Hadronic physics at KLOE

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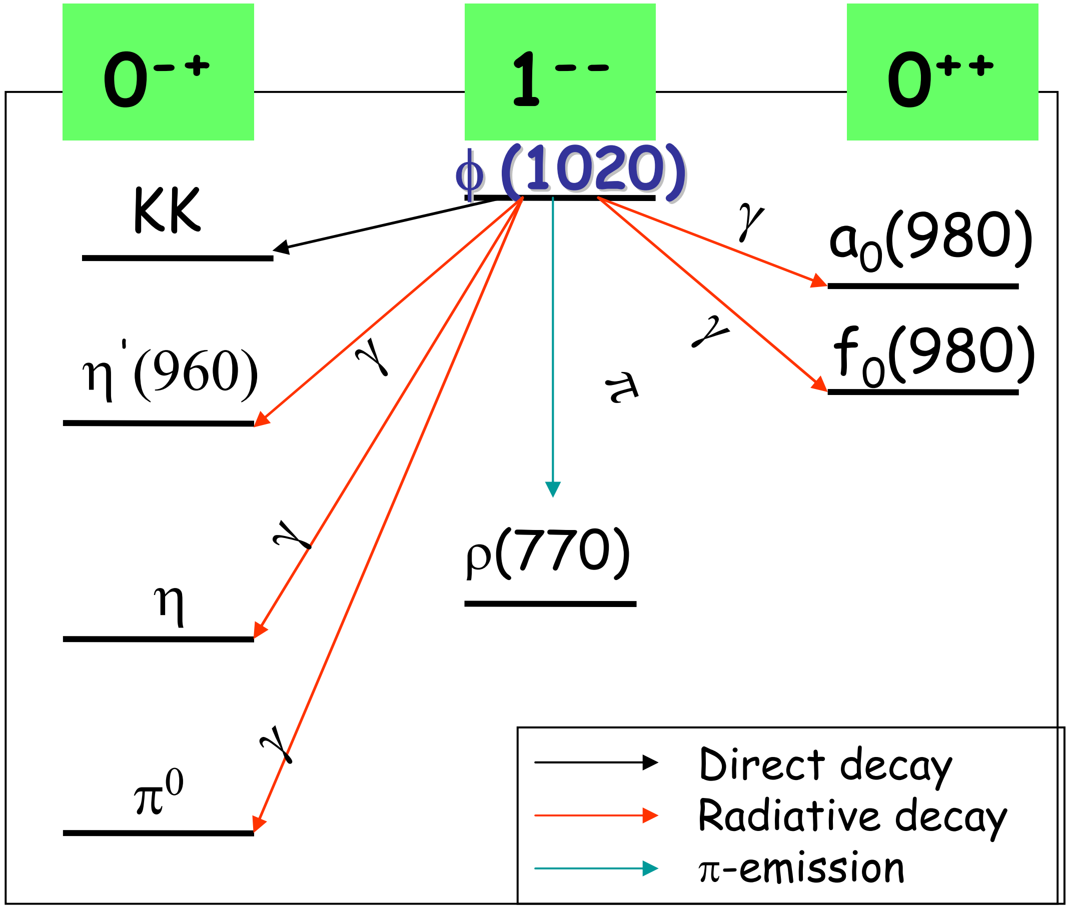
Talk outline

- DAΦNE and KLOE
- Scalar Mesons
  - $\phi \to f_0(980)\gamma \to \pi^+\pi^-\gamma$
  - $\phi \to f_0(980)\gamma \to \pi^0\pi^0\gamma$
  - $\phi \to a_0(980)\gamma \to \eta\pi^0\gamma \to 5\,\gamma$

  } B.R. determination and fit to the $\pi\pi$, $\eta\pi$ spectra.
  - $\phi \to (f0+a0)\gamma \to K^0\bar{K}^0\gamma$ ($K_sK_s\gamma \to \pi^+\pi^-\pi^+\pi^-\gamma$ sensitivity evaluation).
- Pseudoscalar Mesons
  - η-η' mixing angle and η' gluonic content
  - $\eta \to \pi^+\pi^-\pi^0$ (dalitz plot fit)
  - η mass
- $e^+e^- \to \pi^+\pi^-$ cross-Section below 1 GeV
- Kaon physics

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 to study the structure of these mesons, in particular their s-quark content via couplings with the ϕ ($s\bar{s}$)

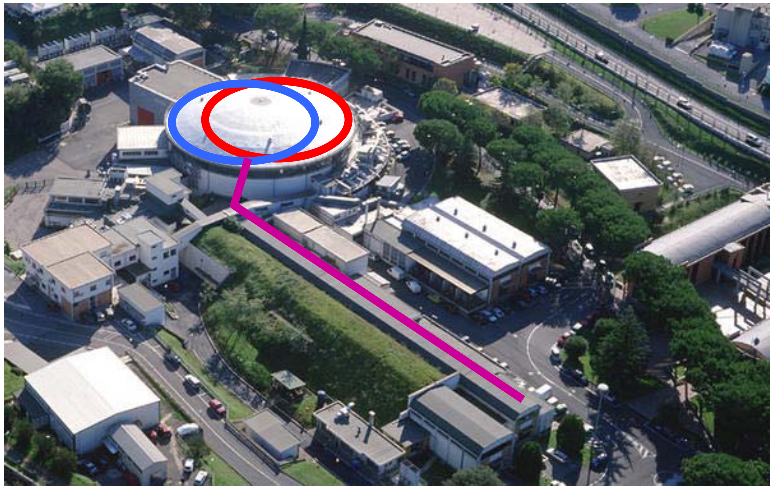


Main decay channels	Branching fraction
→ K^+K^-	49.2 %
→ K_SK_L	34.0 %
→ $\rho\pi$ + $\pi^+\pi^-\pi^0$	15.3 %
→ $\eta\gamma$	1.301 %
→ $\pi^0\gamma$	0.125 %
→ $\eta'\gamma$	6.2×10^{-5}
→ $\pi^0\pi^0\gamma$	~ 10^{-4}
→ $\eta\pi^0\gamma$	$7 \div 8 \times 10^{-5}$
+ "radiative return" to $\pi^+\pi^-$	

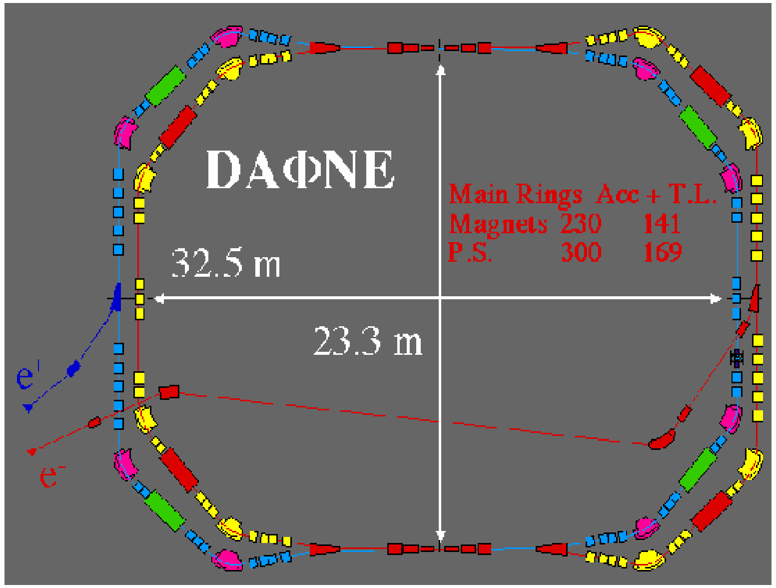
#events in KLOE data = Br.F. × 8 × 10^9 ➔ ~10^8 η; ~10^5 η', $\pi\pi$, $\eta\pi$

The DAΦNE e^+e^- Φ-factory

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



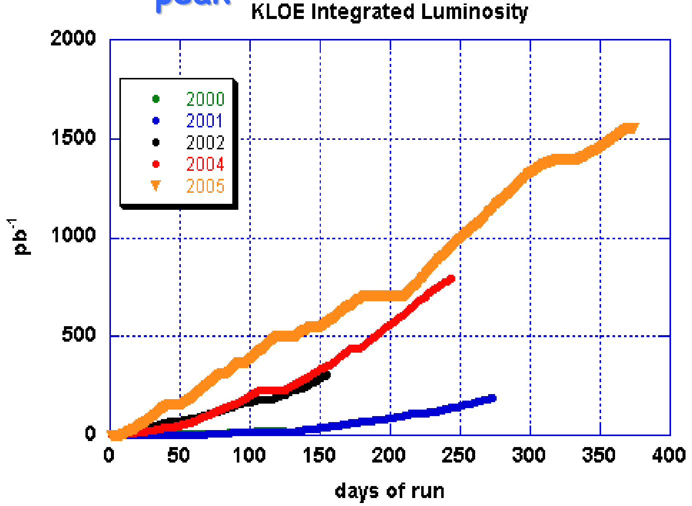
- $\sigma(e^+e^- \to \phi)\sim 3\ \mu b$
- Separate e^+e^- rings to reduce beam-beam interactions
- crossing angle: 25 mrad
- Bunch crossing every 2.7 ns
- injection during acquisition



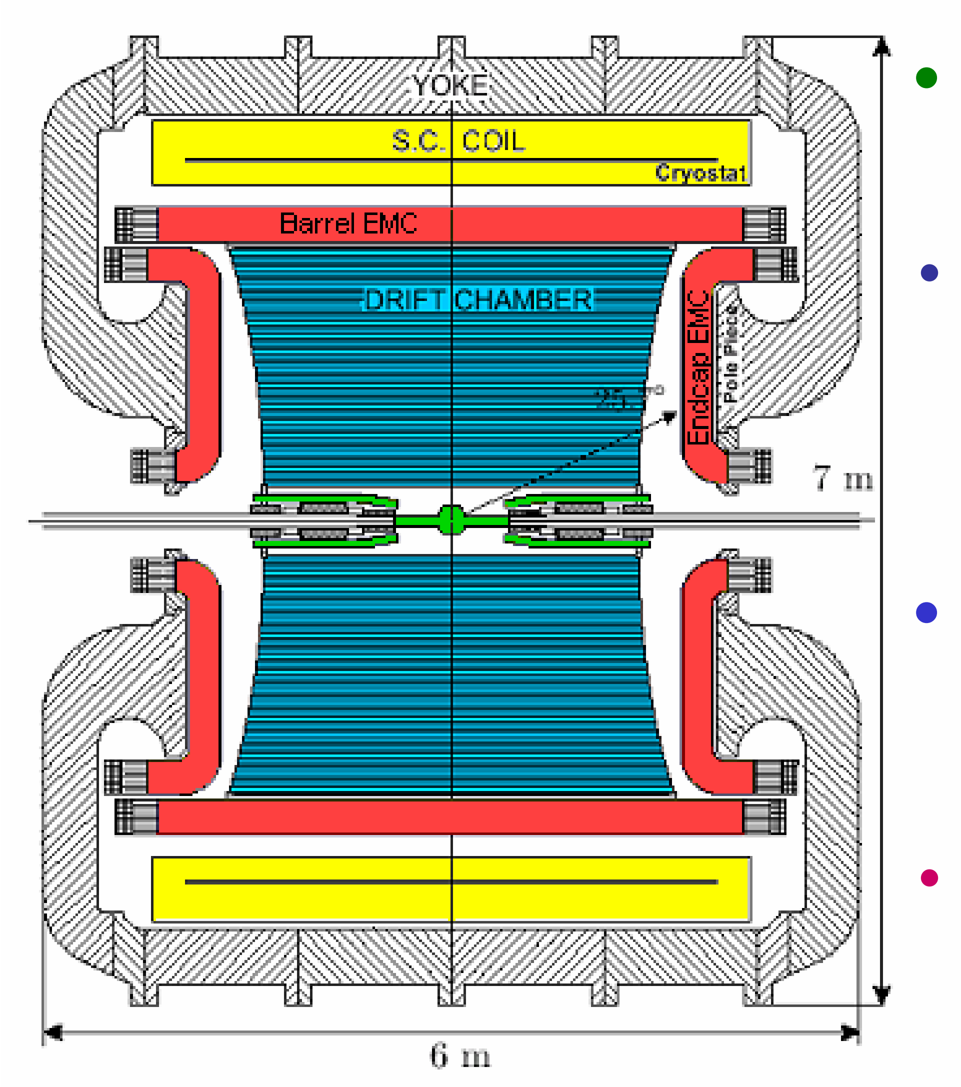
integrated Luminosity 2001-5:

$\int L\,dt = 2.5\ fb^{-1}$

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

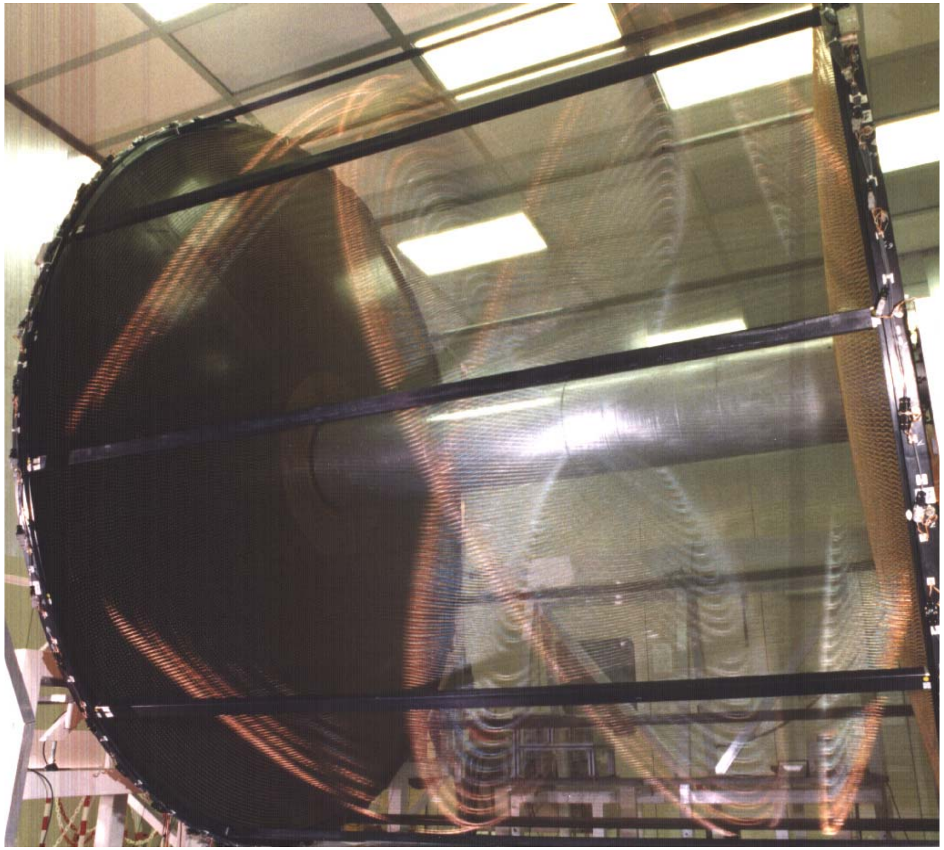


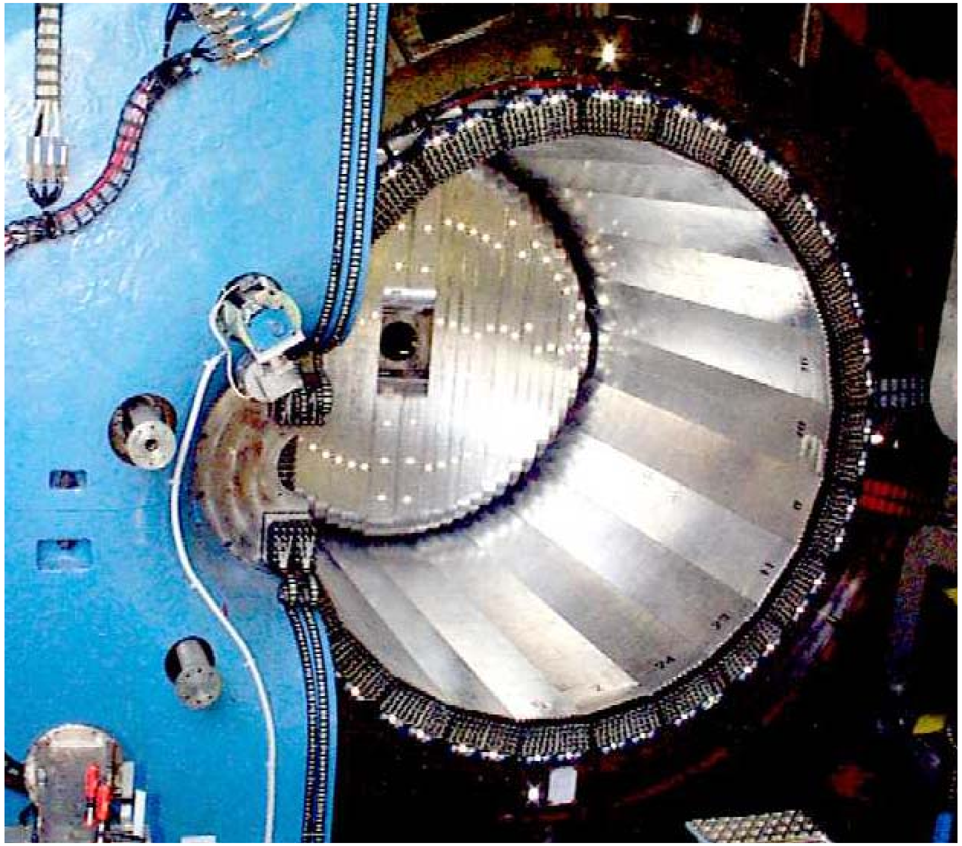
The KLOE experiment



- **Be beam pipe** (spherical, 10 cm ∅, 0.5 mm thick) + **instrumented permanent magnet quadrupoles** (32 PMT's)
- **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)

KLOE detector specifications



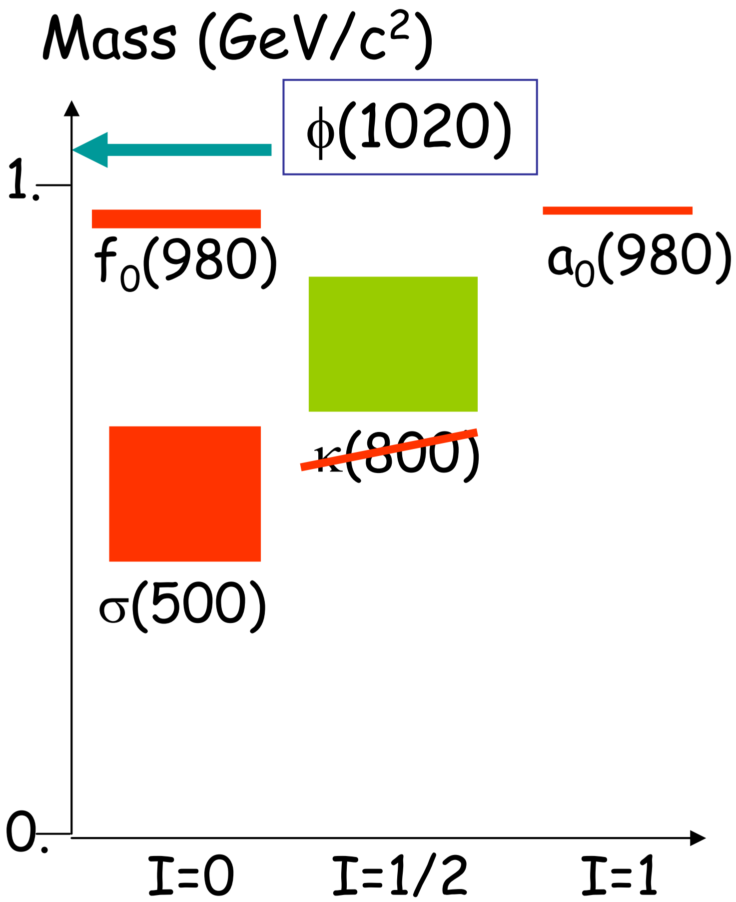


$\sigma_p/p = 0.4\ \%$ (tracks with $\theta > 45°$)
$\sigma_x^{hit} = 150\ \mu m\ (xy),\ 2\ mm\ (z)$
$\sigma_x^{vertex} \sim 1\ mm$
$\sigma(M_{\pi\pi}) \sim 1\ MeV$

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

Scalar mesons

Scalar Mesons



Scalar Mesons Spectroscopy:

f_0(980), **σ(500)** and **a_0(980)** are accessible through $\phi \rightarrow$ **S**γ (κ not accessible)

Questions:

1. Is σ(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, ππ and ηπ.

➔ allows to investigate the inner structure:

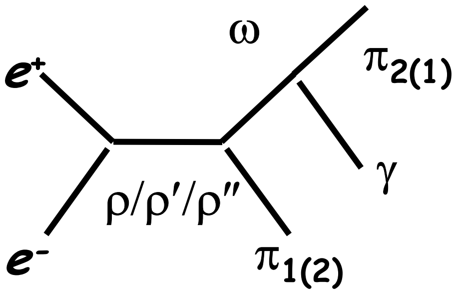
4-quark vs. *2-quark* vs. *KK molecule*

Previous results

KLOE already published f_0 and a_0 results based on a sample 20 times smaller ($20pb^{-1}$) than the statistics of the analyses presented in the following ($\sim 400pb^{-1}$):

Old $\phi \rightarrow f_0(980)\gamma$ analysis

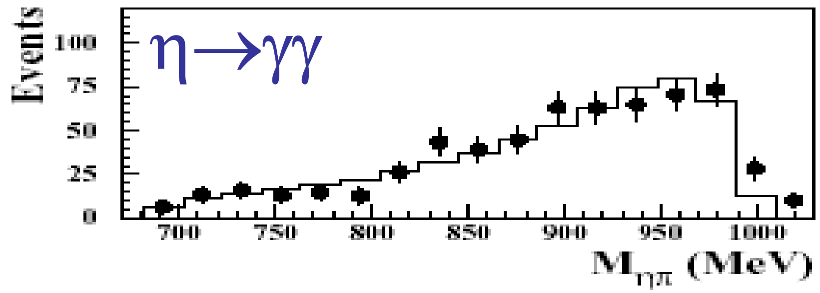
ω background: subtracted assuming no interference with f_0

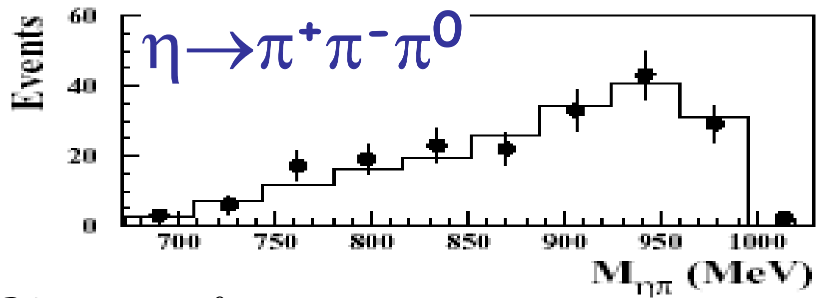


BR $\phi \rightarrow \pi^0\pi^0\gamma$= $(1.08 \pm 0.03stat \pm 0.03syst \pm 0.04norm)\times 10^{-4}$

Physics Letters B 537 (2002) 21-27

$\phi \rightarrow a_0(980)\gamma \rightarrow \eta\pi_0\gamma$





BR $\phi \rightarrow \eta\pi^0\gamma$:

$\eta \rightarrow \gamma\gamma$ = $(8.51 \pm 0.51stat \pm 0.57syst)\times 10^{-5}$

$\eta \rightarrow \pi^+\pi^-\pi^0$ =$(7.96 \pm 0.60stat \pm 0.40syst)\times 10^{-5}$

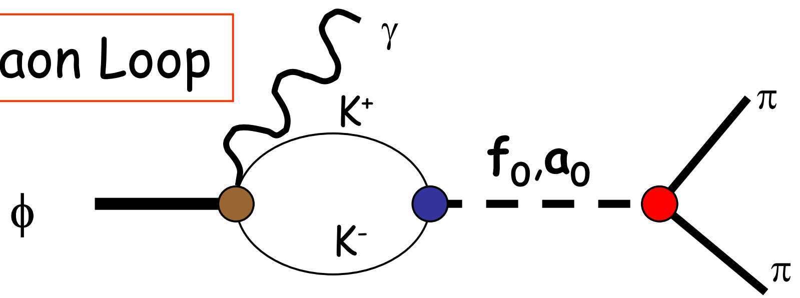
Physics Letters B 536 (2002) 209-216

Old analysis

$$R_{BR} = \frac{BR(\phi \rightarrow f_0\gamma)}{BR(\phi \rightarrow a_0\gamma)} = 6.1 \pm 0.6$$ Physics Letters B 536 (2002) 209-216

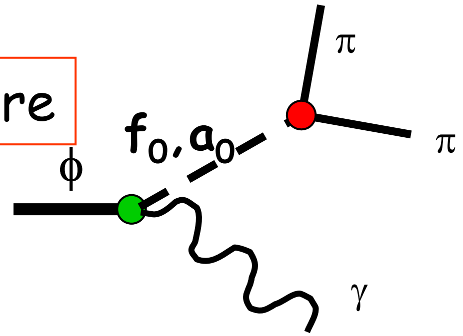
Definition of the relevant couplings

Kaon Loop



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

No Structure



(G.Isidori et al., JHEP0605(2006)049)

S to ϕ	$g_{\phi S\gamma}$	(GeV^{-1})
S to kaons	$g_{SKK}=g_{SK+K-}=g_{SK0K0}$	(GeV)
f_0 to $\pi\pi$ (I=0)	$g_{f0\pi\pi}=\sqrt{3/2}\ g_{f0\pi+\pi-}=\sqrt{3}\ g_{f0\pi0\pi0}$	(GeV)
a_0 to $\eta\pi$ (I=1)	$g_{a0\eta\pi}$	(GeV)
Coupling ratio	$R_{f0}=(g_{f0K+K-}/\ g_{f0\pi+\pi-})^2$	
(S=f_0 or a_0)	$R_{a0}=(g_{a0K+K-}/\ g_{a0\eta\pi})^2$	

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

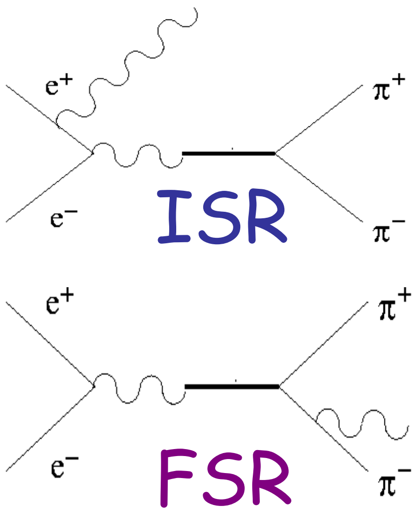
Event selection:

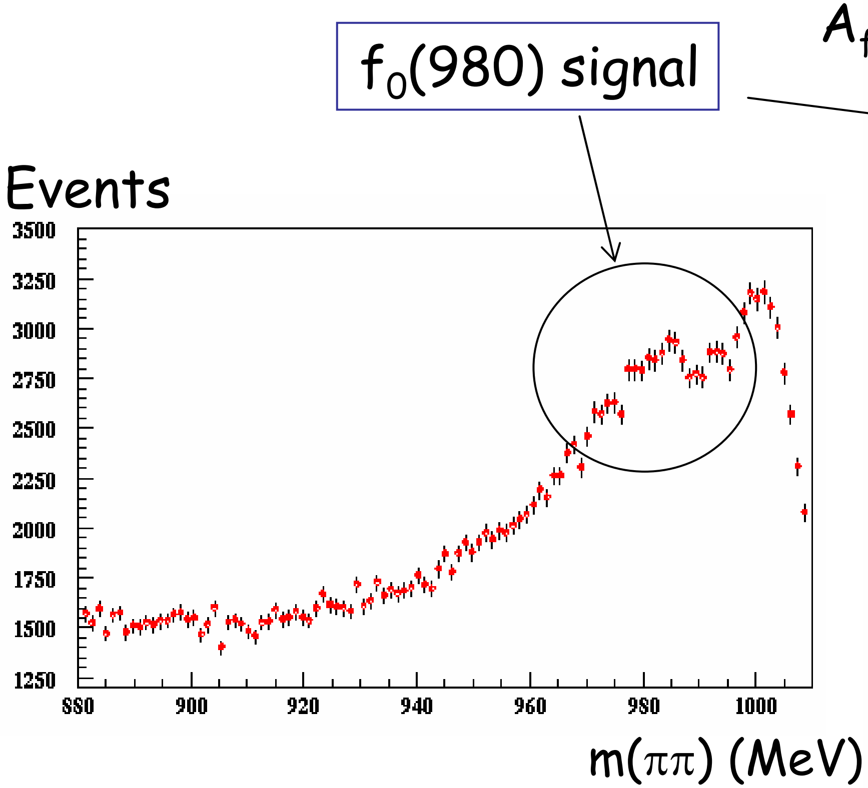
- 2 tracks with $\theta_{\pm}>45^o$; missing momentum $\theta_{\pi\pi}>45^o$ (large angle)
- pion identification through tracking, Time of Flight and Shower shape
- 1 photon matching the missing momentum

