Recent results from KLOE

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1. The KLOE physics program
2. The KLOE detector
3. Status of the experiment
4. Results on neutral kaon decays
5. Results on ϕ radiative decays
6. Conclusions and perspectives

1. The KLOE physics program.

$e^+e^- \to \phi$ W = m_ϕ = 1019.4 MeV σ_ϕ~3 μb

Decay channels	
® **K^+K^- = 49.2%**	Charged Kaon decays + CP/CPT tests
® **$K^0\bar{K}^0$ = 33.8%**	Neutral Kaon decays + CP/CPT tests (ε' / ε)
® $p^+p^-p^0$ **= 15.5%**	3 pion decay ➔ ρπ (ρ shape parameters)
® hg = **1.3%**	Radiative decays: pseudoscalar: η physics
® p^0g = **~10^{-3}**	"
® h'g = **~10^{-4}**	" ➔ pseudoscalar mixing angle
® ppg = **~10^{-4}**	scalar ➔ f0
® hp^0g = **~10^{-4}**	" ➔ a0
® h **e^+e^-** = **~10^{-4}**	Conversion decays: transition form factor $F_{\phi\eta}$
® p^0**e^+e^-** = **~10^{-5}**	" " $F_{\phi\pi}$

e^+e^- ® p^+p^-g Initial state radiation ➔ $\sigma(e^+e^- \to \pi^+\pi^-)$ $2m_\pi < W < m_\phi$

e^+e^- ® f around φ peak (energy scan) ➔ φ resonance parameters

2. The KLOE detector:

Drift chamber

Calorimeter (Pb-scint.fib.)

Magnetic field = 0.56 T

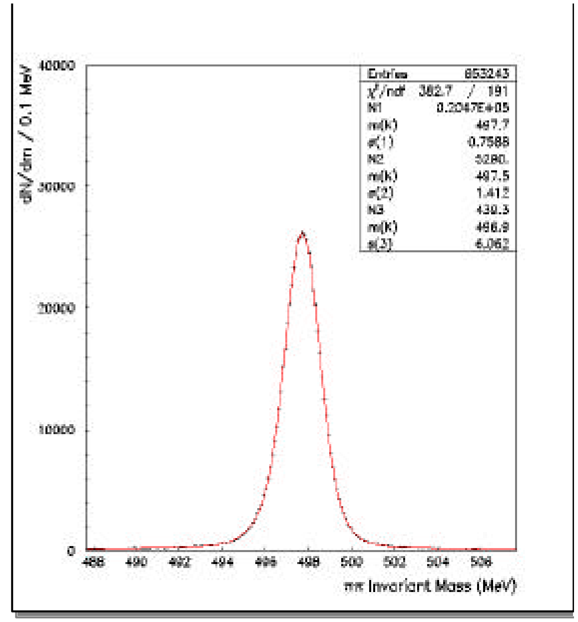
Drift chamber:

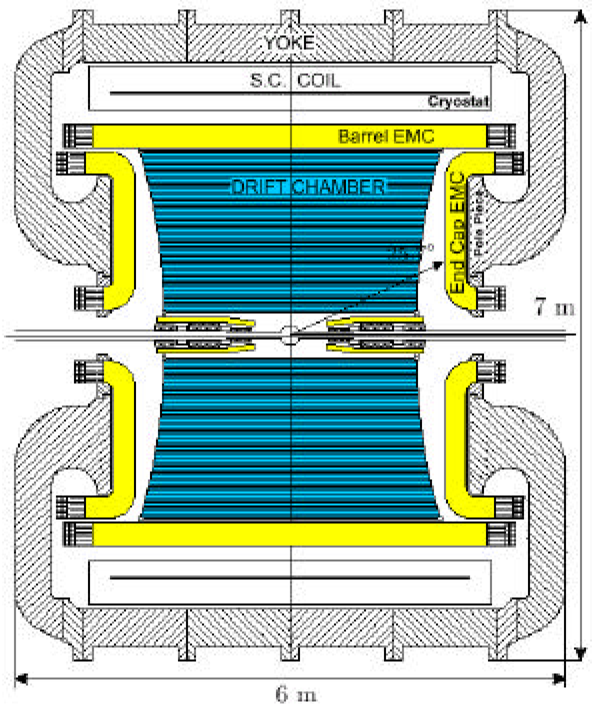
Large volume d=4m l=3.3m

He – Isob 90-10 gas mixt.

Momentum resolution

dp/p < 0.4%





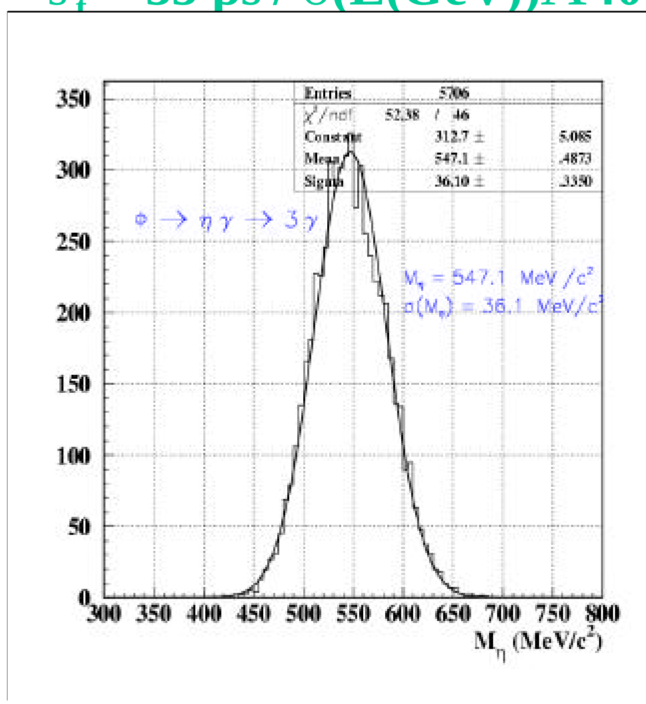
Calorimeter:

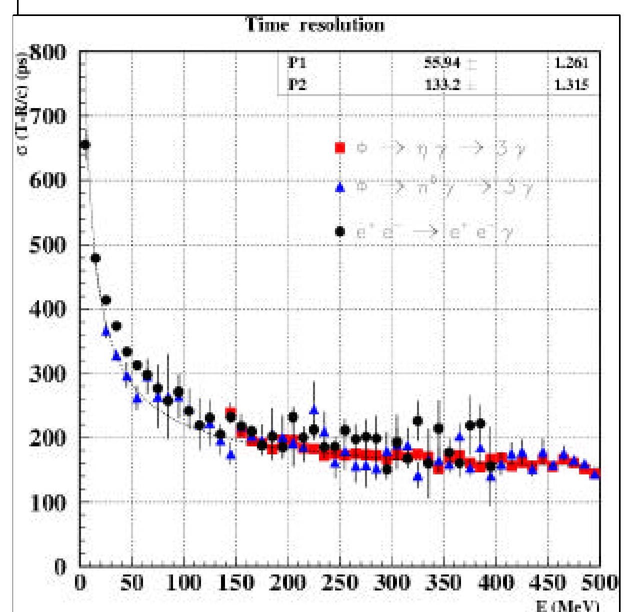
Energy resolution:

s/E = 5.4% / Ö(E(GeV))

