Scalar mesons at KLOE

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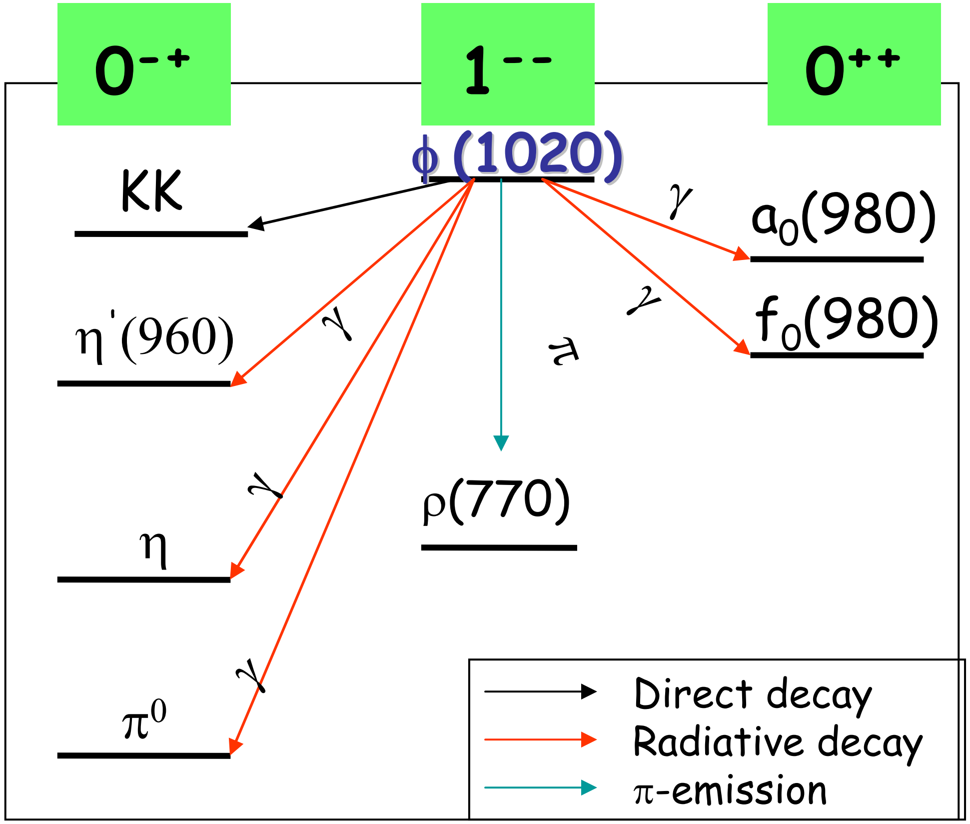
Talk outline

- DAFNE and KLOE
- Scalar Mesons at Φ-factory
  - $\phi \to f_0(980)\gamma \to \pi^+\pi^-\gamma$
  - $\phi \to f_0(980)\gamma \to \pi^0\pi^0\gamma$
  - $\phi \to a_0(980)\gamma \to \eta\pi^0\gamma$
  - Search for $\phi \to (f_0 + a_0)\gamma \to K^0\overline{K}^0\gamma$
- 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 ($s\bar{s}$) and Kaons

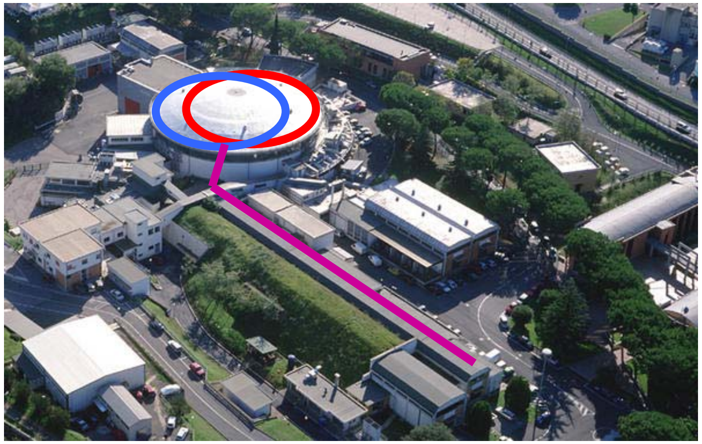


Main decay channels	Branching fraction
→ K^+K^-	49.2 %
→ K_SK_L	34.0 %
→ $\rho\pi$ + $\pi^+\pi^-\pi^0$	15.3 %
→ $\eta\gamma$	1.301 %
→ $\pi^0\gamma$	0.125 %
→ $\eta'\gamma$	6.2×10^{-5}
→ $\pi^0\pi^0\gamma$	~ 10^{-4}
→ $\eta\pi^0\gamma$	$7 \div 8 \times 10^{-5}$
+ "radiative return" to $\pi^+\pi^-$	

