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RTN NETWORK

EURIDICE

European Investigations on DAΦNE and other International Collider Experiments using Effective Theories of Colours and Flavours from the Φ to the ϒ

EU contract no.: ERBFMRXCT2002-0311

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1 Overview of the Project

THE PAST

EURIDICE has been a project in precision studies in particle physics. It was the third in a series of successful research and training networks which collaborated with the experimentalists to give ever more refined predictions and explanations of low energy elementary particle interactions, through the most sophisticated theoretical methods, most of them developed by network members, Chiral Perturbation Theory one of them. The quest for such precision studies started 14 years ago, for what concerns the scientists who constituted the core of the three networks, and was rendered necessary by the planning of high luminosity particle accelerators, like the ϕ-factory DAΦNE in Italy, followed by BaBAR in the USA, BELLE in Japan, VEPP2M in Russia, etc.

THE PRESENT

At the end of its operation, EURIDICE has certainly fulfilled its mission, both in training and in research. As far as training is concerned, almost all the young researchers supported by the network have continued to work in the field of their choice in fundamental research, sometimes with another post-doc position, in some cases with long term or even permanent positions, as described in detail in the report to follow. As what concerns research, a number of fundamental physics quantities pertaining to our knowledge of the Standard Model have been clarified, and new methods to study processes like electron-positron collisions in the very low energy region, below 1 GeV, have been proposed by network members and proved to be effective in giving the required precision, through the combined work of of network members, experimental and theoretical physicists alike. In the sections to follow, these accomplishments will be described in detail, here we mention that the network has given important and lasting contributions to the precision with which a fundamental quantity like the muon anomalous magnetic moment is known, thus opening a window on the possibility of the existence of New Physics, just as the LHC starts working. Obtaining such results has required all the many different competences of the network, both from a theoretical point of view, from the phenomenological and from the experimental side. EURIDICE, like the two networks before, has provided a theoretical framework and an essential support to the groups involved in high-precision physics in Europe and elsewhere. An only partial proof of this is the presence of 2 members of the network in the Particle Data Group, where their expertise has contributed to the inclusion of recent result in Kaon physics and the return to central place of the enigmatic *scalar mesons*, like the well known and *(in)famous* σ-meson, whose properties various network members have been contributed to clarify.

THE FUTURE

The network has completed its mandate in August 2006 with a Final Meeting whose Proceedings, due in 2007, will illustrate both the work accomplished and the new directions to take. Some of these new avenues of research are not included in this Report, because the publications are just now appearing, but will be presented in the Proceedings of the Final Meeting and can be considered part of EURIDICE results. There are still many questions to be answered, especially for what concerns the basic mystery of the origin of CP-violation and whether it is possible to further increase the theoretical precision of $(g-2)_\mu$ or the value of very rare K-decays in studying the role played by Flavour in the New Physics. Such questions are left to the future, and to the many excellent young researchers trained by EURIDICE.

2 A - RESEARCH RESULTS

The EURIDICE project focused on a precise determination of masses, coupling constants and order parameters in the Standard Model. The major theoretical and phenomenological objectives of EURIDICE, stated in Annex I of the contract, can be grouped into six main research projects, respectively:

1. **CP- violation and Cabibbo-Kobayashi-Maskawa (CKM) matrix**
   - *To help clarify the origin of CP-violation*
   - *CP violation and rare decays*
   - *Quantum mechanics and the neutral meson system*
   - *To improve the theoretical precision for the CKM matrix elements*
2. **Chiral Perturbation Theory**
   - *To determine effective low-energy couplings from first principles*
   - *To investigate the order parameters of QCD*
   - *Baryon ChPT and Hypernuclei*
3. **Quark masses**
4. $\alpha_{\mathbf{em}}(\mathbf{M_Z})$ **and the anomalous magnetic moment of the leptons**
   - $(g-2)_\mu$ *and multi-loop calculations*
   - *Precision determination of electroweak parameters*
   - *The electroweak contribution*
   - *Hadronic Effects in electroweak precision observables*
5. **Heavy flavour decays and Heavy Quark Effective Theory (HQET)**
   - *D-decays*
   - *B-decays*
6. **Strong Interaction limit of QCD**
   - α_s *in the infrared region*
   - *Meson and baryon Spectroscopy beyond the naive Quark Model*
   - *New mesons and baryons*

In the sections to follow, the progress achieved towards attainment of these objectives during the four year period will be presented. We shall start with a list of the most interesting results obtained by the network, indicating, for each scientific highlight listed here, which node(s) participated to this research item and the bibliographic references. Node names follow the list in the section *Research effort with list of participant institutions.* Together with the theoretical and phenomenological work, important results have been obtained by the K Long Observation Experiment (KLOE) collaboration, whose progress and achievements will be described in a dedicated subsection prepared by KLOE. All the KLOE Collaboration papers cited here are joint publications between INFN nodes and the Karlsruhe subnode of the DESY Zeuthen node.

2.1 A1. Scientific Highlights

2.1.1 CP- violation and Cabibbo-Kobayashi-Maskawa (CKM) matrix

To help clarify the origin of CP-violation

- A joint Valencia-Vienna collaboration evaluated the isospin breaking corrections to the CP–direct observable ε'/ε [1].
- We have given the first full next-to-leading order analytical results in Chiral Perturbation Theory for the charged Kaon $K \to 3\pi$ slope g and decay rates CP-violating asymmetries. This is a Granada-Berne joint work [2].
- The UAB node together with the Marseille node obtained new results for the matrix elements of strong penguin operators, evaluated in a large-N_c approach, with analytic matching between short- and long-distances. They are very important for our future understanding of ϵ'/ϵ [3]
- INFN/LNF was the first to formulate in 2002 one of the most attractive approaches to explain why we have not observed yet any deviation from the SM in CP-violating observables and rare decays, the so-called Minimal Flavor Violation (MFV) hypothesis, subsequently generalized to the lepton sector [4] and its implementation in Grand Unified theories [5]
- Models of Higgsless electroweak symmetry breaking were built using the approach of effective field theory in a joint collaboration between the Orsay and UK node involving the young researcher supported by the network [6].
- The Lund node with the UAB/Granada group has constructed a hadronic model based on a systematic ladder resummation and has applied this model to the calculation of the kaon B_K parameter in the chiral limit, achieving excellent matching with the short-distance terms [7].
- The full set of $\Delta S = 2$ matrix elements which are required to study K^0-$\bar{K}^0$ have been obtained in lattice QCD by a Zeuthen-Marseille collaboration [8].

CP violation and rare decays

- The INFN/LNF and Naples node has largely contributed to bring forward the beginning of a new era in the study of rare K decays where for the first time it has been possible to obtain firm SM predictions for the two $\ell^+\ell^-$ modes and analyse their correlations with the two $\nu\bar{\nu}$ modes [9].
- The Orsay and Barcelona nodes designed a new method combining flavour symmetries and QCD factorisation to relate $B_d \to KK$ and $B_s \to KK$ decays [10]. The gain in accuracy was used to analyse the impact of supersymmetric models on these decays [11].
- The Orsay and INFN/Bari nodes have made joint studies concerning rare B decays in models with extra dimensions [12].

Quantum mechanics and the neutral meson system

- Entangled pairs of neutral kaons, such as those copiously produced at Daphne by ϕ decays, have been shown to be extremely useful and, in some cases, unique in order to test QM via Bell inequalities, quantum erasure, quantitative complementarity and duality. Most of this five years work is a Barcelona-Torino-Vienna collaboration [13].

