Important
Ce document ne doit pas dépasser 30 pages, dans la mise en page et la typographie fournies par l'ANR. Ce point constitue un critère de recevabilité de la proposition de projet. Les propositions de projet ne satisfaisant pas aux critères de recevabilité ne seront pas évaluées.

Acronym	**PRO-AFTER**		
Titre du projet	Prospectives pour une expérience sur cible fixe sur les faisceaux du LHC : Physique, Design, Intégration, R&D et communication.		
Proposal title	**PRO**spectives for **A** **F**ixed-**T**arget **E**xper**R**iment on the LHC beams : Physics case, Design, Integration, R&D and communication.		
Evaluation Committee	SIMI 5		
Type of research	X Basic Research ☐ Industrial Research ☐ Experimental Development		
International cooperation (if applicable)	X OUI ☐ NON		
Grant requested	502 000,00 €	**Project duration**	48 mois

Ce document ne doit pas dépasser 30 pages, au format fourni par l'ANR (mise en page et typographie). Ce point constitue un critère de recevabilité de la proposition de projet.

1. Executive summary

résumé utilisé dans le document administratif et financier. to be written
+
- Résumé (non confidentiel) du projet en français (Max caractères: 4000)
- Résumé (non confidentiel) du projet en anglais (Max caractères: 4000)
- Objectifs globaux, verrous scientifiques/techniques (Max caractères: 4000)
-Programme de travail (Max caractères: 4000)
- Retombées scientifiques, techniques, économiques (Max caractères: 4000)

A principal aim of this proposal will be to bring in experts in accelerator physics, as well as target detector design to evaluate the feasibility of a viable fixed-target program at CERN and optimize its characteristics, while minimizing costs.

2. Context, position and objectives of the proposal

2.1. Context

Within the Standard Model of elementary-particle physics, Quantum ChromoDynamics (QCD) is the theory of strong interaction, one of the four fundamental interactions in physics. It binds quarks and gluons inside the nucleons and the nucleons inside the nucleus. While one understands QCD at short distances (the perturbative domain), phenomenon such as confinement of quarks and gluons in the nucleons is still not understood at a fundamental level and there is no ab initio understanding of their dynamics within both nucleons and nuclei.

With the advent of the Large Hadron Collider (LHC) at CERN, a new era of particle and nuclear physics has opened. The LHC allows us to delve into QCD dynamics with protons and lead ions accelerated to a record nominal collision energy of 14 TeV and 5.5 TeV respectively – one order of magnitude beyond the previous colliders. The primary goals of the LHC were the discovery of the Higgs boson and the search for physics beyond the Standard Model. Two years after the first recorded collisions, the LHC has however been now recognized as an outstanding machine to study QCD with a remarkable precision thanks to its large reaction rates and the modern detection techniques of its detectors.

Nevertheless, these do not permit us to study processes producing very high longitudinal momentum particles. Such reactions are particularly important in understanding the dynamics and confinement of quarks and gluons which carry the largest momentum fraction of the projectile particles.

By extracting a small fraction of the intense LHC beams to collide it with fixed targets, we can study produced particles without restrictions since the beam comes from one side only.

Using the unprecedented energies of the LHC beams, our project, named AFTER[1] for A Fixed-Target ExperRiment, gives access to new domains of particle and nuclear physics complementing that of collider experiments, in particular the Brookhaven's Relativistic Heavy Ion Collider (RHIC) and the to-be Electron-ion colliders (EIC).

2.2. Position of the project

The multi-TeV energy of the LHC beams would make this fixed-target physics program unique. As simple as it is, the most energetic beam ever allows for the most energetic fixed-target experiment ever. We believe that such a facility will be of much interest to a wide range of hadron, nuclear and particle physicists.

The collision of the high energy LHC beams with fixed targets, including polarized and nuclei targets will greatly expand the range of fundamental physics phenomena accessible at CERN.

The fixed-target mode will allow in general for unprecedented precision measurements of hard QCD processes. In particular, our aim is to study:

- rare configurations of the proton wave function which contain gluon or heavy-quarks with high momentum fraction ;
- the gluon content in the deuteron and neutron in a wide momentum-fraction range;
- the correlation between the proton spin and the gluon angular momentum through the Sivers effect and novel spin-correlations;
- the production of W and Z boson in their threshold domain;
- the melting of excited heavy-quark bound states in the deconfined QCD phase in heavy-ion collisions;
- the nucleus structure function for momentum fraction close and above unity;
- the deconfinement dynamics in the target-rest frame;
- ultra-peripheral collisions in a fixed-target mode.

Compared to the RHIC experiments, which benefit from similar center-of-mass energies, our proposal will bear upon a huge luminosity –typical of a fixed-target set-up– and upon a complete versatility of target species. Compared to Electron-ion collider projects, our proposal will definitely be highly competitive in terms of cost and will be of complementary design with a specific focus on the study of parton content at large momentum fractions, in particular that in terms of gluons.

High-energy fixed-target experiments have already been discussed in the 90's, both at the European LHC and the American SSC. The main differences of our proposal compared to earlier ones are :

- the fact that the LHC is now built and runs –very well indeed–,
- bent-crystal beam-extraction techniques have now been successfully tested at the SPS and the Tevatron up to nearly 1 TeV and they will be tested on the LHC for beam-collimation purposes,

[1] Hence the name of this proposal "PRO-AFTER" for prospectives for "AFTER".

- a number of modern detection techniques have been developed in the meantime –in particular, ultra-granular detectors– and, finally,
- our proposal is by essence a multi-purpose experiment, not only focusing on one specific aspects of particle physics, as was for instance the LHB project.

We believe it is well worth exploring this option and bringing our nuclear and particle physicist colleagues' attention to all these new physics opportunities. To do so, we plan

- to work out the detail of the physics case in adequacy with the current experimental possibilities –and limitations– ,
- to develop a first robust –but ambitious– design of the experiment and its assembly compliant to the physics case, and
- to advertise our project all over the world-physics community to create an experimental collaboration large enough to make this project viable and fruitful for the years to come.

2.3. STATE OF THE ART

The scope of the physics program at such a fixed-target facility is certainly beyond what can be presented here. In particular, a major goal of this proposal will be to map out many of the possible physics avenues. In the following description of the state-of-the-art for the physics, we limit ourself to the next 5 items:

• *Large-x_B domain and gluon distributions*

Whereas momentum sum rules tell us that gluons carry about 40% of the proton momentum at Q^2 = 10 GeV^2, it is very difficult to probe them directly. Deep-Inelastic Scattering (DIS) experiment can only directly probe the target quark content. Indirect information on the gluon content can be extracted from the Q^2 dependence of the quark distribution –the scaling violation– and from sum rules. Recently, it has been re-emphasize [Bra11] that a better knowledge of gluons at high x_B is relevant for the production study of heavy-boson, W' and Z', beyond the Standard Model.

