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**LET ME TELL YOU HOW VIRGO WAS BORN** Interview (February 2016) with Adalberto Giazotto, recently passed away, founder of the Virgo project for gravitational waves detection.

His name is firmly tied to the physics of gravitational waves, the spacetime ripples predicted by Albert Einstein a century ago in the theory of General Relativity. Adalberto Giazotto, an INFN researcher who passed away last 15 November, a tenacious, visionary and far-sighted scientist, former collaborator of Edoardo Amaldi, shared with Alain Brillet the paternity of the Virgo interferometer, the gravitational wave detector implemented in Italy by INFN and the French CNRS (Center National de la Recherche Scientifique) which, with the two LIGO interferometers in the United States, was the protagonist of the recent discovery of gravitational waves. It was Giazotto's idea to build an interferometer in the countryside around Pisa. He had the idea of the Virgo super-attenuators, a chain of highly technological pendulums that effectively isolates the mirrors of the experiment from the movements that would disturb the signals. It was his idea to look for gravitational waves at low frequencies - where they were actually found - an idea first implemented by Virgo and later by LIGO. It was his idea to establish a global network of interferometers with the two LIGOs, so as to create only one big scientific collaboration, an idea that proved to be key to the success in searching for gravitational waves.

In an interview released in February 2016, Giazotto told us how the idea of Virgo came about and what were his feelings when he heard the news of the discovery of gravitational waves, the goal he had pursued for decades.

### How are you feeling during these days of the announcement of the discovery of gravitational waves?

Very happy, even though I am a bit of a spectator. I am very happy with this result, which represents the crowning of a line of research that we at Virgo started decades ago, focusing on low frequencies.



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### You are considered the father of Virgo.

We were the first to say that it was necessary to build a detector capable of observing gravitational waves also at low frequencies. It was the biggest advancement in interferometer technology since these detectors were started to be built in the 1980s. Virgo, finally approved in 1993, was in fact the world's first low-frequency detector, followed by the American Advanced LIGO (Laser Interferometer Gravitational-wave Observatory) project and the KAGRA (Kamioka Gravitational wave detector), project, under implementation in Japan.

### What were the reasons for this choice?

The low-frequency target was dictated by theoretical studies on the structure of neutron star binary systems and black holes as extremely powerful gravitational wave emitters. Moreover, the radio-astronomical signals of pulsars - rotating neutron stars - showed the existence of a relatively large number of stars, capable of emitting periodic gravitational waves at frequencies greater than 10 Hz. At that time, the minimum frequency of gravitational wave signals detected by existing antennas was approx. 100 Hz and, therefore, much higher than that needed to capture astrophysical phenomena such as those described above.

### How did the idea of Virgo come about?

It came thanks to a stroll with Alain Brillet, from CNRS, around the Minerva fountain in the courtyards of La Sapienza University in Rome. It was the early 1980s and the Roman university was hosting a congress on General Relativity. It was on that occasion that, along with the French colleague, we decided to start a collaboration for the construction of Virgo. But the interferometer would never have come about without IRAS (Interferometer for Active Sisma Reduction), which can be considered one of Virgo's ancestors. In fact, in 1987 we demonstrated that it was possible to mitigate seismic noise, which prevented going down to low frequencies and, also due to this result, Italy approved the Virgo experiment.

# The gravitational waves observed by the LIGO/Virgo collaboration were generated by the fusion of two black holes: did that surprise you?

No, I was not surprised that this was the source. Thinking years ago about implementing Virgo, I had chosen to focus on the periodic signals of pulsars and on those, almost periodic, emitted by the systems of coalescing binary neutron stars and black holes. All this in order to have a signal that lasts for at least a few seconds, and not a few milliseconds like those emitted by supernovae explosions. Pulsars, from this point of view, would have been ideal, whose signal is strictly periodic and lasts forever over time. Unfortunately, all the pulsars we tried to observe did not give us any signals. Nature could have made



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us a small gift, letting us see gravitational waves several years earlier. But it was not to be. Einstein had predicted their existence about a century ago.

### Why did it take so long for the first direct observation?

The reason is that these signals are extremely weak and it is therefore extremely difficult to capture them. Advanced Virgo will be able to measure, starting from the second half of 2016, changes in the length of the arms, due to the passage of a gravitational wave, a billion times smaller than the diameter of a hydrogen atom.

### Do you think that the observation of gravitational waves will become more frequent from now on?

Yes, I do. In the end, the LIGO/Virgo collaboration saw two signals, one very shortly after the other. In the future, we may be able to see many more per year

### Including the primordial signals emitted shortly after the Big Bang?

In this case, the observation is much more difficult. But if we were able to capture primordial gravitational waves, it would be a very important result. These signals are, in fact, the only ones that can directly tell us how the universe appeared in its first moments of life, in proximity to the so-called Planck's time (10-43 sec. after the Big Bang) but they are extremely small in intensity compared to those we can now see with Virgo and LIGO.

