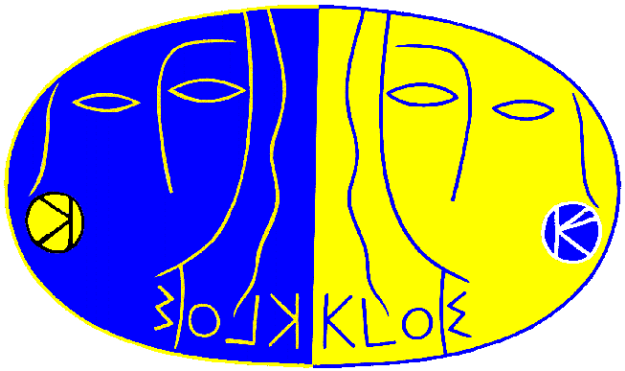
Hadron physics at KLOE: results and prospects



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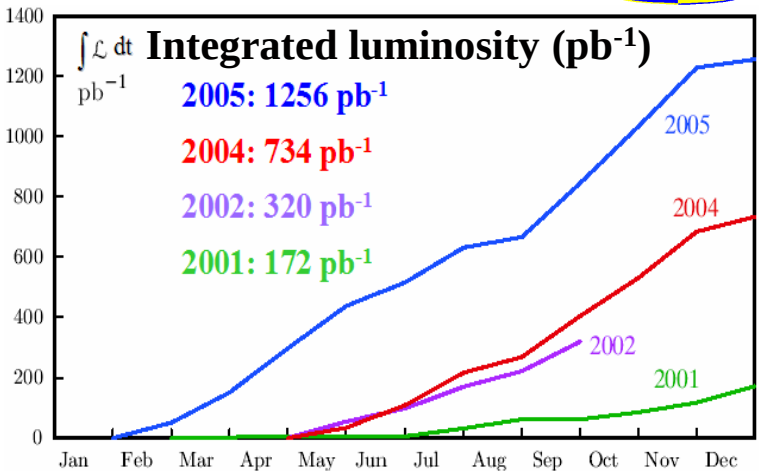
for the KLOE / KLOE-2 Collaborations

ICHEP 2010
23 July 2010 – Paris

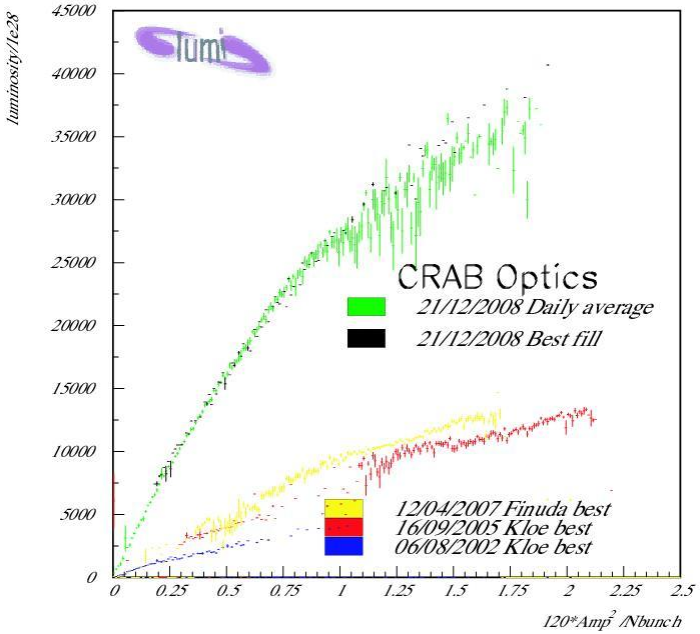
DAΦNE

- Frascati ϕ-factory: e^+e^- collider
  @ $\sqrt{s} \approx 1020$ MeV $\approx M_\phi$; $\sigma_{peak} \approx 3.1$ μb



- Best performances in 2005:
  - $L_{peak} = 1.4 \times 10^{32}\ cm^{-1}s^{-1}$
  - $\int Ldt = 8.5\ pb^{-1}/day$
- KLOE: 2.5 fb^{-1} @ $\sqrt{s}=M_\phi$ ($\Rightarrow 8\times10^9$ ϕ produced)
  + 250 pb^{-1} off-peak @ $\sqrt{s}=1000$ MeV

- DAΦNE upgrade:
  New interaction scheme implemented,
  large beam crossing angle +
  crabbed waist optics



⇒ Luminosity increase: factor ~ 3
$\int Ldt \approx 1\ pb^{-1}/hour$

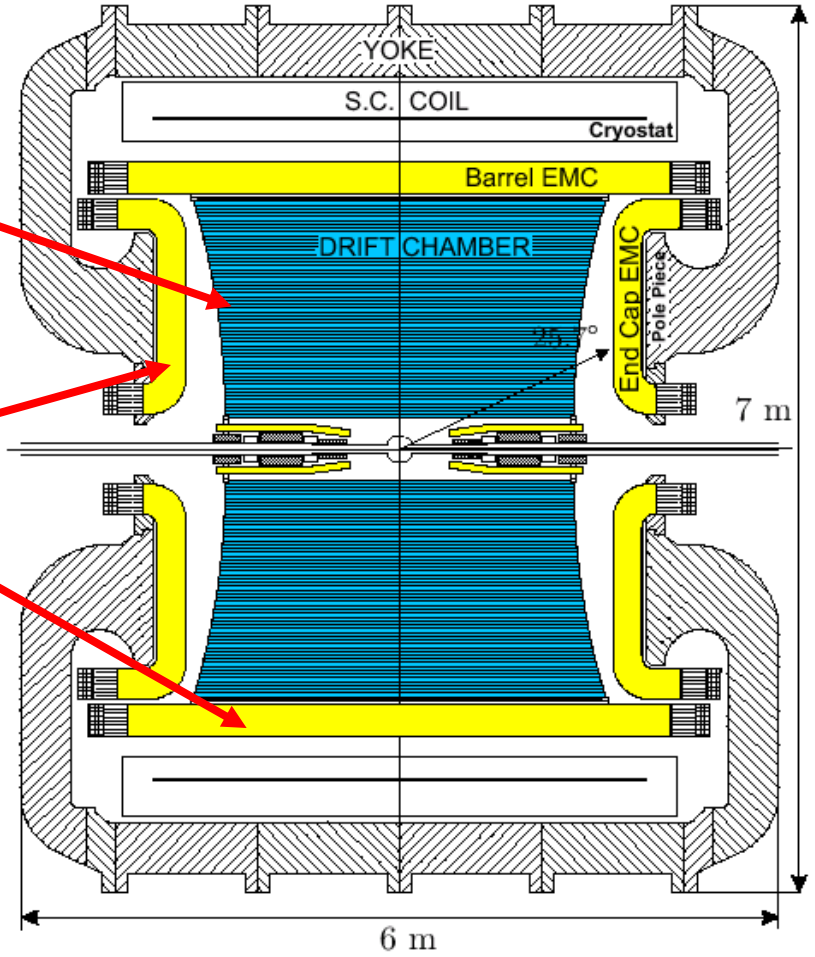
- DAΦNE commissioning start in September 2010
  for the KLOE-2 data-taking

KLOE

Drift chamber:
- gas: 90% He-10% iC_4H_{10}
- $\delta p_T/p_T = 0.4\%$
- $\sigma_{xy} \approx 150\ \mu m$; $\sigma_z \approx 2$ mm
- $\sigma_{vertex} \approx 1$ mm

E.m. calorimeter (Pb-Sci.Fi.):
- $\sigma_E/E = 5.7\% / \sqrt{(E(GeV))}$
- $\sigma_t = 55\ ps/\sqrt{(E(GeV))} \oplus 100\ ps$
- 98% of 4π

Magnetic field: 0.52 T



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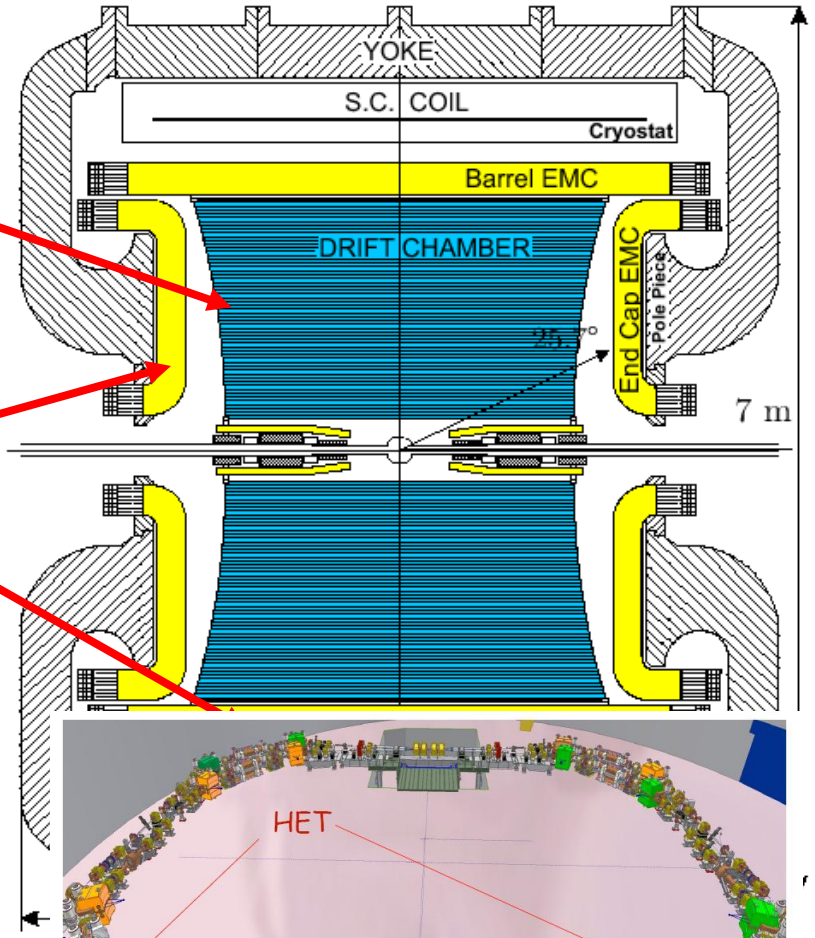
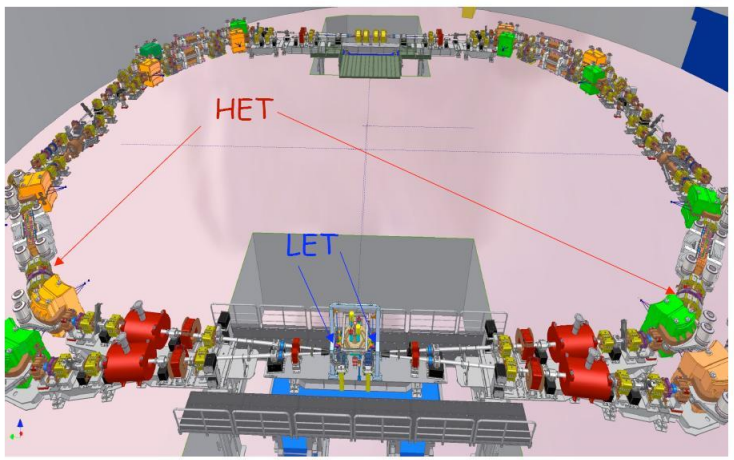




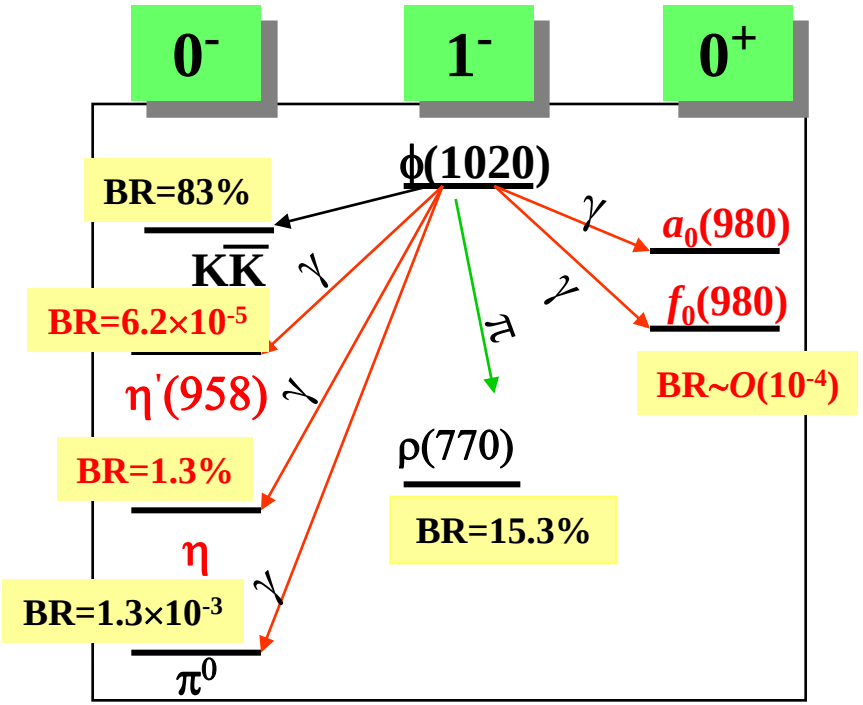
- **KLOE-2: two step upgrade**
  - 1) $e^{\pm}$ taggers for $\gamma\gamma$ physics (already installed)
  - 2) major upgrade(late 2011)
    - inner tracker +
    - new small angle calorimeters

(see F.Archilli's talk – Sess.13)

Physics at a ϕ-factory

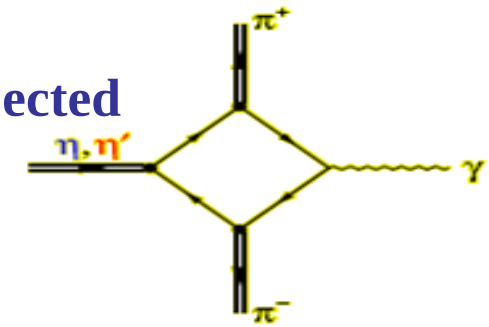
- Kaon physics: $|V_{us}|$ and CKM unitarity, CP and CPT violation, rare decays, χPT tests, quantum mechanics tests
- ϕ radiative decays: pseudoscalar and scalar mesons
- Hadron production in $\gamma\gamma$ collisions
- Hadronic cross-section via ISR [$e^+e^- \to \gamma\,(\pi^+\pi^-)$]: hadronic corrections to $(g-2)_\mu$

Decay channel	Events (2.5 fb^{-1})
K^+K^-	3.7×10^9
$K_L K_S$	2.5×10^9
$\rho\pi + \pi^+\pi^-\pi^0$	1.1×10^9
$\eta\gamma$	9.7×10^7
$\pi^0\gamma$	9.4×10^6
$\eta'\gamma$	4.6×10^5
$\pi\pi\gamma$	2.2×10^6
$\eta\pi^0\gamma$	5.2×10^5



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

- ϕ-factory $\Rightarrow$ $\phi \to \eta\gamma$: large samples of η
  $\Rightarrow L = 2.5\ fb^{-1} \Rightarrow 8 \times 10^9\ \phi \Rightarrow \sim 10^8\ \eta$
- $\eta \to \pi^+\pi^-\gamma$: significant contribution from box anomaly expected
- $M_{\pi\pi}$ distribution needed to evaluate box anomaly vs resonant (ρ-dominated) contributions
- Existing measurements not sufficient for unambiguous interpretation [Benayoun et al., EPJC31, 525 (2003)]



- Recent CLEO result more than 2 σ lower than previous measurements

$\Gamma(\eta \to \pi^+\pi^-\gamma) / \Gamma(\eta \to \pi^+\pi^-\pi^0)$

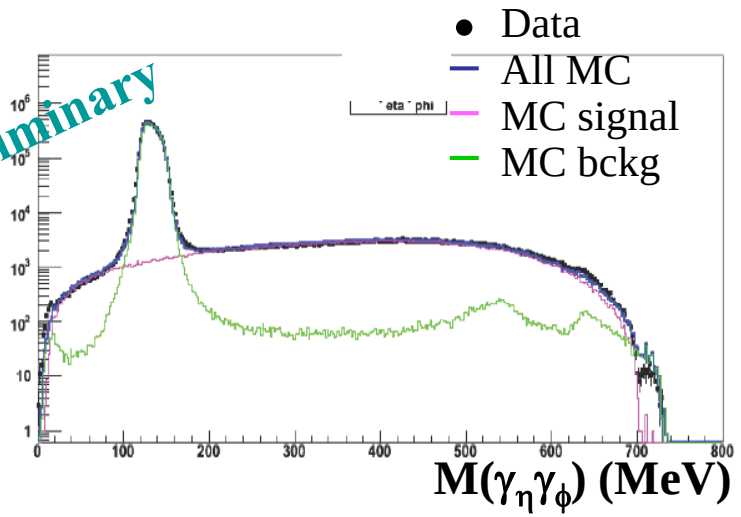
value	events	author	year
0.203 ± 0.008	PDG average		
0.175 ± 0.007 ± 0.006	859	Lopez	2007
0.209 ± 0.004	18 k	Thaler	1973
0.201 ± 0.006	7250	Gormley	1970

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

- $\phi \to \eta\gamma$, $\eta \to \pi^+\pi^-\gamma$: 6×10^5 events in 1.2 fb^{-1}
- Normalization to $\eta \to \pi^+\pi^-\pi^0$
- Main background: $\phi \to \pi^+\pi^-\pi^0$
- Simultaneous fit on $M_{\gamma\gamma}$ and $\cos\vartheta_{\gamma\gamma}$

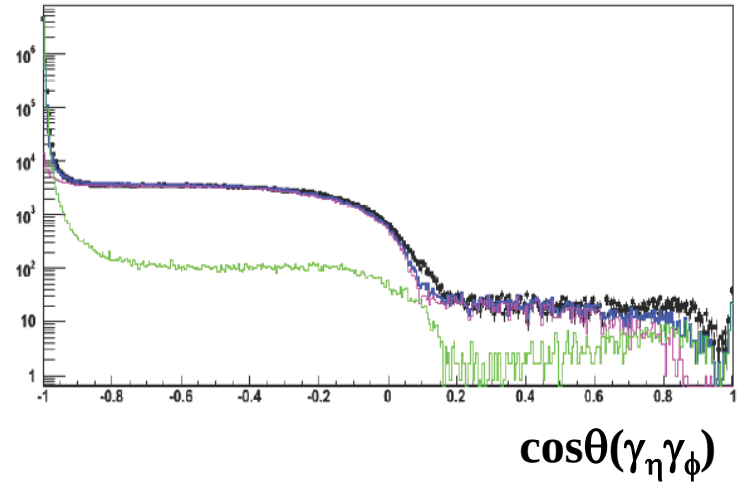
$$\frac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)} = 0.201 \pm 0.006_{\text{stat}\oplus\text{syst}}$$

