Proposal for a
GDR of the Intensity Frontier

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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 NP: 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. 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 NP not by pushing the energy scale but rather the experiment's luminosity.

The intensity frontier could provide signs of NP 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 NP. 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 NP, 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 as 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 flavour physics and currently challenging the SM 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 NP 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 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 [1], 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. The French community proposing this GDR is made up of 61 physicists belonging to 14 different laboratories of the IN2P3 and INP institutes, and one CEA institute, with consolidated partnerships with Universities. They are listed as proponents of this document. The GDR community will be actually much larger, as it will certainly include PhD students and postdocs working in team with the proponents. 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 where 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 SM, through the measurement of the parameters of the CKM matrix. This measurement has room for improvement, and LHCb and Belle II will provide further insight on it, as well as additional tests involving the B_s meson and b baryons.

- **Rare, radiative and semi-leptonic B decays.** Generally mediated by loops, these decays are a powerful probe of NP, 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.

- **Charm and kaon physics.** The study of kaons and charmed mesons has been at the origin of the flavour 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 NP 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.

- **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.

- **Interplay of quark and lepton flavour.** Flavour 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 these topics, summarizing their current status and the proposed near-future work within the GDR.

The GDR will be leaded by two physicists, one theorist and one experimentalist, with the role of promoting a successful collaboration between the two communities. They will be helped by a "comité scientifique" for orienting the scientific activity of the GDR, with representatives from each working group in charge of steering and monitoring the activities, and by a "conseil de groupement" for organization matters, with members from the different participating institutes.

The GDR would function through carefully planned workshops. The format of these meetings would be decided according to the specific needs and objectives. 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.

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. In fact, we further hope to use the GDR as an opportunity to put the younger members of the community in the spotlight. They will be encouraged to participate in the organisation and the discussion and it will be given to the postdocs the responsibility of organizing and chairing the meetings, whenever possible. In addition, we plan to organize a school on "Introduction and Modern developments in flavour physics" for young M2 and PhD students, and we will work to create an environment where PhD students would feel confident to present their work and interact with physicists from other laboratories.

We believe that this proposal is in line with the history and the scientifique policy of our institutes and we are certain that the establishment of the GDR of the intensity frontier will be a further step to consolidate and develop the productivity and the international recognition of the French community working in the field.

2 CP violation

Since its discovery in the kaon system, charge-parity (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 NP 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 CKMFitter collaboration [1], 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 Cabibbo-Kobayashi-Maskawa (CKM) matrix in the SM. In the absence of NP, its sides and angles as determined from various observables all have to agree for the triangle to close. The current status is shown in figure 1 on the left.

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 NP.

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 is only mentioned here for its relationship with the global picture of the CP violation, but will be rather discussed in section 4.

CP violation in the B sector

In the context of BaBar and LHCb, the French community has been one of the main actors in the measurements of the unitarity angles, studying many channels like (quasi-)two-body charmless B decays for the determination of α, $B \to (c\bar{c})K$ for β, $B \to D^{(*)}K^{(*)}$ (with ADS/GLW and GGZS approaches) for γ and finally $B_s^0 \to J/\psi\phi$ for ϕ_s. At the moment the focus is on the analysis of the data coming from the Run2 of LHC (here and in the following Run1 stands for the LHC data taking period 2010-2012 and Run2 for the current one, started in 2015 and expected to last until 2018), 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 the LHCb experiment. The value of ϕ_s is precisely predicted in the SM and sets the scale for the difference between properties of matter and antimatter for B_s mesons. The predicted value is small and therefore the effects of NP 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 [2]. It is the most precise to date, and is shown on figure 1 on the right 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 0.01 rad, 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 expecially provide a probe to NP. 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 CKM mechanism [3, 4]. However, the loop diagrams that dominate the charmless decays can have contributions from new particles in several extensions of the SM, which could introduce additional weak phases [5, 6, 7, 8]. A time-dependent analysis of the three-body Dalitz plot allows measurements of the mixing-induced CP-violating phase [9, 10, 11, 12]. The current experimental measurements of $b \to q\bar{q}s$ decays [13] 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 [14] 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 NP observables with the growing dataset, and with more observed decay modes. One of the long-term goals is to perform full flavour- and time-dependent Dalitz-plot analyses of the $B^0_s \to K^0_S h^+h'^-$ modes (here h is a kaon or pion) 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. [15, 16, 17].

