Studies of light meson decays at KLOE

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on behalf of the KLOE-2 Collaboration
**KLOE detector**

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

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

- $e^+e^-$ collider
- $\sqrt{(s)} = m_\Phi \sim 1019$ MeV
- delivered luminosity (2005)
  $$\int L \, dt \approx 8 \, \text{pb}^{-1} / \text{day}$$
- Collected Data (KLOE):
  - 2.5 fb$^{-1}$
  - 260 pb$^{-1}$ at 1GeV
Physics at a \( \phi \) Factory

- Kaon physics
- Light meson spectroscopy
- Hadron production in collisions
- Search for vector gauge bosons
- Hadronic cross section via ISR, \( \pi^+\pi^- \) contribution to \( (g-2)_\mu \)

Some selected measurements:

- \( \eta \rightarrow e^+e^-e^+e^- \)
- \( \eta \rightarrow \pi^+\pi^-\gamma \)
- \( \eta' \rightarrow \pi^+\pi^-\eta \)
\[ \eta \rightarrow e^+e^-e^+e^- \]

**Theory:**

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

**Experimentally only upper limits**

- \( \text{BR} < 6.9 \times 10^{-5} \text{ CL90}\% \) CMD-2
- \( \text{BR} < 9.7 \times 10^{-5} \text{ CL90}\% \) CELSIUS/WASA

**Other details:**

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

\[ \text{BR}(\eta \rightarrow e^+e^-e^+e^-) = (2.4 \pm 0.2_{\text{stat}} \pm 0.1_{\text{syst}}) \times 10^{-5} \]

**Graph:**

- First Observation!
- \( N_{e_eeee} = 362 \pm 29 \)
- \( \gamma^* \rightarrow e^+e^- \)
- \( \gamma^* \rightarrow e^+e^- \gamma^* \)
- \( \gamma^* \rightarrow e^+e^- \gamma^* \)

**References:**

- C.Jarlskog and H.Pilkuhn, NPB1(1967)264-268
- PRD77:032004 (2008)
\( \eta \rightarrow \pi^+\pi^-\gamma \)

At chiral limit:

- Decay rate off by factor 2 from experiment!

Include FSI by unitarized extensions:
- momentum dependent VMD
- one loop corrections
- one loop + Omnes function
- Chiral Unitary Approach
- Hidden Local Symmetries

Observables: Branching ratio and \( m^2_{\pi\pi} / E_\gamma \) distribution

Previous Measurements

Branching Ratio
- recent CLEO measurement differs by > 3 \( \sigma \) from old results

\( m^2_{\pi\pi} / E_\gamma \) distribution:
- low in statistics
- not efficiency corrected
- ambiguous interpretation

new high precision measurement of both observables
$\eta \to \pi^+\pi^0\gamma$ : Signal Selection

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

\begin{align*}
E_\gamma &= \sqrt{s - E_{\pi^+} - E_{\pi^-} - E_{\phi}} \\
p_\gamma &= |\vec{p}_{\pi^+} + \vec{p}_{\pi^-} + \vec{p}_{\phi}| 
\end{align*}
\[ \eta \rightarrow \pi^+\pi^-\gamma : \text{Normalization Sample} \]

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

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

Preliminary (arXiv:1107.5733):

Consistent with CLEO result!  
$\eta \to \pi^+\pi^-\gamma : \text{ } m_{\pi^+\pi^-}$ Spectrum

- Simplest matrix element:
  \[ |A_\eta(s=0,t=0,u=0)|^2 \propto q^2 E^2_\gamma \sin^2 \theta \]

- 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.

- Form factor factorizes into
  \[ F(s_{\pi\pi}) = F_{PV} \cdot P(s_{\pi\pi}) \]

  - universal, non-perturbative part $F_{PV}$
    \[ F_{PV} = 1 + (2.12 \pm 0.01) s_{\pi\pi} + (2.13 \pm 0.01) s^2_{\pi\pi} + (13.80 \pm 0.14) s^3_{\pi\pi} \]

  - reaction specific, perturbative part $P(s_{\pi\pi})$
    \[ P(s_{\pi\pi}) = 1 + \alpha s_{\pi\pi} + O(s^2_{\pi\pi}) \]
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 \( \alpha \) by fit to spectrum:

\[
\chi^2 = \sum_i^{N_{\text{bin}}} \left( \frac{N_i^{\text{data}} - \sum_j^{N_{\text{bin}}} N_j^{\text{theo}} \varepsilon_j S_{ij}}{\sigma_{N_i^{\text{data}}}^2 + \sigma_{N_i^{\text{theo}}}^2} \right)^2
\]

**Preliminary Result:**

\[
\alpha = 1.32 \pm 0.08_{\text{stat}}^{+0.10}_{-0.09} \pm 0.02_{\text{theo}}
\]

In agreement with WASA-at-COSY result:

\[
\alpha = 1.89 \pm 0.25_{\text{stat}} \pm 0.59_{\text{syst}} \pm 0.02_{\text{theo}}
\]

Study $\eta$-$\pi$ interaction

- Quantum numbers favor scalar resonances

Test predictions of ChPT and extensions

\[ \eta' \rightarrow \pi^+\pi^-\eta \]

- Predictions differ on percent level high precision needed

\[ X = \frac{\sqrt{3}(T_{\pi^+} - T_{\pi^-})}{T_{\pi^+} + T_{\pi^-} + T_\eta} \]
\[ Y = \frac{m_\eta + 2m_{\pi^\pm}}{m_{\pi^\pm}} \cdot \frac{T_\eta}{T_{\pi^+} + T_{\pi^-} + 1} \]

$\alpha_0(980)$ I=1 dominance
Borasoy et al. EPJ A26 (2007) 383

$\text{LN}_c$-ChPT
Escribano et al. JHEP 1105 (2011) 094
\[ \eta' \rightarrow \pi^+ \pi^- \eta \]

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

Previous Measurements:

Dalitz plot projection

- $940 < \text{IM}(\pi\pi\eta)[\text{MeV}] < 980$
- Not background subtracted
- Not efficiency corrected

- MC: Phase space
  - Tuning needed

- Very good resolution in X and Y variables:
  - $\sigma(X),\sigma(y) = 0.02$
  - BES-III: $\sigma(X),\sigma(y) = 0.03$

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

Higher statistics and better acceptance at KLOE-2
Goal: **5 - 10 fb^{-1} in the next 3 years** to extend the KLOE physics program

**yy physics**
- Existence (and properties) of \( \sigma/f0(600) \)
- Study of \( \Gamma(S/PS \rightarrow \gamma\gamma) \)
- PS transition form factor

**Spectroscopy**
- Properties of scalar/vector mesons
- Rare \( \eta \) decays
- \( \eta' \) 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 \( (g-2) \)
Upgrade: DAΦNE

- New Collision Scheme
  - Larger beam crossing angles
  - Crab-waist sextupoles

- Increase in luminosity by factor 3
  - \( \int L \, dt \approx 1\text{pb}^{-1}/\text{h} \)

- First collisions in 2010
- Long shut down times due to severe hardware failures
- DAΦNE commissioning started in November 2011
KLOE-2: New Detectors

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

Small angle calorimeters
- Increase $\gamma$ acceptance ($>21^\circ \rightarrow >10^\circ$)

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

To be finalized this fall!
Summary

- High statistics samples of light mesons produced at KLOE
  - Perform precision measurements
    - $\eta \rightarrow \pi^+\pi^-\gamma$
  - Study very rare decays
    - $\eta \rightarrow e^+e^-e^+e^-$

- 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