

Study of the light meson spectrum in e^+e^- and $\gamma\gamma$ collisions with KLOE at DAΦNE

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on the behalf of
the KLOE collaboration

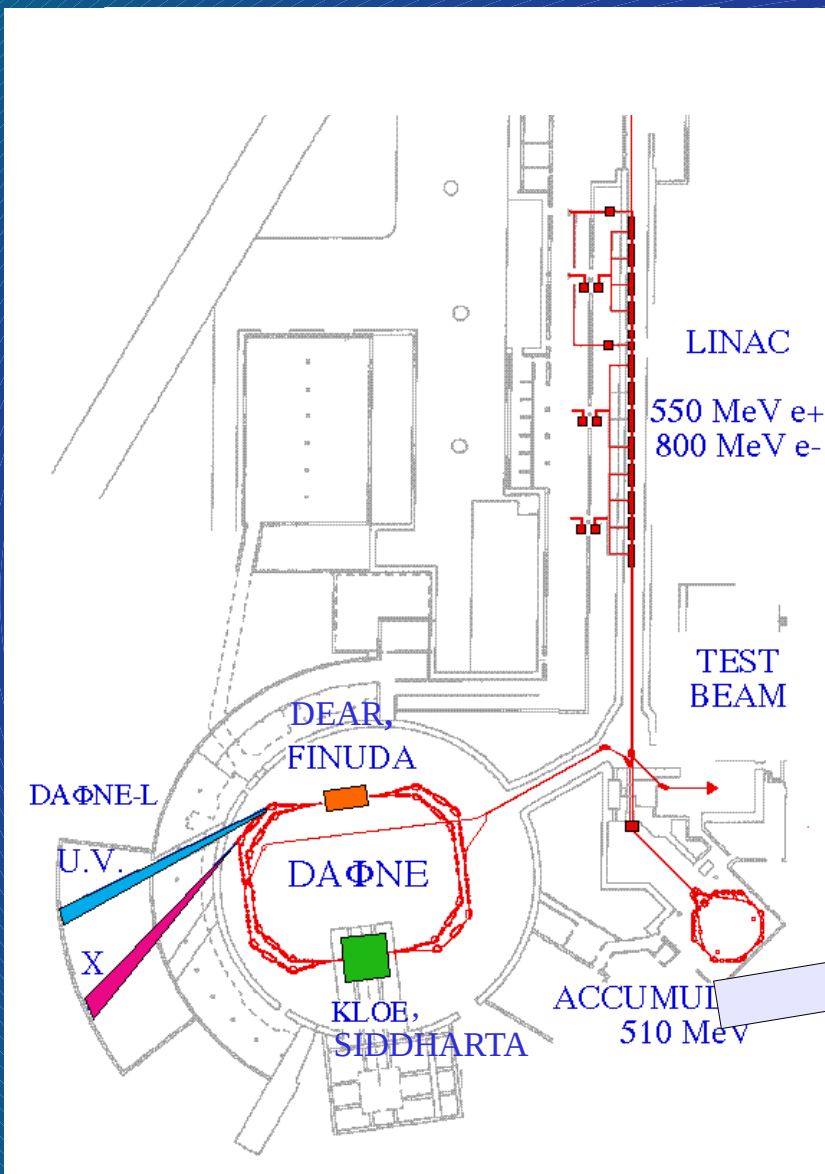


**Int-Jlab Workshop
on
Hadron Spectroscopy**

**Institute of Nuclear Theory
University of Washington
Seattle-USA**



The DAΦNE high luminosity e^+e^- collider



- ◆ $\sqrt{s} = m(\phi) = 1019.4$ MeV, $\sigma(e^+e^- \rightarrow \phi) \sim 3 \mu\text{b}$
- ◆ Independent e^+e^- rings to reduce beam-beam interactions
- ◆ crossing angle: 25 mrad, $p_x(\phi) \sim 12.6$ MeV
- ◆ 105 + 105 bunches, crossing every 2.7 ns
- ◆ injection during acquisition
- ◆ Maximum currents $I(e^+) = 2.4$ A $I(e^-) = 1.5$ A

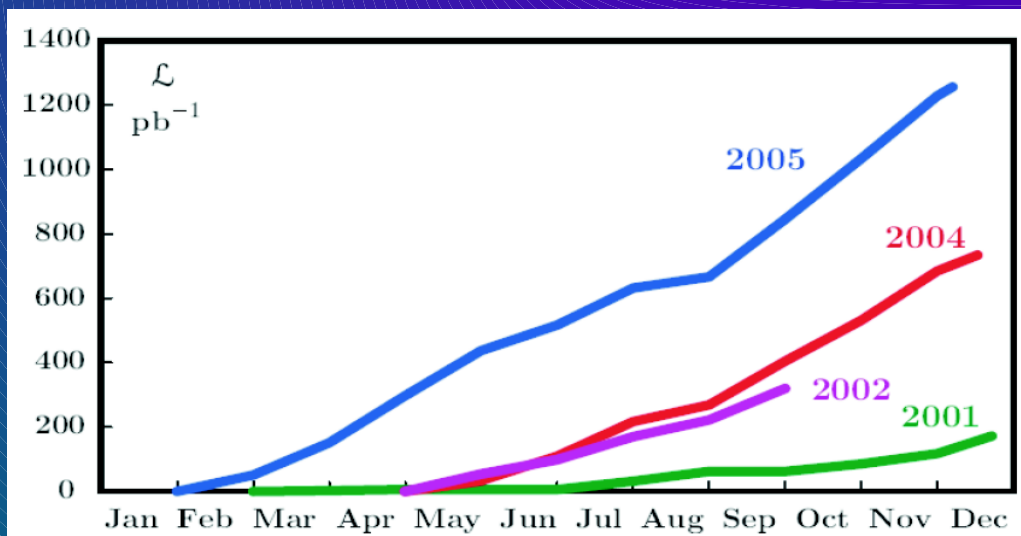
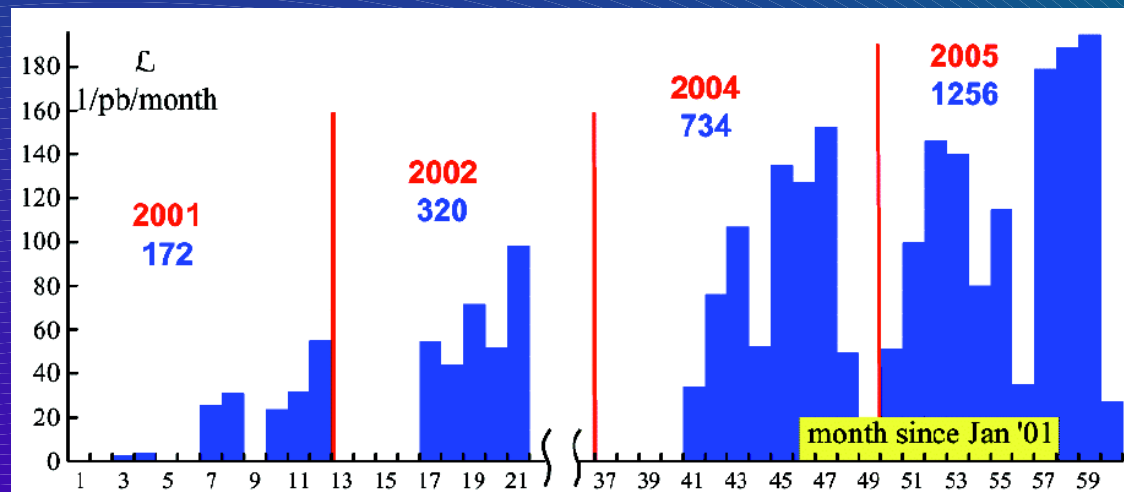


Study of the light meson spectrum in e^+e^- and $\gamma\gamma$ collisions
with KLOE at DAΦNE



Collected data

- ◆ Last run- March 2006
- ◆ Max luminosity 1.3×10^{32}
- ◆ Tot. Integrated 2.5 fb^{-1}
- ◆ $200 \text{ pb}^{-1} @ \sqrt{s} = 1000 \text{ MeV}$



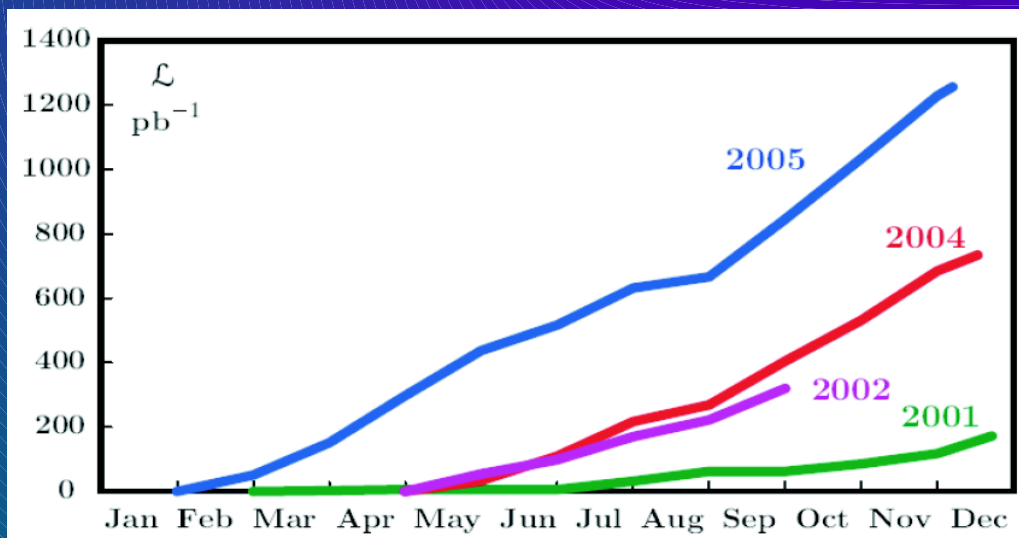
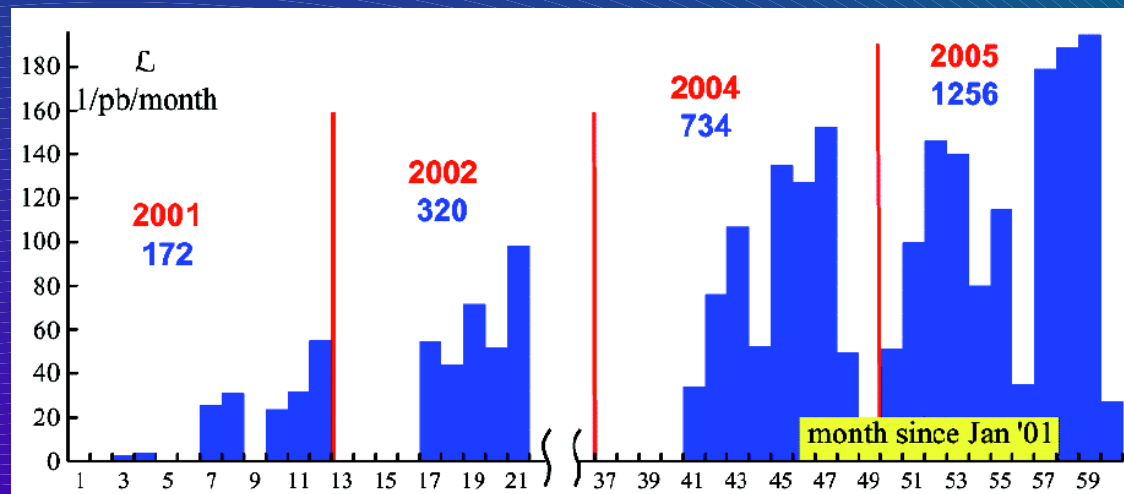
Events on tape 8 billions of ϕ decays

| | | | |
|-------------------|-------------------|---------------|-------------------|
| K^+K^- | 4×10^9 | $\pi^0\gamma$ | 10×10^6 |
| $K^0\bar{K}^0$ | 3×10^9 | $f_0\gamma$ | 2.6×10^6 |
| $\pi^+\pi^-\pi^0$ | 1.2×10^9 | $a_0\gamma$ | 6.3×10^5 |
| $\eta\gamma$ | 100×10^6 | $\eta'\gamma$ | 5.4×10^5 |



Collected data

- Last run- March 2006
- Max luminosity $1.3 \times 10^{32} \text{ cm}^2/\text{s}$
- Tot. Integrated 2.5 fb^{-1}
- $200 \text{ pb}^{-1} @ \sqrt{s} = 1000 \text{ MeV}$



Events on tape
8 billions of ϕ decays

| | | | |
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| K^+K^- | 4×10^9 | $\pi^0\gamma$ | 10×10^5 |
| $K^0\bar{K}^0$ | 3×10^9 | $f_2\gamma$ | 2.6×10^6 |
| $\pi^+\pi^-\pi^0$ | 1.2×10^9 | $\rho^0\gamma$ | 6.3×10^5 |
| $\eta\gamma$ | 1.1×10^6 | $\eta'g$ | 5.4×10^5 |

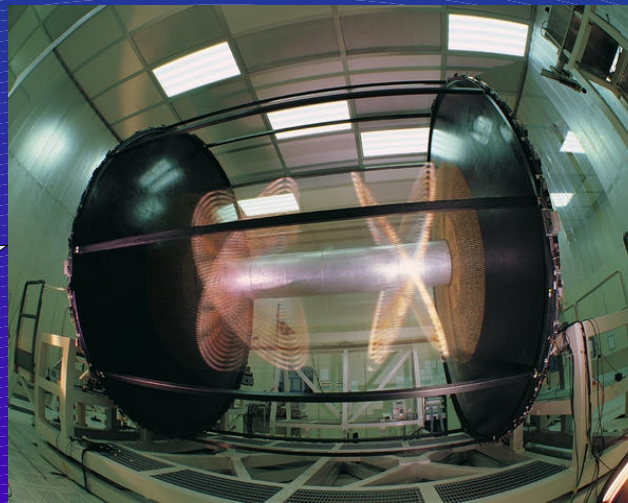
Meson Factory



The KLOE charged particle detector

Cylindrical Drift Chamber

Detector scheme



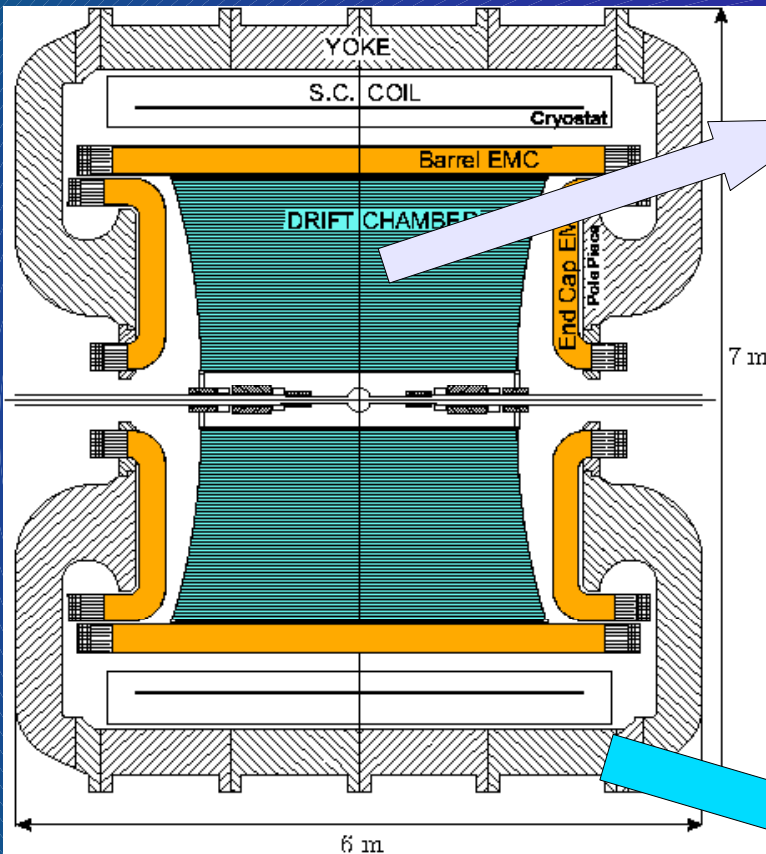
- ◆ Stereo wires structure to reconstruct longitudinal position
- ◆ 52140 wires – 12582 drift cell
- ◆ 90% He 10% iC_4H_{10}

$$\sigma_{vtx} = 1 \text{ mm} \quad \sigma_{pt}/p_t = 0.5\%$$

$$\sigma_{r,\phi} = 200\mu\text{m} \quad \sigma_z = 2 \text{ mm}$$

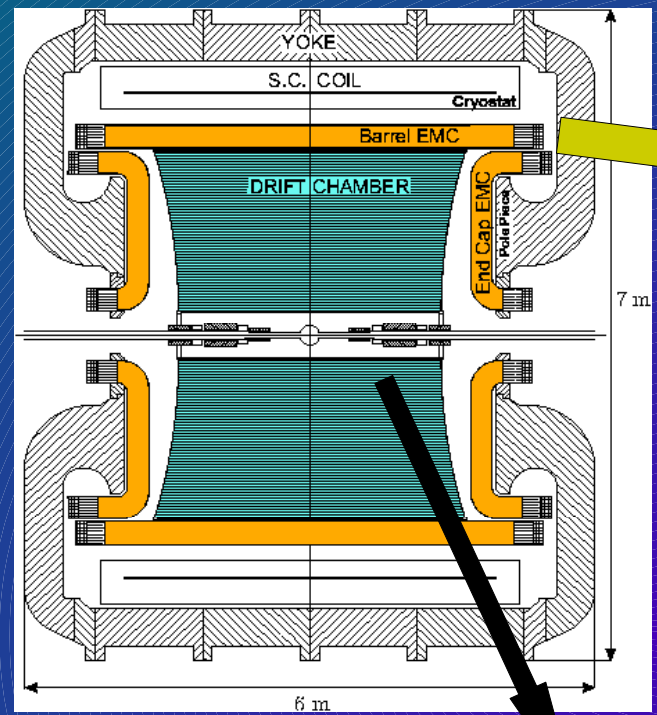
Magnetic yoke.

- ◆ 0.5 T magnetic field
- ◆ Cryogenic coil working at 4.2 °K
- ◆ Coil current 2300 A





The KLOE calorimeters

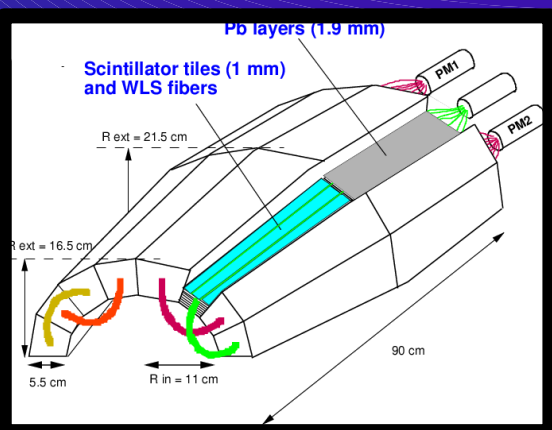


Main calorimeter



Small angle veto calorimeter

Efficiency
20 – 90 %
E 26-125 MeV
 $\sigma_t = 240 \text{ ps}/\sqrt{E}$
(GeV)
covered angle 23°



- ◆ 1 barrel + 2 end-caps
 - ◆ 98% solid angle coverage
 - ◆ High efficiency for low energy photons
 - ◆ two side PM read out, longitudinal position from arrival time
 - ◆ Fine sampling Pb / Scintillating Fibers
 - ◆ Hermetical coverage
- $\sigma_t = 54 \text{ ps}/\sqrt{E(\text{GeV})} \oplus 140 \text{ ps}$
 $\sigma_E/E = 5.7\%/\sqrt{E(\text{GeV})}$

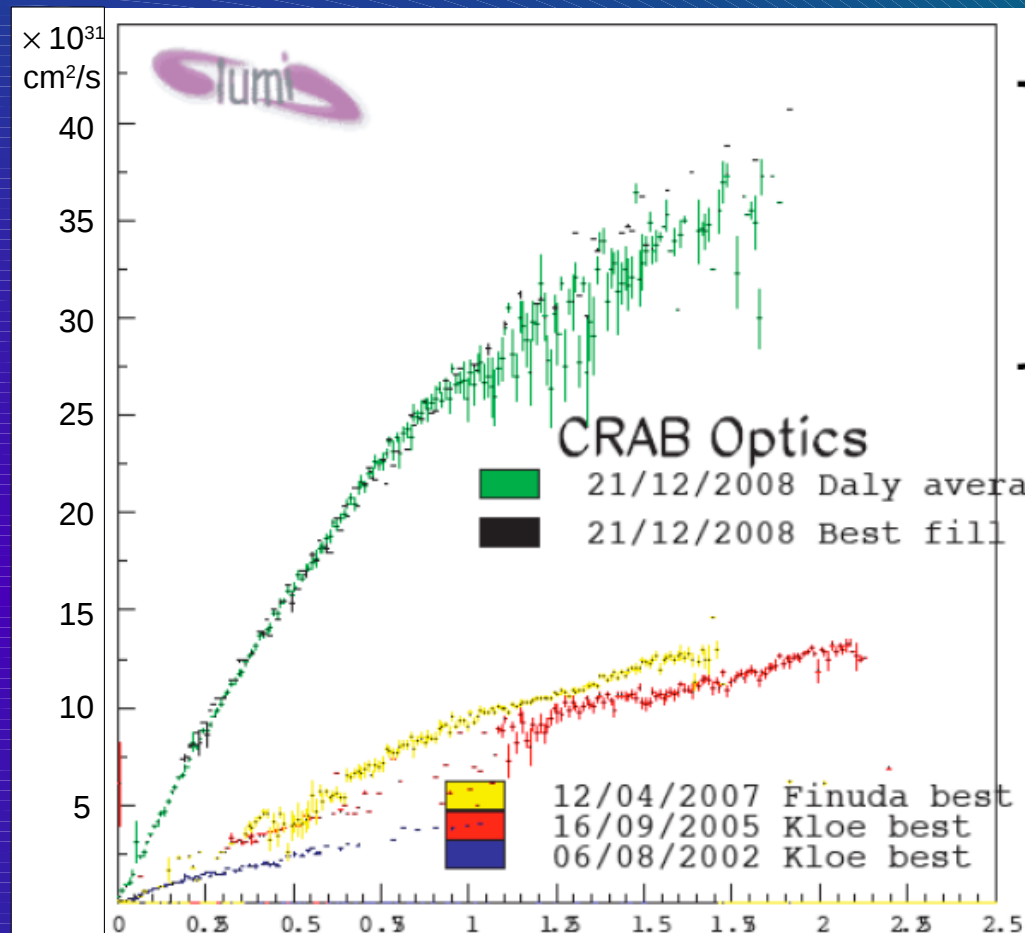
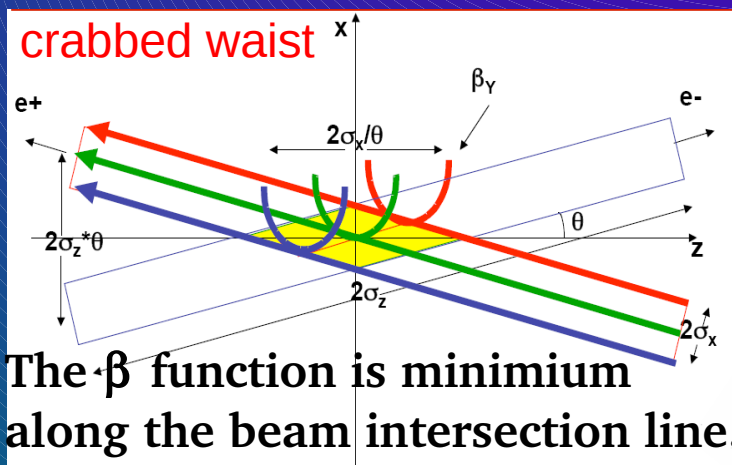
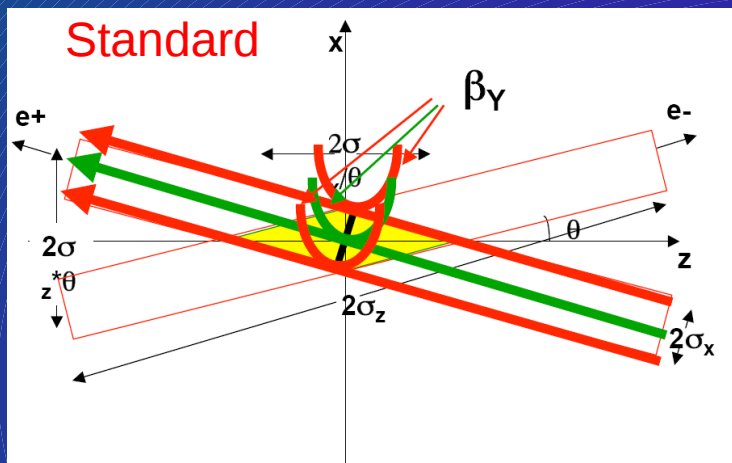
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The DAΦNE upgrade

Machine optic upgrade

- ◆ High Piwinski angle
- ◆ Crabbed waist induced by properly designed sextupole



Expected performances at KLOE-2

- ◆ $L_{\text{peak}} = 5.5 \times 10^{32} \text{ cm}^2/\text{s}$
- ◆ delivered luminosity $0.5 \text{ fb}^{-1}/\text{month}$
- ◆ Increase the KLOE data sample of a factor 10 in few years.

