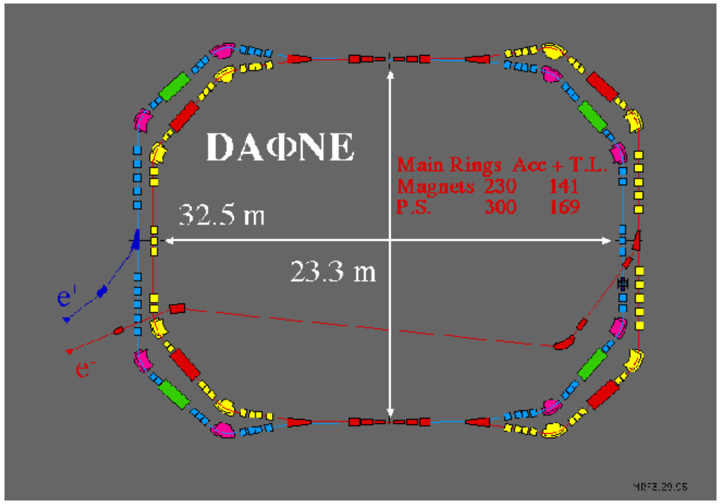
Detection of pseudoscalar and scalar mesons at DAΦNE with KLOE

S. Giovannella
LNF - INFN

for the KLOE collaboration

- DAΦNE and KLOE
- Radiative ϕ decays @ KLOE
- Theoretical models
- Study of fully neutral decays
- Study of charged decays
- A first glance to real data

The DAΦNE ϕ-factory



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

$$\mathcal{L} = 5 \times 10^{32} \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

$2.2 \times 10^{10}\ \phi/\text{year}$ expected

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

- First collisions with KLOE in: 14th April 1999
- $\mathcal{L}_{peak} \sim 2 \times 10^{30} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (with 16 bunches out of 120)
- Lifetime $>$ 1 hour

End 1999/Early 2000 period:
100 pb^{-1} expected

$\Downarrow$

$$\boxed{3 \times 10^8 \phi}$$

The KLOE detector

Electromagnetic calorimeter (EMC)

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

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

Central Drift Chamber (DCH)

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

$$\begin{aligned} \sigma_{V} &= 1\ \mathrm{mm} \\ \sigma_{p_t}/p_t &= 0.5\% \\ \sigma_{R\phi} &= 200\ \mu\mathrm{m} \\ \sigma_{z} &= 2\ \mathrm{mm} \end{aligned}$$

Quadrupoles' calorimeter (QCAL)

Pb/Sci tile calorimeter covering quads inside KLOE to increase hermeticity

Radiative ϕ decays @ KLOE

- $\phi \to \eta\gamma \to \gamma\gamma\gamma$
- $\phi \to \eta\gamma \to \pi^+\pi^-\pi^o\gamma$
- $\phi \to \eta\gamma \to \pi^o\pi^o\pi^o\gamma$
- $\phi \to \eta'\gamma \to \pi^+\pi^-\eta\gamma \to \pi^+\pi^-\gamma\gamma\gamma$
- $\phi \to \eta'\gamma \to \pi^o\pi^o\eta\gamma \to \pi^o\pi^o\gamma\gamma\gamma$
- $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$
- $\phi \to f_o\gamma \to \pi^+\pi^-\gamma$
- $\phi \to a_o\gamma \to \eta\pi^o\gamma \to \pi^+\pi^-\pi^o\gamma$
- $\phi \to a_o\gamma \to \eta\pi^o\gamma \to \gamma\gamma\pi^o\gamma$

MC data processing:

- Signal and background simulation
- Realistic detector simulation
- Full event reconstruction

Real data processing:

- Fast background rejection
- Full event reconstruction
- Event filter for fast identification

Theoretical models

$\eta'(958)$: $I^G(J_{PC}) = 0^+(0^{-+})$ $\pi\pi\eta$ decay
$\eta\,(547)$: $I^G(J_{PC}) = 0^+(0^{-+})$ $\gamma\gamma$, $\pi\pi\pi$

The value of BR($\phi \to \eta'\gamma$) ranges from $\sim 2 \times 10^{-4}$ down to $\sim 10^{-6}$ in case of gluonic content of the η'.
From first observations at VEPP-2M:

$(1.35^{+0.55}_{-0.45}) \times 10^{-4}$ CMD–2 1998

$(6.7^{+3.4}_{-2.9}) \times 10^{-5}$ SND 1998

KLOE will also study the mixing angle between η and η' with $\Delta\theta_p \sim 1^\circ$ measuring the ratio

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

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

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

Model	BR($\phi \to f_o\gamma$)	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}
$K\bar{K}$	10^{-5}	10^{-5}

Recent results from SND and CMD-2:

BR($\phi \to f_o\gamma$) $\sim 3 \times 10^{-4}$

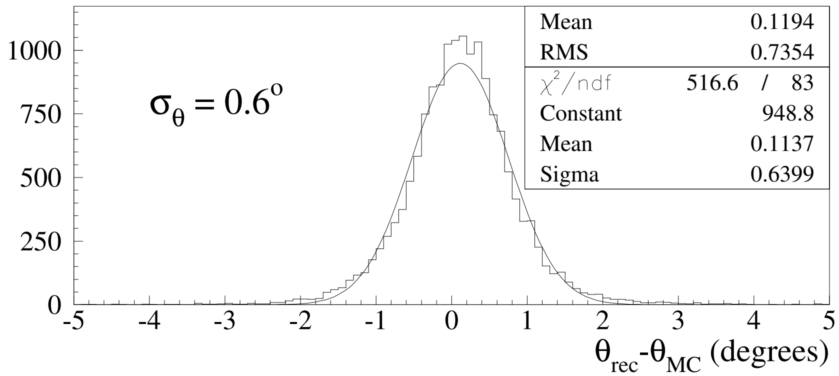
BR($\phi \to a_o\gamma$) $\sim 10^{-4}$

Fully neutral events selection

Decay signature: "$\boldsymbol{n}$" γ's on EMC

Sample selection:

- No prompt hits on QCAL
- $\theta_{\text{rec}} = \text{Z}_{\text{cl}}/\text{R}_{\text{cl}} > 21^\circ$
- "$\boldsymbol{n}$" EMC clusters in Time Window: $|\text{T-R}/c| < 5\sigma_{\text{T}}$



After the selection a kinematic fit using all measured quantities and all possible constraints is performed.

$\phi \to \eta\gamma \to \gamma\gamma\gamma$ decay

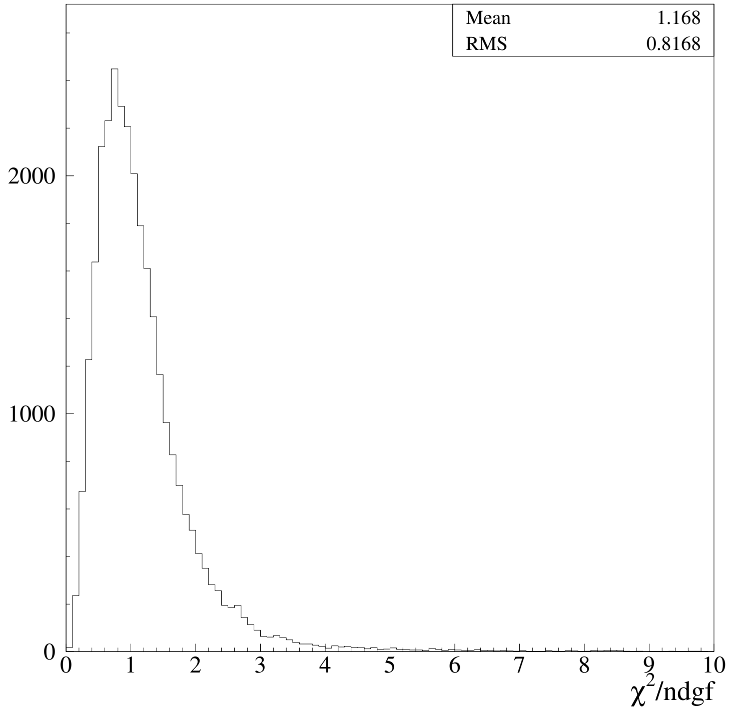
Energy spectrum:

$$E_{\gamma_{\mathrm{rad}}} = 360\,\mathrm{MeV}$$

$$150 < E_{\gamma_\eta} < 500\,\mathrm{MeV}$$

Radiative photon is assigned performing a kinematic fit for the three possible photon's combinations. Fit requires:

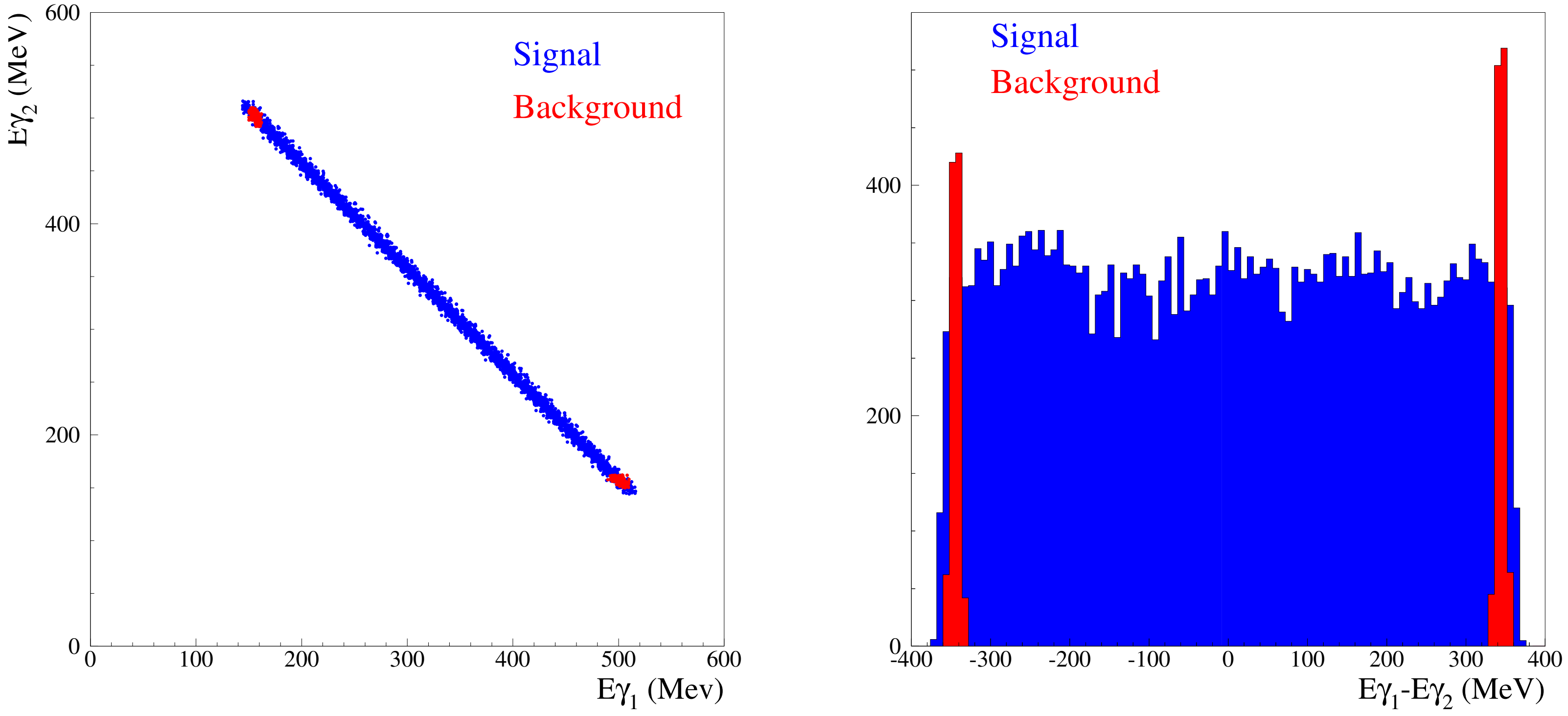
- $\mathrm{T_{cl}} - \mathrm{R_{cl}}/c = 0$ for each cluster
- E and $\vec{p}$ conservation
- $M_{\gamma\gamma} = M_\eta$



$\phi \to \eta\gamma \to \gamma\gamma\gamma$: background rejection

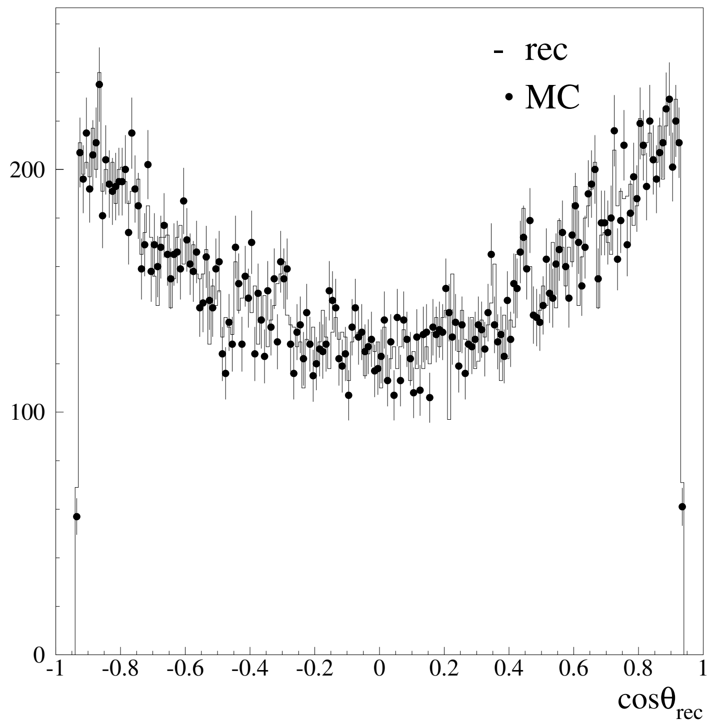
Main background: $\phi \to \pi^o\gamma \to \gamma\gamma\gamma$ (S/B $= 0.49\%/0.13\% = 4$)

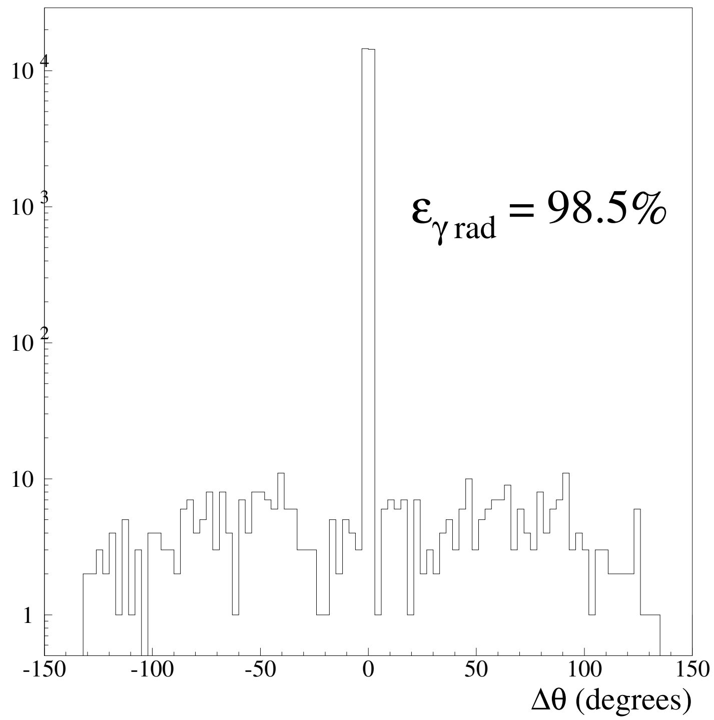
$E_{\gamma_{\rm rad}} = 500$ MeV $\quad E_{\gamma_{\pi^o}} < 500$ MeV



Background rejection requires: $|E_{\gamma 1} - E_{\gamma 2}| < 330$ MeV

$\phi \to \eta\gamma \to \gamma\gamma\gamma$: summary results





Channel	$\varepsilon_{\text{trigger}}$	$\varepsilon_{\text{analysis}}$	$N_{\text{evts}}(1999)$	S/B ratio
Signal	96%	67%	9.6×10^5	—
$\pi^o\gamma$	91%	7×10^{-4}	2500	380

$(\delta BR/BR)_{\text{stat}} = 0.3\%$ $\quad$ $(\delta BR/BR)_{\text{syst}} \sim 1\%$ $\left(\begin{array}{l}\text{cluster rec.} \\ \text{rad. } \gamma \text{ assign.}\end{array}\right)$

$\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ decay

$E_{\gamma_{\text{rad}}}$ peaked @ 45 MeV

$E_{\gamma_{\pi^o}} < 500$ MeV

Three steps fit procedure:

