First KLOE results on scalar mesons

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φ Radiative decays

The rare decays $\varphi \to f_0\gamma$, $\varphi \to a_0\gamma$ are of big interest for light meson spectroscopy:

$f_0(980)$ $I^G(J^{PC}) = 0^+(0^{++})$ $\pi\pi$ decay
$a_0(980)$ $I^G(J^{PC}) = 1^-(0^{++})$ $\eta\pi$ decay

($E_\gamma \sim$ 40 MeV)

Only recently observed at VEPP-2M with poor statistics : BR ~ 10^{-4}

M. N. Achasov et al., Phys. Lett. B479 (2000) 53 (SND collaboration)
M. N. Achasov et al., hep-ex/0005017 (SND collaboration)
R.R. Akhmetshin et al.,Phys. Lett. B462 (2000) 371 (CMD-2 collaboration)
R.R. Akhmetshin et al.,Phys. Lett. B462 (2000) 380 (CMD-2 collaboration)

➨The $q\bar{q}$ nature of f_0, a_0 is controversial since almost half a century.
➨The biggest departures from theoretical predictions are in Γ_{tot} and $\Gamma_{\gamma\gamma}$:

predicted $\Gamma \sim 500$ MeV, observed $\Gamma \sim 50$ MeV

predicted $\Gamma_{\gamma\gamma} \sim 4.5$ KeV for f_0, observed $\Gamma_{\gamma\gamma} < 0.6$ KeV

predicted $\Gamma_{\gamma\gamma} \sim 1.5$ KeV for a_0, observed $\Gamma_{\gamma\gamma} \sim 0.2$ KeV

➨ Possible alternatives $q\bar{q}q\bar{q}$ state or $K\bar{K}$ molecule.

Model for f_0	BR($\phi \to f_0\gamma$)
$(q\bar{q})_{I=0}$	$\sim 10^{-6}$
$(s\bar{s})_{I=0}$	$\sim 10^{-5}$
$(q\bar{q}q\bar{q})_{I=0}$	$\sim 10^{-4}$
$(K\bar{K})_{I=0}$	$\sim 4 \times 10^{-5}$
$(gg)_{I=0}$	$< 10^{-6}$

- $dN/dM_{\pi\pi}$ is sensitive to f_0 structure
- Various models can describe $dN/dM_{\pi\pi}$

➨A precise measurement of the BR $\varphi \to f_0\gamma$, $\varphi \to a_0\gamma$ and of their ratio can help in solving the puzzle.

The high value of BR ~ 10^{-4} for $\varphi \rightarrow f_0 \gamma$, $\varphi \rightarrow a_0 \gamma$ measured at VEPP-2M in 1997 has raised new interest in this field: a lot of models have been worked out.

A long (but not complete!) list of theoretical works on the subject:

1) R. L. Jaffe, Phys. Rev. D19 (1977) 267

2) R. L. Jaffe, hep-ph/0001123

3) J. Weinstein and N. Isgur, Phys. Rev. Lett. 48 (1982) 659

4) F. Close, N. Isgur and S. Kumano, Nucl. Phys. B389 (1993) 513

5) A.. Bramon, G. Colangelo and M. Greco, Phys. Lett. B287 (1992) 263

6) A. Bramon, A. Grau and G. Pancheri, Phys. Lett. B289 (1992) 97

7) J. L. Lucio and M. Napsuciale, Phys. Lett. B331 (1994) 513

8) J. L. Lucio and M. Napsuciale, hep-ph/0001136

9) N. N. Achasov, V. V. Gubin and E. P. Solodov, Phys. Rev. D55 (1997) 2672

10) J. A. Oller and E. Oset, Nucl. Phys. A620 (1997) 438

11) E. Marco, S. Hirenzaki, E. Oset and H. Toki, hep-ph/9903217

12) J. A. Oller, Phys. Lett. B426 (1998) 7

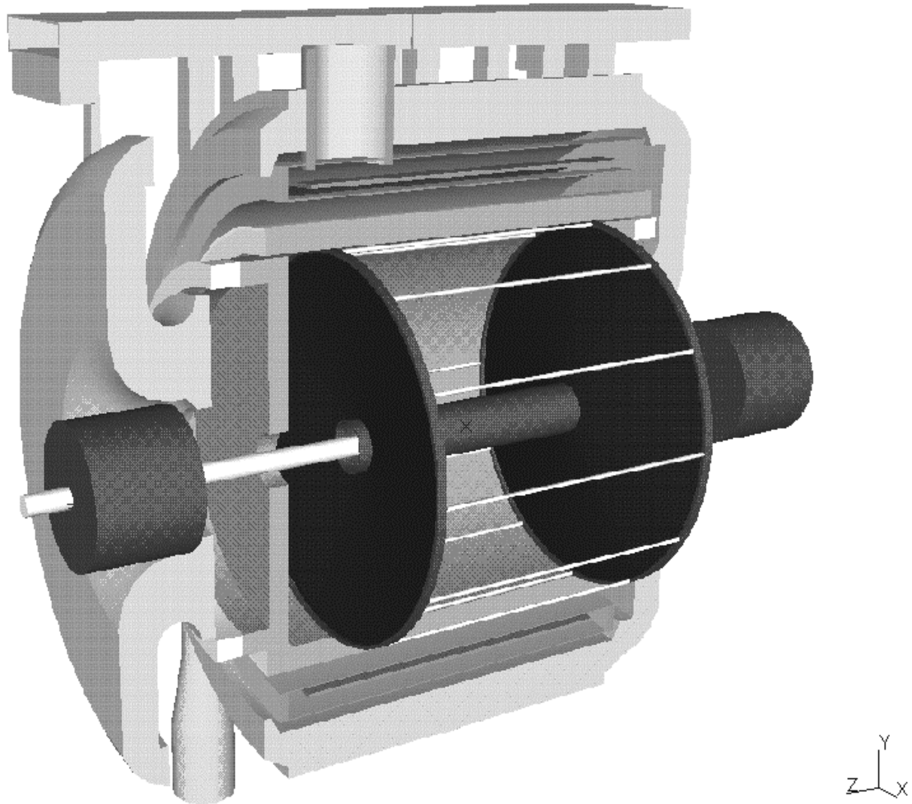
13) D. Black, A. H. Fariborz and G. Schechter, Phys. Rev. D61 (2000) 074001, 074030

14) N. A. Tornqvist, Eur. Phys. Jour. C11 (1999) 359

15) N. A. Tornqvist, hep-ph/9910443

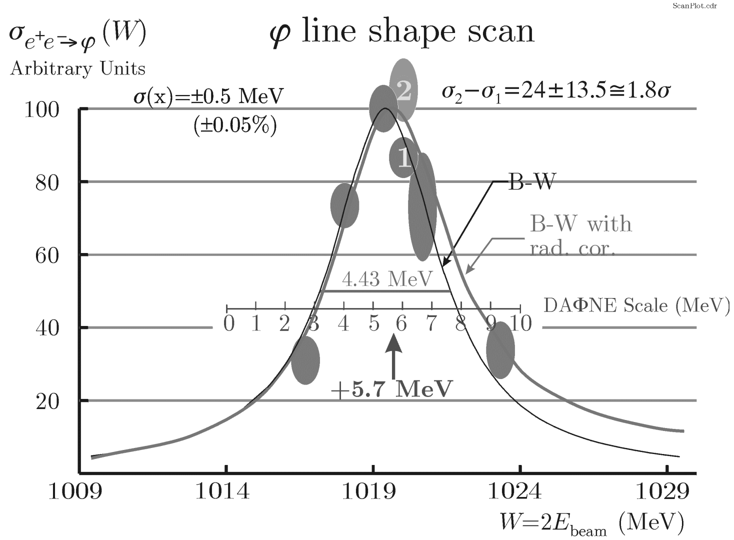
KLOE

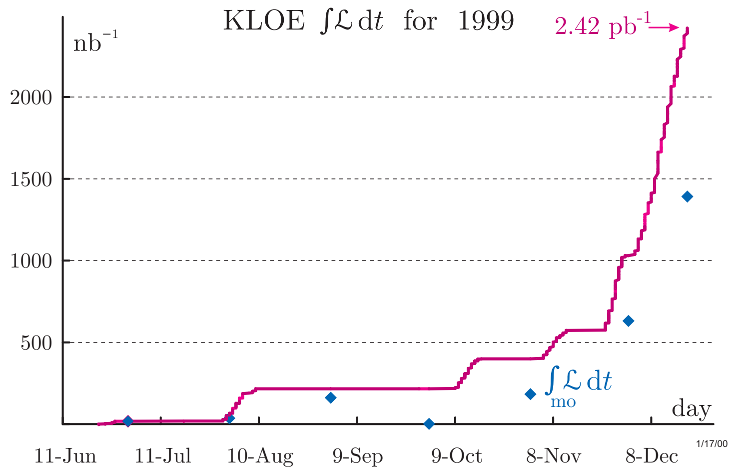
Typical e^+e^- general purpose detector
~5 m diameter & ~4 m length



- **Spherical Al-Be Beam pipe**
  (radius >16 λ_S)
- **Two Quadrupole triplets**
  Calorimeters
  (32 PMs)
- **Helium Stereo Drift Chamber**
  (12,582 Sense Wires)
- **Lead-Scint. Fiber Calorimeter**
  (4,880 PMs)
- **Superconducting Coil at 0.6 T**

Summary of 1999 data taking





1999 total $\int\mathcal{L}\,dt$

2.42 pb^{-1}

~ 7.7×10^6 ϕ's collected

Data taking has restarted few weeks ago.

