η physics and ϕ radiative decays at KLOE

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(on behalf of the KLOE collaboration)

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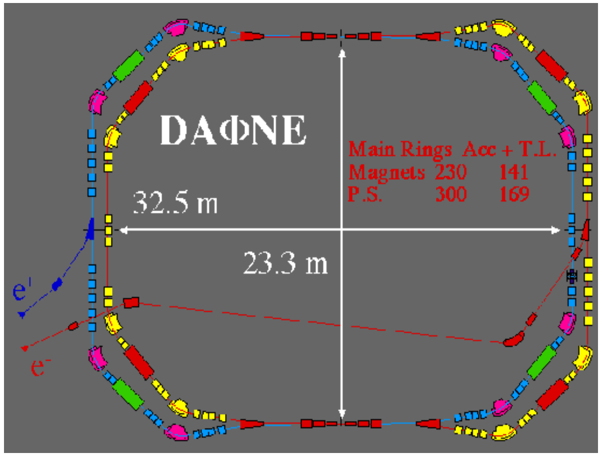
The DAFNE machine and the KLOE detector



- $\sigma(e^+e^- \to \phi) \sim 3\,\mu b$ $\sqrt{s} = m(\phi) = 1019.4\,MeV$
- Independent e^+e^- rings to reduce beam-beam interactions
- crossing angle: 25 mrad, $p_x(\phi) \sim 12{,}6$ MeV/c
- Bunch crossing every 2.7 ns $\int \mathcal{L}\,dt = 2.5\,fb^{-1}$
- injection during acquisition

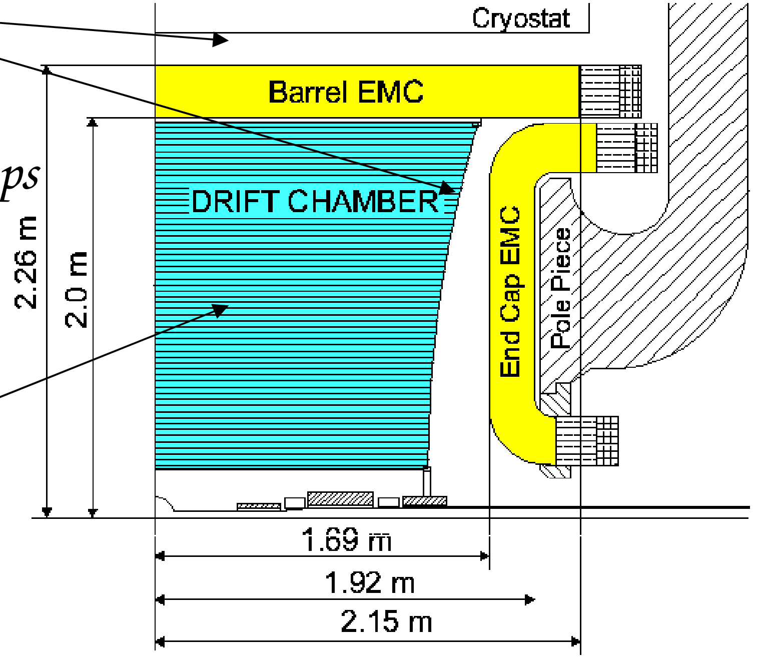
$\mathcal{L}_{peak} = 1.5 \times 10^{32}\ cm^{-2}s^{-1}$

Electromagnetic Calorimeter (EMC)

- Fine sampling Pb / Scifi
- Hermetical coverage
- High efficiency for low energy photons

$\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$

$\sigma_t = 54ps/\sqrt{E(GeV)} \oplus 140\ ps$



Central drift chamber (DCH)

Helium based gas mixture

$\sigma_v = 1\ mm$ $\sigma_{pt}/p_t = 0.5\%$

$\sigma_{r\phi} = 200\ \mu m$ $\sigma_z = 2\ mm$

Talk outline

- Scalar mesons physics
  - $\phi \rightarrow f_0(980)\gamma \rightarrow \pi^0\pi^0\gamma$
  - $\phi \rightarrow a_0(980)\gamma \rightarrow \eta\pi^0\gamma \rightarrow 5\,\gamma$

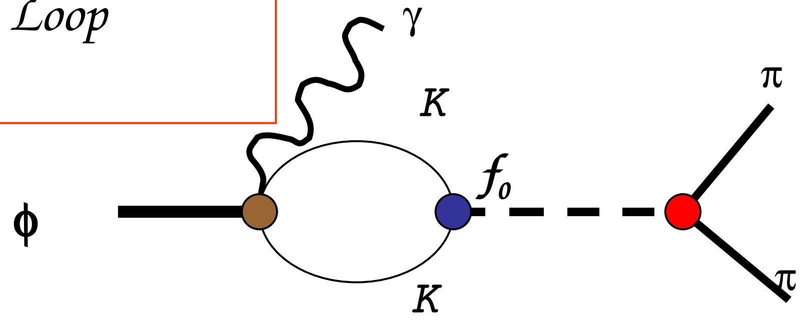
  B.R. determination and
  fit to the $\pi\pi$, $\eta\pi$ spectra [the $\sigma(500)$ puzzle]
  Quark content determination.
  4-quarks 2-quarks KK molecule

  - $\phi \rightarrow (f_0+a_0)\gamma \rightarrow K_S\bar{K}_S\gamma$ ($K_S\bar{K}_S\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-\gamma$ sensitivity evaluation).

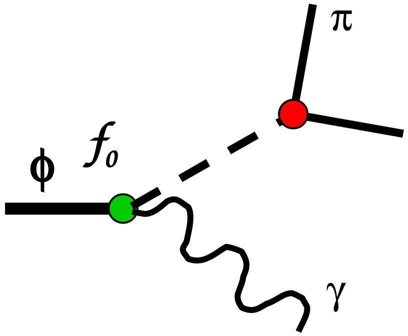
- Pseudo-scalar mesons physics
  - η-η' mixing angle and η' gluonium content
  - η mass

