



INFN NEWSLETTER 82

Istituto Nazionale di Fisica Nucleare

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» INTERVIEW

**POSSIBLE CLUES ON NEW PHYSICS
IN MUON BEHAVIOUR**

Interview with Graziano Venanzoni, INFN researcher at the Pisa division, and co-spokesperson for the Muon g-2 collaboration

Last April 7, media from all over the world reported on the first highly anticipated results obtained by Muon g-2, the experiment hosted in the main US particle physics laboratory, Fermilab, dedicated to precisely measuring the anomalous magnetic moment of the muon, a heavy cousin of the electron. The analysis of the first data acquired by the experiment, carried out by the international collaboration responsible for Muon g-2, has provided new evidence for a discrepancy with the predictions of the Standard Model. This model is the imposing theoretical structure that we use today to describe the nature of sub-atomic particles and their behaviour. Despite the fact that it has not yet reached the statistical significance necessary to obtain the status of “discovery”, the result could represent an exciting clue as to the presence of phenomena and forces that are yet unknown. If confirmed, the result could also anticipate one of those crucial steps in the history of physics and scientific thought.

Launched in 2017, Muon g-2 has benefitted from an important contribution from INFN. As well as being one of the founders of the experiment, INFN continues to perform a central role within the collaboration through the participation of its Naples, Pisa, Rome 2 and Trieste divisions, of the Udine associated group and of the Frascati National Laboratories. In particular, the Italian researchers have provided an essential contribution both in the implementation and data acquisition phase of the experiment and in the data analysis phase. Further evidence of the centrality of INFN activities is the appointment, in September 2020, of Graziano Venanzoni, INFN researcher at the Pisa division, to the role of co-spokesperson for the Muon g-2 collaboration.

Graziano Venanzoni, the Muon g-2 experiment is dedicated to precisely measuring the muon anomalous magnetic moment. Can you please explain to us which muon behaviour this parameter refers to and why it is so important to know its exact value?

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The charged elementary particles that have an intrinsic angular moment called spin, which we can think of as the rotation motion of a spinning top, also possess a magnetic moment, i.e. they produce a magnetic field just the same as a compass needle's. The Standard Model predicts that, for each particle, the value of the magnetic moment is proportional to its spin via a numeric factor that can be calculated and that its value is slightly larger than 2. This factor is usually indicated with the difference between the real value and 2 ($g-2$). This anomaly associated with the magnetic moment was detected for the first time in the electron at the end of the 1940s by a measurement that was awarded the Nobel prize in 1955. Other increasingly precise experiments succeeded and at the beginning of the 2000s, an experiment with more decisive precision, similar to our own, carried out at the Brookhaven laboratory, near New York, discovered an intriguing discrepancy between the theoretical predictions and the experimental result. A more precise confirmation of this difference with the value predicted by theory can help us to understand if it is owed to the influence exercised on muons by unknown particles. The goal of Muon $g-2$ is just that of checking this hypothesis by measuring the muon anomalous magnetic moment with four times the precision of that of Brookhaven. If the discrepancy with what is predicted by the Standard Model was to be confirmed, we would, therefore, be facing a discovery of enormous significance that would open the way for new physics.

On April 7, the Muon $g-2$ collaboration published the first awaited results of the analysis of data collected by the experiment during run 1. What indications did these results provide to the scientific community?

As recorded, the anomaly of the muon magnetic moment has already been known for a long time and is attributed to the quantum fluctuations predicted by the relevant theory, which represents the basis of the Standard Model. Today, we know that all the Standard Model sectors, electromagnetic, weak, and strong, contribute to determining the anomalous magnetic behaviour of the muon. In June 2020, a theoretical collaboration consisting of more than 100 scientists certified the theoretical reference value of the " $g-2$ ", achieving a precision of 400 parts per billion. This same collaboration confirmed the discrepancy with the value measured in Brookhaven. The first results published in April have not only shown that our measurement was in excellent agreement with the preceding one, but made it possible to strengthen the significance of the discrepancy from the Standard Model bringing it to 4.2 standard deviations. In other words, by combining the two measurements, we went from a probability of one in 5,000 that Brookhaven's result was owed to a statistical fluctuation to a one in 40,000 probability.

