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Guidelines from the Physics Preparatory Group' Chair: A recommended format does not really apply, but it will help us to have some justification why the priorities look the way they do (either scientific or related to community interests or both). It will be also helpful to see a brief discussion of the expected challenges to achieve such a program (at the national level) and how the community is prepared to contribute.

Input to the update of the European Strategy on Particle Physics provided by the Spanish Scientific Particle Physics community

(Submitted to the ESPP Physics Preparatory Group - December 2018)

It is the purpose of this document to summarize the general views of the Spanish community concerning the update of the European Strategy for Particle Physics, which has been launched by the European Strategy Session at the CERN Council in its September 2018 session.

A summary of the status and the priorities in the field of Particle Physics of the Spanish community is presented. The input provided here is the result of the work of the various national thematic networks, as well as the output of extended discussions of the whole community in two general meetings that took place in September and October 2018.

It is considered that Spain still needs critical mass in key areas, more coordination and networking among the different Institutes, increased sharing technical and industrial support, and a stable and reliable framework of funding, as well as a more structured community. The creation of a National Institute is still a pending organizational goal. Fortunately the "Centro Nacional de Física de Partículas, Astropartículas y Nuclear" (CPAN) created at the beginning of 2008, had been largely successful in the above objectives, thanks to those efforts, the community is organized nowadays in several national thematic networks, each covering a different area.

After an Executive Summary listing the national priorities, this document contains 7 sections addressing briefly the status of the Spanish community and the main contributions to the different strategy items. Section 8 reports on medium and large national infrastructures which activity has significant relevance to the overall Particle Physics program.

Executive Summary

Energy Frontier

1) Strong commitment of the LHC Spanish Community to the High Luminosity upgrade of the accelerator and detectors (from construction, commissioning and physics exploitation) to optimally profit the ongoing efforts.
2) ILC is well recognized as the only technologically ready machine that could be implemented if Japan offers its construction (with reasonable conditions financial and expertise wise). The physics potential of a program with different steps in center of mass energy, up to ~ 1TeV is well justified. Although a scenario of overlapping pp and ee machines is attractive, it will be difficult to afford for the Spanish community, due to its yet modest size. Other linear collider options, as CLIC are favored -wrt circular- due to its energy upgrade capabilities. [see comments and doc in the mail]
3) FCC-hh is the next ambitious CERN proposal. It is scientifically sound and technologically credible in reasonable time scales. The various phases (e-e, h-h, e-h) program could be adjusted to the evolving international scientific panorama. We believe it is important to allocate the necessary R&D resources already now, to make it feasible. CERN should have an ambitious project already on-going to guarantee the continuity of the laboratory scientific program. The similar China proposal on a circular collider could have a definitive impact. Effort should be paid to integrate Asia strategy in the global HEP vision. HE-HLC

appears an interesting option, also test bench of FCC components. Its physics case vs the resources available should be carefully evaluated.

4) R&D in other acceleration techniques is a must for the future of the field. The AWAKE program should be complemented with other initiatives (laser acceleration, muon collider, etc.). A coordinated effort between CERN and the individual national programs should be build, with well-structured milestones and time-lined achievements.

Neutrinos in accelerators

5) The Spanish neutrino community is committed as its first priority, and within the CERN effort, to LBNF and DUNE scientific program.

Beyond Colliders (astroparticles and cosmology)

6) In the multi-messengers era, astroparticles experiments and cosmological surveys are taking a leading role in the understanding of the universe. The Spanish community is engaged in a rich program from large to small size experiments, well framed in the APPEC roadmap. Within the European Strategy it will be scientifically reasonable to strengthen –without compromising CERN accelerator uniqueness– the already sizable CERN involvement in on going and future endeavors.

Nuclear Physics

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1.- Physics at the High Energy Frontier. The role of the LHC and its upgrade HL-LHC.

Following the main line of the strategy approved in 2006 and its update in 2013, an optimum Spanish participation in **the LHC program and its upgrade HL-LHC** has been so far, and will continue to be for the next years, **our highest priority.**

With the discovery of the Higgs boson in 2012 Particle Physics has entered a new era. The Higgs boson could be the closing piece of the Standard Model (SM), but more likely it opens up the door to physics beyond the Standard Model (BSM), that is known to exist. Consequently, it is of utmost importance to learn as much as possible about the Higgs boson, its interaction with SM particles and with (so far undiscovered) particles beyond the SM. The LHC will remain as the energy frontier machine for many years. We must exploit its potential of discovery of new particles produced in pp interactions.

The first priority of the Spanish groups collaborating in the LHC experiments at CERN is the full exploitation of the data provided by the LHC collider and the participation in the coming upgrade phases of the project.

The Spanish participation at LHC during the last decades included an important contribution to the design, construction, operation, and since 2010 scientific exploitation of the pp collision data at 7 and 8 and 13 TeV, of three detectors: ATLAS (IFAE, IFIC, UAM), CMS (CIEMAT, IFCA, UAM, UO), and LHCb (UB, USC, URL). There has been as well a participation in ALICE (CIEMAT, USC) that was terminated
in 2015. The contribution represents 2.5% to 4.6% (depending on the experiment) of the total capital cost and manpower. The Spanish contribution to the WLCG (LHC Computing Grid) project has been slightly higher (about 4%). Spain hosts one of the 12 Tier1 centers of the GRID worldwide structure for the LHC. This Tier1 is located at PIC, a centre for massive storage and data processing created through a consortium of DECO (Catalan Government) and CIEMAT at the campus of the UAB. In addition, there are three Tier2 centers, one for each LHC experiment with Spanish participation. Finally, Spain also contributed with the participation of IMB-CNM, a microelectronics center with a microfabrication Clean Room, which made an important contribution to LHC experiments proposing and fabricating new detectors technologies for tracking and timing applications.

When the LHC started, in November 2009, all detectors with Spanish responsibility (Silicon Tracker and LAr and TileCal Calorimeter of ATLAS, Muon System and First Level Trigger of CMS, Silicon Tracker and SPD calorimeter of LHCb) were ready. They have been operating extremely well contributing to the smooth data taking process all along these years. They have also adapted well to the rapidly varying LHC running conditions, especially the large increase in pile-up in the case of ATLAS and CMS. Spanish groups assumed important responsibilities in the commissioning, maintenance and operation of those detectors, ensuring their smooth operation, and are also playing a major role in the analysis work leading to many relevant results associated to Flavour, QCD, Electroweak, top quark, Higgs and BSM physics, obtaining good visibility in the exploitation of the huge amount of data delivered by the LHC.

The participation in the LHC project is also well aligned with the Spanish membership of CERN (8% contribution to the global budget) and will help to maximize the scientific, technological and industrial returns.

In the short term, LHC will continue operation with Run 3 starting in 2021, at already twice the design instantaneous luminosity and a foreseen increase of the energy of the collisions to 14 TeV. In the medium term, the already approved high luminosity phase (HL-LHC), which is expected to start by 2026-2027, will bring a major increase in the luminosity, aiming to collect 3000-4000 fb^{-1} of data at 14 TeV by ATLAS and CMS, and 50 fb^{-1} by LHCb. The physics program includes more precise measurements of the Higgs boson properties, SM parameters, physics of the flavour sector of the SM, as well as the direct searches for new phenomena. The expected improvements at the LHC and the HL-LHC in both, precision measurements and searches for BSM physics are significant and will improve our knowledge of nature substantially. They deserve our highest priority now and the corresponding human effort and financial resources.

In order to face the experimental challenges that HL-LHC will impose on the detectors, a major upgrade of their equipment is required. The aim is to cope with the extremely high HL-LHC instantaneous and integrated luminosity, along with the associated radiation levels. There will be major upgrades in tracking detectors, electronics of the calorimeter and muon systems, as well as improved triggers and data acquisition systems. The experiments and their physics potential will benefit of extensions to larger pseudorapidity, particularly in tracking and muon systems. Depending on the upgrade schedule of the individual experiments, some of these activities already took place during the first Long Shutdown period (2013-2014) of the LHC or during the end-of-year maintenance periods: insertion of an additional layer of silicon pixel detector in ATLAS, and upgrade of part the muon system electronics for CMS. In any case, the bulk of the work is still to be done during the Long Shutdown periods 2 (2019-2020) and 3 (2023-2024).