To improve the theoretical precision for the CKM matrix elements

- A detailed numerical study of K_{e3} decays to $O(p^6, (m_d - m_u)p^2, e^2p^2)$ was performed by the Valencia-Vienna group [14] to extract the CKM matrix element $|V_{us}|$ from the experimental K_{e3} decay parameters.
- In 2004, members of the INFN node, in collaboration with external members from Rome and Orsay, have performed the first high-precision determination of the $K \to \pi$ form factor on the Lattice [15], a key element in the extraction of the CKM matrix element V_{us} from $K_{\ell 3}$ decays, through an innovative analysis which later on has been adopted by many other collaborations.
- A joint Valencia-Vienna collaboration studied $SU(3)$ breaking in $K_{\ell 3}$ decays and obtained new determination of the CKM matrix element $|V_{us}|$ [16]. Further estimates of $|V_{us}|$ were obtained from hyperon semi-leptonic decays by the Valencia group [17].
- The determination of the CKM angle γ has been investigated by the Orsay group through CP asymmetries in the three-body decays $B^- \to \pi^+\pi^-K^-$, $B^- \to K^+K^-K^-$, and $B^- \to \phi\phi K^-$ studying also the impact of the decay $B \to \pi\pi$ [18].
- The Orsay group has devised new precision tests involving semileptonic K decays of possible non standard couplings of right-handed quarks to W and of possible deviations from the unitarity of the effective CKM matrix [19].
- In the UK node, current experiment and phenomenology have been combined in work on D-decays with the FOCUS [20, 21] and BaBar Babar [22] collaborations, through the contribution of two young researchers supported by the network, and members of these collaboration, who participated to these studies that are essential to the precision determination of the elements of the CKM matrix.
- For the determination of V_{us}, the UAB/Granada and Lund nodes have calculated the two-loop corrections in the isospin limit : they were found to be significant, thus closing one of the remaining obstacles in improving the experimental precision on V_{us} from semileptonic kaon decays [23].

2.1.2 Chiral Perturbation Theory

- Electromagnetic corrections to hadronic processes were analyzed by the Bern group in a very general setting [24]. In particular, the relation between this splitting and the pertinent low energy effective theory was worked out in detail for a specific field theory model.

- The Bern group together with DESY Zeuthen performed a detailed numerical study [25] of finite volume effects for masses and decay constants of the octet of pseudoscalar mesons. For this analysis, chiral perturbation theory and asymptotic formulae a la Lüscher was used. An extension of the latter beyond the leading exponential term was proposed.

- The generating functional for Green functions of quark currents was given in closed form to next-to-leading order for chiral $SU(3)$ for both strong and nonleptonic weak processes with at most six external states by a Frascati-Vienna collaboration [26].

To determine effective low-energy couplings from first principles

- The leading order low energy couplings mediating kaon decays have been determined from first principles from the matching of lattice QCD with very light quarks with chiral perturbation theory in the epsilon-regime, through a joint Valencia-Marseille collaboration [27].
- The Valencia-Vienna collaboration presented an analysis of the contribution of resonances to the low-energy couplings of $\mathcal{O}(p^6)$ [28].
- The Orsay group has derived a set of coupled equations of the Roy and Steiner type for the S- and P-waves of the $\pi K \to \pi K$ and $\pi\pi \to K\bar{K}$ amplitudes. From experimental data above 1 GeV, tight constraints on the two πK S-waves scattering lengths were obtained. These relations were used to constrain combinations of $O(p^6)$ chiral coupling constants, focusing on flavour symmetry breaking terms related to vector resonances, which proved not to be dominated by resonance contributions. Related observables for the πK atom were investigated [29].
- The Orsay group has obtained sets of sum rules for low-energy constants of the electromagnetic and electroweak chiral Lagrangian, relating them to integrals of QCD three- and four-point correlators [30].
- The parameters of the effective Chiral Lagrangian from first principles, have been investigated through a joint collaboration between Bern and Zeuthen [31]using finite-size scaling studies in lattice QCD .
- Members of the Zeuthen, Marseille and Valencia nodes have pursued the analytical computation of non-singlet vector and axial vector two-point functions in sectors of fixed topology. New QCD simulation algorithms have been developed which allow simulations at fixed topological charge [32] with the aim to extract the low energy constants of the effective chiral Lagrangian.

To investigate the order parameters of QCD

- A systematic method was derived by the Bern group [33] to determine the cusp structure of $K \to 3\pi$ decays. The framework allows one to include real and virtual photons in a systematic manner. It is expected that, using these amplitudes, the $\pi\pi$ scattering lengths $a_0 - a_2$ can be determined with high precision from NA48 data.
- The Orsay group has investigated the effect of vacuum fluctuations of $s\bar{s}$ pairs on three-flavour ChPT. This effect is described by the $O(p^4)$ low-energy constants L_4 and L_6, which are suppressed at large-N_c, violate the OZI rule and are poorly known. A method was proposed to determine the flavour-dependence of chiral symmetry breaking through lattice simulations with dynamical fermions, using masses and decay constants of the pion and the kaon, with only a mild sensitivity to finite-volume effects [34].

ChPT and kaon decays.

- A Bern-UAB/Granada-INFN/Trieste collaboration presented the decisive theoretical prediction for the ratio of radiative and non-radiative Kaon semileptonic decays with percent accuracy (the same as the current experimental one) setting the route to generalizations, such as, e.g., the calculation of the muonic channels that will be measured in future high statistics experiments [35].

$\pi\pi$ and πK scattering

- The spectrum and decay width of $\pi\pi$, πK and πN exotic atoms were systematically analyzed by the Bern group [36]. The results will allow the DIRAC and the PSI Hydrogen group to determine, in principle, the pertinent hadronic scattering lengths with high precision.
- The full two-loop calculation in 3 flavour ChPT of $\pi\pi$ and πK as well as scalar form-factors have been done and used to study the agreement with experiment [37] by a joint Lund-UAB collaboration.

Resonance χPT

- It was demonstrated [38] by the Bern group that near threshold, the $\pi\pi$ scattering amplitude contains a pole with the quantum numbers of the vacuum, commonly referred to as the sigma. Its mass and width was determined within small uncertainties. The derivation does not involve models or parametrizations, but relies on a straightforward calculation based on the Roy equation for the isoscalar S-wave.
- A new analysis of the spectrum of scalar resonances within the large N_c expansion and chiral symmetry was performed by a joint collaboration between Valencia and Vienna [39].
- The Valencia node analysed the vector form factor of the pion at next–to–leading order in the $1/N_C$ expansion [40].
- The Valencia group performed a phenomenological study of the $\langle VVP \rangle$ (vector-vector-pseudoscalar) Green's function within the Resonance Chiral Theory [41] and, together with the Vienna node, of the vector-axial-pseudoscalar Green's function [42].
- The one loop renormalization of the Resonance Chiral Theory Lagrangian including one multiplet of scalar and pseudoscalar resonances was done by the Valencia node [43].
- Various meson decays within the chiral unitarity approach were studied by Valencia together with the UAB group [44].

Baryon ChPT and Hypernuclei

- In a joint UAB/Granada-Valencia collaboration, the complete and minimal $\mathcal{O}(p^2)$ and $\mathcal{O}(p^3)$ baryon SU(3) Chiral Perturbation Theory Lagrangians was constructed [45].

