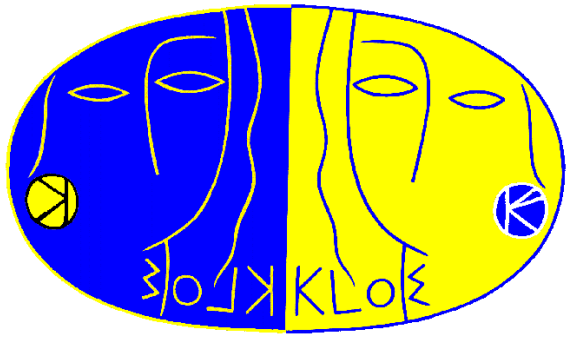
Scalar mesons at KLOE



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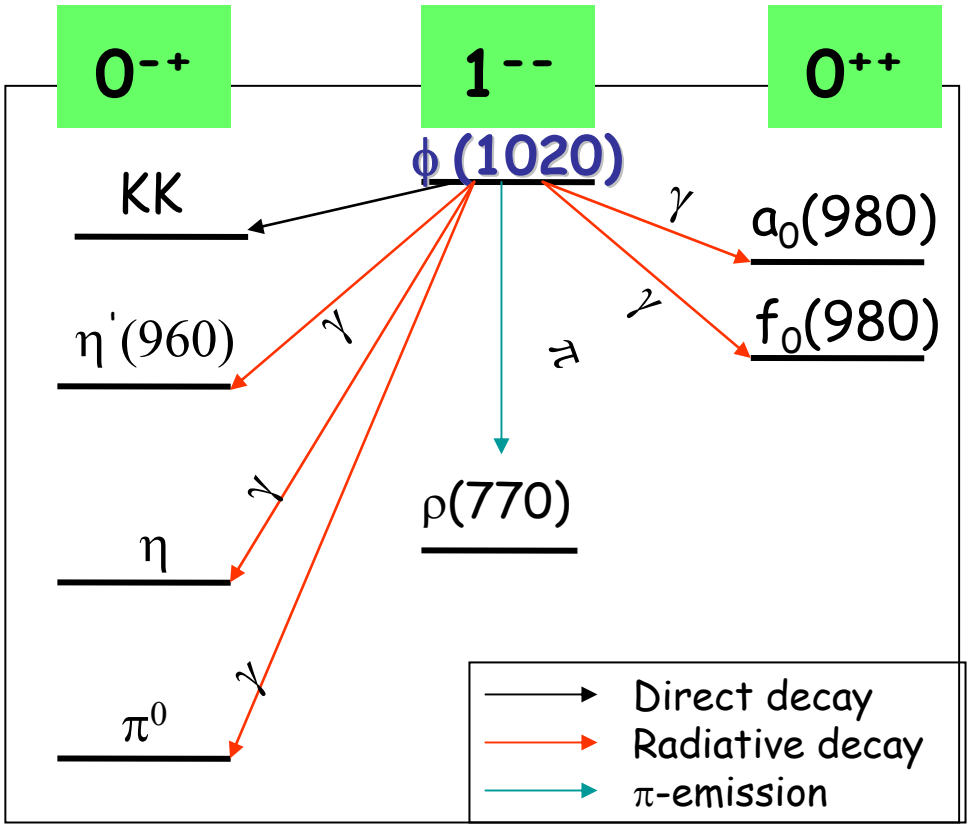
Talk outline

- DAFNE and KLOE
- Scalar Mesons at Φ-factory
  - $\phi \rightarrow f_0(980)\gamma \rightarrow \pi^+\pi^-\gamma$
  - $\phi \rightarrow f_0(980)\gamma \rightarrow \pi^0\pi^0\gamma$
  - $\phi \rightarrow a_0(980)\gamma \rightarrow \eta\pi^0\gamma$
    - 5 photons final state
    - 2 charged pions + 5 photons final state
- Conclusions

Physics at a ϕ – factory:

a window on the lowest mass mesons

ϕ decays give access to light mesons (scalar, pseudoscalar, vector)
These processes allow us to study the structure of these mesons, in particular their s-quark content via couplings with ϕ (ss) and Kaons

