results on light mesons

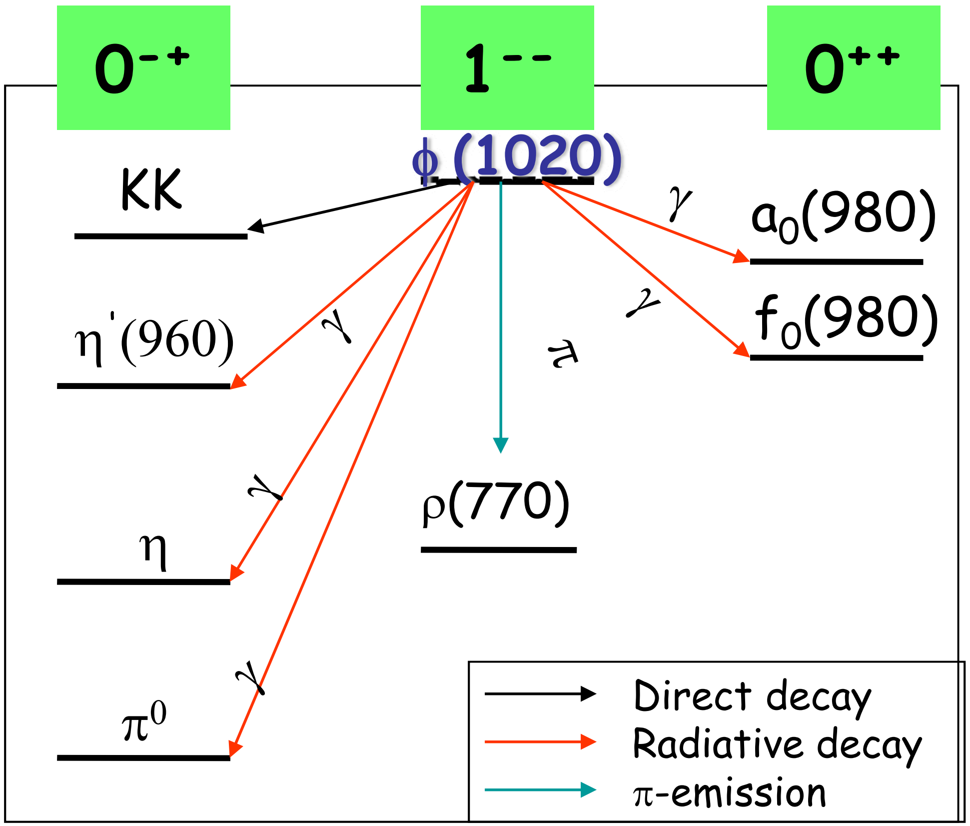
Salvatore Fiore
Sapienza Università di Roma
and INFN Roma
(on behalf of the KLOE collaboration)

Talk outline

- DAϕNE and KLOE
- Scalar Mesons:
  - $\phi \rightarrow a_0(980)\gamma \rightarrow \eta\pi^0\gamma$
  - Search for $\phi \rightarrow K^0\overline{K}^0\gamma$
- Pseudoscalar mesons:
  - $\eta \rightarrow \pi^+\pi^- e^+ e^-$: Branching ratio and decay plane asymmetry
  - η - η' pseudoscalar mixing angle and η' gluonium content
- KLOE-2: $\gamma\gamma$ physics outlook
- 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 $\phi(\overline{s}s)$ and Kaons

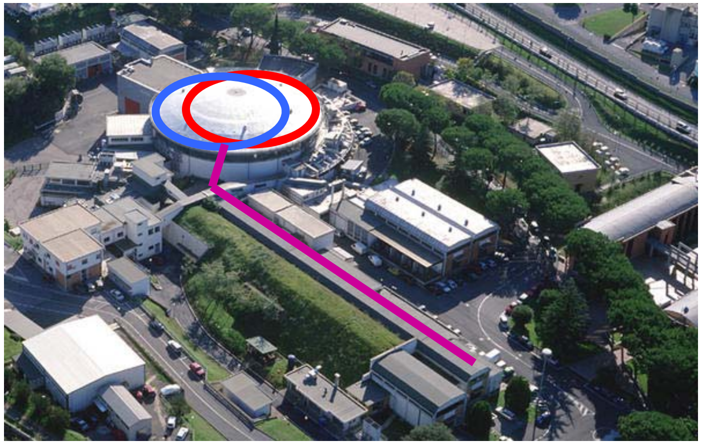


Main decay channels	Branching fraction
→ K^+K^-	49.2 %
→ K_SK_L	34.0 %
→ $\rho\pi$ + $\pi^+\pi^-\pi^0$	15.3 %
→ $\eta\gamma$	1.301 %
→ $\pi^0\gamma$	0.125 %
→ $\eta'\gamma$	6.2×10^{-5}
→ $\pi^0\pi^0\gamma$	~ 10^{-4}
→ $\eta\pi^0\gamma$	$7 \div 8 \times 10^{-5}$
+ "radiative return" to $\pi^+\pi^-$	

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

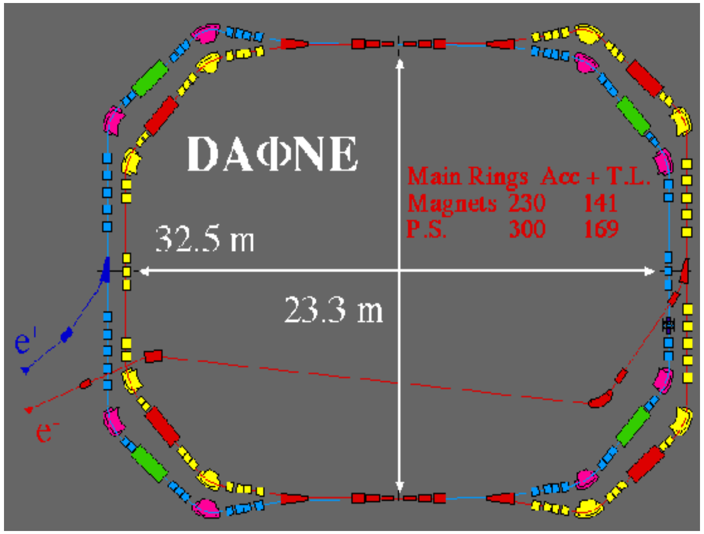
The DAΦNE e^+e^- Φ-factory

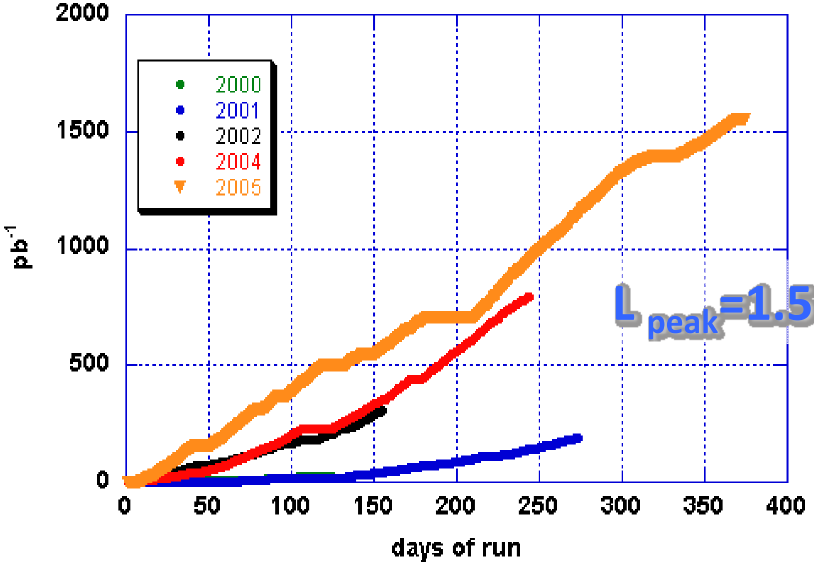
ϕ-factory : an e^+e^- collider with center of mass energy **$\sqrt{s}=m(\phi)=1019.4$MeV**



