ECFA EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS

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Dear Minister,

On behalf of the European Committee for Future Accelerators (ECFA), I would like to thank the Italian particle physics community, and in particular the *Istituto Nazionale di Fisica Nucleare* (INFN), for the hospitality extended to Restricted ECFA, which consists of one representative per CERN Member or Associate Member State plus the Director-General of CERN, during our visit to Italy on 4 and 5 March 2022. We encountered a vibrant, very motivated and well-organised particle physics community and our interactions with them were extremely fruitful and pleasant.

The visit started with a presentation on the research programme and funding of science, followed by a talk by the President of INFN reviewing 70 years of successful research, the present activities in the five INFN research lines and the funding structure. These talks were followed by a series of overview talks on the involvement of Italian groups in current research areas and future projects in particle, nuclear and astroparticle physics. Additional presentations covered the Italian contributions to accelerator and detector research and development (R&D) activities, technology transfer and outreach and, finally, the perspectives of early-career researchers. In addition, large scale EU/ESFRI projects were presented.

Overall, we are impressed by the broad and compelling programme and by Italy's high-quality contributions to front-line research in particle, astroparticle and nuclear physics. The very significant role in accelerator and detector R&D should also be highlighted. We appreciate the strong contributions on the theory side and note in particular the broad coverage and the good alignment with the experimental programme.

The INFN provides an excellent structure for fundamental research in particle physics. We appreciate in particular the excellent interplay between INFN and the universities and consider such a structure as a model for successful organisation of particle physics in a country of Italy's scale.

The four national laboratories (Frascati (LNF), Gran Sasso (LNGS), Legnaro (LNL) and Sud (LNS)) and three national centres (CNAF, GGI, TIFPA) provide excellent infrastructures to complement the INFN and university activities for the realisation of high-quality science projects in particle, nuclear and astroparticle physics. Due to its strong national laboratories, Italy has also been very successful in

exploiting EU funding opportunities and attracting high-profile, large-scale EU science programmes, such as EuPRAXIA on plasma acceleration (LNF). In addition, it is impressive to see that Italy, as a large country, has been able to achieve a positive value for its industrial return from CERN (positively balanced for supplies) most years.

We also note the success of INFN in attracting additional funding contributions via regional funding, in particular via the National Recovery and Resilience Plan (PNRR). Very substantial funding has been requested for a large national centre for high-performance computing, big data and quantum computing, as well as for large accelerator, astroparticle and technology projects. In this context, we support the anticipated upgrade plans of the national laboratories. In particular, we appreciate the interest of LNGS in hosting two major future experiments looking for neutrinoless double-beta decay.

We acknowledge the setting up of a knowledge transfer unit within INFN, which has successfully fulfilled significant technology transfer agreements over the past years. The INFN's contributions to society in general, of which COVID-19-related activities and medical applications are important examples, should also be highlighted.

With a total of 2000 permanent employees, INFN provides a solid basis for carrying out a broad research programme. We were pleased to see a significant proportion of engineers and technicians (~50%) among those employees and we strongly recommend that the current level, which is key for the success of accelerator and detector R&D and indispensable for the design and construction of future facilities and experiments, be maintained. Although the proportion of female employees (26%) is quite high compared to other European countries, steps should be taken to improve the situation further, in particular in theoretical physics, where only 13% of scientists are female.

Compared to international standards, we find that the number of foreign scientists working in Italy is rather low. On the other hand, a significant number of very competent Italian scientists is carrying out research abroad. We suggest that efforts be made to identify the source of this imbalance and to take mitigation measures.

Overall, as mentioned, we think that the INFN structure in collaboration with universities provides an excellent organisational structure for research. However, it would be helpful to improve the stability and continuity of budget allocations, which are important for long-term planning for large particle physics projects. In addition, INFN's efficiency would benefit from fewer bureaucratic hurdles, and we suggest that corresponding mitigation actions should be explored.

Below, we give a brief summary of our assessment of Italian contributions to the various research areas.

Particle physics experiments at accelerators

Italy is very strongly involved in accelerator-based particle physics, with significant participation in experiments at the high-energy frontier as well as at the flavour frontier. Italian groups have achieved high visibility in the energy-frontier Large Hadron Collider (LHC) experiments (ATLAS and CMS). They have had a remarkable impact since their inception via contributions to the conceptual design, construction, commissioning, operation and physics analysis. Their contributions to the detector operation and physics analysis today are very significant. We were also impressed by Italy's outstanding and innovative contributions to the ongoing upgrades of the LHC experiments with the purpose of exploiting the full potential of the accelerator during the high-luminosity phase (HL-LHC). They are involved to a very visible degree in key Phase 1 (e.g. ATLAS New Small Wheel) and Phase 2 (e.g. new inner trackers for ATLAS and CMS, timing detector for CMS) detector upgrade projects. These contributions profit enormously from the aforementioned strong engineering support.

We highly value the Italian community's well-focused involvement and vital role in the two major flavour experiments, Belle II and LHCb, with strong and highly visible contributions to detector operation, data analyses and detector upgrades. This programme is nicely complemented by an interesting programme addressing the physics of charged leptons (MEG II at the Paul Scherrer

Institute, Mu2e at the Tevatron, (g-2) measurements and MUonE). Overall, the Italian community has struck a wise balance between participation in general-purpose accelerator experiments with a broad physics programme and in challenging but interesting studies on smaller experiments.

