Annual Report to the President of the INFN

Il Comitato di Valutazione Internazionale (CVI)

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Introduction

The 2021 annual CVI meeting took place the 14th through 16th of October in Venice. Our charge was to evaluate the accomplishments of the INFN National Scientific Commissions (CSN's), Technology Transfer group, National Laboratories, and Senior Administration; and to advise on priorities. We wish to thank the INFN leadership and staff for the superb planning and hard work to make the meeting possible under difficult circumstances and to select ideal venues for presentations and discussions. The contrast of this in-person meeting with last year's ZOOM version was stark and highly positive, and reminded us that informal discussions are an essential component in making accurate evaluations.

Governance and Strategy

Over the past two years the senior management group has developed into a well-integrated leadership team. We note the increased roles of the Executive Board members – a healthy and effective delegation of authority. The strategic plan is broad and strong, featuring two exciting new initiatives (EuPRAXIA and the Einstein Telescope) along with an outstanding portfolio of continuing and future programs: the LHC at CERN, experiments at other accelerators in Italy and around the world; and underground/undersea experiments at LNGS and LNS.

The budget situation remains satisfactory, with a base funding of ~270M€ plus additional Covid-19 and PNRR funds. Of particular note, INFN has received 160 M€ extra funding for infrastructure over 10 years. The current good budget does not dispel concerns for sustainability, but INFN management is well aware of the problem. INFN involvement in PNRR projects understandably follows traditional strands. However, given the key role of ecological transitions in next years, we suggest that INFN might consider playing a bigger role in this field.

There is also positive news on the personnel front: the "stabilization" process is ending, and INFN could receive up to 82 new positions in 2021 for researchers and technologists via a new extraordinary recruitment plan from the ministry. Of these, 60 positions are for entry-level researchers in INFN's five scientific lines. The plan also calls for an additional 40-50 positions in 2023. This plan for new hires seems well conceived (allocation based on needs agreed with heads of structures rather than by quotas, and with pre-assigned vs. free destinations.) While highly positive, this plan also presents serious challenges: Can enough skilled good people be hired in a short time? Can INFN marshal adequate sustainable technical and financial support for the larger number of researchers? How will INFN manage promotions and advancement to permanent positions of junior researchers, especially during the transition to a new plan for promotions, and because of the possible elimination of the "Ricercatore" rank? We look forward to learning more on these issues at next year's meeting.

Finally, we compliment INFN for its innovative approach to the serious shortage of technicians, by pursuing agreements with Technical High Schools for training and recruitment of high quality people to replace the large number of those retiring.

Recommendation.

GS-1. We encourage INFN to consider increasing the application of its expertise to life sciences and ecology, as part of the strategic plan, and request a "1-pager" on this subject as part of the midterm report.

Central Administration (CA)

The extensive overhaul of central administration continues under the new Director General (DG), with the overall guiding theme "Getting things simple." Reduction and focusing of responsibilities are key steps, with a clear rationale and convincing solutions, and the creation of the new Directorate of Research Services (DRS) should be of great help. Similarly the new Project Management Office is designed to achieve optimal division of duties between central and the local units. Initial indications are promising, but is too early to assess results because the new plan has only been in operation for two months. The DG pointed out that the administrative staffing level is low by comparison with similar organizations, and stated that expansion of administrative staff from 120 to 150-160 is desirable.

Despite the radical changes, CA still has a very horizontal structure: more than 1 in 3 people are head of something. Sharing of responsibilities may be a good incentive to motivate people but may also water down the command chain. Perfect balance is difficult to achieve but assessment in due time is necessary.

Recommendation.
CA-1. We wish to follow up on last year's recommendation: *"The Director General's ambitious program needs prioritization. In due time, it would help to fix targets to be achieved in the coming years."* Specifically, we request that INFN provide a list of targets, milestones, and their status in the Interim Report.

CA-2. We take note of the extensive changes of the CA and see this reorganisation as reasonable, *a priori*. INFN should monitor the effectiveness of the reorganisation (e.g. effective streamlining and simplification of processes, cost reduction, enhanced cooperation among CA and INFN structure), and conduct a semi-formal assessment within 2 years.

CSN1 – Particle Physics at Accelerators

The First National Scientific Committee (CSN1) coordinates INFN activities in Particle Physics at Accelerators. It is a large sector, with 1200 researchers and technologists and an annual budget of 20 M€ along with 2 M€ of external funds. Both personnel and budget have been stable in recent years. A large share, about 60%, is dedicated to the LHC at CERN, with the rest supporting a large portfolio of other experiments addressing flavour physics, charged lepton physics, etc. In general, good progress has been achieved on all fronts despite the difficulties related to COVID. A detailed analysis reveals strong and stable INFN representation in leadership positions and contributions to publications.

In the case of the LHC, many published results exploit the full statistics of Run 2; among the highlights are the observation of new rare processes like the Higgs $\rightarrow \mu\mu$ decay at CMS; $\gamma\gamma$ scattering at ATLAS; and improved measurements of flavor anomalies and discovery of new exotic structure at LHCb. Concerning the Long Shutdown 2, good progress has been seen recently as technical difficulties or Covid-related delays are overcome, enabling ATLAS, CMS and LHCb to be ready for the start of Run 3 in March 2022. A good share of the merit goes to the INFN groups.

ATLAS and CMS will profit from the slight increase of center-of-mass energy to 13.6 TeV and the increased integrated luminosity. The phase-1 upgrade of LHCb will allow the experiment to collect 50 fb-1, a significant increase in luminosity and physics reach over the 9 fb-1 acquired so far.

Strong tensions remain in the schedule of the Phase-II upgrade. The most severe problems concern the inner tracker of ATLAS and the high granularity calorimeter of CMS, where no contingency remains, or it is even negative in some cases. To deal with the delays, discussions on the schedule will take place starting this November. It is likely that Run 3 will be extended by one year, and the experiments are asking for an additional 6 months extension of Long Shutdown 3 (LS3). INFN welcomes this extension, as it will make the schedule of the Phase-II upgrades more realistic. INFN seems to be in a good position to handle the extension, as the CORE money is available and can be spent with a flexible time profile. Having to extend contracts of temporary personnel may bring cost overruns, but this can be mitigated by delaying hiring when possible.

There is also progress in areas of interest beyond the LHC. In flavor physics, Belle-II (superKEKB) recently started data-taking. The detector performs well, and problems preventing the accelerator from reaching the design luminosity are being diagnosed. BES III (BEPCII) continues taking data and producing results with the recent observation of a tetraquark. INFN is also playing a strong role in Charged lepton Physics, in particular in Charged Lepton Flavor Violation, with participation in MEG II (PSI), MU2E, and MUonE (SPS). MEG-II has overcome the drift chamber problems and has started data-taking. MU2E is preparing for a start in 2025, but solenoids are on the critical path. Muon g-2 is about to start Run5. MUonE will have a test run in 2022. At Fermilab INFN groups are searching for effects beyond the Standard Model with the Muon g-2 experiment. Strong collaboration with CSN4 continues on theoretical aspects. In the realm of kaon physics, NA62 has published a first observation of the $K^+ \rightarrow \pi^+ \nu\nu$ decay with 3.5 σ significance so far compatible with the SM. It has successfully completed the Gigatracker update, resulting in a factor 6 reduction of the background. The goal is to collect 80 $K^+ \rightarrow \pi^+ \nu\nu$ low-background events during Run3. The KLOE-2 experiment at Frascati concluded data-taking in 2018 and is now producing its legacy physics results. We are pleased to see INFN involvement and excellent progress in a new experiment under construction SND@LHC to detect neutrinos produced at the LHC, with an interesting physics program and good participation from CSN1.

Large efforts have been made to keep taking data during the COVID periods. Although this has been successful, this sometimes put a heavy burden on the local groups. As travel resumes, changes in the traditional modes of participation are possible. The impact should be carefully monitored.

CSN1 is also active in design for future colliders at the energy frontier following recommendations from the EU Strategy for Particle Physics. Two lines of activities, established by the European Strategy Update, are being pursued. First, the RD_FCC is an initiative to study the feasibility of a Future Circular Collider at CERN, in support of which INFN proposes a detector concept, IDEA, for FCC-*ee* that is also valid for the proposed Chinese CepC collider. The work covers various lines of detector R&D, software for physics benchmarking, among others. Second, INFN performs accelerator and magnet R&D and studies the physics reach for RD_MUCOL, an initiative to explore possibilities for a muon collider. Both initiatives seem to find good support in CSN1, and have synergies with CSN5.

Recommendations:
CSN1-1. The strong LHC program is complemented by a good portfolio of other experiments. It is important to maintain, and increase if possible, the breadth of the CSN1 programs to keep attracting new contributors.
CSN1-2. Because of the extremely tight schedules, CSN1 should make sure to monitor closely the evolution of the LHC Phase II upgrade projects.
CSN1-3. The project management strategy implemented by CSN1, especially on its CERN experiments, may be of help to other CSN's with large projects.

CSN2 – Astroparticle Physics

(Highlights from searches for neutrinoless double beta decay and the **Dark Universe** are covered in the LNGS section of the report.)

The CSN2 portfolio, primarily covering neutrino physics, radiation from the Universe, the Dark Universe and gravitational waves, spans a wide range of experimental activities, from small-scale experiments including some that probe fundamentals of quantum physics and gravitation based on novel ideas, to large flagship experiments of astroparticle physics. An essential aspect of many of these experiments is the development of new experimental techniques and detectors that are also likely to find applications in other fields. INFN scientists have leading roles in a significant number of international collaborations, and have high presence and visibility in the field.

Research supported by CSN2 has resulted many highlights, including:

- **Gravitational waves and VIRGO**: the O3 run that ended in 2020 has resulted in a number of exciting discoveries, including a very massive Black Hole merger with almost 180 solar masses, highly asymmetric mergers, and discovery of two Neutron Star – Black Hole mergers, among the total of almost 60 detected mergers. VIRGO participated in the GW network with about 70% uptime, and during O3 improved its sensitivity to a binary neutron star range of 60 Mpc. VIRGO is implementing upgrades towards the O4 run.
- Studies of **Radiation from the Universe** include space-based spectrometers like AMS, DAMPE and in future HERD, and ground-based cosmic-ray detectors such as AUGER, and gamma-ray telescopes such as MAGIC and the future CTA. AMS and DAMPE have reported precision spectra of cosmic-ray nuclei, isotopes and electrons/positrons, that show unexpectedly rich spectral features, with implications for our understanding of cosmic particle acceleration and propagation. The detection of TeV gamma rays from several gamma-ray bursts (GRBs) by MAGIC allows the study of particle acceleration in these most violent explosions. Auger, providing stunning precision spectra of ultra-high energetic cosmic rays, has so far not seen a clear indication for localized sources, likely due to the lack of event-by-event identification of the mass of the primary. The ongoing upgrade to improve muon identification will provide such data.
- **Neutrino physics:** The INFN community is strongly involved in neutrino oscillation experiments that address two other fundamental questions of neutrino physics: the neutrino mass ordering, and the existence of CP violation in the neutrino sector. Experiments with Italian participation include the long-baseline T2K experiment that found first hints for CP violation; a detector upgrade with strong Italian engagement is in progress. Work at Fermilab concerns both short-baseline and long-baseline experiments, and in particular preparations for DUNE that aims at providing the final word on CP violation in the neutrino sector. INFN is also heavily engaged in the construction of the JUNO 20-kton liquid scintillator detector in China; JUNOs main target is the determination of neutrino mass ordering but it will contribute to a wide range of topics in neutrino physics and neutrino astrophysics.

Smaller-scale CSN2-supported experiments such as ARCHIMEDES and GINGER/GINGERINO probe fundamental features of gravity, via difficult and challenging precision measurements. While speculative, these experiments could have huge impact if anomalies are discovered.

Across this wide range of experimental activities, CSN2 is using its resources efficiently, with high impact. Managing the diverse portfolio of CSN2 experiments, enhancing it and occasionally pruning it is a non-trivial challenge. CSN2 has during the last year introduced a formal and structured procedure for reviewing and improving the monitoring of experiments in the various stages, from the initial concept and design through to the implementation, operation, and upgrades. Having raised this point in last year's review we welcome and support the new measures. CSN2 are well aware that they will have to establish the right balance between the formal project management approach and the effective support for small initiatives and new ideas.

The inclusion of the Einstein Telescope (ET) in the ESFRI list of European facilities was an important step for the project. CSN2 is engaged in preparing for ET, the full scope of which evidently goes far beyond CSN2's means. PNRR funds are proposed both to support the proposal for the Italian site, and to support, in a site-independent way, the development of key technologies and the engagement of Italian industry. Such funding could indeed prove well-timed and decisive; its use will have to be carefully orchestrated for maximum and sustainable impact.

Twenty years after the first DAMA results claiming evidence for the observation of dark matter, the phenomenon is still not understood. Recently the ANAIS and COSINE experiments did not see any annual modulation, but the discrepancy with DAMA is limited to few standard deviations. The SABRE experiment – with NaI crystals of similar purity as DAMA's and with northern and southern sites – was intended to give a decisive answer, but according to its recent Conceptional Design Report, will likely again be limited to a few-sigma result after some years of data taking.

Recommendations:
CSN2-1. The new scheme for managing experiments in CNS2 should be reviewed after 2-3 years, and fine-tuned where appropriate.

CSN2-2. Given the increasing scale of experiments in CNS2, in-depth reviews including external experts should be considered, towards preparing major decision milestones regarding large-scale activities.

CSN2-3. In view of the international competition for the ET site, to secure adequate funding INFN should strongly engage with the Italian government.

CSN2-4. The DAMA data analysis has often been criticized as not transparent. To convince the community, INFN should work with DAMA to make its raw data openly available.

CSN3 – Nuclear Physics
CSN3 supports six strongly interconnected research lines: *Quarks and Hadron Dynamics; Phase Transition in Hadronic Matter; Nuclear Structure and Reactions; Nuclear Astrophysics; Symmetries and Fundamental Interactions; Applications and Societal Benefits.* The research portfolio spans all four INFN national laboratories, as well as a multitude of Italian universities and international radioactive beam facilities. In addition to fundamental nuclear physics research, application-oriented interdisciplinary research is being pursued in radiobiology and biomedicine, matter/antimatter studies, and quantum physics.

CSN3 is in a critical phase. Facility upgrades at LNS and LNL are ongoing and in a crucial stage, and the number of scientists involved in new large external projects (e.g. FAIR in Germany and EIC in the USA) will steadily increase in the coming years. The annual general budget has been constant at approx. 9 MEuro in the past 6 years, and the number of FTE has not changed much during this period (about 500 FTE).
The amount of external funding over the past years has been high, especially from POTLNS, ERC grants, and other Horizon 2020 grants. It will be interesting to see at which level these important contributions can be sustained in the future.

Despite the almost constant number of FTEs, the total number of personnel working on CSN3 projects has increased since 2016 by more than 30% due to more staff working on several projects in different CSNs. A shining example is the collaboration between CSN3 and CSN5 for the new "INFN-4LS" (INFN for Life Science) projects. This shows the interdisciplinary nature of Nuclear Physics and its applications but also carries the risk of too much fragmentation. Presently, CSN3 scientists are involved in 24 projects/ experiments. ALICE (about 130 FTE) and GAMMA (about 50 FTE) represent the two largest projects, while 10 smaller projects have equal or less than 10 FTE. Given the ambitious future plans with strong CSN3 involvement it should be investigated which of these small low-impact projects can be closed within the next 5 years.

It is very encouraging to see that the percentage of female researchers (INFN personnel and associates) has reached around 30% and the number of female CSN3 coordinators in the 21 INFN sections is even higher (43%), demonstrating that CSN3 is a role model in this respect. Interestingly, while the number of Bachelor and Master theses has strongly increased in the past years, the number of finished PhD theses stayed constant at around 20 per year. Of concern, however, is the steep drop in all three stages (Bachelor, Master, PhD) of the number of female students completing their theses. CSN3 should investigate if the complicated Italian system for admission to a PhD thesis is the source of this lack of students (especially female), and find ways to increase the number of PhD students over the next years. In addition, it would be useful to track the careers of Master students from the past 3-4 years to see if they left science due to missing PhD thesis opportunities in CSN3, moved to other CSNs, found thesis projects outside of INFN, or even moved abroad for their PhD.

Young researchers from CSN3 have jointly written a review paper on "Trends in particle and nuclei identification techniques in nuclear physics experiments" focussed on the Italian research, which has been recently published in Rivista Nuovo Cimento. Such work across the CSN3 projects is very appreciated and will act as seed for future collaborations.

Three workshops for the Nuclear Physics Mid-Term Plan are scheduled in early 2022 to discuss the future of nuclear physics research in Italy in the next 5 years, with emphasis on INFN laboratories. It is envisioned to publish three "White Papers" (one each for the nuclear physics program at LNL, LNS, and LNGS/LNF). This exercise is timely and a **summary report on important outcomes should be provided in the next GLV Report in fall 2022.**

CSN3 has coped very well with the pandemic restrictions. All projects continued, although direct participation in external experiments (e.g. Europe, Japan, USA, Canada…) was not possible due to travel restrictions, and participation in experimental shifts was mainly remote. The unused travel funds from 2020/21 have been diverted into projects. As of November 2021, most countries have opened their borders again for business travel of vaccinated persons, with exception of Japan and China.

The Electron-Ion Collider (EIC) has achieved major milestones in 2021. The Conceptual Design Report (CDR) and a Yellow Paper were published, and the project received CD1 (Critical Decision 1) approval from the US Department of Energy. INFN scientists contributed a large part to the EIC CDR and the Yellow Report. The Italian groups agreed to join the ATHENA ("A Totally Hermetic Electron-Nucleus Apparatus") proto-collaboration for the design of a detector that covers the whole EIC physics program, and Silvia Dalla Torre from INFN Trieste has been elected as first spokesperson. **A report and an outline of the INFN contributions for the next 5 years should be given in the next CVI Annual Meeting.**

The setup of the AGATA array at LNL is on track and the new Memorandum of Understanding of the collaboration for the period 2021-2030 has been approved. Just before the 60-year Celebrations in October 2021 the detector-holding structure had been delivered from the UK so that the shipment of detectors from GANIL can start and the array be populated. The plan is to have stable beam experiments in 2022/23 before the first radioactive beams from the new SPES facility will be delivered in 2024/25. NUMEN at LNS is planning to extract nuclear matrix elements for neutrinoless double β-decay ($0\nu\beta\beta$) systems from double-charge exchange reactions. The upgrade of the MAGNEX Spectrometer is on track and the Technical Design Report (TDR) has been published in 2021, allowing the collaboration to proceed with the construction phase. The PANDORA experiment at LNS has finalized their TDR and received approval from the Machine Advisory Committee (MAC). The first years of operation will make use of detectors on loan from the GALILEO collaboration. The LUNA-MV accelerator has finally received the required authorizations and has been installed in the cavern at LNGS. Commissioning has been started and will continue until 2023. The AEGIS and ASACUSA collaborations, focussed on experiments with anti-protons at CERN, will merge in 2022 into the new "Low Energy Antimatter" (LEA) collaboration, allowing to exploit synergies between the two previous competitors.

Several CSN3 groups (Nuclex, ASFIN, and n_TOF/LUNA) are working on an experimental solution of the "X17 puzzle", a hypothetical boson with a mass of 17 MeV that was so far only observed in two experiments at the ATOMKI laboratory in Hungary. Broad speculations surround this hypothetical particle as carrier of a postulated fifth force which could be connected to dark matter, but so far no complementary experiment has been able to reproduce the "ATOMKI anomaly". The experimental efforts within CSN3 are well-defined and could help to quickly solve this puzzle in the next years.

CSN3 continues to publish a good number of high-profile papers. Some examples are:

- ALICE has measured the interaction dynamics between unstable baryons containing strange quarks (hyperons) which serves as important input for Lattice QCD predictions (Nature 588 (2020))
- AEGIS has published the pulsed production of antihydrogen by charge exchange of excited positronium in Nature Physics 19 (2021)
- Members of the GAMMA collaboration were involved in an extensive study that revealed that angular momentum in fission is actually generated after the nucleus splits ("post-scission") (Nature 590 (2021))
- Members of CSN3 have been involved in the measurement of the neutron skin of Pb-208 by the PREX collaboration at Jefferson Laboratory which has implications for the equation of state in neutron stars (Physical Review Letters. 126 (2021)).
- The CLAS experiment at Jefferson Laboratory has shed light on the inner structure of neutrons and protons (Two papers in Nature Physics 17 (2021))

Recommendations:
CSN3-1. Support critical LNL upgrades (and repairs) with high priority to allow timely and full exploitation of new science opportunities (also beyond nuclear physics applications, INFN-4LS)
CSN3-2. Keep a diverse research portfolio but avoid too many small low-impact projects.. Investigate which projects can be closed within the next 5 years.
CSN3-3. Investigate the reasons for the steep drop in female students carrying out Bachelor, Master, and PhD theses in the past 3 years. Discuss with other CSNs and university partners what can be done to lower the barriers for female students to enter these programs.
CSN3-4. Provide a summary report from the outcome of the three Mid-Term Workshops in the next GLV annual report.
CSN3-5. Provide a report (presentation in next CVI meeting) and outline of the planned INFN contributions to the EIC over the next 5 years.

CSN4 – Theory

The award of the 2021 Nobel Prize to Giorgio Parisi, a long-time associate of the INFN, is a testament to the vigor and creativity of the Italian theoretical physics community. After his formal retirement, his association continues as an "associazione come eminente personalità scientifica", an assessment which has now been endorsed by the Nobel Committee.

It is important to emphasize that such success does not occur in a vacuum. Parisi is without doubt a singular talent, but the space for such a talent to achieve its full potential relies on tradition of excellence in Italian theoretical physics. (In the case of Parisi that excellence stretches back through Cabibbo, Touschek, Amaldi, Maiani and Altarelli all the way to Fermi). The career of Parisi encompasses Particle Physics, Equilibrium and non-Equilibrium Statistical Mechanics (with applications to material science and biology) and mathematical methods of Statistical Physics with applications ranging from condensed matter and gravitational systems, biological networks and living aggregates, to socio-economic phenomena. This emphasises the importance of renewed support for basic science across a wide spectrum of topics, with a special emphasis on the creation of opportunities for young people.

This year the CSN4 presented results from the six lines of scientific enquiry,
1) String and Field theory
2) Particle Phenomenology
3) Hadron and Nuclear Physics

4) Mathematical methods
5) Astroparticle Physics and Cosmology
6) Statistical and Applied Field theory
We note that the distribution of personnel among the various lines of enquiry remains roughly constant, with an increase in activity in Astroparticle Physics and Cosmology being compensated with a decrease in Hadron and Nuclear Physics.

A brief report such as this cannot report on all the activities in these six areas. However, we shall mention a few areas, which provide direct support for world-leading INFN activities in experimental physics. INFN activity on the structure of the proton, both for parton distribution functions and for more detailed structures exploring the transverse momentum structure of the proton, has importance for the program of the LHC and the future Electron-Ion-Collider (EIC). Another activity important for the interpretation of LHC data is the field of precision Monte Carlo event modelling where the aMG5_MC@NLO, GENEVA and POWHEG give comprehensive results. Theoretical activities related to the anomalous magnetic moment of the muon and the (g-2) experiment are now crucial for the interpretation of the current and future experimental results. This activity includes, but is not limited to, lattice gauge theory where there is a strong tradition seeded in part by early work of Parisi. The HEPFIT collaboration provides an analysis tool that is fundamental for the interpretation of results in Higgs boson and flavour physics, both in the standard model and in suggested extensions. The Italian community also has the largest European community working on Beyond the Standard Model (BSM) physics, which, inter alia, analyses the potential of future machines such as the muon collider, FCC-ee and FCC-pp to test BSM models. Stimulated by the discovery of gravitational waves there has been renewed activity in numerical modelling and calculations in the post-Newtonian approximation.

We take note of the statistics of gender diversity in CSN4 where the female percentage is between 13.0%(associates) and 15.0%(employees) compared to 22% for researchers in INFN as a whole. The reasons for this gender disparity are many. The limited number of female role models is believed to be part of the reason. In this regard we note that there is a large diaspora of distinguished Italian women theoretical physicists in many parts of the world (a partial list is Bissi (Uppsala), Buonanno (Maryland), Covi (Gottingen), Gori (Santa Cruz), Nappi (Princeton), Lisanti (Princeton), Lunardini (Arizona), Reina (Florida), Verde (Barcelona), Ubiali (Cambridge) and Zanderighi (Munich)).

Recommendation:
CSN4-1. A scheme to re-involve expatriate female scientists in the intellectual life of the country might be beneficial.

CSN5 – Technological and Interdisciplinary Research
The Fifth National Scientific Committee (CSN5) coordinates advanced technological research for INFN experimental activities and promotes the development of instruments, methods and techniques for fundamental physics and their application in other fields. These transversal activities across committees contribute to strengthening links with universities and national research institutes. Many of developed technologies have a significant social and economic impact.

CSN5 carries forward a well-structured research program, centred around three main research lines: detectors, electronics, and computing (36% of the budget in 2020); accelerators and related technologies (29%); and interdisciplinary physics (35%). Note, however, that research activities often overlap and escape rigid classification. Funding is organised in three project categories: Standard experiments (71%), Calls for Proposals (17%), Grants for young researchers (12%). 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. The strong shift of the budget in 2021 and

2022 in favour of Calls for proposals is episodic, due to Covid-19-related extensions and to the exceptional selection of eight Calls in the last two years.

The Covid-19 epidemic had a significant impact on CSN5 activities, which however never stopped (apart from travel). CSN5 identified areas of expertise where the INFN researchers could provide valuable contributions in dealing with the Covid-19 epidemic; significant examples include an interdisciplinary workshop “INFN and the Covid-19 challenge”, held in February 2021, and some Covid-19-related experiments (PLANET, AT-SVB). The CSN5 maintains a continuing positive record as to scientific production, and a leadership role in technological transfer – unsurprisingly, given its mission. Overall, it has a good mix of technological development for core activities, promotion of applied physics, and promotion of collaborations inside and outside INFN.

We are very pleased with the results of CSN5, and appreciate the clarifications about the allocation of resources among the three categories of projects. We find the underlying criteria sensible, in particular that the stated “maintenance of equilibrium among different research areas” does not imply remaining stuck to past allocations, but refers to a “dynamic equilibrium” in which opening of new fields and resource re-allocation are driven by the evolution of the research interdisciplinary frontier.

We take note that CSN5 plays an important role in transferring INFN knowledge to other fields and outside the INFN circle. In particular, medicine-related research is of long standing at INFN and further expansion is welcome in light of the increasing post-pandemic attention to life sciences. From this perspective, the establishment of INFN-4LS is very promising. We wonder whether a similar bridge could be built in the future with social sciences: for instance, advanced calculus (Artificial Intelligence, Machine Learning) is an active research area also in economics (digital currencies are an example of potential interdisciplinary collaboration).
Finally, we compliment CSN5 for their activities and mobilisation of INFN expertise to address relevant issues in the fight against the Coronavirus.

Recommendations. None

KTT – Knowledge and Technology Transfer

The INFN Technology Transfer (KTT) program has gone through an extensive re-organisation building on the experience of past years (Phase 1). In the current organisation (Phase 2), a National Committee (CNTT) manages and supervise KTT, with the assistance of a network of local correspondents. The staff in central administration devoted to KTT has been strengthened in number and skills. The Rules for protection and enhancement of INFN intellectual property have been revised: they cover organisation, patents, collaborations with and service supplied to industry, but do not yet address procurement. The Rules for spin-offs are still under test because of few practical cases.

A new training course was started to promote the right approach to KTT within INFN by providing all INFN staff with the basic knowledge needed to understand the importance of social and economic impact of INFN activities. INFN was granted new funding by the Italian Agenzia per la Coesione Territoriale for the OPEN INFN project. This project is a good opportunity to strengthen INFN KTT capability as its funds must be used to establish a network of high level consultancy services for Intellectual Property management, legal advice, brokerage, staff training, media communication, and dedicated events.

We agree with the INFN thoughtful approach to KTT, which is not marketing INFN knowledge to make money but sharing the INFN knowledge with the Italian society at large – which incidentally greatly needs a boost in scientific and technical innovation. We welcome the advancement in KTT management with the starting of Phase 2 and take note of the impressive progress over the last ten years in number of disclosures, patents, revenues, and other metrics. In our view it is important to maintain regular monitoring of KTT Phase 2 and to envisage a medium-term assessment of achievements. This includes:

i) collecting information in a systematic way, not only about number/revenues of agreements/patents, but also about projects opened but not successful, involvement of INFN researchers, links established with public bodies and private firms, etc.; *ii)* canvassing views of researchers attending training courses.

We look forward to learning about post-Covid resumption of connections with industrial partners.

Recommendations, repeated from 2020 because they are still pertinent
KTT-1 – Explore the feasibility of building joint labs with private companies. We recommend the KTT to develop a study to identify areas where joint labs can make sense and to start a scouting activity with corporates, also international ones.
KTT-2 – Organize regular meetings between researchers, business angels/venture capitalists, and chief technology officers of key companies to expose INFN personnel with possible projects to the real economy. In order to make it operational, we recommend creating a list of stakeholders of KTT, and to provide a calendar to both researchers and stakeholders. The meetings should focus on the presentation of new patents, and potential applications of research activity.
KTT-3 – Streamline the selection process of the resources of R4I, with larger involvement of external evaluators. We suggest a three-step approach:

1. Validation from a research viewpoint by the supervisor within the centre where the researcher works;
2. Assessment by an external panel of the potential industrial viability of the idea. Members of the external panel must be business angels, venture capitalists, or chief technological officers from the private sector. This activity should be organized twice a year to put together a number of options.
3. Final decision by the 'Comitato Nazionale per il Technology Transfer'.

KTT-4 – Build some indicators to evaluate the performance of KTT in comparison with benchmark institutions.

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 1.8×10^{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.

Darkside

With its excellent rejection of electronic background via pulse shape discrimination, and the relatively low-cost target material, dark matter detection in liquid argon (Lar) holds significant promise for a background-free search even for target masses of tens of tons, and promises scalability to even larger targets.

DarkSide is a key experiment uniting earlier initiatives and smaller-scale experiments. It is in competition in particular with xenon experiments XENONnT and PandaX-4t, which are already taking data. However, should a dark matter particle be detected, argon and xenon experiments are complementary when it comes down to determining the couplings.

The DarkSide experiment has undergone several major design changes, partly driven by environmental requirements. It has converged towards an improved design, based on a single-walled titanium vessel separating the detector volume (Underground LAr with the TPC) from the screening volume (atmospheric LAr). Most design choices have been taken, or are scheduled to be taken in the very near future, and a final TDR was submitted on December 1. While final evaluation will have to await the TDR, the current design promises significant simplifications compared to earlier designs, and faster and simpler assembly of the detector. The collaboration considers the remaining risks, e.g. regarding the large scale production of the crucial Gd-loaded plastic scintillator or the timely availability of underground Ar to be acceptable.

The collaboration has elaborated a detailed project execution plan with clear definition of responsibilities between the collaboration and the construction project management, and has attracted an excellent Project Construction Director (though at the time of the CVI meeting, the contract remained to be finalized). While some key positions remain to be filled, this is expected to address to long-standing issue of efficient interaction and coordination with LNGS and its services.

Procurement of the cryostat from CERN has raised a number of administrative issues, but is now addressed at highest levels in INFN.

Despite the positive developments, the timely execution of construction will remain a huge challenge and will require excellent coordination between the team, the LNGS management, INFN and the international partners. Also, significant funding has to be spent in 2022, or else it will be lost.

We are concerned that the remaining risks will cause significant delays. The presented schedule – starting the filling of the detector by the end of 2024 – is extremely optimistic and has zero margin for unexpected issues that are bound to happen.

Recommendations:
DS-1. Given the importance of DarkSide for INFN and science and the complexity of the project, we recommend a timely in-depth review of the TDR. The panel should include several external experts. The review should help the experiment identify remaining technical and organizational issues. Developing a credible and conservative schedule is a crucial outcome of the review.

DS-2. Timely implementation of the experiment requires efficient communication between DarkSide and LNGS, and the cooperation of the experiment's project management and technical staff with LNGS staff and services. INFN should tightly monitor not only Darkside's schedule and progress, but also the integration with LNGS as the host laboratory, and be prepared to take appropriate and timely action in case of deficits and/or delays.

DS-3. We understand the proposed Construction Director will only be part time. It is therefore essential to have a strong on-site deputy who will be in charge whenever needed.

LNS – Laboratori Nazionale del Sud

LNS has a very diverse research portfolio that not only includes experiments at local accelerator facilities but also operation of KM3NeT and other international collaborations, and applied science topics. The local science program – presently on hold for the facility upgrades – is focused on two accelerators, the 15 MV Tandem Van de Graaff and the K800 superconducting cyclotron. Facility improvements include the upgrade of the superconducting cyclotron, the installation of the new fragment separator FRAISE, and the upgrade of the MAGNEX spectrometer for the NUMEN experiment. The LNS facility upgrade is an important step and will start a new era at the facility for research with high-intensity stable and radioactive beams. The total operating budget in 2020 was 39 MEuro, from which 28.5 MEuro were from external funds. The LNS upgrade is on track, with the new cyclotron magnet to be operational by fall 2022 and the first beam extraction scheduled for mid-2023. The support from the Italian government for the POTLNS upgrade (driven by the physics case of the NUMEN project) was limited to a project duration of 32 months with a 4 month extension, but has now been extended an additional 6 month to redress delays caused by the COVID crisis.

An immediate concern is the situation concerning replacement of retiring technicians. In 2021 alone six technicians (about 10% of the total number) retired, and the hiring of new staff was delayed due to the pandemic. As a short-term solution researchers and technologists took over part of the work of technicians but a dedicated effort is required in the coming months to fill the available positions with qualified technicians, especially in view of the critical upgrades that need to be concluded in 2022 for a timely delivery of beam in 2023. Another concern is that the scope of the POTLNS upgrade does not include a beamline that can deliver both stable beams and radioactive beams to users from the FRAISE separator. This would mean that no parallel operation is possible, and less beam will be available for external users. This limitation should be overcome as soon as possible, and a special budget request needs to be developed and submitted in timely manner to the INFN Management.

Life Science and Medical Physics projects continue to play a strong role in the LNS research portfolio. The "Breast Cancer Therapy" (BCT) project using proton and radiotherapy has been funded by the Sicilian government to study and define new therapeutic approaches for the treatment of breast carcinoma. This also includes the use of FLASH therapy with proton and electron beams where cancer cells are irradiated very quickly with very high dose rates of 40 Gray/s up to 1000 Gray/s. The I-LUCE (INFN-Laser Induced Particle Acceleration facility) project is part of the BCT project and aims at using existing knowledge of acceleration by laser-matter interaction. The goal of these two projects is to install a "few hundred" (to be specified in more detail) Terawatt-lasers for the creation of high-intensity proton and ion beams that can be used for medical purposes and beyond. The I-LUCE facility will also be connected to the stable and radioactive beamlines at LNS to allow the study of nuclear reactions in plasma and for nuclear fusion reactions. Another medical physics project is the X-ray tube that was installed in June 2021. It uses the reaction between protons and B-11 to produce a homogeneous and well-defined photon beam for irradiation of cells and 2D imaging with high dose rates up to several Grays. The system is presently being commissioned and validated according to international IAEA protocols. After this, the facility will be available as photon-irradiation facility for users.

The young investigators grant "PRAGUE" (Proton RAnGe measUrements using silicon carbidE, 2020-22) plans to design and construct a detector for the measurement of proton-depth distributions for dosimetry in real time with micrometer precision. The work has received 600 kEuro funding from CSN5 and Horizon2020 and is protected by a patent. This new radiation-hard detector can be operated at very high dose rates (e.g. FLASH therapy) and aims to achieve a precision of 3%.

Progress of various facilities (for more information, see the CSN2 and CSN3 sections)
The PANDORA project has now released its TDR. The program has been reviewed by an INFN-Machine Advisory Committee and no major showstoppers have been identified. The collaboration with the GAMMA collaboration will allow a loan of up to 16 germanium detectors for the first years of operation. Thanks to CSN3 funding, procurement of the first parts of the superconducting magnetic trap has started.

The KM3NeT ARCA seafloor network has undergone a critical design review which resulted in a complete re-design of the junction boxes. In April and September 2021 the first new junction box and 8 out of 10 detector units were installed. In 2022 two new junction boxes and 12 detector units will be installed. For the full KM3NeT with 230 detector units a second main electro-optical cable is required which will be completed in 2022. The six ORCA strings have been in operation for 1.5 years and first experimental results have been shown in conferences in summer 2021. The implementation of ERIC, a European Research Infrastructure Consortium, is underway and the required documents have been sent to the European Board for analysis.

Recommendations:
LNS-1. A dedicated effort is required to fill the available technician positions as soon as possible. Please report in the midterm report about the progress.
LNS-2. Additional funding for a second beamline to deliver stable and radioactive beams simultaneously needs to be secured from the INFN Management.
LNS-3. Provide a presentation in the next CVI meeting in fall 2022 about the medical physics projects (BCT, I-LUCE, X-ray Tube, PRAGUE…) and their goals for the next 5 years

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.

LNL –Laboratori Nazionali di Legnaro

2021 marked the laboratory's 60-year anniversary which was celebrated with a small ceremony in October. The total budget for LNL in 2020 was 27.5 MEuro, from which 18.9 MEuro were INFN special project funds and external funding. The lab 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 is expected to become fully operational by mid-2022.

The tandem has undergone crucial repairs in 2020/21. The *laddertron*, the central element in the tandem, first showed some issues and later broke completely. Due to these repairs, the tandem was only operational for 3 months at the beginning of 2021. It will be running again in April 2022 for the start of the AGATA campaign. The upgrade of ALPI is ongoing, with plans to have its full functionality restored in fall 2022. For the time between spring and fall 2022 it is presently discussed to operate the ALPI re-accelerator at lower energies to allow further repairs on cavities.

The AN2000 and CN accelerators worked (almost) normally in 2020/21 and delivered 600 h and 815 h of beam, respectively. The experiments carried out here are complementary and include elemental microanalysis with nuclear techniques, dosimetry studies for new detectors, angular correlation measurement of electron-positron pairs emitted by internal pair creation (for the investigation of the hypothetical X17 boson from the "ATOMKI anomaly", see CSN3), characterization of targets, and single-ion irradiations of new quantum devices with high spatial precision. The major focus of the lab in 2021 was the ongoing construction of the new radioactive beam facility SPES. The extension of the research program to medical physics applications (medical radioisotope production) is an important step. In the long term the ISOLPHARM (production of carrier-free radiopharmaceutically-relevant isotopes) and LARAMED (study of innovative new radioisotopes) programs will allow LNL (and INFN) to increase its visibility through projects with a high societal benefit.

The installations around the new SPES facility are progressing well. A crucial milestone for 2022 is the installation of fire protection systems to receive the Certification for fire protection (CPI) to permit operation of the cyclotron. This is expected by mid-2022. One critical point that needs special attention and additional funding is the infiltration of ground water into the SPES building which was identified as construction defect. The mitigation of this problem has been discussed in collaboration with the Department of Civil Engineering and Environment at the University of Padova, and solutions have been presented. It is very important that the INFN Management fully supports these repairs and provides additional funds if necessary, as otherwise the long-term operation of the SPES facility might be endangered.

The AGATA project, a major scientific endeavour for LNL and the European Gamma-Ray Spectroscopy Community, is also on track for first beams in 2022. In fall 2021 the detector holding structure was delivered from the UK and installed at LNL, allowing the shipment of detectors from GANIL to start and the array to be populated. The plan is to have stable beam experiments with the Tandem in 2022/23 and first radioactive beams from the new SPES facility in 2024/25. The Program Advisory Committee, with a focus on AGATA proposals, will meet in February and then again in fall 2022 to discuss experimental proposals.

The accelerator group's two main large international projects are the construction and test of a Drift Tube Linac (DTL) for the European Spallation Source (ESS) in Sweden, and a Radiofrequency Quadrupole (RFQ) for the IFMIF (International Fusion Materials Irradiation Facility) in Japan. Unfortunately, the pandemic situation still does not allow any travel to Japan for the continuation of the IFMIF-DONES project and beam commissioning was stopped in 2020 after good progress was made before the pandemic. This program can hopefully continue in 2022 when Japan opens its borders again for international passengers.

The ESS projects continued almost uninterrupted and the first DTL1 was installed in Sweden in August 2021. DTL 2, 3, and 4 have all been shipped and are in various stages of assembly, and will be ready for installation in May 2022, with the fifth and last DTL to follow shortly.

Outreach during the pandemic: The 18th edition of the Master course "Surface Treatments for Industrial Applications," jointly organized by the University of Padova and INFN, took place in 2020 and was well attended despite the pandemic restrictions. In June 2020 a residential course for high school students was organized and remotely attended by 22 students who analyzed experimental data and wrote LNL Internal Reports.

Organisational changes and personnel situation. The new organigram was submitted to the INFN Executive Board in February 2021 and approved with minor modifications in September 2021. LNL has received 10 new entry-level technologist positions (5 new positions and 5 from the stabilization process). However, the small number of researchers (17) is of concern for an accelerator laboratory with such an active science program: only 11% of the LNL employees are in the researcher category, whereas the INFN average is 33% and the average of the four national laboratories is 17% (LNGS- 12%; LNF – 23%; LNS- 20%). We hope that the Extraordinary Recruitment Plan from the Italian Government (MUR) will help to fill this gap. Another concern is that crucial positions for the operation of the accelerator facilities are understaffed since technicians are missing. This leaves critical infrastructure endangered and could lead to delays or even shutdowns. Examples are:

- *Cyclotron operators:* For the upcoming 24/7 operation of SPES in 8h-shifts, at minimum 6 operators are required. Presently one technician and two technologists (engineers) are available. Two more hires are planned in 2022. Given the specialized hands-on training that is required, at least 2 more technicians need to be hired before SPES goes into operation.

- *Tandem operators:* Two retired/soon retiring operators need to be replaced in 2022/23.
- *Vacuum services:* Presently only one technician is responsible for the whole lab. This work (maintenance and installations) is at the moment supported by Tandem-ALPI and cyclotron operators. New operators will also support vacuum services.
- *Radioprotection officers:* The operation of the SPES radioactive beam facility requires "3rd level radiation protection officers". The training for this level requires at least 3 years in a certified environment. Presently two experts are employed, one of them will retire in 4-5 years. One existing technician will be trained in 2022, and a student (via a fellowship) will be trained starting in fall 2022. Given the criticality of the position for the 3rd level radiation protection officer for the whole lab, succession planning should be started early to allow a suitable candidate to get fully trained before the retirement of the present expert.
- *Medical physics projects (ISOLPHARM and LARAMED):* These new projects require dedicated technicians since no technical staff is working on this yet.

Given the delicate situation the lab is experiencing with the construction of a new radioactive beam facility that will become operational soon, continued joint efforts are required by the INFN Management and the LNL Directorate to fill these critical positions in the next 2 years.

Recommendations.
LNL-1. (Repeated and adapted from 2020) Grow and strengthen the lab for the "SPES era". Ensure critical positions are filled in timely manner. This also requires more pre-assigned researcher positions for LNL.
LNL-2. INFN Management should fully support LNL and colleagues from the University of Padova in ensuring that the problems with water leakage into the SPES building are mitigated. Provide additional funding if necessary to mitigate the risk of building damage.
LNL-3. Ensure a timely start of the AGATA campaign in 2022 with stable beam and 2024/25 with radioactive beam from SPES.

CNAF Tier-1 Center: *Computing@Technopole*

CNAF is the National Centre of the INFN dedicated to Research and Development on Information and Communication technologies, with a staff of 60 people. Amongst its responsibilities are the development of Grid middleware, management of the grid and Tier1 of the World-wide LHC Computing Grid (WCLG) infrastructure, and leadership of projects at the national and international level. CINECA is a not-for-profit Consortium that runs the largest Italian supercomputer centre. CINECA is made up of 67 Italian universities, 9 Italian Research Institutions (including INFN, INAF and CNR), 3 Polyclinics and the Italian Ministry of Education and Research (MIUR).

A huge increase in INFN Tier 1 computing resources is foreseen between now and 2025. By 2025 there will be 1-1.2 M HS06 (~100k cores) for the high-throughput computing farm/cloud. (HS06 is the HEP-wide benchmark for measuring CPU performance). There will also be storage of 100 PB on disk and 220 PB on tapes. From 2027 a further increase by a factor of 2 or 3 is foreseen to address HL-LHC computing needs.

In view of this expansion INFN and CINECA have undertaken a joint initiative for a computing centre at Tecnopolo, which offers ~100,000 square metres of space, located about 2 km away from the current CNAF site. There will be six data halls, two of which are assigned to INFN and CINECA to host INFN Tier1 and the Leonardo pre-exascale machine, which will be installed in the hall C2 (2022), whereas the INFN Tier1 will be migrated to the adjacent hall B5 (2023). INFN and CINECA data centers will share technological infrastructure (power and cooling), security and surveillance services, on-call and emergency management shifts. A direct network interconnection will be available between the two data centers.

The migration is scheduled to happen during the LHC Run 3, which makes continuity in the availability of computing resources a high priority. This requires detailed planning of the transfer of the computing, storage and network resources to Tecnopolo. We are pleased to hear that all of these tasks are detailed in a Technical Design Report (TDR) and that a Project Management Plan(PMP), including Gantt chart, quality assurance, manpower, cost, risks has been prepared and should be available by the end of October 2021. The TDR is currently being examined by the Steering Board appointed by INFN Management and the enforcement of the plan will be secured by a task force.

We compliment the new director on restoring progress and implementing our recommendations from last year concerning the TDR and PMP, but remain concerned that significant risks remain, including loss of expert technical personnel, delay in the completion of the building (scheduled for March 2023), and possible flooding of the current CNAF facility.

Recommendation.
CNAF-1. In view of the importance of this migration, INFN should inform the CVI on the implementation of the TDR and the progress of Tecnopolo in the mid-year report.

INFN Outreach

The INFN Communications Office (CO) was established in 2002 and is centered at the INFN Headquarters in Rome. Currently its two Coordinators, four staff members, and four fellows are responsible for press releases and news, communication, outreach and multimedia, social media, as well as public events and exhibitions. The financial support and coordination of outreach activities is organized by the Third Mission Committee (CC3M). While the CO takes care of the central communication, e.g. via websites, the INFN Magazine "Asimmetrie" or the Monthly Newsletter, the CC3M initiates bottom-up initiatives focused on STEM dissemination, educational activities, and teachers training.

INFN outreach has a good mix of traditional public outreach programs and new platforms (social media, web platforms). Before the pandemic the uptake of in-person exhibitions was very good, but due to the pandemic a lot of the activities in 2020/21 had to be shifted onto social platforms (Facebook, Youtube). This "new way of communication" has been taken up well by the audience and e.g. a steep increase of Youtube subscribers has been observed since March 2020. The two largest regular editorial products are the biannual "Asimmetrie" magazine targeted at Italian teachers and students (16000 subscribers, 3000 INFN) and the monthly INFN newsletter (>7000 recipients, bilingual). The Asimmetrie magazine is still sent-out as print-version which seems to be a bit old-fashioned. The CO should check how many recipients really need the print version, and who would accept switching to the digital version to save costs and paper.

The CO also organizes educational programs for teachers and students. These projects are evaluated and funded by the CC3M and organized by a network of INFN divisions. Presently a new program is under development to target 5-13 year-old children to talk with them about science. "INFN Kids" (https://web.infn.it/infn-kids/) was started in 2018 to provide a national platform for educational experiences. Facebook live events like "FISICAXKIDS" could draw as many as 4000 students aged 10-14 per event, and a new collaboration agreement has been reached with the national public TV channel RAI GULP to stream 10 short films (3min long) about "La Fisica tra le Onde" ("Physics in the waves") for kids aged 6-13. Overall, INFN hosts a very active and impressive public outreach program but more activities in southern Italy need to be organized in the coming years. The CO should increase the number of bi-lingual post/ tweets/ articles to reach more international researchers or students in Italy with INFN activities.

Recommendations

Outreach-1. Provide more bi-lingual posts/ tweets on social media on to reach a larger international audience, and check if parts of the "Assimetrie" magazine could also be translated into English (for non-Italian students/ teachers, international schools in Italy)
Outreach-2. Coordinate more events with other Italian institutions.
Outreach-3. Perform more events in Southern Italy (e.g. Bari, Sicily, Sardinia).

Appendix I. Recommendations

GS1 **–** We welcome the extraordinary program allowing INFN to stabilize and enhance its staff.
To make optimum use of this outstanding opportunity and to attract the best scientists and technologists, including Italian scientists who started their careers abroad, INFN should work with the government to gain flexibility in the deployment of these positions:

a. To increase the timescale during which positions are filled.
b. To include positions above entry level.

GS2 **–** INFN mostly depends on governmental support, but has been quite successful in securing funding from additional sources. INFN should further emphasise increasing and managing diversification of funding, which could have even greater importance in these days of fiscal peril.

a. We encourage INFN to develop closer relations with the private sector to build additional sources of funding.
b. For new projects INFN should move hand in hand with new funding sources to make sure they will provide adequate support to sustain a project throughout its life.
c. Investigate possibilities to motivate mid-career and senior scientists to apply for ERC grants, e.g. Consolidator, Advanced, and Synergy Grants.

CA1 – The Director General's ambitious program needs prioritization. In due time, it would help to fix targets to be achieved in the coming years.
CA2 – The Director of Research Services should elaborate a plan of re-organisation of research services and of actions that could enhance INFN capability to obtain grants.
CA3 – (*Last year's recommendation, still valid*) The Director General should launch a service satisfaction survey to be used for quality management of the central administration.

CSN1-1. The strong LHC program is complemented by a good portfolio of other experiments. It is important to maintain, and increase if possible, the breadth of the CSN1 programs to keep attracting new contributors.
CSN1-2. Because of the extremely tight schedules, CSN1 should make sure to monitor closely the evolution of the LHC Phase II upgrade projects.
CSN1-3. The project management strategy implemented by CSN1, especially on its CERN experiments, may be of help to other CSN's with large projects.

CSN2-1. The new scheme for managing experiments in CNS2 should be reviewed after 2-3 years, and fine-tuned where appropriate.

CSN2-2. Given the increasing scale of experiments in CNS2, in-depth reviews including external experts should be considered, towards preparing major decision milestones regarding large-scale activities.

CSN2-3. In view of the international competition for the ET site, to secure adequate funding INFN should strongly engage with the Italian government.

CSN2-4. The DAMA data analysis has often been criticized as not transparent. To convince the community, INFN should work with DAMA to make its raw data openly available.

CSN3-1. Support critical LNL upgrades (and repairs) with high priority to allow timely and full exploitation of new science opportunities (also beyond nuclear physics applications, INFN-4LS)

CSN3-2. Keep a diverse research portfolio but avoid too many small low-impact projects. Investigate which projects can be closed within the next 5 years.
CSN3-3. Investigate the reasons for the steep drop in female students carrying out Bachelor, Master, and PhD theses in the past 3 years. Discuss with other CSNs and university partners what can be done to lower the barriers for female students to enter these programs.
CSN3-4. Provide a summary report from the outcome of the three Mid-Term Workshops in the next GLV annual report.
CSN3-5. Provide a report (presentation in next CVI meeting) and outline of the planned INFN contributions to the EIC over the next 5 years.

CSN4-1. A scheme to re-involve expatriate female scientists in the intellectual life of the country might be beneficial.

(Repeated from 2020 because they still seem relevant)
KTT-1 – Explore the feasibility of building joint labs with private companies. We recommend the KTT to develop a study to identify areas where joint labs can make sense and to start a scouting activity with corporates, also international ones.
KTT-2 – Organize regular meetings between researchers, business angels/venture capitalists, and chief technology officers of key companies to expose INFN personnel with possible projects to the real economy. In order to make it operational, we recommend creating a list of stakeholders of KTT, and to provide a calendar to both researchers and stakeholders. The meetings should focus on the presentation of new patents, and potential applications of research activity.
KTT-3 – Streamline the selection process of the resources of R4I, with larger involvement of external evaluators. We suggest a three-step approach:

1. Validation from a research viewpoint by the supervisor within the centre where the researcher works;
2. Assessment by an external panel of the potential industrial viability of the idea. Members of the external panel must be business angels, venture capitalists or chief technological officers from the private sector. This activity should be organized twice a year to put together a number of options.
3. Final decision by the 'Comitato Nazionale per il Technology Transfer'.

KTT-4 – Build some indicators to evaluate the performance of KTT in comparison with benchmark institutions.

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.

DS-1. Given the importance of DarkSide for INFN and science and the complexity of the project, we recommend a timely in-depth review of the TDR. The panel should include several external experts. The review should help the experiment identify remaining technical and organizational issues. Developing a credible and conservative schedule is a crucial outcome of the review.

DS-2. Timely implementation of the experiment requires efficient communication between DarkSide and LNGS, and the cooperation of the experiment's project management and technical staff with LNGS staff and services. INFN should tightly monitor not only Darkside's schedule and progress, but also the integration with LNGS as the host laboratory, and be prepared to take appropriate and timely action in case of deficits and/or delays.

DS-3. We understand the proposed Construction Director will only be part time. It is therefore essential to have a strong on-site deputy who will be in charge whenever needed.

LNS-1. A dedicated effort is required to fill the available technician positions as soon as possible. Please report in the midterm report about the progress.
LNS-2. Additional funding for a second beamline to deliver stable and radioactive beams simultaneously needs to be secured from the INFN Management.
LNS-3. Provide a presentation in the next CVI meeting in fall 2022 about the medical physics projects (BCT, I-LUCE, X-ray Tube, PRAGUE…) and their goals for the next 5 years

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

LNL-1. (Repeated and adapted from 2020) Grow and strengthen the lab for the "SPES era". Ensure critical positions are filled in timely manner. This also requires more pre-assigned researcher positions for LNL.
LNL-2. INFN Management should fully support LNL and colleagues from the University of Padova in ensuring that the problems with water leakage into the SPES building are mitigated. Provide additional funding if necessary to mitigate the risk of building damage.
LNL-3. Ensure a timely start of the AGATA campaign in 2022 with stable beam and 2024/25 with radioactive beam from SPES.

LNL1 – The INFN Directorate should fully support the organisational restructuring to ensure the future success of the lab.
LNL2 – Ensure timely completion of SPES project to allow first experiments with AGATA in 2022.
LNL3 –_Grow and strengthen the lab for the "SPES era": Ensure key personnel in temporary positions can get permanent positions and start planning for strategic replacement of soon-retiring staff. Prepare a dedicated plan showing where additional staff positions are needed in the next 2 years. Please present a status update of discussions with INFN Directorate and Giunta about this future hiring strategy in the next midterm report.

CNAF-1. In view of the importance of this migration, INFN should inform the CVI on the implementation of the TDR and the progress of Tecnopolo in the mid-year report.

Outreach-1. Provide more bi-lingual posts/ tweets on social media on to reach a larger international audience, and check if parts of the "Assimetrie" magazine could also be translated into English (for non-Italian students/ teachers, international schools in Italy)
Outreach-2. Coordinate more events with other Italian Institutions.
Outreach-3. Perform more events in Southern Italy (e.g. Bari, Sicily, Sardegna).