ERC - CENNS and RICOCHET

PROBING NEW PHYSICS WITH COHERENT ELASTIC NEUTRINO-NUCLEUS SCATTERING AND THE FUTURE RICOCHET EXPERIMENT

RICOCHET

- **IN2P3 Scientific coordinator:** *J. Billard* (IPNL)
- **Local coordinators:**
  S. Marnieros (CSNSM) and *J. Billard* (IPNL)

CENNS: ERC Starting Grant 2018

- **PI:** *J. Billard* (IPNL)
- **Awarded in July 2018**
- Will last from Feb. 2019 to Feb. 2024

RÉSUMÉ

Ever since the Higgs boson was discovered at the LHC in 2012, we had the confirmation that the Standard Model (SM) of particle physics has to be extended. In parallel, the long lasting Dark Matter (DM) problem, supported by a wealth of evidence ranging from precision cosmology to local astrophysical observations, has been suggesting that new particles should exist. Unfortunately, neither the LHC nor the DM dedicated experiments have significantly detected any exotic signals pointing toward a particular new physics extension of the SM so far.

With this research program, we want to take a new path in the quest of new physics searches by providing the first high-precision measurement of the neutral current Coherent Elastic Neutrino-Nucleus Scattering (CENNS). By focusing on the sub-100 eV CENNS induced nuclear recoils, the goal is to reach unprecedented sensitivities to various exotic physics scenarios with major implications from cosmology to particle physics, beyond the reach of existing particle physics experiments. These include for instance the existence of sterile neutrinos and of new mediators, that could be related to the DM problem, and the possibility of Non Standard Interactions that would have tremendous implications on the global neutrino physics program.

To this end, we propose to build a kg-scale cryogenic tabletop neutrino experiment with outstanding sensitivity to low-energy nuclear recoils, called CRYOCUBE, that will be deployed at an optimal nuclear reactor site within the forthcoming RICOCHET neutrino experiment. The key feature of this proposed detector technology is to combine two target materials: Ge-semiconductor and Zn-superconducting metal. We hence want to push these two detector techniques beyond the state-of-the-art performance to reach sub-100 eV energy thresholds with unparalleled background rejection capabilities.

As the proposed CRYOCUBE detector is expected to reach a 5-sigma level CENNS detection significance in a single day, it will be uniquely positioned to probe new physics extensions beyond the SM after only one year of data taking.

The ERC - CENNS research program takes place within the forthcoming RICOCHET low-energy neutrino observatory, that aims at achieving a percentage-level measurement of the CENNS process at the sub-100 eV energy-scale, by combining various detector technologies and target materials. Nowadays, the international collaboration RICOCHET includes members from France (CNRS/IN2P3 - IPNL and CSNSM) and the USA (MIT, Northwestern U. and Wisconsin U.), and benefits from strong synergies with the EDELWEISS and SuperCDMS international collaborations.

1. ENJEUX SCIENTIFIQUES

Neutrinos continue to be a source of scientific wonder in nuclear physics, particle physics, and cosmology. Although much has been learned about the properties of neutrinos, much still pleads for more experimental investigation. What is the scale and structure of neutrino masses? Are neutrinos their own antiparticle? Even a question as simple as whether there are more than three types of neutrinos is the source of serious scientific debate. The answers to these questions are not simply for their own sake; they have significant ramifications as to how we construct our description of the Standard Model (SM) of particle physics and could be the gateway for an entirely new physics paradigm. Over the last decades, various experimental efforts based on a host of techniques and neutrino sources have led to two major conclusions: **i) neutrinos have a mass**, and **ii) they have significant mixing with each other**. Therefore, starting from almost no knowledge about the neutrino sector twenty years ago, we have built a robust, simple, three-flavor paradigm which successfully describes most of the data. However, despite these major breakthroughs, further experimental investigations based on new experimental techniques and unexplored neutrino processes are still dramatically needed to go beyond the SM which, we know from precision cosmology and particle physics, has to be extended.

The measurement of Coherent Elastic Neutrino-Nucleus Scattering (CENNS) has been a holy grail in neutrino physics since its prediction almost 40 years ago [1]. This elastic scattering, inducing sub-keV nuclear recoils, proceeds via the neutral weak current and benefits from a coherent enhancement proportional to the square of the number of nucleons (A^2), suggesting that even a kg-scale tabletop experiment will observe a sizable neutrino signal. This opens the possibility to probe the neutrino sector with orders of magnitude smaller experiments than current and planned kiloton-scale ones with a new approach. The full coherence condition, when the wavelength of the scattering is longer than the size of the nucleus, is guaranteed for nearly all nuclear targets when neutrino energies are below ~10 MeV. Such neutrinos are produced in copious amounts in the Sun and at nuclear power reactors.

