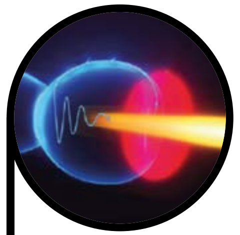
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

ONE YEAR OF RESEARCH AT LNF

LNF HIGHLIGHTS 2023

Some LNF achievements during 2023

SIDDHARTA-2 setup



Principle of betatron X-ray emission
from a Laser WakeField Acceleration (LWFA)

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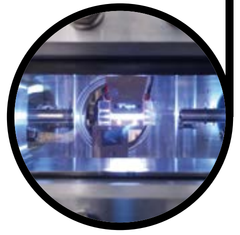

Integrated plasma module consisting of two active plasma lenses used to perform acceleration and focusing experiments

The FLASHMOB setup installed in the Beam Test Facility

Artemisia Project

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

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SUMMARY

FOREWORD

What an exciting year has been 2023 for our Laboratory! The DAΦNE collider has provided a large amount of high-quality data to the SIDDHARTA-2 experiment, which aims at the first observation to date of kaonic deuterium, and at the measurement of its relevant parameters. These data which will be complemented by a second chunk of events being acquired in the first half of 2024, will allow us to unlock the secrets of the QCD in the strangeness sector and contribute to a better understanding of the role of strangeness in the Universe, from nuclei to the stars.

The BTF facility has provided electrons and positrons beams to many users for more than 200 days. Among the many different experiments, it is worth mentioning the one performed by a LNF-RAL-ENEA collaboration aimed at exploring a novel approach to produce 99mTc, without making use of nuclear reactors. The production of this element is particularly relevant since it has important application in medicine. The recent results obtained in BTF could have the potential of a critical development for modern medical imaging for worldwide benefit.

The preparation of our future accelerator, EuPRAXIA, is progressing well. In the context of this ambitious program, at the beginning of the year, the EuAPS project has been launched, a 30-month enterprise financed through PNRR (Piano Nazionale di Ripresa e Resilienza) as part of the Next Generation EU programme. EuAPS aims at achieving some of the scientific objectives of EuPRAXIA through the realization of a distributed user facility to make advanced radiation sources available to user groups. It is the most relevant among several different PNRR initiatives which will be at the centre of our programs for the next two years, a challenging effort, indeed!

On the other hand, “normal” activities go on as much as in the past. In this volume a particular example of the use that is made of our research infrastructure in the field of the study of our cultural heritage is reported. It is a beautiful example of how much the tools and the ideas developed for fundamental science can have an application in a wider domain and can provide benefits to the society as a whole.

What an exciting year has been 2023 for our Laboratory! Year 2024 promises to be as much exciting as the previous one. Stay tuned.

Fabio Bossi / LNF Director

SIDDHARTA-2 HUNTING FOR KAONIC DEUTERIUM AT DAΦNE

The strong interaction, one of the four elementary ones in Nature, is fundamental to explain the structure and stability of matter. Governed by Quantum Chromodynamics (QCD) within the Standard Model of elementary particles, it describes the interactions between quarks and gluons, the fundamental constituents of protons, neutrons, and all other hadrons. Its importance spans from the subatomic scale to astrophysics, including the presently debated inner structure of neutron stars. Despite significant progress in last decade, the low-energy regime of QCD is still not fully comprehended. The main challenge arises from the non-perturbative nature of QCD at low energies,

SIDDHARTA-2 setup

Some members of the SIDDHARTA-2 Collaboration

derived from the very peculiar characteristics of QCD. In this context, innovative experimental techniques are mandatory to provide the necessary experimental inputs for the development of theoretical models and kaonic atoms studies represent a unique laboratory for characterizing the strong interaction at the lowest energy frontier, since they provide direct access to the kaon–nucleon/nuclei interactions at very threshold [1].

Kaonic atoms are systems in which a negatively charged kaon is electromagnetically captured on a nucleus in an atomic orbit, after replacing an (atomic) electrons. These exotic atoms represent a unique scientific case also because kaons are hadrons containing a strange quark. Due to the large kaon mass, the energies of the lowest atomic levels and transitions are resenting the strong interaction; the energy levels are shifted with respect to purely electromagnetic (QED) calculated interactions, and the line widths, defining lifetimes, are broadened. These observables, shifts and widths, can be precisely measured through X-ray spectroscopy, providing fundamental data to probe the strong interaction in the low-energy regime and the strangeness QCD sector, offering an opportunity to refine our understanding of the nature of kaon-nucleon interactions.

Combining the excellent quality of the low-energy kaon beam delivered by the DAΦNE collider with new experimental techniques, the SIDDHARTA-2 collaboration performed unprecedented measurements of kaonic atoms and is presently undergoing the challenging measurement of kaonic deuterium transitions to the fundamental level.

The SIDDHARTA-2 results are awaited by the scientific community for more than 50 years (as long as it took to find the Higgs boson) and obtaining the, is extremely challenging. For kaonic deuterium, which, together with the kaonic hydrogen measured by SIDDHARTA will deliver the isospin-dependent kaon-nucleon scattering lengths, for which theoretical predictions diverge, the signal to be detected is very weak, and characterized by broadened peaks and very small X-ray yield.

The DAΦNE electron-positron collider at the INFN-LNF is a unique source of low-energy, high-intensity kaons, allowing for novel kaonic atoms measurements. Its ability to produce a high flux of kaons stems from the fact that DAΦNE was the first accelerator to develop and utilize an innovative collision method known as the Crab-Waist scheme, to control the strong nonlinear forces produced when two highly focused packets of electrons and positrons collide [2-3].

To achieve the challenging kaonic deuterium measurement goal, the SIDDHARTA-2 experiment was designed to perform high precision X-ray spectroscopy in the high radiation environment of a particle collider. For this reason, the SIDDHARTA-2 collaboration developed innovative fast and very precise Silicon Drift Detectors (SDD) [4] for X-ray spectroscopy and a series of other detectors, such as a kaon trigger and three veto systems to reduce the background.

The initial optimization of the experimental apparatus was accomplished through the measurement of kaonic Helium-4 transitions to the 2p level [5-6], which have yields about 100 times higher than the transitions on the 1s level in kaonic deuterium. The result turned out to be the most precise measurement in a gas target, providing a new experimental input for the theoretical models. In 2023, before starting the kaonic deuterium measurement, a refined optimization and performance check of the experimental apparatus, was realized measuring, for the first time, high-n X-ray transition in kaonic Neon with the unprecedented precision below 1 eV. This result not only provide new data for the kaonic atoms database setting a precedent for future high-precision kaonic atomic measurements, but also confirm a new method the power of these type of measurements for the strategic use in extracting the charged kaon mass, a real puzzle presently, since two very precise measurements already exist, but they are not compatible with each other.