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 flavoured 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 Universe, which seems to require some new sources of CP violation.

It is clear that exploring CP violation in light mesons has implications well beyond the strict context of flavour 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;
- the CP violation results in B physics will be put in relation with the CP violation results in the charm and kaon sectors;
- the GDR will be the forum for brainstorming on future CP violation experiments, for example on the future upgrade of the LHCb experiment (2025-2035).

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 Belle II, 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.

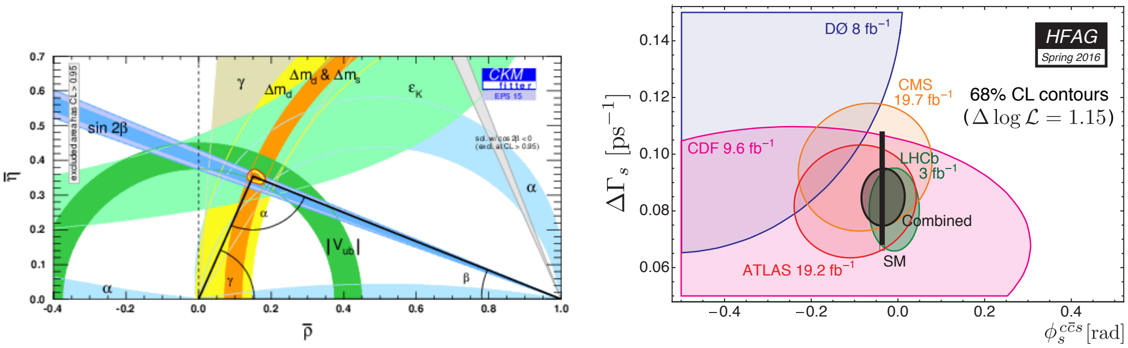


Figure 1: Left plot: the current status of the CKM unitarity triangle test from the CKMFitter collaboration [1]. Right plot: 68% CL regions in B_s^0 width difference $\Delta\Gamma_s$ and weak phase ϕ_s obtained from individual and combined CDF, D0, ATLAS, CMS and LHCb likelihoods of $B_s^0 \to J/\psi\phi$,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

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 SM, and so the most sensitive to variations due to NP. 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 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. 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.

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 SM [18]. 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 [19], as well as of $\mathcal{B}(B \to K\mu\mu)$ [20] and $\mathcal{B}(B_s \to \phi\mu\mu)$ [21], with the theoretical estimates derived in the SM, one finds considerable discrepancies, of the order of 3 to 3.5 standard deviations [22, 23, 24]. The LHCb results of the $B^0 \to K^*\mu\mu$ angular analysis were also recently confirmed by the Belle collaboration [25]. 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 [26], or they indicate the presence of NP couplings. If the second option is adopted, the angular observables of $B \to K^*\mu\mu$ and $B_s \to \phi\mu\mu$ decays provide very stringent constraints on the scenarios of NP. An example of the current constraint is shown in figure 2 on the left.

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 q^2 [27]. 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 with the muon channels and their measurements more precise. In addition, among other observables, they provide a determination 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% due 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 the observable $R_K = \mathcal{B}(B \to K\mu\mu)/\mathcal{B}(B \to Kee)_{\mathrm{low}-q^2}$ was found to be 2.6σ smaller than predicted in the SM [28], as shown in figure 5, which suggests the violation of the universality of the coupling to leptons (LFUV). This is also hilighted by the phenomenological analysis shown in figure 2 on the right. Such a puzzling phenomenon should be scrutinized with higher statistics and tested in other similar situations, for example measuring 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 [29] and then confirmed by LHCb [30], is in between 2 and 4σ larger than what is predicted in the SM [31]. There are very few phenomenologically viable theoretical scenarios of NP which can simultaneously explain that $R_K^{\rm exp} < R_K^{\rm SM}$ and that $R_{D^{(*)}}^{\rm exp} > R_{D^{(*)}}^{\rm SM}$ [32]. 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 $B_s \to D_s^{(*)} \ell \nu_\ell$ decays, 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 proposed for describing the LFUV effects hinted at by R_K allow for lepton flavor violation (LFV) too, after the general connection between LFUV and LFV was emphasized in Ref. [33]. Here it was also shown that the size of the R_K departure from unity alone allows to estimate the natural size expected for LFV B decays to be of the order of 10^{-8}, which happens to be within LHCb reach at Run2. This conclusion was corroborated by a number of follow-up studies, e.g. [34, 35]. 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.

