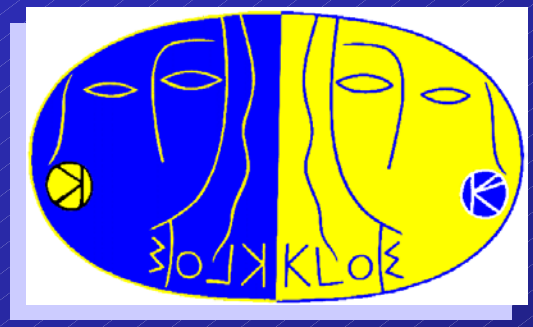
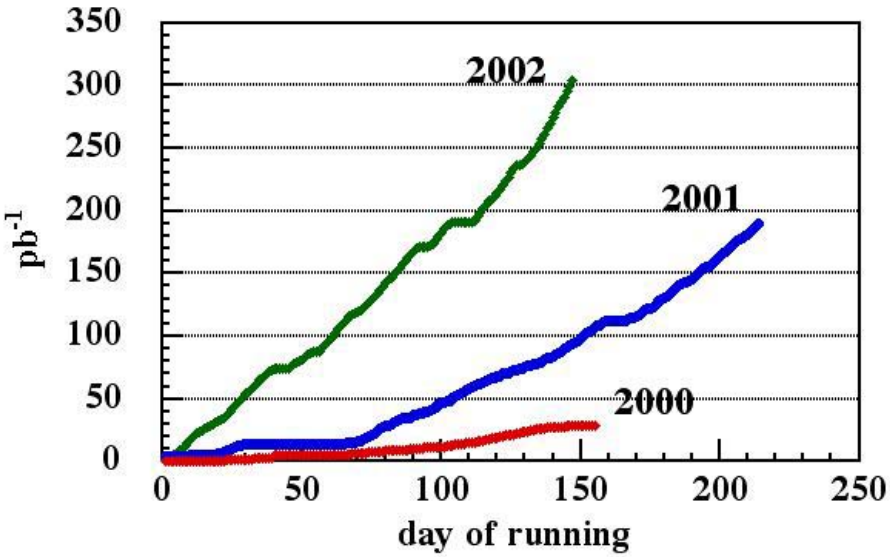


Experimental Measurement of the Φ meson radiative decays into scalars and pseudoscalars mesons

The KLOE Coll. presented by
Camilla Di Donato I.N.F.N. Naples

International Conference on the
Structure and Interactions of the Photon

KLOE data collected



1999 run : **2.5 pb^{-1}**
machine and detector studies

2000 run : **25 pb^{-1}**
7.5x10^{7} ϕ
published results

2001 run: **190 pb^{-1}**
5.7x10^{8} ϕ
analysis in progress

2002 run: **300 pb^{-1}**
9.0x10^{8} ϕ
analysis in progress

KLOE

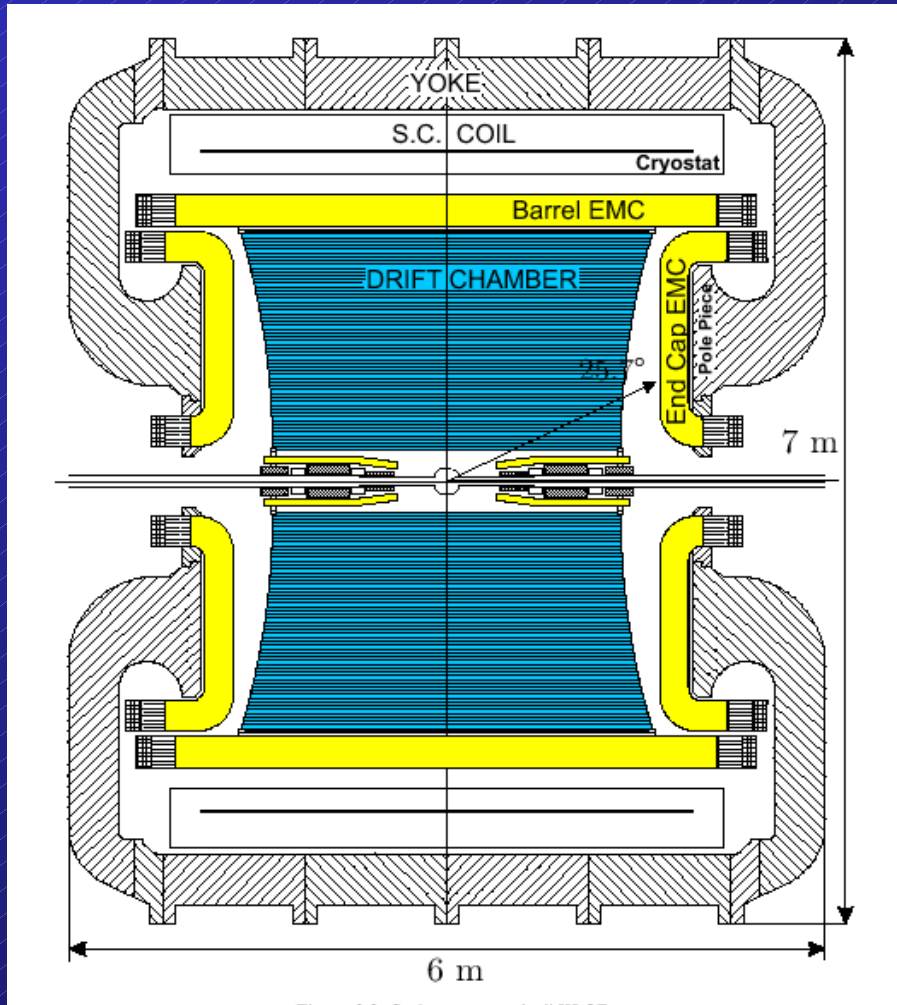
Drift chamber:

- $\delta p/p < 0.4\%$
- $\sigma_{xy} \approx 150\ \mu m$; $\sigma_z \approx 2$ mm

E.m. calorimeter:

- $\sigma_E/E = 5.4\% / \sqrt{(E(GeV))}$
- $\sigma_t = 55\ ps/\sqrt{(E(GeV))} \oplus 40\ ps$
- 98% of 4π

Magnetic field: 0.52 T



Φ radiative decays

- Analysis of 2000 data: $\int Ldt = 16\ pb^{-1}$

$\Phi \to \eta'\gamma$ / $\eta\gamma$	Phys. Lett. **B541** (2002), 45
$\Phi \to \pi^0\ \pi^0\ \gamma$	Phys. Lett. **B537** (2002), 21
$\Phi \to \eta\ \pi^0\ \gamma$	Phys. Lett. **B537** (2002), 209

Φ radiative decays

Pseudoscalar mesons ($J^{PC}= 0^{-+}$)

- η (547) (I=0)
- η'(958) (I=0)

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

- f_0(980) (I=0)
- a_0(980) (I=1)

$\phi \to \eta'\gamma$ / $\phi \to \eta\gamma$

- The mass eigenstates η, η' are related to SU(3) octet-singlet η_8, η_1 through the mixing angle ϑ_P
- Recent studies based on χPT 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 (φ_P)