KLOE "key"features

- Hermetic coverage
- Large geometrical acceptance
- Good measurement of track momentum : $\sigma_p/p \sim 0.5\%$
- Good measurement of photon energy : $\sigma_E /E \sim 6\% / \sqrt{E\,(\mathrm{GeV})}$
- Very good measurement of Time-of-Flight : $\sigma_T \sim 110\mathrm{ps} / \sqrt{E\,(\mathrm{GeV})}$
  (at present limited by lack of data for calibration)
- High efficiency for low energy photons :

  ~ 85% at 20 MeV, > 98% for E>50 MeV,

$\phi \to f_0\gamma \to \pi^0\pi^0\gamma$

BR~1.1x10^{-4}

"Golden" channel for scalar mesons studies:

- the highest total BR
- no final state radiation as in the $\pi^+\pi^-\gamma$ case
- no pseudoscalar mixing angle involved as in the $\eta\pi^0\gamma$ case

Backgrounds channels:

$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$	S/B = 0.52
$\varphi \to \rho\, \pi^0 \to \pi^0\pi^0\gamma$	S/B = 3.0
$\varphi \to a_0\gamma \to \eta\pi^0\gamma \to 5\gamma$	S/B = 3.1
$\varphi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$	S/B = 0.02

Selection criteria:

- No track in drift chamber

- 5 Prompt γ's $|T-R/c|<5\sigma_T$

– $\theta_\gamma>21^0$

$\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$

First kinematic fit with 30 parameters :
- E,T,(x,y,z) for each photon
- Beam Energies
- (x,y,z) of the I.P.

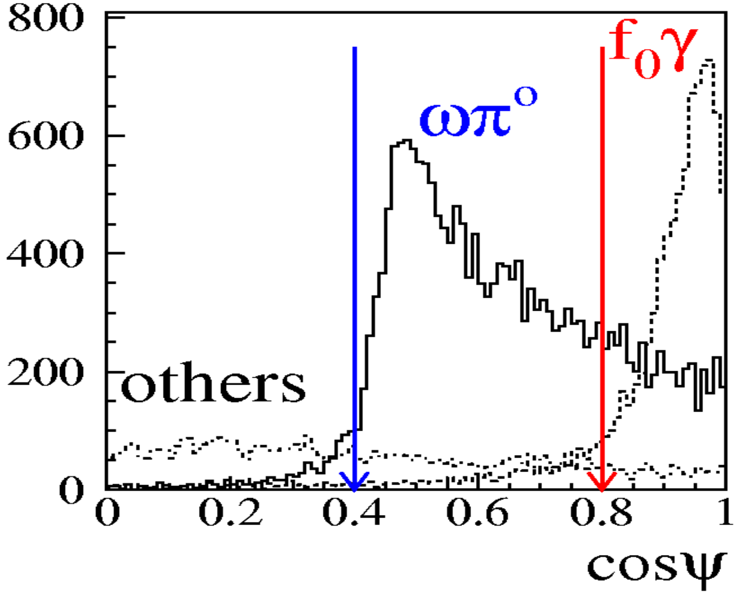
9 Constraints:
- 4-momentum conservation
- $cT_{clu} - R_{clu} = 0$

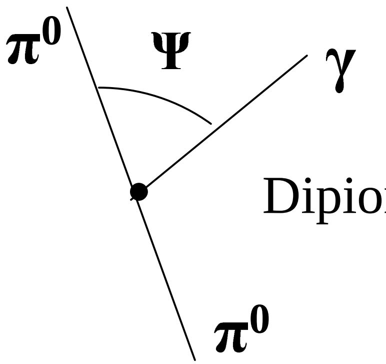
After the first fit we perform a γ pairing procedure (χ^2 minimization) in the $f_0\,\gamma$ hypothesis ($M_{\pi^0\pi^0}$>700MeV) and in the $\omega\pi^0$ hypothesis ($M_{\pi^0\gamma}=M_{\omega}$).

A second fit is then performed requiring two π^0's in the event.