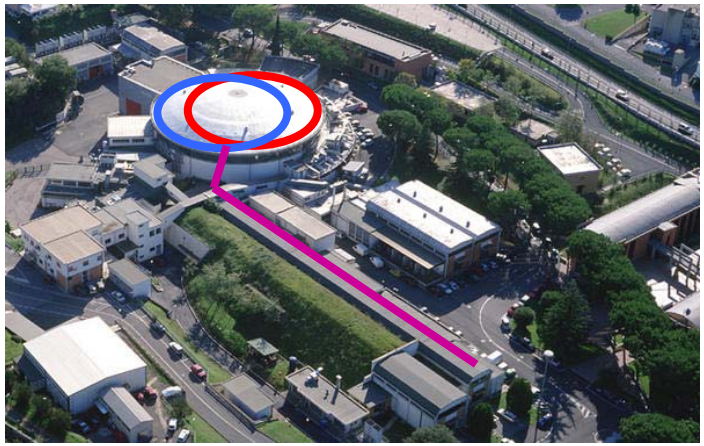


Main decay channels	Branching fraction
→ K^+K^-	49.2 %
→ K_SK_L	34.0 %
→ $\rho\pi + \pi^+\pi^-\pi^0$	15.3 %
→ $\eta\gamma$	1.301 %
→ $\pi^0\gamma$	0.125 %
→ $\eta'\gamma$	6.2×10^{-5}
→ $\pi^0\pi^0\gamma$	$\sim 10^{-4}$
→ $\eta\pi^0\gamma$	$7 \div 8 \times 10^{-5}$
+ "radiative return" to $\pi^+\pi^-$	

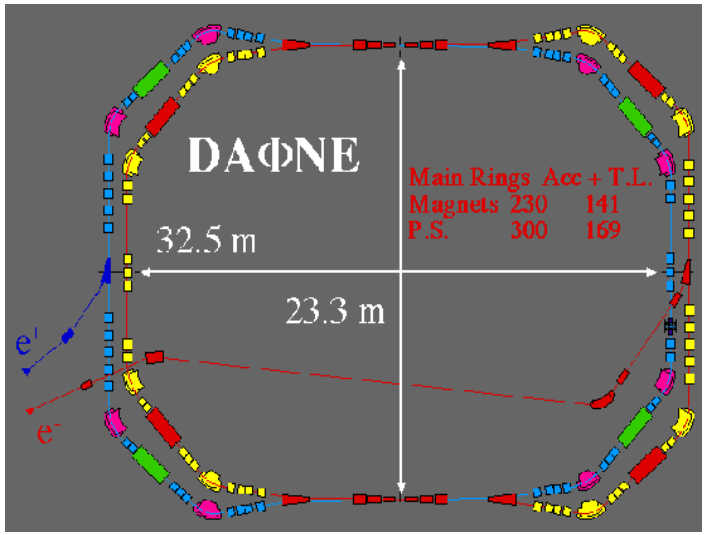
#events in KLOE data = Br.F. × 8 × 10^9 ➔ ~10^8 η; ~10^5 η', $\pi\pi$, $\eta\pi$

The DAΦNE e^+e^- Φ-factory

ϕ-factory : an e^+e^- collider with center of mass energy $\sqrt{s}=m(\phi)=1019.4$MeV



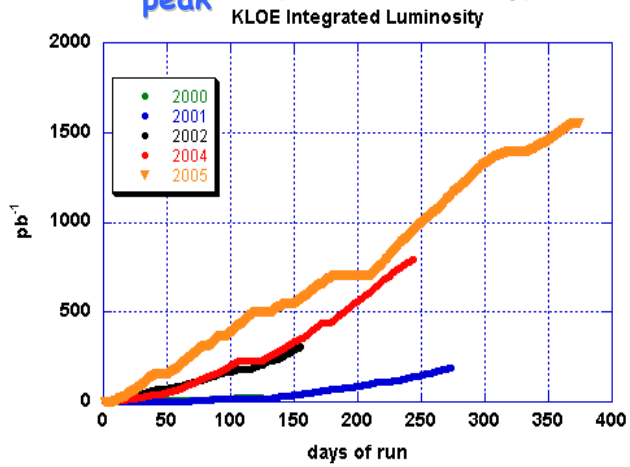
- $\sigma(e^+e^- \rightarrow \phi) \sim 3\ \mu b$
- Separate e^+e^- rings to reduce beam-beam interactions
- crossing angle: 25 mrad
- Bunch crossing every 2.7 ns
- injection during acquisition



integrated Luminosity 2001-5:

$\int L\,dt = 2.4\ fb^{-1}$

$L_{peak} = 1.5 \times 10^{32}\ cm^{-2}s^{-1}$

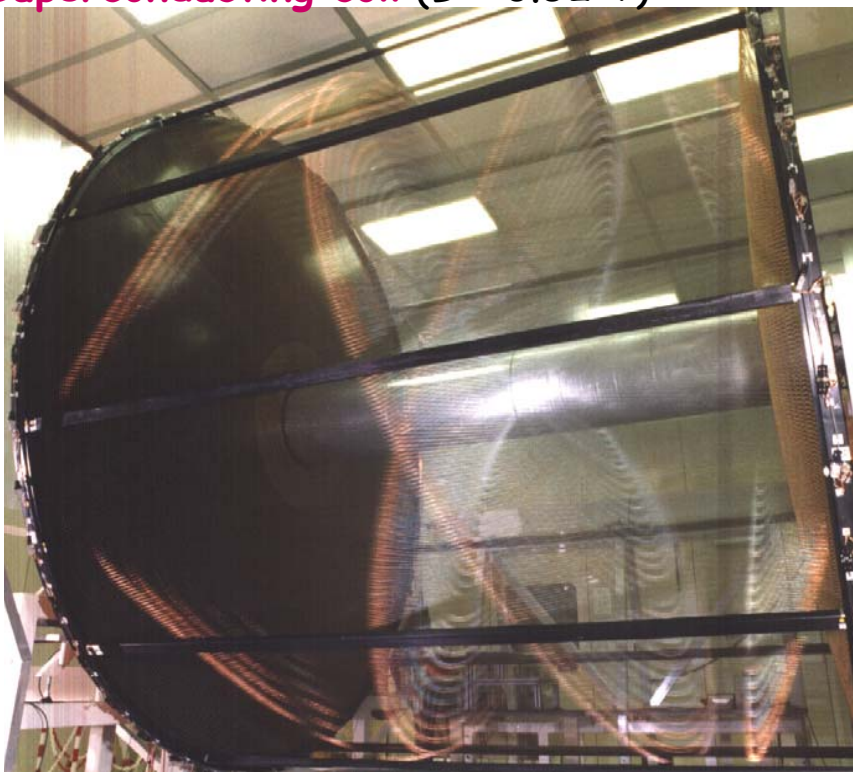


The KLOE detector

Drift chamber (4 m ∅ × 3.75 m, CF frame)

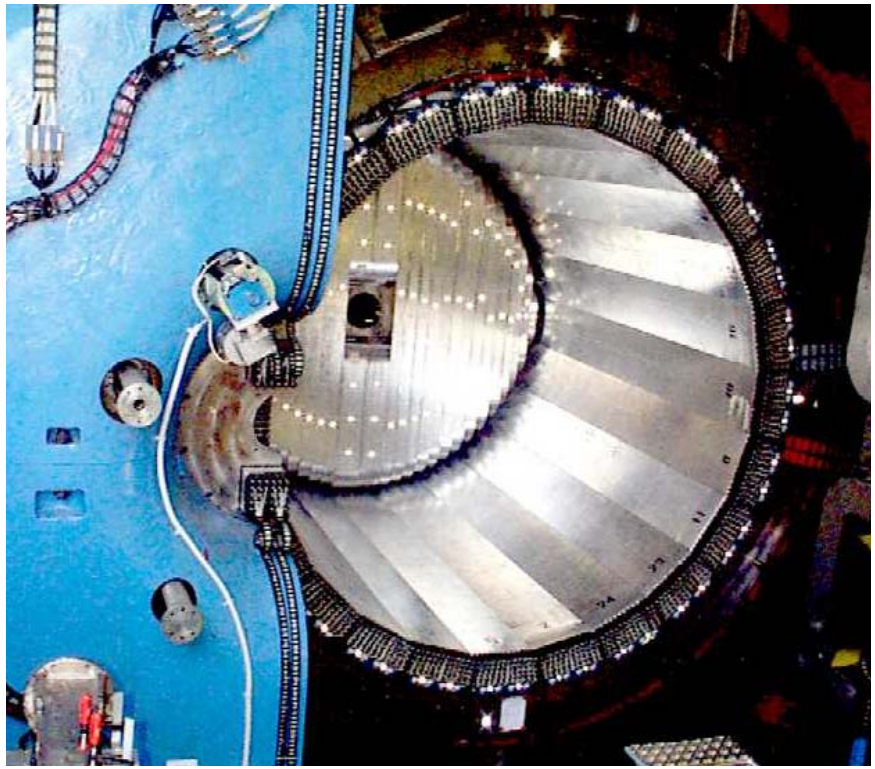
- Gas mixture: 90% He + 10% iso-C_4H_{10}
- 12582 stereo sense wires
- almost squared cells

