Measurement of $\eta \to \pi^0\gamma\gamma$ decay at KLOE.

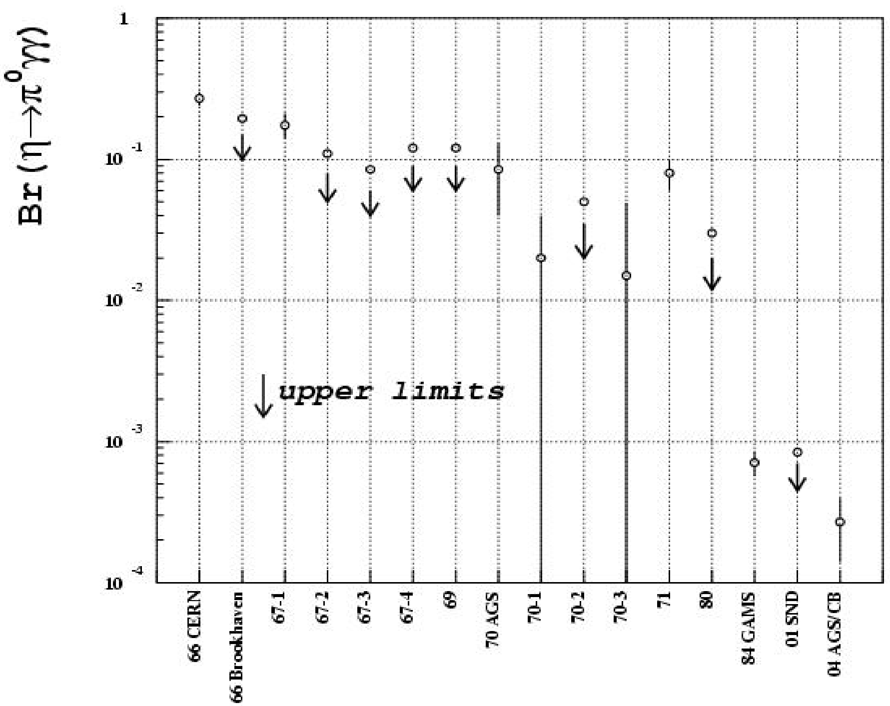
Biagio Di Micco

Università degli Studi di Roma Tre

Outline

- η *production and Br measurements in past experiments;*
- η *production mechanism @ KLOE;*
- $\eta \to \pi^0 \gamma\gamma$ *analysis description;*
- *KLOE preliminary result compared with theoretical predictions.*

η production and Br measurements in past experiments



$\pi^- + p \to \eta + n$

(CERN, Brookhaven, GAMS, Crystal Ball)

$\pi^+ + d \to p + p + \eta$ (67)

$\pi^+ + p \to \pi^+ + p + \eta$ (67,69)

$K^- + p \to \Lambda + \eta$ (70 AGS)

$\pi^+ + n \to \eta + p$ (71)

$\pi^- + n \to \pi^- + n + \eta$ (80)

$\phi \to \eta\gamma$ (SND 01)

