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International Accelerator Facility for Beams of Ions and Antiprotons

page

Note:

This statement given by a subgroup of the steering committee „Large research facilities for basic research“ of the German Science Council concentrates on the scientific and technical investigation of the project. The statement if the project should be funded or not is given by the Science Council itself by a final evaluation of all nine projects. This statement is given in a seperate report.

A. Introduction and background

A.I. Field of research

The **physics of nuclei and hadrons** has undergone a major extension and redirection of its research goals over the past decade, mainly promoted by technical advances, both experimentally resp. accelerator-oriented and theoretically.

Two aspects have had the largest impact on the field.1 They are first the quark-gluon sub-structure and dynamics of the building blocks of nuclei, protons and neutrons, or more generally of hadrons and of nuclear matter. This touches on a fundamental understanding of how the nucleon many-body system comes about and on the origin of the nuclear force. And second the progress made in extending the exploration of nuclei to regions far from stability, up to the limits of their existence, by the development of beams of short-lived nuclei (so-called radioactive beams). Many of these nuclei lie in the paths of nucleosynthesis and are important for the process of element formation in the universe and for astrophysics.

Advances have been made toward determining the internal structure of the building blocks of matter:

- Measurements of the distribution of quarks and antiquarks in nuclei show that these distributions are different from those in free protons or neutrons;
- Several experiments have demonstrated that neutrons and protons experience slightly, but distinctly, different nuclear forces; thus, these forces do not exactly obey the principle of charge symmetry;
- The theoretical analyses of measurements of the structure of the proton and neutron show that the spin of these particles does not have a simple origin in the quarks and that the polarization of the quark-gluon "sea" plays an important role.

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[1] The advances of the field as well as the future prospects have been discussed and documented by various committees and international science forums (for example in the Long Range Plan of the Nuclear Science Advisory Committee (NSAC) to the Department of Energy (DOE) and the National Science Foundation (NSF) in the USA; the Long Range Plan of the Nuclear Physics European Collaboration Committee (NuPECC) in Europe; various evaluations and/or reports from the OECD Mega Science Forum; the recent evaluation of the field of physics, performed every ten years by the National Research Council (NRC) and National Academy of Sciences (NAS) in the USA).

New insights into the properties and structure of nuclei have been gained especially by electron scattering experiments and by creating in the laboratory a variety of new, short-lived elements and isotopes at the limits of nuclear stability. Furthermore, advanced supercomputers and new mathematical techniques allow, for the first time, *ab initio* many-body calculations of the properties of light nuclei, starting with the basic interaction between nucleons, and establishing the importance of the nuclear three-body force.

New insights in studies of matter at very high energy densities have been gained e.g. by theoretical work, which indicated that above a certain energy density quarks will be liberated from their confinement in protons and neutrons and by recent measurements at existing accelerators (SPS at CERN), which have demonstrated that heavy-ion collisions at very high energies cannot be interpreted in terms of simple superpositions of independent nucleon-nucleon collisions.

New results regarding fundamental symmetries have been obtained through studies at low energies, where e.g. precision beta-decay experiments have limited the mass of the electron neutrino to about one hundred-thousandth of that of the electron. They also allowed to test, with unprecedented sensitivity, whether the neutrino might be its own antiparticle.

Also, the connection between nuclear properties and the nature of the universe has been further elucidated, utilizing both intense beams of stable nuclei and new techniques based on beams of short-lived nuclei. By these means, a better understanding of the processes in stars that are crucial to the formation of the elements has been accomplished. These findings are complemented by recent advances in the nuclear physics of supernovae, including the discovery of a new nucleosynthesis process driven by neutrinos.

In the applicant’s point of view the future questions in modern nuclear and hadron physics are:

- How do the nucleon-based models of nuclear physics with interacting nucleons and mesons arise as an approximation to the quark-gluon picture of quantum chromodynamics (QCD)?
- In probing ever-shorter distances within the nucleus, at what point must the description in terms of nucleons give way to a more fundamental one involving quarks and gluons?
- Does the nuclear environment modify the quark-gluon structure of nucleons and mesons?
- What is the origin of quark confinement and how do the gluons behave in hadrons?

The classical nuclear physics models are expected to break down, as more and more energy is crowded into the nuclear volume. The state of nuclear matter in the early instants of the Big Bang raises the following questions:

- What are the phases of matter formed when ordinary nuclei are heated to the very high temperatures and/or compressed to very high densities at which quarks and gluons become deconfined from the nucleons and mesons?
- What are the experimental signatures for a transition to new phases in relativistic heavy-ion collisions?
- What are the implications for the analogous epoch in the Big Bang or for the properties of neutron stars?

In the applicant’s view, the challenges of studying exotic nuclei in the laboratory are:

- What is the quantitative origin of the chemical elements in the Big Bang and continuing to the supernovae we observe in our galaxy and elsewhere?
- What is the influence on element production of the properties of exotic nuclei, especially those near the limits of nuclear stability that become accessible with the advent of intense radioactive beams?
- What qualitatively new features appear in this hitherto unexplored regime of nuclei, and how do they influence stellar properties?

Empirical models of nuclear physics have provided a realistic framework for understanding a rich array of observed nuclear phenomena. Pushing nuclei to their limits reveals new features and leads to new insights and understanding, for example how do nuclei behave when pushed to the limits of their excitation energy, angular momentum, and nuclear binding or can the apparently simple phenomenological models, which describe several nuclear properties so successfully, be related transparently to the basic interactions of the nuclear building blocks.

Recent research places new constraints on the validity of the Standard Model and raises the following questions:

- What are the low-energy manifestations of physics beyond the Standard Model?
- How can precision experiments in nuclear physics reveal them?
- What is the reason for the low neutrino flux from the sun?
- What can studies of neutrinos from supernovae reveal about the properties of neutrino families?
- How will such studies help us understand stellar evolution, including the mechanism responsible for supernova explosions?

Besides the physics of nuclei and hadrons, the **physics of dense plasmas** as part of the broad field of plasma physics will also be dealt with at the new accelerator. In the last years, this field has especially developed by the arrival of high power lasers. Specific achievements included the development of new instrumentation such as the plasma lens, where the transient magnetic field of a high-current plasma discharge was turned into a precision fine-focusing device producing ion-beam spot sizes of 250 micrometer radius and below, or the demonstration of high-energy particle jets arising from the laser plasma interaction process. Also, a laser system for plasma interaction experiments and synergetic use together with ion beams could be implemented. Further important findings were made, when measurements of the energy loss and charge exchange of high-energy heavy ions in fully ionized plasmas clearly demonstrated that the stopping power of such plasmas for heavy ions is considerably larger than that of cold matter.