In August 2017, the COHERENT experiment located at the Spallation Neutron Source (SNS) in Oak Ridge, emitting relatively high energy neutrinos (~50 MeV), has reported the first CENNS detection at the ~7-sigma level [2]. This first result was based only on their CsI[Na] detectors, cumulating a total target mass of 14.6 kg, with an energy threshold of ~4.25 keV. Even though this first detection has only limited sensitivity to new physics, it has proven the existence of this new neutrino detection channel that opens the door to a myriad of new scientific opportunities that will be explored within this research program:

The Neutrino-Magnetic Moment (NMM): as neutrinos oscillate, they must have a non-vanishing mass and sufficiently large mixing with each other. In the case of a Dirac neutrino, the minimal extension of the standard model leads to a small but nonzero neutrino magnetic moment of about 10^{-19} μ_B (Bohr magneton). This theoretical limit is orders of magnitude below the most stringent ground-based limit from GEMMA $\mu_\nu <$ 2.9×10^{-11} μ_B (90% C.L.) [3]. However, in some more general extensions, including new physics at the TeV-scale, the NMM can be as high as 10^{-15} μ_B and 10^{-12} μ_B for Dirac and Majorana neutrinos respectively [4]. Therefore, the observation of an anomalously large NMM, inducing sub-100 eV CENNS spectral distortions, would unambiguously lead to two major conclusions: **1) there is new physics**, and **2) neutrinos are Majorana fermions**; which will have tremendous implications on the global neutrino physics program. *The goal is to provide the first CENNS-based NMM limit down to* $\mu_\nu \sim 10^{-11}$ μ_B *(90% C.L.) by 2024.*

Searching for new massive mediators: the Coherent Elastic Neutrino-Nucleus Scattering is done through the exchange of the Standard Model *Z* boson. Plausible extensions of the SM suggest the presence of an additional vector mediator boson [5], that couples both to the neutrinos and the quarks, called *Z'*. The latter could therefore interfere with the standard CENNS process and modify the observed effective weak nuclear hyper-charge. Fig. 1 (left panel) presents the anticipated 90% C.L. upper limit on the *Z'* coupling that we aim to achieve by the end of this research program. Unlike fixed target (APEX [6]) or collider-style (LHC dielectron searches [7]) experiments, CENNS-based experiments have the unique possibility to scan any *Z'* masses. As the constraint on the *Z'* coupling evolves as $(\text{exposure})^{1/4}$ if not background limited, the CRYOCUBE key feature is its sub-100 eV energy threshold combined with its significant background rejection. *Eventually, we see that within a year, the proposed CRYOCUBE detector will improve by about two orders of magnitude over the current COHERENT result [2].*

Searching for Non Standard Interactions (NSI): new physics that is specific to neutrino-nucleon interaction is currently quite poorly constrained, and is motivated in some beyond-SM scenarios [8]. In the context of a model independent effective field theory, the Lagrangian describing the neutrino-nucleon interaction leads to NSI operators which can either enhance or suppress the CENNS event rate. Fig. 1 (right

