Proposal for an

International Research Training Group

Development and Application of Intelligent Detectors

at the

Ruprecht-Karls-Universität Heidelberg, Germany
University of Mannheim, Germany

and

University of Bergen, Norway
University of Oslo, Norway

Heidelberg, 12 October 2003

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International Research Training Group

Development and Application of Intelligent Detectors

1 General Information

1.1 Program Title

Development and Application of Intelligent Detectors

1.2 Applying Universities

In Germany the universities Heidelberg and Mannheim are applying. In Norway the Universities Bergen and Oslo are applying for the international research training group. The two German universities have cooperation contracts, several of the applying colleagues are coopted members of the appropriate faculties in Heidelberg and Mannheim. Similarly in Norway Bergen and Oslo are cooperating very closely.

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1.4 Summary

The International Research Training Group (IRTG) on intelligent detectors aims at developing and applying detection systems for particle, nuclear and space physics that integrate modern information technologies as key features. The design, building and operation of such detectors is the key for advanced nuclear and particle physics experiments. It requires a profound knowledge in a variety of fields that will be 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 here 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/Mannheim and Norway (Bergen/Oslo), and thus covers complementary aspects of the problem. On both sides many major experiments in high energy elementary particle and nuclear physics are represented: ALICE, ATLAS, BABAR, CBM, CERES, FOPI, H1, HeraB, LHCb in Heidelberg/Mannheim and ALICE, ATLAS, BRAHMS, NA57 and space physics (INTEGRAL, POLAR) in Bergen/Oslo, that all exploit similar techniques. Due to the wide variety of applications, synergy is expected. A productive collaboration within the ALICE experiment has already been established in between Heidelberg and Bergen, thereby contributing complementary technical expertise to the joint design of the ALICE high-level trigger. For example ASIC design and cluster computing are centered in Heidelberg, while FPGA-based hardware/software co-design is centered in Bergen. This project-oriented collaboration will be strengthened by the IRTG since common research interests are already expressed for the major future European facilities: GSI and Tesla.

The installation of the IRTG will generate unique opportunities for participating students. The teaching program will be held in English and will be open to all participants. The students will be lead to the forefront of experimental nuclear, particle and space physics and will be given the chance to acquire hands-on experience on the most advanced design, simulation and analysis tools available today. Complemented with soft-skill seminars that will cover the aspects of work organisation, time planning and presentation techniques, students will receive an international education that is well recognized by the current job research market.

1.5 Anticipated total duration

nine years

1.6 Period of funding

1.4.2004 – 30.9.2008

1.7 Anticipated starting date

Starting date: 01.04.2004

1.8 Anticipated number of participants

In Germany Heidelberg and Mannheim are applying for 18 PhD. stipends and 2 Bat IIa PostDoc positions. 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 ask for 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.

In order to be able to offer an attractive and top-level education program that is tailored to the needs of the participants, two BatIIa positions for postdoctoral fellows are requested (for details of the tasks and the requested profile see section 3.2 below). The number of PostDocs participating in the research activities of the IRTG is estimated to be about 15, providing the necessary intellectual and knowledge-based environment and knowledge from which Ph.D. students will profit.

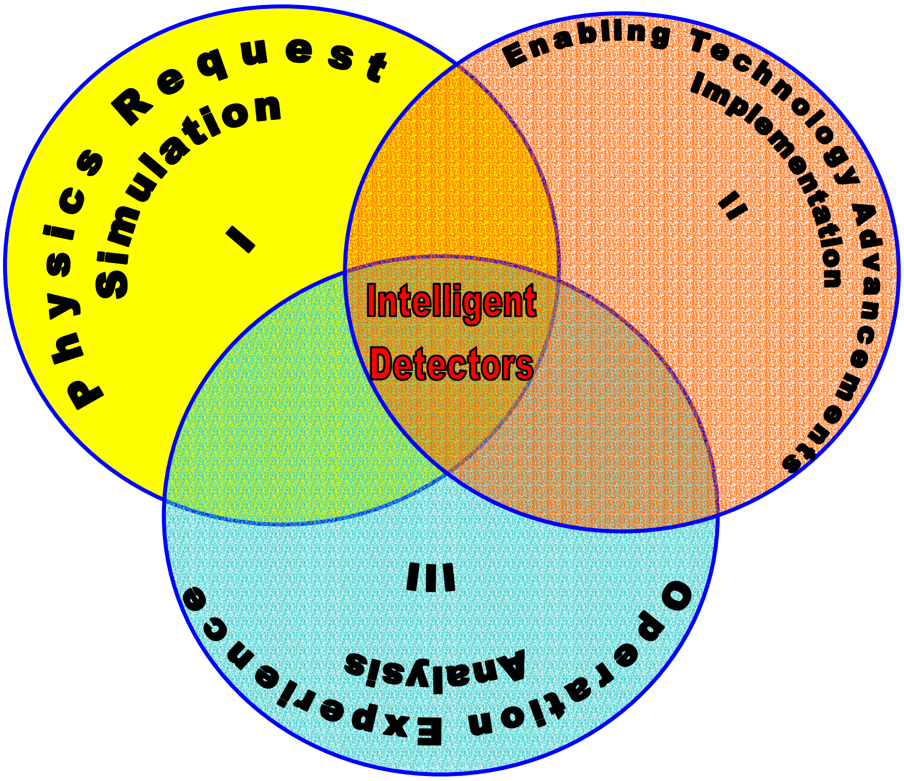
In Norway, a total of eight Ph.D. stipends are being requested in Bergen and Oslo. We note that German Ph.D. stipends are roughly half the size of Norwegian Ph.D. grants. The application includes requests for funding of running costs, e.g. for organising workshops/schools and to cover travel expenses. The total number of Norwegian students participating in the IRTGs educational program is 20. The number of Norwegian postdoctoral fellows involved in the projects related to the IRTG is estimated to be about four.

In summary about 60 Ph.D. students will form the body of the IRTG participating in the regular advanced lectures (see section 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 special offers developed within the IRTG.

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

2 IRTG Profile

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:



I) Fundamental physics like elementary particle, nuclear physics and space 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.

II) 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.

III) 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:

The physics goals have to be well understood. Therefore the underlying physics to be measured with the next generation detection systems is an integral part of the IRTG. The scope of the IRTG is centered around elementary particle physics and high energy nuclear physics. Physics observables have to be modelled by state-of-the-art simulation and reconstruction algorithms in order to define and understand the desired system specifications. Once a system, featuring local intelligence on the detector, is built, its performance and operation will have to be monitored and tuned. The information obtained from the experience of extracting high quality data from running devices is of crucial importance for the design of the next generation systems.

The disciplines required for the research and developments within the framework of the IRTG are:

- Nuclear Physics
- High Energy Physics
- Space Physics
- Detector Physics
- Sensoric
- Microelectronics and Electronics
- Computer Engineering
- Computer Science

Obviously the design of innovative detector concepts requires a profound knowledge of the existing and emerging hardware and software technologies. Since most of the applications will have to run under harsh environmental conditions such as high radiation level or in non-accessible locations, special care must be taken for the fault tolerance of the systems. The disciplines to be exploited range from microelectronics to ASIC design over FPGA applications to hardware/software co-design and compute infrastructures.

The students participating in the IRTG will obtain a broad education ranging from basic physics to modern IT techniques. The skills offered within the IRTG are highly valued in the current job market.

It is clear that there are different ways of addressing the named tasks. In order to make a well founded choice, experience with different realisations is necessary. This experience is typically not available within a single group. The proposed IRTG will make this experience, which is obtained from different groups with different systems optimizing slightly different aspects, available to all the participants and will foster the necessary scientific exchange. The idea of combining the resources available from the German groups with those from the Norwegian groups in Bergen and Oslo is particularly attractive since common projects are already being worked on (ALICE), there are common interests for future developments (GSI future and TESLA) and the local expertise is to a large extent complementary (see section 2.5). Therefore proposed IRTG complements an already existing international research group in Germany and Norway.

Given the large variety of disciplines and research required in the field of intelligent detectors, Ph.D. students have the option to adjust or even change priorities and scope in the course of the thesis work. This has the advantage to minimize the risk of any participating Ph.D. thesis. Thus Ph.D. students have the freedom to choose the priorities and focus of their core work. For example detector research can also include advances in microelectronic, readout and even signal processing.

The subjects of all Ph.D. projects within the IRTG will be chosen such, that they will be in the main scientific focus of two principle investigators, one in Germany and one in Norway. Of course one of them will act as supervisor at the hosting university, while the other will act as supervisor abroad and may act as referee in the graduation procedure.

3 Research Program

The research program emerged from an existing collaboration between Heidelberg and Bergen/Oslo specifically on the ALICE High Level Trigger (HLT), TPC and TRD Detector Control System (DCS), and ALICE physics simulations. Here, the feasibility and implementation of trigger algorithms is being worked on, an appropriate dedicated compute farm concept is being developed, new pattern recognition algorithms are developed and co-implemented in hardware and software on one hand and, on the other hand, a novel detector control system is being developed, using Ethernet as field-bus and embedded Linux systems on the detectors. On the local national scale there is a well established collaboration among the participating groups. The groups from Heidelberg and Mannheim are co-working since years on physics projects, the currently active ones being ATLAS, Hera-B and CBM).

The IRTG aims to extend this fruitful exchange between Heidelberg/Mannheim and Bergen/Oslo to

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

- 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 analysis
- offline data analysis
- GRID computing

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

Techniques developed for existing experiments will be tested for their applicability for future tasks, extended, refined and applied employing the most advanced technologies. Therefore we need to integrate all aspects of the challenge from the basic physics question over the modern implementation to the final analysis of the data into the IRTG.

A collection of currently visible special challenges for each of the steps listed above that will be addressed within the framework of the IRTG is described in section 2.3.

Startup activities/projects supported by the international graduate school are defined by the running programs of the individual participating groups. Possible thesis topics can be found in section 3.2. They cover the full range of activities defined above.

All of the research subjects are embedded into international collaborations, as outlined below. Each of the experiments, listed here, is a collaboration of more than international 100 researchers.

- Analysis, Simulation (ATLAS, ALICE, BABAR, CBM, LHCb)
- (Micro)Electronics development (ALICE TRAP chip, ALICE FPGA co-processor, ATLAS ROB FPGA processor, OASE chip)
- Algorithm development (ATLAS 2^{nd} level trigger)
- Compute infrastructure (ALICE HLT, LHCb Trigger)

It is expected that the ideas and experience with the existing devices will result amongst others in leading contributions to a proposal for the Compressed Baryonic Matter (CBM) experiment at the future GSI facility. The initial principle design of a detector and readout concept will be followed by prototype development and tests and eventually by a full subsystem design and realisation.

