Proposal for a
GDR of the Intensity Frontier

all names

August 27, 2016

1 Introduction

The remarkable success of the "standard model" (SM) of particle physics in describing the particles and their strong, electromagnetic and weak interactions has nevertheless certain limitations. For example, it does not explain dark matter, dark energy, the hierarchy of the fermion masses or the matter-antimatter asymmetry in the universe. There is a general consensus in the physics community that a theory more fundamental than the SM should exist, which is sometimes referred to as "new physics" (NP). The NP is expected to arise and be seen at higher energies, i.e., exploring shorter distances.

There are broadly two categories of searches for new physics: the energy frontier and the intensity frontier. In the former, experiments are designed to try to produce and consequently detect TeV-scale particles directly, i.e. via collisions at high energy. In order to discover new particles, one is required to run at higher energies; such experiments are therefore said to be probing the energy frontier. This is the main approach currently followed by the general purpose detectors, ATLAS and CMS, at the LHC. Instead, in particle physics at the intensity frontier, which will be the focus of this proposal, one probes new physics not by pushing the energy scale but rather the experiment's luminosity.

The intensity frontier could provide signs of new physics in two ways. The first one is measuring SM processes for which theoretical predictions with uncertainties well under control exist: observing a significant discrepancy between the experimental measurement and the prediction would be the sign of new physics. This technique is often applied to study processes which are mediated at leading order by loop diagrams. In such diagrams, yet undiscovered particles, with masses beyond the energy of the collisions, could intervene, modifying the rates and the properties of the decay respect to the SM predictions. These measurements need to be extremely precise, so they require a large quantity of data. The second way is searching for processes which are hugely suppressed or forbidden in the SM, and therefore a measurement automatically signifies NP. This could either probe (effective) couplings which do not exist in the SM, or particles at scales much below the energy frontier but which have not been seen so far due to the fact that they are very weakly interacting with SM particles. Some examples are lepton flavour violating decays, axion searches or neutrinoless double beta decay.

Apart from being a way to discover new physics, the intensity frontier approach also provides constraints and highlights on the nature of the NP and eventually on its flavour structure. In fact, regardless of the experimental strategy which will eventually lead to the discovery of NP, measurements at the intensity frontier are necessary complements to the discovery itself, as they allow to identify the theory beyond the new phenomena through its quantum fingerprints. Additionally, it is likely that this strategy will succeed only through a diversity of measurements.

From the experimental point of view, the challenge with the intensity frontier is to collect a large and pure enough data sample in order to obtain evidence of NP interactions. A detailed understanding of the detectors features and sophisticated analysis techniques are needed to provide a large efficiency for the signal reconstruction and a powerful rejection of the backgrounds. Historically the French community has been very active in this domain, participating to the conception and realization as well to the analysis of the collected data of very successful experiments like, for example NA48 and BaBar. The focus of the French community today is on the LHCb experiment, dedicated to flavor physics and currently challenging the standard model predictions with many precise measurements; its scope extends well beyond the realm of B physics. Worldwide, several other experiments currently search for NP using high-intensity facilities (notably NA62, MEG), some will start their data taking soon (for example Belle II) and other are in the preparatory phase (for example SHIP and COMET).

From the theory side, it is crucial to have the description of the processes in the SM under control. For example, hadronic effects need to be evaluated precisely using various advanced tools, like lattice calculations, effective field theory, sum rules. The French theorists working in this field are very active both in the interpretation of current data in terms of new physics models and in improving the precision on theoretical predictions for key observables.

Given the need to compare the theoretical predictions with the experimental measurements, the interplay between theory and experiment in this field is essential. Theory and experiment then need to come together to correctly interpret the experimental results in terms of theoretical predictions, and to combine all the bounds produced in the different searches, which hopefully will lead towards the discovery of the NP. As a natural need of sharing competences and knowledge, during past years some collaborations have already risen between members of the two communities. A well known example of a fruitful exchange is the CKMfitter collaboration, which originated as a result of a French initiative. More recently, in the context of the study of rare B meson decays, four CNRS PEPS-PTI (Projet Exploratoire Premier Soutien de Physique Theorique et ses Interfaces) of one year each were proposed and accepted: Flagship measurements at LHCb: pursuing precision as a means to discovery in 2012, NouvPhyLHCb in 2014 and PhenoBas in 2015 and 2016. These grants permitted the organization of fruitful workshops, allowing to establish first connections and collaborations between LHCb experimentalists and theorists working on $b \to sll$ transitions.

This interplay is fundamental for the success of the intensity frontier approach, and it needs to be further promoted. Following discussions among people active in the field, the need for a GDR in physics at the intensity frontier has been established. In fact, we believe that the framework of a GDR is necessary for those working on high energy physics who are focused on the intensity frontier, given the current context of particle physics. The successful program of LHCb is pointing to possible hints of NP that should be further investigated sharing the competences. In addition, these hints are mostly observed in the lepton flavour universality tests of B meson decays, so that an approach mixing the quark and lepton sectors is needed.

The role of the GDR will be to bring the French intensity frontier community together, reinforcing the interplay between the different research lines in the field. It will facilitate the collaboration between different laboratories and between theorists and experimentalists, with the purpose of keeping the community in touch and informed about the latest advancements in the field, exchanging ideas and spreading knowledge. In this way the GDR will stimulate the emergence of common projects within the French community and allow it to grow. It will be a way to provide greater visibility of this large community on a national and international level. In addition, we are in a era were new experiments are starting and other being proposed. We believe that there is a real need for experimentalists and theorists in France to come together in order to discuss how research plans for the future should be shaped, including the decision of which experiments to become involved in.

We envisage the GDR to be divided into several working groups, which would both function independently and together. We have identified the following topics where there is currently activity and interest in the French community:

- **CP violation.** Since the B-factories, CP violation in the quark sector has also been proven to be a precise test of the Standard Model, through the measurement of the parameters of the CKM matrix. This measurement has room for improvement, and LHCb and Belle2 will provide further insight on it, as well as additional tests involving the B_s meson and b baryons.

- **Rare, radiative and semi-leptonic decays.** Generally mediated by loops, these decays are a powerful probe of new physics, provided that precise theoretical predictions can be made for experimentally clean observables. The large dataset collected by the LHCb experiment is currently showing the most exciting signs of slight deviations from the theoretical predictions that certainly deserves to be further analysed and deeply understood.

- **Heavy flavour production and spectroscopy.** Not only is this field an ideal framework to test the QCD predictions, but it provides crucial inputs needed for other measurements and interpretations in the search for physics beyond the SM. It further has recently revealed that quarks can form more complex structures than previously believed, i.e. tetraquarks and pentaquarks; the existence of these bound states has now been established though they are not yet fully understood.

- **Charm and kaon physics.** The study of kaons and charmed mesons has been at the origin of the flavor physics. Given the present experimental opportunities, a renewed interest in the analysis of their decays is emerging, as they provide complementary ways to search for new physics effects. Although for the charm physics there is already a large production of data, for the kaons some experimental challenges need to be faced and additional theoretical observables are being proposed.

- **Lepton flavour and the interplay with quark flavour.** Flavor violation in the charged lepton sector is a clear sign of NP by itself, and many experiments are directly searching for it. In addition, given the fact that at the moment some of the most interesting deviations from the SM are observed in lepton flavour universality tests in B meson decays, an approach mixing the quark and lepton sectors and combining measurements and theoretical advancements in both the field is mandatory.

- **Future experiments.** It will be very beneficial for our community to discuss the future of our field, at a time where future upgrades of the LHCb experiment as well as new experiments are being proposed. This GDR could play a role in identifying the priorities for French involvement in order to continue to play an active role in the future.

