Frascati, June 7, 2010

The KLOE-2 project
• Status Report on KLOE/2 at DAΦNE
• The most recent physics result
• The KLOE-2 programme
• Conclusions
KLOE data taking

- A total of 2.5 fb\(^{-1}\) of integrated luminosity at the \(\phi\) peak collected
- About 250 pb\(^{-1}\) collected at 1 GeV for physics in the continuum

Integrated luminosity:
- 2005: 1256 pb\(^{-1}\)
- 2004: 734 pb\(^{-1}\)
- 2002: 320 pb\(^{-1}\)
- 2001: 172 pb\(^{-1}\)
A new collision scheme worked out with
- large crossing angle
- reduced beam size at the crossing point
- sextupole pairs for crab-waist configuration of beam interaction

A factor of 3 in the peak luminosity achieved with the same circulating currents as in the past
Works at DA$\Phi$NE for the run with KLOE-2

Performance still limited in November 2009 by:
- maximum positron current
- beam lifetime
- hardware reliability

<table>
<thead>
<tr>
<th>DA$\Phi$NE upgrade</th>
<th>DA$\Phi$NE</th>
<th>DA$\Phi$NE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIDDIHARTA</td>
<td>FINUDA</td>
<td>KLOE</td>
</tr>
<tr>
<td>$L_{\text{peak}}$ [cm$^{-2}$s$^{-1}$]</td>
<td>$4.53 \times 10^{32}$</td>
<td>$1.5 \times 10^{32}$</td>
</tr>
<tr>
<td>$L_{\text{day}}$ [pb$^{-1}$]</td>
<td>14.98</td>
<td>9.8</td>
</tr>
<tr>
<td>$L_{\text{1 hour}}$ [pb$^{-1}$]</td>
<td>1.033</td>
<td>0.44</td>
</tr>
<tr>
<td>$I_{\text{MAX in collision}}$ [A]</td>
<td>1.52</td>
<td>1.4</td>
</tr>
<tr>
<td>$I^+_{\text{MAX in collision}}$ [A]</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>$N_{\text{bunches}}$</td>
<td>105</td>
<td>111</td>
</tr>
</tbody>
</table>

The first run of the upgraded DA$\Phi$NE was ended in November 2009

Interaction region revised for the compensation of the KLOE magnetic field

Several maintenance and upgrade works done to overcome the collider limitations

- clearing electrodes installed in the positron machines to prevent electron-cloud formation
- LINAC: new positron gun, new accelerating section to be installed in September
- Other elements modified: wiggler, kickers, control system, cryogenic plant, scrapers

Status Report on DAFNE upgrade at EuCARD, April 2010

C. Milardi, EuCARD 1st ANNUAL MEETING, 13-16 April 2010 RAL, Oxfordshire-UK

Status Report on DAFNE upgrade at EuCARD, April 2010
Project status and planning

- The machine commissioning starts by the end of June
- Three-months period scheduled for major tuning of the operation
- Data taking planning as a function of the measured performance
- Upgrade of the LINAC by the end of 2010
- Upgrade of the KLOE detector by the end of 2011
The taggers for $\gamma\gamma$ physics

Detector upgrade for first KLOE-2 run ($\approx 5$ fb$^{-1}$ in 1 year):
2+2 detector stations for leptons in $e^+e^-\rightarrow e^+e^*\gamma^*\rightarrow e^+e^-X$

**LET:**
*Inside KLOE detector*
*LYSO+SiPM*
*\(\sigma_E < 10\% \text{ for } E > 150 \text{ MeV}\)*

**HET:**
*11 m from IP*
*Scintillators + PMTs*
*\(\sigma_E \sim 2.5 \text{ MeV}\)*
*\(\sigma_T \sim 200 \text{ ps}\)*

\[\text{LET: } E_L = 160-230 \text{ MeV}\]

\[\text{HET: } E_H > 400 \text{ MeV}\]
Detector upgrades

Major detector upgrades (late 2011) for second KLOE-2 run:

**INNER TRACKER**
- 4 layers of cylindrical triple GEM
- Better vertex reconstruction near IP
- Larger acceptance for low $p_t$ tracks

**QCALT**
- $W$ + scintillator tiles + SiPM/WLS
- QUADS instrumentation for $K_L$ decays

**CCAL**
- LYSO + APD
- Increase acceptance for $\gamma$’s from IP ($21^\circ \rightarrow 10^\circ$)
Physics issues

KLOE published several results mostly contributing to

- **SM test in the flavor sector** through precise measurements of
  \[ V_{us} \]
  \[ \text{BR}(K \rightarrow e\nu)/\text{BR}(K \rightarrow \mu\nu) \]

- **CPT and quantum mechanics tests** with the analysis of the
  interference pattern of neutral kaons
  \( K_s \) semileptonic decays
  unitary (Bell-Steinberger) relation

- low-energy QCD

- the study of the light scalar sector

- precision measurement of the di-pion cross section for the calculation of the hadronic contribution to the muon anomaly

\[
\begin{align*}
\text{Re}(\epsilon) &= (159.6 \pm 1.3) \times 10^{-5} \\
\text{Im}(\delta) &= (0.4 \pm 2.1) \times 10^{-5}
\end{align*}
\]
Recent publications

