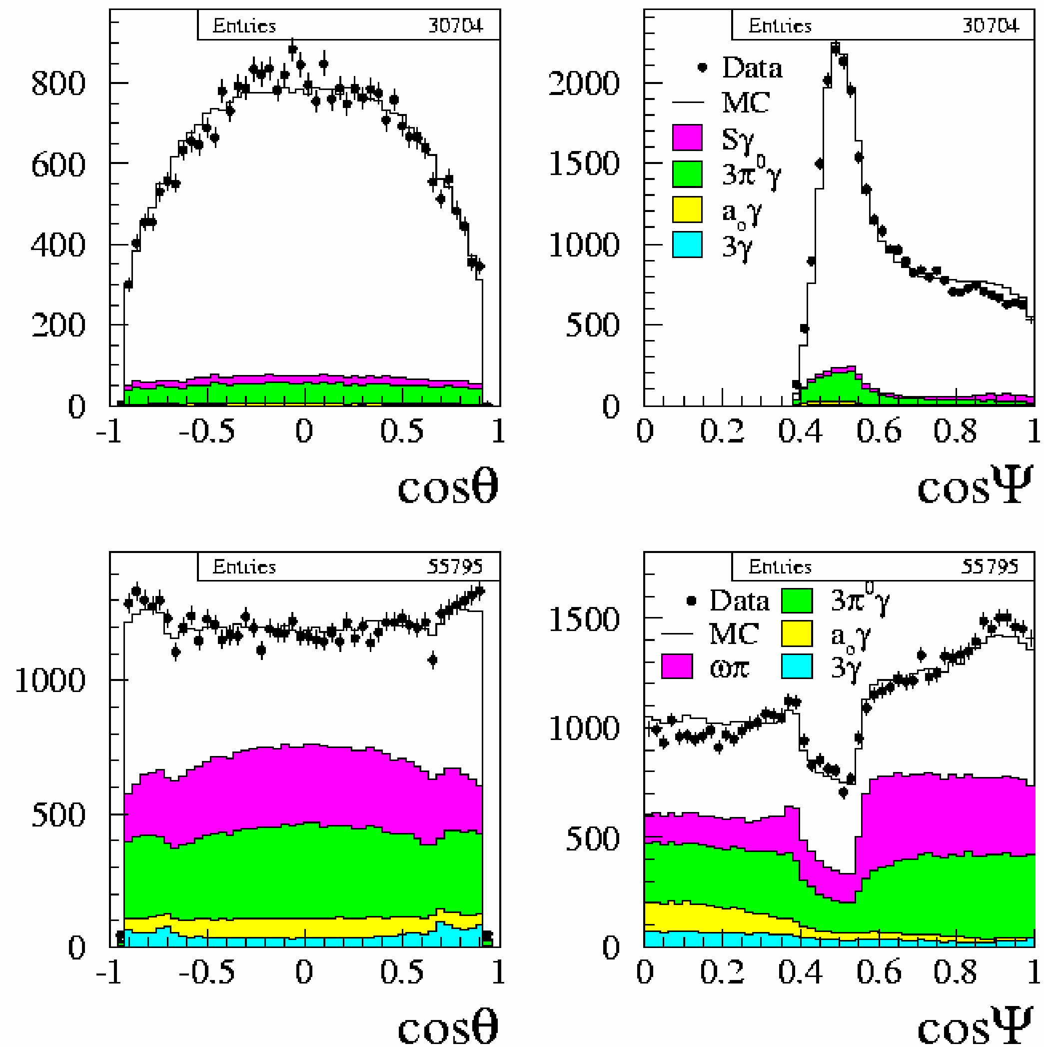
$\omega\pi$ vs $S\gamma$ events (Angular distributions)

$\omega\pi$ events

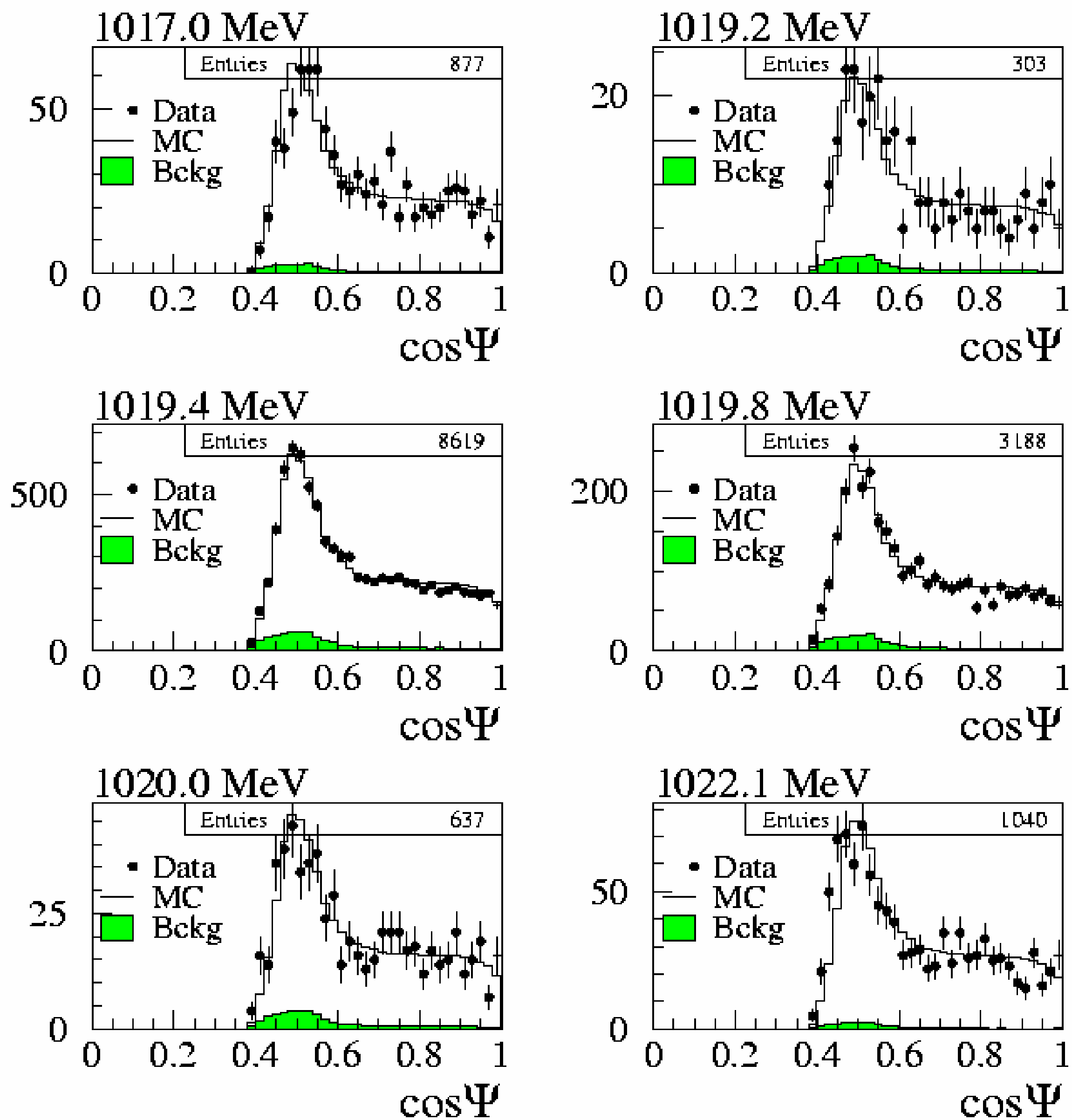
Clear S=1
angular dependence

$S\gamma$ events

Clear S=0
angular dependence



ωπ events vs √s (angular distributions)



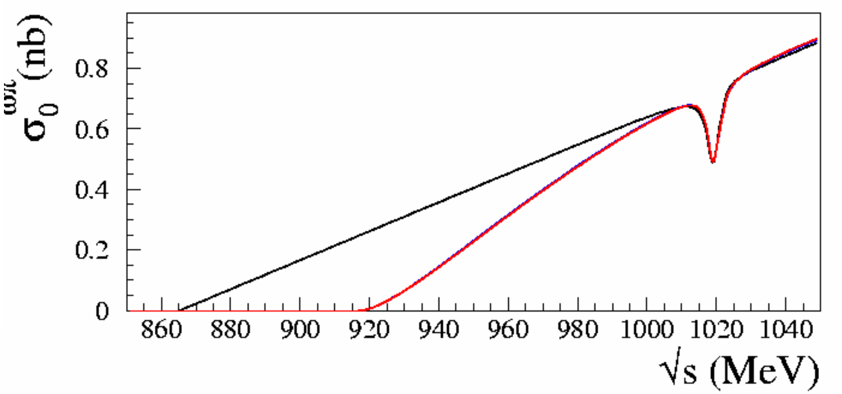
ωπ: energy dependence of the xsec

$$\sigma^{\omega\pi}(\sqrt{s}) = \sigma_0^{\omega\pi}(\sqrt{s}) \left| 1 - Z\frac{M_\phi \Gamma_\phi}{D_\phi} \right|^2 , \qquad (11)$$

where $\sigma_0^{\omega\pi}(\sqrt{s})$ represents the nude cross section for the not-resonant process, Z is the complex interference parameter (i.e. the ratio between the ϕ decay amplitude and the not-resonant process), while M_ϕ, Γ_ϕ and $D_\phi = M_\phi^2 - s - i\sqrt{s}\Gamma_\phi$ are respectively the mass, the width and the inverse propagator of the ϕ meson.

