Proposal for a continuation of the

# International Research Training Group
# **Development and Application of Intelligent Detectors**

at the

Ruprecht-Karls-Universität Heidelberg, Germany

University of Bergen, Norway
University of Oslo, Norway

Anticipated funding period: 01.04.2009 – 30.09.2013
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# Contents

# Chapter 1

# General Information

## 1.1 Program Title

Entwicklung und Anwendung von intelligenten Detektoren
Development and application of intelligent detectors

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## 1.4 Summary

The International Research Training Group (IRTG) on intelligent detectors is developing and applying detection systems for particle and nuclear physics that integrate modern information technologies as key features. The design, development and operation of such detectors is the key for advanced nuclear, particle and astro physics. It requires a profound knowledge in a variety of fields that is made available in the interdisciplinary cooperation of physicists working on detector design, signal readout and data analysis, together with departments that focus on information science and work on signal processing, pattern recognition and data management. Some of the technological aspects involved include the design of application-specific integrated circuits (ASIC), design and programming of circuits implementing programmable electronics (FPGAs) and the design and operation of large scale compute facilities (Cluster, GRID) that have to be considered an integral part of next generation detector systems.

The IRTG links the expertise that is available in Heidelberg and Norway (Bergen/Oslo), and has demonstrated that the scientific exchange leads to new contacts and proposals. The expertise available in the different locations is largely complementary, allowing cross fertilisation and for the participating students offering the possibility for a broader education in partially highly specialized fields.

In both countries many of the recent major experiments in high energy elementary particle and nuclear physics are represented: ALICE, ATLAS, BABAR, CBM, CERES, FOPI, H1, HeraB, LHCb in Heidelberg and ALICE, ATLAS, BRAHMS, NA57 in Bergen/Oslo and by this, a large particle physics background is available to the IRTG. On the technological side there is a nice complementarity: for example ASIC design and cluster computing are well recognized in Heidelberg, while FPGA-based hardware/software co-design is more centered in Bergen.

Project-oriented collaborations among the participating groups will continue to be strengthened by the IRTG. Common research interests are existing and have been pursued in the past, like the ALICE High Level Trigger (HLT), that is run and operated commonly from KIP/Heidelberg and Bergen. In the next funding period of the IRTG the program will focus on the exploitation of the development effort for the experiments ALICE and ATLAS and will lead to common projects for the major future international facilities: FAIR at Darmstadt and the ILC. Specific Projects have been already defined: CBM at FAIR and the Hadron Calorimer at the ILC.

The continuation of the IRTG will give the unique opportunities to involve students on all levels of high energy particle physics from conceptual design

over prototyping to actual running of the experiments. This coming phase will be most interesting as during this period the first LHC data taking and data analysis is going to take place. In particular after the first data has been taken advanced trigger algorithms are expected to be required to be developed, where the IRTG will form an ideal operation basis.
The teaching program is held in English and is open to all local members of the particle physics community . The students are lead to the forefront of experimental nuclear, particle and space physics and are given the chance to acquire hands-on experience on the most advanced design, simulation and analysis tools available today. The IRTG is embedded into the larger Heidelberg Graduate School of Fundamental Physics (HGSFP) that is providing additional more generic education, e.g. soft-skill seminars that will be covering the aspects of work organization, time planning and presentation techniques.

## 1.5 Anticipated duration/ starting date

Duration: continuation 4.5 years
starting: 1. April 2009
ending: 30. September 2013

## 1.6 Anticipated number of participants

In Germany Heidelberg is applying to continue at the existing level of 12 PhD. stipends and 1 Bat IIa PostDoc position. The total number of participating students will be larger by about a factor of two. About 20 additional students funded from other resources will participate in the educational activities of the IRTG [1]. We request funding of increased basic scholarships for the students in order to be more competitive in an economical environment, where the best students are being lost very easily and to accommodate increased cost of living in the high price area of Heidelberg. In order to be able to offer an attractive and top-level education program that is tailored to the needs of the participants, a TVL-13 position is requested for a postdoctoral fellow (for details of the tasks and the requested profile see section refsec:3.23.2 below). The number of PostDocs participating in the research activities of the IRTG is estimated to be about 10, providing the necessary intellectual and knowledge-based environment and knowledge from which Ph.D. students

[1]For reference, see the list of currently active students in the field within the participating groups in Appendix refAppendixC.

will profit. In Norway, a total of eight Ph.D. stipends are being requested in Bergen and Oslo. We note that German Ph.D. stipends are roughly half the size of Norwegian Ph.D. grants. The application includes requests for funding of running costs, e.g. for organizing workshops/schools and to cover travel expenses. The total number of Norwegian students participating in the IRTGs educational program is about 20. The number of Norwegian postdoctoral fellows involved in the projects related to the IRTG is about four. In summary about 30 Ph.D. students will continue to form the body of the IRTG participating in the regular advanced lectures (see section 3 refsec:3). With such a number of students the investments in terms of manpower in specific education is well justified, and in turn a sizeable number of students will benefit from the specific offers of the IRTG.

# Chapter 2

# IRTG Profile

The basic Ansatz of the IRTG will not be changed and is reproduced here from the original proposal: the focus of the proposed International Research Training Group is Intelligent Detectors and Detector Systems. They are characterized by exploiting the latest developments in sensor technology and merging it with the latest advances in electronics and information science. Such systems emerge from the interdisciplinary interplay of three different building blocks (illustrated below) as set forth below:

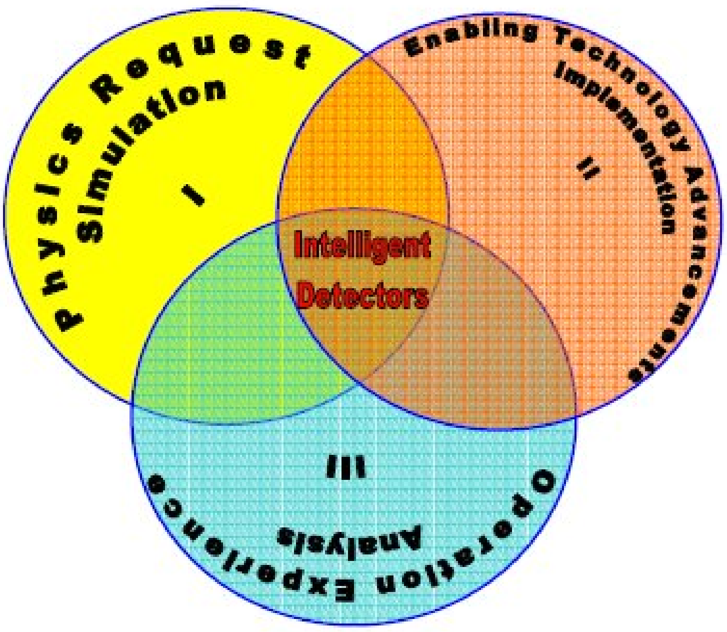


Figure 2.1: irtg

1. Fundamental physics like elementary particle and nuclear physics is one of the major driving forces to advance new detector technology. Experiments that are to be performed in the near future, will present new and challenging problems for data taking and analysis. Very rare signals have to be detected with sufficient accuracy and significance from an extremely large background. The design of modern detection systems is based on the possibility and the knowledge to model the response of the apparatus in detail with respect to the anticipated signal and unavoidable background by means of simulations. The basic task is to derive experimental observables that are linked robustly to the interesting fundamental physics properties of the system. The necessary data rates for many future experiments are so high that the electronics and the data processing has to be considered an integral part of the detector systems. The sensors converting physical observables to electronic signals have to be equipped with on-board intelligence and/or efficient data management in order to form a system capable of fulfilling the physics requirements. The system features must already be incorporated into the design phase of new devices in order to make a realistic assessment of the performance.

