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Istituto Nazionale di Fisica Nucleare

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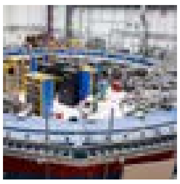

» INTERVIEW

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.

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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

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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*

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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.

RESEARCH

AUGER MEASURES THE ENERGY SPECTRUM OF ULTRA-HIGH ENERGY COSMIC RAYS

The international collaboration of the Pierre Auger Observatory, located in Pampa Amarilla, Argentina, has measured the energy spectrum of ultra-high energy cosmic rays with unprecedented accuracy. Cosmic rays of this type consist of atomic nuclei produced in extragalactic sources and can reach extreme energies, equal to 100 billion billion electron volts. Thanks to the very high accuracy of the measurement, the Auger Collaboration has reported the first observation of a sudden change in gradient at approximately 13 billion billion electron volts in the curve describing the-spectrum development according to energy. This result is particularly important and provides further evidence that the chemical composition of cosmic rays can vary with energy.

The result, which led to the publication of two articles in the scientific journals Physical Review Letters and Physical Review D, selected in the Highlights of the American Physical Society (APS), was obtained thanks to the detection of more than 215,000 high-energy atmospheric cosmic ray showers observed in approximately 15 years of data acquisition.

The Observatory is managed by an international collaboration of more than 400 scientists from 17 different countries, in which Italy is making a decisive contribution with different groups of universities and INFN divisions, the INFN Gran Sasso National Laboratories, the GSSI and the INAF Turin Astrophysical Observatory. In the near future, also thanks to the INFN contribution, detector performance will be further improved as a result of the upgrade of the surface detectors currently in progress. ■

INTERNATIONAL COLLABORATIONS

INFN LEADER OF THE ET AND EUPRAXIA PROJECTS, PRESENTED AT ESFRI

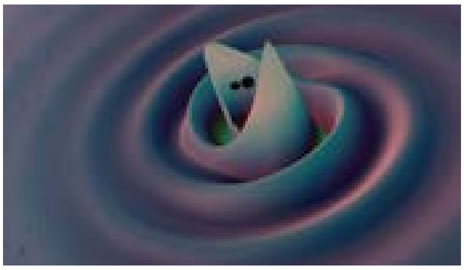
ET Einstein Telescope and EuPRAXIA: two major European research infrastructures, which promise to be competitive at the global level, in gravitational wave research and the development of plasma particle accelerators, respectively. These are the international projects led by INFN, and which the Ministry of Education, Universities and Research has nominated for the forthcoming 2021 Roadmap of ESFRI (European Strategy Forum on Research Infrastructure), the strategic forum that identifies the major research infrastructures for future investment at the European level. Italy, with Sardinia, is one of the two candidate sites to host ET, and is participating with INFN, INAF and INGV, and the Universities of Sassari and Cagliari. For EuPRAXIA, in which our country is participating with INFN, CNR, the Universities of Rome Sapienza and Tor Vergata, ENEA and Elettra Sincrotrone Trieste, it has already been decided by the international scientific community that the headquarters will be at the INFN Frascati National Laboratories.
ET Einstein Telescope is a project for the construction of a gravitational wave terrestrial observatory: an underground interferometer of triangular shape with 10 km long arms, which will use highly advanced technologies compared to those currently available. The main objective of the EuPRAXIA project, on the other hand, is the construction of a new generation of plasma particle accelerators, able to obtain higher energies than those reached by current accelerators with reduced cost and size. ■

GRANT

ERC: STARTING GRANT OF ALMOST 1.5 MILLION EUROS FOR THE SEARCH FOR DARK MATTER WITH THE POKER PROJECT

Andrea Celentano, researcher at the INFN Genoa Division, has been awarded an ERC Starting Grant worth 1.484 million euros, with the POKER (POsitron resonant annihilation into darK mattER) project, dedicated to the search for light dark matter.

The objective of the POKER project, approved for 5 years from December 2020, is to study and demonstrate the feasibility of a light dark matter search approach, with measurements made by colliding an energy beam of positrons on a thick target. The idea on which the experiment is based is already implemented in other experiments like PADME at the INFN Frascati National laboratories, that is using accelerated positrons beams colliding with a target to produce light dark matter particles. To measure possible light dark matter signal events, POKER uses the "missing energy" technique. The detector is actually the target, capable of measuring, for each incident positron, the total energy left inside the target itself. In the case of background events, the entire energy of the incident positron is deposited in the target and in the active veto systems surrounding it. In the event of light dark matter production, on the other hand, the dark matter particles would escape from the detector, carrying a large portion of the energy of the incident positron: the energy measured by the active target would therefore be significantly lower than that of the beam.