- The theoretical (and to some extent experimental) progress experienced in the last 15 years in the field of hypernuclear weak decay has been discussed in a review article [46] by the INFN/Torino group.
- The joint INFN/Torino-Barcelona studies of Ref. [47] contributed to clarify the origin of a long–standing puzzle on the ratio Γ_n/Γ_p between the neutron– and proton–induced decay rates, $\Gamma_n \equiv \Gamma(\Lambda n \to nn)$ and $\Gamma_p \equiv \Gamma(\Lambda p \to np)$.
- A new interpretation of the KEK and FINUDA data, disclaiming the assessments made about deeply bound kaon states in nuclei was proposed by the Valencia group, who also performed in-depth studies at Next-To-Leading order, in Unitary Chiral Perturbation Theory, of meson-baryon scattering with $S = -1$ in S-wave [48].
- A systematic construction of the baryon form factors in all forms of relativistic quantum mechanics was achieved by the Helsinki node, with the collaboration of the young researcher supported by the contract. The results allow a comparison of the phenomenological differences between Galilean and Poincare' covariant quark model results [49].
- A Helsinki-Warsaw collaboration studied the $\eta - nucleon$ and $\eta - nucleus$ interaction and found that a large (about 0.9 fm) $\eta - N$ scattering length is obtained [50].

2.1.3 Quark masses

- The Valencia node and UAB/Granada nodes have obtained important results in the determination of the mass of the strange quark, m_s, and the CKM matrix element $|V_{us}|$ from hadronic tau decays [51].
- From the available $\pi\pi$ data, the Orsay group derived a lower bound for the quark mass ratio $r = m_s/m > 14$ with 95% confidence level, keeping open the possibility of large vacuum fluctuations of $s\bar{s}$ pairs. [52]
- A major achievement of the Lund node in which the young researcher has played an extremely important role, has been the extension of partially quenched ChPT to two loop-order, an important contribution to extrapolation of lattice QCD data to physical quark masses [53].

2.1.4 $\alpha_{em}(M_Z)$ and the anomalous magnetic moment of the leptons

$(g-2)_\mu$ and multi-loop calculations

- A program to solve numerically the system of differential equations for the master integrals of the general massive 2-loop 3- and 4-denominator self-mass diagrams was developed by the joint INFN/Bologna and Warsaw/Katowice collaboration. A novel numerical method to obtain results for values of external four momentum at and close to thresholds and pseudo-thresholds was proposed [54].
- A further very important result is the first independent check of the four-loop QCD β-function and the anomalous dimensions [55] at Zeuthen.

- The famous Adler-Bardeen non-renormalization theorem of the triangle anomaly has been extended to the non-anomalous transversal amplitudes up to two loops by a calculation of the QCD corrections to the singlet currents by the DESY Zeuthen group [56].
- Progress was made also in the calculation of contributions to the Bhabha process at two–loops by the DESY Zeuthen-Warsaw/Katowice collaboration [57] and the complete two-loop virtual plus soft contributions were evaluated in Karlsruhe [58].
- An efficient Monte Carlo program for the simulation of massive particle production including photon radiation was developed [59] by DESY Zeuthen and Warsaw/Katowice nodes.

Precision determination of electroweak parameters

- For the first time a Zeuthen-Warsaw/Katowice-Durham collaboration was able to perform a complete Standard Model calculation, at the two loop level, for the effective leptonic weak mixing angle, $\sin^2\theta_{\rm eff}^{\rm lept}$ and the W-mass M_W. The main impact is a shift of the indirect bound on the Higgs mass from LEP by δM_H =+19 GeV [60].

The electroweak contribution

- The electroweak hadronic contribution to $(g-2)_\mu$ was improved in a joint Barcelona-Marseille analysis via the implementation of the current algebra Ward identities and the inclusion of the correct short-distance QCD behaviour of the relevant hadronic Green's function. New non–renormalization theorems for the non–anomalous sector were also proven [61]

Hadronic Effects in electroweak precision observables

- High precision evaluations of the hadronic contributions to $(g-2)_\mu$ and $\alpha_{em}(M_Z)$ have been performed by DESY Zeuthen, using new data from KLOE (Frascati), CMD-2/SND (Novosibirsk) and from radiative return measurements at BABAR(Stanford) [62], which leads to a substantial reduction of the uncertainty in the $(g-2)_\mu$ prediction.
- The large discrepancy between the e^+e^--data and the τ-data (after applying the known isospin corrections) has been analysed by DESY Zeuthen in [63]. An explanation would be so far unaccounted isospin breaking effects by shifts in masses and widths of charged versus neutral vector-boson states like the ρ.
- The Karlsruhe-Katowice/Warsaw nodes have extended the Monte Carlo generator TAUOLA to include now also the decay mode $\tau \to \nu 5\pi$ [64].
- The PHOKHARA Monte Carlo generator created by a Warsaw/Katowice-Karlsruhe-Valencia collaboration has been substantially improved and extended and is now the standard tool to utilise the Radiative Return at KLOE, CLEO-C, BABAR and BELLE for a precise measurement of the pion form factor and other hadronic cross sections at low energy [65, 66, 67]. The generator has implemented, besides $\pi^+\pi^-$ including final state radiation effects, also 3π, 4π, $2K$ etc.

- Final State Radiation in $\pi^+\pi^-$–production and its impact on the anomalous magnetic moment of the muon has been analysed by Zeuthen/Karlsruhe, Warsaw/Katowice, and INFN/LNF groups [68, 69] The impact of combined ISR and FSR on the pion form factor extraction was investigated together with the model dependence of the FSR corrections.
- A method of a measurement of the electric and magnetic nucleon form factors at B-meson factories through the radiative return was proposed by Valencia-DESY Zeuthen-Katowice/Warsaw nodes in [70]. The extension of the Monte Carlo event generator PHOKHARA to nucleon final states, allowed for detailed feasibility study. The proposed method was successfully used afterwards by BaBar collaboration for extraction of the electric and magnetic proton form factors in a wide range of proton-antiproton pair invariant masses.

2.1.5 Heavy flavour decays and Heavy Quark Effective Theory (HQET)

- The coupled $\eta - N$, $\pi - N$, $\gamma - N$, $2\pi - N$ system was described by a K-matrix method by Warsaw-Helsinki nodes in [71]. The parameters in this model are adjusted to get an optimal fit to $\pi - N \to \pi - N$, $\pi - N \to \eta - N$, $\gamma - N \to \pi - N$ and $\gamma - N \to \eta - N$ data in an energy range of about 100 MeV or so each side of the η-threshold.

Heavy Quarkonia

- A comprehensive review on applications of effective field theory techniques to heavy quarkonium systems has been written and published during the Euridice contract period, with members from the UAB node [72].

τ decays

- The Valencia node studied the decay $\tau^- \to (\pi\pi\pi)^-\nu_\tau$ within the framework of the Resonance Effective Theory of QCD [73] and, in collaboration with the UAB node, both the Scalar and Vector form factors in $\tau \to K\pi\nu_\tau$ [74]

D-decays

- The Oslo subnode has concentrated on developing a heavy-light chiral quark model[75] and applying it to B and D decays.

B-decays

- The Bern group took the first steps towards a complete next-to-next-to-leading logarithmic (NNLL) calculation of the decay rate for $B \to X_s\gamma$ and performed [76] a calculation of the $O(\alpha_s^2)$ contribution to the decay width $\Gamma(\bar{B} \to X_s\gamma)$ which arises from the self-interference term of the electromagnetic dipole operator. This work is an important ingredient for the complete NNLL prediction of this decay width.
- Warsaw-Zürich nodes demonstrated in [77] that the sign of the $b \to s\gamma$ amplitude can be determined from the current data on $b \to sl^+l^-$. This observation is relevant to many popular extensions of the SM. In particular, it excludes a sizeable domain in the parameter space of the MSSM.