Study of the light meson spectrum in e^+e^- and $\gamma\gamma$ collisions with KLOE at DAΦNE



Minimal detector upgrade

Tagger for $\gamma\gamma$ physics: to detect off-momentum e^\pm from $e^+e^- \rightarrow \gamma^*\gamma^* e^+e^- \rightarrow e^+e^- X$

- ◆ LET: Low Energy Tagger (130-230 MeV) calorimeters, LYSO crystal + SiPM
- ◆ HET: High Energy Tagger ($E > 400$ MeV) position sensitive detector (strong energy-position correlation \Rightarrow use the DAΦNE magnets as bending magnets for an e^\pm spectrometer)

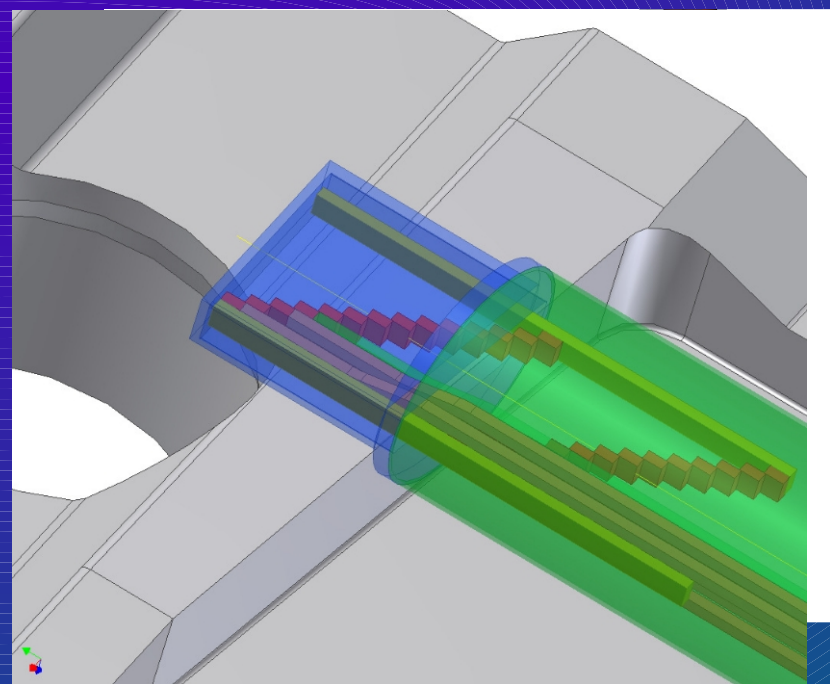
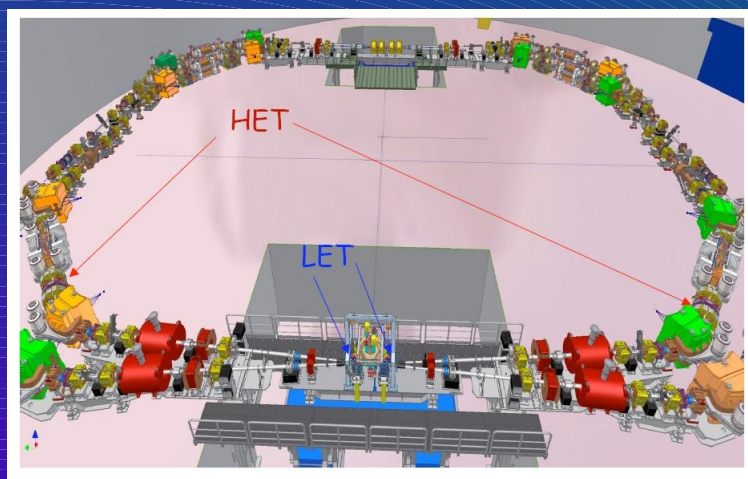
No QCAL on quadrupoles (Pb shielding)

Luminosity goal: $5 \text{ fb}^{-1} @ \sqrt{s} \approx M_\phi$

DAΦNE switch off \Rightarrow 9th November

Detector “roll-in” \Rightarrow end 2009

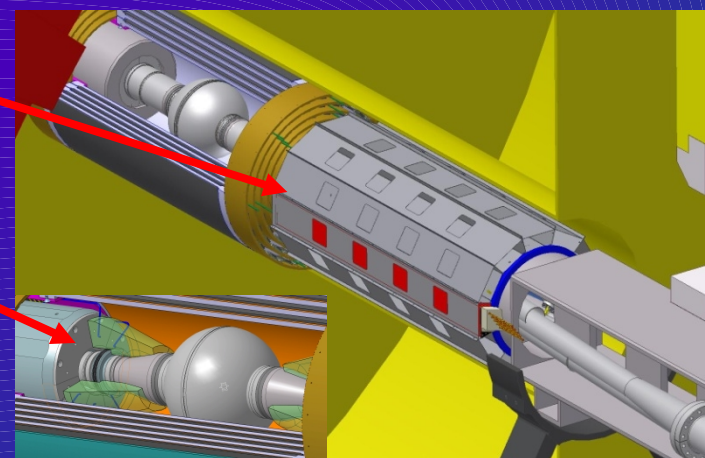
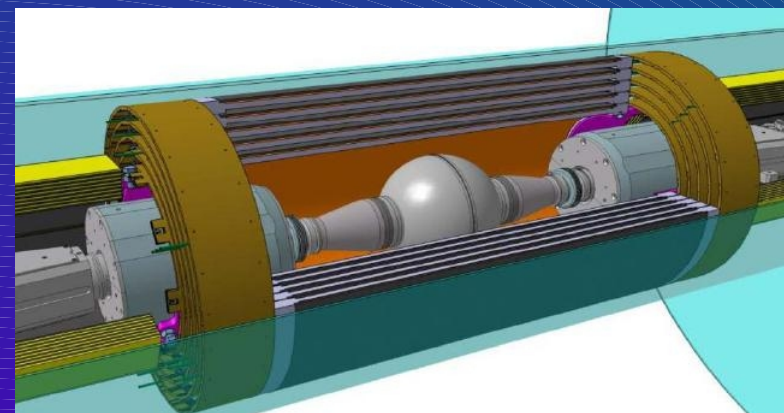
First collisions \Rightarrow March 2010





Major detector upgrade

- ◆ Inner tracker (between the beam pipe and the DC): 5 layers of cylindrical triple GEM: improve vertex reconstruction near the IP increase acceptance for low momentum tracks
- ◆ QCALT: W + scintillating tiles readout by Silicon PM via Wave Length Shifter fibers
- ◆ CCAL: LYSO crystals + APD; close to IP to increase acceptance for photons coming from the IP (min. angle: $21^\circ \rightarrow 9^\circ$)



Schedule and targets

- ◆ Integrated luminosity $> 20 \text{ fb}^{-1}$
- ◆ Time scale > 2011



Status and perspectives in e^+e^- meson production and decay.

- ◆ ϕ decays to scalars, the a_0 parameters, the scalar structure and the instanton model;
- ◆ The σ meson in the η' decay;
- ◆ Search for $\phi \rightarrow (f_0 + a_0)\gamma \rightarrow K^0\bar{K}^0\gamma \rightarrow K_S K_S \gamma$;
- ◆ The determination of the η' gluonium content;
- ◆ Measurement of the $\text{Br}(\eta \rightarrow \pi^+\pi^-\gamma)$ and looking for unconventional CP violation in the decay;
- ◆ ChPT and the $\eta \rightarrow \pi^0\gamma\gamma$ decay

Status and prospects in $\gamma\gamma$ meson production.

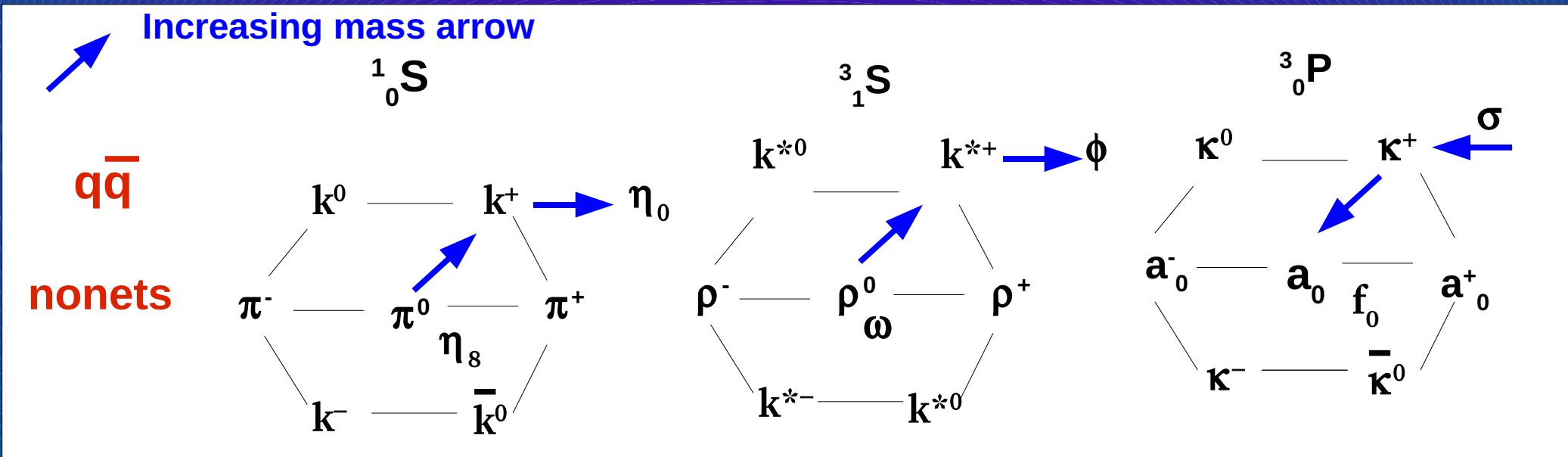
- ◆ Production of the η meson;
- ◆ The σ meson in $\gamma\gamma \rightarrow \pi^0\pi^0$
- ◆ π^0, η, η' form factors and the Light by Light contribution to $(g-2)_\mu$
- ◆ the case of $\pi^0 \rightarrow e^+e^-$



Still open questions on the nature of the light scalars:

$$a_0 \quad f_0 \quad \sigma \quad k$$

The natural answer (2 quarks states in 3_0P configuration) cannot explain the inverted hierarchy.



Why scalars show an inverted mass spectrum respect to the pseudoscalar and vector partners?

Natural explanation in the 4q hypothesis Jaffe $f_0 a_0$ ssdd ssuu σ uudd



Scalars nature can be studied with the ϕ decays

$$e^+e^- \rightarrow \phi \rightarrow (f_0 + \sigma)\gamma \rightarrow \pi^0\pi^0\gamma, \pi^+\pi^-\gamma$$

Eur. Phys. J. C49 (2007) 473

Phys. Lett. B 634 (2006) 148

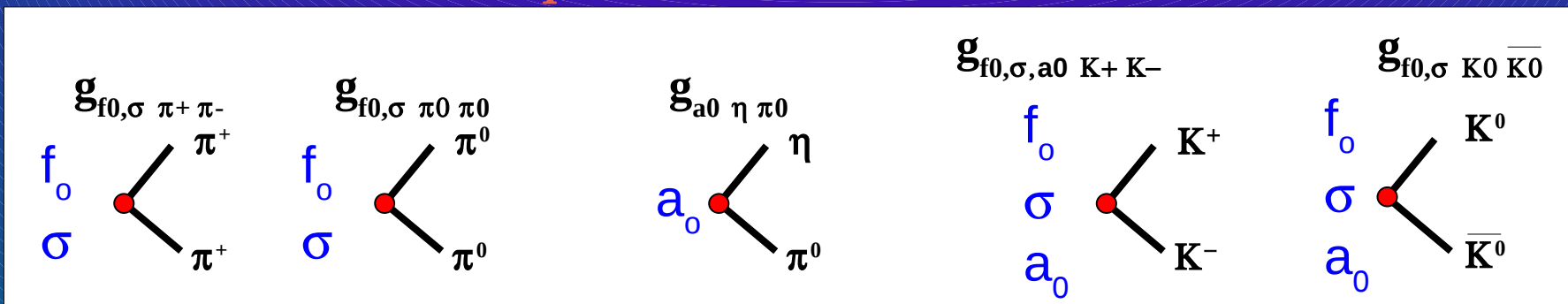
$$e^+e^- \rightarrow \phi \rightarrow a_0\gamma \rightarrow \eta\pi^0\gamma$$

Sensitive
to the scalar structure

$$e^+e^- \rightarrow \phi \rightarrow (a_0 + f_0)\gamma \rightarrow K^0\bar{K}^0\gamma \rightarrow K_s K_s \gamma$$

Sensitive to the a_0 - f_0
interference.

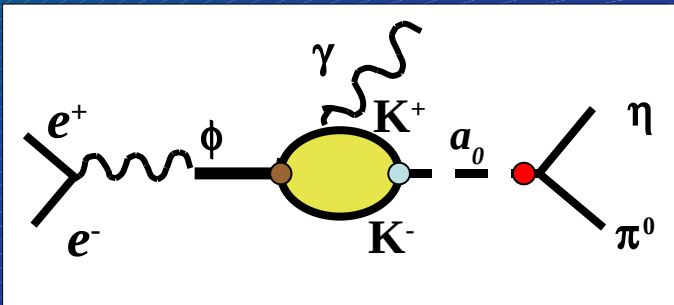
The couplings to the pseudoscalar mesons ($\pi\pi, K^+K^-, \eta\pi$) are sensitive to the quark structure.



Isospin symmetry: $g_{f_0, \sigma \pi^+\pi^-} = 2 g_{f_0, \sigma \pi^0\pi^0}$



Koan loop



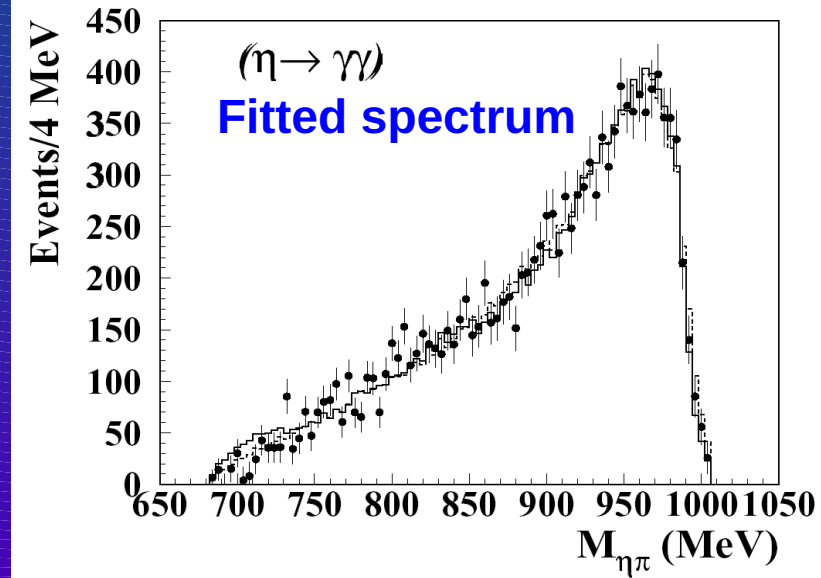
- $g_{\phi K^+ K^-}$
- $g_{S K^+ K^-}$
- $g_S \eta \pi^0$

extraction of $Br(\phi \rightarrow \eta \pi^0 \gamma)$

from event counting (model independent).

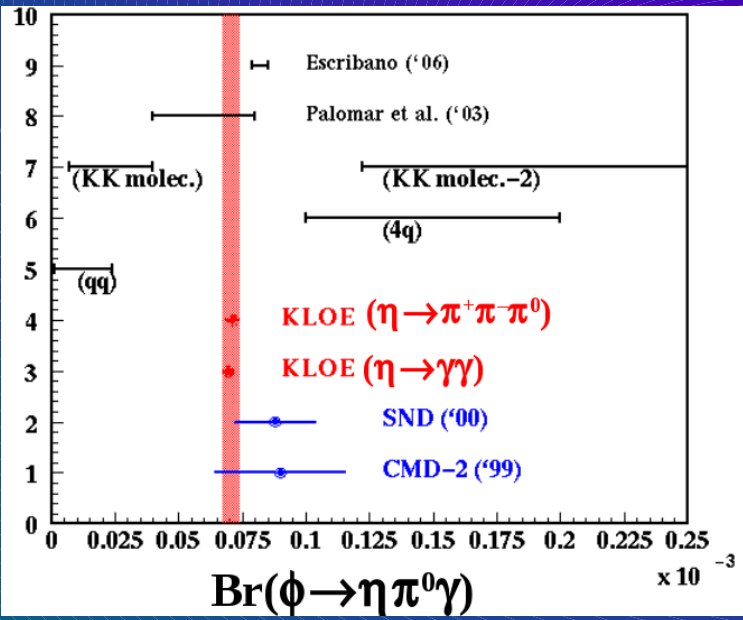
$$\eta \rightarrow \gamma\gamma - Br(\phi \rightarrow \eta \pi^0 \gamma) = (7.01 \pm 0.10_{\text{stat}} \pm 0.20_{\text{syst}}) \times 10^{-5}$$

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



$M_{a_0} = 982.5 \pm 1.6 \pm 1.1 \text{ MeV}$
 $g_{a_0 \eta \pi} = 2.82 \pm 0.03 \pm 0.04 \text{ GeV}$
 $Br(\phi \rightarrow \rho \pi \rightarrow \eta \gamma \pi) = (0.92 \pm 0.40 \pm 0.15) \times 10^{-6}$
 $\delta(\phi \rightarrow \rho \pi \rightarrow \eta \gamma \pi) = (222 \pm 13 \pm 3)^\circ$
 $g_{a_0 K^+ K^-} = 2.15 \pm 0.06 \pm 0.06 \text{ GeV}$

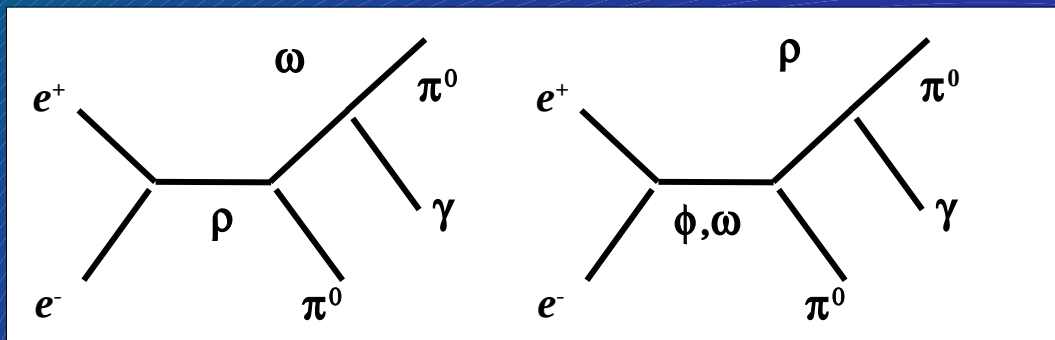
qq: Achasov-Ivanchenko NPB315(1989)
 Close et al., NPB389(1993)
 4q: Achasov-Ivanchenko NPB315(1989)
 KK molec.: Close et al., NPB389(1993)
 Achasov et al., PRD56(1997)
 KK molec.-2: Kalashnikova et al., EPJA24(2005)
 Palomar et al., NPA729(2003): $U\chi PT$
 Escribano, PRD74(2006): Linear σ model





