Studies of light meson decays at KLOE

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on behalf of the KLOE-2 Collaboration

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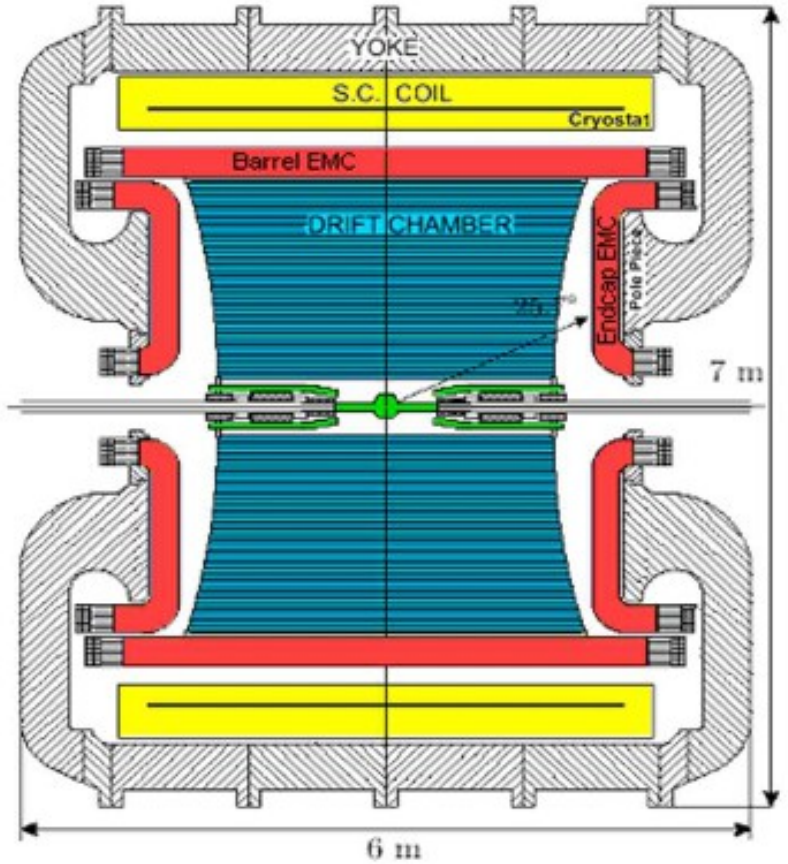
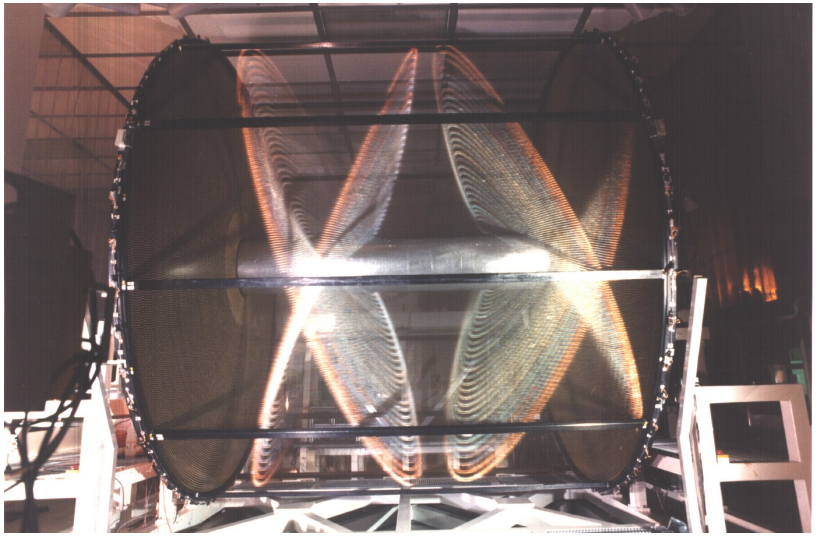
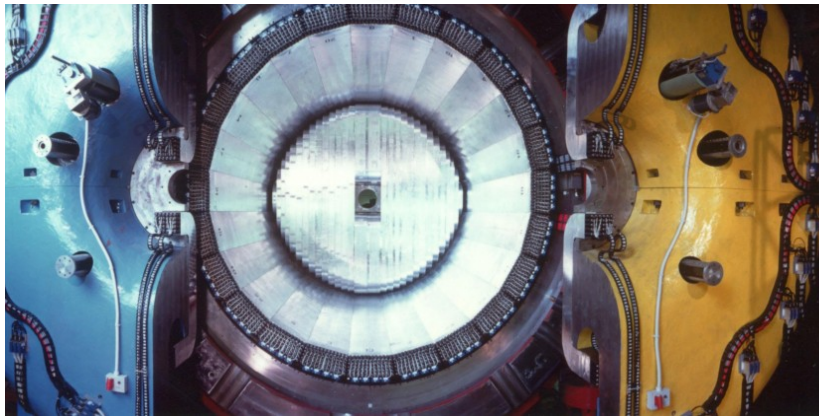
KLOE detector







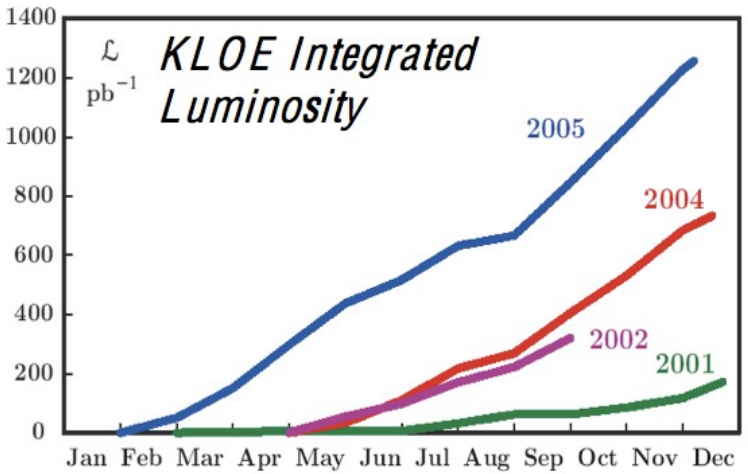
Drift chamber

- Gas mixture: **90% He + 10% C_4H_{10}**
- **$\delta p_t / p_t < 0.4\%$ ($\theta > 45^\circ$)**
- **$\sigma_{xy} \simeq 150\ \mu m$; $\sigma_z \simeq 2$ mm**