Time resolution

s t = 55 ps / Ö(E(GeV))Å40 ps (cal.)Å120 ps (coll.time)

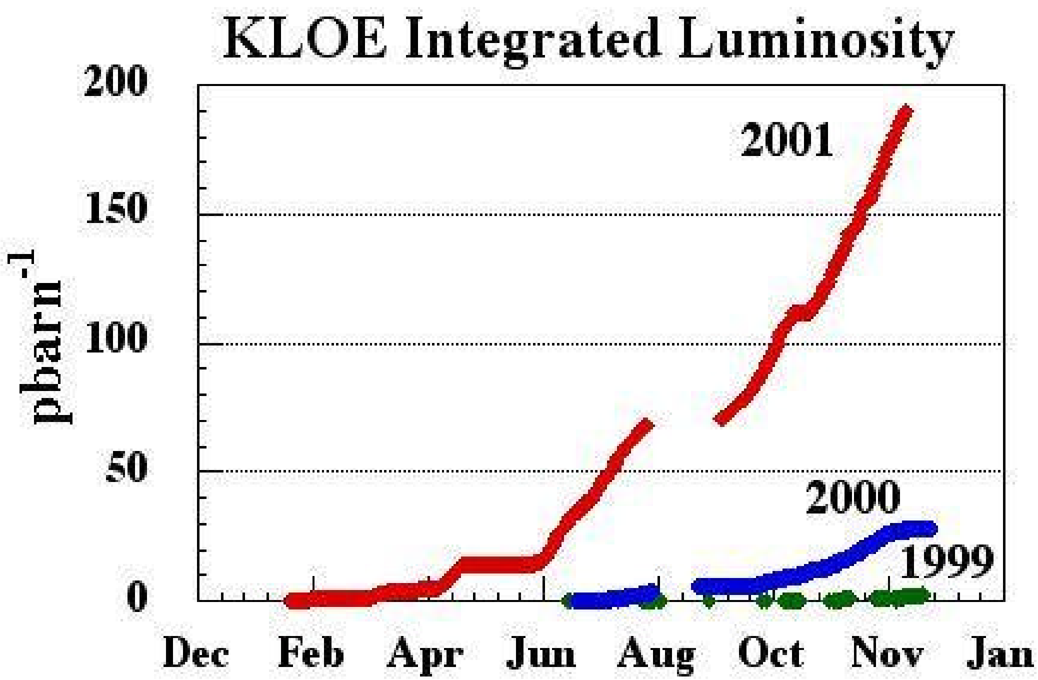


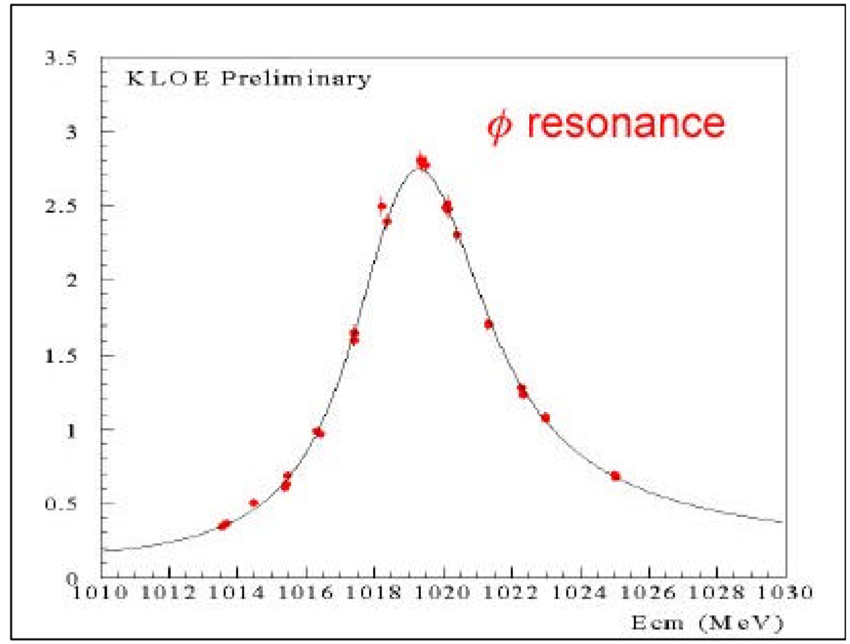


3. Status of the experiment

Data taken from april 1999 to december 2001~ at f peak

+ 1 energy scan





Present day performance:

	peak	average
$L(cm^{-2}\ s^{-1})$	**$5 \cdot 10^{31}$**	**$3.5 \cdot 10^{31}$**
$\int_{day} L\,dt\ (pb^{-1})$	**3**	**1.8**

Analysis status:

2000 data ~completed

(**$25\ pb^{-1}$ → 7.5×10^{7} f**)

2001 data in progress

(**$190\ pb^{-1}$ → 5.7×10^{8} f**)

All results are still ***preliminary***

4.Results on Neutral Kaon decays

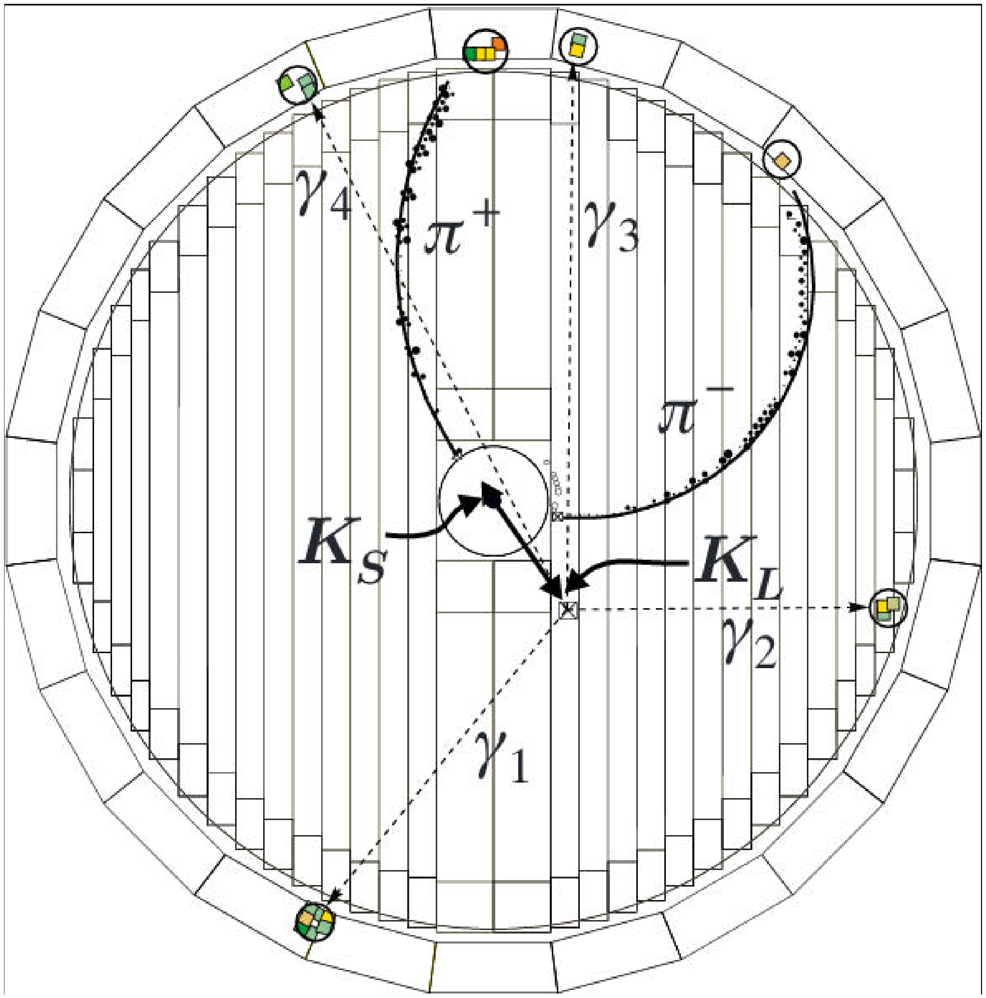
Neutral kaons produced in a
pure quantum $J^{PC} = 1^{--}$ state:

$$|i\rangle = \frac{1}{\sqrt{2}}\left[\left|K^0(\vec{p})\right\rangle\left|\bar{K}^0(-\vec{p})\right\rangle - \left|\bar{K}^0(\vec{p})\right\rangle\left|K^0(-\vec{p})\right\rangle\right]$$

$$= \frac{N}{\sqrt{2}}\left[\left|K_S(\vec{p})\right\rangle\left|K_L(-\vec{p})\right\rangle - \left|K_L(\vec{p})\right\rangle\left|K_S(-\vec{p})\right\rangle\right]$$

$p_K = 110$ MeV $\lambda_S = 6$ mm $\lambda_L = 3.5$ m

Example of $\phi \rightarrow K_S K_L$
- $K_L \rightarrow \pi^0\pi^0$
- $K_S \rightarrow \pi^+\pi^-$



➔ **Tagging:**

pure K_S and K_L beams

→ analysis of kaon decays

→ double ratio ➔ (ε' / ε)

➔ **Interferometry studies**

K_S tagging by identification of K_L interacting in the EmC (“K_L crash”) [~50% of K_L]

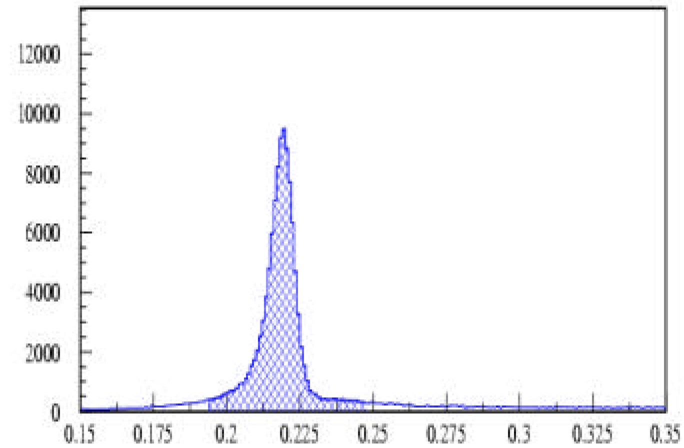
→Selection cuts:

- $E_{clus} > 200$ MeV
- $|\cos(\theta_{clus})| < 0.7$
- $0.1950 \leq \beta^* \leq 0.2475$

(β^* = K_L velocity in the ϕ rest frame)

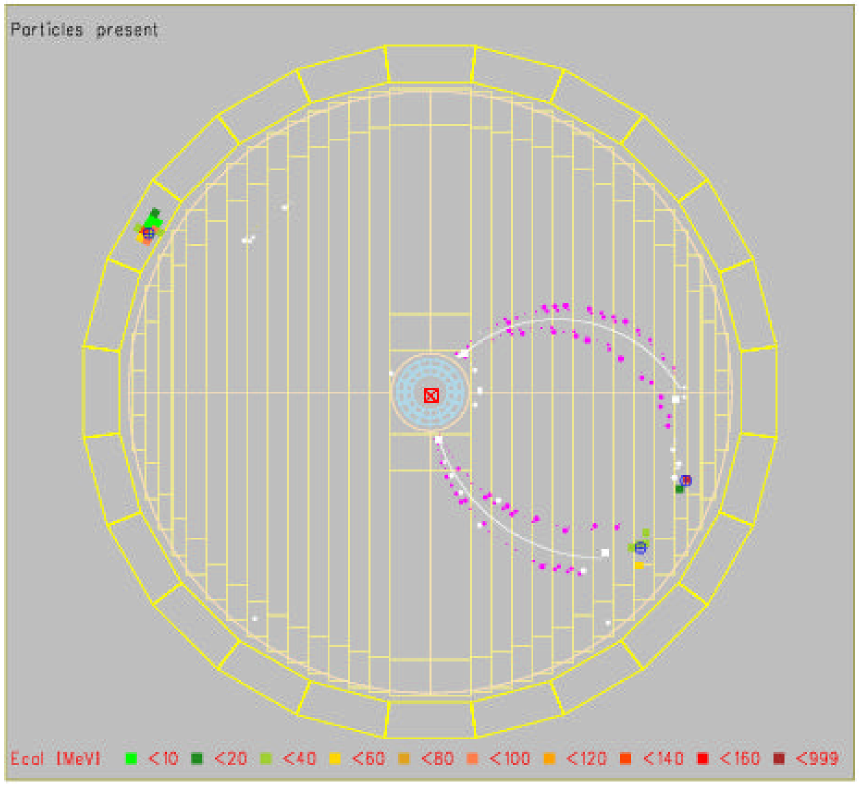
→Position of the K_L → K_S momentum

Tagging efficiency **e_{tag}~ 30%**



β^* distribution of “K_L crash”

Example of $\phi \rightarrow K_S K_L \rightarrow \pi^+\pi^-$ “crash”



KLOE has now about **6 10^7 tagged K_S.**
All channels are accessible.
Results from 2000 data (**5.4 10^6 tagged K_S**) on:

(1) **R**=G(**K_S** → p^+p^- **)** / G(**K_S** → p^0p^0 **)**

(2) **BR(K_S** → $p^\pm$ **$e^\pm$** n **)**

(1) $R = G(K_S \rightarrow p^+p^-) / G(K_S \rightarrow p^0p^0)$

Motivations:

→ First part of double ratio

→ Extractions of Isospin Amplitudes and Phases A_0 A_2 and δ_0-δ_2 ➔➔ consistent treatment of soft γ in $K_S \rightarrow \pi^+\pi^- (\gamma)$ (PDG data contain ambiguities)

