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:
  - $\eta \rightarrow \gamma\gamma\gamma$, $\eta \rightarrow \pi^+\pi^-$ 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.

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

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

aim of the analysis

extracting f_0 properties

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

background sources

$e^+e^- \to \pi^+\pi^-\gamma$ via ISR

(raditive return to ρ and ω)

$e^+e^- \to \pi^+\pi^-\gamma$ via FSR

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

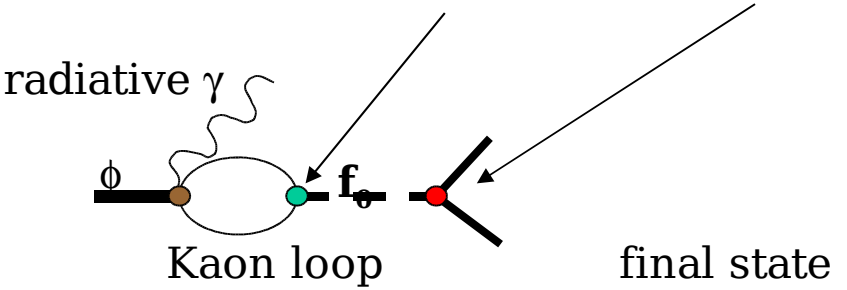
analysis selection

$45 < \theta_\gamma < 135^o$ ISR reduced and not "interfering"

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

phenomenological model

$g^2_{fKK}/4\pi$, $g^2_{f\pi+\pi-}$



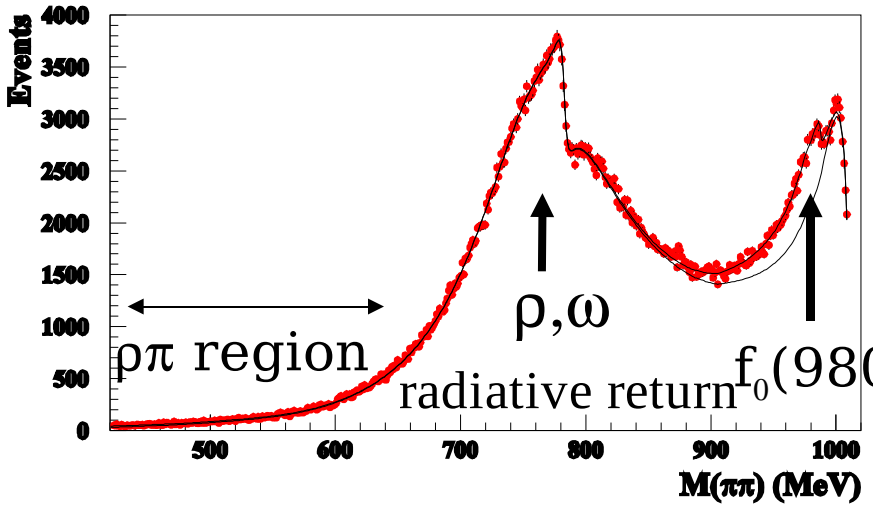
Including ππ rescattering data

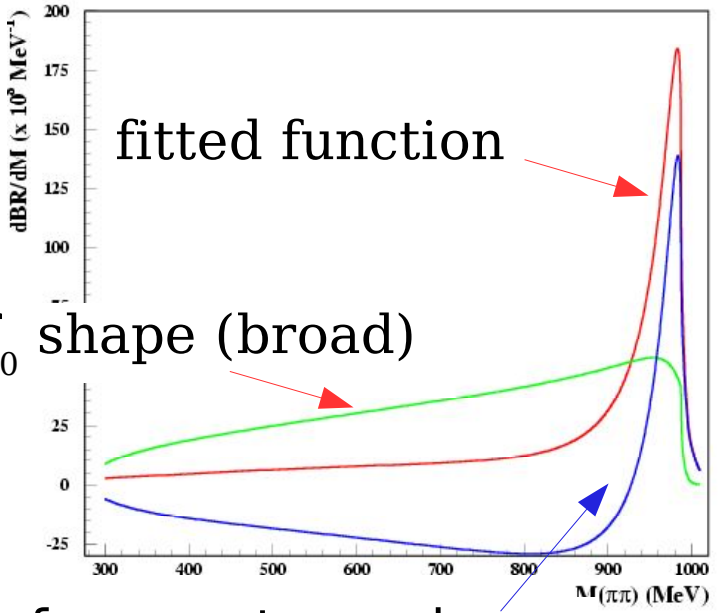
PRD55 (1997) & PRD57 (1998)
N.N. Achasov et al.

