tigations of such phenomena should help to understand the matter-antimatter asymmetry of the universe. For this kind of studies, in which also the group at the institute is involved, LHCb is superior to all other LHC experiments.

Today we know that only about 5% of the mass of the universe consists of normal matter. In addition to this, there must be nearly five times as much so-called Dark Matter, the nature of which is presently completely unknown. There are good arguments to assume that Dark Matter is composed of still undetected elementary particles. If true, these elementary particles should influence the decays of \( B \)-mesons and one should be able to infer their properties by precise measurements.

Experiments with Heavy Nuclei

Another physical question refers to the properties which characterized the matter in the universe immediately after the Big Bang and still before the building blocks of atomic nuclei (protons and neutrons) formed. This state can be generated in high-energy collisions of lead nuclei. However, in order to characterize this so-called quark-gluon plasma, the properties of normal nuclear matter must be known to an accuracy that has not yet been reached today. Here, investigations of proton-lead collisions at the LHC can provide new insight, and the group at the MPIK played an important role in extending the physics programme of LHCb accordingly. A first and very important result for the continued development of the theoretical understanding of the quark-gluon plasma are precise measurements of the influence of nuclear matter on the production of so-called \( J/\psi \)-mesons.
The LHCb Experiment

Elementary Particle Physics at the Terascale

The Large Hadron Collider (LHC) of CERN in Geneva presently is the most powerful accelerator world-wide. It allows to investigate the structure of matter at length scales 1000 billion (\textit{tera}-) times smaller than structures accessible by a light microscope. The goal of LHCb is to look for the limitations of the present Standard Model of particle physics using precision measurements and, together with the other experiments at the LHC, to find answers to the questions of how the universe looked like before the formation of atomic nuclei, why none of the antimatter created in the Big Bang is left in the universe, what determines the masses of the known elementary particles, and what is the nature of Dark Matter.

The LHC and the LHCb Experiment

The LHC storage ring has a diameter of 27 km, lies at a depth of 100 m underground, and allows to collide protons (hydrogen nuclei) or lead nuclei with so far unrivaled high energy in the four interaction zones. The particles in the ring circulate with a velocity of more than 99.99999% of the speed of light. More than 20 million collisions take place per second, in which a part of the kinetic energy of the projectiles is converted into antimatter created in the Big Bang is left in the universe, what determines the masses of the known elementary particles, and what is the nature of Dark Matter.

20 billion events and a data volume of more than 1 petabyte have been recorded. The analysis of the data is done within the world-wide computing grid on cross-linked CPU farms and storage systems.

Schematic view of the ca. 20 m long and 10 m high LHCb detector. The collision point is to the left of the spectrometer magnet (blue). Parts of the tracking system and the Cherenkov detectors are visible on both sides, to the right follow calorimeter and muon system.

Inversely, particle-antiparticle pairs can be created from pure antimatter. For each elementary particle, there is an antiparticle with the same mass and the same spin angular momentum, but with opposite charge. When particle and antiparticle collide, they annihilate, e.g., into two gamma rays (high-energy photons). Inversely, particle-antiparticle pairs can be created from pure energy.

In the Big Bang, equal amounts of matter and antimatter were produced from the initially available energy. As a consequence, one of the central problems of particle physics is the question why there is no antimatter in the present universe. If it would exist, matter and antimatter should be spatially separated. Otherwise, they would annihilate. One could imagine for example, that there are galaxies made from matter and galaxies made from antimatter. However, if this would be true, annihilation radiation from colliding galaxies should be observable in half the cases. In fact no such radiation has been observed, nor are there other indications that considerable amounts of antimatter exist anywhere in the universe.

Collision of the spiral galaxies NGC 2207 und IC 2163, about 114 million light years away. (Photo: Hubble Space Telescope)

The so-called Standard Model of particle physics in principle is able to explain an excess of matter in the universe, but does not describe the observations quantitatively. In our universe, there are approximately 100 billion galaxies, each of which consists of about 100 billion stars. If there would be no physics beyond the Standard Model, then there would be matter for only 100 galaxies. The universe would look completely different.

There are heavy particles, so-called $B$-mesons, which are about 5 times more massive but one hundred thousand times smaller than a hydrogen atom. They are composite particles, the mass of which consists to nearly 100% of antimatter, whereas the mass of their antiparticles is virtually completely matter. These heavy particles are not stable, but decay into daughter particles, in which matter and antimatter are present in equal amounts. Interestingly, it has been found that $B$-mesons decay faster to particular final states than their antiparticles, i.e., there are processes in which antimatter disappears faster than matter. Detailed inves-