CERN-Related Research Programme in Norway
2006-2011

June 30, 2003
Foreword

In the summer of 2002 the Norwegian Research Council invited the CERN-Related research groups to present a scientific strategy document for the period 2006 to 2011 corresponding to a budget envelope of 15 MNOK per year.

The following document, which is the answer to this request, has been produced by the project leaders of the present and future projects in consultation with the project members and international colleagues. It is based on present activities and reasonable expectations for the future evolution of the research field and its infrastructure.

About this document

Part I of this document is self-contained and is intended for readers without a particular knowledge of physics. It starts with a popular scientific introduction followed by an administrative introduction together with a proposed yearly budget for the different activities. Summaries of the four proposed research projects are given.

The four chapters in Part II are meant for the more interested readers and would be particularly useful in the case the document will be the subject of an expert evaluation. Each of these chapters is dedicated to one of the proposed future projects and gives details of present and future activities and how they will be organized. The transition from the present budget period and project organization to the next is also detailed, and some thoughts concerning the period after 2011 are presented.
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Part I

Summary
Chapter 1

CERN-Related Research Programme in Norway 2006-2011

1.1 Scientific Introduction

High energy physics concerns the study of the fundamental constituents of matter, the forces between them and the manifestations of their collective behavior. The study of the constituents has in recent years been based on the use of colliding particle beams, which for the LEP accelerator consisted of circulating bunches of electrons and anti-electrons (positrons), and for the future Large Hadron Collider (LHC) accelerator will consist of oppositely circulating bunches of protons. For the study of collective phenomena, heavy nuclei up to lead are accelerated and are collided against a fixed target made of a heavy metal (SPS, CERN), or again using colliding beams of heavy nuclei (RHIC, Brookhaven). The LHC accelerator will also be used for beams of heavy nuclei, often called ions, and will produce head-on collisions at unprecedented energies.

In our present understanding the physical universe can be described by six fundamental quarks and leptons. The leptons are the electron and two heavier electron-like particles, the muon and the tau in addition to three neutral and very light neutrinos. The two lightest quarks together with the electron and the lightest neutrino are sufficient to describe all the stable matter in the Universe, while the other quarks and leptons were present in equal abundances at the first instances of the Big Bang and can today be observed and studied in high energy reactions. Quarks and leptons are governed by three forces or interactions, the electromagnetic, the weak and the strong interaction, mediated by force carriers. On the present experimental level for the microscopic scale only these three interactions are needed, even though on a macroscopic scale also the gravitational interaction is needed. A theoretical framework, called the Standard Model (SM), which describes all the interactions between quarks and leptons and the force carriers, was developed in the late sixties and early seventies. Through extensive experimental precision measurements, in particular at LEP, the model has now been developed into a perfectly consistent quantum field theory. The Standard Model, which is the ultimate result of a long period of progress in high energy particle physics, describes all physical processes in terms of the strongly and weakly interacting quarks and weakly interacting leptons where the quarks and leptons are grouped pairwise into three generations, successive copies of each other higher up on the mass ladder. That there are three, and only three, such generations was proved at LEP, however, why there are just three,
remains a mystery. Perhaps the biggest success of the Standard Model is the unification of the electromagnetic and the weak forces into the so-called electroweak force, a success comparable to the unification of the electric and the magnetic forces into a single electromagnetic theory by J.C. Maxwell in the 19th century. The Standard Model is a consistent and in principle computable theory, and in spite of extensive precision testing of its numerous predictions no flaw nor inconsistency has been observed so far. Precision measurements at LEP led to the prediction of the top quark mass, the heaviest quark, with a mass out of reach for LEP, but which was later found with the predicted mass at Fermilab. The LEP measurements also points to the Higgs particle, a necessary, but so far unobserved ingredient of the Standard Model, with a predicted mass just at, or outside the energy range of LEP. Since it was not observed at LEP, its discovery is one of the most important goals of future high energy experiments.

In the Standard Model the Higgs particle is responsible for giving masses to the fundamental particles, and its observation would complete the Standard Model puzzle. However, the Standard Model is incomplete. As already mentioned it does not explain the number of particle generations nor the particle masses. In fact among the largest unanswered questions in the model are the large variations in the masses of the constituent particles and in the strengths of the various interactions, together with the enormous mass difference between the Higgs particle(s) and the electroweak force carriers, $W^+$, $W^-$ and $Z^0$ on the one side and the natural Planck scale (the mass scale at which the gravitational energy of a system becomes comparable to the total mass energy) on the other. In the case that the constituent quarks and the force carriers as well as the Higgs particle(s) are not composed of more fundamental objects, these problems may be understood if the Standard Model is a low energy approximation of a larger symmetry unifying all the forces and constituents. Only one such symmetry is known, namely the so called SUSY or Super Symmetry. SUSY requires the introduction of the graviton or the gravitational interaction thus raising the possibility of unifying gravity with the other forces.

The gravitational interaction must play a role at the highest energy scales, and attempts to combine general relativity with quantum mechanics, the two pillars of modern physics, have led to ”string theories” as the only solutions. In these theories two dimensional strings are the fundamental objects, moving in a microscopic space with seven extra dimensions, and very interestingly these theories are consistent only if they are made Super Symmetric.

This is a very strong argument in favour of SUSY. However, SUSY postulates the existence of a supersymmetric partner to every known constituent particle and force carrier, and since such particles have not yet been observed, they are either too heavy and thus out of reach of present day accelerators, or the theory is wrong.

On the other hand supersymmetric particles are the best, and so far the only, candidates for solving one of largest mysteries in astrophysics, namely the problem of dark matter in the universe. It is observed that the amount of matter is at least six times larger than the amount of ordinary matter. This unknown form of matter seems to have only gravitational interaction. SUSY particles are predicted to be very weakly interacting, and if they are also heavy, they would cluster around galaxies and in galaxy clusters and give a perfectly consistent explanation of the dark matter problem.

The possible existence of SUSY particles will in all likelihood be proved at the LHC. On the other hand, if the theory is wrong, and if the constituent particles and force carriers are composite, also this should be observed at the LHC.

Another mystery in astrophysics is the total absence of antimatter in the observable uni-
verse. This is known as the problem of matter - antimatter asymmetry, or CP asymmetry. In high energy experiments it is observed that matter is created from energy together with an identical amount of antimatter. However, in order to explain the amount of matter in the universe, the early universe must have had an excess of matter over antimatter to about one part in a billion. The Standard Model predicts a very small CP asymmetry. However, this asymmetry, which has been observed, is far below the one part in a billion needed to explain the amount of matter in the universe. Several ongoing experiments dedicated to the study of CP asymmetry have not come up with a definitive answer, and it is again hoped that the LHC experiments will provide answers to this problem.

On this background it seems inevitable that the LHC experiments will provide new clues leading to a more complete understanding of the material universe. Optimists even hope that these experiments will make observations pointing to an ultimate theory which unifies all the fundamental forces and constituents of the material universe.

We still know little about the properties of nuclear or hadronic matter, i.e. matter that is composed of quarks and bound by the strong force - one of the fundamental forces in nature. Thus our knowledge about protons and neutrons, the constituents of the nucleus which make up more than 99.9 % of the visible mass of the universe, remains rather sketchy. Even if we know what the basic building blocks of the universe are, we still have a long way to go until we can describe the complex properties of matter and its various manifestations.

Nuclear matter is only one possible manifestation, other phases might exist in the interior of neutron stars. At very high densities and temperatures, the nucleons are expected to dissolve into their constituents and to form a plasma consisting of quarks and gluons - the so-called quark-gluon plasma. Such a phase transition from the quark-gluon plasma into hadronic matter, i.e. into our present-day matter, took place in the early universe, about 1 millisecond after the Big Bang.

But how can high enough temperatures and energies be generated in the laboratory to release the quarks from their hadron cages? By smashing heavy ions together at very high energies large amounts of energy are squeezed into a very small space. This should free the quarks and the gluons into a small bubble of quark-gluon plasma - a new state of matter. In this state, quarks could freely roam over long distances instead of being confined within "bags" of the size of a nucleus, as they are in ordinary nuclear matter.

Exploring the nuclear-matter phase-diagram and identifying its different phases is one of the main challenges of modern nuclear physics. The fundamental endeavor is to understand at various energy scales the properties of the nuclear interaction and its macroscopic manifestations. At low energy densities, hadronic bound states are the degrees of freedom of nuclear matter. At higher energy densities, the degrees of freedom are quarks and gluons, interacting via the strong force.

The equation of state (EOS) of nuclear matter determines the dynamics of heavy-ion collisions and stellar processes, such as supernovae explosions. The compressibility characterizes the ability of nuclear matter to withstand the gravitational pressure. It also defines the maximum mass a neutron star can sustain prior to collapsing into a black hole. This is the motivation behind the exploration of the EOS at 2-5 times the ground-state density and non-zero energy density. In this region, the EOS is governed by the in-medium properties of baryons and mesons.

The focus of the research in the ultrarelativistic energy regime is to study and understand how collective phenomena and macroscopic properties 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 Quantum Chromodynamics (QCD) is the occurrence of a phase transition to a deconfined state, the quark-gluon plasma (QGP).

Even before QCD was established as the fundamental theory of strong interaction, it has been argued that the mass spectrum of resonances produced in hadronic collisions implies some form of critical behaviour at high temperature and/or density. The subsequent formulation of QCD led to the suggestion that this critical behaviour is related to a phase transition. The existence of a phase transition to a new state of matter, the Quark-Gluon Plasma, at high temperatures has been convincingly demonstrated in theoretical calculations (Lattice QCD).

Nuclear matter exists in different phases as function of temperature and density. The liquid phase is realized in atomic nuclei at zero temperature. At low densities, the nucleons behave like a gas. As the temperature is raised, the nucleons are excited into baryon resonances and quark-antiquark pairs (mesons) are produced. At higher temperatures, a phase transition from hadronic matter to quark-gluon matter takes place (deconfinement). The transition temperature is about 170 MeV (at net baryon density zero). Such conditions did exist in the early universe a few microseconds after the big bang and can be created in heavy-ion collisions at ultrarelativistic energies as provided by the accelerators SPS (CERN), RHIC (Brookhaven) and the future LHC (CERN).

1.2 Administrative introduction

1.2.1 The period 1998 to 2005

Prior to 1998 the Norwegian CERN activities were part of the ”Kjernpar” programme under NT. In 1997 it was to decided to discontinue the programme and to transfer the responsibilities for the activities to the Natural Science Faculties at the Universities of Bergen and Oslo. As a result the Norwegian CERN activities have since 1998 been organized in four projects, Particle Physics Analysis, Heavy Ion Physics Analysis, ATLAS Construction and ALICE Construction. ATLAS and ALICE are two large experiments being build by institutes from all over the world for the new CERN accelerator, LHC, which is expected to start in 2007. The high energy physics community is organized inside the Particle Physics Analysis project and is also responsible for the ATLAS Construction, while the nuclear physics community is organized inside the Heavy Ion Physics Analysis project and is also responsible for the ALICE Construction. The two analysis projects also contain part of the Norwegian Theoretical Physics community. A total budget envelope of 99 MNOK was granted for the 8 years 1998 to 2005 in addition to 16 MNOK from the Advanced Equipment pot. In reality another 7-9 MNOK has been added by extra funding to cover ATLAS/ALICE (4.1 MNOK), International Committees (2.4 MNOK), Technical Students (1-2 MNOK) and price compensation on salaries (1-2 MNOK). The average budget has therefore been around 13 MNOK/year. The total budget has been split between the projects as follows: ATLAS (42%), ALICE (22%), Particle Physics Analysis (21%) and Heavy Ion Physics Analysis (15%). Taken together about one third of the funds have been contributed to the LHC experiments, one fourth to student grants, post-docs and engineers, and the rest to travel, exploitation and local infrastructure.

In spite of a rather restricted budget the experience with the relatively long project period of 8 years has been mostly positive. It has given the projects flexibility, improved planning,
better possibilities for communication and scientific collaboration and greater influence in personnel matters. On the negative side has been the lack of price indexations on the materials and running budgets. This has certainly contributed to the tightening of the budgets. However, it should also be noted that the Research Council has been instrumental in providing solutions for the final financing of the large construction projects ATLAS and ALICE where the participants are morally and contractually responsible for parts of the equipment.

The total output of candidates within the CERN-related research programme in the present budget period (up to 2003) is given in Table 1.1.

<table>
<thead>
<tr>
<th>Candidates</th>
<th>HE Particle Physics</th>
<th>HE Nuclear Physics</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Scient</td>
<td>7</td>
<td>12</td>
<td>19</td>
</tr>
<tr>
<td>Cand. Scient</td>
<td>30</td>
<td>24</td>
<td>54</td>
</tr>
<tr>
<td>College Projects</td>
<td>12</td>
<td>18</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td>49</td>
<td>54</td>
<td>103</td>
</tr>
</tbody>
</table>

Table 1.1: Candidates within the CERN-related research programme in the present budget period (up to 2003). HE Particle Physics includes ATLAS and particle theory candidates, and HE Nuclear Physics includes ALICE and nuclear theory candidates.

The overall scientific production for the projects are given in Table 1.2.

<table>
<thead>
<tr>
<th>Publication</th>
<th>HEPP</th>
<th>HENP</th>
<th>Grid</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articles in refereed journals</td>
<td>239</td>
<td>135</td>
<td>17</td>
<td>391</td>
</tr>
<tr>
<td>Talks at int. conferences</td>
<td>37</td>
<td>192</td>
<td>12</td>
<td>241</td>
</tr>
<tr>
<td>Outreach (publ. talks, TV, Radio, others)</td>
<td>153</td>
<td>22</td>
<td>5</td>
<td>180</td>
</tr>
<tr>
<td>Total</td>
<td>429</td>
<td>349</td>
<td>34</td>
<td>812</td>
</tr>
</tbody>
</table>

Table 1.2: Overall scientific production for the CERN-related research programme in the present budget period (up to 2003). Talks at conferences include published talks. In addition two books have been published by project members.

### 1.2.2 The period 2006 to 2011

While the present contract period for the ATLAS and ALICE construction ends in 2005, new contracts are being signed for the period 2006 to 2011. It is therefore natural to define and agree on future Norwegian activities for the same period. The Norwegian community (the 35 experimentalists, theorists and engineers with fixed positions listed in Chapters 2–5) has decided to organize its activities in four projects; High Energy Particle Physics, High Energy Nuclear Physics, Advanced Instrumentation, and Norwegian LHC Computing Grid. The two physics projects will mostly be devoted to harvesting the fruits of the investments in the two large experiments ATLAS and ALICE which are expected to start data-taking in 2007. The development and construction of equipment for the two experiments, mostly based on very advanced technology, has led to contacts and collaboration with instrumentation groups and technological institutes. Some of these activities will continue with the completion and later maintenance, operation and possible upgrades of the experiments, but it is also foreseen that there will be a continued interest and participation in future research and development
(R&D) for electronics, information technology and detector technology. These activities will be organized in the Advanced Instrumentation project.

The analysis of the enormous amounts of data from the LHC experiments will be done within the new concept of a world-wide computing grid (often shortened to grid), which is now being developed. Norwegian physicists have already made very valuable contributions, and it is expected that a first running version of a world-wide computing grid will be operational at the time of the LHC start-up.

At present it is difficult to predict how this activity will evolve far into the project period. However, the computing challenges for the enormous amounts of data coming from the LHC experiments, will certainly be pushing the IT technologies and will lead to new developments and solutions. Both in the interest of the experiments and in order to take part in future developments it is important to be active partners in this work.

1.3 Budgets 2006-2011

Table 1.3 represents a summary of the yearly average figures in kNOK of the budget figures presented by the projects.

<table>
<thead>
<tr>
<th>Project</th>
<th>Running Cost &amp; Hardware</th>
<th>Stipends</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Energy Particle Physics</td>
<td>4265</td>
<td>2300</td>
<td>6565</td>
</tr>
<tr>
<td>High Energy Nuclear Physics</td>
<td>3890</td>
<td>2300</td>
<td>6190</td>
</tr>
<tr>
<td>Nor. LHC Computing Grid</td>
<td>2200</td>
<td>650</td>
<td>2850</td>
</tr>
<tr>
<td>Advanced Instrumentation</td>
<td>400</td>
<td>825</td>
<td>1225</td>
</tr>
<tr>
<td>Committees and outreach</td>
<td>250</td>
<td></td>
<td>250</td>
</tr>
<tr>
<td>Total</td>
<td>11005</td>
<td>6075</td>
<td>17080</td>
</tr>
<tr>
<td>Additional stipends</td>
<td></td>
<td>5800</td>
<td>5800</td>
</tr>
</tbody>
</table>

Table 1.3: Summary of the yearly average figures in kNOK of the budget figures presented by the projects. The stipends below the total must be financed outside the budget of this programme.

The running cost includes instrumentation, computing, commissioning of ATLAS and ALICE, travel and subsistence, R&D for future projects, Theory and estimated cost overruns for the present ALICE and ATLAS construction projects (5.6 MNOK).

Additional expenses for committee and outreach work amount to around 250 kNOK per year. The figures do not include items not related to the scientific activities of the project members such as support to the technical student programme at CERN (estimated to be 750 kNOK/yr), an Industrial Liaison Officer (ILO, 0.8 kNOK/yr), nor the expenses incurred by the Research Council when overseeing the scientific activities (i.e. delegates to the CERN Council and meetings of CERN Resource Review Board, ~ 250 kNOK/yr, and the expert evaluation panel, ~ 200 kNOK/yr).

It is evident that the above figures exceed the budget envelope of 15 MNOK per year. However, the computing costs may be largely absorbed in large national and Nordic initiatives for grid-based scientific computing.

It should be noted that a large fraction of the postdoctoral and doctoral stipends are not covered by the proposed budget for this programme. A survey of the present programme
shows that the universities and other sources currently finance stipends for 2 about MNOK/yr. This figure must increase for the future programme to be a success. The projects, being part of top level international science as well as at the forefront of modern informatics and electronics technology, should be of interest for high level education as well as for its potential contribution to science and technology. It would therefore be justified that the universities exploited these opportunities by allocating a certain number of stipends and fellowships.

Another comment which is worth noting is that the given envelope represents about 13% of the Norwegian CERN contribution. This is far below the average domestic (relative) spending in countries we normally are compared with, but reflects the rather low national budgets given to basic research in Norway, and has pushed the Norwegian community to a strong focalisation on a small number of projects. In this way the quality of the research has been maintained at a high international level, but with the price of a too narrow activity.

1.4 High Energy Particle Physics

After more than a decade of successful operation of the LEP accelerator at CERN, and of accelerators at Stanford and Fermilab in the USA, the Standard Model of elementary particles and their interactions has been verified as a correct model describing fundamental interactions between matter constituents at presently achievable energies. However, it is commonly believed that the model is only an effective, low-energy approximation of some more fundamental theory. Even within the Standard Model there exist several burning unanswered questions, that are expected to be answered using the data collected at the LHC. One of them is the origin of mass of elementary particles. The present concept is that the mass is due to interaction with the so-called Higgs field. The LHC should either confirm the minimal Higgs sector structure of the Standard Model, or provide experimental hints on the real nature of the origin of mass.

Another fundamental and still unanswered question is why all the observed Universe is built of matter, while matter and anti-matter should have been created in equal amounts in the Big Bang. To explain the observed asymmetry (which gave rise to our existence!) the so called CP-asymmetry of elementary interactions is needed. In fact weak interactions described by the Standard Model predict CP asymmetries, however it turns out the magnitude of these is far too small to explain the matter-anti-matter asymmetry of the Universe.

Yet another problem comes from observational evidence that most of the mass of our universe cannot be due to the ordinary matter we know. At least 20% of it must be carried by unknown, weakly interacting particles (dark matter). A supersymmetric extension of the Standard Model provides probably the best known candidate for such a dark matter particle. It also necessitates the existence of the light Higgs boson, in agreement with the present bounds from precise measurements (from LEP among others). Supersymmetric partners of Standard Model particles provide natural cancellations of interactions which otherwise would make the Higgs boson very heavy, and thus solve one of the basic problems of the Standard Model.

Recent theoretical attempts to explain the huge difference in the strengths of the gravitational interaction compared to the interactions comprising the Standard Model propose that gravity can propagate in new space-time dimensions that are inaccessible to the other interactions. These theories make predictions of exotic events at energies accessible to the LHC such as extremely energetic (graviton) resonances and production of microscopic black
holes which evaporate immediately and give spectacular signals in the detector.

1.4.1 Previous and current activities

The DELPHI Experiment

One of the main activities of Norwegian experimental particle physics since the middle of the 1980's has been the study of high-energy electron-positron collisions with the DELPHI experiment at the Large Electron Positron collider (LEP) at CERN. Data-collection started in 1989 and was completed in 2000. The final publications and doctoral theses are expected to be completed during 2003.

