HGF-Research Field Structure of Matter

Programme: Elementary Particle Physics

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I. Major Goals and Overall Strategy

The goal of Elementary Particle Physics is to develop a deeper understanding of the fundamental forces and building blocks of matter and of the structure of space and time, which determine how the universe evolved from its beginnings to the complex structure observed today. These questions directly connect the physics at the smallest and the largest length scales of our universe and thus link the particle and astroparticle programmes at DESY. With the imminent start-up of the Large Hadron Collider (LHC) at CERN particle physics will go beyond the frontier of electroweak symmetry breaking and enter the Terascale, the energy range of Tera electron volts. We expect to derive explanations on the origin of matter, the nature of dark matter, further insights on extra dimensions and the grand unification of forces, all of which will change our view of the world and its interaction at a fundamental level.

The **European Strategy for Particle Physics**, as approved in 2006 by CERN Council, has set the road map for the field. German particle physicists and DESY have provided major input to this strategy. The programmes described below are therefore fully integrated in this strategy.

The pursuit of this strategy requires accelerators capable of colliding particles at extremely high energies, complex detectors able to record the collision products, cutting edge information technologies like the Grid, and the development of the underlying theoretical concepts. These elements have been outlined in the European Strategy: Exploitation of the LHC, followed by a linear electron-positron collider for which the International Linear Collider (ILC) is well prepared to serve energies of up to 1 TeV and, to reach later even higher energies, CLIC, for which R&D is being pursued. Particle physics promises to continue to have a major impact on many other fields of science and society, as it did in the past.

With the end of **HERA** operation in 2007 a major change for German particle physics has occurred. Until then Germany, through DESY, maintained a worldwide visible leadership role in the field of particle physics by providing unique research facilities, such as PETRA, where the gluon was discovered, and HERA, which provided a precise knowledge of the structure of the proton and the strong force. In order to maintain this visibility and to optimally place German particle physics in an increasingly global environment, the **Helmholtz Alliance "Physics at the Terascale"** has been initiated to create new and improved structures for particle physics in Germany. A structured network comprising DESY and FZK, 17 universities and one Max Planck institute has been set up as a tool for a more effective collaboration, in particular between experimentalists and theorists. This concept has raised strong interest in other countries. The DESY activities in particle physics are to a very large extent embedded in this Alliance and the laboratory is committed to ensure the sustainability of the new structures beyond the duration of the Alliance.

A key element to the success of particle physics is the provision of the **scientific infrastructure**. Within Germany, DESY provides world-class expertise on **accelerators**, large **detector systems** and **computing** for particle physics experiments and constitutes a centre of excellence for particle physics theory, while FZK is operating the Tier 1 computing infrastructure for all four LHC experiments. These facilities attract

some of the best scientists from Germany and the world and forge strong scientific collaborations with universities and other research institutes within and beyond Germany. Both centres have ensured that the German particle physics community is recognised as one of the strongest worldwide.

In detail, the **particle physics programme at DESY** will focus on the completion of HERA physics analyses, operation, physics analyses and upgrades of LHC experiments and preparation for a linear collider and its experiments. This programme links the results gained at HERA with the new physics expected at LHC and ILC and thus optimally exploits the interplay and synergy of the physics potential of the three accelerators. This experimental part is complemented by a strong supporting theory programme and by the necessary computing and other infrastructure topics.

While HERA operation ended mid 2007, analysis of the unique data sets is expected to continue at least until 2012. In 2006 DESY joined the two large multi-purpose LHC experiments, ATLAS and CMS, with the aim to continue participation in forefront high energy physics experiments and to contribute the unique expertise on proton structure gained at HERA. The involvement takes place in close collaboration with the German university groups. DESY plays a leading role in both experiments by contributing its large expertise to the integration and commissioning of the detectors, to their maintenance and operation as well as to the physics analyses. In addition DESY provides computing infrastructure for the German groups by housing Tier 2 computing centres for ATLAS, CMS and LHCb. It is planned to further strengthen the participation in the LHC collaborations, in particular through contributions to data analyses and to contributions to detector upgrades required by the expected future increase of the LHC luminosity.

As part of the Alliance, DESY operates an Analysis Centre to support German groups. This includes training of young researchers and provides the possibility to perform a significant part of their analysis at DESY. The centre is operated by DESY personnel and by staff financed through the Alliance. A National Analysis Facility (NAF) complements the Analysis Centre by providing computing resources.

