The International Research Training Group – Development and Application of Intelligent Detectors

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***Abstract*— The International Research Training Group (IRTG) "Development and Application of Intelligent Detectors" is a joint project between the universities in Heidelberg and Mannheim (Germany), Bergen and Oslo (Norway), and Bergen University College (Norway). The IRTG has 8 faculty members from German universities and 12 Norwegian members. The number of PhD students paid by the program or associated to the IRTG is 12 (Germany) plus 5 (Norway). About 20 additional students funded from other resources will participate in the educational activities of the IRTG.**

The IRTG on intelligent detectors aims at developing and applying detection systems for particle, nuclear and space physics that integrate modern information technologies. The design, building and operation of such detectors is the key for advanced nuclear and particle physics experiments. They require a profound knowledge in a variety of fields that is 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.

I. Introduction

The International Research Training Group (IRTG) "Development and Application of Intelligent Detectors" started in October 2004 as a joint project between the universities in Heidelberg and Mannheim (Germany), Bergen and Oslo (Norway), and Bergen University College (Norway). The anticipated duration is nine years. Regular lecture weeks and workshops organized by the IRTG guarantee the exchange of knowledge amongst the students but also between the scientists in Germany and Norway. The IRTG has 8 faculty members from German universities and 12 Norwegian members. The number of PhD students paid by the program or associated to the IRTG is 12 (Germany) plus 5 (Norway). About 20 additional students funded from other resources will participate in the educational activities of the IRTG.

The IRTG on intelligent detectors aims at developing and applying detection systems for particle, nuclear and space physics that integrate modern information technologies. The design, building and operation of such detectors is the key for advanced nuclear and particle physics experiments. They require a profound knowledge in a variety of fields that is 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 computing facilities (Cluster, GRID) that have to be considered an integral part of next-generation detector systems.

The IRTG combines the expertise that is available in Heidelberg/Mannheim with that in 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. These experiments are carried out at large, international accelerator laboratories such as CERN (European Laboratory for Particle Physics) on the border between Switzerland and France, GSI (Gesellschaft für Schwerionenforschung) in Darmstadt, Germany, and Brookhaven National Laboratory in the U.S.A. Similar techniques are employed for ground-based and satellite-based experiments in space physics.

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

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II. IRTG Profile

The focus of the IRTG is on ‘Intelligent Detectors and Detector Systems’. These exploit the latest developments in sensor technology and combine them with the latest advances in electronics and information science. The design and construction requires a combined knowledge of fundamental physics, electronics and information technology, and detector operation and data analysis. These three building blocks are outlined further below:

I) Fundamental physics like elementary particle, nuclear, and space physics is one of the major driving forces for the advancement of 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 to the fundamental physics properties of the system. The necessary data rates for many future experiments are so high that the electronics and the data processing have to be considered an integral part of the detector systems. The sensors converting physical observables into 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 their 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 IRTG aims to link the 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 are represented by the participants of the IRTG. The experience gained during the development and the operation of those systems is essential for success of the next-generation development. The evaluation of the performance of the running systems constitutes another important verification step for 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 IRTG aims at linking these building blocks, namely the experience with running state-of-the-art detectors and information processing systems to arising future needs, the physics requirements to possible detection system performance and the 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 disciplines required for the research and developments within the framework of the IRTG are:

- Nuclear Physics
- High Energy Physics
- Space Physics
- Detector Physics
- Sensor Technology
- 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 over ASIC design and FPGA applications to hardware/software co-design and computing infrastructures.

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 IRTG makes 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

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 their thesis work. This has the advantage of minimizing the risk for failure inherent in any 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 are chosen in such a way that they will be in the main scientific focus of two principle investigators, one in Germany and one in Norway. 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. The students participating in the IRTG obtain a broad education ranging from basic physics to modern IT techniques.

III. IRTG Research Program

The research program emerged from an existing collaboration between Heidelberg and Bergen. The IRTG has extended this fruitful exchange between Heidelberg/Mannheim and Bergen/Oslo to

a) full coverage of all stages of modern intelligent nuclear/particle detection system design and operation, including physics simulation, detector construction, system integration, readout design, development and operation, offline data analysis, and GRID computing

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

All of the research subjects are embedded into international collaborations, with normally more than 100 international researchers participating in a single experiment. Two examples of this are the ALICE experiment at the Large Hadron Collider at CERN and the BABAR experiment at Stanford Linear Accelerator Center in Stanford, California.

The ALICE collaboration consists of more than 1,000 scientists from 28 different countries. Its aim is to search for a new form of nuclear matter, which is believed to have been present in the very early universe, a few microseconds after the Big Bang. The experiment is currently under construction and is expected to begin operations in the year 2007.

The goal of the Babar experiment is to investigate the asymmetry between matter and anti-matter at the most fundamental level. This is achieved by studying the production of B-mesons in electron-positron collisions at high energy. Babar has been collecting data since 1999 and involves around 300 scientists.