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

Kaon Loop

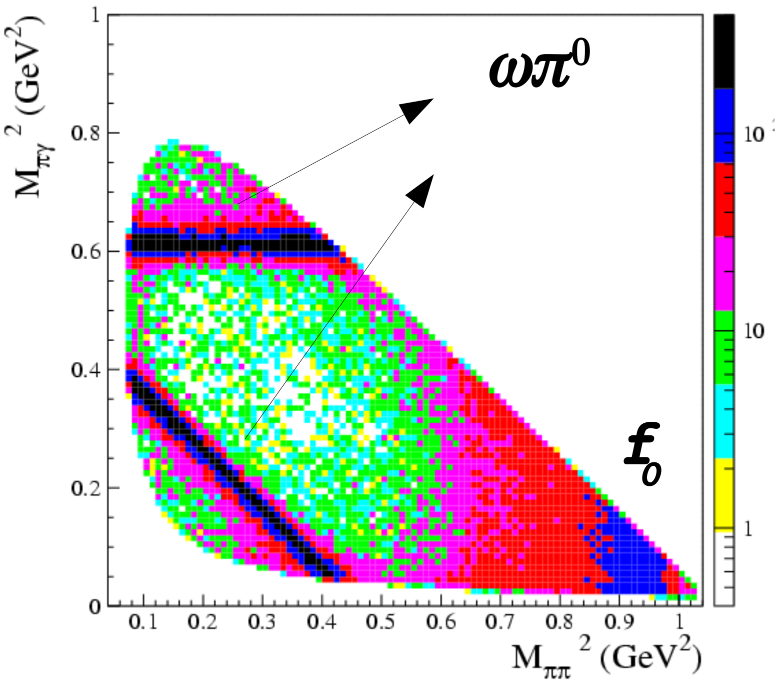


No Structure

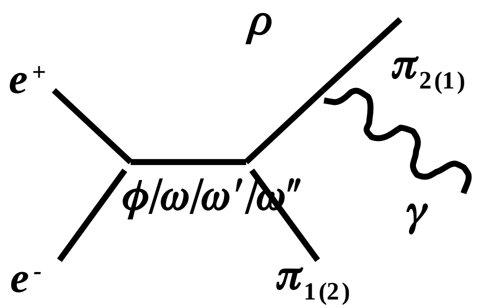


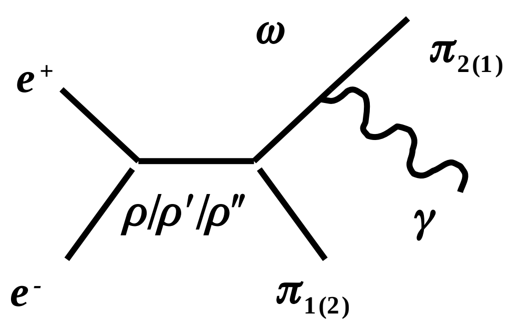
S to φ	$g_{\phi S}$	*Coupling ratio*	$R_{f0}=(g_{f0K+K-}/g_{f0\pi+\pi-})^2$
S to kaons	$g_{SKK}=g_{SK+K-}=g_{SK0K0}$	*(S=f0 or a0)*	$R_{a0}=(g_{a0K+K-}/g_{a0\eta\pi})^2$
f0 to ππ (I=0)	$g_{f0\pi\pi}=\sqrt{3/2}\,g_{f0\pi+\pi-}=\sqrt{3}\,g_{f0\pi0\pi0}$	*a0 to ηπ (I=1)*	$g_{a0\eta\pi}$

The Dalitz plot



Interfering background





Dalitz plot fit

Models: Improved *Kaon-Loop* (introducing the $\phi \rightarrow \sigma(500)\gamma$) - *"No Structure"*

An acceptable fit is obtained with both models:
P(χ^2)(KL)=14%
P(χ^2)(NS)= 4%

$f_0(980)$ *param.*	*NS model*	*KL model*
m_{f0} (MeV)	981 - 987	976 - 987
$g_{\phi f\gamma}$ (GeV^{-1})	2.5 - 2.7	-
$g_{f\pi+\pi-}$ (GeV)	1.3 - 1.4	1.4 -2.0
g_{fKK} (GeV)	0.1 -1.0	3.3 - 5.0
$R=g^2_{fKK}/g^2_{f\pi+\pi-}$	0. - 0.9	3.0 -7.3

NS systematic dominated by the fit stability

KL systematic dominated by several versions of the fitting model.

- ✔ **σ(500)** is **needed** in KL fit [p(χ^2) ~ 10^{-4} → 14%] *EPJ C49 (2007) 473*

  (best σ parameters are: M=462 MeV, Γ=300 MeV – Imposed to the fit);

- ✔ Integral of the |scalar amplitude|^2 evaluated

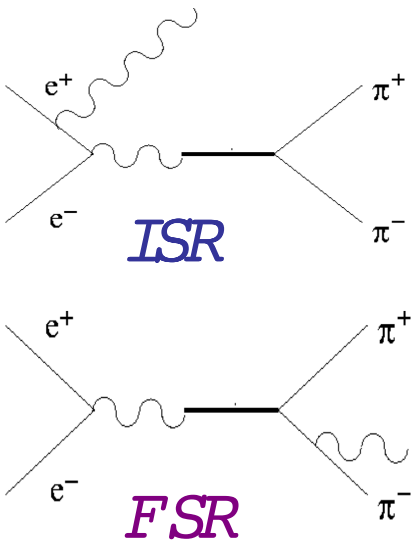
$$Br\left(\phi \to S\gamma \to \pi^0\pi^0\gamma\right)=\left[1.07^{+0.01}_{-0.04}(fit)^{+0.04}_{-0.02}(syst)^{+0.06}_{-0.05}(mod)\right]\times 10^{-4}$$

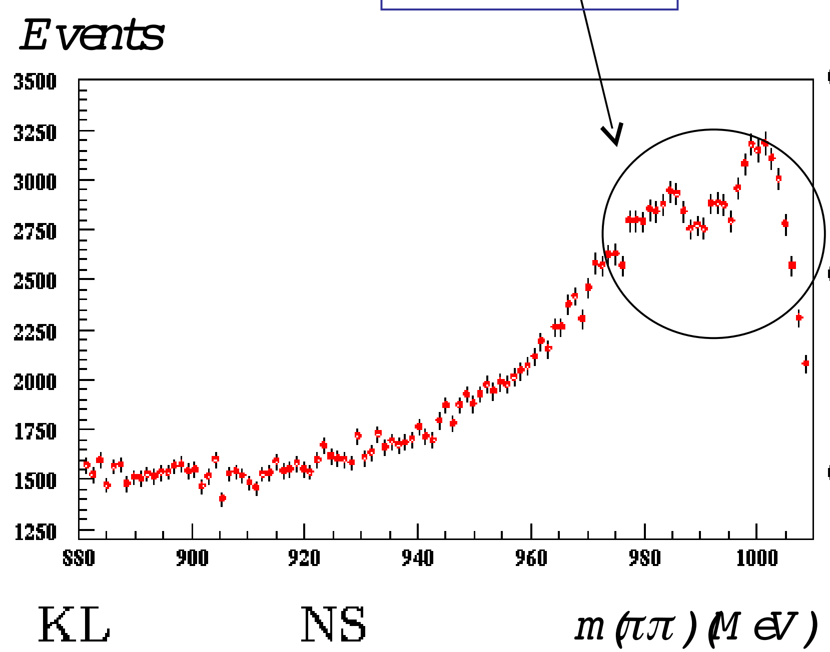
With $BR(\pi^0\pi^0\gamma) \sim 1/2 \times BR(\pi^+\pi^-\gamma)$:

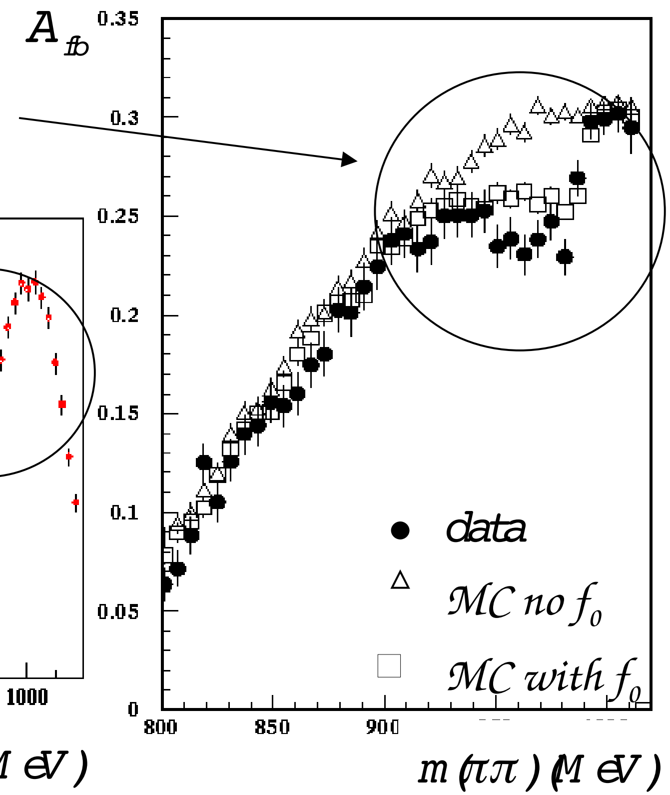
$BR(\phi \rightarrow f_0(980)\gamma) = (3.1 \div 3.5)\times 10^{-4}$, $\Gamma(\phi \; f_0(980)\gamma) = 1.2 \div 1.6$ keV

The $f_0 \to \pi^+\pi^-\gamma$ analysis

Dominant interfering backgrounds







parameter	KL	NS	
m_{f_0} (MeV)	980−987	973−981	⇐ *Mass values agree*
$R = g^2_{f_0 K^+K^-}/g^2_{f_0\pi^+\pi^-}$	2.2− 2.8	2.6− 4.4	⇐ $g_{f_0 K^+K^-} > g_{f_0\pi^+\pi^-}$
$g_{\phi f_0 \gamma}$ (GeV^{-1})	−	1.2− 2.0	⇐ *"Large" coupling to the ϕ*

$BR(\phi \to f_0(980)\gamma \to \pi^+\pi^-\gamma) = 2.1 - 2.4 \times 10^{-4}$ ($\int |\text{Amplitude}|^2$)

In *KL* framework $f_0(980)$ parameters agree with $\pi^+\pi^-\gamma$: $\mathcal{R} > 1$ ($g_{f_0KK} > g_{f_0\pi^+\pi^-}$), masses and integral of the scalar amplitude.

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

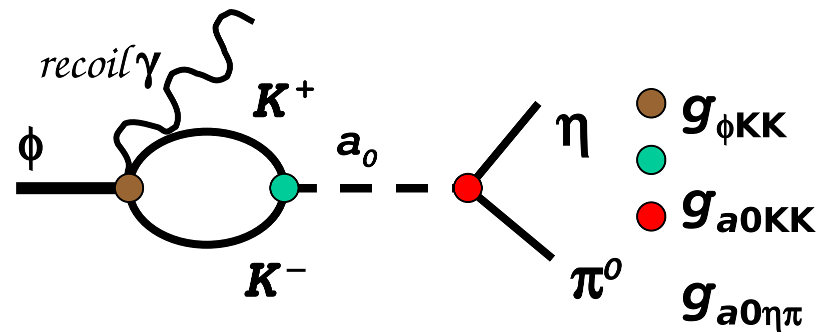
The $a_0(980)$ model parameters are obtained from the $M_{\eta\pi}$ spectrum

Kaon loop (5 parameters)

M_{a0} $g_{a0KK}^2/(4\pi)$,

$g_{a0\eta\pi}/g_{a0KK}$, $Br(\phi \rightarrow \rho\pi^0 \rightarrow \eta\pi^0\gamma)$,

δ (phase between scalar and vector ampl.)

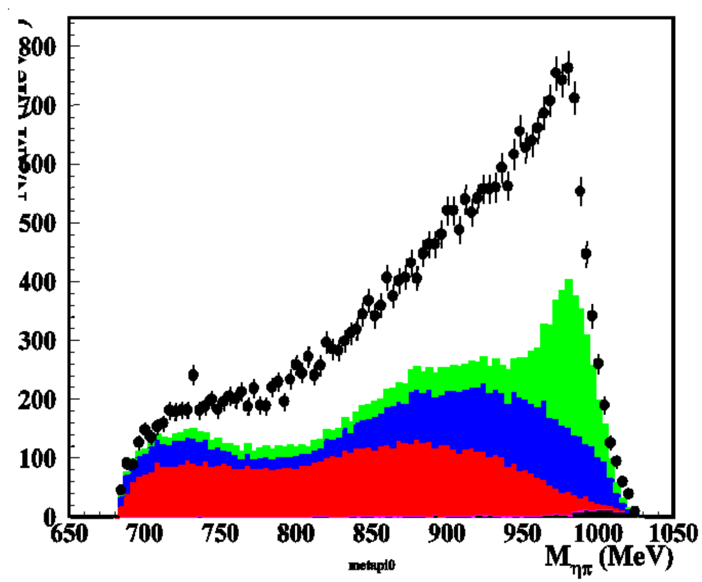


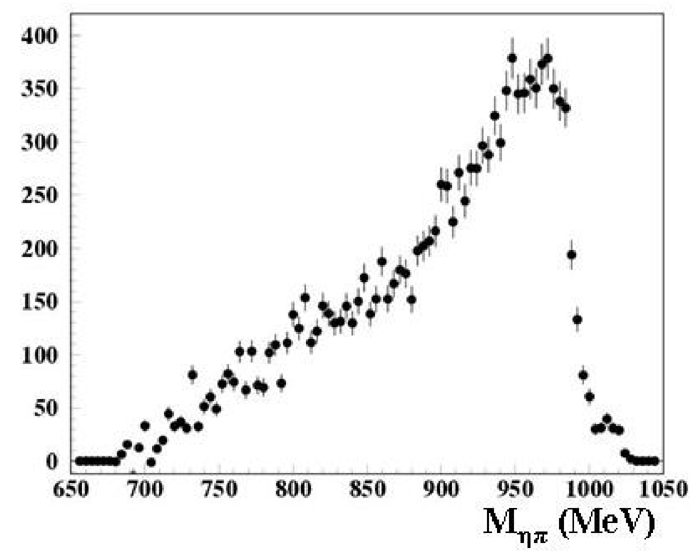
(Achasov - Kiselev Phys.Rev.D68(2003)014006)

