Searches of scalar mesons at KLOE

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for the KLOE Collaboration

- The $\phi \to \pi^o\pi^o\gamma$, $\phi \to \eta\pi^o\gamma$ decays: looking for f_o and a_o mesons
- Analysis of the 5 photons final states:
  - ⋆ $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$
  - ⋆ $\phi \to a_o\gamma \to \eta\pi^o\gamma \to \gamma\gamma\pi^o\gamma$
- Preliminary results on $\phi \to a_o\gamma \to \eta\pi^o\gamma$ with $\eta \to \pi^+\pi^-\pi^o$

The $\phi \to \pi^o\pi^o\gamma / \eta\pi^o\gamma$ decays

These decays allow to investigate the nature of the intermediate state, looking for $f_o(980)$ and $a_o(980)$ scalar mesons.

We are interested in:

- measuring the BR
- finding the shape of the $\pi^o\pi^o$ and $\eta\,\pi^o$ invariant masses

since both are dependent on the mesons' structure.

VEPP-2M published results:

$$\left.\begin{array}{l} \mathrm{BR}(\phi \to \pi^o\pi^o\gamma) = (1.22 \pm 0.098 \pm 0.061) \times 10^{-4} \\ \mathrm{BR}(\phi \to \eta\;\pi^o\gamma) = (0.88 \pm 0.14 \pm 0.09) \times 10^{-4} \\ \text{Phys. Lett. B485 (2000) 349, Phys. Lett. B479 (2000) 53} \end{array}\right\} \text{SND}$$

$$\left.\begin{array}{l} \mathrm{BR}(\phi \to \pi^o\pi^o\gamma) = (1.08 \pm 0.17 \pm 0.09) \times 10^{-4} \\ \mathrm{BR}(\phi \to \eta\;\pi^o\gamma) = (0.90 \pm 0.24 \pm 0.10) \times 10^{-4} \\ \text{Phys. Lett. B462 (1999) 380} \end{array}\right\} \text{CMD-2}$$

The $\phi \to \pi^o\pi^o\gamma/\eta\pi^o\gamma$ decays @ KLOE

The 5 photons final state of the KLOE 2000 data (16.60 pb^{-1}) analysed to look for the following decays:

$$\phi \to f_o\gamma \to \pi^o\pi^o\gamma$$
$$\phi \to a_o\gamma \to \eta\pi^o\gamma \to \gamma\gamma\pi^o\gamma$$

The natural S/B, using SND measurements and PDG values, are:

Bckg. to $\phi \to f_o\gamma$	S/B
$e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$	0.6
$\phi \to \rho\pi^o \to \pi^o\pi^o\gamma$	3.7
$\phi \to a_o\gamma \to \eta\pi^o\gamma \to \gamma\gamma\pi^o\gamma$	3.5
$\phi \to \pi^o\gamma$	0.10
$\phi \to \eta\gamma \to \pi^o\pi^o\pi^o\gamma$	0.023

Bckg. to $\phi \to a_o\gamma$	S/B
$\phi \to \rho^o\pi^o \to \eta\pi^o\gamma$	6.7
$e^+e^- \to \omega\pi^o \to \eta\pi^o\gamma$	50
$e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$	0.14
$\phi \to \rho^o\pi^o \to \pi^o\pi^o\gamma$	1.0
$\phi \to f_o\gamma \to \pi^o\pi^o\gamma$	0.27
$\phi \to \eta\gamma \to \gamma\gamma\gamma$	6×10^{-3}
$\phi \to \eta\gamma \to \pi^o\pi^o\pi^o\gamma$	7×10^{-3}

A preliminar search on $\phi \to a_o\gamma \to \eta\pi^o\gamma$ with $\eta \to \pi^+\pi^-\pi^o$ is also performed

The $\phi \to \pi^o\pi^o\gamma/\eta\pi^o\gamma$ decays: analysis scheme

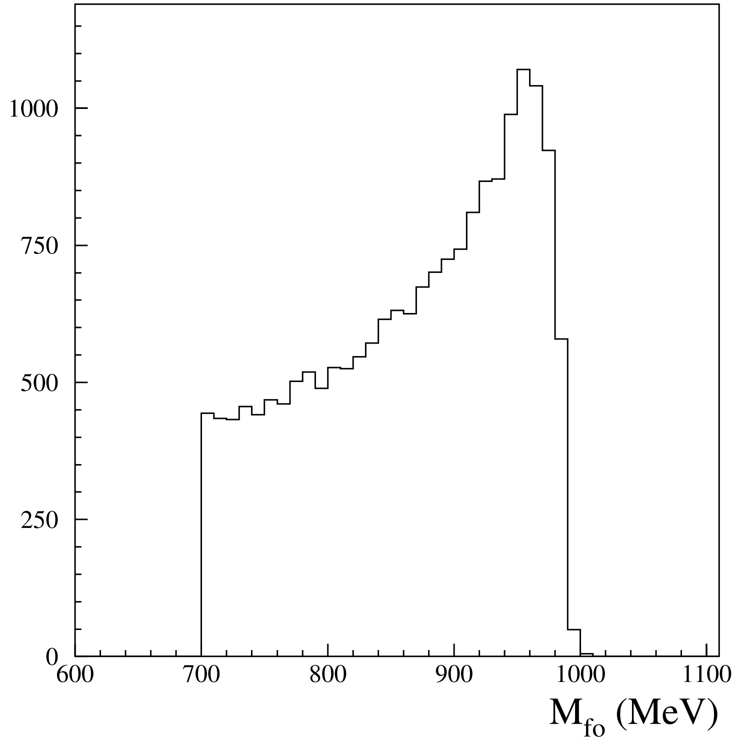
Most of the analysis steps are common to both analysis:

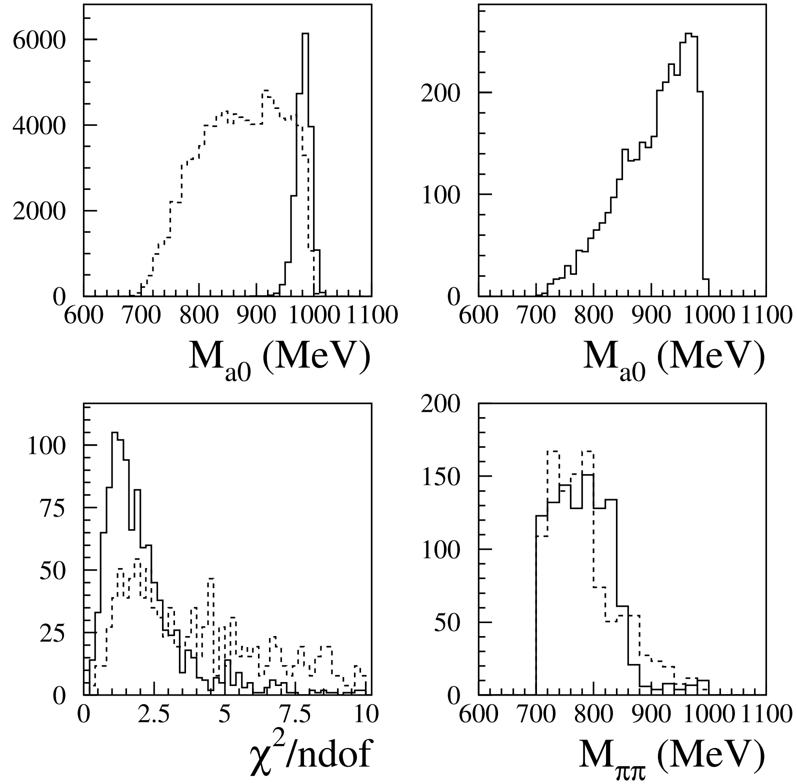
1. Time Window cut to select prompt photons coming from the I.P.: 5 EMC clusters with $E_\gamma > 7$ MeV and ($|\mathrm{T} - \mathrm{R}/c| <$ MIN$(5 \cdot \sigma_\mathrm{T}, 2$ ns$)$)
2. Acceptance cut: $21^\circ < \theta_\mathrm{EMC} < 159^\circ$
3. First kinematic fit requiring the 4-momentum conservation and the "promptness" constraint $(\mathrm{T} - \mathrm{R}/c = 0)$
4. Photons' pairing to look for the best photons combination for the hypotheses: $\pi^o\pi^o\gamma$, $\eta\pi^o\gamma$, $\omega\pi^o$, $\eta\gamma \to \gamma\gamma\gamma$ and $\pi^o\gamma$
5. Second kinematic fit for all best photons combination, constraining also on π^o and η masses of the assigned $\gamma\gamma$ pairs

The $\phi \rightarrow f_o\gamma \rightarrow \pi^o\pi^o\gamma$ decay: MC samples

A "long-tail" f_o shape used to study the decay as function of $M_{\pi\pi}$, in order to have a model independent analysis

For the moment only events with $M_{\pi\pi} > 700$ MeV considered





Different a_o mass shapes bring to a different analysis efficiency

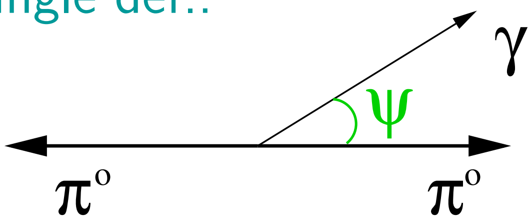
MC "flat" distribution corrected to resemble the SND shape

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

Analysis cuts:

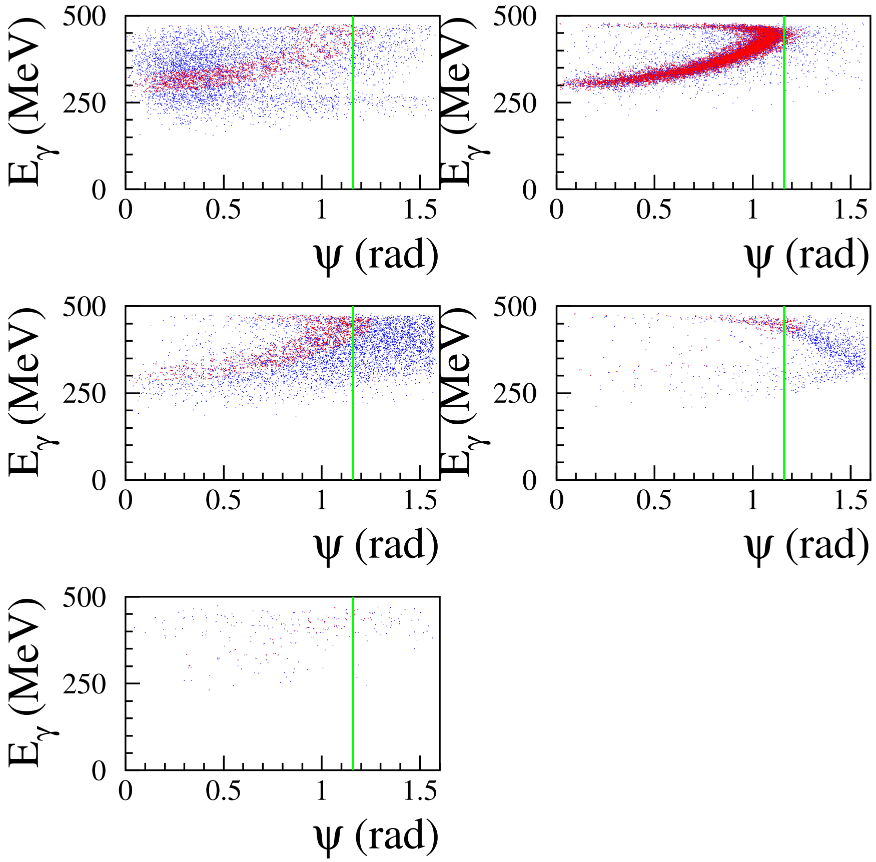
1. $\chi^2/\mathrm{ndof} < 5$
2. $|M_{\gamma\gamma} - M_{\pi^o}| < 5 \cdot \sigma_M$
3. $\cos\psi_{\omega\pi} > 0.4$
4. $\omega\pi^o$ veto: rejection of events with $\chi^2/\mathrm{ndof}_{\omega\pi} < 3$, $|M_{\pi\gamma} - M_\omega| < 3 \cdot \sigma_\omega$

ψ angle def.:



in $\pi^o\pi^o$ rest frame

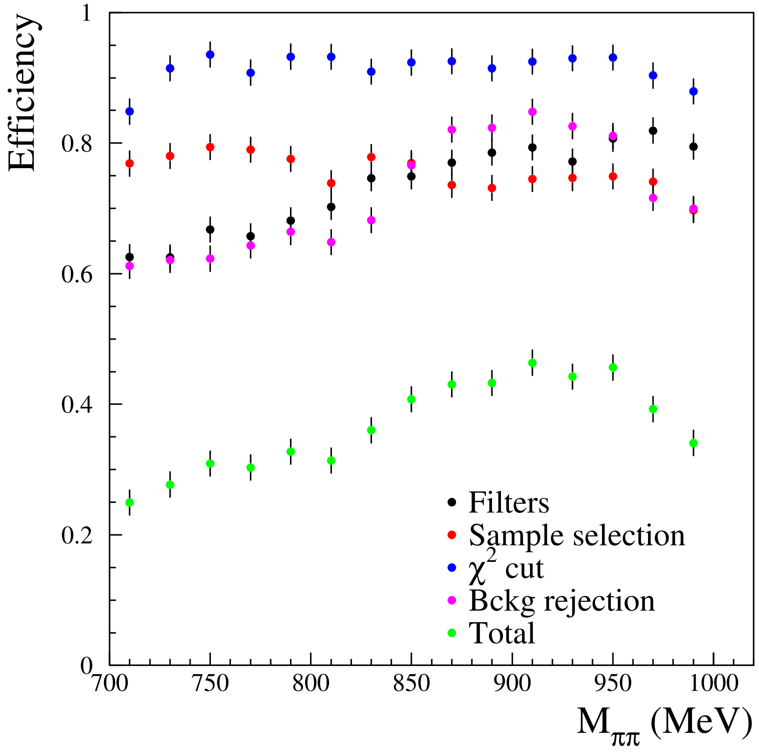
Fit results for $e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$ hypothesis:



The red region is rejected by the $\omega\pi^o$ veto

The green line corresponds to the $\cos\psi_{\omega\pi}$ cut

The $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ decay: analysis efficiencies



Analysis efficiency for the signal evaluated as a function of $M_{\pi\pi}$

Generated mass divided in 20 MeV bins

Total variation of $\sim 30\%$

Decay	$\varepsilon_{\rm ana}$
$\phi \to f_o\gamma \to \pi^o\pi^o\gamma$	39.7%
$e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$	1.2%
$\phi \to \rho\pi^o \to \pi^o\pi^o\gamma$	4.9%
$\phi \to a_o\gamma \to \eta\pi^o\gamma \to \gamma\gamma\pi^o\gamma$	1.9%
$\phi \to \eta\gamma \to \pi^o\pi^o\pi^o\gamma$	5×10^{-4}

The $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ decay: technique for BR evaluation

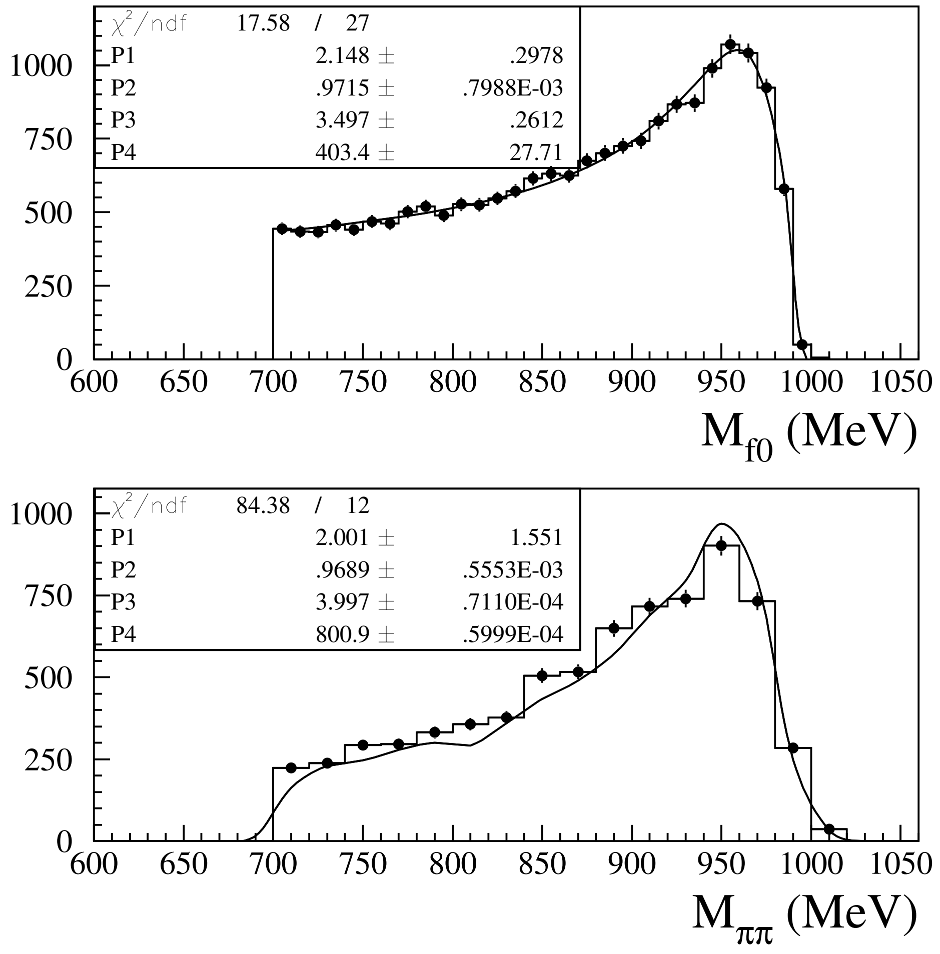
- Even assuming a perfect knowledge of the background, the observed spectrum can be corrected for the analysis efficiency on bin by bin basis only if the reconstruction effects do not modify the shape significantly
- In well reconstructed events the gaussian smearing is ~ 6 MeV
- A wrong photons' combination happens in $\sim 5\%$ of the cases, giving rise to a different shape for the various quantities
- Also wrong clustering $(4 \div 5\%)$ give rise to distorted shapes too
- To take into account these effects, a fit procedure that convolutes any theoretical dN/dM shape with the expected gaussian smearing and the wrong pairing distribution has been developed. These smearing effects have been applied to one of the analytic function used for the EVA generator. The reconstructed $M_{\pi\pi}$ shape was successfully fitted with a smeared fit function
- Same fit procedure applied on $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ MC production
- Once the procedure will be completed, it will be applied on data. BR will be evaluated directly from fit results and the new parameters will be used to reproduce the new shape in MC events

The $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ decay: fitting the MC mass shape

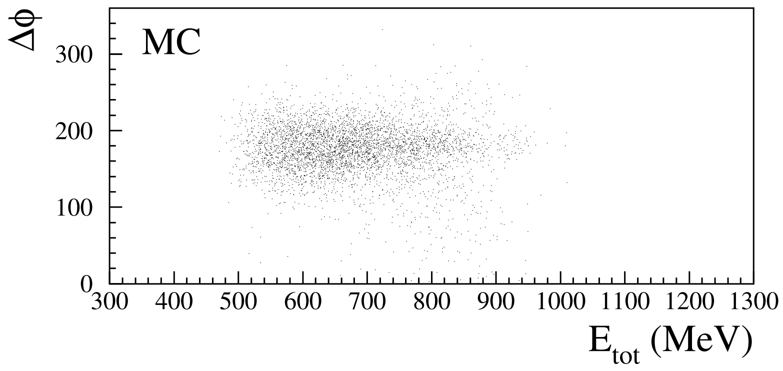
MC generated mass fitted with the analytic form

