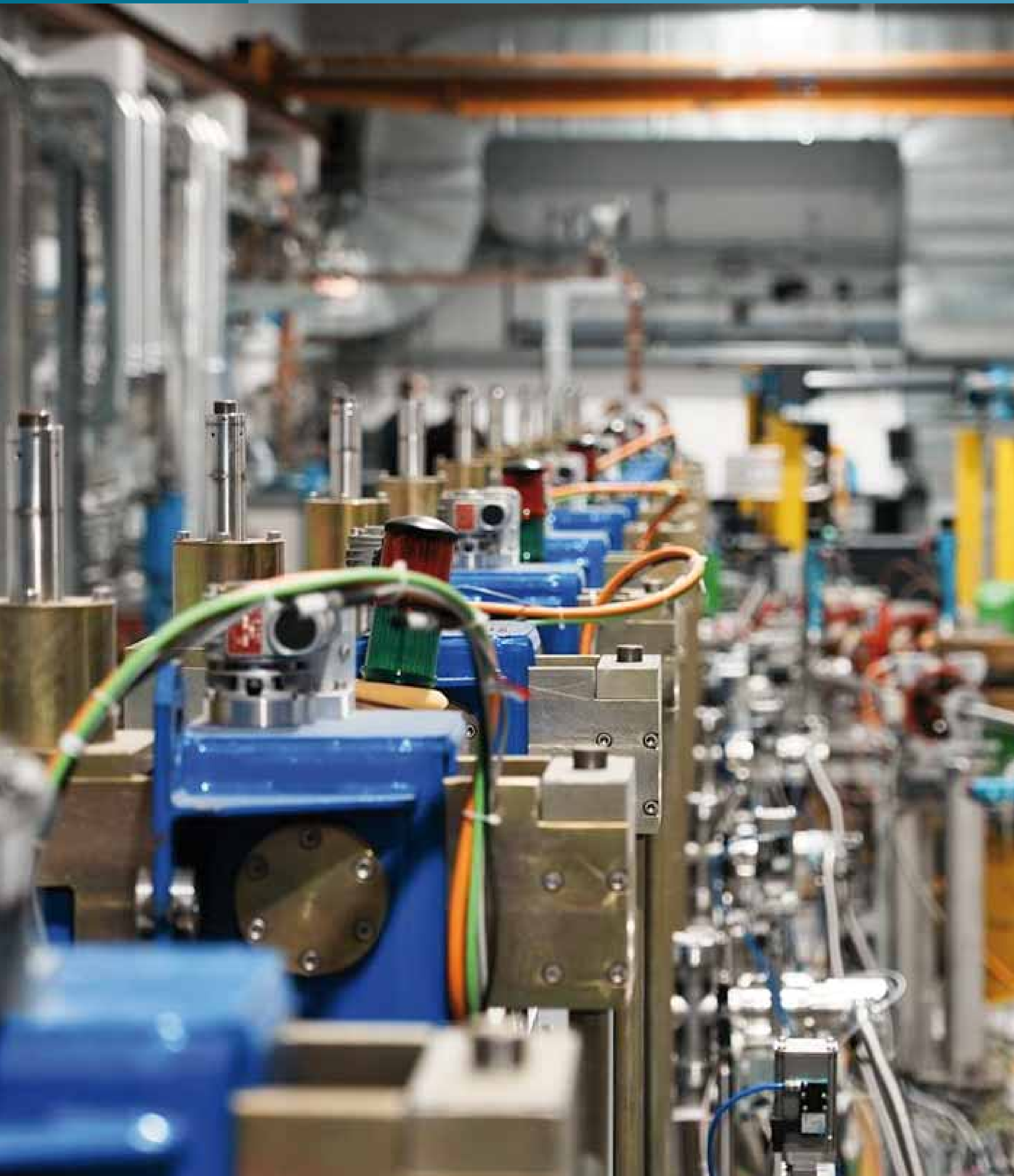
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

LNF HIGHLIGHTS 2020



INFN
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

2020 ONE YEAR OF RESEARCH AT LNF

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

LNF HIGHLIGHTS 2020 | ONE YEAR OF RESEARCH AT LNF

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Summary

Foreword

Year 2020 will be remembered as an exceptionally difficult year. The insurgence of the Covid-19 pandemics has changed the life of hundreds of millions of people all over the world. For several months we have been obliged to stay at home, and for many others to reduce our activities to the essential.

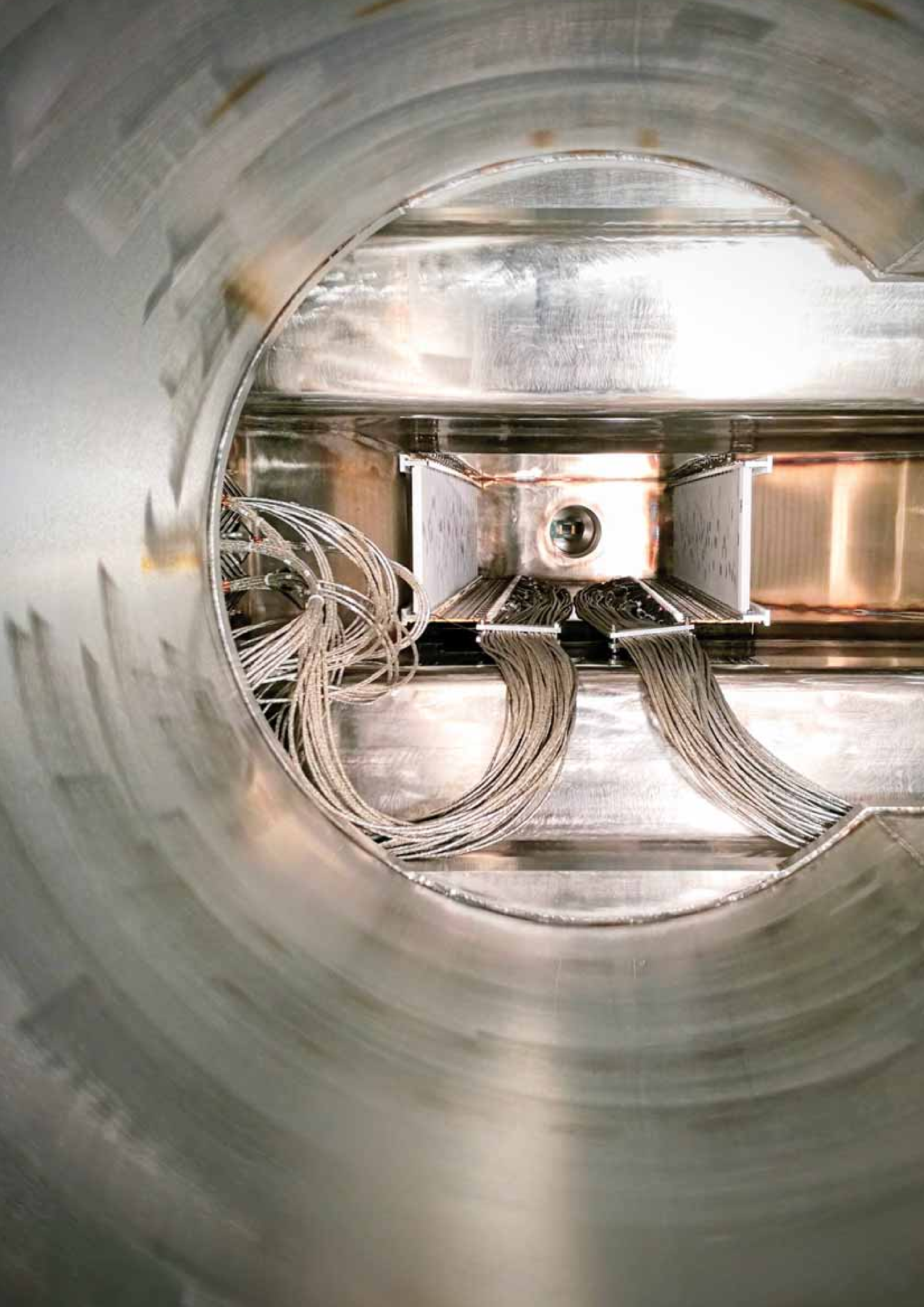
LNF is no exception. After the darkest days of March and April, however, we have learnt how to deal with the situation and to run the laboratory safely. A few programs had to be revised or delayed, many others have been completed successfully.