2. The second cornerstone is the rapid development of modern electronics and information processing technology. Thus, exciting new possibilities for (particle and nuclear) physics detectors are arising. Due to the ever growing integration and better flexible customisation, very complex tasks can nowadays be executed on the detector while simultaneously taking data. The integration of the latest technological possibilities into a new detector design is, however, a very complex task. It requires a profound understanding of all the implications of the choice of a certain technology and should ideally be supported by some experience of its implementation. Acquiring the skills to handle the technologically advanced systems requires special training. The International Research Training Group aims to link in an interdisciplinary fashion basic physics needs with modern cutting-edge electronics and informatics science.

3. The concept of using modern information technology in large scale physics experiments is of course not new. Present day examples for Intelligent Detectors are the running experiments at the Relativistic Heavy Ion Collider RHIC at Brookhaven National Laboratory and the planned experiments at the Large Hadron Collider (LHC) at CERN. Several of these experiments (BRAHMS, ALICE, ATLAS and LHCb) are represented by the participants of the IRTG. Local intelligence is

implemented for trigger needs in form of ASICs evaluating and compressing the data of specific subsystems and performing the decisive event selection. Special hardware is being installed for organising the data flow and for fast pattern recognition. The experience gained during the development and the operation of those systems is essential for success of the next-gneration development. The evaluation of the performance of the running systems constitutes another important verification step of the whole detector concept. This can only be achieved by running through the full analysis chain and trying to derive those signatures that the detector was designed for. Additional challenges have to be mastered in that area, such as monitoring and controlling a very large number of setup parameters and handling huge amounts of output data. The necessary corresponding techniques are included in the menu of activities of the IRTG.

In particular the International Research Training Group aims at linking these building blocks, namely

- the experience with running state-of-the-art detectors and information
- processing systems to arising future needs,
- physics requirements to possible detection system performance and analysis experience to system specification and verification.

This is clearly an interdisciplinary task that needs expertise from several different research areas and research groups. One focus of the next years of IRTG research is the exploitation of the first data to be taken at the LHC accelerator. This requires on one hand the understanding of the vairous detectors and their calibration. Further the event reconstruction has to be furthered to a level, allowing at least a semi automatic reconstruction offline, using the distributed analysis framework on the GRID. In order to verify the online data, quality monitoring infrastructure has to be deployed, allowing both an on-line event reconstruction and the identification of potential problems in the data stream as well as the selection of rare events for physics recording. Such algorithms are subject to constant development and improvement.
In addition this proposed period of the IRTG provides a unique opportunity for new advanced developments, as proven concepts, which have successfully been applied at the LHC detectors, which are now almost fully commissioned, can now be transferred safely to upcoming new challenges at ILC and FAIR. Typical Ph.D. candidates are going to work on both fronts, therefore simultaneously being exposed to two radically different phases of the development

and operation of large scale expents. One example is the joint development of the ALICE and CBM on-line track reconstruction.
The disciplines required for the research and developments within the framework of the IRTG are:

- Nuclear
- Physics
- High Energy Physics
- Detector Physics
- Sensoric
- Microelectronics and Electronics
- Computer Engineering
- Computer Science
- High Performance Computing for on-line/off-line event reconstruction

# Chapter 3

# Research Program

The research program is building on the existing strong collaboration between Heidelberg and Bergen/Oslo specifically on the ALICE experiment with its components TPC and TRD detector , High Level Trigger (HLT) and TRD Trigger, Detector Control System (DCS) and physics simulations. This will be naturally extended to detector operation and physics analysis.
The second major building block for the future interest is ATLAS where strong groups from Germany and Norway are involved in.
The research program is augmented and extended due to new contacts from the current funding period that resulted in two common projects for the future facilities FAIR and ILC.
The visions for the future activities are detailed in the following.

## 3.1 ALICE

### 3.1.1 ALICE - online

The ALICE experiment implements two complex on-line trigger systems, developed, deployed and operated by the computer engineering group at KIP (Lindenstruth). Both triggers received major contributions during the last years by members of the IRTG group and would not have reached successfully the operating state of today without this contribution.
The ALICE High Level Trigger (HLT) is deployed according to schedule as minimum set with about 150 computers but with an infrastructure supporting up to 900 computers. The on-line TPC tracker was co-developed with CBM and allows unprecedented fast event reconstruction. The algorithm scales well and was demonstrated to run on a CELL processor, using the CBM version. The ALICE version is operational at CERN. The algorithm is

of such interest that it is currently being used at the CERN openlab for verification of new processor architectures. During the next funding period we plan to further this algorithms performance by porting it onto a graphics coprocessor as hardware accellerator and by preparing it for the next upcoming high-performance, massively parallel multi-core processor architektures. At this point a strong collaboration with industry is emerging.
The ALICE TRD trigger is installed also at CERN. The most complex part is the Global Tracking Unit (GTU). It implements about 100 high-density FPGAs, processing the tracklet data, being received from the 1080 2,5 GBits/sec fibres. This system was developed by members of the IRTG and is now commissioned. Several trigger algorithms are envisioned to be executed even in first year, which now have to be developed and benchmarked. The GTU presents a fanstastic instrument, as it has access to all high pt tracklets in every event candidate within less than 5 microseconds.
The hardware acceleration concepts and high performance concepts, developed in the framework of the ALICE trigger systems can be also used for generic high performance computing and shall be deployed there also. Appropriate contacts have already been made and small projects been started. We intend to continue in this direction in particular after the CERN trigger systems are fully commissioned and being operated routinely.

### 3.1.2 ALICE - operation and calibration

The ALICE TRD subsystem that was one of the major new detector developments in the last funding period will see its complete installation within about one from now. In order to prepare the system for physics the 1.2 million readout channels need to be consistently calibrated. For this large number of channels new strategies have to be developped and applied for quality assurance and monitoring.
The electron identification, the TRDs most important goal, needs to be optimized making use of real data. Well identified tracks by other subsystems (TPC, ITS) will be used in order to study the response of the TRD in detail and especially map out the inhomogenities. Proton-Proton data that are expected to become available in 2008 will provide very useful information, but the final challenge will be the Pb+Pb interactions, from which 20.000 tracks are expected to simultaneously hit the detector in 2010. All these response studies are necessary and have to be quantitatively concluded before activating the TRD trigger capability that is foreseen for 2011. With proper parameters loaded into the distributed 65.000 node system of the TRD unique event selection capabilities will be achieved. Most importantly, bottomonia states will be made accessible for a first measurement.