A Global fit to determine the pseudoscalar mixing angle and the gluonium content of the eta-prime meson
Study of the a(0)(980) meson via the radiative decay phi ---> eta pi0 gamma with ...
Measurement of $\sigma(e^+e^- \rightarrow \pi^+\pi^- \gamma (\gamma))$ and the dipion contribution to the muon anomaly...
Search for the K(S) ---> e^+e^- decay with the KLOE detector
Precise measurement of $\Gamma(K \rightarrow e \nu (\gamma)) / \Gamma(K \rightarrow \mu \nu (\gamma))$ and study of $K \rightarrow e \nu \gamma$
Search for the decay phi ---> K0 anti-K0 gamma with the KLOE experiment
Technical Design Report of the Inner Tracker for the KLOE-2 experiment
Technical Design Report of the $\gamma\gamma$ tagger system for the KLOE-2 experiment

Submitted:

Physics with the KLOE-2 experiment at the upgraded DAφNE
Measurement of the $\eta \rightarrow \pi^0 \pi^0 \pi^0$ slope parameter $\alpha$ with the KLOE detector

JHEP 0907:105, 2009
PLB 681:5, 2009
PLB 670:285, 2009
PLB 672:203, 2009
EPJ C64:627, 2009
PLB 679:10, 2009
arXiv:1002.2572
LNF:10-14(P)

arXiv:1003.3868
arXiv:1004.1319
Furthermore...

Paper under review from KLOE referees:

Ks lifetime
Measurement of the pion form factor for $M^2(\pi\pi)$ between 0.1 and 0.85 GeV$^2$ with the KLOE detector  
\texttt{arXiv:0912.2205}

Ongoing analysis

Update of the results on interferometry
Measurement of the pion form factor for $M^2(\pi\pi)$ by $\mu\mu(\gamma)$ normalization
Klong lifetime
BR($K^\pm \rightarrow \pi^\pm \pi^+\pi^-$) with the update of all BR's
Ks semileptonic decays
$\eta \rightarrow e^+ e^- e^+ e^-$
$\eta \rightarrow \pi^+ \pi^- \gamma$
$e^+ e^- \rightarrow e^+ e^- \eta$, $e^+ e^- \rightarrow e^+ e^- \pi^0 \pi^0$
The KLOE-2 physics programme

- The programme, discussed in arXiv:1003.3868 (to be published by EPJC) include the improvement of several KLOE measurements and
  - the study of $\gamma-\gamma$ physics based on a sample tagged by a new system for the detection of $e^\pm$ from the process $e^+e^- \rightarrow e^+e^- X$
  - the search for particles from an hidden sector which could explain the dark matter problem
  - precise measurements of the hadronic cross section near threshold and if the upgrade in energy of the collider is approved in the region from 1.02-2.3 GeV

- List of topics include
  - CKM unitarity and lepton universality
  - CPT symmetry and Quantum Mechanics
  - Low-energy QCD
  - Physics in the continuum: $\sigma_{\text{had}}$
  - Physics in the continuum: $\gamma-\gamma$ processes
  - Hidden WIMP dark matter
CKM unitarity

- CKM unitarity as stated in the SM implies the universality of the couplings of quark and leptons through the assumption $G_{ij} = G_\mu V_{ij}$ where $\sum_j |V_{ij}|^2 = 1$
- Universality relations: $G_{ij}$ independent from lepton flavor
- New physics contributions through precision measurements of $V_{us}$
- KLOE performed a comprehensive, consistent set of measurements: BR's, lifetimes, form factor dependence on $Q^2$

$$|V_{us}| \times f_+(0) = 0.2163(5) \text{ from KLOE}$$

<table>
<thead>
<tr>
<th>$K_L e3$</th>
<th>$K_L \mu3$</th>
<th>$K_S e3$</th>
<th>$K^\pm e3$</th>
<th>$K^\pm \mu3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2163(6)</td>
<td>0.2166(6)</td>
<td>0.2155(13)</td>
<td>0.2160(11)</td>
<td>0.2158(14)</td>
</tr>
</tbody>
</table>

- As a result
  $$g_\mu^2/g_e^2 = r_{\mu e} = 1.002(5)$$
- For comparison: $(r_{\mu e})_\pi = 1.0042(33)$; $(r_{\mu e})_\tau = 1.000(4)$
CKM unitarity

- $G_{CKM}$ is also obtained from $K_{\mu 2}$ decays

$$\frac{\Gamma(K_{\mu 2(\gamma)})}{\Gamma(\pi_{\mu 2(\gamma)})} = \frac{|V_{us}|^2}{|V_{ud}|^2} \times \frac{f_K^2}{f_\pi^2} \times \frac{M_K(1-m_\mu^2/M_K^2)^2}{m_\pi(1-m_\mu^2/m_\pi^2)^2} \times 1+\alpha(C_K-C_\pi)$$

