Foreword

This report covers the years 2014 to 2016. During this time, the institute underwent significant evolution, defining the research strategies for the next decade or more. Following the appointment of Joachim Ullrich as president of the Physikalisch-Technische Bundesanstalt, the German national metrology institute in Braunschweig, Thomas Pfeifer was appointed as a director at the institute, starting in May 2014. His new division "Quantum Dynamics and Control" addresses questions such as: When do quantum objects behave as waves or particles? – What is the role of time in quantum systems? – How can chemical reactions be steered by lasers? A second important decision was the appointment of Jim Hinton, starting in December 2014. His division "Non-Thermal Astrophysics", covers problems such as: What are the sites of cosmic particle acceleration? – What impact do relativistic particles have on astrophysical systems? – What does the Universe look like at the highest energies? Overlapping with Werner Hofmann, Jim Hinton will continue the strong involvement of the institute in large-scale high-energy astrophysics projects, with a focus on the CTA gamma-ray observatory.

The scientific infrastructure of the institute has also evolved considerably. After two decades of highly successful operation, the heavy ion storage ring TSR had been taken out of operation, focusing effort on the construction and commissioning of the new cryogenic storage ring CSR that successfully went into operation in 2015. The CSR will allow a range of pioneering new topics in atomic and molecular physics to be addressed. The last of the huge electrostatic tandem accelerators was dismantled, creating space for the new laser laboratories required for Thomas Pfeifer's experiments. An expansion of the workshop building is being planned, to provide space for new large CNC machines required to manufacture the technically very demanding components of planned experiments. Last but not least, the former canteen building was converted to house the kindergarten "Quantenzwerge", increasing the appeal of the institute and its working conditions for young scientists in particular.

During the last three years, important scientific results were achieved across all areas of the institute, and new instruments and experiments are under construction that will bear fruit in the coming years. Some examples of important scientific results and achievements include, for the research area "Crossroads of Particle Physics and Astrophysics":

- First results from the second phase of the GERDA experiment, using new ^{76}Ge detectors and a novel active veto system to further improve the lifetime limits on neutrinoless double beta decay, achieving the world-best background level.
- Improved limits on dark matter detection through nuclear recoils from the XENON100 experiment; the new XENON1T detector is already taking data and the even larger upgrade to XENONnT is under construction – these experiments will define the state of the art on direct dark matter detection.
- The start of data taking of the STEREO detector at ILL Grenoble, to test hints for the existence of sterile neutrinos.
- The new CONUS project aiming to detect coherent neutrino scattering for the first time, with first results expected after a few months of data taking.
- The conclusion of the H.E.S.S. legacy survey of the Galactic plane, resulting in a catalogue of 78 very-high-energy gamma-ray sources as well as new results on individual sources, such as the identification of the Galactic Centre as a cosmic PeVatron accelerator and the first observation of particles escaping from the acceleration zone of a supernova remnant.
- Key steps towards the realization of the CTA as a next-generation gamma-ray observatory were also made, including the foundation of the CTAO Observatory gGmbH with Werner Hofmann as founding director, decisions on the CTA array site locations, and the successful testing of camera prototypes for the small-size and the medium-size CTA telescopes.

Key results in the area of "Quantum Dynamics of Atoms and Molecules" include:

- The most accurate value for the mass of the electron and the most stringent test of CPT symmetry in the baryonic sector with protons and antiprotons using high-precision Penning-trap measurements combined with, among others, state-of-the art bound-state quantum-electrodynamics calculations.
- Photodissociation of an internally cold beam of CH^+ ions in the cryogenic storage ring CSR demonstrating its unique performance with respect to the storage of cold molecular and cluster ion beams.
- The theoretical description and experimental realisation of tunable subluminal pulse propagation and phase detection of X-ray light employing interactions with nuclei embedded in thin-film cavities.
- The development of the concept of a vacuum collider via laser guided re-collisions of electron-positron pairs and of the theory for laser-generated intense gamma rays and neutral matter-antimatter plasmas.
- Highly charged ions (HCI) trapped at low temperatures by sympathetic laser cooling in Coulomb ion crystals for future high-precision spectroscopy and fundamental physics tests.
- The invention and experimental implementation of an ultrafast phase- and amplitude-control and time-gating scheme based on strong laser fields, enabling the time-resolved observation of a Fano resonance, the reconstruction of laser-driven quantum dynamics, and XUV/X-ray frequency combs.

In recognition of these achievements, members of the institute were awarded many prizes and other distinctions. I would like to emphasise that this success would not be possible without the excellent workshops and the support of the different service groups as well as by the administration. I would like to thank all members of the institute, in particular our junior scientists, and partners at universities and outside research institutions for their collaboration, support and enthusiasm.

The following chapters of the report address the areas of "1 Crossroads of Particle Physics and Astrophysics", "2 Quantum Dynamics of Atoms and Molecules", and "3 Service Units, Facts and Figures". Lists of publications, theses, invited talks, teaching activities, organized conferences, and institutional collaborations are provided online.

Werner Hofmann
Managing Director