- The first estimate of the $B \to X_s\gamma$ branching ratio at the next-to-next-to-leading order in QCD was obtained by Warsaw and other nodes and presented at the Final EURIDICE Meeting (http://server.phys.us.edu.pl/ euridice/). Three-loop on-shell diagrams as well as four-loop anomalous dimensions were calculated for this purpose.
- Semileptonic B-decays in the heavy-quark limit of QCD were studied through Bjorken-like sum rules. New results came from considerations of the non-forward amplitude and the systematic use of particular boundary conditions that allow to put bounds on derivatives of the Isgur-Wise function. These results were extended to include $1/M_B$ corrections. It has also been demonstrated that, in the heavy quark limit, the Bjorken-like sum rules imply that the Isgur-Wise function is explicitly known in the BPS limit [78].
- The Orsay group proved QCD factorisation at one loop for the radiative B-decays $B \to \gamma l\nu$, $B \to \gamma\gamma$ and $B \to \gamma l^+l^-$, and large Sudakov logarithms were resummed in the framework of Soft Collinear Effective Theory. The radiative decays $B \to V\gamma$ (with V a vector meson) were also shown to factorise at one loop [79].
- The Orsay group, also in collaboration with INFN/Bari node, studied the factorisation ansatz, pointing out the tests provided by the decay rates of $B \to K_1\pi$, $B \to a_1K$ and $B \to b_1K$. Nonfactorisable contributions to several classes of two-body B-decays were shown numerically significant, even though they are suppressed in the heavy-quark limit (charming penguin, final-state interactions). Experimental data on these decays support this conclusion [80].

2.1.6 Strong Interaction limit of QCD

α_s in the infrared region

- In a joint INFN/LNF and Barcelona/Granada collaboration, the energy dependence of total hadronic cross-sections and its dependence upon the behaviour of α_s in the infrared region has been investigated. A singular α_s formalism has been shown to be necessary and predictions for $\sigma^{tot}_{LHC} = 90 \pm 10\ mb$ at the LHC have been presented [81].

Diffraction and total cross-sections

- Diffractive processes in QCD [82, 83], topics relevant to present and future collider experiments, have also been studied by the UK node.

Photon structure functions

- New, radiatively generated, LO [84] and NLO [85] quark (u,d,s,c,b) and gluon densities in a real, unpolarised photon were proposed by Warsaw and Granada nodes. A global 3-parameter fit, to all available data for the structure function $F_2^\gamma(x, Q^2)$ was performed and a new theoretical approach called ACOT(chi), originally introduced for the proton, to deal with the heavy-quark thresholds was adopted.

Meson and baryon spectroscopy beyond the naive Quark Model

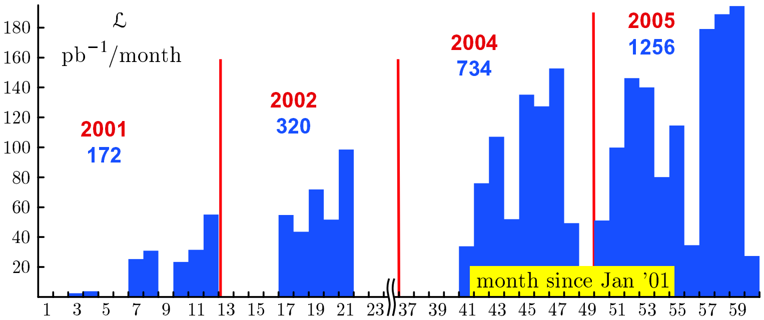
- The properties of the Wilson loop in QCD for large contours were investigated by the Orsay group and the resulting covariant three-dimensional bound state equation for the quarkonium system was studied in the nonrelativistic and ultrarelativistic limits [86].
- The Orsay node used their solutions of Roy-Steiner equations to prove the existence of the light scalar meson $K_0^*(800)$ (also called κ) in a rigorous way, with the following mass and width: $E_\kappa = 658 \pm 13$ MeV and $\Gamma_\kappa = 557 \pm 24$ MeV. [87].
- The Helsinki node collaborated to an extensive review of "Mesons beyond the naive quark model" for Physics Reports, which contains theoretical predictions and experimental observations on possible four-quark states, deuteronlike mesonic states, the light scalars, glueballs and hybrid mesons [88].

New mesons and baryons

- A very large amount of work has been done in spectroscopy of heavy states, especially through the UK node, whose major interest has been in the new hadronic states, both mesons and baryons, that have been freshly discovered during the period of the contract in a series of experiments at BaBar, Belle, Fermilab and JLAB. The focus has been on the interpretation of these states [89, 90, 91, 92] and their relation to QCD dynamics [93, 94, 95].
- The Helsinki node has studied the recently observed new narrow charmonium and charm-strange mesons observed by BaBar, Belle, Cleo and BES - advancing especially the possibility that the 3872 MeV state of Belle is a deuteronlike $D\bar{D}^*$ bound state [96].
- The Valencia group studied a dynamical generation of baryonic resonances and consequent description of many known and new resonances. In particular a resonance of positive strangeness coming from $\Delta\, K$ interaction in $I = 1$ is predicted [97].
- An analysis of pentaquark states to determine spin and parity of the Θ^+, its possible origin as a $K\pi N$ bound state and the existence of hypernuclei of Θ^+ was performed by the Valencia group [98].

2.2 Results and achievements of the KLOE collaboration

Electron and positrons first collided in DAΦNE 1998. Machine start-up problems were such that in April '99 KLOE measured a luminosity several orders of magnitude below design and by the end of 2000 KLOE had collected an integrated luminosity of $\sim$17 pb^{-1}, just barely enough to demonstrate the functionality of KLOE and the feasibility of parts of its program.



Luminosity delivered by DAΦNE to the KLOE experiment in the years 2001-2005.

Early results. Using that data KLOE demonstrated the possibility of using a true, pure K_S-beam, tagged by the observation of the presence of a K_L-meson. Early results where presented at the 2001 Lepton-Photon conference in Rome, see ref. [99], K_S:$\to\pi^+\pi^-\pi^0\pi^0$, K_S semileptonic decays; ref. [100], η' production in ϕ-decays; ref. [101], f_0 and a_0 production in ϕ-decays; ref. [102], the first attempt to measure $e^+e^-\to$hadrons+gam, via initial state radiation.

K_S decays, radiative ϕ decays, f_0, a_0, η, η'. By the end of 2000, in a sample of $\sim 5\times 10^7$ ϕ-decays, KLOE isolated some 624±30 $K_S\to\pi^\pm e^\mp\nu$ events of great purity, obtaining BR=$(6.91\pm 0.37)\times 10^{-4}$, see ref. [103]. These decay mode had remained unknown until 3 years earlier. The quoted result was the first to prove the power of a tagged K_S-beam. With the same data other measurements were performed.

- The reaction $\phi\to\eta\pi^0\gamma$, ref. [104].
- The reaction $\phi\to\pi^0\pi^0\gamma$, ref. [105]. Both used for study of and study of f_0, a_0.
- The ratio $\phi\to\eta'\gamma/\phi\to\eta\gamma$, ref. [106].

Other early results

- The reaction $\phi\to\rho\pi$, is studied in ref. [107].
- The rate for $K_L\to\gamma\gamma$is given in ref. [108].
- The branching ratio for $K^\pm\to\pi^\pm\pi^0\pi^0$, ref. [109].

2001-2002. Beginning with the second half of 2001 DAΦNE operation substantially improved and KLOE succeeded in accumulating data for a luminosity of $\sim$450 pb^{-1}, by the end of 2002. Many measurements were performed by KLOE with this data.

