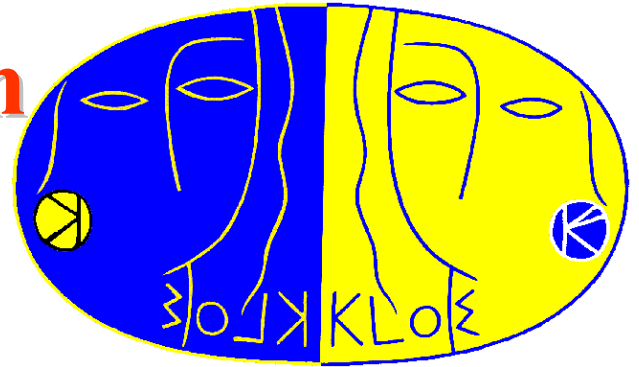


# Studies of radiative $\phi$ meson decays with KLOE



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**Contributed papers: [ABS183](#), [ABS184](#), [ABS185](#)**

## Outline

- **Scalars:**  $\phi \rightarrow f_0(980)\gamma$   
 $\phi \rightarrow a_0(980)\gamma$
- **Pseudoscalars:**  $\phi \rightarrow \eta'\gamma$  /  $\phi \rightarrow \eta\gamma$
- **Conclusions**

**31<sup>st</sup> International Conference on High Energy Physics**

**24-31 July 2002, Amsterdam**

# DAΦNE



- Frascati  $\phi$ -factory:  $e^+e^-$  collider  
 $\sqrt{s} \approx 1020 \text{ MeV} \approx M_\phi$  ;  $\sigma_{\text{peak}} \approx 3000 \text{ nb}$

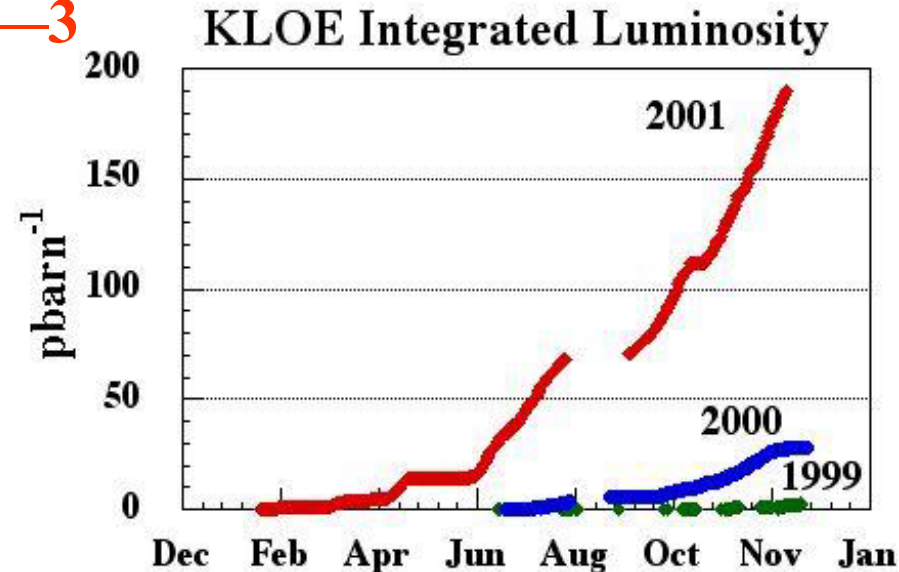
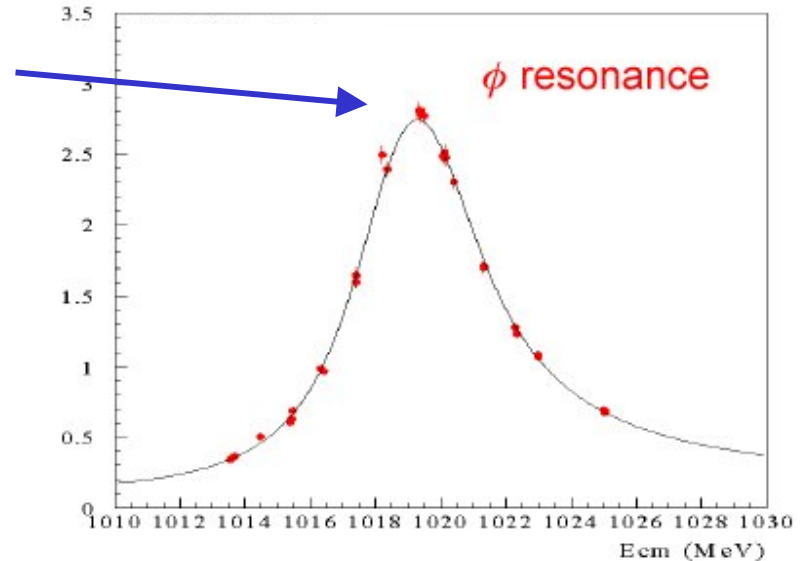
- 2001 performance: peak      average  
 $L(\text{cm}^{-2} \text{ s}^{-1})$        $5 \cdot 10^{31}$        $3.5 \cdot 10^{31}$   
 $\int_{\text{day}} L \text{ dt} (\text{pb}^{-1})$        $3$        $1.8$

- 2002 data taking started on  
 May 1<sup>st</sup>: same luminosity of 2001,  
**background reduction of a factor 2—3**

- Collected data:

2000:  $25 \text{ pb}^{-1} \rightarrow 7.5 \times 10^7 \phi$   
 (analysis completed)

2001:  $190 \text{ pb}^{-1} \rightarrow 5.7 \times 10^8 \phi$   
 (analysis in progress)



# KLOE

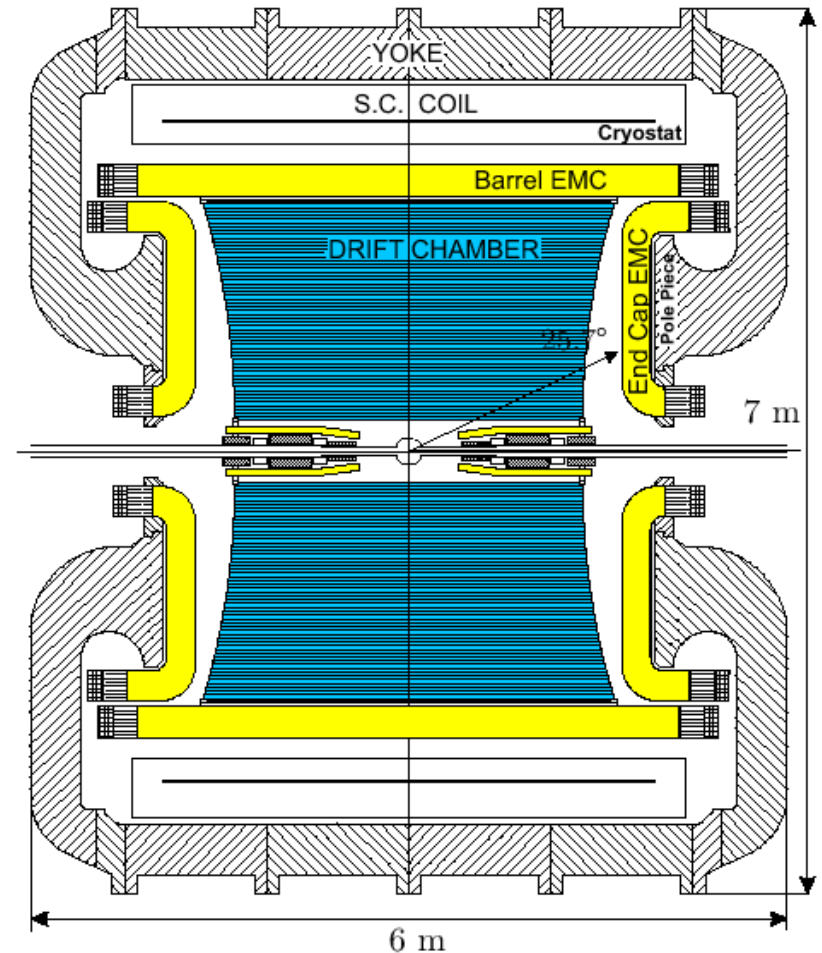


## Drift chamber:

- gas:  $\text{He-}i\text{C}_4\text{H}_{10}$
- $\delta p_T/p_T = 0.4\%$
- $\sigma_{xy} \approx 150 \mu\text{m}$  ;  $\sigma_z \approx 2 \text{ mm}$