This issue of the LNF highlights reports, with pride, our achievements in these difficult times.
Our accelerators have been operated almost continuously during the second half of the year. The PADME experiment at the BTF facility has collected the promised amount of particles-on-target in due time. SPARC has obtained world-record results in the acceleration of electrons with a beam induced plasma.
The construction of new detectors for experiments at CERN has been finalized and, despite the travel restrictions, their installation on site has started successfully.

Outreach activities, which are one important pillar of the LNF mission, have been carried out making use of all the available internet platforms. We have been virtually visited by several thousand guests, researchers, students and ordinary people, a testimony of the wide interest around our science.

In December, we have dedicated a full day to remember Nicola Cabibbo, who started his scientific career at LNF, and who has always been close to the Laboratory and a driving force for its science. This event has virtually linked Frascati's glorious past with the bright future that we are trying to construct every day with enthusiasm and hard work.

Fabio Bossi
LNF Director



Searching for dark photons with PADME

On December the 2nd, the PADME collaboration completed its data taking session (Run II) at the Beam Test Facility.

PADME (Positron Annihilation into Dark Matter Experiment) is an experiment searching for dark matter candidates and in particular a dark photon. To justify the cosmological evidence of other forms of matter producing gravitational effects, but feebly interacting via other forces, some theoretical models postulate the existence of a force bridging our world with that of dark matter[1]. This new "fifth force" would be associated to a mediator particle, named dark photon, similar to the ordinary photon, mediator of the electromagnetic force, but with a non-zero mass.

Dark photons could be produced in the PADME detector, following the annihilation of positrons, created and accelerated by the LNF LINAC, with the electrons of a thin diamond target (1/10 mm thick).

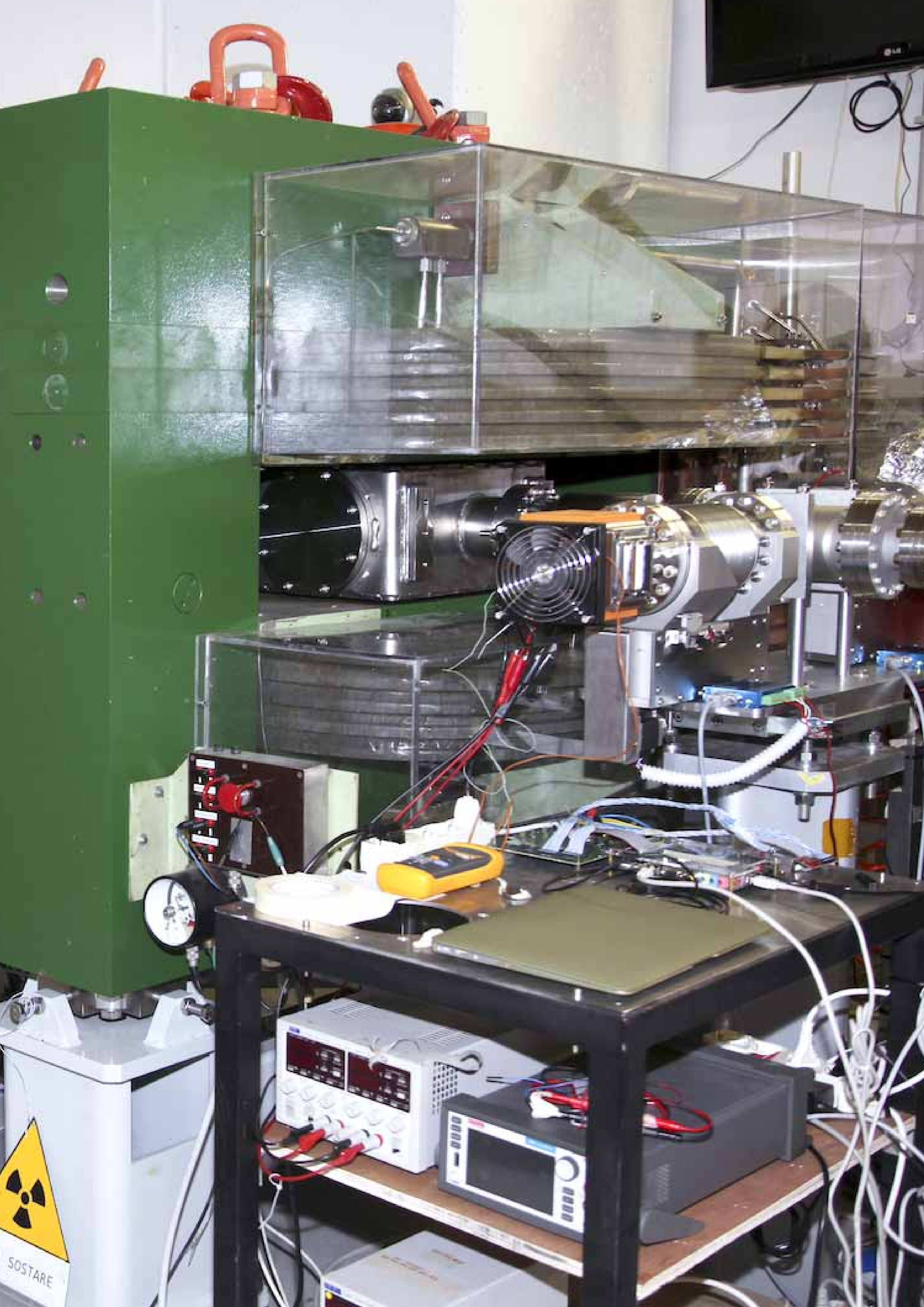
After a Summer devoted to beam optimization studies, from the 15th of September roughly 5×10^{12} positrons impinged on the diamond target. Most of them passed through the target without interacting, whereas only few intercepted an electron of carbon atoms producing secondary particles (electrons, positrons and photons). The dark photon could hide in these interactions.

The analysis of the collected data is now ongoing and will shed light on the evidence (or exclusion) of dark photons existence at these energies. More in detail, data will allow to define constraints on the dark photon mass and on its capability to interact with the known particles and forces. The maximum energy of the positron beam available at LNF is 550 MeV giving the opportunity to explore masses of the dark photon below 23.7 MeV/c^2.

Run II results will enrich the data set available in the scientific community. At present, in this

1. B. Holdom, Phys. Lett. 166B, 196 (1986)

Figure 1. The PADME detector installed on the beam-line 1 of BTF.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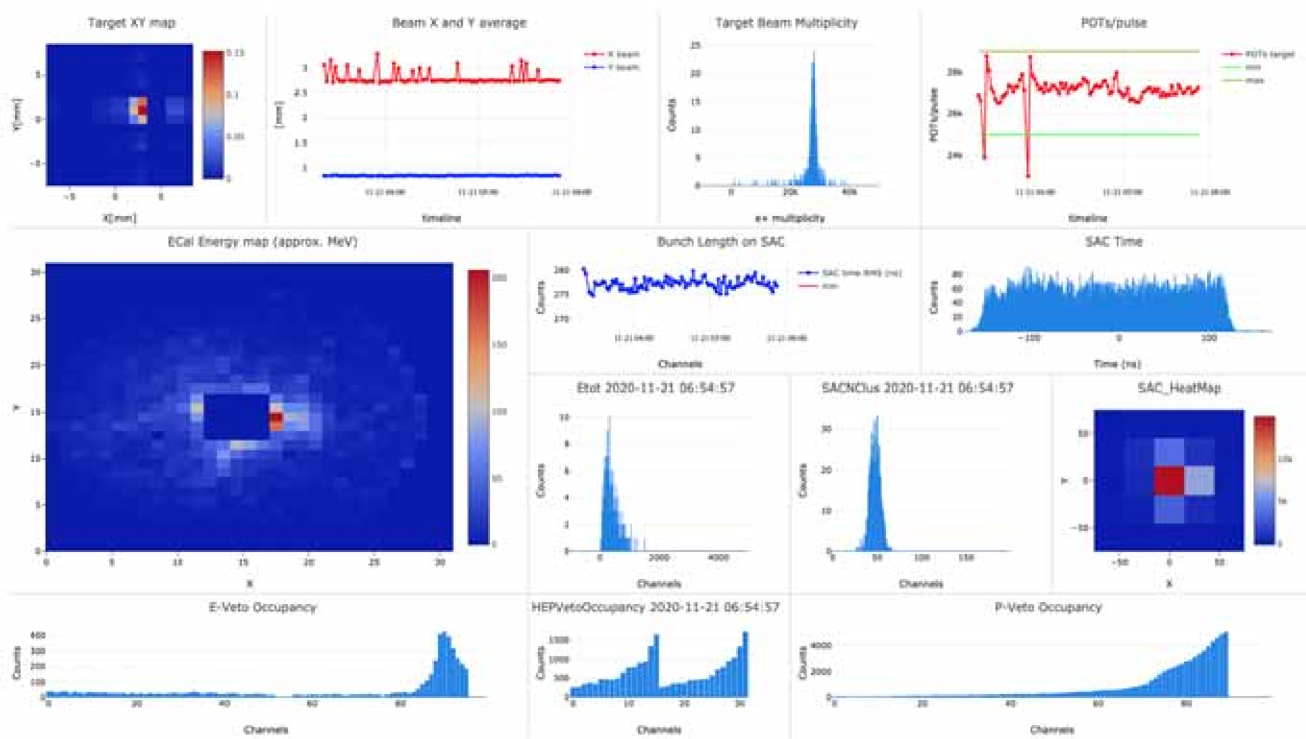