The Spanish LHC groups are participating in detector upgrade activities in ATLAS, CMS and LHCb experiments since day one. The community is strongly committed to
the project and a substantial fraction of their human and financial resources is already dedicated to it. To withstand an instantaneous luminosity of 10^{35} cm^{-2} s^{-1} and having to stand very high doses, ATLAS needs to replace it Inner Tracker. IFIC and IMB-CNM designed many components of the end-cap strip tracker and will produce part of the modules. IFAE and IMB-CNM developed the radiation-hard 3D-pixel technology that has been selected for the innermost layer, and will produce part of the modules. There is also a contribution to the upgrade of the readout electronics and the mechanics of the TileCal ATLAS hadronic calorimeter (IFIC and IFAE respectively). In the case of CMS, IFCA, University of Sevilla and ITA, together with IMB-CNM, are also involved in activities related to the tracker system upgrade for HL-LHC, in particular in the silicon 3D sensors assessment, powering schemes integration and monitoring of stability. In addition, CIEMAT and University of Oviedo is actively working in the upgrade of the muon system which needs revisiting the readout and trigger electronics in order to adapt to the high luminosity scenarios and to improve its performance. First upgrade changes in the muon detector electronics started already during the first Long Shutdown period (2013-2014). In both detectors increasing attention is devoted to the development of precise timing detectors based on the LGAD technology where the Spanish groups (IFAE in ATLAS and IFCA in CMS, both led by IMB-CNM) have special interest. IFAE and CNM will provide such sensors for the new High Granularity Timing Detector (HGTD) of ATLAS. In CMS, its use is being considered to be implemented in endcap dedicated detectors. In LHCb the contribution of Spanish groups (UB, USC, URL, and IFIC) is centered on a new calorimeter front-end electronics, which needs to be developed in order to

handle the 40 MHz readout, and the upgrade of the LHCb forward vertex locator (VELO) to a new detector aiming at unprecedented time resolution. Another important area of interest is a novel concept of tracking consisting of a thin scintillating fiber detector and its readout electronics.

Computing activities for HEP are crucial in the next years to cope with the HL-LHC data processing requirements. Spanish ATLAS, CMS and LHCb Tier-1 and Tier-2 infrastructures will need 20 times more resources for HL-LHC with respect to current ones, being storage the main challenge to address. The Spanish LHC computing community is establishing the main guidelines for the next years, moving towards common implementations: Integrated High Performance Computing, Grid resources and increasing network bandwidth. The development of a new computing model and investment in the computing resources is a strategic effort towards the successful exploitation of the LHC data.

From the theory side, the Spanish HEP community is strongly involved in providing theory predictions for current ATLAS, CMS and LHCb precision measurements and searches. This concerns higher-order corrections for SM processes (e.g. Higgs and top) as well as for BSM physics (Higgs, SUSY, new gauge bosons, vector-like fermions, etc.), flavour phenomenology concerning quark and leptons, as well as for heavy ion physics (PbPb and pPb). Furthermore, the Spanish theory community takes a vital role in the planning and the evaluation of the physics potential of future facilities. (mention some examples of contributions?). These efforts ensure that the Spanish theory community also in the future will continue its strong involvement in the on-going efforts to discover BSM physics.

In summary, The LHC Spanish community believes that the new phase of the LHC project at CERN (LHC Run 3, detector upgrades and HL-LHC physics exploitation) will be a unique (and the best) opportunity to improve our knowledge of the known and explore the limits of the unknown. We consider LHC should constitute the main path in the European Strategy for Particle Physics for the coming years. Therefore, **the full LHC/HL-LHC operation and the exploitation of its physics programme** is fully supported by the community, and we believe it **should be the first priority of Europe for the next years.** From the Spanish side it is then essential to guarantee an adequate support to LHC/HL-LHC activities, and the successful exploitation of its physics program.

Going beyond HL-LHC, the way to higher energies in pp colliders has to be paved (see section 3). Our contribution to LHC and HL-LHC detectors has been based on an extensive R&D program. To maintain and strengthen our position at international level, the R&D program in new detector technologies should be one of our priorities, in particular the development of new tracking devices, precise timing detectors, and very highly segmented calorimeters or more compact electronics for their use at future facilities are the main lines of activity.

2.- Flavour Physics

The understanding of flavour is, together with the electroweak symmetry breaking mechanism and the dark matter origin, one of the fundamental problems of today's particle physics. Since Rabbi asked who ordered the muon, the formulation of the flavour problem has evolved to the origin of the number of generations of quarks and leptons, to the origin of the mixing among different flavours and to the origin of CP violation. The large amount of data collected in kaon experiments, hadron colliders (D0, CDF, LHCb) and the B factories (BaBar and Belle) have established the SM Cabibbo-Kobayashi-Maskawa (CKM) paradigm as the dominant mechanism responsible for CP violation (and flavour mixing). The discovery of the neutrino masses and the improved knowledge of the Pontecorvo, Maki, Nakawa and Sakata (PMNS) mixing matrix are other achievements of paramount importance towards the understanding of the origin of flavour.

Recently, several observables in the flavour sector of the SM have shown anomalies concerning heavy quarks, which can be pointing out BSM physics. The LHCb experiment (also ATLAS and CMS), which will be upgraded in the coming years to be operative during

Run 3, and the Belle-II experiment at KEKB, which is at present starting to taking data, are of high interest to confirm or refute those possible hints of new physics.

The Spanish groups are strongly committed to the LHCb upgrade detector (tracking system and calorimeter) **and to the data physics exploitation** (see section 1)**.** Despite the enormous interest of the physics of Belle II, **the b-physics Spanish scientific community prioritizes the participation in the LHCb experiment.** In Spain there is an important Theoretical Physics community working in flavor phenomenology that closely collaborates with the experimental groups, being deeply involved in the physics exploitation of the data. The Experimental Physics community, whose origins go back to BaBar and CDF, has grown and its current major experimental activities are related to the LHC experiments and especially to LHCb.

Since many important open questions in the SM are related with Flavour Physics, we believe that special attention should be given to ensure that the LHC detectors, analysis techniques, and physics program of the LHC experiments can optimally exploit their potential for flavour physics. **B-physics should represent an important ingredient of the LHC and HL-LHC physics program.**

3.- Physics at the High Energy Frontier: future Linear and Circular Colliders

In this section, we focus on future circular and linear colliders apart from HL-LHC as this has been discussed previously. Several proposals have been developed. The ILC project, a linear collider using superconducting acceleration technology, is by far the most robust and mature technology and already developed its Technical Design Report proposal (ILC-TDR, arXiv:1306.6327). An alternative approach to the ILC, the CLIC concept based on normal conducting technology, is developed under the CERN leadership. Other proposals for future colliders are the energy upgrade of LHC to 26-33 TeV (HE-LHC), the Circular electron positron Collider (CepC) and the Circular proton proton Collider (CPPC) in China and a Future Circular Collider at CERN which could operate initially as an e^+e^- collider (FCC-ee) and later as a hadron collider (FCC-hh) or/and as an ep collider (FCC-he). The extension of the physics programme beyond the LHC will thus require the construction of a new generation of colliders and the development of new cutting edge detectors using much improved detector technologies than those existing at present. In Spain starting in the mid 2000's a continuous effort has been made in this direction. As a result of this, in 2006 the Spanish Network for Future Colliders was created including experimental groups (CIEMAT-Madrid, IFCA-Santander and IFIC-Valencia), technological centres and departments (UB-Barcelona, US-Seville, ITAINNOVA-Aragón, NTC-Valencia, INTA-Madrid and CNM-IMB-Barcelona), accelerator groups (ALBA-Barcelona, CIEMAT and IFIC), and theoretical groups (UGR-Granada, IFT-Madrid, IFCA-Santander, IFIC-Valencia).

