Anton Zeilinger's achievements have been most succinctly described in his citation for the inaugural Isaac Newton Medal of the Institute of Physics (UK):

"For his pioneering conceptual and experimental contributions to the foundations of quantum physics, which have become the cornerstone for the rapidly-evolving field of quantum information."

Anton Zeilinger has been interested in the foundations of quantum mechanics and their applications in quantum information technology - most notably, quantum cryptography and quantum computation - throughout his entire scientific career. After studying physics and mathematics at the University of Vienna, he worked as a PhD student and later on as a research assistant under the supervision of Helmut Rauch at the Technical University of Vienna. As a member of his group, Zeilinger participated in a number of neutron interferometry experiments at the ILL in Grenoble. His first such experiment already confirmed a fundamental prediction of quantum mechanics, the sign change of a spinor phase upon rotation. This was followed by the first experimental realization of coherent spin superposition of matter waves.

He continued his work in neutron interferometry at M.I.T. with C.G. Shull (Nobel Laureate 1995). His work there included dynamical diffraction effects of neutrons in perfect crystals which are due to multi-wave coherent superposition. After his return to Europe, he built up an interferometer for very cold neutrons at the ILL in Grenoble which preceded later similar experiments with atoms. The fundamental experiments there included a most precise test of the linearity of quantum mechanics and a beautiful double-slit diffraction experiment with only one neutron at a time in the apparatus. Actually, in that experiment, while one neutron was registered, the next neutron still resided in its Uranium nucleus waiting for fission to happen.

In the late 1980s, Anton Zeilinger became interested in quantum entanglement. This work resulted in his most significant accomplishments. Both the proposal with Greenberger and Horne, and the experimental realization opened up the field of multi-particle entanglement. The resulting GHZ theorem is very fundamental for quantum physics, as it provides the most succinct contradiction between local realism and the predictions of quantum mechanics. Also, GHZ states were the first instances of multi-particle entanglement ever investigated.

It was the main experimental goal of Anton Zeilinger to experimentally realize such states and to observe the predicted GHZ contradiction with local realism. This was finally achieved in 1998. It took about 10 years after the theoretical ideas because both the understanding of multi-particle entanglement was very rudimentary then and also all experimental tools like sources and method for manipulating and detetcting such states had to be developed. That first observation of multi-particle entanglement opened up new avenues for many novel experiments including optical gates for quantum computers, optical one-way quantum computation and many more. GHZ states have become central in quantum information science. Therefore, they also became an individual entry in the PACS code.

The opportunity and the resources to realize the research program leading to GHZ states arose when in 1990, Zeilinger became Professor of Physics at the University of Innsbruck. Then he started two lines of research. One concerned entangled photons, the other atom optics. There developed a number of ways to coherently manipulate atomic beams, many of which, like the coherent energy shift of an atomic De Broglie wave upon diffraction at a time-modulated light wave, have become cornerstones of today's ultracold atom experiments.

Along the road to GHZ, Anton Zeilinger realized many novel tools for entangled photon physics, for example a bright source for polarization-entangled photons, ways to identify Bell states and methods for producing coherent emission of more than one entangled pair from one crystal. The resulting technology allowed him to perform a number of first quantum information experiments with entangled photons. The first ever use of entanglement in any quantum information protocol was his demonstration of hyperdense coding. His achievements also include the first entanglement-based quantum cryptography, the first quantum teleportation experiment of an independent photon and the first realization of entanglement swapping (i.e. the quantum teleportation of an entangled state).

In 1999, Anton Zeilinger became Professor of Physics at the University of Vienna and again opened up a new field, moving from atom optics to experiments with complex and massive macro-molecules. The successful demonstration of quantum interference for C60 and C70 molecules in 1999 opened up a very active field of research towards quantum interference of macroscopic systems. Key results include the most precise quantitative study to date of decoherence by thermal radiation and by atomic collisions and the first quantum interference of complex biological macro-molecules. This work is continued now by Markus Arndt.

With entangled photons, one of the main focuses of Anton Zeilinger's research since 2000 was to extend experiments testing Bell's inequalities and similar experiments into new realms. Already in Innsbruck, he with his group closed the so-called communication loophole, definitely using rapid random switching of the polarizers. Later he tested a nonlocal realistic theory proposed by Leggett, which includes a broad class, but certainly not all, such theories which are conceptually rather reasonable.

