Light meson spectroscopy with the KLOE experiment

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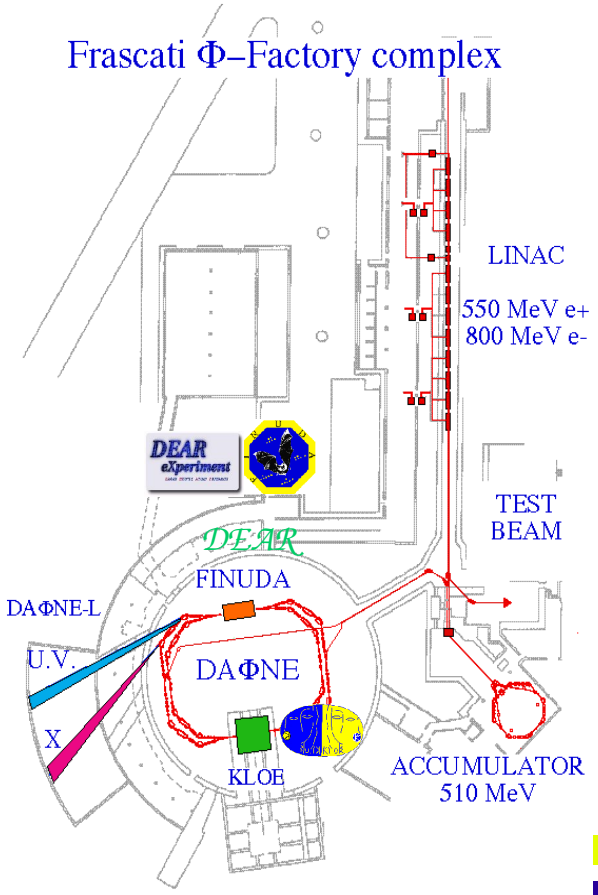
for the KLOE collaboration

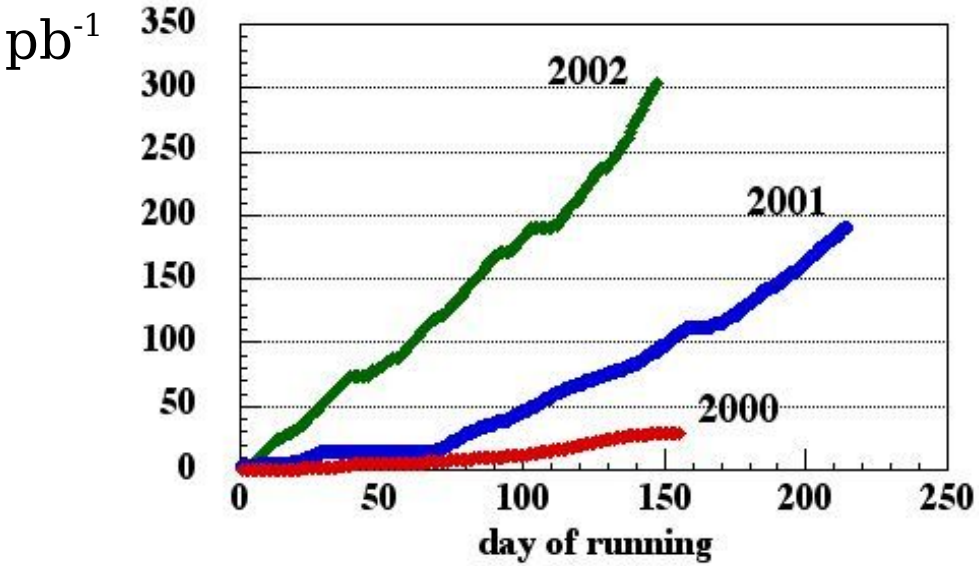
$\sqrt{s} = M_\Phi = 1.02$ GeV

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

- e^+e^- in two separate rings with crossing angle ~25mrad at IP (small Φ momentum p_Φ~13MeV)

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





The KLOE detector

Electromagnetic Calorimeter (EMC)

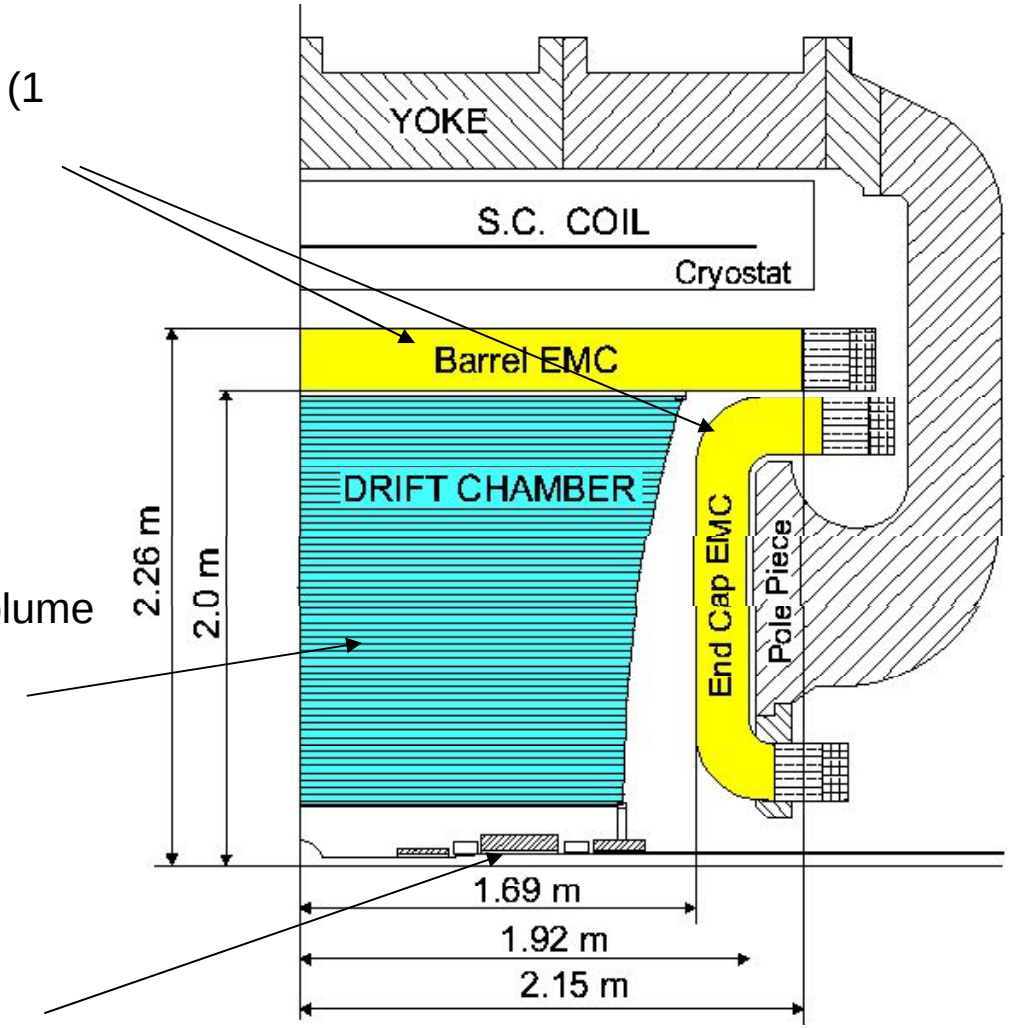
- Fine sampling Pb (0.5 mm thick) / Scifi (1 mm ø)
- Hermetical coverage
- High efficiency for low energy photons
  - $\sigma_E/E = 5.7\%/\sqrt{E(GeV)}$
  - $\sigma_t = 54ps/\sqrt{E(GeV)}$

Central drift chamber (DCH)

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

Quadrupoles' calorimeter (QCAL)

