Annual Report to the President of the INFN

Il Comitato di Valutazione Internazionale (CVI)

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Introduction

The 2022 annual CVI meeting was held in Bari the 12th through 14th of October. Our charge was to evaluate the quality of INFN's programs and management: National Scientific Commissions (CSN's), Technology Transfer group, National Laboratories and Central Administration, and to advise on priorities in allocating resources. We wish to thank the INFN leadership and staff for the superb planning and hard work in arranging a most efficient and productive meeting. As has been our recent practice we now carry out comprehensive biennial reviews of the four national laboratories -- this year LNS and LNL. Our recommendations are compiled in Appendix I. Last year's comments and recommendations on LNF and LNGS are included in Appendix II for reference.

For next year's CVI meeting, in addition to the standard presentations we would like to have presentations on performance evaluation, and on the status and outlook for INFN's PNRR projects.

Executive Summary

Perspectives and Strategy: *INFN has been very successful again this year. The portfolio of programs is outstanding, with a mix of very large, medium and small projects and a remarkable level of leadership that is unmatched. The strategy is to continue to support ongoing activities and national laboratories within the current budget, while securing additional investments to support new science opportunities. INFN's wise choice of projects to submit for PNRR has led to great success: Infrastructure to speed up flagship activities: KM3NET, Advanced photon source for EUPRAXIA, preparations for ET, etc; and ICSC puts INFN in a leadership position for high performance computing in Italy.*

The excellence of INFN has been publicly recognized in the VQR exercise (the national evaluation of public research bodies carried out by ANVUR), where INFN ranks in the top positions according to all significant indicators. INFN should promote its record of excellence to the new ministers, as this could be an excellent way to persuade them that INFN warrants the funding it receives. Exciting initiatives in high performance computing (HPC), quantum computing, and life sciences make the case for the importance of INFN's basic research and its synergy with the more applied PNRR programs. These projects will open new windows, and partnerships will benefit from INFN expertise.

Central Administration: *The INFN central administration has undergone important organizational changes since 2020. Broadly speaking, the CVI appreciates the effort "to modernize" administration. In future meetings, the CVI would like to be updated about the functioning and results of the Directorate of Research Services as well as about the INFN policy concerning individual performance assessment.*

CSN1 - *INFN makes high quality contributions and plays a strong leadership role in a broad set of experiments. The resources and number of FTEs are stable. The section is well managed with regular thorough review of the projects. The LHC recently started Run 3 after a three-year shutdown with important upgrades of the detectors successfully completed on time. Experimentally observed anomalies in flavour physics were a focus of increasing interest in recent years. A new R&D programme, Flavour_RD, has been set-up to study future experimental opportunities. The broad experimental program on charged lepton flavour violation is in general progressing well. INFN's leadership record and contributions to scientific production of all CSN1's experiments are excellent. However, several* *threats originating in the Ukraine crisis may affect the future. The sizeable Russian contribution to the Phase-II upgrade of LHC detectors for the high luminosity LHC, expert manpower for detector operation and contributions to computing may not be delivered, potentially generating additional costs and delays. The increase of electricity cost may impact accelerator running time and operation of computing centers.*

***CNS2** encompasses a healthy and well-managed mix of experiment scales and topics, from table-top experiments to huge installations, with a good balance between established projects, new initiatives and R&D activities. The number of researchers in CSN2 keeps growing steadily and Italian scientists make key contributions to wide range of important experiments. PNRR funds for LNGS, KM3Net, CTA and ET give a tremendous boost to key CSN2 activities and to astroparticle physics and multi-messenger astronomy as a whole. At the same time, a major difficulty for some of CSN2's experiments arises from the loss of Russian suppliers for rare gases, enriched isotopes, crystals, and other special materials. Upcoming critical site decisions for the Einstein Telescope (ET) but also for major next-generation $0\nu\beta\beta$ experiments merit strong engagement and high-level support.*

***DS20k -** With the support of the special review committee appointed by the INFN President, Darkside-20K has made significant progress towards finalizing the design of the detector, completing the TDR documentation and the cost book, and defining construction milestones. Approval of NSF funding represents a big step towards closing the funding gap. Nevertheless, a number of critical issues remain, such as the timely delivery of Underground Argon via the Urania and Aria facilities. We are concerned that the project is still not baselined, as the ongoing process could reveal further delays and cost increases.*

***CSN3** continues to provide a high science output across all six interconnected research lines, and also in cooperation with different CSN sections. Two of the radioactive beam facilities (LNS and LNL) are still being upgraded and will within the next 3-5 years provide exciting new scientific opportunities for Nuclear Physics and Applied Research fields in Italy. Four well-attended workshops at the national laboratories (up to 280 participants) aimed at discussing the mid-term plans for the Italian Nuclear Physics community and to identifying more synergies between the different groups. The AGATA array has now been installed at LNL and carried out the first experimental campaigns. This powerful detector setup will steadily be upgraded during its stay in Italy- also with a large INFN contribution- to become the most powerful gamma-tracking array in Europe.*
Synergetic efforts for future detectors R&D at CERN (ALICE3, NA60+) and the planned Electron-Ion Collider (EIC) in the USA have been identified. However, some of these R&D projects are on a tight schedule and require fast commitment of "special funding" from INFN.

***CSN4 -** The Theoretical Physics program undertaken by INFN collaborators is one of the strongest in Europe, and has at least as great impact as the other scientific powerhouses of Europe, such as the UK or Germany. A particular strength of the Italian program is the close collaboration between experiment and theory. For a relatively small annual budget (INFN staff costs+3M€) the theory program contributes greatly to the success of the INFN experimental program.*

***CSN5** plays a fundamental role in fostering interdisciplinary activities, collaborations across committees, and applied physics research. The CVI is very pleased with the competitive assignment of internal funds after rigorous evaluation. "Grants for young researchers" are especially important, despite their relatively low share in the budget: the CVI recommends that an assessment of the program be conducted both from the perspective of the benefits to INFN as research agency and of the benefit to the grant-winners.*

***KTT** - In consideration of the extensive re-organisation of the INFN Knowledge and Technology Transfer Program (KTT), this topic deserves to be explicitly included in next year's agenda.*

LNS -*With its priority projects: the POTLNS upgrade, the PANDORA plasma trap, and KM3Net, but also with the I-LUCE studies of laser-accelerated beams, LNS is building up facilities that will provide excellent and innovative science opportunities across a diverse range of science topics. The delays in implementing POTLNS and in particular the non-conformities of the industrially manufactured cyclotron magnet are a concern and call for appropriate strategies and fall-back plans. Knowledge transfer between retiring and new staff remains a challenge; the break in accelerator operation has, however, been used to establish a more flexible and efficient organization of personnel. Timely completion of the PNRR-enhanced KM3Net sensor assembly and deployment is demanding. Given that the technology and procedure are mature, completion is within reach with effective project management and focus of resources.*

LNL *is in a critical phase but on track to complete the SPES radioactive beam facility installations within the next 3 years. Construction deficiencies in the building have been identified and the problems are mitigated. Once all missing permits are in place (within the next months), further commissioning of the new cyclotron for radioisotope production can continue to allow operation at full power. The understaffing in safety-critical positions remains a concern which can only be solved with a rigorous hiring plan and succession planning over the next 10 years. This requires continued joint efforts and support from both the LNL and the INFN Management. The AGATA setup, a high priority project of the European Nuclear Structure Community, has been relocated to the lab and successfully started operation in April 2022. Delays at other facilities might warrant another extension of the physics program at LNL beyond 2025.. The tender for a new Data Center, important not only for the LHC Tier-2 Computing Center but also for data acquisition of experimental setups like AGATA, is ongoing. Building construction should start in early 2023 and allow completion and operation within 12 months. The medical isotope production projects LARAMED and ISOLPHARM have a high societal benefit and will be future flagship programs for the lab and INFN. A timely completion of the lab installations will allow a quick start of these programs in the early SPES phases.*

PNRR

The last three hours of the meeting were devoted to PNRR, with the basic goal to inform the CVI and hear our reaction to this exciting major opportunity. First and foremost we note that INFN has been extremely successful in attracting funds for projects under the auspices of the PNRR program, in all four categories: National Centres(1), Infrastructures(9), Ecosystems for Innovation(5), and Extended Partnerships(3). This is testimony to the INFN's success in managing large projects in the past.

The 320M ICSC project will enhance the performance of IT infrastructure for Italian research while offering new opportunities to integrate data analysis in both academia and business, while strengthening the overall security of the system. The various infrastructure projects will enable INFN to maintain and upgrade its world-class national laboratories and accelerate completion of major projects like KM3NET. INFN expertise could be decisive in advancing applications of superconductivity and quantum computing, and its extended partnerships will greatly benefit from INFN's management experience. Modest schedule extensions would greatly benefit many of the projects and reduce risks.