Electromagnetic calorimeter

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

DAΦNE collider

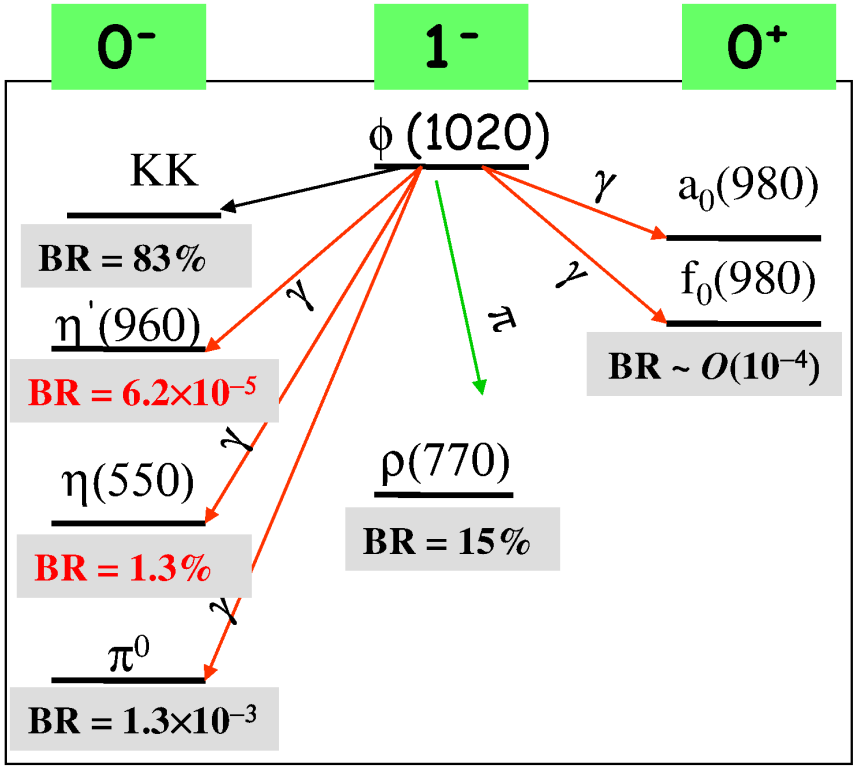


- e^+e^- collider
  - $\sqrt{(s)} = m_\Phi \sim 1019$ MeV
  - delivered luminosity (2005)

    $\int L\,dt \approx 8\ pb^{-1}$ /day

- Collected Data (KLOE):
  - 2.5 fb^{-1}
  - 260 pb^{-1} at 1GeV

Physics at a ϕ Factory



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

- Kaon physics
- Light meson spectroscopy → Some selected measurements:
  - $\eta \to e^+e^-e^+e^-$
  - $\eta \to \pi^+\pi^-\gamma$
  - $\eta' \to \pi^+\pi^-\eta$
- Hadron production in collisions
- Search for vector gauge bosons
- Hadronic cross section via ISR, $\pi^+\pi^-$ contribution to $(g-2)_\mu$

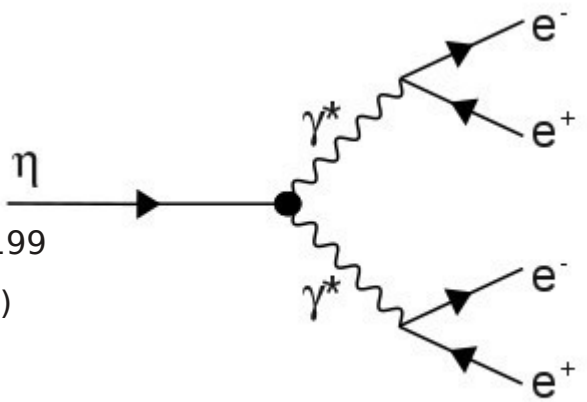
$\eta \to e^+e^-e^+e^-$

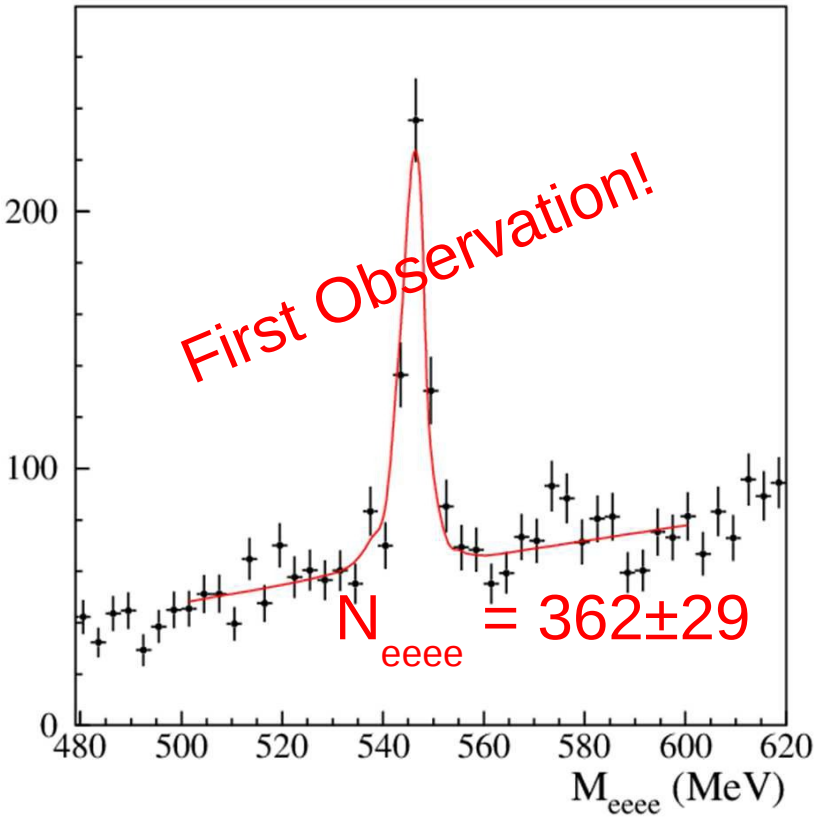
Theory:

- QED: BR($\eta \to e^+e^-e^+e^-$) = 2.6×10^{-5} C.Jarlskog and H.Pilkuhn,NPB1(1967)264-268

Experimentally only upper limits

- BR < $6.9 \cdot 10^{-5}$ CL90% CMD-2 PLB 501 (2001) 191-199
- BR < $9.7 \cdot 10^{-5}$ CL90% CELSIUS/WASA PRD77:032004 (2008)



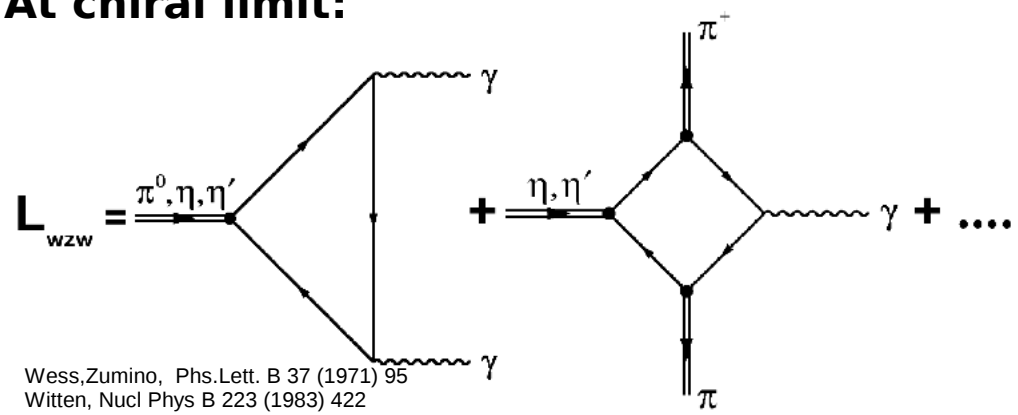


- 1.7 fb^{-1}
- Photon conversion on beam pipe rejected
- MC according to Bijnens and Persson, arxiv:0106130
- FSR included
- Background from ϕ decays subtracted

BR($\eta \to e^+e^-e^+e^-(\gamma)$) = $(2.4 \pm 0.2_{stat} \pm 0.1_{syst}) \times 10^{-5}$
Phys.Lett.B 702 (2011) 324

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

At chiral limit:



Wess,Zumino, Phs.Lett. B 37 (1971) 95
Witten, Nucl Phys B 223 (1983) 422

Decay rate off by factor 2 from experiment !

Include FSI by unitarized extensions:

- momentum dependent VMD — Picciotto, Phys. Rev. D45 (1992) 1569
- one loop corrections — Bijnens, Nucl. Phys. B637 (1991) 709
- one loop + Omnes function — Holstein, Phys Scr T99 (2002) 55
- Chiral Unitary Approach — Borasoy,Nissler, Nucl Phys A 740(2004) 362
- Hidden Local Symmetries — Benayoun et al, EPJ C 31 (2003) 525

Observables: Branching ratio and $m^2_{\pi\pi}$ / E_γ distribution

Previous Measurements

Branching Ratio

- recent CLEO measurement differs by > 3 σ from old results

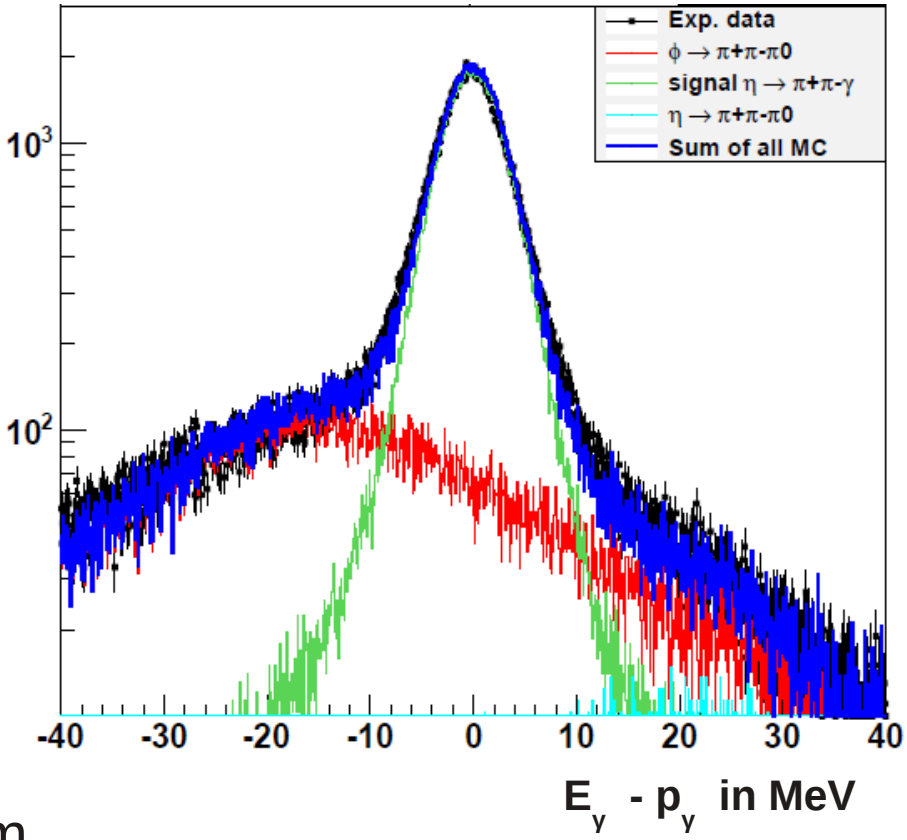
$m^2_{\pi\pi}$ / E_γ distribution:

- low in statistics
- not efficiency corrected
- ambiguous interpretation

→ new high precision measurement of both observables

$\eta \rightarrow \pi^+\pi^-\gamma$: Signal Selection

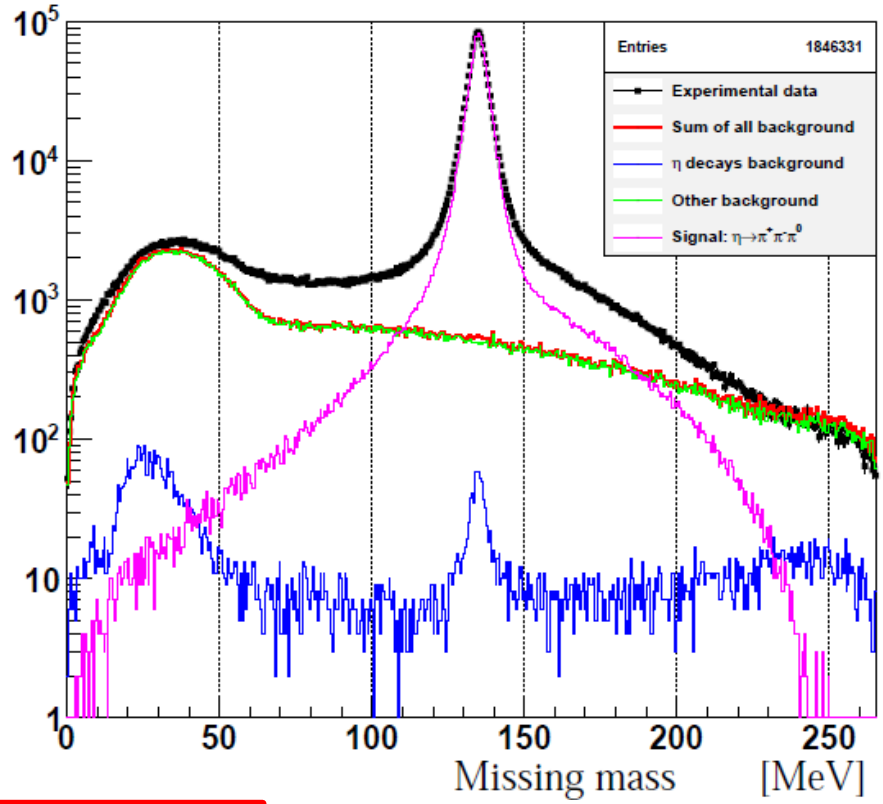
- 558 pb^{-1} analyzed
- Selection conditions based on decay kinematics
- S/B = 10/1
- 204950 ± 450 events reconstructed
- ε = 21.31 ± 0.04 %
- Signal counting from fit to E-P spectrum



$$E_\gamma = \sqrt{s} - E_{\pi^+} - E_{\pi^-} - E_{\gamma_\phi}$$
$$p_\gamma = |\vec{p}_{\pi^+} + \vec{p}_{\pi^-} + \vec{p}_{\gamma_\phi}|$$

$\eta \rightarrow \pi^+\pi^-\gamma$: Normalization Sample

- $\eta \rightarrow \pi^+\pi^-\pi^0$
- B/S = 0.65 %
- 1115805 ± 1056 events reconstructed
- ε = 22.76 ± 0.02 %
- $\sigma(e^+e^- \rightarrow \Phi \rightarrow \eta\gamma)$ = 41.8 ± 0.2 nb
  - BR($\eta \rightarrow \pi^+\pi^-\pi^0$) = 22.41 ± 0.03 ± 0.35%
  - PDG: BR($\eta \rightarrow \pi^+\pi^-\pi^0$) = 22.74 ± 0.28



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

Preliminary (arXiv:1107.5733):

$$\frac{\Gamma(\eta \rightarrow \pi^+\pi^-\gamma)}{\Gamma(\eta \rightarrow \pi^+\pi^-\pi^0)} = 0.1856 \pm 0.0005_{stat} \pm 0.0028_{syst}$$

Consistent with CLEO result! Phys.Rev.Lett. 99 122001 (2007)

$\eta \to \pi^+\pi^-\gamma$: $m_{\pi^+\pi^-}$ Spectrum

- Simplest matrix element:

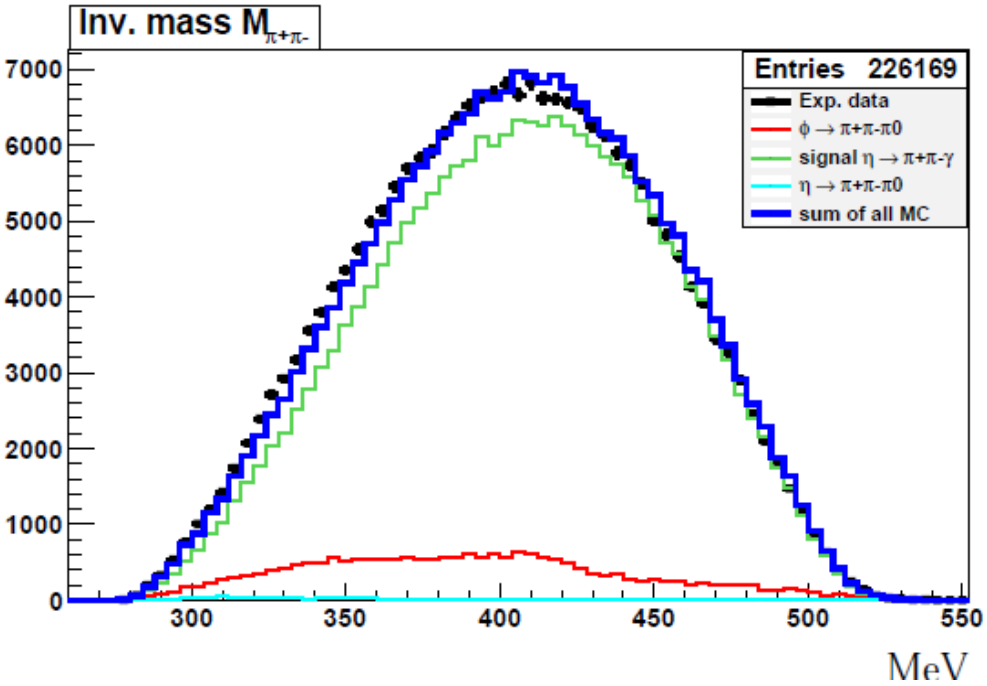
$$|A_\eta(s=0,t=0,u=0)|^2 \propto q^2 E_\gamma^2 \sin^2\theta$$