KLOE preliminary



- Improving the systematics $\Rightarrow$ ~ 1%
- Agreement with the older measurements

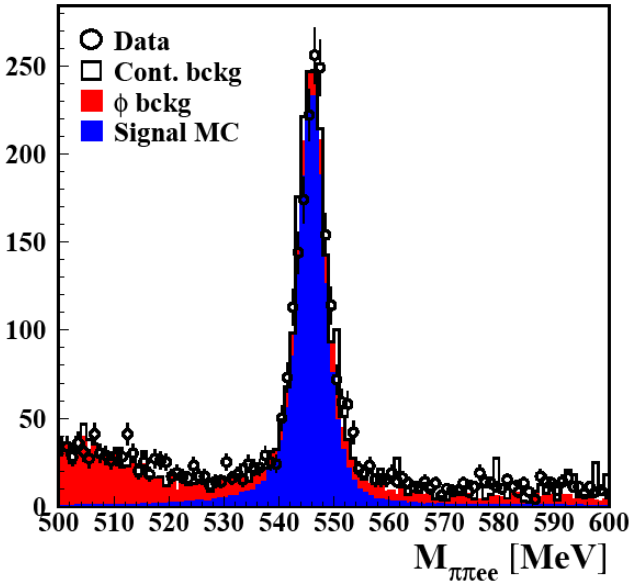
- Prospects:
  - Use the full KLOE data set to investigate the $\pi^+\pi^-$ invariant mass distribution
  - $\eta' \to \pi^+\pi^-\gamma$: ~ 10^5 events expected from first KLOE-2 run
    $\Rightarrow$ combined $\eta/\eta' \to \pi^+\pi^-\gamma$ analysis



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

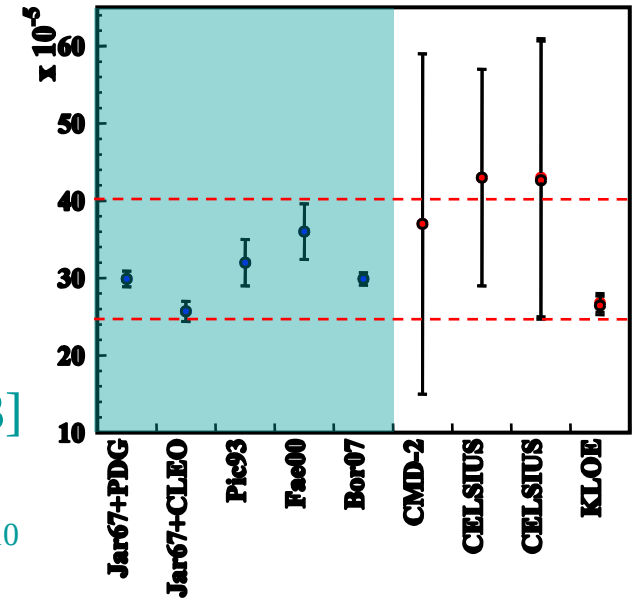
- Rare decay: χPT and VDM predictions $\Rightarrow$ Br ~ 3×10^{-4}
- 2 measurements: CMD-2 4 events
  WASA@CELSIUS 16 events

- Data sample: 1.73 fb^{-1}
- M($\pi^+\pi^-e^+e^-$) distribution:
  fit with signal + background (MC)
  $\Rightarrow$ 1555 ± 52 signal events
  368 background "



$$Br(\eta \to \pi^+\pi^-e^+e^-(\gamma)) = (26.8 \pm 0.9 \pm 0.7) \times 10^{-5}$$

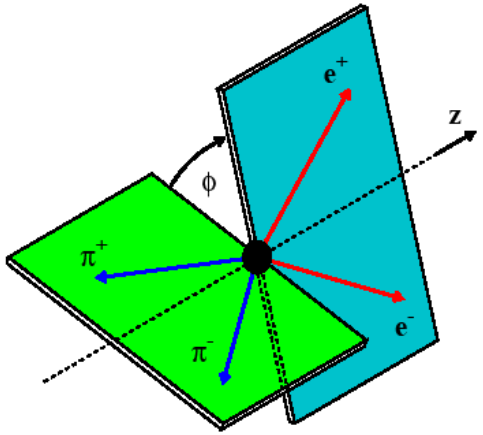
[PLB675(2009)283]



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

- **Plane asymmetry ⇒ test of CP violation**
- **Constraints from Br($\eta \to \pi^+\pi^-$): expt. $A_{CP} < 10^{-4}$**
  th. (SM) $A_{CP} < 10^{-15}$

$$A_{CP} = \frac{N(\sin\phi\cos\phi > 0) - N(\sin\phi\cos\phi < 0)}{N(\sin\phi\cos\phi > 0) + N(\sin\phi\cos\phi < 0)}$$

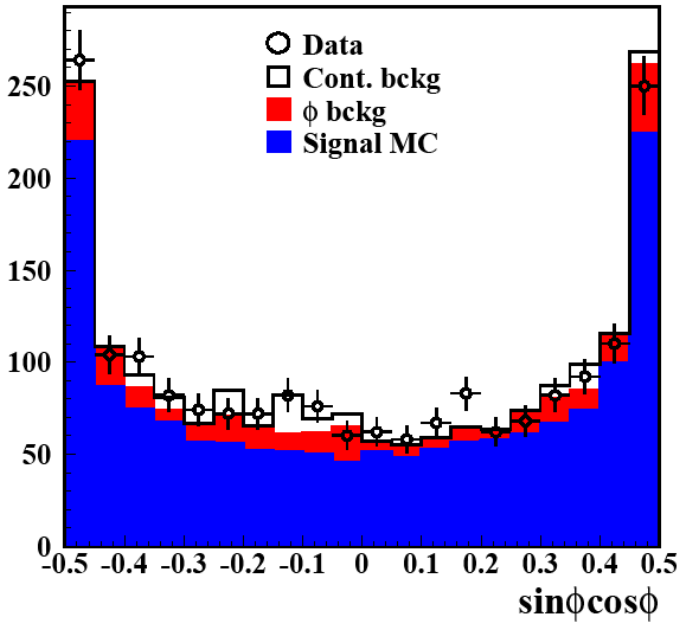


- **Non conventional CP violation mechanism (non CKM) proposed ⇒ A_{CP} up to 2×10^{-2}**

[D.N.Gao MPLA17(2002)]

$A_{CP} = (-0.6 \pm 2.5 \pm 1.8) \times 10^{-2}$

[PLB675(2009)283]



- **KLOE-2**
  - **with $O(10\ fb^{-1}) \Rightarrow \delta Br \sim 1.4\%$ (stat.)**
    $\delta A_{CP} \sim 1.2\%$ (")
  - **reduce systematics**
  - **$O(20\ fb^{-1})$ with IT ⇒ $\delta A_{CP} < 1\%$**

2010

$\eta \to \pi^0\pi^0\pi^0$

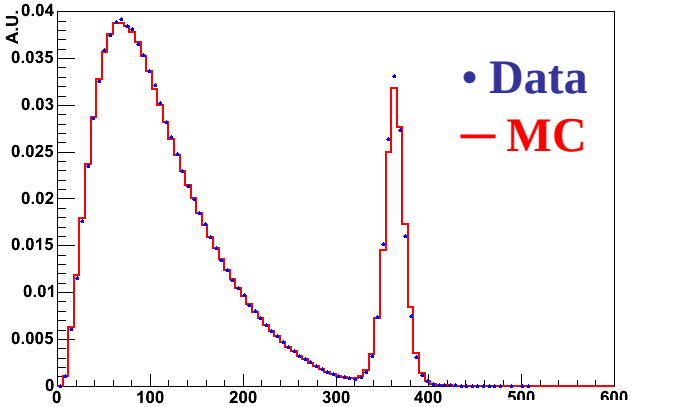
- $\eta \to \pi\pi\pi$ decay $\Rightarrow$ Isospin violation $L_I = -\frac{1}{2}(m_u - m_d)(\bar{u}u - \bar{d}d)$

- Symmetric Dalitz plot:

  $|A|^2 \propto 1 + 2\,\alpha\, Z$ $\Rightarrow$ only one parameter

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

  (ρ = distance from the Dalitz plot center)

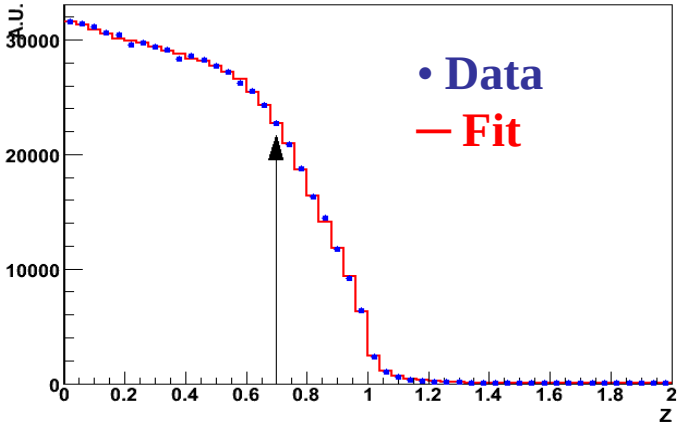


- 450 pb^{-1} ; 7 prompt photons

  $\Rightarrow$ 6.5 $\times 10^5$ events

$$\alpha = -0.0301 \pm 0.0035^{+0.0022}_{-0.0036}$$

[arXiv:1004.1319, submitted to PLB]



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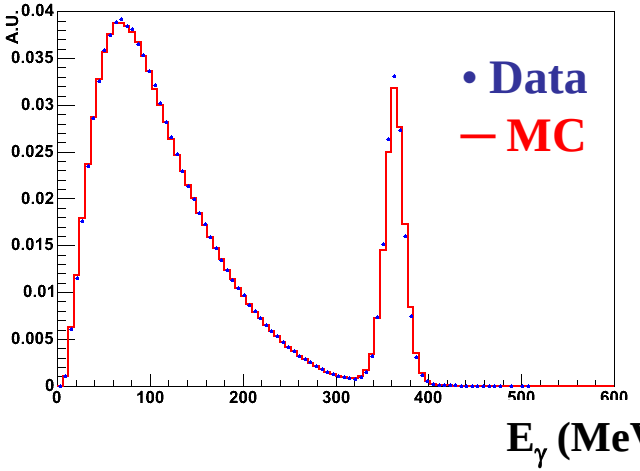

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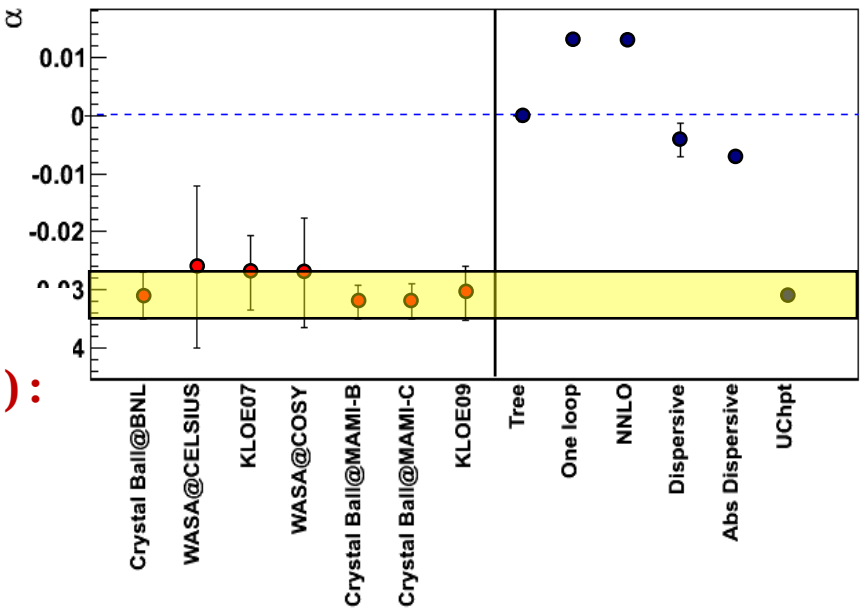
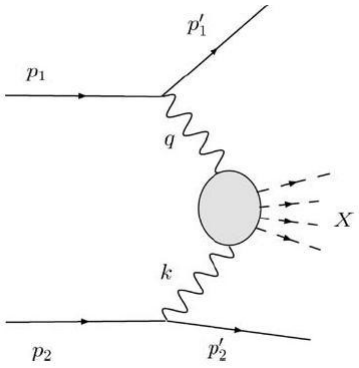


Strong interactions mix the two amplitudes A($\eta \to \pi^+\pi^-\pi^0$) and A($\eta \to \pi^0\pi^0\pi^0$) : from the Dalitz plot of $\eta \to \pi^+\pi^-\pi^0$

$\Rightarrow$ $\alpha = -0.038 \pm 0.003^{+0.012}_{-0.008}$

[JHEP0805(2008)006]

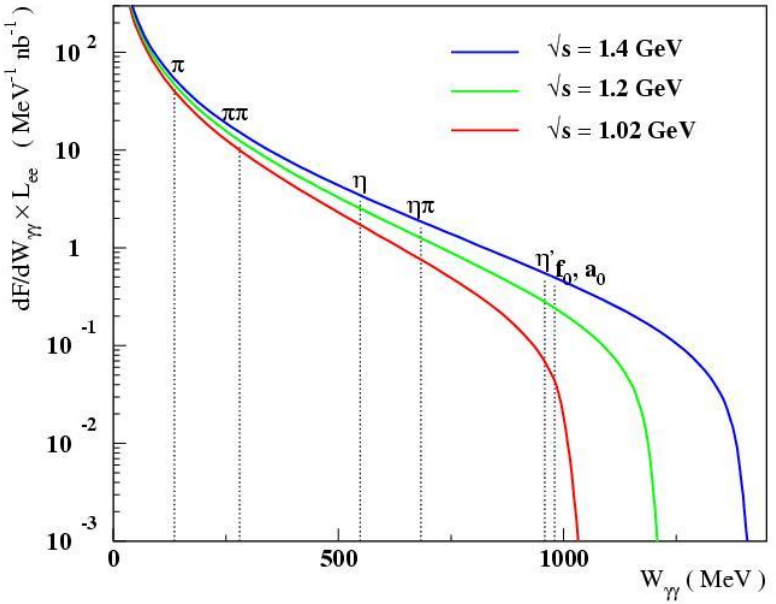
γγ physics



$$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-X$$

$$[C(X) = +1]$$

$$\frac{dN}{dW_{\gamma\gamma}} = L_{int}\frac{dF}{dW_{\gamma\gamma}}\sigma(\gamma\gamma \to X)$$



- **X = ππ ⇒ search for σ(600)**

- **X = π^0, η, (η')**
  - **Γ(X→γγ)**
  - **Transition form factors $\mathcal{F}_{X\gamma^*\gamma^*}(q_1^2,q_2^2)$**
- **KLOE: no $e^\pm$ tagging ⇒ $\sqrt{s}$ = 1 GeV**
- **KLOE-2: $\sqrt{s} = M_\phi$ ⇒ Tagger is essential to reduce the background from the φ and to close the kinematics**
  - **If $\sqrt{s}$ →1.4 GeV ⇒ γγ coupling of $a_0(980)$, $f_0(980)$**

σ(600)

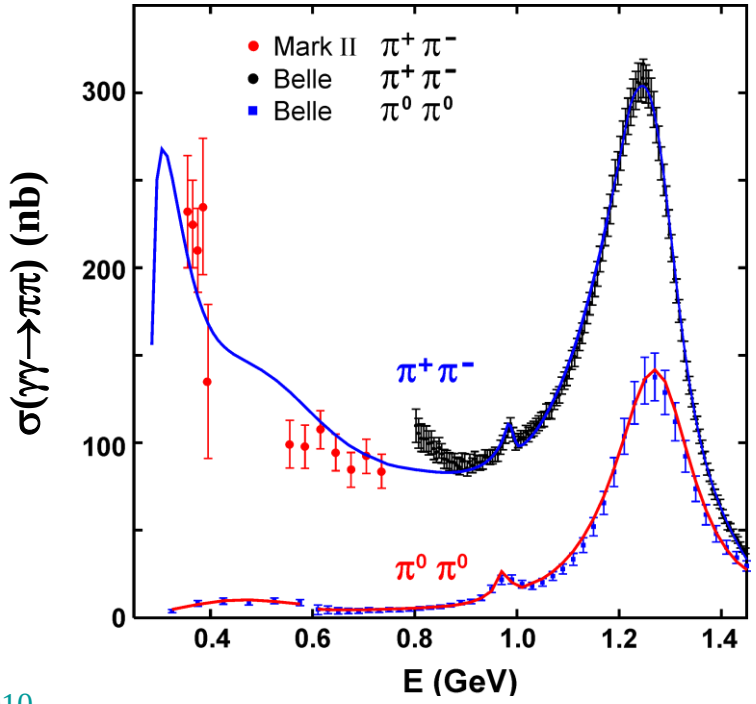
$\gamma\gamma \to \sigma(600) \to \pi\pi$

Motivations: pole in the $\pi\pi$ scattering with vacuum quantum numbers ($J^{PC}=0^{++}$)

$$m_\sigma = 441^{+16}_{-8}\,\text{MeV}, \Gamma_\sigma = 544^{+24}_{-18}\,\text{MeV}$$

[Caprini et al., PRL96(2006)132001]

- **Observations by E791 in $D^+ \to \pi^+\pi^+\pi^-$ (m_σ=478 MeV, Γ_σ=324 MeV) and BES II in $J/\psi \to \omega\pi^+\pi^-$ (m_σ=541±39 MeV, Γ_σ=504±84 MeV) (and by FOCUS, CLEO)**
- **Indirect σ(600) evidence in $e^+e^- \to \pi^0\pi^0\gamma$ Dalitz plot by KLOE**
- $e^+e^- \to e^+e^-\pi\pi$



[from M.Pennington]

