Studies of ϕ decays to $f_0\gamma$ and $a_0\gamma$ with KLOE at DAΦNE

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Studying the radiative decay of the Φ to the scalar mesons f_0 and a_0 has long been recognized as a method to clarify the nature of the two mesons. Both measurements of the rates BR($\phi \rightarrow f_0\gamma$), BR($\phi \rightarrow a_0\gamma$) and of their ratio allow us to discriminate between the different model proposed to describe the structure of these mesons ($q\bar{q}, qq\bar{q}\bar{q}, KK$ molecule).

Much interest has in the last years been devoted to the field of scalar mesons also as a test of theoretical tools (effective chiral models, QCD sum-rules,…) developed to describe the challenging energy region around 1 GeV, where chiral perturbation theory is not reliable anymore and perturbative QCD is still not valid.

Studying f_0 and a_0 at

KLOE has collected ~ 30 pb^{-1} by the end of 2000.
A data sample of 17 pb^{-1} has been so far analyzed, searching for:

☞ f_0 and a_0 fully neutral decays

$$f_0 \rightarrow \pi^0 \pi^0$$

$$a_0 \rightarrow \eta\, \pi^0\, (\eta \rightarrow \gamma\, \gamma)$$

These decays have been studied by looking at 5 photon final state.

☞ $\phi \rightarrow a_0 \gamma \rightarrow \eta\pi^0\, \gamma,\ \eta \rightarrow \pi^+\pi^-\pi^0$

A detailed analysis is going on to estimate systematic errors.

All these analyses are being finalized to measure the $\phi \rightarrow f_0 \gamma$, $\phi \rightarrow a_0 \gamma$ rates and the invariant mass spectrum shape of the resonance, which depends on the meson internal structure.

5 photon final state

$\phi \to f_0 \gamma \to \pi^0 \pi^0 \gamma$
$\phi \to a_0 \gamma \to \eta \pi^0 \gamma, \eta \to \gamma \gamma$

Most of the selection steps are common to the two analyses:

•5 energy deposits in EmC with energy > 7 MeV in the time window $|t-R/c|<\min(5\sigma_t, 2ns)$ to select 5 photons coming from the I.R. (prompt photons).

•Acceptance cut: $21^o < \theta_{EmC} < 159^o$ to exclude the region around the beam pipe.

Many background channels are selected together with the signal.

Expected S/B ratios*:

Background to $\phi \to f_0 \gamma$	S/B
$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0 \gamma$	0.6
$\phi \to \rho^0\pi^0 \to \pi^0\pi^0 \gamma$	3.7
$\phi \to a_0 \gamma \to \eta\pi^0\gamma \to \gamma\gamma \pi^0 \gamma$	3.5
$\phi \to \pi^0 \gamma$	0.10
$\phi \to \eta \gamma \to \pi^0\pi^0\pi^0 \gamma$	0.02

Background to $\phi \to a_0 \gamma$	S/B
$e^+e^- \to \omega\pi^0 \to \eta\pi^0 \gamma$	71
$\phi \to \rho^0\pi^0 \to \eta\pi^0 \gamma$	5.3
$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0 \gamma$	0.14
$\phi \to \rho^0\pi^0 \to \pi^0\pi^0 \gamma$	1
$\phi \to f_0 \gamma \to \pi^0\pi^0\gamma$	0.27
$\phi \to \eta \gamma \to \gamma \gamma \gamma$	6.1×10^{-3}
$\phi \to \eta \gamma \to \pi^0\pi^0\pi^0 \gamma$	7.5×10^{-3}

*Derived from SND collaboration measurements at VEPP-2M (M. N. Achasov et al., Phys. Lett. B485 (2000), 349, V. M. Aulchenko et al., JETP 90 (2000), 1067) and from PDG values.

5 photon final state

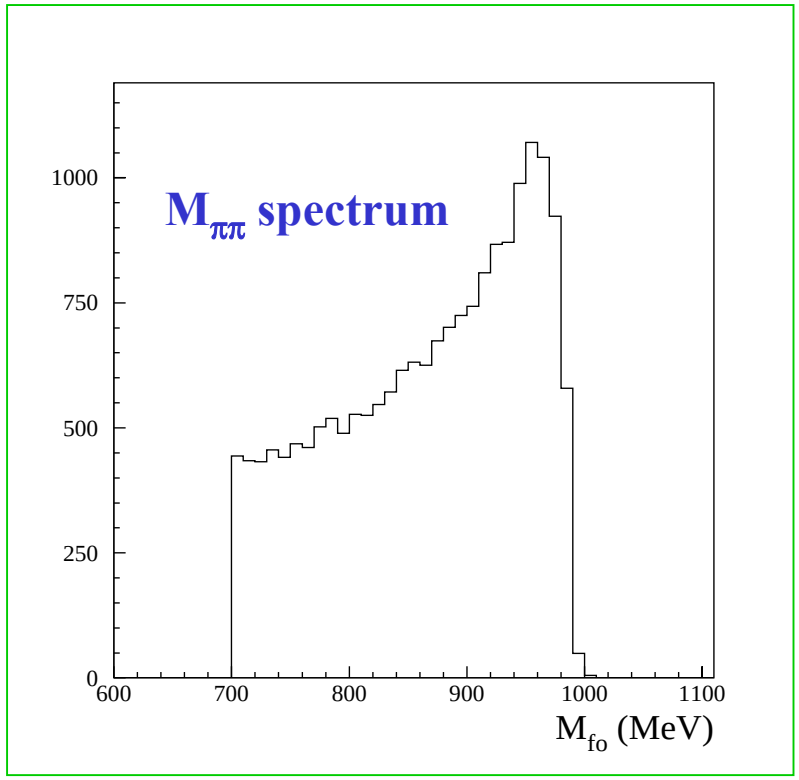
- A first kinematic fit is applied to the selected events with the constraints of total energy and momentum conservation and requiring t-R/c=0 for each prompt photon.

- A photon pairing is performed to look for the best photon combination in the different hypotheses $\pi^0\pi^0\gamma$, $\eta\pi^0\gamma$, $\omega\pi^0$, $\eta\gamma \rightarrow \gamma\gamma\gamma$, $\pi^0\gamma$.