Dalitz plot fit to $\pi^0\pi^0\gamma$

Irreducible background fitted in the amplitude



Fitted parameters: $M_{f_0}, g_{f_0K+K}, g_{f_0\pi+\pi-} (= \sqrt{2} g_{f_0\pi^0\pi^0})$

Background parameters:

$\phi_{\omega\pi^0}, \phi_{\rho\pi^0}, C_{\omega\pi^0}, C_{\rho\pi^0}, \alpha_{\rho\pi}, M_\omega, \delta_{b\rho}$

Interference phase with the scalar amplitude

$\delta_B = \delta_B^{\pi\pi} + \delta_B^{KK}$ (elastic scattering)

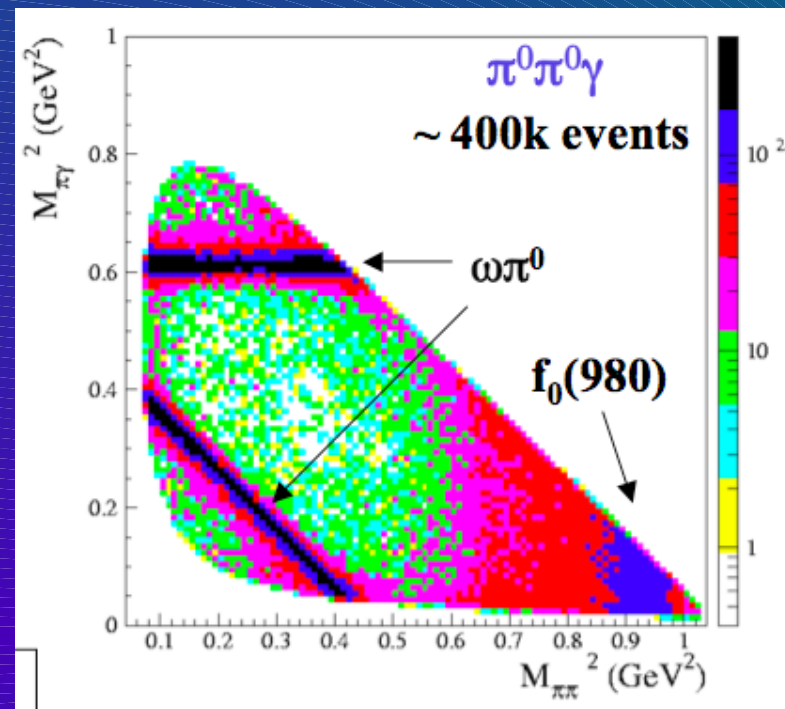
and $\sigma(600)$ parameters fixed

[Achasov-Kiselev, PRD73 (2006)

054029 with PRD 74 (2006)

059902 (E)

+ private communication for $C_{f_0\sigma}$]



Fit result

$M_{f_0} = 984.7 \pm 1.9 \text{ MeV}$
 $g_{f_0K+K} = 3.97 \pm 0.43 \text{ GeV}$
 $g_{f_0p+p-} = -1.82 \pm 0.19 \text{ GeV}$

The σ needed in the fit. $P(\chi^2) \sim 10^{-4}$ without σ

Systematic dominated by fixed parameters.

10 sets of parameters available

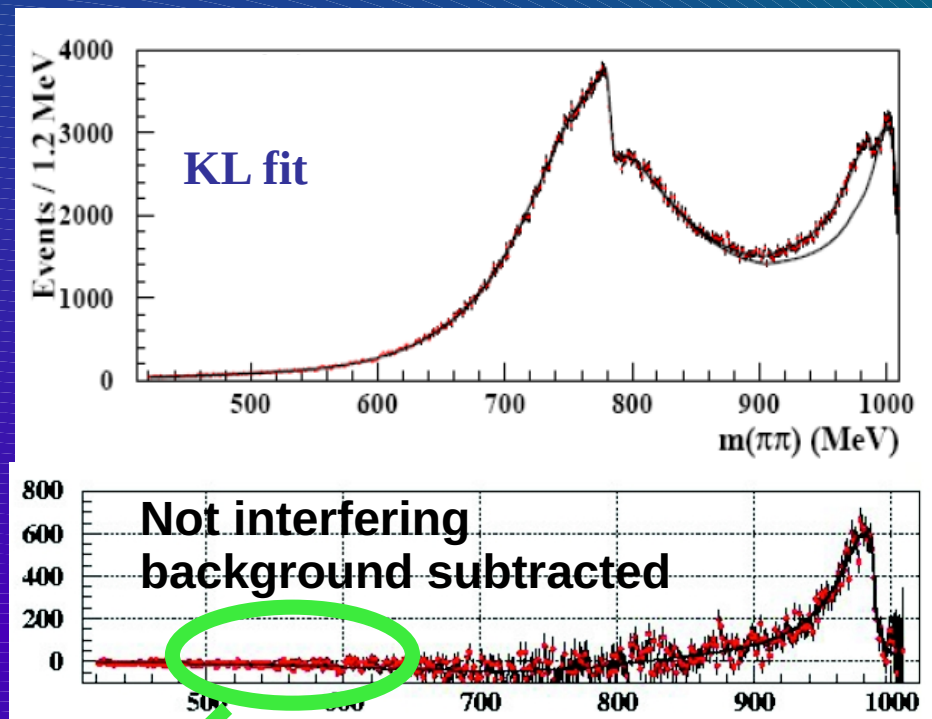
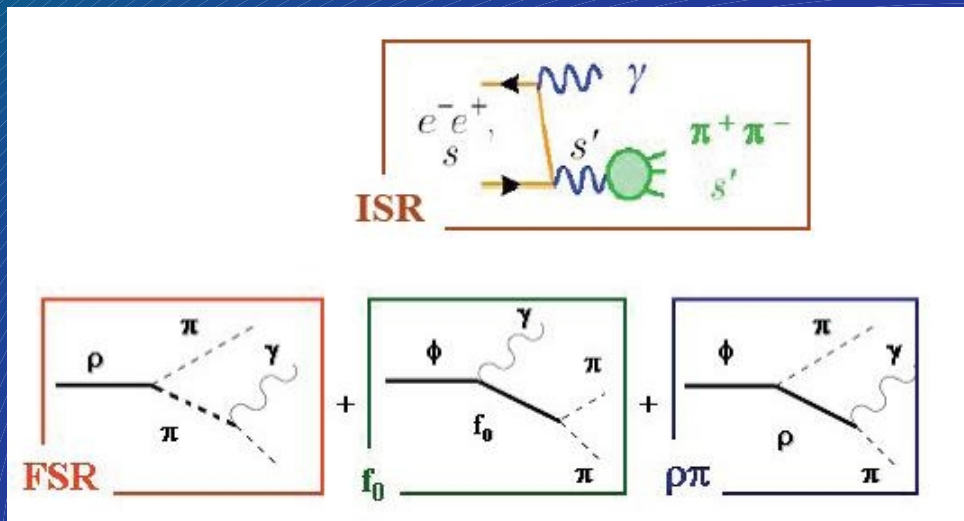
8 with $P(\chi^2) > 1\%$

Values are the mean and the RMS of the fit results.



$M_{\pi^+\pi^-}$ fit to $\pi^+\pi^-\gamma$ events

Irreducible background fitted in the amplitude



- ISR: [Kühn-Santamaria ZPC48 (1990) 455]
Free parameters: M_{ρ^0} , Γ_{ρ^0} , α , β
- FSR fixed [Achasov, Gubin, Solodov PRD55(1997)2672]
- $\rho\pi$: ($\phi \rightarrow \rho^+\pi^-$; $\rho^+ \rightarrow \pi^+\gamma$) VDM, a scale factor ($a_{\rho\pi}$) free
- scalar-FSR interference [Achasov-Gubin PRD57 (1998) 1987]
- fit with σ contribution

Fit result
 $P(\chi^2) = 2.5\%$

| | | |
|----------------|---|-----------|
| M_{f_0} | = | 983.7 MeV |
| $g_{f_0K+K^-}$ | = | 4.74 GeV |
| $g_{f_0p+p^-}$ | = | -2.22 GeV |

no sensitivity to σ shown by the fit

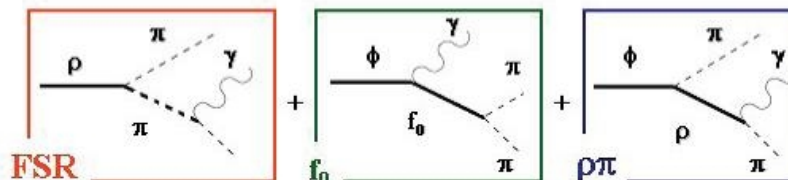
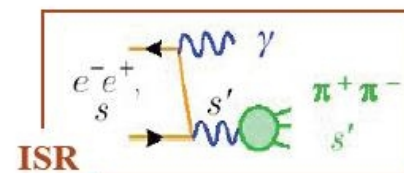
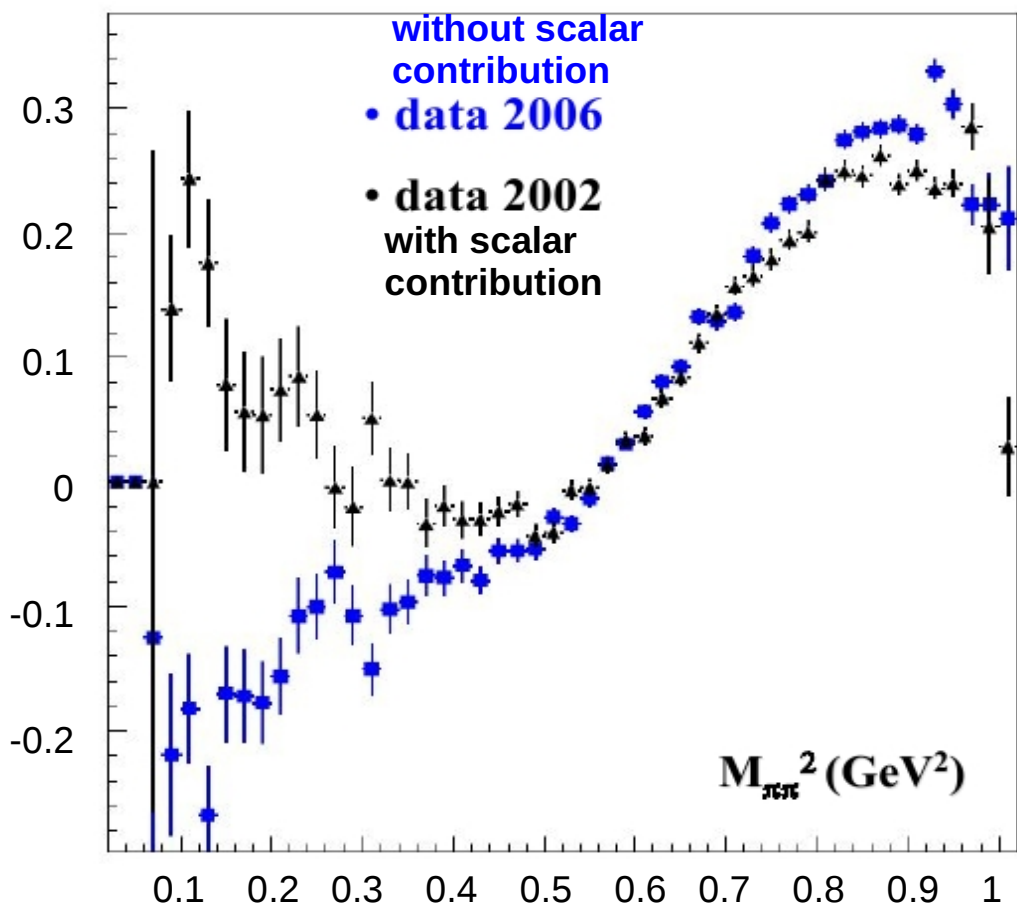


$M_{\pi^+\pi^-}$ fit to $\pi^+\pi^-\gamma$ events at KLOE

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

Amp(ISR) C-odd Amp($f_0+\sigma$) C-even
 Amp(FSR) C-even

Charge Asymmetry



- ◆ with 8 fb^{-1} at KLOE-2 the statistical sensitivity to the σ presence increases of a factor 4;
- ◆ KLOE-2 can be sensitive to σ also in the charged final state.
- ◆ big effort for background handling;
- ◆ fitting the asymmetry is crucial to gain sensitivity to scalars.



Scalar couplings to pseudoscalars 2q versus 4q

Couplings compatible with a 2 quarks hypothesis with $f_0 = s\bar{s}$

KLOE

SU(3)

4q

qq

4q cannot fit the small value of $g_{a_0 KK}$.

| | | | | |
|---|-----------|-----------|------------------------------|--------------------------|
| $(g_{a_0 K+K^-} / g_{a_0 \eta \pi})^2$ | 0.6 - 0.7 | 1.2 - 1.7 | 0.4 q (u,d) | |
| $(g_{f_0 K+K^-} / g_{f_0 \pi+\pi^-})^2$ | 4.6 - 4.8 | $\gg 1$ | $\gg 1$ ($f_0 = s\bar{s}$) | 1/4 ($f_0 = q\bar{q}$) |
| $(g_{f_0 K+K^-} / g_{a_0 K+K^-})^2$ | 4 - 5 | 1 | 2 ($f_0 = s\bar{s}$) | 1 ($f_0 = q\bar{q}$) |



Scalar couplings to pseudoscalars 2q versus 4q

Couplings compatible with a 2 quarks hypothesis with $f_0 = s\bar{s}$

KLOE

SU(3)

4q

qq

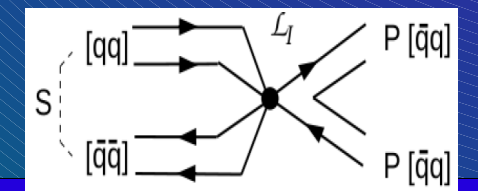
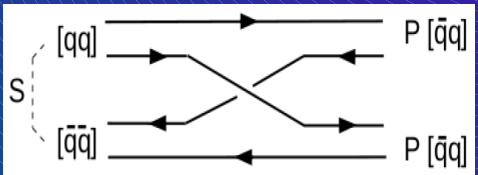
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| $(g_{f_0 K+K-}/g_{a_0 K+K-})^2$ | 4 - 5 | 1 | 2 ($f_0 = s\bar{s}$) | 1 ($f_0 = qq$) |

New model from T'Hooft, Isidori, Maiani, Polosa and Riquer (Phys. Lett. B662 (2008) 424)

Interference between two amplitudes allows small $a_0 KK$ coupling

| | KLOE (KL) | | $ qq\rangle \bar{q}\bar{q}\rangle$ | $q\bar{q}$ |
|----------------------------------|---------------|---|--------------------------------------|--------------------------------------|
| $g_{f_0 K+K-} \text{ (GeV)}$ | 3.97 - 4.74 | } | $c_f = -2.8 - -3.4 \text{ GeV}^{-1}$ | $c_f = -3.9 - -4.8 \text{ GeV}^{-1}$ |
| $g_{f_0 \pi+\pi-} \text{ (GeV)}$ | -1.82 - -2.23 | | $c_f = 20.5 - 24.5 \text{ GeV}^{-1}$ | $c_f = 16.5 - 19.7 \text{ GeV}^{-1}$ |
| | | | ↓ | ↓ |
| $g_{a_0 K+K-} \text{ (GeV)}$ | 2.01 - 2.15 | | 2.1 - 2.5 | 2.4 - 2.9 |
| $g_{a_0 \eta\pi} \text{ (GeV)}$ | 2.46 - 2.82 | | 3.3 - 3.9 | 6.6 - 7.9 |





Scalar couplings to pseudoscalars 2q versus 4q

Couplings compatible with a 2 quarks hypothesis with $f_0 = s\bar{s}$

KLOE

SU(3)

4q

qq

4q cannot fit the small value of $g_{a_0 KK}$.

| | | | | |
|-------------------------------------|-----------|-----------|--------------------------|--------------------|
| $(g_{a_0 K+K-}/g_{a_0 \eta\pi})^2$ | 0.6 - 0.7 | 1.2 - 1.7 | 0.4 q (u,d) | |
| $(g_{f_0 K+K-}/g_{f_0 \pi+\pi-})^2$ | 4.6 - 4.8 | >>1 | >>1 ($f_0 = s\bar{s}$) | 1/4 ($f_0 = qq$) |
| $(g_{f_0 K+K-}/g_{a_0 K+K-})^2$ | 4 - 5 | 1 | 2 ($f_0 = s\bar{s}$) | 1 ($f_0 = qq$) |

New model from T'Hooft, Isidori, Maiani, Polosa and Riquer (Phys. Lett. B662 (2008) 424)

Interference between two ampli-

| | KLOE (KL) | | $[qq][\bar{q}\bar{q}]$ | $q\bar{q}$ |
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| $g_{f_0 K+K-}$ (GeV) | 3.97 - 4.74 | } | $c_f = -2.8 - -3.4 \text{ GeV}^{-1}$ | $c_f = -3.9 - -4.8 \text{ GeV}^{-1}$ |
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| $g_{a_0 \eta\pi}$ (GeV) | 2.46 - 2.82 | | 3.3 - 3.9 | 6.6 - 7.9 |
| $g_{\sigma \pi+\pi-}$ (GeV) | m_σ 441 MeV | | 1.6 - 2.0 | 1.8 - 2.2 |
| $g_{\sigma \pi+\pi-}$ (GeV) | m_σ 541 MeV | | 2.6 - 3.2 | 2.9 - 3.6 |

| | m_σ MeV | Γ_σ MeV | $g_{\sigma \pi+\pi-}$ GeV ⁻¹ |
|---|-------------------|------------------------|--|
| Caprini PRL 96, 132001 (2006) | 441 | 544 | 3.5 |
| CLEO Phys. Rev. D76 012001 | 466 | 446 | 3.5 |
| BES2 Phys. Lett. B645 19 $J/\psi \rightarrow \omega \pi^+ \pi^-$ | 541 | 504 | 3.2 |





σ observed in

| | |
|---|-----------------------------------|
| $J/\psi \rightarrow \pi^+ \pi^- \omega$ | $L(\pi^+ \pi^-) = 0, 1, 2$ |
| $\pi^+ \pi^- \rightarrow \pi^+ \pi^-$ | $L(\pi^+ \pi^-) = 0, 1, 2, \dots$ |
| $D^+ \rightarrow \pi^+ \pi^- \pi^+$ | $L(\pi^+ \pi^-) = 0, 1, 2, \dots$ |

Partial wave analysis in order to disentangle, model dependence, results dependent on heavier vector and scalar resonances.



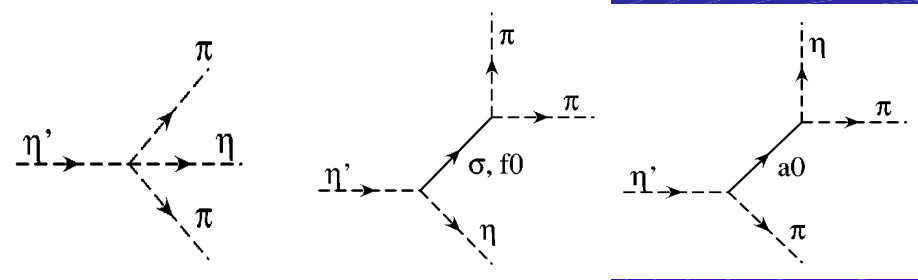
σ meson in $\eta' \rightarrow \pi\pi\eta$ decay @KLOE2

- ◆ Low energy assures no angular excitation.
- ◆ G-parity conservation forbids vector meson exchange.
- ◆ The f_0 contribution is expected to be small. The a_0 contribution is large, but σ is visible in a_0 - σ interference.