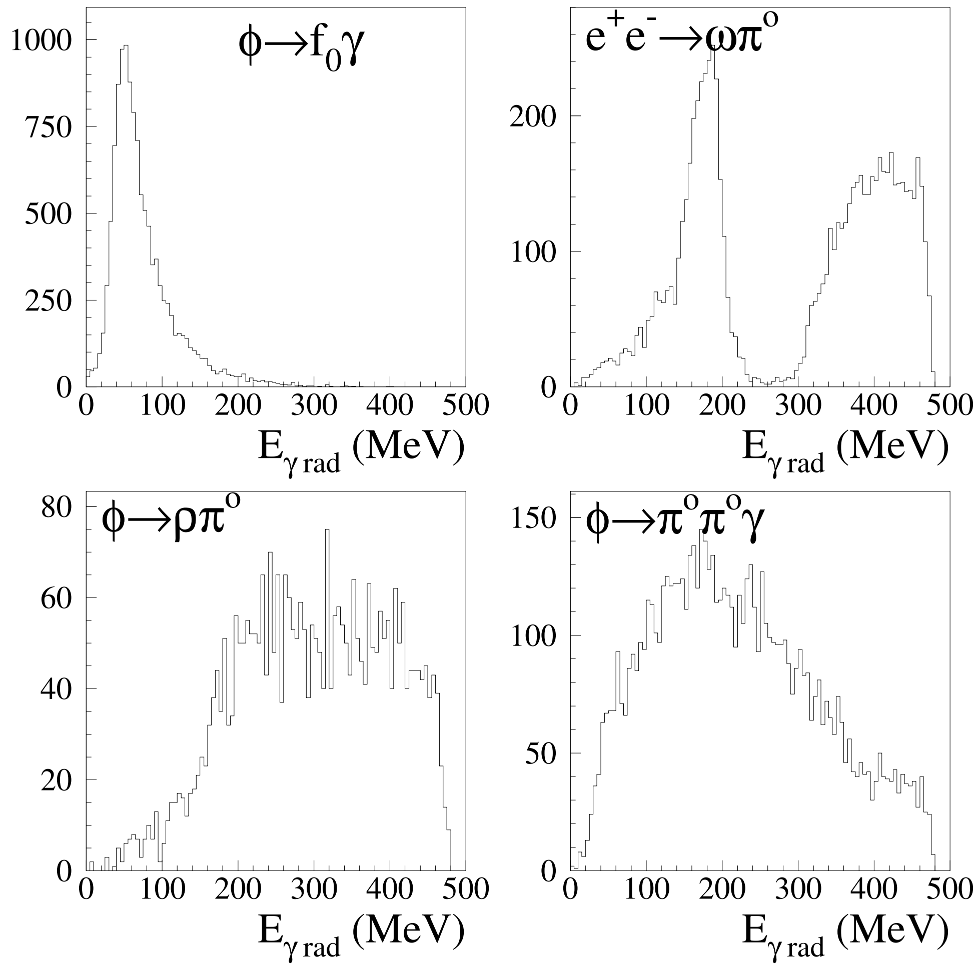
1. Nine constraints applied:
   - $\text{T}_{\text{cl}} - \text{R}_{\text{cl}}/c = 0$ for each cluster
   - E and $\vec{p}$ conservation
2. Photon's pairing into π^o
3. Constraints on π^o mass are also required:
   - $M_{\gamma\gamma} = M_{\pi^o}$ for both $\gamma\gamma$ pairs

Background events

$BR_{\text{signal}} \sim 10^{-4}$

- $e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$
  S/B = 0.46
- $\phi \to \pi^o\pi^o\gamma$
  S/B = 6.7
- $\phi \to \rho\pi^o \to 5\gamma$'s
  S/B = 3.0
- $\phi \to a_o\gamma \to \eta\pi^o\gamma \to 5\gamma$'s
  S/B = 3.1
- $\phi \to \eta\gamma \to \pi^o\pi^o\pi^o\gamma$
  S/B = 0.02

$\phi \to f_o\gamma \to \pi^o\pi^o\gamma$: background rejection



Background rejection requires: $E_{\gamma\,\mathsf{rad}} < 100\,\mathsf{MeV}$

$\phi \to f_o\gamma \to \pi^o\pi^o\gamma$: summary results

Channel	$\varepsilon_{\text{trigger}}$	$\varepsilon_{\text{analysis}}$	$N_{\text{evts}}(1999)$	S/B ratio
Signal	98%	41.1%	13300	—
$\omega\pi^o$	98%	1.8%	1150	12
$\pi^o\pi^o\gamma$	98%	7.7%	340	40
$\rho\pi^o$	98%	0.7%	70	195
$a_o\gamma$	98%	0.6%	60	230
$\eta\gamma$	99%	10^{-4}	120	110

$(\delta BR/BR)_{\text{stat}} = 0.9\%$

$(\delta BR/BR)_{\text{syst}} \sim 2 \div 3\%$ (clustering + fit + bckg subtr.)

Charged events selection

Decay signature: $\boldsymbol{\pi}^+ \boldsymbol{\pi}^-$ "$\boldsymbol{n}$" $\boldsymbol{\gamma}$'s on EMC

Sample selection:

- A vertex near the origin
  - $|X_{\mathsf{v}}, Y_{\mathsf{v}}| < 1.5\,$cm
  - $|Z_{\mathsf{v}}| < 10\,$cm

  with two associated tracks

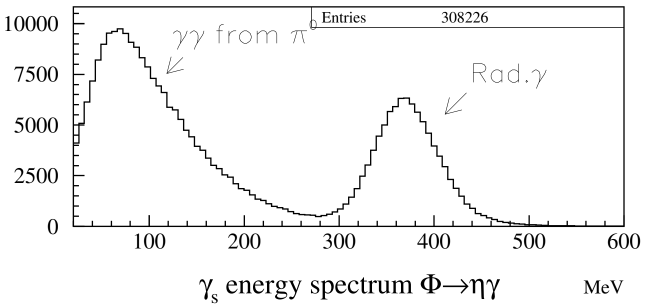
- "$\boldsymbol{n}$" EMC clusters in Time Window

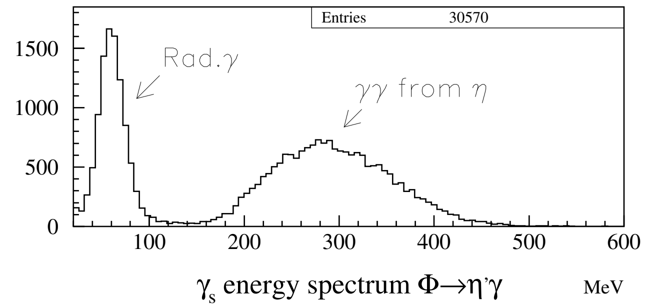
  For $\phi \to f_o\gamma \to \pi^+\pi^-\gamma$ the consistency between neutral cluster and extrapolated photon is also required.

Kinematical fit is then performed

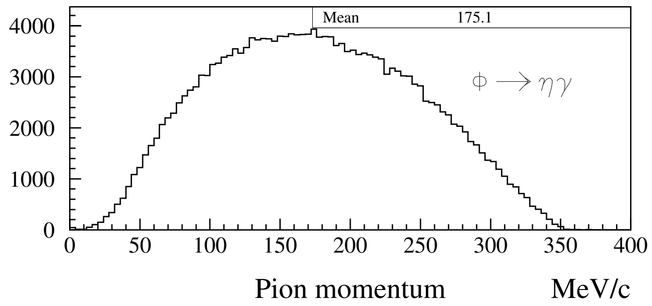
$\phi \to \eta\gamma/\eta'\gamma \to \pi^+\pi^- 3\gamma$'s decays

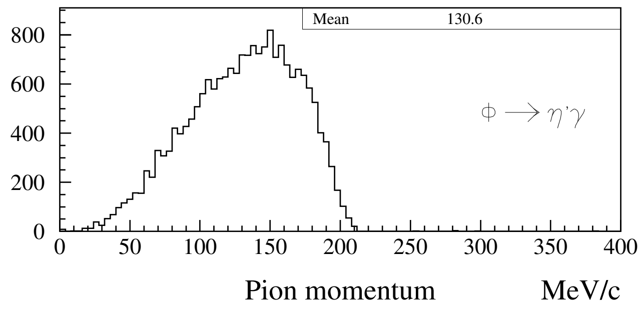
γ's energy spectrum





Pion momentum





$\phi \to \eta\gamma$ decay:

$E_{\rm rad} > 300$ MeV

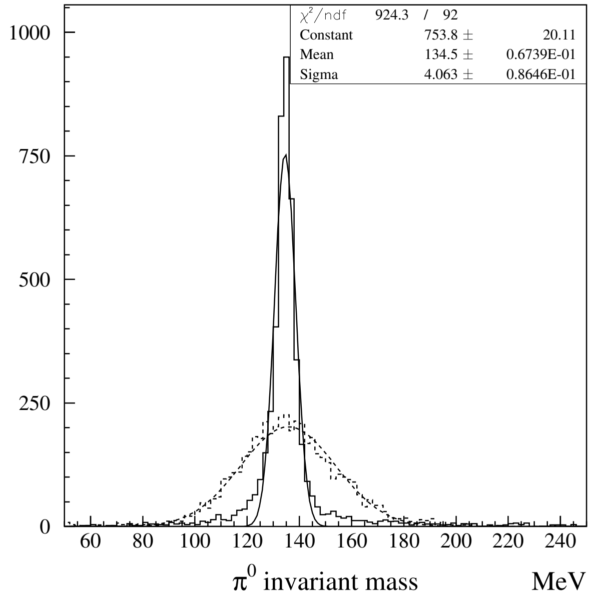
$\phi \to \eta'\gamma$ decay:

$20 < E_{\rm rad} < 150 < E_{\gamma 1}, E_{\gamma 2}$ MeV
$P(\pi^+)$ and $P(\pi^-) < 220$ MeV/c

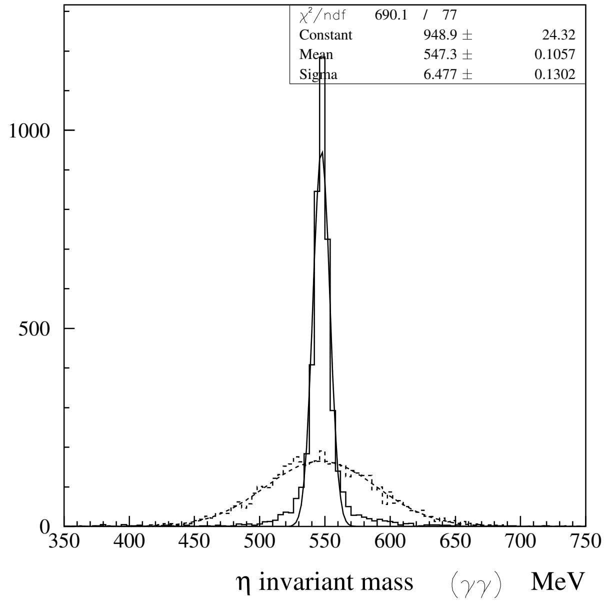
$\phi \to \eta\gamma/\eta'\gamma \to \pi^+\pi^-3\gamma$'s: reconstructed invariant masses

After the γ's assignement, a fit constraining η, η' and π^o masses is performed in both $\eta\gamma$ and $\eta'\gamma$ hypotheses.

$\phi \to \eta\gamma$: π^o mass

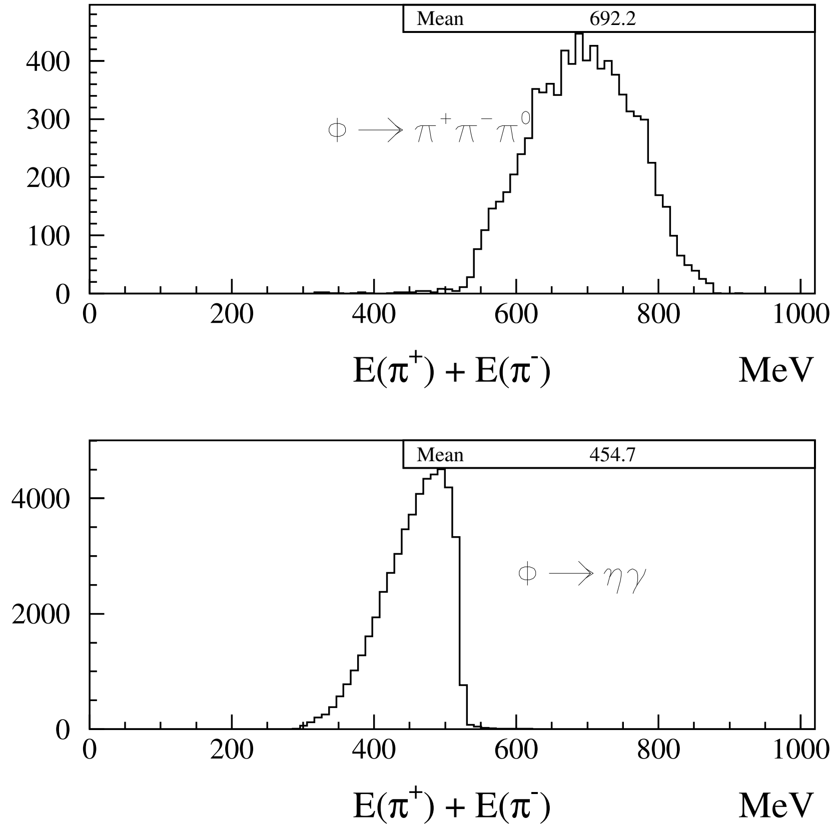


$\phi \to \eta'\gamma$: η mass



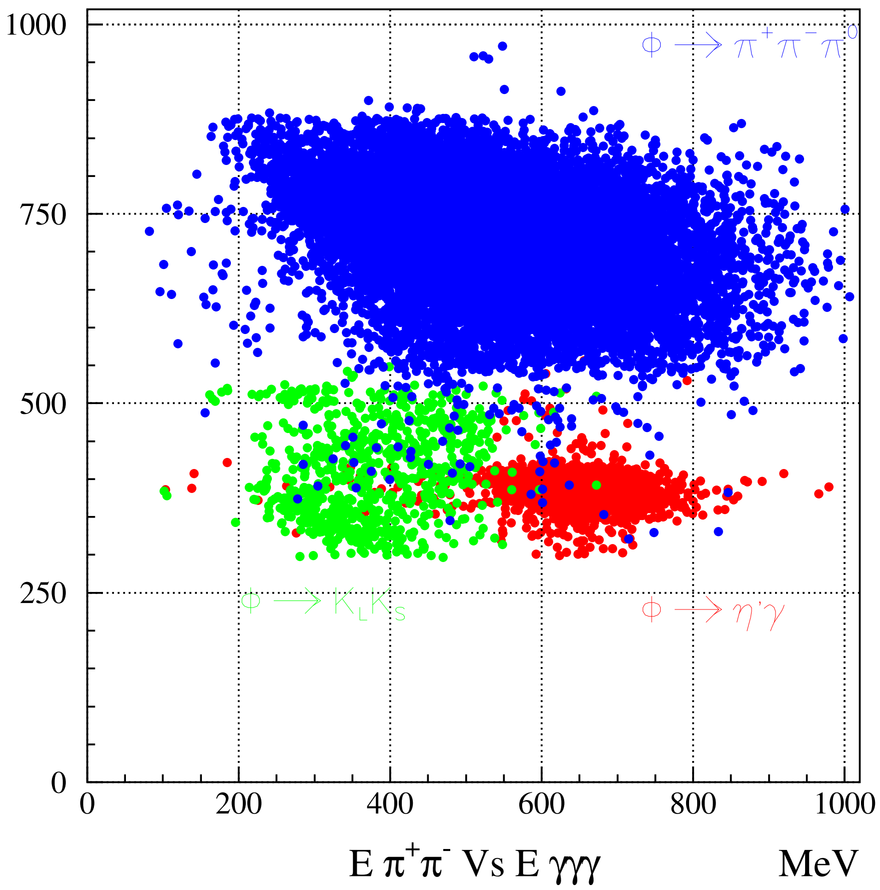
$\phi \to \eta\gamma \to \pi^+\pi^- 3\gamma$'s: background rejection

- Background from $\phi \to K_L K_S \to 2\text{ch} + \gamma$'s is negligible
- Background from $\phi \to \pi^+\pi^-\pi^o$ is reduced requiring: $E(\pi^+) + E(\pi^-) < 550\,\text{MeV}$



$\phi \rightarrow \eta'\gamma \rightarrow \pi^+\pi^-3\gamma$'s: background rejection

- $\phi \rightarrow K_L K_S \rightarrow$ 2ch + γ's bckg: $E_{\gamma\gamma\gamma} > 520$ MeV
- $\phi \rightarrow \pi^+\pi^-\pi^o$ bckg: $E(\pi^+) + E(\pi^-) < 412$ MeV



