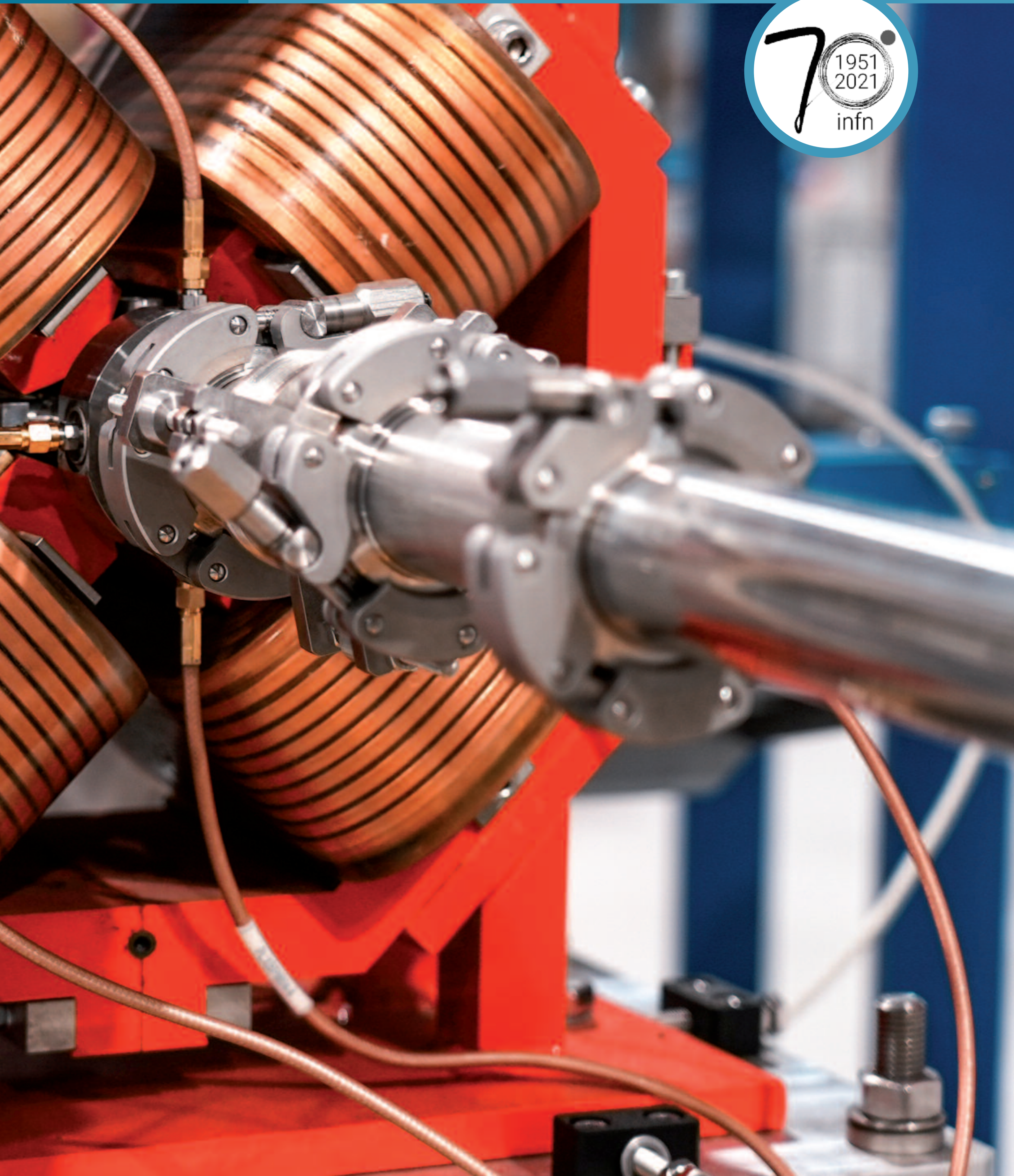
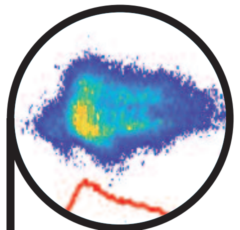
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

ONE YEAR OF RESEARCH AT LNF

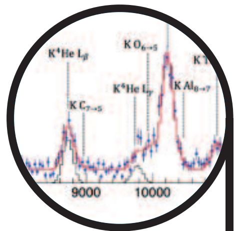
LNF HIGHLIGHTS 2021



Some LNF achievements during 2021



First Free-Electron Laser radiation produced with plasma acceleration at the SPARC_LAB.

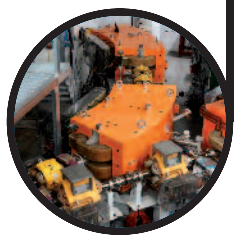


New kaonic atoms produced by the SIDDHARTA-2 experiment at DAΦNE.

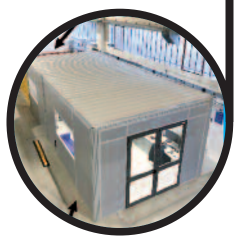
The EuPRAXIA project included in the new Roadmap of the European Strategy Forum on Research Infrastructure.

Celebrations for the centenary of the birth of Bruno Touschek, the father of the first world electron-positron collider.

The retroreflector LaRA, developed by the SCF_Lab group, reached Mars.



Completion of the second Beam Test Facility beam-line.



Commissioning of TEX. A new highpower test-stand for X-band accelerating structures.

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Summary

Foreword

The inclusion of the EuPRAXIA project into the Roadmap of ESFRI, the European Strategic Forum for Research Infrastructures, can be considered the most relevant achievement of the Frascati National Laboratory in 2021. Actually, this important milestone points the way to the future of LNF. Together with our international partners, we are committed in building a new distributed, innovative science infrastructure that will be headquartered in Frascati. In the meanwhile, we have kept producing amazing science with the presently running machines.

SPARC_LAB has demonstrated, for the first time, that it is possible to use a plasma accelerated beam to generate coherent radiation, a result that is the basic proof of principle for the success of EuPRAXIA.

At DAΦNE, the SIDDHARTA-2 experiment has collected a first round of data. This run was initially intended only as a test of the performance of the newly installed detectors. However, the quality of the data was so good that they could be used to produce physics papers.

The construction of the second line of the Beam Test Facility has been completed. The Laboratory has now a new infrastructure that can provide useful electron and positron beams to the physics community. Instruments built at Frascati are successfully operating in several places in the entire world. Now, a piece of our laboratory has even reached Mars, together with the NASA rover Perseverance.

After a long period of closure, motivated by the insurgence of the Covid19 pandemic, we have finally, although with some grain of caution, restarted our meetings in presence. In December, our Laboratory has hosted a part of the three-day symposium dedicated to the memory of Bruno Touschek, one of the key figures in the history of LNF. This has not been only the occasion to remember our glorious past, but also to discuss about our future, together with many friends and colleagues.

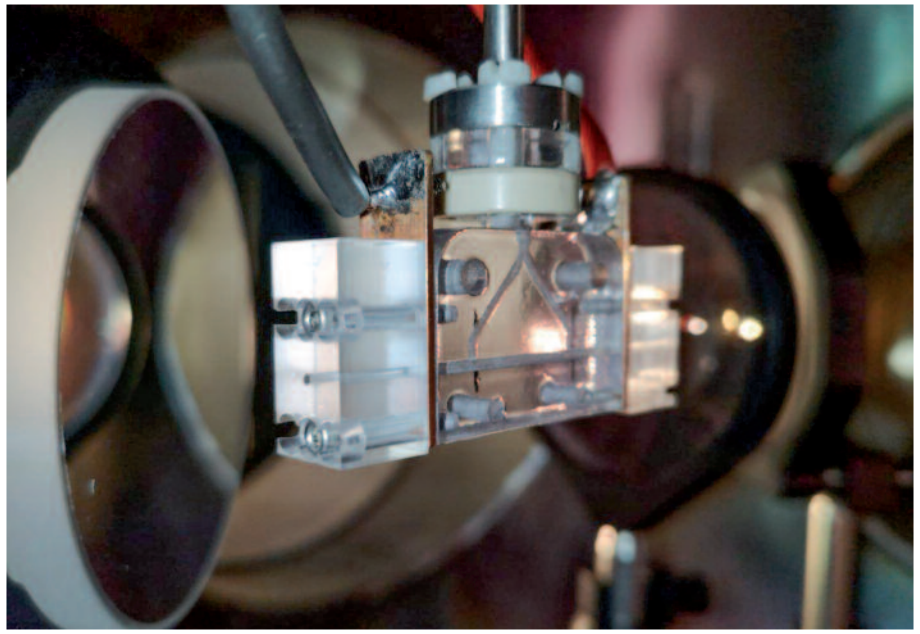
Fabio Bossi
LNF Director

Achievements in plasma acceleration @SPARC_LAB

The use of waves generated in a plasma to accelerate particles is revolutionizing the panorama of particle accelerators, making possible to realize innovative ultra-compact and low-cost infrastructures aimed at fundamental physics experiments or for user applications. Despite the huge accelerating gradients produced in a plasma accelerator (up to three orders of magnitude larger than conventional radio-frequency technology-based accelerators), so far, their use has been limited due to the low quality of the accelerated beam.