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What does the Muon g-2 equipment consist of and how can it perform such precise measurements of the magnetic properties of the muon?

The heart of the experiment is the accumulation ring, inherited from the Brookhaven laboratory, in which a highly uniform magnetic field enables the circulation of muons for thousands of turns during the measuring time of 700 microseconds. The particles are accelerated at speeds close to that of light and injected with the spin direction aligned with the orbit plane. After this, 24 Cherenkov crystal calorimeters distributed within the ring make it possible to measure the energy and time of the electrons emitted in the muon decay and to reconstruct the spin direction. In addition, two straw tube stations, detectors that use ionised gas and are positioned within the vacuum chamber, make it possible to perform a high-precision “tomography” of the muon beam. Using the precise measurement of the muon spin precession frequency and of the magnetic field (measured with special NMR - nuclear magnetic resonance - probes), we measure the magnetic anomaly of the muon with a precision of 460 parts per billion.

This first success of your collaboration was also a success for Italian physics. What was and what continues to be INFN’s contribution to Muon g-2?

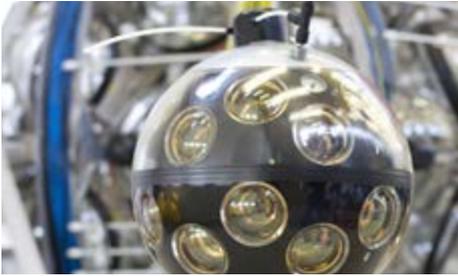
INFN made an extremely important contribution that was much appreciated by the Muon g-2 collaboration. First of all, and thanks also to the collaboration with the CNR (National Research Council) National Institute of Optics, we have constructed a laser calibration system that is essential for achieving precision in measuring the anomalous muon spin precession frequency, called ω_a . In addition, we work on many areas of the experiment. We contribute, in fact, to analysing the ω_a measurement, to studying the beam dynamics, to measuring the magnetic field, to acquiring data, and to reconstructing the data themselves using software. These activities are also performed thanks to the contribution of extremely helpful young researchers. Finally, we hold roles of responsibility in many areas of management of the experiment.

You are one of the two spokespersons for the Muon g-2 collaboration. What did you experience when you observed the results for the first time? And what do you hope that the latter might entail for the future of particle physics?

I had opposing feelings. On the one hand, the enormous excitement and emotion in seeing a result so long awaited; on the other hand, I felt the responsibility, as spokesperson of the experiment, to communicate such an important result. The result that we announced relates to 6% of the data that we expect to acquire by the conclusion of the experiment. In the meantime, we have already acquired the data of a second and third research campaign and a fourth is currently underway. Within a couple of years, the data analysis from the second and third campaigns should be ready, which should make it possible to

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reduce the uncertainty by a factor of 2, thus obtaining an even more precise measurement. The hope is that our efforts, together with the results of other experiments that will be performed in the near future at CERN and in Japan, where the measurement of the anomalous moment of the muon is planned using an alternative method, may confirm the discrepancy in relation to the Standard Model predictions and the existence of new physics. Of course, it could happen that, in light of our results, the theoreticians review their prediction, perhaps finding a value closer to the experimental measurement. But this is an integral part of the way in which science progresses, through a continuous and close exchange between experimental measurements and theoretical predictions. I would, finally, like to say something personal: I would like to dedicate this result to Antonio Anastasi, my first student in Muon g-2, an extraordinary young man with great talent who was, unfortunately, unable to witness the completion of his work. ■