# INFN

### **NEWSLETTER 41** Istituto Nazionale di Fisica Nucleare

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### RESEARCH BABAR PUTS THE DARK PHOTON ON THE ROPES

The dark photon is a particle similar to the electromagnetic wave photon but, unlike the latter, it has a small mass. It is in reality a hypothetical particle, predicted by certain recent theoretical models that describe dark matter, but never observed experimentally.

Thanks to the new results of the BaBar experiment, physicists who from all over the world are trying to understand whether or not this particle actually exists have new and important information to limit the hunting ground. BaBar is an international experiment at the Stanford Linear Accelerator (SLAC) in California, USA, in which Italy, with INFN, has a leading role with the construction of the magnet and of fundamental components of the detector: the peak detector and the muon detector. The accelerator was in operation from 1999 to 2008 and the last year of data acquisition was dedicated precisely to the search for the dark photon. From the data analysis important information now emerges that excludes possible "hideaways" of this hypothetical particle, significantly narrowing the field of investigation. The results were published in the Physical Review Letters journal. In search of the dark photon, INFN is participating in a new experiment that will be called PADME (Positron Annihilation into Dark Matter Experiment) and will start at the INFN Frascati National Laboratories (LNF) in a new experimental room of the linear accelerator test facility, the Beam Test Facility (BTF). The experiment will be the result of an international collaboration involving researchers from Cornell University and from the College of William and Mary (USA), from the MTA Atomki institute in Debrecen, Hungary, and from the University of Sofia, Bulgaria.

Read the focus on PADME <a href="http://home.infn.it/newsletter-eu/pdf/NEWSLETTER\_INFN\_26\_inglese\_pag11.pdf">http://home.infn.it/newsletter-eu/pdf/NEWSLETTER\_INFN\_26\_inglese\_pag11.pdf</a>



### **NEWSLETTER 41** Istituto Nazionale di Fisica Nucleare

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### INFRUSTRUCTURES PROTON SOURCE FOR EUROPEAN SPALLATION SOURCE (ESS) COMPLETED

At the INFN National Laboratories of the South, the construction of the proton source and of the ion beam transport line have been completed. They will move to the European Spallation

Source (ESS), a large European Research Infrastructure, under construction in Lund, Sweden. Once operational, ESS will be the most powerful neutron source in the world dedicated to multidisciplinary research: from life sciences to energy, from environmental and cultural heritage technologies to fundamental physics. ESS represents one of the research projects at the international level with the highest financial investment and is supported by the participation of 17 European countries, including Italy through INFN, the National Research Council (CNR) and Elettra Sincrotrone Trieste The construction of the source and of the transport line are the tangible signs of the international excellence now achieved by INFN laboratories in the field of accelerators. The results obtained with the European Spallation Source injector clearly exceed the project specifications and everything was accomplished within the planned timescale and in full compliance with the agreed budget. Furthermore, the growth of the Italian companies which participated in this scientific adventure was competitive at European level, a symbol of national innovation excellence.

web site: https://europeanspallationsource.se/





### RESEARCH POLICY EUROPEAN STRATEGY ON NUCLEAR PHYSICS PRESENTED IN BRUSSELS

On 27 November at the University Foundation in Brussels, the NuPECC (Nuclear Physics European Collaboration Committee) presented its fifth Long Range Plan (LRP 2017) for Nuclear Physics

in Europe, which takes into account the evolution of basic and applied research in this field and marks the stages of the programme for the coming years. NuPECC's mission, since its foundation in 1988, has been to formulate suggestions and recommendations for Nuclear Physics research in Europe, and for this purpose it has in the past developed four strategic reports (1991, 1997, 2004 and 2010). The final product of the process concluded in Brussels is the volume "NuPECC Long Range Plan 2017: Perspectives for Nuclear Physics", containing recommendations for future developments in Nuclear Physics research, in the various infrastructures and in applications in this field, aimed at investigating key issues such as nuclear matter under different conditions, nuclear interactions and the origin of the elements. Information from nuclear physics on these topics is fundamental for the description of cosmological phenomena, such as neutron stars and their evolution, stellar explosions and energy production in stars. The LRP 2017 was presented in Brussels by the President of NuPECC, Angela Bracco, a Professor at the University of Milan and a researcher at the INFN Milan division, who emphasised, among other things, the leading position of Europe in this area and the collaborative effort among the various countries, crucial to maintaining such leadership.

Among the 90 participants in the event, in addition to representatives of the INFN management and laboratories - with coordinating roles in the European nuclear physics programme - were ESFRI President Giorgio Rossi, ESFRI-PSE President, José Luis Martinez, the Head of the Research Infrastructures Unit of the European Commission, Ales Fiala, European Physical Society President, Rüdiger Voss, and FAIR Scientific Director, Paolo Giubellino.







