# Project Program

Network Title : **EURODAPHNE : High Precision Elementary Particle Physics at the $\phi$ -factory DAΦNE**

Network Short Title : **EURODAPHNE**

## Part A - The Participants

The Contractor

1 Istituto Nazionale di Fisica Nucleare, Frascati Laboratories, INFN-LNF, established in Italy

will act jointly and severally towards the Commission with the following Associated Contractors to perform this Project Programme:

2 Council for the Central Laboratory of the Research Councils, Rutherford Appleton Laboratory, UKRAL, established in Great Britain

3 Institut National de Physique Nucleaire et de Physique des Particules, Orsay,CNRS-IN2P3, established in France

4 Department Sciences Physiques et Mathematiques du Centre National de la Recherche Scientifique, Marseille, CNRS-CPT, established in France

5 Universitat Autonoma de Barcelona, UAB, established in Spain

6 Universitat de Valencia (Estudi General), UVEG, established in Spain

7 Universität Wien, UWIEN, established in Austria

8 Deutsches Elektronen-Synchrotron Institut für Hochenergiephysik Zeuthen; Stiftung des öffentlichen Rechts, DESY-ZEU, established in Germany

9 University of Helsinki, UHELS, established in Finland

10 Universität Bern, UBERN, established in Switzerland

The Contractor and the Associated Contractors are hereinafter referred to jointly as "the Participants".

## Part B - The Joint Programme of Work

### B1 Research Objectives

The main objective is to investigate problems on fundamental symmetries, electroweak and strong QCD physics that may be explored at the European $\phi$-factory DAPHNE, whose completion is expected by the beginning of 1998. The theoretical work will concern: (i) CP and CPT Physics in the Kaon system; (ii) Chiral Perturbation Theory and Models for low-energy dynamics of light and strange quarks; (iii) K and eta Decays; (iv) a novel analysis of pion-pion scattering at threshold and phaseshift structure from K decay; (v)

Total hadronic cross-section in electron-positron collisions below 2 GeV; (vi) Vector Mesons in effective lagrangians; (vii) Gluon dynamics and spectroscopy above the phi-meson; (viii) Nuclear Physics with Kaons from phi-decays. Through these studies the network plans to attain the following research objectives :

1. To help clarify the origin of CP violation.

2. To sharpen existing predictions of Chiral Perturbation Theory.

3. To improve the understanding of rare kaon decays and possibly to disentangle short distance effects.

4. To investigate the implications of precision data on $e^+e^- \to$ hadrons at low energy from both the experimental and the theoretical point of view.

5. To understand the nature of the enigmatic scalar mesons which appear just below 1 GeV and which will be produced in radiative $\phi$-decays.

6. To investigate the interactions of strange and light quarks in baryons and nuclear matter, in particular the properties of strange nuclei, i.e. hypernuclei, formation of kaonic atoms and KN scattering at threshold.

## B.2 Methodological Approach and Work Plan

### Research Method

DA$\Phi$NE is the first of a new generation of $e^+e^-$machines, which promise to bring significant improvements in our understanding of the interactions among elementary particles. This may result because of enormous recent advances in accelerator (high luminosity) and detector technology ( particle identification, data acquisition for $10^{10}$ events per year) during the last 20 years. In a low energy machine like DA$\Phi$NE, most of the activity is centred on the dynamics of the lightest meson states, which are going to be copiously produced. This research will include both electroweak (K decays, CP violation) and strong (vector mesons, low-energy effects of QCD) interaction aspects with the most interest in the important interplay between QCD and electroweak interactions at low energies.

To meet the challenge presented by these experiments, a variety of complementary theoretical tools will be employed. The theorists of the network shall utilize as a main tool Chiral Perturbation Theory which is a systematic method to analyze the low-energy structure of the Standard Model. To compare ChPT predictions with another widely used method for low-energy physics, that of lattice gauge theories, the method of Quenched Chiral perturbation will be employed. To test experimentally some of the foundations of standard ChPT, predictions will be matched against other expansion schemes, like that of Generalized Chiral Perturbation Theory, which is suitable for incorporating the alternative of a small quark condensate in a model independent way. The basic research method consists of developing non-perturbative approaches in a theoretically controllable way, thereby enabling a direct confrontation with experimental results. Such confrontation requires then the ability to extract physically meaningful quantities from the data. One of the important tests to be studied by this collaboration will concern determination of low energy $\pi\pi$ scattering from the high statistics information collected by the KLOE detector at DA$\Phi$NE in $K_{e4}$ decays. These will allow the determination of low energy $\pi\pi$ scattering. The details of this basic process are uniquely connected to the mechanism of spontaneous chiral symmetry breaking, in particular to the size of the $q\bar{q}$–condensate. To extract the $\pi\pi$ phase-shifts from the new data, a new analysis will be started, looking for new solutions to the Roy equations, consistent with past and forthcoming experimental data, such as to allow a precise continuation into the subthreshold region, which uniquely probes the size of the condensate.

