Spanish input on future colliders

[INPUT from CPAN: assume CPAN and networks are introduced] The Spanish high-energy-physics (HEP) community is united in the national network for Particle, Astroparticle and Nuclear Physics CPAN and thematic networks for the LHC, theory, future colliders and instrumentation. The Spanish HEP community is deeply involved in the LHC program at CERN and is firmly committed to the realization of a future large-scale facility in high-energy physics.

[INPUT from the LHC network: assume it will contain the following bottom line] The LHC is the current European flagship project in particle physics, ensuring global leadership for CERN and the European high-energy-physics community. The high-luminosity program should be pursued with the highest priority, and the scientific program should be pursued to adequate completion.

[INPUT from the instrumentation network should be included here] One of the strengths of the Spanish HEP community lies in the excellent ties with technological centers in the development of accelerator and detector technology. In detector R & D the national micro-electronics center CNM in Barcelona has considerable in-house production and post-processing capabilities for Silicon sensors, while the technological institute of Aragon has facilities to characterize the electromagnetic compliance of detector components. Important facilities for accelerator R&D exist at CIEMAT in Madrid, at IFIC in Valencia, at the ALBA synchrotron near Barcelona, at ESS in Bilbao. Spanish institutes for material science, ICMAB in Barcelona and CMAM in Madrid, are active in the deployment of novel super-conductors in accelerator applications.

The Spanish HEP community maintains excellent contacts with the Spanish science industry through INEUSTAR, the association of companies active in the science industry, and through the programs of the CDTI agency of the Ministry of Science, Innovation and Universities, that promotes innovation and technological development of Spanish companies. This tightly connected ecosystem is an important asset to address the challenges of future facilities in high energy physics.

The Spanish HEP community and the national network for future colliders have had a long-term commitment to the R&D and physics studies for the Higgs factory. **The first priority of the Spanish HEP community for a large facility beyond the LHC and HL-LHC is the realization of an electron-positron collider** with sufficient center-of-mass energy and luminosity to produce a large sample of Higgs bosons and top quarks in a clean and calculable environment. This facility can be operated in stages as a “Higgs factory”, a “top factory” and an “electro-weak factory”, that characterize the Higgs boson, the top quark and the electro-weak sector of the Standard Model to a precision that significantly exceeds the LHC and HL-LHC legacy results. While the facility has a broad program beyond Higgs phyics, it will be referred to as a “Higgs factory” for conciseness in the following.

The preference of the Spanish community is in line with the previous European strategy and with road maps defined in Asia and the Americas. To guarantee European leadership in the field of high-energy physics the “Higgs factory” should preferentially be built at CERN or realized elsewhere with a strong CERN involvement.

A Higgs factory can be realized as a large circular collider or as a linear collider, and both designs have complementary strengths:
- A circular collider is under study since the last European strategy update – FCCee, a circular collider with a circumference of O(100 km) - offers a competitive Higgs physics and superb luminosity at the Z-pole, and can be upgraded to reach the top quark pair production threshold. Spanish groups are involved in several aspects of this project.

- A linear collider based on super-conducting or warm RF technology - has the advantage of a considerably smaller footprint and environmental impact, offers longitudinally polarized beams, and is upgradable to a center-of-mass energy above 1 TeV, where it can access vector-boson-fusion Higgs, di-Higgs-boson and ttH production. Spanish institutes have had impact and continue to play important roles in the activities and organization of the development of the Linear Collider, such as the International Development Team and the International Technology Network of the ILC and have made important contributions to the CLIC project.

The Spanish community has not reached a clear consensus in favour of either option, but will support a new “Higgs factory” facility, whether it is a circular or linear collider. **Should a “Higgs factory” project for an electron-positron collider be approved, the Spanish HEP community will lend its full support to the project,** actively contributing to accelerator and detector R&D, the experiment design and Standard Model calculations, and to studies of the scientific program.

Particle physics is a global endeavor and the optimal program for European High Energy Physics depends on the international situation. In the following, we consider concrete scenarios for European and international developments in the years before a decision on the next European facility is made, and indicate the preference of the Spanish HEP community in each case:
- If the FCC feasibility study is successful and funding for the project is identified, the Spanish community will join the project.
- If a Japanese bid is made to realize the International Linear Collider on a competitive time scale, Spanish institutes have expressed an interest to join the project.
- If the FCC program proves not to be viable, or a circular Higgs factory is realized earlier in China, a linear electron-positron collider facility at CERN with two experiments is the preferred alternative for the Spanish community.

If a decision on the Higgs factory is taken, Spanish groups are eager to join the experiments. Spanish institutes have played - and continue to play - an important role in the design of the International Large Detector (ILD) concept that can exploit the scientific opportunities of the Higgs factory. The ILD detector is based on an advanced low-material vertexing and tracking system and a highly granular calorimeter system. It provides precise reconstruction of collision events, which is crucial for the precision measurement program of the Higgs factory. The design can provide competitive performance at all center-of-mass energies considered in the Higgs factory program. The Spanish HEP community is committed the R&D program to develop the key technologies and to the completion of a fully engineered design adapted to the accelerator technology of choice.

The long-term goal of high energy physics, as identified by the previous European strategy update, is sustainable exploration of the energy frontier. Spanish groups are involved in the FCChh project for a proton-proton collider with a center-of-mass energy of O(100 TeV) and in the international muon collider collaboration. Sustainable exploration of the energy frontier must be enabled by a vigorous program in accelerator R&D. Spanish institutes led by CIEMAT have contributed to the development and construction of high-field magnets for the LHC. In recent years, the PRISMAC project at CIEMAT has offered substantial funding for the development of magnets for the HL-LHC and future energy frontier colliders. CIEMAT and ALBA have been active in the EuroCirCol project. CIEMAT and the material science institute in Barcelona have R&D lines exploring high-temperature super-conductors for magnets and . IFIC in Valencia collaborates with CERN on high-gradient RF cavities. The pulsed laser centre in Salamanca investigates laser-driven plasma wakefield acceleration.

An energy-frontier collider experiments represent a significant challenge for the detector technology. Spanish groups have been very active in the development of silicon sensors with the required radiation hardness, in the framework of RD50 colllaboration. Many groups have joined the relevant Detector R&D collaborations to continue this effort.

In summary, Spanish institutes in fundamental physics, Spanish technological centres and the Spanish science industry are committed to making an important contribution to the next European facility in high energy physics. The facility of choice of the Spanish HEP community is a Higgs and top factory with a competitive precision physics programme, irrespective of whether it is implemented as a circular or linear collider. Spanish groups have a long track record in the definition of such a facility and considerable expertise exists regarding all aspects of this project, from accelerator technology to experiment design and from advanced analyses techniques to high-precision Standard Model predictions.