An experiment carried out by the researchers of the SPARC_LAB group of LNF has demonstrated, for the first time, that it is possible to use a plasma accelerated beam to generate coherent radiation, the so called Free-Electron Laser (FEL), in the infrared spectrum range. The result has been obtained by injecting two bunches of electrons (with dimensions of few tens of microns) into the plasma contained in a 3 cm long plastic tube called capillary (fig. 1). To properly operate, it was firstly necessary to create the plasma by

Figure 1.
Picture of the discharge capillary.



ionizing the hydrogen gas through a high voltage electric discharge (fig. 1). Then the two electron packets have been injected. The first bunch (driver) has the function of exciting the accelerating waves in the plasma which are then exploited by the second one (witness) which is accelerated.
The experiment was performed by using a driver and witness bunches separated by about 1.2 ps. The driver charge was set to 200 pC while for the witness the charge was 20 pC.
The high quality of the input witness bunch was maintained during the acceleration in the plasma and, in addition to its high current, it was able to drive the FEL by generating coherent light pulses. An experimental beamline is currently in operation at SPARC_LAB with a FEL consisting of six planar undulators. Each one is composed by 77 pairs of magnets with opposite polarity that make the electron beam travel a sinusoidal path. The light generated in each period is coherently added to the one generated in the previous period, increasing exponentially its intensity. Downstream each undulator, an in-vacuum metallic mirror can be inserted to send the FEL radiation to a calibrated photo-diode. At the exit of the last undulator the radiation spectrum is also measured with an imaging spectrometer equipped with a diffraction grating and a cooled intensified camera (iCCD). A typical FEL pulse measured with a spectrometer downstream the last undulator is shown in fig.2. The experiment obtained light pulses with maximum energies of 30 nJ.

For its relevance, the paper describing these achievements has been accepted for publication by Nature, probably the most prestigious scientific journal world-wide.
Such a proof-of-principle experiment demonstrates the first lasing of a FEL driven by a plasma accelerator. The results indicate that the high-quality of the plasma accelerated beam (with low energy spread and emittance), accompanied by the high stability and reproducibility of the acceleration process, allows to transport the beam along a segmented undulators beamline and amplify FEL light in the near-infrared range. The achieved FEL performances well match the theoretical expectations thanks to the precise knowledge of the beam phase-space, completely characterized from injection and propagation in the plasma up to the capture at its exit.
The published paper also describes how to extend the same methodology and apply it to different energies and contexts, such as the future EuPRAXIA multidisciplinary experimental research infrastructure. EuPRAXIA, also supported through a financial contribution from the MUR, Ministry of University and Research, has recently entered the final roadmap of ESFRI, the European Strategic Forum for Research Infrastructures. These results therefore represent an important milestone towards the use of plasma accelerators for applications dedicated to users coming from different scientific fields.

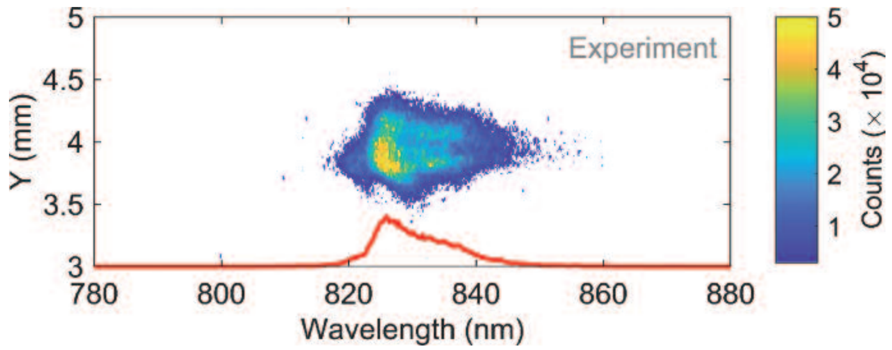


Figure 2. Spectrum of the measured FEL radiation.

LaRA the space laser that took INFN on Mars

The arrival of the NASA rover Perseverance on the Red Planet opened a new phase of exploration and research on Mars. Mars 2020 mission represents a first step of NASA's long-term robotic exploration providing important data relevant to astrobiology research, along with a vast amount of geological information about the landing site and the planet at large that will help to put the astrobiological data into context.
Perseverance landed in the Martian area called Jazero crater after a long journey that lasted about seven months. An international Mars sample return campaign, taking place between 2020 and 2030, sees ESA and NASA involved in three launches. The whole program will allow the exploration of the Mars surface and rigorously document and store a set of samples in canisters in strategic areas to be retrieved later for flight to Earth.
For missions on Mars, the technical equipment used is subject to vibrations and pyro-shock mechanical levels typically harder compared to the Moon missions, because Mars is farther away, rockets involved are huge and the entry, descent and landing through the atmosphere are more violent.
The operating environment of Mars is also difficult for the red dust that covers the surface and that represents one of the problems for any device. Communications can even be

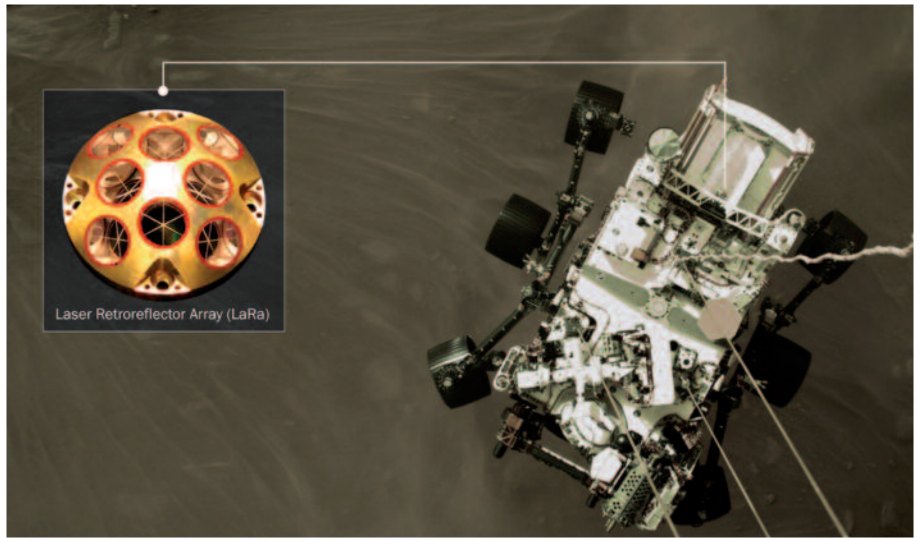


Figure 1. LaRA on Perseverance (Courtesy NASA and INFN).

disrupted due to solar flares or frequent storms. However, the same winds clear at least partially dusted surfaces and optics.
The Perseverance rover is equipped with sophisticated instruments including LaRA, the Laser Retroreflector Array developed and built at LNF, on behalf of ASI, by the SCF_Lab research group. LaRA is an instrument to determine the accurate position of artificial satellites, landers, rovers, and celestial bodies. This is possible measuring the time-of-flight of short laser pulses bounced back by corner-cube retroreflectors made of fused silica (laser telemetry).
The LNF team that worked for the project is composed of experts in mechanics, optics, physics, and electronics to create optimal control and test systems for the verification of the devices that will then go into the space environment.
LaRA is a 2-inch-wide dome dotted with eight holes containing glass corner-cubes that have three mirrored faces positioned at 90-degree to each other. This arrangement makes the light entering the holes reflected in the same direction it came from ("retroreflected").
LaRA underwent several tests before being shipped on Perseverance. Specifically, a wide cycle of characterization of the optical performance, thermo-vacuum tests, vibration and shock qualifications and a biological sterilization. Furthermore, test plans, test procedures, calibrations of all instrumentation involved in the qualification campaign, and data processing, all required approval by space agencies and the respect of rigorous ASI, ESA and NASA quality and product assurance standards. Finally, a complex and articulated End Item Data Package had to be delivered, and it had to pass an accurate pre-agreed verification control matrix of requirements.
The LaRA micro-reflector will enable scientists to perform precise distance measurements using the laser telemetry being able to accurately identify the position of Perseverance on the Martian surface. Furthermore it will help to study Martian geophysics, to allow tests of Einstein's general relativity theory, and to make future landings on the Red Planet more precise and safer.

