



Progress on ϕ radiative decays with the KLOE experiment

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for the KLOE collaboration

outline



- ♦ scalar meson physics:
 - ♦ $f_0 \rightarrow \pi^+ \pi^-$ spectrum measurement;
 - ♦ $f_0 \rightarrow \pi^0 \pi^0$ Dalitz plot analysis;
 - ♦ $a_0 \rightarrow \eta \pi^0$ spectrum measurement
- ♦ η physics:
 - ♦ $\eta \rightarrow \gamma \gamma$, $\eta \rightarrow \pi^+ \pi^-$ upper limits (test of C and CP violation in strong and electromagnetic interactions);
 - ♦ $\eta \rightarrow \pi^0 \gamma \gamma$ (analysis status)
 - ♦ $\eta \rightarrow \pi^+ \pi^- \pi^0$ Dalitz plot analysis and asymmetries measurement;
- ♦ η' physics
 - ♦ $\phi \rightarrow \eta' \gamma \rightarrow \pi^+ \pi^- 7 \gamma$ Br measurement.

$f_0 \rightarrow \pi^+ \pi^-$ spectrum measurement



$$\phi \rightarrow f_0 \gamma \rightarrow \pi^+ \pi^- \gamma$$

aim of the analysis

extracting f_0 properties

from $\pi^+ \pi^- \gamma$ data

background sources

$$e^+ e^- \rightarrow \pi^+ \pi^- \gamma \text{ via ISR}$$

(radiative return to ρ and ω)

$$e^+ e^- \rightarrow \pi^+ \pi^- \gamma \text{ via FSR}$$

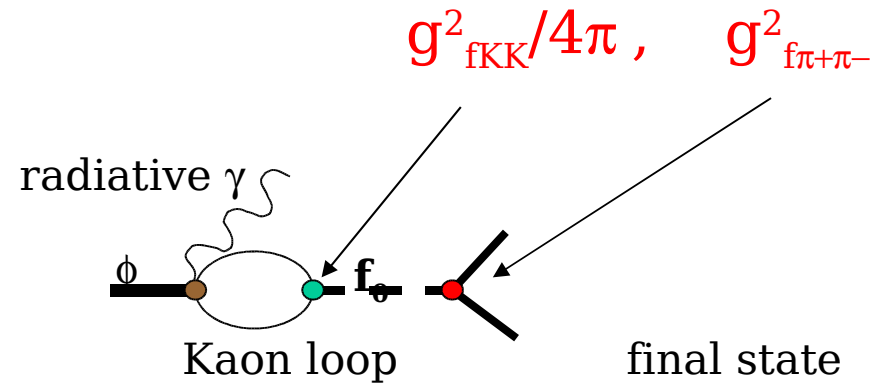
$$\phi \rightarrow \rho^\pm \pi^\mp (\rho^\pm \rightarrow \pi^\pm \gamma) \rightarrow \pi^+ \pi^- \gamma$$

analysis selection

$45^\circ < \theta_\gamma < 135^\circ$ ISR reduced and
not “interfering”

$$\frac{d\sigma}{dM_{\pi\pi}} = |A(\text{ISR}) + A(\text{FSR}) + A(f_0) + A(\rho\pi)|^2$$

phenomenological model



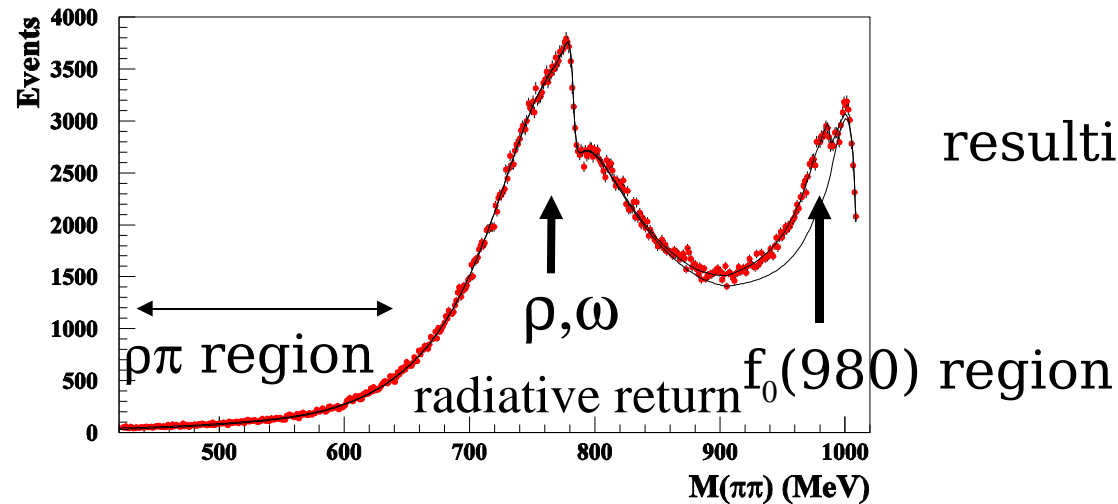
Including $\pi\pi$ rescattering data

PRD55 (1997) & PRD57 (1998)

