# GDR-InF input for the European Strategy for Particle Physics

**The GDR Intensity Frontier**
**31-08-2018**

Research at the intensity frontier allows the detection and interpretation of signs of new physics using large datasets of some of the rarest processes in nature. 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, which has been the case so far at the LHC, higher scales and/or smaller couplings can be probed by experiments at the intensity frontier. Lately the case for the intensity frontier has further been strengthened by several anomalies observed in measurements of rare B decays, the anomalous magnetic moment of the muon and the proton radius.

The GDR-InF, gathering the French community working on the intensity frontier, supports an experimental strategy based on two complementary pillars: large facilities with a wide physics program (LHC, SuperKEKB, HL-LHC, beam dump experiments at SPS, ILC and FCC) and experiments dedicated to specific measurements of crucial observables (EDM, g-2, LFV experiments). This document provides an overview of the experiments in which the GDR-InF physicists are involved, and that we wish to see endorsed by the European Strategy for Particle Physics (ESPP). Members of the GDR-InF currently produce high level physics results with running experiments and perform detector developments to prepare the future ones. Experiments with no involvement in the GDR-InF experimental community, but which are recognized as crucial for the field are also mentioned. Finally, the GDR-InF underlines the interplay between theory and experiments to be supported as part of the strategy.

## Experiments with a wide physics program.

The major players in flavor physics in the upcoming years will be ***LHCb (and its Upgrade I)*** and ***Belle II***: the former exploiting the unprecedented number of b-hadrons produced at the LHC, the latter profiting from the clean $e^+e^-$ environment of KEK. These will improve our understanding of the flavour picture, and probe new physics in a complementary way with high precision measurements of a plethora of observables, part of a well recognized physics program [1,2]. In particular they will allow the clarification of the nature of the intriguing anomalies in some rare B decays via independent measurements, a priority today in particle physics. Traditionally France has strongly contributed to flavor physics. Today five IN2P3 laboratories play a major role in LHCb (CPPM, LAL, LAPP, LPC Clermont and LPNHE, with the perspective of LLR joining). Two laboratories (LAL and IPHC) joining Belle II was an important step towards consolidating the French involvement in this field. Our community requests full support to exploit the data from LHCb, LHCb Upgrade I and Belle II in the next 5-10 years. In addition, Belle II will have to undergo several upgrades of detector systems before 2025, and we hope that IN2P3 will play a large role.

For the future, we believe that the priority is to guarantee the pursuit of a long-term flavor physics program at the HL-LHC, considering that, according to the current schedule, Belle II will end its operations in 2026, and LHCb Upgrade I operations are approved until 2029. For this reason we strongly support the proposal of the LHCb collaboration for an “Upgrade II” of the experiment [3] during the fourth long shutdown of the LHC in 2030. The ***LHCb Upgrade II*** will be the only general flavor experiment at that time horizon. It will operate at a factor 10 higher luminosity, fully exploiting the large luminosity of the accelerator, to reach unprecedented precision in key measurements, e.g. CP violation phases and b->sll and b->dll observables, probing a 90% higher new physics mass scale for fixed couplings.

One way to search for new physics at the intensity frontier relies on the quest for long-lived particles (LLPs), arising naturally in many models, with masses and lifetimes that span many orders of magnitude. Both collider and beam-dump based experiments are needed to probe the large area of parameter space. Additionally, different experiments have complementary backgrounds, providing a powerful cross-check in the event of a discovery. The strong institutional support for such experiments would be welcome whether these might be at the LHC with present detectors and new experiments (e.g. CODEX-b at LHCb) or at the SPS (e.g. SHiP). At the moment, scientists from the IN2P3 are following the proposed SHiP and CODEX-b experiments, requiring detector development in the next five years.

***CODEX-b*** will take advantage of the DELPHI cavern, located 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 backgrounds, and could be instrumented cheaply. If data taking occurs throughout the LHCb Upgrade II, CODEX-b would cover a significant region of the parameter space reached by other much bigger and more expensive dedicated LLPs experiments which have been proposed [4]. If integrated into the LHCb readout, the rest of the event could even be analysed by LHCb.

***SHiP***, in the CERN North Area, involves the dumping of a 400 GeV proton beam from SPS on a heavy target. With $2 \times 10^{20}$ p.o.t. integrated in 5 years, it will probe LLPs with masses below O(10) GeV/$c^2$, potentially unveiling Hidden Portals e.g. dark photons, light scalars and pseudo-scalars or heavy neutrinos [5]. The sensitivity to heavy neutrinos in the mass range between the kaon and the charm mesons will probe for the first time couplings that could also explain baryogenesis and active neutrino masses. Additionally, neutrino cross-sections and angular distributions measurements with large statistics can be performed.