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

$\int L\,dt = 2.4\ fb^{-1} + 0.3\ fb^{-1}$ off-peak



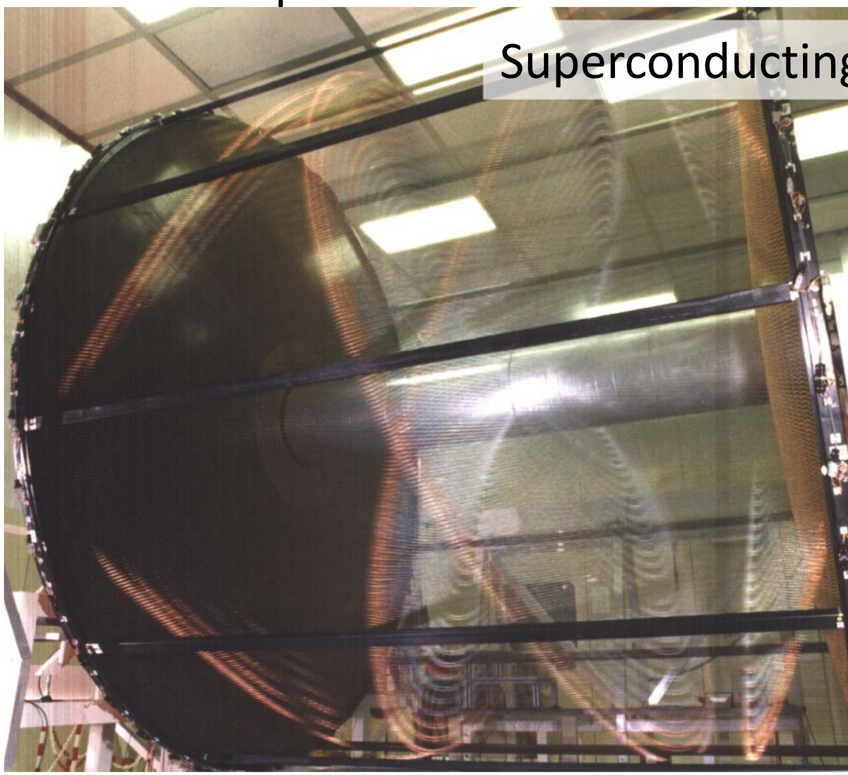


$L_{peak}=1.5\times10^{32}\ cm^{-2}s^{-1}$

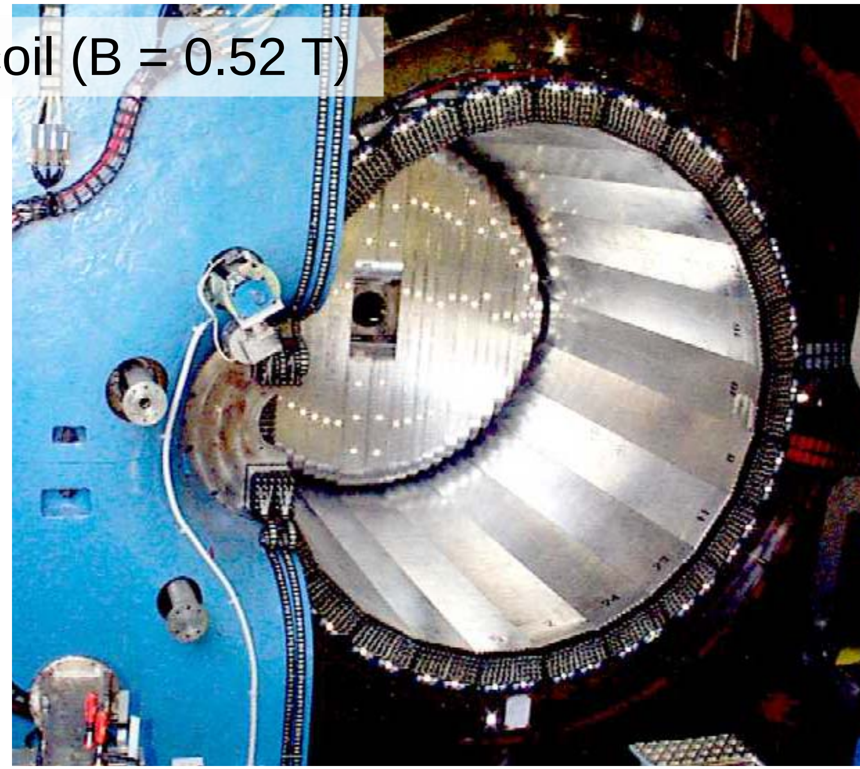
The KLOE detector

Drift chamber (4 m ∅ × 3.3 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)
σ_x^{vertex} ~1 mm
$\sigma(M_{\pi\pi})$ ~1 MeV

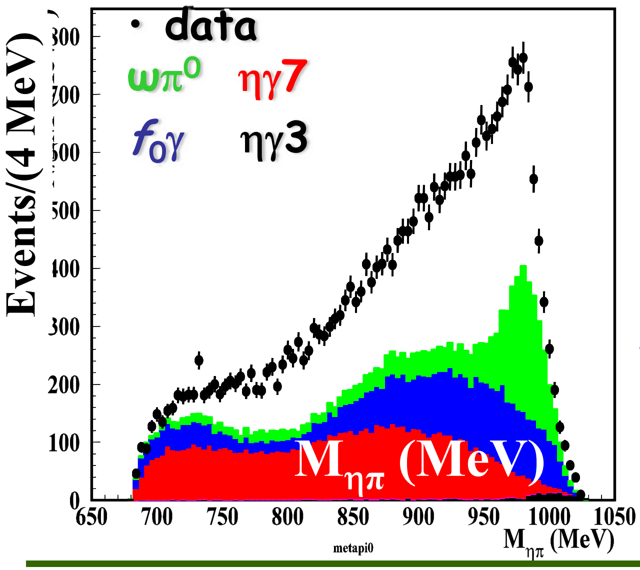
$\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$
$\sigma_t = 54\ ps / \sqrt{E(GeV)} \oplus 140\ ps$
$\sigma_{vtx}(\gamma\gamma)$ ~ 1.5 cm (neutral vertex resolution)

Scalar mesons

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

1) $\eta\to\gamma\gamma$:

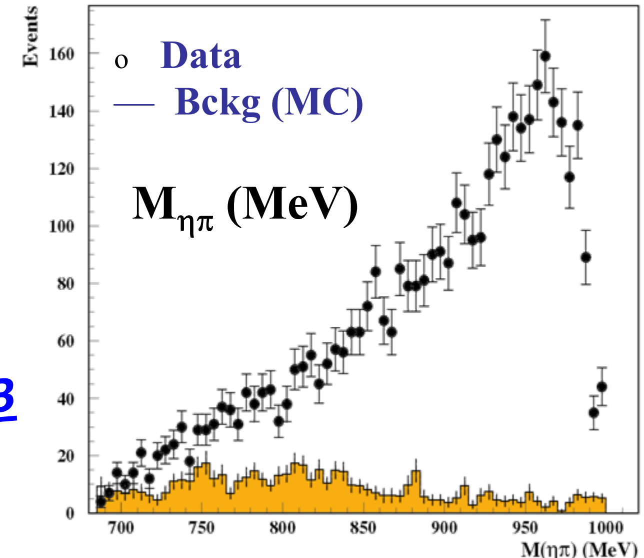
$Br(\phi\to\eta\pi^0\gamma) = (7.01 \pm 0.10_{stat} \pm 0.20_{syst}) \times 10^{-5}$



both obtained from event counting (model independent)

Accepted by Phys.Lett.B

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

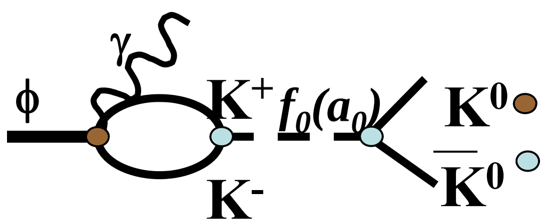


$Br(\phi\to\eta\pi^0\gamma) = (7.12 \pm 0.13_{stat} \pm 0.22_{syst}) \times 10^{-5}$

Combined fit to $M_{\eta\pi}$ spectra from 1) & 2)

✓Good consistency between the two samples: expected R_η=1.73±0.04 [PDG]

Parameter	Kaon-Loop	No structure
M_{a0}(MeV)	982.5 ± 1.6 ± 1.1	982.5 (fixed)
g_{a0KK}(GeV)	2.15 ± 0.06 ± 0.06	2.01 ± 0.07 ± 0.28
$g_{a0\eta\pi}$(GeV)	2.82 ± 0.03 ± 0.04	2.46 ± 0.08 ± 0.11
R_η=BR($\eta\to\gamma\gamma$)/ BR($\eta\to\pi^+\pi^-\pi^0$)	1.70 ± 0.04 ± 0.03	1.70 ± 0.03 ± 0.01



$g_{\phi KK}$

$g_{f0(a0)KK}$

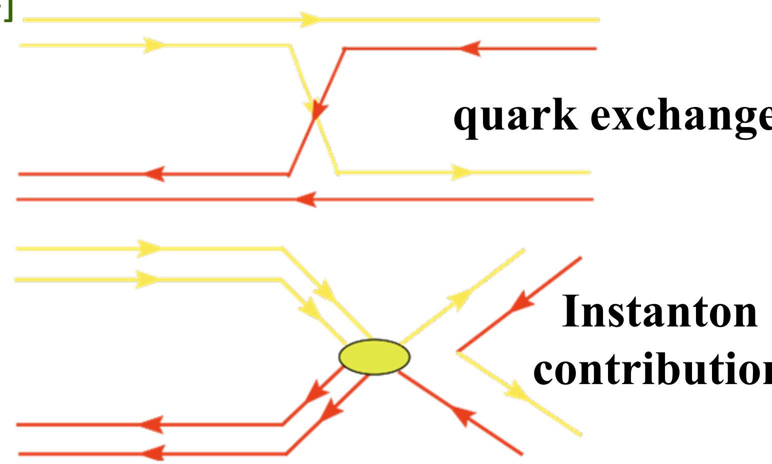
Couplings: $f_0(980)$ vs $a_0(980)$

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



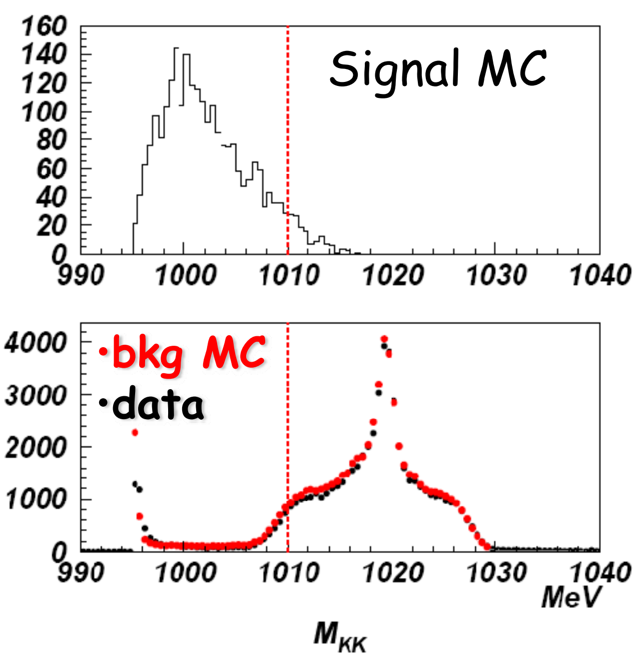
Inputs from KLOE: g_{f0KK} , $g_{f0\pi\pi}$ + masses + φ_P ⇒ output g_{a0KK} , $g_{a0\eta\pi}$

	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

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

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

predicted but no experimental measure exists



$$\int Ldt = 2.18 fb^{-1} \text{ at } \phi \text{ peak}$$

Signal MC: modified Phokhara5

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

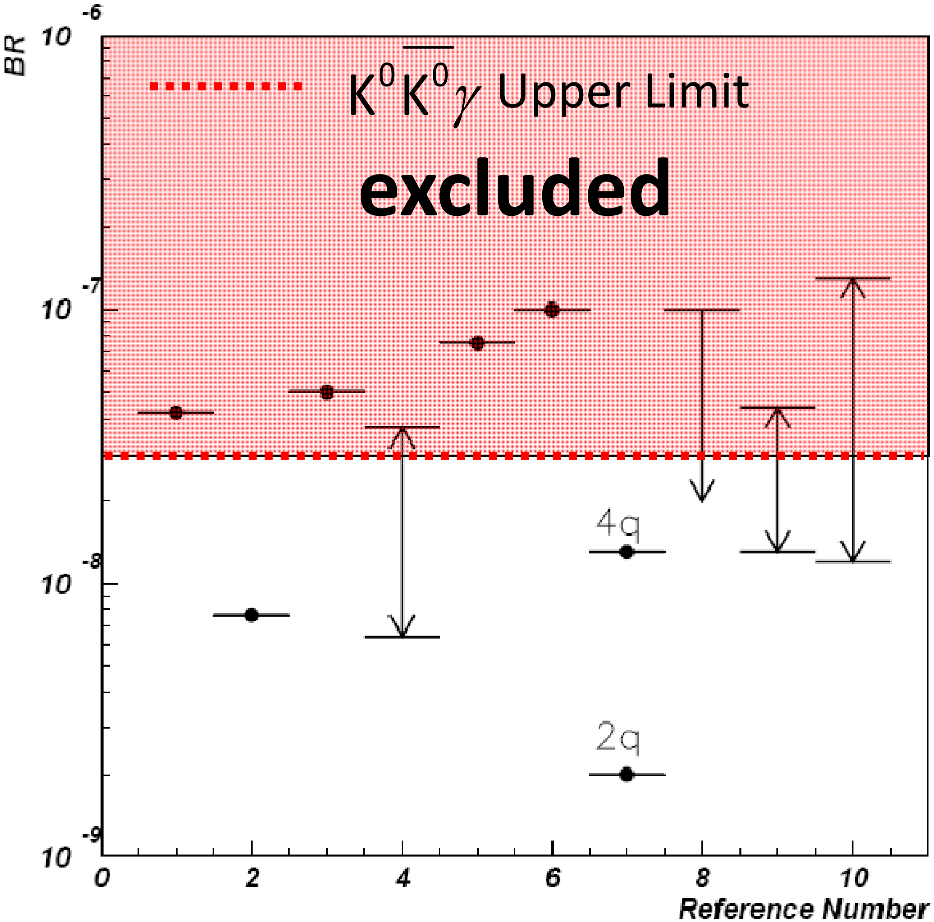
With N_{obs}=5 observed events and N_{bkg}=3.2±0.7 expected background events,