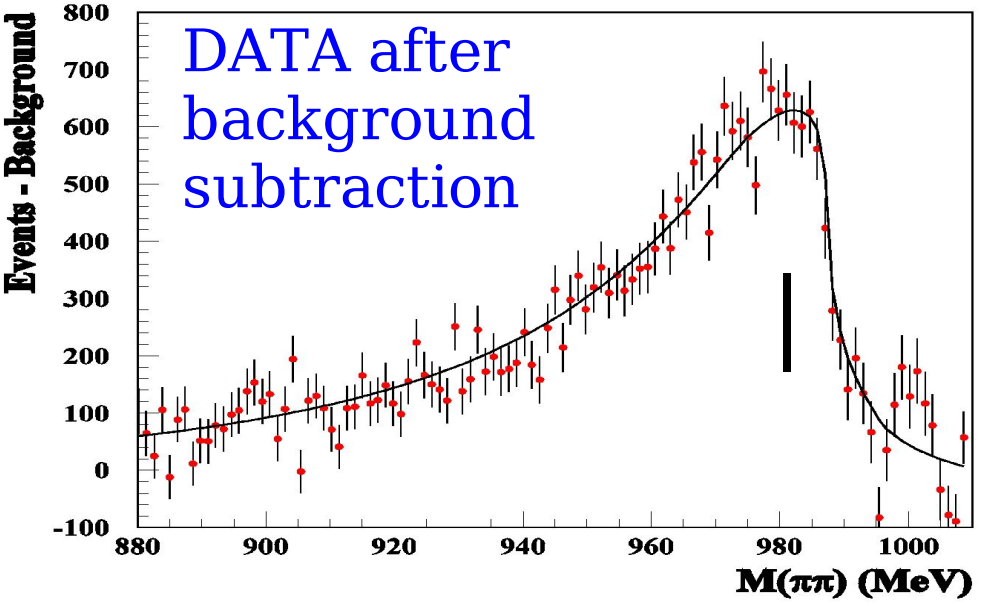
$f_0 \to \pi^+\pi^-$ fit to the spectrum