### 3.1.3 ALICE - physics analysis

The physics analysis will employ the full scope of observables that have been established also by the particating groups in the predecessor experiments at SPS and RHIC.
Having made significant contributions to the central tracking and PID system of ALICE a certain focus will be placed on those where the electron identification is entering. These are most prominently the Quarkonia states J/Ψ and ϒ whose abundance probes significantly the properties of the Quark-Gluon-Plasma. The techniques for the reconstruction of those vector mesons have already ben developped during the current funding period but the application to real data will certainly represent a real challenge ideally suited for students participating ion the IRTG. Direct feed back to the online event selection scheme is expected allowing for a fast optimisation.
As demonstrated by experiments at RHIC (BNL,USA) also particles with open charm and bottom (D- and B- mesons) can be effectively reconstructed by their semileptonic decays. Studying their abundance and flow pattern will give direct access to basic QGP quantities. This type of analysis requires a detailed understanding of the system response and the background that will be established by the successive analysis of proton-proton and heavy ion data.
Besides electron identification, high transverse momenta can be efficiently reconstructed by the TRD subsystem. This gives access to another very important observable in heavy ion collisions: high energy jets loose a significant part of their energy in the deconfined matter state, this effect being called jet quenching. Mapping this effect over the full kinematic region will give access to basic quantities of QCD in its deconfined state.
All these analysis will make use of the full information available in the events and require all the data analysis technology and infrastructure that has been setup for ALICE. GRID computing will be applied on the user level and clearly will evolve by the direct feedback from users to developers. The IRTG offers ideal grounds for advancing these technologies.

## 3.2 ATLAS

The ATLAS detector will be operated and produce physics output as well as practical experiences with a highly complex detector system. The detector aspect is of major relevance for the IRTG and the students involved. ATLAS will for the first time give insights into the problems to be encountered during the operation of such a large-scale technology. The experience gained there will be invaluable for the planning and operation of future large-scale facilities in science and industry. It is planned to strongly involve IRTG student in this exciting endeavour. Their work will also form the basis for a possible ATLAS Upgrade programme, which is currently entering an R&D phase. The improvement of the ATLAS data selection capabilities based on the data gathered during the first year will form a major goal of the work performed in the Heidelberg-KIP group. As a concrete project the group plans to propose an integrated mixed-signal VLSI solution as an input stage of the ATLAS level-1 trigger. This work will be performed in close cooperation with international project partners but also with a second ATLAS group, which is likely to emerge at the PI in Heidelberg in 2008.

## 3.3 LHCb

The LHCb experiment allows a large number of high-precision measurements of different B meson decay properties. The comparison with the Standard Model prediction will offer a way to search for physics beyond our current knowledge and complements the direct searches for New Physics at high $q^2$ by the ATLAS and CMS experiment. The reconstruction and measurements of B decays will rely heavily on excellent track and vertex reconstruction as well as particle identification.

The Heidelberg LHCb group has taken major responsibilities for the construction, commissioning and operation of the LHCb tracking system. The group is thus in charge of one of the key elements of the LHCb experiment. IRTG students will be involved in the operation and calibration of the LHCb tracking detector. Heidelberg students will play a major role in the understanding and optimization of the tracking detector performance. The IRTG provides a stimulating environment in which similar tracking projects, e.g. the work on the ALICE TRD, will lead to significant synergies.

Beyond the engagement in the track reconstruction the Heidelberg LHCb group will involve IRTG students also in the data analysis: It is the aim that Heidelberg contributes to one of the LHCb "flag-ship analysis" namely to the measurement of CP violation in the decay channel $B_s \rightarrow J/\psi\phi$. The work on this topic has already started with contributions by C.Langenbruch one of the current IRTG students.

## 3.4 CBM at FAIR

The Compressed Baryonic Matter Experiment CBM will be installed at the FAIR facility and is expected to take data starting in 2015. It aims at measuring rare probes as signatures of highly compressed baryonic matter that will be produced in heavy-ion collisions at incident energies of 10 - 35 AGeV with so far unprecedented rates. An interaction rate of 10 MHz is targeted even for the heaviest systems, requiring completely new detector and data acquisition technologies. Various groups of the IRTG are already members of the collaboration and will join forces in the framework of the IRTG.

### 3.4.1 TOF system

One PI group (Herrmann) is involved already since 2004 in the design and development of the Time-of-flight system for CBM. The proposal is based on Muiltigap Multi Strip Resistive Plate Chambers (MMRPC) that have been successfully been built and operated by the group in the FOPI experiment. A timing resolution of better than 100 ps has been achieved on a detector area of about 5 $m^2$. In the next 4 years, the technology will have be developped and demonstrated to enhance the intrinsic rate capability of the counters from 20Hz to 10 kHz and to find concepts, to deal with very different hit densities in an efficient manner. The research includes the design of impedance matched wide strip counters as well es the development of high bandwidth electronics with adjustable input impedance. Synergies are expected from the collaboration with analog ASIC designers (Stachel) and electronics groups (Ullaland).
A really 'intelligent' solution will have to be found to make the TOF detector data avalaible for fast event selection within the system that will be developed by the KIP - group (Lindenstruth). Such a solution is necessary to obtain online background reduction in the measurement of open charm (D-mesons) and will determine how close to the production threshold CBM will be able to run.

### 3.4.2 Event selection

The CBM detector system does not implement a dead time system but every sensor produces time stamped hits if the corresponding signals are found above a certain threshold. The advantage of such architecture is the abolishment of any particular latency requirement for any given event. The corresponding data streams exceed 10 Terrabits/sec, also requiring on-line event filtering and selection. Such processing system has similarities with a High Level Trigger, operating at much higher event rates and without a specific trigger system. The KIP computer engineering group (Lindenstruth) will concentrate in aggreement with the CBM management on this subject, using the experience and technologies, developed for ALICE ad LHCb during the last phase of the IRTG.

### 3.4.3 Detector control system

During the first IRTG funding period from 2005 to 2008, a novel FPGA refresh technology based on partial dynamic reconfiguration was developed (Kebschull). The purpose of this technology was to extend the meantime between failures (MTBF) caused by single event upsets (SEUs). Single event upsets affect the FPGA configuration and lead to malfunction of the active design. SEUs are caused by high energy particles passing through the FPGA chip. The novel refresh technology was successfully used for ALICE TPC readout controller (ROC). Current estimates show, that in CBM the radiation doses will be much higher than for ALICE TPC. Therefore, new and more effective radiation tolerance technologies for FPGAs need to and will be explored.

Within this research, we want to investigate the impact of fault tolerance technologies like ECC for RAMs and busses, and we want to design radiation tolerant IP components like CPU, busses, memory controllers and I/O, especially optimized to run on FPGA using the refresh technology.

This work has to be carried out in close cooperation with our Norwegian colleagues in Bergen and Oslo: The application in ROC and DCS will be implemented together with Bergen (Röhrich) and beam test will be done in Oslo (Skaali). These beam test will measure the achieved improvement in radiation tolerance.

Therefore the IRTG is a perfect vehicle to enhance these kind of cooperations.