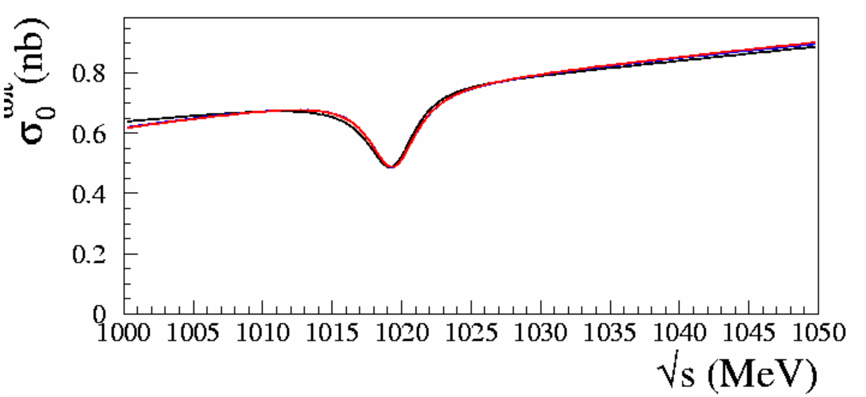
A) Linear dependence

- $\sigma = \sigma_0 \times (1+\alpha\,(\sigma' - M_\phi))$



B) Model ρ/ρ' mesons

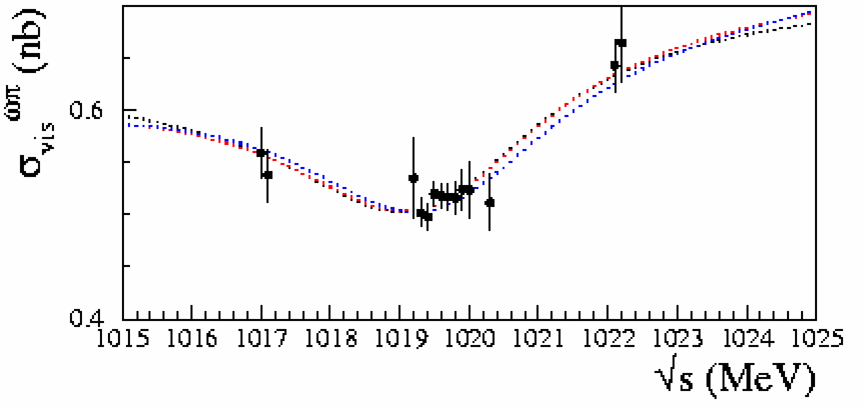
$$\sigma_0^{\omega\pi}(\sqrt{s}) = \frac{K}{s^{3/2}} \left| \frac{M_\rho^2}{D(\rho)} + \frac{A_1 M_{\rho'}^2}{D(\rho')} \right|^2 P_f(\sqrt{s}),$$



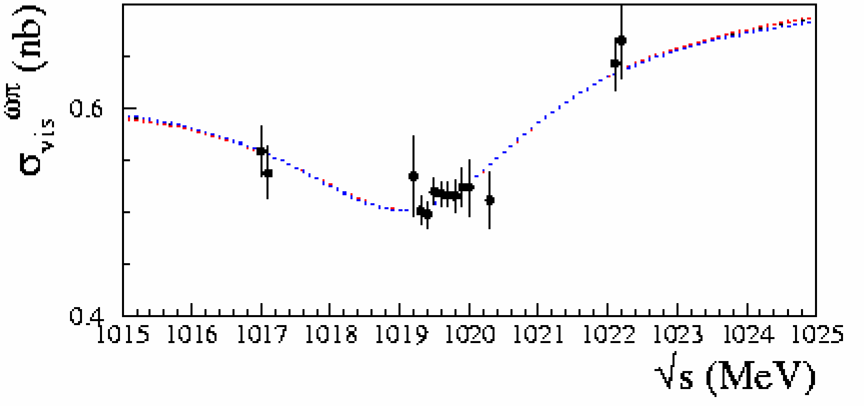
2 different parametrizations of ρ ρ‘ used

ωπ: Fit to the visible xsec

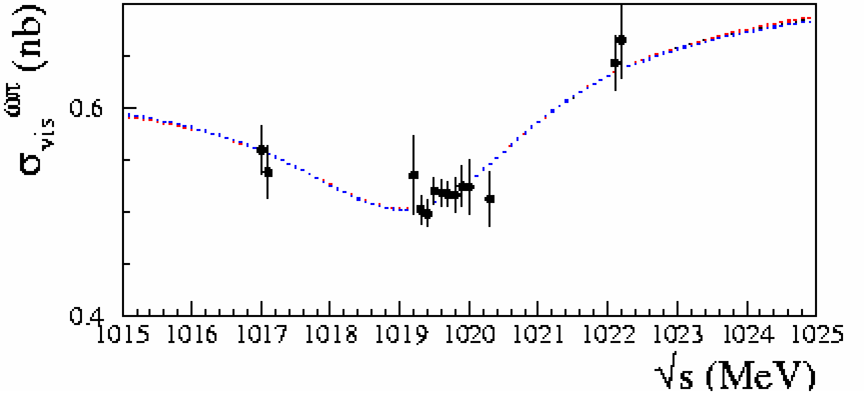
Fit A



Fit B



Fit C



ωπ: FIT RESULTS to the visible xsec

FIT	σ_0 (nb)	$\Re$ (Z)	$\Im$ (Z)	σ'(nb/MeV)	χ^2/ Ndof
(A) σ' fixed	0.731 ± 0.035	0.060 ± 0.020	-0.157 ± 0.030	0.0048	5.0/11
(A) σ' fixed	0.748 ± 0.010	0.049 ± 0.016	-0.152 ± 0.007	0.0073	4.8/11
(A) All free	0.756 ± 0.245	0.041 ± 0.040	-0.148 ± 0.124	0.0098 ± 0.0114	4.5/10
FIT	σ_0 (nb)	$\Re$ (Z)	$\Im$ (Z)	A_1	χ^2/ Ndof
(B) A_1 fixed	0.745 ± 0.014	0.051 ± 0.012	-0.153 ± 0.007	-0.114	5.0/11
(B) A_1 fixed	0.746 ± 0.028	0.050 ± 0.020	-0.153 ± 0.022	-0.150	4.9/11
(B) All free	0.743 ± 0.016	0.054 ± 0.019	-0.154 ± 0.012	-0.005 ± 0.001	5.1/10
FIT	σ_0 (nb)	$\Re$ (Z)	$\Im$ (Z)	A_1	χ^2/ Ndof
(C) A_1 fixed	0.745 ± 0.011	0.052 ± 0.020	-0.154 ± 0.012	-0.114	5.0/11
(C) A_1 fixed	0.746 ± 0.007	0.051 ± 0.001	-0.154 ± 0.001	-0.150	5.0/11
(C) All free	0.743 ± 0.009	0.055 ± 0.016	-0.154 ± 0.006	-0.012 ± 0.002	5.1/10

$$\sigma_0^{\omega\pi} = (0.75 \pm 0.03_{stat}\ {}^{+0.01}_{-0.02})\ \text{nb} \quad (14)$$

$$\Re(Z) = 0.05 \pm 0.02_{stat} \pm 0.01 \quad (15)$$

$$\Im(Z) = -0.15 \pm 0.02_{stat} - 0.01 \quad (16)$$

in good agreement and with similar accuracy with respect to SND results [26]: $\sigma_0^{\omega\pi} = (0.74 \pm 0.02_{stat} \pm 0.04_{syst})$ nb, $\Re(Z) = 0.025 \pm 0.035$, $\Im(Z) = -0.19 \pm 0.05$.

