Future experiments at DAΦNE

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Rome I University & Laboratori Nazionali di Frascati (INFN)

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LNF is a multidisciplinary laboratory where several facilities are run and accessed by internal as well as external users

- 3 Synchrotron Radiation lines (UV, IR, soft X-rays)
- A 800 MeV LINAC test beam facility
- An ultracryogenic gravitational antenna
- A FEL (under construction)

- The DAΦNE Φ—factory e⁺e⁻ collider
The DAΦNE e+e−-collider

Between years 2000-2007 three different experiments have shared the access to the DAΦNE beams, collecting in total ~ 4 fb\(^{-1}\) of data at the Φ resonance peak (1020 MeV)

- **KLOE** devoted mainly to the study of K meson decays, and fundamental symmetries conservation ( ~ 2 fb\(^{-1}\) collected)
- **FINUDA** devoted to hypernuclear physics ( ~1 fb\(^{-1}\) collected)
- **DEAR** devoted to the study of kaonic atoms ( ~1 fb\(^{-1}\) collected)

See S.Fiore, E.Botta, E.Widmann talks, this conference
DAΦNE new interaction scheme

IN 2006 a new interaction scheme based on the use of a large Piwinski angle, in combination with a crabbed waist induced by properly designed sextupoles, has been proposed for DAΦNE.
**DAΦNE parameters: new vs. old**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DAΦNE KLOE</th>
<th>DAΦNE Upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{\text{bunch}}$ (mA)</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>$N_{\text{bunch}}$</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>$\beta_y^*$ (cm)</td>
<td>1.7</td>
<td>0.65</td>
</tr>
<tr>
<td>$\beta_x^*$ (cm)</td>
<td>170</td>
<td>20</td>
</tr>
<tr>
<td>$\sigma_y^*$ (μm)</td>
<td>7</td>
<td>2.6</td>
</tr>
<tr>
<td>$\sigma_x^*$ (mm)</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>$\sigma_z$ (mm)</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>$\theta_{\text{cross}}/2$ (mrad)</td>
<td>12.5</td>
<td>25</td>
</tr>
<tr>
<td>$\Phi_{\text{Piwinski}}$</td>
<td>0.45</td>
<td>2.5</td>
</tr>
<tr>
<td>$L$ ($\text{cm}^{-2}\text{s}^{-1}) \times 10^{32}$</td>
<td>1.5</td>
<td>&gt;5</td>
</tr>
</tbody>
</table>
Detailed calculations performed in Frascati, KEK and Novosibirsk, have confirmed the benefits of this scheme and convinced the Laboratory to implement the hardware upgrade during the 2007.

The actual test and optimization of the new scheme is ongoing during the 2008 SIDDHARTA experiment data taking (see E.Widmann talk)
Present performance

- Stored current in electron beam = 1.79 A in 95 bunches (weak positron beam ≈ 0.45 A)
- Stored current in positron beam = 1.15 A in 120 bunches (no electron beam)
- Stored current of interacting beams at the same time = ≈(1.2 e− 1.1 e+) A in 95 bunches
- Peak luminosity ≈ 2.0x10^{32} cm^{-2}s^{-1}
- Integrated luminosity per day ≈ 8.0 pb^{-1} (measured during operation for Siddharta)
- Integrated luminosity per hour = 0.5 pb^{-1}

SIDDHARTA run needs very low bck !!!
Three proposals have been put forward for the use of this facility:

- The continuation & extension of KLOE physics program with and upgraded detector (KLOE-2 project)
- The use of KLOE with a modified internal region for the study of deeply bound kaonic states (AMADEUS project)
- The extension of the FINUDA run, with essentially the same detector and maybe different targets

The LNF Scientific Committee in May 2008 has assigned the KLOE2 project the highest priority
Physics at a $\phi$-factory

**Not only KAON physics**

$V_{us}$, Medium-Rare $K_{S,L}$ decays, CPT with $K_s$, $K_L$ charge asymmetries,

*Quantum Interferometry, But also:* hadronic cross section, radiative $\phi$ decays. “Natural” luminosity unit: $fb^{-1}$

<table>
<thead>
<tr>
<th>$\phi$ decay</th>
<th>Produced ev/fb$^{-1}$</th>
</tr>
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<tbody>
<tr>
<td>$K^+K^-$</td>
<td>$1.5\times10^9$</td>
</tr>
<tr>
<td>$K_LK_S$</td>
<td>$1.0\times10^9$</td>
</tr>
<tr>
<td>$\eta$</td>
<td>$5\times10^7$</td>
</tr>
<tr>
<td>$\eta'$</td>
<td>$2\times10^5$</td>
</tr>
</tbody>
</table>
Kaon interferometry