The kaonic helium-4 and the kaonic neon results demonstrated the excellent performance of the SIDDHARTA-2 setup in terms of X-ray detection accuracy and background suppression capability, paving the way for the kaonic deuterium measurement. The kaonic deuterium data taking campaign began in May 2023, aiming to collect data for a total integrated luminosity of about 800 pb-1. The first two phases (Run1 and Run2) have been completed in 2023, by collecting an integrated luminosity of about 500 pb-1. The preliminary analysis looks very promising. The third was initiated in February 2024 and is ongoing. This measurement, long awaited by the scientific community, is fundamental for a better and more precise understanding of strong interaction. Moreover, the SIDDHARTA-2 collaboration put forward a proposal for future precision measurements of kaonic atoms, charting the periodic table: EXKALIBUR proposal [7], by using a series of innovative technologies and methods.

The experiments at the DAΦNE collider represent a unique opportunity in the world to unlock the secrets of the QCD in the strangeness sector and contribute to a better understanding of the role of strangeness in the Universe, from nuclei to the stars.

The SIDDHARTA-2 collaboration dedicates their results to their dear colleague and mentor Prof. Carlo Guaraldo, who passed away on 19th May 2024. Prof. Carlo Guaraldo was the initiator of the line of studies on kaonic atoms at the DAΦNE collider in the late '90s. This line of research began with the DEAR experiment, continued with SIDDHARTA, and is currently ongoing with the SIDDHARTA-2 experiment. He coordinated the Hadron Physics series of European projects - Hadron Physics 1, 2, and 3 - from 2004 to 2014. These projects significantly contributed to integrating and advancing physics in this sector in Europe, promoting the coordinated use of European key research infrastructures, developing detectors and scientific tools, and fostering networking between various research communities worldwide. He was also a main actor in the ongoing STRONG-2020 European project, serving as a member of the Executive Board and deputy spokesperson.

Carlo will be greatly missed by all of us!

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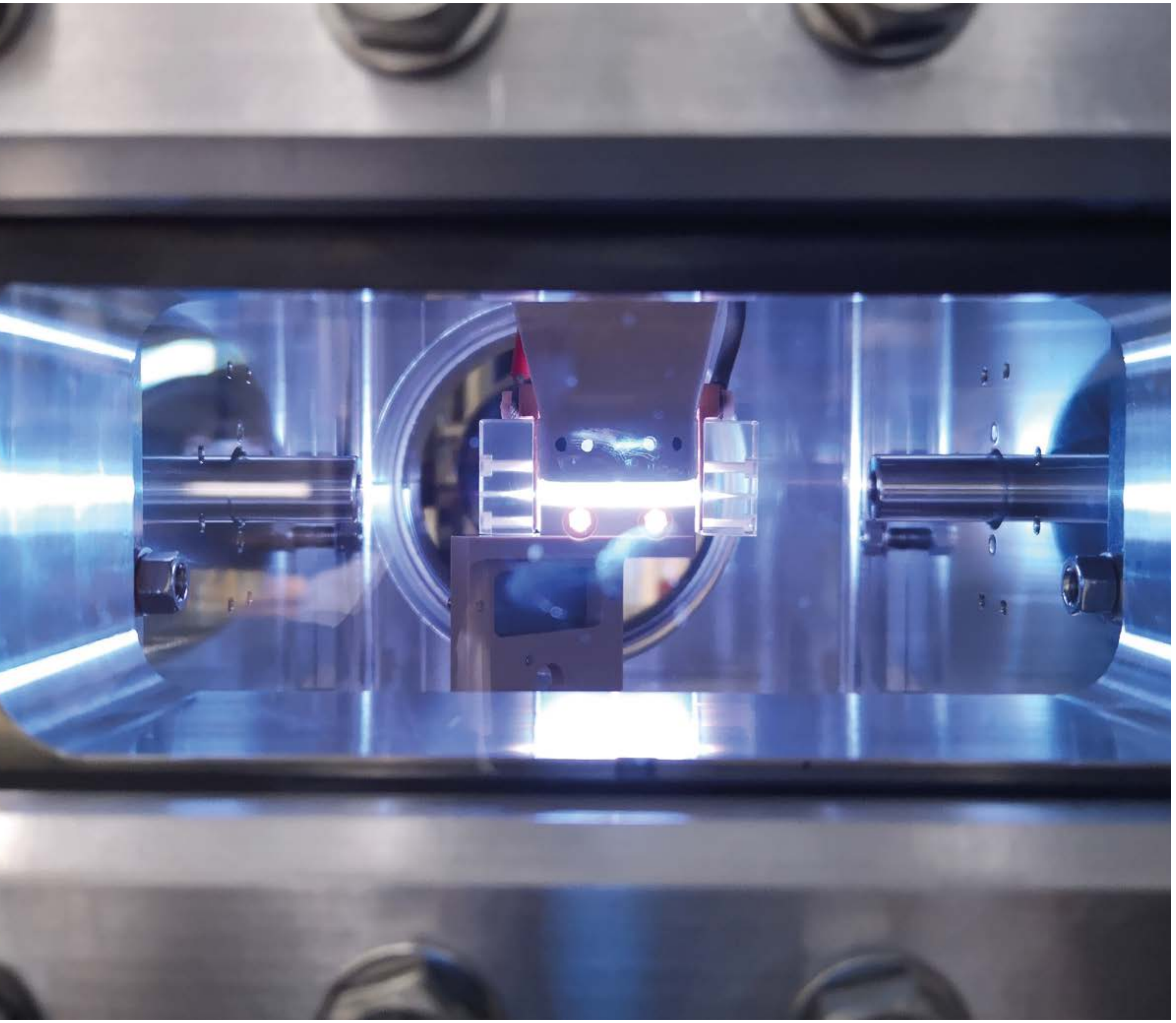
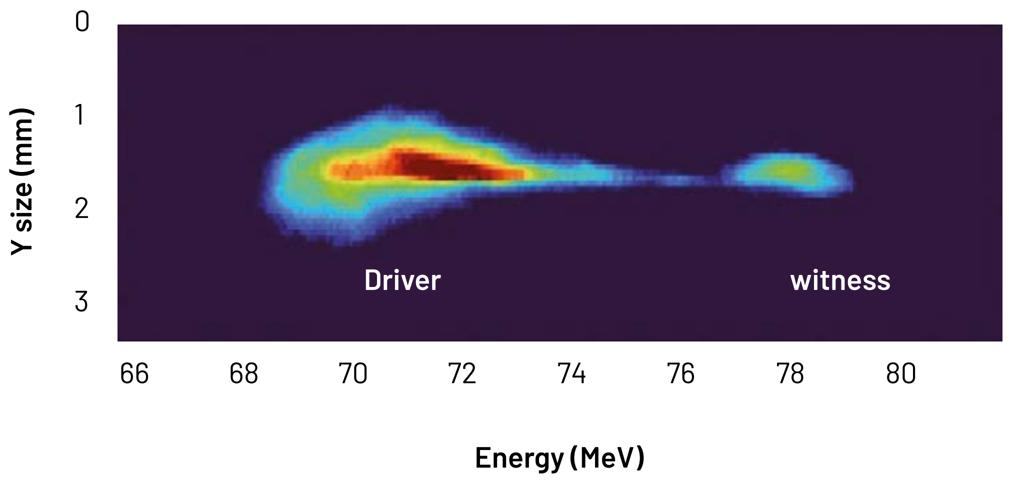


Integrated plasma module consisting of two active plasma lenses positioned on either side of an accelerating section, which is used to perform acceleration and focusing experiments.

