Neutral ϕ decays — status report

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Motivation

Among the most interesting (neutral) ϕ decays are the radiative decays $\phi \to f_0\gamma$ and $\phi \to a_0\gamma$. The measurement of the branching ratios of these decays would shed light on the structure of the f_0 and a_0 mesons, that is, it should allow to discriminate between the different hypotheses for these particles:

- ordinary $q\bar{q}$ state
- four quark state $qq\bar{q}\bar{q}$
- $K\bar{K}$ molecule
- glueball, hybrid, *etc. etc.*

Predictions for branching ratio $\phi \to f_0\gamma$ with $f_0 \to \pi^0\pi^0$

model	predicted branching ratio	reference
$q\bar{q}$	$\lesssim 1.8 \cdot 10^{-5}$	1,4
$qq\bar{q}\bar{q}$	$(3-8) \cdot 10^{-5}$	1,2,4
$K\bar{K}$	$(0.4-1.1) \cdot 10^{-5}$	3,4
glueball	$\lesssim 1 \cdot 10^{-6}$	4

1: N.N. Achasov and V.N. Ivanchenko, Nucl. Phys. B315 (1989) 465
2: N.N. Achasov, "The second DAΦNE physics handbook" (1995) 671
3: N.N. Achasov, V.V. Gubin and V.I. Shevchenko, hep-ph/9605245
4: F.E. Close, N. Isgur and S. Kumano, Nucl. Phys. B389 (1993) 513

Estimation of rates for signal and background

We assume the branching ratio of $\phi \to f_0\gamma$ with $f_0 \to \pi^0\pi^0$ to be $1 \cdot 10^{-5}$ and calculate the expected rates for the signal and background processes based on a luminosity of 1 pb^{-1}. For an estimation of the acceptance for an n-photon final state we use a poor man's guess: $\binom{n}{5} \cdot 0.7^5 \cdot 0.3^{n-5}$ (identical acceptance for neutral and charged particles).

process	# events	comment
$\phi \to f_0\gamma, f_0 \to \pi^0\pi^0$	6	
$\phi \to \pi^0\pi^0\gamma$	6 – 36	
$\phi \to K_S^0 K_L^0$		
$K_S^0 \to \pi^0\pi^0$	60000	E
$K_S^0 \to \pi^0\pi^0, K_L^0 \to \pi^0\pi^0\pi^0$	250	E
$K_S^0 \to \pi^0\pi^0, K_L^0 \to \pi^+\pi^-\pi^0$	140	E
$\phi \to \eta\gamma$		
$\eta \to \pi^0\pi^0\pi^0$	3400	E
$e^+e^- \to \omega\pi^0$		
$\omega \to \pi^0\gamma$	140	invariant mass

Other interesting ϕ decays

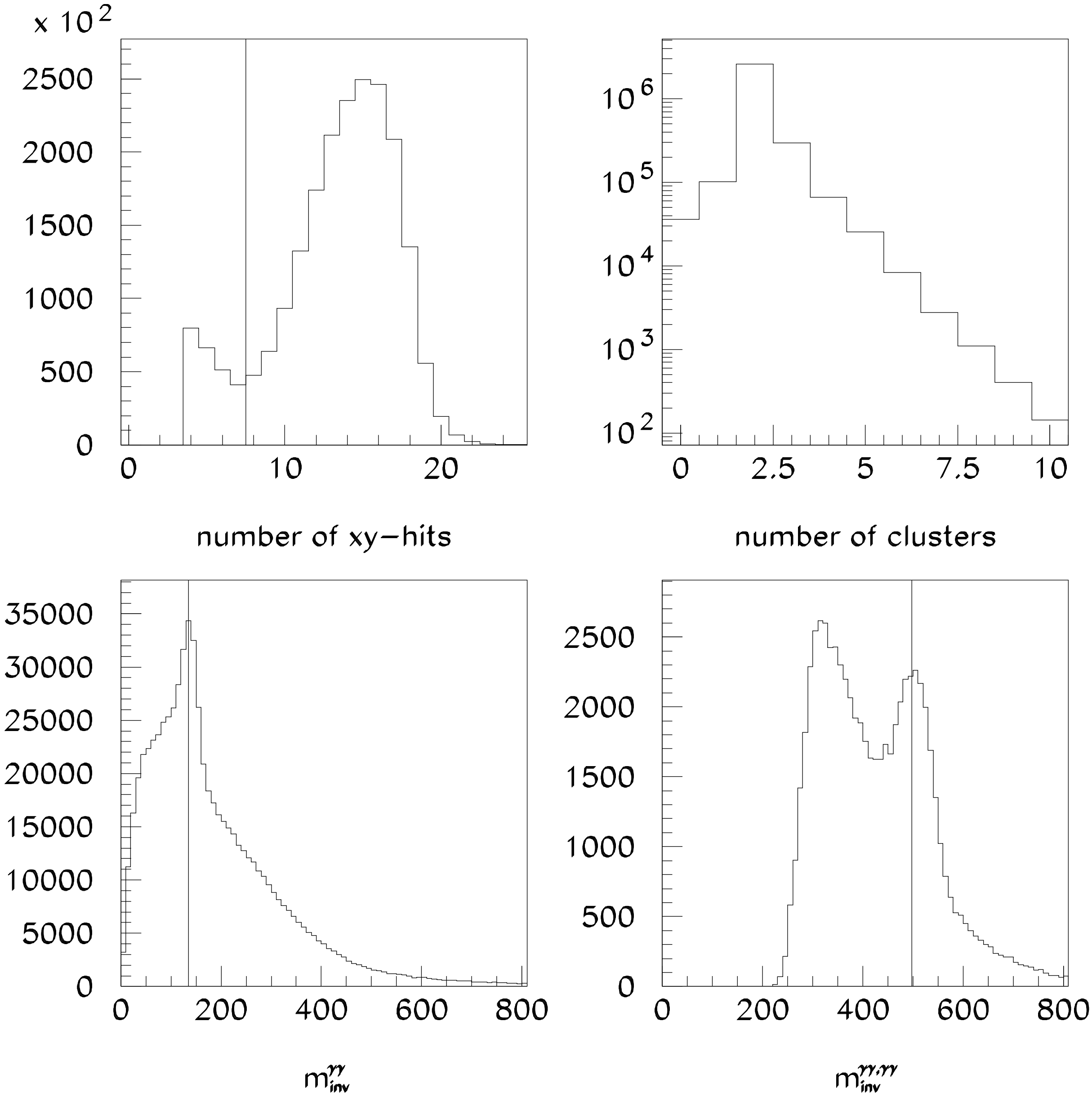
In parallel to the search for $\phi \to f_0\gamma$ and $\phi \to a_0\gamma$ and the study of its main background processes, that is mainly $\phi \to K_S^0 K_L^0$ with $K_S^0 \to \pi^0\pi^0$ and $\phi \to \eta\gamma$ with $\eta \to \pi^0\pi^0\pi^0$, the following decays resulting in a multi-photon final state can be investigated:

- $\phi \to \pi^0\pi^0\gamma$,
  5 photons,
  upper limit from ND ($1 \cdot 10^{-3}$)
- $\phi \to \eta\pi^0\gamma$ with $\eta \to \gamma\gamma$,
  5 photons,
  upper limit from ND ($2.5 \cdot 10^{-3}$)
- $\phi \to \pi^0\pi^0$,
  4 photons, G-parity violating, OZI suppressed,
  not measured yet
- $\phi \to \omega\pi^0$ with $\omega \to \pi^0\gamma$,
  5 photons, G-parity violating, OZI suppressed,
  not measured yet (note however, that the decay $\omega \to \pi^+\pi^-\pi^0$ has a much higher branching ratio)
- $\phi \to \eta'\gamma$ with $\eta' \to \eta\pi^0\pi^0$ and $\eta \to \gamma\gamma$,
  7 photons,
  not measured yet (again, other decay modes of the η' may be more favourable)
- $\phi \to \eta\gamma$ with $\eta \to \pi^0\pi^0$,
  5 photons, P- and CP-parity violating (η decay!),
  (poor) upper limit from SPES-2, Saclay ($2.8 \cdot 10^{-2}$)

Data selection

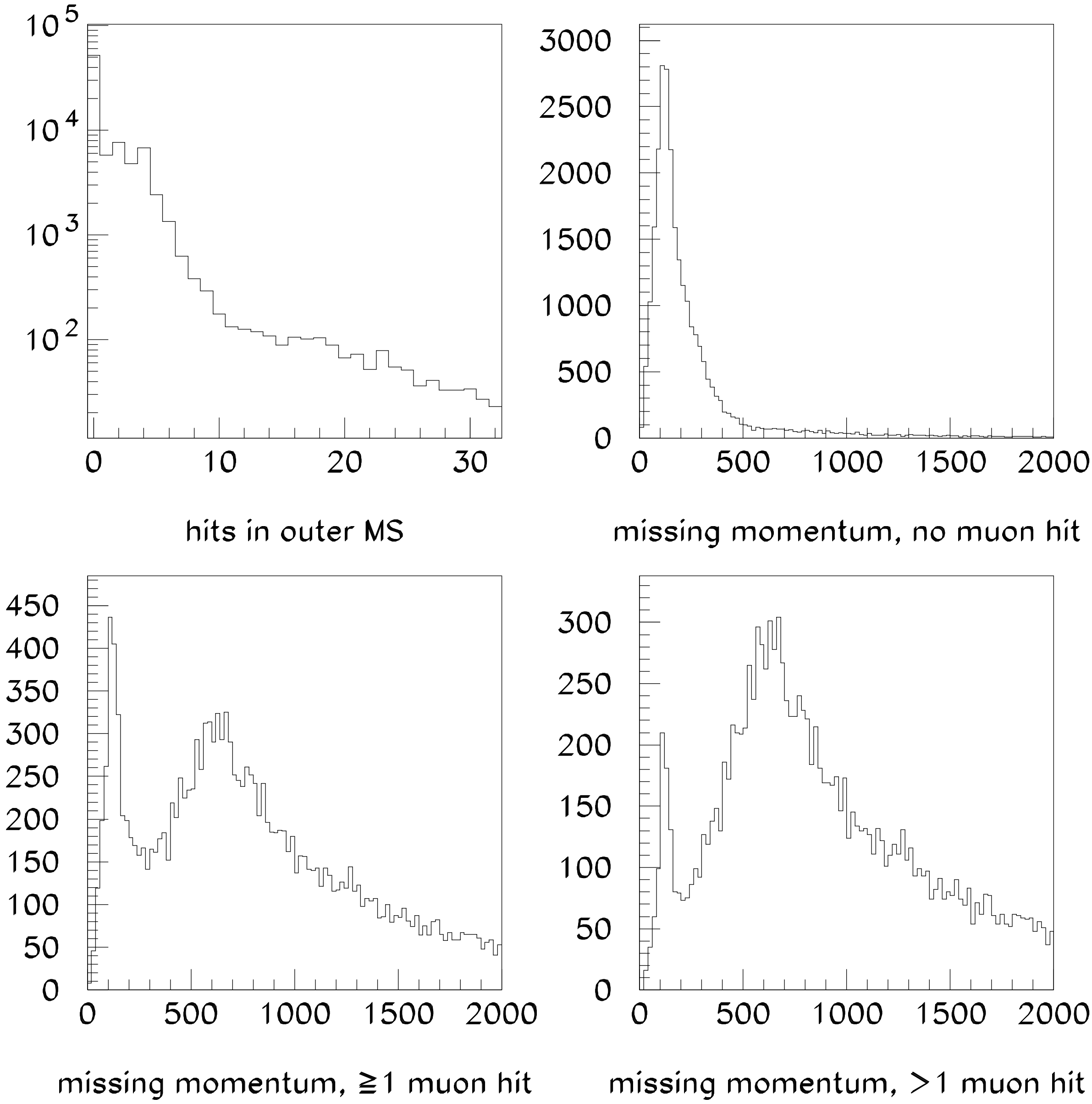
Selection of events with a multi-photon final state:

- no vertex
  (data reduction $\approx 1/2$)
- no good track, *i.e.*, at most one track with ≤ 7 hits
  (data reduction $\approx 1/2$)
- ≥ 4 clusters with $|\cos\theta| < 0.68$
  (data reduction $\approx 1/30 - 1/40$)



Cosmics

Of the selected neutral events, more than a third of the events have at least one hit in the outer muon system!

