Annual Report to the President of the INFN

Il Comitato di Valutazione Internazionale (CVI)

L. d'Agnese, CDP, Italy; M.J. Borge, CSIC, Madrid, Spain; M. Bosman, IFAE, Barcelona, Spain;
A. Brandolini, Banca d'Italia, Italy; J. D'Hondt, Vrije Universiteit Brussel, Belgium (chair);
R.K. Ellis, University of Durham, UK; W. Hofmann, MPI Heidelberg, Germany;
N. Lockyer, Cornell Laboratory for Accelerator-based Sciences and Education, USA

October 2023

Introduction

The 2023 annual CVI meeting was held at LNGS from October 18th to October 20th. It gives us great pleasure to thank the INFN management and the LNGS team for the outstanding hospitality, the inspiring visits of LNGS's underground laboratories and the excellent planning of the meeting. Our charge was to evaluate the performance and quality of INFN's programs and management. In the sequence of biennial reviews of the four INFN national laboratories, this year's reviews focused on LNF and LNGS.

Executive Summary

Perspective and Strategy – INFN is a stronghold in the European and international context for particle, nuclear and astroparticle physics with impactful leadership across the field. The committee was pleased to find INFN in an excellent state with a bold scientific ambition and a management that is preparing INFN for a bright future with world-leading research infrastructures and advanced technologies. The committee recognizes the success of INFN leadership, the President, Executive and laboratory directors, to build upon their advanced technology base, past accomplishments, and infrastructure investments to effectively steer the future science program in exciting new directions and to prepare INFN for significant societal impact in the coming decades. Especially with the highly appreciated and timely PNRR resources, INFN has the capacity to realize its ambition. INFN has an impactful story to tell for a curiosity and technology-driven society. The establishment of an effective dialogue with the Minister of Research and the Prime Minister is testimony to this. Important progress has been made on projects on the ESFRI Roadmap involving INFN, and a successful concerted action between INFN and Prime Minister Meloni established the Einstein Telescope project on this roadmap. Based on a sound strategy to utilize PNRR opportunities for upgrading existing infrastructures and projects instead of initiating new ones, the year 2022 was an important year for INFN to successfully start the PNRR investments for infrastructure and for hiring technologists. The well-balanced portfolio of PNRR-supported projects and the new budgets allocated accordingly will have a decisive impact on realizing several flagship projects that will significantly strengthen INFN's reputation in the international research landscape.

Central Administration and its Directorate of Research Services – INFN is undergoing a program to modernize its Central Administration and provide more effective services to researchers. The new Directorate for Research Services is part of that effort. The CVI has observed significant progress in Central Administration with the completion of the program of outsourcing payroll and the streamlining of the procedures for hiring new personnel. The management of PNRR projects has proven to be a powerful driver of change, fostering cooperation between administrative and research management. An extension of this effort beyond the PNRR is required, both by administrators and researchers, to develop integrated project management skills to manage the economics of programs within the context of the new accrual-based accounting to be implemented by 2026. Extension of integrated project management, pioneered in PNRR programs, and continuous monitoring of performances in administrative, procurement and grant support services are required.

Technology Transfer – Technology Transfer is a small program, but its organization and management are rapidly improving. The growth opportunities are considerable in multiple areas and INFN has a good track record of moving innovative ideas and advanced technology to industry and society. Further investments would be well justified.

Commissione Scientifica Nazionale 1 (CSN1, Fisica delle Particelle) – CSN1 makes strong contributions and plays an important role in a broad set of particle physics experiments at colliders, mainly at CERN but also at many facilities around the world. The experiments are long-term with alternating phases of data collection and upgrading. A steady stream of new results is being produced, notably recent high-precision results in Higgs boson physics from the latest LHC datasets, or in flavour physics from the LHCb and Belle II experiments, at CERN and KEK (Japan), respectively. CSN1 is currently devoting a lot of effort to the construction of upgraded detector parts for the High-Luminosity LHC experiments. The transfer of neutrino accelerator-based experiments from the CSN2 purview to CSN1 further enriches the program with for example the DUNE experiment at Fermilab (USA). CSN1 is also strongly involved in shaping the future of the field by participating in studies for future particle colliders, such as the Future Circular Collider at CERN and the Muon collider facility, and in accelerator and detector R&D. In view of the next update of the European Strategy for Particle Physics, INFN is preparing to further contribute to shaping the future of CERN, so that the Strategy embraces the wide(r) scope of INFN ambitions.

Commissione Scientifica Nazionale 2 (CSN2, Fisica delle Astroparticelle) – CSN2 supports a wide range of experiments in astroparticle physics and the interest in this field continues to grow within INFN. Experiments are highly international and many of the world-leading experiments have strong INFN contributions and leadership. Highlight results have been reported in almost all areas of astroparticle physics, and the construction of major new facilities such as KM3NeT in the Mediterranean Sea or JUNO in China is progressing well. Significant progress has been made in securing the supply of critical isotopes, as required for the LEGEND and CUPID experiments at LNGS (Laboratori Nazionali del Gran Sasso). An important step is also the decision to locate the future LEGEND-1000 experiment at LNGS.

Commissione Scientifica Nazionale 3 (CSN3, Fisica Nucleare) – CSN3 supports a wide range of experiments in nuclear physics that require particle beams with energies from very low (10^3 eV) to very high (10^{12} eV) energies, provided by national and international facilities, including those at CERN. The year 2022 was marked by a number of important events. The series of the Nuclear Physics Midterm Plan meetings in Italy has been completed with over 1000 participants and the first two resultant contributions to EPJ Focus have already been published. This is timely to inform the European Nuclear Long Range plan, preparation of which started at the end of 2022. Important milestones have been achieved in installing, commissioning and first experiments with the coupled AGATA and PRISMA detectors at LNL (Laboratori Nazionali di Legnaro) and the new underground LUNA-MV accelerator at LNGS. In addition, the CVI was informed about the submission of several papers to journals with a very high impact factor.

Commissione Scientifica Nazionale 4 (CSN4, Fisica Teorica) – The INFN program of theoretical physics is strong and fully international. Targeted hiring might be deployed to better serve the strategic needs of the INFN experimental program. It could also provide a tool to resolve the gender imbalance. An increase in the number of post-doctoral positions and their extension to three-year contracts are important tools to attract and retain theoretical talent in Italy.

Commissione Scientifica Nazionale 5 (CSN5, Ricerca Tecnologica) – CSN5 coordinates INFN's research in the field of advanced technologies, enabling its core experimental activities, and promotes the development of instruments, methods and techniques in fundamental physics and their applications in other domains. An extensive program supports various projects, with one project seeding an ERC Consolidator Grant. The number of publications and thesis projects supervised within CSN5 is very high. An analysis of the impact of the grants for young researchers, previously recommended by the CVI, has shown the importance of this initiative as a seed for promoting new ideas, ERC grants and hiring bright candidates. In total 85% of the grant winners have obtained a permanent or a temporary position at INFN or at universities. A similar impact analysis is recommended for the "call for proposal" scheme.

The VIRGO gravitational-wave detector – The VIRGO detector has been critical to the recent major astrophysical discoveries with gravitational waves. The forthcoming program is very exciting, but the European Gravitational Observatory (EGO) and INFN must deliver a state-of-the-art working detector and more investment may be necessary to keep up with the sister interferometer LIGO. A successful VIRGO will be an excellent stepping stone toward hosting the ambitious Einstein Telescope.

The future Einstein Telescope – The Einstein Telescope effort in INFN and the Sardinia site candidacy to host this underground third-generation gravitational-wave observatory have progressed very well, with the strongest support by the Italian government. A design alternative with two spatially separated L-shaped interferometers instead of the previously envisaged triangle configuration is interesting because it promises improved science performance and enables a two-site implementation – potentially a win-win scenario. The dialogue between VIRGO and Einstein Telescope deserves to be strengthened, ensuring that the lessons learned are effectively shared.