The universities in Bergen and Oslo were responsible for designing, constructing and operating DELPHI's primary luminosity detector, the Small Angle Tagger (SAT), and performing the luminosity measurements that were a crucial part of the measurement that showed that there are exactly three light neutrino species in nature. The Norwegian groups also contributed heavily to the improved luminosity detector, the STIC, which was used by DELPHI during 1994–2000.

Additional physics topics addressed by DELPHI with strong Norwegian involvement include precision measurements of tau lepton production and decays, precise measurements of quark-pair production, studies of particles containing a heavy b-quark, searches for exotic processes which are forbidden in the SM, and searches for the Higgs Boson(s) predicted by the SM and SUSY. The many and diverse precision measurements made at LEP established the SM as the precision theory of fundamental particle interactions at energies up to 200 times the proton mass. The prediction of the mass of the top quark before it was discovered at Fermilab in the mid-1990's was an important milestone for the SM.

The HERA-B and WA102 Experiments

Although the HERA-B project never lived up to its original plans of competing with and complementing BABAR with studies of heavy b-quark systems, results have been obtained on the production of systems of the somewhat lighter c-quark in proton-nucleus collisions. These results are used to test models of heavy quark production. This project will terminate naturally at the end of 2003. Related work was performed by Norwegian members of the WA102 collaboration from Oslo. They attacked the problem of the classification of high energy proton-proton interactions. This was used in a search for gluonic states (the gluon is the force particle exchanged in strong interactions) produced in the central region of high energy proton-proton collisions.

The BABAR Experiment

Project members in Bergen have participated in the highly successful BABAR experiment which studies the properties of particles containing b-quarks produced in electron-positron annihilations at SLAC in California. Contributions were made both to the preparation of the experiment (tests of light-fibers, construction of installation tools, reconstruction of photons in the detector) and to many physics results, including the important observation of the violation of charge times parity (space inversion) symmetry (CP) in neutral systems of particles containing heavy b-quarks.
Theoretical Particle Physics

Theoretical particle physics activity in Norway was integrated with the Particle Physics Analysis project in 2000. This merger, considered by both parties a success, has led to better communication between the theoretical and experimental communities as well as several joint efforts. The topics studied in Norway range from those with immediate interest for Norwegian experimentalists (such as decays of particles containing a heavy b-quark), to topics high on the international agenda of particle physics but not studied experimentally in Norway (studies of neutrino masses; neutrinos were thought to be massless until very recently), to topics that explore the extreme limits of particle physics and cosmology (extra space-time dimensions, string theory).

Preparations for the ATLAS Experiment

ATLAS is the next major project for the Norwegian experimental high energy physics community. The planned detector will be about the size of a 5-story office building and weigh about 7000 tons. Since 1998, hardware preparations in Norway for the ATLAS experiment have been organized through the NFR ATLAS Construction project. In parallel, studies of ATLAS relevant physics have been performed by students and physicists from the whole particle physics community. A very significant contribution to ATLAS management has been made through the appointment of one of the project’s physicists as project leader for the Inner Detector (ID) system of ATLAS.

Together with the University of Uppsala, Oslo and Bergen are responsible delivering some 450 detector modules for the Semi-Conductor Tracker (SCT), each equipped with four 6x6 cm$^2$ silicon detectors glued in pairs to a baseboard and equipped with an electronic card for electrical readout of the 768 independent signals per detector. It is Norway’s responsibility to purchase and test about 2000 detectors, to assemble these on the baseboards, and to test about two thirds of the modules after the electronics is mounted in Uppsala. The second largest commitment to the construction of ATLAS is the delivery of cryogenic tanks. In collaboration with SINTEF in Trondheim, technology has been developed and transferred to the Norwegian company SB-verksted, who is in the process of delivering four large cryogenic tanks for storage of liquid nitrogen and liquid argon.

ATLAS physics preparations so far include Higgs Boson, and supersymmetric particle searches, implementation of a computer program for an advanced statistical treatment of search results, searches for new force particles, and searches for particles predicted by new theories with more than the four known space-time dimensions.

1.4.2 Plans for 2006-2011

The BABAR Experiment

The excellent performance of the PEP II B factory provides for various physics opportunities in the short-term future, especially if the LHC programme is delayed. The present BABAR data sample already consists of over 200 million B mesons, enabling studies of CP violation and rare decays, both of which are sensitive for discovering new physics.
The ATLAS Experiment

In 2007 data-taking will start at the LHC, where proton-proton collisions at a center of mass energy of 14 TeV (almost 10 times larger than achieved at present colliders) will take place.

The project will have obligations in the commissioning and the operation of the ATLAS detector and the SCT. We will be required to be active in the general maintenance of the SCT, and it is necessary to be prepared for a scenario where a number of replacement parts are bought, produced and commissioned by us.

Super-symmetry (SUSY) will be one of the major subjects of LHC investigations, and if it is realized in nature, it should be seen after a few months of data-taking. It provides a wealth of possible signatures, and thus it is presently driving the development of the event reconstruction software for the ATLAS detector. There are several interesting physics SUSY analyses which are within the present competence of the Norwegian physics analysis group and should become subjects of theses.

The first step of the LHC Higgs physics program will be to confirm or disprove the existence of one (or perhaps more) Higgs bosons, depending on the results from the Tevatron at Fermilab at the time of the LHC startup. This will require the study of several final states, depending on the mass of the Higgs boson, and benefit from a combined analysis of the search results, similar to what was done at LEP. As larger data samples are collected, and assuming one or more Higgs Bosons are discovered, it will be important to measure their properties to test the Higgs mechanism in detail. The Norwegian ATLAS group has considerable experience with Higgs and other particle searches, precision electroweak measurements, and $b$-quark identification and physics. Thus we have a good potential for making important contributions to the Higgs searches at LHC.

Theoretical Particle Physics

Several of the present theoretical activities concern the central issues to be studied experimentally at the LHC; properties of Higgs Bosons, the phenomenology of super-symmetry, and the violation of CP-symmetry. Thus one can expect experimental and theoretical advances to strongly influence each other. The theoretical research program is long-term in nature and the period 2006-11 is seen to a large degree as a continuous extension of the present activity.

Budget

Since the previous “Physics Analysis” and “ATLAS hardware” projects are merged in the new project structure, the new project plans for an initial budget equal to the sum of the budgets of the two former projects. Particularly in the installation and commissioning phase, the project must plan for a continuous presence at CERN of at least two physicists or engineers. ATLAS computing M&O costs are covered by the Grid project (see Sec. 1.7). The cost to completion is the difference between the total budget for the ATLAS Construction project during the period 1998-2005 and a recent, revised estimate of the actual costs based to a large degree on actual expenditures and signed contracts - the details are documented in the annual reports of the ATLAS Construction project \footnote{http://www.fys.uib.no/~stuga/atlaslocal.html}. The M&O cost estimates and the definitions
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Table 1.4: The High Energy Particle Physics budget for 2006–2011. The expenditures are in kNOK and based on the 2003 price index. Computing costs are covered in the Grid project. The stipends below the total must be financed outside the budget of this programme.

of the categories A and B are described in a report by the CERN Resource Review Board (CERN-RRB-2002-036).

### 1.5 High Energy Nuclear Physics

The focus of the research in the ultrarelativistic energy regime is to study and understand how collective phenomena and macroscopic properties 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 Quantum Chromodynamics (QCD) is the occurrence of a phase transition to a deconfined state, the quark-gluon plasma (QGP).

#### 1.5.1 Previous and current activities

**Nuclear collisions at ultrarelativistic energies: fixed target experiments at the SPS**

With the ultra-relativistic energies attained in the CERN SPS, the QCD phase diagram was explored at high temperatures and small baryon densities. The WA97 and NA57 experiments address strangeness production in Pb-Pb collisions at 158 GeV per nucleon. The WA97 experiment observed a strong increase in the production at mid-rapidity for $\Lambda$, $\Xi$ and $\Omega$ hyperons and anti-hyperons in Pb-Pb collisions with respect to proton induced collisions. The NA57 experiment was designed to investigate the onset of the strangeness enhancement by extending the multiplicity coverage at full SPS energy (158 $A$ GeV). The strangeness production process, because of the early frozen chemical composition, can only act before or during hadronisation and is thus favoured by high gluon densities and reduced strange-quark mass in a chiral symmetric quark-gluon plasma.

Norwegian groups in WA97 and NA57 have had responsibility for the maintenance and development of the track reconstruction program, as well as establishing a correction chain to be used for WA97 data measured in 1996 and for all NA57 data. Norwegian groups have also been strongly involved in the general analysis activities of the experiments, and in the day-to-day operation of the experiment during data-taking periods. The NA57 experiment

15
made its final measurements in autumn 2001. Analysis is still ongoing, and resources for meetings and analysis will be necessary for 2003 and 2004. We expect the final analysis to be terminated during 2005.

Nuclear collisions at collider energies: BRAHMS at RHIC

Nucleus-nucleus collisions at collider energies explore the properties of dense matter close to vanishing baryochemical potential. The experiments at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, with a top energy of $\sqrt{s_{NN}} = 200$ GeV, have recently extended the known phase diagram to near-primordial conditions at centre-of-mass energies an order of magnitude above that of the SPS.

The BRAHMS experiment investigates the yields and $p_T$ spectra for identified charged hadrons as functions of rapidity, and has been highly successful so far. The first physics goal, which to a large extent is completed, is a detailed survey of bulk hadron production in Au-Au collisions at low-to-moderate $p_T$ at a broad selection of rapidities, probing the thermal and chemical conditions over the entire reaction zone. Among the basic questions addressed is the reaction dynamics and degree of stopping, and the strangeness production as a function of rapidity.

The Norwegian groups have participated actively in the development of BRAHMS event reconstruction and efficiency correction software, and in implementing efficient frameworks for physics analysis. Norwegian BRAHMS members have also contributed strongly to the general analysis effort and to data taking activities during RHIC run periods.

The Norwegian heavy-ion community plans active participation in RHIC RUN IV, scheduled during the winter and spring of 2004. The main physics motivation for continued involvement is precision studies of high-$p_T$ charged hadron spectra in Au+Au collisions at all rapidities. High-$p_T$ hadrons probe QGP properties through energy loss for fast coloured partons propagating through the deconfined medium, leading to suppression of yields.

The photon calorimeter PHOS, which is being developed for ALICE, is designed to detect the full energy of electromagnetic showers of photons up to several tens of GeV. For the RHIC 2004 run, the plan is to bring a PHOS prototype to the BRAHMS interaction region. Installation, commissioning and data taking will take place before and during the run period of 2004. The primary objective is accumulating high-$p_T$ $\pi^0$ spectra as a function of centrality and rapidity. Analysis of the high-statistics data set to be accumulated during the 2004 run, is expected to continue throughout the year 2005.

ISOLDE and High Spin Nuclear Structure Studies

The ISOLDE (Isotope Separator On-Line) facility at CERN is a world leading laboratory for production, studies and applied use of short-lived radioactive isotopes of most elements. The Nuclear chemistry group at the University of Oslo takes part in nuclear physics experiments and in development of target sources.

The study of nuclei at high spin gives information about how fast rotations influence the behaviour of the quantum-mechanical system. The nuclear many-body system under rotation may develop various exotic shapes like strongly elongated, axially symmetric hyper-deformed and triaxial shapes where the symmetry is broken. Consequences of triaxiality for a rotating quantum-mechanical system are central issues of the research of the High Spin Physics Group.
Theoretical Nuclear Physics

The principle objective of Norwegian theoretical nuclear physics has during the last decade been to predict and analyze new and extreme forms of matter in the domain of nuclear physics. The focus has been (i) on models and predictions for a quark-gluon-plasma (QGP) and (ii) also on extreme, low-density nuclear states at the driplines, using both few-body (halo physics) and many-body techniques.

Preparations for the ALICE Experiment

The hot and baryon-free region of the QCD phase diagram will be explored in depth by ALICE. The nucleon-nucleon centre-of-mass energy for collisions of the heaviest ions at the LHC will exceed that available at RHIC by a factor of about 30, opening up a new physics domain. Heavy-ion collisions at the LHC access not only a quantitatively different regime of much higher energy density but also a qualitatively new regime mainly. At the high centre of mass energies at LHC, nuclear collisions yield a rich variety of so-called hard non-equilibrating probes (e.g. jets, heavy quarks) which are produced in the first fm/c of the collision. Beyond merely establishing signatures for its existence, the medium-dependence of these hard probes provides an unparalleled possibility for a detailed quantitative study of the transient partonic state.

The ALICE experiment is a dedicated heavy ion detector for the spectroscopy of baryon free partonic matter. The physics goals are to determine the degree of equilibration of quarks and gluons, to measure the energy loss of partons in the hot plasma, to determine the initial and the critical temperature, to measure the degrees of freedom and to study deconfinement and chiral symmetry restoration. Penetrating probes - like photons and dileptons - which do not interact strongly are tools to study the early stages of the reaction. The physics program of the Norwegian groups will be focused on sensitive probes for a deconfined quark-gluon plasma state: direct photons, high-pt $\pi^0$ spectra, jets and heavy quarks (di-electrons from $J/\psi$, $Y$, open charm, strangeness). Therefore, we participate in the design and building of the PHOS electromagnetic calorimeter, which will measure photons up to an energy of 100 GeV, and in the High Level Trigger (HLT) project.

Photon Spectrometer - PHOS

The measurement of photons over a large energy range from 10 MeV to 100 GeV by a high resolution, high granularity electromagnetic calorimeter allows the reconstruction of neutral pions and etas produced at midrapidity and to deduce the direct photon yield. The Norwegian groups participate in the development of the detector and read-out electronics (pre-amplifier and the read-out controller unit). The heavy ion groups have supplied accompanying simulations of the physics capabilities, detector performance and trigger selectivity and rates.

High Level Trigger - HLT

Hard probes are produced with small cross sections and/or have to be detected via rare processes. Due to the large cross section for soft processes, the events are swamped by their reaction products. Without a sophisticated high level trigger scheme, the available data acquisition and recording bandwidth would be saturated by such soft events. The HLT system in ALICE will reduce the data rate from an interaction and detector readout rate of approx. 1 kHz for p+p and about 200 Hz for central Pb+Pb collisions by a factor of 10-100 so that it can match the DAQ/taping bandwidth. The heart of such a system is a fast pattern recognition program running on a farm of clustered SMP-nodes partially equipped
with FPGA co-processor PCI boards. The Norwegian groups are developing fast and parallel tracking codes, running both on CPUs and FPGAs, design and develop PCI-based FPGA co-processors and also contribute to the design and performance monitoring of the PC-farm. Studies that are performed by the local heavy ion groups include the development of methods and algorithms for an on-line selection of rare signals.

1.5.2 Plans for 2006-2011

The ALICE Experiment

Installation and commissioning will commence from 2005 to 2007. ALICE will then take its first data with pp collisions, because the LHC will be commissioned with proton beams, but also because pp physics is an integral part of the ALICE program. Pb+Pb collisions, which provide the highest energy density, are foreseen immediately after the end of the first pp run. For low cross section observables, in particular the hard processes which are a main focus at the LHC, some further 1-2 years of Pb+Pb runs at the highest possible luminosity should provide sufficient statistics. One period of pPb running is required early on, most likely in the 3rd year of LHC operation.

The ALICE offline production and analysis will be based on grid technologies. The ALICE offline software project has developed the grid analysis tool AliEn, which will become the basis of the ALICE offline activity. The Norwegian heavy ion community wants to continue its involvement both in the development and application of offline software.

Theoretical Nuclear Physics

Our future activities will cover QGP physics as well as the low temperature, low density domain of dripline halo-physics (ISOLDE physics). Theoretical heavy-ion physics is addressing the reaction mechanism of relativistic heavy-ion collisions. The goal has been to gain adequate information on the statistical properties of the quark-gluon plasma, primarily of the equation of state. The locally equilibrated state of quark-gluon plasma is formed, however, only in the intermediate stages of the reaction. Thus, any realistic model must include several modules, which are describing the different stages of the reaction. We will continue the development and testing of our hybrid 3D-hydrodynamical models for QGP scenarios: a Multi-Module Model for describing the reaction’s initial pre-equilibrium stage, the intermediate thermally equilibrated hydrodynamical stage, and the final freeze-out stage. In the near future we will concentrate on the possibly most accurate and detailed description of the freeze-out stage. This will enable us to simulate almost all measurable quantities and to study all aspects of the visible signals of QGP formation.

The Bergen-Oslo Nuclear Theory team has played a role in pioneering successful use of few-body models for understanding dripline phenomena, in particular halos (the low temperature, low density regime). The lessons from these studies have also served as guidance for ongoing ab-initio many-body attempts based on nucleonic constituents and their interactions. These studies have also been relevant for heavy-ion reactions and the study of neutron stars. With few, although often exotic, bound states, emphasis is shifting to the continuum part of the spectra for dripline nuclei, posing fundamental questions about few-body-like resonances in many-body systems. Theory for reactions tailored to explore such structures has to be further developed at a quantitative level.
Table 1.5: The HENP budget for 2006–2011. The expenditures are in kNOK and based on the 2003 price index. The stipends below the total must be financed outside the budget of this programme.

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Present and future nuclear physics targets highly energetic and extreme forms of matter which existed only in the early universe or (exist) in the middle of neutron stars and violent cosmic explosions. Thus our link to and dependence on insight in astrophysics has steadily increased, and we aim at a stronger interaction with Norwegian experts in the field.

Budget

Since the previous “Physics Analysis” and “ALICE hardware” projects are merged in the new project structure, the new project plans for an initial budget equal to the sum of the budgets of the two former projects - taking into account the increase of staff in the project over the last years (a new group at HiB and the joining of the Microelectronics Group at UiB). Particularly in the installation and commissioning phase, the project must plan for a continuous presence at CERN of physicists or engineers. ALICE computing M&O costs are covered by the Grid project (see Sec. 1.7). The estimated cost overruns for ALICE construction during the present programme (1.6 MNO) are covered by the installation and commissioning budget during the first two years of the new program.

1.5.3 Nuclear physics after 2011

For ALICE running after 2011, there are a number of running options, the relative importance of which will depend on the initial results. For a direct comparison of the Pb+Pb and pp data, a dedicated pp run at the Pb+Pb centre of mass energy, \( \sqrt{s_{NN}} = 5.5 \text{ TeV} \), is probably advisable. A more complete energy density scan would require additional intermediate-mass ion runs. To map out the the A-dependence further pA runs with different nuclei could be necessary. Additional Pb+Pb runs at lower energy would allow to measure an energy excitation function and to connect to the RHIC results. Finally, some rare processes limited by statistics in the early runs could require additional high-energy Pb+Pb running.

QCD matter at large baryon densities is not sufficiently explored, neither experimentally nor theoretically. Nuclear reaction experiments at the future facility at GSI (e.g. Compressed Baryonic Matter - CBM experiment) aim at a detailed and comprehensive investigation of
super-dense baryonic matter. The research program includes the measurement of penetrating probes, which escape essentially undistorted from the compressed nuclear collision zone. The energies of the heavy-ion beams delivered by the proposed accelerator are optimized for studies of hadronic matter at moderate temperatures but very large baryon densities.

The study of dense matter in the universe will profit in particular from the INTEGRAL satellite and from the next generation of gamma-ray instruments. Despite considerable progress, the physics of core-collapse supernovae and their nucleosynthesis remains to be an active field of research in nuclear astrophysics. The equation of state of very neutron-rich low-entropy nuclear matter up to about five times nuclear saturation density e.g. remains to be an open and important problem. Dense nuclear matter also plays an important role in mergers of two neutron stars and of a neutron star and a black hole. In these events, dense nuclear matter is heated to tens of MeV and most of this energy is emitted in form of weakly interacting particles. It is believed that the annihilation of neutrinos into $e^+e^-$ pairs may give rise to gamma-ray bursts.

1.6 Advanced Instrumentation

Advances in high energy physics and the understanding of the evolution of the universe are only possible with the development of new technologies and improved detection techniques that can be used in upgrades and/or future experiments. Thus, a continuous R&D program is vital for this field.

Microelectronicis is applied in most areas of experimental physics in addition to high energy physics, in particular space physics. Microelectronics activities are therefore an integral part of the experimental activities at the Departments of Physics in Bergen and Oslo. There is also a significant microelectronics activity at the Institute of Informatics in Oslo. Two groups at the Department of Physics in Oslo have been working on silicon sensors for more than two decades; the Electronics groups and the Experimental Particle physics (EPF) group. The Electronics group has 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 EPF group has been working on applications of silicon detectors for high energy physics experiments since the mid 1980's.

The knowledge accumulated during the LHC projects and their predecessors must be maintained, and the current momentum carried over to new projects. The lead time for constructing a large experiment is very long, 5-10 years. This implies that the present instrumentation activities must be redirected to new experiments as soon as the ALICE and ATLAS experiments are in the data taking phase, i.e. not later than 2008-9.