• data

$\omega\pi^0$ $\eta\gamma 7$

$f_0\gamma$ $\eta\gamma 3$





Background subtracted

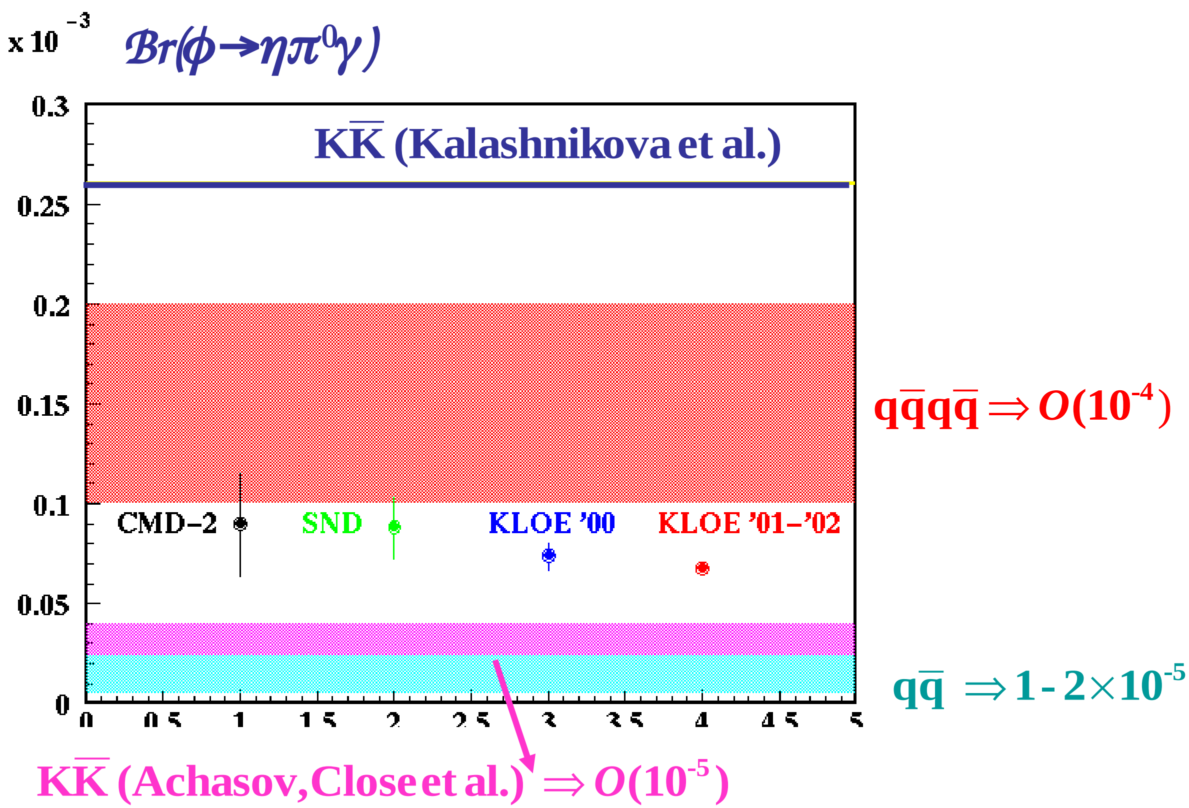
Preliminary results

$N - N_{bkg} = 13099 \pm 172$ events $\varepsilon = 37.9\ \%$

$L = (424.0 \pm 2.5)\ pb^{-1}$ $\sigma_{\phi_{avg.}} = 3090$ nb $Br(\eta \to \gamma\gamma) = (39.38 \pm 0.26)\ \%$

$$Br(\phi \to \eta\pi^0\gamma) = (6.70 \pm 0.09_{stat} \pm 0.24_{syst}) \times 10^{-5}$$

Systematics	$\delta Br/Br$
Bckg subtraction	1.7 %
Photon efficiency curves	1.2 %
Analysis cuts	1.7 %
Luminosity	0.6 %
σ_ϕ	2.5 %
$Br(\eta \to \gamma\gamma)$	0.7 %
Total	3.7 %

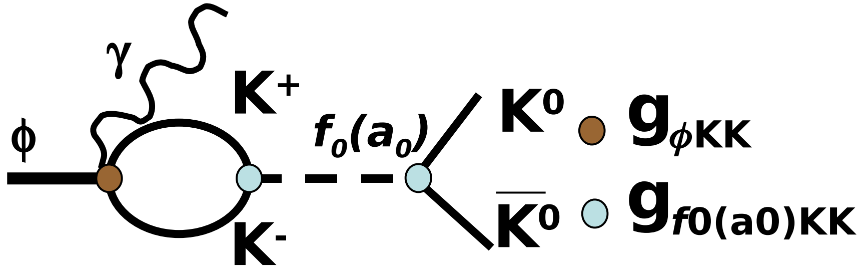


In progress: $\phi \rightarrow (f_0 + a_0)\gamma \rightarrow K_s K_s \gamma$

✔ *Kaon Loop model*

$$BR(\Phi \to (f_0 + a_0)\gamma \to K^0 \overline{K^0}\gamma) = (1.29 \div 4.36)x10^{-8}$$

(Achasov,Gubin Phys.Rev.D64:094016,2001)



✔ *Linear sigma model:*

$$BR(\Phi \to (f_0 + a_0)\gamma \to K^0 \overline{K^0}\gamma) = 7.5x10^{-8}$$

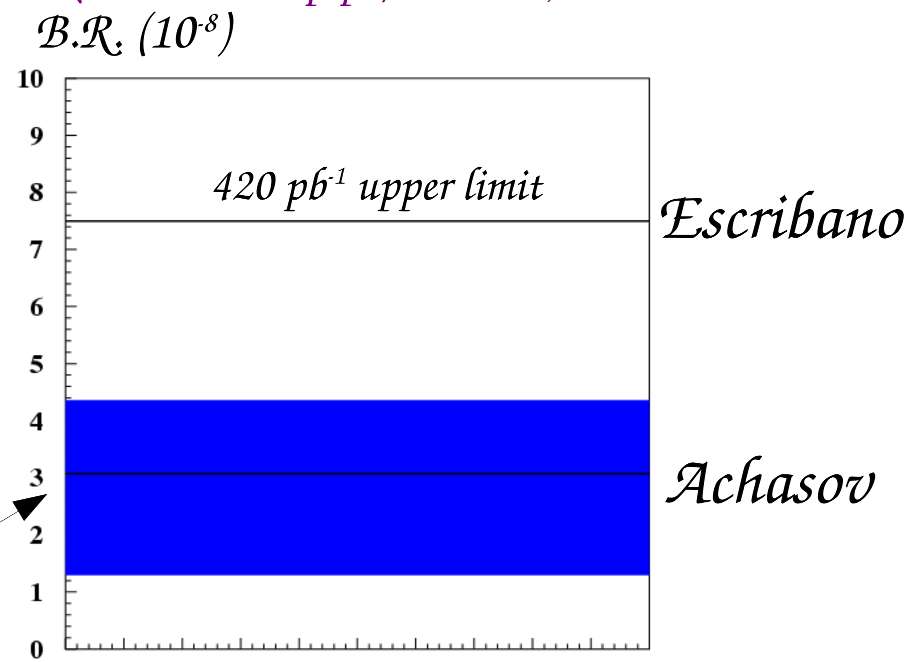
(Escribano, hep-ph/0607325)

Selection efficiency 24.2%

expected 7 background events with 420 pb^{-1}

The whole data sample is 6 times larger.