RESEARCH

VIRGO AND LIGO DISCOVER NEW AND UNEXPECTED BLACK HOLE POPULATIONS

The Virgo and LIGO gravitational wave interferometers have observed the fusion of two black holes of 66 and 85 solar masses, which generated a final black hole of approximately 142 solar masses, a black hole of "intermediate mass" (as black holes of mass between hundreds and hundreds of thousands of solar masses are called). No black hole of this type has ever been observed before with gravitational waves or electromagnetic radiation; its observation can therefore provide useful information to explain the formation of supermassive black holes, giants millions of times heavier than the Sun, which could result from the fusion of black holes of intermediate mass. Moreover, the most massive observed black hole challenges our understanding of the mechanisms of black hole formation: based on current models, a black hole of 85 solar masses cannot be formed by the collapse of a massive star. This detection therefore opens up new perspectives in the study of massive stars and supernovae mechanisms.

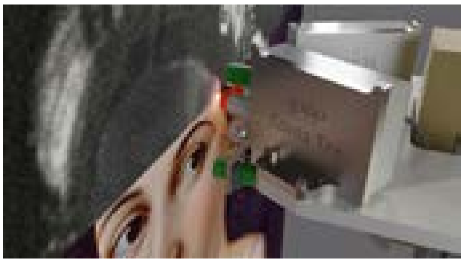
The distance of the source that produced the gravitational wave signal, detected by the three interferometers of the global network on 21 May 2019 and called GW190521, was estimated to be approximately 17 billion light years. Two scientific articles, describing the discovery and its astrophysical implications, were published on September 2, in Physical Review Letters and Astrophysical Journal Letters, respectively. ■

RESEARCH

A CHALLENGE TO QUANTUM MECHANICS FROM ITALIAN RESEARCH

Last September 7, the journal Nature Physics published a theoretical and experimental study carried out by a team of researchers from the Enrico Fermi Research Centre, INFN and the University of Trieste. The publication presents the results of research dedicated to verification of the quantum collapse model proposed by Lajos Diósi and Roger Penrose (DP model). The measurement phase was conducted at the INFN Gran Sasso National Laboratories, while the theoretical analysis was coordinated by the University of Trieste.

The fundamental characteristic of quantum systems is the possibility of existing in different states simultaneously, but the reason why this happens is not clear and is the subject of intense research. According to the DP model, quantum spatial overlapping becomes unstable and decays due to gravity in a time which is shorter the more massive the object is. The collapse generates a random motion, a background tremor, which in the case of electrons and protons is accompanied by the emission of characteristic but weak electromagnetic radiation. The research team went to look for this radiation, detecting a signal a thousand times lower than predicted by the DP model. The measurement therefore sets a record in this type of studies. ■



APPLICATIONS

CLOSE UP ON RAPHAEL: RESULTS OF THE SURVEY CAMPAIGN ON THE FORNARINA PRESENTED

The results of the survey campaign on the Raphael's Fornarina, carried out from January 28 to 30 using innovative techniques and cutting-edge machinery, followed by months of in-depth study and historical and scientific evaluation of the data acquired, were presented on September 21 at the National Gallery of Ancient Art in Palazzo Barberini. The day's proceedings featured INFN, the Barberini Corsini National Galleries, the Cultural Heritage Conservation (CBC) social cooperative and ENEA.

Thanks to the new imaging campaign, it was possible to map the distribution of the chemical elements present on the work with extraordinary accuracy, thus identifying the pigments used and understanding the process with which Raphael applied them.

