REPORT on IRFU activities

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The committee heartily thanks the IRFU management for providing the material with relevant information on the IRFU activities, for organizing very clear presentations and for the visit to a number of IRFU laboratories. The visit was important to better realize the size of several on-going instrumentation fabrications and to focus on unique capabilities of the existing infrastructure. Additional thanks for taking excellent care of all the logistics connected to this meeting.

As a very general remark it is important to point out that the committee is much impressed with the quality of the management and with the high level of performance in the different research areas in which IRFU is very active. There is no doubt that the areas of particle, astrophysics and nuclear physics are living in an extraordinary exciting period with rapid progress on many fronts. For international participations the best return and visibility has been achieved in projects where the scientific potential has been well aligned with the resources deployed for the contributions in hardware and software.

Specific comments on the achievements and recommendations for the future are given below in the sections on management, divisions, external relations and communication, and general strategy. Although reported in the following sections here in brief the committee wants to stress few important points.

- Low-level or marginal contributions to large projects should not have high priority, unless they are clearly part of a long-term strategy, in terms of a scientific or a technical roadmap.

- The infrastructure within IRFU is world class in terms of technology achievements given its historical involvement in Nuclear, High Energy Physics and Accelerator Technology. The business / service provider model delivers a large fraction of the funds for the infrastructure and therefore for the R&D platform. In order to maintain a stable base for funding manpower and investment, a continuous and aggressive acquisition strategy is required.

- The capability for project and personnel investments should not be allowed to deteriorate in the next years. In fact, IRFU cannot afford to jeopardize the benefits provided by its fundamental and applied research, which also have very important international impact.

IRFU Management

The committee appreciated the clear and transparent presentation of the IRFU management structure by its director, setting it into the context of the overall CEA organization, and explaining its evolution over the past years as well as its anticipated challenges for the future.

The recently adopted structure with six divisions of similar size, three focused on science and three more on engineering aspects, seem to be a practical and efficient way to operate. The committee was presented with convincing evidence by the division heads in their talks that the structure provides enough flexibility to put together the resources needed to achieve the research goals as well as important synergies among the divisions in order to fulfill the mission goals of the Institute. The great scientific achievements and the internationally recognized excellence in engineering speak for themselves. The Institute is well managed.

However, the committee also identified some major challenges for operating the Institute. These are well known to the management, and the committee recommends that they continue to receive full attention.

1) The capability for project investments coming from the regular IRFU funding has decreased constantly over the past years, and has reached an alarmingly low level today. The reason for that are the increasing personnel costs which essentially saturate the government subsidy, itself slightly decreasing over the past years. Personnel costs increased in spite of painful staff reductions; and the demands on personal funds are clearly accentuated by the increase in retirement age to 70 years.

2) Project investment funds have to be generated by contractual work, and may be driven by funding opportunities rather than by IRFU's long-term strategic plans. Whereas this can work well for some projects, albeit sometimes with large time fluctuations, it is not feasible for other high-priority science activities. Even though the committee has not yet seen any evidence for it, there is obviously a latent danger that future choices may not be guided by scientific excellence alone.

3) Directly related to the extremely tight budget situation and the change of retirement age, there is a notable slowing down of vital rejuvenation of staff, given the reduced possibilities to hire new staff. This may well impact the long term future of the Institute. A further regrettable effect could be a damping of motivation and enthusiasm for mid-career staff who see their promotion prospects compromised.

4) These career restrictions affect not only the scientific staff, but very much also technicians and draftsmen for whom the Institutes faces the additional difficulty that it has to compete with more attractive employment conditions offered by industry.

The committee judges that this trend has reached a critical level, and negotiations with CEA upper management and the Government need to be pursued with high priority to

address this situation. The committee also encourages IRFU management to explore inventive temporary measures to bridge the years until natural departures for retirement will at least partially unblock the current limitations on hiring young staff.