With the whole statistics scaled conservatively with √L



η,η': mixing and gluonium

The η,η' mesons wave function can be decomposed in the strangeness non strangeness base.

$$|\eta'> = X_{\eta'}|q\bar{q}> + Y_{\eta'}|s\bar{s}> + Z_{\eta'}|gluon>$$

$$|\eta> = \cos\varphi_P|q\bar{q}> + \sin\varphi_P|s\bar{s}>$$

$$X_{\eta'} = \cos\phi_G \sin\varphi_P$$
$$Y_{\eta'} = \cos\phi_G \cos\varphi_P$$
$$Z_{\eta'} = \sin\phi_G$$

$$\frac{Br(\phi\to\eta'\gamma)}{Br(\phi\to\eta\gamma)} = R_\phi = \cot^2\phi_P \cdot \cos^2\phi_G \left(1 - \frac{m_s}{\bar{m}} \cdot \tan\frac{\phi_V}{\sin 2\phi_P}\right)^2 \cdot \left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

Comparing with other decay rates using SU(3) relations:

$$\Gamma(\eta'\to\gamma\gamma)/\Gamma(\pi^0\to\gamma\gamma) = \frac{1}{9}\left(\frac{m_{\eta'}}{m_\pi}\right)^3 \left(5\cos\phi_G\sin\varphi_P + \sqrt{2}\frac{f_q}{f_s}\cos\phi_G\cos\varphi_P\right)^2$$

$$\Gamma(\eta'\to\rho\gamma)/\Gamma(\omega\to\pi^0\gamma) = \frac{C_{NS}}{\cos\varphi_V}\cdot 3\left(\frac{m_{\eta'}^2 - m_\rho^2}{m_\omega^2 - m_\pi^2}\frac{m_\omega}{m_{\eta'}}\right)^3 \cos^2\phi_G \sin^2\varphi_P$$

$$\Gamma(\eta'\to\omega\gamma)/\Gamma(\omega\to\pi^0\gamma) = \frac{1}{3}\left(\frac{m_{\eta'}^2 - m_\omega^2}{m_\omega^2 - m_\pi^2}\frac{m_\omega}{m_{\eta'}}\right)^3 [C_{NS}\cdot\cos\phi_G\sin\varphi_P + 2\frac{m_s}{\bar{m}}C_S\cdot\tan\varphi_V\cdot\cos\phi_G\cos\varphi_P]^2$$

The gluonium coupling is neglected.

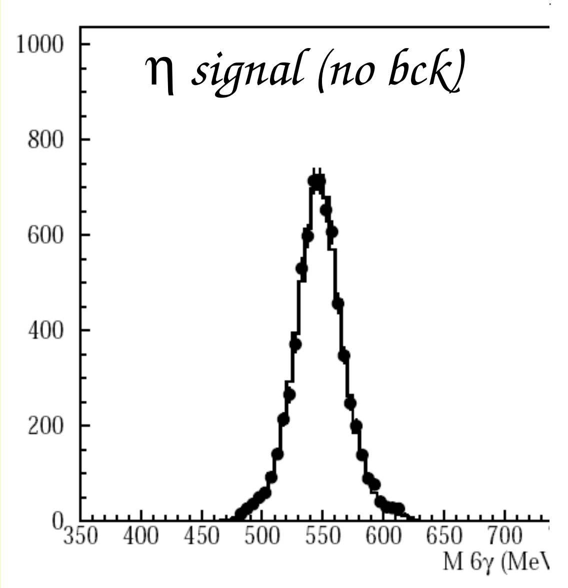
$Br(\phi\to\eta'\gamma)/Br(\phi\to\eta\gamma)$

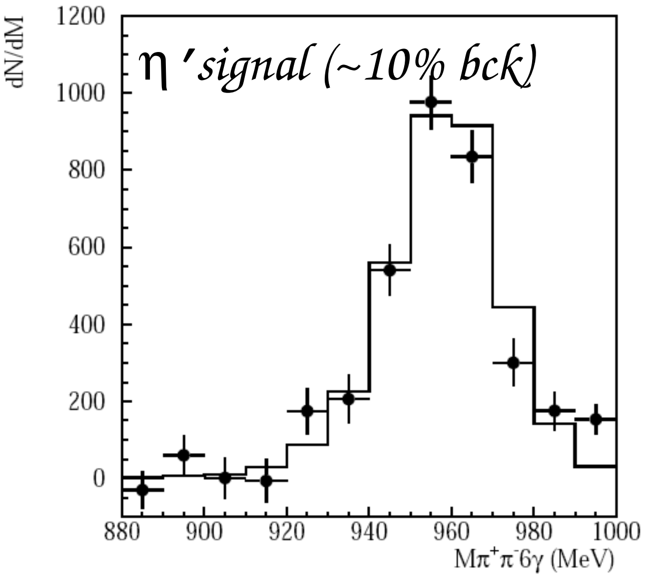
427 pb^{-1} ('01-'02 data)

$N(\eta\gamma) = 1.665\times 10^6$ (no bck)

$N(\pi^+\pi^-7\gamma\text{'s}) = 3750 \pm 60$ ($N_{bckg} = 345$)

$N(\eta'\gamma) = 3405 \pm 61_{stat} \pm 43_{syst}$





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

Using PDG BR($\phi\to\eta\gamma$)

$$Br(\phi\to\eta'\gamma) = (6.20 \pm 0.09_{stat.} \pm 0.25_{syst.})\times 10^{-5}$$

Accepted by PLB (hep-ex/0612029)