## 3.5 Hadron calorimeter at the International Linear Collider (ILC)

Since 2006 the Heidelberg KIP group (Schultz-Coulon) is involved in the R&D activities for a high-performance hadron calorimeter (HCAL) for the International Linear Collider (ILC). The challenging physics goals of the ILC impose stringent demands on the detector, which by far exceed what is possible with present detector technologies. This is particularly true for the calorimetry, as the anticipated jet-energy resolution necessitates the combination of tracking and calorimeter information and consequently a separation of showers originating from neutral and from charged particles. This is only possible with a highly granular calorimeter, which resolves the complete shape of individual showers. Such a calorimeter is presently developed in

the framework of the CALICE collaboration, where the analogue option for the hadronic part (AHCAL) is based on a sampling structure with scintillating tiles individually readout by so-called Silicon-Photomultiplier (SiPM) mounted directly on each tile.
Presently the ILC activities at the KIP comprise the characterization of new Silicon-Photomultipliers, work on test-beam measurements using the first AHCAL prototype and the development of highly integrated electronics for SiPM-readout. Further plans are the development of infrastructure to allow large-scale quality assurance tests of integrated sensor-scintillating systems, which are mandatory when building a calorimeter with millions of channels. The SiPM-studies - also in view of a possible application in medical imaging - are planned in collaboration with the IRTG group at the University of Bergen (G. Eigen et al.); both groups are - among others - partners in a new proposal for the 7th framework program of the EU. Hence, the ILC activities will profit significantly from the scientific exchange fostered by the International Graduate School on Intelligent Detectors, circumstances, which have already been very helpful when initiating the new involvement. Both activities will also profit from the excellent technical infrastructure in Heidelberg. In particular the new HGF Terascale Alliance will be of strong importance for the ambitious electronics and VLSI development.

**Summary:**
Techniques developed for todays experiments are being used under harsh real conditions and are tested for their applicability for future even more demanding tasks. Towards that goal the implemented techniques are extended and refined employing the most advanced technologies.

1. Full coverage of all the stages of modern intelligent nuclear/particle detection system design and operation

    - physics analysis
    - physics simulation
    - detector simulation
    - detector construction, system integration
    - readout design, development and operation
    - trigger design, development and operation
    - data handling and data management
    - online data selection
    - offline event reconstruction

- GRID computing
- High performance computing

2. Development of new, integrated detection techniques for next generation machines (e.g. FAIR, ILC, astrophysics satellites). Here the demands are very high with respect to the event/data rates and efficient real-time processing required for rare signals.

## 3.6 Research topics

The following sections give a brief collection of some of the core research topics foreseen for the upcoming funding period within the framework of the IRTG. They are organized in line with the various stages listed in the workplans set forth in sections 3.1 - 3.5. All subjects cover a rather large field of activities, thus supporting many possible Ph.D. theses.

1. Physics analysis

   After 20 years of development the next few years will give the unique chance to apply now the new detector concepts and extract physics signals. This results will have direct feed-back to further design considerations. Especially 'rare signal' analysis fits into the scope of the IRTG, since this will be even more demanding at future facilities. Identified projects that are of common interest to several groups within the IRTG are:

   - Jet analysis in ALICE and ATLAS
   - Quarkonia production
   - single photons production (ATLAS, ALICE)
   - Charm (Bottom) Tagging by secondary vertices (BABAR, CBM, LHCb, ALICE)

2. Detector simulation

   New detectors are being developped in the context of the IRTG working groups that need detailed response simulations:

   - Multigap Multistrip Resistive Plate Chamber (MMRPC)

     This detector is forseen for the Time-of-flight wall of the CBM experiment at the future FAIR facility, but is also finding more and more customers in other hadron physics experiments.

- Hadronic calorimeter (HCAL) for the International Linear Collider (ILC)

  Here the challenge is to do active calorimetry by tracing the subshowers of all impinging particles by combining tracking and calorimeter information. This concept is also of interest to the muon system of CBM.

3. System integration and operation

   Major subsystem will be interfaced, calibrated and operated in the world largest experiments by the participating groups:

   - TRD of ALICE
   - HLT of ALICE
   - ATLAS Calorimeter Trigger

4. Experiment operation, Slow control

   The harsh environment at the LHC will be topped by the next generation machines thus requiring new strategies for making detector control hardware that very effectively uses FPGAs and other commercial components more radiation tolerant.

5. Electronics design

   New radiation tolerant high density ASIC designs are necessary for the next generation experiments at FAIR and ILC.

6. Data aqusition / Trigger system development

   The classical hardware trigger scheme is planned to be replaced by an software based 'event selection'. The necessary hardware and software tools need to be developped.

7. GRID computing

   The LHC experiments will delived an so far unseen amount of data. The GRID has been developed to cope with this load and will be challenged by real data in the upcoming funding period.

## 3.7 Proposed thesis topics

The following table presents a list of possible thesis topics that would fit into the research program of the IRTG. Common interest in between the various groups can be clearly identified and will serve as starting point for

| | Title | Main Problem Class | Location |
|---|---|---|---|
| 1 | ALICE: Analysis (Jets, Charmonia, Open charm) | Physics, Simulation | HD |
| 2 | ALICE-HLT: high performance on-line event reconstruction | tracking | HD/BE |
| 3 | ALICE-HLT: on-line calibration, data quality monitoring | calibration | HD/BE |
| 4 | ALICE-TRD: high-pt GTU trigger | trigger, VHDL(FPGA) | HD |
| 5 | ATLAS: calorimeter trigger operation | Physics, database | HD |
| 6 | ILC: HCAL development | detector, readout | HD |
| 7 | CBM: CBM - xyter | Electronics | HD |
| 8 | CBM: High resolution TOF Counter (RPC) development | electronics,readout | HD |
| 9 | CBM: event building network | | HD |
| 10 | Distributed control systems | | HD |
| 11 | LHCb | VHDL(FPGA), Algorithms, Simulation | HD |
| 12 | Autonomous computing, GRID computing | computing | HD |

Table 3.2: Table of thesis projects

joint developments. We expect to adjust and/or change priorities during the course of the IRTG depending on the scientific results, achieved.
This list clearly exceeds the funding possibility of the IRTG and may also be filled by some of the contributed Ph.D. students. Candidates will be admitted to the IRTG optimising the exchange in between the German and Norwegian groups. The long list demonstrates the research topics that will be worked on in the participating groups and thus represent the environment into which the IRTG is embedded. Clearly, all the students working on the listed subjects will benefit from the educational program of the IRTG.
Many of the proposed theses relate to the development of complex subsystems of large-scale experiments carried out by international collaborations. These subsystems will be designed, implemented, and run by larger groups of researchers. Many of them have comparable goals and use comparable, up-to-date technology, so that the PhD students assigned to a certain task will benefit hugely from a cooperation. Below closely related theses are compiled. We plan that the German and Norway PhD students will do part of their work at their home institution and at a guest institution. This will

stimulate an intensive cooperation between the involved research groups.

# Chapter 4

# Study Program

Participants of the IRTG are expected to actively participate in the study program. This program should allow students to:

- Deepen their knowledge in their area of research concerning the basic physics questions and instrumentation, and to bridge the gap to actual research work
- Gain expert knowledge in key technologies, while making best use of the expertise available at the German and Norwegian institutions.
- Present their results and exchange their knowledge with other students in seminars and study weeks
- Make contact with the best experts from all over the world and learn from them in topical workshops organised by the graduate school.
- Get the opportunity to participate in research work at other places in the framework of the exchange program.