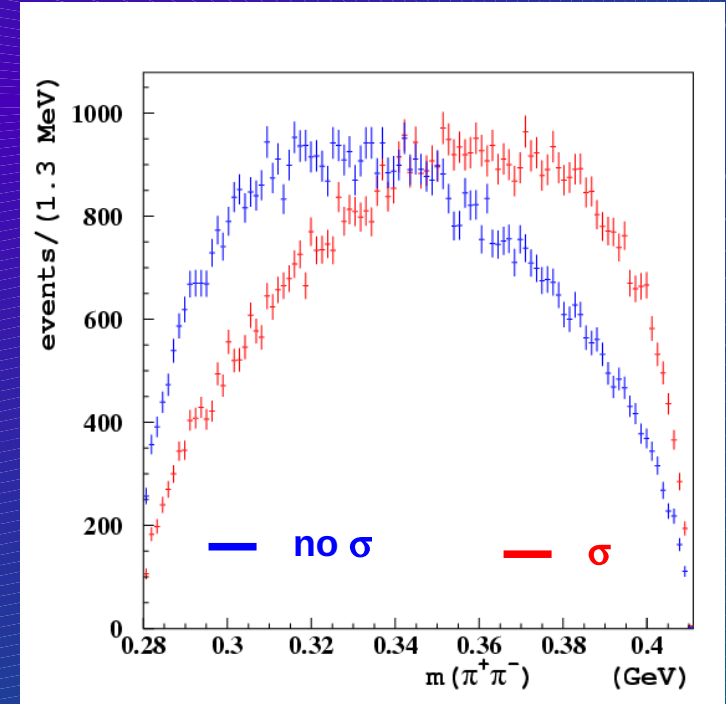
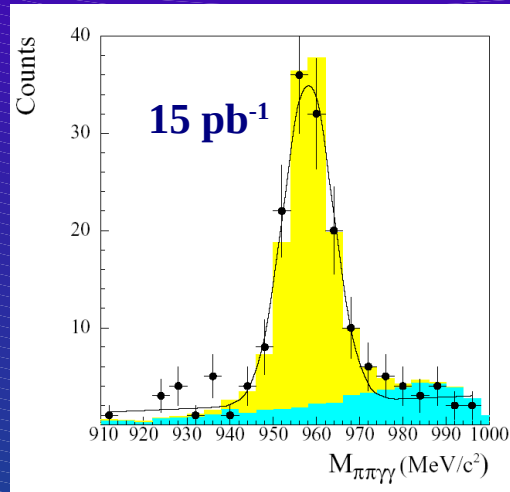
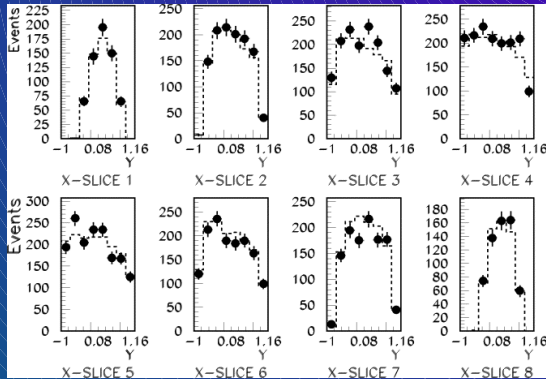
Donskov, hep/ph 0902.3329
 Fariborz, Schechter, Phys. Rev. D60, 034002

$$\eta' \rightarrow \pi^+ \pi^- \eta \quad m_{\pi^+\pi^-} = [0.28-0.411] \text{ GeV}$$

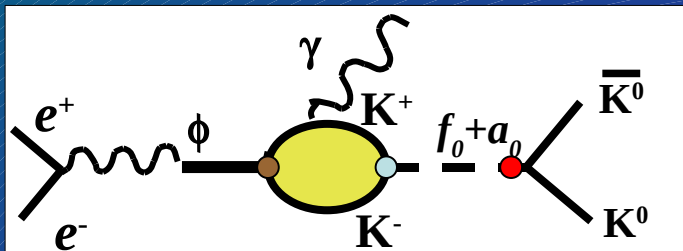
$$0^- \quad 0^+ \quad 0^-$$



VES ~ 6500 events $\eta' \rightarrow \pi^+ \pi^- \eta$ Events expected 730.000
 Phys. Lett. B 651 (2007) 22 $\eta \rightarrow \gamma\gamma$ 287.000
 efficiency (22.8)% 65.500



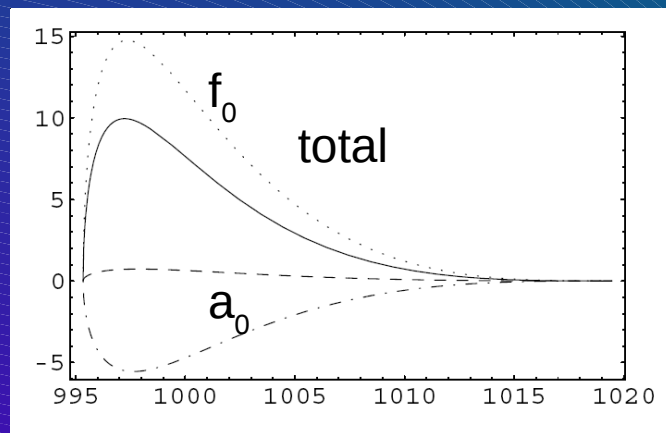
$$X = \frac{\sqrt{3}}{Q} (T_{\pi^+} - T_{\pi^-}); \quad Y = \frac{m_\eta + 2m_\pi}{m_\pi} \frac{T_\eta}{Q} - 1;$$



- $g_{\phi K^+ K^-}$
- $g_{S K^+ K^-}$
- $g_{S K^0 K^0}$

$(10^{-9} \text{ MeV}^{-1})$ R. Escribano, Eur. Phys.J. A31 (2007) 454

$$\frac{dBr(\phi \rightarrow K^0 \bar{K}^0 \gamma)}{dm_{K^0 \bar{K}^0}}$$



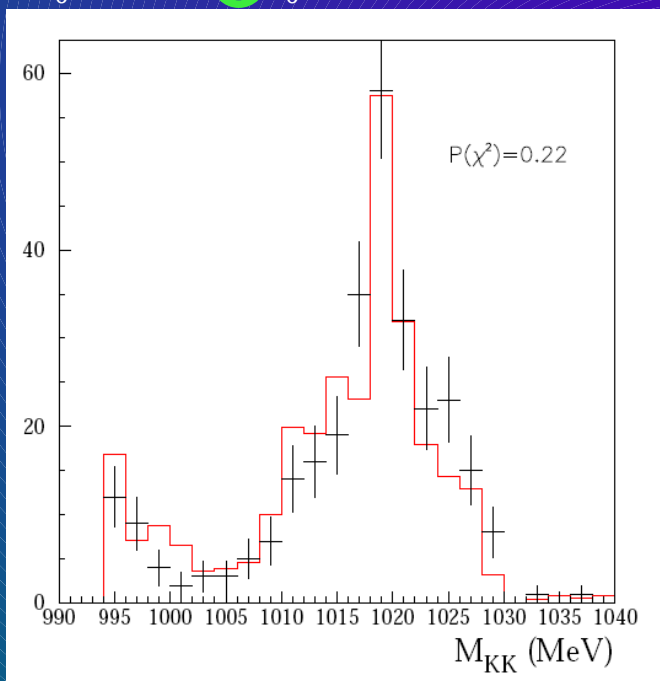
Isospin symmetry relates the couplings

$$g_{f_0 \pi^+ \pi^-} = 2 g_{f_0 \pi^0 \pi^0}$$

$$g_{f_0 K^0 K^0} = g_{f_0 K^+ K^-}$$

$$g_{a_0 K^0 K^0} = -g_{a_0 K^+ K^-}$$

strong destructive interference between a_0 and f_0 is expected in the KK channel

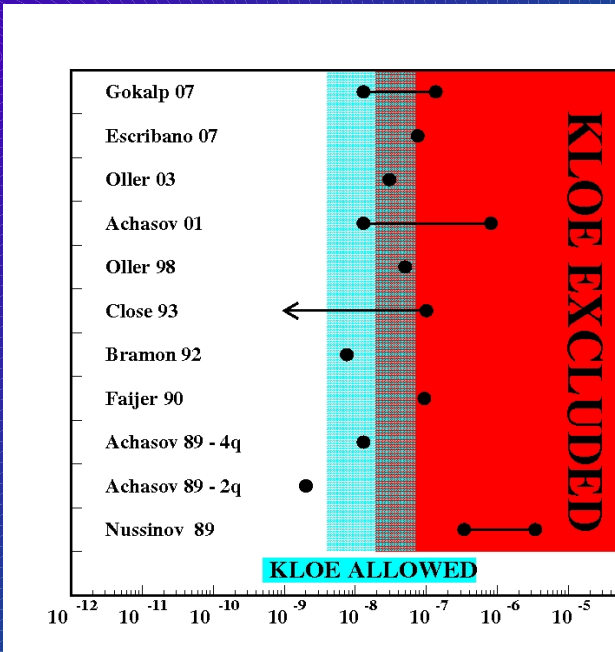


Dataset: 2.2 fb^{-1}

5 events in data ($\epsilon = 24\%$)
 3.2 ± 0.7 exp. background

First experimental result

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





$\phi \rightarrow K^0 K^0 \gamma$ KLOE 2 expectation

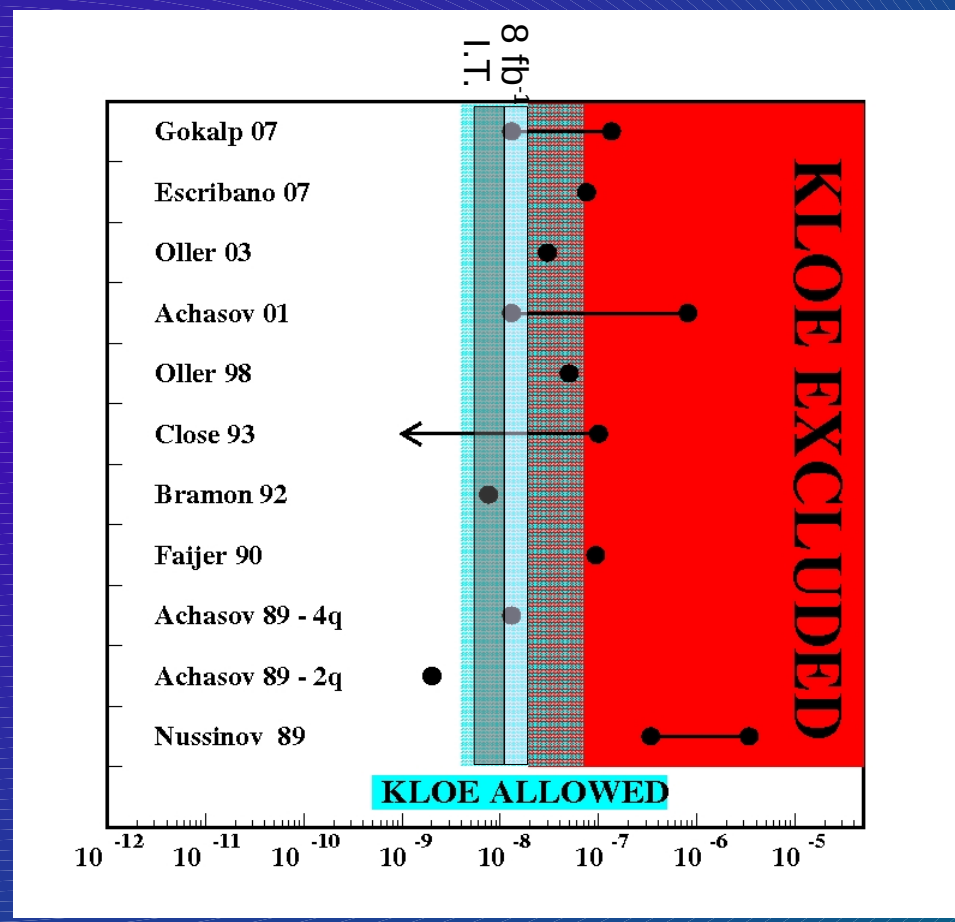
| KLOE | KLOE2 8fb ⁻¹ | Inner Tracker |
|--|-------------------------|--------------------------|
| observed events = 5 | 20 | 20 |
| background events = 3.2 ± 0.7 | 13 | 4 |
| Br[$\phi \rightarrow (f_0 + a_0) \gamma$] < 1.9 x 10 ⁻⁸ | < 1 x 10 ⁻⁸ | < 0.5 x 10 ⁻⁸ |

Main background from CP violating decay:

$$\phi \rightarrow K_s K_L \rightarrow \pi^+ \pi^- \pi^+ \pi^-$$

(1) main background from $K_S K_L$, reducible with better vertex reconstruction

- [1] N.N. Achasov, V.N. Ivanchenko, Nucl. Phys. B315 (1989) 465.
- [2] S. Fajfer, R.J. Oakes, Phys. Rev. D42 (1990) 2392
- [3] J. Lucio, J. Pestieau, Phys. Rev. D42 (1990) 3253.
- [4] A. Bramon, A. Grau, G. Pancheri, Phys. Lett. B289 (1992) 97.
- [5] J.A. Oller, Phys.Lett. B426 (1998) 7.
- [6] N.N. Achasov, V.V. Gubin, Phys. Rev. D64 (2001) 094016.
- [7] S. Nussinov, T.N. Truong, Phys. Rev. Lett. 63 (1989) 1349, Erratum 2003.
- [8] J.A. Oller, Nucl. Phys. A714 (2003) 161.
- [9] R. Escribano, Eur. Phys. J. A31 (2007) 454.
- [10] A. Gokalp, C.S. Korkmaz, O. Yilmaz, Phys. Rev. D75 (2007) 013001.





η, η' : mixing and gluonium

The η, η' mesons wave function can be decomposed in the quark mixing base as in the following (J. L. Rosner, Phys. Rev. D 27 (1983) 1101.).

$$|\eta'\rangle = X_{\eta'} |q\bar{q}\rangle + Y_{\eta'} |s\bar{s}\rangle + Z_{\eta'} |G\rangle \quad |\eta\rangle = \cos\psi_P |q\bar{q}\rangle - \sin\psi_P |s\bar{s}\rangle \quad |q\bar{q}\rangle = \frac{|u\bar{u}\rangle + |d\bar{d}\rangle}{\sqrt{2}}$$

$$X_{\eta'} = \sin\psi_P \cos\psi_G$$

$$Y_{\eta'} = \cos\psi_P \cos\psi_G$$

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

The $\phi \rightarrow \eta, \eta' \gamma$ transition is modeled according a spin flip transition



$$\Gamma(P \rightarrow V \gamma) = \frac{g^2}{4\pi} |p_y|^3$$

$$\Gamma(V \rightarrow P \gamma) = \frac{1}{3} \frac{g^2}{4\pi} |p_y|^3$$

Only quarks participate to the electromagnetic transition, gluonium is spectator. It appears in the η' decay amplitudes only through the normalisation to 1 ($Y_{\eta'} \sim \cos\psi_G$)



On the meaning of gluonium

$Z_{\eta'}$ can be interpreted as a mixing with a glue ball.
 The mass of this glue ball has been determined
 [Hai-Yang Cheng, Phys. Rev. D79 (2009) 014024]

$$\theta_i = 54.7^\circ$$

$$\phi \rightarrow \psi_P$$

$$\phi_G \rightarrow \psi_G$$

$$\frac{c\theta(s\phi - c\theta s\theta_i\Delta_G)m_{\eta'}^2 - s\theta(c\phi + s\theta s\theta_i\Delta_G)^2m_\eta^2 - s\theta_i c\phi_G m_G^2}{c\theta(c\phi - c\theta c\theta_i\Delta_G)m_{\eta'}^2 + s\theta(s\phi - s\theta c\theta_i\Delta_G)^2m_\eta^2 - c\theta_i c\phi_G m_G^2} = \frac{\sqrt{2}f_s}{f_q},$$

$$m_G = (1.41 \pm 0.1) \text{ GeV}$$

The glue-ball is identified as $\eta(1405)$
 copiously produced in $J/\psi \rightarrow \eta(1405)\gamma$

Prediction $\text{Br}(\eta(1405) \rightarrow \gamma\gamma) = 6 \pm 1 \times 10^{-5}$
 Decay never observed



KLOE has fitted:

$$\frac{\Gamma(\eta' \rightarrow \rho \gamma)}{\Gamma(\omega \rightarrow \pi^0 \gamma)} = \frac{z_q^2}{\cos^2 \psi_V} \cdot 3 \left(\frac{m_{\eta'}^2 - m_\rho^2 m_\omega}{m_\omega^2 - m_\pi^2 m_{\eta'}} \right)^3 X_{\eta'}^2$$

$$\frac{\Gamma(\eta' \rightarrow \omega \gamma)}{\Gamma(\omega \rightarrow \pi^0 \gamma)} = \frac{1}{3} \left(\frac{m_{\eta'}^2 - m_\omega^2 m_\omega}{m_\omega^2 - m_\pi^2 m_{\eta'}} \right)^3 \left[z_q^2 Y_{\eta'} + 2 \frac{m_s}{\bar{m}} z_s \tan \psi_V Y_{\eta'} \right]^2$$

taken from a global fit without gluonium

A. Bramon, R. Escribano, M.D. Scadron
 Phys. Lett. B503 (2001) 271

Using KLOE measured branching ratio:

$$R_\phi = \frac{Br(\phi \rightarrow \eta' \gamma)}{Br(\phi \rightarrow \eta \gamma)} = \cot^2 \psi_P \cdot \cos^2 \psi_G \left(1 - \frac{m_s}{\bar{m}} \frac{z_q}{z_s} \frac{\tan \psi_V}{\sin 2\psi_P} \right)^2 \cdot \left(\frac{p_{\eta'}}{p_\eta} \right)^3$$

$$R_\phi = (4.77 \pm 0.09 \pm 0.19) \times 10^{-3}$$

$\phi \rightarrow \eta' \gamma$ $\eta' \rightarrow \pi^+ \pi^- \eta, \eta \rightarrow 3\pi^0$
 $\eta' \rightarrow \pi^0 \pi^0 \eta, \eta \rightarrow \pi^+ \pi^- \pi^0$
 $\phi \rightarrow \eta \gamma, \eta \rightarrow 3\pi^0$

and the ratio:

$$\frac{\Gamma(\eta' \rightarrow \gamma \gamma)}{\Gamma(\pi^0 \rightarrow \gamma \gamma)} = \frac{1}{9} \left(\frac{m_{\eta'}}{m_\pi} \right)^3 \left(5 \frac{f_\pi}{f_q} X_{\eta'} + \sqrt{2} \frac{f_\pi}{f_s} Y_{\eta'} \right)^2$$

E. Kou, Phys. Rev. D 63 (2001) 54027



New global fit with more free parameters: $Z_q, Z_s, \psi_V, m_s/m$

Other input are needed

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

From PDG06

R.Escribano,
J. Nadal

| Parameter | KLOE old fit | KLOE New fit | K. New fit (no Pγγ) | JHEP 05 (2007) 6 |
|-------------|------------------------|-------------------------|-------------------------|------------------------|
| $Z_{\eta'}$ | 0.14 ± 0.04 | 0.105 ± 0.037 | 0.03 ± 0.06 | 0.04 ± 0.09 |
| ψ_P | $(39.7 \pm 0.7)^\circ$ | $(40.7 \pm 0.7)^\circ$ | $(41.6 \pm 0.8)^\circ$ | $(41.4 \pm 1.3)^\circ$ |
| Z_q | 0.91 ± 0.05 | 0.866 ± 0.025 | 0.85 ± 0.03 | 0.86 ± 0.03 |
| Z_s | 0.89 ± 0.07 | 0.79 ± 0.05 | 0.78 ± 0.05 | 0.79 ± 0.05 |
| ψ_V | 3.2° | $(3.15 \pm 0.10)^\circ$ | $(3.16 \pm 0.10)^\circ$ | $(3.2 \pm 0.1)^\circ$ |
| m_s/m | 1.24 ± 0.07 | 1.24 ± 0.07 | 1.24 ± 0.07 | 1.24 ± 0.07 |
| $P(\chi^2)$ | 49% | 17% | 41% | 38% |

Glueonium content @ $\sim 3\sigma$ level confirmed ($Z_{\eta'} = 0: \psi_P = (41.6 \pm 0.5)^\circ, P(\chi^2) = 1\%$)

$\eta' \rightarrow \gamma\gamma$ is the only measurement sensitive to the glueonium

Discrepancy with Escribano-Nadal due to the insertion of $P \rightarrow \gamma\gamma$ decay



Using PDG-08 data

$$\frac{\Gamma(\eta' \rightarrow \gamma\gamma)}{\Gamma(\pi^0 \rightarrow \gamma\gamma)} = \frac{1}{9} \left(\frac{m_{\eta'}}{m_{\pi}} \right)^3 \left(5 \frac{f_{\pi}}{f_q} X_{\eta'} + \sqrt{2} \frac{f_{\pi}}{f_s} Y_{\eta'} \right)^2$$

exact isospin symmetry limit

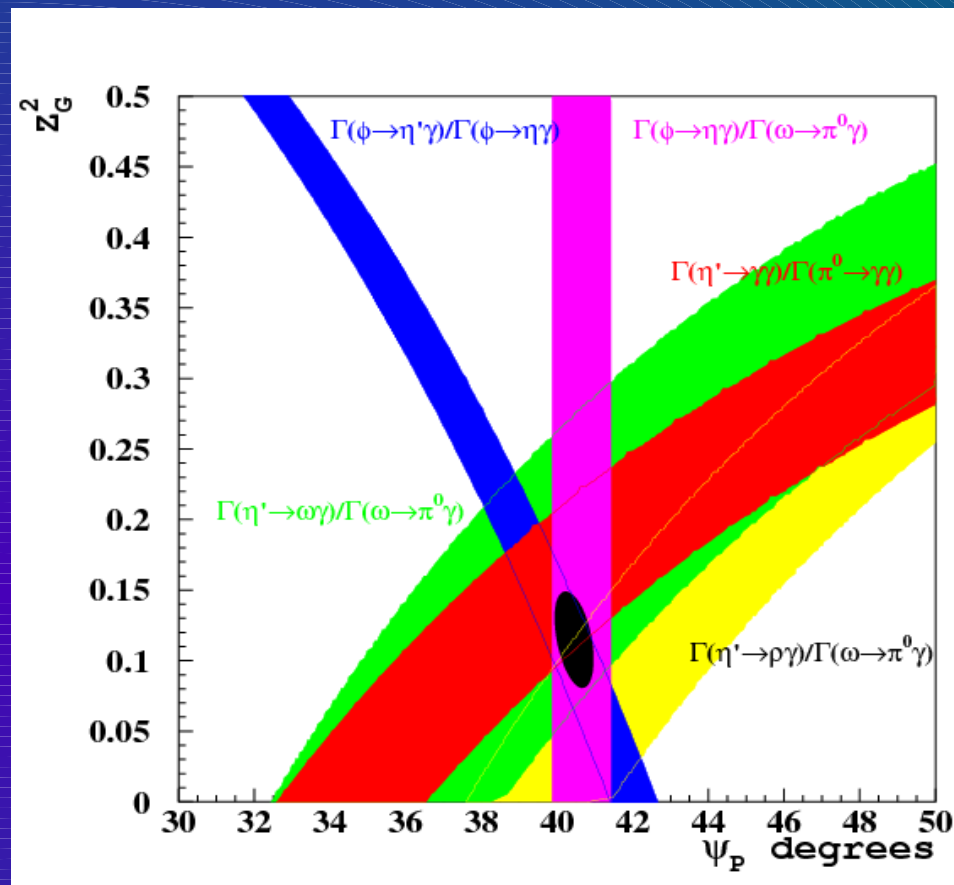
$$f_q/f_{\pi} = 1 \quad f_s/f_{\pi} = \sqrt{2f_K^2/f_{\pi}^2 - 1}$$

f_K/f_{π} from lattice (UKQCD)
 E.Follana *et al.*
 Phys. Rev. Lett. 100 (2008) 062002

$$\chi^2/\text{ndof} = 4.6/3$$

$$P(\chi^2) = 20\%$$

| | |
|-----------|-------------------------|
| $(Z_G)^2$ | 0.115 ± 0.036 |
| ψ_P | $(40.4 \pm 0.6)^\circ$ |
| Z_q | 0.94 ± 0.03 |
| Z_s | 0.83 ± 0.05 |
| ψ_V | $(3.32 \pm 0.09)^\circ$ |
| m_s/m | 1.24 ± 0.07 |





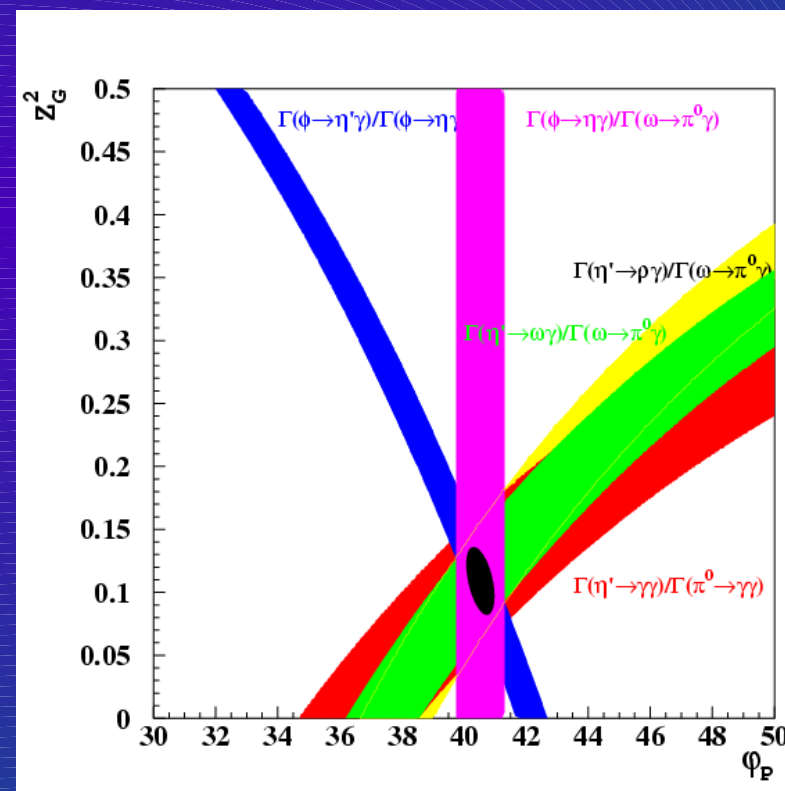
KLOE 2 expectation

1 fb⁻¹

| $\eta'(958)$ DECAY MODES | Fraction (Γ_i/Γ) | events | main bkg |
|--|--------------------------------|--------|---|
| $\pi^+ \pi^- \eta$ | (44.6 ± 1.4) % | 730k | — |
| $\rho^0 \gamma$ (including non-resonant $\pi^+ \pi^- \gamma$) | (29.4 ± 0.9) % | 480k | $\phi \rightarrow \pi^+ \pi^- \pi^0$ |
| $\pi^0 \pi^0 \eta$ | (20.7 ± 1.2) % | 340k | $\eta\gamma$ or KsKI |
| $\omega \gamma$ | (3.02 ± 0.31) % | 50k | $e^+e^- \rightarrow \omega \pi^0$ |
| $\gamma\gamma$ | (2.10 ± 0.12) % | 34k | $e^+e^- \rightarrow \gamma\gamma(\gamma)$ |

All Br can be measured at ~1%
but systematics take the main role.