Several orders of magnitude in ion-beam intensity, bunch compression for much higher beam power, the complementary use of ion-beam and laser beam as plasma generator and/or plasma diagnostics, and vice versa, so-called magnetized targets, etc. will provide technological advances that will allow the production of dense plasmas at much higher temperature, pressure and densities.

In Germany, there are different facilities with electromagnetic probes (S-DALINAC at Darmstadt, MAMI at Mainz and ELSA at Bonn; HERA as a high-energy accelerator at DESY with the HERMES experiment), and facilities with hadrons and/or nuclei as probes (university facilities with smaller accelerators, such as the tandems at Bochum, Erlangen, Heidelberg, Köln, Stuttgart and München; the GSI facility).

Several new nuclear beam facilities with a broad program of research in fundamental nuclear physics and astrophysics, as well as applications of nuclear science are now going into operation, and several future projects are planned or proposed worldwide:

- for nucleus-nucleus collisions in the high temperature regime RHIC at Brookhaven, and the LHC at CERN (ALICE experiment) as the ultra-relativistic accelerator, where the high-temperature region, and thus the phase transition from the baryon-poor nucleonic region to the quark-gluon plasma is being explored;
- radioactive beam facilities already under construction (the RIKEN Radioactive Ion Beam Factory RIBF in Japan) or in planning (Rare Isotope Accelerator (RIA) in the USA);
- the “Joint Project for High Intensity Proton Accelerators” JAERI/KEK at Tokai in Japan with primary research goals in the areas of rare kaon decays and neutrino physics.
- In dense plasma research, a high intensity/power ion beam accelerator project (TeraWatt power ACcelerator TWAC) is underway at ITEP, Moscow.

A.II. The facility itself

II.1. Scientific objectives and research prospects

The principal goal of the research facility planned by the Gesellschaft für Schwerionenforschung (GSI) Laboratory in Darmstadt is to provide the European science community with an innovative accelerator system to perform science concerned with the basic structure of matter, and in intersections with other fields. The facility will provide a range of particle beams from protons and their antimatter partners, antiprotons, to ion beams of all chemical elements up to the heaviest one, uranium.

The new facility consists of a large synchrotron double-ring and a system of associated storage rings for beam collection, cooling, phase space optimization and experimentation. It uses the present accelerators at GSI, a universal linear accelerator (UNILAC) and a synchrotron ring accelerator (SIS18), as the injector. The heart of the new facility, the synchrotron double ring, provides for fast acceleration, utilizing novel cycling superconducting magnets which are presently being developed in collaboration with laboratories in the USA and in Russia.

A key feature of the new facility will be the generation of intense, high-quality secondary beams, in particular beams of short-lived radioactive nuclei and antiprotons. Secondary beams are produced in nuclear reactions induced by beams of stable particles. To achieve the desired high secondary beam intensities, the primary beams must be correspondingly high. A factor of 100 over present in primary beam intensities and up to a factor of 10 000 over present for the secondary radioactive beam intensities are key technical goals of the proposal.

II.1.1 Research program

In the applicant’s view, the overall goal of the research program is a deeper exploration and understanding of the structure of matter at a fundamental level. Within this broader goal, the facility aims at addressing a set of questions for a range of research areas:

- The investigation of nuclei near the limits of binding, and their importance to nuclear astrophysics and to the origin of the chemical elements; this research will use the intense, secondary beams of short-lived nuclei (radioactive beams);
- The study of sub-nucleonic degrees of freedom in the nucleon (hadron), the behaviour of the gluonic degrees of freedom, in particular the phenomenon of confinement, the origin of the nuclear force that binds nucleons in nuclei; this area will rely on the intense, high-quality antiproton beams;
- The study of hot, and in particular compressed, high-density nuclear matter using high-energy collisions between heavy nuclei; these will be provided as intense relativistic heavy-ion beams by the facility;
- The study of hot compressed bulk matter in the plasma state, provided by high-power, compressed ion-bunches at intermediate energies.

In addition to these four key research areas, it is expected that ion beams of high intensity, or with special properties such as fully stripped atoms, or as cooled beams with ultimate velocity sharpness, provide also new research opportunities for intersections with other fields, such as quantum physics of highly stripped, few-electron atoms (QED tests in strong fields, laser-ion interactions, etc.) and biological research, or to more applied areas such as radiation research and/or material research applications.

As the broader research goals GSI mentioned: Firstly, to achieve a comprehensive and quantitative understanding of all aspects of matter that are governed by the strong (nuclear) and the weak force, the two important short-ranged forces out of altogether four known ones, that critically determine the structure of matter at the microscopic level. Secondly, to address the intrinsic complexity and many-body aspects of matter at all levels of its hirarchical structure, in particular at the hadronic level.

The key thrust of the facility will thus be the investigation of the strongly interacting hadronic matter at all aspects, and the physics of many-body systems, including hadronic condensed matter, but extending into the subnuclear regime as well as the regimes of atoms and of hot and dense plasmas.

The antiprotons will provide new opportunities to explore two key questions of hadronic matter at the sub-nuclear level:

- Why do the quarks, the constituents of protons and neutrons, and hadrons in general, never appear as free particles but always in groupings of two or three (or possibly more)?
- How do the nucleons (hadrons) acquire their mass?

Finally, the intense heavy-ion beams provide a new opportunity to study bulk matter in the high-density plasma state, a state of matter of interest for inertial fusion and various scenarios in astrophysical settings, from the interior of large planets to that of stars.

II.1.2 Services

Like for the existing facility at GSI, the service offered to scientists is experimental time, usually referred to as “beam time on target”. As indicated above, the key aspect of the new facility is an increase of primary beam intensities by a factor of 100, of secondary beam intensity of a factor of up to 10000, and of the maximum beam energy by more than a factor of 10. In addition, cooled beams of antiprotons at energies up to 14 GeV and intense short ion pulses with Terawatt power will be made available.

