

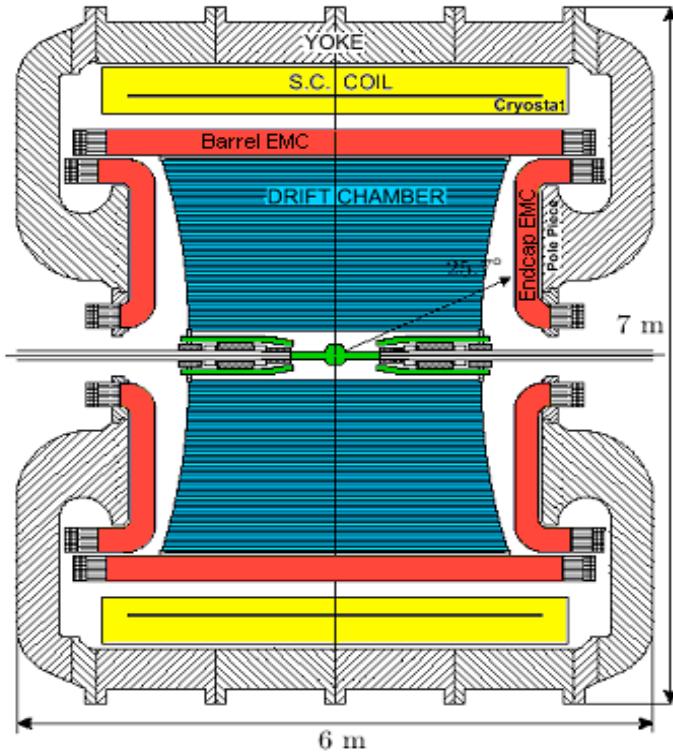
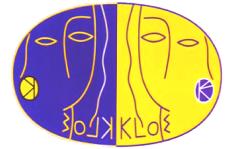
# **HADRONIC PHYSICS WITH KLOE**

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for the KLOE Collaboration**



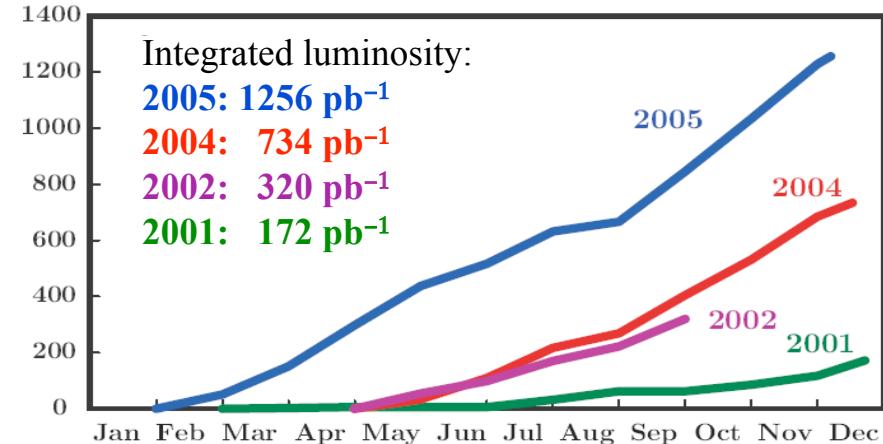
**Les Rencontres de Physique de la Vallée d'Aoste  
La Thuile, Italy – March 1-7, 2009**

# The KLOE experiment at DAΦNE



## Drift chamber

- ❖ Gas mixture:  $90\% \text{ He} + 10\% \text{ C}_4\text{H}_{10}$
- ❖  $\delta p_t / p_t < 0.4\% (\theta > 45^\circ)$
- ❖  $\sigma_{xy} \approx 150 \mu\text{m}; \sigma_z \approx 2 \text{ mm}$



## Electromagnetic calorimeter

- ❖ lead/scintillating fibers
- ❖ 98% solid angle coverage
- ❖  $\sigma_E / E = 5.7\% / \sqrt{E(\text{GeV})}$
- ❖  $\sigma_t = 57 \text{ ps} / \sqrt{E(\text{GeV})} \oplus 100 \text{ ps}$
- ❖ PID capabilities

## Data taking ended on March 2006

- $2.5 \text{ fb}^{-1}$  on tape @  $\sqrt{s} = M_\phi$  ( $8 \times 10^9 \phi$ )
- $\sim 10 \text{ pb}^{-1}$  @ 1010, 1018, 1023 and 1030 MeV
- $250 \text{ pb}^{-1}$  @ 1000 MeV



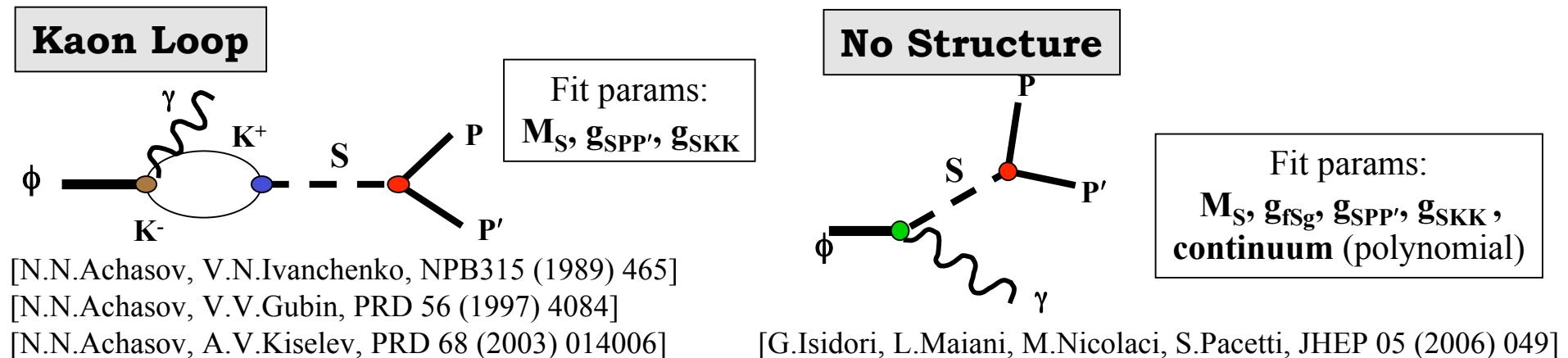
# Light scalars in $\phi$ radiative decays

The structure of scalars below 1 GeV is still an open question:  
 [ $q\bar{q}$ ,  $q\bar{q}q\bar{q}$  (Jaffe '77...), **KKbar molecule** (Weinstein-Isgur '90)...]

**BR and mass spectra** of the radiative decays  $\phi \rightarrow PP'\gamma$  sensitive to the structure of the intermediate scalar mesons

At KLOE:	$PP' = \pi^0\pi^0 \Rightarrow f_0(980)/\sigma(600)$	[EPJC49(2007)473, PLB537(2002)21]
	$\pi^+\pi^- \Rightarrow f_0(980)/\sigma(600)$	[PLB634(2006)148]
	$\eta\pi^0 \Rightarrow a_0(980)$	[New paper in preparation, PLB536(2002)209]
	$K_SK_S \Rightarrow f_0(980)/a_0(980)$	[New paper in preparation]

Phenomenological models used to describe  $\phi \rightarrow S\gamma \rightarrow PP'\gamma$ :



# $e^+e^- \rightarrow \eta\pi^0\gamma$ : search for $a_0(980)$



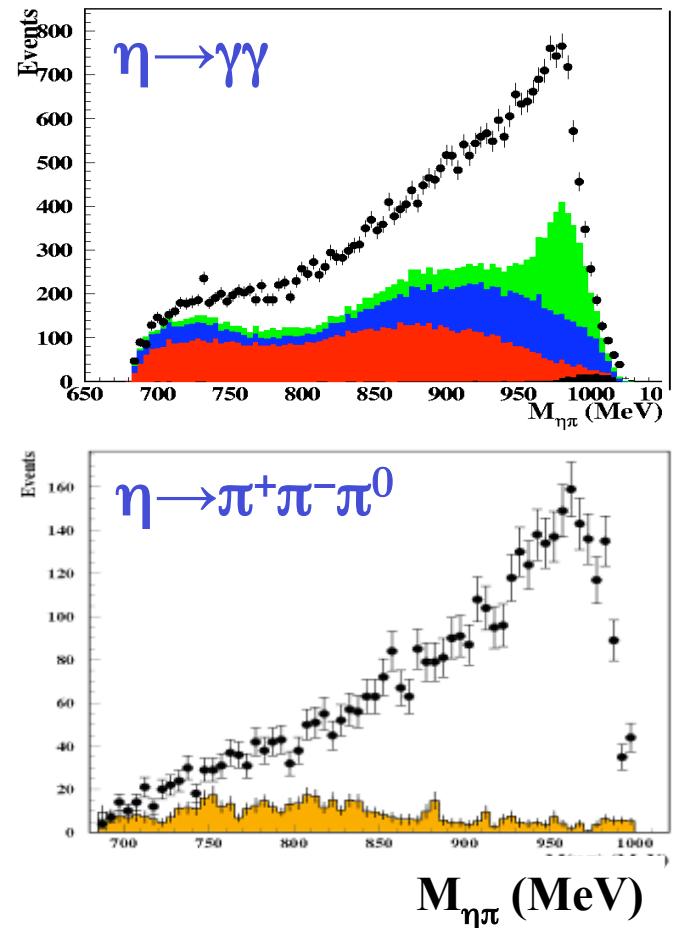
- $\sim 450 \text{ pb}^{-1}$  of  $e^+e^-$  collisions @  $\sqrt{s}=M_\phi$
- Dominated by  $\phi \rightarrow a_0(980)\gamma$
- Decay channels: (1)  $\eta \rightarrow \gamma\gamma$ , (2)  $\eta \rightarrow \pi^+\pi^-\pi^0$
- From event counting:

$$BR(\phi \rightarrow \eta\pi^0\gamma) = (7.01 \pm 0.10_{\text{stat}} \pm 0.20_{\text{syst}}) \times 10^{-5} \quad (1)$$

$$BR(\phi \rightarrow \eta\pi^0\gamma) = (7.12 \pm 0.13_{\text{stat}} \pm 0.22_{\text{syst}}) \times 10^{-5} \quad (2)$$

Combined fit to  $M_{\eta\pi}$  spectra:

Parameter	Kaon Loop	No Structure
$M_{a_0}$ (MeV)	$982.5 \pm 1.6 \pm 1.1$	982.5 (fixed)
$g_{a_0 K\bar{K}}$ (GeV)	$2.15 \pm 0.06 \pm 0.06$	$2.01 \pm 0.07 \pm 0.28$
$g_{a_0 \eta\pi}$ (GeV)	$2.82 \pm 0.03 \pm 0.04$	$2.46 \pm 0.08 \pm 0.11$
$g_{\phi a_0 \gamma}$ (GeV $^{-1}$ )	$1.58 \pm 0.10 \pm 0.16$	$1.83 \pm 0.03 \pm 0.08$
$BR(\phi \rightarrow \rho\pi \rightarrow \eta\pi\gamma) \times 10^{-6}$	$0.92 \pm 0.40 \pm 0.15$	$0.05 \pm 4 \pm 0.07$
$BR(\eta \rightarrow \gamma\gamma)/BR(\eta \rightarrow \pi\pi\pi)$	$1.70 \pm 0.04 \pm 0.03$	$1.70 \pm 0.03 \pm 0.01$
$P(\chi^2)$	10.4%	30.9%

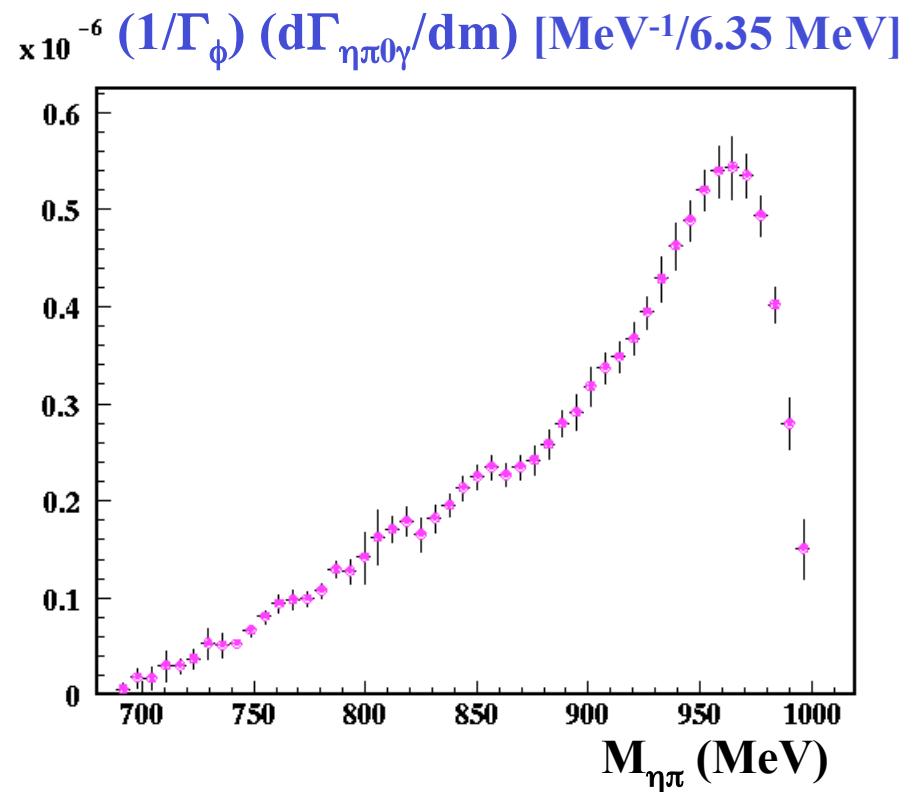


- $R = (g_{aK^+K^-}/g_{a\eta\pi})^2 \sim 0.6-0.7$
- $R_\eta [\text{PDG08}] = 1.73 \pm 0.04$

# $e^+e^- \rightarrow \eta\pi^0\gamma$ : unfolded $M_{\eta\pi}$ distribution



- ❖ To allow better comparison with other experimental results and theoretical models  $\Rightarrow$  unfolding procedure to correct data for detector and resolution effects
- ❖ Bayesian unfolding  
(avoids smearing matrix inversion)  
[G.D'Agostini, NIM A362 (1995), 487]
- ❖ **Average of the two  $M_{\eta\pi}$  distributions**



# $S \rightarrow \pi\pi$ update

PRELIMINARY

$\sim 450 \text{ pb}^{-1}$  of  $e^+e^-$  collisions @  $\sqrt{s} = M_\phi$



- ✓ Different parametrization used in the published  $\pi^0\pi^0\gamma/\pi^+\pi^-\gamma$  analyses
- ✓ Marginal agreement between two channels
- ✓ New (not-combined) fit performed on both spectra with the same scalar description: latest Kaon Loop model with  **$f_0(980)$  +  $\sigma(600)$  + interference**
- ✓ Preliminary results are encouraging: [PRD73(2006)054029+erratum]

Channel	$M_{f_0}$ (MeV)	$g_{f_0KK}$ (GeV)	$g_{f_0\pi\pi}$ (GeV)	$g^2_{f_0KK} / g^2_{f_0\pi\pi}$
$\pi^0\pi^0\gamma$	$984.7 \pm 1.9_{\text{mod}}$	$3.97 \pm 0.43_{\text{mod}}$	$-1.82 \pm 0.19_{\text{mod}}$	$\sim 4.8$
$\pi^+\pi^-\gamma$	$983.7$	$4.74$	$-2.22$	$\sim 4.6$

- Better agreement between the two channels
- Reduced model uncertainties
- Combined fit in progress

# Couplings: $f_0(980)$ vs $a_0(980)$



New theory for scalar mesons:  $S(4q) \rightarrow PP$  decays

[‘t Hooft,Isidori,Maiani,Polosa,Riquer, PLB662 (2008) 424]

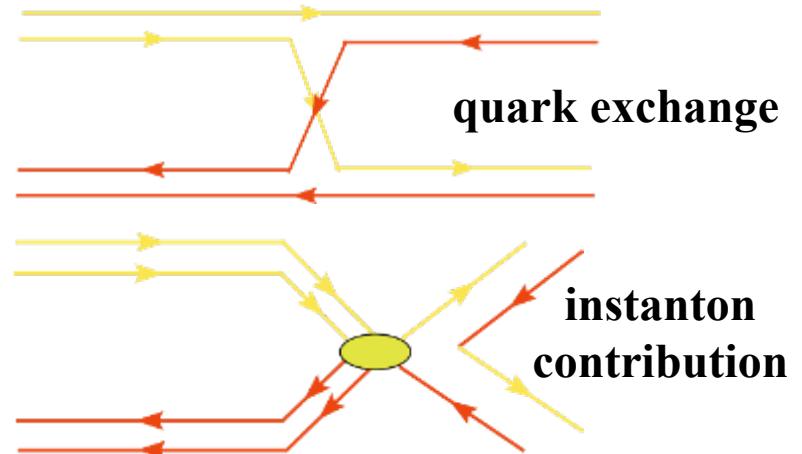
$$\mathcal{L}_{\text{dec}}(S) = c_f O_f(S) + c_I O_I(S)$$

**1. Inputs from KLOE measurements  
( $g_{f0KK}$ ,  $g_{f0\pi\pi}$  + masses +  $\varphi_P$ )**

**2. Extraction of  $c_I$ ,  $c_f$**

**3. Evaluation of  $g_{a0KK}$  and  $g_{a0\eta\pi}$**

**4. Comparison with measured  $g_{a0KK}$ ,  $g_{a0\eta\pi}$**



	KLOE (KL)		[qq] [qbarqbar]	qqbar
$g_{f0KK}$ (GeV)	$3.97 - 4.74$	{	$c_I = (-2.8 - -3.4) \text{ GeV}^{-1}$	$c_I = (-3.9 - -4.8) \text{ GeV}^{-1}$
$g_{f0\pi\pi}$ (GeV)	$-1.82 - -2.23$	}	$c_f = (20.5 - 24.5) \text{ GeV}^{-1}$	$c_f = (16.5 - 19.7) \text{ GeV}^{-1}$
	KLOE (KL+NS)		↓	↓
$g_{a0KK}$ (GeV)	$2.01 - 2.15$		$2.1 - 2.5$	$2.4 - 2.9$
$g_{a0\eta\pi}$ (GeV)	$2.46 - 2.82$		$3.3 - 3.9$	$6.6 - 7.9$

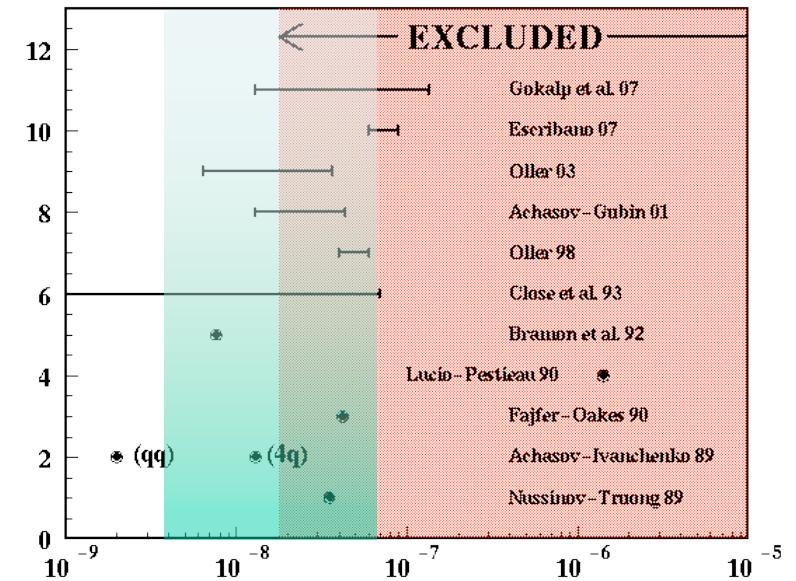


# Search for $\phi \rightarrow K^0 \bar{K}^0 \gamma$

- ❖ Expected to proceed mainly through  $\phi \rightarrow [f_0(980) + a_0(980)]\gamma \rightarrow K^0 \bar{K}^0 \gamma$
- ❖ **Never been observed**
- ❖ Selected channel:  $K_S K_S \gamma \rightarrow \pi^+ \pi^- \pi^+ \pi^- \gamma$  **Clean topology, 24% BR reduction**
- ❖ Signal MC according to phase-space and radiative decay dynamics
- ❖ Selection cuts optimized on MC ( bckg:  $K_S K_L(\gamma)$  ,  $e^+ e^- \rightarrow \pi^+ \pi^- \pi^+ \pi^-(\gamma)$  )
- ❖ 2.18  $\text{fb}^{-1}$  data @  $M_\phi$  :
  - **5 EVENTS IN DATA**
  - **2.5 + 0.7 BCKG EVENTS (MC)**

$BR(\phi \rightarrow K^0 \bar{K}^0 \gamma) < 1.9 \times 10^{-8}$  @ 90% C.L.