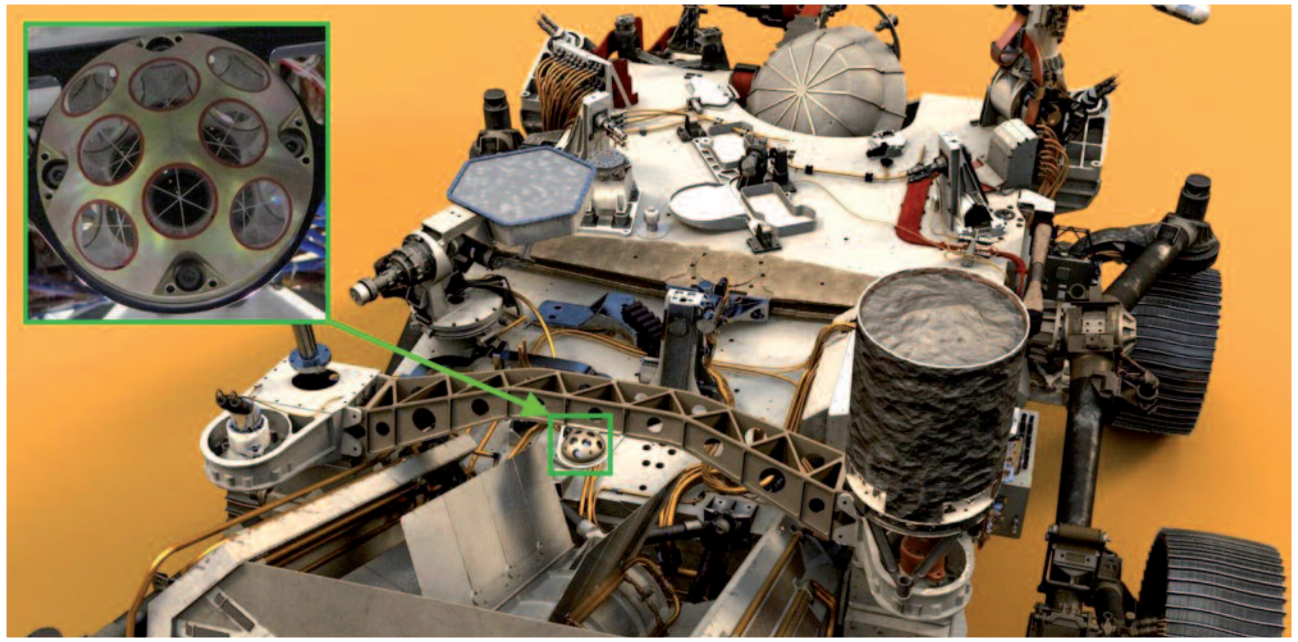


Figure 2. The Perseverance rover. The laser retroreflector LaRA is also shown (NASA JPL).

First kaonic atoms from SIDDHARTA-2 on DAΦNE

On 19 July 2021, the first period of data taking of the SIDDHARTA-2 experiment installed on the DAΦNE collider was successfully completed. This represents a very important milestone towards the achievement of the final goal of the experiment.
SIDDHARTA-2, an experiment carried out within a broad international collaboration between 12 institutes from 7 countries, with support from the EU STRONG-2020 project (G.A. n° 824093), aims to study the strong nuclear interaction through measurements of atomic transitions in exotic atoms, in particular kaonic atoms, where an electron orbiting the nucleus of an atom is replaced by a kaon with negative charge.
The kaon, unlike the electron, is a particle composed of a quark (the strange quark) and an antiquark (the anti-up quark) and interacts with the nucleus through the electromagnetic interaction to which the strong interaction is added. The measurements of X-ray transitions in kaonic atoms allow, therefore, to measure and extract the contribution of the strong interaction in systems with strangeness, being the only method for measuring the interaction between kaons and nucleons at threshold (i.e. at zero-relative energy between the kaon and the nucleus).
About 10 years ago the SIDDHARTA collaboration carried out the world's most precise measurement of atomic transitions in kaonic hydrogen to the fundamental level, as well as the first measurement of kaonic helium-3 and kaonic helium-4 in gas targets. The measurement of kaonic deuterium was, at the time, too difficult (the expected number of events per stopped kaon is about 10 times lower than that of the already difficult kaonic hydrogen measurement).
SIDDHARTA-2, using new technologies, in particular new silicon spectroscopic detectors (Silicon Drift Detectors) and a complex veto system, aims to make the first measurement of kaonic deuterium, an exotic atom composed of a nucleus containing the deuton (proton and neutron) with a negatively charged kaon in atomic orbit. This measurement, together with the kaonic hydrogen one, will allow for the first time to determine the so-called antikaon-nucleon isospin dependent scattering lengths, which are key-ingredients for a better understanding of the theory of strong interaction, Quantum ChromoDynamics, in systems with strangeness, with implications ranging from elementary particle physics and nuclear physics to astrophysics.
The first run of SIDDHARTA-2 was carried out with SIDDHARTINO, a reduced version of SIDDHARTHA-2, with the aim of measuring first kaonic atoms during the commissioning phase of the DAΦNE collider.
DAΦNE is an articulated complex of accelerators that, by colliding electron and positron beams (the antimatter of the

Figure 1. The SIDDHARTA group inside the DAΦNE hall during the installation of SIDDHARTINO.

electron) at high intensities can deliver a beam of kaons, which are produced by the Φ-decay. The production rate of kaons increasing at the same rate as the luminosity of the machine, i.e. the number of electron-positron collisions per unit area and per unit of time. The kaons produced by DAΦNE are characterized by low energy and are therefore ideal, and practically unique in the world, for the study of the strong interaction at threshold, such as, in fact, is being done with the kaonic atoms.
It is important to recall that within DAΦNE, a new collision scheme, the Crab-Waist, was designed and built for the first time in Frascati, which now become a fundamental concept, not only for the design of future machines, but also in pushing the performance of existing lepton colliders beyond the state of the art.

The effectiveness of the new collision approach is continuously reaffirmed by the activity of DAΦNE which, with SIDDHARTA-2, is realizing the third collision period dedicated to the taking of data by experimental apparata with profoundly different characteristics (DEAR, SIDDHARTA and, presently, SIDDHARTA-2).
After a lockdown period that interrupted the activity of the machine for about 10 months, DAΦNE restarted in February 2021 with the aim of providing kaon beams to SIDDHARTINO minimizing the X-ray background induced by collisions on the detector.
During these months the parameters of the electron and positron beams have been appropriately fine-tuned and since May 2021 SIDDHARTINO has started a consistent data taking being able to count on a maximum luminosity of the

Figure 2. Installation of SIDDHARTA-2 setup.

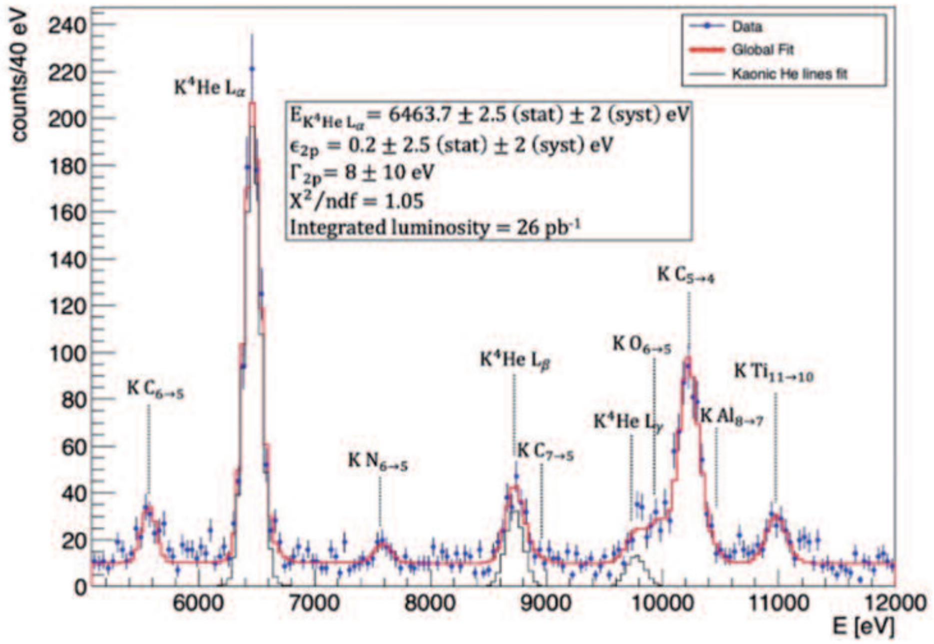


Figure 3. Kaonic helium-4 measured by SIDDHARTINO: (red line) fit of the K^4He energy spectrum. The L_α peak is seen together with the L_β and L_γ ones (black lines). The peaks labeled as KN, KC, KAl, KTi (dotted lines) are the lines of the kaonic atoms produced by kaons stopped in the Kapton walls of the target cell and in other parts of the setup.

order of 8×10^{31} cm^{-2} s^{-1}, a deliberately moderate value to also favor the progressive understanding of the new apparatus. This phase was also fundamental to understand which were the most effective parameters for the reduction of the background. Thus, at the end of the data taking period, the measured background was more than halved.
In this context, SIDDHARTINO measured X-rays corresponding to transitions on the 2p level in kaonic helium-4 with various configurations of the apparatus and two different helium densities.
The analyses of the data allowed to extract the shift and width of the 2p level in kaonic helium-4; the obtained values were: $\varepsilon_{2p} = E_{exp} - E_{em}$ = 0,2±2,5(stat)±2,0(syst) eV and Γ_{2p} = 8±10 eV(stat), respectively.
In particular, this new measurement of the shift, published in an article on the Journal of Physics G[1], represents the most precise one for a gaseous target and is expected to contribute to a better understanding of the kaon-nuclei interaction at low energy.
During the summer 2021, the SIDDHARTA-2 collaboration installed on DAΦNE the complete SIDDHARTA-2 apparatus for the measurement of kaonic deuterium planned for 2022 and 2023.

