ENRICO FERMI MUSEUM AND RESEARCH CENTRE

EXECUTIVE SUMMARY

2026- 2028

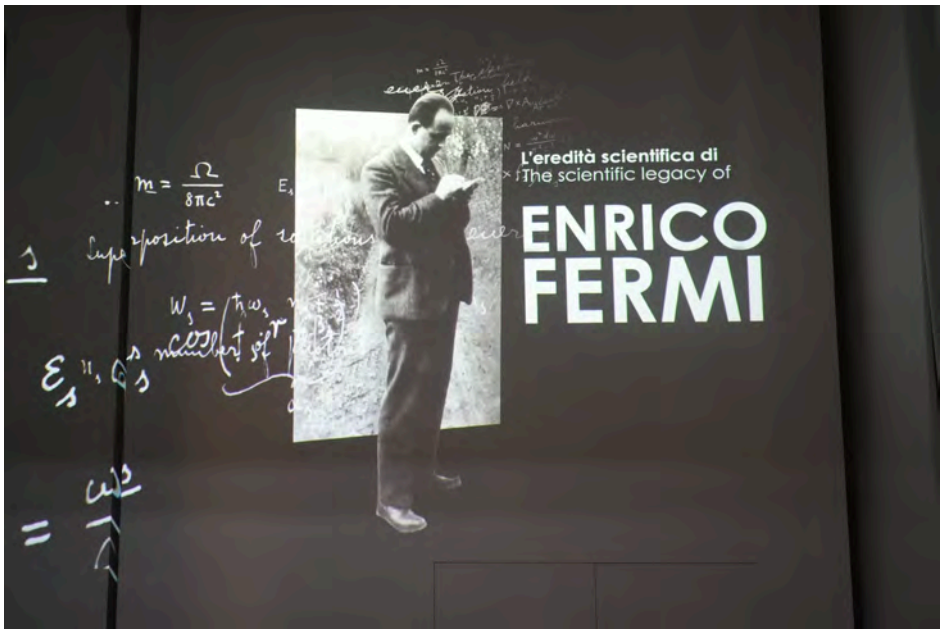
CENTRO RICERCHE ENRICOFERMI

OVERVIEW

Housed within the historic Royal Institute of Physics on Via Panisperna, the Enrico Fermi Historical Museum of Physics and Study and Research Centre (CREF) stands at the unique intersection of scientific heritage and contemporary innovation. This site, the crucible of 20th-century nuclear physics, witnessed the seminal 1934-35 neutron-induced radioactivity experiments led by Fermi and the "Via Panisperna boys"—work that fundamentally redirected the course of modern science. Formally established by parliamentary mandate in 1999 and revitalised by the 2019 restoration of its iconic headquarters, CREF has evolved into a strategic hub where the preservation of historical memory catalyses the production of original knowledge.

The institution's identity is defined by a synergistic duality: while the Museum stewards the scientific legacy of Enrico Fermi, the Research Centre drives cutting-edge, multidisciplinary investigations. This integration ensures that the historical context is not merely a backdrop but an inspiration for high-impact research. Since the full activation of its headquarters in 2019, CREF has transitioned into a new operational era, leveraging its agile organisational structure to foster collaborations with elite universities and international laboratories. By transcending traditional disciplinary silos, the Centre has significantly expanded its global visibility, positioning itself as a nimble yet influential actor in the international scientific community.

Currently, CREF's scientific trajectory is articulated through a rigorous strategic framework. This program consolidates existing expertise while pioneering new frontiers across physics and its interdisciplinary applications, structured around four primary research pillars designed to address the complex challenges of contemporary science.



Strategic Framework: 2025-2027

The 2025-2027 Three-Year Activity Plan formalizes CREF's research architecture into four strategic pillars: Complexity, Applied Physics, Fundamental Physics, and Museology. While each strand pursues distinct, high-level objectives, they are unified by a pervasive multidisciplinary approach and a steadfast commitment to cultural dissemination. A defining feature of this institutional framework is the integration of Artificial Intelligence; originally developed within the Complexity strand, AI has transitioned into a transversal investigative catalyst, providing innovative methodological tools across all four research areas.

CREF's current performance metrics place it at the forefront of the international scientific landscape. This is evidenced by a high-calibre bibliometric output, a proven track record in securing competitive external funding, and an increasing capacity to attract top-tier global talent. This excellence is further bolstered by an expansive network of institutional collaborations that amplify the Centre's impact within the scientific community.

Looking forward, CREF is committed to further sharpening its competitive edge. A key operational priority involves the structural optimization of the Via Panisperna headquarters, specifically the restoration of remaining interior spaces. This infrastructural expansion will provide the specialized laboratory and office environments necessary to scale existing research capabilities. Ultimately, CREF's trajectory remains focused on a dual mission: advancing cutting-edge research to address societal challenges while preserving the historical legacy that serves as an enduring source of inspiration and identity.

Research Strands: Methodological Frontiers

Complexity and Systems Science

While the reductionist paradigm has historically driven fundamental discoveries, it proves insufficient for capturing the non-linear, multiscale dynamics of contemporary socio-economic and biological systems. CREF addresses these challenges by leveraging modern statistical physics and complex systems theory, integrating them with high-performance numerical computing and advanced AI algorithms. This framework enables rigorous modelling of heterogeneous data across diverse domains.

Specifically, the Centre focuses on Complexity for Economic and Technological Development and the Natural Sciences, investigating how innovation impacts global competitiveness and how biological processes—from cellular functions to population dynamics—can be mapped as complex networks. A cornerstone of this strand is the study of the socio-economic impact of Artificial Intelligence, complemented by a strategic partnership with the SONY CSL joint laboratory, which focuses on predictive scenarios for sustainability. Through this approach, CREF transforms stochastic dynamics into actionable insights for global challenges.

Applied Physics: Bridging Innovation and Society

Applied Physics at CREF acts as a transversal bridge, translating fundamental physical laws into high-impact technological solutions. This interdisciplinary effort is primarily concentrated in two high-priority sectors: Medical Physics and Physics for Cultural Heritage, both of which rely on a cross-fertilisation of methodologies from chemistry, biology, and materials science.

Medical Physics and Neuroscience: Strategically aligned with the needs of an aging population, this line focuses on Radio and Hadron Therapy and Quantitative Neuroimaging. CREF is currently advancing high-performance, cost-effective SPECT detection systems and developing innovative radiation dose detectors to maximize therapeutic precision while minimizing collateral damage to healthy tissue. In parallel, neuroscience research utilizes advanced MRI techniques to map the relationship between cortical information processing, metabolic demands, and microstructural substrates. By isolating neuronal signals from physiological noise (such as cardiac fluctuations), the Centre provides new insights into the dynamics of brain fluctuations.

Physics for Cultural Heritage: This strand employs a rigorous material-science approach to the conservation of historical and artistic assets. Using non-invasive analytical techniques—such as X-ray Fluorescence (XRF) and Infrared Spectroscopy (IR)—researchers characterize the composition and degradation of library assets, metallic artefacts, and organic archaeological finds. This interdisciplinary synthesis of physics and materials science not only preserves cultural memory but also reconstructs the technological and production processes of antiquity.

Fundamental Physics: From Quantum Foundations to Galactic Dynamics

The Fundamental Physics macro-area at CREF is dedicated to expanding the frontiers of theoretical and experimental knowledge by bridging foundational inquiries and disruptive technologies. A primary strategic focus is the development of next-generation photonic technologies, in which advanced optical computing systems leverage the interaction of laser light with complex media. By implementing hybrid electronic-photonic neural networks, the Centre aims to redefine computational efficiency for high-complexity problems, utilizing machine learning frameworks to refine optical material characterization and simulate intricate combinatorial systems across both classical and quantum regimes.

In the realm of high-energy physics and astrophysics, the Extreme Energy Events (EEE) project operates a unique national network of cosmic-ray telescopes. This initiative integrates high-level scientific rigor with a sophisticated educational outreach model, extending its observational reach to extreme latitudes through missions such as PolarquEEEst. Parallel to these observations, the Centre investigates galactic kinematics and dynamics, specifically challenging conventional spherical-halo models by exploring dark-matter disc architectures. These models offer a more robust explanation for the velocity fields and rotation curves observed in the Milky Way and other spiral galaxies, providing new insights into the distribution of dark matter.

The macro-area's commitment to cosmic evolution is further evidenced by its research in nuclear astrophysics, which focuses on nucleosynthesis under ionized plasma conditions. By simulating stellar environments with high fidelity, researchers seek to decode the processes governing the formation of chemical elements from the Big Bang to modern stellar reactions. Finally, CREF addresses the most profound open problems in quantum mechanics. Utilizing advanced detectors and AI-driven analysis, the Centre probes the spin-statistics connection and spontaneous wave function collapse, searching for experimental signatures of new physics that could facilitate the formulation of a unified theory of quantum gravity.

The Museum: Research, Legacy, and Global Outreach

The Enrico Fermi Museum serves as the vital interface between historical inquiry and contemporary scientific discourse. Beyond its role as a repository for the 20th-century vanguard of Italian physics, the Museum acts as a dynamic educational hub. In 2024, the institution recorded over 4,600 visitors, with secondary school students representing 71% of the total—a testament to CREF's impact on scientific orientation. This engagement is formalized through integrated programs like the Pathways for Transversal Skills and Orientation (PCTO), which allow students to transition from historical exhibits, such as the recently inaugurated "1934 - Annus Mirabilis" installation, to direct interaction with modern laboratory research.

CREF's influence is amplified by a sophisticated communication strategy and a prestigious network of collaborations, including partnerships with the Italian Scientific Museums Association (AMSI), the Curie Museum in Paris, the Physics Museum at Sapienza University, and the Egyptian Museum in Turin. This ecosystem fosters a continuous dialogue between heritage and innovation, positioning the Centre as a primary expert resource for global media and scientific museology.

Knowledge Dissemination: Bridging History and the Next Generation

The Enrico Fermi Museum serves as a dynamic interface between historical inquiry and future-oriented education, ensuring that Fermi's scientific legacy actively informs contemporary discourse. The institution has seen a consistent upward trajectory in public engagement, recording over 4,600 visitors in 2024. Notably, 71% of this audience consists of secondary school students, highlighting the Museum's role in high-level scientific orientation. This engagement is further deepened through integrated programs, such as the *Pathways for Transversal Skills and Orientation* (PCTO), which bridge the gap between historical exhibits and active laboratory research, providing students with a direct experience of the modern scientific method.

Starting in 2023, the Museum successfully expanded its pedagogical reach to lower secondary students through pilot programs that utilize tailored instructional materials and educational gamification. Beyond academia, the Centre maintains a robust public presence through monthly Open Days and a sophisticated digital strategy. The permanent collection—which innovatively fuses historical artefacts with advanced multimedia installations—was recently enhanced by the "1934 - Annus Mirabilis" exhibit. This installation provides a rigorous reconstruction of the neutron-induced radioactivity experiments that culminated in Fermi's 1938 Nobel Prize, offering a clear narrative of a pivotal moment in global physics.

Beyond its walls, CREF acts as a central node in the national and international scientific museology network. Its research staff are regular contributors to major outreach initiatives, including the European Researchers' Night and prominent science festivals in Genoa and Rome. Furthermore, the Museum serves as a primary expert resource for media productions and high-level debates on the history of science. By fostering strategic collaborations with international partners and scientific operators, the Museum ensures that its mission of dissemination is both impactful and aligned with global best practices in scientific communication.