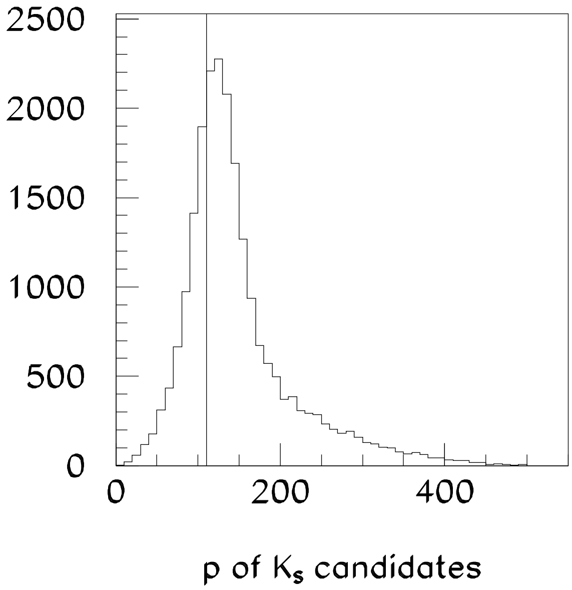


Additional cuts applied to suppress cosmics:

- at most one hit in outer muon system
- upper limit for E_{tot} and p_{miss}, different for different processes

$\phi \to K_S^0 K_L^0$ with $K_S^0 \to \pi^0 \pi^0$

- neutral event
- ≤ 1 hit in outer MS
- $E_{\text{tot}} < 1150\,\text{MeV}$
  $p_{\text{miss}} < 300\,\text{MeV}/c$
- $|m_{\text{inv}}^{\gamma\gamma} - m_{\pi^0}| < 25\,\text{MeV}$
- $|m_{\text{inv}}^{\gamma\gamma,\gamma\gamma} - m_{K_S^0}| < 75\,\text{MeV}$

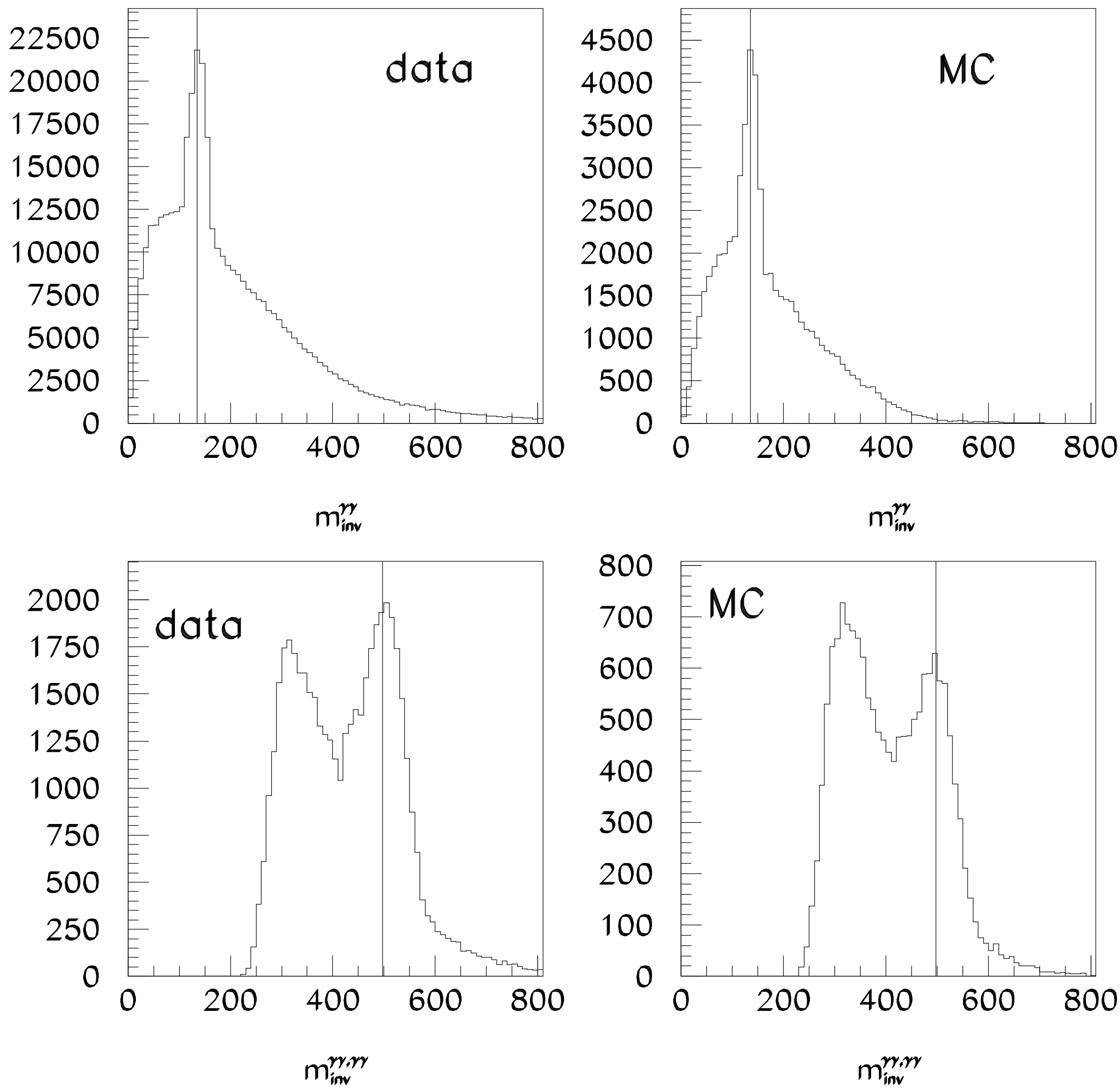


Determination of BR($\phi \to K_S^0 K_L^0$)

- Fitting the invariant mass spectrum $m_{\text{inv}}^{\gamma\gamma,\gamma\gamma}$.
- Counting good K_S^0 candidates, *i.e.*, by applying further cuts to purify the sample.

Since no acceptance and efficiency studies have been done yet, we need to rely on Monte Carlo (cmd2off 2.22/00) for an estimation of these values. The trigger efficiency is assumed to be 100% (!).

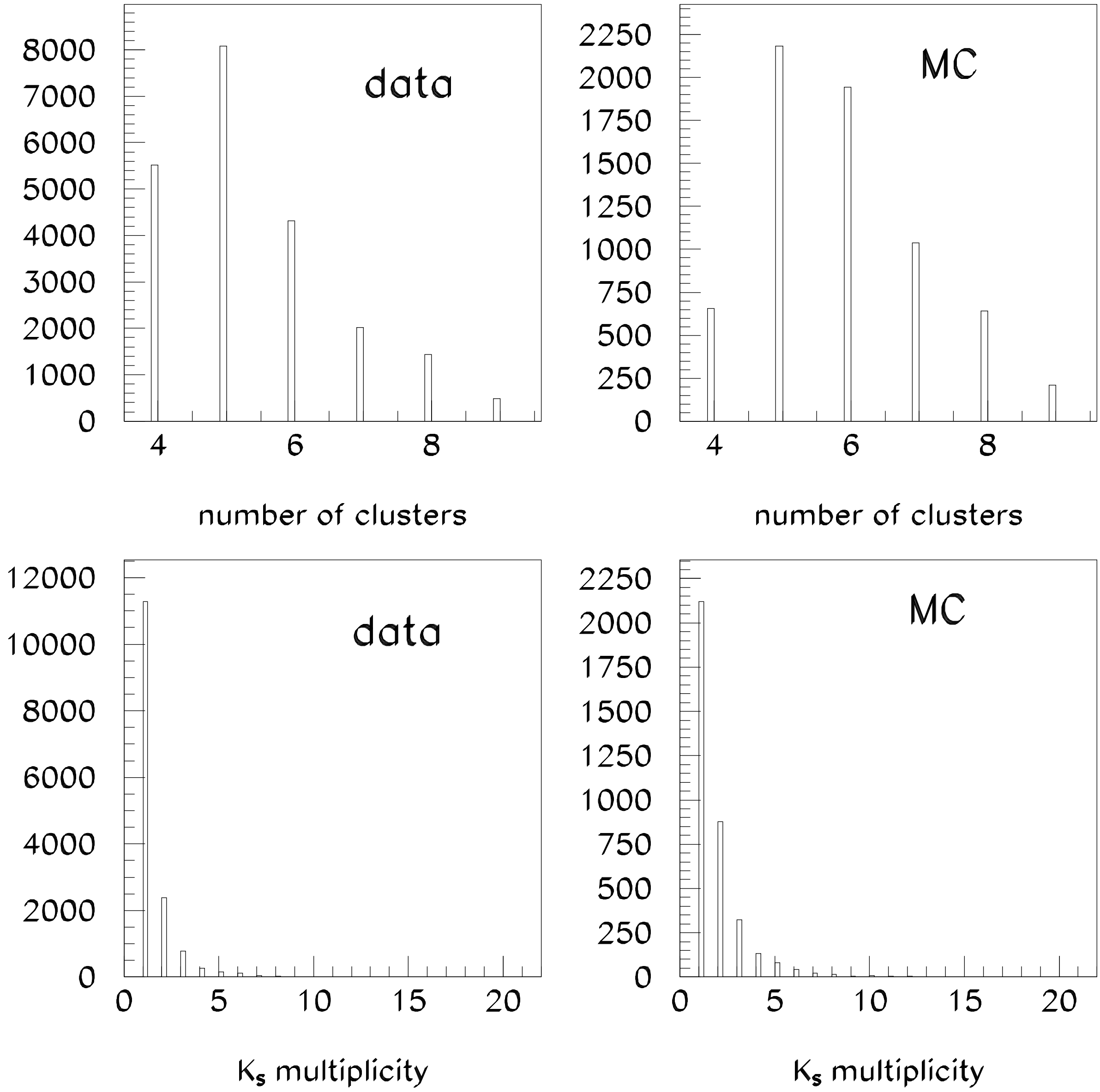
$\phi \to K_S^0 K_L^0$ with $K_S^0 \to \pi^0\pi^0$



Signal to (combinatorial) background better for data!