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

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

$\phi \to \eta'\gamma$ / $\phi \to \eta\gamma$

- φ_P can be extracted from the ratio (Bramon et al., Eur.Phys.J.C7(1999)) :

$$R = \frac{Br(\phi \to \eta'\gamma)}{Br(\phi \to \eta\gamma)} = \cot g^2 \varphi_P \left(1 - \frac{m_s}{\overline{m}} \frac{tg\varphi_V}{\sin 2\varphi_P}\right)^2 \left(\frac{p_{\eta'}}{p_\eta}\right)^3 \quad ; \quad \left(\frac{m_s}{\overline{m}} = 1.45\right)$$

- $Br(\phi \to \eta'\gamma)$ can probe the gluonic content of η'

$$\eta' = X_{\eta'} \, {}^1\!/\!_{\sqrt{2}} \left|u\bar{u} + d\bar{d}\right\rangle + Y_{\eta'} \left|s\bar{s}\right\rangle + Z_{\eta'} \left|glue\right\rangle$$

$\phi \to \eta'\gamma$ / $\phi \to \eta\gamma$

- Decays with $\pi^+\pi^-\,3\gamma$ final state:

$\phi \to \eta\gamma$; $\eta \to \pi^+\pi^-\pi^0$; $\pi^0 \to \gamma\gamma$ Br $\approx 3\times10^{-3}$

$\phi \to \eta'\gamma$; $\eta' \to \pi^+\pi^-\eta$; $\eta \to \gamma\gamma$ Br $\approx 2\times10^{-5}$

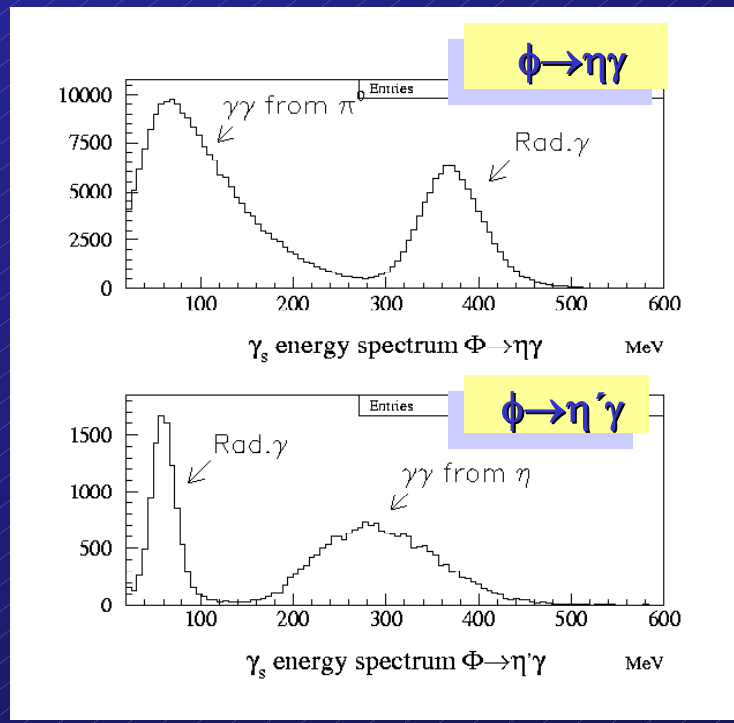
Background from $\phi \to \pi^+\pi^-\pi^0$ and $\phi \to K_L K_S$ (with K_L decaying near the IP)

<u>Analysis cut:</u>

- 1 vertex in IR with 2 tracks
- 3 prompt γ ($E>10$ MeV, $|\cos\vartheta|<0.93$)
- Constrained kinematic fit
- topological cuts on the energy of particles

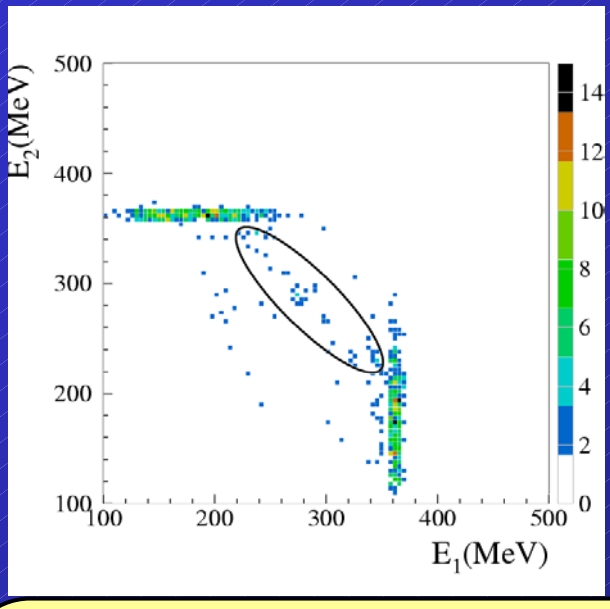
$\varepsilon_{tot}(\eta\gamma) = 37\ \%$

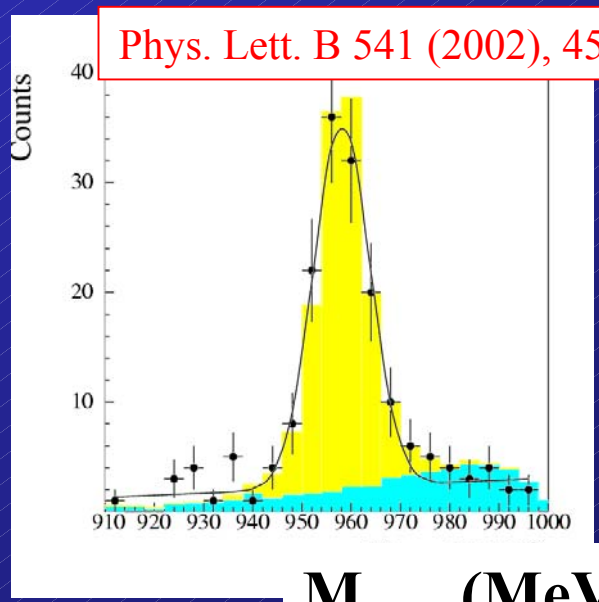
$\varepsilon_{tot}(\eta'\gamma) = 23\ \%$



$\phi \to \eta'\gamma$ / $\phi \to \eta\gamma$

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





$$R = \frac{N_{\eta'\gamma}}{N_{\eta\gamma}} \frac{\varepsilon_{\eta\gamma}}{\varepsilon_{\eta'\gamma}} \frac{Br(\eta \to \pi^+\pi^-\pi^0)\, Br(\pi^0 \to \gamma\gamma)}{Br(\eta' \to \pi^+\pi^-\eta)\, Br(\eta \to \gamma\gamma)} F_\rho =$$

