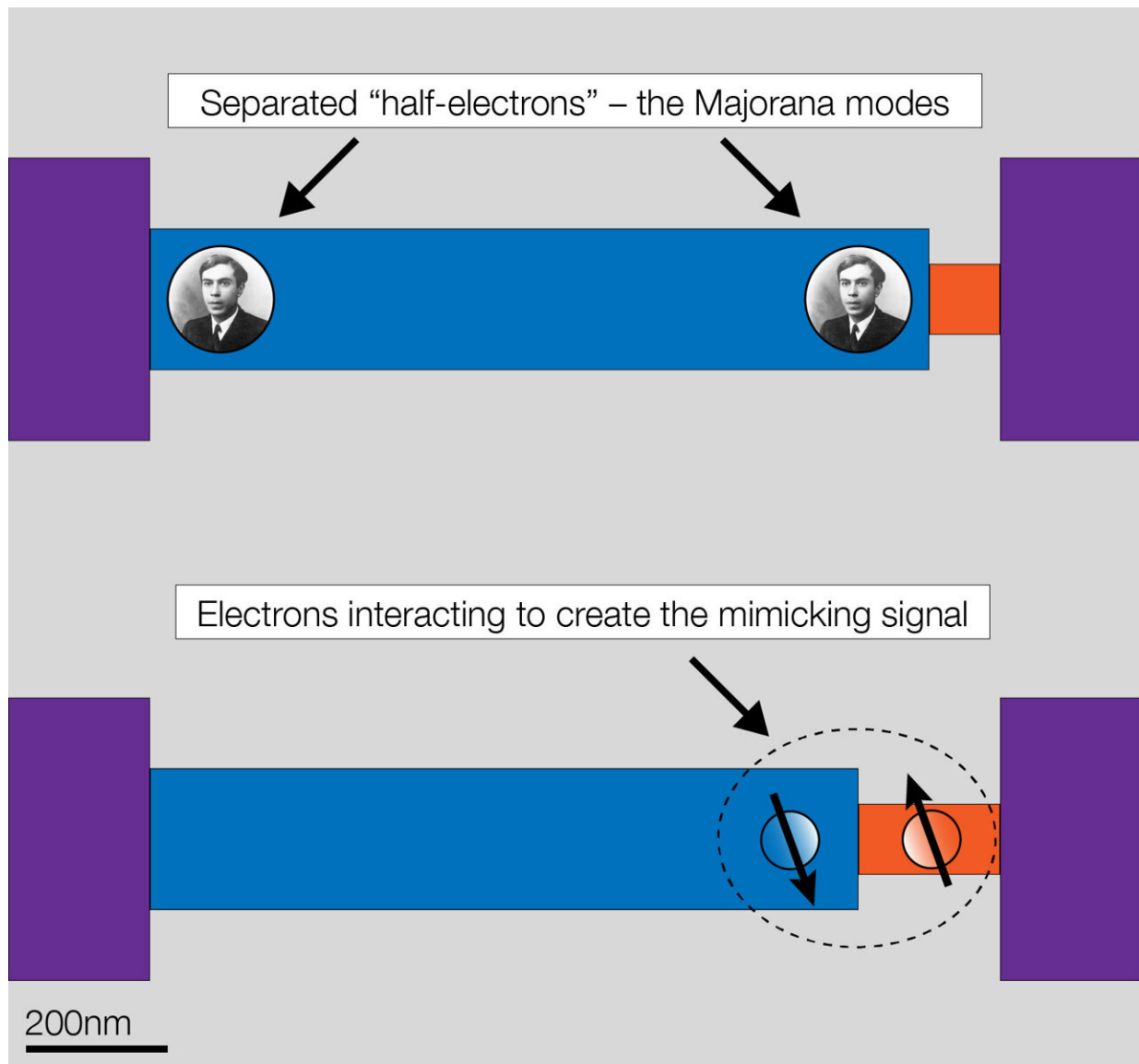


# Scientists advance the understanding of potential topological quantum bits

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The nanowire is suspended between two metal conductors (purple). The

superconductor made of aluminium (blue) covers part of it leaving a gap of exposed inner wire made of indium and arsenic (orange). In the setup with the small junction, the scientists expected to see the separated "half-electrons" in the exposed superconductor -- illustrated by portraits of Ettore Majorana, the Italian physicists for whom they were named. But they did not find anything. In the setup with the big junction, the exposed core of the wire formed a quantum dot and its electrons interacted with the electrons in the superconductor coating forming the mimicking signal. Credit: IST Austria