## E.m. calorimeter (Pb-Sci.Fi.):

- $\sigma_E/E = 5.7\% / \sqrt{E(\text{GeV})}$
- $\sigma_t = 54 \text{ ps} / \sqrt{E(\text{GeV})} \oplus 50 \text{ ps}$
- 98% of  $4\pi$



Magnetic field: 0.52 T

# Scalar mesons ( $J^{PC} = 0^{++}$ )



- $f_0(980)$  ( $I=0$ )       $f_0 \rightarrow \pi^0\pi^0, \pi^+\pi^-$        $\Gamma = 40\text{—}100$  MeV
- $a_0(980)$  ( $I=1$ )       $a_0 \rightarrow \eta\pi$       “      “

$\Rightarrow$  not easily interpreted as  $q\bar{q}$  mesons ( $^3P_0$  nonet)

- **Other interpretations:  $q\bar{q}q\bar{q}$  states (Jaffe '77)**  
 **$K\bar{K}$  molecules (Weinstein-Isgur '90)**
- $\text{Br}(\phi \rightarrow f_0(980)\gamma)$  and  $\text{Br}(\phi \rightarrow a_0(980)\gamma)$  and the mass spectra are sensitive to the nature of these scalar particles:

	$q\bar{q}$	$q\bar{q}q\bar{q}$	$K\bar{K}$
$\text{Br}(\phi \rightarrow f_0\gamma)$	$5 \times 10^{-5}$	$3 \times 10^{-4}$	$10^{-5}$
$\text{Br}(\phi \rightarrow a_0\gamma)$	$2 \times 10^{-5}$	$2 \times 10^{-4}$	$10^{-5}$

- Studied decays (data sample:  $16 \text{ pb}^{-1}$  from the 2000 data,  $\sim 5 \times 10^7 \phi$ )

$\phi \rightarrow f_0\gamma$  ;  $f_0 \rightarrow \pi^0\pi^0 \Rightarrow 5 \gamma$  final state  
 $\phi \rightarrow a_0\gamma$  ;  $a_0 \rightarrow \eta\pi^0$        $\eta \rightarrow \gamma\gamma$       (39%)  $\Rightarrow 5 \gamma$  } Previous meas. at VEPP2M  
 $\phi \rightarrow a_0\gamma$  ;  $a_0 \rightarrow \eta\pi^0$        $\eta \rightarrow \pi^+\pi^-\pi^0$       (23%)  $\Rightarrow 2 \text{ ch. tracks} + 5 \gamma$

first observation  $\leftarrow$



# 5 $\gamma$ final state

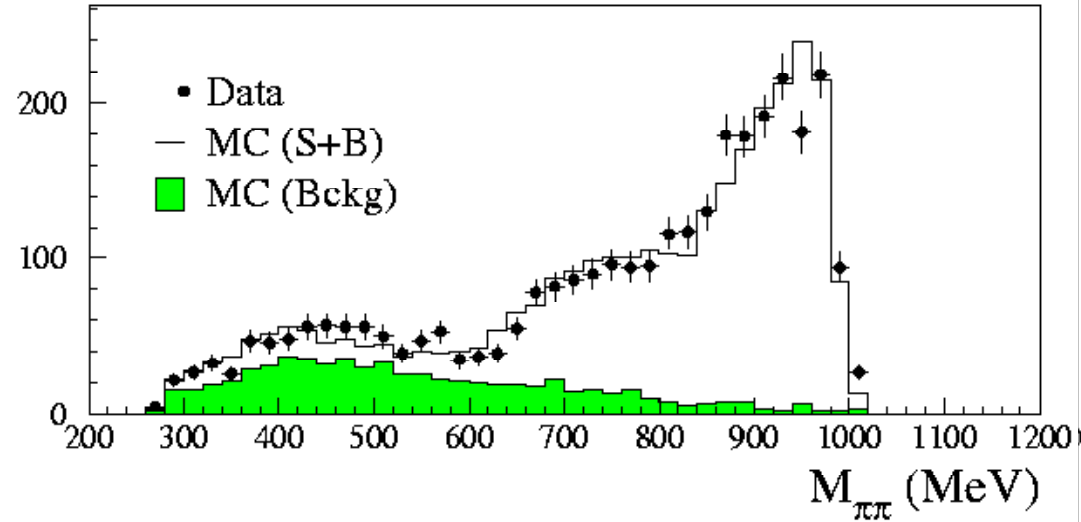
cross sect.(nb)

- **Signal:**  $\phi \rightarrow \pi^0 \pi^0 \gamma$  ( $\phi \rightarrow f_0 \gamma$  ;  $\phi \rightarrow \sigma(500) \gamma$  ;  $\phi \rightarrow \rho^0 \pi^0$ )  
 $\hookrightarrow \pi^0 \pi^0$   $\hookrightarrow \pi^0 \gamma$  ~ 0.35
- $\phi \rightarrow \eta \pi^0 \gamma$  ( $\phi \rightarrow a_0 \gamma$  ;  $\phi \rightarrow \rho^0 \pi^0$ )  
 $\hookrightarrow \eta \gamma$  ~ 0.1
- **Background:**  $e^+ e^- \rightarrow \omega \pi^0 \rightarrow \pi^0 \pi^0 \gamma$  ( $\omega \rightarrow \pi^0 \gamma$ ) ~ 0.5
- $\phi \rightarrow \eta \gamma \rightarrow 3 \gamma$  (with accidental  $\gamma$ 's) (~17)
- $\phi \rightarrow \eta \gamma \rightarrow \pi^0 \pi^0 \pi^0 \gamma$  (with 2 $\gamma$  lost) (~14)
- **Sample selection:**
  - exactly 5 prompt photons
  - $E_\gamma > 7$  MeV
  - $|\cos\vartheta| < 0.93$  to avoid the quadrupole region
  - $\sum_5 E_i > 700$  MeV to reject  $\phi \rightarrow K_L K_S \rightarrow$  neutrals