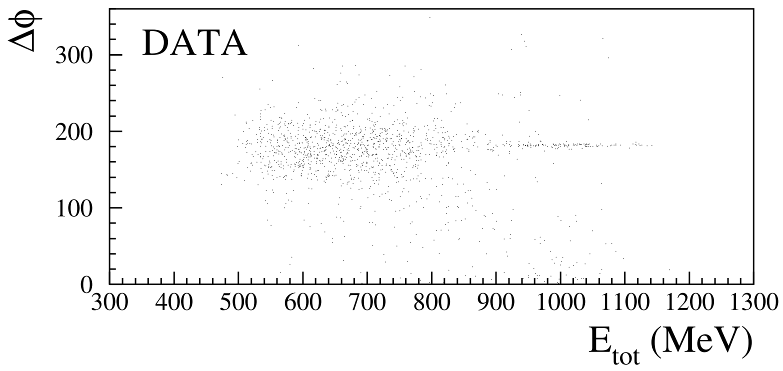
Same curve used to fit reconstructed mass using:

1. bin by bin analysis efficiency
2. 6 MeV gaussian smearing
3. bin by bin pairing efficiency, using a flat bad pairing distribution
4. no clustering effects taken into account



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





$e^+e^- \to \gamma\gamma(\gamma)$ contamination rejected using the the two most energetic clusters of the event:

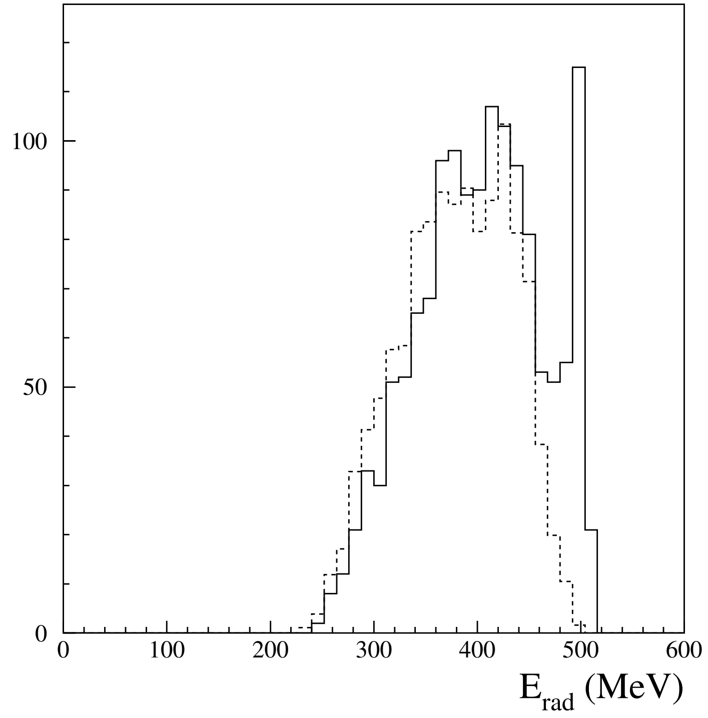
$175^\circ < \Delta\phi < 185^\circ$ and

$E_{\rm tot} > 900$ MeV

$\phi \to \pi^o\gamma$ contamination rejected requiring:

$E_{\gamma\,\rm rad}(\pi^o\gamma) < 480$ MeV

($\sim 3\,\sigma$ cut around the peak)

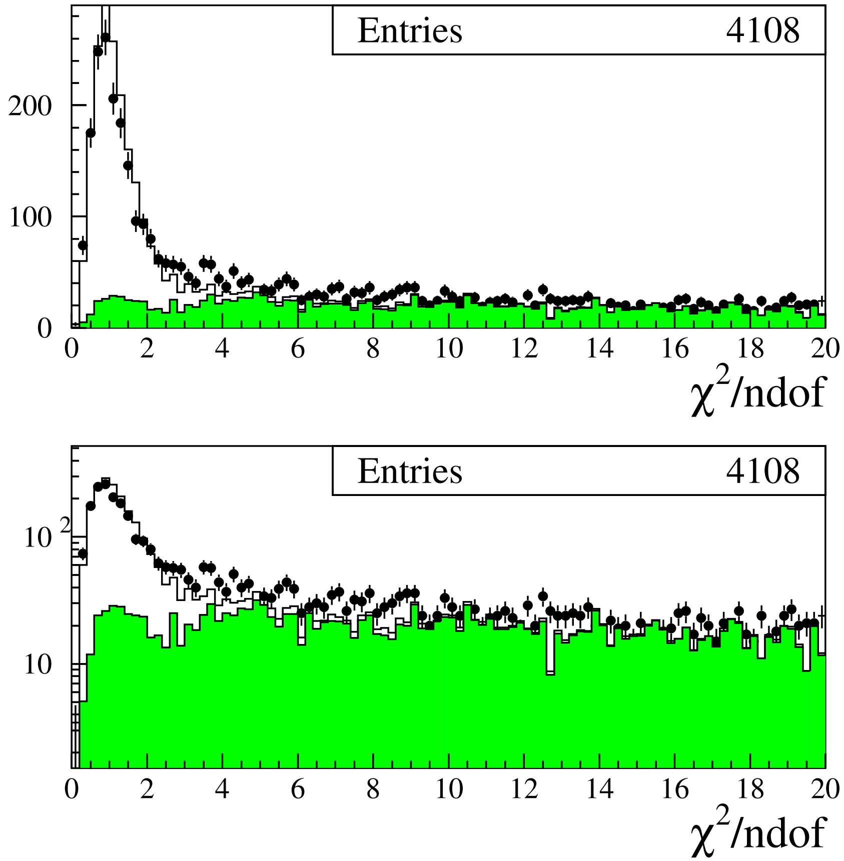


The $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ decay: DATA–MC comparison

Fit procedure not completed & MC f_o mass shape arbitrarly choosen. The comparison is done in 4 steps:

1. $f_o\gamma$ MC events analyzed in slices of $M_{\pi\pi}$ to obtain the various histograms shapes
2. For each mass bin, determination of the scale factor (ScF) that applied on the MC $M_{\pi\pi}$ shape reproduces data
3. The obtained ScF applied to all MC "sliced" histograms to reproduce all the spectra
4. Data–MC distributions compared

χ^2/ndof comparison



The $\phi \rightarrow f_o\gamma \rightarrow \pi^o\pi^o\gamma$ decay: BR evaluation

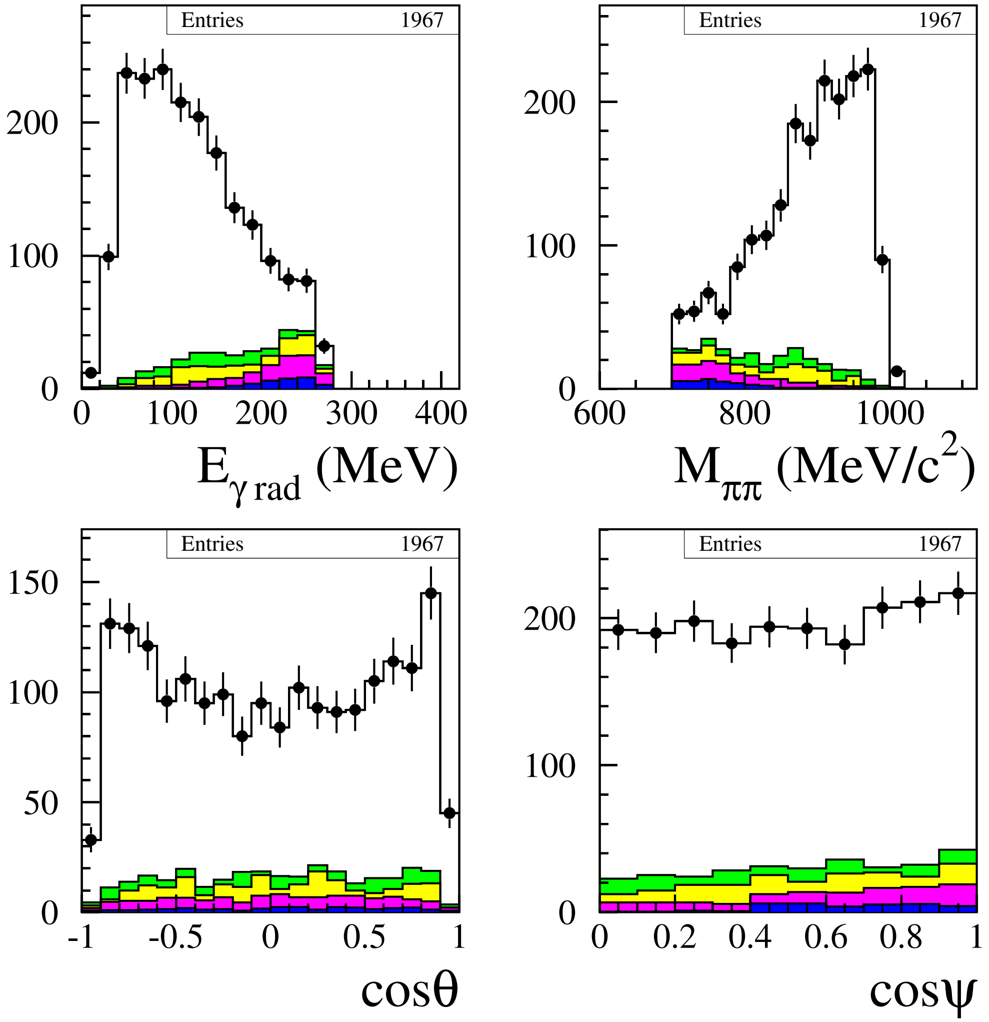
Final events counting (bckg subtracted):

$$N_{f_o\gamma} = 1662 \pm 48$$

BR evaluated using:

- σ_ϕ from $3\,\gamma$'s events
- Bin by bin analysis efficiency (i.e. no wrong clustering and pairing!)