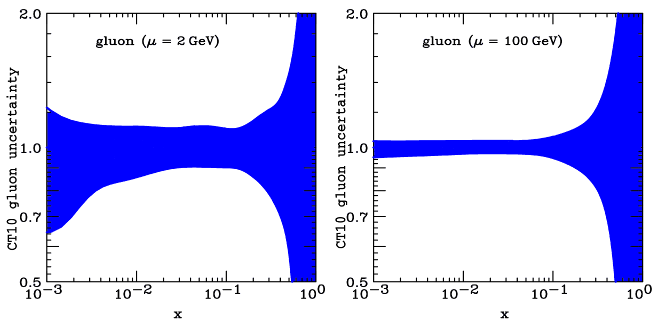


Fig. 1: Gluon-distribution uncertainty in a proton at high x_B for low and high scales, μ.

At large x_B, sum rules are of no help due to the strong suppression of PDF for $x_B \to 1$. The gluon distribution is indeed badly known for x_B>0.2 at any scale, as shown on Fig.1. One of the historical golden probe for gluons [Mar88] is quarkonium hadro-production since it comes from gluon fusion and is thus sensitive to the gluon distribution squared. It may thus be expedient to reassess the possibility to probe gluon with them.

To access the gluon distribution in the neutron, one has to resort to deuterium target. A very interesting studies using ϒ production by E866 [Zhu08] has shown a production ratio pp/pd for ϒ compatible with an isospin symmetry of the gluon with a visibly different behaviour than that of the same ratio for Drell-Yan – sensitive only to the quarks. This study is the most precise to date, but covers only the range $0.1 < x_B < 0.22$. Recently, ϒ production has been measured in dAu collisions by PHENIX in the backward region. Even though, the experimental data are scarce, they may exhibit [Fer11] the first hint for gluon EMC effect for x_B~0.3. As regards the heavy-quark content in the proton, it is surprising that the original 1983 EMC experiment [Aub83], which first observed a large signal for charm at large x_B in $\gamma^* p \rightarrow cX$, has never been repeated.

- *Single spin asymmetries (SSA)*

Recently, it has been re-emphasized that a class of parton-distribution functions, known as “Sivers functions” [Siv89], may be accessed in SSA for hard-scattering reactions involving a transversely polarized proton (see [Bar10] for a recent review). These functions express a correlation between the transverse momentum of a parton inside a polarized proton, and the proton-spin vector. As such they contain information on orbital motion of partons in the proton. Sivers-type single-spin asymmetries have been observed in semi-inclusive DIS (SIDIS) at HERMES [Air05] and COMPASS [Ale05] as well as in single forward π and K productionat Fermilab and Brookhaven (see [Bar10]).

Recently, PHENIX has measured [Ada10] that the transverse SSA in $p^{\uparrow}p$ J/ψ X deviates significantly from zero at x_F ~0.1. If this is confirmed, this would be the first sign of a non-zero Sivers effect for gluons. No such measurement exists yet for open charm and open beauty, neither for isolated photons, which are the other usual probes for gluons.

- *Cold nuclear matter studies*

One of the main asset of a fixed-target experiment is the versatility of the target species. This has been used for instance by the NA38 [Abr98b] experiment which however suffered from a reduced c-m-s energy and limited rapidity range as well as from somewhat less advanced detector technologies compared now. *A contrario*, RHIC detectors benefit from a larger cms energy allowing one to probe smaller xB [Adl06] but with a limited choice of species (only dAU so far) and a limited luminosity. These however brought to light the relevance of color nuclear matter effects to many hard process studied in pA collisions as a baseline for AA collisions.

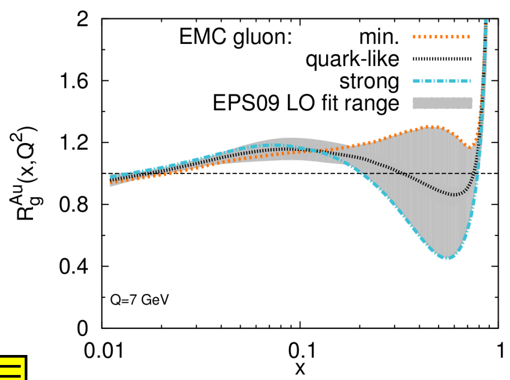


Fig. 2: Gluon-distribution uncertainty in a nucleon in a Au nucleus in the EMC region at 7 GeV.

Anti-shadowing (i.e. a parton excess at a given x_B in a bound nucleon compared to a free one) has recently been found to be non-universal : present in electron-nucleus DIS but absent in DY and neutrino charge current reactions [Kov11]. Similar studies for gluon-initiated process are rare. Gluon distribution in a bound nucleus is indeed poorly known in the anti-shadowing and EMC region, see Fig 2. Heavy-flavour, isolated γ and quarkonia are ideal candidates for such investigations. In the case of J/ψ, we have however shown [Fer09] that kinematical effects specific to their production mechanism [Lan06, Lan08, Hab08] should be taken into account if (anti-)shadowing was to be studied. It may thus be better to resort to the production studies of $\chi_{c,b}$ and $\eta_{c,b}$ whose production kinematics is closer to that of DY and for which QCD corrections are expected to be smaller [Art08, Bro11]. The backward region with hydrogen target using the 2.76 TeV LHC Pb beam can also be used to probe gluon in lead in a lower x_B domain, along the same lines as future measurements during expected Pbp runs at the LHC [Had11].

It is also clear now that a systematic study of large-x_F (be it positive or negative) effects, such as intrinsic charm, energy loss and Sudakov effect, can only be achieved with a global analysis of several hadronic reactions, with several of targets in a large enough rapidity range.

- *QGP and the path quarkonium sequential suppression*

Sequential suppression of quarkonia [Mat86] has been long considered as a thermometer of the deconfined phase of QCD created in the most central relativistic heavy ion collisions. An anomalous suppression of J/ψ was indeed observed at SPS [Abr99] and then at RHIC [Ada07, Ada08], partly attributed to quarkonium melting in the QGP. The first data from the LHC [Pil11, Sil11] seem however to indicate that a novel mechanism, charm recombination, could strongly compete with the suppression induced by the melting process. Specific studies at lower energies –where the number of charm is too low for recombination to appear– which would be focused on the excited states $\chi_{c,b}$ and ψ(2S) seem thus to be required. This statement will remain valid nearly independently of the LHC results to come in the next years, since, by essence, these energy range are complementary physics-wise. Such novel quarkonium studies would require a better resolution than previous SPS experiments and a state-of-the-art photon calorimetry with similar – if not larger– luminosities.