Most recent measurements

$Br(\eta \to \pi^0 \gamma\gamma)$

AGS/Crystall Ball
Phys. Lett. B 589 (2004) 14

$\pi^- + p \to \eta + n$

$N_\eta = 3\times10^7$

$(2.7 \pm 0.9_{stat} \pm 0.5_{syst})\times10^{-4}$

SND – Novosibirsk
Nucl. Phys. B600 (2001) 3

$\phi \to \eta\,\gamma$

$N_\eta = 2.6\times10^5$

$< 8.4 \times10^{-4}$

GAMS2000
Nuovo Cimento A 71 (1982) 497

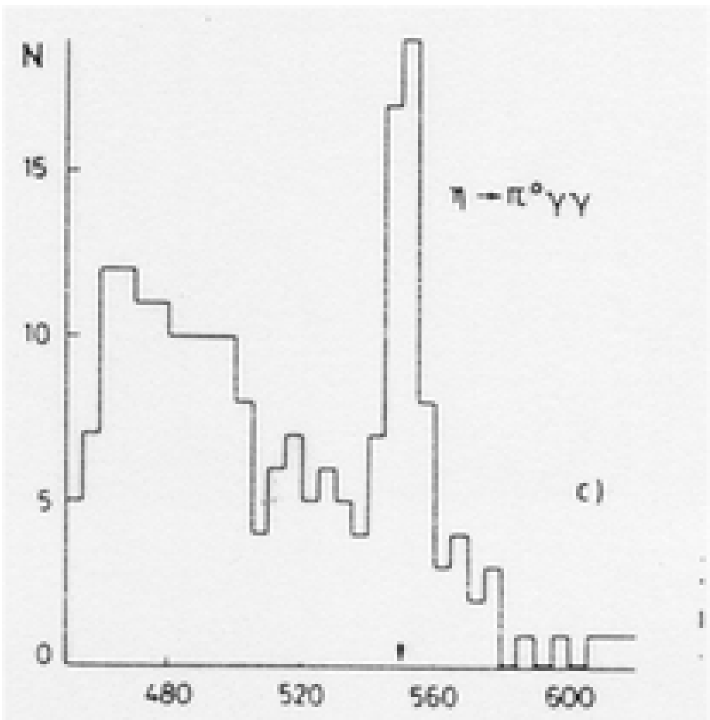
$\pi^- + p \to \eta + n$

$N_\eta = 6\times10^5$

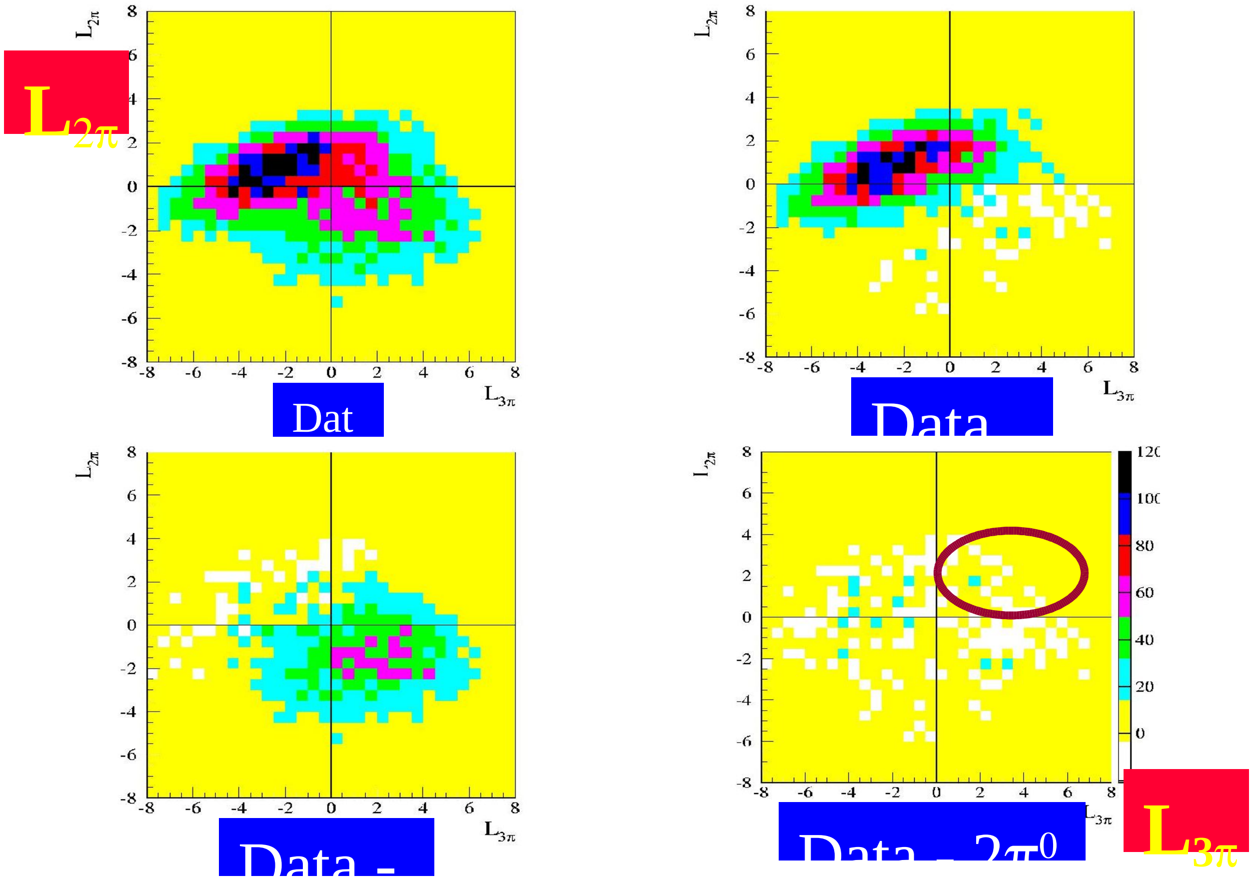
$(7.2 \pm 1.4)\times10^{-4}$

GAMS – CB comparison

GAMS:
evidence of the signal



Crystall Ball:
evidence of the signal



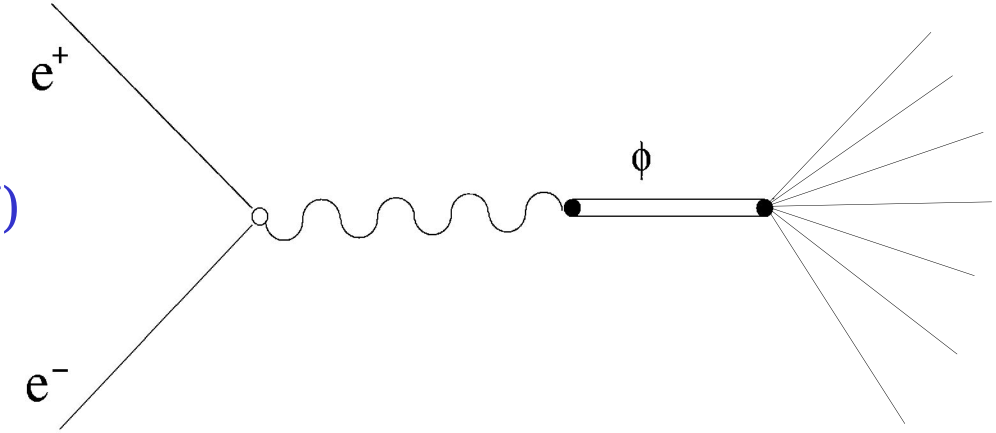
The DAΦNE apparatus

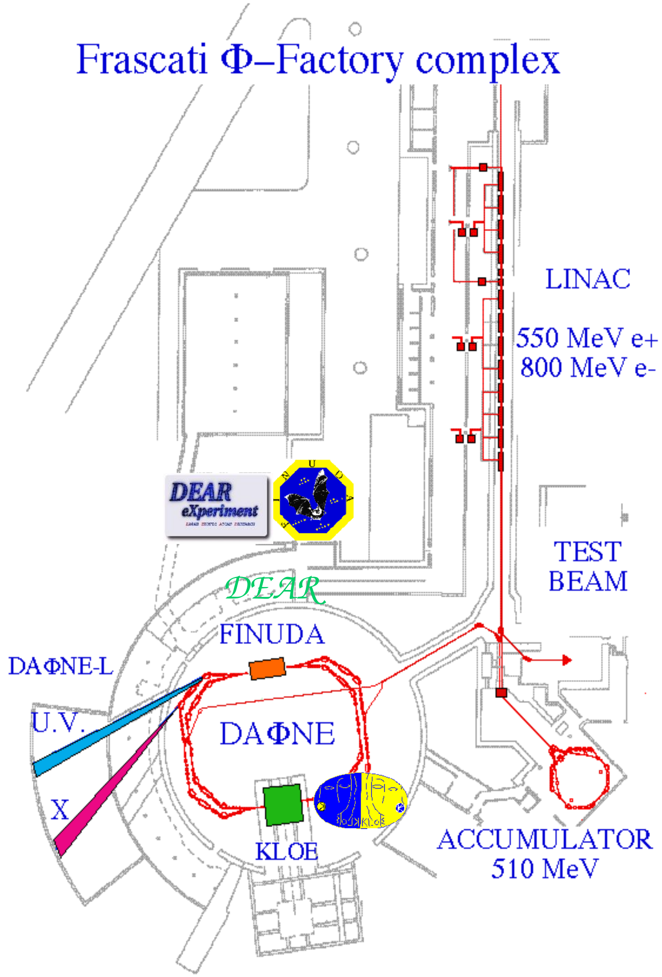
$\sqrt{s} = M_{\Phi} = 1.02$ GeV

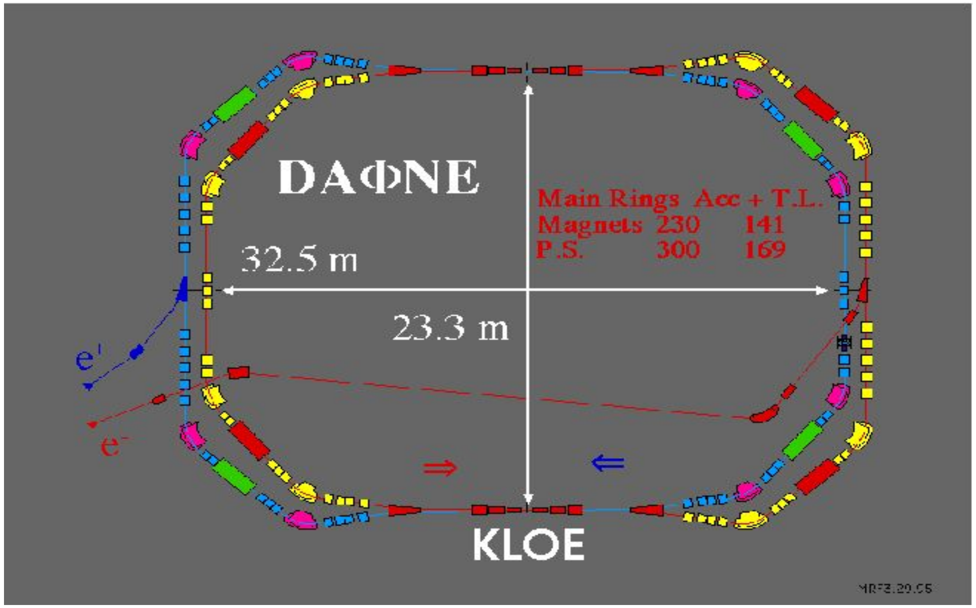
$\sigma(\Phi) \approx 3.3\ \mu b$

e^+e^- in two separate rings with crossing angle ~25mrad at IP

(small Φ momentum p_{Φ}~13MeV)







KLOE collected luminosity

Decay	BR(%)
$\phi \rightarrow K^+ K^-$	49.1
$\phi \rightarrow K_S K_L$	33.8
$\phi \rightarrow \rho \pi / \pi^+\pi^-\pi^0$	15.6
$\phi \rightarrow \eta \gamma$	1.26

2001+2002 integrated luminosity

$L_{int} \sim 450\ pb^{-1}$

$N_{\phi} \sim 1.5\times10^{9}$

$N_{\eta} \sim 1.9\times10^{7}$

2004 collected luminosity

$L_{peack} = 11\times10^{31}$

$L_{average} = 8.3\times10^{31}$

$L_{int} = 750\ pb^{-1}$

2005 estimated luminosity (until July)

$L_{int} > 1000\ pb^{-1}$

The KLOE detector

Electromagnetic Calorimeter (EMC)

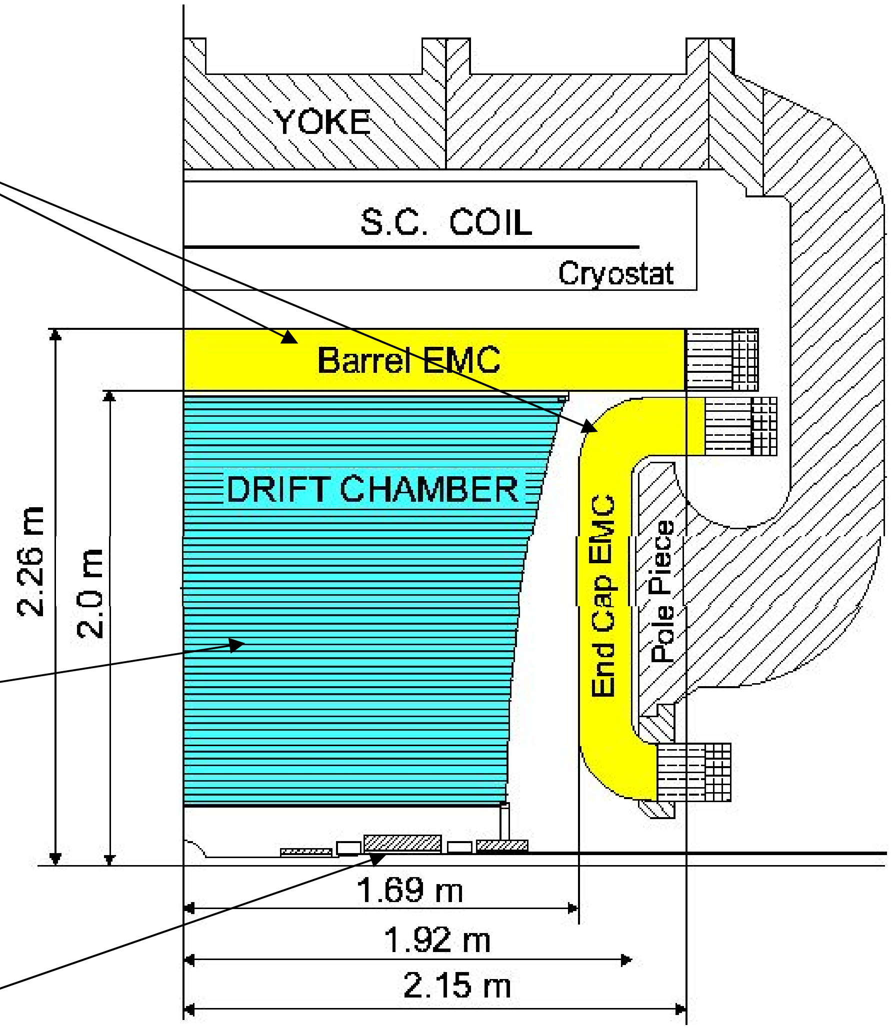
- Fine sampling Pb (0.5 mm thick) / Scifi (1 mm ø)
- Hermetical coverage
- High efficiency for low energy photons
  - $\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$
  - $\sigma_t = 54ps/\sqrt{E(GeV)}$

Central drift chamber (DCH)

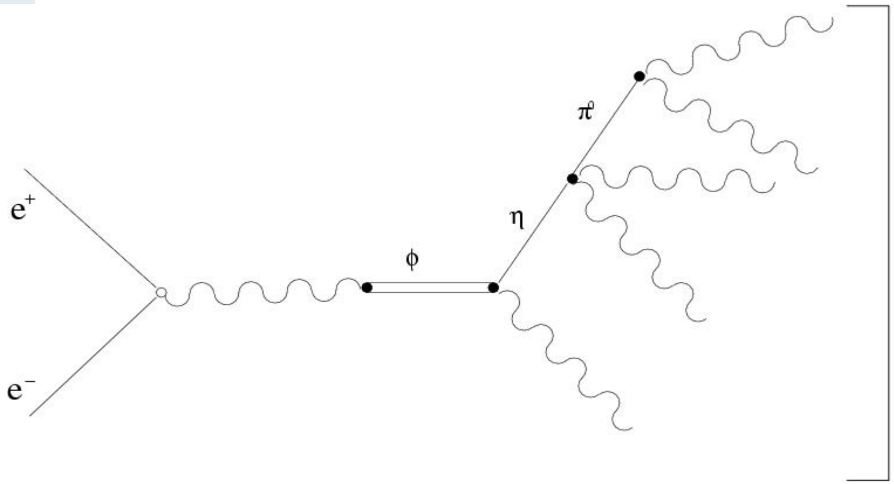
- Large detection volume
- Uniform tracking and vertexing in all volume
- Helium based gas mixture
  - $\sigma_v = 1$ mm $\sigma_{pt}/p_t = 0.5\%$
  - $\sigma_{r,\phi} = 200$ µm $\sigma_z = 2$ mm

Quadrupoles' calorimeter (QCAL)

- Pb/Sci tile calorimeter covering quads inside KLOE



$\eta \to \pi^0\gamma\gamma$ @KLOE



5γ
final sate

Background

$< 5\gamma +$ accidental

$\phi \to \eta(\to\gamma\gamma)\gamma$

$\phi \to \pi^0(\to\gamma\gamma)\,\gamma$

$e^+e^- \to e^+e^-(\gamma)$, $e^+e^- \to \gamma\gamma$

5γ

$\phi \to f_0(\to\pi^0\pi^0)\gamma$

$\phi \to a_0(\to\eta\pi^0)\,\gamma$

$e^+e^- \to \omega(\to\pi^0\gamma)\pi^0$

$\phi \to \rho^0(\to\eta\,\gamma)\gamma, \rho^0(\to\pi^0\gamma)\gamma$

$> 5\gamma$

$\phi \to \eta(\to 3\pi^0)\gamma$

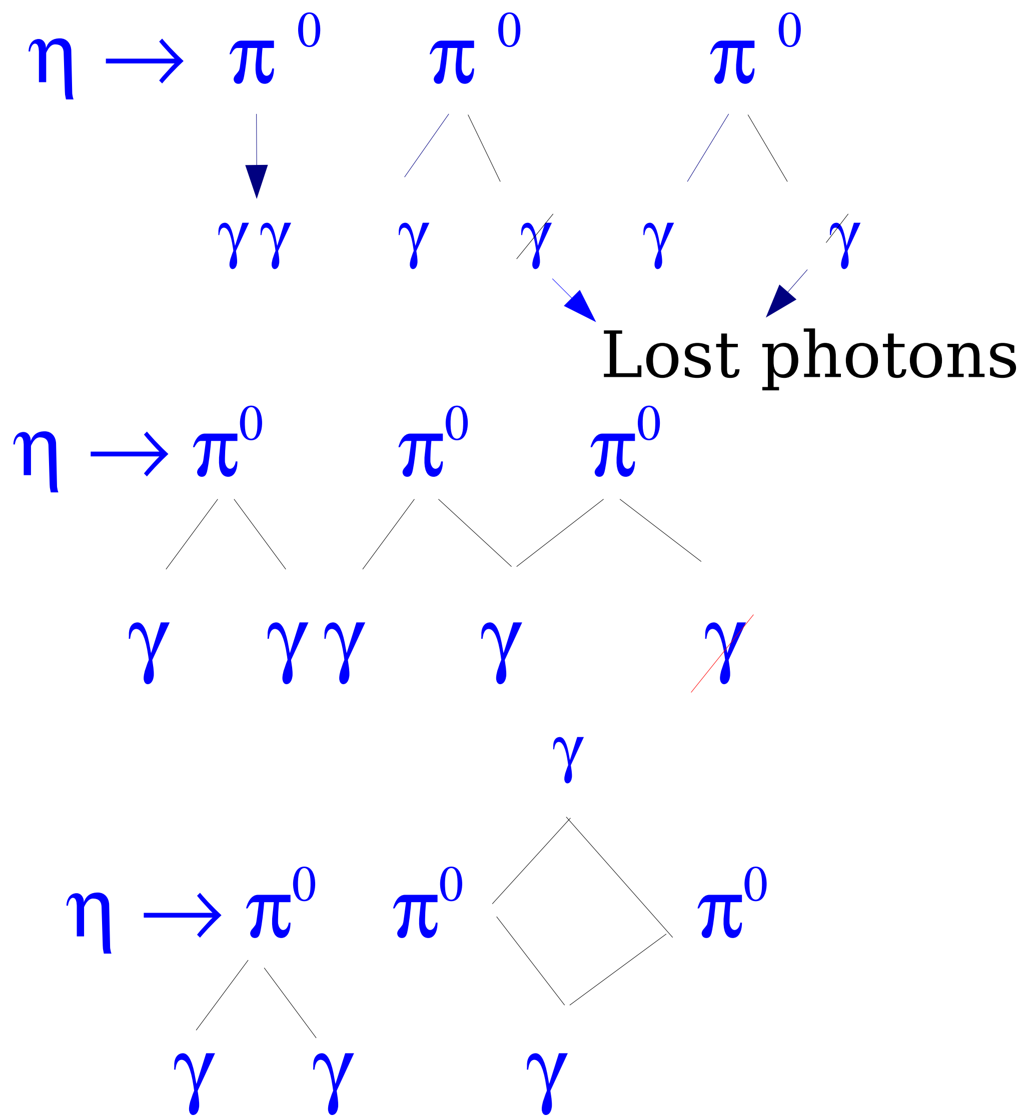
2 lost

1 lost – 1 merged

2 merged

$\eta \rightarrow 3\pi^0$ background

There are 3 possible cases.



Identified through a kinematic fit procedure constraining the 3 π^0 and the η masses.