Astrophysics division (SAp)

The astrophysics division (SAp) has a long history of success and excellent prospects for the future. It has participated in an impressive set of instruments, projects and missions which are currently in successful operation (XMM-Newton, INTEGRAL, Fermi, Cassini, Hershel, Planck, Kepler, IRAM, CFHT, ...), under development (JWST, ArTeMiS, Asto-H) and in planning (Euclid, SVOM, SPICA, ELT-METIS, CTA, Athena+, ...). This has led to the capability to attract international staff of the highest level. As an illustration of this, it is remarkable that IRFU/SAp currently hosts 7 ERC grantees, clearly a very large number for the size of the division.

The IRFU/SAp division participated, and in some cases led, in a number of major discoveries and advancements in astrophysics and cosmology during the last years, thanks to the fruitful exploitation of their participation in space missions and ground-based instruments. Recent examples of most renowned breakthroughs with major involvement/leadership from SAp researchers include:

- The cosmological evolution of galaxy clusters does not match the predictions from the standard cosmological paradigm (based on work using XMM-Newton and Planck data).
- Galaxy mergers play only a minor role in the cosmic history of star formation (based on work using the key programme GOODS-Herschel, along with IRAM and CFHT data).
- Disk instabilities are able to feed super-massive black holes, which has helped to establish the recent belief that mergers may not be driving super-massive black hole growth (based on numerical work using major French and European computing facilities, through competitive access).
- Development of the Ramses code to study large-scale structure and galaxy formation. The code has been extensively used, and has shown in particular that galaxies can be fed by cold gas flows.
- Discovery of the filamentary structure in molecular clouds, a key to understanding star formation (based on work using Herschel data).
- Detection for the first time of gravity dipole oscillation modes in the Sun, revealing rotation of the innermost regions of the Sun (based on work using SOHO).
- A theory showing that Saturn's satellites are made from Saturn's rings material, extracted through tidal forces.
- The first all-sky catalogue of very high-energy sources with the Fermi mission (micro-quasar work under leadership by IRFU/SAp).

This is only a short glimpse of a truly impressive number of scientific papers with participation of IRFU/SAp researchers (including almost 50 Nature and Science papers in the last six years).

Best return and visibility has been achieved in projects where the scientific potential has been well aligned with the resources deployed for the contributions in hardware

and software. Euclid, where SAp has managed to keep instrument leadership at all levels, is a very good example to follow for participation in future projects. IRFU has the potential to capitalize on scientific expertise and interest from SAp and SPP, plus technical know-how on IR and high-energy detectors, electronics, etc.

For participation in future projects IRFU should look for a leadership role, with accompanying technical capabilities and the potential to make unique contributions.

Low-level or marginal contributions to large projects should not have high priority, unless they are clearly part of a long-term strategy, in terms of a scientific or a technical roadmap. Attention should be paid, for example, to IRFU's participation in projects like ELT-METIS or CTA, where a proper plan to gain leadership in the scientific exploitation, matching the technical contributions to these projects, should be put in place.

Particle Physics Division (SPP)

A very rich activity programme was presented, carried out by excellent scientific and technical staff. We were impressed by the good integration between SPP and the engineering divisions, and noted also the good cooperation with the other science divisions. It is remarkable that four of the SPP staff have received highly competitive ECR awards.

IRFU can be proud to have been a central part of the three major break-through results in particle physics and cosmology last year, namely the discovery of the (or a) Higgs boson by ATLAS and CMS at the LHC, the measurement of the third neutrino mixing angle theta-13 (T2K and Double Chooz), and a precise measurement of the expansion rate of the Universe at high redshift, probing deep into the epoch of deceleration using the new technique of BAO in the Lyman-alpha forest. All three of these results point already to directions for future experimentation.

The way to the Higgs boson is paved by a very important and substantial work on measuring Standard Model physics at LHC, and indeed the two related ERCs illustrate that IRFU can be commended particularly in this field.

Fully consistent with the recent update of the European Strategy of Particle Physics, and exploiting the extraordinary impact of IRFU in ATLAS and CMS so far, the best possible involvement in the high-luminosity LHC phase should be foreseen. After the well-defined phase-1 upgrade for ATLAS within the New Small muon Wheels (NSW) project using a detector technology (micromegas) developed by IRFU, SPP should decide on specific phase-2 upgrade involvements for both ATLAS and CMS in a timely way.