The decay time distribution of the KL,KS pairs has characteristic interference term at a $\phi$-factory $\rightarrow$ K interferometry

$$I(f_1,t_1;f_2,t_2) = C_{12} \left| \eta_1 \right|^2 e^{-\Gamma_L t_1 - \Gamma_S t_2} + \left| \eta_2 \right|^2 e^{-\Gamma_S t_1 - \Gamma_L t_2}$$

$$- 2 \left| \eta_1 \right| \left| \eta_2 \right| e^{-(\Gamma_S + \Gamma_L)(t_1 + t_2)/2} \cos[\Delta m (t_2 - t_1) + \phi_1 - \phi_2]$$

$$\eta_i = |\eta_i| e^{i\phi_i} = \langle f_i | T | K_L \rangle / \langle f_i | T | K_S \rangle$$

$$f_i = \pi^+\pi^-, \pi^0\pi^0, \pi\nu, \pi^+\pi^-\pi^0, 3\pi^0, \pi^+\pi^-\gamma \ldots \text{etc}$$

Measuring different $f_i$ with different final states $\rightarrow \text{CP,TCP,QM}$ test can be achieved
KLOE experiment

- **Be beam pipe** (spherical, 10 cm Ø, 0.5 mm thick) + **instrumented permanent magnet quadrupoles** (32 PMT’s)
- **Drift chamber** (4 m Ø × 3.75 m, CF frame)
  - Gas mixture: 90% He + 10% C₄H₁₀
  - 12582 stereo–stereo sense wires
  - $\sigma_p/p = 0.4\%$ (tracks with $\theta > 45^\circ$)
- **Electromagnetic calorimeter**
  - lead/scintillating fibers (1 mm Ø), 15 $X_0$
  - $\sigma(t) = 54$ ps/$\sqrt{E(\text{GeV})} \oplus 50$ ps
  - $\sigma(E)/E = 5.7\%/\sqrt{E(\text{GeV})}$
- **Superconducting coil** ($B = 0.52$ T)
KLOE-2: physics motivations

KLOE2 with 20 fb$^{-1}$ will improve all the KLOE physics program but will extend also to

- Studies on CPT and QM violation with neutral kaons interferometry
- Tests of Lepton Flavor Violation with charged $K_{e2}$ decays
- Studies on $C, P, CP$ violation and Chiral Perturbation Theory using $\eta, \eta', \text{and } K_S$ decays
- Studies of the $\gamma\gamma$ physics at the $\phi$ peak

<table>
<thead>
<tr>
<th>Channel</th>
<th>Present benchmark</th>
<th>KLOE-2@20fb$^{-1}$</th>
</tr>
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<tbody>
<tr>
<td>$\text{BR}(K_S \to \pi e\nu)$</td>
<td>1.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>$\text{BR}(K_S \to \pi^0\pi^0\pi^0)$</td>
<td>$&lt;10^{-7}$</td>
<td>$&lt;10^{-8}$</td>
</tr>
<tr>
<td>$\text{BR}(\eta \to \pi^+\pi^-e^+e^-)$</td>
<td>30%</td>
<td>1%</td>
</tr>
<tr>
<td>$\text{BR}(\eta \to \pi^+\pi^-)$</td>
<td>$&lt;1.3x10^{-5}$</td>
<td>$&lt; 10^{-7}$</td>
</tr>
</tbody>
</table>
γγ physics at KLOE2

\[ e^+e^- \rightarrow e^+e^- \gamma\gamma^* \rightarrow e^+e^- (\pi^0\pi^0, \pi^0, \eta) \]

- Two stations are needed to cover the interesting energy spectrum:
  - LET (Low Energy Tagger). Inside KLOE, after QD0
  - HET (High Energy Tagger). At ~6m from IP, after first dipole
- The idea is to use the same magnets of DAΦNE as a magnet spectrometer for \(e^+/e^-\) in the final state
The extended KLOE2 physics program is not only based on the increased DAFNE luminosity but also on better systematics and larger acceptance due to:

- The insertion of an *inner tracker*
- The insertion of *crystal calorimeters* in the low $\theta$ region
- The modification of the *quadrupole calorimeters*
- The insertion of a *tagging system* for $\gamma\gamma$ events

The roll-in plans are:

- **Step 0**: To be performed *during spring-summer 2009*. Roll-in of the present detector with minimal upgrades
- **Step 1**: To be performed most likely *during the fall of 2010*. Insertion of the more demanding upgrades with the goal of a longer data taking campaign
Inner tracker: the C-GEM

First tracking layer of KLOE is at 30 cm from the IP. Many analyses will benefit of an inner tracker, provided its material budget is kept at the 1-2% $X_0$ level.