The DarkSide experiment under constructed at LNGS – The DarkSide project has made enormous progress over the last year, strongly supported by the DarkSide Review Committee. While recent changes in detector design and assembly still require significant engineering and the cost and schedule implications of these changes remain to be fully understood, and while underground argon delivery and purification remain critical, the DarkSide Review Committee and the CVI are reasonably optimistic about the prospects of the project.

Laboratori Nazionali del Gran Sasso (LNGS) – The LNGS is establishing itself as the premier underground laboratory in the world. The LNGS has a world leading broad program in astroparticle, nuclear and particle physics and has expanded to include novel geophysics and biology experiments. The laboratory's present scientific program is highly impactful, and the future program will build upon the present success. The laboratory is operating safely and is well managed.

Laboratori Nazionali di Frascati (LNF) – INFN has a major ambition to develop advanced plasma-based accelerator technology with the EuPRAXIA project (European Plasma Research Accelerator with eXcellence In Applications) included in the ESFRI Roadmap. The CVI congratulates the LNF management on very significant progress on all fronts, including the establishment of the headquarters of the EuPRAXIA initiative at LNF. After several years of decreasing numbers, the CVI has noted an increase in LNF staff numbers for researchers and engineers. In addition, successful actions have been taken to engage more technicians. The DAFNE accelerator complex at LNF has been running smoothly and continues to deliver beams to impactful experiments and beam test facilities. In the transition to the future EuPRAXIA, the LNF management must develop a transition plan, including considerations for the current DAFNE program.

Laboratori Acceleratori e Superconduttività Applicata (LASA) – LASA, jointly operated by the University of Milan and INFN, is an international center of excellence for accelerator technology with more than thirty years of experience in innovative acceleration schemes and applications of superconductivity for magnets and accelerator cavities. Benefiting from the PNRR-funded IRIS project (Innovative Research Infrastructure on applied Superconductivity), for which LASA acts as national coordinator, LASA is expanding its capabilities and renovating its infrastructures. High-level negotiations are ongoing with the University of Milan to transfer the operation of LASA infrastructures to INFN, enabling INFN's ambition for LASA to become the hub of the National Superconductivity Network, open to academic and industrial partners, while maintaining its competencies and facilities in the field of superconducting particle acceleration technologies. While the combined program is attractive, the INFN must verify whether they have sufficient capacity to accomplish the full program.

Computing Services and the National Centre ICSC – INFN has addressed its growing need for computing power with a two-pronged approach: at the end of 2023 its main data center will move to a new hall in the Tecnopole Bologna, and in 2026 a major transformation of its data centers and communication network will take place within the context of the PNRR-funded ICSC project (Italian Centre for SuperComputing). In addition to the new infrastructure, ICSC involves the development of 10 computationally intensive research programs across various disciplines and research institutions in Italy. INFN (as the hub) is responsible for both the design and implementation of the infrastructure and for the overall supervision of the program. The infrastructure procurement phase and the writing of contracts with spokes to disburse the funds have been successfully completed, but the issues of the economic sustainability of the program and infrastructure beyond 2026, and the balance between public and private interests in the various research initiatives, require competencies beyond the traditional area of expertise of INFN. It is important for INFN leadership to dedicate resources and develop a detailed plan to address these challenges.

Long report

Perspectives and Strategy

INFN is a stronghold in the European and international context for particle, nuclear and astroparticle physics with impactful leadership across the field. The committee was pleased to find INFN in an excellent state with a bold scientific ambition and a management preparing INFN for a bright future with world leading research infrastructures and advanced technologies. Especially with the strongly appreciated and timely PNRR resources, INFN has the capacity to realize its ambition. INFN has an impactful story to tell for a curiosity and technology driven society. The realization of an effective dialogue with the Minister of Research and the Prime Minister is testimony to this.

The INFN budget for 2022 amounted to 579 M€, of which 166 M€ was contributed by PNRR, 121 M€ from specific projects and 292 M€ directly from the Minister of Research. From the ministerial budget, INFN has the ambition to keep the allocation to salaries below 50%, so that the talented INFN personnel can adequately invest in technologies and research. To maintain INFN's capacity, the increased budget from the Ministry by 8% between 2021 to 2022 was essential to match the additional costs coming from inflation.

Based on a sound strategy to utilize PNRR opportunities for upgrading existing infrastructures and projects instead of initiating new ones, the year 2022 was an important year for INFN to successfully start the PNRR investments for infrastructure and for hiring technologists. Enabled by the regular capacity of INFN, but especially boosted by the temporary PNRR resources, numerous research infrastructures established under the leadership of INFN are emerging at the forefront of science. The well-balanced portfolio of PNRR-supported projects and the new budgets allocated accordingly will have a decisive impact on realizing several flagship projects that will significantly strengthen INFN's reputation in the international research landscape. From a larger portfolio detailed in this report, two examples are INFN's central leadership in EuPRAXIA at LNF and the implementation of the top-ranked (4^{th} in the world) ICSC computing center near Bologna. Planning of INFN career paths for the personnel hired with PNRR funds after 2026 requires timely attention.

The committee was impressed by the unique opportunity for LNGS to become the world-wide reference laboratory for the neutrinoless double-beta decay searches with LEGEND1000 and CUPID, and for dark matter searches with DarkSide and XENONnT/DARWIN. In addition, the new LUNA-MV ion accelerator at the Bellotti facility is a unique reference in the field of nuclear astrophysics.

Important progress has been made on projects on the ESFRI Roadmap involving INFN, and a successful concerted action between INFN and Prime Minister Meloni established the Einstein Telescope project on this roadmap.

Many of INFN's scientific ambitions are enabled (1) by research facilities at CERN and (2) by CERN's capacity to assist progress with other and future research facilities. In view of the next European Strategy for Particle Physics, INFN is preparing to further contribute to shaping the future of CERN, so that the Strategy embraces the wide(r) scope of INFN ambitions.

A 12-year INFN investment plan of 160 M€ is approved to start in 2024 with the objective of maintaining the INFN research infrastructures. Special additional attention might be required in the short term for some of the (nuclear) facilities and from 2026 for the computing facilities.

In the area of fostering talented personnel, the CVI applauds the INFN management for enabling the excellent and timely opportunity to promote approximately 220 persons (researchers and technologists) to their next career stage within the INFN organization.

The INFN is well positioned for impactful contributions in various key directions of accelerator R&D towards future particle physics colliders and other applications. A strong commitment of INFN to the European R&D roadmaps for accelerators and detectors will impact INFN's capacity to act on future strategies in the field.

To further evaluate the state of the INFN organization, at the occasion of the annual meeting in 2024, the CVI would like to be informed about the following aspects:

- *an analysis of the INFN research infrastructures that require maintenance budgets in addition to the approved and resource loaded 12-year plan,*
- *how the use and development of AI methods and the related dedicated AI skills are fostered throughout INFN,*
- *the environmental impact of the INFN,*
- *the actions taken by INFN to improve the gender diversity among researchers and technologists,*
- *the ability of INFN to attract and retain foreign scientists,*
- *and the feasibility and impact of tenure track positions in INFN with respect to equivalent positions at universities.*

Central Administration

The central administration of INFN has recently started a program to modernize its processes and improving its skill mix. This year two key elements of this program have been accomplished. The payroll process has been successfully externalized (incidentally, as suggested by the CVI in the past) and an extensive hiring program has been completed, substantially improving the ratio of employees with university education to those who have only high school education (diploma).

Another recommendation of CVI has been implemented with the completion of a customer satisfaction survey involving the users of administrative services. More than the absolute value of the satisfaction score (7.2), the trend over time will allow to measure progress. It is therefore important to repeat the effort in the next years.