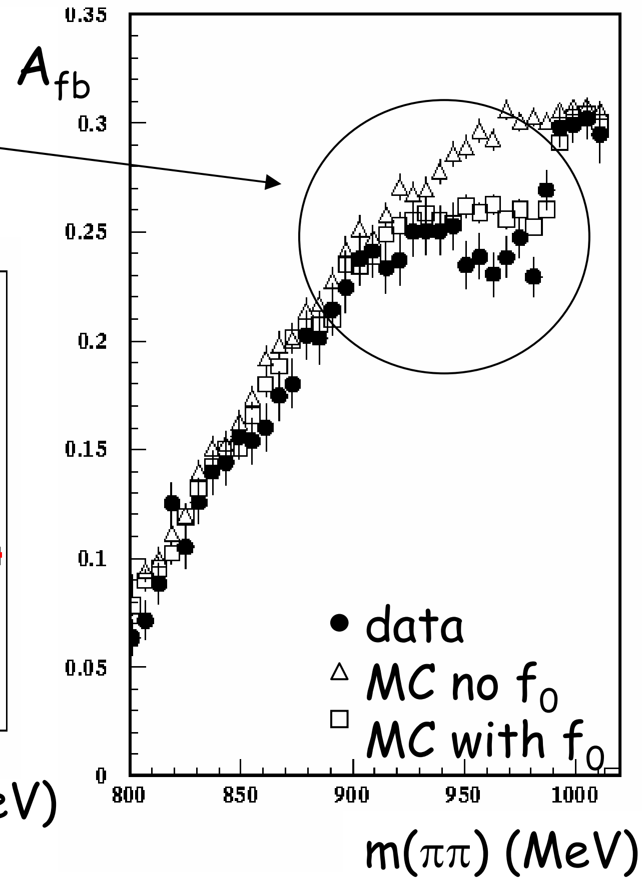
$\Rightarrow$ 6.7 ×10^5 events / 350 pb^{-1}

$$A_{FB}(s) \equiv \frac{\int_0^1 d\cos\theta \frac{d^2\Gamma}{ds\,d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d^2\Gamma}{ds\,d\cos\theta}}{\int_0^1 d\cos\theta \frac{d^2\Gamma}{ds\,d\cos\theta} + \int_{-1}^0 d\cos\theta \frac{d^2\Gamma}{ds\,d\cos\theta}}$$

The $\pi^+\pi^-\gamma$ final state is dominated by:
Initial State Radiation
Final State Radiation

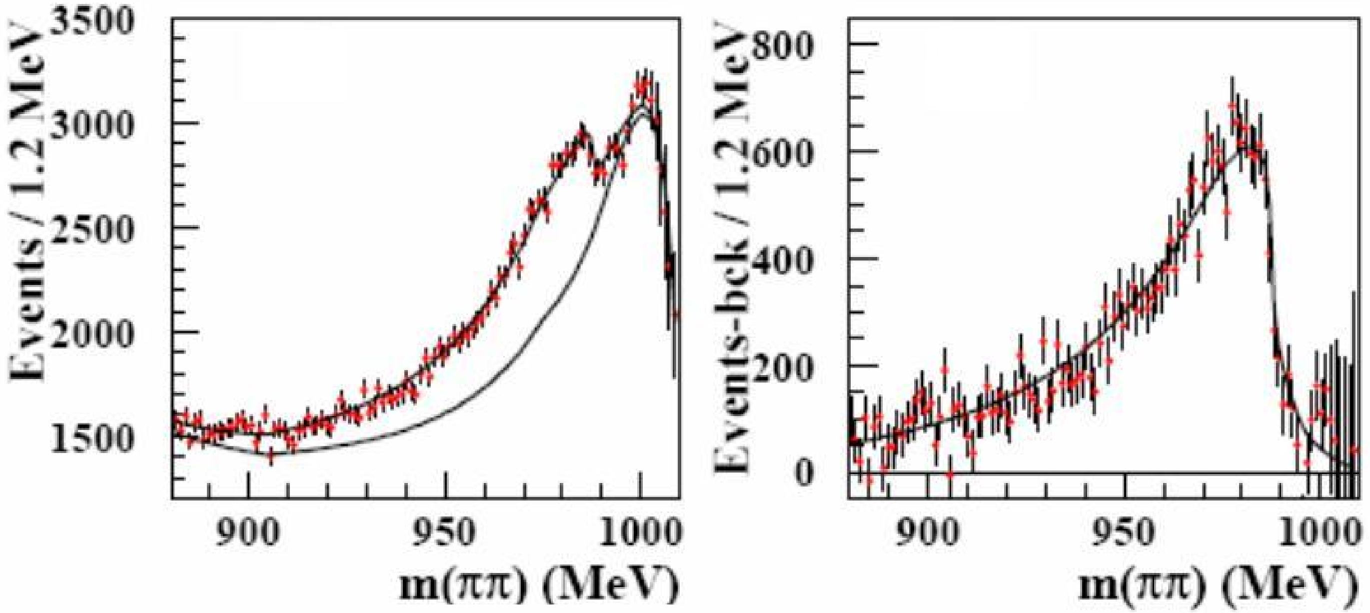






Fit of the mass spectrum

We use 2 different models for the scalar amplitude: Kaon-loop (KL)
No-Structure (NS)



An acceptable fit is obtained with both models:
$P(\chi^2)$(KL)=4.2%
$P(\chi^2)$(NS)=4.4%

P.L.B634 ,148 (2006)

parameter	KL	NS	
m_{f_0} (MeV)	980−987	973−981	⇐ Mass values ok
$R = g^2_{f_0 K^+K^-}/g^2_{f_0 \pi^+\pi^-}$	2.2− 2.8	2.6− 4.4	⇐ $g_{f0K+K-} > g_{f0\pi+\pi-}$
$g_{\phi f_0 \gamma}$ (GeV^{-1})	−	1.2− 2.0	⇐ "Large" coupling to the ϕ

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

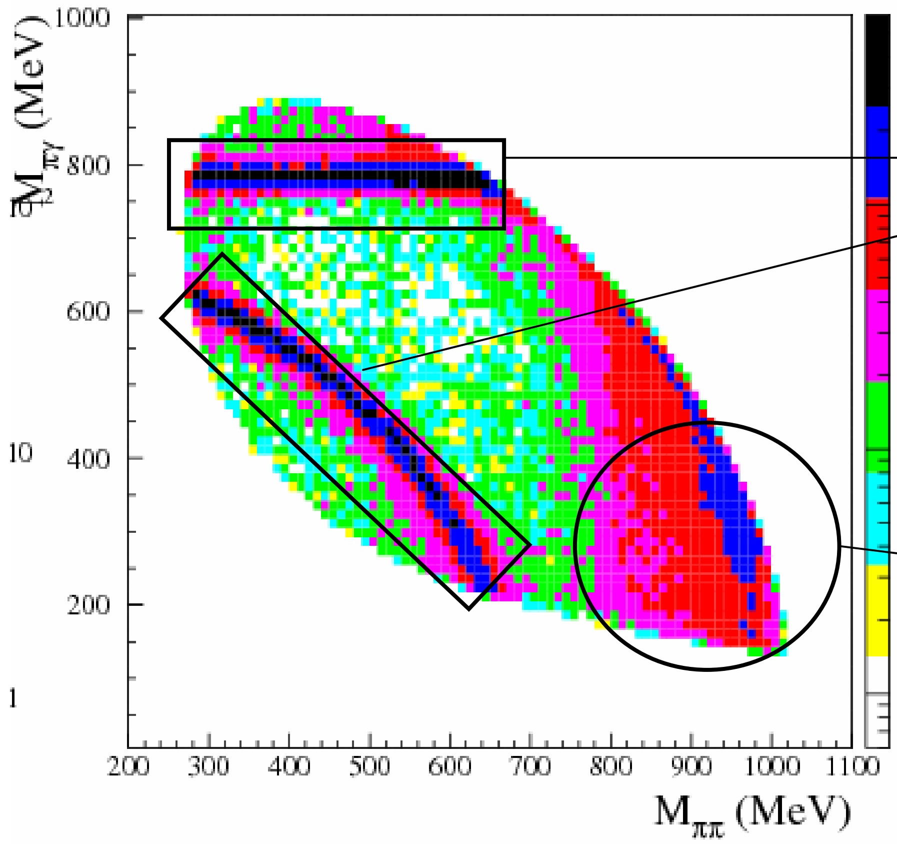
The $\pi^0\pi^0\gamma$ analysis

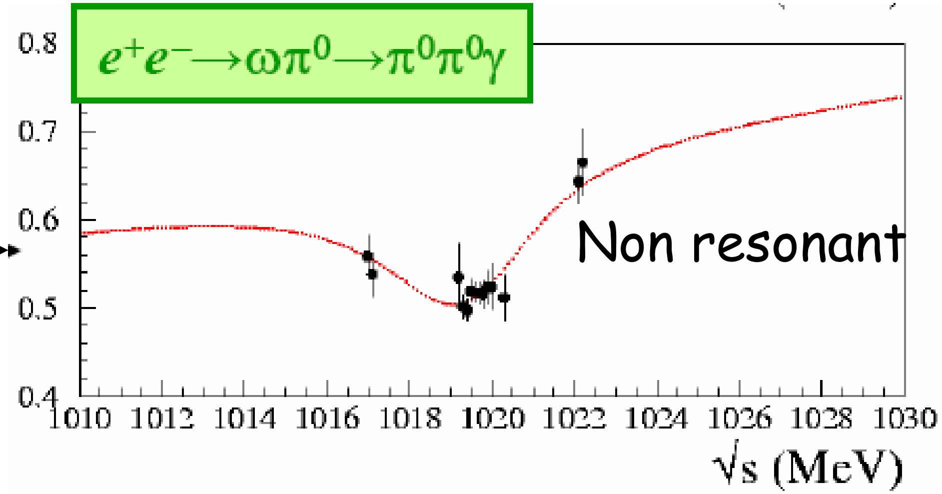
Event selection:

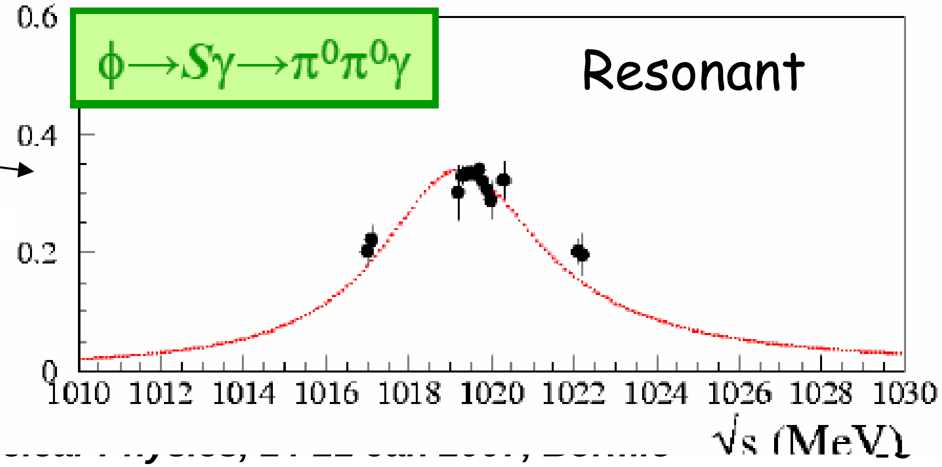
- 5 photons with $\theta_\gamma > 21^o$; no tracks;
- Kinematic fit → energy-momentum conservation;
- Kinematic fit → π^0 masses: choice of the photon *pairing* to π^0's

$\Rightarrow$ 4 ×10^5 events / 450 pb^{-1} $\Rightarrow$ analysis of Dalitz-plot

2 components in the Dalitz-plot







Dalitz plot fit

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

A good fit
is obtained with
both models:
$P(\chi^2)$(KL)=14%
$P(\chi^2)$(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

Comments:

- **σ(500)** is **needed** in KL fit [$p(\chi^2) \sim 10^{-4} \to 14\%$!]
  (best σ parameters are: M=462 MeV, Γ=300 MeV – Imposed to the fit);
- f_0(980) parameters agree with $\pi^+\pi^-\gamma$ analysis KL ⇒ **R > 1** ($g_{f0KK} > g_{f0\pi^+\pi^-}$)
- NS fit gives large $g_{\phi f0\gamma}$ but R<1 (??);
- BR extracted: ∝ integral of $|\text{scalar amplitude}|^2$

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

Accepted by EPJC (hep-ex/0609009)

With $BR(\pi^0\pi^0\gamma) \sim 1/2 \times BR(\pi^+\pi^-\gamma)$ and neglecting KK:
➔ $BR(\phi \to f_0(980)\gamma) = (3.1 \div 3.5) \times 10^{-4}$, $\Gamma(\phi \to f_0(980)\gamma)$ = 1.2 ÷ 1.6 keV

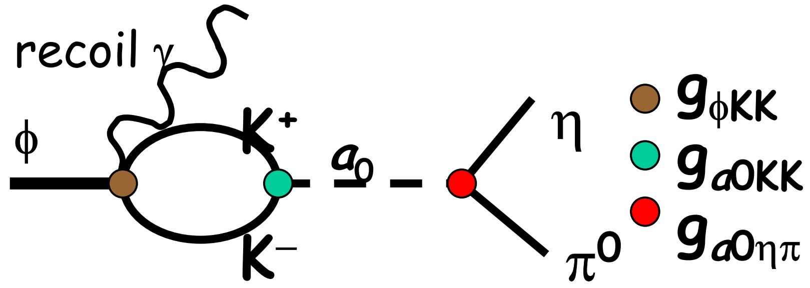
The $\eta\pi^0\gamma$ analysis

To extract the relevant $a_0(980)$ parameters we fit the $M_{\eta\pi}$ spectrum

Two different models exploited:

1. 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 ampl.)