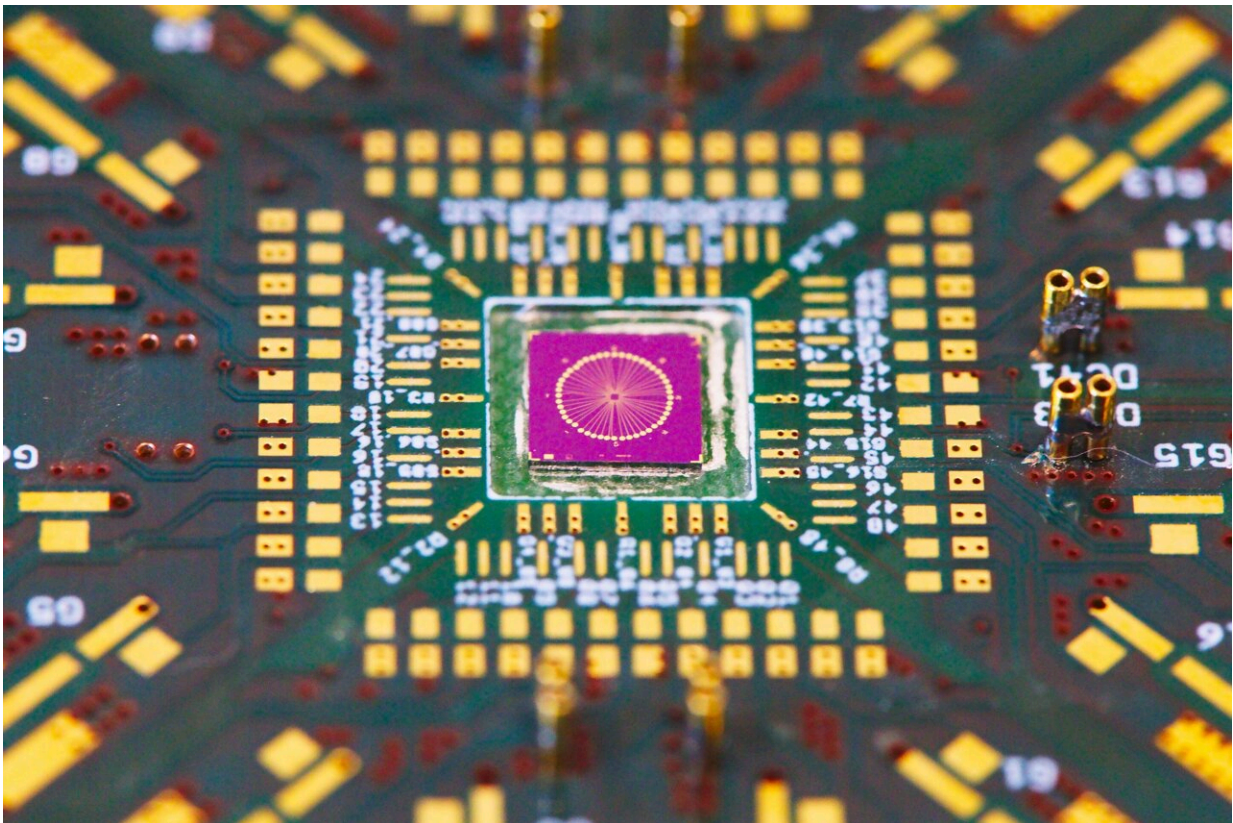
Quantum computers promise great advances in many fields—from cryptography to the simulation of protein folding. Yet, which physical system works best to build the underlying quantum bits is still an open question. Unlike regular bits in your computer, these so-called qubits cannot only take the values 0 and 1, but also mixtures of the two. While this potentially makes them very useful, they also become very unstable.

One approach to solve this problem bets on topological qubits that encode the information in their spatial arrangement. That could provide a more stable and error-resistant basis for computation than other setups. The problem is that no one has ever definitely found a topological qubit yet.

An international team of researchers from Austria, Copenhagen, and Madrid around Marco Valentini from the Nanoelectronics group at IST Austria now have examined a setup which was predicted to produce the so-called Majorana zero modes—the core ingredient for a topological qubit. They found that a valid signal for such modes can in fact be a false flag.

## **Half of an electron**

The experimental setup is composed of a tiny wire just some hundred nanometers—some millionths of a millimeter—long, grown by Peter Krogstrup from Microsoft Quantum and University of Copenhagen. These appropriately-called nanowires form a free-floating connection between two metal conductors on a chip. They are coated with a superconducting material that loses all electrical resistance at very low temperatures. The coating goes all the way up to a tiny part left at one end of the wire, which forms a crucial part of the setup: the junction. The whole contraption is then exposed to a [magnetic field](#).