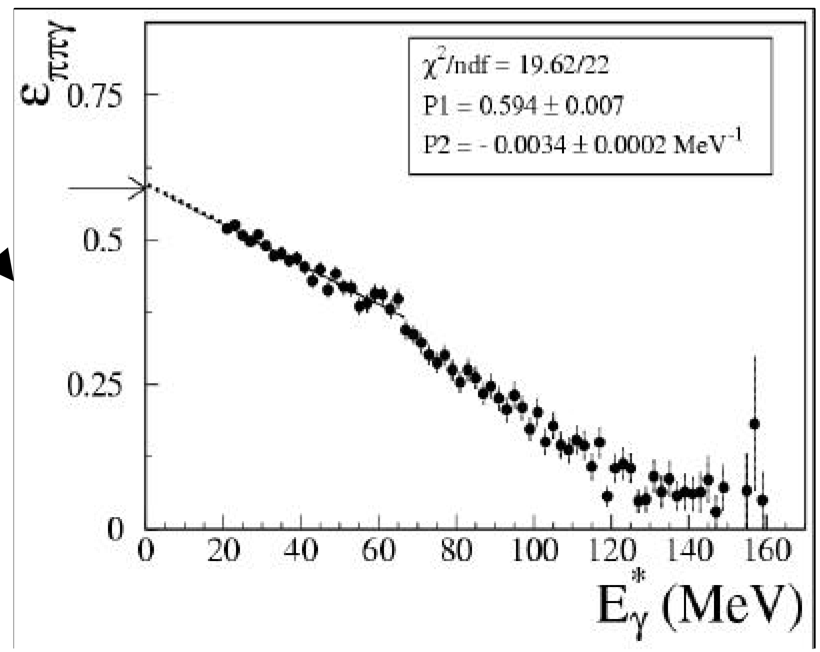
[*Cirigliano, Donoghue, Golowich 2000*]

Selection procedure:

1. K_S tagging

2. $K_S \rightarrow \pi^+\pi^-(\gamma)$ two tracks from I.P + acceptance cuts: **fully inclusive** measurement (E_γ^* up to $E_{\gamma\ max}^*$=170 MeV) $\varepsilon_{\pi\pi\gamma}(E_\gamma^*)$ from MC ➔ folded to theoretical γ spectrum ➔ correction

$D = (-3.4 \pm 0.1) \times 10^{-3}$



3. $K_S \rightarrow p^0p^0$

neutral prompt cluster

(E_γ>20 MeV and (T-R/c) < $5\sigma_t$)

at least 3 neutral prompt clusters

($\pi^0 \rightarrow e^+e^-\gamma$ included)

Result:

$N_{ev}(K_S \rightarrow \pi^+\pi^-) =$ **1.098 x 10^6**
$N_{ev}(K_S \rightarrow \pi^0\pi^0) =$ **0.788 x 10^6**

$R = 2.239 \pm 0.003_{stat} \pm 0.015_{syst}$

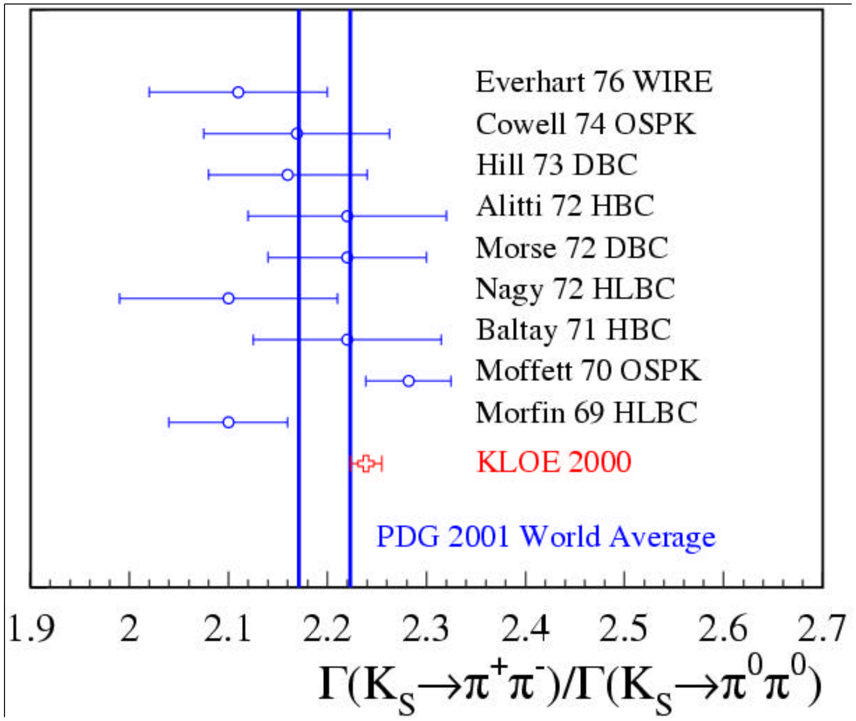
→ stat. uncertainty at 0.14% level
→ contributions to "systematics":

tagging eff. Ratio	**0.55%**
photon counting	**0.20%**
tracking	**0.26%**
Trigger	**0.23%**
Total syst. uncertainty	**0.68%**

PDG 2001 average is

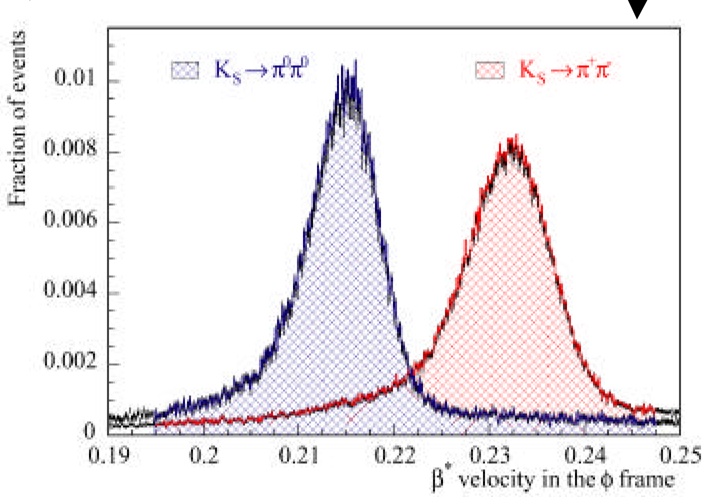
2.197 ± 0.026

(without clear indication of E_γ^*cut)



With 2001 data (180 pb-1) improvement on:

→ absolute scale → tagg.eff. Bias
→ statistics of control sub-samples
→ E_γ^* spectrum



(2) BR($K_S \rightarrow p^{\pm} e^{\pm} n$)

Motivation:

→ If (**CPT ok**) .AND. ($\Delta S = \Delta Q$ at work):

$\Gamma(K_S \rightarrow \pi^{\pm} e^{\pm} \nu) = \Gamma(K_L \rightarrow \pi^{\pm} e^{\pm} \nu)$

$BR(K_S \rightarrow \pi^{\pm} e^{\pm} \nu) = BR(K_L \rightarrow \pi^{\pm} e^{\pm} \nu) \times (\Gamma_L/\Gamma_S)$

$= (\mathbf{6.704 \pm 0.071}) \times 10^{-4}$

(using all PDG information).