RESEARCH INFRASTRUCTURES

NEUTRINOS: FIRST SIX COMPONENTS OF THE KM3NET UNDERSEA TELESCOPE INSTALLED AT A DEPTH OF 3500 METRES

The expansion of the IDMAR submarine infrastructure – coordinated by the INFN Southern National Laboratories and co-funded by the Sicily Region - with a new junction box delivering electricity and allowing submarine connections and the installation of five new strings of detectors of the neutrino telescope KM3NeT/ARCA were concluded with success. The operations took place at approximately 80 km off Capo Passero, in Sicily, at a depth of up to 3,500 metres. The ARCA telescope, together with ORCA situated off Toulon in France, will constitute the multi-site KM3NeT submarine telescope that, in its final configuration, will occupy a total volume of one cubic kilometre, exploiting the interaction of sea water with neutrinos. The submarine observatory will thus enable scientists to identify the sources of high-energy neutrinos coming from catastrophic events in the universe and to study the fundamental properties of these particles. In its final configuration, the KM3NeT/ARCA experiment includes a network of more than 200 strings of detectors that are 700 metres high; each string is made of 18 optical modules. These modules are equipped with ultra-sensitive light sensors able to record the extremely weak flashes of light generated by the particles produced when cosmic neutrinos interact with water in pitch darkness and in the depths of the Mediterranean Sea. In total, six strings of detectors are now operating, representing the initial nucleus of the KM3NeT/ARCA neutrino telescope. In addition to the six strings already operating in ORCA, the ARCA strings enable KM3NeT to exceed the sensitivity of the previous ANTARES experiment, in data acquisition since 2008, which was also set up with a strong Italian contribution.

INFN, with its Southern National Laboratories, the divisions of Catania, Genoa, Naples, Bologna, Bari and Rome, and the Salerno associated group, is involved in integrating the recently installed measurement lines, part of the optical modules, all of the basic modules and part of the electronic and mechanical components. ■

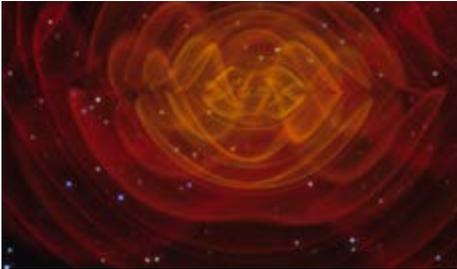


RESEARCH

THE CLAS EXPERIMENT SHEDS LIGHT ON THE INNER STRUCTURE OF NEUTRONS AND PROTONS

A study conducted by an international group of researchers based on the data collected by the CLAS detector, an experiment housed in the Jefferson Lab until 2018 and run with a decisive INFN contribution, provides new details on the inner structure of nucleons (protons and neutrons composing the atomic nucleus). The study was published on April 12 on the journal Nature. Thanks to a methodology that exploits polarised electron beams accelerated at low energies, it was possible to reconstruct the movement and arrangement of the quarks within target protons, with a spin oriented in a strong magnetic field, by analysing the distribution of the electrons after their interaction with the same protons. The measurement, together with other similar ones that will be performed by the CLAS successor, CLAS12, may improve the capacity of quantum chromodynamics (QCD, the physics theory that describes the strong fundamental force) to account for the complex interactions between quarks and gluons and how these determine the mass and spin of nucleons.

The CLAS measurement represents the latest result of a research field inaugurated in the early 2000s, that aims to improve our knowledge of the inner structure of nucleons and the accuracy of theoretical models that we use to describe it. Today, these models do not offer sufficiently accurate predictions for low-energy interactions in which the QCD generalisations are not applicable. ■