Consistency check using KLOE couplings from  
 $\phi \rightarrow \pi\pi\gamma$ ,  $\phi \rightarrow \eta\pi\gamma$  in the Kaon Loop model



# Search for $\gamma\gamma \rightarrow \sigma(600) \rightarrow \pi^0\pi^0$

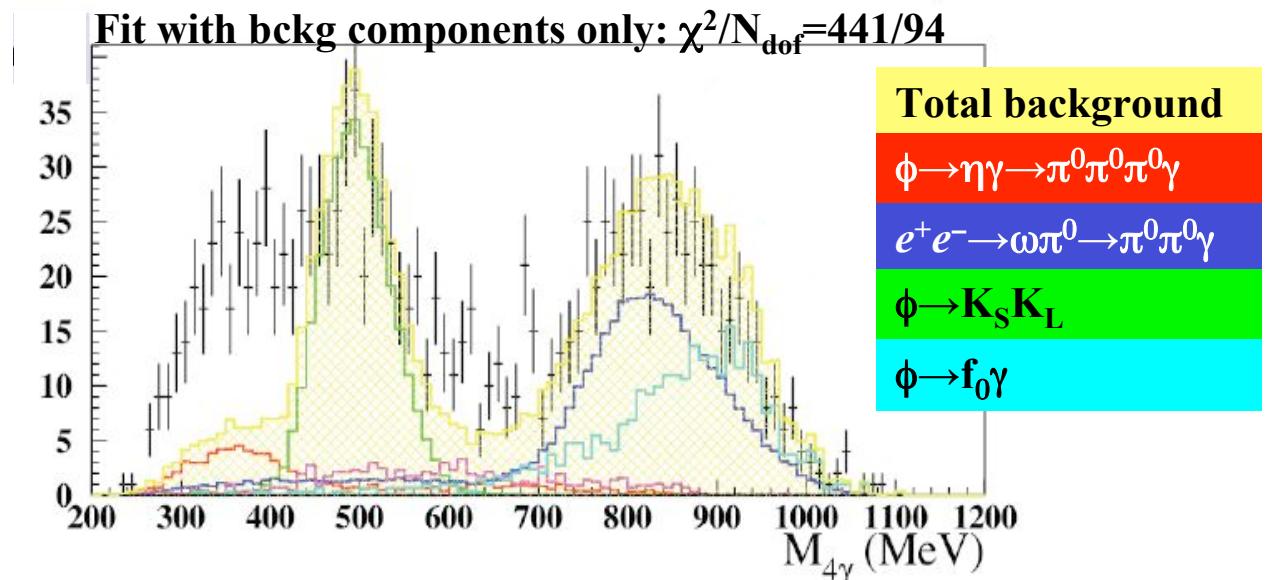
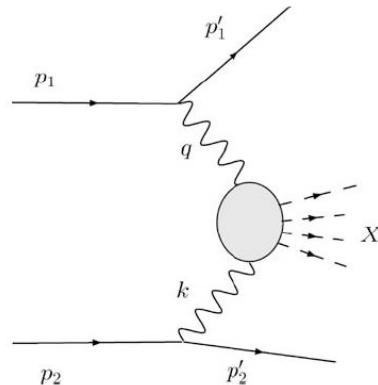


**PRELIMINARY**

- Long debate about the experimental evidence of the  $\sigma(600)$  meson
- Evidence for a  $\pi^+\pi^-$  bound state from E791, CLEO, BES
- Values of mass and width with large uncertainties
- **Indirect evidence in the  $e^+e^- \rightarrow \pi^0\pi^0\gamma$  Dalitz plot analysis @ KLOE**

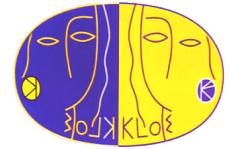
**KLOE preliminary: 11 pb<sup>-1</sup> @  $\sqrt{s} = 1$  GeV** (1/20 of the off-peak data sample)

$e^+e^- \rightarrow e^+e^-\pi^0\pi^0$



**Excess of events w.r.t. the known background in the  $\gamma\gamma \rightarrow \sigma(600) \rightarrow \pi\pi$  region**

# The $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ decay

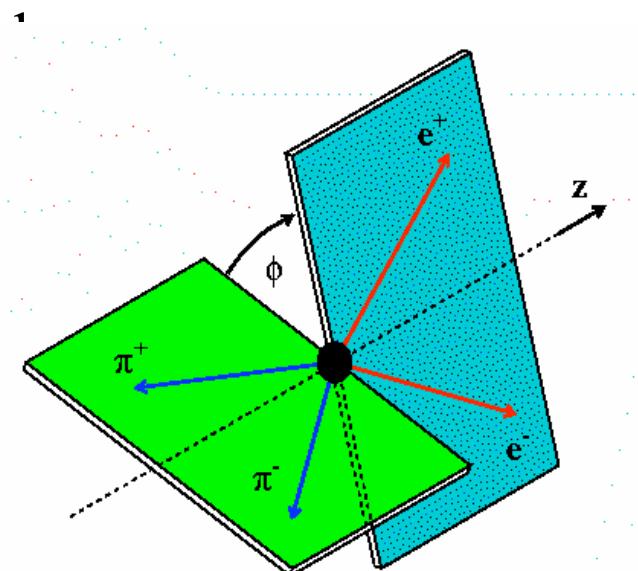


- ✓ Poorly measured (4 events CMD-2, 16 events CELSIUS-WASA)
- ✓ BR predicted by ChPT and VMD models ( $2.6 \div 3.6 \times 10^{-4}$ )
- ✓  $\eta$  structure, using virtual photon
- ✓ Angular asymmetry between  $e^+ e^-$  and  $\pi^+ \pi^-$   
**test of non-CKM CP violation**  
[D.Gao, Mod.Phys.Lett.A17 (2002) 1583]

Within SM constrained by  $\text{BR}(\eta \rightarrow \pi^+ \pi^-)$ :

using experimental upper bound:  $A_\phi < 10^{-4}$

using theoretical predictions:  $A_\phi \sim 10^{-15}$



**The unconventional CPV term increases  $A_\phi$  up to  $10^{-2}$**

# $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ : event counting

arXiv:0812.4830



Data sample:  $1.73 \text{ fb}^{-1}$

PID con ToF EMC info

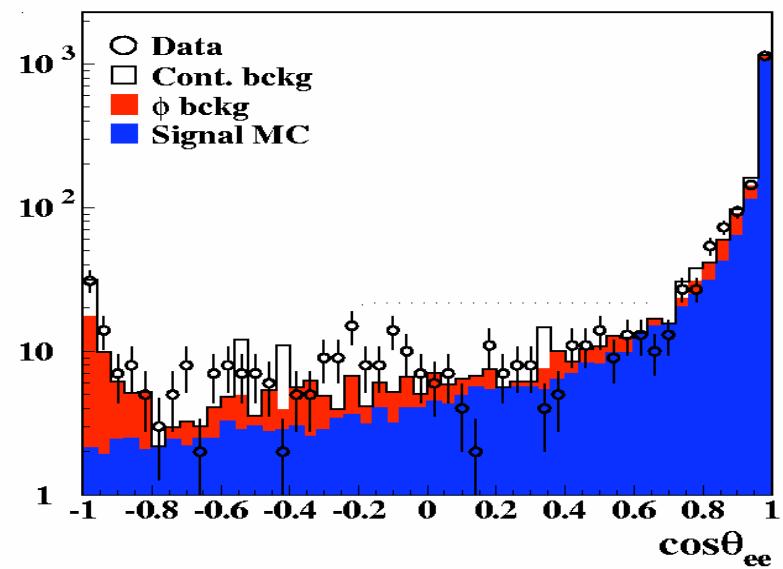
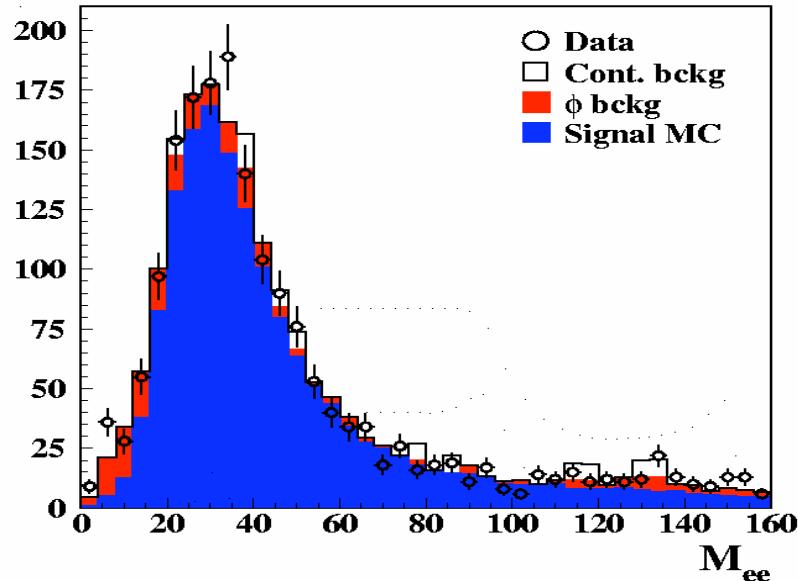
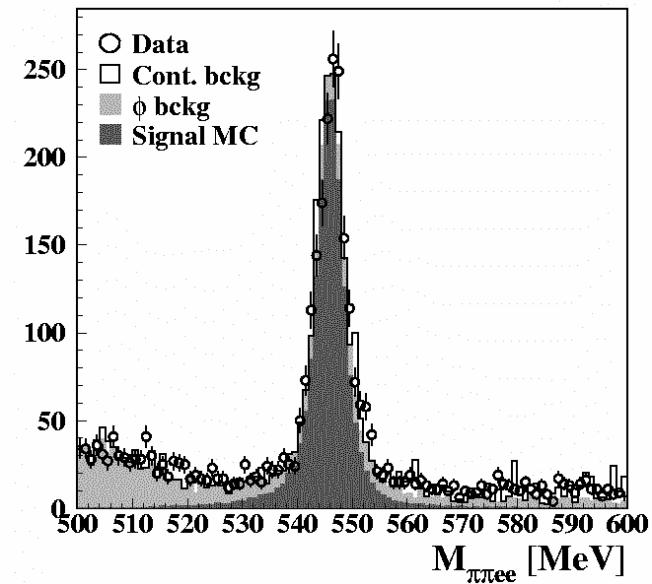
Fit on  $M_{\pi\pi ee}$  side bands for background

Photon conversion on Beam Pipe rejected

Counting on  $M_{\pi\pi ee}$  in the signal region:

$$N_{\pi\pi ee} = 1555 \pm 52 \text{ (368 bkg evts)}$$

Analysis efficiency: 8%

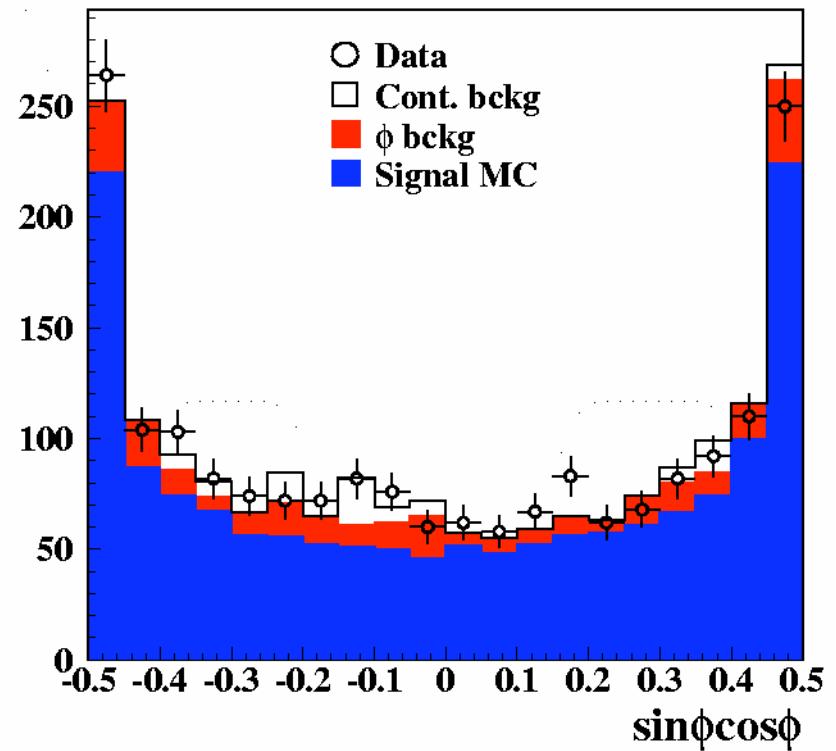
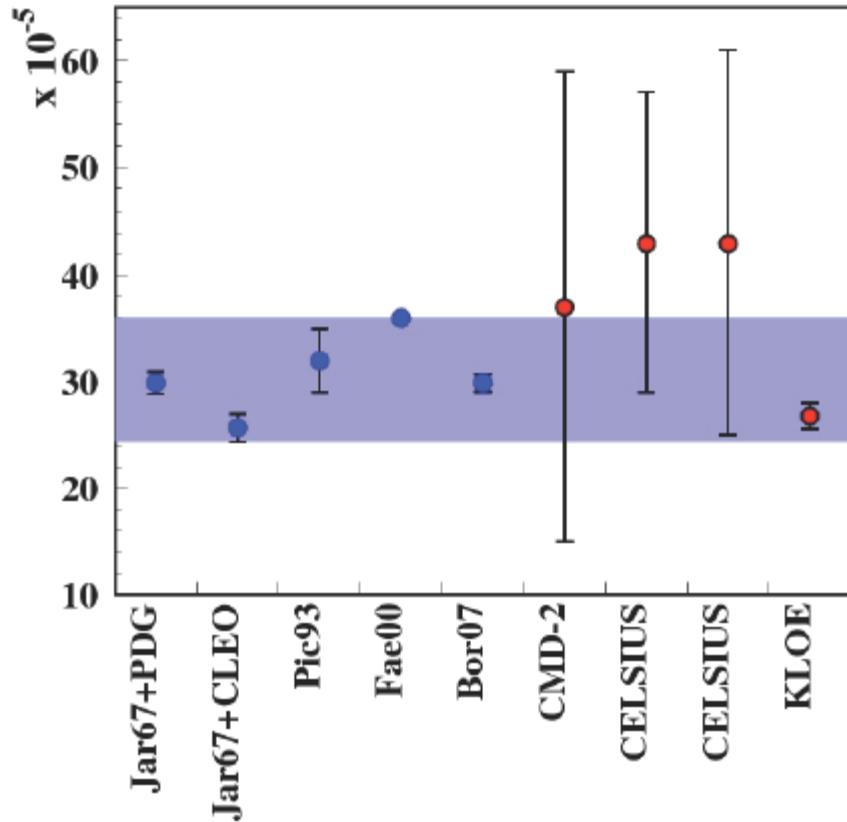


# $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ : results

arXiv:0812.4830



$$\text{BR}(\eta \rightarrow \pi^+ \pi^- e^+ e^-(\gamma)) = (26.8 \pm 0.9_{\text{stat}} \pm 0.7_{\text{syst}}) \times 10^{-5}$$

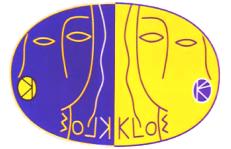


$$A_\phi = \frac{N_{\sin\phi \cos\phi} - N_{-\sin\phi \cos\phi}}{N_{\sin\phi \cos\phi} + N_{-\sin\phi \cos\phi}}$$



$$A_\phi = (-0.6 \pm 2.5_{\text{stat}} \pm 1.8_{\text{syst}}) \times 10^{-2}$$

*1<sup>st</sup> measurement!*



# $\eta/\eta'$ mixing: gluonium content in $\eta'$

$$R_\phi = \frac{BR(\phi \rightarrow \eta' \gamma)}{BR(\phi \rightarrow \eta \gamma)} = (4.77 \pm 0.09_{stat} \pm 0.19_{syst}) \times 10^{-3}$$