- As a result
  $$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$
  is verified at the $6 \times 10^{-4}$ level
CKM unitarity

• New-physics contributions in the effective Lagrangian of the order $v^2 / \Lambda^2$
• Strong constraints from FCNC
  → new physics encoded by shifts of both $G^\mu$ and $G^\text{semil}$
  $$G^\text{CKM} = G^\mu (|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2)^{1/2} = G^\mu (1 + \Delta^\text{semil} - \Delta^\mu)$$
  leading to a unitarity-violating term $\Delta^\text{CKM}$
  $$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 + \Delta^\text{CKM}$$
• Precision electroweak tests constrains $\Delta^\text{CKM}$ to $-9.5 \times 10^{-3} < \Delta^\text{CKM} < 10^{-4}$
• From leptonic and semileptonic kaon decays $\Delta^\text{CKM} = -0.0001(6)$
  → a probe of the 10 TeV scale
CKM unitarity and lepton universality

• New-physics could affect the helicity-suppressed kaon decays only
  - $V_{us}$ from semileptonic decays as expected in the SM
  - $V_{us}$ from leptonic decays smaller than expected

• $R_{\mu 23}$ is used to constrain Higgs-mediated scalar currents

$$R_{\mu 23} = \frac{f_+(0)}{f_k / f_\pi} \left( \frac{V_{us}}{V_{ud}} \right) \left( \frac{f_k}{f_\pi} \right)_{\mu 2} \frac{|V_{ud}|_{0^+ \rightarrow 0^+}}{|V_{us}| f_+(0)} \approx \left| 1 - \frac{m_k^2}{m_{H^0}^2} \frac{\tan^2 \beta}{1 + \varepsilon_0 \tan \beta} \right|$$
To improve on this field both, LQCD calculations, and experimental accuracy must be improved

KLOE-2 measurements: semileptonic BR’s and lifetimes

<table>
<thead>
<tr>
<th></th>
<th>%err</th>
<th>BR</th>
<th>τ</th>
<th>δ</th>
<th>I_{Kl}</th>
<th>%err</th>
<th>BR</th>
<th>τ</th>
<th>δ</th>
<th>I_{Kl}</th>
</tr>
</thead>
<tbody>
<tr>
<td>K_{e3}</td>
<td>0.2163(6)</td>
<td>0.28</td>
<td>0.09</td>
<td>0.19</td>
<td>0.15</td>
<td>0.09</td>
<td>0.24</td>
<td>0.09</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>K_{\mu3}</td>
<td>0.2168(7)</td>
<td>0.30</td>
<td>0.10</td>
<td>0.18</td>
<td>0.15</td>
<td>0.15</td>
<td>0.27</td>
<td>0.10</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>K_{e3}</td>
<td>0.2154(13)</td>
<td>0.67</td>
<td>0.65</td>
<td>0.03</td>
<td>0.15</td>
<td>0.09</td>
<td>0.35</td>
<td>0.30</td>
<td>0.03</td>
<td>0.15</td>
</tr>
<tr>
<td>K_{e3}</td>
<td>0.2173(8)</td>
<td>0.39</td>
<td>0.26</td>
<td>0.09</td>
<td>0.26</td>
<td>0.09</td>
<td>0.38</td>
<td>0.25</td>
<td>0.05</td>
<td>0.26</td>
</tr>
<tr>
<td>K_{\mu3}</td>
<td>0.2176(11)</td>
<td>0.51</td>
<td>0.40</td>
<td>0.09</td>
<td>0.26</td>
<td>0.15</td>
<td>0.41</td>
<td>0.27</td>
<td>0.05</td>
<td>0.26</td>
</tr>
<tr>
<td>Aver</td>
<td>0.2166(5)</td>
<td>0.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
LQCD calculations

- From the dispersion parametrization of the $f_{f_f}$ dependence from momentum transfer, based on analyticity constraints and CT theorem experimental measurement of the ratio $f_{K}/f_{\pi}/f_{+}(0) = 1.225(14)$
CPT symmetry and QM

- The study of interference with neutral kaon pairs at the \( \phi \)-factory is a probe of CPT symmetry and QM at the Planck scale
- The sensitivity and variety of the interference phenomena for the unique, special circumstance
  \[ \Delta M \sim \frac{1}{2} \Gamma_s \]
- With KLOE-2 we plan to improve on the vertex resolution with an inner tracker, realized with
- The GEM technology chosen for the super-light material
- The vertex resolution is expected to improve by a factor of 3 in the region of interest

\[
I(\pi^+\pi^-, \pi^+\pi^-; \Delta t) \propto e^{-\Gamma_L\Delta t} + e^{-\Gamma_s\Delta t} - 2e^{-\frac{(\Gamma_s + \Gamma_L)}{2}\Delta t} \cos(\Delta m\Delta t),
\]
Table 2: Material budget for a CGEM layer detector (active area)