3.1 Research topics

The following sections give a brief outline of some of the core research topics foreseen within the framework of the IRTG. They are organized in line with the various stages listed in the workplan set forth in section 3. All subjects cover a rather large field of activities, thus supporting many possible Ph.D. theses. The link to the currently planned Ph.D. thesis topics, as summarized in section 3.2, is given as well demonstrating the synergy potential in between the German and Norwegian groups. Note that a given thesis topic shall contain aspects that place it into several research areas.

3.1.1 Physics simulation

(related thesis topics: 1,2,3,4,5,9,10,18)

Interesting physics signals for ‘new’ physics typically have small cross sections. Once identified they are one of the main motivation driving the development of intelligent detectors.

Several examples of the search for rare events are represented in the IRTG:

- particles with large transverse momentum in high multiplicity environment (ALICE) to define JET candidates
- electron pairs with large transverse momentum of single electrons in high multiplicity environment (ALICE) to define vector meson (J/ψ, Y) candidates
- single photons (ATLAS, ALICE)
- secondary vertices to detect long lived particles (BABAR, CBM, LHCb, ALICE)

The common problem is to define a signature that is specific enough to discriminate the background, while keeping the signal with high efficiency. The proper way depends strongly on the environment, i.e. on the specific experiment. Detailed simulations are necessary in order to define the procedure and verify its correctness. Typically two stages of simulations are necessary. In a first step the response of the detector to traversing particles needs to be simulated in detail. For rare signals with probabilities below 10^{-4} per interaction, a second step is necessary, which is the generation of a large enough event sample that actually allows to reconstruct the signal in a realistic environment. This step, which is a subject of active research, has to include the background sources and must be as realistic as possible. The standard detector response can be parametrised, keeping as much as possible of the detector signal correlations as possible. The parametrisation can be used to produce a sufficient number of events to study the actual rare signal. The methods require the use of efficient code and large scale compute facilities. The results are of crucial importance to define the requirements for the detection systems.

3.1.2 Detector simulation

(related thesis topics: 5, 19, 20, 27, 39, 42, 43)

The global physics simulation is based on a detailed understanding of the individual detector components. Within the scope of the IRTG especially the signal generation, the digitisation process and the digital processing units are of importance. The tools to describe the signal processing chain range from analogue signal description by solving the Maxwell equations (with programs like MAFIA, GARFIELD) to describing digital filters by the appropriate hardware description language. An effort will be made for future trigger tasks to include hardware based descriptions (VDHL) of intelligent data processing systems into the physics simulation environment in order to describe as realistic as possible the response of the final implementation of the trigger algorithm.

3.1.3 System integration

(related thesis topics: 6,7,8,13)

Several groups participating in the IRTG have designed and built advanced intelligent electronics for major recent and future experiments (ALICE, ATLAS, CMS, HERA-B). Since the systems have typically a large number of configuration parameters test systems have to be designed, to be built and operated in order to find the proper parameter set and validate the system behaviour. Interface aspects from trigger to data acquisition, and from data acquisition to analysis environments have to be examined. Slow control tasks, able to cope with close to 100,000 individual nodes have to be developed to monitor the functioning of all components of the system.

3.1.4 Readout design, development & operation

(related thesis topics: 17, 19, 20, 22, 32, 33, 34, 35, 40, 41)

The design of detector readout systems represents the most direct interface between the physics of the sensors and the possibilities offered by modern electronics. The applications range from processing of very fast analogue signals over electronics designs for extremely harsh environments to mixed mode designs that allow to process analogue and digital information on the same chip. Some details of the challenges are described in the following paragraphs:

High precision timing electronics

Modern Time-of-Flight (TOF) systems consist of several 10.000 channels with time resolutions in the order of 50ps. Based of the Resistive Plate Chamber with glass electrodes the system cost and performance are mostly determined by the available electronics. The signals require a very fast low noise analogue amplifiers with a bandwidth in excess of 10 GHz and a high resolution TDC system. In order to make the signals available for fast trigger processing, a digital treatment of the output signals such as cluster finding, slewing correction and matching in geometrically close planes, is necessary. For systems currently under consideration for the CBM experiment, it is of great importance whether those tasks can be combined into a single chip eventually with multiple channels.

Radiation tolerant designs with commercial grade technology

There is a large and increasing amount of electronics with increasing complexity mounted on the detectors, being used for readout, control and management of the entire system. For example complete embedded linux systems are used already todate as detector control systems. Although fully customized development of radiation hard electronics is well understood, not everything can be developed in a cost-effective manner. On the other hand, recent studies show a clear indication of increasing radiation tolerance of deep sub-micron electronics. Except for the area of vertex detectors, which are typically mounted very close to the interaction region the bulk of electronics is only required to be radiation tolerant. While single event upsets cannot be eliminated in principle, their effect can be mitigated by deploying appropriate computer science techniques, such as redundancy and error correction circuitry, thus making the appropriate devices tolerant with respect to radiation-induced failure. The advantages are at hand, basically permitting the utilization of a wide variety of available low-cost commercial hardware. However, certain rules have to be followed and to be developed in order to have such radiation robust designs, which are developed further in this work package.

Design techniques for high performance mixed mode circuits

The integration of sensitive analogue building blocks like amplifiers, ADCs or DLLs onto chips with significant digital activity can lead to performance degradation due to cross talk from the digital to the analogue part. This is a problem for many designs and a detailed study of the various cross talk mechanisms is important. Possible remedies like shielding techniques, low-sensitivity analogue designs or “quiet” digital logic families are part of this work package.

3.1.5 Trigger design, development & operation

(related thesis topics: 4, 5, 6, 14, 16, 26, 27, 28, 29)

Modern detector systems produce an extremely high data stream in the order of hundreds of Terabytes/s. The physically relevant events are usually embedded as an incredibly small fraction of it, say, 10^{-12}, and have to be filtered out by non-trivial algorithms. Just to transfer the data to computers running such algorithms constitutes a major yet unsolved problem for the next generation of detectors. This challenge will be addressed within the scope of the IRTG (see 2.3.6) since this Ansatz is especially attractive for very complex trigger signatures.

Alternatively, for the more standard requirement that localized information can lead to a trigger decision, it is clear that data filtering has to take place as closely as possible to the detectors to reduce the need for data transfer and management, and to reduce cost and complexity of the data taking and processing system. In order to extend detector front-ends with powerful data processing facilities, the most computational efficient devices have to be integrated: ASICs, where the algorithms are known and stable; FPGAs, where highly parallel algorithms with little control structures as well as efficiency are required; DSPs for more complex algorithms; and conventional CPUs, partly embedded as hard of soft FPGA cores. These devices are necessary to host those systems, and to integrate them into the overall data processing system of the experiment. Thus, such intelligent detector front-ends have to be programmed in a much more complex way than are current computer systems. The programmability covers many different types of computer systems, from conventional CPUs to highly parallel hardware structures, all in one system. To develop and operate such systems, possible architectures have to be investigated, efficient ways to do hardware/software co-design must be implemented, programming and simulation models have to be developed for the individual special-purpose components as well as for the interaction of them, and eventually software frameworks have to be elaborated that will permit programming, monitoring and controling these systems by non-specialists.

3.1.6 Data handling and data flow management

(related thesis topics: 21, 22, 28, 29)

Basically all experiments designed thus far implement a certain hierarchy, commencing with a trigger decision that is derived by a small subset of trigger detectors and trigger circuitry, which then starts the readout of the remaining detectors and which typically produces a much larger amount of data. Subsequent trigger layers then refine the first basic trigger decision that is derived under the largest timing constraint, which basically vetoes most of the events.

The GSI future program foresees a new paradigm that implements a constant-walk readout of all detectors. In this scenario, all (sub)detectors implement autonomous readout systems, producing time tagged compressed data, which is shipped immediately off the detectors. The following signal processing chain merges the relevant parts and implements the necessary pattern and event reconstruction algorithms without any particular timing constraint for a given event. One advantage of this system is the availability of any part of the event information at any level of the signal processing hierarchy.

Obviously this paradigm imposes a variety of challenges, to be mastered prior to its detailed conception. First, the entire detector infrastructure is required to be time synchronized in order to allow the unambiguous merging of the individual data streams. Second, the readout rate has to be much larger, the processing layers have to be rather powerful, and finally, the requirements on networks and connectivity are higher compared to the separated trigger and readout data paths. For instance, discrete event simulations are required in order to understand in detail the dead time behaviour of the system and in order to avoid biases.

3.1.7 Online data analysis

(related thesis topics: 11, 15)

Basically, all large detector systems of existing and planned experiments will produce a very large amount of data at the end of the already sophisticated hierarchical trigger system. However, from an information point of view the content of relevant physics data at the output of the trigger scheme is still small, thereby allowing further selection and corresponding improvement of the physics sensitivity, particularly with respect to rare events. This is typically implemented by running a full analysis of the event on-line and by extracting the appropriate features of the event or rejecting it completely. Such High-Level-Triggers are a combination of an analysis farm and a real-time system, combining high-rate processing with a massively parrallel computer architecture. Such HLT systems are often implemented as PC compute farms of more than 1000 processors. The operation of such large scale system, the data management, data flow orchestration and resource management is a challenge in itself and is part of the research program of the IRTG.

An operating High-Level-Trigger will severely affect the data recorded from the experiment and must therefore be very well understood. The implemented algorithms must be designed to be resistant to noise and a changing environment. This can only be accomplished by detailed simulations, which also are executed on high-performance (GRID) farms as discussed below. Full analysis of the event is as necessary as the microscopic simulation of the detector response to a potential event itself. The algorithms must be designed to be robust, minimizing the sensitivity to chaniging calibration parameters. The on-line detector system will have some of its calibration parameters change on-line, which any HLT has to be able to cope with in order to avoid a complex (re)calibration procedure. The development, implementation and verification of such algorithms are part of the IRTG.

3.1.8 Offline data analysis

(related thesis topics 1, 3, 12, 38)

The modern detector systems produce unprecedented amounts of data. The analysis strategy and the software tools need to be adapted to deal with this situation. The system aspects can be exercised on currently available data or on simulation data that are produced in order to prepare for the future analysis. Offline analysis results also provide the reference for the Online algorithm and Offline analysis is therefore indispensable for the assessment of the quality of a trigger / data taking system. Two examples for the tasks envisioned within the IRTG are detailed below:

BABAR analysis

BABAR is a B meson experiment designed to investigate CP violation that routinely runs in production mode and delivers a huge amount of data. The projected integrated luminosity until 2005 is foreseen to reach at least 500 fb^{-1}, corresponding to 10^9 recorded B decays.