Like the existing facility the new one will be operated as an international user facility. The facility will support logistic services, for example guest office, lodging facilities, office rooms to support the user community.

II.1.3 Technical strengths and weaknesses

The project builds on the existing facilities and on the expertise of GSI in accelerator technology, in particular in the field of synchrotrons, storage rings, and beam cooling systems. The essential technical innovations and new developments are:

- Fast cycling super conducting magnets for up to 2 T for very fast ramp rates of up to 4 T/s;
- The improvement of a cosθ magnet type, which allows higher fields of up to 4 T or more and fast cycling operation of up to 1 T/s (from presently .07 T/s);
- Development of specific electrode structures for pick-up and kicker systems;
- A new technical design of a cold electron beam with a maximum energy of up to 500 keV;
- Development of a superposition of a longitudinal magnetic field of about 1 Tesla and a simultaneously low electron temperature for electron cooling;
- Development of cost effective RF-bunch compression systems for short (~ 50 ns) intense (10^{12}) ion pulses with Terawatt beam power.

In the applicant's view the facility's main strength is that the accelerator concept chosen for the proposed extension offers at higher intensities for radioactive ion beams all experimental options for fixed target, in-ring, stopped, and trapped beams. It can be used, supplemented by the HESR, for a new generation of experiments with antiproton beams. It allows to extend the experiments with relativistic heavy ions to higher energies, and provides high power short ion bunches.

GSI does not see any serious shortcomings. According to GSI it is feasible to construct the proposed facility to meet the performance requirements for scientific research, the technologies and experiences required to build the proposed facility reside within GSI. In areas where new expertise will be required for the new project GSI is addressing solutions by establishing collaborative efforts with experienced laboratories to import the technology and to train new staff.

II.1.4 National and International networks and programs

GSI is involved in a number of formal networks and programs addressing both current research activities and R&D work for the future project. It is expected that these and/or similar networks will also exist or be newly formed in connection with the new facility.

European (EC) networks and programs:

Name of the Network/ Program	**Brief Description**
FINUPHY (Frontiers in Nuclear Physics)	Concerted Action Program of all major nuclear physics facilities in Europe to coordinate their present activities and future plans
Access to Large Scale Infrastructure	This EC program gives financial support to European research groups that perform experiments at GSI (mainly travel and subsistence costs).
RTD R3B	EC Research and Technical Development (EC-RTD) project network with European partner institutions addressing the design of the instrumentation for the radioactive ion beam program planned at the future GSI facility.
RTD EURISOL	EC Research and Technical Development (EC-RTD) project network with European partner institutions addressing the design of and research at a potential large scale ISOL facility in Europe.
RTD SHIP-Trap	EC Research and Technical Development (EC-RTD) project network with European partner institutions addressing the design of and research at trap facilities for heavy radioactive nuclei.
RTD EUROTRAP	EC Research and Technical Development (EC-RTD) project network with European partner institutions addressing the design of and research at trap facilities for spectroscopic studies.
RTD NIP-Trap	EC Research and Technical Development (EC-RTD) project network with European partner institutions addressing the design of and research at trap facilities for symmetry studies.
RTD HITRAP	EC Research and Technical Development (EC-RTD) project network with European partner institutions addressing the design of and research at traps for heavy highly charged ions.
RTD ECRIS	EC Research and Technical Development (EC-RTD) project network with European partner institutions addressing the design of advanced ECR ion sources.

Others Associations / Networks:

Name of Network/ Association	**Description**
Helmholtz-Gemeinschaft Deutscher Forschungszentren (HGF)	GSI is a member of the HGF.
NuPECC (Nuclear Physics European Collaboration Committee)	The Nuclear Physics European Collaboration Committee (NuPECC) is an associated Expert Committee of the European Science Foundation (ESF). It is part of a European network in nuclear physics and defines major future thrusts of the field (NuPECC Long-Range Plans for Nuclear Physics).

Name of Network/ Association	Description
	According to the applicant’s view, the GSI plans for a new facility are in line with NuPECC recommendations for a next generation European nuclear physics in-flight facility (see: “Radioactive Nuclear Beam Facilities”, NuPECC Report, April 2000).

Nation-wide the GSI is involved in the so-called “Verbundforschung”. This program aims at fostering collaborations between German universities and national and international research infrastructures/projects, financed by the Federal Ministry for Education and Science.

With special emphasis on research and technical developments, GSI presently funds 92 RTD contracts with research groups from 20 German universities. Some 5,000 TEUR per year are spent for this RTD program wich is also known as the GSI model.

Bilateral programs exist with France (Centre National de Recherche Scientfique (CNRS), the Commisariat á L’Energie Atomic (CEA)) and with INFN, Italy.

With special regard to the new project, a Memorandum of Understanding has very recently been concluded by GANIL (Grand Accelerateur National d’ Ions Lourds), letters of Intent have been received from KVI Groningen, the Netherlands and the University of Cracow, Poland, proposals are being prepared by the Russian Academy of Science and a number of Russian research institutes to participate in R&D projects and facility construction. In addition, collaboration agreements are under preparation with CERN and laboratories from France, Italy, Japan, Russia, and the USA for specific topics associated with the new facility.

II.1.5 Enlarging/upgrading

The running time of the new facility will be 10 to 15 years. On medium and longer terms, the conceptual design offers several opportunities for further enlarging/upgrading at a later stage. These include:

- a further intensity increase by a factor of 10 by upgrading the injector linac and direct injection of very low charge-state ions (e.g. U^{7+}) into the large synchrotron rings
- a further upgrade of the energy by raising the magnetic field strengths through lowering the helium temperature to 1.8 K
- further beam pulse compression for the production of extremely intense ion pulses with pulse-lengths below 10 ns
- re-injection of secondary antiproton beams into the large synchrotron for acceleration up to 30 GeV
- Production of intense kaon beams
- Production of intense and collimated neutrino beams from weakly decaying light elements for the study of neutrino oscillations

II.2. Transfer of the research results

The planned facility primarily aims at basic research in the areas nuclear and hadron physics, plasma and atomic physics. GSI expects that the new accelerator and experimental technologies will also have an impact on application-oriented fields without giving predictions on specific applications that might result from the new facility. The envisaged research into plasma physics with intense ion and laser pulses may have a large potential for the long-term goal of inertial confinement fusion reactor systems.

