Draft 0 for the GDR-INF Input for the European Strategy for Particle Physics

Physics at the intensity frontier is crucial in allowing us to detect and interpret signs of new physics. If new particles are found by direct searches, then indirect tests are needed to study the new physics structure and couplings. If on the other hand no direct evidence for new physics is found in collisions, as is the case at present, higher scales and/or smaller couplings can be probed by experiments at the intensity frontier.

The French community working on the intensity frontier underline the importance of an experimental strategy based on the complementarity of two pillars: large facilities with a wide physics program (HL-LHC, beam dump experiments at SPS, FCC) and small scale experiments dedicated to specific relevant measurements (EDM, g-2, lepton flavor violating experiments).

We believe that it is crucial to support the pursuit of a long-term flavor physics program. In recent years, LHCb is the major player in this context, exploiting the unprecedented number of b-hadrons collected, and recently it has been joined by the Belle2 experiment, which has recently starting operating. These experiments improve our understanding of the flavour picture and probing new physics in a complementary way. In fact over the last few years certain LHCb measurements have indicated intriguing anomalies and it is essential to clarify the nature of these anomalies with independent Belle2 measurements, profiting from the clean e^+e^- environment of the machine, and with future LHCb upgrades. The French community has played a major role in LHCb since the beginning of the experiment. Five IN2P3 laboratories are currently involved in the collaboration (CPPM, LAL, LAPP, LPC Clermont and LPNHE), while two IN2P3 laboratories (IPHC and LAL) are involved in Belle2. At the horizon of 2026, Belle2 will have ended its operations, while LHCb operations are approved until 2029. In February 2017, in order to support a longer term flavor physics program at the HL-LHC, we have submitted to the LHCC an expression of interest for an LHCb “Upgrade II” experiment (http://cds.cern.ch/record/2244311/files/PII_EoI_final_v3.pdf), to take place during the fourth long shutdown of the LHC in 2030. The LHCb “Upgrade II” will allow to fully exploiting the High-Luminosity LHC for flavor physics studies. The large luminosity provided by the machine will greatly improve the precision on many observables sensitive to new physics, and additionally widen the set of measurements beyond those currently accessible.

In many models of New Physics, as well as in the Standard Model (SM) itself, long-lived particles (LLPs) arise naturally, with possible masses and lifetimes that span many orders of magnitude. It is extremely difficult to build a single experiment with good sensitivity to all LLPs. A mixture of collider and beam-dump based experiments is therefore necessary to probe the largest possible area of parameter space. Additionally, different experiments have complementary backgrounds, providing a powerful cross-check in the event of a discovery. We believe that a strong institutional support for all such experiments proposed in Europe will be welcome whether they would take place at the LHC with present detectors and new experiments (ex: Codex-b at LHCb) or at the SPS (e.g. SHIP). At the moment, scientists from the IN2P3 follow SHiP and Codex-b experiments.

The proposed CODEX-b experiment would greatly extend the reach of the LHCb experiment for LLPs. It will take advantage of the old DELPHI cavern, situated behind a concrete wall next to the LHCb experimental area. This site of around 1000 cubic meters would only require a small amount of additional shielding in order to suppress SM backgrounds, and could be instrumented cheaply, for example with RPCs. If data taking will occur throughout the LHCb’s Upgrade II, CODEX-b would cover a significant part of the parameter space reached by other much bigger and more expensive dedicated LLPs experiments which have been proposed (see http://inspirehep.net/record/1620901). More advanced technologies, for example tracker layers with timing measurements, would allow CODEX-b to also measure the LLP mass for certain classes of LLP models. CODEX-b could also be trivially integrated into LHCb readout, thus providing an interesting capability to “tag” any signal candidates and examine the rest of the interaction within LHCb.