Scientific Vitality and Strategic Growth

The Centre's intellectual output reflects an agile yet high-impact research environment. During the 2022-2024 period and the first quarter of 2025, CREF produced over 330 indexed publications and two patents, garnering more than 10,000 citations. This productivity is matched by an active presence in the international arena, with over 300 conference presentations—more than half by invitation—and nearly 100 active framework agreements and collaborations worldwide.

The human capital driving this success includes 23 staff members, approximately 100 research associates, and 32 PhD students and fellows. This lean structure has proven exceptionally effective in attracting competitive resources, securing over €1.6 million in funding in the last two years. These resources are currently being channeled into critical infrastructure, including new laboratories for nuclear astrophysics, particle detector development, and advanced tomographic scanners for cultural heritage.

Research and historical legacy to inspire

To ensure the long-term viability of its mission, CREF employs a rigorous internal monitoring and governance system. Under the oversight of the Scientific Director and the Internal Evaluation Committee, the Centre conducts annual audits based on four key pillars: scientific quality, competitive funding acquisition, human capital development, and societal contribution.

This structured approach ensures that CREF remains a dynamic bridge between the scientific heritage of the past and the challenges of the future. As it enters the next triennium, the Centre is uniquely positioned to consolidate its role as an international hub where multidisciplinary research and historical legacy converge to inspire the next generation of scientific leaders.

INFRASTRUCTURE, RESEARCH LABORATORIES, INSTRUMENTATION

Cultural Heritage Laboratory

The CREF's Physics Laboratory for Cultural Heritage is engaged in the study of materials of historical and artistic interest using non-invasive and non-destructive analysis techniques and is located on the -1 floor of the building. It is currently equipped with instruments for X-ray fluorescence spectroscopy (XRaman, XGlab-Bruker), Raman spectroscopy (XRaman, XGlab-Bruker), Fourier transform infrared spectroscopy (FTIR Nicolet IS5 Conservat-IR, Thermo Fisher Scientific) and hyperspectral imaging (IQ Specim – Konica Minolta). The laboratory also has dedicated workstations with ample computing power for imaging data analysis using dedicated software (VGStudio Max, Volumegraphics) and small accessories such as a laboratory analytical balance, dryer, standard samples, press, reagents, oven and basic materials. The laboratory also has the consumables necessary to carry out the experiments. To expand its diagnostic capabilities, the laboratory plans to acquire an imaging system, specifically X-ray Computed Tomography (CT), which will allow the internal structure of objects to be examined without altering their integrity. CT will allow inclusions, cavities, defects and multilayer structures to be identified, providing details that are inaccessible using other techniques. The data collected will also enable the creation of 3D models for advanced analysis through the development of new investigation protocols and for museum enhancement. The adoption of this technology will strengthen the laboratory's research activities, promoting cooperation with other institutions in the field of knowledge, protection and enjoyment of cultural heritage.

Figure: Spaces in the CREF Physics Laboratory for Cultural Heritage.

Resources: The laboratory has demonstrated its ability to attract external funding through participation in competitive calls for proposals (ISIS@MACH project completed in 2024). The infrastructure is therefore expected to be strengthened through participation in competitive

calls for proposals and further funding opportunities for the purchase of new research equipment.

Computational Photonics Laboratory

The Computational Photonics Laboratory is dedicated to experimental research in Photonic Technologies and Artificial Intelligence and is equipped with the necessary infrastructure for the creation of photonic computing machine prototypes and the implementation of associated optical experiments. The laboratory has three stabilised optical tables, two continuous emission laser sources in the visible spectral band and one pulsed source (100 femtoseconds) in the near infrared, two spatial modulators for visible and infrared light based on liquid crystals, video cameras and optical detectors, optical components and optomechanical accessories. There are workstations based on conventional computers dedicated to theoretical investigation, numerical simulations and data analysis. For the engineering of complex photonic materials characterised by disorder and non-linearity that serve as physical computing platforms, the laboratory collaborates with prestigious international research institutes such as ETH Zurich.

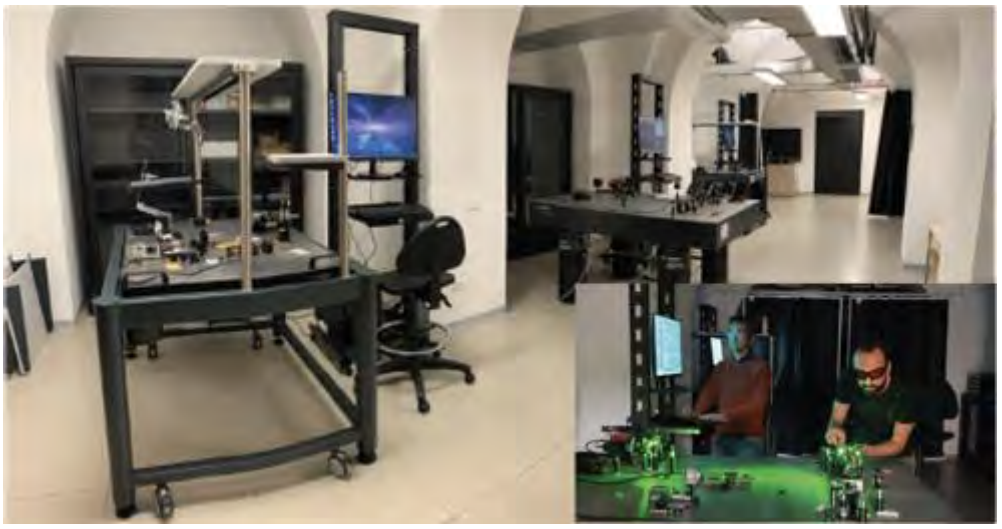


Figura: Spazi del laboratorio di Fotonica Computazionale del CREF ed esperimenti in corso.

Resources: The laboratory has attracted external resources totalling €520,000. External funding under the National Recovery and Resilience Plan (PNRR) 2022, Mission 4 “Education and Research” - Component 2 “From Research to Business” - Investment 1.2 “Funding for projects presented by young researchers”, funded by the European Union - NextGenerationEU. Project “Comp-SECOONDO” entitled “Computational Second-order Nano-oxides Nonlinear Disordered Photonics”. Funding €300,000. Duration 3 years. Principal Investigator (PI) Romolo Savo

Funding under the MUR PRIN 2022 call for proposals, PHERMIAC project entitled ‘Photonic High-Energy cosmic-RaMonitoring via Ising machines and Advanced Combinatorial optimisation’: Claudio Conti (PI) - Sapienza University of Rome), Fabrizio Coccetti (Co-PI, Head of CREF Unit), budget €220,000.

Extreme Energy Events Laboratory

The Extreme Energy Events (EEE) laboratory is located on floor -1, room 403, of the historic building that houses the Enrico Fermi Research Centre (CREF). Inside the laboratory, shown in the figure below, there is one of the EEE network's muon tracking telescopes.

The telescope consists of:

- 3 Multigap Resistive Plate Chambers (MRPC) detectors: gas detectors, approximately 2 m^2 in area, which allow the reconstruction of the passage point of subnuclear particles with cm^2 precision and a time resolution of the order of 250 ps;
- VME crate (CAEN Spa) for readout, housing: two Time to Digital Converter modules (V1190A and V1190B, CAEN Spa), a PC crate interface module (Bridge USBV1718 CAEN Spa) and a custom electronic "trigger" card (equipped with a GPS receiver for telescope time synchronisation);
- a custom weather station (based on Arduino);
- 1 custom power supply to provide the voltage necessary for the operation of the MRPC detectors;
- 2 computers: one dedicated to power supply management and one dedicated to data acquisition;
- Tektronix WaveRunner 8254M oscilloscope (2.5 GHz, 40GS/s);
- 1 portable accessory detector based on scintillators (Cosmic Box).

The EEE Project laboratory at CREF: visible are the mechanical support structure for the three MRPC detectors, the two PCs for managing detector operation and an oscilloscope for checks.

The telescope, which is part of a network of 50 telescopes installed throughout Italy (most of which are located in secondary schools that actively collaborate with the EEE Project), allows cosmic ray muons to be detected and tracked with great precision. it is then possible to correlate their flow with local environmental parameters or, through GPS synchronisation, to study correlations between events over large distances. To date, more than 130 billion muon tracks have been acquired by the EEE network and used for various analyses. The transformation of tracking and coincidence algorithms between muons from the same shower using the Quadratic Unconstrained Binary Optimisation (QUBO) approach is also

being studied, in order to perform certain analyses using a photonic computer currently being developed at CREF. At the same time, the use of Artificial Intelligence (AI) systems for network monitoring tools is being designed.

In addition to participating in the joint data collection phases of the EEE Project, the CREF laboratory is used to test new hardware solutions for use throughout the network for possible future upgrades, but also for outreach activities such as guided tours or daily educational workshops during which measurements can also be taken using the portable scintillator-based detector, called Cosmic-Box.

In the coming years, the laboratory will be used for:

- testing the efficiency of Silicon Photomultiplier-based particle detectors: the telescope's tracking capability can be exploited to measure the efficiency of other detectors (without affecting data acquisition within the EEE measurement programme)
- assembling and testing detectors: the equipment in the laboratory allows scintillator-based detectors to be assembled and tested for future upgrades of the EEE detector network.
- the material and equipment can be used to build cloud chamber-type detectors for the Fermi Centre's third mission activities.
- Expansion of the range of outreach events: installation of monitors, posters, etc.

Resources: The CREF infrastructure is expected to be strengthened through synergistic participation in competitive tenders for the purchase of new research materials and equipment to be used both jointly and specifically for each laboratory.

Laboratorio Sony Csl-Rome

Il Sony Computer Science Laboratories – Rome (Sony CSL-ROME) è ospitato al primo piano (mostrato nell'immagine a lato) della palazzina storica sede del Centro Ricerche Enrico Fermi (CREF) grazie ad un accordo scientifico con il CREF. In questo senso esso rappresenta un esempio unico di collaborazione pubblico-privato per lo sviluppo scientifico e tecnologico. Il laboratorio fa parte della rete dei laboratori Sony CSL, con sedi a Tokyo, Kyoto e Parigi e si distingue per un approccio interdisciplinare volto a risolvere sfide globali.

Al centro di un nutrito ecosistema di istituzioni pubbliche e private, italiane e internazionali, il laboratorio porta avanti attività teorico-computazionale organizzata secondo tre linee di ricerca principali, ognuna delle quali si concentra su tre dei temi più dibattuti al momento: le Città Sostenibili e il modo in cui concepirle e realizzarle, gli Ecosistemi dell'Informazione e il modo in cui curare le loro patologie (disinformazione, polarizzazione, tossicità), il ruolo che l'Intelligenza Artificiale potrebbe avere nelle nostre vite combinata con il potere della nostra creatività. Il fine ultimo è quello di svolgere ricerca di frontiera riconosciuta sulle più importanti riviste internazionali e mirare ad avere un impatto concreto nelle diverse aree di interesse. Il laboratorio si avvale degli strumenti e dei metodi più avanzati della fisica statistica, della scienza della complessità e dei dati, della scienza delle reti, del machine learning e dell'Intelligenza artificiale. A tal fine sfrutta estese risorse computazionali sia in loco sia nel cloud e collaborazioni con i più importanti centri di supercomputing europei. Infine, il laboratorio svolge un'intensa attività di comunicazione e disseminazione atta a costruire una posizione di rilievo scientifico per l'iniziativa congiunta Sony-CREF rispetto ai

principali stakeholder del territorio, a livello locale, nazionale e internazionale. Questo impegno si traduce in attività di comunicazione come event managing, partnership a scopo divulgativo e scientifico, creazione e diffusione di informazioni inerenti alle attività di ricerca. Le attività descritte mettono entrambi i centri di ricerca all'interno di un network capillare di professionisti e di una rete fruttuosa di relazioni pubbliche.