The dataset used for a specific analysis will thus become increasingly large, comprising thousands of files and Terabytes of data. The distributed storage of data and the intensive usage of GRID computing tools is mandatory for the successful analysis of the future BABAR data sample. Regional computing centres will not only be used - as in the past - for the event simulation but must also be accessible for distributed physics analysis jobs. The development of a specific analysis GRID application is needed.

A GRID based physics analysis of the BABAR data is thus a two-fold challenge. It provides access to unique physics results and, at the same time, explores the possibilities of the GRID software.

ALICE simulations

ALICE is the dedicated heavy ion experiment at the LHC and will explore the properties of the Quark-Gluon-Plasma that will be produced in Pb + Pb collisions at a center-of-mass energy of 5.5 ATeV. Up to 20000 charged particles are expected to be produced in central collisions. The correlation within the multi-particle final states are of special interest to the heavy ion community, since the properties of the QGP are expected to be seen most clearly in the correlation of rare probes, such as jets or high mass dileptons with the number, average momenta, average flavour of and the relative orientation within the soft particle background. Since ALICE aims at measuring the final state as complete as possible, the special challenge of the ALICE experiment is its tremendous archiving rate of up to 1 Gbyte/s. The experiment will produce data volumes of several Petabyte/year starting in 2007. To prepare the analysis tools detailed high statistics simulations are required. They will be used to exercise the analysis framework. Results of the analysis will be used to define the initial physics and measurement program of ALICE.

A GRID based simulation environment (AliEn) has been prepared to meet the needs in CPU compute power and data storage. Physics topics to be covered are event-by-event correlations and rare signal searches. The technological challenges are the same as described for the BABAR analysis effort allowing for substantial synergy.

3.1.9 GRID computing

(related thesis topics: 23, 24, 25)

Cluster Operating Systems – GRID Computing

Both off-line and higher level on-line event processing requires massive parallel processing systems, which are typically deployed as PC farms, as they present the best price/performance ratio. In the case of on-line systems their interface to the detector front-end is done through the standard bus interfaces, such as PCI(-X). The size of such clusters may well exceed 1000 processors. The management and scalability of such farms, in particular also with respect to reliability, are open issues requiring further research and development. On the long run some kind of cluster operating system is foreseen, basically taking care of the internal resource management and self-organization of the system. Such infrastructure is developed in this work package. Reliable, autonomous large scale PC farms are particularly important as building blocks (tier centers) for DataGRID type GRID systems for the offline processing of physics data.

Cluster Interconnect networks for GRIDs

High-bandwidth and low-latency communication is one of the most important goals for the implementation of cluster systems. The communication infrastructure merges the individual cluster nodes to a high-performance computer, which is required for the various tasks outlined above. On one hand high throughput and low latency is required in the trigger environment, such as the ALICE HLT, and on the other hand, the avoidance of network transaction overhead becomes increasingly important for the off-line analysis of the data. This work package concentrates on all aspects of high performance cluster interconnects with respect to the physics applications.

Data management for physics experiments

To date, experiments are known to produce data of the scale of petabytes per year. Such amounts of data are typically distributed and replicated over various compute centers. The scalable and reliable storage of mass data with the given scale is a challenge, requiring new concepts and research. Further new data management, replication and caching strategies must be developed in order for systems of this scale to operate. Appropriate database systems for the indexing of data objects are required in order to permit the processing of entire runs. Although such systems exist to date in principle, their scalability is either questionable or has been demonstrated to be inadequate. New principles must be developed and deployed.

3.2 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 joint developments. We expect to adjust and/or change priorities during the course of the IRTG depending on the scientific results, achieved.

	Title	Main Problem Class	Loc
1	Performance of a High pt Global Tracking Trigger for ALICE	Physics, Simulation	HD
2	Development of an open charm trigger for ALICE	Physics, Simulation	BE
3	Reconstruction of open charm and bottom yields with ALICE from displaced vertices of electron candidates	Physics, Simulation	HD
4	Trigger requirements and settings for an efficient Dilepton trigger for J/ψ and Y resonance with ALICE	Physics, Simulation	HD
5	Development of a L0/L1 trigger for the PHOS detector in ALICE	Simulation, VHDL, C, Electronics	OS BE
6	Full scale slice test of ATLAS calorimeter trigger and its integration into the data acquisition and higher level triggers	Tests, Measurements	HD
7	Full scale slice test of ATLAS Readout Buffer and its integration into the data acquisition	Tests, Measurements	MA
8	Experimental investigation of ATLAS level-1 trigger performance based on signals form the liquid argon and tile calorimeter	Tests, Measurements	HD
9	Heavy quark production at LHC	Physics, Simulation	HD
10	Search for isolated electrons and photons at the LHC with special emphasis on level-1 trigger requirements.	Physics, Simulation	HD
11	2nd Level Trigger Algorithms for ATLAS	C, algorithms	MA
12	GRID based analysis of B decays, BABAR	GRID, simulation, physics	HD
13	Intelligent Monitoring of ALICE TRD subsystem	Analysis, Databases	HD
14	FPGA Coprocessor based High Level Trigger for ALICE	VDHL, C, algorithms	HD
15	Fast tracking algorithms for the ALICE HLT	Simulation	BE
16	LHCb track trigger: Data link and implementation	VHDL(FPGA), Algorithms, Simulation,	HD
17	Readout and data reduction for the LCHb tracking chambers	VHDL(FPGA), Electronics	HD
18	Development of an open charm trigger for CBM	Physics, Simulation	HD
19	High resolution intelligent TOF system for CBM	Microelectronics	HD
20	Electron ID with high rate TRD (CBM)	Physics, Microelectronics	HD
21	CBM: High rate online data processing	Strategy and technology	HD
22	CBM: High rate online data readout & processing	Architecture	MA
23	GRID – Data Management for Physics simulation	Software	HD
24	Reconfigurable computing networks based on integrated specialized processors	Architecture	MA

25	GRID Cluster operating system	Computer Science	HD
26	Programming, monitoring, and control of systems consisting of FPGAs, DSPs, and embedded CPUs	Software framework	MA
27	FPGA/Coprocessors: Integration of VHDL and C++ description	Software (VHDL, C++)	HD
28	FPGA/Coprocessors: Hardware/software co-design	Software (VHDL, C++)	BE
29	FPGA-Coprocessors: Programming in High Level Languages	CHDL, Handel-C, System-C	MA
30	Load sharing between FPGAs, DSPs, and embedded CPUs	Architecture, programming	MA
31	Kalman filter for FPGA co-processors	C++, VHDL	BE HD
32	Mixed mode electronics: ADC + Processor	Microelectronics	HD
33	Time discretising switched preamps	(Micro)Electronics	HD
34	High speed readout systems	(Micro)Electronics	HD
35	Radiation tolerant designs with commercial grade technology	VHDL, Electronics	HD
36	Low noise digital logic	Microelectronics	MA
37	High resolution, low power DLL circuits	Microelectronics	MA
38	Analysis of data from the INTEGRAL and POLAR satellites	Physics, Analysis	BE
39	Development of the next generation satellite based gamma and X-ray imaging systems	Physics, Simulation	BE
40	Reliable readout electronic and online data processing	VHDL, Electronics	BE OS
41	Si detectors for harsh environments (to be confirmed)	Microelectronics	OS
42	New integration methods for semi-conductor sensors and electronics	Physics, instrumentation	OS
43	New sensor materials for particle detection	Physics, electronics and materials	OS

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.

Germany	Norway	Topic
F. Eisele	B. Stugu	9
P. Fischer	B. Svensson	36, 37
N. Herrmann	B. Skaali	18, 20
V. Lindenstruth	D. Röhrich	14, 15
R. Männer	K Ullaland	26, 31
K. Meier	S. Stapnes	6
J. Stachel	T. Tveter	2, 3
U. Uwer	G. Eigen	12
V. Lindenstruth	H. Helstrup	21
P. Fischer	K. Broenstad	39
K. Meier	J. Stadsnes	38
J. Stachel	J. Nystrand	1, 5

The personal involvement of the participating researchers can be judged from the exemplary collaboration matrix above. Note that typically a researcher has at least two or three collaborating colleagues with common projects in the IRTG. We present only one example for simplicity. The research topic numbers are the indices of the table above.

4 Study Program

Participants of the graduate school 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.

The study program will have the following components which are discussed in more detail below:

1. An advanced regular lecture program (in english) covering basic courses in particle physics and astrophysics. These courses will be organised independently at Heidelberg and in Bergen/Oslo. If, however, a subject is only offered at one location, exchange lecturers will present such courses in a condensed format at the other location.
2. An exchange program between the institutions with two components:
   2.1 The offer of compact (lab) courses (1-2 weeks) allowing students to get special training which they cannot get at their home institute.
   2.2 Extended stays (3-6) months to visit research groups and participate in their research program working on a well defined mini project. Such a visit has of course to fit into the main thesis work and will in most cases be realised in the framework of common research projects
3. A lecture week every spring alternating between Heidelberg and Bergen/Oslo for members of the school. The lecture program will cover special advanced subjects in physics and instrumentation covered by both local and external lecturers. The week will also give students a platform to present and discuss their work.
4. A yearly international school on intelligent detectors combined with a 1 day topical conference in fall also alternating between Heidelberg and Norway. This program will be offered also to outside participants.
5. A bi-weekly graduate school seminar will be organised at every place by the students to have a regular meeting place. The program will comprise both internal reports and seminars by invited guests.

4.1 Regular advanced lectures

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

The following advanced lectures are planned to be offered regularly:

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

Most of these subjects are already offered regularly. In Heidelberg this is partly organised inside the graduate school of particle physics astrophysics and cosmology or it is part of the course program for advanced students.

In addition lectures will be offered on an irregular basis depending on demand in the areas:

- CP violation
- Hadron physics
- Space physics
- Digital signal processing
- Computer architectures
- Pattern recognition
- Data management
- Software engineering / modelling and simulation

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.

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, adtmitted to the IRTG will be admitted with topics that help to extend the international collaboration between the participating groups. The existing and future projects such as preparation work for a linear collider project (TESLA) or for the future GSI accelerators are ideal candidates here, as their timelines extend more than a decade into the future.