In the subsequent sections of this document we will provide a brief description to highlight the interest of the working group topics, summarising their current status and the proposed near-future work of the French community.

The GDR would function through carefully planned workshops. More specifically, we plan to organize a general kick-off meeting, to bring the whole community together in order to define and consolidate collaborations and goals. This would be followed by a series of working group meetings, more intimate and focused on specific themes. These smaller meetings would allow detailed discussions and brainstorming within the specific topic of the working group, allowing close collaborations to emerge by really working together. Regularly, global workshops involving all the members of the GDR will be organized, where more general talks and discussions will be held and where we will ensure to share the advancements of the working groups and to address the connections between them. This is particularly important since there is a clear interplay between the different working groups. For example the charm and kaon physics will have to address specific experimental and theoretical issues of the field, but the results obtained will certainly have to be interpreted in the global CP violation picture and in relation with the other rare decays studies. There might be overlaps with other GDRs (Neutrino, Terascale) on some topics, and so we plan to organise common sessions with them to address these specific issues. One of the purposes of the GDR will be also to have a wider look into what is done in the same field in other countries or in experiments where the French community is not currently directly involved, but which still represent an interest for the field. Presenting ourselves as a unified community, we will aim in establishing productive interactions inviting occasionally speakers from other experiments, ensuring in this way that we keep the connection with the whole field.

The format of these meetings would be free, and decided according to the specific needs and objectives. Younger members of the community will be encouraged to participate in the organisation and the discussion. In fact, we further hope to use the GDR as an opportunity to put the younger members of the community in the spotlight. One way to do so will be by giving to the postdocs the responsibility of organising and chairing the meetings. In addition, we will work to promote the emergence of a young and dynamic generation of physicist working in the field and educated in France, for example throughgh the organization of a school on "Introduction and Modern developments in flavor physics" for young M2 and PhD students, and creating an environment where PhD students would feel confident to present their work and interact with physicists from other laboratories.

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2 CP Violation

Since its discovery in the kaon system, CP violation has been an intriguing field. A lot of efforts have been put in understanding it, as, a part from the interest of the phenomenon by itself and of its relations with the matter/antimatter asymmetry, it is a very powerful probe for NP. In fact, CP violation is particularly interesting because, in the SM, it originates from a single parameter. All the CP violating observables in the K, D and B meson sectors are thus directly related, and their combined study provides a highly powerful test of the whole SM dynamics. Instead, most model of New Physics are far less restrictive and allow for a plethora of new CP-violating sources. Most of the delicate interplays between observables expected in the SM will no longer hold in the presence of new dynamics at the TeV scale. In this respect, one activity of the French community, the CKM fitter collaboration, is precisely to test the coherence of CP violation measurements. It is embodied in the well known Unitary Triangle (UT), a consequence of the unitarity of the CKM matrix in the SM. In the absence of New Physics, its sides and angles as determined from various observables all have to agree for the triangle to close.

When experimentally testing SM predictions, it is fundamental that the theoretical precision matches the experimental accuracy. A priori, this looks challenging because CP-violation is a purely hadronic phenomenon in the SM, originating from the quark couplings. However, dedicated strategies have been designed and CP-violating observables are actually among our best windows to look through when searching for NP. For example, in CP-violating asymmetries, most of the uncertainties cancel between the numerator and the denominator, so that we can construct measurable quantities with small uncertainties. Alternatively, some observables are predicted to be so small that they can be considered forbidden in the SM, and simply observing a non-zero value would unequivocally signal the presence of New Physics.

The French community has been deeply involved in CP-violation dedicated experiments for many years (CPLEAR, NA48, BaBar, LHCb). It has been building and maintaining key elements, like trigger systems, calorimeters and particle identification detectors. In addition, it has acquired expertise in several powerful techniques needed to study CP-violation: amplitude analyses, tagged-time-dependent angular analyses, flavour tagging, neutral objects reconstruction. Let us describe briefly the current status and some activities planned in the near future for CP-violation measurement in the B sector and in other observables. The specific case of CP-violation in the D and K sectors will be discussed in section 4.

CP-violation in the B sector

The French community has been involved more specifically in the measurements of the unitarity angles α, γ and ϕ_s. Among other decay channels, the following have been studied in detail: $B_{(s,d)} \to D^0 K^{*0}$, $B_{(s,d)} \to \bar{D}^0 hh$, $B_s^0 \to D_s K$, $B_s^0 \to J/\psi\phi$, $B_s^0 \to J/\psi \bar{K}^{*0}$. At the moment the focus is on the analysis of the data coming from the Run2 of LHC, particularly on the measurement of the ϕ_s angle and on the study of the charmless b-hadron decays.

The measurement of ϕ_s is one of the most important goals of LHCb experiment. The value of ϕ_s is precisely predicted in the Standard Model and sets the scale for the difference between properties of matter and antimatter for Bs mesons. The predicted value is small and therefore the effects of New Physics could change its value significantly. The ϕ_s measurement with Run1 data from LHCb has been obtained analyzing $B_s^0 \to J/\psi KK$ and $B_s^0 \to J/\psi\pi\pi$ decays. It is the most precise to date, and is shown on Figure 4 combined with the measurements of other experiments. With the increasing precision that will be obtainined using the Run2 data of LHCb, and even more the data coming from the upgrade that will lead to an error of the order of 0.01rad, it will become fundamental to control the sub-leading contributions coming from penguin diagrams. These diagrams are doubly Cabibbo suppressed respect to the tree diagrams, nevertheless their contribution has not yet been precisely estimated in QCD. The effort to control this contribution will require a strong collaboration with the theorists and eventually exploring new approaches.

Another field in which the experimental French groups have been very active in the B-factories era, and still are nowadays in LHCb, is the CP-violation related studies of charmless b-hadron decays. These decays have a number of theoretical applications and provide a probe to new physics. For instance, the decays $B^0 \to K^0_S\pi^+\pi^-$ and $B^0 \to K^0_S K^+K^-$ are dominated by $b \to q\bar{q}s$ ($q = u, d, s$) loop transitions. Mixing-induced *CP* asymmetries in such decays are predicted to be approximately equal to those in $b \to c\bar{c}s$ transitions, *e.g.* $B^0 \to J/\psi K^0_S$, by the Cabibbo-Kobayashi-Maskawa mechanism **??**. However, the loop diagrams that dominate the charmless decays can have contributions from new particles in several extensions of the Standard Model, which could introduce additional weak phases **????**. A time-dependent analysis of the three-body Dalitz plot allows measurements of the mixing-induced *CP*-violating phase **????**. The current experimental measurements of $b \to q\bar{q}s$ decays **?** show fair agreement with the results from $b \to c\bar{c}s$ decays (measuring the weak phase β) for each of the scrutinised *CP* eigenstates. There is, however, a global trend towards lower values than the weak phase measured from $b \to c\bar{c}s$ decays. The interpretation of this deviation is complicated by QCD corrections, which depend on the final state **?** and are difficult to handle. An analogous extraction of the mixing-induced *CP*-violating phase in the B^0_s system (ϕ_s) will, with a sufficiently large dataset, also be possible with the $B^0_s \to K^0_S K^\pm\pi^\mp$ decay, which can be compared with that from, *e.g.* $B^0_s \to J/\psi\,\phi$.