energy range, the only available data have been collected by other experiments with alternative methods such as electron-positron beams collision, dump experiments, and mesons decays. Furthermore, the data analysis will also provide precious information related to another field of research: quantum electrodynamics (QED). In fact, as mentioned before, the collisions between electrons and positrons, produce final states populated by 2 or 3 photons. These processes are known and studied in a theoretical framework but either no data exist at PADME energies or are very scarce. The data of Run II will be precious for the comprehension of these processes in an unexplored regime.

The PADME data taking could be performed thanks to an efficient organization of the laboratory personnel and of the researchers of the collaboration. In particular, PADME collaborators invested resources in the development of remote-control tools for the experiment, allowing to minimize the number of people present on-site in the experiment Control Room. This solution not only helped in complying with the rules of social distancing but also offered the possibility to the researchers of external groups, to participate to the data taking.

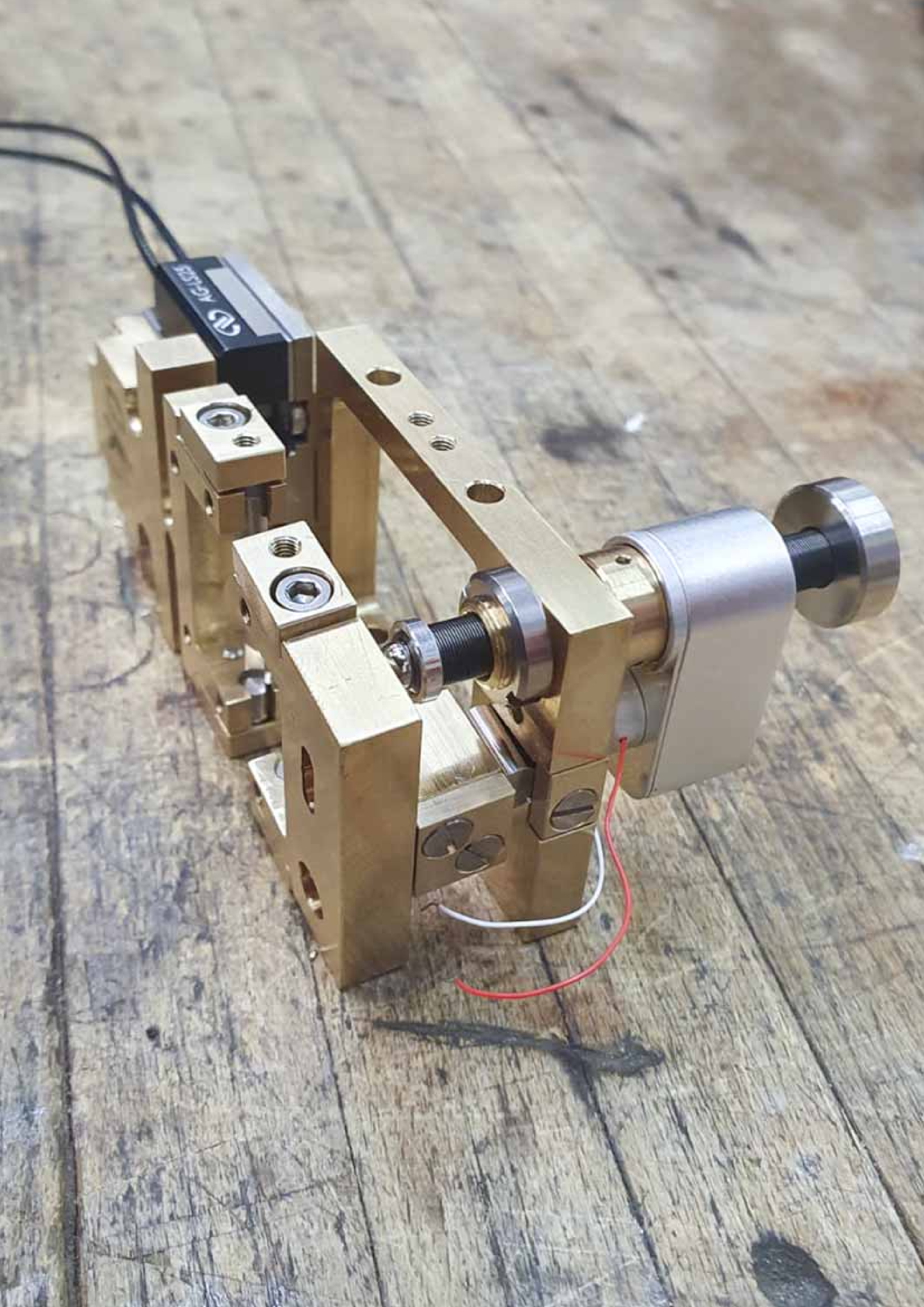
PADME is an international collaboration. It is composed of researchers from LNF, INFN Lecce unit, INFN Torino unit and Politecnico di Torino, INFN Roma 1 e Roma 2 units, University of Sofia, MTA Atomki of Debrecen, Cornell University and College of William and Mary of

Figure 2. The screenshot of the web page showing relevant plots of subdetectors performance during Run2 data taking.

Williamsburg in the USA. With the impossibility to travel, this new way of cooperation allows to keep alive the research activity.

The hunt for dark matter at LNF is not yet over. The collaboration is already looking to the future of PADME with a project that will exploit the possibility of having a more intense positron beam, extracted from one of the DAΦNE ring.

Figure 3. Some of the PADME collaborators standing for a picture in Summer 2020.



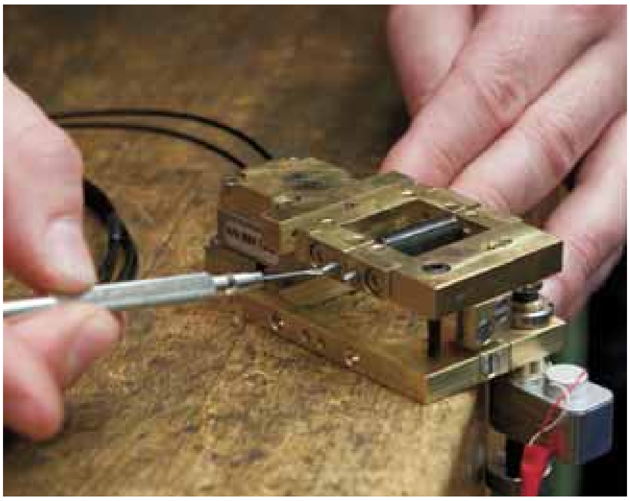
SHERPA: Slow High-efficiency Extraction from Ring Positron Accelerator

SHERPA (Slow High-efficiency Extraction from Ring Positron Accelerator) is the name of a project, that received a two-years (2020-2022) grant by the fifth scientific commission of INFN, to study novel techniques for positrons extraction from the DAΦNE collider complex. The final goal is to set up a new beam-line able to deliver positron spills of milliseconds duration with excellent emittance and energy spread allowing a strong decrease of the background and of the pile-up generated by normal bunched beams.

The most common approach to slowly extract particles from a ring, it is performed increasing the beam betatron oscillations approaching a tune resonance. This is obtained applying a proper sextupole configuration to reach an unstable region of the phase space in one of the transverse planes. In this way, particles slowly approaching the unstable resonant frequency characterised by the extraction separatirx, are gradually ejected from the circulating beam.