Sensitivity to the gluonium
also without the $\eta' \rightarrow \gamma\gamma$





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

- ◆ Poorly measured (4 events CMD-2, 16 events CELSIUS-WASA)
- ◆ Br predicted by Chiral Perturbation Theory and VMD models $(26 \div 36) \cdot 10^{-5}$
- ◆ η structure using virtual photon

D. N. Gao, Mod. Phys. Lett. A17(2002) 1583

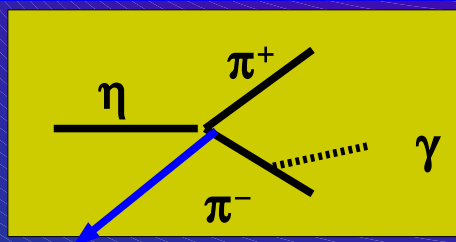
CP violation source not constrained by CKM measurements and neutron electric dipole moment

$$\mathcal{O} = \frac{1}{m_\eta^3} G \bar{s} i \sigma_{\mu\nu} \gamma_5 (p - q)^\nu s \bar{\psi} \gamma^\mu \psi$$



asymmetry in the particle decay angle

Within the SM:



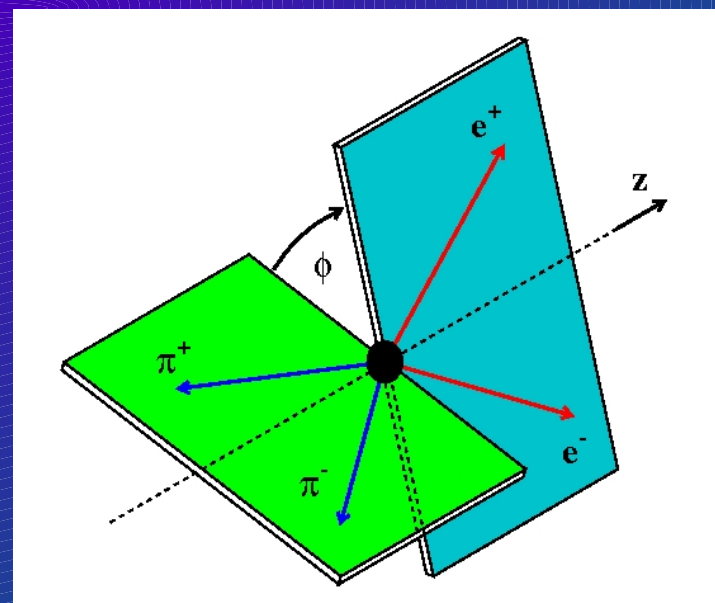
$$A_\phi < 10^{-4}$$

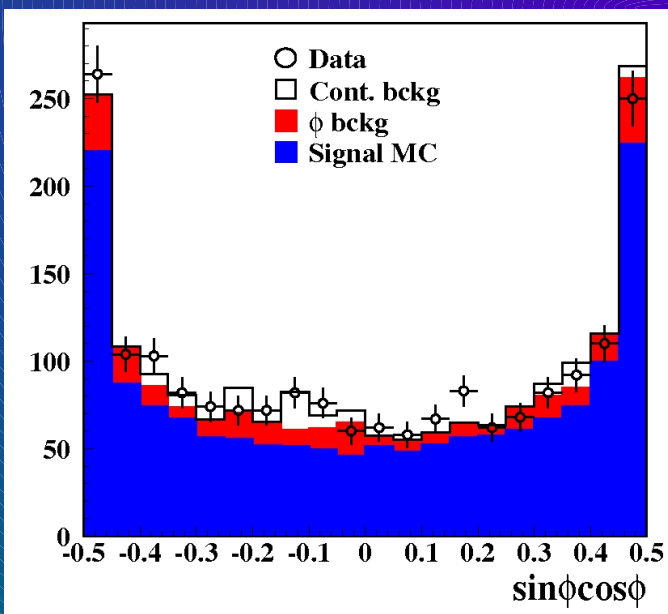
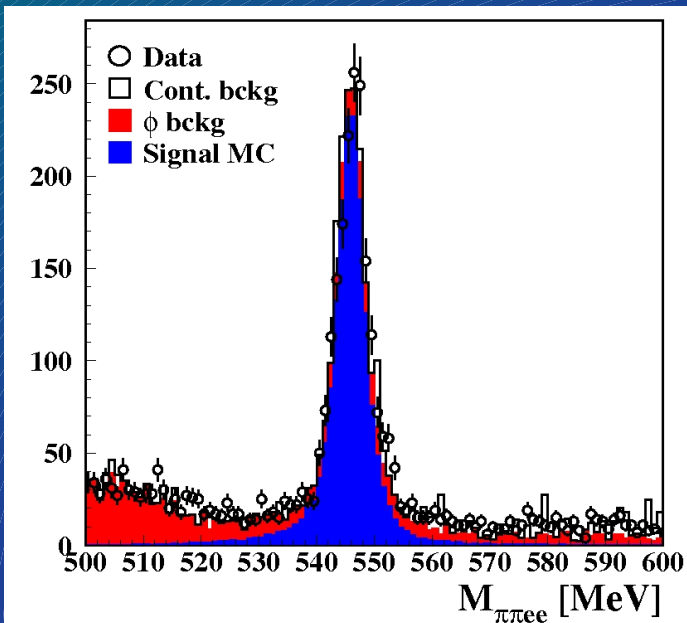
S. M.

$$A_\phi \sim 10^{-15}$$

$\text{Br}(\eta \rightarrow \pi^+ \pi^-) < 1.3 \times 10^{-5}$
 KLOE, Phys. Lett. B606
 (2005) 276

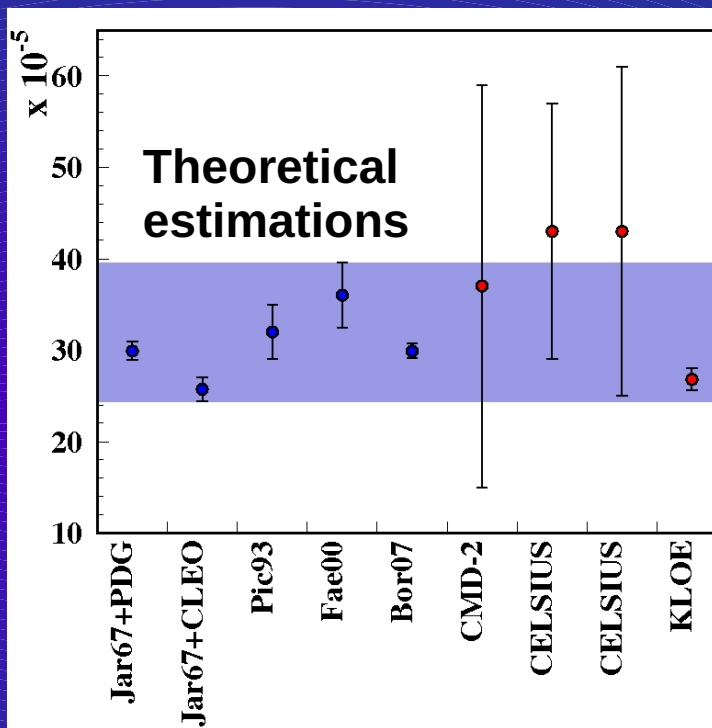
The unconventional CPV term can increase A_ϕ up to 10^{-2}





BR($\eta \rightarrow \pi^+ \pi^- e^+ e^- (\gamma)$)
 $(26.8 \pm 0.9_{Stat.} \pm 0.7_{Syst.}) \times 10^{-5}$

KLOE-2



Asymmetry statistical error decreases from 2.5 to 1.2 just for luminosity.

$|G| < 1$

The inner tracker improves the reconstruction of 4 tracks.

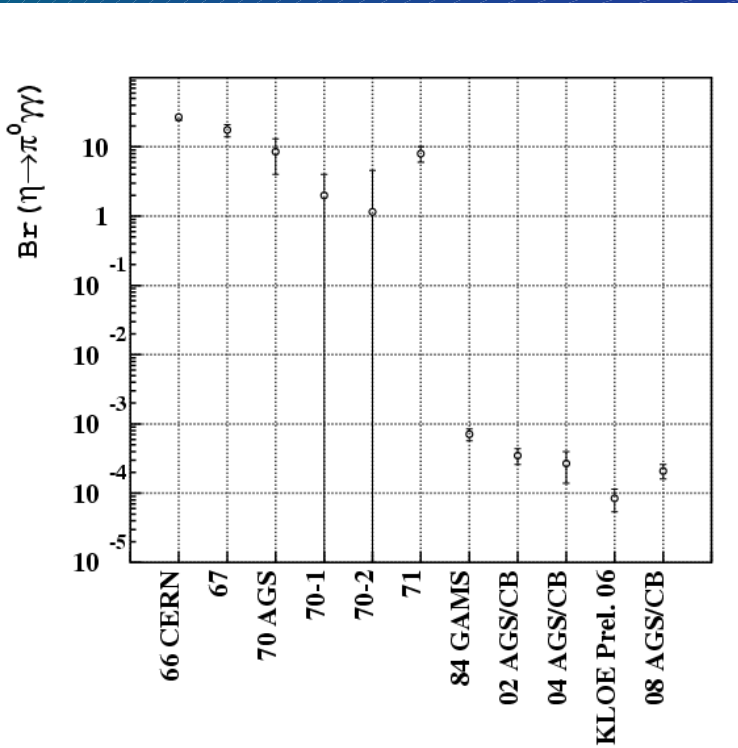
$A_\phi = (-0.6 \pm 2.5_{Stat.} \pm 1.8_{Syst.}) \cdot 10^{-2}$
 $|G| < 1.8$

First measurement of the CP asymmetry and attempt to constraint $|G|$.



The $\eta \rightarrow \pi^0 \gamma \gamma$ decay

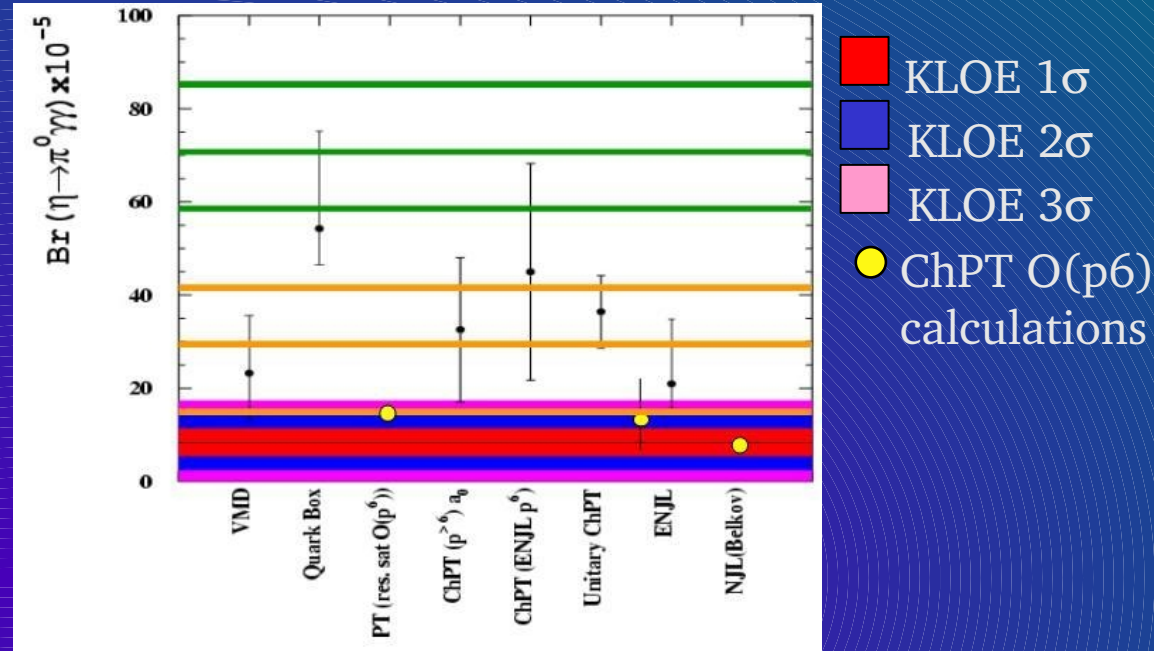
Past measurements (very long history)



$p^4 \Gamma \sim 7.18 \times 10^{-3} \text{ eV}$

} 2.2 σ discrepancy

Theoretical predictions

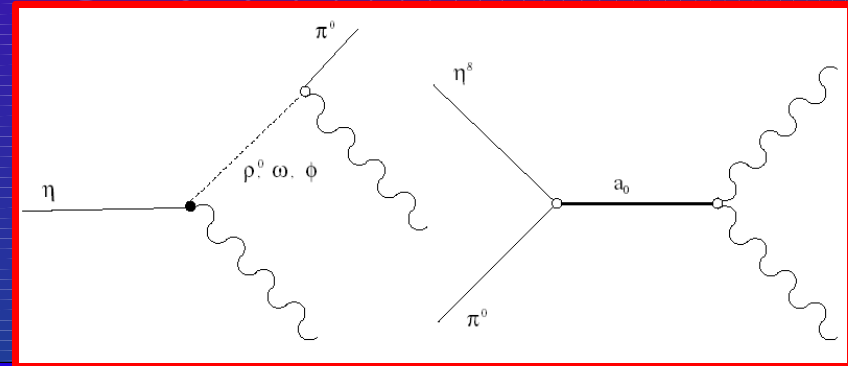
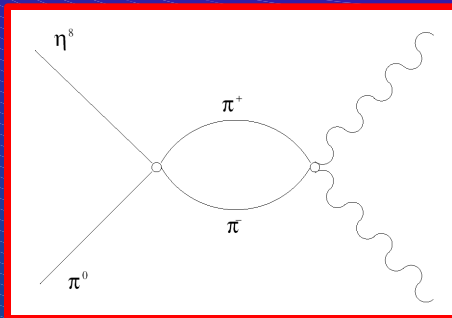
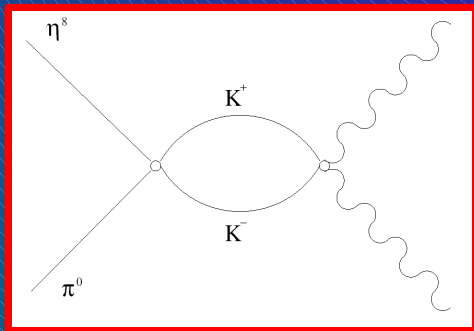


VMD and scalar exchange start at p^6

p^6 VMD $\Gamma \sim 0.18 \text{ eV}$

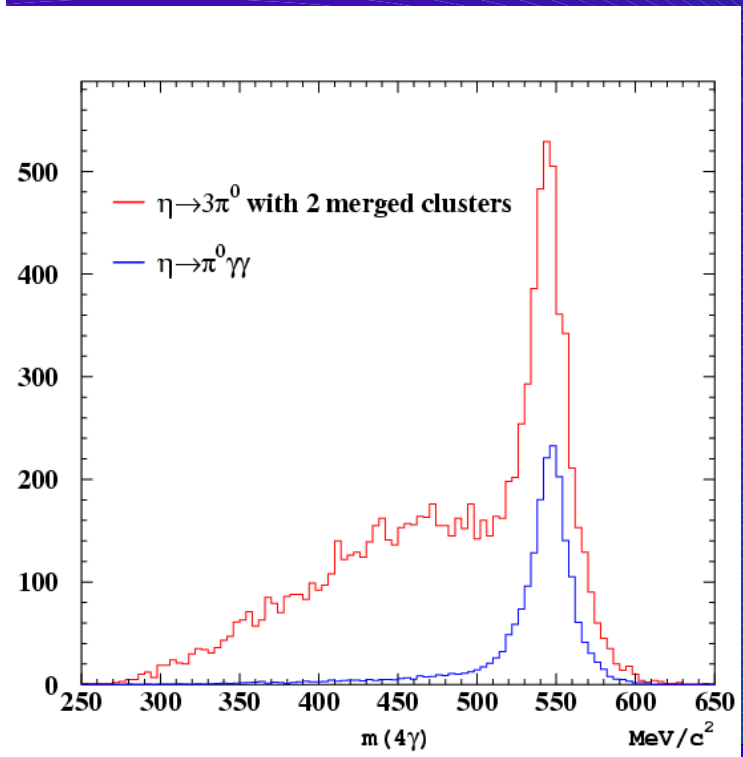
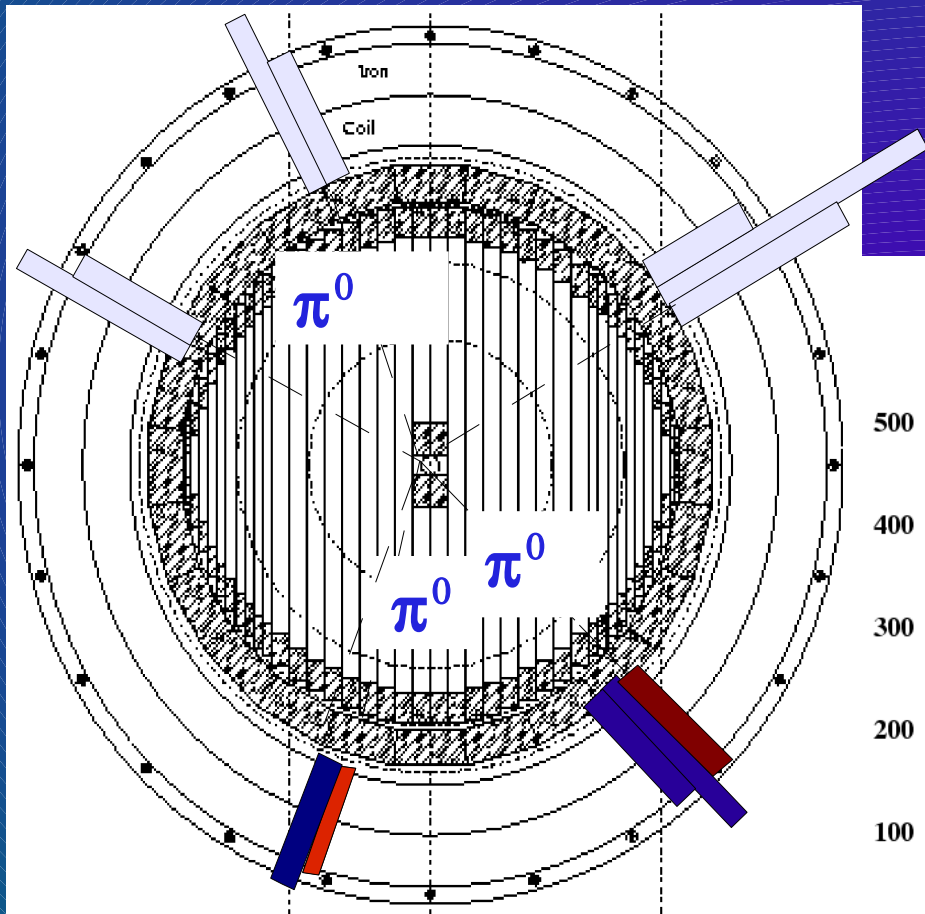
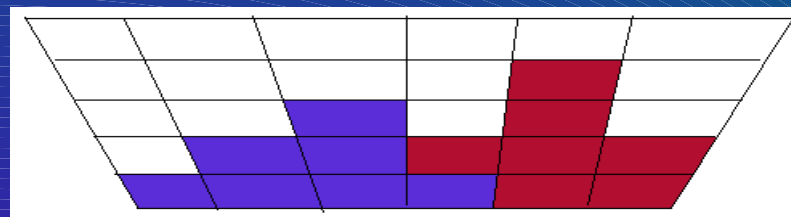
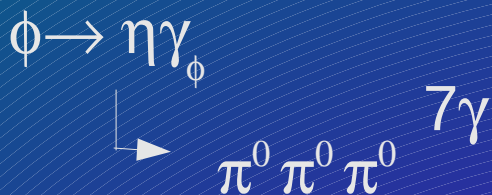
Full VMD $\Gamma \sim 0.31 \text{ eV}$