Figure: Detail of the spaces at Sony CSL-Rome.

Risorse: Sony CSL finanzia l'iniziativa congiunta con undici ricercatori (tra full-time e part-time) di Sony CSL-Rome e Sony CSL-Paris, le attrezzature di ricerca, l'acquisto di dati e comprende costi di viaggio, pubblicazione e disseminazione dei risultati, organizzazione di eventi. L'investimento annuale di Sony CSL si aggira intorno ad 1.5 milioni di euro. Il CREF, oltre a mettere a disposizione di Sony CSL-Rome uno spazio dedicato all'iniziativa congiunta, fornisce servizi essenziali quali utenze, accesso alla rete, pulizia, sicurezza, etc. In aggiunta il CREF finanzia due ricercatori post-doc dedicati all'iniziativa congiunta per un costo complessivo di circa 60 mila euro l'anno. A queste risorse si aggiungono risorse provenienti da progetti esterni nazionali ed internazionali.

Neuroimaging Laboratory

The NQN project is based at the Neuroimaging Laboratory/MARBILab. This is a joint laboratory run in cooperation between CREF and the Santa Lucia Foundation, and is located at the latter's headquarters. The laboratory is directed by the scientific director of NQN and consists of a Neurophysics section (which brings together the activities of CREF) and a Neuropsychology section (which includes the activities of Santa Lucia).

The laboratory has space for staff, who access computing resources directly or remotely. These include a grid computing engine for distributed computing (128+ computing nodes), with the necessary infrastructure for neuroimaging data processing, a comprehensive database for neuroimaging data, integrated with central storage on SAN (200 TB). In addition, there are eight high-performance workstations (including GPU capabilities) and numerous optimised software tools (both general-purpose and locally developed) for neuroimaging data processing. The laboratory is permanently connected to the CREF headquarters via a stable VPN (LAN to LAN).

The laboratory's main equipment is a human-scale 3T MRI scanner. The scanner is owned by the Santa Lucia Foundation and is accessible to CREF researchers under an agreement that provides equal conditions with internal staff. It is a scanner designed, configured and used exclusively for research activities. The scanner (Siemens Prisma) is characterised by

excellent stability (guaranteed by daily quality controls and monthly calibrations) and very high performance (64 reception channels, two transmission channels, gradients capable of simultaneously reaching 80 mT/m and 200 T/m/s, highly homogeneous magnet with high-power shim amplifiers). 32- and 64-channel head coils are available, as well as coils for acquiring nuclei other than hydrogen.

The scanner is particularly suitable for functional imaging, and agreements with international research partners (Center for Magnetic Resonance Research in Minnesota, Harvard Medical School and others) allow the sharing of experimental scan sequences (code) that are not commercially available. A research agreement with Siemens also allows low-level programming of the scanner. Over time, complete and integrated solutions for physiological monitoring, stimulation and subject feedback have been developed. These include a pulse oximeter, respiratory belt, capnograph with CO_2 and O_2 sampling, push-button panels, trackballs and other transducers for interaction with the volunteer, a camera system for digitising limb position, and divisive stimulation systems, including stereoscopic ones for virtual reality. All signals are synchronised with the scan via optical triggering.

The laboratory also has a mechanical workshop, a stimulation programming and simulation environment, and spaces for managing volunteers and patients.

Figure:Left: one of the laboratory's open spaces. Right: auxiliary equipment developed for the Siemens Prisma 3T scanner.

Risorse: La fondazione Santa Lucia finanzia il laboratorio congiunto garantendo i locali, gli impianti e i servizi e la manutenzione dello scanner. L'investimento annuale della Santa Lucia si aggira sui 600000 €, di cui 240.000 € assorbiti dalla manutenzione dello scanner. Il CREF contribuisce con il proprio personale, con piccola strumentazione e con le dotazioni di calcolo.

Laboratorio Radio e Adro Terapia

The RAT research line plans to develop a laboratory located on floor -1 dedicated to the creation of instrumentation and measurements at CREF. This will be a joint laboratory run in cooperation between CREF and the Department of Basic and Applied Sciences for Engineering (SBAI) of Sapienza University of Rome. The laboratory will be directed by the scientific manager of RAT.

The laboratory will have space for staff, who will have direct or remote access to the instrumentation, computing resources and data acquisition systems. These will include a spinning machine for scintillating fibres (currently housed at the SBAI Department but owned by CREF), bench-top electronic systems for powering readout systems and data acquisition (NIM and VME), an oscilloscope, and a computer for data acquisition and analysis.

There will also be a high-performance workstation (including GPU capabilities) and optimised software tools (both commercial and locally developed) for data processing and Treatment Planning System optimisation.

The laboratory's main equipment will initially be dedicated to the production of scintillating fibre trackers of different thicknesses, particularly for the detection of ultrafast neutrons. Prototype nuclear imaging systems with organic scintillators enriched with high-Z elements will also be developed. The scintillators, produced at the SBAI section, will be characterised at the section's laboratory and then assembled at the CREF laboratory in prototype modules of the SPECT imaging detector. Finally, a wearable dosimeter for radiometabolics with Lutetium 177 will be assembled, characterised and evaluated.

The laboratory also has a programming and simulation environment and spaces for the management of temporary staff and collaborators.

There are also plans to create installations to expand the range of outreach events, including those dedicated to physics for cancer treatment: installations, monitors, posters, etc.

Resources: The SBAI Department finances the joint laboratory by providing premises, facilities and services and the use of the Department's mechanical workshop. CREF contributes with its own staff, instrumentation and computing equipment.

SCIENTIFIC AND PROJECT ACTIVITIES

Brief description of the main lines of research and their objectives

In recent years, CREF has undertaken intensive work to develop strategic lines of research with a high scientific impact. This year, these have been organised into four main areas, as illustrated below and described briefly.

Complexity

The research area on Complexity is divided into several closely interrelated activities. This field of study ranges from statistical physics to its applications in the natural sciences, socio-economic development and the analysis of the impact of artificial intelligence.

In the field of **Statistical Physics and Complex Systems in Natural Sciences**, a notable achievement has been the development of the innovative Laplacian Renormalisation Group (LRG). This method offers a powerful new tool for analysing the multiscale structure of heterogeneous complex networks, overcoming the limitations of traditional techniques. It allows for iterative simplification of networks, identifying clusters of "similar" nodes at different resolutions, and has gained international recognition, such as the cover of Nature Physics in 2023. It has also provided new perspectives for the study of modularity and mesoscopic organisation of networks. In parallel, stochastic models of graphs based on maximum entropy have been developed, which are useful as null models for the validation and reconstruction of real networks. These theoretical approaches have been successfully applied to various interdisciplinary areas, including the analysis of ecosystem robustness, the study of brain activity time series (fMRI), epidemiological modelling during the pandemic, and preliminary analysis of climate dynamics.

Future objectives in this area include further enhancing the "LRG" theory, completing its physical-statistical formulation by extending the Fluctuation-Dissipation relations and applying it to new types of networks, such as marked networks, relevant to the study of spin glasses and neuroscience. The aim is to improve clustering techniques to manage large networks and enable real-time analysis, as well as to characterise scale-invariant disordered systems and analyse non-ergodic phenomena such as Griffiths phases. The applications of "LRG" will be extended to a wide range of systems: from gene activation and brain networks (to understand pathological mechanisms and psychiatric disorders) to the modelling of tumour genesis, from drug interactions to infrastructure networks (electrical, communication), epidemiological networks, online disinformation networks and economic networks. The study of maximally entropic null models and the application of stochastic models and machine learning, such as Reservoir Computing, to multiscale analysis and short-term forecasting of climate dynamics will also continue, in collaboration with organisations such as the Copernicus Climate Change Service (C3S) and SONY CSL. Finally, the link between the optimal structures observed in ecological and economic mutualistic networks and optimal transport theory will be explored.

In the field of **Complexity for Economic and Technological Developmen**t, CREF has consolidated the Economic Fitness and Complexity (EFC) method. This innovative, data-driven approach, based on complex networks and machine learning, models economies to predict their growth and competitiveness, demonstrating predictive

capabilities superior to those of the IMF and being adopted by international institutions such as the World Bank and the Joint Research Centre (JRC) of the European Commission. Through the analysis of bipartite networks, such as Country-Product networks, EFC identifies productive capacities and suggests development trajectories. Alongside EFC, digital data has been analysed and phenomena such as the spread of (dis)information and online dynamics have been studied, leading to the identification of structures such as "echo chambers". Methods derived from Network Theory were also developed and applied, in particular null models based on maximum entropy, to distinguish relevant signals from statistical noise in complex economic and social networks, allowing structures to be validated and significant behaviours to be identified, such as coordination in the spread of disinformation.

For the future, the goal is to enhance the EFC to address concrete issues related to technological innovation, environmental and social sustainability, the labour market and global value chains, with an eye to policy implications. The theoretical foundations of the EFC will be explored in greater depth, studying the spatial dynamics of "capabilities", integrating it with microeconomic company data and linking it to optimal transport theory and other economic and ecological theories. The analysis will be extended to new "items" such as services and labour mobility. Multilayer economic complexity will be studied, integrating data on industrial production, labour, patents and scientific research, and "green" innovation and the link between competitiveness and environmental impact will be analysed. The development and application of maximally entropic null models for different types of networks and research in Computational Social Science will continue, also in connection with funded projects such as the PRIN PNRR "CODE". Strong emphasis will be placed on the dissemination of results through training and outreach activities, such as the EFC Spring School.

With regard to the commitment to the issue of the **impact of Artificial Intelligence (AI) on the Socio-Economic Fabric and Innovation**, the research has led to the development of new AI algorithms, such as "Dreaming Learning", which enables continuous and creative learning by exploring the "Adjacent Possible", managing non-stationary data and mitigating known problems such as "Catastrophic Forgetting" and "Model Collapse". "Lyapunov Learning", based on the "Edge of Chaos" principle, has also been introduced to extend these capabilities to multidimensional data. AI tools, in particular Large Language Models (LLMs), have been successfully employed to analyse large amounts of unstructured data, such as patents, in order to map technological expertise and predict innovation trajectories, an approach that has received recognition from the European Patent Office. Preliminary studies have also been launched on the impact of AI on the world of work and on the evolution of online social dynamics, with a particular focus on the role of moral values.