Main combinatorial background from $\phi \to K_S^0 K_L^0$ itself!

$\phi \to K_S^0 K_L^0$ with $K_S^0 \to \pi^0 \pi^0$



The Monte Carlo fails miserably to describe the data, probably mainly due to a completely wrong simulation of the K_L^0 interactions.

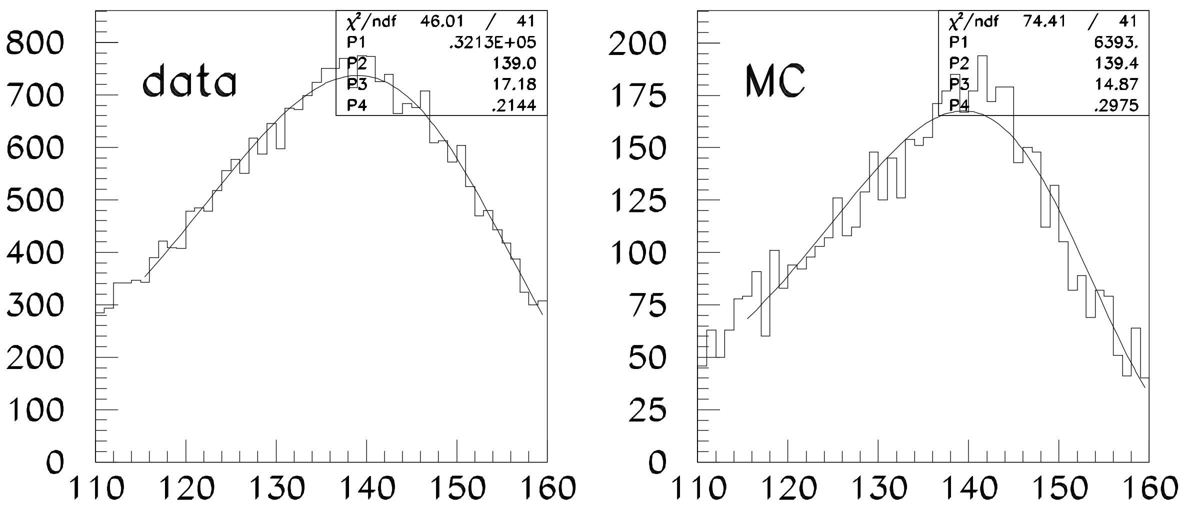
$\phi \to K_S^0 K_L^0$ with $K_S^0 \to \pi^0 \pi^0$

To get a meaningful branching ratio, we therefore need to

- understand the multiple entries in the invariant mass window $|m_{\text{inv}}^{\gamma\gamma,\gamma\gamma} - m_{K_S^0}| < 75\,\text{MeV}$
- find other means of purifying the event sample than by simply cutting on the number of clusters
- get the acceptance and the efficiency from data rather than from Monte Carlo

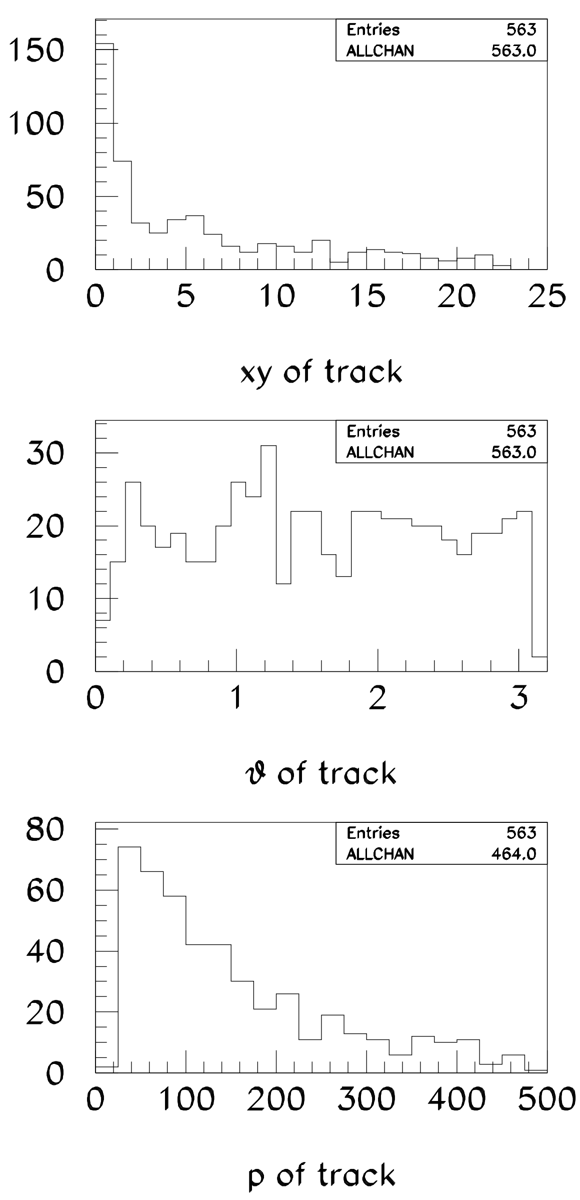
$m_{\text{inv}}^{\gamma\gamma}$ and tracks for good K_S^0 candidates

To check the cut on the invariant mass $m_{\text{inv}}^{\gamma\gamma}$ and the track cut applied in the data selection step, we use "good" K_S^0 candidates (*i.e.*, events with at most 5 clusters; similar results for 4 clusters only):



$\phi \to K_S^0 K_L^0$ with $K_S^0 \to \pi^0\pi^0$

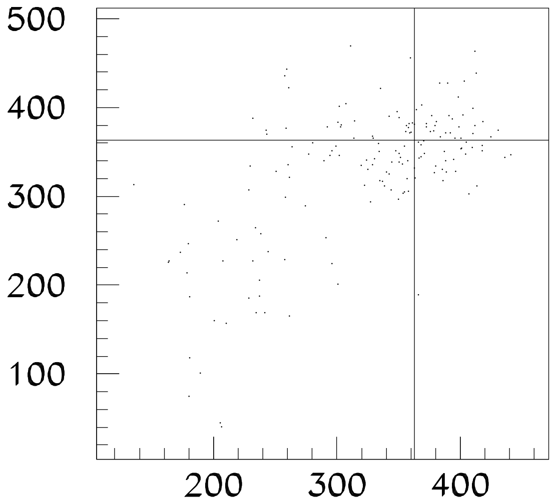
data



- $\approx$ 4% of the K_S^0 candidates have a track
- $\approx$ 8% of the events with a track have a hit in the outer MS

$\phi \to \eta\gamma$ with $\eta \to \pi^0\pi^0\pi^0$

- neutral event
- ≤ 1 hit in outer MS
- $|E_{\text{tot}} - 2E_{\text{beam}}| < 150\,\text{MeV}$
  $p_{\text{miss}} < 200\,\text{MeV}/c$
- seven clusters
- $|m_{\text{inv}}^{\gamma\gamma} - m_{\pi^0}| < 25\,\text{MeV}$
- $|m_{\text{inv}}^{\gamma\gamma,\gamma\gamma,\gamma\gamma} - m_\eta| < 150\,\text{MeV}$



$p^{\gamma\gamma,\gamma\gamma,\gamma\gamma}$ versus E_γ

Determination of BR($\phi \to \eta\gamma$)

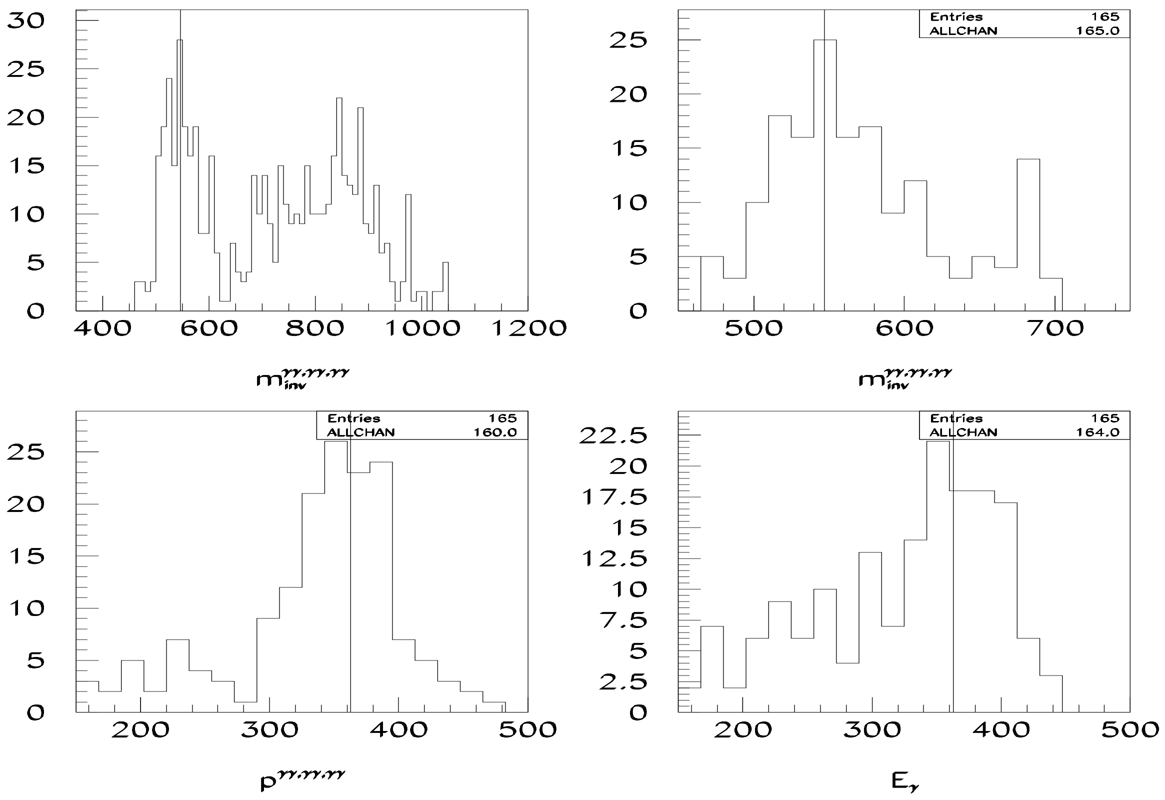
- Fitting the invariant mass spectrum $m_{\text{inv}}^{\gamma\gamma,\gamma\gamma,\gamma\gamma}$.
- Counting good η candidates, *i.e.*, by applying further cuts to purify the sample (*e.g.* $p^{\gamma\gamma,\gamma\gamma,\gamma\gamma} \geq 300\,\text{MeV}/c$, $E_\gamma \geq 250\,\text{MeV}$.)

Acceptance and reconstruction efficiency from Monte Carlo simulation, trigger efficiency assumed to be 100%.