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Gluonium content in  $\eta'$  evaluated using Rosner model: [Rosner PRD27(1983) 1101]  
[Kou PRD63(2001)54027]

$$|\eta'\rangle = X_{\eta'} \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle + Y_{\eta'} |s\bar{s}\rangle + Z_{\eta'} |glue\rangle$$

$$|\eta\rangle = \cos\varphi_P \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle - \sin\varphi_P |s\bar{s}\rangle$$

$$X_{\eta'} = \cos\phi_G \sin\varphi_P$$

$$Y_{\eta'} = \cos\phi_G \cos\varphi_P$$

$$Z_{\eta'} = \sin\phi_G$$

SU(3) relations between decay modes:

$$\frac{\Gamma(\eta' \rightarrow \rho \gamma)}{\Gamma(\omega \rightarrow \pi^0 \gamma)} = C_{M2} Z_{NS} \left( \sin(\varphi_G) \cos(\varphi_P) \right)^2$$

$$R_\phi = \cot^2(\varphi_P) \cos^2(\varphi_G) \left( 1 - C_V \frac{Z_{NS}}{Z_N} \frac{1}{\sin(2\varphi_P)} \right)^2 \left( \frac{p_{\eta'}}{p_\eta} \right)^3$$

$$\frac{\Gamma(\eta' \rightarrow \gamma \gamma)}{\Gamma(\pi^0 \rightarrow \gamma \gamma)} = C_{M1} \left( 5 \cos(\varphi_G) \sin(\varphi_P) + \sqrt{2} \frac{f_q}{f_s} \cos(\varphi_G) \cos(\varphi_P) \right)^2$$

$$\frac{\Gamma(\eta' \rightarrow \omega \gamma)}{\Gamma(\omega \rightarrow \pi^0 \gamma)} = C_{M3} \left( Z_{NS} \sin(\varphi_G) \cos(\varphi_P) + 2 C_V Z_S \sin(\varphi_G) \sin(\varphi_P) \right)^2$$

Gluonium content extracted using  $Z_N$ ,  
 $Z_{NS}$  evaluated assuming  $Z_{\eta'}^2 = 0$ :

[Bramon et al., EPJC 7 (1999); PLB 503 (2001)]

$$\varphi_P = (39.7 \pm 0.7)^\circ$$

$$Z_{\eta'}^2 = 0.14 \pm 0.04$$

$$P(\chi^2) = 49\%$$

# $\eta/\eta'$ mixing: gluonium content in $\eta'$



Preliminary

Global fit with more free parameters (also  $Z_N$ ,  $Z_{NS}$ ,  $\phi_V$ ,  $m_s/m$ )

Other SU(3) relations need to be included :

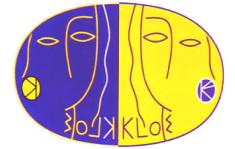
$$\frac{\Gamma(\omega \rightarrow \eta\gamma)}{\Gamma(\omega \rightarrow \pi^0\gamma)}, \quad \frac{\Gamma(\rho \rightarrow \pi^0\gamma)}{\Gamma(\omega \rightarrow \pi^0\gamma)}, \quad \frac{\Gamma(\phi \rightarrow \eta\gamma)}{\Gamma(\omega \rightarrow \pi^0\gamma)}, \quad \frac{\Gamma(\phi \rightarrow \pi^0\gamma)}{\Gamma(\omega \rightarrow \pi^0\gamma)}, \quad \frac{\Gamma(K^{*+} \rightarrow K^+\gamma)}{\Gamma(K^{*0} \rightarrow K^0\gamma)}$$

Parameter	KLOE published	New fit	New fit (no P $\gamma\gamma$ )
$Z_{\eta'}$	$0.14 \pm 0.04$	$0.105 \pm 0.037$	$0.03 \pm 0.06$
$\phi_P$	$(39.7 \pm 0.7)^\circ$	$(40.7 \pm 0.7)^\circ$	$(41.6 \pm 0.8)^\circ$
$Z_{NS}$	$0.91 \pm 0.05$	$0.866 \pm 0.025$	$0.85 \pm 0.03$
$Z_S$	$0.89 \pm 0.07$	$0.79 \pm 0.05$	$0.78 \pm 0.05$
$\phi_V$	$3.2^\circ$	$(3.15 \pm 0.10)^\circ$	$(3.16 \pm 0.10)^\circ$
$m_s/m$	$1.24 \pm 0.07$	$1.24 \pm 0.07$	$1.24 \pm 0.07$
$P(\chi^2)$	49%	17%	40.7%

- Gluonium content @  $\sim 3\sigma$  level confirmed
- Forcing  $Z_{\eta'}=0$  :  $\phi_P = (41.6 \pm 0.5)^\circ$  with  $P(\chi^2)=1\%$
- Discrepancy with Escribano-Nadal (  $Z_{\eta'} = 0.04 \pm 0.09$  ,  $\phi_P = (41.4 \pm 1.3)^\circ$  ) [JHEP05(2007)006] due to the insertion of  $P\gamma\gamma$  transitions

$$\sigma(e^+e^- \rightarrow \omega\pi^0)$$

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Interference pattern between non-resonant  $e^+e^- \rightarrow \omega\pi^0$  and  $\phi$  decays:

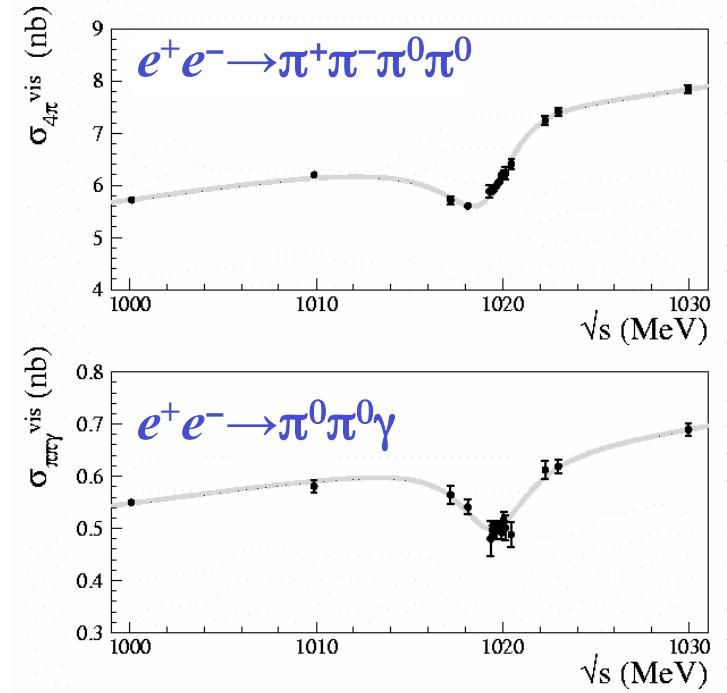
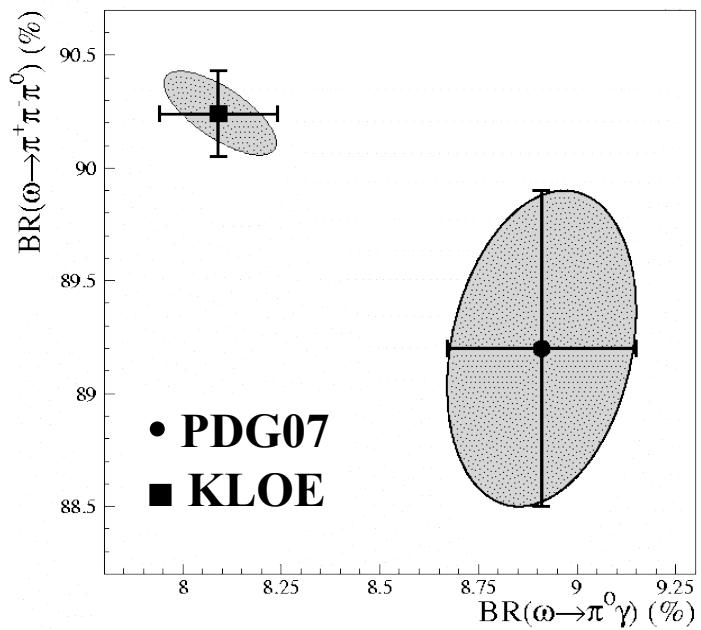
$$\sigma(\sqrt{s}) = \sigma_0(\sqrt{s}) \left| 1 - Z \frac{M_\phi \Gamma_\phi}{D_\phi} \right|$$

Model indep.  $\sigma_0(\sqrt{s}) :$

$$\sigma_0(\sqrt{s}) = \sigma_0 + \sigma'(\sqrt{s} - M_\phi)$$

From  $\Gamma(\omega \rightarrow \pi^0\gamma)/\Gamma(\omega \rightarrow \pi^+\pi^-\pi^0)$  + unitarity (rare BRs ( $\sim 2\%$ )):

$$\begin{aligned} \text{BR}(\omega \rightarrow \pi^+\pi^-\pi^0) &= (90.24 \pm 0.19)\% \\ \text{BR}(\omega \rightarrow \pi^0\gamma) &= (8.09 \pm 0.14)\% \end{aligned}$$



From fit parameters +  $\text{BR}(\omega \rightarrow \pi^+\pi^-\pi^0)$ :

$$BR(\phi \rightarrow \omega\pi^0) = \frac{\sigma_0^{\omega\pi} |Z_{4\pi}|^2}{\sigma_\phi} = (5.63 \pm 0.70) \times 10^{-5}$$

OZI + G-parity violating

$$\text{SND}(2000) : BR(\phi \rightarrow \omega\pi^0) = (5.2^{+1.3}_{-1.1}) \times 10^{-5}$$



# $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma(\gamma))$ measurement

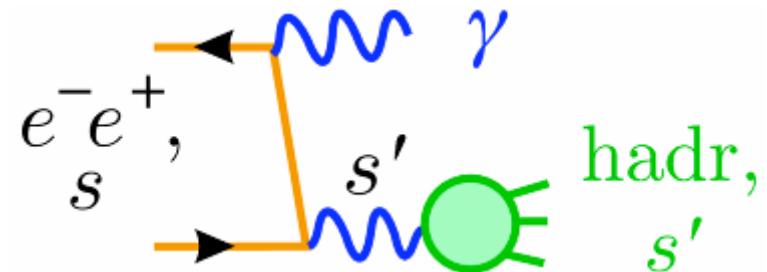
The comparison between experiment and theory for the muon anomaly  $a_\mu$  is a precise test of SM  
 Theoretically, the error on  $a_\mu$  is dominated by the hadronic contribution, that have to be evaluated from data  
 $e^+e^- \rightarrow \pi^+\pi^-$  in the range < 1 GeV contributes 70% to  $a_\mu$ !

KLOE has shown, for the first time, that it is possible to measure  
 $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma)$  at fixed  $\sqrt{s}$  with high accuracy using ISR to  
 extract  $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$  for  $\sqrt{s'}$  from  $2M_\pi$  to  $\sqrt{s}$

[PLB606(2005)12]

Neglecting FSR effects:

$$s \frac{d\sigma_{\pi\pi}}{dM_{\pi\pi}^2} = \sigma_{\pi\pi}(s) \times H(s)$$



Requires precise calculations of the radiator function  $H(s)$

→ PHOKHARA MC NLO generator

[H. Czyż, A. Grzelińska, J.H. Kühn, G. Rodrigo, EPJC27(2003) ]



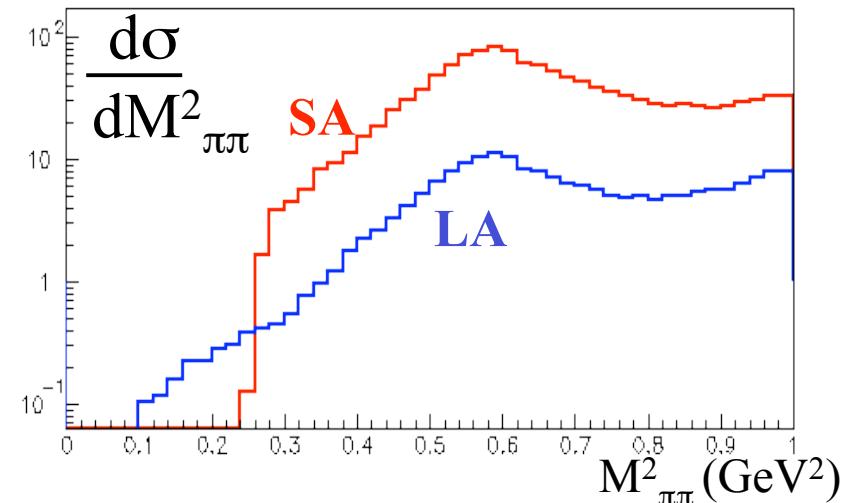
# $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma(\gamma))$ measurement

$$\frac{d\sigma_{\pi\pi\gamma}^{obs}}{dM_{\pi\pi}^2} = \frac{\Delta N_{\text{Obs}} - \Delta N_{\text{Bkg}}}{\Delta M_{\pi\pi}^2} \cdot \frac{1}{\varepsilon_{\text{Sel}}} \cdot \frac{1}{\int L dt}$$

- Background rejection with PID using EMC info ( $e\bar{e}\gamma/\mu\bar{\mu}\gamma$ ) and kin. cuts ( $\phi \rightarrow \pi\pi\pi$ )
- **Efficiencies mostly evaluated on data with two independent methods**
- Luminosity from Bhabha scattering events with  $55^\circ < \theta < 125^\circ$  [EPJC47(2006)589]  
[Generator used for  $\sigma_{\text{eff}}$ : BABYAGA (NPB758(2006)22)]

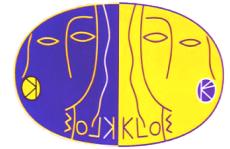
Two samples used:

- 1) **Small angle:  $\theta_{\pi\pi} < 15^\circ$  or  $\theta_{\pi\pi} > 165^\circ$** 
  - Higher cross section (21 nb vs 3 nb)
  - Less background
  - Kinematically limited
- 2) **Large angle:  $50^\circ < \theta_\gamma < 130^\circ$** 
  - Higher background (FSR +  $\phi \rightarrow \pi^+\pi^-\pi^0 / f_0\gamma$ )
  - All  $M_{\pi\pi}$  spectrum



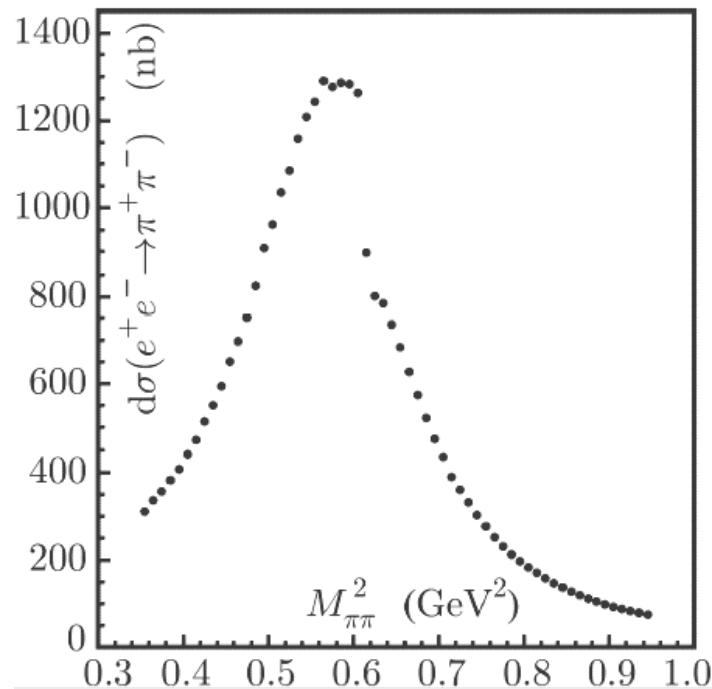
# $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma(\gamma))$ measurement

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## SMALL ANGLE ANALYSIS

$\sigma_{\pi\pi}$  vs  $M_{\pi\pi}^0$ , undressed from vacuum polarization and inclusive for FSR



Results are also expected in near future from:

- $\pi\pi\gamma/\mu\mu\gamma$  ratio
- photon detected at large angle
- off-resonance data (1GeV)

$$a_\mu^{\pi\pi} = \frac{1}{4\pi^3} \int_{0.35\text{GeV}^2}^{0.95\text{GeV}^2} ds \sigma(e^+e^- \rightarrow \pi^+\pi^-) K(s)$$

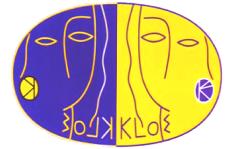
$a_\mu^{\pi\pi}(0.35-0.95 \text{ GeV}^2) =$   
 $(387.2 \pm 0.5_{\text{stat}} \pm 2.4_{\text{syst}} \pm 2.3_{\text{the}}) \times 10^{-10}$

Systematic errors on  $a_\mu^{\pi\pi}$ :