High energy physics experiments for the future

An important particle physics project after the completion of the LHC in 2007 is a linear electron-positron collider. While the LHC is understood to be mainly a discovery machine, a linear collider is a machine of precision measurements. The Higgs boson, to take an example, is expected to be discovered at the LHC. However, to determine whether this is the SM Higgs or a SUSY Higgs it is necessary to cleanly reconstruct many decay channels, a task ideally suited to a linear collider. However, R&D on the detector and associated readout of the detector data is needed to meet stringent performance requirements. It should be noted that
about half of the major subsystems in the conceptual design of a detector for the TESLA collider proposed by the DESY laboratory are based on silicon sensors.

In the heavy-ion field the planned Compressed Baryonic Matter experiment at GSI, Germany is a natural follow-up of the ALICE program. Important physics questions would include the production of heavy quarks in nuclear matter. Due to the low energies involved the rate would be low, and successful measurements would require high rate collisions and triggers, and corresponding high-speed detectors and ADC’s. This would represent a great challenge for developers of instrumentation.

Instrumentation for the future

Products of particular relevance for high energy physics experiments which are also of interest for innovative Norwegian industry include silicon-based radiation and photon sensors, System-on-Chip ASIC’s (SOC), embedded solutions (processor based instrumentation), networking technology, and special circuits developed for tight integration with detectors. The Norwegian companies Nordic VLSI and Chipcon specialize in components and solutions for analogue, digital and mixed-signal applications, in particular for the communication market. IDEAS, whose first products were based on detector front-end electronics developed for CERN, now focuses on detection modules for gamma, beta and x-ray cameras for applications in medicine, industrial inspection, and physics. SINTEF, partly in collaboration with AME, Horten, develops and produces silicon-based radiation detectors.

The new Norwegian Nano- and Microtechnology Centre (NMC) offers exciting possibilities for R&D and manufacturing of micro-systems. The research program is currently under definition. A project for the period 2003-6 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 will address the requirements and fabrication of novel sensors for operating in harsh environments. These issues are highly relevant for instrumentation of high energy physics experiments. What is missing at the moment is a program for development of silicon-based detectors fully integrated with processing and readout electronics, which would significantly increase their value and will also be required by high energy and space physics experiments and industrial customers (Si-detectors are by themselves ”non-intelligent” devices).

Budget

The budget for the project is shown in Table 1.6. The spending profile reflects the completion of the ALICE and ATLAS construction activities at the startup of the LHC physics programme.

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Table 1.6: The budget for the Instrumentation Project during 2006–2011. The expenditures are in kNOK and based on the 2003 price index.
1.7 Norwegian LHC Computing Grid

The goal of this project is to optimize the preparations for the analysis of the data that will be collected by the ALICE and ATLAS experiments from 2007. The computing needs of the experiments and the Norwegian share of these needs are summarized here. A plan for the preparations is sketched which is based on experience in grid computing gained via the NorduGrid project and manipulation of large datasets through participation in so-called data challenges (generation and post-processing of a large number of Monte Carlo simulated events). An important element of the strategy is to coordinate Norwegian needs and efforts with the existing frameworks of the LHC Computing Grid Project (LCG) organized by CERN, the Nordic Data Grid Facility (NDGF) organized by the NOS-N, and the local organizations and centres for scientific computing in Norway (the NOTUR programme and its successor, Parallab and USIT).

Grid computing and the LHC

Several petabytes ($10^6$ gigabytes) of data will be collected per year by each of the LHC experiments. The computing power to process these data, and to produce and process the comparable amounts of simulated data required for analysis, is estimated to be equivalent to something like 100,000 of today's personal computers. Data storage, network capacity and computing power double (for fixed cost) approximately every 12, 9, and 18 months, respectively. The different time constants associated with these basic elements of computing lead naturally to the idea of a computing grid whereby geographically dispersed computing resources are seamlessly shared. This vision of computing is particularly driven by the requirement of efficient processing of the large amounts of LHC data by 6000 scientists from 500 institutions spread world-wide. In the same way that the World Wide Web gives us efficient access to information, the World Wide Grid is foreseen to give us efficient access to computing capacity and data storage in the future.

CERN-related Norwegian Grid Activities

During the last 2 years the CERN-related Norwegian grid activities have been dominated by the NorduNet-2 financed project NorduGrid. The aim of the project was to create a grid-based computing infrastructure in the Nordic countries. The core NorduGrid environment consists of seven test-sites (Bergen, Copenhagen, Helsinki, Lund, Oslo, Stockholm and Uppsala), mostly dedicated to development and testing of the software which links the sites (the so-called middleware). Up to 17 sites linking 900 processors and 7 Terabytes of disk storage (5 of these in Norway) have been used successfully in phase 1 of the ATLAS data challenges. This is in fact one of the largest operational grids in the world. While the NorduGrid middleware is by no means complete, the project aims to continue taking an active part in the construction of the World Wide Grid.

The Norwegian ALICE computing activity is centered on High Level Trigger (HLT) development. The HLT makes on-line event selection and compression and will consist of a PC farm of around 1000 nodes. When offline or when not fully utilized, the HLT can be operated as a compute farm within the CERN DataGrid framework. A prototype HLT farm of 11 nodes with dual processors was installed at the University of Bergen in 2001.

The Norwegian ALICE group intends to establish a grid-based offline analysis framework in Norway, centered on Parallab in Bergen and USIT in Oslo. A prototype ALICE analysis
grid framework, AliEn, has already been used for cross-continent production. The Norwegian groups intend to install and operate AliEn on the HLT cluster in the close future, as an important step toward full-fledged ALICE offline activity.

The Nordic Data Grid Facility

The NOS-N has financed a pilot project whose aim is to lay the foundation for a large-scale, multidisciplinary facility for data-intensive computing in the Nordic countries. This Nordic Data Grid Facility would, in 2006, consist of several thousand processors, a petabyte of fast disk storage and several petabytes of slower tape-based storage. This would correspond to several times the requirements of the Nordic LHC community, and thus also serve the growing computing and storage demands of biomedical, earth, space and astrophysical sciences.

Budget

The cost sharing (hardware, network, consumables and manpower) of the LHC Computing Grid will be part of the Computing Memorandum of Understanding (MoU) with CERN, which is due in 2005. It is foreseen that this MoU will consist of a part common to all 4 LHC experiments, and separate parts for each experiment. Based on present knowledge, the total cost of the ATLAS offline computing to be paid by the collaboration from 2006 is about 17 MCHF per year. These costs are to be covered mainly by in-kind contributions in the form of regional facilities (such as NDGF) made available to the LHC Computing Grid and correspond roughly to a Norwegian contribution, for both the ALICE and ATLAS activities, of about 2.2 MNOK per year.

There should be at least one Norwegian grid-expert tightly coupled to the ALICE and ATLAS computing activities. This post-doc position should in fact be filled now, be partly based at CERN, and serve as the contact between the LCG and the Norwegian community. From 2006 this position should insure that the ALICE and ATLAS simulation and analysis software run continuously on a Norwegian/Nordic grid with LCG-compatible middleware.

In order to continue successful participation in the LHC data challenges, occasional access to 100–200 CPU’s and permanent storage of at least an additional 20 TB is required during 2003-5. We will apply for CPU-resources at existing installations (e.g. Parallab) but must continuously invest in disk servers to store the produced simulation data on the grid.

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Table 1.7: Annual and total costs for Norwegian LHC Grid Computing in kNOK. The cost for the “regional center” includes hardware, network, consumables and manpower.

The projected costs of the project, including the crucial period of preparations before 2006, are summarized in Table 1.7. Note that the post-doc position should start in the present programme period as well as the investments in permanent storage for the pilot project.
Part II

Details of the four projects
Chapter 2
High Energy Particle Physics

Particle physics comprises the study of nature’s basic constituents, or building blocks, and the forces which are at work when they interact.

Although many of the outstanding problems were addressed at CERN’s large electron-positron collider LEP, and several are under investigation at Fermilab’s proton-proton collider, the Tevatron, in the US, there will remain a lot of unanswered questions to attack at the LHC. Obtaining answers to these questions is crucial for us to understand in which direction the current theories should be developed.

The Standard Model is a model (many physicists would even call it a theory), containing a combined field theoretical description of the electromagnetic and weak interactions (the electroweak theory), and the strong interactions between coloured quarks, Quantum Chromo Dynamics or QCD for short. Significant parts of these theories were worked out in the late sixties and early seventies. However, when the LEP experiments started data taking in 1989, many important questions had not yet found their experimental answers. Among the outstanding points at that time were:

- How many families of matter particles (with two quarks, one charged and one neutral lepton in them) exist? (The theory only told us that the particles came in such families, not how many there were.) Precisely how heavy were the new heavy bosons (discovered experimentally in the early eighties), and how wide? (All particles have a width, inversely proportional to their life-time.)

- The width of the neutral, heavy boson ($Z^0$) is directly related to the number of families (as long as the neutrinos in the families are light, which seems to be the case, at least for all known families. Thus the number of such families could be measured!

- The theory could not predict the important weak angle $\theta_W$, so it had to be measured precisely.

- Did the $\tau$ lepton show the characteristics expected in the Standard Model?

- A lot of tests on the theory of the strong interactions, QCD, had to be performed. Among these were:

  - Did model predictions of the event shapes in events consisting of particle jets emerging from strongly interacting quarks and gluons coincide with the observations at all energies?
- Could the “running” (energy dependence) of the strong coupling constant which was predicted be confirmed?
- Could the so-called gluon self coupling (necessary in theories like QCD) be revealed?
- Could studies of heavy quark systems give more information on fundamental symmetries?

- The most widely accepted method to obtain particle masses in the Standard Model, is via the so called Higgs mechanism. A prediction of this mechanism is the existence of a spin-zero boson, the Higgs boson. Unfortunately the Standard Model can not predict the mass of the Higgs boson. However, the relative strengths of the couplings of the Higgs boson to the known particles are predicted, and such predictions could be checked once the Higgs boson was found. Despite strong, long term efforts, the Higgs boson was not discovered at LEP.

- The Standard Model, despite its many and impressive successes, has several important weaknesses. In order to find out in which direction a more complete theory would evolve, there were also large efforts at LEP to try to find situations where the Standard Model was incapable of explaining the results. Clear indications of such “beyond-the-Standard-Model” physics were not found. Among new physics extensively searched for, were manifestations of Super-Symmetry (SUSY, symmetry between fermions and bosons), where many new particles and interactions are expected, and decays of the $\tau$-lepton and of the $Z^0$-boson which are forbidden in the Standard Model.

High quality answers to many of the questions listed above, were obtained at LEP. Therefore it is highly appropriate to consider LEP, and the Norwegian contribution to DELPHI, an indisputable success. However, some important questions were not resolved at LEP. Among those were: the Higgs boson was not observed, manifestations of Supersymmetry were not observed, none of the attempts to find signs of break-down of the Standard Model were successful. These unclarified points take important parts in the argumentation for the need for, and interest in, the new LHC collider. The higher energies attainable there, will allow the unambiguous confirmation of the missing links from LEP if our theoretical picture is correct. And if this is not the case, there is every reason to believe that LHC will give the necessary inputs to change the theoretical landscape of particle physics...

### 2.1 Previous and current activities in Norway

#### 2.1.1 LEP/DELPHI

One of the main activities of Norwegian experimental particle physics since the middle of the 1980’s has been the study of high-energy electron-positron collisions with the DELPHI experiment at the Large Electron Positron collider (LEP) at CERN. Data-collection started in 1989 and was completed in 2000. The final publications and doctoral theses are expected to be completed during 2003.

The Norwegian groups’ contributions and results at LEP are summarized here. For more details the reader is referred to the annual reports of the *Experimental Particle Physics:}*
*Physics Analysis* project [1]. Some of the results were obtained within the old Research Council project organization which existed prior to 1998.

The universities in Bergen and Oslo were responsible for designing, constructing and operating DELPHI's primary luminosity monitor, the *Small Angle Tagger* (SAT). In addition, the Norwegian groups wrote the detector-dependent software (simulation, reconstruction) for the main DELPHI data analysis chain, and the dedicated, high-performance simulation and analysis software needed for DELPHI's luminosity determination. This was a crucial part of the measurement that showed beyond a doubt that there exist three light neutrino species in nature. The SAT detector and associated software ensured a high quality luminosity determination in DELPHI from LEP start-up in 1989 to the end of 1993, when the STIC detector took over.

The STIC was a more ambitious project, involving CERN, ITEP (Russia) and 10 European university groups including both the Norwegian groups. The Norwegian groups contributed to the conceptual and mechanical design of the STIC, the extensive beam-tests of the prototypes, major parts of the trigger electronics, and the readout of both the lead-scintillator calorimeter and the internal silicon detector. The replacement of the SAT with the STIC led to a reduction of the systematic uncertainty on the integrated luminosity by nearly a factor of 3.

Important parts of DELPHI's muon identification software were also developed by the Norwegian group.

Particles which are heavier than those kinematically accessible as real particles (so-called virtual particles), can give measurable effects in the experimental observables. These effects can be calculated in relativistic quantum field theory via loop-diagrams where the virtual particles take part. From precise measurements of production and decay of the $Z^0$-boson, DELPHI could already early in the 1990's predict the top-quark's mass to be close to 175 GeV/c$^2$. It was a great triumph for the LEP measurements when the top-quark was detected, at Fermilab, USA, in the middle of the nineties with the mass predicted at LEP.

For many reasons most particle physicists are convinced that the Standard Model is not the final say - it can only be a good low-energy effective description of Nature. To find the correct way ahead, it is therefore important to subject the Standard Model to detailed tests and try to find out where and how it breaks down. The Norwegian community has performed several such detailed tests looking for processes which are forbidden in the Standard Model. Among these have been searches for forbidden decays of the tau lepton and of the $Z^0$.

Norwegian physicists also contributed heavily to the studies of the $\tau$-lepton. In particular $\tau$ lepton branching fractions and $\tau$ polarization were measured. The polarization measurement in the muon decay channel of the $\tau$ is illustrated in Fig. 2.1. The measurement of $B(\tau \to \mu \nu_\tau \nu_\tau)$ was the world's most precise in the 2002 edition of the Review of Particle Properties [2]. Furthermore, searches for lepton flavor violation were performed in the modes $\tau \to e\gamma$ and $\tau \to \mu\gamma$. The decays $\tau \to K\nu(n\pi^0)$ ($n \geq 0$) were also studied.

Another important test of the Standard Model performed by members of the Norwegian project has been the precise measurement of production of quark pairs at the highest center-of-mass energies which were available at LEP. The distribution of the reduced energy, as illustrated in Fig. 2.2 for a particular beam energy, shows good agreement with the expectation of the Standard Model. No deviations from the Standard Model were found.

Studies of particles containing the heavy $b$-quark have continuously been an important part of the LEP measurements. $B\bar{B}$-mixing (where a $B$-meson oscillates into a $\bar{B}$-meson or the opposite) was studied in Norway, as well as measurements of certain $B$-meson decays and
Figure 2.1: The spectrum of the ratio of the muon momentum to the beam momentum, $P/P_{beam}$, for candidate $\tau \rightarrow \mu \nu \bar{\nu}$ decays. The circles are data and the solid line is simulation for the fitted value of the average polarization. The hatched area is background and the dashed and dotted lines correspond to the positive and negative polarization contributions respectively.

Figure 2.2: The reconstructed reduced energy for the $e^+e^- \rightarrow q\bar{q}(\gamma)$ process at $\sqrt{s} = 205$ GeV.

life-time measurements of charged and neutral $B$-mesons.

In the later years the Norwegian group contributed with an advanced statistical treatment of search data, in the search for new particles. The method is used by all the four LEP experiments and by several of the working groups responsible for the combination of LEP search results, both for combining different search channel and experiments.

The search for the Higgs boson, the particle whose existence is necessary in the most widely accepted mechanism for giving the particles their masses, was frequently discussed in the international press in year 2000, and has been an important activity for the Norwegian groups. Precision measurements from LEP imply a most probable Higgs boson mass around 100 GeV/$c^2$. With all data from the four LEP-experiments analyzed, the significance for a Higgs boson at close to 115 GeV/$c^2$ turned out somewhat below two standard deviations. The final result is shown in Fig. 2.3. This is not enough to claim a discovery. Now LEP is dismounted in order to make way for the Large Hadron Collider, LHC, at CERN. If the Higgs boson really is so light as around 115 GeV/$c^2$, there is a large probability that it will be observed by the Tevatron experiments at Fermilab. If it is significantly heavier, it will, if it exists, with a very high probability be observed at the LHC accelerator at CERN.

Searches for new physics beyond the Standard Model have to a large extent focused on searches for Super-Symmetric particles. Project members have played a crucial role in DEL-
Figure 2.3: The final, published, combined result for the Higgs search at LEP. One sees that the observed result is everywhere consistent with the background expectation indicated by the dark (±1σ) and light (±2σ) bands.

Figure 2.4: MSSM Higgs bosons: regions excluded at 95% CL in the $m_H^{max}$ scenario. The dark shaded areas are the regions not allowed by the MSSSM model in this scenario. The unshaded region remains to be explored at the TeVatron and LHC.

PHI's searches for Higgs bosons in the Minimal Super-symmetric Standard Model (MSSM). The region excluded by DELPHI in the MSSM scenario where all the other free parameters are tuned to give the worst sensitivity to the lightest scalar Higgs boson ($m_H^{max}$) is shown in Fig. 2.4.

2.1.2 LHC/ATLAS

ATLAS is the next major involvement for the Norwegian experimental high energy physics community. The planned detector will be about the size of a 5-story office building and weigh about 7000 tons. The overall detector layout is shown in figure 2.5.

The complex design of ATLAS is due to the fact that it should be a general purpose detector system. This implies that the detector should allow ATLAS physicists to study all potentially interesting processes in proton-proton collisions at LHC energies (14 TeV). In addition to optimising for discovery of new particles, such as the Higgs, the detector should be an instrument to perform high precision studies of abundantly produced particles such as $B$-mesons, top quarks, $W$ and $Z$ bosons. Therefore the design includes a silicon pixel system to identify secondary vertices from $B$-mesons; a high precision tracking system for reconstructing particle momenta; an electromagnetic calorimeter for identifying photons and electrons and measuring their energies; a hadron calorimeter for reconstructing quark (or "jet") energies; and finally an outer tracking system situated in a toroidal magnetic field for identifying muons and measuring their momenta.

Since 1998, hardware preparations in Norway for the ATLAS experiment have been orga-
nized through the NFR ATLAS Construction project. In addition, some financial resources have been obtained through NFR funding of large scale equipment to the universities. The aim has been to contribute to the development, prototyping and construction of components for the ATLAS detector. Large human and financial resources have been involved, and it seems like we are about to accomplish the aims, although some financial overruns will have to be covered by using funding from years after 2005. In parallel, studies of ATLAS relevant physics have been performed by students and physicists from the whole particle physics community. It should also be mentioned that a very significant contribution to ATLAS management has been made through the appointment of one of the project’s physicists as project leader for the Inner Detector (ID) system of ATLAS.

**Contributions to the construction of the SCT**

Based on experience from the DELPHI/SAT tracker the Norwegian groups chose to contribute to the SCT (Silicon Tracker), which is one of three subsystems in the Inner Detector (the ID). The ID, shown in Fig. 2.6, is the track reconstruction system of ATLAS.

One challenge of the SCT has been to produce silicon microstrip detectors which are resistant to high doses of radiation. After an intensive development phase involving SINTEF and other vendors, a robust detector design has been achieved.

The SCT consists of about 20000 large area silicon microstrip detectors, each divided into 768 independent sensors. The sensors are strips with a pitch of 80 micrometers. The sensors are bonded together in pairs, and a total of about 7.5 million individual electronics channels are to be read out. The construction of the SCT is a world-wide undertaking with the participation of 31 institutes from 13 countries. Together with the University of Uppsala, Oslo and Bergen are responsible delivering some 450 detector modules, shown in Fig. 2.7, each equipped with four 6x6 cm² silicon detectors glued in pairs to a baseboard and equipped with an electronic card (a 'hybrid') for electrical readout of detector signals. It is Norway's responsibility to purchase and test about 2000 detectors, and to assemble these
Figure 2.6: The ATLAS inner detector. The detector is 7 m long and has a diameter of 2.3 m.

on the baseboards. In Uppsala the modules are equipped with read-out electronics. The completed modules are then tested in one of the three institutes before delivery for mounting in the SCT system.

This activity has had many aspects:

- The development of radiation hard silicon detectors: Our task was to irradiate and test detectors designed and fabricated by SINTEF. Our tests showed that these detectors would withstand the large irradiation doses expected at the LHC, and hence the project has contributed significantly to the understanding of irradiation effect in silicon.

- Quality assurance of serially produced detectors: Detectors for use in the experiments have been purchased from the Japanese company Hamamatsu. A total of 1950 detectors have been ordered and delivered. As of June 1, 2003, 1930 of the detectors have been inspected and tested. The testing is expected to be completed by the end of June, 2003. Close to 99% of the detectors are found to be of excellent quality and will be used for the production of detector modules. Testing has run smoothly thanks to temporary and permanent staff at the technical, engineering and research levels in Bergen.