Systematics are dominated by knowledge of η,η' branching ratios

Previous KLOE results *Phys. Lett. B541 (2002)*

$$R = (4.70 \pm 0.47_{stat} \pm 0.31_{sys})\cdot 10^{-3}$$

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

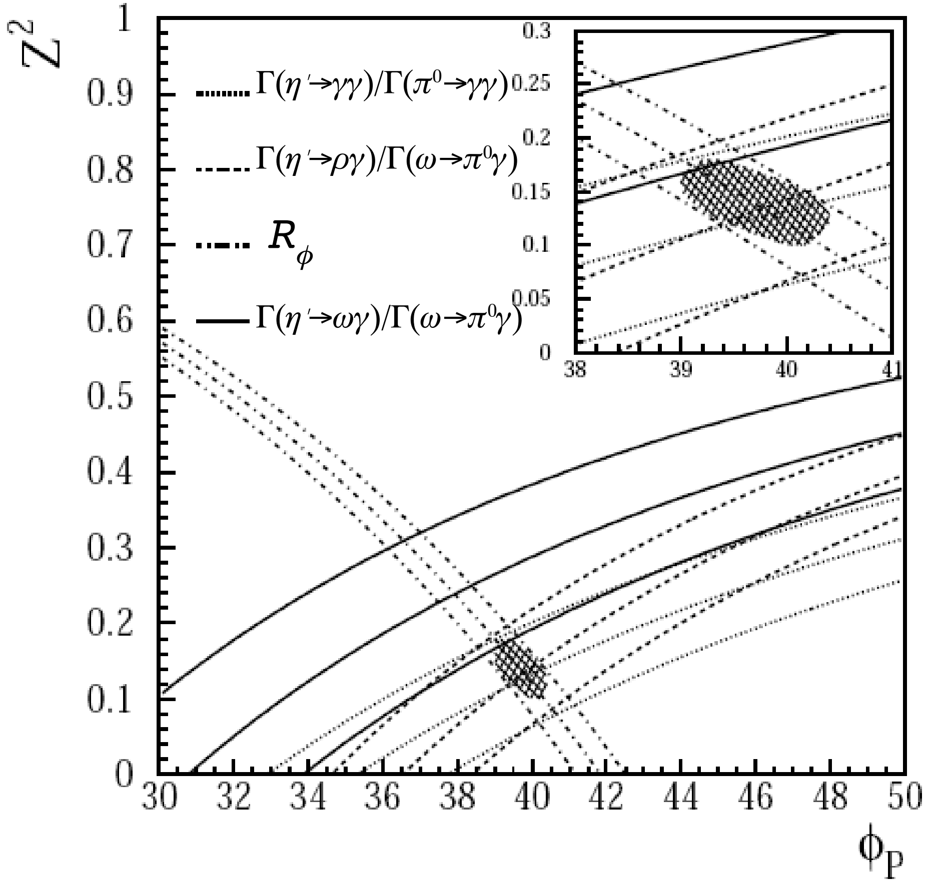
η' gluonium content

Fit results

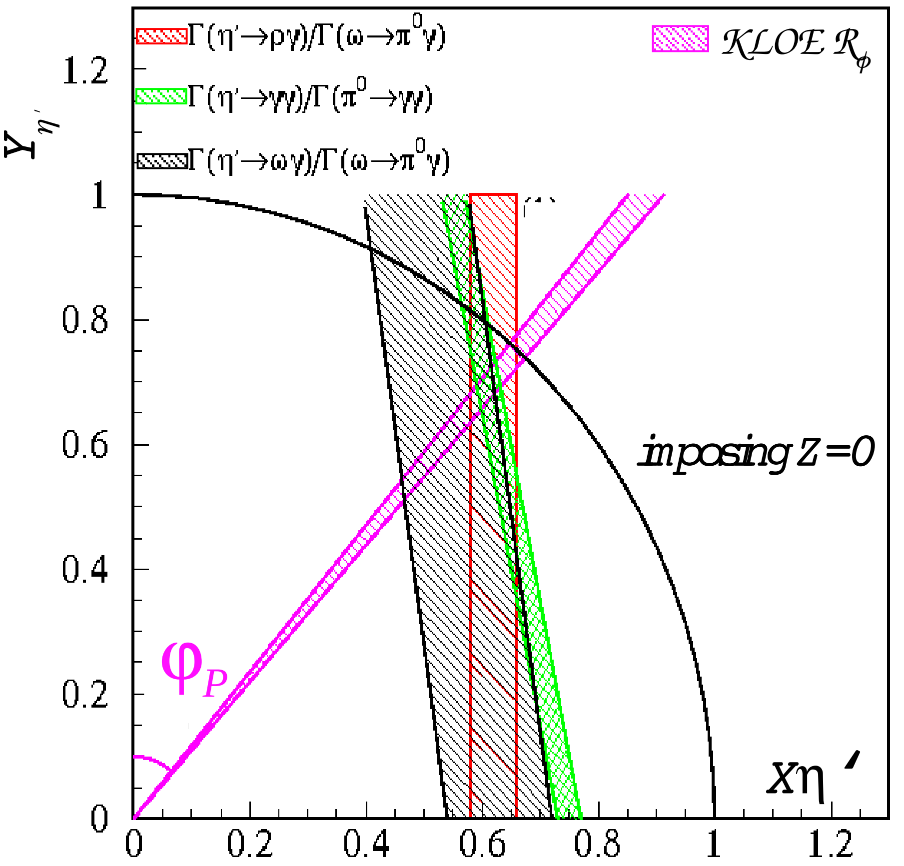
$\phi_P = (39.7 \pm 0.7_{tot})°$
$|\phi_G| = (22 \pm 3)°$

$\sin^2\phi_G = Z^2 = 0.14 \pm 0.04$

49% χ^2 probability



1% χ^2 probability



Status of the η mass measurement

The two most recent and precise measurements show a 8s discrepancy on the η mass :

GEM [COSY, Julich]

$M_\eta = (\, 547.311 \pm 0.028 \pm 0.032 \,)\ MeV/c^2$

[M. Abdel-Bary et al., Phys. Lett. B 619 (2005) 281]

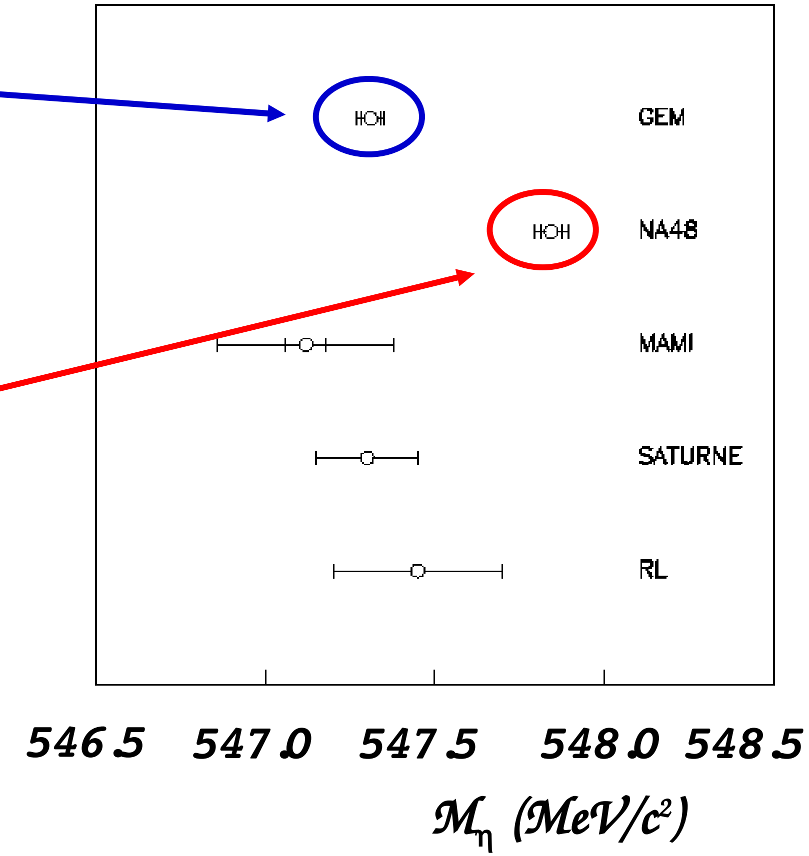
Missing mass in p + d → ^{3}He + η

NA48

$M_\eta = (\, 547.843 \pm 0.030 \pm 0.041 \,)\ MeV/c^2$

[A. Lai et al., Phys. Lett. B 533 (2002) 196]