$\phi \to \eta\gamma/\eta'\gamma \to \pi^+\pi^-3\gamma$'s: summary results

$\phi \to \eta\gamma \to \pi^+\pi^-\gamma\gamma\gamma$

Channel	$\varepsilon_{\text{trigger}}$	$\varepsilon_{\text{analysis}}$	$N_{\text{evts}}(1999)$	S/B ratio
Signal	98%	37%	3.1×10^5	—
$K_L K_S$	100%	$< 1 \times 10^{-5}$	< 400	> 800 (1)
$\pi^+\pi^-\pi^0$	94%	$< 1 \times 10^{-5}$	< 440	> 720 (1)

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

Channel	$\varepsilon_{\text{trigger}}$	$\varepsilon_{\text{analysis}}$	$N_{\text{evts}}(1999)$	S/B ratio
Signal	97%	31%	2100	—
$\eta\gamma$	98%	$\sim 4 \times 10^{-5}$	~ 36	~ 58
$K_L K_S$	100%	$< 1 \times 10^{-5}$	< 400	> 5 (1)
$\pi^+\pi^-\pi^0$	94%	$< 1 \times 10^{-5}$	< 440	> 4.5 (1)

(1) evaluated with 10^5 events

A first glance to real data

KLOE data taking

- First collisions on 14th April 1999
- Short period of ϕ scan
- One month of parassitic running
- First period of continuos data taking: July 30th $\div$ August 8th

Total integrated luminosity:

$$\mathcal{L} \sim 200\,\text{nb}^{-1}$$

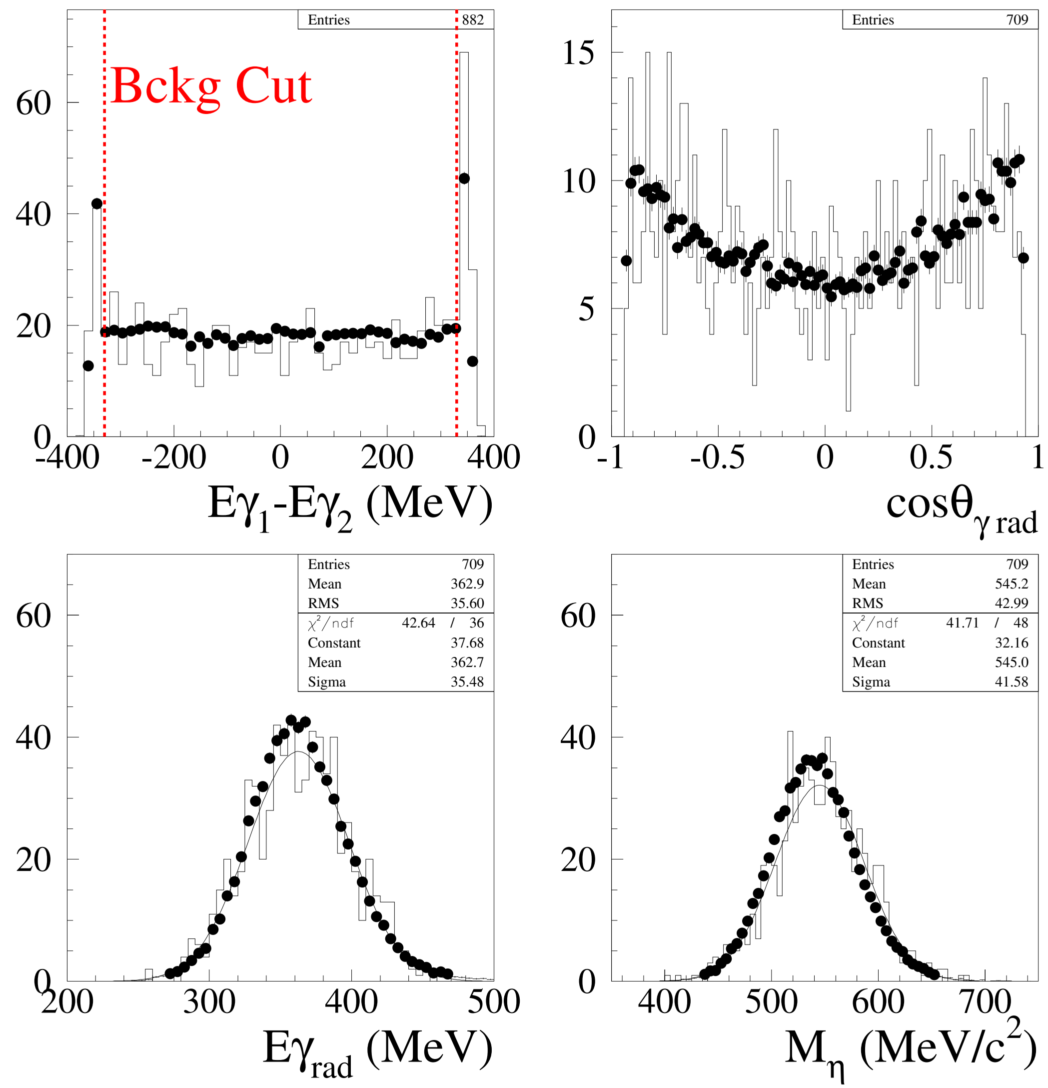
Radiative decays study

Analysis has been performed on first $89\,\text{nb}^{-1}$ of data with similar trigger conditions out of the $150\,\text{nb}^{-1}$ already reconstructed

Sample obtained after background rejection with a fast calorimeter based filter and classification of radiative events

Preliminary studies performed on fully neutral decays of:
$\phi \rightarrow \eta\gamma, \pi^o\gamma, f_o\gamma$

