R & D for Antimatter Spectroscopy

M. Amoretti[1], C. Amsler[2], G. Bonomi[3], L. Cacciapuoti[4]
C. Carraro[1,5], M. Doser[3], R. Drullinger[4] G. Ferrari[6], A. Kellerbauer[3],
I. Johnson[2], V. Lagomarsino[1,5], R. Landua[3], G. Manuzio[1,5],
M. Prevedelli[7], H. Pruys[2], L. Ricci[8], C. Regenfus[2], G. Testera[1],
G.M. Tino[4]

Neutral Atom Trap (NEAT) Collaboration

1. Istituto Nazionale di Fisica Nucleare, Sezione di Genova, I-16146 Genova
2. Physik-Institut, Zurich University, CH-8057 Zurich, Switzerland
3. EP Division, CERN, CH-1211 Geneva 23, Switzerland
4. Dipartimento di Fisica e LENS - Universita' degli Studi di Firenze, INFN - Sezione di Firenze, I-50019
5. Dipartimento di Fisica, Universita' di Genova, I-16146 Genova
6. Dipartimento di Fisica e LENS - Universita' degli Studi di Firenze, INFN - Firenze, I-50019
7. Universita' di Bologna e INFN - Sezione di Firenze
8. Dipartimento di Fisica - Universita' di Trento, I-38050 Trento-Povo

The production and detection of cold antihydrogen atoms at the AD (M. Amoretti et al., Nature 419 (2002) 456; G. Gabrielse et al., Phys. Rev. Lett. 89, (2002) 213401) was a fundamental milestone towards a high precision comparison of matter with antimatter, in particular a test of the CPT invariance or the weak equivalence principle (WEP).

For CPT the best limits in the lepton sector are ~ 10^{-12} for the electron-positron magnetic moment (g-2) (R. S. Van Dyck et al., Phys. Rev. Lett. 59 (1989) 26) and , in the baryon sector , ~ 10^{-10} for the antiproton-proton charge-to-mass ratio (G. Gabrielse et al., Phys. Rev. Lett. 82 (1999) 3198). Measuring the 1S to 2S transition frequency with trapped antihydrogen at sub-K temperature and comparing with hydrogen would lead to a precision of $\Delta E/E < 10^{-15}$. The ultimate precision of 10^{-18} requires cooling of the trapped atoms e.g. with a powerful Lyman α laser.

According to theoretical considerations, a violation of the WEP for antimatter is unexpected at the level higher than about 10^{-6} (M.M. Nieto, T. Goldman Phys. Rep. 205 221 (1991). However, no measurements exist on the gravitational matter-antimatter interaction. The availability of very cold neutral antimatter such as antihydrogen will allow, e.g with time of flight methods or atomic interferometry techniques, a test of the WEP for antimatter by comparing matter and antimatter acceleration in the Earth gravitational field. Sub-mK energies are necessary to perform atomic fountains experiments and obtain a sensitivity below 10^{-6}-10^{-8}.

Therefore, trapping antihydrogen atoms and cooling down to mK-μK energies is the experimental challenge that has to be solved next before designing the appropriate apparatus. The NEAT collaboration is actively working on an R&D programme using protons, electrons and/or negative ions. In particular we concentrate on

- the experimental study of electric and magnetic field configurations (sextupole and octupole fields) allowing the production and trapping of antihydrogen in the same volume;
- the development of a sufficiently strong Lyman α laser for laser cooling, possibly down to the recoil limit of about 1 mK (~ 0.1 μeV);
- the study of the cooling procedure to reach the sub-mK range;
- the study of other routes to trap and cool antihydrogen (e.g. using positive antihydrogen ions).

An AD experiment incorporating these technologies will be proposed once this R&D program is successfully completed. Given the time scale of the preparations, construction, and measurements, we believe that the earliest time for antiproton experiments would be 2007. The Italian part of NEAT has submitted a funding proposal to INFN, which is currently under review.