- We obtained an upper limit for the rate of the C-forbidden decay $\eta\to 3\gamma$, ref. [110].
- Measurement of $\sigma(e^+e^-\to\pi^+\pi^-\gamma)$ and extraction of $\sigma(e^+e^-\to\pi^+\pi^-)$, of importance for the hadronic correction to the muon anomaly, ref. [111].
- Upper limit to the rate for $\eta\to\pi^+\pi^-$, a forbidden process, ref. [112].
- An important parameter of the ϕ-meson is its leptonic width which KLOE has measured directly, ref. [113].
- Thanks to the availability of a pure K_S beam KLOE has obtained the most stringent limit on the CP violating transition $K_S\to\pi^0\pi^0\pi^0$, ref. [114].

Mostly using tagged kaon beams KLOE has also undertaken a wide program of measuring all large and small absolute decay rate of all species of K-mesons. We often have measured absolute branching ratio, used unitarity constraint and measured lifetimes as well.

- The K_L lifetime has been measured from the time dependence of the $3\pi^0$ mode, ref. [115].
- We have measured the dominant K_L branching ratios and lifetime, ref. [116] by K_S tag.
- The absolute value of BR($K^\pm \to \mu^\pm \nu$) is obtained from charged kaon tag, ref. [117].
- The decay $f_0 \to \pi^+\pi^-$ has been studied in ref. [118], determining the f_0 mass and its couplings to ϕ, $\pi^+\pi^-$ and $K\bar{K}$.
- We find BR($K_S \to e^\pm \pi^\mp \nu$)=$(7.046 \pm 0.091) \times 10^{-4}$ and a charge asymmetry of $(1.5 \pm 10) \times 10^{-3}$, consistent with CPT invariance we obtain the most stringent test of the $\Delta S = \Delta Q$ rule, $\Re x_+$=$(-1.2 \pm 3.6) \times 10^{-3}$, ref. [119].
- The most accurate value for $\Gamma(K_S \to \pi^+\pi^-)/\Gamma(K_S \to \pi 0)$=2.2549$\pm$0.0054, ref. [120].
- For K_L-mesons we have measured the form factor parameters for $K_L \to \pi e \nu$, ref. [121] and BR($K_L \to \pi^+\pi^-$), ref. [122].
- The KLOE precision measurement of the luminosity at 1.02 GeV, necessary for the measurement of $\sigma(\pi^+\pi^-)$ is described in ref. [123].
- A full Dalitz plot analysis of $\phi \to \pi^0\pi^0\gamma$ has been performed to extract the f_0 parameters, [124].
- The first observation of Quantum Interference in the two kaon system is to appear in Phys. Lett. B [125].
- A complete analysis of kaon decays using KLOE data and unitarity leads to new stringent limits on CPT invariance [126].

2.3 Most relevant joint publications

In this section we list a selection of five of the most significant joint publications by the network. These publications have had a high impact on the field, they are all classified in the *topcite = +50* range by the data base Spires of Stanford University. We list the 5 papers ranking them according to the highest citation count. For each of them, we indicate the objective to which they refer to and the nodes which have participated to this work. Copies of these 5 papers are included as Annex.

Following this list, we have listed two highest impact publications in particle physics, namely The Review of Particle Physics of the years 2004 and 2006 where the authorship includes two members of our network from different nodes. Strictly speaking this is not a network publication because it is really a global world wide activity, independently supported, and as such it does not acknowledge the support of the network. However, we consider that the contribution by the two members of our network reflects the overall achievements of the EURIDICE project and wish to acknowledge it here.

Finally, in order to render at least a very partial credit to the many excellent publications of the network, we list ten other joint publications which have been very important for our joint work and which have had a high impact on the community. We indicate in **bold face** the name of young researchers participating to one of these publication while supported by the network.

Five highest impact Joint Publications

1. Nodes : **INFN-DESY Zeuthen/Karlsruhe**

   Objective : $\alpha_{em}(M_Z)$ **and the anomalous magnetic moment of the leptons**

   Task : σ_{total} : Hadronic Effects in electroweak precision observables

   Title : *Measurement of* $\sigma(e^+e^- \to \pi^+\pi^-\gamma)$ *and extraction of* $\sigma(e^+e^- \to \pi^+\pi^-)$ *below 1-GeV with the KLOE detector*

   Authors : By KLOE Collaboration (A. Aloisio et al.). Jul 2004. 20pp.

   Published in Phys.Lett.B606:12-24,2005 e-Print Archive: hep-ex/0407048

   Cited 74 times

2. Nodes : **Lund-UAB**

   Objective : Theoretical studies in **Chiral Perturbation Theory**

   Task : Rare K-decays

   Title : *K(l3) decays in chiral perturbation theory*

   Authors : Johan Bijnens (Lund U., Dept. Theor. Phys.) , Pere Talavera (Barcelona, Polytechnic U.) . LU-TP-03-10, Mar 2003. 22pp.

   Published in Nucl.Phys.B669:341-362,2003 e-Print Archive: hep-ph/0303103

   Cited 72 times

3. Nodes : **Valencia-Vienna**

   Objective : **CP Violation and Cabibbo-Kobayashi-Maskawa Matrix**

   Task : CKM Matrix and rare K-decays

   Title : *K(e3) decays and CKM unitarity*

   Authors : V. Cirigliano (Valencia U., Caltech) , H. Neufeld (Vienna U.) , H. Pichl (PSI, Villigen) . IFIC-03-41, MAP-293, UWTHPH-2003-22, PSI-PR-03-13, Jan 2004. 13pp.

   Published in Eur.Phys.J.C35:53-65,2004 e-Print Archive: hep-ph/0401173

   Cited 61 times

4. Nodes : **Warsaw/Katowice-DESY Zeuthen/Karlsruhe**

   Objective: $\alpha_{em}(M_Z)$ **and the anomalous magnetic moment of the leptons**

   Task : Monte Carlo Methods and radiative corrections for σ_{had} at KLOE and PEPII

   Title : *The Radiative return at Phi and B factories: FSR at next-to-leading order*

   Authors : Henryk Czyż, Agnieszka Grzelińska (Silesia U.), Johann H. Kühn (Karlsruhe U., TTP) , German Rodrigo (CERN)

   Published in Eur.Phys.J.C33:333-347,2004 e-Print Archive: hep-ph/0308312

   Cited 52 times

5. Nodes : **Bern-DESY Zeuthen**

   Objective: Theoretical Studies in **Chiral Perturbation THeory**

   Task: Lattice QCD and Chiral Perturbation Theory

   Title : *The Pion mass in finite volume*

   Authors : Gilberto Colangelo (Bern U.) , Stephan Dürr (DESY, Zeuthen) . DESY-03-177, Nov 2003. 17pp.

   Published in Eur.Phys.J.C33:543-553,2004 e-Print Archive: hep-lat/0311023

   Cited 53 times

Contribution by INFN/Naples and Helsinki nodes to the Review of Particle Physics

1. S. Eidelman et al., REVIEW OF PARTICLE PHYSICS. PARTICLE DATA GROUP. Phys.Lett.B592:1,2004.

   Cited 3343 times in the HEP (SPIRES-SLAC) database.

2. W.-M. Yao et al., REVIEW OF PARTICLE PHYSICS. J.Phys.G33:1-1232,2006.

   Cited 187 times in the HEP (SPIRES-SLAC) database.

Other important high impact joint publications

Valencia-UAB

D. Jido, J.A. Oller, E. Oset, A. Ramos, U.G. Meissner, *Chiral dynamics of the two Lambda(1405) states*, Nucl.Phys.A725:181-200,2003 [nucl-th/0303062].

