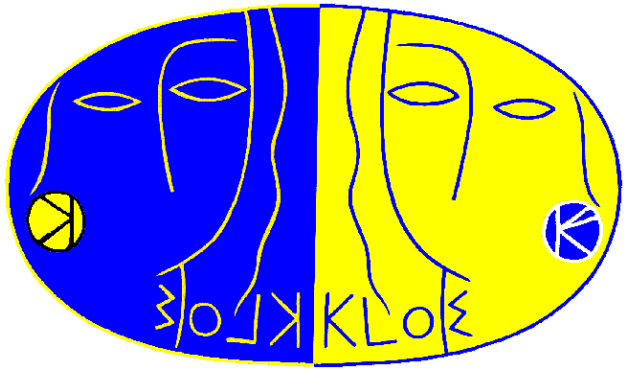
Hadron physics at KLOE and KLOE-2



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for the KLOE / KLOE-2 Collaborations

DIPARTIMENTO DI FISICA

SAPIENZA
UNIVERSITÀ DI ROMA

INFN
Istituto Nazionale di Fisica Nucleare

EPS HEP 2011

22 July 2011 – Grenoble

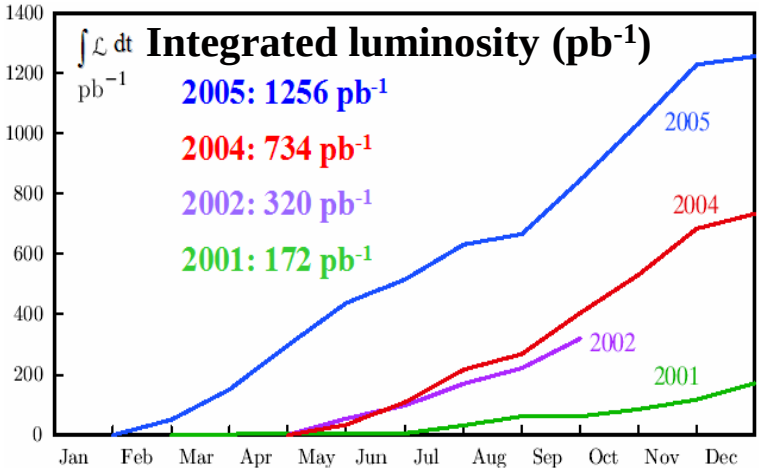
Outline

- **DAΦNE**
- **KLOE / KLOE-2**
- **Recent results on Hadron Physics:**
  - $\eta \to \pi^+\pi^-\gamma$
  - $\eta \to e^+e^-e^+e^-$
  - **Search for dark forces ($\phi \to \eta e^+e^-$)**
  - **$\gamma\gamma$ physics:**
    - $\gamma\gamma \to \eta$
    - $\gamma\gamma \to \pi^0\pi^0$
- **Conclusions**

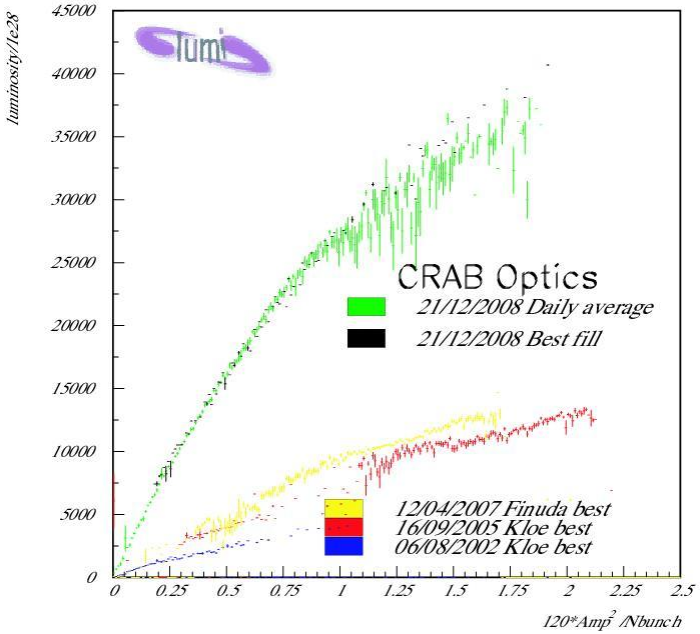
DAΦNE

- 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} @ $\sqrt{s}=M_\phi$ ($\Rightarrow 8 \times 10^9$ ϕ produced)
  + 250 pb^{-1} off-peak @ $\sqrt{s}=1000$ MeV



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



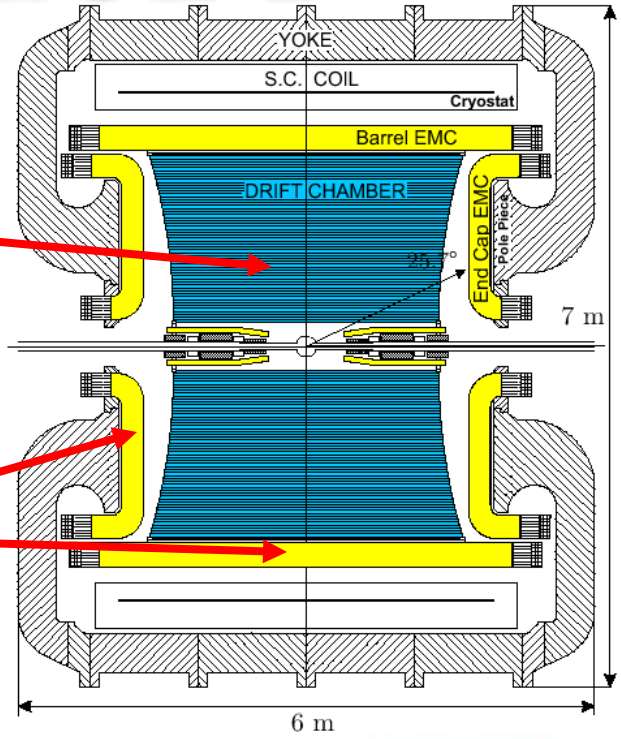
⇒ Luminosity increase expected: factor ~ 3
  $\int Ldt \approx 1\ pb^{-1}/hour$
- DAΦNE commissioning will restart in October 2011

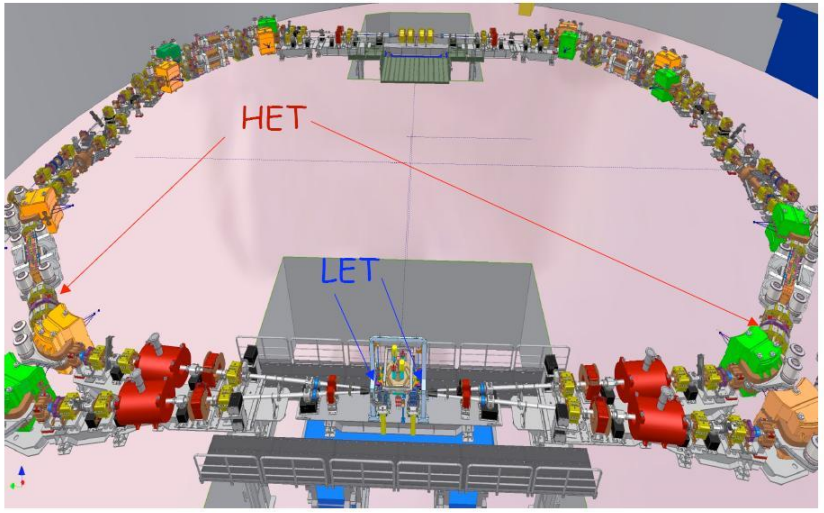
KLOE/KLOE-2

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





- **KLOE-2: a two step upgrade**

1) First run (~ 5 fb^{-1} @ ϕ peak)

   $e^{\pm}$ taggers for $\gamma\gamma$ physics (already installed)

2) Major upgrades (Summer 2012) (L>20 fb^{-1})

   inner tracker +

   new small angle calorimeters

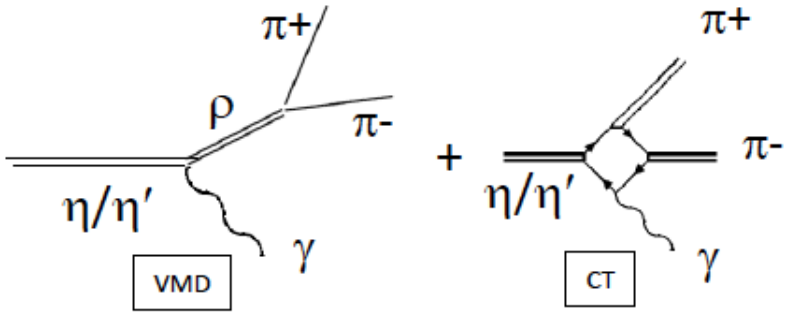
(see D.Moricciani's talk–Detector R&D session)

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

- **Study of the box anomaly: test of ChPT and its unitarized extensions**

  [Benayoun et al. EPJC31(2003)525; Holstein, Phys. Scripta, T99(2002)55; Borasoy, Nissler, NPA740(2004)362, Picciotto PRD45(1992)1569]

- **Sizeable effect of the Contact Term expected both in $\Gamma(\eta \to \pi^+\pi^-\gamma)$ and in the $M_{\pi\pi}$ distribution**



- **CLEO result (2007) is 2 – 3 σ lower than previous measurements**

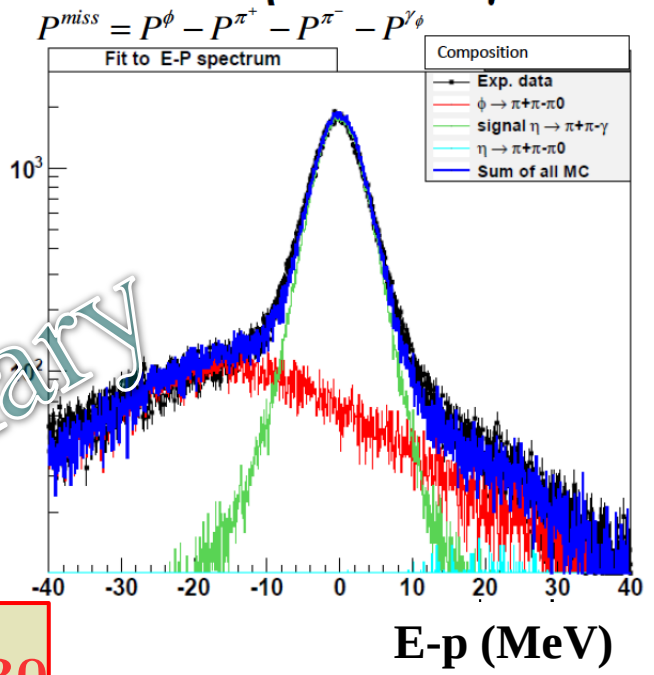
$\Gamma(\eta \to \pi^+\pi^-\gamma) / \Gamma(\eta \to \pi^+\pi^-\pi^0)$

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

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

- $\phi \to \eta\gamma$, $\eta \to \pi^+\pi^-\gamma$: L = 558 pb^{-1}
- Main background: $\phi \to \pi^+\pi^-\pi^0$
- Signal extraction from fit to E-p

$(P^\mu = P^\mu_\phi - P^\mu_{\pi^+} - P^\mu_{\pi^-} - P^\mu_{\gamma_\phi})$ ~ 2 × 10^5 events



Preliminary

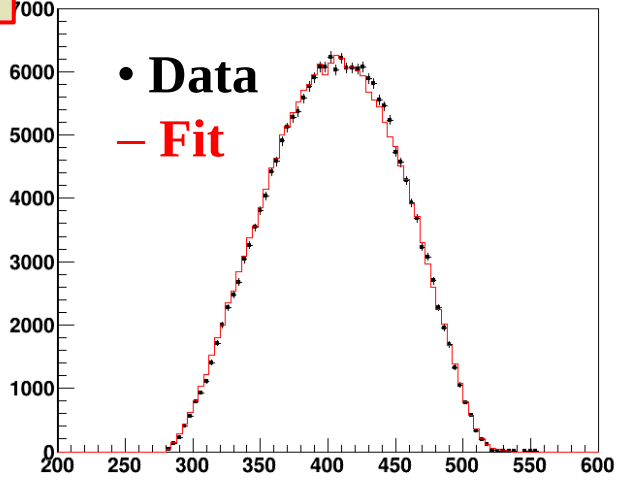
$$\frac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)} = 0.1838 \pm 0.0005 \pm 0.0030$$

- $M_{\pi\pi}$ distribution (bckg subtracted)
- Fit with CT + VMD

  [parametr. from Picciotto Phys. Rev. D45 (1992), 1569]

- KLOE-2: $\eta' \to \pi^+\pi^-\gamma$ ⇒10^5 events expected

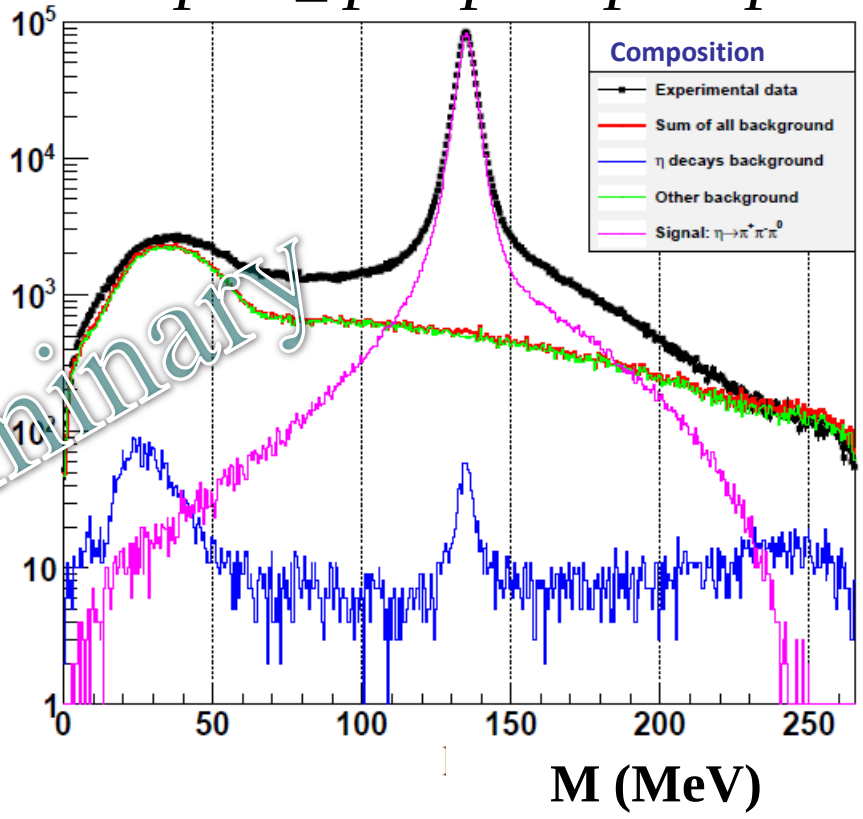
  $M_{\pi\pi}$ lineshape more sensitive to CT



Normalization Sample: $\eta \to \pi^+\pi^-\pi^0$

- $\eta \to \pi^+\pi^-\pi^0$
- $\mathcal{L} = 558\ pb^{-1}$
- $N(\eta \to \pi^+\pi^-\pi^0) = 1.19 \times 10^6$
- $\varepsilon = (22.77 \pm 0.02)\%$
- B/S=0.65%
- $\sigma(e^+e^- \to \phi \to \eta\gamma) = 41.8 \pm 0.2$ nb

$$P^{miss} = P^{\phi} - P^{\pi^+} - P^{\pi^-} - P^{\gamma_\phi}$$



$BR(\eta \to \pi^+\pi^-\pi^0) = (22.41 \pm 0.03 \pm 0.35)\%$

$PDG'10: BR(\eta \to \pi^+\pi^-\pi^0) = (22.74 \pm 0.28)\%$

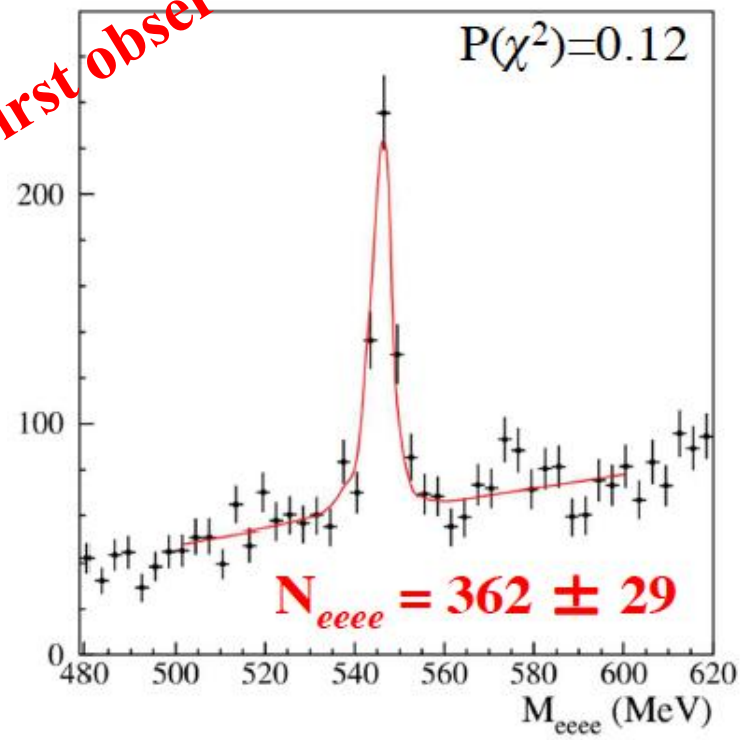
$\eta \to e^+e^-e^+e^-$

- **Theoretical predictions: BR ~ 2.4 – 2.6 ×10^{-5}**

- **BR < 6.9×10^{-5} @90%C.L. (CMD-2, 2001)**
  BR < 9.7×10^{-5} @90%C.L. (WASA, 2008)
  (2 evts, with 1.3 bckg)

- **Data sample: 1.7 fb^{-1}**
- **MC simulation according to Bijnens and Persson** [hep-ph/0106130]
- **e^+e^- pairs from photon conversions in the beam pipe and Drift Chamber wall rejected**

First observation



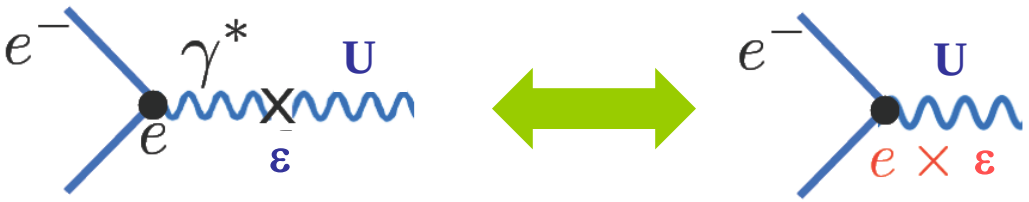
- **Fit with signal + background from continuum ($e^+e^-\to e^+e^-\gamma$ with γ conversion)**

$$BR(\eta \to e^+e^-e^+e^-(\gamma)) = (2.4 \pm 0.2_{stat} \pm 0.1_{syst}) \times 10^{-5}$$

accepted by PLB [arXiv:1105.6067]

Search for dark forces

- **Recent astrophysical observations (PAMELA, ATIC, INTEGRAL, DAMA/LIBRA) can be interpreted by assuming the existence of a light dark sector that interacts with SM particles through a mixing of a new gauge boson, U with *O*(1 GeV) mass, with the photon**

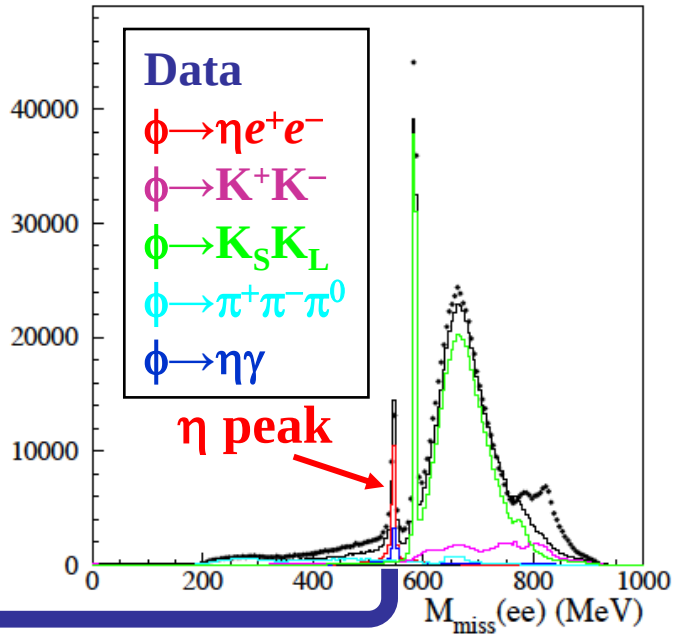


[Arkani-Hamed et al. PRLD79(2009), 015014
Essig et al., PRD80(2009)015003]

- **If the mixing parameter ε ~ 10^{-3} – 10^{-4} ⇒ could be observable at KLOE**
- **Signature: $\phi \to \eta U$, $U \to \ell^+\ell^-$**

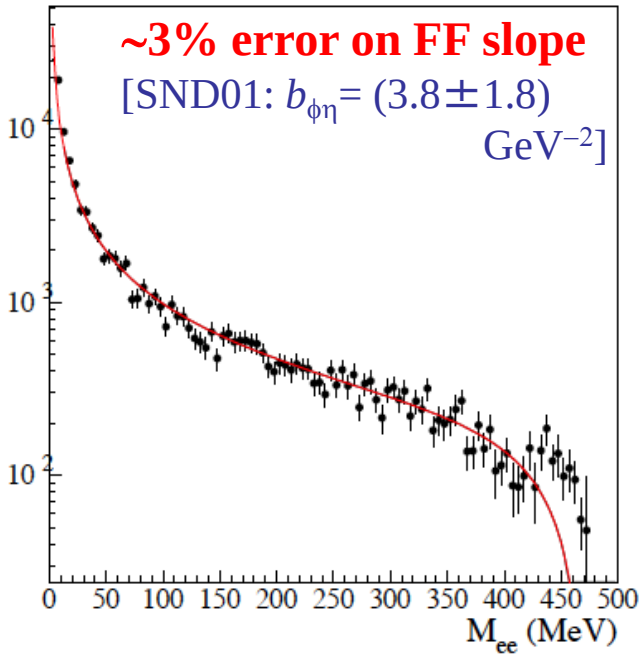
  ⇒ $\phi \to \eta e^+e^-$ $\eta \to \pi^+\pi^-\pi^0$
- **Main bckg: Dalitz decay**
- **Analyzed sample: 1.5 fb^{-1}**
- **Best $\pi^+\pi^-\gamma\gamma$ match to the η mass**

~14000 $\phi \to \eta e^+e^-$ ($\eta \to \pi^+\pi^-\pi^0$) candidates

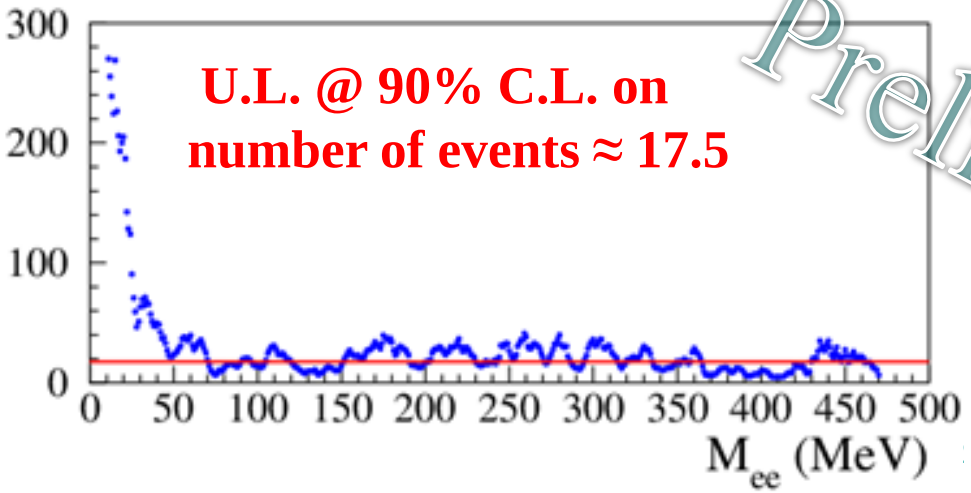


535 < $M_{miss}(ee)$ < 560 MeV

Limit on ε from $\phi \to \eta e^+ e^-$



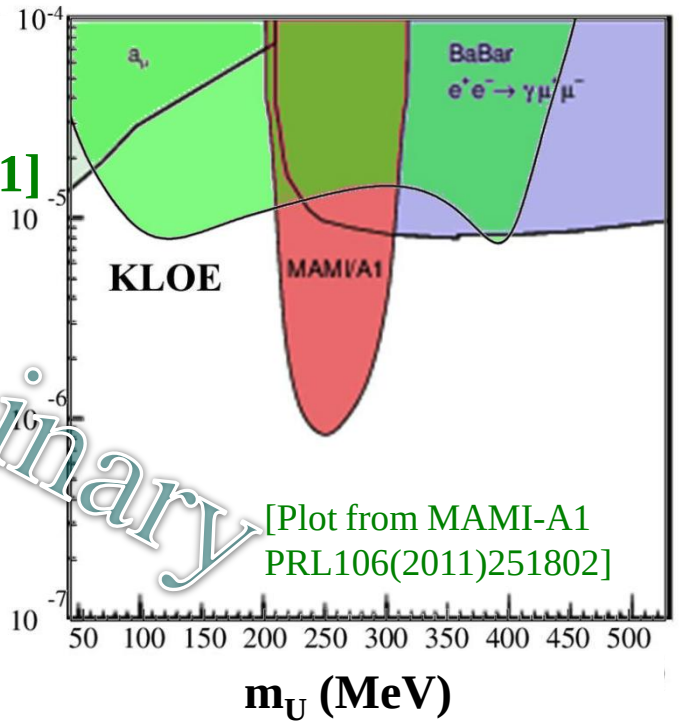
- $\phi \to \eta U$ MC sample divided in subsamples of 1 MeV in "true" M_{ee}
- Bckg from fit to M_{ee} distribution excluding the 5 bins around the selected one [parametrization from Landsberg, Phys.Rep.128(1985)301]
- Upper limit evaluated with the CL_S method



[arXiv:1107.2531]

Preliminary

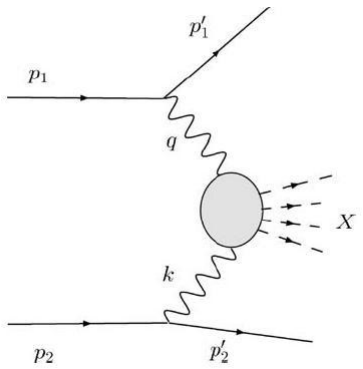
$\alpha'/\alpha = \varepsilon^2$



[Plot from MAMI-A1 PRL106(2011)251802]

July

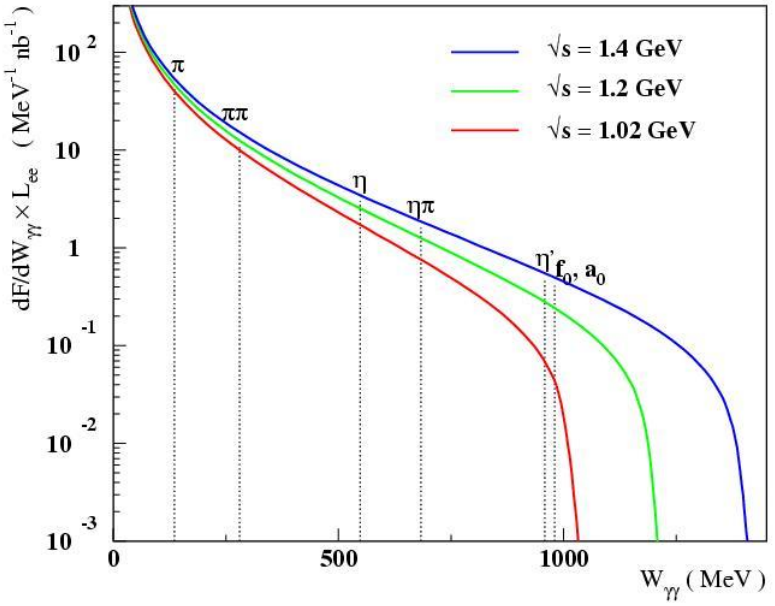
γγ physics



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

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

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



- X = $\pi^0\pi^0$ ⇒ search for σ(600)

- X = π^0, η
  - Γ(X→γγ) (KLOE-2: Γ(π^0→γγ) @ ~ 1%)
  - Transition form factors $\mathcal{F}_{X\gamma^*\gamma^*}(q_1^2,q_2^2)$

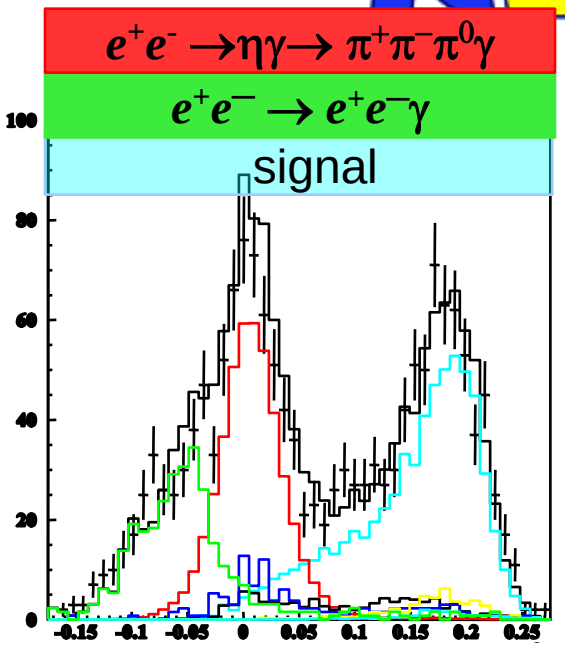
  (input for calculation of the Light-by-Light contribution to g-2 of the muon)

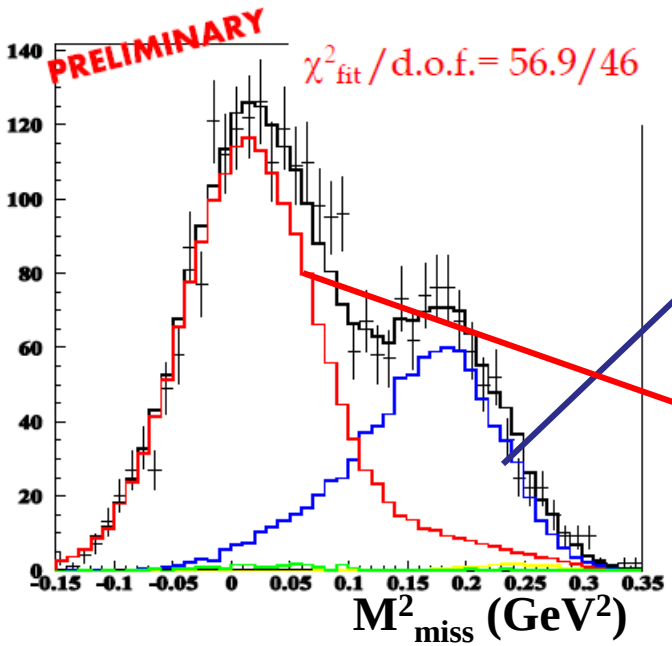
- KLOE: no $e^\pm$ tagging ⇒ √s = 1 GeV
- KLOE-2: √s = M_ϕ ⇒ Tagger is essential to reduce the background from the φ and to close the kinematics

$\gamma\gamma \rightarrow \eta$

- Data sample: 240 pb^{-1} off-peak ($\sqrt{s}$ = 1 GeV)
- Main bckg: $e^+e^- \rightarrow \eta\gamma$ with γ lost
- $\gamma\gamma \rightarrow \eta$; $\eta \rightarrow \pi^+\pi^-\pi^0$
- Fit to η longitudinal momentum (p_L) and missing mass (M_{miss})

⇒ 650 signal events





- $\gamma\gamma \rightarrow \eta$; $\eta \rightarrow \pi^0\pi^0\pi^0$
- Fit to the missing mass distribution:

⇒ 921 signal events

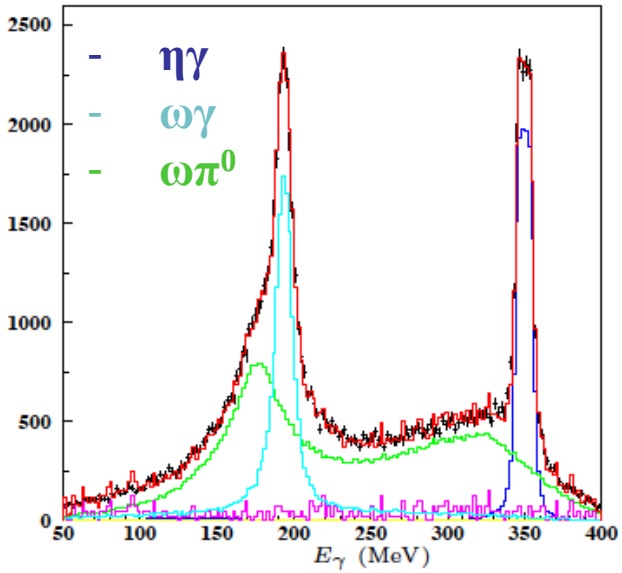
⇒ Work in progress to extract the cross-section

1760 $e^+e^- \rightarrow \eta\gamma$ events

[arXiv:1107.3782]

$\sigma(e^+e^- \to \eta\gamma)$ @1 GeV

- $e^+e^- \to \eta\gamma \to \pi^+\pi^-\pi^0\gamma$: 3 photons + 2 tracks
  - pion ID
  - kinematic cuts to suppress background from kaons
  - kinematic fit

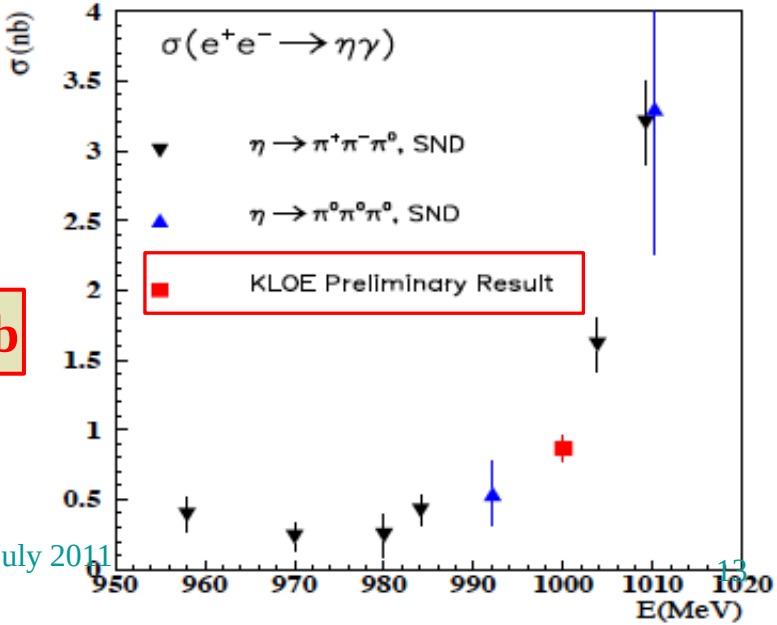


$\sigma(e^+e^- \to \eta\gamma, 1\ \text{GeV}) = (0.866 \pm 0.009 \pm 0.093)$ nb

[arXiv:1107.3782]

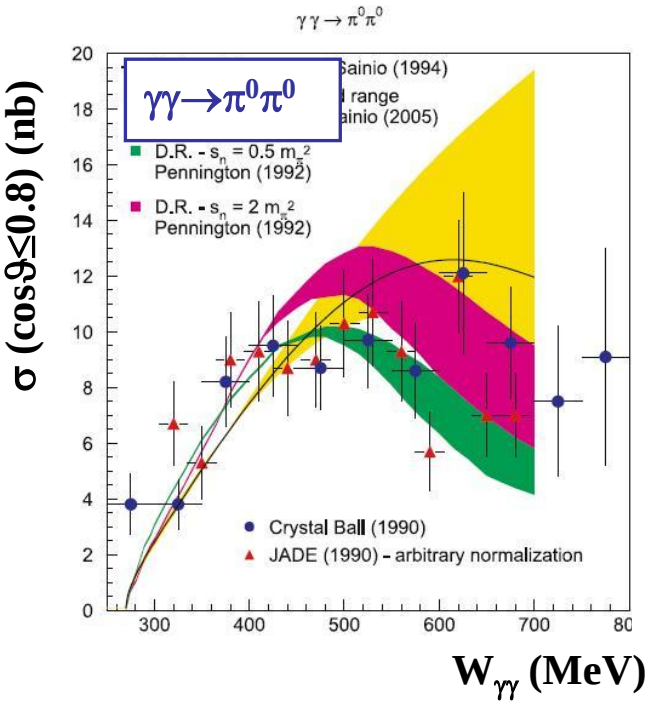
- In agreement with the result from $\eta \to \pi^0\pi^0\pi^0$:

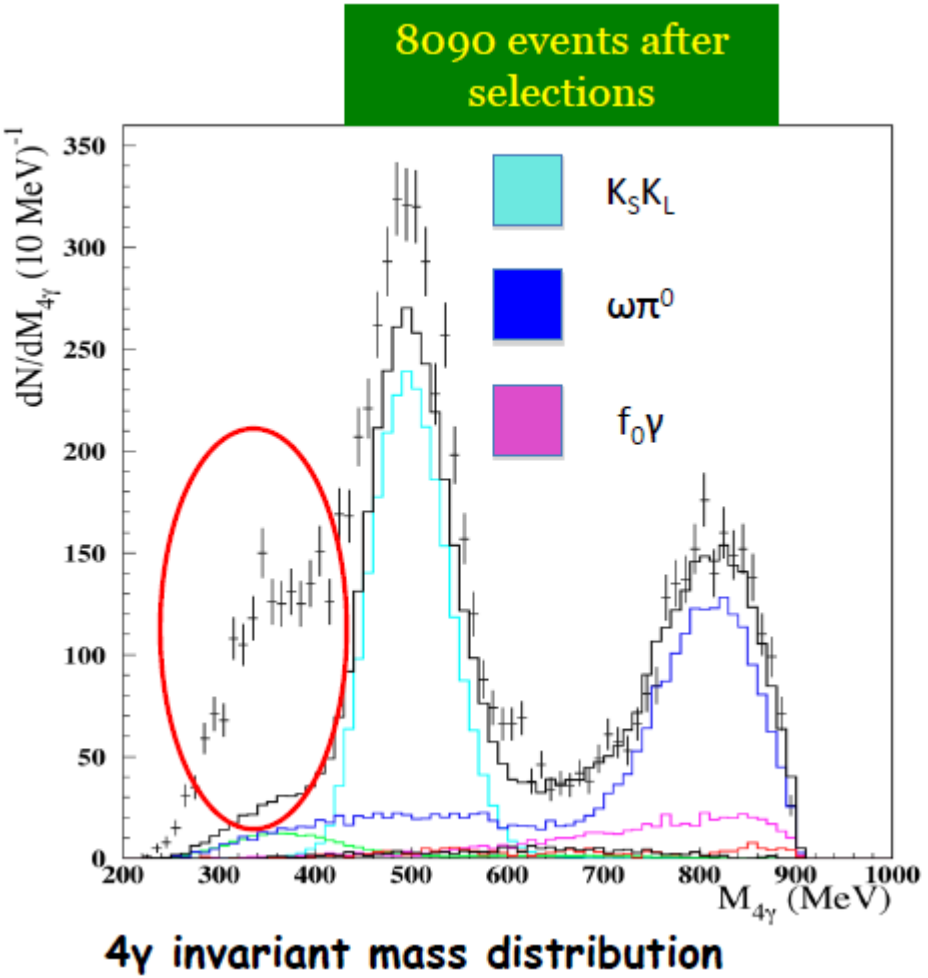
$\sigma(e^+e^- \to \eta\gamma, 1\ \text{GeV}) = (0.875 \pm 0.018 \pm 0.035)$ nb



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

- $e^+e^- \rightarrow e^+e^- \pi^0\pi^0$
- 240 pb^{-1} off-peak ($\sqrt{s}$ = 1 GeV)
- Selected sample: 4 prompt photons
- Excess of events with respect to background in the low mass region
- $\gamma\gamma \rightarrow \pi^0\pi^0$ cross-section evaluation in progress





KLOE-2: O(10 fb^{-1}) at $\sqrt{s} = M_\phi$ with $e^\pm$ tagging

⇒ 2% statistical accuracy using the same energy bin as Crystal Ball (~20% error)

Conclusions

- **KLOE published more than 20 papers on hadron physics (scalar mesons, η / η′ decays, hadronic cross section, …)**

  ↳ (see G.Venanzoni's talk tomorrow - Top and EW Physics session)

- **KLOE is continuing to exploit the high statistics samples of light mesons collected at DAΦNE to perform precision measurements in hadron spectroscopy and to look for very rare decays**

- **KLOE-2: > 20 fb^{-1} in the next 3 ─ 4 years**

  Rich program of measurements in hadron physics [Eur.Phys.J.C68(2010),619]

  - **study of η and η′ decays**
  - **η / η′ mixing**
  - **search for dark forces**
  - **γγ processes at $\sqrt{s} = M_\phi$ (with the $e^\pm$ taggers):**

    $\Gamma(\pi^0 \to \gamma\gamma)$, $P\gamma\gamma$ transition form factors, search for the σ(600)

⇒ KLOE-2 is ready to start a new data-taking

Spare slides

KLOE-2 physics program

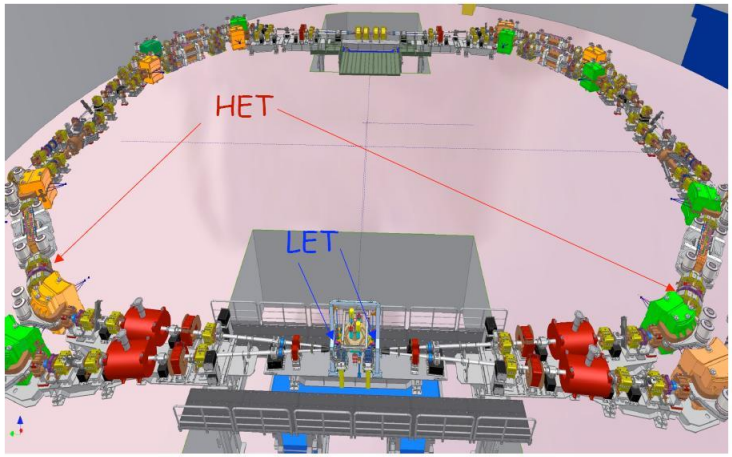
Goal: ~20 fb^{-1} in the next 3 – 4 years to extend the KLOE physics program

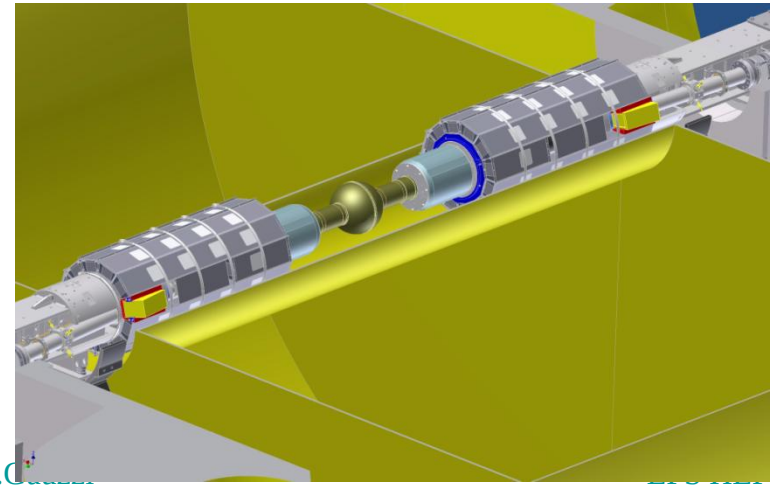
Eur. Phys. J. C68(2010)619

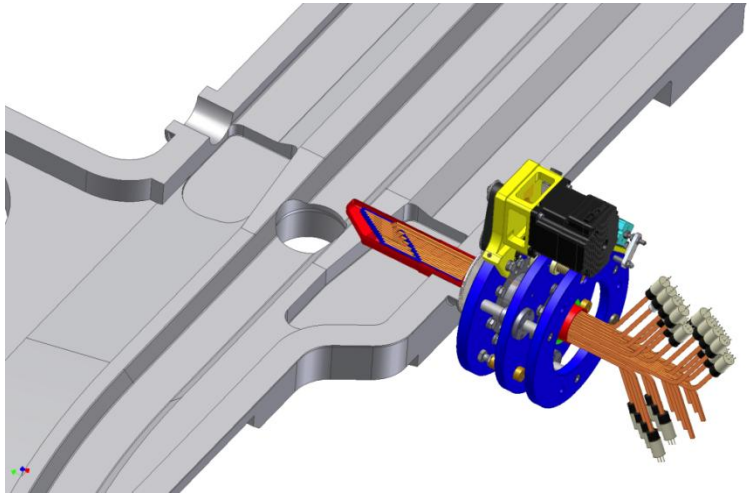
- **$\gamma\gamma$ physics**
  - **Existence (and properties) of $\sigma(600)$**
  - **Study of $\Gamma(S/P\rightarrow\gamma\gamma)$**
  - **P transition form factor**
- **Light meson spectroscopy**
  - **Properties of scalar/vector mesons**
  - **Rare η decays**
  - **η' physics**
- **Kaon physics**
  - **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 $(g_\mu-2)$**

From KLOE to KLOE-2

- **Two step upgrade:**
  - **1) First run (~ 5 fb^{-1} @ $\sqrt{s} = M_\phi$)**
    - ***e*$^{\pm}$ taggers for γγ physics:**
    - **– Low Energy Tagger (E_e=130-230 MeV)**
      - **2 calorimeters, LYSO + SiPM; near the IP**
      - **$\sigma_E/E < 10\%$ for E > 150 MeV**
    - **– High Energy Tagger (E_e > 400 MeV)**
      - **Scintillator hodoscope + PMTs;**
      - **after the first dipole, ~ 11 m from IP**
      - **pitch: 5 mm ⇒ σ_E = 2.5 MeV; $\sigma_t \approx$ 200 ps**

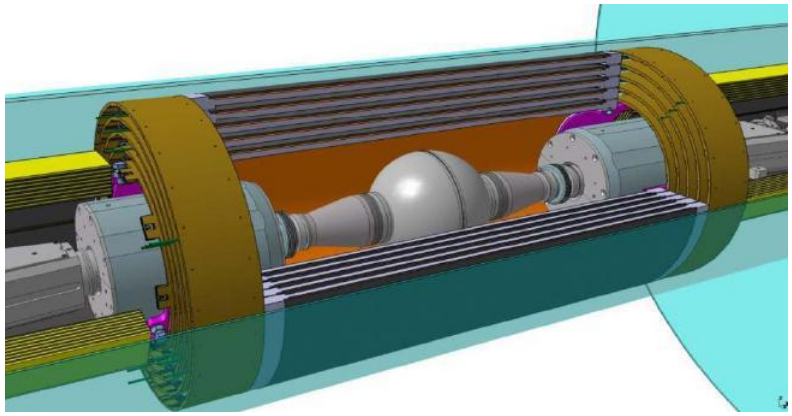






From KLOE to KLOE-2

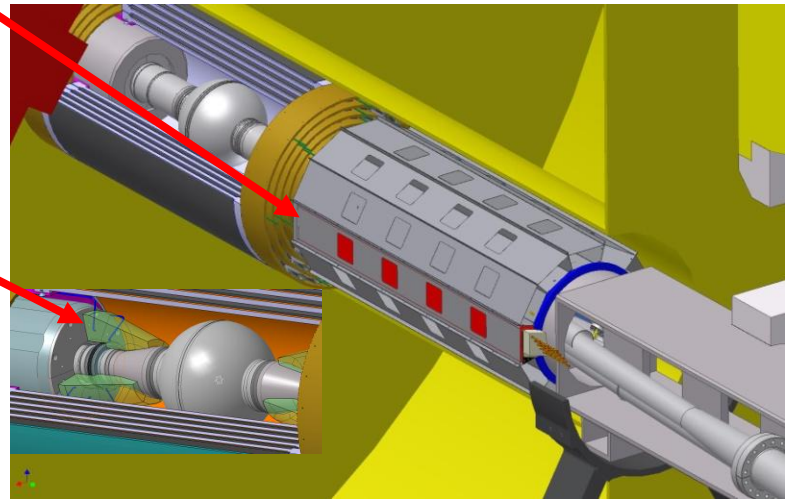
2) Major upgrade (Summer 2012)
(goal : lunimosity > 20 fb^{-1})



- **Inner tracker : 4 layers of cylindrical triple GEM to improve acceptance for low momemtum tracks**

- **QCALT: W + scint. tiles + SiPM**

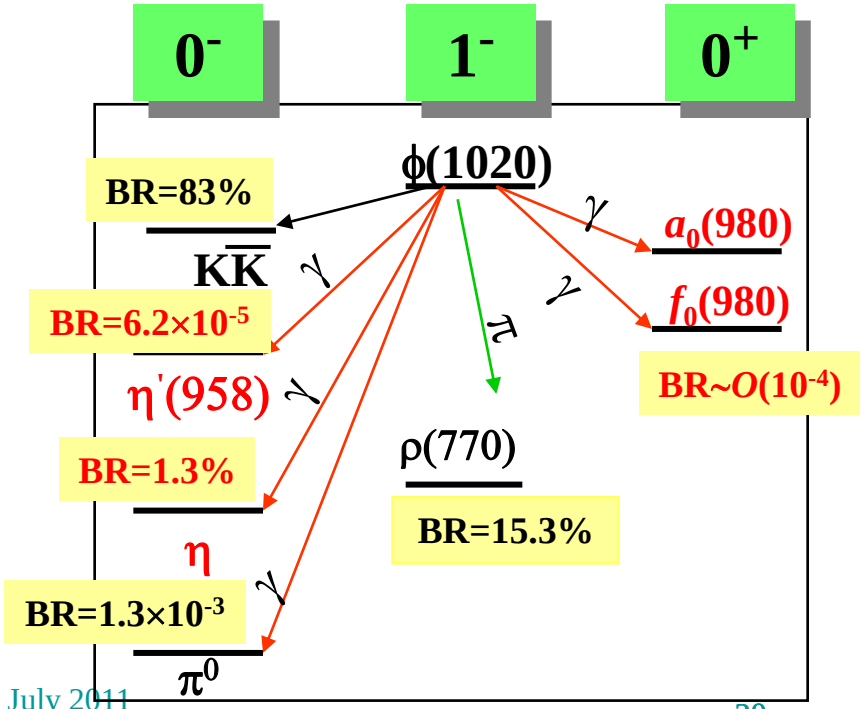
- **CCALT : LYSO + APD**
  to increase acceptance for γ's from the IP



Physics at a ϕ-factory

- **Kaon physics: $|V_{us}|$ and CKM unitarity, CP and CPT violation, rare decays, χPT tests, quantum mechanics tests** (see C.Bloise's talk – Flavour Physics session)
- **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 $(g-2)_\mu$** (see G.Venanzoni's talk tomorrow - Top and EW Physics session)

Decay channel	Events (2.5 fb^{-1})
K^+K^-	3.7×10^9
K_LK_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



Results on hadron physics

- **Published papers:**

- $\Gamma(\phi\to\eta'\gamma)/\Gamma(\phi\to\eta\gamma)$, PLB 541 (2002) 45
- $\phi\to\eta\pi^0\gamma$, PLB 536 (2002) 209
- $\phi\to\pi^0\pi^0\gamma$, PLB 537 (2002) 21
- $\phi\to\pi^+\pi^-\pi^0$, PLB 561 (2003) 55
- $\eta\to\gamma\gamma\gamma$, PLB 591 (2004) 49
- $\sigma(e^+e^-\to\pi^+\pi^-)$, PLB 606 (2005) 12
- $\eta\to\pi^+\pi^-$, PLB 606 (2005) 276
- $\Gamma(\phi\to l^+l^-)$, PLB 608 (2005) 199
- $\phi\to\pi^+\pi^-\gamma$, PLB 634 (2006) 148
- η mass, JHEP 12 (2007) 073
- $e^+e^-\to\pi^0\pi^0\gamma$, EPJC 49 (2007) 473

- $\Gamma(\phi\to\eta'\gamma)/\Gamma(\phi\to\eta\gamma)$, PLB 648 (2007) 267
- $\eta\to\pi^+\pi^-\pi^0$, JHEP 05 (2008) 006
- $e^+e^-\to\omega\pi^0$, PLB 669 (2008) 223
- $\sigma(e^+e^-\to\pi^+\pi^-)$, PLB 670 (2009) 285
- η/η' mixing, JHEP 07 (2009) 105
- $\eta\to\pi^+\pi^-e^+e^-$ PLB 675 (2009) 283
- $\phi\to K^0K^0\gamma$, PLB 679 (2009) 10
- $\phi\to\eta\pi^0\gamma$, PLB 681 (2009) 5
- $\eta\to\pi^0\pi^0\pi^0$, PLB 694 (2010) 16
- $\sigma(e^+e^-\to\pi^+\pi^-)$, PLB700 (2011) 102
- $\eta\to e^+e^-e^+e^-$, accepted by PLB

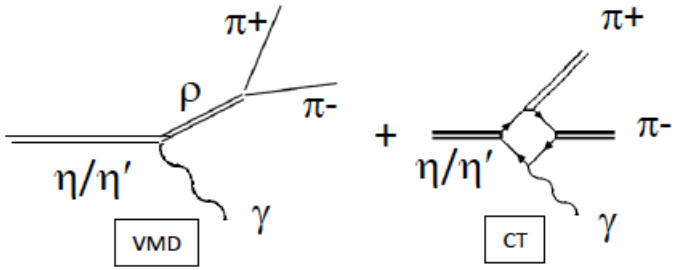
- **Ongoing analyses:**

- $\eta\to\pi^+\pi^-\gamma$
- $\eta\to\pi^0\gamma\gamma$
- $\phi\to\eta e^+e^-$
- $\gamma\gamma\to\eta$
- $\gamma\gamma\to\pi^0\pi^0$

Box anomaly

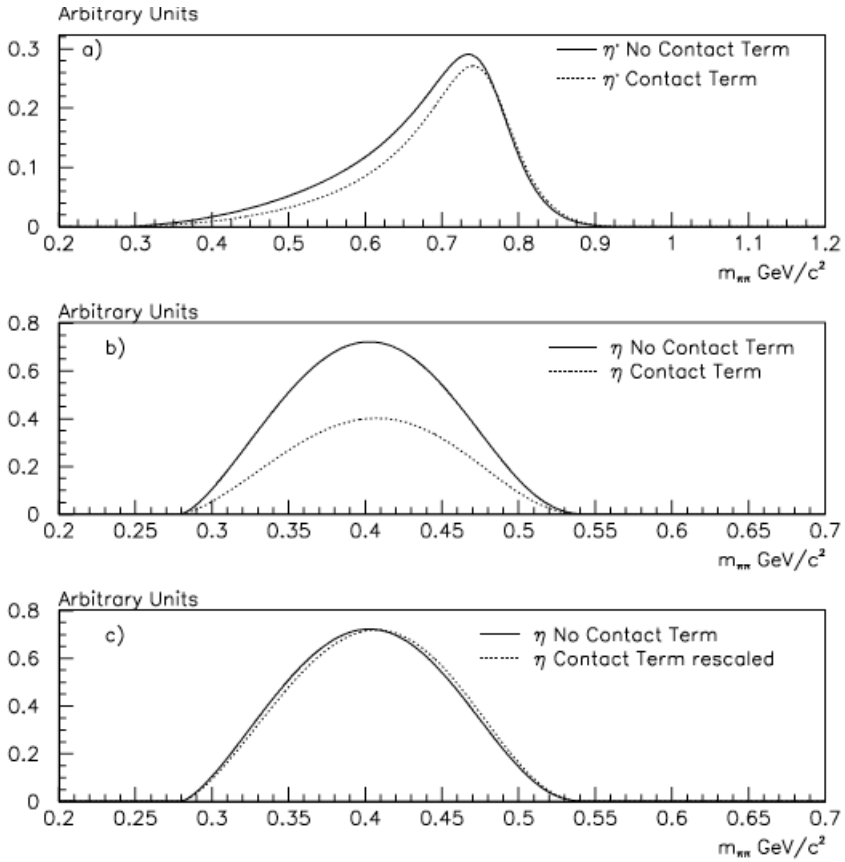
- **HLS model:**

[Benayoun et al., EPJC31, 525 (2003)]



- $\eta' \to \pi^+\pi^-\gamma$: $M_{\pi\pi}$ shape is affected by the contact term

- $\eta \to \pi^+\pi^-\gamma$: $M_{\pi\pi}$ shape slightly sensitive to contact term; effect on the value of the BR



$e^+e^- \rightarrow h'U$

- If there is a higgs-like particle (h') in the dark sector , with $m_{h'} < M_U$

  $\Rightarrow$ higgs'-strahlung $e^+e^- \rightarrow U^* \rightarrow Uh'$, with $U \rightarrow \ell^+\ell^-$

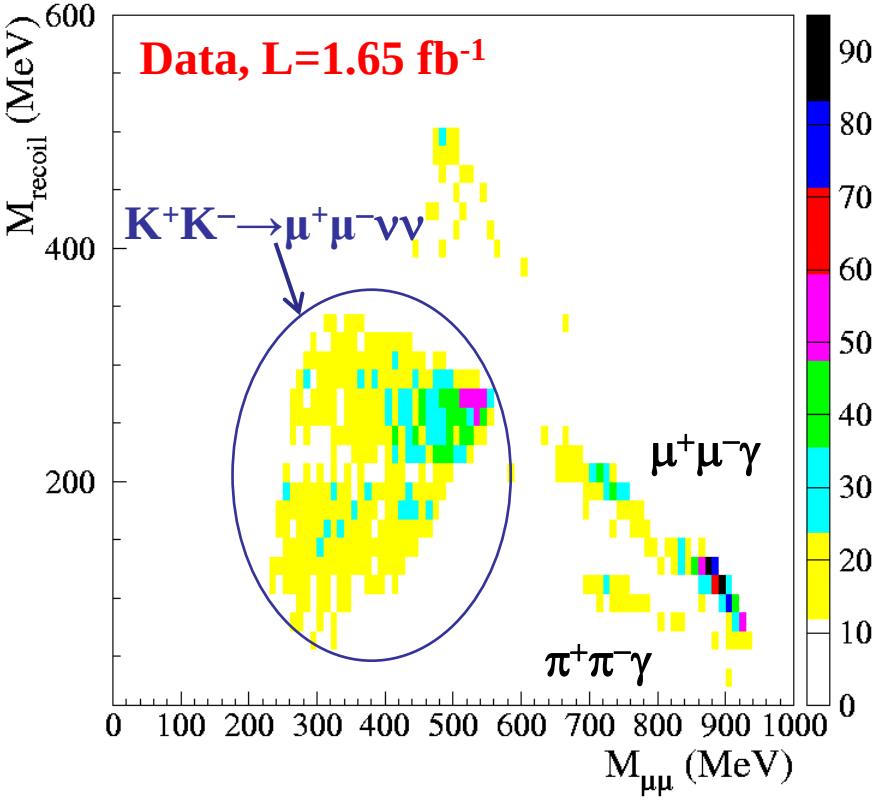
- Signature: $e^+e^- \rightarrow \ell^+\ell^-$ + missing energy (h′ not detected)
- e^+e^- final state not selected by our Event Classification $\Rightarrow$ use $\mu^+\mu^-$
- Background processes

$\phi \rightarrow K^+K^-$, $K^\pm \rightarrow \mu^\pm \nu$

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

$e^+e^- \rightarrow \mu^+\mu^- \gamma$, $\pi^+\pi^- \gamma$

} with γ lost



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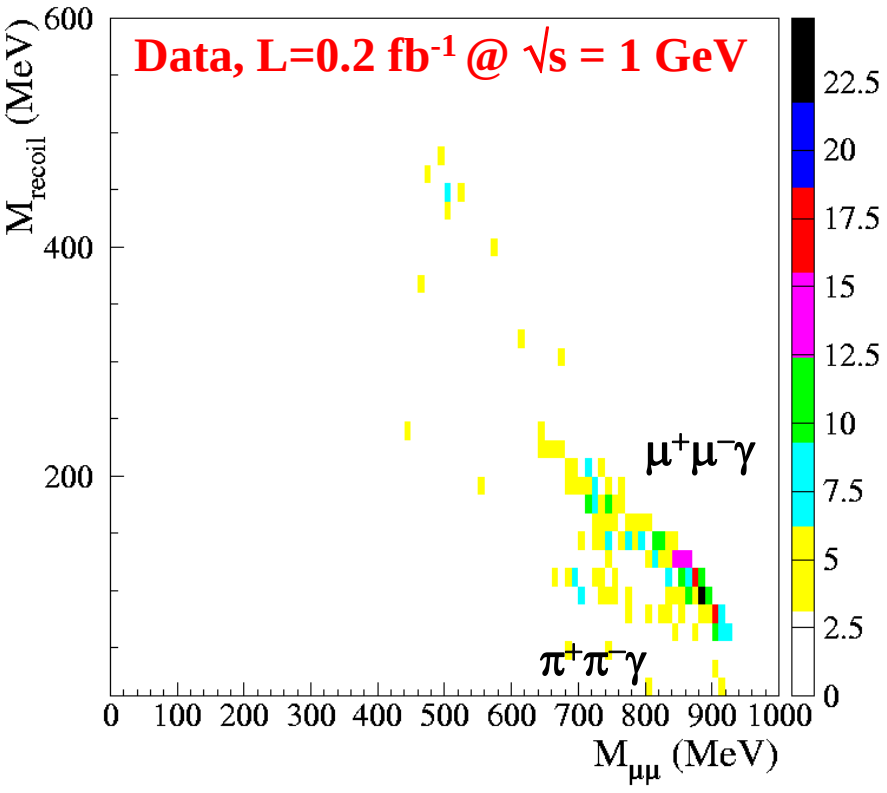
  $\phi \rightarrow \pi^+\pi^-\pi^0$
  $e^+e^- \rightarrow \mu^+\mu^-\gamma$, $\pi^+\pi^-\gamma$ } with γ lost
- Most background comes from ϕ
  $\Rightarrow$ strongly reduced by looking at off-peak data
- KLOE-2: Inner Tracker insertion should give major benefits to the analysis



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

- 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)

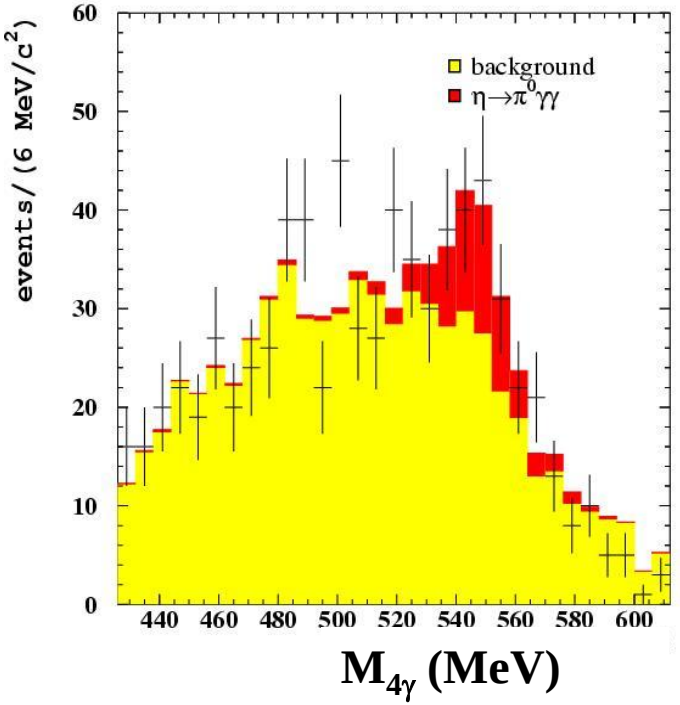
  $(22.4 \pm 4.6 \pm 1.7) \times 10^{-5}$ Crystal Ball@MAMI(2007)

  $(22.1 \pm 2.4 \pm 3.8) \times 10^{-5}$ 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 $\pm$ 2.7 $\pm$ 1.4) $\times$ 10^{-5}



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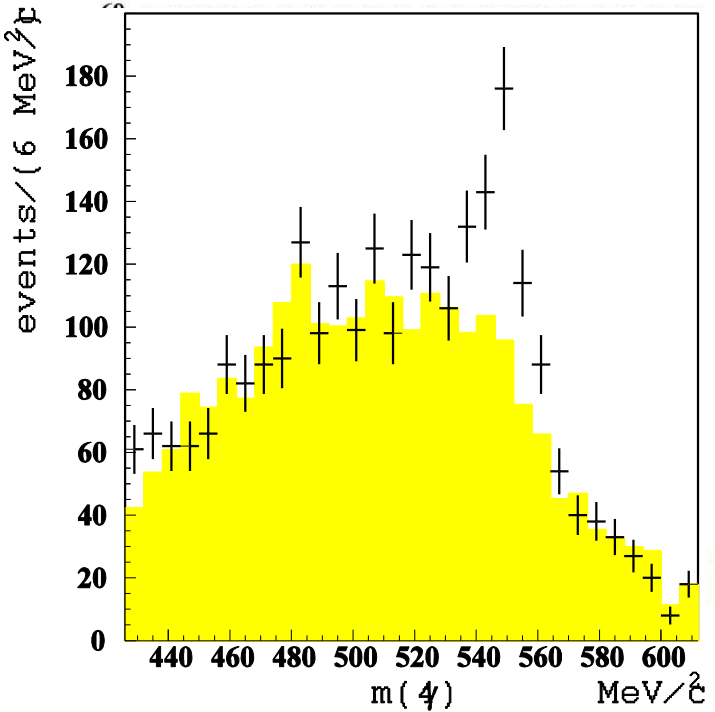
- L $\approx$ 450 pb^{-1}

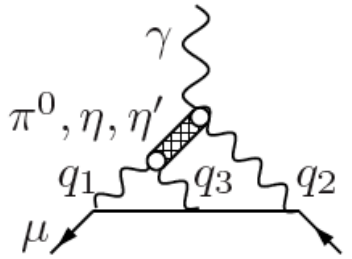
$\Rightarrow$ Br($\eta \to \pi^0\gamma\gamma$) = (8.4 $\pm$ 2.7 $\pm$ 1.4) $\times$ 10^{-5}

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

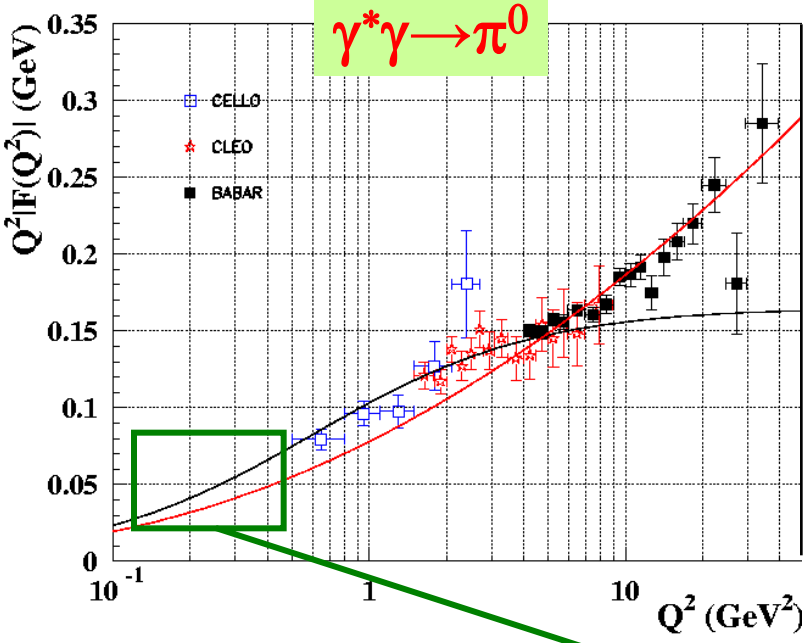


$\gamma\gamma \rightarrow$ single pseudoscalar

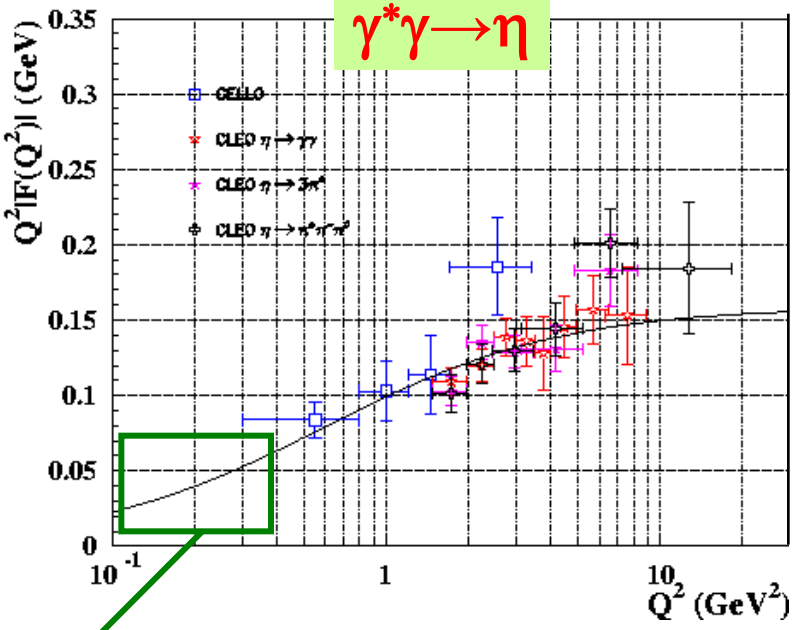
- Measurement of $\Gamma(P \rightarrow \gamma\gamma)$
- Transition form factors $\mathcal{F}_{P\gamma^*\gamma^*}(q_1^2, q_2^2)$:
  - input for the calculation of the Light-by-Light scattering contribution to g-2 of the muon



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



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



KLOE-2

$\Gamma(\pi^0 \to \gamma\gamma)$

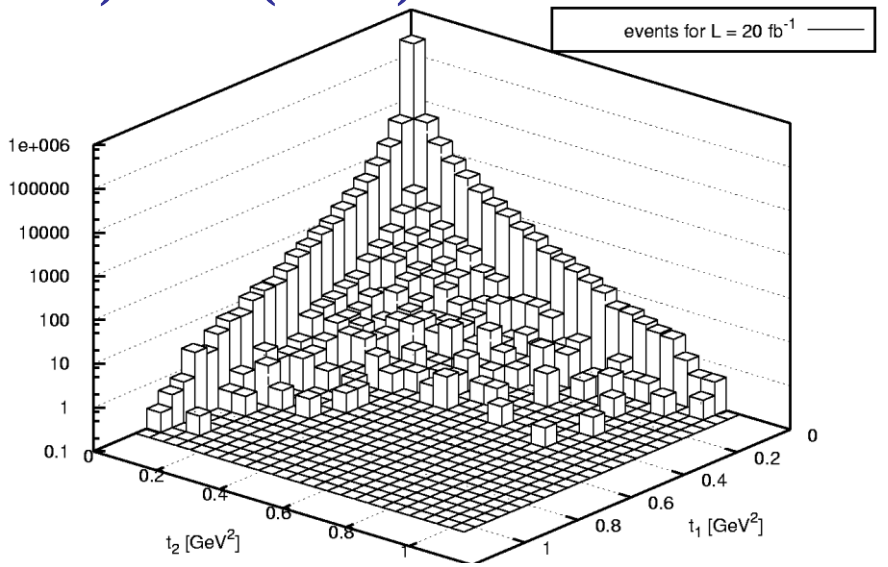
- **PrimEx $\Rightarrow \Gamma(\pi^0 \to \gamma\gamma) = (7.82 \pm 0.14 \pm 0.17)$ eV (2.8%)**
  [PRL106(2011)162303]