The $\phi \to \eta\gamma \to \gamma\gamma\gamma$ decay



– Data

• MC

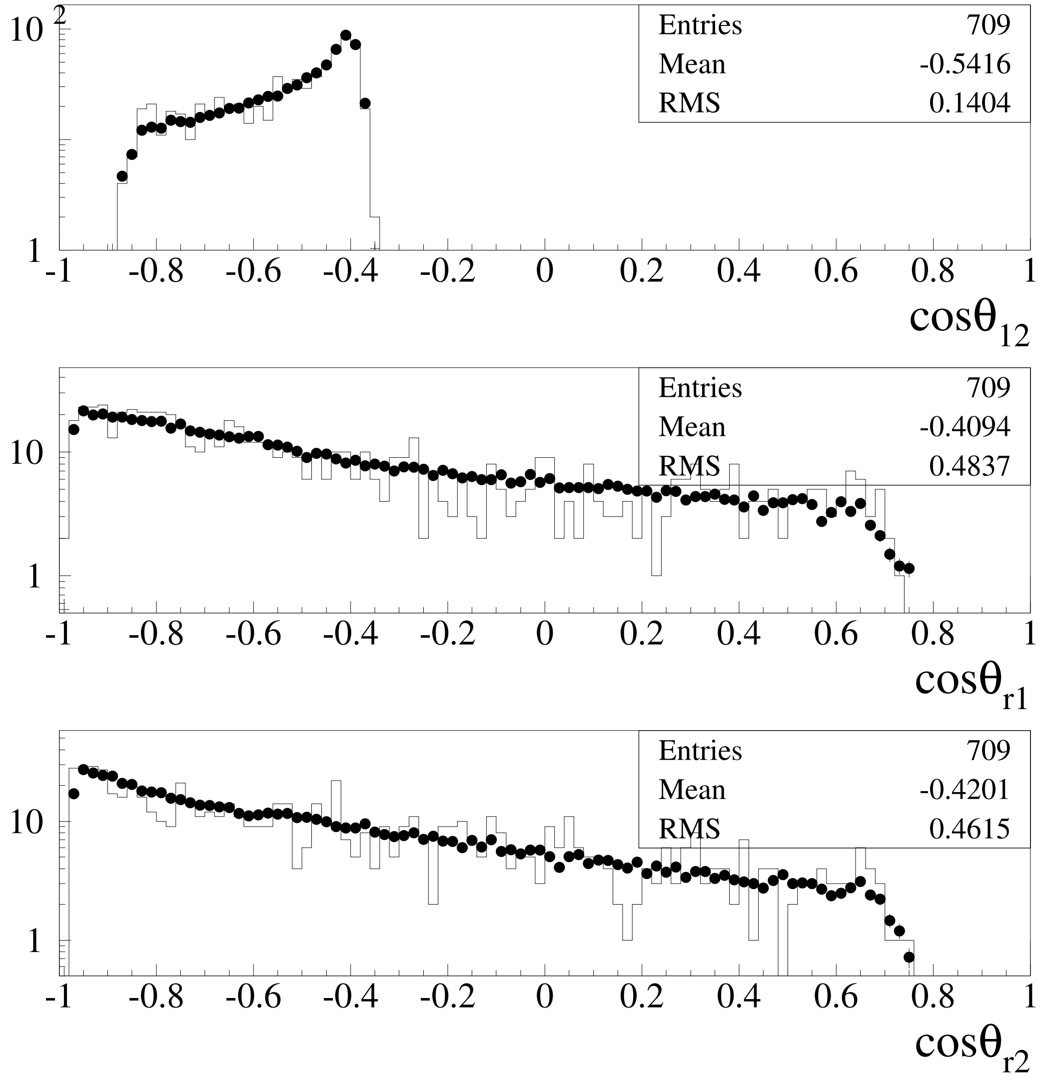
$M_\eta = 545.0\,\mathrm{MeV}/c^2$

$\sigma_\eta = 41.6\,\mathrm{MeV}/c^2$

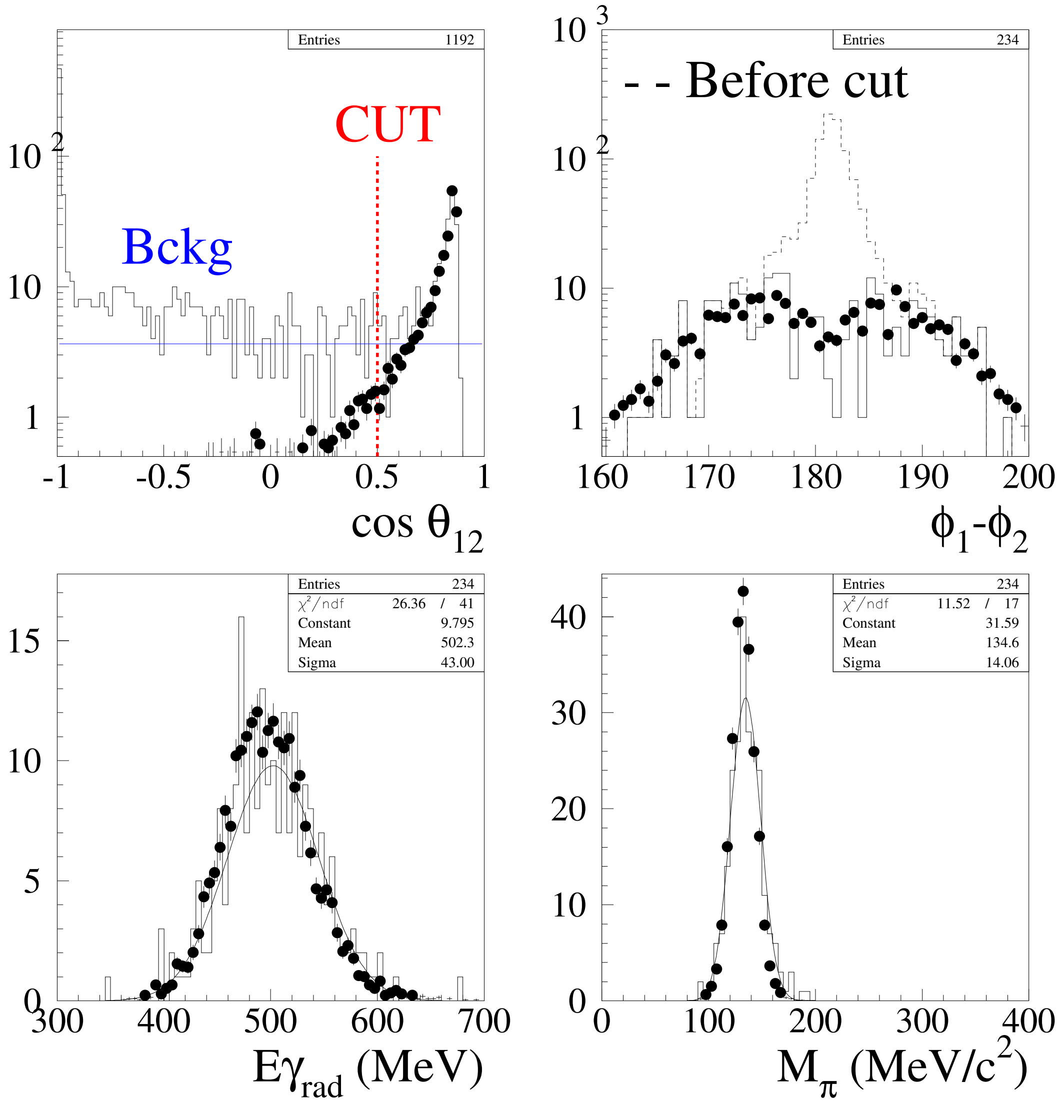
$\mathrm{Nev}_{\mathrm{exp}} = 771$

$\mathrm{Nev} = 709$

The $\phi \to \eta\gamma \to \gamma\gamma\gamma$ decay



The $\phi \to \pi^o \gamma$ decay



– Data

• MC

$M_{\pi^o} = 134.6\,\mathrm{MeV}/c^2$

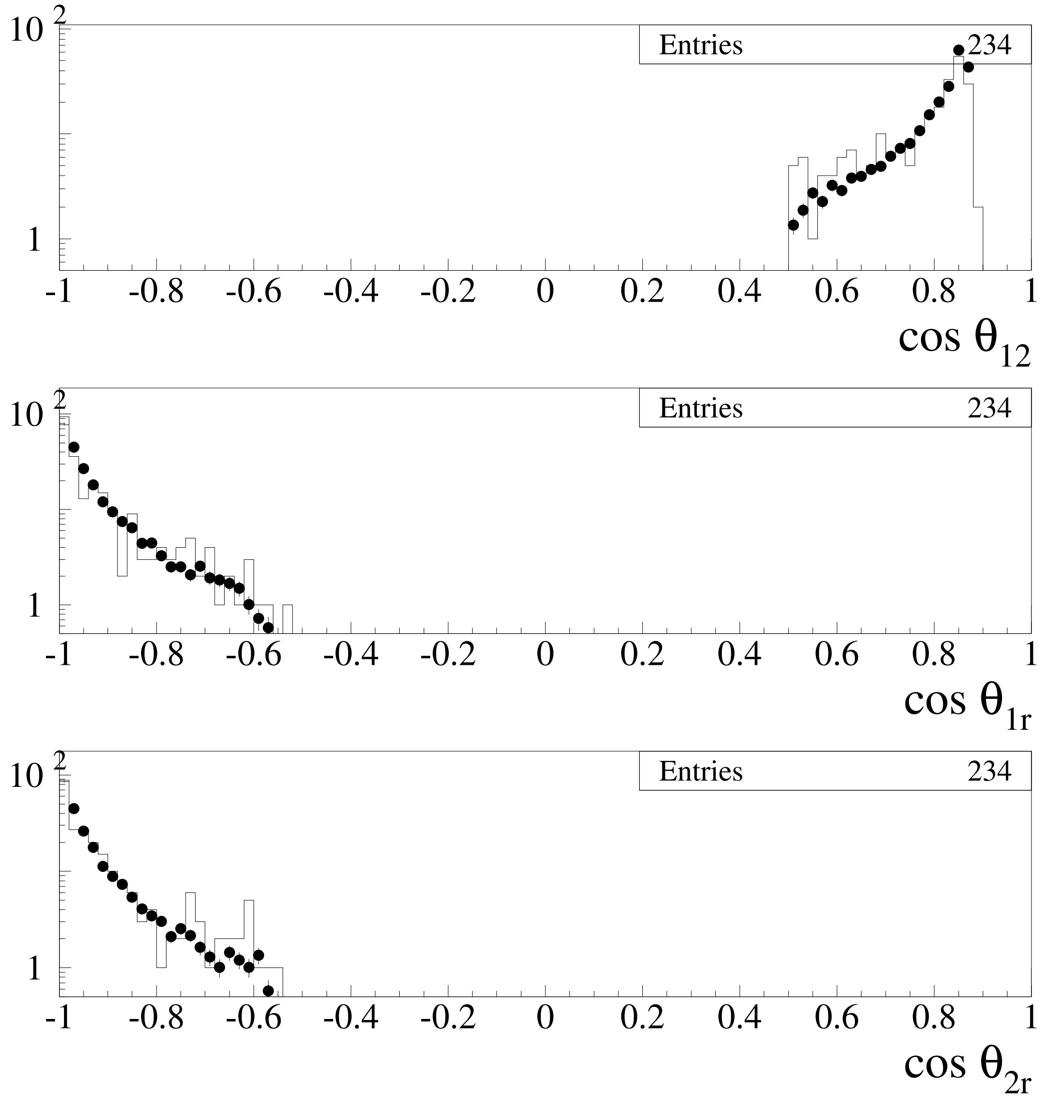
$\sigma_{\pi^o} = 14.1\,\mathrm{MeV}/c^2$