TOPCITE = 50+

Cited 78 times

INFN/Bari-CNRS/IN2P3

P. Colangelo, F. De Fazio, T.N. Pham, *The Riddle of polarization in $B \to VV$ transitions*, Phys.Lett.B597:291-298,2004 [hep-ph/0406162].

TOPCITE = 50+

Cited 51 times

Valencia-UAB/Granada

Elvira Gamiz, Matthias Jamin, Antonio Pich, Joaquim Prades, Felix Schwab, *V_{us} and m_s from hadronic τ decays*, Phys.Rev.Lett.94:011803,2005 [hep-ph/0408044].

Cited 48 times

DESY Zeuthen-Warsaw/Katowice-Durham

M. Awramik, **M. Czakon**, A. Freitas, G. Weiglein, *Precise prediction for the W boson mass in the standard model*, Phys.Rev.D69:053006,2004 [hep-ph/0311148].

Cited 43 times

Orsay-Durham

Johannes Hirn, Jan Stern, *The Role of spurions in Higgsless electroweak effective theories* Eur.Phys.J.C34:447-475,2004 [hep-ph/0401032].

Cited 42 times

Valencia-Vienna

V. Cirigliano, G. Ecker, H. Neufeld, A. Pich, *Meson resonances, large N(c) and chiral symmetry*, JHEP 0306:012,2003 [hep-ph/0305311].

Cited 39 times

Marseille-UAB

Thomas Hambye, Santiago Peris, Eduardo de Rafael *Delta I = 1/2 and ϵ'/ϵ in large N_c QCD* JHEP 0305:027,2003 [hep-ph/0305104]

Cited 37 times

INFN-Bern-Vienna

Gino Isidori, **Christopher Smith**, Rene **Unterdorfer** *The Rare decay* $K_L \to \pi^0\mu^+\mu^-$ *within the SM*, Eur.Phys.J.C36:57-66,2004 [hep-ph/0404127]

Cited 37 times

Lund-UAB/Granada

Johan Bijnens, Elvira Gamiz, Edisher Lipartia, Joaquim Prades, *QCD short distance constraints and hadronic approximations*, JHEP 0304:055,2003 [hep-ph/0304222]

Cited 24 times

Vienna-Valencia

V. Cirigliano, G. Ecker, M. Eidemüller, **Roland Kaiser**, A. Pich, J. Portoles, *The* $\langle SPP \rangle$ *Green function and SU(3) breaking in* K_{l3} *decays*, JHEP 0504:006,2005 [hep-ph/0503108]

Cited 24 times

3 Part B-Comparison with the Joint Program of Work (Annex I of the contract)

3.1 Research Achievements

The network has obtained important results in the field of high precision estimates of a number of fundamental quantities measured through low energy interactions of elementary particles. All the tasks indicated to the attainment of the objectives were addressed by the nodes. The methodology used has been the one indicated in the original project and based on Effective Field Theories of Colour and Flavour and related theoretical techniques, like

Tasks

Methodology

- Chiral Perturbation Theory
- Large N_c- expansion
- QCD Lattice simulations
- Heavy Quark Effective Theory
- Exact Renormalization Group
- QED and Perturbative QCD
- Quantum Mechanics

In the objective related to CP violation and the determination of the CKM matrix (Objective 1) the most important results have concerned the determination of the matrix element V_{us} with high precision. The most recent determination, $|V_{us}|0 = 0.2248 \pm \ 0.0020$, was obtained through both theoretical and experimental efforts. Chiral perturbation theory, lattice QCD, $1/N_c$ expansion have been the main theoretical tools, implemented as well by perturbative techniques, whenever applicable. From the point of view of phenomenology, the network has participated to the analysis of processes from the two B-factories, Belle and BaBar, which have led to the most precise determination of other CKM matrix elements, obtained from a determination of the angles of the unitarity triangle. Scientists from various nodes and young researchers supported by the network were involved in these analyses, following the project tables with task assignments. For Objective n. 2, refining predictions from Chiral Perturbation Theory, there has been intense activity in in a large number of ChPT calculable processes, extending the predictions from two to the three flavour case, and completing a number of calculations to order p^6 . Concerning determination of quark masses (Objective n.3) some of the efforts leading to the determination of V_{us} have also allowed a new determination of the strange quark mass, $m_s = 81 \pm 22 MeV$.

Objective 1

Objective 2

Objective 3

Major research results concerns the reduction of the theoretical error on the value of the anomalous magnetic moment of the muon. To this end, one needs to evaluate different contributions, like light-by-light scattering, higher order electroweak terms, and mostly the hadronic contribution, which is estimated through knowledge of the $e^+e^- \to hadrons$ cross-section from threshold to asymptotic energies. This error has been reduced, in agreement with the network work program, through an intense phenomenological activity based on many items, among them :

Objective 4

- development of a method to measure the hadronic e^+e^- cross-section below 1 GeV
- development of a a MonteCarlo simulation program to implement radiative corrections
- precision estimate of the luminosity through radiative Bhabha events
- good theoretical modelling for the pion form factor and Final State Radiation

Thanks to the large number of data appearing during the period of operation of this network from experiments like BaBar, Belle, Focus, KLOE, CLEO, etc., B- and D-meson decays could be studied and models for these interactions refined. The network had a large activity in this direction and participated to global efforts to study quarkonium properties and structure through Heavy Quark Effective Theories. For the same reason, namely availability of a large amount of new data, meson spectroscopy occupied center stage with new states, both mesons and baryons, to be studied. The network was very active in proposing interpretations in terms of hybrids, glueballs, four quark states. Concerning the latter, the question of the σ-meson was addressed both phenomenological as well as theoretically, and a value for its mass and width proposed.

Objective 5

Objective 6

From the brief panorama of the network research results, one can see that all the objectives were approached and important breakthrough obtained. In addition, and following both the task assignments and the milestone table, there has been an intense activity aimed at proposing experiments for future machines, like the proposed $\tau - charm$ factory or the upgrade in energy and luminosity of DAΦNE . Throughout its operation, the network research effort has been in line with the milestone table proposed in the original project. The Fourth Periodic Report shows that all the milestones have been reached.

Milestones

3.2 Research effort with list of participant institutions

The research effort of the participant has been in agreement with the work program, as show in the Fourth Periodic Report, with a total of 173 researchers involved during the period of operation, to be compared with the originally proposed 169.

RESEARCH EFFORT OF THE PARTICIPANTS

The network consisted of 1 Coordinator and 11 participants, 10 of which from Member States and 1 from Switzerland. Some of the teams include researchers belonging to different institutions, as we specify in the following.

1. Istituto Nazionale di Fisica Nucleare [INFN-LNF] established in Italy which includes external team members from Sezione INFN di Roma1, Sezione INFN di Roma3, Sezione INFN di Napoli, Sezione INFN di Bari, Sezione INFN di Perugia, Sezione INFN di Bologna, Sezione INFN di Trieste, Sezione INFN di Torino

2. University of Valencia [UVEG] established in Spain which includes external team members from University of Madrid

3. Universitat Autonoma de Barcelona [UAB] established in Spain which includes external team members from Universidad de Granada, Universitat de Barcelona, Universitat Politecnica de Catalunya

4. CNRS-CPT Luminy, Marseille [CNRS-DR12] established in France

5. CNRS - Institut National de Physique Nucleaire et de Physique des Particules [CNRS/IN2P3] established in France, which includes external team members from IPN- Orsay, LPT - Orsay, Ecole Polytechnique - Palaiseau, LPNHE - Paris.