3.1 - Considerations on the physics case for future machines

The **International Linear Collider (ILC)** with center-of-mass energies between 250 GeV and 1000 GeV has a mature technical design that is ready for construction. The ILC will be a Higgs boson factory where the clean operating environment, low backgrounds, adjustable beam energies and polarizations will allow model-independent measurements of the Higgs-boson absolute couplings to SM fermions and gauge bosons, most of them to better than 1% precision, as well as determining their CP properties. ILC can make precision measurements of the Higgs boson self-coupling to an accuracy of typically 10-20%. The ILC will be also a precision top quark factory. The adjustable beam energy and clean operating environment will allow determining the top quark mass to a precision of 50 MeV or better. Also, the ILC will be able to produce new BSM particles up to half its centre-of-mass energy, and sensitive to new force particles Z' with masses ranging up to 7-12 TeV.

The ILC250 with its high luminosity and the possibility to polarize both beams offers great opportunities to measure with high precision the couplings of the Higgs and gauge bosons (where roughly similar precisions are expected at CLIC/FCC-ee). This will allow discriminating between the SM and many different BSM models, e.g. through exotic/invisible Higgs decays. This includes in particular Dark Matter discoveries. Going to lower energies, high-precision measurements of SM processes can be performed (GigaZ, WW threshold), offering a high potential for the indirect discovery of BSM physics. Extended to higher energies, the ILC will give access to the top quark properties and in particular to the Higgs self-coupling.

The **Compact Linear Collider (CLIC)** project may open the possibility of multi-TeV e^+e^- collisions. A first, low-energy phase collecting 500 fb^{-1} at a centre-of-mass energy of 380 GeV (CLIC staging document: CERN-2016-004, arXiv:1608.0753) which would allow the two main Higgs boson production mechanisms, through Higgs-strahlung and vector-boson-fusion. The Higgs boson couplings to W bosons can be determined to excellent precision, as well as competitive measurements of electroweak couplings of the top quark. After that, the machine will be upgraded to reach centre-of-mass energies in the multi-TeV regime, where it can study associated production of Higgs bosons and top quarks, vector-boson scattering and di-Higgs boson production. Its unique multi-TeV reach is key to fingerprint new massive particles and search for new phenomena that escaped detection at the LHC. While the CLIC design is somewhat less mature than that of the ILC, the low-energy stage forms a realistic and affordable option for the period following the LHC.

With the discovery of a relatively light Higgs boson, the interest in **Circular e^+e^- colliders (FCC-ee, CepC)** has revived. Groups in Europe (First Look at the Physics Case of TLEP, arXiv:1308.6176) and China (CEPC-SPPC Preliminary Conceptual Design, IHEP-CEPC-DR-2015-01) are investigating a circular **e^+e^-** collider, with high luminosity at centre-of-mass energies up to 250 GeV. Its main target is the measurement of Higgs boson couplings at or below the per cent level. Eventually it could reach the top quark pair production threshold. The top quark Yukawa coupling to the Higgs boson and the Higgs boson self-coupling could only be accessed indirectly due to the limited centre-of-mass energy. Synchrotron energy loss of the beams effectively prevents reaching higher energies.

A 100 TeV pp **Circular hadron collider (FCC-hh)** is under consideration following the completion of the LHC and high-luminosity LHC physics programs, to probe new energy scales, allowing us to hunt for new fundamental particles roughly an order of magnitude heavier than we can possibly produce with the LHC, and new particles the LHC may produce in small numbers will be produced with up to a thousand times higher rate (arXiv:1607.01831 [hep-ph], arXiv:1606.09408 [hep-ph], arXiv:1606.00947 [hep-ph]). Many years of intensive work are still needed to arrive at a complete description. Operating the FCC-hh with heavy ions is also an option that is being considered (arXiv: 1605.01389 [hep-ph]). A design study by the Chinese community for a similar machine but with smaller centre-of-mass energy (20-30 TeV) is also ongoing (arXiv:1510.05754).

Studies on the physics program of a **proton-electron collider (FCC-he)** at the FCC facility are also taking place, although results have only been documented for a Large Hadron Electron Collider (LHeC) (arXiv: 1206.2913 [physics.acc-ph]), a possible precursor of the FCC-he. The physics program is centred in the exploration of high precision measurements of deep inelastic scattering (DIS) measurements at the energy frontier.

The High Energy LHC (HE-LHC) is a study aimed at exploring the possibility to upgrade the present LHC ring to reach 27 TeV centre-of-mass collision energy, substituting the present LHC superconducting magnets with ones with much higher fields, of up to 20 Tesla. (https://cdsweb.cern.ch/record/1344820/files/cern-2011-003.pdf). The physics case of a high-energy upgrade of the LHC is similar to that of the FCC-hh, although with a smaller energy reach.

3.2 - Spanish detector R&D activities related to future colliders

The main R&D activity of the Spanish groups in relation to the above described future facilities are related to two aspects. On one side in the tracking systems, pixel and strip semi-conductor detectors, with excellent space-point resolution in systems of extremely low mass and low power consumption. The activity focuses on the sensor performance and quality tests, module assembly, connectivity, powering, system engineering, alignment and data extraction. On the other, in highly segmented calorimetry inside the CALICE Collaboration, the mechanics of the semi-digital hadron calorimeter and its final detector interface readout electronics are the challenges.

Spanish groups (IFIC, NTC, IFCA, UB and ITAINNOVA) are involved in several aspects of the Belle II using DEPFET technology for the vertex detector, including passive components, digital handling processor, critical temperature controller, environmental monitoring system, noise propagation effect of power cables and the electromagnetic susceptibility of the electronics. DEPFET remains one of the main candidates for the vertex detector of future energy-frontier electron-positron colliders (ILC, FCCee, and CEPC). Further DEPFET applications include X-ray imaging on satellites and in the X-ray Free Electron Laser.

CNM-IMB, UB, US and IFCA have also worked on microstrip sensors, which combines signal amplification –allowing the thinning of the sensor's substrate– and resistive electrodes –allowing the implementation of the charge-division method for the determination of the hit position along the strip direction (LGAD and a new concept called i-LGAD). The application of LGAD devices to the Linear Colliders (LC) tracking is a spin-off of its original aim as timing devices for high radiation environments, this technology is being proposed as vertex locator technology for the LHC experiments: AFP2 and HGTD (ATLAS); and CT-PPS (CMS). UB has worked on Geiger-mode avalanche photo-diodes (GAPD´s) fabricated in a conventional CMOS process with internal gain and ultra-high speed, which constitute the basic cells of Silicon Photomultipliers (SiPMs). The group analysed and proposed methods to limit that noise for application in ILC and CLIC. Apart from LC uses, since the apparition of GAPDs in CMOS in 2003 most of the applications were bioassays in which labels are identified by the emission of fluorescence light.

HV-CMOS is assuredly emerging as the prime candidate technology for future tracking sensors for ionising radiation for particle physics and numerous other applications. It is a priority to study these types of devices in view of future high luminosity collider applications (HL-LHC and beyond, e.g. FCC). UB and IFCA are involved in the CERN RD50-HV-CMOS design which includes several types of test structures, from diode arrays for TCT studies, amplified structures with different pitches for resolution studies and assessment of S/N and other parameters (e.g. cross talk) and time resolution enhanced matrices.

CIEMAT is part of the CALICE Collaboration since 2007. The group has worked in the tests of Silicon-ECAL and Scintillator-HCAL prototypes but its main contribution is related to the SDHCAL (Semi Digital Hadronic Calorimeter) been one of the major contributors to the collaboration. A ~1 m^3 prototype has been build and the results obtained in beam tests shows a good energy resolution, linearity and an extraordinary tracking capability, making it an excellent option for future experiments. The SDHCAL is one of the two options considered for the hadron calorimeter of the ILD experiment at ILC [TDR ILC] and for the Chinese CEPC-SppC detector [CEPC PreCDR]. The group is facing now some the specific challenges associated to the ILD calorimetry, both in mechanics (as the use of electron beam welding technologies) and electronics (due to the huge number of channels to deal with) that can be applied to the CEPC-SppC.