Full VMD + a_0 $\Gamma \sim 0.42 \pm 0.20 \text{ eV}$





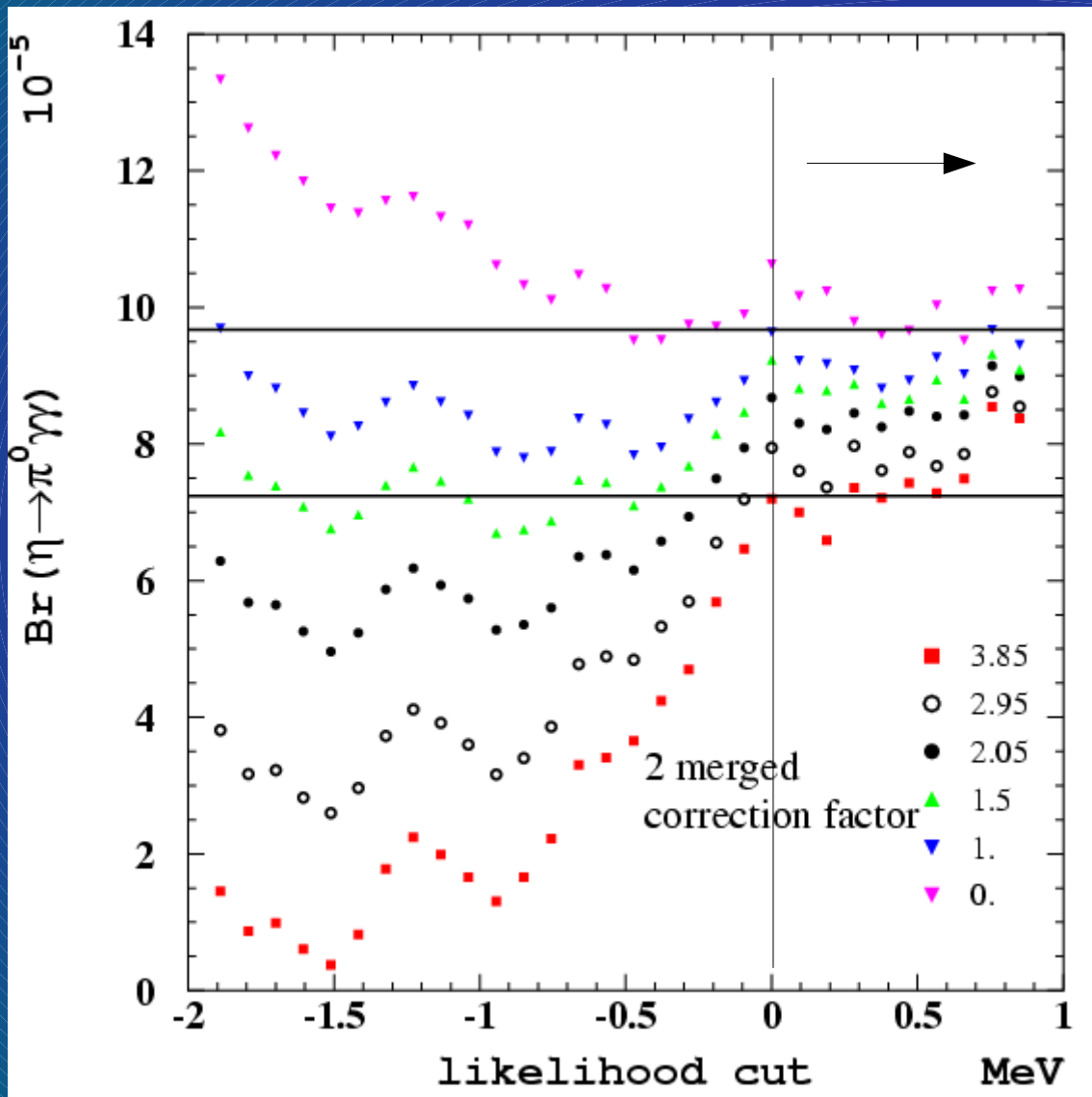
The merging of photons



If 2 merged clusters background is underestimated, it is counted as a signal



Background + likelihood systematic

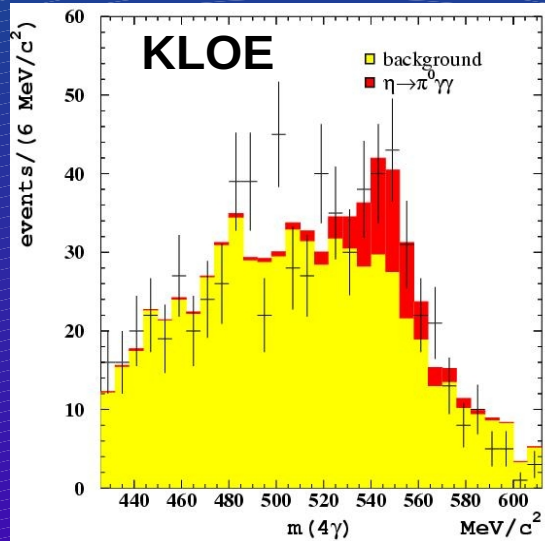
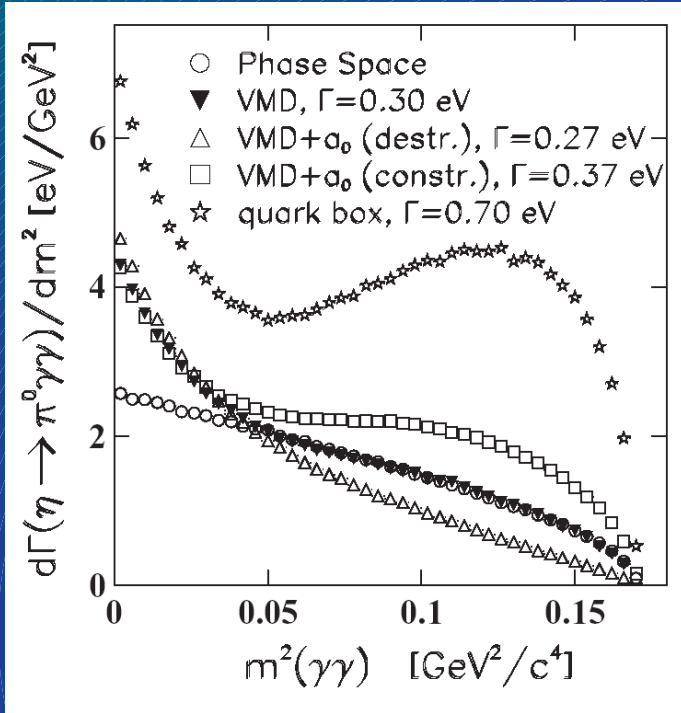


Selected region

1.1 systematic error
(background composition and
likelihood cut)



The Br and the $m_{\gamma\gamma}$ spectrum



N events at KLOE 2 1300
(efficiency included)

dBr/Br (stat.) 3%
(20% present uncertainty)

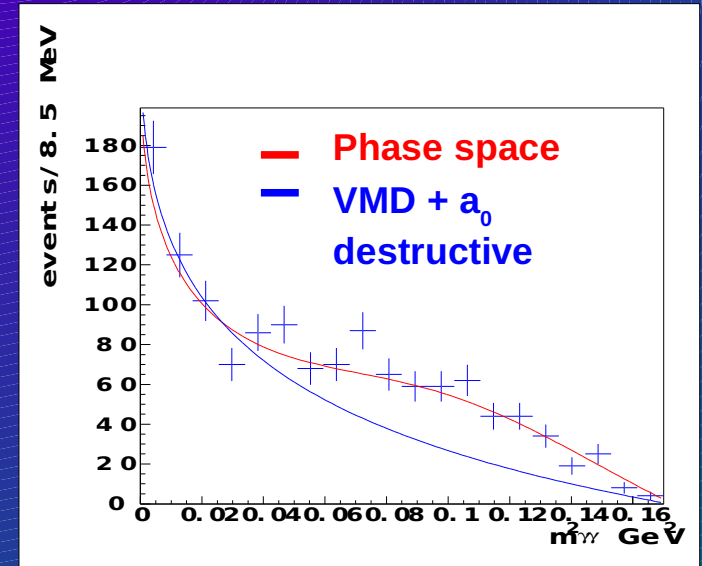
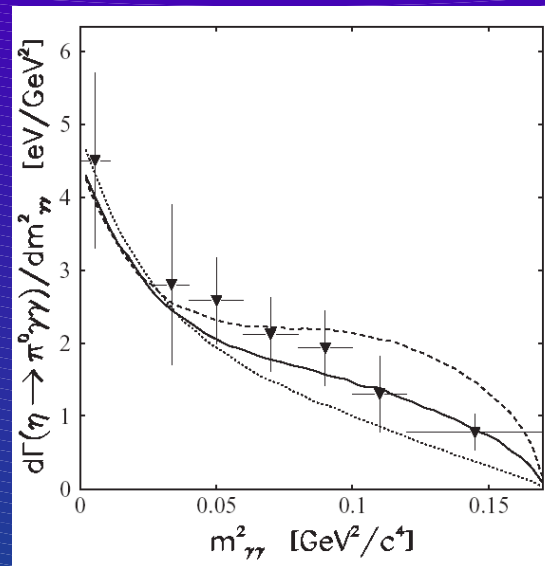
AGS/CB 08

Phys. Rev. C 78, 015206 (2008)

KLOE2

sensitivity to the spectrum

The $m_{\gamma\gamma}$ spectrum can be also analysed with good accuracy.





$\gamma\gamma$ Physics at KLOE and KLOE 2

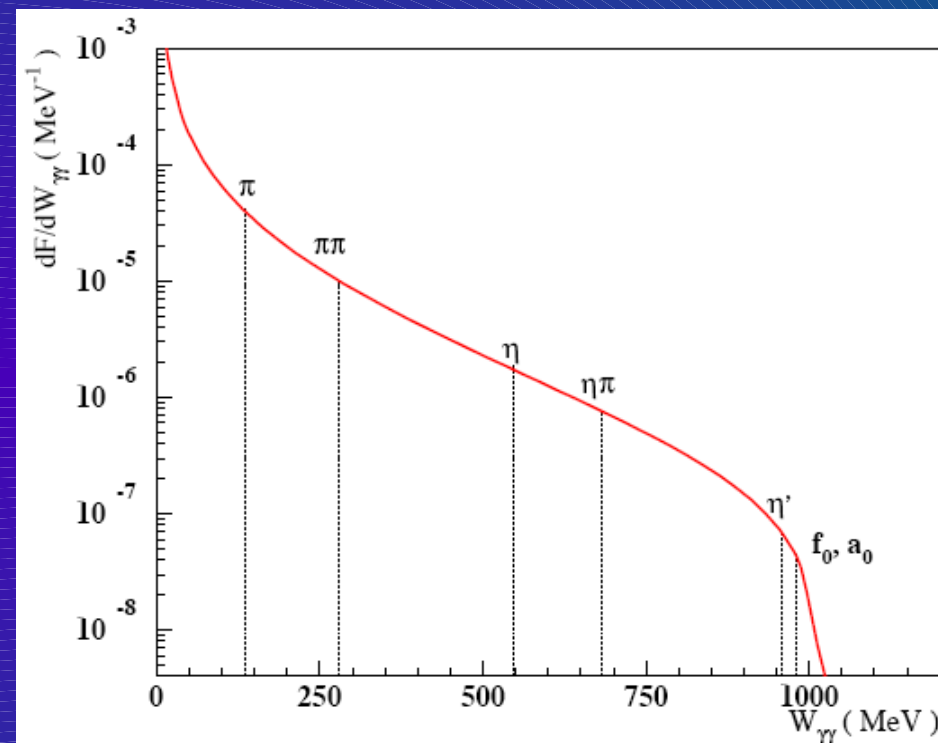
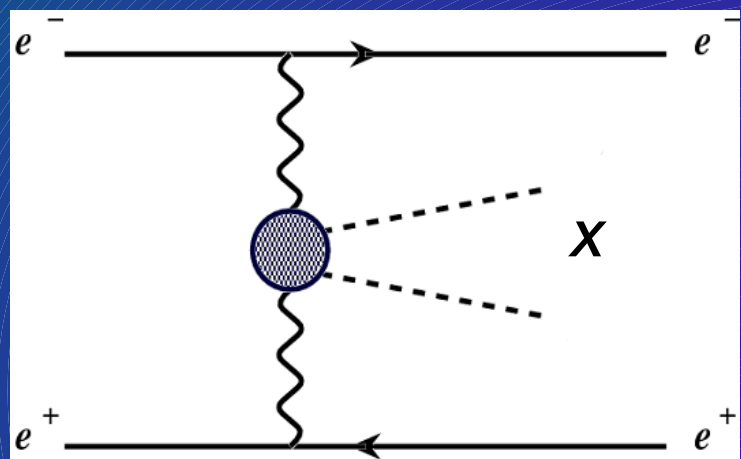
Study of the light meson spectrum in e^+e^- and $\gamma\gamma$ collisions
with KLOE at DAΦNE



$\gamma\gamma$ Luminosity

Weizsäcker-Williams approximation

$$|q_\gamma^2| \ll W^2$$



$$\sigma_{e^+e^- \rightarrow e^+e^-X} = \frac{16\alpha^2 \Gamma_{X\gamma\gamma}}{m_X^3} \left(\ln \frac{E_b}{m_e} \right)^2 \left((y^2 + 2)^2 \ln \frac{1}{y} - (1 - y^2)(3 + y^2) \right)$$

$$y = m_X / (2E_b)$$

Study of the light meson spectrum in e^+e^- and $\gamma\gamma$ collisions
with KLOE at DAΦNE



$$e^+e^- \rightarrow e^+e^-\eta (\rightarrow \pi^+\pi^-\pi^0)$$

Data Sample: 250 pb⁻¹ @ $\sqrt{s} = 1$ GeV

Main Background: $\phi \rightarrow \eta \gamma$ (γ undetected at small angle)

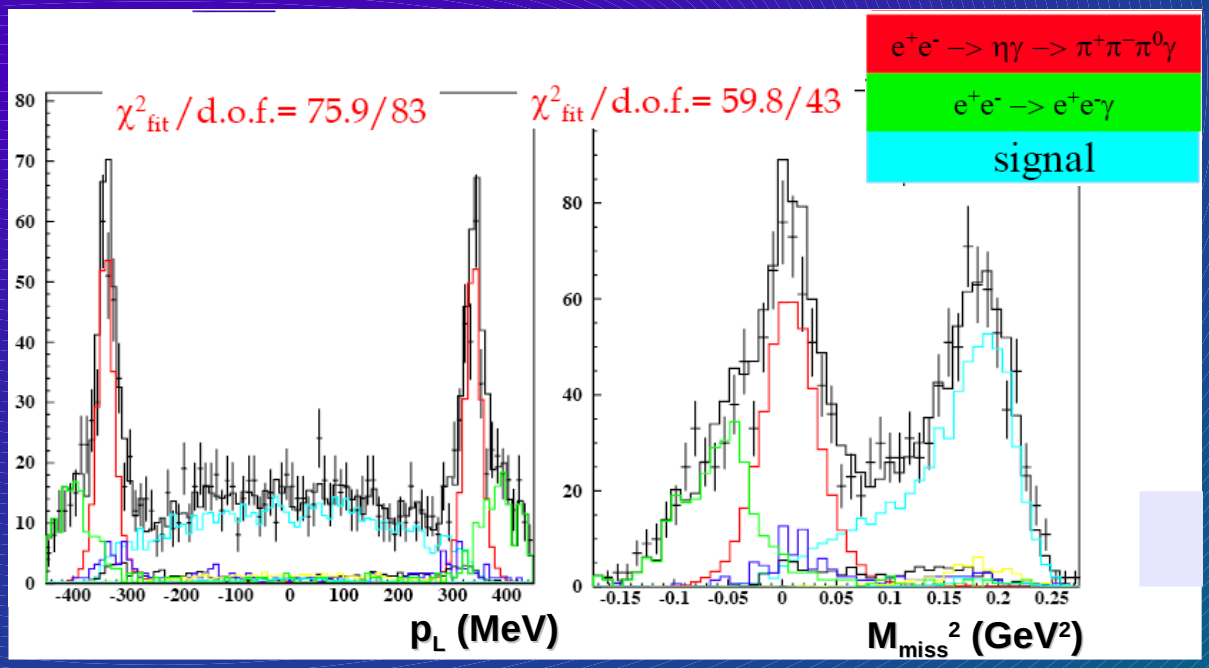
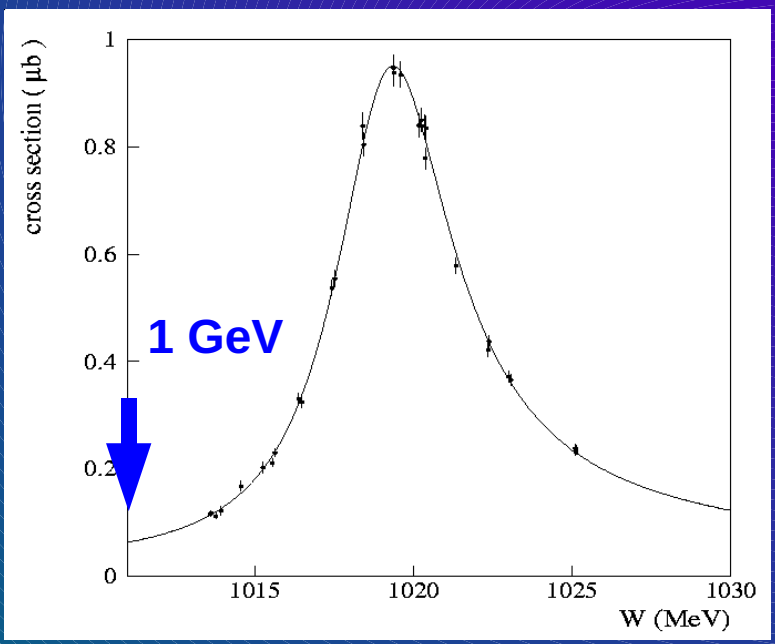
Bkg signature: $P_L = |\vec{p}_y| \cos \theta \sim |\vec{p}_y| = |p_{miss}^{\vec{}}| = \frac{m_\phi^2 - m_\eta^2}{2m_\phi} \sim 360$ MeV

$N_{sig} = 646$

$N_{sig} = 625$

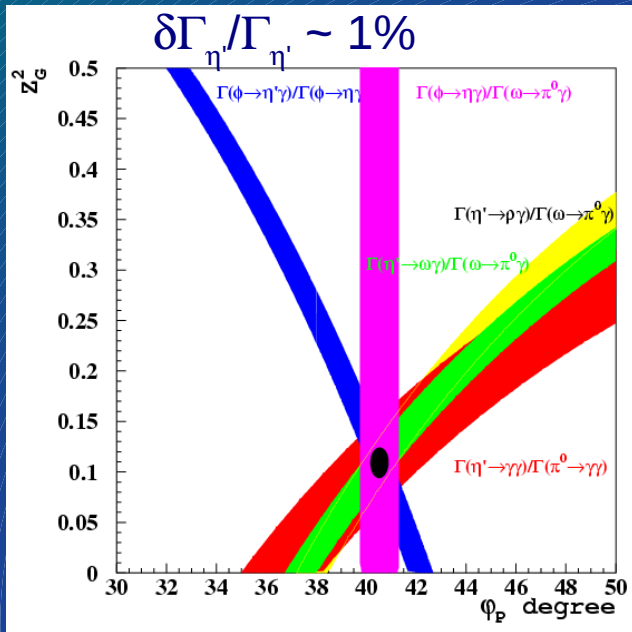
Bkg dumping

$\delta\Gamma/\Gamma \sim 5\%$ same order of present accuracy.

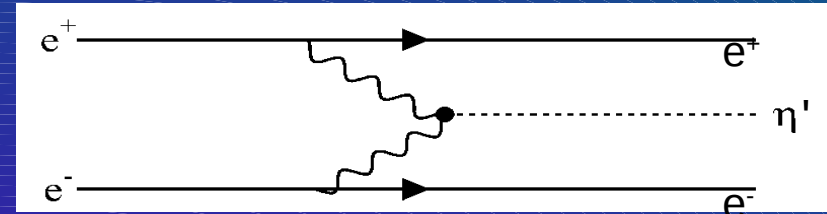




Measurement of the η' width @KLOE2



$$\Gamma_{\eta'} = \frac{\Gamma_{\eta' \rightarrow \gamma\gamma}}{Br(\eta' \rightarrow \gamma\gamma)}$$



$$\sigma_{e^+e^- \rightarrow e^+e^-\eta'}(s) = \frac{8\alpha^2\Gamma_{\eta' \rightarrow \gamma\gamma}}{m_{\eta'}^3} \times \left[f\left(\frac{m_{\eta'}^2}{s}\right) \left(\ln\frac{m_V^2 s}{m_e^2 m_{\eta'}^2} - 1\right)^2 - \frac{1}{3} \left(\ln\frac{s}{m_{\eta'}^2}\right)^3 \right]$$

background

| $\sqrt{s} \text{ GeV}$ | $e^+e^- \rightarrow \eta' e^+e^-$ | | $e^+e^- \rightarrow \phi(\gamma) \rightarrow \eta'\gamma(\gamma)$ | | S/\sqrt{B} |
|------------------------|-----------------------------------|-------------------------------|---|-------------------------------|--------------|
| | σ (pb) | events at 1 fb^{-1} | σ (pb) | events at 1 fb^{-1} | |
| 0.987 ($2m_{K^+}$) | 2.3 | 2300 | 0.23 | 230 | 152 |
| 0.995 ($2m_{K^0}$) | 2.9 | 2900 | 0.67 | 670 | 112 |
| 1.020 (m_ϕ) | 5.1 | 5100 | 190 | 190000 | 12 |
| 1.2 | 20 | 20000 | 1.2 | 1200 | 578 |
| 1.4 | 39 | 39000 | 5.8 | 5800 | 512 |

Very long run at low energy would be required.