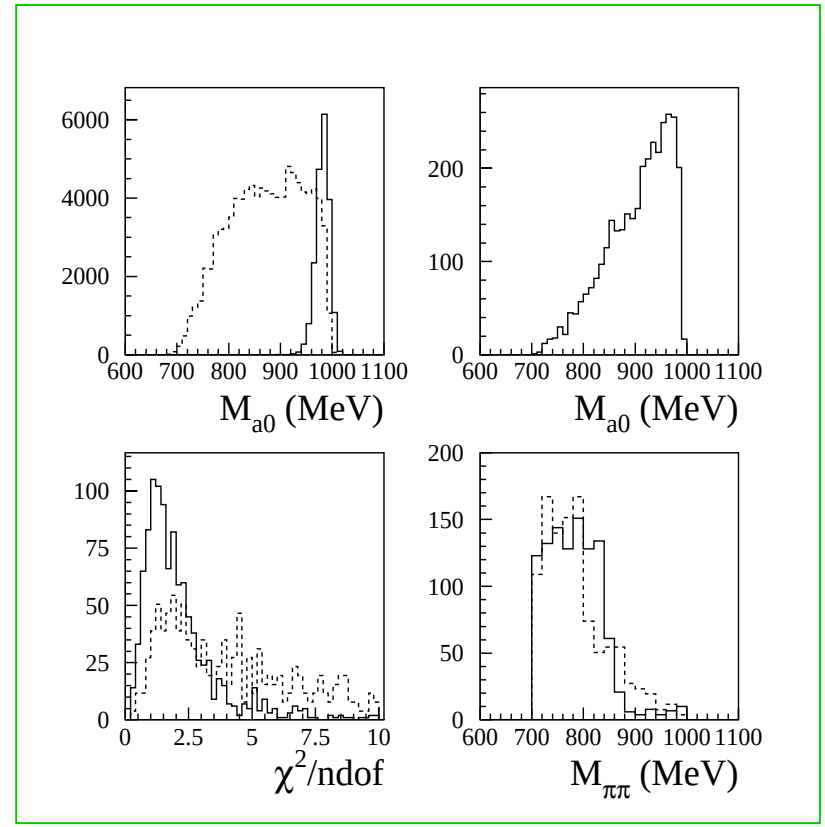
- A second kinematic fit is applied to each of the best combinations: further constraints on π^0 and η masses are required to the assigned $\gamma\gamma$ pairs.

The $\phi \to f_0\gamma \to \pi^0\pi^0\gamma$ decay: MC simulation

A generator* with different parametrizations for the signal is implemented in our MC: a "long-tail" f_0 distribution has been chosen for this analysis. A cut at $M_{\pi\pi}$ = 700 MeV is applied.



Also the a_0 background rejection efficiency depends on the MC parametrization. MC flat spectra have been corrected to reproduce SND distributions.



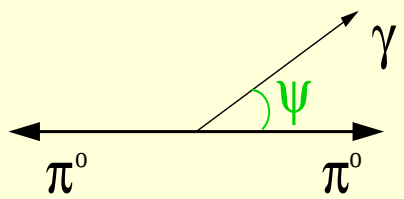
* K. Melnikov et al., Phys. Lett. B477 (2000), 114

The $\phi \to f_0\gamma \to \pi^0\pi^0\gamma$ decay: *S* selection and *B* rejection

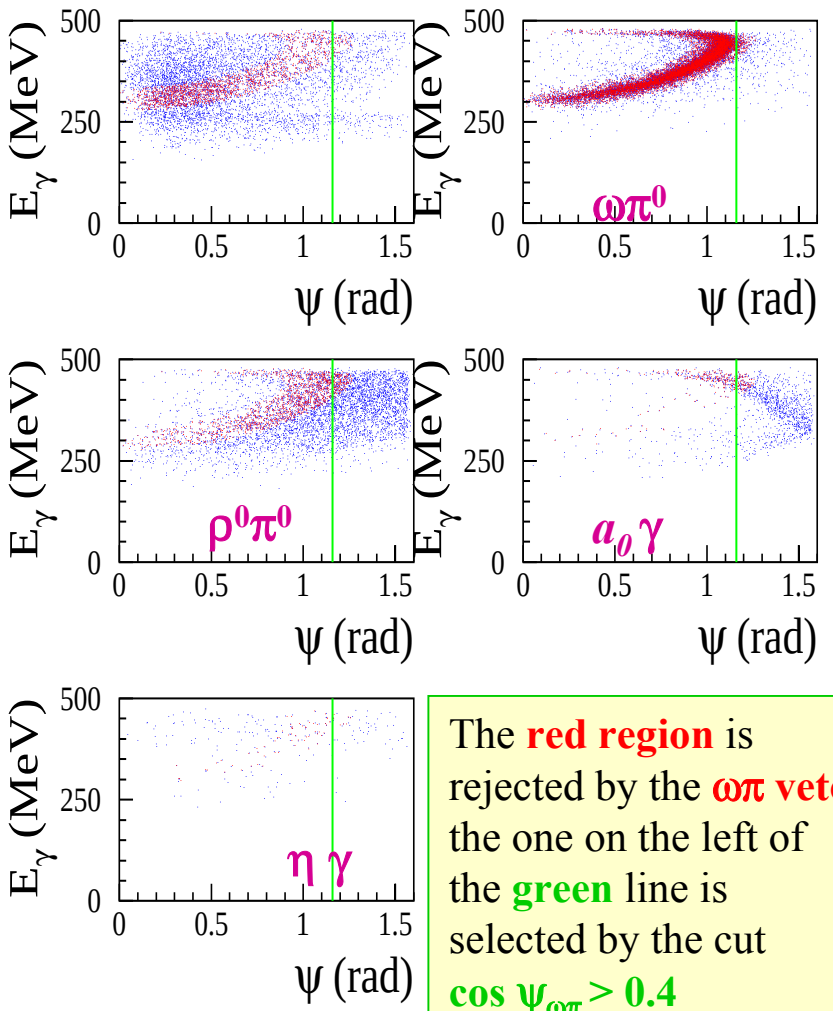
The following cuts are applied to the 5γ event sample:

- $\chi^2/\mathrm{ndf} < 5$
- 5σ cut on the reconstructed π^0 mass
- $\chi^2_{\omega\pi}/\mathrm{ndf} < 3$ and 3σ cut on the reconstructed ω mass to veto $e^+e^- \to \omega\pi^0$
- **$\cos\psi_{\omega\pi}$** > 0.4 to reduce $\phi \to a_0\gamma$, $\phi \to \rho_0\pi_0$ background

ψ angle definition:



- further cuts are applied to reject $\gamma\gamma\gamma$ events from $e^+e^- \to \gamma\gamma(\gamma)$ and $\phi \to \pi^0\gamma$