1. D.L. Sirghi et al., A new kaonic helium measurement in gas by SIDDHARTINO at the DAΦNE collider, J. Phys. G: Nucl. Part. Phys. in press https://doi.org/10.1088/1361- 6471/ac5dac

Commissioning the second line of the Beam Test Facility

The Beam Test Facility (BTF) is a versatile infrastructure of the DAΦNE accelerator complex. It consists of a magnetic transfer line that transports the LINAC beam in a dedicated experimental area available for external users. During 2021, the upgrade work of the infrastructure has been completed and now two beam lines are available: BTF1 and BTF2. With the new setup, the facility is now able to serve more users and to satisfy different experimental requests.
In the new configuration, the BTF initial beamline is split after entering the former experimental hall (BTFEH1) by a fast-ramp pulsed dipole (DHPTB102). The characteristics of the two beam lines differ slightly:

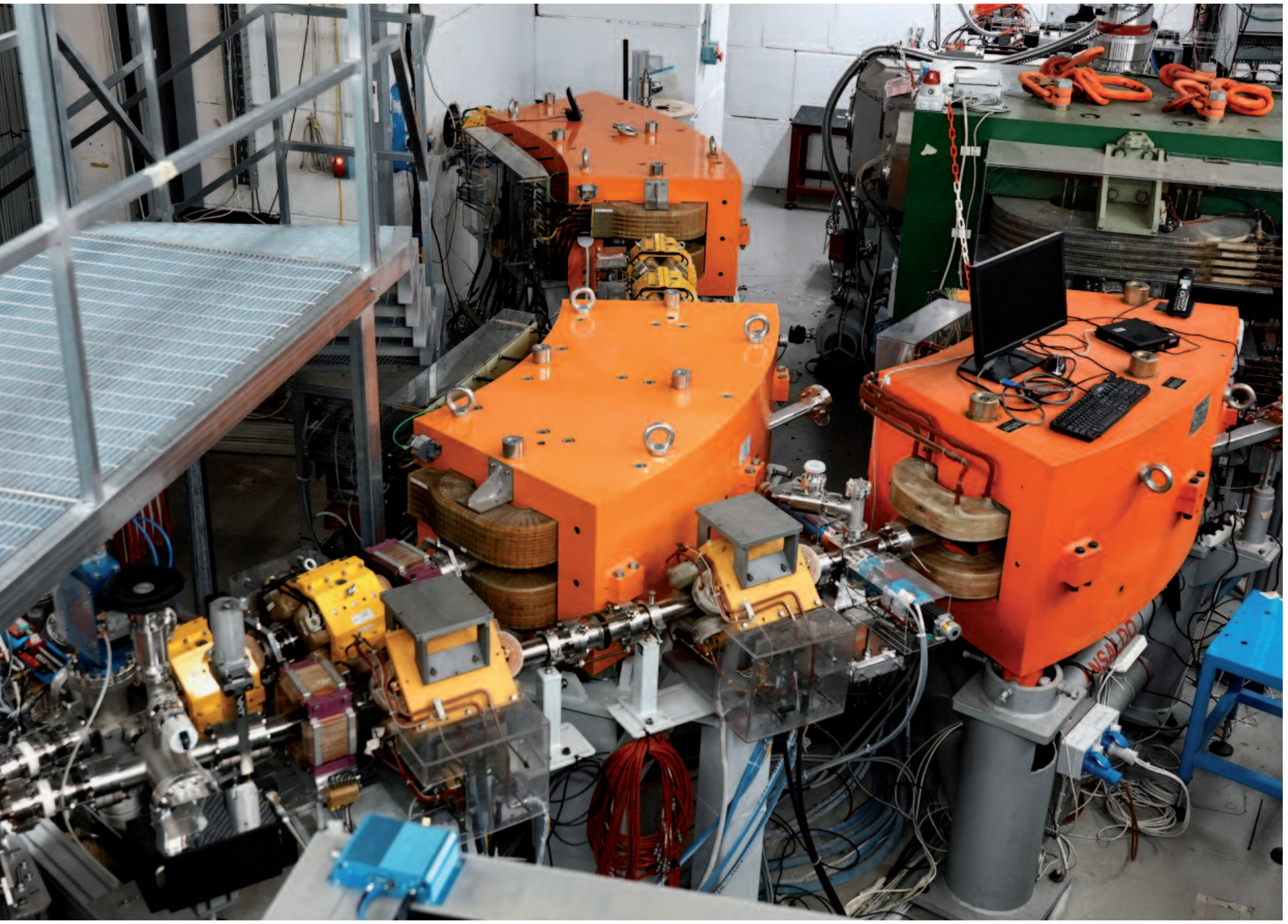
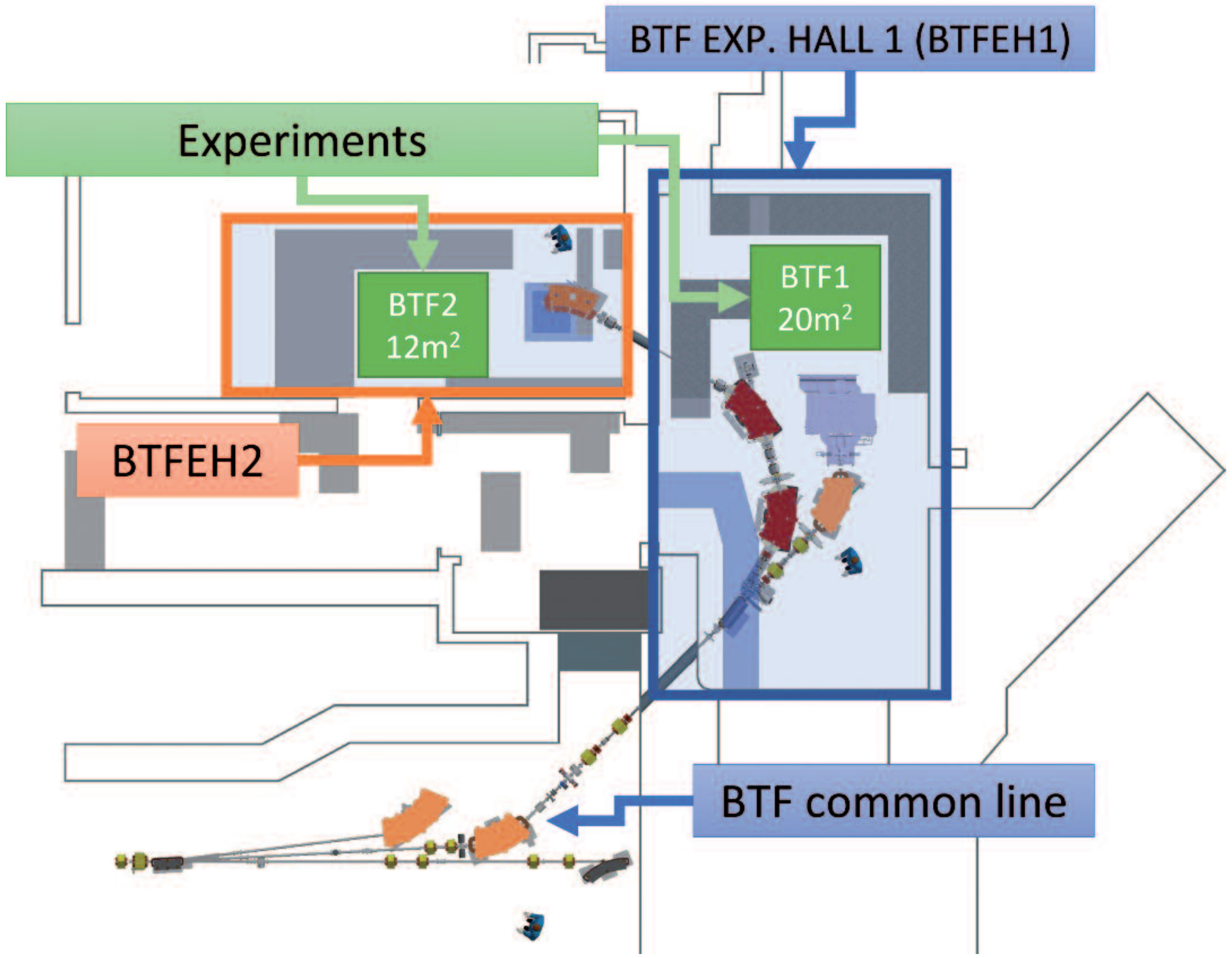


Figure 1. Photo showing the two BTF beamlines: on the right the DHSTB002 dipole just in front of the PADME magnet (green object); on the left the sequence of two dipoles, DHSTB201 and DHSTB202, diverting the beam towards BTFEH2.