Activity on PNRR has been a significant effort, with CA involved in reporting activity ("*rendicontazione*"), legal activities, recruiting as well as a major effort in procurement, challenging procurement skills of the organization: volumes are substantially higher than those in the past, especially in highly competitive sectors like information technology. Shorter time frames may increase the risk of formal vulnerabilities in the process, with potential risks of administrative claims ("*ricorsi*").

The program is being so far perceived as a success not only in meeting interim deadlines, but also in pioneering a new way of working. We received positive signals about the progress in the integration between administrative and scientific "cultures". The integration appears more clearly at central level, favored by PNRR management.

A major challenge going forward will be the transformation from cash-based to accrual reporting which is required by law by 2026. This change will not affect administrative personnel only. It will force the entire organization to consider future costs deriving from unexpected events in projects as the event occurs, not when the expenses are actually paid, identifying sources of funds to pay for cost overruns at a much earlier moment in project life.

New hires in administration, often attracted by the reputation of INFN more than by the salary which remains uncompetitive compared to those of the private sector, can be champions of the new approaches as well as cultural change.

Recommendations:

CA-1 *– Plan for adequate and early training of resources for accrual-based reporting, including:*

- *an in-depth, technical training for administrative staff (including REGIS, the reporting IT system for public administrations developed by the Ragioneria Generale),*
- *and the basic concepts for managers of research.*

CA-2 *– Assign some project management tasks to junior/high potential new hires – the end objective being to train "project controllers".*

CA-3 *– Review early performance of procurement process in the first PNRR tenders: throughput times, effectiveness of competition, risk of supplier claims.*

Directorate of Research Services

The Directorate for Research Services (Direzione Servizi alla Ricerca, DSR) is a new structure involved in two new activities: central, integrated support for grant application and management, and PNRR project management. In addition to those two activities DSR has responsibility over Technology Transfer, that will be dealt with in a separate section of this report.

The service for grant applications oversees a process that starts with the identification of grant opportunities, continues with the support to researchers in preparing and submitting grant proposals and extends its support to grant management post award.

An integrated approach to this activity has, in principle, several advantages: identifying all opportunities for research grants benefits from significant synergies across different lines of research since individual calls may be of interest of several researchers; support for researchers in preparing and presenting their proposal should benefit from the accumulation of expertise by a dedicated team.

The directorate has started recording applications and success rates, but time will be needed to observe changes and evaluate the effectiveness of the new structure. A thorough evaluation will imply measuring success rates of applications against past years and other institutions. A potential element of vulnerability for INFN with respect to other research institutions in Italy, especially universities, lies in the more limited incentives INFN researchers have in securing important grants like the ERCs. Universities often assign important positions to researchers who have secured an ERC, while INFN researchers obtaining this type of grant do not obtain immediate career advancements.

PNRR projects are managed with a dedicated project management organization, supervised by DRS, and an interdisciplinary supervision by a committee composed of senior staff. This organization has helped to overcome early issues in projects, but programs are of course still ongoing, and risks of delays increase towards the end, since early PNRR milestones are generally less demanding.

Based on the initial success, INFN leadership is considering the extension of this approach to other projects, but doing that will require solving at least two issues: finding sufficient staff with project management skills and addressing the limited time availability of senior staff to supervise projects outside their specific research area.

Recommendations:
DSR-1 *– Measure in a systematic way the performance of grant applications. Identify gaps, with respect to other institutions who excel in securing grants, using two performance indicators: the number of applications per researcher, and the success rate of applications. Use findings from this analysis to provide feedbacks to applicants.*
DSR-2 *– Define a strategy and objectives for INFN in the acquisition of grants. More grants will provide additional resources but acquiring them may create a drag on researchers' time and their attention to existing experiments. Based on this strategy, consider reviewing incentives to researchers who acquire grants.*
DSR-3 *– Plan for the scale up of PNRR model to manage projects to other initiatives/programs, including:*

- *the training of additional staff in project management skills,*
- *and decide how to address the need of many senior resources to monitor multiple projects and overcome cross-functional issues; either appoint commissions for groups of projects or increase reliance on newly trained project managers.*

Technology Transfer

The INFN has a clear strategy statement for Technology Transfer (TT). It plans to move innovative ideas and advanced technology to the marketplace in order to benefit the society as a whole. There is a well integrated organization structure with three arms: a national committee for TT, a network of local representatives, and a service office with legal patent support.

The proof-of-concept PoC R4I program (2018) is effective but small (4-5/yr). The INTEFF program (2021) supports small grants. Nevertheless, active patents and subsequent license agreements give competitive success numbers compared to NETVAL (national numbers). This is an indication the structure is working well. CSN5 wins most of the patents & licenses, with a good record in medical field. The OPEN INFN program is 1.8 M€ (multi-year) initiative for training & increased links with industry (2022). Training programs are important in a basic science environment to ensure the technical staff and scientists are knowledgeable about opportunities.

Italy is known internationally for its strong links to superconducting magnet and cavity production technology companies of very high quality (e.g., ATLAS toroidal coils, ESS, TESLA). Given the impressive track record of TT transfer to industry, INFN should focus on the new opportunities in quantum computing, sensors, medical applications, and high temperature superconductor cable and magnets.

TT is a potential growth area for INFN. It is a small program, only 2 people in the service office for example, and capturing much less than 1% of the budget. A first step would be to develop a prioritized strategic plan for TT with a portfolio of 1-2 ambitious projects and a cadre of small projects, identifying opportunities where possible.

The INFN present approach is to "push" inventions and technology developments to industry rather than "pull." The preferred approach is "pull" and although the approach is changing, more is needed. INFN does reward its inventors, which is critical to maintain. The present 50% number is competitive. Continuing to improve the culture within INFN by training and further incentives is important.

The ultimate goal is not to raise profits from TT, but to allow the Italian economy and society to benefit from the INFN's great know-how and technological capacity.

Recommendations:
TT-1 *– Increase funding for TT. Further investment in the TT organizational areas is critically needed to fully exploit the multiple opportunities.*
TT-2 *– Attempts to integrate industry into the TT organization should be beneficial.*

CSN1

CSN1 coordinates INFN activities in particle physics at accelerators and promotes research and R&D for future projects in the field. Its rich program is organized in five lines of research: physics at hadron colliders, flavour physics, charged lepton physics, proton structure and R&D for future accelerators. The number of FTEs in the experiments is stable across the years (833 in 2022). It is complemented by an additional number of FTEs contributing to synergetic R&D activities with a slight upward trend (53). The FTE fraction is approximately constant at 70%, as well as the fraction of women (21.9%). All indicators of scientific productivity and quality of INFN contribution are excellent. The base budget (20 M€) has been constant until 2022. It is complemented by special funds for HL-LHC upgrade (4.9 M€) and various competitive funds (1.7 M€) for computing, whose amount varies with the year according to the expected needs. INFN decided to transfer the activities from accelerator-related neutrino experiments, so far under CSN2 purview, to CSN1. The transfer of the Fermilab (USA) neutrino experiments with its review process started in 2023. It will lead to an 9% increase in personnel and 13% in budget that will be made effective in the 2024 budget.

Here we report some highlights of the activities in the various research lines. At the CERN LHC, many full Run2 analyses are still coming to fruition with improved analysis techniques including, e.g., more precise measurements of Higgs coupling or evidence for four top quarks production by ATLAS and CMS. Many searches for beyond the Standard Model physics are also performed. The INFN-related Phase-1 upgrade of the ATLAS and CMS detectors was successfully completed during the 3-years Long Shutdown 2. Run 3 started by mid-2022, with the LHC running at the increased energy of 13.6 TeV. Commissioning took place and first results became available. The High Luminosity LHC upgrade of ATLAS and CMS is progressing, with most INFN projects close to or at production phase. The CMS spending profile is expected to peak in 2023, and ATLAS in 2024. There are some concerns about potential delays as the contingency for completion is in some cases below one year, even after a full revision of the schedule. Cost is another source of concern. A series of additional costs have been identified, in part due the loss of the Russian contribution, extra costs of the construction and impact of the change of exchange rate CHF/€. The total amount is estimated to be about 12 M€, 20% of the nominal cost (N.B. 14% of contingency was included in the initial budget allocation by INFN to cover the upgrade cost).