ITAINNOVA group works in collaboration with the other Spanish groups, both for tracking and calorimetry, in a power supply system based on supercapacitors compatible with the power pulsing technology.

The IFIC and IFCA groups, with support from the technological institutes, are deeply involved in the design of the experiments for the ILC and CLIC.

The Spanish community is heavily engaged and participates in the design/performance studies of the ILD detector concept of ILC and on physics studies for both ILC and CLIC. Most of the groups are members of the ILD and CLICdp collaborations. Several groups (IFIC, IFCFA, INTA, CNM-IMB) contribute to the design and benchmarking of the ILD forward tracking system. In addition, IFIC also keeps contact and collaborates in activities related with FCC-ee and CepC like the production of its Concept Design Report, CDR.

Maybe this description of the participation of the groups can be shortened. Nevertheless it should concisely and include contribution from ALL (IFAE,..) groups and initiatives. See comments received.

3.3 - Accelerator R&D

On Accelerator Technology, during the past 20 years there has been a significant activity in Spain for developing and constructing accelerator components as contributions to major International Projects and Facilities like LHC, HL-LHC, CLIC and its test facility CTF3 at CERN, ILC and its test facility ATF2 in KEK, XFEL at DESY, FAIR at GSI, IFIMIF and others; and even for complete accelerator complex as the Spanish Synchrotron Radiation Source, ALBA-CELLS in Barcelona.

In particular, the ALBA accelerator division has a consolidated experience acquired during the design and construction phases of the ALBA machine. More specifically in the design and fabrication of resistive and special magnets (including magnetic measurements), beam instrumentation, vacuum or Radio Frequency (RF). Furthermore the ALBA workshops and the magnetic and RF laboratories have been made available for own and exterior use. The ALBA accelerator group is participating in the CLIC project for the beam test of the Stripline Kicker Damping Rings (DR) prototype, Beam Instrumentation and RF systems and in the FCC project in the FCC-hh Vacuum activities (EuroCirCol H2020). (See section 8)

The Electrical Engineering Division of CIEMAT expertise is basically focussed on Superconductivity (SC) and RF and it includes an experimental facility for manufacturing and testing superconducting magnets based on NbTi technology and also for assembling accelerator components. The group has collaborated in the ILC SC magnets R&D, in the construction and industrialization of XFEL components (SC magnets, Movers, Phase Shifters and Control Systems) and also for the CLIC-CTF3 (Resistive magnets, Ultrafast Stripline Kickers, Ultra Precise Moving Tables, and Power Extraction Structures (PETS)). Currently the group is involved in CLIC project, particularly in the development of Permanent Magnet based Gradient Dipoles for CLIC DRs and in the fabrication of Accelerating Structures Prototypes; in the HL-LHC developing a superconducting nested dipole as part of the Spanish contribution; and in EuroCirCol and the FCC project in the joint R&D effort for High Field Superconducting Magnets (16Tesla) for HE-LHC or FCC-hh. Furthermore, the group has developed during these years a unique experience in the industrialization process of accelerator components that could be crucial in the participation in Future Accelerator projects.

The Accelerator group of IFIC has actively contributed to study the beam dynamics for LHC collimation system and the Beam Delivery Systems (BDS) of CLIC and ILC-ATF2. The group has also designed and constructed Beam Position Monitors and a Stripline DR Kicker prototype (in collaboration with CIEMAT) for CLIC-CTF3 project and Optical Transition Radiation (OTR) Beam Size Monitors and a halo Collimator for ATF2-ILC project. Currently the group is involved in the High-Gradient (HG) Normal Conducting CLIC RF R&D effort, more specifically in extending the CLIC HG RF technology for medical applications. To consolidate this effort the group is constructing an S-Band high-power test stand, which will be capable of performing high power tests and a complete breakdown analysis of RF components up to 30 MW.

Future Spanish contributions to Particle Physics Accelerators will be probably conditioned by a number of factors like:

- From the point of view of participants, it is very likely that the actors that are now involved in international collaborations will continue to participate in future accelerators projects contributing with their experience, expertise, and facilities, which have been developed over the last 10 to 20 years. Other actors may join, as the ESS Bilbao with a strong potential either in know-how and experimental facilities, as well as other smaller university groups in the UPC-Barcelona and the University of Huelva.

- From the point of view of technological choices, some strategies are now under consideration. As a significant example CIEMAT has decided to be deeply involved in the technology of High Field SC magnets based on Nb_3Sn for applications in future accelerators projects as HE-LHC or FCC-hh. In general we could conclude that the Spanish accelerator groups involved in the Future Accelerator network has a solid programme that has a strong potential not only from the scientific and technological point of view, but also strategically, and industrially.

- From the industrial point of view, participation of national companies in this sector is becoming more and more relevant when deciding the corresponding in-kind contributions. In this regard and in parallel with the scientific and technological development in the Public Institutions, an interesting industrial fabric related to accelerator technologies has been established in our country, part of them framed by the INDUCIENCIA-INEUSTAR federation (Spanish Industry for Science Association), which is able to compete successfully in technologies such as SC and resistive magnets, normal conducting RF, power converters, beam instrumentation and others.

3.4 - PRIORITIES

The Spanish community is very much concerned of having a long-time gap between the end of HL-LHC programme and the start in operation of a future machine following. This is felt as a high-risk period with negative impacts to the field and as such it should be reduced as much as possible. Realistic plans for a future collider should consider very seriously this fact.

Beyond the LHC physics programme the priorities of the Spanish community can be summarized following:

- Given the latest LHC physics results and those of the field, in general our clear priority is for an e^+e^- collider extendable in energy and capable to reach at least 550 GeV. At this level both e^+e^- proposals, ILC and CLIC, are supported with a preference for the ILC as a more mature technology and for its faster implementation. The present ILC proposal, conceived as a Higgs factory at 250 GeV centre-of-mass energy with potential upgrades to higher energies, is positively seen to make the project realistic and feasible. If the Japanese government supports to construct and to host the ILC250, the Spanish community is eager to participate in this new endeavour and gives its full support. Circular e^+e^- machines (FCC-ee and CepC) are supported as a Higgs factory and only in case the linear collider projects fail to materialize.

- A possible future contribution from Spain to ILC250 should be negotiated in close collaboration with the rest of interested European countries. The participation of the CERN lab to this possible European contribution in technology and science as well as logistics is considered essential. A similar structure which presently exists for the DUNE neutrino programme at FERMILAB should be created. At the same time having more labs in addition to CERN which have central roles in the development of collider High Energy physics is noticed as a very positive feature to pursue that reinforces the strength of the field.

- A strong R&D programme to develop the needed technologies for the future CERN projects following LHC is mandatory and fully supported by the Spanish community. This includes detector and accelerator R&D. In the case of Spain, the development of high-field superconducting magnets for either HE-LHC or FCC-hh is our main line of activity.

- For the HE-LHC and FCC-hh proposals the Spanish community understands that at this stage both projects need to develop a common technology mainly for high-field magnets. For the period of the next 4-5 years no urgent need is felt to decide on which project to support more. Hence both are supported expecting for results from HL-LHC which may also help finding the best way to go.

- Future developments on accelerator technologies like plasma acceleration or muon colliders are also supported. The CERN program of AWAKE should be continued.

- Any of the above future activates should be compatible with the successful completion of the LHC and HL-LHC physics program. Therefore, any future activity should have a realistic plan to accommodate resources accordingly.

4.- Neutrino Physics in Accelerators

Neutrino oscillation experiments led to the historical discovery of neutrino mass through flavour oscillations, but they will continue to provide answers to key questions in particle physics (CP violation in the lepton sector, mass hierarchy, sterile neutrinos, violation of unitarity of the neutrino mixing matrix, ...). In addition, deep underground detectors offer powerful physics synergies with e.g. proton decay searches, detection of geophysical, solar, atmospheric and supernova neutrinos.