The charmless three-body analyses provide a long-term physics program that can profit from the LHCb upgrade. In fact, these analyses proceed in increasingly complex steps, which become more and more sensitive to new physics observables with the growing dataset, and with more observed decay modes. One of the long-term goals is to perform full flavor- and time-dependent Dalitz-plot analyses of the $B^0_s \to K^0_S h^+h'^-$ modes to measure the weak phases β and ϕ_s. Moreover, with the upgrade of LHCb, more modes, eventually with more neutral hadrons, are being considered. Recent theoretical and experimental activities have focused on the determination of the CKM angle γ from charmless B meson decays using and refining the methods proposed in Refs. **???**.

CP-violation in the D and K sectors

For a complete picture of CP violation, and to test the CKM paradigm, CP violation in K and D physics should be studied in parallel to that in B physics. Details will be discussed in section 4.

CP-violation in other observables

In the SM, CP violation is a purely flavored phenomenon, arising from the presence of three families of matter particles. This partly explains its strong suppression in physical observables, and thereby their high sensitivity to non-standard sources of CP violation. At the same time, this feature is not fully understood and raises several questions:

- CP violation by the strong interaction is mysteriously absent from the SM. If present, it would deeply alter the picture, in particular for electric dipole moments. This is the so called strong CP problem. In this context, the French community is actively involved in the next generation of neutron EDM experiments.

- The study of CP violation could have deep cosmological consequences. For example, one solution to the strong CP problem involves a new particle, the axion, whose relic density could play a role in the context of dark matter. Another puzzle is the origin of the baryon asymmetry of the Univerve, which seems to require some new sources of CP violation.

Thus, exploring CP violation in light mesons has implications well beyond the strict context of flavor physics, and may shed new lights on some of the most fundamental puzzles.

Plans for the GDR

In the next five years, the GDR will provide the opportunity to continue the measurements started many years ago, using the full run2 dataset of the LHC, and to explore new routes. In summary:

- the effort on the measurement of ϕ_s will continue, with a focus on controlling the sub-leading penguins contributions;

- several additional ways to measure γ and α will be explored, using for example charmless B decays, in order to overconstrain the UT;
- we will have the opportunity to explore the CP violation in baryons, largely produced at the LHC, and this is currently a mostly unexplored field, complementary to the meson field;
- the first results of the Belle II experiment will be discussed, and their complementarity with the LHCb results will be assessed;
- CP violation in charm, still to be discovered, will be searched for;
- the theoretical advancement in CP violation in kaon, like lattice studies of the ε' matrix elements, will be followed, together with the achievements of the NA62 experiment, currently in data taking and aiming to mesure the $K^+ \to \pi^+ \nu\nu$ branching fraction.
- the CP violation results in B physics will be put in relation with the CP violation results in the charm and kaon sector;
- the GDR will be the forum for brainstorming on future upgrade of the LHCb experiment (2025-2035), as well as on future CP violation experiments in general.
- the theoretical advancement in CP violation in kaon, like lattice studies of the ε' matrix elements, will be followed, together with the achievements of the NA62 experiment, currently in data taking and aiming to mesure the $K^+ \to \pi^+ \nu\nu$ branching fraction.

For all these items, the synergy between experimental and theoretical communities is essential, because a major discovery can not come if the uncertainties are not under control in both places. Advances in controlling hadronic effects, for example using lattice simulations of QCD or analytic tools like sum rules can be expected. The new data coming from the LHC and soon from Belle2, as well as from NA62 will certainly allow to make important advancements in the CP violation field, and we need to ensure to provide our contribution and to correctly interpret the measurements in the global CP violation picture.

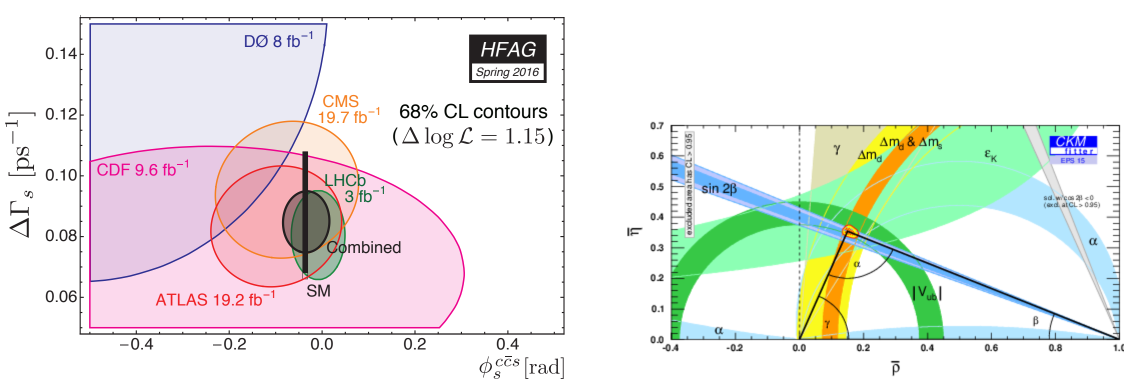

Figure 1: Left plot: 68% CL regions in B_s^0 width difference $\Delta\Gamma_s$ and weak phase ϕ_s obtained from individual and combined CDF, D0, ATLAS, CMS and LHCb likelihoods of $B_s^0 \to J/\psi\phi$, $B_s^0 \to J/\psi KK$, $B_s^0 \to J\psi\pi\pi$ and $B_s^0 \to D_s^+ D_s^-$. The expectation within the Standard Model is shown as the black rectangle. Right plot: the current status of the CKM unitarity triangle test from the CKMFitter collaboration.

3 Rare, radiative and semileptonic B decays

Rare decays of B mesons are natural candidates to be studied within the indirect approach: being dominated by loop and box diagrams, they are very suppressed in the Standard Model, and so the most sensitive to variations due to new physics. Among them, radiative B decays, with the emission of a virtual or real photon, as well as semileptonic B decays are extremely interesting, as the theory has the instruments to perform very precise predictions. A joint work between experimentalists and theorists has allowed to identify an ensemble of observables which are at the same time sensitive to the couplings to different possible sources of New Physics (NP) and as immune as possible to non factorizable QCD effects. With the abundance of data produced by the LHC collisions, for the first time some of these decays can be observed, their properties measured and the prediction tested with better precision than ever.

For example , the LHCb collaboration has produced a large set of results, related to the exclusive $b \to s\ell\ell$ decay modes, which are currently dominating the field. In the special case of the $\mathcal{B}(B_s \to \mu\mu)$, the CMS collaboration is also significantly contributing and after combining the results of the two experiments, it turned out that the long searched $\mathcal{B}(B_s \to \mu\mu)$ is only slightly lower than, but compatible with, the value predicted in the Standard Model (SM). The $B_d \to \mu\mu$ decay has also been seen, its branching ratio turning out to be compatible with the value predicted by the SM.

On the other hand, after comparing the experimental values of $B \to K^*\mu\mu$ angular observables, as well as of $\mathcal{B}(B \to K\mu\mu)$ and $\mathcal{B}(B_s \to \phi\mu\mu)$, with the theoretical estimates derived in the SM, one finds considerable discrepancies, of the order of 3 to 3.5 standard deviations. The LHCb results of the $B^0 \to K^*\mu\mu$ angular analysis were also recently confirmed by the BELLE collaboration. It appears, however, that the most significant discrepancies occur near the charm production threshold, a region notoriously difficult for the theoretical description of these decays. In fact in this region it is required an accurate estimate of the hadronic matrix element of a non-local operator corresponding to disconnected $c\bar{c}$-diagrams, which cannot be computed by means of numerical simulations of QCD on the lattice. For that reason, as of now, it is not clear whether the current discrepancies are due to the lack of theoretical control of the $c\bar{c}$ contributions, or they indicate the presence of NP couplings. If the second option is adopted, the angular observables of $B \to K^*\mu\mu$ and $B_s \to \phi\mu\mu$ decay modes provide very stringent constraints on the scenarios of NP.

On top of the very rich set of results involving muons, LHCb has also performed an angular analysis of the $B^0 \to K^*ee$ decay mode in the low dilepton invariant mass region. The results found are in agreement with SM but currently quite limited in statistics. With more data coming, the electron channels will be more and more competitive and their measurements more precise. Among other observables, they actually provide a measurement of the photon polarization, as the di-electron are emitted by a virtual photon in some part of the kinematic space. This is a complementary measurement to the one of the decays involving real photons, like $B_s \to \phi\gamma$ and $B \to K^*\gamma$. In the SM the photon polarization in $b \to s\gamma$ transition is known to be left (right) for a b ($\bar{b}$) quark, modulo effect of the order of 4% du to the quark masses and the emission of soft gluons. Any deviation from this precise expectation would be a clear sign of NP. In the next years precise measurements of the photon polarization in $b \to s\gamma$ transitions are expected to come, but some challenges need to be faced, like for example the study of the resonant K^* structure, which needs a close collaboration between theorists and experimentalists.

Another experimental result which has also provoked some interest in the flavor physics community is that $R_K = \mathcal{B}(B \to K\mu\mu)/\mathcal{B}(B \to Kee)_{\text{low}-q^2}$ was found to be 2.6σ smaller than predicted in the SM, which suggests the violation of universality of the coupling to leptons (LFUV). Such a puzzling phenomenon should be scrutinized with higher statistics and tested in other similar situations, such as R_K at high-q^2's, R_{K^*}, $R_{\Lambda^{(*)}}$ at both low- and high-q^2. This observation is adding to an already noted problem of $R_{D^{(*)}} = \mathcal{B}(B \to D^*\tau\nu_\tau)/\mathcal{B}(B \to D^*\mu\nu_\mu)$ for which the experimental result, first measured at the B-factories and then confirmed at LHCb, is $(2 \div 4)\sigma$ larger than predicted in the SM. There are very few phenomenologically viable theoretical scenarios of NP which can simultaneously explain that $R_K^{\text{exp}} < R_K^{\text{SM}}$ and that $R_{D^{(*)}}^{\text{exp}} > R_{D^{(*)}}^{\text{SM}}$. To further understand the origin of the LFUV one can envisage doing the angular analysis of all the mentioned decay modes, and from the ratios of angular observables check whether or not a similar size of the LFUV is indeed observed. Furthermore, to facilitate a comparison with theory it is more sound to compare $B_s \to D_s^{(*)}\ell\nu_\ell$ because the theoretical uncertainty related to the chiral extrapolation in the light valence quark on the lattice is completely avoided in this way. Moreover, the emission of soft photons can differently affect $B^- \to D^{0(*)}\ell^-\bar{\nu}_\ell$ and $B^0 \to D^{-(*)}\ell^+\nu_\ell$, the modes which are usually averaged. Such a problem is much less significant if one works with $B_s \to D_s^{(*)}\ell\nu_\ell$ decays.

Most of the models that aim at describing the LFUV effects allow for the lepton flavor violation (LFV) too. For that reason it is of great interest to measure the LFV modes such as $B_s \to \mu\tau$, $B \to K^{(*)}\mu\tau$, $B_s \to \phi\mu\tau$, which can now be probed thanks to the large statistics achievable at the LHC. The experimental bounds on $\mathcal{B}(B_s \to \mu e)$ and $\mathcal{B}(B_s \to K^{(*)}\mu e)$ can also be greatly improved. These results can be very useful for phenomenology of the LFV decays and for the bigger picture that could ultimately lead to a theory of flavor of quarks and leptons.

The French community is largely active both on the experimental and theoretical side on rare, radiative and semileptonic decays. In the need of exchanging results, it has been promoting in the past years the aforementioned PEPS-PTI projects and the related workshops, successfully followed by the community. They clearly established the need of a GDR as a regular framework where the discussions and the collaboration could take place on a more regular basis. The following topics should be addresses:

- For the radiative decays direct measurements of the photon polarisation through $B0 \to f_C P\gamma$ and $B \to (hhh)\gamma$ modes, prospects in the suppressed $b \to d\gamma$ transitions and search for $B_s \to \gamma\gamma$ (and maybe also a word about radiative modes in the charm sector). Develop this part, check it is ok with the other exp searches.

- For the LFUV, we should elaborate a general scenario of NP, in an effective field theory approach, allowing to isolate the observables which are most sensitive to the couplings to the vector (scalar) and/or axial (pseudoscalar) operators. Experimenters and theorists will elaborate on the feasibility of the distribution of $B_{(s)} \to D^*_{(s)}\ell\nu_\ell$ according to the polarization of the outgoing vector meson. Furthermore, a contact with other leptonic observables should be made in order to test several plausible scenarios of NP which result in LFUV. New experimental results on the ratio measurements will be provided by LHCb, but are also expected from BelleII.

- For the angular analyses of $b \to sll$ transitions, with the new and more accurate experimental data, it becomes mandatory to assess the hadronic uncertainties on the theory side. Lattice QCD and the QCD sum rule practitioners will try and evaluate the size of theoretical errors and discuss the appropriate methodology on how to account for various sources of systematic uncertainties. We should explore the $B^0 \to K^*\tau\tau$ channel and define new observables taking into account the direct access to the *tau* polarization. The study of $b \to s\ell\ell$ transition in b-baryons is quite new and the identification of interesting observables for the $\Lambda_b \to \Lambda^*\mu\mu$ may be interesting. Possible phenomenological ideas on how to relate the hadronic quantities in several decay modes will be discussed as they might be helpful in canceling a large part of hadronic uncertainties. Ideas on how to treat the non-resonant $c\bar{c}$-contributions would be very welcome. The phenomenological interpretation of the experimental results will allow to shed lights on which physics beyond standard model best fits the data.

- The LFV direct searches will soon provide new results. It will be crucial to work on a package that could include all the possible constraints relevant to LFV at low and high energy and see what are the lessons one can learn about the Yukawa sector from the data.

- Finally we should assess the current situation concerning the extraction of the Yukawa couplings from experimental data, clarifying in which way those data can be related to the low-energy physics observables and b-decay observables in particular. In order to address the issue of "*Which theory of flavor?*" we will try and combine the searches made at Belle II with those made at NA62 and KOTO experiments. We should also address the issue of (in)compatibility of the conclusions found in the Yukawa sector through the low-energy experiments with the LHC findings at the TeV-scale.

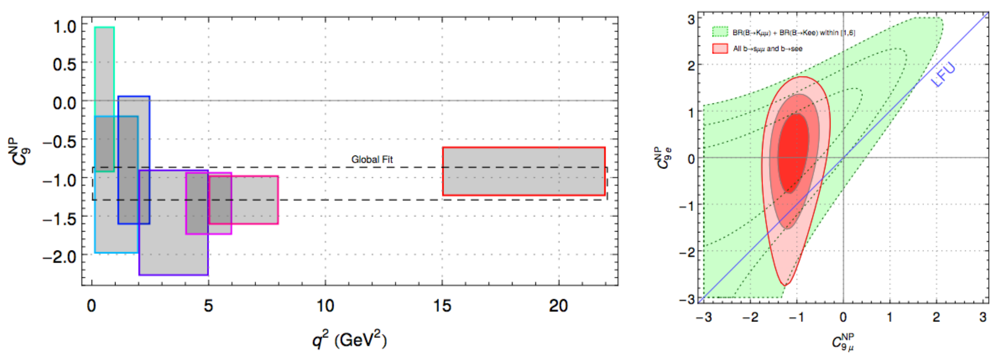

Figure 3 – Left: Bin-by-bin fit of the one-parameter scenario with a single coefficient $\mathcal{C}_9^{\rm NP}$. Right: Fit with independent coefficients $\mathcal{C}_{9\,\mu}^{\rm NP}$ and $\mathcal{C}_{9\,e}^{\rm NP}$.

Figure 2: From arXiv:1605.06059v1 **will develop the caption**

4 Charm and Kaon Physics

In the LHC collisions, a large part of the proton-proton cross section goes into charm and strange quarks production. the $c\bar{c}$ cross-section is roughly 10% of the total inelastic cross-section, so that charm hadrons are produced extremely copiously. Their short but measurable decay times make them relatively simple to reconstruct and separate from background.The LHCb detector has developed dedicated triggers registering large samples of charm hadron decays and is currently exploring the best strategy to collect a large quantity of kaon decays. In fact, charm and kaon physics provides complementary insights into flavor physics to this obtained from the b sector. This working group will asses specific questions concerning the charm and kaon experimental and theoretical issues.

Charm physics

Theoretically, CP violation in charm mesons is expected to be very small because the GIM mechanism is much more powerful for $c \to u$ transitions than for $s \to d$ or $b \to s, d$ transitions. The CP violation in decay is therefore expected to occur at below the per mil level in the SM. At the same time, New Physics need not to respect this peculiar feature, so these observables provide almost-null tests of the Standard Model. Additionally, compared to beauty or strange hadrons, the mixing of neutral charm hadrons is slow, with both the $x = \Delta m/\Gamma$ and $y = \Delta\Gamma/(2\Gamma)$ parameters at around the percent level.

The CP violation in charm decays has not been observed so far, and the existing experimental limits are at the few per mil level. The theoretical predictions of charm CPV are difficult as long distance contributions dominate; CPV in decay close to the present experimental limits could be accommodated within the SM or could be signs of NP, and a progress on the theory side is required to disentangle the two. Similarly, in the case of mixing, or CP violation in the interference of decay and mixing, more precise experimental results are needed to stimulate progress on the theoretical predictions.

In addition, charmed hadrons are also an interesting place to study rare and forbidden transitions, for example FCNC or lepton number violating decays. The most recent studies of charmed hadron decays within the French community were performed on the rare decays $D^+_{(s)} \to \pi\mu\mu$ (with same sign muons) and $D^0 \to K\pi\mu\mu$. The former is of interest because the copious production rate of charmed hadrons allows effective limits to be placed on Majorana neutrinos. The latter is the charmed counterpart of $B \to K^*\mu\mu$ and has now been observed for the first time by LHCb, albeit within a dimuon q^2 region dominated by the ω and ρ resonances. It should in principle share much of the same phenomenology of $B \to K^*\mu\mu$, with the complication of much higher backgrounds from decays to hadronic resonances (such as $K\pi\rho$) which subsequently decay to dimuon pairs. Once that a large signal yields become available, an angular analysis will be of prior interest.

In the upcoming period, the most critical work will be the following.

- Improve the limits on CPV, both in decay and the interference of mixing and decay, as well as to make ever more precise measurements of charm mixing parameters using both the $D \to hh$ and $D \to K_s hh$ decay modes with the full Run II LHCb dataset.
- LHCb should obtain large samples of FCNC decays such as $D^0 \to K\pi\mu\mu$. Potentially this will allow for an observation of the nonresonant (in the dimuon spectrum) decay and a measurement of angular observables similar to the ones which characterise $B \to K^*\mu\mu$.
- Make more precise measurements of charm hadron lifetimes, in particular in the less well understood baryon sector. This could aid the development of HQE tools and techniques required to eventually obtain precise SM predictions for mixing and CPV in the charm sector.

Kaon physics

Kaon physics is the birthplace of CP violation, and has played a central role in establishing the CKM picture in the past five decades. Kaon mixing and decays belong traditionally to the most constraining processes for physics beyond the SM. Currently, two main aspects are relevant for our proposed plans.

First, advances in lattice QCD may help to finally shed new light on the precisely measured direct CP-violation parameter ε'. Second, theorists will be following closely the NA62 experiment which aims at $K^+ \to \pi^+ \nu\nu$. Any hint of discrepancy with the SM there would have implications for the other meson sectors.

In addition, the discrepancies found in recent LHCb and B-factory data, in particular in the quantity known as R_K **?**, provide motivations for searches of certain K decays, in particular lepton-flavor violating (LFV) ones of the kind $K \to (\pi) e\mu$. Interestingly, the R_K effect is consistent in magnitude and size with other discrepancies observed in the flavor sector. Without further assumptions, lepton flavour non universality (LFNU) at a non-SM level implies LFV at a non-SM level. In fact, to account for R_K one needs to invoke new interactions distinguishing between leptons of different generations, for example lepton-lepton couplings with a new vector boson or quark-lepton couplings with a scalar leptoquark. The fermions involved in such interactions are generally not in the mass eigenbasis – this basis doesn't even exist at the scale of these interactions, usually above the EWSB scale. After EWSB, rotation of the quark and lepton fields to the mass eigenbasis generates LFV effects along with the LFNU ones.

One theoretically appealing way to generate new-physics shifts of the required size is to invoke an effective interaction involving dominantly quarks and leptons of the third generation **?**. Then, the amount of LFNU pointed to by R_K actually allows to quantify rather generally the expected amount of LFV to be in the ballpark of 10^{-8}, which happens to be within reach at LHCb's run 2. This argument, reported in Refs. **??**, motivates searches of LFV B decays as a promising direction at LHCb.

This very argument has implications in K physics as well, in decays of the kind $K \to (\pi)\ell\ell'$, such as $K_L \to e^\pm \mu^\mp$ and $K^+ \to \pi^+ e^\pm \mu^\mp$. Experimental limits on these modes are more than ten years old: $\mathcal{B}(K_L \to e^\pm \mu^\mp) < 4.7 \times 10^{-12}$ **?**, $\mathcal{B}(K^+ \to \pi^+ e^- \mu^+) < 1.3 \times 10^{-11}$ **?**, $\mathcal{B}(K^+ \to \pi^+ e^+ \mu^-) < 5.2 \times 10^{-10}$ **?**. Theoretical expectations for the above decays are straightforwardly calculable after suitably normalising the decay modes of interest in order to cancel phase-space factors. Defining $\beta^{(K)}$ as the ratio of the new-physics Wilson coefficient responsible for the decay in the numerator over the SM Wilson coefficient responsible for the normalising decay, we get

$$\frac{\Gamma(K_L \to e^\pm \mu^\mp)}{\Gamma(K^+ \to \mu^+ \nu_\mu)} = |\beta^{(K)}|^2 \; , \tag{1}$$

$$\frac{\Gamma(K^+ \to \pi^+ \mu^\pm e^\mp)}{\Gamma(K^+ \to \pi^0 \mu^+ \nu_\mu)} = 4|\beta^{(K)}|^2 \; . \tag{2}$$

To get a numerical idea of the effects to be expected, we need a model predicting $|\beta^{(K)}|^2$. For the sake of definiteness, here we use "model A" of Ref. **?** (any other motivated model, for example Ref. **?**, will do), thereby obtaining $|\beta^{(K)}|^2 = 2.15 \times 10^{-14}$. Use of eqs. (1) then implies

$$\mathcal{B}(K_L \to e^\pm \mu^\mp) \approx 6 \times 10^{-14} \; , \tag{3}$$

where we have used $\mathcal{B}(K^+ \to \mu^+ \nu_\mu) \approx 64\%$ and $\Gamma(K^+)/\Gamma(K_L) \approx 4.2$ **?**. In addition

$$\mathcal{B}(K^+ \to \pi^+ e^\pm \mu^\mp) \approx 3 \times 10^{-15} \; . \tag{4}$$

after use of $\mathcal{B}(K^+ \to \pi^0 \mu^+ \nu_\mu) \approx 3\%$.

While the K^+ LFV mode is clearly too suppressed (within the considered model!), the K_L one, eq. (3), has a branching ratio close to 10^{-13}. Such a rate may actually well be reachable at the NA62 experiment. As concerns LHCb, it should be noted that, although K mesons are produced copiously, their lifetimes are typically too long for the detector size – with the exception of the K_S. A dedicated study is thus necessary to understand the actual LHCb capabilities for the above decays.

SAYS WHY IT IS IMPORTANT THE GDR FOR THIS PHYSICS

5 Heavy Flavor Production and Spectroscopy

Quantum Chromodynamics (and the quark model out of which it grew) is one of the fundamental building blocks of the Standard Model. It has been extensively validated over the decades, and is very well understood. However, due to the non-perturbative behaviour that follows from the large self-coupling of low-energy gluons, the practical implications of QCD are still very much an active subject of research. This was vividly illustrated in the realm of spectroscopy recently, when the first compelling observation of pentaquark ($qqqq\bar{q}$) states was made by LHCb [**?**] just over fifty years after their existence was predicted [**?**]. This discovery came as a surprise to experimentalists and theorists alike: the possible existence of such states was known, but the quark composition of quasi-stable pentaquark resonances (let alone their masses, widths, and production mechanisms) was not.

More broadly, results from QCD and strong physics are frequently needed as inputs to other measurements or to their interpretation. For example, there is considerable interest in the decays $\overline{B} \to D^{(*)}\ell^- \overline{\nu}_\ell$: the ratio of branching fractions (in a restricted region of phase space) for $\ell = \mu$ and $\ell = \tau$ can be used to test lepton universality. The current world average, combining results from LHCb, BABAR and Belle, is in tension at the 4σ level with Standard Model expectations **?**. One of the important systematic uncertainties in this measurement is associated with the spectrum and properties of excited charm resonances D^{**}, which could contaminate the final state with feed-down from $\overline{B} \to D^{**}\ell^- \overline{\nu}_\ell$: here, input from spectroscopy is needed for the measurement itself. There are numerous instances in which QCD input is needed for the interpretation of measurements, notably for $B^0 \to K^{*0}\mu^+\mu^-$ in which an overall tension of 3.4σ with the SM prediction of **?** has been seen. The significance of this tension depends strongly upon the SM theory prediction and its uncertainties. To take a third and final example, QCD processes are an inherent background to all physics at the LHC, and in some cases Monte Carlo predictions of their spectrum need to be included in the fit itself. Tuning of the Monte Carlo models requires not only work from the phenomenology community but also measurements of production cross-sections across a range of transverse momentum and pseudorapidity.

The HEP community in France is engaged in this field, both on the experimental and theory sides. For practical reasons most experimental measurements have come from LHCb in recent years. LHCb-France has been involved on multiple fronts: spectroscopy of exotica, spectroscopy of non-exotic resonances and measurements of production rates. This list is not exhaustive, and there are far too many results to discuss them individually; purely by way of illustration we point to recent contributions by French groups to studies of exotic 4- and 5-quark resonances [**?**, **?**], discoveries of two Ξ_b resonances and precise measurements of their mass splittings [**?**, **?**], and measurements of the J/ψ production cross-section with the new 13 TeV LHC data [**?**]. Numerous theory groups are also actively involved, and we do not dare attempt an exhaustive listAs well as hadron production, there is substantial French expertise in spectroscopy theory. For example, the opening theory review talk at the 2014 Workshop on Heavy Quark Baryons at LHCb[1], a workshop organised by LHCb to which external experts were invited, was given by a member of IPNL. This is both recognition of this expertise and an illustration of the demand for productive exchanges between theory and experiments.

During the coming years, several analyses in this area are planned by LHCb-France and will be followed in the framework of the GDR. By way of example, these include:

- Studies in beauty baryon spectroscopy following on from the observations of three Ξ_b resonances;
- Searches for the doubly heavy Ξ_{cc} baryons;
- Measurements of production cross-sections at new centre-of-mass energies (including the 13 TeV Run-2 data and in heavy-ion collisions).

Assuming that the Ξ_{cc} searches are successful, they in particular will lead to fruitful exchanges with theory: their masses and properties will have immediate implications for QCD models, and theory input will be very useful for the next step, namely observing and studying their excitations.

[1] `https://indico.cern.ch/event/317758/`

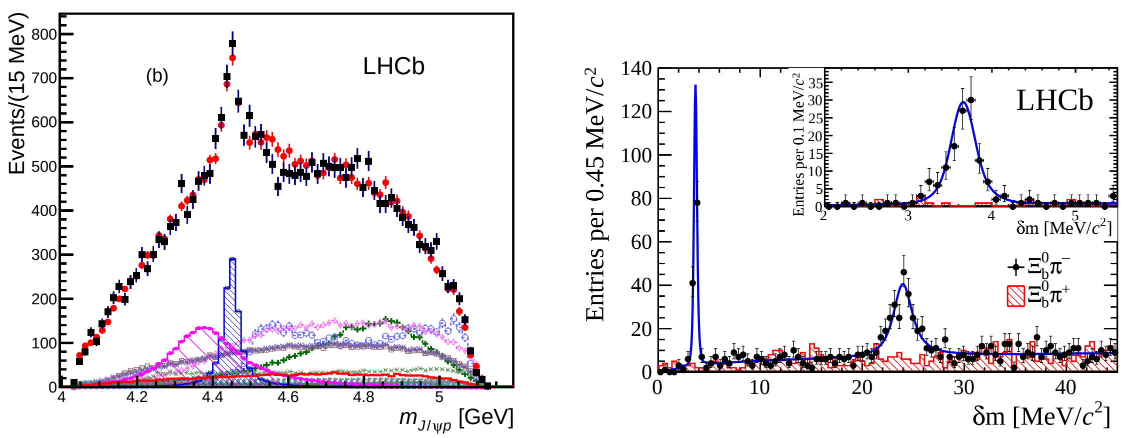

Figure 3: Left: Results of a fit to $\Lambda_b^0 \to J/\psi\, K^- p$ decays in the Run 1 LHCb data. The figure is taken from Ref. **?**, which reported the first observation of these two pentaquark states, the $P_c(4380)^+$ and $P_c(4450)^+$. Their amplitudes are shown as hatched magenta and blue histograms. Right: Results of a fit to the $\Xi_b^0\pi^-$ spectrum in the Run 1 LHCb data. The figure is taken from Ref. **?**, which reported the first observation of these two resonances, the $\Xi_b'^-$ and Ξ_b^{*-}. Inset: zoom around the first peak.

6 Interplay of quark and lepton flavour

As previously highlighted, many of the observables whose experimental measurements reveal lingering tensions with respect to the SM theoretical expectations consist in a large variety of (very) rare processes, among them semi-leptonic or leptonic meson decays.

Particularly interesting examples of these are the semi-leptonic and leptonic R_K ratios, $R_K = \mathcal{B}(B \to K\mu\mu)/\mathcal{B}(B \to Kee)_{\text{low}-q^2}$ (exhibiting a 2.6σ deviation from its SM prediction), and $R_K^{\text{leptonic}} = \mathcal{B}(K \to \mu\mu)/\mathcal{B}(K \to ee)$. Both the latter observables could signal the violation of lepton flavour universality, which might possibly be a consequence of charged lepton flavour violation[2].

Understanding these tensions (if confirmed) calls upon extensions of the SM, leading to modifications of its flavour paradigm. While many New Physics constructions address the hadronic sector, others aim at explaining the experimental tensions from the leptonic point view. By itself, flavour violation in the charged lepton sector is an unambiguous signal of New Physics. The experimental effort devoted to search for cLFV in a variety of processes (MEG, Mu2e, Mu3e, COMET, LHCb, SuperB, future FCC-ee and LC, ...) implies that in the near future the different bounds will become much stronger, further lending hope to a possible observation.

From a theoretical point of view, it is also important to stress that certain well-motivated constructions called upon to address the quark flavour puzzle have unavoidable implications regarding lepton flavours as well. Examples of such constructions include extended Higgs sectors (several realisations of 2HDM, type II seesaw, ...), extended gauge sectors (e.g., additional Z' bosons) or additional symmetries - flavour symmetries, or gauge ones, such as left-right symmetric models -, and finally larger frameworks as general Supersymmetry, extra dimensional models and Grand Unified Theories.

In all cases, it is clear that one must carefully evaluate the possible contributions to the distinct charged lepton flavour observables: these include purely leptonic processes, such as radiative $\ell_i \to \ell_j\gamma$, 3-body $\ell_i \to 3\ell_j$, etc., or processes involving hadron as is the case of semileptonic tau decays (such as $\tau \to \ell_i$+light hadrons), leptonic and semileptonic B, D and K meson decays, ..., and finally Higgs and Z flavour violating decays. The expected contributions must be confronted with the available (and soon to be improved) bounds, which will further allow to constrain the parameter space of different theoretical models, possibly impacting on the associated predictions regarding flavour violation in the hadron sector. The synergy between the observables might allow to readily exclude some of these well-motivated scenarios, and possibly to discriminate among distinct realisations of flavour violating models (see, e.g., **???**).

It is important to stress that the studies above referred to will also have a natural impact on other flavour conserving observables, as is the case of the muon anomalous magnetic moment $(g-2)_\mu$ or electric dipole moments of leptons. The exploration of these observables (already foreseen in the present Scientific Proposal) might offer additional insight into the lepton and quark flavour puzzle.

Considering the interplay between quark and lepton flavour violation, combining the informations and data arising from each sector, is thus relevant (and even mandatory!) to fully understand the underlying theory of flavour, and constrain - or even identify - the New Physics model at its origin.

[2]For recent studies on R_K^{leptonic}, see for example **???**.

7 Future Experiments

There are a large variety of future experiments at the intensity frontier starting or planning in the coming years. Here we have divided them into two categories: flavour physics experiments which can indirectly probe high energy scales through precision measurements and experiments searching directly for physics beyond the Standard Model. One of the role of the GDR will be to promote the discussions on which are the priorities and the complementarities among the different physics topics, and which are the most promising experiments where the French community should contribute. The mix of data analysis and preparation of new experiments which will characterizes the coming years will be a unique opportunity to ensure the continuity of the successful French involvement in the intensity frontier field.

Le premier tient au fait que la diversification des expÃľriences fait que le domaine concernÃľ par ce GDR correspond toujours Ãă des expÃľriences en cours et dâĂŹautres en prÃľparation. Je nâĂŹai pas le dÃľtail de tous les projets, mais je note (en mâĂŹappuyant sur le cours dâĂŹIsabelle Ãă Gif en 2015) quelques dates approximatives des projets citÃľs dans le texte : MEG-II 2016-19, Mu3e >2018-20, Mu2e 2020-23, COMET 2020-21, KOTO 2018-20 et Belle-II 2018->2023-25. Je connais beaucoup moins les manips de recherche des WISP, mais je lis dans le TDR de SHiP que Ãğa pourrait dÃľmarrer au plus tÃťt en 2025 et je prÃľsume que parmi les autres manips citÃľes les calendriers sâĂŹÃľtalent largement dans les 10 ans Ãă venir. Par ailleurs nous savons que pour LHCb (NA62 avec) les donnÃľes Run 2 sâĂŹarrÃłtent fin 2018 et reprendront en 2021 pour 2-3 ans. CâĂŹest bien lâĂŹillustration que dâĂŹaujourdâĂŹhui Ãă 2023-25 (7-9 ans !) nous aurons un mix prise de donnÃľes - prÃľparation manip - analyse. Il parait donc extrÃłmement judicieux dâĂŹavoir un forum dâĂŹÃľchange et de concertation pour bien valoriser les diffÃľrentes contributions et faciliter les transferts dâĂŹexpertise et de manpower (un peu oser peut-Ãłtre) entre ces projets.

7.1 Future experimental programs related to CP violation, rare decays of heavy flavours and lepton flavour violating processes

As far as CP violation and rare b-flavoured hadrons or τ decays are concerned, the two main players at the horizon of 2025 are the upgraded LHCb experiment at CERN and the Belle II experiment at KEK. The synergy and complementarity between the two projects has been assessed clearly in the past and we should ensure within the GDR to follow the progress in both the collaborations. In this respect, we can profit of the connexions established already by members of the GDR with the KEK collegues in the framework of the TYL/FJPPL (Franco-Japan Particle Physics Laboratory) and with the participation into the Belle II-Theory Interface Platform" (B2TIP: https://confluence.desy.de/display/BI/B2TiP+WebHome), a joint theory-experiment effort to study the potential impacts of the Belle II program.

Several large or medium scale projects related to Flavour Physics are envisaged to probe Beyond Standard Model Physics. Among them, there are prospective studies to educate the possibility to run the LHCb spectrometer in the High Luminosity phase of the LHC or to make use of high intensity beam lines (*e.g.* SPS and FCC injectors) with fixed target experiments.

A possible long-term strategy for high-energy physics at colliders, after the exploitation of the LHC and its High Luminosity upgrade, considers a tunnel of about 100 km circumference, which takes advantage of the present CERN accelerator complex. The Future Circular Collider (FCC) concept follows on the successful experience and outcomes of the LEP-LHC complex of experiments. A possible first step of the project is to fit in the tunnel a high-luminosity e^+e^- collider aimed at studying comprehensively the electroweak scale with centre-of-mass energies ranging from the Z pole up to beyond the $t\bar{t}$ production threshold. A 100 TeV proton proton collider is considered as the ultimate goal of the project. Future Circular Collider study groups have been formed in a design study hosted by CERN, aiming at a Conceptual Design Report and a review cost in time for next European Strategy milestone (2018-2019). The unprecedented statistics at the Z pole ($\mathcal{O}(10^{12-13} Z$ decays) potentially delivered by the high-luminosity e^+e^- collider can be studied in particular to explore further the Flavour Physics case at large.

In that framework, several French teams, gathering small groups of experimentalists and phenomenologists, are contributing to the design study in Flavour studies. There is a Physics potential of the measurements of rare decays of b-hadrons, which can complement the anticipated results from the current and foreseen b-Physics programs (LHCb upgrade and SuperKEKB B-factory). In that respect, French contributions are mainly focused on rare electroweak penguins which are likely unique to the FCC: $B^0 \to K^*(892)\tau^+\tau^-$ and $B_s \to \tau^+\tau^-$. The large statistics at the Z pole can be used as well to scrutinize in particular Lepton Flavour Violating (LFV) Z decays, which would serve as an indisputable evidence for New Physics if seen. Heavy right-handed neutrals are natural candidates to explain LFV phenomena. They can be as well searched for directly at FCC-*ee*. A number of low energy experiment are addressing this very question through the search for LFV by muon capture on nuclei (*e.g.* COMET in Japan and Mu2e at FNAL) or the radiative decay of large ensemble of muons (*e.g.* MEG and Mu3e at PSI).