In accord with the experience obtained so far from running the IRTG the doctoral education in Heidelberg was modified and new regulations have been set up with the installation of the Heidelberg Graduate School for Fundamental Physics (HGFSP). Those rules are planned to be applied to all Heidelberg physics students in the near future. The most important regulations are:

- Besides their main advisor students will be assigned two co-advisers to monitor the progress.
- The advisory committee will define together with the student general educational modules offered by the HGFSP and also suggest conferences and workshops that should be attended during the PhD study.

The course work can be fulfilled by attending the Heidelberg Graduate Days that was established as a well received tool for graduate student education.

- The students are requested to spend a total of 16 SWS (semester periods per week) on general physics education. Of those 8 SWS can be covered by group meetings and colloquia, and 8 SWS have to be of more general nature like the participation in the Heidelberg Graduate Days or in the IRTG schools or Journal Clubs.

In order to allow for sufficient time for doing research the IRTG does not plan to install more formal lectures nor further requirements. To enhance the scientic level of knowledge we will offer editional seminars and workshops/school focussing on specific subjects. This concept was successfully tested during the present running period of the IRTG and will be refined (see section 4.4).
Therefore the study program of the IRTG will have the following components:

- General lectures will be offered in the context of the Heidelberg Graduate Days organized by the HGFSP. This teaching concept for graduate students was developed within the IRTG and its predecessors and will be further supported by the IRTG.
- In continuation of the current activities schools and lecture weeks on specialized subjects is being organized on a bi-annual basis.
- Topical workshops are organised by the IRTG management (if possible in conjunction or in temporal vicinity to conferences).
- A bi-weekly IRTG seminar is held with topics choosen by the students obeying the general requirements formulated in sections 4.4 and 4.7.2.

Norwegian students are invited to participate to the program points 1 - 3 for short visits, and are participating to point 4 while they are staying for some longer time in Heidelberg. Note that we don't request any more that students have to spend a minimum amount of time in the partner institutions.

## 4.1 Regular advanced lectures

. The members of the IRTG will participate for a minimum of four semesters in general advanced lectures offered in Heidelberg and Bergen, which will cover Basic Physics, Experimental Techniques and the Informatics Aspects. Advanced lectures will included the following subjects:

- Experimental probes of fundamental interactions
- Standard model of particle physics
- Observing the big bang
- Cosmology
- Particle detectors
- Relativistic heavy ion physics
- (Micro) Electronics
- High performance computing

These lectures are fully integrated into the teaching activities of the faculties and the time spent is fully accountable as part of the teaching duties ('Lehrdeputat'). In order to profit maximally from the available expertise and preparation, we also plan to offer these courses in Norway if they are scheduled for Heidelberg and vice versa. Accordingly, the lecturers of the desired courses will be invited to give a compact course at the partner institutions.
Most of these activities will be included into the "Heidelberg Graduate Days" that were established as a very efficient way of graduate student education.

## 4.2 Exchange program

An integral part of the study program is an exchange program for students between the partner institutions. A strong motivation for this is of course the stimulation of international exchange and of common projects. It must be stressed however that such a program can only be successful if the visits to the partner institutions are strongly coupled to the thesis work of the students. This is naturally the case if they work in common research projects. Students applying for the IRTG will be preferably admitted with topics that help to extend the international collaboration between the participating groups.
The existing and future projects as described in the research chapter are ideal candidates here, as their timelines extend for more than a decade into the future.
The exchange program will be based on two concepts:

- Sharing common lecture in the context of the regular events.

- Long term stays for individual students on a project basis:

  Typical examples of projects are:

  – participation at beam tests of subdetectors and data evaluation
  – testing of common readout chains together with detectors where several institutions have delivered components.
  – getting familiar with Grid-Computing for simulation or analysis

## 4.3 IRTG workshops and schools

IRTG workshops and schools address subjects that are specific to the profile of the IRTG. They are meant to deepen the knowledge in the interdisciplinary field that the IRTG is covering. As described in the Intermediate Report the most successful events were those with a direct involvement of the students and their interaction in common projects and small mixed groups. It is planned to further develop this concept by

- 'coached' lectures, e.g. the students are asked to seek and present answers to priorly defined questions from common advanced lectures,
- project oriented lab tasks addessing detector technologies,
- project oriented design tasks for FPGAs and ASICs.

In general the students have to present the results of their group work at the end of a 3 - 5 day workshop, exercising at the same time their 'hard' and 'soft' skills.
The table below gives an overview of both the planned lecture weeks and schools for the next two years of the IRTG. The tentative organisers are listed as well:

| Year | Type | Place | Topic | Organisers |
|---|---|---|---|---|
| 2008 Spring | Lecture | Heidelberg | LHC physics | Uwer |
| 2008 Fall | School | Bergen | detector calibration | Eigen |
| 2009 Spring | School | Heidelberg | fast event selection | Schultz-Coulon |
| 2009 Fall | Workshop | Heidelberg | LHC - first results | Stachel |
| 2010 Spring | Workshop | Oslo | First HI-results from LHC | Tveter |

Table 4.1: Planned workshops and schools

## 4.4 Bi-weekly Seminars

This seminar represents the core of the local IRTG operation. Participation is mandatory for all students. The seminar serves several goals:

- Students train their presentations and discussion skills by reporting on
  - progress in their own work,
  - latest development in their field (Journal Club like),
  - topics on general interest.
- One status report is expected from each member of the IRTG once per year.
- External speakers (including e.g. postdocs from the participating groups) are invited to broaden the scientific scope represented by the IRTG members themselves. The external speakers are selected according to the demands or suggestions of the students. It is planned to shift more responsiblities for the selection and organisation process to the student members of the IRTG in order to also develop their organisational skills.
- The seminar represents a regular date that stimulates mutual interactions and exchanges among the participants that is vital for the success of the IRTG.

The seminar is open to all members of the IRTG and to non-member students in the participating groups.

## 4.5 Soft skill seminars

Soft skill seminars will be offered in close collaboration with the HGFSP. Actually, it is planned that the HGFSP will coordinate the effort and ensure that the typical subjects are covered. All members of the IRTG including the Norwegian ones are eligible for participation.

## 4.6 Post doc position

To efficiently implement the teaching activities, i.e. to organize the lecture weeks, the travels and the bi-weekly seminar, a post-doc is absolutely necessary. In addition the students are offered the possibility to get help by a more experienced person also on scientific questions. As experience has shown this offer to discuss more general questions with an independent person on the sub-advisor level is well received. In order to match the needs of the IRTG, candidates for this position have to possess the following profile:

- Pursue research in one of the fields of the IRTG, preferably with connections into others, and at the forefront of technological developments.
- Have good interdisciplinary knowledge of physics and computer science to fertilise the discussion.
- Have good communication skills to serve as an 'attractor' for the heterogeneous group of students co-working in the IRTG.
- Have organisational skills to help running the schools and the exchange program.