34 @ 8fb^{-1}

Possible at higher energies

Study of the light meson spectrum in e^+e^- and $\gamma\gamma$ collisions
with KLOE at DAΦNE

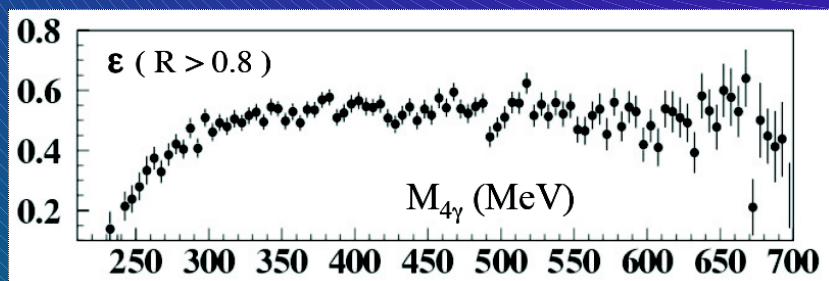
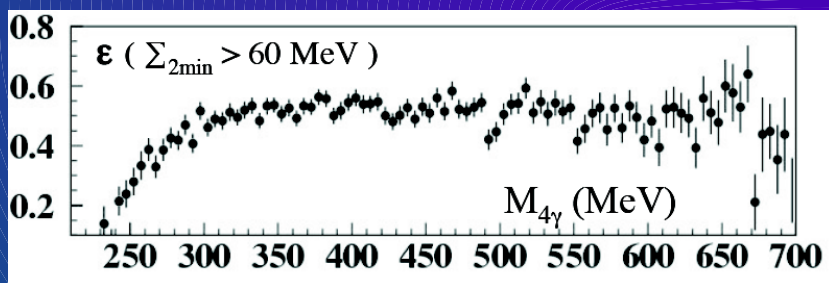


$$e^+e^- \rightarrow e^+e^-\pi^0\pi^0$$

Event characteristics

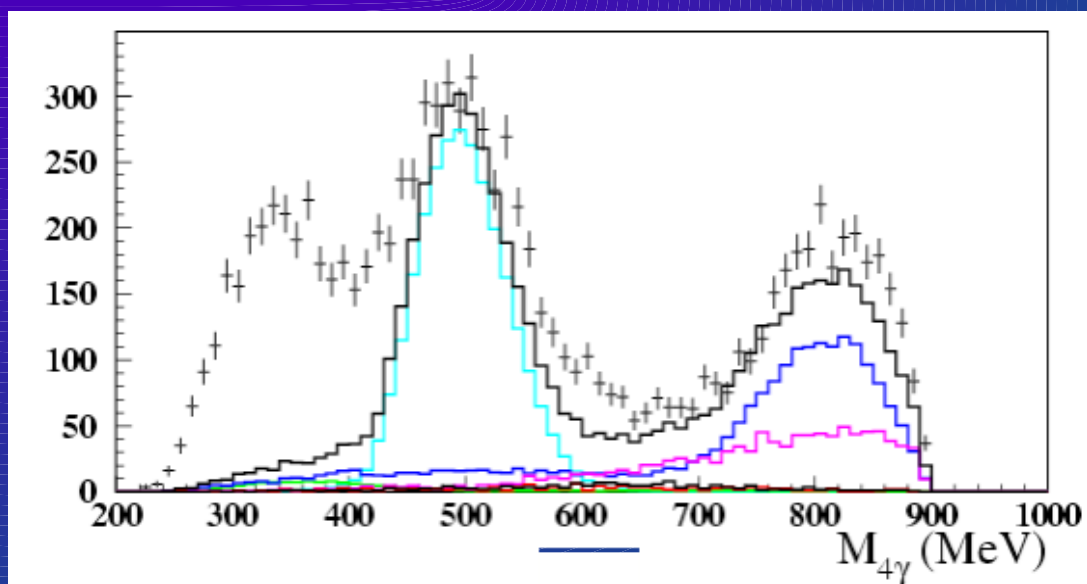
- ◆ outgoing electrons are undetected;
- ◆ Missing energy (kinematic is not closed);
- ◆ Background from events with undetected energy:

$K_s K_L$ (K_L passing calorimeter without energy deposition)



Analysis strategy

- ◆ 4 ($E > 15$ MeV) clusters in the calorimeter
- ◆ DC tracks veto
- ◆ $\Sigma E_{\min}(2 \text{ clusters}) > 60$ MeV
- ◆ $(4 \text{ cluster energy}) > 0.8 \times (\text{all visible energy})$



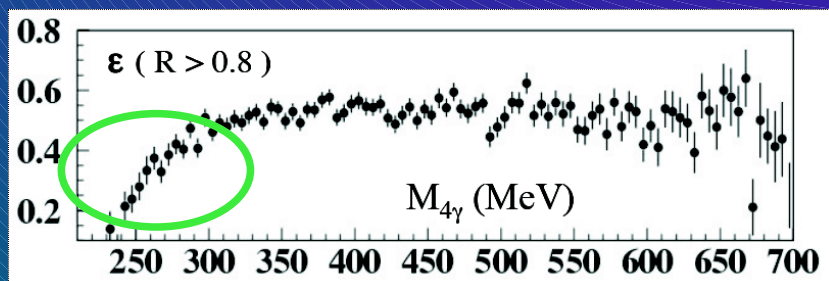
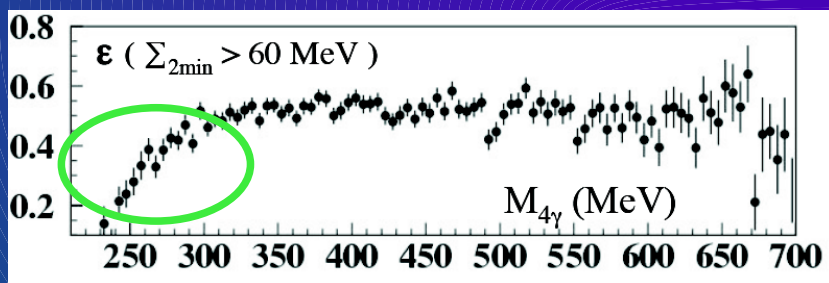


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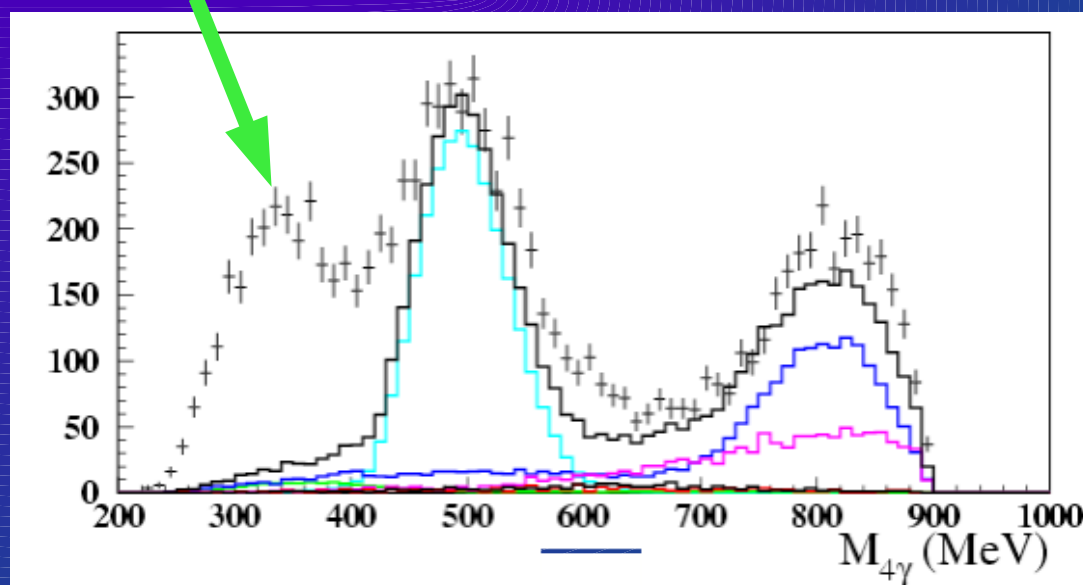


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Event excess (~ 4000)

Shape strongly efficiency dependent



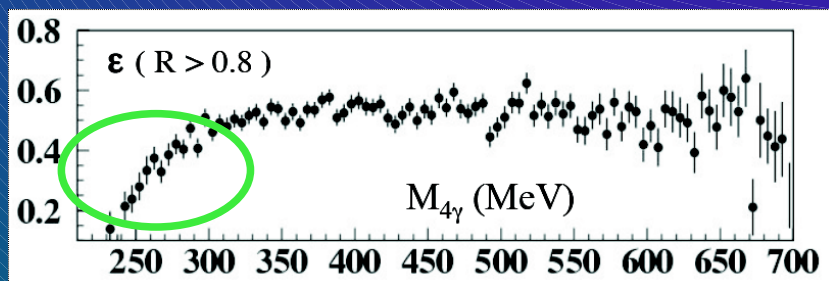
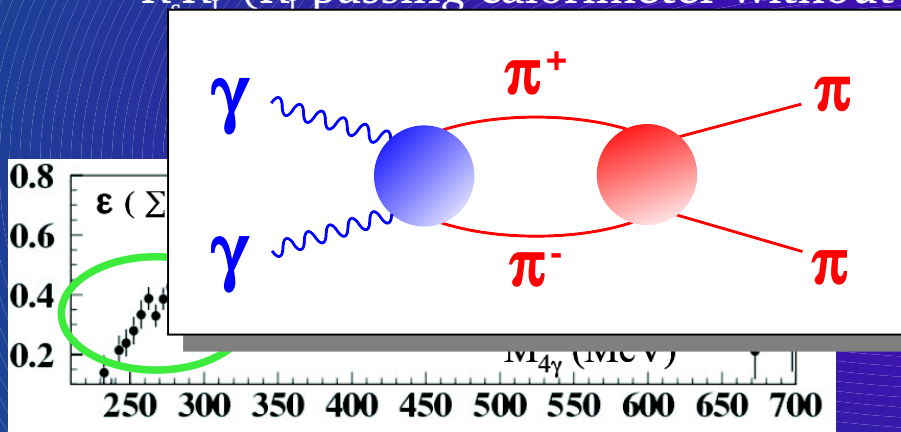


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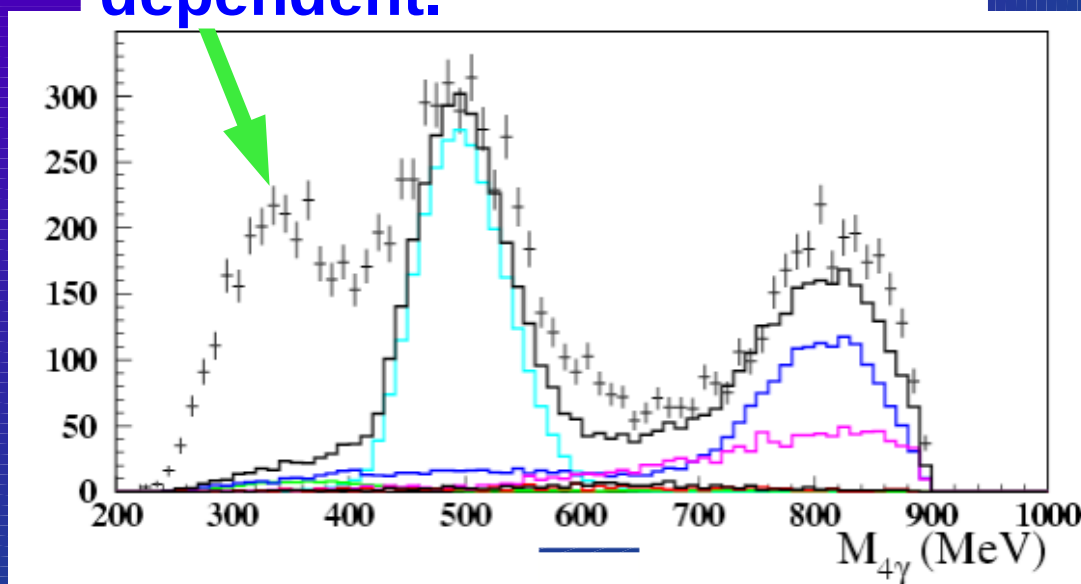
K, K_s (K_s passing calorimeter without



Analysis strategy

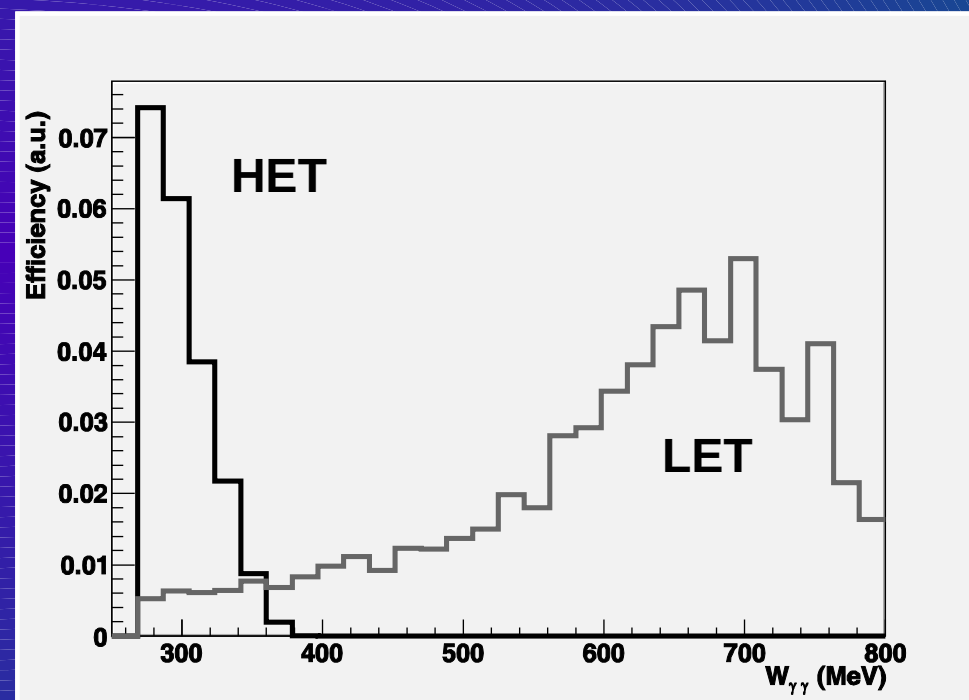
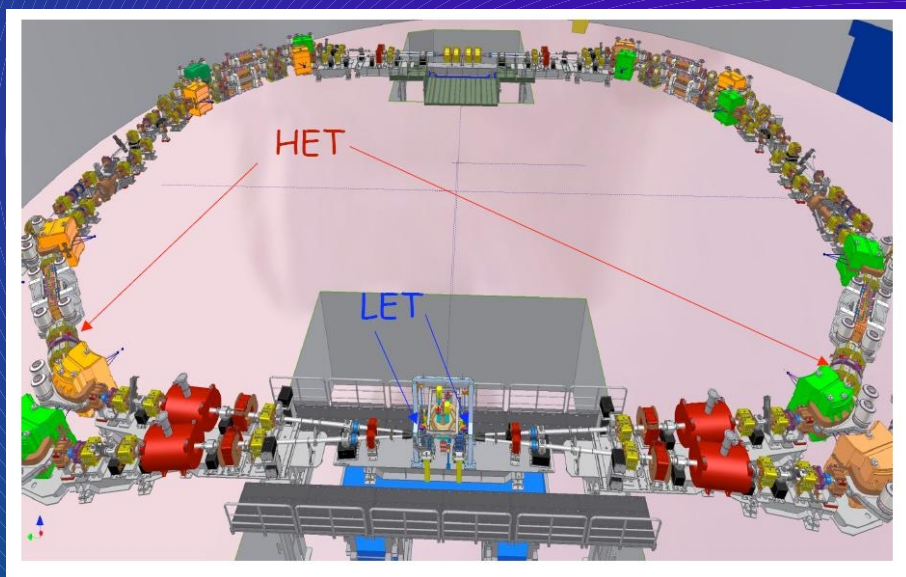
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- ◆ $\Sigma E_{\min}(2 \text{ clusters}) > 60$ MeV
- ◆ $(4 \text{ cluster energy}) > 0.8 \times (\text{all visible energy})$

σ extraction needs partial wave analysis and is model dependent



Run at the ϕ peak

- ◆ Background much more difficult to handle $\Rightarrow \gamma\gamma$ Tagger
- ◆ Kinematic can be closed measuring e^+e^- momenta





(g-2)_μ contribution

F. Jegerlehner, A. Nyffeler arXiv: 0902.3360

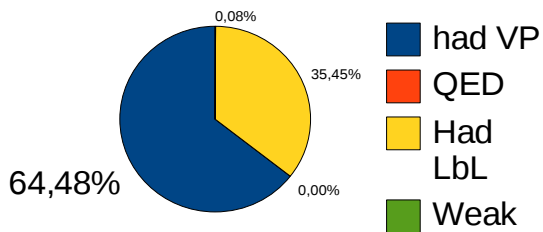
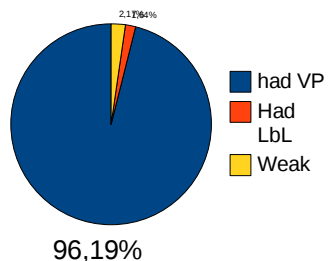
$$a_{\mu}^{\text{exp}} = 1.16592080(63) \times 10^{-3}$$

$$a_{\mu}^{\text{the}} = 1.16591790(65) \times 10^{-3}$$

$$\Delta a_{\mu} = 3.2 \sigma$$

a_{μ} fractional contribution
(QED (99.99%) excluded)

Δa_{μ} fractional
contribution



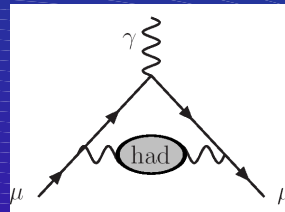
$$a_{\mu}^{\text{LbL};\pi^0} = -e^6 \int \frac{d^4 q_1}{(2\pi)^4} \frac{d^4 q_2}{(2\pi)^4} \frac{1}{q_1^2 q_2^2 (q_1 + q_2)^2 [(p + q_1)^2 - m_{\mu}^2][(p - q_2)^2 - m_{\mu}^2]}$$

$$\times \left[\frac{\mathcal{F}_{\pi^0 * \gamma * \gamma}(q_2^2, q_1^2, q_3^2) \mathcal{F}_{\pi^0 * \gamma * \gamma}(q_2^2, q_2^2, 0)}{q_2^2 - m_{\pi}^2} T_1(q_1, q_2; p) + \frac{\mathcal{F}_{\pi^0 * \gamma * \gamma}(q_3^2, q_1^2, q_2^2) \mathcal{F}_{\pi^0 * \gamma * \gamma}(q_3^2, q_3^2, 0)}{q_3^2 - m_{\pi}^2} T_2(q_1, q_2; p) \right],$$

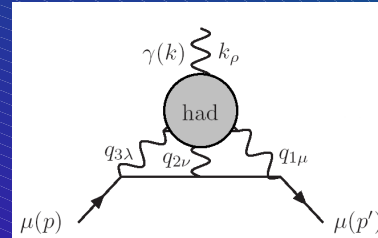
Small q^2 values are leading.

Main uncertainty sources

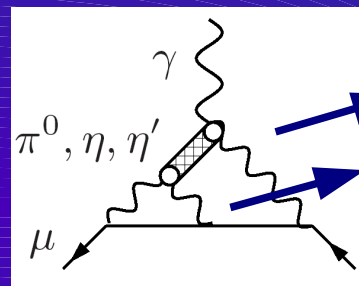
Hadronic Vacuum polarization



Hadronic Light by Light

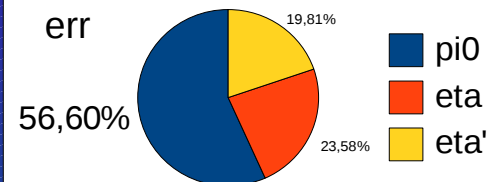
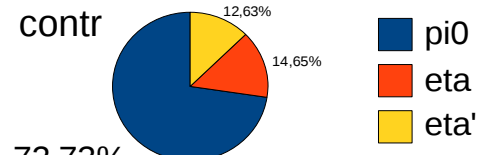
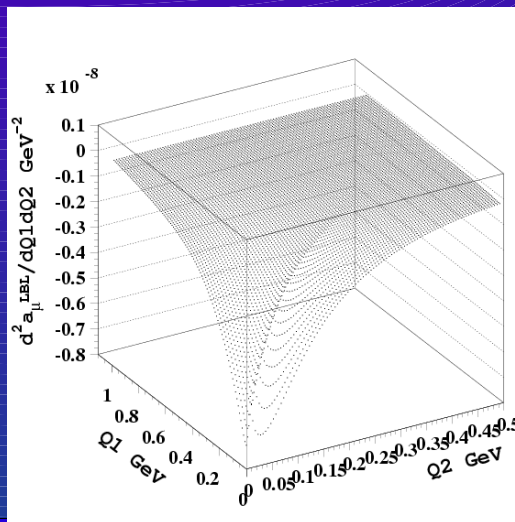


Pseudoscalar exchange



$$F_{PS}(q^2, q_3^2, 0)$$

$$F_{PS}(q^2, q_1^2, q_2^2)$$



Study of the light meson spectrum in e^+e^- and $\gamma\gamma$ collisions
with KLOE at DAΦNE



Possible parametrisations

Several form factors have been proposed to full fill accurate theoretical predictions for the high energy behavior):

Bijnens Persson, hep-ph/0106130

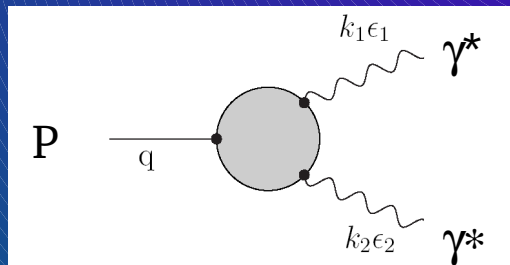
$$F(0,0) = 1$$

Theoretical constraints:

$$q^2 \rightarrow \infty \quad F(q^2, 0) \sim 1/q^2$$

$$F(q^2, q^2) \sim 1/q^2$$

Perturbative QCD limits.