FIRST ELECTRONS ACCELERATED BY THE NEW PROTOTYPE PLASMA ACCELERATOR CAPILLARY

In the field of particle accelerators, the interest is growing in the development of compact accelerating structures capable of overcoming the current limitations of conventional ones based on RF pulses. In this context, research activity is moving toward plasma technology-based devices capable of producing accelerating gradients on the order of tens of GV/m, to be compared with the tens of MV/m achievable by conventional techniques. Recent experiments have also shown that such plasma structures can also be used to focus high-energy particle beams, called Active Plasma Lenses (APLs), due to the high magnetic field gradients produced, in the kT/m scale, by the intense ionization currents of neutral gas. The result is to focus high-energy beams over distances of a few centimeters, unlike the meters required with conventional techniques based on permanent magnets or electromagnets.

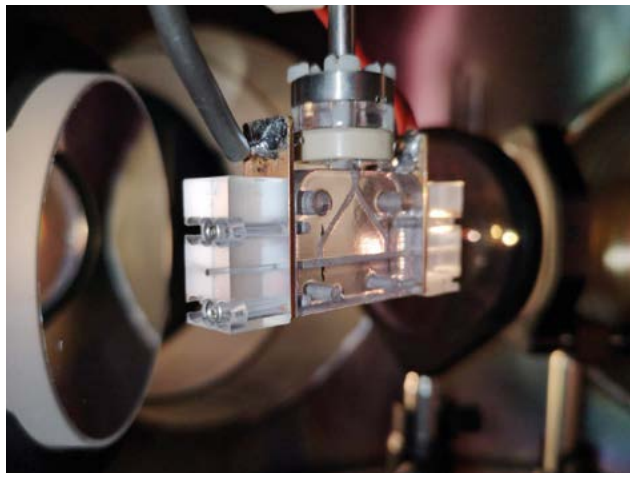
The combined use of such plasma-based elements, which are integrated into single accelerator modules could meet the demand for high accelerating gradients in structures having extremely small dimensions. In this context, the results obtained in the experiments that began in July 2023 at SPARC_LAB can be considered. Indeed, here the first acceleration tests were performed with the compact all-plasma-based module shown in Fig.1. The results



Energy spectra measured with the 'beam-driven plasma acceleration' technique at the output of the plasma accelerator module. Single energy spectrum of driver and witness acquired during the experimental campaign. The energy increase corresponds to 30 mm of plasma, equivalent to approximately 200 MV/m of accelerating gradient.

obtained during these tests were proposed and accepted for publication in the international journal Physical Review E (April 2024).

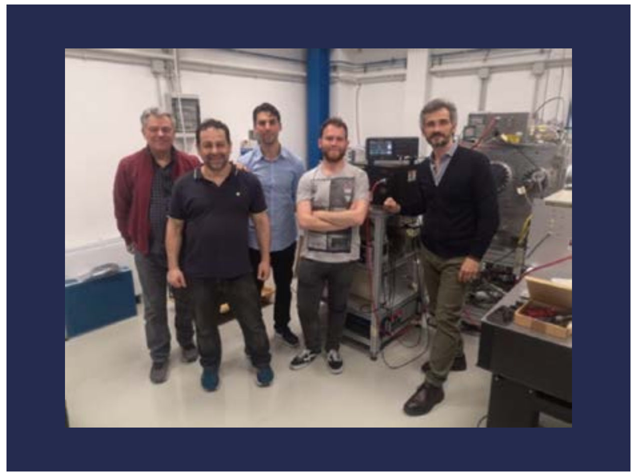
Such a device integrates within it two active lenses, necessary to optimize the transverse dimensions of the beam at the entrance of the accelerating section and allow its capture at the exit, and a centrally arranged accelerating element. The technique for plasma formation is based on the use of high-voltage pulses capable of producing ionization of a column of gas (nitrogen) created between two electrodes by means of a number of vertical injection channels. In the tested module, a single plasma channel having a diameter of 2 mm was created, where each of the three elements, all 30 mm in length, is bounded by a pair of electrodes.



The different plasma conditions required in the three sections, in order to produce the focusing and acceleration of electron bunches with a 200/50 pC charge (driver/witness) at different times, can be separately controlled by the synchronism and amplitude of the high voltage pulses used for the plasma formation. For this purpose, current pulses of around 600 A were used for the lens plasma and around 250 A for the accelerating section, which were also set 14 μs ahead of current pulses. Energy measurements performed during the experiments showed stable and accelerated beams with gradients up to about 200 MV/m.

This plasma accelerator module, entirely designed in the Frascati National Laboratories, is based on the use of discharge capillaries and represents the first prototype of a plasma device capable of integrating the use of focusing and accelerating elements built within the same structure. Design and development of such plasma devices is included in the European project EuPRAXIA for plasma-based accelerators, funded by the Ministry of University and Research (MUR) and recently entered in the roadmap of ESFRI, the European strategic forum for research infrastructures.

The inventors Angelo Biagioni, Riccardo Pompili, Valerio Lollo, Donato Pellegrini and Massimo Ferrario, with the support of the INFN, filed a patent proposal for the tested device.



First laboratory tests conducted at PLASMA_LAB with the composite capillary prototype. In the picture, left to right, are Valerio Lollo, Donato Pellegrini, Riccardo Pompili, Lucio Crincoli and Angelo Biagioni.

EuAPS PROJECT

EuAPS stands for EuPRAXIA Advanced Photon Sources, it is a 30-month project financed through PNRR (Piano Nazionale di Ripresa e Resilienza) as part of the Next Generation EU programme to fund for construction of an integrated system of research and innovation infrastructures. INFN results as the lead institution while, CNR and the University of Tor Vergata, are co-participants.

The project has a budget of more than 22.3 million euros and is part of the European project EuPRAXIA, already part of the ESFRI roadmap, and which envisages the creation of a distributed European user facility of advanced radiation sources (FEL, betatron, positron) driven by plasmaaccelerated electron beams.

