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XENON1T MEASURES THE RAREST DECAY PROCESS EVER OBSERVED IN THE UNIVERSE

The universe is almost 14 billion years old. An inconceivable length of time by human standards, yet compared to some physical processes, it is but a moment. There are radioactive nuclei that decay on much longer time scales. XENON1T, a detector for the search of dark matter at INFN Gran Sasso National Laboratory, has now directly measured for the first time the so-called double electron capture of xenon-124, that is the rarest decay process ever recorded in a detector. The half-life measured for xenon-124 - the time after which half of the radioactive nuclei have decayed away - is about one trillion times longer than the age of the universe. The new result, published on April 25th on Nature, provides information about the nuclear structure relevant for further investigations on rare processes.

XENON1T has as its main scientific goal the direct search for dark matter in the form of WIMP (weakly interacting massive particles), and is currently the largest detector ever made for this purpose, with a sensitive mass of 2 tonnes of xenon, and at the same time it presents the smallest background ever obtained. Thanks to these characteristics, since 2017 it is the most sensitive experiment for WIMP search. It is based on a time projection chamber with liquid/gas xenon: it is a cylindrical detector, about one meter in diameter and height, filled with liquid xenon at a temperature of -95 °C. In XENON1T the interaction of a particle with a xenon nucleus is given by a weak flash of scintillation light accompanied by a few electrons, which are converted into a flash of light once in the gaseous xenon. Both light signals are recorded thanks to ultrasensitive photosensors, and allow information on the 3D position and energy of each event.

In the double electron capture process, during which the xenon-124 is transformed into tellurium-124, two protons of the xenon nucleus simultaneously capture two electrons of the first surrounding level, transforming into two neutrons, with the emission of two neutrinos. The electronic cloud reacts to the lack of two electrons captured with a cascade process, which leads to the emission of a fixed amount of energy. In the case of



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xenon, this energy corresponds to about 64 keV. The measure therefore consisted in seeking an excess of events with energy equal to the expected one, compared to the background, almost constant in energy, present in the detector. Using an internal mass of xenon equal to 1.5 tonnes, and a data acquisition time of approximately 180 days, 126 events were observed in the expected energy region. Using this first-ever measurement, the scientists calculated the enormously long half-life of 1.8×10²² years for the process.

The new results show how effective the XENON1T detector is in detecting rare processes and rejecting background signals. Having observed this process directly, in fact, demonstrates how powerful the XENON1T detection method actually is – also for signals that are not from dark matter – thanks to the effort put in reducing the natural radioactive background of the experiment.

XENON1T acquired data from 2016 until December 2018 when it was switched off. The scientists are currently upgrading the experiment for the new XENONnT phase which will feature a three times larger active detector mass, together with a reduced background level. This upgrade will boost the detector's sensitivity. The INFN, with the LNGS and the divisions of Bologna and Turin, has been part of the XENON1T project since its inception in 2009. With the more recent contribution of researchers from the INFN divisions of Naples and Ferrara, the Italian groups are also involved in the current extension of the project, with the XENON1T detector, under construction at the LNGS.