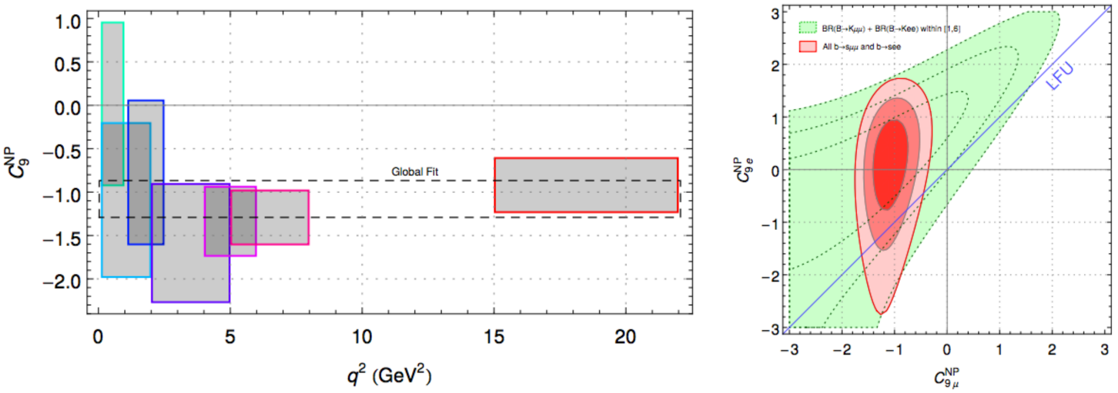


Figure 2: Phenomenological analysis of the rare decays constraints on NP from [24]. The left plot shows the global fit results of the Wilson coefficients when only the new physics coefficient C_9^{NP}, currently exhibiting the largest deviation from 0, is left floating. The fit is performed in different bins of q^2. The right plot shows the constraints in the hypothesis of independent electron and muon coefficients C_{9e}^{NP} and $C_{9\mu}^{NP}$, which is a test of lepton flavor universality.

Plans for the GDR

Following and improving the good experience of the PEPS-PTI projects on rare decays, the following topics would be addresses in the context of the GDR with a strict collaboration between theorists and experimentalists.

- 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 τ polarization. The study of $b \to s\ell\ell$ transition in b-baryons is quite new and the identification of interesting observables for the $\Lambda_b \to \Lambda^* \mu\mu$ decay 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 SM best fits the data.

- For the photon polarization measurements, the $B^0 \to K^* ee$ will benefit of the additional statistics collected already by the Run2 of LHCb. In addition, direct measurements of the photon polarisation in the radiative decays $B0 \to f_{CP}\gamma$ and $B \to (hhh)\gamma$ modes (here h is a kaon or a pion) will be pursued, with a detailed study of the resonant structure of the decay. The complementarity and interplay with the measurements at Belle II will be addressed. It will be worth also to explore the possibility of observing the suppressed $b \to d\gamma$ transitions and search for $B_s \to \gamma\gamma$ decays.
- Concerning 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 $B_{(s)} \to D^*_{(s)} \ell \nu_\ell$ decays 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, with a direct involvement of the French groups, but are also expected from Belle II.
- The LFV direct searches will soon provide new results, both in LHCb and later in Belle II, as well as in dedicated experiments (COMET, MEG, Mu2e, Mu3e). 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. The interplay with the lepton sector here is crucial, and will be addressed with more details in section 6.
- 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 "*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 the (in)compatibility of the conclusions found in the Yukawa sector through the low-energy experiments with the LHC findings at the TeV-scale.

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 flavour physics to the ones obtained from the b sector. In the context of the GDR, we will profit of the previous experimental experience of the French community in these domains to try to extract the most of the physic potential for charm and kaon physics within LHCb, but we will of course follow the results of the currently ongoing dedicated experiments like NA62. Their is a clear interplay with the studies concerning CP violation and rare decays in the charm and kaon sectors with those in the b sector. Thanks to the GDR, the community will have the possibility to come together and analyze all the results of flavour in a general framework.