If only the f_o meson contributes and neglecting the interference with $\phi \rightarrow \rho^o\pi^o \rightarrow \pi^o\pi^o\gamma$:

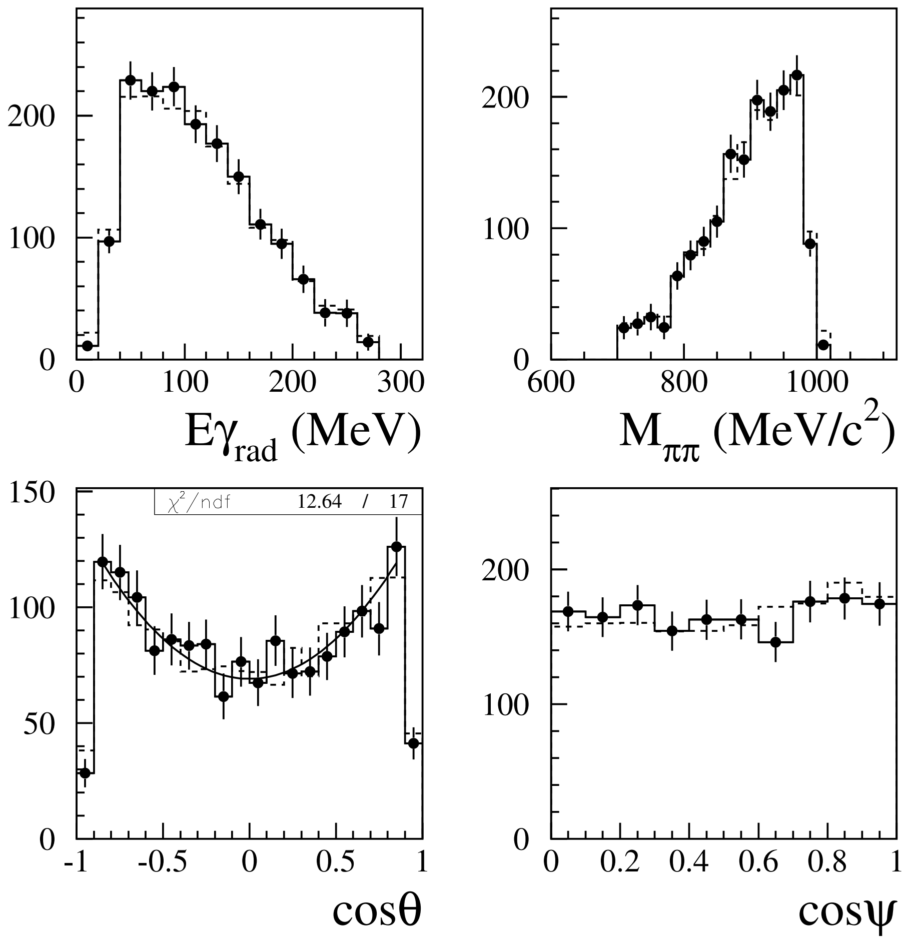


$$\mathrm{BR}(\phi \rightarrow f_o\gamma \rightarrow \pi^o\pi^o\gamma) = (\,0.79 \pm 0.02\,(\mathrm{stat.})\,)\cdot 10^{-4}$$

$[M_{\pi\pi} > 700$ MeV$]$

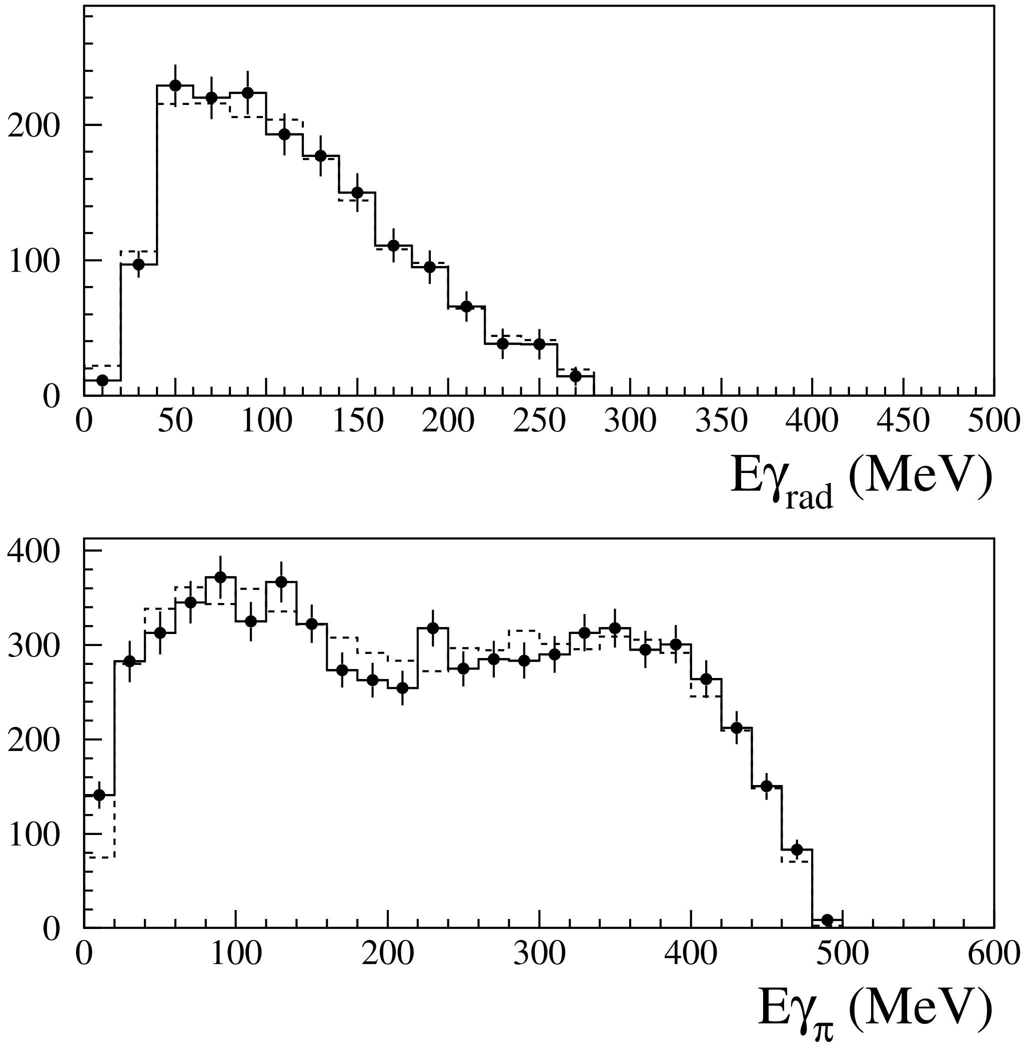
The $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ decay: final distributions

After background subtraction:

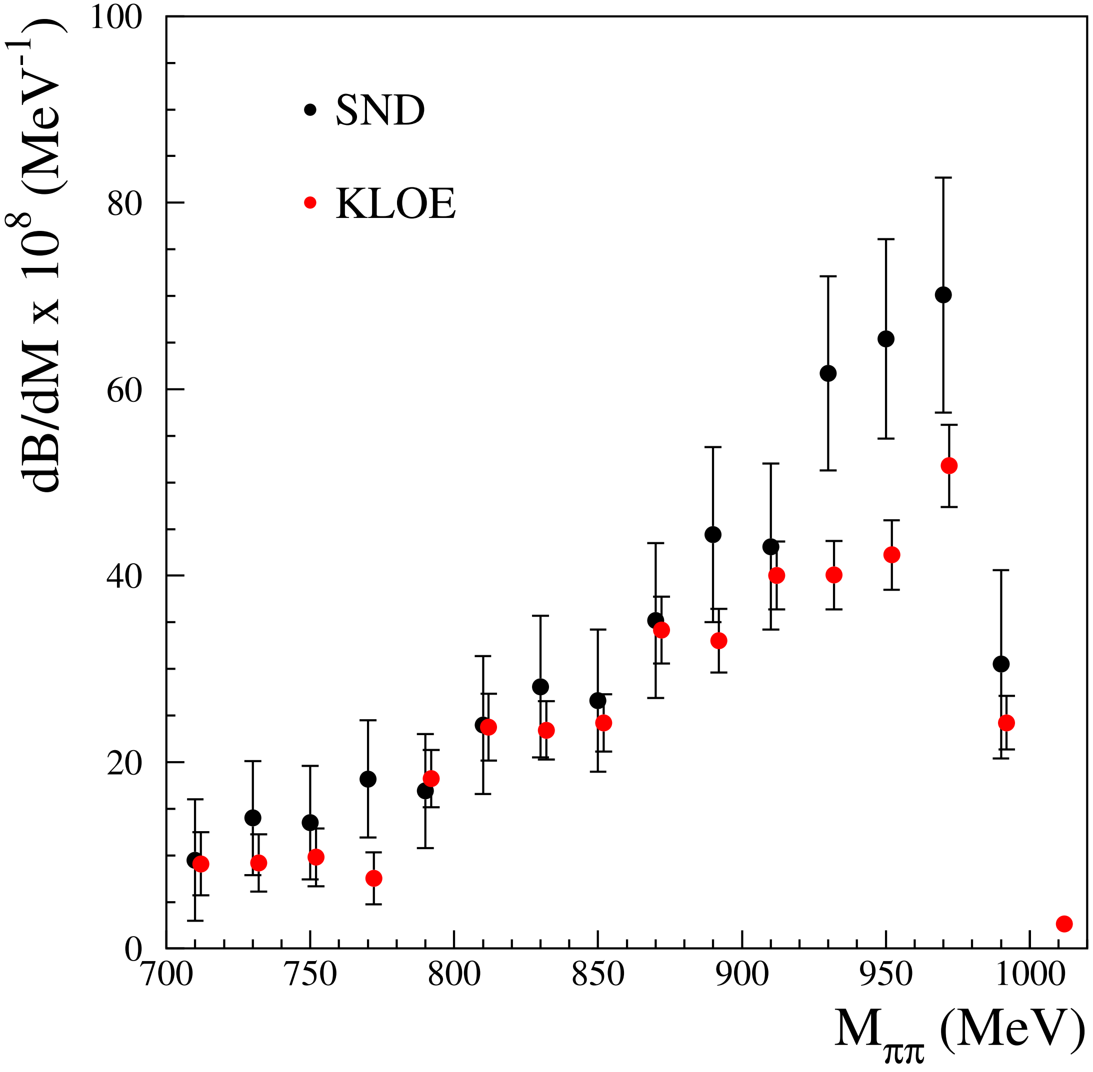


Preliminary: DATA-MC scale factors applied to all distributions

The $\phi \rightarrow f_o\gamma \rightarrow \pi^o\pi^o\gamma$ decay: energy distributions



The $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ decay: KLOE/SND comparison



Preliminary:

- Each bin scaled down only with MC efficiency and ScF
- No systematic correction due to bad clustering and photons pairing
- Still tuning the background subtraction