6. Universiy of Durham [DUR] established in the United Kingdom which includes external team members from Oxford University, University of Manchester

7. University of Lund [ULUND] established in Sweden which includes external team members from University of Oslo, Norway

8. University of Helsinki [UHELS] established in Finland

9. DESY Zeuthen [DESY Zeuthen] established in Germany which includes external team members from University of Karslruhe

10. University of Bern [UNIBE] established in Switzerland which includes external team members from University of Zurich

11. Universitat Wien [UWIEN.ITP] established in Austria

12. Warsaw University [Warsaw] established in Poland which includes external team members from IPJ (Soltan Institute of Nuclear Studies), Warsaw and University of Silesia, Katowice

The network had two subnodes

- University of Oslo, Norway, as a subcontractor of University of Lund, Sweden
- University of Karslruhe, Germany, as a subcontractor of DESY Zeuthen, Germany

3.3 Overall Organization, management and public outreach

Executive Committee

The network activities were organized through the Executive Committee, constituted of the 12 scientists-in-charge, and implemented by representatives from the two subnodes, i.e. Karlsruhe (DESY-Zeuthen subnode) and Oslo (Lund subnode), the representative from the Granada team, the monitor of progress in B-physics, L. Oliver from the Orsay node, and the Analysis Coordinator of the KLOE experiment, J. Lee-Franzini from the LNF-INFN node.

Co-ordination

Coordination and communications among nodes were based on the Team Committee constituted by the scientists in charge, who exchanged frequent e-mails and telephone calls to discuss and plan both network meetings as well as the training programme. Exchanges among the node scientists were based on common interests and in some cases long term collaborations, and difficulties have always been easily resolved. The overall spirit of this network was very positive, and cooperative, with the overall Coordinator held responsible to keep track of various deliverables, like training and periodic reports.

Dis-semination of results

Very early on, the network established its own web page where the status of the network activities could then be regularly checked through the network web page,

http://www.lnf.infn.it/theory/rtn/ with posting of announcement of meetings as well as available. In the web page, it was also possible to follow the publication record of each member of the network, through a link to the Stanford University data base SPIRES.

Conference participation

To disseminate the network research activities, scientists from the network, including young researchers, attended many International Meetings, where they gave plenary or otherwise invited talks as well acted as convenors of dedicated sessions.

Public outreach took place through a number of writings and public lectures related to network activities. A very partial list includes :

Public outreach

- ⋆ A description of the life and work of Richard Dalitz, a member of Oxford University faculty, and a fundamental figure in particle physics, prepared by F. Close from the UK node, and published in national newspapers in the UK.
- ⋆ Presentations and articles for non-specialists in correspondance of the 30th anniversary of the discovery of the J/Ψ [127]
- ⋆ Seminars and Colloquia held during Open Laboratory Days of Frascati National Laboratories or during the Physics Meetings with High School teachers, held yearly in October, in Frascati and attended by more than 200 Italian high school teachers.
- ⋆ Public lectures by G. Pancheri on the life of the Austrian physicist Bruno Touschek, who was the first to propose e^+e^- collisions in Frascati in 1960, held at U. of Vienna, in Kazimierz during Photon2005, Town Hall of Frascati, Liceo Pilo Albertelli in Rome, etc.
- ⋆ Colloquia and public lectures on *Women in Science* by G. Pancheri, in Helsinki University, Rome Science 2003, etc.

Organization of meetings

The network research and training activity was enforced through a number of meetings organized by the network, where also external participants were invited, both as attendees and speakers. The list includes:

network wide

- *Collaboration Meetings:* a total of 7 Collaboration meetings were held, namely

- Start-up Collaboration Meeting held in Frascati in October 2002
- Collaboration meetings in Orsay in 2003, Vienna in 2004, Frascati in 2005, Marseille in 2006
- Midterm Review Meeting held in Frascati in February 2005
- Final Meeting held in Kazimierz, Poland, in August 2006

• *Topical Workshops:* Small workshops focused on particular tasks or research objectives were held on the following topics

Topical Workshops

- Meson Spectroscopy in Barcelona, 2004
- Chiral Dynamics in Valencia, 2003 and 2005
- Sigma hadronic and $(g-2)_\mu$ in Pisa, 2003
- Hadronic Atoms in Trento, 2003, and Bern, 2005

• *LNF Spring School "Bruno Touschek":* The School , which was started in 1996 to train young researchers from the TMR network EURODAPHNE and young experimentalists from KLOE , FINUDA and DEAR collaborations, was held yearly, during the third week of May, mostly with financial support from INFN

The School

In addition to meetings and workshops, networking activities included also regular exchanges between nodes to complete or start new research project. We have listed in the annual reports many of the secondments which took place.

Networking activities

Overall, the success of the research program was based on the fact that the network included almost all the European experts in Effective Field Theories, and that these experts had the frequent chance of meeting together and discuss their views. Another positive element of this network was its ability to move young researchers trained in one node to another node, without loss of continuity in the young researcher's work, since often the young researchers had already collaborated with scientists of the new node. This is for instance the case of the young researcher Agnieszka Grzelińska, author of one of the top 5 joint publications of the network while in Poland, afterwards to join the Karlsruhe subnode as a EU supported young researchers. The increased knowledge obtained by bringing together various facets of theoretical research in the field of Effective Field Theories in Europe has resulted in high joint productivity, good employment record of the post-docs and fruitful collaboration with the experimental groups, KLOE in particular. All this could have hardly been achieved by the national programs, where bi-lateral Memoranda of Understanding abound, but which lack the overall strength of a many countries network.

3.4 Training Overview

Filling the training positions

The network encountered no difficulties in filling the training positions. Most of the training was advertised during the first year, and most positions were filled starting from the second year. Still, some nodes delivered the training immediately, others in the last two years. Positions were advertised through the Cordis site, and through the distribution list of CERN theory division, which reaches all European theoretical physics groups, and through national lists, like INFN Theoretical Physics National Commission (CSN4). Applications came both from young researchers reached through these lists as well as from personal contacts between scientists. It should be noted in fact that this was the third of three successful Research and

Training networks, and the network scientists in some cases had already excellent candidates for pre-doc or post-doc positions Appointments were decided locally, but approved by the Network Team Committee during the periodic Executive Committee Meetings held at least once a year. Our training objective was of 302 person month of young researchers, of which 48 pre-doc and 254 post-doc. Of these 302 person-months, 278 were to be provided with EU funding, the remaining 24 by the Bern node, with funding through the Swiss government. Pre-doc training was proposed to be in the amount of 48 months, from the INFN-LNF (24 pm) and the Durham node (24). At the end , the network has delivered 329.5 person-months of which:

PRE-DOC AND POST-DOC

- 27 months of predoc training versus 48 in the Contract
- 302.5 of post-doc training versus 254 in the contract, 23 of which funded by the Swiss government, the remaining through EU funding.

Permission was requested for the change from pre-doc to post doc. In the INFN case, the change affected Stephanie Trine who came to the INFN /LNF node 5 months before formally obtaining her PhD and was hired initially as a pre-doc. We have listed her training as post-doc, because when she came she had completed her PhD thesis requirements at University of Louvain, but her training was more in the spirit of preparing a young researcher to make the transition from a student to a professional position. After the network position, Stephanie Trine obtained a Post-doc position for tree years with the theory group at University of Karlsruhe. Similar considerations were also valid in the Durham case. Neither of these two changes affected the project, since in both cases the young researchers were really in the early stages of an independent research activity.