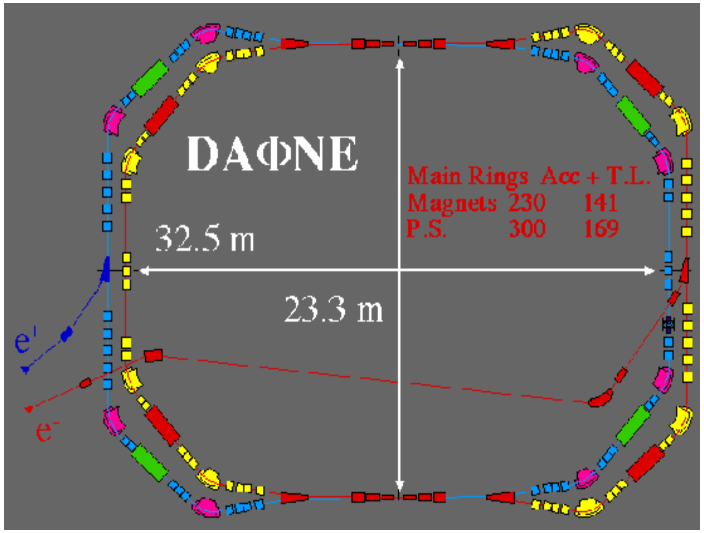
#events in KLOE data = Br.F. × 8 × 10^9 → ~10^8 η; ~10^5 η', $\pi\pi$, $\eta\pi$