Superconducting coil (B = 0.52 T)



Calorimeter

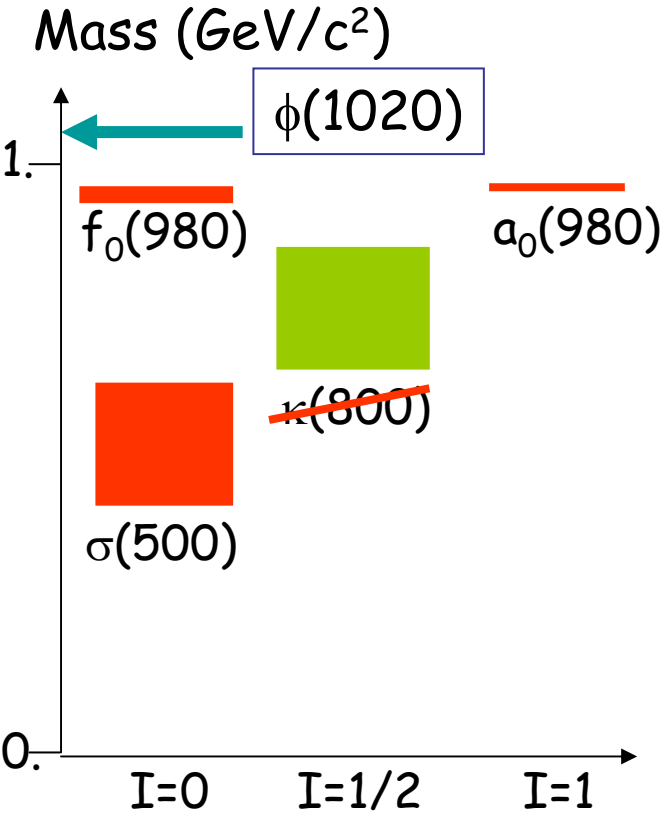
- lead/scintillating fibers (1 mm ∅), 15 X_0
- 4880 PMT's
- 98% solid angle coverage



$\sigma_p/p = 0.4$ % (tracks with $\theta > 45°$)
$\sigma_x^{hit} = 150$ μm (xy), 2 mm (z)
σ_x^{vertex} ~1 mm
$\sigma(M_{\pi\pi})$ ~1 MeV

$\sigma_E/E =$ 5.7% /√E(GeV)
σ_t = 54 ps /√E(GeV) ⊕ 50 ps
$\sigma_{vtx}(\gamma\gamma)$ ~ 1.5 cm (neutral vertex resolution)

Scalar Mesons at a Φ-factory



Scalar Mesons Spectroscopy:

$f_0(980)$, $\sigma(500)$ and $a_0(980)$ are accessible through $\phi \rightarrow S\gamma$ (κ not accessible)

Questions:

1. Is $\sigma(500)$ needed to describe the mass spectra ?
2. "couplings" of $f_0(980)$ and $a_0(980)$ to $\phi \cong |s\bar{s}\rangle$ and to KK, $\pi\pi$ and $\eta\pi$.