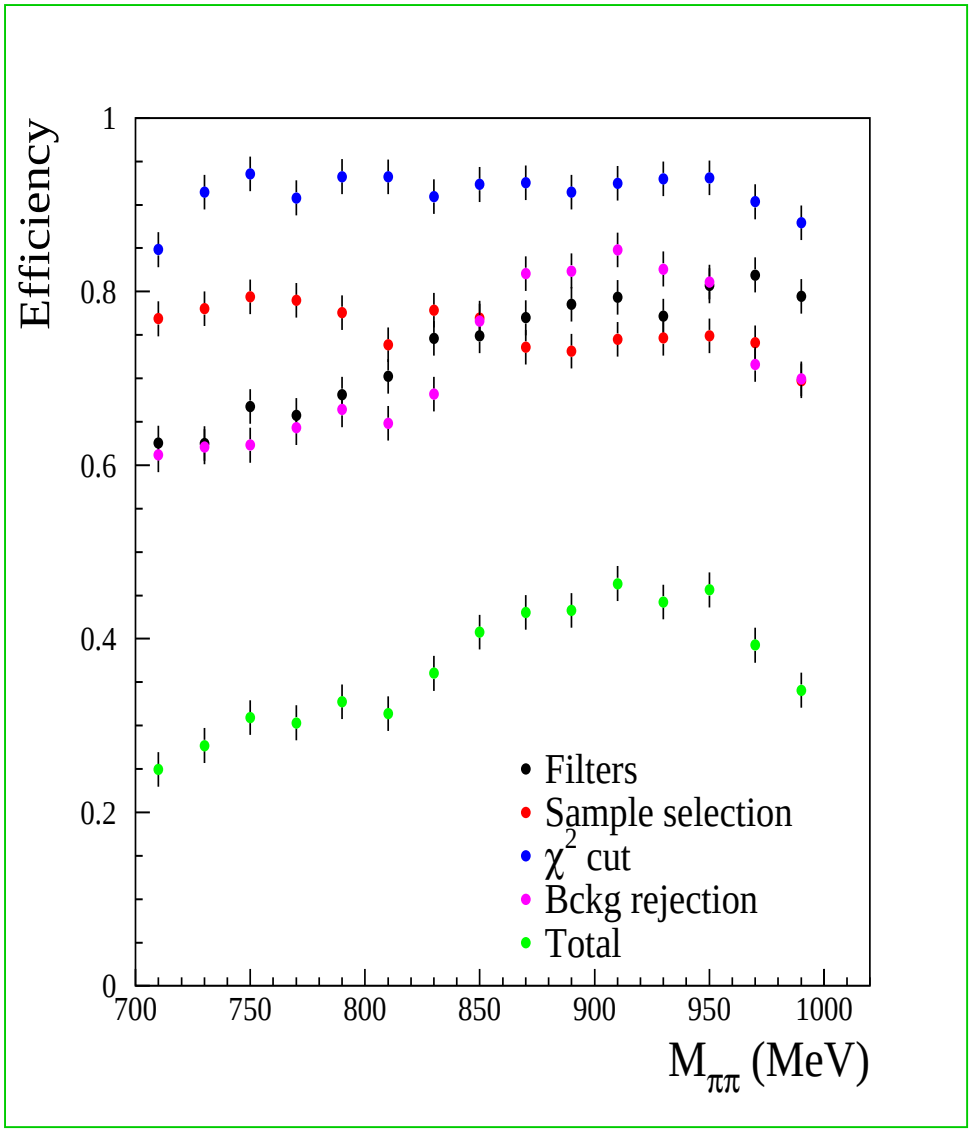


The **red region** is rejected by the **$\omega\pi$ veto**, the one on the left of the **green** line is selected by the cut **$\cos\psi_{\omega\pi} > 0.4$**

The $\phi \to f_0\gamma \to \pi^0\pi^0\gamma$ decay: selection efficiencies

The analysis efficiency has been evaluated as a function of $M_{\pi\pi}$ by dividing the $M_{\pi\pi}$ in 20 MeV slices.

Background to $\phi \to f_0\gamma$	ε
$\phi \to f_0\gamma \to \pi^0\pi^0\gamma$	39.7%
$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$	1.2%
$\phi \to \rho^0\pi^0 \to \pi^0\pi^0\gamma$	4.9%
$\phi \to a_0\gamma \to \eta\pi^0\gamma \to \gamma\gamma\pi^0\gamma$	1.9%
$\phi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$	5×10^{-4}



The $\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$ decay: DATA-MC comparison

To take into account the dependence of the kinematic distribution shapes on the f_0 model:

• the MC $M_{\pi\pi}$ spectrum is divided into slices and for each one the histogram shape of the different variables under study is obtained

• after subtracting the expected background from the observed $M_{\pi\pi}$ spectrum, for each slice a scale factor is evaluated that, applied to the MC distribution, allows to reproduce data

• the MC histograms corresponding to each $M_{\pi\pi}$ slice are weighted with this scale factor; the sum of the histograms is compared with data.

The $\phi \to f_0\gamma \to \pi^0\pi^0\gamma$ decay: DATA-MC comparison

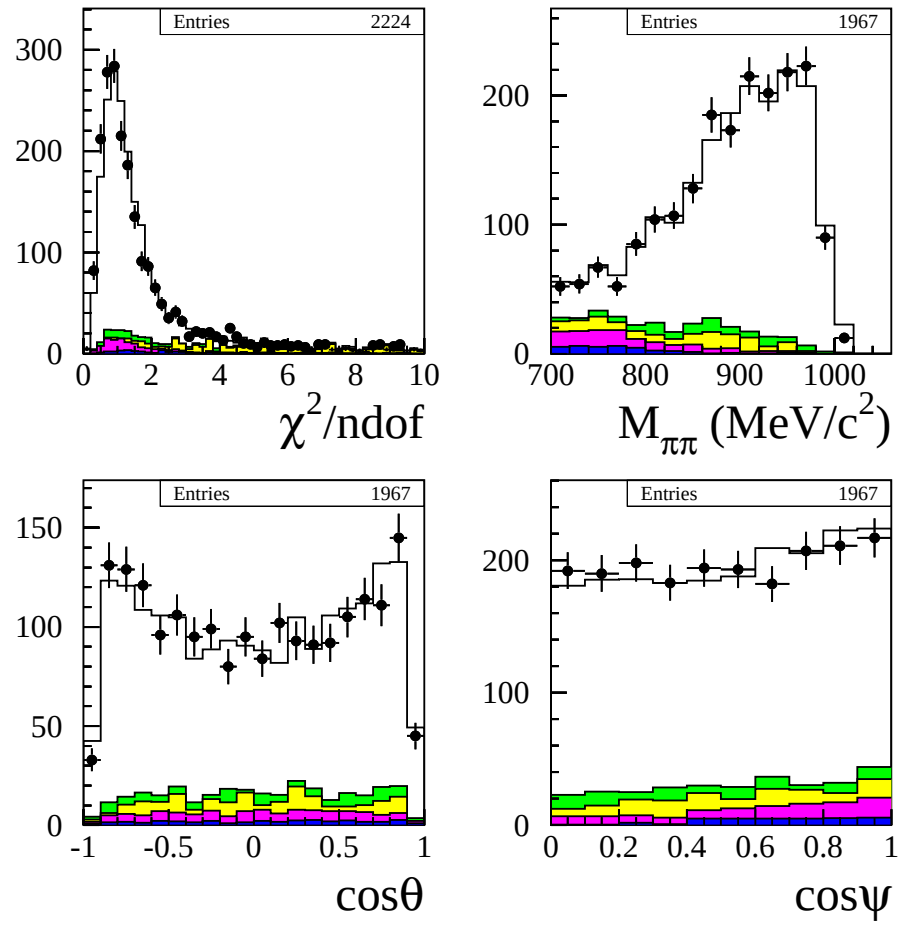
Signal distributions
before background subtraction