EuAPS, led by Massimo Ferrario (INFN-LNF), aims to achieve some of the scientific objectives of EuPRAXIA through the realization of a distributed user facility to make advanced radiation sources available to user groups; these consist of a plasma-based betatron source to produce partially coherent soft X-rays (at the National Laboratories of Frascati), see figure, a highpower medium and high repetition rate laser (CNR-INO in Pisa) and a high-power laser at the National Laboratories of the South – Catania (LNS). The University of Tor Vergata, CNR-ISM (RM) and CNR-ISM (PZ), will take care of the diagnostic part, the necessary X-beam manipulations and the experimental chambers for users. The INFN-Milan group, to which personnel from both the Institution and the Department of Physics belong, is responsible for the fundamental task of theoretical and simulation studies aimed at the design and optimization of the betatron source.

Principle of betatron X-ray emission from a LWFA. Electrons trapped at the back of the wakefield are subject to transverse and longitudinal electrical forces; subsequentlythey are accelerated and wiggled to produce broadband, synchrotron-like radiation in keV energy range.

The project officially started in December 2022, is structured on four work packages that focus on the project management and dissemination part (WP1), the betatron radiation source to be realized at the Frascati National Laboratories (WP2), the realization of the high-power laser at the INFN-LNS in Catania laboratories (WP3), and finally WP4 that identifies all the activities of the CNR-INO site in Pisa for the realization of the high-power medium and high repetition rate laser. More details are available in the “EuPRAXIA Advanced Photon Sources PNRR_EuAPS Project” report (INFN-23-12-LNF), published in April 2023.

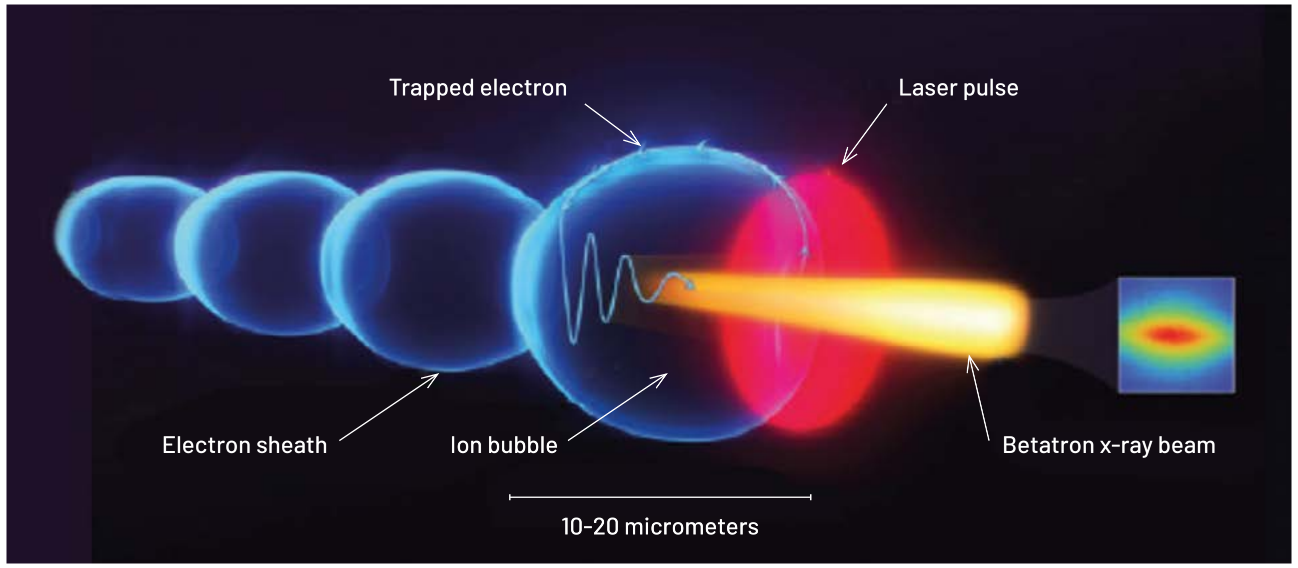
The deadline for the awarding of all tenders and purchasing contracts, set by the Minister for December 31, 2023, was successfully reached for almost all procurement processes. In detail, out of the total available budget of about 20.9 million euros for scientific instrumentation, civil infrastructure and contracts for the recruitment of researchers and technologists, almost 19.3 million euros were committed and spent, thus accounting for more than

92 percent of the available budget despite the fact that on July 1st 2023, became operative the legislative decree of the public contract, which entailed the acquisition of new rules and new regulatory references that resulted in the lengthening of the time of some procurement procedures.

It is also for this reason that the Minister of the University and Research (MUR), given the changed national regulatory environment in the area of public contracts, as well as the evolution of the international scenario and the related existing procurement difficulties, in order to facilitate the proper project activities, at the beginning of 2024 granted the request to extend the deadline for the few unsuccessful tenders and the use of some tender savings.

The year 2024 began with intensified planning activities in preparation for the production, delivery, and installation of scientific instrumentation. Procedural, physical, and financial reporting has become a significant part of the dedicated staff effort, the official platform devoted to the reporting is operational, and the physical progress are already up to date. The project is proceeding according to schedule except for some delays related more to the high number of checks required to finalize the various purchase contracts, which will take a few weeks. There is a possible six-month extension for the project that is being seriously considered.

All of this has been and is possible thanks to an extraordinary effort of the experienced staff of the agencies involved, the RUPs involved in the purchasing process, the dedication of the administrative department, and the enthusiasm and energy of the new staff hired on the project.



Principle of betatron X-ray emission from a LWFA. Electrons trapped at the back of the wakefield are subject to transverse and longitudinal electrical forces; subsequentlythey are accelerated and wiggled to produce broadband, synchrotron-like radiation in keV energy range.

DIRECT ELECTRONUCLEAR PRODUCTION OF ^{99m}Tc PRECURSOR AT THE BTF

T Technetium, the first artificially synthesized chemical element, plays a critical role in nuclear medicine as one of its isotopes, the metastable technetium-99 (^{99m}Tc), is one of the main radionuclides used today in the diagnostic field. It was discovered by Emilio Segrè in 1938, via artificial production in a molybdenum strip sent from Ernest O. Lawrence's Berkeley Radiation Laboratory cyclotron coming from a dismissed (and radioactive) accelerator part. Technetium is nowadays produced mainly by humans: it is a shiny gray crystalline transition metal placed between manganese and rhenium in the periodic table, having the symbol Tc and atomic number 43. Every year, hundreds of kilograms of ^{99}Tc and its precursor, ^{99}Mo, are produced as fission products in nuclear reactors.

Naturally occurring technetium is very rare, made by a spontaneous fission product in uranium and thorium ores, or the product of neutron capture in molybdenum ones. Since technetium isobars neighbors are both stable, the possibility of technetium stable odd-even isotopes is excluded: that's why technetium does not exist in nature except in traces[CLR02]. Technetium that is accessible is entirely synthesized: it was only after amassing adequate amounts that researchers could delineate its physical and chemical characteristics. This approach enabled the identification of natural Technetium on Earth and the detection of its presence in cosmic formations.