The studies of the deconfined phase of QCD nowadays goes beyond quarkonium studies. Heavy-quark energy loss is also recognized as an interesting probe as well as elliptic flow and related azimuthal asymmetries. It is thus relevant to emphasize that an apparatus able to study quarkonium melting with high precision will also allow one to carry out these complementary studies of QGP.

- *W and Z production*

With the advent of Fermilab and the LHC, W and Z bosons are nearly now part of the bread-and-butter physics of the standard model. However, their production studies at sub-TeV energies is still state-of-the-art. Recently, first spin-asymmetry production data from RHIC at 500 GeV were released and brought new information on information Δq and Δq [Ada11, Agg11]. Studies at the lower RHIC energy, 200 GeV, are for the time being out of reach. This would give us much information on the quark content at larger x_B or maybe on specific dynamical effects appearing near threshold. Similarly, their production study in pA collisions, out of reach at RHIC, would bring unique information on the quark distribution at very high momentum fraction, maybe above unity.

- *Ultraperipheral collisions in the nucleus rest frame*

Ultra-relativistic grazing nuclei can scatter electromagnetically with a coupling proportional to their atomic charge, Z, since the interaction would be coherent over the entire nuclei. For a lead-lead collisions, Z^2 is close to 7000, which compensates the smallness of α_{em}, the 2-photon cross section can then compete with that of pomeron exchange. At relativistic energies, the photon-photon or photon-nucleon are energetic enough to create particles. J/ψ production in UPC was for instance measured by PHENIX in AuAu collisions [Afa09] and preliminary studies are carried out by ALICE [xxx]. Such type of analysis have never been carried out successfully at fixed-target set-ups, mainly because of the lack of collision energy. In pA collisions with a 7 TeV beam, the nucleus target A can be used as a photon source in order to reproduce some of the semi-inclusive photoproduction measurements done at HERA and potentially some exclusive reactions as done at JLab and Hera (see for instance [Had05] and [Air08]).

Within this context, some important areas of the strong interaction studies have been left apart because they were so far technically not accessible:

- the study of strong interaction at very large xB, up to 1, i.e. the study of nucleon structure were the entire momentum is carried by a single parton.

Contribution à l'état de l'art :

- NA50 : Frédéric
- Hermes : Cynthia
- ALICE : Cynthia + D2I

2.4. Objectives, originality and novelty of the project

The principal goal of this proposal is to form a new collaboration of high energy particle experimentalists, accelerator physicists and theorists who will explore the physics opportunities and feasibility of extracting the 7 TeV LHC proton and 2.75 TeV lead beams to provide a viable high-energy fixed-target experimental program at CERN, beyond the four years of this proposal.

As aforementioned, beam extraction by bent crystal is now becoming mature with successful test at SPS (450 GeV) and at the Tevatron (900 GeV) and planned test at the LHC (3.5 or 7 TeV) to collimate the beam. It has been evaluated by one of us [Ugg05a,Ugg05b] that flux of the order of 10^8 Hz for proton and 10^5 Hz for lead ion are easily extractable.

We have evaluated [Bro11] that this provides with instantaneous luminosities of the order of tens of $\mu b^{-1} sec^{-1}$ for 1cm-long target, i.e. 3 orders of magnitude larger that of BNL-RHIC and comparable to that of the LHC for LHCb and ALICE experiments. These numbers can easily be multiplied by 10 using a longer target.

A central aim of this proposal will thus be to explore the new physics opportunities available at the extraordinary laboratory energies which would be accessible using the LHC beams in a fixed-target mode. These are

1) the gluon content of proton, neutron and nucleus, particularly at large x_B;
2) the cold nuclear matter effects at work in proton-nucleus collisions at x_F ~-1;
3) the deconfinement dynamics in the whole backward hemisphere;
4) Single spin asymmetries in heavy-quark, direct γ and quarkonium production;
5) W and Z production near threshold in pp and pA collisions;

In addition to outlining the physics opportunities, our collaboration will also look into prospective designs of experimental facilities capable of making measurements over the full range of fixed-target kinematics. This will then require state-of-the-art simulations to back up the design and specific R&D actions. Some innovative detector techniques have already been identified as very valuable to progress toward a new generation of fixed target experiment:

- The ultra-granular W+Si calorimetry developed for the International Linear Collider by the CALICE collaboration provides an original imaging approach to calorimetry. This technology has been granted by ANR in 2010 through the CALIIMAX project which purpose is to qualify a complete electromagnetic calorimeter with an unprecedented level of components integration in a pulsed mode. This technology is also envisioned for the CHIC project (Charm in Heavy Ion Collisions) at SPS which goal is to measure the production of the χ_c in heavy ion collisions at SPS energies. Several simulations (see figure below) have already demonstrated that such a technology is very well suited to separate electromagnetic showers in a very busy environment. Since the CHIC project is developed at LLR, we plan to have strong synergy between CHIC, AFTER and CALICE.

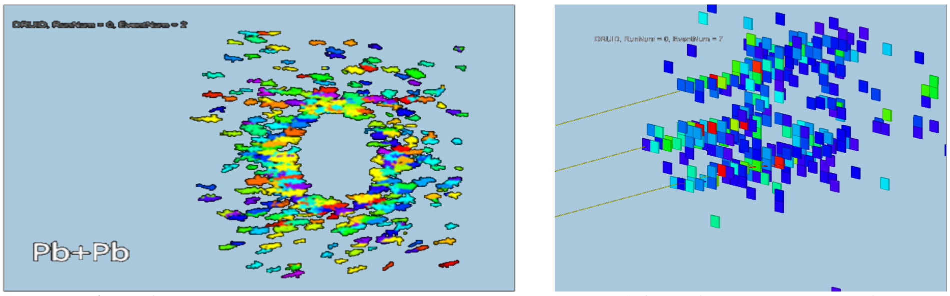


Figure 3 Left: photons occupancy as reconstructed by the CALICE detector in a typical Pb+Pb collision at SPS. Right: performance of the calorimeter in shower separation; three photons separated by a 2cm distance when impacting the detector.