Only one measurement (CMD-2 1999):

$= (\mathbf{7.2 \pm 1.4}) \times 10^{-4}$

Selection procedure

- → Vertex with two tracks from I.P.
- → kinematics (against huge $\pi^+\pi^-$ "background")
- → time of flight (electron vs pion)
- → final signal variable = $E_{miss}-|p_{miss}|$

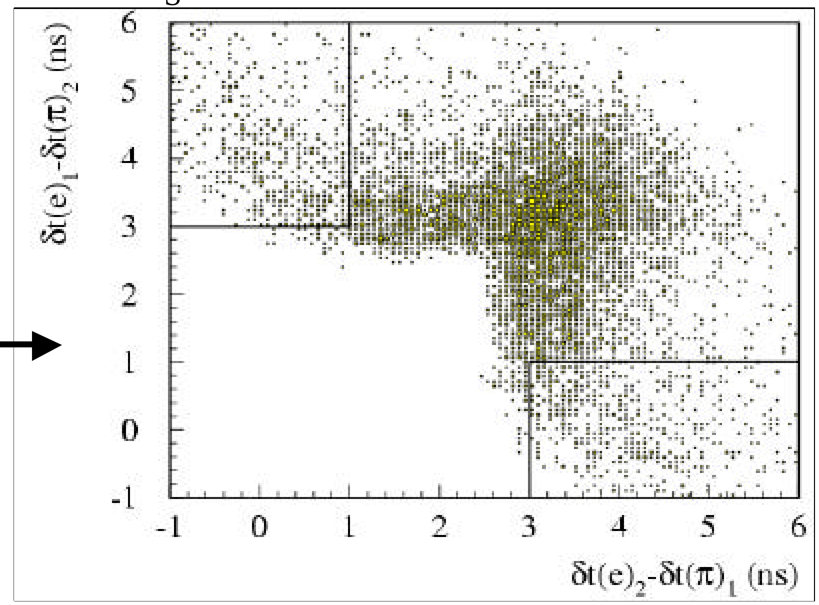
BR evaluation:

- → normalization to $K_S \rightarrow \pi^+\pi^-$ (σ(BR)~0.5%)
- → both charge states are considered

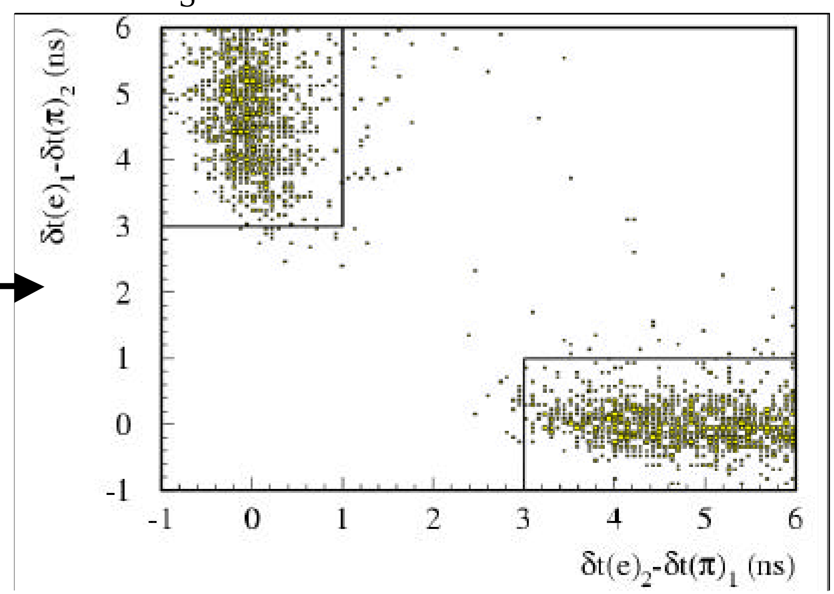
  (well separated → charge asymmetry)

ToF selection illustrated for MC:

1. $K_S \rightarrow \pi^+\pi^-$ MC events



2. $K_S \rightarrow \pi^{\pm} e^{\pm} \nu$ MC events



Result:

→ $N_{ev}(K_S \to \pi^{\pm} e^{\pm} \nu)$ = **627 ± 30**

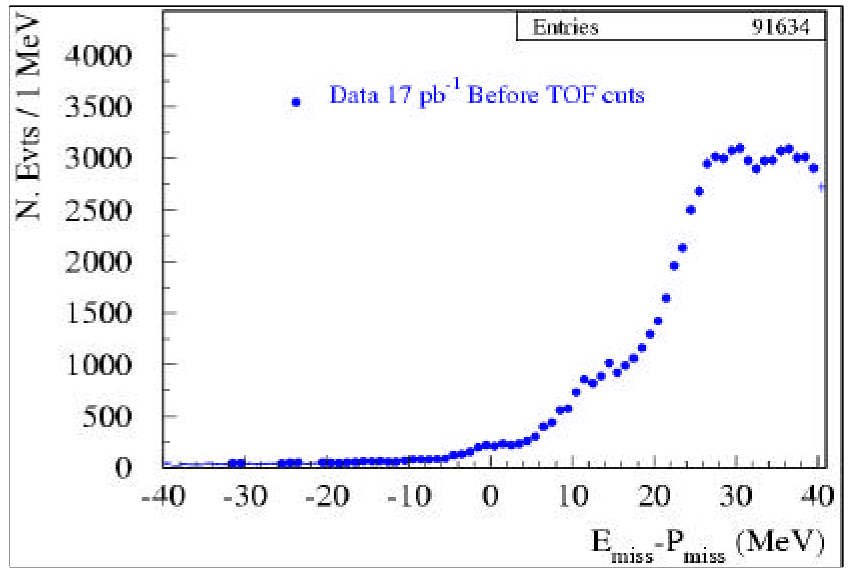
[after the fit, residual background subtraction is included]

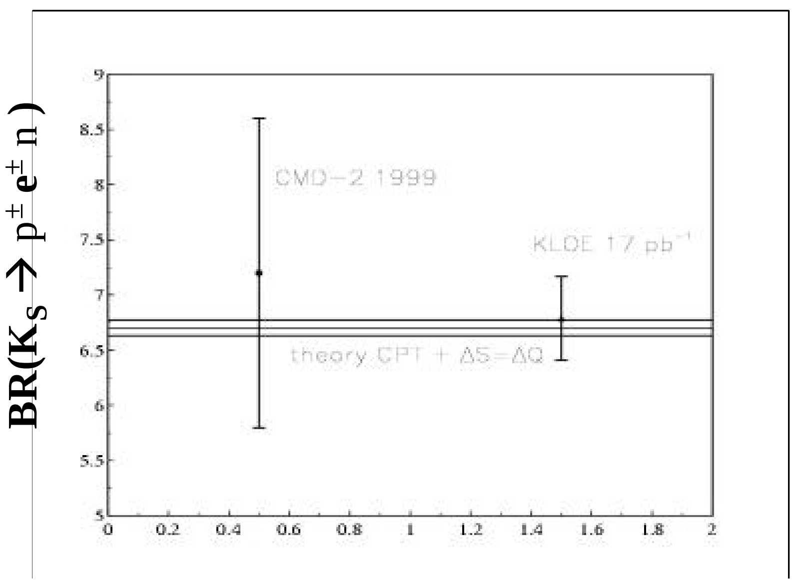
BR(K_S → $p^{\pm}$ $e^{\pm}$ n) = (6.79 ± 0.33$_{stat}$ ± 0.16$_{syst}$) x 10^{-4}