KLOE PRELIMINARY

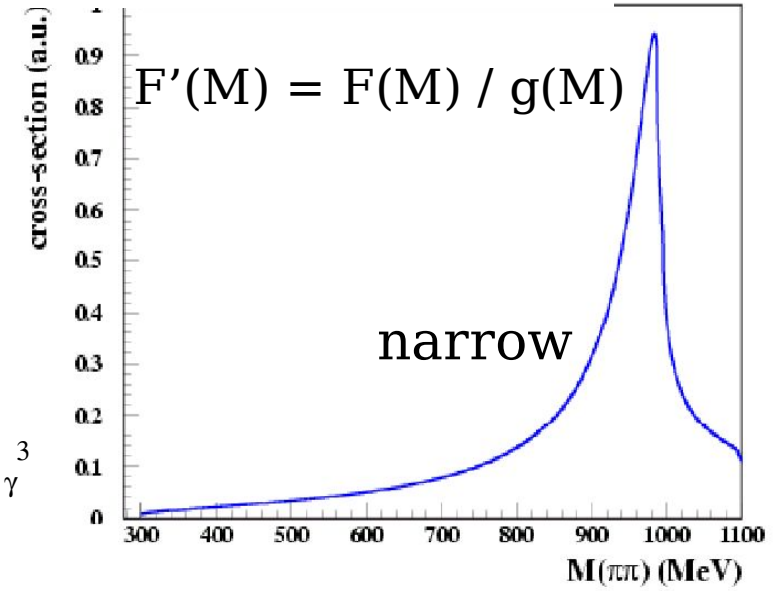
full spectrum







$g(M) \sim E_\gamma^3$



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

KLOE PRELIMINARY

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

A(ISR) C-odd

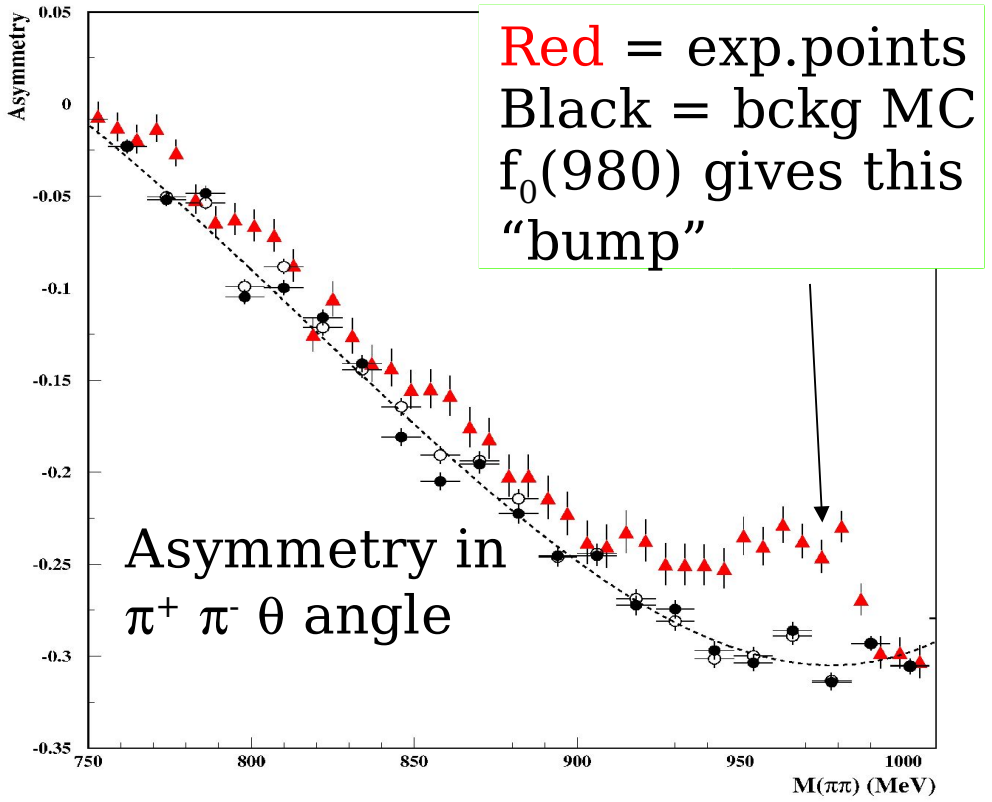
A(FSR) C-even

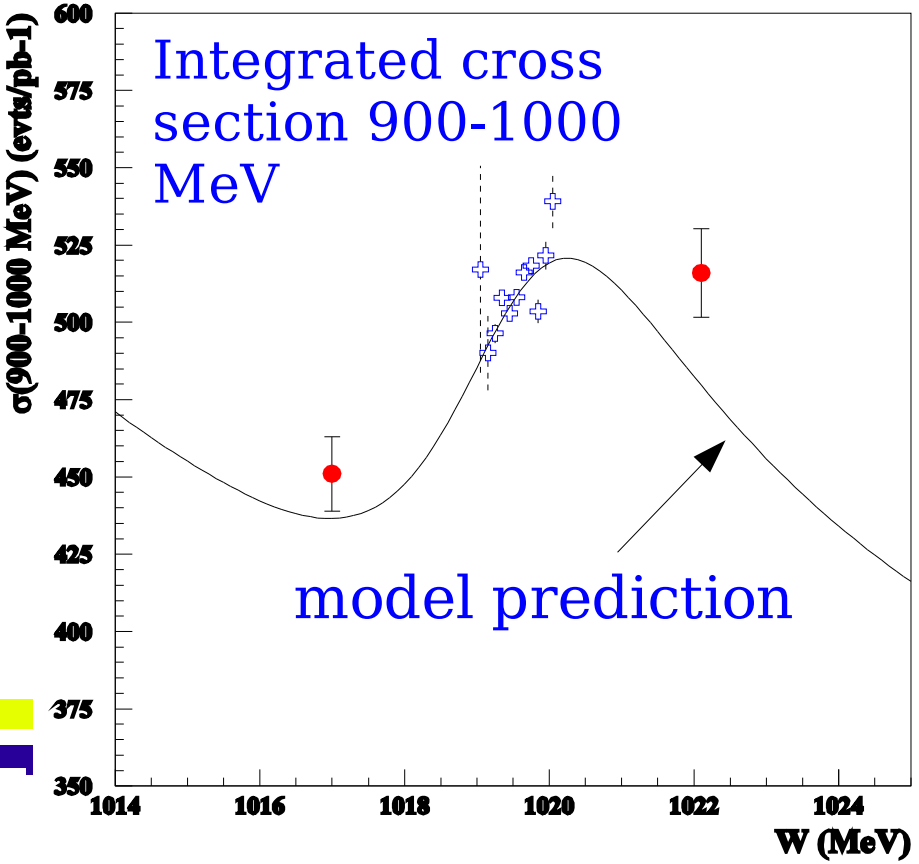
A(f0) C-even

A(tot) not defined symmetry for the interference among the terms.

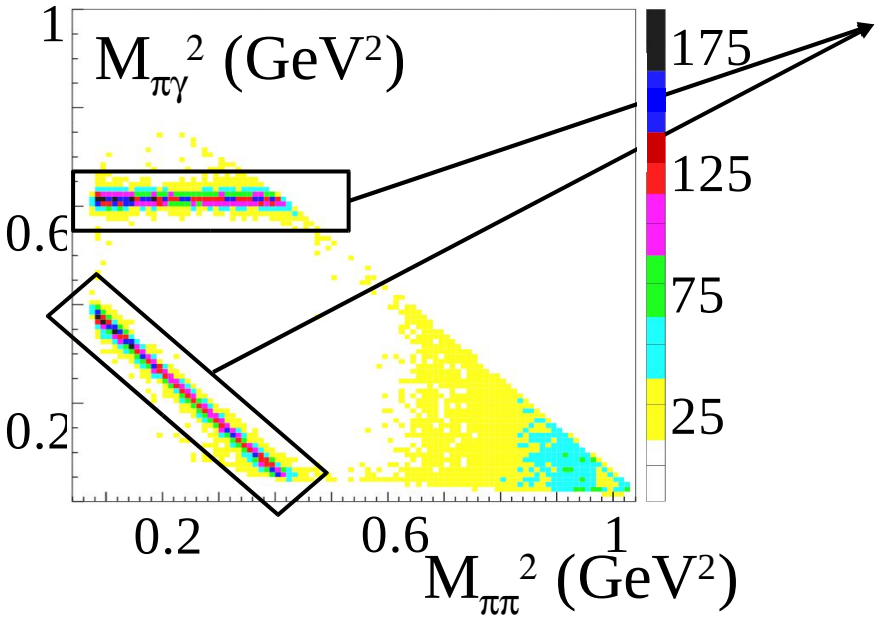
$$A = \frac{N(\theta > 90°) - N(\theta < 90°)}{N(\theta > 90°) + N(\theta < 90°)}$$