$$B.R.(\phi \to K^0\overline{K^0}\gamma) < 1.9 \cdot 10^{-8} \text{ at } 90\% \text{ C.L.}$$

Phys.Lett.B 679 (2009), 10

using Unified Approach, by G.J.Feldman and R.D.Cousins (Phys. Rev. D57 (1998) 3873)

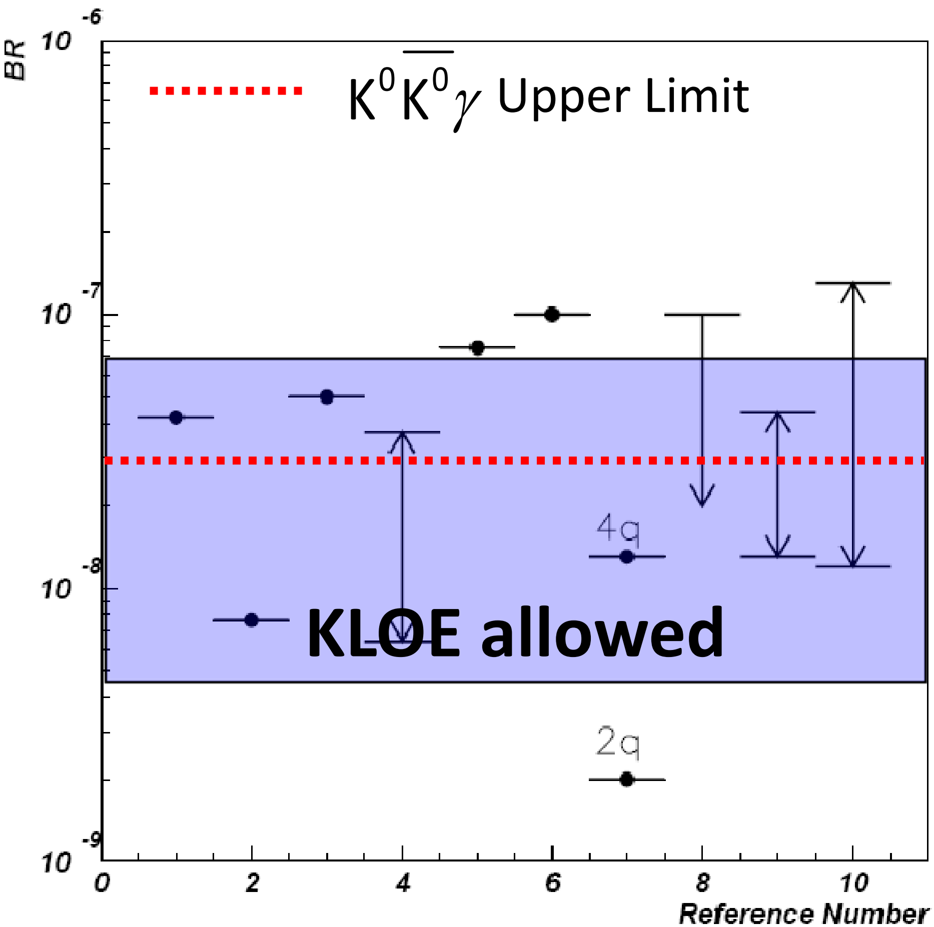
Comparison with theoretical estimates



1. **S.Fajfer, R.J.Oakes (Low-E effective Lag.)**
   Phys.Rev.D42 (1990) 2392
2. **A.Bramon, A.Grau, G.Pancheri (no explicit S)**
   Phys.Lett.**B289**, 97 (1992)
3. **J.A.Oller (UχPT)**
   Phys.Lett.**B426**, 7 (1998)
4. **J.A.Oller (UχPT)**
   Nucl.Phys.A714 (2003) 161
5. **R.Escribano (S and P mesons Ab Initio)**
   Eur.Phys.J.**A31**, 454 (2007)
6. **S.Nussinov, T.N.Truong,**
   Phys.Rev.Lett.63 (1989) 1349, Erratum 2003
7. **N.N.Achasov, V.N.Ivanchenko (Kaon Loop)**
   Nucl.Phys.**B315**, 465 (1989)
8. **J.Lucio, J.Pestieau (f_0 only)**
   Phys.Rev.D42 (1990) 3253
9. **N.N.Achasov, V.V.Gubin (SND data K-Loop)**
   Phys.Rev.**D64**, 094016 (2001)
10. **A.Gokalp, C.S.Korkmaz, O.Yilmaz (KLOE K-Loop)**
    Phys.Rev.D75(2007) 013001

Comparison with theoretical estimates

<u>*Consistency with KLOE measurements*</u>



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

Pseudoscalar mesons

$\eta \to \pi^+\pi^- e^+ e^-$ branching ratio

- η decay into ππee predicted with a branching ratio of 26÷36x10^{-5}
- At KLOE η mesons produced by radiative decay $\phi\to\eta\gamma$, monochromatic photon of 363 MeV: 1.7 fb^{-1} of ϕ-decays data → 7x10^7 η's , 0.24 fb^{-1} off the ϕ peak (background evaluation), 50 fb^{-1} of signal MC