Future objectives in this area focus on exploring the potential and limitations of AI. It is planned to make intensive use of LLMs to study and predict innovation dynamics, especially in relation to sustainability (pollution, critical raw materials, energy transition), extending the analysis to scientific publications and code repositories such as GitHub. The aim will be to map technological skills on a geographical and semantic basis and to measure the distances between technical fields in order to anticipate recombinant innovations. LLMs will also be used to investigate complex social phenomena, such as discontent and inequality, starting from discussions in online communities. On the theoretical front, Artificial Creativity algorithms such as Dreaming Learning and Lyapunov Learning will be explored in depth, studying their formal foundations and applying them to real-world problems (climate, ecosystems) and different types of generative AI. AI systems supporting human creativity will be developed, including autonomous agents and models for human movement analysis (Large Movement Model - LMM), with an initial focus on dance. The socio-economic impact

of AI on the labour market will be quantified, analysing occupational exposure, emerging skills and the role of public opinion and ethics. Finally, the interaction between human values and values embedded in AI systems ("Responsible AI") will be studied, assessing how AI understands moral constructs and what role it plays in online discussions.

Innovation and Predictive Scenarios for Sustainability are at the heart of the CREF-Sony Joint Initiative (JICS). This unique public-private partnership aims to integrate science, art and public engagement to address global challenges aligned with the Sustainable Development Goals (SDGs). Among the results already achieved is the enhancement of the "what-if" platform dedicated to the concept of the "15-minute city", the study of which was published in Nature Cities, gaining international resonance. The application of the EFC framework to the analysis of accessibility and urban mobility has been initiated, and a smart city pilot project has been launched in collaboration with Sony Semiconductor Solutions and Sapienza, which uses advanced sensors for traffic and road safety analysis while respecting privacy. In addition, analyses have begun on the information ecosystem (Infosphere) and human-AI interaction for Augmented Creativity, using methods such as Dreaming Learning and initiating the development of the Large Movement Model.

Looking ahead, JICS aims to further develop "what-if" technologies to analyse accessibility, inclusiveness and urban economic dynamics, creating advanced metrics and modelling tools for global urban planning, which will be implemented in dashboards for policy makers. Research will continue on the 15-minute city and the use of EFC to understand urban inequalities. On the Infosphere front, the analysis of information dynamics (bias, recommendation systems) will be deepened and tools and strategies will be developed to improve the quality, diversity and transparency of information accessible online, countering polarisation and toxicity, for example through a public discourse analysis platform and a browser plugin. In the field of Augmented Creativity, human-AI synergy will be studied, non-stationary AI approaches will be enhanced, and the Large Movement Model will be developed, extending its applications from dance to rehabilitation, sport and cultural preservation, with the aim of fostering the emergence of a new generation of AI to support human capabilities.

Applied Physics

Applied Physics translates discoveries in Fundamental Physics into technological innovation, bridging the gap between the investigation of the laws of nature and their practical application. It is a highly interdisciplinary field that encompasses areas of great importance, from medical physics to the conservation of cultural heritage, from materials science to environmental science. Applied Physics plays a crucial role in these sectors, not only in the more traditional field of developing new investigative technologies, but also by promoting fruitful cross-fertilisation between different methodological approaches, both experimental and modelling and computational.

In particular, developments in **medical physics** have revolutionised healthcare by improving diagnostic capabilities and treatment methods on the one hand, and the potential of biomedical research on the other. On the other hand, the growing **role of physics in the field of cultural heritage knowledge and enhancement** contributes to more effective preservation of cultural heritage, a goal of great importance, particularly for a nation rich in cultural heritage. The CREF macro-area dedicated to Applied Physics focuses on these two sectors.

In recent years, the field of Applied Physics has produced numerous results in its various branches.

With regard to **neuroscience and quantitative neuroimaging,** we have developed techniques for measuring cerebrovascular reactivity (CVR). CVR is the ability of blood vessels to respond to vasoactive stimuli. We have developed a technique for measuring CVR by administering small doses of CO2, and we have acquired data on healthy volunteers and Alzheimer's patients. We have also begun to develop a method for extracting metabolic information (oxygen consumption) from CVR data. This information will be combined with metabolic information obtained from spectroscopic data in order to enrich the metabolic characterisation of brain function, on which we have already obtained and published numerous results. Functional experiments with MR spectroscopy included a visual stimulus capable of generating functional deactivation, administered in a block design. The results confirmed significant deactivation in the occipital lobe. Spectroscopic data support the hypothesis of metabolic decoupling during deactivation. In particular, we observed a mismatch between lactate and glutamate dynamics, suggesting a transient decoupling between cytoplasmic and mitochondrial metabolism.

It should be noted that the reliability of spectral quantification is altered by patient movement. This effect is particularly critical in functional studies, which investigate temporal variations in metabolic content and are subject to progressive volunteer fatigue. To overcome this limitation, we have developed, in collaboration with Sapienza, INFN and CNR, an innovative AI-based predictive motion correction technique that can identify the subject's movements and, based on a model, predict movement in the immediate future in order to adapt the scanning parameters in real time.

The extension of metabolic techniques to subjects with brain diseases is not straightforward. We have therefore developed magnetic resonance techniques based on 23Na imaging in combination with quantitative magnetic resonance imaging to identify potential biomarkers of disease and explore pathophysiological processes underlying microstructural tissue damage and cognitive impairment. Sodium plays a fundamental role in many physiological and biochemical functions. In particular, sodium homeostasis is associated with neuroinflammation, with potential sensitivity to vascular and metabolic alterations.

One of the most significant problems with sodium imaging is its poor SNR, mainly due to the low gyromagnetic ratio and quadrupole relaxation.

To mitigate this problem, we have developed specific denoising techniques (based on Unbiased Non Local Mean, U-NLM) and integrated them with calibration techniques for the absolute quantification of sodium. Data acquisition is currently underway on a cohort of AD patients.

The **Radio and Hadron Therapy** line has achieved results on all ongoing projects. In particular, the ReSPECT project aims to use plastic scintillators, known for their signal speed, low cost and ease of manufacture, enriching them with high Z impurities (such as bismuth) to improve the photoelectric absorption of gamma rays. The Laboratory of Electrochemistry and Organic Synthesis (LEOS) and CREF have developed polymerised scintillators containing these impurities. The characterisation of these samples was a crucial activity for the project and allowed the behaviour of various fluorophores to be selected as the concentration of “impurities” varied, in order to maximise performance. In addition, the performance of the detector as a whole was evaluated using Monte Carlo simulations. This required the development of a simulation tool that could take into account the system as a whole. The performance obtained in this way guides the choice of crucial parameters such

as the size of the scintillator segments and the characteristics of the readout electronics. With regard to radiotherapy and heavy particle therapy, the MULTIPASS project has its roots in the results obtained with the Dose Profiler tracer (now at CNAO). In addition, the MONDO project has enabled us to build the first prototypes of compact fibre detectors and to develop an initial version of the readout sensor. The results obtained and the know-how acquired were then further developed and refined thanks to the development of dedicated MC tools that allowed us to simulate the MULTIPASS detector in its entirety. These in silico studies are the first crucial steps towards improving radiotherapy and neutron analysis and have allowed us to identify a multi-particle fibre tracker as the optimal instrument. In order to study the clinical context of RT and CPT, in synergy with the SBAI department, FRED (Fast paRticle thErapy Dose evaluator) was developed, a treatment planning software based on fast Monte Carlo simulations (up to a thousand times faster thanks to GPUs). FRED optimises treatment plans, reducing the dose and damage to healthy organs, and supports evaluations for VHEE and photon techniques. The FLASH effect, which reduces toxicity in healthy tissues under UHDR conditions, has also been studied. A feasibility study has also been carried out for the development of a UHDR mode delivered beam monitor detector that exploits air fluorescence. Over the last two years, measurement campaigns have been completed to verify the feasibility of such a detector.

The **Physics for Cultural Heritage line** has been active in developing new investigation methodologies applied to the study of composite materials of historical and artistic interest in the field of library assets, metals, bone and wood finds, and ceramics. The use of machine learning and artificial intelligence techniques on spectroscopic data has provided significant results in the classification and extraction of microscopic benchmarks.

In the field of library heritage, a new investigation methodology has been developed for the study of manuscript texts. In particular, spectroscopy and machine learning techniques have been applied to define the attribution of the text based on the composition of the inks. The procedure was successfully applied to the study of an autograph manuscript by the Jesuit Antonio Vieira, one of the great European authors of the 17th century, considered the father of the Portuguese language. In particular, one main author and four secondary authors were identified, who contributed to the process of revising, censoring and reorganising the work.

In the field of metal studies, the effectiveness of a new methodology for identifying metal alloy processing techniques in ancient Egypt has been demonstrated through X-ray diffraction and fluorescence combined with machine learning techniques, applying classification methods and integrating the results with information on macroscopic characteristics. The study involved 12 copper alloy objects, part of the funerary equipment of the architect of Pharaoh Kha and his wife Merit, dating back to the middle of the 18th dynasty, kept at the Egyptian Museum in Turin. The study allowed the identification of the methods and processes used to work the alloys.

As part of the study of bone and wood finds, the first studies were carried out on the identification of reference biomarkers based on combustion conditions through the application of combined infrared spectroscopy, diffraction and neutron scattering techniques. The microstructural changes in the bone finds during the combustion process were studied. The methodology developed was successfully applied to finds from the burial site known as “Ipogeo delle Ghirlande” (Grottaferrata, Lazio), dating back to the 1st-2nd century AD. The study provided significant insights into funeral rites in the imperial age.

The study of ceramics was conducted as part of the PRIN 2022 SLOW SUMER project, which aims to examine the use, reuse and recycling of materials in ancient Sumerian society between 2500 and 2000 BC. The project is based on the integration of chemical-physical,

archaeological and philological data and the application of advanced scientific methods and machine learning.

Fundamental Physics

The vast field of research in Fundamental Physics is divided into four well-established areas, ranging from Photonic Technologies and Artificial Intelligence to the study of Open Problems in Quantum Mechanics, including the Extreme Energy Events Project and the study of the Kinematics and Dynamics of Galaxies. In addition to these, a new line of research dedicated to Nuclear Astrophysics with Innovative Sources is expected to be launched in the near future. The Fundamental Physics research area at the Fermi Centre is characterised by rapid evolution, with a growing number of researchers, an excellent level of research output and an equally excellent level of publication citations.

The research project on **Photonic Technologies and Artificial Intelligence** aims to develop new photonic systems with the goal of creating innovative optical computing machines capable of overcoming the limitations of traditional computing machines, offering higher performance and consuming less energy. This research project includes both experimental and theoretical activities. The experimental activity explores the use of laser light and its interaction with complex photonic media to address combinatorial optimisation problems and to implement hybrid electronic and photonic neural networks. The theoretical activity aims to develop advanced mathematical models for the simulation of combinatorial systems that can be represented as spin systems and to test the efficiency of new computing algorithms. In the long term, the inclusion of quantum algorithms could increase computing speed and suggest innovative encryption methods. The use of “ultrafast” (femtosecond) pulsed laser sources is a key element of the laboratory's research and allows the study of materials of interest in the optimal nonlinear regime. The laboratory has recently demonstrated the creation of the first large-scale “deep” photonic neural network based on multiple scattering of laser pulses and non-linear second harmonic generation in disordered polycrystalline samples manufactured by assembling lithium niobate nanocrystals (LNO) In the future, there is the possibility of: building a photonic Ising machine with multi-body interaction, based on multiple scattering of laser pulses and nonlinear second harmonic generation in disordered polycrystalline samples fabricated by assembling lithium niobate (LNO) nanocrystals; building a large-scale linear Ising machine using continuous laser light and free-space propagation; developing an innovative “phase unwrapping” technique for two-dimensional quadrant phase maps, based on a classification procedure using convolutional artificial neural networks.