Using $\eta \rightarrow 3\pi^0$ from $\pi^- + p \rightarrow \eta + n$

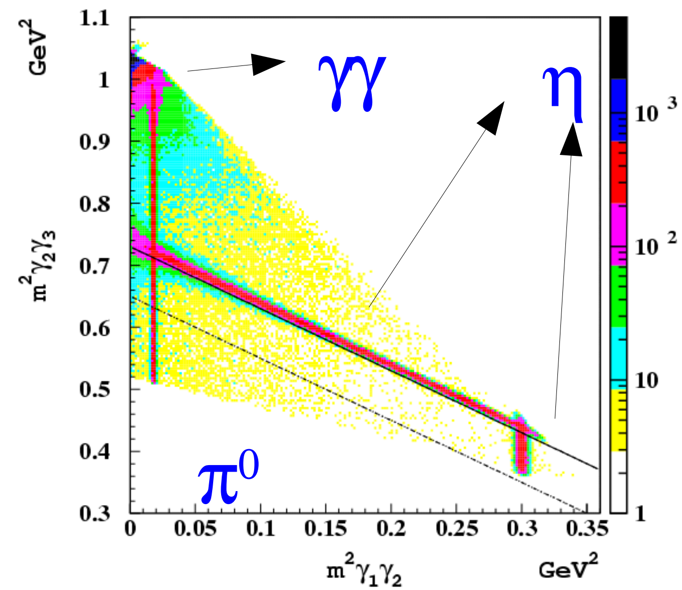


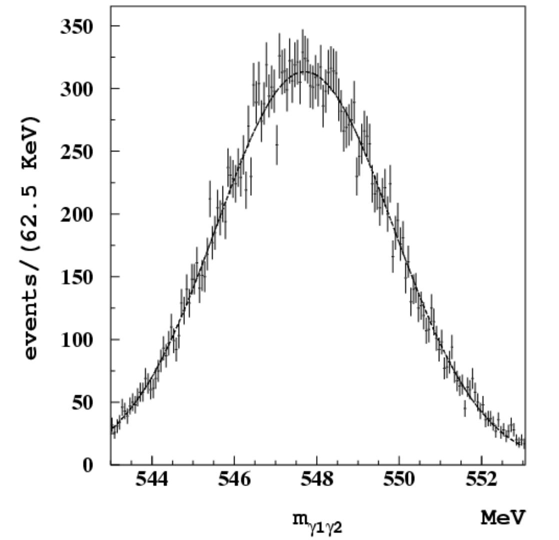
Measurement of the η mass.

$\phi \to \eta\gamma \ (\eta \to \gamma\gamma)$ ⟶ η mass

$\phi \to \pi^0\gamma \ (\pi^0 \to \gamma\gamma)$ ⟶ π^0 mass

$E_1 < E_2 < E_3$





- The photon energies are over constrained by a kinematic fit which links the energy to the position and times of the clusters.
- The time scale and t_0 is calibrated run by run using $e^+e^- \to \gamma\gamma$
- The mean position of the interaction vertex is determined by Bhabha events and cross-checked with $\pi^+\pi^-\gamma$ events.
- The dis-alignment of the calorimeter respect to the Drift Chamber is evaluated using $\pi^+\pi^-\gamma$ comparing the extrapolated tracks with the cluster position.

Results and systematics

The result is dependent from the knowledge of the sqrt(s). It is calibrated using the resonance curve of the $\phi \to K_S K_L$.

$$m(\phi) = 1019.483 \pm 0.011 \pm 0.025\ MeV/c^2$$

CMD-2 Phys. Lett. B578, 285

PRELIMINARY

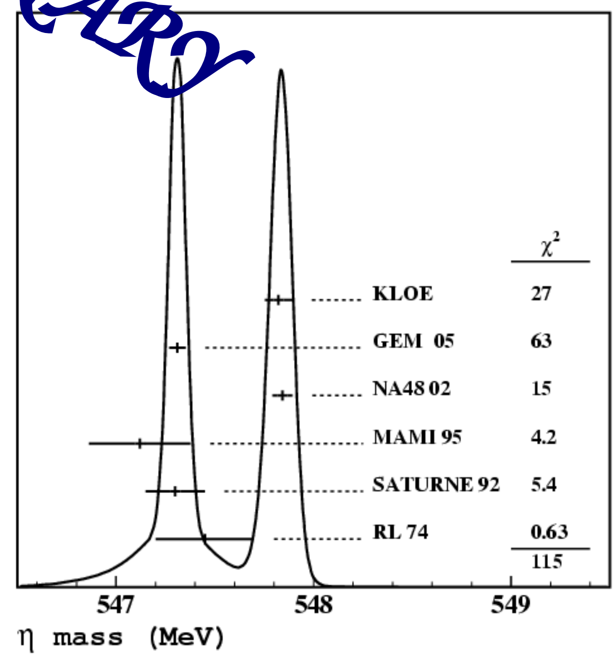
$$M(\pi^0) = (134990 \pm 6_{stat} \pm 30_{syst})\ keV$$

$$M(\pi^0)_{PDG} = (134976.6 \pm 0.6)\ keV$$

$$M(\eta) = (547822 \pm 5_{stat} \pm 69_{syst})\ keV$$

- NA48 compatibility: 0.24 σ
- Independent measurement with the $\eta \to \pi^+\pi^-\pi^0$ decay mode in progress: $m_\eta = 547.95 \pm 0.15$ MeV/c^2 (very preliminary fully in agreement with the $\gamma\gamma$ channel)

Systematic table	err./(tot.err.)
Calorimeter calibration	1%
Calorimeter linearity	1 %
Vertex position	1 %
Azimuthal dependence	18 %
Polar dependence	8 %
Dalitz plot cut + corr.	67 %



conclusions

- KLOE confirms large value for the ϕ coupling to a_0 and f_0 (both charged and neutral) that are predicted by the 4 quarks model;
- The σ is needed to describe the observed $\phi \rightarrow f_0\gamma \rightarrow \pi^0 \pi^0 \gamma$ spectrum in the KL approach;
- We should reach the sensitivity to probe also $f_0 \rightarrow$ KK in the ϕ decay;
- KLOE data combined with other decay ratio indicate a presence of a small gluonium content in the η' meson;
- The experimental puzzle on the η mass is confirmed, now we have two clusters of measurements 8σ away.

outlook

250 pb^{-1} @$\sqrt{s}$ = 1 GeV, 4 scan points around m(ϕ)

- $\pi\pi\gamma$ without the background coming from the ϕ ;
- $\gamma\gamma\to\pi\pi$ to search for the σ meson;
- $e^+e^-\to\omega\pi^0$ cross section measurement;
- Study of the f_0 and of the FSR.

On peak data 2 fb^{-1}

- Combined fit to $\pi^0\pi^0$ and $\pi^+\pi^-$ f_0 channels;
- Search for $f_{0,}a_0\to$ KK;
- $\eta\to\pi^+\pi^- e^+ e^-$, $\eta\to\pi^0\gamma\gamma$, $\eta\to e^+e^-\gamma$, $\eta\to e^+e^-e^+e^-$
- Dalitz plot analysis $\eta'\to\pi\pi\eta$ (extracting scalar mesons contribtion)

Perspectives KLOE 2

Technical proposal

- Factor 5 peak luminosity increasing changing few components of the machine and the Interaction Region
- Minimal detector upgrade (Inner tracker, EMC read-out, $\gamma\gamma$ tagger)

Physics program

- Testing Quantum Mechanics through Kaon interferometry
- Lepton universality, CKM matrix, unitarity and rare kaons decay ($K_s \to \pi^0 \pi^0 \pi^0$)
- Hadron cross section (up to 2 -2 .4 GeV), α_{em} through Bhabha scattering.
- Scalar structure via $\gamma\gamma$ interaction, η and η' decays
- baryon electromagnetic form factors, $e^+e^- \to \bar{p}p$, $\bar{n}n$, $\bar{\Lambda}\Lambda$

Scalar physics at KLOE

$\phi \rightarrow f_0(980)\,\gamma;\ f_0(980)\ (I=0) \rightarrow \pi^0\pi^0,\ \pi^+\pi^-$

$\phi \rightarrow a_0(980)\,\gamma;\ a_0(980)\ (I=1) \rightarrow \eta\pi^0$

What is the quark content?

