Detection of f_o and a_o at DAΦNE with KLOE

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for the
KLOE Collaboration

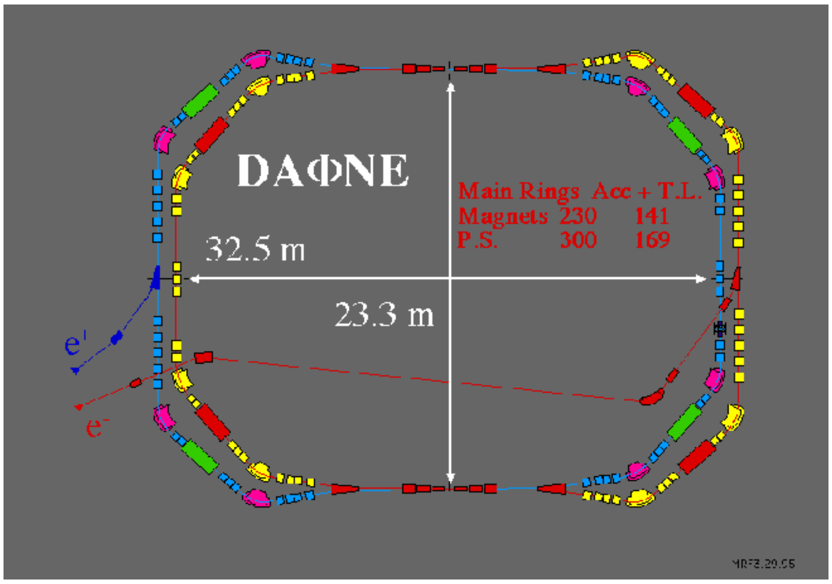
WHS99 – Frascati, Italy
March 11th, 1999

- **DAΦNE and KLOE**
- f_o **and** a_o **models**
- **Search for** $\Phi \to f_o\gamma$ **using** $f_o \to \pi^o\pi^o/\pi^+\pi^-$ **decay channels**
- **Search for** $\Phi \to a_o\gamma \to \eta\pi^o\gamma$ **using** $\eta \to \gamma\gamma/\pi^+\pi^-\pi^o$ **decay channels**
- **Conclusions**

The DAΦNE collider

e^+e^- collider at Φ peak with very high luminosity:

$$\mathcal{L}_{\rm max} = \mathbf{5 \times 10^{32}\ cm^{-2}\ s^{-1}}$$



$\sigma(\mathbf{\Phi}) \sim \mathbf{4.4 \mu b}$ $\Longrightarrow$ $\mathbf{2.2 \times 10^{10}\ \Phi/year}$

$\mathbf{M_{\Phi} \sim 1.02\ GeV/c^2}$ $\mathbf{\Gamma_{\Phi} \sim 4.4\ MeV}$

Φ decay	K^+K^-	K_LK_S	$\rho\pi$	$\pi^+\pi^-\pi^o$	$\eta\gamma$	others
BR (%)	49.5	34.4	12.9	1.9	1.3	~ 1

DAΦNE commissioning: end of March 1999

100 pb^{-1} expected in 1999 $\Longrightarrow$ $\mathbf{5 \times 10^8 \Phi}$

The KLOE detector

Electromagnetic calorimeter (EMC)

- Fine sampling Pb (0.5 mm thick) / SciFi (1 mm ⌀)
- Hermetical coverage
- High efficiency for low energy photons

$$\sigma_{\mathrm{E}} = 5\%/\sqrt{\mathrm{E\ (GeV)}} \qquad \sigma_{\mathrm{T}} = 50\ \mathrm{ps}/\sqrt{\mathrm{E\ (GeV)}}$$
$$\sigma_{\mathrm{x,y}} = 1.2\ \mathrm{cm} \qquad \sigma_{\mathrm{z}} = 1.2\ \mathrm{cm}/\sqrt{\mathrm{E\ (GeV)}}$$

Central drift chamber (DCH)

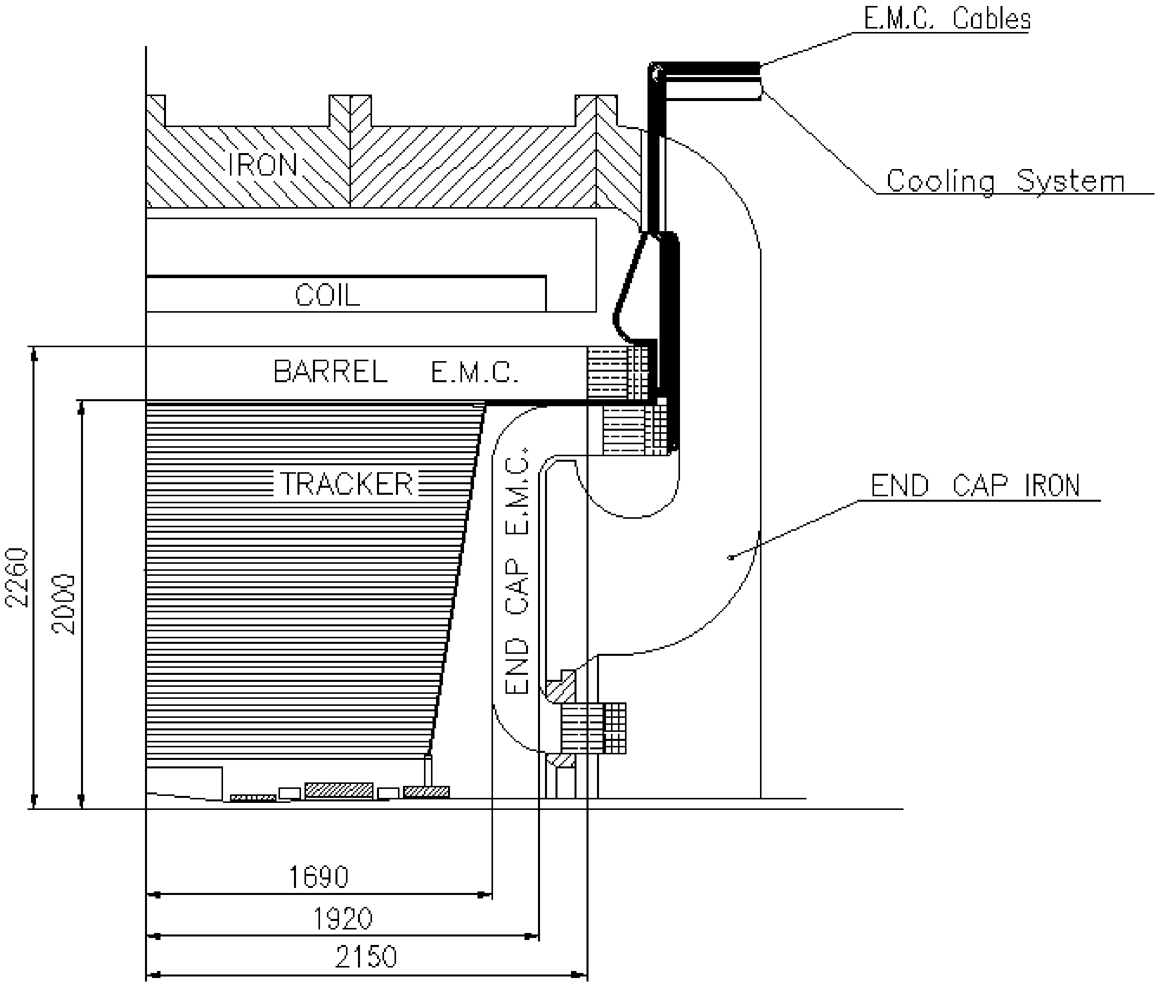
- Large detection volume
- Uniform tracking and vertexing in all volume
- Helium based gas mixture