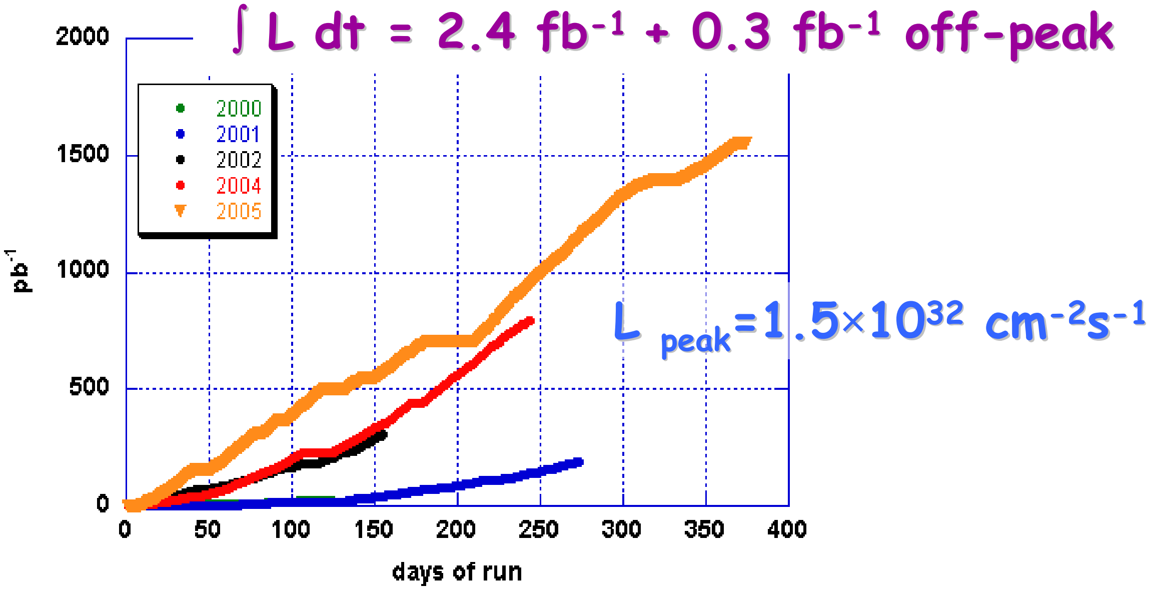
The DAΦNE e^+e^- Φ-factory

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



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



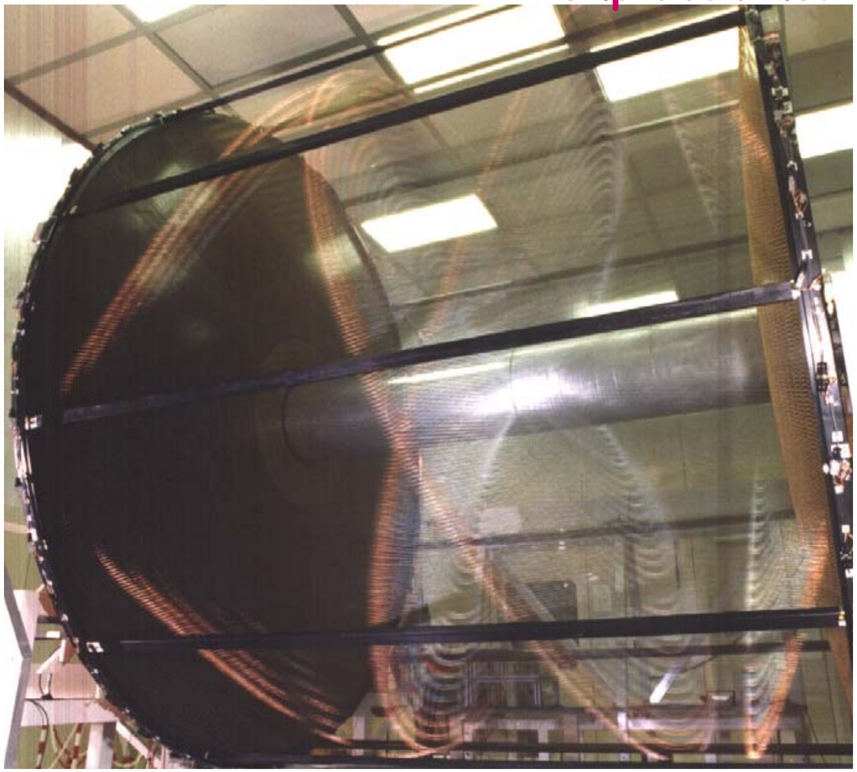


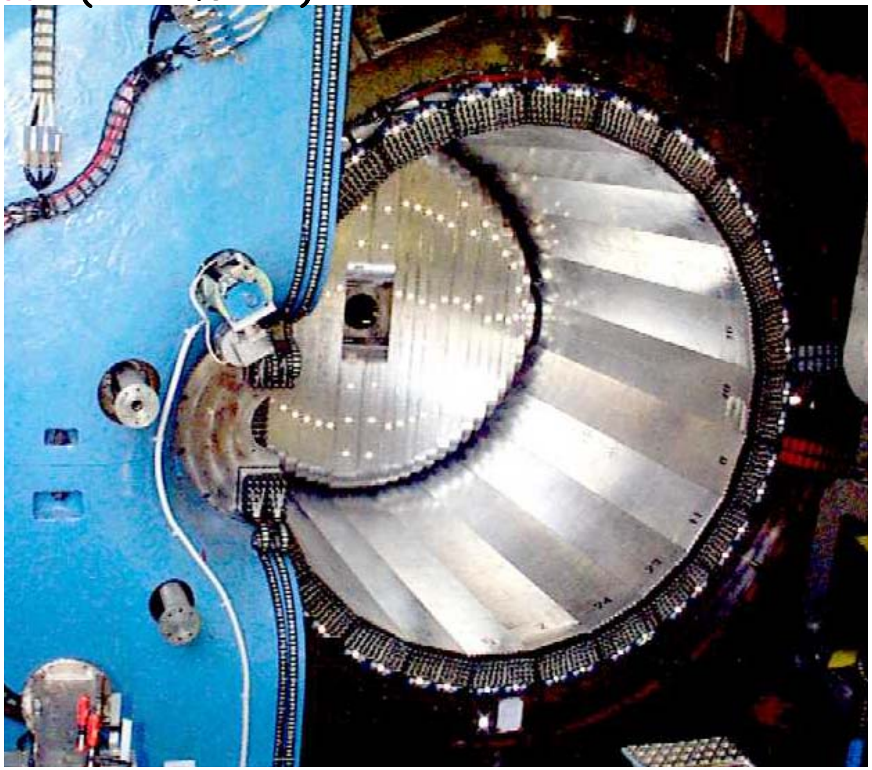
The KLOE detector

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

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

Superconducting coil (B = 0.52 T)

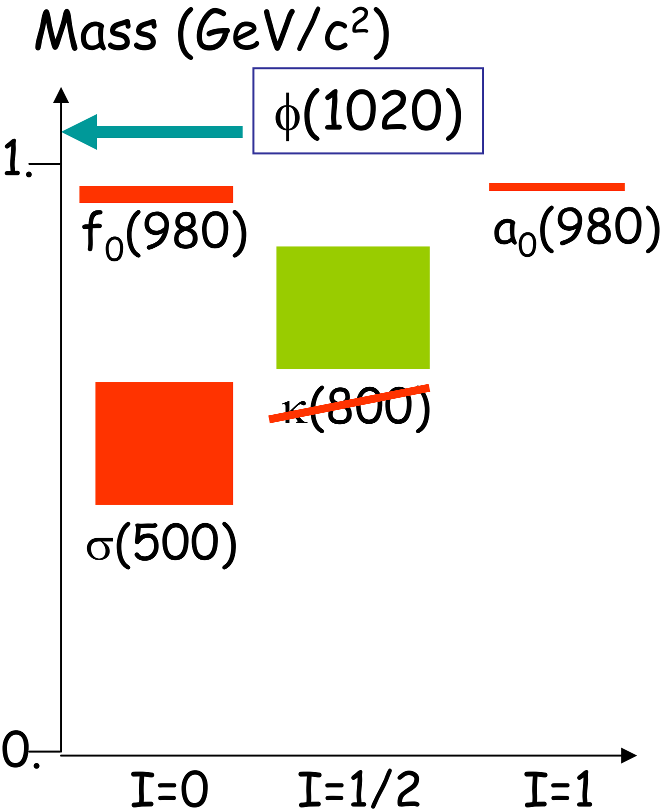




$\sigma_p/p = 0.4\ \%$ (tracks with $\theta > 45°$)
$\sigma_x^{hit} = 150\ \mu m\ (xy),\ 2\ mm\ (z)$
$\sigma_x^{vertex} \sim 1\ mm$
$\sigma(M_{\pi\pi}) \sim 1\ MeV$

$\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$
$\sigma_t = 54\ ps / \sqrt{E(GeV)} \oplus 50\ ps$
$\sigma_{vtx}(\gamma\gamma) \sim 1.5\ cm$ (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)

