STARTPAGE

HUMAN RESOURCES AND MOBILITY (HRM)
ACTIVITY

MARIE CURIE ACTIONS
Research Training Networks (RTNs)

PART B

"HardQCD@LHC"

Dynamics of Short-Distance Strong Interactions at LHC

Proposal Description

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1 Scientific Quality of the Project

1.1 Research Topic

High energy physics is about to enter a new age when the Large Hadron Collider (LHC) starts operating in 2007. LHC is a proton collider that will function at the highest energy ever attained, with the potentiality to explore new and unfathomed realms of high energy physics. LHC is expected to be a key player in exploring spontaneous symmetry breaking in the Standard Model and in discovering New Physics phenomena. However, the focus on a high-energy hadron machine poses important demands upon the understanding of Quantum Chromodynamics (QCD), the theory of strong interactions in the Standard Model. A very large number of strong-interaction processes takes place at such high energies. Such processes may mimic or hide New Physics signals, and thus they need to be accurately understood and modelled. Signals for New Physics processes should be computed with very high accuracy, since accurate knowledge of their cross section will help in determining their couplings. Therefore, a failure to understand the QCD processes in detail would hamper the full physics programme of LHC.

In the last couple of years, there have been *major new advances* in QCD, thanks to significant improvements in the event simulation programs (so far an invaluable tool to help experimentalists in their analysis of the scattering processes), in the way they deal with multi-jet production and in their matching with one-loop perturbation theory, and thanks to breakthroughs in exact two-loop and resummed calculations. Those advances will allow us to test QCD to an unprecedented level of accuracy at HERA, the Tevatron and LHC.

The aim of the research training network `HardQCD@LHC` will be to focus the European expertise in applications of QCD, in order to achieve an understanding of the collisions between protons at LHC to an unprecedented level of accuracy. The HardQCD@LHC network presents itself with a young and energetic leadership: most of its team and task leaders have been instrumental in the strong new advances in QCD mentioned above, and are poised to lead the QCD theoretical community to meet the new challenges presented by LHC physics.

The HardQCD@LHC network focuses on the following physics goals, which we see as essential for the optimal exploitation of LHC:

(i) advances in the complete modelling of hard interaction events at hadron colliders, such as the Tevatron and LHC, in hadron-level event generators, through an improvement of their theoretical accuracy, programming structure and interoperability;

(ii) refinement of precision of the QCD predictions at Tevatron and at LHC, by the use of exact two-loop and resummed parton-level cross sections;

(iii) prediction of QCD backgrounds associated with new processes and particles expected to be produced at LHC.

In order to implement the plan above it will be essential to train, in a unified European effort, young theoreticians for doing research in this field, both at the doctoral and at the postdoctoral level. On this aspect, which is treated at length in Sect. 2, the HardQCD@LHC team and task leaders plan to draw also from the experience of the senior members of the network, who coordinated the previous TMR network QCDNET.

Although the emphasis of this network is on achieving theoretical breakthroughs, for this type of work an intense exchange with our experimental colleagues is essential. We will therefore invite the Heads of the Higgs and QCD/SM working groups of the ATLAS and CMS Collaborations to meetings of the network management board, where they may provide consultancy on the physics issues of the network tasks.

1.2 Project Objectives

Within the topics outlined above, we have identified six areas, listed below, in which important new objectives can be achieved using the collective expertise of the network. In each area the key activities, where major breakthroughs can be anticipated, are shown *in italics.*

1. Hard processes and resummations (JET)

This task covers the following items:

`Standard hard processes in hadronic collisions.` All traditional hard production processes occur in hadronic collisions: jets, heavy flavour or direct photon production. The objectives of this task are: to improve our understanding of these processes by performing phenomenological studies on available data (Tevatron results will play a prominent role in this context), providing *calculations for important processes* when needed, improving the accuracy of perturbative results by *including resummation of effects enhanced* in particular regions of phase space, (Sudakov logarithms, transverse momentum logarithms); to improve our *understanding of small x effects* in the high energy regime of the LHC. Small x effects are hardly visible at present energy colliders, but may play an important role at the LHC.

`Numerical NLO computations.` At present, the overwhelming majority of next-to-leading (NLO) computations are based upon techniques, which require the analytical evaluation of virtual diagrams. One-loop diagrams have been computed so far up to five external legs analytically. Substantial progress has been made recently on the numerical computation of these diagrams; by combining these techniques with methods for the numerical computation of tree diagrams (see the paragraph on "Computer simulations" **SIM**), work on this area will lead to the fully-numerical computation of physical observables in hadronic physics. A successful achievement of this program will open the way to a fully numerical hadron-level *event generator with NLO corrections.*

`Numerical methods for resummations.` Resummation methods are based on a careful analysis of the kinematics of the emission process, which strictly depends on the observable studied, and involves a fair amount of analytical work. Recently, techniques to perform resummation using numerical methods have been proposed, which apply to a large class of observables. Work in this area will lead to predictions for *observables whose resummation has never been performed.* From the theoretical point of view, the *matching with fixed-order results* will be carried out, and the interplay with non-perturbative physics studied. The final goal is that of achieving an understanding of these topics similar to that achieved at LEP.

2. Parton distribution functions and small-x (PDF)

The task will concentrate on the *most precise possible determination of the parton distributions* using the most up-to-date data from fixed-target experiments, HERA and the Tevatron, and the *uncertainties on the partons and on physical cross sections.* This will be done at the current level of NLO accuracy and will also make the NNLO extraction of partons and predictions of cross sections as complete as possible. The success of the theoretical frameworks will be judged by the quality of the comparison to data. The possibility of violation of symmetries such as isospin and $s(x) = \bar{s}(x)$ will be investigated. Special emphasis will be required on *incorporating the effects of heavy partons* (charm, bottom) for all processes. Also, improvements from *resummation of* $\ln(1/x)$ *corrections* at higher orders in α_S will be investigated and implemented, since the high energies used at the LHC will necessarily probe partons at low values of x, particularly for high rapidity final states.

3. Higgs and vector bosons (HWZ)

One of the prime objectives of the LHC is to shed light on the dynamics of electroweak symmetry breaking which is realized in nature. This goal will be addressed by studying the production of W, Z and Higgs bosons, and their subsequent decay, in a hadron collider environment. Quantitative comparisons with theoretical models require the knowledge of cross sections at an accuracy that can only be achieved by *including higher order QCD corrections.* Examples include single and multiple production of real or virtual W and Z bosons, and, above all, the various Higgs production channels such as gluon fusion, vector boson fusion and Higgs production in association with other heavy particles (W, Z, top and bottom). The general objective of this task is to provide *improved calculations of signal and background cross sections of sufficient accuracy.* The goal is to enable measurements of electroweak parameters with a precision which is dominated by experimental limits where possible. One outstanding example here is the measurement of Higgs properties, in particular the extraction of Higgs couplings at the LHC.

4. Next-to-Next-to-Leading Order Computations (NNLO)

The high energy available at the LHC leads us to investigate strong interaction dynamics in a new kinematical regime characterized by very short distance scales, by highly suppressed power effects, by the interaction of dense partonic systems, and by the production of complex partonic final states. The suppression of power corrections in this kinematical regime makes the perturbative prediction more reliable than at lower energies, and therefore the relevance of large higher order corrections is enhanced. Our general objective is to compute the *NNLO corrections to cross sections of basic QCD processes with very large NLO corrections*, or when the *dominant error of a measurement is due to unknown higher order corrections.* At the LHC, the initial state always involves coloured partons, therefore the prediction for the physical cross section of any process requires a precise prediction for the evolution of the parton density functions. One of our main objectives is the *completion of the computation of the DGLAP evolution kernels at NNLO accuracy.* Furthermore, the use of the parton evolution equations at NNLO accuracy in a theoretically consistent way assumes the extraction of the parton density functions from fits to data using partonic cross sections also at NNLO accuracy. Therefore, in order to achieve the planned precision for any kind of cross section measurements, the partonic cross section of some basic processes, such as the inclusive jet cross section, is also needed at NNLO accuracy.

5. Computer simulations (SIM)

The structure of typical events at the LHC is extremely complex, with hundreds of particles scattered around in all corners of phase space. The only realistic way to confront precise theoretical calculations of both signal and background processes with this experimental reality is to use complete hadron-level event generators (EvG). This task will cover the following items.

`Matching EvG's and NLO computations.` Improved computations of total rates and of large-angle single-parton emissions within EvG's can be achieved by using NLO, rather than LO, matrix elements. Recently, formalisms to match EvG's and NLO computations have become available. Work in this area will result in the *implementation of the hard processes* crucial for the LHC and the Tevatron experimental analysis. Theoretically, more progress is expected on the formalism; in particular, new techniques will be explored, in order to *reduce or eliminate the negative-weight events* stemming from loop corrections, and to *improve the accuracy of the showers to the next-to-leading logarithm.*

`Phenomenological aspects of EvG's.` Work in this area will cover improvements in the *treatment of the radiation in processes involving heavy particles*, such as W, Z, the top quark, and the Higgs. In addition a *comprehensive comparison between predictions of different EvG's, as well with existing experimental data* is foreseen.

`Small-`x `processes and underlying events.` The high energy at LHC means that small-x evolution becomes important for many processes and here the standard parton showers based on DGLAP evolution become inadequate. Therefore we need to *develop the existing small-x generators* based on *e.g.* CCFM evolution. Also the high densities of partons at the LHC means that we need to *improve the models for multiple scatterings* to better describe the omnipresent underlying event.

`EvG's of new generation.` On the technical side, we need to *develop common interfaces to implementations of different models* (in particular for hadronization) as well as to external input such as *PDF libraries.* This should preferably be done within the framework on the *next generation event generators written in C++* such as Pythia7 and Herwig++ based on the ThePEG platform.

6. Beyond-the-Standard-Model phenomena (BSM)

`Calculations and simulations of backgrounds to BSM physics.` *Improved calculations and simulations of complex background processes*, such as multijet production with or without vector bosons and lepton pairs, are a high priority for the search for new physics beyond the Standard Model. Powerful new tools for automatic computation of such processes have been developed by network members and these need to be *interfaced with simulation programs* under development by other teams, making use of recent progress in this area to achieve the necessary level of precision and reliability.

`QCD corrections to BSM processes.` In BSM theories such as supersymmetry (SUSY), the *calculation of QCD effects with higher precision* is essential for the accurate extraction of model parameters from BSM signals, or for setting reliable limits in the absence of signals.

`SUSY MC++.` New object-oriented simulation programs being developed for LHC by network teams need to include BSM processes. A major objective of the network is the *inclusion of the minimal supersymmetric standard model* (MSSM) in the programs under development. *Reliable simulation of associated QCD effects*, such as gluon radiation from SUSY particles, is essential for the interpretation of SUSY signals.

`QCD effects in other BSM scenarios.` Competitive non-SUSY models of BSM physics formulated in recent years (little Higgs, extra dimensions) involve new particles and new production mechanisms for SM particles. *Correspondingly, new QCD effects need to be calculated and simulated* for these models, together with the *associated background processes.*

1.3 Scientific Originality of the Project

There is nowadays no doubt that the Standard Model (SM), which has been formulated about thirty years ago, is able to successfully describe the interactions of the elementary particles through the electroweak and strong forces. Fundamental constituents of the SM, such as the electroweak gauge bosons and the top quark, without which the theory would not be internally consistent, have been discovered at the $Sp\bar{p}S$ and Tevatron hadron colliders at CERN and FNAL respectively. Countless tests of the theory have been performed, mainly by the LEP and SLC electron-positron colliders at CERN and SLAC, respectively, and by the HERA lepton-proton collider at DESY, with a precision rarely attained in any experimental science.

Yet, the SM needs to be investigated further, since one of its building blocks, the Higgs boson, which rules the mechanism describing the high-energy unification of the electromagnetic and the weak forces, still defies discovery. As the LEP results and theoretical considerations suggest, the Higgs boson lies just beyond the energy reach of LEP. Other theoretical arguments also hint at the existence of a more fundamental theory (such as supersymmetry), of which the SM in its electroweak sector is the low-energy limit, leading to a deeper level of unification of forces. These arguments currently receive support from LEP results, and especially from studies of atmospheric and solar neutrinos, which have provided firm evidence of beyond-the-Standard-Model (BSM) physics.

It is therefore clear that high-energy particle physics stands at a crucial phase of its history. As historically is the case for hadron machines, LHC is particularly suited for discovery studies. One of its main goals will in fact be the search for the Higgs boson. Furthermore, experimental evidence suggests that BSM physics is within reach of LHC. Thus, LHC will also search for signals of BSM physics, that might shed light on the possible unification of forces, and for indirect clues on the early history of the Universe.

However, a detailed and precise comprehension of the collisions between protons at LHC requires an understanding of QCD to an unprecedented level of accuracy. In fact, in order to devise viable experimental analyses for discovery, realistic estimates of signal and background processes must be given; this task is much more complex than in any of the past and present colliders, because of the much larger energy available for such processes to take place.

The HardQCD@LHC network proposes a framework for fostering research on QCD to achieve the level of accuracy required, and it aims to offer an excellent environment for training young researchers and bringing them to the forefront of the QCD technologies. The state-of-the-art of the areas, which we believe will have the strongest impact on LHC physics, can be summarised as follows:

a) Fixed-order computations: NLO results are available for many SM and supersymmetry processes; a very few NNLO computations have also been performed.

b) Resummations: NLL and a few NNLL results have been obtained for a limited number of processes.

c) Parton densities: precise NLO determinations are available, thanks to HERA data. Approximate NNLO results, and estimates of PDF uncertainties due to experimental errors, have also been given.

d) Hadron-level event generators: the core of applications relies on the codes developed in the eighties, based on $2 \to 2$, tree-level hard processes. Formalisms and implementations for incorporating NLO matrix elements, or multi-leg tree level matrix elements, into event generators have only recently appeared.

This situation is largely unsatisfactory in view of the requirements of LHC phenomenology. We can easily identify the weaknesses of each of the issues above:

a) Fixed-order computations: although the current formalisms allow the computation of cross sections to NLO accuracy for any number of particles, we are limited in practice by the fact that no loop diagram with more than five legs, and entering into an NLO calculation, has ever been computed in QCD. Furthermore, for a few processes the NLO results will not be accurate enough to be competitive with experimental errors.

b) Resummations: current techniques are not flexible, since they require a dedicated analysis for each process and each observable; jet observables are in general not resummable with such methods. Only a very limited number of small-x resummation results are available. New classes of enhanced contributions are not yet fully understood.

c) Parton densities: no consensus has been reached on the meaning of PDF uncertainties. Exact NNLO-evolved sets cannot be fitted, since the exact evolution kernels are not available at the required level of accuracy.

d) Hadron-level event generators: the energy available for hard processes at the LHC implies the necessity of reliable estimates of total rates, and large-angle emission kinematics. None of these features is available in generators based on $2 \to 2$ hard processes.

We believe that these weaknesses demand that work be done in order to achieve the following results:

a) Fixed-order computations: methods must be developed, which allow the straightforward computation of NLO observables for any number of final-state particles; it is realistic to assume that such methods will be based on numerical techniques. At NNLO, the definition of general algorithms, similar to those now available at the NLO, is necessary in order to compute arbitrary observables with generic acceptance cuts; this requires a detailed understanding of the infrared structure of QCD at the two-loop level.

b) Resummations: more flexible approaches will have to be developed, in order to tackle the cases of observables which are impossible to treat with analytical techniques. Examples already exist of fully-numerical techniques. The case of processes affected by small-x physics phenomena will have to be considered more carefully, possibly through the development of suitable event generators. Resummation techniques will be extended to new classes of enhanced contributions.

c) Parton densities: a firm agreement on PDF uncertainties, both from experimental and theoretical errors (the latter mainly neglected so far), will have to be reached. The completion of the computation of three-loop evolution kernels will be the key ingredient to obtain fully-consistent NNLO densities. Finally, all the new data available from HERA and Tevatron will have to be included in the fits, in order to increase the predictive power of perturbative QCD.

d) Hadron-level event generators: the incorporation of NLO and multi-leg, tree-level matrix elements into event generators is still in its infancy. Progress in this field is of crucial importance in order to give experiments tools that describe physical reality with a high degree of accuracy, allowing them to accurately design the analyses for searches for new physics. Technically, advancements are necessary at the level of programming structure and interoperability between different generators.

These achievements will be instrumental in defining a coherent and realistic framework for Higgs and BSM searches, with many new phenomenological results expected, constituting a wholly new and original research program.

We believe that these goals will be achieved in the next few years, because all the prominent experts of the fields mentioned above are members of the HardQCD@LHC network.