We chose the GEM technology with an unconventional cylindrical geometry. Challenging mechanics, but a single layer prototype is already been built and tested. (see Bencivenni talk, this conference)

- 70 cm length max.
- 5 Layers 13-26 cm from IP
- $\sigma_{r\phi} \sim 200 \, \mu m$
- $\sigma_z \sim 500 \, \mu m$
- Total $X_0 \sim 2\%$

Factor 3 improvement in the vertex resolution@IP (5 $\rightarrow$ 1.5 mm)
Effect of the Inner tracker

The inner tracker improves also the acceptance of the low $p_t$ tracks from IP (i.e. $\pi, e$ secondary from $K^\pm, K_S, \eta$) up to a 40-50%. Reducing the B field to 0.3 T can give similar enhancement (machine?)

\[ \alpha, \beta, \gamma \] accuracy vs luminosity

The improved vertex resolution improves by a factor 3 the measurement of the QM-CPT violating parameters $\alpha, \beta, \gamma$ that can be extracted by the $K_L$, $K_S$ interferometry

\[ \dot{\rho} = -i \rho H + i \rho H^+ + L(\rho, \alpha, \beta, \gamma) \]

AT MOST $\alpha, \beta, \gamma = O\left(\frac{M_K^2}{M_{\text{PLANCK}}}\right) \approx 2 \times 10^{-20} \text{ GeV} \]
The KLOE EmC has proven an excellent device for several physics analyses but some systematic limitations have been observed. Rare or semi-rare decay such as $K_S \rightarrow 3\pi^0$, $K_S \rightarrow \gamma\gamma$, $K^\pm \rightarrow e^\pm\nu$, $\eta \rightarrow \pi^0\gamma\gamma$ will benefit by the insertion of new low $\theta$ and quads calorimeters both for bckg reduction and for increasing acceptance.

$K_S \rightarrow \gamma\gamma$:

- red = signal
- blue = background

w/o low $\theta$ CAL

with low $\theta$ CAL
QCALT: a Quad Calo with Tiles

- Scintillator-tiles + WLS + SiPM

- **wedge:** 20 towers along Z
- **tower:** 5 layers of square tiles 5x5x0.5 cm³
- 3.5 mm Tungsten used as absorber to reduce space
- Total calorimeter depth 4.75 cm equivalent to 5.5 $X_0$

Integrated design with machine I.R.

ADC counts
CCALT as Low Energy Taggers

Both HET and LET are needed for $\gamma\gamma$ physics: CCALT acts like a LET!

Technology: PbWO + SiPM
- 3x10 crystals
- 5 cm thick (enough to contain shower due to high impact angle)
- 3x3 mm$^2$ SiPM (2 for each crystal)

- $\sim$2pe/MeV expected $\Rightarrow \sigma_{E/E} = 5\div10\%$
HET positioning

- Technology: Si micro strip + plastic scintillator
- Dipole is used as a spectrometer
- Energy resolution depends on strip pitch (final design by March 2009)
Summary & conclusions

- After 7 years of operation, the first period of life of DAΦNE has come to its end.
- A new design of the I.R. has been implemented during 2007 and is now under testing. The new facility will reasonably deliver ~ 20 fb\(^{-1}\) in a four year period (2010-2013).
- KLOE2 will enlarge the KLOE physics program, mainly based on \(K\) and \(\eta\) physics, focusing also on \(\gamma\gamma\) physics and QM-Kaon interferometry.
- Several detector upgrades, Inner Tracker, QUAD calo, \(\gamma\gamma\) Tagger, will increase acceptances and decrease systematics of the KLOE detector.
Spare slides
KLOE data taking

\[ L_{\text{int}}/ \text{month} \ (\text{pb}^{-1}) \]

- 2001-2005 \( L_{\text{int}} = 2482 \ \text{pb}^{-1} \)
- 2004-2005 \( L_{\text{int}} = 1990 \ \text{pb}^{-1} \)
- Best conditions: Sept/Oct/Nov 2005 \( \Rightarrow 179/189/194 \ \text{pb}^{-1} \)

stable luminosity, beam energy and backgrounds
$K_S \rightarrow \gamma \gamma$: an experimental puzzle for ChPT

KLOE has already announced (and is ready to publish) a result which differs of $\sim 3\sigma$ from a previous NA48 measurement.

Theoretically, this result is very relevant since KLOE excludes large contributions $O(p^6)$ to the amplitude, which are instead implied by NA48.

