» INTERVIEW

THE COMPUTER OF THE FUTURE IS A QUANTUM COMPUTER: ITALY PART OF THE US QUANTUM COMPUTING PROJECT

Interview with Anna Grassellino, Director of the Quantum Materials and Systems Center (SQMS) and researcher at Fermilab in Chicago.

Harness quantum properties to create a computer and sensors with unmatched performance. Over the next five years, this will be the main mission of the Superconducting Quantum Materials and Systems Center (SQMS), a research center coordinated by Fermilab (Fermi National Accelerator Laboratory), which at the end of August was awarded $115 million in funding by the U.S. Department of Energy (DOE) as part of the National Quantum Initiative. A goal for the pursuit of which SQMS will be called on to overcome the technological and scientific challenges that are inherent in the innovative quantum information sector, starting from those concerning the development and construction of superconductive materials capable of extending the average life time of qubits, the units based on which quantum computers work. The role played by INFN will also be fundamental to achieve such goals. Thanks to a contribution of $1.5 million, INFN will collaborate in the initiative by providing its skills and capabilities, recognised worldwide, in the fields of theoretical physics and the development of precision sensors, and through the construction of a test facility for the validation of quantum devices at the Gran Sasso National Laboratories. Coordinating the activities of the project is SQMS Director Anna Grassellino, an Italian researcher at Fermilab, who started her career at INFN.*

What objectives has SQMS set itself?

SQMS has two main objectives and they are related to the two main research areas of the center, which are computing and sensing. The first objective is to build a quantum computer that performs better than similar computers built so far. The second concerns the implementation of sensors that exploit the progress we expect to achieve with quantum superconductive technologies for the search for dark matter or elusive particles such as dark photons.

» INTERVIEW

In the field of quantum technologies, what are the problems that need to be overcome in order to build quantum computers with similar performance to that we are used to with the technology available today?

To obtain the results just described, it will be of fundamental importance to increase the quantum coherence of the devices available today, the qubits, which differ according to the solutions adopted for their production. Coherence, i.e. the ability to avoid loss of information deriving from absorption of the photons that convey it, is in fact the true limitation of quantum technologies. Indeed, the average life of qubits, which is currently very limited, depends on it. To increase coherence, our center will focus on superconductivity and the development of higher performance, two and three-dimensional qubits based on this technology. The reason for this choice depends on the fact that Fermilab has a consolidated experience in the implementation of superconductive cavities, on which three-dimensional qubits depend, the operation of which we have already demonstrated at quantum levels. While our industrial partner, Rigetti, based in Silicon Valley, California, is able to provide us with two-dimensional superconductive qubits to work on.

To better understand quantum computing, can you explain what a qubit is?

From the point of view of a quantum computer, a qubit is a device in which the information unit of the computer resides, which is able to be both in two distinct states, 0 and 1, as in a classical bit, as well as in overlapping states. This is possible precisely because of the superposition principle of quantum mechanics. This possibility, which in computing translates into greater computing and execution capabilities, can be implemented in different ways, depending on the architectures with which the qubits are produced: assuming that there is a single photon in these devices, this, if not measured, will be in overlapping states. That said, in the qubits we use, on the other hand, there is a discrete number of photons, which in turn will be in overlapping states. It is therefore very important to continue the study of the physics of materials and superconductivity in order to improve the production processes of these objects, so that there is no photon absorption and therefore no loss of information.

How will INFN contribute to SQMS's activities?

In addition to the research areas already mentioned, SQMS is involved in those regarding physics and algorithms. INFN will contribute to all four activities related to these areas. In particular, the facility that will be created at the Gran Sasso National Laboratories will be fundamental to study how radioactivity affects qubit coherence. Thanks to their location and the shielding provided by

» INTERVIEW

the rock walls, the Gran Sasso laboratories have, in fact, very low natural radioactivity. We will also use the cryogenic systems in use there for experiments such as CUORE to cool our devices, trying to increase their average life time. Finally, the laboratories will be responsible for the control and characterisation of the qubits themselves. INFN will also participate in the development of the algorithms and will provide its support in the study aimed at identifying a way of using the sensors that will be implemented in the field of dark matter research.

What will be your responsibilities as director of the center?
I am very excited about the recent appointment, although it will obviously involve important responsibilities, including coordination of the over 200 employees of SQMS. A more managerial role than I'm used to, but that doesn't mean I'll give up research. I will try to continue my laboratory activity in parallel with that of director, while at the same time aiming to promote progress in quantum technology.

You belong to the category of highly successful scientists who have decided to develop their career abroad. Can you tell us your story and the reasons that brought you to the United States?
I left Marsala and studied in Pisa, where I graduated in electronic engineering. After that, I arrived at Fermilab as a summer student in an INFN exchange program, which can be considered as my springboard. I was pleasantly impressed by the international atmosphere at Fermilab. That's why I went back to the United States to get my PhD in physics from the University of Pennsylvania, with a thesis at TRIUMF, the Canadian particle accelerator. I was subsequently hired at Fermilab, where I stayed. So, the reasons that led me to leave Italy are more related to the fact that I was more enthusiastic about the work that was going on here than the possibility of having greater opportunities. Indeed, I don't think I am part of the brain drain and I don't even like to talk about it, also because the relationship between Fermilab and INFN has been going on for 40 years and the contacts with my colleagues in Italy are constant. Moreover, when we talk about big science, which has a global dimension and propensity, this definition loses its meaning, and INFN is aware of this, being one of the few Italian entities able to attract many researchers from abroad. ■

**Born in Marsala, Anna Grassellino holds a PhD in Physics from the University of Pennsylvania and a Master Degree in Electronic Engineering from the University of Pisa. Today she lives in the United States, in Batavia, Illinois, where she is Senior Scientist, Deputy Chief Technology Officer and Deputy*

» INTERVIEW

Head of Applied Physics and Superconducting Technology Division at Fermilab. Her area of research is radio frequency superconductivity, a key technology for particle accelerators and detectors and quantum applications. She is known for the discovery of nitrogen doping of SRF (Superconducting Radio Frequency) cavities, which has boosted the performance of accelerators worldwide. Her pioneering work on increasing the quality factor of SRF cavities has earned her recognition with several awards, including President Obama's Presidential Early Career Award, DOE Early Career Award, IEEE Particle and Accelerator Science and Technology Award and Frank Sacherer Prize. She is also visiting professor at Northwestern University.