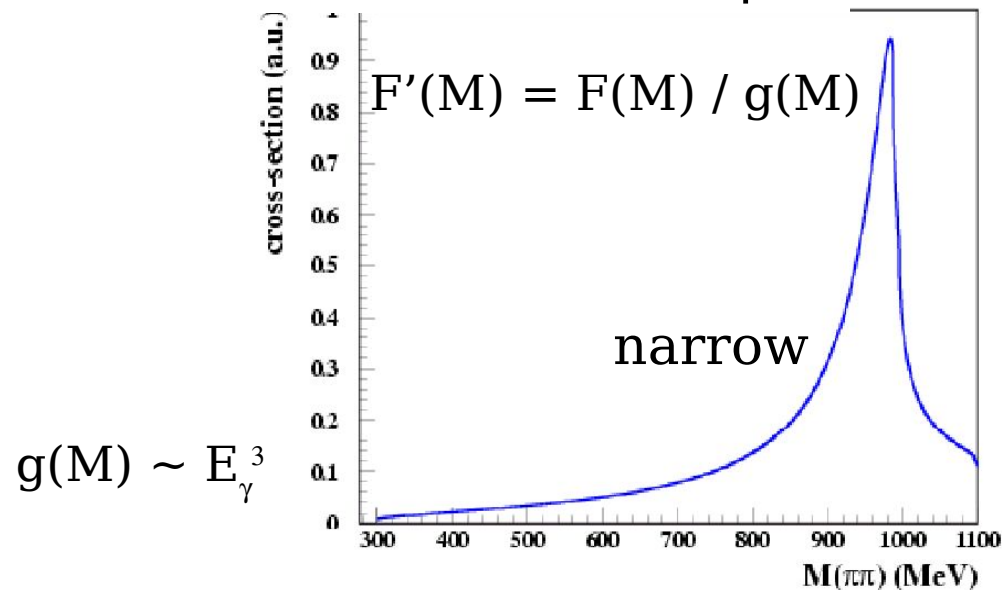
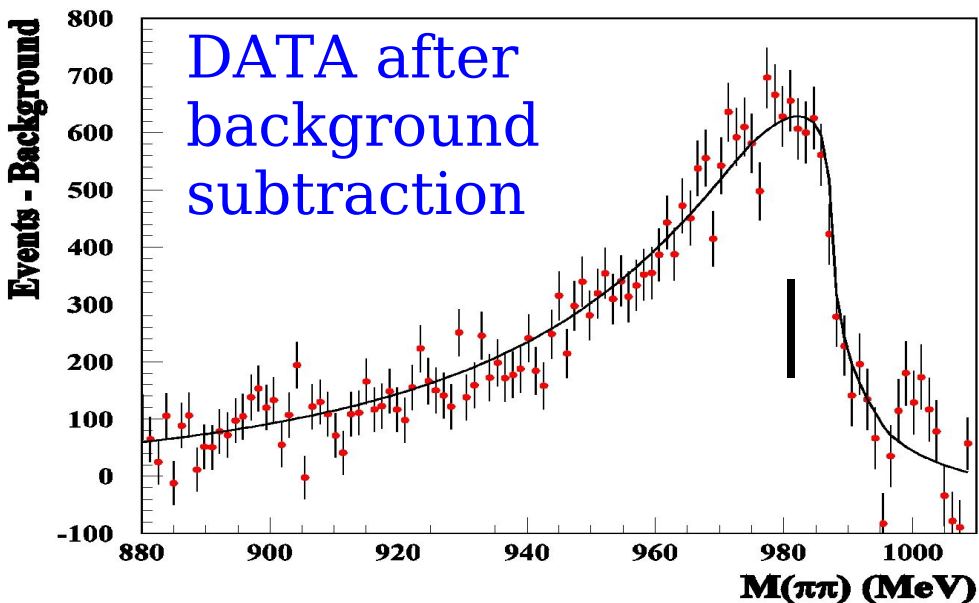
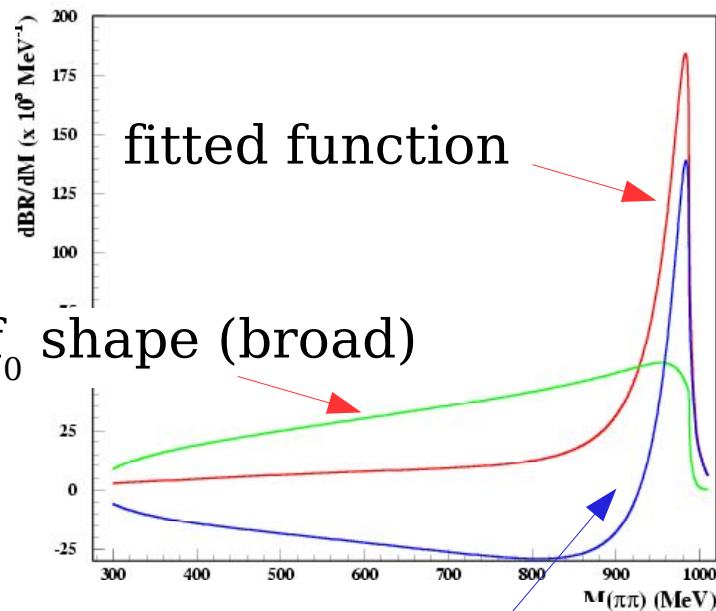
N.N. Achasov et al.

$f_0 \rightarrow \pi^+ \pi^-$ fit to the spectrum

full spectrum



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$f_0 \rightarrow \pi^+ \pi^-$ forward-backward asymmetry and \sqrt{s} dependence