Long-term strategies for the intensity frontier at large colliders should involve the International Linear Collider (***ILC***) and the Future Circular Collider (***FCC***). The improved measurement of the electroweak parameters could be first provided by the ILC in early 2030s. French physicists have been involved in the detector and accelerator R&D and in the analysis preparation (e.g. on the measurement of top and bottom electroweak couplings), and will certainly play a role in the experiment if approved. The final decision on ILC is expected by the end of 2018. The FCC project, to which some GDR-InF physicists are contributing, foresees a new accelerator of 100 km circumference at CERN at the horizon of 2035 [6]. The first phase could be a high-luminosity $e^+e^-$ collider (FCC-ee), while a 100 TeV proton-proton collider (FCC-pp) is the ultimate goal. The FCC-ee could continue the comprehensive study of the electroweak scale, driven by the high luminosity at the four electroweak thresholds crossed (Z, W, H, top). The flavour physics program in the quark and lepton sectors is an invaluable complement to the electroweak physics case, and will benefit from the unprecedented statistics at the Z pole, 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 the highly-resolved vertexing of heavy-flavoured weakly-decaying particles. For example, if the current flavour anomalies persist, FCC-ee will allow the analysis of the $B \to K^* \tau\tau$ decay, as well as the search for lepton flavor violating Z decays.

## Experiments dedicated to specific measurements of crucial observables.

GDR-InF physicists are involved in experiments dedicated to the ***search for permanent electric dipole moments*** (EDM), probing 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 $\theta_{QCD}$ term or new sources of CP violation. Measurements of EDMs from various systems (e.g. neutron, electron) are required to disentangle the origin of CP violation. Along with the Hg EDM, the neutron EDM offers the most sensitive probe to the $\theta_{QCD}$ term. EDM experiments are also a tool to investigate the electroweak baryogenesis scenario. The neutron EDM experiment at the Paul Scherrer Institute [8] is the leading neutron EDM experiment, with a new limit about to be published, at the level of $10^{-26}$ ecm. A new experiment, n2EDM, is under construction and it will start operating in 2021, improving the sensitivity by one order of magnitude in the next decade and exploring the $10^{-28}$ ecm region in its second phase in 2030. Three French laboratories are involved in the project (CSNSM, LPC Caen, LPSC).

The ***muon g-2/EDM experiment at J-PARC*** sees also contributions from GDR-InF physicists. Using a design different from the concurrent experiment at FNAL, it is expected to provide a new measurement for the muon anomalous magnetic moment,  a quantity with one of the largest, most puzzling and durable deviations from the standard model predictions at the moment. Some technological challenges are shared with ***COMET*** (COherent Muon to Electron Transition) at J-PARC, in which three IN2P3 laboratories are involved (LPC-Caen, LPC Clermont, LPNHE). COMET will improve the current limits on $\mu \to e$ conversion by two to four orders of magnitude in five years from now, with a strong impact on models predicting lepton flavor violation (LFV) [7]. LFV in charged leptons is extremely suppressed in the standard model.

Nevertheless, it could be largely enhanced in some new physics scenarios, additionally motivated by the recent lepton flavour non-universality anomalies in rare B decays. COMET will provide insights complementary to those from LHCb and Belle II, the latter being particularly adapted to measure LFV processes in tau decays.

## Experiments with no involvement of the GDR-InF experimental community.

We encourage the ESPP to endorse the following other intensity frontier experiments that we consider relevant for the field, despite the lack of involvement of the GDR-InF experimental community: g-2 at FNAL; NA62, KLEVER, KOTO and KLOE for the search of rare kaon decays; BES III for the study of charmed mesons; direct axion searches; LFV experiments Mu2e, MEG and Mu3e; GBAR and AEgIS for studying gravity in antimatter.

## Role of theory.

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 personpower, numerical simulations are also demanding in terms of computing power and algorithmic techniques. Several labs in France are dedicated to theoretical work relevant to the intensity frontier (CPT, CEA, IPNL, IPNO, LAPTh, LPC, LPSC, LPT, LPTHE). The interpretation of experimental 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 and furthermore to European initiatives promoting theory-experiment collaborations.

[1] https://cdsweb.cern.ch/record/1443882/files/LHCB-TDR-012.pdf
[2]https://confluence.desy.de/download/attachments/35002985/b2tip-main-ptep.pdf?version=28&modificationDate=1530097508643&api=v2
[3] http://cds.cern.ch/record/2244311/files/PII_EoI_final_v3.pdf
[4] http://inspirehep.net/record/1620901
[5] https://cds.cern.ch/record/2007686/files/SPSC-P-350-ADD-1.pdf
[6] https://inspirehep.net/record/1498493/files/PoS(BEAUTY2016)058.pdf
[7] http://comet.kek.jp/Documents_files/PAC-TDR-2016/ COMET-TDR-2016_v2.pdf
[8] https://www.psi.ch/nedm/nedm-project