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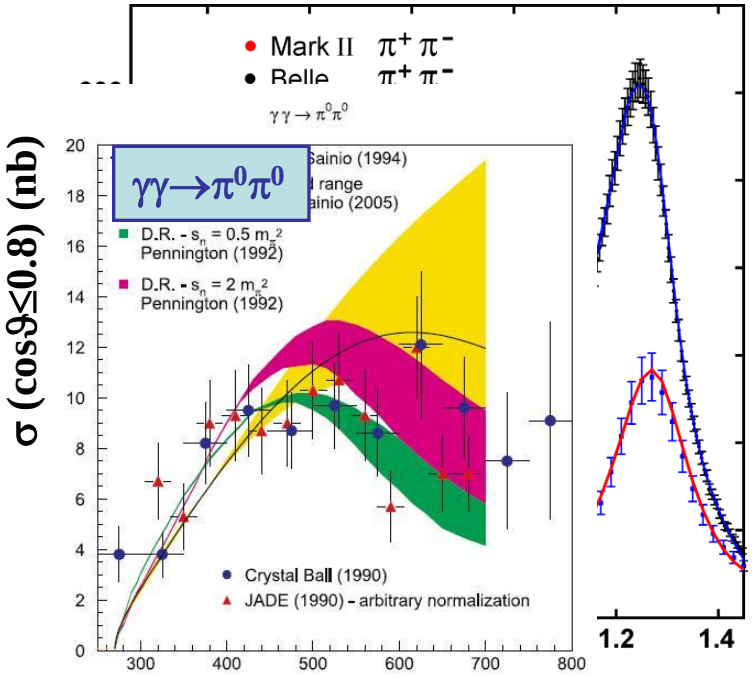
- **Indirect $\sigma(600)$ evidence in $e^+e^- \to \pi^0\pi^0\gamma$ Dalitz plot by KLOE**

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

  $\pi^0\pi^0 \Rightarrow$ **golden channel**

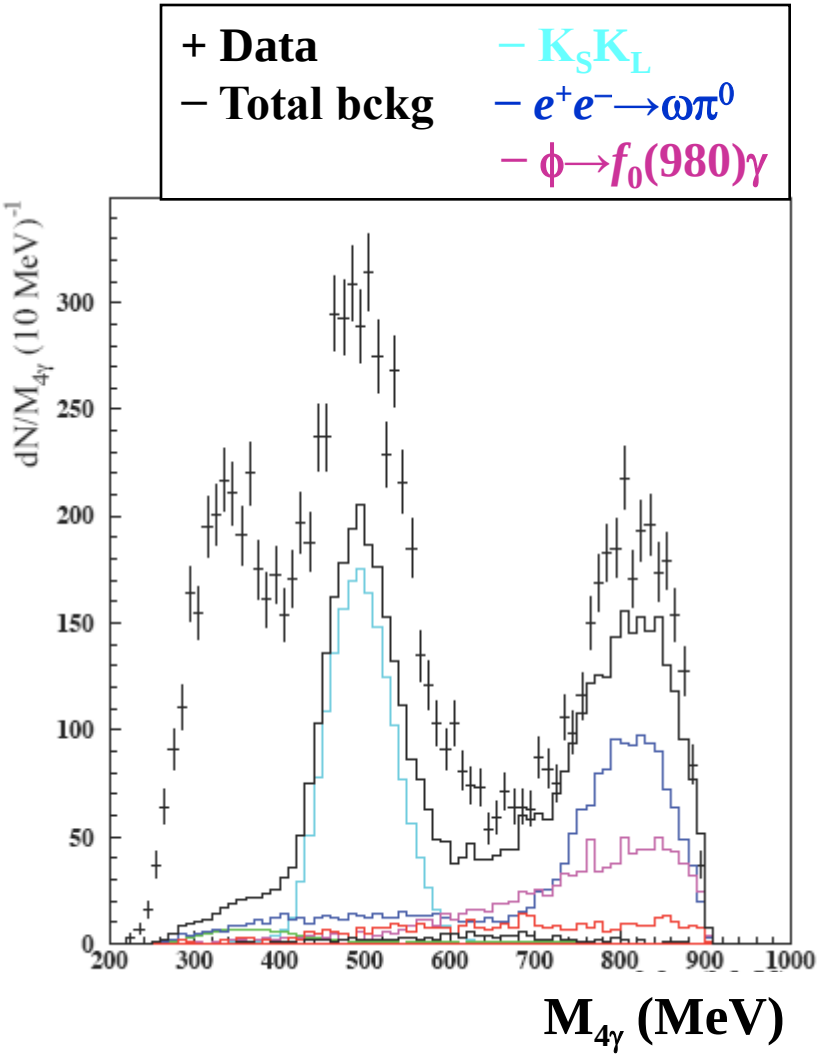
  $\pi^+\pi^-$: **large background from** $e^+e^- \to e^+e^-\mu^+\mu^-$ **and from** $e^+e^- \to \pi^+\pi^-\gamma^* \to \pi^+\pi^-e^+e^-$



$\gamma\gamma \to \pi^0\pi^0$

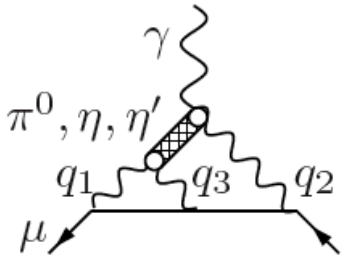
- KLOE: 240 pb^{-1} off-peak ($\sqrt{s}$ = 1 GeV)
  no $e^{\pm}$ tagging
- ~ 10000 events with 4 prompt γ's
- ~ 4000 events after bckg subtraction
- $\gamma\gamma \to \pi^0\pi^0$ cross-section evaluation in progress

KLOE-2: O(10 fb^{-1})at $\sqrt{s} = M_\phi$ with
$e^{\pm}$ tagging
$\Rightarrow$ 2% statistical accuracy
using the same energy bin as Crystal Ball

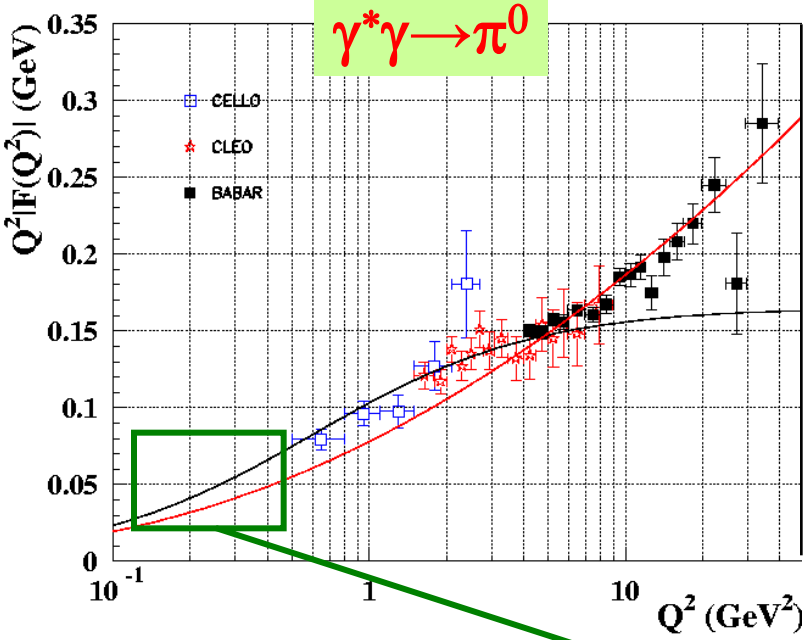


$\gamma\gamma \rightarrow$ single pseudoscalar

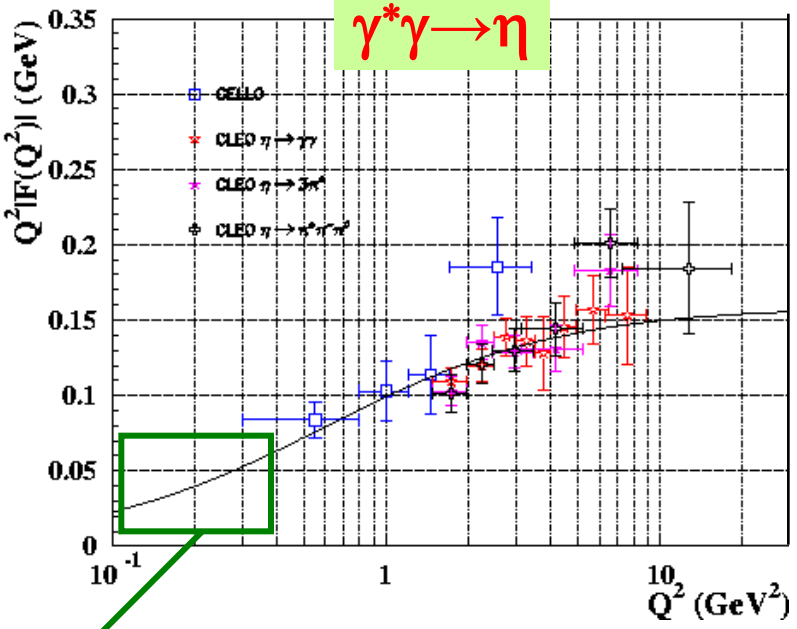
- Measurement of $\Gamma(P \rightarrow \gamma\gamma)$
- Transition form factors $\mathcal{F}_{P\gamma^*\gamma^*}(q_1^2, q_2^2)$:
  - input for the calculation of the Light-by-Light contribution to g-2 of the muon



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



$\gamma^*\gamma \rightarrow \eta$



KLOE-2

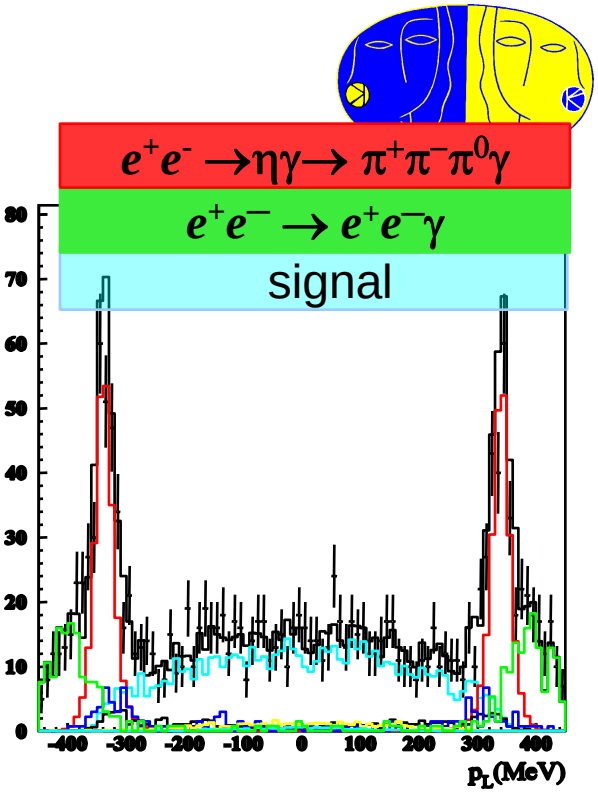
$\gamma\gamma \rightarrow \eta$

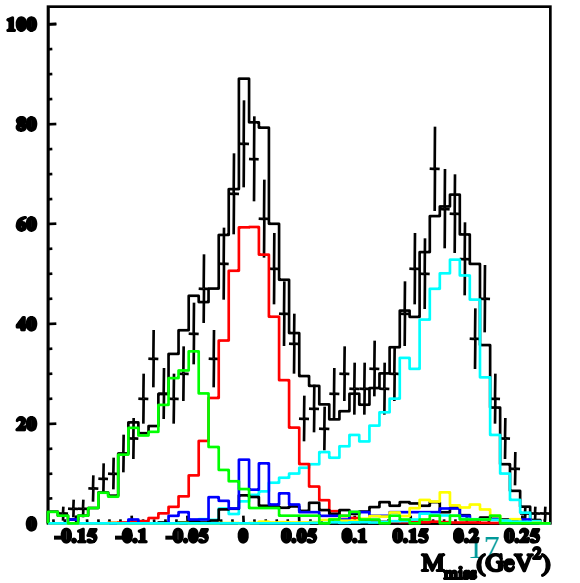
- **KLOE: 240 pb^{-1} off-peak ($\sqrt{s}$ = 1 GeV) without $e^{\pm}$ tagging**

- **Selected decay channel: $\eta \rightarrow \pi^+\pi^-\pi^0$**
- **Main bckg: $e^+e^- \rightarrow \eta\gamma \rightarrow \pi^+\pi^-\pi^0\gamma$**

- **Fit to η longitudinal momentum (p_L) and missing mass (M_{miss})**
  $\Rightarrow$ ~ 600 events

- **Extraction of $\sigma(e^+e^- \rightarrow e^+e^-\eta)$ and $\Gamma(\eta \rightarrow \gamma\gamma)$ in progress**



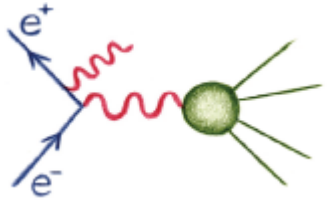


$\sigma(e^+e^- \to \text{hadr.})$ below 1 GeV

- ~ 3 σ discrepancy between $a_\mu^{SM} - a_\mu^{exp}$ $[a_\mu = (g_\mu - 2)/2]$
- $a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{had}$ → main contribution to the uncertainty on a_μ^{SM}

$$a_\mu^{had,LO} = 1/(4\pi^3)\int_{4m_\pi^2}^{\infty} \sigma(e^+e^- \to \text{hadr.})K(s)\,ds \quad ; \quad K(s) \sim 1/s$$

- $\sigma(e^+e^- \to \text{hadr.})$ below 1 GeV is dominated by $e^+e^- \to \pi^+\pi^-$
- φ - factory: fixed √s ⇒ Initial State Radiation method



$$s \cdot \frac{d\sigma(e^+e^- \to \pi^+\pi^- + \gamma)}{ds_\pi} = \sigma(e^+e^- \to \pi^+\pi^-)\, H(s, s_\pi)$$

- Two different analyses: (1) photon emitted at Small Angle (S.A. analysis)

[PLB606(2005)12, PLB670(2009)285]

(2) photon emitted at Large Angle (L.A. analysis)

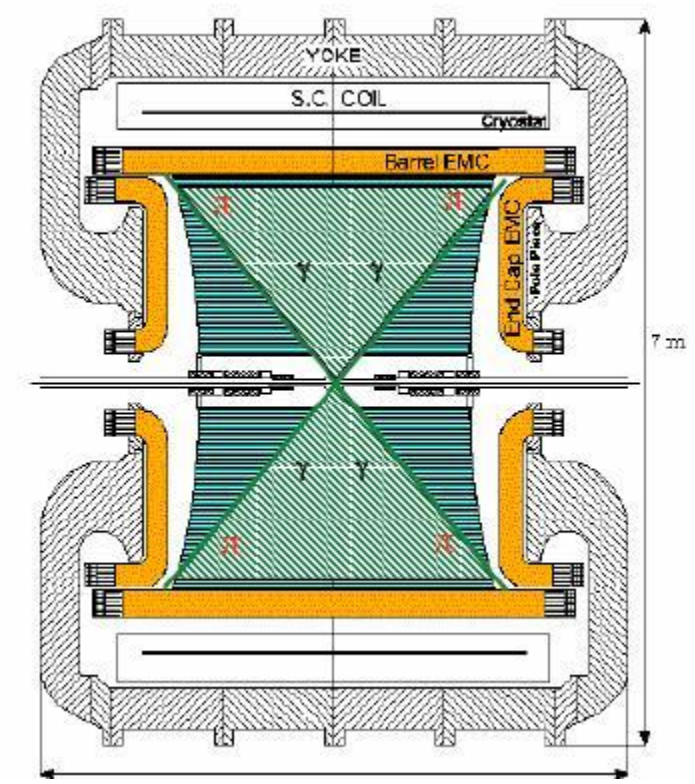
[arXiv:1006:5313, submitted to PLB]

L.A. analysis

- 2 pions at large angle (ϑ>50°)
- Photon detected at large angle (ϑ>50°)
- Kinematics closed
- Threshold region accessible
- Lower statistics
- Larger contribution from FSR

Larger background from $\phi \to \pi^+\pi^-\pi^0$

Irreducible background from $\phi \to f_0\gamma \to \pi^+\pi^-\gamma$



Use data collected at $\sqrt{s}$ = 1 GeV, below the ϕ peak:

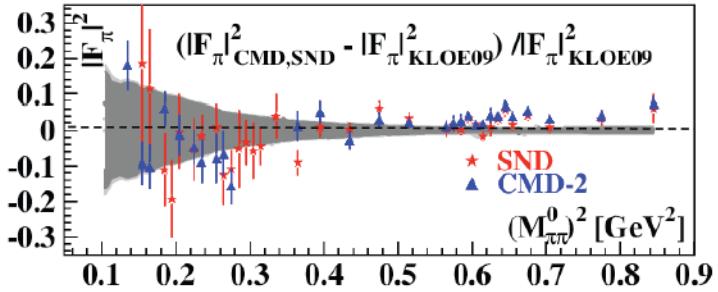
233 pb^{-1} from 2006 data-taking

Result on L.A. analysis

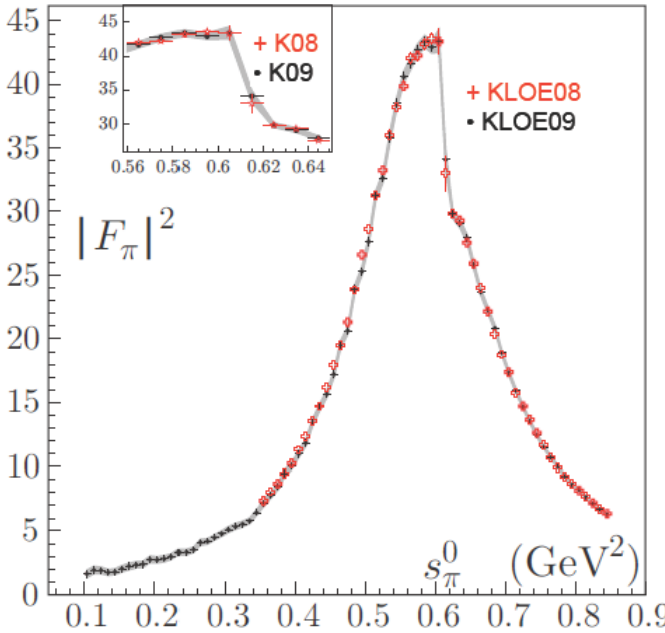
- **Good agreement between S.A. (KLOE08) and L.A. (KLOE09) analyses**

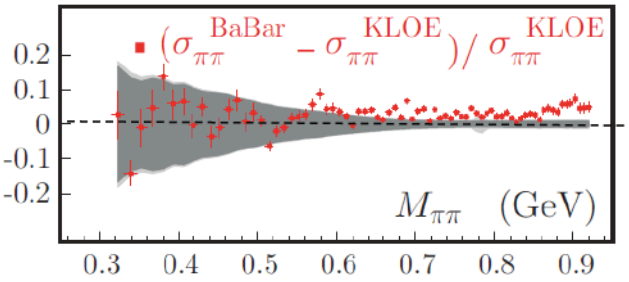
$a_\mu^{\pi\pi}(0.1\text{–}0.85\ \mathrm{GeV}^2) = (478.5 \pm 2.0_{stat} \pm 4.8_{sys} \pm 2.9_{theo}) \times 10^{-10}$