- Construction and production of detector modules: Oslo has taken an active part in developing and testing procedures for assembly of detectors on baseboards to a precision of better than +/- 5 microns. After a very substantial effort the mounting is now under control to the required precision, and serial production of modules has started. It seems like we will reach our goal which is to produce and qualify about 400 modules before mid 2004.

- Testing of detector modules: A large effort is going into testing of the electrical properties of completed modules. The modules are returned from Uppsala after they have been equipped with hybrids and bonded there. Both in Bergen and Oslo setups are now operational and the first modules have already been tested.
In addition, the project has responsibilities to finance a number of items for the SCT; silicon detectors, module baseboards, readout ASIC’s and the Inner Detector cooling system.

ATLAS Common Fund Contributions

The second largest commitment to the construction of ATLAS is the delivery of cryogenic tanks. In collaboration with SINTEF in Trondheim, technology has been developed and transferred to a Norwegian company, SB-verksted (located in Drammen), who is in the process of delivering four large cryogenic tanks for storage of liquid nitrogen (2 of the tanks) and liquid argon. Some technical and other problems have been encountered. The most serious one was that the production company went bankrupt. However, the company reopened and production of the tanks is now running well. In addition to this delivery, there will be a cash contribution to the Common Fund.

Although these deliveries are expected to be completed well before 2006, considerable manpower and financial resources will have to be spent on maintaining and operating the SCT system and on the general maintenance and operation of ATLAS.

Physics studies

ATLAS physics preparations so far include SUSY simulation studies, Higgs search studies in the $H \rightarrow \gamma \gamma$ channel, implementation of the ALRMC (A Likelihood Ratio Monte Carlo) program for statistical treatment of search results or low-statistics measurements in C++; searches for multiple Higgs production, searches for gravitons in the $\ell^+\ell^-$ and $\gamma\gamma$ channels, searches for extra gauge bosons, and studies of radion production as a signature for extra dimensions. In addition, a huge effort has been made on a Nordic computing-grid initiative (NorduGrid), including a very successful contribution to ATLAS’ data challenges. The latter described in greater detail in Section 5.2.2.
Other short-term ATLAS plans and activities

The Norwegian groups plan to contribute to the detector-dependent technical software (simulation and reconstruction) for the Inner Detector during 2003–2005.

Short-term plans related to ATLAS physics analysis include preparations of searches for the Standard Model Higgs boson, searches for Supersymmetry (including an extended Higgs sector), searches for signals of extra dimensions (gravitons, black hole production), extra symmetries (through the existence of extra gauge bosons), and other beyond-the-Standard-Model physics, as well as measurements of the properties of heavy quarks (e.g., decays $B \rightarrow K\mu^+\mu^-$ and $B \rightarrow K^{*0}\mu^+\mu^-$ in high statistics samples) and heavy quark systems (notably the $B\bar{B}$ system). In order to perform these studies it is of vital importance to have a vigorous PhD programme, and to establish good computing infrastructure.

2.1.3 The BABAR experiment

This is only a condensed summary of the Bergen BABAR analysis contributions. For more details, as well as for information on general BABAR achievements, the reader is referred to the annual Physics Analysis Project reports [1].

Project members in Bergen have invested big efforts in the BABAR experiment, and made significant contributions to BABAR physics analysis related to $CP$-violation in the $B^0$-system, among them the important time-distribution measurement shown in Fig. 2.8, and to several $B$ meson decays.

Current activity by Bergen physicists (spring 2003) includes branching fraction measurements of $J/\psi K\pi$, $\psi(2S)K\pi$, $J/\psi K\pi\pi$, $\psi(2S)K\pi\pi$ final states, as well as studies of $B \rightarrow K^\ast\gamma$ and related channels. Inclusive channels like $B \rightarrow X\ell^+\ell^-$, $K^{(*)}\ell^+\ell^-$ are also studied. Physicists in the Norwegian group also contribute to technical studies related to the running of BABAR’s electromagnetic calorimeter. Bergen physicists have also contributed methods and software related to maximum likelihood fitting of the Unitarity Triangle parameters, and performed detailed investigations using this tool.

Bergen has also contributed significantly to studies of the exclusive final states $B^0 \rightarrow J/\psi K^0_S$, $B^0 \rightarrow \psi(2S)K^0_S$, $B^\pm \rightarrow J/\psi K^\pm$, and $B^\pm \rightarrow \psi(2S)K^\pm$ with $J/\psi$ and $\psi(2S)$ reconstruction in $e^+e^-$ and $\mu^+\mu^-$ final states, and $K^0_S$ in $\pi^+\pi^-$. Branching fractions have been measured, and factorization has been tested. Also $B^0 \rightarrow J/\psi K^0_S$, $\psi(2S)K^0_S$ have been studied, with $K^{*-}$ in the $K^+\pi^-$ final state.

Important work has also been done by Bergen on electro-weak penguin decays like $B \rightarrow K\ell^+\ell^-$, $K^*\ell^+\ell^-$. Another important Bergen contribution to BABAR software has been the construction of the photon error matrix related to the reconstruction of photons in BABAR’s electromagnetic calorimeter, and thus of crucial importance to any final state containing photons.

In preparations for the construction of a light pulser for monitoring the CsI crystals Bergen has performed tests of various light fibers regarding aging and light output as a function of curvature. Bergen has further produced 60 installation tools needed for the mounting of the pre-amplifiers to the back of the CsI crystals in the BABAR electromagnetic calorimeter.

2.1.4 The HERA-B and WA102 experiments

One of the activities of the Norwegian HERA-B members in Oslo has been the study of charmonium production at HERA-B. In particular they have studied the fraction of $J/\psi$ produced
Figure 2.8: Time distribution measurements for $B^0$ and $\bar{B}^0$ tags and the CP asymmetry for charmonium modes for CP-odd and even states. The solid curves show the results of the fit and the shaded regions represent backgrounds.

in radiative decays of $\chi_c$-states produced in $pC$ and $pTi$ (proton-carbon and proton-titanium) interactions at $\sqrt{s} \approx 42$ GeV. Charmonium, as well as other resonances, were reconstructed through their $\mu^+\mu^-$ decays. The $\chi_c$-states were reconstructed by combining an associated photon with the muon pair. Production cross sections and their nuclear dependencies were measured and compared to QCD-based models for heavy quark production.

Another main activity on the Norwegian HERA-B community has been the study of 2-body hadronic decays ($V^{0\pi}$s): $K_S^0 \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow p\pi^-$, $\phi \rightarrow K^+K^-$, and $K^{0*} \rightarrow K^-\pi^+$. Also the cross section ratios $K^0/\bar{K}^0$ for 920 GeV $pC$ and $pTi$ interactions were determined.

Related work was performed by Norwegian members of the WA102 collaboration from Oslo. They attacked the problem of the classification of high energy proton-proton interactions. This was used in a search for gluonic states produced in the central region of $pp$ collisions at 450 GeV/c.
2.1.5 Theoretical particle physics

The theory activities of Jan Olav Eeg, Hallstein Høgåsen, Carsten Lütken and Per Osland were integrated with the Project in the year 2000. This merging has been very stimulating, and led to better understanding of related activities, as well as several joint activities.

The particle theory research in Bergen has been focused on the following topics: (i) neutrino physics (studies of neutrino masses), (ii) QCD vertex functions (in particular, the structure of the three-gluon and quark-gluon vertices), (iii) extended Higgs sector (the Two-Higgs-Doublet Model, including CP-violating effects), (iv) contact interaction studies (including a recent study of LEP2 data and studies of beam-polarization effects for a linear collider), (iv) phenomenology of extra dimensions (of relevance for searches at the LHC), (iv) mathematical physics (Euler sums related to Feynman diagrams, and “quantum groups”).

The particle theory in Oslo has focused on the following topics: i) String theory, ii) Quark spectroscopy and quark correlations, iii) Decays of mesons containing heavy quarks, and its relation to CP-violation.

A NorFA-funded network, “Discovery Physics at LHC”, coordinated by professor Paula Eerola, Lund, was approved and funded for 2001–2003. The students and researchers in Bergen and Oslo have in this way been able to strengthen the Nordic collaboration via schools, workshops (the first one was organized in Oslo, March 2001, the next one will be in Bergen, May 2003) and student exchanges.

2.1.6 Statistics of candidates and scientific production

The number of candidates having obtained their degrees within the ATLAS and Elementary Particle Physics: Physics Analysis projects during the time span 1998–August 2002 are listed in Table 2.3. The names of the candidates can be found in the annual reports of the projects [1]. As of September, 2002, there were 13 doctoral and 11 master students working on their degrees within these 2 projects. There are also 12 projects carried out by students from Gjovik College appearing in several of the tables, but not listed explicitly in Table 2.1.-

The numbers of publications in the various categories for the time span 1998–August 2002 are listed in Table 2.4. The corresponding publication lists and further details can be found in the relevant project’s annual reports [1] from 1998 through 2002.

Still end 1998.

2.2 Plans for 2006–2011

In 2007 data-taking will start at the Large Hadron Collider (LHC), where proton-proton collisions at a centre of mass energy of 14 TeV (almost 10 times larger than achieved at present colliders) will take place. Norway participates in the construction of the LHC as a member state of CERN. Norwegian research groups participate in the construction of the ATLAS detector, one of the two general purpose experimental facilities to operate at the LHC.

Scientifically the research program at the LHC is expected to be extremely rewarding. After more than a decade of successful operation of the LEP accelerator at CERN, and of accelerators at Stanford and Fermilab in the USA, the Standard Model of elementary particles has been verified as a correct model describing fundamental interactions between matter constituents at presently achievable energies. However, it is commonly believed that
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Table 2.1: M.S. candidates from the ATLAS Construction and Elementary Particle Physics: Physics Analysis projects from 1998 to April, 2003. There are an additional 12 student-projects from Gjøvik College not listed here.
<table>
<thead>
<tr>
<th>Name</th>
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Table 2.2: Ph.D. candidates from the ATLAS Construction and Elementary Particle Physics: Physics Analysis projects from 1998 to April, 2003.

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Table 2.3: Candidates from the ATLAS Construction and Elementary Particle Physics: Physics Analysis projects from 1998 to August, 2002.

<table>
<thead>
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<th>Number</th>
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<tbody>
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<td>Articles in refereed journals</td>
<td>239</td>
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<tr>
<td>Books</td>
<td>1</td>
</tr>
<tr>
<td>Published talks at intl. conferences</td>
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<tr>
<td>Other reports and talks</td>
<td>449</td>
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<tr>
<td>Outreach (articles, talks, exhibitions)</td>
<td>132</td>
</tr>
<tr>
<td>Outreach (newspapers, radio, TV)</td>
<td>21</td>
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</tbody>
</table>

Table 2.4: Numbers of publications and outreach contributions from the ATLAS Construction and Elementary Particle Physics: Physics Analysis projects from 1998 to August, 2002.
the model is only an effective, low-energy approximation of some more fundamental theory. Even within the Standard Model there exist several burning unanswered questions, that are expected to be answered using the data collected at the LHC. One of them is the origin of mass of elementary particles. The present concept is that the mass is due to interaction with the so-called Higgs field. The LHC should either confirm the minimal Higgs sector structure of the Standard Model, or provide experimental hints on the real nature of the origin of mass.

Another fundamental and still unanswered question is why all the observed Universe is built of matter, while matter and anti-matter should have been created in equal amounts in the Big Bang. To explain the observed asymmetry (which gave rise to our existence!) the so-called CP-asymmetry of elementary interactions is needed. In fact weak interactions described by the Standard Model predict CP asymmetries, however it turns out the magnitude of these is far too small to explain the matter-anti-matter asymmetry of the Universe. Yet another problem comes from observational evidence that most of the mass of our Universe cannot be due to the ordinary matter we know. At least 20% of it must be carried by unknown, weakly interacting particles (Dark Matter). A supersymmetric extension of the Standard Model provides probably the best known candidate for such a Dark Matter particle. It necessitates the existence of the light Higgs boson, in agreement with the present bounds from precise measurements (from LEP among others). Supersymmetric partners of Standard Model particles provide natural cancellations of interactions which otherwise would make the Higgs boson very heavy, and thus solve one of the basic problems of the Standard Model.

2.2.1 ATLAS

Commissioning and running of ATLAS

The project will have obligations in the commissioning and the operation of ATLAS and the SCT. This requires a substantial presence at CERN, both for debugging and understanding the SCT, and for general operation of the detector. We will be required to be active in the general maintenance of the SCT, and it is necessary to be prepared for a scenario where a number of replacement parts are bought, produced and commissioned by us. It is desirable to have at least one physicist or high level technician permanent present at CERN in order to take care of work expected from us as part of commissioning and running the SCT. In addition it is likely that every ATLAS physicist will take data-acquisition shifts when ATLAS is running, maybe a few weeks each year per physicist. Operation of ATLAS is costly, and we will have to contribute financially to ATLAS Maintenance and Operation.

The search for Higgs bosons with ATLAS at LHC

Electroweak and short-distance strong interactions are apparently described with impressive precision by the so-called Standard Model of fundamental particles and interactions. The Higgs mechanism is an integral part of this model which describes how three of the four vector bosons which mediate the weak and electromagnetic forces obtain mass (electroweak symmetry-breaking). A related feature of the mechanism also offers an explanation for how the fundamental matter particles, leptons and quarks, obtain mass. The Higgs mechanism is the only part of the Standard Model which remains unconfirmed. The main predictions of the Higgs mechanism are that there should exist at least one incomplete multiplet of heavy particles with spin 0 and that the coupling strengths of the Higgs bosons to matter particles should be proportional to their mass.
Understanding the origin of electroweak symmetry-breaking is considered so important that the Higgs search served as the first (but not only) benchmark for the design and optimization of the ATLAS and CMS general-purpose detectors at LHC.

The LEP collider was shut down in November, 2000. At that time there was provisional but weak evidence (significance of about 3 standard deviations) for Higgs boson production at the extreme limit of LEP’s combined sensitivity at a Higgs boson mass of about 115 GeV/c\(^2\). The final results, after extensive detector calibration and analysis optimization, indicate a signal significance reduced to about 1.7 standard deviation, in other words there is no significant evidence for Higgs production within the Standard Model at LEP. Searches for Higgs bosons predicted by other models (among them, minimal Supersymmetry) as well as the most serious contender for the Higgs mechanism (Technicolor)? also resulted in negative results.

The CDF and D0 experiments at Fermilab’s proton-antiproton Tevatron collider have begun to collect data after extensive upgrades of the collider and the detectors. The laboratory plans to collect data until the results from LHC become superior to Fermilab’s, perhaps a year or so after the LHC startup. During this time the experiments estimate that they can clearly reject the SM Higgs hypothesis up to the 95\% CL limit established by electroweak precision measurements (around 200 GeV/c\(^2\)), or provide observational evidence up to about 175 GeV/c\(^2\) (with a hole in the sensitivity between 125 and 155 GeV/c\(^2\)), or make a clear discovery if the mass is in the region preferred by the electroweak precision measurements and the inconclusive direct search results from LEP around 115 GeV/c\(^2\). Thus it is possible that the Tevatron may provide interesting results that influence the LHC program for Higgs boson searches.

The first step of the LHC Higgs program will be to confirm or disprove the existence of one (or perhaps more) Higgs bosons, depending on the results from the Tevatron at the time of the LHC startup. This will require the study of several final states, depending on the mass of the Higgs boson, and benefit from a combined analysis of the search results, similar to what was done at LEP. Assuming at least one Higgs boson is discovered, the next step will be the detailed study of its properties (mass, decay width, production rates, branching ratios). With higher luminosity one can make direct tests to confirm that the observed particle is a scalar boson (spin-parity determination) and, although exceedingly difficult even with the highest luminosities expected at LHC, the study of pair-produced Higgs bosons would allow the form of the unknown Higgs potential to be probed.

The Norwegian ATLAS group has considerable experience with Higgs and other particle searches, precision electroweak measurements, and \(b\)-quark identification and physics. Thus we have a good potential for making important contributions to the Higgs searches at LHC.

Concerning the search for Higgs bosons and new physics there are plans to analyze final states involving two and four charged leptons.

**Searches for Supersymmetry**

Supersymmetry (SUSY) will be one of the major subjects of LHC investigations, and if it is realized in Nature, it should be seen after a few months of data-taking. It provides a wealth of possible signatures, and thus it is driving already now the reconstruction software development for the ATLAS detector. There are several interesting physics SUSY analyses which are within the present competence of the Norwegian physics analysis group and can become subjects of theses. Below some examples are given.
• Reconstruction of the masses of the supersymmetric partners of the top and bottom quarks (stop and sbottom). Existence of relatively light stop quark is important from the point of view of the stability of the mass of the Higgs boson. Stop and sbottom mass measurements require insight into interesting reconstruction aspects connected with hardware activities of Norwegian groups. Tagging of b-quark jets, which requires precise understanding of the central silicon tracker detector is an example.

• Study of the polarisation of the top quarks and τ leptons from decays of supersymmetric particles. Spin or “handedness” information, which are essential to prove that the Supersymmetry is indeed the source of observed effects, can be accessed this way. Final states containing τ leptons and top quarks are supposed to be important in the many of the SUSY models allowed by the present constraints.

• Topological searches for SUSY, based on reconstructing and counting “objects” like “missing” transverse energy, leptons, photons, jets and b-jets with high transverse momentum. Analyses of this type will be important at the start-up of the data-taking to explore the characteristics of new physics.

• Rare decays of B mesons. For example, the branching fraction of yet unobserved decay \( B_s \rightarrow \mu^+ \mu^- \) is supposed to be on the level of \( 10^{-9} \) in the Standard Model and around 10 times larger in SUSY (assuming sparticles with masses of the order of 1 TeV, thus quite heavy). Measurement of the Standard Model branching fraction is expected to be within the reach of ATLAS. Precise understanding of the track reconstruction close to the primary vertex is essential for this type of analyses.

• Search for the lightest Higgs boson from the decays of supersymmetric particles. Accompanying signature of “missing” transverse energy and/or of high energy leptons facilitates the observation of the \( h \rightarrow b\bar{b} \) decay compared to the Standard Model case.

### 2.2.2 Theoretical particle physics

Theoretical particle physics aims to relate experimental facts to theoretical frameworks, as well as to study the internal consistency of such frameworks, and finally to suggest phenomena that can be studied at present and future high-energy particle accelerators.

In order to be effective, research in theoretical particle physics must quickly be able to pick up and build on new ideas that come up, as well as on emerging experimental evidence in a variety of fields. Therefore, the planning will not be very detailed, we here only outline some broad features of what is foreseen over the next years.

Over the next few years, the particle physics research will concentrate on the following broad areas:

1. **CP violation.** This includes CP violation within the Two-Higgs-Doublet Model, with applications to the LHC, a topic currently studied by Ph.D. student Wafaa Khater. We foresee extensions of this into the near future (beyond Khater’s Ph.D. programme). Also, we study CP violation in the Minimal Supersymmetric Standard Model (MSSM), with Ph.D. student Alexander Vereshagin.

2. **Supersymmetry phenomenology.** This work includes how to determine masses of short-lived supersymmetric particles from cascade decays, in collaboration with Ph.D. student
Borge Gjelsten in Oslo. A new Ph.D. student, Are Raklev, is also likely to work in this area. The main applications will presumably be for experiments at the LHC.

3. **Extended Higgs sector.** This topic includes studies of the “Standard-Model-Like scenario”, how one at various future accelerators can discriminate against the Standard Model, if some other “similar” model is realized in Nature.

4. **Extra dimensions.** The phenomenology of extra dimensions will continue to be studied (in particular, we will study angular distributions which are characteristic of graviton exchange). At the moment Ph.D. student Erik Dvergsnes is working on this, we foresee extensions of this into the near future (beyond his Ph.D. programme), both for the LHC and for a Linear Collider.

5. **Neutrino physics.** Much of the recent experimental work in this area has taken place in Japan and Canada. Since an interesting experiment is now being prepared with a beam from CERN, and since there are many fundamental questions related to neutrino masses, our involvement in this topic will also continue.

6. **B-physics.** Decays of particles containing heavy quarks, especially B-mesons will be studied extensively at the LHC. Some data are already available from other experiments. When LHC is in operation, a lot of data on B-physics will be available, and comparison with theory will be performed. Thus, precise calculations of the decays will be needed, in order to see if the Standard model is correct in describing nature up to the available energies, or if new physics is needed. Especially, we will see if one parameter (as it is in the Standard Model) is enough to describe CP-violation.

Ph. D. student Aksel Hiorth will finish his work on B-physics within a few months, but a couple of master students will work on aspects of these problems. Colleagues in Zagreb (Picek, Kumericki) and Ljubljana (Fajfer) will also be involved in this research.

7. **Quark spectroscopy and quark correlations** We work on various aspects of quark spectroscopy, and together with colleagues at Univ. of S. Carolina (Myhrer et al.) we continue our studies of quark-quark correlations to describe electroweak observables of baryons.