1.4 Research Method

The aims and objectives of the network have been described in detail in the previous sections. To summarise, our goals are: (i) to improve the understanding of QCD and the precision of QCD calculations, in order to match the experimental accuracy of the complex processes expected at the LHC; (ii) to apply QCD to the new processes and particles expected at LHC. To attain these objectives we will employ a wide range of complementary methods and techniques. Most of these are well tried and tested, but novel calculational techniques will also need to be developed to solve particular problems.

In what follows, we list the most important research methods that we will employ, in relation to the project objectives.

Theoretical techniques

The calculation of strong interaction processes at high energies can in most cases be factored into short- and long-distance parts. The former can be calculated in perturbation theory, using Feynman diagrams, as an expansion in the strong coupling constant. This is the primary tool for exploring the structure of the theory and calculating physical quantities. In *fixed-order* calculations a large number of diagrams must be evaluated exactly and computer algebra programs are often useful. In this respect, we can identify three directions: (a) tree-level processes with many final-state particles; (b) one-loop corrections with many final-state particles; (c) two-loop corrections to processes with few final-state particles. Techniques for dealing with (a) are well established, and most of the effort will be devoted to develop methods for more efficient, new implementations. Solutions to (b) and (c) are not fully designed yet, and they will presumably involve a mixture of numerical and analytical techniques, the latter being mostly relevant to (c). Furthermore, in some regions of the final-state phase space the leading contributions of a particular class of diagrams can be identified and *resummed* to all orders. These resummed series must then be *matched* to fixed-order calculations, in order to reduce the dependence of the prediction on arbitrary (but unavoidable) theoretical parameters, the renormalisation and factorisation scales.

The calculations mentioned above are performed using quarks and gluons as the fundamental fields. To make contact with experiment, the effects of confinement into hadrons must be included. This is achieved by modelling the non-perturbative long-distance effects, through computer-simulation models that include parton showers and hadronisation. Such techniques are fairly well established, and have been fundamental, through the use of codes such as Pythia and Herwig, for the successes of the experimental programs of the past twenty years. Much less developed is a line of research that has been opened only recently, which aims at matching fixed-order calculations, either at one loop or for many-body final states, to Monte Carlo models. New methods relevant to event generators will include extensive use of object-oriented programming techniques; members of the network have proven technical skills to cope with this advancement.

In our opinion, purely numerical approaches are truly novel both in fixed order computations as well as in resummations, opening the possibility of computing the complex final states relevant to LHC physics.

Comparison with experiment

Numerical implementation of the theoretical results is necessary in order to make comparisons with experiment. This involves a variety of techniques, mostly based on multi-dimensional integration. Because of delicate cancellations between potentially singular parts of the calculation, special numerical techniques are needed. Some of the most advanced algorithms have been developed by members of the network, and more will be needed as the calculations become more complex.

Comparisons with existing experimental data provide precision tests of the theory. In some cases the data can be used to give information on non-perturbative quantities (for example the parameters relevant to hadronisation of quarks and gluons, or the parton distributions at a particular resolution scale), in other cases the predictions have no free parameters and the theory is tested at a fundamental level. Members of the network have a long and highly-valued expertise on these topics.

The confrontation of QCD theory with experimental data is greatly improved by using Monte Carlo event generators. The fact that these generators provide complete final states of observable particles in particle collisions, means that any experimental observable can be obtained and compared with data. It is one of main objectives of the planned network to make a big effort to improve and broaden the scope of such generators. Extensive comparison with Tevatron data will help to refine the ideas for the modelling of the underlying event, which will play an important role at the LHC.

It is crucial to have good communication with experimentalists, to ensure an efficient two-way flow of information. In recent years, members of the network have established strong links with *all* the LEP, HERA and Tevatron Collaborations. In addition, it is our intention (see Sect. 4 on the Proposed management and organizational structure) to invite the Heads of the Higgs and SM/QCD working groups of the ATLAS and CMS Collaborations at LHC to the meetings of our management board. Such links created by the network will, for example, help ensure that *detectors and triggers* are optimally exploited for measuring the physics processes of most interest, and will provide us with information about the types of particles and kinematic regimes that will be accessible.

Finally, the understanding of high-energy SM processes at hadron colliders will be enhanced in the coming years by high-luminosity data from the upgraded CDF and D0 detectors at the Tevatron. Here the work of the network will be greatly aided by the participation of the USA team members, who have strong links with the Tevatron experiments.

Predictions for LHC

A very important output of our research will be improved predictions for strong interaction processes at LHC, both as precision tests of QCD and as new physics signals and backgrounds. We will pay particular attention to the theoretical *uncertainties* in the predictions, and will explore a variety of experimentally measurable quantities to help sharpen the comparison between theory and experiment and to facilitate the discovery of new physics.

Once evidence of new phenomena has been found, its interpretation will rely on detailed calculations and complete simulations of the many alternative BSM scenarios. Some of the most studied scenarios at present are supersymmetry or extra spatial dimensions. Supersymmetry implies a plethora of new strongly-interacting particles, and the dominant new processes at the LHC will then be SUSY QCD interactions, to which the entire range of QCD techniques developed within the SM will need to be extended. In the case of extra dimensions, the new interactions may be primarily (weak-scale) gravitational, but they will lead to new final-state configurations of strongly-interacting jets, heavy quarks, which have yet to be calculated.

1.5 Work Plan

The tasks which will be carried out by the teams are divided into the six areas listed in Section 1.2. For each area we list below the convenor who will coordinate activities, the principal tasks, and their approximate timescales in months from the start of the contract, *e.g.* (0-24) means the first two years. The timelines of the tasks are summarized in Fig. 1. However, in such a fast-moving and fundamental area of research, timescales for the solution of all the various problems cannot be predicted with certainty.

The teams participating in the tasks are indicated in Table 1. More precise team involvement and anticipated collaborations are described in the individual team pages (see Sect. 3).

1. Hard processes and resummations (JET)
Coordinator: P. Nason (Milano)

1. Jet production and jet structure: (*a*) phenomenological analysis of upcoming Tevatron results (0–48); (*b*) Sudakov effects for very high transverse momentum jets (0–12); (*c*) small-x effects in low transverse momentum jets: minijet production (0–12); (*d*) improving the accuracy of perturbative results by applying and extending the techniques for the resummation of perturbative contributions enhanced in particular regions of phase space (12–24).

2. Heavy flavour production: (*a*) analytic resummation for transverse momentum distribution of $t\bar{t}$ and $b\bar{b}$ pairs, and comparison with MC@NLO models (0–24); (*b*) phenomenological studies of the b and c fragmentation function including upcoming CLEO data for charm, and applications to the Tevatron; (0–24) (*c*) bottom and charm production in the high energy regime (0–48).

3. Direct photon production: (*a*) phenomenological study with upcoming HERAb data, in order to solve inconsistencies among older data sets (direct photon production is relevant to PDF measurements) (0–12); (*b*) comparison of different photon isolation criteria (12–36).

4. Numerical NLO computations: automatic computation of NLO processes at the LHC (0–48).

5. Resummation of Sudakov logs: numerical implementation of present NLL formalism; extension of present formalism to include further subleading effects (0–48).

6. Resummation of small-x effects: matching with standard perturbation theory (0–48).

7. Power corrections and interface with soft physics: (*a*) assessment and parametrization of power corrections in simple collider processes (e.g. Drell-Yan pair production) (24–48); (*b*) small-x physics and underlying event structure at the LHC (24–48).

2. Parton distribution functions and small-x (PDF)
Coordinator: R. Thorne (Cambridge)

1. Precise determination of parton distributions and their uncertainties at NLO (0–48).

2. Incorporation of available NNLO information into determination of parton distributions and predictions using these distributions (0–48).

3. Investigation of whether currently assumed symmetries, e.g. isospin and strange = antistrange are violated, and the consequences examined (0–24).

4. Inclusion of heavy quark contributions in correct manner for all processes and at each order (0–36).

5. Investigation of importance of $\ln(1/x)$ corrections in parton distributions and cross sections, and development of correct treatment for most precise results (12–48).

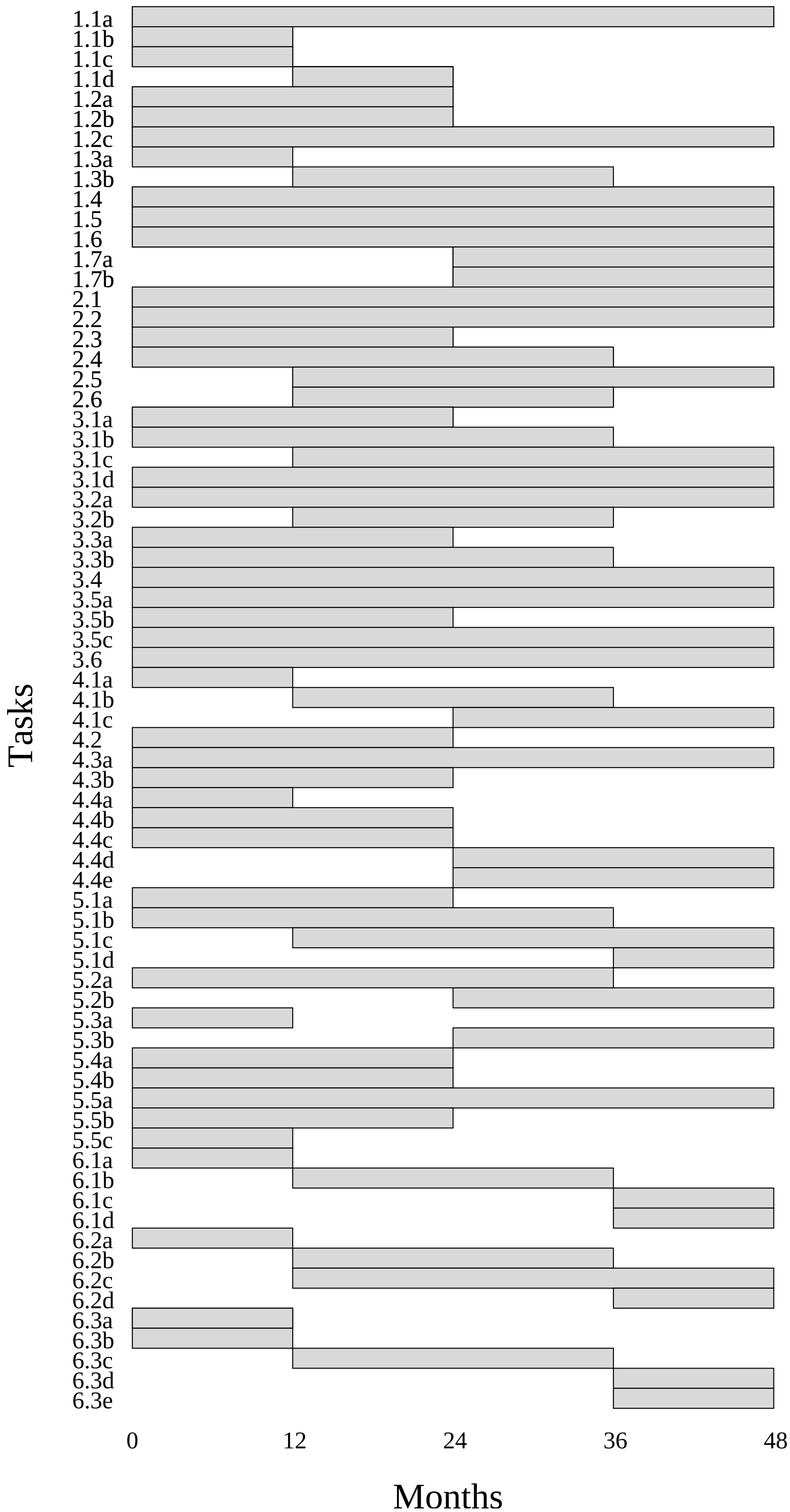

Figure 1: Timelines of the task milestones.

6. Higher order corrections to fragmentation functions (12–36).

3. Higgs and vector bosons (HWZ)
Coordinators: V. Del Duca (Torino), D. Zeppenfeld (Wisconsin)

1. single and multiple production of real or virtual W and Z bosons: (a) NLO corrections for weak boson fusion processes (0–24); (b) analysis of QCD and electroweak processes as backgrounds to Higgs production with NLO tools (0–36); (c) matching of NLO matrix elements and parton shower programs (12–48); (d) improved determination of W boson mass (0–48).

2. Higgs production via gg fusion: (a) improved calculations for cross sections and distributions at NLO and NNLO (0–48); (b) NLO corrections for Hjj production (12–36).

3. Higgs production via WW fusion: (a) matching of NLO matrix elements and parton shower programs (0–24); (b) study of electroweak double-log contributions (and ensuing evolution equations) (0–36).

4. Associated production $H + W(Z)$, $H + t\bar{t}(b\bar{b})$: matching of NLO matrix elements and parton shower programs (0–48).

5. Backgrounds to Higgs production: (a) NLO Monte Carlo programs (0–48); (b) diphoton background for Higgs searches (0–24); (c) study of resummation effects (0–48).

6. Higgs couplings: strategies for determining Higgs boson parameters at the LHC, systematic study and reduction of theoretical uncertainties (0–48).

4. Next-to-Next-to-Leading Order Computations (NNLO)
Coordinator: Z.Trócsányi (Debrecen)

1. General NNLO techniques: (*a*) development of general methods for computing jet cross sections at NNLO accuracy, for processes involving only final state QCD partons (0–12), and (*b*) for processes involving hadrons in the initial state (12–36); (*c*) studying the extension of these methods to other (electroweak, supersymmetric) gauge theories (24–48).
2. Computation of the evolution of parton distribution functions at NNLO accuracy (0–24).
3. Two-loop calculations: (*a*) computation of new two-loop master integrals involving more than one massive external legs (0–48); (*b*) calculation of two-loop matrix elements for heavy quark production (0–24).
4. Development of NNLO parton-level Monte Carlo programs for: (*a*) $e^+e^- \to 2$ and 3 jets (0–12); (*b*) Drell-Yan process (0–24); (*c*) $pp \to$ Higgs boson (0–24); (*d*) $pp \to$jet+X (24–48); (*e*) $pp \to$V+jet (24–48).

5. Computer simulations (SIM)
Coordinators: L. Lönnblad (Lund), S. Frixione (Genova)

1. Multijet: (*a*) development of more efficient multijet matrix element generators (0-24); (*b*) interfacing of multijet matrix element generators to parton shower event generators (0-36); (*c*) comparative studies of predictions of combined ME+PS generators (12-48); (*d*) recommendations and assessment of remaining uncertainties in background estimates (36-48).

2. NLO: (*a*) Development of matching of NLO matrix element and parton showers (0-36); (*b*) Development of NLL parton showers (24-48);

3. Phenomenology: (*a*) Simulation of QCD dynamics of vector bosons, top, Higgs and proposed new particles (0-12); (*b*) Comparison between event generator model predictions and confrontation with existing data (24-48).

4. Small-x and underlying events: (*a*) Improving existing CCFM based generators (0-24); (*b*) Improving models for multiple scatterings and underlying events (0-24).

	Team	1. JET	2. PDF	3. HWZ	4. NNLO	5. SIM	6. BSM
1.	Italy - Spain	*		*	*	*	*
2.	Durham IPPP	*	*	*	*	*	*
3.	France	*	*	*	*	*	*
4.	Germany	*	*	*	*	*	*
5.	Great Britain	*	*	*	*	*	*
6.	Italy	*	*	*	*	*	
7.	Netherlands	*	*	*	*		
8.	Sweden	*		*		*	*
9.	CHDH	*		*	*	*	
10.	CERN	*	*	*	*	*	*
11.	Japan	*		*		*	*
12.	USA	*	*	*	*	*	

Table 1: Involvement of the network teams in the six different tasks

5. Next generation: (*a*) Continued development of the next generation event generators in C++ (0-48); (*b*) Common interfaces to implementations of different models (0-24); (*c*) Standardized interface to PDF libraries (0-12).

6. Beyond-the-Standard-Model phenomena (BSM)
Coordinator: B. Webber (Cambridge)

1. QCD corrections to BSM processes: (*a*) survey of BSM processes and setting of priorities for higher-precision calculations (0-12); (*b*) performing high-priority calculations (12-36); (*c*) updating of Tevatron limits and expectations for BSM signals at LHC (36-48); (*d*) performing lower-priority calculations as time permits (36-48).