[arXiv:1006:5313, submitted to PLB]

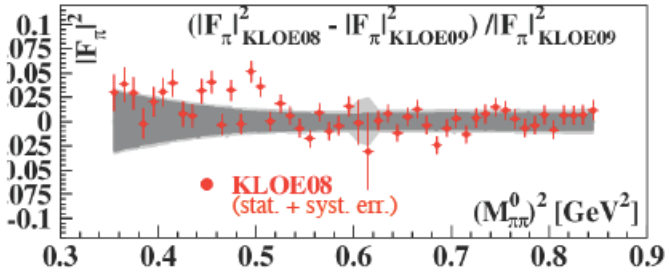


Agreement with CMD-2 and SND





Above 0.6 GeV BaBar higher by 2 – 3%



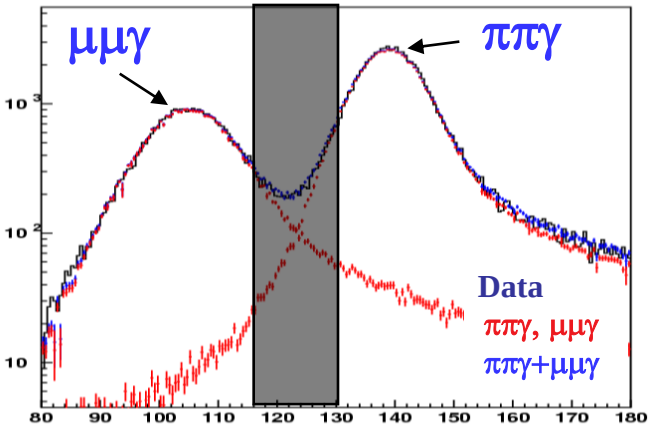
(Grey band = L.A. error)

- **3.2 σ discrepancy a_μ^{SM} - a_μ^{exp} confirmed**

Prospects on σ_{had}

- **In progress:** $|F_\pi|^2$ **from the ratio** $\sigma(e^+e^-\to\pi^+\pi^-\gamma)/\sigma(e^+e^-\to\mu^+\mu^-\gamma)$

$$|F_\pi(s')|^2 \approx \frac{4\left(1+2m_\mu^2/s'\right)\beta_\mu}{\beta_\pi^3} \quad \frac{d\sigma_{\pi\pi\gamma}/ds'}{d\sigma_{\mu\mu\gamma}/ds'}$$



- **Many factors cancel in the ratio:**
  - **radiator function**
  - **luminosity from Bhabhas**
  - **vacuum polarization**

$$\left(\sqrt{s}-\sqrt{p_1^2+M_{trk}^2}-\sqrt{p_2^2+M_{trk}^2}\right)^2-(p_1+p_2)^2=0$$

- **KLOE-2:**

  $\delta\sigma \sim 0.4\%$ for $\sqrt{s} < 1$ GeV with ISR @ 1 GeV, 2 fb^{-1}

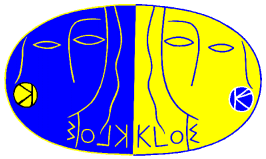
  $\delta\sigma \sim 2\%$ for $1<\sqrt{s} < 2$ GeV with energy scan

  (if DAΦNE energy $\to$ 2 – 2.5 GeV)

Conclusions

- **Important results have been achieved by KLOE in hadron physics:**
  - **η rare decays: $\eta\to\pi^+\pi^-\gamma$, $\eta\to\pi^+\pi^-e^+e^-$, $\eta\to e^+e^-e^+e^-$**
  - **Dalitz plot of $\eta\to 3\pi$**
  - **η–η' mixing and gluonium in η'; $\eta\to\pi^0\gamma\gamma$, ……**
  - **Precision measurements of Br($\phi\to f_0(980)\gamma$) and Br($\phi\to a_0(980)\gamma$) and of the scalar resonance parameters**
  - **Upper limit for $\phi\to(f_0/a_0)\gamma\to K^0\overline{K}^0\gamma$**
  - **$\gamma\gamma$ physics: $\gamma\gamma\to\pi^0\pi^0$ and $\gamma\gamma\to\eta$ at $\sqrt{s}$ = 1 GeV**
  - **$\sigma(e^+e^-\to$hadr.) with ISR: Small Angle + Large Angle analyses confirm the 3.2 σ discrepancy between a_μ^{SM} and a_μ^{exp}**
- **KLOE-2 data-taking start in September 2010:**
  - **$e^\pm$ taggers for $\gamma\gamma$ physics are being installed**
  - **possibility of new and more precise measurements in hadron physics**

KLOE-2 physics program



Goal: ~20 fb^{-1} in the next 3 – 4 years to extend the KLOE physics program at DAΦNE upgraded in luminosity (approved) and energy up to 2.4 GeV (under discussion):

G.Amelino-Camelia et al., arXiv:1003.3868, DOI:10.1140/epjc/s10052-010-1351-1

- **$\gamma\gamma$ physics**
  - **Existence (and properties) of $\sigma(600)$**
  - **Study of $\Gamma(S/P\rightarrow\gamma\gamma)$**
  - **P transition form factor**
- **Light meson spectroscopy**
  - **Properties of scalar/vector mesons**
  - **Rare η decays**
  - **η' physics**
- **Kaon physics**
  - **Test of CPT (and QM) in correlated kaon decays**
  - **Test of CPT in K_S semileptonic decays**
  - **Test of SM (CKM unitarity, lepton universality)**
  - **Test of χPT (K_S decays)**
- **Dark matter searches**
  - **Light bosons @ O(1 GeV)**
- **Hadronic cross section**
  - **$\alpha_{em}(M_Z)$ and $(g_\mu-2)$**

Spare slides

Result on L.A. analysis

- **Good agreement between S.A. (KLOE08) and L.A. (KLOE09) analyses**

$a_\mu^{\pi\pi}(0.1\text{–}0.85\ \mathrm{GeV}^2) = (478.5 \pm 2.0_{stat} \pm 4.8_{sys} \pm 2.9_{theo}) \times 10^{-10}$

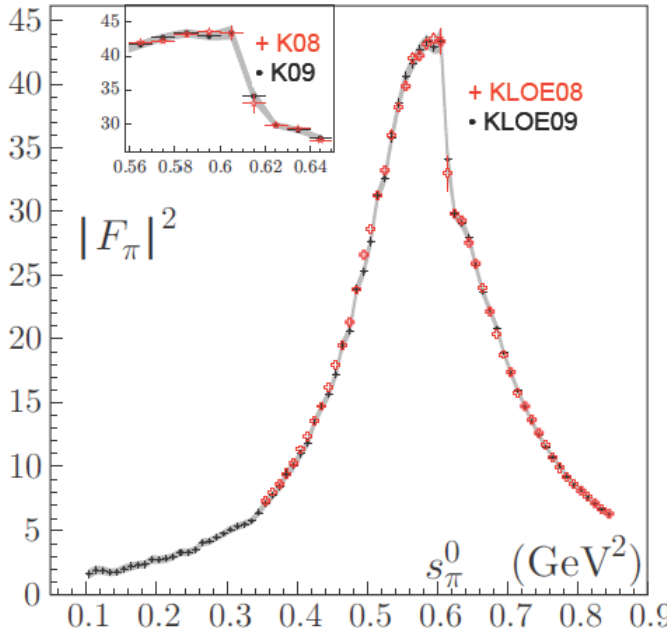
[arXiv:1006:5313, submitted to PLB]

- **Agreement with CMD-2 and SND, some difference with BaBar**
- **3.2 σ discrepancy $a_\mu^{SM} - a_\mu^{exp}$ confirmed**
- **In progress: measurement of the $\sigma(e^+e^- \to \pi^+\pi^-)$ from the ratio $\pi^+\pi^-\gamma$ / $\mu^+\mu^-\gamma$ (radiator function, int. luminosity and vacuum polarization cancel)**
- **KLOE-2:**

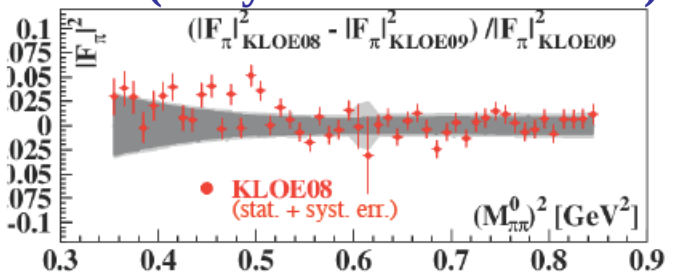
$\delta\sigma \sim 0.4\%$ for $\sqrt{s} < 1$ GeV with ISR @ 1 GeV, 2 fb^{-1}

$\delta\sigma \sim 2\%$ for $1 < \sqrt{s} < 2$ GeV with energy scan

(if DAΦNE energy → 2 – 2.5 GeV)

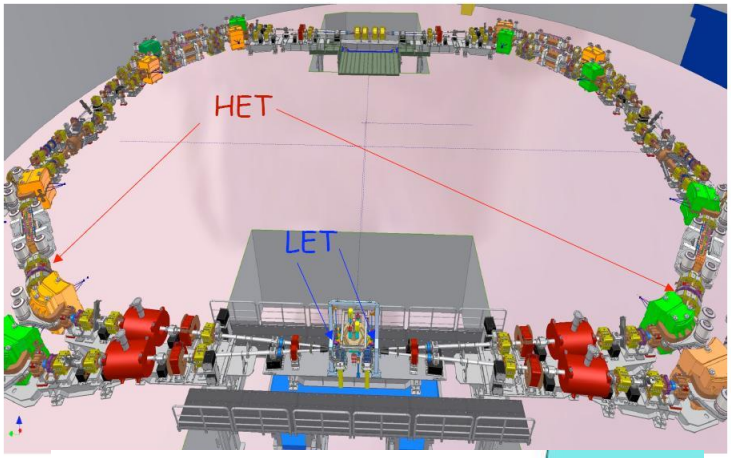


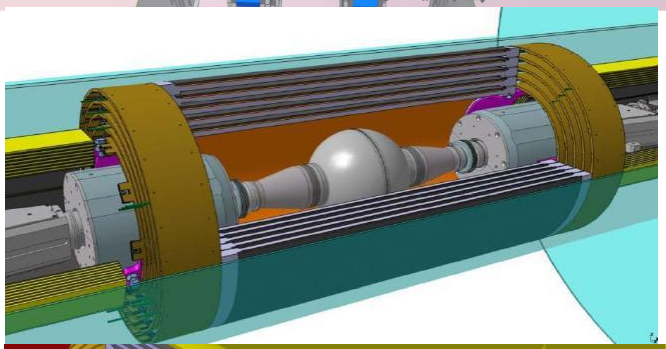
(Grey band = L.A. error)

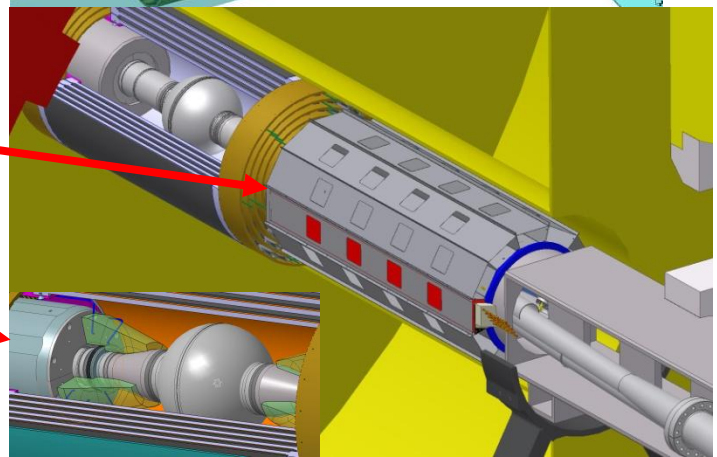


KLOE-2

- **Two step upgrade:**
  - **1) First run (~ 5 fb^{-1} in one year data-taking)**
    - ***e*$^{\pm}$ taggers for γγ physics:**
      - **Low Energy Tagger (E_e=130-230 MeV)**
        Inside KLOE
        Calorimeters: LYSO + SiPM
      - **High Energy Tagger (E_e > 400 MeV)**
        11 m far from IP
        Scintillators + PMT
  - **2) Major upgrade (late 2011)**
    - **Inner tracker : 4 layers of cylindrical GEM**
    - **QCALT: W + scint. tiles + SiPM**
    - **CCAL : LYSO + APD**

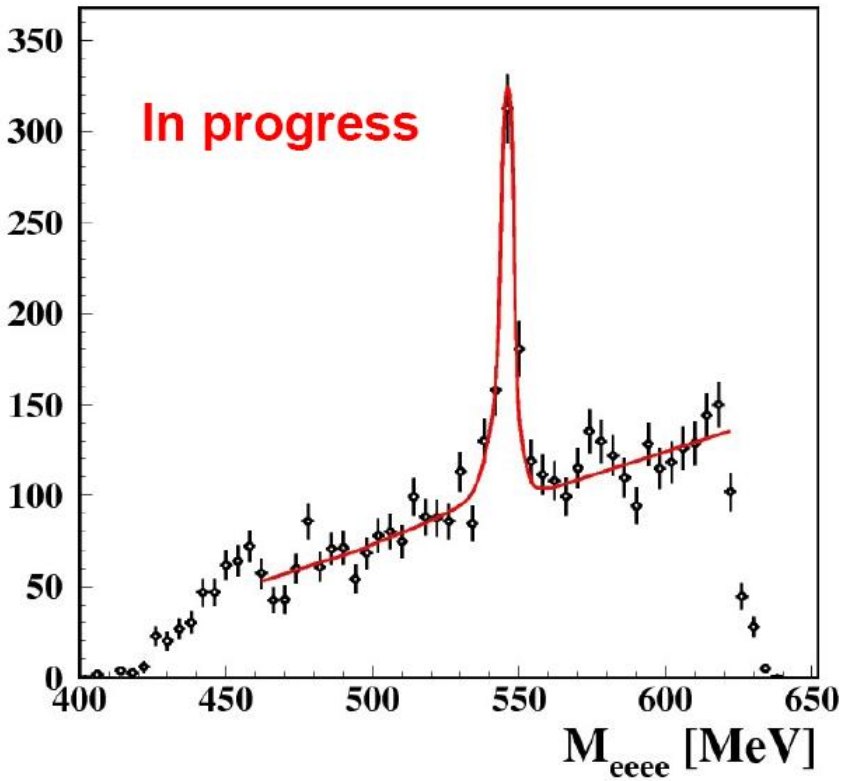






$\eta \to e^+e^-e^+e^-$

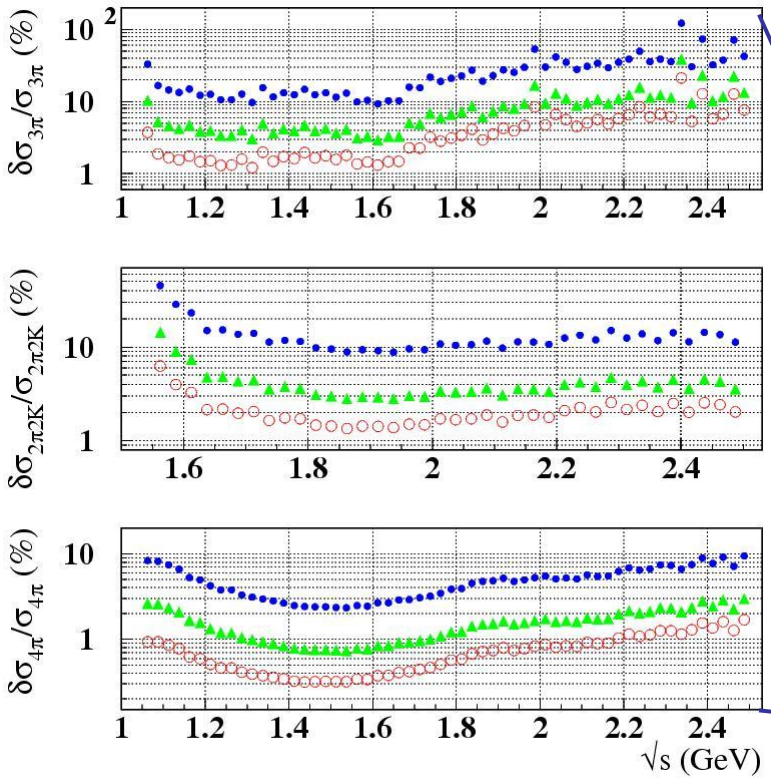
- **Never observed before**
  Br < 6.9×10^{-5} @90%C.L. (CMD-2)
- **Theoretical predictions: ~ 2.5 – 2.6 $\times10^{-5}$**
- **Same data set analyzed for $\eta \to \pi^+\pi^-e^+e^-$**
- **MC simulation according to**
  Bijnens and Persson [hep-ph/0106130]
- **Fit with signal + background from continuum**

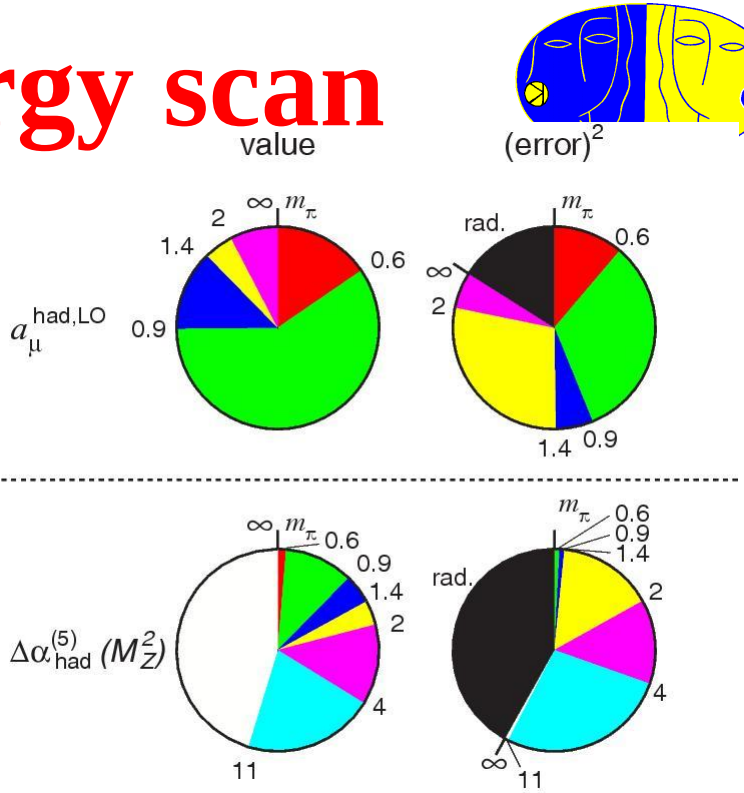


413 ± 31 events ⇒ first evidence

σ_{had} with energy scan

- The region 1- 2.5 GeV contributes 55% to δa_μ and 40% to $\delta\Delta\alpha_{had}^{(5)}$

