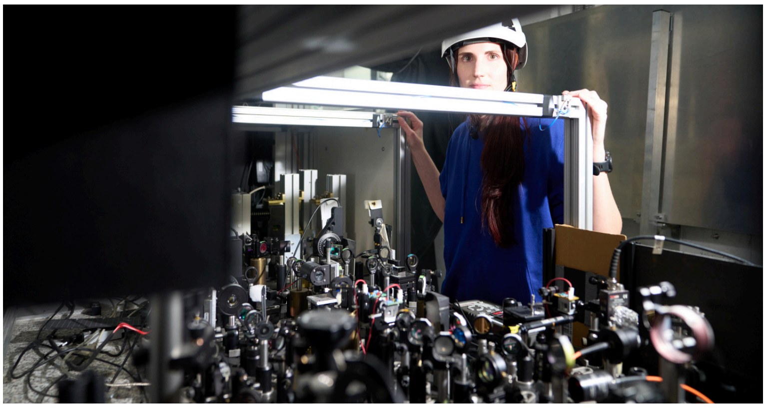
CERN: FIRST LASER COOLING OF A CLOUD OF POSITRONIUM ATOMS



Published in Physical Review Letters as the "Editor's Highlight", the results were obtained by the AEgIS collaboration at CERN, which the Italian Institute for Nuclear Physics also contributes to, and they are very interesting both for fundamental physics and its possible technological developments.

For the first time, a cloud of positronium, the lightest atom in nature, was cooled using a laser. The scientific collaboration of the AEgIS experiment obtained the expected experimental proof of this process. INFN (the Italian Institute for Nuclear Physics) also makes a significant contribution to this collaboration. The result, published last February 22 in *Physical Review Letters* as the "Editor's Highlight", was obtained using a special laser system based on an alexandrite crystal and specifically developed to meet the requirements of this experiment: high intensity, large bandwidth, and long pulse duration. The temperature of the positronium atoms produced by a porous silicon dioxide target at room temperature, struck by a beam of positrons, decreases from 380 Kelvin to 170 Kelvin. This corresponds to a reduction in the transverse velocity component from 54 km/s to 37 km/s.

Positronium is the little brother of hydrogen, with a positron replacing the proton. As a result, it is lighter than hydrogen by a factor of approximately 2,000, so that it is, in fact, the lightest atom existing in nature. It is an unstable atom: in a vacuum and in its fundamental state (with parallel spins of two particles), it annihilates with a lifetime of just 142 nanoseconds (billionths of a second). The positronium cooling must occur during its brief life and this makes it very challenging to replicate this process, compared to ordinary atoms. The use of a wideband pulsed laser has the advantage of cooling a big portion of the positronium cloud, doubling its actual lifetime and making a greater number of atoms available for further experiments after the cooling.

The scientific goal of the AEgIS experiment, one of the experiments that operates in the CERN Antimatter Factory, is to measure the gravitational acceleration of antihydrogen, as a test for the antimatter of Einstein's weak equivalence principle. The latter is a cornerstone of the general theory of relativity, according to which a body that falls freely in a vacuum subjected to a gravitational field follows a trajectory in space that is independent of the composition of the body itself. In the case of AEgIS, antihydrogen is obtained using a reaction between positronium in an excited state and trapped antiprotons. The lower the speed of the positronium, the greater the probability that it will form antihydrogen: this is why it is important to cool the positronium atoms to reduce the kinetic energy as much as possible.

The possibility of creating a dense cloud of cold positronium atoms also makes spectroscopy measurements with unprecedented precision possible. Moreover, it paves the way for the first experiments to measure the gravitational interaction on an antimatter system composed only of leptons. It also makes it possible to produce more intense sources of hydrogen for gravitational measurements like those that the AEgIS collaboration intends to make in the future.

“The availability of positronium atoms that are cold enough doesn’t only concern fundamental physics research, but is also of wider interest”, explains Ruggero Caravita, INFN researcher who leads the AEgIS international collaboration. “Positronium cooled via laser has, in fact, peculiar features that make it an attractive system, including for its potential technological impact. In particular, it paves the way for Bose-Einstein condensation of a system composed of antimatter, a result already obtained in the case of ordinary antimatter cooled by a laser”. “A Bose-Einstein condensate of positronium”, Caravita continues, “is a strong candidate for creating a pulsed source of monochromatic gamma rays in the laboratory using stimulated annihilation of the condensate. If these also proved coherent, as recently hypothesised, a pulsed laser would be created in the gamma-ray spectrum, with a vast range of scientific and technological applications, from gamma-ray spectroscopy to medical imaging”.

The AEgIS collaboration shares the results obtained with an independent research group, which used a different technique and published the results in arXiv the same day as AEgIS.

INFN is one of the scientific leaders and one of the main financial backers of the AEgIS experiment, which has always been Italian powered. As part of INFN’s LEA (Low Energy Antimatter) collaboration, which groups together the Institute’s various scientific activities in this sector into a single project, a new state-of-the-art machine for producing pulsed beams of positronium is being built at the Antimatter Laboratory of the University of Trento and the INFN National Centre TIFPA. This will be one of the approximately ten “Surko traps” – which is what these devices are called – existing in the world. The device will be created with an innovative transmission geometry and will form the basis of a completely new generation of experiments to manipulate cold positronium with laser beams. Research groups of the University of Trento, the INFN National Centre TIFPA of Trento, the INFN Milan Division and the University of Milan, the Polytechnic University of Milan, and the INFN Pavia Division and the University of Brescia are part of the AEgIS scientific collaboration.