2. SUSY MC++: (*a*) release of Standard-Model versions of object-oriented simulation programs for LHC (0-12); (*b*) inclusion of MSSM particles, production processes and decays (12-36); (*c*) testing and documentation of programs (24-42); (*d*) handover of new programs to LHC experiments for data challenges, full detector simulations. (36-48).

3. QCD effects in other BSM scenarios: (*a*) survey of non-SUSY BSM models and their important backgrounds (0-6); (*b*) setting of priorities for new calculations (6-12); (*c*) performing high-priority calculations (12-36); (*d*) updating of Tevatron limits and expectations for signals and backgrounds at LHC (36-48); (*e*) performing lower-priority calculations as time permits (36-48).

2 Training and Transfer of Knowledge Activities

2.1 Content and quality of the training and transfer of knowledge programme

The training programme will be coordinated by Dr Michelangelo Mangano, a member of the CERN team. The main objective of the training programme is to provide *young European researchers* in theoretical particle physics with the *most complete range of skills in phenomenology of particle physics.* Those skills are to enable them to carry the subject forward into the coming LHC era, when these skills will be essential for the optimal exploitation of LHC. Furthermore, of great importance is the *exchange of information with experimentalists*, so that the young phenomenologists we aim to train are fully aware of the experimental issues involved in the analysis of the highly complex data provided by LHC.

Network potential and complementarity. The training programme is fully integrated with the research programme. Since the main tenets of the research programme of this network, the shower Monte Carlo programmes (involving typically tens of thousands of lines of language code) and the NNLO calculational techniques, require each the integrated effort of pools of 10 to 20 researchers, it is not conceivable that the main goals of the training programme could be carried on in a single research institution. The network provides therefore the *best possible infrastructure* for the young students to draw from the knowledge of all the experts in the field, enabling them to cover aspects of their training complementary to those available at the home institution.

Rationale for the requested number of young researchers. The aim of this network is to *train the young researchers* to do *front-line research*, in order to help to achieve the project objectives set out in Sect. 1.2 and 1.5. Therefore, the rationale for the requested number of person-months of early-stage researchers (ESR) and experienced researchers (ER) is determined by the physics goals. We request a total of 234 person-months of ESR and 144 person-months of ER, which corresponds, on average, to 39 person-months of ESR and 24 person-months of ER per each of the six physics tasks set out in Sect. 1.2. The breakdown according to team and project objectives is provided in Table 2.

Research Training Sessions. In order to *maximise the impact* of the *training and transfer of knowledge* programme on the *existing graduate-student community*, during the first year of the network we plan a series of 3-month in-depth topical Research Training Sessions (RTS) driven by the physics tasks, and hosted by *centres of excellence* on the topics involved. RTS are conceived to boost the research training of already existing Ph.D. students toward the end of their Ph.D. course, by bringing them abreast of the most advanced technologies in the research field. Furthermore, RTS will have the added value of greatly increasing the mobility of already existing Ph.D. students, and of introducing the network to the particle physics community.

Accordingly, we require 6 allotments of 3 ESR person-months to the CERN team for a Research Training Session (RTS) on the SIM and BSM tasks, to be held at CERN, coordinated by M.L. Mangano and M. Seymour, and by S. Frixione, L. Lönnblad and B. Webber as task leaders; 8 allotments of 3 ESR person-months to the IPPP team for an RTS on the PDF and NNLO tasks, coordinated by N. Glover and J. Stirling, and by R. Thorne and Z. Trócsányi as task leaders; 4 allotments of 3 ESR person-months to the Italy team for an RTS on the JET task, coordinated by S. Catani and G. Heinrich, and by P. Nason as task leader; 6 allotments of 3 ESR person-months to the CHDH team for an RTS on the HWZ task, coordinated by R. Harlander, and by V. Del Duca and D. Zeppenfeld as task leaders. This corresponds to a total of 72 ESR person-months to be delivered through Research Training Sessions. Each RTS will then be concluded by a *topical workshop* to which *world leading experts* on the topics will

	Team	ESR/ER	Pers.-month	Topic	Tasks
1.	Italy-Spain	ER	24	NNLO general algorithms	NNLO
				Higgs signal & background	HWZ
		ESR	24	MC@NLO, jet shapes	SIM, JET
		ESR	6	resummations, heavy flavours	JET
2.	Durham IPPP	ESR	8 × 3	Research Training Session	PDF, NNLO
		ESR	6	2-loop amplitudes for $Q\bar{Q}$	NNLO
		ESR	6	global fits with errors	PDF
		ESR	6	QCD corrections to SUSY	BSM
3.	France	ER	24	Higher orders, resummations	JET
				NLO corrections to WWjet	HWZ
		ESR	6	Higher orders, resummations	JET
		ESR	6	NLO corrections to WWjet	HWZ
4.	Germany	ER	24	NNLO corrections to PDF's	PDF
		ESR	12	Finite width effects	HWZ
		ESR	12	Multiple interactions	SIM
5.	Great Britain	ER	24	Higgs signal & background	HWZ
				QCD effects in new particles	BSM
		ESR	12	SUSY HERWIG++	BSM
6.	Italy	ESR	4 × 3	Research Training Session	JET
		ER	24	th. & phen. hard processes	JET,NNLO
7.	Netherlands	ESR	36	resummation, heavy flavours	JET
				NNLO Drell-Yan, Higgs	NNLO
8.	Sweden	ER	24	event generator development	SIM
9.	CHDH	ESR	6 × 3	Research Training Session	HWZ
		ESR	12 + 12 + 6	NNLO infrared formalisms	NNLO
10.	CERN	ESR	6 × 3	Research Training Session	SIM, BSM

Table 2: Requested early stage (ESR) and experienced (ER) researchers per network team, in terms of the objectives for the research project. In some instances, the teams present two possible research profiles for the ESR or ER.

be invited.

ESR & ER. Starting with the second year of the network, we plan to distribute one ESR contract of 36 months and another of 24 months in order to fund normal courses of Ph.D. studies (to be complemented by local fundings of the host institutions); we plan 5 ESR contracts of 12 months, with the aim of extending the normal course of Ph.D. studies through an additional year. That is conceived for graduate students who are particularly motivated and determined to continue academic research, in order to *broaden their expertise and skills*, and make them *more competitive* on the international postdoctoral market *vis-à-vis* their American counterparts, whose normal course of Ph.D. studies lasts between four and seven years. The additional year could be taken between the normal second and third year, in order not to interfere with writing a Ph.D. thesis; in addition, we plan 7 ESR contracts of 6 months, with the aim to *expose* the recipient Ph.D. students to *research methods and approaches* different from the ones of their home team, by enhancing their mobility and *exploiting the complementarity* of the network teams.

We plan to hire 6 experienced researchers with 24-month contracts starting in October 2005, in order to *enhance the transfer of knowledge* between teams that our *highly specialised field* strongly demands. The by-then Ph.D. graduates trained in the Research Training Sessions as outlined above would become natural candidates for those ER appointments.

A `Career Development Plan` (CDP) for each young researcher will be established by the training and human-resource coordinators and by the team leader to which the young researcher is associated. The CDP will explicitly addresses the young researcher's training needs and research goals, and later assesses whether those goals have been achieved.

Proposed mixture of ESR & ER. In this network we request a total of 234 person-months of ESR and 144 person-months of ER. Namely, in the first year of the network we plan to make 24 ESR appointments of 3 months dedicated to the Research Training Sessions; starting with the second year of the network we plan one 36-month, one 24-month, five 12-month, seven 6-month ESR appointments, and six 24-month ER appointments (for each network team, the timelines of the ESR & ER appointments are given in Part A of this proposal). Our goal is *not* to increase substantially the *number* of Ph.D. research students (we co-finance only two new Ph.D. studentships; on the other hand, 234 person-months are equivalent to 6.5 appointments of 3 years each, and 6.5 more Ph.D. students would only represent a 18% increase on our present-day pool of Ph.D. students); rather our goal is to *improve the quality* of the research training of the Ph.D. students who are mostly paid through local fundings, by increasing their mobility and exploiting the complementarity of the network teams as regards the different research methods and approaches. Then the necessary transfer of knowledge is delivered through the six 24-month ER appointments. The combination of *better research training* and *enhanced transfer of knowledge* will also help in *overcoming the fragmentation* between different network teams. We think that the mixture of ESR & ER proposed above suits best the research training needs of our particle physics phenomenology community, while complying with the specific objectives of the RTN directions.

Research and Training infrastructure of each team is displayed here. The goal is to show that all teams are of high quality both in research and training, and present a suitable environment for the training and the transfer of knowledge of the requested ESR's and ER's.
`Italy-Spain team` The members of the team are actively engaged in research, and in teaching and tutoring at graduate and undergraduate level. The Torino and Milano groups both operate a Doctoral program in Physics, which provides a wide range of graduate courses. Furthermore, the Torino group is involved in the International School of Advanced Study of the University of Torino (ISASUT).
`Durham IPPP team` involves the Director and Deputy Director of the *Institute for Particle Physics Phenomenology* (IPPP) at Durham, which is the only research institution world-wide dedicated specifically to the phenomenology of particle physics, and is the foremost institute dedicated to organising workshops and courses in many of the areas covered by the scientific programme of the network. Young researchers will not only attend these but will also participate fully in the activities of the IPPP through extended visits funded by the network.
`France team` The home laboratories of all team members have frequent high energy physics seminars. The team members are experienced Ph.D./postdoc advisors as well as teachers in graduate and doctoral schools in physics. The team is coordinated by one of the organisers of the *Les Houches Workshop* "Physics at TeV colliders". This framework contributes originally and efficiently to the training of young researchers, whose participation is strongly supported: the latter not only benefit from lectures on the latest developments in the field but can also *collaborate* with many senior physicists on actual research projects.
`Germany team` All four institutions in team Germany offer a wide range of research and training activities and host large numbers of seminars. In addition, DESY hosts an annual summer

students programme and is member of the graduate college "The Standard Model of Particle Physics - structure, precision tests and extensions" and Aachen has a graduate college "Elementary Particle Physics at the TeV Scale" for PhD students in experimental and theoretical particle physics. Aachen as well as DESY are also members of the Sonderforschungsbereich "Computational Theoretical Particle Physics", together with Karlsruhe and Berlin universities.

`Great Britain team` Cambridge and Edinburgh provide excellent research facilities and a wide range of relevant graduate courses, workshops and seminars. Members of the Great Britain team serve as conveners of international workshops and organisers of regular international summer schools, like the recent Scottish University Summer School on LHC phenomenology.

`Italy team` members work in close contact with other theory groups and with experimentalists participating in the current programs at CERN, DESY and Tevatron, and are normally involved in the training of doctorate students. They partecipate with Italy-Spain team members to the organization of the National School of Theoretical Physics being held in Parma every year, and of the Cortona National Meeting on Theoretical Physics, which is aimed at postdocs and young researchers nationwide, and encourages them to present their research work to an audience of senior physicists.

`Netherlands team` For early-stage researchers, the Netherlands team has extensive experience educating Ph.D. students working on network task topics. Besides through personal interaction, the team offers extensive training through lectures, both general and topical, via the Dutch Research School for Theoretical Physics (DRSTP), either at special schools, or the many universities associated with the DRSTP. Experienced researchers fully take part in the active research program at NIKHEF and Leiden, are encouraged to participate in international workshops, and collaborate with other teams to further develop and explore particular subjects.

`Sweden team` The Lund/Uppsala team has solid experience in the training of early-stage and experienced researchers. In the last five years Gustafson, Ingelman and Sjöstrand have in total had ten PhD students graduating and four post-docs. The groups in Lund and Uppsala belong to two of the major universities in Sweden with broad research programs and educations in physics, providing a top-class research infrastructure.

`CHDH team` University of Zürich, ETH Zürich and PSI Villigen offer a broad spectrum of specialized training opportunities in particle physics and computational science, which are aimed towards an excellent instruction of graduate students and early-career postdoctoral researchers. Most sites of this team have also active research groups on the LHC experiments.

`CERN team` gives young researchers access to unrivalled training opportunities through the *CERN Academic Training programme*, which covers all aspects of high energy physics. CERN Theory Group also operates a *programme for students*, whereby students are hosted for periods as long as one year, and work under the supervision of some Theory Division member (working of course along the lines of the PhD thesis topic proposed by their official university advisor). CERN offers office space, and access to the infrastructure, in addition to scientific supervision, but cannot provide financial support to the students, which will be covered by network funds. M.L. Mangano, as the network training coordinator, and M. Seymour, as the CERN team leader, will be responsible for hosting the network young researchers.

`Japan team` At KEK, Hagiwara often organizes workshops and schools for both Ph.D. students and postdoctoral fellows. Graduate courses are offered at Hiroshima (supervised by Kodaira), Kyoto (supervised by Uematsu) and Tohoku (supervised by Hikasa).

`USA team` members have successfully trained numerous graduate students and postdocs in phenomenological applications of quantum field theory and collider physics. Many of these individuals now hold faculty positions at leading institutions around the world, and are team members on the present proposal. Key personnel for providing such training include G. Sterman, S. Dawson, K. Ellis, Z. Bern and L. Dixon. Furthermore, many of the team members belong to the CTEQ

Collaboration. CTEQ runs a summer school which, since 1992, has trained over 700 graduate students, postdocs and senior physicists in QCD and its application to collider physics. The CTEQ Collaboration plans to alternate schools between Europe and the USA in coming years.

Participation in workshops, schools and conferences

We itemize here the different network meetings and schools we envisage along the duration of the network:

`Network Meetings` of a duration of up to a week shall be organised on a yearly basis, for the first three years of the duration of the network. They will provide broader opportunities for young researchers to interact with each others and with senior researchers, to present the results of their own research and to learn of the latest research novelties. They will be held in Less Favoured Regions, namely in Dresden, Debrecen and Valencia.

`Summer Schools` on QCD phenomenology shall be organised, one in 2006 (in a Less Favoured Region of Sweden) and the other in 2008 (in the Netherlands). They will be addressed to the network trainees and lectured by the network senior researchers. They will last about ten days and will contemplate also presentation drills by the young researchers, which will allow them to sharpen their presentation skills, with the goal of reaching a clear, effective and concise manner of presentation.

The timing of the two Summer schools is such as to benefit fully from the involvement of the USA team, which comprises members of the Collaboration of Theory and Experiment in QCD (CTEQ) group. The CTEQ group runs yearly the *CTEQ Summer School*, which offers in-depth courses on a wide range topics directly related to this research project, at an ideal level to broaden the expertise of the network's young researchers. The CTEQ School takes place in Europe and North America in alternate years. It will occur in Europe in 2005 and 2007.

`Research Training Sessions` of the duration of three months shall be organised during the first year of the network, as detailed above. They will focus on any of the main lines of research of this network. At these sessions the young researchers will be exposed to the cutting-edge issues of the research topics examined. They will be held at CERN, Durham, Karlsruhe and Firenze.

`Topical Workshops` of a duration of about three days shall be organised during the first year of the network, toward the end of each of the Research Training Sessions mentioned above, and at a later stage during the network life-time, as required by the network members. The topics and locations of the first four such workshops will be *Recent advances in higher order calculations* (Durham), *Shower Monte Carlo programs and multi-jet production* (CERN), *Signals and backgrounds for Higgs production* (Karlsruhe) and *Analytic and numeric resummations* (Firenze). At these meetings the young researchers will be able to report on the progress achieved during the in-depth Research Training Sessions, and present their results in an informal way. In this occurrence, the interbreeding between different network teams will occur naturally, and will foster further the exchange between young researchers.

`Young Researchers' Meetings` shall be organised by the young researchers themselves. Such meetings have proved highly successful in the previous TMR network QCDNET. They will provide further training in communication and project management skills, and will allow for transfer of knowledge from the experienced researchers hired by the network to the early-stage researchers.

`Final Network Conference` shall be organised during the last year of the duration of the network. It will be widely publicised and will showcase the achievements of the network. Members of the particle physics community world-wide shall be invited. The timing is such that the conference will occur during the first year of operation of LHC. It will be held in a Less Favoured Region.

Gender aspects of training. Proper integration of gender aspects into the training programme will be ensured by the network's Human Resource Coordinator, Dr. Gudrun Heinrich. She will sit on the network management board (see Sect. 4.1) and will be involved in all the stages of the recruitment of early-stage and experienced researchers (see Sect. 2.3).

