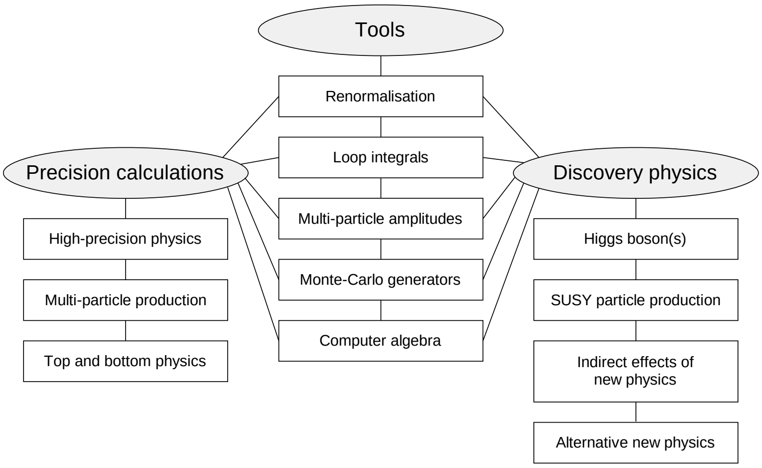
As a network, we can make intelligent use of our collective expertise to set important new objectives which are beyond the capabilities of individual institutions or teams. These objectives can be classed in the following three areas. In each area, the key activities where major breakthroughs can be expected are shown in *italics* (see also the graph below).



(i) Tools. Many tools for high-energy physics have been developed by members of our network. On the one hand, these include Monte Carlo generators that can directly be used by experimentalists. On the other hand, analytical and numerical methods have been developed for the evaluation of large numbers of Feynman diagrams, which are needed to construct suitable Monte Carlo generators. At present there are severe limitations on the number of particles (legs) and number of loops that can be calculated. However, exploiting the physics potential of the LHC and ILC requires the development of even more sophisticated tools for more precise calculations of multi-leg and/or multi-loop processes. It is crucial to develop the tools in such a way that they can be transferred to extensions of the SM, such as the minimal supersymmetric (SUSY) extension of the SM , the Minimal Supersymmetric Standard Model (MSSM).

(1) Renormalization

Renormalization plays a crucial role in particle physics. The renormalization counterterms are needed in all precision calculations and we will provide *complete renormalization of the SM at two-loops* as well as of the *MSSM at one loop*. The *Higgs sector of the MSSM* is particularly interesting and we will work out the renormalization needed for *observables in the Higgs sector at two-loop order including CP-violating effects*. We will also *improve the predictions for physical observables using renormalization group methods* and determine the *mass spectrum of extensions of the SM* by relating the masses to parameters at a high-energy scale.

(2) Loop integrals

Complicated short-lived quantum fluctuations or loop effects alter the size of physical cross sections and open up a window to physics at energy scales far above those attainable in human-made accelerators. Their evaluation is vital, and we will develop both analytical and numerical techniques for evaluating *multi-particle one-loop graphs*, *two-loop vertex* and *two-loop box graphs* with and without internal masses that are vital for strong and weak interaction processes at the LHC and ILC. The underlying mathematical methods, involving for instance generalized harmonic polylogarithms and an automatized use of Mellin-Barnes integrals, will be further improved.

(3) Multi-particle amplitudes

New particles will be observed through their decays into various SM particles — jets, leptons, etc. Multi-particle tree graphs yield the leading-order estimate of the size of new physics effects, but generally evaluation at higher orders is required. We will extend our techniques for automatically calculating tree graphs to the evaluation of *the one-loop amplitudes for processes with more than four external legs* such as four-fermion production at the LHC and ILC. We will study a new class of recursion relations, recently discovered by studying duality between

Yang-Mills gauge theories and topological string theory and extend these techniques to obtain *improved recursion relations for tree-level as well as one-loop multi-particle amplitudes*.

(4) Monte Carlo generators

Numerical methods play an essential role in determining precise predictions for physical observables. We will *construct and validate generators* suitable for tree processes and work on the *automated evaluation of strong and weak interaction corrections* at one loop. A major focus will be to combine strong QCD and weak corrections in *Monte Carlo programs that can be used to analyze LHC data*. Moreover, we will implement *SUSY spectrum calculations* into Monte Carlos.