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, NP need not to respect this peculiar feature, so these observables provide almost-null tests of the SM. 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 CP violation are difficult as long distance contributions dominate; CP violation 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. The current bounds are shown in figure 3 on the left.

In addition, charmed hadrons are also an interesting place to study rare and forbidden transitions, for example flavour changing neutral currents (FCNC) or lepton number violating decays. The most recent studies of charmed hadron decays within the French community were performed on the rare decays $D^+_{(s)} \to \pi\mu\mu$ [36] with same sign muons and $D^0 \to K\pi\mu\mu$ [37]. 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 ρ) which subsequently decay to dimuon pairs. Once that a large signal yield becomes available, an angular analysis will be of prior interest.

Plans for the GDR

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

- Improve the limits on CP violation in charm, both in decay and the interference of mixing and decay, as well as 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 Run2 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 non-resonant (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 heavy quark effective theory (HQE) tools and techniques required to eventually obtain precise SM predictions for mixing and CP violation 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 well help to finally shed new light on the precisely measured direct CP violation parameter ϵ'_K. Over the last years, lattice-QCD progress in the evaluation of $K \to \pi\pi$ matrix elements has been no less than astonishing. As a result, a mature, first-principle SM calculation of ϵ'_K/ϵ_K is no more just a dream. We should emphasize that this quantity, along with ϵ_K itself, is among the most formidable probes of physics beyond the SM, as it is able to probe NP scales as large as 10^4 TeV. Second, theorists will be following closely the NA62 experiment, which aims at observing the ultra-rare and ultra-clean $K^+ \to \pi^+\nu\nu$ decay. The potential of this experiment, as well as of KOTO for the corresponding channel with a neutral pion, is shown in figure 3 on the right. Any hint of discrepancy with the SM in either of the K-physics quantities mentioned above 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 [28], provide motivations for searches of certain K decays, in particular lepton-flavour violating ones of the kind $K \to (\pi)e\mu$. In fact, R_K may be naturally explained by a Fermi-like, TeV-scale new interaction involving third-generation quarks and leptons only [33]. At the energy scales of the decaying mesons, this interaction will produce, along with LFUV effects such as R_K, also LFV B decays, whose natural magnitude can be estimated to be in the ballpark of 10^{-8} by just using the departure of R_K from unity [33]. That argument can be extended to K decays as well, in particular those of the kind $K \to (\pi)\ell\ell'$ such as $K_L \to e^\pm\mu^\mp$ and $K^+ \to \pi^+ e^\pm \mu^\mp$. Limits on these modes are more than ten years old: $\mathcal{B}(K_L \to e^\pm\mu^\mp) < 4.7\times10^{-12}$ [38], $\mathcal{B}(K^+ \to \pi^+ e^- \mu^+) < 1.3\times10^{-11}$ [39], $\mathcal{B}(K^+ \to \pi^+ e^+ \mu^-) < 5.2\times10^{-10}$ [40]. Theoretically, their expected magnitudes can be estimated after suitably normalizing them to cancel phase-space factors [41]. The NP flavor structure can further be specified by using, for definiteness, flavor models proposed in connection with the R_K result, e.g. [34, 35], obtaining:

$$\mathcal{B}(K_L \to e^\pm\mu^\mp) \approx 6 \times 10^{-14} \,, \mathcal{B}(K^+ \to \pi^+ e^\pm \mu^\mp) \approx 3 \times 10^{-15} \,. \tag{1}$$

While the K^+ LFV mode is clearly too suppressed, the K_L one has a branching ratio close to 10^{-13}. Such a rate may actually well be reachable at the NA62 experiment. Concerning 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.

Plans for the GDR

The above considerations can be translated in a number of interesting directions to be pursued in the framework of the GDR.

- Closely follow the impressive progress in the lattice-QCD evaluation of direct and indirect CP violation in the kaon sector. The French community has a tradition in lattice QCD and in kaon physics, and can play a leading role in establishing possible discrepancies in the mentioned quantities, and in their interpretation.

- The meetings organized in the context of the present GDR will allow to invite members of the NA62 collaboration, giving the opportunity to have regular exchanges with them. In this way our network will follow closely the progress in the search of the $K^+ \to \pi^+ \nu \bar{\nu}$ decay and of the LFV decays of K mesons.

- An open question is, as mentioned, the possible reach of LFV K decays by LHCb itself. Optimistic remarks on this possibility actually emerged in informal discussions preceding the writing of the present document. This possibility deserves a dedicated study, and the GDR will be instrumental to frame progress in this direction.

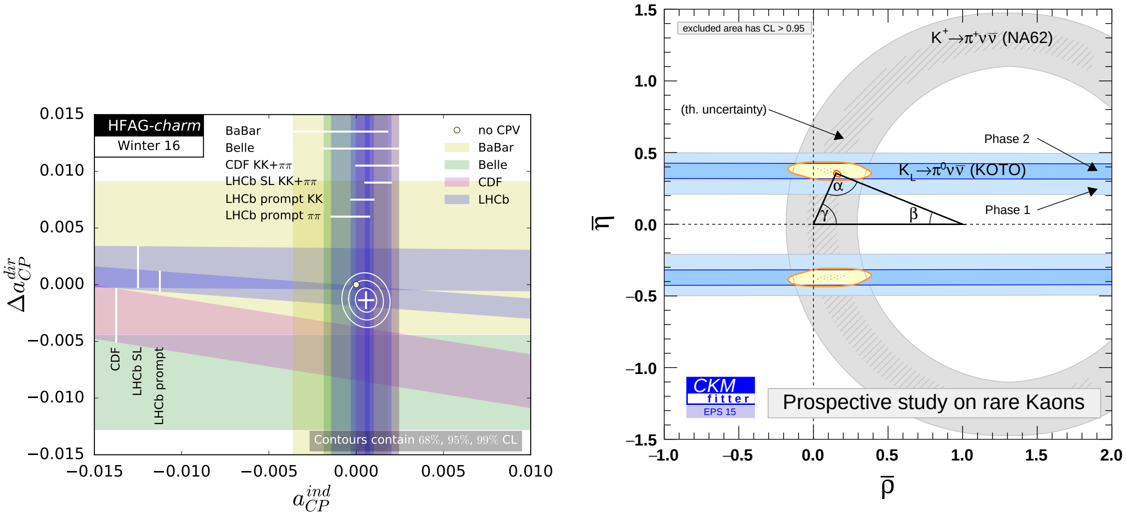


Figure 3: Left plot: summary of the current constraints on direct and indirect CP asymmetry in the charm sector; the overall picture is, with the present uncertainties, consistent with no CP violation observed in the D mesons sector. Right plot: Constraints in the $(\bar{\rho}, \bar{\eta})$ plane, using a prospective scenario for the NA62 and KOTO experiments, from the CKMfitter group . For NA62, a measurement of $\mathcal{B}(K^+ \to \pi^+ \nu\nu)$ with a 10% accuracy is assumed; for its corresponding constraint (light gray), the theoretical contribution to the uncertainty is indicated by the dashed region. For KOTO, a two-step prospective scenario is assumed: first, a 3σ evidence for the $\mathcal{B}(K^+ \to \pi^0 \nu\nu)$ (Phase 1, lighter blue), followed by a later measurement of $\mathcal{B}(K^+ \to \pi^0 \nu\nu)$ with 10% accuracy (Phase 2, darker blue). For the combined NA62+KOTO constraint, the theoretical contribution to the uncertainty is indicated with the dashed region.

5 Heavy flavour production and spectroscopy

Quantum Chromodynamics (QCD), and the quark model out of which it grew, is one of the fundamental building blocks of the SM. 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 [42] just over fifty years after their existence was predicted [43]. This discovery, illustrated in figure 4 left, 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 SM expectations [31]. 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 [44] 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.