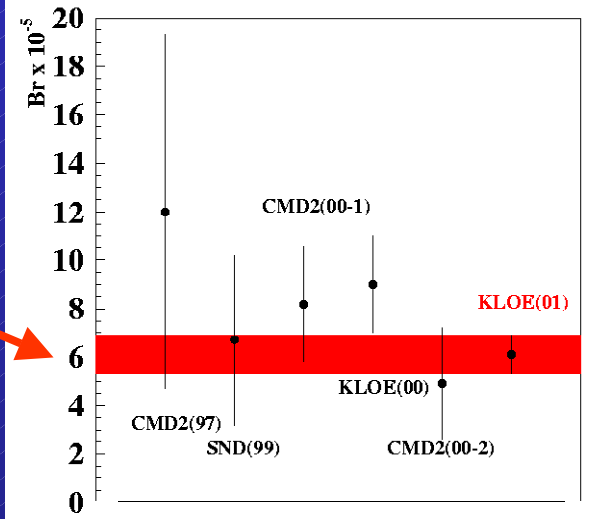
$$= (4.70 \pm 0.47 \pm 0.31) \times 10^{-3}$$

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

$\phi \to \eta'\gamma$ / $\phi \to \eta\gamma$

- Using PDG value for Br($\phi \to \eta\gamma$):

  $\Rightarrow$ Br($\phi \to \eta'\gamma$) = $(6.10 \pm 0.61 \pm 0.43) \times 10^{-5}$



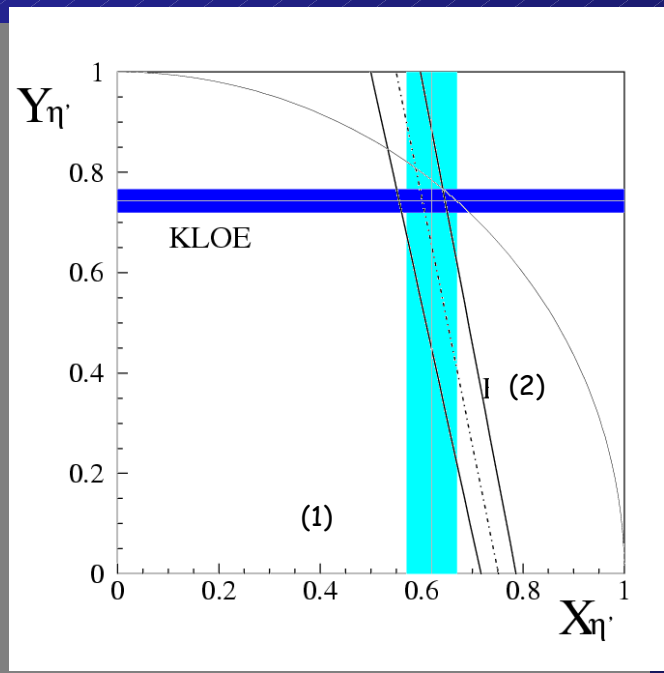
- Pseudoscalar mixing angle:

  $\varphi_P = (41.8 \pm 1.7)^\circ$ (flavor)

  $\Rightarrow \vartheta_P = (-12.9 \pm 1.7)^\circ$ (octet-singlet)

- Gluonic content of η':

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



Consistency check: if $Z_{\eta'}=0 \Rightarrow |Y_{\eta'}|=\cos\varphi_P$

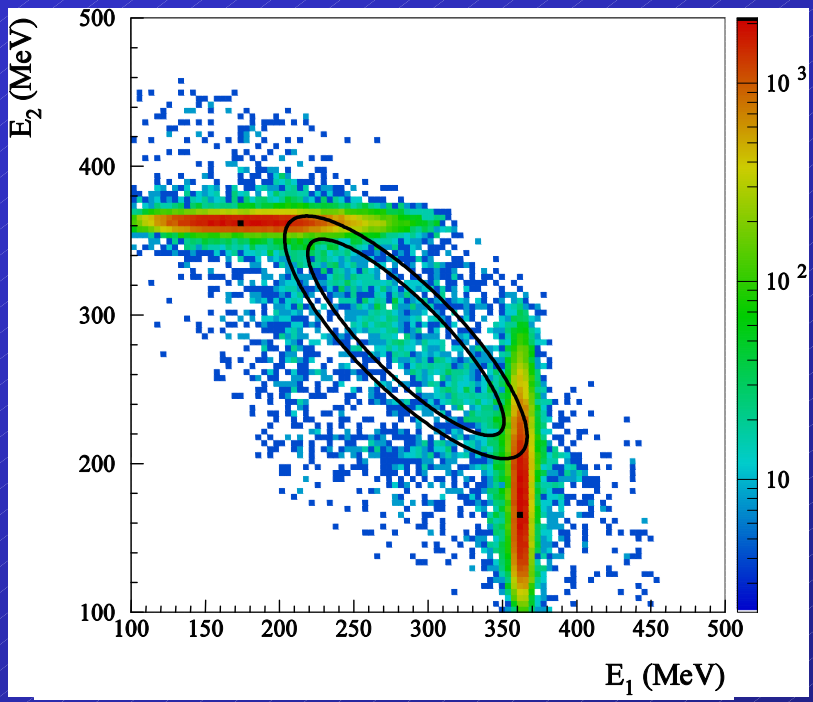
other constraints on $X_{\eta'}$ and $Y_{\eta'}$ from:

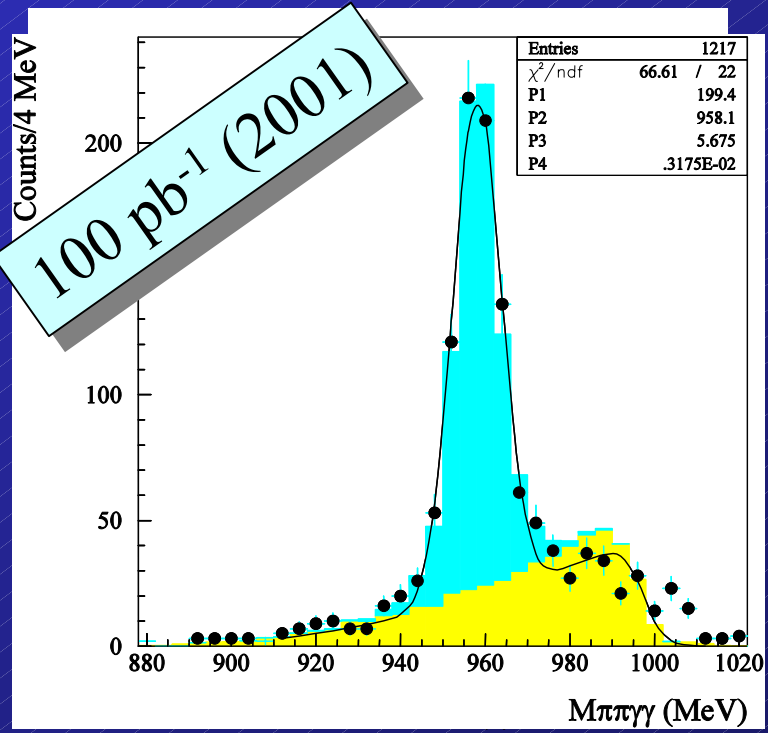
(1) $\Gamma(\eta' \to \rho\gamma)/\Gamma(\omega \to \pi^0\gamma)$