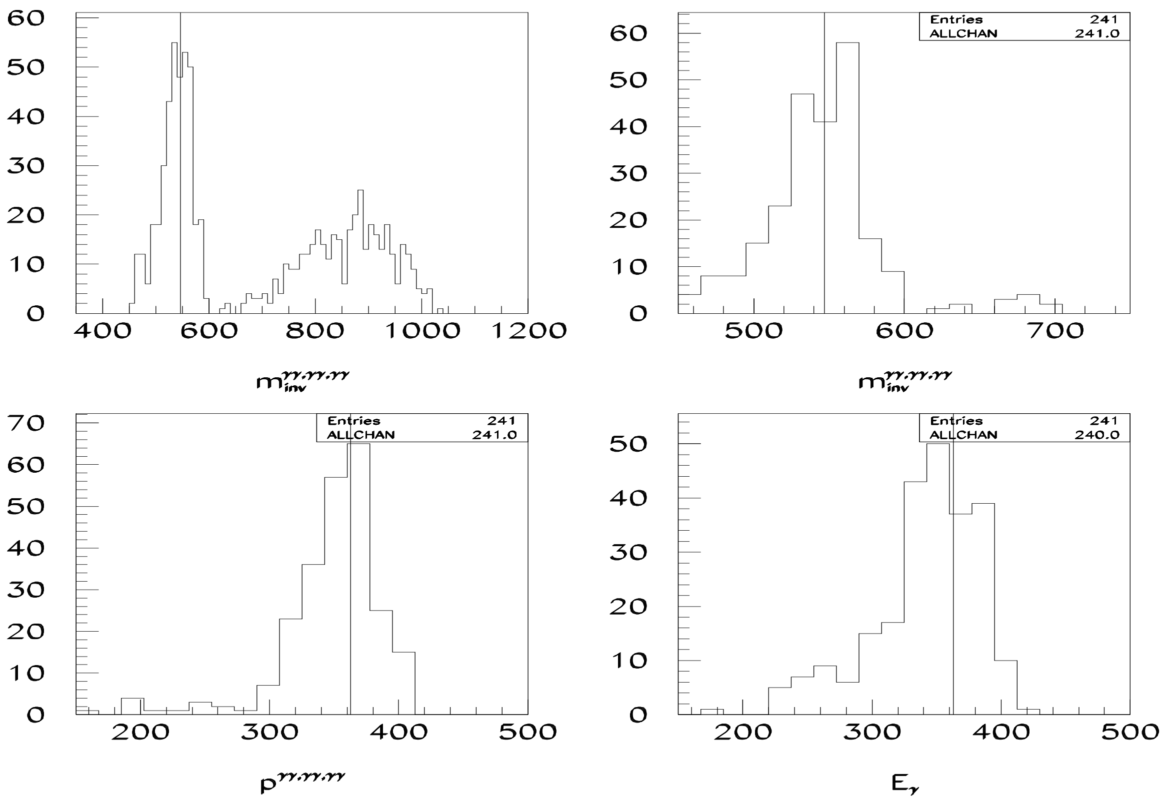
The obtained branching ratio is $\approx 1.0\%$ (1.2%), with a statistical error of $\approx 15\%$ and a so far unknown systematic error ...

$\phi \to \eta\gamma$ with $\eta \to \pi^0\pi^0\pi^0$

data

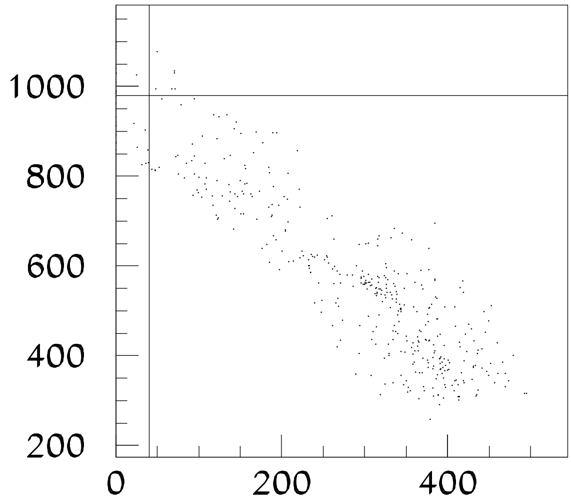


Monte Carlo for $\phi \to \eta\gamma$

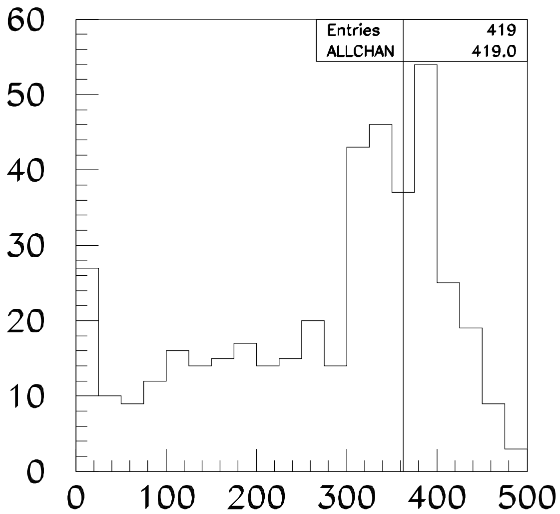


$\phi \to \pi^0\pi^0\gamma$ and $\phi \to f_0\gamma$ with $f_0 \to \pi^0\pi^0$

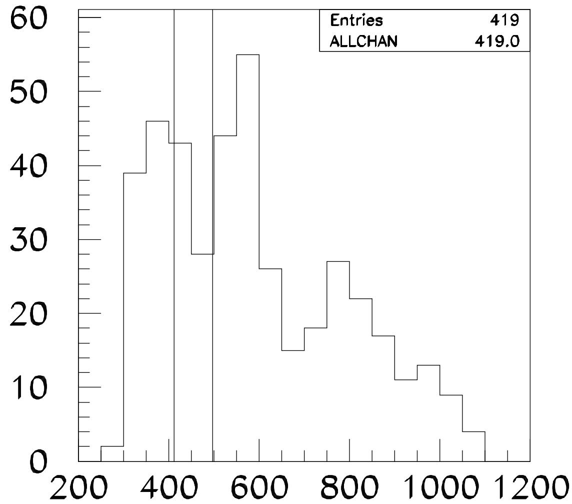
- neutral event
- ≤ 1 hit in outer MS
- $|E_{\rm tot} - 2E_{\rm beam}| < 150\,{\rm MeV}$
  $p_{\rm miss} < 200\,{\rm MeV}/c$
- at most 5 clusters
- $|m_{\rm inv}^{\gamma\gamma} - m_{\pi^0}| < 25\,{\rm MeV}$



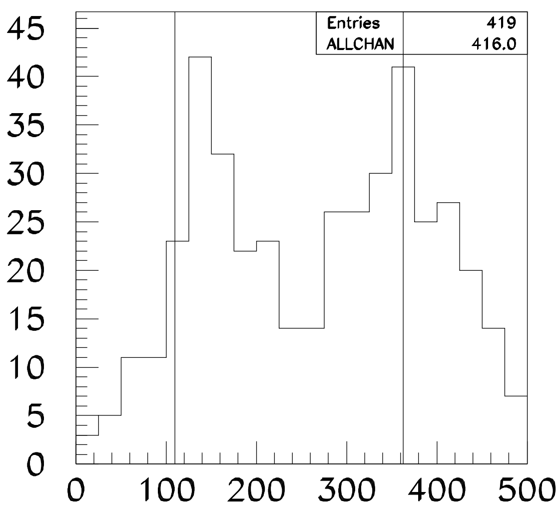
$m_{inv}^{\gamma\gamma,\gamma\gamma}$ versus E_γ