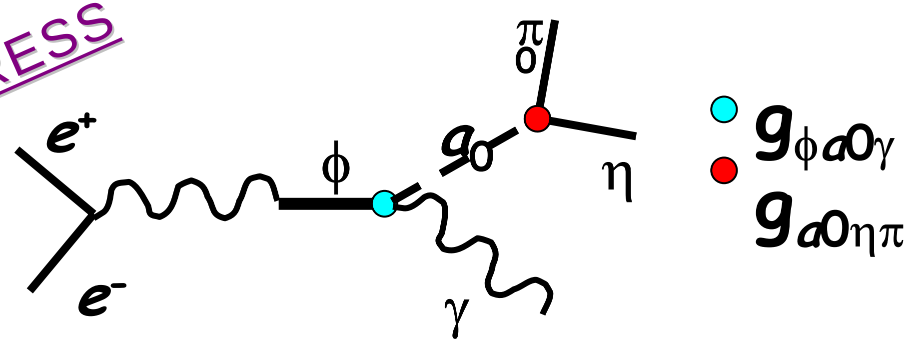
(Achasov - Ivanchenko Nucl.Phys.B315(1989)465,
Achasov - Gubin Phys.Rev.D63(2001)094007,
Achasov - Kiselev Phys.Rev.D68(2003)014006)

2. No structure (8 parameters)

   M_{a0}, $g_{a0\eta\pi}$, $g_{\phi a0\gamma}$,
   g_{a0KK}, c_0 and c_1 (complex)

   $[\Gamma_{a0} = \Gamma(m;\ g_{a0\eta\pi}\ ,\ g_{a0KK})]$

IN PROGRESS



(G.Isidori et al., JHEP0605(2006)049)

Analysis scheme

- dominant scalar contribution from $\phi \to a_0(980)\gamma$ with $a_0(980) \to \eta\pi^0$
  (exp. Br $\approx$ 7-8 $\times 10^{-5}$ – KLOE 2000 data)
- vector contribution $\phi \to VP$; $V \to P'\gamma$ ($V = \rho,\omega$ $P,P' = \eta,\pi^0$)
  (exp. Br $\approx$ 0.3-0.5 $\times 10^{-5}$ - VDM calculations)
- $\eta \to \gamma\gamma \Rightarrow 5\,\gamma$ final state

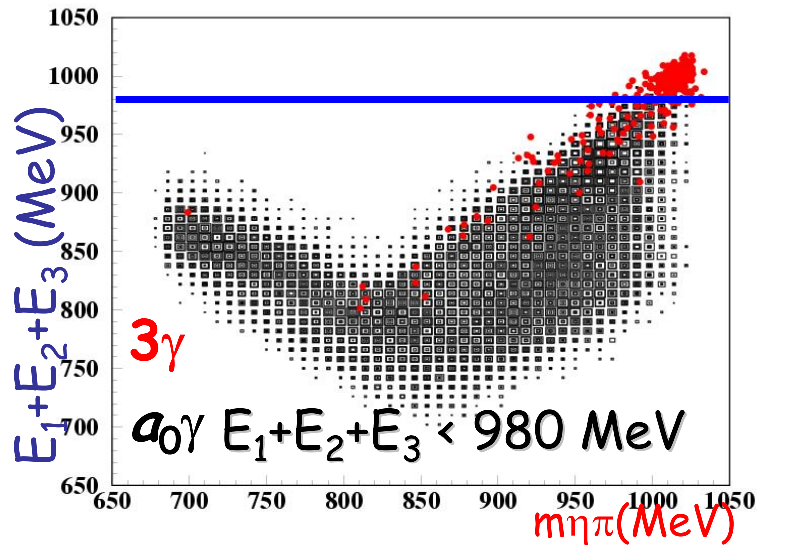
Analyzed sample: $\int L dt$ = 424 pb^{-1}
Pre-selection of 5 photon events
kinematic fit

Background Process		*Exp. 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

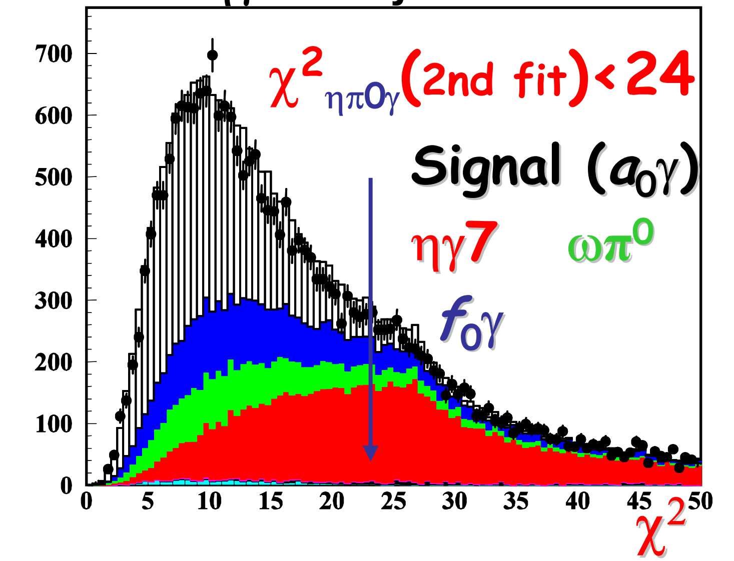
lost or merged photons

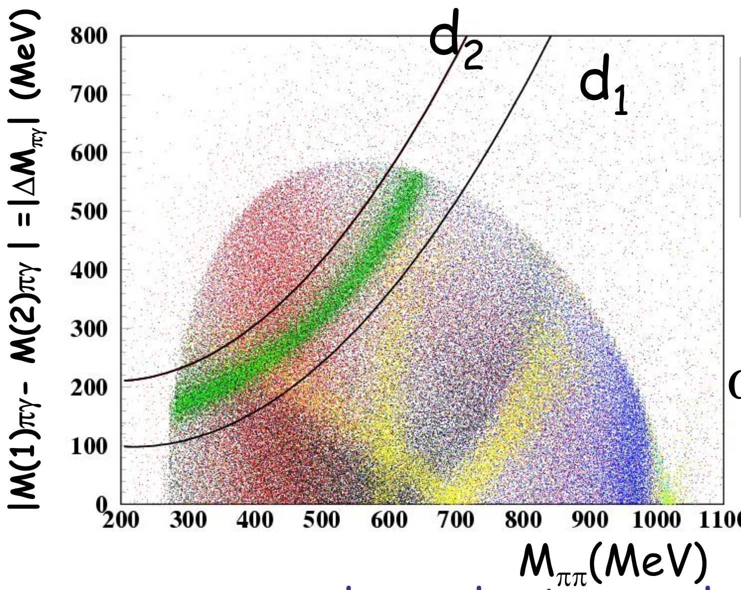
accidental or split clusters

3γ event rejection



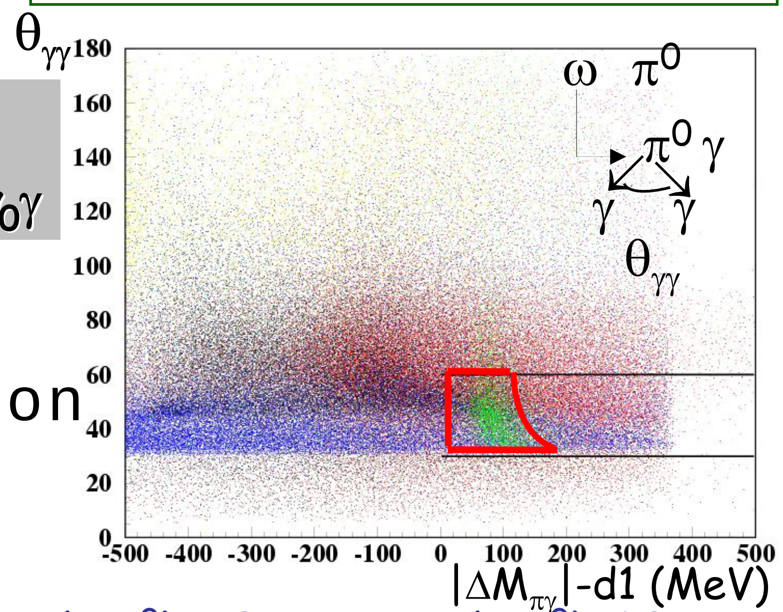
ηγ7 rejection





$\omega\pi^0$	$\eta\gamma7$	
$f_0\gamma$	$\eta\gamma3$	$a_0\gamma$

$\omega\pi^0$ rejection

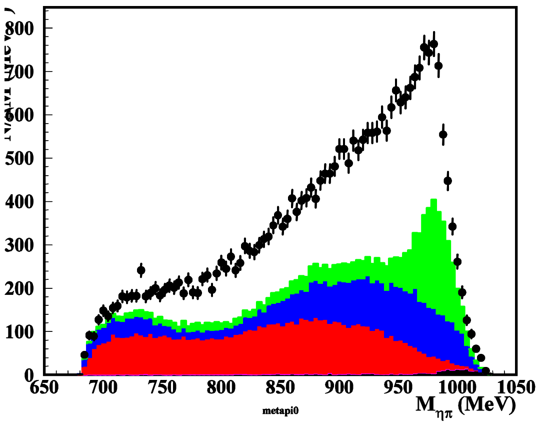


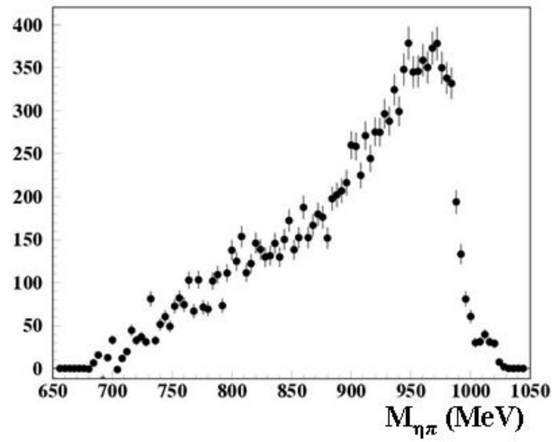
Cut: $|\Delta M_{\pi\gamma}| < d_1$ .OR. $|\Delta M_{\pi\gamma}| > d_2$ .OR. $\theta_{\gamma\gamma}(\omega\pi^0) < 30°$ .OR. $\theta_{\gamma\gamma}(\omega\pi^0) > 60°$

Background evaluation

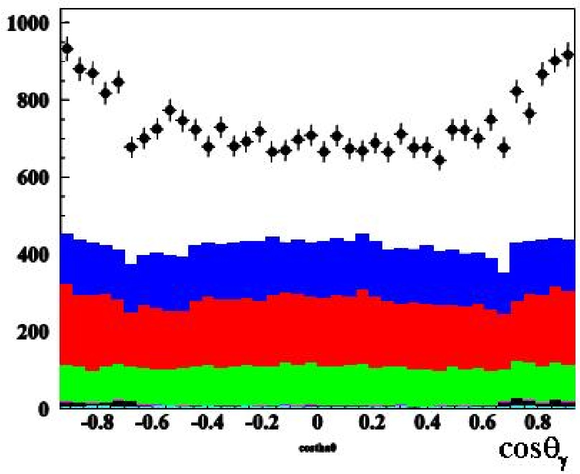
- We rely on MC simulation for the description of the background shape and determine the several background components directly on data
- A weight (Nfit / Nexpected(MC)) for each process has been determined from data

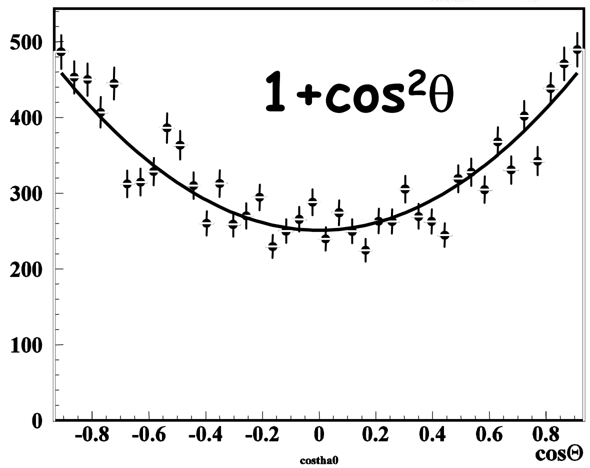
- data
- $\omega\pi^0$ $\eta\gamma 7$
- $f_0\gamma$ $\eta\gamma 3$