2.2 Impact of the training and/or transfer of knowledge programme

As we mentioned in the previous section, the main objective of the training programme is to provide young researchers (YR) with the most complete range of skills in phenomenology of particle physics. The most direct benefit to the YR's is to *master the tools* they will need to *do front-line research* in particle physics. However, there are also indirect assets, which depend on the kind of skills the YR's will acquire. Basically we can divide the skills into analytic and numeric: (*a*) the analytic skills have an important intellectual value: they give the young researchers access to the *most sophisticated applications* of *gauge field theories* in the Standard Model of particles (see Sect. 1.4); (*b*) the numeric skills have an important practical value: they are to make the young researchers acquainted with *complex software architectures* of *object-oriented languages*, like `C++`, which will be very important in their careers, whether they choose to remain in the academic environment or decide to work in *industry, administration or finance.* However, the most important indirect skill the YR's will acquire is to ask themselves questions, and thus to devise problems and to solve them. This *problem solving* attitude is the mainstay on which their way of thinking will be based, and will guide them through their professional careers, wherever those might be. Proof of it is the fact that young physicists who have left the academic environment are being successfully employed world-wide for managerial jobs by financial and consulting companies, think-tank groups, and industry.

Within particle physics phenomenology, the skills mentioned above are to enable them to carry the subject forward into the coming LHC era, when these skills will be essential for LHC optimal exploitation. LHC, currently built at CERN, is a joint enterprise of most of the European States. In addition to the human assets and resources outlined above, LHC and CERN are expected to have *a large impact at the European Community level* in terms of outsourcing, computing capabilities (GRID) and web-based services (*e.g.* the World Wide Web was invented at CERN).

Impact on the research student community. As outlined in Sect. 2.1, during the first year of the network we plan a series of 3-month Research Training Sessions (RTS) driven by the physics tasks, in order to *maximise the impact* of the training and transfer of knowledge programme on the existing graduate-student community. In fact RTS are aimed at already existing Ph.D. students toward the end of their Ph.D. course, and are conceived to *boost their research training* by making them acquainted with the most advanced technologies in the research field.

Starting with the second year of the network we plan one 36-month, one 24-month, five 12-month, seven 6-month ESR appointments, and six 24-month ER appointments. We point out that while only the equivalent of 6.5 three-year ESR are explicitly included for support in the proposal, a large number of network nodes has access to local funding for the payment of Ph.D. fellowships supporting ESR. Thus, as explained in the `proposed mixture` in Sect. 2.1, we think we can have a much bigger impact at the level of the student community by improving the quality of the research training of the Ph.D. students who are mostly paid through local fundings. That will be achieved by increasing their mobility and exploiting the complementarity of the network teams as regard to the different research methods and approaches.

In addition, the 36-, 24- and 12-month ESR's as well as the 24-month postdocs would be

	Network Team	Early stage researchers (pers-month)	Experienced researchers (pers-month)	Total	Contributing researchers (individuals)	Contributing researchers (pers-month)
1.	Italy - Spain	30	24	54	10	394
2.	Durham IPPP	42	0	42	7	216
3.	France	12	24	36	8	305
4.	Germany	24	24	48	14	576
5.	Great Britain	12	24	36	7	211
6.	Italy	12	24	36	11	437
7.	Netherlands	36	0	36	5	158
8.	Sweden	0	24	24	5	197
9.	CHDH	48	0	48	12	451
10.	CERN	18	0	18	8	324
	Total	234	144	378	87	3269
11.	Japan				19	461
12.	USA				29	696
	Overall Total	234	144	378	135	4426

Table 3: Number of researchers to be financed by the network - Number of researchers included in the network

strongly encouraged to take secondments of a length varying between one and three months, in order to enhance further the transfer of knowledge and to maximise the impact of the training programme on particle physics phenomenology at EC and international levels. Extrapolating from the figures of the past few years, the network nodes plan to train and lead to a Ph.D. degree approximately 40 young researchers. The number of postdoctoral fellows requested (6) seems therefore adequate to contribute to the training of the ESR's and to enhance the transfer of knowledge between teams that research in particle physics strongly demands. The by-then Ph.D. graduates trained in the Research Training Sessions would become natural candidates for those ER appointments.

Finally, most of the network-sponsored ESR and ER appointments are *phased so as to terminate in 2007, when LHC is commissioned to commence operations.* That is conceived so as to bring the bulk of the training and transfer of knowledge programme to fruition when we expect that it will be needed most.

2.3 Planned recruitment of early-stage and experienced researchers

The overall contribution of the proposed network to the training of young researchers is quantified in Table 3. We request a total of 234 person-months of early-stage researchers (ESR) and 144 person-months of experienced researchers (ER), which gives 62% ESR versus 38% ER. That corresponds, on average, to 39 person-months of ESR and 24 person-months of ER per each of the six physics tasks set out in Sect. 1.2.

Advertisement of ESR and ER vacancies. The goal of the advertising phase is to attract the best possible applicants for each physics task involved. The main targets are the Ph.D. students and postdocs of the network teams, however, by exploiting the 30% envelope of person-months of the network research budget foreseen by the FP6 rules to attract young researchers from Third Countries, we shall conduct a world-wide search.

All the institutes and centres of research involved in the network are equal-opportunity employers who seek actively gender balance, as explicitly stated in all their job vacancies. The human resource coordinator will advertise ER and ESR vacancies through:

- a page on the network web site dedicated to job vacancies;
- e-mailing world-wide to all the major high-energy groups and facilities;
- scientific journals such as CERN Courier, Nature, Physics Today.

In addition, for ESR vacancies she will contact world-wide the major universities with high-energy interests.

ESR and ER Selection shall be organised in four stages:

(*i*) The human resource coordinator advertises ESR and/or ER positions, specifying the number of available positions, and eventually the desired profiles.

(*ii*) Candidates apply, indicating in the application which tasks they prefer to work on and which team they wish to join. They may choose more than one task and/or team, in order of preference.

(*iii*) The human resource coordinator compiles the ER list and/or the ESR list. The management board makes a short list out of candidates on the ER list and/or the ESR list in such a way that *all the tasks are adequately represented.*

(*iv*) The teams are invited to choose candidates from the ER short list and/or the ESR short list, keeping into account the candidate preferences on tasks and eventually on teams, and the *overall balance between tasks.*

Gender issues. Unfortunately, in the areas of research that pertain to this network there are no women with permanent staff appointments in Europe (conversely, 4 out of the 20 senior researchers of the USA team are women). At present, the women researchers active in those areas in Europe are 3 post-doctoral fellows and 3 Ph.D. research students: they are active members of this proposal. Except for Dr. Heinrich (who has more than 10 years of research experience), they are eligible for a postdoc position within this network. We shall encourage them to apply for such positions. Furthermore, we shall encourage women with a diploma giving access to doctoral studies to apply for ESR positions. In general, we shall *address the needs* women may have as regard to *different life patterns* (re-entry after childbirth, relocation in order to avoid the separation of families). As for permanent staff appointments, our goal over the next few years is to arrive at a representation of women comparable to the one in the USA team, which is consistent with the long-term goal of the EC Work Programme to reach gender balance.

Living requirements. All teams are willing to provide to the recruited young researchers assistance with accomodation and living requirements. Some sites (like CERN, Durham IPPP, DESY, Debrecen) also have access to living quarters where visitors can be accommodated temporarily.

	Team	Scientist in charge	Number of researchers	Number of students
1.	Italy-Spain	V. Del Duca	10	3
2.	Durham IPPP	N. Glover	7	3
3.	France	E. Pilon	8	2
4.	Germany	F. Krauss	14	10
5.	Great Britain	M. Krämer	7	4
6.	Italy	S. Catani	11	4
7.	Netherlands	E. Laenen	5	1
8.	Sweden	J. Rathsman	5	6
9.	CHDH	T. Gehrmann	12	3
10.	CERN	M. Seymour	8	0
11.	Japan	J. Kodaira	19	10
12.	USA	L. Dixon	29	10

Table 4: Teams and researchers involved

3 Quality and Capacity of the Network Partnership

3.1 Collective Expertise of the Research Teams

The proposed network comprises 10 teams from 7 Member States of the European Community (France, Germany, Great Britain, Italy, Netherlands, Spain, Sweden), 2 Associated States (Hungary[1] and Switzerland[2]), an International European Interest Organization (CERN), and 2 unfunded teams from "Third Countries" (Japan and USA).

The criteria for selection applied to all teams are: (*i*) high quality of research, (*ii*) proven expertise in the research area of the proposal, (*iii*) the ability to play a significant role in achieving the research training objectives of the network. In addition, the USA team is poised to play a significant role in the research training programme of the network, while the Japan team is considered important to the research programme of the network. Therefore, the participation of the USA and Japan teams is very much in the interests of the network and the European Community.

In total, the network comprises 94 senior theoretical particle physicists together with 41 postdocs and 56 Ph.D. research students. Out of these, 58 senior physicists together with 29 postdocs and 36 Ph.D. students constitute the 10 European teams, that will hire early-stage and experienced researchers financed by network funds. The teams, the senior researchers in charge of each team, the number of (faculty and post-doctoral) researchers and the number of research students to be involved in network activities are listed in Table 4.

[1]At present Hungary is a Candidate Country, which will join the EC as a Member State in May 1, 2004.
[2]Switzerland has agreed to the terms of association with FP6, and thus it is eligible to receive EC funding.

3.1.1 Italy-Spain team

Organisation and scientist in charge: Vittorio Del Duca, INFN, Torino

Principal research personnel: **Milano-Bicocca**: G. Marchesini (100%), P. Nason (100%), C. Oleari (100%); **Roma III**: M. Greco (50%), 1 postdoc (50%); **Torino**: V. Del Duca (100%), L. Magnea (100%), R. Pittau (50%), 1 postdoc (100%), 3 students; **Valencia** G. Rodrigo (70%).

Total: 8 senior researchers, 2 postdocs, 394 pers.-months, 3 students.

Expertise of the network team: the team consists of leading University and Istituto Nazionale di Fisica Nucleare (INFN) researchers in theoretical particle physics, with expertise in perturbative QCD, Standard Model and BSM phenomenology. The team plans to contribute to the following physics tasks:
JET: heavy quark production, prompt photon production, numerical NLO computations, threshold resummations, small-x resummations, forward-jet physics, Mueller-Navelet jets, power corrections and renormalons.
HWZ: Higgs boson production in association with jets, Higgs couplings, backgrounds to a Higgs boson decaying into photons.
NNLO: general methods for computing jet cross sections at NNLO accuracy, string-inspired techniques for multi-loop calculations of matrix elements.
SIM: multi-jet matrix element generators, shower Monte Carlo generators, matching shower Monte Carlo and NLO computations.
BSM: backgrounds to BSM processes, QCD corrections to BSM processes, QCD effects in other BSM scenarios.

Research and training environment: The members of the team are actively engaged in research, and in teaching and tutoring at graduate and undergraduate level. The Torino and Milano groups both operate a Doctoral program in Physics, which provides a wide range of graduate courses. Furthermore, the Torino group is involved in the International School of Advanced Study of the University of Torino (ISASUT).

Existing research links with other teams: The team members have ongoing collaborations with members of IPPP, Italy, CHDH, Netherlands, CERN and USA teams.

Two recent relevant publications
"QCD radiative corrections to prompt diphoton production in association with a jet at hadron colliders", V. Del Duca, F. Maltoni, Z. Nagy, Z. Trócsányi, JHEP **04** (2003) 059 [hep-ph/0303012].
"Next-to-leading order jet distributions for Higgs boson production via weak boson fusion", T. Figy, C. Oleari and D. Zeppenfeld, hep-ph/0306109. Accepted for publication by Phys. Rev.D.

3.1.2 Durham IPPP team

Organisation and scientist in charge: E.W. Nigel Glover, IPPP, Durham.

Principal research personnel: N. Glover (50%), R. Roberts (50%), P. Richardson (50%), A. Signer (50%), J. Stirling (50%), 2 postdocs (100%).

Total: 5 senior researchers, 2 postdocs, 216 pers.-months, 3 students.

Expertise and proposed research: The team consists of leading UK researchers in perturbative QCD and related phenomenology, with particular expertise in hard processes, strong radiative corrections, parton distributions, next-to-next-to-leading order calculations, shower Monte Carlos and beyond the standard model phenomena. The team will contribute to the attainment of all of the project tasks as follows:
JET: improved predictions for jet cross sections and substructure including NNLO effects, determination of α_s and parton densities using HERA and Tevatron data, development of algorithms and code for numerical NLO predictions of multi particle final states, numerical resummation of Sudakov logs, numerical studies of large high energy logarithms to next-to-leading log accuracy.
PDF: improved determinations of parton density functions from global fits to scattering data, improved error estimates and the incorporation of NNLO effects in a systematic way.
HWZ: precision calculations of Higgs, W and Z boson cross sections, transverse momentum and rapidity distributions, improved determination of W boson mass, strategies for determining Higgs boson parameters at the LHC.
NNLO: development of numerical NNLO predictions for QCD scattering processes at LHC and at linear colliders, two-loop matrix elements for heavy quark and vector boson pair production.
SIM: development of HERWIG event generators, matching of fixed-order calculations with parton showers, implementation of new processes and higher-order corrections in HERWIG, extension of parton showers to beyond leading log accuracy.
BSM: calculation of QCD corrections to supersymmetric processes, improved estimates of supersymmetric cross sections, signals and backgrounds.

Research and training environment:

The new UK Institute for Particle Physics Phenomenology (IPPP), has excellent dedicated research facilities and hosts regular meetings and workshops in all areas covered by the scientific programme of the network. The Durham group specialises in the training of research students, providing some 180 lectures each year on all aspects of particle theory. Many staff members serve as convenors of working groups of major workshops such as those based at CERN and Les Houches and act on the scientific advisory panels of major conferences. Young researchers will be actively involved in international collaborations by the team members, which will expose them to a variety of different approaches and styles of doing research and will help them to develop their own "research personality". They will also be given the opportunity to present the results of their research at conferences and workshops.

Existing research linkages with other participating teams: The various team members have on-going collaborations with a large number of other network members and further researchers in Aachen, Cambridge, CERN, DESY, Dresden, Hamburg, Karlsruhe, KEK, München, Milano, Southampton, Torino, Zürich, Würzburg, US node.

Two most significant recent publications
"Uncertainties of predictions from parton distributions. 1: Experimental errors," A.D. Martin, R.G. Roberts, W.J. Stirling and R. Thorne, Eur. Phys. J. **C28** (2003) 455.
"Two-loop QCD helicity amplitudes for $e^+e^- \to 3$ jets," L.W. Garland, T. Gehrmann, E.W.N. Glover, A. Koukoutsakis and E. Remiddi, Nucl. Phys. **B 642** (2002), 227.

3.1.3 France team

Organisation and scientist in charge: Eric Pilon, CNRS, LAPTH Annecy.

Principal research personnel: **Annecy** Jean-Philippe Guillet (100 %), Eric Pilon (80 %), Antonio Polosa (70%); **Grenoble** Michaël Klasen (100%), 1 student; **Orsay** Michel Fontannaz (70%); **Paris 6** Matteo Cacciari (70%), Gavin Salam (70%), 1 student; **Saclay** David Kosower (75%). **Total**: 7 senior researchers, 1 postdoc, 305 pers.-months, 2 students.

Expertise and proposed research.
The team has experience in and will contribute to the following network tasks:

JET: Photon, light meson, and jet production with hadrons and photons at NLO. Development and improvement of the base of computer codes `PHOX-Family` calculating these processes, in particular NLO corrections to correlation observables and resummation of large logarithmic higher order corrections. Refinement of heavy quark cross sections, using matched (NLO+NLL resummed) calculations and a theoretically motivated inclusion of non-perturbative corrections. Procedures for automating final-state resummations and their matching with fixed-order calculations. Production and decay of heavy quarkonia in the CSM and NRQCD. Resummations of jet shapes in the Born-limit (Sudakov logs). Resummation of small-x effects (Mueller-Navelet jets, small-x induced features of underlying events). Development of new analytical and numerical methods to calculate one loop multiparton amplitudes. Power corrections.

PDF: Determination of α_s and of the photon's PDF's from the photon structure function at NLO. NNLO DGLAP evolution codes. Small-x splitting functions and PDF behaviour. Analyses of PDF's in moment space, aiming at parametrization-independent predictions for observable quantities.

HWZ: Diphoton background for Higgs searches at the LHC.

SIM: Small-x shower algorithms. Maintenance and development of `Alpgen`, and phenomenological applications of this programme to multijets physics at LHC.

BSM: Virtual SUSY particle effects, including CP-violating phases. SUSY particle production and decay at NLO in various SUSY breaking models.