SHERPA proposes a cheaper and less bulky solution[1] that uses coherent processes in bent crystals to steer positrons from the ring. This non-resonant technique, already successfully used mainly in hadron accelerators, will provide a continuous multi-turn extraction with high-efficiency. Realizing this for sub-GeV leptons is challenging and will represent the first positron beam obtained with crystal extraction.

1. M. Biryukov et al., "Crystal channeling and its application at high-energy accelerators", Springer Science Business Media (1997) ISBN: 9783642082382.



sub-GeV electrons have been deflected by ultrathin crystals with promising results at the MAMI and SAGA accelerators. At the DAΦNE Beam Test Facility (BTF), an attempt to deflected positrons using crystals has been done, proving the proof of concept of this idea[2-3].

The first beneficiary of this new extracted beam could be the PADME experiment, currently strongly limited by the lengths of the positron pulses of the BTF that cannot be increased more than few hundreds of nanoseconds.

The SHERPA experiment, led by a young researcher that worked in his early career at CERN, for its subject and its high technological content, requires the know-how of researchers from all the LNF divisions: research, accelerator, and technical ones.

2. S. Bellucci et al., "Deflection of a 100-MeV positron beam by repeated reflections in thin crystals", JETP Lett. 98 (2014), 649-651.

3. S. Bellucci et al., "Using a deformed crystal for bending a sub-GeV positron beam", Nucl. Instrum. Meth. B 252 (2006), 3-6.

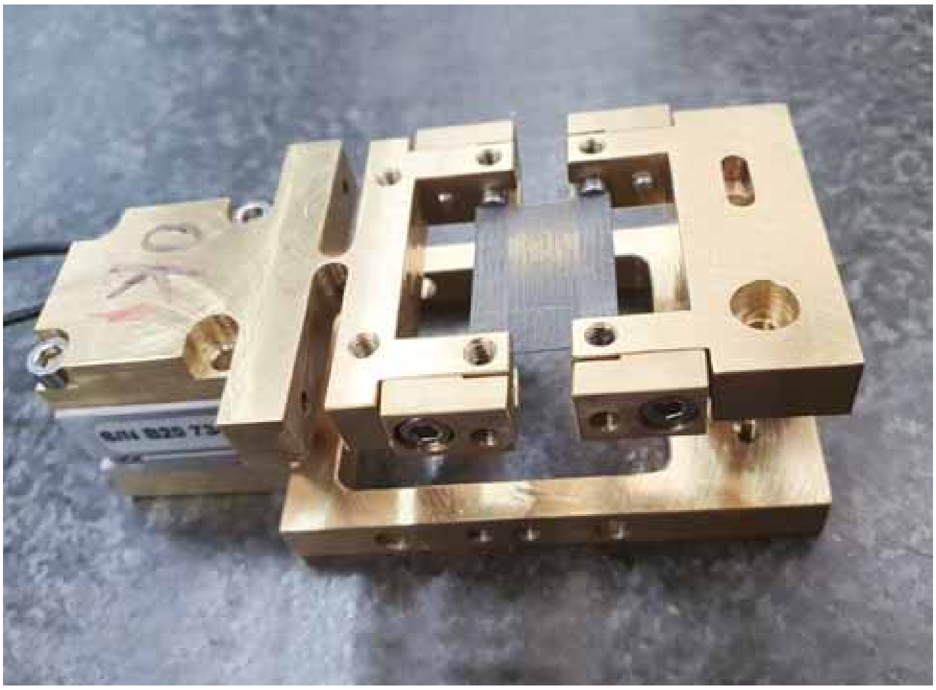


Figure 1. The mechanical holder of the bent Silicon crystal of the SHERPA project.

During these two years, the work program of the formed collaboration foresees:

- the study of the possible optical configurations of the DAΦNE complex that allow crystal slow extraction of positrons;
- the design and construction of a crystal prototype with the characteristics necessary for the slow extraction;
- the realization of an experimental apparatus for the crystal characterisation at the BTF;
- the crystal prototype characterization with the beam.

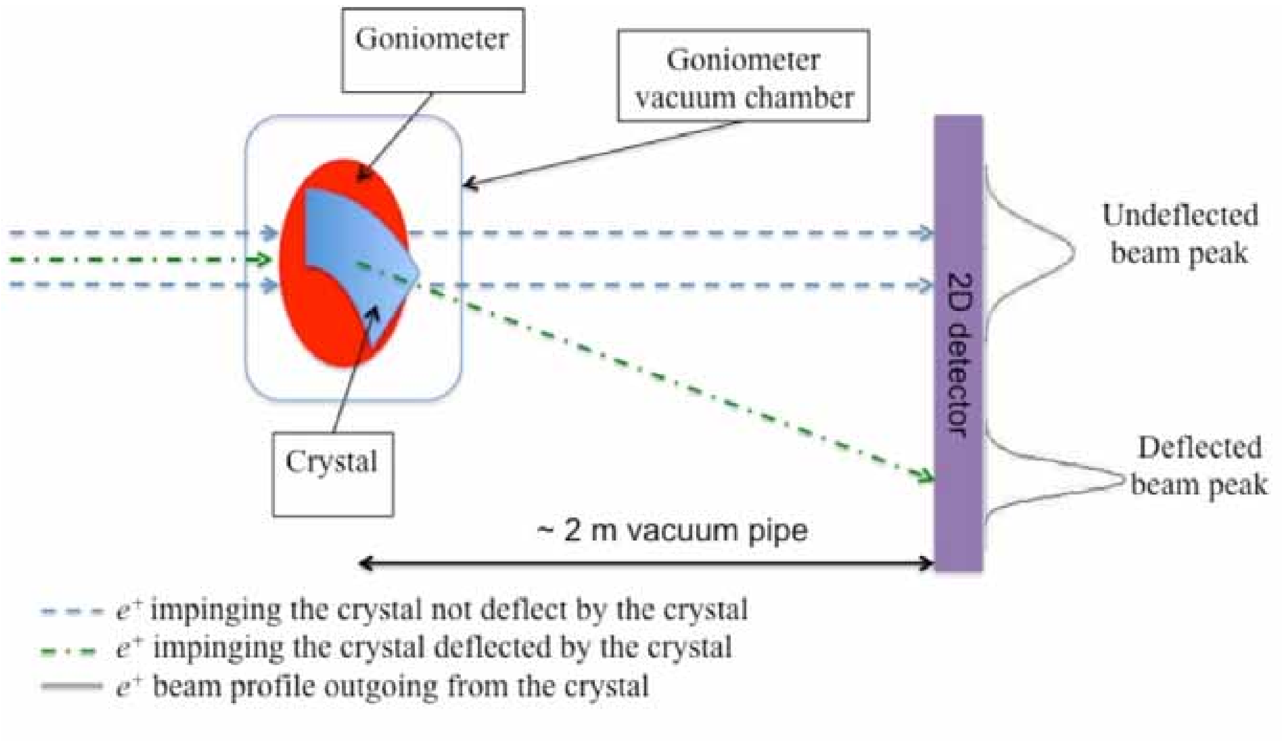
For the first item of the list, two possibilities are under study: extraction of positrons from the DAΦNE main rings or the use of the damping ring. The main ring solution could be more efficient as it allows the usage of numerous devices (quadrupoles, kickers, beam monitors, sextupoles, etc.) to manage and control the beam parameters. On the other hand, this option requires greater efforts in terms of know-how, manpower and costs of operation. The damping ring solution is instead more simple and cheaper, but harder to be optimized due to the lower adaptability and tuneability of the damping machine.
In 2020, both solutions have been preliminarily investigated by the SHERPA team, obtaining promising results. In both cases minimal modifications to the present main and damping ring hardware configurations will be necessary.

The simulation work performed, aimed at tracking particles trajectories in order to optimize

the crystal extraction parameters: angular deflection range needed, crystal longitudinal and transversal positions, transversal displacement range at the extraction point, longitudinal position and geometry of the extraction septum.
The design and construction of the bent crystal is performed in cooperation with the colleagues of the INFN unit of Ferrara. The most used material is single crystal Silicon thanks to its high purity (99.99995 %) and low dislocations number (< 1 cm^2). This material is easily available from semiconductor companies.