<table>
<thead>
<tr>
<th>Component</th>
<th>times</th>
<th>material ($X_0$)</th>
<th>quantity</th>
<th>% of $X_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 GEMs</td>
<td></td>
<td>Copper: $3 \times 2\mu m$ Cu ($X_0=14.3 mm \times 0.8$)</td>
<td></td>
<td>0.067</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kapton: $3 \times 50\mu m$ kapton ($X_0=286 mm \times 0.8$)</td>
<td></td>
<td>0.042</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total:</td>
<td></td>
<td>0.109</td>
</tr>
<tr>
<td>1 Cathode</td>
<td></td>
<td>Copper: $1 \times 2\mu m$ Cu</td>
<td>$X_0$</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kapton: $1 \times 50\mu m$ kapton</td>
<td>$X_0$</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total:</td>
<td></td>
<td>0.030</td>
</tr>
<tr>
<td>1 Readout</td>
<td></td>
<td>Copper: $1 \times 2\mu m$ Cu</td>
<td>$X_0=0.95$</td>
<td>0.013</td>
</tr>
<tr>
<td>anode</td>
<td></td>
<td>Kapton: $2 \times 50\mu m$ kapton</td>
<td>$X_0$</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total:</td>
<td></td>
<td>0.047</td>
</tr>
<tr>
<td>1 Shielding</td>
<td></td>
<td>Aluminum: $1 \times 10\mu m$ Al ($X_0=89 mm \times 1$)</td>
<td></td>
<td>Total: 0.011</td>
</tr>
<tr>
<td>1 Honeycomb</td>
<td></td>
<td>NOMEX: $1 \times 3$mm Nomex ($X_0=1.3125 mm \times 1$)</td>
<td></td>
<td>Total: 0.023</td>
</tr>
<tr>
<td>2 CF skins</td>
<td></td>
<td>CF: $2 \times 250\mu m$ CF ($X_0=250 mm \times 1$)</td>
<td></td>
<td>Total: 0.160</td>
</tr>
</tbody>
</table>

Total: 0.380
From KLOE to KLOE-2

- Decoherence (loss of total entanglement between kaons) can be traced back to modifications in QM.
- CPT violation at the Planck scale from Quantum Gravity.
- Sensitivity limited by statistics.
- Improvements in the vertex resolution from $1 \rightarrow 0.3 \tau_s$ equivalent to a factor of 3-4 in statistics.

<table>
<thead>
<tr>
<th>$\gamma$</th>
<th>$\tau$</th>
<th>Parameter</th>
<th>Present best measurement</th>
<th>KLOE-2 (25 fb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_\tau \rightarrow \pi e\nu$</td>
<td>$A_L$</td>
<td>$\Delta m$</td>
<td>$5.288 \pm 0.043 \times 10^{-5} \text{s}^{-1}$</td>
<td>$\pm 0.05 \times 10^{-5} \text{s}^{-1}$</td>
</tr>
<tr>
<td>$\pi^- \pi^- \rightarrow \pi^- \pi^-$</td>
<td>$\beta$</td>
<td>$\gamma$</td>
<td>$1.1 \pm 0.3 \times 10^{-24} \text{GeV}$</td>
<td>$\pm 0.3 \times 10^{-24} \text{GeV}$</td>
</tr>
<tr>
<td>$\pi^- \pi^- \rightarrow \pi^- \pi^-$</td>
<td>$\alpha$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- From $\pi^- \pi^-$ to $\pi^- \pi^-$, $\Delta m$ can be measured with precision.
- Improvements in vertex resolution lead to better statistics.

- The $K_{\ell 3}$ channel is also explored for $\Delta m$ measurements.
Low-energy QCD

- Kaon and $\eta$ decays in a clean environment
- The only experiment with $K_s$ pure beams
- KLOE-2 can study kaon channels with BR's to $10^{-9}$
- Rare $K_s$ decays: $K_s \rightarrow 3 \pi, \gamma\gamma, \pi^0\gamma\gamma, \pi^0 l^+l^-, \pi^+\pi^-\gamma, \pi^+\pi^-e^+e^-$
- $\eta$ decays: $\pi^0\gamma\gamma, \pi^+\pi^-e^+e^-, ee\epsilon\epsilon$
- $\eta'$ decays: improvement of the BR's to 1%
- $\phi \rightarrow \eta e\epsilon, \eta \mu\mu$ interesting also for the dark-force searches
- $\phi \rightarrow K_s K_s \gamma$

\[ BR(K_s \rightarrow \gamma\gamma) \]
2 small barrels of 24 crystals each with length 10-13 cm and transversal area from 1.5x1.5cm$^2$ to 2x2cm$^2$

The angular acceptance is extended to $10^\circ$

Ks $\rightarrow \gamma\gamma$

with CCAL

Ks $\rightarrow \pi^0\pi^0$

w/o CCAL

Dodecagonal Barrel

Crystal

1.8-2.2 cm

10-13 cm
KLOE: global fit result

KLOE-2 expectation measuring $\eta'$ BRs with 1% accuracy

Sensitivity to the gluonium also without the $\eta' \rightarrow \gamma\gamma$ decay
η - η' - G mixing: from KLOE to KLOE-2