The Extreme Energy Events (EEE) Project is an experiment for measuring and studying cosmic rays on Earth, associated with an innovative and incisive programme for the dissemination of scientific culture. With the aim of distributing detectors throughout the country, EEE plans to install cosmic muon tracking telescopes in Italian schools: students and teachers are involved in all stages, from the construction of the detectors to the analysis of the data. Although they were discovered over a century ago, the study of cosmic rays is still at the centre of advanced research, addressing fundamental questions in physics, astrophysics and cosmology. The EEE Project is unique in terms of its continuity of operations and nationwide coverage as an experiment for the ground-based measurement and monitoring of cosmic radiation, with a strong and innovative programme for the dissemination of scientific culture, which, since 2005, has seen several hundred students involved in its activities every year. The PolarquEEEst Mission was created within the EEE Project, for which three compact scintillation detectors were built to study and monitor the flow of cosmic rays at extreme latitudes, the POLA-R detectors (POLA-01/02/03). In 2018,

POLA-01 was installed on board the Nanuq boat, which circumnavigated Svalbard measuring the cosmic ray flux up to 82° N. The three detectors were then installed at the Ny Alesund base on the Svalbard Islands (Norway), at the Dirigibile Italia station, for the study and continuous monitoring of cosmic ray flux at extreme latitudes. The flux measured by the detectors reveals annual periodicity (summer-winter effect) and can investigate the possible decline in flux in accordance with the solar cycle. The continuation of the measurement campaign at Ny Alesund will cover the entire duration of the solar cycle (11 years) and allow ongoing periodicity studies to continue.

The main objectives of the **research line on Galactic Kinematics and Dynamics** include the study, through the measurement of galactic velocity fields, of the dark matter disc (DMD) model, where DM is hypothesised to be confined, particularly in the discs of spiral galaxies. These correspond to mass and kinematic profiles that differ from the standard model, in which DM forms an almost spherical halo with an isotropic velocity distribution. The kinematic structure of phase space is also investigated, both in our galaxy and in external galaxies, relating it to the dynamic mechanism that gave rise to it. These studies are made possible by data collected by the European Space Agency's Gaia satellite, launched in 2013, which has revolutionised our understanding of the Milky Way (MW) thanks to angular measurements with a precision of between 20 and 200 microarcseconds. Future datasets from the Gaia mission will further extend kinematic studies and at the same time provide further confirmation of the statistical deconvolution method developed to measure the MW rotation curve as accurately as possible. Future objectives include analysing the velocity field of the Milky Way (MW) to obtain valuable information on the rotation curve and its dependence on vertical height relative to the galactic plane. These investigations will provide a comprehensive view of the kinematics and dynamics of the Milky Way; mapping the velocity fields of external galaxies, through the use of two-dimensional measurements of the radial and transverse velocity components obtained with the innovative method developed. This approach will allow us to constrain the inflow and outflow of neutral hydrogen in the outer regions of galaxies. By analysing the interaction between dark matter (DM) and baryonic matter (BM), it will be possible to study the formation of spiral arms and the distribution of matter, providing new insights into the formation and evolution of galaxies; the analysis of the geometry of dark matter (DM) distribution, in particular through the rotation curves of the Milky Way and external galaxies; the investigation of DM in disc galaxies through strong gravitational lensing observations.

The research line on Open Problems in Quantum Mechanics (PAMQ) involves an integrated theoretical and experimental programme aimed at addressing open problems in quantum mechanics and its unification with gravity. The research focuses mainly on the analysis of the spin-statistics connection and the spontaneous collapse of the wave function, using advanced techniques of atomic physics in a series of experiments that exploit cutting-edge technologies. To date, the two main theoretical strands that predict a violation of spin statistics are: the “Quon” model and Quantum Gravity (QG). PAMQ investigates models of spontaneous collapse (Continuous Spontaneous Localisation (CSL)) and models of gravity-induced collapse developed by Diosi and Penrose (DP), which offer a rigorous phenomenological approach. PAMQ aims to test the fundamental symmetries of the Standard Model with ever-increasing resolution. These results provide fundamental input to phenomenological models, such as Quon, and will allow the experimental verification of new parastatistics models. Among the significant results, PAMQ has already constrained the NCQG theta-Poincaré and Minimal Length models to about one-tenth of the Planck scale. A prototype setup based on an active Broad-Energy-Germanium (BEGe) detector is under development, with the aim of testing theta-Poincaré NCQG and Minimal Length down to the Planck scale, improving sensitivity by more than an order of magnitude. The VIP-open-systems experiment, with its improved apparatus, is producing limit values for the

violation of the Pauli Exclusion Principle (PEP) that are orders of magnitude higher than what is currently known. As for spontaneous collapse models, PAMQ will increase the sensitivity of spontaneous radiation measurements, both from a theoretical point of view, by applying the new theory to generalised (non-Markovian) collapse models, and from an experimental point of view with a new germanium detector, which will allow the exploration of recent unified models of gravity and quantum mechanics.

The new line on **Nuclear Astrophysics with innovative sources** aims to study and measure the nuclear processes involved in the formation of elements in astrophysics, extending the measurements of the cross sections of relevant nuclear processes – which to date have been measured mainly in the laboratory, with elements in neutral form – to the plasma environment, where elements appear in their ionised form. The latter scenario more accurately reproduces the stellar environment in which the processes occur in nature and allows for a more realistic estimate of the parameters of interest. Nuclear physics therefore plays a fundamental role in the study of the relative abundances of elements in the universe: an accurate measurement of the cross sections for fusion processes, neutron capture and beta decay half-lives is strategic for evaluating the competition between possible processes and estimating which of them will take place. The project aims to outline an experimental campaign aimed at measuring fusion processes and beta decay half-lives in an ionised environment. The latter can be created using a high-intensity laser, which, when it reaches a target composed of the isotope to be analysed, produces immediate ionisation of the isotope, leading to the formation of plasma, in an attempt to reproduce the stellar environment as accurately as possible. To date, there are measurements of cross sections for fusion processes with neutral elements and a single measurement in a plasma environment, but it is necessary to collect sufficient statistics to significantly estimate the presence of an effect in the fusion process due to electron screening. Another aspect concerns the study of the variation of beta decay half-lives in plasma with some observations made at the storage rings. This project, planned in collaboration with the PANDORA project experimental group, aims to extend the PANDORA scientific programme. In particular, the project aims to expand the thermodynamic domain of plasma produced by the Electron Cyclotron Resonance (ECR) method through measurements in laser-produced plasma.

Enrico Fermi Museum

CREF's dual mission combines the enhancement of the historical and scientific heritage linked to the Physics Institute in Via Panisperna with the promotion of cutting-edge research. Historical research activities and communication strategies are intrinsically linked in order to achieve these goals.

The historical research conducted by CREF has focused on reconstructing the scientific, institutional and biographical events linked to the Royal Institute of Physics during the crucial period when Italian physics was at the forefront of the international scene. Among the results obtained is a significant in-depth study of key figures such as Pietro Blaserna and Orso Mario Corbino, analysing their leadership roles, their relationships with Enrico Fermi and his group, and their relationships with other eminent figures such as Guglielmo Marconi, also in relation to the research policy of the time. Particular attention has been paid to the often overlooked contribution of the female scientists who worked at the Institute (from Matilde Marchesini to Ginestra Giovene) and to Fermi's collaborations with female scientists in the United States (such as Leona Woods and Maria Goeppert-Mayer), also contributing to the aims of the CREF's Gender Equality Plan. The scientific trajectories of figures such as Gian Carlo Wick, Franco Rasetti and Bruno Pontecorvo were studied, and the period

following Fermi's departure was analysed, with the leadership of Edoardo Amaldi and the entry into operation of the Cockroft-Walton accelerator. These studies, based on rigorous analysis of archival sources and publications, have already produced concrete results for outreach and the multimedia world, directly feeding into the contents of the Enrico Fermi Museum, such as the historical timeline in the new entrance and the installation “1934-Annus mirabilis”.

The future objectives of historical research aim to investigate little-known aspects of the period between the unification of Italy and the post-war period, using a multidisciplinary approach. For 2025, on the occasion of important anniversaries, specific research is planned on the figure of Arturo Malignani and his patent for electric light bulbs, with a view to publishing a historical-scientific work. A documentary film dedicated to Ginestra Giovene is also planned. Research will continue to reconstruct physics research in Rome during the war, to explore the trajectories of “minor” figures and to celebrate the centenary of quantum mechanics (2025) by studying its reception in Italy through journals such as Il Nuovo Cimento and the role of academies.

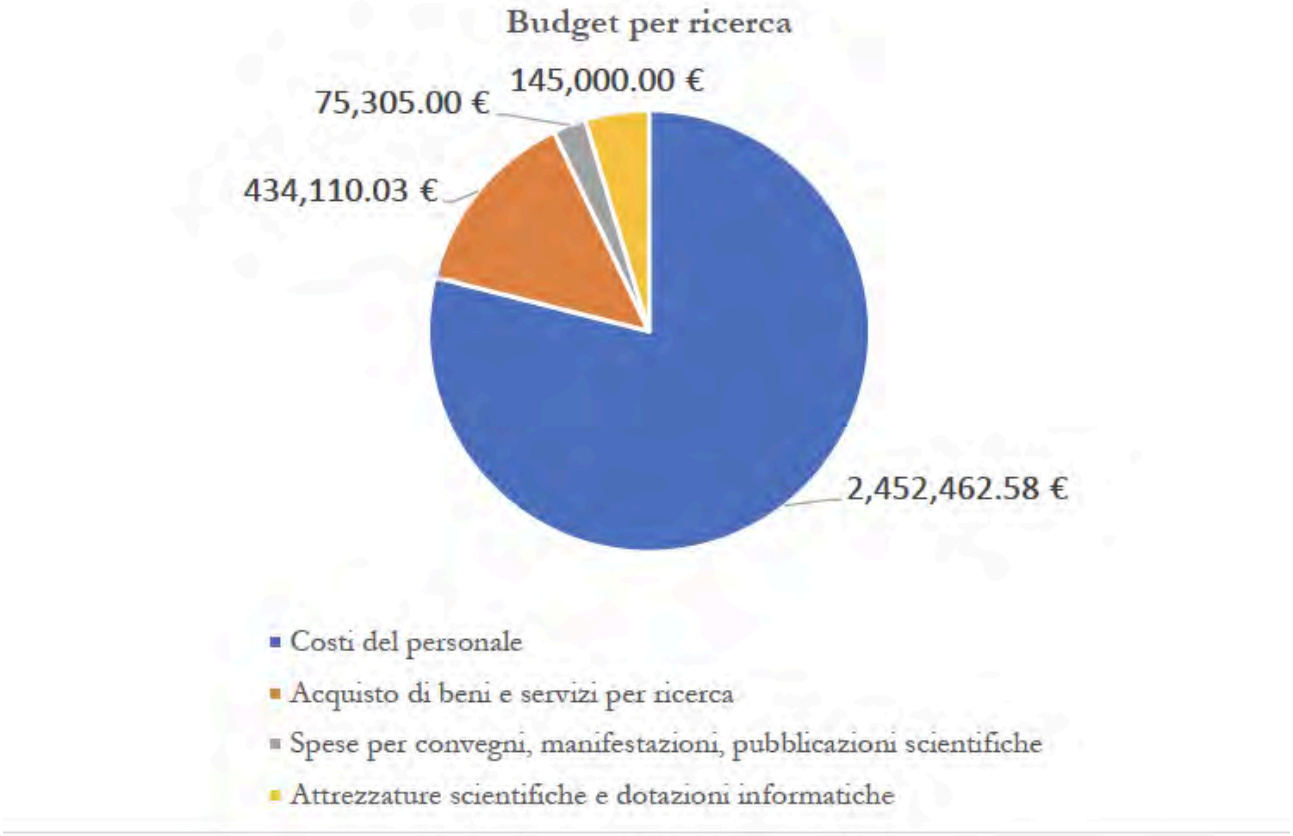
The aim is to provide a more accurate picture of this historical period, highlighting the cultural and educational value of the history of physics.