$\varphi \to \eta\gamma$: energy dependence of the cross sections

$$12\pi\, \Gamma_{\phi}^{e^+e^-}\, \Gamma_{\phi}^{\eta\gamma} \left| \frac{e^{i\pi}}{D_\phi} + \frac{R_\rho}{D_\rho} + \frac{R_\omega}{D_\omega} \right|^2 \left(\frac{M_\phi}{\sqrt{s}} \right)^3 \left(\frac{Q_\eta(\sqrt{s})}{Q_\eta(M_\phi)} \right)^3 \qquad (3)$$

3 Fit parameters :

– α normalization

– M_ϕ , Γ_ϕ

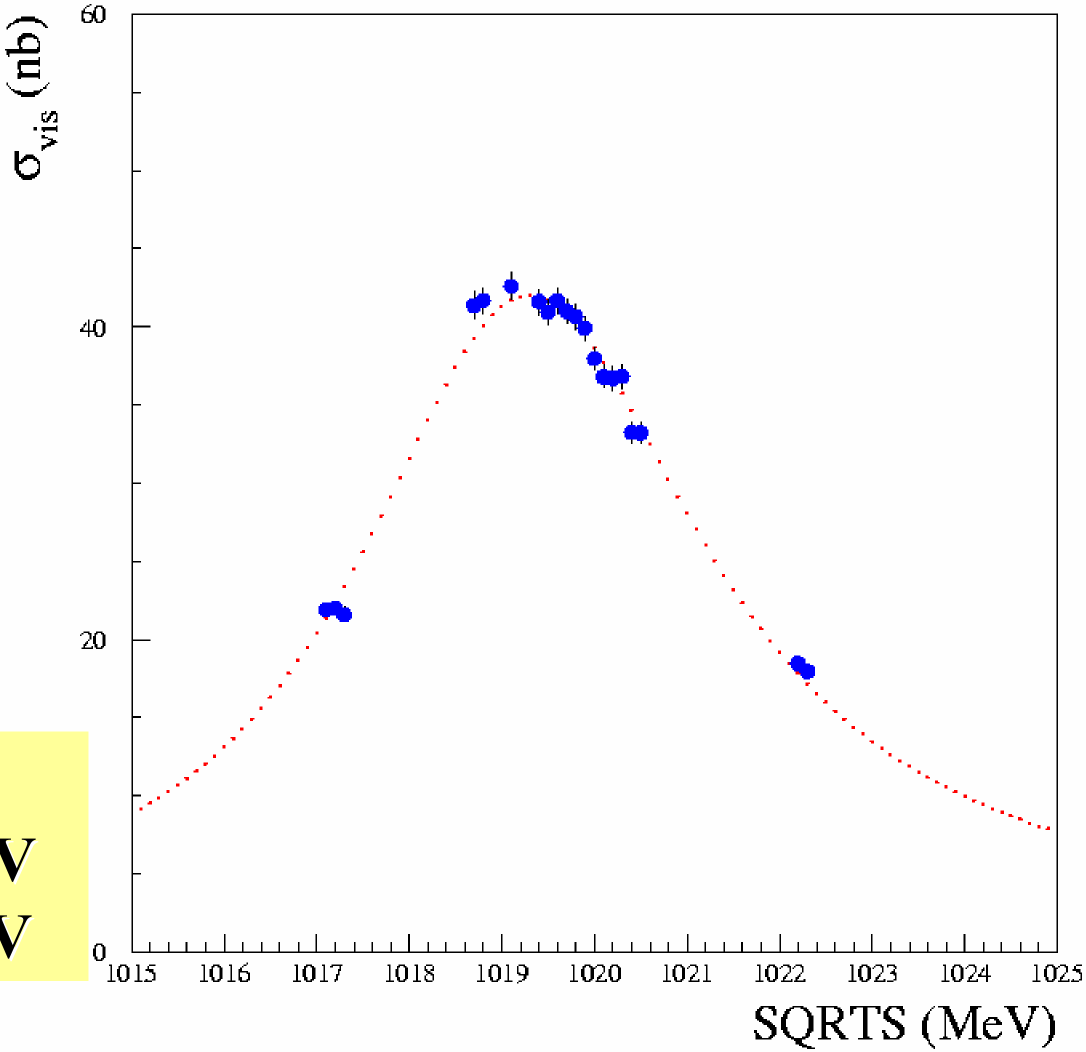
We use Γ_ϕ^{ll}(KLOE) = 1.320 ±0.017 ±0.015 keV

$\chi^2 = 16.8/17$

α = **1.014 ± 0.010**

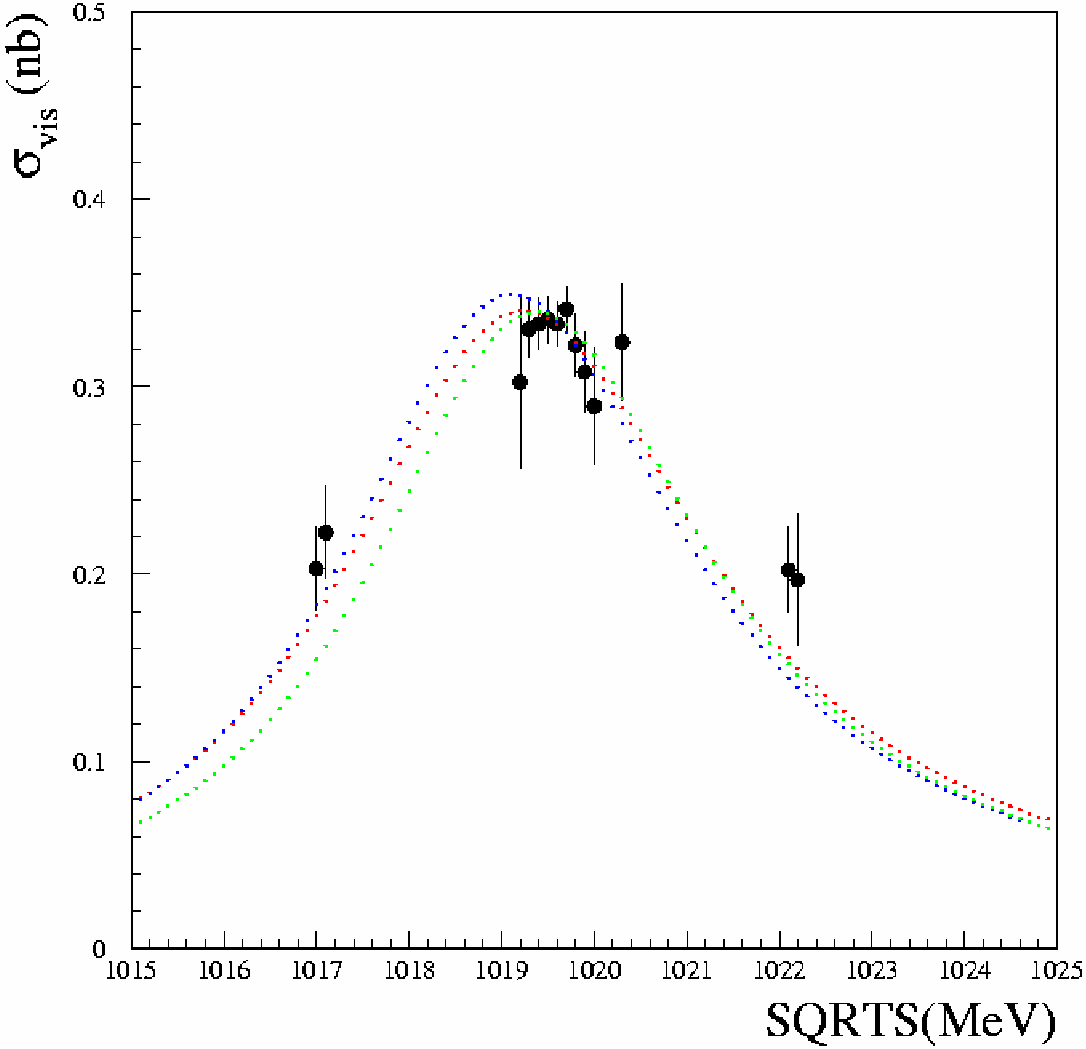
Mϕ = 1019.4X ± 0.01 MeV

$\Gamma\phi$ = 4.36 ± 0.09 MeV



$\varphi \rightarrow f_0\, \gamma$: energy dependence of the xsec

$$\sigma_0^{S\gamma}(s) = 12\pi \Gamma_\phi^{e^+e^-} \Gamma_\phi^{S\gamma} \left| \frac{1}{D_\phi(s)} \right|^2 \left(\frac{M_\phi}{\sqrt{s}} \right)^3 R_\Gamma(s)$$



$f_0\gamma$: Determination of BR ($\phi \to f_0\gamma \to \pi^0\pi^0\gamma$)

FIT	α	M_ϕ (MeV)	Γ_ϕ (MeV)	χ^2/ Ndof
(A) All free	1.319 ± 0.012	1019.34 ± 0.01	4.60 ± 0.09	13.9/11
(B) Γ_ϕ fixed	1.285 ± 0.001	1019.21 ± 0.35	4.358	17.2/12
(C) M_ϕ, Γ_ϕ fixed	1.223 ± 0.001	1019.46	4.26	21.8/12

From the valus of α we determine the value of $\Gamma(\phi \to f_0\gamma)$ at M_ϕ which is proportional to $\left(g_{f_0}^{K^+K^-} g_{f_0}^{\pi^+\pi^-}\right)^2$. **We get $\Gamma(\phi \to \pi^0\pi^0\gamma)$ = (0.498 ±0.005 ±0.022) keV**. The systematic error is dominated by the variation of the three fits. When dividing by $\Gamma_\phi(M_\phi)$ we determine the $BR(\phi \to f_0\gamma)$ to be:

$$\mathbf{BR(\phi \to \pi^0\pi^0\gamma) = (1.057 \pm 0.046_{fit} \pm 0.017_{norm}) \bullet 10^{-4}}$$

where the normalization error reflects our knowledge of Γ_ϕ^{ll}. The result is in pretty good agreement with our old measurement.