To steer by channeling sub-GeV leptons, is more challenging compared to the case of high energy hadrons. In fact, it is necessary to reduce the thickness of the bent crystal to limit electronic dechanneling (the effect whereby the particles exit the atomic channel due to the interaction with the atomic electrons). To obtain a reasonable channeling efficiency, it is necessary to reduce the thickness of the crystal to tens of μm, pushing at the technological limit the bending capability avoiding breaking and disuniformity.
At present, 25 samples of Silicon are under preparation at an American company site, while the delicate step to reduce the thickness down to ~15 μm will be carried out in the INFN-Ferrara laboratories.

When the ~15 μm foils will be ready, they will be glued on a special support and mounted on a



dedicated active holder able to impart the chosen curvature to the crystal. The holder is an extremely sophisticated mechanical object. A picture of the first prototype, realized by the LNF mechanical workshop, is shown in fig. 1.

The holder is active and, thanks to two dedicated piezo-motors, is able to bend the crystal with a very high precision.

The final curvature will be measured using an optical diffractometry techniques, before preforming the tests on the BTF beam.

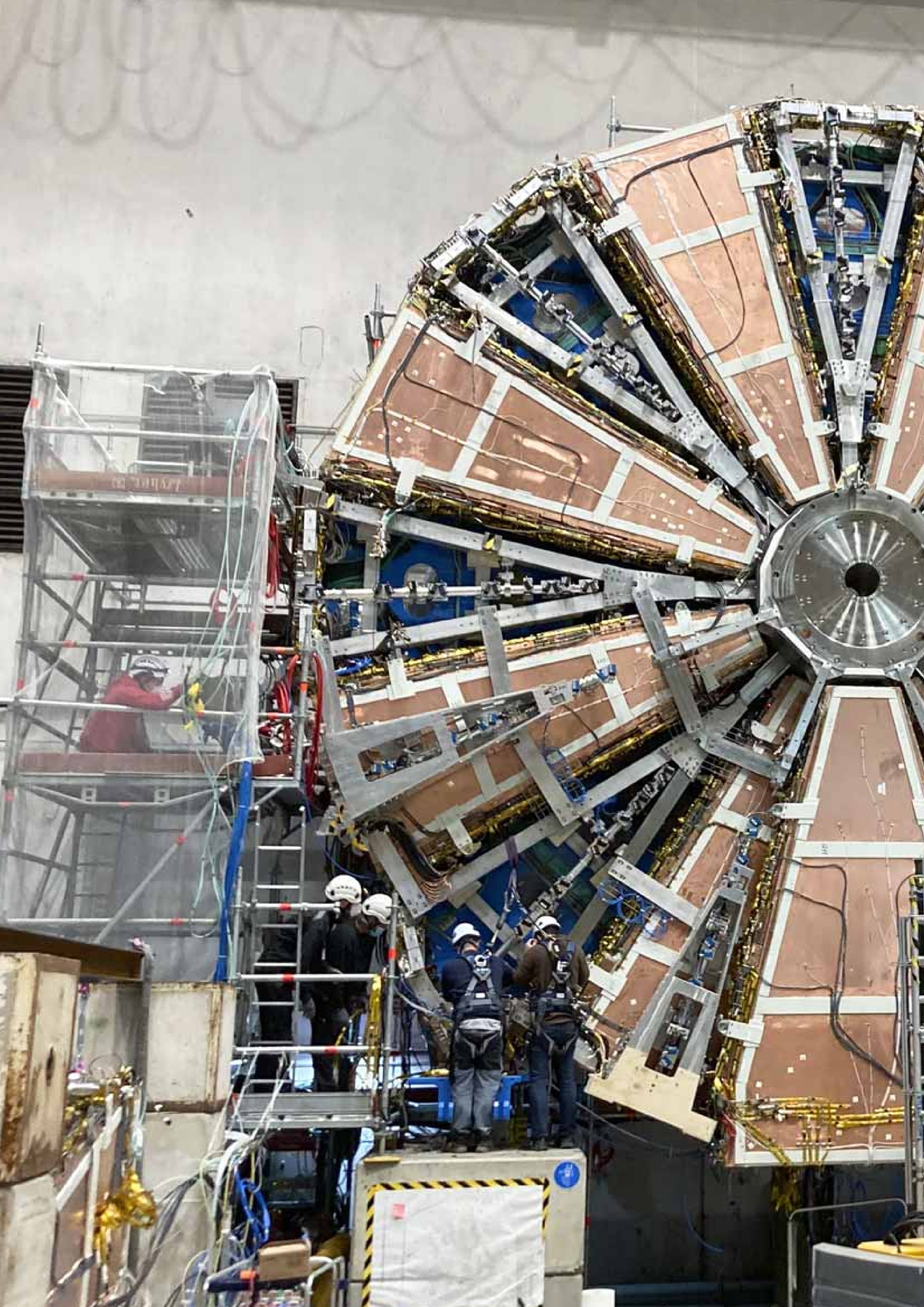
To measure the crystal deflection angle and its efficiency, an experimental apparatus composed of three main parts will be used. These are the movimentation system to orient the crystal (goniometer), a 2D pixel-detector, to measure the deflected particles with respect to the incomings, and the vacuum chambers containing all the above-mentioned devices. These later are necessary to reduce the effects of the particles multiple scattering due to air that, at these energies, would spoil the channeling capabilities. A scheme of the basic experimental setup of SHERPA at the BTF is shown in fig. 2.

The design of the vacuum chambers has been realized by the vacuum group of the accelerator division and are now under construction at external firms.

For the goniometer, a commercial device was bought, while for the tracking system three different detectors are under study: the first is based on MIMOSA sensor, used in the PADME experiment, the second on the ALPIDE chip, developed for the ALICE experiment, and the third rely on TimePix3 device, developed by the ADVACAM company. This last one, at present, is the best candidate to be used for the first measurements at BTF in 2021 and two detectors (100 and 300 mμ thick) are at LNF for preliminary tests.

The success of the SHERPA project will demonstrate, for the first time, the possibility to use thin bent crystals to deflect and slowly extract sub-GeV positron spills. This will open the possibility to manage positrons accumulated, and eventually accelerated, in a storage ring. Moreover, the study of positron beam steering using bent crystals will provide a know-how that could be applied, in the future, for several operations at accelerating machines such as collimation, extraction and beam splitting, providing a valuable contribution to the particle acceleration field.

Figure 2. A scheme of the apparatus that will be used by SHERPA to study the channeling effect of a bent-crystal using the positron BTF beam.



The ATLAS MicroMegas detectors

The Large Hadron Collider (LHC), the largest and most powerful particle collider in the world, is at present in a maintenance phase (Long Shutdown 2 - LS2) in order to allow interventions to increase the particle collision rate.

At the same time, also the four detectors: ATLAS, CMS, LHCb and ALICE, installed on its interaction points, are undergoing major upgrade processes to be able to exploit at best the potentiated accelerator.

For the ATLAS experiment the major upgrade of the Muon Spectrometer is given by the New Small Wheel project, a new generation of muon detectors capable of operating in a flux of collisions approximately ten times larger compared to Run2 condition. In particular, to realize this project, two complementary new technologies have been chosen: small-strip Thin Gap chambers optimized for triggering, and MicroMegas detectors designed for precision tracking.

MicroMegas are gas detectors in which a 5 mm gap between two parallel electrodes is filled with a Ar:CO2 gas mixture (93:7) and a thin metallic micromesh is placed between the two electrodes, held by pillars with a pitch of few millimeters and a height of about 128 μm (see fig. 1).