- The ALICE CMOS technology…. **to be written by Andry. Synergy between ALICE, CHIC and AFTER must appear. It would be good to show some simulation results**
-

The target-rapidity domain is particularly interesting for ion-nucleus collisions since it cannot be accessed in ion-ion colliders and may thus reveal new insights into the formation of the quark-gluon plasma. In addition, detectors need to be designed to detect particles produced in the target-rapidity domain, for example dilepton pair to measure PDF at large target x_B or new baryons containing heavy quarks. Our project would become even more competitive is we can prove that we are able to detect single and double diffractive reactions where the target proton or nucleus remains intact in order to access the gluon-rich phenomenology of diffractive processes or to study, for the first time, ultra-peripheral collisions in a fixed-target mode. The fixed target facility could also be designed to provide high energy secondary hadron beams and this surely also deserve some attention in our future investigations.

The extraction of the high-energy LHC beams in a form usable for fixed-target experiments brings extraordinary challenges for particle and accelerator physics, including efficient extraction, and radiation issues.

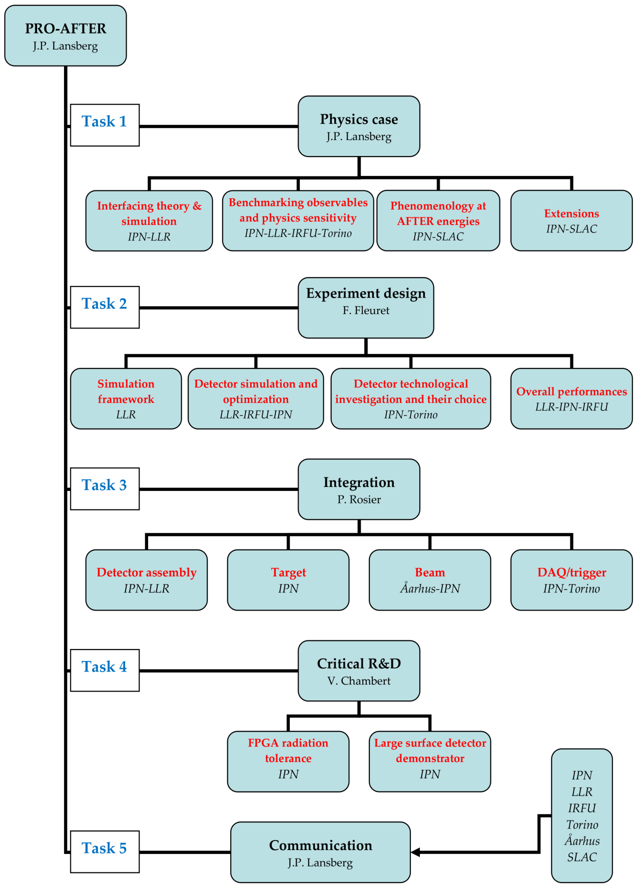
3. SCIENTIFIC AND TECHNICAL PROGRAMME, PROJECT ORGANISATION

3.1. SCIENTIFIC PROGRAMME, PROJECT STRUCTURE

The principal objective of this project is to promote the benefit of a fixed target program with the extracted 7 TeV LHC beam towards in particular, among many other accessible subjects, a very precise study of the QCD evanescence regime, the QCD at large xB and of the Cold Nuclear Matter effects which affect the production of many mechanisms in proton-nucleus collisions. The main output will be a Conceptual Design Report which will include the following items:

In order to improve the efficiency of our investigations, we have structured the proposal in 5 tasks :

1. Physics case
2. Experimental design
3. Integration
4. Critical R&D
5. Communication



These five tasks will involve participants from the different partners and will require regular contact to perform the different activites which we have identified

We have identified x milestones …

After an initial scientific paper on the potential offered by a fixed target experiment on the LHC co-signed by three participants of the proposal and Pr. S.J. Brodsky (SLAC, Stanford U.) to be submitted for publications.

Nevertheless, some specification in spring, our activities will focus on ...
c and more involved studies including discussions on the decision on the orientation of the project will require more intense discussions at some point.

Lastly, we plan to advertise our ideas in international conferences.

First communications have already been delivered by J.P.Lansberg in international conference last year. We plan to increase our visibility in the community via further participation to international conferences and also through more topical seminars. We have already organized two one-day workshop in Orsay in the framework of French Research Network Hadronic Physics and Quantum Chromodynamics (GDR Physique Hadronique et Chromodynamique Quantique).

We plan to continue to organize regular one-day meeting each trimester with expert from outside the consortium in addition to 3 workshops (one of the physics case, one of the simulation, one for the integration) involving a larger numbers of participants, expert in the corresponding fields.

3.2. Project management

3.2.1 Coordination of the scientific activities

As described above, the scientific activities are grouped in 5 tasks. All the tasks depend on inputs or outputs for at least another and most on two or three. This calls for an efficient coordination between the activities, especially for activities carried out only by one partner.

For the work done by the French partners (all within 10km), we thus plan to have monthly meeting where the work progress will be presented. This is important for the integration of the postdocs. Our 3 labs benefit from video conference system which will be used to allow for the co-partner members to join these meetings.

Each trimester the task coordinators will meet to discuss the progress. Since the tasks are time-dependent, they could adapt the proposal timeline if they expect a work to be finished late or early. The minute of the meeting will be made available to all the participants via a wiki-type website. This is particularly relevant for activities for which various expertises are required and where suggestions should be first shared between all the concerned members before attacking practical problems.

Each semester, we plan to organize more formal and larger meeting open to external participants upon invitation (for instance, experts to discuss specific issues) or to colleagues that would join our effort during the 4 years of the proposal. This will be the occasion for the post-docs to present preliminary results and to prepare the writing of the conceptual design report (and the mid-term report). Such meeting will be important to keep all the members informed on the project progress such that everyone would deliver attractive communications in international workshops and conferences.

3.2.2 Management of the human resources (post-docs)

Their recruitment procedure will be as follows: for each topic (three post-docs should be recruited during the time of the project, each of them in a different topic), an international job offer will be made, using « spires » website as well as each of the partners website.

All application folders will be made accessible electronically to each permanent member of the french partner. For each topic, three permanent members will have the responsibility to establish independently a short list of preferred candidates. If needed, candidates will be invited for an interview. The main emphasis will be made on the scientific level of the candidates, and on the adequacy to the project. In particular the real motivation of the candidate for the proposed project will be very important for the final decision.It will be eventually taken by the coordinator of the partner by which the post-doc will hired.

3.2.3 Management of the financial resources

Each partner will have a minimal budget to help members to attend workshops, conferences and to travel in order to meet experts, as well as invitation money to benefit from the expertise of colleagues in the field by organizing short visits or one month stays in their laboratory. Each partner coordinator will be responsible for the use of this part of the budget.

The budget to organized the 3 milestone workshops will be managed by IPNO, although we plan to organize them with the local help of the 3 french partner and the scientific support of the foreign co-partner.