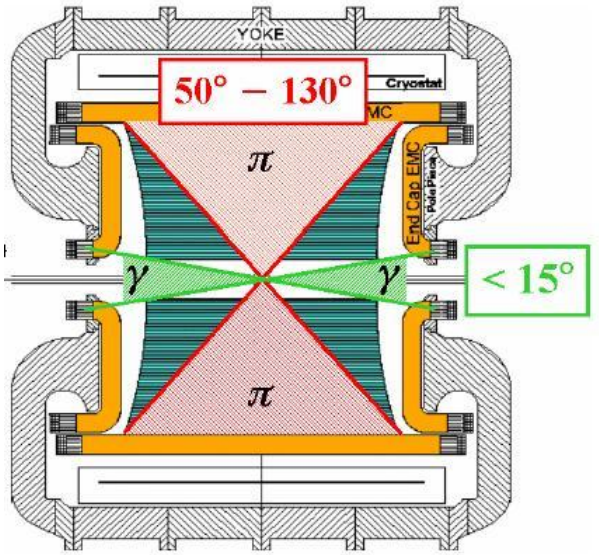




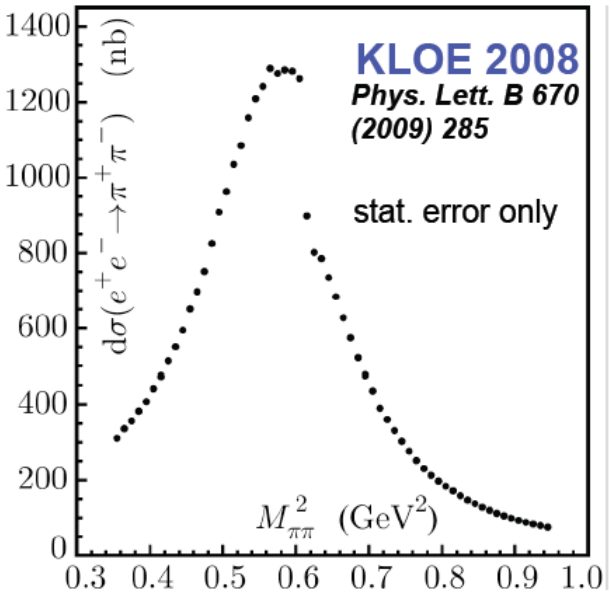
- **Published BaBar results**
  89 fb^{-1} (ISR)
- ▲ **BaBar × 10**
- o **KLOE-2 energy scan: 20 pb^{-1}/point**
  @ L= 10^{32} cm^{-2} s^{-1}, 25 MeV bin
  ⇒ 1 year data-taking

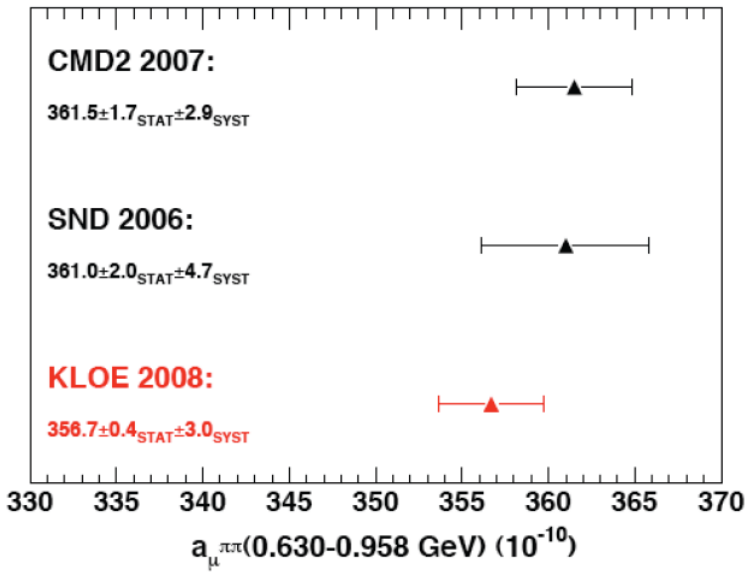
S.A. analysis

- 2 pions at large angle (ϑ>50°)
- Photon at small angle (ϑ<15° - not detected)
  to reduce FSR
- 240 pb^{-1} from 2002 data-taking



$a_\mu^{\pi\pi}$ (0.35–0.95 GeV^2) = (387.2±0.5$_{stat}$±2.4$_{syst}$±2.3$_{th}$)×10^{-10}





Result on L.A. analysis

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

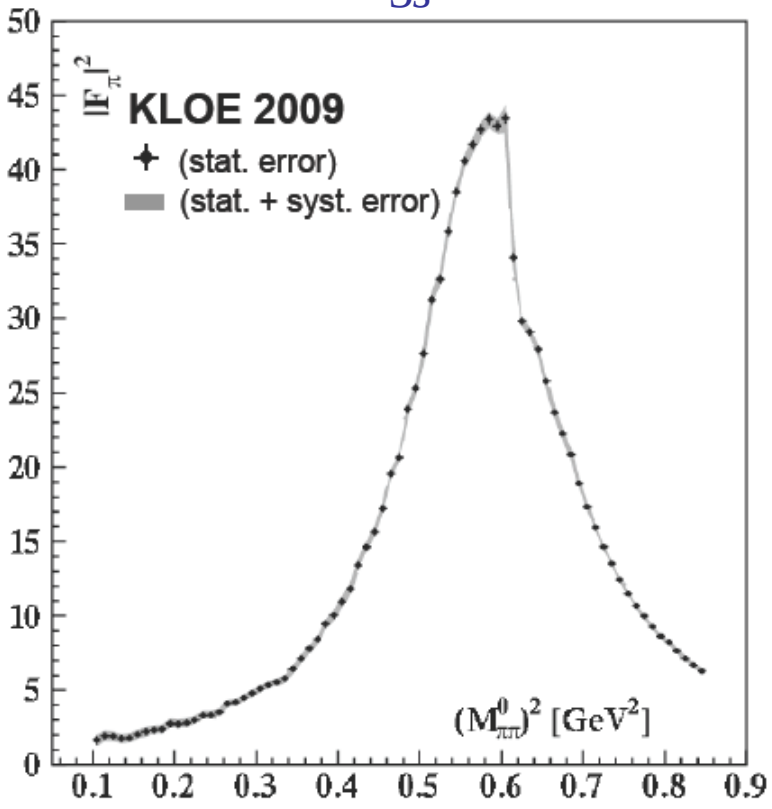


Table of systematic errors on $a_\mu^{\pi\pi}$(0.1-0.85 GeV^2):

Reconstruction Filter	< 0.1%
Background	0.5%
$f_0+\rho\pi$	0.4%
Omega	0.2%
Trackmass	0.5%
π/e-ID and TCA	< 0.1%
Tracking	0.3%
Trigger	0.2%
Acceptance	0.4%
Unfolding	negligible
Software Trigger	0.1%
Luminosity($0.1_{th} \oplus 0.3_{exp}$)%	0.3%

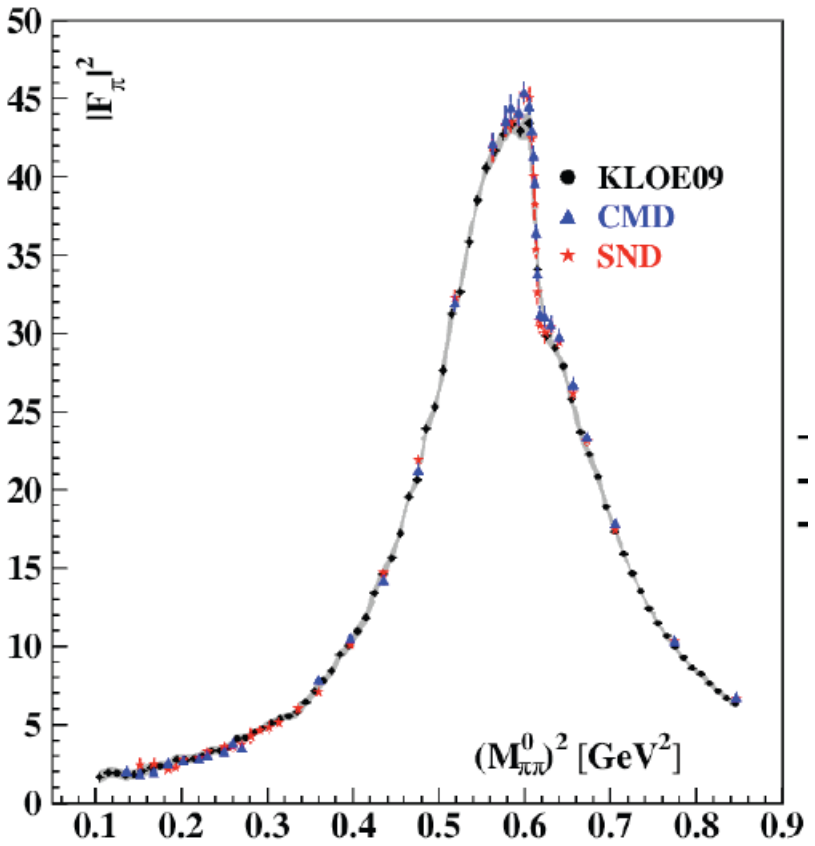
experimental fractional error on $a_\mu^{\pi\pi}$ = 1.0 %

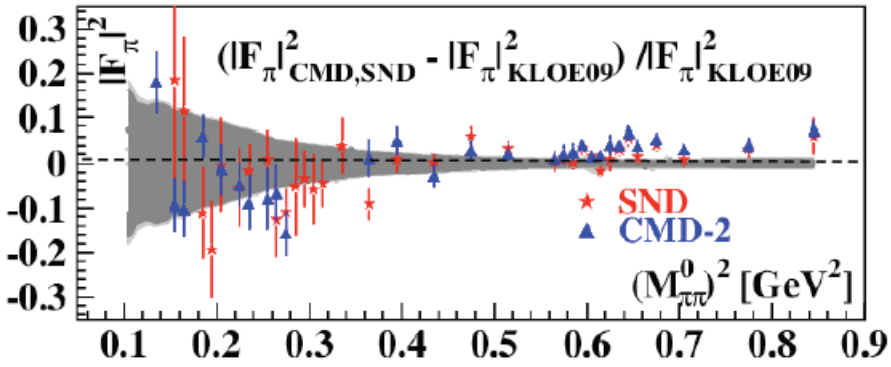
FSR resummation	0.3%
Radiator H	0.5%
Vacuum polarization	< 0.1%

theoretical fractional error on $a_\mu^{\pi\pi}$ = 0.6 %

$$a_\mu^{\pi\pi}(0.1\text{–}0.85\ \text{GeV}^2) = (478.5 \pm 2.0_{stat} \pm 4.8_{sys} \pm 2.9_{theo}) \times 10^{-10}$$

KLOE vs CMD-2 / SND

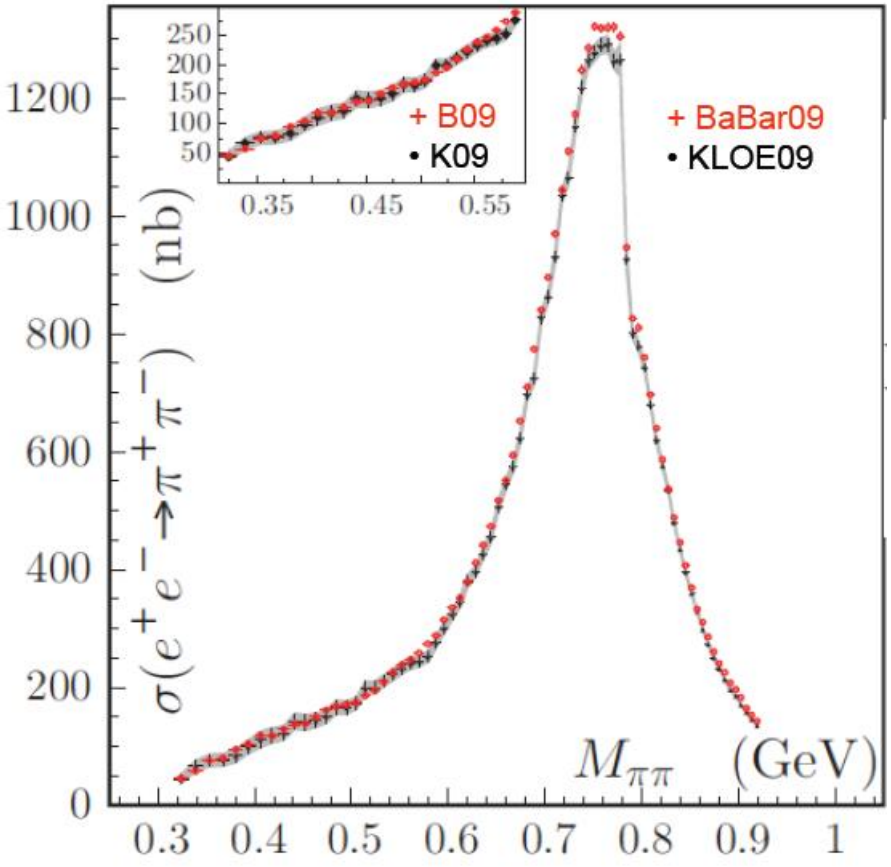


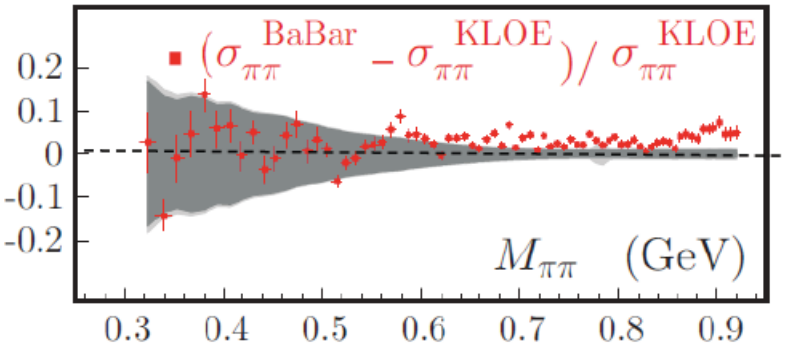


(Grey band = KLOE error)

- **Good agreement below the ρ peak**
- **Above the ρ peak KLOE slightly lower**

KLOE vs BaBar

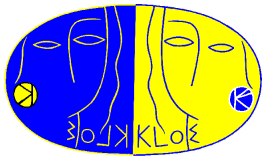




(Grey band = KLOE error)

- **Good agreement below 0.6 GeV**
- **Above 0.6 GeV BaBar higher by 2 – 3%**

$a_\mu^{\pi\pi}$ for different expt.



$a_\mu^{\pi\pi}(0.35\text{-}0.85 GeV^2)$:

KLOE08 (small angle) $a_\mu^{\pi\pi} = (379.6 \pm 0.4_{stat} \pm 2.4_{sys} \pm 2.2_{theo}) \cdot 10^{-10}$

KLOE09 (large angle) $a_\mu^{\pi\pi} = (376.6 \pm 0.9_{stat} \pm 2.4_{sys} \pm 2.1_{theo}) \cdot 10^{-10}$

$a_\mu^{\pi\pi}(0.152\text{-}0.270\ GeV^2)$:

KLOE09 (large angle) $a_\mu^{\pi\pi} = (48.1 \pm 1.2_{stat} \pm 1.2_{sys} \pm 0.4_{theo}) \cdot 10^{-10}$

CMD-2 $a_\mu^{\pi\pi} = (46.2 \pm 1.0_{stat} \pm 0.3_{sys}) \cdot 10^{-10}$

$a_\mu^{\pi\pi}(0.397\text{-}0.918\ GeV^2)$:

KLOE08 (small angle) $a_\mu^{\pi\pi} = (356.7 \pm 0.4_{stat} \pm 3.1_{sys}) \cdot 10^{-10}$

CMD-2 $a_\mu^{\pi\pi} = (361.5 \pm 1.7_{stat} \pm 2.9_{sys}) \cdot 10^{-10}$

SND $a_\mu^{\pi\pi} = (361.0 \pm 2.0_{stat} \pm 4.7_{sys}) \cdot 10^{-10}$

BaBar $a_\mu^{\pi\pi} = (365.2 \pm 1.9_{stat} \pm 1.9_{sys}) \cdot 10^{-10}$

$f_0(980)$, $a_0(980)$

- **Measurement of Br($\phi \to S\gamma \to PP\gamma$) and extraction of the parameters from fit of the Dalitz Plot or invariant mass distributions**
- **Hints for the $\sigma(600)$ presence in $\pi^0\pi^0\gamma$ Dalitz plot**

PLB634(2006)148
EPJC49(2007)473
NPB(PS)186(2009)290
PLB681(2009)5

- $\phi \to (f_0/a_0)\gamma \to K^0\overline{K}^0\gamma$

$$Br(\phi \to K^0\overline{K}^0\gamma) < 1.8 \times 10^{-8} \quad @\ 90\%\ C.L.$$

[PLB679(2009)10]

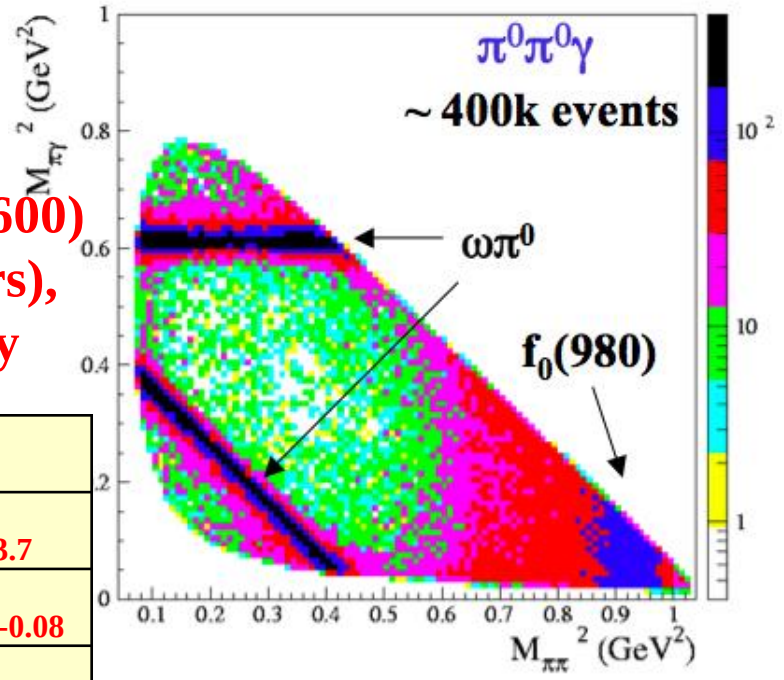
Parameter	$\pi^+\pi^-\gamma$	$\pi^0\pi^0\gamma$	$\eta\pi^0\gamma$
M_S (MeV)	983.7	$984.7 \pm 1.9_{mod}$	$982.5 \pm 1.6 \pm 1.1$
g_{SKK} (GeV)	4.74	$3.97 \pm 0.43_{mod}$	$2.15 \pm 0.06 \pm 0.06$
g_{SPP} (GeV)	–2.22	$-1.82 \pm 0.19_{mod}$	$2.82 \pm 0.03 \pm 0.04$
g^2_{SKK} / g^2_{SPP}	~4.6	~4.8	~0.6