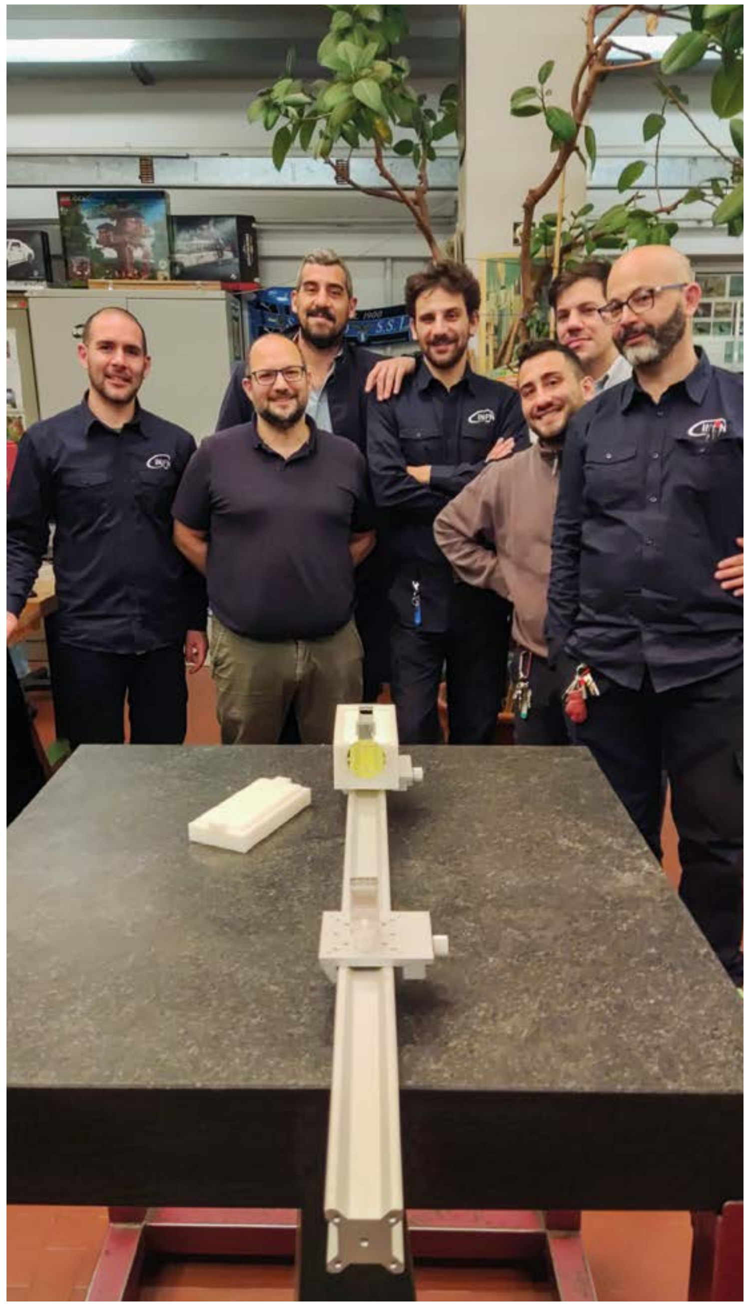
As said, the most commonly occurring Tc isotope is the $^{99m\mathrm{Tc}}$, a widely used radioisotope in nuclear medicine for diagnostic imaging, for the detection of diseases (i.e. Alzheimer's, certain cancers, and heart disease)[A09] and for the study of organ structure and function. The ^{99m}Tc isotope emits 140 keV photons when it decays to ^{99}Tc, this photon energy is ideally suited for efficient detection by scintillation instruments such as gamma cameras. So ^{99m}Tc is particularly useful for nuclear medicine procedures because it can be chemically incorporated into small-molecule ligands and proteins that, when injected into the body, will concentrate in specific organs or tissues so that increasing the detection of its 1 decay products. The data collected by the camera are analyzed to produce detailed structural and functional images for the medical investigations.

The FLASHMOB setup installed in the Beam Test Facility

The ^{99m}Tc precursor: ^{99}Mo

Another crucial reason of the widespread use of this radioisotope derives from the fact that ^{99m}Tc ($t_{1/2}$ = 6 h) is produced via the decay of its parent radionuclide, ^{99}Mo ($t_{1/2}$= 66 h). ^{99}Mo longer decay time permits manipulation, storage and shipping to medical center with a reasonable time buffer preceding the ^{99m}Tc production.

^{99m}Tc is currently made through a multi-step process that begins with the neutron irradiation of fissile uranium (235U) contained in High Enriched Uranium (HEU) or Low Enriched Uranium(LEU) targets in a nuclear reactor. This irradiation causes 235U to fission and produces ^{99}Mo and many other fission products. After the irradiation, the targets are chemically processed to separate ^{99}Mo from other fission products. The ^{99}Mo is then adsorbed onto an alumina column that is contained in ~ 1cm diameter cylinders. The columns are shipped in radiation-shielded cartridges known as Technetium generators, supplied to nuclear medicine departments around the world, providing a convenient source for imaging patients throughout the day.



LNF SPCM group after the FLASHMOB holder production.

RAL, FISMEL and BTF groups before starting the FLASHMOB run.

Tens of millions citizens [24e] in the world benefit each year from ^{99}Mo\\$^{99m}$Tc related nuclear medicine procedures, accounting for about 80% of all nuclear medicine procedures and 85% of diagnostic scans in nuclear medicine worldwide. Since there are only five nuclear reactors in the world capable of producing the 99Mo\99mTc, any delay in the supply chain impacts patient care by preventing access to the most up-to-date treatments, imaging, and diagnostic tests.

Following a major shortage of ^{99}Mo during the 2009–2010 period, challenges arising from aged reactor production facilities as well as complications in transporting radiopharmaceuticals during the pandemic period catalyzed the exploration of local production methods for ^{99}Mo/^{99m}Tc.

RAL and INFN-LNF collaboration

In the framework of a scientific collaboration with INFN Laboratori Nazionali di Frascati (INFN-LNF), researchers from the Rutherford Appleton Laboratory (RAL, UK) and ENEA explored an alternative approach to produce ^{99m}Tc without relying on nuclear reactors, using instead high energy electron beam produced by the DAΦNE Beam Test Facility (BTF)[24a], located at INFN-LNF.

The BTF provides electron/positron primary and secondary beams in a wide range[24b] of intensity, energy, beam spot dimensions, and divergence, mainly for detector development, calibration purposes, short and long-time-based fixed target experiments opened to various scientific communities, mostly belonging to HEP[24c][24d].