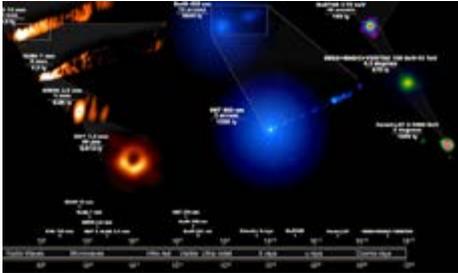


RESEARCH

GRAVITATIONAL WAVES: THE ROADMAP FOR THE NEXT 20 YEARS PUBLISHED ON NATURE

The scientific journal Nature recently published a review dedicated to the near future of gravitational waves research: one of the most exciting research areas in recent years. This research field was characterised by epochal discoveries, such as the first observation of gravitational waves announced by the LIGO-Virgo collaborations in February 2016, and the detection of the merging of two neutron stars observed, for the first time, both with gravitational waves by the LIGO and Virgo interferometers and with electromagnetic radiation by telescopes on Earth and in space, in 2017. The work is focussed on the next 20 years and it discusses the most important projects for physics and gravitational astronomy according to the Gravitational Wave International Committee (GWIC), a body created in 1997 to facilitate international collaboration and cooperation in the construction and operation of the principal infrastructure dedicated to gravitational wave research. Two flagship projects, in particular, involve a significant contribution from Italy and INFN: the European observatory ET (Einstein Telescope)*, for which our country has proposed Sardinia as host site, and the LISA (Laser Interferometer Space Antenna) space detector, whose launch into orbit is expected around the mid-2030s. Together with the interferometry detectors, the Pulsar Timing Arrays (PTA) telescopes will continue to grow with networks of new antennae, more sensitive wide-band receivers providing unique information on the dynamics of the largest galaxies in the universe. ■

* The Einstein Telescope was submitted to the European Strategy Forum on Research Infrastructure (ESFRI) Roadmap 2021. In light of these developments, the scientific institutions that coordinate the project, INFN and Nikhef, recently expanded the ET organisational structure, establishing a new project's management, to which Prof. Fernando Ferroni (INFN and GSSI) and Prof. Jo van den Brand (Nikhef) have been designated. ■



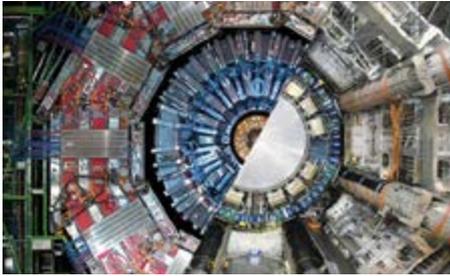
INTERNATIONAL COLLABORATIONS

EARTH AND SPACE TELESCOPES UNITED FOR THE LONGEST OBSERVING RUN OF A BLACK HOLE

A new and extended observation run promises to give an unprecedented view of the black hole at the centre of the M87 galaxy, the first image of which was produced in 2019 by the Event Horizon Telescope (EHT) collaboration, and of the system that feeds it.

The data were collected between the end of March and mid-April 2017 by a team of 760 scientists and engineers from almost 200 institutions and 32 countries, using 19 observatories funded by research agencies and bodies from all over the world. INFN, INAF National Institute for Astrophysics, ASI Italian Space Agency and various Italian universities also participated in this significant international effort. The observations focused on particle jets produced by the black hole of the M87 galaxy, which emit radiation across the whole electromagnetic spectrum, with different characteristics for each black hole that vary over time. This variability made it necessary to coordinate the observations of many telescopes, both on Earth and in space, thus covering all the bands of the electromagnetic spectrum.

The data collected, in combination with other observation runs conducted by EHT, will make it possible to conduct studies in some highly contested fields of astrophysics, as well as to provide new information on the origins of cosmic rays, extremely energetic particles that bombard the Earth from outer space. The jets emitted by black holes are, in fact, considered the most probable source of high-energy cosmic rays, but there are still many open questions on the mechanisms that regulate their production. ■

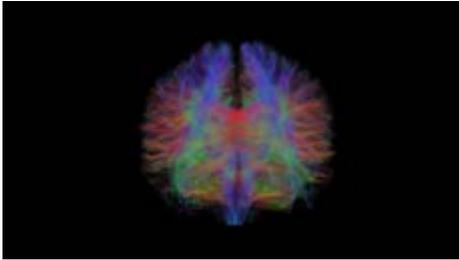


TECHNOLOGICAL RESEARCH

EUROPEAN R&D PROJECT FOR FUTURE DETECTORS, AIDAInnova KICKS OFF

AIDAInnova, a research and technological innovation project for developing new solutions for future particle detectors, is at the starting gates. Approved last November by the European Commission, with funding of 10 million euro, AIDAInnova recently gathered more than 300 experts to discuss activities and plan the next steps for achieving the project's ambitious goals. AIDAInnova will explore the application of innovative technological solutions, in order to validate their measuring and discovery potential, to future accelerators for high-energy and neutrino physics: vertex detectors and silicon trackers that will also implement time measurement (4D); large-area and volume gas detectors that are resistant to radiations and high particle flows; innovative, high-granularity (5D), large-scale calorimetry; and large-volume cryogenic detectors for neutrinos.