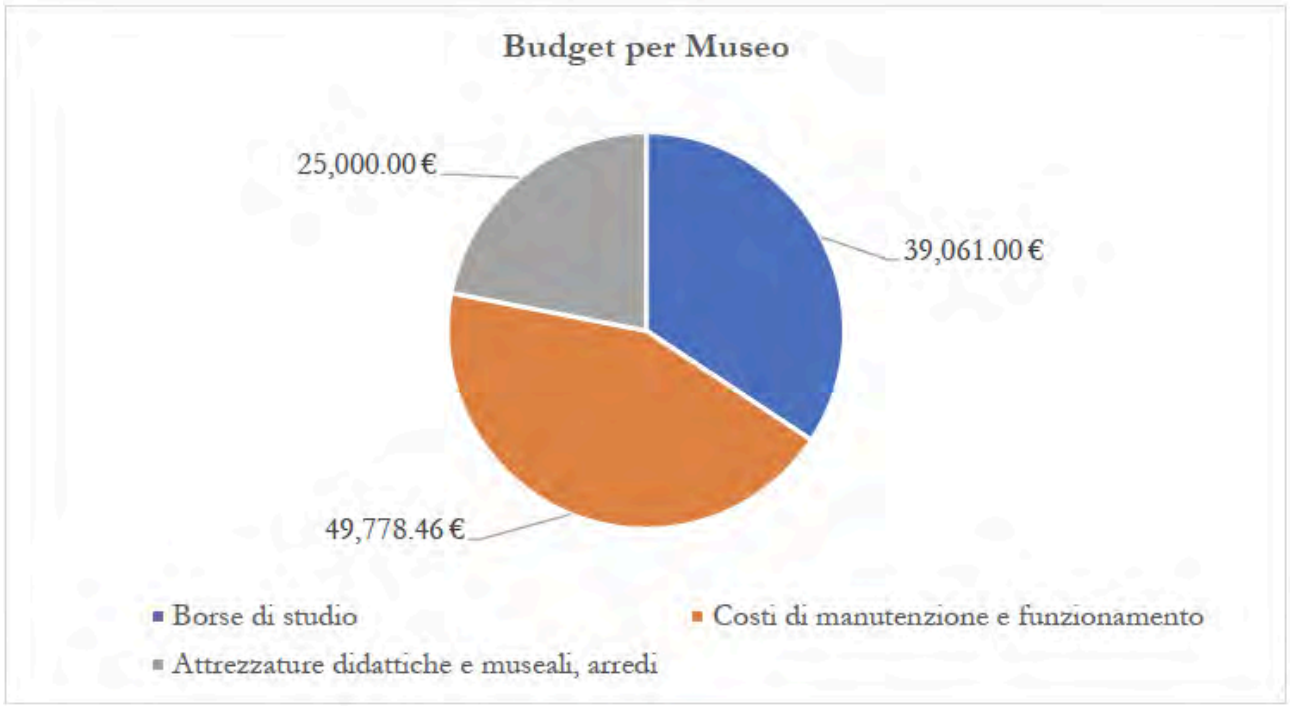
CREF's communication strategy has achieved significant results in connecting the past, present and future. The institutional website has been revamped and a modern, interactive website dedicated to the Museum has been created, which facilitates booking and offers in-depth materials.

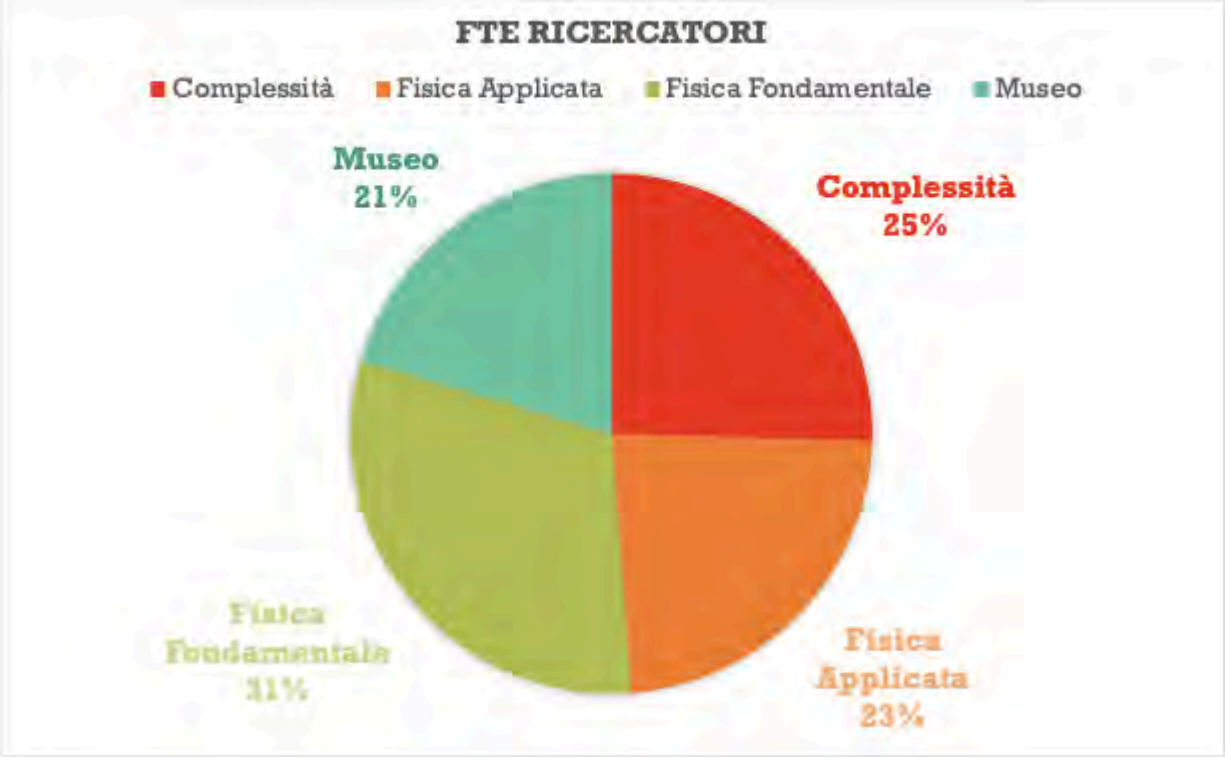
Public awareness of the historic building in Via Panisperna has grown thanks to events and conferences supported by a dynamic visual identity that combines historical and modern elements. Dissemination has been enhanced through conferences (‘Open Lectures’, a series on the Manhattan Project), archived on YouTube, and strategic management of social media channels (with proven growth in followers) and the newsletter. Participation in national events (Quantum Weeks, Rome Future Week) and collaborations with the media (Rai, Mediaset) have consolidated CREF as a point of reference for the history of Italian physics.

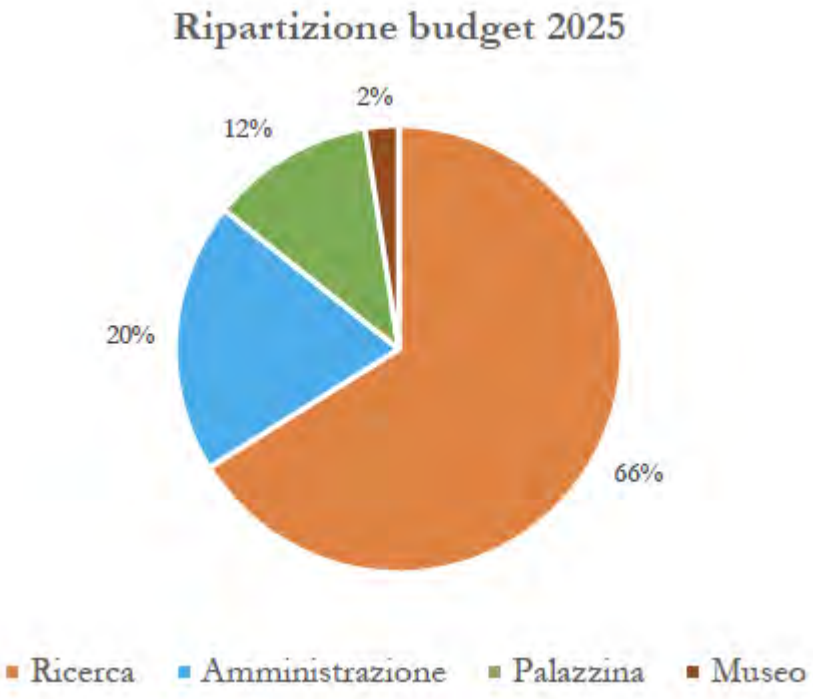
Future communication objectives are aimed at further supporting the growth and visibility of the organisation and the museum. The aim is to simplify the communication of research by grouping it into research areas, disseminating the results and promoting CREF as a training centre to attract talent. The intention is to encourage collaborations and enhance research infrastructure. For the Museum, the aim is to facilitate access to visits, enrich the online experience before and after visits, preserve historical memory and promote the idea of a dynamic science museum. Efforts will be made to increase visibility and engage different audiences with targeted and scientifically rigorous content. Seminars will also be offered to improve researchers' communication skills. The overall objective is to raise awareness of CREF's role, provide clear information and engage the public, consolidating the institution's identity as a meeting place for history, research and communication.