(2) $\Gamma(\eta' \to \gamma\gamma)/\Gamma(\pi^0 \to \gamma\gamma)$

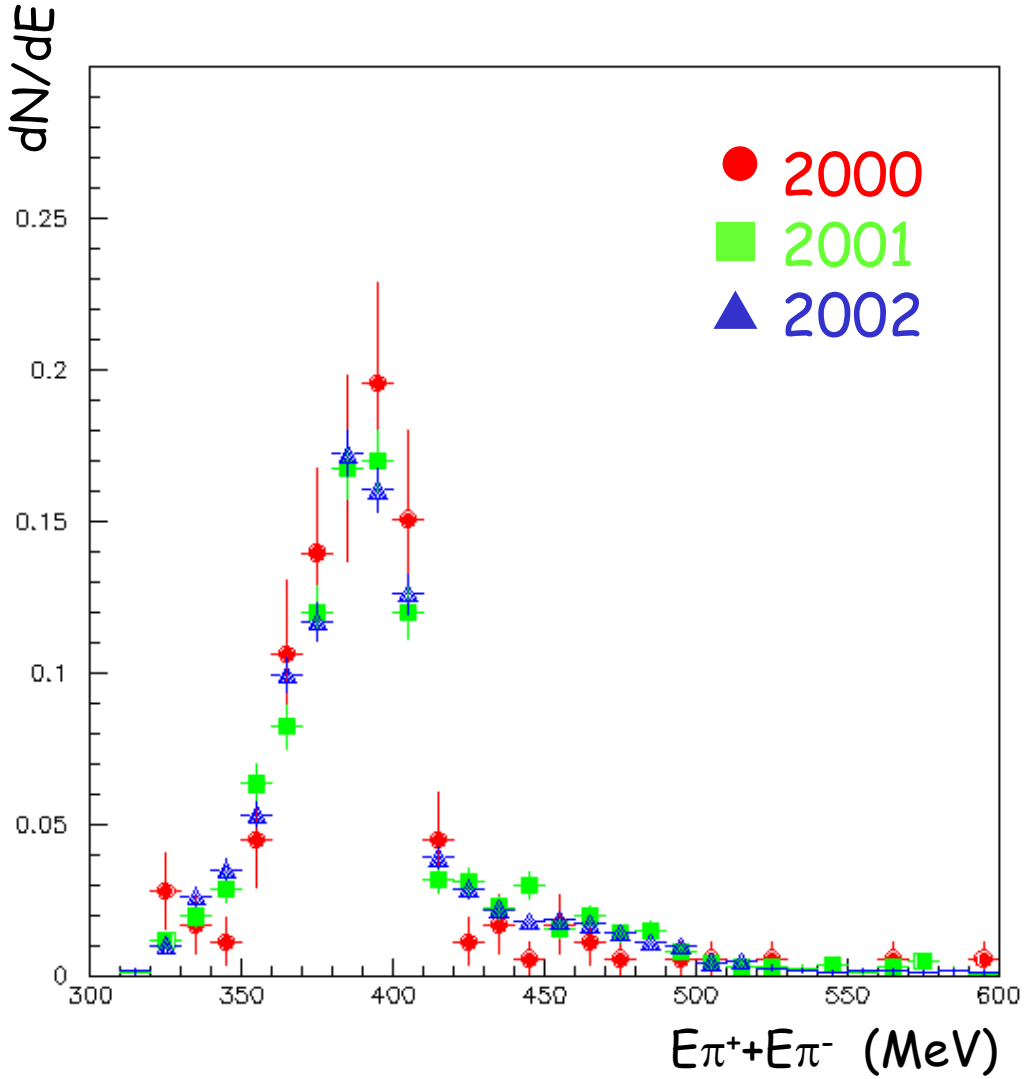
$$X_{\eta'}^2 + Y_{\eta'}^2 = 0.94^{+0.06}_{-0.09}$$

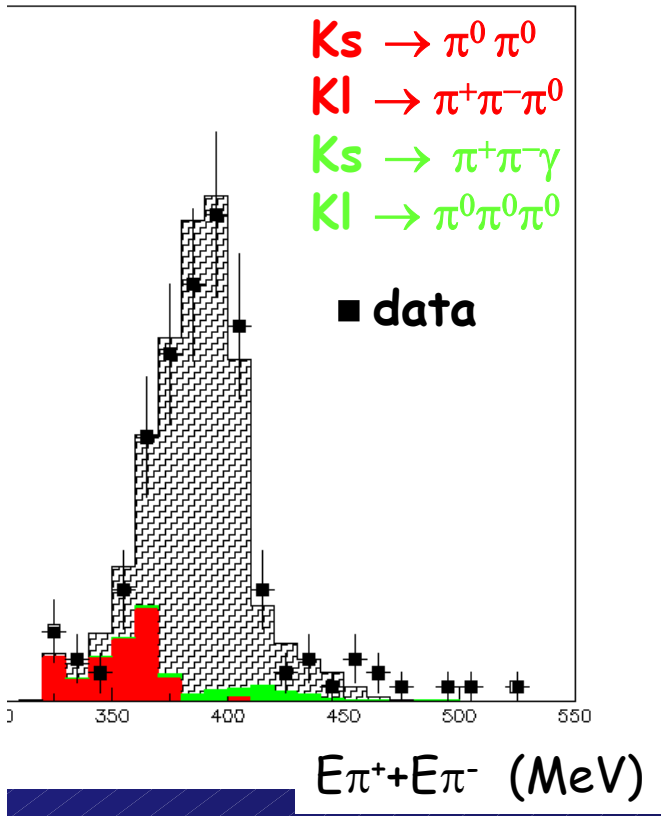
$\phi \to \eta'\gamma$ / $\phi \to \eta\gamma$





$\phi \to \eta'\gamma \to \pi^+\pi^- 7\gamma$





$Br(\phi \to \eta'\gamma) = (7.05 \pm 0.50^{+0.53}_{-0.46}) \times 10^{-5}$

$\phi \to f_0(980)\,\gamma$ / $a_0(980)\,\gamma$

- The scalar mesons $f_0(980)$ $a_0(980)$ are not easily interpreted as qq states

- Jaffe(1977) suggested qqqq states
- Weinstein, Isgur (1990) suggested KK molecule

- Both BR and scalar mass spectra are sensitive to nature

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

Models

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

f_0 model	$s\bar{s}(u\bar{u}+d\bar{d})/\sqrt{2}$	$(u\bar{u}+d\bar{d})/\sqrt{2}$	$s\bar{s}$
$g^2_{f0KK}/(4\pi)$ (GeV^2)	2.3 $(=g^2_{a0KK}/4\pi)$	0.15 $(=g^2_{a0KK}/4\pi)$	0.3 $(=2g^2_{a0KK}/4\pi)$
$g_{f0\pi\pi}/g_{f0KK}$	0.3—0.5	2	0.5
$Br(\phi\to\pi^0\pi^0\gamma)\times10^4$	~ 1	~ 0.15	~ 0.2

a_0 model	$s\bar{s}(u\bar{u}-d\bar{d})/\sqrt{2}$	$(u\bar{u}-d\bar{d})/\sqrt{2}$
$g^2_{a0KK}/(4\pi)$ (GeV^2)	2.3 $(=g^2_{f0KK}/4\pi)$	0.15 $(=g^2_{f0KK}/4\pi)$
$g_{a0\eta\pi}/g_{a0KK}$	0.91	1.53
$Br(\phi\to a_0\gamma)\times10^4$	~ 2	~ 0.2