An application that was developed at the existing SIS/ESR facility is tumour therapy with ion beams. Presently, negotiations are ongoing for a dedicated therapy center at Heidelberg that will be constructed in cooperation with industry. This ion beam therapy center will allow the treatment of about 1000 patients per year.

GSI has devoted one scientist position (1 FTE) to technology transfer and patent applications.

Spin-offs cannot be predicted today. Potentials are seen in electronics and fast data acquisition developments that are associated with the project.

A.III. The institutions participating in the project

GSI has a long-standing tradition in both planning and operating large accelerator and experimental facilities. At present GSI operates a modern accelerator complex, consisting of the linear accelerator UNILAC, the heavy-ion synchrotron SIS18 and the experimental storage ring ESR. With these facilities, ions can be accelerated up to 90 % of the velocity of light. Moreover, cooled secondary beams of unstable nuclei are available for the research program as well as beams of highly ionized atoms up to bare uranium nuclei.

The accelerators are complemented by some 20 experimental areas, equipped with large spectrometers and detector systems, which offer world-wide unique opportunities for fundamental studies in nuclear and atomic physics, but also for application-oriented research in plasma physics, materials research, biophysics and for radiation research. All major detector systems (e.g. HADES, FOPI, ALADIN, KAOS, LAND, TAPS) have been built with strong participation from universities and other institutes or in international collaborations. This holds also for the CERN SPS experiments NA45, NA49 and WA98, where GSI played a major role.

GSI is a user facility with primarily external users. The laboratory has thus become a focal point where scientists from both domestic and foreign universities and other research institutions collaborate. Altogether, there are more than 1,000 scientists from over 130 institutes in 30 countries participating in the research and development work at GSI.

The current research program, carried out by the GSI users, is based on three key activities:

- nuclear structure research with unstable nuclei,
- studies of hot and compressed hadronic matter,
- atomic physics with high charge-state heavy ions.

Besides these major programs, there is a strong activity aiming at new developments in accelerator physics and technology. Additional areas of research are: plasma physics, materials research, biophysics and radiation-medicine including a project for tumor therapy with ion beams.

Most of the present and potential new users come from universities, university scientists played a decisive role in this discussion process. In particular, scientists from university also carry an important share in the design of the detector instrumentation planned for the new facility.

The proposal for an antiproton facility has been primarily induced by external groups both from national and European institutes. With regard to the technological developments of the planned accelerator complex, national and international collaborations already exist in the following areas:

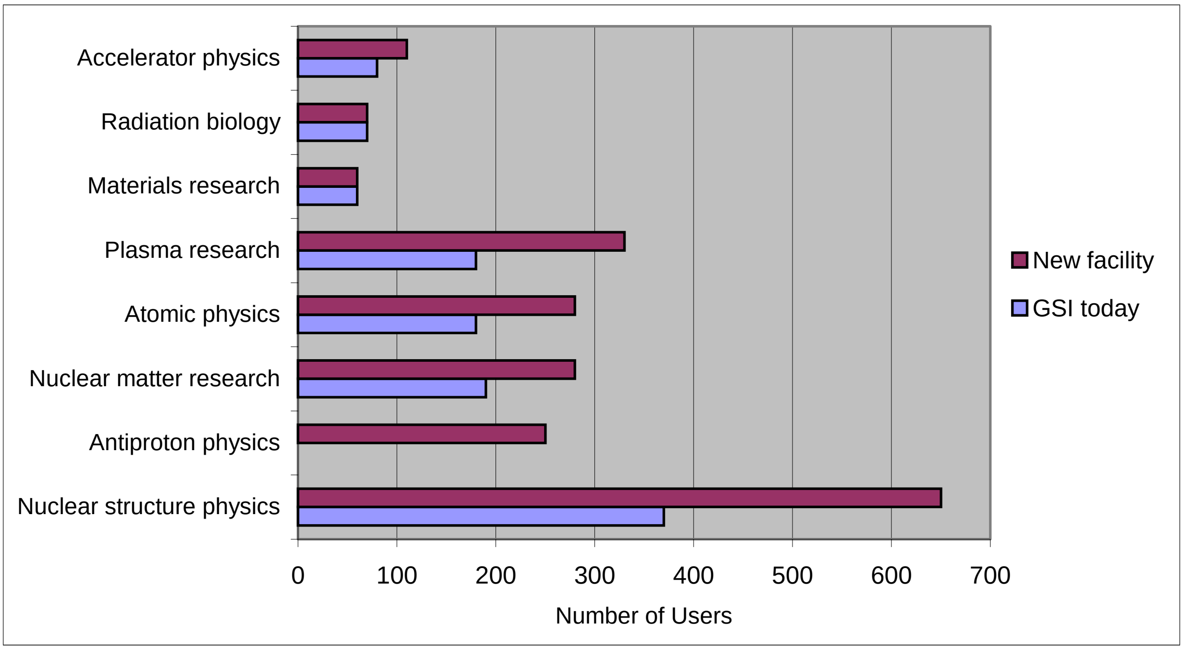
Country	Institute	Specific competence and contribution
Russia	Joint Institute for Nuclear Research (JINR), Dubna	- fast cycling superconducting magnets - iron dominated window-frame superconducting magnets
	Budker Institute for Nuclear Physics (BINP), Novosibirsk	- high-energy electron cooling of antiprotons - beam compression systems for the generation of short intense ion pulses - Design of an electron–ion collider for electron scattering experiments off unstable nuclei
USA	Brookhaven National Laboratory (BNL), Brookhaven	- cosθ-type superconducting magnets
Germany	University of Frankfurt	- Design of the proton linac
	Technical University Dresden	- Cryogenics
	Technical University Darmstadt	- Field calculations for magnets and accelerator structures

A.IV. Users of the Research Facility

All key activities outlined in the planned research program will rely on and benefit from the use of the facility. These activities are:

- the study of nuclei near the limits of binding and of importance to the origin of the chemical elements, as well as to tests of the Standard Model (nuclear structure physics, nuclear astrophysics, and studies on fundamental interactions and symmetries);
- the study of the sub-nucleonic quark-gluon degrees of freedom in the nucleon and other hadrons and the origin of the nuclear force that binds nucleons in nuclei with beams of antiprotons (hadron spectroscopy and hadronic matter physics (QCD));
- the study of hot, compressed nuclear matter at high nucleonic density (nuclear and hadronic matter physics studied in relativistic heavy-ion collisions)
- the investigation of hot plasmas at unprecedented temperatures, pressures and densities (physics of dense strongly coupled plasmas).
- the study of Quantum Electrodynamics (QED) and of ultra-strong (electric and magnetic) field effects in ion-atom collisions and in ion-matter interactions (atomic physics with relativistic, highly charged ions, including applications with ion beams).