8. **String theory** The ultimate level of unification would include gravity, and for this purpose superstring theories have been invented. These are ‘theories of everything’, so in particular they have the super-gauge-symmetry built into them. This allows us to analyze super-gauge-theories in new and surprising ways, which in some cases have yielded astonishing insight into these theories.

One of the long-standing projects is to use some of the tools and insights provided by string theory to extract ‘exact’ properties of gauge-theories.

Ph.D. student Håkon Enger will still work within this field

Much of this planned research will be carried out by doctoral-degree students and a number of master students. Of course, a healthy visitor and travel budget is essential in order to carry this through at an international level.

In addition to the NorFA-network (coord. P. Eerola, Lund) mentioned above, we participate in other networks. P. Osland participates in the NORDITA-project: “Astroparticle
physics and cosmology” (coord. S. Hannestad) and the NorFA network: “Theoretical Particle Physics and Cosmology” (coord. P. Damgaard). J.O. Eeg participates in the EU-funded network EURIDICE (coord. G. Pancheri), and C.A. Lütken participates in a network on Strings funded by NorFa (coord. P. Di Vecchia).

2.2.3 BABAR plans until 2007

The excellent performance of the PEP II B factory provides for various physics opportunities. The present BABAR data sample already consists of over 200 million B mesons, enabling studies of CP violation and rare decays, both of which are sensitive for discovering new physics. The sample of B-mesons is expected to increase to over a billion by 2007, further improving the discovery potential of BABAR.

The analysis efforts which we started in Bergen and want to continue in the future fall under these topics. Our contributions to rare decays consist of an inclusive study of the electroweak penguin decay $B \to X_s \ell^+ \ell^-$ as well as the exclusive channels $B \to K + \pi^\prime s \gamma$, where the $K$ and the pions form a higher $K^*$ resonance. In the $B \to X_s \ell^+ \ell^-$ analysis our goals are to conduct the first observation of this decay and to measure its branching fraction within the next year and later update the analysis with higher statistics to explore the lepton forward-backward asymmetry, as this is one of the most sensitive tests for new physics. The exclusive radiative modes provide excellent master thesis topics similarly as the exclusive charmonium modes and yield interesting tests with high statistics including CP violation.

Measurements of the CKM matrix and the unitarity triangle provide an important test of the Standard Model as new physics effects may enter here. Considerable progress concerning precise measurements is expected within the next few years as many new results will become available and theoretical uncertainties will be reduced. Thus it is important to continue with the unitarity triangle fitting and conduct analyses that are helpful in constraining the allowed region. One analysis we have started in Bergen consists of a study of the time-dependent CP asymmetry in $B \to D^0 K_s$, which allows $\sin(2\beta + \gamma)$ to be measured. With the present BABAR data sample a first measurement of the branching fraction is expected but for a reasonable measurement of the CP asymmetry a sample of 500 fb$^{-1}$ is necessary.

2.2.4 Manpower

The permanent staff members that will participate in The High Energy Particle Physics Project are listed in Table 2.5.

Long-range and consistent support is needed from the Physics Departments at the Universities of Oslo (UiO) and Bergen (UiB), with respect to permanent staff. Several of the project members will retire in the project period (Buran, Høgåsen, Lillestøl), and timely replacements are needed to maintain the present level of activity. Their successors must be hired well before their retirement to ensure continuity. The project will also work to expand the number of staff, but at the time of writing it seems more realistic to put efforts into maintaining the present staff numbers.

The project will have a large number of possibilities for interesting and challenging subjects for master and doctor degrees. In addition post-docs and doctoral students are needed to fulfill the ambitious goals of the project. A constant number of 3 post-docs (2 experimental, 1 theoretical) and 6 doctoral students (4 experimental, 2 theoretical) would be natural in such a project.
<table>
<thead>
<tr>
<th>Name</th>
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<tr>
<td>Lars Bugge</td>
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<td>Kjell Martin Danielsen (techn.)</td>
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<td>Jan Olav Eeg (theory)</td>
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<td>Anna Lipniacka</td>
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<td>Carsten Lilthken (theory)</td>
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Table 2.5: Permanent staff members that will participate in *The High Energy Particle Physics Project*

### 2.2.5 Budget

Since the previous “Physics Analysis” and “ATLAS hardware” projects are merged in the new project structure, and since the running-in and possible repairs and other maintenance of the ATLAS Silicon Tracker system presents a serious and very important challenge, it seems reasonable that the new “High Energy Particle Physics” project plans for an initial budget somewhat larger than either of the two former projects’ early grants, but not as large as the sum since many of the project members will combine several roles in the ATLAS experiment. Particularly in the installation and commissioning phase, the project must plan for a continuous presence at CERN of at least two physicists or engineers. In addition to the salary costs implied by the previous section, the estimated running costs would, according to the argumentation above, be of the order 2.5–3 MNOK/year. ATLAS computing M&O costs are covered by the Grid project, see Chapter 5. The cost to completion is the difference between the total budget for the ATLAS Construction project during the period 1998-2005 and a recent, revised estimate of the actual costs based to a large degree on actual expenditures and signed contracts. The details are given in the annual reports of the ATLAS Construction project. The M&O cost estimates and the definitions of the categories A and B are described in a report by the CERN Resource Review Board (CERN-RRB-2002-036).
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Table 2.6: The High Energy Particle Physics budget for 2006–2011. The expenditures are in kNOK and based on the 2003 price index. The stipends below the total must be financed outside the budget of this programme.

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**Bibliography**


Chapter 3

High Energy Nuclear Physics

We still know little about the properties of nuclear or hadronic matter, i.e. matter that is composed of quarks and bound by the strong force - one of the fundamental forces in nature. Thus our knowledge about protons and neutrons, the constituents of the nucleus which make up more than 99.9% of the visible mass of the universe, remains rather sketchy. Even if we know what the basic building blocks of the universe are, we still have a long way to go until we can describe the complex properties of matter and its various manifestations.

Nuclear matter is only one possible manifestation, other phases might exist in the interior of neutron stars. At very high densities and temperatures, the nucleons are expected to dissolve into their constituents and to form a plasma consisting of quarks and gluons - the so-called quark-gluon plasma. Such a phase transition from the quark-gluon plasma into hadronic matter, i.e. into our present-day matter, took place in the early universe, about 1 millisecond after the Big Bang.

But how can high enough temperatures and energies be generated in the laboratory to release the quarks from their hadron cages? By smashing heavy ions together at very high energies large amounts of energy are squeezed into a very small space. This should free the quarks and the gluons into a small bubble of quark-gluon plasma - a new state of matter. In this state, quarks could freely roam over long distances instead of being confined within "bags" of the size of a nucleus, as they are in ordinary nuclear matter.

3.1 Ultrarelativistic Heavy Ion Collisions

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 various energy scales the properties of the nuclear interaction and its macroscopic manifestations. At low energy densities, hadronic bound states are the degrees of freedom of nuclear matter. At higher energy densities, the degrees of freedom are quarks and gluons, interacting via the strong force.

The equation of state (EOS) of nuclear matter determines the dynamics of heavy-ion collisions and stellar processes, such as supernovae explosions. The compressibility characterizes the ability of nuclear matter to withstand the gravitational pressure. It also defines the maximum mass a neutron star can sustain prior to collapsing into a black hole. This is the motivation behind the exploration of the EOS at 2-5 times the ground-state density and non-zero energy density. In this region, the EOS is governed by the in-medium properties of
baryons and mesons.

The focus of the research in the ultrarelativistic energy regime is to study and understand how collective phenomena and macroscopic properties 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 Quantum Chromodynamics (QCD) is the occurrence of a phase transition to a deconfined state, the quark-gluon plasma (QGP). Primordial matter at the birth of the universe consisted of such a plasma.

3.2 The phase diagram of nuclear matter

![Phase Diagram](image)

Figure 3.1: The phase diagram summarising the present understanding about the structure of nuclear matter at different densities and temperatures.

Even before QCD was established as the fundamental theory of strong interaction, it has been argued that the mass spectrum of resonances produced in hadronic collisions implies some form of critical behaviour at high temperature and/or density. The subsequent formulation of QCD led to the suggestion that this critical behaviour is related to a phase transition. The existence of a phase transition to a new state of matter, the Quark-Gluon Plasma, at high temperatures has been convincingly demonstrated in theoretical calculations (Lattice QCD).

A generic form of the QCD phase diagram is shown in Fig. 3.1. The net baryon density is the density of baryons minus the density of anti-baryons. Nuclear matter exists in different phases as function of temperature and density. The liquid phase is realized in atomic nuclei at zero temperature. At low densities, the nucleons behave like a gas. As the temperature is raised, the nucleons are excited into baryon resonances and quark-antiquark pairs (mesons)
are produced. At higher temperatures, a phase transition from hadronic matter to quark-gluon matter takes place (deconfinement). The transition temperature is about 170 MeV (at net baryon density zero). Such conditions did exist in the early universe a few microseconds after the big bang and can be created in heavy-ion collisions at ultrarelativistic energies as provided by the accelerators SPS (CERN), RHIC (Brookhaven) and the future LHC (CERN). In highly compressed cold nuclear matter - as it may exist in the interior of neutron stars - the baryons lose their identity and dissolve into quarks and gluons. A first-order phase transition is expected at low temperatures and high densities. The critical density, at which this transition occurs, however, is not known. The research program at the new facility at GSI aims for the exploration of the high-density area of the phase diagram. This approach is complementary to the investigations performed at the CERN-SPS, the RHIC facility at Brookhaven, USA, at the future LHC facility (ALICE project) at CERN.

3.3 Details of present (and past) experimental programme

3.3.1 History - 1998-2002

The study of relativistic heavy ion collisions provides a unique opportunity to search for a new predicted state of matter - the quark-gluon plasma (QGP). The quark-gluon plasma transition must have happened in the early universe; this is perhaps the most compelling motivation for its study in laboratory experiments. A number of experimental signatures which could signal the QGP have been proposed. Based on a careful evaluation of all experimental results from the CERN lead program 1993-2000, including the enhanced strange particle production from our NA57 and WA97 experiments, it was concluded that a deconfined state of quarks and gluons (QGP?) most likely was observed in the laboratory. The CERN results strongly increased the expectations for the Brookhaven RHIC experiments which test the CERN findings and extend the known phase diagram at much higher centre-of-mass energies. The first RHIC physics run in the summer of 2000 revealed a regime closer to nuclear transparency and primordial conditions than ever observed before in heavy ion collisions. Presently RHIC is running at full energy, $\sqrt{s_{NN}} = 200$ GeV. We participate in the RHIC BRAHMS experiment which studies the properties of strongly interacting matter both in the nuclear fragmentation region and in a central almost baryon-free region. As an integral part of the experimental program for LHC, a dedicated heavy ion collider (ALICE) that will take data from year 2007 has been accepted. With a centre-of-mass energy of 5.5 TeV per nucleon, this will bring us into the true high-energy heavy-ion regime with a qualitatively improved environment for the study of strongly interacting matter. From then on, the Norwegian heavy ion community will concentrate its activity on the ALICE detector.

The ISOLDE (Isotope Separator On-Line) facility at CERN is a world leading laboratory for production, studies and applied use of short-lived radioactive isotopes of most elements. The Nuclear chemistry group at the University of Oslo takes part in nuclear physics experiments and in development of target sources.

The study of nuclei at high spin gives information about how fast rotations influence the behaviour of the quantum-mechanical system. The nuclear many-body system under rotation may develop various exotic shapes like strongly elongated, axially symmetric hyper-deformed and triaxial shapes where the symmetry is broken. Consequences of triaxiality for a rotating quantum-mechanical system are central issues in high spin physics.

Nuclear theory in Norway has always worked in close contact with experimental activity
and has aimed at describing observed nuclear properties in terms of theoretical models. The theoretical activity has been centred around the study of the properties of nuclear matter at extreme conditions, from new collective states of elementary particles (quark-gluon plasma) to extreme nuclear states (for example exotic nuclei near the proton and neutron drip lines, super-heavy elements, hypernuclei and neutron stars). In all these areas there is experimental activity going on at CERN, and theorists and experimentalists share a common responsibility for obtaining new and unified understanding of this important part of subatomic physics.

### 3.3.2 Nuclear collisions at ultrarelativistic energies: fixed target experiments at the SPS

The WA97 and NA57 experiments address strangeness production in Pb-Pb collisions at 158 GeV per nucleon.

The WA97 set-up is shown schematically in Figure 3.2. The target and the silicon telescope were placed inside the homogeneous 1.8 T magnetic field of the CERN Omega magnet. The heart of the WA97 spectrometer was the silicon telescope consisting of 7 planes of silicon pixel detectors with a pixel size $75 \times 500 \mu m^2$, and of 10 planes of silicon microstrips with a $50 \mu m$ pitch. The telescope had $5 \times 5 \text{ cm}^2$ cross section and contained $\approx 0.5 \times 10^6$ channels. This tracking device was placed 60 cm behind the target (90 cm for the p-Be and p-Pb reference runs) slightly above the beam line and inclined (pointing to the target) in order to accept particles at central rapidity and medium transverse momentum.

The WA97 experiment observed a strong increase in the production at mid-rapidity for $\Lambda$, $\Xi$ and $\Omega$ hyperons and anti-hyperons in Pb-Pb collisions with respect to proton induced collisions. This enhancement exhibited a marked hierarchy, i.e. the $\Omega$ enhancement is larger than that of the $\Xi$, and the $\Xi$ enhancement is larger than that of the $\Lambda$.

The NA57 experiment was designed to investigate the onset of the strangeness enhancement by extending the multiplicity coverage at full SPS energy (158 A GeV/c). Hyperon results are presented in figure 3.3.

Several interesting features can be noted. The general enhancement pattern observed
by WA97 is confirmed (the four most central bins correspond to the WA97 centrality bins). The particles having at least one quark in common with the nucleon ($\Lambda$ and $\Xi^-$) all show a rather continuous increase with multiplicity, whereas the situation for the particles having no common quark with the nucleon ($\bar{\Lambda}$, $\Xi^+$ and $\Omega^- + \bar{\Omega}^+$), the situation is less clear. The $\Lambda$ distribution is rather flat, the $\Omega^- + \bar{\Omega}^+$ distribution is compatible with a continuous increase with multiplicity. The $\Xi^+$ distribution shows a strong suppression in the lowest multiplicity bin. The distributions shown in figure 3.3 contain all data for $\Omega^- + \bar{\Omega}^+$, but only 1998 data for $\Xi^-$ and $\Xi^+$. The onset of enhanced strangeness production is also studied by energy dependence. Results from lead-lead interactions at 40 A GeV/c compared to results from 160 A GeV/c are shown in figure 3.4. The points shown here are obtained using a multiplicity cut corresponding to the three most central bins in the 160 A GeV/c data. The $\Xi^-$ yield is quite similar in the two data samples, whereas the antiparticle yields are significantly suppressed in the more hadron-rich environment of the lower energy collisions.

Norwegian groups in WA97 and NA57 have had responsibility for the maintenance and development of the track reconstruction program, as well as establishing a correction chain to be used for WA97 data measured in 1996 and for all NA57 data. Norwegian groups have also been strongly involved in the general analysis activities of the experiments, and in the day-to-day operation of the experiment during data-taking periods.

The groups in Bergen (at the University of Bergen and Bergen University College) have been responsible for the track reconstruction program and for the event mixing program in the correction chain. Lately these groups have also taken responsibility for coordinating the corrections of $\Lambda/\bar{\Lambda}$ ratios in the NA57 1998 data sample.

The Oslo group has had responsibility for the changes of the simulation programs necessary to adopt the new correction chain. Also several trigger efficiency studies have been carried out. Students in Oslo continued to work on the analysis of kaon production from data measured by WA97.

A continued strong involvement in the NA57 data analysis is foreseen for the coming years. With Kristin Fanøbst’s move from the University of Bergen to Bergen University College, much of the activity will be concentrated in the latter group, where both Helstrup and Fanøbst will keep their specific responsibilities for components in the analysis chain, as well as take part in the overall analysis effort.

More details on the experiments WA97 and NA57 may be found at the web page http://www.cern.ch/WA97/ and in references given in the publication list.

3.3.3 Nuclear collisions at collider energies: BRAHMS at RHIC

The experiments at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, with a top energy of $\sqrt{s_{NN}} = 200$ GeV, have recently extended the known phase diagram to near-primordial conditions at centre-of-mass energies an order of magnitude above that of the SPS. The first RHIC physics run in the summer of 2000, employing Au-Au beams at $\sqrt{s_{NN}} = 56$ and 130 GeV, revealed a regime closer to to the Bjorken limit of nuclear transparency than ever observed before in heavy ion collisions. Subsequent runs have taken place at full energy, $\sqrt{s_{NN}} = 200$ GeV, utilizing the colliding systems Au-Au (2001–2002), $p$–$p$ (2002) and $d$–Au (2003). The Norwegian heavy-ion groups participate in the RHIC BRAHMS experiment which studies the properties of strongly interacting matter, both in the baryon-rich nuclear frag-
Figure 3.3: The yields per participant \( \langle N_{\text{wound}} \rangle \) measured by NA57 expressed in units of yields observed in p-Be collisions.

Figure 3.4: Energy dependence of \( \Xi \) and \( \Omega \) yields measured by NA57.
mentation zone, and in the baryon-poor centre-of-mass region.

The BRAHMS detector consists (shown in Fig. 3.5) of two movable magnetic spectrometer arms, the forward \((1.3 \leq \eta \leq 4.0)\) and the mid-rapidity arm \((-0.1 \leq \eta \leq 1.3)\). Local tracking is done by TPC’s and drift chambers, and particle momenta are obtained from deflection of the spectrometer tracks in the dipole magnets placed between tracking stations. Particle identification is then achieved using velocity data from time-of-flight measurements and Cherenkov counters. The particles \(\pi^\pm, K^\pm, p\) and \(\bar{p}\) can be identified over a wide rapidity range \((y \leq 4\) for \(\pi, y \leq 3.4\) for \(p\)) and over an approximate transverse momentum range of \(0.2 \leq p_T \leq 3\) GeV/c, dependent on \(y\) and particle type. Trigger information plus interaction point and centrality determination is provided by several global detectors: beam-beam counters positioned at \(\eta = 3 - 4\), a multiplicity barrel covering the range \(-2.2 \leq \eta \leq 2.2\), and zero-degree calorimeters.

In connection with the proton-proton run, the BRAHMS setup was enhanced with inelastic counters for efficient triggering on \(p-p\) collisions, and spectrometer triggers were added for full use of the luminosity. Recently, during the 2003 \(d-Au\) run, a threshold Cherenkov detector and an additional time-of-flight wall have been added in the MRS for improving PID at high transverse momentum.

The BRAHMS experiment investigates the yields and \(p_T\) spectra for identified charged hadrons as functions of rapidity, and has been highly successful so far. The first physics goal, which to a large extent is completed, is a detailed survey of bulk hadron production.

![BRAHMS detector diagram](image)

**Figure 3.5:** The BRAHMS detector.
at low-to-moderate $p_T$ at a broad selection of rapidities, probing the thermal and chemical conditions over the entire reaction zone. Among the basic questions addressed is the reaction dynamics and degree of stopping, and the strangeness production as a function of rapidity. Another important objective, requiring dedicated high-statistics runs, is studying the hard tail of hadron spectra ($p_T > 2$ GeV/c), in order to probe the early stages of ultrarelativistic heavy ion collisions.

Selected BRAHMS physics highlights from the Au-Au survey program are presented below.

![Figure 3.6: Distributions of $dN_{ch}/d\eta$ for centrality ranges of, top to bottom, $0 - 5\%$, $5 - 10\%$, $10 - 20\%$, $20 - 30\%$, $30 - 40\%$ and $40 - 50\%$. Statistical uncertainties are shown for all points.](image)

BRAHMS has measured the charged particle multiplicity $dN_{ch}/d\eta$ over a wide pseudo-rapidity ($\eta = -\ln[\tan(\theta/2)]$) interval (-4.7 < $\eta$ < 4.7) for both $\sqrt{s_{NN}} = 130$ and 200 GeV. The charged particle production in central (0 - 5%) Au-Au collisions at $\eta = 0$ increases from 553±36 at $\sqrt{s_{NN}} = 130$ GeV to 625±55 at $\sqrt{s_{NN}} = 200$ GeV. The particle production per participant pair increases slightly at mid-rapidity, suggesting a soft- and a hard-scattering particle production component. At high pseudorapidity, shifted to the reference frame of the beam ($\eta' = \eta - \eta_{beam}$) the particle production per participant saturates and is also independent of beam energy, consistent with the limiting fragmentation picture.

The antiparticle-particle ratios $N(\pi^{-})/N((\pi^{+})$, $N(K^{-})/N((K^{+})$ and $N(\bar{p})/N(p)$, integrated over $p_T$ and centrality (0 - 20%), are displayed in Figure 3.7. At midrapidity the $N(\bar{p})/N(p)$ ratio is 0.75±0.04 (compared to 0.64±0.07 at $\sqrt{s_{NN}} = 130$ GeV) indicating a significant increase in reaction transparency from the lower RHIC energy. The ratios are well reproduced by statistical model calculations assuming a constant temperature of $T \approx 170$ MeV and a strongly rapidity dependent baryochemical potential.