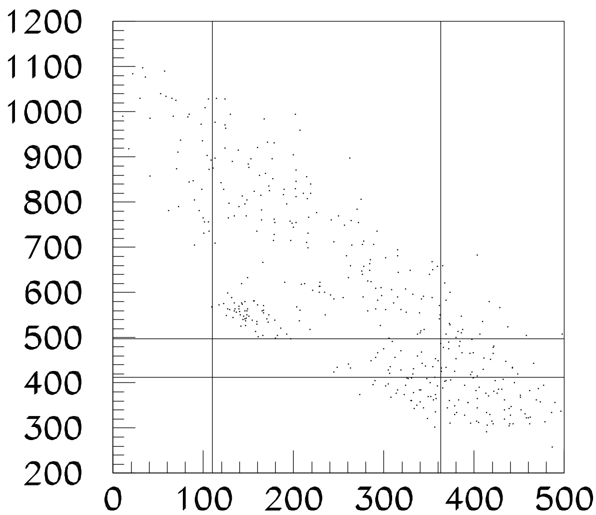
E_γ



$m_{inv}^{\gamma\gamma,\gamma\gamma}$



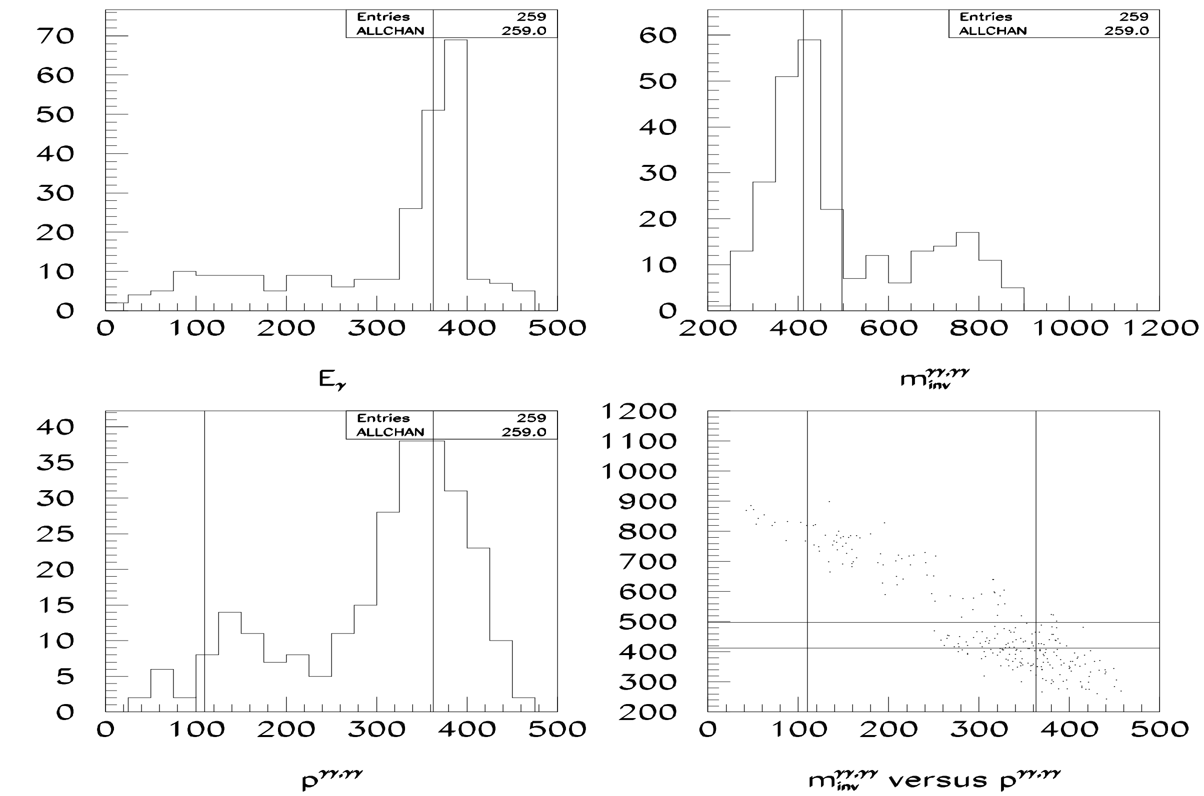
$p^{\gamma\gamma,\gamma\gamma}$



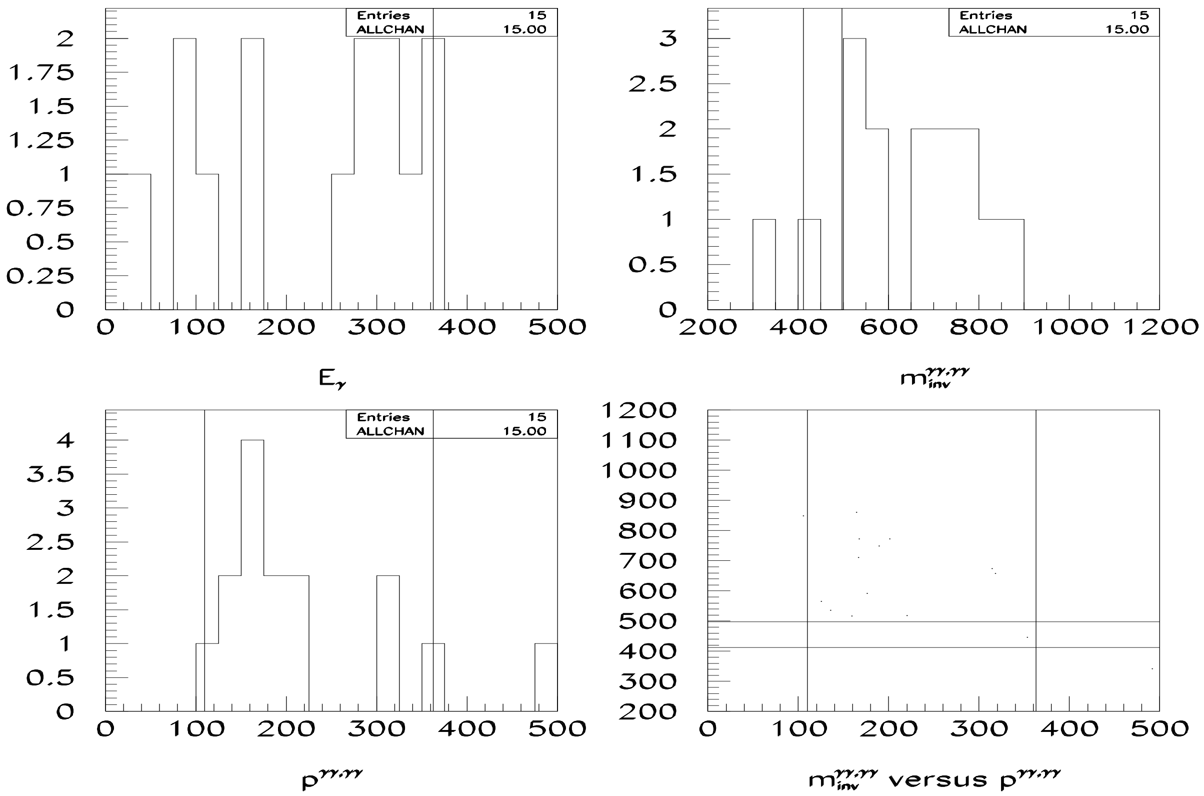
$m_{inv}^{\gamma\gamma,\gamma\gamma}$ versus $p^{\gamma\gamma,\gamma\gamma}$

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

Monte Carlo for $\phi \to \eta\gamma$

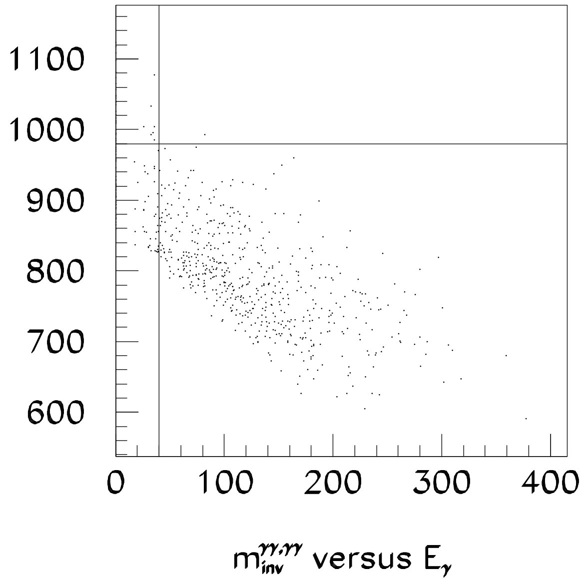


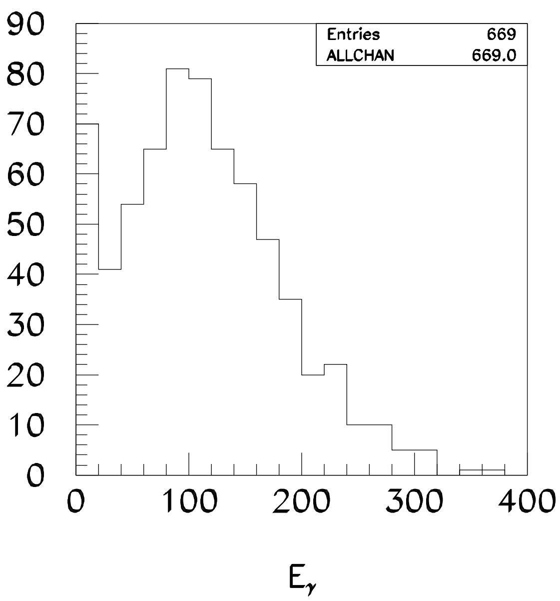
Monte Carlo for $\phi \to K_S^0 K_L^0$

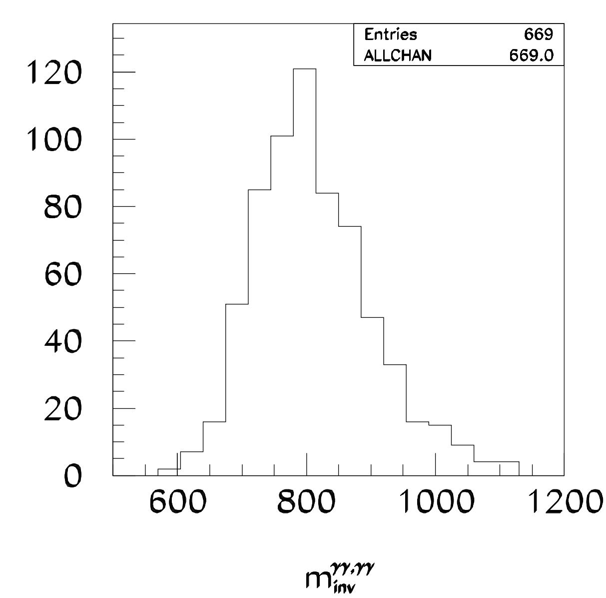


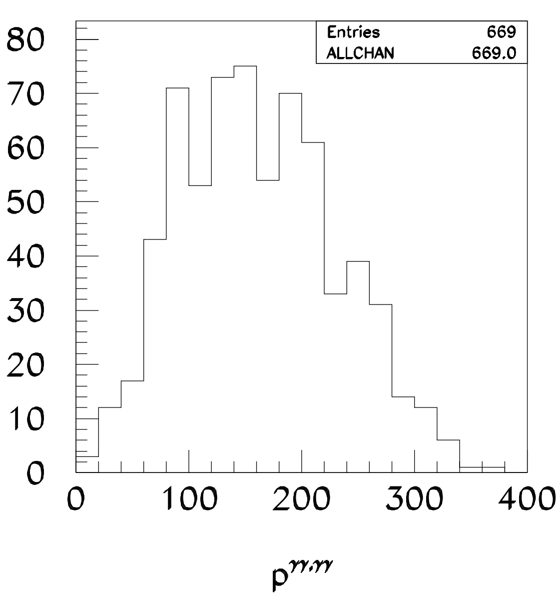
$\phi \to \eta\pi^0\gamma$ and $\phi \to a_0\gamma$ with $a_0 \to \eta\pi^0$

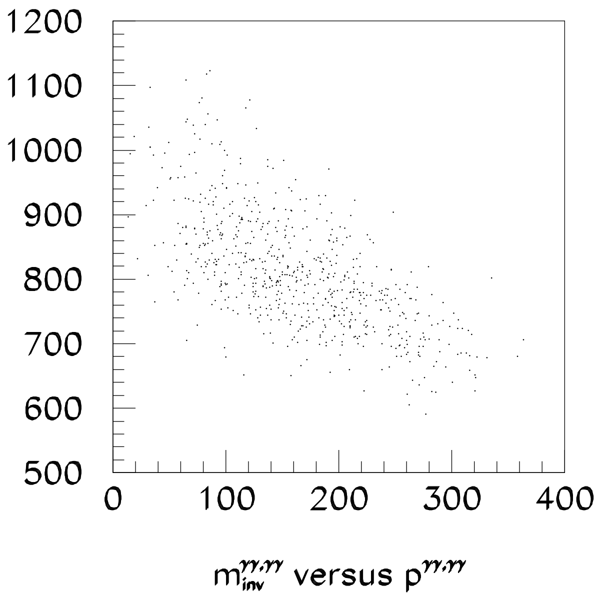
- neutral event
- ≤ 1 hit in outer MS
- $|E_{\text{tot}} - 2E_{\text{beam}}| < 150\,\text{MeV}$
  $p_{\text{miss}} < 200\,\text{MeV}/c$
- at most 5 clusters
- $|m_{\text{inv}}^{\gamma\gamma} - m_{\pi^0}| < 25\,\text{MeV}$
  $|m_{\text{inv}}^{\gamma\gamma} - m_{\eta}| < 75\,\text{MeV}$