Research and training environment: the team members are based at principal theoretical physics laboratories in the two leading research regions in France, Paris (Orsay, Paris VI, Saclay) and Rhône-Alpes (Annecy, Grenoble). Both regions have well-established graduate schools in theoretical physics, and the team members are experienced Ph.D./postdoc advisors. Saclay is the principal site of the Atomic Energy Commission. In the 2003 PALMARES review, Grenoble and Orsay ranked among the best four French universities in scientific research and teaching quality. All team members have close ties with experimental physicists working on the LHC (ATLAS) and other collider (Tevatron, HERA, LC) programmes. Annecy and Grenoble are located in the vicinity of CERN.

Existing research linkages with other participating teams: the various team members have on-going collaborations with a large number of other network members. Annecy & Orsay: CERN, Firenze, Hamburg, KEK, Würzburg; Grenoble: Edimburgh, CERN, KEK; Paris 6: Lund, both Italian teams, USA team; Saclay: USA team.

Two recent relevant publications
"A full NLO study of direct photon pair production in hadronic collisions", T. Binoth, J-Ph. Guillet, E. Pilon and M. Werlen, Eur. Phys. J. **C16** 311, 2000.
"Is there a significant excess in bottom hadroproduction at the Tevatron?", M. Cacciari and P. Nason, Phys. Rev. Lett.**89** 122003, 2002.

3.1.4 Germany team

Organization and scientist in charge: Frank Krauss, Dresden University for Technology

Principal research personnel (% time): Aachen: M. Beneke (50%), W. Bernreuther (100%), 4 postdocs (1× 80%, 3× 100%), 6 grad students.
DESY: J. Blümlein (80%), A. Brandenburg (100%), T. Riemann (50%), S. Moch (80%), 2 postdocs (100%), 1 grad student.
Dresden: F. Krauss (80%), 3 grad students.
Hamburg: G. Heinrich (80%).
Total: 7 senior researchers, 7 postdocs, 576 pers.-months, 10 students.

Expertise and research: The team consists of leading German researchers on aspects of perturbative and non-perturbative QCD and collider phenomenology. The team has expertise on all fields addressed by the network and proposes active participation in all tasks, as follows:
JET: Top-pair production, including spin and decays of the top at NLO, NLO corrections to heavy flavor production and other strong processes, re-summation of NNLL Sudakov logarithms, power corrections to hard processes, automation of NLO computations.
PDF: Precision determination of PDFs at NLO and NNLO, of the strong coupling constant $\alpha_s(M_Z)$, incorporation of heavy flavors, study of small-x effects, NLO fragmentation functions.
HWZ: Finite width effects in processes with unstable particles (W, Z, H, $\ldots$), study of Higgs production and decay and precision background calculations.
NNLO: Complete NNLO evolution of parton densities and of relevant physical observables, NNLO computations involving massive states.
SIM: Construction of a new EvG in C++, matching of EvGs with (automated) NLO calculations, models for multiple scatterings.
BSM: Inclusion of BSM models, QCD radiation off non-SM particles.

Research and training environment: All four places (Aachen, DESY, Dresden, Hamburg) are centers for active research in theoretical high-energy physics in Germany and host large numbers of visitors and seminars. The universities and DESY offer a wide range of lectures and have strong experimental groups on CMS and LHCb at LHC, H1, ZEUS and HERMES at HERA, D0 at Tevatron, and BaBar at SLAC. DESY is the leading laboratory of experimental research in high-energy physics in Germany. It offers the unique *ep* collider HERA and currently is one of the leading laboratories preparing for the next linear collider and its experimental programme. It also plays a major role in neutrino astrophysics experiments as AMANDA and ICECUBE at the South Pole. DESY and Dresden are supplied with excellent large-scale computing facilities needed for many of the tasks above. Altogether, this provides an outstanding training environment for young scientists from other European countries.

Existing research linkages with other participating teams: The various team members have on-going collaborations with a large number of other network members and further researchers. Aachen: Bologna, CERN, DESY, Durham, Freiburg, Karlsruhe, Zürich. DESY: Amsterdam, CERN, Karlsruhe, Leiden, Milano, München, Paris, US node, Japanese node. Dresden: Cambridge, CERN, Durham, Firenze. Hamburg: Annecy, Durham, Paris, Würzburg, Zürich.

Recent relevant publications:
1. *Top quark spin correlations at hadron colliders: Predictions at next-to-leading order QCD*, W. Bernreuther, A. Brandenburg, Z. G. Si and P. Uwer, Phys. Rev. Lett. **87** (2001) 242002.
2. *QCD Analysis of Polarized Deep Inelastic Scattering Data and Parton Distributions*, J. Blümlein and H. Böttcher, Nucl. Phys. **B 636** (2002) 225.

3.1.5 Great Britain team

Organisation and scientist in charge: Michael Krämer, University of Edinburgh.

Principal research personnel: Cambridge: R Thorne (90%), B Webber (50%), 2 postdocs (50%), 2 postgraduate students. **Edinburgh:** R Ball (100%), M Krämer (50%), 1 postdoc (50%), 2 postgraduate students.
Total: 4 senior researchers, 3 postdocs, 211 pers.-months, 4 students.

Expertise and proposed research: The team consists of leading UK researchers in perturbative QCD and collider phenomenology, with expertise and proposed participation in all the network tasks, as follows:

JET: resummation and power corrections in event shape distributions and in heavy-quark fragmentation; automated numerical calculation of NLO cross-sections; impact of fits to jets on parton distributions and/or interpretation of data in terms of possible new physics.

PDF: determination of parton distributions and associated uncertainties, both experimental and theoretical, using global fits to data; development of improved treatment of heavy flavour production cross-sections and of small-x and large-x resummations necessary for precision analyses.

HWZ: calculation of QCD corrections to Higgs production and background processes; examination of precision possible in cross-section predictions, and relevance of W and Z production for luminosity determination.

NNLO: development of approximate and appropriate NNLO hard cross-sections from available information where exact expressions are not available.

SIM: matching of (NLO) matrix elements and parton showers; development of next-generation object-oriented event generators.

BSM: calculation of QCD effects in new particle production and decay; updating of expectations for BSM signals and backgrounds at LHC.

Research and training environment: The Cambridge particle physics group is one of the largest in the UK, with interests ranging from M-theory to small-x physics. The Edinburgh members are a dynamic young group focusing on QCD, Higgs and SUSY studies, in close contact with experts in high performance computing. Both Cambridge and Edinburgh provide excellent research facilities and a wide range of relevant graduate courses, workshops and seminars. Members of the Great Britain team serve as conveners of international workshops and organisers of regular international summer schools, like the recent Scottish University Summer School on LHC phenomenology.

Existing research linkage with other participating teams: The Great Britain team has well established collaborative links with CERN, Fermilab, the IPPP Durham, the MPI München, and the Universities of Genova, Milano, Oregon and Uppsala.

Recent relevant publications:

"Matching NLO QCD computations and parton shower simulations," S. Frixione and B. R. Webber, JHEP **0206** (2002) 029.

"NLO QCD corrections to $t\bar{t}H$ production in hadron collisions," W. Beenakker, S. Dittmaier, M. Krämer, B. Plümper, M. Spira and P.M. Zerwas, Nucl. Phys. B **653** (2003) 151.

3.1.6 Italy team

Organisation and scientist in charge: Stefano Catani, Director of Research, INFN, Firenze.

Principal research personnel: **Bologna**: E. Remiddi (60 %); **Ferrara**: D. Comelli (50 %), M. Moretti (50 %), 1 student; **Firenze**: S. Catani (100 %), M. Ciafaloni (100 %), D. Colferai (100 %); **Genova**: S. Frixione (100 %), G. Ridolfi (100 %); **Parma**: S. Laporta (100 %), L. Trentadue (100 %), 3 students; **Pavia** F. Piccinini (50 %).
Total: 9 senior researchers, 2 postdocs, 437 pers.months, 4 students.

Expertise of the network team: the team consists of leading University and Istituto Nazionale di Fisica Nucleare (INFN) researchers in theoretical particle physics, with expertise in theory and phenomenology of QCD and the Standard Model. The team plans to contribute to the following physics tasks:
JET: resummation of Sudakov logs and phenomenological applications to jet, heavy-quark, Drell–Yan pairs and vector boson production; study of the high-energy cross-sections for the production of heavy-flavour and Mueller-Navelet jets; theory and phenomenology of isolated-photon production at hadron colliders; studies of production, fragmentation and decay of heavy quarks;
PDF: study of the low-x behaviour of the splitting functions and of the gluon density in the renormalization-group-improved small-x approach;
HWZ: precision calculations (total cross section and associated distributions) for Higgs boson production via gg fusion; study of electroweak double-log contributions (and ensuing evolution equations) to fusion production processes of Higgs and vector bosons;
NNLO: developments of general methods and formalisms to compute QCD observables at NNLO accuracy; computation of the evolution of the parton distributions at NNLO accuracy; developments of analytic methods for the precise and fast evaluation of multi-loop Feynman integrals;
SIM: development and improvement of matching of NLO matrix elements and MC event generators; computations of multiparton matrix elements and matching with parton showers.

Research and training environment: Researchers in the team work in close contact with other theory groups and with experimentalists participating in the current programs at CERN, DESY and Tevatron, and are normally involved in the training of doctorate students. They participate with people in the Italy-Spain team to the organization of the National School of Theoretical Physics being held in Parma every year. This school aims at providing doctorate students from various Universities with intensive background and research courses. They also collaborate with members of the Italy-Spain team to the organization of the Cortona National Meeting on Theoretical Physics, which is aimed at postdocs and young researchers nationwide, and encourages them to present their research work to an audience of senior physicists.

Existing research links with other teams: The team members have ongoing collaborations with members of the following teams: IPPP, UK, Germany-Hungary-Switzerland, Italy-Spain, France, CERN, Japan.

Two recent significant publications:
"Soft-gluon resummation for Higgs boson production at hadron colliders," S. Catani, D. de Florian, M. Grazzini and P. Nason, JHEP **0307** (2003) 028.
"Renormalisation group improved small-x Green's function," M. Ciafaloni, D. Colferai, G. P. Salam and A. M. Stasto, hep-ph/0307188, Phys. Rev. D in press.

3.1.7 Netherlands team

Organisation and scientist in charge: Eric Laenen, NIKHEF.

Principal research personnel: NIKHEF: E. Laenen (90%), J. Vermaseren (50%), 2 postdocs (70%), 1 student. Leiden: W. van Neerven (50%)

Total: 3 senior researchers, 2 postdocs, 158 pers.-months, 1 student.

Expertise of the network team. The expertise of the NIKHEF-Leiden theory team consists of precision calculations of important observables in high-energy scattering, in particular the inclusion of high-order, multi-loop QCD quantum corrections to these observables. Further team expertise lies in providing more accurate predictions of heavy quark and Higgs boson production characteristics at higher order, as well as in the development and application of all-order resummation techniques.

Within the HardQCD@LHC network we intend to work on the following topics:
JET: confrontation with data of various hard scattering observables, computed at NLO, and/or improved via resummation. Further development and application of resummation methods, in particular numerical resummation methods.
PDF: calculation of NNLO corrections to evolution equation for parton distibution functions, a required ingredient for all NNLO calculations of any observable at the LHC.
HWZ & NNLO: calculation of inclusive and differential Higgs boson production cross sections at NLO and NNLO.

Research and training environment. NIKHEF, the Dutch national institute for high energy physics, is a quite large, active research center. It provides an excellent training environment for young researchers, as offers a wide range of topical graduate courses and colloquia. The high-energy group of the Lorentz theoretical physics institute at Leiden University has a distinguished tradition in research and training young scientists.

Existing research linkages with other participating teams. Team members have on-going collaborations with a number of other network members, as well as other researchers. *NIKHEF*: DESY-Hamburg, DESY-Zeuthen, Paris-LPTHE, Fermilab, Torino, Stony Brook. *Leiden*: Stony Brook.

Two recent relevant publications:
"Non-singlet structure functions at three-loop: fermionic contributions", S. Moch, J. Vermaseren, A. Vogt, Nucl. Phys. **B646** (2002) 181.
"NNLO corrections to the total cross-section for Higgs boson production in hadron-hadron collisions" V. Ravindran, J. Smith and W. van Neerven, Nucl. Phys. **B665** (2003) 325.

3.1.8 Sweden team

Organisation and scientist in charge: Johan Rathsman, Uppsala University.

Principal research personnel: Lund: G. Gustafson (90%), L. Lönnblad (90%), T. Sjöstrand (90%), 4 students. Uppsala: G. Ingelman (50%), J. Rathsman (90%), 2 students.

Total: 5 senior researchers, 197 pers.-months, 6 students.

Expertise of the network team: The Swedish team has a long and distinguished record of theory–experiment integrated QCD physics studies: parton cascades in the initial and final state, hadronization (the Lund string model), jet physics, hadronic final states, underlying events, etc. Members of the team have developed several well-known Monte Carlo event generators, which are used in all high energy laboratories for analyses of experimental results and for preparation of new experiments.
Within the HardQCD@LHC network we propose in particular to work on the following topics:
JET: resummation of soft and collinear logarithms and the connection to power-corrections.
HWZ & BSM: improve the description of parton cascading and hadronization in a broad range of standard model and new physics processes, such as supersymmetry and extra dimensions.
SIM: match NLO calculations to parton showers and study the interplay with nonperturbative physics; meet the need for sustained development and support of our widely-used generators, both by extending them to new physics processes and by improving the precision of the existing descriptions (e.g. of underlying events and small-x effects); write fully modernized event generators in C++.

Research and training environment: The team has solid experience in the training of young researchers, through supervision of many graduate students and several postdocs. Members of the team also teach graduate students at their respective universities. Our close link to the experimental community is important for a young researcher to become a full-fledged physicist. In particular, the Monte Carlo event generators facilitate detailed tests of various theories and models against data. This offers graduate students and postdocs a unique research experience in topics that will be of large interest in the years ahead, for physics studies at future colliders such as the LHC. In the past, graduate students from Lund/Uppsala has continued as postdocs doing academic research both in particle physics and in biophysics as well as going to research positions in industry.

Existing research links with other participating teams:
The team members have research links with the Durham IPPP, Great Britain, Italy-Spain, Italy, France, CERN and USA teams.

Two recent relevant publications:
"High-Energy-Physics Event Generation with PYTHIA 6.1", T. Sjöstrand, P. Edén, C. Friberg, L. Lönnblad, G. Miu, S. Mrenna and E. Norrbin, Computer Phys. Commun. 135 (2001) 238
"The thrust and heavy-jet mass distributions in the two-jet region", E. Gardi and J. Rathsman, Nucl. Phys. B **638** (2002) 243

3.1.9 Switzerland – Germany – Hungary (CHDH) team

Organization and scientist in charge: Thomas Gehrmann, Universität Zürich.

Principal research personnel: **Universität Zürich:** Thomas Gehrmann (80%); **ETH Zürich:** Zoltan Kunszt (100%); **Debrecen:** Zoltan Trocsanyi (60%); **Karlsruhe:** Robert Harlander (100%); **MPI München:** Stefan Dittmaier (50%), Stefan Weinzierl (100%); **Würzburg:** Thomas Binoth (50%); plus 5 postdoctoral researchers (400%) and 3 students.
Total: 7 senior researchers, 5 postdocs, 451 pers.-months, 3 students.

Expertise and proposed research: The team groups together many leading researchers in the field of multi–loop higher order corrections. Besides this specific qualification, most team members have considerable experience in one or more further aspects of QCD at LHC. Experience and activities in the different tasks are as follows.
JET: Nearly all team members have extensive experience in jet physics calculations in higher orders in QCD. Especially Z. Kunszt has made numerous ground-breaking contributions to NLO calculations of jet observables. The activities of the team are largely aimed towards specific NLO calculations (hadronic four jets, single top quarks, photon pairs), automatization of NLO calculations and NNLO calculations of jet observables (see below).
HWZ: Two team members (R. Harlander and S. Dittmaier) are among the world's leading experts for Higgs and vector boson production. Contributions to this task will involve virtual SUSY effects on Higgs production and improvements of resummation techniques relevant to vector boson production.
NNLO: All members have a strong involvement in NNLO computations, the leader of this task (Z. Trocsanyi) is also a member of the team. Among the NNLO issues addressed by team members are the derivation and practical implementation of an infrared subtraction scheme at NNLO, the construction of a first partonic NNLO Monte Carlo program, the study of finite top mass effects in Higgs production at NNLO and the derivation of two-loop matrix elements for heavy quark production at LHC.
SIM: Concerning event simulation, considerable relevant programming experience is present, since Z. Trocsanyi, S. Weinzierl, S. Dittmaier, T. Binoth and Z. Kunszt have co-authored different widely used NLO parton level event generator programs. Plans for future contributions overlap with the JET and NNLO tasks expanded above and involve the construction of NLO and NNLO event generators for specific processes.