Same procedure but in this case the fit requirement is not enough. We cut on the energy and direction of the lost photon, determined by the fit.

In this case we identify the merged photons using cluster shaping. We build a likelihood that can distinguish between merged and not merged clusters.

Background abundance

channel	σ (nb)
$\phi \to f_0(f_0 \to \pi^0\pi^0)\gamma$	0.30
$\phi \to a_0\gamma, a_0 \to \eta\pi^0, \eta \to \gamma\gamma$	0.26
$\phi \to \eta(\eta \to 3\pi^0)\gamma$	13.8
$\phi \to \eta(\eta \to \gamma\gamma)\gamma$	16.9
$\phi \to \pi^0(\eta \to \gamma\gamma)\gamma$	4.16
$\phi \to \rho^0\pi^0, \rho^0 \to \eta(\to \gamma\gamma)\gamma$	0.04
$\phi \to \rho^0\pi^0, \rho^0 \to \pi^0\gamma$	0.11
$e^+e^- \to \omega(\omega \to \pi^0\gamma)\pi^0$	0.45
$e^+e^- \to \gamma\gamma$	7.5
$e^+e^- \to e^+e^-(\gamma)$	1.5×10^3

What are we looking for?

$\sim 10^{-4}\eta \quad \sim 10^{-6}\phi$

Among neutral events

with the same final state

$\eta \to \pi^0\gamma\gamma \sim 8\text{x}10^{-3}\text{nb}$

Analysis scheme

5 and only 5 prompt photons → Total energy > 800 MeV → Kinematic fit with energy momentum conservation

Prompt photon

$|t - r/c| < \min(5\sigma_t, 2\text{ns})$

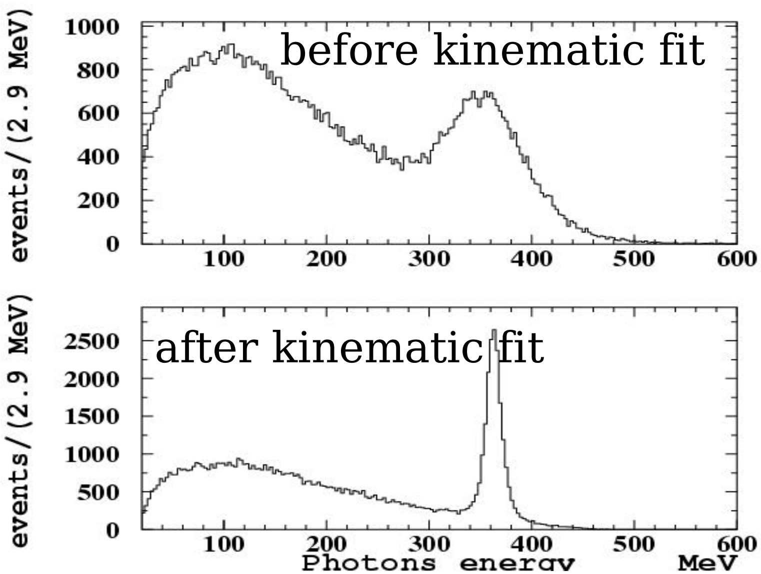
not associated to a charged track

Kinematic fit features

improves photon energy resolution

push accidental clusters to 0 energy

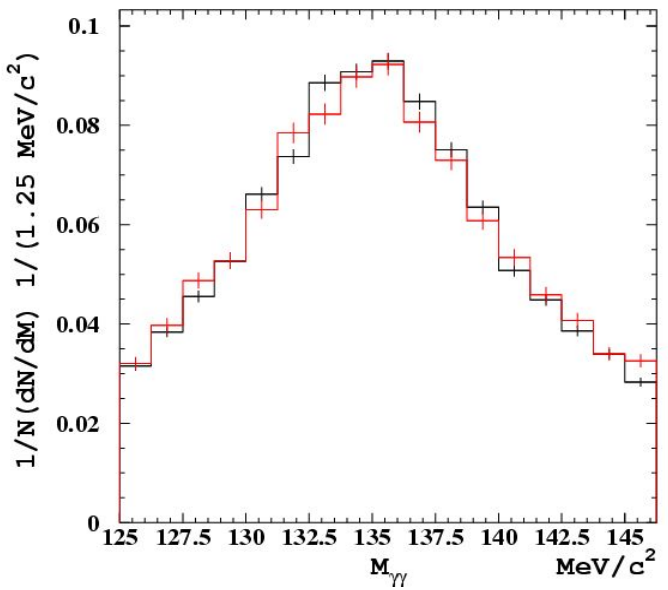
DATA-MC comparison of energy distribution



The most energetic photon is in the main part of cases that coming from the $\phi \rightarrow \eta\gamma$ decay (363 MeV)

We build the invariant mass $m_{4\gamma}$ of the 4 least energetic photon to search for the signal.

DATA – MC comparison



DATA

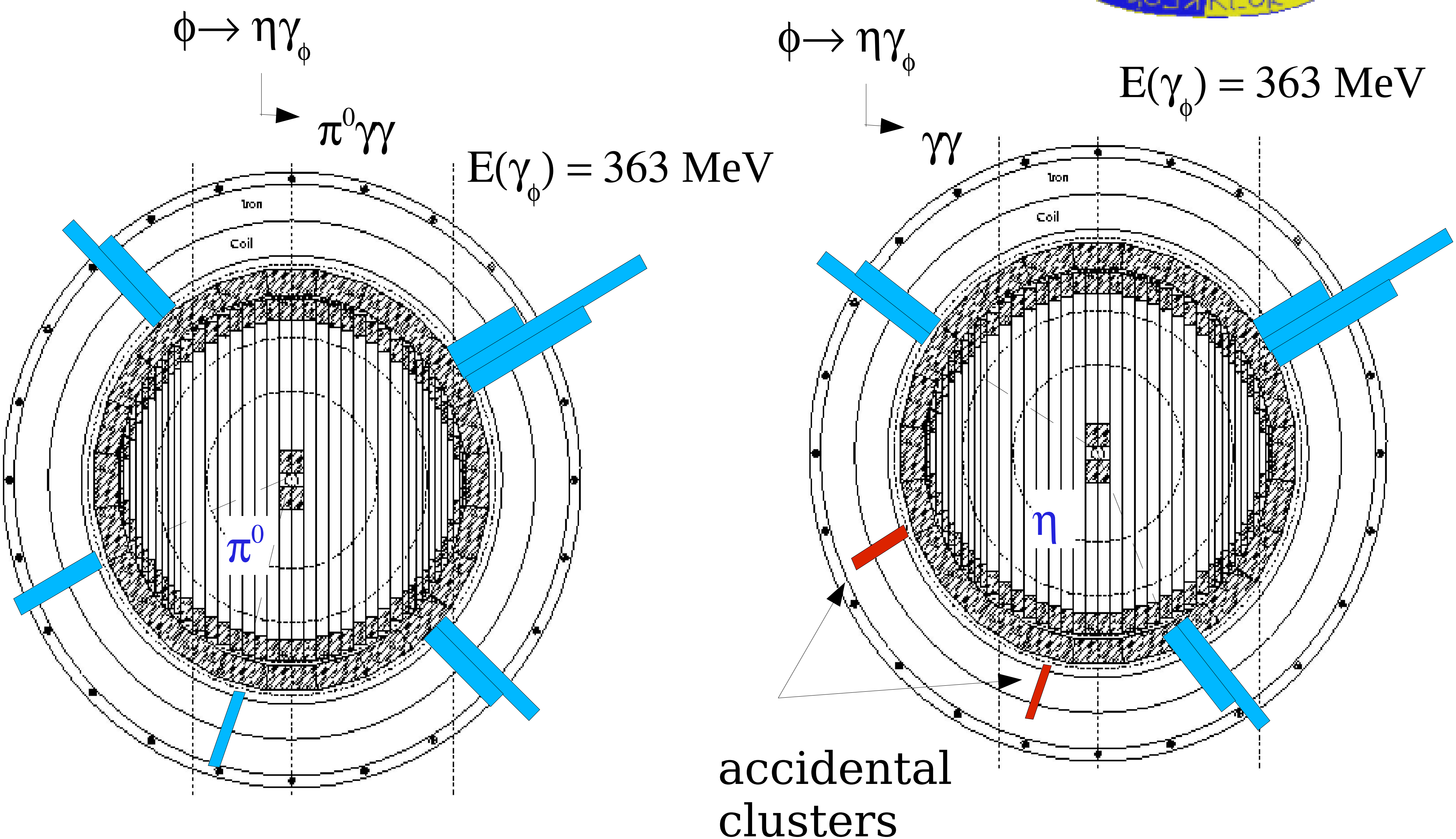
MC

the π^0 peak is well reproduced

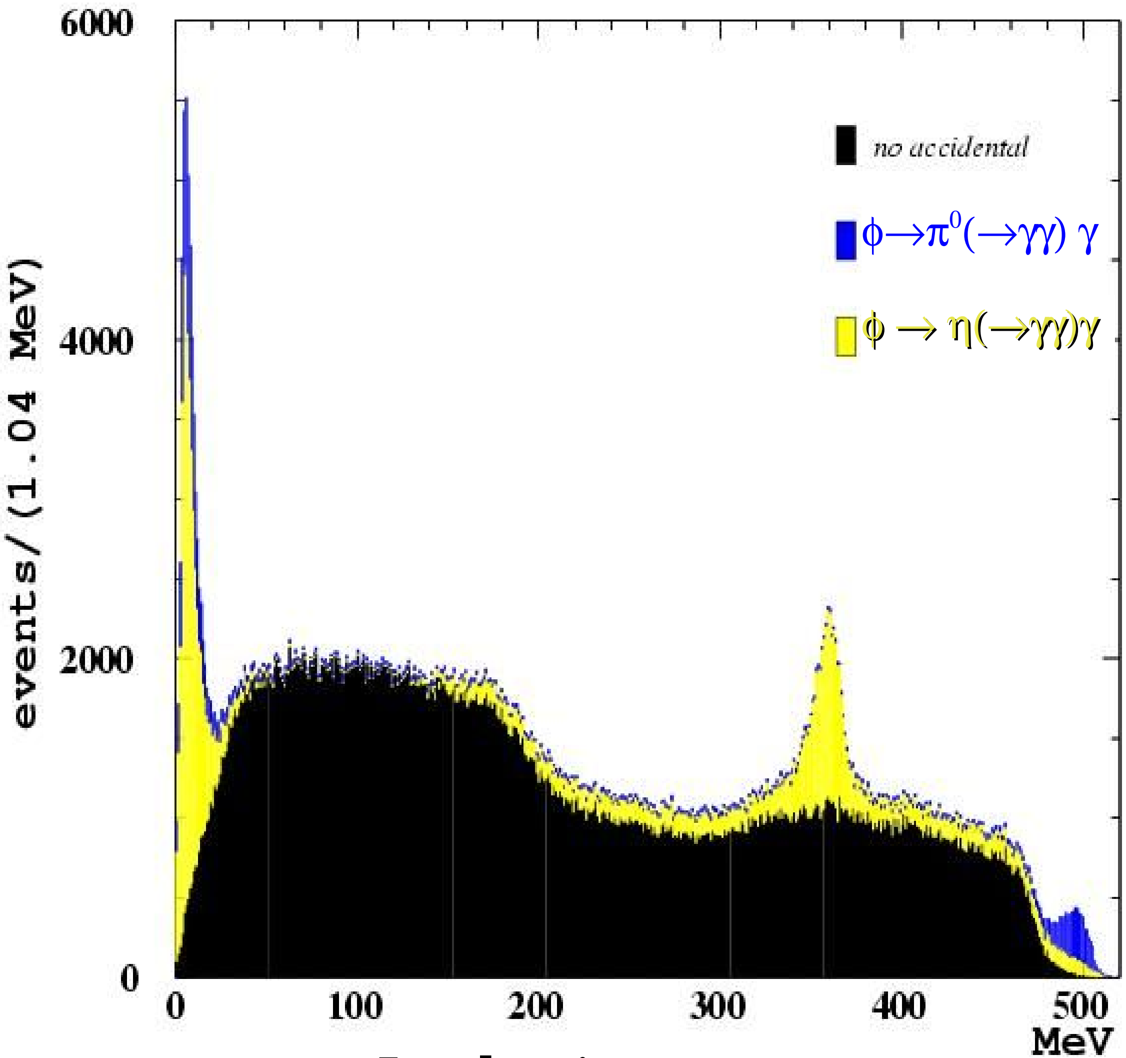
$m_\pi(MC) = 134.93 \pm 0.04\ MeV/c^2$

$m_\pi(DATA) = 135.08 \pm 0.07\ MeV/c^2$

Signal and accidental background topologies

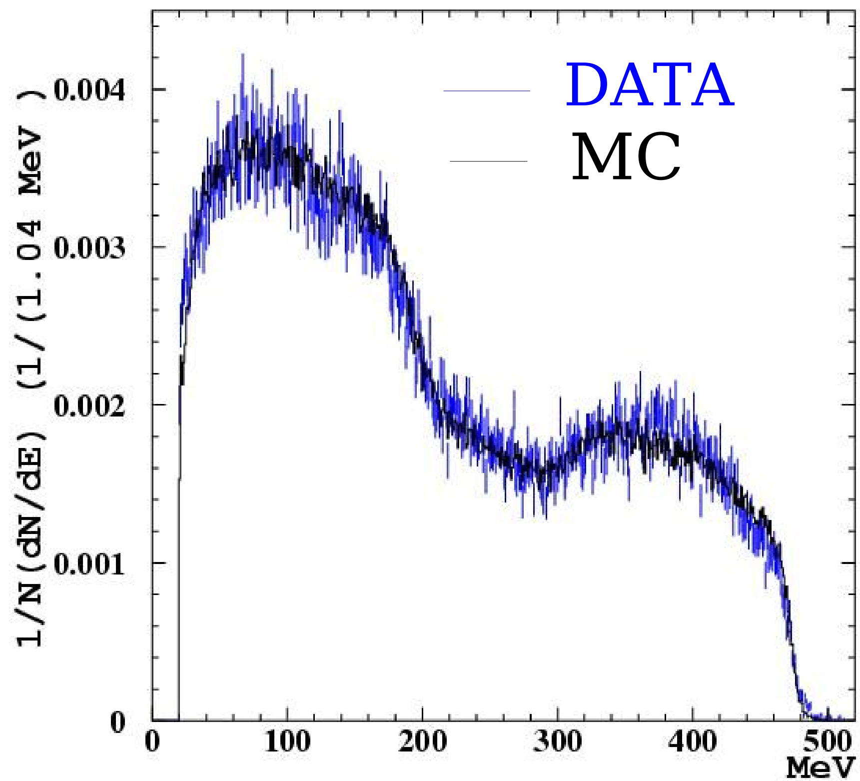


< 5 γ + accidental rejection



Inclusive energy
after kinematic fit

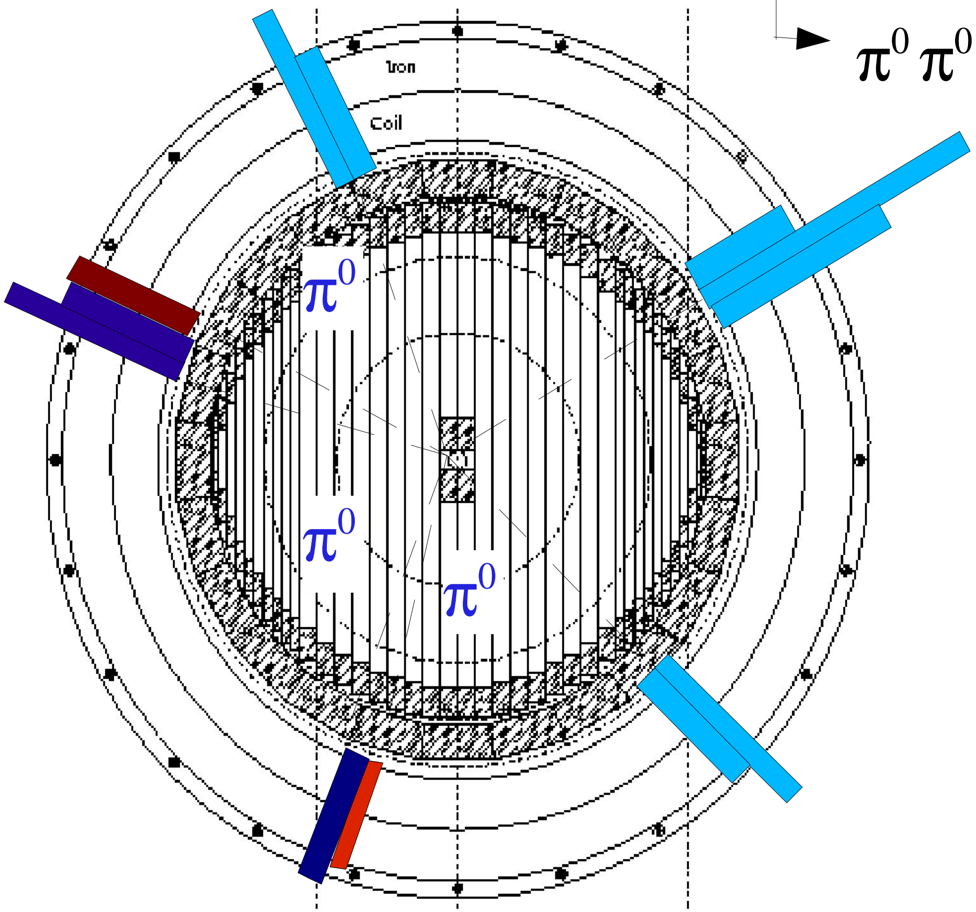
E> 20 MeV
$\theta_\gamma > 21°$



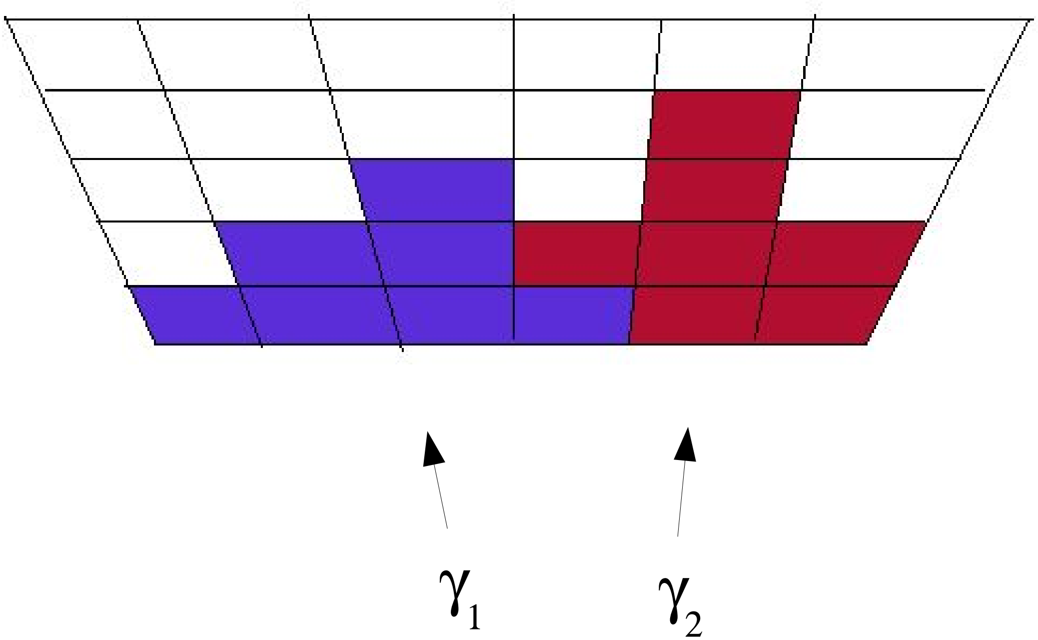
Merged clusters background topology

$\phi \rightarrow \eta\gamma_{\phi}$

$\rightarrow \pi^0\pi^0\pi^0 \quad 7\gamma$



rms, asimmetry are used to identify merged clusters



Merged clusters identification

Shower shape variables are used to identify merged clusters :

mean

$$x,y,z,t_{mean} = \frac{\sum_i^{n.cells} x_i \cdot E_i}{\sum_i^{n.cells} E_i}$$

rms

$$x,y,z,t_{rms} = \frac{\sum_i^{n.cells} E_i \cdot (x_i - x_{mean})^2}{\sum_i^{n.cells} E_i}$$

skewness

$$x,y,z,t_{skew} = \frac{\sum_i^{n.cells} (x_i - x_{mean})^3}{\sum_i^{n.cells} E_i}$$

We find the distribution of this varibles (ξ_κ) for good clusters and for merged ones, then we build the likelihood:

$$L^{good,merged} = \prod f_k^{good,merged}(\xi_k)$$

and we use the ratio as a discriminating variable:

$$r = \log\left(\frac{L^{good}}{L^{merged}}\right)$$

Likelihood ratio

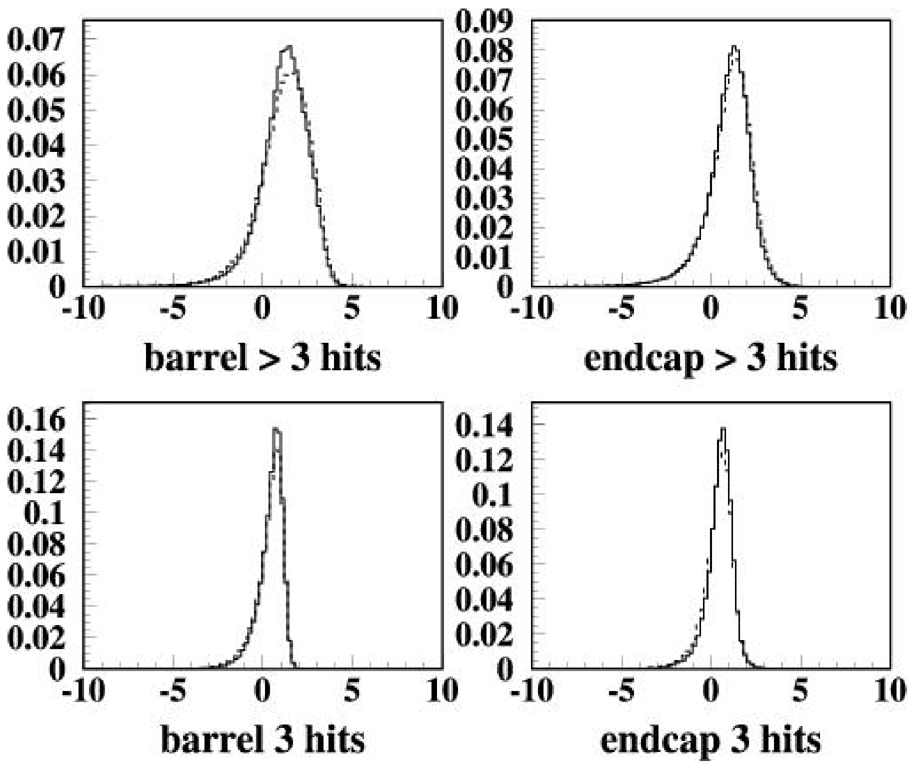
$$r = \log\left(\frac{L^{\text{good}}}{L^{\text{merged}}}\right)$$

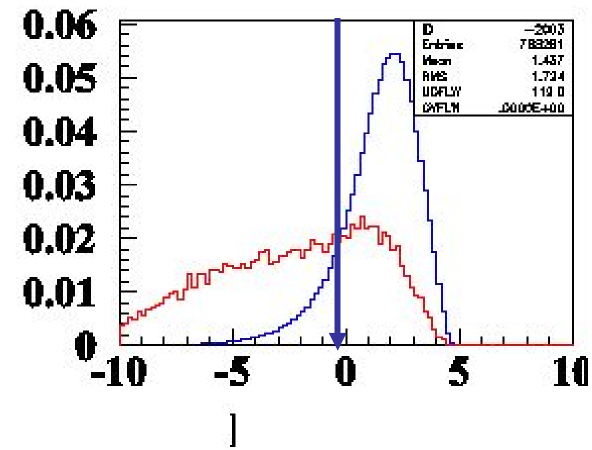
good-merged discrimination

—— **good**
—— **merged**

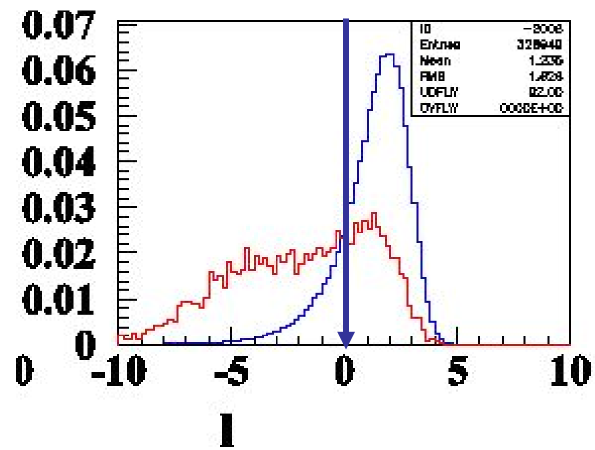
DATA-MC comparison

—— **DATA**
------ **MC**



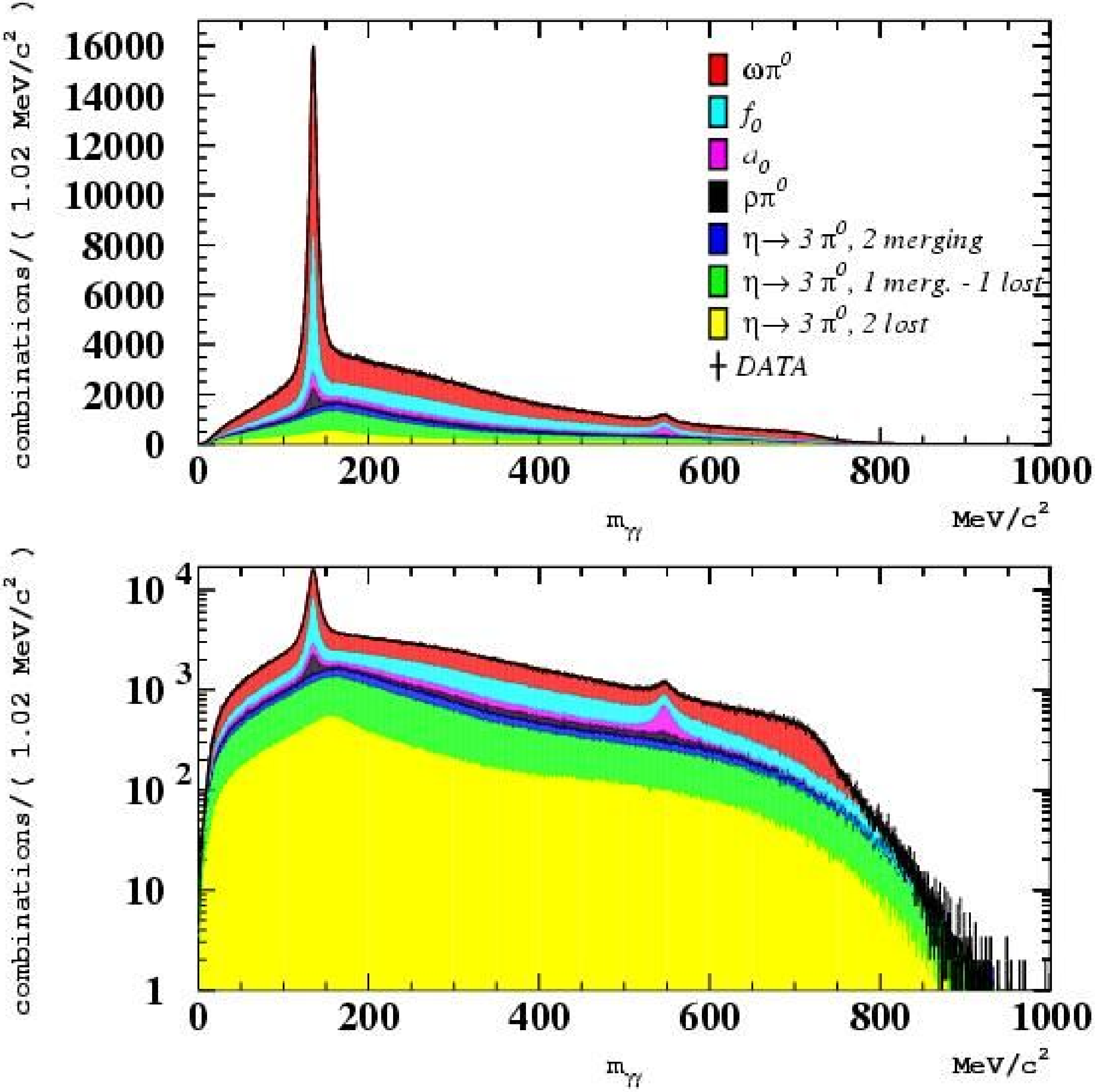


barrel



endcap

Background composition



Background composition obtained by fitting $m_{\gamma\gamma}$ distribution

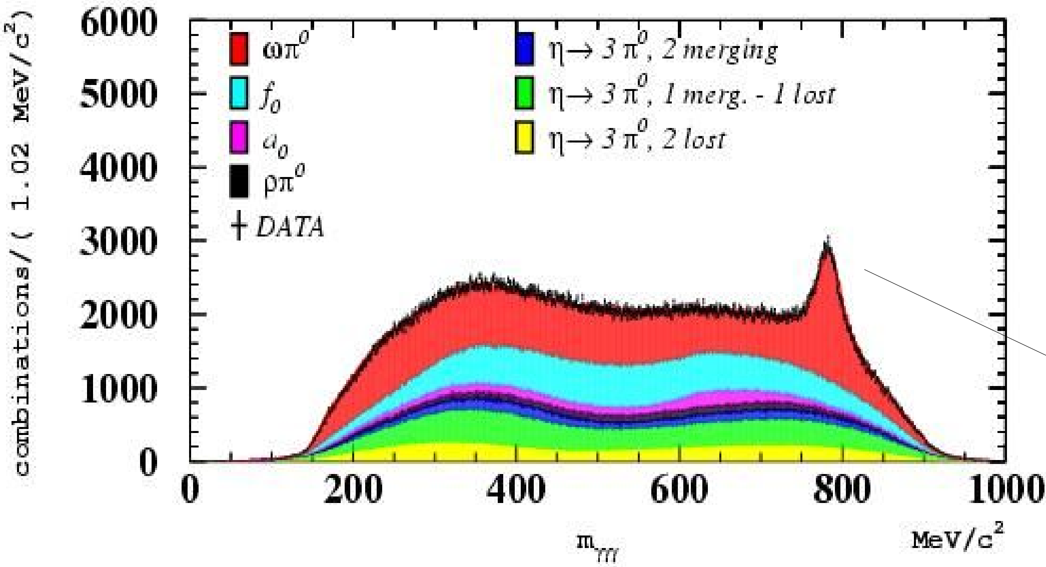
Correction factors

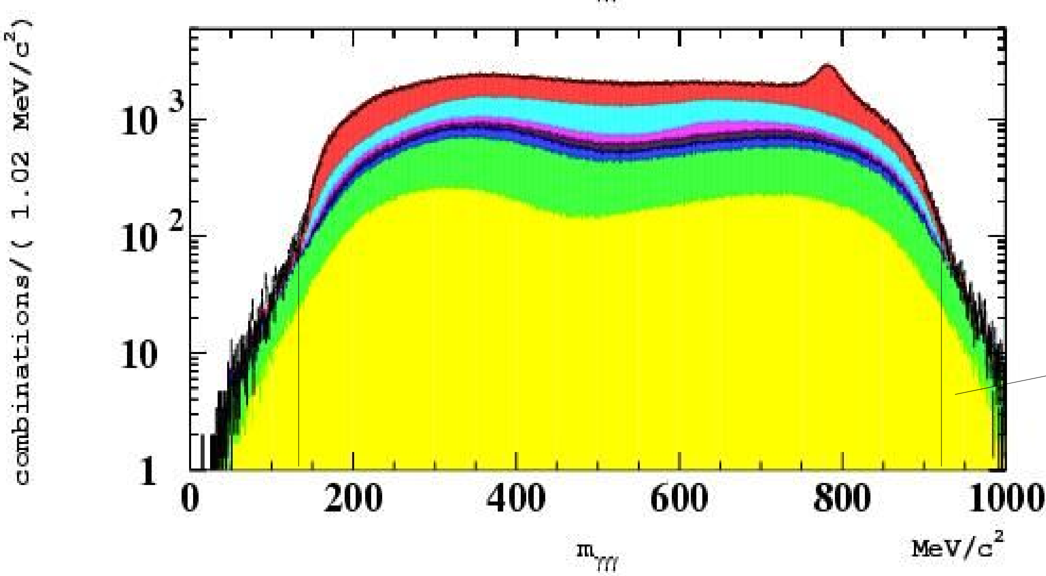
Channel	Correction factor
$\omega\pi^0$	0.704 ± 0.008
f_0	1.07 ± 0.04
a_0	0.68 ± 0.04
$\rho\pi^0$	0.4 ± 0.1
η 2 merged	2.9 ± 0.3
η 1 lost 1 merged	1.50 ± 0.09
η 2 lost	0.76 ± 0.06

~ 900 bins

$\chi^2 = 1.2$

Background composition check





Correction factors obtained by the previous fit

Very nice reproduction of the ω peak

$\omega\ \pi^0$

$\rightarrow \pi^0\gamma$

Completely given by the 2 lost and 1 merged–1 lost normalization

5γ rejection

$\phi \to f_0(\to\pi^0\pi^0)\gamma$

$\phi \to a_0(\to\eta\pi^0)\,\gamma$

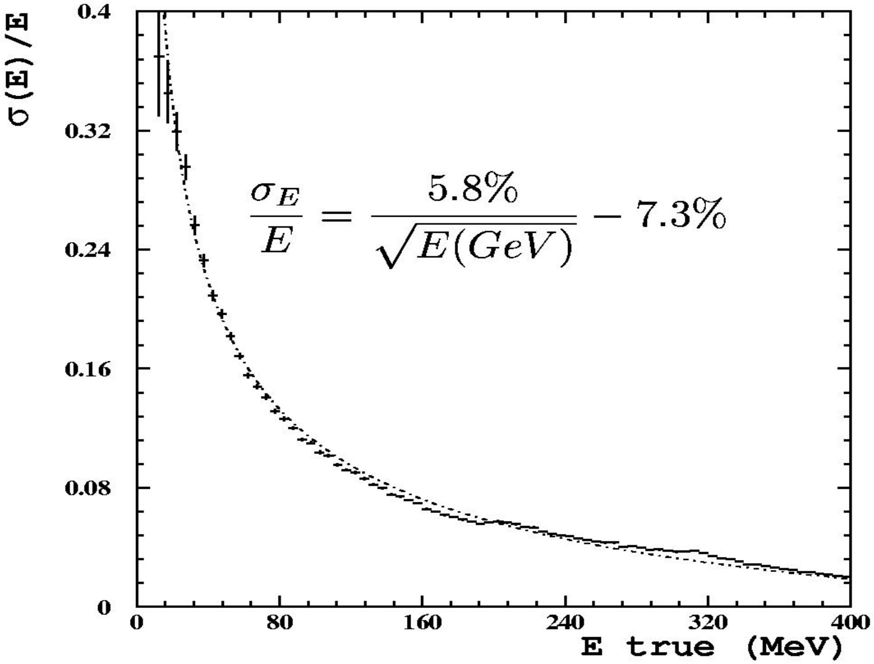
$e^+ e^- \to \omega(\to\pi^0\gamma)\pi^0$

$\phi \to\rho^0(\to\eta\,\gamma)\gamma,\rho^0(\to \pi^0\gamma)\gamma$

$$S^2(2\pi^0) = \frac{(m(\gamma_1\gamma_2) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}} + \frac{(m(\gamma_2\gamma_3) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}}$$

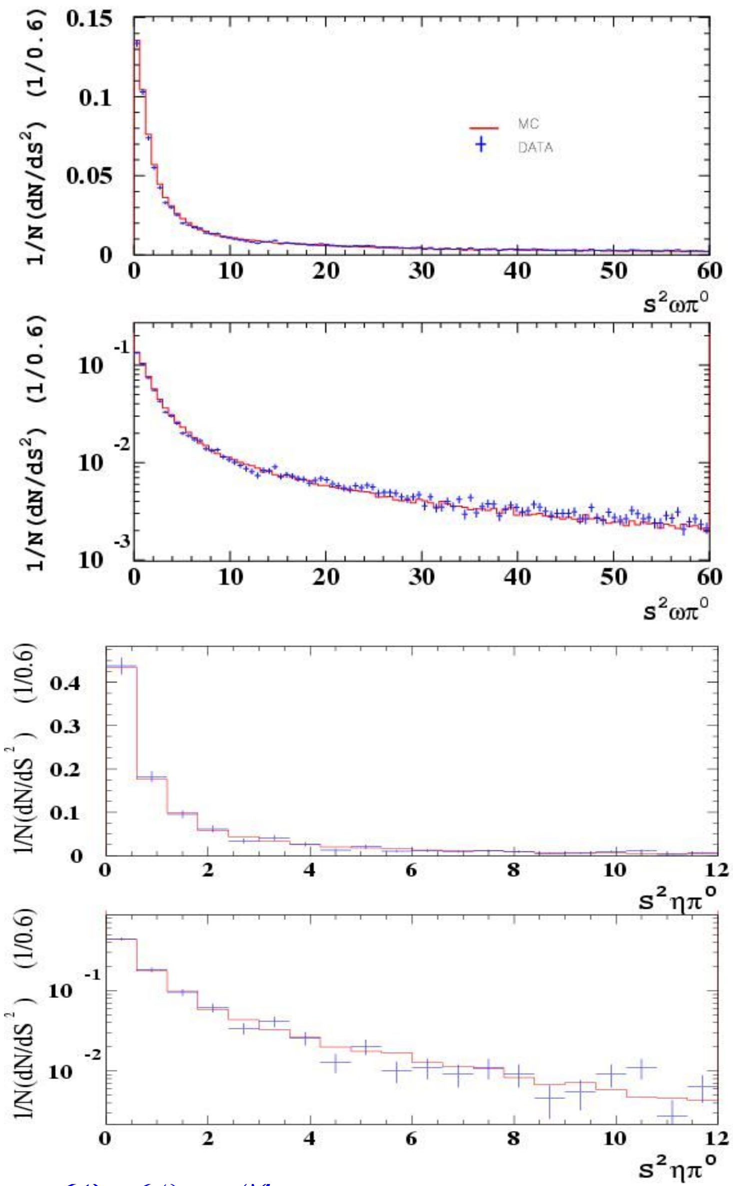
$$S^2(\eta\pi^0) = \frac{(m(\gamma_1\gamma_2) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}} + \frac{(m(\gamma_2\gamma_3) - m(\eta))^2}{\sigma^2_{m(\eta)}}$$

$$S^2(\omega\pi^0) = \frac{(m(\gamma_1\gamma_2) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}} + \frac{(m(\gamma_2\gamma_3) - m(\pi^0))^2}{\sigma^2_{m(\pi^0)}} + \frac{(m(\gamma_1\gamma_2\gamma_3) - m(\omega))^2}{\sigma^2_{m(\omega)}}$$

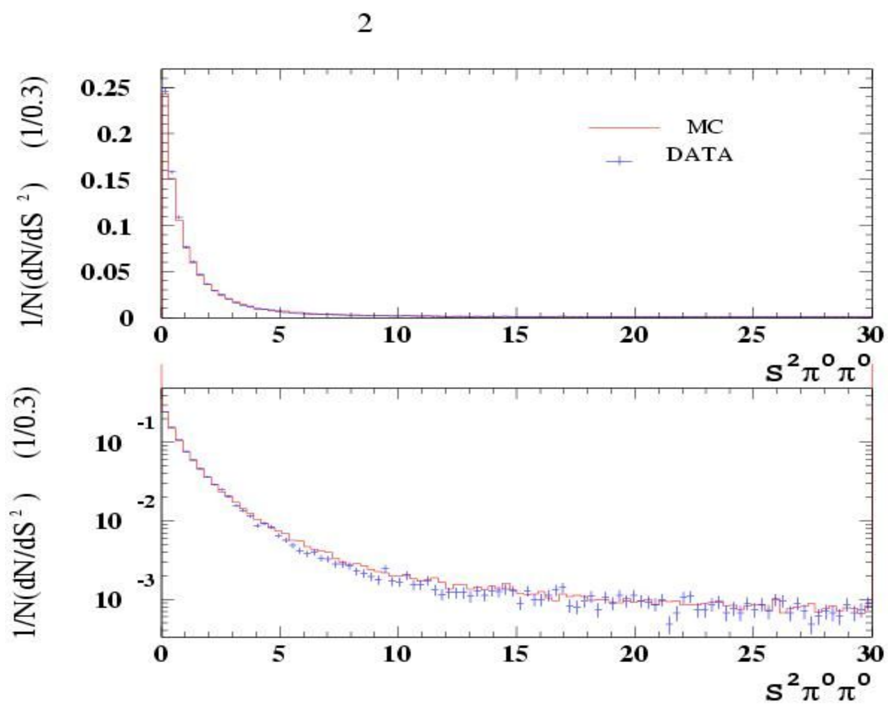


Rejected vetoing the π^0, η, ω masses.

DATA-MC comparison of the S^2 variables



Good DATA-MC agreement



Cut summary

Cut	$\epsilon(\eta \to \pi^0\gamma\gamma)$	DATA sample
5 prompt clusters	60.8 ± 0.2 %	3044659
Etot > 800 MeV	93.46 ± 0.13 %	1935296
kinematic fit with π^0 passed	99.65 ± 0.03 %	1917490
Global efficiency - DATA reduction	56.6 ± 0.2 %	3.213 ± 0.002 %

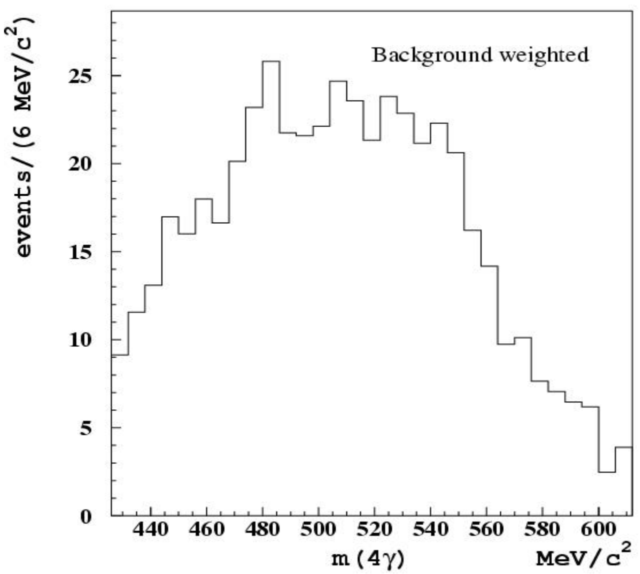
Optimized cut	relative efficiency	DATA selected.
$\theta_\gamma > 21°$	94.07 ± 0.13 %	574474
$E_{min} > 20$ MeV	91.17 ± 0.16 %	286516
2 lost rejection	95.00 ± 0.13 %	246602
$\chi^2_{\pi^0} < 15$	57.40 ± 0.30 %	128197
$S^2(\omega\pi^0) > 30$	71.8 ± 0.4 %	34446
$S^2(\pi^0\pi^0) > 7$	83.4 ± 0.3 %	12157
$S^2(\eta\pi^0) > 8$	62.4 ± 0.5 %	4422
$16° < \theta_{\gamma x} < 164°$	97.7 ± 0.2 %	4136
$E_{\gamma x} < 76$ MeV	92.0 ± 0.4 %	3550
Likelihood r < -0.5 barrel, $< 0.$ end-caps	53.7 ± 0.7 %	1034
EVCL	98.92 ± 0.19 %	
Global efficiency (data suppression)	4.72 ± 0.08 %	$(1.73 \pm 0.05) \times 10^{-5}$

$m_{4\gamma}$ distribution for signal and background

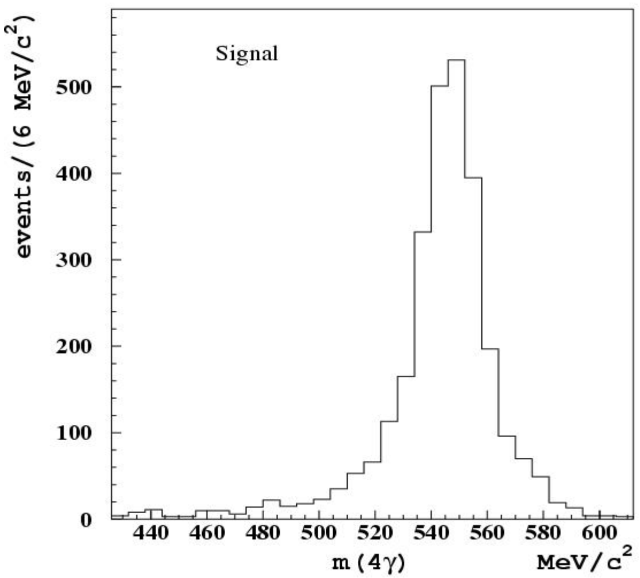
The signal content is evaluated by fitting the $m_{4\gamma}$ distribution of the least energetic photons.

A binned likelihood approach is used, taking into account the finite size of MC statistic.

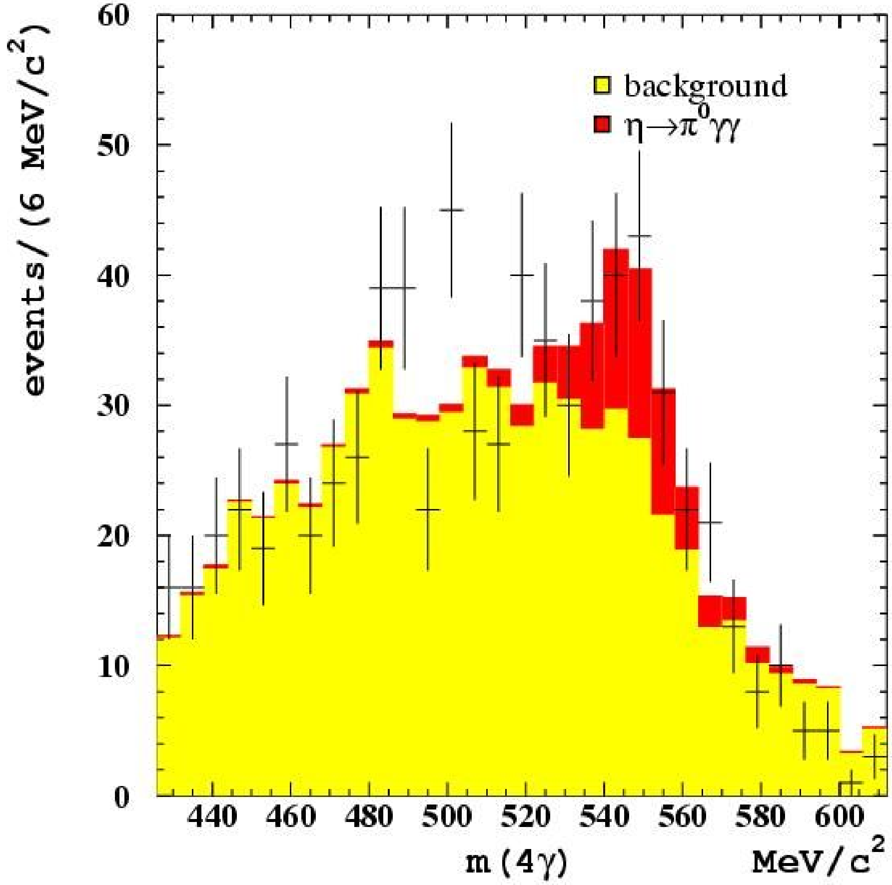
$m_{4\gamma}$ distribution of the back-ground, obtained by the MC simulation.



$m_{4\gamma}$ distribution of the signal, obtained by the MC simulation.



Fit result



The shape of background + signal after fit well reproduce the DATA.