Pb/Sci tile calorimeter covering quads inside KLOE



outline

- scalar meson physics:
  - $f_0 \to \pi^+\pi^-$ spectrum measurement;
  - $f_0 \to \pi^0\pi^0$ Dalitz plot analysis;
  - $a_0 \to \eta\pi^0$ spectrum measurement and Dalitz plot;

  } to study scalars' nature (qq,qqqq,KK molecules)
- η physics:
  - $\eta \to \gamma\gamma\gamma$, $\eta \to \pi^+\pi^-$ upper limits (test of C and CP violation in strong and electromagnetic interactions);
  - $\eta \to \pi^0\gamma\gamma$
  - $\eta \to \pi^+\pi^-\pi^0$ Dalitz plot analysis;
- η' physics
  - $\phi \to \eta'\gamma \to \pi^+\pi^- 7\gamma$ Br measurement;
- ϕ leptonic width 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

(radiative return to ρ and ω)

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

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

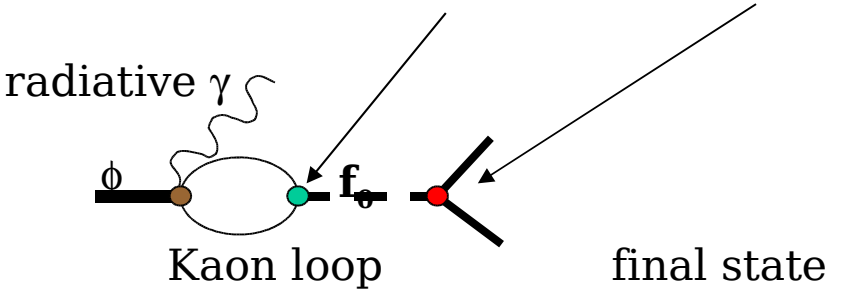
analysis selection

$45^o < \theta_\gamma < 135^o$ 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 $\pi\pi$ rescattering data

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

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

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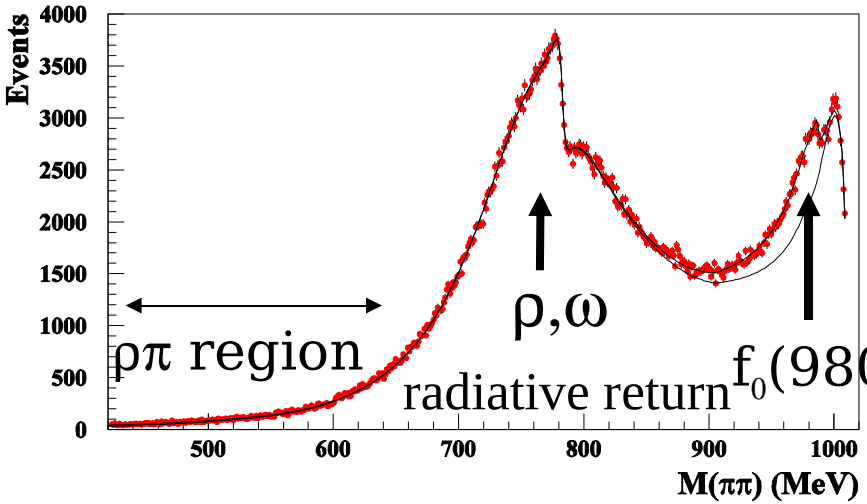
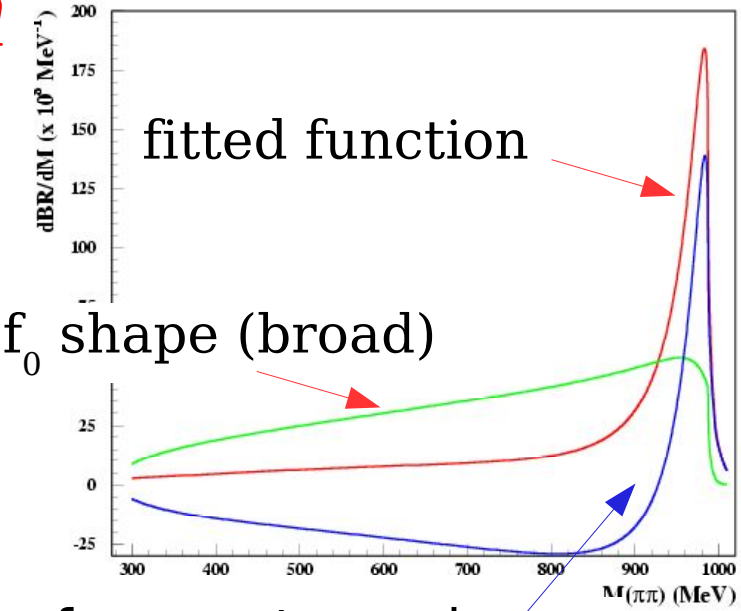
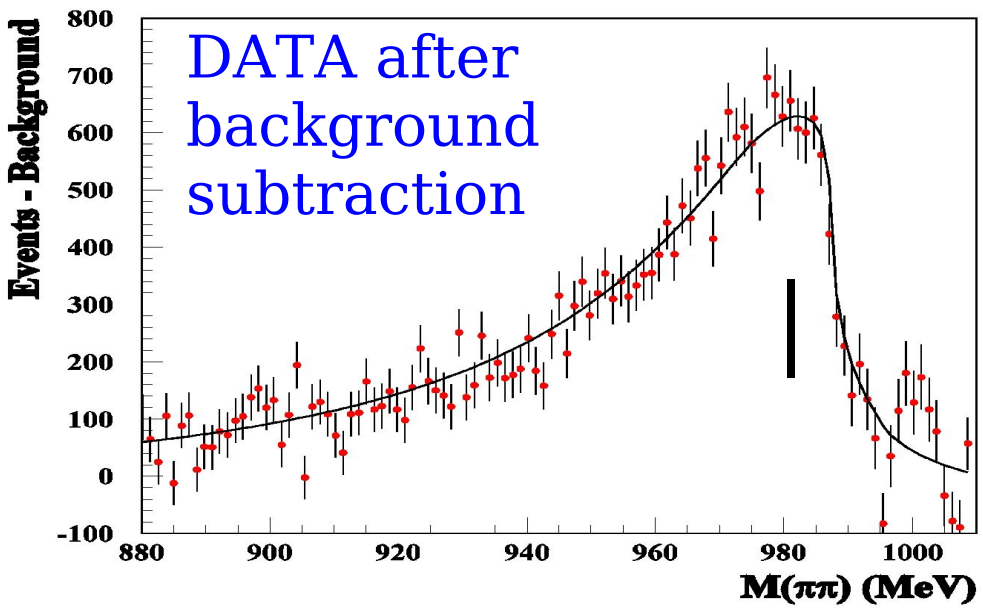
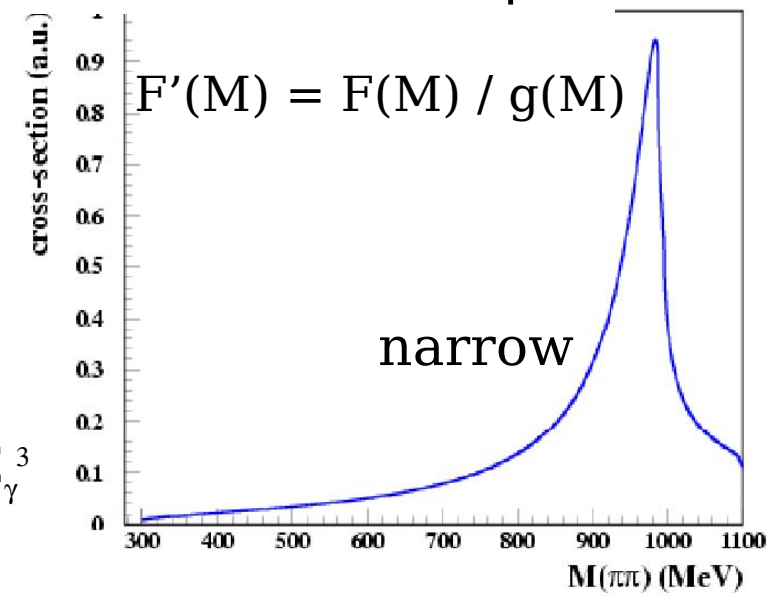
full spectrum