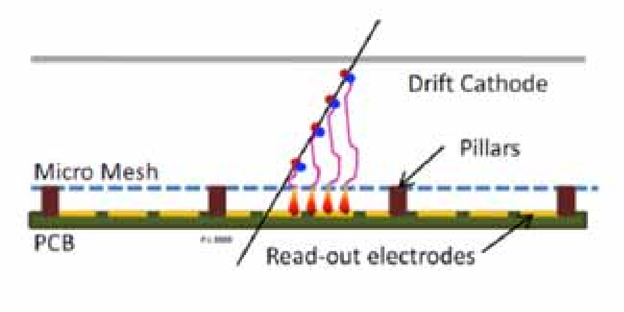


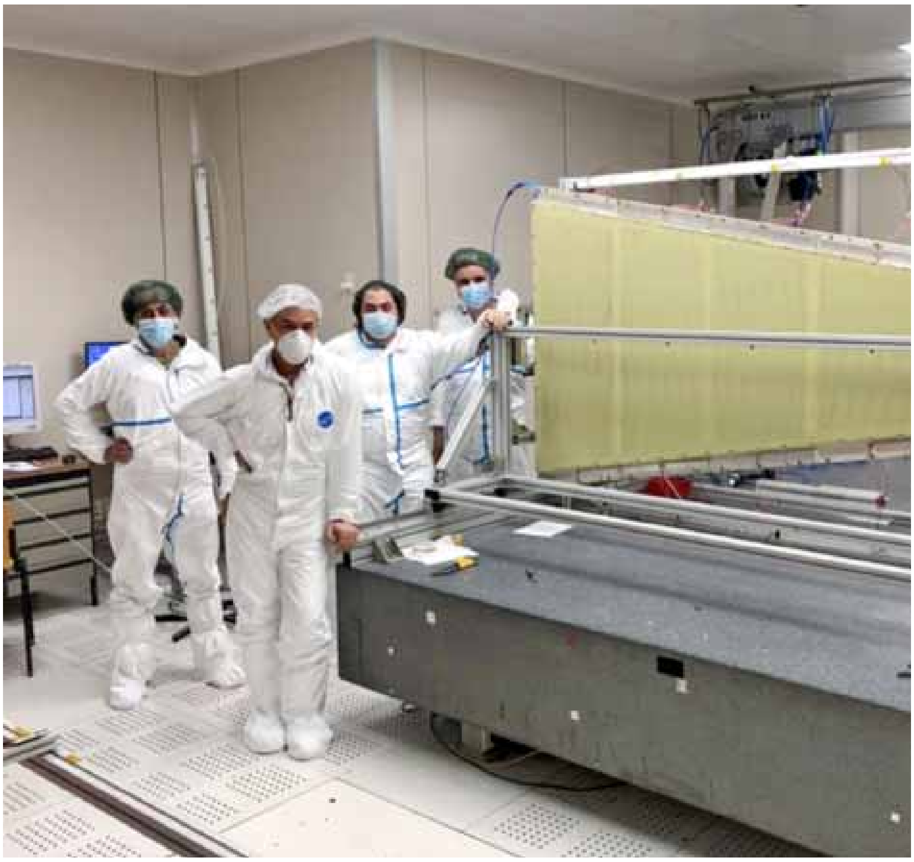
Figure 1. Schematic layout of a Micromegas detector.

The drift electrode, with a 300 V voltage applied, and the mesh, which is grounded, define the drift region, where the ionization takes place, and the low electric field (~600 V/cm) leads the produced electrons towards the mesh. Following the field lines, the electrons enter the very thin amplification region between the mesh and the read-out electrode, which is segmented into strips (with a pitch of about 400 μm), where a ~ 600 V voltage is applied. Due to the very high electric field (40 - 50 kV/cm) the electrons produce avalanches with a gain of the order of 10^4. The thin amplification gap allows a fast ions evacuation, which occurs in about 100 ns, and allows Micromegas to operate in highly irradiated environments. These chambers are designed to provide a space resolution of about 100 μm and a tracking efficiency better than 95% per single plane.

The Italian collaboration, led by the Frascati group, has been extremely important for the realization of these detectors, taking care for the optimization of the critical elements and developing solutions to improve their functionality and operation.

Seven different INFN groups were involved to realize overall 33 chambers. The construction work took several years and ended in October 2020. Now all Micromegas detectors are at CERN, under test with cosmic muons, waiting for being inserted in the ATLAS spectrometer.

Figure 2. Some members of the Frascati ATLAS group during the construction of the last MicroMegas chamber.



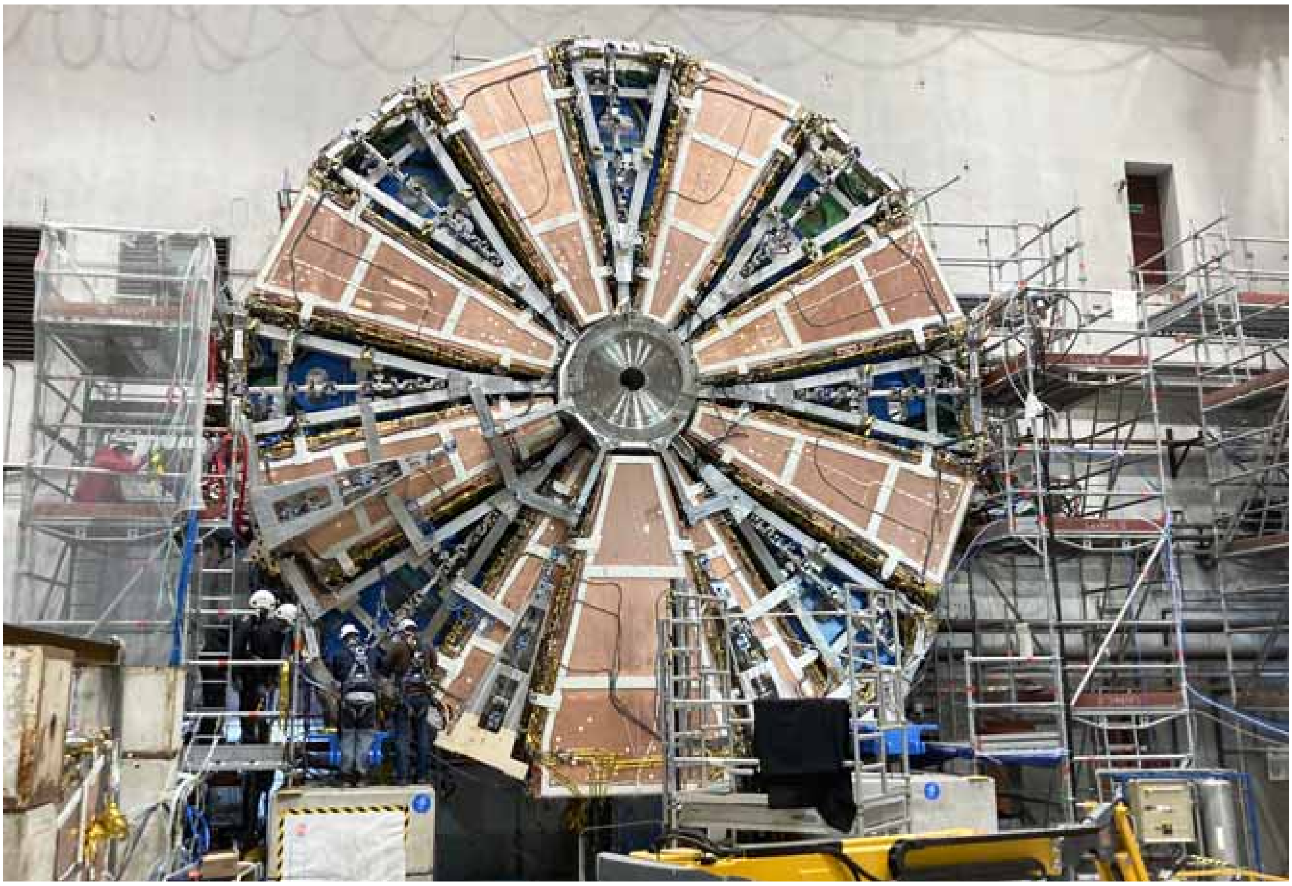


Figure 3. The assembly at CERN of one New Small Wheel.

Figure 2 shows some members of the LNF ATLAS group during the construction of the last MicroMegas. They are dressed in coveralls and they wear protective masks, because the construction work must be conducted in a perfectly clean ambience. In fact, any speck of dust that could be present on the electrodes, could be source of unwanted discharge phenomena which in the end could jeopardize the chamber performance. Therefore, the assembly work takes place in a cleanroom: a special ambience where air is continuously filtered to keep the level of dust below a minimum value. Like a surgical squad, people working in cleanrooms must be properly dressed in order not to contaminate the environment. Furthermore, all the chamber components must undergo an extreme cleaning procedure before being assembled.