With KLOE-2 we can reach an accuracy comparable or better than the one of NA48.
Dafne run 11 Nov 2008

Luminosity [cm$^{-2}$ s$^{-1}$] - on line FARM process

Current [mA]

Integrated luminosity [nbarn$^{-1}$]
KLOE has already published the best results on $a_0/f_0$ production in $\phi$ radiative decays, relevant for the determination of their nature.

We have also presented the best limit on their decays into kaon pairs, relevant to determine their coupling with the strange quark.

With KLOE-2 we can give the final answer to this long standing puzzle.
Electrons trajectories
The KLOE Calorimeter:

\[ \sigma(E)/E = 5.7\%/ \sqrt{E(\text{GeV})} \]
\[ \sigma(t) = 54 \text{ ps}/ \sqrt{E(\text{GeV})} \oplus 50 \text{ ps} \]
\[ \varepsilon \geq 95\% \text{ for } 20 \text{ MeV photons} \]
\[ \sigma_{\text{vtx}}(\gamma\gamma) \sim 1.5 \text{ cm} \text{ (}\pi^0 \text{ from } K_L \rightarrow \pi^+\pi^-\pi^0) \]

- Pb-scintillating fibers matrix: \(<\rho> \sim 5 \text{ g/cm}^3, <X_0> \sim 1.6 \text{ cm}\)
- 4880 PMTs
- 98\% hermetic coverage
The KLOE Drift Chamber:

- 90% He, 10% iC$_4$H$_{10}$ ($X_0=900\text{m}$)
- 12582 stereo sense wires
- structure in C-Fibre (<0.1 $X_0$)
- Non saturated drift velocity
- 2x2 (inner) & 3x3 (outer) cm$^2$ squared cell size

\[ \sigma_p/p = 0.4\% \text{ (tracks with } \theta > 45^\circ) \]
\[ \sigma_x^{\text{hit}} = 150\ \mu\text{m (xy), 2 mm (z)} \]
\[ \sigma_x^{\text{vertex}} \sim 1\ \text{mm} \]
\[ \sigma(M_{\pi\pi}) \sim 1\ \text{MeV (from } K_S \rightarrow \pi^+\pi^-) \]
**CPTV: Quantum interference**

\[
I(f_1, t_1; f_2, t_2) = C_{12} \left| \eta_1 \right|^2 e^{-\Gamma_{L} t_1 - \Gamma_{S} t_2} + \left| \eta_2 \right|^2 e^{-\Gamma_{S} t_1 - \Gamma_{L} t_2} - 2|\eta_1||\eta_2| e^{-\left(\Gamma_{S} + \Gamma_{L}\right)(t_1 + t_2)/2} \cos[\Delta m(t_2 - t_1) + \phi_1 - \phi_2]\]

- interference pattern \(I(\Delta t)\) for different final states \(f_1, f_2\) give access to different parameters
- a good vtx resolution is required: \(\sigma(\Delta t) < \tau_S\)
  \(\rightarrow\) quest for an improvement of inner tracking!
- several QG models predict CPTV terms in the interference time evolution

\[
f_1, f_2 = \pi^{\pm} l^{\mp} \nu
\]

**Large \(\Delta t\):** \(\Re \delta_K - \Re \left( \frac{d^*}{a} \right)\)

**Small \(\Delta t\):** \(\Im \delta_K + \Im \left( \frac{c^*}{a} \right)\)

Semileptonic decays give access to \(\delta_K\)
In the EHNS model the interference pattern contains 3 CPTV parameters: $\alpha, \beta, \gamma \sim \mathcal{O}(M_K^2/M_{\text{Planck}}) \sim 10^{-20}$ GeV

KLOE measurements still worse than CPLEAR

In the BMP model CPTV modifies the concept of antiparticle and $K_S K_L$ state deviates from Bose statistics via a parameter $\omega$:

$$|\omega| \sim \mathcal{O}(M_K^2 / M_{\text{Planck}} \Delta \Gamma)^{1/2} \sim 10^{-3} \div 10^{-4}$$

Preliminary KLOE measurement is already at $10^{-4}$ level. KLOE2 can go up to $10^{-5}$
Physics goals in the region $1 \leq \sqrt{s} \leq 2.5$ GeV

**Hadronic cross section:** Provide $R$ measurement for $a_\mu$ and $\alpha_{em}$ determination.
Perform an accurate energy scan. Improve by a factor of 10 the present BABAR exclusive cross section measurements. Afford the only inclusive $\sigma_{had}$ measurement since ’80s.

**Vector meson spectroscopy:**
study $\rho$, $\omega$, $\phi$ recurrences and their place in hadron multiplets. Understand the nature of $\rho(1900)$ (glueball?).