Research and Museum Budget






FTE RICERCATORI
Complessità
Fisica Applicata
Fisica Fondamentale
Museo
Museo
21%
Complessità
25%
Fisica
Fondamentale
31%
Fisica
Applicata
23%


Ripartizione budget 2025
2%
12%
20%
66%
Ricerca
Amministrazione
Palazzina
Museo

Ongoing projects and sources of funding

In addition to FOE 2025, amounting to €3,678,503.00, the external funding for ongoing research projects is indicated below:

ID PROGETTO	TITOLO PROGETTO	ENTE FINANZIATORE	IMPORTO COMPLESSIVO PROGETTO	STANZIAMENTI DI BUDGET 2025
2022_Savo_PNRR_SECOONDO	Comp-SECOONDO	Ministero università e ricerca	300.000,00 €	183.349,30 €
2024_CODE_PRINPNRR22	Coupling Opinion Dynamics with Epidemics	Ministero università e ricerca	32.591,00 €	27.040,79 €
2024_DIGITRANSITION_PNRR	Transizione Digitale M1C1 PNRR NextGenerationEU	Presidenza del Consiglio dei ministri - Dipartimento per la trasformazione digitale	286.048,00 €	164.700,00 €
2024_FONDO_TUCCI_TIBETANO	Studio diagnostico dei manoscritti 1326 ga e 1326 ka del Fondo Tucci Tibetano - convezione CREF-CNR-ISC	C.N.R. - Istituto dei Sistemi Complessi	1.500,00 €	1.500,00 €
2024_MULTIPASS_PRINPNRR22	MULTIPle trAcker for Secondary particleS monitoring	Ministero università e ricerca	131.645,00 €	130.071,70 €
2024_NET	ScieNcE Together - HORIZON-MSCA-2023-CITIZENS-01	Consiglio Nazionale delle Ricerche	19.968,31 €	13.135,18 €
2024_PHERMIAC_PRIN22	Photonic High-Energy cosmic-RaMonitoring via Ising machines and Advanced Combinatorial optimization	Ministero università e ricerca	49.400,00 €	21.830,69 €
2024_RECENTRE_PRINPNRR22	REal-time motion CorrEctioN in magneTic REsonance	Ministero università e ricerca	20.264,00 €	14.668,97 €
2024_RESPECT_PRIN22	Towards a new family of nuclear imaging gamma detectors	Ministero università e ricerca	106.408,80 €	76.069,45 €
2024_SINVASC	SINVASC_ The signal in the noise: advanced MRI methods for the characterization of the vascular component of BOLD spontaneous fluctuations - PNRR- PE MNESYS SPOKE 2 - Bando a cascata	Seconda Università degli Studi di Napoli	249.618,75 €	226.741,21 €
2024_SLOWSUMER_PRIN22	SLOW SUMER. Repair, Reuse, Recycling and Southern Mesopotamian Society in the Changing World of 2500-2000 BC	Ministero università e ricerca	56.205,18 €	41.997,89 €
2024_TRIPLE_T_PRINPNRR22	Triple T – Tackling a just Twin Transition: acomplexity approach to the geography of capabilities, labour markets andinequalities	Ministero università e ricerca	177.497,00 €	138.261,18 €
2024_WECARE_PRIN22	WEaving Complexity And the gReen Economy	Ministero università e ricerca	89.134,00 €	69.791,41 €
Progetto da codificare	Attivazione contratto di ricerca PNRR M4C2 - Inv. 1.2 "Sviluppo di imaging funzionale MR ad alta risoluzione per lo studio di fisiologia e funzione cerebrale"	Ministero università e ricerca	109.000,00 €	*In attesa del decreto di concessione del finanziamento*
IMPORTO COMPLESSIVO DEI PROGETTI DI RICERCA			**1.629.280,04 €**	**1.109.157,77 €**

Scientific output and trends 2024-26

The organisation's main scientific output, broken down by year, is listed below. It includes only contributions to indexed journals or volumes. Minor outputs and publications resulting from large international experiments in which the organisation played a minor role are excluded.

2024

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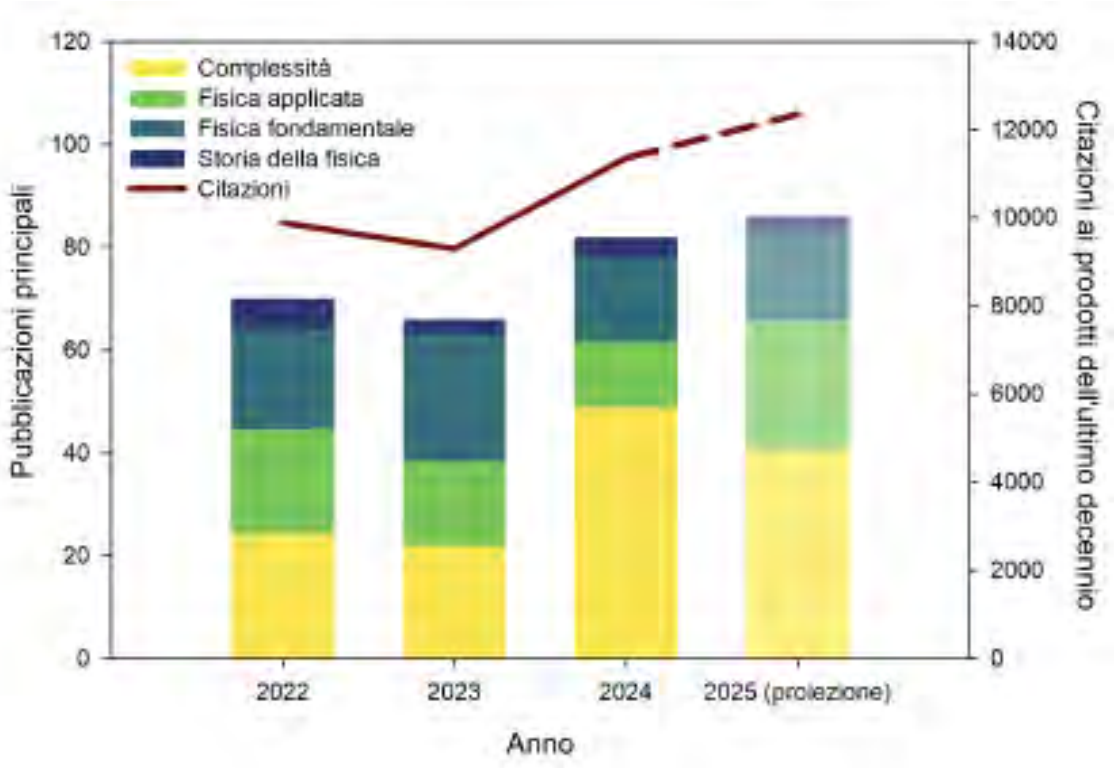
Summary chart of scientific output over the last three years

The trend in publications over the last three years is shown in the figure, which also includes a projection for the current year based on data collected up to the end of March. The same figure shows the citations received in the three-year period in question by the main scientific output of the last ten years, and the relative projection for the current year.



Television productions, radio broadcasts and documentaries

2024, concept and screenplay for the documentary film Omaggio a Ginestra (with A. La Rana and A. Scillitani) Artemide Film-Zanichelli. Short film on the life and work of Ginestra Giovene Amaldi.
2024, participation in the programme “Enrico Fermi una vita atomica - Nel secolo breve” (Enrico Fermi: an atomic life - In the short century) on Rai Storia (https://www.raiplay.it/video/2024/11/Nel-secolo-breve--
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2024, consultancy and participation in the documentary ‘Nel mondo dei fatti - Storia di Enrico Fermi’ (In the world of facts - The story of Enrico Fermi) Focus Mediaset (https://mediasetinfinity.mediaset.it/documentari/nelregnodeifatti-storiadienricofermi_SE000
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2024, participation in the programme ‘Fermi tutti: c'è la vasca dei pesci rossi’ (Everyone stop: there's the goldfish bowl) on Radio3scienza.
(https://www.raiplaysound.it/audio/2024/10/Radio3-Scienza-del-22102024-b5982cbc-cb0f-4eb0-8cf9-b4b133a148b4.html). 2025, assistance and organisation of filming for a RaiCultura special dedicated to the event for the presentation of the new installation Annus Mirabilis on 10 December – https://www.raicultura.it/speciali/viaggioalcentrodellatomogliesperimentidel1934
2025, assistance and organisation of filming for the programme “Ulisse il piacere della scoperta” (Ulysses, the pleasure of discovery), Rai, episode dedicated to the atomic bomb, broadcast at the end of May. Conferences, workshops, refereeing for journals, scientific committees In the three-year period 2022-2024, CREF researchers contributed with over 300 presentations at conferences, of which over 150 were by invitation. There has been a strong presence on conference organising committees and scientific committees, with over a hundred in total for the organisation of over 100 conferences and workshops.

Framework agreements and Conventions

Framework agreement and convention with the National Research Council (CNR)
Framework agreement and operational convention with the National Institute for Nuclear Physics (INFN)
Framework agreement and operational convention with the Santa Lucia Foundation in Rome
Framework agreement with Mercatorum Telematic University and the Study Centre of the Chambers of Commerce of Rome
Framework agreement with the Brera Academy of Fine Arts
Framework agreement with Tor Vergata University - Department of History, Cultural Heritage, Education and Society
Framework agreement with the Central Institute for Graphics
Framework agreement with the Municipality of Mentana
Framework agreement with the Academy of Fine Arts in Rome
Framework agreement with the Central Institute for the Pathology of Archives and Books
Framework agreement with the Historical Archives of the Pontifical Gregorian University
Operating agreement with the University of Bologna• Agreement with the GARR Consortium
Agreement with the “Policlinico Riuniti” University Hospital in Foggia
Framework agreement with the Département des Sciences de l'Antiquité of the University of Geneva
Memorandum of Understanding with the Institut Curie (Paris)
Memorandum of Understanding with the Science and Technology Facilities Council (UK)

Memorandum of Understanding with Complexity Hub Vienna, Sony Rome, King's College London
Over 70 agreements with secondary schools for the EEE project and for the history of physics
Over 20 agreements for PCTO with secondary schools and Sapienza University of Rome.

OUTREACH ACTIVITIES AND SOCIAL IMPACT

Support for advanced training

CREF actively promotes the training of young scientific talent through a structured and diversified advanced training programme, in line with its third mission and in close collaboration with academic institutions and strategic partners. Among the initiatives

● Doctoral scholarships. Through agreements (Sapienza, Tor Vergata, Roma Tre and the University of Bologna), CREF funds doctoral scholarships in Physics, History of Physics and Electronic Engineering. Doctoral students are involved in CREF's museum and scientific dissemination activities.

● Curricular internships in physics and communication and training scholarships for undergraduates, graduates and doctoral students interested in participating in dissemination and teaching activities related to the Museum.

● Scientific updating and networking for university students, PhDs and postdocs: International Day of Light 2024, organised by the Young Minds group in Via Panisperna on optics and photonics, with talks by experts from universities (Sapienza, Roma Tre), the National Research Council and CREF, and a round table on cutting-edge topics such as "Photonics between Artificial Intelligence and Quantum Information". CREF also hosted PhD Days, exchange and training days for PhD students, with the Universities of Roma Tre and IMT in Lucca.

● Seminars held by leading figures from the academic world on cutting-edge research in the field of physics, open to students and researchers from other universities and research institutions, including remotely (e.g. Rachel Grange ETH Zurich, Sushil Mujumdar (Optics Laboratory in TIFR, Mumbai), Prof François Lafond (Oxford University), Samir Suweis (University of Padua)

● Schools and workshops for interdisciplinary skills: Summer school on "Economic fitness **and complexity" in collaboration with UNU-MERIT in Maastricht. (Third edition) Aimed at** PhD students, young researchers and professionals, the summer school offers a comprehensive introduction to the framework of economic complexity, alternating theoretical and practical courses with expert presentations on advanced applications of the methodology in different areas of the social sciences. In April 2025, the first edition of a multidisciplinary Hackathon (neuroscience, statistical and network physics, computer science) will be organised as part of the international 'BrainHack' project. This initiative will involve young researchers from different university faculties, promoting collaboration, networking and the exchange of skills in complementary fields, with a specific focus on the brain.