Background subtracted





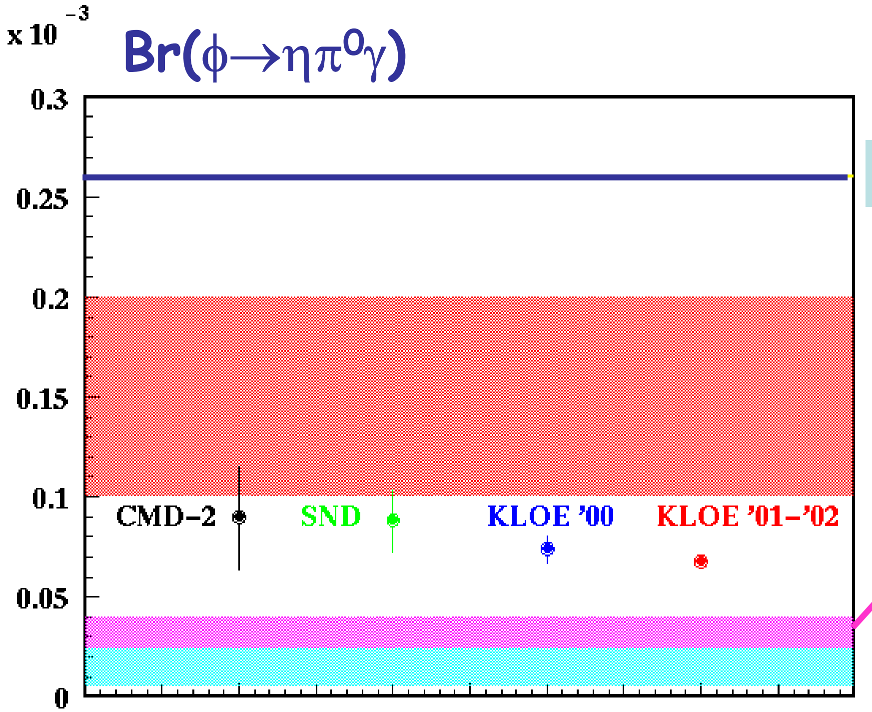
Preliminary results (I)

- N - ΣiBi = 13099 ± 172 events
- ε = 37.9 %
- L = (424.0 ± 2.5) pb-1 (0.6 % uncertainty – EPJC47)
- σ_ϕ = 3090 nb from $\sigma(\phi \rightarrow \eta\gamma)$ = (40.2 ± 1.0) nb
- $Br(\eta \rightarrow \gamma\gamma)$ = (39.38 ± 0.26) %

Preliminary

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

Preliminary results (II)



Achasov-Ivanchenko Nucl.Phys.B315(1987),465
Achasov-Gubin Phys.Rev.D56(1997),4084
Close-Isgur-Kumano Nucl.Phys.B389(1993),513
Kalashnikova et al., Eur.Phys.J.A24(2005),437

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

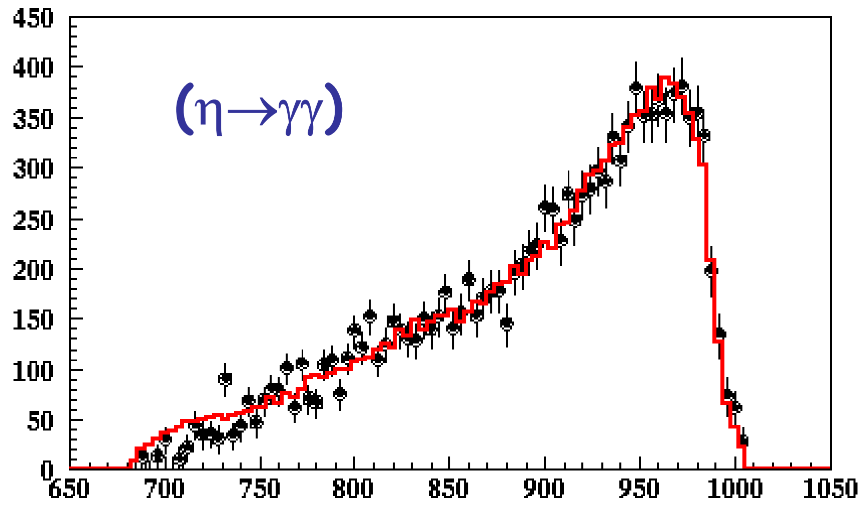
Systematics	$\delta Br/Br$
Bckg subtraction	1.7 %
Photon efficiency curves	1.2 %
Analysis cuts	1.7 %
Luminosity	0.6 %
σ_ϕ	2.5 %
$Br(\eta\to\gamma\gamma)$	0.7 %
Total	3.7 %

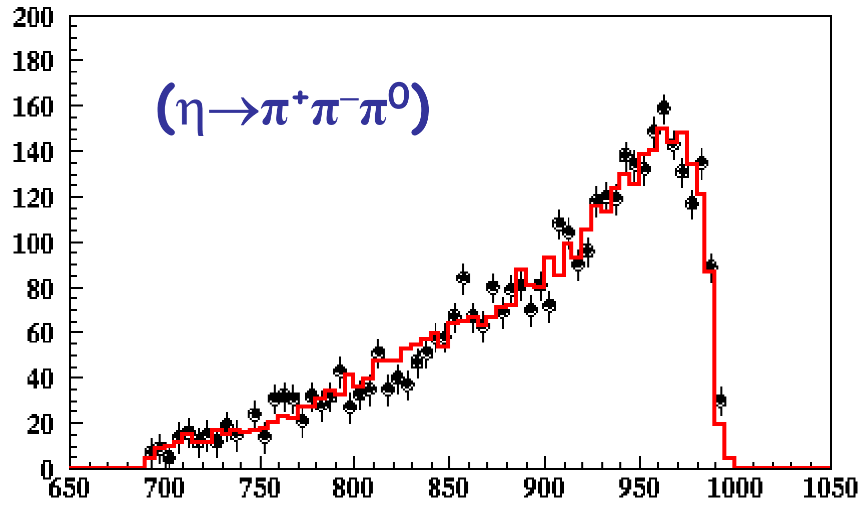
To extract the relevant $a_0(980)$ parameters we have to fit the $M_{\eta\pi}$ spectrum

Kaon loop fit

Combined fit: charged and neutral channel

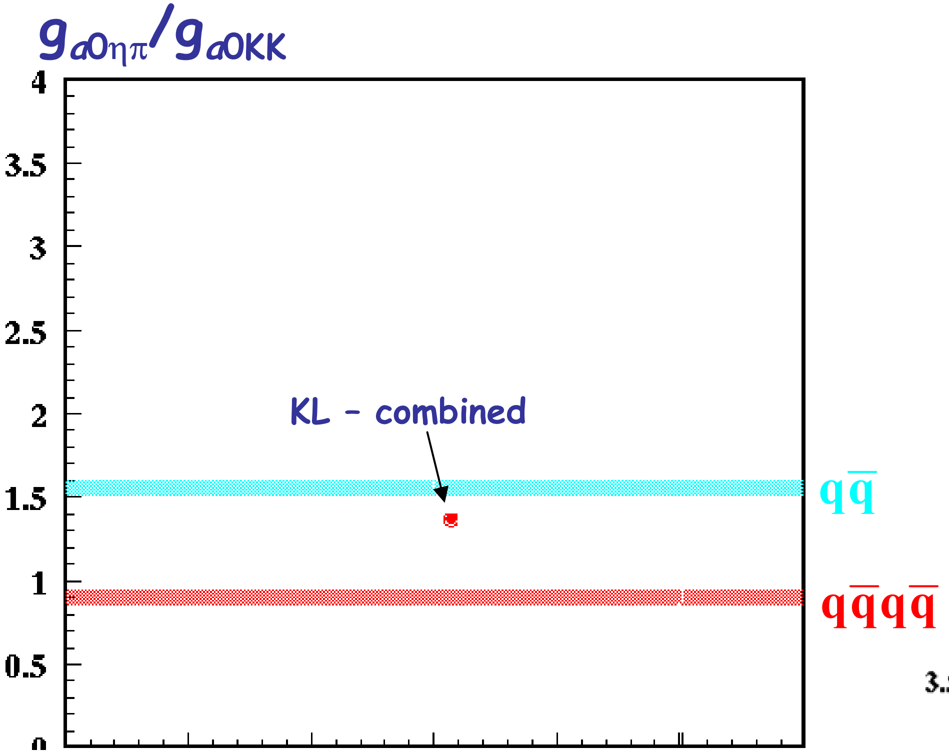
	Fit value	Uncert.
M_{a0} (MeV)	984.6	1.4
$g_{aKK}^2/(4\pi)$ (GeV^2)	0.356	0.019
$g_{a\eta\pi}/g_{aKK}$	1.35	0.031
δ (°)	207	12
Br($\rho\pi$)-VDM	8.90E-07	3.80E-07
$Br(\eta\to\gamma\gamma)/Br(\eta\to\pi^+\pi^-\pi^0)$	1.58	0.04
χ^2	183.96	
ndf	139	
$P(\chi^2)$	0.006	



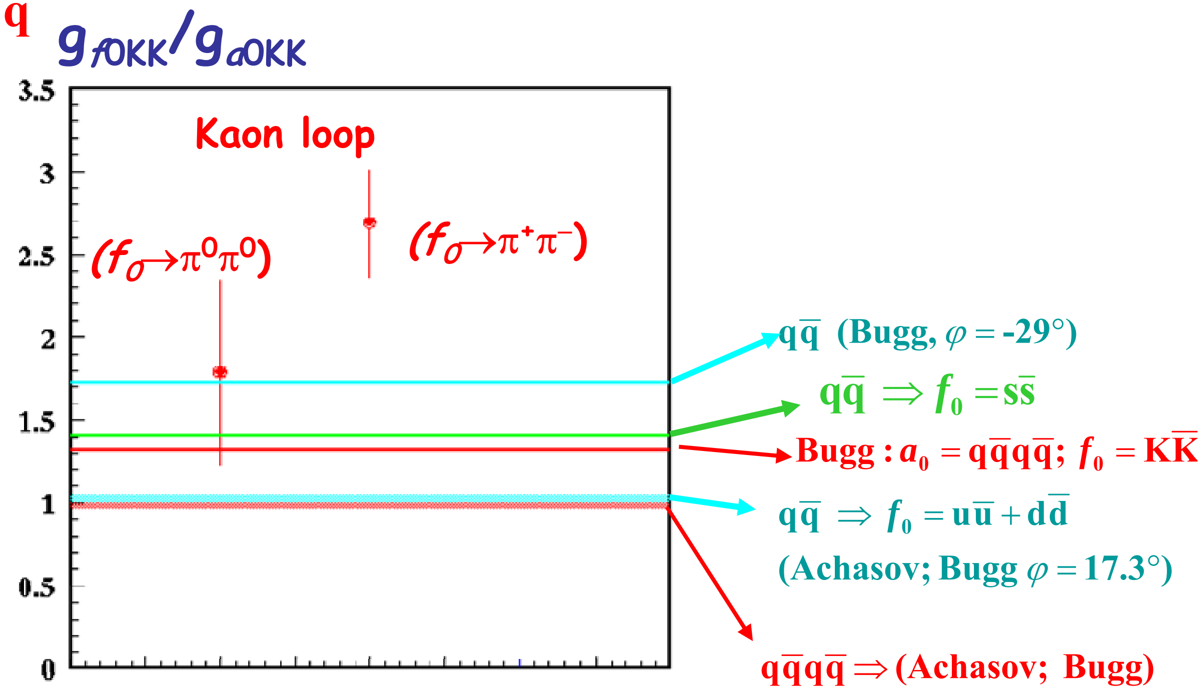


Preliminary

Couplings: $g_{a0\eta\pi}/g_{a0KK}$ and f_0/a_0



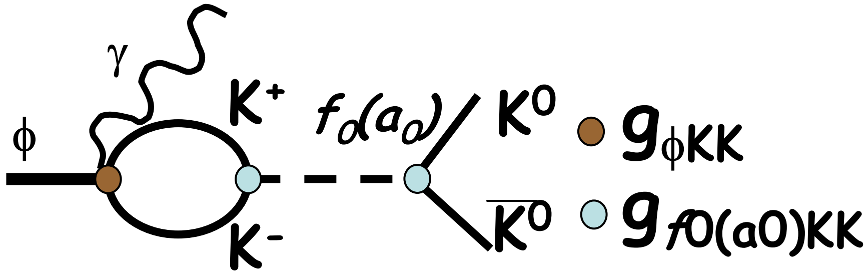
φ = mixing angle of *s* and non-*s* quarks in f_0 and σ



Achasov-Ivanchenko Nucl.Phys.B315(1987),465
Achasov-Gubin Phys.Rev.D56(1997),4084
Bugg Eur.Phys.J.C47(2006),45
Eur.Phys.J.C47(2006),57
Close-Isgur-Kumano Nucl.Phys.B389(1993),513
Kalashnikova et al., Eur.Phys.J.A24(2005),437

In progress: $\Phi \to (f_0 + a_0)\gamma \to K^0\overline{K^0}\gamma$

- ***Kaon Loop model:*** ϕ meson couples to $f_0(a_0)$ through a charged kaon loop



$$BR(\Phi \to (f_0 + a_0)\gamma \to K^0\overline{K^0}\gamma) = (1.29 \div 4.36)\text{x}10^{-8}$$ (Achasov,Gubin Phys.Rev.D64:094016,2001)

- ***Linear sigma model:*** same graph as *kaon loop*, different coupling evaluations for $g\phi KK$ and $gf0(a0)KK$

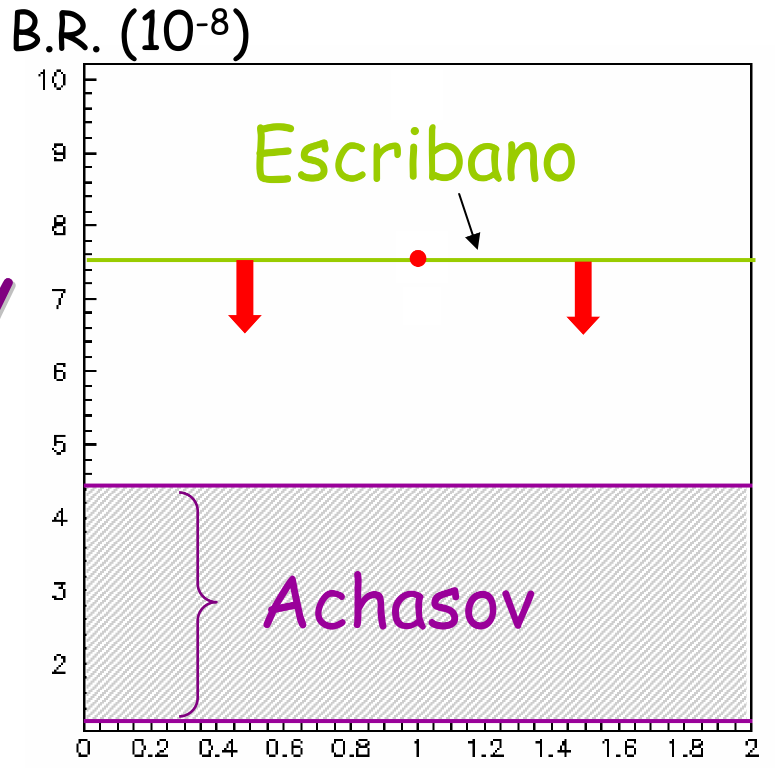
$$BR(\Phi \to (f_0 + a_0)\gamma \to K^0\overline{K^0}\gamma) = 7.5\text{x}10^{-8}$$ (Escribano, hep-ph/0607325)