The Spanish community is actively working in accelerator and reactor based neutrino oscillation experiments for more than 20 years, providing very relevant results to improve our understanding of neutrino properties. Currently, IFAE, IFIC and UAM neutrino groups are involved in the T2K long-baseline experiment in Japan and CIEMAT is participating in the Double Chooz reactor neutrino experiment in France.

The CERN Neutrino Platform was created following the recommendations by the 2013 European Strategy for Particle Physics. This is CERN undertaking to foster and contribute to fundamental research in neutrino physics at particle accelerators worldwide. It includes the provision of a facility at CERN to allow the global community of experts to develop and prototype the next generation of neutrino detectors and therefore is CERN's main contribution to a globally coordinated programme of neutrino research. The Spanish groups supported this initiative, participated since the beginning and have leading roles in the R&D program. CIEMAT, Granada University, IFAE and IFIC are nowadays heavily involved in the R&D program at the CERN Neutrino Platform, developing liquid argon TPC detectors and new near detector concepts for the upcoming long-baseline neutrino experiments. In particular, they participate in the protoDUNE liquid argon TPC prototypes (NP02 and NP04 CERN experiments) for the Deep Underground Neutrino Experiment (DUNE) and in the near detector developments for T2K-II.

DUNE is considered within the Spanish community and also on an international level the most advanced project to serve as future flagship neutrino experiment that will answer the questions of the CP violation and mass hierarchy within one decade of data taking. The DUNE collaboration is currently composed of about 1,200 collaborators from 180 institutions worldwide, including CERN. The US Department of Energy (DOE) formally approved in 2016 plans for construction of the first two (out of four) large underground caverns at the Sanford Underground Research Facility for DUNE and excavation started in July 2017. DOE also approved in July 2018 Fermi National Accelerator Laboratory to proceed with its design of PIP-II, an accelerator upgrade project that will provide increased beam power to generate an unprecedented stream of neutrinos. CERN is currently working on the first of four cryostats for the DUNE detectors based on new technology and plays a central role in the development of the DUNE cryogenic facility and infrastructure. Several European countries (UK, France, Switzerland and Italy) have signed Cooperative Research and Development Agreements with Fermilab and/or DOE for their contribution to the Neutrino Program.

The Spanish groups are already playing a leading role in the development of the DUNE detectors and related physics program. Their contribution to the DUNE far detectors will be a continuation of the work done for protoDUNE, and the expertise acquired during the R&D, construction, operation and data analysis of the prototypes at CERN will be directly applied to the design and construction of the DUNE far detectors. With the aim of maximizing its scientific impact, the Spanish community is developing a common strategy for a coherent and coordinated participation in DUNE.

A solid neutrino oscillation physics program is being established at Fermilab for the construction and operation of the DUNE long-baseline neutrino experiment with a strong involvement of the European neutrino physics community, in which CERN plays a central role. The national community considers of high priority for the next years to support and enhance the Spanish participation in this program.

5.- Astroparticle Physics

The act of observing the phenomena occurring in the Universe in a coordinated way with "messengers" of different nature has brought Astroparticle Physics to a new era. Thanks to the combination of state-of-the-art detection techniques, innovative analysis and calibration tools, Astroparticle Physics has experienced a rapid development that is shedding new light on the way we understand the most violent phenomena of the Universe, its dark side, the Physics of the Big Bang and their connection to the Micro-Cosmos, represented by the study of the fundamental particles and their interactions.

The Spanish community's visibility and size has been steadily increasing since the last update of the European Strategy for Particle Physics. Therefore it has notably contributed to the major past and current experiments on gravitational waves, gamma rays, atmospheric and cosmic neutrinos, charged cosmic rays, dark matter, dark energy surveys, axions and neutrinoless double beta decay. The impact of theoretical research has been outstanding too.

The Spanish community is aligned with the update on long-term strategies put forward by the Astroparticle Physics European Consortium (APPEC) at the beginning of 2018. We endorse the societal, organizational and scientific recommendations issued for the period 2018-2026. The recommendations discussed in this document follow the approach issued in the APPEC roadmap to go beyond the current framework set by the Standard Models of Particle Physics and Cosmology. We therefore group our set of recommendations on two lines of action:

- Large scale infrastructures that provide vital inside into the Universe through the exploitation of the information provided by confirmed messengers (gravitational waves, high-energy neutrinos, gamma rays and charged cosmic rays). We recommend to **secure the operation of the running experiments to fully exploit the scientific potential of their data**. We also recommend to **set a coherent program of funding such that our community can contribute to the construction of future large scale experiments**.
- Medium scale infrastructures to study dark matter, axions and the nature of neutrino and its mass. We **support the continuation of a rich program of measurements and detector R&D that allows the community to pursue the search to the level of discovery.** We recommend that, within the constraints imposed by the current funding framework, funds are allocated to **guarantee an adequate involvement of the Spanish groups on current projects and the next generation of experiments**.

As reflected in the APPEC roadmap and to further strengthen the synergies with satellite missions and ground-based, we endorse projects aiming at getting new insights on our understanding of the cosmological parameters, in particular the nature of dark energy. In this regard, we support the active participation of Spanish groups in the international collaborations in charge of current and forthcoming cosmological surveys (both satellite-based and ground-based), which will provide crucial information on the dark universe and other relevant issues for particle physics, such as the absolute scale of neutrino masses.

In the era of the multi-messenger approach to the understanding of the Universe, **we stress the importance of coordinating the efforts of the Spanish groups** through networks or projects that integrate different multi-disciplinary lines of research, such that a further connected community of experimentalists and theoreticians can develop, in an efficient way, a coherent program of activities. From the technology point of view, **we must strengthen the links between research institutions and the industry,** now that large scale infrastructures are being upgraded or begin their design and construction phases. It is also key to **guarantee a continuous and unconditional support to the big infrastructures installed in our country** (i.e., Canfranc Underground Laboratory, Observatory of El Roque de los Muchachos). The goal is to extract the maximum scientific and technological profit of the variety of experiments that are either taking data already or have been approved to run at those research infrastructures.

It is indisputable that the most compelling clues hinting to the existence of new phenomena, not contemplated in the Standard Model for Particle Physics, come from measurements and observations done with astroparticle messengers. This has created tight and fruitful connections between the disciplines of Particle and Astroparticle Physics. This link is conspicuously displayed in the rewarding relations the astroparticle community has with CERN. We **strongly support a larger involvement of CERN in future Astroparticle Physics endeavors through a sharing of the technological know-how, infrastructures and human resources**. We e**ncourage the development of coordinated actions in areas of common interest** like theory, R&D for new detector technologies, open data, education and outreach.

6.- Theoretical Physics

This paragraph has been taken from the contribution to Energy Frontier, please modify/complete as you consider. Emphasis of the fact that we have a large and well-known community, active in all physics issues (colliders, neutrinos, astro, cosmo, nuclear, unification, etc..)

From the theory side, the Spanish HEP community is strongly involved in providing theory predictions for current ATLAS, CMS and LHCb precision measurements and searches. This concerns higher-order corrections for SM processes (e.g. Higgs and top) as well as for BSM physics (Higgs, SUSY, new gauge bosons, vector-like fermions etc.), flavour phenomenology concerning quark and leptons, as well as for heavy ion physics (PbPb and pPb). Furthermore, the Spanish theory community takes a vital role in the planning and the evaluation of the physics potential of future facilities, in particular the ILC/CLIC/FCC-ee and HL/HE-LHC. High experimental precision anticipated for future e^+e^- machines can only fully be exploited if it is matched with theory predictions at the same level of accuracy (or better). There is also a strong effort in the Spanish HEP theory community in trying to understand what is the fundamental theory underlying the SM and its unification with gravity. These efforts may also give us hints on what physics BSM to search for at future colliders. All these combined efforts will ensure that the Spanish theory community, also in the future, will continue its strong involvement in the ongoing efforts to discover BSM physics.