Given the sizeable third neutrino mixing angle theta-13 there is high scientific interest justifying an involvement in a global long baseline neutrino oscillation experiment. On a shorter term, a decisive reactor experiment on sterile neutrinos would be also valuable. A strategic plan for future work in neutrino experiments should be developed in partnership with the SPhN division.

The cosmology and astroparticle physics activities of IRFU are remarkable and highly visible. Following the excellent results obtained with SNLS, BOSS and Planck, future work with eBOSS/BigBoss and ultimately Euclid will bring a new era of precision to cosmology, and address the mystery of dark energy: is it a cosmological constant, evidence of new physics or a breakdown of General Relativity?

Future options in the study of high energy phenomena in the universe will depend on the evolution in the field, and it can be hoped that, following HESS-II, CTA as flagship project with strong IRFU participation will be the future focus.

There is also a relevant contribution to the GBAR experiment, exploiting well nuclear physics techniques, to measure gravitation in antimatter.

Particle physics and cosmology are living in an extraordinarily exciting period with rapid progress on many fronts. SPP has to continue its effort to select carefully from many high-class options a few focal directions in their strategic planning, as ultimately their resources will not be sufficient to contribute in a significant way to all of them. Flexibility will be required to consider, and adapt to, possible major global evolutions in the coming years, such as for example an emerging e+e- collider project.

The Nuclear Physics division (SPhN)

The IRFU research in Nuclear Physics addresses very relevant questions in harmony with the long range plan for Europe prepared by NuPECC. In general IRFU plays a prominent role in this vibrant and vital area of research thanks to its rather complete contribution in experiments, theory and techniques. Especially good internal collaborations are established with the SIS, SACM and SEDI divisions. The committee recommends to keep this trend and to enhance the coherent contributions within IRFU onto each project. The scientific productivity is impressive and particular effort is made in training Ph. D. students and post doctoral fellows.

Quark-Gluon Plasma research

The participation in the ALICE collaboration actively contributes to questions on quark and gluon plasma and on the equation of state. For the ALICE upgrade for high luminosity LHC IRFU is involved in the Muon Forward tracker detector designed to overcome the actual limitations and broaden the physics portfolio by measuring charmoniums and bottomiums. The committee appreciates the coherence of the group involved in the di-muon physics having responsibilities for both the detector and the data analysis and appreciates also the close collaboration with the local theory group.

Hadron structure research

For this area IRFU scientists are important players on two sites, at CERN with the experiment COMPASS and at Jefferson Laboratory with the CLAS experiment with much coherence in the two physics programs. The involvement in detector construction for COMPASS-II and CLAS12 is strong and new data takings are planned in both cases. To translate all the observations into clear physics outputs will require further theoretical contributions from perturbed QCD. For the longer term future, towards an electron-ion collider, both groups could definitely bring cutting edge technology for detectors and

scientific experience. Indeed, they have already contributed to the white book and by operating the related workforce more coherently IRFU can aim more.

Nuclear structure research

Several topics at the frontier of nuclear structure and reactions are addressed. In particular experiments are made and/or planned at GANIL, RIKEN, Jyvaskyla and INFN/LNL on the evolution of shell effects, collectivity, and shapes and on superheavy nuclei. For very exotic nuclei there is an outstanding program at RIKEN within the ERC grant MINOS. The balance between the activity performed in house (GANIL) and abroad is very good. This is a key point in view of the future best use of the new facility SPIRAL2/GANIL to which IRFU has strongly contributed and will contribute. At GANIL the third campaign with the AGATA array (after Legnaro and GSI) will start soon and IRFU is playing a mayor role in this large European collaboration. The theory group is collaborating closely with experiments. Very interesting results on quantic and ab initio methods for many body were obtained. The ESNT initiative for collaboration in theory is a success and should be encouraged continuously.