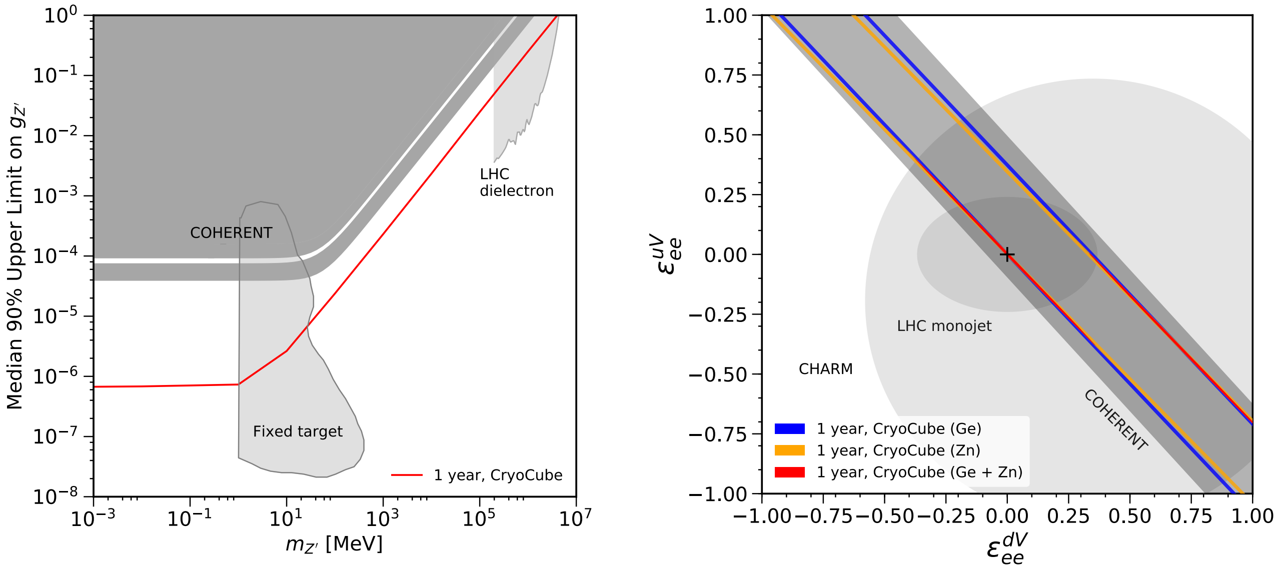

Figure 1 - Projected sensitivities of the CryoCube detector to new physics searches in the low-energy CENNS sector where a 50 eV energy threshold and an electromagnetic background rejection power of 10^3 *is assumed (see Work Package 1)*. ***Left***: constraints on Z' searches assuming unified coupling to the quarks. The results are shown as 90% C.L. upper limits on the Z' coupling. Also presented are current leading constraints from the APEX fixed target experiment [6], LHC dielectron searches [7], and COHERENT [2]. ***Right*****:** constraints on Non-Standard neutrino-quark Interactions in the neutrino-electron sector. Results are shown as 90% C.L. allowed regions. Also shown are current experimental constraints from LHC mono-jet searches [10], CHARM [9], and COHERENT [2]. The cross represents the Standard Model. Figures adapted from [12].

panel) shows the 90% C.L. allowed regions derived from several particle physics experiments including CHARM [9], LHC mono-jet searches [10], the recent COHERENT result [2], and the CryoCube anticipated sensitivity. The CryoCube result is shown as: Ge only (blue), Zn only (orange), and Ge + Zn combined (red). Due to the interferences between the couplings, CENNS constraints lead to two allowed regions (not visible for COHERENT as they overlap). We can therefore appreciate the complementarity between these two targets which breaks the degeneracy along the up- and down-quark neutrino-electron couplings. Such neutral current NSI constraints, as expected from CryoCube, will be mandatory to future long-baseline experiments exploring the neutrino mass hierarchy, *e.g.* DUNE [11]. *After only one year of data taking, the goal is to reach sensitivities to potential NSI two orders of magnitude stronger than existing ones.*

2. PROJET

In the following, we first give a brief description of the future Ricochet experiment that will host the CryoCube detector array, and then present in detail the ERC - CENNS research program.

Ricochet is a newly formed international collaboration that aims at building the first low-energy CENNS neutrino observatory dedicated to physics beyond the Standard Model [13]. As of today, it is a USA (Massachusetts Institute of Technology, Northwestern University, and University of Wisconsin) and France (IPNL and CSNSM) wide collaboration which began in 2012. Since November 2017, Ricochet is officially a master project of the IN2P3. The CNRS local coordinators of Ricochet are respectively S. Marnieros and J. Billard from the CSNSM and the IPNL. *The first key feature* of the Ricochet program, compared to other planned or ongoing CENNS projects, is to aim for a kg-scale experiment with unparalleled background rejection down to the $O(10)$ eV energy threshold. *The second key feature* is to combine several targets (Ge, Si, Zn and Os) and cryogenic detector techniques to benefit from target complementarity in the quest of new physics searches.

Within the CENNS - ERC research program, the French Ricochet groups (CNRS/IN2P3 - IPNL and CSNSM) will develop a novel detector design (CryoCube) to be integrated into the Ricochet cryostat among other cryogenic detector devices developed by two other Ricochet groups, MIT and Northwestern University. Therefore, a parallel effort to the CENNS - ERC research program, dedicated to setting up the future Ricochet low-energy neutrino observatory, is also ongoing. This parallel task, that benefits from the effort of all the existing and **future** groups within the Ricochet international collaboration, includes:

- *Defining the optimal nuclear reactor experimental site* : for now the sites under consideration are ***1)*** a shallow site located 80 meters away from the two 4.25 GW nuclear reactors of the Chooz power plant

(France) [14], ***2)*** the near hall of the Double Chooz experiment [13] (400 meters away from the two reactors), and ***3)*** the MIT research reactor which has a shallow site located few meters away from a 5.5 MW nuclear reactor [15]. *Other potential sites are also being investigated both in France and the USA.*

- *Designing the experimental setup:* cryogenic needs and cryostat design, 300K-to-1K cabling, passive shielding strategy, muon veto, data acquisition system and data processing pipeline.

CENNS - ERC: RESEARCH PROGRAM

The ERC starting grant CENNS, ***awarded in July 2018***, has two objectives:

1) Develop a new detector technology dedicated to CENNS, called CRYOCUBE, with unprecedented sensitivity to low-energy nuclear recoils ***(2019 - 2022)***.
2) Achieve a percentage-level precision CENNS measurement down to the O(10) eV energy-scale leading to unparalleled sensitivities to various new physics scenarios ***(2022 - 2024)***. This second objective will follow the integration of the CRYOCUBE detector into the forthcoming RICOCHET experiment in 2022.

The success of this project relies on a challenging 5-year research program subdivided into three interconnected work packages (WP). The first two WP are driven by **detector technology innovation** while the third one focuses on **the science of CENNS**.

WP 1: Single crystal detector design - The objective of this first package is to reach $O(10)$ eV energy threshold combined with $O(10^3)$ background rejection power with a single 30-gram crystal for both technologies envisioned: Ge-semiconductor and Zn-superconducting metals.