KLOE: global fit result

KLOE-2 expectation measuring also η' width with 1.4% accuracy

Run at $\sqrt{s} \geq 1.2$ GeV required
Physics in the continuum: hadronic cross-section

Hadronic cross section at low energy to obtain hadronic contributions to $(g-2)_\mu$

\[ \alpha(M_Z) \]

Independent measurements of $\pi\pi\gamma$ cross section with
- small-angle photons
- large-angle photons and $s = 1 \text{ GeV}^2$ to avoid the badly-known scalar contributions
- with $\pi\pi\gamma$ normalization to $\mu\mu\gamma$ event

Di-pion cross section as a functions of $s$ using ISR events and the radiator function $H(s,s')$
KLOE results

- The most recent result with photons at large angle are from $s = 0.1 \text{ GeV}^2$ very near the dipion threshold
- Results consistent with the analysis of events with photons at small angle
Comparison with BaBar

Agreement within errors below 0.6 GeV; BaBar higher by 2-3% above
Normalization to $\mu\mu\gamma$

- The measurement does not depend from corrections for vacuum polarization and from the luminosity measurement.
- The analysis is well advanced: preliminary results in Summer.

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

$m_\mu$-ID in the $\rho$ region to be carefully controlled.
The results on $(g-2)_\mu$

KLOE-2 results with photons at large angle not included yet

The 2% discrepancy with BaBar above the $\rho$ peak to be investigated

Next KLOE results with the sample normalized to $\mu\mu\gamma$ can give an answer

Improvement by a factor of 2 in $a_\mu^{HLO}$ calls for both, improvements of the di-pion cross section near threshold, and the multi-hadronic cross section in the [1-2.5] GeV region
A reduction of the uncertainty on $\sigma_{\text{had}} @ (1 < \sqrt{s} < 2) \text{ GeV}$ from 5% to 1% needed to have

$$\frac{\Delta \alpha_{\text{em}}(M_Z)}{\alpha_{\text{em}}(M_Z)} \sim (1-4) \times 10^{-4}$$

Significant source of uncertainty (given the precision reached on other e.w. fundamental couplings)

$$\frac{\delta G_{\mu}}{G_{\mu}} \sim 8.6 \times 10^{-6}$$

$$\frac{\delta M_Z}{M_Z} \sim 2.4 \times 10^{-5}$$

While $\alpha_{\text{em}}(m_e)$ is known with an incredible precision [$\sim 3 \times 10^{-9}$], the error on $\alpha_{\text{em}}(M_Z)$ - the effective coupling relevant at the electroweak scale - is much larger because of hadronic uncertainties.
Data taking proposal at KLOE-2

The 0.7% uncertainty in $\sigma_{\text{had}}$ at $\sqrt{s} < 1$ GeV can be reduced to 0.4% with $O(fb^{-1})$ off-peak integrated luminosity at DAFNE.

Reduction of the uncertainty on $\sigma_{\text{had}}$ @ $(1 < \sqrt{s} < 2)$ GeV from 5% to 2% is also needed to have $\delta a_{\mu,\text{had,LO}}$ and $\delta a_{\mu,\text{SM}} \approx 4.2 \times 10^{-10}$.

Di-pion production threshold:
Run at $s \leq 1$ GeV$^2$

Direct scan above 1 GeV with DAΦNE upgrade in energy.
Physics in the continuum: $\gamma\gamma$ physics

Meson $\gamma\gamma$ widths

Pseudoscalar FF and contribution to LbL

Scalar study via $\pi\pi$ spectrum

$L_{\text{int}} = 1 \text{ fb}^{-1}$

<table>
<thead>
<tr>
<th>$\sqrt{s}$ (GeV)</th>
<th>$\pi^0$</th>
<th>$\eta$</th>
<th>$\eta'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.02</td>
<td>$4.1 \times 10^5$</td>
<td>$1.2 \times 10^5$</td>
<td>$1.9 \times 10^4$</td>
</tr>
<tr>
<td>2.4</td>
<td>$7.3 \times 10^5$</td>
<td>$3.7 \times 10^5$</td>
<td>$3.6 \times 10^5$</td>
</tr>
</tbody>
</table>
Pseudoscalar $f f$ and LbL

$\gamma \gamma \rightarrow P \quad \Rightarrow \quad F(P^2,q^2,0)$

Tagged sample needed for background reduction.

Ongoing studies at KLOE on the off-peak sample.