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

$\phi \to \rho^0\pi^0$

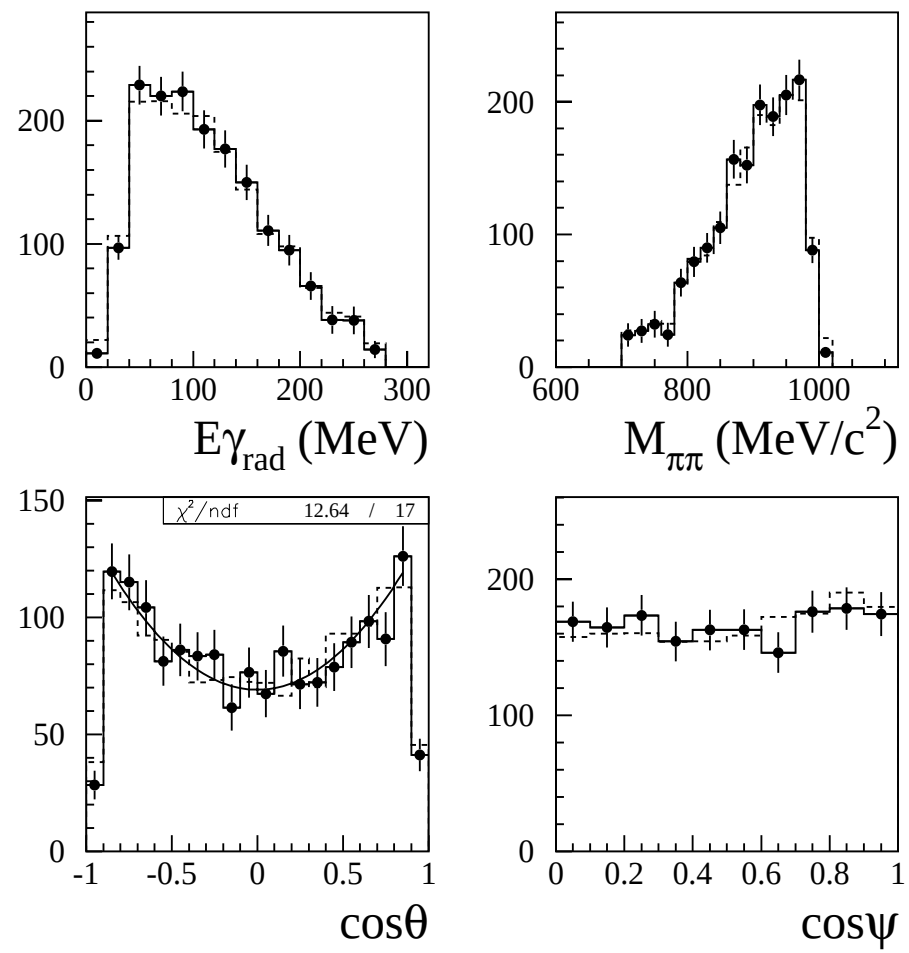
$\phi \to a_0\gamma$

$\phi \to \eta\gamma$



The $\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$ decay: DATA-MC comparison

Signal distributions
after background subtraction



The $\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$ decay: BR evaluation…

After background subtraction:

$$N_{fo} = 1662 \pm 48$$

Each $M_{\pi\pi}$ bin population is corrected by the MC analysis efficiency.
The BR is evaluated using the σ_ϕ value from $\phi \rightarrow \eta\gamma \rightarrow \gamma\gamma\gamma$ measured by KLOE
$\sigma(e^+e^- \rightarrow \phi) = (3.17 \pm 0.01 \pm 0.14)\ \mu b$ (KLOE internal memo n° 234, April 2001).

In the hypothesis that the signal interference with $\phi \rightarrow \rho^0\pi^0 \rightarrow \pi^0\pi^0\gamma$ is negligible:

$$\mathbf{BR(\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma) = (7.9 \pm 0.2_{stat}) \times 10^{-5}}$$

…and fit to $M_{\pi\pi}$ spectrum

A fit procedure is under development to extract the value of the BR directly from the fit to the experimental spectrum of different f_0 models.

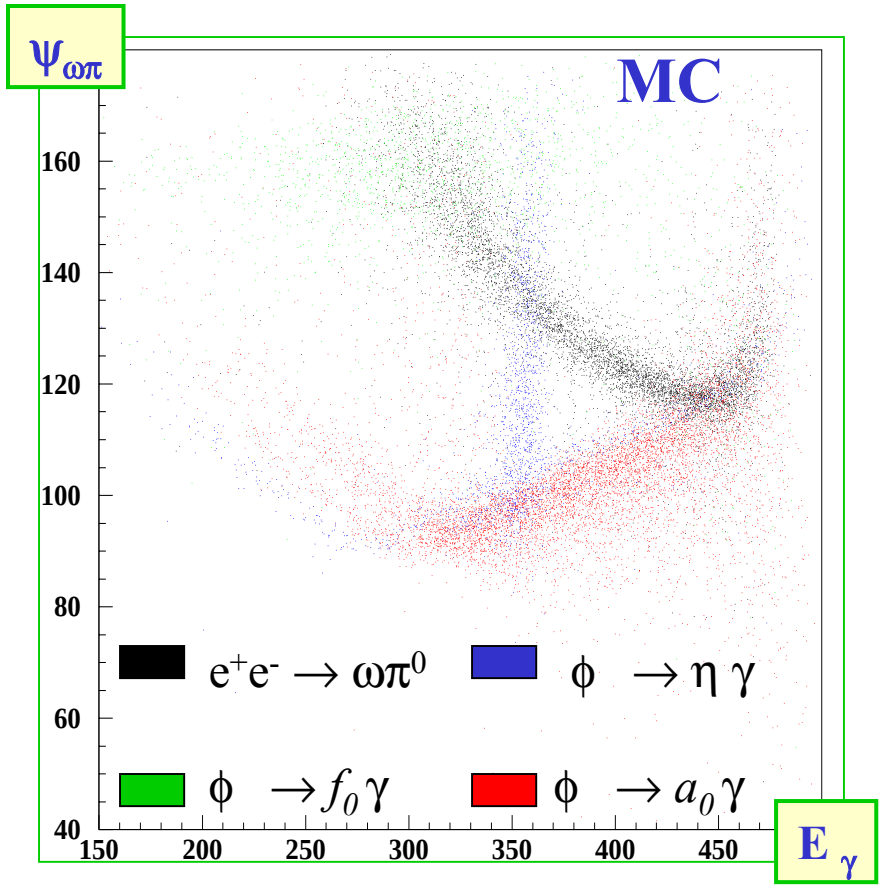
This fit procedure is also intended to take into account the experimental resolution and reconstruction effects (gaussian smearing of the theoretical *dN/dM* distribution, distortion due to wrong photon pairing, wrong clustering effects.).