# $\phi \rightarrow \pi^0 \pi^0 \gamma$



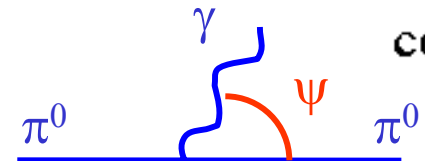
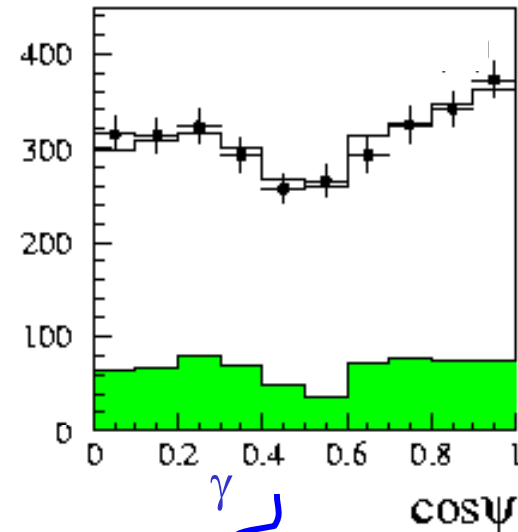
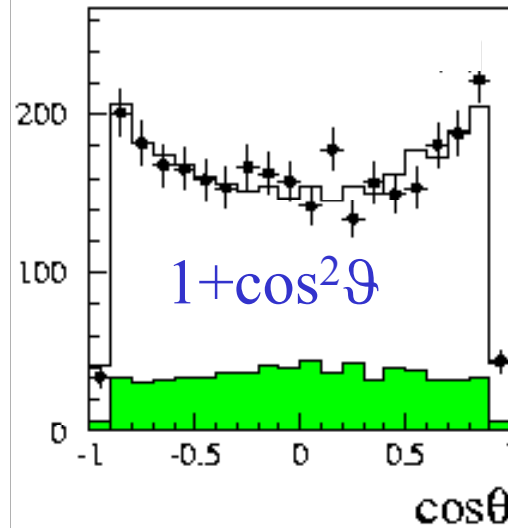
- **Constrained kinematic fit to improve resolutions**
- **Photon pairing**
- $|M_{\gamma\gamma} - M_{\pi}| < 5\sigma(M_{\pi})$
- **Reject events with:**  
 $|M_{\pi\gamma} - M_{\omega}| < 3\sigma(M_{\omega})$



$\Rightarrow$  **3102 events**  
 $\langle \epsilon \rangle = 40\%$

**Estimated backgr. (~20%)**

$e^+e^- \rightarrow \omega \pi^0 \rightarrow \pi^0 \pi^0 \gamma$	$339 \pm 24$
$\phi \rightarrow \eta \pi^0 \gamma$	$166 \pm 16$
$\phi \rightarrow \eta \gamma \rightarrow \pi^0 \pi^0 \pi^0 \gamma$	$159 \pm 12$



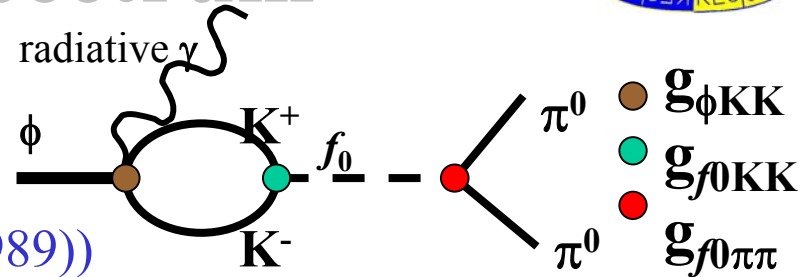
# Fit to $M_{\pi\pi}$ spectrum



## • Model :

1)  $\phi \rightarrow f_0 \gamma$  dominated by kaon loop

(Achasov-Ivanchenko, Nucl.Phys.B315(1989))



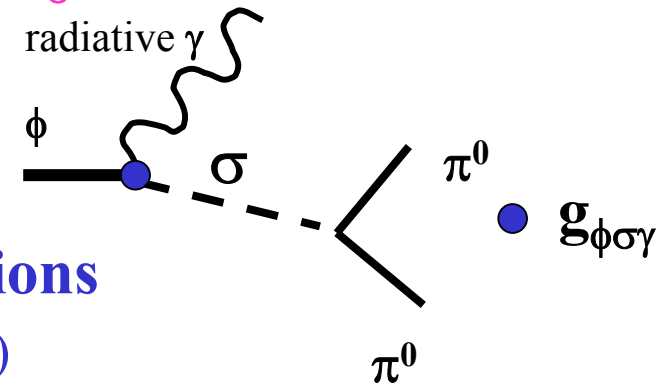
2)  $f_0$  propagator with finite width corrections

3)  $\sigma(500) \Rightarrow$  B-W with  $M_\sigma = 478$  MeV and  $\Gamma_\sigma = 324$  MeV

(Fermilab E791-Phys.Rev.Lett.86(2001)770)

4) point-like coupling of  $\sigma(500)$  to  $\phi$

(Gokalp, Yilmaz, Phys.Rev.D64(2001))



5)  $\rho\pi$  + interference term parameterizations

from Achasov-Gubin, (Phys.Rev.D63(2001))

## • Two fits:

Fit A :  $|(\phi \rightarrow f_0 \gamma) + (\phi \rightarrow \rho^0 \pi^0)|^2$

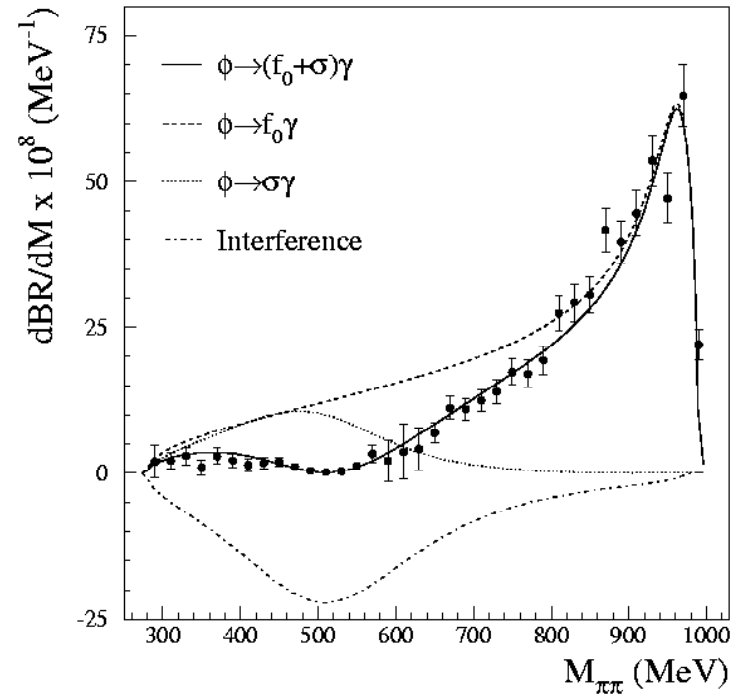
Fit B :  $|(\phi \rightarrow f_0 \gamma) + (\phi \rightarrow \sigma \gamma) + (\phi \rightarrow \rho^0 \pi^0)|^2$

Free parameters:  $M_{f_0}$ ,  $g_{f_0 KK}^2$ ,  $g_{f_0 \pi\pi}^2 / g_{f_0 KK}^2$ ,  $g_{\phi\sigma\gamma}$  and  $\text{Br}(\phi \rightarrow \rho^0 \pi^0 \rightarrow \pi^0 \pi^0 \gamma)$