Within PNRR- funded projects, ICSC stands out as a key infrastructure for the entire research activity in Italy, aiming at offering services in High Performance Computing and Big Data analysis to academic and private sector institutions. INFN will play a leading role in the overall project management and infrastructure building, leveraging its extensive capabilities in management of large research projects. A challenge for the project is the development of a funding model after the 2022-2026 period when PNRR funds will expire. INFN has developed an initial hypothesis entailing the acquisition of revenues on the private market for cloud-based computing services, but significant management attention should be devoted to make sure that a full-fledged business plan is developed.

Perspectives and Strategy

President Zoccoli summarised the current status of budget and staffing, and presented his outlook for the future. This has been a stable year for INFN, with a 2021 budget of 383M€ (261M bases + 162M one-shots), with an increase in store for 2022. However, inflation will be a challenge, as will keeping personnel costs below 50%. Multiyear infrastructure funds from PNRR, 300-400M to be spent over 3 years, will have a huge impact, in addition to funds in hand for Eupraxia (108M), CINECA (120M with 50% co-financing with EuroHPC), and the 12-year INFN infrastructure project (160M). The strategy is to continue to support ongoing activities and national laboratories within the current budget, while securing additional investments to support new science opportunities, e.g. Darkside, DUNE, ET and novel technology R&D (Superconductivity, Quantum initiatives).

Approximately 6000 personnel are engaged in INFN activities: ~2000 have permanent positions, with 163 on fixed-term contracts. The permanent staff consists of ~33% researchers, ~31% technicians, ~19% technologists and ~15% administrative staff; in addition ~1500 young researchers are supported by PhD grants, research grants and postdoc scholarships. The age distribution is healthy, but stability is threatened by a recently imposed 60% increase in the cost of new postdoc contracts.

The Ukraine/Russia situation is having various impacts. The loss of Russian involvement has resulted in unavailability of expertise, resources, and special materials (titanium, enriched isotopes, etc.). Though somewhat mitigated by decreased consumption, increased energy costs are also worrisome (especially for the national laboratories) and could even triple in the future to 35M.

INFN is a major player in the European Strategy Forum on Research Infrastructures (ESFRI), competing for two projects prominent on the 2021 Roadmap: EUPRAXIA and ET, and the Italian government has guaranteed 350M in support of ET if the Italian site is selected.

As mentioned above, PNRR is having major impact. INFN's sensible and successful strategy has been to secure projects related to its core activities and where possible, technologies that could be transferable: so far approvals include IRIS (60 M), KMNET (67M), ET (50M), ICSC (320M +41M Cloud infrastructure). The goal is to hire ~200 new people to accomplish the projects, and to devise a plan for stability after the PNRR projects are completed. Modest schedule extensions would greatly benefit many of the projects and reduce risks.

Comments:

INFN has been very successful again this year. The portfolio of programs is outstanding, with a mix of very large, medium and small projects and a remarkable level of leadership that is unmatched. They have made a wise choice of projects to submit for PNRR with great success: Infrastructure to speed up flagship activities: KM3NET, Advanced Photon Source for EUPRAXIA preparations for ET, etc.; and ICSC puts INFN in leadership position for high performance computing in Italy. One caveat: ET preparations should not interfere with the ongoing VIRGO runs.

The excellence of INFN has been publicly recognized in the VQR exercise (the national evaluation of public research bodies carried out by ANVUR), where INFN ranks in the top positions according to all significant indicators. INFN should promote its record of excellence to the new ministers, as this could be an excellent way to persuade them that INFN warrants the funding it receives. Exciting initiatives in high performance computing (HPC), quantum computing, and life sciences make the case for the importance of INFN's basic research and its synergy with the more applied PNRR programs. These projects will open new windows, and partnerships will benefit from INFN expertise. It could help to have statistics showing how INFN's performance compares with CNR and other relevant institutions.

Recommendations
P&S-1: INFN has a great story to tell and should make sure to transmit it in a way that resonates with the government, industry and the public (a few suggestions are given above).
P&S-2: INFN should compile data on their success in winning ERC grants, and use it to show how the number of grants has varied with time, and how Italy and the INFN compare with other countries.
P&S-3: INFN should consider providing professional grant-writing support.

Central Administration (CA)

The INFN central administration has been undergoing important organizational changes since 2020. Among them we have taken note of the full outsourcing of payroll and human resource management from January 2023 and the reduction of high-level positions in the administration, which should be conducive to a less horizontal structure. These points were raised in the CVI Reports for 2020 and 2021, respectively. More broadly, there is a noteworthy determination of INFN to digitalize administration processes and procedures. We are pleased with the ongoing customer satisfaction survey, recommended in the CVI Report for 2019, which may play an important role in enhancing service quality as well as fostering collaboration between researchers and administrative staff, which is key to a proper functioning of INFN. Overall, we appreciate the effort "to modernize" the administration.

The PNRR initiave has had a huge impact on INFN, as discussed below in this Report. We understand that hiring a consultancy agency to help with PNRR administrative burden was necessary in this frantic phase in the light of extant administrative weaknesses. On the other hand, we acknowledge that this might be an opportunity to develop internal abilities and skills.

In previous CVI reports we underlined the importance of creating the Directorate of Research Services (DRS) and expressed some surprise that an autonomous structure had not been foreseen before in the INFN. In the currently very competitive research environment, supporting investigators along the whole grant process is definitely a highly specialized activity that requires specific skills and knowledge and takes considerable time. In 2022, little information was provided about the DRS, apart from noting that it is understaffed. Given its importance, we would like to know more about its functioning and results.

The Director General raised the issue of individual performance assessment as regards employees at the 4^{th}-8^{th} levels. However, the assessment of individual performance is a much broader issue, particularly important for an institution pursuing research excellence like the INFN: it might matter for wage bonuses, promotions, career progression, etc. We are fully aware that this is a very sensitive issue with staff and unions but remain most interested in knowing more about the current INFN policy concerning individual performance assessment, if any, and whether there is any intention to develop a different policy. Moreover, we wonder whether there is any link between the VQR exercise (which we understand to be an assessment at the institute level) and the assessment of individual performance.

Recommendations: None

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CSN1 – Particle Physics at Accelerators

Over 800 FTEs are assigned to CSN1 to manage activities in particle physics at accelerators, with an annual budget of 20 M€ complemented by 3.5 M€ for high-luminosity LHC detector construction. Personnel and budget levels have been stable in recent years. About 60% of the resources are dedicated to the LHC, while the rest covers experiments at other accelerators addressing flavour physics, charged lepton physics, proton structure and R&D for future accelerators.

The LHC recently started Run 3 after a three-year shutdown for important maintenance and installation of upgrades to the detectors. Despite difficulties related to COVID, the large and complex Phase-1 upgrades of ATLAS, CMS and LHCb were successfully completed on schedule, as seen by early results on detector commissioning. Run 3 is expected to last until the end of 2025, with ATLAS and CMS

collecting twice the existing amount of integrated luminosity and LHCb quadrupling it. Preparations for Phase 2 LHC upgrades are ongoing, with installation starting in 2026 under a revised schedule. Run 3 computing needs should be covered, the CNAF relocation project is going well, and intensive R&D in computing has led to a more manageable model for the high luminosity phase.
In general, INFN's leadership record and contributions to scientific production of all CSN1's experiments are excellent. Experimentally observed anomalies in flavour physics have been a focus of increasing interest in recent years. Many results have been collected, among others by LHCb, Belle-II, BES-III. An upgrade of NA62 resulted in a much-improved background level. CSN1 has set up a new R&D programme (Flavour_RD) to study current and future experimental opportunities to contribute to flavour physics, including at the FCC-*ee*. The broad experimental program on charged lepton flavour violation is in general progressing well, despite a few delays. Further diversification of CSN1's particle physics program at accelerators could be achieved by including future large accelerator-based neutrino experiments currently under CSN2, like DUNE (USA), Hyper-Kamiokande (Japan) and Juno (China).

Several problems that may affect the experimental program during the coming years will require close follow-up by INFN. Most serious, the Ukraine crisis may have important consequences: a) The significant increase of the cost of electricity may impact the running time of accelerators and operation of computing centers. Already the LHC has cancelled a two weeks Pb-Pb run at the end of 2022, b) The Russian contribution to the large LHC detectors amounts to 10%. It covers construction of Phase-2 detector elements for the upgrade, many experts needed for operations, and a significant contribution to computing. Its future is uncertain and may generate increased cost for the experiments. c) Instabilities in the CHF/Euro exchange rate changes create additional tension in the budget.

Recommendations
CSN1-1 INFN should strongly engage in shaping the strategy of CERN and the LHC experiments to promptly address and mitigate the many implications of the Russian crisis.

CSN1-2 CSN1 should emphasize their strong leadership in various areas of the LHC Phase-2 upgrade, anticipating the eventual need of contingency resources. They should make sure to communicate clearly to the funding agency and society the excellence of their research and its long-term positive impact on society.

CSN1-3 INFN should evaluate the possibility of moving the large accelerator-based neutrino experiments from CSN2 to CSN1, carefully considering all implications and the input of all parties.

CSN2 – Astroparticle Physics

The portfolio of CSN2 covers the full spectrum of astroparticle experiments, grouped into the thematic areas of (i) Neutrino Physics, (ii) Radiation from the Universe, (iii) Studies of the Dark Universe, and (iv) Gravitational Waves. Part of the work is carried out in space in close collaboration with the Italian Space Agency. CNS2 encompasses a healthy mix of experiment scales and topics, from table-top experiments to huge installations, with a good balance between established projects, new initiatives and R&D activities. The Darkside 20K experiment is of sufficient scale and complexity that we have devoted a separate section to it below.

Italian scientists make key contributions to a wide range of important experiments. They are highly visible in leadership roles in international collaborations: close to 40% of leadership roles are held by INFN personnel. The number of researchers in CSN2 keeps growing steadily, from 2016 to 2022 by a factor 1.5, demonstrating the attractiveness of the field. Similarly, the number of publications from CSN2 shows a steady rise. A significant increase in the number of bachelor and masters theses in recent years demonstrates efficient engagement of young scientists. Among the many science highlights we mention here only the CUORE record limits for neutrinoless double beta decay from 1 T yr exposure, with 2 T yr of data already in hand; the first science publications from the CTA LST telescope on La Palma; XENON-nT demonstrating a record low background and showing that the low-energy excess observed in XENON-1t was likely caused by traces of tritium; the wealth of results on black-hole (BH) Merger and BH statistics, as well as neutron star-neutron star mergers from the Virgo O3.

PNRR funds give a tremendous boost to key CSN2 activities and to astroparticle physics and multimessenger astronomy as whole, with the refurbishment and upgrading of LNGS infrastructure, future-proofing the laboratory and enhancing the quality of service for LNGS users; the additional KM3Net strings, allowing realization of nearly 2/3 of ARCA; and the contribution of 3 LST telescopes and additional SST telescopes to CTA, restoring CTA South as the full-energy-range observatory that was originally planned, and greatly increasing its capabilities. The latter project is INAF-led but with strong INFN involvement. Long term sustainability & follow-up costs are a general concern, but seem to be sufficiently addressed for these projects. PNRR also provides important support for R&D on the Einstein Telescope (ET) and the Sardinia site candidacy.

The situation in Ukraine / Russia impacts experiments, in terms of loss of expertise and manpower (which seems manageable), and loss of suppliers for rare gases, enriched isotopes, crystals, and other special materials (which is extremely critical). For example, the CUPID neutrinoless double beta decay experiment is fully stalled for lack of enriched ^{100}Mo, and the DarkSide 20K Titanium vessel has to be replaced by a stainless-steel vessel. A number of projects under installation or commissioning suffered delays due to COVID, but are now generally proceeding well.

The general strategy, review procedures and project follow-up within CSN2 work well, and to optimise its portfolio CSN2 is appropriately terminating some projects, in line with earlier CVI recommendations. For large projects or projects in critical stages, intense reviews such as provided by the Forti committee for DarkSide 20K, including external experts, are very helpful and set an excellent example & standard.

Our concerns include:

- the information that cooperation with China on space experiments is under political re-evaluation, with potential severe consequences for major projects such HERD;
- the fact that the percentage of female coordinators / PIs in CNS2 seems decreasing over the last years;
- the continued lack of open information about DAMA data and backgrounds, greatly undermining the credibility of the experiment, and its value for science. Open and transparent data are a key aspect of modern science.

Recommendations:
CSN2-1: For the long term, laboratories and agencies should consider developing a common strategy to secure stable, reliable and affordable supply chains for materials such as enriched isotopes, rare gases and crystals

CSN2-2: LEGEND-1000 is preparing for the DOE CD-1/3A with LNGS and SNOLAB as alternative sites. INFN should work with European agencies involved in the project to generate attractive conditions for hosting LEGEND-1000 at LNGS.

CSN2-3: The decision to create a German Center for Astrophysics in Lusatia – with very significant resources – is a significant push for the ET project and adds a new player in the game. INFN and Italy should develop their strategy in this context and seek strategic alliances.

Darkside 20K

Since the last CVI meeting, and with the advice by the special review committee appointed by the INFN President ("Forti Committee"), Darkside-20K has made significant progress towards finalizing the design of the detector, completing the TDR documentation and a preliminary cost book, and defining construction milestones. The committee (which we recommended last year) has had a major and positive impact on the evolution of the project, and its continued in-depth reviewing and detailed recommendations are extremely beneficial both for INFN and DarkSide 20K. A significant step is the formal approval of NSF funding. A Resource Review Board was established and had its first meeting. Critical positions in the organization chart were recently filled, in particular the Project Construction Director (Marzio Nessi, 1/4 time), and the Deputy Director, Andrea Zani (near full time). Project management is being formalized, with tracking milestones for monthly tracking/reporting and regular schedule updates.

A major design modification concerns the radio-pure vessel for the Time Projection Chamber. Instead of being formed from titanium, it now has to use selected stainless steel because the titanium required is unavailable because of the Russia-Ukraine conflict. Background estimates remain acceptable provided low-activity stainless steel can be obtained and is not contaminated during production. Vendor selection and qualification are in progress, but production will require continuous monitoring and attention.

Concerns:

- Issues with China are impeding procurement of the Gadolinium-doped veto shield, and could result in delays and/or cost increases.
- Installation of the Urania facility has been long-delayed and on the critical path, but crucial agreements were finally signed.
- Occupancy of the NOA facility for producing the Photo Detection Units (PDU's) continues to slip for reasons we do not fully understand.
- The cost and schedule of Darkside 20K are still not baselined and major uncertainties remain. The baselining process could reveal significant delays and significant cost increases. Inflation is likely an additional concern.

Recommendations:

DS-1: The interfacing with LNGS regarding the installation of DS20K, the definition of interfaces towards the infrastructure and of the mutual responsibilities, and the daily coordination have improved, but a) Documentation needs to be finalized and processes streamlined; and b) Wherever possible, INFN and LNGS should require approved cost and schedule baselines before committing long-term resources.

DS-2: LNGS, DarkSide-20K and INFN management need to do whatever is needed to get the NOA facility producing PDU's.

DS-3: Reaching the design performance is crucial for the success of DarkSide-20K; the experiment must absolutely avoid any shortcuts that could endanger quality and radiopurity of components.

DS-4: DarkSide-20K sensitivity plots based on "full volume" and 20 years exposure may give an over-optimistic view, compared to more conservative sensitivity estimates of other experiments. The collaboration should produce an updated explanation of their sensitivity estimates and of the background assumptions and measurements on which they are based.

CSN3 – Nuclear Physics

Note: For a detailed discussion of the status and scientific highlights from the three affiliated national laboratories (LNS, LNL, and LNGS), please refer to their respective sections.

The research portfolio of CSN3 spans the four INFN national laboratories, a multitude of Italian universities, the CERN LHC, Jefferson Lab, and international radioactive beam facilities. In addition to fundamental nuclear physics research, application-oriented interdisciplinary research is being pursued in hadron therapy, biomedicine, matter/antimatter studies, and quantum physics. CSN3 consists of 24 activities within six strongly 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 900, highlighting the cross-disciplinary work of nuclear physicists with other CSN projects. The base funding (assignments) is fluctuating around 6 MEuro, plus ~3 MEuro for "Mission" and "Specific" funding (with changing ratios).

ALICE (~ 130 FTE) and GAMMA (~ 50 FTE) represent the two largest projects, while 8 smaller projects have ≤ 10 FTE. New rules have been implemented to track projects towards the end of their research program and/or with very low FTE, along with increased effort to merge projects with technological synergies into focus groups, as has been successfully done for the "Low-Energy Antimatter" (LEA) projects and is now being investigated for the projects JLab12, EIC, and MAMBO. Facility upgrades at LNS and LNL are still ongoing, while the LUNA-MV accelerator is now being commissioned and will start operation in 2023.

CSN3 hosts two ERC Starting Grants from external young scientists (University of Naples and University of Edinburgh/ UK) which perform experiments at the LUNA accelerators. Given the exciting scientific programs, efforts should be made to identify more "champions" to push forward ERC Grant applications.

AGATA (Advanced GAmma Tracking Array), a high-priority, travelling detector array of the European Nuclear Structure community funded by 12 countries, has been installed at LNL and started taking data in April 2022. It is presently operated with 1π geometry (up to 15 Triple Clusters). The installation at LNL foresees a maximum of 2π angular coverage (corresponding to 27 TC and three empty spots for the beamline). The mid-term plan, for which the MOU has been signed, is the purchase of 25 new TC detectors to achieve 3π geometry (45 TCs) by 2030. Recently, the AGATA steering Committee approved the extension of AGATA at LNL for two more years (until 2025).

A big effort of the whole CSN3 community in 2022 was dedicated to the *"Nuclear Physics Mid-Term Plan in* Italy," featuring well-attended workshops at LNS, LNL and LNGS, with an upcoming workshop at LNF focused on future nuclear physics at LNF with DAΦNE and EUPRAXIA, and detector technologies. These workshops are an important occasion for the Italian and international Nuclear Physics Communities to strengthen collaborations and plan for exploiting upcoming new facilities.

The Electron-Ion Collider (EIC) has achieved major milestones in 2021 with the publication of the Conceptual Design Report (CDR) and a Yellow Paper. INFN scientists are contributing strongly to the ATHENA *("A Totally Hermetic Electron-Nucleus Apparatus")* proto-collaboration for the design of a detector that covers the whole EIC physics program, led by Silvia Dalla Torre from INFN Trieste as spokesperson. However, a Detector Proposal Advisory Panel by Brookhaven National Laboratory and Jefferson Laboratory has selected the ECCE *("EIC Comprehensive Chromodynamics Experiment")* proposal as the reference design for the first EIC detector. Efforts are now underway to merge the two proposals into the "EPIC" project. INFN has taken a leading role in the silicon tracker and the dual-radiator Ring Imaging Cherenkov (dRICH) detector, with R&D efforts estimated to be ~1 MEuro until 2025/26.

INFN groups have identified synergies on detector R&D activities between the new ALICE Inner Tracking System (ITS3) and future ALICE 3 detectors (>2033), the EIC ATHENA detector developments, and the NA60+ upgrades at the CERN SPS. This includes common technologies like MAPS (Monolithic Active Pixel Sensors), radiation-hard SiPMs (silicon photomultipliers), etc. which also have very similar development timelines.

The LHC Experiment Committee (LHCC) has endorsed the R&D program for ALICE3 for monolithic timing detectors and photon sensors with integrated fast electronics, and CSN3 groups have the possibility to take leading roles in both projects (MAPS as well as RICH detectors with aerogel and SiPMs). These technologies will have a strong involvement of Italian industrial partners, and a detailed proposal will be presented in fall 2022. Prototypes should be ready by 2025/26 for the final ALICE3 TDR. Discussions with INFN management are ongoing to fund these prototypes at 2.5-3 MEuros for 3 years.

Recommendations:
CSN3-1: Secure time-critical "Special" funding (3 MEuro until 2025/26) for the R&D phase of ALICE3 detectors. Discuss with INFN management and other CSNs about faster procedures for getting larger funding for high risk-high reward R&D projects.

CSN3-2: Identify more "champions" for ERC grant applications to secure additional funding and attract more researchers to INFN projects.

CSN4 – Theory

The work of the theoretical committee is divided into 6 scientific lines (the percentages in parentheses give the number of FTEs in each line.)

1) Strings and Field theory (28.5%)
2) Particle Physics Phenomenology (16.5%)
3) Hadronic and Nuclear Physics (7.6%)
4) Mathematical Methods (13.7%)
5) Astro-particle Physics and Cosmology (12.4%)
6) Statistical and Applied Field theory (1.3%)

The publication record, as estimated using bibliometric data, is in line with previous years, and even somewhat improved. CSN4 participates in the training of young people by teaching activities of the INFN staff, and through 5 schools at the GGI Institute in Florence and directly. The lifeblood of the theoretical physics program is the entry of smart young researchers. INFN facilitates this activity by funding PhD fellowships. Because of the savings in travel funds due to the Covid emergency, the INFN-CSN4 was also able to offer 16 new post-doctoral positions in 2021, higher than the number offered the previous year. Although new legal requirements may increase the cost of hiring post-docs, every effort should be made to maintain the number of these positions.

An outstanding problem in CSN4 is that the percentage of female researchers, currently ~ 15%, is significantly lower than in the other CSNs, even lower if only researchers with permanent contracts are counted. We take note of the measures taken to help redress this imbalance: INFN has adopted a Gender Equality plan in 2022, an Affirmative Action plan in 2019, and has also created the Baldo-Ceolin prize for theoretical master theses by female authors. We encourage CSN4 to be mindful of the gender imbalance in all aspects of its work. Achieving true gender equality will require persistence.
We note the strong theoretical support in planning for the EIC and MUonE experiments. The proposed Einstein Telescope (ET) will explore black-hole systems and their environment, neutron star mergers and strong field gravity with unprecedented precision. Interpretation of ET data will require sophisticated theoretical modelling, currently performed in *iniziative specifiche* TEONGRAV and IMDARK. Investment in this theoretical work will allow INFN scientists to take ownership of the science and attract young people to the field, even in the event of an adverse site decision.

Recommendation
CSN4-1: In view of the bid to host the Einstein telescope, CSN4 should try to further raise the profile of forward-looking theoretical preparations for gravitational wave physics.

CSN5 – Technological and Interdisciplinary Research

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 (e.g. medical imaging, cancer therapy, environment and cultural heritage analysis and protection).

Traditionally CSN5 has three research lines, which however may overlap. Fund allocation is relatively stable over time across the research lines: "detectors, electronics and computing" accounted for 48 per cent of the budget in 2021, "accelerators and related technologies" for 21 per cent, and "interdisciplinary physics" for the remaining 31 per cent. Funding is organised in three project categories: Standard experiments (62 per cent of the 2021 budget), Calls for proposals (26 per cent) and Grants for young researchers (12 per cent). Standard experiments 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.

We have taken note of the good gender balance among CSN5 coordinators (44% female, although less than a third of the total FTEs are women) and of the improving performance in scientific production, both in absolute terms and per FTE. We greatly appreciate the CSN5 emphasis on fostering interdisciplinary activities, collaborations across committees, and applied physics research. We are very pleased with the competitive assignment of internal funds after rigorous evaluation, and understand that this extends to different stages of the projects. For instance, we regard the refusal of requests for the extension of projects, when not clearly motivated, as a good disciplinary device.

As in past years, we are particularly interested in the "Grants for young researchers." Despite the relatively small size of the overall CSN5 budget, Grants are an important tool to foster future excellence and attract brilliant young researchers, which is particularly important in view of the ageing of INFN staff. Since Grants have been running for several years, the time is ripe for an assessment of the program. Such an assessment should adopt a twofold perspective:

i) *INFN as research agency* – Is the scheme effective in attracting first-rate young scientists? What is the relationship, if any, with ERC or other similar competitive funding? Do INFN Grants act as a "stepping stone" in getting future external funding or could they discourage efforts to obtain additional funding? Do Grant-winners remain with the INFN or do they move to other national or foreign institutions?

ii) *Researchers* – Is the post-Grant performance of researchers who have been awarded a grant better than the performance of comparable researchers?

Recommendation
CSN5-1. Plan a review of the "Grants for young researchers" scheme and report on it at the 2023 CVI meeting.

Knowledge and Technology Transfer (KTT)

The INFN Knowledge and Technology Transfer program (KTT) has gone through an extensive re-organisation. At the meeting in Venice in 2021, a specific presentation was devoted to "Status of the INFN KTT at the onset of a new phase," and the GLV Report for 2022 provides limited information about this "new phase". We suggest that KTT should explicitly feature in next year's agenda, and single out the following among possible items for discussion:

i) Preliminary results from the "OPEN INFN - Open INnovation from Fundamental Nuclear research" project;

ii) Results/assessment of the R4I program since its start;

iii) Results/assessment of the activity of the INFN Agent at the European Patent Office (EPO) and ability to involve researchers and technologists with respect to IP protection;

iv) Results/assessment of the training program on Technology Transfer developed in the period 2021-2023.

LNS – Laboratori Nazionali del Sud

LNS supports an extaordinarily broad range of research activities: nuclear physics, astroparticle physics, medical applications of nuclear physics, environmental and energy research, cultural heritage and the development of accelerators and ion sources. To support its work, LNS depends on and has succeeded in attracting significant external (regional, EC) funding to supplement its base budget.

LNS is building up facilities that will provide excellent and innovative science opportunities in the years to come. The POTLNS upgrade of the Superconducting Cyclotron, beamlines and spectrometer has the goal of delivering high intensity light ion beams with power of several kW and intensities up to 10^{14} pps. The new fragment separator FRAISE will accept intense primary beams and produce high-quality radioactive beams. The MAGNEX spectrometer is designed to work with intense stable beam, for the study of rare processes related to neutrino physics, and is upgraded for the NUMEN experiment measuring nuclear matrix elements relevant for the interpretation of neutrinoless double beta decay. The PANDORA plasma trap will allow investigation of nuclear processes in plasma under stellar conditions, initially with GALILEO HPGe detectors. The KM3Net / ARCA neutrino detector will provide, with 130 of 230 detector strings (DUs), close to a km^3 sensitive volume for neutrino astronomy. A new entry is work on plasma acceleration (I-LUCE), for which a staged implementation is planned, initially for cancer therapy (BCT), later with higher laser power for nuclear physics applications & stellar astrophysics, complementing PANDORA.

For the major upgrades of the cyclotron, the beamline and spectrometer, accelerators have been shut down since mid-2020, delayed by Covid, the general difficulty in procuring technical and construction materials, and non-conformities of the cyclotron magnet produced in industry. A solution to address these non-conformities was not evident at the time of the CVI meeting. Even without this problem, completion of POTLNS is expected not before mid-2024 (1.5-2 yrs delay compared to initial schedule). The Tandem should resume operation with about 1 yr delay. User interest remains strong and users are eagerly awaiting the re-start of operations.

We endorse completion of POTLNS, KM3Net, and PANDORA as the top-level priorities and focus of the resources of LNS. The issues with the company building the cyclotron magnet need to be urgently resolved, and it is appropriate that high levels of INFN management engage.

LNS uses the shutdown for a revision of the organization of services and operations, with a matrix scheme for improved use of personnel and its capabilities. Machine learning tools are prepared to support automatic and unsupervised operation, freeing human resources, and further improving operational safety. A regular exchange between LNS and LNL technical divisions has been established, to share knowledge and experience.

Knowledge transfer from experienced retiring staff to new junior personnel remains critical, in large part because hirings were delayed during Covid. Temporary additional administrative support during the transition period might help to speed up hiring. Also for I-LUCE, arrangements for effective knowledge transfer will prove crucial, and LNS will need outside laser expertise to ensure timely success of I-LUCE.

Recommendations:

LNS-1: LNS together with the INFN management should develop contingency plans in case delivery of the cyclotron magnet is further delayed.

LNS-2: LNS and INFN should ensure that with the completion of POTLNS, approval procedures are well-prepared and that the ion source for high-current injection is ready, so that NUMEN can start high-statistics data taking as soon as possible. For the approval procedures, lessons learned at LNL should prove useful. We request an update on POTLNS status in the midterm report.

LNS-3: KM3Net is one of the reasonably straight-forward PNRR projects, and the technology of KM3Net-DUs is now mature and procedures and quality control are well established. Nevertheless, the assembly of KM3Net Digital Optical Modules and DUs on the time scale of PNRR will be challenging. Schedule and progress must be carefully monitored. INFN institutes and institutes abroad should support DU production by increasing support for the production sites at LNS and Caserta.

LNS-4: While science demand for the Tandem is still strong, experiments should emphasize novel questions over standard and repetitive topics. On the time scale of 5 years, the science case for continued operation of the Tandem should be re-assessed, also in view of the increasing cost of operation.

Laboratori Nazionali di Legnaro (LNL)

LNL is currently operating three accelerators: the 15-MV tandem accelerator with the ALPI and PIAVE superconducting linear accelerators, the 7-MV "CN", and the 2.5-MV "AN2000" Van-de-Graaff accelerators. As part of the new SPES facility, a high-current B70 cyclotron has been installed and will be put in operation once all permits are received. The XTU tandem is up and running again after extensive special maintenance, and the upgrades of the PIAVE and ALPI reaccelerators have also been completed. Among others, extraordinary funds were approved by the Machine Advisory Committee for the upgrade of the ALPI vacuum system. In 2022 the nominal available beamtime has reached pre-pandemic values again (about twice as much as in 2021, 1476 hours beam-on-target), and stable beam has been delivered in spring 2022 to the newly installed AGATA spectrometer for nuclear structure investigations. This high-priority campaign is expected to receive 99 days of beam time, about 90% of the scheduled time at the Tandem-ALPI-PIAVE complex between February and December 2022.

The AN2000 and CN accelerators delivered a record-high 1621 hours and 1361 hours of beam in 2021 for application-based research, such as elemental microanalysis, dosimetry, and radiation damage studies, as well as neutron physics investigations. This shows the continued interest of external users to work with these smaller accelerators.

Progress at SPES

The completion of the SPES facilities and plants is ongoing and on a good path. The new B70 cyclotron, which in 2020 already accelerated a proton beam of 950 μA up to 1 MeV, cannot be operated yet at its maximal beam energy due to the still pending revision of the fire prevention plan for the SPES building. Once this Certification for fire protection (CPI) is received (expected in late 2022), the ramp-up of the cyclotron and further commissioning can start towards operation with 70 MeV, 750 μA proton beams for the production of radioactive beams. This would allow the operation with re-accelerated radioactive beams from the cyclotron (SPES β phase) in 2024/25.

The tenders for the high-resolution mass separator (HRMS) will be completed in early 2023, and the components are expected to be delivered by mid-2024, with operation by mid-end 2025. In the meantime, a sufficient purification of the radioactive beams can be achieved with the low-resolution mass separator (LRMS) and element-selective isobaric laser ionization. Once the HRMS is operation, the mass resolution can be increased further by a factor of 100 and will allow measurements with a much wider area of pure radioactive nuclei. Installations for safety, radioprotection, and radio-isotope production have gone ahead, e.g. the replacement of the cooling water system, an upgrade of the control system, and the nuclear ventilation system. The target-ion source complex has now been installed in the ISOL bunker. Ground water infiltration into the SPES building remains a serious concern. A mitigation plan has been developed in collaboration with the Department of Civil Engineering and Environment at the University of Padova, and a geotechnical company has been hired and started in October 2022 with the work on internal perimeter sealing of the building. This work will continue over the following months and also involves the temporary removal of already-installed plant installations.

The medical physics applications and medical radioisotope production (LARAMED and ISOLPHARM) will become an important flagship program for the laboratory and provide a platform for high visibility. ISOLPHARM is an INFN patent and will allow the carrier-free production of unconventional (new) medical radioisotopes with the ISOL method. LARAMED is already well integrated into the national and international research networks (e.g. agreements with hospitals in the Veneto region and the European Medical Radionuclide Program PRISMAP). As a starting point for the new laboratories the production of the theranostic pair Cu-64/Cu-67 has been suggested. While the construction of the new radiochemistry laboratories in the SPES building is finished, the facilities and plants still need to be completed.

A timely completion of the laboratories should have a high priority for the next year to allow a quick start of this medical isotope program when the B70 cyclotron is up and running. It is also highly recommended to explore ERC Starting or Consolidator Grant opportunities for this project since it would allow to secure additional funding for personnel and special equipment.

Progress at AGATA and the new Data Center

The AGATA spectrometer, a major scientific endeavour for LNL and the European Gamma-Ray Spectroscopy Community, arrived in Legnaro fall 2021 and successfully started its first physics campaign with stable beam on target in April 2022. The stable beam experiments with the Tandem will continue in 2023 until first radioactive beams from the new SPES facility will become available in 2024/25. Discussions within the AGATA collaboration are ongoing to leave the setup at LNL for two more years to compensate for delays at other facilities. LNL is also working on a new Data Center which will benefit the AGATA online data processing, as well as the expansion of the LHC Tier-2 center for ALICE and CMS. The tender process is ongoing, and the building construction is scheduled to start in early 2023. The start of the operation of the new Data Center is subsequently planned for February 2024.

Progress in external Accelerator Physics projects

The accelerator group's two main large international projects are the construction and test of Drift Tube Linacs (DTLs) for the European Spallation Source (ESS) in Sweden, and a Radiofrequency Quadrupole (RFQ) at IFMIF (International Fusion Materials Irradiation Facility) in Japan. The IFMIF activities, funded by the European Union via a "Fusion for Energy" tender, have been extended to 2024. Since the beginning of the pandemic travel restrictions to Japan allowed only remote participation with a few European collaborators onsite. Japan has finally dropped its entry restrictions in November 2022 which will allow LNL members to start working onsite again. In the meantime, the IFMIF team could condition the RFQ in late 2021 and operate it at full power, and is planning to accelerate a deuteron beam to 5 MeV until 2023.

The EU Project DONES-PrepF has finished the design phase of a European facility in Spain for material tests for nuclear fusion. Now the construction phase will start with national in-kind contributions, and INFN will be one of the Italian institutions to contribute significant technical developments.

For the ESS project, INFN will contribute five Drift Tube Linacs. One of them (DTL1) has already been installed and successfully commissioned in 2021. Three more DTLs are in various stages of installation and are planned to be commissioned until late spring 2023. The last DTL5 is being assembled in Lund and will be transported into the ESS tunnel in September 2023.

Outreach during the pandemic: The Master course "Surface Treatments for Industrial Applications" is jointly organized by the University of Padova and INFN. In 2021 the 19th edition took place which was attended by a large number of students and industrial partners.

Organisational changes and personnel situation

LNL has presently 126 permanent and 20 fixed-term employees. However, only 16 of them (11%) are researchers which is the lowest of all four National Laboratories (for example, LNF has 23% in the Researcher category). Of concern is the age profile of the LNL researchers – five will retire within the next 4 years, seven more within the next 10 years. This calls for a well-laid out succession plan to avoid further shrinking and to be prepared for the new science opportunities in the SPES era. With an additional young researcher position (in addition to the timely replacement of retired researchers) the lab would be much better equipped for the upcoming increase of science output and influx of new users. The new organigram was approved in September 2021.

The understaffing of critical technician positions continues to be major concern, as well as the high age profile. Several operators are on sick leave due to overworking and health issues which leaves the accelerator operation in a very vulnerable position and could lead to critical delays of maintenance or even shutdowns of the facilities. The specialized hands-on training of newly hired operators (for the Tandem-PIAVE-ALPI complex as well as the new cyclotron) is ongoing but requires time, so a timely hiring of new technicians for other soon-retiring operators is critical. Other critical positions for the operation of an accelerator facility which have not yet been filled are the e.g., the Technical Plants Manager, several Safety and Radioprotection officers, technicians for vacuum, cryogenics, and the medical isotopes program etc. Fellowships are used to hire young entry-level technicians-in-training to develop a pool of trainees.

As emphasized last year, this critical personnel situation requires a continued joint effort between the LNL Directorate and the INFN Management.

Recommendations:
LNL-1: Ensure critical and safety-relevant positions are filled with sufficient staff to avoid a shutdown of facilities.

LNL-2: Continue developing and executing a detailed hiring plan for the next 10 years to "rejuvenate" the lab for the SPES era. This includes growing the number of researcher positions by at least one.

LNL-3: Complete the installations for LARAMED/ISOLPHARM now to allow a quick start when the cyclotron becomes operational.

LNL-4: Outline a detailed plan for the first 5 years of LARAMED/ISOLPHARM operation. Try to secure additional funding via an ERC Grant application (Starting/ Consolidator).

PNRR

The last three hours of the meeting were devoted to PNRR, with the basic goal to inform the CVI and hear our reaction to this exciting major opportunity. First and foremost we note that INFN has been extremely successful in attracting funds for projects under the auspices of the PNRR program, in all four categories: National Centres(1), Infrastructures(9), Ecosystems for innovation(5), and Extended Partnerships(3). This is testimony to the INFN's success in managing large projects in the past. The relevant projects are listed by class and scope in Table 1. The largest projects from a financial point of view are the National Centres and Infrastructure projects. Sustainability, especially for National Centres, will present a major challenge after the 3-year PNRR funding ceases. We comment on this in some detail in the section below on the Italian Centre for SuperComputing (ICSC).

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Name	Type	LEAD INSTITUTION	Budget (M€)	INFN Budget (M€)	INFN Staff
ICSC	National Centre	INFN	320	48.1	46
KM3NETRR	Infrastructure	INFN	67.2	59.3	38
IRIS	Infrastructure	INFN	60	39.5	32
ETIC	Infrastructure	INFN	50	33.9	25
TERABIT	Infrastructure	INFN	30.6	19.9	23
LNGS-FUTURE	Infrastructure	INFN	20.1	19.6	7
EU-APS	Infrastructure	INFN	22.3	14.9	8
CTA+	Infrastructure	INAF	71.4	12.7	13
ITINERIS	Infrastructure	CNR	155	5.1	5
EBRAINS	Infrastructure	CNR	-	0.43	1
SAMOTHRACE	Ecosystem	SICILIA	-	6.6	5
ROME TECHNOPOLE	Ecosystem	LAZIO	121	2.8	4
TUSCANY HEALTH	Ecosystem	TOSCANA	-	0.54	1
RAISE	Ecosystem	LIGURIA	117	0.5	-
ECOSISTER	Ecosystem	EMILIA-ROMAGNA	112	0.47	1
PE4-NQSTI	Partnership	UNI CAMERINO	117	6.4	-

PE15-SPACE	Partnership	POLITECNICO TO	115	2.6	-
PE1-FAIR	Partnership	CNR	50	1.6	-
TOTAL			>1,406	>275	209

Table 1 PNRR projects of the four types described in the text with INFN participation, ordered by the INFN Budget share in each type. Blank columns indicate that the budget is not yet fixed. Note that the additional staff required for these projects is more than 200.

PNRR I: National Centers. ICSC – Italian Center for SuperComputing

ICSC is one of five National Centres foreseen and it aims to build an integrated infrastrucure of High Performance Computing (HPC) Centers and large databases devoted to research for academic and business purposes for the benefit of Italian institutions and companies. It will do so by integrating current data centers and data transmission networks dedicated to research in Italy into a single, cloud-based infrastructure made up of 24 HPC and Big Data Centers, partly already existing. It will offer High Performance Computing (HPC), Terabit per second data transmission services, and integrated access to data by all research institutions in Italy.
The project also includes the development of dedicated data management and data analysis applications for eight research fields: fundamental research and space economy, astrophysics and cosmos observations, earth and climate, environment and natural disasters, multiscale modeling and engineering applications, materials and molecular science,silico medicine and omics data, digital society and smart cities.

The project will receive 320 million euro from PNRR, in the 2022-26 period, and is structured with a Hub and Spoke model, with the Hub receiving and distributing funds and monitoring the execution of the various project components carried forward by the eleven spokes. The spokes include spoke 0, dedicated to infrastructure buildup, spoke 1, for the planning and design of ICSC evolution, and spoke 10 dedicated to quantum computing. These three spokes focused on basic technologies will develop infrastructures and services for the other eight spokes each devoted to one of the specific applications mentioned before.

The governance of the project will be primarily ensured by the role of the Hub, which has the legal status of a private foundation with founding members including 25 universities, 12 research institutions and 14 private corporations and research foundations. The last group of founding partners should support the process of technology transfer of research and the business use of the infrastructure.

The project will enhance the performance of IT infrastructure for Italian research while offering new opportunities to both academia and business to integrate data analysis and strengthen the overall security of the system. INFN, as manager of the Hub and co-leader of spoke 1 can leverage its proven capabilities in managing large-scale projects for research infrastructure and apply them to the management and oversight of one of the largest technology projects in the country. The immediate challenge of the project will be to ensure the implementation and integration of all modules according to a quite rigid timescale, with each of the 11 spokes in charge of its infrastructure design, technology procurement and system implementation. A second challenge, however, is the need to ensure continuing funding for the infrastructure beyond 2026. This is essential to sustain over time a service requiring significant operational costs and frequent infrastructure renewals.

To meet this challenge INFN has developed a reasonably conceived, although initial, plan for economic sustainability after 2026, envisaging a yearly revenue of 58 million Euro. Most of the revenues will imply contracts and grants still to be acquired with a significant proportion deriving from computing services sold to private entities on the market. The plan, however, does not provide margins to pay for infrastructure renewal (that should be about 30 million per year, to fund replacement of 150 million-worth equipment every five years), nor funds from INFN for that purpose, so additional funding should be identified. The hub organization includes an Innovation/ Business development function responsible for developing future revenues. The transition from an almost entirely PNRR-funded to partially market-funded model entails important challenges such as generating revenues ahead of 2026 to avoid an instant drop in funding after PNRR, and defining responsibilities for revenue generation between hub and spokes, including the reallocation of resources in case the market potential of various spokes will not reflect their initial sizing.

Recommendations:
ICSC-1: Give the Business Development/Innovation function the task, to be completed in 12 months, to write a complete business plan for the horizon after 2026 with a growth path to sustainability and a plan for evolution of governance.

ICSC-2: Make sure Hub and Spoke leadership devote sufficient attention to future revenue generation, not only to infrastructure building

ICSC-3: Ensure integration of spoke 0 (design of infrastructure) with spoke 1 (Future HPC and big data) to guarantee a smooth evolution of architecture

ICSC-4: Look for opportunities to find technical (e.g cost sharing) or commercial synergies with other players offering cloud services on the market
ICSC-5: Consider the appointment in the Hub of a high-level technical function, like a Chief Technology Officer, to ensure coordination of design and identification of potential design and procurement synergies across spokes

PNRR-II: Infrastructures

The infrastructure projects target major improvements of existing operations – strongly boosting the capabilities of the groups involved – or development of new fields of competence in good synergy with existing ones. Laboratories like LNGS and LNF in particular will benefit. The KM3Net underwater neutrino experiment will be further equipped in order to reach science mode, and Italy will be well positioned to propose Sardinia as a site for the Einstein Telescope. Expertise in new technologies, like High Temperature Superconductors or Space Technologies, with potential important applications will be boosted. For some of the most challenging projects an extension beyond the three years allotted for completion of the task would lead to a better end-result. Table 1 gives a summary of the chosen projects.

Recommendation:
INF-1: INFN should make the case for an extension beyond three years for these challenging projects.

PNRR-III: Ecosystems for Innovation and Extended Partnerships.

The total funds in these programs are 1.3G€ for 12 Ecosystems for Innovation (EI) and 1.61G€ for 15 Extended Partnerships (EP). INFN participates in 5 EI and 3 EP, which by their nature are collaborative programs with many institutions participating. INFN is not the overall leader at the hub in any of these projects, and in most cases does not even have responsibility for the spoke(s) and hence INFN involvement is often quite small (see Table 1 for details). However, although the main aims of these projects are far from INFN core competences, INFN can contribute its extensive experience of collaborative work and the delivery of such work packages to external organizations. Efficient administration by the Hub will be necessary to complete these projects in the three years allotted, and INFN should insist on this as a condition to remain involved.

The five EI with INFN involvement are: ECOSISTER: Sustainable digital transition in Emilia-Romagna (uniBO); RAISE: Robotics and AI for Socio-economic Empowerment (uniGE); ROME TECHNOPOLE: Energy transition, digital transition, health & bio-pharma (uniRM1);SAMOTHRACE: SiciliAn Micro nanOTecH Research And Innovation CEnter (uniCT); and THE: Tuscany HEalth(TOSCANA).

The three EP with INFN involvement are: PE1: Artificial intelligence: foundational aspects (CNR); PE4: Quantum science & technology (uniCAM); and PE15: Space Activities (PoliTO).

APPENDIX I. Recommendations

Perspectives and Strategy-1: INFN has a great story to tell, and should make sure to transmit it in a way that resonates with the government, industry and the public (a few suggestions are given above).

P&S-2: INFN should compile data on their success in winning ERC grants. Has the number increased, and how do Italy and the INFN compare with other countries?
P&S-3: INFN should consider providing professional grant-writing support.

Central Administration – None.

CSN1-1 INFN should strongly engage in shaping the strategy of CERN and the LHC experiments to promptly address and mitigate the many implications of the Russian crisis.

CSN1-2 CSN1 should emphasize their strong leadership in various areas of the LHC Phase-2 upgrade, anticipating the eventual need of contingency resources. They should make sure to communicate clearly to the funding agency and society the excellence of their research and its long-term positive impact on society.

CSN1-3 INFN should evaluate the possibility of moving the large accelerator-based neutrino experiments from CSN2 to CSN1, carefully considering all implications and the input of all parties.

CSN2-1: For the long term, laboratories and agencies should consider developing a common strategy to secure stable, reliable and affordable supply chains for materials such as enriched isotopes, rare gases and crystals

CSN2-2: LEGEND-1000 is preparing for the DOE CD-1/3A with LNGS and SNOLAB as alternative sites. INFN should work with European agencies involved in the project to generate attractive conditions for hosting LEGEND-1000 at LNGS.

CSN2-3: The decision to create a German Center for Astrophysics in Lusatia – with very significant resources – is a significant push for the ET project and adds a new player in the game. INFN and Italy should develop their strategy in this context and seek strategic alliances.

DarkSide 20K-1: The interfacing with LNGS regarding the installation of DS20K, the definition of interfaces towards the infrastructure and of the mutual responsibilities, and the daily coordination have improved, but a) Documentation needs to be finalized and processes streamlined; and b) Wherever possible, INFN and LNGS should require approved cost and schedule baselines before committing long-term resources.

DS-2: LNGS, DarkSide-20K and INFN management need to do whatever is needed to get the NOA facility producing PDU's.

DS-3: Reaching the design performance is crucial for the success of DarkSide-20K; the experiment must absolutely avoid any shortcuts that could endanger quality and radiopurity of components.

DS-4: DarkSide-20K sensitivity plots based on "full volume" and 20 years exposure may give an over-optimistic view, compared to more conservative sensitivity estimates of other experiments. The collaboration should produce an updated explanation of their sensitivity estimates and of the background assumptions and measurements on which they are based.

CSN3-1: Secure time-critical "Special" funding (3 MEuro until 2025/26) for the R&D phase of ALICE3 detectors. Discuss with INFN management and other CSNs about faster procedures for getting larger funding for high risk-high reward R&D projects.

CSN3-2: Identify more "champions" for ERC grant applications to secure additional funding and attract more researchers to INFN projects.

CSN4-1: In view of the bid to host the Einstein telescope, CSN4 should try to further raise the profile of forward-looking theoretical preparations for gravitational wave physics.

CSN5-1. Plan a review of the "Grants for young researchers" scheme and report on it at CVI 2023.

Knowledge and Technology Transfer: None

LNS-1: LNS together with the INFN management should develop contingency plans in case delivery of the cyclotron magnet is further delayed.

LNS-2: LNS and INFN should ensure that with the completion of POTLNS, approval procedures are well-prepared and that the ion source for high-current injection is ready, so that NUMEN can start high-statistics data taking as soon as possible. For the approval procedures, lessons learned at LNL should prove useful. We request an update on POTLNS status in the midterm report.

LNS-3: KM3Net is one of the reasonably straight-forward PNRR projects, and the technology of KM3Net-DUs is now mature and procedures and quality control are well established. Nevertheless, the assembly of KM3Net DOMs and DUs on the time scale of PNRR will be challenging. Schedule and progress must be carefully monitored. INFN institutes and institutes abroad should advance DU production by increasing support for the production sites at LNS and Caserta.

LNS-4: While science demand for the Tandem is still strong, experiments should emphasize novel questions over standard and repetitive topics. On the time scale of 5 years, the science case for continued operation of the Tandem should be re-assessed, also in view of the increasing cost of operation.

LNL-1: Ensure critical and safety-relevant positions are filled with sufficient staff to avoid a shutdown of facilities.

LNL-2: Continue developing and executing a detailed hiring plan for the next 10 years to "rejuvenate" the lab for the SPES era. This includes growing the number of researcher positions by at least one.

LNL-3: Complete the installations for LARAMED/ISOLPHARM now to allow a quick start when the cyclotron becomes operational.

LNL-4: Outline a detailed plan for the first 5 years of LARAMED/ISOLPHARM operation. Try to secure additional funding via an ERC Grant application (Starting/ Consolidator).

Italian Center for SuperComputing-1: Give the Business Development/Innovation function the task, to be completed in 12 months, to write a complete business plan for the horizon after 2026 with a growth path to sustainability and a plan for evolution of governance.

ICSC-2: Make sure Hub and Spoke leadership devote sufficient attention to future revenue generation, not only to infrastructure building

ICSC-3: Ensure integration of spoke 0 (design of infrastructure) with spoke 1 (Future HPC and big data) to guarantee a smooth evolution of architecture

ICSC-4: Look for opportunities to find technical (e.g cost sharing) or commercial synergies with other players offering cloud services on the market

PNRR INF-1: We encourage INFN to make the case for an extension beyond three years for these challenging projects.

APPENDIX II: 2021 CVI Reports on LNGS and LNF

LNGS – Laboratori Nazionale del Gran Sasso

LNGS hosts an exciting interdisciplinary program – 22 operating experiments covering a wide range of topics spanning astroparticle physics, nuclear physics and nuclear astrophysics, relativity and basic quantum physics, up to evolutionary biology, in a good mix of large-scale experiments, smaller experiments and exploratory R&D studies. LNGS is the home laboratory for several world-leading experiments focused on two key questions in modern particle/astroparticle physics: the nature of Dark Matter; and the nature of neutrinos, probed via neutrinoless double beta decay ($0\nu\beta\beta$). In both areas, improved next-generation experiments are in preparation.

Particular highlights of the LNGS program include

- The publication in late 2020 of the detection of solar neutrinos from the CNO cycle by BOREXINO, and the improvement of the thermal stabilization of the detector, which allowed further improvement of the measurement with the data collected up to October 2021, when the decommissioning of BOREXINO started. The collaboration was recently awarded the EPS Cocconi prize.
- The successful commissioning of XENONnT, and the start of the first science run. Despite the need to operate at reduced drift voltage, performance of the detector is excellent, and data collected during 2021 and early 2022 should probe the intriguing low-energy excess detected in XENON1t, with improved control of tritium levels in the detector, aiming to rule out this background.
- The final results from GERDA set a 1.8 x 10^{26} yr limit for neutrinoless double beta decay ($0\nu\beta\beta$) in ^{76}Ge and demonstrated background-free operation; the 1 T yr results from CUORE set a limit of of 2.2×10^{25} yr for ^{130}Te.
- An important technical result of CUORE is also the successful demonstration of long-term stable operation of a very large cryogenic setup with excellent uptime, paving the path towards the improved CUPID experiment.

The installation of LUNA-MV is progressing, with LUNA400 and LUNA-MV to be operated in the future as a facility. A rich physics program is outlined both for LUNA-MV and for the continuation of LUNA400, and a program committee is being installed to select and monitor experiments.

Major experiments at LNGS continued to operate throughout the pandemic, and the installation and commissioning of new experiments such as LEGEND-200 and XENONnT progressed very well. This represents an extraordinary achievement of LNGS management and the experimental teams.

Scales and complexity of underground astroparticle experiments are ever-increasing; their design and installation are challenging, and demands on the lab's facilities and services are increasing accordingly. Upgrades of LNGS facilities, planned or in progress, include a cryogenic platform for test and measurement of detectors and devices at very low temperatures, the STELLA facility for large-scale state-of-the-art material screening, a new ICP-MS facility and supporting instruments, the 450 m^2 NOA clean room facility, advanced workshops with copper 3D-printing, and an underground workshop for machining of materials with minimal activation. Utilities and power systems are also being upgraded. These measures, which significantly enhance the value of LNGS for its users and further improve the quality of user support, ensure that the lab will remain attractive and will prepare it for the coming generation of very large experiments. The increase in engineering staff achieved through the extraordinary recruitment plan is essential to provide adequate support for the planning, installation and support of operation of such experiments.

With these measures, LNGS is well-prepared but nevertheless has to develop a long-term strategy to maintain its role, given the increasing number of underground labs world-wide, and enhancement / expansion of other facilities. Work towards a 5-10 year strategic plan is in progress; given the time scales of large experiments, longer-term considerations should be included. Cooperation and coordination with other labs are crucial strategic elements, as well as sharing of specialized facilities of general interest – such as material screening. We commend the plans of LNGS to work with other European underground laboratories to optimize their use.

LNGS was recently selected as the only suitable European lab for new $0\nu\beta\beta$ decay experiments. We support the strategy for international coordination of these and even larger future experiments, where LNGS will act as host, supported by R&D at other laboratories. LNGS is also collaborating with SNOLAB on strategy for future Dark Matter experiments.

Recommendations:
LNGS-1. Environmental impact concerns have in the past resulted in significant delays and/or termination of experiments. The process for safety and environmental impact evaluation has been streamlined by the lab, and the interaction with local authorities has greatly improved. Nevertheless, INFN and the respective ministries will have to strongly support LNGS towards finding pragmatic solutions for remaining open issues.

LNGS-2. The recent North America - Europe Workshop on Future of Double Beta Decay has revealed interesting perspectives, and in particular a path towards two major next-generation experiments (in addition to CUPID), one of which could be located at LNGS. INFN and LNGS should make strong efforts to attract LEGEND-1000 to LNGS. This will require raising an appropriate funding share in Europe, in interaction with European funding agencies, under the promotion by INFN and MUR.

LNGS-3. Approval procedures for experiments that receive a significant fraction of their funding via CNS2 are sometimes unclear, with parallel approval paths for CSN2 funding and LNGS underground space. Requests to CSN2 and LNGS must be coordinated *before* approvals.

LNF –Laboratori Nazionali di Frascati

The Frascati National Laboratory (LNF), the largest and the oldest of the INFN National Laboratories, is devoted to the development, construction and operation of accelerators, and the design and construction of forefront particle detectors for particle, nuclear and astroparticle experiments. The research infrastructure comprises the DAFNE *e+e-* collider and Beam Test Facility complex, SPARC_LAB for R&D on novel techniques of particle acceleration and the future EuPRAXIA@SPARC_LAB infrastructure, SCF_LAB to characterize lasers, large assembly halls with several clean rooms and various technical services. More recent installations include COLD, a cryogenic laboratory, and TEX, a RF X-BAND test facility under completion. In 2020, LNF had 318 employees with permanent contracts, 30 with fixed-term contracts, 216 associated (including Cosenza University) and 188 external users. Here we report on recent highlights and the impressive list of achievements during the course of last year despite the difficulties related to the Covid outbreak.

The EuPRAXIA H2020 Design Study is a multinational effort to build two plasma-based accelerator facilities to drive a Free Electron Laser. The EuPRAXIA@SPARC_LAB project is the Italian branch implementing the beam-driven technique. In addition, LNF, with a strong leadership role in the whole project, will host the headquarters. The project is taking off with many relevant milestones reached recently:

- EuPRAPXIA submitted an ESFRI application in 2020, which has been positively resolved in June 21; Italian government funds (108 M€) have been secured.
- The work towards delivering a Technical Design Review in 2025 within a budget envelope of 6.5 M€ has started, including the acquisition of computing hardware and constructing the TEX facility. A final draft of the building design to host the new machine has been submitted, for an overall cost of

32 M€. The final layout of the new machine is being elaborated, and a preliminary expense profile for the overall project is available, showing limited contingency.
- Excellent results were obtained at SPARC_LAB with the observation of 133 MV/m acceleration in plasma and of FEL lasing.
- The TEX facility will be used to test RF structures for EuPRAXIA, but also for CLIC and in the context of the LATINO project providing access to new technologies to private companies.

Operation restarted at the DAFNE/BTF complex in May 2020 with a modified schedule, running first in Linac mode and later in collider mode. In the BTF1 area, the PADME experiment successfully recorded its first data during 2020 after optimizing background conditions, accumulating 50% of the statistics foreseen for the dark photon search. A second run is foreseen in 2022. In January 2021 the installation of the BTF2 area was resumed. First users are expected in fall 2021. The DAFNE collider also restarted operation for the SIDDHARTA-2 experiment. An initial run to optimize the beam conditions took place. The data collected with Siddhartino, 1/6 of the full detector, provided high-quality data of Kaonic Helium. The exploitation of the data collected by the previous collider experiments, KLOE and KLOE-2 is ongoing, with a final round of reprocessing, many active analyses, and measures for data preservation. The DAFNE-Light laboratory worked mainly with conventional radioactive sources rather than DAFNE synchrotron radiation, serving 34 experiments. A mailing service of samples was put in place during COVID-19 time.

The cryogenic laboratory COLD is a relatively new facility equipped with devices capable of measuring ultra-low temperatures (down to 10 mK). It specializes in the development of detectors for photons in the microwave region, like the QUAX haloscope for axion search or Qubit superconducting quantum sensors, offering promising fundamental research lines in the future. The successful completion of the large production of muon chambers for one of the ATLAS New Small Wheels now being installed in the experiment, is also worth noting.

We acknowledge the concerns about running two large facilities in parallel, EuPRAXIA and the DAFNE complex, and commend LNF for the steps taken to address these questions: are there enough resources to run both of them? Which in-situ fundamental physics program should be pursued? A discussion program has been setup to evaluate, with the help of the LNF scientific committee, possible fundamental physics activities: two at DAFNE and an axion search. Depending on the outcome, cost and required manpower would eventually be evaluated.

We take note of the situation of the technical personnel, already at a minimum with a large number of retirements expected in the coming years. Will there be enough skilled personnel to build and run EuPRAXIA@SPARC_LAB in the future? Steps have been taken to mitigate this problem. Various temporary positions covering different technical area of expertise have been opened. We appreciate the new initiative of establishing a collaboration, together with industries from the region, with a local technical institute to set up a training program for selected young potential future technicians.

Recommendation.

LNF-1. Clarify the priorities of LNF in the future and the corresponding manpower needs. Please address this in the midterm report.