On March 27-28, 2023, the feasibility experiment was carried out and the target setup was irradiated in the BTF Experimental Hall (BTFEH1) with 2 direct supervision from the LNF Radioprotection Service (FISMEL). The research team effectively utilized a 504 MeV pulsed electron beam, featuring a pulse duration of 10 nanoseconds and a high charge of approximately 1010 electrons per second, within a dedicated timeframe of 3 hours. This electron beam was employed to irradiate a molybdenum target within a novel experimental setup collaboratively designed by RAL, Beam Test Facility (BTF), and the Mechanical Design and Construction Service (SPCM). The experimental configuration comprised a 3D printed holder unit containing 5 thin molybdenum foils and an extended unit housing 25 foils within a dedicated polyethylene box. This arrangement offered the flexibility to examine both the pure electronuclear process, observed in the first unit, and a combined photo - and electro-nuclear regime, in the extended ones. In the latter, both electronuclear and photoproduction processes occurred concurrently within the target material.

The first unit was mainly intended for the measurement of the ^{100}Mo(e, e'n)^{99}Mo cross section at 504 MeV, thus providing a valuable input to the assessment of the physical model used in the Monte Carlo code.

The observation and quantification of the direct electronuclear production of ^{99}Mo from natural molybdenum involved the measurement of the activity of ^{99m}Tc generated either in the first small unit and in the extended one. Within this scope, subsequent to irradiation, the overall target was transferred from the BTF experimental hall to the FISMEL laboratory, where the activity of the radionuclei produced has been assessed by gamma spectroscopy, using a High Purity Germanium detector (HPGe) operated at low temperatures. Overall, the preliminary results of the radionuclide activities in all the irradiated foils show a good agreement between simulations and experimental data, in the energy range of interest. Most importantly, the measured 99Mo activity as predicted confirms the success of the feasibility study. These results provide promising evidence for the potential of direct electronuclear production as a viable alternative for the production of the 99mTc radiopharmaceutical.

The direct electronuclear production on a suitably designed target should offer several advantages over the 'classical' photonuclear method, including reduced environmental dose and fewer spurious secondary radionuclides produced. Furthermore, the electronuclear proposed method promises to be more suitable to match a new paradigm proposed to produce ^{99}Mo in a post-pandemic scenario, as reported in the correspondence of Nature[Pie22]. In particular, the investigated method can potentially improve the post-process of extraction of ^{99}Mo from thin foils irradiated according to the specific needs of a hospital, matching the modularity and proximity criteria of the new paradigm.

Moving forward, the team will focus on designing a well-optimized ^{100}Mo enriched target to maximize the ^{99}Mo activity, building upon the positive outcomes of this study.

The recent results obtained in BTF could have the potential of a critical development for modern medical imaging for worldwide benefit.

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The Kick-off Meeting took place at LNF on the 23th and 24th of Februrary 2023.

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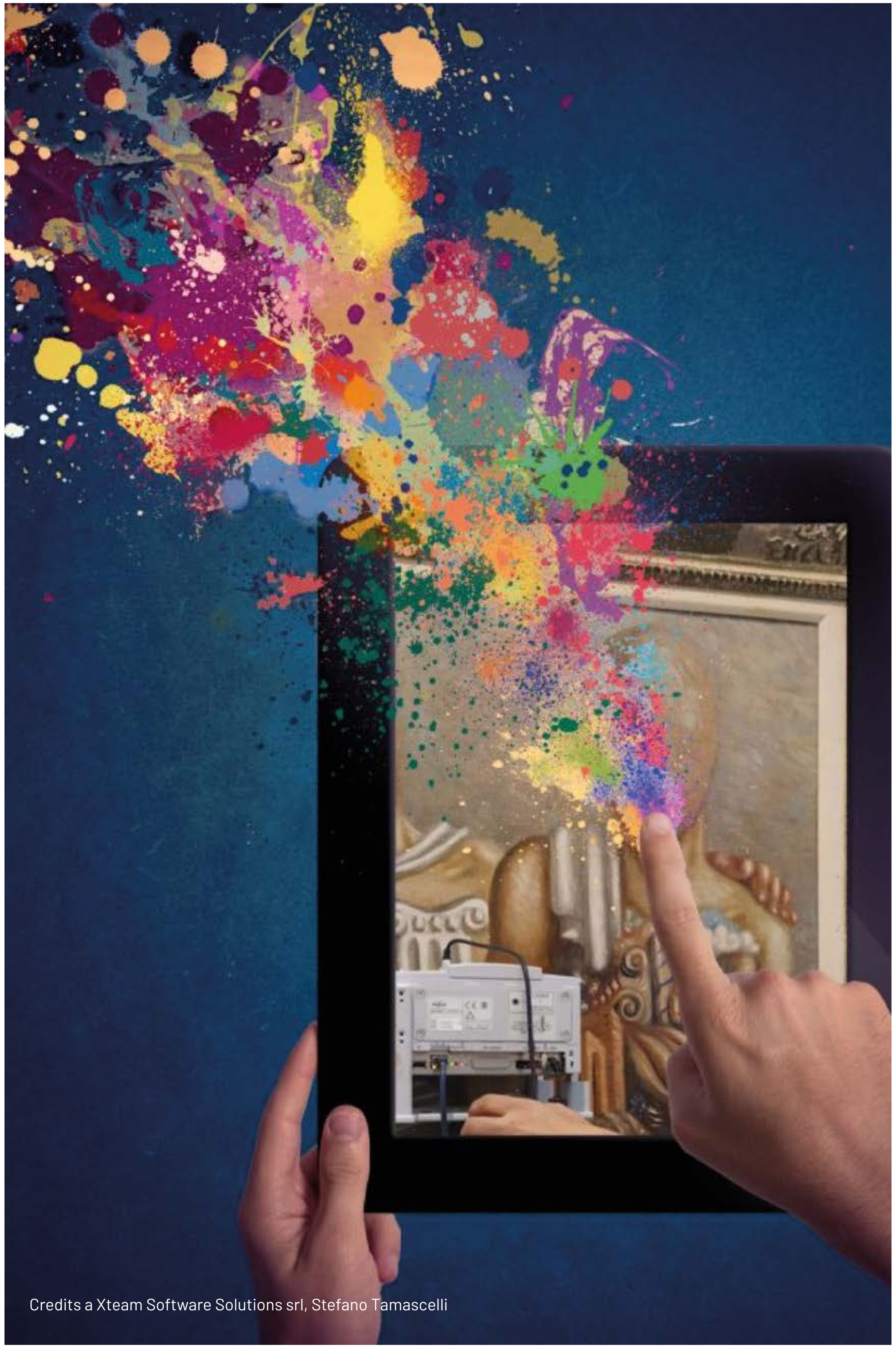
COSMIC WISPERS IN THE DARK UNIVERSE: THEORY, ASTROPHYSICS AND EXPERIMENTS KICK OFF MEETING AT LNF

The agenda and timetable are available at https://agenda.infn.it/event/33570/. More than 50 researchers from European Universities and Research Institutes attended in person and further 50 researchers participated online. The workshop was preceded on the 22nd by a seminar open to the general public by Prof. Caterina Braggio (https://agenda.infn.it/event/34604/) held at the LNF main auditorium Touschek, discussing experimental searches in the field of WISP dark matter. The video (in Italian) is available on LNF YouTube channel (https://www.youtube.com/watch?v=ylQk30CzEL4).