7.- Interface with Nuclear Physics

This section needs to be condensed/summarized, if possible in a similar approach as done for the Astroparticles section. In this case following the main recommendations of the NuPEEC strategy from 2017. See comments received,

The understanding of the Universe from basic principles is an ambitious goal that involves many physics disciplines. Nuclear, particle and astroparticle physics play a key role in this context. The main objective of nuclear physics is the understanding of the fundamental properties of nuclei starting from their building blocks, the nucleons, and eventually from the quark and gluon degrees of freedom of Quantum Chromodynamics (QCD). To this aim, detailed knowledge about the structure of hadrons, the residual forces between nucleons stemming from their constituents, and the limits of the existence of the nuclei and of the hadrons themselves, is required. Nuclei are unique since they are the playground for the strong, weak and electromagnetic forces. Nuclei constitute an exceptional laboratory for fundamental physics, in many cases complementary to particle physics and astroparticle physics. Additionally, nuclear physics findings guide applications across several fields and have an impact on our understanding of the chemical element production in astrophysical environments.

The Spanish Nuclear Physics community plays an important role in advanced research at the European scale and worldwide. The main goals are in line with those defined by the recent Long Range Plan drawn up in 2017 by NuPECC, the Nuclear Physics European Collaboration Committee. The research topics addressed by Spanish groups included experimental research, theoretical activities and applications. Concerted efforts with other countries are integrated within European projects such as the ENSAR2 and HandronPhysics3 integrating activities, collaborative projects such as RD50 and innovative training networks.

Accelerator facilities

NuPECC urges for the completion and exploitation of the ESFRI flagship facility FAIR, and its four scientific pillars APPA, CBM, NUSTAR and PANDA. FAIR is a unique assembly of accelerators and experimental facilities that will allow for a large variety of unprecedented forefront research in physics and applied sciences; it is expected that FAIR will be a host laboratory for basic research for about 3000 scientists from about 50 countries. NUSTAR (Nuclear Structure, Astrophysics and Reactions) is the collaboration where the Spanish experimental nuclear physics community is involved, focussed on the investigation of nuclear structure, astrophysics, and reactions. The NUSTAR Board of Representatives, with five elected scientists, has had a Spanish member since its conception. The interests of the Spanish Nuclear Physics community are concentrated in DESPEC/HISPEC, MATS and R^3B. Spain has played a leading role in the definition of the Physics case for DESPEC and in the design, research and development, and construction of the advanced instruments. The spokespersons of the BELEN, DTAS, FATIMA and MONSTER collaborations belong to Spanish institutions. Several contributions to the construction of HISPEC detectors such as AGATA, HYDE and NEDA detectors also exist. Spain has been strongly involved in the MATS collaboration, including the coordination of the Technical Design Report. Spanish groups also play a significant role in the study of reactions with high-energy secondary beams R^3B, an important tool to explore static and dynamic properties of nuclei far-off stability. R^3B has at present a Spanish spokesperson. Spanish groups participating in R^3B have focused their main interest on the design and construction of the CALIFA (CALorimeter for In Flight detection of γ-rays and high energy charged pArticles) detector.

CERN infrastructures are of extraordinary importance in shaping nuclear research. The ISOL facilities with low energy and reaccelerated exotic beams offer opportunities for scientific discoveries to probe questions that concern the atomic nucleus and nuclei in the cosmos. In Europe, these include the ESFRI facility SPIRAL2 along with SPES, and the energy and intensity upgrade of HIE-ISOLDE at CERN. ISOLDE can take full advantage of the recent upgrades at CERN, driven by the LHC Injectors Upgrade and specifically of the new Linac4 with its higher proton currents and the PS Booster, with increased proton beam energy. These upgrades allow for higher radioactive beam intensities and simultaneous operation of two target stations to deliver beams to the many low energy and high-energy (up to 10 MeV/nucleon from HIE-ISOLDE) experiments. ISOLDE aims to attract new users by constructing a storage ring behind the HIE-ISOLDE post-accelerator, which will open up new possibilities in the fields of fundamental symmetry studies, atomic and nuclear physics. Spanish scientists have contributed to the success of the physics research at ISOLDE, using both slow and post-accelerated beams; they have played a key role in the upgrade of the facility.

At CERN there is a strong contribution from Spanish research groups to n_TOF, the neutron time of flight facility, which is designed to study neutron-nucleus interactions for neutron kinetic energies ranging from a few meV to several GeV. The study of neutron-induced reactions is of interest in a wide range of research fields, from stellar nucleosynthesis, symmetry breaking effects in compound nuclei to applications of nuclear technology, including the transmutation of nuclear waste. Several Spanish groups have proposed key measurements at n_TOF and continue to develop instrumentation and analysis methods to fully exploit the facility, including the EAR2 beam line.

Instrumentation

Advanced instrumentation is a key element leading to progress in nuclear physics. Nuclear and particle physics may have developed along different paths, but they often employ very similar technologies. While nuclear physics experiments have increased in scope and complexity over time, they are still smaller than large particle detectors such as those involved in LHC experiments. This makes it possible for the nuclear physics groups to work in small or medium size collaborations and to transfer easily technologies to applications and industry. Small-scale facilities play and important role in detector tests and calibrations. Two small accelerators, in Madrid (CMAM) and Seville (CNA), have dedicated beam lines for this purpose. Strong efforts have been devoted by Spanish research groups to the development of state-of-the-art equipment for the full exploitation of FAIR. Part of this equipment can already be employed at present facilities such as LNL (Italy), GANIL (France), Jyväskylä JYFL (Finland), ISOLDE and other. AGATA, the next generation γ-ray tracking array, with a strong Spanish contribution, will have unprecedented resolving power that will help reshape experimental studies.

Symmetries and Fundamental interactions

Fundamental interactions exhibit symmetries and symmetry breaking features extending from the small to the large scale. There is a growing interest in complementary approaches to probe fundamental interactions, and renewed awareness of the impact of key experiments reaching the high precision frontier. These experiments, in occasions, offer higher sensitivity to energy and mass scale exceeding those in reach by present and future collider experiments, providing access to effects beyond the standard model of particle physics. Nuclear Physics has played a major role in establishing the fundamental laws of physics, a notable example being parity violation in weak interactions. Nuclear Physics and the technologies it involves, play a crucial role in high precision experiments, including parity violation studies, searches for time reversal violating electric dipole moments (EDMs) of particles, and the investigation of the V_{ud} matrix element of the Cabibbo-Kobayashi-Maskawa quark-mixing matrix, obtained from superallowed nuclear beta decays by precise mass and half-life measurements. The search for neutrino-less double beta decay requires a proper quantification of nuclear transition operators that can be investigated in nuclear physics experiments.

Nuclear theory

The strong interaction described by quantum chromodynamics is responsible for binding neutrons and protons into nuclei and for the many aspects of nuclear structure and reaction physics. Combined with the electroweak interaction, it determines the properties of nuclei, but it is not yet clear how the nuclear chart arises from these underlying fundamental interactions. Several nuclear models have been developed to describe nuclear properties; their predictive power has steadily increased in the last decade. Spanish theory groups are involved in the three main approaches to address the properties of nuclei (bound states and continuum) as well as the properties of nuclear matter: *ab initio* methods, shell model approaches, and models based on density functional theory. Reaction theory groups are working on the understanding of reaction mechanisms, the simultaneous treatment of the reaction dynamics and underlying structure and effective interactions, and on features that appear at threshold regimes, such as the coupling to breakup channels in reactions involving weakly bound nuclei.

Neutrino physics

The precise measurement of neutrino properties is one of the highest priorities in fundamental particle physics, involving many global experiments. The oscillation experiments still are qualified to address the mass hierarchy, CP violation in the lepton sector, sterile neutrinos, and other issues. The direct detection experiments depend on the interactions of neutrinos with bound nucleons inside atomic nuclei, the planned advances in the scope and precision of these experiments require a commensurate effort in the understanding and modelling of the hadronic and nuclear physics of these interactions, which is incorporated as a nuclear model in neutrino event generators. A proper understanding of the physics requires the collaboration of specialists in strong interactions and electroweak physics including theorists and experimentalists from both nuclear, particle and astroparticle physics communities. Spanish theory groups are very active in the design and implementation of event generators, new nuclear calculations and using the knowledge of electron–nucleus scattering as input to neutrino scattering. The existence of sterile neutrinos that could explain the deficit of reactor antineutrinos at very short distances can be also tested with the improvement of experimental decay data of fission products.