A different aspect of Chiral Perturbation Theory, namely the low–energy realization of the four–fermion weak hamiltonian, will be applied in the analysis of nonleptonic and radiative kaon decays. By this way it should be possible to extract several next–to–leading order couplings of the theory which have not been determined yet from the analysis of KLOE data. This program will lead to a deeper understanding of long–distance effects in kaon decays and possibly open some windows on short distance physics. To fulfill this program the theoretical analysis of nonleptonic and radiative kaon decays at the next–to–leading order will be completed and updated.

Another challenge is presented by the measurement of the total $e^+e^-$ hadronic cross-section, which, through the optical theorem, can give information on the hadronic contributions to $\alpha_{QED}(M_{Z^0})$ and $(g-2)_\mu$. Considerations from precision physics suggest that the goal should be to measure the cross-section at the level of a few percent. This could allow a reduction of the error on $a_\mu$ such as to be closer to the contribution from virtual light-by-light scattering. To extract the total cross-section a certain amount of modeling is necessary, since, in contrast to LEP, at low energy the theoretical shape of the total cross-section cannot be calculated from first principles. Important cross-checks will be obtained by studying connections between form-factor measurements at DAΦNE and tau-lepton decays through isospin and SU(3) relations between multipion final states. More information on electroweak quantities requires models for light-by-light contributions. Various models, such as the Hidden Symmetry Scheme and related models which incorporate vector mesons in chiral lagrangians, can be used to estimate this hadronic contribution and to compare it with current estimates.

Since a limit to precision measurements in $e^+e^-$collisions is due to the presence of QED radiative corrections, the techniques employed for a full evaluation of these effects, will include standard next-to-leading corrections to the second order of QED, leading logarithmic approximation to deal with higher order corrections, and Monte Carlo event generators for data analysis and simulations. Monte Carlo simulations and soft photon summation techniques will also be applied to determine the effects of infrared radiative corrections on the precision attainable in detector calibration through QED processes like quasi-real Compton scattering.

Spectroscopy issues, scalar mesons, hybrids and scalar glueballs, will be attacked with a variety of theoretical techniques. In particular, amplitude analysis packages to study isospin violations at the $\phi$ through its radiative final states decays into $a_0$ and $f_0$, will be developed. A new project, the dynamical calculation of the decays of the $\phi$ will make use of Schwinger-Dyson and Bethe-Salpeter equations, in a framework which provides a consistent alternative approach to lattice techniques.

## Work Plan

To meet the objectives, the theoretical activity of the group will be organized along the following main physics issues :

(i) **CP and CPT Physics in the Kaon system**

(ii) **Theoretical issues in Chiral Perturbation Theory**

(iii) **K-meson, $\eta$ and $\eta'$ decays**

(iv) $\pi\pi$ **scattering at threshold and phase-shifts**

(v) **Structure and role of vector mesons**

(vi) **Total hadronic cross-section in $e^+e^-$ collisions below 2 GeV**

(vii) **Hadron spectroscopy at the $\phi$**

(viii) **Gluon dynamics and spectroscopy above the $\phi$**

(ix) **Nuclear Physics with Kaons**

In addition to the theoretical activity along the above lines, the network will organize special working groups in direct contact with experimentalists with the aim of providing the framework for extracting physics results relevant to the above subjects, from the forthcoming data, i.e. in particular:

1. **CP group** to extract the CP , T and CPT parameters
2. **Kaon and $\eta$ Decay group** for the measurement and interpretation of various rare and not so rare kaon and $\eta$ decays, in particular the confrontation of ChPT predictions with the data, e.g. the scalar radius in $K_{\mu 3}$ decays,
3. $\pi\pi$ **group** for the measurement of $\pi\pi$ phase-shifts from $K_{l4}$ decays, a measurement of fundamental importance in low energy physics,
4. $(g-2)_\mu$ **group** for the measurement of the total hadronic cross-section in $e^+e^-$ collisions in the region below 2 GeV, a measurement which can significantly reduce the theoretical error on the estimate for g-2 of the muon,
5. $\gamma\gamma$ **group** for two photon physics at DA$\Phi$NE, where there is yet no technical proposal, although the machine has been designed so as to allow for the necessary small angle tagging, and one of the aims of the relevant network team will be to assist in preparing the proposal. This will include further insight into the theoretical problem (one- and two-loop ChPT calculation, dispersive approach or other) as well as preparation of the Monte Carlo program for two photon physics.
6. **radiative correction group** for the evaluation of radiative corrections to all the DA$\Phi$NE experiments. This group will work in close connection with everyone else, and in particular with the g-2 group, since the relative measurement requires knowledge of the radiative corrections to a fraction of a per cent, in the DA$\Phi$NE energy region, a precision not yet to be found in the literature.