First conclusions ..

- As shown in this presentation, when neglecting the interference between $\omega\pi$ and $S\gamma$ we are able to distinguish the most relevant features of the $\pi\pi\gamma$ events:
  - There is a clear resonant – not resonant component
  - The not resonant component is dominated by $e^+e^- \rightarrow \omega\pi \rightarrow \pi\pi\gamma$ events with a well defined spin 1 angular dependence.
  - The resonant component is a scalar
  - If we fit the not-resonant component we find the parameters describing the interference with the ϕ meson to be in reasonable agreement with SND.
  - If we fit the resonant component we find that the two points far away the ϕ peak are not perfectly described by our model. However **we extract the BR ($\phi \rightarrow \pi\pi\gamma$)**
  - All of this work has been summarized in a KLOE Memo 319
  - Submitted today!

Improved K-loop parametrization

N.N.Achasov, private communication

- 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

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

- New parametrization of the ππ phase:

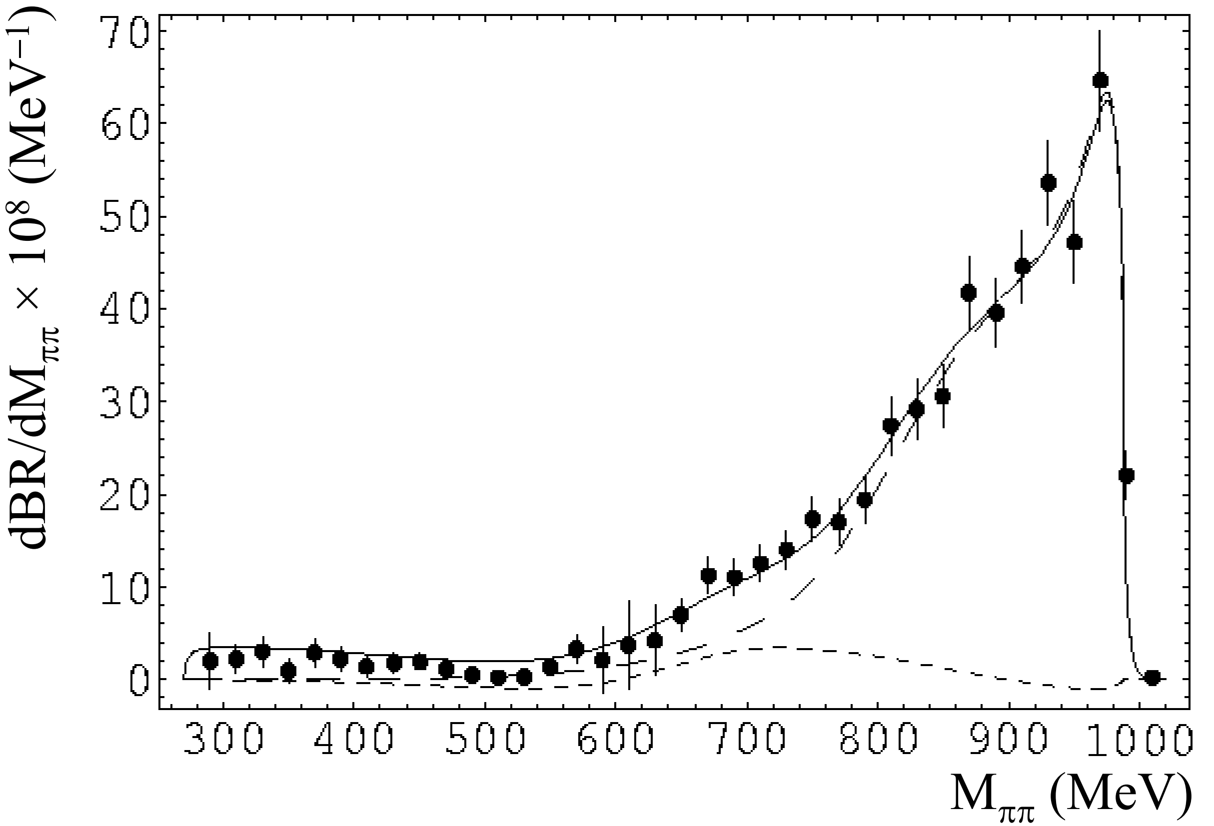
$$\tan(\delta_B^{\pi\pi}) = -\frac{p_\pi}{2m_\pi}\left(b_0-b_1\frac{p_\pi^2}{(2m_\pi)^2}+b_2\frac{p_\pi^4}{(2m_\pi)^4}\right)\frac{1}{1+p_\pi^2/\Lambda^2}$$

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

Results with the new parametrization

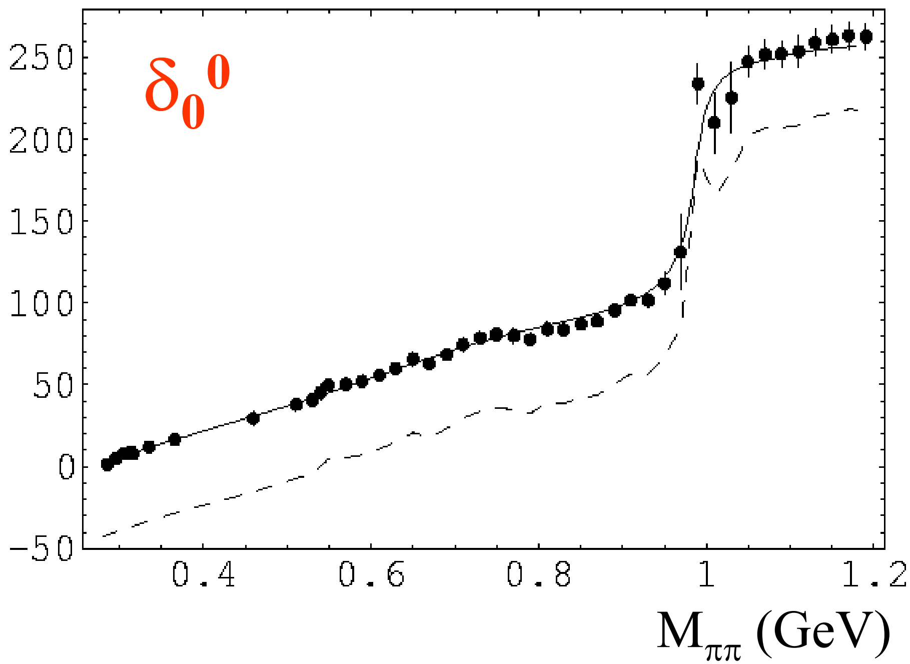
Achasov-Kiselev: combined fit to KLOE 2000 + ππ scattering data

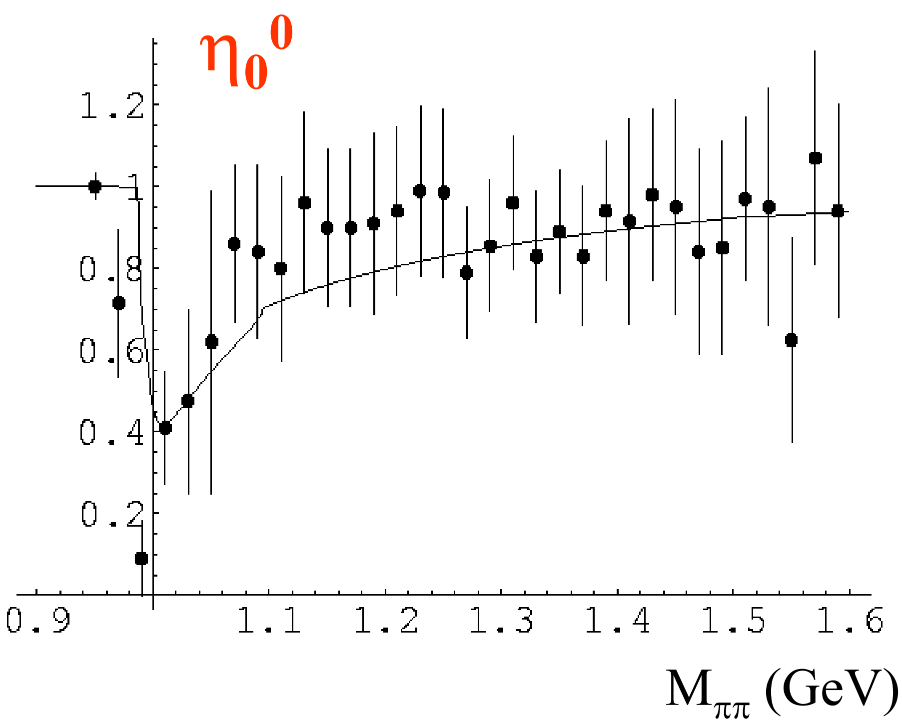
$dBR/dM_{\pi\pi}$ (KLOE 2000 data)