Not trivial f_0, a_0 almost degenerate,

but f_0 heavily coupled to the $K\bar{K}$ channel.

Alternative approaches

$q\bar{q}$ $\ ^3P_0$

Quarks in 1 orbital angular momentum, 1 spin state

f_0 a_0

$s\bar{s}(u\bar{u}+d\bar{d})$ $s\bar{s}(u\bar{u}-d\bar{d})$

The decay rate $\phi\rightarrow S\gamma$ can distinguish
(Achasov-Ivanchenko, NPB315 (1989) 465)

KK molecules

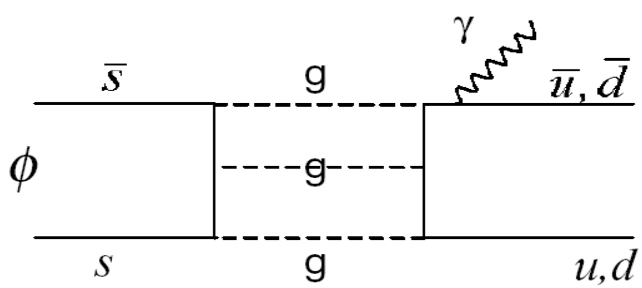
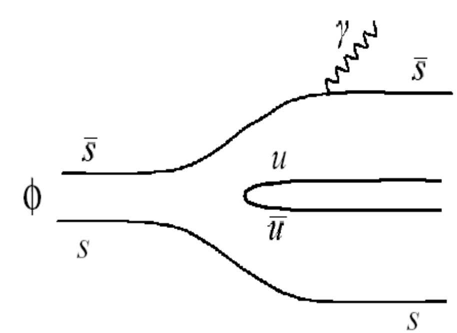
Ozi forbidden  Ozi allowed 

Table 3
Fixed parameters used in the fit for $\cos^2 \varphi_G$ and $\cos^2 \varphi_P$

Parameter	f_q	f_s	C_{NS}	C_S	$\frac{m_s}{\bar{m}}$
Value	1 ± 0.01	1.4 ± 0.014	0.91 ± 0.05	0.89 ± 0.07	1.24 ± 0.07

C_{NS},C_S OZI rules effect reducing the vector and pseudoscalar function overlap

f_q, f_s are the f_P pseudoscalar decay constant after a rotation in the q,s base.

$<0|J^a_{\mu 5}(0)|P(p)>=if_P p_\mu$

$<0|J^a_{m5}(0)|P_q(p) + P_s(p)>=if_P p_\mu$

$<0|J^a_{m5}(0)|P_q(p)> = if^q_P p_\mu$

$$\begin{pmatrix} f_\eta^q & f_\eta^s \\ f_{\eta'}^q & f_{\eta'}^s \end{pmatrix} = \begin{pmatrix} f_q \cos\phi_q & -f_s \sin\phi_s \\ f_q \sin\phi_q & f_s \cos\phi_s \end{pmatrix}$$

Proposal to upgrade DAΦNE in luminosity (and energy)

DANAE Letter of Intent

C. Biscari, D. Alesini, R. Bedogni, M.E. Biagini, R. Boni, M. Boscolo, B. Buonomo, M. Calvetti, M. Castellano, A. Clozza, G.O. Delle Monache, E. Di Pasquale, G. Di Pirro, A. Drago, A. Esposito, L. Falbo, A. Gallo, A. Ghigo, S. Guiducci, M. Incurvati, P. Iorio, C. Ligi, F. Marcellini, C. Marchetti, G. Mazzitelli, C. Milardi, L. Pellegrino, M.A. Preger, L. Quintieri, U. Rotundo, R. Ricci, C. Sanelli, M. Serio, F. Sgamma, B. Spataro, A. Stecchi, A. Stella, S. Tomassini, C. Vaccarezza, M. Zobov, *INFN-LNF, Frascati, Italy*

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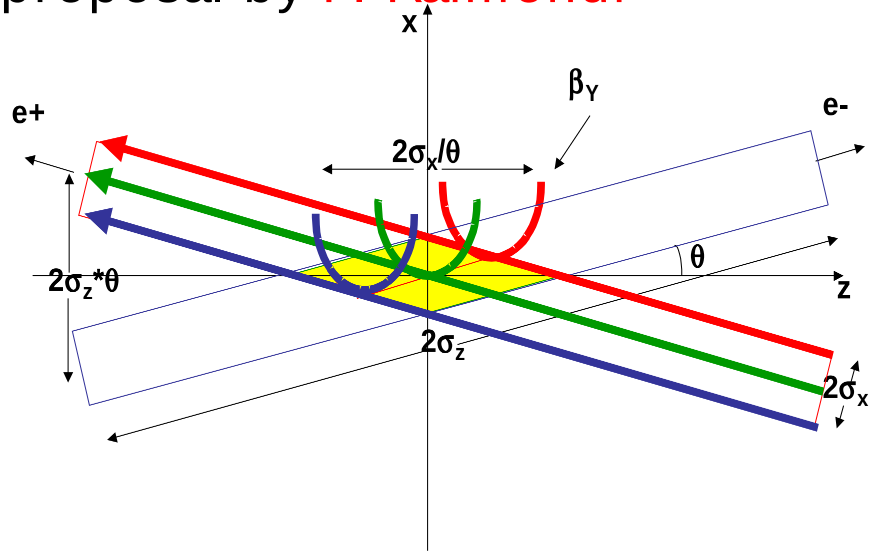
Energy @ center of mass (GeV)	1.02	2.4
Integrated Luminosity per year (fb^{-1})	>10	>1
Total integrated luminosity (fb^{-1})	>50	>3
Peak luminosity ($cm^{-2}s^{-1}$)	$>10^{33}$	$>10^{32}$

Alternative proposal to upgrade DAΦNE in luminosity

proposal by P. Raimondi



Crabbed waist is realized with a sextupole in phase with the IP in X and at π/2 in Y

Crabbed waist scheme at DAΦNE

- increase L by a factor *O*(5)
- requires minor modifications
- relatively low cost

Experimental test at DAΦNE in autumn 2007

If successful KLOE-2 data taking could start already in 2009

EoI for KLOE-2 at upgraded DAΦNE

Expression of Interest

for the continuation of the KLOE physics program

at DAϕNE upgraded in luminosity and in energy

March 31, 2006

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