In order to find suitable candidates funding is requested for a full TVL-13 position. This is the standard level of salary for postdocs in the participating groups - and also adequate for the responsibilities attached to the IRTG position.

## 4.7 Procedural details

The IRTG fits without any special effort into the graduate programs of the German and Norwegian universities. The standard rules for acceptance criteria are valid.

### 4.7.1 Admission to the IRTG

In order to maintain the high standard that the current activities in the field have reached in the various participating groups, the positions available from the IRTG are announced worldwide. Candidates are selected by the admission commission on the basis of the achievements of the diploma exams the originality and quality of the diploma project and an oral presentation of the candidate about the diploma project (or equivalent). This concept was exercised so far and found to be useful to find candidates that show the necessary skills for the interdisciplinary work between experimental physics, engineering and informatics. This selection is not necessarily always coinciding with the best grades in the often theoretically oriented diploma exams. Therefore interesting candidates that can demonstrate from some project work innovative and creative ideas are given the chance to present themselves in front of the admission commission and up to now some of those candidates were very successful.

### 4.7.2 Supervision and Performance evaluation

All the graduate students participating in the IRTG have their thesis advisors at their home institutes. Thus a day-by-day interaction is guaranteed providing the most efficient monitoring of the progress of the thesis project. On the Heidelberg side each student will be assigned two co-advisors. For the IRTG students one of them will be picked from our partner universities in Bergen or Oslo.

For long-term visits at the partner institution a specific mentor (faculty member of the host institution) will be assigned for each student serving as contact for any problem that might arise during those stays. This mentor will keep track of the project work that the student is pursuing and will help to integrate the foreign students into the social activities of the hosting group. The students will report regularly on the progress of their work in the bi-weekly seminar that is part of the IRTG. Due to the interdisciplinary character of the IRTG, special efforts will be made so that all the students can follow the presentations and that the subjects are discussed in depth. Besides the internal IRTG seminar, all projects are embedded into large international collaborations, providing numerous opportunities for status reports at workgroup and collaboration meetings. At the later stage of their work the participants will present their achievements at international conferences by poster presentations or talks. For the students the interaction with the full international community is of special importance to acquire visibility to the outside world and to get into contact with other projects that might be of importance for their future careers. The IRTG will support the participation of each participating student in at least one major conference in the last 2 years of her/his thesis work.

### 4.7.3 Doctoral degree

The final performance control is the acceptance of the doctoral thesis and the successful oral defense of the thesis according to the local rules of the participating institutions. As done up to now the doctoral degrees will be issued by the parent institution in which the student is enrolled, according to the local rules.

The IRTG still is willing to support the mobility of the students although the experience on this point is rather disappointing. At this point we expect a strong shift towards stays at CERN in order to participate and prepare first data taking. This process has already begun and many ITRG members meet more frequently at CERN than at the appropriate partner institution. Students will be encouraged to continue their work at any partner institution, including CERN, e.g. if some interesting development happened during the project work phase. This exchange has and will continue to broaden the scope of activity and experience of the students while woring on their thesis project. Joint thesis projects are possible by admitting the mentor of the student into the examination commission at the university that is awarding the degree.

# Chapter 5

# Visiting scientist program

In continuation of the current practise we plan to continue with the invitation of experts on various fields of physics, detector design, readout electronics and compute infrastructure to the different activities of the IRTG, e.g. seminars, schools and workshops, according to the needs of the participants of the IRTG. This includes speakers for the Heidelberg Graduate Days ("Heidelberger Graduiertentage") that are supplying the core knowledge listed in section 4.1.

We plan to extend the frequency of invitations to external speakers by direct involvement of the students. Students taking actively part in the invitation process, suggesting subjects and speakers, will be granted a free common dinner with the invited speaker. By this we hope to encourage students to play a more active role in the specific weekly seminar program.

The duration of the schools is typically 4 days, work shops last 3 days and seminars are done on a daily basis.

# Chapter 6

# Organizational Structure

The IRTG organization remains as sketched below, emphasizing the binational nature. The body of the IRTG is the IRTG board, which includes all participating faculty members and two students from each country, which are elected by the participating students by simple majority. The IRTG board meets twice a year during a lecture week or school.

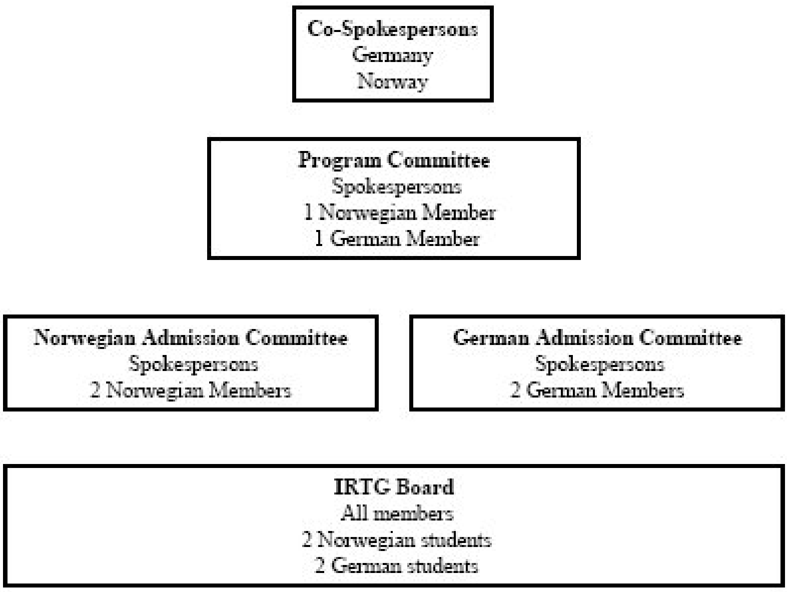


Figure 6.1: Organizational Structure

The term of a spokesperson is two years. The current spokespersons are Prof. Dr. Norbert Herrmann for Germany and Prof. Dr. Dieter Röhrich for Norway. The two national spokespersons are elected by all members the

IRTG board. The schools and lecture weeks (see section 4) are organized by the IRTG program committee with the membership of the spokespersons (ex officio) plus one elected national member.
Admission to the IRTG is performed nationally by the two national admission committees. In order to ensure coherence within the IRTG both spokespersons are ex officio members of both admission committees.
The responsibility for the proper organization of the biweekly local seminars is rotating on a semester basis amoung the local professors. It is the responsibility of the national spokesperson to ensure proper execution of the program.

# Chapter 7

# Infrastructure

## 7.1 Affiliation with (inter)national research projects

The research to be performed as part of the IRTG is closely related to the major current and new activities in experimental elementary particle and nuclear physics in Europe and USA. The participating groups are involved into running experiments at RHIC (BNL), SPS (CERN), BABAR (SLAC) and SIS (GSI). They contribute major parts to the preparation and execution of upcoming LHC experiments at CERN: ALICE, ATLAS and LHCb. The IRTG students of this proposed extension will have the unique opportunity to participate in the first data taking of the world largest accellerator infrastructure.

Significant contributions to the future FAIR facility at GSI and especially to the design of the Compressed Baryonic Matter experiment (CBM) are planned and expected by the CBM collaboration. This is manifested in the participation to several Joint Research Activities as part of the I3HP initiative within the sixth and seventh framwork program of the EU. On a similar level the ILC activities are part of the seventh framwork program of the EU.