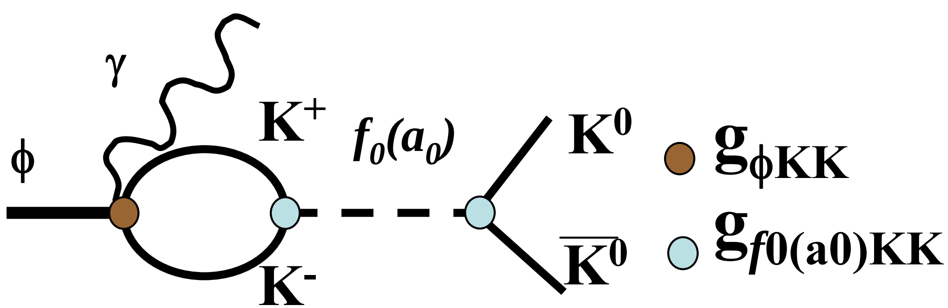
Questions:

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 $\phi \to f_0(980)\gamma \to \pi\pi\gamma$ analyses

Published results

$f_0 \to \pi^+\pi^-$

B.R.($\phi \to f_0(980)\gamma \to \pi^+\pi^-\gamma$) = 2.1 ÷ 2.4 × 10^{-4} **[PLB634(2006)148]**
(from integral of |Amplitude|^2)

$f_0 \to \pi^0\pi^0$

$$BR(\phi \to f_0\gamma \to \pi^0\pi^0\gamma) = \left[1.07^{+0.01}_{-0.04}(fit)^{+0.04}_{-0.02}(syst)^{+0.06}_{-0.05}(mod)\right]\times 10^{-4}$$

[EPJC49(2007)473]

Kaon-Loop fit results

$\pi^0\pi^0$: σ(600) [fixed values] needed to describe data

$\pi^+\pi^-$: not sensitive to σ(600)

both channels: f_0(980) strongly coupled to KK

Parameter	$\pi^+\pi^-\gamma$	$\pi^0\pi^0\gamma$	
M_{f0} (MeV)	980–987	$976.8 \pm 0.3^{+0.9}_{-0.6}$	± 10.1
g_{f0KK} (GeV)	5.0–6.3	$3.76 \pm 0.04^{+0.15}_{-0.08}$	$^{+1.16}_{-0.48}$
$g_{f0\pi\pi}$ (GeV)	3.0–4.2	$-1.43 \pm 0.01^{+0.01}_{-0.06}$	$^{+0.03}_{-0.60}$
$g^2_{f0KK} / g^2_{f0\pi\pi}$	2.2–2.8	$6.9 \pm 0.1^{+0.2}_{-0.1}$	$^{+0.3}_{-3.9}$

- Confidence intervals given by exp. systematics, except for KL in the $\pi^0\pi^0\gamma$ channel (theory)
- Marginal agreement between $\pi^0\pi^0$ and $\pi^+\pi^-$

$\phi \rightarrow f_0(980)\gamma \rightarrow \pi\pi\gamma$ updates

- ✓ Attempt to describe both spectra with a unique scalar amplitude: **$f_0(980) + \sigma(600)$ + interference**
- ✓ Two changes in $\sigma(600)$ couplings w.r.t. PRD73(2006)054029
- ✓ Preliminary results are encouraging:

Channel	M_{f0} (MeV)	g_{f0KK} (GeV)	$g_{f0\pi\pi}$ (GeV)	$g^2_{f0KK} / g^2_{f0\pi\pi}$
$\pi^0\pi^0\gamma$	$984.7 \pm 1.9_{mod}$	$3.97 \pm 0.43_{mod}$	$-1.82 \pm 0.19_{mod}$	~4.8
$\pi^+\pi^-\gamma$	983.7	4.74	–2.22	~4.6

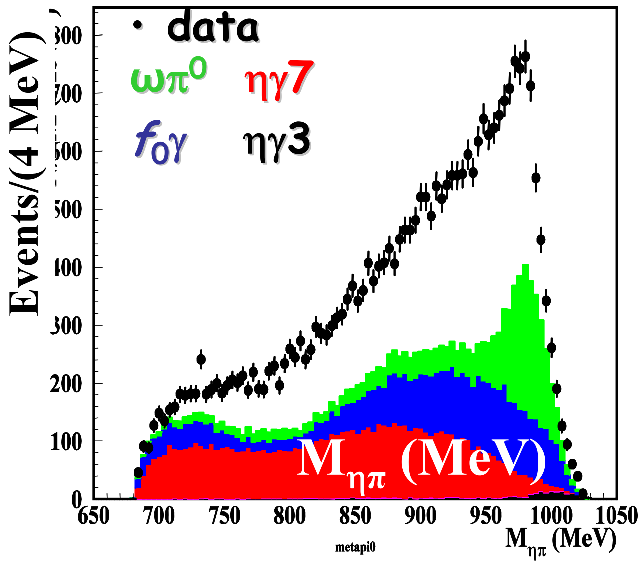
preliminary

- **Better agreement between the two channels**
- **Reduced model uncertainties**
- **Other uncertainties under evaluation**