The LHCb experiment contributes to flavour physics. Highlights of the full Run2 analysis include the first evidence of direct CP violation in charm, and more precise measurements of the lepton universality observables R_K and R_{K^*}, now consistent with the Standard Model. CSN1 reviewed the status of the flavour physics field and concluded that the potential of precision measurements remains very interesting. During LS2, LHCb made a major overhaul of its apparatus with important contributions from INFN. The commissioning and installation extended during Run 3 and into 2023. An incident during the end of the year shutdown in 2022 damaged a foil surrounding LHCb p-p interaction region, impeding a proper positioning of the vertex detector and reducing its performance. The replacement of the foil during the next shutdown should solve the problem. On the other hand, the Belle II experiment at KEK (Japan) completed its first run in 2022. Highlights include a first measurement of B^0 decay to neutral pion pairs. Data taking should resume at the end of the year with increased machine luminosity. The BESIII experiment at BEPCII (China) collected $\psi(3770)$ data in 2021-23, producing many results like the evidence of a new neutral tetraquark composed of charm and strange quarks ($Z_{cs}(3985)$). Concerning future contributions to flavour physics, CSN1 is considering participation in a second upgrade of LHCb, currently targeting Run 5 and whose total cost is estimated at 175 M€. We support INFN's view to encourage LHCb to downscale somewhat the upgrade and implement as many as possible of its features already in Run 4. On the other hand, Belle II considers an upgrade during LS2 starting in 2027 that would maximize physics reach at full luminosity. CSN1 is evaluating its possible participation. Kaon physics is addressed by the NA62 experiment that has shown that the expected 15-20% precision on the measurement of $BR(K^+ \rightarrow \pi^+ \nu\nu)$ is within reach. Future upgrades are under considerations (High Intensity Kaon Experiments) with possible participation from INFN.

The main highlight in charged lepton physics is the new result of the Muon g-2 experiment at FNAL, confirming and increasing the significance of the long-standing discrepancy between the theory prediction and the experimental value, currently at 4.2 σ. New results have also just been published by MEG-2 ($\mu \rightarrow e\gamma$). Last but not least, INFN prepares for the future of particle physics with a strong commitment to R&D for the Future Circular Collider project aimed at constructing a 91 km-circumference e^+e^- circular collider at CERN to operate as electroweak and Higgs factory, followed by a hadron collider in the same tunnel. INFN is also strongly committed to the design of a 10 TeV Muon Collider facility, whose components like superconducting magnets, RF cavities have strong synergies with other future collider projects. Specific funds are provided for accelerator R&D to boost the participation of INFN accelerator community.

The hand-over from CSN2 to CSN1 of the accelerator-based neutrino experiments has started, involving members from both sections for a smooth transfer of reviewer expertise. The experiments concerned so far are the short-baseline ICARUS and the long-baseline DUNE at Fermilab. The ICARUS 600T, originally operating at Gran Sasso, was moved to Fermilab and started data-taking by mid-2022. DUNE, on the other hand, aims at starting science in 2028. INFN's contribution is broad & strong. The construction of the Far Detector Photon Detection System, to be installed in the Sanford Underground Research Facility, has entered the construction phase with an important INFN commitment. The Near Detector SAND also relies on various INFN contributions. The magnet of the KLOE experiment at Frascati will be reused, as well as its electromagnetic calorimeter. There are some concerns about possible delays in that part of the project. The Straw Tube Tracker is in the design and prototyping phase, while GRAIN (a Liquid Argon detector) will be tested at LNL. INFN is also involved in the ProtoDune program at the CERN Neutrino Platform and in SND@LHC, a compact neutrino experiment that recently published the first observation of neutrinos produced at collider.

CSN1 manages large projects with spending profiles peaking in time, potentially overlapping, a point that deserves attention. It is also worth noting that the future of CERN FCC project will have strong implications for the field of particle physics and consequently for INFN, whose activities are tightly linked to CERN. The mid-term report of the FCC project expected in 2024 will be an important milestone, as well the next European Strategy for Particle Physics update expected around 2026.

CSN2

CSN2 supports research in astroparticle physics and specifically in the four research lines (i) Dark Universe, (ii) Radiation from the Universe, (iii) Neutrino Properties and (iv) General Relativity and Quantum Physics. CSN2 is a bottom-up committee, representative of the community. The community engaged in CSN2 increased by a factor 1.5 from 2015 to 2022 (from 931 to 1549 persons, from 660 to 991 FTE), demonstrating the attractiveness of the field. The level of funding of CSN2 activities increased but not fully commensurate with the increase in personnel; over the last three years, the budget was constant at 13.7 M€. CSN2 supports an interesting and appropriate mix of large, mid-scale, and small experiments, and of “safe” and highly innovative / high risk / high impact experiments. The portfolio of almost 50 experiments in CSN2 appears large, given the size of the community and the budget, but this portfolio is well managed by CSN2, with clear procedures, steady monitoring of progress and detailed attention to critical cases. Apart from few cases (e.g., experiments being terminated), the engagement (measured as the typical FTE per person) is good. CSN2 is of course aware that taking on new initiatives will usually require termination of other less promising activities.

Excellent science is being done in CSN2. Experiments are highly international, with 95% of FTE in international collaborations, in which Italian groups are well represented. Many world-leading experiments have strong Italian contributions and leadership. CSN2 researchers tremendously benefit from PNRR funds which provide a unique boost for underground infrastructure (LNGS), neutrino and gamma-ray astronomy (KM3Net and CTA), and the preparation of ET, further strengthening INFN’s role. The PNRR-driven expansion of large-scale computing and high-speed networking will prove beneficial for many of CSN2’s instruments.

Only few selected highlights can be listed here. Highlights from “Radiation from the Universe” include the AMS2, CALET, DAMPE precision measurements of primary and secondary cosmic rays and isotopes; an additional AMS tracking layer will significantly increase acceptance of AMS. The AUGER upgrade in progress with strong INFN contributions will allow measuring CR composition event by event, for better understanding of spectra and anisotropies. With XRO / IXPE, gamma-ray polarization provides a key new handle; already ~100 papers appeared on variety of source classes.

In the area “Dark Universe”, XENONnT provides improved DM limits, with the lowest ^{222}Rn background ever achieved; the experiment is now in science run 2. EUCLID was successfully launched in 2022 and has provided first images, towards determining the properties of dark energy and dark matter on universal scales. Construction of new DM experiments such as DarkSide and COSINUS is progressing.

In “Neutrino Physics”, CUORE deserves mention, with stable running and new results for 2 T yr exposure. LEGEND-200 data taking has started; the measured background is consistent with target value. JUNO construction has started and is progressing well.

KM3Net supports a very broad program in neutrino physics, from neutrino oscillations to neutrino astrophysics. PNRR support allows the ARCA detector to reach critical mass, providing additional 65 DUs; the implementation is largely on track. The deployment of DUs progressing well; the past technical problems regarding sea infrastructure and DU reliability look solved. In ARCA, 28 ARCA DUs are taking data, with promising first science results. Since PNRR covers the production of additional DUs, but not transport & deployment, the respective funding of personnel beyond PNRR may still need to be resolved.

Gravitational wave experiments (VIRGO, ET) are covered elsewhere in this report, but also the range of smaller experiments probing basics of gravitation and quantum dynamics deserves mention (ARCHIMEDES, GINGER, GRAFIQO, SATOR-G, ...).