1) Each single crystal detector, Ge and Zn, will be instrumented with dedicated heat sensors expected to lead to ~50 eV energy thresholds for both 30-gram Ge- and Zn-crystals [16].
2) In Ge-semiconductor, the background rejection is done by measuring both the heat and ionization energies which ratio depends on the nature of the interacting particle: electronic recoil (backgrounds) or nuclear recoil (CENNS signal). The plan is to reach ~10 eV (RMS) ionization resolution to provide a rejection power of 10^3 down to the energy threshold thanks to low-capacitance inter-digited electrodes combined with to-be-designed HEMT-(High Electron Mobility Transistor) preamplifiers [17] (see WP 2).
3) In Zn-detector, due to the vanishing quasiparticle-phonon coupling in superconducting metals below ~100 mK and the difference in thermalization processes between electronic recoil backgrounds and CENNS-induced nuclear recoils, we expect vastly different heat pulse shapes between these two populations of events [18].

WP 2: From a single crystal to a CRYOCUBE detector array - The objective of this second package, that will start in 2019, is to develop the CRYOCUBE detector, *i.e.* an array of 30-gram cryogenic detectors with outstanding performance, cumulating to a total target material mass of about 1 kilogram.

1) The CRYOCUBE solution proposed here consists in an array of 3 x 3 x 3 = 27 single 30-gram Ge and Zn highly performing crystal detectors packed together following a Rubik's cube like topology in a 8 x 8 x 8 cm^3 radio-pure infrared-tight copper box. Based on recent work, the CRYOCUBE will have its own cryogenic suspension system to ensure that the detectors will be running in optimal conditions [19].
2) To ensure optimal energy resolutions in both heat and ionization we will develop new HEMT-preamplifiers, based on previous work [17], which are known to have the lowest current noise [20]. As they can be operated at 1 K, they can be mounted very near the detectors, hence minimizing the stray capacitance of the cabling down to 10 pF, as targeted for the energy resolutions discussed in WP 1.

WP 3: Precision measurement of CENNS - After completion of WP 1 & 2 (by 2022), the objective of this third work package is to provide the first high precision measurement of the CENNS process down to $O(10)$ eV and derive world-leading constraints on various exotic models.

1) By the end of 2022, after the detector has been installed in the RICOCHET cryostat, a careful commissioning is mandatory. We will therefore develop an in-situ calibration technique based on a multiple detector coincidence approach using low-energy mono-energetic neutron sources such as Y/Be (152 keV) and Sb/Be (23 keV) that should provide calibration systematics down to the %-level.
2) From various envisioned sites, after a single day of data taking, we expect to reach a ~5-sigma CENNS detection level. After a few months we will provide world-leading sensitivities to a wealth of new physics scenarios thanks to this promising and yet-to-be-explored neutrino detection mechanism. This task will then focus on the science data analysis that will predominantly be done by the students and postdocs.