$e^+e^- \to \eta\pi^0\gamma$: search for $a_0(980)$

1) $\eta\to\gamma\gamma$: K-L

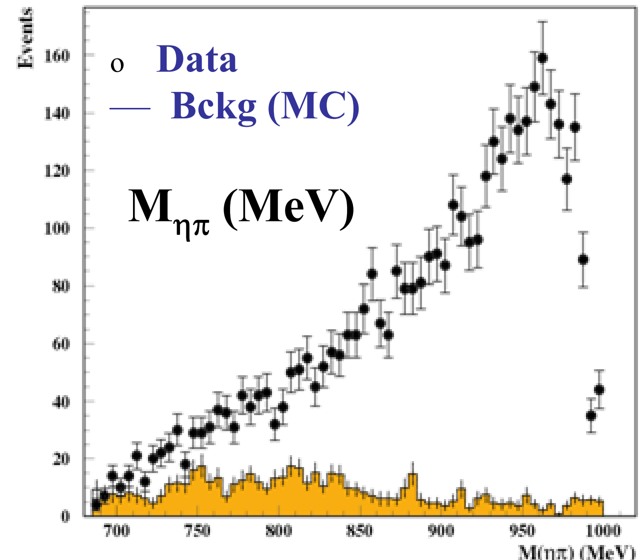
$Br(\phi\to\eta\pi^0\gamma) = (6.98 \pm 0.10_{stat} \pm 0.23_{syst}) \times 10^{-5}$



obtained from event counting (model independent)

to be published

2) $\eta\to\pi^+\pi^-\pi^0$: K-L



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

3) Combined fit to $M_{\eta\pi}$ spectra from 1) and 2), same modeling as $f_0(980)$

$R = (g_{aK^+K^-} / g_{a\eta\pi})^2 = 0.58$ (KL)

0.67 (NS)

✓Good consistency between the two samples: expected R_η=1.68±0.10 [PDG]

Parameter	Kaon-Loop
M_{a0} (MeV)	982.5 ± 1.3 ± 2.7
g_{a0KK} (GeV)	2.15 ± 0.05 ± 0.17
$g_{a0\eta\pi}$ (GeV)	2.82 ± 0.04 ± 0.12
$g_{\phi a0\gamma}$ (GeV^{-1})	1.59 ± 0.09 ± 0.16
R_η=BR($\eta\to\gamma\gamma$)/ BR($\eta\to\pi^+\pi^-\pi^0$)	1.70 ± 0.04 ± 0.05

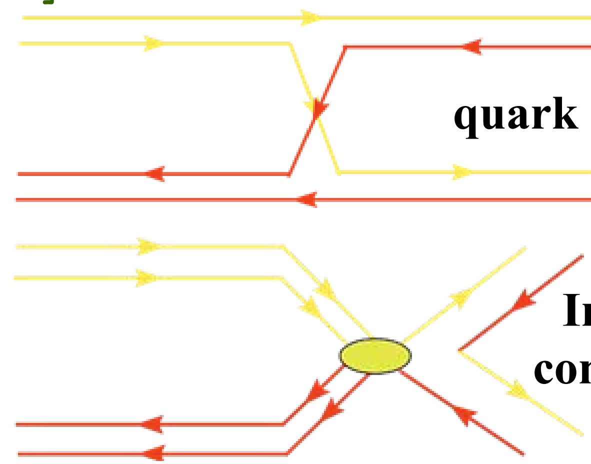
Couplings: $f_0(980)$ vs $a_0(980)$

New theory for scalar mesons: S(4q)→PP decays

['t Hooft,Isidori,Maiani,Polosa,Riquer, PLB662 (2008) 424]

$$\mathcal{L}_{dec}(S) = c_f O_f(S) + c_I O_I(S)$$

Processes	$\mathcal{A}_{th}([qq][\bar{q}\bar{q}])$ with inst.	no inst.	best fit	$\mathcal{A}_{th}(q\bar{q})$ with inst.	no inst.	$\mathcal{A}_{expt}$
$\sigma \to \pi^+\pi^-$	input	input	1.6	input	input	3.22 ± 0.04
$\kappa^+ \to K^0\pi^+$	7.3	7.7	3.3	6.0	5.5	5.2 ± 0.1
$f_0 \to \pi^+\pi^-$	input	[0–1.6]	1.6	input	[0–1.6]	1.4 ± 0.6
$f_0 \to K^+K^-$	6.7	6.4	3.5	6.4	6.4	3.8 ± 1.1
$a_0 \to \pi^0\eta$	6.7	7.6	2.7	12.4	11.8	2.8 ± 0.1
$a_0 \to K^+K^-$	4.9	5.2	2.2	4.1	3.7	2.16 ± 0.04



Inputs from KLOE: g_{f0KK} e $g_{f0\pi\pi}$ + masses + φ_P ⇒ **output** g_{a0KK} e $g_{a0\eta\pi}$

	KLOE (KL)		[qq] [qbarqbar]	qqbar
g_{f0KK} (GeV)	3.97 – 4.74	}	c_I = (-2.8 – -3.4) GeV^{-1}	c_I = (-3.9 – -4.8) GeV^{-1}
$g_{f0\pi\pi}$ (GeV)	-1.82 – -2.23		c_f = (20.5 – 24.5) GeV^{-1}	c_f = (16.5 – 19.7) GeV^{-1}
			⇓	⇓
g_{a0KK} (GeV)	2.15		2.1 – 2.5	2.4 – 2.9
$g_{a0\eta\pi}$ (GeV)	2.82		3.3 – 3.9	6.6 – 7.9