In view of its size and role for the science community, the new user facility will be operated on an international basis. It is expected that the number of external users will increase from presently 1000 to about 2000 scientists per year. The bar diagram compares, for the various research programs, the present user numbers with those estimated for the new facility. The spectrum of users will range from individual investigators and smaller groups performing short-term experiments to large collaborations running long-term programs over several years.



Note: Number of users at the existing (first beam) and expected at the new facility (second beam) in the various research programs.

The planned facility is primarily devoted to basic research. According to the applicant's view, the broad spectrum of ion species, energies and intensities will, however, also be of interest to a number of private-sector companies or other semi-governmental institutions. As an example, the facility will allow detailed tests of the irradiation hardness of electronic modules or even of entire satellite components and thereby simulate their reliability in outer space. The GSI claims, that also detailed studies of the radio-biological effects, that astronauts would be exposed to during long-term space missions, can be carried out at the facility.

To apply for access to the accelerator and experimental facilities, a written proposal has to be submitted, which is then reviewed by an international program advisory committee (PAC). The peer review system is seen as well-established for experimental proposals.

For user groups from universities and from non-profit research centers, all accelerator and experimental access are provided free of charge. User fees, charged for research groups from commercial companies, are subject to negotiations.

Presently, 220 doctoral students and 140 postdoctoral fellows are involved in GSI based projects. With the new facility, increasing numbers are expected. All section leaders of GSI are at the same time full professors at a German university. In addition, 25 senior scientists give lectures at the universities nearby. On-site GSI offers several general colloquia and a wide spectrum of topical seminars associated with the research conducted at the institute.

The fields of work open to scientists trained at the new facility cover a wide range from fundamental research to applied work in the commercial sector. The expertise that is acquired ranges from nuclear and particle physics or plasma physics to materials research, biophysics and medical physics. It also comprises fields like electrical engineering, electronics, mathematics and computer science.

The GSI uses days of the open house, exhibitions, a popular brochure and newsletters to keep the public informed about the project and to allow the greater public to follow the progress of the project. In the year 2000, GSI started a travelling exhibition “Journey to the Big Bang”, which partly also addresses the research planned at the new facility. The exhibition has so far been shown at 29 schools all over Germany and is booked for fifteen further locations until March 2003. For the end of 2002 /beginning of 2003, GSI plans to show a dedicated exhibition on the future project on-site. A condensed version of this exhibition will also been sent on travel, in particular to schools and universities. The GSI will continue and enhance in certain aspects its information of the general public about scientific results obtained at the new facility.

A.V. Project management, location, costs and schedule

V.1. Project management

The institutional structure has not been defined at the present stage. GSI suggests the possibility of an Economical Interest Group EIG or of an European Economical Interest Group EEIG to be discussed. First positive experiences have been made with the structure of an EIG/EEIG at GANIL in France where scientists from two different funding agencies are working together in the laboratory at CAEN under one management. Such a structure allows the different partners to bring their staff into the Center without the need of creating new labor, administrative or retirement structures. On the other hand, this structure of an EEIG allows to manage the project in a very direct way, independent of a large administrative overhead from each country. Salary structures and benefits would remain under the control of each partner for his own staff. Otherwise the EEIG would function autonomously with its Directorate supervised adequately by Administrative and Scientific Councils, similar to a GmbH.

The EEIG will have the overall responsibility for operation as well as of maintenance of the facility. The project is under the responsibility of the Project Leader (PL) (and deputies), who is heading the Management Board (MB). The Management Board defines the project in agreement with the Directorate of the EEIG and the User group, manages the project and its planning as a whole, from scientific- to financial- and to international aspects. The Management Board contains a selected group of sub-project leaders, the integration coordinator, the administrative and financial coordinator and some outside members who are representing the interests of contributing institutions other than the consortium partners. All sub-project leaders are members of the Technical Board, headed by a Technical Coordinator (with deputies), who reports to the project leader. The Project Leader and the Technical Coordinator are in charge of building the facility within the budget and on-time to the specifications outlined and defined by the Management Board.

The Directorate is assisted by outside advisory and evaluation boards, like the present External Scientific Advisory Committee (ESAC) or the External Technical Advisory Committee (ETAC). ESAC and ETAC provide advice on the scientific, technical and financial matters of the project and will evaluate all proposed major project modifications. The standing scientific advisory committee of GSI, the “Wissenschaftlicher Rat” with 12 international members, advises the GSI management in all scientific and technical questions connected to the current and future programs at the GSI facilities.

According to the applicant’s view, quality assurance procedures will be implemented in all stages of the project, e.g., in planning, design, hardware and software production. Quality assurance procedures will be those of industrial standards adapted to the specific needs of the proposed project. They are also based on the procedures developed and successfully applied to the previous major research infrastructure project carried out at GSI, the construction of the SIS/ESR accelerator facility including several large-scale spectrometers and detector systems.

The GSI envisages a selection, where the budget from the different funding partners is managed by the International Center according to the rules of an EEIG. Other participating institutes are managing their funds related to the joint project according to a memorandum of collaboration established between them and the Center. The project leader and the sub-project leaders are responsible for their individual project budget. The budget is managed by the administrative coordinator in each sub-project. A controlling group (Controlling) monitors the money flow.

V.2. Location

The new facility builds on the existing one and uses the existing synchrotron SIS18 as injector. This determines the new buildings to be located east of the present GSI area. The large synchrotron SIS 100/200 will be installed in a tunnel 24 meters below ground.

South to the new synchrotron double ring the various collector/storage rings and the experimental facilities will be installed. These installations will be set up above ground on an area that corresponds approximately to that of the existing facilities (about 14 ha). Presently this area belongs to the State of Hessen.