3. GENÈSE ET CALENDRIER

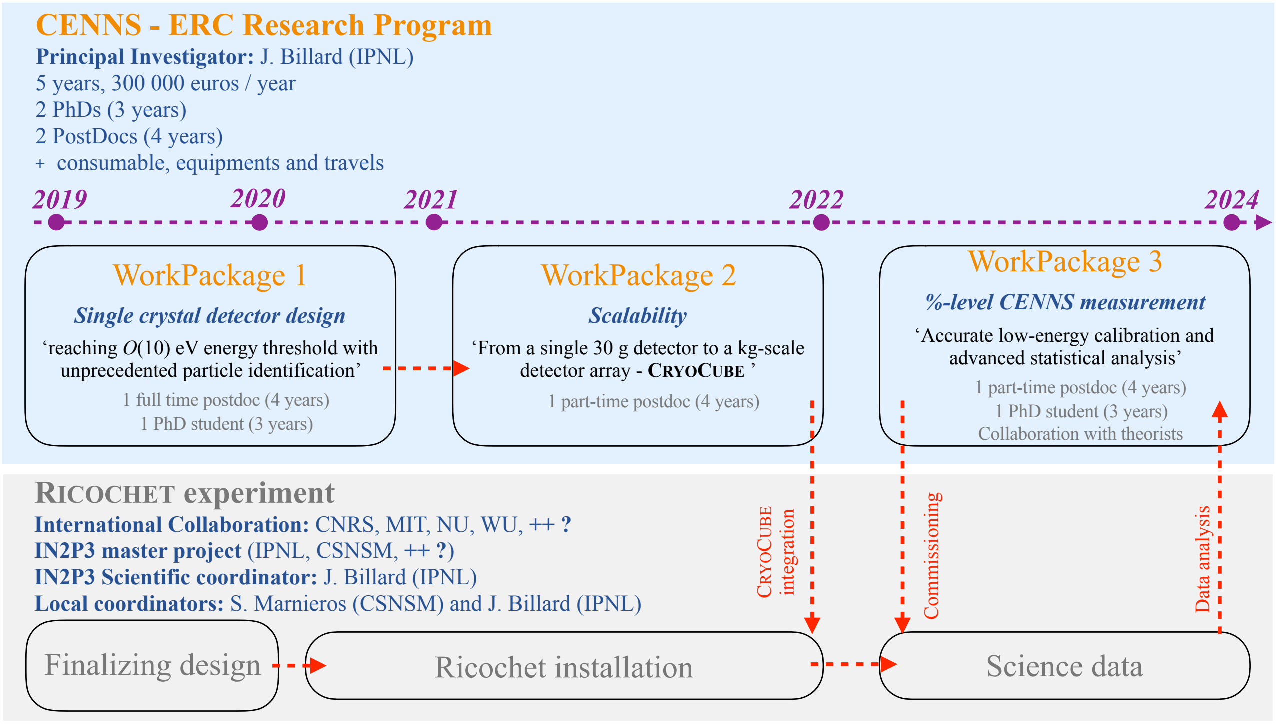

Figure 2 - Anticipated calendar of the CENNS - ERC research program and its interconnection with the setting up of the forthcoming Ricochet low-energy neutrino observatory.

As stated above, the Ricochet project started in 2012 but has only acquired significant momentum with the recently awarded CENNS - ERC starting grant in July 2018, the approval of Ricochet as an IN2P3 master project in 2017, and other grants received by the US collaborators (Heising-Simons foundation, MISTI, and others). We give hereafter a brief history of the Ricochet integration in the IN2P3 scientific landscape:

- *June 2016* - first presentation of Ricochet, as a new and growing activity of the IPNL Dark Matter group, during the **IPNL scientific council**. Ricochet is received with great interest by the committee.
- *November 2017* - Ricochet becomes **a master project of the IN2P3**, even though it has not received the financial support that was asked for from the institute in 2018.
- *July 2018* - **CENNS - ERC awarded** to fund the detector R&D (CryoCube) to be integrated in the Ricochet experiment by 2022 and deliver science results by 2024.
- *December 2018* - Ricochet and the CENNS - ERC will be presented at the next **IPNL scientific council**.

Figure 2 shows an anticipated timeline of the CENNS - ERC research program (*within the blue contour)* and its interconnection with the forthcoming Ricochet low-energy neutrino observatory (*within the grey contour*). As described in the figure above, we aim for an integration of the future CryoCube detector array in the Ricochet cryostat by 2022 in order to deliver first science results by 2024. ***It is therefore of first importance that Ricochet gathers complementary human and financial resources from the IN2P3 to be ready by 2022 in order to be well synchronized with the CENNS - ERC research program.***

Few technological steps have already been accomplished:

- **WP 1.1** - *dedicated to reach ~50 eV energy threshold* - In May 2018, within the EDELWEISS R&D collaborative effort we achieved an unprecedented 55 eV heat energy threshold with a 32 g Ge crystal detector operated above ground *(paper in preparation)*.
- **WP 1.3** - *dedicated to achieve a* 10^3 *electromagnetic background rejection in Zn detectors* - thanks to the collaborative effort between the MIT, CSNSM and IPNL Ricochet groups, we have successfully tested a first Zn detector with very encouraging results regarding the expected vanishing quasiparticle-phonon coupling. Three summer students from MIT came to IPNL to actively contribute to this project.
- **WP 2.1** - *dedicated to conceive the CryoCube detector assembly* - we have recently designed and built a new suspension system that will be used for the future CryoCube assembly that can keep vibration levels below a few nanometer (RMS) at the detectors, essential to ensure their optimal performance [19].

- **WP 2.2** - *dedicated HEMT-based cold electronics* - First tests on HEMT preamplifiers, mostly focusing on their characterization, before their coupling to an actual Ge-bolometer, are ongoing.

The scientific productions (up to now) related to this work are the following:

- A first proposal paper studying the scientific potential of the future RICOCHET experiment at the Near Hall of the Double Chooz experiment: *J. Billard, R. Carr, J. Dawson, et al., J. Phys. G* ***44****, 105101 (2017)*
- A phenomenological paper about the prospects for exploring New Physics in Coherent Elastic Neutrino-Nucleus Scattering: *J. Billard, J. Johnston, and B. J. Kavanagh, arXiv:1805.01798 (accepted in JCAP)*
- A hardware paper describing a novel vibration decoupling system to be used for the CRYOCUBE detector array: *R. Maisonobe, J. Billard, M. De Jesus, et al., JINST* ***13****, T08009 (2018)*

4. ETAT DE L'ART

Thanks to its exceptionally rich science program, Coherent Elastic Neutrino-Nucleus Scattering has led to significant worldwide experimental efforts, over the last decades, with several ongoing and planned dedicated experiments based on a host of techniques. Most of these experiments are, or will be, located at nuclear reactor sites producing low-energy neutrinos (<10 MeV) at the exception of COHERENT which is looking at higher neutrino energies (~50 MeV) emitted from the Spallation Neutron Source (SNS) in Oak Ridge. We give hereafter a brief description only of the planned or ongoing experiments that aim at probing the low-energy range ***(sub-100 eV)*** of the CENNS signal[1]:

- **CONNIE** is currently taking data using Si-CCD (Charge-Coupled Device) 30 meters away from the 3.8 GW nuclear reactor core from the Alberto Nuclear Power Plant in Brazil. They have a total Si target mass of 4 g exposed to a neutrino flux of about $8x10^{12}$ $cm^{-2}.s^{-1}$. Even though they managed to reach a very **low-energy threshold of 7 eVee** (electron equivalent, ~100 eV nuclear recoil equivalent), as they have **no (or poor) background discrimination**, they are dominated by internal backgrounds. From their engineering run, they observed a background rate in the low-energy region of about **3000 event/kg/day/keVee**, which is two orders of magnitude larger than the expected CENNS signal. A new science phase based on a larger payload of 100 g total target mass with cleaner materials has started in 2016 [21].
- **MINER** is a planned cryogenic bolometer-based experiment that will be located at the 1 MW thermal power research reactor from the Mitchell Institute in Texas. The experiment will use Si and Ge bolometers with a total target mass of 10 kg combined with a **projected energy threshold of 200 eV** with ***possible*** **background discrimination**. The great originality of this project is that the core is movable such that the distance between the core and the detectors can vary from 2 to 10 meters. This is perfectly well suited to study the existence of sterile neutrinos with meter-scale oscillations. Their expected gamma and neutron backgrounds are respectively about **200 and ~1000 event/kg/day/keV** below 100 eV, hence about two orders of magnitude above the expected CENNS rate [22].
- **NuCLEUS** is a few-gram-scale planned cryogenic bolometer-based experiment that has not yet settled on a precise nuclear reactor site. It is planned to use a combination of $CaWO_4$ and Al_2O_3 detectors with **no *intrinsic* particle identification**. The NuCLEUS strategy is to focus primarily on lowering the energy threshold, at the cost of drastically reducing the size of the individual bolometers (~0.5 gram), and to get an *indirect* background rejection power of ~100 for external backgrounds thanks to surrounding veto detectors [23]. By tuning their heat sensors exclusively to out-of-equilibrium phonons, they have successfully demonstrated a **20 eV energy threshold using a 0.5 g Al_2O_3 detector** [24].

It should be noted that RICOCHET, NuCLEUS and BASKET (a detector R&D effort, led by CEA-Saclay and the CSNSM) are forming a consortium, dedicated to the exchange of knowledge (background simulations, reactor neutrino spectra, and so on), for which the ***signature of the agreement is planned for end-2018****.*

5. RESSOURCES ET MOYENS

Going back to Figure 2, the tasks that belong to the CENNS - ERC starting grant (*within the blue contour)*, namely the detector R&D and the CENNS science outputs, are financially **fully covered by the ERC starting grant**. However, the tasks that fall into the construction of the forthcoming RICOCHET experiment (*within the grey contour*) have yet to be covered. Therefore, there is an urgent need to gather additional and significant human and financial ressources dedicated to setting up the low-energy neutrino observatory

---

[1] *Other planned or ongoing experiments, with higher energy thresholds, are: TEXONO, NuGEN, RED-100 and CONUS (which has recently announced a 2.4 sigma CENNS detection with an energy threshold of 100 eVee, equivalent to ~300 eV nuclear recoil).*

RICOCHET. Following the CENNS - ERC awarded in July 2018, the collaboration is actively seeking additional collaborators within the IN2P3 laboratories, where the detectors will be developed and where the experiment is foreseen to take place. It is therefore a unique opportunity to further strengthen the French, and more precisely the IN2P3, **leadership** in the context of both **neutrino physics** and **cryogenic detection techniques**. Following the ERC award, several groups outside the IPNL and CSNSM have expressed some interest in joining this new experiment. The realizations needed for the project (see Sec. 6) match very well the expertise of IN2P3 laboratories. A kick-off meeting will be organized in the beginning of 2019 to make official the declarations of intent of all groups. We take the opportunity of this brief review to ask for two major outcomes from the IN2P3 Scientific Council:

1) Support for a request that IN2P3 upgrades RICOCHET from an **R&D oriented Master Project**, to a **regular Master Project**, as the R&D part is covered by the CENNS - ERC grant, and that it is now time to plan and design this future experiment. It is worth noticing that despite its acceptation as an IN2P3 master project, RICOCHET has not yet received any financial support from the institute.
2) Propose a timeline for a thorough review and evaluation of the RICOCHET experiment by the Scientific Council. This calendar should take into consideration the objective of **starting the data taking by 2022**.

The members of the RICOCHET international collaboration are committed to deliver any required documents (Conceptual Design Report, or else), following a specified timeline, dictated by the IN2P3 Scientific Council, to realize this exciting new project that is foreseen to take place in France and based on French expertise in cryogenic detectors.