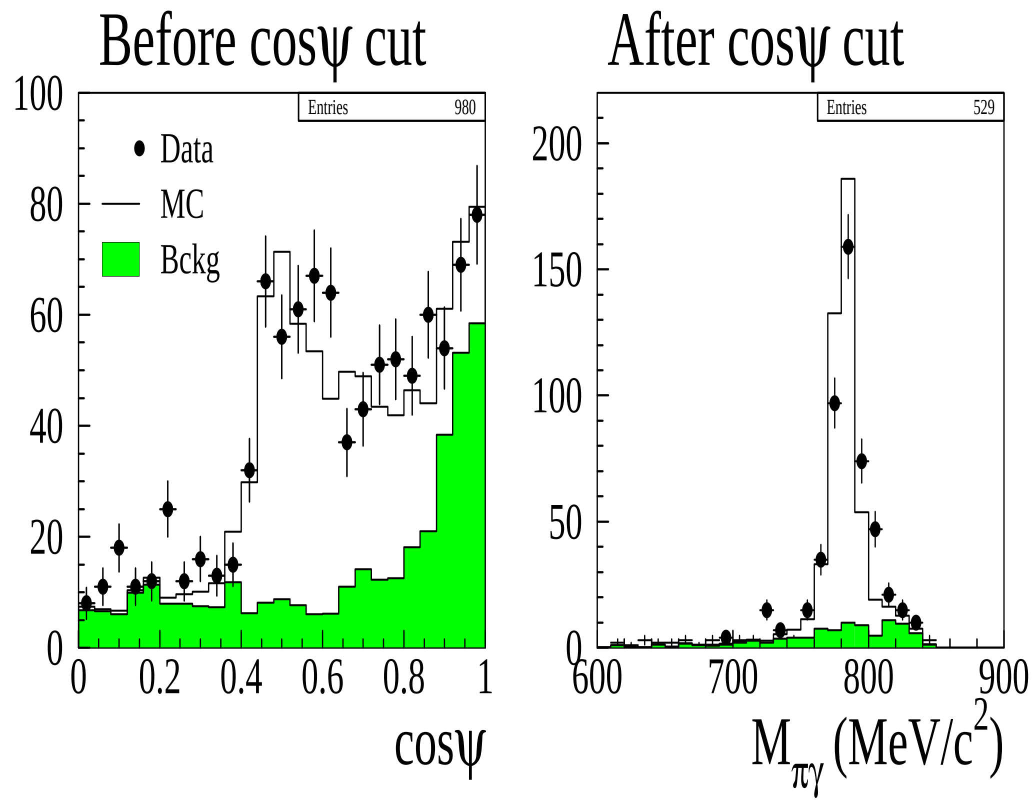
$\varphi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$

Background from $e^+e^- \rightarrow \omega^0\pi^0$ rejected cutting on cos(Ψ) angle (J=0 for f_0, J=1 for ω).





Dipions-rest frame



This cut affects also the other background channels but has negligible effect on the signal.

$\varphi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$

Events found in the 1.84 pb^{-1} sample:

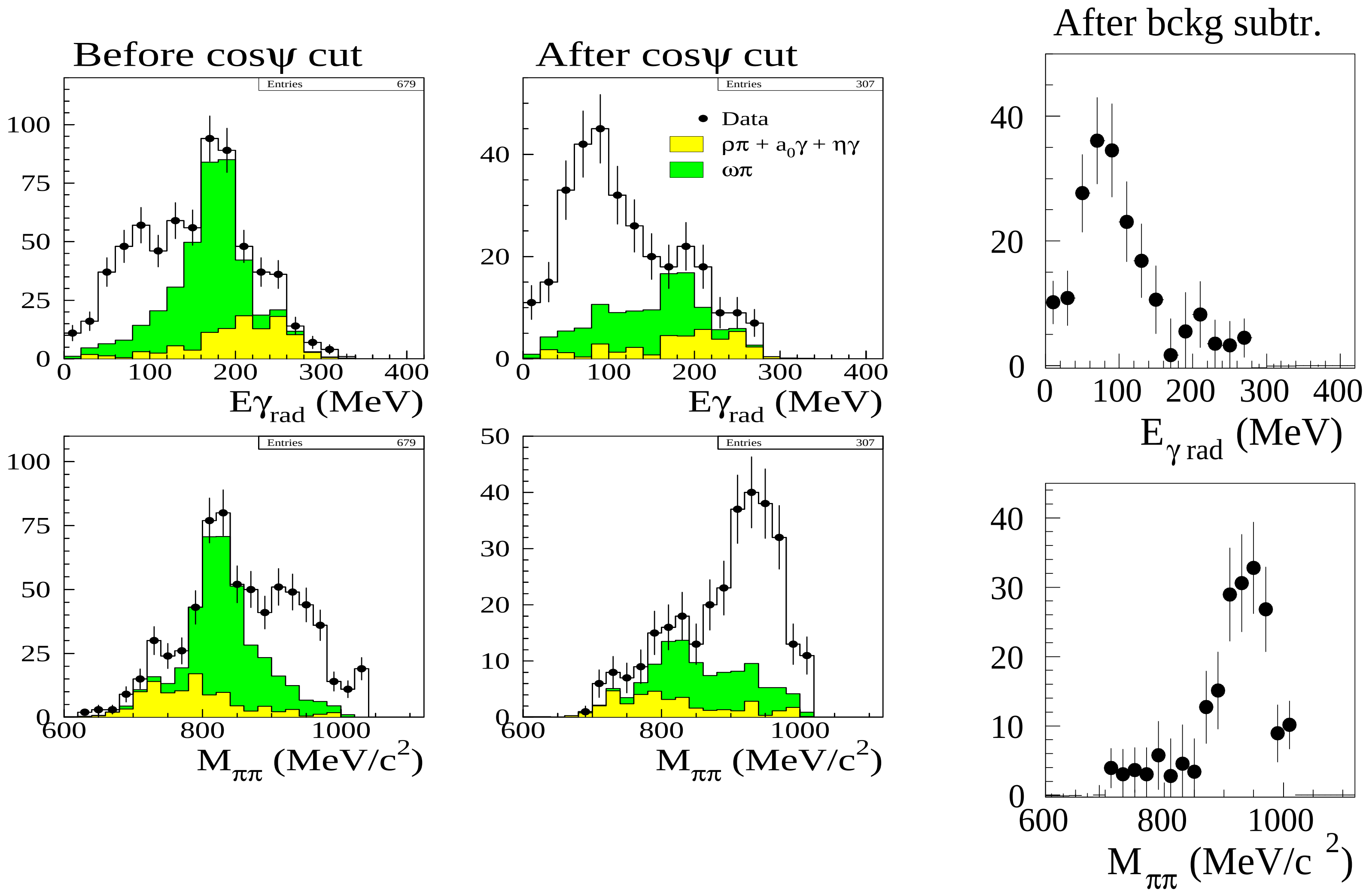
$f_0\,\gamma$ events:	*$\omega\pi^0$ events:*
$\varepsilon_{f_0\,\gamma} = 39.6\%$, $\varepsilon_{\omega\pi} = 6.3\%$, (S/B=3.3)	$\varepsilon_{\omega\pi} = 35.2\%$,$\varepsilon_{f_0\,\gamma} = 4.2\%$, (S/B=15.9)
For $M_{\pi\pi}$ > 700 MeV:	
$N_{obs} = 307 \pm 18$ $N_{bkg} = 112 \pm 11$ $N_{\pi\pi\gamma} = 195 \pm 22$	$N_{obs} = 529 \pm 23$ $N_{bkg} = 93 \pm 10$ $N_{\omega\pi} = 436 \pm 25$
$BR=(0.81 \pm 0.09_{stat} \pm 0.06_{syst})\times 10^{-4}$	**$\sigma=(0.67 \pm 0.04_{stat} \pm 0.05_{syst})$ nb**
$BR=(1.034 \pm 0.066 \pm 0.046)\times 10^{-4}$ (SND) $BR=(0.92 \pm 0.08 \pm 0.06)\times 10^{-4}$ (CMD-2)	Comparable with the SND result (M.N. Achasov et al., Nucl. Phys. B569 (2000) 158)

Preliminary estimation of systematic error:

Clustering (splitting/merging)	2.5%
Event Selection	5%
Kinematic Fit	4%
Luminosity	3%

Total Systematic Error	7.5%

$\varphi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$



$\phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma \rightarrow 5\gamma$

BR~3.5x10^{-5}

Backgrounds channels:

$\varphi \rightarrow \rho\,\pi^0 \rightarrow \eta\pi^0\gamma$ *BR~0.5x10^{-5}*

$e^+e^- \rightarrow \omega\pi^0 \rightarrow \eta\pi^0\gamma$ σ ~ 6pb

$\varphi \rightarrow f_0\,\gamma \rightarrow \pi^0\pi^0\gamma$ *BR~1x10^{-4}*

$\varphi \rightarrow \rho\,\pi^0 \rightarrow \pi^0\pi^0\gamma$ *BR~3x10^{-5}*

$e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma$ σ ~ 0.6nb

Negligible background from $\eta\gamma \rightarrow 3\gamma$, $\eta\gamma \rightarrow 7\gamma$

Selection criteria:
- No track in drift chamber
- 5 Prompt γ's $|T-R/c|<5\sigma_T$
– $\theta_\gamma>21^0$
- Total energy > 900 MeV

First kinematic fit with 30 parameters :
- E,T,(x,y,z) for each photon
- x,y,z of the I.P.
- Beam Energies
9 Constraints:
- 4-momentum conservation
- cT_{clu} - R_{clu} = 0

$\phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma \rightarrow 5\gamma$

After the first fit we perform a γ pairing procedure (χ^2 minimization) requiring:

$\chi^2_{\eta\pi 0\gamma} < \chi^2_{\pi 0\pi 0\gamma}$, $\qquad \chi^2_{\eta\gamma} > 2$

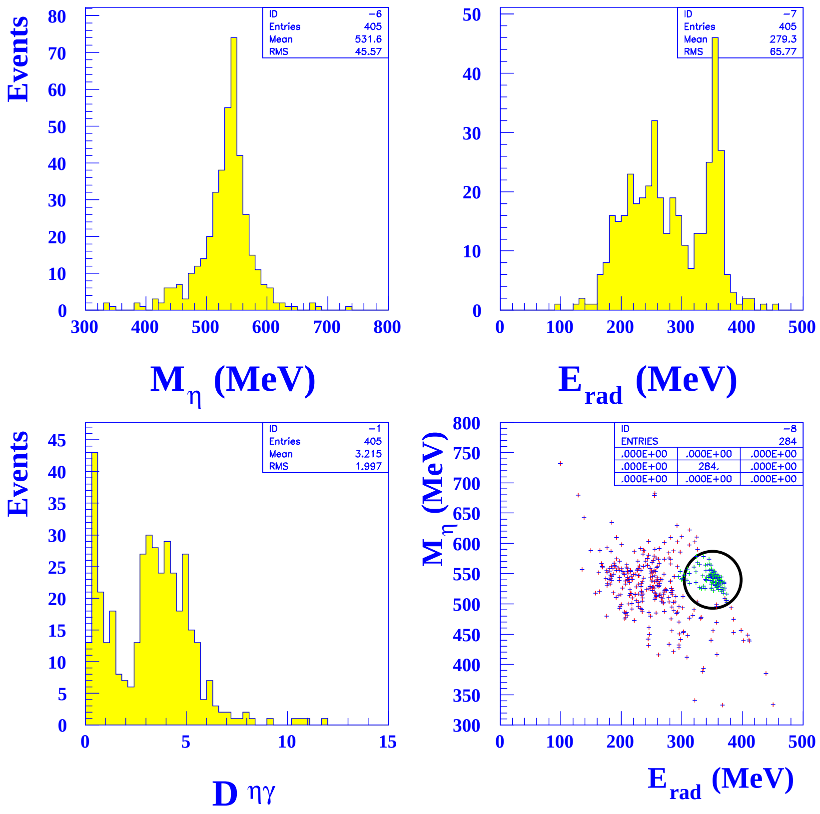
Additional cuts:

$\cos(\Psi) < 0$, $\cos(\alpha) > -0.8$

Ψ = angle between η and γ

α = angle between the $\gamma\gamma$ coming from η

We then perform a second fit requiring also $M_{\pi 0}$ and M_η as constraints.



Rejection of $\eta\gamma$ background for the events with $\chi^2_{\eta\pi 0\gamma} < \chi^2_{\pi 0\pi 0\gamma}$: the circle in the scatter plot shows the rejected region with $\chi^2_{\eta\gamma} > 2$

$\phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma \rightarrow 5\gamma$

Final cuts:

- $\chi^2_{\eta\pi 0\gamma} < 2.5$
- 3σ cut on $\mathbf{M}_{\pi^0}$ **and** $\mathbf{M}_\eta$

$\varepsilon_{\eta\pi 0\gamma} = 23\%$

Events found in the $2.4 pb^{-1}$ sample:

$N_{obs} = 74 \pm 9$

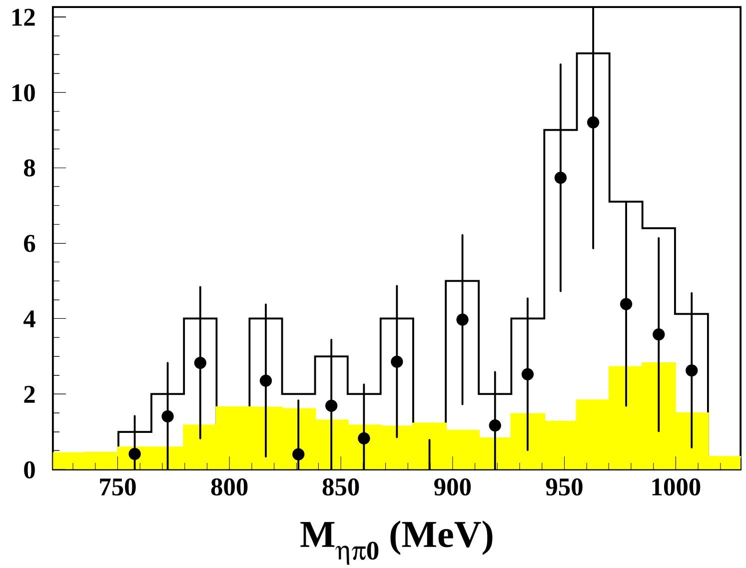
$N_{bkg} = 27 \pm 6$

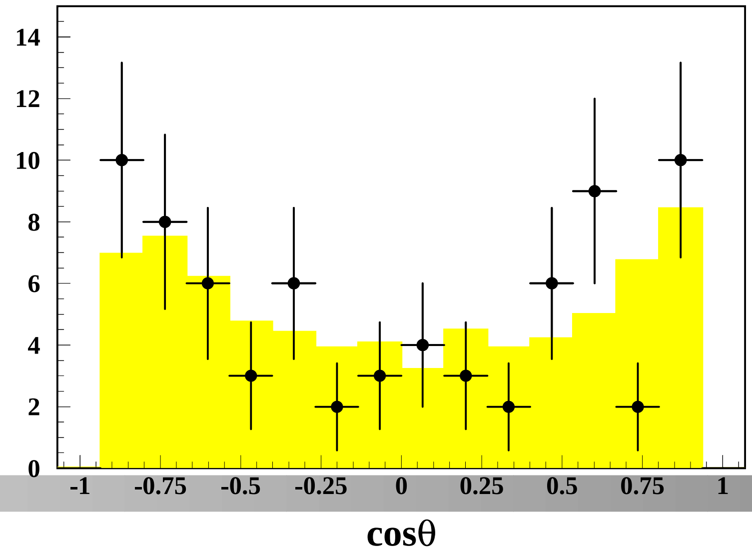
$N_{\eta\pi\gamma} = 47 \pm 10$

$\mathbf{BR = (0.69 \pm 0.15_{stat} \pm 0.10_{syst}) \times 10^{-4}}$

$BR = (0.88 \pm 0.14 \pm 0.09) \times 10^{-4}$ (SND)

$BR = (0.90 \pm 0.24 \pm 0.10) \times 10^{-4}$ (CMD2)





$\varphi \rightarrow f_0\gamma \rightarrow \pi^+\pi^-\gamma$

BR= $(0.41 \pm 0.10 \pm 0.12) \times 10^{-4}$ (CMD-2)

High background from continuum (S/B ~ 0.04):

$e^+e^- \to \gamma\gamma^* \to \pi^+\pi^-\gamma$ *(Initial State Radiation)*

$e^+e^- \to \gamma^* \to \pi^+\pi^-\gamma$ *(Final State Radiation)*

Interference with FSR ($\pi\pi$ in the same C=+1 state): the sign of the interference is still unknown!

Selection criteria:

- *two tracks with a vertex near the I.P. ($R<8$ cm, $|Z|<15$ cm)*
- *one prompt neutral cluster ($0.8 < \beta < 1.2$)*
- $25^0 < \theta_{TR} < 155^0$

This criteria select also $ee\gamma$, $\mu\mu\gamma$, and $\pi^+\pi^-\pi^0$: further cuts are required.

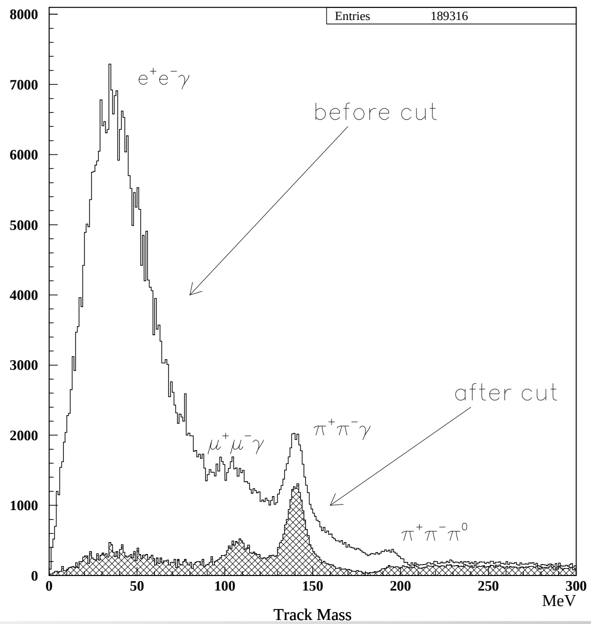
$\varphi \rightarrow f_0\gamma \rightarrow \pi^+\pi^-\gamma$