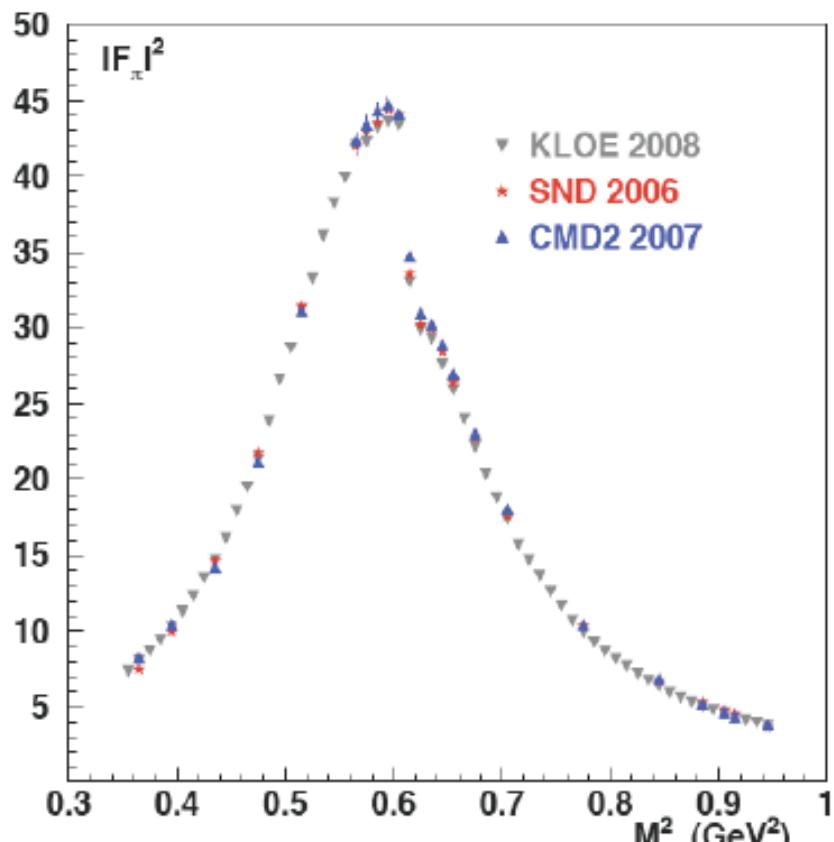
Reconstruction Filter	negligible
Background	0.3%
Trackmass/Miss. Mass	0.2%
$\pi/e$ -ID and TCA	negligible
Tracking	0.3%
Trigger	0.1%
Acceptance ( $\theta_{\pi\pi}$ )	0.1%
Acceptance ( $\theta_\pi$ )	negligible
Unfolding	negligible
Software Trigger	0.1%
$\sqrt{s}$ dep. Of H	0.2%
Luminosity ( $0.1_{\text{th}} \oplus 0.3_{\text{exp}}$ )%	0.3%
FSR resummation	0.3%
Radiator H	0.5%
Vacuum polarization	0.1%

Theoretical fractional error = 0.6 %

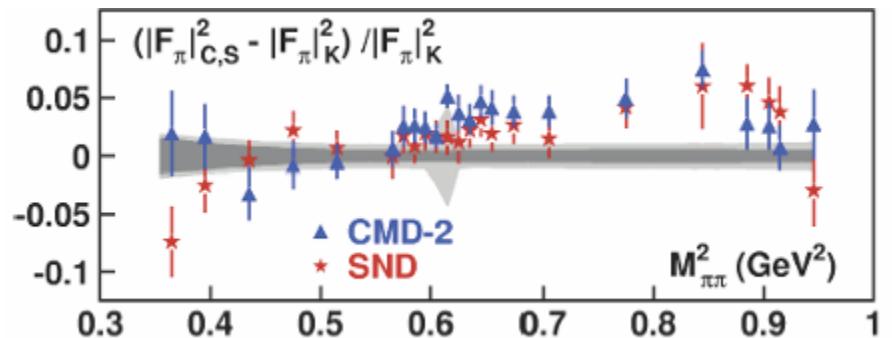
# Comparison with CMD2/SND on $|F_\pi|^2$



$$|F_\pi|^2 = \frac{3s}{\pi\alpha^2\beta_\pi^3} \sigma_{\pi\pi}(s)$$



**Statistical errors only**

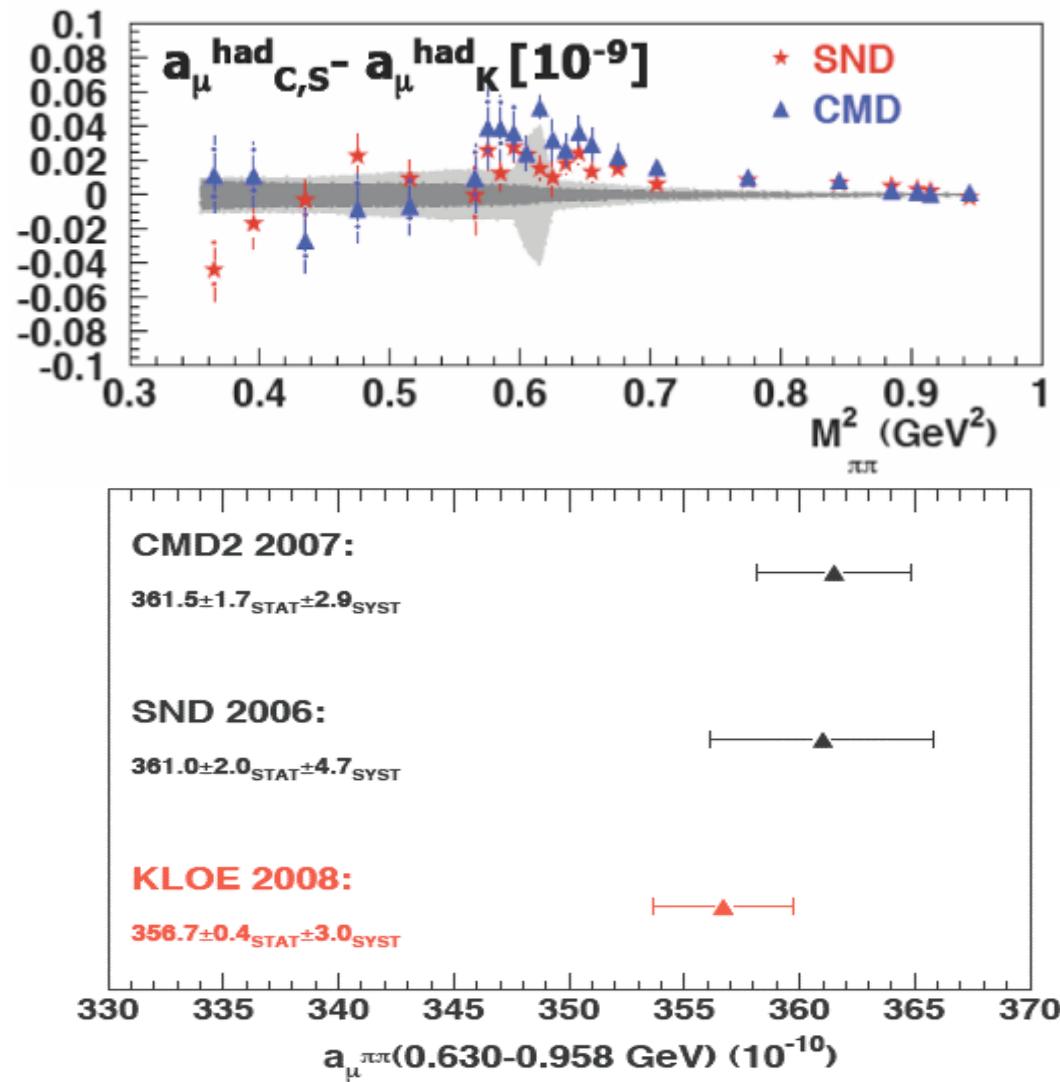


**Grey band: KLOE total error**  
**Data points: CMD2/SND experiments**

**CMD2 and SND data have been averaged over width of KLOE bin (0.01 GeV<sup>2</sup>)**



# Comparison with CMD2/SND on $a_\mu^{\pi\pi}$



Average value:  $359.2 \pm 2.1$  with  $\chi^2/\text{ndf} = 1.24/2$

# Conclusions

❖ Important results have been obtained by KLOE in hadronic physics:

**Measurement of  $\text{BR}(\phi \rightarrow f_0(980)\gamma)$  and  $\text{BR}(\phi \rightarrow a_0(980)\gamma)$**

**Large couplings of  $f_0(980)/a_0(980)$  to  $\phi$  and to KK**

**$\sigma(600)$  needed in the description of the  $\pi^0\pi^0\gamma$  Dalitz plot**

**Upper limit set for  $\phi \rightarrow \text{KK}\gamma$**

**Excess of events in the  $\sigma(600)$  mass region for  $e^+e^- \rightarrow e^+e^-\pi^0\pi^0$**

**BR + first measurement of the CPV plane asymmetry for  $\eta \rightarrow \pi^+\pi^-e^+e^-$**

**Gluonium content @  $3\sigma$  level in  $\eta'$  using the Rosner model**

**Accurate measurement of Dalitz plot parameters for  $\eta \rightarrow \pi\pi\pi$  [JHEP05(2008)006]**

**Precise measurement of  $\eta$  mass [JHEP12(2007)073]**

**Forbidden  $\eta$  decays:  $\eta \rightarrow \pi^+\pi^-$ ,  $\eta \rightarrow \gamma\gamma\gamma$  [PLB 606 (2005) 276]**

Not shown today

**Precise measurement of the main  $\omega$  BR's and of  $\text{BR}(\phi \rightarrow \omega\pi^0)$**

**$\pi\pi$  contribution to the muon anomaly with (  $0.6\%_{\text{exp}} \oplus 0.6\%_{\text{theo}}$  ) uncertainty**

❖ DAΦNE upgrade + KLOE2: new and more precise measurements will follow

# Future prospects: KLOE2

New scheme to increase DAΦNE luminosity by a factor  $O(5)$  is being implemented  
(large crossing angle + “crabbed waist”)

Program:

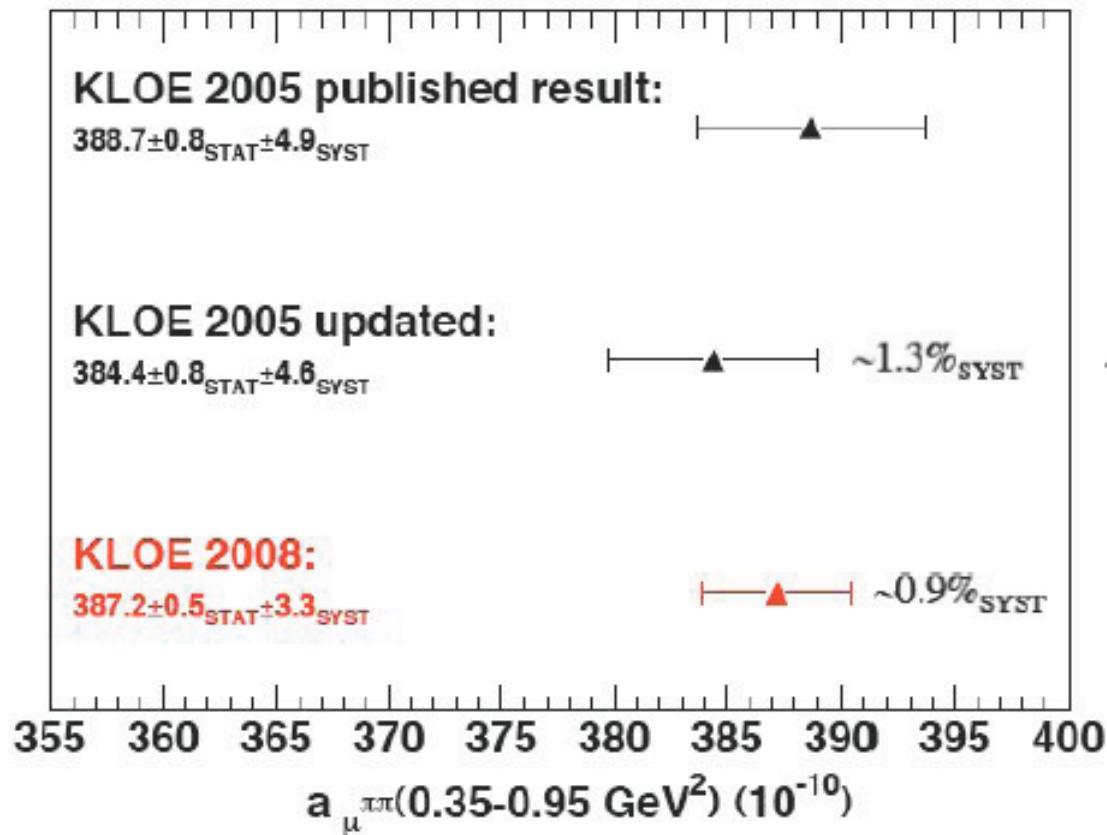
1. **New KLOE data-taking will start at the end of 2009**, with the present detector + **tagger for  $\gamma\gamma$  physics**  $\Rightarrow \sim 5 \text{ fb}^{-1}$
2. **Detector upgrade**: inner tracker, new small angle calorimeters...
3. **KLOE-2 data taking**  $\Rightarrow 50 \text{ fb}^{-1}$  in 3 – 4 years

**KLOE-2 physics program:**

- ❖ **Kaon physics: CKM unitarity, Quantum Mechanics tests, lepton universality ( $K^\pm \rightarrow e^\pm\nu$  /  $K^\pm \rightarrow \mu^\pm\nu$ ),  $K_S$  rare decays**
- ❖ **Light hadrons: search for  $\sigma(600)$  in  $\gamma\gamma \rightarrow \sigma \rightarrow \pi^0\pi^0$ ,  $\phi \rightarrow (f_0/a_0)\gamma \rightarrow KK\gamma$  rare  $\eta$  decays,  $\eta'$  physics**

# $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma(\gamma))$ measurement

PLB 670 (2009) 285



# Comparison with to 2005



error table on exp. systematics

PLB606(2005)12

This work (2008):

Trigger	0.3%
Reconstruction filter	0.6%
Background	0.3%
$M_{\text{tik}}$ cuts	0.2%
Particle ID	0.1%
Tracking	0.3%
Vertex	0.3%
Acceptance	0.3%
Unfolding	0.2%
Luminosity ( $0.5_{\text{th}} \oplus 0.3_{\text{exp}}$ )%	0.6%

$$\Sigma_{\text{exp},2005} = 0.9\% (\oplus 0.9\% \text{ Th})$$

Trigger	0.1%
Reconstruction filter	-
Background	0.3%
$M_{\text{tik}}$ cuts	0.2%
Particle ID	-
Tracking	0.3%
Vertex	-
Acceptance	0.1%
Unfolding	-
Software Trigger	0.1%
$\sqrt{s}$ dep. of H	0.2%
Luminosity ( $0.1_{\text{th}} \oplus 0.3_{\text{exp}}$ )%	0.3%

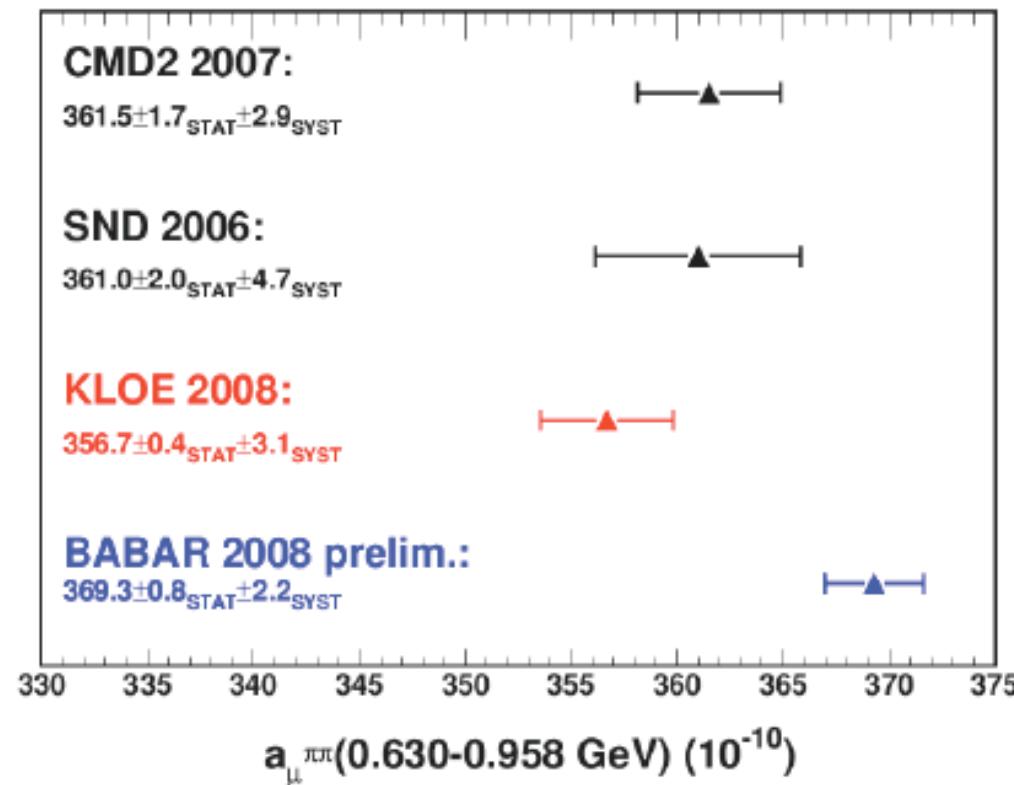
$$\Sigma_{\text{exp},2008} = 0.6\% (\oplus 0.6\% \text{ Th})$$

- Many systematic effects improved !
- Almost everywhere efficiencies evaluated on data by two independent methods

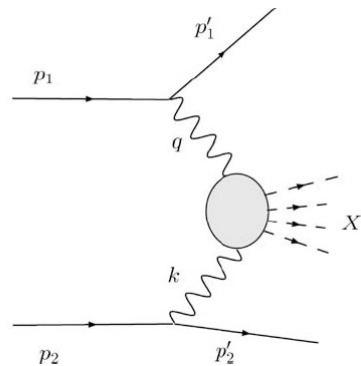
- 30% CV inefficiency recovered in 2002 by additional software trigger level
- Improved offline-event filter -> syst.error <0.1%
- new generator BABAYAGA@NLO theory error from 0.5% to 0.1%
- Trigger efficiency updated due to a doublecounting