3.3. Description by task

3.3.1 Task 1 : Physics case

The coordinator for this task is J.P. Lansberg. It will involve all the French partners (IPNO, LLR and IRFU) and will benefit from the beginning from the participation of Prof. S.J. Brodsky from the associated partner « SLAC ». Additional contributions from colleagues external to the proposal is very likely, though not formalized yet at the moment of the proposal submission. The aim is to work out the detail of the strongest physics case possible in adequacy with the input of task 2 « Experimental design ». This will imply a constant interaction between these tasks and justify the participation of members in both tasks.

<u>Livrables :</u> publication in international refereed journal for activities B. and C. ; chapter(s) for the Conceptual Design Report (CDR), see task 5.

- *A. Interfacing theory and simulation*

For observables which are already recognized as benchmarks for the accomplishment of the overall project, we will work at the generation of events feeding in the simulation of task 2. In particular, we can mention basic QCD reactions such as the prediction of Drell-Yan pais, J/ψ and Υ, heavy quarks, isolated photons. To do so, we would preferentially use Monte-Carlo tools such as Madgraph (and its extension to quarkonia, MadOnia), Pythia, Herwig, EPOS, …

In case we have to tackle with processes where existing codes are known not to be sufficient, e.g. where NLO and NNLO corrections are needed, we would envision to provide instead functional forms for the signal that may be encoded in the simulation framework of task 2. For quarkonia, a special attention will also be drawn on polarization degrees of freedom.

Milestones : Event generation for Task 2 for key processes ; Interface of information beyond the cross section to the simulation ; Event generation for Task 2 for processes newly identified in activity C or benchmarked in activity B ; Update of event generations after feed-back from Task 2 and 3.

- *B. Benchmarking observables and physics sensitivity*

For studies such as gluon and heavy-quark PDFs in the proton, gluon PDFs in the neutron, nuclear PDFs and spin-related densities, it is important to first determine which probes are best suited in order to draw a hierarchy in the process to be simulated. This requires are prior careful studies of some reactions, let us cite isolated photon, charmonium/ bottomonium and heavy-flavour productions to measure gluon PDF. It may very well be that some reactions bring information in different phase space and thus impose various detection requirements which would be then precisely quantified in the simulation and which can influence the design. It is also relevant to foresee the future improvement in the years to come thanks to other experimental studies when benchmarking observables. This activity is very close to the first one and hence to the task 2.

This activity will also be very important to decide which process should be studied in pp, pA, PbA and/or Pbp collisions, as well as to if the target polarization is worth. This will strongly influence the eventual physics case.

Milestone(s) : Determination of the experimental precision (for Task 2) needed to improve the current knowledge of our key quantities ; Determination of the kinematical where the process should be studied (thus generated in activity 1).

- *C. Phenomenology at AFTER energies*

As mentioned earlier, the collision of the LHC beams with fixed targets, including polarized and nuclei targets, will expand the range of fundamental physics phenomena accessible at similar set-ups. Naturally, it will be necessary to develop a complete phenomenology of the reactions which can be studied as such energies (115 GeV with the 7 TeV p beam and 72 GeV with the 2.76 TeV Pb beam).

Let us cite the detail studies of

- W and Z production cross sections near threshold,
- quarkonium production in the limit $x_F \to 1$,
- production rate of multi-heavy baryon states,
- ultra-peripheral collisions where the target is the photon emitter,
- $\chi_{c,b}$, $\eta_{c,b}$ and associated quarkonium production in pp, pA and PbA collisions,
- etc.

Ideally, this activities will trigger –and then benefit form– the work of other theorists outside the proposal, which would then apply their ideas that a new range of species, energies and luminosities made available by AFTER. We expect the publication of a first letter physics co-signed by 4 members of proposal (S.J. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg) to initiate this process.

Milestone(s) : Determination of the rates and the theoretical uncertainties for the aforementioned key studies, if needed (see task 2 and activities A. and B.) their momentum and angular dependences ; Studies of specific branchings and decay channels .

- *D. Extensions (secondary beams, B physics, neutrino, ...)*

In order to further widen the scope of the physics-case exploration, it is also important to open the door to additional flagships beyond those we have identified. For instance, once the beam is extracted, it can be envisioned to use it to produce ultra high energy secondary beams. Delimiting a physics case for these requires a knowledge beyond the one of the members. Contributions from the outside will be then called for. The same is true for CP violation and neutrino physics. Depending on these external contribution, we would consider enriching the overall physics case of the project.

Milestones : Feasibility study of second beams (in relation with task 2 and 3); Evaluation of interest in relation with activity B and C.

3.3.2 Task 2 : Experimental design

The coordinator for this task is F. Fleuret. It will involve all the french partners (IPNO, LLR and IRFU) and will benefit from the beginning from the participation of members of the associated partner « INFN Torino ».

The goal of this task is to develop a detailed simulation of the apparatus to investigate its performances based on the physics simulations performed in Task 1. PD2 will be in charge of maintaining the full set-up and performing the performances studies in order to optimize the design of the detector.

As a starting point, after having set up the simulation framework (A), we will incorporate the technologies previously mentioned and already identified as promising in the detector simulation (B): the ultra-granular W+Si technology for the calorimetry and the CMOS technology for vertexing/tracking. The other parts of the detector envisioned must be investigated (C) before including in the simulation framework.

Livrables :

- *A. Simulation framework*

To perform this task we will take advantage of the expertise gained by the LLR in the context of Calice/ILC project, where a simulation framework, Mokka (mokka.in2p3.fr), based on GEANT4, has been developed to perform full simulations of the detector. The core idea of Mokka is to serve as a user interface between a geometry database which can be easily modified trough steering files and GEANT4 to simulate the interaction of incoming particles inside the detector. Gabriel Musat, one of the creators of Mokka will be in charge of the development and maintenance of the AFTER project within the Mokka framework. We expect to have a first version of the simulation framework roughly two months after the beginning of the project.

Milestones : fully operational simulation framework after six months

- *B. Detector simulation and optimization*

    - ECAL (coordinator: FF/LLR): the ultra-granular W+Si electromagnetic calorimeter developed by the CALICE collaboration has been simulated at LLR within the Mokka framework. We will take advantage of this expertise to implement the AFTER calorimeter geometry. We will also exploit the Garlic reconstruction code and test its performances in the specific environment of heavy ion collisions (very high multiplicity). This task will be started by FF for the first six months of the project. Then it will be taken in charge by PD2. The results obtained will be discussed with our Calice colleagues in order to optimize the performance of the calorimeter in such a busy environment.