Nuclear astrophysics

Nuclear properties and nuclear reactions have a strong link to the evolution and properties of the Universe. From the lives and deaths of starts, to the galactic evolution, Nuclear Physics links processes that operate at femtometer scales to structures that spans thousands of light years. The understanding of the origin and evolution of the chemical elements requires experimental and theoretical efforts together with observations. Nuclear processes play an important role in the understanding of astrophysical scenarios. Complementary information from charged particles, signals in the electromagnetic spectrum, neutrino winds and gravitational waves help to understand events under extreme conditions, such as supernovae, or neutron star mergers. Fundamental nuclear properties and reactions using radioactive beams at large-scale facilities provide fundamental input to nuclear astrophysics. The design and construction of a possible nuclear astrophysics reaction facility is under consideration at the Canfranc Underground Laboratory.

Applications and societal benefits

Applications derived from basic nuclear physics research have a large impact in many aspects of everyday life, including areas as diverse as nuclear medicine, energy and security. Recent achievements in particle therapy and radiotherapy within the new paradigm of a theranostic approach are some recent examples of direct benefits from nuclear physics. These applications are only possible thanks to a solid basic knowledge on nuclear structure and decay, nuclear reactions and nuclear properties, and to the developments of associated technologies, such as accelerator science, advanced instrumentation and computing. The Spanish Nuclear Physics community continues to build on its strong record of accomplishments to answer fundamental societal needs, specifically on nuclear data for energy, environmental applications, medical imaging, dosimetry and radiotherapy.

8.- National Scientific Infrastructures

This section needs an introductory statement.
Contribution from CTA missing (my fault)

ALBA

The ALBA synchrotron light source is an instrument that provides solutions to societal challenges, from health to energy production and storage, from environmental challenges to advances in communication, from understanding to preserving our cultural heritage. It is a Spanish public entity in which the national and regional governments play an equal role. It has been in operation since 2012.

The core of the infrastructure is the accelerator system, which includes a Linac that produces a 100 MeV electron beam, a booster that accelerates the beam to 3 GeV and the low-emittance storage ring, working in top-up mode, where synchrotron radiation is produced with photon energies ranging from infrared to the hard X-ray regime up to 60 keV, using dipoles and different kinds of insertion devices as photon sources.

The beamlines (BLs), located around the synchrotron, are the experimental stations where the synchrotron light is exploited. Currently, eight BLs are in operation and four more in construction, each specializing in a different technique covering the needs of diverse scientific communities. These specialisms include the X-ray magnetic circular dichroism capacity of the BOREAS BL, a key tool for magnetic studies on thin layers and nanostructures, and the high-resolution 3D imaging of biological cells available at the cryo-soft x-ray microscope of the MISTRAL BL, whose penetration power makes imaging possible at the level of 30 nm full cells, without altering their morphology by slicing.

ALBA serves more than 4000 users from the academic and industrial world. It has contributed to the increase in the Spanish user community by one order of magnitude since it came into operation, and attracts competitive international users, hailing from as many as 40 different countries. As an example, in 2017, more than 1700 researchers visited the facility, two thirds national and one third international.

ALBA fosters technology transfer to high technology companies and the development of a previously non-existent Spanish industrial user community. All key performance indicators are competitive with those of sister facilities, for example the number and impact factor of peer-reviewed publications based on beamtime, operation availability and stability, data management, user support and industrial usage.

ALBA has created a network of international links and fruitful collaborations with national research facilities, also through the use of ancillary laboratories. A good example is the measurement of dipoles for the storage ring of the SESAME project, carried out through a collaboration with CERN as part of the H2020 CeSsaMag project. The ALBA accelerator team, whose priority is the operation and development of the synchrotron, is also involved in several projects that go beyond the synchrotron radiation community, an example being its participation on the two main future colliders being designed by CERN: FCC and CLIC with participation in the preparation of the corresponding Conceptual Design Reports.

For CLIC ALBA has been and is developing technologies and tools for the CLIC damping ring, including novel diagnostics, the RF system, tools for simulations of beam instabilities; and testing of the fast kickers.

For the FCC design, ALBA is leading a Work Package on the H2020 EuroCirCol project, aimed to develop the design and the critical technologies for this future collider. In concrete ALBA is leading the group designing the FCC vacuum system, but also doing studies for the incorporation of High Temperature Superconductors in the vacuum screen as well as developing new image techniques for determining the beam dimensions using the Speckles interferometry technique.
Other participations in H2020 projects, involving international collaboration for new developments in accelerators, are the ARIES project, which is an Integrating Activity project which aims to develop European particle accelerator infrastructures; and the XLS-CompactLight Project, the key objective being to demonstrate, through a conceptual design, the feasibility of an innovative, compact and cost effective FEL facility.

So, in summary, the ALBA team is the first group within Spain which has dealt with the design, construction and operation of a complex accelerator infrastructure and has built up experience in all its technologies: magnets, radiofrequency, diagnostics, vacuum, control systems, fast electronics, precise mechanical engineering design and integrated infrastructures for complex accelerators and experiment systems. It is now an active member of international collaborations for state of the art accelerator physics and technology, offering key contributions to new synchrotron light facilities and Particle Physics accelerator projects. In addition, the infrastructures and laboratories developed during the ALBA construction, like magnetic measurements, RF power, vacuum and metrology laboratories, are now available for future developments, and for collaborations with other institutions.

ALBA is a member of the recently created League of European Accelerator-based Photon Sources (LEAPS), within which it contributes to the general European scientific and technological strategy. The aim of LEAPS is to enhance European science, innovation and integration through closer cooperation and coherence in developing and implementing new technologies, better engagement with industry, broadening its user community and improving outreach and training programs.

CNA (Centro Nacional de Aceleradores)

The Centro Nacional de Aceleradores (CNA), located at Seville, is one of the Spanish ICTS (Singular Research and Technological Facilities), which are user-oriented facilities, characterized by an open access, which are unique in their respective domains. CNA has a staff of 62 persons, a basic budget of 1.25 M€ per year, and about 100 proposed experiments carried out per year, selected by an external scientific committee. About 10% of these experiments are proposed by foreign researchers and companies.

CNA has six major facilities: A 3MV Tandem Accelerator, an 18 MeV Cyclotron, a 1MV Tandetron, a compact accelerator for 14C, a 60Co Irradiator, and a PET-CT scanner. The scientific objectives of the centre are defined in its strategic plans, and include Ion beam Analysis Techniques, Nuclear Physics and Technology, Accelerator mass spectrometry, Irradiation, Radiopharmacy and Nuclear Imaging, Proton therapy and Fusion-related research.

CNA has an international orientation, and it participates in several European projects: The Nuclear Physics European project ENSAR2, the radioecology project COMET, the medical accelerator ITN network OMA, the EUROFUSION program, H2020 contracts and ITER contracts. Recently, a CNA researcher (E. Viezzer) obtained an ERC project.

CNA is a suitable environment for the test of detectors and electronics, under a radiation environment. Irradiation experiments using photons, from the 60Co sources, as well as protons, up to 18 MeV from the tandem and the Cyclotron, and neutrons form the recently installed neutron beam line, have been used to see the response of detectors and electronic equipment under controlled conditions.

Of particular interest for the European strategy of particle physics, is the collaboration of CNA, along with IFCA, IMB-CNM and IFIC, in the CERN RD-50 collaboration. This collaborations aims to study in detail the effect of irradiation on Si detectors, with the objective of having ready the most adequate detector equipment for the High Luminosity LHC, in which the detectors of will be subject to high irradiation dose. CNA contributes with its capabilities associated to the IBIC (Ion Beam Induced Current) technique, which has been applied to investigate, with a resolution of a few microns, the change produced by irradiation on detectors. Thus, CNA, along with IFCA, IMB-CNM and IFIC, can contribute as a cluster of Spanish centres to develop and test detector and electronic equipment to be used in the harsh radiation environment of future particle physics facilities.