# Comparisons on $a_{\mu}^{\pi\pi}$



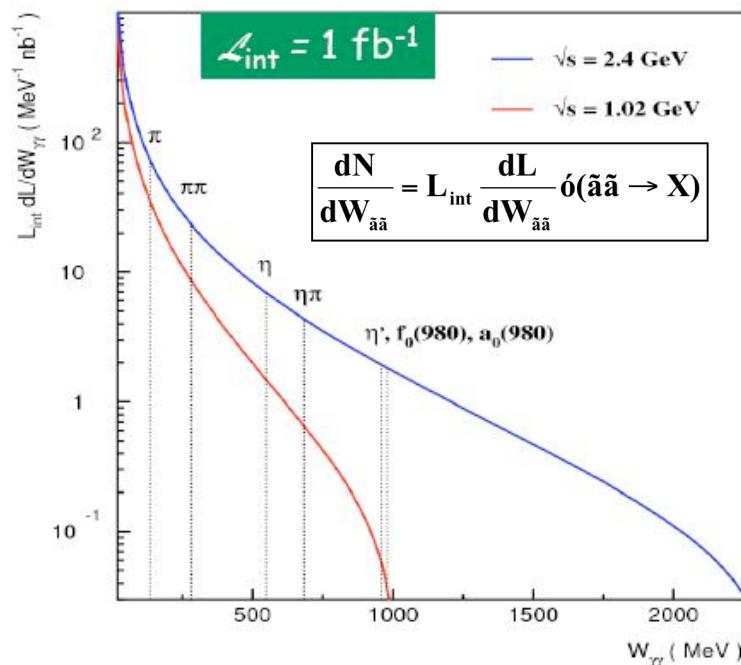
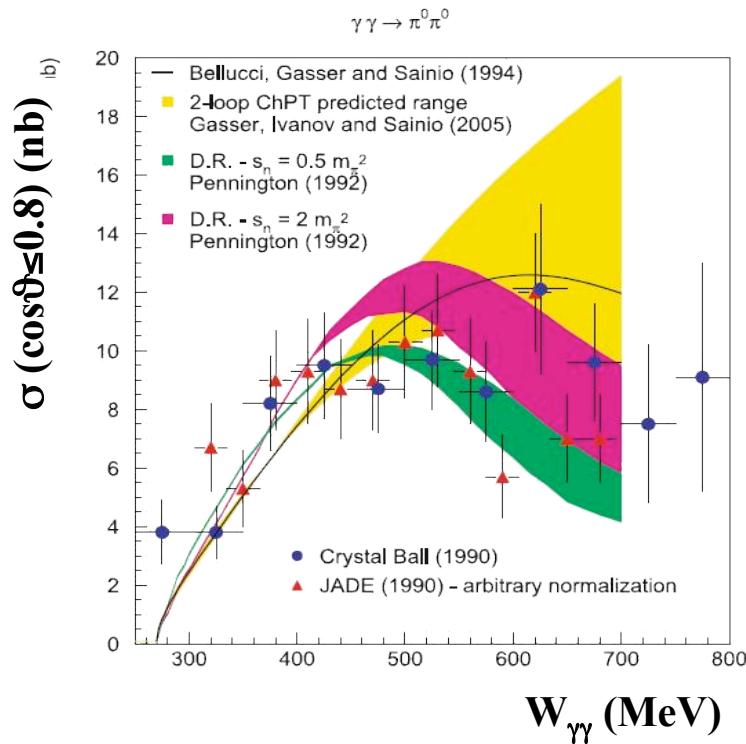
# $\gamma\gamma$ physics @ KLOE/KLOE2



$$e^+ e^- \rightarrow e^+ e^- \tilde{a}^* \tilde{a}^* \rightarrow e^+ e^- X$$

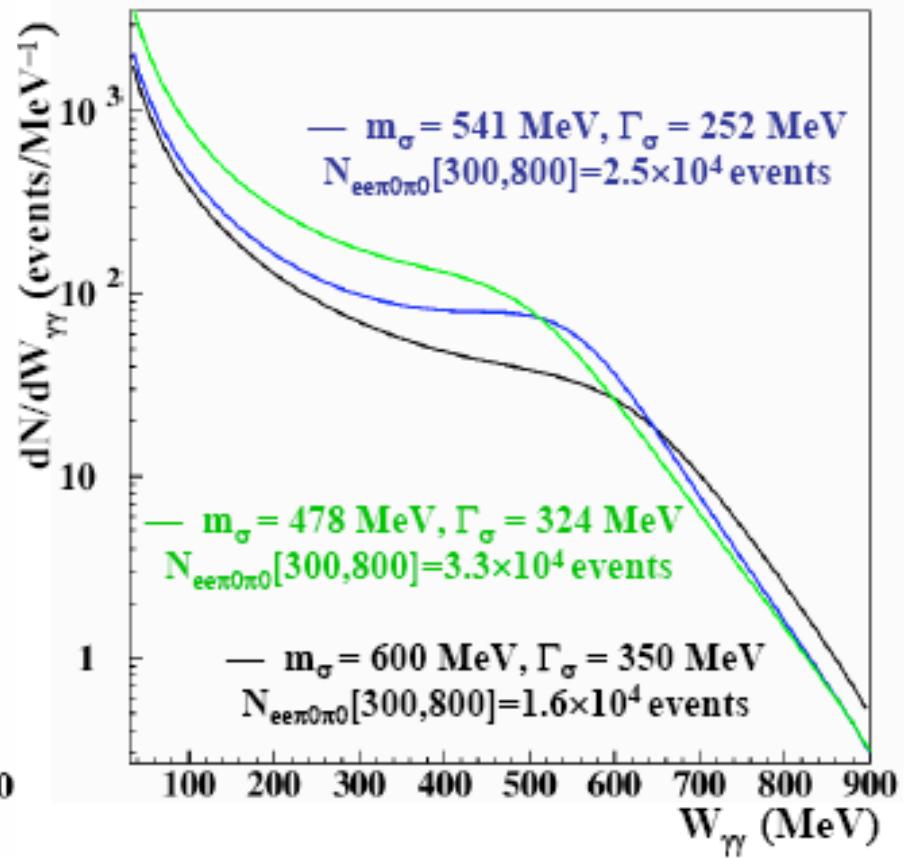
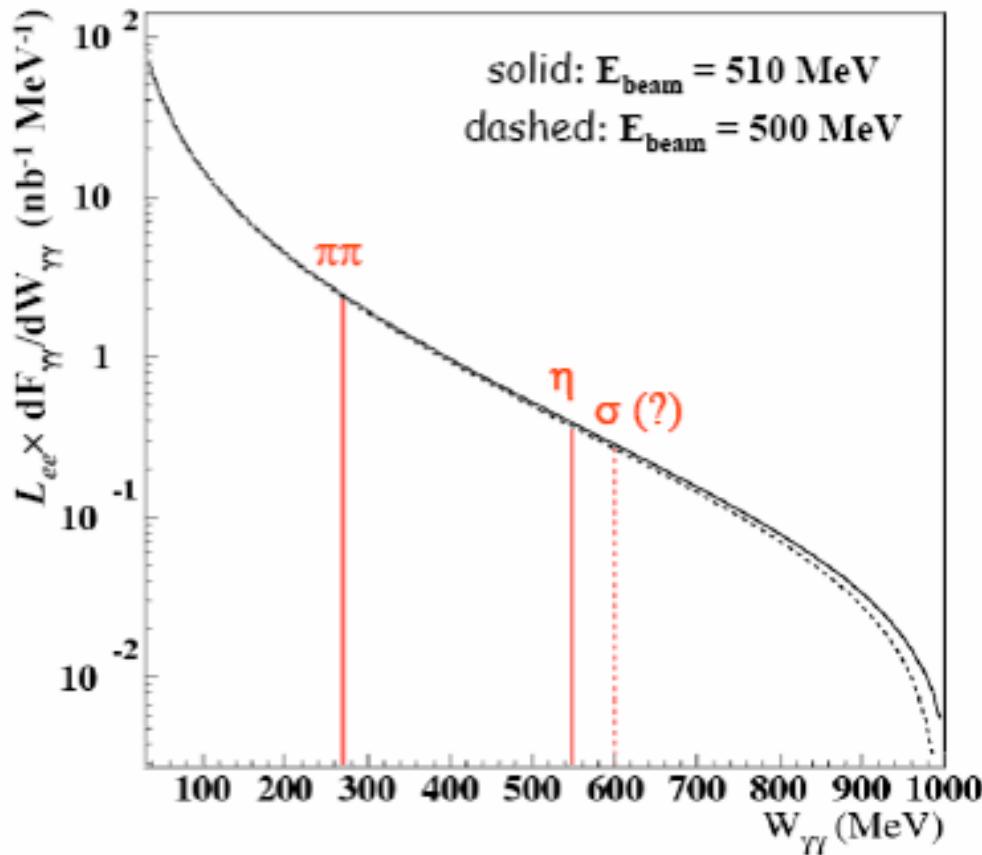
$$[J^{PC}(X) = 0^{\pm+}, 2^{\pm+}]$$

- $X = \pi^0, \eta, \eta' \Rightarrow \Gamma(P \rightarrow \gamma\gamma)$
- $X = \pi^0 \pi^0 \Rightarrow \gamma^* \gamma^* \rightarrow \sigma(600) \rightarrow \pi^0 \pi^0$   
with  $L=5 \text{ fb}^{-1} \Rightarrow \text{err.} \approx 2\%$



# KLOE: $\gamma\gamma \rightarrow \sigma$ production

$e^+ e^- \rightarrow e^+ e^- \sigma \rightarrow e^+ e^- \pi^0 \pi^0$ ,  
event yield with 250 pb<sup>-1</sup>:



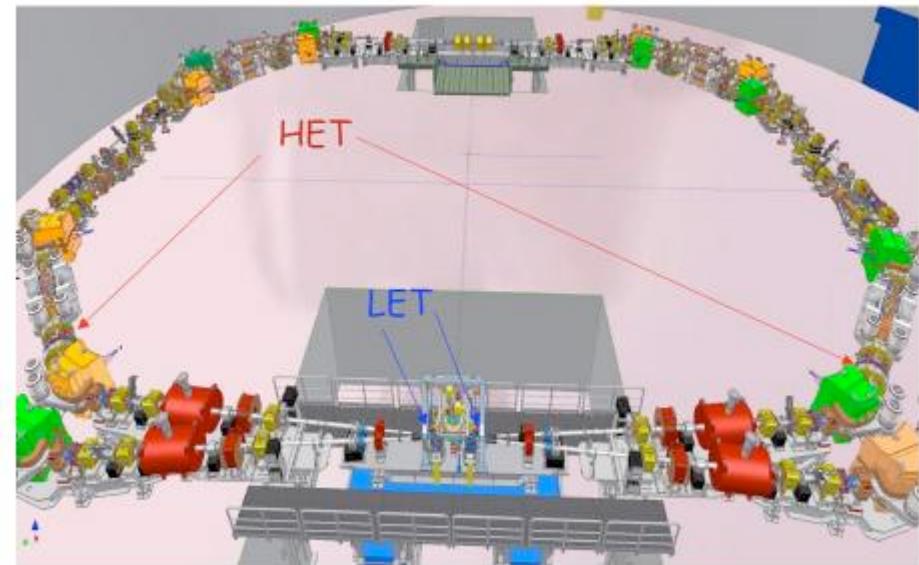
No loss in statistics from  
1020 MeV to 1000 MeV

$\pi^+\pi^-$ : too much background from ISR/FSR

$\pi^0\pi^0$ : expected (not interfering) background:  
 $e^+e^- \rightarrow \omega\pi^0 \rightarrow \pi^0\pi^0\gamma$   
 $e^+e^- \rightarrow \omega\gamma_{ISR} \rightarrow \pi^0\gamma\gamma_{ISR}$

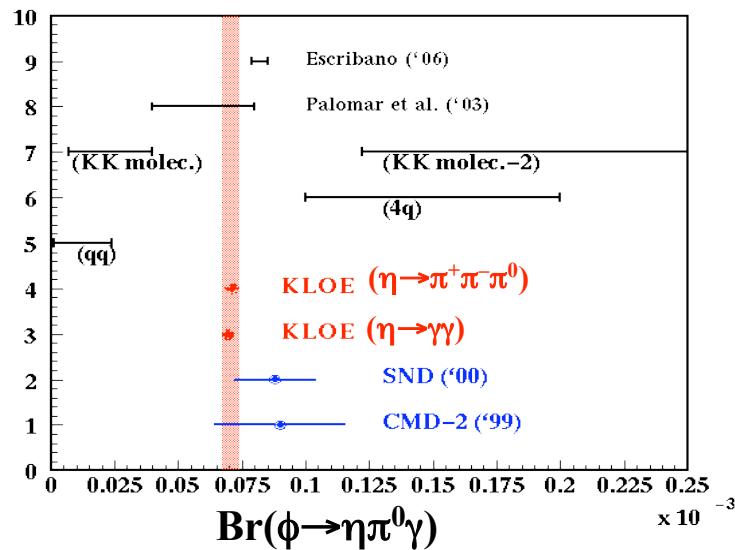
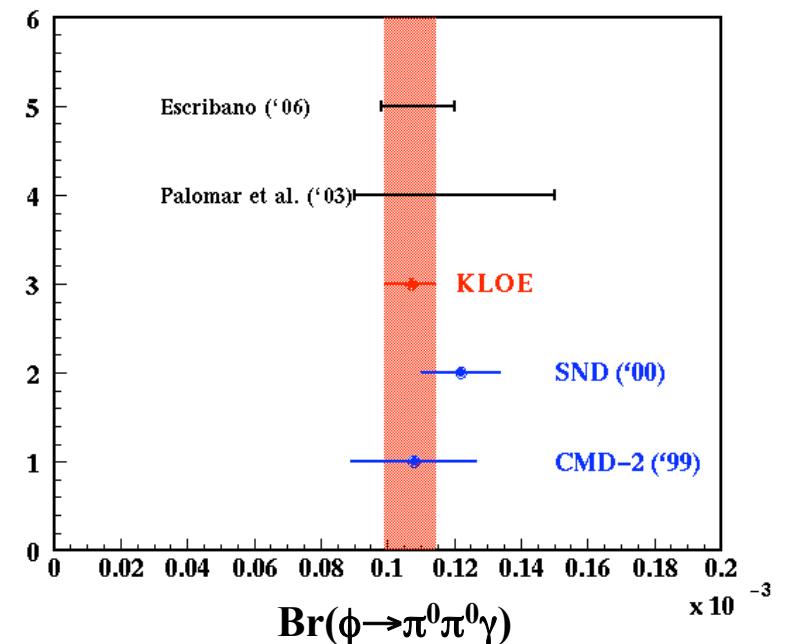
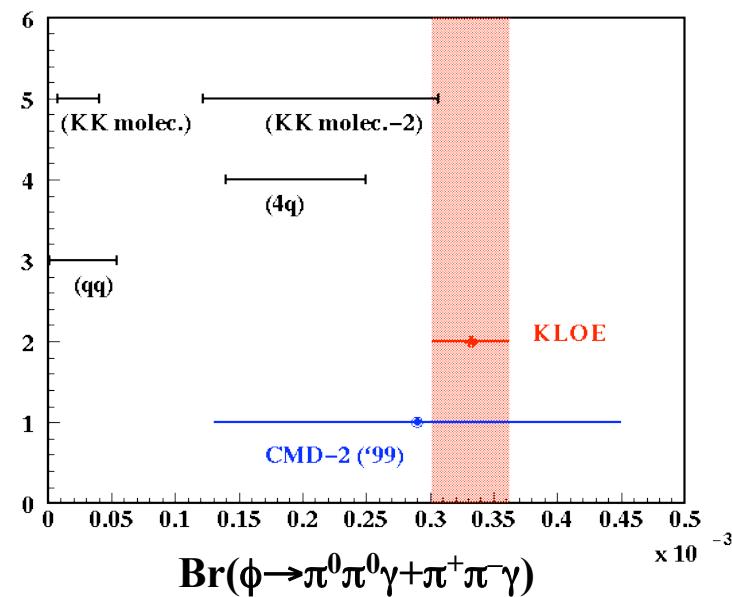
# Tagger for $\gamma\gamma$ physics

- $e^\pm$  tagger needed to reject background from  $\phi \rightarrow K_S K_L$  ( $K_L$  lost,  $K_S \rightarrow \pi\pi$  S/B  $\sim 10^{-3}$ - $10^{-4}$ ) and to improve resolution on  $W_{\gamma\gamma}$
- 2 detectors:
  - LET (Low Energy Tagger)  
Crystals + SiPM  
 $\sigma_E/E = 5 - 10\%$  ,  $\sigma_t \sim 2$  ns  
@  $E_e \approx 200$  MeV
  - HET (High Energy Tagger)  
uses dipoles as  $e^\pm$  spectrometer  
position detector needed ( $\sigma < 1$  mm)  
@ 11 m from IP
- Coincidence will cover the interesting  $W_{\gamma\gamma}$  range



	$E_e'$ (MeV)	$E_\gamma$ (MeV)
LET	(165 - 235)	(275 - 345)
HET	(330 - 390)	(120, 180)

# BR of scalar mesons



- qq: Achasov-Ivanchenko NPB315(1989)  
Close et al., NPB389(1993)
- 4q: Achasov-Ivanchenko NPB315(1989)
- KK molec.: Close et al., NPB389(1993)  
Achasov et al., PRD56(1997)
- KK molec.-2: Kalashnikova et al., EPJA24(2005)
- Palomar et al., NPA729(2003): U $\chi$ PT
- Escribano, PRD74(2006): Linear  $\sigma$  model

# Couplings of scalar mesons

		S U(3)		
		4q	qqbar	
$(g_{aK^+K^-}/g_{a\eta\pi})^2$	<b>0.6 – 0.7</b>	1.2 – 1.7		0.4
	SND (2000) : $1.8 \pm 2.5$			
$(g_{fK^+K_-}/g_{f\pi^+\pi_-})^2$	<b>4.6 – 4.8</b>	>> 1	>> 1 ( $f_0 = \text{ssbar}$ )	1/4 ( $f_0 = \text{nnbar}$ )
	CMD-2 (1999) : $3.61 \pm 0.62$			
	SND (2000) : $4.6 \pm 0.8$			
	BES (2005) : $4.21 \pm 0.33$			
$(g_{fK^+K_-}/g_{aK^+K_-})^2$	<b>4 – 5</b>	1	2	1