Excellent progress is observed regarding last year’s recommendations: (1) Regarding the isotope procurement for CUPID and LEGEND-1000, solutions are likely in hand and in discussion with respective agencies; (2) a decision was taken by DOE and the collaboration to baseline LEGEND-1000 at LNGS, giving the lab a unique role in exploring neutrinoless double beta decay; and (3) as reported elsewhere, excellent progress was made towards securing INFN’s role in the Einstein Telescope.

Concerns:
CSN2-1 *– The uncertain status of the cooperation with China in space experiments, in particular for HERD where a large community is involved and where INFN should push to resolve the situation.*
CSN2-2 *– The continued refusal of DAMA to open their data undermines credibility of experiment.*
CSN2-3 *– An observation in CSN2 is that many small and innovative experiments start from ERC grants, but run out of resources or time and then require CSN2 support. It is encouraged to inform/involve CSN2 prior to ERC submission.*
CSN2-4 *– The gender (im)balance in CSN2 remains a concern; the situation is stable but not improving and requires the continued attention of CSN2 management and INFN.*

CSN3

CSN3 continues to provide a high science output across all six interconnected research lines: Quarks and Hadron Dynamics; Phase Transitions in Hadronic Matter; Nuclear Structure and Reactions; Nuclear Astrophysics; Symmetries and Fundamental Interactions; Applications and Societal Benefits. The number of FTE’s working on CSN3 projects remains constant (~500 FTE) but the overall number of people has increased steadily to approximately 800, highlighting the cross-disciplinary work of nuclear physicists with other CSN projects. The percentage of women is relatively high between 25-35% and the fraction is even higher reaching 50% at the level of defended master’s theses.

CSN3 supports an interesting and appropriate mix of large, mid-scale, and small experiments, and of “safe” and highly innovative / high risk / high impact experiments. The portfolio of 23 experiments is well managed by CSN3, with clear procedures and detailed attention to critical cases when the number of participants in certain experiments is too low. In this case they proactively propose closing the activities and propose joining other experiments. This has already been done for LEA (Low Energy Antimatter) and it should probably happen with JLab12 and EIC groups.

Excellent science is being done in CSN3. Only few selected highlights can be listed here. Highlights from *Quark and Hadron Dynamics* are the precise determination of the ^{48}Ca form factor with implications for the neutron-star equation of state (PRL, JLAB) and benchmark for proton polarizabilities at A2 (PRL). Important also to notice the highly significant contributions of INFN groups to the Yellow Report of the EIC, including simulations and R&D work. In the line of *Phase Transition in Hadronic Matter* we highlight the good performance of ALICE and among their results the violation of universality of charm fragmentation.

In the area of *Nuclear Structure and Reactions* several impactful results have been achieved, e.g., the possible evidence of an Efimov state in ^{12}C (NPA), the short-range pairing interaction probed by extensive lifetime measurements of proton-rich nuclei done with AGATA-VAMOS at GANIL that revealed a perfect conservation of seniority quantum number in N=50 (PRL). The NUMEN team has prepared a Prog Part Nucl Phys publication on heavy-ion double change-exchange reactions to be delivered in 2023. Multinucleon transfer studies, in particular proton and two proton transfer, were studied with PRISMA to determine the reaction mechanism, the much larger 2p transfers compare with calculations demonstrating the presence of strong proton-proton correlations (PLB). Within the *Nuclear Astrophysics* line: in addition to the study of Coulomb free pp scattering (Nature Com 2023), we highlight the results of LUNA400 on the reaction of $^{12,13}C$(p,gamma) to determine the $^{12}C/^{13}C$ ratio in Asymptotic Giant Branch (AGB) stars. The PANDORA experiment is getting ready to make the beta-decay studies in plasma, a pending subject since many years.

In the line of *Symmetries and Fundamental Interactions* we highlight the investigation of the possible violation of the Pauli principle in atomic transitions of ancient roman lead (PRL) and the spectroscopic determination of the hyperfine splitting of muonic atoms (FAMU @RAL). In the line of *Applications and Societal benefits*, FOOT will complete the apparatus in 2024 however, it is already taking data at HIT and CNAO for nuclear reaction measurements for hadron therapy and radioprotection in space, first results already published (JINST). In addition, it is important to mention the new infrastructure at SPES-MED aiming to identify new production methods of isotopes for theranostics medical studies.

At the level of R&D activities, the INFN groups have identified synergies based on the new ALICE Inner Tracking System (ITS3), the EIC e_PIC detector, and the NA60+ upgrades at the CERN SPS. These synergies are very important and they will require dedicated funds as well as to understand whether ALICE3 will be realized.

Recommendations:
CSN3-1 *– LNL with the proactive support of INFN should try to keep AGATA with its vibrant program beyond 2025 allowing for the study of radioactive nuclei produced in the SPES Facility.*
CSN3-2 *– The coming years are crucial for the upgrade of accelerators at LNS and start of SPES. It is important that the recent advancements in both laboratories are kept at the same pace. Funding and personnel should be provided in order to avoid extra delays.*

CSN4

The Italian program of theoretical physics pursued by the INFN in CSN4 continues to be one of the most successful in Europe. INFN researchers are fully integrated into European research and have international impact. The INFN theoretical community pursues research over a wide range of topics, divided into six lines of research. String and Field theory, Particle physics phenomenology, Hadronic and Nuclear Physics, Mathematical methods, Astro-particle physics and Cosmology, Statistical and applied physics. The overall satisfaction with the level of theoretical support provided to INFN experimental activities appears to be good. Conference talks and participation in international schools appears to be recovering after the pandemic. The committee was pleased to hear of the restoration of the theoretical effort at LNF, which was a CVI recommendation in a previous year.

The tools used by the INFN to manage the program in decreasing order of importance are:

1. the running of recruitment processes for INFN research staff positions,
2. the organization of training activities for young researchers,
3. the recruitment of Italian and international researchers for post-doctoral positions,
4. and the management of *iniziative specifiche* as national networks focused on topics of current research.

In the 2022 call for CSN4 researcher positions, the percentage of female winners (16.7%) exceeded the female percentage in applicants, (13.5%). The situation regarding gender balance in CSN4 still remains unsatisfactory. This gender imbalance displays some features. First, the percentage of females for INFN associates is 14.2% but only 11.7% for INFN staff who have gone through the INFN recruitment process. Second, gender balance is better for researchers working in Hadronic and Nuclear Physics and Astroparticle physics and Cosmology. Note is taken of the efforts to redress the imbalance, such as the Baldo-Ceolin prize for women in theoretical physics and the 25 new bursaries to support female 1st-year master students, distributed equally between the five National Scientific Committees. The efficacy of these initiatives in addressing the gender imbalance remains to be seen.

The training of young researchers occurs in the INFN is several ways. First, the organization of schools for PHD students at the Galileo Galilei Institute. In addition, the INFN funds PhD fellowship at Universities and INFN staff supervise theses both at the undergraduate and post-graduate level.

The INFN funds post-doc positions in three ways. First, it co-funds research bursaries (*assegni di ricerca*) together with university physics departments. Second, via the recently created Cabibbo fellowship which funds 2 years at LNF + 1 year at one of the INFN Sections attached to the 3 universities in Rome. Third, by running its own post-doctoral program either for foreign citizens or for Italians who have worked abroad for at least three years. This last program, which currently funds 14 positions per year is crucial to prevent a loss of Italian talent, attracted by more favorable economic treatment elsewhere in Europe. Because of the newly agreed mid-February deadline for post-doctoral positions, in terms of timing of the award of post-doctoral positions there is no reason why these INFN positions should not be competitive with other European countries. We encourage the INFN to consider increasing the number of these positions and their duration with a view to attracting/returning talent to Italy.

The progam of Iniziative Specifiche (IS) appears to be dynamic. The committee examined the case of TEONGRAV, where the number of adherents has grown significantly in response to the greater interest in gravitational waves. The IS appear to run over many years. The committee endorses the review of the IS every 3 years (including by international referees), particularly if hard choices are made regarding ending old projects and starting new ones.