Rapidity densities $dN/dy$ for identified hadrons $\pi^{\pm}$, $K^{\pm}$, $p$ and $\bar{p}$ have been extracted over the entire interval $y \approx 0 - 3$ (refer to Figure 3.8.) The yields of the various charged hadrons drop less than 10% over the first unit of rapidity, where the baryochemical potential is low and particle-antiparticle pair production dominant. The rapidity distributions of protons and $K^{+}$ are significantly wider than those of the corresponding antiparticles $\bar{p}$ and $K^{-}$. A smooth
Figure 3.7: Antiparticle-to-particle-rations as a function of rapidity. The vertical lines show the statistical errors while the caps indicate the combined statistical and systematic errors.

Figure 3.8: BRAHMS preliminary: Rapidity densities $dN/dy$ versus rapidity for $p^\pm$, $K^\pm$, $p$ and $\bar{p}$. The data has been reflected about $y = 0$.

transition is seen between the central region and the fragmentation zone at $y \approx 3$, with SPS-like chemical conditions. Evidence of collective flow has been found at all rapidities, with the flow velocity falling at forward $y$.

The net proton number at mid-rapidity drops dramatically with rising $\sqrt{s_{NN}}$ from AGS up to RHIC energies, demonstrating the increasing transparency of the reaction (see Figure 3.9.) At RHIC the pair production mechanism is responsible for most of the baryon yields at mid-rapidity, while the bulk of the net protons are found at forward rapidities.

More details can be found at http://www4.rcf.bnl.gov/brahms/WWW/brahms.html and in references given in the publication list.
Figure 3.9: BRAHMS preliminary: Net proton distributions as functions of rapidity, for different center-of-mass energies. All data sets refer to 0 – 10% central collisions.

3.3.4 Toward the ALICE Experiment

The hot and baryon-free region of the QCD phase diagram will be explored in depth by ALICE. The nucleon-nucleon centre-of-mass energy for collisions of the heaviest ions at the LHC will exceed that available at RHIC by a factor of about 30, opening up a new physics domain. Heavy-ion collisions at the LHC access not only a quantitatively different regime of much higher energy density but also a qualitatively new regime mainly.

At the high centre of mass energies of $\sqrt{s_{NN}} = 5.5$ TeV at LHC, nuclear collisions yield a rich variety of so-called hard non-equilibrating probes (e.g. jets, heavy quarks) which are produced in the first fm/c of the collision. Beyond merely establishing signatures for its existence, the medium-dependence of these hard probes provides an unparalleled possibility for a detailed quantitative study of the transient partonic state. Hard processes can be calculated using perturbative QCD. In particular, very hard strongly interacting probes, whose attenuation can be used to study the early stages of the collision, are produced at sufficiently high rates for detailed measurements. Furthermore, weakly interacting hard probes become accessible. Direct photons (but in principle also $Z^0$ and $W^\pm$ bosons) produced in hard processes will provide information about nuclear parton distributions at very high $Q^2$.

To make full use of these possibilities requires sufficient integrated luminosity at collider energies to analyse very rare hard probes such as e.g. bottomonium production or $Z$-production in nucleus-nucleus collisions. Moreover, for the interpretation of these observables one needs to calibrate the medium-dependence of hard probes with respect to their unmodified behaviour. This requires benchmark measurements in $p-p$ and $p-A$ collisions at comparable $\sqrt{s_{NN}}$, and systematic scans in energy $\sqrt{s_{NN}}$ and nuclear size $A$. Ultrarelativistic heavy ion collisions at the LHC at a center-of-mass energy of about 5.5 TeV per nucleon might create a reaction volume with an energy density of about 1000 GeV/fm$^3$, which is orders of magnitude larger than the critical energy density needed for the creation of a quark-gluon plasma. The initial temperature will be about 1 GeV, and an enormous number of particles may be produced in
a single event.

The ALICE experiment is a dedicated heavy ion detector for the spectroscopy of baryon free partonic matter (Fig. 3.10). The physics goals are to determine the degree of equilibration of quarks and gluons, to measure the energy loss of partons in the hot plasma, to determine the initial and the critical temperature, to measure the degrees of freedom and to study deconfinement and chiral symmetry restoration. Penetrating probes - like photons and dileptons - which do not interact strongly are tools to study the early stages of the reaction.

Figure 3.10: The ALICE detector.

The physics program of the Norwegian groups be focused on sensitive probes for a deconfined quark-gluon plasma state:

1. Direct photons, high-pt π^0 spectra, jets
2. Heavy quarks: di-electrons (J/ψ, Y), open charm, strangeness

Therefore, we participate in the design and building of the PHOS electromagnetic calorimeter, which will measure photons up to an energy of 100 GeV, and in the High Level Trigger (HLT) project. An overview is presented at \( \text{http://www.fys.uio.no/elg/alice} \), from which also the latest ALICE status report can be downloaded.

**Photon Spectrometer - PHOS**

The measurement of photons over a large energy range from 10 MeV to 100 GeV by a high resolution, high granularity electromagnetic calorimeter (20000 PbWO_4 crystals with dimensions 2.2 x 2.2 x 20 cm, readout by Avalanche Photo Diodes - APDs) allows the reconstruction of neutral pions and etas produced at mid-rapidity. Spectra of pions can be studied up to very high \( p_T \); by comparing inclusive photon spectra and pion spectra, direct photons emitted
by the hot quark-gluon plasma can be deduced. The Norwegian groups participate in the
development of the detector and read-out electronics (pre-amplifier and the read-out controller
unit). The pre-amplifier has been modified for APD readout. Laboratory and beam tests are
in progress. The Norwegian groups currently work on a design and implementation plan for
the complete front-end and read-out electronics for PHOS. A new DAQ system for lab and
beam tests has been developed and is operational.

The heavy ion groups have supplied accompanying simulations of the physics capabilities
(acceptance and efficiency estimates for π0 reconstruction) and detector performance (punch-
through effect in the PIN-diode, comparison of APD and PIN readout in respect to the
signal-to-background ratio of π0 reconstruction). Simulations of counting and trigger rates
have been done for HIJING and PYTHIA events. Tests of various trigger algorithms (pure
analogue summing, digital filter operations and a combination of both) have been performed.

High Level Trigger - HLT

Hard probes are produced with small cross sections and/or have to be detected via rare
processes. Due to the large cross section for soft processes, the events are swamped by their
reaction products. Without a sophisticated high level trigger scheme, the available data
acquisition and recording bandwidth would be saturated by such soft events. Online event
reconstruction of events containing 10000 or more charged particles and selecting interesting
events makes it possible to exploit the full luminosity and to collect sufficient statistics of
hard probes.

The HLT system in ALICE solves the dilemma of the mismatch of the interaction and
detector readout rate (approx. 1 kHz for p+p and about 200 Hz for central Pb+Pb) and the
DAQ/taping rate (10-20 Hz). This is achieved by event rejection, region-of-interest selection
and data compression techniques. The heart of such a system is a fast pattern recognition pro-
gram running on a farm of clustered SMP-nodes partially equipped with FPGA co-processor
PCI boards. The Norwegian groups are developing fast and parallel tracking codes, running
both on CPU’s and FPGA’s, design and develop PCI-based FPGA co-processors (see Fig.
3.11) and also contribute to the design and performance monitoring of the PC-farm. Studies
that are performed by the local heavy ion groups include the development of methods and al-
gorithms for an on-line selection and inspection of dielectron candidates in order to reject back-
ground in the quarkonia-signal, a momentum filter for increasing the open charm signal, de-
tection of jets, the sharpening of the dimuon trigger and the pile-up removal in p+p collisions.
detector is by far the largest source of data, the efficient collection of data on the detector
is essential. Therefore, the Norwegian groups are involved in the design and implementation
of the Readout Controller Unit (RCU) of the TPC front-end electronics. More details may
be found at http://www.cern.ch/ALICE, http://www.fys.uio.no/elg/alice and the AL-
ICE project status report.

3.3.5 ISOLDE studies

ISOLDE at CERN is the largest facility in the world for production and investigation of short-
lived nuclei. Detailed descriptions of ISOLDE can be found at http://isolde.web.cern-
ch/ISOLDE/welcome.html. The basic parts of the facility are two on-line mass separators,
the GPS (general purpose separator) and HRS (high resolution separator). REX-ISOLDE, a post-accelerator for radioactive beams, is now a facility open for users. The isotope separators are CERN facilities, whereas the post-accelerator is classified as an experiment.

The nuclear chemistry group has participated in several projects at the isotope separators during the last year. These experiments have been directed toward two different regions of nuclei, i.e. the region beyond the doubly magic nucleus $^{132}$Sn and the region of strong octupole softness around the masses 220-230.

3.3.6 High spin nuclear structure studies

The goal of the nuclear structure project is a better understanding of the interactions between the nucleons. The study of nuclei at high spin give information about how these extreme conditions influence the behaviour of the quantum-mechanical system.

The nuclear many-body system may under rotation develop various exotic shapes. Most appealing are the strongly elongated, axially symmetric hyper deformed (HD) shapes with axis ratio 3:1, which are predicted in certain regions but still not realized experimentally. Nuclei may also develop shapes where the axial symmetry is broken. Consequences of triaxiality for a rotating quantum-mechanical system are central issues in high spin physics. Presently the group focuses on the search for and understanding of triaxial superdeformed (TSD) band structures in the region around Lu and Hf.

The main experimental facility for the nuclear structure experiments is the Euroball IV detector array currently situated at IRfS, Strasbourg, France. The Gammasphere facility at LBNL, Berkeley (USA) and GASP at INFN Legnaro (Italy) are additional spectrometers also used in the research.

3.3.7 Theoretical nuclear physics

Nuclear theory is dealing with problems that are relevant and essential to the CERN-related experimental activity.

Theoretical heavy-ion physics is addressing the reaction mechanism of relativistic heavy-ion collisions. The goal has been to gain adequate information on the statistical properties of
the quark-gluon plasma, primarily of the equation of state. The locally equilibrated state of quark-gluon plasma is formed, however, only in the intermediate stages of the reaction. The initial and final stages are far out of equilibrium and difficult to model, but very important to understand in order to obtain an accurate description of the reaction which is comparable to experimental results. Thus, any realistic model must include several modules, which are describing the different stages of the reaction. The final, so-called freeze-out module is particularly important because it describes the observables which are compared to experiment.

BONN-TT has played a role in pioneering successful use of few-body models for understanding drilpine phenomena, in particular halos (the low temperature, low density regime). The lessons from these studies have also served as guidance for ongoing ab-initio many-body attempts based on nucleonic constituents and their interactions. These studies have also been relevant for heavy-ion reactions and the study of neutron stars.

3.3.8 Short term plans - 2003–2005

The NA57 experiment made its final measurements in autumn 2001. Analysis is still ongoing, and resources for meetings and analysis will be necessary for 2003 and 2004. We expect the final analysis to be terminated during 2005.

In BRAHMS, several analysis projects utilizing existing data sets are in rapid progress. A survey of the bulk hadron production — particle ratios, spectra and yields — is carried out for \( p - p \) and \( d - Au \) collisions. These studies aim at providing reference spectra from hadronic sources, as opposed to the possibly deconfined system formed in Au-Au collisions. A paper on like-particle ratios from \( p - p \) collisions is in preparation. Important questions are connected to system size effects, for instance on stopping and strangeness production, and the properties of cold versus hot nuclear matter. A high-\( p_T \) pilot study with limited statistics is also addressing rapidity-dependent behaviour of the hard tail of charged hadron spectra from Au-Au collisions.

The Norwegian heavy-ion community plan active participation in RHIC RUN IV, scheduled during the winter and spring of 2004. The main physics motivation for continued involvement is precision studies of high-\( p_T \) spectra in Au+Au collisions at all rapidities. Other investigations requiring high statistics involve HBT interferometry and coalescence. Increased luminosity, improved PID capabilities and spectrometer triggers will facilitate the accumulation of high-quality spectra.

High-\( p_T \) hadrons are messengers from the early stages of ultrarelativistic heavy ion collisions, with jet formation through hard scattering of partons. They also probe QGP properties through energy loss for fast coloured partons propagating through the deconfined medium, leading to suppression of yields.

Information on early dynamics is also carried by direct photons, which only interact electromagnetically, and escape from the system without re-interaction. Their two main sources are prompt production from parton collisions during the initial stage, and thermal production in the QGP.

Earlier RHIC runs have revealed very interesting high-\( p_T \) phenomena, consistent with a picture with extensive jet production, but where partons traveling a long way through the plasma are absorbed or slowed:

- The high-\( p_T \) tail of hadron spectra from central collisions is suppressed, both compared to scaled yields from \( p - p \) collisions and from peripheral Au-Au collisions.
- Back-to-back correlations between high-$p_T$ hadrons is observed in peripheral collisions, but disappear in central collisions where the reaction volume is larger.

- Anomalous hadron ratios, with $p$, $\bar{p}$ yields dominating over meson yields, are seen at mid-rapidity for $p_T > 1.5 - 2$ GeV/cat $p_T \geq 3$ GeV/c.

**Identified charged hadron spectra**

The main ambition of the Norwegian BRAHMS contingent for the 2004 run is to measure high-statistics identified charged hadron spectra to high $p_T$ at selected rapidities over the entire accessible range, as function of collision centrality. An interesting question is whether the medium is more diluted at higher rapidities, which might be revealed through a diminished suppression effect.

With the new threshold Cherenkov detector C4 installed in MRS, pions can be identified up to $p \approx 9$ GeV/c over a rapidity interval extending up to $y \approx 1.3$. In the FS arm, the Ring Imaging Cherenkov Detector (RICH) allows $\pi - K$ separation up to $p \approx 25$ GeV/c and $K - p$ separation up to $p \approx 35$ GeV/c. With recent upgrades and with full luminosity, we hope to do detailed studies of particle composition up to $p_T \approx 4 - 5$ GeV/c, exploring a large part of the reaction zone. Such data on high-$p_T$ identified hadrons will be very valuable in order to understand the mechanisms for parton transport and hadron formation, system evolution and the interplay between soft and hard processes.

**PHOS and $\pi^0$ spectra**

The photon calorimeter PHOS, which is being developed for ALICE, consists of PbWO$_4$ crystals with dimensions 2.2 x 2.2 x 20 cm. PHOS is designed to detect the full energy of electromagnetic showers of photons up to several tens of GeV. For the RHIC 2004 run, the plan is to bring a PHOS prototype, 1000 crystal matrix, to the BRAHMS interaction region, equipped with electronics, cooling system and a charged particle veto detector. Placed on the outer side of the beampipe it can in principle be moved to cover all rapidities. Installation, commissioning and data taking will take place before and during the run period of 2004. An application for financial support for a doctoral student dedicated to this project (Truls Martin Larsen) has been submitted to the Research Council.

The primary objective is accumulating high-$p_T\pi^0$ spectra as a function of centrality and rapidity. Such measurements will be complementary to those made by PHENIX and STAR at mid-rapidity ($\pi^0$ and charged hadrons) and BRAHMS' own measurements of charged hadrons at a wide range of rapidities. The suppression behaviour for the $\pi^0$ spectrum tails will be studied at selected $y$ values to probe the plasma properties in various parts of the reaction zone. A comparison of $\pi^0$ spectra to available charged hadron spectra at various $y$ would also give important clues on the hadron production mechanism. A search for direct photons will also be carried out if statistically feasible. This requires precision knowledge of the neutral hadron background.

The application of the PHOS prototype for $\pi^0$ measurement in the BRAHMS interaction region represents a very interesting physics project in its own right. Highly valuable for our ALICE preparations is also the testing of the PHOS detector response in a realistic collider high-multiplicity environment, with the associated software development and refinement of reconstruction algorithms. After RUN IV we will consider possible prolongation of
our BRAHMS involvement with one more running season for continued PHOS testing, depending on whether the aims of our high-\( p_T \) measurements and detector studies have been fulfilled.

### 3.3.9 Statistics of candidates and scientific production

The number of candidates having obtained their degrees within the Heavy Ion Physics / ALICE and theory project from 1998 to June 2003 are listed in Table 3.1. The current candidates (cand.scient. and dr. scient.) are listed in Tables 3.2 and 3.3.

<table>
<thead>
<tr>
<th>Degree</th>
<th>Number of candidates</th>
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<tbody>
<tr>
<td>Dr.scient.</td>
<td>1 + 2 + 9</td>
</tr>
<tr>
<td>Cand.scient.</td>
<td>7 + 8 + 9</td>
</tr>
<tr>
<td>Bergen University College projects</td>
<td>10 + 8 + 0</td>
</tr>
</tbody>
</table>

Table 3.1: Combined student statistics, ALICE Construction, Heavy Ion Physics and Nuclear Theory.

<table>
<thead>
<tr>
<th>Name</th>
<th>Experiment</th>
<th>University</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knut Aurbakken</td>
<td>ALICE</td>
<td>Bergen</td>
</tr>
<tr>
<td>Sondre Bø</td>
<td>ALICE</td>
<td>Bergen</td>
</tr>
<tr>
<td>Elin Enger</td>
<td>BRAHMS</td>
<td>Oslo</td>
</tr>
<tr>
<td>Gaute Grastveit</td>
<td>ALICE</td>
<td>Bergen</td>
</tr>
<tr>
<td>Manuel Henriquez</td>
<td>WA97</td>
<td>Oslo</td>
</tr>
<tr>
<td>Per Thomas Hille</td>
<td>ALICE</td>
<td>Oslo</td>
</tr>
<tr>
<td>Are S. Martinsen</td>
<td>ALICE</td>
<td>Bergen</td>
</tr>
<tr>
<td>Mads Mikelsen</td>
<td>BRAHMS</td>
<td>Oslo</td>
</tr>
<tr>
<td>Svein Lindal</td>
<td>BRAHMS</td>
<td>Oslo</td>
</tr>
<tr>
<td>Ronny Lystad</td>
<td>BRAHMS</td>
<td>Bergen</td>
</tr>
<tr>
<td>Ketil Røed</td>
<td>ALICE</td>
<td>Bergen</td>
</tr>
<tr>
<td>Sten Ingvar Solli</td>
<td>ALICE</td>
<td>Oslo</td>
</tr>
<tr>
<td>Gaute Øvrebekk</td>
<td>ALICE</td>
<td>Bergen</td>
</tr>
<tr>
<td>Kenneth Aamodt</td>
<td>ALICE</td>
<td>Bergen</td>
</tr>
</tbody>
</table>

Table 3.2: Master students on the Heavy Ion / ALICE project (status June 2003).

The number of publications are listed in Table 3.4. Publications in Theoretical Nuclear Physics are not included.

### 3.4 Plans for 2006-2011

#### 3.4.1 ALICE - short and long term plan

**Short term period - 2003-2005**

- Finish the design and prototyping of the RCU (TPC-FEE)
Table 3.3: Doctoral students on the Heavy Ion / ALICE project, paid by The Research Council, Quota program, Marie Curie program (status June 2003).

<table>
<thead>
<tr>
<th>Name</th>
<th>Experiment</th>
<th>University</th>
<th>Funded by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torsten Alt</td>
<td>ALICE</td>
<td>Heidelberg/Bergen</td>
<td>M.C.</td>
</tr>
<tr>
<td>Jens I. Jørdre</td>
<td>BRAHMS</td>
<td>Bergen</td>
<td>NFR</td>
</tr>
<tr>
<td>Jørgen Lien</td>
<td>ALICE</td>
<td>HiB</td>
<td>HiB</td>
</tr>
<tr>
<td>Constantin Loizides</td>
<td>ALICE</td>
<td>Frankfurt/Bergen</td>
<td>M.C.</td>
</tr>
<tr>
<td>Bjørn H. Samset</td>
<td>BRAHMS</td>
<td>Oslo</td>
<td>NFR</td>
</tr>
<tr>
<td>Anders S. Vestbø</td>
<td>ALICE</td>
<td>Bergen</td>
<td>NFR</td>
</tr>
<tr>
<td>Thomas Vik</td>
<td>ALICE</td>
<td>Oslo</td>
<td>NFR</td>
</tr>
<tr>
<td>Zhongbao Yin</td>
<td>BRAHMS/ALICE</td>
<td>Bergen</td>
<td>Q.P.</td>
</tr>
</tbody>
</table>

Table 3.4: Combined publication statistics, ALICE Construction and Heavy Ion Physics projects.