Research in nuclear reactions and applications

This research has a twofold objective, to understand mechanisms and to meet the needs in applications. The participation in n_TOF at CERN is for neutron capture studies while the very timely fission fragment studies are improving predictions of antineutrino spectra, useful for the NUCIFER reactor experiment (with strong IRFU participation). The committee notices the best mixture of high-energy and nuclear physicists in IRFU to study neutrino-related science. Further collaboration between SPhN and SPP in the DOUBLE CHOOZ, NUCIFER and STEREO experiments should be encouraged, because beneficial to physics beyond standard model, nuclear fission/ interaction, and nuclear applications. The activity on spallation reactions reinforces the IRFU contribution to ESS.

In *summary*, the committee is much impressed by the results and plans for all topics. The programs at CERN and JLAB should be pursued as planned. The applied program is based on a strong tradition, and is well integrated with other activities including neutrino physics. Because of the very appealing program of SPIRAL2/GANIL and of the large investment made and to be made by IRFU, it will be very important to fully exploit the excellent physics potentials there. The extension of the AGATA array will be very relevant for the best realization of the SPIRAL2 physics program.

Accelerator, Cryogenics & Magnetism division (SACM)

IRFU owns and manages an impressive portfolio of accelerator science and technology. This includes, but is not limited to sources, superconducting (sc) RF systems for electron, proton and ion accelerators, sc magnets, and cryo-technology. Engineering capabilities and investments in key technologies place IRFU in a strong position to make significant contributions to the recently updated European strategy for particle physics (CLIC, ILC, HL-LHC, HE-LHC, FAIR). The same technologies allow key contributions to major European construction projects beyond particle physics (IFMIF, SPIRAL II, ESS, X_FEL, JT60 SA, W7X, ITER), that are either on-going or will start in the near future.

Strategic goals

SACM strives to develop and operate a unique infrastructure that provides a platform for R&D and for involvement in future high tech projects. Production of components, individual or in series, is part of this strategy. The infrastructure, which is largely used to support these projects, allows R&D on High Field Magnets, SC-RF and high intensity sources. The external funding received drives much of the investment into the infrastructure. In that sense, the resources are well aligned within SACM with the strategic priorities of IRFU.

Assessment

The infrastructure within SACM is world class. IRFU picked its "sweet spot" in terms of technology involvement given its historical involvement in Nuclear, High Energy Physics and Accelerator Technology. The business / service provider model at SACM delivers a large fraction of the funds for the infrastructure and therefore the R&D platform. In order to maintain a stable base of manpower and materials & supplies funding, a continuous and aggressive acquisition strategy is required. A significant fraction, in some cases the majority, of the people and the infrastructure are funded through outside projects. Such a strategy requires a robust QA and risk management plan, in which a clear understanding of who carries the cost and schedule risk is necessary. This needs to be developed as part of the acquisition process and not later on to avoid loss of reputation for the institute. An accelerator physics / beam dynamics / technology backbone would further support the presented strategy. It should be partially funded out of the project budgets, since the research funding inside CEA cannot fully support it anymore. Presently this effort seems too small to support on-going work and to develop future involvements in other projects.

Systems Engineering Division (SIS)

The General Engineering Division has a rich portfolio of activities concerning the design, development, deployment and maintainance of innovative complex instruments for the physics program of IRFU. The work in mechanical engineering is to great extent devoted to the construction of magnets and accelerator components while that for instrumentation and controls is devoted mainly to detectors and measuring systems, telescopes and space instruments. High capability exists for simulation, modelization, and design validation, control systems providing several important engineering and industrial follow ups. Important achievements with relevant know-how concern Magnet Safety Systems, Muscade (the remote supervision web module), EPICS (Experimental Physics and Industrial Control System), and Cryomechanisms.

The good structure of SIS facilitates the integration of the multi-disciplinary aspects characterising the activity of this division. Among the challenging projects there are the development of the beam dump for SPIRAL2 and the protection system for the T2K magnets of the JPARC. Of great societal impact is the automatic syringe filling for nuclear medicine.

Assessment

The infrastructures within SIS are world class. The SIS division presents well-integrated capabilities from mechanical engineering to computer control. The activities of this division exploit very well the available infrastructures and are very instrumental for the success of the various and different programs carried out by IRFU in basic and applied researches. In general this division supports well the mission directorates across IRFU. The particularly strong ties with the SACM division are very important and are based on a longstanding tradition of collaboration in many projects of different size and aim. More resources are required to ensure a healthy physics portfolio for the institute itself and not only for the projects the institute is involved in.