➔ allows to investigate the inner structure:

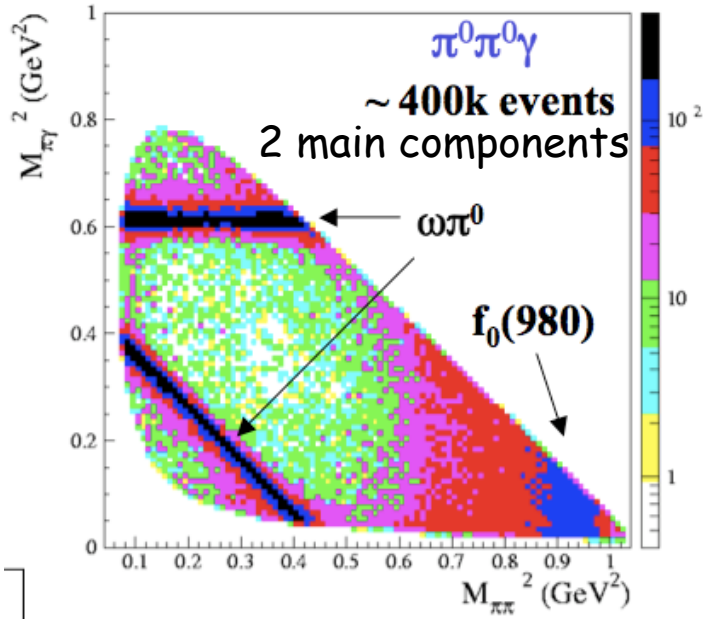
4-quark vs. *2-quark* vs. *KK molecule*

Kaon-Loop model:

(Achasov - Ivanchenko Nucl.Phys.B315(1989)465,
Achasov - Gubin Phys.Rev.D63(2001)094007,
Achasov - Kiselev Phys.Rev.D68(2003)014006)

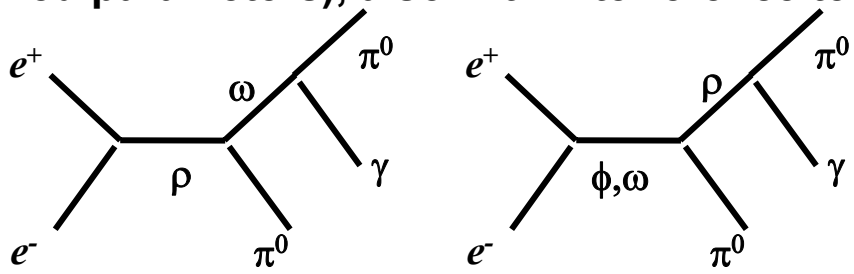
The $\pi^0\pi^0\gamma$ analysis

- 5 photons with $\theta_\gamma > 23^\circ$ and no tracks; Kinematic fit → energy-momentum conservation; π^0 masses: choice of the photon *pairing* to π^0's



- **σ needed in the fit: P(χ^2) ~ 10^{-4} without σ**
- **σ completely fixed (no artificial improvement by enlarged parameter set)**

Irreducible background fit in the amplitude (fixed parameters), also with interference terms



Fit parameters: M_{f0}, g_{f0K+K-}, $g_{f0\pi+\pi-}$ (=$\sqrt{2}$ $g_{f\pi0\pi0}$)

$f_0(980)$ param.	NEW Kaon-Loop result
m_{f0} (MeV)	984.7 ± 1.9
$g_{f\pi+\pi-}$ (GeV)	-1.82 ± 0.19
g_{fKK} (GeV)	3.97 ± 0.43

preliminary

Systematic dominated by model-dependent fixed parameters.
10 sets of parameters available, 8 give P(χ^2) > 1%
K-L results are the mean, and the errors are the RMS, of fit results

$$BR(\phi \to S\gamma \to \pi^0\pi^0\gamma) = \left[1.07^{+0.01}_{-0.04}(\text{fit})^{+0.04}_{-0.02}(\text{syst})^{+0.06}_{-0.05}(\text{mod})\right]\times 10^{-4}$$

[EPJC49(2007)473]

The $\pi^+\pi^-\gamma$ analysis

- 2 tracks with θ_t>45°; missing momentum $\theta_{\pi\pi}$>45° (large angle)
- pion identification through tracking, Time of Flight and Shower shape
- 1 photon matching the missing momentum

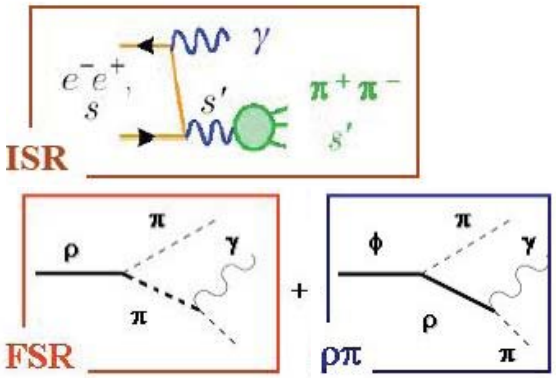
$\Rightarrow$ 6.7 $\times 10^5$ events / 350 pb^{-1}