<table>
<thead>
<tr>
<th>Publication</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Articles in refereed scientific journals</td>
<td>12 + 108</td>
</tr>
<tr>
<td>Articles in other scientific journals</td>
<td>4 + 9</td>
</tr>
<tr>
<td>Talks and presentations at international conferences</td>
<td>16 + 151</td>
</tr>
</tbody>
</table>

- Participation in the design and prototyping of the PHOS FEE (based on the TPC-FEE)
- TPC and PHOS beam test
- HLT FPGA co-processor - algorithms and system integration

Installation in 2005-2007
- PHOS modules - FEE
- TPC electronics - RCU
- HLT farm

Commissioning in 2007

Data taking 2007-2011

ALICE will take its first data with pp collisions, because the LHC will be commissioned with proton beams, but also because pp physics is an integral part of the ALICE program. ALICE will in fact require some minimum amount of pp running throughout its operation: During the initial few years longer periods to both commission the detector and to take pp physics data, and later in the program shorter periods to start-up and calibrate the detector prior to every heavy ion period. Pb+Pb collisions, which provide the highest energy density, are foreseen immediately after the end of the first pp run. Even if of short duration and at low initial luminosity, this first physics pilot run will provide already a wealth of information on global event properties and large cross section observables, as it was the case during the very
successful commissioning of RHIC. For low cross section observables, in particular the hard processes which are a main focus at the LHC, some further 1-2 years of Pb+Pb runs at the highest possible luminosity should provide sufficient statistics. One period of pPb running is required early on, most likely in the 3rd year of LHC operation. This will provide reference data and will allow to determine nuclear modifications of the nucleon structure functions (shadowing), which is necessary for the interpretation of the Pb+Pb data. The best way to study energy density dependencies is to use lower-mass ion systems. We plan to study first Ar+Ar collisions over a period of 1-2 years. The global running scenario for the first 5-6 years of LHC running can be summarized as follows:

- Regular pp runs at $\sqrt{s} = 14$ TeV
- 2-3 years Pb+Pb collisions
- 1-2 years Ar+Ar
- 1 year p+Pb like collisions (p-, d-, α-Pb)

**Offline analysis 2007-2011**

The Norwegian groups are heavily involved in the offline analysis of the WA97 and NA57 experiments at SPS with responsibilities in the coordination of the main tracking software in WA97/NA57 for central components in the analysis and correction chains. Norwegian Universities also made a visible contribution to the offline production and analysis in WA97/NA57, accounting for about 20% of the total computing resources in the experiments. Along with the general physics output, these activities have also generated a significant know-how in the organisation and management of high volume physics data analysis and distributed computing. Similar activities are now also carried out in BRAHMS.

The ALICE offline production and analysis will be based on grid technologies. The ALICE offline software project has developed the grid analysis tool AliEn, which will become the basis of the ALICE offline activity. AliEn can be interfaced to a long range of grid middleware fabric, including the European Data Grid supported by the CERN IT division.

The Norwegian heavy ion community wants to continue its involvement both in the development and application of offline software. Norwegian Alice grid activities will be coordinated by the group at Bergen University College. We have been fortunate also to attract interest from Parallab, the well established Parallel Computing Laboratory with strong links to Department of Informatics at University of Bergen. The combined expertise from Parallab and the heavy ion community will form a very strong group inside ALICE analysis, with coverage of all aspects of the offline software complex, which should provide for important visibility both within ALICE and within the informatics community. Aspects of grid-computing are further elaborated in the LHC Computing Grid project (see Chapter 5). This project provides further integration between Norwegian grid activities within the ATLAS and ALICE activities.

**ALICE running after 2011**

For the later phase, there are a number of running options, the relative importance of which will depend on the initial results. For a direct comparison of the Pb+Pb and pp data, a dedicated pp run at the Pb+Pb centre of mass energy, $\sqrt{s_{NN}} = 5.5$ TeV, is probably advisable.
A more complete energy density scan would require additional intermediate-mass ion runs. To map out the the A-dependence further pA runs with different nuclei could be necessary. Additional Pb+Pb runs at lower energy would allow to measure an energy excitation function and to connect to the RHIC results. Finally, some rare processes limited by statistics in the early runs could require additional high-energy Pb+Pb running. The list of running options for the second phase is summarised below:

- Dedicated pp or pp-like runs at $\sqrt{s} = 5.5$ TeV/nucleon
- Possibly another A+A system (O-O, Kr-Kr, Sn-Sn)
- Possibly another p(d,α)-A system
- Possibly low energy Pb+Pb run
- Further high energy Pb+Pb collisions

### 3.4.2 Nuclear physics beyond ALICE

Figure 3.1 has illustrated the complementary approaches of present and future ultrarelativistic collider experiments and next-generation fixed-target experiments toward a better understanding of the microscopic properties of strongly interacting matter. Colliders will address the physics of hot, deconfined QCD matter. Experiments at moderate energies will concentrate on the properties of hadrons in compressed nuclear matter, using penetrating probes, and on mapping the QCD phase diagram to locate the critical point and the phase boundary at large densities.

Novel phases of strongly interacting matter are expected to occur in the core of neutron stars where the density exceeds that of nuclei by up to a factor of 10. In this case, a variety of competing structures is predicted, such as condensates of mesons, a large population of hyperons or a plasma of quarks and gluons. Further progress in the understanding of the behaviour of strongly interacting matter at high densities requires new information on the properties of hadrons in dense nuclear matter, the deconfinement phase transition from hadronic to quark-gluon matter at high baryon densities, and the nuclear equation-of-state at high baryon densities.

**Super-dense baryonic matter - heavy ion physics with the Compressed Baryonic Matter experiment at GSI**

QCD matter at large baryon densities is not sufficiently explored, neither experimentally nor theoretically. Nuclear reaction experiments at the future facility at GSI (e.g. Compressed Baryonic Matter - CBM experiment) aim at a detailed and comprehensive investigation of super-dense baryonic matter. The research program includes the measurement of penetrating probes, which escape essentially undistorted from the compressed nuclear collision zone. The energies of the heavy-ion beams delivered by the proposed accelerator are optimized for studies of hadronic matter at moderate temperatures but very large baryon densities.

**Dense nuclear matter in the universe**

Violent collisions between heavy nuclei promise insight into an unusual state in nature, that of highly compressed nuclear matter. In addition to its relevance for understanding fundamental
aspects of the strong interaction, this form of matter may exist in various so far unexplored phases in the interior of neutron stars and in the core of supernova explosions.

The study of dense matter in the universe will profit in particular from the INTEGRAL satellite, launched on October 17, 2002 (the space physics group at UiB is involved in this project) and from the next generation of gamma-ray instruments. Despite considerable progress, the physics of core-collapse supernovae and their nucleosynthesis remains an active field of research in nuclear astrophysics. The equation of state of very neutron-rich low-entropy nuclear matter up to about five times nuclear saturation density remains an open and important problem.

Dense nuclear matter also plays an important role in mergers of two neutron stars and of a neutron star and a black hole. In these events, dense nuclear matter is heated to tens of MeV and most of this energy is emitted in form of weakly interacting particles. It is believed that the annihilation of neutrinos into $e^+e^−$ pairs may give rise to gamma-ray bursts.

Neutron stars are unique "cosmic laboratories" in which our theories of dense nuclear matter at densities exceeding $10^{15}$ g/cm$^3$ are used to construct stellar models and can then be confronted with astronomical observations. Nuclear physics should try to explain the observed properties of neutron stars. On the other hand, observations of neutron stars can be used to test and to constrain nuclear theory under extreme astrophysical conditions, far from those in the laboratory.

3.4.3 Theory activity in 2006 – 2011

The principle objective of Norwegian theoretical nuclear physics has during the last decade been to predict and analyze new and extreme forms of matter in the domain of nuclear physics. The focus has been (i) on models and predictions for a quark-gluon-plasma (QGP) and (ii) also on extreme, low-density nuclear states at the driplines, using both few-body (halo physics) and many-body techniques. The choice coincides with NUPECC recommendations, and members of our joint Bergen-Oslo team (BONTT) have also been called on to take part in the coining of the European and international priorities.

The BONTT activity has attracted a substantial number of students, and still does. It has also constituted the backbone for extensive international collaboration, such as the coordination of the RNB7 (Russian-Nordic-British Theory) collaboration, the leading theory group in Europe in halo physics, and the management of the European infrastructure facility BCPL (Bergen Computational Physics Laboratory). Our commitments are long-term commitments. Thus we expect also in the next decade to aim at underpinning the LHC-ALICE and ISOLDE activities at CERN. An added challenge is to strengthen our involvement at GSI, in view of the recent decisions on a substantial upgrade.

BONTT has had an active role in drafting the FP6 Integrated Infrastructure Initiative proposals in nuclear physics, and the theory network (TNET) of the EUROpean Nuclear Structure proposal (EURONS), is based on and coordinated by RNB7 (UK member). We also participate in another Integrated Infrastructure Initiative "Hadron Physics", in Networking and Joint Research activities. BCPL, which is separately suggested to continue its very popular activity, is applied for as a single European Infrastructure to provide further transnational access to European users. A large fraction of this is used for general nuclear physics problems. In addition, BCPL also applied for the continuation of the successful Marie Curie doctoral training activity under FP6.

Present nuclear physics targets highly energetic and extreme forms of matter which ex-
isted only in the early universe or (exist) in the middle of neutron stars and violent cosmic explosions. Thus our link to and dependence on insight in astrophysics has steadily increased, and we aim at a stronger interaction with Norwegian experts in the field. Studying the nuclear stuff under extreme conditions not only allows us to shed more light on the Universe we live in, it also puts our understanding of the creative processes involved and transition between bound and continuum structures under strong scrutiny. We expect the substantial investments being made in the coming decade to add substantially to the nuclear paradigm.

With Fig. 3.1 as guidance, our future activities will cover most domains; those of the QGP physics, but also the low temperature, low density domain of dripline halo-physics (ISOLDE physics). To this end we will continue the development and testing of our hybrid 3D-hydrodynamical models for QGP scenarios. We are developing a Multi-Module Model for describing the reaction's initial pre-equilibrium stage, the intermediate thermally equilibrated hydrodynamical stage, and the final freeze-out stage. In the near future we will concentrate on the possibly most accurate and detailed description of the freeze-out stage. This will enable us to simulate almost all measurable quantities and to study all aspects of the visible signals of QGP formation.

With few, although often exotic, bound states, emphasis is shifting to the continuum part of the spectra for dripline nuclei, posing fundamental questions about few-body-like resonances in many-body systems. Theory for reactions tailored to explore such structures has to be further developed at a quantitative level.

BONNT is also involved in current extension of many-body theory to encompass loosely bound nuclei, taking scattering between the nucleonic constituents more properly into account within a framework that aims at becoming self-consistent. A challenge is to include lessons from few-body (cluster) modeling of light halo nuclei.

BONNT takes part in this truly international endeavor also by sharing students, thus giving them a wide training. This kind of work is vital for future experimental success and thus a key element in the long-range plan. Contact with the nuclear chemists should be improved now when REX-ISOLDE is operating, also as a user facility where Scandinavian groups already take part.

We will only be true participants in this challenge if we have human capital involved, i.e. Norwegian participants and a Norwegian home base strong enough to operate both as host and participant. The recent hiring of L. Bravinia has improved the situation considerably. Since our commitments are projects of long-term nature, the Universities must already now assess the situation and take measures to prevent Norwegian theory in the field to go sub-critical.

### 3.4.4 Manpower

In order to harvest the fruits of time and money invested, human resources are needed for extracting the physics results. This requires a concerted effort toward NFR and the institutes in Oslo and Bergen.

The ALICE physics analysis program would need sufficient money for hiring stipendiats – at least one post-doc and three doctoral students per year and per institute dedicated to ALICE – and also for offering good working conditions to master students.

Long-range and consistent support is needed from the physics departments, with respect to permanent staff. Timely replacement of the professors Bernhard Skaali and Gunnar Løvhøiden (who reach age 67 in 2005 and 2006, respectively) is needed just to maintain the present level of activity. The situation is similar for the theory activity where Engeland re-
ties before the new project period, and Osnes and Vaagen reach retirement age during the new project period. Their successors must be hired well before their retirements, to ensure continuity. The ALICE analysis activity and the planned involvement in the CBM program also calls for an additional associate professorship in experimental heavy-ion physics in Oslo within a reasonable timescale.

The Norwegian hardware responsibilities within ALICE - the ongoing development and the upcoming periods of installation and commissioning - put an increasing demand on technical manpower. Since actual detector installation and commissioning will commence shortly, the vacant technical position in Bergen should be filled as soon as possible. At present, the electronics group in Oslo has a full-time senior engineer working on ALICE, while the Oslo heavy-ion group has a 40% share. This arrangement has been very successful and must be made permanent or expanded in favour of ALICE. It is, however, not quantitatively sufficient in view of our accelerating ALICE involvement, and also a full senior engineer position connected with the Heavy Ion / ALICE project in Oslo should be announced in the near future.

The present situation for Norwegian High Energy Nuclear Physics with respect to permanent scientific staff is summarized in Tables 3.5, 3.6 and 3.7; non-permanent staff can be found in Table 3.3.

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kristin Fanebust, college lecturer</td>
<td>Bergen University College</td>
</tr>
<tr>
<td>Håvard Helstrup, professor</td>
<td>Bergen University College</td>
</tr>
<tr>
<td>Arne Klovning, senior research scientist</td>
<td>University of Bergen</td>
</tr>
<tr>
<td>Gunnar Løvhøiden, professor</td>
<td>University of Oslo</td>
</tr>
<tr>
<td>Joakim Nystrand, associate professor</td>
<td>University of Bergen</td>
</tr>
<tr>
<td>Bjørn Pommeresche, senior engineer</td>
<td>University of Bergen</td>
</tr>
<tr>
<td>Dieter Röhrich, professor</td>
<td>University of Bergen</td>
</tr>
<tr>
<td>Bernhard Skaalii, professor</td>
<td>University of Oslo</td>
</tr>
<tr>
<td>Trine S. Tveter, professor</td>
<td>University of Oslo</td>
</tr>
<tr>
<td>Kjetil Ullaland, associate professor</td>
<td>University of Bergen</td>
</tr>
<tr>
<td>Jon Wikne, senior engineer</td>
<td>University of Oslo</td>
</tr>
<tr>
<td>David Wormald, senior engineer</td>
<td>University of Oslo</td>
</tr>
</tbody>
</table>

Table 3.5: Permanent staff in the physics departments in Bergen and Oslo working within the Heavy Ion / ALICE project.

The doctoral students presently associated with the heavy-ion project will have their dissertations in the years 2003 – 2004. A very serious shortcoming of the present budget is the lack of funding for hiring new doctoral students during the period 2003 – 2005. This grave problem should be addressed immediately.

### 3.4.5 Budget

The funding frame for the next 6-years period is based on a set of assumptions, which is not necessarily complete:

- The High Energy Nuclear Physics (HENV) program will be fully funded by the Research Council;
<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Csaba Anderlik, research scientist</td>
<td>University of Bergen</td>
</tr>
<tr>
<td>Larissa Bravina, professor</td>
<td>University of Oslo</td>
</tr>
<tr>
<td>Laszlo P. Czernai, professor</td>
<td>University of Bergen</td>
</tr>
<tr>
<td>Torgeir Engeland, professor</td>
<td>University of Oslo</td>
</tr>
<tr>
<td>Morten Hjorth-Jensen, professor</td>
<td>University of Oslo</td>
</tr>
<tr>
<td>Eivind Osnes, professor</td>
<td>University of Oslo</td>
</tr>
<tr>
<td>Jan Vaagen, professor</td>
<td>University of Bergen</td>
</tr>
</tbody>
</table>

Table 3.6: Staff in the physics departments of Bergen and Oslo working within the nuclear theory activity.

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Einar Hagebo, professor</td>
<td>University of Oslo</td>
</tr>
<tr>
<td>Per Hoff, professor</td>
<td>University of Oslo</td>
</tr>
</tbody>
</table>

Table 3.7: Staff in the nuclear chemistry group of Oslo, working on CERN-related projects.

- The experimental Norwegian nuclear physics at high energies will be concentrated on ALICE;
- A new nuclear physics instrumentation project will be launched in 2009;
- Funding for nuclear theory is included under HENP;
- Doctorate and Post. Doc. stipends are fully funded from 2006. This may permit the faculties to fund some stipends already in 2004-05 with reimbursement of expenses in 2006.
- It is assumed that computing will be covered under a separate budget for the Norwegian LHC Computing Grid project for ATLAS and ALICE.
- The universities will supply the necessary infrastructure and engineering resources.

The HENP budget for 2006–2011 is summarized in Table 3.8. The expenditures are in kNOK and based on the 2003 price index.

Travel expenses scale with the number of participating physicists. The travel activity will be high in 2006 and 2007 during installation and commissioning. When the current experimental heavy-ion program coalesces with data taking at ALICE in 2007-08 there will be at least 20 physicists plus students who will require travel funding. In addition, the estimated cost overruns for ALICE construction during the present programme (1.6 MNOK) are covered by the installation and commissioning budget during the first two years of the new program.

The ALICE M&O costs are categories A (common) and B for project deliverables, PHOS and HLT for Norway. Category B shall cover all repairs and upgrades. Total ALICE category A costs have been estimated to reach a level of around 6 MCHF in 2007 (no estimates for following years). Assuming a 1,2% contribution from Norway, the 2007 level will be around...
<table>
<thead>
<tr>
<th>Expenditure</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>SUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALICE installation, commissioning</td>
<td>1300</td>
<td>1300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2600</td>
</tr>
<tr>
<td>ALICE M&amp;O cat A</td>
<td>300</td>
<td>400</td>
<td>500</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>3000</td>
</tr>
<tr>
<td>ALICE M&amp;O cat B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>250</td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td>Travel &amp; subsistence</td>
<td>2000</td>
<td>2000</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>14000</td>
</tr>
<tr>
<td>Other HENP experiments</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>900</td>
</tr>
<tr>
<td>Theory</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>1500</td>
</tr>
<tr>
<td><strong>SUM</strong></td>
<td>4000</td>
<td>4100</td>
<td>3650</td>
<td>3800</td>
<td>3900</td>
<td>3900</td>
<td>23350</td>
</tr>
<tr>
<td>Doctoral stipends</td>
<td>1650</td>
<td>1650</td>
<td>1650</td>
<td>1650</td>
<td>1650</td>
<td>1650</td>
<td>9900</td>
</tr>
<tr>
<td>Post doc. stipends</td>
<td>650</td>
<td>650</td>
<td>650</td>
<td>650</td>
<td>650</td>
<td>650</td>
<td>3900</td>
</tr>
<tr>
<td><strong>SUM STIPENDS</strong></td>
<td>2300</td>
<td>2300</td>
<td>2300</td>
<td>2300</td>
<td>2300</td>
<td>2300</td>
<td>13800</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>6300</td>
<td>6400</td>
<td>5950</td>
<td>6100</td>
<td>6200</td>
<td>6200</td>
<td>37150</td>
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<tr>
<td><strong>Additional stipends</strong></td>
<td>2850</td>
<td>2850</td>
<td>2850</td>
<td>2850</td>
<td>2850</td>
<td>2850</td>
<td>17100</td>
</tr>
</tbody>
</table>

Table 3.8: The HENP budget for 2006–2011. The expenditures are in kNOK and based on the 2003 price index. The stipends below the total must be financed outside the budget of this programme.

400 kNOK. It is realistic to assume that this contribution will increase during the period. Category B expenses have not been estimated, but a range of 250 to 400 kNOK is assumed.

The stipend budget is based on 7 doctoral stipends and 2 post-doctoral stipends. Only a fraction of these can be financed by the budget of this programme. Additional stipends are required for theory.

The Norwegian share of the ALICE Cost-to-Completion, 177 kCHF, was paid in May, 2003 from the reimbursement from CERN to the Research Council of a loan given for the construction of LEP. The Research Council has divided the money between the ATLAS and ALICE projects.
Chapter 4

Advanced Instrumentation

4.1 Detector technology R&D

An advance in high energy physics and the understanding of the evolution of the universe is only possible with the development of new technologies and improved detection techniques that can be used in upgrades and/or future experiments. Thus, a continuous R&D program is vital for this field. An important project after the completion of the LHC in 2007 is a Linear electron-positron Collider. While LHC is understood to be mainly a discovery machine, a Linear Collider is a machine of precision measurements in many final states that allows one to pin down the New Physics. The Higgs boson is expected to be discovered at LHC. However, to determine whether this is the SM Higgs or a SUSY Higgs it is necessary to cleanly reconstruct many decay channels. This is a matter of resolution and backgrounds. Technology and technology R&D must be considered as integrated elements of experimental particle and heavy-ion physics projects. The knowledge accumulated during the LHC projects must be maintained, and the current momentum carried over to new projects. The lead time for constructing a large experiment is very long, 5-10 years. This implies that the instrumentation activities must be redirected to new experiments as soon as the ALICE/ATLAS are in the data taking phase, i.e. not later than 2008-9. In the heavy-ion field this could be the planned Compressed Baryonic Matter experiment at GSI, Germany. Interesting physics questions would be the production of heavy quarks in nuclear matter. Due to the low energies involved the rate would be low, and successful measurements would require high rate collisions and triggers, and corresponding high-speed detectors and ADC’s. This would represent a great challenge for developers of instrumentation. The measurement and identification of rare reaction products emitted in ultrarelativistic heavy-ion collisions require experimental techniques based on large-area, high-granularity, low-mass, high-speed detectors. The totality of these requirements can typically only be fulfilled with gaseous detectors with low-power, high-speed analogue and digital electronics directly integrated on the detectors. Alternative solutions are prohibitively expensive.