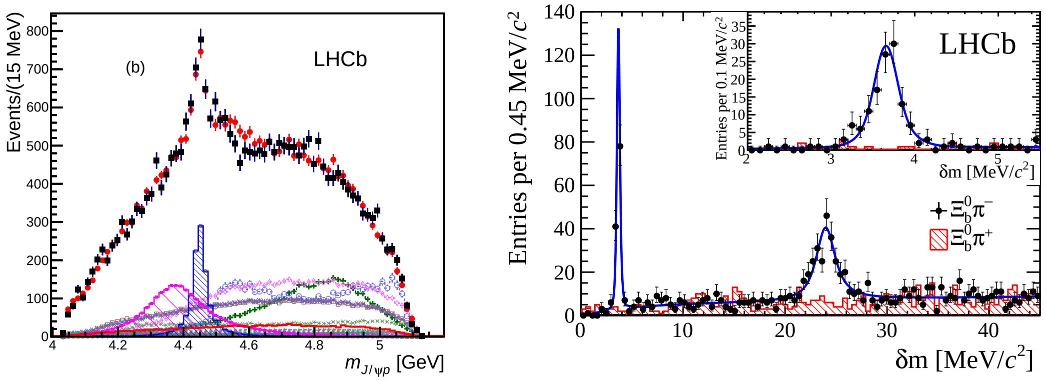


Figure 4: Left plot: results of a fit to $\Lambda_b^0 \to J/\psi\, K^- p$ decays in the Run1 LHCb data. The figure is taken from Ref. [42], which reported the first observation of these two pentaquark states, the $P_c(4380)^+$ and $P_c(4450)^+$. Their amplitudes are shown as hatched magenta and blue histograms. Right plot: results of a fit to the $\Xi_b^0\pi^-$ spectrum in the Run1 LHCb data. The figure is taken from Ref. [45], which reported the first observation of these two resonances, the $\Xi_b'^-$ and Ξ_b^{*-}. The inset shows a zoom around the first peak.

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 [46, 47], discoveries of two Ξ_b resonances and precise measurements of their mass splittings [48, 45] (illustrated in figure 4 right), and measurements of the J/ψ production cross-section with the new 13 TeV LHC data [49]. Numerous theory groups are also actively involved, and we do not dare attempt an exhaustive list. As well as hadron production, there is substantial French expertise in spectroscopy theory.

Plans for the GDR

During the coming years, several analyses in this area are planned by members of LHCb in 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 Run2 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.

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, see figure 5), 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. For recent studies on R_K^{leptonic}, see for example [50, 51, 52].

Understanding these tensions, if confirmed, calls upon extensions of the SM, leading to modifications of its flavour paradigm. While many NP 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 NP. The experimental effort devoted to search for charged LFV in a variety of processes (MEG, Mu2e, Mu3e, COMET, LHCb, Belle II, FCC-ee and LC, just to remind some of the current and planned experiments) 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 (e.g., several realizations 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

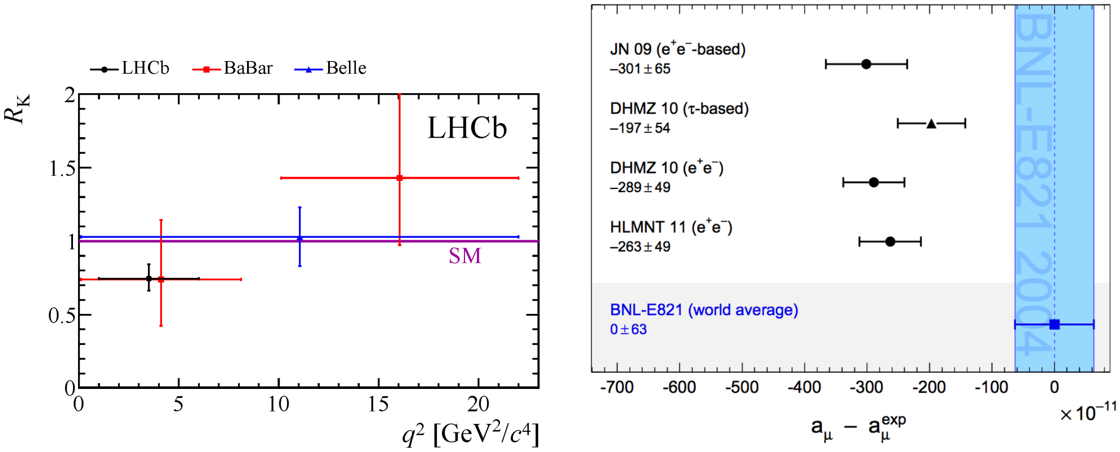


Figure 5: Left plot: Measurements of the lepton universality observable R_K from LHCb and the B-factories. The LHCb result at low q^2 exhibits a 2.6σ deviation from the SM prediction. Right plot: Compilation from the PDG of recent published results for $a_\mu = \frac{(g_\mu - 2)}{2}$ (in units of 10^{-11}), subtracted by the central value of the experimental average.

between the observables might allow to readily exclude some of these well motivated scenarios, and possibly to discriminate among distinct realizations of flavour violating models (see, e.g., [53, 54, 55]).