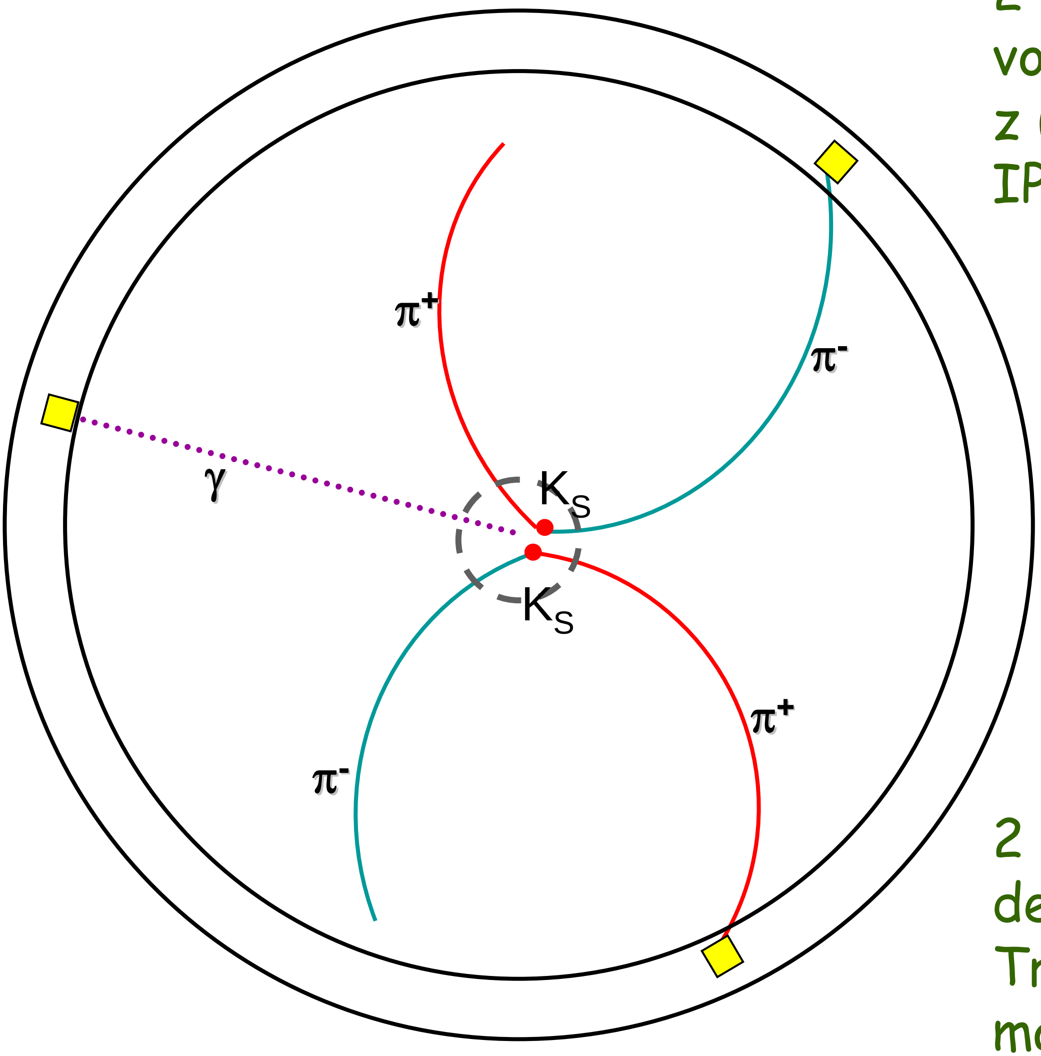
Searching for $\phi \to K^0\overline{K^0}\gamma$

- $K^0\overline{K^0}\gamma$ final state is a $J^{PC}= 0^{++}$ symmetric quantum state, coming from $f_0(980)$ ed $a_0(980)$ scalar mesons decays
- Possible final states will be K_SK_S or K_LK_L
  - Invariant mass $\in$ [995,1020] MeV ($2m(K_0) \to m(\phi)$)

- K_SK_S final state chosen for its larger detection efficiency with both K_S decaying in $\pi^+\pi^-$ ($B.R.(K_S \to \pi^+\pi^-) = 0.692$)

$K^0\overline{K^0}\gamma$ final state predicted but never searched for before

Final state requirements



2 vertices inside a cylindrical volume of 3 cm radius, ±8 cm along z (K_S decay vertices close to the IP, K_S: $\beta < 0.2$, $\lambda < 6$mm)

1 photon from I.P.
($0 < E\gamma < 23.8$ MeV) coming from the IP compatible with missing momentum

2 charged tracks from each K_S decay vertex
Tracks should have invariant mass equal to the K_S mass, in the hypotesis of being $\pi^{\pm}$

$K_S K_S$ selection

Signal MC: modified Phokhara5(*)

- Signal generated with factor 10^3 on expected B.R.
- Implemented model: $\frac{d\Gamma_s}{dm} \propto E_\gamma^3 \sqrt{1-\frac{4m_{K0}^2}{m^2}}$