Milestones : first implementation in the simulation framework after six months. Performance studies for the following two years

- VERTEXING/TRACKING (coordinator: AR/IRFU): the CMOS technology spectrometer currently investigated by the ALICE collaboration for the MFT detector will be used. This task will be started by AR for the first six months of the project. Then it will be taken in charge by PD2 who will be in close connection with the ALICE development. To this end, because the ALICE MFT is not as developed as CALICE, PD2 will participate to the ALICE effort for the reconstruction algorithm.

Milestones : first implementation in the simulation framework after six months. Performance studies for the following two years

- *C. Detector technological investigation and their choice*
  - MUON (coordinator: CH/IPN): Several techniques such as Resistive Pad Chambers or micro-megas have already been identified to perform the muon ID/trigger. These techniques still necessitate further investigations before inserting them in the simulation framework. We plan to investigate all the techniques available as well as the possibility to magnetize the Fe absorber in the first year of the project. After one year, the chosen technology will be inserted into the simulation set-up.

Milestones : choice of technology after one year. Implementation and performance studies in the following two years

- HCAL/PID (coordinator: D2I/IPN): to complete the set-up and give access to a large variety of physics process, the capability to measure the energy of high momentum jets as well as the capability to separate charged hadrons are crucial. We haven't yet started any investigation neither for a Hadronic Calorimeter nor for a particle ID detector such as Cerenkov detector. We plan to spend the first two years to investigate these techniques and search for new partners to help us making progress in these tasks. If some partners are identified, these new detectors will be inserted in the simulation framework.

Milestones: identify techniques and partners in the first two years. First simulations and detector optimizations in the following year.

- *D. Overall performance*

The study of the overall performances is a transverse task which will be in close connection with task 1 and task 3. For the first year of the project the performances will be evaluated with the vertex + tracking + calorimeter systems for simple processes such as quarkonia states. When new systems will be added, we will extend the area of investigation to other physics processes.

Milestones : overall performances with vertexing+tracking+calorimetry in the first two years. Then study with muons in the following year. Add other technologies when additional partners are identified.

3.3.3 TASK 3 : INTEGRATION

The coordinator for this task is P. Rosier. It will involve all the french partners (IPNO, LLR and IRFU) and will benefit from the beginning from the participation of members of the associated partner "Aarhus U."

A group composed of several partners will be created and will act for the Integration engineering in the following way:

- participation in the different detectors reviews,
- providing of an environmental inputs for the single detectors,
- keeping of an updated data base as a list of elements,
- check of the interfacing with help of a CAD system, and
- participation in the validation of solutions with the management board.

Livrables :

- *A. Detector assembly*

The IPNO partner (coordinator: P.Rosier) has a long-experience in experiments assembly as for the Di Muon Arm ALICE experiment and others. The resources specialized in mechanical and instrumentation engineering will take in charge the design of the detector framework linked with the beam and with the environment like the hall where could sit the experiment. The livrable will consist in the assembly drawing, feasibility study and assembly procedures of all the detectors concepts in respect with the physicist's requirements.

Milestones : The activity will follow the detector reviews and the feasibility study report will be written for the conceptual design report.

- *B. Target*

[TO BE CHECKED : WRITTEN BY A NON EXPERT : JPL]
We plan to investigate on the various possible types of target (e.g. active or not). In particular, we will carefully look at the consequence on the vertex detector size – and thus cost–, the acceptance limitation in the backward and forward regions as well as the versatility to change the species. We expect to be able to make a choice of target type after one year and to insert the target characteristic (length, species, ...) in the simulation setup.

Several techniques for the polarizing the target exist, we plan to analyze and quantify carefully the advantage and disadvantage of each as regards the figure of merit of the polarization, the relaxation time, the aperture of the target window – especially relevant for measurement in the target-rapidity region– and the consequence on the detector geometry. We will also search for new partners to help us making progress in this task. When some partners are identified, the polarization parameter of the target will be inserted in the simulation framework.

Ask JP Didelez.

Milestones :

- *C. Beam*

A priori contribution by Ulrik Uggerhoej to be written

Milestones :

- *D. DAQ/Trigger*

contribution by J. Peyré. to be written

Milestones :

3.3.4 Task 4 : Critical R&D

The coordinator for this task is V. Chambert. It will mainly involve IPNO which will carry out the tests. However, the other partners will be involved ….

Coordination ; Partners ; livrables

to be written

Livrables :

- *A. FPGA radiation tolerance*

V. Chambert to be written

Milestones :

- *B. Large surface detector demonstrator*

B. Genolini to be written

Milestones :

3.3.5 Task 5 : Communication

The coordinator for this task is J.P. Lansberg. It will naturally involve all the french partners and the associated partners.
to be written

Livrables :

- *A. Advertizing the project*

Aim to advertise our project all over the world-physics community to create an experimental collaboration large enough to make this project viable and fruitful for the years to come.

to be written
In parallel to this, we will reinforce the contacts already established with beam experts at CERN.

- *B. CDR writing*

to be written
Pheno first, then generic sim, then advance simu, then integration
to be written

3.3.6 TASK-CONNECTION SUMMARY

Fig. 5 (left) summarizes the connection between tasks with the corresponding responsibilities. All 5 tasks will contribute to the dissemination through the CDR. The physics case will give (event generation) and receive inputs (kinematical cuts, ...) from the design task. The design will then feed information in the integration task (detector geometry, ...) from which it will receive feed-back (constrains, performance) as well as from the result of the critical R&D activities (technology choice, constrains...).

3.4. TASKS SCHEDULE, DELIVERABLES AND MILESTONES

The tasks schedule is summarized in the Fig 5 (right).