Recommendations:

CSN4-1 *– The Executive board should investigate the possibility of targeted hiring procedures for researchers (in the area of theoretical physics), which might better serve the strategic needs of the INFN.*

CSN4-2 *– Some doctoral training activities should also continue to be targeted towards the future experimental activities of the INFN.*

CSN4-3 *– To make the case for an increased number of post-doc fellowships, it would be important to collect and analyze data from other European countries, with respect to the number, duration and employment conditions of post-doc positions.*

CSN5

CSN5 coordinates advanced technological research for INFN core experimental activities and promotes the development of instruments, methods and techniques for fundamental physics and their application in other fields. Its activities involve about 600 FTEs and have a significant social and economic impact. A prominent fraction of FTEs (32%) are women. The number of publications is very large, and CSN5 is enthusiastically involved in the "researchers' night" organized at universities. CSN5 naturally deals with activities that have impact on society, e.g., financing projects for diagnosis and clinical treatments, environmental analysis, and cultural heritage.

CSN5 has three research lines which may overlap dedicated to accelerators (superconducting systems, cavities and coating), detectors, electronics and computing (detectors, quantum sensing, AI) and Interdisciplinary physics (dosimeters, hadron therapy, AI in medical applications). Their activities can give rise to high-TRL patents for industry. Funding allocation is relatively stable over time, around 6,2 M€ and across the research lines with "detectors, electronics and computing" getting in 2022 about 40%, similar amount for "interdisciplinary physics" and half for "accelerators" around 20%.

Funding for projects is distributed in three categories: Standard projects (84) of 2-4 years receiving up to 100 K€/y, Calls for proposals (12) of 3-4 years receiving up to a total of 1 M€ and Grants for young researchers (17). The large number of simultaneous projects in 2022 is partially due to delays introduced by the pandemic-period. This number will reduce in the coming years.

Standard projects account for the core of CSN5 research: they aim to foster new ideas, high risk-high impact projects, seed projects and medium-small experiments supporting wider activities. Calls for proposals select exceptional and very challenging projects involving high numbers of researchers. As example the ERC consolidator grant DANAE is seeded from the BULLKID and BULLKID2 projects and the Techno-CLS EIC Pathfinder project dedicated to emerging technologies for crystal-based gamma-ray Light Sources. Other interesting highlights are the production of radiation detector of in-vivo dosimetry for astronauts within FIRE project and state of art for ultra-low power detectors within the ARCADIA project.

The CSN5 emphasis on fostering interdisciplinary activities is highly considered. The competitive assignment of internal funds after rigorous evaluation, as well as the follow up at the different stages of the projects is important. Following the request of last year's CVI to review the impact of Grants for young researchers, it is found that Grant winners have demonstrated the ability to realize a successful career as researchers and develop new research projects. The young researchers grant winners stay in 85% of the cases in academia, either at INFN or at universities. One can conclude that this is a good tool for identifying promising researchers and improves their motivation allowing for independence and leadership in projects.

Recommendations:
CSN5-1 *– CSN5 should report on the impact, uniqueness and significance of the "Calls for proposals" projects. It should indicate the connection and collaboration with groups outside Italy, and how they are the seed for EU-projects.*
CSN5-2 *– CSN5 should use the committee in charge of the selection of the projects to identify the best (young) researcher projects that have the potential to become an ERC grant. Once the grant project is successfully realized, they can serve as proof-of-principle for the ERC request.*

VIRGO

The observation of gravity waves and the surprising results about black holes and neutron stars is one of the most exciting new fields in all of science. LIGO, and now VIRGO, measure ripples in space-time due to the most violent events in the cosmos using kilometer-scale highly sensitive interferometers. As a part of the International Gravity Wave Observational Network, the VIRGO role is critical in identifying the sky location of the source. Improvement of a factor of ten over just LIGO was demonstrated after the first VIRGO observation. LIGO performance is characterized by a number, which represents the ability to detect a binary neutron star (BNS) merger, typically in the range 100 Mpc (1 pc or parsec is 3.26 light years). The VIRGO BNS merger performance is about 40-50 Mpc. KAGRA, located in Japan is just beginning with 0.7 Mpc. A gravitational wave event, measured by both LIGO and VIRGO, at 4 Giga parsecs has been observed, the furthest yet.

Science from Observation Runs O1-O3 have definitively identified 90 binary black-hole mergers and numerous binary neutron star mergers, some with gamma ray bursts, and numerous surprises including BH with masses that should not exist. There is also evidence of spin precession. All this incredible data has opened an exciting new field of gravitational astronomy. Presently LIGO and VIRGO are viewing events from about 60% of the universe. Both LIGO and VIRGO are attempting to double the sensitivity for Run O4. Unfortunately, the VIRGO upgrade ran into noise issues which have yet to be resolved and O4 has started without VIRGO. One problem discussed was the poor performance of the "marginally stable recycling cavities". LIGO uses "stable recycling cavities" which are preferred but are much more expensive and require more space. Until this problem is resolved, improved reliable performance of VIRGO will be limited. The collaboration recently stated they will join O4 in March of 2024 even with reduced performance and regardless of whether the noise issues have been resolved.

Recommendations:
VIRGO-1 *– The committee supports joining the important O4 science run in March.*
VIRGO-2 *– A plan for two reviews of VIRGO is underway by EGO, one technical and one regarding organizational challenges. The committee supports these in-depth reviews and would like to be informed of the outcome. Much can be learned from these two reviews in preparation for the Einstein Telescope Project.*

Einstein Telescope

Since the discovery of Gravitational Waves (GW) in 2015, LIGO/VIRGO have achieved a range of important results, including the observation of Black Hole (BH) mergers over a wide BH mass range, neutron star mergers, the link between mergers and r-process nucleosynthesis, measurements of the Hubble constant, the confirmation that GW propagate at the speed of light, and constraints on the nuclear equation of state. As the next-generation GW detector, the Einstein Telescope (ET) is a key instrument for exploring the Dark Age of the early Universe. ET addresses a broad science scope, covering the evolution of Black Holes from early Universe until today; primordial Black Holes and the GW background; precision tests of general relativity; Dark Matter & Dark Energy; cosmology; as well as nuclear physics. ET requires significant R&D in interferometer physics and technology, going far beyond the current state of the art. ET will require a complex & challenging technical infrastructure, including the world's largest vacuum system. Italy is proposing Sardinia (Sos Enattos) as site for ET, a region with very low seismic noise.

Towards ET in general and in supporting the Sardinia site candidacy in particular, INFN achieved and reported very impressive progress since last CVI meeting:

- highest levels of the Italian government have pledged demonstrative and highly visible support of the project;
- a high-level Scientific and Technical Committee was formed, advising the ministry;
- a letter of commitment for support of Sardinia ET construction is in preparation;
- a PNRR project is progressing, both supporting the site candidacy, and advancing instrument technology in general;

- supported by EC INFRADEV funding, ET is working towards defining organizational structure;
- via a joint agreement with IFAE, INFN and NIKHEF, CERN became involved in the R&D program for and the design of the ET vacuum system;
- theory engagement is growing, supported via three Iniziativa Specifiche (INDARK, NEUMATT, TEONGRAV);
- and the science performance of different instrument configurations has been evaluated for a wide range of science cases.

INFN rightly emphasized that in the increasingly important context of multi-messenger astronomy, the science case of GW instruments continues to evolve, with the ability to localize sources gaining in importance. With this in mind, a configuration with two spatially separated L-shaped interferometers of 15 km arm length is investigated and promoted by INFN as alternative to the 10 km triangle; this configuration provides interesting features, namely (i) improved science performance, in particular regarding source localization; (ii) less challenging implementation (but still requiring technology well beyond current state of the art), reducing the risks; (iii) somewhat higher cost, but the configuration enables a two-site solution and additional funding sources. The CVI considered this a promising approach worth pursuing.