- the BTF1 is dedicated to experimental installations requiring high intensity mainly using the LINAC primary beam. This is generally foreseen for long-term activities (more than a week) and presently is exclusively devoted to PADME (Positron Annihilation into Dark Matter Experiment), a fixed target experiment for dark matter-related research;
- the BTF2 is instead intended for short-term beam tests (less than a week) requiring a medium or low intensity. The beam is produced by the primary LINAC electron beam impinging on a secondary target (TGTTB001) located at the begin of the transfer line (see fig. 2).

The two beamlines transport primary and/or secondary beams in two different Experimental Halls. The BTFEH1 hosts the BTF1 line and the BTF2 transfer line toward BTFEH2. This latter is reached by means of a long drift section (3 m long) crossing the wall separating the two experimental halls. The BTFEH2 has been created in the area that formerly was the facility control room and that now has been moved upstairs close to the main DAΦNE control room.
The completion of BTF2 installation with the final beam commissioning, took place along 2021, but the idea of realizing a second BTF line dates to 2016, when a detailed proposal was submitted to the INFN Machine advisory



Committee. After some iterations, the project was approved in 2017 and the money-flow started in 2018. Part of the necessary funds were also supplied by the AIDA-2020 Grant Agreement 654168.
The BTF2 deployment was taking several years since it required a long sequence of operations: the realization of some civil constructions, the acceptance tests of all new line-elements, the implementation of the necessary new software tools. In these activities were involved different Services of the Accelerator and Technical Divisions of the laboratory.
Most of the building refurbishment and of the new bunker shielding preparation were executed under the supervision of the Civil Engineer Service. This led to a partial re-routing of the DAΦNE main rings cabling, since some power cables were passing through the involved areas. This threatening task was completed in due time, without affecting the operation of the DAΦNE collider, profiting of the shutdown periods. This work was executed by the Electronics and Diagnostics Service of the Accelerator Division, while the deployment of the power and interlock

Figure 2.
Layout of the Beam Test Facility. The beam from the LINAC is transported towards two experimental halls: the former available BTFEH1 and new build BTFEH2. All the magnetic elements of the two beam lines are outlined (see text for more details) The available free space for the experimental equipment is also indicated for both experimental areas.

cables was done under the responsibility of the Electric Service of the Technical Division.
The completion of the BTF2 upgrade work had an interruption in 2020 to permit the PADME collaboration to perform its second data taking run. For the BTF staff this was considered a good occasion to test the performance of the first common, new tract, of the BTF beamline driving the beam in the BTFEH1 on the PADME detector.
The improvement of the beam quality registered by PADME was the proof that the work was proceeding as expected and in 2021 the BTF2 was then completed without any further stop.
The mechanical components of the new BTF2 line had to match several highly demanding space constrains in both the experimental halls. In some places, the BTF1 and BTF2 elements are close less than few centimeters. An accurate check of the mechanical tolerances was therefore necessary to avoid installation problems. This task was executed by the Mechanical Engineering Service of the Accelerator Division that put in place and aligned all the magnets and the vacuum chambers in both the experimental halls. After having controlled the position of all BTF common line elements,

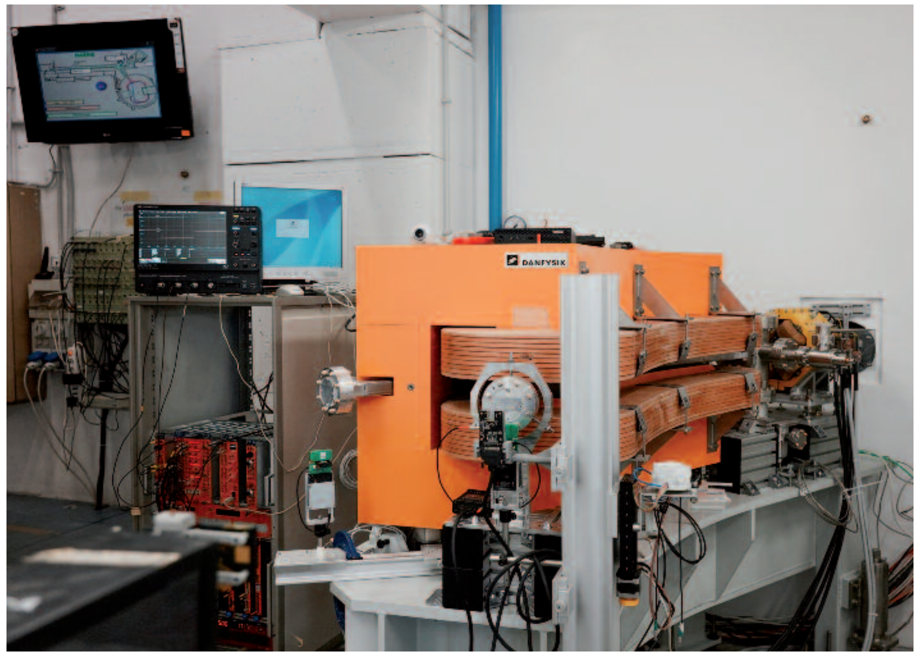


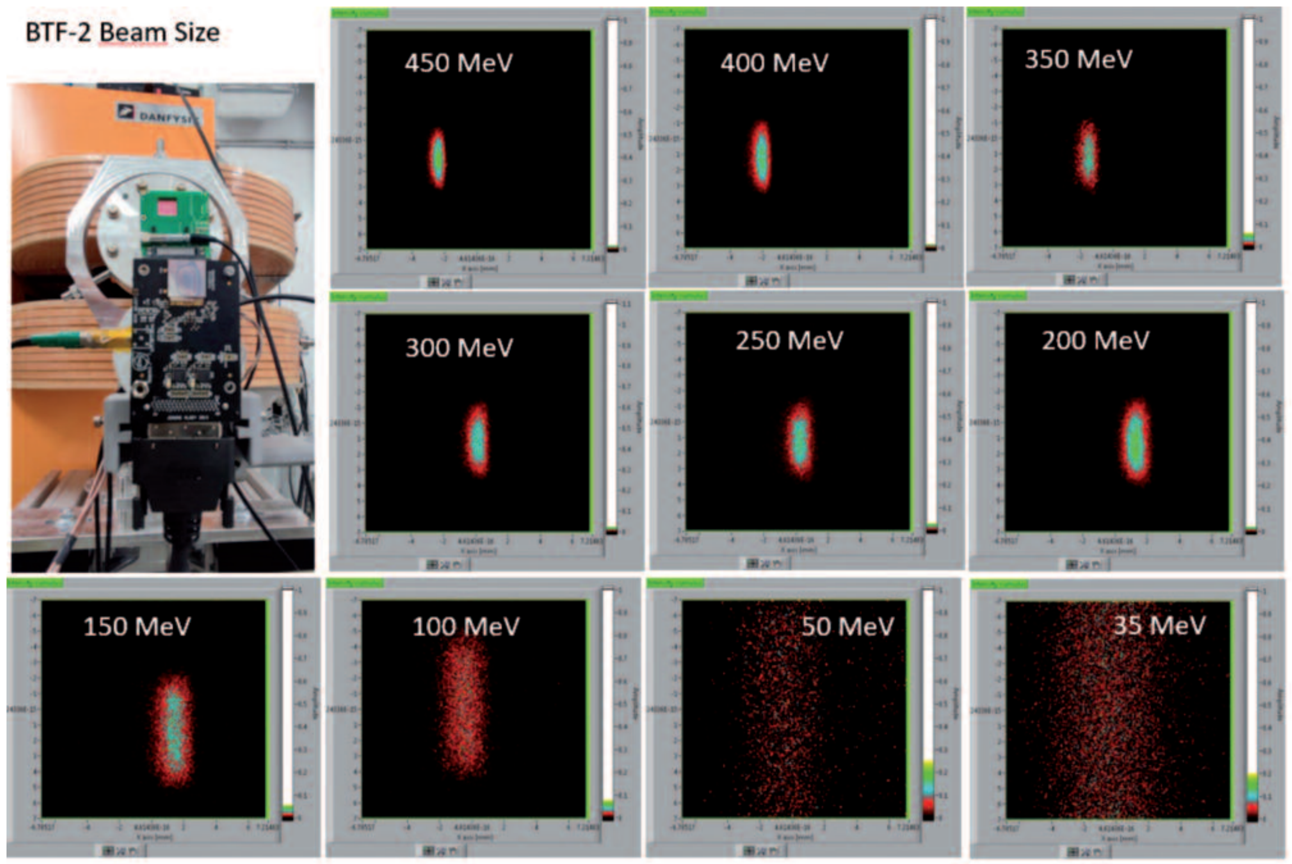
Figure 3. The last dipole of BTF2 line. In front of the beam exit window a Timepix detector is mounted. It has been used to characterize the beam during the commissioning phases.

located in the LINAC tunnel, amidst the 2021 winter pandemic peak, it was possible to position the BTF2 line elements with less than 0.1 mm error.