The hardware costs related to the construction of the future RICOCHET experiment (cryostats, cabling, shielding, and so on) **are estimated to be approximately 1 M€**, to be shared among the French and USA collaborators according to a sharing scheme that will be the object of a Memorandum of Understanding (MoU). The following tables list the Human and Financial resources related to RICOCHET :

Human resources (IN2P3):

Lab	Name	First name	Category	FTE 2018	FTE 2019
IPNL	Billard	Julien	Researcher	0.5	0.8
IPNL	De Jesus	Maryvonne	Researcher	0.3	0.5
IPNL	Augier	Corinne	Univ.	0.1	0.1
IPNL	Sanglard	Veronique	Univ.		0.1
IPNL	Cazes	Antoine	Univ.		0.1
IPNL	Gascon	Jules	Univ.	0.1	0.1
IPNL	Juillard	Alexandre	IT	0.2	0.5
IPNL	Vagneron	Lionel	IT	0.2	0.2
IPNL	Charlieux	Florence	IT	0.2	0.2
IPNL	Ducimetiere	David	IT (Univ.)	0.15	0.15
IPNL	Maisonobe	Romain	PostDoc	0.5	left on 09/2018
IPNL	Misiak	Dimitri	PhD	0.8	0.8
CSNSM	Giuliani	Andrea	Researcher	0.1	0.2
CSNSM	Marnieros	Stefanos	Researcher	0.15	0.2
CSNSM	Dumoulin	Louis	Researcher	0.1	0.1
CSNSM	Bergé	Laurent	IT	0.15	0.2
CSNSM	Olivieri	Emiliano	IT	0.15	0.25
CSNSM	Oriol	Christine	IT		0.2
	TOTAL			**3.7**	**4.7**

RICOCHET personnel in IN2P3 laboratories with their corresponding Full-Time-Equivalent (FTE) for 2018 and projected for 2019.

Financial resources:

Project Title	Funding source	Amount (euros)	Period
CENNS	**ERC** *(PI: J. Billard)* *Starting Grant*	1 500 000	2019 - 2024
CryoZinc	**ANR** *(PI: J. Billard)* *JCJC* *Awarded but then declined due to unauthorized overlap with ERC*	250 000	*Declined*
Cryogenic Neutrino Detectors	**MISTI** *(MIT - IPNL)* *MIT-France exchange program*	20 000	2018 - 2020
RICOCHET	**PICS** *(MIT - CSNSM - IPNL)* *International Program for Scientific Cooperation*	18 000	2018 - 2021
RICOCHET	**IN2P3 project support** *Master project*	Requested 105 000 *Received 0 in 2018*	2018 - 2021

6. RÉALISATIONS TECHNIQUES

The following technical realizations will be achieved during the CENNS - ERC research program:

1. It will push the performance of Ge-bolometers beyond the state-of-the-art by providing nuclear and electronic recoil discrimination down to sub-100 eV.
2. If successful it will also bring a new cryogenic detector technology to the field of low-energy and rare-event searches, namely cryogenic superconducting metals (Zn).
3. The final technological deliverable of this program is to build an entire array of 27 individual detectors (50% Ge and 50% Zn), called the CRYOCUBE (see WP 2) that will have tremendous applications in neutrino physics, dark matter physics and the non-proliferation of nuclear weapons.
4. Eventually, this CRYOCUBE will be accompanied by its dedicated low-temperature (~1K) cryogenic preamplifiers that will also find various applications for cryogenic experiments.

This research program is therefore heavily R&D oriented. To successfully achieve the various technological objectives, the team benefits from the strong support of the technical services from IPNL and CSNSM that have the required knowledge and experience to fulfill the different tasks. Additionally, thanks to the joint interest from EDELWEISS and RICOCHET in developing HEMT-preamplifiers, there is the possibility to benefit from the expertise in cold electronics from the CEA-Saclay to achieve the fourth task above-mentioned. Finally, some lab equipment will be acquired: wire bonders, micro handling systems, clean benchs and a clean tent, to ensure the fabrication of the CRYOCUBE detector array in optimal conditions.
These technical realizations are fully supported by the ERC grant.

The following technical realizations will be achieved in setting up the RICOCHET experiment (see Fig. 2):

1. Design of the infrastructure of the RICOCHET experiment: cryostat, shielding (lead, polyethylene, copper), and its integration at its future nuclear reactor site.
2. Develop the warm electronics and a dedicated DAQ. For this task, and task #4 above mentioned, a MoU is foreseen between the EDELWEISS and RICOCHET collaborations to benefit from their common interest in low-noise cold and warm electronics dedicated to cryogenic bolometers.

The tasks to be achieved within the context of setting up the future RICOCHET experiments are quite sizable and have to be fulfilled in a timely fashion with the ERC. This will again be done thanks to the assistance from the various technical services from the IN2P3 labs involved: Instrumentation, Electronics, Computing, and Mechanics.

These technical realizations are not yet covered. To that end, and in addition to the support from the IN2P3 asked for here (see Sec. 5), the RICOCHET collaboration is also actively looking for new collaborators to further strengthen its technical resources in France and overseas.