**$\gamma\gamma$ physics:** Study $\eta'$, $f_0$, $a_0$ production and their $\gamma\gamma$ width (related to the quark structure of the hadron).

The program is wide and spread over many topics. All together they offer a rich experimental field.
Hadronic contribution to $\alpha_{em}(M_Z)$ is very important in the region $1<\sqrt{s}<2.5$ GeV. If not measured at few % level is going to be the limiting factor for future precision calculation (linear collider physics). B factories are already doing it!

Energy scan
20 pb$^{-1}$ per point

Radiative return
with 2 fb$^{-1}$ at 2.4 GeV

$\pi^- \pi^+ \pi^0$
Simulation results for a $\pi$ track from $K_s \rightarrow \pi\pi$

<table>
<thead>
<tr>
<th></th>
<th>$\Delta x @\text{pca}$</th>
<th>$\Delta z @\text{pca}$</th>
<th>$\Delta p_x @\text{pca}$</th>
<th>$\Delta x @\text{vertex}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IT</td>
<td>0.6 mm</td>
<td>0.9 mm</td>
<td>1.2 MeV/c</td>
<td>1.9 mm</td>
</tr>
<tr>
<td>No IT</td>
<td>1.7 mm</td>
<td>2.2 mm</td>
<td>1.6 MeV/c</td>
<td>4.9 mm</td>
</tr>
</tbody>
</table>

- $\Delta x @\text{pca}$: difference of x coord. between the pca of track wrt the vertex and the vertex
- $\Delta z @\text{pca}$: difference of z coord. between the pca of track wrt the vertex and the vertex
- $\Delta p_x @\text{pca}$: difference of momentum $p_x$ between the track at pca to the vertex and the vertex
- $\Delta x @\text{vtx}$: sigma of the difference of x coord. between the reconstructed vertex and MC vertex
Preliminary Spatial Resolution

\[ \sigma^2_{(\text{global})} = \sigma^2_{(\text{GEM})} + \sigma^2_{(\text{tracker})} \]

\[ \sigma^2_{(\text{GEM})} = 250 \mu m^2 - 140 \mu m^2 \sim 200 \mu m^2 \]

GEM residuals with respect to the track reconstructed by the drift tubes
CCALT: a Crystal Calo with Time

- **Technology:** LYSO crystals + APD

- 4 LYSO \((\text{Lu}_{1.8}\text{Y}_{0.2}\text{SiO}_{5}:\text{Ce})\) crystals from Saint-Gobain tested:
  - 3 pieces: 1.5x1.5x15 cm\(^3\)
  - 1 piece: 2x2x15 cm\(^3\)

- Cosmic-ray test with PM
- Cosmic-ray test with APD
- BTF testbeam with APD + MAR8A amp

- Found 2 new LYSO like providers:
  - SCIONIX (LYSO)
  - ZEKOTEK (LSF)
CCALT: Crystal calorimeter

LYSO crystal

SiPM

APD
BTF Testbeam results

- 1x1 cm² beam
- 1 crystal 2x2x13 cm³ (<1 \( R_m \))
- 1 day data taking

Energy resolution

\[
\frac{\sigma_E}{E} = \frac{8\%}{\sqrt{E} \text{ (GeV)}} \oplus 16\%
\]

Time resolution

\[
\sigma_T = \frac{82 \text{ ps}}{\sqrt{E} \text{ (GeV)}} \oplus 293 \text{ ps}
\]

250 pe/MeV, 380 ps @ 50 MeV
**Decoherence and CPT violation**

Modified Liouville – von Neumann equation for the density matrix of the kaon system:

\[ \dot{\rho}(t) = i[H\rho + \rho H^+] + L(\rho) \]

- extra term inducing decoherence:
  - pure state => mixed state

Possible decoherence due quantum gravity effects:

**Black hole information loss paradox** => Possible decoherence near a black hole.

Hawking [1] suggested that at a microscopic level, in a quantum gravity picture, non-trivial space-time fluctuations (generically space-time foam) could give rise to decoherence effects, which would necessarily entail a violation of CPT [2].

J. Ellis et al. [3-6] => model of decoherence for neutral kaons => 3 new CPTV param. \( \alpha, \beta, \gamma \):

\[ L(\rho) = L(\rho; \alpha, \beta, \gamma) \]

\[ \alpha, \gamma > 0 \quad , \quad \alpha \gamma > \beta^2 \]

At most:

\[ \alpha, \beta, \gamma = O\left(\frac{M_K^2}{M_{PLANCK}}\right) \approx 2 \times 10^{-20} \text{ GeV} \]