The exchange program will be based on two concepts:

1. The institutions will offer compact (lab)courses over periods of 2 to 3 weeks which are open also to foreign students to provide education and training which are important for their thesis work and career and which are not available at their home institutions. Typical examples for such courses are:

   - High speed ASIC design (with lab work) (Heidelberg)
   - High speed digital design (Bergen)
   - Si detectors and nano/microtechnology (Oslo)
   - Introduction to RHIC data analysis and rare signal simulation (Bergen)
   - Cluster and Grid computing (Heidelberg)

   Specifically, in Heidelberg we will offer the introduction to two classes of problems

   a) Hardware design
   b) Software modelling (C++)

   For both activities, we request the support of a PostDoc position each within the framework of the IRTG. The candidates for those positions are supposed to be actively involved in the research programs specified above, but to devote about 50% of their time to the definition and monitoring of the course activities. This includes startup help, installation of test benches.

2. The institutions will offer longer term stays for students to participate in their research program. Special expertise is available in Bergen and Heidelberg, for which a technology transfer is foreseen by extended exchange visits (periods of 3 to 6 month) of the participants. The second motivation for participating in the exchange visit program is the extension of the general knowledge of the problem class that the students are involved in, e.g. software oriented people will get the chance to understand the hardware level, 'designers' will be given the opportunity to understand the basic physics motivation that drives the effort, physics analysis can be complemented by a working knowledge of some design tools. It is this broad interdisciplinary education that helps physicists to successfully perform on the job market. Such an exchange will broaden the expertise and knowledge of the students. It will however normally also be done inside common research projects and only if the student and his mentor can expect at least a strong longer term benefit for the project.

   Typical examples of projects would be:
   - 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

We expect that in first years at least 50% of the students will participate in the exchange program and that this fraction will increase with time as we expect more common projects to start.

4.3 Lecture weeks

We plan to organise one lecture weeks per year in spring which are mandatory for all participants and where they live together at one place. One motivation for this is to strengthen the contacts and the coherence within the graduate school. The other one is to guarantee some minimal impact of the study program for every participant.

The lectures are held by internal and external lecturers on commonly interested subjects. All participating faculty member will represent their field of expertise (see appendix B) in regular intervals (typically once per 3-4 years). During this week also a good fraction of time will be dedicated to reports of students on their own work giving them a chance to express them selves and to get critical feedback to their work. This week is for participants only.

The lecture week will be organized alternatingly by the Heidelberg/Mannheim and Bergen/Oslo groups, one of the two weeks will happen every year in Germany and one in Norway, starting in Heidelberg, organized by V. Lindenstruth and followed by Bergen, organized by D. Röhrich.

4.4 Workshops, schools

Each year (in fall) a school will be organized as part of the outreach program of the IRTG. The school will combine lectures with a topical conference. The school will be open to the public, it will be advertised and we hope that at least 50% of the participants will come from outside. The program will consist of a series of lectures on advanced subjects by invited speakers and at the end by a one day topical conference on instrumentation covering recent results in the area. One important aspect of the school and topical conference is the outreach to the field in the local area. So far a corresponding program is not yet available neither in Heidelberg nor in Norway. However, the discussed program is an international extension of the "Heidelberg Graduiertenkurse", which have proven to be very effective and successful. Here a school is held for an entire week where students have the option to attend two classes – one in the morning and on ein the afternoon during the week. At this point more than 150 students participate in each school, where more than 50% are from outside Heidelberg.

The table below gives an overview of both the planned lecture weeks and schools for the first four years of the IRTG. The tentative organisers are listed as well:

Year	Type / Place	Topic	Organisers
2004 Fall	School / Heidelberg	Programmable hardware/hardware programming	Lindenstruth
2005 Spring	Lecture Week / Oslo	Introduction to Relativistic Heavy Ion Physics	Tveter
2005 Fall	School / Bergen	Fast pattern recognition	Roehrich
2006 Spring	Lecture Week / Mannheim	Pixel Detectors	Fischer
2006 Fall	School / Heidelberg	Frontieres of Particle Identification	Herrmann
2007 Spring	Lecture Week / Bergen	Introduction to Physics of and Beyond the Standard Model	Eigen
2007 Fall	School / Oslo	On-detector electronics and signal processing	Skaali

The program for the following years will be adjusted to the latest developments.

4.5 Biweekly Seminars

In order to train students presentation skills, biweekly seminars are organized locally. It is mandatory for all students to present their work either in case of an accepted presentation at a conference, or when he or she approaches the end of the thesis. Further at least one status report is expected from each student per year. The attendance of the seminar is mandatory. The seminars are complimented by external speakers. The external speakers are selected according to the demands or suggestions of the students. The responsibility for the proper organization of the seminars is rotating on a semester basis amoung the local professors.

4.6 Soft skill seminars

Soft skill seminars covering basic techniques like work organisation, team management, presentations and rhetoric will be offered on an irregular basis according to the need expressed by the students. The seminars will be given by external professional lecturers that specialize in the field and readily available at the participating universities.

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 will be announced worldwide. Candidates will be selected by an admission commission on the basis of the achievements of the diploma exams the originality and quality of the diploma project an oral presentation of the candidate about the diploma project (or equivalent).

The basic idea is to find candidates that show the necessary skills for the anticipated interdisciplinary work between experimental physics, engineering and informatics. This 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 will be given the chance to present themselves in front of the admission commission.

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.

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 (see section 4.5). 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 will be the acceptance of the doctoral thesis and the successful oral defense of the thesis according to the local rules of the participating institutions. The doctoral degrees will be issued by the parent institution in which the student is enrolled, according to the local rules. The IRTG will though help to support the mobility of the students, should they decide to continue their work at the partner institution, e.g. due to some interesting development during the project work phase. Joint thesis projects will be realized by admitting the mentor of the student into the examination commission at the university that is awarding the degree.

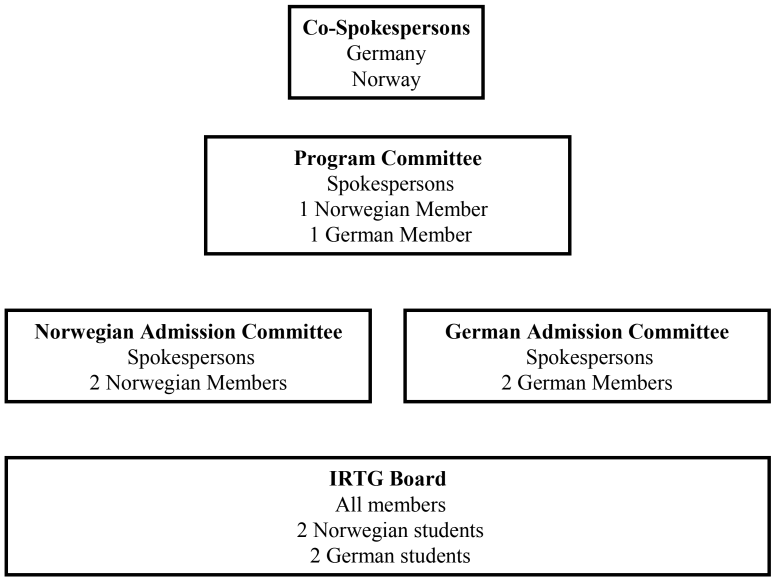
5 Visiting scientist program

Experts on various fields of physics, detector design, readout electronics and compute infrastructure will be invited to the different activities of the IRTG, as described above, according to the needs of the participants of the IRTG. The following is an exemplary list of candidates and lecture subjects, which have been discussed at the time of the writing of this proposal.

- Dr. A. Andronic — GSI — TRD Detectors
- Dr. R. Brun — CERN — Data Analysis
- Prof. Dr. C. Blume — Frankfurt — Detector Simulation
- Dr. P. Fonte — Uni. Coimbra, Portugal — ToF Detectors
- Dr. W.F.J. Müller — GSI — DAQ Concepts
- Dr. L. Musa — CERN — Detector Electronics
- Prof. Dr. A. Reinefeld — Berlin — GRID Computing
- Dr. V. Radecka — BNL, USA — Front-end Electronics
- Prof. Dr. H. Ritter — LBL, USA — QGP Physics at RHIC
- Dr. F. Sauli — CRN — Gas Detectors
- Dr. H. Simon — NERSC — Cluster Computing
- Prof. Dr. R. Stock — Frankfurt — HI Physics
- Prof. Dr. J.P. Wessels — Uni. Münster — TRD Physics
- Dr. H.Wieman — LBL, USA — TPC detectors
- Dr. C. Williams — CERN — ALICE ToF

6 Organizational Structure

The IRTG organization, sketched below, emphasizes 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 at least once a year during a lecture week or school.



The term of a spokesperson is two years. The initial 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 spoke spersons (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.

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), HERA (DESY), BABAR (SLAC) and SIS (GSI). They contribute major parts to the preparation of upcoming LHC experiments at CERN, ALICE, ATLAS and LHCb.

Significant contributions to the future heavy ion facility at GSI and especially to the design of the Compressed Baryonic Matter experiment (CBM) are planned. This is manifested in the participation to several Joint Research Activities as part of the I3HP initiative that has recently been awarded by the EU. Similar intentions exist for the preparation of the TESLA facility.

7.2 Available infrastructure at German institutes

7.2.1 Scientific personal

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

	Physikalisches Institut Heidelberg	Kirchhoff Institut, Heidelberg	Universitaet Mannheim
C4	2	2	2
C3	2	2	-
C1	2	1	2
BAT	6	6	4

7.2.2 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:

	Physikalisches Institut Heidelberg	Kirchhoff Institut, Heidelberg	Universitaet Mannheim
Electronics	8	12	0.5
Mechanics	20	8	

7.2.3 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.

The chair for circuit simulation is presently being set up. The infrastructure for chip design is fully available, and test environments will be available soon. These will include a fully automated wafer prober, environmental chamber and high speed digital and analog test equipment.

The faculty in Heidelberg hosts several CIP pools for student use and a Hardware Praktikum for lab courses and hands-on exercises. The figure left shows a picture of one of the available 12 seats. Each workbench features a PC with a PCI bus extender, a logic analyser, a DSO and an AWG signal source. For design courses the available CIP pools have all necessary software installed, including the complete Mentor and Cadence tool suite.

7.2.4 ASIC Laboratory at Heidelberg University[2]

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 Max-Planck-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.