# Fit results

	A	B
$\chi^2/\text{ndf}$	109.5/33	43.2/32
$M_{f_0}$ (MeV)	$962 \pm 4$	$973 \pm 1$
$g^2_{f_0\text{KK}}/(4\pi)$ (GeV <sup>2</sup> )	$1.29 \pm 0.14$	$2.79 \pm 0.12$
$g^2_{f_0\text{KK}}/g^2_{f_0\pi\pi}$	$3.22 \pm 0.29$	$4.00 \pm 0.14$
$g_{\phi\sigma\gamma}$	—	$0.060 \pm 0.008$



$\rho\pi$  contribution  $\Rightarrow$  negligible

$$\text{Br}(\phi \rightarrow \pi^0 \pi^0 \gamma) = (1.09 \pm 0.03 \pm 0.05) \times 10^{-4} \text{ (Fit B)}$$

(SND:  $(1.22 \pm 0.10 \pm 0.06) \times 10^{-4}$  ; CMD-2:  $(1.08 \pm 0.17 \pm 0.09) \times 10^{-4}$ )

$\Rightarrow$  Large  $f_0$ - $\sigma$  destructive interference at  $M_{\pi\pi} < 700$  MeV

(see also the work of Gokalp and Yilmaz (Phys.Rev.D64(2001)on the SND spectrum)





# $\phi \rightarrow \eta \pi^0 \gamma$ (with $\eta \rightarrow \gamma \gamma$ )

- **Constrained kinematic fit to improve resolutions**
- **Photon pairing: (1)  $\pi^0 \pi^0 \gamma$  ; (2)  $\eta \pi^0 \gamma$**   
 $\Rightarrow$  **reject  $\pi^0 \pi^0 \gamma$  events**
- $M_{\pi \pi} < 760$  MeV (reject  $f_0 \gamma$  events)
- $|M_{\gamma \gamma} - M_{\eta}| < 3\sigma(M_{\eta})$

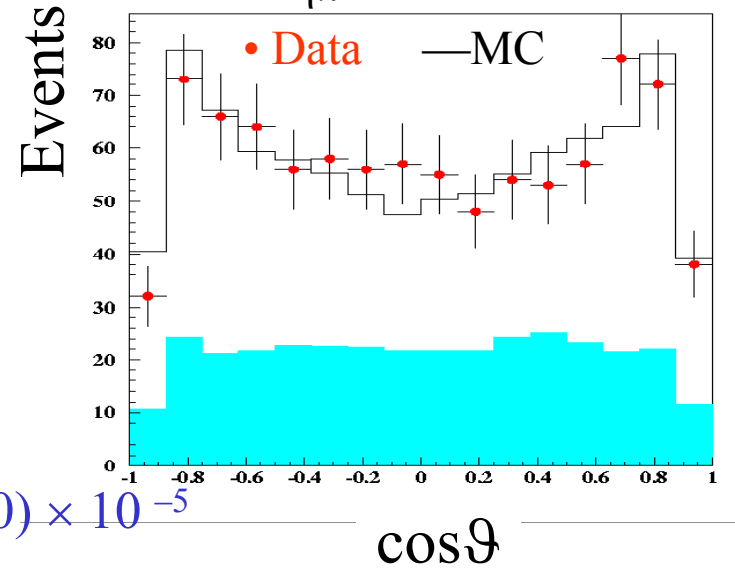
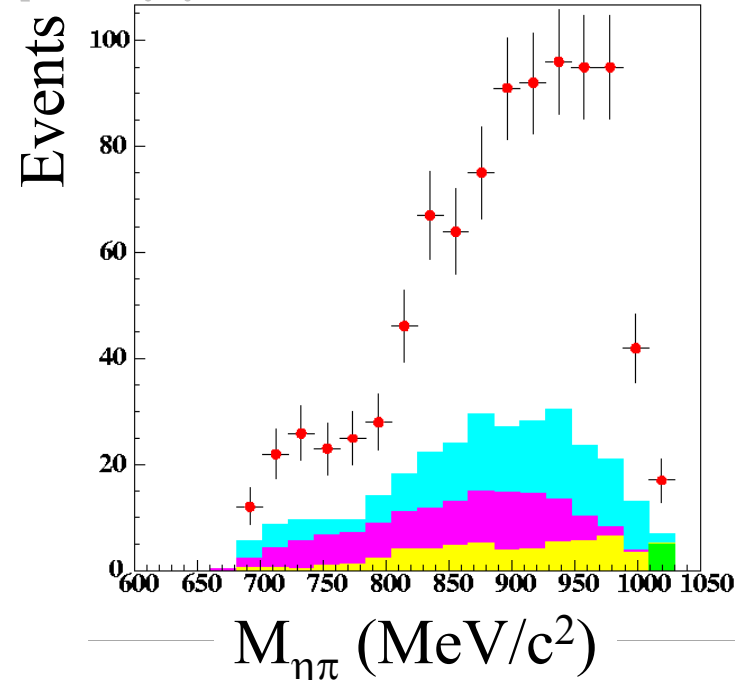
$\Rightarrow$  **916 events**

$\langle \epsilon \rangle = 32 \%$

• Estimated backgr.: (~30%)	
$e^+e^- \rightarrow \omega \pi^0 \rightarrow \pi^0 \pi^0 \gamma$	$54 \pm 6$
$\phi \rightarrow \pi^0 \pi^0 \gamma$	$152 \pm 16$
$\phi \rightarrow \eta \gamma \rightarrow \pi^0 \pi^0 \pi^0 \gamma$	$98 \pm 10$
$\phi \rightarrow \eta \gamma \rightarrow \gamma \gamma$	$5 \pm 2$

$$\text{Br}(\phi \rightarrow \eta \pi^0 \gamma) = (8.51 \pm 0.51 \pm 0.57) \times 10^{-5}$$

SND :  $(8.8 \pm 1.4 \pm 0.9) \times 10^{-5}$  ; CMD-2:  $(9.0 \pm 2.4 \pm 1.0) \times 10^{-5}$



# $\phi \rightarrow \eta \pi^0 \gamma \rightarrow \pi^+ \pi^- + 5\gamma$ ( $\eta \rightarrow \pi^+ \pi^- \pi^0$ )



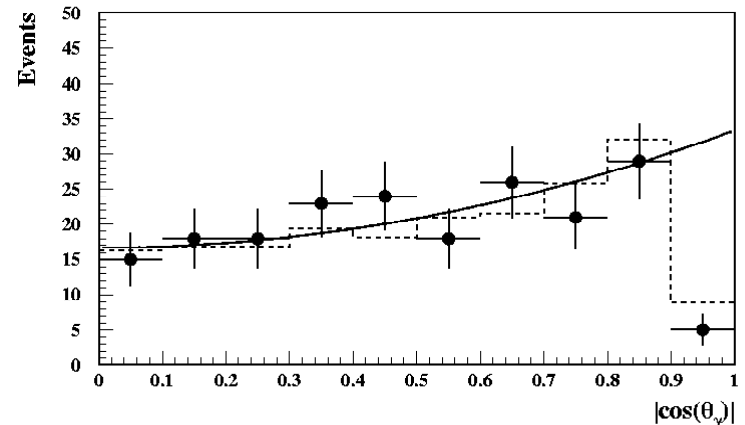
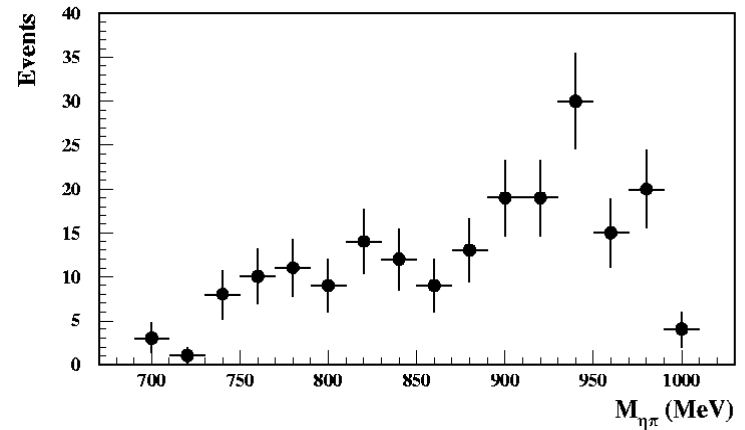
- No background with the same final state
- Backgr.: 2 Tracks + 3/4 photons ( $e^+e^- \rightarrow \omega \pi^0$  ;  $\omega \rightarrow \pi^+ \pi^- \pi^0$ )  
( $\phi \rightarrow \eta \gamma$  ;  $\eta \rightarrow \pi^+ \pi^- \pi^0$ )