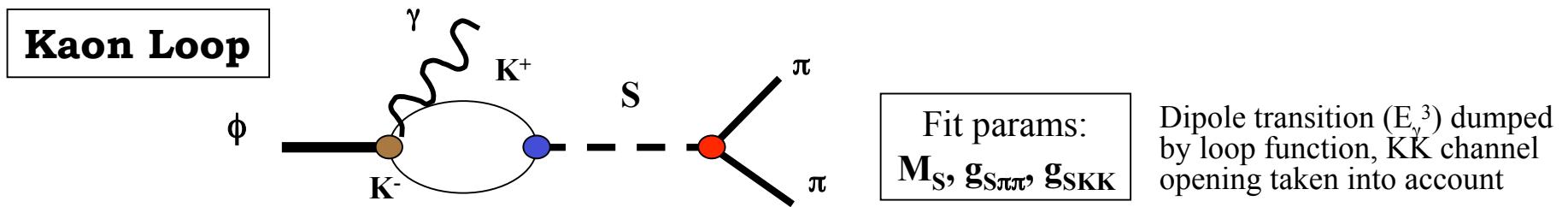


# Light scalars in $\phi$ radiative decays

$\sim 450 \text{ pb}^{-1}$  of  $e^+e^-$  collisions @  $\sqrt{s} = M_\phi$

Contributions from  $\phi \rightarrow S\gamma$ , with  $S=f_0(980)/\sigma(500)/a_0(980)$  searched for in  $\pi\pi\gamma$ ,  $\eta\pi\gamma$  final state. Large and partly unknown continuum backgrounds, with sizable interference

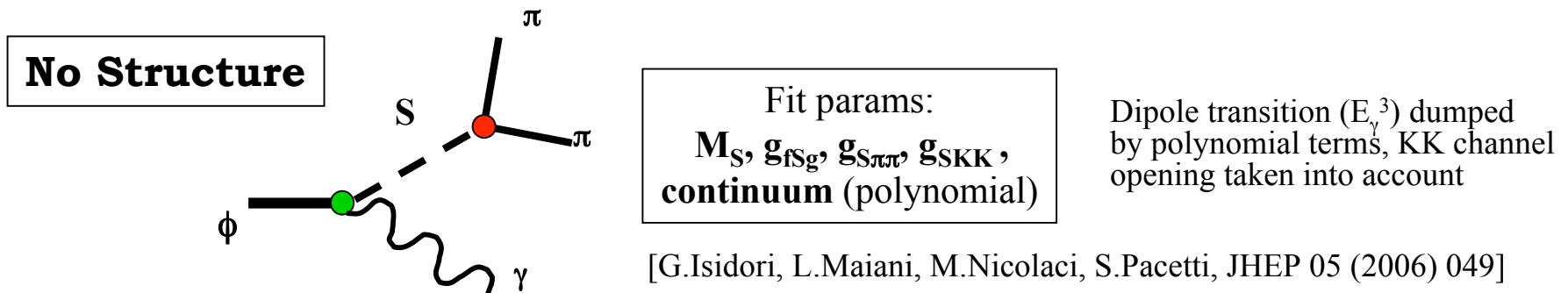
Both  $\text{BR}(\phi \rightarrow S\gamma)$  and scalar mass spectra are sensitive to scalar structure



[N.N.Achasov, V.N.Ivanchenko, NPB315 (1989) 465]

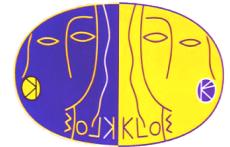
[N.N.Achasov, V.V.Gubin, PRD 56 (1997) 4084]

[N.N.Achasov, A.V.Kiselev, PRD 68 (2003) 014006]

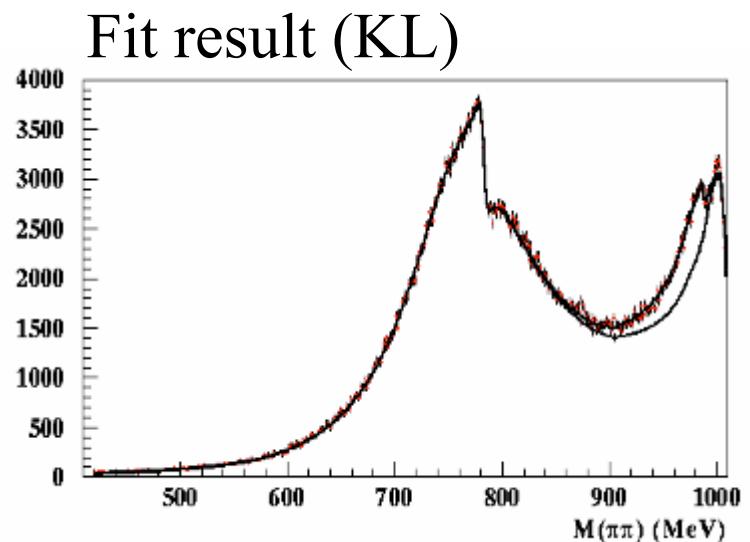
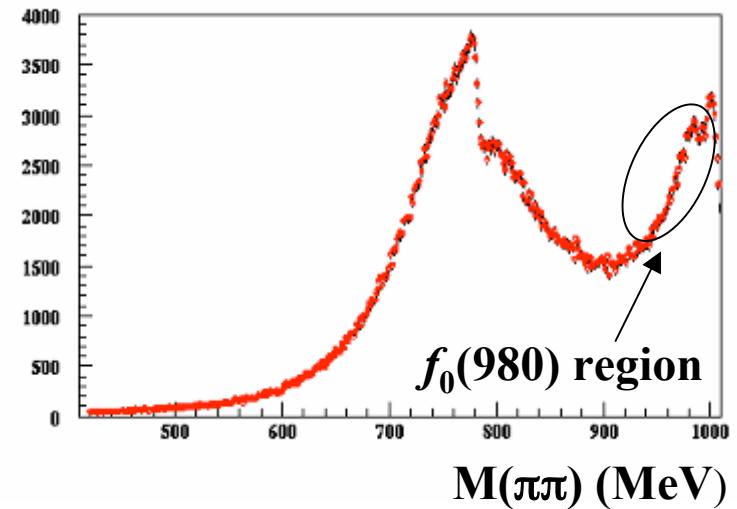


# The $\pi^+\pi^-\gamma$ final state

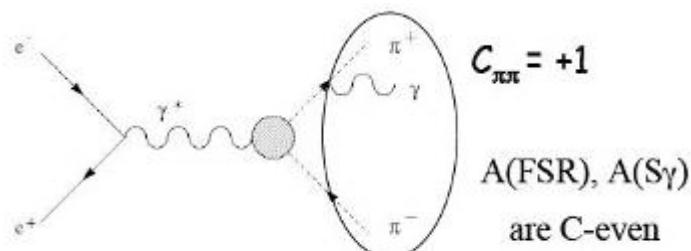
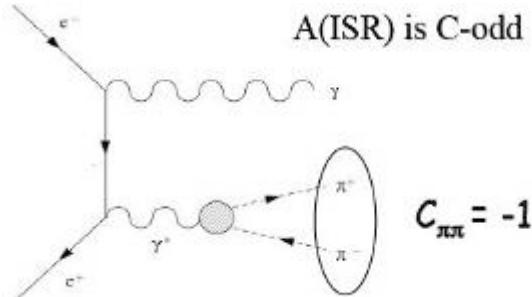
KLOE, PLB 634 (2006) 148



- ❖  $e^+e^- \rightarrow \pi^+\pi^-\gamma$  events with the photon at large angle ( $45^\circ < \vartheta_\gamma < 135^\circ$ )
- ❖ Main contributions: ISR+FSR
- ❖ Search for the  $f_0$  signal as a deviation on  $M(\pi^+\pi^-)$  spectrum from the expected ISR + FSR shape
- ❖  $e^+e^-\gamma$  bckg events rejected using EMC  
 $\mu^+\mu^-\gamma$  and  $\pi^+\pi^-\pi^0$  bckg suppressed by means of kinematics
- ❖ **676,000 events selected** (2001+2002)

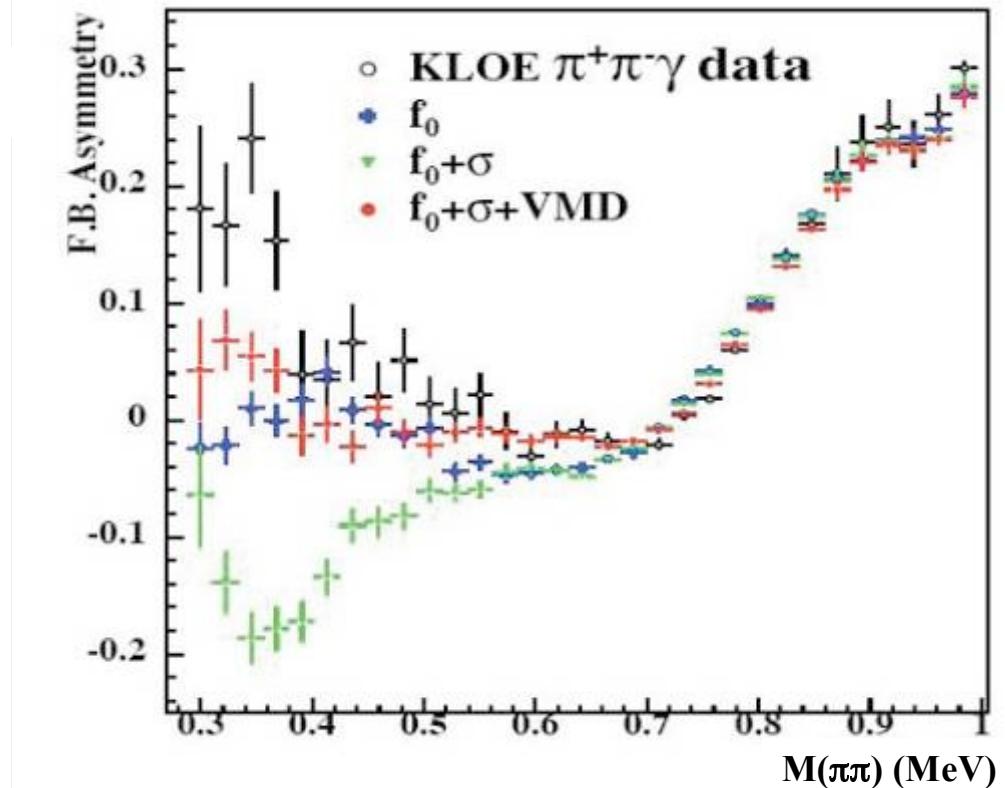


# $\pi^+\pi^-\gamma$ : Forward-backward asymmetry



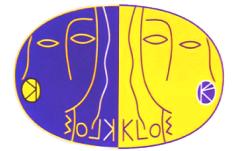
$$A_{FB} = \frac{N(\vartheta_+ > 90^\circ) - N(\vartheta_+ < 90^\circ)}{N(\vartheta_+ > 90^\circ) + N(\vartheta_+ < 90^\circ)}$$

- ❖ Clear  $f_0(980)$  signal
- ❖ Data-MC agreement recovered also at low  $M(\pi\pi)$   
[Panzeri, Shekhtsova, Venanzoni,  
PLB642(2006),342]
- ❖ Improved simulation with  $f_0$  and  $\sigma$  parameters from  $\pi^0\pi^0\gamma$  analysis  
[Panzeri, Shekhtsova, Venanzoni,  
arXiv0706.3027]

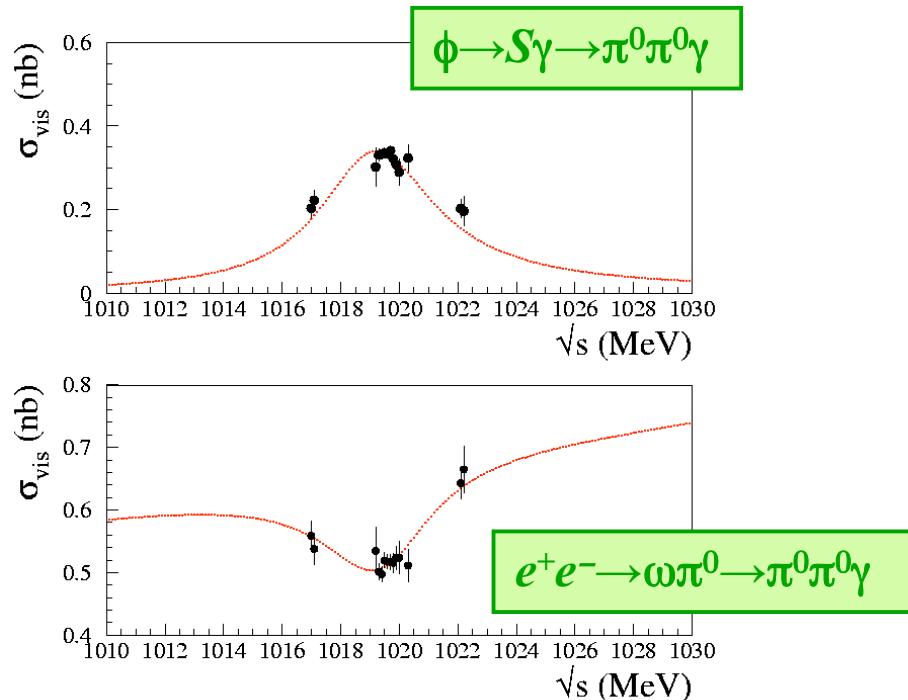
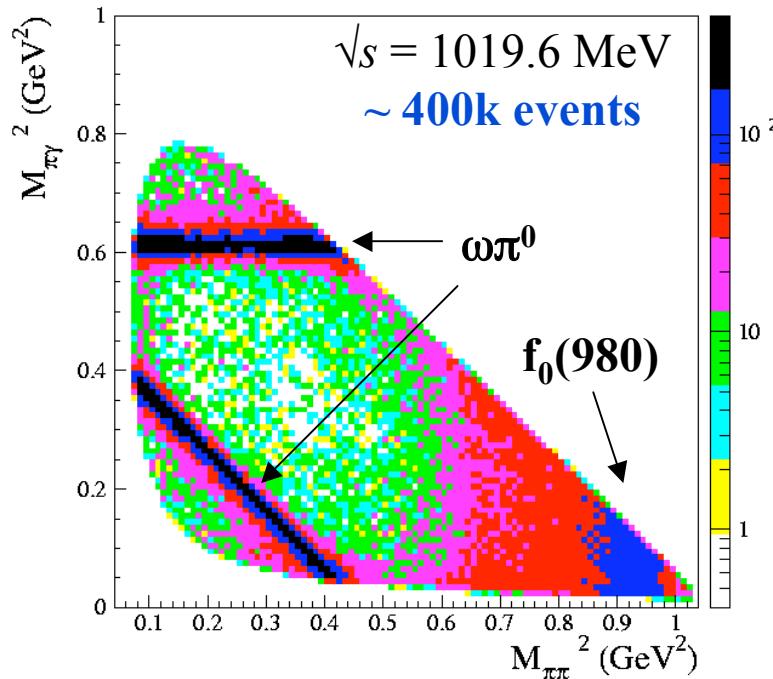


# The $\pi^0\pi^0\gamma$ final state

KLOE, EPJC 49 (2007) 473



Two main contributions to  $\pi^0\pi^0\gamma$  final state @  $M_\phi$ :



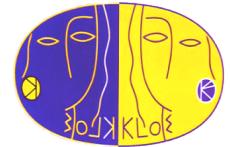
Bi-dimensional analysis of Dalitz-plot, with interference between two channels

Improved KL parametrization [PRD73(2006)054029]:

**combined fit to  $\pi\pi$  scattering data and** to already published KLOE data on  $\phi \rightarrow S\gamma$  gives ten sets of parameters able to describe both distributions

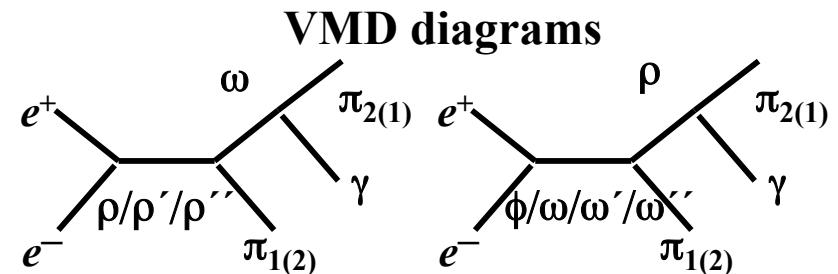
# KLOE: $e^+e^- \rightarrow \pi^0\pi^0\gamma$

KLOE, Eur. Phys. J. C 49 (2007) 473

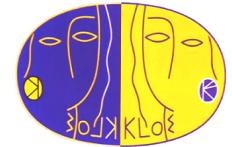


Fit to the  $\pi^0\pi^0\gamma$  Dalitz plot

$$\frac{d\sigma}{dm} = \left( \frac{d\sigma}{dm} \right)_{VMD} + \left( \frac{d\sigma}{dm} \right)_{Scalar} + \left( \frac{d\sigma}{dm} \right)_{interf}$$