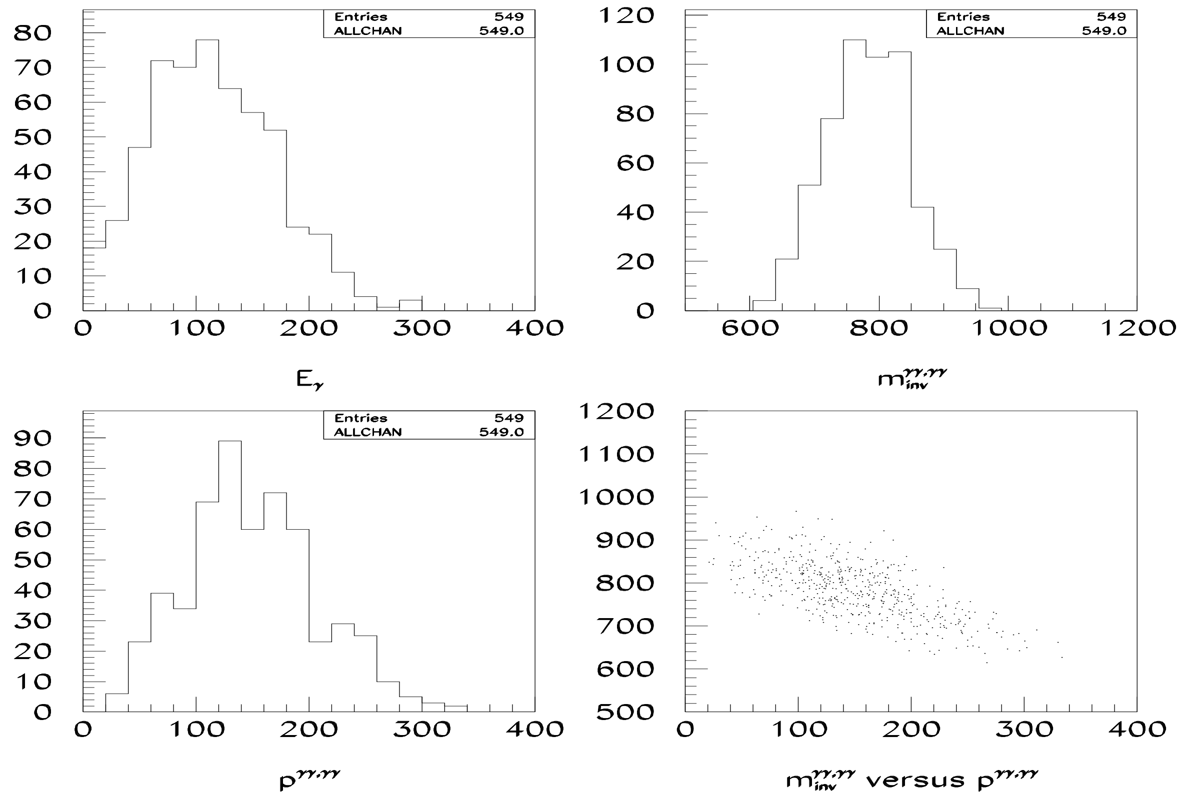




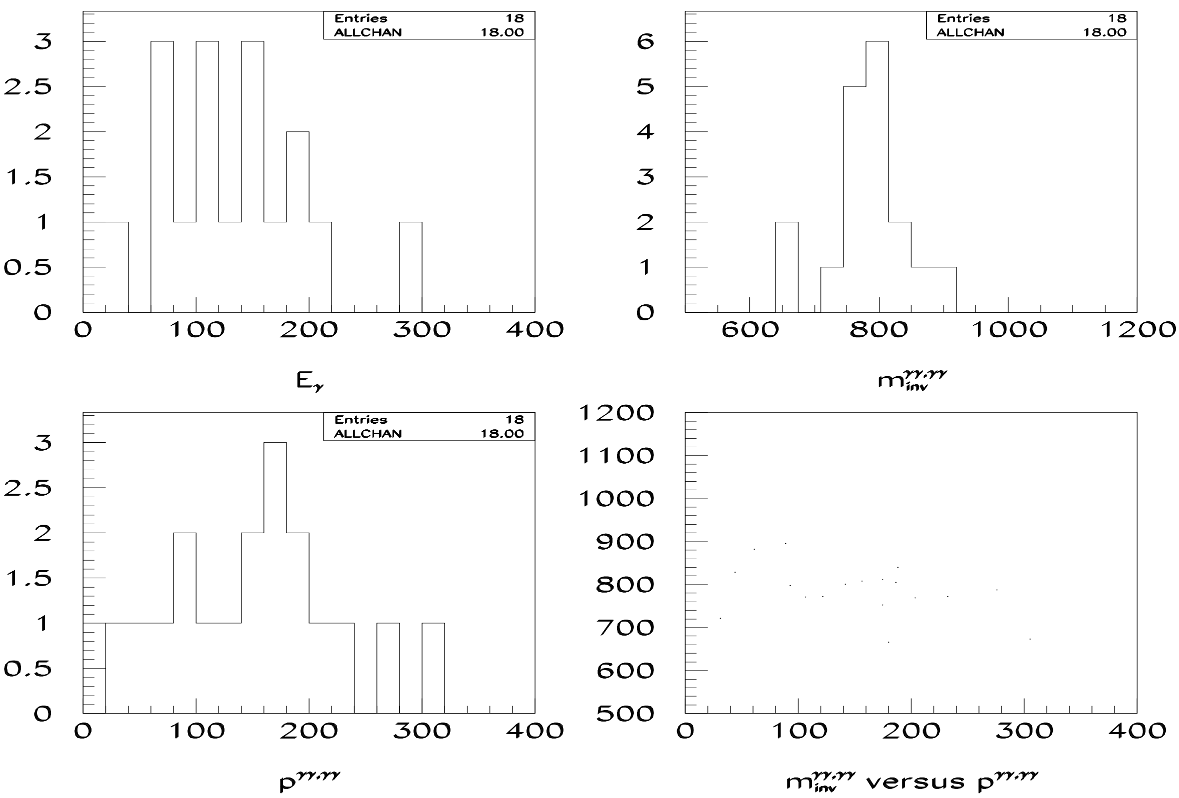


$\phi \to \eta\pi^0\gamma$ and $\phi \to a_0\gamma$ with $a_0 \to \eta\pi^0$

Monte Carlo for $\phi \to \eta\gamma$

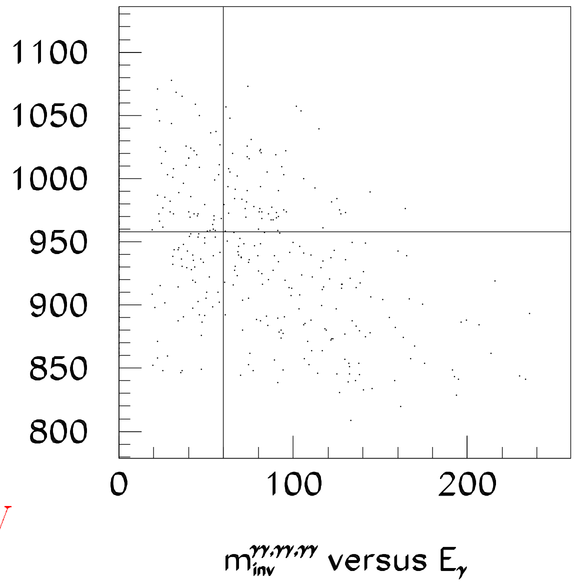


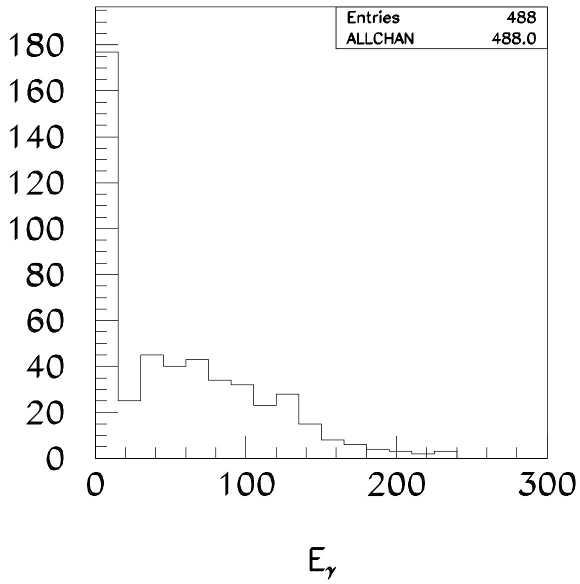
Monte Carlo for $\phi \to K_S^0 K_L^0$

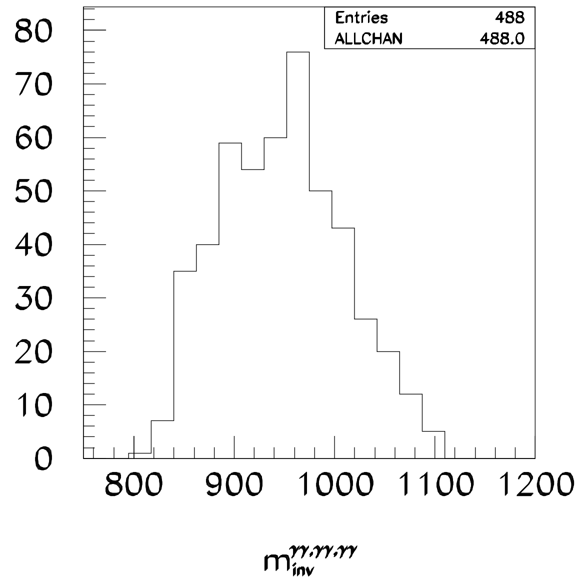


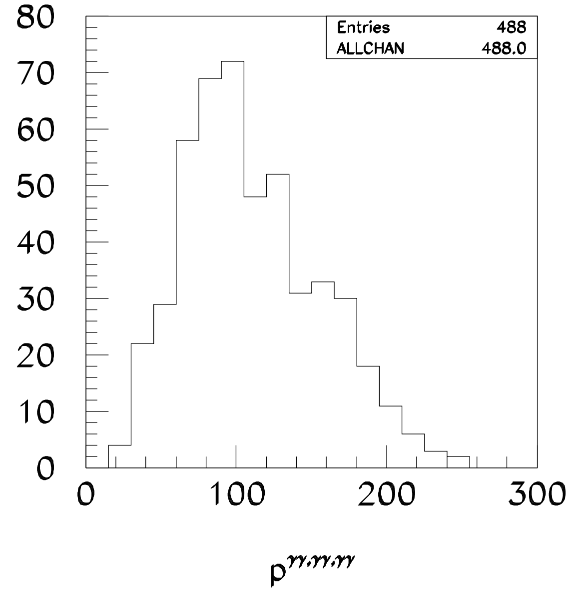
$\phi \to \eta'\gamma$ with $\eta' \to \eta\pi^0\pi^0$

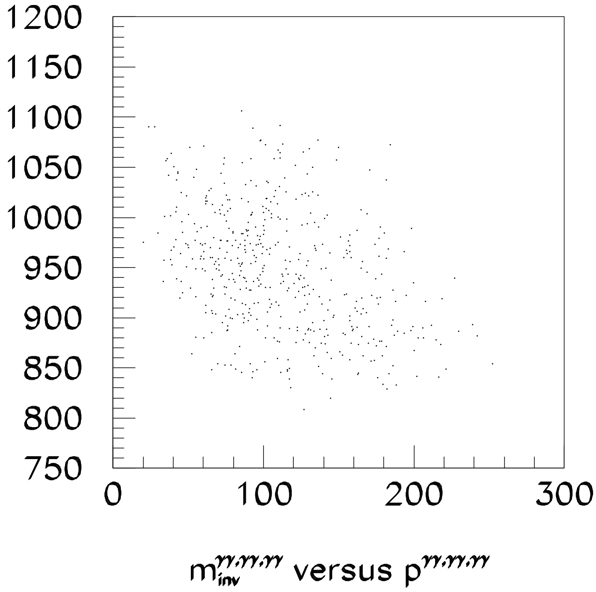
- neutral event
- ≤ 1 hit in outer MS
- $|E_{\rm tot} - 2E_{\rm beam}| < 150$ MeV
  $p_{\rm miss} < 200$ MeV$/c$
- at most 7 clusters
- $|m_{\rm inv}^{\gamma\gamma} - m_{\pi^0}| < 25$ MeV
  $|m_{\rm inv}^{\gamma\gamma} - m_{\eta}| < 75$ MeV
- $|m_{\rm inv}^{\gamma\gamma,\gamma\gamma,\gamma\gamma} - m_{\eta'}| < 150$ MeV