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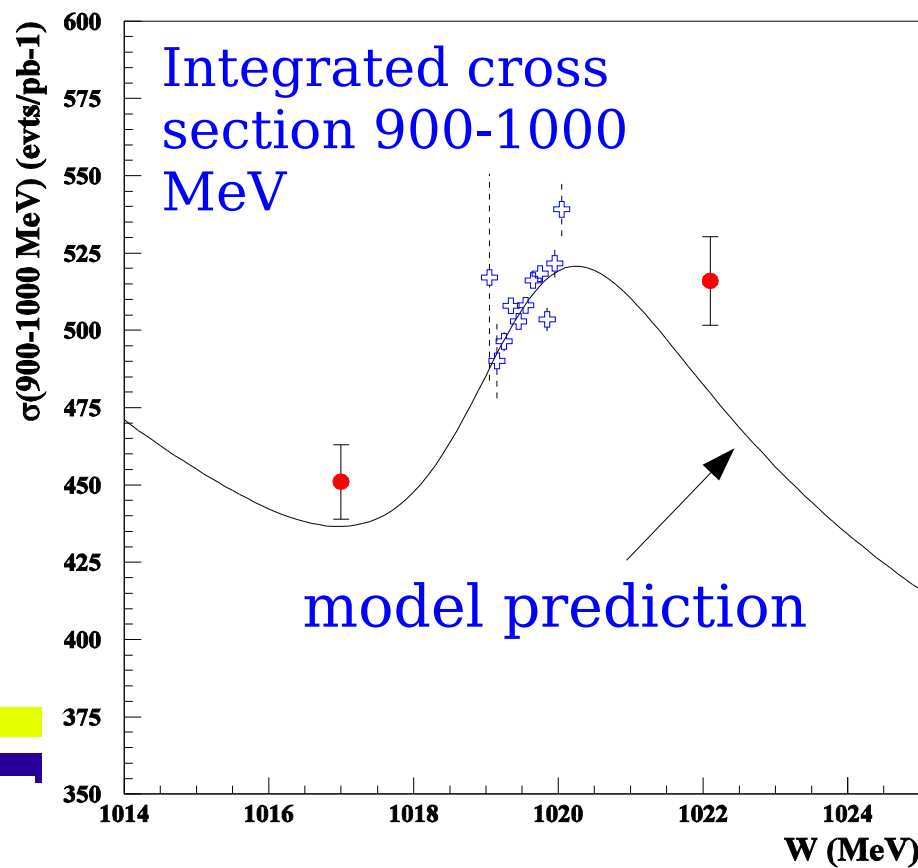
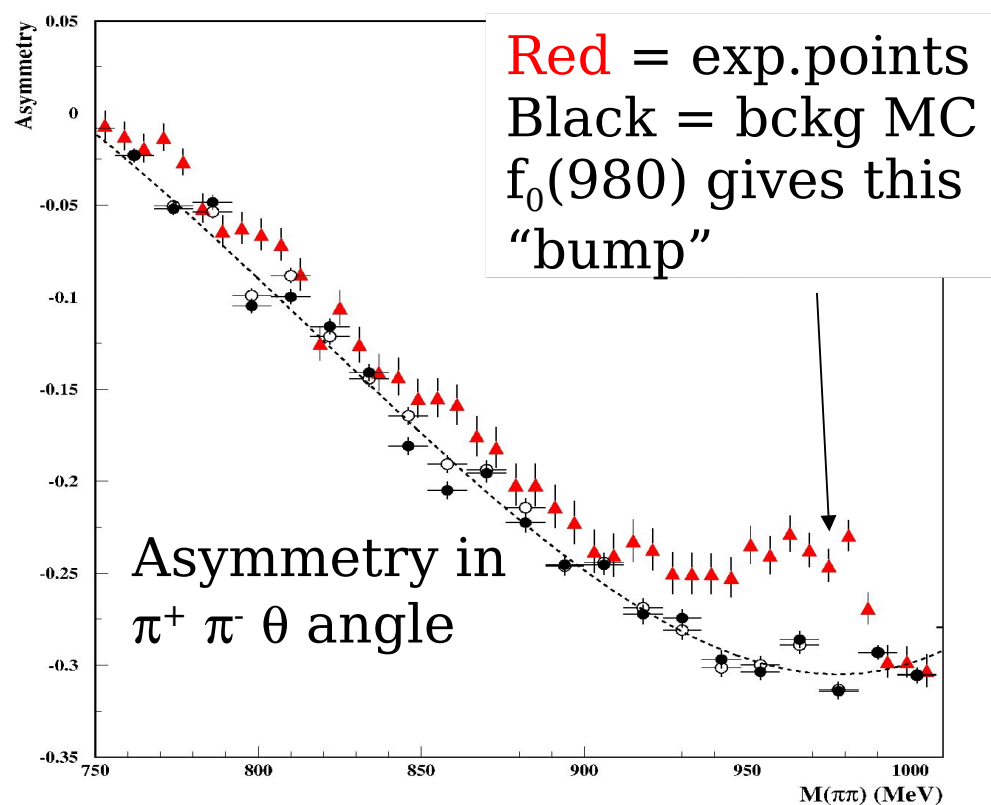
$\pi^+ \pi^-$ system:

$A(\text{ISR})$ C-odd
 $A(\text{FSR})$ C-even
 $A(f_0)$ C-even

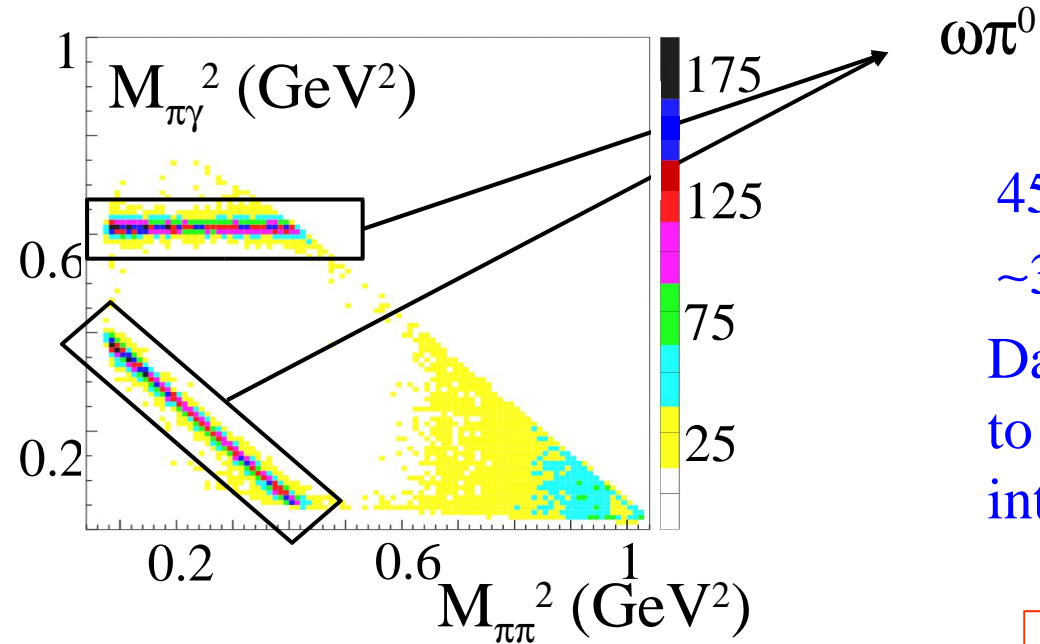
$A(\text{tot})$ not defined symmetry for the interference among the terms.

$$A = \frac{N(\theta > 90^\circ) - N(\theta < 90^\circ)}{N(\theta > 90^\circ) + N(\theta < 90^\circ)}$$

The cross section follow the behaviour given by the fitted model at different \sqrt{s}