Results with the new parametrization

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



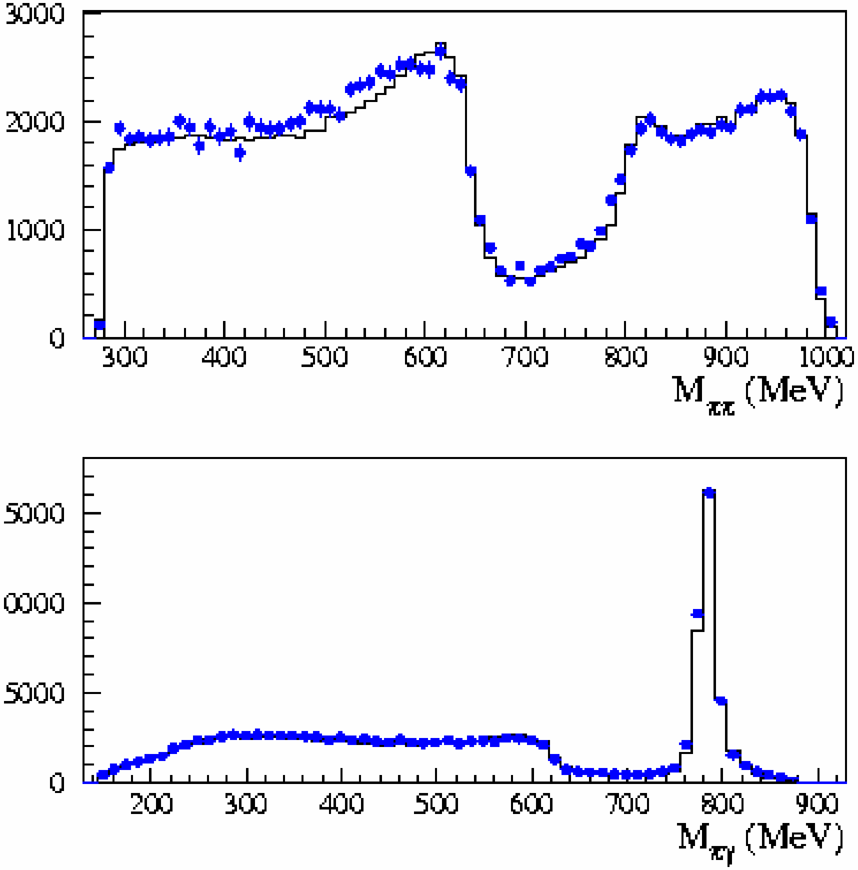


Fit results: new K-loop parametrization

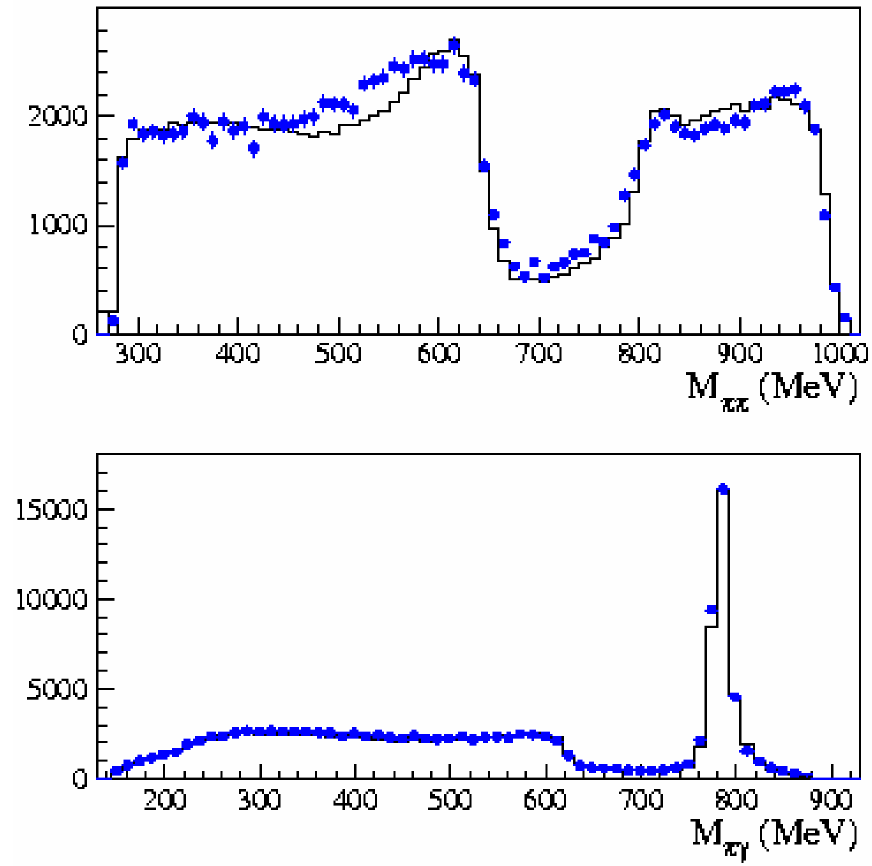
	f_0 only	$f_0 + \sigma$ (M_σ fixed)	$f_0+\sigma$	$f_0 \to \pi^+\pi^-$
M_{f0} (MeV)	986.2 ± 0.2	981.9 ± 0.3	981.3 ± 0.7	$981 - 985$
$g_{fK^+K^-}$ (GeV)	5.8 ± 0.1	3.96 ± 0.05	3.78 ± 0.08	$3.9 - 6.5$
$g_{f\pi^+\pi^-}$ (GeV)	-2.88 ± 0.02	-1.78 ± 0.02	-1.74 ± 0.04	$2.8 - 3.8$
M_σ (MeV)	—	—	578 ± 5	
$g_{\sigma\pi\pi}$ (GeV)	—	-1.91 ± 0.03	-1.83 ± 0.05	
$g_{\sigma KK}$ (GeV)	—	-0.66 ± 0.07	-0.68 ± 0.05	
$\lvert C_{f0\sigma} \rvert$ (GeV)	—	3.6 ± 4.5	9.3 ± 5.9	
$\alpha_{\rho\pi}(\phi)$	0.78 ± 0.08	0.59 ± 0.05	0.64 ± 0.05	
$C_{\omega\pi}$ (GeV^{-2})	0.813 ± 0.004	0.844 ± 0.008	0.841 ± 0.007	
$\phi_{\omega\pi}$	1.4 ± 0.1	0.7 ± 0.1	0.6 ± 0.1	
$C_{\rho\pi}$ (GeV^{-2})	0.3 ± 0.2	0.1 ± 0.1	0.1 ± 0.2	
$\phi_{\rho\pi}$	3.1 ± 0.7	1.8 ± 2.5	1.5 ± 0.9	
M_ω (MeV)	782.1 ± 0.3	782.3 ± 0.3	782.1 ± 0.2	
δ_{b_ρ} (degree)	63 ± 9	56 ± 5	48 ± 8	
χ^2/ndf	$2944.4 / 2677$	$2718.7 / 2673$	$2702.0 / 2672$	
$P(\chi^2)$	0.18×10^{-3}	26.4%	33.8%	

Fit results: new K-loop parametrization

$f_0 + \sigma$ (M_σ fixed)