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 $(g-2)_\mu$ (see figure 5 right for the current status) or electric dipole moments of leptons. The exploration of these observables, foreseen in this GDR, might offer additional insights into the lepton and quark flavour puzzle.

Plans for the GDR

Considering the interplay between quark and lepton flavour violation, combining the informations and data arising from each sector, is not only relevant but even mandatory to fully understand the underlying theory of flavour, and constrain, or even identify, the NP model at its origin. The GDR of the intensity frontier will be a unique opportunity to share the competences in the quark and lepton sectors and to fully exploit this interplay.

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 SM. 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 characterize the coming years, illustrated indicatively by figure 6 for some of the experiments discussed in this proposal, will be a unique opportunity to ensure the continuity of the successful French involvement in the intensity frontier field.

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. The involvement of France in LHCb is clearly established. For Belle II, we can profit of the connexions among some members of the GDR with the KEK colleagues in the framework of the TYL/FJPPL (Franco-Japan Particle Physics Laboratory) and also of the current 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 impact of the Belle II program.

Several large or medium scale projects related to flavour physics are envisaged to probe physics beyond the SM. 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, or proposals for a Gamma Factory at CERN with a wide physics potential in the intensity frontier [56].

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 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. FCC 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, with $\mathcal{O}(10^{12-13})$ 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 NP, 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).

Weakly interacting new light particles searches

Weakly interacting new light particles, commonly called WISPs, have as two canonical candidates 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 $\mathcal{L} \supset -\frac{1}{4} g_{a\gamma\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$. ALPs 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.

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 (requiring 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 physics beyond the SM. 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. Recently, they have also been advocated to explain the 7σ anomaly in the Be nuclear transition [57].

Intensity frontier experiments searching for WISPs 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 potential; 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 flavour experiments effort will continue in the future also within LHCb and Belle II. Other upcoming dedicated experiments include:

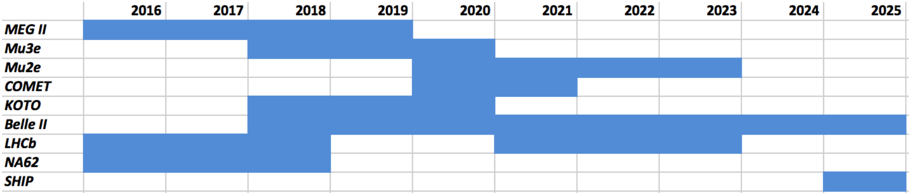
- Axion haloscopes (magnetic resonant cavity experiments) ADMX-HF, YMCE and WISPDMX at the University of Washington, Yale and Hamburg respectively are all expected to report results soon, probing axion masses in the μeV range.
- The FUNK experiment in Karlsruhe uses a dish antenna to search for dark 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, using a magnetic field to search for ALPs produced in the sun, 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 NP 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 for, 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. for 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 interact with the plasma physics community.

Plans for the GDR

One objective of the GDR will be to address the complementarity of the high intensity machines, at large scale apparatus or low-energy experiments. Discussions inside the GDR will 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. Although it will not be possible to participate actively to all the experiments related to the field, it will be crucial within the GDR to discuss them and follow their advancement both from the theoretical and the experimental point of view. This will eventually allow to select those more interesting for they scientific potential and in which a larger involvement will be beneficial for the French community at the intensity frontier.



	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
MEG II	■	■	■	■						
Mu3e			■	■	■					
Mu2e					■	■	■	■		
COMET					■	■				
KOTO			■	■	■					
Belle II			■	■	■	■	■	■	■	■
LHCb	■	■	■			■	■	■		
NA62	■	■	■							
SHIP										■

Figure 6: Timeline of the data taking periods for some of the experiments discussed in the proposal. Although not comprehensive of all the activity ongoing in the intensity frontier field, and providing only approximative dates, this timeline highlights the mixture of data taking and experiment preparation that will characterize the next years and that is one of the motivations of this GDR.

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 Belle II, and also for other flavour experiments outside B-physics, for example NA62, as well as 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 the "GDR of the 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 of the 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 domain, 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.

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