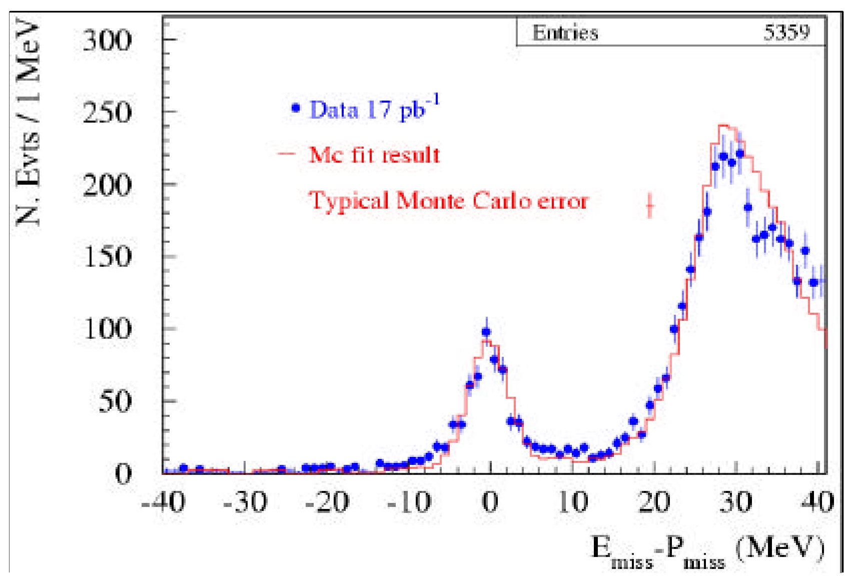
→ stat. uncertainty at 4.7% level

→ contributions to systematics:

tag eff, ratio	**0.6%**
tracking + vertex	**2.0%**
time of flight	**0.8%**
trigger + t0	**0.9%**
Total systematics	**2.4%**







5.Results on ϕ radiative decays

1. ϕ → Pseudoscalar + γ → hγ → p^0γ → h'γ

According to quark model:

→ assuming: no other content (e.g. gluonic))

p^0 = (uu-dd)/√2

h = cosa_P (uu+dd)/√2 + sin$a_P$ss

h' = -sina_P (uu+dd)/√2 + cos$a_P$ss

→ assuming: ϕ = ss state (α_V=0)

→ assuming: no OZI-rule violations

g(ϕ → η'γ) = $F_s\cos\alpha_V\cos a_P - F_q\sin\alpha_V\sin a_P$

g(ϕ → ηγ) = $F_s\cos\alpha_V\sin a_P + F_q\sin\alpha_V\cos a_P$

(α_V α_P = mixing angles in the flavour base)

(F_s F_q = form factors)

$$\mathbf{R} = \frac{G(f \rightarrow h'g)}{G(f \rightarrow h\,g)} = \mathbf{cotg}^2 a_P \left(\frac{\mathbf{K}_{h'}}{\mathbf{K}_h}\right)^3$$

Decay chain used: (same topology 2T + 3 photons / final states different kinematics)

(a) $\phi \rightarrow \eta\gamma \rightarrow \pi^+\pi^-\pi^0\gamma \rightarrow \pi^+\pi^-\,3\gamma$

(b) $\phi \rightarrow \eta'\gamma \rightarrow \eta\,\pi^+\pi^-\gamma \rightarrow \pi^+\pi^-\,3\gamma$

Selection:

→ 2t ($E_{T1}+E_{T2}<430$ MeV) + 3γ: kin. fit (no mass constraint)

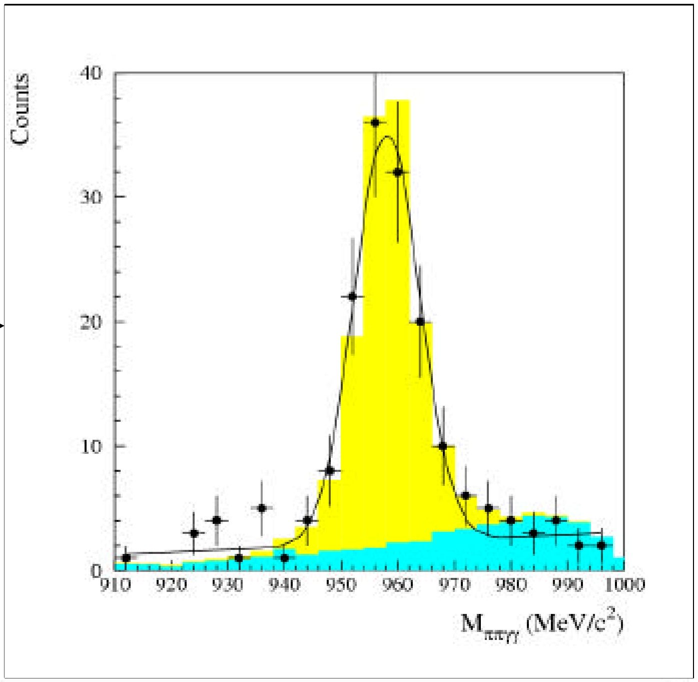
→ only (a) and (b) (negligible bkg.) BUT [N(b) ~ N(a) / 100]

Results:

N(a) = **50210 ± 220**

N(b) = **125 ± 13** $_{\textbf{stat +bck}}$

Invariant mass spectrum of η'γ →

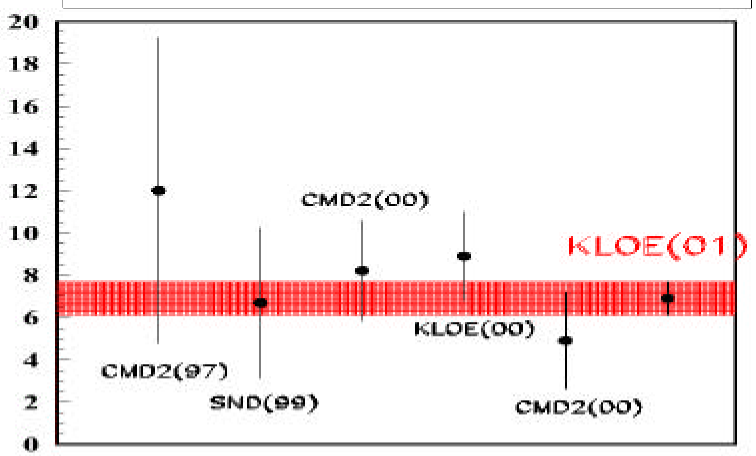


$$R = \frac{BR(\phi \rightarrow \eta'\gamma)}{BR(\phi \rightarrow \eta\gamma)} = \mathbf{(5.0 \pm 0.5_{stat} \pm 0.3_{syst}) \times 10^{-3}}$$