During the meeting many topics were discussed ranging from axion generation in String Theory and WISPs as cold dark matter candidates to white dwarfs cooling by axion-like particles and the search with atom interferometry for light particles composing the dark energy. The action expects to consolidate and open stable collaborations among researchers from different European countries, train young researchers in the field of WISPs with an interdisciplinary approach at the interface between particle physics, astrophysics and cosmology and assure the European leadership in this field of research by outlining a roadmap to WISP discovery.

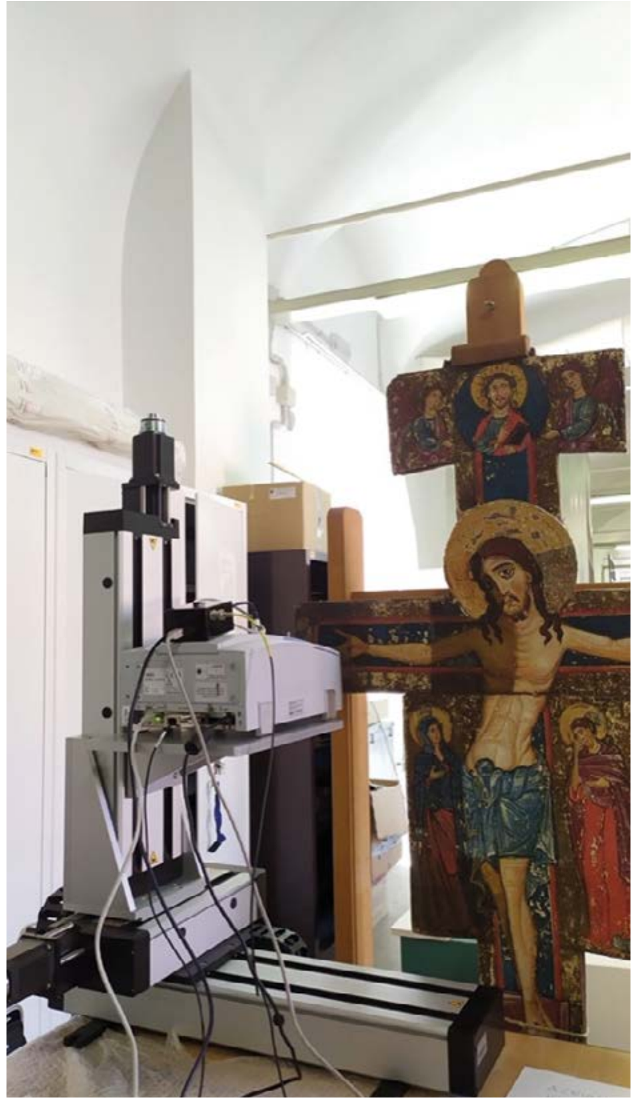


Credits a Xteam Software Solutions srl, Stefano Tamascelli

THE ROLE OF TECHNOLOGICAL INNOVATION IN THE ANALYSIS AND PRESERVATION OF CULTURAL HERITAGE: THE ARTEMISIA PROJECT.

The DafneLight Synchrotron Radiation Laboratory is one of the nodes of the INFN Cultural Heritage Network CHNet dedicated to advanced technologies applied to diagnostics for cultural heritage. Thanks to the growing community of users of the synchrotron light facility, the laboratory has also become part of the Research Infrastructure of the Technological District for Cultural Heritage of Lazio (DTC), the excellence center dedicated to the protection and enhancement of cultural heritage.

ARTEMISIA, an acronym for ARTificial intelligence Extended-Multispectral Imaging Scanner for In-situ Artwork analysis, is an experimental project funded by the Lazio Region and the Ministry of University and Research. Its purpose is to create an integrated advanced diagnostic tool to support restorers and art historians in analyzing the materials that make up artworks and their state of preservation.



ARTEMISIA is an interdisciplinary collaboration between the INFN and a partnership comprising various institutions, including La Sapienza University of Rome, the Central Institute for Restoration (ICR), and two private companies.

The technology has been implemented to integrate various point spectroscopy techniques into an automated mapping system for non-invasive and non-destructive elemental (X-Ray Fluorescence) and broad-spectrum molecular analysis (FT-IR, SWIR, UV) for in-situ spectroscopy. Thanks to this kind of portable technology, artworks do not need to be moved to a laboratory to be analyzed. By exploiting the different penetration depth of the electromagnetic radiation used, the system can analyse different layers of a painting, from the most superficial (varnishes and degradation products) to the deeper ones (pigments and preparatory drawings). This tool complements traditional investigations carried out using synchrotron radiation on micro cross-sections of paintings, without being a destructive analysis.