Research and training environment: The network team is centered around the University of Zürich, which is embedded in a very flourishing scientific environment, having close ties to the theoretical and experimental groups of ETH Zürich and PSI Villigen. Together, these institutions offer a broad spectrum of specialized training opportunities in particle physics and computational science, which are aimed towards an excellent instruction of graduate students and early-career postdoctoral researchers. Most sites of this network team have also active research groups on the LHC experiments.

Cooperation with other teams: U. Zürich: Bologna, Durham, Aachen, Hamburg, **ETH Zürich:** SLAC, Durham, **Debrecen:** Torino, Oregon, **Karlsruhe:** BNL, **MPI München:** DESY, CERN, Parma, Edinburgh, **Würzburg:** Hamburg, Orsay, Annecy.

Recent relevant publications:
T. Gehrmann and E. Remiddi, *Analytic continuation of massless two-loop four-point functions*, Nucl. Phys. B **640** (2002) 379.
R.V. Harlander and W.B. Kilgore, *Next-to-next-to-leading order Higgs production at hadron colliders*, Phys. Rev. Lett. **88** (2002) 201801.

3.1.10 CERN team

Organisation and scientist in charge: Michael Seymour, CERN Theoretical Physics Division.

Principal research personnel: [SS: senior staff (tenured); S: staff (tenure track)] G. Altarelli (SS 50%), M. Mangano (SS 50%), M. Seymour (S 100%), plus 5 postdoctoral fellows (475%).

Total: 3 senior researchers, 5 postdocs, 324 pers.-months.

Expertise and proposed research: The proximity to the LHC experiments and annual workshops on LHC physics give us a central role in linking the theoretical work of the network to predictions for, and ultimately analysis of, LHC data. The four LHC experiments have upcoming mock data challenges, in which huge samples of data will be simulated and analysed and members of the CERN team will provide crucial input. We therefore expect to contribute to most network tasks. Our specific experience and planned contributions to the tasks are:
JET: Algorithms for tree-level and one-loop calculations of hard processes; Calculations of top quark production, spin correlations and phenomenological analyses; Resummation of Sudakov logarithms in many processes and observables; Non-global effects and resummation of non-global logarithms; Improved jet definitions and the interplay between their details and the associated logarithms; Non-perturbative (power-suppressed) corrections to perturbative observables.
PDF: Calculations of hard processes with incoming massive quarks and analysis of mass effects; phenomenological impact of $\ln 1/x$ resummations.
HWZ: Multi-boson production; QCD effects in vector boson fusion; 'Invisible' Higgs signals.
NNLO: Singularity structure of NNLO cross sections; Towards general algorithms for NNLO calculations; $e^+e^- \to 2$ and 3 jets at NNLO; '$2 \to 1$' type processes at NNLO.
SIM: HERWIG++, a general purpose event generator for the LHC era; Improved algorithms for parton showers, hadronization and underlying events; Validation and tuning of new algorithms on existing data; Matrix element corrections to parton shower algorithms.
BSM: NLO calculations for SUSY and other BSM models; Extend Prospino, with NLO corrections for many SUSY processes; BSM phenomenology and QCD backgrounds; Extraction of SUSY parameters from LHC data; Extend general-purpose program MadGraph to include SUSY.

Research and training environment: The team consists of members of the CERN TH Division, which has 20 staff members, 35 Postdoctoral fellows and an average of 30 visitors. Its research programme is very diverse, with approximately 30% of its activity directly related to this network. We therefore provide a healthy training environment for ESRs from throughout the network, with the right balance of in-depth education on specific topics and acquisition of general knowledge on a wide range of subjects. Four seminars take place each week, in addition to weekly seminars in the Experimental Physics Division and a CERN-wide Colloquiem. Lecture series on particle physics regularly take place in CERN's Academic Training programme, and Workshops on LHC physics are organised each year. As well as the LHC itself, CERN hosts many experimental activities vital to the programme of the network and collaboration between members of the TH Division and the experimentalists is an important element of our activity.

Existing research links with other participating teams: the CERN team has links with essentially all the other teams of the network.

Two most significant recent publications
"HERWIG 6: An event generator for hadron emission reactions with interfering gluons (including supersymmetric processes)", G. Corcella *et al.*, JHEP **0101** (2001) 010 [arXiv:hep-ph/0011363].
"ALPGEN, a generator for hard multiparton processes in hadronic collisions", M.L. Mangano, M. Moretti, F. Piccinini, R. Pittau and A. Polosa, JHEP **0307** (2003) 001 [arXiv:hep-ph/0206293].

3.1.11 Japan team

Organization and scientist in charge: Jiro Kodaira, Hiroshima University

Principal Research Personnel: Hiroshima: J. Kodaira (50%), Kyoto: T. Uematsu (30%), KEK: K. Hagiwara (50%), Y. Shimizu (50%), T. Kaneko (50%), M. Kurihara (50%), J. Fujimoto (50%), T. Ishikawa (50%), H. Kawamura (50%) Tohoku: K. Hikasa (30%), Y. Sumino (50%), Niigata: Y. Koike (50%), Juntendo: K. Tanaka (50%), Yokohama: K. Sasaki (50%), Kogakuin: K. Kato (30%), Rikkyo: H. Tanaka (30%), plus approximately 3 postdocs (80%) and 10 graduate students.

Total: 16 senior researchers, 3 postdocs, 461 pers.-months, 10 students.

Expertise of the network team: The Japan team consists of leading researchers in perturbative QCD and related phenomenology. While activity is in all the task areas of the network, we propose in particular to address the following topics:
HWZ(JET): Prediction of heavy quark and Higgs production and their decays with minimal theoretical uncertainties including the higher order and all-order resummation effects in the standard model. Power corrections in high-energy processes and relation to the perturbation theory (all-order resummation, renormalon, etc.). The infrared structure of electroweak theory and application to high-energy processes.
BSM: Phenomenological analyses of SUSY and other possible models with detailed studies of background from the standard model.
SIM: Development of event generators equipped with parton shower method both in QCD and QED. Extension of the program package GRACE to construct a set of high precision event generators of QCD processes which are required for the analysis of experimental data at LHC.

Research and training environment: The team is composed of permanent staff belonging to several Universities and KEK. Research activity covers the whole area associated with particle physics. All Universities are producing young researchers in the theoretical particle physics. KEK provides excellent research facilities, workshops, seminars and schools for the graduate students.

Existing research linkages with other participating teams:
Hiroshima – DESY(Zeuthen); KEK – Annecy.

Two recent relevant publications:
Electroweak Sudakov at Two Loop Level, M. Hori, H. Kawamura and J. Kodaira, Phys. Lett. **B491** (2000) 275;
GR@PPA 4B: A Four Bottom Quark Production Event Generator For PP / P Anti-P Collisions, S. Tsuno, K. Sato, J. Fujimoto, T. Ishikawa, Y. Kurihara, S. Odaka, T. Abe, Comput.Phys.Commun.**151** (2003) 216-240.

3.1.12 USA team

Organisation and scientist in charge: Lance Dixon, SLAC
Principal research personnel (all at 50%)**:** Brookhaven: S. Dawson, W. Kilgore, W. Vogelsang; Florida State, L. Reina; FNAL: K. Ellis, W. Giele, S. Mrenna; Hawaii: K. Melnikov; Michigan State: J. Pumplin, C. Schmidt, W.-K. Tung; Oregon: D. Soper; Penn State: J. Collins; Rochester: L. Orr; SLAC: L. Dixon; SUNY Buffalo: D. Wackeroth; SUNY Stony Brook: J. Smith, G. Sterman; UCLA: Z. Bern; Wisconsin: D. Zeppenfeld. Plus approximately 9 postdocs and 10 students.
Total: 20 senior researchers, 9 postdocs, 696 pers.-months, 10 students.

Expertise of the network team: The USA team has strong, broad expertise in developing and refining predictions for collider processes in the Standard Model and extensions of it. This expertise includes: computations of a variety of QCD, electroweak and Higgs boson processes at NLO, and selected processes at NNLO, development of techniques for resumming several types of infrared logarithms, construction of Monte Carlo simulation programs, and global analysis of parton distribution functions. They propose to participate in the following network tasks:
JET: Heavy flavor production (NNLO contributions); automated numerical computation of NLO processes at the LHC; automated resummation of infrared logarithms in event-shape and jet-shape distributions.
PDF: All aspects, but in particular: precise determination of NLO pdfs and uncertainties; extension to include NNLO information.
HWZ: All aspects, but in particular: Single production of real or virtual W and Z bosons, Higgs production via gg fusion (rapidity distributions and eventually a parton-level Monte Carlo at NNLO); Higgs production via WW fusion; associated Higgs production.
NNLO: General NNLO techniques, particularly evaluation of unresolved phase-space integrals; computation of new two-loop master integrals and matrix elements, including those for heavy quark production; development of NNLO parton-level Monte Carlo programs.
SIM: Matrix elements and parton showers; comparison between different event generators and confrontation with existing data.
Research and training environment: The USA team contains both university- and national laboratory-based physicists. There is close contact between team members and experimentalists, both at the US national labs (two of which are participating in the LHC, and which operate the two existing hadron colliders, the Tevatron and RHIC), and among the university groups, which coexist with strong collider experimental efforts. Substantial computing resources are available. Team members have an outstanding record of training and supervising students and postdocs from around the world in collider phenomenology. Many of the USA team members belong to the CTEQ Collaboration. In addition to performing global fits to parton distribution functions, CTEQ runs a summer school which, since 1992, has trained over 700 graduate students, postdocs and senior physicists in QCD and its application to collider physics. The CTEQ Collaboration plans to alternate schools between Europe and the USA in coming years.
Existing research linkages with other participating teams:
UCLA – Saclay – SLAC; Fermilab – Paris 6 – NIKHEF; Brookhaven – Karlsruhe; Fermilab – Durham; Fermilab – Lund; Michigan State – Torino – Brookhaven; Oregon – Edinburgh.
Two recent relevant publications:
"Associated Higgs production with top quarks at the Large Hadron Collider: NLO QCD corrections," S. Dawson, C. Jackson, L. H. Orr, L. Reina and D. Wackeroth, Phys. Rev. D **68**, 034022 (2003)
"Dilepton rapidity distribution in the Drell-Yan process at NNLO in QCD," C. Anastasiou, L. Dixon, K. Melnikov and F. Petriello, Phys. Rev. Lett. **91**, 182002 (2003).

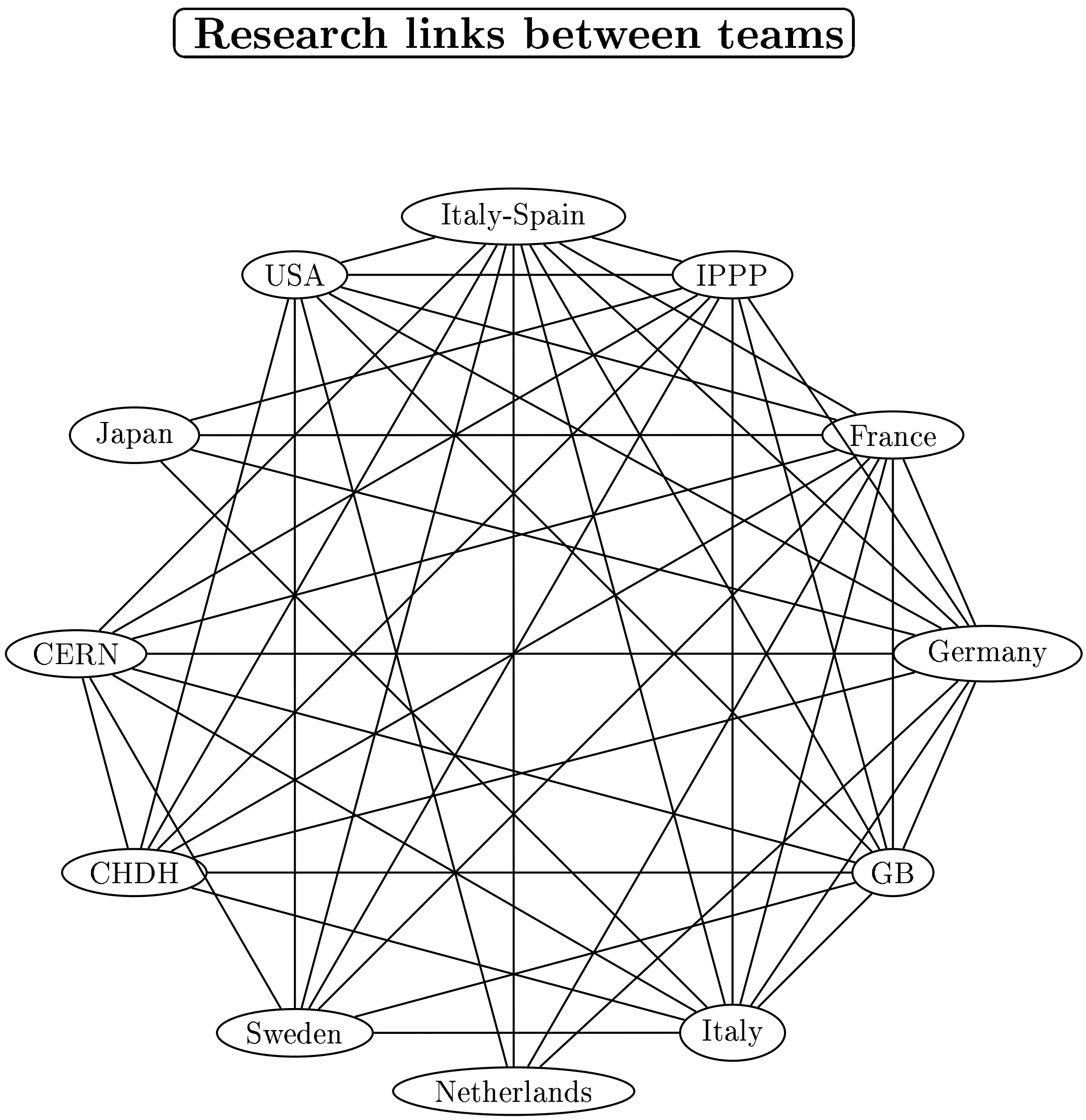

Figure 2: Research links between network teams

3.2 Intensity and quality of networking

Interactions and collaborations between researchers of different institutions are mainstays of present-day research in the phenomenology of particle physics. This is basically due to two main factors: (*a*) on a very specialised topic, of the size, let us say, of a sub-task in the Work Plan, Sect. 1.5, very few people (of the order of five to ten) usually work world-wide; (*b*) the extreme sophistication of the tools that are necessary to tackle almost any project in present-day particle physics phenomenology makes it virtually impossible for a stand-alone researcher to make a significant impact on that project. This implies that there can hardly be any advancement on a specific topic in particle physics phenomenology without a close interaction between the researchers working on that topic. Proof of it is that 2.4 is the average of co-authors of different network teams on the "recent relevant publications" mentioned in the pages of the European teams in Sect. 3.1. In addition, building on this "de facto" situation, is the fact that quite a few fruitful collaborations between teams were already established during the previous HCM network "QCD at High Energy" and TMR network QCDNET.

In practical terms, the collaboration between researchers of different institutions usually occurs through e-mail exchanges and occasional visits. While the former will continue, the latter will be *strongly enhanced by establishing this network.* Furthermore, the exchange of information and the collaboration between members of different teams will be fostered by the yearly Network Meetings, and will be boosted during the first year of the network life-time by the Research Training Sessions and the Topical Workshops as outlined in Sect. 2.1. The exchange of information and the collaboration between teams will also be enhanced by the transfer of knowledge provided by the network postdocs through periodic secondments between network teams, and at the Summer Schools and Young Researchers Meetings as outlined in Sect. 2.1.