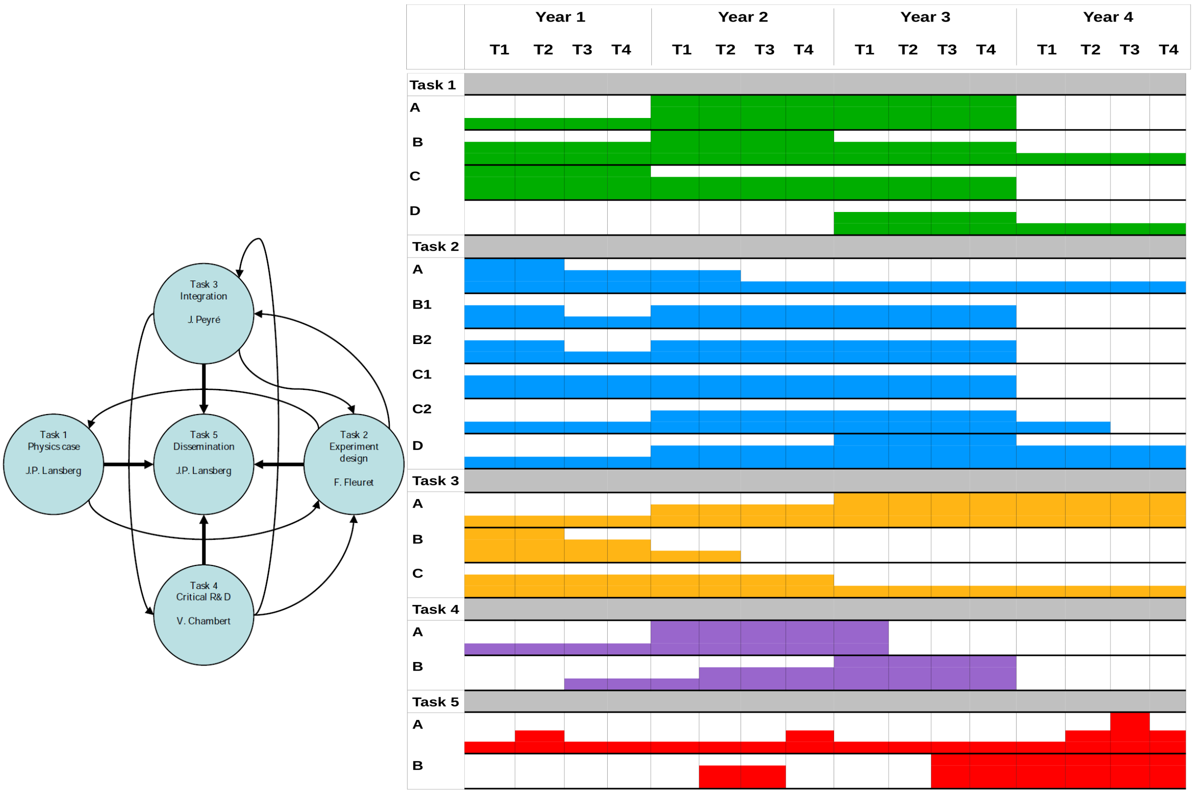


Fig 5. left: Task-connection summary; right: task and activity timeline

4. DISSEMINATION AND EXPLOITATION OF RESULTS. INTELLECTUAL PROPERTY

The obtained results will be published in peer reviewed journals and communicated in international conferences.

Part of the budget will be devoted to the participation to conferences.

We will in particular enforce the participation of PhD students and post-docs to national and international conferences to increase their visibility.

Post-docs and students should benefit from the project .

Since several promising junior scientist are members of the project, the time scale of four years should give them the opportunity of increasing their visibility, in particular by taking the responsibility of part of the project, by training PhD students and post-docs, and by getting the financial support in order to push their own ideas and projects.

The project should also be the basis of stronger links with foreign countries with which collaboration either are running since years, or will be developed based on the project. The on-going collaboration are with Italy, Spain, Belgium, USA, Germany.

Future collaborations are expected with China.

to be written

5. CONSORTIUM DESCRIPTION

5.1. PARTNERS DESCRIPTION & RELEVANCE, COMPLEMENTARITY

to be written
We would like to emphasize the facts that our proposal involves outstanding issues at the junction between particle physics and nuclear physics, but also involving expertises from three different communities,

Research programs involving two of three communities are common, much less when they involves the three.

Our proposal also involves young permanent researchers … combined with the expertise of senior researchers.

This should impulse a renewal in the QCD and hadron physics community, and will certainly have an important impact in the support of the experimental efforts during the next decade.

We now present the various members of the 3 partners, with their participation to the project and their expertises.

Partner 1: IPNO

This partner gathers members of an institute with a long-standing tradition in the study of hadronic physics, both a medium energies at GSI (PANDA) and JLab (CLAS) and at high energies at BNL-RHIC (PHENIX) and CERN (NA50 & ALICE).

J.P. Lansberg is a specialist of phenomenology of QCD, in particular quarkonium physics. He has strong interests in the connection between theoretical and experimental particle physics. He supervises 2 postdocs, J. Albacete who works on …, and C. Lorcé who works on … During the first year of the project, they will both contribute to the physics case with theoretical and phenomenological works

C.Hadjidakis is a specialist of experimental hadronic physics between particle and nuclear physics. She worked on exclusive reactions for the CLAS and HERMES collaborations and now on heavy-ion collisions for ALICE at the LHC.

The laboratory also benefits from a very strong technical division expertised in cutting edge experimental technologies proved by the excellent contribution to the aforementioned experiments.

to be written
V. Chambert, the head of the instrumentation and computing division of IPNO (which gather more than xx people), D2I, is an expert on … Her group contributed to … of ALICE and to … of CLAS.

B. Genolini

P. Rosier the head of IPNO Detector R&D group

J. Peyré, the former head of IPNO D2I,

J.P. Didelez is a world expert on target polarization.

All the members of IPNO working on this project have regular meetings, ...

Partner 2: LLR

This partner gathers members of an institute with a long-standing tradition in the study of …
to be written

Partner 3: IRFU

This partner gathers members of an institute with a long-standing tradition in the study of …
to be written

Partner 4: INFN Torino

This partner gathers members of an institute with a long-standing tradition in the study of …
to be written

Partner 5: Physics Dept. Aarhus U.

This partner gathers members of an institute with a long-standing tradition in the study of …
to be written

Partner 5: SLAC National Laboratory, Stanford U.

This partner is represented by Prof. Stanley. J. Brodsky who is worldwide renowned expert on particle physics, and particularly on hadronic physics, author of more than 500 papers with more than 30000 citations. He is the principal investigator for SLAC for a Stanford-

France proposal on AFTER with F. Fleuret, C. Hadjidakis and F. Fleuret. He is therefore a very natural support for our proposal.

5.2. Qualification of the project coordinator

J.P. Lansberg, 34 years old, is first class CNRS associate researcher at IPNO. After postdocs in Ecole Polytechnique (France), Heidelberg (Germany) and Stanford (USA), he has been hired by CNRS in 2010.

He is an expert in perturbative QCD and in phenomenology of strong interaction, in particular in the production of heavy-quark bound states. He is now supervising two post-docs on this subject.

He has organized 4 international workshops for which he was also the editor of the proceedings. He is the principal investigator for the French side of a Stanford-France project on AFTER. He is principal investigator for the French side for a FCCPL and a IN2P3-COPIN project on quarkonium physics. He has also been elected as a representative of the IPNO institute council and is the convener of the working group « Electron-ion colliders and future experimental project » of the GDR PH-QCD. Finally, he is contributing to the long-term prospectives of both IPNO and IN2P3-IRFU.