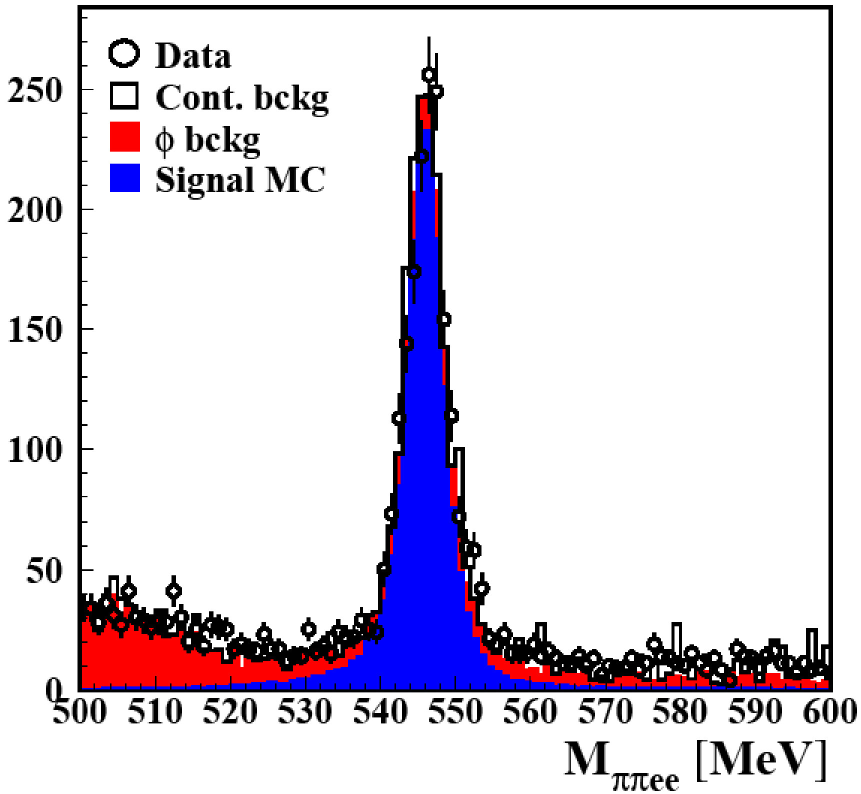
✓FSR included by PHOTOS MC

✓4-track events, mass assignment through π decay ID or TOF, kinematic fit

✓Background:

- ✓ϕ-decays ($\pi^+\pi^-\pi^0$ or ηγ, $\eta\to\pi^+\pi^-\pi^0$, $\pi^+\pi^-\gamma$)
- ✓continuum (radiative Bhabha + conversion)

✓Background rejection through kinematic costraints, and then fitting the background components out of the signal region



$\eta \to \pi^+\pi^- e^+ e^-$ branching ratio

- η decay into ππee predicted with a branching ratio of 26÷36x10^{-5}
- At KLOE η mesons produced by radiative decay $\phi\to\eta\gamma$, monochromatic photon of 363 MeV: 1.7 fb^{-1} of ϕ-decays data → 7x10^{7} η's , 0.24 fb^{-1} off the ϕ peak (background evaluation), 50 fb^{-1} of signal MC

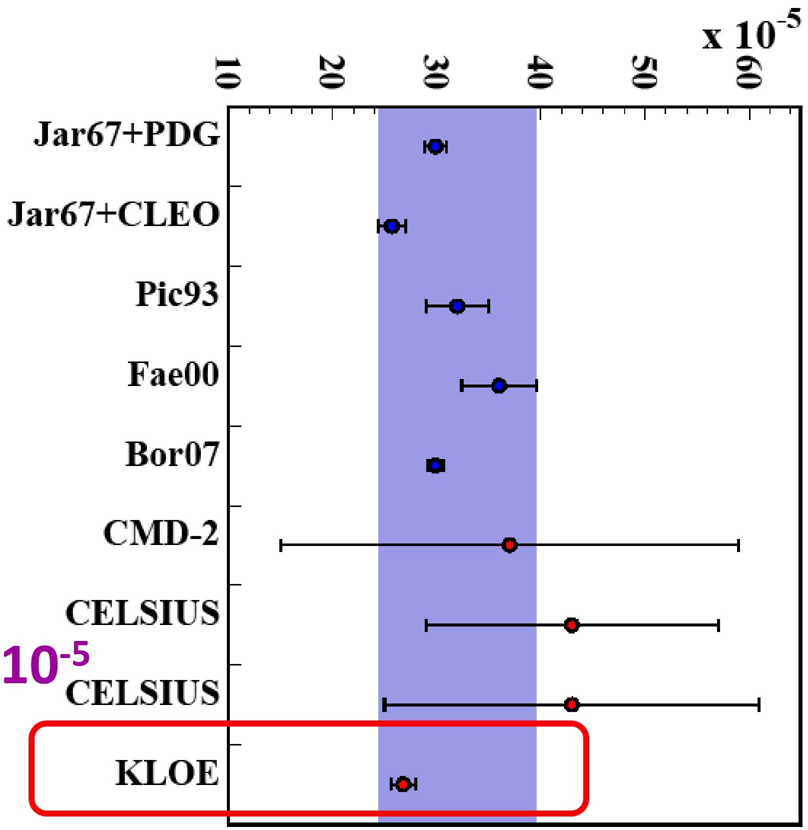
✓FSR included by PHOTOS MC

✓4-track events, mass assignment through π decay ID or TOF, kinematic fit

✓Background:

- ✓ϕ-decays ($\pi^+\pi^-\pi^0$ or ηγ, $\eta\to\pi^+\pi^-\pi^0$, $\pi^+\pi^-\gamma$)
- ✓continuum (radiative Bhabha + conversion)

✓Background rejection through kinematic costraints, and then fitting the background components out of the signal region



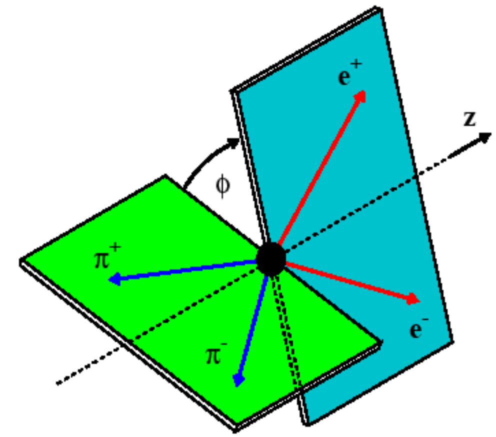
$BR(\eta\to\pi^+\pi^-e^+e^-(\gamma)) = (26.8\pm0.9_{stat}\pm0.7_{syst}) \times 10^{-5}$

Phys.Lett.B 675 (2009), 283

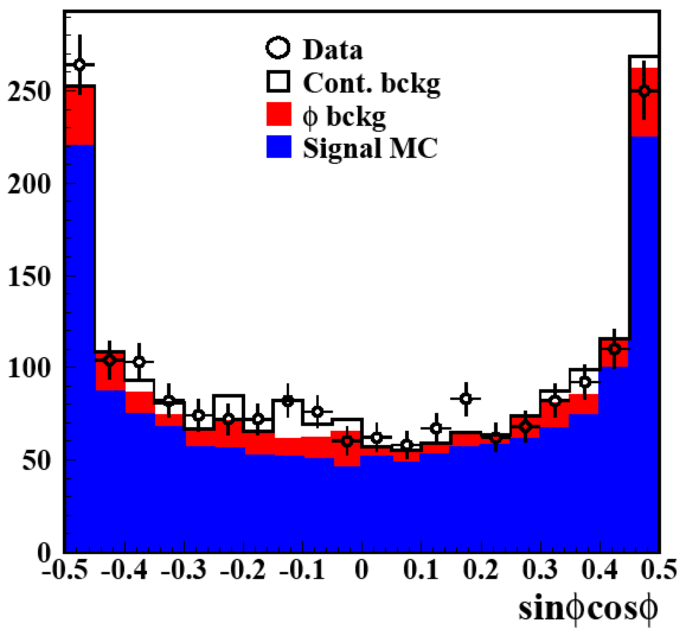
$\eta \rightarrow \pi^+\pi^- e^+ e^-$ decay plane asymmetry

A possible CP violating mechanism has been proposed, which could induce interference between electric and magnetic decay amplitudes