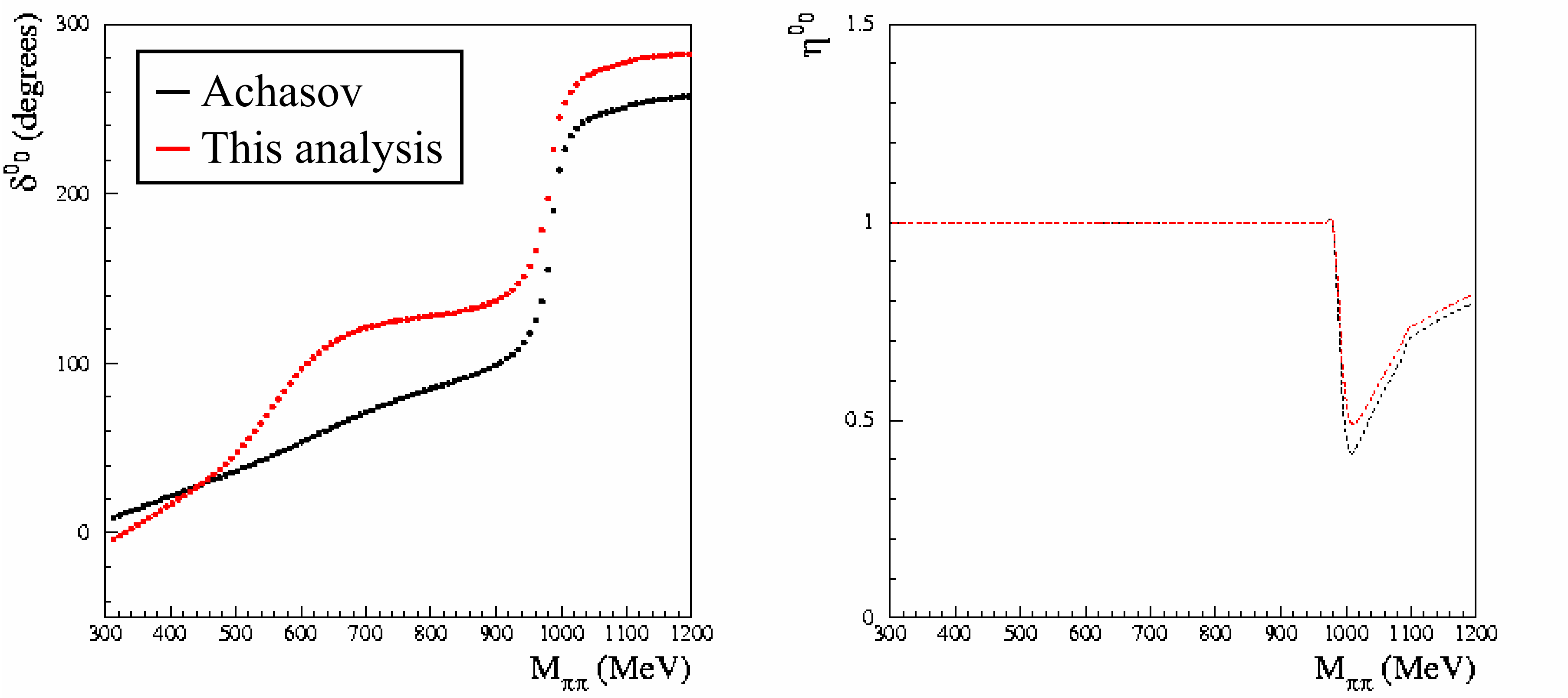


f_0 only



K-loop fit results: $f_0 + \sigma$ (M_σ fixed)

The fit parameters obtained in the $f_0+\sigma$ case do not give a good parametrization of δ_0^0



Achasov: **some theoretical restrictions** (analyticity of the amplitudes…) **have to be imposed in the fit**. We have to include them!

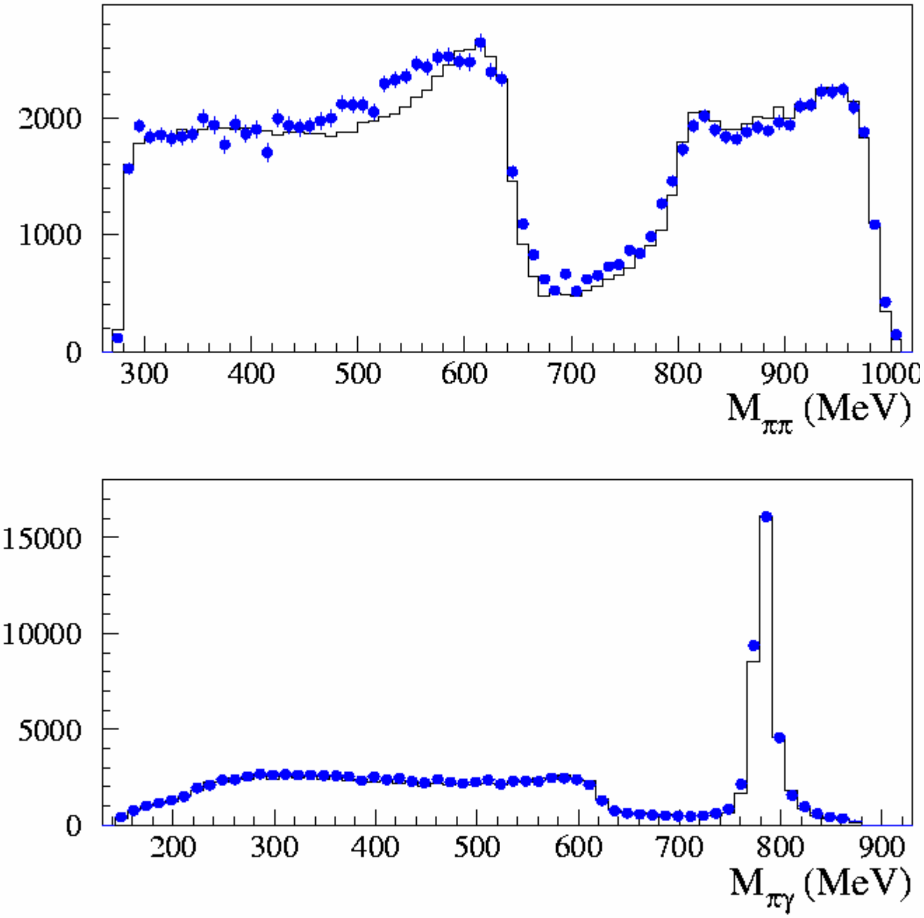
K-loop fit results: $f_0 + \sigma$

- Discussing with Achasov we realized that the parameters of σ and the kk, pp phases are very much related.

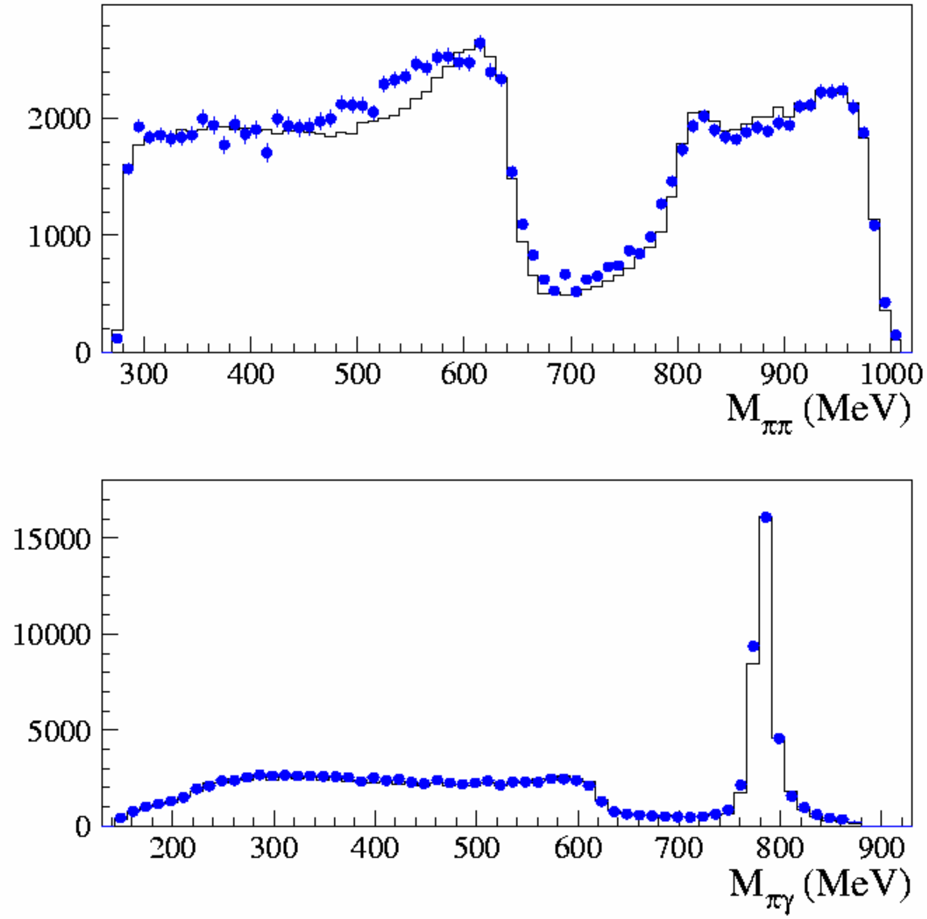
- To let them vary freely we should either fit also δ^0_0 or impose a lot of theory restrictions which are not so easy to implement in our fitting function.