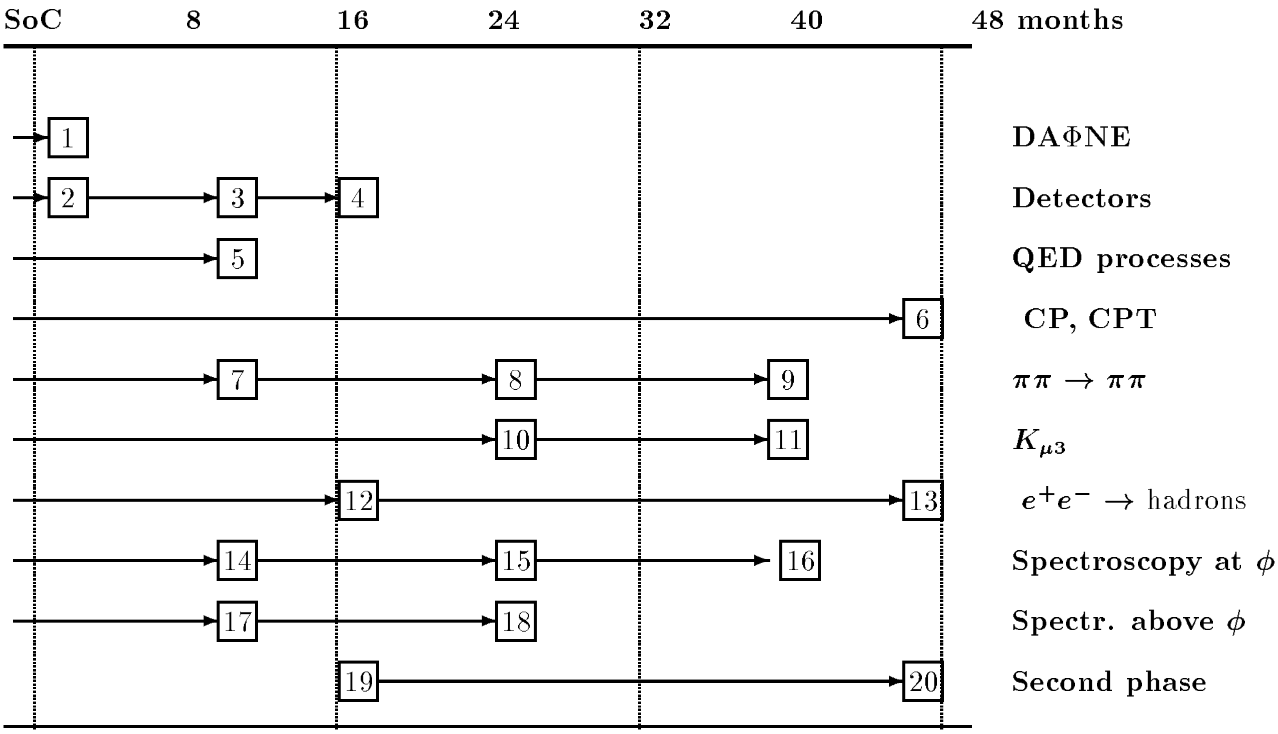
In Table 1 the specific tasks, which each team will collaborate to realize, are shown. In this table, the teams are indicated by participant number, as defined in the Contract.

EURODAPHNE Scientific Plan and Tasks Assignments

| Country | IT | GB | FR | | ES | | AT | DE | FI | CH |
|---|---|---|---|---|---|---|---|---|---|---|
| Participant Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **CP and CPT physics in the Kaon system** | X | | | X | | X | X | | X | |
| **Theoretical issues in ChPT** | | | | | | | | | | |
| Standard ChPT | X | | X | X | X | X | X | | X | X |
| Quenched ChPT | X | | | X | | | | | X | X |
| Chiral Symmetry Breaking | | | X | X | | X | X | | X | X |
| **K-meson, $\eta$ and $\eta'$ decays** | | | | | | | | | | |
| $K_{\mu 3}$ | X | | | X | | | | | | X |
| $K_{e4}$ | X | X | X | X | | | | | X | X |
| All other decays | X | | X | X | X | X | X | | X | X |
| QED Radiative corrections | X | | X | | | | | X | | |
| **$\pi\pi$ scattering at threshold and phase-shifts** | X | | X | X | X | X | X | | X | X |
| **Structure and role of Vector Mesons** | | | | | | | | | | |
| Vector Mesons in Eff. Lagrangians | X | | | | X | X | | | X | |
| Vector Meson spectroscopy | | X | | | X | | | | | |
| **$e^+e^-$ cross-sections below 2 GeV** | | | | | | | | | | |
| $e^+e^- \to hadrons$ and $(g-2)_\mu$ | | | | X | X | X | | X | | |
| $\gamma\gamma \to hadrons$ | X | X | X | | | | | | | X |
| QED Radiative corrections | X | | X | | | | | X | | |
| QED Processes for calibration | X | | X | | | | | | | |
| **Hadron spectroscopy at the $\phi$** | | X | X | | | X | | | X | |
| **Gluon dynamics and spectroscopy above the $\phi$** | | X | X | | | | | | X | |
| **Nuclear Physics with Kaons** | X | X | | | X | X | | | | |