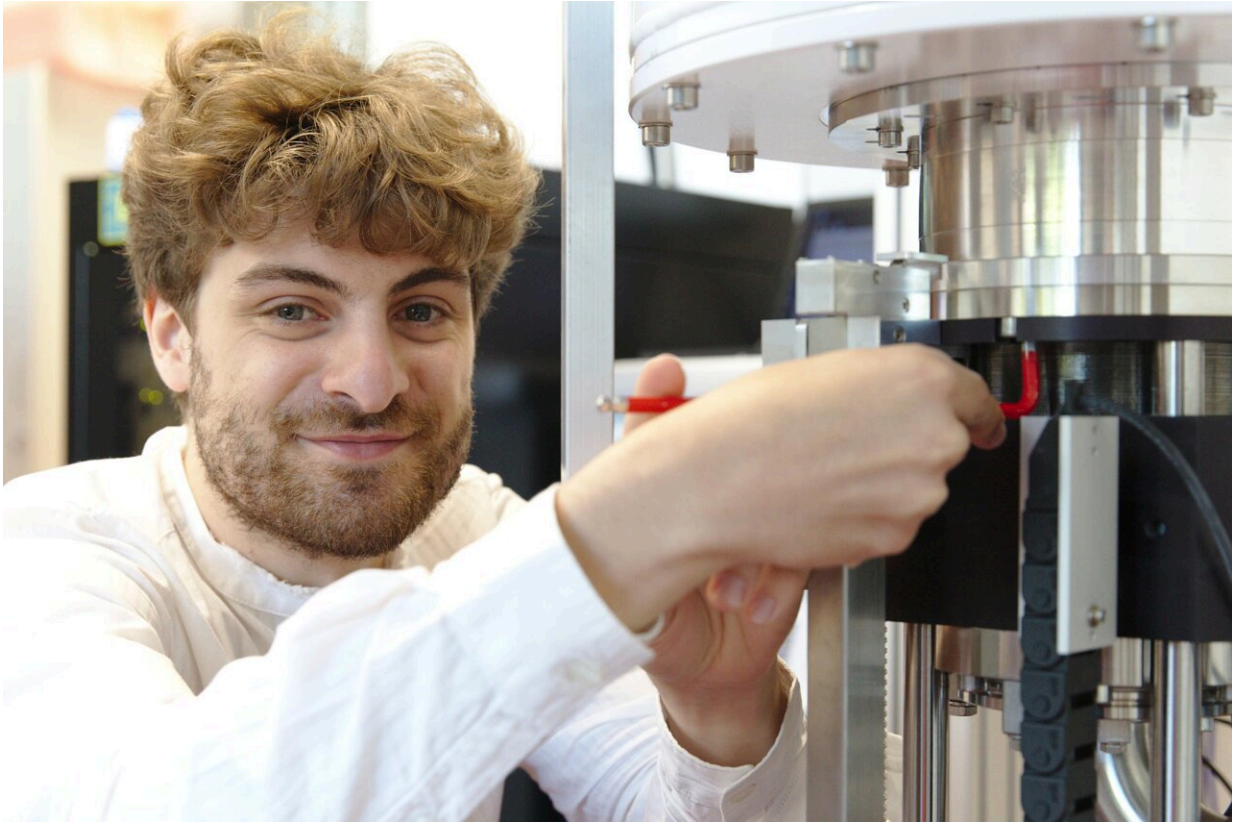
Printed circuit board for mounting the nanowire sample. Credit: IST Austria

The scientists' theories predicted that Majorana zero modes—the basis for the topological qubit they were looking for—should appear in the nanowire. These Majorana zero modes are a strange phenomenon, because they started out as a mathematical trick to describe one electron in the wire as composed of two halves. Usually, physicists do not think of electrons as something that can be split, but using this nanowire setup it should have been possible to separate these "half-electrons" and to use them as qubits.

"We were excited to work on this very promising material platform," explains Marco Valentini, who joined IST Austria as an intern before becoming a Ph.D. student in the Nanoelectronics group. "What we expected to see was the signal of Majorana zero modes in the nanowire, but we found nothing. First, we were confused, then frustrated. Eventually, and in close collaboration with our colleagues from the Theory of Quantum Materials and Solid State Quantum Technologies group in Madrid, we examined the setup, and found out what was wrong with it."

## **A false flag**

After attempting to find the signatures of the Majorana zero modes, the researchers began to vary the nanowire setup to check whether any effects from its architecture were disturbing their experiment. "We did several experiments on different setups to find out what was going wrong," Valentini explains. "It took us a while, but when we doubled the length of the uncoated junction from a hundred nanometers to two hundred, we found our culprit."



Marco Valentini working in the lab. Credit: IST Austria

When the junction was big enough the following happened: The exposed inner nanowire formed a so-called quantum dot—a tiny speck of matter that shows special quantum mechanical properties due to its confined geometry. The electrons in this quantum dot could then interact with the ones in the coating superconductor next to it, and by that mimic the signal of the "half-electrons"—the Majorana zero modes—which the scientists were looking for.

"This unexpected conclusion came after we established the theoretical model of how the quantum dot interacts with the superconductor in a magnetic field and compared the [experimental data](#) with detailed

simulations performed by Fernando Peñaranda, a Ph.D. student in the Madrid team," says Valentini.

"Mistaking this mimicking signal for a Majorana zero mode shows us how careful we have to be in our experiments and in our conclusions," Valentini cautions. "While this may seem like a step back in the search for Majorana zero modes, it actually is a crucial step forward in understanding [nanowires](#) and their experimental signals. This finding shows that the cycle of discovery and critical examination among international peers is central to the advancement of scientific knowledge."

**More information:** M. Valentini et al., "Nontopological zero-bias peaks in full-shell nanowires induced by flux-tunable Andreev states," *Science* (2021). [science.sciencemag.org/lookup/ ... 1126/science.abf1513](https://science.sciencemag.org/lookup/doi/10.1126/science.abf1513)

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