According to the applicant’s view, the envisaged construction plans, with the large synchrotron being installed below ground and the remaining experimental facilities being set up above ground, are optimized to the specific soil conditions of the Darmstadt region. Civil construction costs are silimar to any other location in Germany. In the applicant’s view, choosing other locations in Germany or Europe would lead to exceeded overall costs due to the investment value of the present facility, which amounts about 250 MEuro.

V.3. Costs

The costs for the accelerators and storage rings are partly based on the scaling of past experience with the SIS/ESR project. The cost for civil construction is based on studies of an experienced engineering company that investigated two solutions. The infrastructure costs included, are also based on scaling from the existing facility.[2]

Costs for R&D:

Components	**Total Staff (FTE)**[3;4]	**Capital Cost (million €)**	**Staff Cost (million €)**[5]	**Total Cost incl. Staff (million €)**
Future facility at GSI	25 (for 3 years)	15	3.8	18.8

Cost estimates for construction:

Components	**Total Staff (FTE)**[6]	**Capital Cost (million €)**	**Staff cost2 (million €)**[7]	**Total Cost incl. Staff (million €)**
Future facility at GSI	140 (for 5 years)	670[8]	35	705

Development and construction Total	775 FTE years	685	38,5	723.8

[2] The GSI feels that the cost estimates are within a bandwidth of about ± 15 %. In prices for the year 2001, without inflation rate estimates for the duration of the project.
[3] FTE = full time equivalent one man per year.
[4] This does not include redirected staff from the present GSI personnel (20 FTE).
[5] Staff costs of 50.000 € for 2000 (average of all qualifications) have been used for this estimation.
[6] This does not include redirected staff from the present GSI personnel (120 FTE).
[7] The realization of the new facility will require an increase of the present temporary and permanent staff by 20 %.
[8] This number differs slightly from the 675 million € facility cost given in the Conceptual Design Report, since that number already contained 5 million € for R&D which is now included in the first line on ‘Costs for R&D’.

Cost estimates for operation:

Operation	**Capital Cost (million €)**	**Staff Cost (million €)**	**Total Cost incl. Staff (million €)**[9]
Operation of the new accelerator facility at GSI per year	59,0	20,0	79,0

Since the beginning of the year 2001, GSI receives extra funding by the Federal Government for R&D work related to the planning of facility. In this way, 10 scientist/engineer positions (10 FTE) will be financed over the next three years.

GSI is presently in the process of preparing and establishing a network of collaborations. It builds and expands on the already existing substantial network with the present facility, but will include new institutions and universities. A definite statements how the project will be financed can not be made so far.

[9] This assumes that about 75-85 % of the total budget of the future GSI will be assigned to the accelerator facility in the sense of “Operating an International Research Infrastructure” as defined by the HGF.

V.4. Schedule

The proposed schedule consists of 2-3-years of pre-construction research and development (R&D) followed by a 7-year construction phase. The proposed schedule includes:

Date	**Construction**
2001 – 2003	R&D work
started in 2001	SIS18 upgrade
start in 2003	Civil construction
2003 – 2004	Prototype testing of SIS 100 and SIS 200 magnets
after 2004	construction of magnets
until 2008	SIS18 upgrade, super fragment separator and associated equipment ready for radioactive ion beam experiments
2010	completion of SIS 100/200

Like the existing one the new facility will be operated about 6000 hours per year. The scientific lifetime of the facility is estimated to be at least 15 years (without upgrade) and about 25 years with further upgrades.

B. Statement and Recommendations

B.I. Field of Research

A comprehensive and quantitative understanding of all aspects of matter that are governed by the strong (nuclear) and the weak force, the two important short-range forces out of altogether four known ones, that critically determine the structure of matter at the microscopic level is still an extraordinary challenge in the field of nuclear and hadron physics. One goal encompasses all aspects of hadronic matter, including the investigation of the fundamental symmetries and interactions that are relevant for this regime. Another issue concerns the intrinsic complexity of the structure of matter. Many-body aspects play an important and often decisive role at all levels of the hierarchical structure of matter. They determine the behavior of matter as it appears in our physical world. This complexity is also manifestly true for the hadronic regime of matter.

The physics of nuclei and hadrons, nucleus-nucleus collisions at relativistic energies, the physics of dense plasmas studied with intense ion beams, the atomic physics of highly-stripped swift ions and the study of ion-matter interactions with heavy-ion beams have played and are still playing an important role in Germany. This has been achieved, on the one hand, through a combination of supporting research at universities, with and without small accelerator facilities; and, on the other hand, by a strong participation, and often leadership in research at large-scale facilities.

The proposed Future Facility at the Gesellschaft für Schwerionenforschung (GSI) Laboratory in Darmstadt, underlines the important role of nuclear and hadron physics in Germany and will provide the European science community with a world-wide unique and technically innovative accelerator system to perform future forefront research in the sciences especially concerned with the basic structure of matter. The facility will provide a unique range of particle beams from protons and their antimatter partners, antiprotons, to ion beams of all chemical elements up to the heaviest one, uranium, with highly increased intensities.

B.II. Scientific Program

Due to a combination of beams ranging from protons up to the heaviest ions of mass number 238 and of energies ranging from a few hundreds MeV up to 20 – 30 GeV, the Future Facility aims at attacking important problems in four different scientific areas:

- Radioactive Ions beams,
- Nucleus-Nucleus Collisions,
- Hadronic Physics with anti-protons,
- Plasma and Atomic physics.

Radioactive Ions beams will have the highest potential of discovery, both in nuclear structure and astrophysics implications. The exploration of nuclei up to the limits of nuclear binding (proton- and neutron drip-lines) is the prerequisite for a global understanding of nuclear structure. The present nuclear structure knowledge indicates severe problems and with the Future Project, GSI will be in a unique role for their solution.

GSI, presently world leader in superheavy element research and with a strong tradition in discovering nuclei far from stability, is in a unique role with an increase of primary beam intensities by a factor of 100, of secondary beam intensity of a factor of up to 10.000, and of the maximum beam energy by more than a factor of 10. This will position GSI at the forefront in radioactive beam research world-wide.

The new accelerator system will permit a strongly improved mapping of the nuclear chart towards the drip-lines (perhaps analogous to astronomical galaxy surveys towards increasing redshift) and addresses the impact of nuclear structure on e.g. neutron skins and halos (neutron and proton density distributions), the identification and strengths of shell closures, the behaviour of giant resonances etc.