4.2 Technology for radiation detector systems

The technological trend of the last decade, which can safely be extrapolated also into the next ten years, can be characterized by:
- New detector materials; radiation tolerant/hard detectors; improvement in energy and spatial resolution; high data rates; high granularity and large area detectors;

- Large scale integration of detector elements and readout/processing electronics; System-On-Chip (SOC) electronics; programmable logic (FPGA) replacing application specific integrated circuits (ASIC), continued increase in processing power (Moore’s law);

- New methods for integration of detectors and electronics, and designs for reducing the power consumption. Currently the power budget for pixel detectors with electronics is 5-10 kW/m², which means that a high capacity cooling system is required;

- Increased focus on ultra high performance trigger processing systems for selection of rare physics events from an enormous flow of raw data, and to reduce the data volume to be stored on recording media to a manageable level.

4.2.1 R&D and commercial products in Norway

Silicon radiation detectors

SINTEF, partly in collaboration with AME, Horten, develops and produces Si-based radiation detectors. SINTEF offers prototyping and production of various categories of detectors, such as: single- and double-sided microstrip detectors, pixel detectors, pad detectors and drift chambers. Their radiation detector product line also includes micro-systems and micro-mechanics. SINTEF has had around 40 customers the last three years, among those, the ALICE ITS detector with a significant order for double-sided detectors. AME has more than 25 years experience in designing, developing and producing silicon based photo-detectors. AME shares a wafer fabrication unit with SINTEF.

Electronics and instrumentation

Products of particular relevance for particle and nuclear physics experiments would be SOC ASIC's, embedded solutions (processor based instrumentation), networking technology, and special circuits developed for tight integration with detectors. Low noise pre-amplifiers is a domain very specific for radiation detection electronics, also interesting for space instrumentation. The number of Norwegian companies doing in-house R&D in these fields is small. Nordic VLSI and Chipcon specialise in components and solutions for analogue, digital and mixed-signal applications, in particular for the communication market. IDEAS, whose first products were based on detector front-end electronics developed for CERN, now focuses on detection modules for gamma, beta and x-ray cameras for applications in medicine, industrial inspection, and physics.

4.2.2 Microelectronics at the Universities

Microelectronics is applied in most areas of experimental physics in addition to particle and nuclear physics, in particular space physics. Microelectronics activities are therefore an integral part of the experimental activities at the Departments of Physics in Bergen and Oslo. There is also a significant microelectronics activity at the Institute of Informatics in Oslo.

\(^1\) System-on-Chip
However, the groups are marginally staffed and are operating under difficult economical con-
straints.

4.2.3 The Norwegian Nano- and Microtechnology Centre (NMC)

This new laboratory offers exciting possibilities for R&D and manufacturing of micro-systems. It is a common laboratory for SINTEF and the UiO, partly financed by the Norwegian Research Council. The laboratory will focus on research in joint projects with staff at the Department of Physics, UiO. It contains a new processing line for 6” wafers. 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.

"Advanced Sensors for Micro-Systems"

This project is a Strategic University Program (SUP) for the period 2003-2006 at the Depart-
ment of Physics, UiO. Two groups at the Department of Physics have been working on silicon sensors for more than two decades; the Electronics groups and the Experimental Particle physics (EPF) group. In the Electronics group MSc and PhD students have been studying fundamental issues related to the detection of ionizing radiation using semicon-
ductors, most of them in collaboration with the Department of Microsystems at SINTEF Electronics and Cybernetics. The EPF group has been working on applications of silicon 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 (UiO) is coordinating the activity in "Defect / Material Characterization".

4.3 Collaboration between universities, university groups and research institutions

The strong and internationally visible Norwegian activities in the ALICE and ATLAS projects have their basis in the collaboration and sharing of responsibilities between groups at the Depart-
ment of Physics at the Universities of Bergen and Oslo (it should be noted that the groundwork for this collaboration was laid during the LEP/DELPHI project). These collaborations have been set up and driven by personal initiatives from the project members. The projects have successfully merged the activities of several physics and technology oriented research groups. Both in Bergen and in Oslo the (micro)electronics groups and electronics laboratories are firmly integrated in the scientific programs. Neither SINTEF nor NMC has so far defined a program for development of fully integrated Si-detectors with processing and readout electronics, which would significantly increase the value and will also be required by customers (Si-detectors are by themselves "non-intelligent" devices).

2”Advanced Sensors for MicroSystems, Project Plan”, authors: B.G. Svensson (UiO), A.Yu. Kuznetsov (UiO), E.V. Monakhov (UiO), T.G. Finstad (UiO), B. Sundby Avset (SINTEF)
4.4 Budget

The budget for the project is shown in Table 4.1. The spending profile reflects the completion of the ALICE and ATLAS construction activities at the startup of the LHC physics programme.

<table>
<thead>
<tr>
<th>Expenditure</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>SUM</th>
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<td>R&amp;D</td>
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<td>100</td>
<td>100</td>
<td>400</td>
<td>700</td>
<td>1000</td>
<td>2400</td>
</tr>
<tr>
<td>Doctoral stipends</td>
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<td>550</td>
<td>550</td>
<td>1100</td>
<td>1100</td>
<td>1100</td>
<td>4950</td>
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<td>650</td>
<td>650</td>
<td>1500</td>
<td>1800</td>
<td>2100</td>
<td>7350</td>
</tr>
</tbody>
</table>

Table 4.1: The budget for the Instrumentation Project during 2006-2011. The expenditures are in kNOK and based on the 2003 price index.
Chapter 5

Norwegian LHC Computing Grid

In this chapter we describe the plans of the common computing-grid project for the Norwegian groups participating in the ATLAS and ALICE experiments at CERN. The goal is to optimise the preparation for the analysis of the data to be provided by the Large Hadron Collider (LHC) from year 2007. We present some ideas on how such a program could be carried out, based on some experience we accumulated, both in the area of grid computing and in manipulating large sets of data through so-called data challenges. Based on the current knowledge we summarise the computing needs for the ALICE and ATLAS experiments. We propose to join our efforts within the existing frameworks of the LHC Computing Grid Project (LCG) and the Nordic Data Grid Facility (NDGF), as well as local organisations and centres for scientific computing in Norway (NOTUR, Parallab and USIT).

5.1 Grid and Computing at LHC

High energy physics is facing the task of accumulating and analysing huge amounts of data to be produced by the Large Hadron Collider (LHC) at CERN from 2007. Several Petabytes (10^15 bytes) of data will be collected per year by the four LHC experiments. The computing power needed to process all these data, and produce comparable amounts of simulated data, is estimated to be of the order of \( \sim 100,000 \) CPU’s in today’s PC equivalent. The data from the LHC will have to be replicated at several regional centres, where, in addition, all simulated data will be produced. New visions of computing have emerged from the requirements of efficient processing of these large amounts of data by 6000 scientists from 500 collaborating institutes spread world-wide.

Grid computing, which is now being actively developed in international collaborations originating from CERN, opens a challenging new approach to low cost high performance computing. A useful metric for the rate of technological change is the average period during which speed or capacity doubles or, more or less equivalently, halves in price. For storage, networks, and computing power, these periods are around 12, 9, and 18 months, respectively. The different time constants associated with these three exponentials have significant implications and lead to the idea of grid.

The grid is a technology to share and access seamlessly computing resources that are not subject to a centralized control. The grid will be the future infrastructure of computing and data management. The computing resources are connected together through a layer of software called the middleware, which uses standard, open, general purpose protocols and
interfaces. This middleware forms the glue binding the resources into a virtual system. In the same way as the World Wide Web gives us access to information, the World Wide Grid will give us access to computing capacity and data storage in the future.

The Grid will play a decisive role in the future development of computer and data management in society. The implied future access to vast databases for scientific, technological, geological, meteorological, economic, demographic, literary, artistic etc. data and the use of enormous computer capacity to analyse and synthesize these data will radically enhance the possibilities for scientific and technological research, industrial and commercial management, cultural and political activities and so on.

![Diagram of LHC Grid Computing Model: Distributed Virtual Computing Center.](image)

In the CERN LHC Computing Review, a hierarchical model was used as the basis for the resources and cost estimates for the offline computing. The LHC Computing Grid Project (LCG), launched in September 2001, will provide the platform for the coordination of the World Wide Grid projects with relations to the LHC experiments. The model is being tested in a series of Data Challenges (DC's) that are being performed during the Phase-1 of the LCG project (2002-2005). The experience gained during these exercises and in the various grid projects will be used to formulate the Computing Technical Design Reports (TDR). A second phase of the LCG project is envisaged, from 2006 through 2008, to oversee the construction and operation of the initial LHC computing system.

The present Virtual World Wide Computing Model, shown in figure 5.1, foresees a virtual Facility, with a Tier-0 centre at CERN, some Regional Facilities Tier-1 (including the Nordic
Data Grid Facility) and some National Facilities. The role of the different categories of facilities would be defined by the services they offer to the experiments. The CERN computing system (Tier-0 + Tier-1) will be mainly dedicated to the data acquisition, the calibration of the detectors, the processing of the raw data and will also be part of the overall analysis facilities.

5.2 Grid activity in Norway

During the last 2 years, the CERN-related Norwegian grid activities have been dominated by the NorduGrid project.

5.2.1 NorduGrid

The aim of NorduGrid is to create a grid-based computing infrastructure in the Nordic countries. The project includes universities and research centers in Denmark, Finland, Norway (Bergen, Oslo) and Sweden. Starting in May 2001 the project was originally funded for a period of 18 month by a grant of 2.2 M DKK from Nordunet2. Three post-docs and two senior researchers form the key group of the project.

NorduGrid is a grid research project which:

- develops openly available middleware (NorduGrid Toolkit),
- operates a production quality grid Testbed,
- pursues basic research on the grid computing and surveys current grid technologies,
- exposes the infrastructure to end-users in different scientific communities.

The NorduGrid environment consists of seven core test-sites (Bergen, Copenhagen, Helsinki, Lund, Oslo, Stockholm and Uppsala), mostly dedicated to development and testing of the middleware. Several production centres in Denmark (LSCF), Norway (Parallab) and Sweden (Monolith, Ingyar, Grendel, and Seth) entered the project by setting up their resources with the NorduGrid middleware. Even a few test sites in Canada, Japan and Switzerland have joined NorduGrid.

5.2.2 NorduGrid achievements

Successful deployment of the NorduGrid Testbed (17 sites, with up to 900 shared computing units and 7 Terabytes of dedicated disk storage (5 TB are located in Oslo), together with the robust and reliable performance of the NorduGrid Toolkit, has allowed researchers in Nordic countries to use grid-computing in their everyday work. One of the biggest successes has been the participation in massive simulation tasks within the framework of the ATLAS experiment.

In order to design and optimize the LHC detectors, to learn how to deal with unprecedented large amounts of data, and to prepare for the physics analysis, it is mandatory to simulate LHC data. ATLAS and ALICE opted for a series of Data Challenges of increasing size and complexity to prepare and test the software in stages.

The Nordic ATLAS research groups, with an important Norwegian contribution, were the first ones who could entirely use grid tools to complete their share of the task. They participated to the three phases of the first Data Challenge (DC1), which started in July
At the same time, DC1 served as a realistic application that allowed valuable inputs to the development of grid tools.

The simulation part of ATLAS DC1 (phase 1) corresponded to 71,000 CPU-days. Due to this huge amount of computing power, it was essential to distribute the task between 37 institutes from 18 countries. More than 3000 processors were used worldwide to produce 30 Terabytes of data in 35 000 files of nearly 1 Gigabyte each.

The testbed included 6 Linux clusters across Denmark, Norway (Bergen, Oslo) and Sweden. Despite having slightly different operating systems and hardware characteristics, the clusters performed as a single virtual computing center, having jobs distributed in an optimal way, and writing the output onto a dedicated storage area in Oslo.

The second phase of DC1 started beginning of this year. Pile-up events were mixed with the previously simulated events. Pile-up is due to the fact that at high luminosity, the average number of minimum-bias events is 23 per bunch crossing. NorduGrid again made a substantial contribution to the 60 TB of data produced by ATLAS. Around 50 institutes world-wide took part in the exercise. A well defined strategy of how to replicate and access the large world-wide distributed datasets has been worked out. To facilitate the access, since not all production sites will be accessible via grid tools, the data is being replicated to 8 sites, including Oslo.

The reconstruction of the simulated data, such that they become directly available for distributed physics analysis, has just started, with special emphasis on the use of grid tools. During the Easter holiday, NorduGrid processed nearly 30% of the whole ATLAS load. This would not be possible without the exceptional availability of the Norwegian sites. Parallab (64 CPU’s), a student cluster in Oslo (16 CPU’s) and the two dedicated smaller clusters in Oslo and Bergen did 90% of the job. These data were urgently needed by the physics and
trigger communities. Figure 5.2 shows a recent picture of the NorduGrid monitor. It is now possible for Nordic physicists and students to simulate and analyse large, time consuming data sets, necessary for the success of the planned physics program. Up to now, all physics studies were based on fast and unrealistic simulations.

5.2.3 NorduGrid and Nordic Data Grid Facility

The NOS-N committee approved the next common Nordic Grid project. The Interim Steering Group allocated 600 000 NOK to ensure the continuation of the very solid work demonstrated in the NorduGrid project and a safe transition to the next phase (June 2003-December 2004), whose main task will be grid deployment in the Nordic countries, aiming at laying a foundation for a joint, large scale, multi-disciplinary Nordic Data Grid Facility (NDGF). NDGF would be a Regional Grid Centre at the “Tier-1” level, consisting of a few thousand powerful PC’s, disk servers and tape robots. The final decision on the centre will be taken toward the end of the pilot phase.

NorduGrid (a research project) intends to be complementary to the Nordic Data Grid Facility (an infrastructure) and provide it with the middleware to deploy. In a recent meeting, the participating institutes decided to pursue the NorduGrid project with essentially the same core team of six full-time-equivalent researchers. As of May 1st, salaries and contributions to limited travel will be covered by these institutes. In addition to some NDGF support, seven Nordic institutes have applied for a five-year NorFa “Grid Research” network (300 000 NOK per year). We wish to get support for a post-doc to join the LHC-related grid activities.

NorduGrid has grown into one of the largest operational grids in the world. However, the existing NorduGrid solution is by no means complete, as there are many missing services and components. The grid technologies are developing rapidly, and the voids will eventually be filled. This project aims to take an active part in the process, providing an advanced grid solution, suitable not only for simple tests, but for deployment on an industrial scale.

5.2.4 Toward more grid activities

The Norwegian ALICE computing activity is centered on High Level Trigger (HLT) development. The HLT will consist of a PC farm of around 1000 nodes, in order to make on-line event selection and compression. The parallel layout of the HLT farm will provide important cross fertilisation to the grid-based offline activities. The overall architecture is similar to a grid Tier-1 center and it is indeed planned to operate the HLT as a small grid Tier-1 when ALICE is not operational. Therefore, when offline or when not fully utilized, the HLT compute farm can be operated within the CERN DataGrid framework. The relevant functionality here is being developed within the fabric management part of the DataGrid project (the so-called Work Package 4). In order to facilitate fault tolerance in the HLT farm an appropriate software framework is being developed. This work is done in part within the DataGrid project in the fabric management work package and therefore automatically part of the standard DataGrid package. A prototype HLT farm of 11 nodes with dual processors were installed at the University of Bergen in 2001.

The Norwegian ALICE group intends to establish a grid based offline analysis framework in Norway, centered on Parallab in Bergen and USIT in Oslo. A prototype ALICE analysis grid framework, AliEn, has already been used for cross continent production. The Norwegian groups intend to install and operate AliEn on the HLT cluster in the close future, as an
important step toward full-fledged ALICE offline activity.

5.2.5 Reports and Presentations

In the last two years, the members of the project - mainly through NorduGrid - have already contributed to many publications:

- 17 scientific reports,
- 12 presentations at scientific meetings,
- 1 outreach brochure,
- 3 interview articles,
- 1 encyclopedia article.

5.3 Cost sharing and expected Norwegian contribution

The cost sharing (hardware, network, consumables and manpower) of the LHC computing grid will be part of the Computing Memorandum of Understanding (MoU) with CERN, which is due in 2005. It is foreseen that this MoU will consist of a part common to all 4 LHC experiments, and separate parts for each experiment. The numbers given below will evolve with time with a more detailed understanding of the detectors and of the physics programmes. Here we summarise the estimates for the costs in the case of ATLAS:

- Assuming a flat spending profile (LHC start-up in mid 2007), i.e. buying 30% in 2006, 30% in 2007 and 40% in 2008, the initial hardware costs are expected to be about 35 MCHF. A rough estimate puts the initial cost of the central installation of data storage and processing power at CERN to be 11 MCHF, to be spent in the years 2006-2008.

- It is expected that, from 2009 onward, approximately one third of the initial hardware investment will be needed annually for replacement and upgrades. For consumables and manpower (to run the facilities outside CERN) the yearly costs are estimated to be 7 MCHF. In addition it is estimated that 2 MCHF are needed for ATLAS specific core computing activities, covered by Software Agreements.

Based on the present knowledge, the total costs (ATLAS case) of the offline computing to be shared by the collaboration from 2006 onward will be of the order of 17 MCHF per year, to be covered to a large extent in form of in-kind contributions, e.g. in the form of regional facilities. These costs do not include the hardware and manpower for the CERN T0/T1 (∼11 MCHF) that are a host-laboratory responsibility and budgeted in the CERN cost to completion Council papers.

5.3.1 Grid Project: period 2006-2011

Based on the above estimates, the Norwegian contribution to the ATLAS offline computing will be of the order of 1.1 M NOK \(^1\) per year from 2006. If we assume a similar contribution

\(^1\) We assume a Norwegian contribution to CERN of 1.2%. We use 1 CHF = 5.25 NOK.
to ALICE, we arrive to an expected contribution of roughly 2.2 MNOK per year from 2006 onward.

The costs for the offline computing to be shared by the ATLAS and ALICE institutes include the part of the regional facilities accessible by the institutes, the networking costs, the consumables and the manpower to run and maintain the regional centre.

In order for the present grid project to achieve its goals, we propose to join our efforts within two existing/planned frameworks: the LHC Computing Grid Project (LCG), common to the 4 LHC experiments, and the suggested Nordic Data Grid Facility (NDGF), if that becomes reality, including its local centres inside Norway. In any case, we count on a strong collaboration with national bodies/centers: NOTUR or the follow-up program, in general, and the computing centers (Parallab and USIT), in particular. We should keep in mind, however, that even if we would get substantial service from those facilities, the CERN programme should have at least one local grid-expert person tightly coupled to the experimental activities. The IT-service institutions will not have the expertise to do all the work necessary for ATLAS and ALICE simulation and analysis software to run continuously on top of a Nordic/Norwegian grid (with the CERN/LCG-compatible middleware).

One has to remember that we propose to analyse the LHC data over many years with a huge, complex system that does not exist today. It is unlikely that the system we will use to handle the first data in 2007 will be working in its final form in 2006 and that the system we use in 2007 will not change substantially from then until 2012. This fully justifies both a long term grid project in the CERN-related programme and a necessary short term (pilot) project.

5.3.2 Grid Project: period 2003-2005

Norway is already invited to contribute to the first phase of LCG (2003-2005). What will be learned is crucial for the long term period. This activity is already going on and is essential in the years 2003-2005 despite not being called a separate project of the present CERN program.

Given the fact that the Norwegian groups are participating actively to both grid development and to data challenges from Norway, we propose the following contribution:

- Manpower based partly at CERN and paid by the research council for a period of 2-3 years. The person will serve as a contact between the CERN experiments (through LCG) and the Norwegian LHC grid community.

- Hardware resources based in Norway. These resources exist partly at a low scale, mainly as part of NorduGrid and of the ALICE High Level Trigger setup. This contribution could be a starting point for a Norwegian grid computing and storage resource (Oslo-Bergen) running both ATLAS and ALICE applications. Two “clusters” of 50-100 CPU’s and at least 10 Tb disk space each, one in Bergen and one in Oslo will allow us to fulfill our responsibilities toward our collaborations and to scale up the pilot project now, in order to efficiently prepare the crucial period after 2006. We will apply for CPU-resources at existing installations (e.g. Parallab). The need to increase the disk capacity is rather urgent (~ 300 000 NOK for 10 Tt).

We stress the fact that all what has been achieved is already an in-kind contribution and that what is being prepared is an important investment for the future, namely the optimisation of the Norwegian long term contribution to the computing resources and, last but not least,
the preparation for the analysis of the LHC data, the ultimate goal of the current CERN research program.