## 7.2 Available infrastructure at German institutes

### 7.2.1 Scientific personal

The available infrastructures to the IRTG are the same as described for the original proposal except for two items:

1. The Technical Informatics of Mannheim was moved from Mannheim University to the ZITI at Heidelberg. The infrastructural resources are currently integrated into the ASIC laboratory of Heidelberg University.

2. The Physkalische Institut of Heidelberg will get a new building on the Campus (Neuenheimer Feld) in direct vicinity to the Kirchhoff Institut. Direct communication among the various groups participating in the IRTG will be significantly enhanced when living essentially under the same roof. Ground breaking for the new building is expected for 2010.

The following table gives a summary of the scientific personal that is available to the Heidelberg groups participating in the IRTG:

| | Physikalisches Institut | Kirchhoff Institut |
|---|---|---|
| C4 | 2 | 2 |
| C3 | 2 | 2 |
| C1 | 2 | 1 |
| TVL | 6 | 6 |

### 7.2.2 Technical Personal

Technical personnel is available to the different groups on a project basis from centralized and commonly used workshops. The following table gives the approximate number of people available to the groups participating in the IRTG:

| | Physikalisches Institut | Kirchhoff Institut |
|---|---|---|
| Electronics | 8 | 12 |
| Mechanics | 20 | 8 |

### 7.2.3 ASIC Laboratory at Heidelberg University

Microelectronics is one essential building block for the development and integration of intelligent detectors. The only way to combine low noise, low power, possibly radiation hard, low cost and intelligent signal processing and

acquisition systems is by virtue of developing highly advanced integrated microelectronic devices. Therefore, foreseeing this trend, the ASIC Laboratory Heidelberg was founded in 1994 as a joint facility of the Institute for High Energy Physics and the Physics Institute of Heidelberg University together with the MaxPlanck-Institute for Nuclear Physics. Later the Institute for Applied Physics of Heidelberg University joined the lab and subsequently merged with the Institute for High Energy Physics into the present Kirchhoff-Institute for Physics (KIP), which hosts the ASIC lab on its site [1].
The positive evolution of the Lab is also well represented by the personnel employed: Starting with 6 people in 1994, the head-count has grown to more than 30 scientists 2008.

## 7.3 Available infrastructure at Norwegian institutes

### 7.3.1 Scientific personal

The following table gives a summary of the scientific personal that is available to the groups participating in the IRTG:

| | UiB | UiO | HiB |
|---|---|---|---|
| Professor | 3 | 4 | 1 |
| Assoc. Professor | 4 | - | - |

### 7.3.2 Technical Personal

Technical personnel are available to the different groups on a project basis from centralized and commonly used workshops. The following table gives the approximate number of people available to the groups participating in the IRTG:

| | UiB | UiO | HiB |
|---|---|---|---|
| Electronics | 4 | 2 | - |
| Mechanics | 2 | 2 | - |

### 7.3.3 Office and laboratory space

The participating groups are equipped with sufficient office and laboratory space to host the graduate students and their activities. The offices are equipped with workstations with appropriate compute power and network links.

[1] For details refer to http://wwwasic.kip.uni-heidelberg.de

### 7.3.4 Laboratories at UiB

**The cleanroom** Class 10000 cleanroom equipped with a semi-automatic probe station for inspecting and probing microstrip detectors. This includes GPIB operated stepper motors, powersupplies, current and capacitance meters, switching unit. Furthermore, a VME based data-aquisition system for powering and reading out signals from the front-end electronics of silicon detector modules.

**The detector laboratories** Laboratory for detector development: HV-power supplies, CAMAC-, VME- and PCI-based data acquisition systems, measurement equipment, electronics design tools, electronics prototype production facility.

**The microelectronics laboratory** The microelectronics lab was established in 1988 in as a result of the increasing demand for advanced electronics in space physics instrumentation. Its main purpose is to serve as an environment for education and research in microelectronics related to experimental physics. The activity is focused on embedded sensor electronics, ranging from analogue amplifier and shaper design to digital control and support circuits. Both full custom ASIC design and high level language design of FPGAs is supported. The microelectronics laboratory is a member of Europractice, which makes available a wide range of leading edge IC, FPGA, Electronics Systems, and Microsystems design tools, plus Intellectual Property Blocks (IP). It is equipped with HP and Sun workstations and PCs running Windows and Linux. A number of instruments are available in the lab, and at the Department of Physics, including a Vanguard Networked PCI-X/PCI Bus Analyzer and Exerciser and mixed signal oscilloscopes.

### 7.3.5 Laboratories at UiO

**The Oslo Cyclotron Laboratory (OCL)** The Oslo Cyclotron Laboratory (OCL) was established in 1978, and is based on a Scanditronix MC35 cyclotron. This multi-purpose machine can produce beams of protons, deuterons, 3He and alpha, with energies ranging from 5 to 45 MeV, and intensities from around 10 pA to 100 $\mu$A.The accelerator is thus far more versatile than many specialized ones found elsewhere.
Current projects at the OCL include, but are not limited to:

- Study of the structure of thermally excited nuclei at low spin.
- Production of radionuclides (18F, 211At) for medical purposes.

- Radiation hardness tests of electronic components being evaluated for possible use with the ALICE detector.

Apart from the cyclotron itself, power-supplies and beam-lines, the laboratory infrastructure comprises specialized detectors, advanced data-acquisition electronics and computer equipment. VME based front-end processors plus Sun workstations and PC's running Linux are used. Many of the technical solutions, mechanics, electronics and software, have been developed locally.

**Research group laboratories** The research groups for electronics, particle physics and nuclear physics operate laboratories for the design and construction of experimental specific detector and data processing electronics. A wide range of CAD tools for electronic design is available. The groups can also acquire development tools distributed through the membership of the University of Oslo in the Europractice organization. The laboratories feature a wide range of test and measurement equipment, software packages, and Real-Time development systems.
A common electronics laboratory offers central facilities for surface mounted circuit technology etc. For ASIC development there is collaboration with SINTEF and the Institute of Informatics.

**The cleanroom** A cleanroom for silicon module assembly is equipped with high precision assembly tables, including test facilities for silicon modules.

**Norwegian Microtechnology Centre** The new Norwegian Microtechnology Centre (NMC) is part of a national programme on micro-technology. NMC is a joint laboratory operated by the research organization SINTEF, the University of Oslo, and industry. The construction has been partly financed by the Norwegian Research Council. The Centre is located on the Oslo University campus.
NMCs core competence is the development of micro-components and complete instrumentation systems based on microcomponents. The laboratory is equipped with a processing line for 3" wafers. The research will include ASICs, micro-system manufacturing, MEMS, packaging technology, photonics and radiation detector systems. Scientists from SINTEF will collaborate with professors and students of the University of Oslo in order to design and prototype new micro-systems.