The added value of AIDAInnova is providing an environment for discussion for researchers working on different projects; over the four years of the project, more than 150 physicists and engineers, in almost all the INFN divisions, will be involved, and some 40 research grants will be offered. Industry will also participate in the consortium of some 45 beneficiaries from 15 different countries. For Italy, which has been awarded 18% of the European funding, INFN will participate alongside the CAEN SpA and Eltos SpA firms, and the Fondazione Bruno Kessler. ■



COLLABORATION AGREEMENTS

INFN AND SANTA LUCIA IRCCS FOUNDATION WORK TOGETHER TO APPLY MEDICAL PHYSICS TO NEUROSCIENCE

A collaboration between INFN and the Santa Lucia IRCCS Foundation of Rome, the leading Italian research institute in neuroscience, has been signed. The goal is to study life sciences, exploiting the skills and tools of medical physics, and to develop new diagnostic tools to make tests for preventing neurological diseases more accessible and effective.

A crucial example for neuroscience research is magnetic resonance, a known technology that has, however, immense possibilities for development. Magnetic resonance equipment captures the vibrations that the hydrogen nuclei, present in every organism, undergo in a magnetic field. The research is currently focused on studying other atoms, thus opening the possibility of going into the details of physiological and biochemical mechanisms that are, in part, still unexplored.

In addition, for neuroscience, the development of increasingly powerful equipment also means a greater capacity for analysing details. Today, the best diagnostic results are obtained with machines that operate at 3 teslas, which also make it possible to see the microscopic structures that compose the nervous system. The research of INFN, together with Santa Lucia IRCCS, will also include the use of ultra high-field (7 tesla) magnetic resonance machines exclusively for research purposes, to develop models that help us understand the deepest dynamics of the nervous system. ■

**PUBLIC ENGAGEMENT****INFN FOR THE ITALIAN RESEARCH DAY IN THE WORLD**

On April 15, on the anniversary of the birth of the Italian genius Leonardo da Vinci, the fourth Italian Research Day in the World was celebrated. This day was instituted in 2018 by the Ministry of

Education, University and Research, in cooperation with the Ministry of Foreign Affairs and International Cooperation, and the Ministry of Health, with the aim of promoting and showcasing the skills and contribution of Italian researchers in the world of research, as well as the image of Italy as a Country that produces excellence in science and innovation. INFN and its researchers participated in numerous events throughout the whole day: from a big scientific marathon organised by the Festival of Sciences of Rome to many meetings with consulates, embassies, and overseas Italian Cultural Institutes.■

[*INFN for the Italian Research Day in the World*](#)



TAKE PART IN

FISICA X KIDS: TELLING CHILDREN ABOUT SCIENCE

From “ghost neutrinos” and “atom-breakers” to a trip through the universe: Fisica x Kids is a series of online events streamed live every Thursday at 11:00 on the INFN [Facebook](#) page and [Youtube](#)

channel. This series is dedicated to children and teenagers from 8 to 12 and the aim is to bring them closer to some basic physics themes with animations, drawings and direct interaction with researchers. Fisica x Kids started last April 29 with [Neutrini Fantasma](#) with **Giuliana Galati**, researcher at the University of Bari and INFN and coordinator of the CICAP Course for Mystery Investigators, then continued on May 6 with [Rompiatomi e altre storie sulla materia](#) with Pierluigi Paolucci, researcher at the INFN Napoli division. Both events saw a strong participation of children and teenagers, with more than 200 classes connected from all over Italy. Thursday 13 May at 11:00 Fernando Ferroni, professor of physics at the GSSI and researcher at the INFN Gran Sasso National Laboratories, will close the series, leading the children on a journey through the cosmos, towards its most remote corners; an adventure among stars, planets and black holes, [Dove sta andando l'universo](#). (in Italian)

FROM MAY 17 TO 19: INFN JOINS PINT OF SCIENCE 2021

“Pint of Science”, the festival where researchers speak about their research in bars and pubs, is back this year in an online edition. INFN researchers will join the festival.