As suggested for the SACM division also for this division a QA and risk management plan, needs to be developed as part of the acquisition process and not later on to avoid a possible loss of reputation for the institute.

Electronics, Detectors, and Computing Division (SEDI)

The committee acknowledges the exhaustive documentation describing in detail the many activities in which the division is successfully involved. The committee appreciates and congratulates the division for:

i) the large effort invested in the program of technology transfer to industry;
ii) the collaborative and interdisciplinary attitude of the division;
iii) the successful investment in system engineering and integration studies ;
iv) the observed care for metrology and systematic tests to prove the performances of detectors in the R&D phase;
v) the effort devoted to civil interests and demonstrated by the effective engagement in medical applications.

Furthermore, the committee congratulates the managerial team for the variety of experiments to which SEDI participates which are all of prime importance in fundamental physics research. On this line, the committee encourages the Division to maintain strong involvement in LHC experiments while still strengthening the very successful R&D activities in the detector and electronics domains.

Gaseous detectors

The impact of SEDI on R&D, production and running of gaseous detectors, in particular of Micromegas, is highly visible and internationally recognized. There is a large request for Micromega detectors, spanning from the thousand square meter for the LHC upgrades, to the few thousands for neutrino experiments to the 10 thousands for ILC applications. CEA is directly involved in the industrialization and technology transfer of Micromegas to industry; this effort shall be strongly sustained, maintained and carefully monitored. SEDI shall invest to play the leading role in this effort.

Microelectronics

The microelectronics road map clearly shows that the involvement of SEDI in the development of low noise frontends, analog memories and MAPS is of major importance

for many experiments that rely on the timely completion of the R&D to adopt the technologies for future large scale applications. The committee strongly recommends sustaining this effort.

Electronics

The competence and ingenuity of SEDI in the electronics domain is internationally recognized and has long traditions. Again many successful examples were illustrated: analog and digital electronics developments, digital architectures, advanced real time systems, Selective Readout Processors, advanced FPGA technologies and more; the division is encouraged to pursue this path, paved over many years by successful work in international collaboration.

Software engineering and development

The large and diversified efforts invested in this innovative area of research demonstrate a wide and progressive vision of the SEDI managerial team; it is considered as a strategic investment to be fully supported by IRFU.

Computing services & infrastructure

The committee acknowledges and congratulates SEDI for the steady investment in the computing environment that brought the contribution of IRFU as high as 25% of the French effort in the LHC Grid project.

Recommendation. The committee observes a strong participation of SEDI in several innovative and challenging projects that imply "large scale" productions. Many times SEDI has direct responsibilities for timely delivery of the final products. It would be appropriate to face these engagements with the support of careful risk analysis plans and detailed Quality Assurance and Quality Control activities in order to safely meet the final goals.

External relations and communications

IRFU exemplifies a diversified program with a dynamical roadmap, well focused on strategic questions in which the physics goals are always placed as first priority. IRFU demonstrated with several examples how the ambitious objectives are achieved via a careful planning where the leading key word is "Collaboration" and where the external relations become fundamental to complete a mission. IRFU is strongly oriented towards international research, and collaboration with large research organizations (CERN, ESO and ESA) and international laboratories (DESY, RIKEN, NASA, GANIL, ESS, JLab). The active participation of IRFU in Labex P2IO (Physics of the Two Infinities) fosters fundamental research, cooperation and international visibility between universities, engineering schools, national funding agencies and the large laboratories.

It is evident that the management provides clear directions in case a project cannot find direct expertise in-house by enhancing the collaboration with external partners who participate in the project, bringing their knowledge and competence. Such an attitude,

that encourages the stakeholders to maintain a leading role in their field of expertise, assures constructive collaborations bound to last along years of collaboration. The IRFU strategy can be summarized in few words: " be part of a collective adventure". The management is strongly supported to maintain this wide variety of expertise and services exploiting the support from the external collaborations.