2 Tracks + 6 photons  
( $\phi \rightarrow K_S K_L \rightarrow \pi^+ \pi^- \pi^0 \pi^0 \pi^0$ )

- 1 vertex in IR with 2 tracks
- 5 prompt  $\gamma$  ( $E > 10$  MeV,  $|\cos\vartheta| < 0.93$ )
- Constrained kinematic fit
- $M_{\pi^+\pi^-} < 425$  MeV (reject  $K_S \rightarrow \pi^+\pi^-$ )

$\Rightarrow$  197 events       $\langle \epsilon \rangle = 19\%$   
estimated backgr.  $4 \pm 4$  events

$$\text{Br}(\phi \rightarrow \eta \pi^0 \gamma) = (7.96 \pm 0.60 \pm 0.47) \times 10^{-5}$$



# Fit to the $M_{\eta\pi}$ spectra

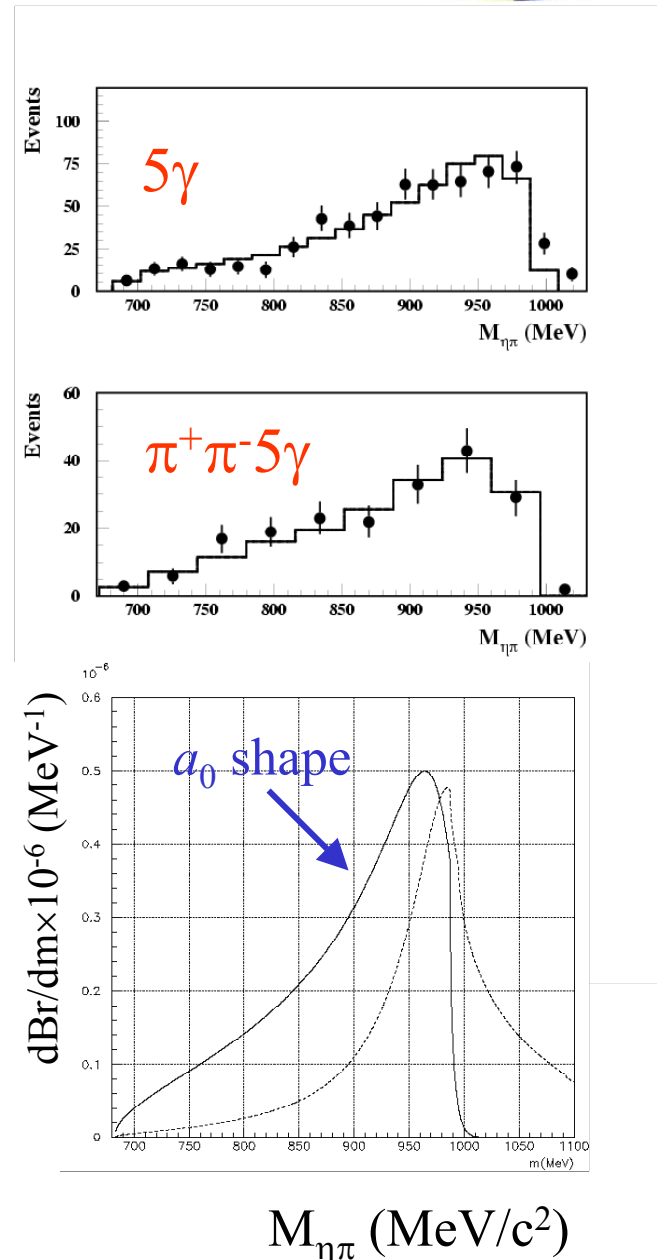


- Same model as for the  $f_0$  (kaon loop)
- Combined fit, relative normalization fixed to  $\text{Br}(\eta \rightarrow \gamma\gamma)/\text{Br}(\eta \rightarrow \pi^+\pi^-\pi^0)$
- Free parameters:

$g^2_{a_0KK}$ ,  $g_{a_0\eta\pi}/g_{a_0KK}$  and  $\text{Br}(\phi \rightarrow \rho^0\pi^0 \rightarrow \eta\pi^0\gamma)$   
 $M_{a_0} = 984.8 \text{ MeV}$  (PDG) fixed

$\chi^2/\text{ndf}$	27.2/25
$g^2_{a_0KK}/(4\pi) \text{ (GeV}^2\text{)}$	$0.40 \pm 0.04$
$g_{a_0\eta\pi}/g_{a_0KK}$	$1.35 \pm 0.09$
$\text{Br}(\phi \rightarrow \rho^0\pi^0 \rightarrow \eta\pi^0\gamma)$	$(0.5 \pm 0.5) \times 10^{-5}$

$$\text{Br}(\phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma) = (7.4 \pm 0.7) \times 10^{-5}$$



$M_{\eta\pi} \text{ (MeV/c}^2\text{)}$

# Summary of fit results



- Comparison with predictions from Achasov-Ivanchenko, Nucl.Phys.B315(1989)

	KLOE	$s\bar{s}(u\bar{u} + d\bar{d})/\sqrt{2}$	$(u\bar{u} + d\bar{d})/\sqrt{2}$	$s\bar{s}$
$f_0$ model				
$g^2_{f_0KK}/(4\pi)$ (GeV <sup>2</sup> )	2.79±0.12	2.3 (=g <sup>2</sup> <sub>a0KK</sub> /4π)	0.15 (=g <sup>2</sup> <sub>a0KK</sub> /4π)	0.3 (=2g <sup>2</sup> <sub>a0KK</sub> /4π)
$g_{f_0\pi\pi}/g_{f_0KK}$	0.50±0.01	0.3—0.5	2	0.5
Br(φ→π <sup>0</sup> π <sup>0</sup> γ)×10 <sup>4</sup>	1.09±0.07	~ 1	~ 0.15	~ 0.2
		$s\bar{s}(u\bar{u} - d\bar{d})/\sqrt{2}$	$(u\bar{u} - d\bar{d})/\sqrt{2}$	
$a_0$ model				
$g^2_{a_0KK}/(4\pi)$ (GeV <sup>2</sup> )	0.40±0.04	2.3 (=g <sup>2</sup> <sub>f_0KK</sub> /4π)	0.15 (=g <sup>2</sup> <sub>f_0KK</sub> /4π)	
$g_{a_0\eta\pi}/g_{a_0KK}$	1.35±0.09	0.91	1.53	
Br(φ→a <sub>0</sub> γ)×10 <sup>4</sup>	0.74±0.07	~ 2	~ 0.2	