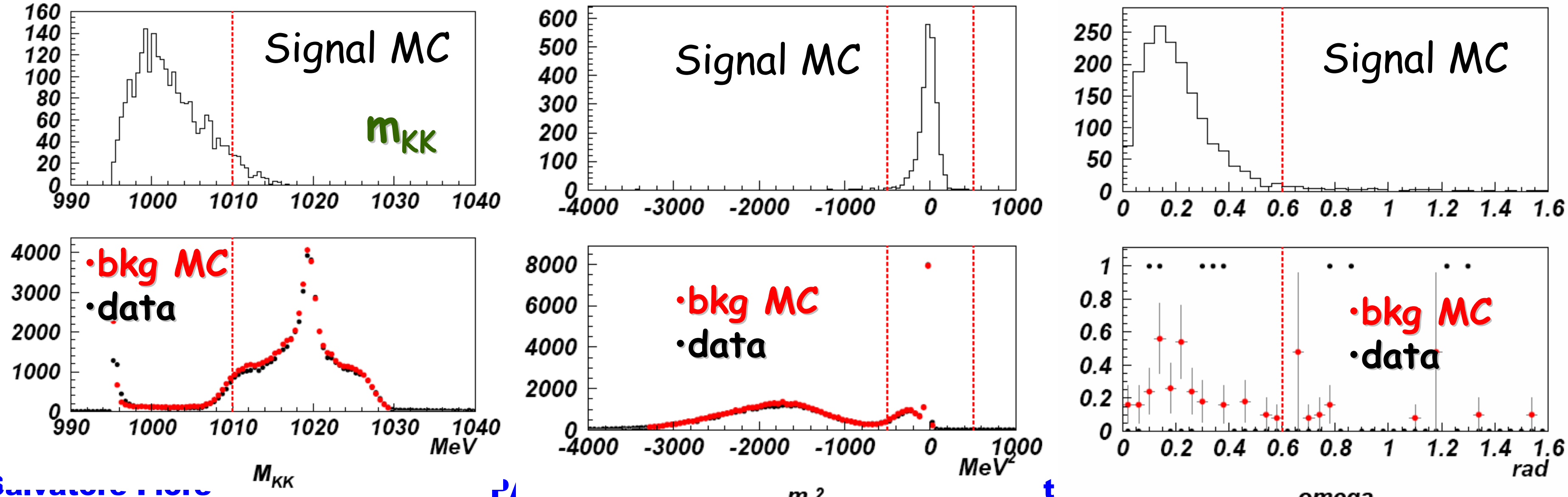
(*)G.Rodrigo, Nucl.Phys.Proc.Suppl.**169**,271 (2007)

Signal Selection

- m_{KK}< 1010MeV and $-500 > E^2_{miss} - P^2_{miss} > 500\,\mathrm{MeV}^2$
- **1 cluster not associated** with tracks with:

  time and **direction** compatible with a photon from the IP

  Ω<0.6 rad (angle between the missing momentum and the direction of the cluster with respect to the IP)



Upper Limit result

❖ Upper Limit calculation:

$$B.R.(\Phi \to K^0\overline{K}^0\gamma) < \frac{UL(\mu_{sig})\ @\ 90\%CL}{\int L dt \cdot \sigma(e^+e^- \to \Phi) \cdot \frac{1}{2} \cdot B.R.(K_S \to \pi^+\pi^-)^2 \cdot \varepsilon}$$

with:

$$\sigma(e^+e^- \to \phi) = 3.09\mu b \qquad \int L dt = 2.18 nb^{-1}$$

$$B.R.(K_S \to \pi^+\pi^-)^2 = (0.692)^2 \qquad \varepsilon = 24.8\%$$

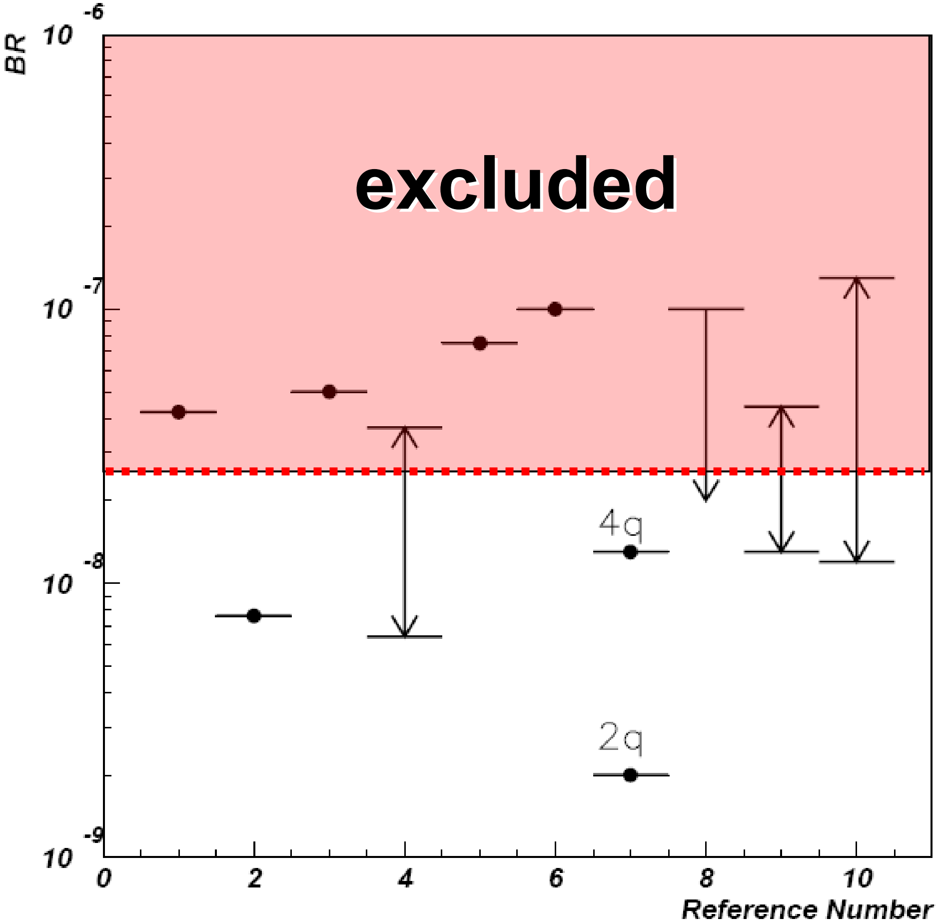
❖ With N_{obs}=5 observed events and N_{bkg}=3.2 expected background events,