Overcoming disciplinary boundaries. As detailed in Sect. 1.3, in order to reach the accuracy that will be demanded by many LHC experiments, a plethora of *sophisticated calculations of production rates* will have to be performed, with an *unprecedented level of accuracy.* Those calculations will require a dedicated pool of researchers, which cannot be found either in the traditional theoretical community, often prone to less applicative aspects of the Standard Model, or in the experimental community, which lacks the theory tools necessary to confront the complex calculations mentioned above. In those respects, this network will greatly help to *overcome the disciplinary boundaries* between *theorists* and *experimentalists*, and thus to create a *better structured phenomenological community.*

Less Favoured Regions. The Spanish component of the Italy-Spain team, as well as about half of the Germany team members are located in Less Favoured Regions. Part of the CHDH team is located in an Associated Country (Hungary). That is equivalent to 8% of the contributing researchers listed in Table 3. However, the researchers based in the Less Favoured Regions and in Hungary have *strong research links* with several network teams, as can be seen from the "existing research linkages" in the team pages of Sect. 3.1, or from the list in Sect. 3.3. In order to *maintain and foster those research links*, we have doubled the provision of networking funds to those members of the Italy-Spain and Germany teams who are located in Less Favoured Regions, and to the Hungarian component of the CHDH team. Then, 30 months of ESR and 24 months of ER appointments will be placed in the Less Favoured Regions or in Hungary (which is equivalent to 13% of the ESR and 17% of the ER requested appointments, respectively). In addition, we plan to hold one network meeting in Dresden (Germany), one in Valencia (Spain) and one in Debrecen (Hungary), in order to favour furthermore the integration with the other network teams of those members who are located in Less Favoured Regions. Finally, also the Final Network Conference and a Summer School will be held in Less Favoured Regions.

3.3 Relevance of Partnership Composition

Existing research collaborations between the network teams have been outlined in the team pages in Sect. 3.1 and are summarised by the "dial" of Fig. 2. Here we shall itemise them according to the project tasks of the Work Plan, Sect. 1.5, listing at the end of each task some of the strong research links.

JET Strong research links: Oregon – Edinburgh; Torino – NIKHEF; Durham – Torino – Genova; Milano – Genova – Firenze – CERN; Annecy – Hamburg – Orsay.

PDF There is a long established and continuous collaboration between Cambridge and the IPPP group on the determination of parton distributions at NLO and NNLO and their uncertainties. Studies of the same kind are carried out at DESY in collaboration with NIKHEF and the experimental groups at HERA. Also links between Cambridge and the USA team on developments in heavy flavour physics for PDF's, and between Cambridge, IPPP and Netherlands teams on the implementation of approximate NNLO contributions in global fits.

HWZ Members of the Italy-Spain, Germany, France, Italy, Great Britain, Netherlands, CHDH and USA teams have joined in various combinations to perform the most advanced calculations to-date on the signal and backgrounds for Higgs production. Strong research links: Torino – Milano – Karlsruhe; Brookhaven – Karlsruhe; CERN – Firenze; Edinburgh – München; Michigan State – Torino – Brookhaven.

NNLO Members of the Italy-Spain, IPPP, Germany, Italy, Netherlands, CHDH and USA teams have been teaming up in recent years, and their collaboration has determined a groundbreaking progress in NNLO calculations for jet cross sections and for the evolution of parton distribution functions. Strong research links: Durham – Zürich – Bologna; Torino – Debrecen; DESY – NIKHEF; UCLA – Saclay – SLAC; Hamburg – Zürich.

SIM The Great Britain and Sweden teams have collaborated on the development of ThePEG, a framework for object-oriented event generation. Strong research links: Cambridge – Lund; Fermilab – Lund; Cambridge – Genova – Milano; Cambridge – Dresden – Firenze; CERN – Annecy – Ferrara – Pavia – Torino; CERN – Dresden.

BSM Members of the Germany, Great Britain, CERN, Japan and USA teams have collaborated on creating a generic user interface for event generators of beyond-Standard-Model processes. Strong research links: Cambridge – Durham; Cambridge – Dresden.

It is one of the research goals of the network to *strengthen the existing collaborations* and to *build new ones*, right at the onset of the network. That should be greatly helped by the Topical Workshops as outlined in Sect. 2.1.

Third-Countries teams. Two teams (Japan and USA) out of the 12 teams are based outside the EC. The USA and Japan teams will not receive any EC funding, but their participation is very much in the interests of the network and the European Community: the USA team comprises some of the best QCD theorists world-wide and is poised to play a significant role in the research training programme of the network, while the Japan team is considered important to the research programme of the network, in particular for its expertise on computer-simulation models.

4 Management and Feasibility

4.1 Proposed management and organizational structure

The overall management of the network will be undertaken by V. Del Duca as the network coordinator, assisted by the management board, which will act as the *global* ruling body of the network, and by the steering committee, which will have *local* power over the network teams.

The **network coordinator** will mainly be in charge of *general networking activity* (distribution of funds, preparation of annual reports, publication of opened positions for early-stage and experienced researchers) and of the organization of *annual network meetings.*

The **network management board** is chaired by the network coordinator and is composed by S. Frixione, L. Lönnblad, P. Nason, R. Thorne, Z. Trócsányi, B. Webber and D. Zeppenfeld, as the leaders of each task described in the Work Plan section, by G. Heinrich as the human resource coordinator and by M.L. Mangano as the training coordinator (see Fig. 3). The members of the management board will be in daily e-mail contact to take any decision needed by the network. The management board will meet twice a year, however it can meet at any time, if needed and requested by its members. Together with the team leaders, it is responsible for the selection of candidates to be recruited as researchers (see Sect. 2.3 on the Recruitment of early-stage and experienced researchers). The management board is to report on *training and research activities* in each area, and will give the list of publications of their teams in international reviews as well as the list of talks in international conferences or workshops related with the activities of the network in each area. The task leaders will be responsible for the scientific progress of their tasks, will ensure that all the tasks are adequately represented in the network activity and, together with the training coordinator, will make sure that a good training is provided locally for each of their early-stage and experienced researchers. The human resource coordinator will ensure that women are appropriately considered in opened positions. In addition, the *Heads of the Higgs and QCD/SM working groups of the ATLAS and CMS Collaborations* shall be invited to selected meetings of the management board. They will offer consultancy on the physics issues of the network tasks.

The **steering committee** is composed by S. Catani, L. Dixon, V. Del Duca, T. Gehrmann, E.W.N Glover, J. Kodaira, M. Krämer, F. Krauss, E. Laenen, E. Pilon, J. Rathsman, M. Seymour as the leaders of each team (see Fig. 3). The members of the steering committee will be in daily e-mail contact to take any decision needed by the network. The steering committee can meet at any time, if needed and requested by its members. Together with the management board, it is responsible for the selection of candidates to be recruited as researchers (see Sect. 2.3 on the Recruitment of early-stage and experienced researchers). The team leaders will be responsible for the funds they get from the network coordinator to cover both the *appointment* and *networking* finances, and to follow the *activities* and *results* of the experienced and early-stage researchers employed in their team. They will report on physics issues and financial aspects of their team at each meeting of the steering committee.

The **advisory committee** is composed by G. Altarelli, J. Blümlein, M. Ciafaloni, M. Fontannaz, J-Ph. Guillet, Z. Kunszt, M.L. Mangano, G. Marchesini, T. Sjöstrand, J. Stirling, W. van Neerven, B. Webber as the most senior people of the network. Its role is to advise the network coordinator. The advisory committee can meet at any time, if needed and requested by the network coordinator.

The **training coordinator** will take care of *global training* for early-stage and experienced researchers by helping to organise the Research Training Sessions, Summer Schools and Young

Researchers Meetings outlined in Sect. 2.1 and by organising lectures at CERN dedicated to early-stage and experienced researchers. Those meetings will allow a detailed follow-up of the training activities according to the different research objectives. The local training in the different teams will be organised by the leaders of each team together with the task leaders.

The **human resource coordinator** will advertise opened positions (see Sect. 2.3 on the Recruitment of early-stage and experienced researchers), will make sure that women are highly considered for appointments, and will offer career advice to the early-stage and experienced researchers employed by the network. We will pay special attention in our network to the positions in *research, industry* or *finance* obtained by the early-stage and experienced researchers when their contract with the network is finished. The human resource coordinator will track the career paths of early-stage and experienced researchers, will put the results on the web, and will make enquiries to be filled in by the early-stage and experienced researchers to be sure that the training was properly performed.

Financial management strategy. The network coordinator will be responsible for the use of the network funds. The funds will be transferred to the central administration of the Istituto Nazionale di Fisica Nucleare (INFN), and will be used the cover all the expenses related to the network, as detailed in Sect. 7.

The research and networking funds will be delivered to each team year by year. The network coordinator will provide the teams with the research funds to appoint early-stage and experienced researchers as specified in Table 2. The networking funds will be distributed according to the number of person-months present in each team, as summarised in Table 3. The team coordinator will be responsible for sharing this money between the different members of the team, following their person-month participation in the network (in accordance with the policy set out in Sect. 3.2 and 6, the network members based in Less Favoured Regions will see their travel allowance doubled). The way money is spent in the different teams will be reported yearly by the team leaders to the network coordinator.

Dissemination of results. We shall set up a *network web site*, where the whole activity of the network (job vacancies, research programmes, physics tasks) can be followed.

There are basically two types of output of the research conducted in this network: research papers and computer program codes.
`Research Papers` showing the research activity of the network teams and the collaborations between them will be posted on the world-renowned “arXiv e-print archive”, which constitutes nowadays the standard on the dissemination of results in physics, math and statistics research. They will be also sent to the leading journals in physics research, as is usual practice.
`Computer Program Codes` on global fits of parton densities, event generators, higher-order corrections to jet production rates will be most of the mainstays of the network research. Besides being introduced to the particle physics community through the arXiv e-print archive, they will be made available through the network web site.

We shall make sure that in any such outputs there is a clear and visible indication of the EC endorsement and sponsorship.

Network Management Board

Network coordinator
V. Del Duca

Human Resource coordinator
G. Heinrich

Training coordinator
M.L. Mangano

Task coordinators

JET	P. Nason
PDF	R. Thorne
HWZ	D. Zeppenfeld
NNLO	Z. Trócsányi
SIM	S. Frixione, L. Lönnblad
BSM	B. Webber

Consultants
Heads of Higgs and QCD/SM working groups of ATLAS and CMS

Network Steering Committee

Team coordinators

1. Italy-Spain	V. Del Duca
2. Durham IPPP	N. Glover
3. France	E. Pilon
4. Germany	F. Krauss
5. Great Britain	M. Krämer
6. Italy	S. Catani
7. Netherlands	E. Laenen
8. Sweden	J. Rathsman
9. CHDH	T. Gehrmann
10. CERN	M. Seymour
11. Japan	J. Kodaira
12. USA	L. Dixon

Advisory Committee

G. Altarelli, J. Blümlein, M. Ciafaloni, M. Fontannaz, J-Ph. Guillet, Z. Kunszt, M.L. Mangano, G. Marchesini, T. Sjostrand, J. Stirling, W. van Neerven, B. Webber

Figure 3: Network management structure

4.2 Management know-how and experience of network co-ordinator

The network coordinator has served on the UK Particle Physics and Astronomy Research Council (PPARC) Review Panel charged to establish an Institute for Particle Physics Phenomenology (IPPP), and has been PPARC referee for the UK Joint Infrastructure Fund (JIF) application for the establishment of a Durham Centre for Fundamental Physics. He has been convenor at several European conferences and workshops.

4.2.1 Management know-how and experience of the management board

S. Frixione has been convenor, as well as rapporteur of plenary talks, at several conferences and workshops world-wide.

L. Lönnblad has been active in the organization of working groups in different long-term workshops. Among other things he organised the two-photon event generator group for the "Physics at LEP2" workshop in 1995 at CERN, the High-ET and jets group of the "Future physics at HERA workshop" in 1996 at DESY and the QCD Cascades study group of the "Monte Carlo Generators for HERA" workshop in 1999 at DESY.

P. Nason is theorist consultant of the Experimental Particle Physics Group (Gruppo I) of Italian INFN, and is National Leader of a subproject group of INFN (Iniziativa Specifica PR21). He has been convenor, as well as rapporteur of plenary talks, at several conferences and workshops world-wide.

R. Thorne has been co-organizer of workshops (Small-x Workshop Oxford, 2000, and TeV Scale Physics 2002), and convenor at DIS2002 meeting (Krakow).

Z. Trócsányi has been a team leader in two previous EC networks. He is a professor of physics at the University of Debrecen, where he leads the Ph.D. program in particle physics. He has served on the organising committees of international conferences, and is a member of the Hungarian CERN Committee, the European Committee for Future Accelerators (ECFA) and the Committee of the Hungarian National Science Foundation.

B. Webber is Head of Theoretical High Energy Physics group, Cavendish Laboratory, Cambridge, and has been team leader in the previous network QCDNET. He is member of CERN Scientific Policy Committee, chairman of UK PPARC Review Panel on High Performance Computing, grantholder of various PPARC research grants, and organiser of various meetings e.g. Cambridge Workshop on TeV-Scale Physics (July 2002).

D. Zeppenfeld is Co-Principal Investigator on a large DOE research grant at the University of Wisconsin. He has organized various conferences and summer schools at Wisconsin as well as the 1999 "QCD and weak boson physics" workshop at Fermilab. He has been a convenor at conferences and workshops world-wide.

4.3 Management know-how and experience of network teams

Italy-Spain team

V. Del Duca has served on the UK Particle Physics and Astronomy Research Council (PPARC) Review Panel charged to establish a UK Institute for Particle Physics Phenomenology (IPPP), and has been PPARC referee for the UK Joint Infrastucture Fund (JIF) application for the establishment of a Durham Centre for Fundamental Physics. In addition, he has been convenor at several European conferences and workshops.
M. Greco has been organising "Les Rencontres de La Thuile", a conference dedicated to parti-

cle phenomenology since 1987. He served on the EPS High Energy Committee, and has been Director of the Research Division of INFN Laboratori Nazionali di Frascati.
G. Marchesini has been a local coordinator of two previous HCM and TMR networks, and has served as national coordinator of a COFIN project, a research network of the Italian Ministry of University. At present he is coordinator on an INTAS project, organizer of the yearly National School of graduate students in Theoretical physics, president of the INFN committee for theoretical physics (Group IV).
P. Nason is National Leader of a subproject group of INFN (Iniziativa Specifica PR21), and is theorist consultant in Group I of INFN (experimental particle physics).

Durham IPPP team

The Durham group is the largest in the UK; its team includes the Director, the Deputy Director and staff of the Institute for Particle Physics Phenomenology, which has excellent dedicated research facilities and hosts regular meetings and workshops in areas of interest to the network.

The team has co-organised several international summer schools - the CTEQ school on QCD phenomenology in 2001, the Scottish Universities Summer School on LHC phenomenology in 2003 and is planning to organise the CTEQ school in 2005. Many of the staff members serve as convenors of working groups of major workshops and act on the scientific advisory panels of major conferences.

In addition, there are excellent contacts with high energy experimental groups at the Rutherford Appleton Laboratory (RAL) as well as the major european laboratories at CERN and DESY which will enable regular discussions on the various aspects of the project with H1, ZEUS, ATLAS and CMS and other high energy experiments.

France team

Team members have wide experience in organizing international workshops, schools, conferences etc. Recent involvement includes the annual Rencontres de Moriond International QCD conference, the International DIS-2003 Workshop in St.Petersburg, the QCDN-02 workshop at Ferrara, the Baryon 2004 conference at Palaiseau. Michel Fontannaz has been head of the Laboratory of Theoretical Physics in Orsay and principal coordinator of the European HCM project: Physics at High Energy Colliders (CHRX-CT93-0357). Matteo Cacciari has been organizer of the second meeting of the young researchers (QCDNET-YR 2002) of the network "Quantum ChromoDynamics and the Deep Structure of Elementary Particles" in Parma in 2002, and of the IFAE 2002, the annual meeting of the Italian particle physicists. The Annecy members are in the organizing committee of the "Les Houches" workshop "Physics at TeV Colliders", whose aim is to bring together experimentalists and theorists working on the phenomenology of upcoming TeV colliders. This workshop offers a fruitful framework to train young physicists and to have them involved in research collaborations with experienced researchers. This Workshop occurred successfully in 1999, 2001 and 2003 and is expected to take place every two years. Jean-Philippe Guillet has been the Annecy team leader for the network "Quantum ChromoDynamics and the Deep Structure of Elementary Particles" (FMRX-CT98-0194) in the Fourth Framework Programme "Training and Mobility of researchers".

Germany team

Most of the staff members at all three places have wide experience in organizing and hosting large international conferences in high energy physics, and in the organisation of teaching and training activities. For many years, DESY has been organising the international topical bi-annual conference "Loops and Legs in Quantum Field Theory". It also offers at both of its sites an annual Summer Student Programme to train young scientists. Many of the team members are members of different Graduate Schools in Germany. The Aachen and DESY teams work together in the Sonderforschungsbereich Transregio 9 "Computergestützte Theoretische Teilchenphysik" ("Computational Theoretical Particle Physics") which also includes Berlin and Karlsruhe Universities.