### AWARDS

# LNF LEADS THE QUEST FOR UNDERSTANDING THE FOUNDATIONS OF PHYSICS

Whether we can observe quantum behaviours in macroscopic objects or not, and under which conditions, is a major question in quantum physics. An answer in the positive direction will boost

the quest for the use of the weirdness of quantum mechanics in a much larger set of physical systems, not restricted to the microscopic world.

A team of scientists including the group of the Frascati National Laboratories (LNF-INFN) led by Catalina Oana Curceanu have joined in a consortium to address this fundamental quest from an innovative standpoint, supported by a FET (Future and Emerging Technologies) 4.4 M€ grant awarded by the European Commission (EC). The Collaborative Project "TEQ" (Testing the large-scale limit of quantum mechanics) puts together 8 leading European research groups and the MSquared company to explore quantum effects at the large scale under the support of the EC Horizon 2020 research framework programme. The project is one of the only 26 funded proposals out of 374 submitted to the latest call for Future and Emerging Technologies projects.

The team will levitate a small particle within a well-controlled environment, with low temperature and low vibrations. In such an environment an indirect test of the QSP can be performed by analyzing carefully the noise that affects the centre of mass motion of the trapped particle. The measured noise will then be compared to theoretical predictions from different models – some of which assume a breakdown of QSP.



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# DAMPE: LOOKING FOR DARK MATTER IN COSMIC RAYS

The scientific journal Nature has published the first results of the DAMPE (DArk Matter Particle Explorer) experiment, in orbit on a satellite since December 2015. The experiment measures the flow of very high energy cosmic electrons and positrons (from 55 GeV to 4.6 TeV). For the first time, the direct measurement of these particles in space highlights and measures a sharp change, a "break", in their flow according to energy. At energies exceeding 0.9 TeV, the electron and positron flow changes and "dips", decreasing more rapidly with increasing energy. This phenomenon had recently been measured only by ground experiments, with indirect observations, much greater uncertainty and still partly preliminary results.

DAMPE, the first Chinese astrophysical satellite, is one of the five space mission projects of the Strategic Pioneer Program on Space Science of the Chinese Academy of Science (CAS). It is an international collaboration involving more than 100 scientists, technicians and students from Chinese, Italian and Swiss institutions led by the CAS Purple Mountain Observatory (PMO). Italy is involved with a research group of approx. twenty scientists form the Perugia, Bari and Lecce divisions of the National Institute for Nuclear Physics and the Universities of Perugia, Bari and Salento.

The detector has been designed to measure the flows of electrons, photons, protons and nuclei, with a greater precision and energy range than the already active experiments. The importance of the recent DAMPE measurement is related to the research and study of the electron and positron sources at TeV energies, whether they are objects of an astrophysical nature - for example, pulsars - or whether their presence is partly due to dark matter, as it would seem possible given the characteristics of the positron flow observed up to those energies by the AMS-02 experiment on the International Space Station. Launched on 17 December 2015 from the Chinese Jiuquan Satellite Launch Center in the Gobi Desert,



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DAMPE orbits at a distance of approx. 500 km, from which it tries to detect possible signals of the presence of dark matter by studying the characteristics of ordinary cosmic particles. In its first 530 days of scientific activity, starting from 8 June of this year, it has detected 1.5 million cosmic electrons and positrons with energies exceeding 25 GeVs: data characterised by an unprecedented energy resolution and level of contamination from background particles. Thanks to these characteristics, the detector is able to measure the direction of arrival of the cosmic photons with great accuracy and, at the same time, to differentiate the nuclear species that make up the cosmic rays and their trajectory. DAMPE is also capable of measuring the flow of nuclei in the range between 100 GeV and 100 TeV, thus providing new data and information to understand the origin and propagation of high energy cosmic rays.

DAMPE has a total weight of approx. 1900 kg, of which 1400 kg are represented by the four scientific experiments, including the heart of the detector, the silicon tracker, entirely built by Italian researchers with the coordination of the INFN. The technology of this detector - originally developed in the 80's for elementary particle physics experiments in accelerators - was used for the first time in space by Italian physicists with the AMS-01 experiment, which flew for ten days on the Discovery Space Shuttle in 1998. This was followed by other experiments - such as PAMELA and FERMI on satellites, and AMS-02 on the ISS - all operating since many years in orbit around the Earth. DAMPE is part of a programme of space missions, such as those mentioned above, but also of terrestrial ones such as CTA-MAGIC, AUGER and Advanced VIRGO, or submarine observatories, such as Km3net, with the aim of studying all the messengers of the cosmos. It will thus be possible to study the most hidden properties of the universe with a strongly synergistic approach.



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### Cover

Bullet Cluster image with the distribution of the Dark Matter (blue). Credit: X-ray: NASA/CXC/CfA/ M.Markevitch et al.; Lensing Map: NASA/STScl; ESO WFI; Magellan/U.Arizona/ D.Clowe et al. Optical: NASA/STScl; Magellan/U.Arizona/D.Clowe et al.;