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





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



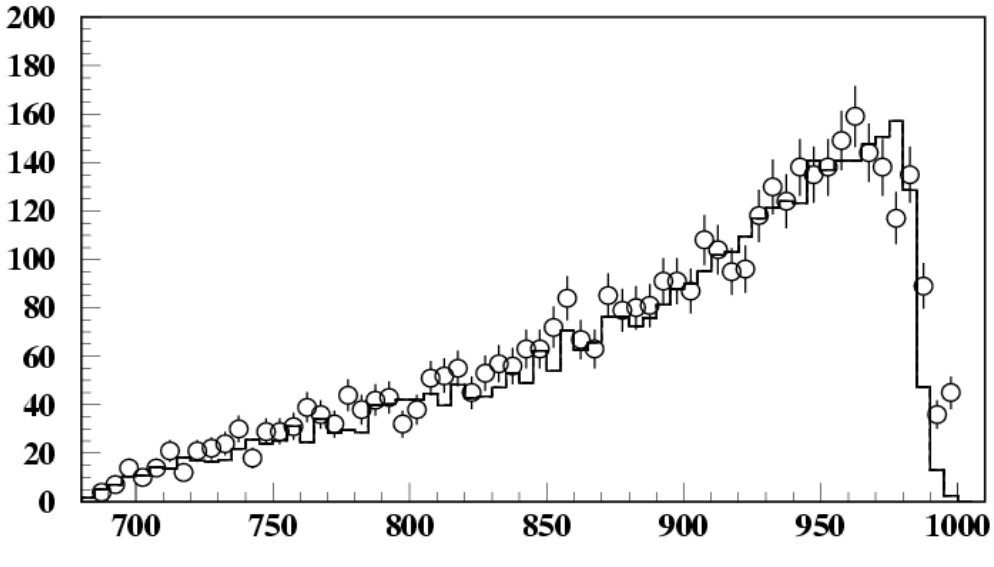
$\omega\pi^0$

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



B. Di Micco

η *physics at KLOE*

Usually studied at hadron machines.

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

$\phi \rightarrow \eta\gamma$ η *sample* ~ 18×10^6

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.*

$\eta \to \gamma\gamma\gamma$

Violates C, BR < 5×10^{-4} @95% CL PDG ' 02 (GAMS2000)

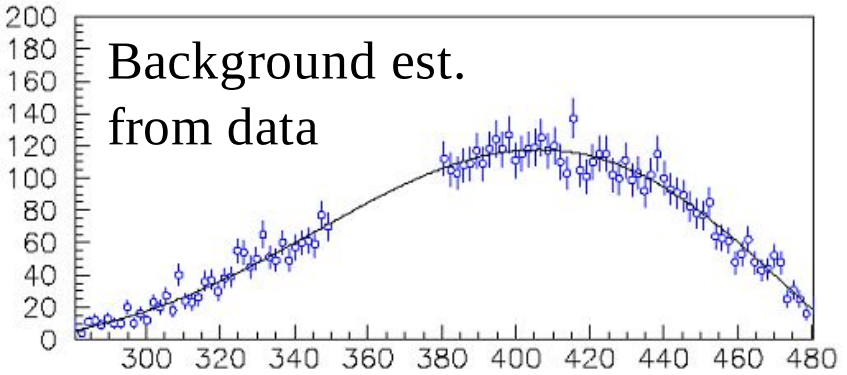
$\phi \to \eta\gamma$ (E_{rad} = 363 MeV), $\eta \to \gamma\gamma\gamma$ } **4γ**

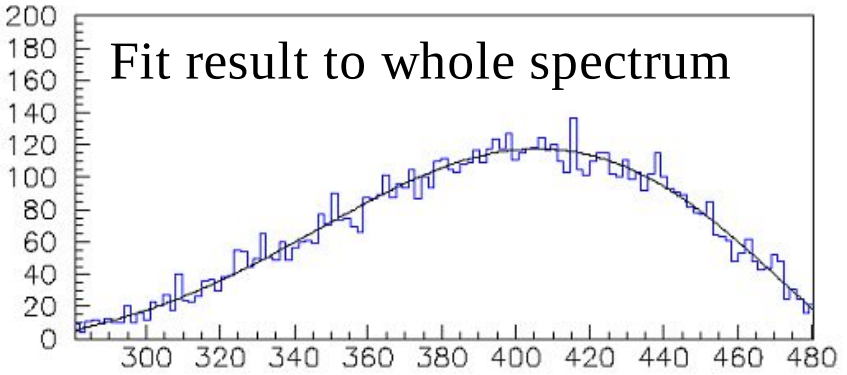
Require 4γ with E>50 MeV, $|\cos\theta|<0.91$

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

Kinematic fit to improve energy resolution

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





E_{max} (MeV)

