Thesis abstract Sarah GEFFROY

"Low-energy antiproton manipulation studies and the production of antihydrogen"

The Standard Model predicts that every particle has an antiparticle of identical mass and opposite charge, yet the matter-antimatter asymmetry observed in the Universe remains unexplained. Testing CPT conservation with antimatter thus provides a probe of possible new physics. Since the Standard Model does not include gravity, another avenue to new physics with antimatter is to test the Weak Equivalence Principle, on which the theory of General Relativity is based. The GBAR experiment, installed at the ELENA decelerator ring, part of CERN's "Antimatter Factory", aims to measure the free-fall acceleration of antihydrogen, produced as a coolable $\bar{H}^+$ ion through two successive charge-exchange reactions between a very low-energy antiproton beam and a cloud of positronium (Ps).

This thesis contributes to three stages of this programme. A discrepancy between the simulated (100%) and measured (68%) transmission of the decelerated antiproton beam through the GBAR accumulation trap motivated a measurement of the transverse emittance of the ELENA beam, using a scan method adapted to GBAR's electrostatic Einzel lenses. At the nominal 100 keV energy, the measured emittance agrees with the ELENA beam-optics model, but at 6 keV it is about twice as large as expected, an effect attributed to space charge and confirmed by SIMION and RF-Track simulations. The emittance of the beam extracted from the trap was also measured, showing that the trap fringe field further degrades the beam, with a trade-off between confinement and beam quality depending on the trapping field (3 T versus 5 T).

The cross section of the first charge-exchange reaction, $\bar{p} + Ps \rightarrow \bar{H} + e^-$, is measured for the first time at 4 and 6 keV, yielding (10.6 ± 4.8) and $(20.2 \pm 2.6) \times 10^{-16}$ cm² respectively, in excellent agreement with an exact three-body theoretical model. Due to a large range of predictions for the second reaction $\bar{H} + Ps \rightarrow \bar{H}^+ + e^-$, a dedicated measurement campaign was pursued for the matter-equivalent reaction using ELENA's H^- beam and a photo-dissociation scheme (in the framework of the ANR project SPHINX) to provide H atoms.

First results from the SPHINX project are presented: a 1.82 σ excess is observed at 6 keV, consistent with a signal near the reaction's kinematic threshold, but still dominated by a common background whose likely origin and mitigation strategies are discussed.