Irreducible backgrounds fit in the amplitude

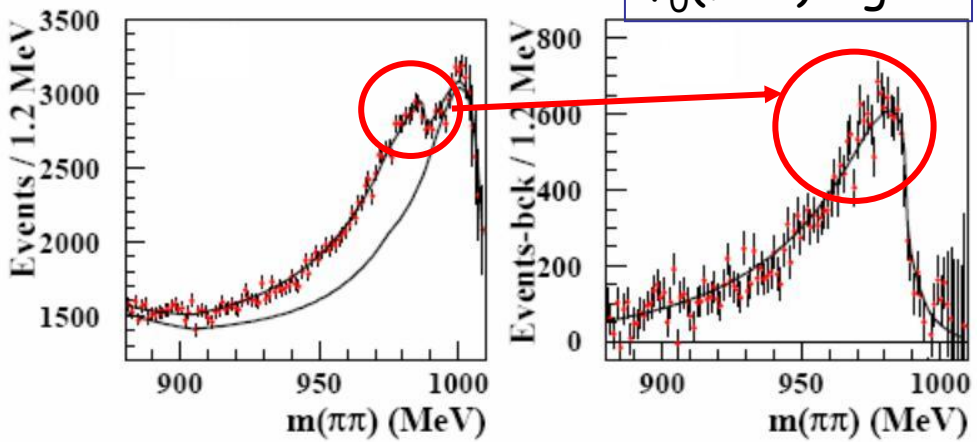
- Kaon-Loop fit with σ contribution

- no sensitivity to σ shown by the fit

- systematic error to be evaluated



$f_0(980)$ signal



- **ISR:** [Kühn-Santamaria ZPC48 (199(
  - **Free parameters: $M_{\rho 0}$, $\Gamma_{\rho 0}$, α, β**
- **FSR fixed** [Achasov,Gubin,Solodov PRD55(1997)2672)]
- **ρπ:($\phi \to \rho^\pm\pi^\mp$; $\rho^\pm \to \pi^\pm\gamma$) VDM, a scale factor ($a_{\rho\pi}$) free**
- **scalar-FSR interference** [Achasov-Gubin PRD57 (1998) 1987]

NEW Fit result $P(\chi^2) = 2.5\%$

M_{f0} = 983.7 MeV
g_{f0K+K-} = 4.74 GeV
$g_{f0\pi+\pi-}$ = -2.22 GeV

preliminary

B.R.($\phi \to f_0(980)\gamma \to \pi^+\pi^-\gamma$) = 2.1 ÷ 2.4 × 10^{-4}
(from integral of |Amplitude|²)

[PLB634(2006)148]

The $\eta\pi^0\gamma$ analysis

To extract the relevant $a_0(980)$ parameters we fit the $M_{\eta\pi}$ spectrum with the Kaon loop (5 parameters): M_{a0}, $g_{a0KK}^2/(4\pi)$, $g_{a0\eta\pi}/g_{a0KK}$,
$Br(\phi \to \rho\pi^0 \to \eta\pi^0\gamma)$, δ (phase between scalar and vector amplitude)

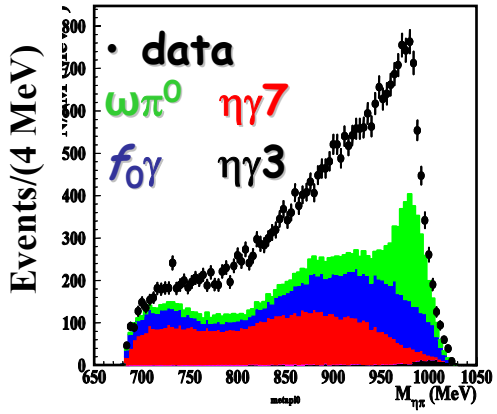
- dominant scalar contribution from $\phi \to a0(980)\gamma$ with $a0(980) \to \eta\pi0$ (Br $\approx$ 7-8 $\times 10^{-5}$ KLOE '00)
- vector contribution $\phi \to VP$; $V \to P'\gamma$ ($V = \rho,\omega$ $P,P' = \pi^0,\eta$) (Br $\approx$ 0.3-0.5 $\times 10^{-5}$ - VDM)