Analysis scheme

- **We look for $K_SK_S\gamma$ events, with both K_S decaying in** $\pi^+\pi^-$
- **Trigger requirement**
- **Two Vertices** close to IP (regeneration rejection)
- **# of tracks**: two tracks attached to each vertex are required
- **Cut on K_S reconstructed invariant mass and momenta**
- **Cut on E^2miss-P^2miss**

Preliminary: efficiency and sensitivity

- The preliminary **selection efficiency** we obtained is **24.2%**
- The expected number of **background events** is **7**



B.R. sensitivity: $7.5 \cdot 10^{-8}$ @ 90%C.L with 420 pb^{-1} MC sample

Preliminary

Evaluated according to: G. J. Feldman and R. D. Cousins, Phys. Rev. D57 (1998) 3873

Pseudoscalar mesons

BR($\phi\to\eta'\gamma$)/BR($\phi\to\eta\gamma$): Motivations of this analysis

- BR($\phi\to\eta'\gamma$) can probe the $s\bar{s}$ and gluonium content of η'
- The ratio R= BR($\phi\to\eta'\gamma$)/BR($\phi\to\eta\gamma$) can be related to the $\eta-\eta'$ mixing parameters and determine the mixing angle in the flavor basis φ_P, the best parameter for a description of the mixing
- The two mixing parameter, has emerged from EχPT and phenomenological analyses, in the flavor basis are equal apart from terms which violate OZI-rule

Method: measurement of

$$R = \frac{BR(\phi \to \eta'\gamma)}{BR(\phi \to \eta\gamma)}$$

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

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

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

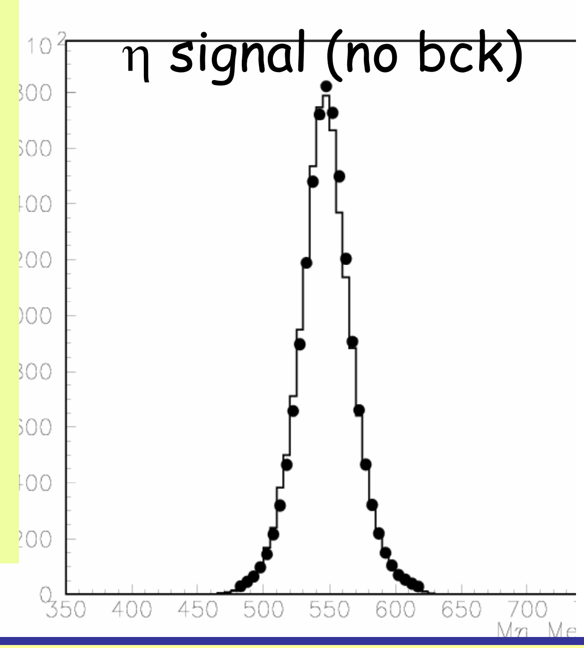
$Br(\phi\to\eta'\gamma)/Br(\phi\to\eta\gamma)$

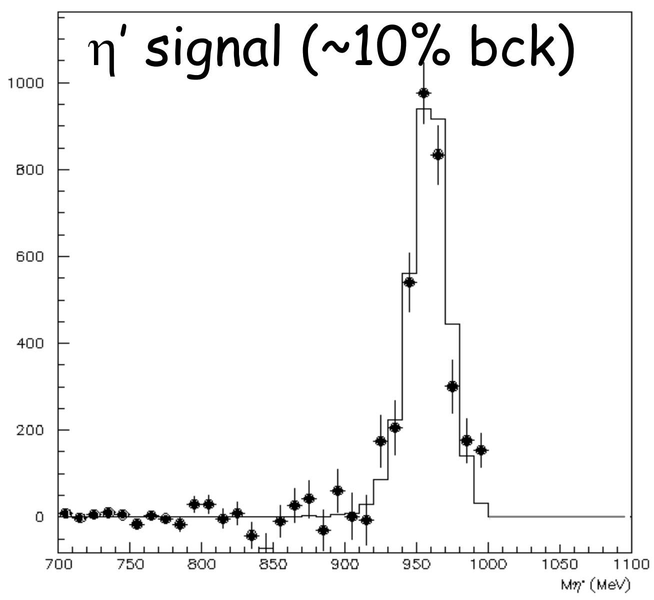
427 pb^{-1} ('01-'02 data)

$N(\eta\gamma)$ = 1665000 ± 1300
(no bck)

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

$N(\eta'\gamma) = 3405 \pm 61_{stat} \pm 28_{syst}$





$$R = (4.79 \pm 0.09_{stat} \pm 0.20_{sys}) \cdot 10^{-3}$$

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

$$BR(\phi \to \eta'\gamma) = (6.24 \pm 0.12 \pm 0.28) \cdot 10^{-5}$$

Submitted to 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

- Using the approach by Bramon et al. [Eur. Phys. J. C7, 271(1999)] and introducing a possible gluonium content via $\cos^2\phi_G$ one can extract the η-η' mixing angle φ_P:

$$R_\phi = \cot^2\varphi_P \cdot \cos^2\phi_G \left(1 - \frac{m_s}{\bar{m}} \cdot \frac{C_{NS}}{C_S} \cdot \frac{\tan\varphi_V}{\sin 2\varphi_P}\right)^2 \cdot \left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

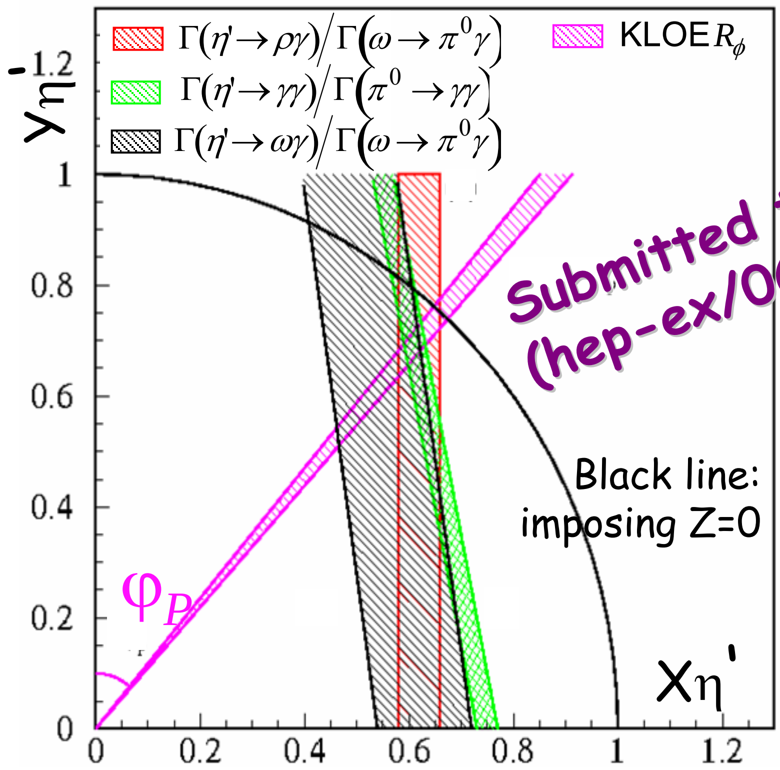
$$\varphi_P = (39.7 \pm 0.7_{tot})^0$$
$$|\phi_G| = (22 \pm 3)^0$$

- Combined analysis to evaluate possible gluonium content of η' (4 constraints in X-Y-plane)

$$\eta' = X\frac{1}{\sqrt{2}}|u\bar{u} + d\bar{d}> + Y|s\bar{s}> + Z|glue>$$

$$X^2 + Y^2 + Z^2 = 1$$

$$(\sin\phi_g)^2 = Z^2 = 0.14 \pm 0.04$$



Submitted to PLB (hep-ex/0612029)

$\eta \to \pi^+ \pi^- \pi^0$ analysis

The $\eta \to 3\pi$ decay is sensitive to isospin symmetry breaking due to light quark mass difference $m_u - m_d$.

$$A(s,t,u) = \frac{1}{Q^2} \frac{m_K^2}{m_\pi^2} (m_\pi^2 - m_K^2) \frac{M(s,t,u)}{3\sqrt{3}F_\pi^2}$$

with: $$Q^2 \equiv \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$$

$$\hat{m} = \frac{m_u + m_d}{2}$$

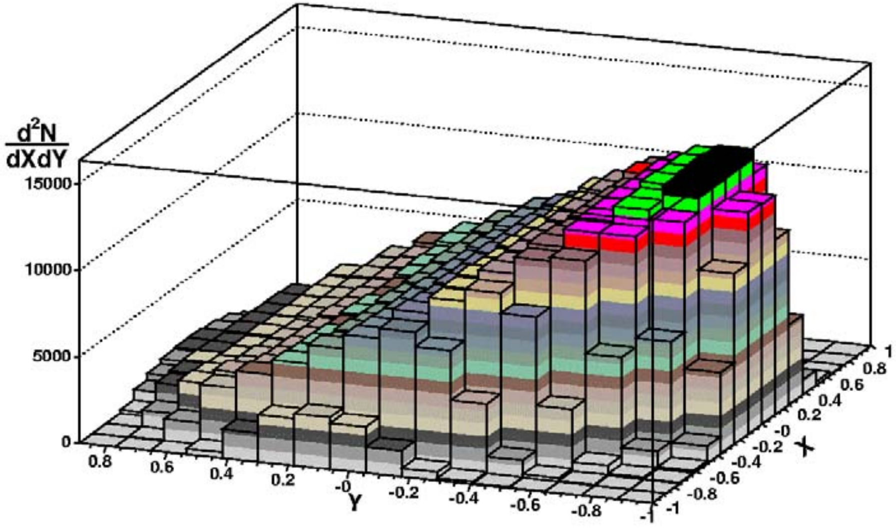
$$\Gamma(\eta \to 3\pi) \propto |A|^2 \propto Q^{-4}$$

The amplitude decay A(X,Y) is expanded around the center of the Dalitz-plot as:

$$|A(X,Y)|^2 \approx 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3$$

Preliminary $\eta \to \pi^+ \pi^- \pi^0$ results

N_{events} = 1.377 Mevts (450 pb^{-1})



$$a = -1.090 \pm 0.005(stat)^{+0.008}_{-0.019}(syst)$$

$$b = 0.124 \pm 0.006(stat) \pm 0.010(syst)$$

$$d = 0.057 \pm 0.006(stat)^{+0.007}_{-0.016}(syst)$$

$$f = 0.14 \pm 0.01(stat) \pm 0.02(syst)$$

correlation matrix

	a	b	d	f
a	1	-0.226	-0.405	-0.795
b		1	0.358	0.261
d			1	0.113
f				1

Fitting with the C-violating parameters *c* and *e* left free we obtain:

$$c = 0.002 \pm 0.003(stat) \pm 0.001(syst) \qquad e = -0.006 \pm 0.007(stat)^{+0.005}_{-0.003}(syst)$$

- **From our preliminary results (hep-ex/0410072)**

  $Q^2_\eta = 22.8 \pm 0.4$

  (B. V. Martemyanov and V. S. Sopov, Phys. Rev. D 71 (2005) 017501)

- **Using Dashen rule** $\left(m^2_{\pi+} - m^2_{\pi 0}\right)_{EM} = \left(m^2_{K+} - m^2_{K0}\right)_{EM}$

  $Q^2_D = 24.2$

  J. Kambor, C. Wisendanger and D.Wyler, Nucl. Phys. B 465 (1996) 215

- **Large NC evaluation confirms deviation from Dashen rule:** $Q^2_{LNC} = 22.0 \pm 0.6$

Measurement of the η (and π^0) masses

Two recent measurements done with different techniques:

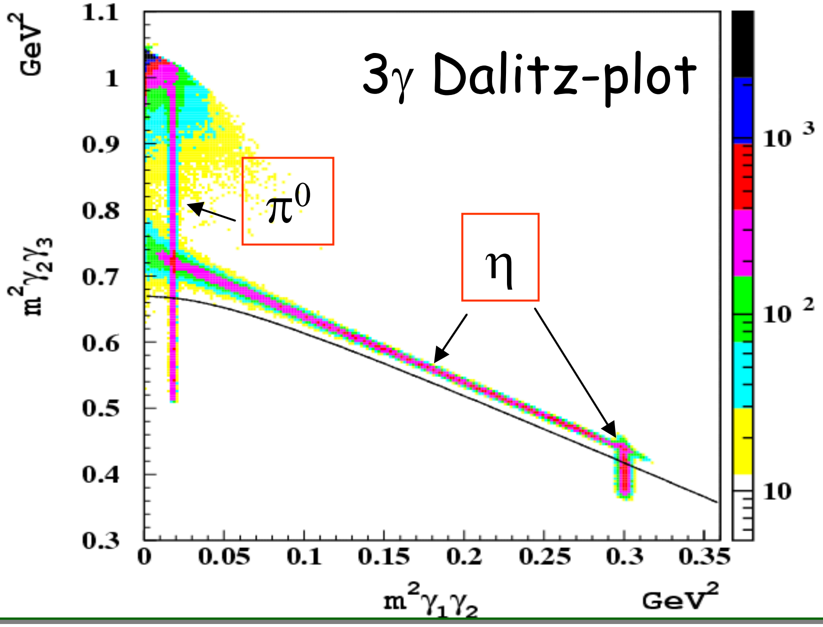
- GEM (COSY) $p+d \rightarrow {}^3He+\eta$ ➔ $M(\eta)=(547311 \pm 28 \pm 32)$ keV/c^2
  (missing mass technique)
- NA48 (CERN) $\pi^-+p \rightarrow n+\eta$ ➔ $M(\eta)=(547843 \pm 30 \pm 41)$ keV/c^2
  ($\eta \rightarrow 3\pi^0$ reconstruction)

8 σ discrepancy: $\delta M(\eta)=(532 \pm 41 \pm 52)$ keV/c^2 (errors added in quadrature)

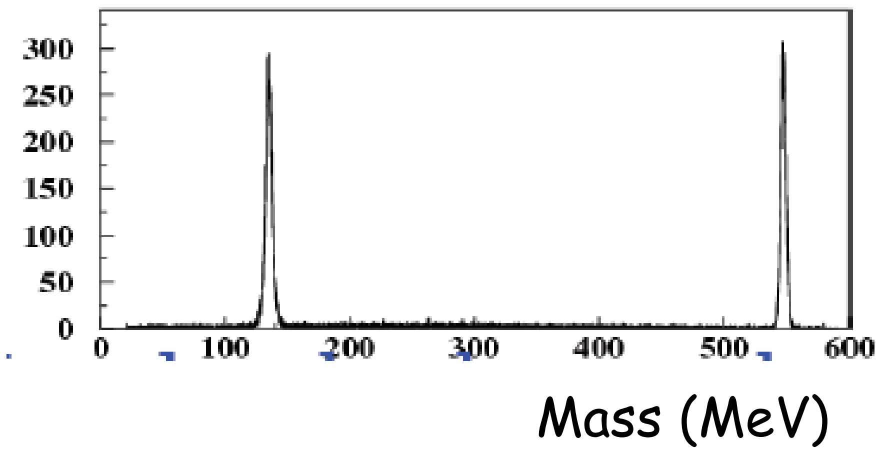
KLOE: $\phi \rightarrow \eta\gamma$; $\eta \rightarrow \gamma\gamma$ **check with** $\phi \rightarrow \pi^0\gamma$; $\pi^0 \rightarrow \gamma\gamma$

Technique: kinematic fit mostly based on photon positions and timing;

ϕ energy-momentum and vertex position from large angle Bhabha scattering

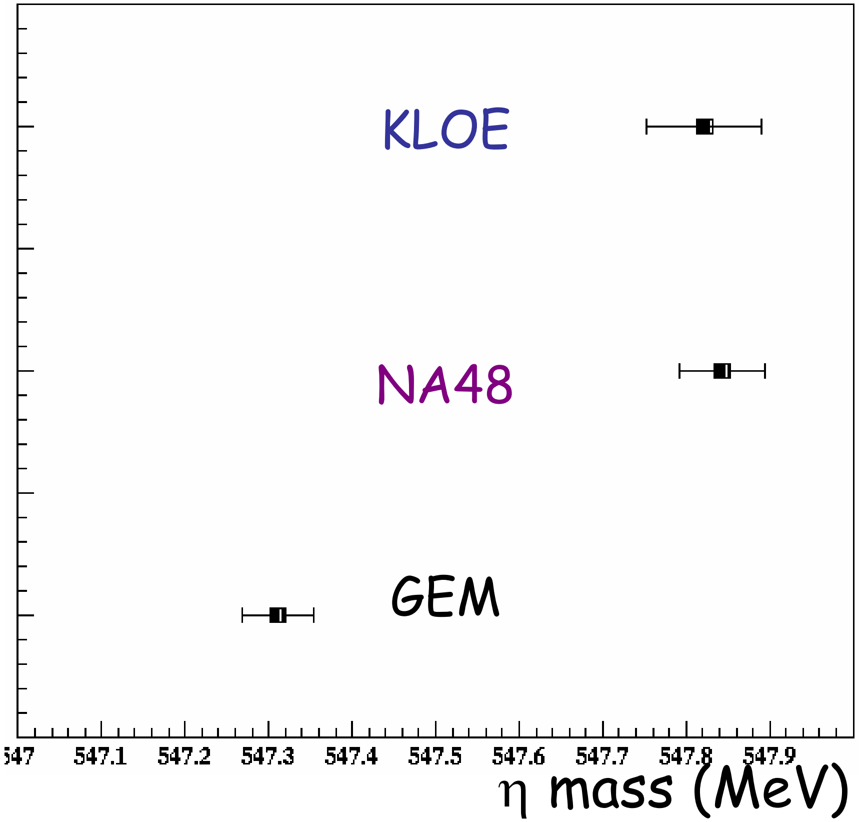


The π^0 and the η peak are well defined



Preliminary results

- The statistical uncertainty is ~negligible
- Systematic uncertainties from knowledge of $\sqrt{s}$ and vertex position (work in progress to reduce it)



The η mass is in agreement with NA48 and in disagreement with GEM

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

Preliminary

The π^0 mass is well in agreement with PDG value

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

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

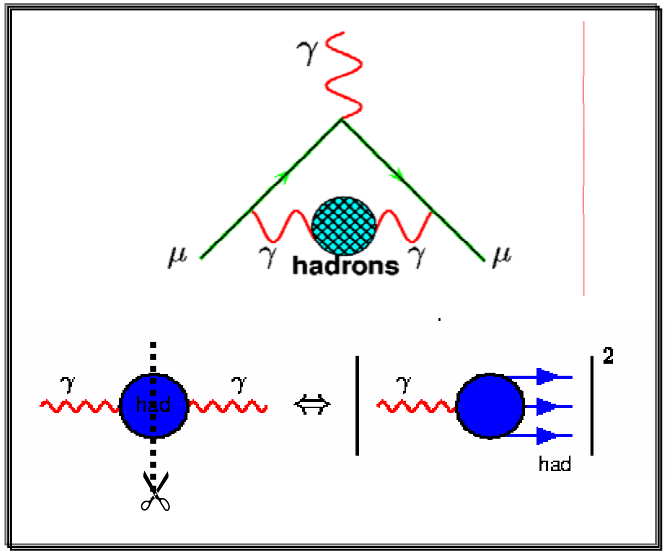
$e^+e^- \rightarrow \pi^+\pi^-$ cross-Section below 1 GeV

Motivation for $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$

- Hadronic contribution a_μ^{hadr} is limiting the standard model prediction for $(g-2)_\mu$!

a_μ^{had} is estimated by means of a dispersion relation (intrinsically ~$1/s^2$):

$$a_\mu^{had} = \frac{1}{4\pi^3} \int_{4m_\mu^2}^{\infty} \sigma_{had}(s)\, K(s)\, ds$$



- Experimental input into dispersion integral at low energies where pQCD is not applicable

- Dominant channel below 1 GeV is $e^+e^- \rightarrow \rho \rightarrow \pi^+\pi^-$, which contributes with ca. 70% to the total value of a_μ^{had}

$\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ needed with $\leq$ 1% precision!

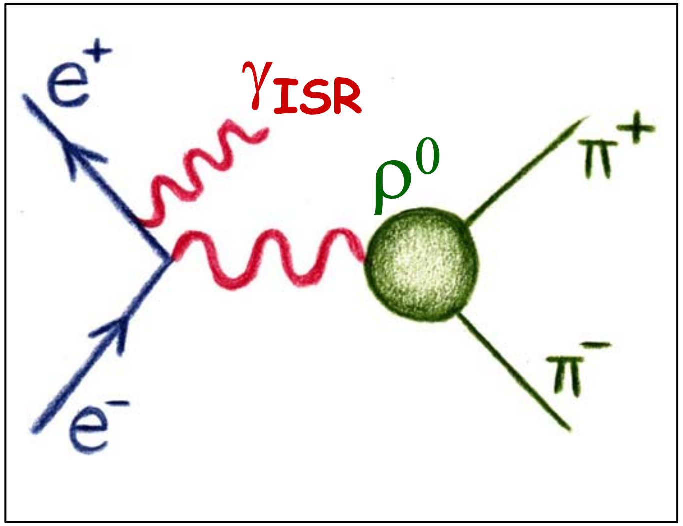
$\sigma(e^+e^-\to\pi^+\pi^-)$ with ISR:

Modern particle factories, such as **DAΦNE are designed for a fixed center-of-mass energy**: $\sqrt{s} = m_\phi$ = 1.02 GeV in the case of DAΦNE

Energy-scan not possible!

Complementary approach:
Consider events with **Initial State Radiation (ISR)**

S. Binner, J.H. Kühn, K. Melnikov, Phys.Lett. B459 (1999) 279



$$M^2_{hadr}\frac{d\sigma(e^+e^-\to hadrons+\gamma_{ISR})}{dM^2_{hadr}} = \sigma(e^+e^-\to hadrons)\,H(M^2_{hadr})$$

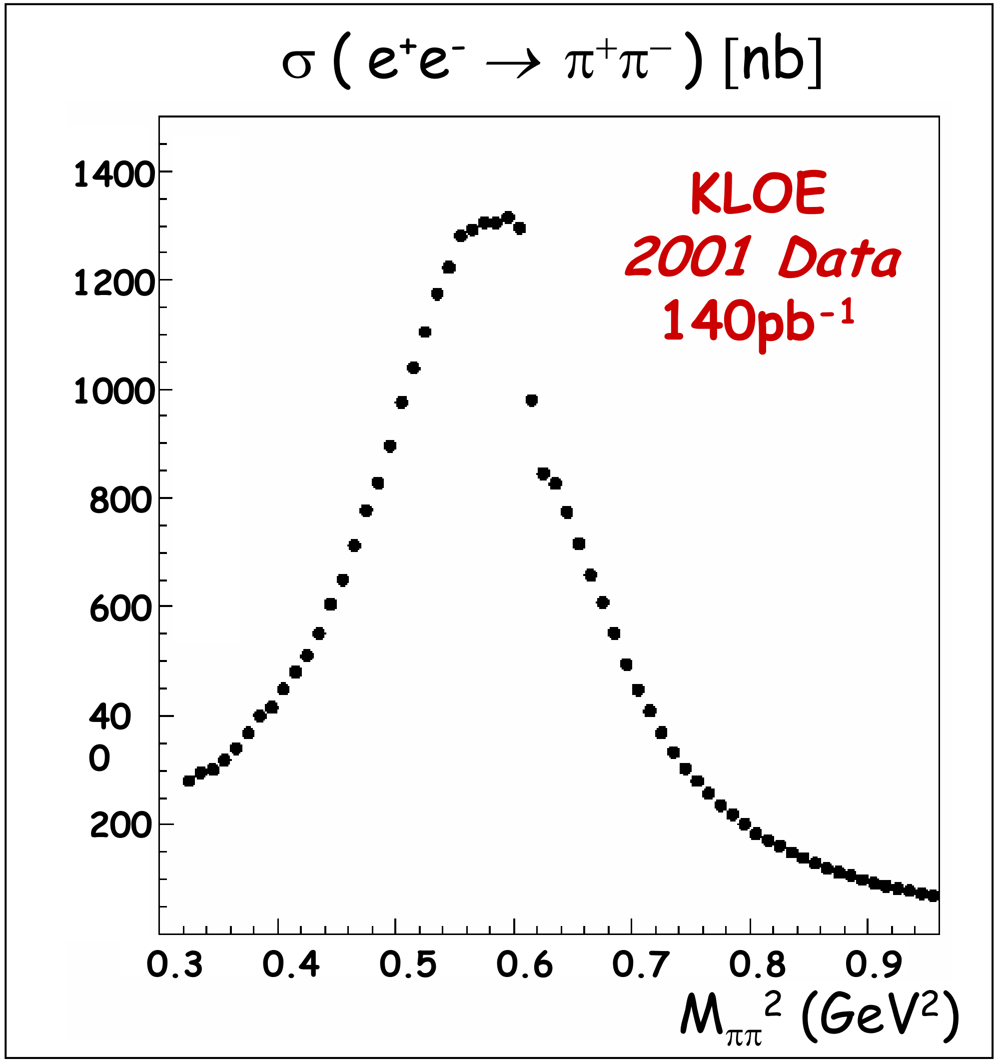
- Requires precise calculations of the radiator **H**
- Requires precise understanding of effects from Final State radiation (*FSR*)

H. Czyz, A. Grzelinska, J.H. Kühn, G. Rodrigo, Eur. Phys. J. C33 (2004), 333
Pancheri, Shekhotsova, Venanzoni, Phys. Lett. B642, (2006) 342

First published result:

Published Result:

Phys. Lett. B606 (2005) 12



Statistical error negligible (1.5 Million events)

Contrib. to syst. error on a_μ^{had}:

Acceptance	0.3%
Trigger	0.3%
Tracking	0.3%
Vertex	0.3%
Offline reconstruction filter	0.6%
Particle ID	0.1%
Trackmass cut	0.2%
Background	0.3%
Unfolding effects	0.2%
Total experim. Syst.	**0.9%**
Luminosity (LA Bhabhas)	0.6%
Vacuum polarization	0.2%
FSR corrections	0.3%
Radiator function	0.5%
Total theoretical Error	**0.9%**
TOTAL ERROR KLOE	**1.3%**

(CMD-2: 0.9%, SND 1.3%)

Work in progress on $d\sigma_{\pi\pi\gamma}/dM_{\pi\pi}^2$:

- A new analysis is carried out at small photon angles using 2002 data (240pb^{-1}) with improved machine background and calibration conditions. This alone should allow for a reduction of the total systematic error on $\sigma_{\pi\pi}$ to <1%.