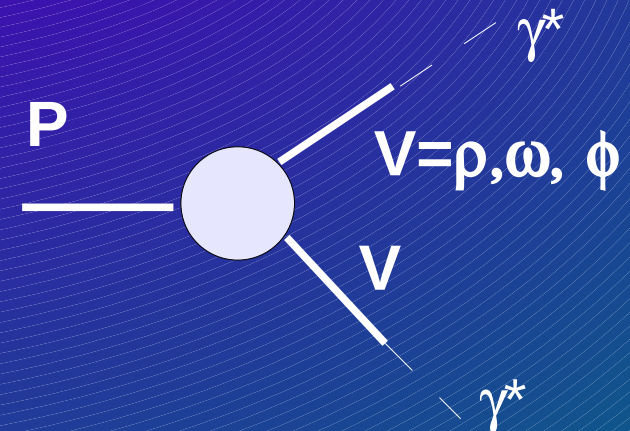
$$F(k_1^2, k_2^2) = 1$$

$$F(k_1^2, k_2^2) = \frac{m_\rho^4}{(m_\rho^2 - k_1^2)(m_\rho^2 - k_2^2)}$$

$$F(k_1^2, k_2^2) = \frac{m_\rho^2}{(m_\rho^2 - k_1^2 - k_2^2)}$$

$$F(k_1^2, k_2^2) = \frac{m_\rho^4 - \frac{4\pi^2 F_\pi^2}{N_c} (k_1^2 + k_2^2)}{(m_\rho^2 - k_1^2)(m_\rho^2 - k_2^2)}$$

Double Vector Meson Dominance





Studying form factors in the Dalitz decays

Time-like region π^0, η

| | Intermediate channel | | Events |
|----------------------------------|------------------------------------|--------------------------|-------------------|
| $\pi^0 \rightarrow e^+e^-\gamma$ | $\phi \rightarrow \pi^+\pi^-\pi^0$ | $\pi^+\pi^-e^+e^-\gamma$ | 8×10^7 |
| $\pi^0 \rightarrow e^+e^-e^+e^-$ | $\phi \rightarrow \pi^+\pi^-\pi^0$ | $\pi^+\pi^-e^+e^-e^+e^-$ | 1.3×10^5 |

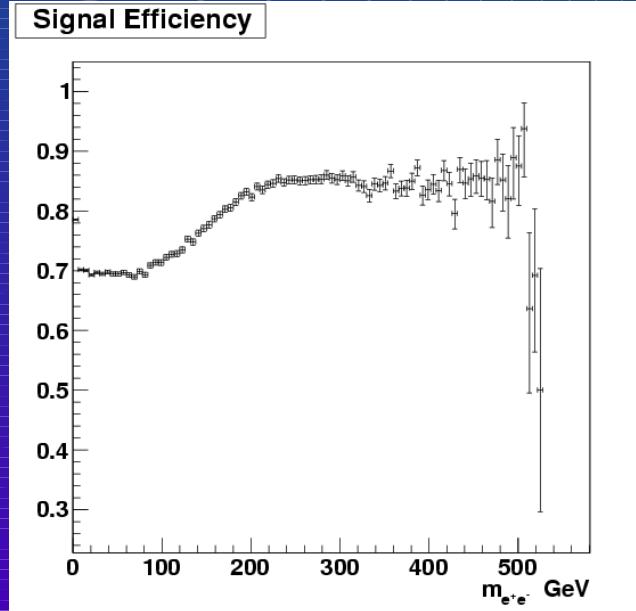
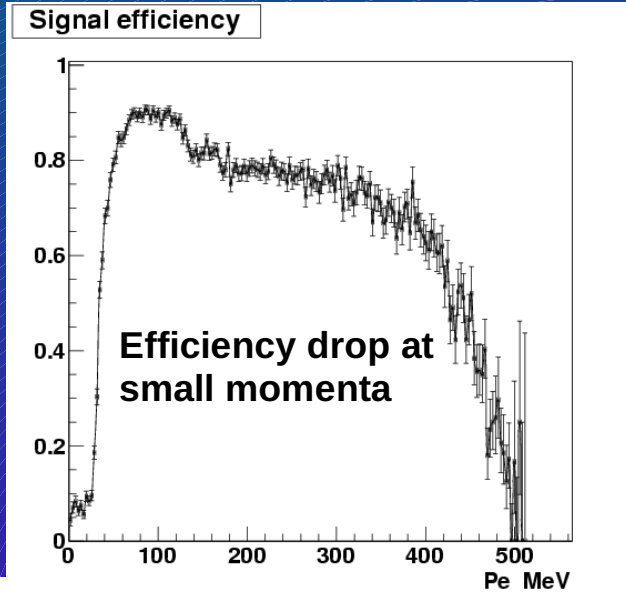
| | | | |
|---------------------------------|-------------------------------|----------------|-------------------|
| $\eta \rightarrow e^+e^-\gamma$ | $\phi \rightarrow \eta\gamma$ | $e^+e^-\gamma$ | 2.4×10^5 |
| $\eta \rightarrow e^+e^-e^+e^-$ | $\phi \rightarrow \eta\gamma$ | $e^+e^-e^+e^-$ | 2.3×10^4 |

Study of the light meson spectrum in e^+e^- and $\gamma\gamma$ collisions
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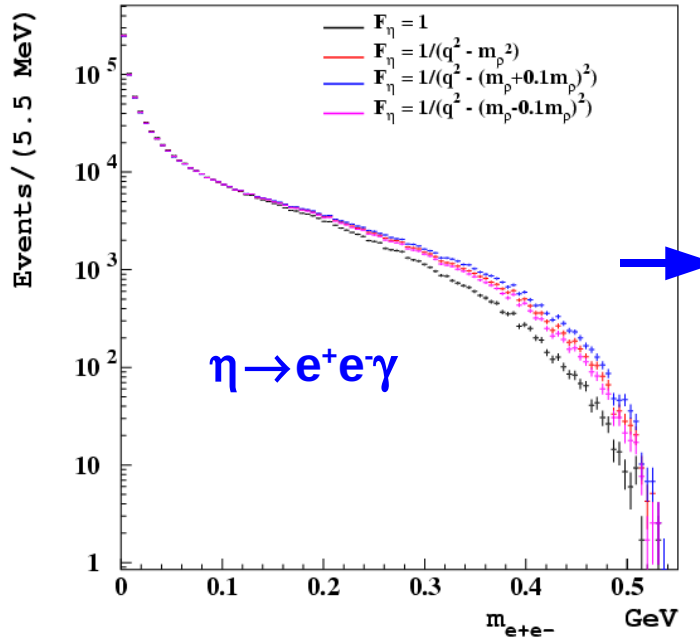


$\eta \rightarrow e^+e^- \gamma, \mu^+\mu^- \gamma$ form factor $F_\gamma \gamma^* \gamma^*$ at KLOE2.

Efficiency curve as a function of e^- momentum.

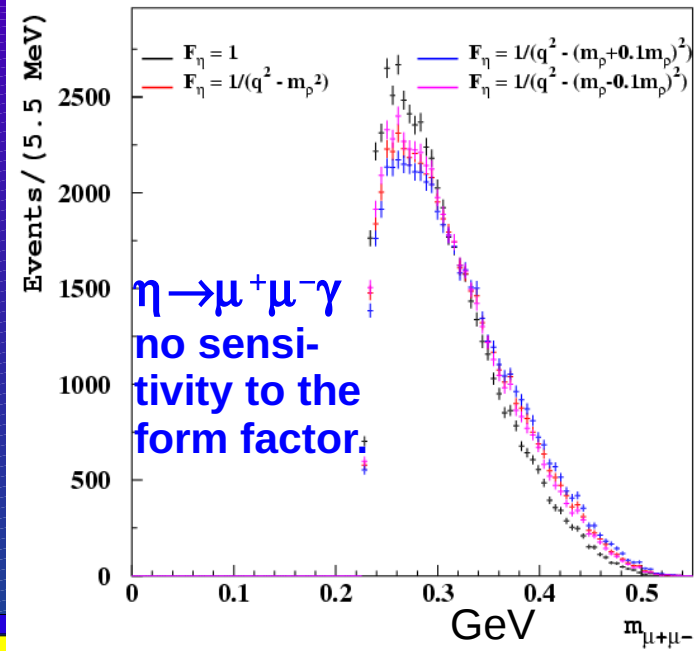
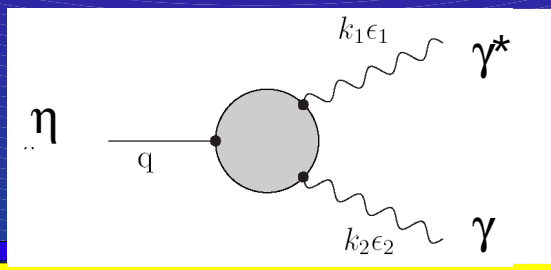


sensitivity in the whole $m_{e^+e^-}$ range.



VMD form factor usually used for description.

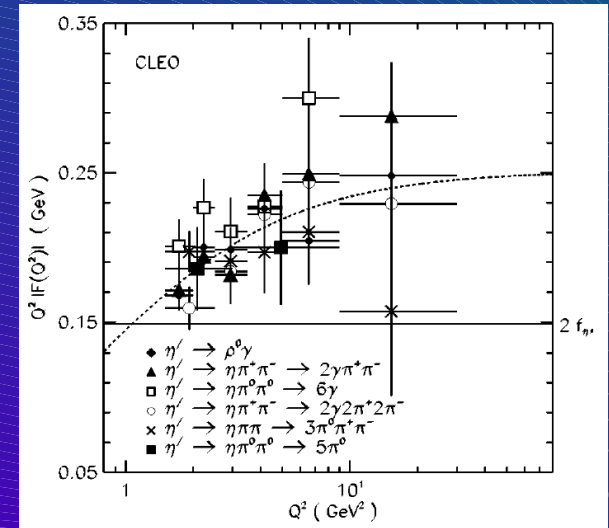
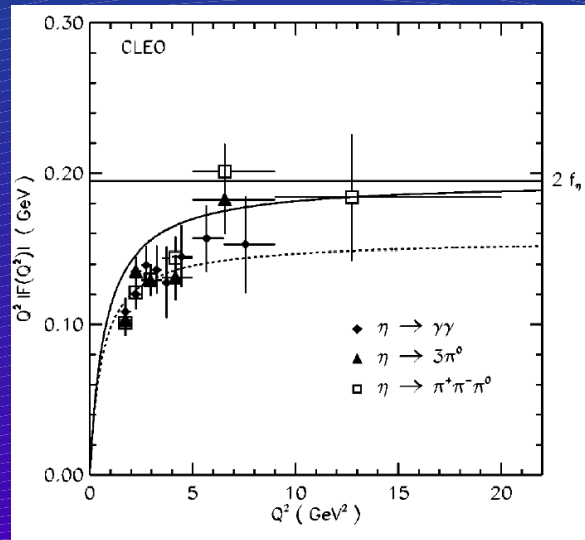
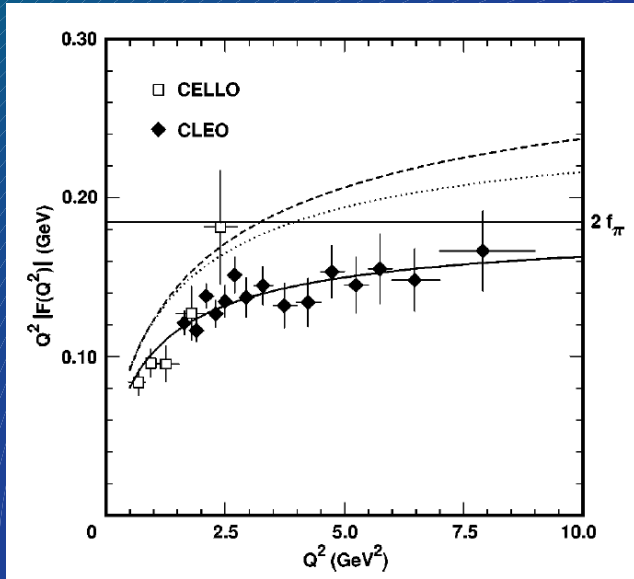
Good sensitivity to the form factor shape. Systematic uncertainty will be the main issue.



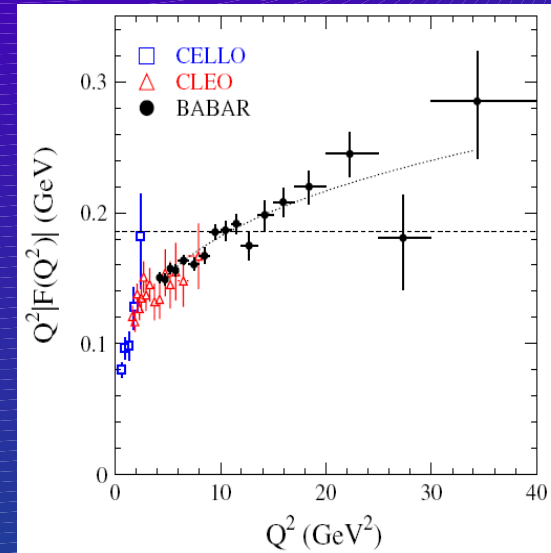
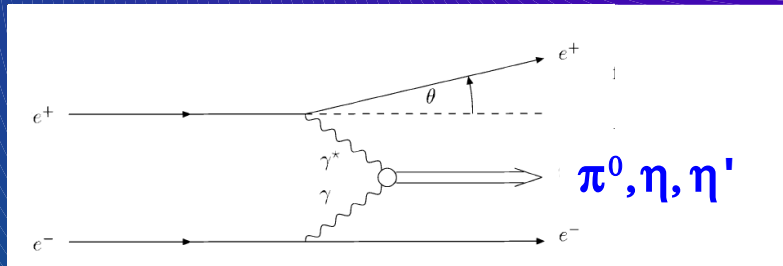
$\eta \rightarrow \mu^+\mu^- \gamma$
no sensitivity to the form factor.



Today data available only for $F\gamma^*\gamma$ from CELLO, CLEO, Babar



New interesting data from Babar



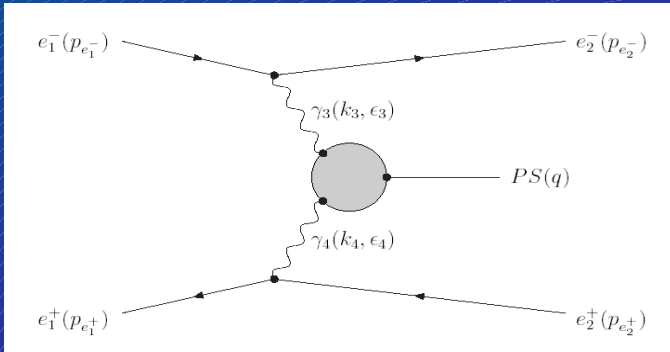
PRD80 (2009)
052002

Is the asymptotic limit more far than expected?



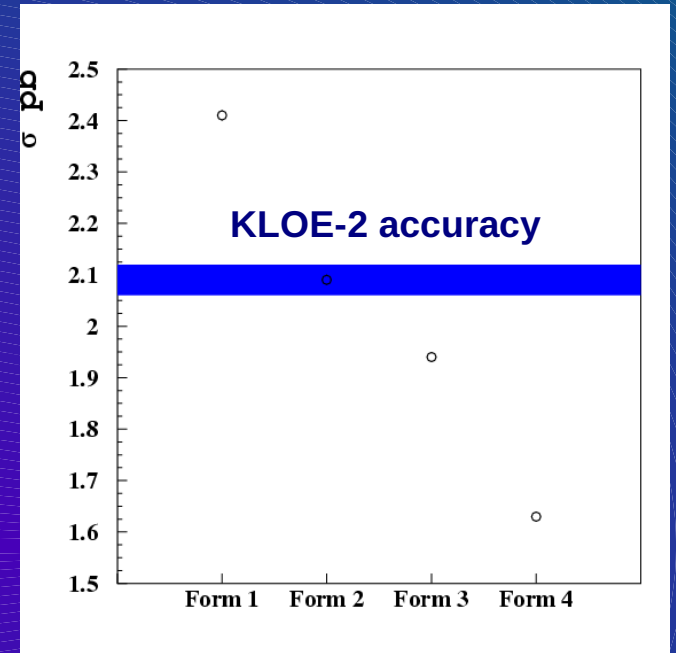
$e^+e^- \rightarrow e^+e^-P$ at KLOE 2

Outgoing leptons in the detector.

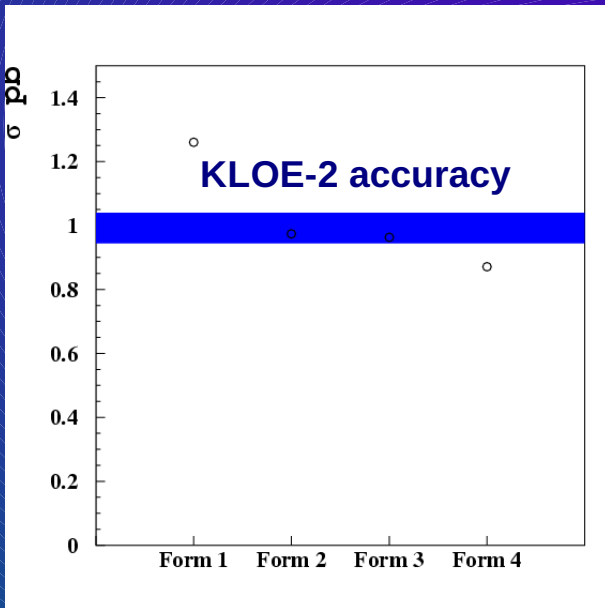


π^0

Bijnens Persson, hep-ph/0106130



η



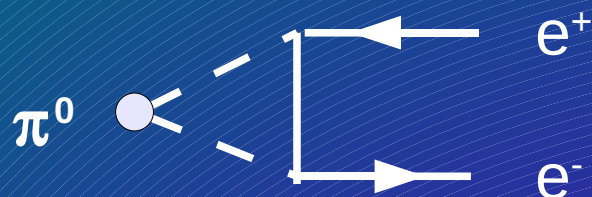
η'

No way without going to higher energies..

- ◆ π^0 : The 4 form factors are clearly identifiable;
- ◆ η : KLOE-2 can distinguish form factor 1,4 and 2-3.
- ◆ Using tagger we could reach sensitivity to distinguish form factor 2 from 3 (under study).



A look at the $\pi^0 \rightarrow e^+e^-$



$$B = \frac{Br(\pi^0 \rightarrow e^+e^-)}{Br(\pi^0 \rightarrow \gamma\gamma)} = 2\beta \left(\frac{\alpha m_e}{\pi m_{\pi^0}} \right)^2 |R(\pi^0 \rightarrow e^+e^-)|^2$$

$$\Im R(\pi^0 \rightarrow e^+e^-) = \frac{\pi}{2\beta} \ln \frac{1-\beta}{1+\beta} \quad \begin{array}{l} \text{Model independent.} \\ \text{On shell photons} \end{array}$$

$$\Re R(\pi^0 \rightarrow e^+e^-) = 0 \Rightarrow B = B^{min} = B^{unit} \quad \text{Unitarity bound} \quad B \geq B^{unit} = 4.75 \times 10^{-8}$$

Model dependent, loops with large off-shell photons. It depends on the $F\pi^0\gamma^*\gamma^*(q_1^2, q_2^2)$

Using double VMD form factor [1] obtains: $B = (6.41 \pm 0.19) \times 10^{-8}$

B_{exp} (KTeV) [2] = $(7.39 \pm 0.29 \pm 0.25) \times 10^{-8}$ it is at 2σ

From ChPT and $\eta \rightarrow \mu^+\mu^-$ [3] gets $(8.3 \pm 0.4) \times 10^{-8}$

@KLOE2

Copious number of η from $\phi \rightarrow \eta\gamma$ 2000 $\eta \rightarrow \mu^+\mu^-$ expected (allow to make the theoretical prediction more reliable).

[1] Amettler et al. PRD48 (1993) 3388

[2] Abuzaid et al. PRD75 (2007) 012004

[3] D. Gomez et al., PRL80 (4633) 1998



Theorist experimental interactions

what we like

- ◆ they provide Monte Carlo generators;
- ◆ they provide usable model to fit our data;
- ◆ they make clear statements about what can be used to validate their models;

what we like really a lot

- ◆ they provide Fortran code with their model to fit :-)

what we don't like

- ◆ if their model is ruled out they say it isn't a problem;
- ◆ if it is a problem they say that the data are wrong;
- ◆ the model goodness depends on the conclusions.



Conclusion & Outlook

- New KLOE data on a_0 together with the old f_0 results nicely agree with the 4 quark hypothesis in the instanton model;
- First upper limit on $\phi \rightarrow (f_0 + a_0)\gamma \rightarrow K^0 K^0 \gamma \rightarrow K_S K_S \gamma$, sensitivity near the observation threshold;
- Refit of the η' gluonium content confirms the 3σ KLOE claim, the main sensitive measurement has been identified with the $\eta' \rightarrow \gamma\gamma$;
- Precise measurement of the $\eta \rightarrow \pi^+ \pi^- e^+ e^- (\gamma)$ branching ratio and first measurement of the CP violating asymmetry.

OUTLOOK: see next talk of P. Gauzzi



The C violating $\eta \rightarrow \gamma\gamma\gamma$

- ◆ Signal topology: $\phi \rightarrow \eta\gamma \rightarrow 4\gamma$
- ◆ Kinematic fit with energy momentum conservation

$$N_{\eta \rightarrow 3\gamma} \leq 63.1 \quad \text{at 90\% CL,}$$
$$\leq 80.8 \quad \text{at 95\% CL.}$$

$$\text{BR}(\eta \rightarrow \gamma\gamma\gamma) \leq 1.6 \times 10^{-5} \quad \text{at 90\% CL}$$
$$\leq 2.0 \times 10^{-5} \quad \text{at 95\% CL}$$