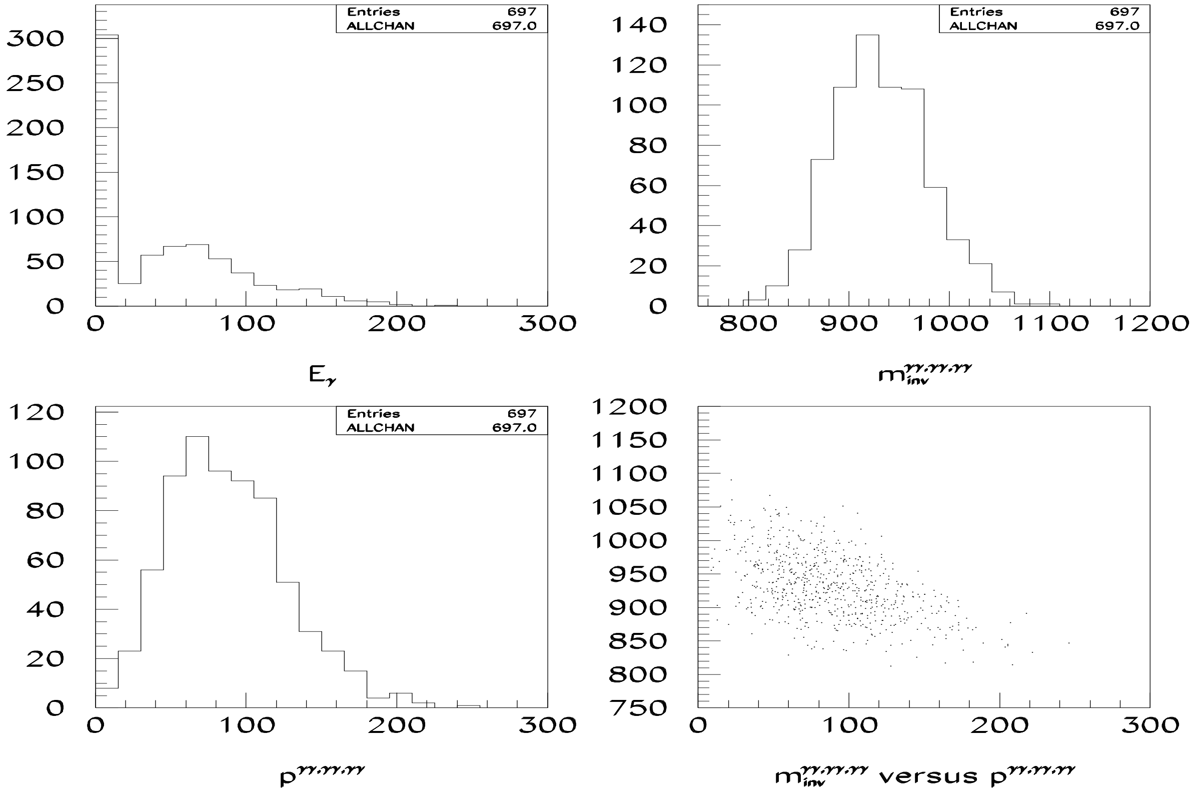




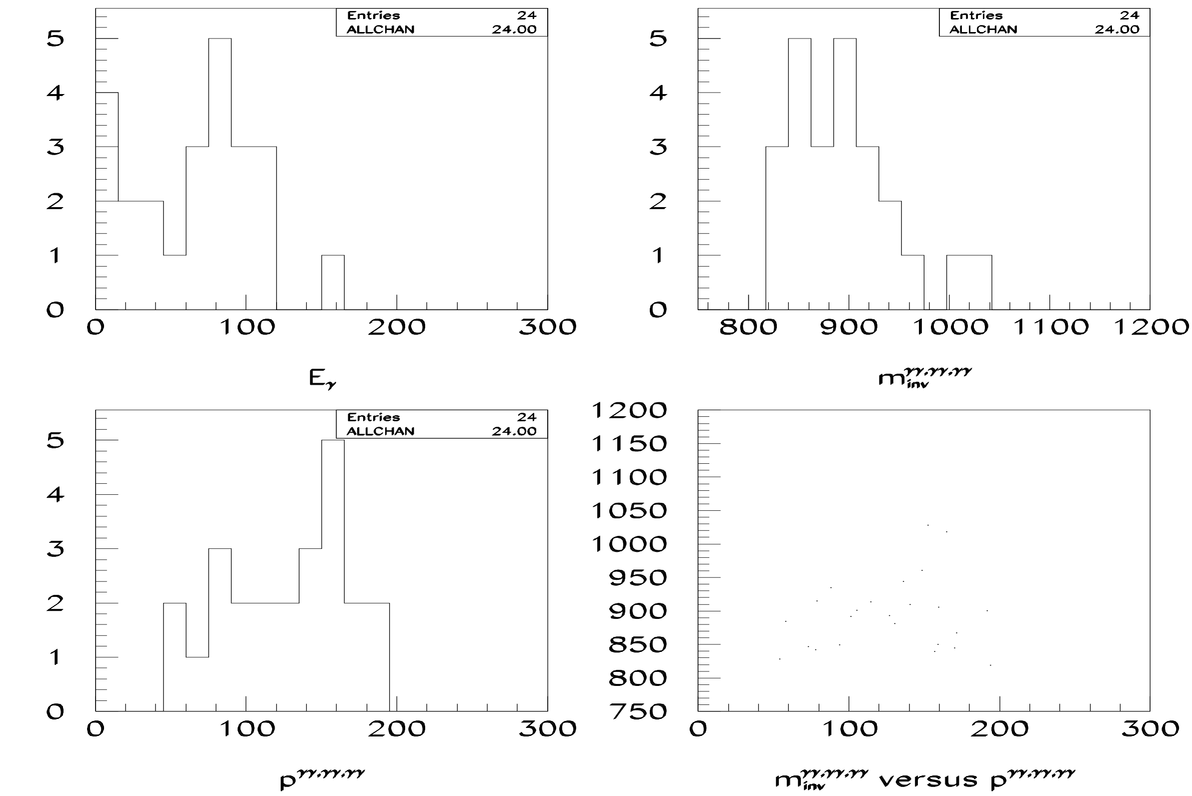


$\phi \to \eta'\gamma$ with $\eta' \to \eta\pi^0\pi^0$

Monte Carlo for $\phi \to \eta\gamma$



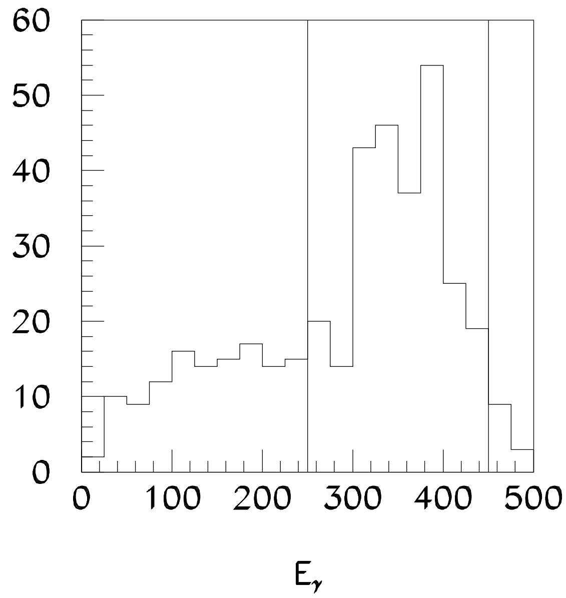
Monte Carlo for $\phi \to K_S^0 K_L^0$

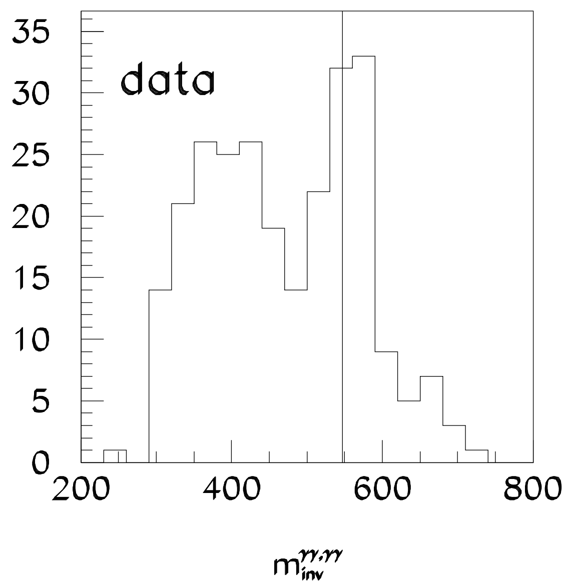


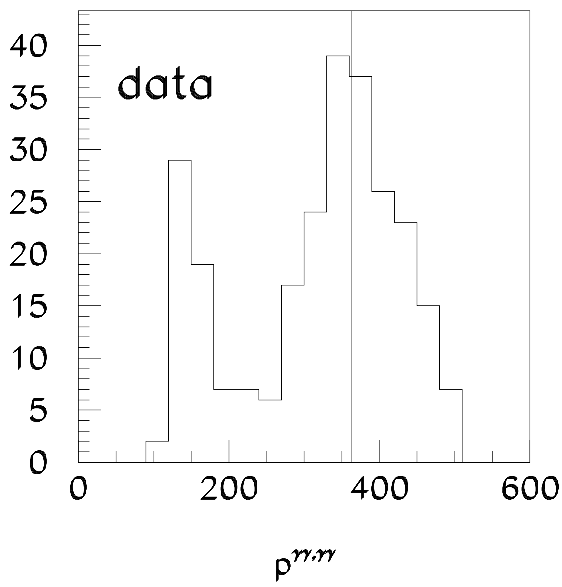
$\phi \to \eta\gamma$ with $\eta \to \pi^0\pi^0$

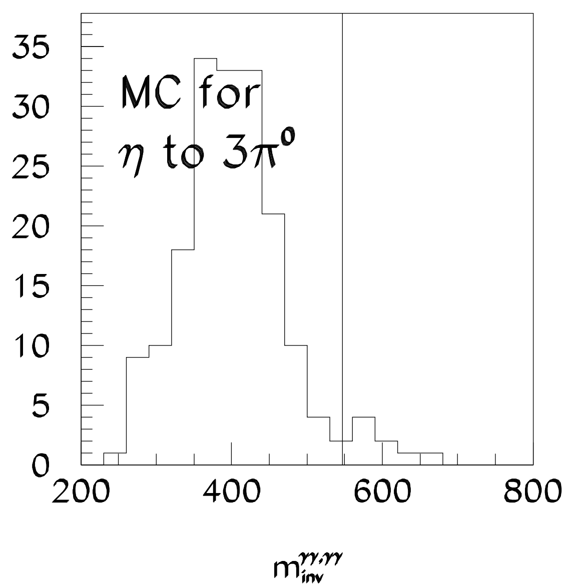
use the $\phi \to \pi^0\pi^0\gamma$ sample:

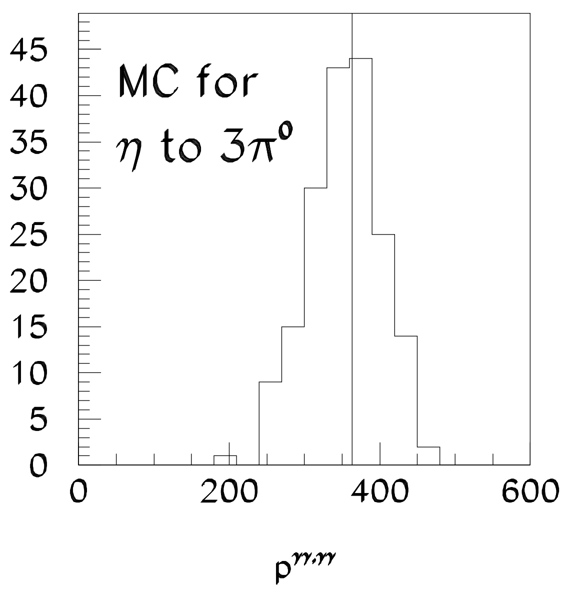
- neutral event
- ≤ 1 hit in outer MS
- $|E_{\text{tot}} - 2E_{\text{beam}}| < 150\,\text{MeV}$
  $p_{\text{miss}} < 200\,\text{MeV}/c$
- 5 clusters
- $|m_{\text{inv}}^{\gamma\gamma} - m_{\pi^0}| < 25\,\text{MeV}$



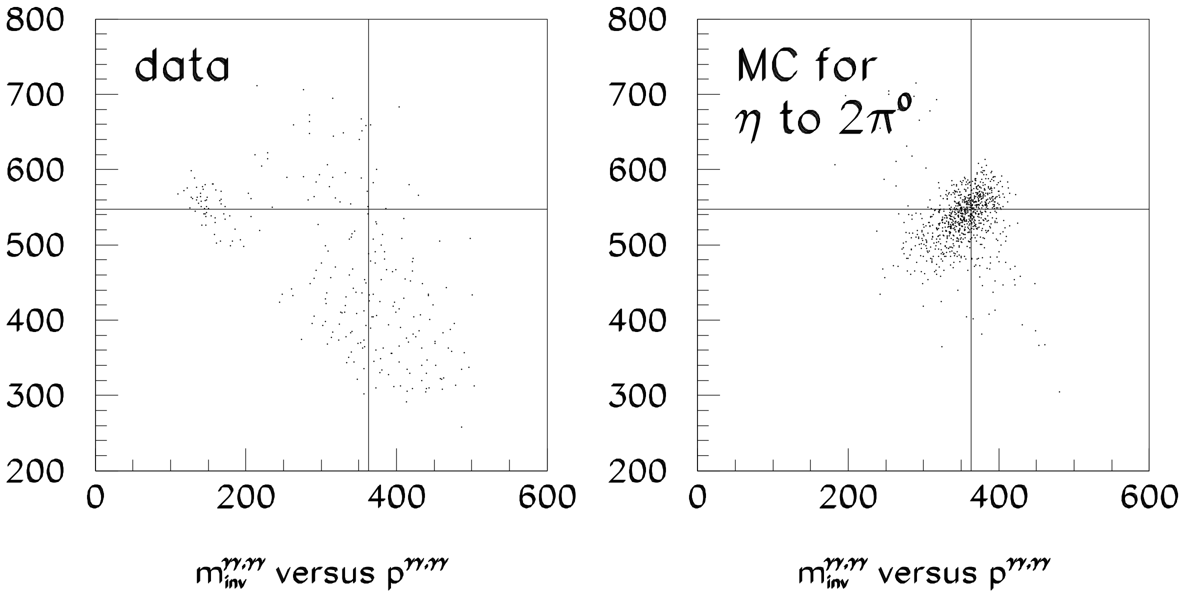








$\phi \to \eta\gamma$ with $\eta \to \pi^0\pi^0$

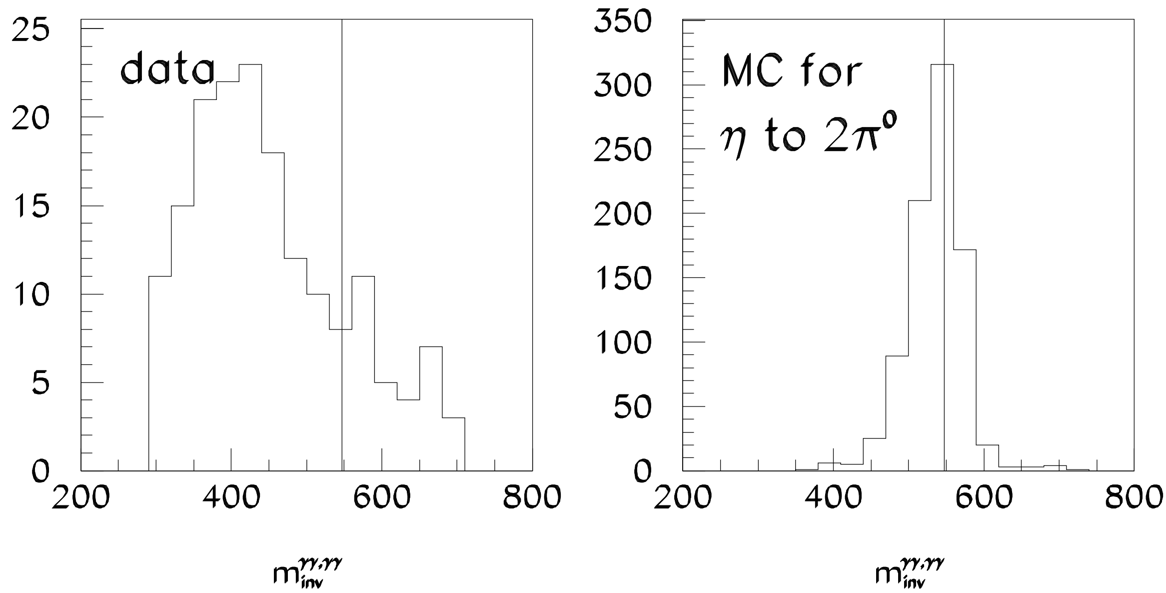


Determination of BR($\eta \to \pi^0\pi^0$)

To get a very preliminary upper limit for the branching ratio BR($\eta \to \pi^0\pi^0$), we in addition to the above cuts and the cut $250\,\mathrm{MeV} < E_\gamma < 450\,\mathrm{MeV}$ apply the following cut on the momentum of the η candidate:

$$250\,\mathrm{MeV}/c < p^{\gamma\gamma,\gamma\gamma} < 450\,\mathrm{MeV}/c$$

$\phi \to \eta\gamma$ with $\eta \to \pi^0\pi^0$



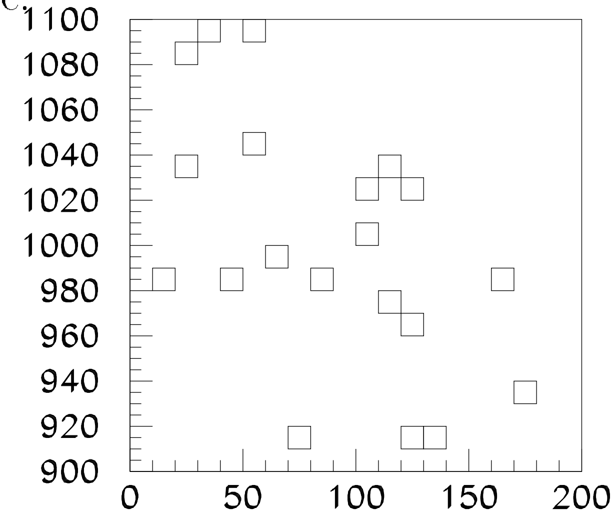
Assuming that we see at most 10 events of the type $\phi \to \eta\gamma$ with $\eta \to \pi^0\pi^0$, the upper limit for the branching ratio is $\approx 8 \cdot 10^{-3}$. Again, acceptance and efficiency is determined from Monte Carlo simulation (trigger efficiency 100%) and studies of the systematic error have not been done yet.

This very preliminary value however shows, that we have a good chance to determine a better upper limit for the branching ratio $\mathrm{BR}(\eta \to \pi^0\pi^0)$ than has been accomplished so far!

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

use again the $\phi \to \pi^0\pi^0\gamma$ sample:

- neutral event
- ≤ 1 hit in outer MS
- $|E_{\rm tot} - 2E_{\rm beam}| < 150\,{\rm MeV}$
  $p_{\rm miss} < 200\,{\rm MeV}/c$
- 4 clusters
- $|m_{\rm inv}^{\gamma\gamma} - m_{\pi^0}| < 25\,{\rm MeV}$



$m_{inv}^{\gamma\gamma,\gamma\gamma}$ versus $p^{\gamma\gamma,\gamma\gamma}$

For both possible background processes (*i.e.*, $\phi \to K_S^0 K_L^0$ and $\phi \to \eta\gamma$), the Monte Carlo simulations do not result in a single event!

Note that the above plot may also be a powerful tool to look for $\phi \to f_0\gamma$ with $f_0 \to \pi^0\pi^0$, where the radiative γ escapes detection.

What remains to be done ...

- Monte Carlo simulation
  For most of the interesting processes, most notably for $\phi \to f_0\gamma$ and $\phi \to a_0\gamma$, we need to have Monte Carlo generators. In addition, an improved description of the K_L^0 interactions would certainly help, too!

- efficiencies
  All efficiencies, including the Neutral Trigger efficiency, have to be determined from data, *e.g.* with the process $\phi \to \pi^+\pi^-\pi^0$.

- CsI calibration
  We plan to re-calibrate the 93 data. This should result in a somewhat better resolution and hopefully removes the annoying mismatch between data and simulation.

- Luminosity
  We need more data! Our competitors are not sleeping ...

  - ND
    Luminosity collected at ϕ: $3\,\mathrm{pb}^{-1}$
    calorimeter (acceptance and σ_E/E): 65%, $4\%/\sqrt{E[\,\mathrm{GeV}]}$
  - SND
    Luminosity collected at ϕ: roughly the same as CMD-2
    calorimeter (acceptance and σ_E/E): 90%, 4 – 6%
  - KLOE at DAΦNE
    Luminosity collected at ϕ: nothing yet, but ...
    calorimeter (acceptance and σ_E/E): 98%, $5\%/\sqrt{E[\,\mathrm{GeV}]}$
  - E-94-016 at Jefferson Lab

We should at least immediately look at the data already collected!