- $f_0$  parameters are compatible with  $q\bar{q}q\bar{q}$  model
- $a_0$  parameters seem not compatible with  $q\bar{q}q\bar{q}$  model



# $\phi \rightarrow \eta' \gamma / \phi \rightarrow \eta \gamma$

- The mass eigenstates  $\eta$ ,  $\eta'$  are related to the SU(3) octet-singlet  $\eta_8$ ,  $\eta_1$  through the mixing angle  $\vartheta_P$
- Recent studies based on  $\chi$ PT and phenomenological analyses suggested a two mixing angle scenario
- In the quark flavour basis the two mixing angles are almost equal  $\Rightarrow$  mixing is described by only one parameter ( $\varphi_P$ )

$$\eta = \cos \varphi_P \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle - \sin \varphi_P |s\bar{s}\rangle$$

$$\eta' = \sin \varphi_P \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle + \cos \varphi_P |s\bar{s}\rangle$$

$\varphi_P$  can be extracted from the ratio (Bramon et al., Eur.Phys.J.C7(1999)) :

$$\mathbf{R} = \frac{\text{Br}(\phi \rightarrow \eta' \gamma)}{\text{Br}(\phi \rightarrow \eta \gamma)} = \cotg^2 \varphi_P \left( 1 - \frac{m_s}{\bar{m}} \frac{\text{tg} \varphi_V}{\sin 2\varphi_P} \right)^2 \left( \frac{\mathbf{p}_{\eta'}}{\mathbf{p}_{\eta}} \right)^3 ; \left( \frac{m_s}{\bar{m}} = 1.45 \right)$$

- $\text{Br}(\phi \rightarrow \eta' \gamma)$  can probe the gluonic content of  $\eta'$



# $\phi \rightarrow \eta' \gamma / \phi \rightarrow \eta \gamma$

- Same final state  $\pi^+ \pi^- 3\gamma$ :

$\phi \rightarrow \eta \gamma ; \eta \rightarrow \pi^+ \pi^- \pi^0 ; \pi^0 \rightarrow \gamma \gamma$

$\text{Br} \approx 3 \times 10^{-3}$

$\phi \rightarrow \eta' \gamma ; \eta' \rightarrow \pi^+ \pi^- \eta ; \eta \rightarrow \gamma \gamma$

$\text{Br} \approx 2 \times 10^{-5}$

- Backgr.:  $\phi \rightarrow K_L K_S$  (with  $K_L$  decaying near the IP),  $\phi \rightarrow \pi^+ \pi^- \pi^0$

- Data sample :  $16 \text{ pb}^{-1}$  from the 2000 data ( $\sim 5 \times 10^7 \phi$ )

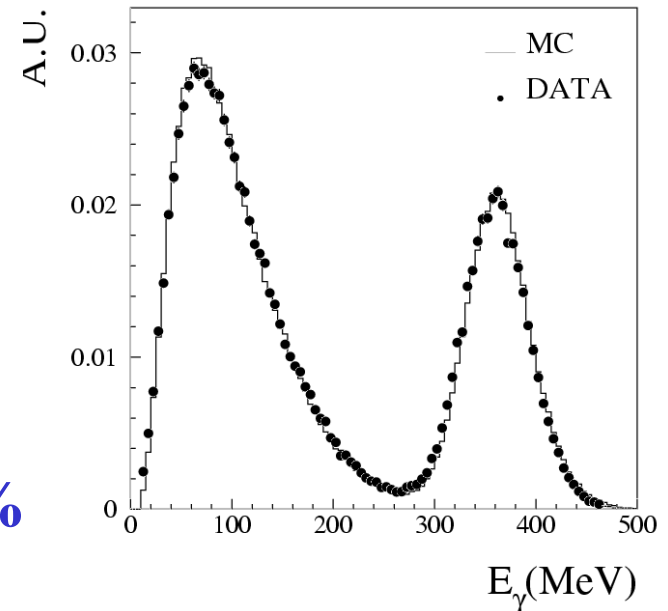
- 1 vertex in IR with 2 tracks
- 3 prompt  $\gamma$  ( $E > 10 \text{ MeV}$ ,  $|\cos \vartheta| < 0.93$ )
- Constrained kinematic fit

$\phi \rightarrow \eta \gamma$ :

- $320 < E_{\gamma}^{\text{rad}} < 400 \text{ MeV}$

- $E_{\pi^+} + E_{\pi^-} < 550 \text{ MeV}$  (reject  $\pi^+ \pi^- \pi^0$ )

$\Rightarrow N(\eta \gamma) = 50210 \pm 220 \text{ events} \quad \varepsilon = 37 \%$

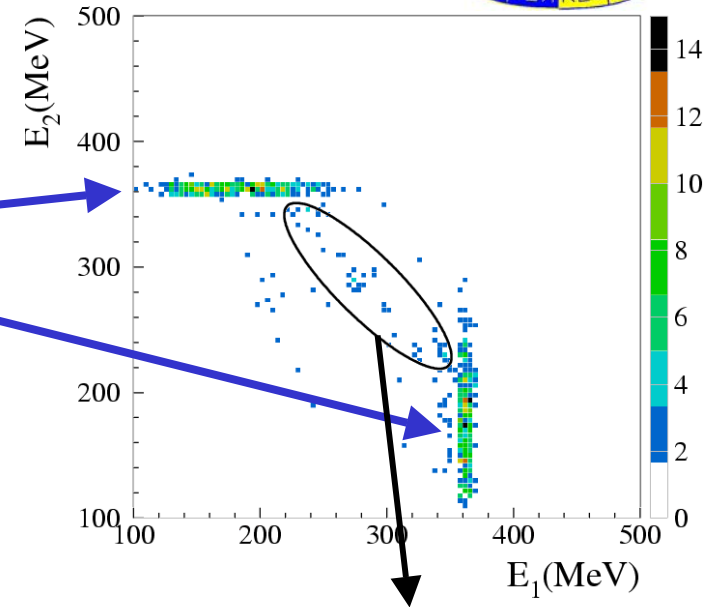


# $\phi \rightarrow \eta' \gamma / \phi \rightarrow \eta \gamma$



## $\phi \rightarrow \eta' \gamma$ :

- Main background is  $\phi \rightarrow \eta \gamma$
- Selection: elliptic cut in the plane of the two most energetic photons

