CERN researchers see shape shifting in gold nuclei

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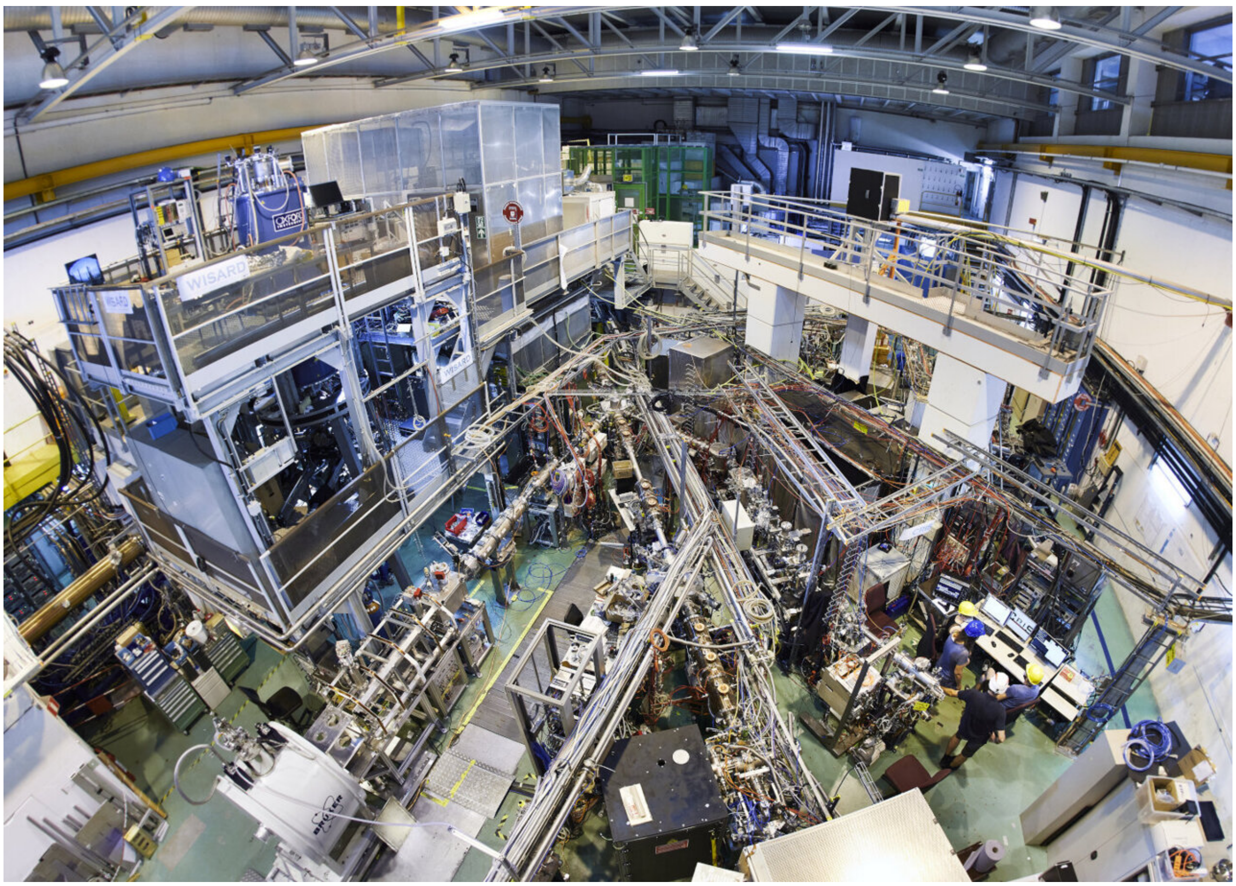


The ISOLDE facility hall, where the RILIS, Windmill and ISOLTRAP set-ups are located. Credit: CERN