(5) Computer algebra

The complexity of multi-particle multi-loop processes requires the use and development of algebraic programs based on systems like `MATHEMATICA`, `MAPLE` or `FORM`. We will further refine these packages and apply them to *automatically generate and calculate one-loop amplitudes with more than four external legs*, as well as *two-loop amplitudes*. A common problem is the handling of the systems of equations relating loop integrals. We will develop *algebraic packages to exploit the integral relations and solve for the master integrals*. As most of the outstanding problems can only be solved by intense use of computer algebra programs such as `FORM`, involving very long run-times, parallel versions of this code have to be developed.

(ii) Precision Calculations. In order to exploit the potential of large colliders as much as possible, precision calculations including both strong and electroweak corrections are mandatory. These calculations, needed for both the LHC and the ILC, require the use of the sophisticated tools developed within and outside our network to calculate higher-order radiative corrections and processes with a larger number of particles. These calculations should not only be performed in the SM but also in extensions thereof since the new physics indirectly gives rise to extra corrections to SM processes. Moreover, once new physics has been established it has to be taken into account in all analyses. Therefore we aim at developing tools that are model independent and flexible.

(6) High-precision physics

At hadron colliders all processes are affected by sizable effects of the strong interaction which are typically at the order of 20–50%. The calculation of these strong corrections is vital for the analysis of all experiments. We aim to compute the strong interaction corrections for important processes such as vector boson pair production including *finite quark mass effects at next-to-leading order* as well as the dominant effects at *next-to-next-to-leading order*. *Next-to-next-to-leading QCD corrections to the Drell–Yan process and single W- and Z-boson production* are of key importance, since these processes serve as luminosity monitors at LHC. Next-to-leading order electroweak effects are expected to be of a similar size as the next-to-next-to-leading order strong effects. We will evaluate *the weak corrections to strong processes* and implement them in *Monte Carlo generators*. At high energies, the electroweak corrections become more important owing to the appearance of large logarithmic effects and can reach 20% or more at LHC energies. Therefore, we will use our new tools to evaluate the *large strong and electroweak corrections for the most important processes at the LHC* such as those required for accurate measurements of the W mass. In particular, we will *identify the large electroweak logarithms and resum them* and calculate the *large polynomial electroweak corrections in the MSSM Higgs sector* relevant for both LHC and ILC processes. We will use and extend soft gluon resummation techniques to improve SM predictions for Higgs production via gluon fusion and to estimate power-suppressed effects affecting the determination of the jet energy scale at hadron colliders.

In the cleaner environment of lepton colliders the accuracy of the experiments is much higher, and theoretical predictions need to be often more precise. This requires a more complete inclusion of higher-order electroweak corrections besides those of the strong interaction. In order to improve the current level of precision tests of the electroweak theory, in particular in view of the prospective experimental accuracies at the ILC, complete *two-loop corrections to fermion-pair production processes* and *Bhabha scattering* are required.

(7) Multi-particle production

For processes with four fermions in the final state, the *full one-loop corrections* are required in order to match the accuracy of the ILC, in particular in the threshold region for W-pair production. The predictions and Monte Carlo generators for *six fermion production* will be improved by including higher-order corrections. At the LHC, multi-particle states are extremely abundant and potentially can mask the production and decay of heavy objects. We will use the new techniques and tools developed within the network to compute the *strong corrections to processes with four and six particles* in the final state. Moreover, *tree-level generators* will be developed to describe LHC processes with even more particles in the final state.

(8) Top and bottom physics

The production and decay properties of top and bottom quarks are sensitive probes of possible effects of new physics. So far, we do not know very much about the top quark and its interactions, although the large top quark Yukawa coupling gives it a unique relationship with electroweak symmetry breaking. Amongst other things, we will compute the *strong corrections to single top production and top-pair production* at the LHC. We will identify strategies for determining the top quark properties and *constrain models with non-standard top interactions*. For what concerns the bottom quark, the experimental results at the B factories started a new phase of precision measurements, which will continue at the LHC. Precision calculations in *semileptonic and radiative B decays* have become necessary. We will study strong and electroweak corrections to these processes and their impact on the determination of the CKM matrix elements and the quark masses.