- $UL(\mu_{sig})$ at 90% C.L. = 6.79 using Unified Approach, by G.J.Feldman and R.D.Cousins (Phys. Rev. D57 (1998) 3873)

$$B.R.(\phi \to (f_0 + a_0)\gamma \to K^0\overline{K}^0\gamma) < 1.7 \cdot 10^{-8} \text{ at } 90\%\ C.L.$$

Theoretical estimates

$$BR(\Phi \rightarrow (f_0 + a_0)\gamma \rightarrow K^0\overline{K^0}\gamma)_{Theo} = (0.2 \div 140)\times 10^{-8}$$



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7. **N.N.Achasov, V.N.Ivanchenko,** Nucl.Phys.**B315**, 465 (1989)
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10. **A.Gokalp, C.S.Korkmaz, O.Yilmaz,** hep-ph/0702214

Theoretical estimates

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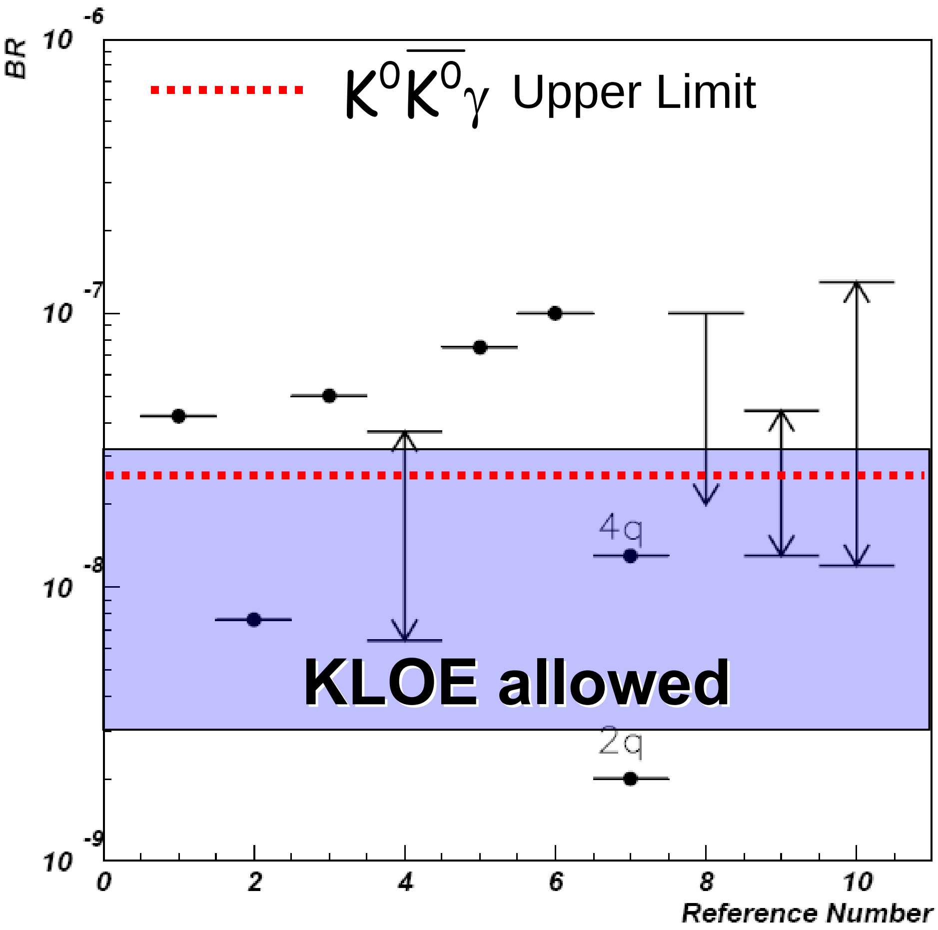

Consistency with KLOE measurements

Using $g_{f0\pi\pi}$, $g_{a0\eta\pi}$ couplings as measured with f_0, a_0 KLOE analyses and inserting these couplings in the Kaon-Loop model it is possible to check **consistency of different KLOE measurements done in the scalar meson sector**

The obtained range is consistent with our Upper Limit

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; consistency with instantons' model
- $\phi \to f_0(980)\gamma \to K_S K_S \gamma$:
  First result ever for the upper limit on this decay channel; Comparison with theoretical estimates and consistency with KLOE measurements from scalars