Moreover, the current heavy-ion physics programme and the plans for strong involvement in future projects (ALICE3, NA60++ and the Electron–Ion Collider (EIC)) are particular strengths, although a potential conflict of resources between the ALICE3 and EIC commitments may arise.

We expect that the high level of engagement in the operation and analysis at all the LHC experiments will be maintained in the future. Finally, we welcome the start of activities towards Italian engagement in the physics and detector studies and the allocation of a budget line towards a future accelerator project (the Future Circular Collider (FCC)) at CERN. The strong Italian engagement in the recently established ECFA studies (workshops towards a Higgs/electroweak/top factory with the goal of fostering cooperation among the various e^+e^- Higgs-factory activities) is also highly appreciated.

Theory

Broad coverage on the theory side, including all major research fields from phenomenology to string theory, is exhibited, with a leading role in several areas. We appreciate, in particular, the deep interplay between theoretical and experimental activities, as demonstrated by the exceptional activities on Monte Carlo generators for LHC physics and the strong engagement in future projects like the FCC and EIC. In theory, in particular, many Italian researchers are carrying out postdoctoral work abroad, but only a small fraction returns to take up a job in academia in Italy.

Accelerators and detectors

ECFA congratulates Italy for getting EuPRAXIA included in the ESFRI roadmap and for securing INFN funding for the beam-driven plasma acceleration site. In this context, we recommend raising funds and developing a synergetic programme for the high-energy physics application of plasma acceleration.

ECFA is impressed by Italy's broad participation in the European roadmap for accelerator R&D, covering three of the five research lines (high-field superconducting magnets, plasma acceleration and muon colliders). Efforts to implement R&D and test infrastructures for high-field magnets in Milan and Salerno are supported as an important contribution to the development of future accelerator facilities. The research on high-temperature superconducting (HTS) magnets paves the way for a more energy-efficient future hadron collider by operating superconducting magnets at higher temperature. ECFA strongly encourages this R&D effort and suggests that a coherent European programme be set up. The various contributions of Italian groups to performance optimisation and to a technically feasible design of a high-energy muon collider are recognised and supported. Good coordination of the various activities should be ensured among the European roadmap contributors, through CERN and by involving the new Italian Accelerator Technology Committee.

On the detector side, the large proportion of engineers and technicians among INFN staff makes it possible to make important and visible contributions to a very broad and diverse experimental programme. In addition to the construction of current detectors (e.g. LHC Phase 1 and Phase 2 upgrades), R&D is being launched for future projects (FCC, EIC, ALICE3, DUNE, HyperK) and potential synergies identified. The planned integration of these activities into the ECFA roadmap on detector R&D is appreciated. We also support that a certain fraction of the detector R&D budget should be reserved for "blue-sky" R&D.

Astroparticle physics and cosmology

INFN spans a very broad programme, ranging from high- and low-energy cosmic rays to high- and low-energy neutrinos, direct dark matter detection and neutrinoless double-beta decay, gravitational waves and multi-messenger astronomy. Like in the accelerator-based experiments, the international reputation of INFN in this field is excellent, and the national laboratories LNGS and LNS provide the infrastructure

to carry out experiments at the front line of current research. At present, the Gran Sasso laboratory is considered to be the most important underground laboratory in Europe.

The very substantial funding requested under the PNRR for three main astroparticle projects (KM3NeT, CTA and the Einstein Telescope (ET)) offers an excellent opportunity to establish or contribute significantly to these larger astroparticle physics experiments, which reach a scale similar to that of accelerator projects. It should be noted that successful application of KM3NeT would guarantee the realisation of ARCA. The ET is gaining traction, becoming a flagship project in Italy, with the candidate host site in Sardinia. We consider the strategic positioning within the ET Infrastructure Consortium as essential.

Nuclear physics
Italy has a strong and broad nuclear physics research programme that makes good use of the national laboratories LNS and LNL. In addition, the Italian nuclear physics community participates in the European nuclear physics programme. A particular strength of the low-energy programme lies in its interconnection with many other INFN research activities, ranging from dark matter searches and neutrinoless double-beta decay to medical applications.

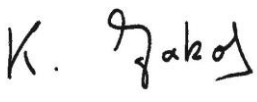
Computing
The INFN distributed computing federation, which has been gradually improved over time, provides strong computing infrastructure, currently delivering 7–20% of the computing resources of the LHC experiments. We are also impressed by the successful acquisition of EU funding for the supercomputer Leonardo being installed in the "Technopolo" in Bologna, as well as by the bid submitted for an Italian Centre of Scientific Computing (ICSC) on the scale of ~400 M€ under the PNRR.

Outreach
We heard a presentation about well-structured and organised outreach and education programmes, carried out by a core-staff team. Under these programmes, a diverse set of outreach activities is carried out using a variety of tools and resources, reaching out to the public and decision makers.

Perspective from the young generation
Last but not least, a survey of Italian early-career researchers showed that they are generally satisfied with their jobs, despite the sometimes stressful and competitive research environment and salaries that are lower than in the private sector and other countries. Concerning the duration of PhD work, ECFA recommends that an extension of funding for PhD positions beyond three years should be considered. We also note that there is a larger proportion of female researchers among the younger generation than in older generations. We deem it important to ensure that they have adequate career prospects in order to reduce the larger gender imbalance at later career stages.

In conclusion, we wish to stress again that the committee is very impressed with the high quality of the activities of the Italian particle physics community and its contributions to and achievements in many top-level international projects.

Yours sincerely,



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Chair of ECFA

cc: Professor Antonio Zoccoli, INFN President