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

- $f_0(980)$ (I=0) $\quad f_0 \to \pi^0\pi^0,\ \pi^+\pi^-$
- $a_0(980)$ (I=1) $\quad a_0 \to \eta\pi$

- **Studied decays (data sample: 16 pb^{-1} from the 2000 data,~5×10^{7}ϕ)**

$\phi \to f_0\gamma$; $f_0 \to \pi^0\pi^0$ $\Rightarrow$ 5 γ final state

$\phi \to a_0\gamma$; $a_0 \to \eta\pi^0$ $\eta \to \gamma\gamma$ (39%) $\Rightarrow$ 5 γ

} Previous meas. at VEPP2M

$\phi \to a_0\gamma$; $a_0 \to \eta\pi^0$ $\eta \to \pi^+\pi^-\pi^0$ (23%) $\Rightarrow$ 2 ch. tracks +5 γ

first observation ↵

5 γ final states

cross sect.(nb)

- **Signal:** $\phi\to\pi^0\pi^0\gamma$ $(\phi\to f_0\gamma\ ;\ \phi\to\sigma(500)\gamma\ ;\ \phi\to\rho^0\pi^0)$ ~ 0.35
  $\hookrightarrow \pi^0\pi^0$ $\hookrightarrow \pi^0\gamma$
  $\phi\to\eta\pi^0\gamma$ $(\phi\to a_0\gamma\ ;\ \phi\to\rho^0\pi^0)$ ~ 0.1
  $\hookrightarrow \eta\gamma$
- **Background:** $e^+e^-\to\omega\pi^0\to\pi^0\pi^0\gamma$ ~ 0.5
  $\phi\to\eta\gamma\to 3\gamma$ **(with accidental γ's)** (~17)
  $\phi\to\eta\gamma\to\pi^0\pi^0\pi^0\gamma$ **(with 2γ lost)** (~14)

- **Sample selection:**
  - **exactly 5 prompt photons**
  - **$E_\gamma > 7$ MeV**
  - **$|\cos\vartheta| < 0.93$ to avoid the quadrupole region**
  - **$\Sigma_5 E_i > 700$ MeV to reject $\phi\to K_L K_S\to$ neutrals**

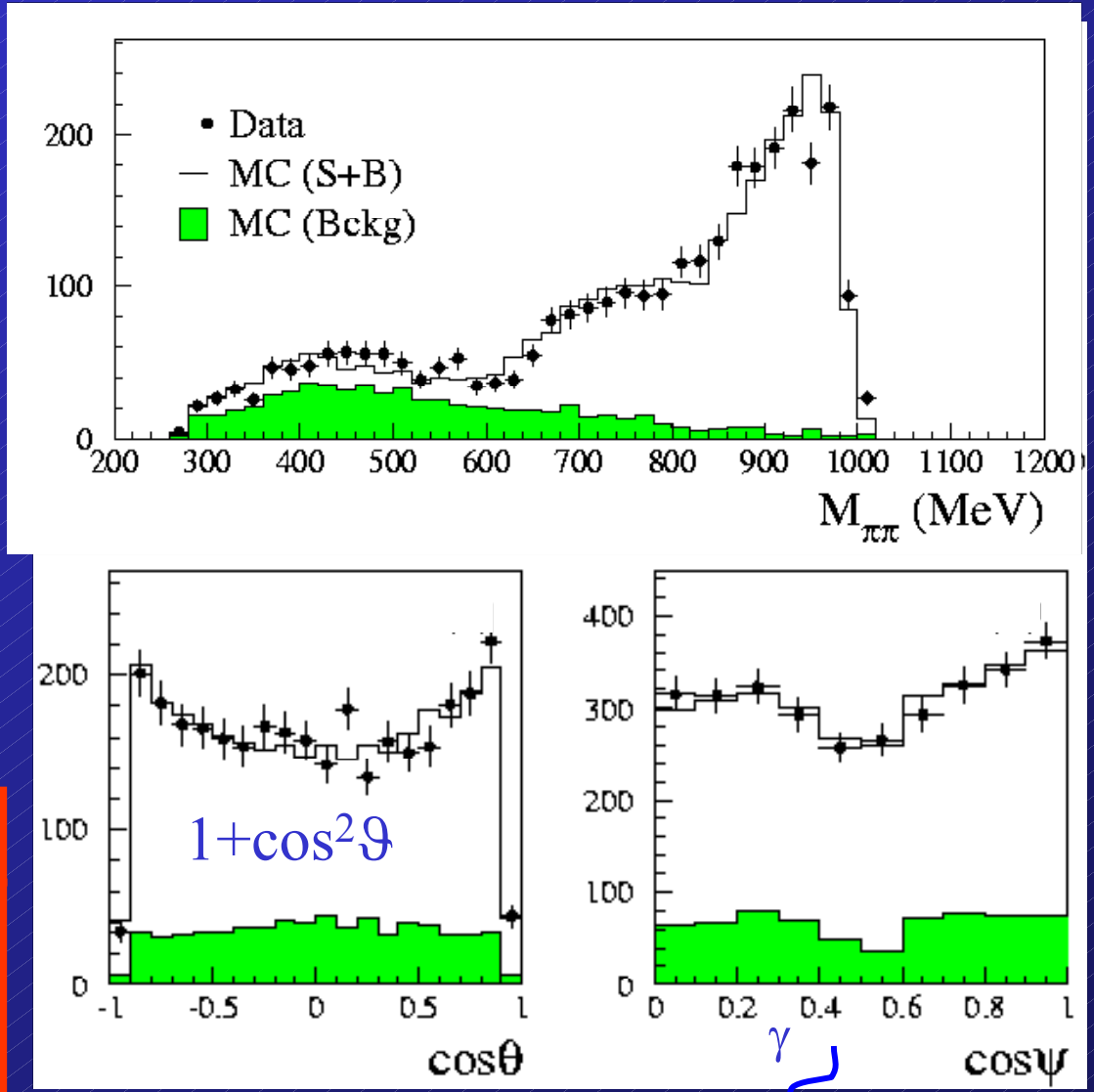
$\phi \to \pi^0\pi^0\gamma$

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

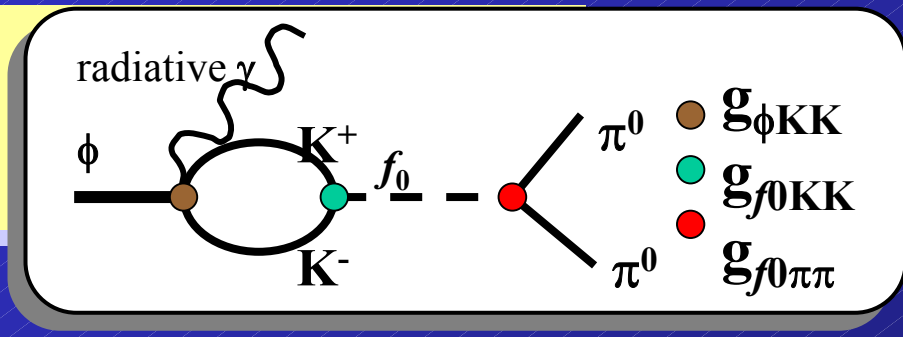
$\Rightarrow$ 3102 events

$\langle\varepsilon\rangle = 40\%$

Estimated backgr. (~20%)	
$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$	339±24
$\phi \to \eta\pi^0\gamma$	166±16
$\phi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$	159±12