Several groups in other countries (France, Germany, Russia), also participating to the project, implemented the solutions developed in Italy to complete their fraction of chambers production.
The ATLAS collaboration, to be able to stand the increased LHC luminosity, selected for the upgrade of the innermost end-cap muon stations the novel Micromegas technology. The instrumented area covered by Micromegas at the New Small Wheels is unprecedented ~1280 m^2 corresponding to around 2.1 million channels to be readout (see fig. 3).

From the construction of the chambers to the qualification of the sectors for the wheels, a great deal of work was necessary in a systematic way, with a high level of accuracy in every step. Many challenging issues and interesting problems appeared, and they have been solved thanks to a professional teamwork that spanned over different countries. The LNF ATLAS team contributed to this effort considerably and the professional and technical skills developed, now are available for other future challenging projects.

High quality electron beams generated with plasma experiment

The development of new techniques for particle's acceleration, able to provide high gradients within smaller spaces, is of paramount importance for the development of future machines. During 2020, the researchers of the SPARC_LAB group continued to do forefront researches in this field and were able to successfully accelerate a high-quality electron beam, using the innovative technique of plasma acceleration. The experiment highlighted, for the first time, the possibility to reduce the energy spread during acceleration and this important result has been documented in a paper published on the prestigious scientific journal Nature Physics[1].

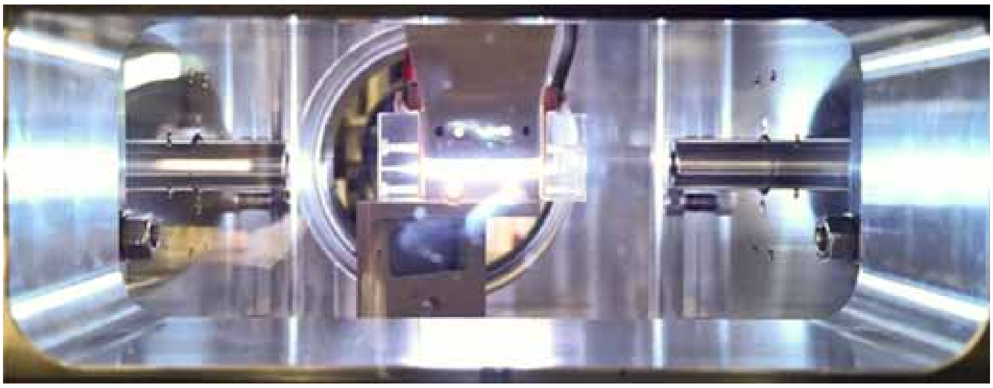


Figure 1. Discharge capillary used in the experiment and installed in the SPARC_LAB interaction vacuum chamber.

1. R. Pompili et al., "Energy spread minimization in a beam-driven plasma wakefield accelerator", Nature Phys. 17 (2021) 4, 499-503.

Figure 2. The SPARC photo-injector where a laser pulse, hitting a metallic cathode, provides the source for the electron beam.

The acceleration of an electron bunch was obtained by imprinting a positive energy-chirp on the beam (particles in the head with larger energies than those on the tail) before it enters into the plasma. By doing so it is possible to pre-compensate the energy spread induced by the plasma itself thus giving the possibility to minimize it at the exit.

The experiment was carried out with the SPARC photo-injector (see fig. 2), that generated and pre-accelerated two distinct electron bunches, driver and witness. Using a 3 cm-long capillary containing hydrogen gas, ionized in plasma by a high voltage discharge (fig. 1), accelerating fields of the order of 230 MV/m were generated by the driver and used to accelerate the witness. Figure 3 shows the two bunches at the plasma exit measured through a magnetic spectrometer. Witness and driver initially had the same energy of about 89 MeV. The plasma density was set to 2×10^{15} cm^{-3} during the experiment. In such a way, by positioning the witness about 1 picosecond after the driver, it was possible to exploit the accelerating field produced in the plasma by the driver itself.

The complexity of the experiment is remarkably, above all considering the dimensions that are involved. The two bunches have sizes of few tens of microns and must be placed in the plasma with precision of the order of microns. This advancement in the generation of high-quality

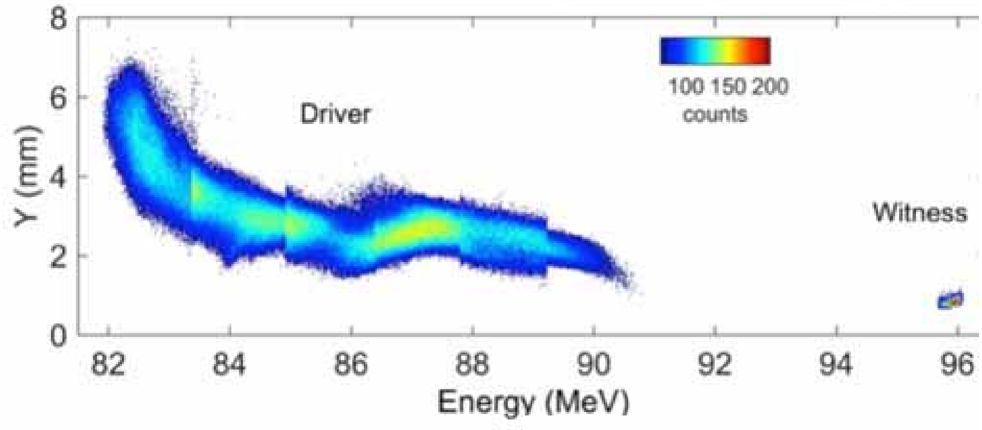


Figure 3. Driver (left) and witness (right) after acceleration in 3 cm of plasma. The two bunches had the same energy of 89 MeV before entering into the plasma.

beams is of paramount importance because it makes the accelerated beam really “usable” for applications such as Free-Electron Lasers (FEL). For that reason, a pilot experiment is currently in progress at SPARC_LAB with the aim to inject the plasma accelerated witness into the undulators to obtain FEL radiation emission.

The published manuscript also describes how the same method can be scaled to larger energies and different configurations, such as the future user-facility of EuPRAXIA@SPARC_LAB.

EuPRAXIA@SPARC_LAB represents another step toward the realization of the EuPRAXIA project that, in February 2020, was granted by 108 M€ by the Italian Ministry of University and Research for the implementation of the preparatory phase. EuPRAXIA will be a European facility dedicated to the development of a FEL based on plasma acceleration, besides being equipped with a linear accelerator with high gradient “X-band” advanced technology.

The international community involved in this enterprise includes more than forty institutes across Europe plus observers from all over the world. The LNF has been identified by this collaboration as the headquarter of the project, thanks also to the strong commitment of the Italian Government that indicated EuPRAXIA a mature initiative to be inserted in the roadmap of ESFRI.

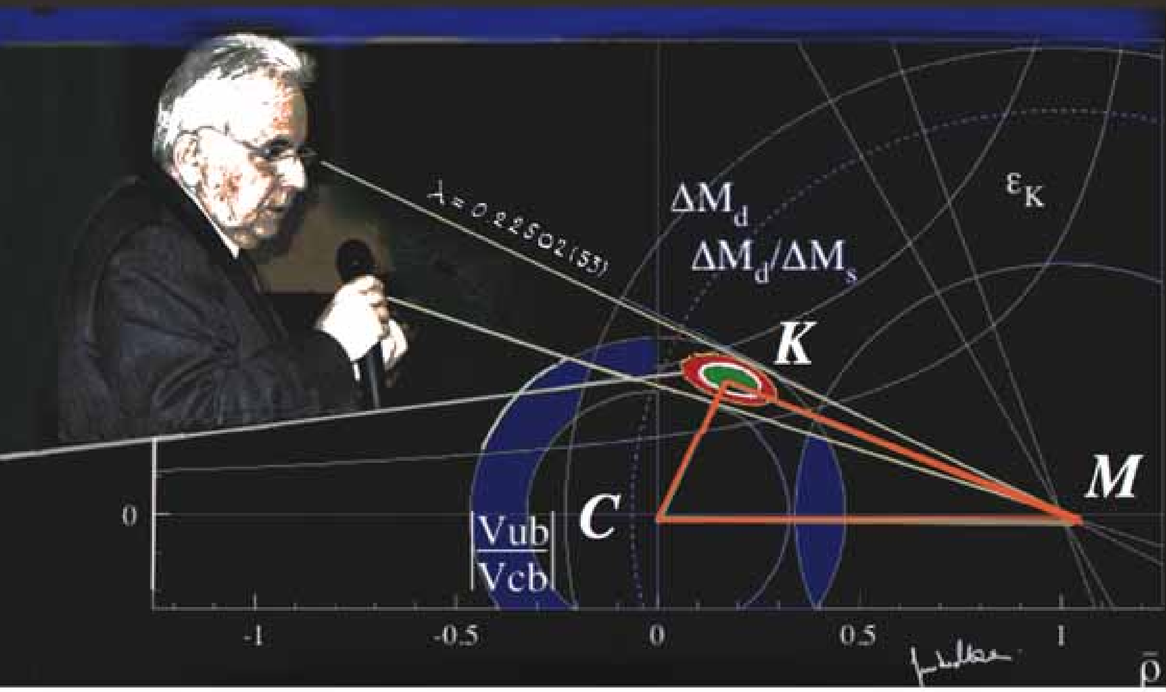
ESFRI, the European Strategy Forum on Research Infrastructures, is a strategic board to develop the scientific policy of Europe and to strengthen the international cooperation. The roadmap document selects the best European scientific future facilities based on a thorough evaluation and selection procedure. To become part of this document, represent a guarantee toward the possibility to have funds and support from European member states.