# Chapter 8

# Funding

## 8.1 Funding (German side)

### 8.1.1 Scholarships for PhD students

We ask for the support of 12 students for the German groups participating in the IRTG. In order to be able to attract the most active and capable students we have to offer an increased salary for the interdisciplinary work profile. It should be noted that PhD student in informatics and electrical engineering typically enjoy full TVL-13 positions. In order to be at least partially competitive we request for each student the increased stipends.
Subtotal for 4.5 years:

| | | |
|---|---|---|
| Base amount | 4,5 x 12 x 12 x 1.365 € | = 888.452 € |
| Additional support | 4,5 x 12 x 12 x 103 € | = 66.744 € |
| Family support | 4,5 x 12 x 2 x 205 € | = 22.140 € |
| (for an average of 20% of all students) | | |
| Sum | | 977.336 € |

### 8.1.2 Postdoc position

The postdoc position is necessary to maintain the coherence of the program and to organize the communication and exchanges, and setting up the schools for making use of the most advanced design and analysis tools available today. The scientific work also represents a focussing element were all students can participate. The duties connected to the postdoc positions are detailed in section 4.6.
Postdocs in all the participating groups are payed according to TVL-13 In order not to discriminate among people on the same level of experience and

education, and to be able to motivate people to join into the educational activities of the IRTG, we ask for a positions according to the TVL tariff.
Subtotal for 4.5 years:

Estimate 4,5 x 50.000 €= 225.000 €

### 8.1.3 Joint activities

Two joint lecture weeks/schools will be organized each year, one being internal to the IRTG participants the other one being a school that is open to the public. The location will alter in between Germany and Norway.
We base our funding estimate on the assumption that all the participants of the IRTG will participate in the internal lecture week or workshop.
4.5 x (6 students + 1 Postdoc + 3 faculty) x (350 €+ 5x100 €) = 38.250 €
A flight from Frankfurt to Bergen costs 350 €, the estimate for housing and food is 100 /Euro/day (120 for Norway)

### 8.1.4 Travel of students and postdoc

We anticipate that many of the students will be have to be present during data taking at CERN and have to participate in collaboration meetings. To motivate a number we calculate the cost for each student to spend 2 weeks at CERN per year.

4.5 x 13 x 2 x 1000 €= 120.000 €.

### 8.1.5 Participation in international conferences

Each student and the postdoct is given the chance to present her/his results on an international conference twice.
2 x 13 x 1.500 €= 39.000 €.

### 8.1.6 Mobility costs

The cost for long term exchanges of students is divided among the participating institution in the following way: The travel expenses are supplied by the home institute of the student while the local expenses are covered by the host institutes.

1. Travel money for German students to Norway

Estimated from the past some (≈ 4) participating students will visit the partner university once per year.

We therefore ask for

4.5 x 4 x 350 €: 6000 €

2. We anticipate on average about 2 visits of Norwegian students for project work in Heidelberg. The cost is estimated to 400 €/month/person.

   Therefore we ask:

   4.5 x 2 x 400 €: 4.000 €.

### 8.1.7 Support for visiting scientists

External lecturers and speakers are invitetd to workshops and seminars. The cost for the invitation of an external lecturer is estimated to 2000 €per 4day course, 1000 €for short term visit.
We therefore ask for a total of 30.000 €.

### 8.1.8 Coordination cost

Based on the experience up to now we ask for 5.000 €.

### 8.1.9 Total Sum

The total requests amounts to XXX €.

## 8.2 Funding (Norwegian side)

The available funding on the Norwegian side is detailed below:

| | | | |
|---|---|---|---|
| Total costs: | Stipends: | | 17948 kNOK |
| | Running costs: | (757 kNOK per year) | 3408 kNOK |

Cost sharing:

| | | |
|---|---|---|
| UiB: 3 stipends | + | 1500 kNOK |
| HiB: 1 stipend | + | 308 kNOK |
| UiO: 3 stipends | + | 1600 kNOK |

### 8.2.1 Scholarships for PhD students

We ask for the support of 7 students for the Norwegian groups participating in the IRTG; 3 stipends from UiB, 3 from UiO and 1 from HiB:

UiB: 3 * 4 years = 3 * 4 * 641 kNOK = 3 * 2564 kNOK = 7692 kNOK
UiO: 3 * 4 years = 3 * 4 * 641 kNOK = 3 * 2564 kNOK = 7692 kNOK
HiB: 1 * 4 years = 1 * 4 * 641 kNOK = 1 * 2564 kNOK = 2564 kNOK
Sum: 17948 kNOK

### 8.2.2 Postdoc positions

None.

### 8.2.3 Joint activities

Two joint lecture weeks/schools will be organized each year, one event internal to the IRTG participants, the other one will be open to the public. The location will alternate between Germany and Norway. We base our funding estimate on the assumption that most of the participants of the IRTG will participate in the mandatory internal 5 day lecture week or workshop: 4.5 x (7 students + 11 faculty) x (3000 NOK + 5x(1250+730) NOK) = 1045 kNOK
The cost for the invitation of an external lecture is estimated to 15000 NOK per 4 day course. We therefore ask for 4.5 x 1 x 15000 NOK = 67 kNOK

### 8.2.4 Mobility costs

The cost for long term exchanges of students is divided among the participating institution in the following way: The travel expenses are supplied by the home institute of the student while the local expenses are covered by the host institute.
i) Travel money for Norwegian students to Germany Typically half of the participating students will visit the partner university once per year. We therefore ask for
4.5 x 2 x 3000 NOK = 27 kNOK
ii) We expect visits of German students to the advanced courses and project work in Bergen/Oslo. The cost is estimated to 10000 NOK/month/person. On average about 4 German students will spent about 1 months in Norway: 4.5 x 4 x 10000 NOK = 180 kNOK
iii) We anticipate that many of the students have to be present at CERN during data taking. We assume that each student spends three weeks per year at CERN:
4.5 x 7 x (4000 + 21x(1400 + 650)) = 1482 kNOK

### 8.2.5 Support for visiting scientists

External experts will be invited to the bi-weekly local seminars according to the needs of the project and the students. This will happen about 2 times/year. The total cost amounts to
4.5 x 2 x 10000 NOK = 90 kNOK.

### 8.2.6 Participation at international conferences

The students have to be given the chance to present their achievements and themselves at international conferences. We ask for the support of the visit of one major conference per year. The necessary total amount is
4.5 x 7 x 15000 NOK = 472 kNOK.

### 8.2.7 Soft skill seminars

None (taken care of by the German partners).

### 8.2.8 Coordination cost

Specific costs will occur for the organisation of the public schools for advertising and secretarial help for the organisation. The necessary amount is estimated to
4.5 x 10000 NOK = 45 kNOK

# Chapter 9

# Publications

# Chapter 10

# Signatures

**Approval by the rectorate of Heidelberg University**
The rectorate strongly supports the grant application to the Deutsche Forschungsgemeinschaft to maintain the International Graduate School on 'Intelligent Detectors' based on an intense collaboration with the University of Bergen and the University of Oslo.
In the case of a positive decision by the DFG, the University will provide the necessary infrastructure and the work space for the Ph.D. students from the partner universities during their mobility period.

**Ruprecht-Karls-Universität Heidelberg**

**For the applicants**
**German principal Investigator** **Norwegian principal investigator**

(Prof. Dr. Norbert Herrmann) (Prof. Dr. Dieter Roehrich)