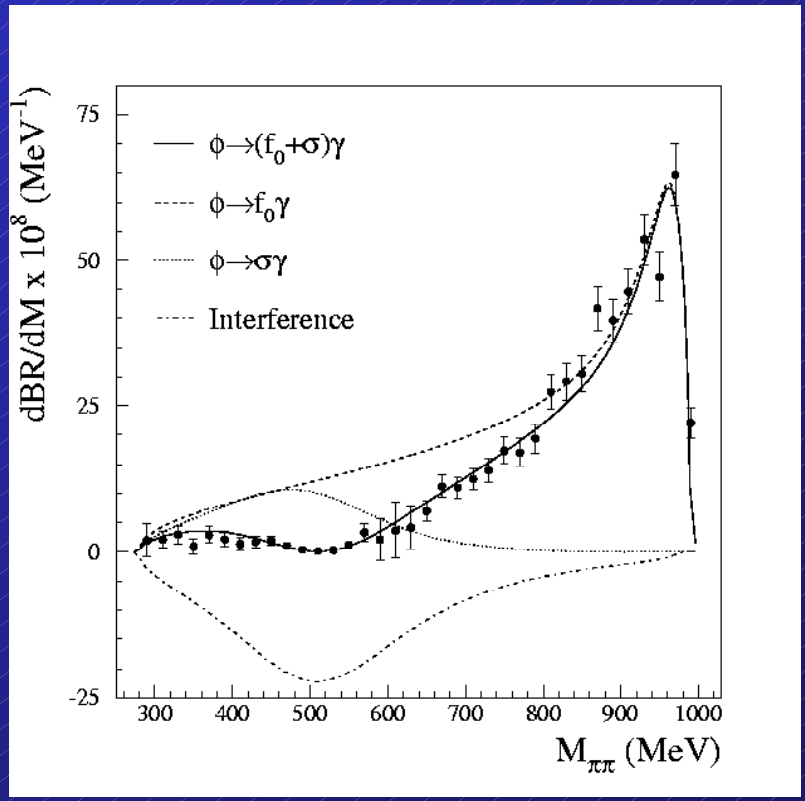
Fit to $M_{\pi\pi}$ spectrum



- **Model :**
  1) $\phi \to f_0\gamma$ **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_σ**=478 MeV and** Γ_σ**=324 MeV**
     (Fermilab E791-Phys.Rev.Lett.86(2001)770)
  4) **point-like coupling of** $\sigma(500)$ **to** ϕ
     (Gokalp,Yilmaz,Phys.Rev.D64(2001))
  5) $\rho\pi$ **+ interference term parameterizations from Achasov-Gubin,** (Phys.Rev.D63(2001))
- **Two fits:**
  Fit A : $|(\phi \to f_0\gamma) + (\phi \to \rho^0\pi^0)|^2$
  Fit B : $|(\phi \to f_0\gamma) + (\phi \to \sigma\gamma) + (\phi \to \rho^0\pi^0)|^2$
  Free parameters: M_{f0}, g^2_{f0KK}, $g^2_{f0\pi\pi}/g^2_{f0KK}$, $g_{\phi\sigma\gamma}$ **and** $(g_{\phi\rho\pi}g_{\rho\pi\gamma})^2$

Fit results

	A	B
χ^2/ndf	109.5/33	43.2/32
M_{f0} (MeV)	962±4	973 ±1
$g^2_{f0KK}/(4\pi)$ (GeV^2)	1.29±0.14	2.79 ±0.12
$g^2_{f0KK}/g^2_{f0\pi\pi}$	3.22±0.29	4.00±0.14
$g_{\phi\sigma\gamma}$	—	0.060 ±0.008



($\rho\pi$ contribution negligible)

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

(SND: (1.22±

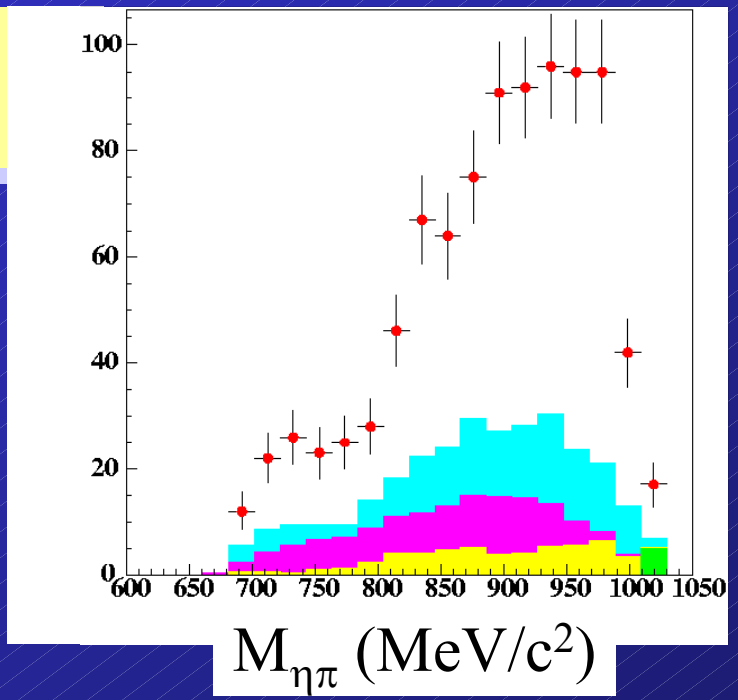
$Br(\phi\to f_0\gamma)= (4.47 \pm 0.21) \times 10^{-4}$

⇒ Lar < 700 MeV

$\phi \to \eta\pi^0\gamma$ (with $\eta \to \gamma\gamma$)

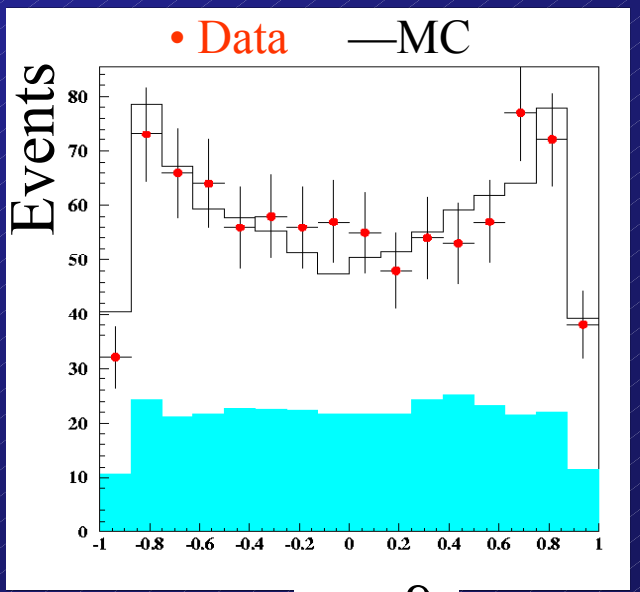
- Constrained kinematic fit to improve resolutions
- Photon pairing: (1) $\pi^0\pi^0\gamma$; (2) $\eta\pi^0\gamma$
  $\Rightarrow$ reject $\pi^0\pi^0\gamma$ events
- $M_{\pi\pi} < 760$ MeV (reject $f_0\gamma$ events)
- $|M_{\gamma\gamma} - M_\eta| < 3\sigma(M_\eta)$