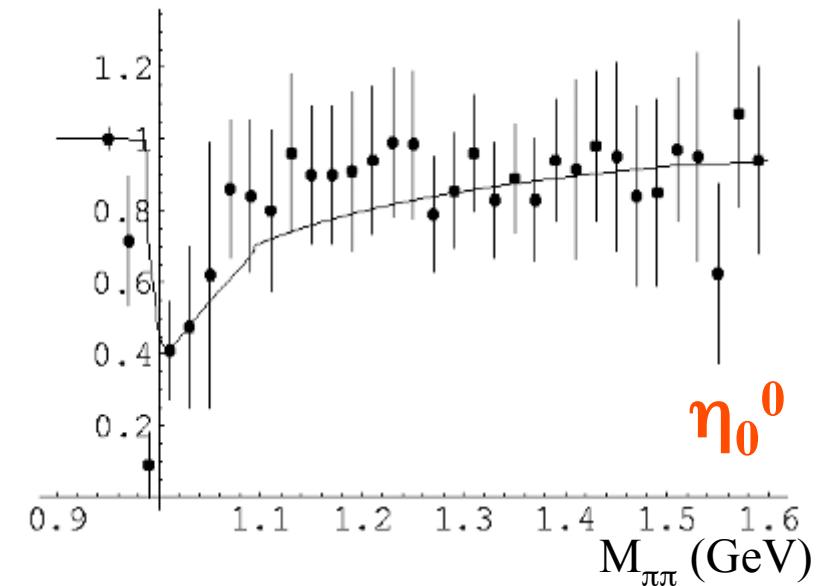
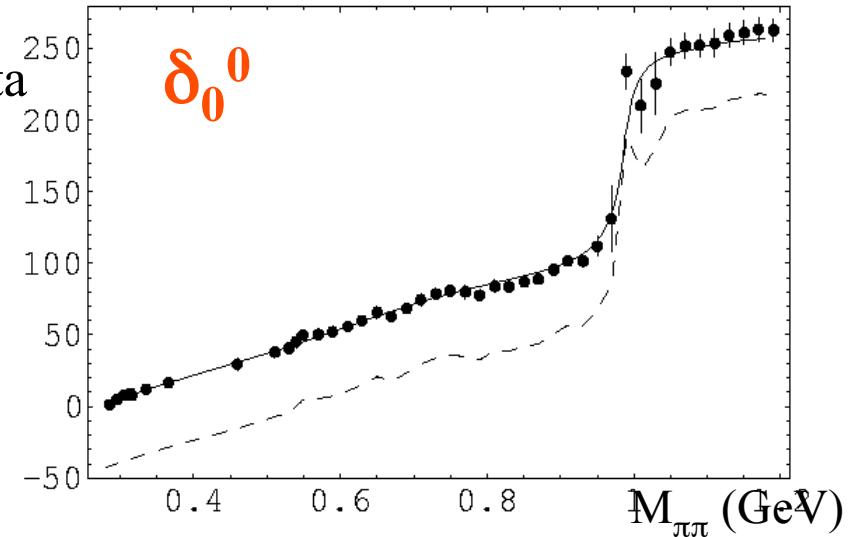
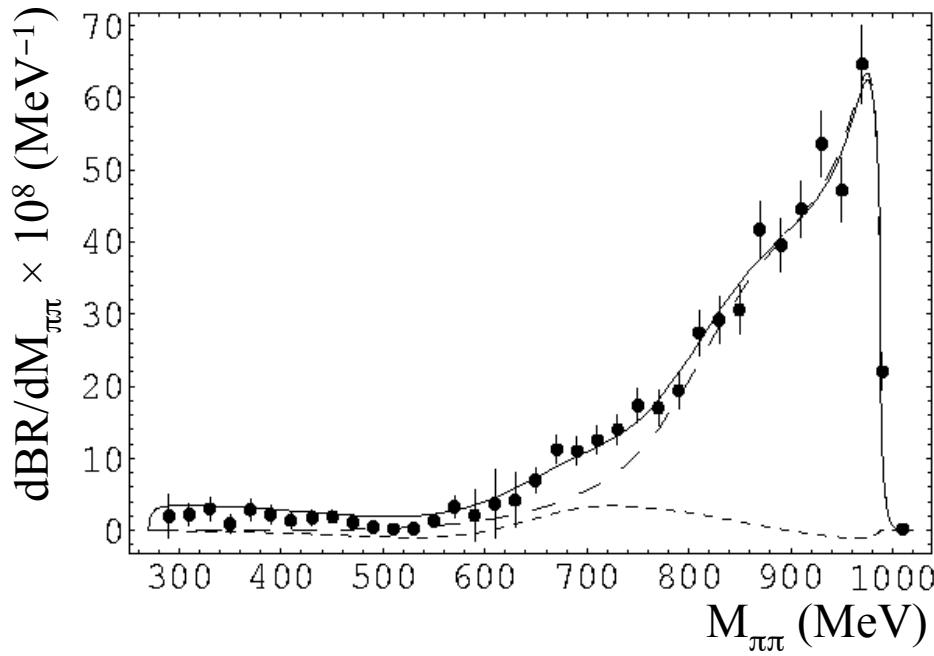
- ❖ Fit Dalitz plot with both No-Structure and Kaon Loop models for data taken @ 1019.75 MeV
- ❖ Improved description for KL [N.N.Achasov, A.V.Kiselev, PRD73 (2006) 054029]
  - ✓ Insertion of a KK scattering phase
  - ✓ New parametrization of  $\pi\pi$  scattering phase  $\delta_0^0$
  - ✓ **Scalar contributions:  $f_0(980)$  and  $\sigma(600)$**
  - ✓ **Combined fit to  $\pi\pi$  scattering data and** to already published KLOE data on  $\phi \rightarrow S\gamma$  gives ten sets of parameters able to describe both distributions



## Improved Kaon Loop parametrization

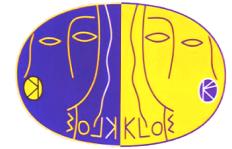
Combined fit to KLOE 2000 +  $\pi\pi$  scattering data

**dBR/dM <sub>$\pi\pi$</sub>  (KLOE 2000 data)**



# $S \rightarrow \pi\pi$ : fit results

KLOE, Phys. Lett. B 634 (2006) 148  
 KLOE, Eur. Phys. J. C 49 (2007) 473



## KL fit results:

$\pi^0\pi^0$ :  $\sigma(600)$  [fixed values]  
 needed to describe data  
 $\pi^+\pi^-$ : not sensitive to  $\sigma(600)$

both channels:  $f_0(980)$   
 strongly coupled to KK

## NS fit results:

both channels: only  $f_0(980)$   
 sufficient to describe data

$\pi^0\pi^0$  vs  $\pi^+\pi^-$ : larger  $g_{\phi f_0 \gamma}$   
 but weaker KK coupling

$$BR(\phi \rightarrow S\gamma \rightarrow \pi^0\pi^0\gamma) = [1.07^{+0.01}_{-0.03}(\text{fit})^{+0.04}_{-0.02}(\text{syst})^{+0.05}_{-0.06}(\text{mod})] \times 10^{-4}$$

Parameter	$\pi^+\pi^-\gamma$	$\pi^0\pi^0\gamma$
$M_{f_0}$ (MeV)	980–987	<b><math>976.8 \pm 0.3^{+0.9}_{-0.6} \pm 10.1</math></b>
$g_{f_0KK}$ (GeV)	5.0–6.3	<b><math>3.76 \pm 0.04^{+0.15}_{-0.08} {}^{+1.16}_{-0.48}</math></b>
$g_{f_0\pi\pi}$ (GeV)	3.0–4.2	<b><math>-1.43 \pm 0.01^{+0.01}_{-0.06} {}^{+0.03}_{-0.60}</math></b>
$g_{f_0KK}^2 / g_{f_0\pi\pi}^2$	2.2–2.8	<b><math>6.9 \pm 0.1^{+0.2}_{-0.1} {}^{+0.3}_{-3.9}</math></b>

Parameter	$\pi^+\pi^-\gamma$	$\pi^0\pi^0\gamma$
$M_{f_0}$ (MeV)	973–981	<b><math>984.7 \pm 0.4^{+2.4}_{-3.7}</math></b>
$g_{f_0KK}$ (GeV)	1.6–2.3	<b><math>0.40 \pm 0.04^{+0.62}_{-0.29}</math></b>
$g_{f_0\pi\pi}$ (GeV)	0.9–1.1	<b><math>1.31 \pm 0.01^{+0.09}_{-0.03}</math></b>
$g_{f_0KK}^2 / g_{f_0\pi\pi}^2$	2.6–4.4	<b><math>0.09 \pm 0.02^{+0.44}_{-0.08}</math></b>
$g_{\phi a_0\gamma}$ (GeV $^{-1}$ )	1.2–2.0	<b><math>2.61 \pm 0.02^{+0.31}_{-0.08}</math></b>

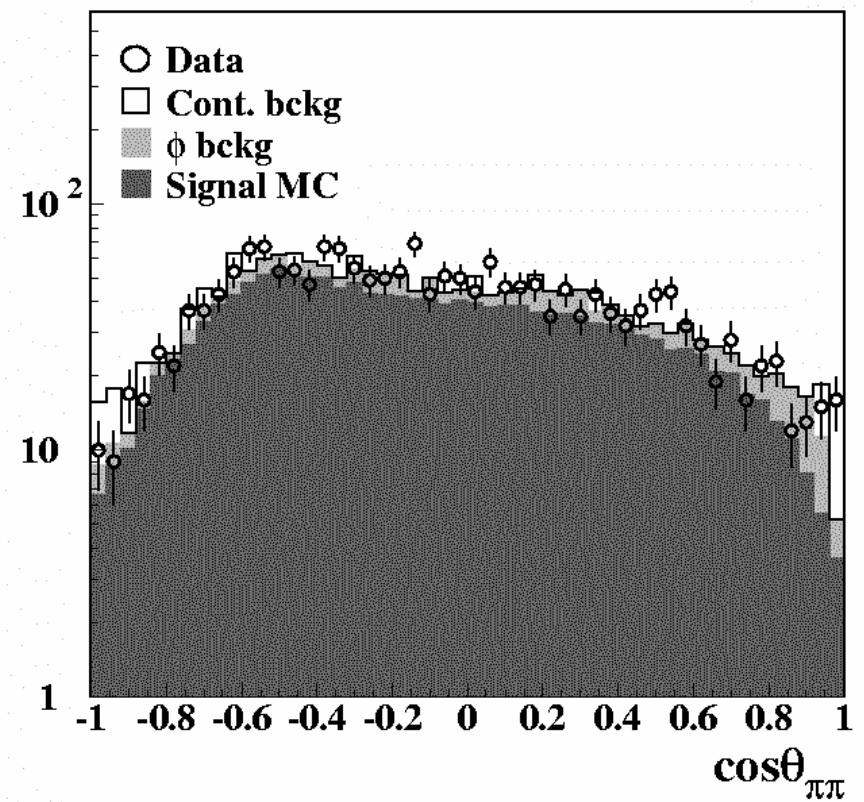
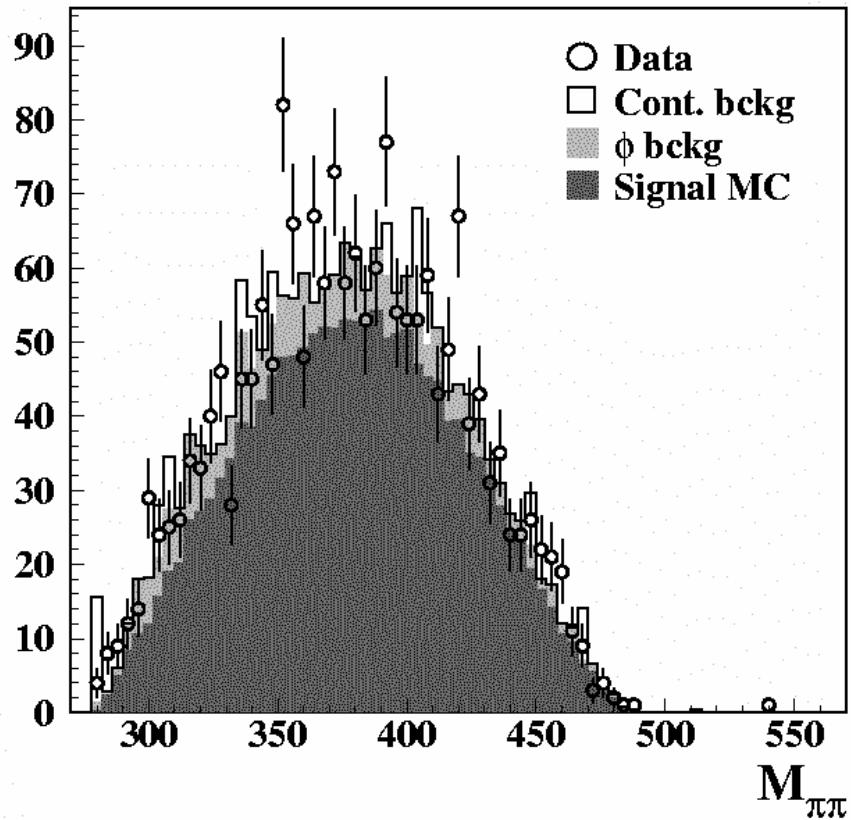
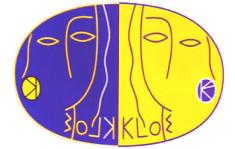
No Structure

Parameter	$\pi^+\pi^-\gamma$	$\pi^0\pi^0\gamma$
$M_{f_0}$ (MeV)	973–981	<b><math>984.7 \pm 0.4^{+2.4}_{-3.7}</math></b>
$g_{f_0KK}$ (GeV)	1.6–2.3	<b><math>0.40 \pm 0.04^{+0.62}_{-0.29}</math></b>
$g_{f_0\pi\pi}$ (GeV)	0.9–1.1	<b><math>1.31 \pm 0.01^{+0.09}_{-0.03}</math></b>
$g_{f_0KK}^2 / g_{f_0\pi\pi}^2$	2.6–4.4	<b><math>0.09 \pm 0.02^{+0.44}_{-0.08}</math></b>
$g_{\phi a_0\gamma}$ (GeV $^{-1}$ )	1.2–2.0	<b><math>2.61 \pm 0.02^{+0.31}_{-0.08}</math></b>

Confidence intervals given by exp. systematics,  
 except for KL in the  $\pi^0\pi^0\gamma$  channel (theory)

Marginal agreement between  $\pi^0\pi^0$  and  $\pi^+\pi^-$

# $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ : data-MC comparison



# $\eta'$ gluonium content

KLOE, PLB 648 (2007) 267



Formal parametrization for  $\eta'$  gluonium content measurement:

$$|\eta'\rangle = X_{\eta'} \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle + Y_{\eta'} |s\bar{s}\rangle + Z_{\eta'} |glue\rangle$$

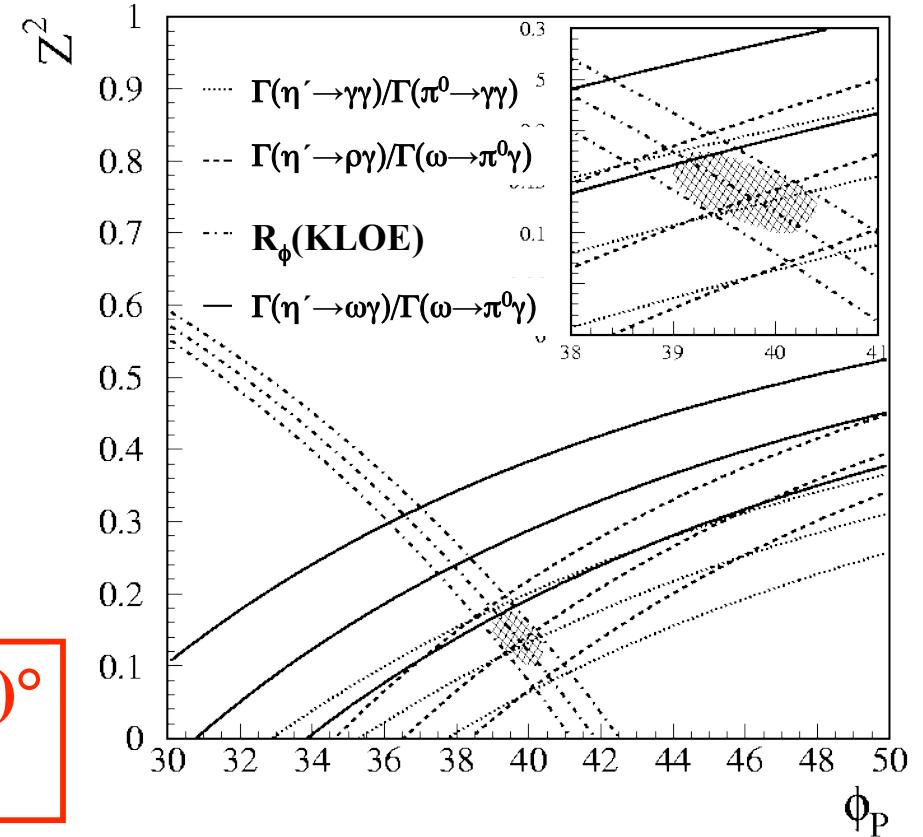
$$|\eta\rangle = \cos\varphi_P \frac{1}{\sqrt{2}} |u\bar{u} + d\bar{d}\rangle - \sin\varphi_P |s\bar{s}\rangle$$

Using SU(3) relations between decay modes and the corresponding measured BRs:

$$\begin{aligned} \chi^2/N_{\text{dof}} &= 1.42/2 \\ \cos^2\phi_G &= 0.86 \pm 0.04 \\ \cos^2\phi_P &= 0.592 \pm 0.012 \end{aligned}$$

$$\begin{aligned} \varphi_P &= (39.7 \pm 0.7)^\circ & |\phi_G| &= (22 \pm 3)^\circ \\ Z_{\eta'}^2 &= 0.14 \pm 0.04 \end{aligned}$$

$$\begin{aligned} X_{\eta'} &= \cos\phi_G \sin\varphi_P \\ Y_{\eta'} &= \cos\phi_G \cos\varphi_P \\ Z_{\eta'} &= \sin\phi_G \end{aligned}$$



$$\sigma(e^+e^- \rightarrow \omega\pi^0)$$

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Interference pattern between non-resonant  $e^+e^- \rightarrow \omega\pi^0$  and  $\phi$  decays:

$$\sigma(\sqrt{s}) = \sigma_0(\sqrt{s}) \left| 1 - Z \frac{M_\phi \Gamma_\phi}{D_\phi} \right|$$

Model indep.  $\sigma_0(\sqrt{s}) :$

$$\sigma_0(\sqrt{s}) = \sigma_0 + \sigma'(\sqrt{s} - M_\phi)$$

Fit results:

Parameter	$\pi^+\pi^-\pi^0\pi^0$	$\pi^0\pi^0\gamma$
$\sigma_0^i(\text{nb})$	$7.89 \pm 0.06 \pm 0.07$	$0.724 \pm 0.010 \pm 0.003$
$\Re_i(Z)$	$0.106 \pm 0.007 \pm 0.004$	$0.011 \pm 0.015 \pm 0.006$
$\Im_i(Z)$	$-0.103 \pm 0.004 \pm 0.003$	$-0.154 \pm 0.007 \pm 0.004$
$\sigma'_i(\text{nb/MeV})$	$0.064 \pm 0.003 \pm 0.001$	$0.0053 \pm 0.0005 \pm 0.0002$

From  $\Gamma(\omega \rightarrow \pi^0\gamma)/\Gamma(\omega \rightarrow \pi^+\pi^-\pi^0)$  + unitarity using rare BRs ( $\sim 2\%$ ):