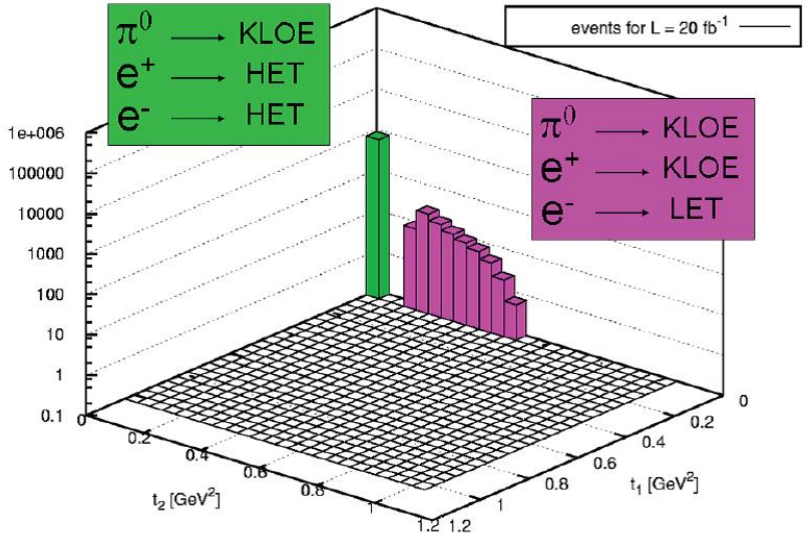
- **KLOE-2 will extract the partial width from $e^+e^- \to e^+e^-\pi^0$ ($\pi^0 \to \gamma\gamma$)**
- **HET · HET coincidence will select $q^2 \approx 0$ for both virtual γ**

$$\sigma_{tot} \propto [\Gamma(\pi^0 \to \gamma\gamma)]^2$$

$$\sigma_{tot}(s = M_\phi^2) \simeq 0.28 \text{ nb}$$

- **Taking into account acceptance and efficiencies**
  $\Rightarrow$ $O(10^4)$ events expected in 5 fb^{-1}
  $\Rightarrow$ ~ 1% accuracy reachable on $\Gamma(\pi^0 \to \gamma\gamma)$





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

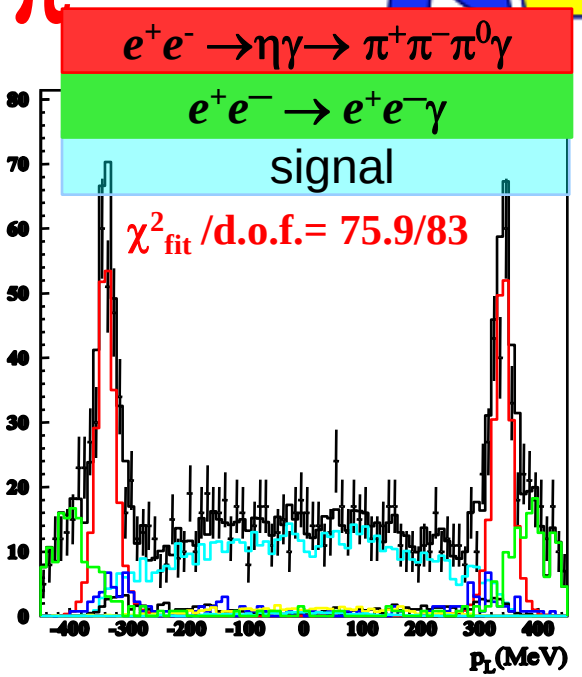
- **KLOE: 240 pb^{-1} off-peak ($\sqrt{s}$ = 1 GeV)**
- **Sample: 2 γ + 2 tracks with opposite charge**
- **Main bckg: $e^+e^- \to \eta\gamma \to \pi^+\pi^-\pi^0\gamma$**
  (with the recoil photon lost in the beam pipe)

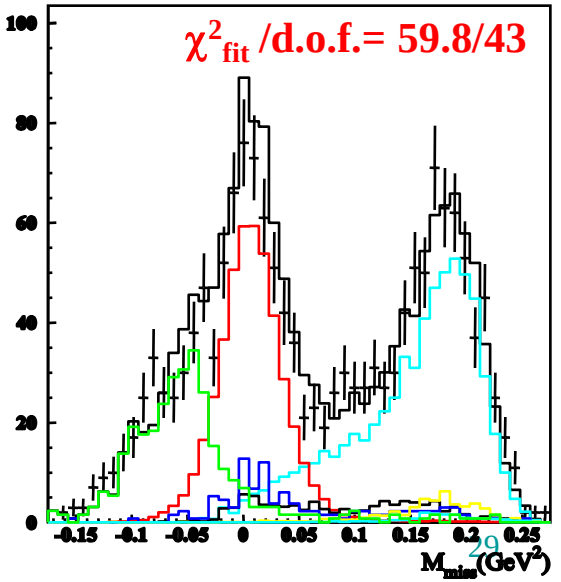
		ϵ
Signal	η	0.196
	$\eta\gamma$	9.1×10^{-3}
	$\omega\pi^0$	6.5×10^{-5}
	$\pi^+\pi^-\pi^0$	1.5×10^{-5}
	K^+K^-	1.9×10^{-5}
	K_SK_L	2.6×10^{-5}
	$e^+e^-\gamma$	$\mathcal{O}(10^{-7})$

$\Rightarrow$ **1576 events after the selection**

- **Fit to η longitudinal momentum (p_L) and missing mass (M_{miss})**

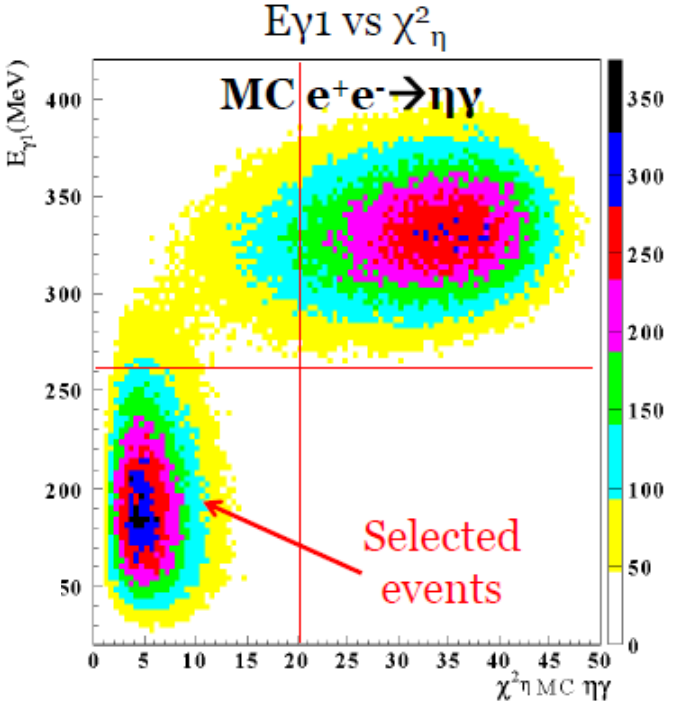
$\Rightarrow$ **650 signal events from fit**

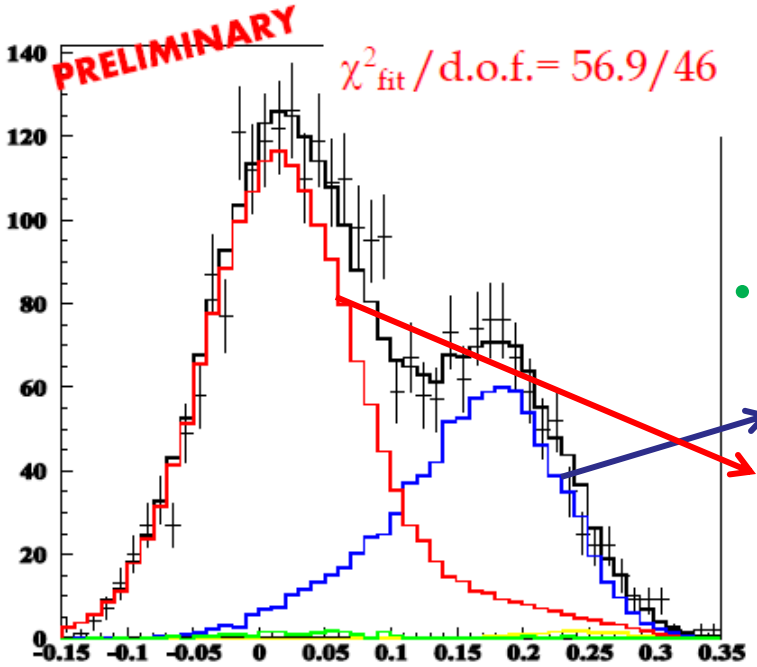




$\gamma\gamma \to \eta$, $\eta \to \pi^0\pi^0\pi^0$

- **Events with 6 prompt photons and no tracks**
- **Background: $e^+e^- \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$**
  (with the recoil photon lost in the beam pipe)
- **Cut on the most energetic photon (< 260 MeV)**
  and on the χ^2 of the kinematic fit





- **Fit of the missing mass distribution:**

⇒ 921 signal events

⇒ 1760 $e^+e^- \to \eta\gamma$ events

$\sigma(e^+e^- \to \eta\gamma \to \pi^0\pi^0\pi^0\gamma$, 1 GeV)=
= (0.285 ±0.005$_{stat}$) nb

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

- $e^+e^- \rightarrow e^+e^- \pi^0\pi^0$
- 240 pb^{-1} off-peak ($\sqrt{s}$ = 1 GeV)
- Selected sample: 4 prompt photons
- Best photon pairing to match two π^0's

$$\chi^2_{pair} = \left(\frac{M_{ij} - m_{\pi 0}}{\sigma(E_i, E_j)}\right)^2 + \left(\frac{M_{lk} - m_{\pi 0}}{\sigma(E_l, E_k)}\right)^2$$

$$\frac{\sigma(E_i, E_j)}{M_{ij}} = \frac{1}{2}\left(\frac{\sigma_{E_i}}{E_i} \oplus \frac{\sigma_{E_j}}{E_j}\right)$$

$$M_{ij}^2 = 2E_iE_j(1 - \cos\theta_{ij})$$