$\Rightarrow$ 916 events $\quad \langle\varepsilon\rangle = 32\ \%$



- Estimated backgr.: (~30%)

$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$	54±6
$\phi \to \pi^0\pi^0\gamma$	152±16
$\phi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$	98±10
$\phi \to \eta\gamma \to \gamma\gamma\gamma$	5±2



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

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

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

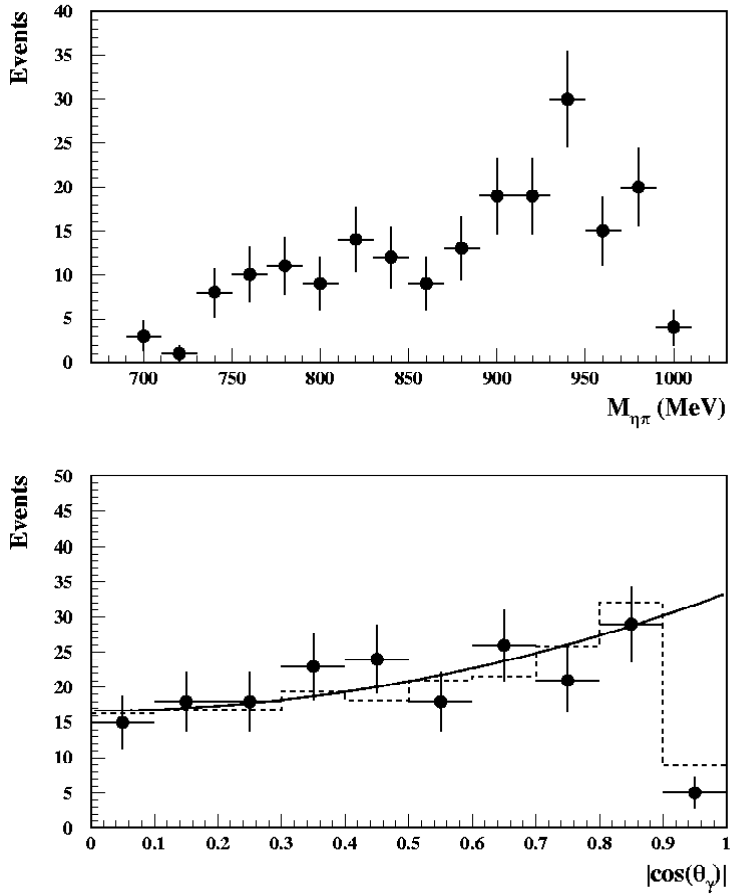
- No background with the same final state
- Backgr.: 2 Tracks + 3/4 photons ($e^+e^- \to \omega\pi^0$; $\omega \to \pi^+\pi^-\pi^0$)
  ($\phi \to \eta\gamma$; $\eta \to \pi^+\pi^-\pi^0$)

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

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

$\Rightarrow$ 197 events $\langle\varepsilon\rangle$=19%
estimated backgr. 4±4 events

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



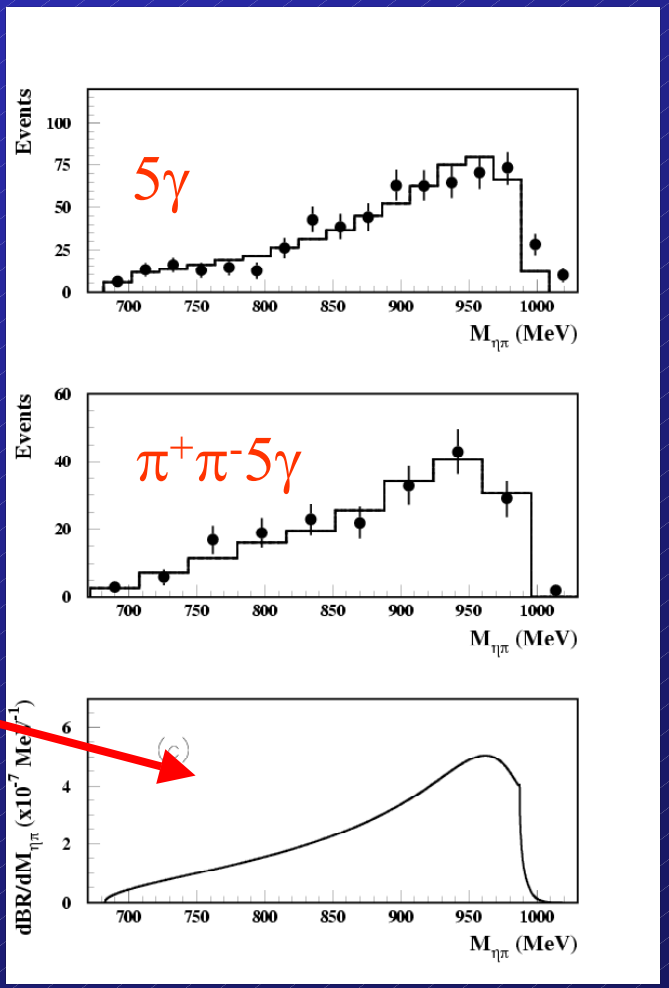
Fit to $M_{\eta\pi}$ spectrum

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

g^2_{a0KK}, $g_{a0\pi\pi}/g_{a0KK}$ and Br($\phi\to\rho^0\pi^0\to\eta\pi^0\gamma$)

M_{a0}=984.8 MeV (PDG) fixed

χ^2/ndf	27.2/25
$g^2_{a0KK}/(4\pi)$ (GeV^2)	0.40 ± 0.04
$g_{a0\eta\pi}/g_{a0KK}$	1.35 ± 0.09
Br($\phi\to\rho^0\pi^0\to\eta\pi^0\gamma$)	(0.5 ± 0.5) × 10^{-5}