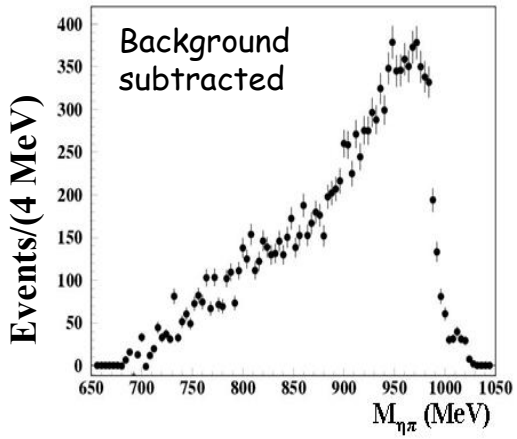
— $\eta \to \gamma\gamma$ final state

$\eta \to \gamma\gamma \Rightarrow$ 5 γ final state: pre-selection of 5- γ events + kinematic fit

$\int Ldt = 424\ pb^{-1}$

Background Process (after pre-selection)		*S/B (MC)*
$\phi \to f_0(980)\gamma \to \pi^0\pi^0\gamma$	$f_0\gamma$	~ 0.7
$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$	$\omega\pi^0$	~ 0.4
$\phi \to \eta\gamma$; $\eta \to \pi^0\gamma\gamma$	$\eta\gamma5$	~ 70
$\phi \to \eta\gamma$; $\eta \to \pi^0\pi^0\pi^0$	$\eta\gamma7$	~ 0.2
$\phi \to \eta\gamma$; $\eta \to \gamma\gamma$	$\eta\gamma3$	~ 15
$\phi \to \pi^0\gamma$	$\pi^0\gamma$	~ 30
Total S/B		~ 0.1



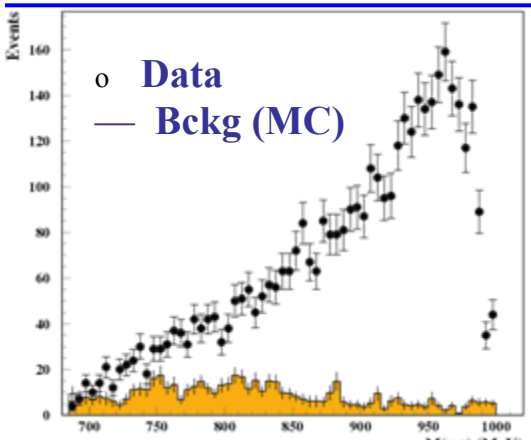


$Br(\phi \to \eta\pi^0\gamma) = (6.98 \pm 0.10_{stat} \pm 0.23_{syst}) \times 10^{-5}$

obtained from event counting (model independent).

to be published

$\eta \to \pi^+\pi^-\pi^0$ final state



$\eta \to \pi^+\pi^-\pi^0 \Rightarrow \pi^+\pi^- + 5\,\gamma$ final state, $\int Ldt = 380\ pb^{-1}$

1 vertex close to I.P. with 2 tracks + 5 good photons

No background process with the same final state of the signal:

$Br(\phi \to \eta\pi^0\gamma) = (7.12 \pm 0.13_{stat} \pm 0.24_{syst}) \times 10^{-5}$

to be published

$M_{\eta\pi 0}$ fit to $\eta\pi^0\gamma$ events

Kaon-Loop model (see previous slides), both presented channels

Fitted parameters: M_{a0}, g_{a0K+K-}, $g_{a0\eta\pi}$, strength and interference phase of $\rho\pi$ background

	Fit result	stat.	syst.	
M_{a0}	982.5	± 1.3	± 1.0	MeV
g_{a0K+K-}	2.15	± 0.05	± 0.06	GeV
$g_{a0\eta\pi}$	2.82	± 0.04	± 0.04	GeV
$g_{\phi a0\gamma}$	1.59	± 0.09	± 0.16	GeV^{-1}
Br(VDM)	$(0.92$	± 0.40	± 0.15)	$\times 10^{-6}$
δ(VDM)	(222	± 12	± 3)°	