The $\phi \to \eta\pi^o\gamma$ decay: $\gamma\gamma\gamma$ background rejection

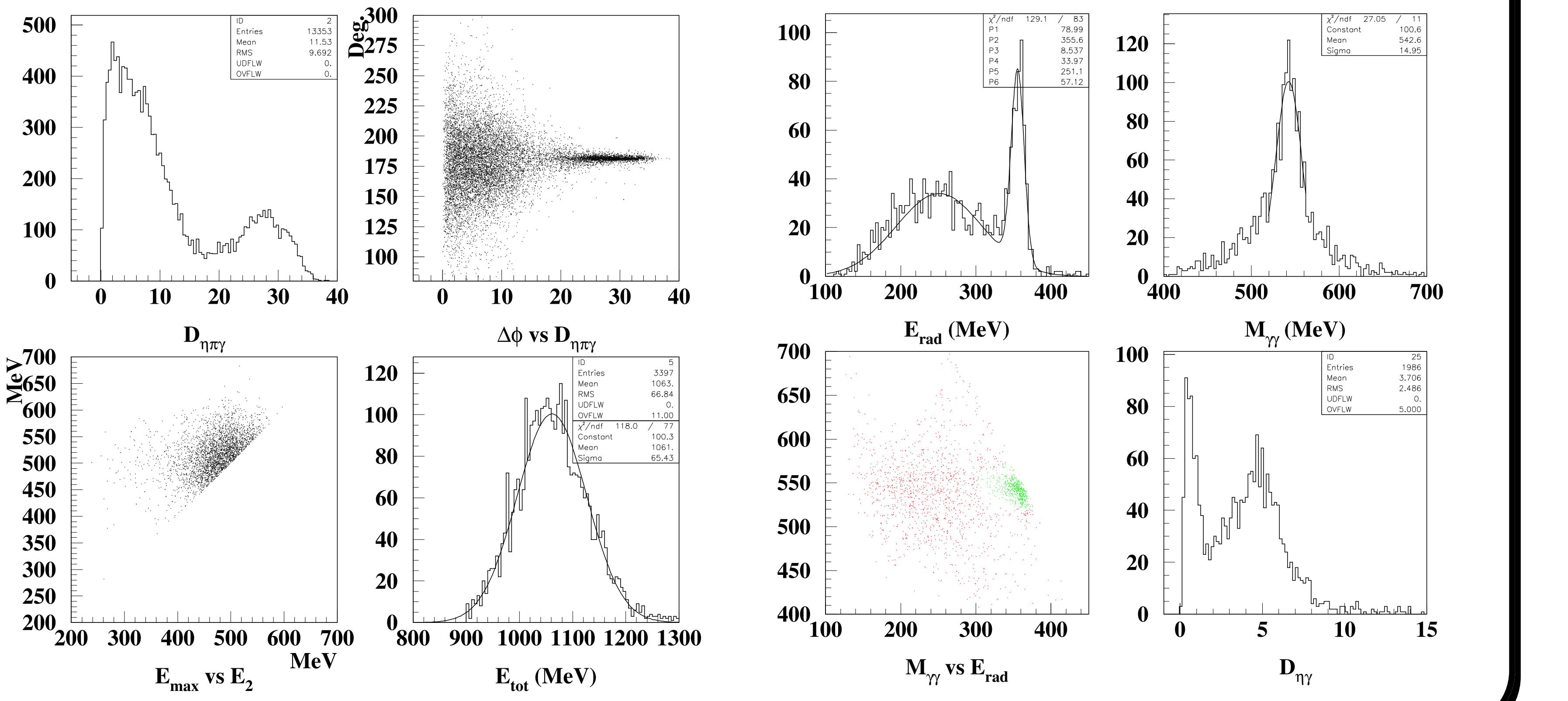
$\gamma\gamma\gamma$ background events rejected using the χ^2 value of the photons' pairing

$e^+e^- \to \gamma\gamma(\gamma)$ rejection:

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

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

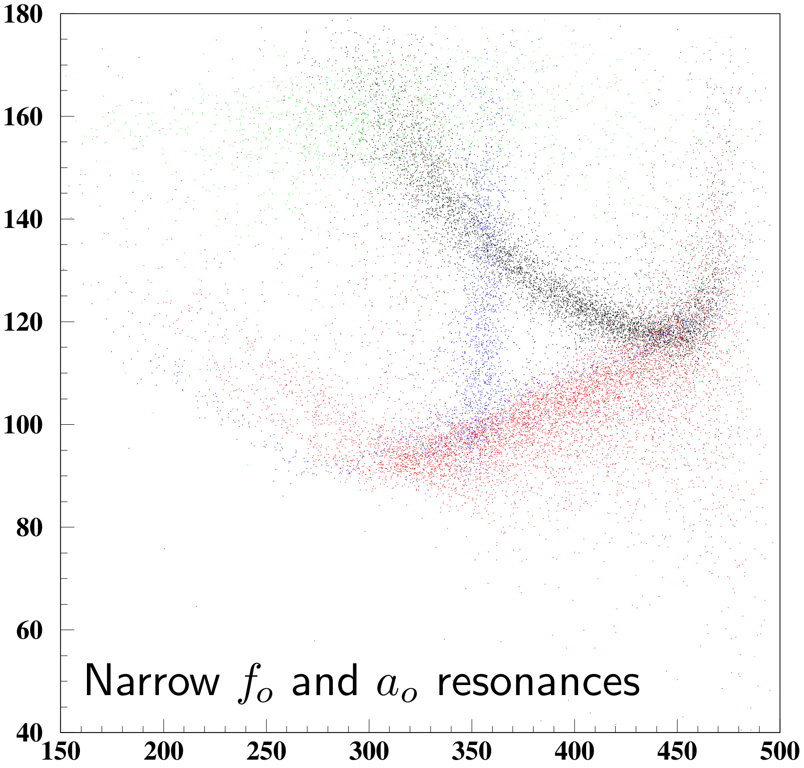
$$D_{\eta\gamma} = \sqrt{\chi^2_{\eta\gamma}} > 2$$

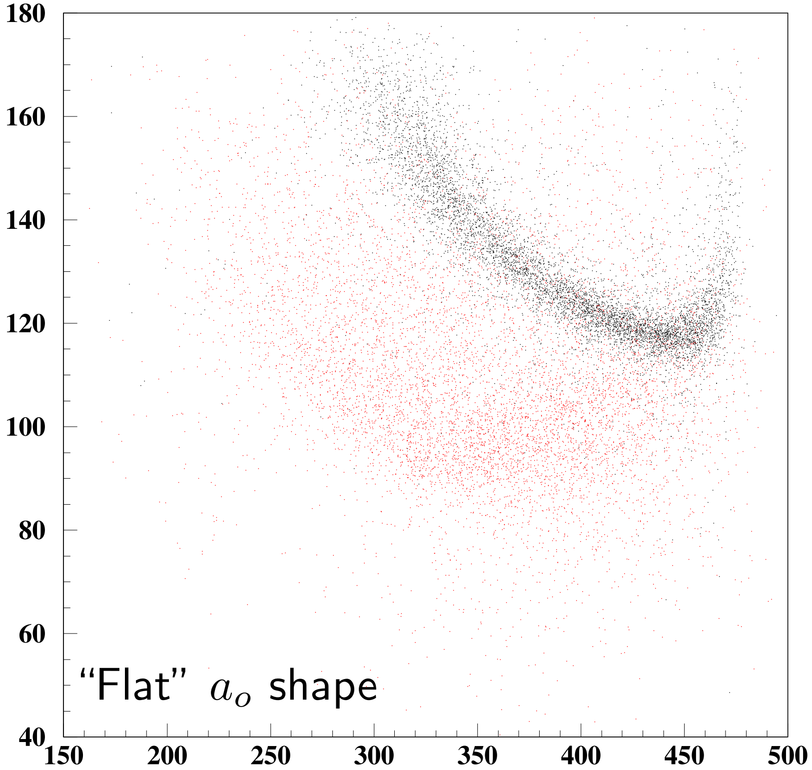


The $\phi \to \eta\pi^o\gamma$ decay: $\pi^o\pi^o\gamma$ background rejection (I)

Sample composition after second fit ($\chi^2/\mathrm{ndof} < 10$): 10% $\phi \to \eta\pi^o\gamma$, 80% $\phi \to \pi^o\pi^o\gamma$, 10% $\phi \to \eta\gamma \to 7\gamma$'s

Fit results for $e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$ hypothesis: $\psi_{\omega\pi}$(deg) *vs* E_γ (MeV)





$\phi \to a_o\gamma \to \eta\pi^o\gamma$ $\quad$ $e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$

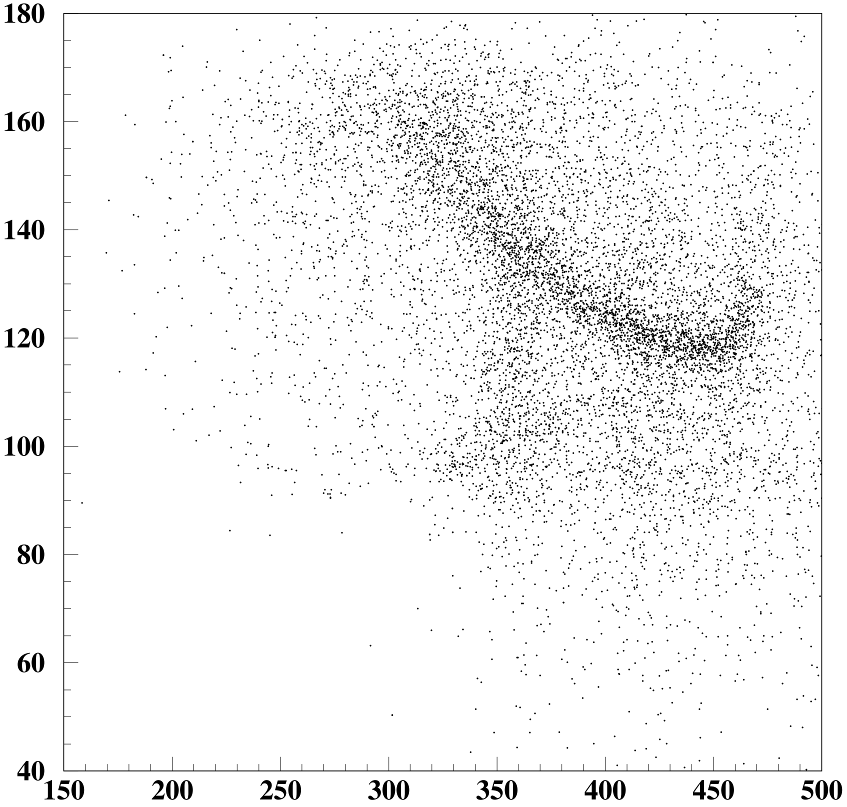
$\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ $\quad$ $\phi \to \eta\gamma \to \gamma\gamma\gamma$