→ a_P = **(40.8 ± 1.7)°** [$\theta_P = (-13.9 \pm 1.7)^o$]

$\alpha_P = (\ 39.3 \pm 1.0)^o$ J/ψ decays and others [*Feldmann Kroll 2002*]

→**BR(f → h’g) = (6.5 ± 0.6$_{stat}$ ± 0.4$_{syst}$) x 10^{-5}**



2. $\phi \rightarrow$ Scalar (0^{++} quantum numbers) + γ [$f_0(980)$ I=0, $a_0(980)$ I=1]

$\rightarrow p^0p^0g$ ($f_0\gamma$ $\sigma\gamma$, f_0, $\sigma \rightarrow \pi\pi$) $\rightarrow$ 5γ final state

$\rightarrow p^+p^-\gamma$ (“) $\rightarrow$ 2t + 1γ final state: huge background from:

ISR (radiative return)

FSR + interference (signal “hidden”)

$\rightarrow hp^0g$ ($a_0\gamma$ a_0 $\rightarrow \eta\pi$) [$\eta \rightarrow \gamma\gamma$] $\rightarrow$ 5γ final state (40%)

[$\eta \rightarrow \pi^0\pi^0\pi^0$] $\rightarrow$ 9γ final state (32%)

[$\eta \rightarrow \pi^+\pi^-\pi^0$] $\rightarrow$ 2t + 5γ final state (23%)

Motivations:

f_0, a_0, not easily interpreted as qq states; other interpretations suggested:

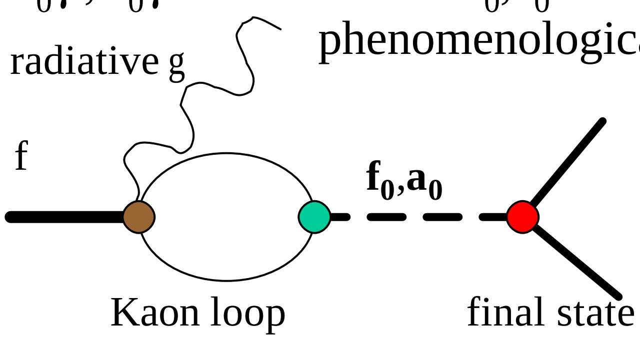
$\rightarrow$ qqqq states (lower mass) [*Jaffe 1977*];

$\rightarrow$ KK molecule ($m(f_0,a_0) \sim 2m(K)$) [*Weinstein, Isgur 1990*];

$\rightarrow$ $f_0(980)$, $a_0(980)$ and σ ➔ lowest mass scalar qq nonet [*Tornqvist 1999*]

$\phi \rightarrow f_0\gamma$, $a_0\gamma$ ➔ sensitive to f_0,a_0 nature [*Achasov, Ivanchenko 1989*]:

phenomenological framework (**kaon loop** model) ➔ coupling constants



- g(ϕKK) from $\Gamma(\phi \rightarrow K^+K^-)$
- g(f_0KK) g(a_0KK)
- g($f_0\pi\pi$) g($a_0\eta\pi$)

➔ f_0, a_0 model $M(\pi^0\pi^0)$ $M(\eta\pi)$ spectra

f → p^0p^0g

Main background sources (5g final states):

$e^+e^- \to \omega\pi^0 \quad \omega \to \pi^0\gamma$

$\phi \to \eta\pi^0\gamma \quad \eta \to \gamma\gamma$

Other background sources (not 5γ final states):

$\phi \to \eta\gamma \quad \eta \to \gamma\gamma\ (3\gamma)$ or $\eta \to \pi^0\pi^0\pi^0\ (7\gamma)$

Selection procedure:

→ 5 prompt γ $E_\gamma > 7$ MeV

→ kinematic fit (without mass const.)

Result:

N_{ev} = **2438 ± 61**

➔ $BR(\phi \to \pi^0\pi^0\gamma) = (1.09 \pm 0.03_{stat} \pm 0.05_{syst})\times10^{-4}$

CMD-2	$(0.92 \pm 0.08 \pm 0.06)\times10^{-4}$
SND	$(1.14 \pm 0.10 \pm 0.12)\times10^{-4}$

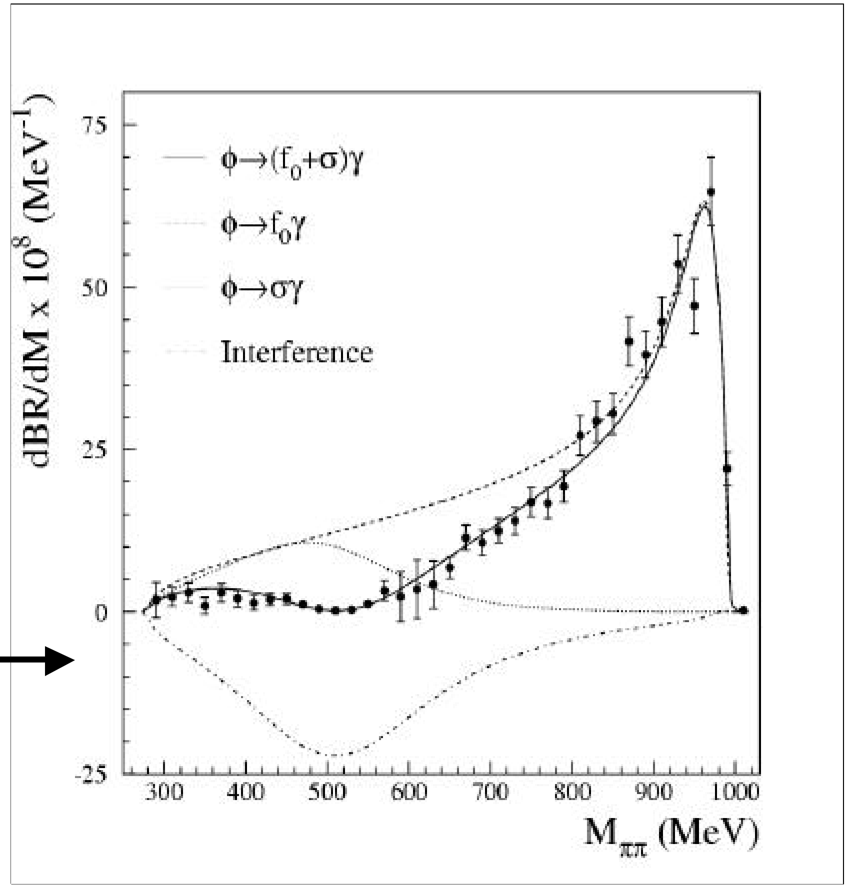
Fit to the $M_{p^0p^0}$ spectrum (kaon loop):

contributions from $\phi \to f_0\gamma$

$\phi \to \sigma\gamma$

+ "strong" negative interference

negligible contribution $\phi \to \rho^0\pi^0 \to \pi^0\pi^0\gamma$



Fit results:

$M(f_0)$ = **973 ± 1** MeV

$g^2(f_0KK)/4\pi$ = **2.79 ± 0.12** GeV^2

$g(f_0\pi\pi)/g(f_0KK)$ = **0.50 ± 0.01**

$g(\phi\sigma\gamma)$ = **0.060 ± 0.008**

$BR(\phi \to f_0\gamma \to \pi^0\pi^0\gamma) = (1.49 \pm 0.07)\times10^{-4}$

f → hp^0g

Measured in 2 final states:

(Sample 1) $\eta \to \gamma\gamma$ (5γ)

→ $\pi^0\pi^0\gamma$ is the main background

→ 5γ selection (see $\pi^0\pi^0\gamma$) + kinem. fit

(Sample 2) $\eta \to \pi^+\pi^-\pi^0$ (2t + 5γ)

→ Negligible bckg with the same topology:

$e^+e^- \to \omega\pi^0$ $\omega \to \pi^+\pi^-\pi^0$ 2t + 4γ

$\phi \to K_S K_L$ (K_L prompt decay) 2t + 4/6γ

→ 2t + 5γ selection + kinem.fit

Results:

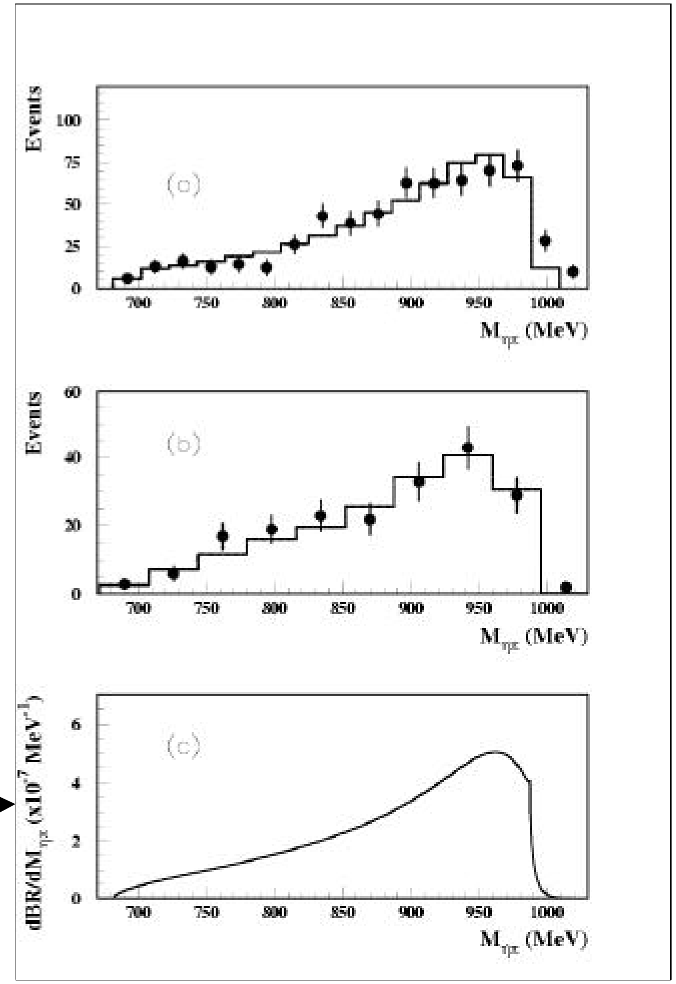
(Sample1) N_{ev} = **916** N_{bck} = **309 ± 20**

→ BR($\phi \to \eta\pi^0\gamma$) = $(8.5 \pm 0.5_{stat} \pm 0.6_{syst})x10^{-5}$

(Sample2) N_{ev} = **197** N_{bck} = **4 ± 4**

→ BR($\phi \to \eta\pi^0\gamma$) = $(8.0 \pm 0.6_{stat} \pm 0.5_{syst})x10^{-5}$

CMD-2	(9.0 ±2.4 ±1.0) x 10^{-5}
SND	(8.8 ±1.4 ±0.9) x 10^{-5}



Combined fit to the $M_{hp}0$ spectra:

dominated by $\phi \to a_0\gamma$

negligible $\phi \to \rho^0\pi^0 \to \eta\pi^0\gamma$

Fit results:

$M(a_0)$ = 984.8 MeV (PDG)

$g^2(a_0KK)/4\pi$ = **0.40 ± 0.04** GeV^2

$g(a_0\eta\pi)/g(a_0KK)$ = **1.35 ± 0.09**

→ BR($\phi \to a_0\gamma \to \eta\pi^0\gamma$) = (7.4 ± 0.7)x10^{-5}

Interpretation of KLOE results on scalars [within the context of **kaon-loop** with point-like coupling of scalars to kaon pairs framework]:

(preliminary)

parameter	KLOE result	4q model
$g^2(f_0KK)/4p$ (GeV^2)	**2.79 ± 0.12**	"super-allowed" (few GeV^2)
$g(f_0pp)/g(f_0KK)$	**0.50 ± 0.01**	0.3-0.5
$g^2(a_0KK)/4p$ (GeV^2)	**0.40 ± 0.04**	"super-allowed" (few GeV^2)
$g(a_0hp)/g(a_0KK)$	**1.35 ± 0.09**	0.91

→ 4q doesn't describe a_0 parameters;

→ 4q compatible with f_0 parameters;

→ f_0/a_0 ratio sensitive to isospin mixing [*Close Kirke 2001*]:

$$\frac{BR(f \rightarrow f_0 g)}{BR(f \rightarrow a_0 g)} = 6.0 \pm 0.6 \; ; \quad \frac{g^2(f_0KK)}{g^2(a_0KK)} = 6.9 \pm 1.0$$

if $F_{f0}(R) = F_{a0}(R)$ ➔ $q_S = (47 \pm 2)^o$ [no isospin mixing ➔ $\theta_S = 45^o$]

6. Conclusions and perspectives

→ ***DAFNE*** performance has improved considerably during the first two years of KLOE data taking

→ ***KLOE*** detector well performing and under control

→ From ***2000 data*** (25 pb^{-1}) results on:

K_S decays

ϕ radiative decays

improve previous "PDG" knowledge

→ Analysis of ***2001 data*** (190 pb^{-1}) in progress. Expected new results will be:

rare K_S decays [→ $\pi^+\pi^-\gamma$, → $\gamma\gamma$, limits on → 3π]

K_L decays [→ $\gamma\gamma$, → $\pi^0\pi^0$ ….]

$K^\pm$ decays

η decays (6 x10^6 η produced) [chiral perturbation theory checks]

hadronic cross-section $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ $2m_\pi < W < m_\phi$

→ ***Data taking 2002*** starting now ➔ 500 pb^{-1} realistic by end of the year