7. Summary and Outlook

The ATRAP second generation facility was commissioned in 2006. A general overview of the renewed experimental setup for the second phase of the ATRAP experiment is presented in this thesis.

The Jülich team contributed successfully with the construction of a new antiproton annihilation detector system. This extended detector system will allow to optimize the production of cold antihydrogen atoms to permit the optical observations and measurements. The purpose of the here presented work was the development of offline software for Monte Carlo simulations, data reconstruction, physics analysis and interpretation. Extensive Monte Carlo simulations concerning the track fitting and vertex reconstruction have been developed. Different event generators, magnetic field distributions as well as data reconstruction algorithms on simulated data were established. To improve the detector position resolution, a constraint-fit procedure was adopted. Further possible improvements by applying certain cuts on the data were investigated. The antiproton annihilation detection system and its readout electronics were installed, tested and optimized. Real-time measurement with the antiproton annihilation detector system was performed during the scheduled beam activities at CERN in fall 2006. The radial position resolution is consistent with the Monte Carlo results.

The Jülich team was also responsible for the final design of an Ioffe-quadrupole trap, its construction and mechanical stability. The stability of charged particles in the combined Penning-Ioffe trap has been confirmed by the ATRAP collaboration so that probably the first attempts to trap antihydrogen atoms will take place during the beam time 2007.

After antihydrogen atoms will be trapped successfully, the ATRAP collaboration plans to work towards a high precision measurement of the antihydrogen 1S-2S transition frequency. The inhomogeneous magnetic field of the Ioffe trap broadens and shifts the antihydrogen spectral lines [HZ93]. It will therefore be necessary to cool the trapped antihydrogen as deep as possible in order to reduce the spatial extent of the trapped antihydrogen cloud. The quadrupole magnetic traps offer deeper radial well depths and provide stronger radiative decay-induced cooling [PSNY06] than higher order multipole magnetic traps. However, higher order multipole magnetic traps can offer smaller radial magnetic field close to the center axis to reduce any gradient-related loss of confined antiprotons [FS04]. A nested magnetic trap apparatus consisting of an octupole, a quadrupole and mirror coils is currently under design by the Harvard team.

The full energized octupole trap will capture cold antihydrogen atoms that are produced near its center. The trapped antihydrogen can be laser-cooled via Lyman-α laser light at 121.56 nm to the recoil limit which corresponds to a temperature of about 1.3 mK [MvdS99]. Laser cooling of trapped hydrogen has already been demonstrated with a pulsed Lyman-α source. Cooling should be even more efficient with a continuous wave Lyman-α source [EJW99] which is presently under construction for the ATRAP experiment at the University of Mainz. After laser cooling of antihydrogen atoms, the octupole field will be ramped back to zero meanwhile the quadrupole field will be ramped up to hold and compress the antihydrogen atoms for laser spectroscopy.

The final step towards accurate test of the CPT symmetry will be a high-precision measurement of the antihydrogen 1S-2S transition frequency and to compare it to that of hydrogen. Many challenges lie ahead so an interesting and exciting future is expected to come.