- this would result in an <u>observable asimmetry</u> in the angle between the planes containing the pions and the electrons, of the order of 10^{-2}



$$A_\phi = \frac{N_{\sin\phi\cos\phi>0} - N_{\sin\phi\cos\phi<0}}{N_{\sin\phi\cos\phi>0} + N_{\sin\phi\cos\phi<0}}$$



- the asymmetry has been evaluated on the final event sample to be
  $A_\phi = -(0.6 \pm 2.5 \pm 1.8) \times 10^{-2}$

Phys.Lett.B 675 (2009), 283

<u>first measurement of A_ϕ</u>

- also checked with a control sample

η' meson

- BR($\phi \to \eta'\gamma$) can probe the ss and gluonium content of η'
- The ratio R= BR($\phi \to \eta'\gamma$)/BR($\phi \to \eta\gamma$) can be related to the η-η' mixing parameters and determine the mixing angle in the flavor basis φ_P, the best parameter for a description of the mixing
- Using the approach by Bramon et al. [Eur. Phys. J. C7, 271(1999)] and introducing a possible gluonium content via $\cos^2\varphi_G$, KLOE extracts the η-η' mixing angle φ_P by measuring the quantity:

$$R_\phi = \frac{BR(\phi \to \eta'\gamma)}{BR(\phi \to \eta\gamma)} = \cot^2\varphi_P \cdot \cos^2\varphi_G \left(1 - \frac{m_s}{\overline{m}} \cdot \frac{Z_q}{Z_s} \cdot \frac{\tan\psi_V}{\sin 2\varphi_P}\right)^2 \cdot \left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

Phys.Lett.B 648 (2007), 267

$$= (4.77 \pm 0.09_{stat} \pm 0.19_{syst}) \times 10^{-3}$$

using similar η and η' decay chains:
$\pi^+\pi^-7\gamma$ for the η', 7γ for the η

$$\phi \to \eta'\gamma, \eta' \to \pi^0\pi^0\eta, \eta \to \pi^+\pi^-\pi^0$$
$$\eta' \to \pi^+\pi^-\eta, \eta \to \pi^0\pi^0\pi^0$$
$$\phi \to \eta\gamma, \eta \to \pi^0\pi^0\pi^0$$

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

$$\eta = \cos\varphi_p \frac{1}{\sqrt{2}}|u\overline{u} + d\overline{d}> - \sin\varphi_p |s\overline{s}>$$

$$X_{\eta'} = \sin\varphi_p \cos\varphi_G, Y_{\eta'} = \cos\varphi_p \cos\varphi_G, Z_{\eta'} = \sin\varphi_G$$

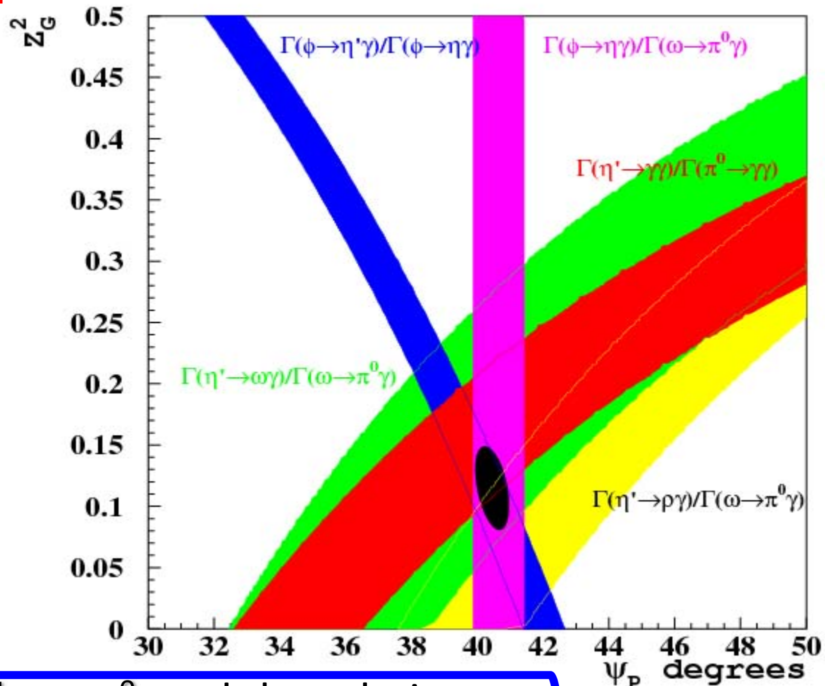
The η-η' mesons wave function can be decomposed in the quark mixing base
(J.L. Rosner, Phys.Rev.D27(1983) 1101

η' gluonium content

New global fit with more free parameters: Z_q, Z_s, ψ_V, m_s/m , plus from PDG06:

$$\frac{\Gamma(\omega\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)} \quad \frac{\Gamma(\rho\to\pi^0\gamma)}{\Gamma(\omega\to\pi^0\gamma)} \quad \frac{\Gamma(\phi\to\eta\gamma)}{\Gamma(\omega\to\pi^0\gamma)} \quad \frac{\Gamma(\phi\to\pi^0\gamma)}{\Gamma(\omega\to\pi^0\gamma)} \quad \frac{\Gamma(K^{*+}\to K^+\gamma)}{\Gamma(K^{*0}\to K^0\gamma)}$$

Parameter	KLOE old fit	KLOE new fit	PDG08+$\omega\pi^0$
$Z_{\eta'}^2$	0.14±0.04	0.105±0.037	0.115±0.036
φ_P	(39.7±0.7)°	(40.7±0.7)°	(40.4±0.6)°
Z_q	0.91±0.05	0.866±0.025	0.936±0.025
Z_s	0.89±0.07	0.79±0.05	0.83±0.05
ψ_V	3.2°	(3.15±0.10)°	(3.32±0.09)°
m_s/m	1.24±0.07	1.24±0.07	1.24±0.07
$P(\chi^2)$	49%	17%	20%



We also fit PDG08 data, using KLOE measurement for $\phi\to\omega\pi^0$, and the relation:

$$\frac{\Gamma(\eta'\to\gamma\gamma)}{\Gamma(\pi^0\to\gamma\gamma)} = \frac{1}{9}\left(\frac{m_{\eta'}}{m_\pi}\right)^3\left(5\frac{f_\pi}{f_q}X_{\eta'} + \sqrt{2}\frac{f_\pi}{f_s}Y_{\eta'}\right)^3 \qquad f_q/f_\pi = 1,\ \ f_s/f_\pi = \sqrt{2f_K^2/f_\pi^2 - 1}$$ in the exact isospin symmetry limit

E. Kou, PRD63(2001)54027

f_K/f_π from lattice QCD (UKQCD) E. Follana et al., PRL100(2008)062002

Gluonium content confirmed at 3σ (if $Z_{\eta'}=0$, $\varphi_P=(41.65\pm0.5)°$, $P(\chi^2)=1\%$)

Z_G can be interpreted as a mixing with a glueball with m_G = (1.41 ± 0.1) GeV (η(1405)) determined using KLOE fit results [Hai-Yang Cheng, Phys. Rev. D79 (2009) 014024]

More to come:

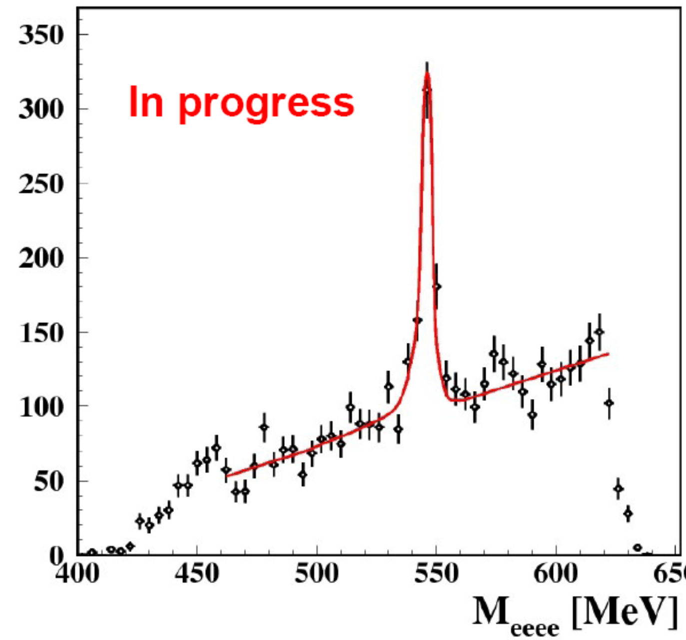
- measurement of $\dfrac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)}$
  - Data sample of $6\text{x}10^5$ events in 1.18 fb^{-1} after selection
  - **preliminary result:** $\dfrac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)}$ **= 0.2014±0.0004±0.0063**

    (PDG: 0.202±0.007)

- $\eta \to e^+e^-e^+e^-$: process never observed.
  - CMD-2 gives an upper limit :

    $BR(\eta \to e^+e^-e^+e^-) < 6.9\text{x}10^{-5}$
  - theoretical predictions are

    $BR(\eta \to e^+e^-e^+e^-) = 2.52\text{-}2.64\text{x}10^{-5}$

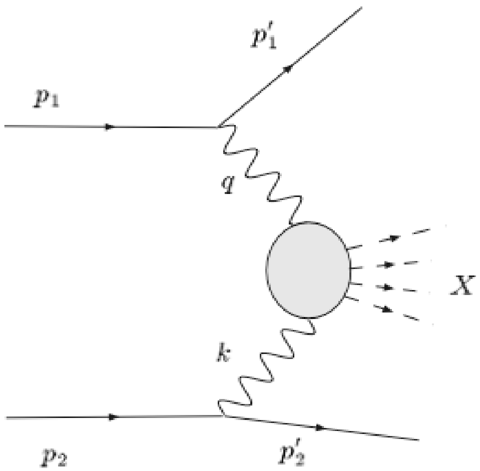


KLOE: 413±31 events in data sample:

first evidence

The near future: KLOE-2

- KLOE will restart taking data at the beginning of 2010 on the DAFNE collider, on the ϕ peak.
- Expected integrated luminosity for 2010 is $5fb^{-1}$
- The detector is being upgraded for $\gamma\gamma$ physics measurements



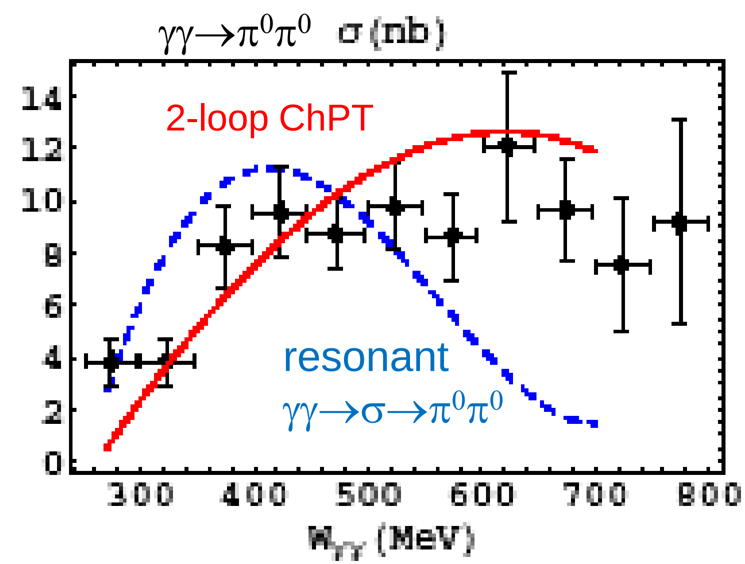
$\gamma\gamma$ physics stands for $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- + X$

this process gives access to $J^{PC} = 0^{\pm+}, 2^{\pm+}$ states:

$\pi\pi$ (σ), η, η', f_0 , a_0

In the low-energy region, for $W_{\gamma\gamma}$<1GeV, present experimental situation is unsatisfactory:

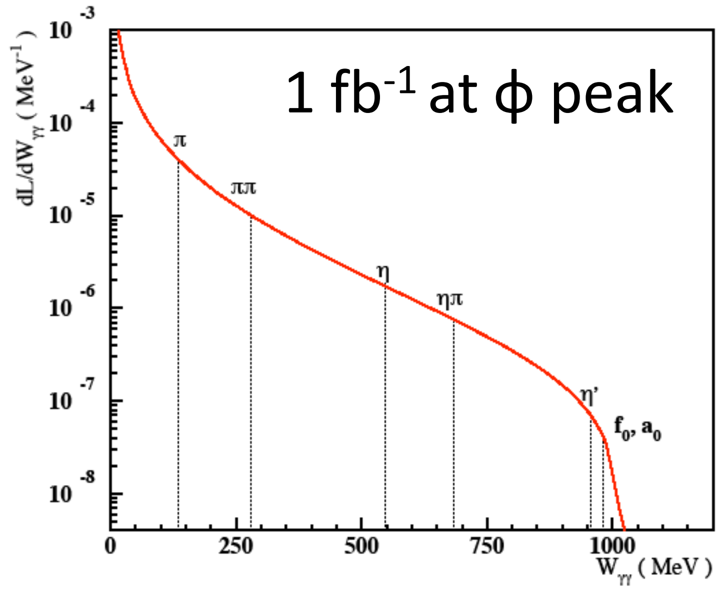
- small data samples and large backgrounds
  → large stat. and syst. uncertainties
- small detection efficiencies and particle ID for low-mass hadronic states



gamma-gamma physics in a Φ-factory

$\gamma\gamma$ physics can be done at a ϕ–factory, on the ϕ peak:

Access to many interesting final states through photon emission from both colliding electron and positron



TRUE, BUT...