BR($\eta \to 3\gamma$) ≤ 1.6×10^{-5} @ 90% CL

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

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

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

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

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

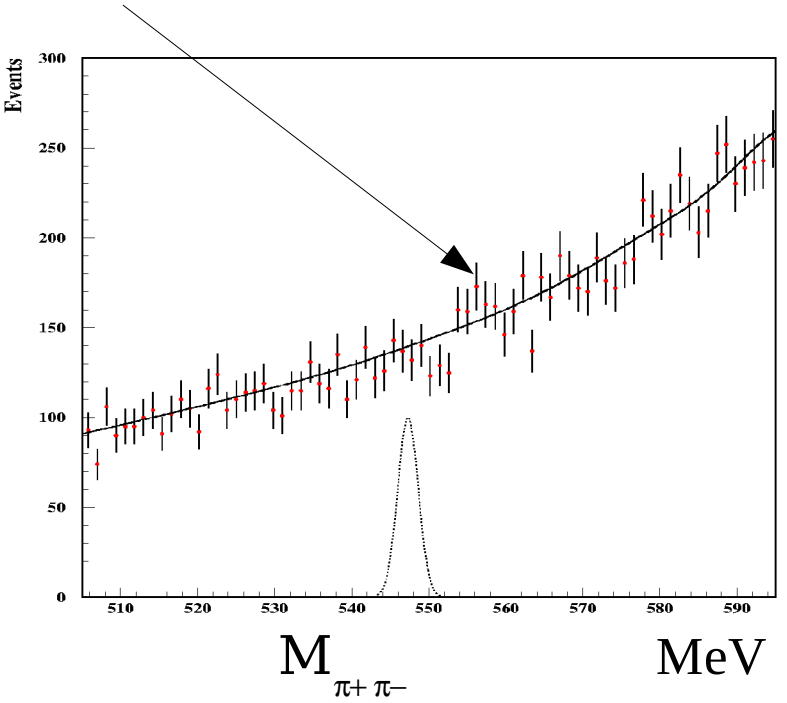
$N_{UP} < 21.1$ @ 90% C.L

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

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

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

fitted spectrum from f_0 analysis



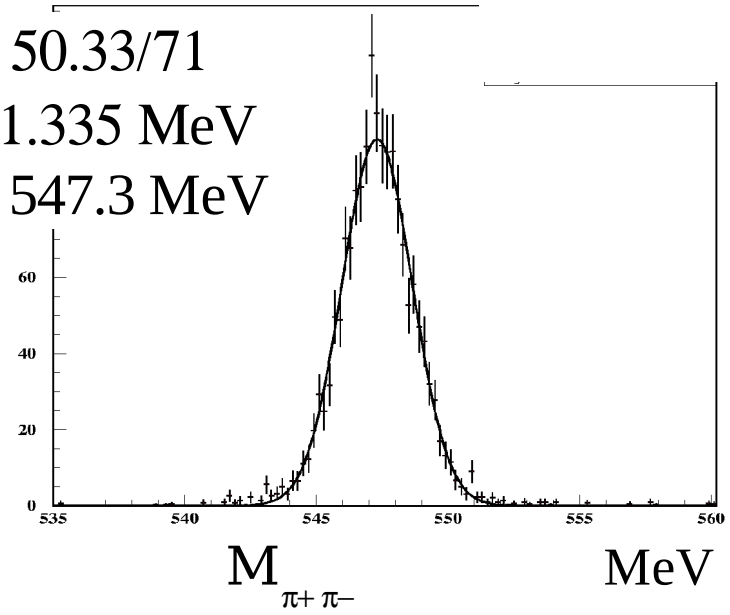
KLOE PRELIMINARY

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

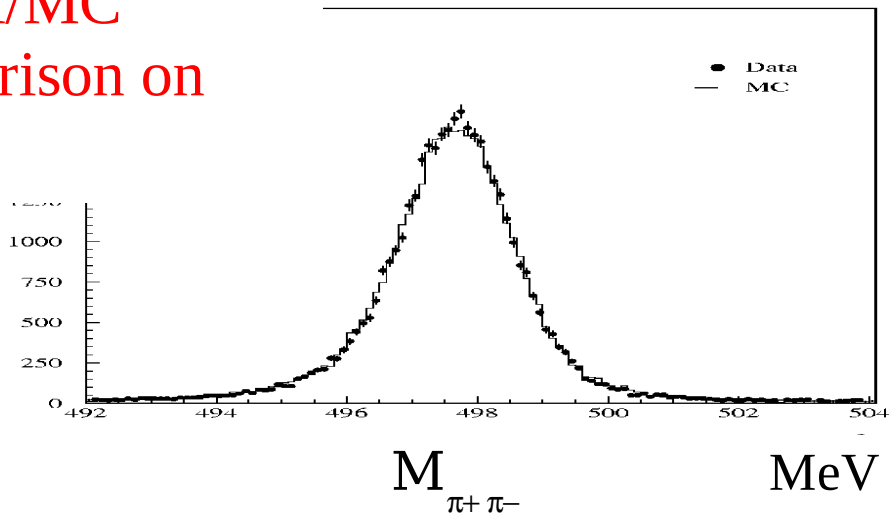
$\chi^2 = 50.33/71$

$\sigma = 1.335$ MeV

$m = 547.3$ MeV



DATA/MC comparison on MK_s



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

Theoretical predictions: $\Gamma(\eta\to\pi^0\gamma\gamma)$ **[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.)**
χPT+VMD+scalars	**0.42 ± 0.20**	**(Ametller et al.)**
χPT+ENJL	**0.58 ±0.30**	**(Bellucci-Bruno)**

Experimental η production

PDG(2002) GAMS

$Br(\eta \to \pi^0\gamma\gamma) = 7.2 \pm 1.4\ x10^{-4}\ (0.85 \pm 0.18\ \text{eV/c}^2)$

Crystall Ball (2004)

$Br(\eta \to \pi^0\gamma\gamma) = 2.7 \pm 0.9 \pm 0.5\ x10^{-4} (0.32 \pm 0.15\ \text{eV/c}^2)$