The Vacuum Service of the Accelerator Division, after having designed and supervised the production of some new elements, was taking care of the new line operation. This required the installation of motorized vacuum elements (scrapers, beam stopper, and targets), vacuum pumps, gauges, and beam exit windows. The new designed scrapers and especially the new vacuum exit windows, consisting in titanium-foils with thickness down to 25 μm, were a good choice for improving the beam quality and all the pumps operating on the BTF were keeping the vacuum of both lines stable at 10^{-9} mbar.

Special care was necessary to isolate the PADME detector area. Here the vacuum is dynamically reached by a turbomolecular pump and (in principle) it is not compatible with the BTF sealed ionic vacuum. To have a protection in case of an unexpected vacuum vent, a safety system consisting of a static and a fast-reaction valve (operation time < 14ms) was installed. This system interlocks and stops a possible pressure increase in the BTF lines caused by any accidents. This vacuum structure has proven to be robust in matching the two different vacuums, resulting only in a slightly degraded vacuum limit in the last BTF1 section.

To realize the BTF2 line, ten new magnets were necessary: four dipoles, and six quadrupoles. For all, the design performance was reached within tolerances both for the integrated field and the multipole amplitude. The design and commissioning of the magnets was performed by the



Electrotechnics Engineer Service of the Accelerator Division. Power supply ripples below 200 ppm were measured during the duration tests. During these tests, the personnel of the Control System Service of the Accelerator Division verified the relatability of the magnets control system. The drivers of this software tool, fully nested in the main DAΦNE slow control system, were developed during the power supply construction in strong connection with the company that realized them. One of the most important tests was that of the splitting magnet DHPTB102. This is a special dipole able to ramp-up at 300 A in less than 100 ms.

The realization of BTF2 demanded the realization by the Fluid Plants and the Electrical Plants Services of the Technical Division of a new cooling pumping station of 160 kW with the corresponding routing of water pipelines and the installation of control sensors and interlocks. The new plant was timely powered up in 2020 for the technical commissioning of the magnets and the services.

The last phase of the technical commissioning of the two beamlines involved the Radioprotection Service and LINAC staff that performed safety system tests for both the experimental halls. In BTFEH1 the lack of free space imposed to redesign the hall preparation actions (search procedure). This is a defined sequence of operations that any human must do before exiting the hall and allowing the subsequent beam firing. This work was done by the LINAC Service while implementing BTFEH2 new safety system. Finally, to get the permission for starting the operation of the beam lines, a radioprotection test was performed. It consisted in firing a beam with a defined flux in both the areas towards a dump. The outside-wall radiation background was then checked by the Radioprotection Service.

Figure 4. Spot size at different beam energies measured at the exit of BTF2 line with the Timepix detector. On the left of the figure the detail of the detector positioning is also shown.

Before sending the beam along BTF2, a proper time was dedicated to set up the new BTF1 beam optics. After that, in few hours, the first beam was transported through BTF2. A Timepix detector, whose new holders were designed and produced by the Design and Mechanical Service of the Technical Division, was used to monitor the beam characteristics.

In just three days, secondary beams of different energies, bunch multiplicity and particle type (electrons/positrons) were successfully registered in the new experimental hall (see fig. 4).

The final design of the new beamlines was carefully studied to get the following beam parameters on both branches: ~ millimetric beam spot size and beam divergence less than 1 mrad at 500 MeV. The results obtained for the beam transverse parameters of BTF2 turned out to be better than in simulation. A sub-millimetric beam spot on both axes was measured even if with, as expected, a reduced multiplicity capability with respect to BTF1. At the BTF2 final window, it was obtained the best 450 MeV, single particle, gaussian-profiled beam: around 300 μm of sigma, on both axes.

EuPRAXIA included in the ESFRI roadmap

Figure 1. Rendering of the EuPRAXIA building that will be constructed at LNF.

After a long and thorough process of evaluation, the Board of ESFRI, the European Strategy Forum on Research Infrastructure that identifies large facilities on which is more profitable to invest at European level, has admitted the EuPRAXIA project in its 2021 roadmap update[1]. This is an important result that strengthens at European level the strategic value of the EuPRAXIA project of which the INFN is one leading institution. The main objectives of EuPRAXIA are extensively illustrated in the Conceptual Design Report[2], the outcome of a 3-million-euro Horizon 2020 grant that was provided to study the feasibility of a new generation particle accelerator plasma driven, capable of obtaining higher energies with reduced costs and dimensions.

One of the main challenges of constructing future accelerators, it is the possibility to reach higher energies to explore new territories. Presently, this ambition is questioned by many technological limitations, and scientists are investigating the possibility to develop new acceleration methods. The EuPRAXIA project relies on plasma acceleration techniques where an ionized gas, excited by a laser or a particle beam, is used as a mean to accelerate the electrons injected into it. This new approach promises to revolutionize the accelerator sector, not only enhancing their energy performance, but also making them more compact (at least 10 times smaller) and thus cheaper.

The capability to build accelerators with these characteristics would have an important impact not only in the field of high-energy particle physics. It would allow the construction of compact sources of X-ray laser radiation (free electron laser) useful in diagnostic imaging and in various industrial sectors and applied research. These sources will be used, for instance, to investigate the structure of bacteria and viruses, providing valuable information for the development of therapies and vaccines. The aim of EuPRAXIA is therefore to demonstrate the functionality of a plasma accelerator and at the same time create a free electron laser available for a wide international community. Once this technology would have been consolidated, the new machines will offer the prospect of being installed in small research centers such as university laboratories, hospitals, or industries.

The EuPRAXIA proposal was developed by a consortium of over 40 institutes from academia and industry of which 10 are from European countries (Italy, France, Germany,

1. https://www.esfri.eu/latest-esfri-news/new-ris-roadmap-2021
2. R.W. Assmann et al., EuPRAXIA Conceptual Design Report, Eur. Phys. J. Special Topics 229, 3675-4284 (2020)

Portugal, Poland, United Kingdom, Czech Republic, Sweden, Switzerland, Hungary).
Italy, with INFN's Frascati National Laboratory, will host the headquarter of this new research infrastructure and one of the two main experimentation centers (the second is still being defined). The commitment made by the Italian Minister of University and Research to host the infrastructure at the LNF and to start its construction with a financial contribution of 108 million euro, it is supported by the formal expressions of commitment, at the government level, of four other EU countries: United Kingdom, Portugal, Czech Republic, and Hungary. The overall cost of the project, with its various centers, has been estimated at around 500 million euro and its realization, expected by 2028, will involve hundreds of young scientists and engineers with distributed expertise in physics of plasmas, accelerators, lasers, and the most advanced technologies in the electronic and computer science.