3.4.1 Integration into the research program

Special efforts have been taken to integrate the young researchers in the research programme and never to just let them without guidance. The integration of young researchers took place through the following main avenues :

INTEGRATION

- *Research activity* As one can see from the periodic reports, the young researchers have a very good publication record in refereed journals or in the form of electronic preprints, and Proceedings of International Conferences.
- *Participation to joint research projects* Some of the young researchers were or had been PhD students of other scientists in the network, and, through the collaboration already established between nodes, they could easily be integrated after moving to a different country. A typical case is Rene' Unterdorfer, pre-doc in INFN/LNF, where he came while completing his thesis with the scientist in charge of the Vienna node, who was collaborating with one one of the Frascati scientists. Thus mobility was accomplished, while the young researcher could complete his research project and continue with other members of the same research group. Cases like this have been very common in our network. At the end, the list of joint publications includes many young researchers, even in the top 5 .

  JOINT RESEARCH PROJECTS
- *Collaboration Meetings* All the young researchers have had the opportunity to participate to the Collaboration meetings, present their work and interact with the senior scientists.

- *LNF Spring School* The yearly Spring School held in Frascati in May has often brought all the young researchers together and allowed them to know each other in a friendly setting. The young researchers participating to the Spring School were asked to make a presentation of their work during a dedicated session. This has proved a very successful strategy in allowing senior scientists to meet and evaluate young researchers applying for a position in the network. LNF SPRING SCHOOL

3.4.2 Training measures

The measures undertaken in the training program concerned both individual and common training. Common training was performed through attendance to the Frascati Spring School, participation to the Collaboration Meetings and the topical Workshops dedicated to the research topics of interest for the young researcher. Individual training consisted in collaboration exchanges and secondments to other nodes to work on common projects. Part of training measures were also those which provided a good integration of the young researchers in the network, and we refer the reader to the previous subsection.

As for complementary skills, we think that, beyond the basic training in research, the most important training a research network can provide is the ability to relate and integrate in a different country, learning the language, and learn to collaborate with research groups beyond one's own advisor. This was accomplished to a very large extent. In addition, attention was devoted to training in presentation and workshop organization. For the Midterm meeting, all the young researchers were asked to come to the site of the meeting a few days in advance and rehearse their presentation with the Coordinator. For these presentations, the young researcher were offered to use a a unified format, which was useful for the less experienced young researchers, although they were also free to use their own format, if so preferred. COM– PLEMENTARY SKILLS

In the Frascati node, the young researchers collaborated to the preparation of the annual reports, mostly in the compilation of joint publications, which gave them an important overview of the entire network as well as bringing them in contact and to the attention of all the network. REPORTING SKILLS

Finally, the LNF Spring School (LNFSS), attended by many young researchers from the network, always included in its program one or more Historical Sessions, where distinguished lecturers would present or discuss highlights in the History of Physics in Europe . Examples of such sessions include: PHYSICS HISTORY

- *The November 1974 revolution* in LNFSS04
- Movie produced by INFN on *Bruno Touschek and the Art of Physics* in LNFSS05
- *From LEP to LHC* by L. Maiani in LNFSS06

3.4.3 Promotion of equal opportunities.

The network has had a good proportion of women in leading positions, since 4 out of the 17 members of the Executive Committee were women, namely the Coordinator, the scientist in charge of the Warsaw node, the scientist in charge of the Granada team and the KLOE experiment analysis coordinator. Their presence in high management and research positions has certainly increased the visibility of women in the field.

Among the 23 young researchers trained during the entire period of operation, 7 of them were women, representing a proportion of 30% young women scientists, higher than what is usually reported for the presence of women in the field of theoretical physics (according to INFN statistics of the year 2000, in Italy only 11% of the total number of theoretical particle physicists with permanent positions were women).

Special attention has been devoted in all the nodes to training and retaining of young women physicists, by extending their contract whenever possible so as to allow flexibility for special personal needs. We consider that the presence of women in leading positions in this network has increased the awareness of all the node scientists to the special plight of women physicists and that this reflects the good record in training of young women researchers.

3.4.4 Multidisciplinarity

This is a network in theoretical particle physics with phenomenological applications. From this point of view, multidisciplinarity is hard to be included. We can however notice that the close collaboration between experimentalists and theorists in our network already allows for a large and partly unique exchange between different fields in the same discipline. In addition, the training in the field of Quantum Mechanics, an important component of the research effort of the the Barcelona and Vienna node, has involved a certain degree of interdisciplinarity.

3.5 Industry connections

Connections with industry were not in the network project, nonetheless a certain degree of intersectorial activity was provided by the connections between the KLOE collaboration (to which there belonged some network members from INFN/LNF and DESY Zeuthen/Karlsruhe nodes) and industries which had provided parts of the detectors.

3.6 Recommendations

Most of the members of this network have participated to three such networks, starting in 1992. At the time, the construction of a new particle accelerator with high beam intensity, DAΦNE was approved. In this machine, electrons and positrons were made to collide with a center of mass energy at which the resonance ϕ, a bound state of strange quarks and anti-quarks, could be generated in millions, thus allowing high statistics studies of all light mesons. The need to investigate in depth all the physics possibilities of such machine led to the formation of the first HCM EU funded network, which gathered through Europe all the foremost experts in the field. This network was then followed by a TMR funded network and ultimately by the present one, object of this final report. The networks provided the theoretical backbone for the experimental work done by the Collaboration and were instrumental in bringing about the many physics results appearing from the KLOE collaboration, many of which are cited here. A very important component of the network have been the young researchers, most of whom have done very good research and are continuing in their chosen field. From most points of view, all the scientists of this network consider it to have been a success, which can be ascribed to :

- a specific project with identifiable objectives with realistic milestones, in our case provided also by the experimental collaborations which had clear goals, like reaching a given precision in a certain measurement, etc.

- a collaborative atmosphere between the research nodes, based on reciprocal respect and close collaboration links
- a set of a few different but interconnected research groups, which could provide students to train as well as provide a mobility web, whereupon the young researchers could easily collaborate with different nodes : the network was the provider of a very mobile setting, in a reasonably protected environment
- an Executive Team of scientists who were in close connection to each other and could easily contact each other and take decisions
- a set of common activities, like Workshops, and Schools, which would bring together the young researchers.

Finally, a comment of the network idea, in itself. Research Training networks have a unique structure created by the European Union during more than 15 years. In particle physics, such many countries collaborations were common practice in experimental physics, but did not exists in theoretical physics, except in a very loose sense, and usually involving not more than two or three groups. The novelty of having a common project and training of young researchers to the attainment of such project has clearly brought important results : throughout Europe young researchers can move between countries and research groups without fearing to loose connections with their home institution. Indeed young European post-docs expect the announcement of which networks will be funded and the relative available research positions are by now part of the reality of post-doc employment and predoc training. There are however some problems with the program as it had developed in FP6. The main criticism lies in the low success rate. For the future, we think that one should try to increase the success rate of such networks because Europe has many excellent research groups deserving funding at EU level, more than the present few.

RECOMMENDATIONS FOR THE FUTURE

To summarise, our final recommendations are :

1. (re)establish a maximum funding level for networks, such as to ensure an overall success rate not lower than 30%
2. introduce a science monitor, expert in the field, assigned to follow the progress of each network at the time of the Midterm Review together with the EU officer in charge
3. introduce a final Meeting with the presence of the scientific monitor
4. limit the annual reports to purely deliverable items, like training months, joint publications and cost statements, leaving the scientific part to the Midterm and Final Reports
5. the balance between pre-doc (ESR) and post-doc should be kept a moderate level (30 -40% at most) instead of placing too much emphasis on pre-doctoral students whose training should be done predominantly at their home institutions.

We hope that some of our recommendations can be accepted for the future of this program. In conclusion we wish to say that this is an excellent program and that intensifying European Collaboration among scientists and exchanges and joint work with young researchers is and will remain an important goal which deserves as much support as possible.

3.7 Bibliography

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