- We therefore followed a much more simple approach:
  - (Fit A) we left free only the f_0 parameters + VDM
  - (Fit B) as (Fit A) leaving the sigma mass to vary

K-loop fit results: $f_0 + \sigma$ (MASSES)

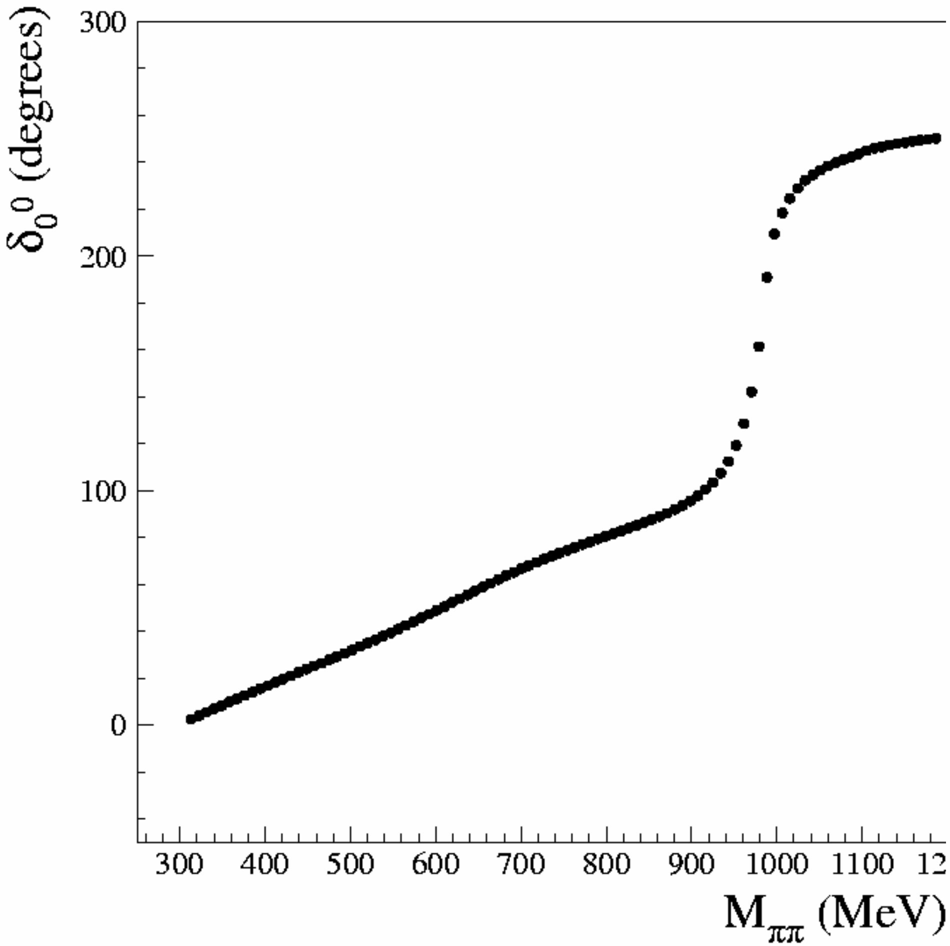


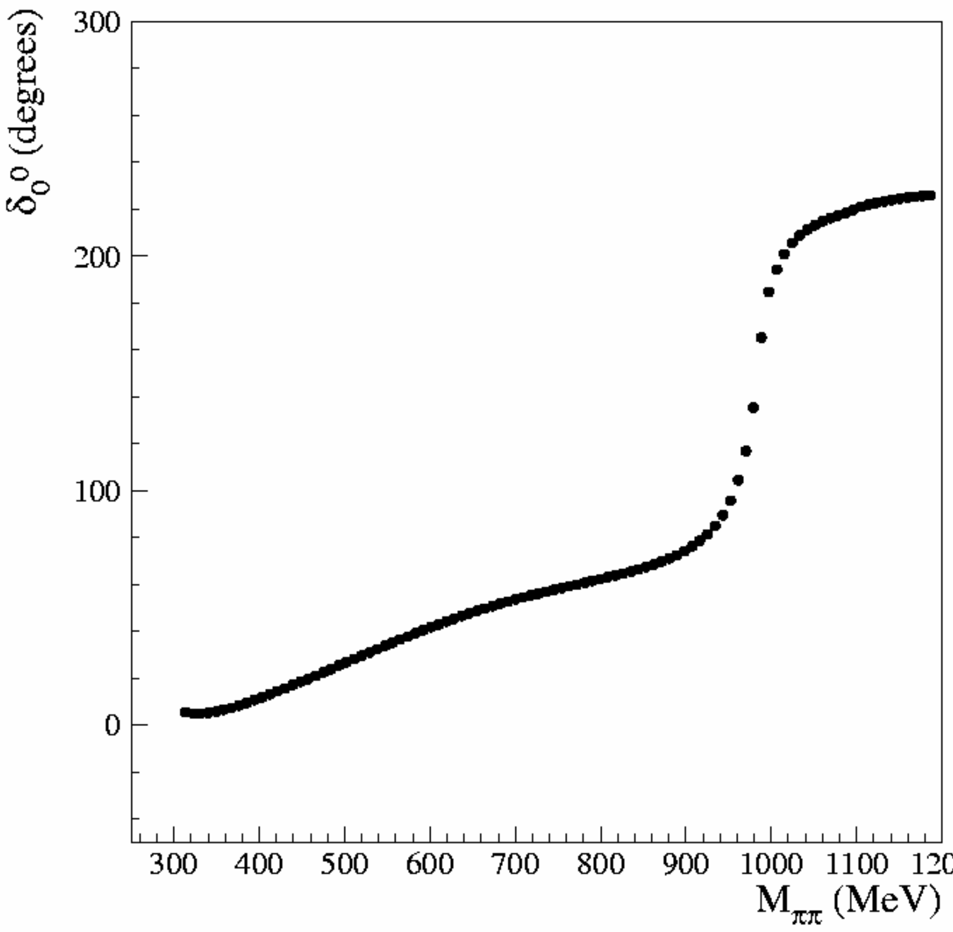
f0 + Vdm + Sigma FIXED



f0 + Vdm + Sigma Free

K-loop fit results: $f_0 + \sigma$ (phases)

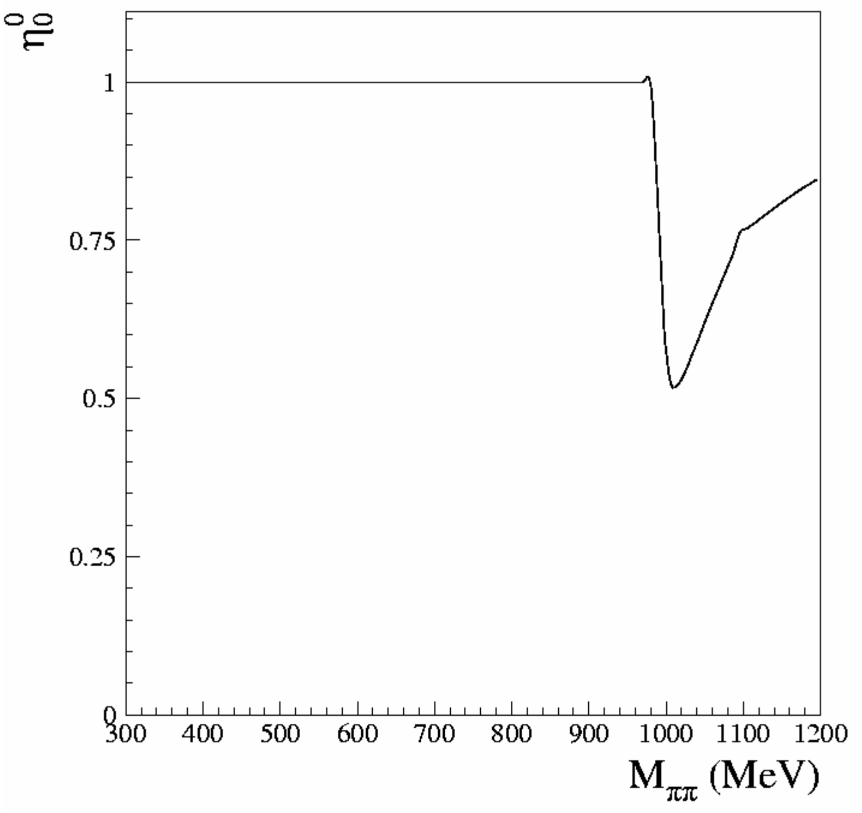


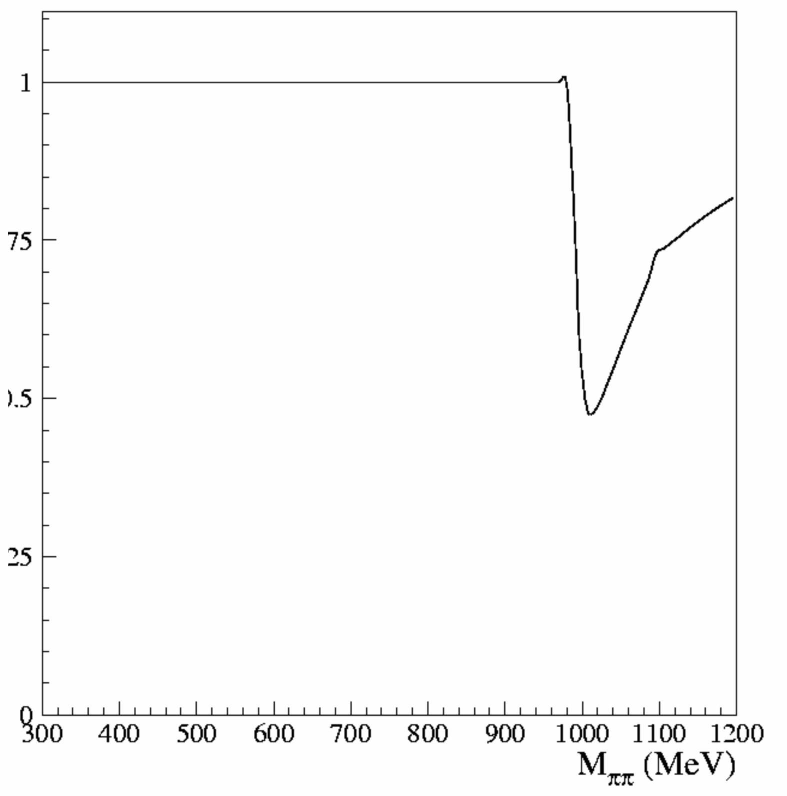


f0 + Vdm + Sigma FIXED

f0 + Vdm + Sigma Free

K-loop fit results: $f_0 + \sigma$ (phases)