- Form factor for realistic description

$$|A_\eta(s_{\pi\pi})|^2 = |A_\eta(0,0,0)\cdot F(s_{\pi\pi})|^2$$

- Use model independent approach based on ChPT and dispersive analysis

Stollenwerk et al.
Phys.Lett.B 707 (2012), 184



- Form factor factorizes into $F(s_{\pi\pi}) = F_{PV}\cdot P(s_{\pi\pi})$
  - universal, non-perturbative part F_{PV}

$$F_{PV} = 1 + (2.12\pm0.01)\, s_{\pi\pi} + (2.13\pm0.01)\, s_{\pi\pi}^2 + (13.80\pm0.14)\, s_{\pi\pi}^3$$

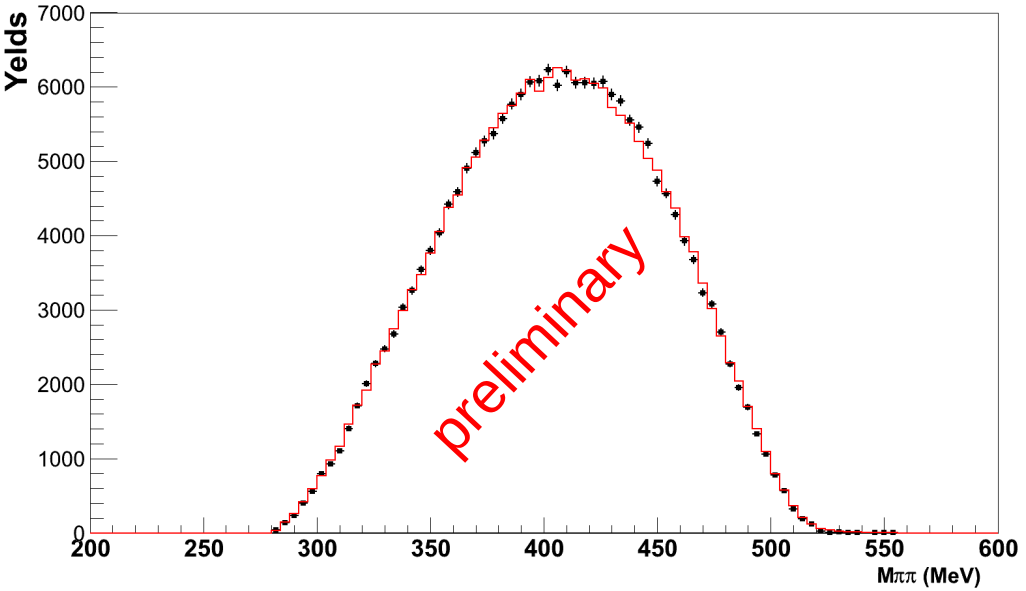
  - reaction specific, perturbative part $P(s_{\pi\pi})$

$$P(s_{\pi\pi}) = 1 + \alpha\, s_{\pi\pi} + O(s_{\pi\pi}^2)$$

$\eta \rightarrow \pi^+\pi^-\gamma$: $m_{\pi^+\pi^-}$ Spectrum

Shape described by a single parameter

$$|A_\eta(s_{\pi\pi})|^2 = |A_\eta(0,0,0)\cdot F_{PV}(1+\alpha\, s_{\pi\pi})|^2$$



Determine α by fit to spectrum:

$$\chi^2 = \Sigma_i^{N_{bin}} \frac{\left(N_i^{data} - \Sigma_j^{N_{bin}} N_j^{theo}\, \varepsilon_j\, S_{ij}\right)^2}{\sigma^2_{N_i^{data}} + \sigma^2_{N_i^{theo}}}$$

ε_j : Efficiency

S_{ij} : Smearing matrix

$$\sigma_{N_i^{theo}} : \Sigma_j^{N_{bin}} N_j^{theo}\left(\sigma_{\varepsilon_j} S_{ij} + \varepsilon_j\, \sigma_{S_{ij}}\right)$$

Preliminary Result:

$$\alpha = 1.32 \pm 0.08_{stat}\ {}^{+0.10}_{-0.09}{}_{syst} \pm 0.02_{theo}$$

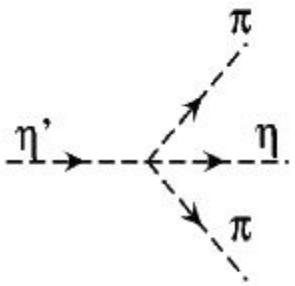
In agreement with WASA-at-COSY result:

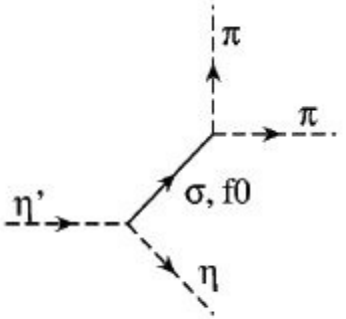
$$\alpha = 1.89 \pm 0.25_{stat} \pm 0.59_{syst} \pm 0.02_{theo}$$