SHIP is an experiment to be carried out at the new Beam Dump Facility (BDF) in the CERN North Area. The 400 GeV proton beam from SPS will be dumped on a heavy target with the aim of integrating $2\ 10^{20}$ p.o.t. in 5 years. A dedicated detector, based on a long vacuum tank followed by a spectrometer and particle identification detectors, will allow probing a variety of models featuring LLPs with masses below O(10) GeV/c^2. The main focus will be on the Hidden Portals: dark photons, light scalars and pseudo-scalars, and heavy neutrinos. The sensitivity to heavy neutrinos will allow for the first time to probe, in the mass range between the kaon and the charm mesons, a coupling range that could explain also baryogenesis and active neutrino masses. SHiP is designed to be a discovery experiment, with less than 0.1 expected background events from Standard Model particle interactions. A dedicated section of the SHiP detector will allow the study of Hidden Sector particles interacting with atomic electrons and nuclei in an unexplored parameter range. With this detector, neutrino cross-sections and angular distributions can also be studied. Tau neutrino and antineutrino deep inelastic scattering cross sections will be measured with a statistics 1000 times larger than currently available, with the prospect to extract the F4 and F5 structure functions, never measured so far, and to perform new tests of lepton universality.

A possible long-term strategy for high-energy physics at colliders, after the exploitation of the HL-LHC, considers a new accelerator of 100 km circumference, taking advantage of the present CERN accelerator complex: the Future Circular Colliders (FCC). A possible first step of this project would be to fit in the tunnel a high-luminosity e^+e^- collider (FCC-ee) aimed at studying comprehensively the electroweak scale, while building a 100 TeV proton-proton collider (FCC-pp) is considered the ultimate goal and defines the infrastructure. The mainstream physics case of the FCC-ee is driven by the four electroweak thresholds which are crossed (Z, W, H, top high-luminosity factories): all relevant electroweak parameters can be measured with unprecedented precision, pinpointing if needed the complete two-loops calculations in the SM. We see the Flavour Physics program as an invaluable complement to this physics case, in particular if the current Flavour anomalies are persistent. The unprecedented statistics at the Z pole potentially delivered by the FCC-ee (O(5 10^{12}) Z decays are expected) can be studied to explore further the flavour Physics at large, both in the quark and lepton sectors. In addition, FCC-ee benefits of the large boost of the b-hadrons produced in Z decays, the cleanliness of the e^+e^- experimental environment, the production of all heavy-flavoured hadrons, and, not the least, the highly-resolved vertexing of heavy-flavoured weakly-decaying particles.

Lepton flavor violation (LFV) in neutral leptons is a phenomenon well established through the measurement of neutrino oscillations. Dedicated experiments search for LFV in the charged sector, a process extremely suppressed in the SM but potentially enhanced in some New Physics scenarios. For example, COMET (COherent Muon to Electron Transition) at J-PARC will improve the current limits on $\mu \to e\gamma$ by two to four orders of magnitude in five years from now, with a strong impact on the models predicting lepton flavor violation. Three IN2P3 laboratories are currently involved (LPC-Caen, LPC Clermont, LPNHE).

The search for permanent electric dipole moments (EDM) probes potential New Physics at energy scales between 1 TeV and 10^3 TeV. With the present experimental sensitivities, a non-zero measurement would either reveal a tiny value of the θ_{QCD} term or new sources of CP violation. Measurements of EDM from various systems (neutron, electron and so on) are required to disentangle the origin of the CP violation process. Along with the Hg EDM, the neutron EDM offers the most sensitive probe to the θ_{QCD} term. EDM experiments are also a tool to investigate the electroweak baryogenesis scenario. The neutron EDM experiment at the Paul Scherrer Institute is participating in this EDM quest. It is the leading neutron EDM experiment worldwide, with a new limit about to be published, at the level of 10^{-26} ecm. A new experiment, n2EDM, is currently under construction and it will start operating in 2021. It aims to improve the sensitivity level by one order of magnitude in the next decade and explore the 10^{-28} ecm region in a second phase at the 2030 horizon. Three French laboratories are involved in the project (CSNSM, LPC Caen, LPSC).

Last but not least, theoretical predictions and interpretations, crucial for advances in the field, may involve a large variety of tools, from formal approaches to phenomenological and numerical techniques. While most theoretical activities essentially require only manpower, numerical simulations are also demanding in terms of computing power and algorithmic techniques. Note that the interpretation of results, whether this be model independent in terms of effective field theories or model dependent, serves as inspiration for model building and further leads to new ideas for experiments. Theoretical progress is clearly dependent on experiments for guidance, but inversely theoretical ideas can frame future experiments. Therefore any strategy on the future of experimental particle physics must be accompanied by a vision concerning the support to provide to particle theory.