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Nicola Cabibbo
Memorial Symposium

Martedì 15 Dicembre 2020, ore 10:00

https://agenda.infn.it/e/CabibboMemorial2020



A dieci anni dalla scomparsa di Nicola Cabibbo vogliamo rendergli omaggio dedicando una giornata a ricordare la sua figura di fisico teorico di statura internazionale attraverso le testimonianze dei suoi allievi e collaboratori

Organizzatori

Pierluigi Campana
Marco Ciuchini
Luciano Maiani
Guido Martinelli
Antonio Masiero
Antonio Zoccoli

Susanna Bertelli
Fabio Bossi
Maria Cristina D'Amato
Paola Gianotti
Elena Patrignanelli
Sara Reda
Elisa Santinelli

Programma

Chair: Luisa Cifarelli (BO)

10:00	Opening	Antonio Zoccoli (BO)
10:15	Cabibbo a Frascati	Luciano Maiani (Roma I)
10:45	L'angolo di Cabibbo	Luca Silvestrini (Roma I)
11:15	Coffee break	
11:45	Cabibbo a Roma I e II	Guido Martinelli (Roma I)
12:15	Cabibbo Manager della scienza: dall'INFN all'ENEA	Pier Giorgio Picozza (Roma II)
12:45	Assegnazione Cabibbo fellowship	
13:00	Lunch break	
14:00	Il progetto APE	Giorgio Parisi (Roma I)
14:30	Cabibbo a NA48	Patrizia Cenci (PG)
15:00	La fisica del flavour	Gino Isidori (Zurich)
15:30	Modello Standard o Teoria Standard?	Riccardo Barbieri (PI)
16:00	Coffee break	
16:30	La fisica della rottura della simmetria elettrodebole	Gian Francesco Giudice (CERN)
17:00	Ricordi	

Nicola Cabibbo Memorial Symposium

On December the 15th took place the Nicola Cabibbo Memorial Symposium. Ten years after his death, INFN honored Nicola Cabibbo by dedicating a day to remember his figure as a theoretical physicist of international stature, through the testimonies of his students and collaborators.

The original intention was to host the event at the Frascati National Laboratory, the place where Nicola Cabibbo began his brilliant career and to which he was always remained close. Unfortunately, the pandemic affecting the planet forced to hold the event in online mode, but this did not reduce the participation (more than 400 subscribers) and not even the warmth that the Italian community of particle physicists put to pay homage to one of his most illustrious exponents.

The symposium represented an occasion to retrace the steps of the scientific and managerial career of Nicola Cabibbo and also to analyze the legacy that a personality of this caliber leaved us.

After his beginnings as an INFN researcher, in 1969 he became a university professor in L'Aquila and then moved to Rome teaching both theoretical physics and physics of elementary particles at Sapienza and Tor Vergata universities. Member of the Lincei Accademy since 1987, he is known to the world of physics above all for the theory of universality in weak interactions. This was postulated to make sense of the behaviour that was observed for the leptons and quarks. For down and strange quarks, he introduced an angle (now called Cabibbo angle) which explained the mixing of quarks in terms of a rotation between their mass eigenstates and their weak eigenstates. Pioneer in the usage of numerical simulations for studying Quantum Chromo Dynamics, he was among the promoters of the Array Processor Experiment (APE), one of the first attempts of parallel computing.
From 1983 to 1992 he was president of INFN and from 1993 to 1998 of ENEA. In 1993 he was named by Pope John Paul II president of the Pontifical Academy of Sciences.

The characteristic that was more often emphasized by the speakers at the symposium, was the breadth of interests and the genuine pleasure that Cabibbo showed along his life in probing the unknown. A character of great humanity, Cabibbo's true legacy is represented not only by the light he spread out on many obscure aspects of science, but also by the students and colleagues he was able to inspire.

The Fellowship Program, dedicated to his memory, launched two years ago by the LNF with the support of the three INFN sections of the Roman area, fits into this context.

The symposium, opened by the INFN president Antonio Zoccoli, was chaired by Luisa Cifarelli, and saw a roundup of eminent personalities of particle physics community:

Figure 1. Nicola Cabibbo during an interview taking place at the LNF library.

Luciano Maiani, Guido Martinelli, Piergiorgio Picozza, Giorgio Parisi, Partizia Cenci and Riccardo Barbieri to run through the personal and scientific life of Cabibbo; Luca Silvestrini, Enrico Nardi, Gino Isidori, Gian Francesco Giudice to point out the importance that his figure still has in today science. A great success was also the closing session dedicated to the memories. Here, many attendees expressed their gratitude and shared with all participants and the Cabibbo family representers some personal memory.

Figure 2. Some of the speakers and of the attendees of the symposium.

LNF in numbers

The LNF personnel, at the end of 2020, consists of 315 units, including 28 with a fixed term contract, plus 169 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	70	3	73
Engineers	58	12	70
Administrative employees	36	9	45
Technicians	123	4	127
Tot.	287	28	315

Table 1. LNF personnel at December 2020.

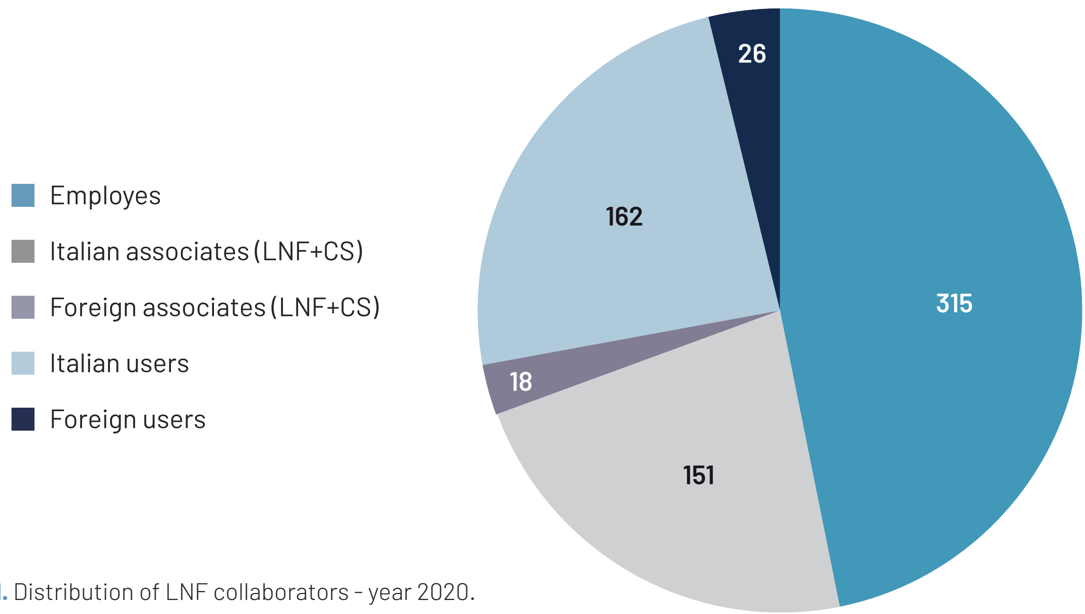


Figure 1. Distribution of LNF collaborators - year 2020.

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LNF HIGHLIGHTS 2020

ONE YEAR OF RESEARCH AT LNF

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