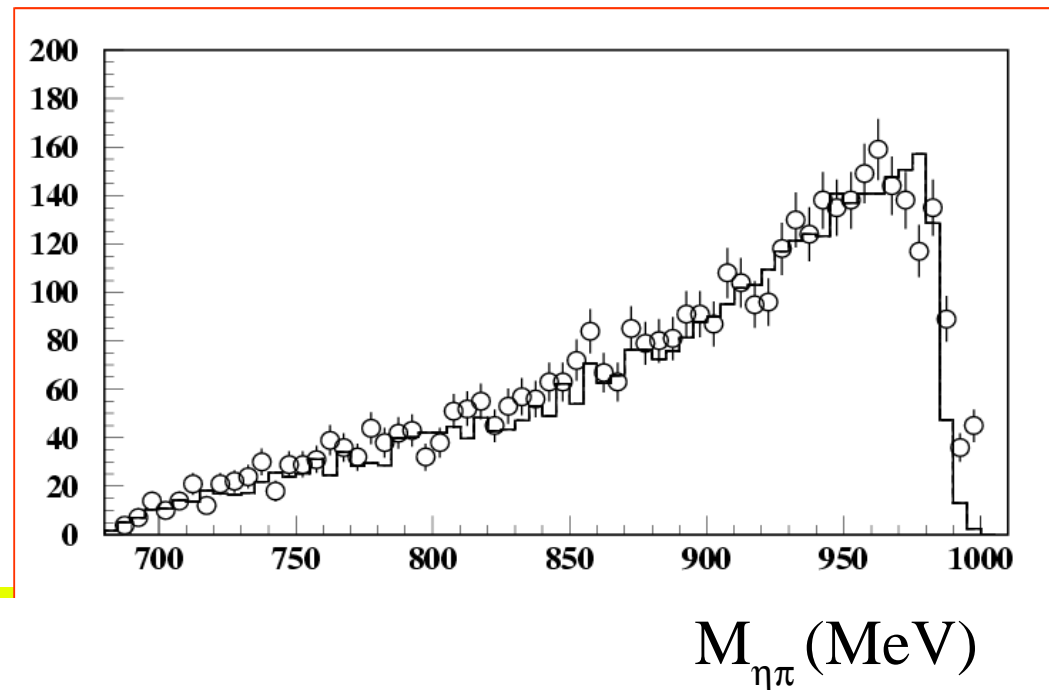
$$f_0 \rightarrow \pi^0 \pi^0, a_0 \rightarrow \eta \pi^0$$



450 pb⁻¹ allow for high statistical analysis,
~30000 events assigned to scalar + γ

Dalitz plot analysis in progress: the objective is
to extract all possible contributions taking
into account interferences with the background.

Properties of $a_0(980)$
[comparison with $f_0(980)$]
Check of the *kaon-loop*
approach in a
“background free”
environment



η physics at KLOE

Usually studied at hadron machines.

At KLOE $\mathcal{L} \sim 500 \text{ pb}^{-1}$ (2001+2002)

$\phi \rightarrow \eta \gamma$ η sample $\sim 18 \times 10^6$

η decays studied and/or under study



$\eta \rightarrow \gamma \gamma \gamma$ Test of C symmetry in $e.m$ and strong interactions
(*Phys. Lett. B* (591) pp. 49-54 (2004))

$\eta \rightarrow \pi^+ \pi^-$ Test of P and CP symmetry in $e.m$ and strong int.

$\eta \rightarrow \pi^0 \gamma \gamma$ ChPT description of the decay

$\eta \rightarrow \pi^+ \pi^- \pi^0$ Dalitz plot analysis: ChPT description and asymmetries studies.

$\eta \rightarrow \pi^0 \pi^0 \pi^0$ Dalitz plot analysis.

$\eta \rightarrow \pi^+ \pi^- \gamma$ Br and photon energy study.

$$\eta \rightarrow \gamma\gamma$$

Violates C, $\text{BR} < 5 \times 10^{-4}$ @95% CL

PDG '02 (GAMS2000)



$$\phi \rightarrow \left. \begin{array}{l} \eta\gamma \\ \gamma\gamma \end{array} \right\} 4\gamma \quad E_{\text{rad}} = 363 \text{ MeV}$$

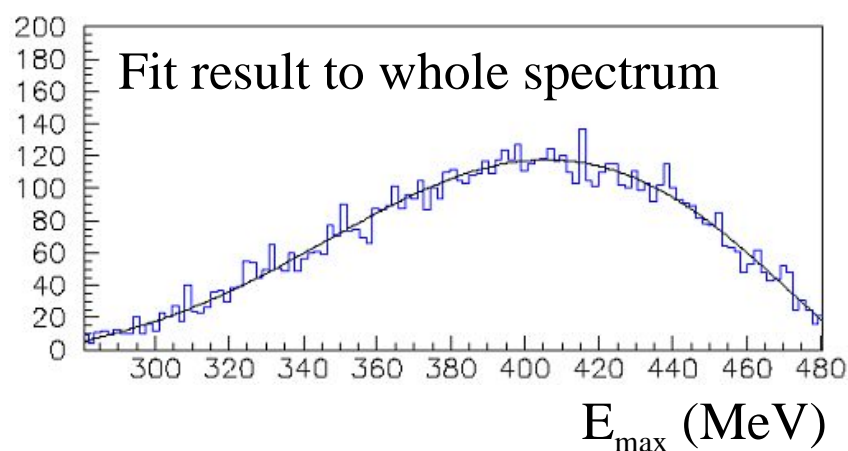
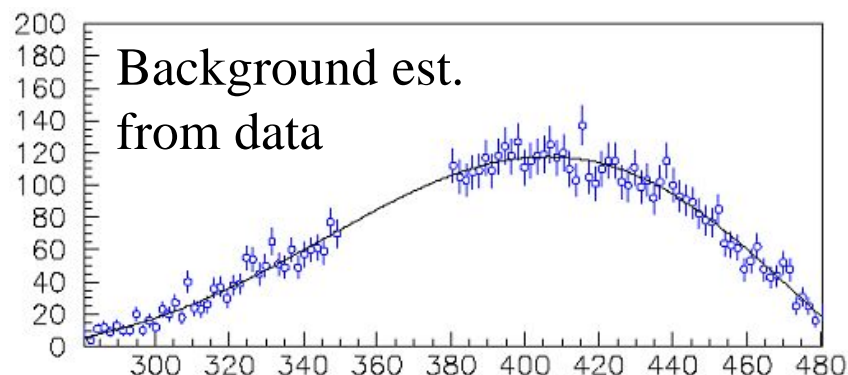
Require 4γ with $E > 50 \text{ MeV}$, $|\cos\theta| < 0.91$

$\theta_{\gamma} > 15^\circ$ to reduce 3γ bckgr

Kinematic fit to improve energy resolution

$m(\pi^0)$ veto eliminates $e^+e^- \rightarrow \omega\gamma$ and 5γ background

$$\rightarrow \pi^0\gamma$$



$\text{BR}(\eta \rightarrow 3\gamma) \leq 1.6 \times 10^{-5}$ @ 90% CL

Phys. Lett. B (591) pp. 49-54 (2004)

$$\eta \rightarrow \pi^+ \pi^-$$

$\pi^+ \pi^- \gamma$ data sample

$$45 < \theta_\gamma < 135^\circ \quad \varepsilon = 16.6 \%$$

from the fit: $N_s = -22 \pm 24$ events

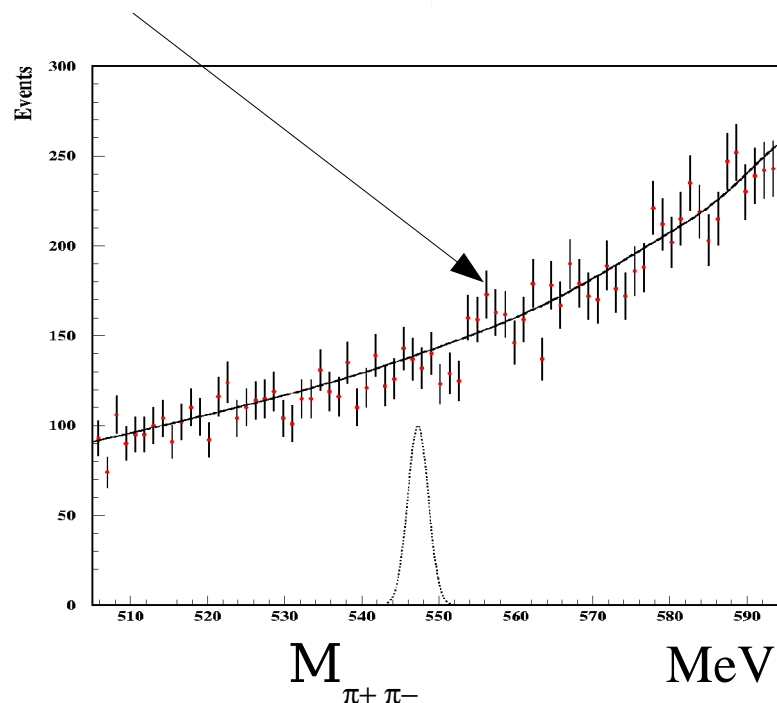
$$N_{UP} < 21.1 \text{ @ } 90\% \text{ C.L.}$$

being $N_\eta = 1.43 \times 10^7$ we obtain:

$$\text{Br}(\eta \rightarrow \pi^+ \pi^-) < 8.9 \times 10^{-6} \text{ @ } 90\% \text{ C.L.}$$

$$\text{PDG(2002)} < 3.3 \times 10^{-4} \text{ @ } 90\% \text{ C.L.}$$

fitted spectrum from f_0
analysis

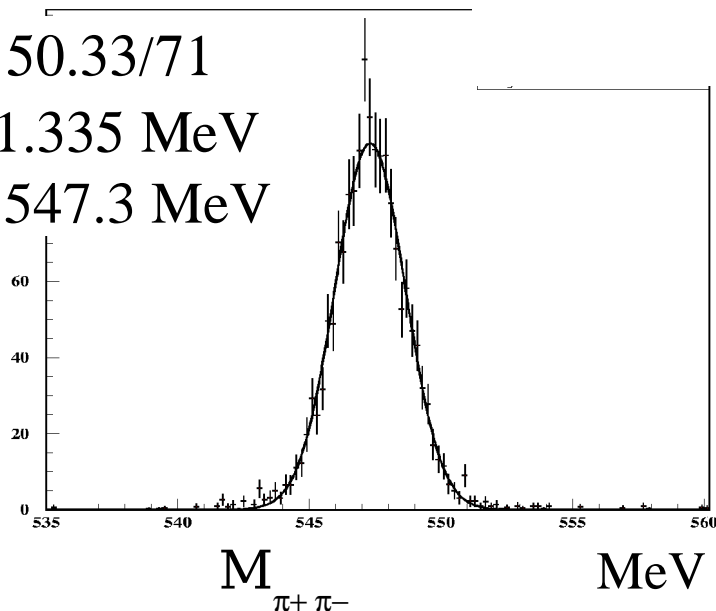


$\eta \rightarrow \pi^+ \pi^-$ MC

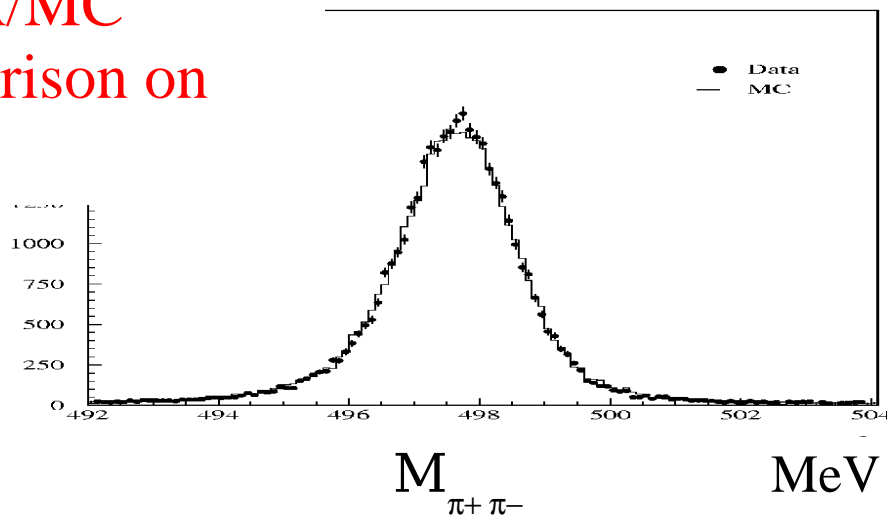
$$\chi^2 = 50.33/71$$

$$\sigma = 1.335 \text{ MeV}$$

$$m = 547.3 \text{ MeV}$$



DATA/MC
comparison on
 M_{K_s}



$\eta \rightarrow \pi^0 \gamma \gamma$, *Br measurement*



Theoretical predictions:	$\Gamma(\eta \rightarrow \pi^0 \gamma \gamma)$ [eV]	
VDM	0.30 ± 0.16	(Ng-Peters)
Vector+axial res.	0.47 ± 0.20	(Ko)
Quark-box diagram	$0.70 - 0.92$	(Ng-Peters, Nemoto et al.)
χ PT+VMD+scalars	0.42 ± 0.20	(Ametller et al.)
χ PT+ENJL	0.58 ± 0.30	(Bellucci-Bruno)

PDG(2002) GAMS

$$\text{Br}(\eta \rightarrow \pi^0 \gamma \gamma) = 7.2 \pm 1.4 \times 10^{-4} \quad (0.85 \pm 0.18 \text{ eV}/c^2)$$

Crystall Ball (2004)

$$\text{Br}(\eta \rightarrow \pi^0 \gamma \gamma) = 2.7 \pm 0.9 \pm 0.5 \times 10^{-4} \quad (0.32 \pm 0.15 \text{ eV}/c^2)$$

SND(2001) $\text{Br}(\eta \rightarrow \pi^0 \gamma \gamma) < 8.9 \times 10^{-4}$

Experimental η production

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

$$\phi \rightarrow \eta \gamma$$

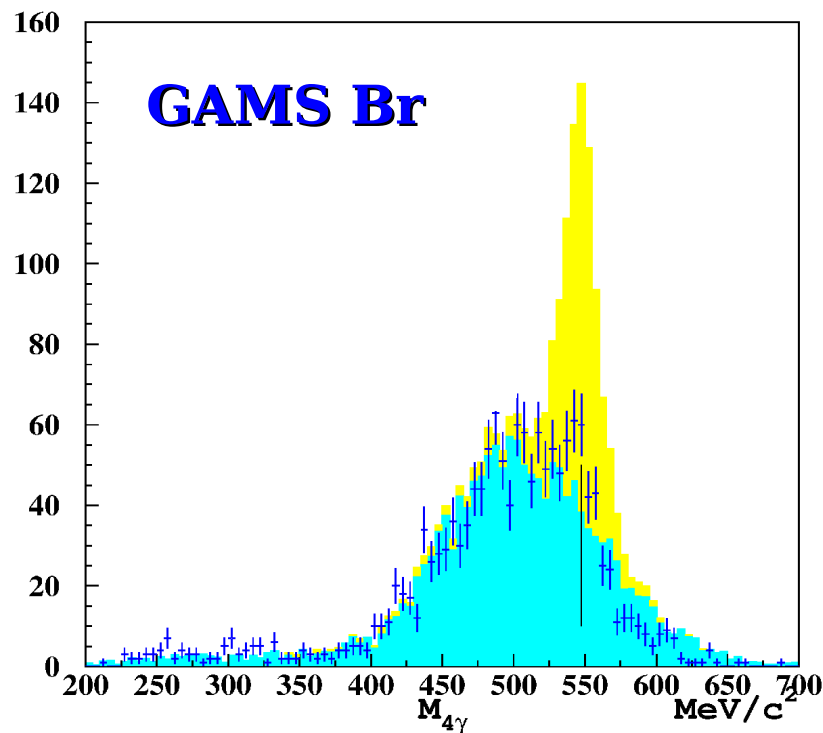
$\eta \rightarrow \pi^0 \gamma \gamma$ analysis sketch

$$\left. \begin{array}{l} \Phi \rightarrow \eta \gamma \\ \quad \quad \quad \searrow \\ \quad \quad \quad \pi^0 \gamma \gamma \end{array} \right\} \begin{array}{l} 5\gamma \text{ final state} \\ \sigma = 8\text{pb} \quad \text{GAMS Br} \end{array}$$

main background sources

$\eta \gamma \rightarrow \pi^0 \pi^0 \pi^0 \gamma$ (cut off rejecting merged clusters and lost photons configurations)

$f_0 \gamma \rightarrow \pi^0 \pi^0 \gamma$, $a_0 \gamma \rightarrow \eta \pi^0 \gamma$, $\omega \pi^0 \rightarrow \pi^0 \pi^0 \gamma$ (cut off rejecting the masses of the decaying products)



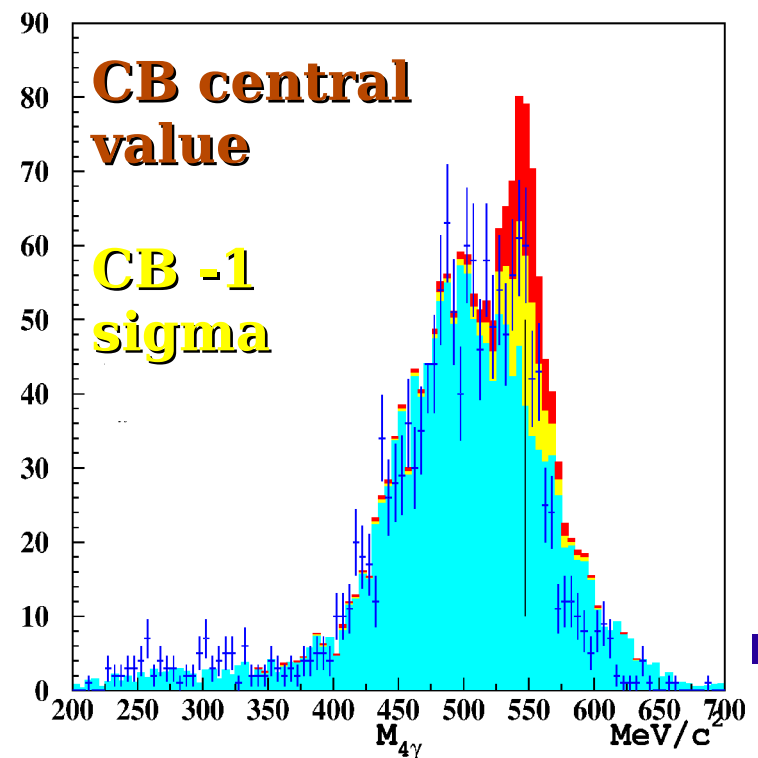
$\epsilon = 5.7\%$



Preliminary analysis shows:

- GAMS overestimates Br
- Indication of signal at CB level

Work in progress to improve background rejection



$\eta \rightarrow \pi^+\pi^-\pi^0$ Dalitz plot analysis



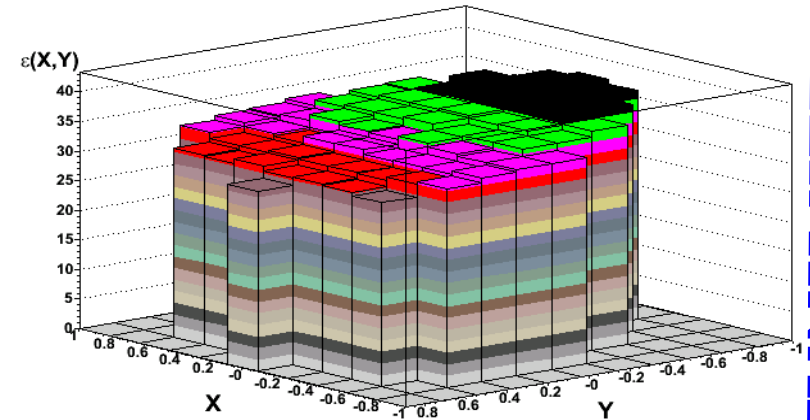
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analysis strategy

- looking for
 - 2 charged tracks from I.P
 - 3 prompt photons
- kinematic fit with energy-momentum constraints to improve photon energy resolution.

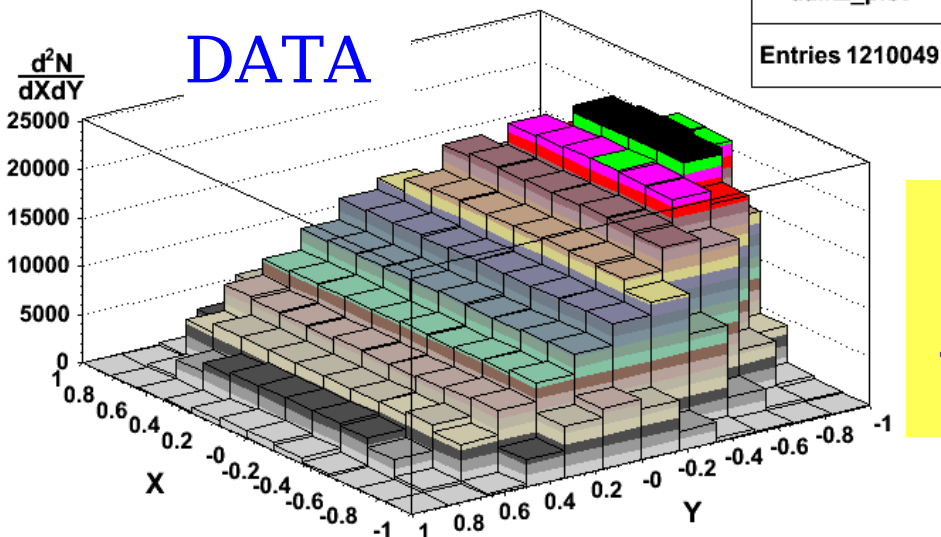
$$X = \sqrt{3} \frac{T_+ - T_-}{Q_\eta} = \frac{\sqrt{3}}{2M_\eta Q_\eta} (u - t)$$

$$Y = \frac{3T_0}{Q_\eta} - 1 = \frac{3}{2m_\eta Q_\eta} \left\{ (m_\eta - m_{\pi^0})^2 - s \right\} - 1$$



Efficiency $\approx 36\%$

$$|\mathcal{A}(X,Y)|^2 = 1 + aY + bY^2 + cX + dX^2 + eXY + fY^3$$



		Ⓒ		Ⓒ	
a	b	c	d	e	f
-1.075 ± 0.008	0.118 ± 0.009	$-0.5 \pm 4 \times 10^{-3}$	0.049 ± 0.008	-0.004 ± 0.010	0.13 ± 0.02
$-0.012/0$	$-0.007/0.01$	$0/2 \times 10^{-3}$	$-0.004/0.007$	$-0.002/0.011$	$0/0.03$

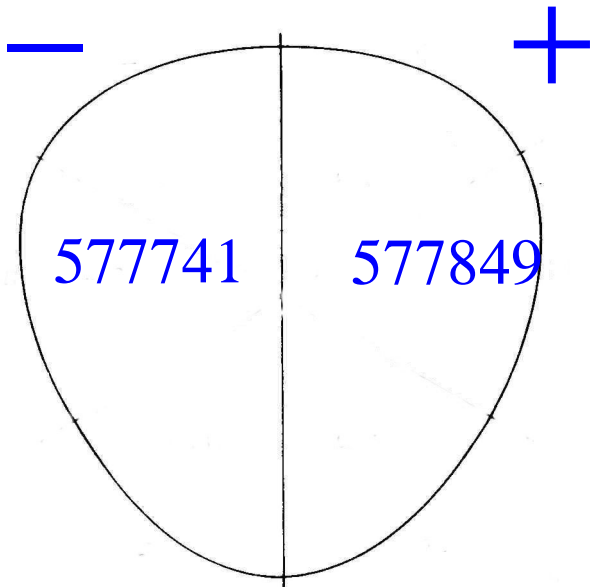
10 June 2004

$\eta \rightarrow \pi^+\pi^-\pi^0$ asymmetries studies **KLOE** **PRELIMINARY**

$$A = \frac{N^+ - N^-}{N^+ + N^-}$$

$$A_q = \frac{N_1 + N_3 - N_2 - N_4}{N_1 + N_2 + N_3 + N_4}$$

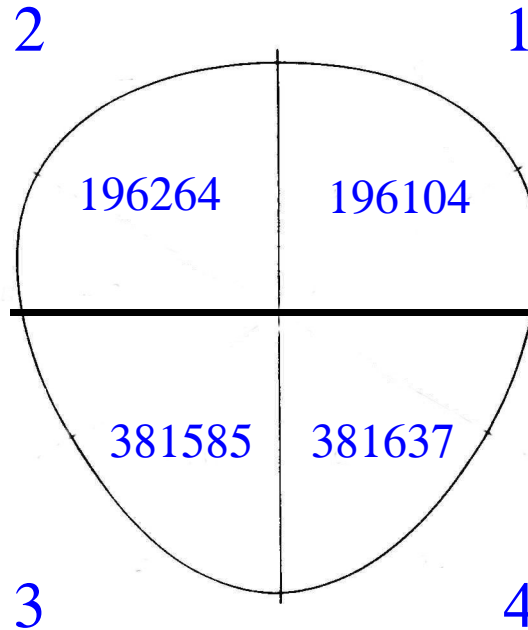
$$A_s = \frac{N_1 + N_3 + N_5 - N_2 - N_4 - N_6}{N_1 + N_2 + N_3 + N_4 + N_5 + N_6}$$