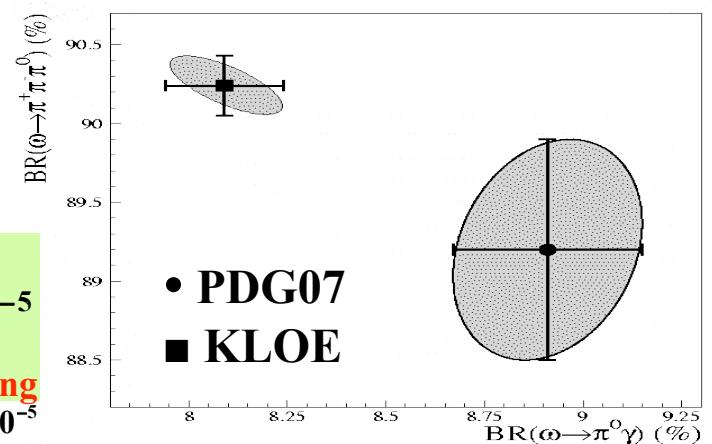
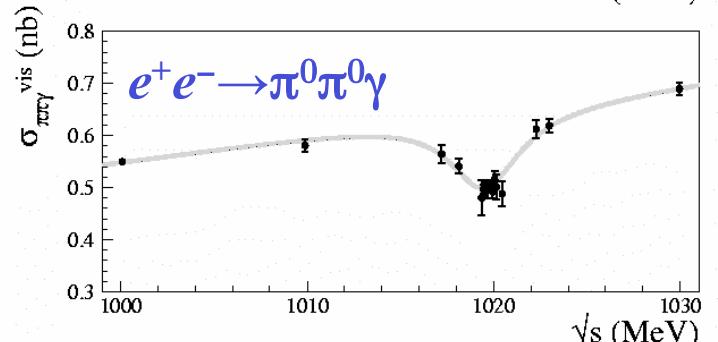
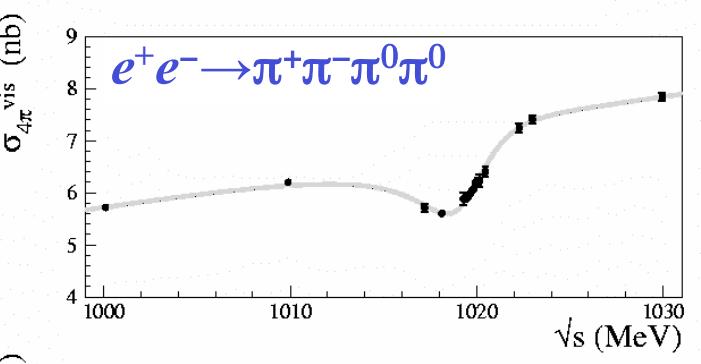
$$\begin{aligned} \text{BR}(\omega \rightarrow \pi^+\pi^-\pi^0) &= (90.24 \pm 0.19)\% \\ \text{BR}(\omega \rightarrow \pi^0\gamma) &= (8.09 \pm 0.14)\% \end{aligned}$$



$$BR(\phi \rightarrow \omega\pi^0) = \frac{\sigma_0^{\omega\pi} |Z_{4\pi}|^2}{\sigma_\phi} = (5.63 \pm 0.70) \times 10^{-5}$$

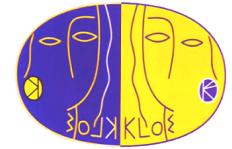
OZI + G-parity violating

SND(2000) :  $BR(\phi \rightarrow \omega\pi^0) = (5.2^{+1.3}_{-1.1}) \times 10^{-5}$

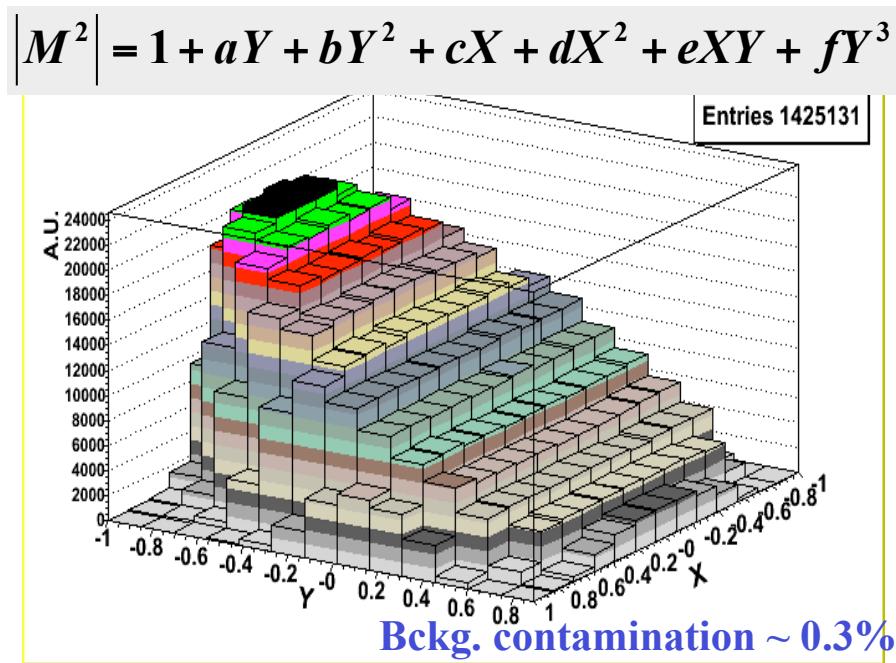


# KLOE: $\eta \rightarrow \pi^+ \pi^- \pi^0$ dynamics

EPJC05(2008)006



**19×10<sup>6</sup>**  $\eta$  from  $\phi \rightarrow \eta\gamma$ . Tagging: recoil monochromatic photon (363 MeV)



$$\begin{aligned} a &= -1.090 \pm 0.005 \text{ (stat)} {}^{+0.008}_{-0.019} \text{ (syst)} \\ b &= 0.124 \pm 0.006 \text{ (stat)} \pm 0.010 \text{ (syst)} \\ d &= 0.057 \pm 0.006 \text{ (stat)} {}^{+0.007}_{-0.016} \text{ (syst)} \\ f &= 0.14 \pm 0.01 \text{ (stat)} \pm 0.02 \text{ (syst)} \\ c &= 0.002 \pm 0.003 \text{ (stat)} \pm 0.001 \text{ (syst)} \\ e &= -0.006 \pm 0.007 \text{ (stat)} {}^{+0.005}_{-0.003} \text{ (syst)} \end{aligned}$$

Lowest order current algebra ( $b=a^2/4$ )  
not satisfied

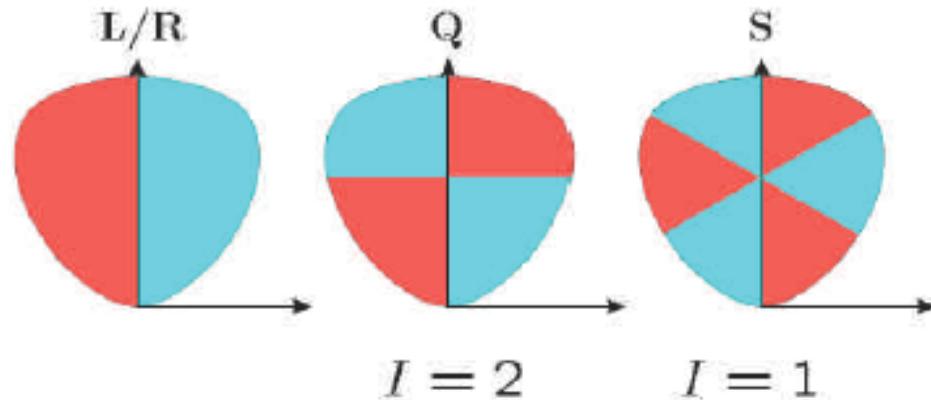
C-parity conservation

Borasoy-Nissler, Eur. Phys. J. A 26 (2005):

$$a = -1.20 \pm 0.07 \quad b = 0.28 \pm 0.05 \quad c = 0.05 \pm 0.02$$



C-parity conservation tested also with the charge asymmetries:



**Left-Right** C-invariance  
**Quadrant** C-invariance in  $\Delta I=2$  amplit.  
**Sextant** C-invariance in  $\Delta I=1$  amplit.  
 (see J.G.Layter *et al.*, Phys.Rev.Lett.29 (1972) 316)

$$A_{LR} = \frac{N_1 - N_2}{N_1 + N_2} \quad A_Q = \frac{N_1 + N_3 - N_2 + N_4}{N_1 + N_3 + N_2 + N_4} \quad A_S = \frac{N_1 + N_3 + N_5 - N_2 + N_4 + N_6}{N_1 + N_3 + N_5 + N_2 + N_4 + N_6}$$

$$A_{LR} = (-0.09 \pm 0.10 \text{ (stat)} {}^{+0.09}_{-0.14} \text{ (syst)}) \times 10^{-2}$$

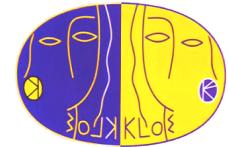
$$A_Q = (-0.05 \pm 0.10 \text{ (stat)} {}^{+0.03}_{-0.05} \text{ (syst)}) \times 10^{-2}$$

$$A_S = (-0.08 \pm 0.10 \text{ (stat)} {}^{+0.08}_{-0.13} \text{ (syst)}) \times 10^{-2}$$

All asymmetries consistent with zero at  $10^{-3}$  level

# $\eta \rightarrow \pi^0 \pi^0 \pi^0$ dynamics

PRELIMINARY  
KLOE, arXiv:0707.4137



Dalitz plot density described with a single parameter:  $|A|^2 \propto 1 + 2\alpha z$

$$z = \frac{2}{3} \sum_{i=1}^3 \left( \frac{3E_i - M_\eta}{M_\eta - 3M_\pi} \right)^2 = \frac{\rho^2}{\rho_{\max}^2}$$

$E_i$  : Energy of the  $i$ -th pion in the  $\eta$  rest frame  
 $\rho$  : Distance from the center of the Dalitz plot  
 $\rho_{\max}$  : Maximum value of  $\rho$

$17 \times 10^6$   $\eta$  from  $\phi \rightarrow \eta \gamma$ . Tagging: recoil monochromatic photon (363 MeV)

Three different purity samples of photon pairing into  $\pi^0$ :

1. **LOW**      Purity = 75.4% ,  $\epsilon$  = 30.3%
2. **MEDIUM**    Purity = 92.0% ,  $\epsilon$  = 13.6%
3. **HIGH**       Purity = 97.6% ,  $\epsilon$  = 4.3%

$$\alpha = -0.027 \pm 0.004_{\text{stat}}^{+0.004}_{-0.006 \text{syst}}$$

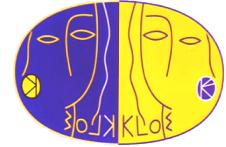
Systematics related to different purity results

Current best measurement from Crystal Ball:  $\alpha = -0.031 \pm 0.004_{\text{stat+syst}}$

Chiral unitarity approach calculation [Borasoy-Nissler,Eur.Phys.J.A26(2005)]:  $\alpha = -0.031 \pm 0.003$

# KLOE: $\eta \rightarrow \pi^0 \pi^0 \pi^0$ dynamics

**PRELIMINARY**  
KLOE, arXiv:0707.4137



Systematics:

$\gamma$  energy  
resolution

	Low Pur. $\sigma_{\alpha}^{syst} (\cdot 10^{-3})$	Med. Pur. $\sigma_{\alpha}^{syst} (\cdot 10^{-3})$	High Pur. $\sigma_{\alpha}^{syst} \alpha (\cdot 10^{-3})$
RES	-9	-4	-3
Range	-4	-4	$-3 + 3$
Purity	$-1 + 3$	+4	-4
BKG	0.	0.	$-1 + 1$
$M_{\eta}$	-1	-2	-5
<b>Total</b>	$-10 + 3$	$-6 + 4$	$-8 + 3$

Previous preliminary KLOE result:

$$\alpha = -0.014 \pm 0.004_{\text{stat}} \pm 0.005_{\text{syst}}$$

New preliminary KLOE result:

$$\alpha = -0.027 \pm 0.004_{\text{stat}}^{+0.004}_{-0.006_{\text{syst}}}$$

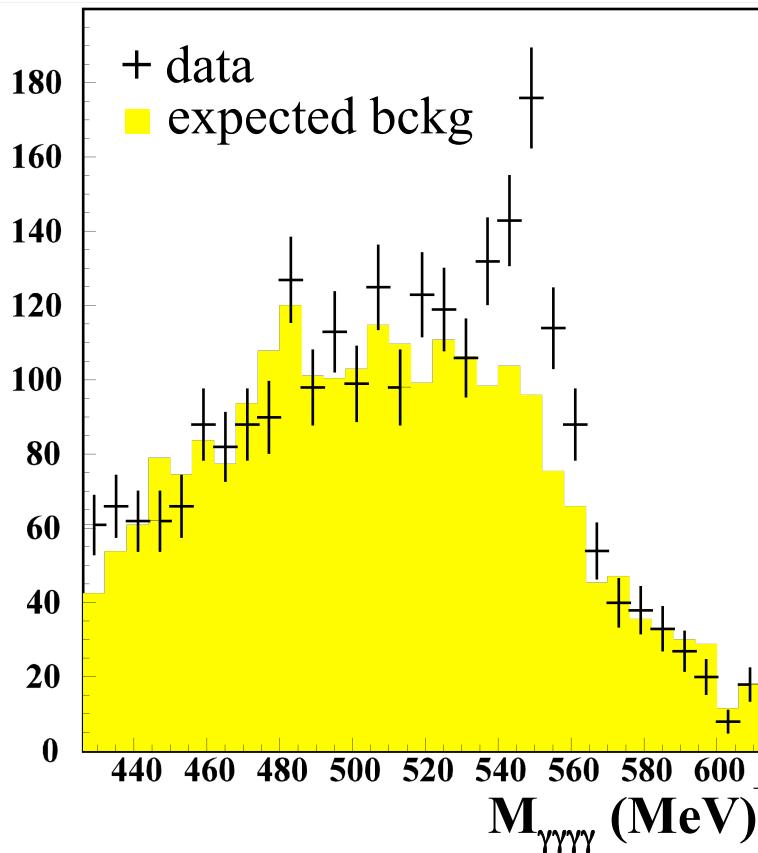
The  $M_{\eta}$  value used in generation was taken from PDG, 500 keV less than new KLOE measurement. This gave larger accessible phase space in data, and thus a higher value of  $\alpha$ . **Now the difference is properly taken into account**



# A flash on $\eta \rightarrow \pi^0 \gamma\gamma$

ChPT “golden mode”:  $p^2$  null,  $p^4$  suppressed,  $p^6$  dominates  
KLOE has presented a  $3\sigma$  signal (only 1/5 of full statistics)

$$\text{BR}(\eta \rightarrow \pi^0 \gamma\gamma) = (8.4 \pm 2.7_{\text{stat}} \pm 1.4_{\text{syst}}) \times 10^{-5}$$



**CB@MAMI-B:**  $\text{BR} = (22.5 \pm 4.6 \pm 1.7) \times 10^{-5}$   
**CB@AGS:**  $\text{BR} = (22.1 \pm 2.4 \pm 3.8) \times 10^{-5}$

**Analysis repeated with  $1.5 \text{ fb}^{-1}$   
(2005 data):**

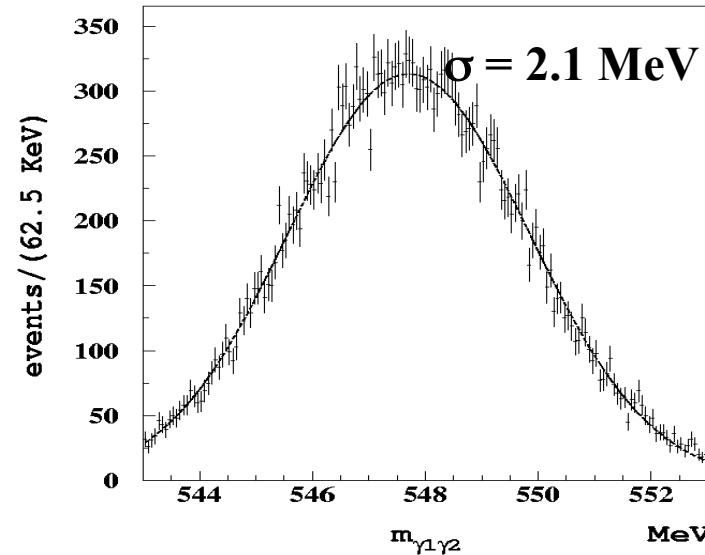
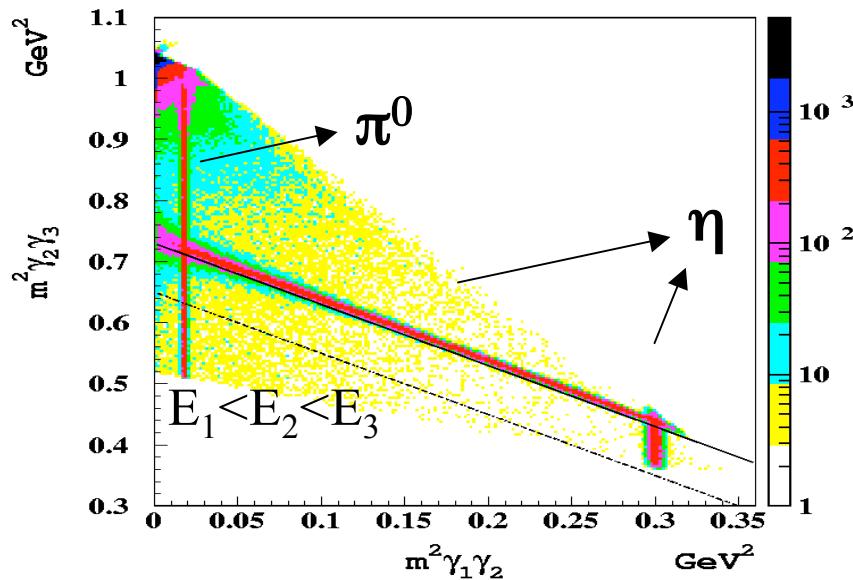
- the signal is confirmed
- BR updated result with the full sample will have  $\sim 15\%$  error

# Measurement of $\eta$ mass

EPJC12(2007)073



- ❖  $17 \times 10^6 \eta$  from  $\phi \rightarrow \eta\gamma$ : Kinematic fit applied on  $\phi \rightarrow \gamma\gamma\gamma$  events
- ❖  $\eta$  and  $\pi^0$  selected by looking at different Dalitz plot regions



$$M_\eta = (547.874 \pm 0.007 \pm 0.029) \text{ MeV}$$

Mass scale checked with  $M_{\pi^0}$ :  $1.4 \sigma$  from PDG06

Systematics dominated by uniformity of the detector response