$P_{bkg} = 0.907 \pm 0.049$

$P_{sig} = 0.093 \pm 0.031$

$N_{DATA} = 735$

$N_{bkg} = 667 \pm 36$ $N_{sig} = 68 \pm 23$

$\varepsilon(\eta \to \pi^0\gamma\gamma) = 4.63 \pm 0.09$ (only stat)

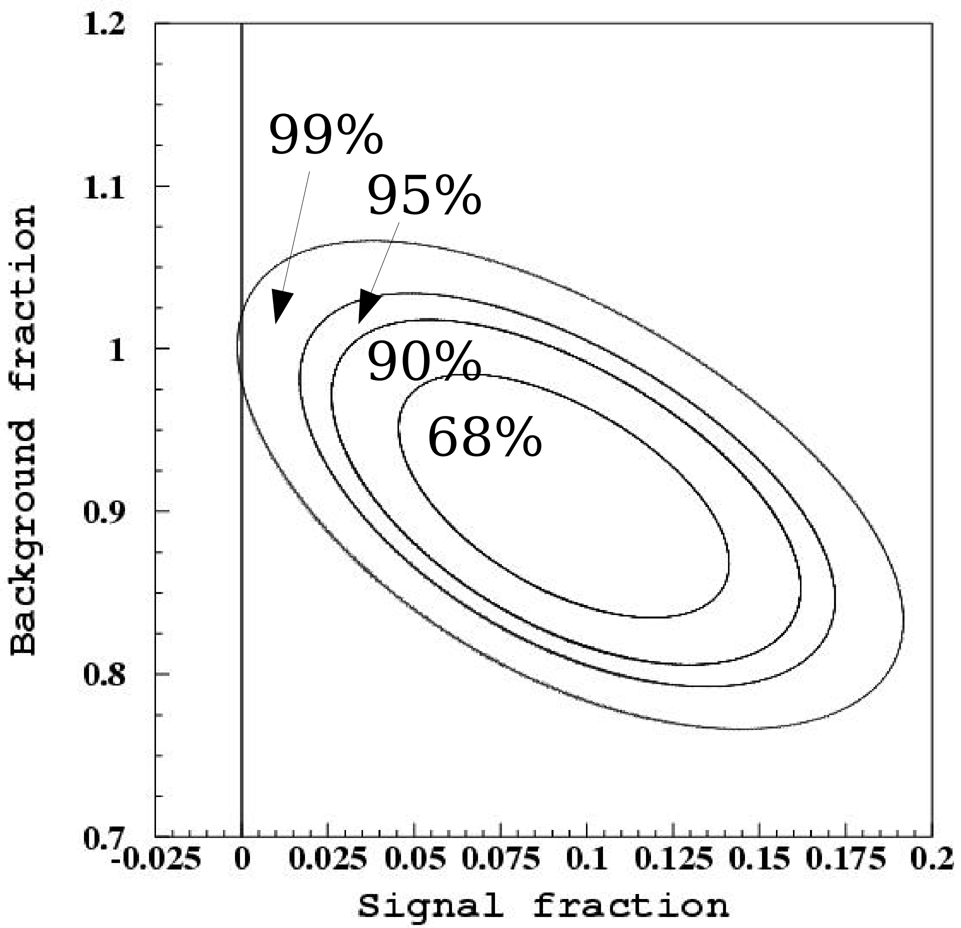
$N(\eta \to 3\pi^0) = 2288882$

$\varepsilon(\eta \to \pi^0\pi^0\pi^0) = 0.378 \pm 0.08_{syst} \pm 0.01_{stat}$

$$\frac{Br(\eta \to \pi^0\gamma\gamma)}{Br(\eta \to 3\pi^0)} = \frac{N(\eta \to \pi^0\gamma\gamma) \cdot \epsilon(\eta \to 3\pi^0)}{N(\eta \to 3\pi^0) \cdot \epsilon(\eta \to \pi^0\gamma\gamma)} = (2.43 \pm 0.82) \times 10^{-4}$$

$$Br(\eta \to \pi^0\gamma\gamma) = (8.0 \pm 2.7) \times 10^{-5}$$

Statistical significance



Systematic

- *Br dependence by the bin width;*
- *Br dependence by the lower cut on* $m_{4\gamma}$;
- *Br dependence by the higher cut on* $m_{4\gamma}$.

Br dependence by the bin width

Bin width variation:

2 – 9 MeV

chosen bin width:

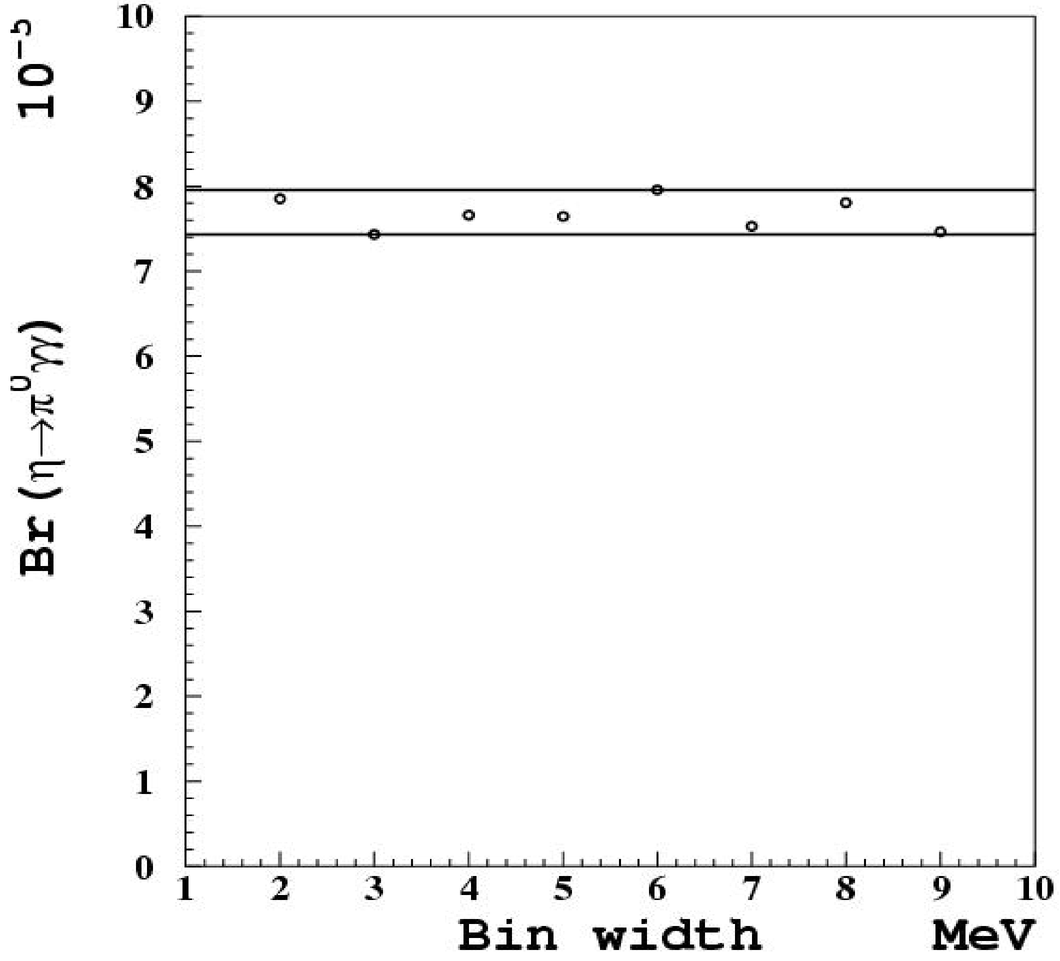
6 MeV

correction:

-0.26×10^{-5}

error:

0.26×10^{-5}



Br dependence by the lower cut on $m_{4\gamma}$

cut variation:

378 – 478 MeV

chosen cut:

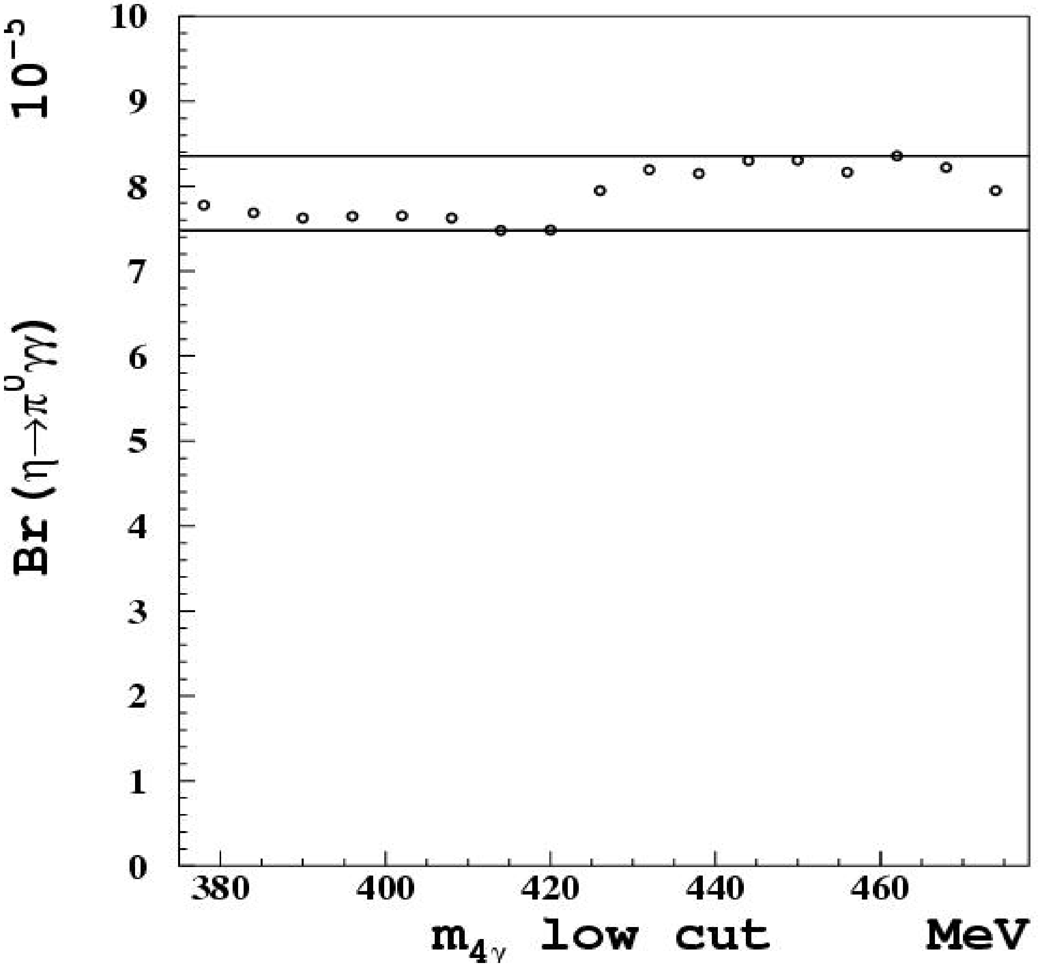
426 MeV

correction:

0.

error:

0.44×10^{-5}



Br dependence by the higher cut on $m_{4\gamma}$

cut variation:

570 – 720 MeV

chosen cut:

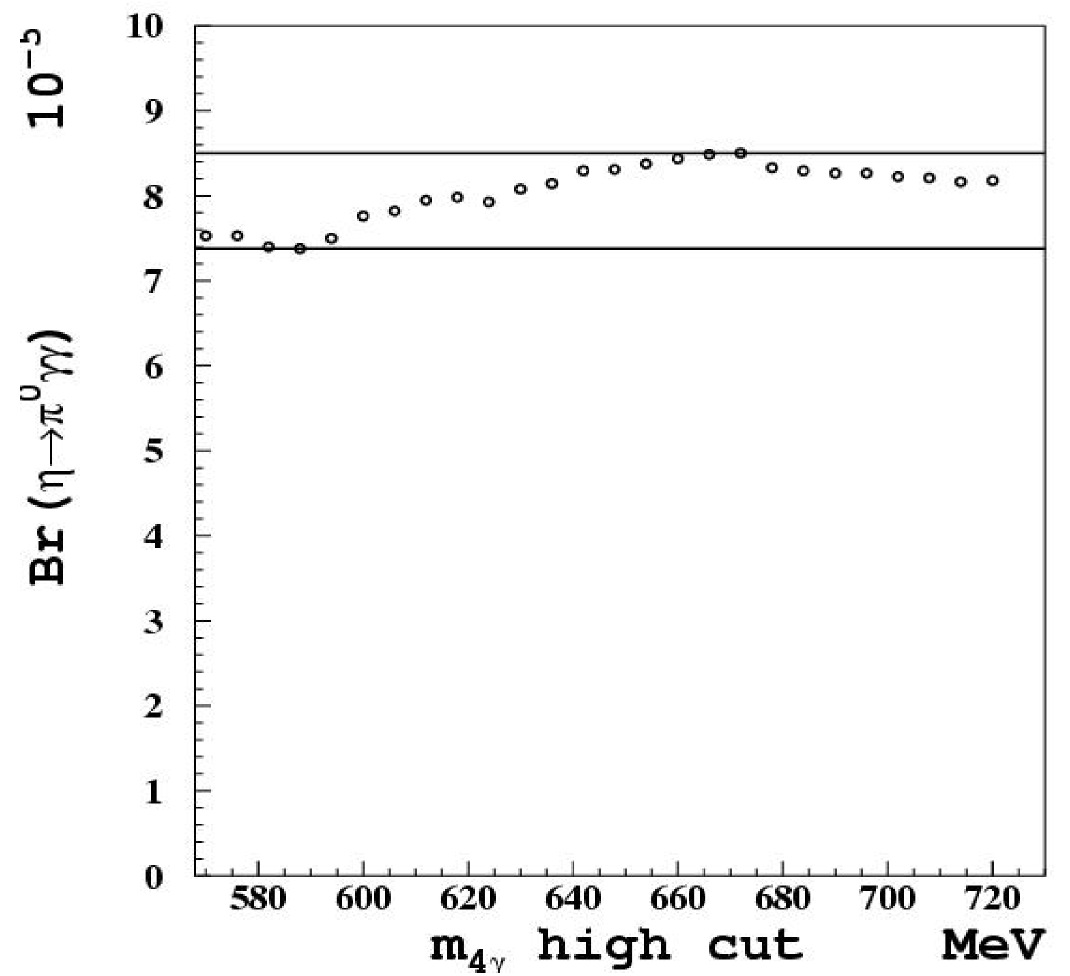
612 MeV

correction:

0.

error:

0.56×10^{-5}



Preliminary result

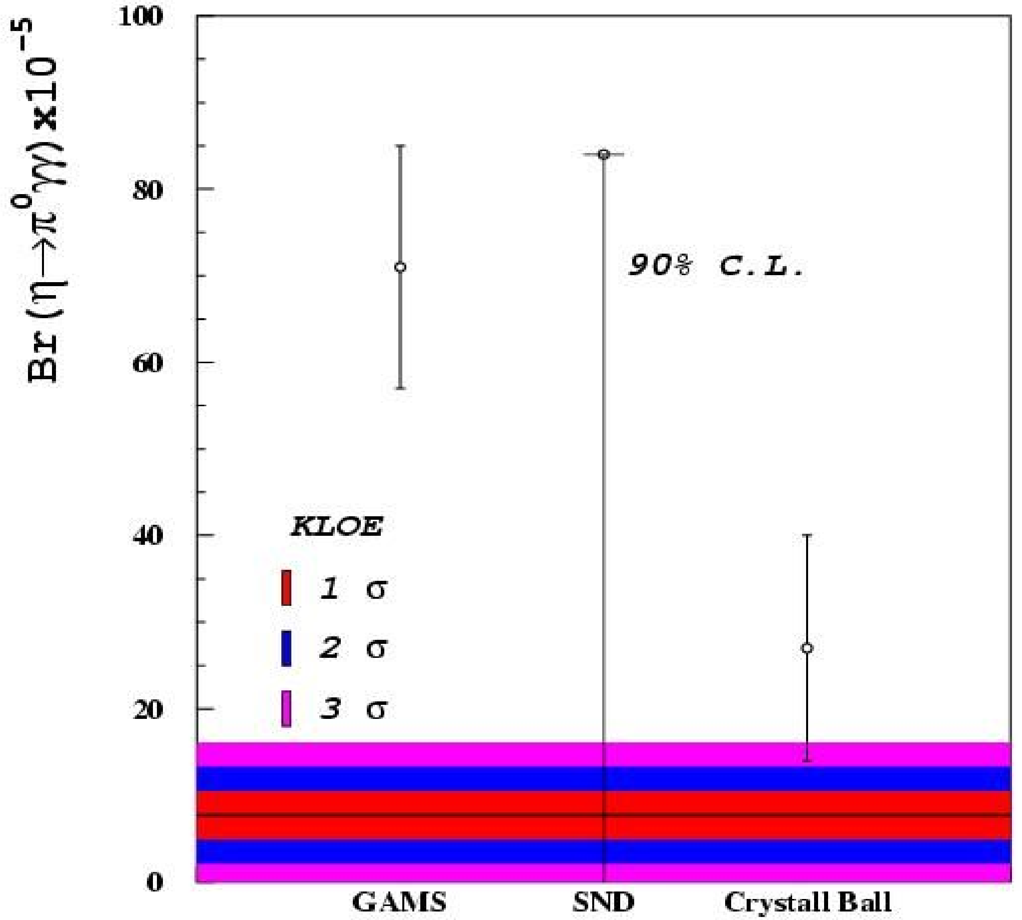
Systematic error	
bin width	0.26×10^{-5}
low energy cut	0.44×10^{-5}
high energy cut	0.56×10^{-5}
Overall	0.8×10^{-5}

correction	
Fit result	8.0×10^{-5}
bin width correction	-0.26×10^{-5}
Result	7.7×10^{-5}

Result

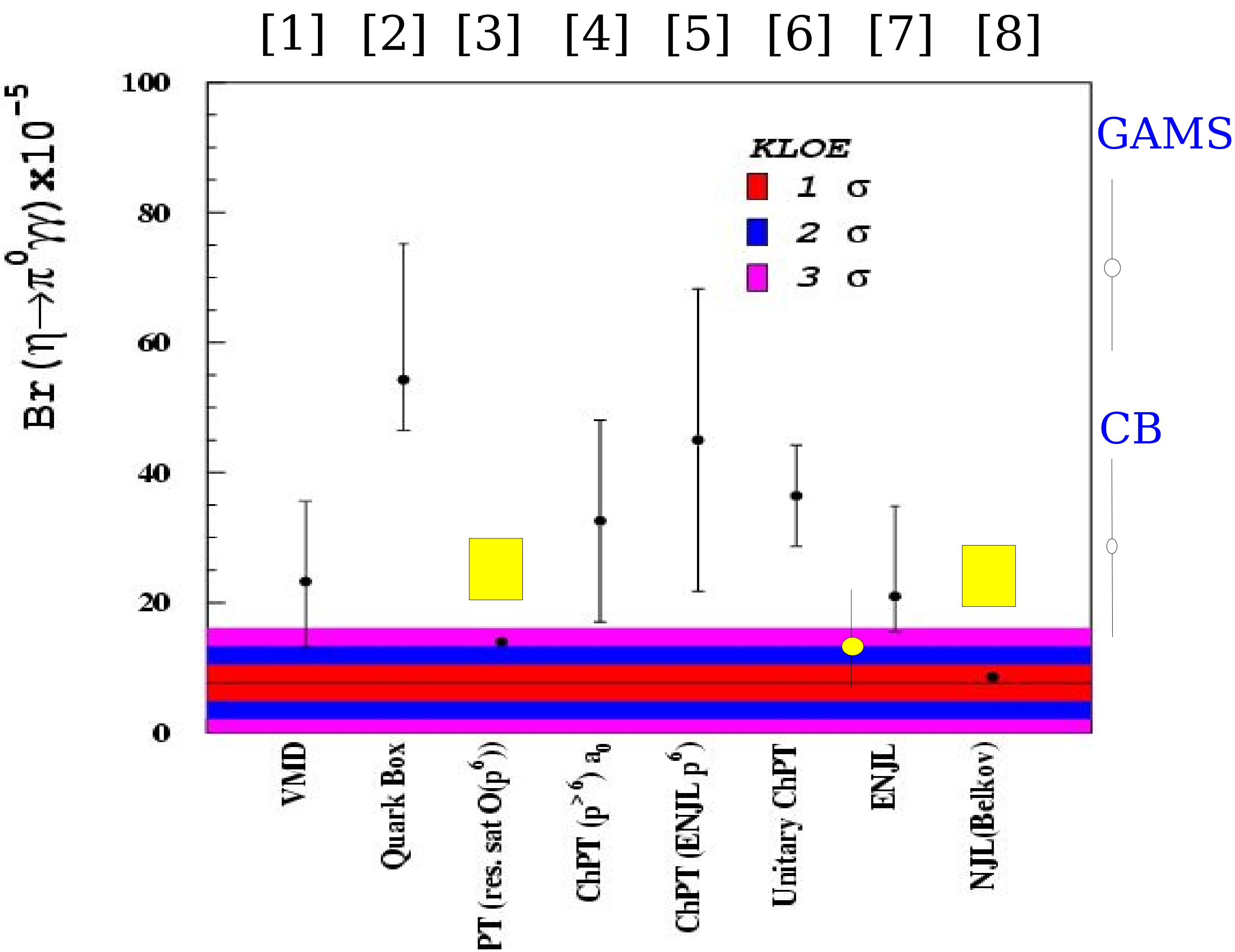
$$Br(\eta \to \pi^0 \gamma\gamma) = (7.7 \pm 2.7 \pm 0.8) \times 10^{-5}$$

Comparison with more recent experiments



Comparison with theoretical predictions

- p^6 calculation seems enough



[1] *J.N. Ng and D. J. Peters, Phys. Rev. D46 (1992) 5034*

[2] *J.N. Ng and D. J. Peters, Phys. Rev. D47 (1993) 4939*

[3-4] L. Ametller, J. Bijnens, A. Bramon, F. Cornet, Phys. Lett. B276 (1992)

[5] S. Bellucci and C. Bruno, Nucl. Phys. B452 (1995) 626

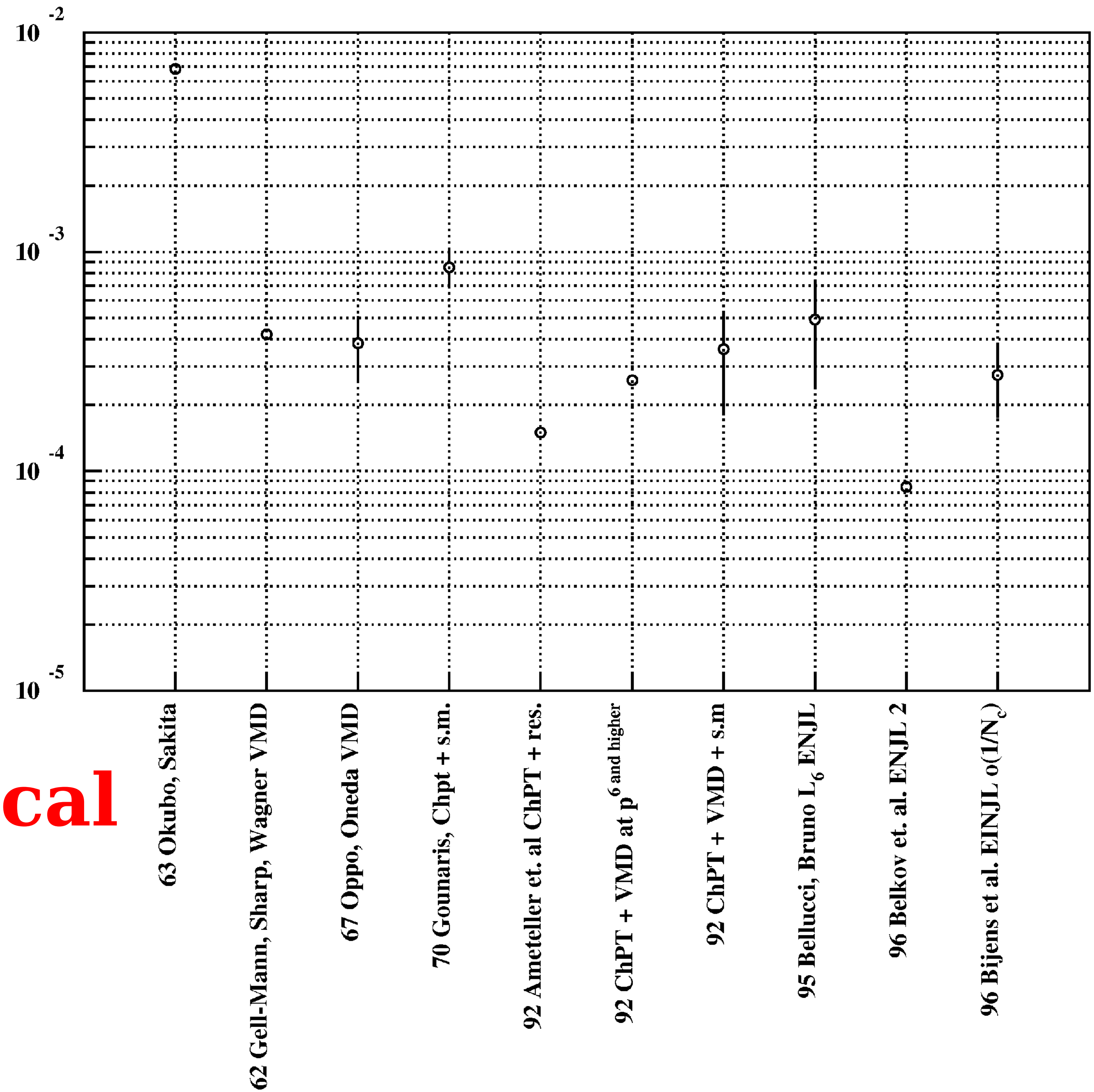
[6] E. Oset, J. R. Pelaź and L. Roca, Phys. Rev. D67 (2003) 073013

[7] J. Bijnens, A. Fayyazuddin and J. Prades, Phys. Lett. B379 (1996) 209

[8] A. A. Belkov, A. V. Lanyov, S. Scherer, J. Phys. G 22 (1996) 1383

Conclusions

- KLOE and CB measurements are in disagreement with the GAMS observation;
- The confirmation of KLOE result will indicate a succesfully explanation of the decay rate by the P^6 ChPT ;
- With 2004+2005 KLOE DATA the statistical error on the measurement can go down to 10% level.



Theoretical history