$$\mathcal{A} = (-0.009 \pm 0.093) \cdot 10^{-2}$$

$$\mathcal{A}_{PDG} = (-0.09 \pm 0.17) \cdot 10^{-2}$$

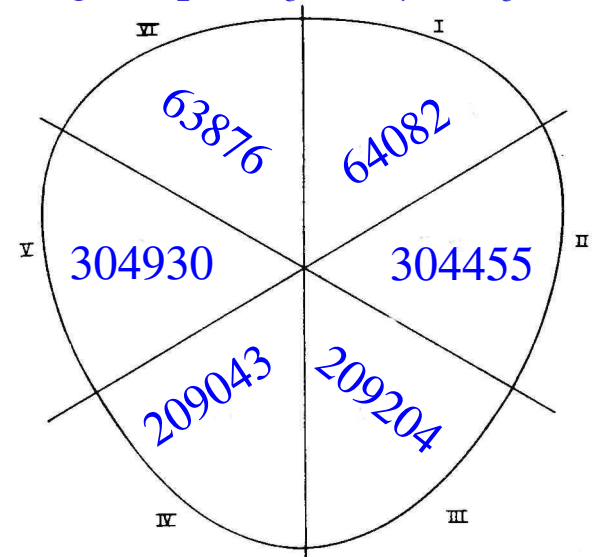
Left-Right Asymmetry



$$\mathcal{A}_q = (-0.02 \pm 0.09) \cdot 10^{-2}$$

$$\mathcal{A}_{PDG} = (-0.17 \pm 0.17) \cdot 10^{-2}$$

Quadrant Asymmetry



$$\mathcal{A}_s = (0.07 \pm 0.09) \cdot 10^{-2}$$

$$\mathcal{A}_{PDG} = (0.18 \pm 0.16) \cdot 10^{-2}$$

Sextant Asymmetry

$$\phi \rightarrow \eta' \gamma \rightarrow \pi^+ \pi^- 7 \gamma$$

- charged $\Rightarrow \eta' \rightarrow \eta \pi^+ \pi^-$ and $\eta \rightarrow \pi^0 \pi^0 \pi^0$
- neutral $\Rightarrow \eta' \rightarrow \eta \pi^0 \pi^0$ and $\eta \rightarrow \pi^+ \pi^- \pi^0$

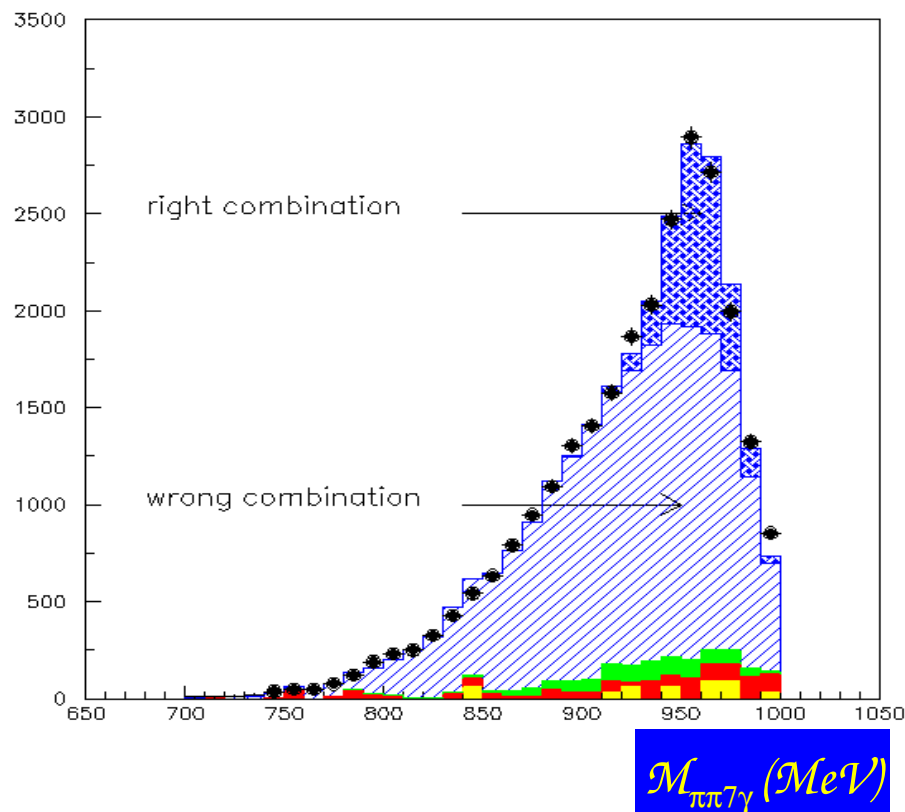
$M_{\eta'}$ from $\pi^+ \pi^- 6 \gamma$ (we should discard 1 photon among the seven ones), we keep all combinations and subtract from MC.

$$R = \frac{BR(\phi \rightarrow \eta' \gamma)}{BR(\phi \rightarrow \eta \gamma)} = \frac{N^{\eta' \gamma}}{N^{\eta \gamma}} \frac{\varepsilon^{\eta \gamma} BR(\eta \rightarrow 3\pi^0)}{BR_{crg} \varepsilon_{crg} + BR_{ntr} \varepsilon_{ntr}} \cdot K_{\rho}$$

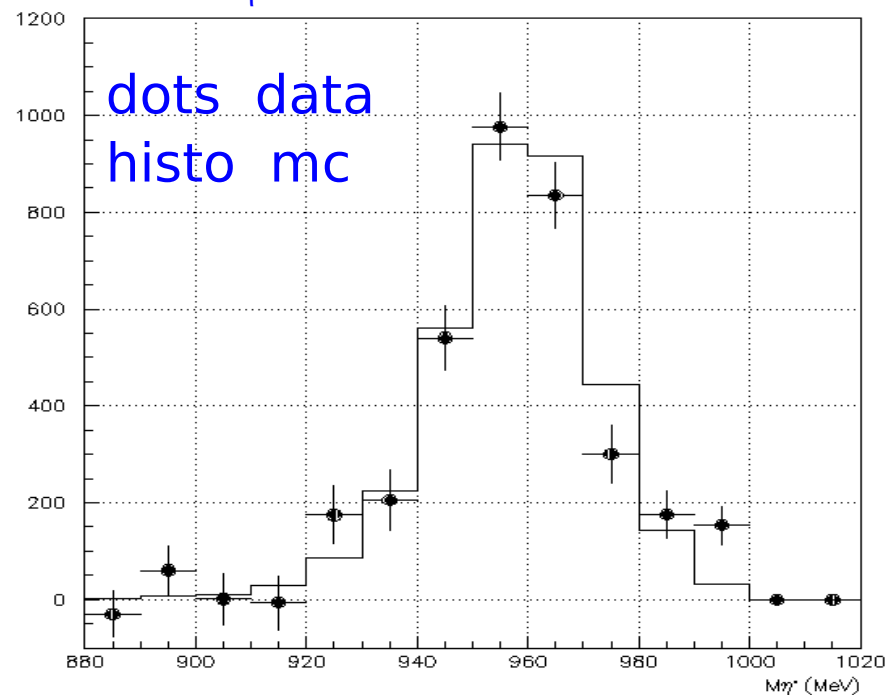
$$R = (4.89 \pm 0.09) \cdot 10^{-3}$$



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$$N_{\eta'} = 3401 \pm 61 (\text{stat.}) \pm 31 (\text{bkg. sub.})$$



Conclusions



- ◆ a ϕ factory is a clean environment where to study scalar and pseudoscalar meson physics;
- ◆ KLOE has already published in this field;
- ◆ a lot of new results are coming out.