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

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

$\phi \to \eta\gamma$

$\eta \to \pi^0\gamma\gamma$ *analysis sketch*

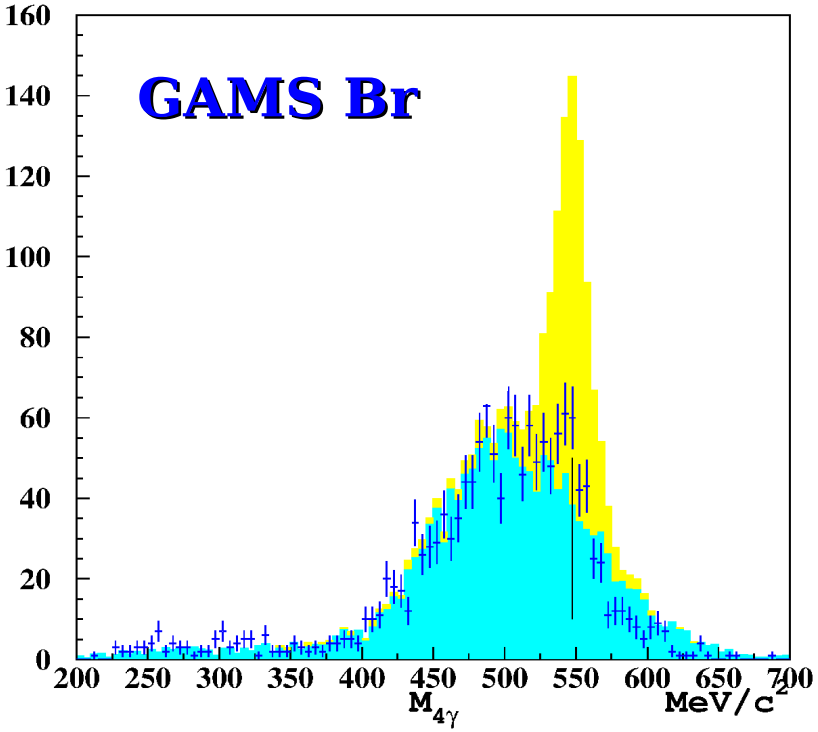
$\Phi \to \eta\,\gamma$; $\eta \to \pi^0\gamma\gamma$ } 5γ final state

$\sigma = 8$pb GAMS Br

main background sources

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

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

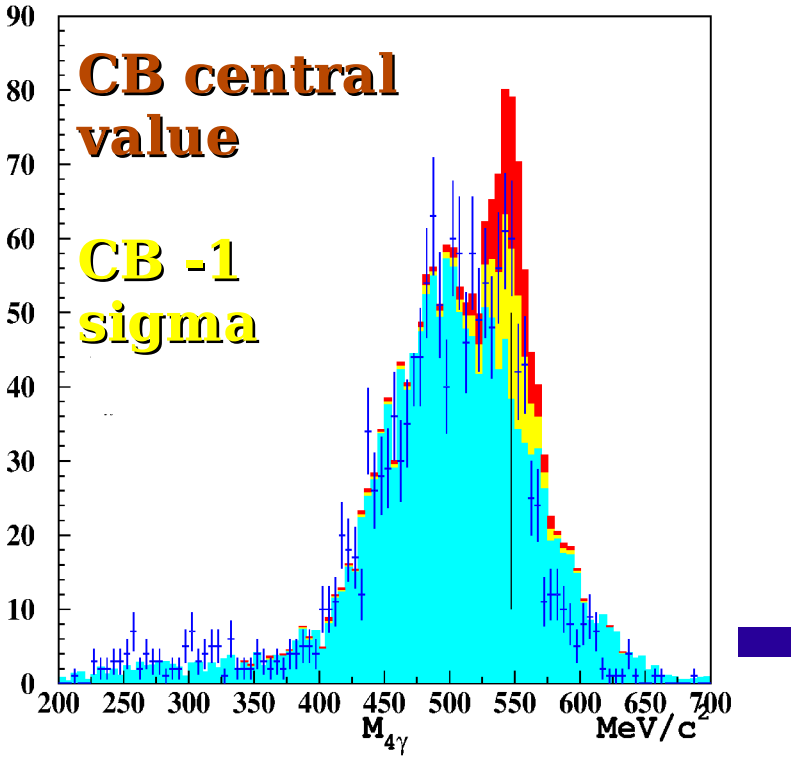


$\varepsilon = 5.7\%$

Preliminary analysis shows:

- GAMS overestimates Br
- Indication of signal at CB level

Work in progress to improve background rejection



$\eta \to \pi^+\pi^-\pi^0$ *Dalitz plot analysis*

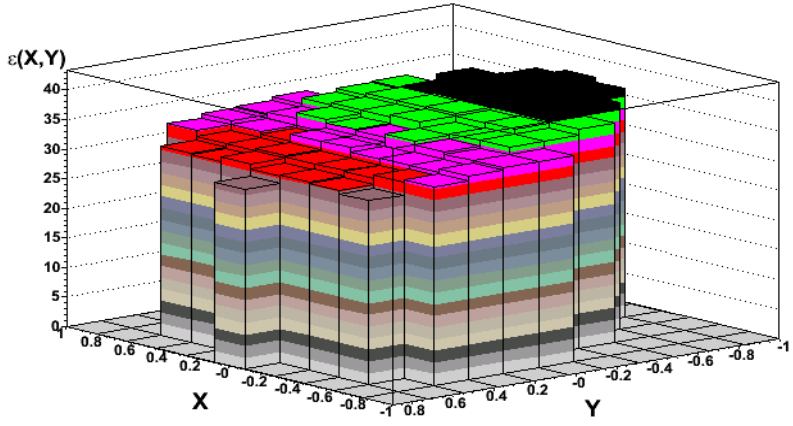
KLOE PRELIMINARY

analysis strategy

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

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

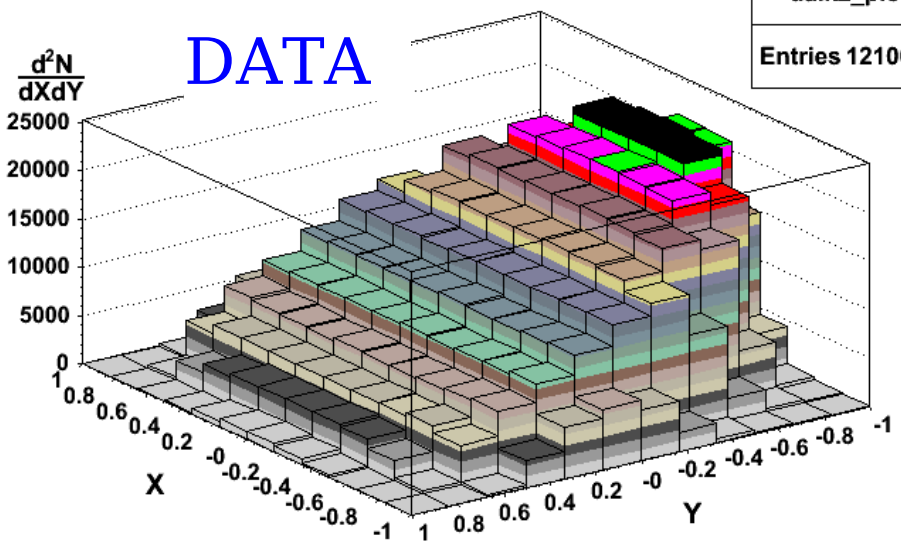
$$Y = \frac{3T_0}{Q_\eta} - 1 = \frac{3}{2m_\eta Q_\eta}\left\{\left(m_\eta - m_{\pi^0}\right)^2 - s\right\} - 1$$



Efficiency ≈ 36%

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

DATA

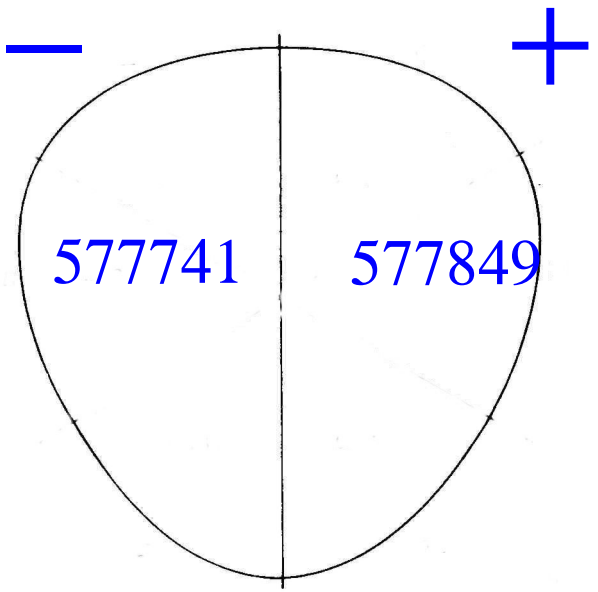


a	b	c	d	e	f
-1.075 ± 0.008	0.118 ± 0.009	-0.5 ± 4 x10^{-3}	0.049 ±0.008	-0.004 ±0.010	0.13 ±0.02
-0.012/0	-0.007/ 0.01	0/2x10^{-3}	-0.004/ 0.007	-0.002/ 0.011	0/0.03