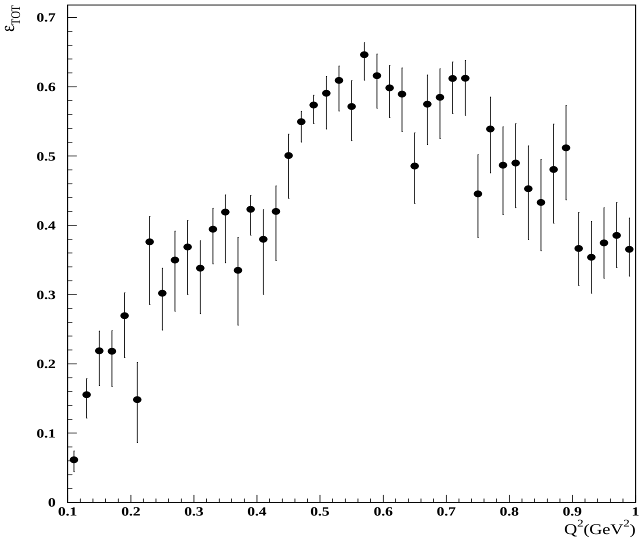
Further cuts:

- likelihood method to identify $ee\gamma$ events (selection efficiency for pions ~ 95%, rejection power for electron ~ 94%)

- tracks and photon in the Barrel region ($45^0 < \theta < 135^0$)

- cut on M_{TR} obtained applying 4-momentum conservation in the hypothesis of pion mass ($130\ MeV < M_{TR} < 150\ MeV$)





Total selection efficiency

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

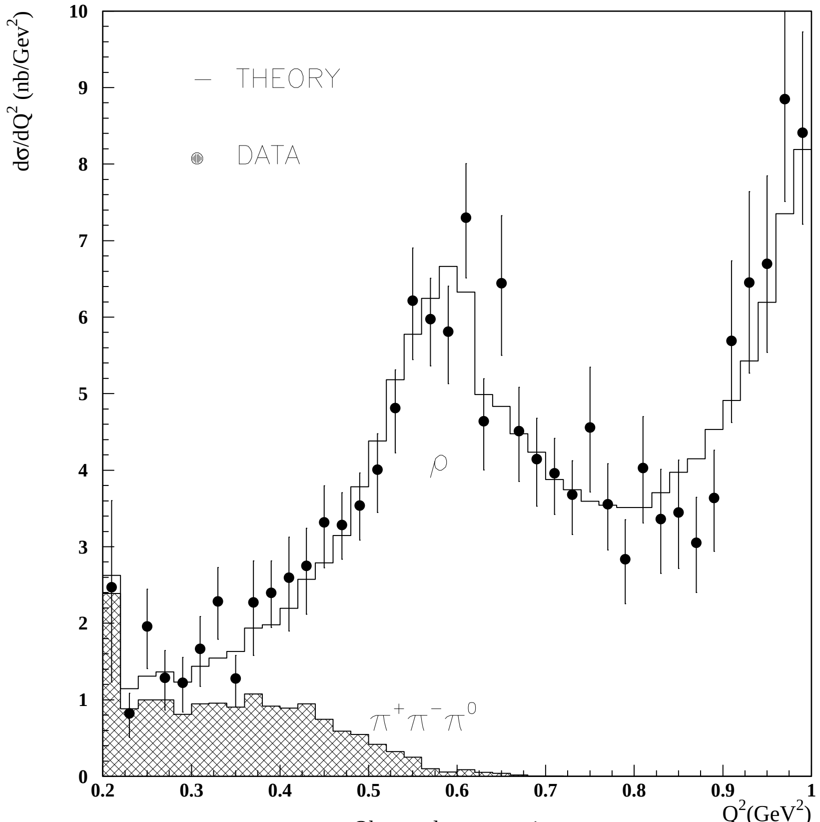
Fit to the Q^2 specrum for the events selected in the 1.8pb^{-1} sample:

$$Q^2 = s - 2E_\gamma \sqrt{s} = M^2_{\pi\pi}$$

Fitting the Q^2 specrum in the region $Q^2 < 0.84$ GeV^2 and extrapolating in the photon energy range 20 MeV $< E_\gamma <$ 120 MeV we find an eccess of 35 ± 160 events with respect to ISR+FSR background.

Assuming isospin symmetry and ignoring interference with FSR we obtain:

BR < 1.64$x10^{-4}$ @ 90% CL



Observed cross-section

Conclusions

•In 1999 the KLOE detector worked perfectly, collecting 2.42 pb^{-1}.

•With the data taken in ~ 3 weeks in 1999 we have reached a statistical accuracy on BR($\varphi \to f_0\gamma$), BR($\varphi \to a_0\gamma$) comparable to the VEPP-2M results.
(See "KLOE first results on hadronic physics", The Kloe collaboration, hep-ex/0006036, Contributed paper to ICHEP2000, Osaka)

•The KLOE collaboration is working hard to pin down all systematic effects.