These results enter directly into astrophysics and are essential for the energy generation and abundance composition resulting from explosive stellar events (novae, supernovae, X-ray bursts, neutron star mergers) which are the sites for nucleosynthesis processes like the rp- and r-process.

The **nucleus-nucleus collision program** aims at producing high-density baryon-rich matter and its transition to a quark-gluon plasma. The properties of hadronic matter under these conditions are relevant for the understanding of supernovae and neutron star formation. The capabilities of the Future Facility are carefully chosen to produce matter of highest density and highest strangeness content. Recent theoretical developments indicate that the baryon-poor transition at high temperature (studied at RHIC and LHC) may be of second order, whereas the baryon-rich transition at low temperature (to be studied at the Future Facility) may be of first order. The Future Facility will address this question. It will also allow searches for precursor phenomena of the chiral symmetry transition and a predicted low-temperature phase transition towards chiral superconductivity. The complex nuclear matter program will be in the position to answer questions concerning the phase transition from baryon-rich matter to quark and gluon plasma. It explores the phase diagram of hadronic matter in a way explored by colliders.

The knowledge of the properties of hadronic matter under these conditions are highly relevant for astrophysical applications. The equation of state of hot and dense nuclear matter plays a direct role in two astrophysical environments (the big bang as an example for the baryon-poor regime and neutron stars standing for the baryon-rich regime). The Future Facility will be able to explore temperature and density regimes in the baryon-rich region which are decisive in determining

- the critical stellar mass leading either to supernova explosions or black hole formation or,
- the fate of binary pulsars, leading to neutron star mergers, and their possible connection to gamma-ray bursts and/or strong gravitational wave signals from such events which will become available soon.

The **hadron program** is based on the availability of high energy, cooled anti-protons resulting in high intensity and high resolutions. It will reach the region of charm production and allow a comparison with theoretical models based on lattice gauge theories. It will answer fundamental questions concerning the confinement of quarks. This is one of the highest priorities of the new machine. The hadron program is a key ac-

tivity of the Future Project and has therefore to be integrated and supported by the overall scientific strategy of GSI.
With its advanced technical specifications, the Future Facility is aimed at addressing a spectrum of key questions in nuclear, atomic and plasma physics. Although the proposed plasma physics program is not covered similarly by other institutions, the program is scarcely focussed and does not have comparable quality and originality like the other scientific areas. Also GSI is not sufficiently integrated into the national like international networks of inertial fusion research. At the moment, plasma physics should not have the high priority like the other scientific areas. GSI should focus more on basic research in plasma physics by using their comprehensive experiences in the generation of dense plasmas of low density and high temperature than on potential applications for inertial fusion. Nevertheless, the activities should keep in touch with the technological efforts to develop controlled fusion devices for energy generation.

Finally by combining the use of relativistic ion beams and a high power laser the Future Facility allows to do unique experiments in plasma physics (study of material under extreme conditions of density and temperature) and atomic physics (QED at high z-value).

Cooled antiproton beams with high luminosity combined with a detector sensitive to photons and hadronic final states, provide a unique strong interaction entrée to high precision studies of hadrons containing charmed quarks or antiquarks.

Exciting the gluon fields in the presence of charmed quarks would create new states of hadronic matter (hybrids) in a kinematical region that is optimal for theoretical interpretation by calculations using QCD on a lattice. Determining the spectroscopy of such states and comparing with their analogues containing light quarks can reveal the strong interaction dynamics of the gluon fields, which are believed to be the agents of confinement.

B.III. Technology

The proposed Future Facility is an effective combination of pulsed synchrotrons and storage rings that builds on existing in-house expertise and technical leadership. The proposal builds on existing accelerators and experimental infrastructure and is thus cost-effective. GSI is a world-leader in high-intensity heavy ion beams and heavy-ion beam-coolers, the technologies and experiences required to build the proposed facility reside within GSI. However, also major technical innovations and new developments are essential which require solutions by establishing collaborative efforts with experienced laboratories to import the technology and to train new scientific staff.

The concept allows serving several different experimental programs at the same time with little loss of efficiency for each individual experiment. For the rare isotope program, the in-flight technique offers the unique advantage of very fast and chemistry independent production and correspondingly short development paths.

Synchrotrons are low duty-factor machines with intrinsic intensity limitations. There is an associated modest risk for the rare isotope and plasma physics programs, since the proposal assumes high instantaneous heavy ion intensities that are higher than what has been achieved for any synchrotron so far.

The proposal has little risk of failure, and a world-class scientific program would be possible even if the nominal intensity would be lower by some factor of 2-4. The development of high ramp-rate synchrotron magnets is progressing well and is likely to succeed. Even if this development would fall short by a factor of two in ramp rate, this would not be a show-stopper since this would only reduce the overall intensity by a factor of two or less. The novel broad-band metal-alloy cavities, that are being proposed for the bunch compression, are based on developments at KEK, FNAL, and BNL. If more conventional ferrite cavities would have to be used the performance would not be reduced significantly.

One option for enlarging the facility which has not been considered so far would be to add a post-accelerator section after the gas-stopping facility to add an ISOL-type capability to the present facility. An intensity upgrade by up to a factor of ten would be possible with direct injection from a suitably built linac into the SIS100. In addition, the energy can be increased by some 30% by reducing the operating temperature of the SC magnets in the SIS200. Bunch compression to 10 ns duration is considered to be very ambitious. An energy upgrade for the anti-proton beam via injection into the SIS100 or SIS200 would be rather straightforward. In the case of increasing the science program there are doubts whether a competitive kaon or neutrino facility could be added without major new investments in accelerators.

For the antiproton and compressed hadronic matter programs the choice of synchrotrons is the only viable option. For the rare isotope program, a CW-linac could deliver higher intensities, but it would be less well matched for the program with cooled beams. The chosen technology is suitable for the activities the Future Facility will address.

GSI with its excellent skilled accelerator physicists and engineers is well positioned to carry out the Future Facility. Approval of the project will no doubt attract additional experts to the laboratory.