$\gamma\gamma$ events acquired at the ϕ peak would suffer from ϕ decays as background

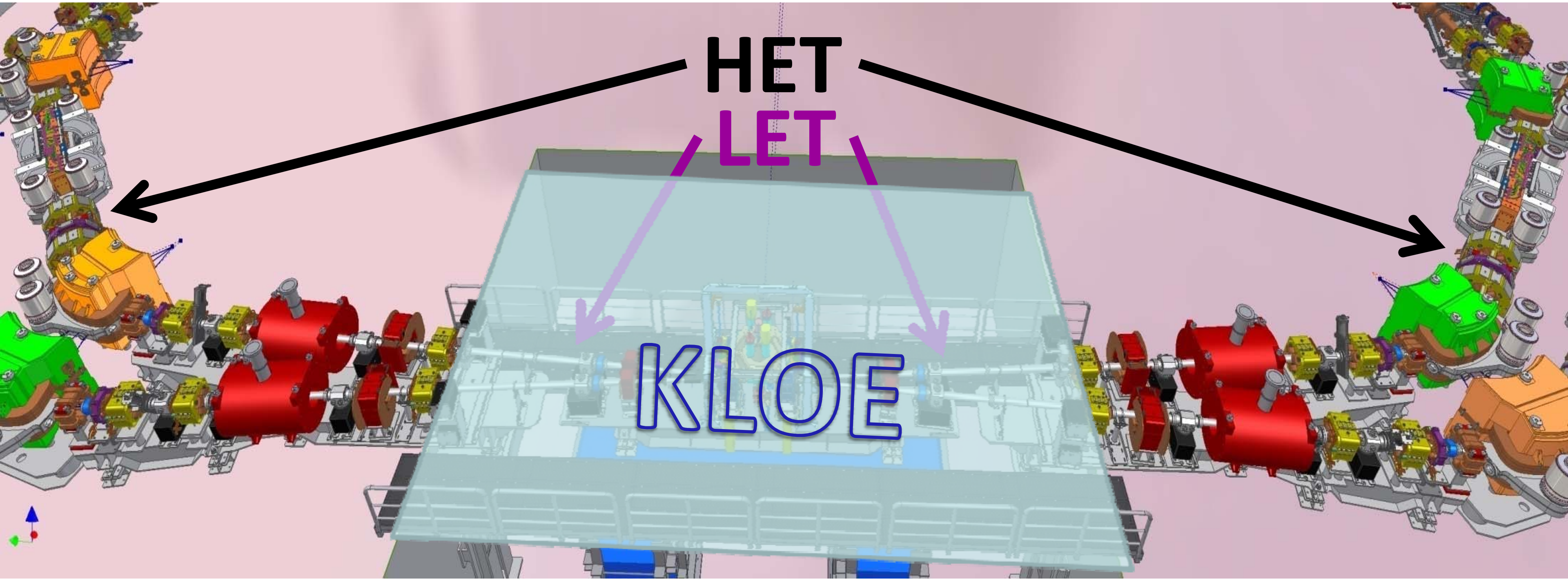
$\gamma\gamma$ channel	(L = 10 fb^{-1})
$e^+ e^- \to e^+ e^- \pi^0$	4×10^6
$e^+ e^- \to e^+ e^- \eta$	1×10^6
$e^+ e^- \to e^+ e^- \pi^+\pi^-$	2×10^6
$e^+ e^- \to e^+ e^- \pi^0\pi^0$	2×10^4

	Missing particle	Events	Background for :
$K_S(\pi^0\pi^0)\ K_L$	K_L	$\sim 10^9$	$\pi^0\pi^0$
$K_S(\pi^+\pi^-)\ K_L$	K_L	$\sim 2 \times 10^9$	$\pi^+\pi^-$
$\pi^+\pi^-\pi^0$	π^0	$\sim 10^9$	
$\eta(\gamma\gamma)\ \gamma$	γ	$\sim 10^8$	η
$\pi^0(\gamma\gamma)\ \gamma$	γ	$\sim 5 \times 10^8$	π^0

tagging $\gamma\gamma$ events by detecting e^+e^- is mandatory to reduce backgrounds, together with P_T kinematical selection on the tagged events.

The new tagging system in KLOE

Scattered electrons escape from the KLOE *detector along the DAFNE beam lines*
Magnetic elements will deflect these "off-energy" particles out of vacuum tubes.
Four tagging stations will be added: their task will be to identify $e^+e^- \rightarrow e^+e^- \gamma^*\gamma^*$ events through the detection of off-energy electrons close to the nominal beam trajectories



Combining all the possible tagging combinations, we can get $500\ pb^{-1}$ of clean $\gamma\gamma$ physics during 2010 data taking

Conclusions

- $\phi \to \eta\pi^0\gamma$ with 5 γ final state and $\pi^+\pi^-$+ 5 γ final state:

  New published result for Branching Ratio and couplings; consistency with 4 quark instantons' model

- $\phi \to K^0\overline{K^0}\gamma$:

  First published result ever for the upper limit on this channel; Comparison with theoretical estimates and consistency with KLOE measurements from scalars

- $\eta \to \pi^+\pi^- e^+ e^-$:

  great improvement of BR accuracy, first measurement of decay plane asymmetry

- η/η' mixing angle and gluonium content:

  new improved fit results confirm gluonium content for η'

- first observation of $\eta \to e^+ e^- e^+ e^-$, and $\frac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)}$ on the way

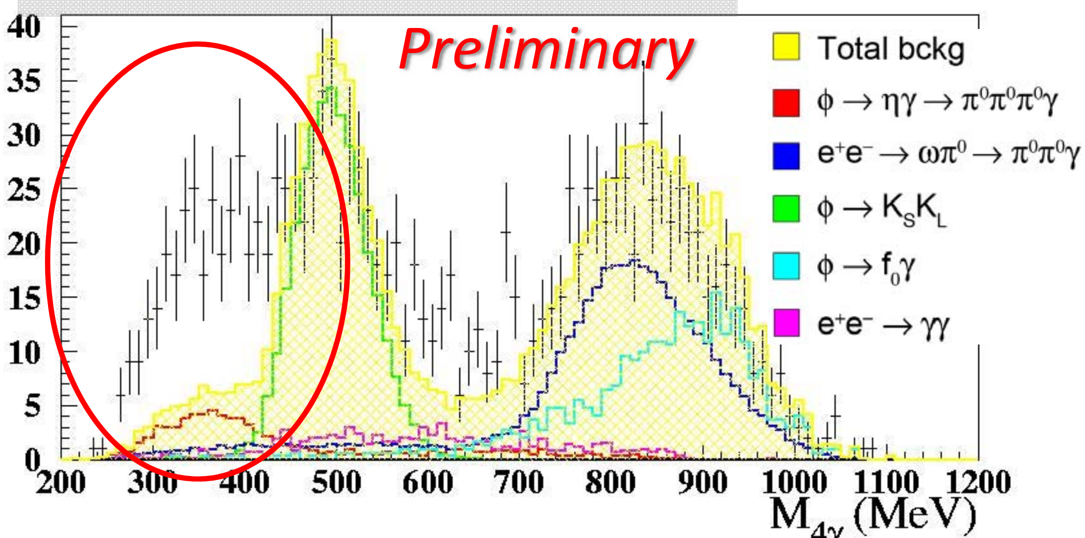
Outlook

With 5 fb^{-1} acquired by KLOE at DAFNE during 2010:

- Increase of $\phi \to K^0 \overline{K^0} \gamma$ statistics, setting UL below 10^{-8} or seeing signal
- Improvement of η' gluonium content accuracy (η' BR's down to 1%)
- γγ physics will enrich the KLOE physics program probing new interesting processes and improving Γ(η'→γγ) accuracy

11 pb^{-1} out of 230 available @ $\sqrt{s}$=1GeV

Excess of events: hint of σ meson?



η' BR's down to 1%

+ Γ(η'→γγ) accuracy to 1%