Br($\phi\to a_0\gamma\to\eta\pi^0\gamma$)= (7.4 ± 0.7) × 10^{-5}

Summary of fit results

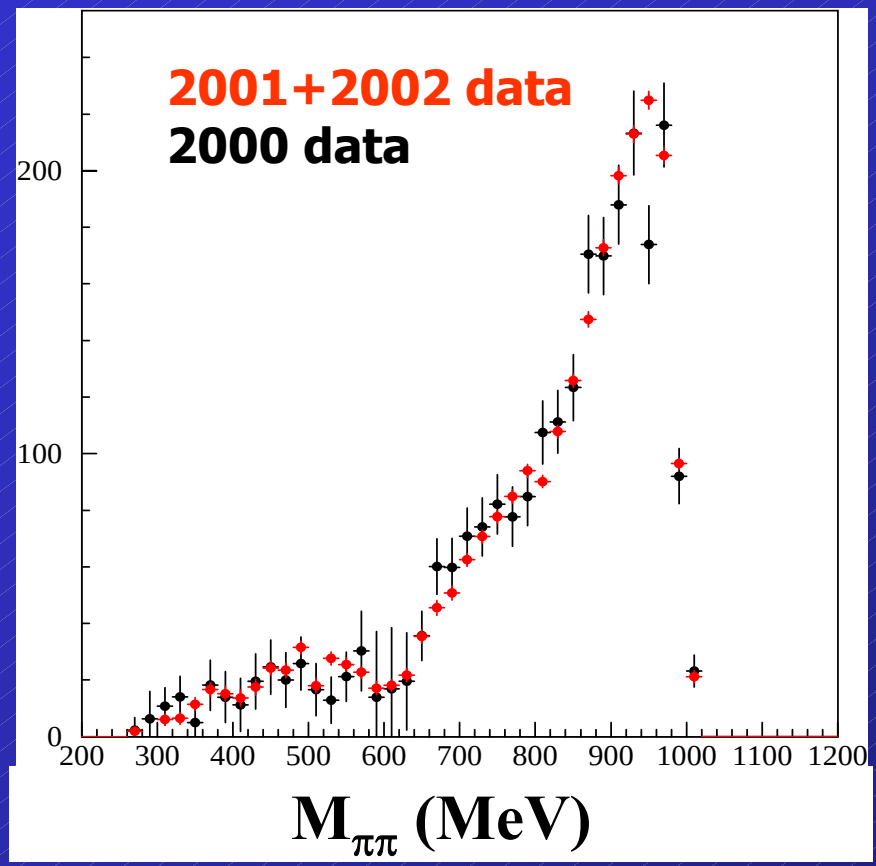
- Comparison with predictions from Achasov-Ivanchenko, Nucl.Phys.B315(1989)

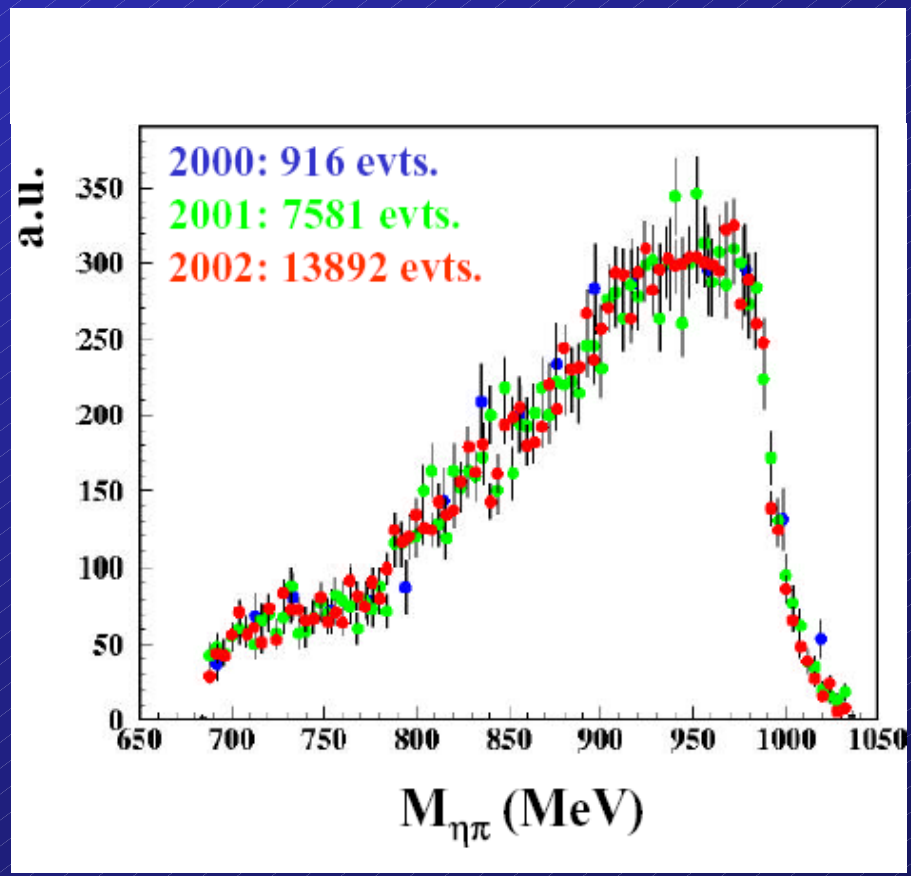
f_0 model	KLOE	$s\bar{s}(u\bar{u}+d\bar{d})/\sqrt{2}$	$(u\bar{u}+d\bar{d})/\sqrt{2}$	$s\bar{s}$
$g^2_{f0KK}/(4\pi)$ (GeV^2)	2.79±0.12	2.3 $(=g^2_{a0KK}/4\pi)$	0.15 $(=g^2_{a0KK}/4\pi)$	0.3 $(=2g^2_{a0KK}/4\pi)$
$g_{f0\pi\pi}/g_{f0KK}$	0.50±0.01	0.3—0.5	2	0.5
$Br(\phi\to\pi^0\pi^0\gamma)\times10^4$	1.09±0.07	~ 1	~ 0.15	~ 0.2

a_0 model		$s\bar{s}(u\bar{u}-d\bar{d})/\sqrt{2}$	$(u\bar{u}-d\bar{d})/\sqrt{2}$
$g^2_{a0KK}/(4\pi)$ (GeV^2)	0.40±0.04	2.3 $(=g^2_{f0KK}/4\pi)$	0.15 $(=g^2_{f0KK}/4\pi)$
$g_{a0\eta\pi}/g_{a0KK}$	1.35±0.09	0.91	1.53
$Br(\phi\to a_0\gamma)\times10^4$	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**

$\phi \rightarrow f_0(980)\,\gamma$ / $a_0(980)\,\gamma$





Conclusions

First KLOE published papers on ϕ radiative decays, 2000 events:

- **Br($\phi \to \eta'\gamma$) =** $(6.10 \pm 0.61 \pm 0.43) \times 10^{-5}$
- φ_P = **(41.8 ± 1.7)°** **(flavor)**

- **Br($\phi \to \pi^0\pi^0\gamma$) =** $(1.09 \pm 0.03 \pm 0.05) \times 10^{-4}$
- **Br($\phi \to f_0\gamma$) =** $(4.47 \pm 0.21) \times 10^{-4}$
- **Br($\phi \to a_0\gamma$) =** $(7.4 \pm 0.7) \times 10^{-5}$

Analysis in progress on 2001+2002 events $\Rightarrow$ 500pb^{-1}: more statistic and models with more free parameters

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==== Author : KLOE Collab. (Speaker: Camilla Di Donato) Type : Experimental Measurement of the Phi meson radiative decays into scalars and pseudoscalars mesons.

The Kloe experiment has measured the radiative decays of the Phi meson into pi0, eta and eta'(958); these measurements are relevant to assess the mixing in the pseudoscalar nonet as well as to evaluate the gluon content in the eta'(958). Moreover also the radiative decays into pi0 pi0 gamma and eta pi0 gamma have been measured. These decays are dominated by the final states f0(980) and a0(980). The measurement of the branching ratios and of the pi0-pi0 or eta-pi0 invariant mass spectrum helps to understand the controversial nature of the above scalar mesons.
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