DESY's particular expertise lies in the development of advanced accelerators. With the construction of the XFEL and the decision to employ superconducting acceleration technology for the ILC, DESY is ideally positioned to lead the European effort in the further development of the ILC. DESY intends to continue its active role in the development of a linear collider and to remain a strong partner in the global efforts on detector and accelerator developments.

The research programme of the **DESY theory group** covers a broad spectrum of topics, ranging from collider physics over particle cosmology to lattice gauge and string theory. An important task is to support present and future experimental programmes. As a leading centre for theoretical particle physics in Europe, the theory group also coordinates and hosts high level research and training events, in close collaboration with German universities and other national and international partners.

The particle physics programme at FZK will focus on operation and upgrade of the powerful Grid-based **Tier 1 computing infrastructure** needed both for data storage and reconstruction, especially at the LHC. DESY and FZK also contribute to worldwide efforts to develop tools for the Grid, in particular in the field of data storage.

II. Programme Topics

1. HERA

Operation of the electron-proton collider HERA ended in June 2007. Between 1992 and 2007 HERA delivered the expected luminosity, out of which about 0.5 fb^{-1} can be used for analysis by each of the two colliding beam experiments H1 and ZEUS. HERMES recorded collisions of polarized leptons with polarized protons of a thin internal gas target. HERA-B which finished data taking earlier, studied heavy quark physics in proton-nucleus interactions.

The fundamental physics questions tackled at HERA span a broad range and include proton structure function measurements, the determination of electro-weak parameters, investigations of QCD and searches for new particles and physics phenomena. Examples of outstanding results are precision

determinations of the parton density functions (PDFs) of the proton and of the strong coupling constant. Their fundamental importance for precision measurements at the LHC has been worked out over several years in a series of HERA-LHC workshops.

Key results of HERMES, using longitudinally polarised targets, are precise determinations of the contribution of quarks and gluons to the nucleon spin. Using a transversely polarised proton target pioneering results on the transverse spin structure of the proton and the first estimate on the total angular momentum of valence quarks were obtained. HERMES data prove increasingly useful for tests of QCD lattice calculations.

To **conclude the analysis of the complete data set** final calibrations will be obtained and all data will be reprocessed in a consistent manner. These steps are necessary to achieve the maximum sensitivity and precision. Furthermore, the H1 and ZEUS collaborations will combine their results in common analyses. These analyses will produce results with much improved systematic errors by taking advantage of the complementary design of the detectors. All activities will be integrated with the Analysis Centre to facilitate the transfer of know-how from HERA into LHC analyses.

In addition to the important contributions from collaborating institutes it is mandatory that DESY continues to play a lead role in these activities. This requires sufficient man power and computing resources for simulation and analysis of the data. Here the concepts developed within the framework of the LHC computing Grid will be applied.

2. LHC

In 2006 DESY joined the two large experiments **ATLAS** and **CMS**. The LHC programme is expected to deliver a fundamentally new understanding of particle physics. For this reason DESY is participating strongly in this endeavour. This engagement will maintain DESY's leadership role as a major laboratory for high energy physics and lay the foundation for experimentation and physics analysis at future colliders. It allows DESY to enhance its expertise in particle physics, to fulfil its role towards German universities and to remain attractive for students and scientists.

The participation of DESY in the LHC programme has **two components**: DESY has set up groups to participate through detector contributions and physics analyses in the ATLAS and CMS collaborations. DESY has achieved a high visibility and impact in both collaborations which is underlined by the fact that several coordination tasks are confided to DESY physicists. Secondly, DESY provides computing resources and user support as Tier 2 centre and it houses the NAF. This contribution matches the charge of DESY to provide sustained support for the German particle physics community. These strategic decisions by the laboratory were highly welcomed by the German universities. The DESY activities in this field are fully integrated into the Alliance.

The DESY experimental groups which include three **Helmholtz Young Investigator Groups** contribute to the preparation of the physics analyses of the experiments in the area of electroweak and top quark physics as well as searches for Higgs and supersymmetry. QCD analyses and studies of the proton structure are other important fields of activity. Once collision data become available DESY is prepared to contribute to the physics analyses of the collaborations. The LHC analysis activities are expected to increase during the next programme period and will be integrated in the Analysis Centre.