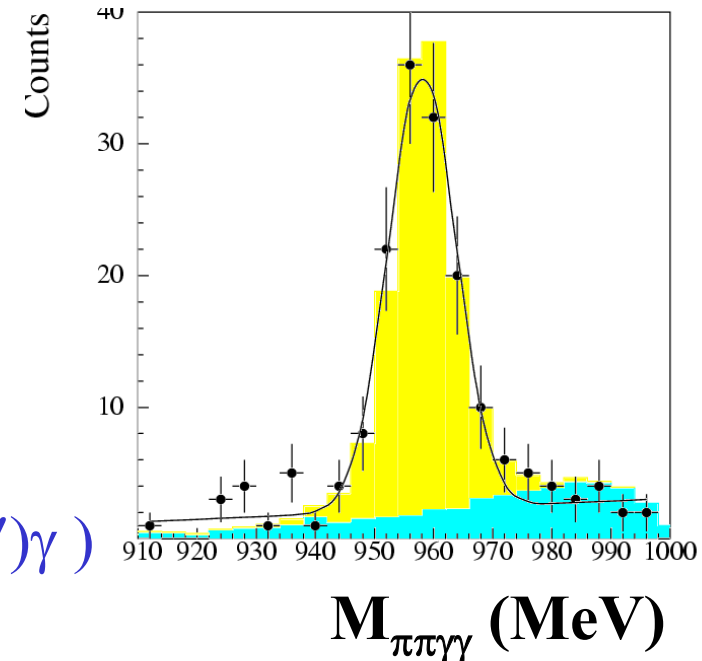


$N(\eta' \gamma) = 120 \pm 12 \pm 5$  events  $\epsilon = 23 \%$

$$R = \frac{N_{\eta' \gamma}}{N_{\eta \gamma}} \frac{\epsilon_{\eta \gamma}}{\epsilon_{\eta' \gamma}} \frac{\text{Br}(\eta \rightarrow \pi^+ \pi^- \pi^0) \text{Br}(\pi^0 \rightarrow \gamma \gamma)}{\text{Br}(\eta' \rightarrow \pi^+ \pi^- \eta) \text{Br}(\eta \rightarrow \gamma \gamma)} F_\rho =$$

$$= (4.70 \pm 0.47 \pm 0.31) \times 10^{-3}$$

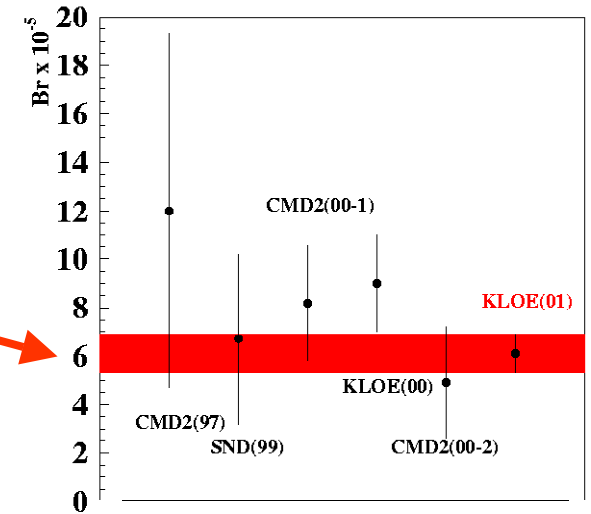
- $F_\rho = 0.95$  (interference with  $e^+ e^- \rightarrow \rho \rightarrow \eta(\eta') \gamma$ )





# $\phi \rightarrow \eta' \gamma / \phi \rightarrow \eta \gamma$

- **Mixing angle:**  $\varphi_P = (41.8 \pm 1.7)^\circ$   
 $\Rightarrow \vartheta_P = (-12.9 \pm 1.7)^\circ$
- **Using  $\text{Br}(\phi \rightarrow \eta \gamma) = (1.297 \pm 0.003) \%$  (PDG)**  
 $\Rightarrow \text{Br}(\phi \rightarrow \eta' \gamma) = (6.10 \pm 0.67 \pm 0.45) \times 10^{-5}$   
 PDG :  $(6.7^{+5.3}_{-3.1}) \times 10^{-5}$



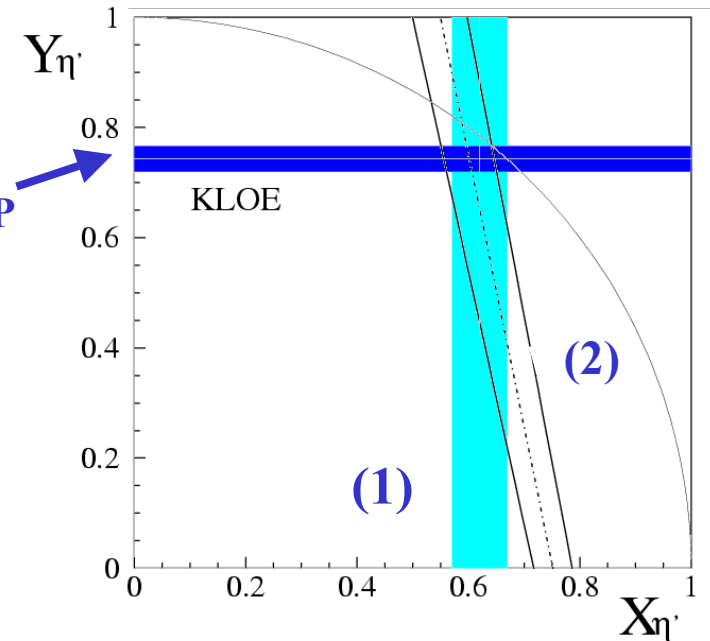
- **Gluonic content of  $\eta'$ :**

$$\eta' = X_{\eta'} \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle + Y_{\eta'} |s\bar{s}\rangle + Z_{\eta'} |\text{glue}\rangle$$

**Consistency check:** if  $Z_{\eta'} = 0 \Rightarrow |Y_{\eta'}| = \cos \varphi_P$   
 other constraints on  $X_{\eta'}$  and  $Y_{\eta'}$  from:

- (1)  $\Gamma(\eta' \rightarrow \rho \gamma) / \Gamma(\omega \rightarrow \pi^0 \gamma)$
- (2)  $\Gamma(\eta' \rightarrow \gamma \gamma) / \Gamma(\pi^0 \rightarrow \gamma \gamma)$

$$\Rightarrow X_{\eta'}^2 + Y_{\eta'}^2 = 0.94^{+0.06}_{-0.09}$$





# Conclusions



- With the 2000 data KLOE studied the radiative decays of the  $\phi$  into scalar and pseudoscalar mesons
- We measured the branching ratios of :
  - $\phi \rightarrow \pi^0 \pi^0 \gamma \quad \Rightarrow \quad \text{Phys.Lett.B537(2002)}$
  - $\phi \rightarrow \eta \pi^0 \gamma \quad \Rightarrow \quad \text{“ “ B536(2002)}$
- reducing the experimental uncertainties
- We evaluated the couplings of  $f_0$  ( $a_0$ ) to  $K\bar{K}$  and to  $\pi\pi$  ( $\eta\pi$ ) from the fit to the invariant mass spectra
- Pseudoscalar mixing angle in the quark flavor basis, and best measurement of  $\text{Br}(\phi \rightarrow \eta' \gamma) \Rightarrow \text{Phys.Lett.B541(2002)}$
- Other KLOE results:  $K_S \rightarrow \pi e \nu$  (Phys. Lett.B535(2002)),  
 $\Gamma(K_S \rightarrow \pi^+ \pi^- (\gamma)) / \Gamma(K_S \rightarrow \pi^0 \pi^0)$  (Phys.Lett.B538(2002))
- Analysis on 2001 data ( $190 \text{ pb}^{-1}$ ) is in progress, results on  $f_0 \rightarrow \pi^+ \pi^-$  are also expected, other  $300 \text{ pb}^{-1}$  from 2002 data taking are foreseen