- **KLOE-2:**
  - **$O(10\ fb^{-1}) \Rightarrow$ sensitivity to Br($\phi \to KK\gamma$) $\to \sim 10^{-8}$**
    with IT $\Rightarrow$ " $\sim 0.5 \times 10^{-8}$ $\Rightarrow$ first observation possible
  - **contributions of $f_0(980)$, $a_0(980)$,$\sigma(600)$ exchanges in $\eta' \to \eta\pi\pi$ decays**
  - **$a_0(980)$ parameters can be improved**

[Fariborz-Schechter PRD60(1999)034002]

$e^+e^- \to \pi^0\pi^0\gamma$: $f_0(980)$

- Data sample: 450 pb^{-1} $\Rightarrow$ ~ 4×10^5 events
- Two contributions: $\phi \to S\gamma$ and $e^+e^- \to \omega\pi^0$
- Dalitz plot fit: Kaon Loop with $f_0(980)$ and $\sigma(600)$ (σ with fixed parameters), "No structure" with $f_0(980)$ only



$f_0(980)$ param.	KL model	NS model
M_{f0} (MeV)	$976.8 \pm 0.3\ ^{+10.1}_{-0.6}$	$984.7 \pm 0.4^{+2.4}_{-3.7}$
$g_{\phi f\gamma}$ (GeV^{-1})	$2.78^{+0.02}_{-0.05}{}^{+1.32}_{-0.05}$	$2.61 \pm 0.02^{+0.31}_{-0.08}$
$g_{f\pi+\pi-}$ (GeV)	$-1.43 \pm 0.01^{+0.03}_{-0.60}$	$1.31 \pm 0.01^{+0.09}_{-0.03}$
g_{fK+K-} (GeV)	$3.76 \pm 0.04\ ^{+1.17}_{-0.49}$	$0.40 \pm 0.04^{+0.62}_{-0.29}$
$(g_{fK+K-}/g_{f\pi+\pi})^2$	~ 6.9	~ 0.09
$P(\chi^2)$	14.5 %	4.2 %

$\sigma(600)$ fixed parameters :
[Achasov,Kiselev,PRD73(2006)054029]
M_σ=462 MeV; Γ_σ=286 MeV
$g_{\sigma K+K-}$=0.5 GeV
$g_{\sigma\pi+\pi-}$= 2.4 GeV

- KL fit without $\sigma(600)$ $\Rightarrow$ $P(\chi^2) \to 10^{-4}$

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

$f_0(980)$ parameters

- Fit the $\pi^0\pi^0\gamma$ Dalitz plot and the $M(\pi^+\pi^-)$ distribution with the same scalar amplitude (with $\sigma(600)$ with fixed parameters)
- Latest version of the Kaon Loop model [N.Achasov]

$\sigma(600)$ fixed parameters :
M_σ=462 MeV; Γ_σ=286 MeV
$g_{\sigma K+K-}$=0.5 GeV
$g_{\sigma\pi+\pi-}$= 2.4 GeV
Achasov,Kiselev,PRD73(2006)054029

$f_0(980)$ param.	$f_0\to\pi^0\pi^0$	$f_0\to\pi^+\pi^-$
M_{f0} (MeV)	984.7	983.7
$g_{f0\pi+\pi-}$ (GeV	-1.82	-2.22
g_{f0K+K-} (GeV)	3.97	4.74
$R=(g_{f0K+K-}/g_{f0\pi+\pi-})^2$	~ 4.8	~ 4.6

- Agreement between the two channels
- Next: combined fit

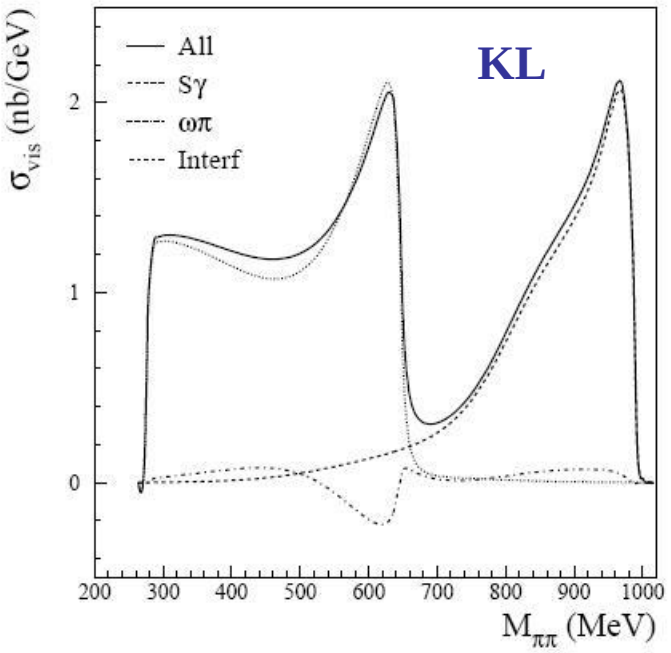
	$f_0\to\pi^0\pi^0$	$f_0\to\pi^+\pi^-$
$g_{\phi f0\gamma}$ (GeV^{-1})	$2.61 \pm 0.02^{+0.31}_{-0.08}$	1.2 – 2.0

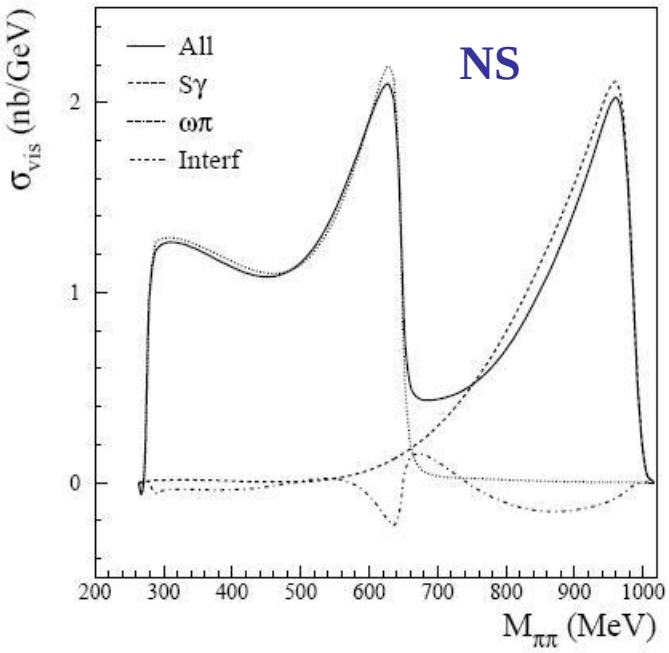
- $g_{\phi f0\gamma}$ from fit to No Structure model (point-like coupling $\phi f_0\gamma$)

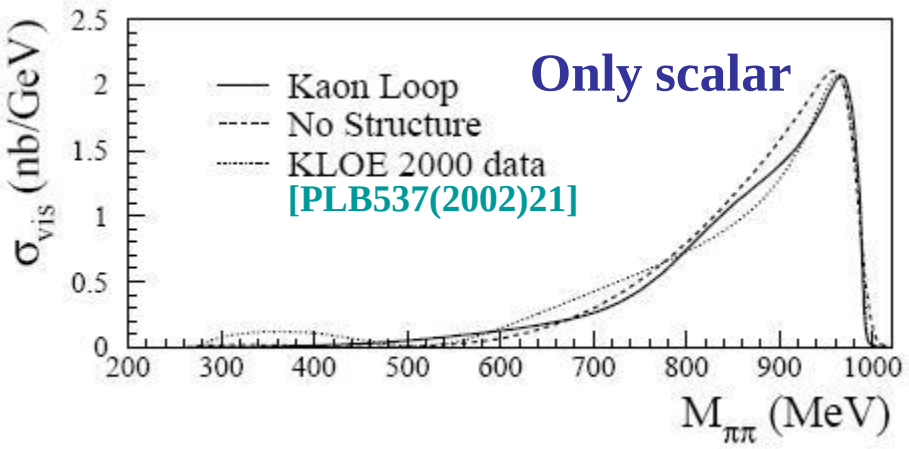
[G.Isidori, L.Maiani et al., JHEP0605(2006)049]

Fit results

Scalar + $\omega\pi^0$

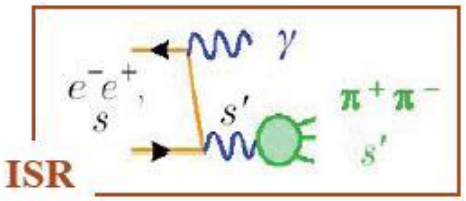


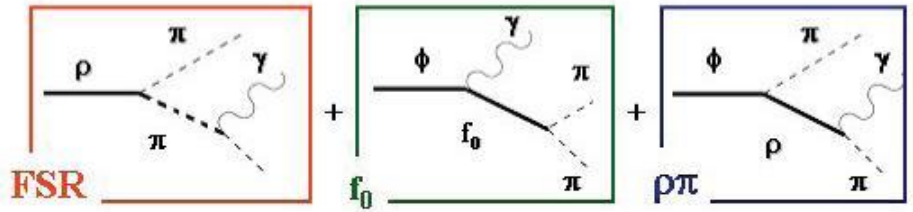


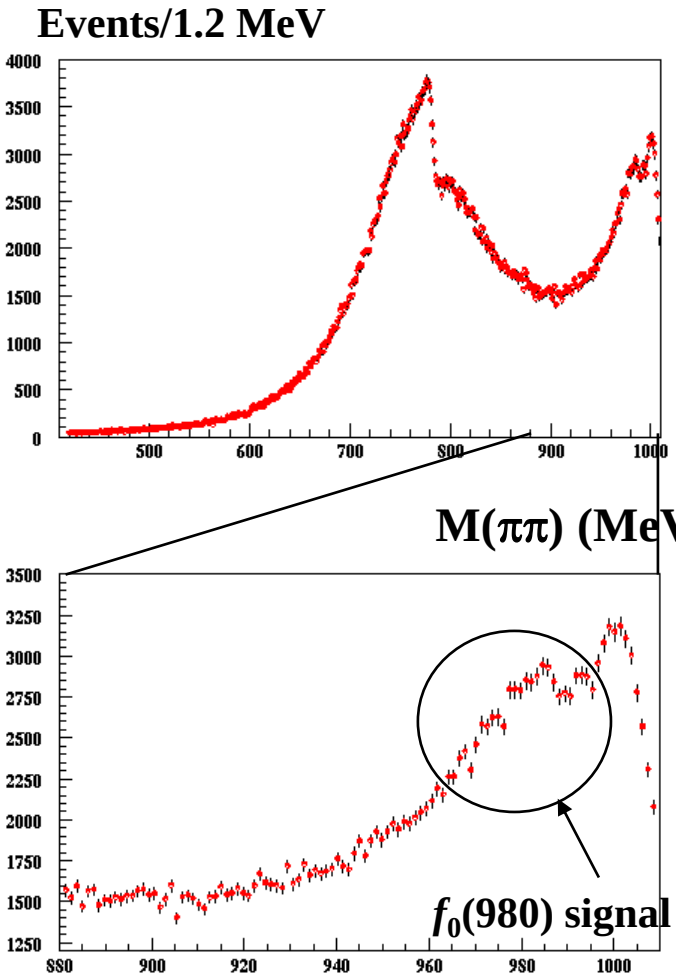


$e^+e^- \to \pi^+\pi^-\gamma$

- **Main contributions**

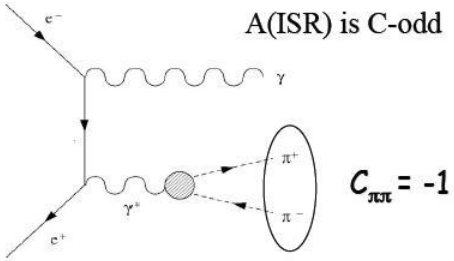


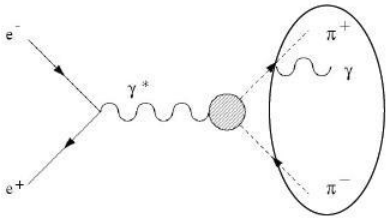




- **Event selection:** 2 charged tracks and missing momentum at large angle ($\vartheta > 45°$) + photon matching missing energy and momentum
- Data sample: 350 pb^{-1} at ϕ peak
  $\Rightarrow 6.7\times10^5$ events selected

F-B asymmetry

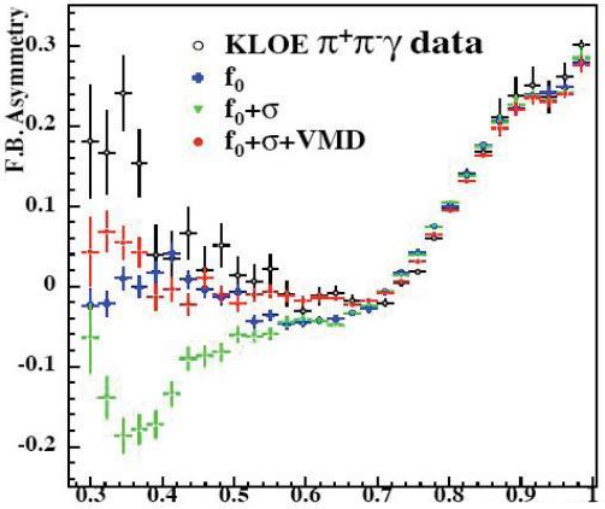




$$A_{FB} = \frac{N(\vartheta_+ > 90°) - N(\vartheta_+ < 90°)}{N(\vartheta_+ > 90°) + N(\vartheta_+ < 90°)}$$

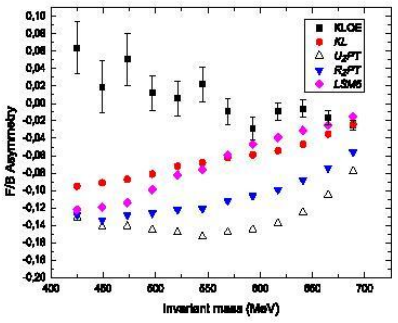
- $f_0(980)$ evidence at $M(\pi\pi) \approx 980$ MeV
- Simulation with f_0 and σ parameters from $\pi^0\pi^0\gamma$ analysis

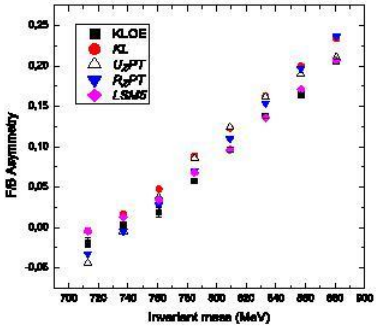
  [Pancheri, Shekhovtsova Venanzoni, arXiv0706.3027]

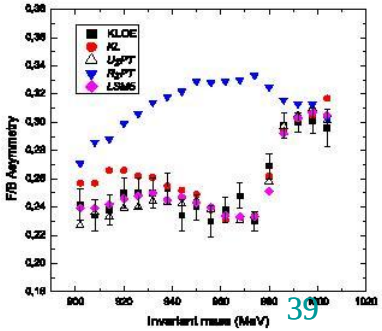


- Recent analysis by A.Gallegos et al. [arXiv:0908]: comparison of KLOE data with 4 different models: KL, RχPT, UχPT and LσM

P.Gauzzi







Unfolded $M_{\eta\pi}$ distribution

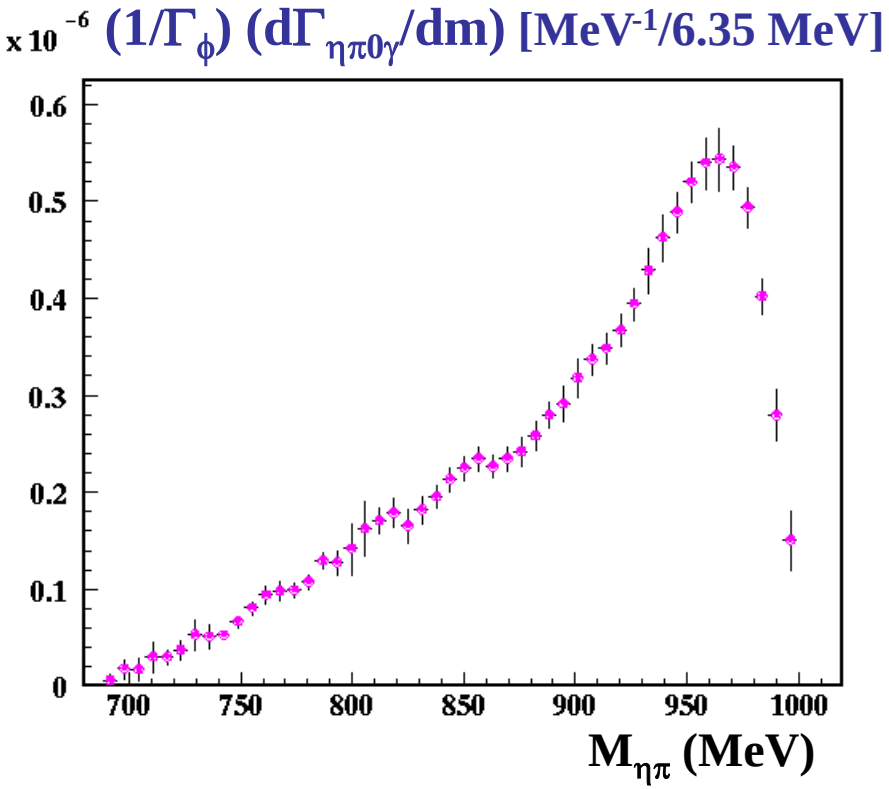
- To allow better comparison with other experimental results and theoretical models ⇒ unfolding procedure to correct data for detector and resolution effects

- Bayesian unfolding

(avoids smearing matrix inversion)

[G.D'Agostini, NIM A362 (1995), 487]