The formation of the lab was initially driven by the demand for ASIC-based, highly integrated readout electronics employed in High Energy Physics' experiments, such as H1, HERA-*B* and ATLAS. This spectrum soon broadened to its present scope: The lab integrated the chips into the detectors, the development of optical sensors like CMOS cameras was started, chips for biomedical and molecular-biological applications were developed. Furthermore, the lab started to develop radiation hard electronics and chips with embedded microprocessors, both in commercial cutting edge deep sub-micron CMOS technology. Last but not least research with chips implementing genetic algorithms (i.e. evolvable hardware) is performed.

This evolution is also well represented by the personnel employed: Starting with 6 people in 1994, the head-count has grown to more than 30 scientists 2003.

Infrastructure

The ASIC lab consists of the two departments, i.e. design and test:

Theore of the design department is 7 UNIX servers (HP, SUN and Linux). The figure left shows part of this setup. The ASIC compute cluster is mainly used for simulation and verification tasks, while the less demanding applications, like schematic entry are performed de-central on smaller workstations and PCs, using the Cadence DFWII and MentorGraphics EDA software packages. Of these software packages, the lab owns about 30 license seats,

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

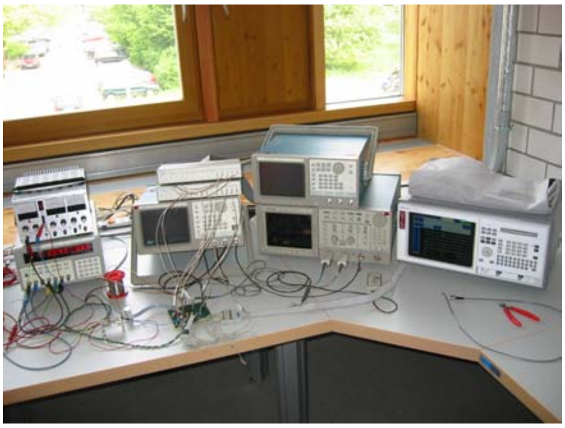
which together with the experience compiled by a number of senior designers, enables the lab to successfully develop analogue, digital and mixed mode ICs in any given technology.

The test department features a large variety of test and measurement equipment like high-speed DSOs (2.5GHz), logic and network analyzers, signal sources and power supplies. All instruments are pooled within the ASIC test laboratory and made available to all participating projects.

A clean room (figure right) is available for wafer handling, testing and medium-scale assembly. It is equipped with two (full-automatic Suss PM2000 and manual Suss PM60) wafer probe stations, an HP 82000 chip tester, an F&K Delvotek 6400 automatic bonder and an MEI manual bonder. This setup is essential for the next generation intelligent detectors as the trend clearly drives a tight integration of the electronics with the detectors. Already to date the electronics is typically mounted in form of multi chip modules in chip-on-board technology directly on the detectors and thus implementing the shortest possible signal paths while maintaining the smallest material contribution in the active area.

Projects

Among other projects, the lab has successfully developed a variety of chips, which are all being used in their appropriate detector environment: H1 VLQ, H1 CIPix, ADO (a temperature compensated quartz oscillator), FASTSAMP (a transient recorder) and HELIX128.



The current projects include readout chips for the ALICE TPC and TRD detectors, ALICE TRD Trigger, ATLAS L1 Calorimeter Trigger, the Beetle and OTIS readout chips for LHC*b*, a Retina Scanner (Hartmann-Schack wave-front sensor to measure the retina of the human eye), Electronic Visions (Opto-electronic sensors and evolvable hardware), DUNE (readout for a satellite borne dust telescope and a PeptideChip (a chip for molecular-biological synthesis). The figure shows as example a test set-up for the OTIS chip, which is mounted on a small PCB.

7.2.5 Electronics Laboratories at Mannheim University

The department has two electronics laboratories, fully equipped to develop large-scale hardware and FPGA processors up to small series production (several hundred pieces). Available are: 1) All software required to design and simulate digital and analog electronic circuitry, FPGA designs, PC boards, and systems. 2) All equipment to stuff and test prototypes. 3) All measurement devices and systems to electrically test PC boards and systems. 4) All software required to develop test software, operating software for the special-purpose processors, and application software including physics algorithms. The available infrastructure allow, for example, ten persons to concurrently develop FPGA-based ROB/trigger processors for ATLAS, and the 1st level trigger processor of HERA-B (this one alone about 200 boards). The computing infrastructure is excellent.

A state of the art design environment for FPGA and ASIC standard cell design and verifacation is maintained by the chair for computer architecture. A SUN-Cluster for the design tools is operated and some special LUNIX Servers are used for simulation services. A hardware lab with logic state analyzer and high speed sampling oszilloscope is available.

The chair for circuit simulation is presently being set up. The infrastructure for chip design is fully available, test environments will be available soon. These will include a fully automated wafer prober, environmental chamber and high speed digital and analog test equipment.

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.

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

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

Space Physics Group:
The INTEGRAL laboratory was established in connection with the development, prototyping, manufacturing and testing and delivery of flight quality subunits to the INTGRAL IBIS (Imager on Board Integral Satellite) Veto subsystem. It mainly consists of general equipment for detector prototyping and testing, miscellaneous gamma-ray sources, equipment for thermal cycling, equipment for development of electronics and PCB design, access to clean room, access to mechanical workshop.

The Space Physics group at Department of Physics, UiB, is establishing a laboratory with electron and ion beams of energies less than about 200 keV/unit charge. Detectors can be mounted inside the UHV vacuum chamber on a pedestal with 4 degrees of freedom. Most of the equipment is already acquired and partly assembled. A modest funding and some work still remains. The aim is to have the laboratory operational by end of 2004.

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

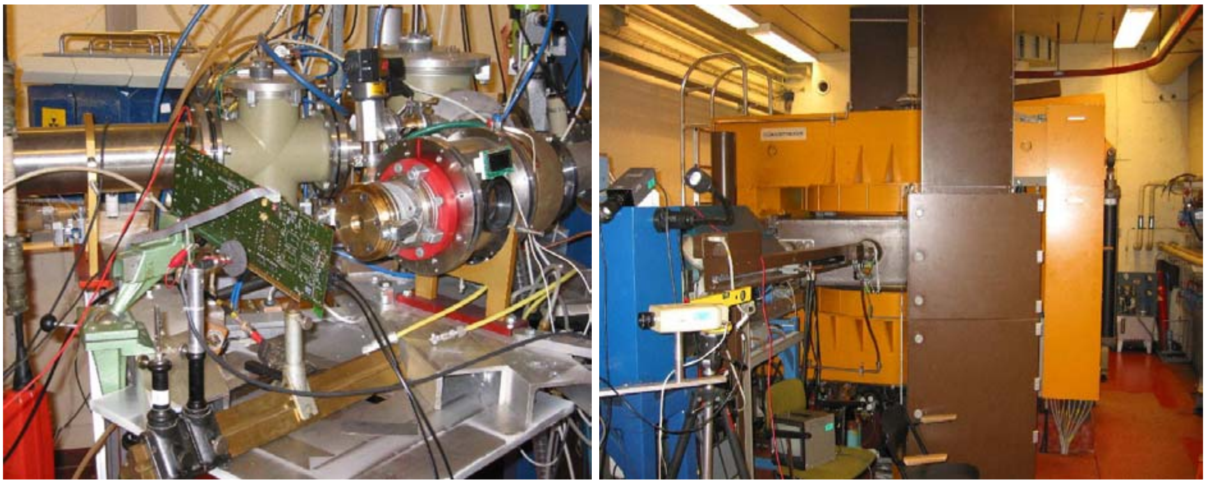
The Oslo Cyclotron Laboratory (OCL)

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 µA.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.

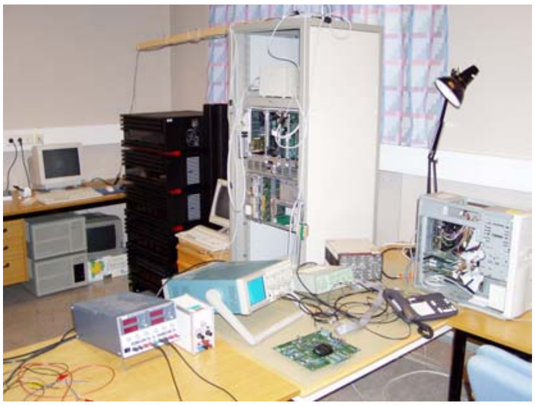


Left figure: Irradiation setup for electronic components. Right figure: The cyclotron.

Research group laboratories

The research groups for electronics, space physics, 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.



Current development projects include front-end and readout electronics for the PHOS and the TPC detectors of ALICE, in collaboration with groups in Germany, Russia, Bergen and CERN, and Si-detector systems and front-end electronics for the ATLAS Inner Detector.

The cleanroom

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

Computational physics

An advanced programme in Computational physics has been under construction the last year at the Department of Physics. Currently 10 courses are given, mainly for Master studies, but more advanced courses are being planned. The scientific programme is a collaboration between the Department and other university institutes and external institutions, like the Simula Research Laboratory which was established in 2001.

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. The inauguration will take place end September 2003.

NMCs core competence is the development of micro-components and complete instrumentation systems based on micro-components. The laboratory is equipped with a processing line for 6” 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.

The NMC will focus on research in joint projects with staff at the Department of Physics, University of Oslo. The research program is currently under definition. A project in “Advanced Sensors for Micro-Systems” has been proposed to the Norwegian Research Council, with project members from the University of Oslo and SINTEF. This project is a Strategic University Program (SUP) for the period 2003-2006 at the Department of Physics, University of Oslo. Two groups at the Department of Physics have been working on Si sensors for more than two decades; the Electronics groups and the Experimental Particle physics (EPP) group. In the Electronics group MSc and PhD students have been studying fundamental issues related to the detection of ionizing radiation using semiconductors, most of them in collaboration with the Department of Microsystems at SINTEF Electronics and Cybernetics. The EPP group has been working on applications of Si detectors for high energy physics experiments since the mid 1980's. The SUP addresses issues regarding the requirements and fabrication of novel sensors for operating in harsh environments. Two types of sensors are considered; (i) silicon detectors for ionizing radiation and (ii) high temperature silicon carbide gas sensors.

The CERN RD50 project – Development of Radiation Hard Semiconductor Devices for Very High Luminosity Colliders – complements the SUP summarized above. B.G. Svensson (Oslo) is coordinating the activity in "Defect / Material Characterization".