7. ANALYSE SWOT

	Helpful to achieving the objective	**Harmful** to achieving the objective
Internal origin attributes of the organization	**Strengths** • Only project aiming for **particle identification** down to 50 eV energy thresholds. • Only project aiming for a **percentage-level CENNS measurement** down to 50 eV after only one year of data taking *(projected for 2024)*. • Explores a new cryogenic detector technology (Zn) • Combination of two monolithic targets: **Ge** and **Zn** • Combines various research groups from USA and France with strong expertise in cryogenic detectors and with large visibility in the neutrino community • *55 eV energy threshold with a 32 g detector operated above ground **already demonstrated.***	**Weaknesses** • Need to demonstrate the background rejection capabilities for both technologies (Ge and Zn), which requires significant R&D efforts which are entitled to some risks. • Due to the intense R&D effort required, Ricochet is not expecting to take data before 2022, but will quickly compensate its later starting date, with respect to the international competition, thanks to its unique kg-scale payload combined with 50 eV energy threshold and $O(10^3)$ background rejection.
External origin attributes of the environment	**Opportunities** • Thanks to its design, the CryoCube detector array will have unprecedented sensitivity to sub-GeV Dark Matter masses, and could hence be placed at an underground site to perform leading light dark matter searches. • Such compact neutrino detector opens the way also to practical and industrial applications such as: ***1)*** nuclear reactor monitoring and ***2)*** the non proliferation of nuclear weapons.	**Threats** • Not getting Ricochet ready to host the CryoCube by 2022 in order to be well synchronized with the ERC - CENNS timeline • No sufficient fundings or not enough manpower to deploy Ricochet at an optimal reactor site in France. • No evidence of new physics signals.

REFERENCES

[1] D. Z. Freedman, Phys. Rev. D **9**, 1389 (1974)

[2] D. Akimov *et al.*, “Observation of Coherent Elastic Neutrino Nucleus Scattering”, Science, (2017)

[3] A. G. Beda, *et al.* [GEMMA collaboration], Phys. Part. Nucl. Lett. **10**, 139–143 (2013)

[4] M. Lindner, B. Radovcic, and J. Welter, JHEP **1707**, 139 (2017)

[5] E. Bertuzzo, F. F. Deppisch, S. Kulkarni, Y. F. P. Gonzalez, R. Z. Funchal, JHEP **1704**, 073 (2017)

[6] S. Abrahamyan, *et al.* [APEX Collaboration], Phys. Rev. Lett. **107**, 191804 (2011)

[7] M. Aboud, *et al.* [ATLAS Collaboration], Phys. Lett. B **761**, 372-392 (2016); V. Khachatryan, *et al.* [CMS Collaboration], Phys. Lett. B **768**, 57-80 (2017)

[8] J. Barranco, O. G. Miranda, and T. I. Rashba, Phys. Rev. D **76**, 073008 (2007)

[9] J. Dorenbosch, *et al.* [CHARM Collaboration], Phys. Lett. B **180**, 303-307 (1986)

[10] J. A. Friedland, M. L. Graesser, I. M. Shoemaker, and L. Vecchi, Phys. Lett. B **714**, 267-275 (2012)

[11] P. Coloma and T. Schwetz, Phys. Rev. D **95**, 079903 (2017)

[12] J. Billard, B. Kavanagh, J. Johnston, *et al.*, *to appear in JCAP 2018,* arXiv:1805.01798

[13] J. Billard, R. Carr, J. Dawson, *et al.*, J. Phys. G **44**, 105101 (2017)

[14] V. Wagner, « *The Very-Near-Site at Chooz: A new experimental hall to study coherent neutrino nucleus scattering* », at the Groupement De Recherche Neutrino, June (2018).

[15] A. Leder, A. J. Anderson, J. Billard *et al.*, JINST **13** no. 02, P02004 (2018)

[16] S. Marnieros, « Détecteurs cryogeniques et leurs applications en Astrophysique et Astroparticules », Habilitation à diriger des recherches, Université Paris-Sud, (2014). http://hal.in2p3.fr/tel-01088881

[17] A. Phipps, A. Juillard, B. Sadoulet et *al.*, *Under review in JINST,* arXiv:1611.09712 (2016)

[18] N. E. Booth and D. J. Goldie, Supercond. Sci. Technol. **9**, 493–516 (1996)

[19] R. Maisonobe, J. Billard, M. De Jesus *et al.*, JINST **13**, T08009 (2018)

[20] G. Dong *et al.*, Applied Physics Letters **105**, 013504 (2014)

[21] A. Aguilar-Arevalo, *et al.*, [CONNIE collaboration], J. Phys. Conf. Ser. 761(1), 012057 (2016)

[22] G. Agnolet, et al., arXiv:1609.02066 (2016)

[23] R. Strauss *et al.*, Eur. Phys. J. C **77**, 506 (2017)

[24] R. Strauss *et al.*, Phys. Rev. D **96**, 022009 (2007)