- In addition, one can extract $\sigma(e^+e^-\to\pi^+\pi^-)$ by performing a normalization with muon events:

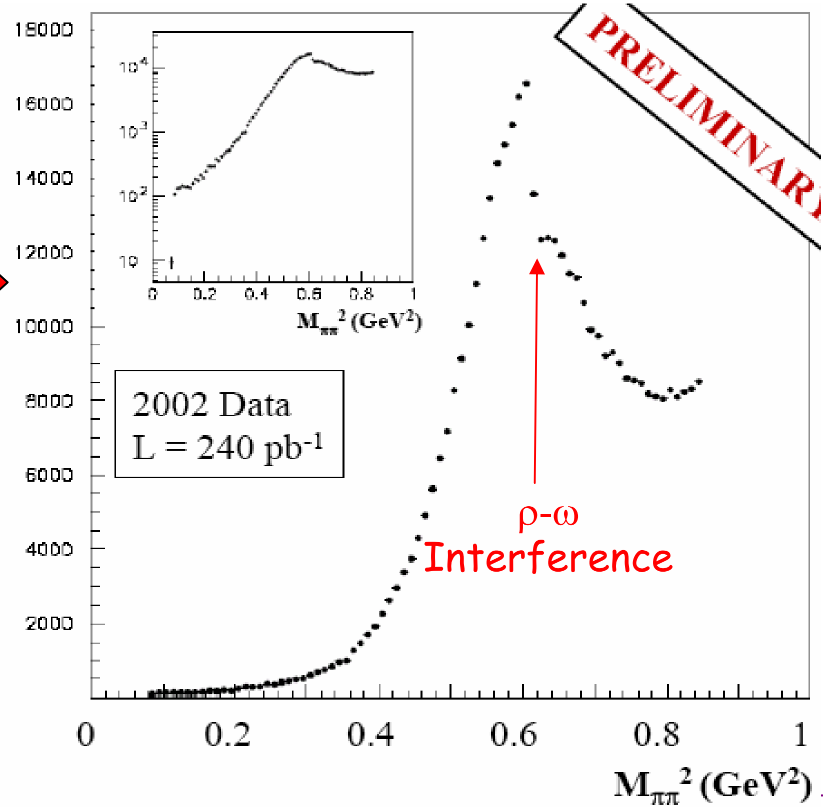
$$\sigma_{\pi\pi}^{Born}(s') \approx \frac{d\sigma_{\pi\pi\gamma}^{obs}/ds'}{d\sigma_{\mu\mu\gamma}^{obs}/ds'}\sigma_{\mu\mu}^{Born}(s')$$

many effects cancel in the ratio:
- *Vacuum Polarisation*
- *Luminosity*
- *Radiator function*

- Analysis with photons detected at large angle allows us to access the 2-pion-threshold region.

Main limitation is caused by the contribution from model dependent effects of ϕ decays ($\phi\to f_0\gamma$, $\phi\to\rho\pi$) and Final State Radiation from pions.

$\to$ Estimate these effects from MC:
- *PHOKHARA [EPJ C47(2006) 617]*
- *Pancheri/Shekhovtsova/Venanzoni [PLB 642 (2006) 342]*



Hadronic physics analyses at KLOE:

$\phi \to \pi^+\pi^-\pi^0$	Dalitz plot analysis	PLB 561(2003) 65	
$\phi \to f_0\gamma \to \pi^+\pi^-\gamma$	f_0 coupling to ϕ, $\pi\pi$, KK	PLB 634(2006) 148	
$\phi \to f_0\gamma \to \pi^0\pi^0\gamma$	BR($\phi \to \pi^0\pi^0\gamma$) to 5%	PLB 537(2002) 21	PDG06
	Dalitz plot analysis, stat/syst improvements	accepted by EPJ	
$\phi \to \omega\pi^0 \to \pi^0\pi^0\gamma$	Dependence of σ_{vis} on $\sqrt{s}$	Preliminary	
$\phi \to \eta\,\pi^0\gamma$	BR($\phi \to a_0(980)\,\gamma$) to 10%	PLB 536(2002) 209	
	stat/syst improvements	Preliminary	
$\phi \to \eta'\gamma$ ($\eta\gamma$)	$\Gamma(\phi \to \eta'\gamma)/\Gamma(\phi \to \eta\gamma)$ to 12%, mixing angle to 5%	PLB 541(2002) 45	PDG06
	stat/syst improvements	Preliminary	
$\eta \to \gamma\gamma$	η mass measurement	Preliminary	
$\eta \to \pi^+\pi^+\pi^0$	η mass measurement, Dalitz plot analysis	Preliminary	
$\eta \to \pi^0\pi^0\pi^0$	Dalitz plot analysis	Preliminary	
$\eta \to \pi^0\gamma\gamma$	BR, $m_{\gamma\gamma}$ spectrum	Preliminary	
$\eta \to \pi^+\pi^-$	Upper Limit on BR at 10^{-5}	PLB 606(2005) 276	PDG06
$\eta \to \gamma\gamma\gamma$	Upper Limit on BR at 10^{-5}	PLB 591(2004) 49	PDG06
$e^+e^- \to \pi^+\pi^-\gamma$	$a_\mu\,\vert_{had}$ ($0.35 < s_\pi < 0.95$ GeV^2) to ~ 1%	PLB 606(2005) 12	
	$a_\mu\,\vert_{had}$ down to threshold, $\mu^+\mu^-\gamma$ normalization	Preliminary	
$e^+e^- \to e^+e^-$ ($\mu^+\mu^-$)	$\Gamma_{lept}(\phi)$ to 1.5% and lepton universality test	PLB 608(2005) 199	PDG06
etc...			

Kaon physics

Of course, the main effort of the KLOE collaboration is on Kaon physics:

- Extraction of the **Vus** element of the CKM matrix from 5 semi-leptonic decays of neutral and charged kaons
  $\Rightarrow$ test of ***CKM Unitarity***
- **CPT** tests: first measurement of K_S semi-leptonic asymmetry
- Kaon **interferometry** in $\pi^+\pi^-\pi^+\pi^-$ final states:
  $\Rightarrow$ bounds on ***quantum coherence*** + ***CPT violation***
- Reduced upper bound on $K_S \to \pi^0\pi^0\pi^0$ ***CP violating decay***
- Precision measurement of $K_S \to \pi^+\pi^-(\gamma)/\ K_S \to \pi^0\pi^0$
- Measurement of K_L and $K_S \to \gamma\gamma$ $\Rightarrow$ ***ChPT test***
- Measurement of K_L and $K^\pm$ **lifetime**
- Measurement of K_L and $K^\pm$ **main B.R.s**

Recent Kaon analyses:

$K_S K_L \to \pi^+\pi^-\pi^+\pi^-$ CP and CPT violation	Quantum Interference Bell-Steinberger rel. + KLOE data	PLB 642 (2006) 315 Accepted by JHEP	
$K_S \to \pi^0\pi^0\pi^0$	UL on BR at 10^{-7}	PLB 619 (2005) 61	PDG06
$K_S \to \pi e \nu$	BR to 1.3%, form factor slope, charge asymmetry	PLB 636 (2006) 173	PDG06
$K_S \to \pi^+\pi^-, \pi^0\pi^0$	$\Gamma(\pi^+\pi^-)/\Gamma(\pi^0\pi^0)$ to ~0.25%	Accepted by EPJC	PDG06
$K_L \to \pi l \nu, \pi\pi\pi$	Absolute BR's to ~ 0.5% K_L lifetime from Σ(BR)=1	PLB 632 (2006) 43	PDG06
K_L lifetime	from $K_L \to \pi^0\pi^0\pi^0$ to ~ 0.5%	PLB 626 (2005) 15	PDG06
$K_L \to \pi e \nu$	Form factor slopes	PLB 636 (2006) 166	PDG06
$K_L \to \pi e \nu \gamma$	BR to ~ 2 %	Preliminary	
$K_L \to \pi^+\pi^-$	BR to 1.1%	PLB 638 (2006) 140	PDG06
$K_L \to \gamma\gamma$	$\Gamma(\gamma\gamma)/\Gamma(\pi^0\pi^0\pi^0)$ to 1.1%	PLB 566 (2003) 61	
$K^+ \to \pi^+\pi^0\pi^0$	BR to 1.4%	PLB 597 (2004) 139	
$K^+ \to \mu^+\nu$	Absolute BR to ~ 0.27%	PLB 632 (2006) 76	PDG06
$K^\pm \to \pi^0 l^\pm \nu$	Absolute BR's to ~ 1.5%	Preliminary	
$K^\pm$ lifetime	two independent measurements	Preliminary	
etc…			

What's next?

Hadronic physics

- Measurement of $\sigma_{\pi\pi}$ without resonant background from ϕ
- Determination of f_0 and FSR parameters
- $\sigma(e^+e^- \to \omega\pi^0)$ vs. $\sqrt{s}$
- Search for $\sigma(600)$ with off-peak data using the reaction $\gamma\gamma \to \pi^0\pi^0$

Off-peak data

- Combined fit of both charged and neutral $\pi\pi\gamma$ final states and searches for $f_0/a_0 \to KK$
- Single and Double Dalitz η decays, $\eta \to \pi^0\gamma\gamma$, η' decays
- ...

2 fb^{-1}

Kaon physics

- Measurement of $BR(K_S \to \pi^+\pi^-\pi^0)$, $BR(K_S \to \pi^+\pi^- e^+ e^-)$
- Improve on $UL(K_S \to \pi^0\pi^0\pi^0)$, $UL(K_S \to e^+ e^-)$
- Improve on semileptonic BRs, lifetimes and form factors
- $BR(K_L \to \pi\pi)$ to few 10^{-3}
- $\Gamma(K^\pm \to e^\pm \nu)/\Gamma(K^\pm \to \mu^\pm \nu)$ to few 10^{-2}
- ...

2 fb^{-1}

What's next? KLOE2

A new scheme to increase DAΦNE luminosity by a factor O(5) has been proposed by P.Raimondi (***crab waist collisions***) – test in autumn 2007

If successful a new round of measurements with an improved KLOE detector could start in 2009

*The KLOE detector has proven to well face the challenge, nevertheless **something can be improved**:*

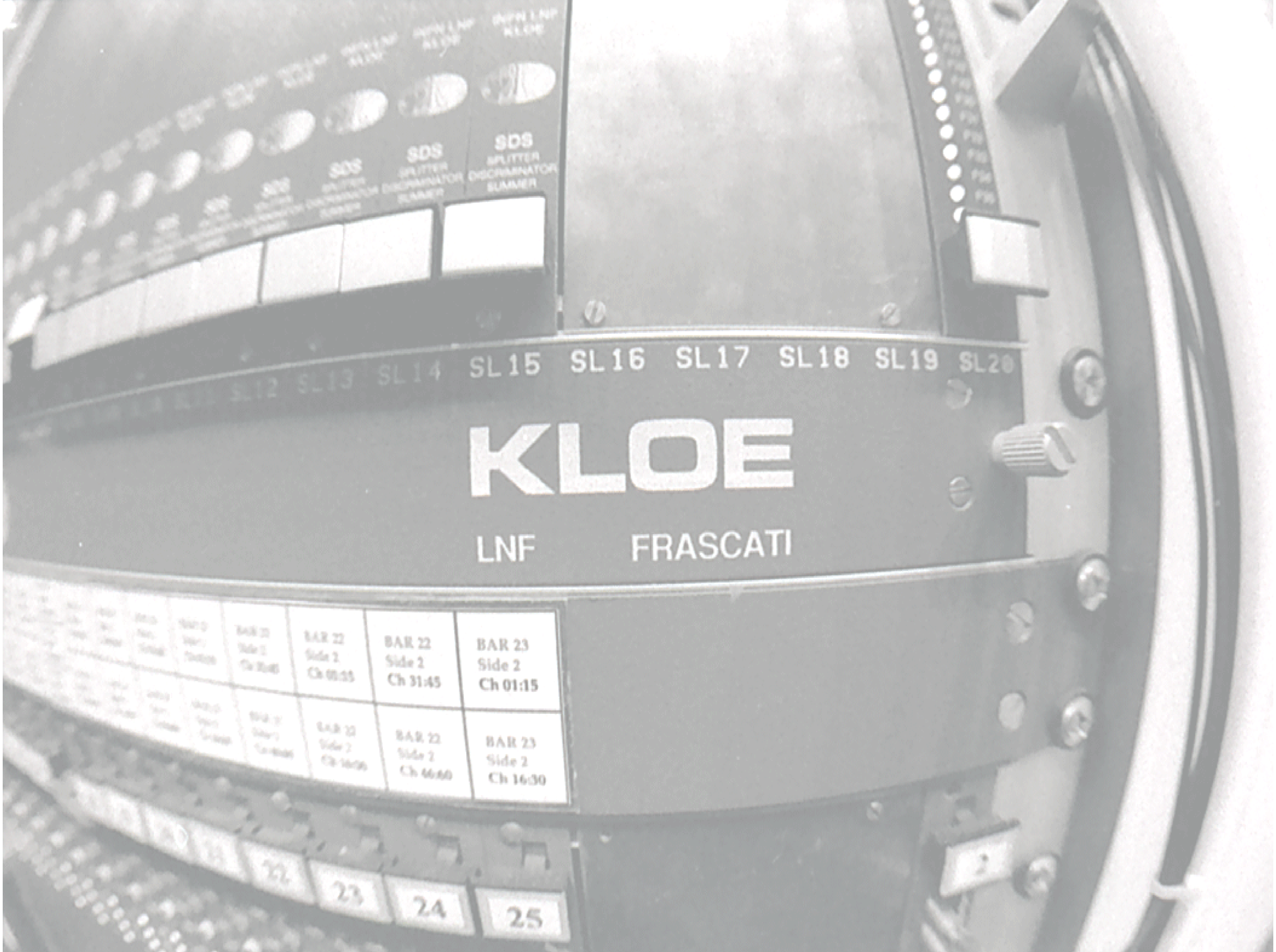
- add an **inner tracker**
- add a **tagging system** for $e^+e^- \rightarrow e^+e^-\gamma\gamma$
- increase the **EMC read-out granularity**
- update / upgrade **the data acquisition**

What's next? KLOE2

- **Time evolution of entangled kaon states**, reach the sensitivity to the Planck scale: tests of CPT-symmetry and quantum mechanics
- **e–μ universality** ($K \to e\nu$ / $K \to \mu\nu$) and the **mass of the muon neutrino**
- **universality of the weak coupling** to leptons and quarks, CKM matrix unitarity
- **rare K_S decays** (semileptonic charge asymmetry, $K_S \to \pi^+\pi^-\pi^0$, $K_S \to \pi^0\pi^0\pi^0$)
- **light mesons**: structure of scalars (via $\gamma\gamma$ interaction), η and η' physics
- **$\sigma(e^+e^- \to$ hadrons)**, muon anomaly, evolution of α_{em}
- **baryon electromagnetic form factors**, $e^+e^- \to pp$, nn, $\Lambda\Lambda$
- *… and more*

a new exciting challenge!

who wants to join us is welcome!!!


SDS
SPLITTER
DISCRIMINATOR
SUMMER
SL 15
SL 16
SL 17
SL 18
SL 19
SL 20
KLOE
LNF
FRASCATI
BAR 22
Side 2
Ch 31:45
BAR 23
Side 2
Ch 01:15
BAR 22
Side 2
Ch 46:60
BAR 23
Side 2
Ch 16:30
23
24
25