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



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

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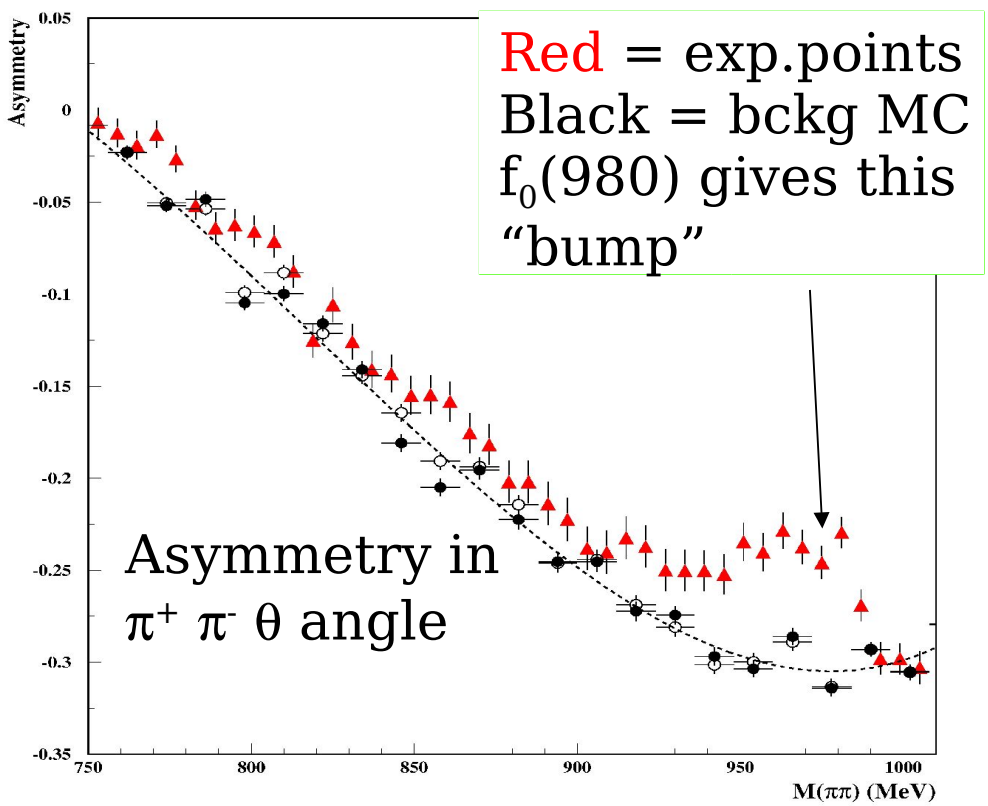
$\pi^+\pi^-$ system:

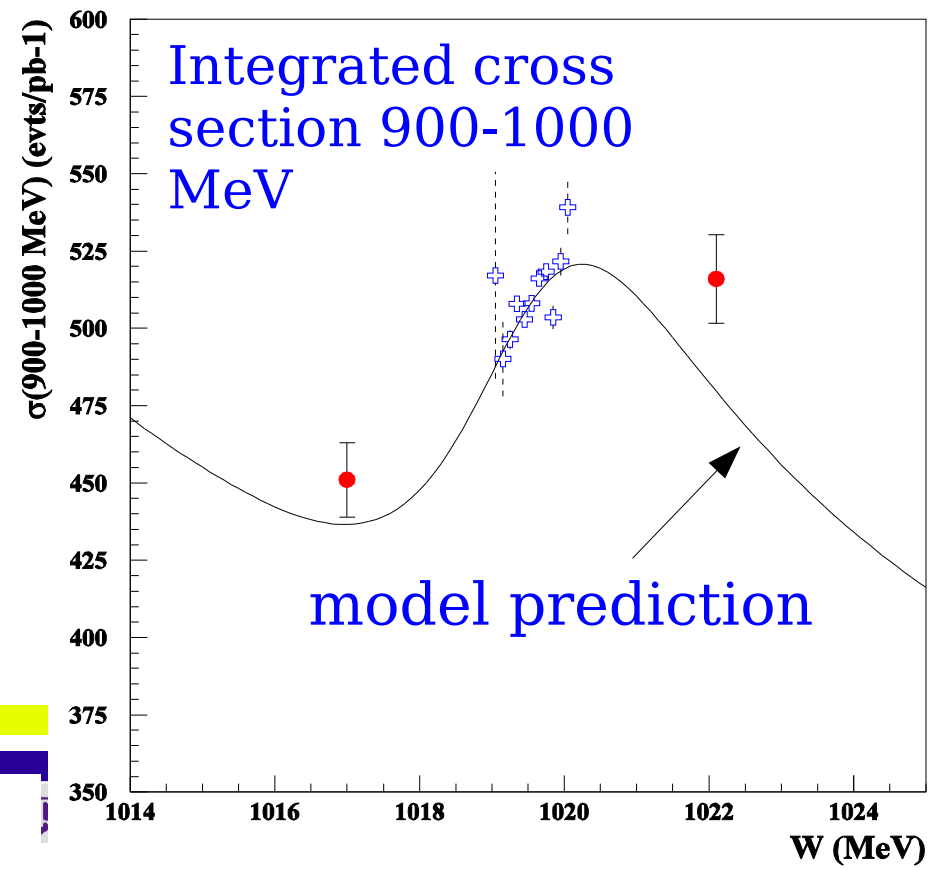
A(ISR) C-odd
A(FSR) C-even
A(f0) C-even

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 $\sqrt{s}$



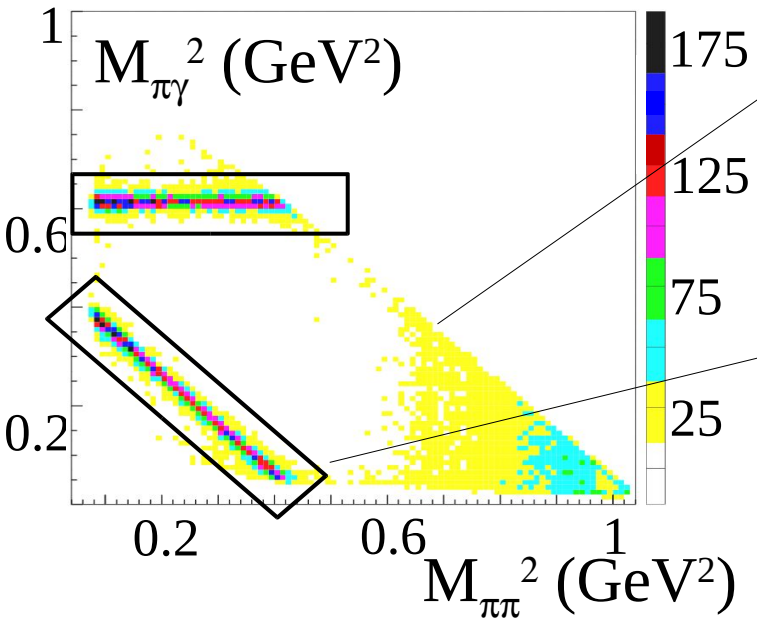


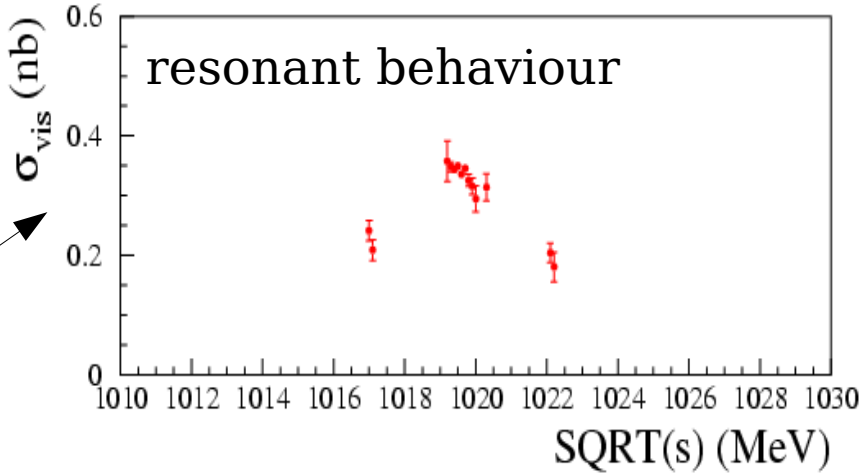
$f_0 \rightarrow \pi^0\pi^0$

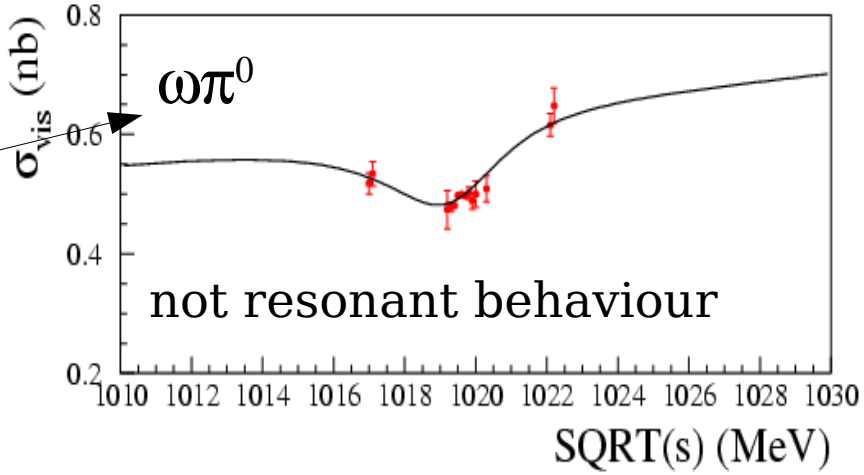
- decay channels: $\phi \rightarrow f_0\gamma \rightarrow \pi^0\pi^0\gamma$

5 prompt clusters
π^0 requirement
kinematic fit

Br interesting to test $q\bar{q}$ or $q\bar{q}q\bar{q}$ and KK molecules hyptotheses.







$a_0 \to \eta\pi^0$

- decay channels: $\phi \to a_0\gamma \to \eta\pi^0\gamma$

$\eta \to \pi^+\pi^-\pi^0$ 5 prompt clusters 2 chrged track $Br(\phi \to a_0\gamma) = 7.45 \pm 0.19 \times 10^{-5}$

$\eta \to \gamma\gamma$ 5 prompt clusters no charged track $Br(\phi \to a_0\gamma) = 7.25 \pm 0.15 \times 10^{-5}$

2002 KLOE result
Phys.Lett.B53 (2002) 209

$Br(\phi \to a_0\gamma) = 7.4 \pm 0.7 \times 10^{-5}$

(2002 DATA)

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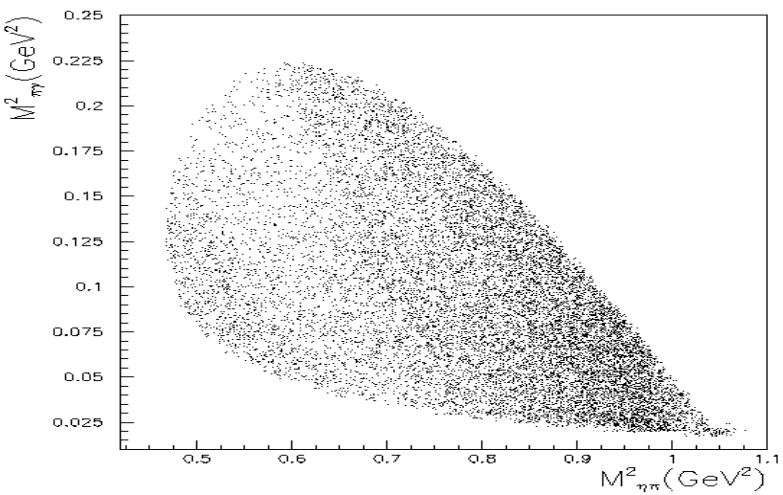
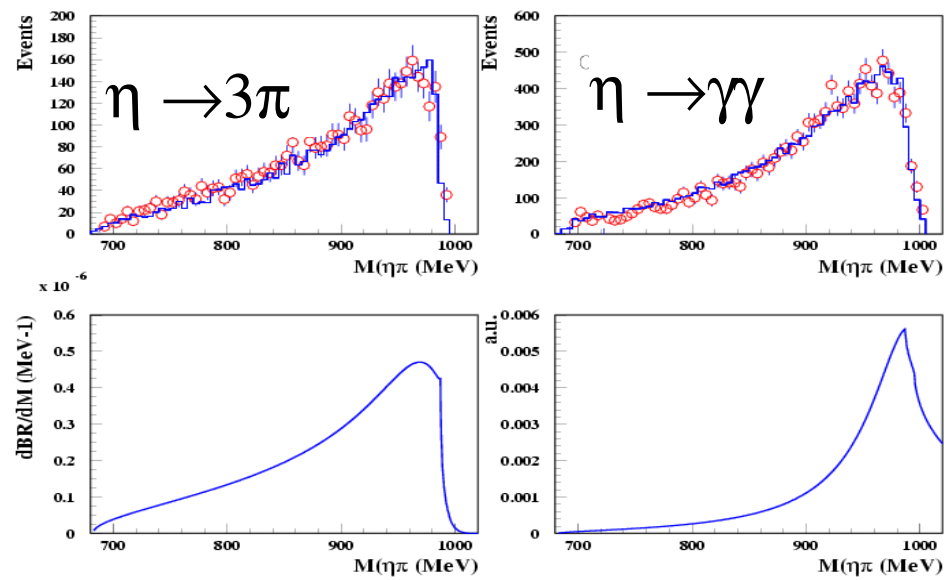


Dalitz plot $\eta \to \gamma\gamma$ channel

Properties of $a_0(980)$ - Check of the *kaon-loop approach* in a "background free" environment



resulting curve fitted to both spectra

$F'(M) = F(M) / g(M)$
$g(M) \sim E_\gamma^3$

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* ~ 19×10^6

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.*

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

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

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

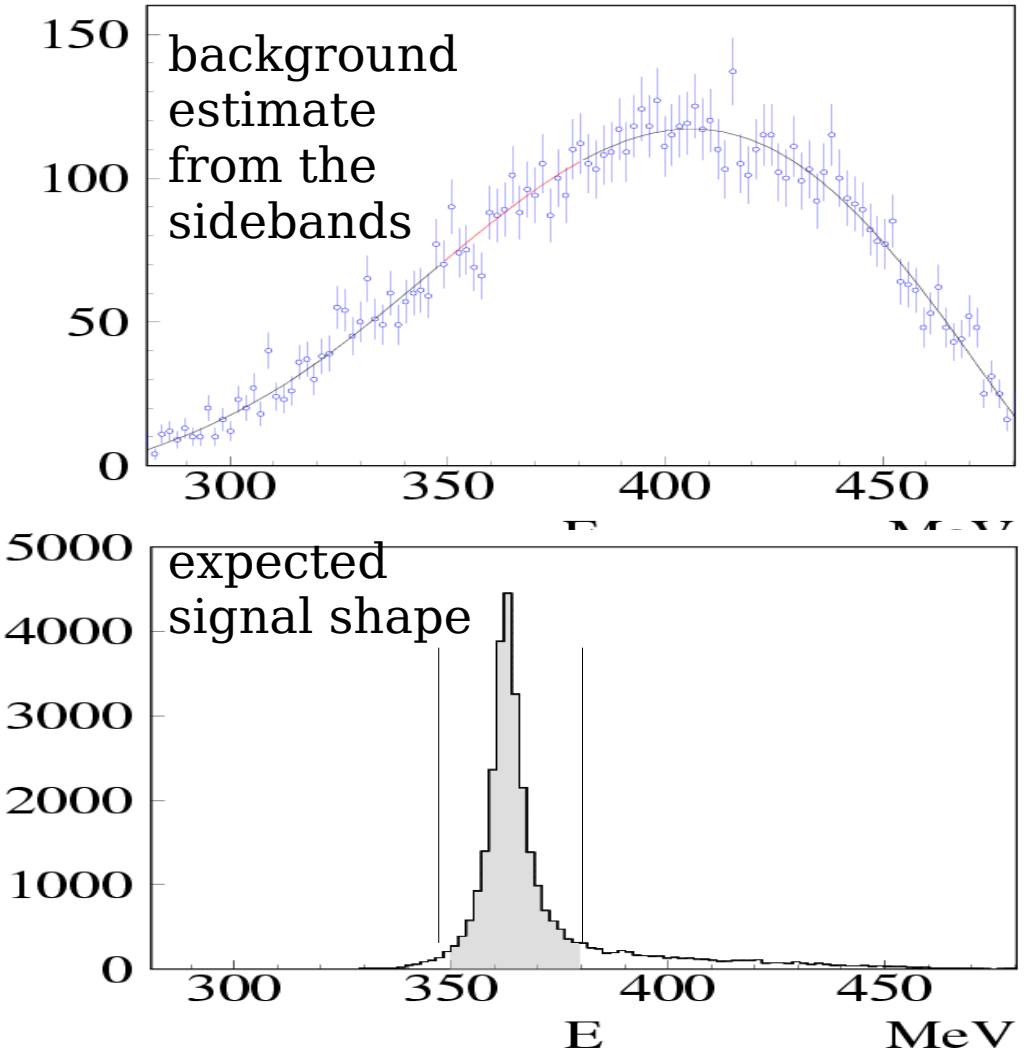
Require 4γ with E>50 MeV, |cosθ|<0.91

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

Kinematic fit to improve energy resolution

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

$\pi^0\gamma$



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

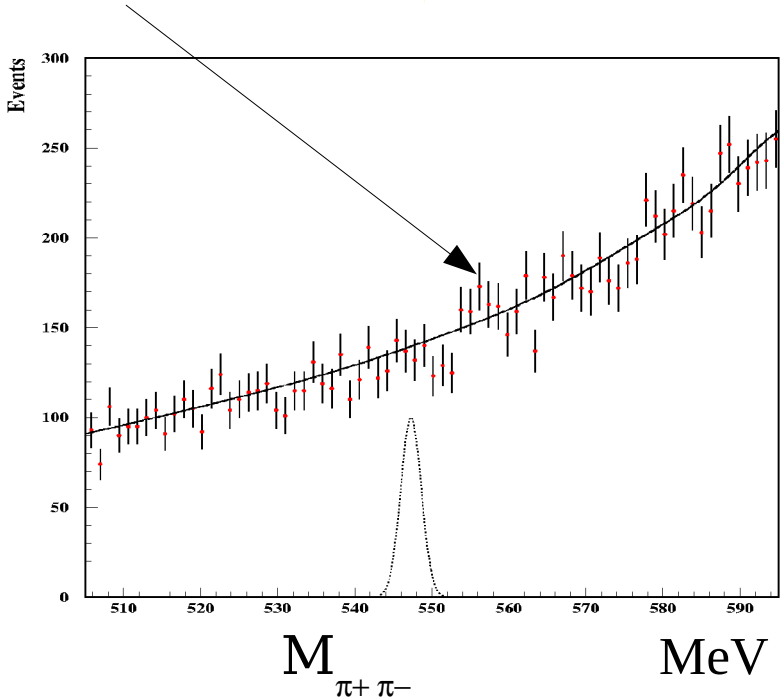
$45 < \theta_\gamma < 135^o$ $\varepsilon = 16.6\ \%$

from the fit:

$Br(\eta\to\pi^+\pi^-) < 1.3\times10^{-5}$ @90% C.L.

PDG(2002) $< 3.3\times10^{-4}$ @90% C.L.

fitted spectrum from f_0 analysis



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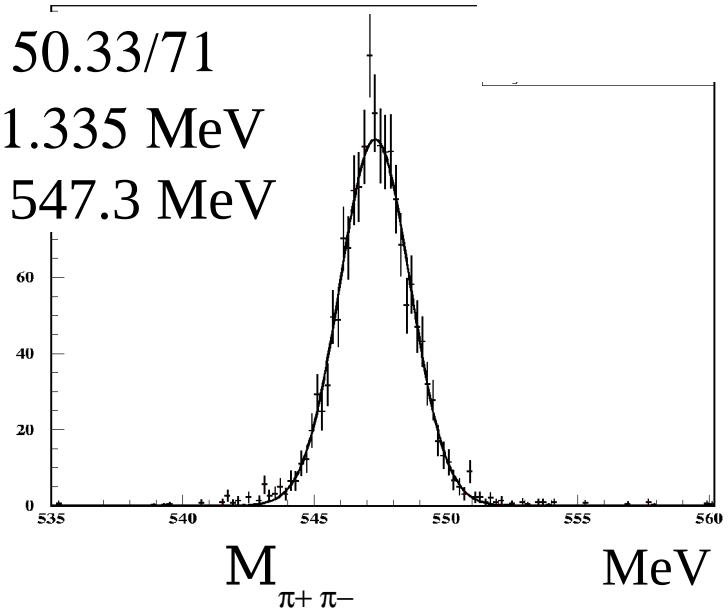
$\eta\to\pi^+\pi^-$ MC

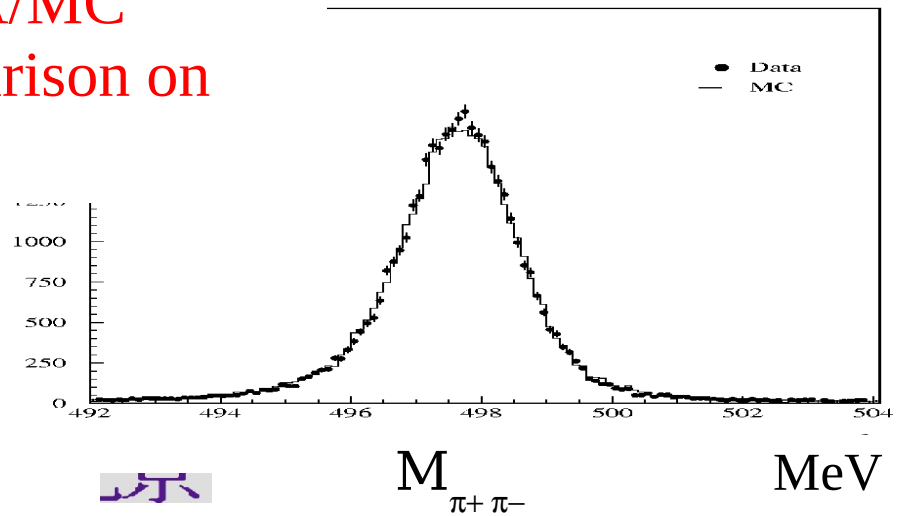
$\chi^2 = 50.33/71$

$\sigma = 1.335$ 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

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

Crystall Ball (2004)

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

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

SND(2001) $Br(\eta \to \pi^0\gamma\gamma) < 8.9x10^{-4}$

$\phi \to \eta\gamma$

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

$\Phi \to \eta\,\gamma$
$\quad\quad \hookrightarrow \pi^0\gamma\gamma$ } 5γ final state
σ = 8pb GAMS Br

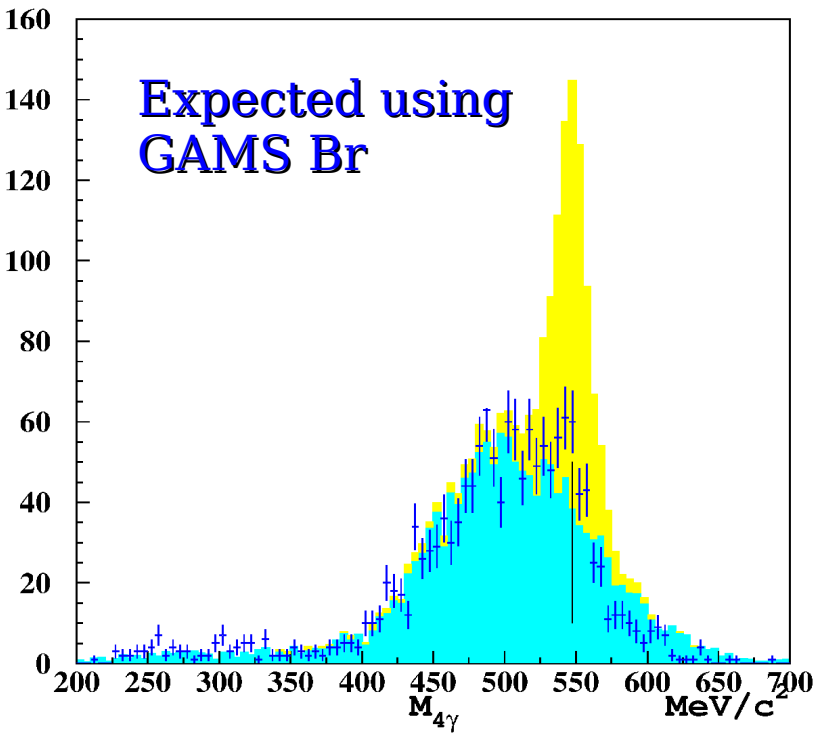
main background sources

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

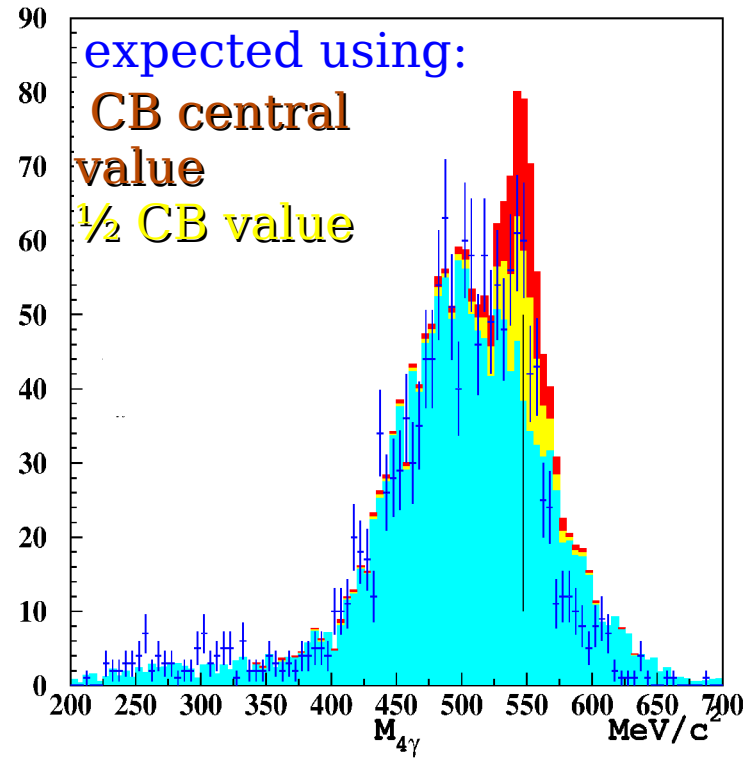
$f_0\gamma \to \pi^0\pi^0\gamma$, $a_0\gamma \to \eta\pi^0\gamma, \omega\pi^0 \to \pi^0\pi^0\gamma$ *(cut off rejecting the masses of the decaying products)*

Preliminary analysis shows:
- GAMS overestimates Br
- Indication of signal at CB level

Work in progress to improve background rejection



ε= 5.7%



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

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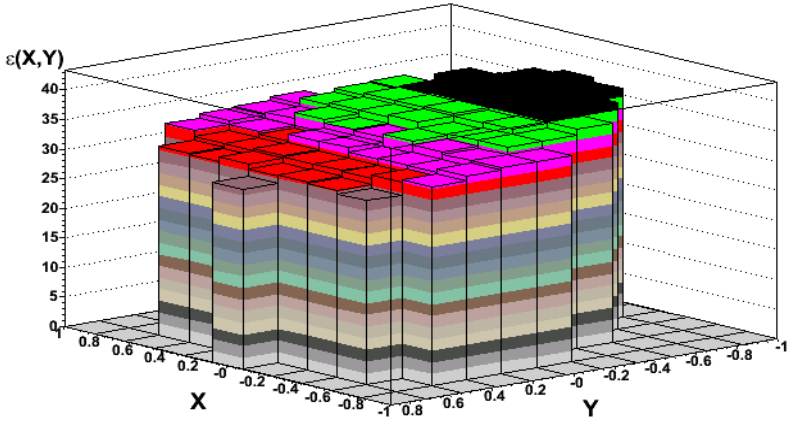
analysis strategy

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

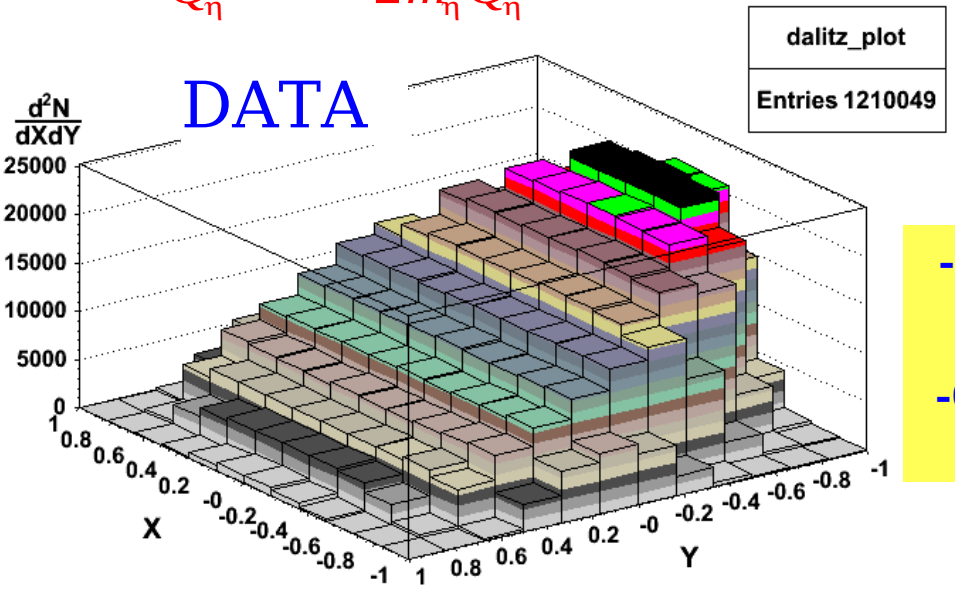
$$X = \sqrt{3}\frac{T_+ - T_-}{Q_\eta} = \frac{\sqrt{3}}{2M_\eta Q_\eta}(u-t)$$

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



Efficiency ≈ 36%

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



a	b	c (ℂ)	d	e (ℂ)	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

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

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

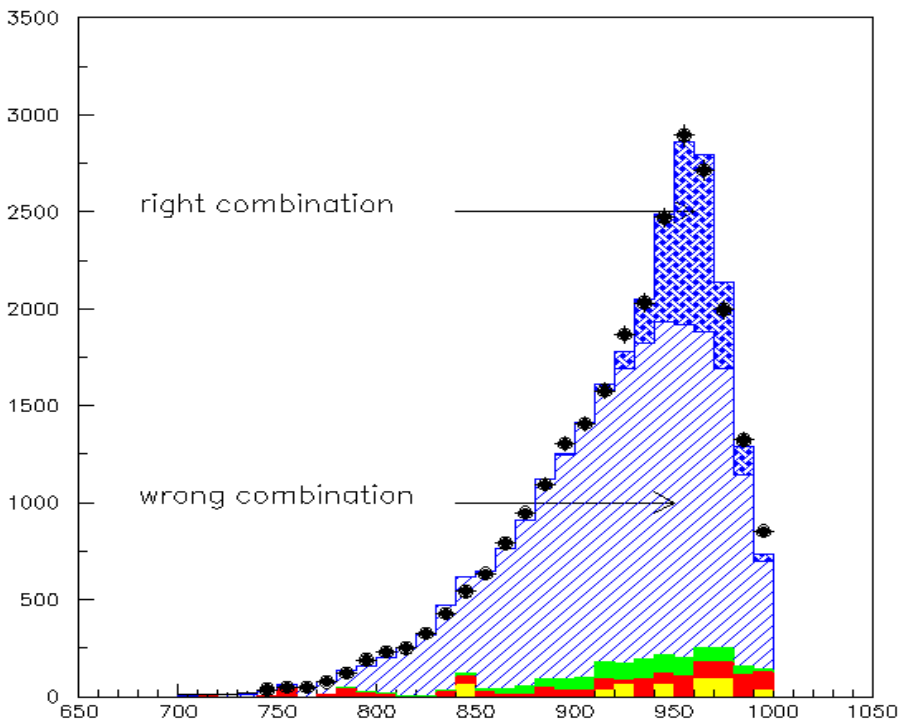
$M_{\eta'}$ from $\pi^+\pi^- 6\gamma$ (we should discard 1 photon among the seven ones), we keep all combinations and subtract from MC.

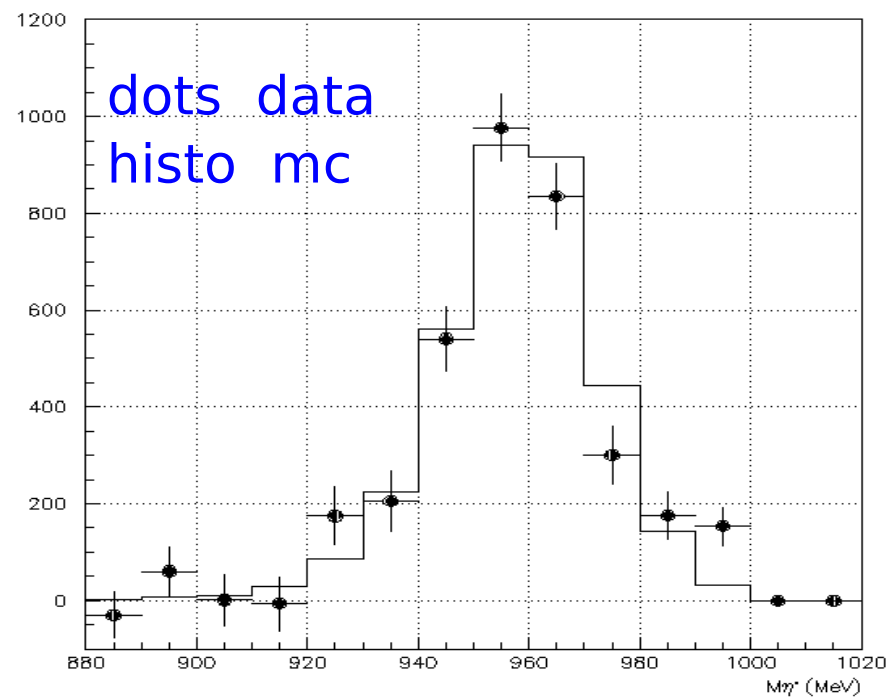
$N_{\eta'} = 3401 \pm 61(\text{stat.}) \pm 31(\text{bkg. sub.})$

$R = 4.9 \pm 0.1_{stat} \pm 0.2_{syst}$

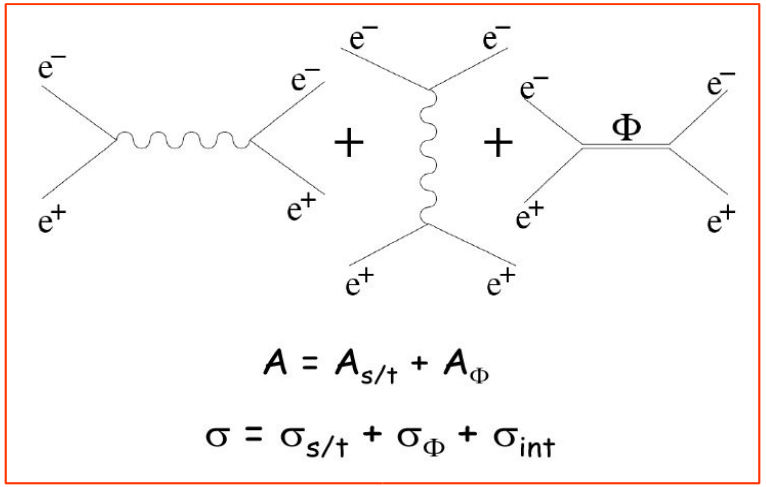
$$R = \frac{BR(\phi \to \eta'\gamma)}{BR(\phi \to \eta\gamma)} = \frac{N^{\eta'\gamma}}{N^{\eta\gamma}} \frac{\varepsilon^{\eta\gamma} BR(\eta \to 3\pi^0)}{\left[BR_{crg}\varepsilon_{crg} + BR_{ntr}\varepsilon_{ntr}\right]} \cdot K_\rho$$

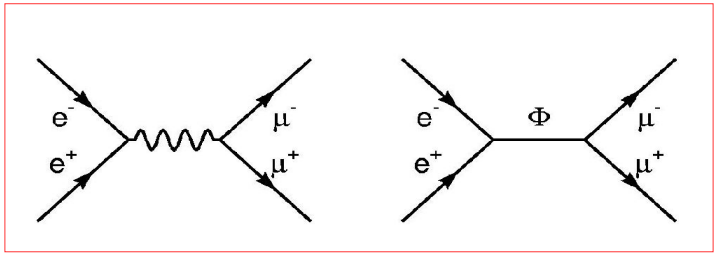
2000 DATA
Phys. Lett. B541 (2002)
$R = 4.7 \pm 0.5_{stat} \pm 0.3_{syst}$
175 events





ϕ *leptonic width measurement*





$$\sigma_{\rm int} = \frac{3\alpha\Gamma_{ll}}{M_\Phi}\frac{s-M_\Phi^{\ 2}}{(s-M_\Phi^{\ 2})^2+s\Gamma_\Phi^{\ 2}}\int_{\cos\theta_1}^{\cos\theta_2} f_{ll}(\theta)d\cos\theta$$

Bhabha

$$f_{ee}(\theta) = 2(1+\cos^2\theta - \frac{(1+\cos\theta)^2}{1-\cos\theta})$$

$$\Gamma_{ll} = \Gamma_{ee}$$

muons

$$f_{\mu\mu}(\theta) = \beta_\mu(1+\cos^2\theta+(1-\beta_\mu^{\ 2})\sin^2\theta)$$

$$\Gamma_{ll} = \sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}$$

Γee from forward backward asymmetry:

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

- high sensitivity;
- luminosity uncertainity free;
- partial cancellation of systematics on efficiency and background subtraction.