During his postdoc in Stanford, he started to discuss with S.J. Brodsky (SLAC) and F. Fleuret (LLR) the opportunity of proposing a fixed-target experiment on the LHC beams. He has delivered five talks last year on this project in international conferences and has been therefore naturally chosen by the members of the projects as the coordinator.

5.3. Qualification and contribution of each partner

Partner **IPNO**	Name	First name	Position	PM	Contribution to the project
Responsible	LANSBERG	Jean-Philipe	CR1 CNRS	20	Project coordinator ; Coordinator for the tasks: « Physics case « and « Communication »
Other members	HADJIDAKIS	Cynthia	CR2 CNRS	10	Detector technological investigations : muons
	DIDELEZ	Jean-Pierre	DR1 CNRS emeritus	5	Target polarization
	CHAMBERT	Valérie	IR1 CNRS / Director of IPNO Instrumentation & computing division	12	Coordinator for the task « Critical R&D » ; Detector assembly : electronics
	GENOLINI	Bernard	IR1 CNRS	12	Detector assembly : detection ; Detector technological investigations : HCal/PID
	ROSIER	Philippe	IR1 CNRS / Head of IPNO Detector R&D group	7	Coordinator for the task « Integration » ; Detector assembly : mechanics
	PEYRE	Jean	IRHC CNRS	7	Detector assembly : DAG/Trigger
	ZERGUERRAS	Thomas	IR2 CNRS	9	Large surface detector demonstrator

	KY	Beng-Yun	IE2 CNRS	6	FPGA radiation tolerance test
	Computer	engineer	IR2 CNRS	3	FPGA radiation tolerance test
	OZIOL	Christophe	IE1C CNRS	1	Board drawing for FPGA radiation tolerance test
				?	UPC ?
	ALBACETE	Javier	Postdoc CNRS	2	Physics case : pA collisions, CGC, initial state condition for QGP
	LORCE	Cédric	Postdoc Paris-Sud	3	Physics case ; spin physics and exclusive processes

Partner **LLR**	Name	First name	Position	PM	Contribution to the project
Responsable	FLEURET	Frédéric	DR2 CNRS	20	Coordinator for the task «Experiment design» ; Detector simulation & optimization : Electromagnetic calorimeter
Other members	MUSAT	Gabriel	IR2 CNRS	5	Simulation framework

Partner **IRFU**	Name	First name	Position	PM	Contribution to the project
Responsable	RAKOTOZAFINDRABE	Andry	xx-CEA	12	Detector simulation & optimization : Vertex / tracking

Co-partner **INFN Turin**	Name	First name	Position	PM	Contribution to the project
Responsable	xx	xx	xx	xx	
Other members	xx	xx	xx	xx	

Co-partner **Aarhus U.**	Name	First name	Position	PM	Contribution to the project
Responsable	xx	xx	xx	xx	
Other members	xx	xx	Xx	xx	

Co-partner **SLAC**	Name	First name	Position	PM	Contribution to the project
Responsable	BRODSKY	Stanley J.	Professor	5	Physics : phenomenology and extension

* à renseigner uniquement pour les Sciences Humaines et Sociales
** à renseigner par rapport à la durée totale du projet

Participation to other contracts:

	Name	PM	Project name, financing institution, grant allocated	Project title	coordinator name	Start and end dates

N°	F. Fleuret, C.Hadjidakis, J.P.Lansberg,	2, 1, 2	Stanford-France Center for Interdisciplanry studies, 8000$ for a year	High-energy physics with a fixed target experiment using the multi-TeV proton and nuclear LHC beams : motivation, simulation and feasibility	J.P. Lansberg & S.J.Brodsky	05/11 → 05/12
N°						

6. Scientific justification of requested ressources

to be written

As much as possible, the 3 postdocs which should be hired will share his/her 2 year presence between two (out of the three) french laboratories involved.

so that it will strengthen the relations between permanent members of these teams. Besides, on the administrative side, each of the three post-doc will be payed by a single laboratory during his two years stay, although he will belong to two laboratories.

He/she will benefit of practical facilities (visiting office and computer access) to spend working time in other laboratories involved in the project when needed for the realization of the project.

to be written

6.1. Partner 1 : IPNO Equipment

1. *Equipment*

Equipement for critical R&D activities :

- FPGA test : 12 000 €
- Demonstrator 40 000 € (too much ?)

2. *Staff*

A 2-year postdoc for the physics-case task (event generation, specific phenomenological developments, Technical Design Report writing)

A 1-year postdoc or engineer position for the Integration task

[Fournir les profils à pourvoir pour les personnels à recruter]

3. *Subcontracting*

4. *Travel*

10000 €/year travel in (invitation)

Long-term invitations for senior experts (physics case, design, integration, critical R&D, Communication) : 2 x 1 month /year : 5000€

Short-term invitations for seminar and discussion with experts (physics case, design, integration): 5 x 1 week /year : 2500€

10000 €/year travel out (mission)

Shift (critical R&D) : 1k€/year

Conferences : 7k€/year (Participation to workshop and conferences abroad to advertize the project, to meet experts to received their feedback and to present our results)

Workshop organization for the whole project : 3 x 10 000€

Quick-off meeting (early 2013)
Mid-term meeting (mid 2014)
Conclusion meeting (end 2016)

TOTAL : 110k€

5. *Costs justified by internal procedures of invoicing*

6. *Other expenses*

6.2. Partner 2 : LLR

1. *Equipment*

2. *Staff*

3. *Subcontracting*

4. *Travel*

3000 €/year travel in (invitation)

Long-term invitations for senior experts (physics case, design, integration) : 1 x 1 month /year : 2500€

Short-term invitations for seminar and discussion with experts (physics case, design, integration): 2 x 1 week /year : 500€

2000 €/year travel out (mission)

Conferences : 2k€/year (Participation to workshop and conferences abroad to advertize the project, to meet experts to received their feedback and to present our results)

TOTAL : 20 k€

5. Costs justified by internal procedures of invoicing

6. Other expenses

6.3. Partner 1 : IRFU

1. Equipment

2. Staff

One-yea out of the three year for the postdoc the dectector design

3. Subcontracting

4. Travel

1500 €/year travel in (invitation)

Long-term invitations for senior experts (physics case, design, integration) : 1 x 1/2 month /year : 1250€ (1 month / 2years)

Short-term invitations for seminar and discussion with experts (physics case, design, integration): 1 x 1 week /year : 250€

500 €/year travel out (mission)

Conference : 0.5k€/year (Participation to a workshop to meet experts to received their feedback and to present our results)

TOTAL : 8 k€

5. Costs justified by internal procedures of invoicing

6. Other expenses

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Note importante : les annexes éventuelles au document scientifique doivent être déposées sur le système de soumission sous forme de documents séparés.