● Emerging skills in Artificial Intelligence: Aware of the transformative potential of Natural Language Processing (NLP) and Large Language Models (LLMs) for scientific research,

CREF, in collaboration with Pi School, has organised an advanced course for its researchers and external collaborators. This initiative aims to provide advanced skills in these technologies to accelerate discovery and innovation in various scientific disciplines, with a particular focus on physics. The partnership with Pi School, founded by Translated and a leader in practical AI training, ensures a high standard of quality in the training offered.

Continuing and lifelong professional training

CREF collaborated with the Science Net consortium in organising training days for science journalists (2024 and 2025 editions) with the participation of its research staff. The focus of the first edition was on nuclear energy, while the second was on quantum mechanics.

In 2024, it participated in a pedagogical masterclass to offer school administrators, teachers and educators the opportunity to learn about teaching new technologies and the activities offered in this sector as part of the Karriere Quantum Project, organised by the German Ministry of Research in collaboration with the Goethe Institut d'Europa.

New methods of communication and dissemination of knowledge.

CREF is currently engaged in multi-channel communication strategies to broaden the dissemination of scientific knowledge and reach a diverse audience. In particular, articles on LinkedIn and carousels with graphics on Instagram. It also participates in documentaries and radio and television programmes, offering editorial and scientific advice. It is also committed to devising initiatives aimed at experimenting with new teaching approaches that are engaging and scientifically rigorous.

Interactive scientific games inspired by common game formats (such as bingo and memory) and adapted to different age groups, starting from nursery school. The aim is to make learning the basic concepts of particle physics a direct and engaging experience through movement and the reproduction of experiments. The materials produced are available for reproduction, loan and export to science festivals.

Diversified itineraries within the Museum for different age groups with specific modes of interaction and play (treasure hunt, Winterthur model for object analysis, interactive installation “Fermions and Bosons”).

“Science and Art” exhibition: in collaboration with institutions such as Città della Scienza, CNR-INO and the University of Florence (UniFI), an exhibition will be organised in May 2025 that will explore the intersection between artistic and design objects and fundamental concepts of optics, offering a new perspective on science.

Multimedia Installation ‘The Experiments of 1934’: on the occasion of the ninetieth anniversary, CREF has created a multimedia and immersive installation dedicated to the historic experiments of 1934. Through testimonies, narratives, documents and 3D reconstructions, visitors will be able to independently explore the scientific and human journey of this fundamental discovery, connecting personal memories with a rigorous historical and scientific reconstruction.

Production and management of cultural heritage: use of and access to museums and scientific collections.

Housed in the historic building in Via Panisperna (CREF headquarters) covering approximately 400 square metres and reopened to the public in March 2022 after the pandemic, the Enrico Fermi Museum is a dynamic reference point **for scientific**

dissemination, connecting the scientific legacy of Enrico Fermi and his group with contemporary scientific challenges and new generations.

A Technical Committee, composed of CREF researchers and supervised by the Scientific Director, coordinates and promotes the Museum's activities and collections, constantly monitoring its work through six-monthly reports on its functioning, attendance and development interventions.

The Museum aims to be a bridge between the past and the future, illustrating how the exploration of matter has been intertwined with the historical events of the 20th century, making science accessible to a non-specialist audience through an informal, diverse and engaging learning experience.

To achieve this goal, the Museum:

Actively involves research staff in outreach and third mission activities, participating in science festivals, setting up laboratories, exhibits and temporary exhibitions, organising conferences, presentations and debates on the history of physics, and offering itself as an information hub for **media productions related to the history of Via Panisperna.**

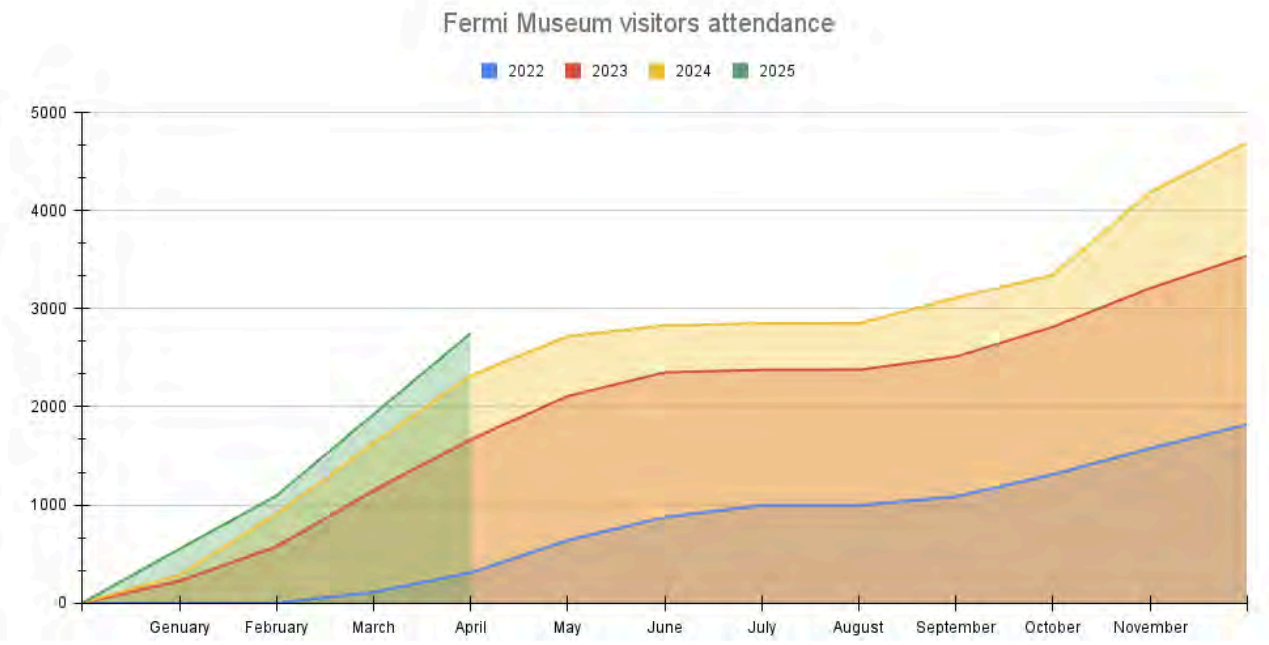
Organises specific activities for schools, including PCTO (Pathways for Transversal Skills and Orientation) and interactive visits to the CREF laboratories, enriching the museum experience.

Promotes a policy of networking through collaborations with prestigious Italian and international museums (AMSI, Curie Museum, Sapienza Physics Museum, Egyptian Museum).

It has created a strong identity as a point of reference for the history of Fermi and the Via Panisperna group, but also as a place of exchange and continuous dialogue between history, research and **dissemination.**

Access to the Museum and its collections is mainly guaranteed to schools on Wednesday mornings by appointment, with additional openings (Tuesday and Thursday) during periods of high school attendance. Monthly open days are organised for the general public. Dedicated visits for scientific societies and small groups are also possible by reservation.

Although the main target audience is secondary schools, since 2023, pilot visits have been successfully launched for lower secondary schools and fifth-year primary school classes, leading to the development of teaching materials and specific activities for these age groups.



In 2024, the Museum welcomed over 4,600 visitors, 71% of whom were students, confirming the public's growing interest .

At the organisational level, guided tours are conducted by the scientific staff of the organisation (who devote 10% of their time to these activities), supported by junior and training scholarships specifically dedicated to museum activities.

In summary, the Enrico Fermi Museum represents a strategic initiative by CREF to disseminate scientific culture, promote its history and engage the public, with a particular focus on the younger generations and the local area.

Public engagement activities

CREF acts as a dynamic link between the scientific heritage of the past and the challenges of the future, with the aim of making science accessible and relevant to the younger generation.

Making research results accessible through the website and social media channels, in particular LinkedIn, where informative articles on the organisation's publications are published and disseminated through a fortnightly newsletter.

Direct contact with research work and methodology through direct interaction with researchers and visits to laboratories as an integral part of the museum tour for schools.

Transversal skills and orientation courses (PCTO): in 2025, CREF launched a PCTO (Project Competences, Training and Orientation) in collaboration with the Sapienza Department of

Pysics Archive and Library: high school students will have the opportunity to conduct research in the archive on a topic related to the history of the Royal Institute of Physics and to present their research in a creative way (video, laboratory, graphics, etc.).

in a MAB-oriented course. A second PCTO on Physics for Cultural Heritage is planned for the 2025-2026 academic year.

● The Extreme Energy Events (EEE) project – "Science in Schools" is an innovative programme for the dissemination of scientific culture focused on the measurement and analysis of cosmic radiation at ground level. Launched as a pilot project in 2005, it actively involves around 80 Italian secondary schools in a cosmic ray physics experiment. Students and teachers participate in all stages, from the construction of muon detectors (telescopes based on Multigap resistive plate chambers) installed in schools to the analysis of the data collected. The EEE is a national cosmic ray observatory that studies the flux at the local level and investigates large-scale correlations. In 2018, the PolarquEEEst Mission was launched, with the installation in 2019 of three compact scintillation detectors in Ny Ålesund (Svalbard) in collaboration with the CNR, to study cosmic rays at extreme latitudes.

● **Santa Lucia Open Day Brain Awareness Week In 2024, for** Brain Awareness Week, the Enrico Fermi Research Centre and the Santa Lucia Foundation are organising an Open Day for secondary school and university students: a valuable opportunity to see first-hand how neuroscience is applied to rehabilitation and discover new frontiers in medical research on the brain.

● Actively contributing to the discussion on STEAM disciplines and the importance of gender balance through a conference on the presence of women in science throughout history. In particular, conferences on: The presence of female researchers in Via Panisperna between the late 19th and early 20th centuries, Laura Fermi, Lise Meitner, Marie Curie and a study day dedicated to Ginestra Amaldi, one of the first to popularise science in Italy using the mass media.

● Organising a series of conferences on the history of science to encourage open and critical reflection on the implications of scientific choices in today's society. For the 2024 series of "Open Lectures: Intertwining Physics and History", CREF proposed four conferences entitled "Manhattan Project: A Multi-Voiced Narrative". A multi-voice account'. During the conferences, the Manhattan Project was recounted from a scientific and historical point of view, with its human and ethical implications. To do this, we chose to rely on the voices of exceptional witnesses, with a perspective on events that was all the more interesting because it was less official and celebrated.

● Intensify our commitment to the dissemination of scientific culture through participation in scientific and cultural events and exhibitions. In particular, CREF participates in Researchers' Night at the Città dell'altra Economia (Rome): a "special night" dedicated to science, with numerous free events, including live scientific experiments and demonstrations, exhibitions and guided tours, conferences and informative seminars, shows and concerts. A project initiated and promoted by the European Commission since 2005 and funded by HORIZON-MSCA-2023-CITIZENS-01-01 with Marie Skłodowska-Curie actions. CREF is also a partner in the Genoa Science Festival, participating each year with workshops for children, conferences and virtual tours of the Centre.

● Strategically use the organisation's social media channels to amplify the reach of initiatives, share informative content and stimulate interaction with the public.