$\mathrm{Nev}_{\mathrm{exp}} = 146$

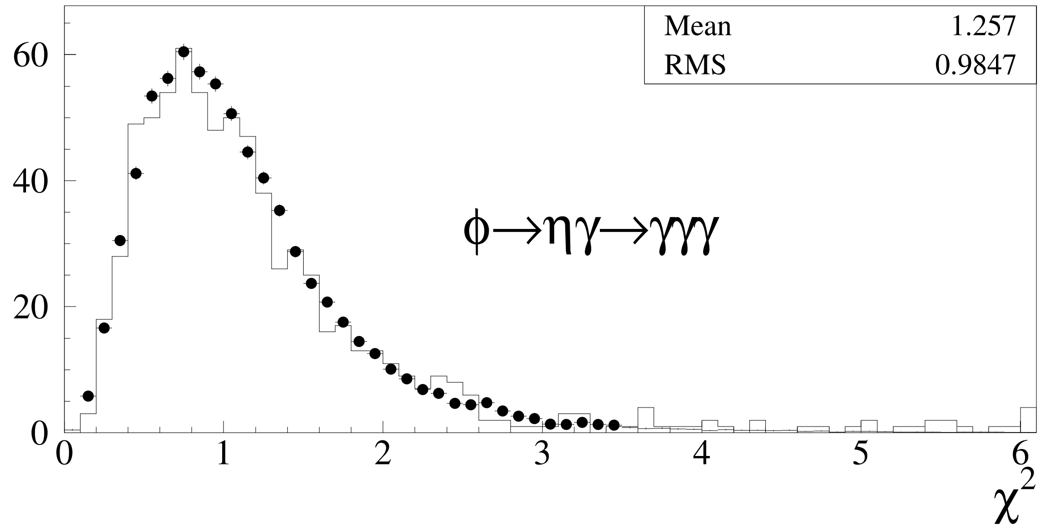
$\mathrm{Nev} = 234$

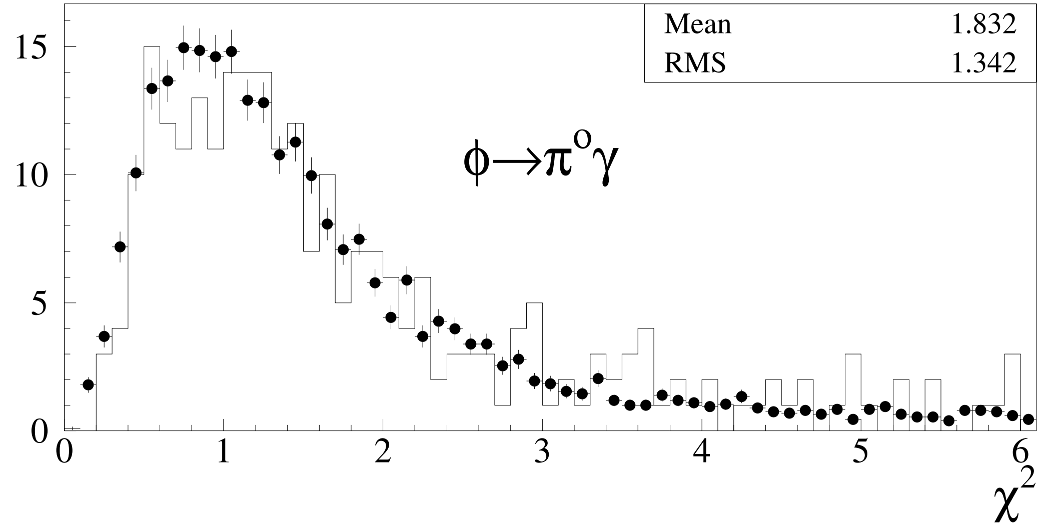
$\mathrm{Nev}_{\mathrm{bkg}} = 74$

The $\phi \to \pi^o \gamma$ decay

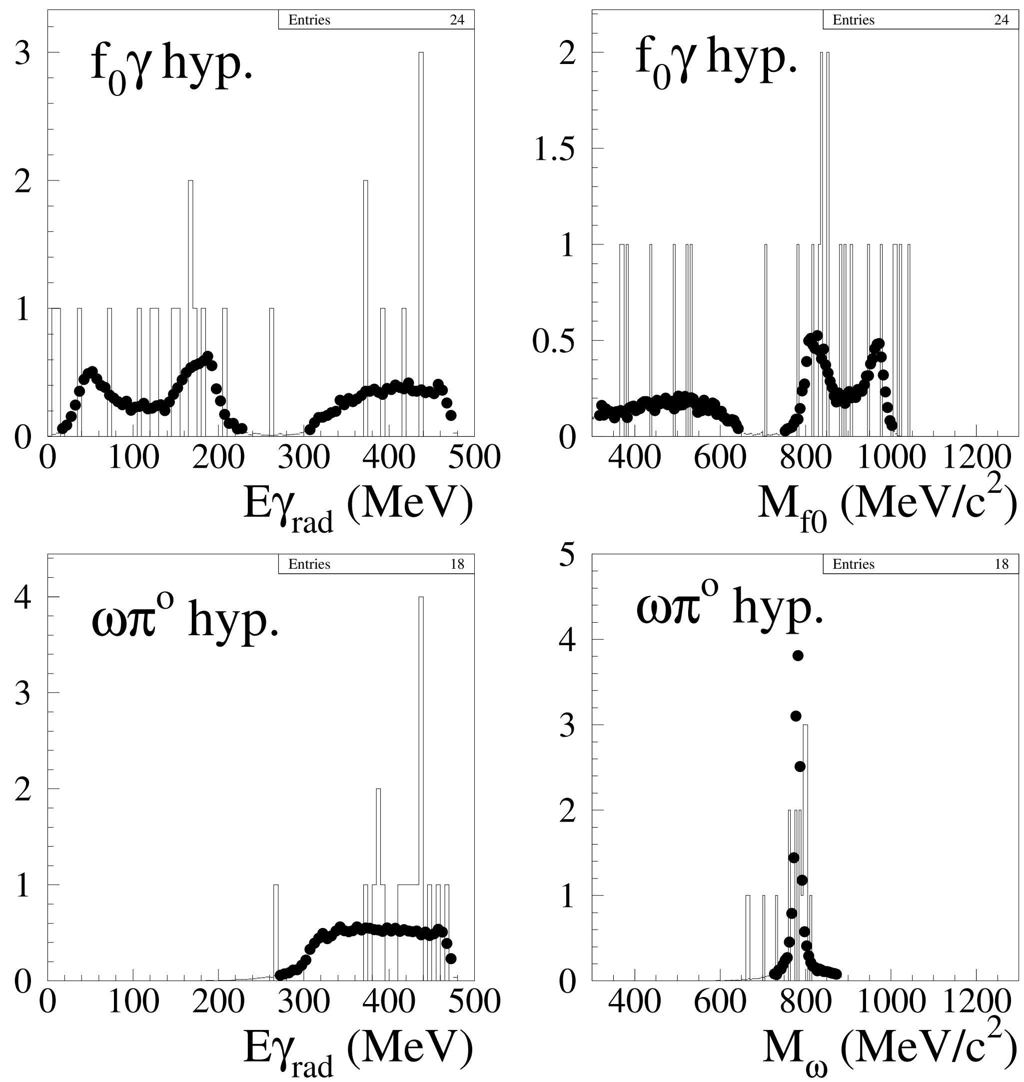


χ^2 distributions





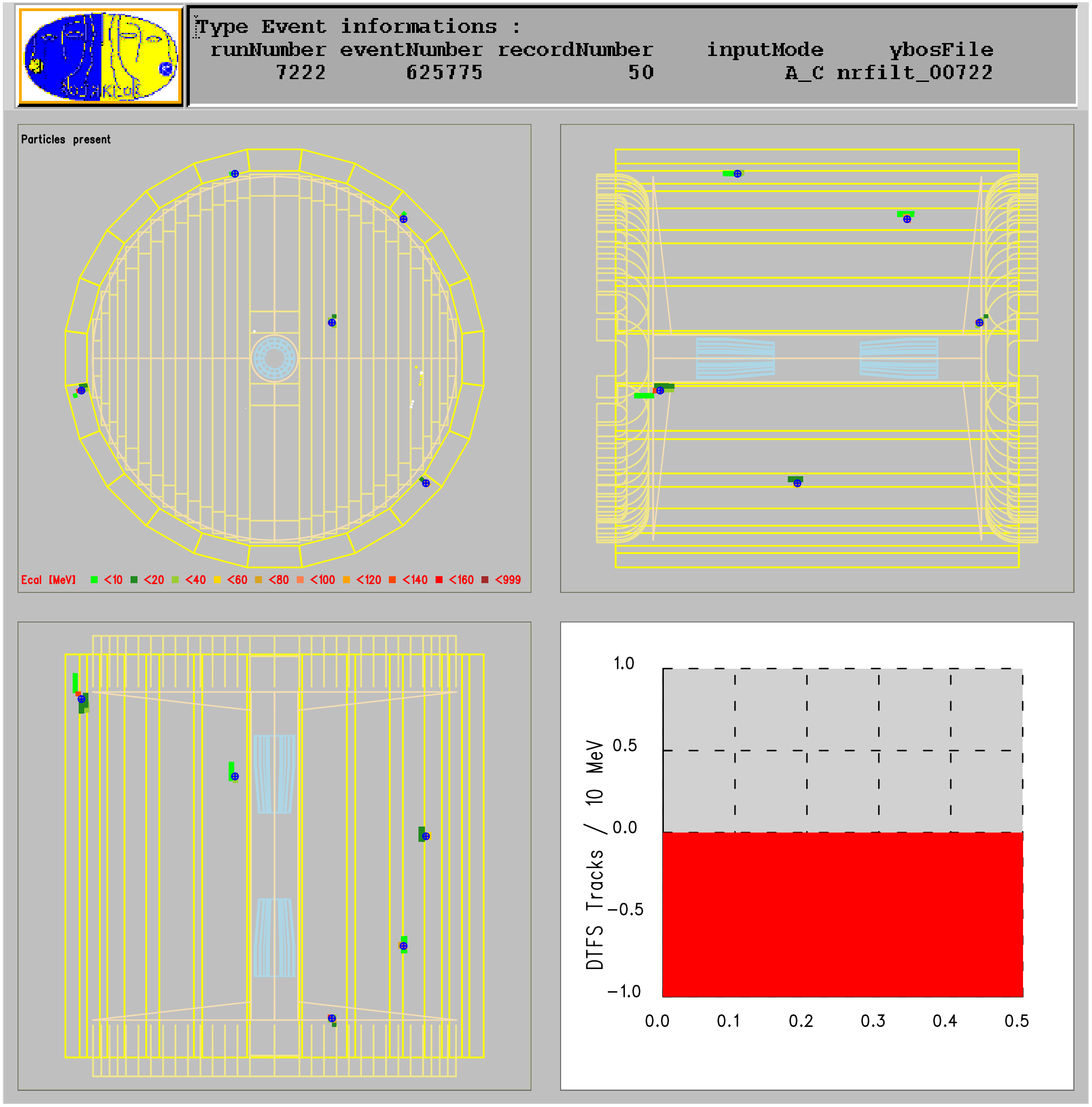
5 γ's events



– Data

- MC
  ($f_o\gamma + \omega\pi^o$ events)

$\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ candidate



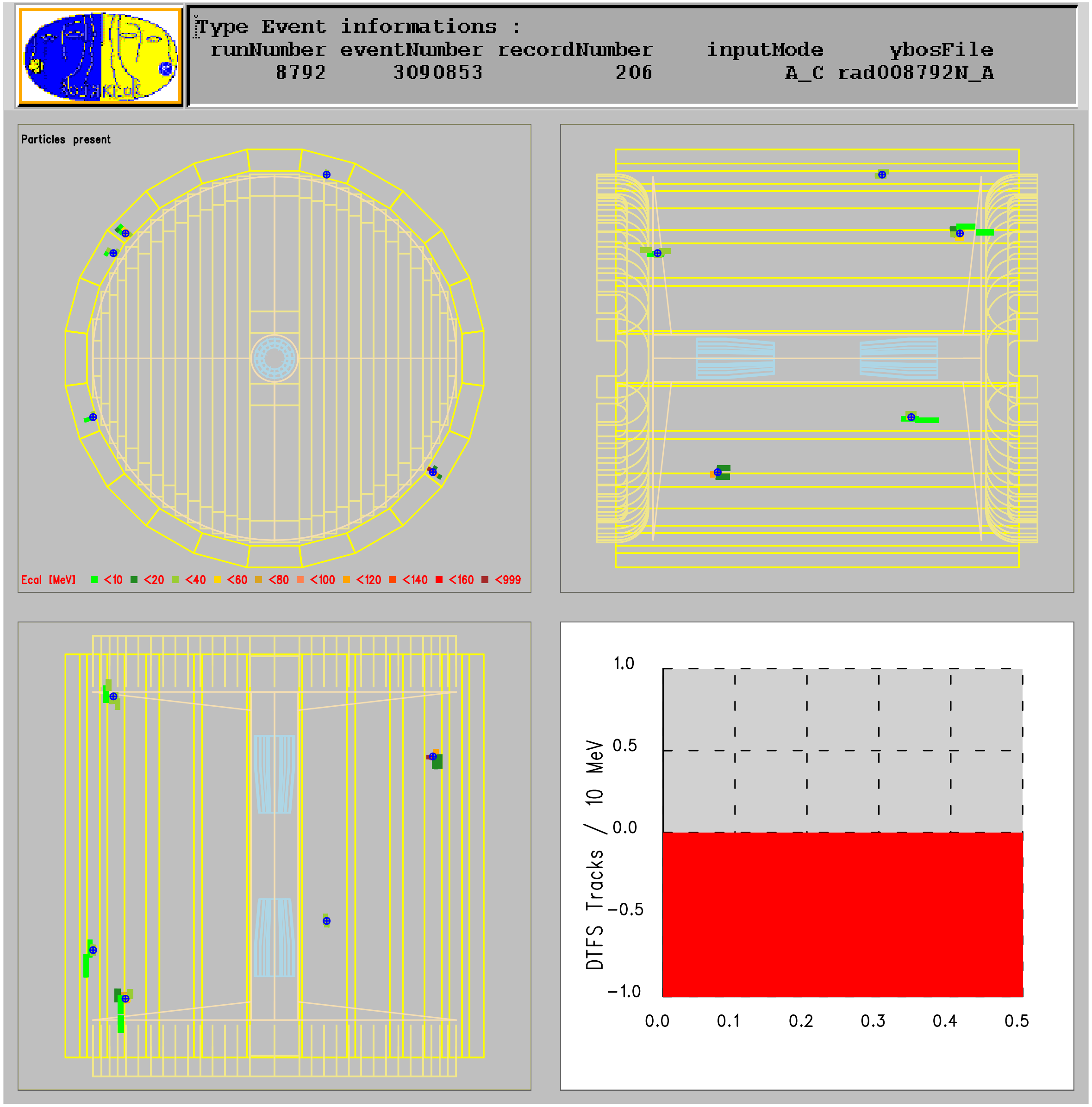
$$E_{\gamma\ rad} = 189.7\ \text{MeV}$$

$$M_{f_0} = 889.7\ \text{MeV}/c^2$$

$$M_{\pi^o_1} = 137.6\ \text{MeV}/c^2$$

$$M_{\pi^o_2} = 136.3\ \text{MeV}/c^2$$

$\phi \to \omega\pi^o \to \pi^o\pi^o\gamma$ candidate



$$E_{\gamma\,\mathrm{rad}} = 439.2\ \mathrm{MeV}$$

$$M_{\omega} = 775.8\ \mathrm{MeV}/c^2$$

$$M_{\pi^o_1} = 132.7\ \mathrm{MeV}/c^2$$

$$M_{\pi^o_2} = 120.2\ \mathrm{MeV}/c^2$$

Conclusions

- KLOE and DAΦNE joined operation has just started
- The study of ϕ radiative decays is one of the first analysis items
- Both charged and neutrals final states has been studied analysing MC events obtained with a realistic detector simulation and a full event reconstruction
- In the next KLOE run the BRs of these decays are expected to be measured with an accuracy of few percent
- First data on fully neutral decays show a good agreement with MC distributions