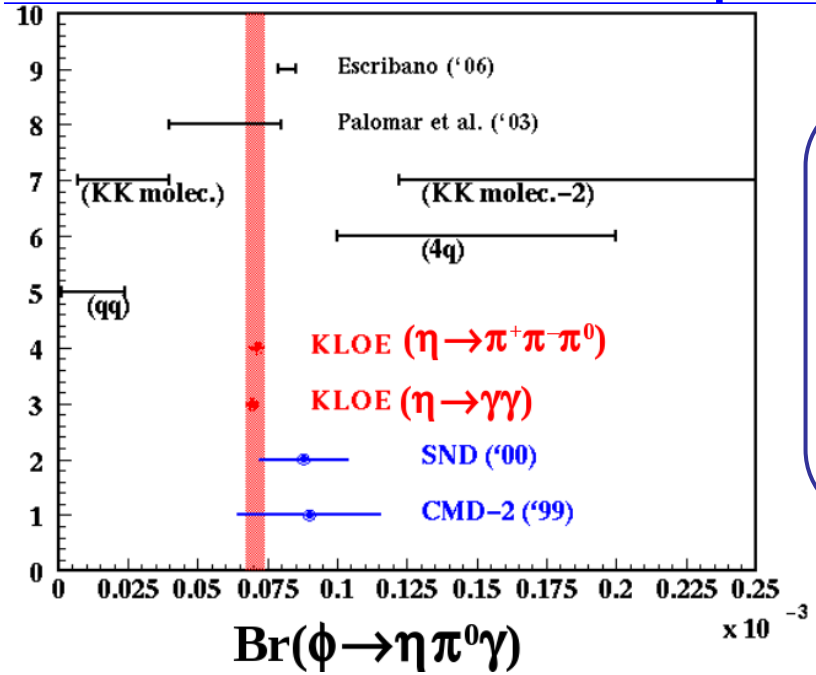
VDM= $\phi \to \rho\pi \to \eta\gamma\pi$

to be published

Correlation matrix			
M_{a0}	1.000		
g_{a0KK}	0.931	1.000	
$g_{a0\eta\pi}$	0.584	0.550	1.000

Strong correlation between M_{a0} and KK coupling: pay attention in comparing with other experiments

Comparison with scalar models and theoretical predictions



qq: Achasov-Ivanchenko NPB315(1989)
Close et al., NPB389(1993)
4q: Achasov-Ivanchenko NPB315(1989)
KK molec.: Close et al., NPB389(1993)
Achasov et al., PRD56(1997)
KK molec.-2: Kalashnikova et al., EPJA24(2005)
Palomar et al., NPA729(2003): UχPT
Escribano, PRD74(2006): Linear σ model

In the 2 quarks picture the f_0 prefers an ss structure
4q not able to accommodate small g_{a0KK} coupling

	KLOE	SU(3)		
		4q	qqbar	
$(g_{aK^+K^-}/g_{a\eta\pi})^2$	0.6 – 0.7 SND(2000): 1.8±2.5	1.2 – 1.7	0.4	
$(g_{f0K^+K^-}/g_{f0\pi^+\pi^-})^2$	4.6 – 4.8 CMD2(1999): 3.61±0.62 SND(2000): 4.6±0.8 BES(2005): 4.21±0.33	>>1	>>1 (f_0=ssbar)	1/4 (f_0=nnbar)
$(g_{f0K^+K^-}/g_{aK^+K^-})^2$	4 - 5	1	2 (f_0=ssbar)	1 (f_0=nnbar)

Conclusions

Scalar Mesons:

- $\phi \to f_0(980)\gamma \to \pi^+\pi^-\gamma$ and $\phi \to f_0(980)\gamma \to \pi^0\pi^0\gamma$:
  update of published result, new improved fit and coupling evaluation

- $\phi \to a_0(980)\gamma \to \eta\pi^0\gamma$ with 5 photons final state and 2 charged pions + 5 photons final state:
  New result for Branching Ratio and couplings, to be published

Next to come:

- Combined fit to the two $f_0(980)\gamma$ decay channels
- $\phi \to f_0(980)\gamma \to K_S K_S \gamma$ decay channel