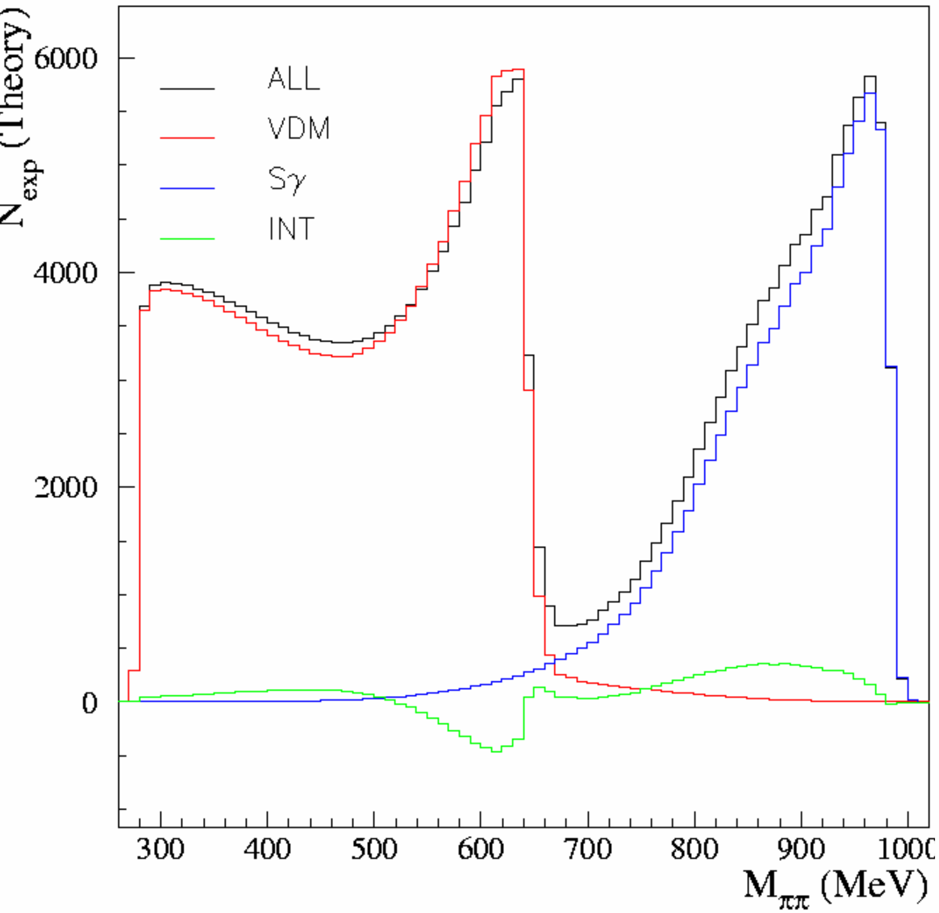


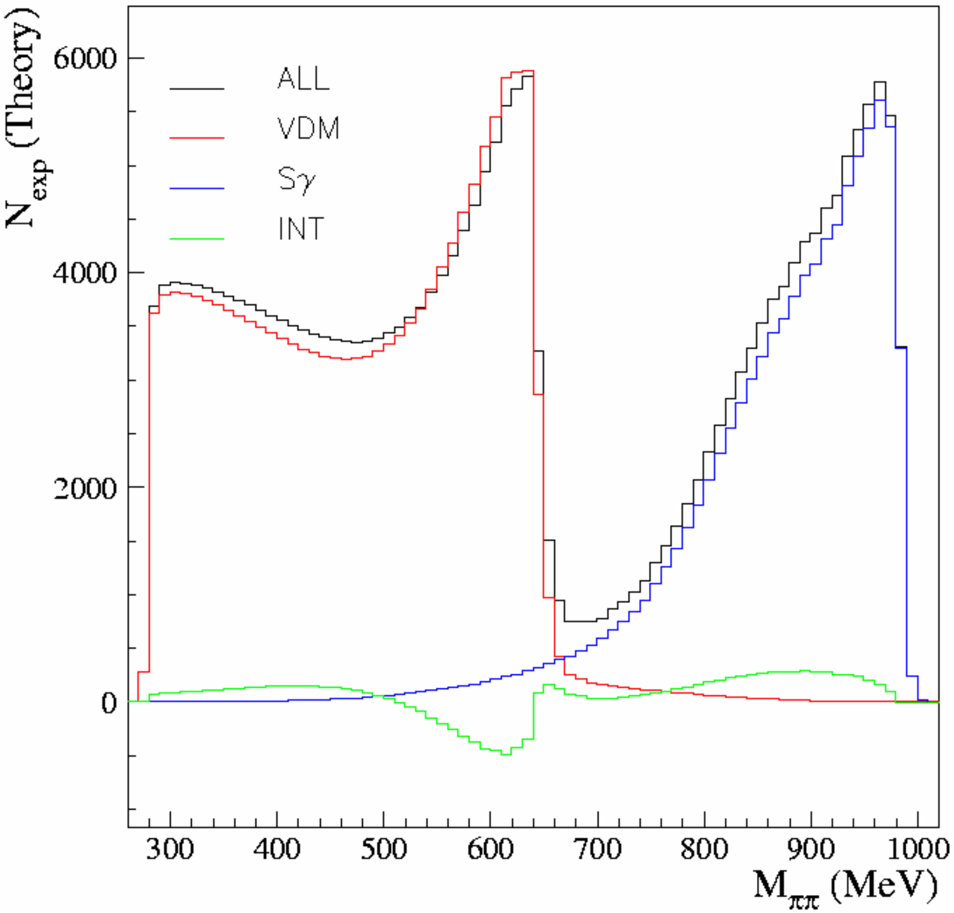


f0 + Vdm + Sigma FIXED

f0 + Vdm + Sigma Free

K-loop fit results: $f_0 + \sigma$ (compositions)





f0 + Vdm + Sigma FIXED

f0 + Vdm + Sigma Free

Fit results:

	$f_0 + \sigma$ (M_σ fixed)	**$f_0 + \sigma$ (M_σ free)**	**$f_0 \rightarrow \pi^+\pi^-$**
M_{f0} (MeV)	**987.1 ± 0.1**	**987.2 ± 0.1**	**981 – 985**
$g_{fK^+K^-}$ (GeV)	**3.53 ± 0.04**	**3.80 ± 0.07**	**3.9 – 6.5**
$g_{f\pi^+\pi^-}$ (GeV)	**–1.95 ± 0.01**	**–2.03 ± 0.01**	**2.8 – 3.8**
M_σ (MeV)	**541**	**484.6 ± 21.9**	
$\alpha_{\rho\pi}(\phi)$	0.76±0.18	0.69 ± 0.05	
$C_{\omega\pi}$ (GeV^{-2})	0.826 ±0.003	0.827 ± 0.001	
$\phi_{\omega\pi}$	0.21 ±0.03	0.47 ± 0.05	
$C_{\rho\pi}$ (GeV^{-2})	0.198 ±0.045	0.62 ± 0.23	
$\phi_{\rho\pi}$	3.14 ± 1.98	3.14 ±2.45	
M_ω (MeV)	**782.1 ± 0.3**	**782.2 ± 0.2**	
δ_{b_ρ} (degree)	7.5 ± 3.2	31.0 ± 4.0	
χ^2/ndf	2862/ 2676	2845 / 2675	
$P(\chi^2)$	0.6 %	**1.1 %**	

Conclusions

- **S-dependence of $\pi^0 \pi^0 \gamma$ x-sec done!**
- **KLOE memo submitted.**
- **Fit results to the Dalitz at 1019.6 with KL improved parametrization is reasonable !**
- **+ It has a good $\pi\pi$ phase behaviour.**
- **Other points at different $\sqrt{s}$ to be fit ….**

We will proceed with the writing of the dalitz-fit Documentation and then go for the final blessing