$\phi \to a_o\gamma \to \eta\pi^o\gamma$

$e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$

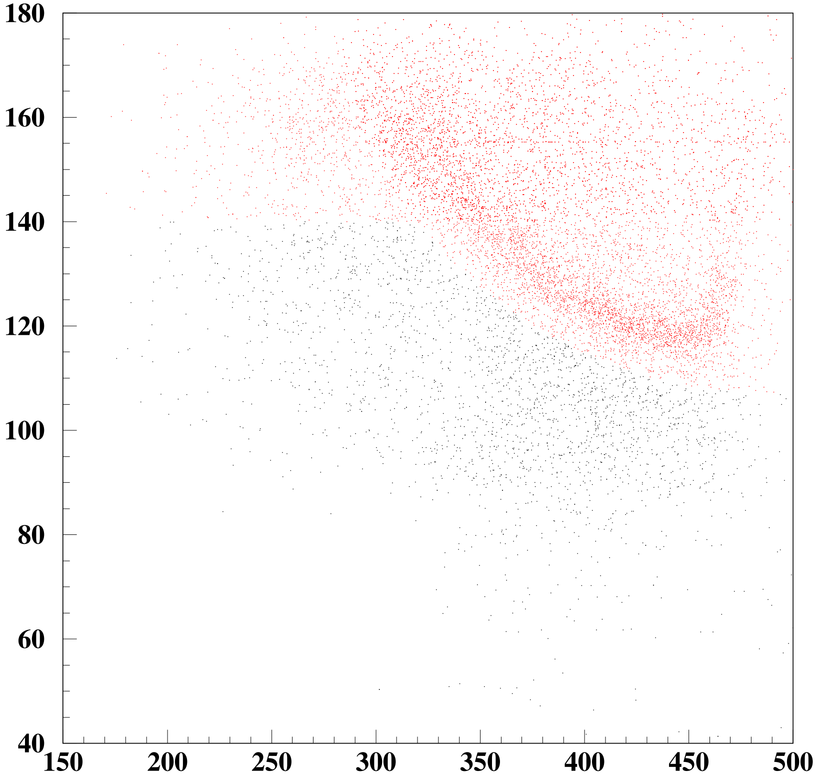
The $\phi \to \eta\pi^o\gamma$ decay: $\pi^o\pi^o\gamma$ background rejection (II)

REAL DATA



$\psi_{\omega\pi}$(deg) *vs* E_γ (MeV)

MC EVENTS



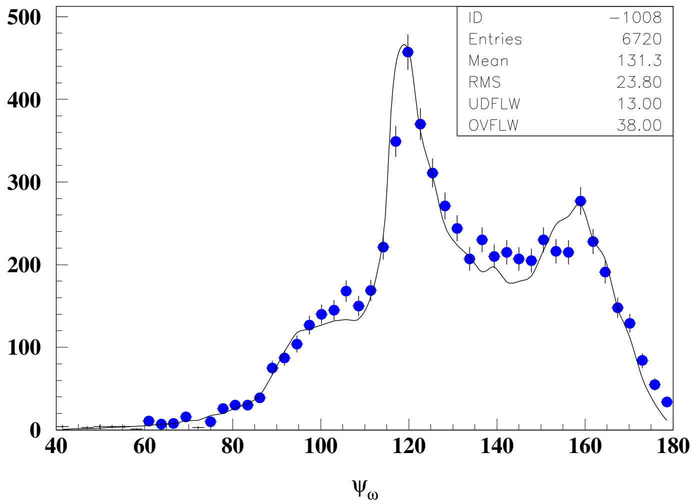
$\psi_{\omega\pi}$(deg) *vs* E_γ (MeV)

The red region is rejected

The $\phi \to \rho\pi^o \to \pi^o\pi^o\gamma$ events populates the same region of $\psi_{\omega\pi}$ and E_γ variables. A further cut is applied: $\chi^2_{\pi\pi\gamma} - \chi^2_{\eta\pi\gamma} > 3$

The $\phi \to \eta\pi^o\gamma$ decay: sample composition (I)

$\psi_{\omega\pi}$ used to check the sample composition. Data $\psi_{\omega\pi}$ distribution fitted with: (1) $\phi \to \eta\pi^o\gamma$ + $\phi \to \rho^o\pi^o \to \pi^o\pi^o\gamma$, (2) $e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$, (3) $\phi \to f_o\gamma \to \pi^o\pi^o\gamma$ and (4) $\phi \to \eta\gamma \to 7\gamma$'s

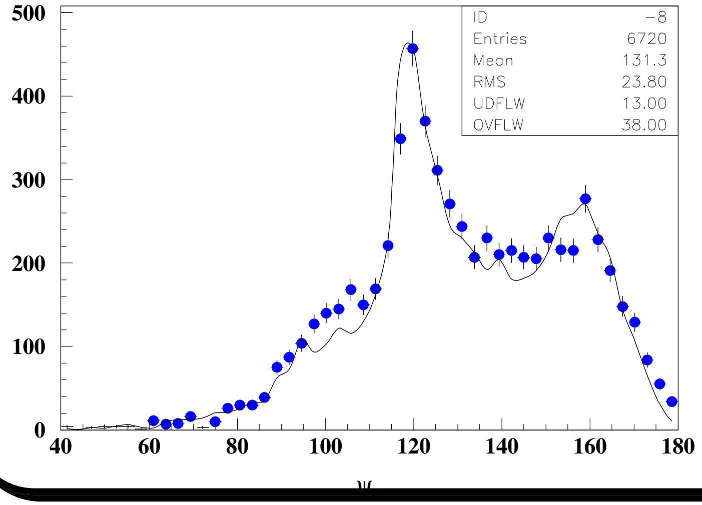


$\alpha_1 = 1.25$

$\alpha_2 = 0.8$

$\alpha_3 = 0.8$ (narrow f_o shape)

$\alpha_4 = 0$ (FIXED)



$\alpha_1 = 1$ (FIXED)

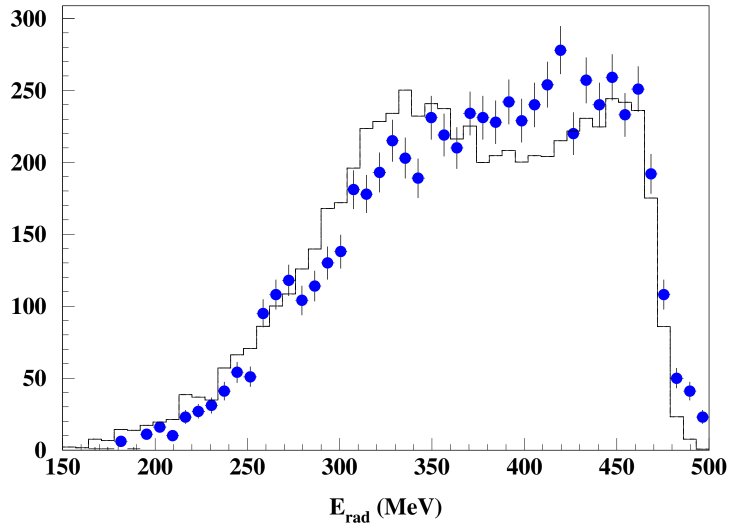
$\alpha_2 = 0.8$

$\alpha_3 = 0.8$ (narrow f_o shape)

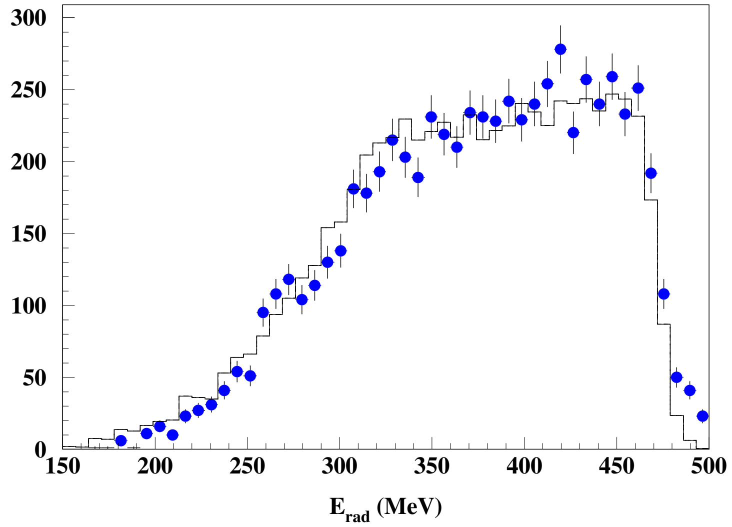
$\alpha_4 = 0.95$

The $\phi \to \eta\pi^o\gamma$ decay: sample composition (II)