- Average of the two $M_{\eta\pi}$ distributions



$\phi \to \eta\pi^0\gamma$: $a_0(980)$

1) $\eta \to \gamma\gamma$ (Br=38.31%) $\Rightarrow$ 5 photon final state
Total background = 55%

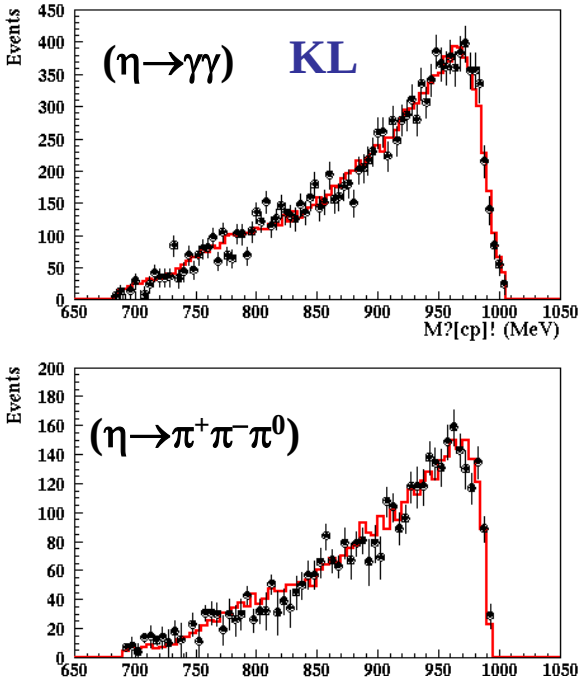
$$Br(\phi \to \eta\pi^0\gamma) = (7.01 \pm 0.10_{stat} \pm 0.20_{syst}) \times 10^{-5}$$

2) $\eta \to \pi^+\pi^-\pi^0$ (Br=22.73%)$\Rightarrow$ 5γ + 2 tracks
Total background = 15%

$$Br(\phi \to \eta\pi^0\gamma) = (7.12 \pm 0.13_{stat} \pm 0.22_{syst}) \times 10^{-5}$$

- Combined fit of the two M($\eta\pi^0$) distributions
  $\Rightarrow$ Free parameter: $R_\eta = Br(\eta \to \gamma\gamma)/Br(\eta \to \pi^+\pi^-\pi^0)$

	KL	NS
M_{a0} (MeV)	982.5 ± 1.6 ± 1.1	982.5 (fixed)
g_{aK+K-} (GeV)	2.15 ±0.06 ± 0.06	2.01 ± 0.07± 0.28
$g_{a\eta\pi}$ (GeV)	2.82 ± 0.03± 0.04	2.46 ± 0.08 ± 0.11
$g_{\phi a\gamma}$ (GeV^{-1})	1.58 ± 0.10± 0.16	1.83± 0.03 ± 0.08
Br(VDM) $\times 10^6$	0.92 ± 0.40 ± 0.15	~ 0
R_η	1.70±0.04± 0.03	1.70 ±0.03 ± 0.01
$R=(g_{aK+K-}/g_{a\eta\pi})^2$	0.58 ± 0.03± 0.03	0.67 ± 0.06 ± 0.13
$P(\chi^2)$	10.4%	30.9%



[PLB681(2009),5]

M_{a0} PDG: 985.1 MeV- Belle:$982.3^{+3.2}_{-4.8}$ MeV
$\Gamma_{tot}(a_0)$=80 – 105 MeV
(PDG: 50-100 MeV, Belle: $76.5^{+17.5}_{-10.1}$ MeV
• VDM very small
• PDG $\Rightarrow R_\eta = 1.73 \pm 0.04$

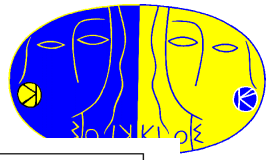
a_0 and f_0 couplings

		SU(3)		
		4q	qqbar	
$(g_{a0K+K-} / g_{a0\eta\pi})^2$	0.6 – 0.7	1.2 – 1.7	0.4	
	Crystal Barrel: 0.525 ± 0.043			
	SND (2000) : 1.8 ± 2.5			
$(g_{f0K+K-}/g_{f0\pi+\pi-})^2$	4.6 – 4.8	>> 1	>> 1 (f_0=ssbar)	1/4 (f_0=nnbar)
	CMD-2 (1999) : 3.61 ± 0.62			
	SND (2000) : 4.6 ± 0.8			
	BES (2005) : 4.21 ± 0.33			
$(g_{f0K+K-}/g_{a0K+K-})^2$	4 – 5	1	2	1

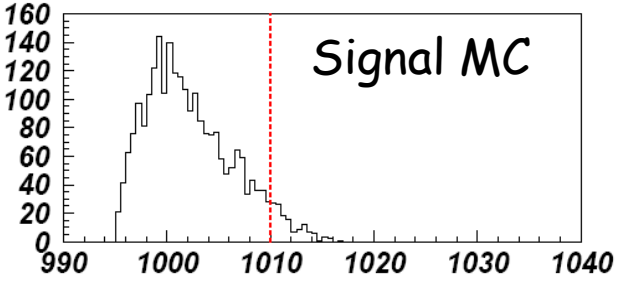
- Large $g_{\phi S\gamma}$ ⇒ sizeable *s* quark content ?

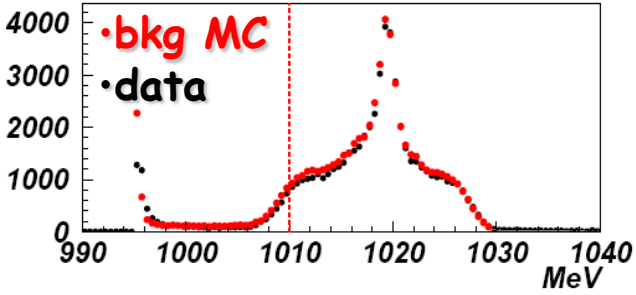
Meson	$g_{\phi M\gamma}$ (GeV^{-1})
π^0	0.13
η	0.71
η'	0.75
$a_0(980)$	1.6 – 1.8
$f_0(980)$	1.2 – 2.8

$\phi \to (f_0/a_0)\gamma \to K^0\bar{K}^0\gamma$



- $K^0\bar{K}^0$ with scalar quantum numbers ($J^{PC}=0^{++}$)
- Small phase space($2M_K \le M_{KK} \le M_\phi$)
  $\Rightarrow$ small Br expected ($10^{-9} - 10^{-7}$)
- "Golden channel" $\phi \to K_S K_S \gamma \to \pi^+\pi^-\pi^+\pi^-\gamma$
- Analyzed sample: 2.18 fb^{-1}
- 5 events in data and 3.2 background events (MC)
  ($\pi^+\pi^-\pi^+\pi^-(\gamma)$ from $\phi \to K_S K_L$ and from continuum)





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

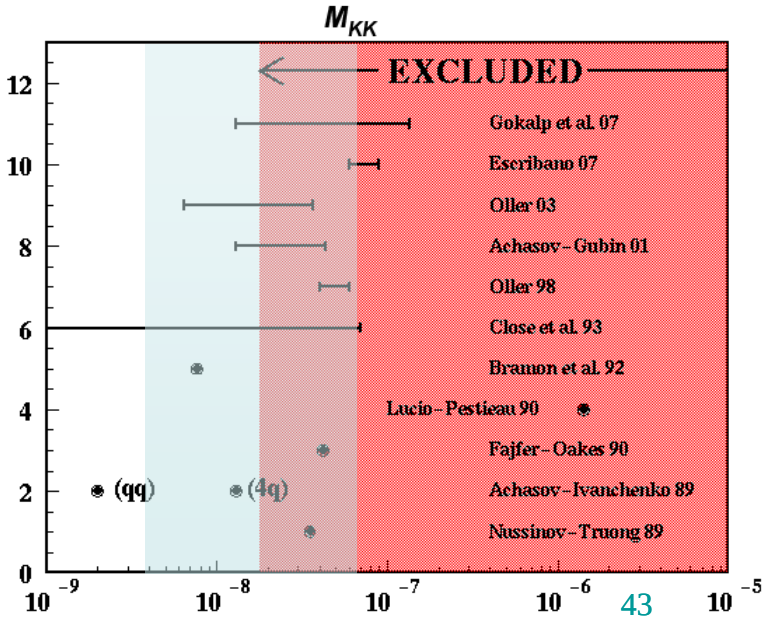
[PLB679(2009),10]

- Consistency check: using the KLOE couplings from $\phi \to \pi\pi\gamma$, $\eta\pi^0\gamma$ in the Kaon Loop model

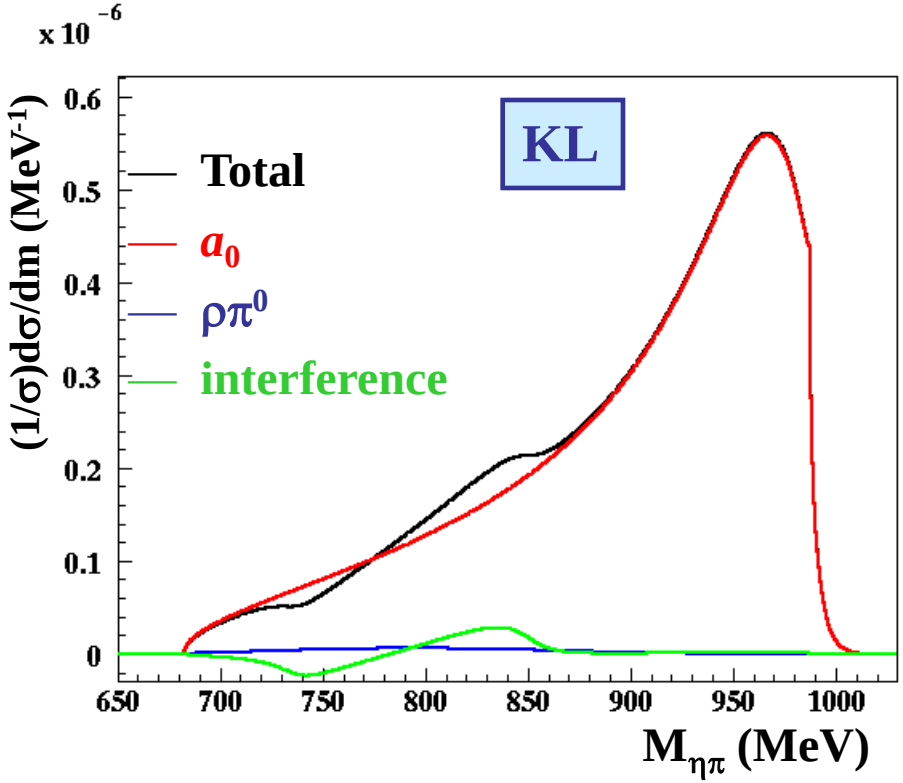
$\Rightarrow$ $Br(\phi \to K^0\bar{K}^0\gamma) = 4 \times 10^{-9} - 6.8 \times 10^{-8}$

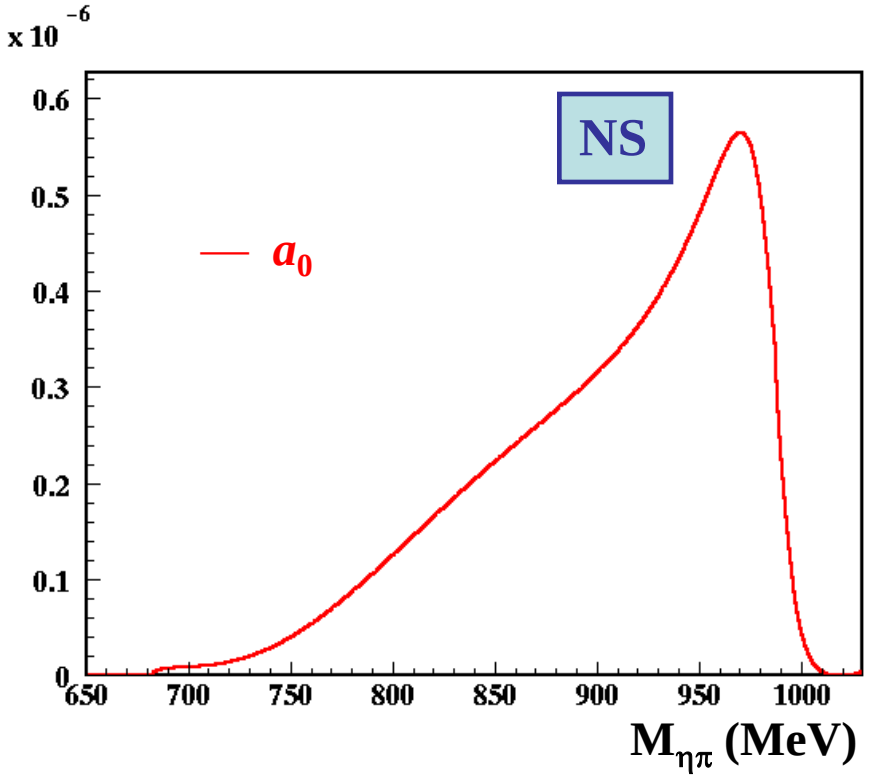
- KLOE-2 sensitivity (with Inner Tracker) $\Rightarrow$ 0.5×10^{-8}

$\Rightarrow$ First observation possible

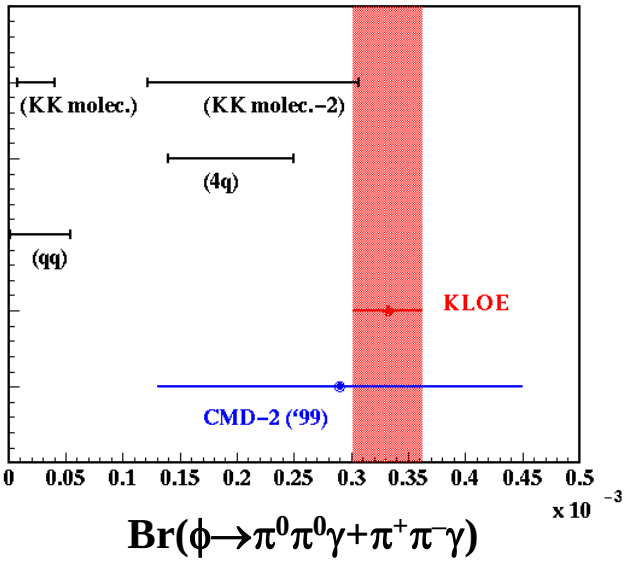


$a_0(980)$ shape

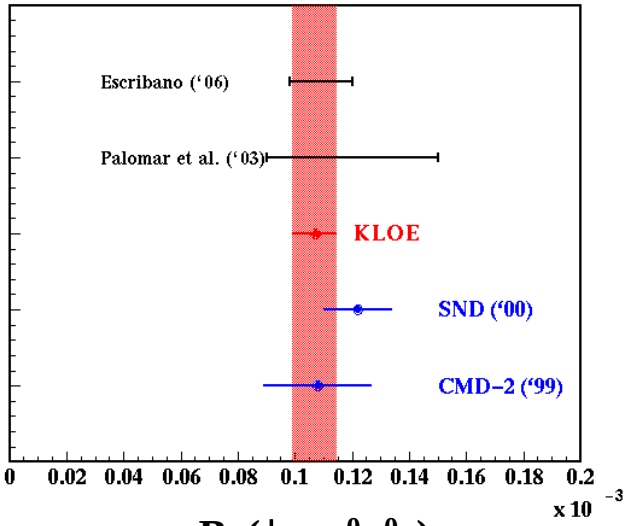

x 10 −6
(1/σ)dσ/dm (MeV-1)
KL
Total
a0
ρπ0
interference
Mηπ (MeV)


x 10 −6
NS
a0
Mηπ (MeV)

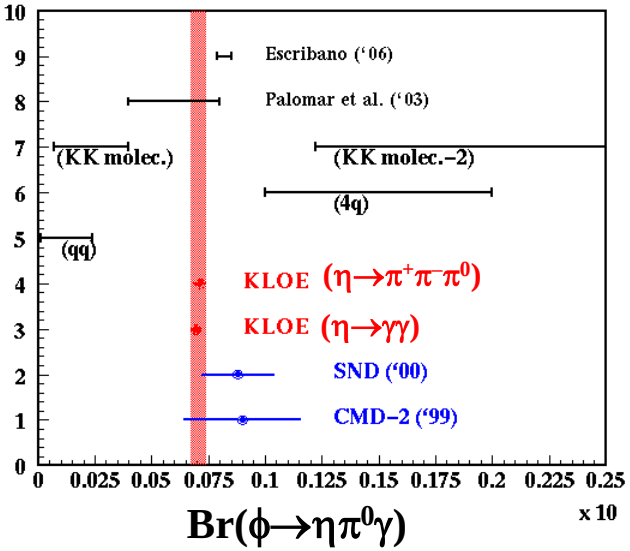
Branching ratios



$Br(\phi \to \pi^0\pi^0\gamma + \pi^+\pi^-\gamma)$



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



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

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): UχPT
Escribano, PRD74(2006): Linear σ model

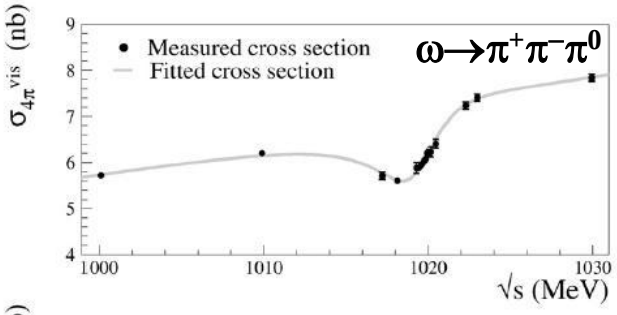
$e^+e^- \to \omega\pi^0$

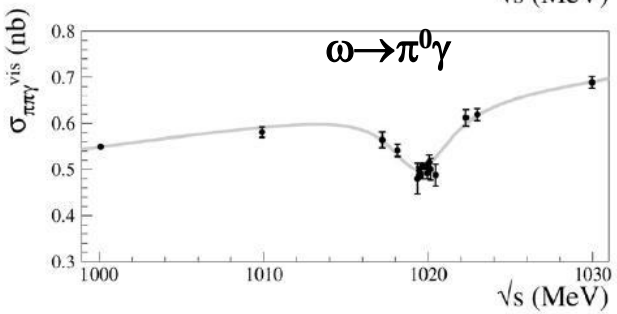
- 600 pb^{-1} with $1000 < \sqrt{s} < 1030$ MeV
- Interference with $\phi \to \omega\pi^0$ (OZI and G-parity viol.)

$$\sigma_{vis}(\sqrt{s}) = \sigma_{nr}(\sqrt{s})\left(1 - Z\frac{M_\phi \Gamma_\phi}{D_\phi(\sqrt{s})}\right)$$