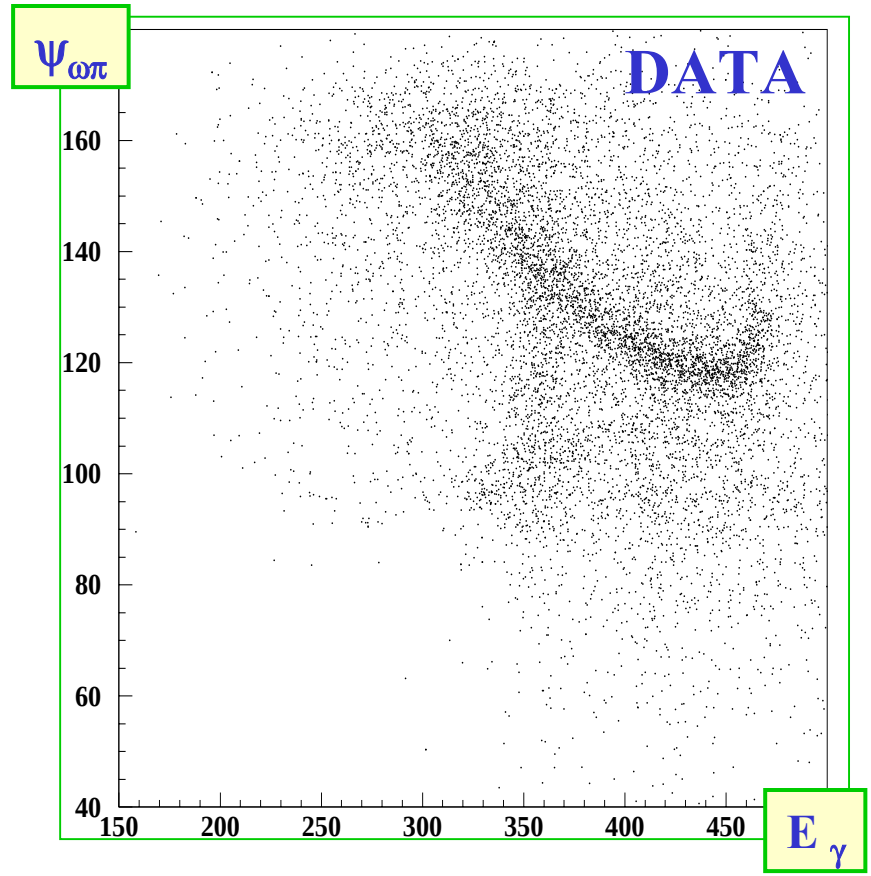
These smearing effects have already been applied to the analytical function used in the MC generator and the obtained mass spectrum well reproduces the reconstructed $M_{\pi\pi}$ distribution.

The $\phi \to a_0\gamma \to \eta\pi^0\gamma$ decay: $\pi^0\pi^0\gamma$ rejection

After the second kinematic fit (χ^2/ndf < 10) the background contamination is still high. Sample population: 10% $\phi \to \eta\pi^0\gamma$, 80% $\phi \to \pi^0\pi^0\gamma$, 10% $\phi \to \eta\gamma \to 7\gamma$s.

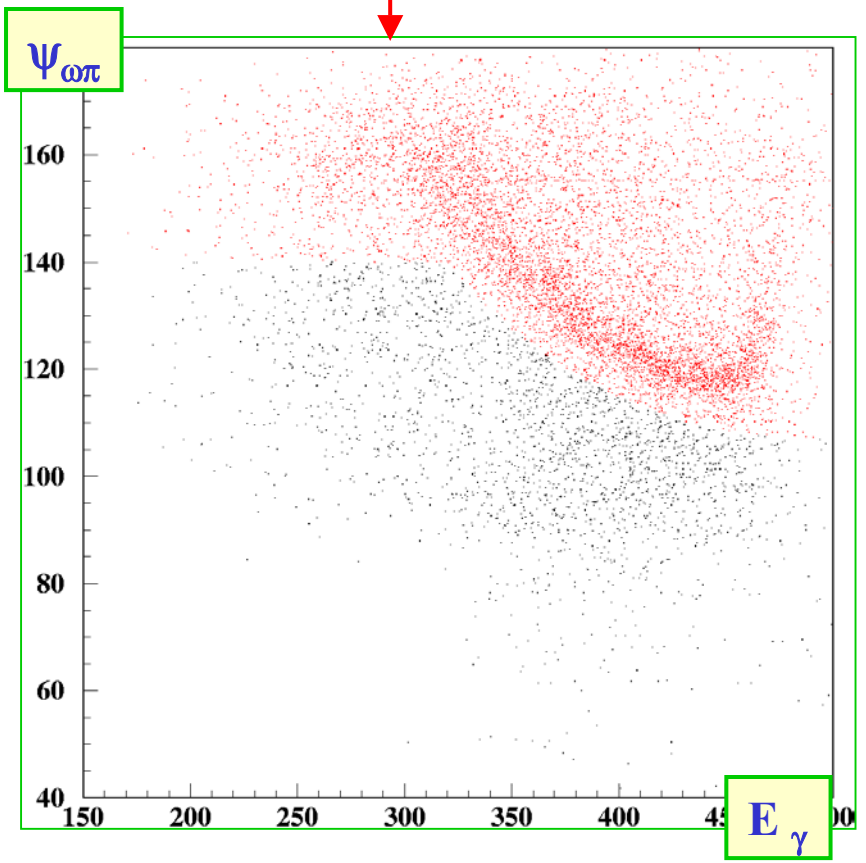
In the $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ hypothesis, $\psi_{\omega\pi}$(deg) vs **radiative photon energy E_γ**(MeV)



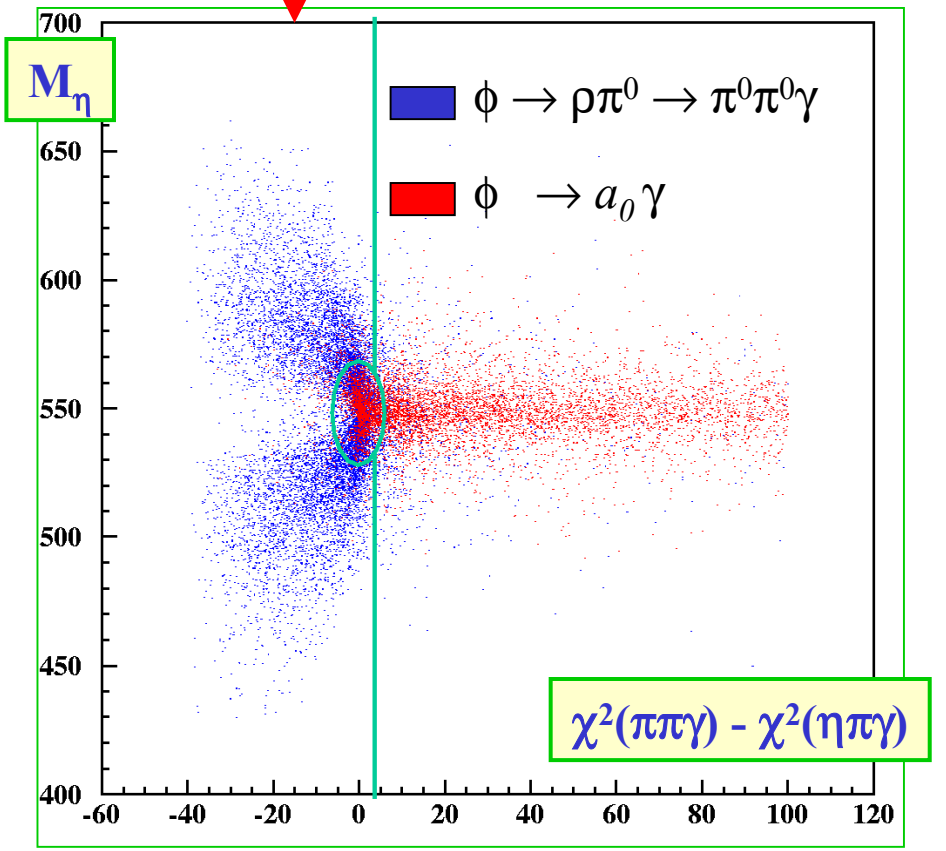


The $\phi \to a_0\gamma \to \eta\pi^0\gamma$ decay: $\pi^0\pi^0\gamma$ rejection

The **red region** is rejected to suppress $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ background