CNA strategy for the future relies in increasing its internationalization. CNA sees itself as a middle size, cross disciplinary accelerator facility that is complementary to large, international accelerator facilities with a focus on basic research, both in nuclear and in particle physics. CNA aims to increase its international visibility, the exchange of personnel with larger facilities, and the number of international research proposal carried out in its facilities. This complementarity of CNA to larger facilities is not limited to the development of instrumentation. CNA can provide hands-on training on accelerator and detector techniques, which would be useful to young researchers aiming to participate in experiments at larger facilities. Also, through the strong collaborations that CNA has with Spanish high technology companies (Alter Technology, AVS), it can facilitate the access of these companies to the larger facilities.

LSC (Laboratorio Subterráneo de Canfranc)

The Laboratorio Subterráneo de Canfranc (LSC), located in the Pyrinees, belongs to the Spanish ICTS and has strong connections with the Laboratori Nazionali del Gran Sasso (LNGS) in Italy. The possibility to establish an Underground Global Research Infrastructures organization between the underground laboratories [LSC(Spain), LNGS (Italy), SNOlab (Canada), Boulby (UK), LSM (France), Kamioka (Japan), and CallioLab (Finland)] is under consideration. Current and near-future generation experiments require share of work load and facilities between underground laboratories.
The instrumented 1600 m^2 below 800 m of limestone rocks mainly host double beta decay and dark matter experiments and a number of facilities to support the research activities carried out by experimental collaborations. Radon-free air delivered by a radon abatement system (220 m^3/h) is monitored with a radon detector system with mBq/m^3 sensitivity. The Ultra Low Background Service includes seven very low background HPGe detectors for gamma spectroscopy and the BiPo detector for radio-purity assay on planar geometry samples which uses the Bi-Po b-a sequence in the ^{238}U and ^{232}Th radioactive chains to measure the contamination at ultra-low level, complemented with an ICP_MS instrument with ppt sensitivities for specific isotopes. Very low radioactivity shielding materials provided by the lab are improved with the Copper Electroforming Service, a unique facility among operating underground laboratories, that produces radio-pure copper parts using the electroforming technique.
The LSC has an active program on double beta decay and dark matter searches. At the LSC, double beta decay experiments make use of two different techniques: searches with pressured Xenon gas and R&D with oxide bolometers. NEXT is the flagship experiment in the LSC, which aims to lead the search for neutrino-less double beta decay worldwide by

demonstrating the best scaling needed to reach a half-life sensitivity better than 10^{27} years. The CROSS demonstrator consists on a composite bolometer with pulse-shape sensitivity to the surface interaction by using a superconducting thin film temperature sensor. It is recognized as part of the CUPID R&D activities towards a ton-scale DBD detector based on bolometers. The LSC program on direct dark matter detection includes ANAIS, the first experiment that can directly verify the DAMA/LIBRA annual modulation, ArDM/DarkSide-20k, contributing to the international effort on next generation massive liquid argon detectors, and TREX, a high pressure gas TPC demonstrator filled with argon or neon to search for low mass WIMPs. The LSC is support new opportunities, such as DAMIC, dark matter in the silicon bulk of charged-coupled devices and the Global Argon Program.

MICRONANOFABS (Spanish Network of Micro and Nano Fabrication Clean Room Facilities) is a networked Singular Facility (ICTS) composed of three nodes:

- Clean Room of the National Microelectronics Center in Barcelona (IMB-CNM)
- Institute of Optoelectronic Systems and Microtechnologies in Madrid (ISOM-UPM)
- Nanophotonics Technology Center in Valencia (NTC-UPVLC)

The mission of MICRONANOFABS network is to support the Spanish and European Research groups and industries in their research in the fields of Micro and Nano Fabrication and Photonics, three areas of activity which have been considered Key Enabling Technologies (KET's) by the European Commission. KET's are expected to help on finding new solutions for the different societal challenges identified within the Framework Programme Horizon-2020 and may find a place in the development of innovative products for our everyday life.

Among the three nodes, the one that has active participation in particle physics is the first one, the Clean Room of the IMB-CNM. It is dedicated to the development and application of innovative technologies in the field of Microelectronics together with other emerging Micro/Nanotechnologies. It is embedded administratively in the Instituto de Microelectrónica de Barcelona - Centro Nacional de Microelectrónica (IMB-CNM), a research centre belonging to the Spanish Council of Scientific Research (CSIC). Not only the Clean-Room facilities are part of the institute building complex, but also the scientific support for the Clean-Room activities lays mainly on the human resources of the IMB-CNM research groups.

Thus, the SBCSIC-CNM aims at helping national and international research groups to carry out R&D activities thanks to the availability of a set of complete micro and nanotechnologies and processes housed in a highly specialized Clean-Room environment devoted to R&D&i of excellence, conducted by an expert team. Thanks to the operational procedures in place and to the reliability and repetitiveness of the processes offered, the Clean Room also supports industrial partners. Such support ranges from technology awareness to the development of basic demonstrators, or small series of prototypes. Such activities have been open to external access by being a Spanish ICTS, and also a labelled reference European Infrastructure, in past and present EC Framework INFRA Programmes.

Because of the transversal nature of the technologies developed, the range of applications that can be covered in the facility is very broad, i.e., biomedical applications, environment, food, energy and mobility, safety and security, communications, consumer electronics, space, big science, etc. For all these applications the most outstanding results of last years have been in the following families of devices:

- Semiconductor devices including power devices and radiation detectors;
- Integrated circuits
- Sensors, actuators and MEMS;
- Nanoscale devices and actuators;
- Lab-on a chip systems; and devices polymer.

The main capabilities are:

- Processing Techniques
    - Metalization (Evaporation - Sputtering)
    - Thermal Processes and CVD
    - Ionic Implantation
    - Photolitography
    - Nanolitography
    - Dry and Wet etching
    - Microsystems MEMS Post Processing
- Packaging and Integration
    - Wafer Dicing
    - Packaging: Wire Bonding, Flip-Chip...
    - Reverse Engineering and Reliability
    - Electronic Circuits and Systems IntegrationOctober 18
- Device, circuit and system characterization
    - Electrical Characterization
    - Physics Characterization

CMAM (Centro de Micro-Analisis de Materiales)

The Centre for Microanalysis of Materials, CMAM, is a research infrastructure of Universidad Autónoma de Madrid, located at the Campus of Cantoblanco, in Madrid, Spain. A dedicated building is housing a tandem electrostatic accelerator, its extension beam lines and experimental stations, and additional complementary setups for sample preparation and characterization techniques.

At CMAM, both associated and external researchers, make forefront research in the areas of Materials Science, Condensed Matter Physics, Archaeometry, Nuclear Physics, Life Sciences and Radiometry. CMAM also participates, as a university centre, in supporting and carrying out teaching and training activities.

The main equipment at CMAM is a 5MV electrostatic ion accelerator equipped with a coaxial Cockcroft-Walton charging system and built in 2002 by the European firm High Voltage Engineering Europa, HVEE. It is still nowadays among the most competitive in terms of the variety of accelerated ions, stability and definition of ion energy, maximum achievable energy, fast operation and simplicity of maintenance.

Seven experimental stations and their corresponding beamlines are operative at CMAM. They cover the already mentioned applications of nuclear physics. Reaction of nuclei of astrophysical interest has been done. The studies on 12C complemented measurements in other facilities giving rise to a Nature publicación in 2005.

The access to CMAM infrastructures and instruments is open and competitive via a comprehensive and transparent beamtime allocation system based on proposals submitted electronically that are evaluated by an external scientific committee. The number of beam time delivered to users is of 1500 h with a success rate of 92 %.

Acronyms

Need to define the group acronyms used in the text below (at the end of the doc)