WASA-at-COSY Collab.
Phys.Lett.B 707 (2012), 243

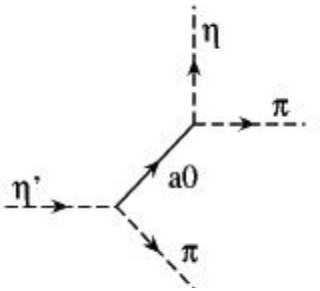
$\eta' \to \pi^+\pi^-\eta$

- Study η-π interaction
  - Quantum numbers favor scalar resonances

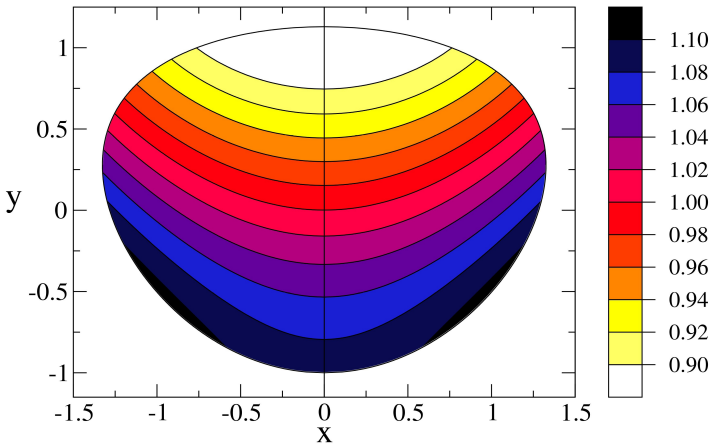




[Faribortz-Schechter,PRD60(1999)034002]

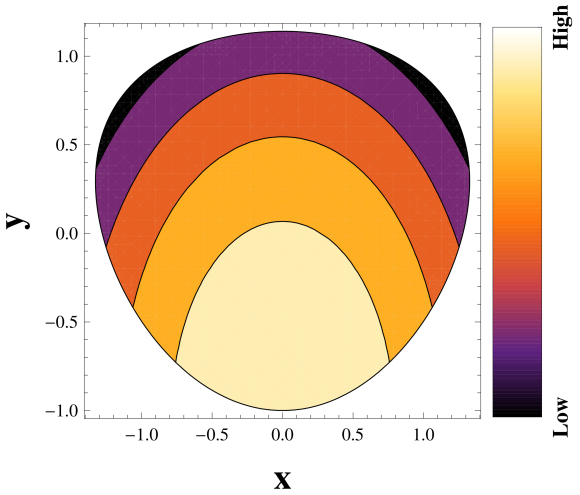


- Test predictions of ChPT and extensions



$a_0(980)$ I=1 dominance

Borasoy et al. EPJ A26 (2007) 383



LN_c-ChPT

Escribano et al. JHEP 1105 (2011) 094

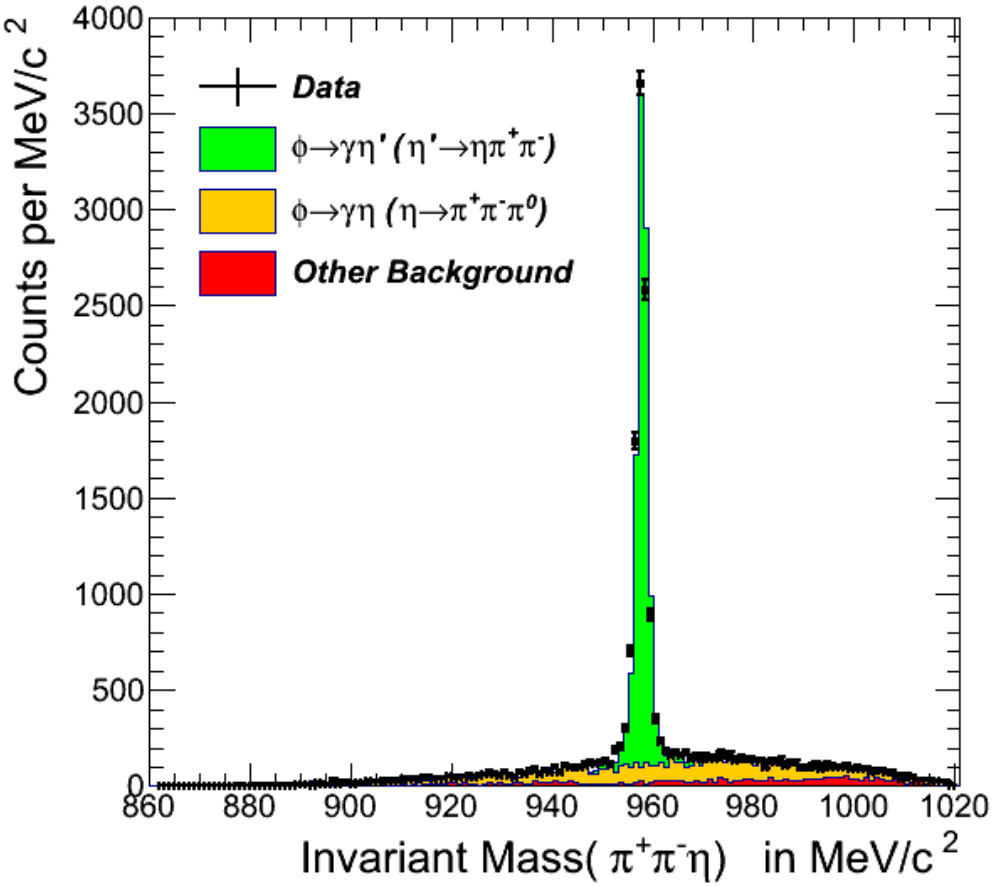
$$X = \frac{\sqrt{3}(T_{\pi^+} - T_{\pi^-})}{T_{\pi^+} + T_{\pi^-} + T_\eta}$$

$$Y = \frac{m_\eta + 2m_{\pi^\pm}}{m_{\pi^\pm}} \frac{T_\eta}{T_{\pi^+} + T_{\pi^-} + T_\eta} - 1$$

- Predictions differ on percent level → high precision needed

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

- 1.7 fb^{-1} analyzed
- Background suppression by multiple hypothesis kinematic fitting
- Main background $\eta \rightarrow \pi^+\pi^-\pi^0$
- B/S = 0.2
- ε = 23%
- 10160 ± 110 events reconstructed



Previous Measurements:

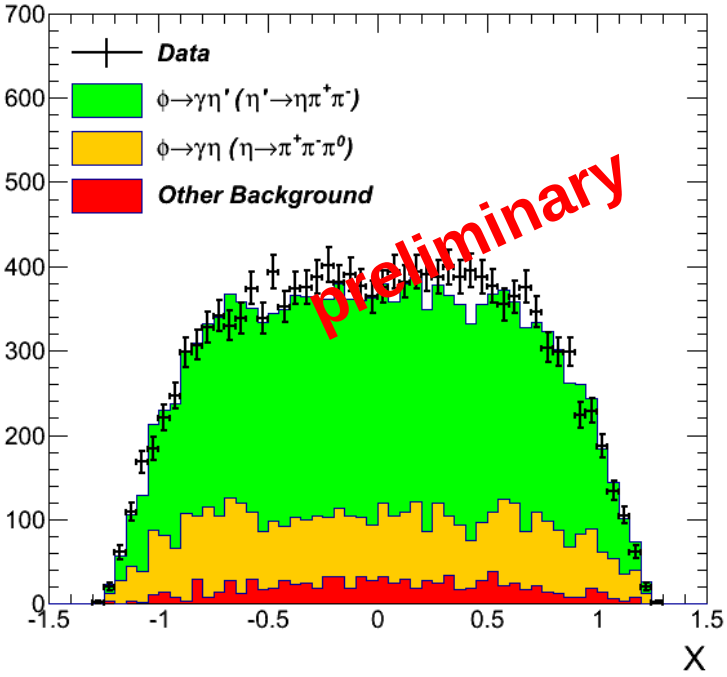
BNL (sum)	1400 events	Phys. Rev. D10 916 (1974)
CLEO	6700 events	Phys. Rev. Lett. 84 26 (2000)
VES	7000 events	Phys. Lett. B651, 22-26 (2007)
BES III	44000 events	Phys. Rev. D83, 012003 (2011)

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

Dalitz plot projection

- 940 < IM(ππη)[MeV] < 980
- Not background subtracted
- Not efficiency corrected

- MC: Phase space
  - Tuning needed



- Very good resolution in X and Y variables:
  - σ(X),σ(y) = 0.02

BES-III: σ(X),σ(y) = 0.03
Phys. Rev. D83, 012003 (2011)

- Efficiency drop for large |X|, i.e. low momentum pions

Higher statistics and better acceptance at KLOE-2

KLOE → KLOE-2

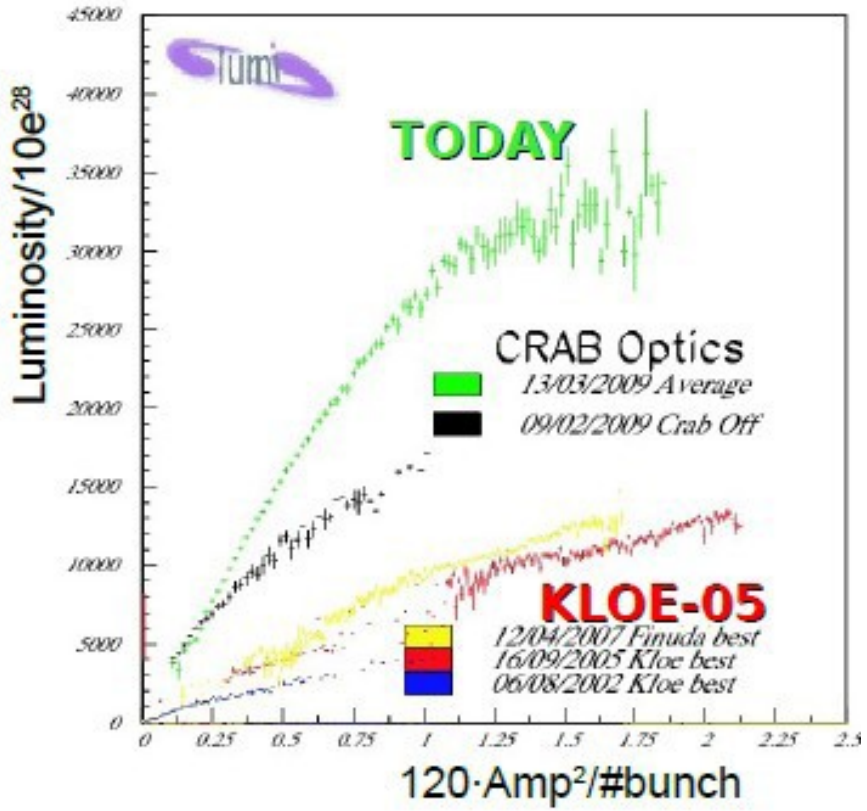
Goal: **5 - 10 fb^{-1} in the next 3 years to extend the KLOE physics program**

γγ physics	
	Existence (and properties) of σ/f0(600)
	Study of Γ(S/PS→γγ)
	PS transition form factor
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 KS semileptonic decays
	Test of SM (CKM unitarity, lepton universality)
	Test of ChPT (KS decays)
Dark matter searches	
	Light bosons @ O(1 GeV)
Hadronic cross section	
	$\alpha_{em}(M_Z)$ and (g-2)