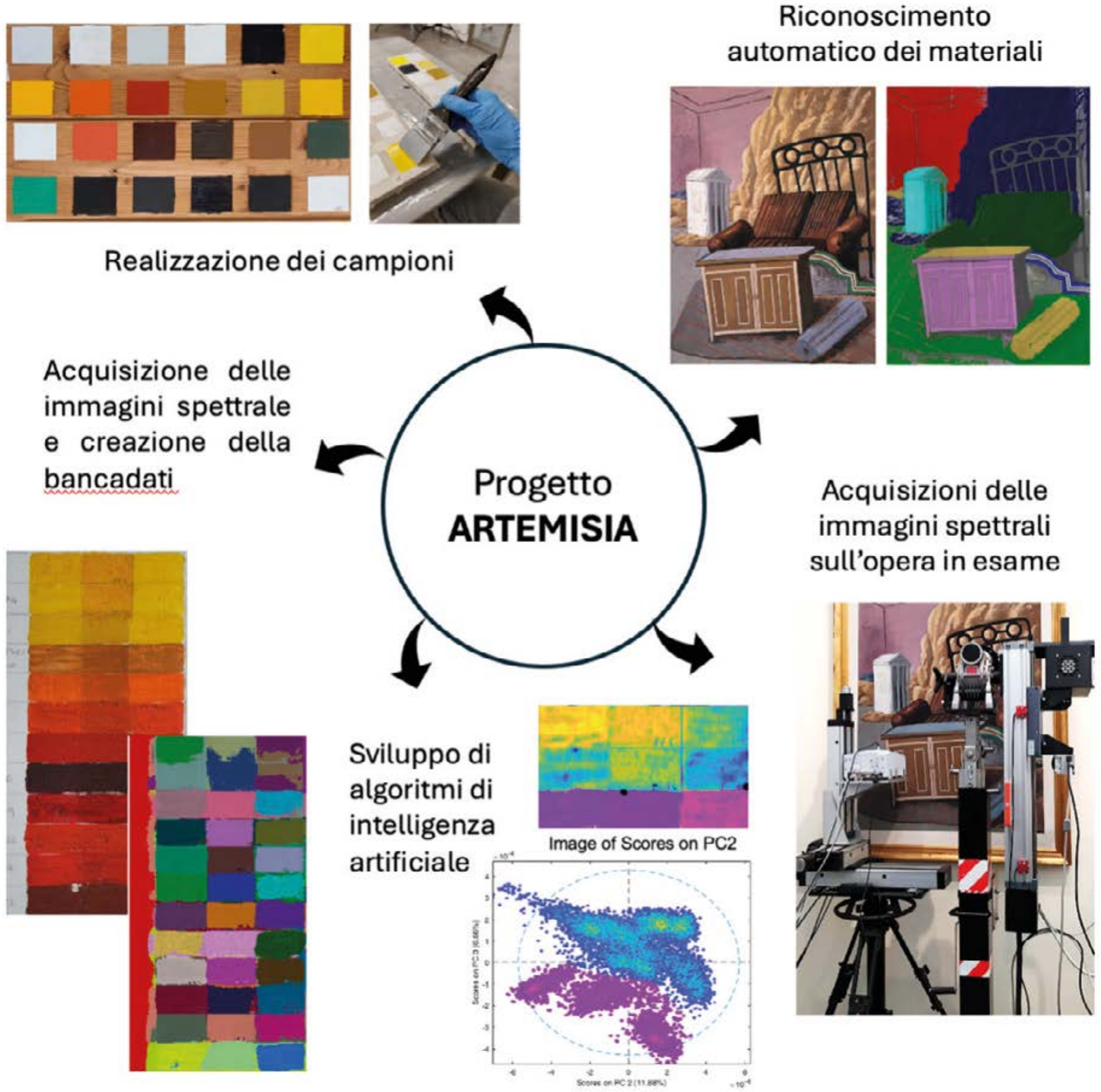
The prototype thus created has been used to analyse one of Giorgio de Chirico's most significant works, the painting "Furniture in the Room" (1927) preserved in the collection of the Carlo Bilotti Aranciera Museum in Villa Borghese, Rome. Regarding the technique used by the artist, interesting results have emerged. The artist's binder was oil, consistent with what is reported in the Piccolo trattato di tecnica pittorica (Little Treatise on Painting Techniques), a sort of true "recipe book" of colors and techniques used by the artist himself. As for pigments, the following were identified:

- **Zinc white: both pure and mixed with other pigments.**
- **Cobalt blue: present in the painting.**
- **Earths for warm tones: red, brown, and purple.**

Additionally, degradation products such as carboxylates were detected, which naturally form from the interaction of zinc (contained in zinc white pigment) with oil.

Project ARTEMISIA reveals the potential that connect scientific and technological advancements to the art world. Specifically, ARTEMISIA serves as a bridge between STEM disciplines and the humanities. The possibility of using tools like the one developed in the ARTEMISIA project not only in collections but also in museums and permanent collections would allow for the dissemination of often overlooked information, such as painting techniques, making art even more accessible and appreciated by the public.

In summary, ARTEMISIA represents a significant step toward integrating art, science, and technology, enriching our understanding and preservation of cultural heritage.

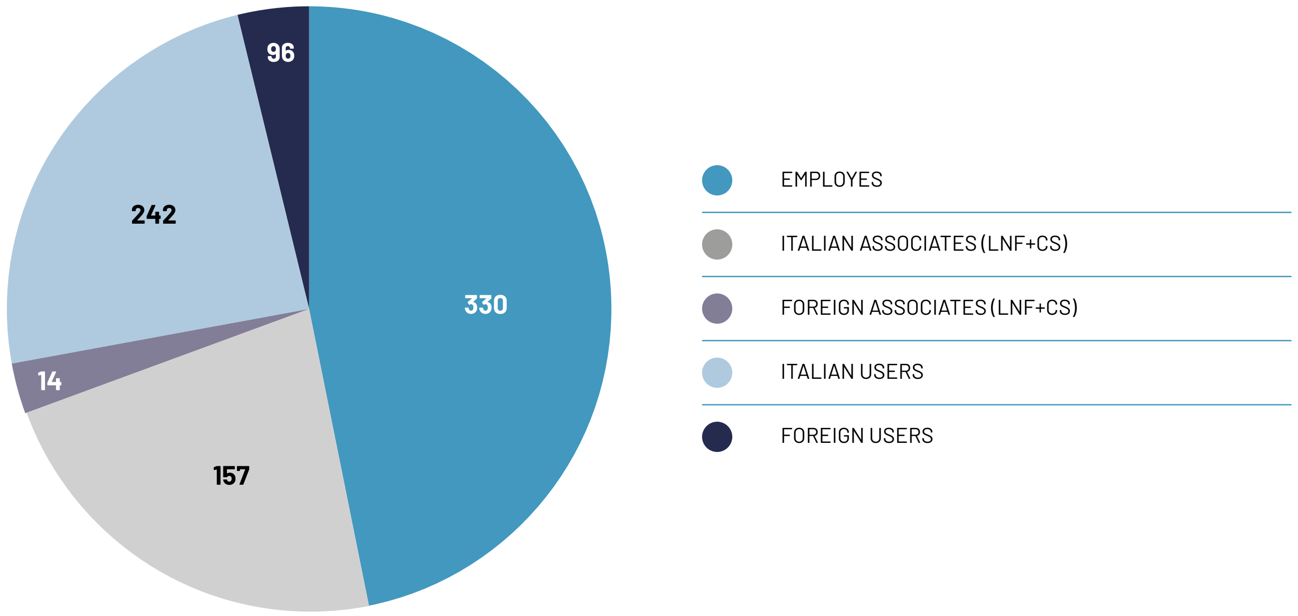


LNF IN NUMBERS

The LNF personnel, at the end of 2023, consists of 309 units, including 29 with a fixed term contract, plus 154 associate members. Among these, theare are university and PhD students, young post-Docs and employees from universities or other research institutions. Associate members work alongside staff members and likewise take part in the Laboratory's activities. Tab. 1 shows the division of the LNF personnel among the different profiles.

	STAFF	TEMP.	TOT.
RESEARCHER	70	0	70
ENGINEER	75	19	94
ADMINISTRATIVE	38	7	45
TECHNICIAN	98	23	121
TOT.	281	49	330

Table 1.
Snapshot of the LNF personnel at December 2023.



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LNF HIGHLIGHTS 2023

ON YEAR OF RESEARCH AT LNF

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