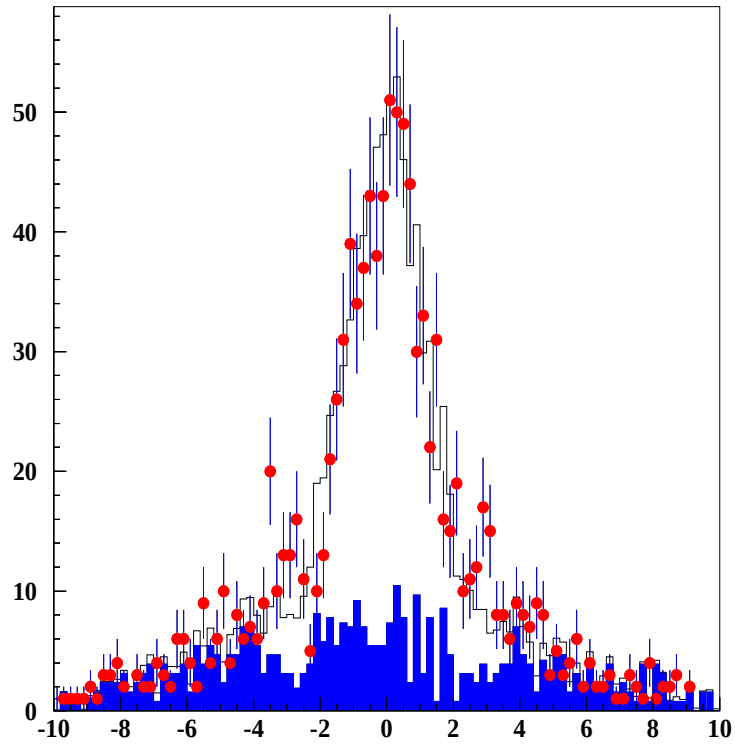


A cut in the plane M_η vs $\chi^2(\pi\pi\gamma) - \chi^2(\eta\pi\gamma)$ is used to reject $\phi \to \rho\pi^0 \to \pi^0\pi^0\gamma$



The $\phi \to a_0\gamma \to \eta\pi^0\gamma$ decay: 7γs and 3γs rejection

$\phi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$ events populate mainly the tails of η mass distribution. A two sigma cut is applied to reject 7γs background.



M_η/σ_η

The background from $e^+e^- \to \gamma\gamma(\gamma)$ is rejected by a cut on the photon pairing χ^2 in the πηγ hypothesis:

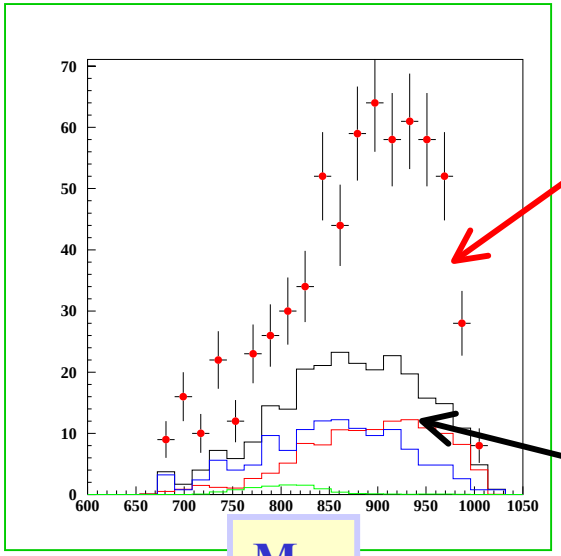
$$D_{\eta\pi\gamma} = \sqrt{\chi^2_{\eta\pi\gamma}} < 17$$

while a cut on the same χ^2 in the πγ hypothesis

$$D_{\eta\gamma} = \sqrt{\chi^2_{\eta\gamma}} > 2$$

allows to reject $\phi \to \eta\gamma \to \gamma\gamma\gamma$ events.

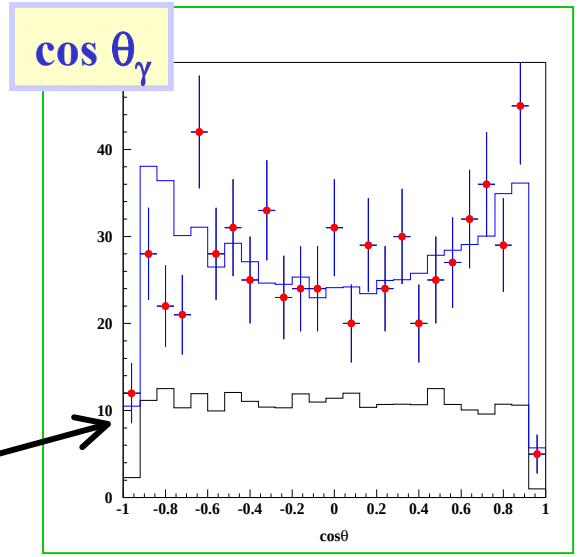
The $\phi \to a_0\gamma \to \eta\pi^0\gamma$ decay: final distributions

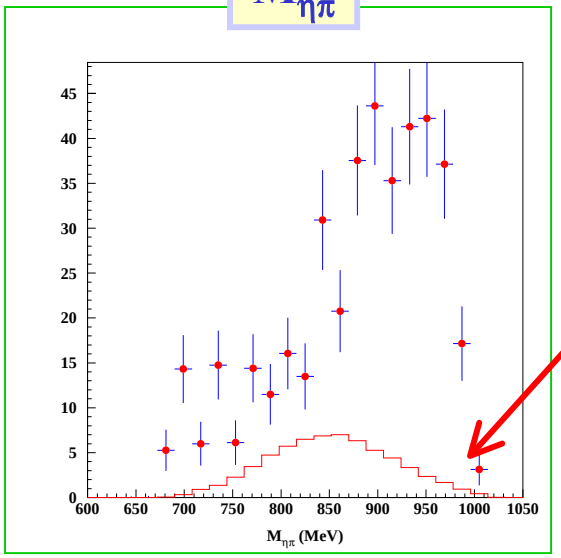


MC expectation for

- $e^+e^- \to \omega\pi^0 \to \eta\pi^0\gamma$
- $\pi^0\pi^0\gamma$ final state
- $\phi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$

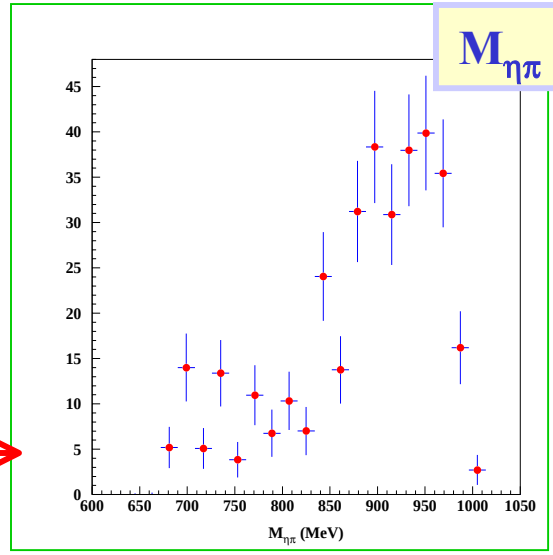
total background





MC expectation for
$\phi \to \rho\pi^0 \to \eta\pi^0\gamma$

After background subtraction



The $\phi \to a_0\gamma \to \eta\pi^0\gamma$ decay: BR evaluation

After all the cuts:

$N_{\eta\pi\gamma} = 666 \pm 26$

$N_{bckg} = 253 \pm 11$

$BR(\phi \to \eta\pi^0\gamma) = (7.4 \pm 0.5_{stat}) \times 10^{-5}$

Background to $\phi \to a_0\gamma$	ε
$\phi \to a_0\gamma \to \eta\pi^0\gamma$	27.2%
$e^+e^- \to \omega\pi^0 \to \eta\pi^0\gamma$	25.8%
$\phi \to \rho^0\pi^0 \to \eta\pi^0\gamma$	27.1%
$e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$	3.5×10^{-3}
$\phi \to \rho^0\pi^0 \to \pi^0\pi^0\gamma$	5%
$\phi \to f_0\gamma \to \pi^0\pi^0\gamma$	$1.4\text{-}3 \times 10^{-3}$*
$\phi \to \eta\gamma \to \gamma\gamma\gamma$	3.3×10^{-6}
$\phi \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$	5.4×10^{-4}

* Depending on the f_0 model

Subtracting the contribution from the $\phi \to \rho\pi^0 \to \eta\pi^0\gamma$ decay*, in the hypothesis that the interference with the signal is negligible, we find:

$$\mathbf{BR(\phi \to a_0\gamma \to \eta\pi^0\gamma) = (5.8 \pm 0.5_{stat}) \times 10^{-5}}$$

* $Br(\rho^0 \to \eta\gamma) = (3.0 \pm 0.3) \times 10^{-4}$, M.N. Achasov et al., JETP Lett. 72 (2000), 282; R. R. Akhmetshin et al., Phys. Lett. B509 (2001), 217.

Preliminary results on $\phi \to a_0\gamma \to \eta\pi^0\gamma$, $\eta \to \pi^+\pi^-\pi^0\gamma$

Selection steps and background rejection:

- 1 vertex in the interaction region with 2 connected tracks + 5 prompt photons
- acceptance cut: $21^o < \theta_{EmC} < 159^o$

Channel	# events/pb^{-1}
$\phi \to a_0\pi^0 \to \eta\pi^0\gamma$	60
$\phi \to \rho^0\pi^0 \to \eta\pi^0\gamma$	9
$e^+e^- \to \omega\pi^0 \to \eta\pi^0\gamma$	1
$\phi \to \eta\gamma \to \pi^+\pi^-\pi^0\gamma$	9000
$e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$	7000
$\phi \to K_S K_L$, $K_S \to \pi^+\pi^-$, $K_L \to \pi^0\pi^0\pi^0$	10000
$\phi \to K_S K_L$, $K_S \to \pi^0\pi^0$, $K_L \to \pi^+\pi^-\pi^0$, $K_L \to l^\pm\pi^\pm\nu$	15000

As in the case of 5 photon final state:

- first kinematic fit to constrain the event
- photon pairing
- second kinematic fit with the constrain on the π^0 mass

Preliminary results on $\phi \to a_0\gamma \to \eta\pi^0\gamma$, $\eta \to \pi^+\pi^-\pi^0\gamma$

Analysis efficiency for signal and background channels:

Channel	ε
$\phi \to a_0\pi^0 \to \eta\pi^0\gamma$	21.4%
$\phi \to \eta\gamma \to \pi^+\pi^-\pi^0\gamma$	$< 1 \times 10^{-4}$
$e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\pi^0\pi^0$	1×10^{-4}
$\phi \to K_S K_L$, $K_S \to \pi^+\pi^-$, $K_L \to \pi^0\pi^0\pi^0$	$< 1 \times 10^{-5}$
$\phi \to K_S K_L$, $K_S \to \pi^0\pi^0$, $K_L \to \pi^+\pi^-\pi^0$, $K_L \to l^\pm\pi^\pm\nu$	1×10^{-5}

BR evaluation:

186 events surviving all the cuts

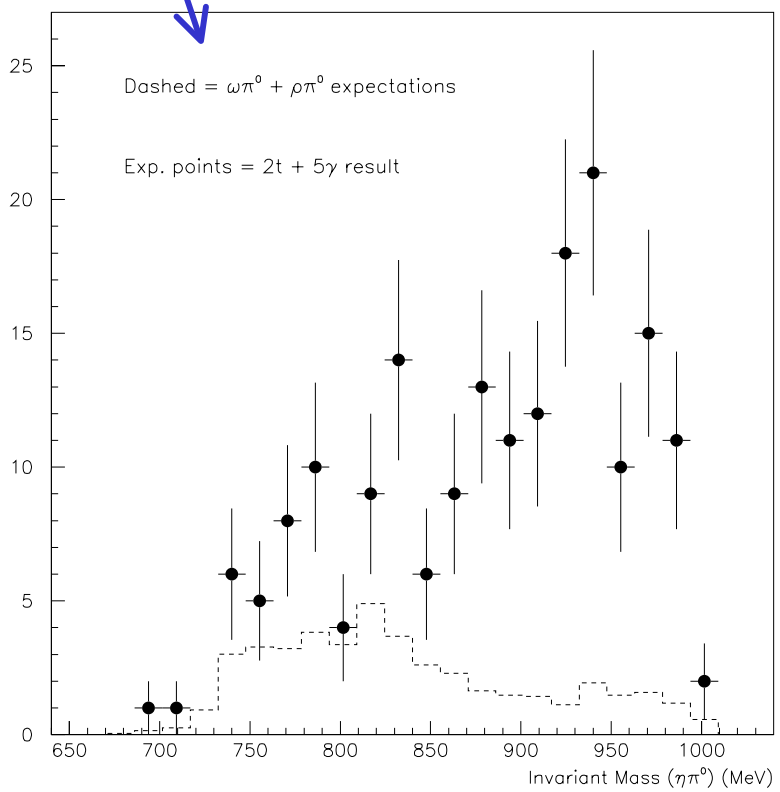
$$\mathbf{BR(\phi \to \eta\pi^0\gamma) = (6.7 \pm 0.9_{stat}) \times 10^{-5}}$$

The decay $\phi \to \eta\gamma \to \gamma\gamma\gamma$ is used to evaluate the number of ϕs.