Legal entity and organization of ET are under discussion; the stated current Italian preference for an IGO is plausible, given the experience from SKA (IGO) and CTA (ERIC), and given the various limitations and restrictions of an ERIC. Evidently, ET organization will incorporate the lessons learned from EGO/VIRGO.

Recommendation:
***ET-1** – The CVI considers it important to strengthen the dialog between ET and EGO/VIRGO to share knowledge and reduce risks for ET.*

DarkSide

Based on its excellent background rejection capabilities, DarkSide aims at providing world-leading limits on interactions of dark matter particles, or their discovery, with sensitivity approaching the neutrino floor. Over the last year, the DarkSide project has made enormous progress. The work and impact of the DarkSide Review Committee (Forti Committee) deserves high praise. The committee – with two major annual meetings and many smaller meetings in between – has proven highly beneficial both for DarkSide and LNGS as a host lab. Major progress was achieved in virtually all areas of DarkSide – most visible is the installation of the huge cryostat in Hall C of LNGS. The project now has reference baseline, a full cost book, and improved project management e.g., including change control procedures. The impressive NOA facility at LNGS is ready and testing of SiPMs is underway, showing excellent yield. The – in the past often difficult – interaction with host lab has much improved. A construction MoU among funding agencies is being signed.

On the other hand, DarkSide introduced significant changes in design and installation procedures at a very late stage, in particular concerning the addition of a heavy neutron shield around the TPC (driven by poor radiopurity of the cryostat foam), a change of argon delivery from gas to liquid (triggered by the lack of Canadian funding for pressurized skids), and a dramatic change of TPC assembly procedure; the TPC is now assembled inside the cryostat. At the time of the CVI meeting, these changes were not fully engineered; construction had started but no detailed installation plan existed. In particular, the revision of TPC assembly procedure raises potential safety issues, with a large number of complex parallel activities in Hall C. The impact of these changes on schedule and cost is not yet fully understood; it needs to be emphasized that the project already has a small funding deficit, and no contingency is available. Other items still on the critical path include Underground

Argon extraction and purification, and procurement of the Gd-loaded PMMA. The collaboration was forced to adjust to a different delivery method of the argon from the USA because the original high-pressure gas proposal was not funded by the Canadian Foundation for Innovation. A new solution, transporting liquid, is cost effective and should be satisfactory.

DarkSide has been and is stress-testing the system, revealing weaknesses in procedures and interfacing between the host lab and the experiment. While future large experiments are likely more accommodating than DarkSide in this respect, the lessons learned from the DarkSide experience will nevertheless prove beneficial towards better defining and formalising the interaction between the lab and its experiments.

Overall, the DarkSide Review committee and the CVI are reasonably optimistic about the outlook of the project.

Recommendations:
DS-1 *– DarkSide currently has a "reference baseline", but must establish a real baseline asap.*
DS-2 *– Open engineering issues (neutron shield, argon interface, installation scheme) need to be addressed urgently.*
DS-3 *– The foreseen change control procedures must be followed so that the project, funders, review panels, and lab management are always in sync. The RRB must be involved where funding implications are possible.*
DS-4 *– With the construction MoU being signed, work should start towards a post-construction MoU, covering commissioning and ultimately operation.*

LNGS

The laboratory has a world-leading broad program in particle physics, geophysics, and biology experiments. The laboratory's present and future scientific program and the many projects surrounding the scientific and infrastructure upgrades are well managed.

The laboratory ongoing science program is productive with leading results in dark matter and $0\nu\beta\beta$ decay searches. The activity level is high. Experiments are running well, and the lab is making good progress on all future planned activities. Significant resources are needed to decommission Borexino after a very successful science program. COBRA is also being decommissioned. Unfortunately neither the Lab nor INFN can find a solution to removing LVD. The collaboration is largely non-existent and a hurdle is that permission from Russia is needed to decommission the detector. Combined with the CUPID experiment, the early indication is that DOE "alternatives" analysis supports Gran Sasso as the preferred location for LEGEND-1000K. This will put the lab in the world leading competitive position for $0\nu\beta\beta$ decay for the next two decades.

Importantly, Darkside-20k, the flagship dark matter search experiment, is making very good progress on all fronts. Comments and recommendations have been noted elsewhere in this report. The 400 m^2 NOA silicon test and packaging facility is working well. It is presently supporting the large production for Darkside-20k.

Enrico Bellotti facility has been inaugurated and the experimental program with the 3.5 MV accelerator has begun and a call for experiments sent out to the community. The committee congratulates the collaboration for the excellent ongoing work at LUNA 400kV and at Bellotti facility. The facility is a unique facility for nuclear astrophysics in the world and places the lab in a leading position. Eventually the 400 KV machine will move to Bellotti facility after a potential upgrade.

Significant funds have been made available by the government (from the Italian National Recovery and Resilience Plan (PNNR)) in improving laboratory infrastructure, 12 infrastructure packages in total. Two of the new infrastructure facilities are in Hall B, STELLA (Sub Terranean Low Level Assay), and the Cryo-platform, which contains two dilution refrigerators for testing of detectors. A new large central liquid nitrogen production plant will be constructed to serve multiple users. A new computer facility will come to LNGS and will be a node in the national system.

Recommendation:
LNGS-1 *– The committee recommends that INFN should carefully consider more staff resources to LNGS to ensure the growing program of complex big projects are well supported.*

LNF

The 2023 budget for LNF is 53 M€, including 21 M€ from the PNRR, which is a significant increase compared to previous years. The budget excludes electricity costs and salaries. After several years of decreasing numbers, the CVI notes the increase of LNF's personnel numbers for researchers and engineers. To engage more technicians, a fruitful collaboration was started in 2021 with a technical school in the region. Students come to the laboratory for internships, while LNF researchers go teaching at the school. Very recently, the first technicians trained in the context of this collaboration have been hired by INFN. Attracting ICT profiles remains a challenge and therefore an important point of attention for the lab in light of the implementation of a new computing center.

The DAFNE complex has been running smoothly and continues to successfully deliver beams to impactful experiments, i.e., the SIDDHARTA-2 experiment and the PADME experiment, and to beam test facilities. In the transition to the future EuPRAXIA, the LNF management must develop a transition plan including considerations for the current DAFNE program.

INFN has an important ambition to develop advanced plasma-based accelerator technology. The headquarters of the multinational EuPRAXIA initiative will be located at LNF, demonstrating LNF's commitment to a successful implementation. In addition to the allocated budget of 108 M€ to EuPRAXIA, the laboratory has received the authorization for the construction of the buildings and the process of writing the TDR has started. The CVI congratulates the LNF management on the very significant progress for EuPRAXIA@SPARC_LAB on all fronts, i.e., in the area of authorization, construction, design, and the establishment of a committee to review in 2023 the cost-and-schedule on the basis of the draft TDR. EuAPS (Advanced Photon Source) has received PNRR support of 22.3 M€ (INFN + CNR), mostly for the construction of the betatron source, but the implementation is on a tight schedule.

Recommendation:
LNF-1 *– The CVI recommends the INFN and LNF management to continue their focus on a timely and successful implementation of the EuPRAXIA flagship infrastructure.*

Milano-LASA and PNRR IRIS

Milano-LASA is an International Excellence Particle Accelerator Technology Center with more than thirty years of experience, operated jointly by University of Milan and INFN. It has a longstanding tradition of activities in the field of innovative acceleration schemes, applications of superconductivity with the main expertise in magnets and SRF cavities for fundamental science and societal applications. Furthermore, it has strong links with industrial partners and an effective transfer of know-how.