$$\sigma_{\mathrm{v}} \sim 1\ \mathrm{mm} \qquad \sigma_{\mathrm{p_t}}/\mathrm{p_t} \sim 0.5\%$$
$$\sigma_{\mathrm{R\Phi}} \sim 200\ \mu\mathrm{m} \qquad \sigma_{\mathrm{z}} \sim 2\ \mathrm{mm}$$

Quadrupoles' calorimeter (QCAL)

- Pb/Sci tile calorimeter covering quads inside KLOE

The KLOE detector



The $f_o\,, a_o$ models

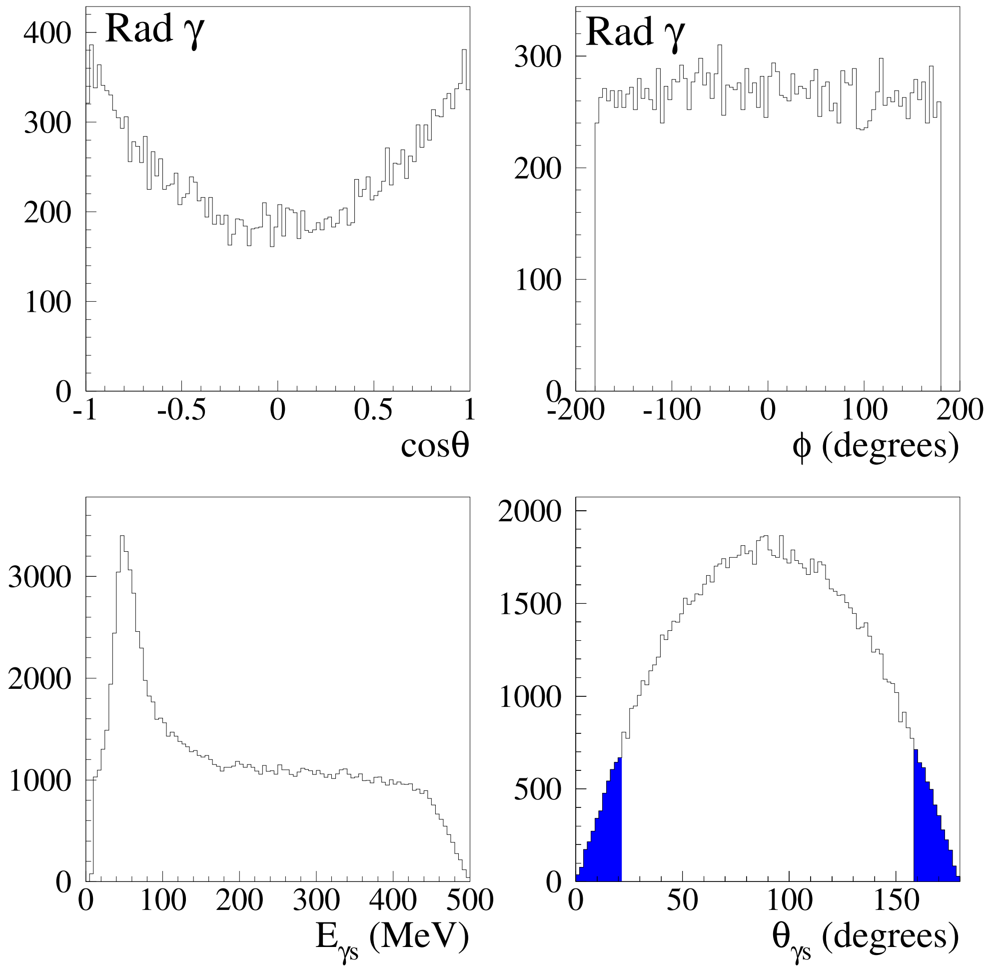
$f_o(975)$: $J_{PC} = 0^{++}$ $I^G = 0^+$ $\pi\pi$ decay
$a_o(980)$: $J_{PC} = 0^{++}$ $I^G = 1^-$ $\eta\pi$ decay

The structure of scalar mesons is unclear. The rate of $\Phi \to f_o\gamma, a_o\gamma$ is sensitive to it.

f_o, a_o model	$\mathrm{BR}(\Phi \to f_o\gamma)$	$\mathrm{BR}(\Phi \to a_o\gamma)$
$q\bar{q}$	5×10^{-5}	2×10^{-5}
$q\bar{q}q\bar{q}$	2×10^{-4}	2×10^{-4}
$K\bar{K}$ molecule	10^{-5}	10^{-5}

Following recent results from SND and CMD2 collaborations, the 4-quark model seems to be the more realistic one to describe data.

The $\Phi \to f_o\gamma \to \pi^o\pi^o\gamma$ decay



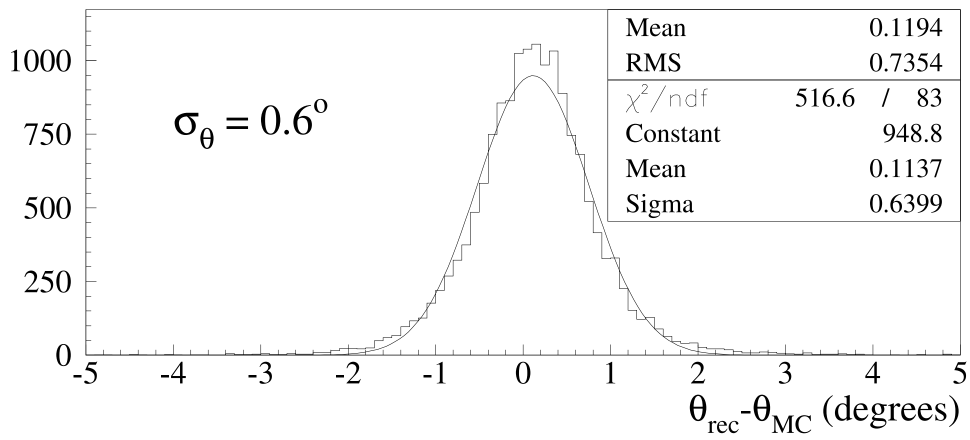
- **Radiative γ angular distribution:** $1 + \cos^2\theta$
- **Decay signature: 5 photons in EMC with** $10 < \mathbf{E}_\gamma < 510$ **MeV** $(\mathbf{E}_{\gamma\,\mathbf{rad}} \sim 45$ **MeV**$)$
- **26% of the events have at least one γ in QCAL region**

$\Phi \to f_0\gamma \to \pi^0\pi^0\gamma$: sample selection

Analysis of MC events obtained with a realistic detector simulation + full event reconstruction

- **No prompt hits on QCAL**
- $\theta_{\mathbf{rec}} = \mathrm{Z_{cl}/R_{cl}} > \mathbf{21}^\circ$

$\Big\}$ **Acc = 72.8%**



- **5 EMC clusters in Time Window** ($|$**T-R/c**$| < \mathbf{5}\sigma_\mathbf{T}$)

$\Big\}$ $\varepsilon_{\mathbf{rec}} = \mathbf{86.9\%}$

(Inefficiencies: $\sim 3\%$ losses, $\sim 4\%$ merging, $\sim 5\%$ splitting)

Total selection efficiency: $\varepsilon_{\mathbf{sel}} = 63.2\%$

$\Phi \rightarrow f_o\gamma \rightarrow \pi^o\pi^o\gamma$: constrained fit procedure

- **30 input parameters**
  - E, T, $\vec{R}$ of 5 photons
  - Primary vertex coordinates
  - E_{e^+} E_{e^-}

- **11 constraints**
  - T-R/c = 0 for each photon
  - 4–momentum conservation
  - $M_{\gamma_1\gamma_2} = M_{\pi^o}$
  - $M_{\gamma_3\gamma_4} = M_{\pi^o}$

A first fit is performed without the last two constraints to correctly group photons coming from π^o's

A second fit is done using all constraints

After χ^2 cut $\Longrightarrow$ $\varepsilon_{\rm ANA} = \mathbf{51.3\%}$

$\Phi \to f_o\gamma \to \pi^o\pi^o\gamma$: background events

$$BR(\text{signal}) = 1.1 \times 10^{-4\star}$$

Resonant backgrounds considered:

- $\Phi \to \pi^o\pi^o\gamma$

  $\mathrm{BR} = 1.5 \times 10^{-5\,\dagger}$ $\quad\varepsilon_{\mathrm{ANA}} = 52.8\%$
- $\Phi \to \rho\,\pi^o \to \pi^o\pi^o\gamma, \eta\pi^o\gamma \to 5\gamma\text{'s}$

  $\mathrm{BR} = 3.3 \times 10^{-5}$ $\quad\varepsilon_{\mathrm{ANA}} = 33.3\%$
- $\Phi \to a_o\gamma \to \eta\pi^o\gamma \to 5\gamma\text{'s}$

  $\mathrm{BR} = 3.25 \times 10^{-5\,*}$ $\quad\varepsilon_{\mathrm{ANA}} = 43.9\%$
- $\Phi \to \eta\gamma \to \pi^o\pi^o\pi^o\gamma$

  $\mathrm{BR} = 4.057 \times 10^{-3}$ $\quad\varepsilon_{\mathrm{ANA}} = 5 \times 10^{-4}$

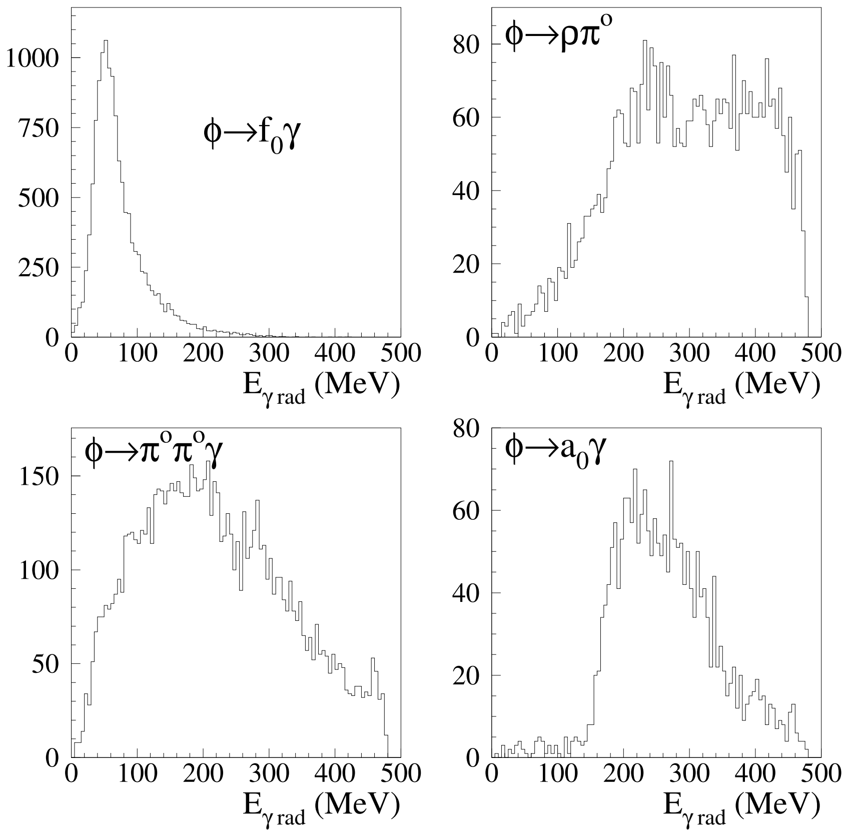
- **No other background sources from Φ decays**

$\star$ $BR(\Phi \to f_o\gamma) = (3.42 \pm 0.30 \pm 0.36) \times 10^{-4}$ (Achasov et al. – Phys.Lett.B440)

$\dagger$ Bramon, Grau, Pancheri – Phys.Lett.B283 – 1992

$*$ $BR(\Phi \to \eta\pi^o\gamma) = (0.83 \pm 0.23) \times 10^{-4}$ (Achasov et al. – Phys.Lett.B438)

$\Phi \rightarrow f_o\gamma \rightarrow \pi^o\pi^o\gamma$: background rejection

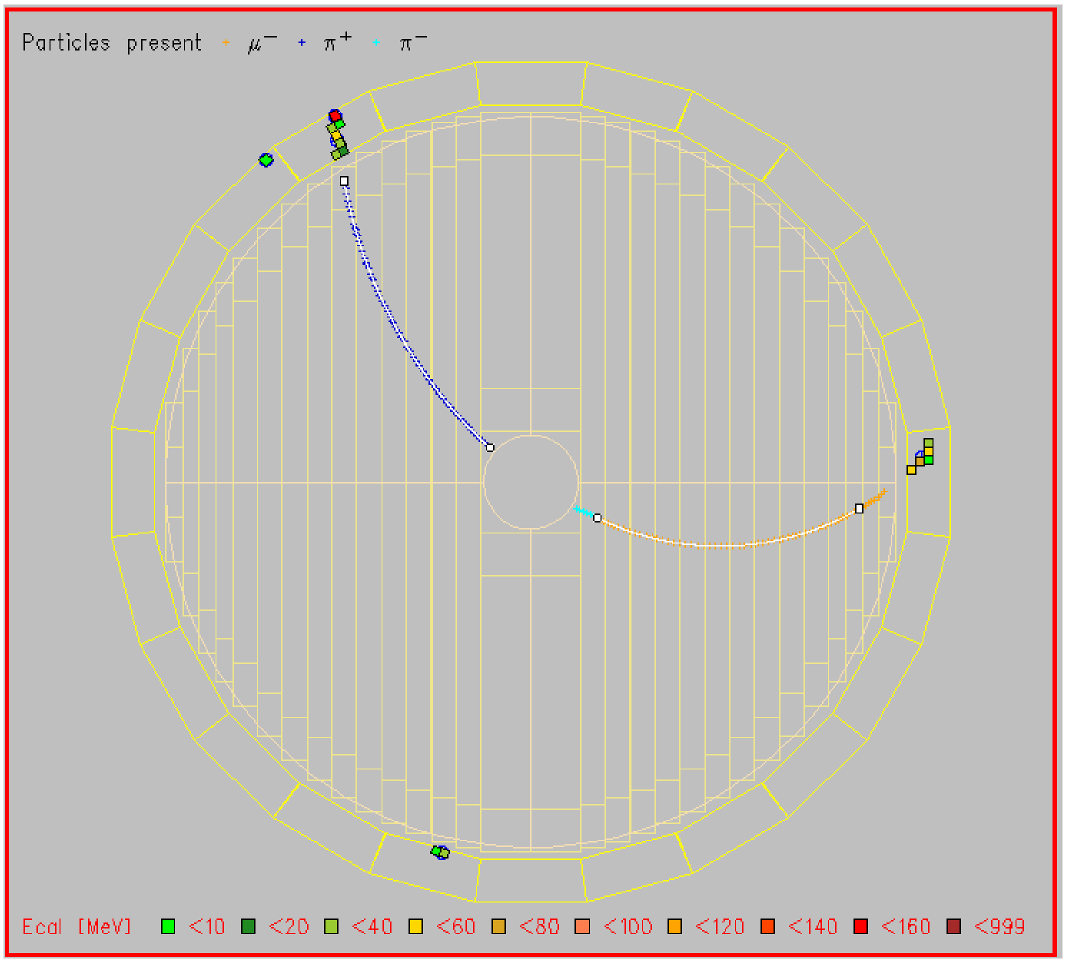


$\mathbf{E_{\gamma\,rad} < 100\ MeV} \quad \Longrightarrow \quad \varepsilon_{f_o\gamma} = 41.1\%$

Bckg	$\rho\,\pi^o$	$\pi^o\pi^o\gamma$	$a_o\gamma$	$\eta\gamma$
S/B	197	39	232	111

$\mathrm{N}(f_o\gamma)_{1999} \sim 55000 \quad \Longrightarrow \quad \frac{\delta\mathrm{BR}}{\mathrm{BR}}_{\,\mathrm{stat}} = 0.7\%$

The $\Phi \to f_o\gamma \to \pi^+\pi^-\gamma$ decay



Decay signature:

- **Two charged particles with $370 < p < 500$ MeV/c**
- **A photon with $E_{\gamma\,rad} > 10$ MeV**

Contribution to $e^+e^- \to \pi^+\pi^-\gamma$ at Φ peak

f_o	$e^+e^- \to \Phi \to f_o\gamma \to \pi^+\pi^-\gamma$	
ISR	$e^+e^- \to \gamma\gamma \to \gamma\rho^* \to \pi^+\pi^-\gamma$	BR $\sim 1.0 \times 10^{-3}$
FSR	$e^+e^- \to \Phi \to \rho^* \to \pi^+\pi^-\gamma$	BR $\sim 2.7 \times 10^{-4}$
VDM	$e^+e^- \to \Phi \to \pi\rho^* \to \pi^+\pi^-\gamma$	BR $= (2.5 \div 7.2) \times 10^{-5}$

The $\pi^+\pi^-$ pair from FSR and f_0 are in the same C$(\pi^+\pi^-) = +1$ state $\Longrightarrow$

Interference is expected

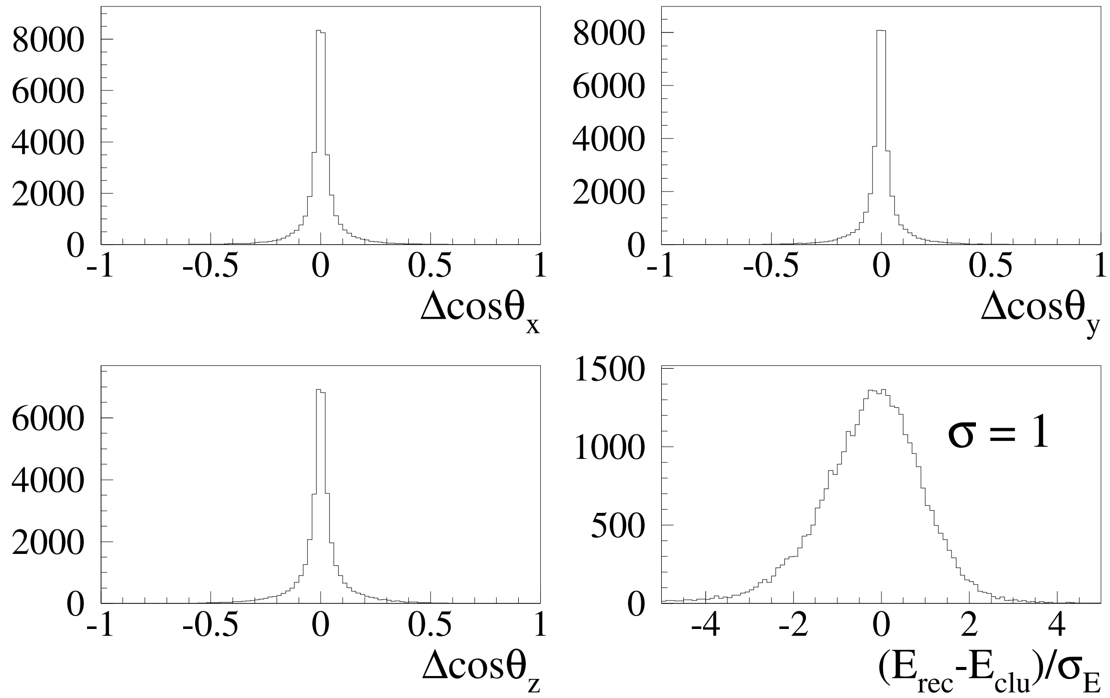
Assuming BR$(\Phi \to f_o\gamma) = 3.4 \times 10^{-4\star}$:

- Positive interference:
  BR$(\Phi \to f_o\gamma \to \pi^+\pi^-\gamma) = 2.5 \times 10^{-4}$
- Negative interference:
  BR$(\Phi \to f_o\gamma \to \pi^+\pi^-\gamma) = 3.6 \times 10^{-5}$

$\star$ M.N.Achasov et al. – Phys.Lett.B440 – 1998

$\Phi \to f_0\gamma \to \pi^+\pi^-\gamma$: sample selection

- **No prompt hits on QCAL** } **Acc = 90.7%**
- **A vertex ($|\mathbf{X}_\mathrm{v}, \mathbf{Y}_\mathrm{v}| < \mathbf{1.5\,cm}$ $|\mathbf{Z}_\mathrm{v}| < \mathbf{10\,cm}$) with two tracks** } $\varepsilon_{\mathbf{trk}} = \mathbf{86.3\%}$
- **A neutral cluster consistent with extrapolated γ ($\cos\theta_{\mathbf{trk\text{-}clu}} > \mathbf{0.8}$)** } $\varepsilon_{\mathbf{clu}} = \mathbf{85.9\%}$



Total selection efficiency: $\varepsilon_{\mathrm{sel}} = 67.2\%$

$\Phi \to f_o\gamma \to \pi^+\pi^-\gamma$: background events

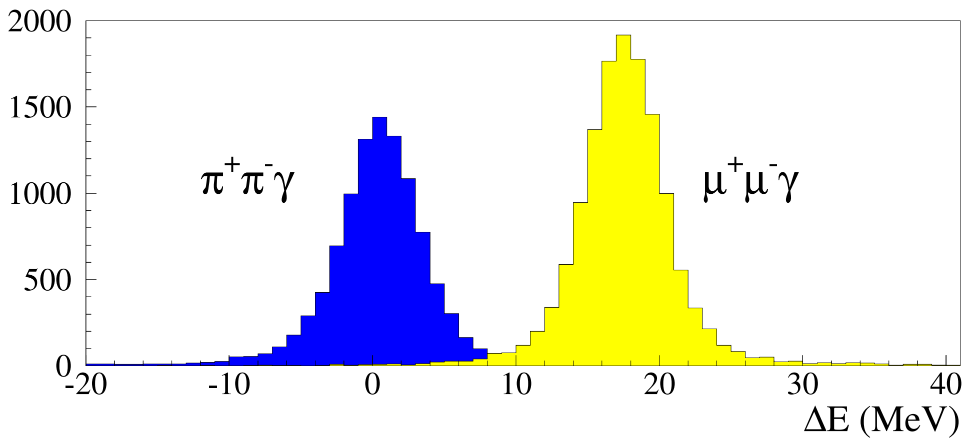
The only other relevant background is:

- $e^+e^- \to \mu^+\mu^-\gamma$ BR $= 1.3 \times 10^{-5\star}$

It can be fully controlled using $\Delta E = E_\gamma - E'_\gamma$ where:

$$\begin{aligned} E_\gamma &= |\vec{p}_\Phi - (\vec{p}_+ + \vec{p}_-)| \\ E'_\gamma &= M_\Phi - (E_+ + E_-) \end{aligned}$$

E_+, E_- are obtained assuming the pion mass

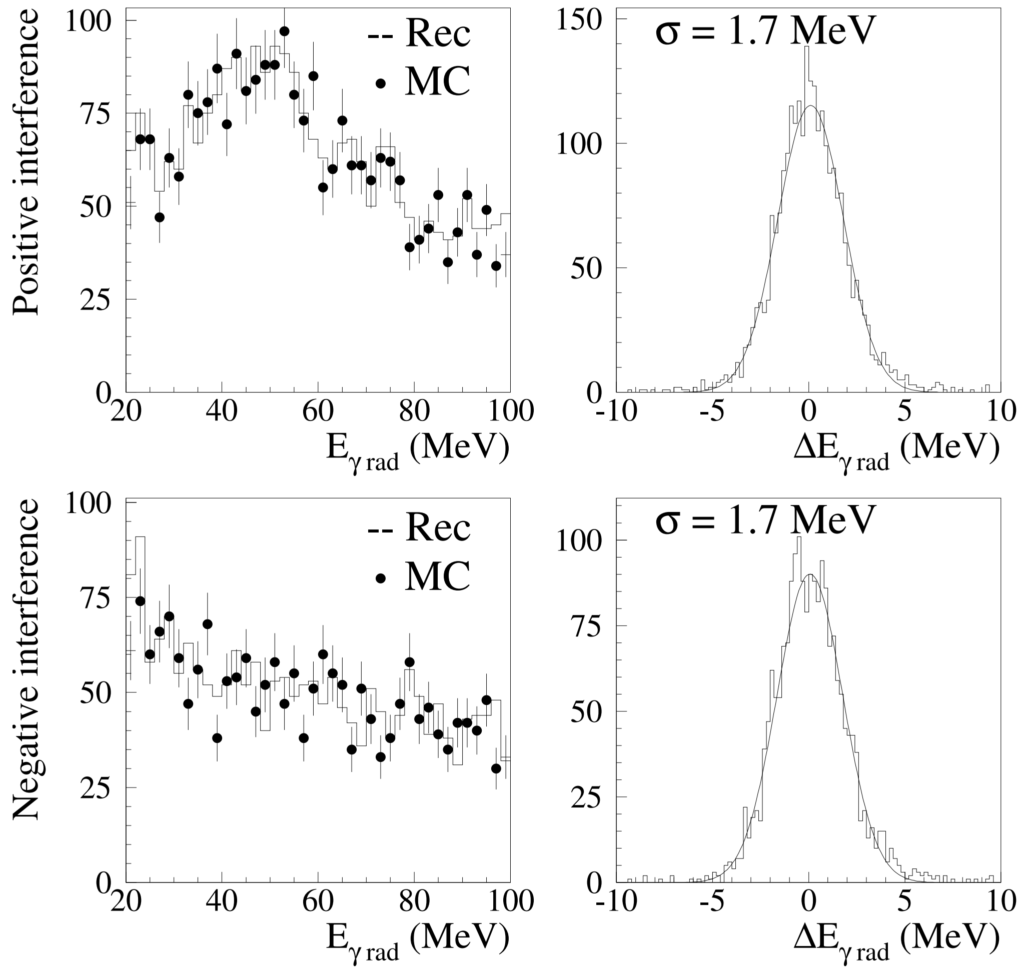


$\mathbf{\Delta E < 8\ MeV} \quad \Longrightarrow \quad \mathbf{R_J \sim 70}$

$\star$ CMD2 – ICHEP '98

$\Phi \rightarrow f_0\gamma \rightarrow \pi^+\pi^-\gamma$:
final selection cuts

- $\cos\theta_\gamma < 0.9, \; \cos\theta_{\pi\gamma} < 0.9$ Reduce ISR, FSR
- $20 < E_\gamma < 120$ MeV Reduce ISR, Φ bckg.

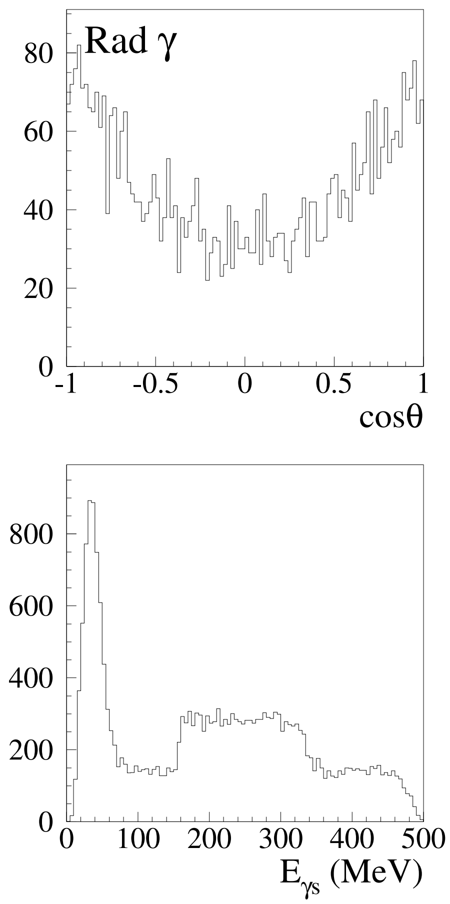


$\varepsilon_+ = 58\%$ $\varepsilon_- = 52\%$ $\varepsilon_{\rm bckg} = 26\%$

Work is in progress to fit the energy spectrum

$\mathbf{N(+)_{1999} \sim 125000}$ $\mathbf{N(-)_{1999} \sim 18000}$

The $\Phi \to a_o\gamma \to \eta\pi^o\gamma \to 5\gamma$'s decay



- **Radiative γ angular distribution:** $1 + \cos^2\theta$
- **Decay signature: 5 photons in EMC with** $10 < \mathbf{E}_\gamma < 510$ **MeV** $(\mathbf{E}_{\gamma\,\mathbf{rad}} \sim 40$ **MeV)**
- **Same sample selection as** $\Phi \to f_o\gamma \to 5\gamma$**'s:** $\theta_{\mathbf{rec}} > \mathbf{21}^\circ$ $+$ **5 EMC clusters in TW**

$\Phi \to a_o\gamma \to \eta\pi^o\gamma \to 5\gamma$'s: background events

$$BR(\text{signal}) = 3.25 \times 10^{-5\star}$$

Resonant backgrounds considered:

- $\Phi \to f_o\gamma \to \pi^o\pi^o\gamma$ — $\mathrm{BR} = 1.1 \times 10^{-4\,*}$
- $\Phi \to \pi^o\pi^o\gamma$ — $\mathrm{BR} = 1.5 \times 10^{-5\,\dagger}$
- $\Phi \to \rho\,\pi^o \to \pi^o\pi^o\gamma \to 5\gamma$'s — $\mathrm{BR} = 2.9 \times 10^{-5}$
- $\Phi \to \rho\,\pi^o \to \eta\pi^o\gamma \to 5\gamma$'s — $\mathrm{BR} = 4.0 \times 10^{-6}$
- $\Phi \to \eta\pi^o\gamma \to 5\gamma$'s — $\mathrm{BR} = 2.1 \times 10^{-6\,\dagger}$

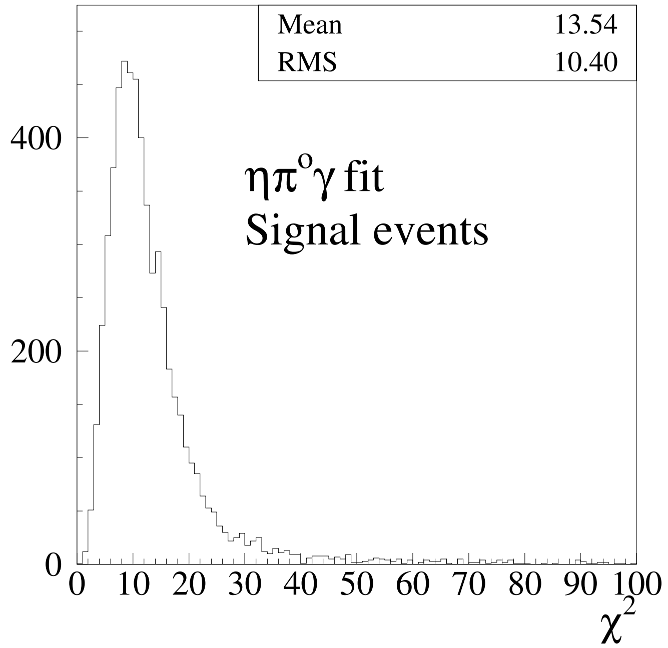
$\star$ $BR(\Phi \to \eta\pi^o\gamma) = (0.83 \pm 0.23) \times 10^{-4}$ (Achasov et al. – Phys.Lett.B438)

$*$ $BR(\Phi \to f_o\gamma) = (3.42 \pm 0.30 \pm 0.36) \times 10^{-4}$ (Achasov et al. – Phys.Lett.B440)

$\dagger$ Bramon, Grau, Pancheri – Phys.Lett.B283 – 1992

$\Phi \to a_o\gamma \to \eta\pi^o\gamma \to 5\gamma$'s: **fit results**

Two fits are performed in the $\eta\pi^o\gamma$, $\pi^o\pi^o\gamma$ hypotesis



- $\eta\pi^o\gamma$ selection: $\chi^2_{\eta\pi^o\gamma} < 30$ and $\chi^2_{\pi^o\pi^o\gamma} > 30$
- $\eta\pi^o\gamma$ bckg. rejection: $\chi^2_{a_o\gamma} < \chi^2_{\eta\pi^o\gamma}$
- Final rad. photon energy cut: $10 < E_{\gamma\,\mathbf{rad}} < 90$ MeV

Bckg	$f_o\gamma$	$\pi^o\pi^o\gamma$	$\rho\,\pi^o \to \pi^o\pi^o\gamma$	$\rho\,\pi^o \to \eta\pi^o\gamma$	$\pi^o\eta\gamma$
S/B	11	76	44	186	104

$\varepsilon_{a_o\gamma} = 34.0\%$ $\quad$ $\mathrm{N}(a_o\gamma)_{1999} \sim 16000$ $\quad$ $\frac{\delta\mathrm{BR}}{\mathrm{BR}}_{\mathrm{stat}} = 1.4\%$

The $\Phi \to a_o\gamma \to \eta\pi^o\gamma \to \pi^+\pi^-5\gamma$'s decay

- **Decay signature:**
  - A primary vertex with two associated tracks
  - 5 photons in EMC with $10 < E_\gamma < 510$ MeV ($E_{\gamma\,\mathbf{rad}} \sim 40$ MeV)

- **Sample selection:**
  - 1 vertex with:

    $\sqrt{X_v^2 + Y_v^2} < 10$ cm

    $|Z_v| < 10$ cm

    $\chi_v^2 < 5$

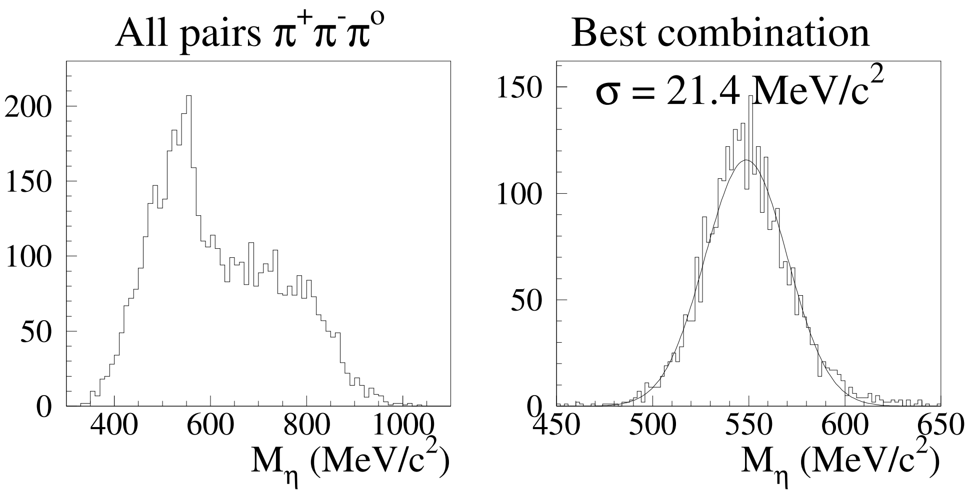
  - 2 associates tracks
  - 5 EMC neutral clusters in Time Window ($|\text{T-R/c}| < 5\sigma_T$)

$\Phi \rightarrow a_o\gamma \rightarrow \eta\pi^o\gamma \rightarrow \pi^+\pi^-5\gamma$'s: **fit procedure**

- First fit requiring:

  - $|$T-R/c$|$ = 0 for each photon
  - 4–momentum conservation

- Photons pairing into π^o's + best selection of $\pi^+\pi^-\pi^o$ combination to get η



- Second fit requiring also constraints on masses:

  - $M_{\gamma_1\gamma_2} = M_{\gamma_3\gamma_4} = M_{\pi^o}$
  - $M_{\pi^+\pi^-\pi^o} = M_\eta$

$\Phi \to a_o\gamma \to \eta\pi^o\gamma \to \pi^+\pi^- 5\gamma$'s: **background events**

$$BR(\text{signal}) = 1.9 \times 10^{-5\star}$$

Resonant backgrounds considered:

- $\Phi \to \eta\pi^o\gamma \to \pi^+\pi^- 5\gamma$'s   BR $= 1.24 \times 10^{-6\,\dagger}$
- $\Phi \to \rho\,\pi^o \to \eta\pi^o\gamma \to \pi^+\pi^- 5\gamma$'s   BR $= 2.37 \times 10^{-6}$

Summary results on signal and background:

Decay	$a_o\gamma$	$\eta\pi^o\gamma$	$\rho\,\pi^o$
ε	24%	5%	2%
S/B		74	96

$$\mathrm{N}(a_o\gamma)_{1999} \sim 9500 \qquad \Longrightarrow \qquad \frac{\delta\mathrm{BR}}{\mathrm{BR}}_{\,\mathrm{stat}} = 2.1\%$$

$\star BR(\Phi \to \eta\pi^o\gamma) = (0.83\pm0.23)\times10^{-4}$ (M.N.Achasov et al. – Phys.Lett.B438)

$\dagger$ Bramon, Grau, Pancheri – Phys.Lett.B283 – 1992

Conclusions

- **KLOE will start its first data taking end of March. An integrated luminosity of 100 pb^{-1} is expected in 1999.**

- **One of the first KLOE analysis items will be the study of $\Phi \to f_o\gamma$, $\Phi \to a_o\gamma$ decays.**

- **The following channels have been studied analysing MC events obtained with a realistic detector simulation and a full event reconstruction:**

$$\Phi \to f_o\gamma \to \pi^o\pi^o\gamma$$
$$\Phi \to f_o\gamma \to \pi^+\pi^-\gamma$$
$$\Phi \to a_o\gamma \to \pi^o\eta\gamma \to 5\gamma s$$
$$\Phi \to a_o\gamma \to \pi^o\eta\gamma \to \pi^+\pi^-5\gamma s$$

- **Assuming the quoted luminosity, the BR of these decays will be measured with an error of $\sim \mathbf{1 \div 2}\,\%$**

$\Phi \to f_o\gamma$ decay @ KLOE: summary results

- $\Phi \to f_o\gamma \to \pi^o\pi^o\gamma$

Summary results on signal and background:

Decay	$f_o\gamma$	$\rho\,\pi^o$	$\pi^o\pi^o\gamma$	$a_o\gamma$	$\eta\gamma$
ε	41.1%	0.7%	7.7%	0.6%	10^{-4}
S/B		197	39	232	111

$\mathrm{NEV}_{1999} \sim 55000 \quad \Longrightarrow \quad \frac{\delta\mathrm{BR}}{\mathrm{BR}}_{\mathrm{stat}} = 0.7\%$

- $\Phi \to f_o\gamma \to \pi^+\pi^-\gamma$

Summary results on signal and background:

Decay	$f_o\gamma(+)$	$f_o\gamma(-)$	$\pi^+\pi^-\gamma$	$\mu^+\mu^-\gamma$
ε	58%	52%	26%	0.7%
S/B(+)			1.5	1593
S/B(−)			1/4	206

$\mathrm{N}(+)_{1999} \sim 125000 \qquad \mathrm{N}(-)_{1999} \sim 18000$

$\Phi \to a_o\gamma$ decay @ KLOE: summary results

- $\Phi \to a_o\gamma \to \pi^o\eta\gamma \to 5\gamma\,\mathrm{s}$

Summary results on signal and background:

Decay	$a_o\gamma$	$f_o\gamma$	$\pi^o\pi^o\gamma$	$\rho\,\pi^o$ $\rho \to \pi^o\gamma$	$\rho\,\pi^o$ $\rho \to \eta\gamma$	$\pi^o\eta\gamma$
ε	34%	0.8%	2.6%	2.4%	1.6%	4%
S/B		11	76	44	186	104

$\mathrm{NEV}_{1999} \sim 16000 \quad \Longrightarrow \quad \frac{\delta\mathrm{BR}}{\mathrm{BR}}_{\mathrm{stat}} = 1.4\%$

- $\Phi \to a_o\gamma \to \pi^o\eta\gamma \to \pi^+\pi^-5\gamma\,\mathrm{s}$

Summary results on signal and background:

Decay	$a_o\gamma$	$\eta\pi^o\gamma$	$\rho\,\pi^o$
ε	24%	5%	2%
S/B		74	96

$\mathrm{NEV}_{1999} \sim 9500 \quad \Longrightarrow \quad \frac{\delta\mathrm{BR}}{\mathrm{BR}}_{\mathrm{stat}} = 2.1\%$