# Comparison with other experiments



	← $\phi$ decays →			← other →	
$f_0$	KLOE	SND <sup>(1)</sup>	CMD-2 <sup>(1)</sup>	WA102 <sup>(2)</sup>	E791 <sup>(3)</sup>
$M_{f_0}$ (MeV)	973±1	970±5	975±7	987±8	977±4
$g^2_{f_0KK}/(4\pi)$ (GeV <sup>2</sup> )	2.79±0.12	2.47±0.73	1.48±0.32	0.39±0.06	0.02±0.05
$g^2_{f_0KK}/g^2_{f_0\pi\pi}$	4.00±0.14	4.6±0.8	3.61±0.62	1.63±0.46	0.2±0.5
$g_{\phi\sigma\gamma}$	0.060 ±0.008				
$a_0$	KLOE	SND		E852 <sup>(4)</sup>	Crystal Barrel <sup>(5)</sup>
$M_{a_0}$ (MeV)	984.8 (fixed)	995 <sup>+52</sup> <sub>-10</sub>		991±3	999±6
$g^2_{a_0KK}/(4\pi)$ (GeV <sup>2</sup> )	0.40±0.04	1.4 <sup>+9.4</sup> <sub>-0.9</sub>		0.22±0.03	
$g_{a_0n\pi}/g_{a_0KK}$	1.35±0.09	0.75±0.52		1.05±0.06	0.93—1.07

(1)  $f_0\gamma \oplus \rho\pi$ ;  $\sigma$  contribution negligible (CMD2: combined  $f_0 \rightarrow \pi^0\pi^0$   $f_0 \rightarrow \pi^+\pi^-$ )

(2) WA102 (CERN): centrally produced  $K^+K^-$ ,  $\pi^+\pi^-$  in pp at 450 GeV/c

(3) E791 (Fermilab):  $f_0$  production in  $D^{\pm}_S \rightarrow \pi^-\pi^+\pi^{\pm}$

(4) E852 (BNL):  $a_0$  production in  $\pi^-p \rightarrow \eta\pi^+\pi^-n$  and  $\pi^-p \rightarrow \eta\pi^0n$  at 18.3 GeV/c

(5)  $\bar{p}p \rightarrow \pi^0\pi^0\eta$

# Scalar mesons ( $J^{PC} = 0^{++}$ )

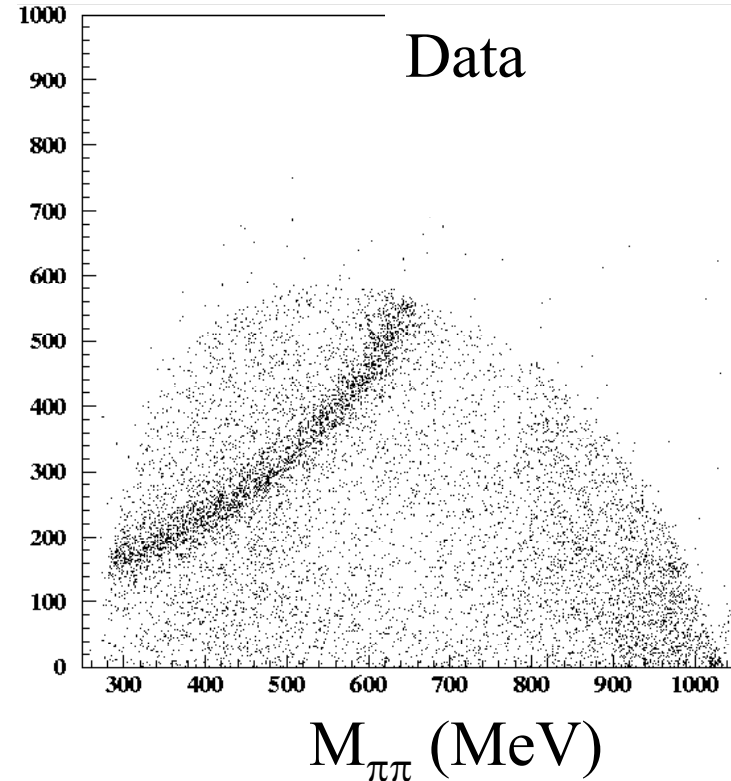
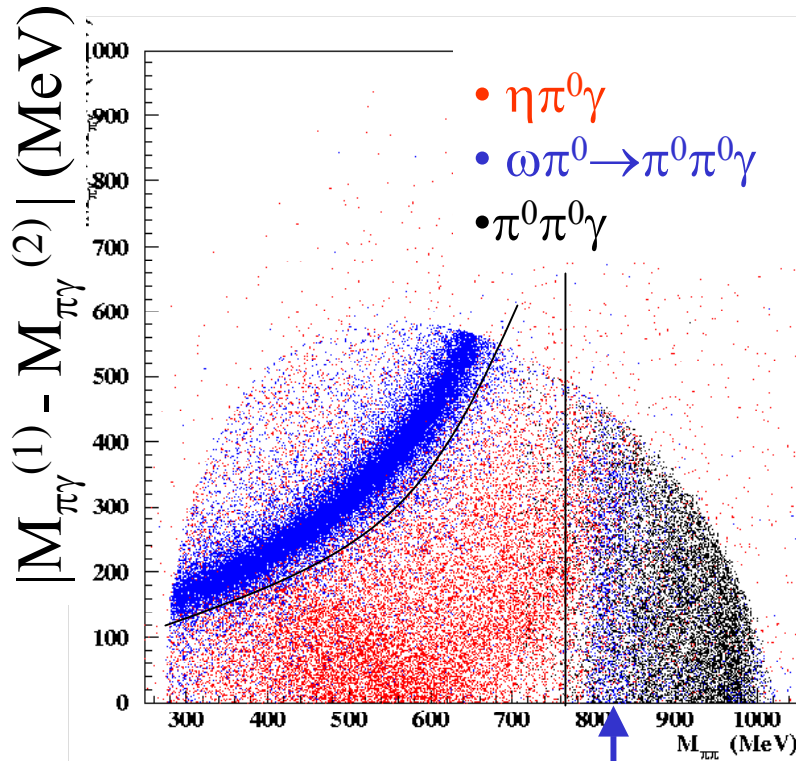


- $f_0(980)$  ( $I=0$ )       $f_0 \rightarrow \pi^0\pi^0, \pi^+\pi^-$        $\Gamma = 40\text{—}100$  MeV  
sizeable ss contents; strongly coupled to KK
- $a_0(980)$  ( $I=1$ )       $a_0 \rightarrow \eta\pi$       “      “  
coupled to KK
- Possible interpretation ( $^3P_0$  nonet):       $f_0 = s\bar{s}$  ;  $a_0^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$
- $f_0$ - $a_0$  mass degeneracy
- $f_0 \rightarrow \pi\pi$  decay is OZI suppressed
- small  $\gamma\gamma$  partial width (0.3—0.4 keV)
- small masses wrt the  $^3P_2$  nonet ( $\sim 1500$  MeV)
- other candidates for the  $^3P_0$  nonet ( $a_0(1450)$ ,  $f_0(1370)$ ,  $f_0(1710)$ )

$\Rightarrow f_0(980)$   $a_0(980)$  are not easily interpreted as  $q\bar{q}$  mesons

- **Other interpretations:  $q\bar{q}q\bar{q}$  states (Jaffe '77)**  
 **$K\bar{K}$  molecules (Weinstein-Isgur '90)**

# $\pi^0\pi^0\gamma$ rejection



- Parabolic cut to reject  $\omega\pi^0$   
 $\oplus M_{\pi\pi} < 760$  MeV to reject  $f_0 + \omega\pi^0$  wrong pairing
- $\pi^0\pi^0\gamma$  MC-simulation with the experimental  $M_{\pi\pi}$  spectrum