The **contributions of DESY to the detectors** are designed to complement the activities of German university groups which provided large contribution to the development and the construction of many detector components and they will take advantage of the special expertise at DESY in the operation of large particle detectors and their infrastructure. The main DESY activities thus include support for the **integration and commissioning** of the large detectors, contributions to the **data acquisition** and **high level trigger** systems, **computing and software** including support service in the form of detector alignment. A centre at DESY is being set up to allow part of these tasks to be performed remotely and to strengthen the links to the experimental facilities and groups at CERN. Contributions to the construction of the detectors are initially limited to smaller components in the forward region for **luminosity**

measurement (ATLAS), **forward calorimeters** and **beam condition monitors** (CMS). DESY is committed to contribute to the completion of the trigger and data acquisition systems required in 2010 before the nominal LHC luminosity will be reached.

In preparation of anticipated LHC luminosity upgrades and the linear collider, participation in **detector upgrades** are planned within the framework of the **Virtual Detector Laboratory** of the Alliance in close collaboration with German universities. The projects are selected according to their relevance for the long-term perspectives of the laboratory. Candidates for such projects are contributions to R&D and construction to the tracking systems which will have to be replaced during the next decade and which in both experiments have a strong German participation. Increase of the LHC luminosity will also require upgrades of the data acquisition and high level trigger systems which constitute a natural evolvement of the current DESY activities and are of high relevance also for detectors at a linear collider.

3. Electron-Positron Linear Collider

DESY is a world leader in the development of a linear e^+e^- collider, the next future global project after the LHC, and is committed to contribute to it also in future. The activities are well embedded in the international structures of the Global Design Effort for the ILC in which all major HEP laboratories, including CERN, take active part. DESY particularly contributes to the ILC project management through the expertise gained for the TESLA project and profits in a major way from the construction of the XFEL which is built in similar technology. The important role in the ILC development is underlined by three EU projects on machine and detector R&D which have been acquired with DESY as coordinating institute. The focus of DESY in the coming years will be to use the technological installations to improve the **accelerating gradient** and exploit the **synergy with XFEL** to industrialise the production of superconducting cavities. A Young Investigator Group, jointly with the University of Hamburg, as part of the Alliance and a joint professorship with the TU Berlin will be new elements of a programme promoting progress on **advanced accelerator** topics, vital for particle physics and other fields.

DESY's ILC **activities for detectors** and the accelerator are closely integrated internationally and with the German University groups in particular through the Alliance. The latter also provides a framework for education of students as is evidenced by the success of Alliance schools on topics of the accelerator and analysis techniques.

DESY plays a central role in the development of **novel tracking detectors** and **calorimeters** for the ILC, and is involved in the development of **vertex detectors**. The ongoing effort for novel detector technologies will shift towards large-scale prototyping work and integrated tests. Possible spin-offs of novel detector concepts are under study, for example the application of silicon based photomultipliers to medical imaging. Collaboration with the detector developments for the new high intensity photon sources is emerging. DESY intends to improve the technological base of the laboratory to enhance leadership in the area of tracking and calorimetric detectors.

With the formation of the ILD concept in 2007 DESY is expanding its **coordinating role** in the design effort for one of the ILC detectors. This work is carried out in close cooperation with international partners including Asia and in particular with groups from Japan. This role requires DESY to invest in the development of detector technologies, in software tools for advanced simulation and performance studies, and in project management tools. This will allow DESY to enhance its leading role in the development of a detector concept for the ILC.

4. Theoretical Particle Physics

The DESY theory group, in close collaboration with local university groups and the research group of the John-von-Neumann Institute for Computing (NIC), pursues a vigorous and broad research programme which rests on four pillars: phenomenology (Hamburg, Zeuthen), cosmology (Hamburg), string theory (Hamburg) and lattice gauge theory (Zeuthen). Through close collaboration with the experimental groups it is an integral part of the particle physics programme of DESY. With its post-doc and guest programme,

the organization of conferences, workshops and schools, the theory group fulfils a service for the German Particle Physics community and represents a centre for theoretical particle physics in Europe.

Central research topics in **phenomenology** are QCD and Standard Model processes at the LHC, Higgs physics and supersymmetry at LHC and ILC, and precision studies for colliders including novel tools for massive computations using computer algebra. In **cosmology** the group engages in matter-antimatter asymmetry, in particular leptogenesis, dark matter, inflation and cosmic neutrinos. Closely related are studies of very weakly interacting "hidden sector" particles and work on phenomenological aspects of grand unified theories (GUTs), as well as their embedding into the heterotic string. The dualities between (supersymmetric) gauge theories and **string theory** are the main theme of the string group. The **lattice field theory groups** at NIC and DESY develop advanced technologies in non-perturbative computations in QCD, effective theories and the Higgs sector of the Standard Model with applications to precision calculations for phenomenology and the investigation of strong interactions in the Higgs sector.