One objective of the GDR is to address the complementarity of these high intensity machines, at large scale apparatus or low-energy experiments. Discussions inside the GDR will also help to identify the emerging technologies and those already mastered at IN2P3 which could play an important role for future experiments, helping the French groups to propose key contributions.

7.2 Weakly interacting new light particles searches

In this subsection we focus on searches for weakly interacting new light particles, commonly called WISPs, of which the two canonical candidates are hidden photons and axion-like particles. Experiments to search for these are in many cases very cheap, and can often recycle older experiments.

The best motivated WISP is the QCD axion itself, which is expected to solve the strong CP problem but is associated with new physics above 10^9 GeV. Its mass may lie anywhere in the sub-eV range, and it is a very well-motivated dark matter candidate.

Axion-like particles (ALPs) are (pseudo)-scalars, perhaps cousins of the QCD axion but which do not obtain their masses from QCD. They are characterised by their coupling to photons in a Lagrangian term $\mathcal{L} \supset -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$. These are highly motivated from top-down constructions as generically arising when symmetries are broken at high scales, and also make attractive dark matter candidates. On the other hand, and perhaps most importantly, there have recently been several studies indicating possible discoveries of such particles in various astronomical observations: either as an explanation for excessive white dwarf cooling or anomalous transparency of the universe to gamma rays, and most excitingly as an explanation for the soft excess of X-rays from the coma cluster (at 200 eV) and/or the oscillatory modulation of X-rays from the Perseus cluster (and even, perhaps, an explanation for an observed 3.55 keV X-ray line). These hints all point to a very light ALP ($< 10^{-12}$ eV) with a coupling $g_{a\gamma\gamma} \sim \mathcal{O}(10^{-11} \div 10^{-12})\mathrm{GeV}^{-1}$. However, while this is a very interesting region to probe, such a particle could have a wide range of masses and couplings. For the motivation of the hidden photon (line 424), maybe it is worth quoting also the 7 sigma anomaly in the Be nuclear transition (?).

Hidden photons are new (massive) gauge bosons which mix kinetically with the visible photon via a dimensionless kinetic-mixing parameter χ. While one motivation of these is as a possible explanation for the 3σ discrepancy between the measured and calculated value of the muon dipole moment – this would require a hidden photon in the $\mathcal{O}(100)$ MeV range with $\chi \sim \mathcal{O}(10^{-3})$ – they also appear generically in top-down constructions of beyond-the-Standard Model physics. They have been proposed as perhaps the most natural force carriers for light dark matter particles, or could even make up the dark matter themselves. Intensity frontier experiments searching for these either search for the particles as dark matter or attempt to directly produce them. In the dark matter case, the assumption that there is a large abundance of particles all around us greatly enhances the reach; on the other hand, for the very light ALPs this is unlikely to be the case. The dark matter searches consist of resonant cavities, helioscopes, and now many more exotic suggestions. Direct searches are broadly photon regeneration experiments (light shining through a wall), electron colliders or beam dumps. Flavour experiments like BaBar, Belle, KLOE and NA48 have been searching for and putting limits on hidden photons, and the flavor experiments effort will continue in the future also within LHCb and Belle II. Other important upcoming experiments include:

- Axion haloscopes (magnetic resonant cavity experiments) ADMX-HF, YMCE and WISPDMX at the University of Washington, Yale and Hamburg respectively are all expected to report results soon, probing axion masses in the μeV range.

- The FUNK experiment in Karlsruhe uses a dish antenna to search for dark matter hidden photons.
- The helioscope SHIPS at Hamburg searches for hidden photons produced in the sun.
- The REAPR and ALPS-II photon regeneration experiments at Fermilab and DESY respectively will attempt to directly produce ALPs or hidden photons in the lab.
- The IAXO helioscope at CERN uses a magnetic field to search for ALPs produced in the sun. It is expected to operate over the next decade and there are significant synergies with the French community.
- The SHIP beam dump experiment using the SPS proton beam at CERN has a substantial input from French theorists and experimentalists. It has the potential to search for messengers of New Physics portals (and additional particles) in the MeV-GeV range. Heavy Neutral leptons (neutrino portal), dark photons (vector portal), light scalars (scalar portal) and pseudoscalars (ALP) can be searched as well as possible supersymmetric partners (neutralinos, sgoldstinos, axinos, saxions...). The SHiP beamline will be a perfect arena to plan experiments to detect the interactions of the above mentioned particles with matter, i.e. an accelerator based direct dark matter search.
- There will be electron beam-dump experiments HPS, DarkLight and MESA at SLAC, JLab and Mainz respectively, with the latter running in about 2020. These will provide high intensity competition to hidden-photon searches in the $10 - 1000$ MeV range.
- The BMV experiment at Toulouse received ANR funding in 2014 to build phase two and complement its 2007 results. It can perform photon regeneration searches; it also included an X-ray regeneration experiment.
- There is also a proposal to use the Tore Supra tokamak at Cadarache to search for ALPs. This would be particularly interesting to unite with the plasma physics community.

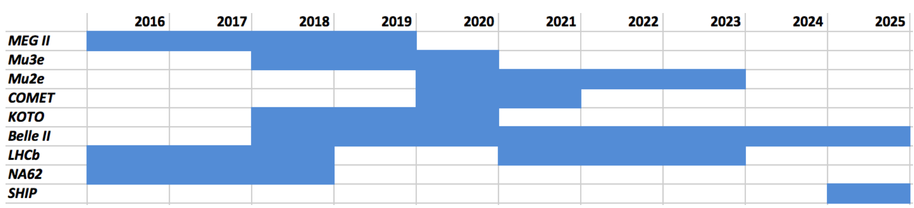

Figure 4: Expected timeline for some of the experiments cited in the text.

8 Conclusion

The intensity frontier is a strategic approach to search for new physics: historically, many of the discoveries in high-energy physics came first as indirect evidence in high-intensity experiments, and only afterwards were confirmed by direct, targeted searches. The intensity frontier is, furthermore, a domain in which the French particle physics community has been traditionally very competitive.

In addition, and interestingly enough, tantalizing hints of beyond-SM effects exist in data from recent and present experiments at the intensity frontier, among the others LHCb, the B-factories, and experiments having measured the anomalous magnetic moment of the muon. More data on all of these discrepancies are expected to come from the new generation of experiments that are starting or being planned.

Theoretical progress will ensure the theory predictions to error-match the experimental accuracy of the planned experiments. Furthermore, additional clean observables have been proposed, and more are under investigation for the LHCb upgrade, for the Belle upgrade, for other flavor experiments outside B-physics, for example NA62, and for experiments aimed at new light-particle searches.

In short, we are in the favorable circumstance of interesting data flowing from experiments, more data expected to come, and of a French community with more than the critical size and the international reputation to be competitive in these searches and their interpretation. We therefore consider timely and strategic to form a "GDR Intensity Frontier". This will allow for a financially well-defined structure to pursue collaborations within the community, beneficial among the other things to strengthen the interaction between the experimental and theoretical parties involved. Furthermore, the "GDR Intensity Frontier" will be the place to share our experience and our knowledge, reinforce existing bounds and inspire new collaborations, thereby ensuring that the French community stays competitive, and continues to focus on the most promising topics of the field. Finally, it will provide a forum to discuss the future of the field, and naturally promote the emergence of a young and dynamic generation of physicists active in the field, and educated in France. This latter point will be crucial to transmit the heritage of our community and to consolidate its international competitiveness over time.