Among the major recent international achievements, one should mention ATLAS superconducting toroid as well as superconducting (SC) cavities for TESLA, XFEL and ESS. On 17th of February the last in-kind magnet (out of the 54 corrector magnets) was tested and delivered by INFN (Milano-LASA) to CERN, with a ceremony at LASA to celebrate the event. Assembly and test as cold mass is being underway. The contract has been extended to allow INFN to participate to the commissioning in next years with a value of the project 3.5 M€ INFN + 3.5 M€ CERN. The human capital at Milano-LASA has been enlarged by PNRR funds (IRIS) for both partners, reaching 40 members from INFN (11 PNRR) and 13 from U. of Milan (6 PNRR).

Profiting from the PNRR program, the IRIS (Innovative Research Infrastructure on applied Superconductivity) program responded to a call by the MUR Ministry under the “Recovery Funds” to create a new distributed infrastructure in applied superconductivity in Italy by utilizing existing infrastructures, competences, skills and by expanding them with new laboratories. The six poles for the new or renewed infrastructures are Frascati (INFN), Genova (INFN, CNR-Spin, UniGE), Napoli (UniNA), Lecce (UniSalento), Salerno (INFN e UniSA) and with Milano (LASA e UNIMI) as the coordinator of the program. The IRIS Scientific and Technological goals include: the building and testing of a low consumption demo MgB_2 HTS transmission line L=140m, at T=20 K. Setting up an International Excellence Centre (Salerno) for High Power SC cables testing. To perform R&D on ReBCO HTS: dipoles for future HF magnet applications for next generation HEP machines (e.g., FCC-hh). To build demo HTS magnets for low energy consumption. In addition, they plan to train the new generation of scientists/technicians. In fact, in the first of these schools they had 61 participants demonstrating the importance and interest of these training activities.

In the last 3 years, there has been a renewed interest of INFN in supporting and consolidating the international role of LASA by identifying areas for which LASA may play the role of a INFN “National Centre”. As part of the PNRR-IRIS program and with a significant contribution of INFN in 2023, the construction of an extension based on two laboratories will begin within the LASA premises: one called SML (Superconducting Magnet Laboratory) and the other AATF (Advanced Accelerator Test Facility) for a total of 2100 m^2 spread over an underground bunker and two external floors. The shielded bunker should be capable of hosting high current small e-LINACs and/or ERL demonstrators. These new laboratories will be available in 2025, together with a refurbishment of old LASA electric and fluid services. The other PNRR funds will be used to increase the staff (long term). These activities will have important societal impacts on the environment by the development of energy saving magnets and energy transport at “zero emission”. Similarly, applications in heavy ion therapy by enabling a rotatable gantry and/or compact gantry with SC magnet. At the core of the mission of INFN the developments of prototypes and test of HTS for next generation colliders.

The IRIS project is very advanced with more than 50% of the budget already spent and more than 75% of the personnel hired. The advisory committee for the IRIS program is chaired by F. Bordry and already met in May 2023. The construction phase finishes in 2025, and an operation of a minimum of ten years is expected. The ambition is that the Research Infrastructure (IR) should be partially self-financing (economic sustainability), with 50% operational money from participating institutes continuing supporting the IR beyond the end of PNRR and the other 50% from external funding from special funds of INFN and /or Minister (MUR) as well as from competitive projects, EU projects, international projects, collaborations with CERN, CEA, etc. Due to the close relations of Milano-LASA with the local industry, contracts with industry, for instance for fusion programs or high-power lines, are expected.

Recommendation:
MLASA-1 *– The combined program is attractive and at the same time aggressive, the CVI recommends to INFN to verify whether they have enough capacity to accomplish the full program.*

Computing Services and ICSC

INFN has addressed its growing need of computing power with a two-pronged approach: in the short term its main data center will move to a new hall in the Tecnopolo Bologna, jointly operated with CINECA, which is undergoing a significant upgrade of space and capacity; in 2026 a major transformation of its data centers and communication network will take place within the context of a broader PNRR project called ICSC.

The short-term upgrade is projected to expand computing capacity in the Tecnopolo center. Current INFN center is limited at 1.6 MW and will transfer to a new, shared center reaching a capacity of 16 MW in 2023-2026, and then expanding to 24 MW, of which 10 MW will be available for INFN, effectively increasing its resources by a factor of six. The project, after some 6-months delay due to component shortages, is expected to reach its first milestone by the end of 2023, with the opening of the INFN dedicated hall in the Tecnopolo center.

The ICSC initiative is part of a broader PNRR program devoted to the development of 5 "strategic centers" for research. All initiatives are developed with a so-called "hub and spoke" model, with the hub acting as a center responsible for planning, disbursing the funds and monitoring the research initiatives carried forward by the spokes.

The ICSC hub is jointly operated by INFN and CINECA, while the 11 spokes include spoke 0, for the development of the data center and Terabit communication network, spoke 1, for the planning of the future architecture of the infrastructure and 9 "vertical" spokes, dedicated to specific, computation-intensive disciplines, including material sciences, in-silico medical applications, space and cosmos observation and quantum computing.

INFN has an overall leading role as manager of the hub, as well as leader in developing the data center infrastructure and the Terabit network, plus involvement in 4 out of 9 vertical spokes.

Implementation of investments in the infrastructure spoke seems to be well under way, in line to complete the tendering process by year end 2023; out of 120 M€ of foreseen tenders more than 80% of tenders have already been launched.

The INFN role as manager of the hub has successfully addressed the short-term issue of writing the contracts with spokes to disburse the funds.

One of the most important issues from the strategic viewpoint is the economic sustainability of the program and infrastructure beyond 2026. INFN envisaged a preliminary sizing of resources needed and a potential identification of their sources for a total of 58 M€ per year. This figure has updated the initial estimate of 50 M€, also including 12 M€ to fund for innovation projects as well as the renewal of infrastructure.

These projections, however, have yet to be supported by a comprehensive action plan. A person has been appointed within the hub structure as business development manager, to develop partnerships with private sector and progress in this direction.

The spokes have the task to develop research projects in their specific field of applications and they are doing so also by receiving proposals from the private sector, from companies who joined the spoke as partners, and pay a fixed yearly fee for participating to the spoke activity, as well as from calls open to external entities.

The spokes have received a total of 42 proposals from 10 of their private partners. PNRR funds will be used to pay most of the cost sustained by the spokes for this activity (about 15 M€ out of 19 M€). Private partners are contributing to the development of projects with own resources in kind, to an unknown extent (besides paying the yearly fees).

The role of INFN in ICSC requires addressing two distinct challenges, beyond the execution of buildout of infrastructure for spoke 0 and the disbursing of funds to the other spokes and the supervision of their programs:

- develop an actionable program for the sustainability of the hub beyond 2026,
- and to make sure that the development of the other spokes (where INFN is not leader) will provide opportunities that also benefit the INFN-led hub and Spoke 0, while protecting INFN's reputation as overall leader of the program.

The first challenge shows only initial progress from last CVI meeting. Developing a plan for funding future infrastructure will require relationships with potential users to secure revenues, which is still in the initial stage.

The second challenge will become more complex as the research program of the individual spokes grow. A particularly delicate element is the need to make sure that an appropriate balance of public and private interests is achieved in the development of projects proposals involving private sector entities. This issue is present both for the proposals presented by the spoke partners as well as for those accepted in the open calls. It calls for competencies and expertise which are not typical of INFN, that has been so far acting mainly as a recipient of public funds for research, not as an entity allocating them also to private sector.

Recommendations:
CS-1 *– Expand the task of the person in charge of business development beyond exploring the partnership issue, requesting the development of a full-fledged business plan (i.e., cost and revenue) for operations after 2026, including services provided to other research institutions.*
CS-2 *– Develop a framework for evaluating the sharing of benefits and costs for private and public partners in the cooperations developed by spokes. Make sure that the logic for project selection and the contractual obligations for resource contributions and IP utilizations are consistent with a proper balancing of benefits and costs between the parties.*