Studies with EKHARA Monte Carlo generator

$(e^+e^- \rightarrow e^+e^-\pi^0$ added in a new version)

<table>
<thead>
<tr>
<th>Tag</th>
<th>Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0 \rightarrow KLOE$</td>
<td>(KLOE)</td>
</tr>
<tr>
<td>$e^+ \rightarrow HET$</td>
<td>(HET)</td>
</tr>
<tr>
<td>$e^- \rightarrow HET$</td>
<td>(HET)</td>
</tr>
<tr>
<td>$\pi^0 \rightarrow KLOE$</td>
<td>(KLOE)</td>
</tr>
<tr>
<td>$e^+ \rightarrow LET$</td>
<td>(LET)</td>
</tr>
<tr>
<td>$e^- \rightarrow KLOE$</td>
<td>(KLOE)</td>
</tr>
</tbody>
</table>

Preliminary

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- Sergiy Ivashyn (Katowice, Kharkov)

http://prac.us.edu.pl/~ekhara
Fit to $p_L$ and $M_{\text{miss}}^2$ with signal and background shapes

$\sim 600$ signal events

$\chi^2_{\text{fit}} / \text{d.o.f.} = 75.9/83$

$\chi^2_{\text{fit}} / \text{d.o.f.} = 59.8/43$

- Extraction of $\sigma(e^+e^- \rightarrow e^+e^-\eta)$ and $\Gamma_{\gamma\gamma}$ in progress
- Statistical accuracy on $\Gamma_{\gamma\gamma}$ comparable with existing measurements
Dark forces

Recent puzzling astrophysical observations (PAMELA, ATIC, INTEGRAL, DAMA) can be interpreted by postulating the existence of some secluded gauge sector with at least one low ($\mathcal{O}(1 \text{ GeV})$) mass force mediator ("$U'$ boson")

The secluded sector can be used to explain the dark matter puzzle. Hence the nickname of "dark forces"

Standard Model particles are weakly coupled with the secluded ones through a kinetic mixing mechanism with a strength $\varepsilon$ that can be of order up to $10^{-2} - 10^{-3}$

The cross sections of these processes scale typically as $1/s$, thus their observation at lower energy colliders is in principle favourite wrt higher energies ones, as long as kinematically allowed.
Processes to search for

"Dark photon" (U boson) resonant production in $e^+e^- \rightarrow \ell^+\ell^- \gamma$ events

"Higgs'-strahlung" in $e^+e^- \rightarrow \ell^+\ell^- + \text{missing energy events}

On shell $U$ boson production
Radiative decay channels with one photon replaced by one $U$ meson and $\text{BR} \sim \varepsilon^2 \text{BR}(\rightarrow \gamma X)$

For $\text{BR}(\rightarrow \gamma X) \sim 10^{-2}$, $\sim 10^9$ mesons are needed to reach a sensitivity to $\varepsilon \sim 10^{-3}$

At DAFNE $3 \times 10^9 \phi / \text{fb}^{-1}$ are produced. The channel to look at is $\Phi \rightarrow \eta U$

The $\eta$ meson can be identified through its $3\pi$ or $\gamma \gamma$ decays

A study on the potentials of KLOE, using present statistics, was done by Reece and Wang (arXiv:0904.1743)

The conclusion of the work is that KLOE(2) can be sensitive to mixing parameters down to $\varepsilon \sim 10^{-3}$
U-boson associated to $\eta$ decays

Reece and Wang  \textit{arXiv:0904.1743}

<table>
<thead>
<tr>
<th>$X \rightarrow YU$</th>
<th>$n_X$</th>
<th>$m_X - m_Y$ (MeV)</th>
<th>$\text{BR}(X \rightarrow Y + \gamma)$</th>
<th>$\text{BR}(X \rightarrow Y + \ell^+\ell^-)$</th>
<th>$\epsilon \leq$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta \rightarrow \gamma U$</td>
<td>$n_\eta \sim 10^7$</td>
<td>547</td>
<td>$2 \times 39.8%$</td>
<td>$6 \times 10^{-4}$</td>
<td>$2 \times 10^{-3}$</td>
</tr>
<tr>
<td>$\omega \rightarrow \pi^0 U$</td>
<td>$n_\omega \sim 10^7$</td>
<td>648</td>
<td>8.9%</td>
<td>$7.7 \times 10^{-4}$</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>$\phi \rightarrow \eta U$</td>
<td>$n_\phi \sim 10^{10}$</td>
<td>472</td>
<td>1.3%</td>
<td>$1.15 \times 10^{-4}$</td>
<td>$1 \times 10^{-3}$</td>
</tr>
<tr>
<td>$K_L^0 \rightarrow \gamma U$</td>
<td>$n_{K_L^0} \sim 10^{11}$</td>
<td>497</td>
<td>$2 \times (5.5 \times 10^{-4})$</td>
<td>$9.5 \times 10^{-6}$</td>
<td>$2 \times 10^{-3}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \pi^+ U$</td>
<td>$n_{K^+} \sim 10^{10}$</td>
<td>354</td>
<td>-</td>
<td>$2.88 \times 10^{-7}$</td>
<td>$7 \times 10^{-3}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow \mu^+\nu U$</td>
<td>$n_{K^+} \sim 10^{10}$</td>
<td>392</td>
<td>$6.2 \times 10^{-3}$</td>
<td>$7 \times 10^{-8}$</td>
<td>$2 \times 10^{-3}$</td>
</tr>
<tr>
<td>$K^+ \rightarrow e^+\nu U$</td>
<td>$n_{K^+} \sim 10^{10}$</td>
<td>496</td>
<td>$1.5 \times 10^{-5}$</td>
<td>$2.5 \times 10^{-8}$</td>
<td>$7 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