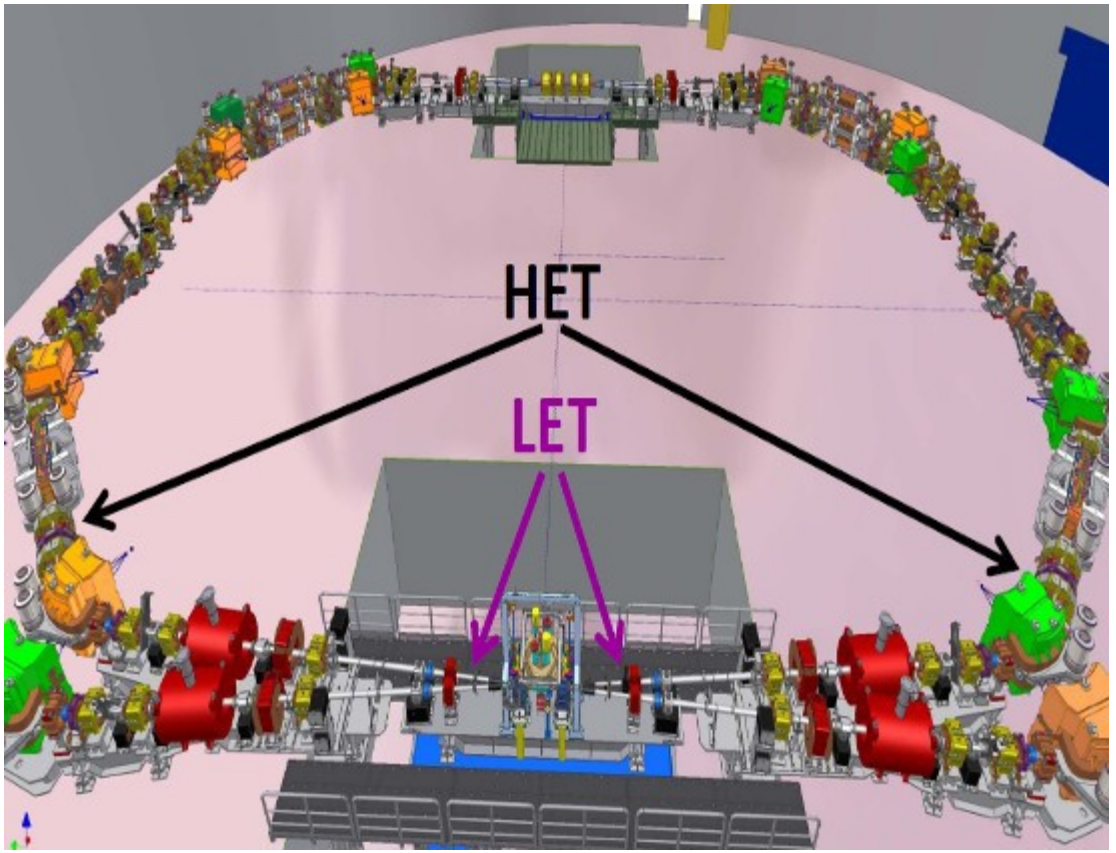
Eur.Phys.J.C68(2010)619

Upgrade: DAΦNE

- New Collision Scheme
  - Larger beam crossing angles
  - Crab-waist sextupoles
- Increase in luminosity by factor 3
  - $\int L\,dt \approx 1 pb^{-1}/h$
- First collisions in 2010
- Long shut down times due to severe hardware failures
- DAΦNE commissioning started in November 2011



KLOE-2: New Detectors

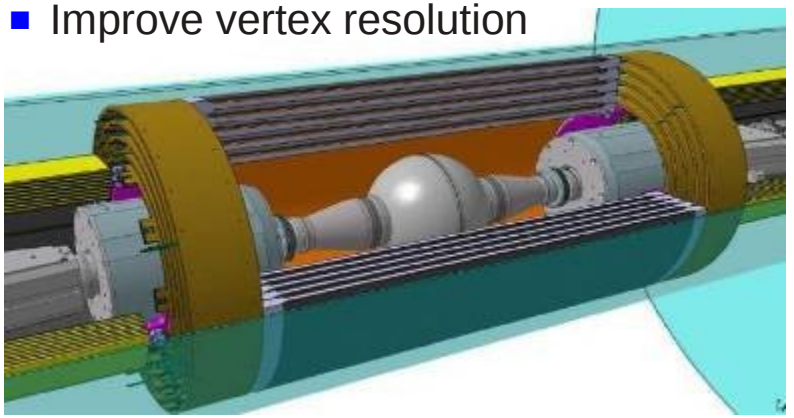


Taggers for γγ physics

- Measure momenta of leptons in $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- X$

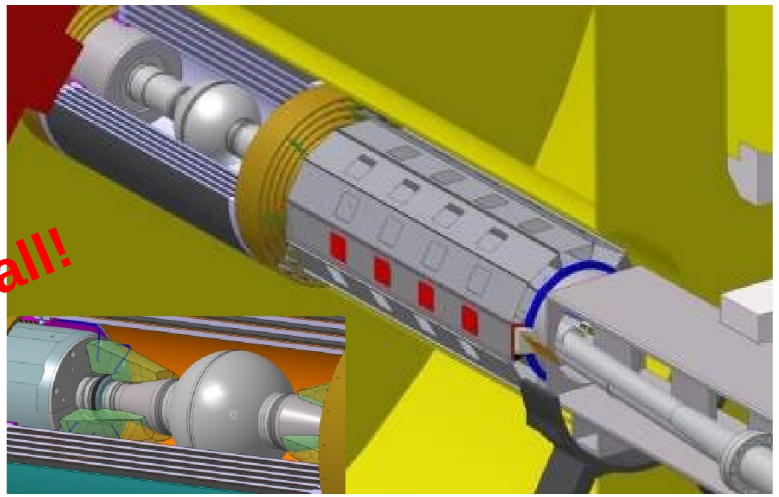
Inner Tracker

- 4 layers cylindrical triple GEM
- Increase acceptance for low P_T particles
- Improve vertex resolution



Small angle calorimeters

- Increase γ acceptance (>21° → >10°)



To be finalized this fall!

Summary

- High statistics samples of light mesons produced at KLOE
  - Perform precision measurements
    - $\eta \to \pi^+\pi^-\gamma$

$$\frac{\Gamma(\eta \to \pi^+\pi^-\gamma)}{\Gamma(\eta \to \pi^+\pi^-\pi^0)} = 0.1856 \pm 0.0005_{stat} \pm 0.0028_{syst}$$

preliminary

$$\alpha = 1.32 \pm 0.08_{stat} \; {}^{+0.10}_{-0.09\,syst} \pm 0.02_{theo}$$

  - Study very rare decays
    - $\eta \to e^+e^-e^+e^-$

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

Phys.Lett.B 702 (2011) 324

- KLOE-2 is going to start a new data taking campaign
  - DAΦNE commissioning in progress
  - Detector ready to take data
  - Rich physics program
  - Detector upgrades finished this year