In particular, the results presented concerned the survey carried out with "macro fluorescence X-ray scanning" (MA-XRF) on Raphael's work by Emmebi Artistic Diagnostics and Ars Mensurae and implemented with tools developed within MUSA (Multichannel Scanner for Artworks), a project implemented with the funding of the Regione Lazio and the collaboration of the INFN Roma Tre Division, CHNET (INFN Cultural Heritage Network), CNR ISMN, the Department of Sciences of Roma Tre University and the Department of Basic and Applied Sciences for Engineering of the Sapienza University of Rome. ■

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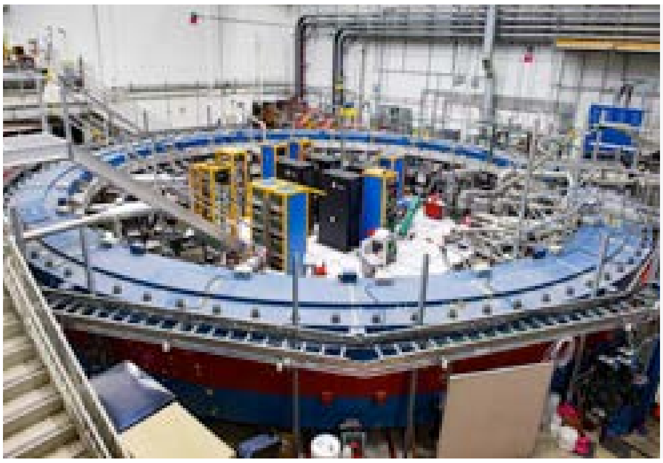

MUON G-2, AWAITING THE FIRT RESULTS

After three years of activity, the Muon g-2 international collaboration, Fermilab's experiment dedicated to the precision measurement of the anomalous magnetic moment of the muon, is preparing to release its first results, which could pave the way for a new physics. The analysis of the data collected so far could in fact shed light on a new class of subatomic constituents associated with the fluctuations of the so-called false vacuum, the quantum field that pervades space apparently devoid of matter. Coordinating the activities foreseen during the phase preceding publication is Graziano Venanzoni, an INFN researcher from the Pisa division, recently elected by the Muon g-2 collaboration as the new spokesperson of the experiment, an appointment that also comes in recognition of the fundamental role played by INFN in the project.

One of the properties of charged particles with their own rotation (spin) is that they possess a magnetic moment which, to use an analogy, can be compared to the magnetic field of the needle of a compass. In the family of leptons, to which muons, electrons and tauons belong, the magnetic moment is nevertheless characterised by a peculiarity attributable to these particles only, which exhibit a magnetic moment value different from the one predicted by the standard model (equal to 2). The deviation from the theoretical predictions is calculated by subtracting that foreseen by the theory from the measured value, indicated with the letter g (hence the name of the Muon g-2 experiment). The existence of the anomaly was first identified in 1947 in the electron, thanks to an experiment conducted by Polykarp Kusch and Henry Foley, a discovery that won the two physicists the Nobel Prize in 1955. The most recent confirmation, on the other hand, dates back to the early 2000s, and is due to the E821 experiment of the Brookhaven National Laboratory in Upton, which focused on the study of muons.

In order to explain the magnetic moment anomaly, the existence of interactions between muons and

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virtual particles generated by the constant fluctuations of quantum vacuum energy has been proposed. To verify this hypothesis, however, it is necessary to measure the discrepancy of g compared to its theoretical value with absolute precision. This is what is being done with Muon g-2 at Fermilab, which aims to provide definitive proof of the muon's magnetic moment anomaly, a result that could reveal valuable information for future research into the unknown particles populating the false vacuum.
The result of an international collaboration, in which INFN is participating with one of the most numerous research groups involved, including the Naples, Pisa, Roma 2 and Trieste divisions, the associated group of Udine and the Frascati National Laboratories, Muon g-2 uses Fermilab's accelerators to generate muon beams with speeds close to the speed of light. Once stored inside a circular magnet, the muons reach the experiment's detectors. In order to increase the performance of Muon g-2, which aims to improve the accuracy of the measurements made in Brookhaven by a factor of 4, the experiment uses 24 extremely sensitive calorimeters, whose control is entrusted to a laser calibration system developed by INFN in collaboration with the CNR’s National Institute of Optics. Moreover, to avoid any errors in the data analysis that could compromise the results of Muon g-2, and in particular those related to subjective conditioning, the collaboration has adopted the so-called blind analysis, which involves the inclusion of an artificial and unknown constant during data acquisition, a constant that is revealed only at the end of the calculation procedures. Finally, INFN’s involvement also concerns the data analysis activity of the experiment, to which, together with five other research groups, it makes a 20% contribution. In addition to the interest in what they may reveal, the first results of Muon g-2, which refer to its first data acquisition cycle (run 1) carried out in 2018, will be used to improve the accuracy of the next results, which will be taken from the two subsequent data acquisition cycles in 2019 and 2020.

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