B.IV. Project Management, Location, Costs, Schedule

There is intense worldwide interest in especially the exotic beam capabilities. Thus a timely commitment and start of construction is important for gaining the greatest research payback. The time schedule for pre-construction research and development and the construction phase is ambitious, but not unreasonable. The nearly simultaneous development, procurement, and installation of many different systems poses a serious management challenge. Delays of the project could have scientific and financial consequences. To address this issue, GSI plans to hire young people and train them in project management during the development phase. This approach has been successfully used at GSI in the past, and is feasible for the Future Facility. To prevent to fall behind schedule GSI should develop a management strategy in time which could include an increased contribution of external partners.

Cost and schedule have been validated by an experienced external technical advisory committee. From the present point of view, the broad and in many respects unique scientific program can be realized in a synergetic and thus cost-effective way, both scientifically and technically.

By realisation of the Future Facility, GSI will become a European user facility with primarily external users. Financing of the construction can only be done by a national and international network of collaborations. The high proportion of foreign financing like in building detectors or major parts of them, parts of the accelerator system, superconducting magnets or cooling systems – at present 25 % – is worth recognising. Yet GSI should try to involve more external partners and to sharpen the profile of the proposed science program.

GSI is an excellent choice for the location of the proposed facility. Much of the needed expertise already exists at GSI. There is no other place in Europe where a comparable facility and set of capabilities could be realistically envisioned without enormously increased costs. The new facility builds upon existing injector accelerator and experimental infrastructure needed. GSI has an excellent infrastructure to accommodate users and is easy to reach due to its central location in Europe with excellent connection to a major international airport.

Traditionally GSI has very close contacts to user groups from national and international universities. With concern to the Future Facility, GSI is surrounded by many universities with strong research programs in hadronic and nuclear physics and, in addition, nuclear astrophysics. Despite of the various successful cooperations in astrophysics, the required in-house competence in that field of research is not as sufficient as for the other scientific areas at GSI. GSI should establish an astrophysics-centre with permanent in-house competence, but mainly driven by external users.

GSI is the leading facility of nuclear physics and heavy-ion research in Europe. Existing major radioactive beam facilities in Europe are REX-ISOLDE and GANIL - the Future Facility will far exceed the capability of either. There are no plans to implement any of the other capabilities elsewhere in Europe (anti-proton storage ring, 22-30 GeV/nucleon heavy ions, heavy-ion driven plasma physics). With regard to nuclear structure research with radioactive ion beams, a complementary rather than an overlapping project for an ISOL-type facility (EURISOL) is presently under discussion in Europe. In particular, the nature of in-flight production makes the Future Project approach more suitable for studying the most weakly produced nuclei farthest from stability where the highest physics payback is likely to occur. Research at LHC does not address questions concerning nuclei far from stability.

Outside of Europe, the planned facility competes with the existing NSCL, RIKEN, and ISAC facilities, and in addition, with the RIF facility under construction at RIKEN, and the proposed RIA facility under construction in the USA. With the exception of low-mass nuclei, the primary beam intensities of the Future Facility will far exceed those of all existing facilities. All these foreign facilities are funded as national facilities without request for international funding. Only the RIKEN facility will have storage rings, but the Future Facility will outperform the projected RIKEN storage ring capability since synchrotrons are better matched to storage rings than cyclotrons. The high density hadronic matter research program extends in energy beyond the capability at Brookhaven National Laboratory and thus achieves much higher mass density. In principle, the SPS at CERN can reach these energies. Due to the enormous worldwide community for exotic beam research there is a need for several complementary advanced-generation facilities, in particular for facilities in each of the three main geographical areas (North America, Europe, Japan). There are no known plans for a competing anti-proton facility in the world.

Because of its outstanding aspects, GSI will be attractive to international collaborations. Within Europe, this facility needs to be integrated more explicitly into the long term research plans for Europe.

B.V. Users of the Facility

Being a user facility, GSI is open to all national and international research groups. The access to the new facility will be organized similar to the well-established peer review system for experimental proposals of the existing facility and is guaranteed for user groups from universities and from non-profit research centers. Access proceedings and requirements do not differ from other existing user facilities.

The success of the new facilities will depend a lot on the participation of teams from universities in Germany and foreign countries in Europe and even overseas. It will be a main issue to attract the hadron physics and astrophysics user communities in the

required extend to the Future Facility. In particular, the future planning of chair allocations in the relevant research areas at German universities will be of paramount importance.
The planning and realization of the new facilitiy will offer a broad range of academic and non-academic training opportunities in essential science and non science areas, such as basic physics, applied physics, materials science, mechanical and electrical engineering, computer science, information technology and management competences. To a large extent, the same is true for the period during the operation and scientific exploitation of the Future Facility.

The demands of the laboratory infrastructure of the Future Facility will be different to the existing facility, both in terms of the increased number of users and in the way they impact GSI, e.g. in the length of the runs or the interactions with accelarator operations. GSI should develop a strategy of adaptation to prevent significant problems.

B.VI. Transfer of Research Results

The planned facility primarily aims at basic research in the areas nuclear and hadron physics, plasma and atomic physics. From today's point of view, the envisaged rare isotope research program will have a major impact on astrophysics and observational astronomy. The dense hadronic matter program is relevant to the understanding of neutron stars and supernovae. The plasma physics program may have an impact on inertial confinement fusion by means of heavy ion beams.

Specific applications of the exotic beam research cannot be predicted in detail. Applications and spin-offs could be possible in medicine (diagnosis and therapy with specifically tailored isotopes, and possibly exploitation of the high spatial resolution of the beams for direct therapy), in condensed matter and semiconductor studies, or in surface studies (with the ability to a soft landing of radioactive isotopic probes on surface structures).

C. Conclusion

The Future Project makes forefront research possible with ion and antiproton beams and is in Europe the central instrument for research especially concerned with the basic structure of matter. The Future Project offers a singular research infrastructure for radioactive ion beams, nucleus-nucleus collisions, and hadronic physics. Research in the area of plasmas physics does not have the meaning like the aforementioned research areas, a development of inertial fusion is not to be pursued. The accelerator and detector system are world-wide uniquely and technologically extremely innovative. The technological innovations which can be expected are attainable, parallel developments could however lead to a temporal delay of the overall project. The user community is of high performance and extensive, the Future Project will be of high attractiveness for international scientists. The financial plan is convincing, the international share to be financed must amount to however at least 25%. The calculated additional amount of staff (140 full time equivalent one man per year) is necessary.