$\eta \to \pi^+\pi^-\pi^0$ asymmetries studies

KLOE PRELIMINARY

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

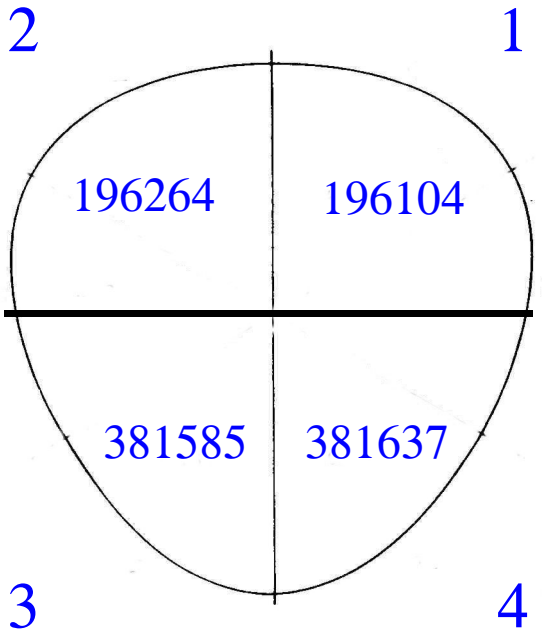


$\mathcal{A} = (-0.009 \pm 0.093) \bullet 10^{-2}$

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

Left-Right Asymmetry

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

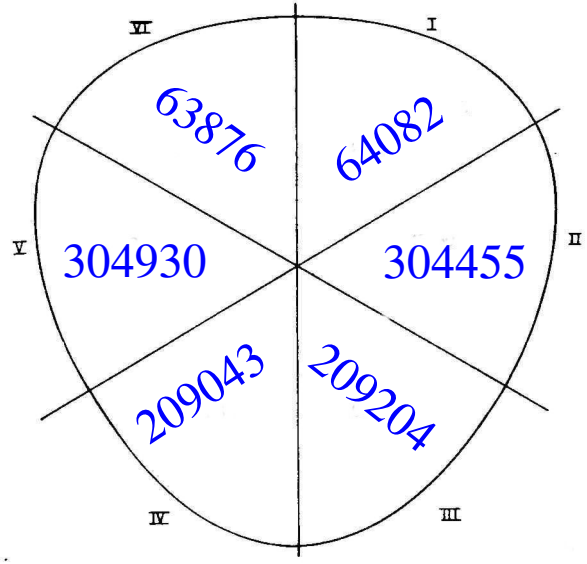


$\mathcal{A}_q = (-0.02 \pm 0.09) \bullet 10^{-2}$

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

Quadrant Asymmetry

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



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

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

Sextant Asymmetry

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

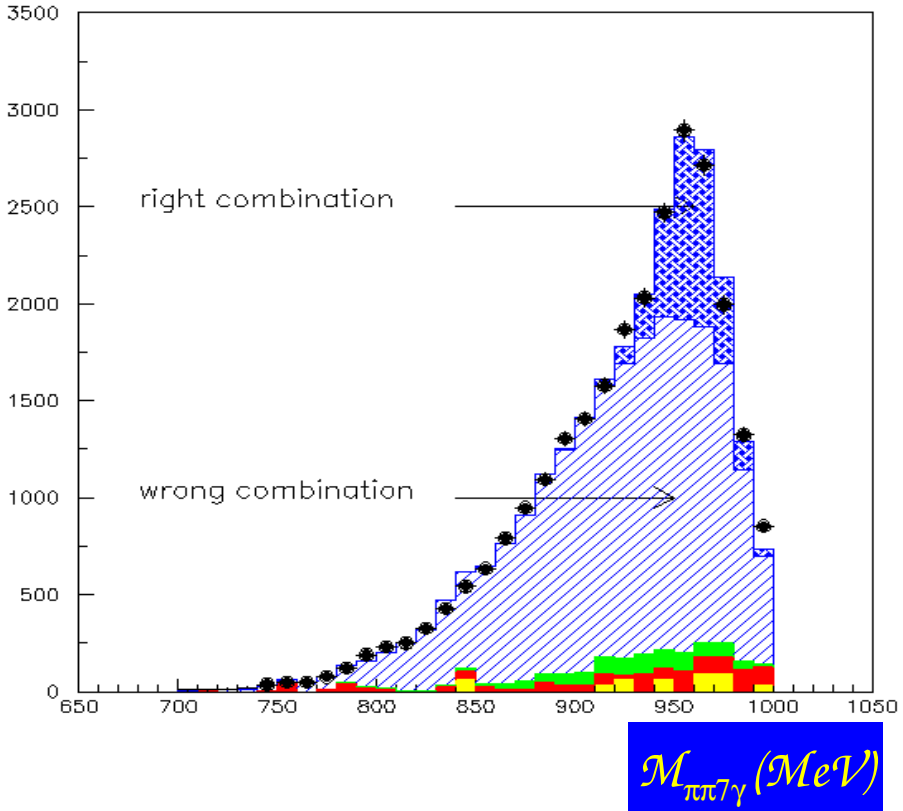
- charged $\Rightarrow \eta' \to \eta\pi^+\pi^-$ and $\eta \to \pi^0\pi^0\pi^0$
- neutral $\Rightarrow \eta' \to \eta\pi^0\pi^0$ and $\eta \to \pi^+\pi^-\pi^0$

KLOE PRELIMINARY

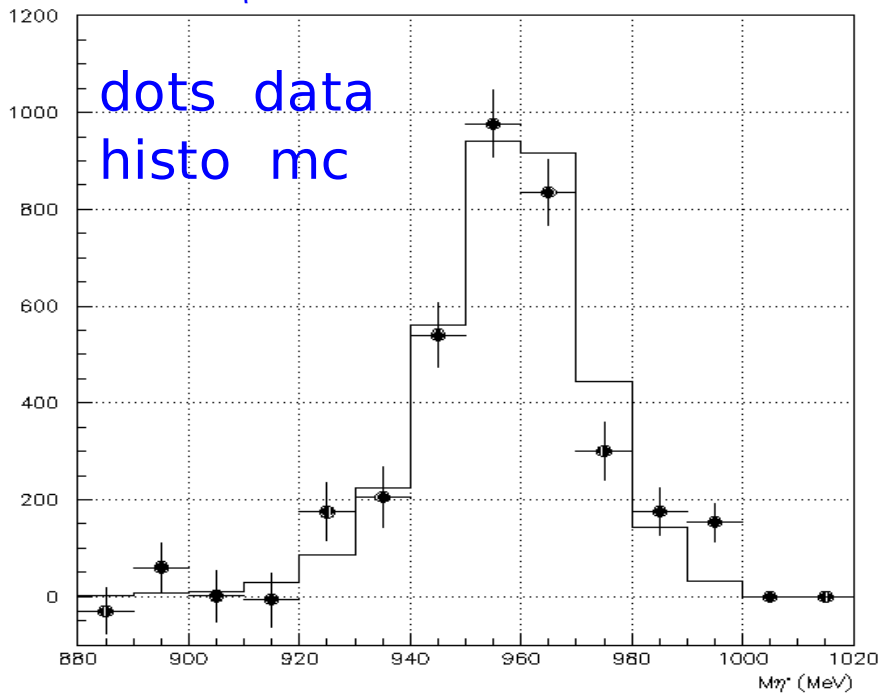
$M_{\eta'}$ from $\pi^+\pi^-6\gamma$ (we should discard 1 photon among the seven ones), we keep all combinations and subtract from MC.

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

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



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



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.