Great Britain team

The Cambridge and Edinburgh Particle Physics Groups have organised major international conferences and summer schools, most recently the Cambridge workshop on TeV-Scale Physics (July 2002) and the 57th Scottish University Summer School on LHC phenomenology (August 2003). Members of the team serve on scientific review committees for the British Research Council PPARC and on the CERN Scientific Policy Committee. Bryan Webber is head of the High Energy Theory Group at the Cavendish Laboratory and has been a team leader in previous EC HCM and TMR networks.

Italy team

Team members (S. Catani, M. Ciafaloni, L. Trentadue) have organized and are still involved in the organization of International Conferences and Workshops (QCD Conference in Montpellier since 1998, Rencontres de Moriond on QCD and Hadronic Interactions from 1999 to 2002, HEP-MAD in Madagascar since 2002) and of International and National topical meetings (QCDNET99, Annual Italian Meeting on LEP Physics and on High-Energy Physics since 1988, Cortona National Meeting on Theoretical Physics for about 10 years). M. Ciafaloni has acted as local coordinator in previous HCM and TMR Networks (PHEC and QCDNET) and in Research Projects of National Interest in Italy.

Netherlands team

NIKHEF, as the Dutch national institute for high-energy physics, has as its mission to coordinate and support the activities in experimental particle physics in the Netherlands. As such it has ample management expertise regarding large Europe-wide collaborations. The NIKHEF-Leiden theory team has moreover been a member of the succesful TMR Research Network "Quantum Chromodynamics and the Deep Structure of Elementary Particles", with Leiden forming the network team and NIKHEF a subnode.

Sweden team

The Lund/Uppsala team has been very active in the organization of different long-term workshops. This includes numerous assignments as organizers and/or working group conveners, covering most of the major workshops on physics at LEP1, LEP2, HERA, LHC and TESLA during the last fifteen years. We have also been active in the organization of several workshops on a smaller scale, in Sweden. In addition, the Lund group started in 2001 a series of informal workshops on 'Small-x evolution', with participation from several of the other teams in this application, intended to bring together theory and experiments in this area and establish a common forum called 'The Small-x Collaboration'. The two groups were active in the TMR research network 'Quantum Chromodynamics and the Deep Structure of Elementary Particles'. They have also had a number of postdocs, funded by the TMR framework and from other sources, and are well acquainted with the management efforts needed for this.

Switzerland – Germany – Hungary (CHDH) team

T. Gehrmann has served on the grant selection committee of the German national scholarship foundation. He is a member of the "Central computing cluster board" of Zürich University, which advises the university management on future strategies for investments into scientific computing and computational science. He has been convenor at several topical workshops and presented rapporteur talks on QCD at major conferences. He organized a six-month workshop evaluating the physics prospects of the operation of the HERA collider with a polarized proton beam.

Z. Kunszt has been a team leader in two previous EC networks, and has served as organizer or convener at several topical LHC physics workshops. Like the network coordinator, he has served on the UK PPARC Review Panel charged to establish a UK Institute for Particle Physics Phenomenology (IPPP).

Z. Trócsányi has been a team leader in two previous EC networks. He is a professor of physics at the University of Debrecen, where he leads the Ph.D. program in particle physics. He has served on the organising committees of international conferences, and is a member of the Hungarian CERN Committee, the European Committee for Future Accelerators (ECFA) and the Committee of the Hungarian National Science Foundation.

CERN team

Members of the CERN team hold and have held in the past important management positions. Among others, these include: TH Division Leader, chair of the Academic Training programme, membership in the scientific review committees of various laboratories and institutions (CERN, Frascati national Laboratory, Saclay DPhT, UK PPARC, Portugal Science Fundation, etc). In addition, members of the team have had a long experience in the organization of large-scale Workshop activities, held at CERN on a regular basis.

Japan team

KEK is only a high-energy experimental facility in Japan. Among theoretical members there, Y. Shimizu has been a coordinator of the computer simulation studies on the standard model and K. Hagiwara is a leader of the phenomenological studies including both standard model and new ones like SUSY. He is also organizing workshop and school for graduate students in the area of interest to the network every year. J. Kodaira is one of the leading researchers in the field of QCD in Japan and has been a member of the advisory committees of many workshop such as the series of loops and legs conference and spin conferences. Young researchers (students) who are working in the field of the network tasks are mainly produced from Hiroshima, Kyoto and Tohoku.

USA team

Members of the USA team have significant experience in organizing workshops, schools and conferences, including the CTEQ summer schools, the SLAC Summer Institute, the US "Loopverein" (radiative corrections for linear colliders), the Tevatron Run II physics workshops, and the 2003 Lepton-Photon Symposium. Members have also held leadership roles, such as CTEQ spokesperson and Fermilab theory department head, and many are experienced in managing research grants.

5 Relevance to the Objectives of the Activity

The main objective of this network is to advance the modelling of the strong interactions between particles, with the aim of improving the understanding of QCD, the strong sector of the Standard Model, and therefore refining the precision of the SM predictions. That refining is crucial to assess the occurrence of new physics phenomena beyond the Standard Model. The *most immediate beneficiary* of this undertaking will be the *LHC community*, and therefore *European particle physics*. LHC is the highest energy collider ever built. It will contribute to boost even further European particle physics to the forefront of the physics research world-wide. The action undertaken by this project can only reinforce that trend. We expect, though, that also the US particle physics community that is part of this network and gravitates about the Tevatron will benefit from this action. In turn, this network will benefit from their highly qualified expertise.

Some of the benefits we envisage at the level of the *European Community* and of the European particle physics community are:

- a better integration with the experimental physics community;
- the creation of a phenomenological community in particle physics;
- a sharp rise in the expertise of young researchers in the phenomenology of particle physics, led by the enhancement of the dedicated research training;
- the establishment and/or the consolidation of long-term durable collaborations;
- a reduction of the "brain drain" of European scientific forces toward Third Countries.

Here we comment in detail on those issues, and briefly outline their practical implementation:

Integrating the experimental expertise. In order to reach a synergetic effect with the LHC community, an *intense exchange with our experimental colleagues is essential.* Many members of the network are in daily contact with experimentalists, and are routinely invited to talk in the working group meetings of their collaborations (in addition, Dr. V. Del Duca, the network coordinator, is a member of the CMS Collaboration; Drs. S. Frixione, M. Greco and G. Ridolfi are members of the ATLAS Collaboration; Dr. M.L. Mangano, the training coordinator, is a member of the CDF Collaboration). We plan to enhance the exchange of information and ideas with our experimental colleagues by inviting the Heads of the Higgs and QCD/SM working groups of the ATLAS and CMS Collaborations to the meetings of the network management board.

Shaping a phenomenological community. As described in the paragraph on *Overcoming disciplinary boundaries* in Sect. 3.2, with the advent of LHC the level of the sophistication in modelling and calculations in particle physics needs to make a leap forward. To tackle succesfully such a challenge, the enthusiastic efforts of a few people will not suffice any more. An integrated phenomenological community in particle physics must be formed, in order to be able to act effectively as a *liaison* between the *theoretical* and *experimental* particle physics communities.

Enhancing training and transfer of knowledge. All the network teams present *highly qualified research training infrastructures*, as detailed in Sect. 2.1. At present, the 10 European teams of the network comprise 29 postdocs and 36 Ph.D. research students. We expect that those students will be the prime beneficiaries of the 24 three-month ESR appointments linked to the Research Training Sessions, as outlined in Sect. 2.1. In addition, careful consideration will be given to *integrate students from the Less Favoured Regions* of Europe, as detailed in Sect. 6.

We expect that through the ESR appointments planned by this network, which complement and integrate the Ph.D. fellowships supported by the local fundings of the network teams, a very large fraction of students interested in doing research in particle physics will be involved. The six ER appointments will contribute to the training of the ERS's, thus enhancing the transfer-of-knowledge potential of the network.

All this will help to create a *large and qualified work force*, with the potential of *tackling succesfully* the complex models and calculations that are necessary to make accurate predictions of production rates at LHC and future colliders.

Long-term durable collaborations. Extrapolating from the fact that several collaborations between network teams have been in place for some years, and most of them were initiated by the previous HCM network "QCD at High Energy" and TMR network QCDNET (in addition, most of the team and task leaders of this network were trained in "QCD at High Energy" and QCDNET), it is clear that the potential of establishing durable collaborations between the network teams, in terms of research, training and transfer of knowledge, is very high. Conversely, it will not be possible to maintain the existing collaborations between network teams to the present level relying only on local funds. Therefore, the approval of this network would be very beneficial in that respect.

Increasing the pool of available researchers. Many young European future particle physicists are trained in research in non-European institutions. While we find that beneficial in most cases, due to the high qualification of the institutions involved, we realise that in some cases that choice is due to the limited number of opportunities of graduate studies in particle physics in European institutions, as well as to the economic un-attractiveness of Ph.D. fellowships in some European countries. Many of those who leave Europe decide then to remain in those non-European countries, because of better job opportunities, in research or elsewhere. We think, thus, that the research training programme of this network could help to *reduce the brain drain* of European scientific forces toward Third Countries.

6 Added Value to the Community

Some of the goals of this network are:

- to favour a closer collaboration and integration between researchers coming from several different regions of Europe, in particular as regard to the ones coming from the Less Favoured Regions;
- to enhance women representation in the area of particle physics dealt with by this network, by actively seeking and implementing gender balance in ESR and ER appointments;
- to increase the attractiveness of Europe for researchers of Third Countries.

Here is how we propose to tackle those issues:

Less Favoured Regions. The very advanced nature of present-day particle physics phenomenology has positive and negative sides to it:

On the positive side, it implies that there can hardly be any advancement on a specific topic without a close integration between the researchers working on that topic. In that respect, the integration of teams or groups from Less Favoured Regions of Europe occurs naturally. As outlined in Sect. 3.2, it is our intention to favour that tendency further by:

(i) allocating more networking funds to those members of the Italy-Spain and Germany teams who are located in Less Favoured Regions and to the Hungarian component of the CHDH team;

(ii) placing 30 months of ESR and 24 months of ER appointments in the Less Favoured Regions or in Hungary. That is equivalent to 13% of the ESR and 17% of the ER appointments requested overall, respectively;

(iii) hosting the three yearly network meetings in Less Favoured Regions, namely one in Dresden (Germany), one in Valencia (Spain) and one in Debrecen (Hungary);

(iv) hosting a Summer School in a Less Favoured Region of Sweden, and the Final Network Conference in a Less Favoured Region to be chosen.

On the negative side, the advanced nature of present-day particle physics phenomenology causes in our network an under-representation of teams or groups resident in the Less Favoured Regions (only 8% of the contributing researchers listed in Table 3 are based in Less Favoured Regions and in Hungary). We are aware of this problem (the network coordinator is a native of a Less Favoured Region). We plan to remedy this situation to the best of our possibilities by *attracting students from the Less Favoured Regions* to our Research Training Sessions and by carefully considering them for ESR and ER appointments.

Gender issues. In the areas of research that pertain to this network there are no women with permanent staff appointments in Europe. Therefore, a proper integration of the gender aspects into the training programme is strongly needed. In order to ensure that, we have appointed Dr. Gudrun Heinrich as the network's Human Resource Coordinator. She will sit on the network management board, and will be involved in the ESR and ER selection process, making sure that the *women researchers and students* receive a *careful consideration* for ESR and ER appointments, as detailed in Sect. 2.3. Furthermore, she will co-lead one of the Research Training Sessions, as outlined in Sect. 2.1.

Attractiveness of Europe. While there is a significant participation of experimentalists from Third Countries in European particle physics, and in particular in the LHC project, the participation of the theorists' community is still rather limited. We plan to use the *30% envelope* of person-months of the network research budget foreseen by the FP6 rules to *attract young researchers from Third Countries*, thus increasing even further the European competitiveness in particle physics.

	Team	research training (A)	research training (B)	management (C)	other (D)
1.	Italy-Spain	62877	6986	141022	0
2.	Durham IPPP	46527	5170	0	0
3.	France	52390	5821	0	0
4.	Germany	72444	8049	0	0
5.	Great Britain	47850	5317	0	0
6.	Italy	48252	5361	0	0
7.	Netherlands	48299	5367	0	0
8.	Sweden	42095	4677	0	0
9.	CHDH	63512	7057	0	0
10.	CERN	44587	4954	0	0
11.	Japan	0	0	0	0
12.	USA	0	0	0	0
	Total	528833	58759	141022	0

Table 5: Indicative financial information on the network project (excluding expenses related to the recruitment of early-stage and experienced researchers).

7 Indicative Financial Information

Using the basic living, travel, mobility and career exploratory allowances and the country-dependent correction coefficients provided in the RTN Work Programme and Handbook, and the breakdown provided in Tables 2 and 3 at page 17 and 22 of this document, respectively, we have estimated the expenses associated with the appointment of early-stage and experienced researchers to be about 1.62 Million Euro. These expenses will constitute 69% of the overall network budget, which thus amounts to about 2.35 Million Euro.

Table 5 outlines the breakdown of the expenses *not* related to the appointment of early-stage and experienced researchers. These expenses will fund the activities of the network teams. The headings of Table 5 refer to:

Research/Training (A): contribution to costs linked to the participation of researchers not recruited by the network in networking activities (network meetings, conferences, training actions, secondments)
Research/Training (B): contribution to the organisation and the implementation of the project (research costs linked to the training of researchers recruited by the network, publication of vacant posts, exchange of information and of materials)
Management (C): 6% of the total network budget, that will be paid towards the management of the project (hiring of part-time administrative staff, establishment and maintenance of a web site, organisation of the network meetings, auditing of the financial reports of the network).
Other expenses (D): none.

Note that the Research/Training (A+B) expenses include a provision for indirect costs (overheads) of 10% of the direct expenses.

The funds will be transferred year by year from INFN to the network teams by the network coordinator.

8 Previous Proposals and Contracts

EU Third Framework Programme "Human Capital and Mobility", Network "Physics at High Energy Colliders", acronym "QCD at High Energy", contract number CHRX-CT93-0357 (DG 12 COMA), contract period 01/12/1993 – 31/05/1997.

EU Fourth Framework Programme "Training and Mobility of Researchers", Network "Quantum Chromodynamics and the Deep Structure of Elementary Particles", acronym "QCDNET", contract number FMRX-CT98-0194 (DG 12 - MIHT), contract period 25/03/1998 – 24/03/2002.

EU Fifth Framework Research Training Network Proposal "Quantum Chromodynamics and Fundamental Interactions at High Energy", acronym "QCDHE", proposal number RTN2–2001–00117, not funded.

EU Sixth Framework Research Training Network Proposal "Physics of Strongly Interacting Particles at Future Colliders: QCD and Beyond", acronym "STRONGNET", proposal number FP6-503928, not funded.

The main differences between the present HardQCD@LHC proposal and the earlier QCDHE and STRONGNET proposals are:

- Updated scientific objectives, namely focussing of the research programme on precision calculations and numerical simulations, for the applications of QCD at LHC, Tevatron and HERA;
- Membership is theorists only, in order to keep the research programme focussed; however, given the utmost importance we attribute to the exchange of information with our experimental colleagues, we are to invite the Heads of the Higgs and QCD/SM working groups of the ATLAS and CMS Collaborations to the meetings of the network management board;
- A further expanded training programme. Its main new features are the Research Training Sessions, which will be held in the first year of the network, and are designed to boost the research training of already existing Ph.D. students;
- Hosting of all the yearly network meetings, the final network conference and a Summer school in Less Favoured Regions.

Does the research presented in this proposal raise sensitive ethical questions related to:	**YES**	**NO**
Human beings		×
Human biological samples		×
Personal data (whether identified by name or not)		×
Genetic information		×
Animals		×

Table 6: Information on ethical aspects of the research presented.

9 Other Issues

Outreach Programme. The establishment of this network will provide a good opportunity to increase public awareness of particle physics and of the interplay between theory and experiment in particle physics. Many network members are involved in outreach programmes, either directly or through the schools and conferences they organise. We shall organise a set of public lectures, aimed at the public at large, and of particle physics master classes, aimed at school children.

Ethical aspects of our research are dealt with in Table 6.

We confirm that the research presented in this proposal does not involve:

- research activity aimed at human cloning;
- research activity intended to modify the genetic heritage of human beings;
- research activity intended to create human embryos;
- research involving the use of human embryos or embryonic stem cells.

ENDPAGE

HUMAN RESOURCES AND MOBILITY (HRM)
ACTIVITY

MARIE CURIE ACTIONS
Research Training Networks (RTNs)

PART B

"HardQCD@LHC"