(iii) Discovery Physics. Our network focuses on questions related to electroweak symmetry breaking and the origin of mass together with the (related) quest for more general symmetries and other features than those already proven to exist. Among the main challenges to be met at the LHC and ILC are the discovery of the Higgs, the search for SUSY particles and the determination of their properties, and the identification of any possible new physics that could show up at the TeV scale. In particular, we will explore mechanisms for stabilizing the huge hierarchy between the weak scale and the Planck scale.

(9) Higgs boson(s)

The Higgs boson as one of the key ingredients of the Standard Model is still undiscovered. If it exists, it will almost undoubtedly be discovered at the LHC. However, its spin properties, its quantum numbers, and its couplings with other particles must be measured with high precision for its identification. Therefore, we will develop and work out in detail *improved strategies for searching for and identifying the Higgs boson*. In SUSY models, the phenomenology of Higgs bosons can be completely different from the SM. We will systematically study and develop strategies for *Higgs search in non-standard scenarios*. We will also make more *precise predictions of the Higgs production cross sections and transverse momentum distributions including strong and electroweak corrections and taking into account CP-violating effects*.

(10) SUSY particle production

SUSY particles are among the most eagerly anticipated physics targets of the LHC and the ILC. Therefore, we will *develop strategies for identifying supersymmetry at the LHC* and improve the theoretical predictions for production and decays of SUSY particles. Exploiting the calculational flexibility of the tools developed in this network, we are planning, for instance, to perform *full one-loop calculations for the production of SUSY particles including their decay*. The LHC and ILC have quite different strengths and will therefore yield highly complementary results. We will perform *detailed studies of the synergy of the LHC and ILC in searches for supersymmetry and other kinds of new physics and work out the expected physics gain*. Another crucial area of study is *CP and flavour violation in extended SUSY models* and the impact they may have on SUSY mass spectra and the production and decays of SUSY particles.

(11) Indirect effects of new physics

Precision measurements of rare decays can provide important constraints on the SM and its extensions. They can be performed at dedicated facilities at low energies but also at the LHC. We will calculate *NLO SUSY effects in radiative and rare B decays* and derive *constraints from B and K physics on the SUSY particle spectrum*. Moreover, we will study the *impact of SUSY particles on the determination of the CKM matrix*.

(12) Alternative new physics

We will study the effects of other possible new particles and interactions at high-energy scales on a large variety of LHC and ILC observables. We will investigate *CP-violating effects in the leptonic sector* and the *phenomenological consequences of different SUSY scenarios on neutrino physics*. We will *derive constraints on new physics models from bounds on the dark matter relic density*. We will also be concerned with other more speculative theories such as *little-Higgs theories*, Kaluza-Klein excitations in theories of *extra dimensions*, which are motivated by string theory, and phenomenological implications of a *non-commutative space-time*.

The different tasks require different and complimentary expertise and will be treated accordingly by the appropriate sub-groups of the overall collaboration. The allocation of these tasks between the participants is shown in Table 1. The convenors in collaboration with the participants will closely monitor the progress in each task and the *scientific committee* will come up with recommendations for any necessary change in the work plan.

Participants	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
(i) **Tools**																	
(1) Renormalization		●	●	●		●	●	●	●	●	●	●	●		●	●	●
(2) Loop integrals	●	●		●			●	●	●	●		●	●		●	●	●
(3) Multi-particle amplitudes	●	●	●	●		●	●	●		●		●	●	●	●	●	●
(4) Monte Carlo generators	●	●		●		●	●	●		●			●	●	●		●
(5) Computer algebra	●	●		●		●	●	●		●		●	●		●	●	●
(ii) **Precision calculations**																	
(6) Electroweak Physics	●	●	●	●			●	●	●	●		●	●		●	●	●
(7) Multi-particle production	●	●		●			●	●		●		●	●		●		●
(8) Top and Bottom physics		●	●	●	●		●		●	●		●		●	●	●	●
(iii) **Discovery Physics**																	
(9) Higgs physics	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●
(10) SUSY particle production	●	●	●	●	●	●	●	●	●		●	●	●	●	●		●
(11) Indirect effects of new physics		●		●	●		●		●	●		●		●			
(12) Alternative new physics	●	●	●	●	●	●	●		●		●	●	●		●		

Table 1: Allocation of tasks among the participants