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

Parameter	$e^+e^- \to \pi^+\pi^-\pi^0\pi^0$	$e^+e^- \to \pi^0\pi^0\gamma$
σ_0 [nb]	$7.89 \pm 0.06 \pm 0.07$	$0.724 \pm 0.010 \pm 0.003$
$\Re e(Z)$	$0.106 \pm 0.007 \pm 0.004$	$0.011 \pm 0.015 \pm 0.006$
$\Im m(Z)$	$-0.103 \pm 0.004 \pm 0.003$	$-0.154 \pm 0.007 \pm 0.004$
σ' [nb/MeV]	$0.064 \pm 0.003 \pm 0.001$	$0.0053 \pm 0.0005 \pm 0.0002$





[PLB669(2008)223]

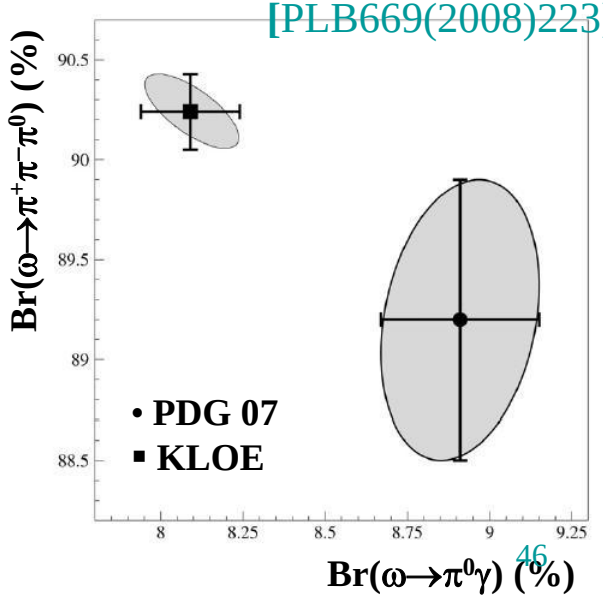
- From $\sigma_0(\pi^0\gamma)/\sigma_0(\pi^+\pi^-\pi^0)$ (with rare Br's from PDG)

$\mathrm{Br}(\omega \to \pi^+\pi^-\pi^0) = (90.24 \pm 0.19)\%$

$\mathrm{Br}(\omega \to \pi^0\gamma) = (8.09 \pm 0.14)\%$ (~3 σ from PDG)

$(8.92 \pm 0.24)\%$

$\Rightarrow \mathrm{Br}(\phi \to \omega\pi^0) = (4.4 \pm 0.6) \times 10^{-5}$



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

- χPT: $O(p^2) \propto Q = 0$;

  $O(p^4)$ @ tree level = 0; $O(p^4)$ @ 1 loop suppressed by G-parity

  $\Rightarrow O(p^6)$ test

- Recent measurements $\Rightarrow$ Br($\eta \to \pi^0\gamma\gamma$): $(7.2 \pm 1.4) \times 10^{-4}$ GAMS (1984)

  $< 8.4 \times 10^{-4}$@90% C.L. SND (2001)

  $(22.4 \pm 4.6 \pm 1.7) \times 10^{-5}$ Crystal Ball@MAMI(2007)

  $(22.1 \pm 2.4 \pm 3.8) \times 10^{-5}$ Crystal Ball@AGS (reanalysis)

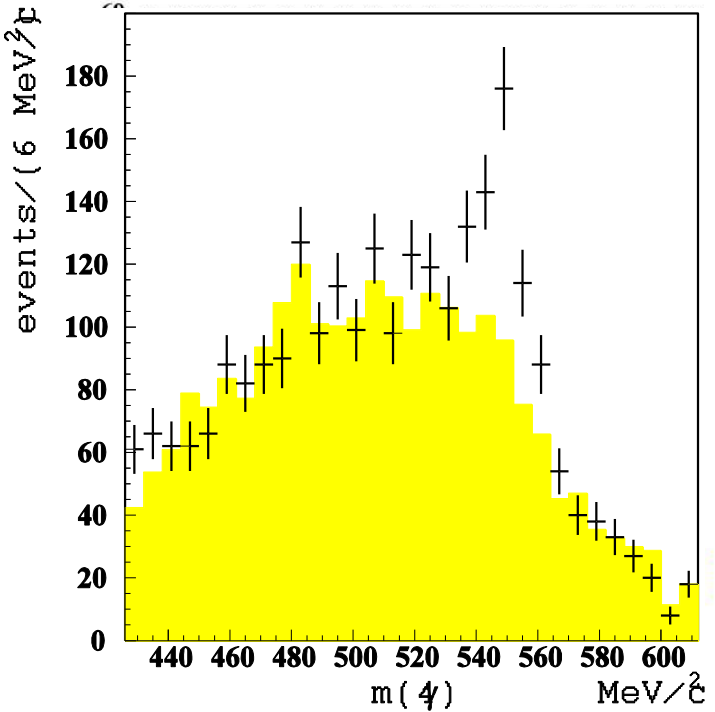
- KLOE $\Rightarrow$ $\phi \to \eta\gamma$; $\eta \to \pi^0\gamma\gamma$
- Backg.: (1) 5γ processes: $\phi \to a_0\gamma$, $f_0\gamma$;

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

  (2) $\phi \to \eta\gamma$; $\eta \to \pi^0\pi^0\pi^0$
- L $\approx$ 450 pb^{-1}

$\Rightarrow$ **Br($\eta \to \pi^0\gamma\gamma$) = (8.4 ± 2.7 ± 1.4) × 10^{-5}**

- 1.5 fb^{-1} $\Rightarrow$



Mixing η/η´

- $\phi \to \eta'\gamma$; $\eta' \to \eta\,\pi^+\pi^-$; $\eta \to \pi^0\pi^0\pi^0$
  $\eta' \to \eta\pi^0\pi^0$; $\eta \to \pi^+\pi^-\,\pi^0$
- $\phi \to \eta\gamma$; $\eta \to \pi^0\pi^0\pi^0$

} Final state: $\pi^+\pi^- + 7\,\gamma$

$L = 427\ pb^{-1}$

$N_{\eta'\gamma} = 3407 \pm 61 \pm 43$ ev.

$N_{\eta\gamma} = 16.7 \times 10^6$ ev.

$$R = \frac{Br(\phi \to \eta'\gamma)}{Br(\phi \to \eta\gamma)} = (4.77 \pm 0.09 \pm 0.19) \times 10^{-3}$$

[systematics dominated by $\delta Br(\eta' \to \eta\pi\pi) = 3\%$]

$\Rightarrow$ $Br(\phi \to \eta'\gamma) = (6.20 \pm 0.11 \pm 0.15) \times 10^{-5}$

- Pseudoscalar mixing angle: $\left|q\bar{q}\right\rangle = \frac{1}{\sqrt{2}}\left(\left|u\bar{u}\right\rangle + \left|d\bar{d}\right\rangle\right)$

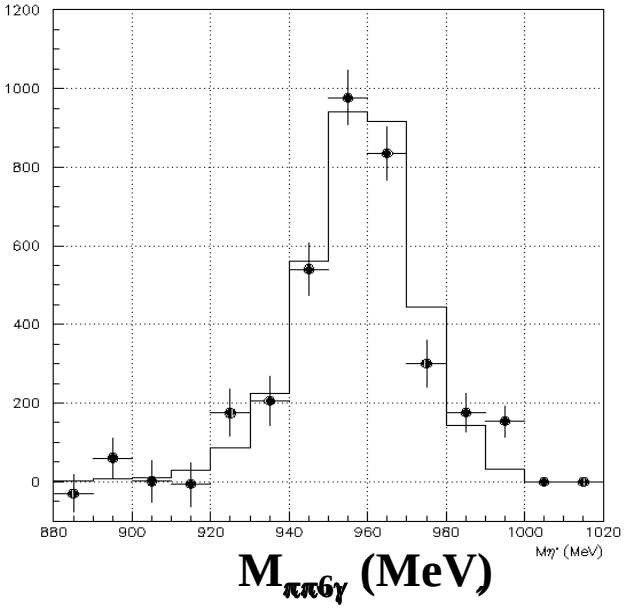
$$\eta = \cos\varphi_P \left|q\bar{q}\right\rangle - \sin\varphi_P \left|s\bar{s}\right\rangle$$

$$\eta' = \sin\varphi_P \left|q\bar{q}\right\rangle + \cos\varphi_P \left|s\bar{s}\right\rangle$$

$$R = \cot^2\varphi_P \left(1 - \frac{m_s}{\bar{m}} \cdot \frac{C_{NS}}{C_S} \cdot \frac{\tan\varphi_V}{\sin 2\varphi_P}\right)^2 \cdot \left(\frac{p_{\eta'}}{p_\eta}\right)^3$$

$\varphi_P = (41.4 \pm 0.3 \pm 0.9)^\circ \Rightarrow \vartheta_P = (-13.3 \pm 0.3 \pm 0.9)^\circ$

Inv.mass of $\pi^+\pi^-$+ 6γ out of 7



$M_{\pi\pi 6\gamma}$ (MeV)

[PLB648(2007)267]

η´ gluonium content

$$\eta' = X_{\eta'}|q\bar{q}\rangle + Y_{\eta'}|s\bar{s}\rangle + Z_{\eta'}|G\rangle$$

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

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

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

[Rosner PRD27(1983) 1101, Kou PRD63(2001)54027]

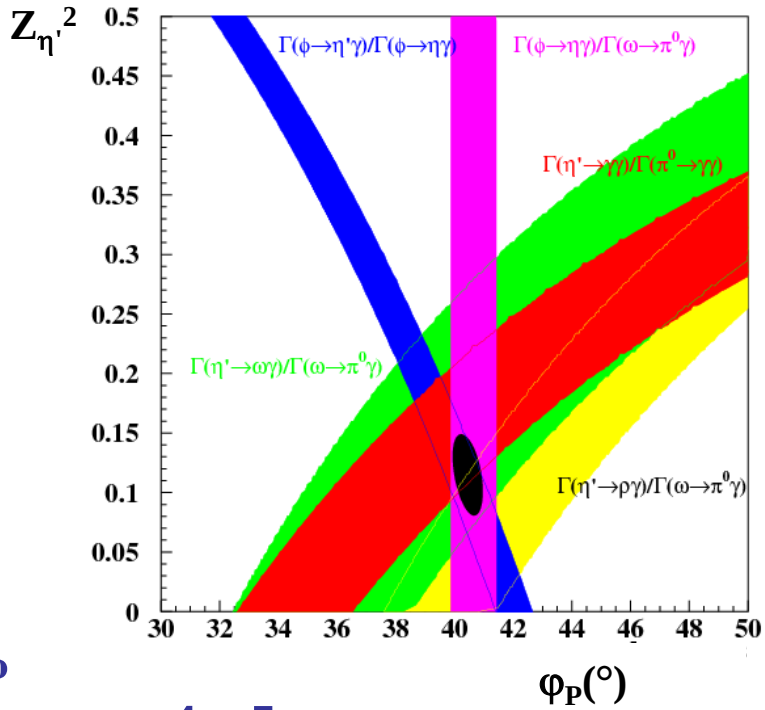
New fit: $R = \cot^2\varphi_P \cos^2\varphi_G \left(1 - \frac{m_s}{\bar{m}} \cdot \frac{C_{NS}}{C_S} \cdot \frac{\tan\varphi_V}{\sin 2\varphi_P}\right)^2 \cdot \left(\frac{p_{\eta'}}{p_\eta}\right)^3$

$$\frac{\Gamma(\eta' \to \gamma\gamma)}{\Gamma(\pi^0 \to \gamma\gamma)}, \frac{\Gamma(\eta' \to \rho\gamma)}{\Gamma(\omega \to \pi^0\gamma)}, \frac{\Gamma(\eta' \to \omega\gamma)}{\Gamma(\omega \to \pi^0\gamma)}, \frac{\Gamma(\omega \to \eta\gamma)}{\Gamma(\omega \to \pi^0\gamma)},$$

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

PDG08+ KLOE ω→π⁰γ

	New fit	PLB648
$Z_{\eta'}^2$	0.12 ± 0.04	0.14 ± 0.04
φ_P (deg.)	40.4 ± 0.6	39.7 ± 0.7
C_{NS}	0.94 ±0.03	0.91 ±0.05
C_S	0.83 ±0.05	0.89 ±0.07
φ_V (deg.)	3.32 ± 0.10	3.2
m_s/m	1.24 ± 0.07	1.24 ± 0.07
χ^2/ndf	4.6/3	1.42 / 2
P(χ^2)	20%	49%



KLOE-2: by measuring the main η' Br's @ 1%

⇒ statistical significance of $Z_{\eta'}^2$ will increase to 4 – 5 σ

[JHEP07(2009)105]

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

- $\eta \to \pi\pi\pi$ decay $\Rightarrow$ Isospin violation $\quad L_I = -\frac{1}{2}(m_u - m_d)(\bar{u}u - \bar{d}d)$

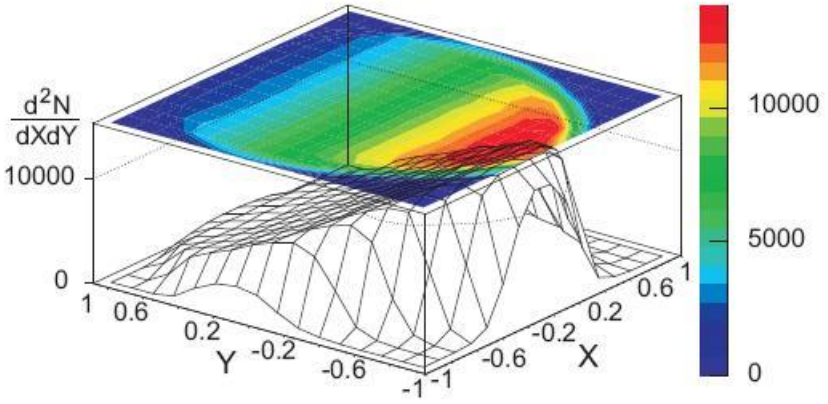
$\phi \to \eta\gamma$; $\eta \to \pi^+\pi^-\pi^0 \Rightarrow \pi^+\pi^- + 3\gamma$ ($E_{\gamma rec}$ = 363 MeV)
450 pb^{-1} $\Rightarrow$ 1.34 × 10^6 events in the Dalitz plot

$$X = \sqrt{3}\frac{E_+ - E_-}{Q}\,;\; Y = 3\frac{E_0 - m_0}{Q}$$

$$(Q = m_\eta - 2m_{\pi^\pm} - m_{\pi^0})$$

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

a	$-1.090 \pm 0.005\ ^{+\,0.008}_{-\,0.019}$
b	$0.124 \pm 0.006 \pm 0.010$
c	$0.002 \pm 0.003 \pm 0.001$
d	$0.057 \pm 0.006\ ^{+\,0.007}_{-\,0.016}$
e	$-0.006 \pm 0.007\ ^{+\,0.005}_{-\,0.003}$
f	$0.14 \pm 0.01 \pm 0.02$
$P(\chi^2)$	73%



- c, e compatible with zero (C violation)
- fit without cubic term (fY^3) $\Rightarrow P(\chi^2) \sim 10^{-6}$

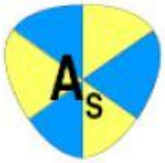
[JHEP0805(2008)006]

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

- **Asymmetries ⇔ C violation**

Left-right asymmetry(*c*, *e* parameters) $A_{LR} = (9 \pm 10^{+9}_{-14}) \times 10^{-4}$

Quadrant asymmetry: $\not C$ in $\Delta I = 2$ $A_Q = (-5 \pm 10^{+3}_{-5}) \times 10^{-4}$



Sextant asymmetry: $\not C$ in $\Delta I = 1$ $A_S = (8 \pm 10^{+8}_{-13}) \times 10^{-4}$

PDG'06 ⇒

$A_{LR} = (9 \pm 17) \times 10^{-4}$

$A_Q = (-17 \pm 17) \times 10^{-4}$

$A_S = (18 \pm 16) \times 10^{-4}$

- **All asymmetries compatible with zero at 10^{-3} level**

[JHEP0805(2008)006]

$\eta \to \pi^0\pi^0\pi^0$:fit procedure

The fit is done using a binned likelihood approach

We obtain an estimate of α by minimizing

$$-\sum_i n_i \log\left(\nu_i(\alpha)\right)$$

Where:

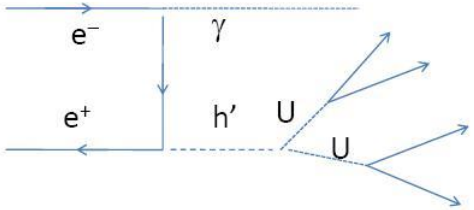
n_i = recostructed events

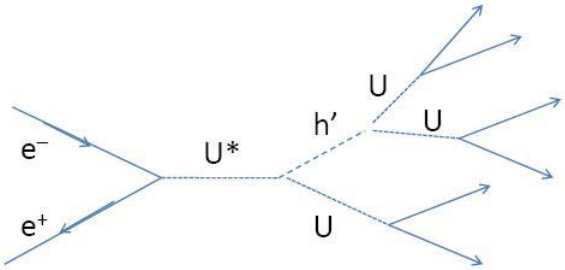
ν_i = for each MC event (according pure phase space):

- ✓ **Evaluate its z_{true} and its z_{rec} (if any!)**
- ✓ **Enter an histogram with the value of z_{rec}**
- ✓ **Weight the entry with $1 + 2\ \alpha\ z_{true}$**
- ✓ **Weight the event with the fraction of combinatorial background, for the signal (bkg) if it has correct (wrong) pairing**

Dark Matter search

- **Recent unexpected astrophysical observations (PAMELA, ATIC, INTEGRAL, DAMA/LIBRA) can be interpreted by assuming the existence of a low mass [*O*(1 GeV)] dark matter sector that interacts with SM particles through a mixing of a new gauge field, U, with hypercharge**
- **Possible signatures:** [Essig et al., arXiv:0903.3941]
  - **if $m_U < M_\Phi \Rightarrow e^+e^- \to U\gamma \to \ell^+\ell^-\gamma \Rightarrow$ resonances in $\ell^+\ell^-$ invariant mass**
  - **if there is a Higgs-like particle (h') in the dark sector, with $m_{h'} < M_\Phi$**
    higgs'-strahlung $e^+e^- \to U^* \to Uh'$, with $U \to \ell^+\ell^-$
    two leptons + missing energy (h' undetected)
  - **if $m_{h'} < 2\, m_U \Rightarrow$ multilepton events**





- **If mixing parameter $k \to 10^{-2} - 10^{-3} \Rightarrow \sigma \sim 1$ pb (observable at KLOE-2)**