Most recently, Zeilinger's group performed an experiment closing for the first time the so-called freedom of choice loophole in the Bell experiments. Also, in a parallel experiment, they were able to show the nonclassicality of an individual system based on the Kochen-Specker-paradox for spin-1. This experiment provides one of the most simple realizations or confirmations of non-contextuality of quantum physics. Recent fundamental experiments include a non-local delayed choice experiment and an experiment on entanglement swapping where the measurement by a third party decides at a later instant whether two particles already registered are already entangled or not.

All these experiments again gave rise to further technologies for new quantum information tasks, particularly for quantum cryptography and for all-optical quantum computation. The most interesting avenue in all-optical quantum computation is the linear optics one-way quantum computer which, like some fundamental experiments, requires ultra-fast switching of photonic polarization and the identification of entangled states. There, Zeilinger realized many fundamental concepts in quantum computation including a realization of Grover's search algorithm, various quantum games, a quantum prisoner's dilemma and most recently the simulation of Heisenberg spin chains.

In quantum cryptography, Zeilinger's group is developing a prototype in collaboration with industry. While most of the community was working on the much easier scheme of using weak laser pulses, Zeilinger based his approach exclusively on the more demanding scheme using entangled photons. Recently, an understanding in the scientific communizy emerged that entanglement is a necessary condition for unconditional security of the quantum channel.

Zeilinger's experiments on the distribution of entanglement over large distances began with both free-space and fiber-based quantum communication and teleportation between laboratories located on the different sides of the river Danube. This was then extended to larger distances across the city of Vienna and most recently over 144 km between two Canary Islands, resulting in a successful demonstration that quantum communication with satellites is feasible.

In 2005, Zeilinger with his group again started a new field, the quantum physics of mechanical cantilevers. The group was the first to demonstrate experimentally the self-cooling of a micro-mirror by radiation pressure, that is, without feedback. That phenomenon can be seen as a consequence of the coupling of a high-entropy mechanical system with a low-entropy radiation field. This work is now continued independently by Markus Aspelmeyer.

Currently, Zeilinger is interested in further fundamental tests of quantum mechanics over large distances including experiments on higher-dimensional Hilbert spaces. This in part builds on his observation in 2000 that orbital angular momentum of photons can be entangled, which resulted in a very rich research field followed by a number of groups world-wide. Higher-dimensional entanglement work also includes multi-path entanglement and the study of the connection of a number of mutually unbiased bases and entanglement in higher-dimensional Hilbert space. Here, like in earlier work of Zeilinger, a very interesting interplay between fundamental questions and possible novel applications in quantum information science is emerging. He is also very interested in realizing momentum entanglement for ultra-cold atoms.

Anton Zeilinger is also active to provide scientific leadership in the foundations of quantum mechanics and in the field of quantum information science. As an example, we mention that his EU network “The Physics of Quantum Information”, which started in 1996, was the first such international activity world-wide.

Anton Zeilinger’s international awards include the Wolf Prize, the King Faisal Prize of Science and the Newton Medal of the Institute of Physics. While still at Innsbruck University, he built its Physics Department to be a prime center of quantum optics. The Institute of Quantum Optics and Quantum Information IQOQI of the Austrian Academy of Sciences, located both in Innsbruck and Vienna, was created to provide a continuing joint platform. In the report “Controlling the Quantum World” by the National Research Council of the U.S. National Academies, this Institute is mentioned as “an example of outstanding quality”.

Anton Zeilinger has continuously succeeded to inspire younger researchers towards high quality research. To date, many of his former students or post-docs have become professors at various institutions world-wide. These include Paul Kwiat (Bardeen Professor at the University of Urbana-Champaign), Jian-Wei Pan (Professor at the University of Science and Technology of China), Dirk Bouwmeester (Professor at UC Santa Barbara and Leiden), Gregor Weihs (Professor at the University of Innsbruck), Jörg Schmiedmayer (Professor at the TU Vienna), Harald Weinfurter (Professor at LMU Munich), Markus Oberthaler (Professor at Heidelberg University), Markus Arndt and Markus Aspelmeyer (Professors at the University of Vienna), Christoph Simon (Professor at the University of Calgary), Herman Batelaan (Professor at the University of Nebraska) and Gabriel Molina-Terriza (Senior Lecturer at Macquarie University, Australia).