Ongoing analysis on KLOE data
First milestones at KLOE-2

- The KLOE-2 analysis board worked out the milestone to focus the efforts of the collaboration

- $\gamma\gamma$ physics: measurement of the acceptance vs $Q^2$
- $\phi \to \eta e^+ e^-$: measurement of the form factor
- $\eta' \to \eta \pi^+ \pi^-$: measurement of the $M_{\pi\pi}$ distribution
- $\phi \to K_s K_s \gamma$: improved upper limit, first evidence of the decay

- Exclusion plot for $e^+ e^- \to U \gamma \to l^+ l^-\gamma$,
  $e^+ e^- \to \eta U \to \eta l^+ l^-$
  $e^+ e^- \to h \gamma \to X_{\text{Miss}} l^+ l^-$

- $K_s \to \pi^0 \pi^0 \pi^0$
- $K_s K_s \to \pi^0 \pi^0 \pi^+ \pi^-$ Measurement of $\text{Im}(\varepsilon'/\varepsilon)$
Conclusions

- KLOE has been able to address many topics of fundamental physics with precision measurements in kaon physics, $\eta/\eta'$ decays, low-mass scalars, and hadronic cross section.
- The physics programme will continue at KLOE-2 which is ready for data taking at the upgraded DAΦNE.

- Machine commissioning by the end of June
- A tagger system for $\gamma\gamma$ events has been installed
- The construction of the
  - inner tracker for improving on vertex reconstruction at the IR and
  - calorimeters to instrument the quadrupole region and to detect small-angle photons

has been started to be ready for installation by September, 2011.
Spares
CMD2 2007:
361.5 ± 1.7_{STAT} ± 2.9_{SYST}

SND 2006:
361.0 ± 2.0_{STAT} ± 4.7_{SYST}

KLOE 2008:
356.7 ± 0.4_{STAT} ± 3.0_{SYST}

\(a_{\mu} \pi (0.630 - 0.958 \text{ GeV}) \times 10^{-10}\)
**Hadronic contribution to $(g-2)_\mu$**

\[ \Delta a_\mu^{\text{had}}(0.35-0.85 \text{GeV}^2): \]

- **KLOE08 (small angle)**
  \[ a_\mu^{\text{had}} = (379.6 \pm 0.4_{\text{stat}} \pm 2.4_{\text{sys}} \pm 2.2_{\text{theo}}) \cdot 10^{-10} \]

- **KLOE09 (large angle)**
  \[ a_\mu^{\text{had}} = (376.6 \pm 0.9_{\text{stat}} \pm 2.4_{\text{sys}} \pm 2.1_{\text{theo}}) \cdot 10^{-10} \]

\[ \Delta a_\mu^{\text{had}}(0.152-0.270 \text{GeV}^2): \]

- **KLOE09 (large angle)**
  \[ a_\mu^{\text{had}} = (48.1 \pm 1.2_{\text{stat}} \pm 1.2_{\text{sys}} \pm 0.4_{\text{theo}}) \cdot 10^{-10} \]

- **CMD-2**
  \[ a_\mu^{\text{had}} = (46.2 \pm 1.0_{\text{stat}} \pm 0.3_{\text{sys}}) \cdot 10^{-10} \]

\[ \Delta a_\mu^{\text{had}}(0.397-0.918 \text{GeV}^2): \]

- **KLOE08 (small angle)**
  \[ a_\mu^{\text{had}} = (356.7 \pm 0.4_{\text{stat}} \pm 3.1_{\text{sys}}) \cdot 10^{-10} \]

- **CMD-2**
  \[ a_\mu^{\text{had}} = (361.5 \pm 1.7_{\text{stat}} \pm 2.9_{\text{sys}}) \cdot 10^{-10} \]

- **SND**
  \[ a_\mu^{\text{had}} = (361.0 \pm 2.0_{\text{stat}} \pm 4.7_{\text{sys}}) \cdot 10^{-10} \]

- **BaBar**
  \[ a_\mu^{\text{had}} = (365.2 \pm 1.9_{\text{stat}} \pm 1.9_{\text{sys}}) \cdot 10^{-10} \]
Cross section

On shell $U$ boson production

Multilepton events
\[ R_\phi = \frac{BR(\phi \rightarrow \eta'\gamma)}{BR(\phi \rightarrow \eta\gamma)} = (4.77 \pm 0.09_{stat} \pm 0.19_{syst}) \times 10^{-3} \]

Gluonium content in \( \eta' \) evaluated using Rosner model:

\[ |\eta'\rangle = \frac{1}{\sqrt{2}} \left[ uu + dd \right] + Y_{\eta'} |s\bar{s}\rangle + Z_{\eta'} |\text{glue}\rangle \]

\[ |\eta\rangle = \cos \phi_p \frac{1}{\sqrt{2}} \left[ uu + dd \right] - \sin \phi_p |s\bar{s}\rangle \]

\[ X_{\eta'} = \cos \phi_G \sin \phi_p \]

\[ Y_{\eta'} = \cos \phi_G \cos \phi_p \]

\[ Z_{\eta'} = \sin \phi_G \]