Communications

The involvement and dedication of IRFU to information and communication actions is impressive. The internal communication is carefully managed and the plan established to inform all the staff via Intranet website, topical meetings, assemblies, science and technology conferences. This assures that all employees are exposed to the totality of information, well documented and updated.

As well, a complete education and training program in scientific and technical disciplines is put in place to the benefit of the staff, scientific advisors, project managers and P2IO employees. More than 600 training actions were established and at least the same investment is expected for the years to come. Education of students and teachers is also of a major interest for IRFU, resulting in the organization of tours of the laboratory for students from all backgrounds, creation of schools, arranging encounters between researchers and the general public, participating to the training of teachers. The IRFU web page is also an important tool and thus it should be kept well updated and improved during the years.

IRFU conducts an extremely active programme in external communication and outreach. In many occasions, of high international visibility, IRFU researches organized exhibits, hold conferences of large attendance, communicate to the general public on hot topics in elementary particles and succeed to bring complex arguments, like the history and evolution of galaxies, down to the understanding of the large public thanks to innovative 3D projections.

The extraordinary communication capacities of IRFU, respect to the employers, scientific community and large public, are decisive for the image of the institute and to promote the Institute's activities through all types of scientific and multimedia channels; the effort should be maintained and highly supported.

General Strategy

We congratulate IRFU on a strategic approach that has been very successful in bringing their significant technical and scientific resources to bear on the major scientific questions in particle physics, nuclear physics and astrophysics. At the same time, there is encouragement of creativity and new ideas, leading to a diverse portfolio of projects, supported by an outstanding and highly productive staff. The cross-cutting project-based matrixed organization is an effective way to engage the broad range of expertise required for experiments in particle physics, nuclear physics and astrophysics, drawing on IRFU's advanced technical resources in accelerators, detectors and computing. The management seems highly engaged in the scientific activities, and has established open communication channels with the Divisions.

One problem that was brought to our attention in the review is the recent change in retirement age, which threatens to create a gap at the young end of the demographic distribution, as older workers stay longer and make it difficult to hire young researchers in the meantime. A plan is needed in order to smooth out the demographics and allow renewal of the organization. Any solution will require some additional funding, for example, incentives for early retirement, or extra support to hire new staff in the next five years, in anticipation of future retirements.

We were pleased to learn that management is already working in this direction, and encourage this strategic approach.

The overall scientific strategy is driven by the scientific staff and is generally very well developed. However, sometimes the strategy may tend to be guided by opportunities for external funding in some areas. This entrepreneurial spirit has been very successful, but must function within an overall scientific and technological strategic framework aimed at the most promising and well-positioned projects in which IRFU can play major leadership or enabling technical roles. The current portfolio is reasonably well balanced, but as it evolves the management will have to choose its investments carefully. From time to time it may be useful to establish Divisional or inter-Divisional study groups to evaluate a particular research area, bringing in seminar speakers with relevant expertise and carrying out an evaluation of the experimental directions and the opportunities for IRFU to contribute. This would help inform the decisions before commitments are made, and could also help build consensus within IRFU on the right strategic direction.

The financial structure of IRFU has most of the resources committed to personnel, with very little additional funding to enable R&D activities. This is perhaps the weakest aspect of the current organization; conversely this can be described as a major opportunity waiting for a creative solution. Internal funding to jump-start new initiatives or support small-scale R&D efforts could unleash scientific productivity and enable early development that is crucial for next-generation scientific programs. While it is difficult to come up with even modest additional funding in this constrained economic era, it may be worth pursuing this idea at the higher levels of the CEA organization, as the benefits could be very substantial.

Finally, we note that the strategic use of IRFU as a “brand” has not been strongly developed to date. We do not know if this intentional or not. If funding issues continue to be a problem, then it may be useful to develop the IRFU brand, for example by succinctly defining the mission, the core capabilities and the unique role it plays within the overall scientific ecosystem of France. This would serve to highlight IRFU’s leadership roles and its unique technical resources, and could be extended by refreshing the web presence and other promotional materials with more up to date materials.