$\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}$ from $\mu\mu$ cross section:

- fully energy correlated systematics cancel out in $\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}$ evaluation.

ϕ *leptonic width measurement*

analysis sketch

$e^+e^- \to e^+e^-$

r_{vertex} < 10 cm from the I.P.

53° < θ < 127°

To cut ISR and FSR background:

W'/W > 0.95 w' final energy of e^+e^-

$$\frac{W'}{W} = \sqrt{\frac{\sin\theta_1 + \sin\theta_2 - |\sin(\theta_1+\theta_2)|}{\sin\theta_1 + \sin\theta_2 + |\sin(\theta_1+\theta_2)|}}$$

$e^+e^- \to \mu^+\mu^-$

r_{vertex} < 10 from the I.P.;

970 MeV < $P(\mu^+) + P(\mu^-)$ < 1010 MeV

Total calorimeter energy < 700 MeV

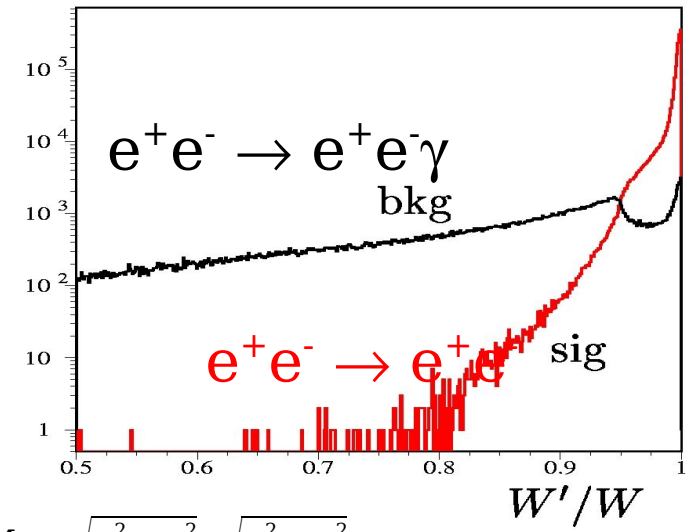
53° < θ < 127°

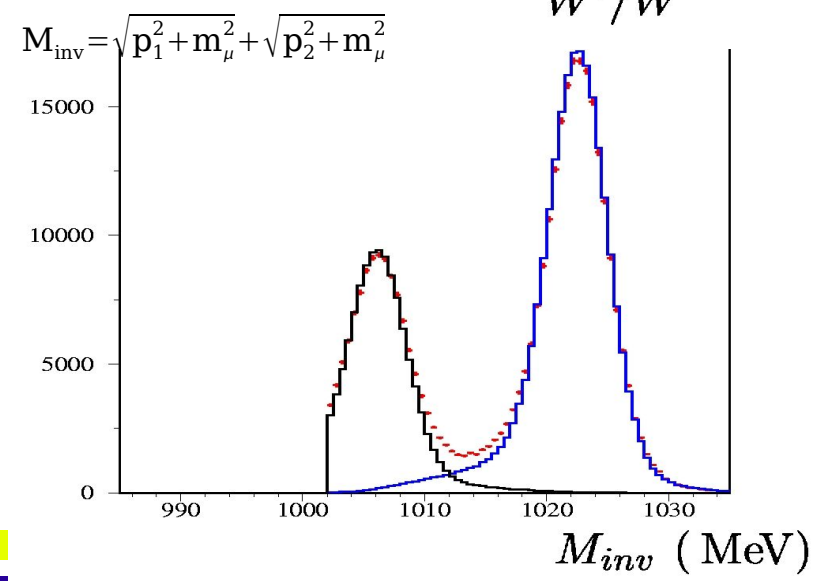
W'/W > 0.985

(efficiency loss below 0.98)

π contamination evaluated from data

2% contamination





ϕ *leptonic width measurement*

results

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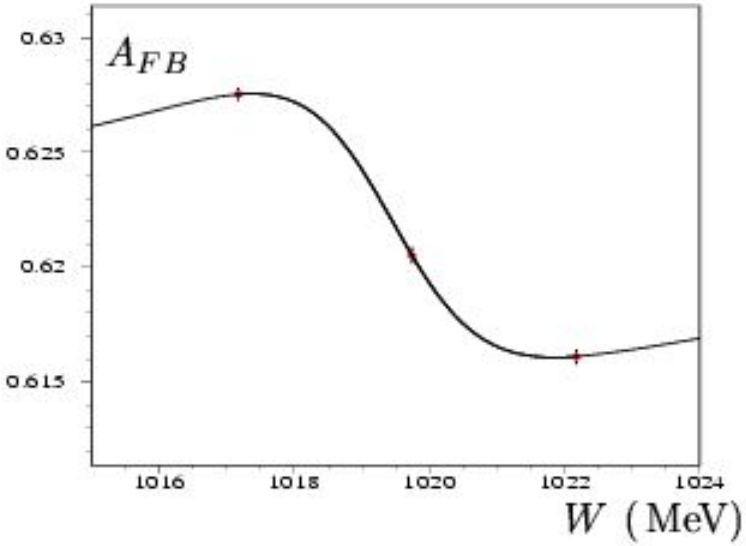

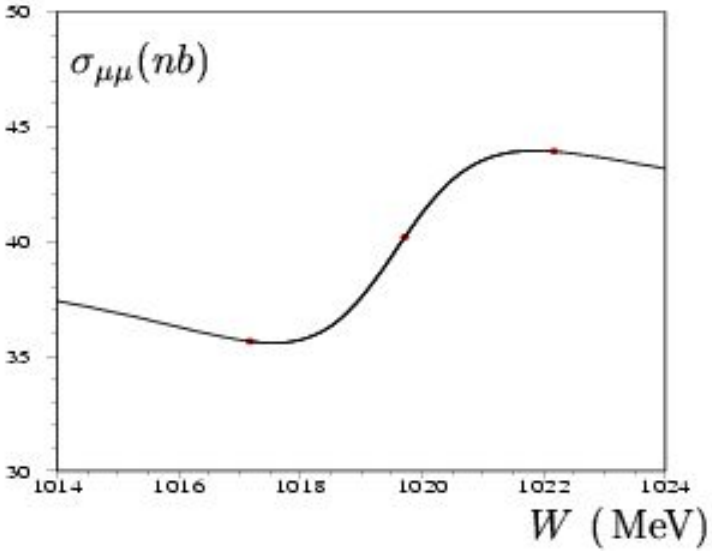

Γ_{ee} = 1.32 ± 0.05 ± 0.03 keV

M_ϕ = 1019.50 ± 0.08 ± 0.03 MeV

$A_{FB}(M_\phi)$= 0.6212 ± 0.0002 ± 0.002

$\sqrt{\Gamma_{ee}\Gamma_{\mu\mu}}$ = 1.320 ± 0.018 ± 0.016 keV

M_ϕ = 1019.63 ± 0.04 ± 0.03MeV

$\sigma(M_\phi)$ = 39.2 ± 0.04± 0.4 nb

Lepton universality $\Gamma_{ee}=\Gamma_{\mu\mu}$ @ 3%

Γ_{LL} =1.320 ± 0.017 ± 0.015 keV

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.