8. Funding

8. 1 Funding (German share)

8.1.1 Scholarships for PhD students

We ask for the support of 18 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 BatIIa positions. We intend to maximize the number of students participating to the projects and ask for each student the increased stipends.

Subtotal for 4.5 years:

Base amount	4,5 x 12 x 18 x 1.365€=	1.326.780€
Family support (estimated 20% of all students)	4,5 x 12 x 4 x 205€=	44.280€
Sum		1.371.060€

8.1.2 Postdoc positions

The postdoc positions are necessary to implement the unique and specific educational program of the IRTG, namely the installation of courses and project work making use of the most advanced design and analysis tools available today. The duties connected to the postdoc positions are detailed in section 3.2.

Postdocs in all the participating groups are payed according to BatIIa. 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 2 postdoc positions according to the BatIIa tariff.

Subtotal for 4.5 years:

Estimate	4,5 x 2 x 50.000 € =	450.000€

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.

i) Internal workshop
We base our funding estimate on the assumption that all the participants of the IRTG will participate in the mandatory internal 5day lecture week.

4.5 x (18 students + 12 faculty) x (350€ + 5x100€) = 114.750€

A flight from Frankfurt to Bergen costs 350€ (note all flights to Norway are included here), the estimate for housing and food is 100€/day (120 for Norway)

ii) Participation to the school activities:

4.5 x (18 students + 6 faculty) x (5x100€) = 54.000€

iii) External lectures
The cost for the invitation of an external lectures is estimated to 2000€ per 4day course.
We therefore ask for

4.5 x 3 x 2000€ = 27.000€

iv) Invited speakers at the topical workshops

4.5 x 5 x 1000€ = 22.500€

8.1.4 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 institutes.

i) Travel money for German students to Norway
Typically half of the participating students will visit the partner university once per year.

We therefore ask for
4.5 x 9 x 350€ = 14.145 €

ii) We expect visits of Norwegian students to the advanced courses and project work in Heidelberg. The cost is estimated to 400€/month/person. On average about 10 Norwegian students will spent about 3 month in Germany.

Therefore we ask:

4.5 x 10 x 3 x 400 € = 54.000 €

8.1.5 Support for visiting scientists

External experts will be invited according to the needs of the project and the students to the bi-weekly local seminars. This will happen at about every 3^{rd} time, i.e. 8 times/year. The total costs amounts to

4.5 x 8 x 1000€ = 36.000 €

8.1.6 Participation to international conferences

The students and the postdocs 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 20 x 1500 € = 135.000 €

8.1.7 Soft skill seminars

External professional lecturers will be hired for soft skill seminars that will be organized with a frequency of about one per year. The cost for these activities are estimated to

4.5 x 2000 € = 9.000 €

8.1.8 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 5000 € = 22.500 €

Most of the coordination overhead is expected to be carried out by the locally available staff and secretaries. The funds requested are for position advertising, invitations of applicants, etc.

8. 2 Funding (Norwegian share)

Total costs:
Stipends: 17120.00 kNOK
Running costs: 4003. kNOK (890 kNOK per year)

Cost sharing:
UiB: 4 stipends + 2000 kNOK
HiB: 1 stipend + 500 kNOK
UiO: 3 stipends + 1500 kNOK

8.2.1 Scholarships for PhD students
We ask for the support of 8 students for the Norwegian groups participating in the IRTG; 4 stipends from UiB, 3 from UiO and 1 from HiB:

UiB: 4 * 4 years = 4 * 4 * 535 kNOK = 4 * 2140 kNOK = 8560 kNOK
UiO 3 * 4 years = 3 * 4 * 535 kNOK = 3 * 2140 kNOK = 6420 kNOKHiB:
1 * 4 years = 1 * 4 * 535 kNOK = 1 * 2140 kNOK = 2140 kNOK

Sum: 17120 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.
i) Internal workshop
We base our funding estimate on the assumption that all the participants of the IRTG will participate in the mandatory internal 5 day lecture week:
4.5 x (8 students + 12 faculty) x (3000 NOK + 5x(1100+680) NOK) = 1071 kNOK

ii) Participation to the school activities:
4.5 x (8 students + 6 faculty) x (5x(1100+680) NOK) = 560.7 kNOK

iii) External lectures
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 = 67.5 kNOK

iv) Invited speakers at the topical workshops
4.5 x 1 x 10000 NOK = 45 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 4 x 3000 NOK = 54 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 10 German students will spent about 3 months in Norway:
4.5 x 10 x 3 x 10000 NOK = 1350 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 8 x 15000 NOK = 540 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 50000 NOK = 225 kNOK.

Appendices

A) Signatures

Approval by the rectors of the Universities of Heidelberg and Mannheim

The rectorate strongly supports the grant application to the Deutsche Forschungsgemeinschaft to establish an International Graduate School on 'Intelligent Detectors' together with the University of Mannheim, University of Bergen and University of Oslo.

In the case of a positive decision by the Deutsche Forschungsgemeinschaft 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

Universität Mannheim

For the applicants

German principal investigator

(Norbert Herrmann)

Norwegian principal investigator

(Dieter Roehrich)

B) Participants previous work in the field

To give a more detailed overview of the existing research program, the activities of the individual participating faculty members are described below. The various activities complement each other and form the basis for the interdisciplinary attempt to advance detector technology by linking it to modern IT concepts. As can be seen the existing projects match well the planned activities of the IRTG.

German participants:

Heidelberg

F.Eisele, U.Uwer (PI): H1, HeraB, LHCb, BABAR

The research concentrates on the study of rare decay modes of heavy b and c Quarks at the B-factory of SLAC and starting in 2007 at the large Hadron Collider (LHC) at CERN. The most challenging task is the precision measurement of the free parameters of the CKM matrix and their relation to CP violation. While the BABAR engagement concentrates on data analysis, the LHC-b tasks in the next 3 years concentrate on the development and construction of tracking detectors, readout electronics and the development of trigger algorithms. The data analysis at LHC and the access to the huge data volumes will be organised using GRID computing. This technique will be already tested and evaluated by us during the analysis of data from the BABAR experiment using the GRID center at Karsruhe. For the LHC-B experiment the group is in charge of constructing one third of the tracking (straw) detectors of the outer tracking system, to provide the radiation hard frontend electronics and the fast Gigabit link to transfer the data from the detector to the off detector electronics, and it will also work on fast trigger algorithms using the tracking detectors.

More specifically, the group develops a radiation hard 32 channel TDC which is included on the front end board. This is based on sizeable experience as the group has already delivered several large ASIC’s for high energy experiments (HERAB,H1, ZEUS experiment) in the last years . Events from the TDC are read out with a trigger rate of about 1 MHz. The digitized data is serialised and the transferred via optical fibres at a rate of 1.6 Gbit/s to large buffer boards, which sparsify the data and make them available to a huge farm of trigger processors which then take a next trigger decision within about 300 ms. It is planned to also use the tracking data to improve the signal/background ratio early in the data flow. We are going to develop fast filter algorithms for this task. In the farer future we plan to engage also in developments for a Linear Collider project in collaboration with DESY.

N.Herrmann (PI): FOPI, ALICE, CBM

The extraction of the properties of hot and dense nuclear media from heavy ion reactions requires the measurement of rare probes. The group is involved in experiments at 1-2AGeV at the SIS accelerator of GSI addressing the question of possible medium modifications of hadrons due to chiral symmetry of QCD by the measurement of strange particle close to the free nucleon nucleon production threshold. The rate capability of the experiment is extended by implementing FPGA based scanners for Flash ADC data readout with local hit recognition in DSPs to cope with production capabilities of 10^{-4}/collision. Analysis strategies are developed to reconstruct strange resonances with (Ξ–baryon) and without (Φ–meson) secondary vertex conditions.

A second activity is the modelling of the dedicated high pt electron trigger that is being built for the ALICE experiment at LHC making use of the tracking capability and the particle identification features of the Transition Radiation Detector. Its final task is the sufficient enhancement of events containing hard probes (J/Ψ, Υ mesons, thermal dilepton pairs, jets) probing the properties of the Quark-Gluon-Plasma under LHC conditions. The parameters of the 65000 CPU system (Lindenstruth, KIP) are being derived from detailed MC simulations that are performed in the ALIROOT C++ environment.

Both ingredients simulation and hardware development are necessary to define the specifications for the CBM (Compressed Baryonic Matter) experiment that is suggested for the future GSI program at an incident beam energy of 20-30AGeV. The most challenging task is the detection of charmed particles as probes for the conditions during the hot and dense phase of the reaction. Simulations that are currently being performed indicate that reaction rates of 10^7 interaction per second are necessary to achieve the reconstruction of a sufficient number of D and J/Ψ mesons. New concepts for detectors and detector readout are clearly necessary, to which the group is currently contributing in developing high resolution, high rate, high granularity TOF counters (RPC type).

V. Lindenstruth (KIP) ALICE, CBM

The research in nuclear and particle physics requires complex data readout and selection systems. For instance in case of the ALICE TRD data rates exceeding 15TB/sec are produced, resulting in the development of highly integrated massively parallel readout and signal processing systems. At higher data processing layers PC farms are typically deployed, as for example foreseen for the ALICE HLT or LHCb L1 Trigger. The GSI future program presents a combination of high requirements for event processing and throughput.

The main focus of the group is the application of computer science in the field of physics, in particular in high-performance trigger, tracking and readout systems. Amongst other projects, the group has developed a prototype PC cluster with 75 processors, processing events at rates close to 2 MHz, and has developed various high-performance tracking and online processing algorithms, which also use FGPA Coprocessors for the LHC experiments. In the area of microelectronics a very low power deep submicron tracking- and trigger processing chip was developed, integrating 21 10-Bit, 10 MHz ADCs together with four 120 MHz RISC Processors on one die, and incorporating more than 6 million transistors. The group is also developing an infrastructure for autonomous PC clusters, which are seen as building blocks for new GRID systems, as well as for high-performance higher layer trigger systems.

For CBM appropriate research and development projects have already started, which further the development of the existing projects that are centered around LHC.

K. Meier (KIP) ATLAS

ATLAS is one of the two major general purpose detectors currently under construction for the Large Hadron Collider (LHC) at CERN. It features large solid angle detection of leptons, jets and missing transverse momentum. Like all experiments at hadron machines a major challenge is to reliably detect the small cross-sections of electro-weak or new physics in the massive background of inelastic interactions mediated by the strong interaction among the protons and their constituents. The required data reduction is of the order of 6 to 9 orders of magnitude. A large fraction of this reduction has to be achieved at an input rate of 40 MHz and within a time frame of 2 microseconds dictated by the limited length of the data pipelines of the sub-detectors. This difficult task is handled by the level-1 trigger which is based on hardware implementations of complex pattern recognition algorithms.

The Heidelberg group at the Kirchhoff-Institut für Physik has taken over full responsibility for the so-called Pre-Processor of the ATLAS level-1 calorimeter trigger. This device receives about 8000 analogue channels from the ATLAS calorimeter and generates digital output data calibrated in time and transverse energy. The Pre-Processor is based on a couple of cutting-edge technologies like mixed-signal electronics, multi-chip module technology and high speed digital links. The Heidelberg group has finalized the design and prototyping of the Pre-Processor and will now concentrate on the spectrum of full system implementation to be operational at the first day of ATLAS data taking. The trigger is closely related to the physics analysis of ATLAS. This aspect will become more important in the years to come. The group will prepare itself well for physics analysis to profit from the substantial technical work carried out during the preparation of the ATLAS project.

J.Stachel (PI): CERES, ALICE

The group is involved in the CERES experiment at the CERN SPS and the ALICE experiment at the LHC in various hardware, trigger, software, and data analysis and physics studies. The physics interest is on the discovery and study of a new state of matter, the so-called quark-gluon plasma. Specifically, the probes we are investigating are hadron production, correlations and associated fluctuations, and electromagnetic probes in the low-mass sector to study modification of the light vector mesons and its association to the chiral phase transition and in the high mass section to the physics of the J/Ψ and Upsilon and of production of open charm and beauty. These are valuable probes of the deconfined state of matter.

In CERES the group has developed the Ring Imaging Cherenkov counters, their read-out electronics and a hardware electron trigger. Recently, the experiment was upgraded by a large TPC of a novel type - cylindrical with drift from a central high voltage cylinder to the outside cylinder covered with multi wire proportional chambers with cathode pad read-out. The group was responsible for the design of the TPC, the construction of the read-out chambers and the development and operation of the integrated read-out electronics. This involved in particular the development of two ASICs, a low noise preamplifier/shaper circuit (PASA), and a switched capacitor array. The group has developed the tracking software of the TPC, as well as the global tracking between all detectors.

In ALICE, the group is focussing on the TPC and the TRD. For the TPC, the group was responsible for the design of the read-out chambers and is now performing part of the construction of these chambers. The group is also responsible for the design of a charge-sensitive low noise PASA based on the experience gained in CERES. In the TRD, the group has designed the read-out chambers and is producing a large fraction of the total of 540 chambers. For the read-out of the detector a low noise custom PASA was designed, as well as the read-out boards and multichip modules that bring out signals of the 1.2 Million read-out channels. Also, the group shares responsibility for the control of the detector with the group of Prof. Lindenstruth and has responsibility for the detector services. J. Stachel is Project Leader of the TRD. Jointly with other collaborating institutes the algorithms for electron identification and tracking are being developed.

Mannheim

P. Fischer (LS): ATLAS Pixel, DEPFET, Xray-Pixel

The ATLAS pixel group builds one of the largest pixel detectors for the LHC. The development of the highly specialized front end-ASICs for the amplification, sparsification and buffering of the signals of 10^8 pixels has been a main activity of P. Fischer before he came to Mannheim University. Other fields were the development of readout ASICs for a novel type of semiconductor devices, the DEPFET, and the construction of a high resolution 'DEPFET Bioscope' for Xray autoradiography. Further areas were the development of counting pixel readout chips for the detection of X-rays, studies of various sensor materials (Si, GaAs, CdTl, Diamond) using these chips, the construction of a beam telescope using double sided silicon sensors, and a "photoscope" system for fast photon detection.

R. Männer (LIV): OPAL, CERES, HERA-B, ATLAS

The group has been involved in the development of special-purpose trigger processors for high-energy physics for three decades. Originally at the Physics Institute of the University of Heidelberg, the group focussed on problem-specific system software to speed up data taking (1975-1979), but switched then to the hardware setup of high-performance multiprocessors (1980-1985). For the CERES experiment, the group developed a systolic trigger processor consisting of 28.160 processing elements (1985-1989). This system, consisting of 440 ASICs occupying 1 m^2 board space, operated at CERN for many years. With the establishment of the "Lehrstuhl für Informatik V" at Mannheim University, the group grew to a department, part-times consisting of about 50 persons, split up into several groups:

The first group focussed on the development of hardware processors. They developed, together with Siemens/Munich the world's fastest neuro computer SYNAPSE (1988-1993), which was sold commercially by Siemens/Nixdorf. As a follow-up project, this group developed, together with DESY, the 1^{st}-level-Trigger of HERA-B (1993-2003). Via 1.500 glass fibers, this system reads in detector date at a rate of 1 Terabit/s, and tracks about 200 particles every 96 ns. The processor consists of about 100 special-purpose processors of size 36×40 cm^2 and the same number of smaller communication processors.

The second group of the department focussed on FPGA-based systems right after the first devices were commercially available. A first trigger processor using a Hough transform was developed for OPAL (1989-1992), before the department formally became a member of the ATLAS as well as the CMS collaboration at CERN. For two years the group designed an ASIC for the 1^{st}-level trigger of CMS, and an FPGA-based 2^{nd}-level trigger processor for ATLAS. However it turned out that participation in three large-scale experiments (HERA-B, ATLAS, and CMS) was not possible on the long run, and the department redrew from CMS. A number of FPGA processors were developed (1993-2003) for ATLAS, the latest of which will be used in the ATLAS readout buffer system (1.600 pieces).

The department also developed hardware and software systems for other applications (real-time volume rendering, real-time image processing, 3D reconstruction, virtual reality, etc.). Due to their orientation to practical applicability, the department spun off (1995-2002) six companies (Medical Communications GmbH, Silicon Software GmbH, Volume Graphics GmbH, VRmagic GmbH, Acconovis GmbH, and teas scribos GmbH), and two more are to be founded shortly.

Norwegian participants:

D. Roehrich, J. Nystrand (Nuclear Physics Group,UiB);
T. Tveter (Nuclear Physics Group, UiO): NA57, BRAHMS, ALICE

Exploring the nuclear-matter phase-diagram and identifying its different phases is one of the main challenges of modern nuclear physics. The fundamental endeavour is to understand at the various energy scales the properties of the nuclear interaction and its macroscopic manifestations. The focus of the research in the ultra-relativistic energy regime is to study and understand how collective phenomena and macroscopic properties, involving many degrees of freedom, emerge from the microscopic laws of elementary particle-physics. Specifically, heavy-ion physics addresses these questions in the sector of strong interactions by studying nuclear matter under conditions of extreme temperature and density. The most striking case of a collective bulk phenomenon predicted by QCD is the occurrence of a phase transition to a deconfined chirally symmetric state, the quark gluon plasma (QGP).

The experimental program to study ultrarelativistic heavy ion collisions includes participation in experiments at the AGS (E802/E859), SPS (NA35/NA49/NA57/WA94/WA97/WA98), RHIC (STAR, BRAHMS, PHENIX) and LHC (ALICE). Current activities focus on the production of multistrange baryons at SPS (NA57), strangeness production and stopping at RHIC (BRAHMS) and study of hard probes (pion and photon spectra at high-pt, jets, J/Ψ,Y, open charm) at ALICE .

Local expertise covers physics and detector simulations, data acquisition, cluster computing, trigger algorithms, fast TPC pattern recognition, fast event reconstruction, FPGA co-processor algorithms, data analysis and physics interpretation. The group has taken responsibilities in the ALICE High Level Trigger and the TPC and PHOS front-end electronics.

K. Ullaland: Satellite instrumentation, ALICE

At the Physics Department there is considerable experience in the development and use of radiation detectors and related discrete electronics. The work has traditionally been associated with research in high-energy physics and space physics (CERN- and ESA-related). Gradually over the past years, however, the department's industrial instrumentation research group, especially for applications within the oil industry, has also adopted the knowledge. This interdisciplinary tradition makes a firm foundation for a successful accomplishment of the proposed project. An important factor in this regard is the microelectronics laboratory.

Typically, an integrated detector system consists of sensors, preamplifiers, shaping amplifiers, and digital read-out electronics. Recently, a new development in integrated circuits has offered a new option to implement digital post processing: large, fast FPGAs (field-programmable gate arrays) with large internal memory blocks. Arbitrary digital circuits can be implemented in FPGAs, and they can be reconfigured within milliseconds at any point during use. FPGAs blur the boundary between software and hardware: they approach the performance of ASICs while maintaining the flexibility of programmable processors. The microelectronics activity includes design, simulation, production and testing of analogue and mixed analogue-digital VLSI systems. Sensor interface electronics is an important field. The Microelectronics group work in close cooperation with the Industrial Instrumentation group, the Space physics and the Subatomic physics sections. Common interests are development of fast, compact, low-effect and radiation-tolerant electronics for space crafts and rockets, and within the development of multi channel electronics for industrial instrumentation and high-energy physics. The group is involved, for example, in the development of the Readout Controller Unit (RCU) of the ALICE TPC-FEE and the FPGA co-processor for the ALICE HLT.

K. Brønstad, J. Stadsnes (Space Physics Group): INTEGRAL and POLAR

The INTEGRAL (International Gamma Ray Laboratory) mission is a ESA project dedicated to the fine spectroscopy and imaging of celestial gamma-ray sources. Gamma-ray bursts are one of the exotic and poorly understood phenomena that INTEGRAL was launched to investigate. They are by far the most powerful events known to occur since the Big Bang, and the mechanisms fuelling them are still unknown. Launched last autumn, INTEGRAL is designed to detect hard X-ray and gamma-ray sources in the energy range 15 keV-10 MeV. The satellite contains an imager and a spectrometer, plus X-ray and optical monitors. Gamma-ray sources are often highly variable, fluctuating on timescales of minutes or seconds, despite their size. This makes it crucial to record information simultaneously at different wavelengths. The Bergen group has provided hardware parts for the IMAGER instrument which will detect photons in the energy range from 70 keV to 10 MeV.

The Polar Ionospheric X-ray Imaging Experiment (PIXIE) is one of the instruments on board of the POLAR spacecraft. It is an electronic camera which images the earth's aurora in x-rays. The x-rays measured by PIXIE are generated when energetic electrons strike the upper atmosphere. By imaging these x-rays and measuring their energies across a broad energy range, PIXIE determines the fluxes and characteristic energies of the parent electrons. This information is used to determine other important characteristics of the ionosphere, and of the interactions between the earth's upper atmosphere, ionosphere, radiation belts, and magnetosphere. The Department of Physics was involved in the development of proportional chambers including readout electronics.

B. Stugu, G. Eigen (Particle Physics Group): BABAR, ATLAS

The group has taken part in the development of radiation hard silicon detectors for ATLAS. Detectors that will survive ten years of operation in the experiment have successfully been developed. Now we are in the production phase, and production detectors are tested in a clean room facility at the department of physics in Bergen. For the BABAR experiment there was participation in the development of the monitoring system for the CsI electromagnetic calorimeter. One of the group members is actively pushing the development of solutions for electromagnetic calorimetry for the detector at the proposed Next Linear Collider. The group plays a very active role in physics studies with BABAR data. In addition, simulation studies of physics in ATLAS have started. The group installed a small cluster of PCs connected to the NORDUGRID network and, in the future, we want to take part in the development of the facility and install and run software for physics simulations studies using the Grid.

H. Helstrup (HiB): NA57, ALICE

Modern relativistic heavy ion experiments produce complex events containing huge amounts of data. Analysis of such events produce computing challenges to achieve correct reconstruction of the particles produced in the collision, as well as more technical challenges in how to cope with the huge data volume within available computing and storage resources. Members of the technical computing group have major responsibilities in the development and application of the WA97/NA57 analysis chain, including track reconstruction and efficiency/acceptance corrections. The group is also involved in software development for

ALICE, both within High Level Trigger and in general analysis. The group is responsible for coordinating Norwegian GRID activities within ALICE.

B. Skaali (Electronics Group, Oslo): ALICE

The group has considerable experience in design and construction of detector electronics, starting with the LEP-DELPHI detector and up to the current PHOS and HLT/TPC ALICE projects. A major task is the coordination of the design and production of the complete front-end electronics and readout chain for the PHOS calorimeter – a novel high-resolution photon spectrometer for ultra-relativistic heavy-ion physics.

The group is now also focusing on new activities around the concept of reconfigurable technology, in collaboration with the Institute of Informatics and commercial companies. Hardware upgrades have so far mainly consisted of a substitution of a complete system or at least substitution of circuit boards. With the advent of reconfigurable hardware (FPGAs) one is provided with almost the same upgrade possibility as with software. As the semiconductor technology is shrinking, larger hardware systems can be integrated into a single device. Thus, System-on-Chip (SoC) devices are going to contain more and more complex processing units, memory and interfaces.

S.Stapnes (Particle Physics Group, Oslo): ATLAS

The Particle Physics Group is strongly involved in construction of the ATLAS silicon tracker. This has covered R&D for radiation hard silicon detectors, ASIC/hybrid design and testing, assembly methods for silicon modules and systems, low mass cooling and thermal management. Future research interests cover new sensors material, new integration methods for sensors and electronics, improved power and thermal management, and low cost semi-conductor detectors. All these goals are important for future trackers in High Energy Physics and also highly relevant for new medical imageing methods and systems. This work will be connected to the new Norwegian Nano- and Microtechnology Centre in Oslo, which is opening this year.

B.G. Svensson (Electronics Group, Oslo): Mircroelectronics

The new Norwegian Nano- and Microtechnology Centre in Oslo offers exciting possibilities for development and production of Microsystems. The Centre will focus on joint research projects with staff at the Department of Physics. The processing line for 6” wafers will be used for research, prototyping and production. The group is engaged in the project “Advanced Sensors for MicroSystems” that has been proposed to the Norwegian Research Council. The project addresses issues regarding the requirement and fabrication of novel sensors for operating in harsh environments, based on two types: i) silicon detectors for ionizing radiation, and ii) high temperature silicon carbide gas sensors.

C) Physics education in Norway

From 2003 forward, the educational scheme in physics at the Universities in Bergen and Oslo will follow a 3+2+3 sequence. This represents three years for a Bachelor of Science degree, two additional years for a master's degree, and a final three year Ph.D. study (four years if teaching obligations are included). The master's degree is a prerequisite for a Ph.D. study. The first 5 years are roughly equivalent to the German *Diplom.*

The regular doctoral programmes are based on— and are a continuation of the Norwegian graduate degrees, or an equivalent qualification. A doctoral programme consists of course work amounting to 1 semester study load, a major research period and the writing of a dissertation that has to be defended in a formal disputation. It takes 3 years or more to complete the doctoral degree.

Ph.D. students in Norway are considered employees and are paid full union wages. A Norwegian Ph.D. grant is therefore about NOK 535 000 (including overhead). Grants are given either by the Norwegian Research Council for three years as research project grants or by the Universities for 4 years (teaching obligations are included). Foreign students may compete on an equal footing for these grants. In addition, a scholarship scheme has been established by the Norwegian Ministry of Education and Research in order to facilitate access to higher education in Norway for students from Developing countries and Eastern Europe.

A successful implementation of this International Research Training Group will require additional 8 Ph.D. stipends. We expect that 4 stipends will come from the University of Bergen, 3 from the University in Oslo and 1 from the Bergen University College. Discussions with the Rector's office and Faculty Dean about the application procedure for the funding have started.

D) Current PhD students, topics and advisers of the German groups

The following PhD. students are currently performing their thesis work on topics that fit into the goals of the IRTG:

Name	Thesis topic	Adviser
U.Stange*	Development of a radiation-hard TDC chip	Eisele
M. Merschmeyer	Deep subthreshold Ξ- detection in HI collisions at 2 AGeV (FOPI)	Herrmann
L.Benabderahmane	Threshold production of Neutral strange particles in HI collisions (FOPI)	Herrmann
E. Cordier	Development of high resolution TOF system on RPC basis	Herrmann
R. Schneider	ALICE TRD Tracklet Merger	Lindenstruth
M. Gutfleisch	Fast signal processing in ALICE TRD and HLT	Lindenstruth
C. Reichling	High Performance multi port memories for embedded applications	Lindenstruth
T. Steinbeck	High Performance Cluster Communication framework for ALICE HLT	Lindenstruth
A. Wiebalck	Cluster RAID	Lindenstruth
F. Pister	GRID Fault Tolerance	Lindenstruth
R. Panse	Cluster Fault Tolerance	Lindenstruth
D. Atanasov*	TagNet Scheduling Unit for high-performance, high rate Trigger systems	Lindenstruth
G. Toralba	Torus Network Fault Tolerance	Lindenstruth
T. Krawutschke	Ethernet Protocol expansions for use as reliable data transport for detector control systems	Lindenstruth
A. Nesterov	Peptide Chip	Lindenstruth
A. Gröpl	The Trigger Decision Unit of the 1st-level triggers of HERA-B	Männer
C. Hinkelbein	Programming Framework for FPGA Processors	Männer
A. Kugel	FPGA Coprocessors in Trigger/DAQ of ATLAS	Männer
Y. Maoyuan	System integration of the FPGA based ATLAS Readout Buffer	Männer

M. Müller	ATLAS Readout System	Männer
A. Khomich	ATLAS 2^{nd}-Level Trigger Algorithms	Männer
O. Brosch*	FPGA Trigger Processor for FOPI / GSI	Männer
P. Meshkow	Construction and System Integration of the ATLAS Level-1 Pre-Processor	Meier
F. Foehlisch	Testbeam and Simulation Studies of the ATLAS Level-1 Trigger	Meier
S.Jourevich	Low mass electron pairs in 158 AGeV Pb-Au collisions	Stachel
J. Milosevich	Flow analysis in Pb-Au collisions	Stachel
W.Ludolphs*	Open charm in 158 AGeV Pb-Au collisions	Stachel
T.Mahmoud*	Development of TRD readout chambers	Stachel
D.Emschermann*	Signal processing and Readout of the ALICE TRD chambers	Stachel
J.Mercodo	ALICE TRD	Stachel
D.Wiedner	Radiation hard optical link based on CERN GOL including the link receiver	Uwer
M.Walter	Study of straw-detector performance under high-rate irradiation	Uwer

*Funded by the DFG Graduiertenkolleg GRK 36,
"Experimentelle Methoden der Kern- und Teilchenphysik"

E) Current PhD students, topics and advisers of the Norwegian groups

The following PhD. students are currently performing their thesis work on topics that fit into the goals of the IRTG:

Name	Thesis topic	Adviser
I. Ofte	Study of the inclusive radiative penguin process B -> X_s l+l- (BABAR)	Eigen
K. Fanebust	Hyperon production in Pb+Pb collisions (NA57)	Roehrich
J.I. Jordre	Strangeness production at RHIC energies (BRAHMS)	Roehrich
Z.Yin	High-pt pion spectra at RHIC (BRAHMS)	Roehrich
A. Vestbo	High Level Trigger (ALICE)	Roehrich
T. Vik	Fast Kalman Filter for the ALICE HLT (ALICE)	Skaali
A. Aksnes	Global mapping of energetic electron precipitation and atmospheric effects	Stadsnes
A. Åsnes	Study of onset and expansion of magnetospheric substorms	Stadsnes
T. Huse	ATLAS silicon detector construction and physics simulations (ATLAS)	Stapnes
H. Sandaker	ATLAS silicon detector construction and physics simulations (ATLAS)	Stapnes
B. Gjelsten	ATLAS physics and simulation studies (ATLAS)	Stapnes
L.G. Johansen	Radiation hardness studies of silicon microstrip detectors for the ATLAS-SCT (ATLAS)	Stugu
O. Øye	Development of a setup for ATLAS-SCT detector module testing/ Simulation studies of signatures for extra dimensions in ATLAS (ATLAS)	Stugu
B. Mohn	Simulation studies of Higgs production in ATLAS/ Quality tests of detector modules for the ATLAS-SCT (ATLAS)	Stugu
NN	Physics of defects/nanoclusters in high resistivity silicon for radiation detectors	Svensson
NN	Suitable gate dielectric fi SiC devices operating at high temperatures	Svensson

B. Samset	Particle production and stopping in RHIC collisions (BRAHMS)	Tveter
J. Lien	Readout Controller Unit for the ALICE TPC (ALICE)	Ullaland

F) List of publications of the participating German faculty members 2000-2003

Prof .Dr. F.Eisele, Physikalisches Institut, Universität Heidelberg

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By HERA-B Collaboration (I. Abt et al.). DESY-02-187, Nov 2002. 16pp.
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Paperback (December 1999) Springer Verlag; ISBN: 3540666966

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The H1 Project

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Fra Fysikkens Verden, nr 1-2003, s.5-6, ISSN-0015-9247

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