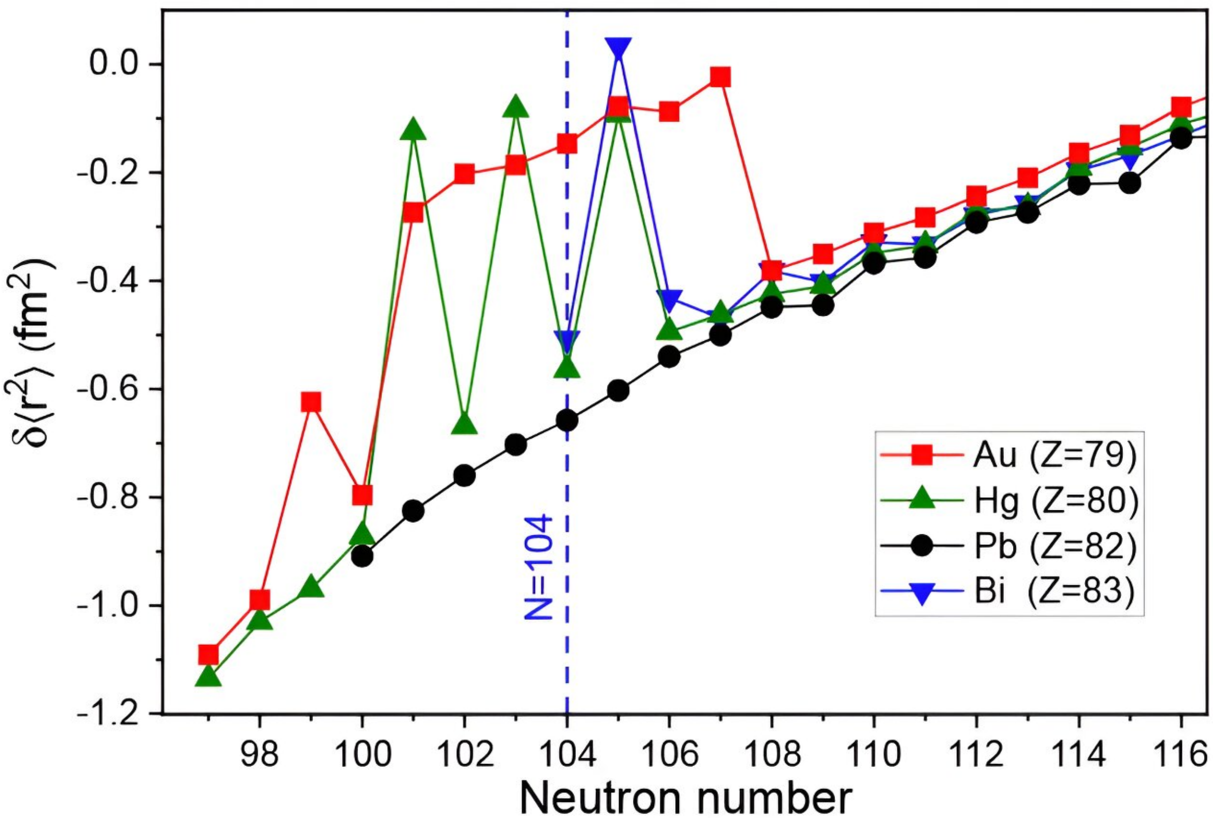
A little like humans, the nuclei of atoms tend to shrink as they lose weight. But atomic nuclei are complex quantum systems formed from neutrons and protons that are themselves composite particles made of quarks. As such, their usually spherical or nearly spherical shapes do not always simply shrink as particles are removed from their interior. In fact, exotic, neutron-deficient mercury and bismuth nuclei have been seen to alternate dramatically from football (soccer) shapes to rugby ball shapes as single neutrons are removed from the nucleus.

A new study conducted at CERN's ISOLDE facility now finds that neutron-deficient gold nuclei also display such shape shifting. The finding, described in a paper just published in *Physical Review Letters*, comes a little more than 50 years after the phenomenon was first discovered in the light mercury nuclei, also at ISOLDE. Belated happy golden anniversary, shape shifting.

To investigate gold nuclei, which have 79 protons, the team behind the new study used three set-ups at ISOLDE (called RILIS, Windmill and ISOLTRAP), each with a specific function. The combined power of the three set-ups allowed the team to determine the radii of gold nuclei with 104 neutrons all the way to 97 neutrons—that's 21 fewer neutrons than that of the gold that can be found in rivers.

The results are striking. Given a previously observed transition from nearly spherical shape at neutron number 108 to a rugby ball at neutron number 107, followed by a plateau of rugby balls until neutron number 104, a possible continuation of the plateau and a transition back to nearly spherical shapes was expected.

This continuation of the plateau was observed, as was the transition, which occurs at neutron number 101 and is a near-mirror image—centered at neutron number 104—of the previously seen transition (see figure below). However, an extra shape-staggering blip was also observed at neutron number 99.



Changes in the mean-squared radii of gold, bismuth, mercury and lead nuclei around neutron number (N) 104. A sharp increase followed by a decrease indicates shape transition. Credit: James Cubiss et al.

"This pattern in nuclear shape evolution is unlike any other we've seen before," says James Cubiss, lead author of the paper.

"In contrast to the mercury and bismuth nuclei, in which the staggering shows that football and rugby ball shapes are almost evenly matched in terms of the competition to minimize their binding energies, rugby balls win in the gold nuclei near neutron number 104. But they only just win, as evidenced by the shape staggering at neutron number 99 and the sudden jump back towards football-like shapes."

The theorists in the team went on to perform state-of-the-art model calculations of nuclear radii and compare them with the data. They found that the model is able to follow the wandering gold nuclei, but only if certain other data are used to constrain the calculations.

Fifty years on, the phenomenon of shape shifting still poses a tremendous challenge for nuclear theory.

More information: J. G. Cubiss et al, Deformation versus Sphericity in the Ground States of the Lightest Gold Isotopes, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.202501

Provided by CERN