SU(3) relations between decay modes:

Gluonium content extracted using \( Z_N, Z_{NS} \) evaluated assuming \( Z^2_{\eta} = 0 \):

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

[Brannon et al., EPJC 7 (1999) ; PLB 503 (2001)]

\[ \phi_p = (39.7 \pm 0.7)^\circ \]

\[ Z^2_{\eta'} = 0.14 \pm 0.04 \]

\[ P(\chi^2) = 49\% \]
Global fit with more free parameters (also $Z_N$, $Z_{NS}$, $\phi_V$, $m_s/m$)

Other SU(3) relations:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Old fit</th>
<th>New fit</th>
<th>New fit (no $P_{\gamma\gamma}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Z_{\eta_0}$</td>
<td>$0.14 \pm 0.04$</td>
<td>$0.105 \pm 0.037$</td>
<td>$0.03 \pm 0.06$</td>
</tr>
<tr>
<td>$\phi_\Pi$</td>
<td>$(39.7 \pm 0.7) ^\circ$</td>
<td>$(40.7 \pm 0.7) ^\circ$</td>
<td>$(41.6 \pm 0.8) ^\circ$</td>
</tr>
<tr>
<td>$Z_{\eta_S}$</td>
<td>$0.91 \pm 0.05$</td>
<td>$0.866 \pm 0.025$</td>
<td>$0.85 \pm 0.03$</td>
</tr>
<tr>
<td>$Z_\Sigma$</td>
<td>$0.89 \pm 0.07$</td>
<td>$0.79 \pm 0.05$</td>
<td>$0.78 \pm 0.05$</td>
</tr>
<tr>
<td>$\phi_\Sigma$</td>
<td>$3.2 ^\circ$</td>
<td>$(3.15 \pm 0.10) ^\circ$</td>
<td>$(3.16 \pm 0.10) ^\circ$</td>
</tr>
<tr>
<td>$m_s/m$</td>
<td>$1.24 \pm 0.07$</td>
<td>$1.24 \pm 0.07$</td>
<td>$1.24 \pm 0.07$</td>
</tr>
<tr>
<td>$P(\chi^2)$</td>
<td>$49%$</td>
<td>$17%$</td>
<td>$40.7%$</td>
</tr>
</tbody>
</table>

- Gluonium content @ ~3σ level confirmed
- Forcing $Z_\eta = 0$ : $\phi_P = (41.6 \pm 0.5) ^\circ$ with $P(\chi^2) = 1\%$
- Discrepancy with Escribano-Nadal ($Z_\eta = 0.04 \pm 0.09$, $\phi_P = (41.4 \pm 1.3) ^\circ$) due to $P_{\gamma\gamma}$ transitions
Gluonium content of the $\eta'$ obtained from the KLOE measurements of $\phi$ radiative decays into $\eta$-$\eta'$ (but not only ...)

A recent work, by Chen et al., PRD79:014024(2009), obtains from the KLOE result, a glueball mass of $1.4\pm0.1$ GeV

somewhat in contrast with the glueball mass from improved staggered fermions confirming the results of ... calculations of $M_G>2.1$ GeV
Long debate about the experimental evidence of the $\sigma(600)$ meson
Evidence for $\pi^+\pi^-$ bound state (E791, CLEO, BES) from Dalitz plot analyses
Values of mass and width with large uncertainties
Indirect evidence in the $e^+e^-\rightarrow\pi^0\pi^0\gamma$ Dalitz plot analysis @ KLOE

Only process to measure directly the $\sigma\gamma\gamma$ coupling $\rightarrow$ infer structure

$\pi^0\pi^0$ preferred w.r.t. $\pi^+\pi^-$ due to smaller background contamination

Pennington, arXiv:0906.1072
\( \gamma\gamma \rightarrow \pi^0\pi^0 \) at low energies

Cleanest channel to assess existence and nature of the \( \text{\dagger} \) meson

ChPT

Resonant contribution

\[ \eta_0 \eta_0 \rightarrow \text{\dagger} \rightarrow \text{\dagger} \]

• LET (Low Energy Taggers) are LYSO calorimeters placed inside KLOE
• HET (High Energy Taggers) are scintillator hodoscopes placed at 11m on the beam line
The detector is composed by a LYSO crystal matrix with SiPM readout.

130-230 MeV/c electrons are tagged in this position.
The hodoscope is composed by two rows of 15 3x5x6 mm³ scintillators + 2 3x5x120 mm³ scintillators for coincidence to be inserted in the DAFNE beam-pipe with a dedicated motorized driver.
Le stazioni di tagging - HET

I pozzetti per l’installazione del rivelatore sono su DAFNE.
Il sistema di movimentazione è pronto

Alla partenza di DAFNE verranno inserite due strip di scintillatori per controllare i livelli di radiazione
La struttura modulare disegnata per QCALT con gli schermi in Pb e la slitta per l’installazione del LET è stata realizzata in officina a Frascati

LET e FEE pronti per l’installazione

L’inserimento di beam pipe e LET in corso