Fit result checked by comparing E_γ distributions



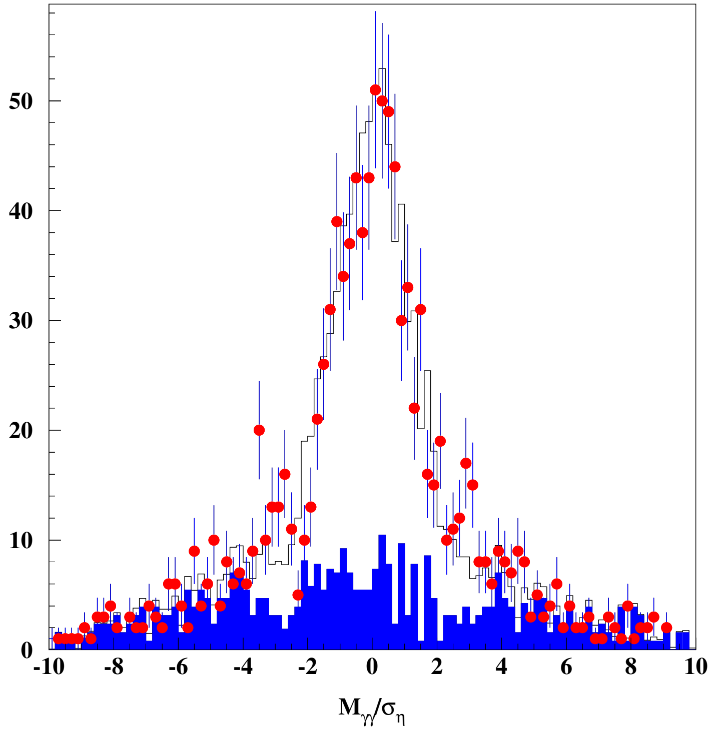
$$\alpha_1 = 1.25$$
$$\alpha_2 = 0.8$$
$$\alpha_3 = 0.8 \quad \text{(narrow } f_o \text{ shape)}$$
$$\alpha_4 = 0 \quad \text{(FIXED)}$$

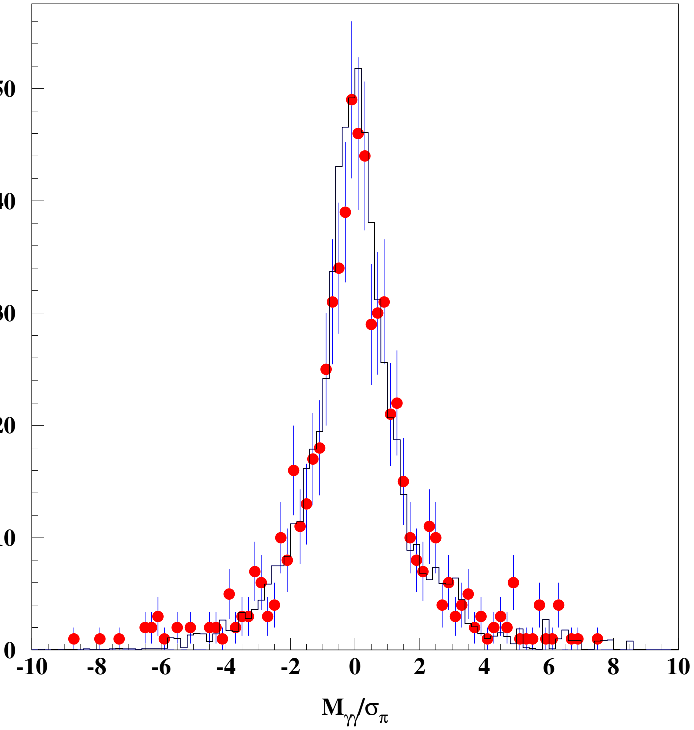


$$\alpha_1 = 1 \quad \text{(FIXED)}$$
$$\alpha_2 = 0.8$$
$$\alpha_3 = 0.8 \quad \text{(narrow } f_o \text{ shape)}$$
$$\alpha_4 = 0.95$$

The $\phi \to \eta\pi^o\gamma$ decay: $\phi \to \eta\gamma \to 7\gamma$'s rejection

The $\phi \to \eta\gamma \to \pi^o\pi^o\pi^o\gamma$ events populates the tails of the η mass distribution

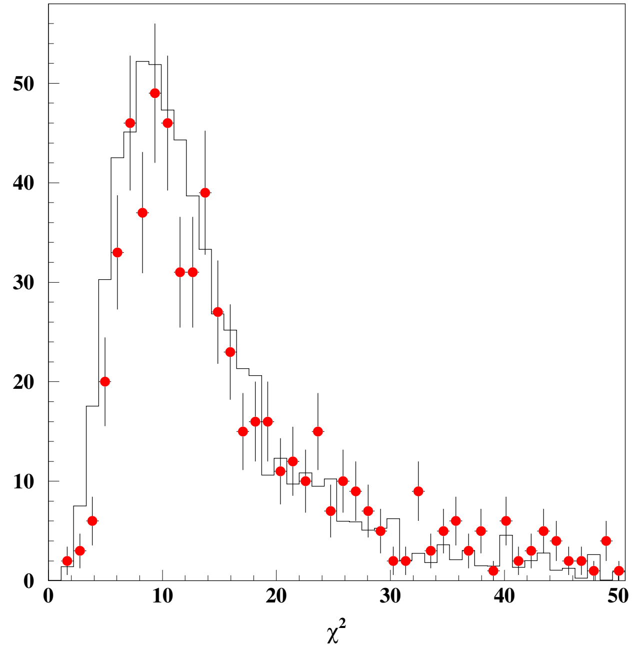




A $2\,\sigma$ cut is applied to reduce this background

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

Process	Efficiency
$\phi \to a_o\gamma \to \eta\pi^o\gamma$	27%
$\phi \to \rho\pi^o \to \eta\pi^o\gamma$	27%
$e^+e^- \to \omega\pi^o \to \eta\pi^o\gamma$	27%
$e^+e^- \to \omega\pi^o \to \pi^o\pi^o\gamma$	3.5×10^{-3}
$\phi \to \rho\pi^o \to \pi^o\pi^o\gamma$	5%
$\phi \to f_o\gamma \to \pi^o\pi^o\gamma$	1.4×10^{-3}
$\phi \to \eta\gamma \to \gamma\gamma\gamma$	2×10^{-6}
$\phi \to \eta\gamma \to \pi^o\pi^o\pi^o\gamma$	5×10^{-4}



Final events counting: $N_{\eta\pi\gamma} = 666 \pm 26$ $N_{\mathrm{bckg}} = 256 \pm 11$

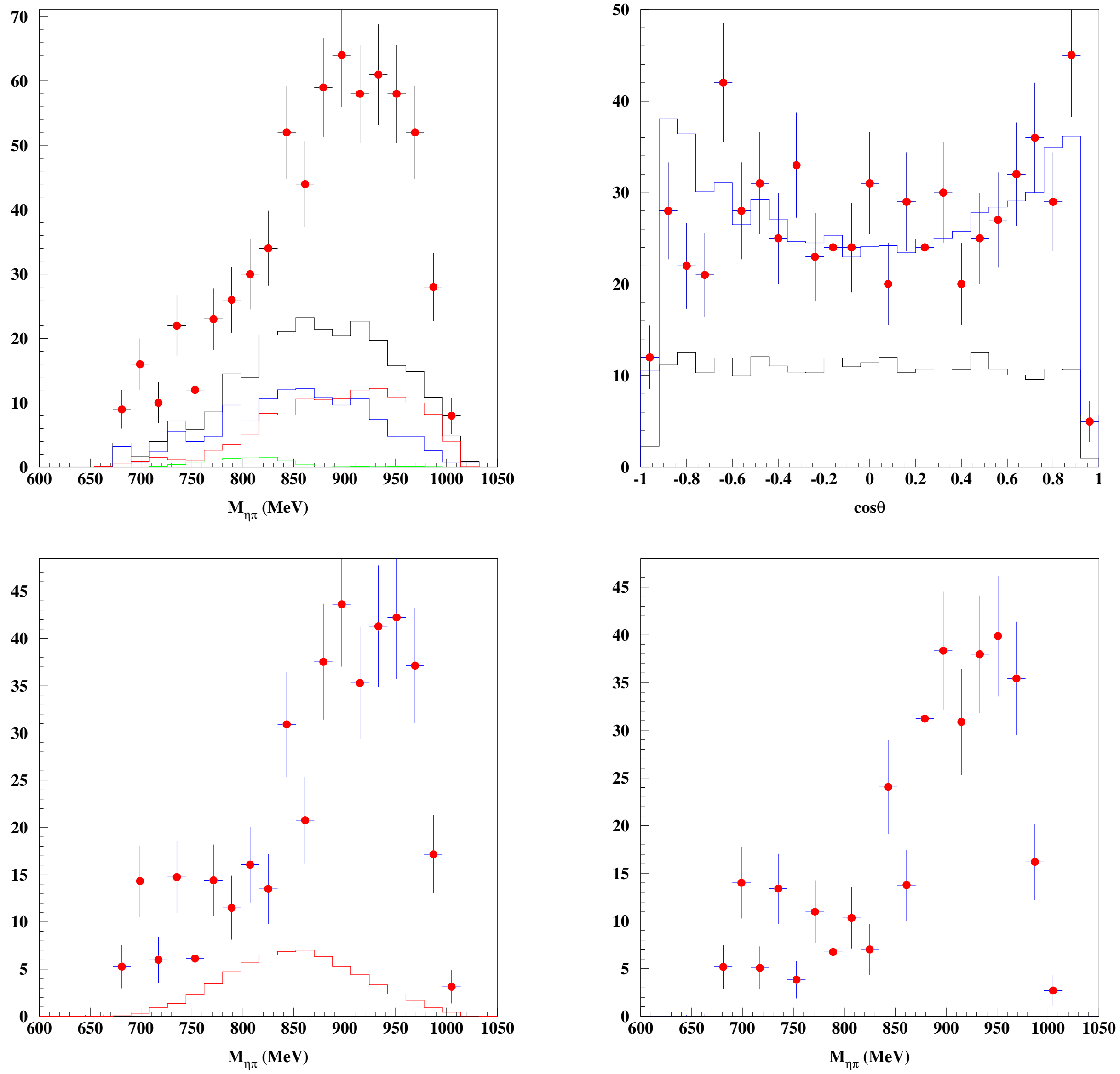
$$\mathrm{BR}(\phi \to \eta\pi^o\gamma) = (\,0.73 \pm 0.05_{\mathrm{stat.}}\,) \cdot 10^{-4}$$

Neglecting the interference between $\phi \to a_o\gamma \to \eta\pi^o\gamma$ and $\phi \to \rho\pi^o \to \eta\pi^o\gamma$:

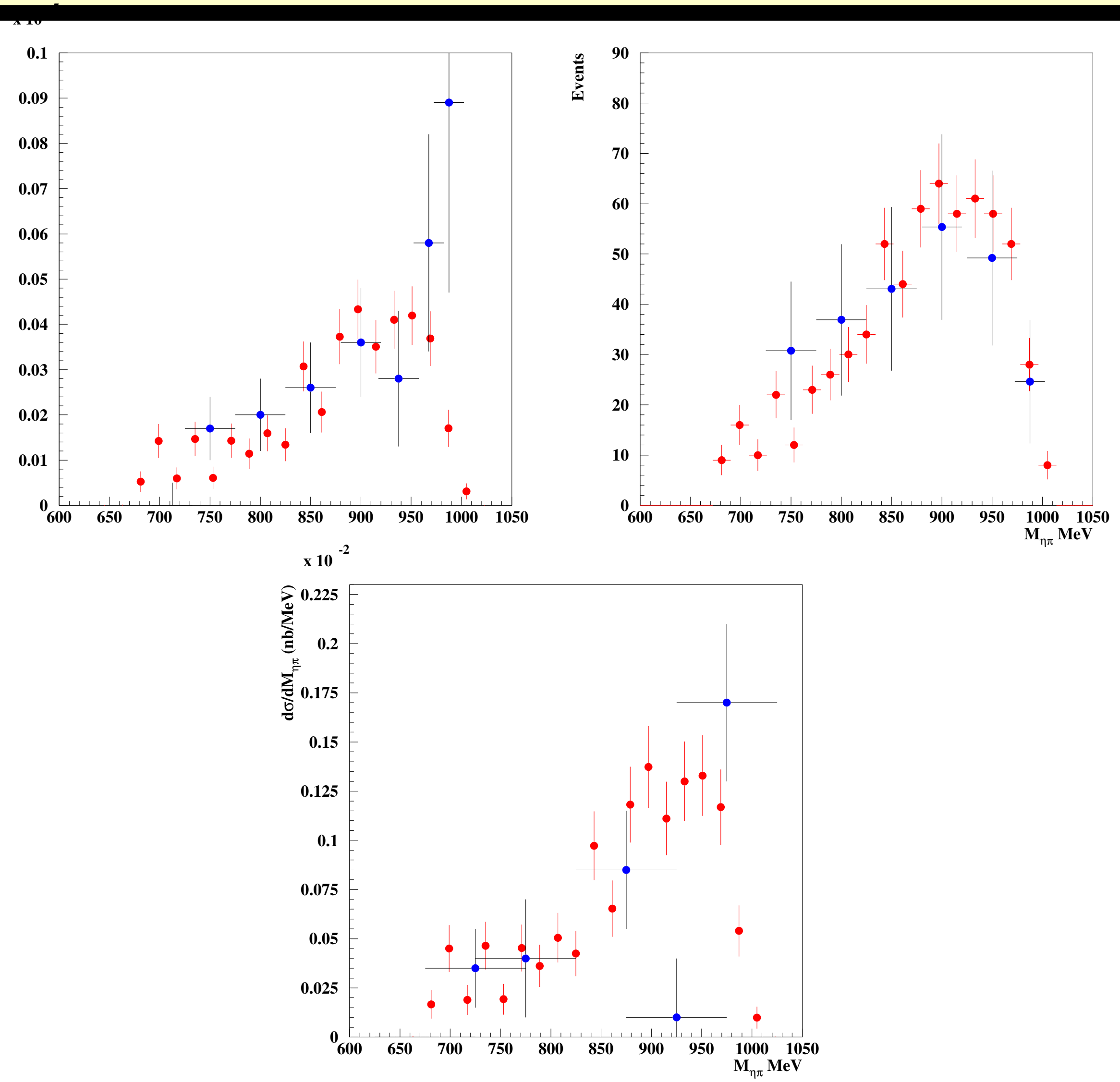
$$\mathrm{BR}(\phi \to a_o\gamma \to \eta\pi^o\gamma) = (\,0.65 \pm 0.05_{\mathrm{stat.}} \pm 0.23_{\mathrm{syst}}\,) \cdot 10^{-4}$$

[the big systematic error is largely dominated by the $\mathrm{BR}(\rho \to \eta\gamma)$ uncertainty]

The $\phi \rightarrow \eta\pi^o\gamma$ decay: final distributions



The $\phi \rightarrow \eta\pi^o\gamma$ decay: KLOE/VEPP-2M comparison



Preliminary: KLOE distributions not scaled for bin by bin efficiency

The $\phi \to \eta\pi^o\gamma \to \pi^+\pi^-\pi^o\pi^o\gamma$ decay

Signature: 2 tracks and 5 prompt photons

Process	BR	$\varepsilon_{\rm ana}$
$\phi \to a_o\gamma \to \eta\pi^o\gamma \to \pi^+\pi^-\pi^o\pi^o\gamma$	2×10^{-5}	21.4%
$\phi \to \rho\pi^o \to \eta\pi^o\gamma \to \pi^+\pi^-\pi^o\pi^o\gamma$	3×10^{-6}	
$e^+e^- \to \omega\pi^o \to \eta\pi^o\gamma \to \pi^+\pi^-\pi^o\pi^o\gamma$	4×10^{-7}	
$\phi \to \eta\gamma \to \pi^+\pi^-\pi^o\gamma$	3×10^{-3}	$< 1\times10^{-4}$
$e^+e^- \to \omega\pi^o \to \pi^+\pi^-\pi^o\pi^o\gamma$	2×10^{-3}	1×10^{-4}
$\phi \to K_SK_L \to \pi^+\pi^-\pi^o\pi^o\pi^o$ $\star$	3×10^{-3}	$< 9\times10^{-6}$
$\phi \to K_SK_L \to \pi^o\pi^o\pi^+\pi^-\pi^o$ $\star$	5×10^{-3}	1×10^{-5}
$\phi \to K_SK_L \to \pi^o\pi^o\ell\pi\nu$ $\star$		

$\star$ with K_L decaying before drift chamber

Events selection:

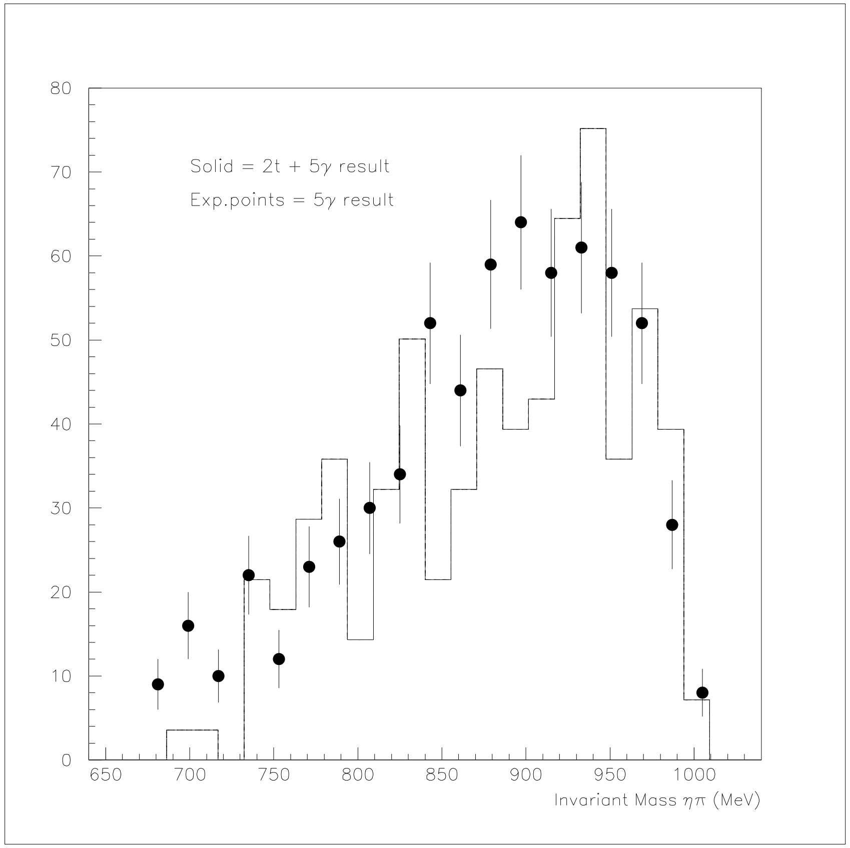
- 1 vertex with 2 tracks + 5 prompt photons with $21^\circ < \theta < 159^\circ$
- $|\vec{p}_{\rm tot}| < 200$ MeV$/c$ and $800 < E_{\rm tot} < 1020$ MeV
- $P(\chi^2_{\rm fit1}) > 0.02$, $P(\chi^2_{\rm pair}) > 0.02$ and $P(\chi^2_{\rm fit2}) > 0.02$
- $E_{\gamma\,\rm min} > 10$ MeV, $E_{\gamma\,\rm min} + E_{\gamma\,\rm max} > 10$ MeV, $p_1 + p_2 < 420$ MeV

The $\phi \to \eta\pi^o\gamma \to \pi^+\pi^-\pi^o\pi^o\gamma$ decay

A very preliminary measurement on KLOE 2000 data (186 events found) gives:

$$\mathbf{BR(\phi \to \eta\pi^o\gamma) = (\,0.67 \pm 0.09_{stat.}\,) \cdot 10^{-4}}$$

in agreement with the 5γ's result



Conclusions

- Search of $\phi \rightarrow f_o\gamma$, $\phi \rightarrow a_o\gamma$ decays performed using KLOE 2000 data (16.60 pb^{-1})

- Analysis of the 5γ's final states gives:
  - $\star$ $\mathrm{BR}(\phi \rightarrow f_o\gamma \rightarrow \pi^o\pi^o\gamma) = (\,0.79 \pm 0.02_{\mathrm{stat.}}\,) \cdot 10^{-4}$
  - $\star$ $\mathrm{BR}(\phi \rightarrow \eta\pi^o\gamma) = (\,0.73 \pm 0.05_{\mathrm{stat.}}\,) \cdot 10^{-4}$
  - $\star$ $M_{\pi\pi}$, $M_{\eta\pi}$ shapes in agreement with VEPP-2M

- A preliminary study of the neutral/charged channel $\phi \rightarrow a_o\gamma \rightarrow \eta\pi^o\gamma$ with $\eta \rightarrow \pi^+\pi^-\pi^o$ gives a BR measurement in agreement with the previous one:

  $\star$ $\mathrm{BR}(\phi \rightarrow \eta\pi^o\gamma) = (\,0.67 \pm 0.09_{\mathrm{stat.}}\,) \cdot 10^{-4}$