All the events will be available on the [Facebook](#) page and on the [Youtube](#) channel of Pint of Science Italia. (in Italian)

MAY 19, 5:00 PM: THE HIDDEN MUSIC OF THE UNIVERSE. VIRGO AND THE CHASE FOR GRAVITATIONAL WAVES

In collaboration with Centrale dell'Acqua di Milano – Mmspa (CAMi)

First of a series of events dedicated to some of the big INFN research infrastructures, in collaboration with [Centrale dell'Acqua di Milano](#) – MMspa.

With Chiara Meroni, member of the INFN Executive Board, Giovanni Losurdo, INFN researcher and Spokesperson of Virgo Collaboration and Luca Montani, MMspa Head of Communications and Institutional Relations.

The event will be transmitted on CAMi [Facebook](#) page and [Youtube](#) channel. (in Italian)

29 MAY: AWARD CEREMONY FOR THE VI ASIMOV PRIZE

The award ceremony will take place on the [YouTube](#) channel of the Asimov Prize.

For further details and for the list of finalists: <https://www.premio-asimov.it/edizioni/edizione-2021/> (in italiano)

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LPA2: PROTONS ACCELERATED WITH LASERS FOR HADRONTHERAPY

A recent result obtained by the LPA2 (Laser Driven Proton Acceleration Applications) experiment could pave the way for the creation of a new generation of more effective and compact medical devices for hadrontherapy that exploit charged particles such as protons to destroy tumour cells. The experiment is funded by the INFN National Scientific Committee dedicated to technological and interdisciplinary research (CSN5), in collaboration with the National Research Council (CNR) National Institute of Optics (INO). Thanks to the use of a laser that can generate very short pulses, the INFN researchers managed to produce, select and transport a beam of protons with optimal intensities, and therefore with optimal energies, for oncological treatments.

The main aim of LPA2 is to form and guide proton beams generated by lasers with enough energy and precision on tumour cells and in less time, thus optimising the efficacy of treatment sessions and their length. The LPA2 project constitutes the first application, in Italy, of a beam of protons produced by laser and guided towards a precise irradiation point.

The experimental run was carried out at the Intense Laser Irradiation Laboratory (ILIL) of the INO, where a laser system able of generating very short, high-power (up to 200 terawatt) pulses has been operating since 2018. The system is funded by the CNR in the context of the development of the European “Extreme Light Infrastructure” (ELI). Using the laser to activate a mechanism called Target Normal Sheath Acceleration (TNSA), it was possible to produce and accelerate a proton beam with intensity that is of interest for future important biomedical applications.

The proton beam transport system, constructed and designed at the INFN Southern National Laboratories (LNS), in collaboration with the INFN Milan division, is the fruit of experience gained in the recent past with four projects funded by the same CSN 5. Together with advanced diagnostic and dosimetry systems, they have, finally, enabled researchers to select and focus a proton beam with energy of 6 MeV and to

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distribute the latter in a single release with a dose of radiation 300,000 times higher than that absorbed during radiography and lasting 10 nanoseconds. This is an experimental measurement that paves the way for the potential use of laser-driven proton beams, including ultra-flash therapy, i.e. where the dosage rate may even exceed nine times the quantity of that conventionally used in clinical practice today. The use of these regimens, which are still wholly unexplored, may constitute a significant advantage in reducing the secondary undesired effects on healthy tissues by increasing the efficacy of the radiotherapy treatment in the same timeframe.

LPA2 is part of one of the strategic research threads of INFN: the transfer of technological solutions to medicine from the area of research into the fundamental constituents of matter, a sector in which the institute holds a long tradition and international supremacy. ■

***Italian National Institute
for Nuclear Physics***

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Muon g-2 - Credit: Reidar Hahn, Fermilab

CONTATTI

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