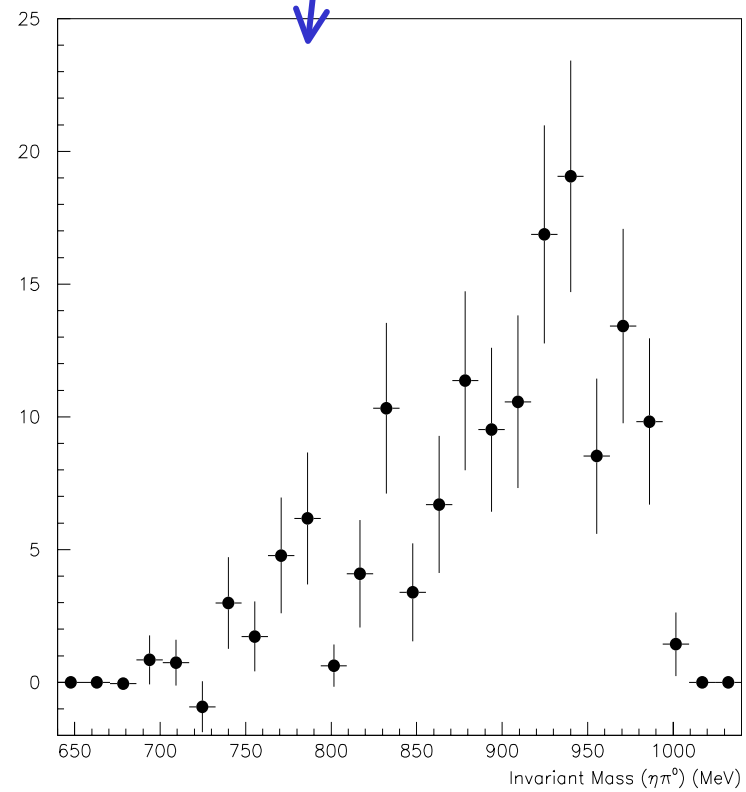
Preliminary results on $\phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma$, $\eta \rightarrow \pi^+\pi^-\pi^0\gamma$

Final SPECTRUM

before…



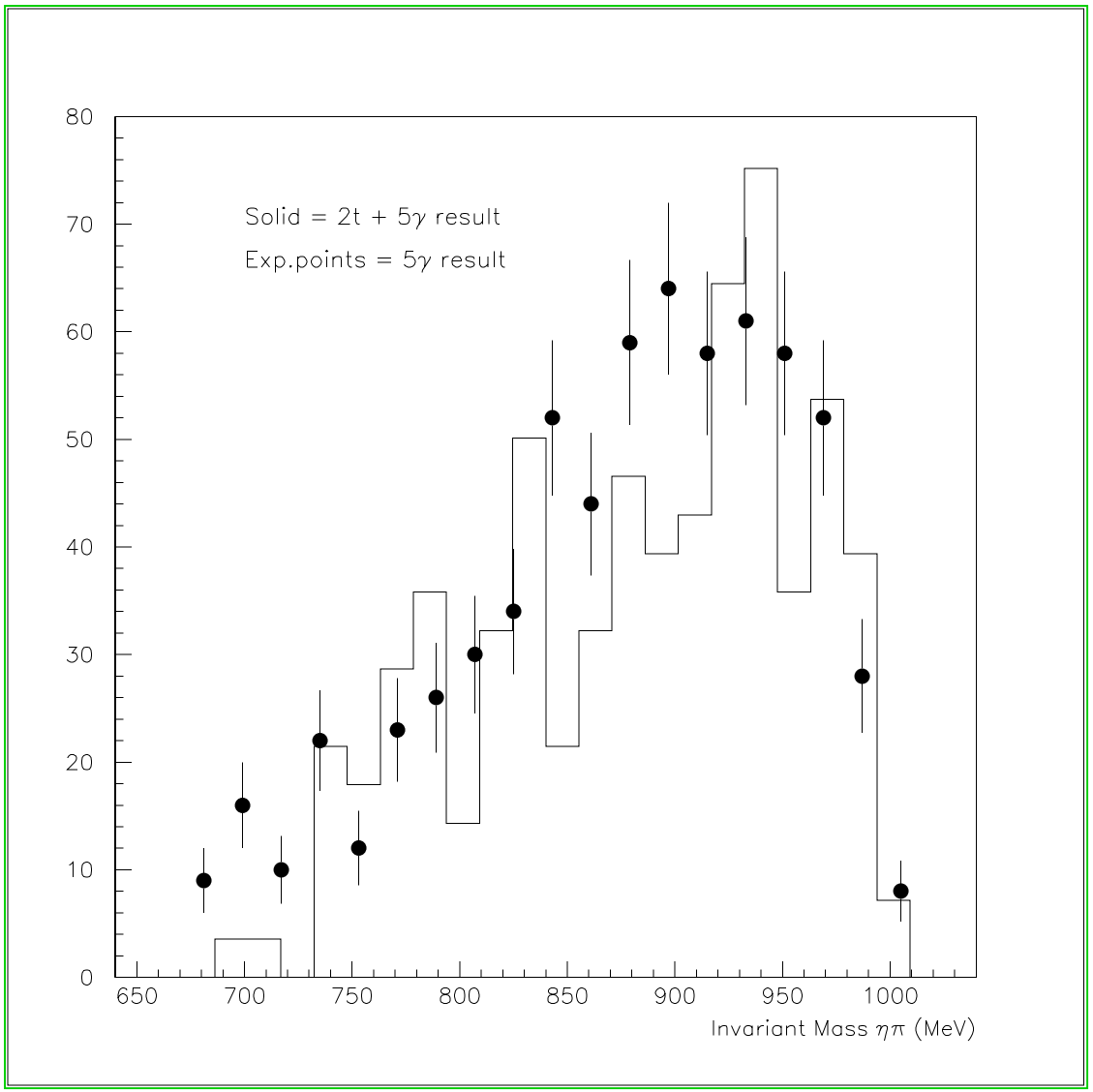
…and after background subtraction



Preliminary results on $\phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma$, $\eta \rightarrow \pi^+\pi^-\pi^0\gamma$

Comparison with the neutral channel

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



Conclusion:

In KLOE we have performed the analysis of ϕ radiative decay to f_0 and a_0 with ~17 pb^{-1} collected in 2000:

$BR(\phi \to f_0\gamma \to \pi^0\pi^0\gamma) = (7.9 \pm 0.2_{stat}) \times 10^{-5}$	$M_{\pi\pi} > 700$ MeV
$BR(\phi \to a_0\gamma \to \eta\pi^0\gamma) = (5.8 \pm 0.5_{stat}) \times 10^{-5}$	from the channel $\eta \to \gamma\gamma$
$BR(\phi \to \eta\pi^0\gamma) = (6.7 \pm 0.9_{stat}) \times 10^{-5}$	from the channel $\eta \to \pi^+\pi^-\pi^0$

KLOE collaboration hep-ex/0107024

corresponding to

$$\frac{BR(\phi \to f_0\gamma)}{BR(\phi \to a_0\gamma)} = \frac{3 \times (7.9 \pm 0.2_{stat})}{5.8 \pm 0.5_{stat}} = 4.1 \pm 0.4_{stat}$$

The analyses are going on in order to evaluate the systematic errors which should not exceed 10%.

A preliminary analysis of the decay $\phi \to f_0\gamma \to \pi^+\pi^-\gamma$ has also been performed:

$$\mathbf{BR(\phi \to f_0\gamma \to \pi^+\pi^-\gamma) < 1.64 \times 10^{-4}}$$

KLOE collaboration hep-ex/0006036

which confirms the indication of destructive interference with non-resonant background $e^+e^- \to \pi^+\pi^-\gamma$, as suggested by SND and CMD-2 data (hep-ex/9907005).

The high values found for the branching ratios of $\phi \to f_0\gamma$ and $\phi \to a_0\gamma$ are at least 1 order of magnitude larger than what expected if they were members of the $q\bar{q}$ nonet.

The value found for the ratio of the branching ratios agrees very closely with that predicted by F. Close* based on the picture that these systems have a compact $qq\bar{q}\bar{q}$ core surrounded by a $K\bar{K}$ cloud.

* hep-ph/0106108