Table 1: *List of specific tasks which the teams, indicated by participant number, will work on during this research project*

### B.3 EURODAPHNE Schedule and Milestones




**Legend : SoC=Start of Contract**

1 DAΦNE commissioned
2 DEAR in operation
3 KLOE and FINUDA in operation
4 Data analysis starts
5 QED calibration processes at work
6 $\epsilon'/\epsilon$ determined
7 Theoretical predictions for amplitude at order $p^6$ completed
8 Theoretical work for extraction of $\pi\pi$ phases from $K_{e4}$ decays completed
9 Size of quark condensate determined
10 Theoretical work for $K_{\mu 3}$ decay analysis completed
11 Scalar radius in $K_{\mu 3}$ determined
12 Interplay between measurements at DAΦNE and $\tau$-decays investigated
13 Radiative corrections to hadronic cross section completed
14 Theoretical work on $a_0/f_0$ mixing effects completed
15 Full dynamical predictions for $\phi \to a_0/f_0\gamma$ completed
16 Theoretical assessment on scalar and vector mesons
17 Theoretical work on excited Vector Mesons assessed
18 Signals for C=+ states for DAΦNE second phase computed
19 Beginning of theoretical work on DAΦNE Second Phase
20 Completion of report on physics at DAΦNE Second Phase

## B.4 Research Effort of the Participants

This network consists of 1 Coordinator and 9 Associated Contractors. Some of the teams consist of researchers belonging to legally different institutions. In the following we specify the structure of the network.

1. Participant 1 : INFN Frascati National Laboratory which includes external team members from

   INFN Sezione di Roma1 dell'Universitá di Roma La Sapienza

   INFN Sezione di Roma2 dell'Universitá di Roma Tor Vergata

   INFN Sezione di Roma3 della III Universitá of Roma

   INFN Sezione di Perugia dell'Universitá di Perugia

   INFN Sezione di Napoli dell'Universitá di Napoli

   INFN Sezione di Parma dell'Universitá di Parma

   INFN Sezione di Pavia dell'Universitá di Pavia

   INFN Sezione di Torino dell'Universitá di Torino

2. Participant 2 : Rutherford Appleton Laboratory which includes external team members from

   University of Oxford

   University of Durham

   University of Manchester

   and **Subcontractor**

   University of Thessaloniki, Greece

3. Participant 3 : DPT-IPN Université de Paris-Sud-IN2P3/CNRS which includes external team members from

   LAL Université de Paris-Sud-IN2P3/CNRS

   LPTHE Université de Paris-Sud/CNRS

   Université de Picardie

   Université de Paris VI-IN2P3/CNRS

4. Participant 4 : CPT du CNRS at Marseille Luminy which has no external team members

5. Participant 5 : Universitat Autonoma de Barcelona which includes external team members from

   Universitat de Barcelona

   and **Subcontractor**

   Universidad de Granada

6. Participant 6 : Universitat de Valencia which has no external team members

7. Participant 7 : Universität Wien which has no external team members

Table 2: Subcontractors

| *N.*° | legal entity of partner | legal entity of subcontractor | project of the subcontractor |
|---|---|---|---|
| 2 | UKRAL | University of Thessaloniki, Greece | Modern formulation of the Vector Dominance idea, classification of its valid predictions and present experimental status, Hybrids and glueballs |
| 5 | UAB | Universidad de Granada, Spain | Chiral Lagrangian formulation of Vector Mesons and Vector Mesons spectroscopy |
| 8 | DESY-ZEU | University of Karlsruhe, Germany | Hadronic cross-sections and determination of hadronic contribution to $(g-2)_\mu$ |
| 9 | UHELS | University of Lund, Sweden | CP violation in K-mesons system, Vector Mesons in CHPT, Chiral Symmetry Breaking and CHPT, K and $\eta$ decays, $K_{e4}$ and $\pi\pi$ Quenched CHPT |

8. Participant 8 : DESY Institut für Hochenergiephysik at ZEUTHEN which includes **Subcontractor**

   Universität Karlsruhe

9. Participant 9 : University of Helsinki which includes **Subcontractor**

   University of Lund

10. Participant 10 : Universität Bern which includes external team members from

    Universität Zürich

In Table 2 the work plan for subcontractors is shown.