Work on collider physics will be carried out in close collaboration with the new Analysis Centre of the Helmholtz Alliance. Several other existing networks, involving all aspects of the current research programme, shape the interaction of the theory group with its national and international partners.

The main strategic goals for the next funding period are to play a leading role in collider phenomenology in the Analysis Centre Activities in particle cosmology and DESY's role as a leading interdisciplinary centre for mathematical physics should be maintained. The position of Zeuthen as a leading centre for lattice field theory should be continued. It is planned to establish new Junior Research Groups at the interface of the current main research activities.

5. Support for large facilities

DESY is operating three test beams, which are used primarily for detector development projects. Both within the Alliance and within EU programmes the test beams are widely used by groups from DESY and German and international partners. The operation and improvement of this very productive facility remains a high priority for DESY. A matching upgrade programme will be pursued.

Depending on the needs of the community DESY will develop additional facilities. An example of this is a **detector test facility using a high-field magnet**, which has been made available by DESY, and which is used very successfully by a number of international groups for dedicated detector studies.

DESY is committed to support Alliance partners in the area of designing, engineering and operating large detectors. A dedicated group will be set up, which can provide these services. This group will serve as the interface between the external partners, and the powerful infrastructure available at DESY. Suitable projects will be selected on the basis of the Alliance programme.

6. Computing Programme for Particle Physics

German particle physics groups are heavily involved in the preparation of the four big experiments at the LHC and in other ongoing particle physics experiments. These high rate experiments – in particular those at the LHC – produce unprecedented amounts of data. Transparent and efficient access to this data by more than 5000 collaborators from about 300 institutes in 50 countries poses a major challenge, which is to be met by the worldwide LHC Computing Grid (wLCG) project. It comprises the central computing centre at CERN (Tier 0) and eleven global distributed Tier 1 centres. The latter serve the Tier 2 and Tier 3 centres where the analysis of the data takes place.

6.1. Computing for particle physics at FZK

On the request of, and in close collaboration with, the German particle physics community, FZK has taken up the task of developing, installing and operating the Grid Computing Centre Karlsruhe (GridKa) as the German Tier 1 centre of the wLCG serving all four LHC experiments as well as four other international particle physics experiments. The build-up started in 2002 with the second phase "Main set-

up for data taking" completed in 2008. GridKa is expected to operate at least until 2022. Continuous scale up of compute and storage capacity, the corresponding development and implementation of middleware upgrades and a failsafe operation to meet the requirements of the wLCG MoU is the challenge for the forthcoming years. Grid computing technology today also has a strong impact on other fields of science. Consequently, the GridKa installation has been extended to include additional resources of other communities like Auger and fifteen virtual organizations of the German Grid Initiative D-Grid. Within the particle physics programme GridKa collaborates closely with the international user community and the members of the wLCG project at CERN and elsewhere. Adequate access for the Tier 2 centres in Germany and in Europe, particularly for those in Eastern Europe, will be assured in the coming years. FZK contributes substantially to the development of software tools and hardware components for a new worldwide scientific computing infrastructure.

6.2 Computing for particle physics at DESY

DESY is responsible for the largest Tier 2 in Germany, serving the LHC experiments ATLAS, CMS and LHCb. In addition, DESY is operating the National Analysis Facility (NAF) as the computing infrastructure of the Analysis Centre to support the national scientists with interactive LHC data analysis capabilities. Particle physics at DESY is supported by sophisticated Grid based infrastructures for the HERA experiments, IceCube, ILC and for the theory groups, in particular lattice QCD. For all these tasks, DESY has set up a software development programme in order to actively contribute to the Grid development. In particular in the field of the management of large data volumes, which is the central part of the Grid software development programme, DESY is a major developer and contributor to LHC-Grid with the dCache package. The laboratory will continue to develop, support and disseminate the data management software package dCache, analysis software packages and grid software.

III. Summary

DESY has been a cornerstone of particle physics in Germany and one of the leading laboratories worldwide for close to fifty years. The future particle physics programme is embedded in the Helmholtz Alliance "Physics at the Terascale" in which DESY continues to perform outstanding research at the energy frontier and to provide support for German university groups. The proposed research plan is designed to continue to attract the best national and international researchers to come to DESY, which also requires the sustained support of the Alliance with its new structures. Through the development of novel computing in the context of the Grid, FZK plays a key role in the analysis of the large data samples taken at present and future experiments. The strategy outlined above aims at maintaining DESY as centre of excellence in particle physics also after the end of operation of the in-house collider HERA.