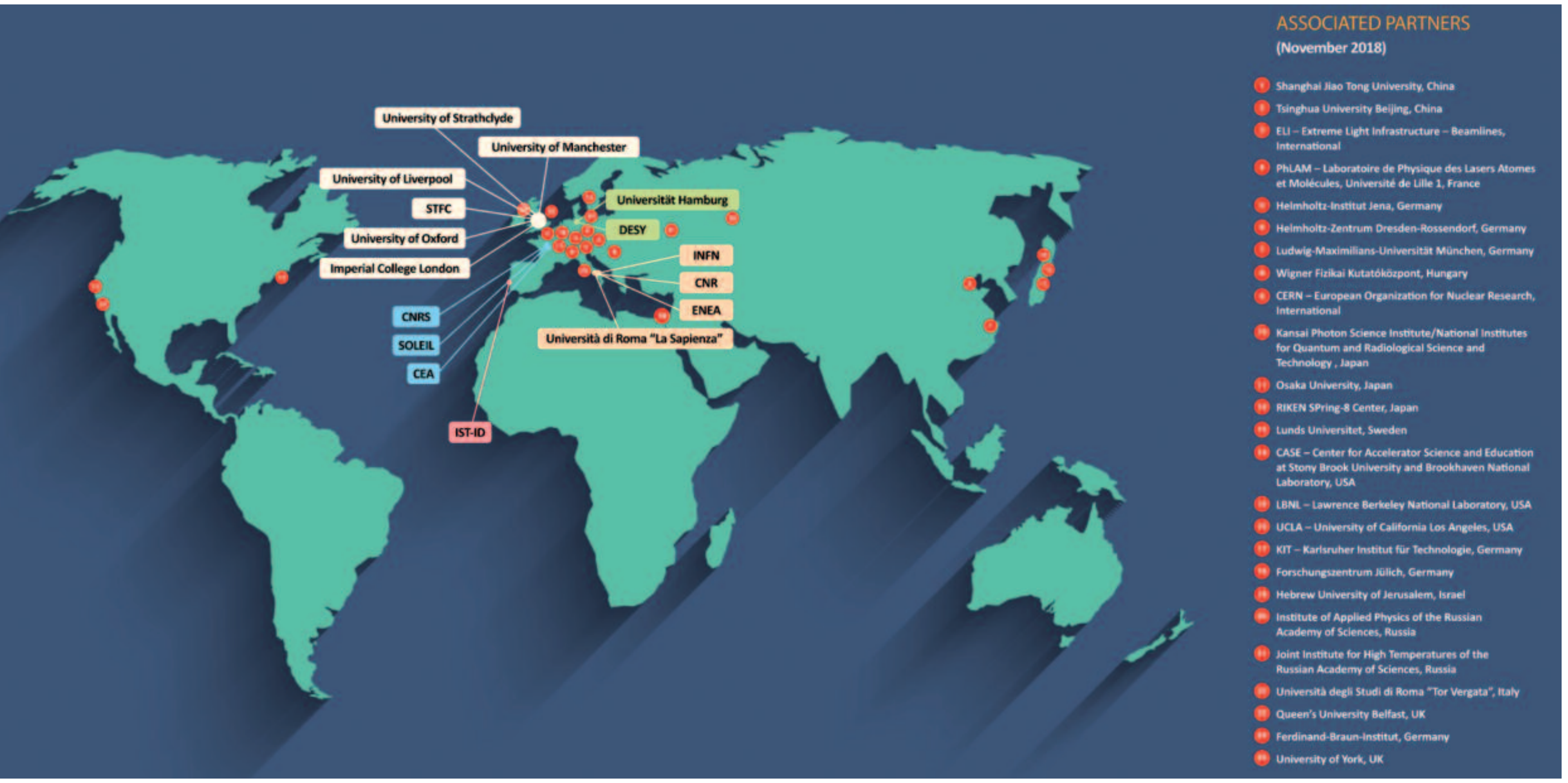


Figure 2. Members and associated partners of the EuPRAXIA Consortium.

Inauguration of the new TEX facility

As part of the preparatory activities of the EuPRAXIA@SPARC_LAB project, a high-power test-stand for X-band accelerating structures, called TEX ("TEst stand for X-band"), is currently under commissioning at LNF. The X-band (11.994 GHz) is at present the most advanced radiofrequency (RF) technology used in particle accelerators, having demonstrated capability of providing accelerating gradients up to 100 MV/m and beyond. This technology allows to achieve top level performances, but it requires great expertise in the RF design, fabrication techniques and conditioning procedures. Therefore, to get practice in this field, it has been decided to implement at LNF a new high-power test-stand.
To hosts the new facility, building 7 of LNF has been completely renovated and currently it houses: a plasma laboratory, an RF laboratory for accelerating structures tuning, a storage area, a control room, the modulator cage and the concrete bunker where the component tests will be performed. A meeting room has been also realized, to host on-site technical discussions. The building refurbishment, and the X-band source commissioning with all the necessary sub-systems, required the involvement of all the Services of the Accelerator and Technical Divisions of LNF, with the support of the Radioprotection and Safety groups. The facility will be mainly used for testing X-band prototypes, LINAC modules, radiofrequency components

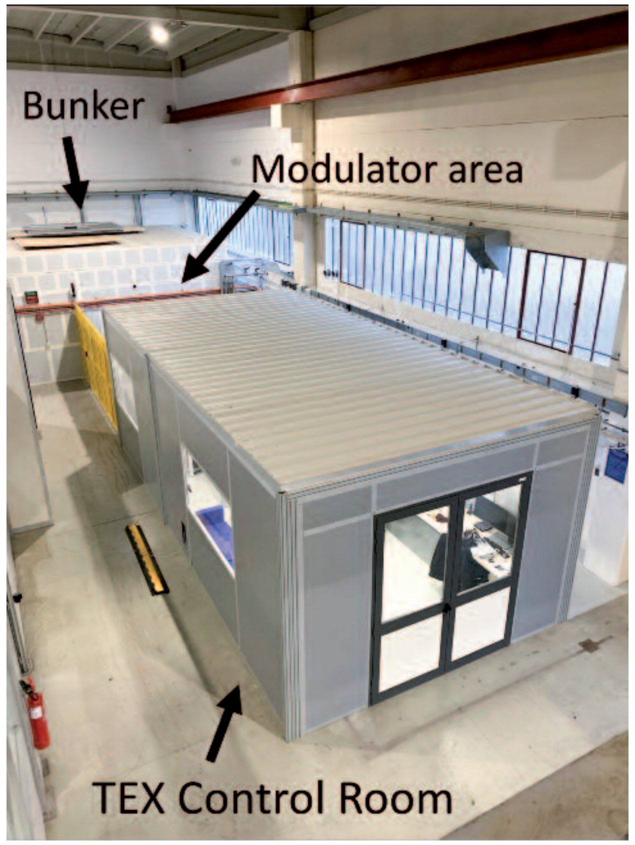


Figure 1.
View of the TEX facility.

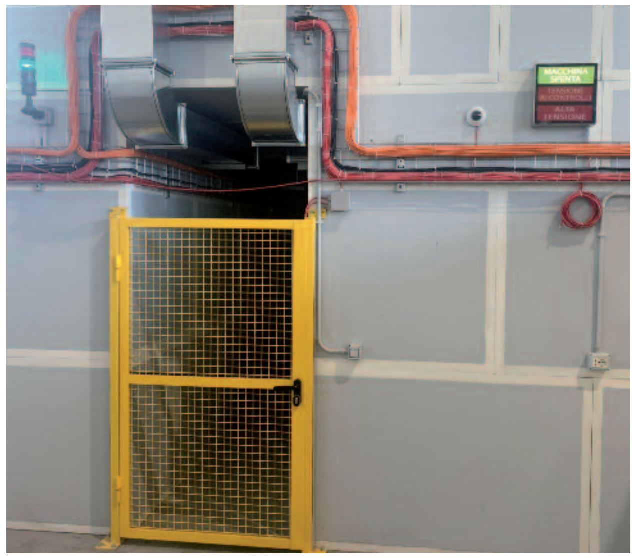


Figure 2.
Concrete shielded bunker.

Figure 3.
TEX Control Room.

and their sub-systems. Moreover, new conditioning procedures, dark current studies, beam diagnostics, high level applications and safety systems tests will also take place here. The facility (fig. 1) is conceived has an infrastructure opened to external national and international users, not only of the research world, but also of the industrial sectors. This is one of the services that INFN will offer to the external community throughout the LATINO project. This, funded by the regional government of Lazio, aimed at promoting and increasing the technology transfer from excellence research centres to the local industrial territory.

The X-band test-stand is based on a pulsed solid-state modulator feeding a klystron tube. The input RF pulse is generated by a Low-Level RF system (LLRF) and amplified to a power of more than 800 W by a commercial solid state driver amplifier realized by Microwave Amps. The first klystron that will be used is a CPI VKX8311A provided by CERN (fig. 5). This klystron can provide RF pulses with length up to 1.5 µs, with a peak output power up to 50 MW at a repetition rate of 50 Hz. The klystron is powered by a ScandiNova k400 solid state modulator designed to deliver pulses up to 450 kV, 335 A and 1.5 µs flat top length at 100 Hz repetition rate. In figure 4 the pulsed modulator in place and the X-band klystron during its installation are shown.

The solid-state technology of the pulsed modulator allows to reach a high stability of the output pulse with a high compactness of the overall system with respect to conventional line-type modulators. In fact, it requires only about 6 m^2 of footprints. In tab. 1 the main parameters of the power source are reported.

The power generated by the source is transported into a concrete bunker designed to test high-power RF components by a standard WR90 waveguide network. Five ion pumps with getters will ensure the ultra-high vacuum needed by the system. In a secondary phase, as part of the X-band waveguide component testing, a X-band BOC pulse compressor will be installed to increase the output power.

To drive the source, a commercial 2856 GHz Low-Level RF system (provided by Instrumentation Technologies) is used. This has been adapted with an Up/Down converter,

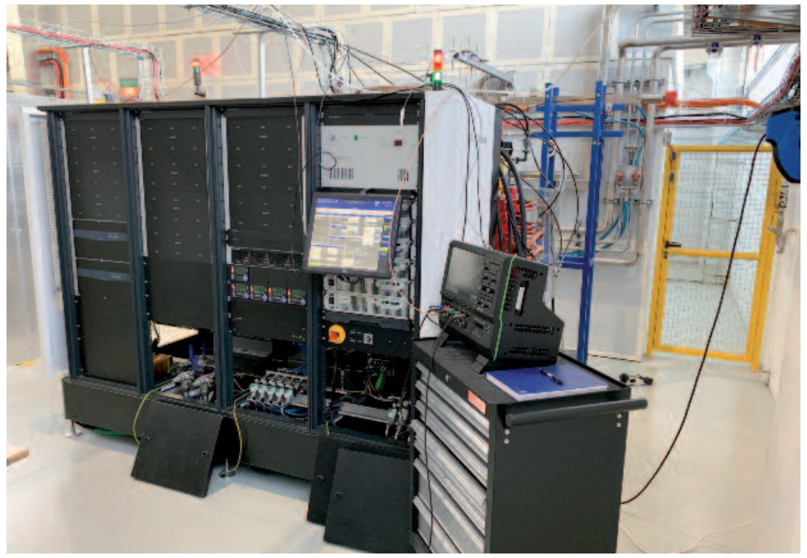


Figure 4. Solid state modulator installed near the TEX bunker.

Figure 5. VKX8311A klystron during the installation.