It is expected that the ideas and experience with the existing devices will result e.g. in leading contributions to a proposal for the Compressed Baryonic Matter (CBM) experiment at the future FAIR facility (GSI). 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.

IV. IRTG Study Program

The main components of the IRTG Study Program are advanced regular lecture programs, exchange programs between the institutions, lecture weeks, and a yearly, international school on intelligent detectors.

The members of the IRTG will participate for a minimum of two semesters in general advanced lectures, which will cover Basic Physics, Experimental Techniques and the Informatics Aspects. These courses are organized independently in Heidelberg, Bergen, and Oslo. The lectures are fully integrated into the teaching activities of the faculties and the time spent is fully accountable as part of the teaching duties.

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, admitted to the IRTG are admitted with topics that help to extend the international collaboration between the participating groups. 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 visits (3 to 6 months) of the participants. The institutions will also 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.

A lecture week, mandatory for the participants and where they stay together at one place, is held every year, usually in the spring. The lectures are given by internal and external lecturers on subjects of common interest. All participating faculty member will represent their field of expertise in regular intervals (typically once per 3-4 years). During this week, a good fraction of the time will be dedicated to reports of students on their own work, giving them a chance to improve their presentation techniques and get critical feedback on their work. The lecture weeks are alternating between Heidelberg/Mannheim and Bergen/Oslo.

Each year, usually in the fall, a school is organized as part of the outreach program of the IRTG. The school combines lectures with a topical conference. The school is open to the public, and the goal is 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 brief 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 has 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 in the afternoon during the week. At this point more than 150 students participate in each school, where more than 50% are from outside Heidelberg.

V. IRTG Activities 2004 - 2006

Since the start in October of 2004, the IRTG has organized three lecture weeks/schools/workshops, and has financed the visits of several students and faculty members to the participating institutions.

The first workshop was held in Bergen in March/April of 2005. It consisted of two parts. The first part coincided with the second workshop in a series on the "Critical Point and Onset of Deconfinement" in heavy ion collisions. The number of participants was about 70, half of them members of the ITRG and half from outside. The focus of the workshop was on phase transitions in nuclear matter and what heavy-ion collisions can tell us about them and about the phase diagram of nuclear matter. The lecturers included some of the leading experts in the field.

The physics workshop was followed by a topical workshop on "Advanced Instrumentation for Future Accelerator Experiments", aimed primarily at the students of the IRTG. Of the 17 lecturers, 4 were from the IRTG and 13 were invited experts from outside.

In September of 2005, a lecture week on "Programmable Hardware and Hardware Programming" was held at the University of Heidelberg. The lectures covered the fundamentals of hardware design and VLSI design, using the hardware design language VHDL as example. The lectures held in the morning were followed by practical work in the electronics laboratory in the afternoon. In the laboratory, the theory from the morning sessions was practised. The students had the chance of developing and making their own designs, which were translated into hardware using the appropriate tools. This combination of theory and practice, in which the excellent lab facilities of the Kirchhoff-Institut für Physik were used, was much appreciated by the students.

A second lecture week was held in March of 2006 at the University of Oslo. The meeting provided an introduction to high-energy particle and nuclear physics. Of the 8 lecturers, 4 were from the IRTG and 4 were invited experts. The lectures were held in the morning, and the afternoons were devoted to student presentations. Each PhD student, who had been active for more than one year, was required to give a 30 min. presentation of his/her work at the workshop. There were a total of 13 student presentations at the meeting.

Several students from Heidelberg have been visiting Bergen for typically 2-3 weeks. One postdoc from Heidelberg has stayed in Bergen for a longer period of time (1 year). Unfortunately, the number of Norwegian participants travelling to Germany has been lower than anticipated and should be increased in the future.

VI. Conclusions and Outlook

The first 18 months of the IRTG on Development and Application of Intelligent Detectors must be characterized as highly successful. Three meetings have been organized, and the visits to the partner institutes by students and faculty have been highly valuable. The meetings have been appreciated by the students, who have participated in them.

One important reason behind the success is probably that the IRTG was formed with existing, established research groups as basis. Although the School has added significantly to the quality of the graduate teaching at the participating institutes, it has not lead to any fundamental changes in the underlying principles of how PhD students are educated. The changes have rather widened the scope of the existing PhD programs, which are all based on work performed within strong research groups, at the forefront of science and current technology.

A postdoc has been hired within the framework of the IRTG. It is foreseen that he will spend considerable time in Bergen to start-up new activities related to the CBM project at GSI. In the fall of 2006, a workshop on "Frontiers of Particle Identification" will be organized in Heidelberg. This will be followed by a lecture week on data acquisition and on-line computing at the University of Bergen in the spring of 2007. In the fall of 2007, a workshop is planned, where the commissioning and hopefully also first results of the Large Hadron Collider at CERN will be discussed.

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