Parameter	Unit	Value
Frequency	GHz	11.994
RF Output Peak power	MW	50
RF pulse length	µs	1.5
Gain	dBm	48
Modulator Peak Power	MW	140
Operational Voltage Vk	kV	425
Operational Current Ik	A	325
PRF Range	Hz	1-50
Flat top flatness	%	< ±0.25
Pulse to pulse stability	ppm	< 50

Table 1.
TEX RF source parameters

developed at LNF, to work at 11.994 GHz.

The necessary civil engineering works, together with the procurement of the hardware components, were concluded by the end of August 2021 (fig. 2). Then, the commissioning of the source started with the modulator and the klystron installation. The site acceptance test of the modulator was concluded on 10 November 2021 and immediately after, the entire waveguide network layout was installed, as illustrated in fig. 6 (a, b, c).

At the same time, the commissioning of the control system, LLRF system and the test of the safety system were carried out. All the controllers of the vacuum pumps, gauges and LLRF system were installed in a conditioned area next to the TEX control room (see fig. 3).

Currently, the waveguide system is terminated on two RF loads and it will be tested with high-power RF to condition the entire setup at the maximum power. Subsequently, the first prototype of a X-band high-gradient accelerating structure, just arrived from CERN, will be installed, and tested. This structure, realized within the CLIC project, is shown in fig. 7.

Figure 6.
a) Waveguide layout terminated on two RF loads inside the bunker.
b) Waveguide layout system outside the concrete bunker.
c) Control system, Vacuum system and LLRF system installed in the rack room.

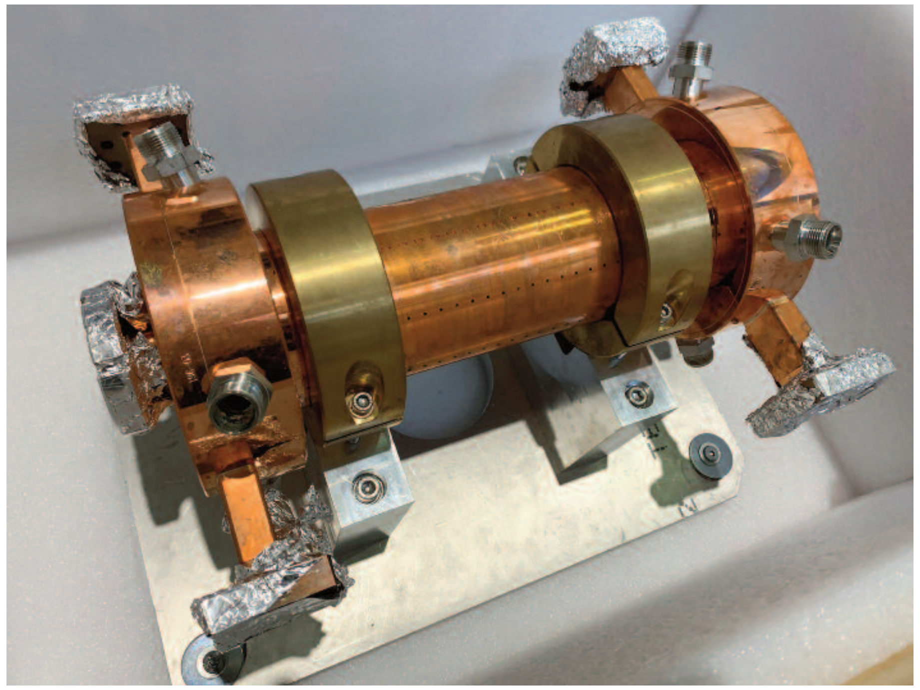


Figure 7. X-band accelerating structure prototype, for the CLIC project, provided by CERN.

Bruno Touschek memorial symposium

To celebrate the centenary of the birth of Bruno Touschek, the father of the first world electron-positron collider, a three-day memorial symposium (2 -4 Dec. 2021) was organized by the three main institutions where Touschek gave major scientific contributions: the Physics Department of Sapienza University of Rome, the Frascati National Laboratory of the INFN and the Accademia Nazionale dei Lincei. The meeting, was the occasion for eminent physicists – including the two Nobel laureates Carlo Rubbia and Giorgio Parisi – to celebrate his memory, his brilliant and multifaceted personality, as well as his legacy to the fields of theoretical physics and the development of particle accelerators

Touschek was born in Vienna, and like many of his contemporaries, he went through the dramatic period of World War II. Luckily, after that, he had the possibility to experience the enthusiasm and the excitement of the post-war reconstruction phase, contributing actively to the revival of fundamental physics in Europe.

Called at LNF by Giorgio Salvini for his expertise on the theory and functioning of accelerators, he rapidly became a reference point not only for the newborn laboratory, but also for the University of Rome Sapienza where he was first appointed as a lecturer and eventually became a full professor in 1978.

In 1960, Touschek suggested the idea of exploiting particle-antiparticle annihilations in the same accelerator as a fundamental tool for studying the basic building blocks of matter and their interactions. Under his guide, the first electron-positron collider AdA (Anello di Accumulazione) and then ADONE were built at the Frascati National Laboratory opening a new era in particle physics.

Parallelly to his work at LNF, Touschek mentored a new generation of theorists in Rome, including Nicola Cabibbo, one of the first students graduating with him, who went on to become a leading figure in the world physics. Touschek was also named member of the Accademia Nazionale dei Lincei in 1972, therefore the last day of the symposium took place at this premises. Here Giorgio Parisi, former student of Cabibbo, in his talk emphasized his academic descent from Touschek.

The rich Touschek's scientific legacy has been the subject of the three-day symposium, spanning a wide collection of topics of particle physics, accelerator science and its many applications and future perspectives, neutrino physics, multimessenger astronomy.

Figure 1. The official poster of the symposium, reproducing one of Touschek's funny drawing.

Side of the scientific aspects, during the symposium there was also room for memories and anecdotes on Touschek's life. Some personal ones were directly reported by Francis Touschek, Bruno's elder son, special guest with his wife during all three days of the event. At LNF, Francis Touschek was also the main actor in the ceremony that unveiled the official plaque that named the Visitor Center of the laboratory after his father. "This was an extremely touching moment", said Francis Touschek. "Not only for me but also for my wife. I've been extremely proud to have the opportunity to show to my family which great man my father was".

Figure 2. Francis Touschek remembering his father during the LNF day of the symposium.

LNF in numbers

The LNF personnel, at the end of 2021, consists of 302 units, including 25 with a fixed term contract, plus 225 associate members. Among these, there 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.
Researchers	69	0	69
Engineers	66	7	73
Administrative employees	37	5	42
Technicians	105	13	118
Tot.	277	25	302

Table 1. LNF personnel at December 2021.

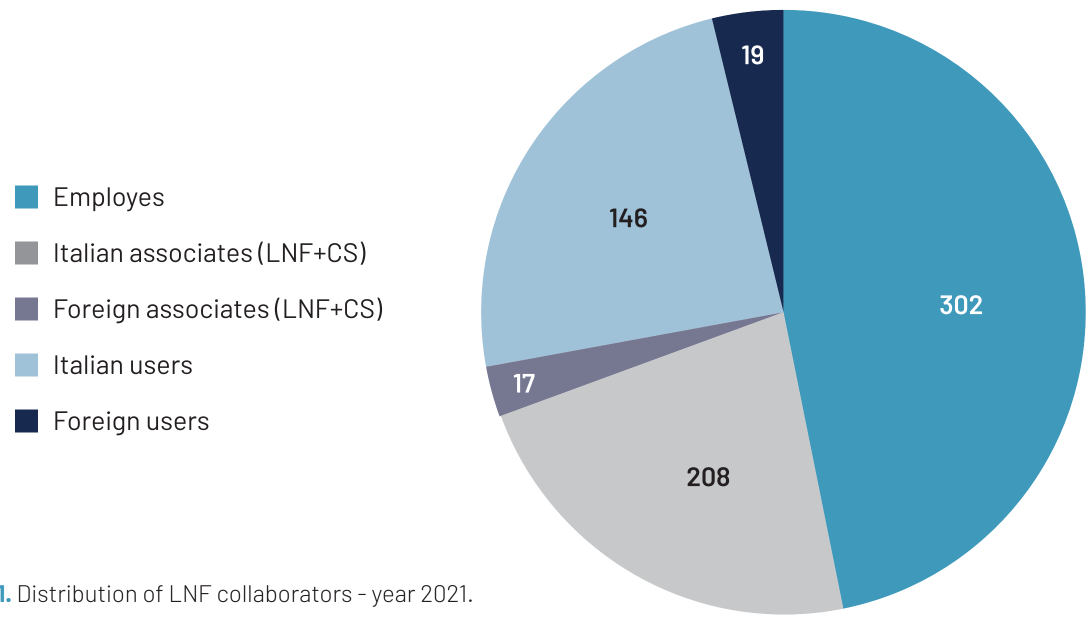


Figure 1. Distribution of LNF collaborators - year 2021.

LNF HIGHLIGHTS 2021

ONE YEAR OF RESEARCH AT LNF

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati