BERTHA: BettER Timing precision for Hyper-kAmiokande

Project Coordinator: Mathieu Guigue

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2.1 Scientific context

The presence of more matter than antimatter in the visible Universe is one of the most puzzling problems in our current understanding of the Universe. This matter-antimatter asymmetry is usually expressed in terms of the baryon asymmetry as it is possible that the larger proportion of electrons vers positrons is compensated with an excess of antineutrinos over neutrinos. This baryon asymmetry appears to be rather small with one extra baryon for every billion pairs of baryon-antibaryon [1, 2]. It was proposed by Sakharov [?] that such asymmetry could arise from a perfectly symmetric Universe if three conditions exist. One of them is the existence of CP (charge conjugaison and parity transformation) violation processes. In the quark section, Say clever things about CP violation in the quark sector that justify looking into CP violation sources in leptonic sector (EFT?).

In the leptonic sector, CP violation sources are being actively searched in the neutrino and antineutrino oscillations phenomenon. Neutrino flavor oscillations were first discovered by the Super-Kamiokande (SK) experiment in Japan [3] and in the SNO experiment in Canada [4] by observing the electron neutrino flux coming from the Sun. For these discoveries, the 2015 Nobel Prize in Physics was awarded to T. Kajita and A. B. McDonald. This phenomenon can be explained by assuming that the neutrinos have non-zero but small masses, leading to non-degenerate neutrinos mass states and the possible presence of mass and flavor eigenstates mixings.

From these breakthrough, a broad international program has been initiated to measure the parameters needed to describe the oscillation patterns, i.e. three mixing angles θ_{13}, θ_{23} and θ_{13} and two mass squared differences Δm^2_{21} and Δm^2_{31} along with a CP violation phase δ_{CP}. In this PMNS (for Pontecorvo-Masaka-Nakagawa-Sakata) framework, the neutrinos change flavor as they travel in space. Let's consider the probability for muon neutrinos to oscillate into muon neutrinos, called ν_μ *disappearance probability*:

$$\begin{aligned} P\left(\nu_\mu \to \nu_\mu\right) &= 1 - \left(\cos^2\theta_{13}\sin^2 2\theta_{23} + \sin^4\theta_{23}\sin^2 2\theta_{13}\right)\sin^2\left(\tfrac{\Delta m^2_{31} L}{4E}\right) \\ &\simeq 1 - \sin^2 2\theta_{23}\sin^2\left(\tfrac{\Delta m^2_{31} L}{4E}\right). \end{aligned} \tag{1}$$

Equation (1) shows that it is possible to enhance the oscillatory by tuning the neutrino energy E and the oscillation length L in order to determine the value of Δm^2_{31}. This makes accelerator long-baseline neutrino (LBL-ν) oscillation experiments excellent places to measure such oscillation pattern and extract constraints on the mixang angles and mass square differences. Let us point out here that this oscillation probability is identical in the case of muon antineutrinos.

Now the probability for muon neutrino to oscillate into electron neutrinos, called ν_e *appearance probability*, can be written as:

Maybe rewrite the oscillation probability with only the main CP-conserving term and the CP violating term...

$$\begin{aligned} P\left(\nu_\mu \to \nu_e\right) &= \sin^2\theta_{23}\frac{\sin^2 2\theta_{13}}{(A-1)^2}\sin^2\left[(A-1)\Delta_{31}\right] \\ &- \alpha\frac{\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}\cos\theta_{13}\sin\delta_{CP}}{A(1-A)}\sin\Delta_{31}\sin\left(A\Delta_{31}\right)\sin\left[(1-A)\Delta_{31}\right] \\ &+ \alpha\frac{\sin 2\theta_{12}\sin 2\theta_{13}\sin 2\theta_{23}\cos\theta_{13}\cos\delta_{CP}}{A(1-A)}\cos\Delta_{31}\sin\left(A\Delta_{31}\right)\sin\left[(1-A)\Delta_{31}\right] \\ &+ \alpha^2\cos^2\theta_{23}\frac{\sin^2 2\theta_{12}}{A^2}\sin^2\left(A\Delta_{31}\right), \end{aligned} \tag{2}$$

with $\alpha = \Delta m^2_{21}/\Delta m^2_{31} \sim 0.03$, $\Delta_{31} = \Delta m^2_{31} L/4E$. The term $A = 2\sqrt{2}G_F n_e E/\Delta m^2_{31}$ (where n_e is the electron density) is related to the matter effect induced when neutrinos are crossing the Earth. This oscillation probability pattern is interesting for two reasons. First it allows to measure the θ_{13} parameter which turned out to be non-zero as measured by T2K [5], RENO [6] and Daya Bay [7] experiments. Secondly this term depends on whether we are considering neutrinos or antineutrinos; indeed this would change the sign of both $\sin\delta_{CP}$ and A, leading to a change of the third term sign and therefore in the oscillation pattern by about ∓ 30 % if δ_{CP} is close to $\pm\frac{\pi}{2}$. By looking at the differences between the oscillation patterns for neutrino and antineutrinos as a function of the neutrinos energy, the δ_{CP} phase can be determined.

Long-baseline neutrino oscillations experiments are therefore unique playgrounds because of their capabilities to precisely determine various oscillations parameters such as θ_{23}, δm^2_{32}. They could also observe CP violation in the leptonic sector by comparing the electron neutrino and antineutrinos appearance probabilities.

Currently, two LBL-ν experiments are taking data: NOνA (for NuMI Off-axis ν_e Appearance) in the Unites States and T2K (Tokai To Kamioka) in Japan. These two experiments are taking data for about a decade and will continue providing the most precise measurments of the neutrino mixing parameters for the next decade, until the next generation experiments (DUNE and Hyper-Kamiokande) will start taking data.

The T2K experiment is a long-baseline neutrino oscillation experiment running across Japan that aims at constraining mixing parameters by looking at muon neutrino beam flavor oscillations. The experimental setup is as follow: a muon neutrino beam is produced by shooting $30-$GeV protons onto a graphite target at the J-PARC complex on the East Coast of Japan. These hadrons, mostly pions,

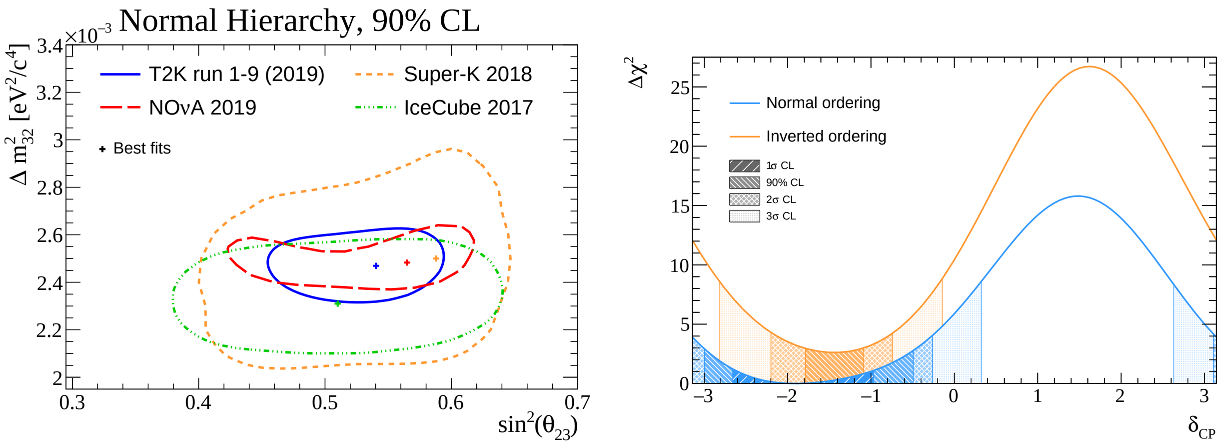


Figure 1: Results of the T2K recent oscillation analysis. Measurements of θ_{23} and Δm^2_{32} by T2K, NOνA and Minos (left) and constraints on the CP violation phase $\delta_{\rm CP}$ from the 2021 oscillation analysis (right).

then decay into muons neutrinos inside a 200 m-long tank before arriving onto a suite of detectors called ND280. The selection of neutrino or antineutrino beam can then be done by changing the current direction in a set of magnetic horns next to the target; if the current is positive (negative), π^+ (π^-) will be focused and decay into μ^+ and ν_μ (μ^- and $\bar{\nu}_\mu$), leading to a neutrino beam into ν-mode ($\bar{\nu}$-mode). Due to the very close distance to the vertex location, the muon neutrinos don't have the time to oscillate before being detected by these detectors, allowing the monitoring of the muon neutrino flux and electron muon contamination. Then 295 km away from J-PARC is the far detector, Super-Kamiokande. This detector consists in a cylindrical tank filled with water equipped with photomultipliers that detect Cherenkov light produced by charged particles created by the interaction of the beam muon and electron neutrinos with the water. The detector can easily distinguish between e and μ using the shape of the Cherenkov ring and exclude background with a high efficiency. The incoming neutrino energy E_ν is reconstructed using the kinematics of the outgoing lepton, namely its energy E_l and the angle $\theta_l$between the lepton and the beam direction:

$$E_\nu = \frac{2M'_n E_l - \left((M'_n)^2 + m_l^2 - M_p^2\right)}{2\left(M'_n - E_l + \sqrt{E_l^2 - m_l^2}\cos\theta_l\right)}. \tag{3}$$

T2K is the first neutrino experiment to implement the so-called "off-axis technique" that consists in placing the near and far detectors 2.5° away from the beam axis direction, peaking the neutrino energy around 600 MeV and leading to a maximum disappearance probability of the muon neutrinos at the far detector.

Thanks to the total statistics of 3.13×10^{21} protons − on − target (POT) accumulated since 2009, T2K is producing the world best measurement of some of the mixing parameters. Indeed, by combining all the appearance and disappearance samples collected in neutrino and antineutrino mode, constraints can be placed on θ_{23} and Δm^2_{32} such as shown on figure 1. Recently first hints on the value of the $\delta_{\rm CP}$ were published in Nature [8]. As shown on figure 1, a maximum CP violation with $\delta_{\rm CP} \approx -\frac{\pi}{2}$ seems preferred by the most recent datasets. Moreover, CP conservation corresponding to $\sin\delta_{\rm CP} = 0$ has been excluded with 95 % C.L. T2K will continue taking data for the next couple of years and reach 20×10^{21} POT. If the current measurement $\delta_{\rm CP} \approx -\frac{\pi}{2}$ remains the same at the end of T2K, CP-conserving values should be excluded at more than 3 σ.

In order to reach a $5 - \sigma$ discovery of CP violation in the leptonic sector, a new generation of LBL-ν experiments are needed, namely the DUNE and Hyper-Kamiokande experiments. The DUNE experiment will implement a off-axis with a 1000 km long baseline and a set of four liquid argon TPC as far detector. Utilising on the expertise gained from the current

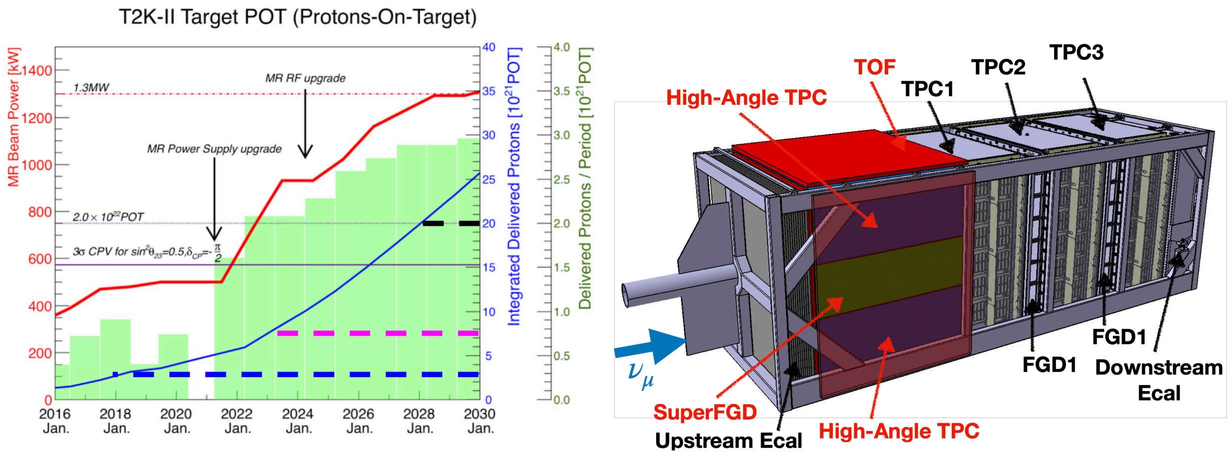


Figure 2: Left: upgrade of the muon neutrinos beam until the start of Hyper-Kamiokande. Right: upgrades to ND280. In red are the new detectors added to the composite detector.

experiments, the Hyper-Kamiokande experiment is a long-term program initiated in Japan which aims at upgrading the key components of the current T2K experiment and also building new detectors to fully profit from these upgrades.

Upgrades to prepare the HK program One key element that is being upgraded is the proton main ring used to produce the neutrino beam at J-PARC . This upgrade is twofold: first, the number of pulses per second will be doubled to reach one pulse every 2.5 s. Second, as represented on figure 2, the power beam power will be increased from 515 kW to 1.3 MW. These upgrades will triple the number of POT by period, and thus the statistics at the far site.

ND280 is a magnetized composite detector consisting of several Fine Grained Detectors (FGD) and Time Project Chambers (TPC) surounded by calorimeters. Because of the orientation of these detectors, the reconstruction of the outgoing lepton is not very efficient for $\cos\theta_l \geq 0.4$. The upgrade the T2K collaboration is working on aims at better reconstructing particles coming out of the neutrino interaction vertex with a high angle with respect to the beam direction. Since the far detector SK has no dependence on the reconstruction efficiency with the lepton angle, it is important that constraints on the neutrino cross-sections are obtained over the entire kinematic phase space in order to reduce the systematic uncertainties at the far detector. Such improvement in the reconstruction acceptance can be achieved by replacing part of ND280 with a new horizontal fully active carbon target (Super-FGC) surrounded by two horizontal TPCs (High-Angle TPC) and six Time-Of-Flight (TOF) planes. This upgrade will be installed in 2022 and fully and commissionned before the beginning of Hyper-Kamiokande, so that Hyper-Kamiokande fully benefit its upgraded performances during the beam data taking period. Indeed this upgrade along with better modeling of the neutrino cross sections will help reduce the overall systematics uncertainties on the number of events at the far detector from about 10 % down to 3 %.

HK detector description One of the major components of this program is the construction of a new large-scale water Cherenkov neutrino detector in the Kamioka mines. As depicted on figure 3, this new far detector called Hyper-Kamiokande of 250 ktons of pure water will have a fiducial volume 8 times larger than the current SK detector and will be instrumented with about 20,000 20-inch photomultiplier tubes (PMTs). The PMTs have improved quantum efficiency of 24 % with a photon timing resolution reduced to 1.5 ns and the detector photocoverage should reach 20 %. An outer water Cherenkov detector surrounding the inner detector and equipped with 8,000 3-inch PMTs will be used to detect charged particles entering the detector. The construction and exclavation work has started in April 2020 and this new detector should start taking data in 2027. After 10 years of data taking,

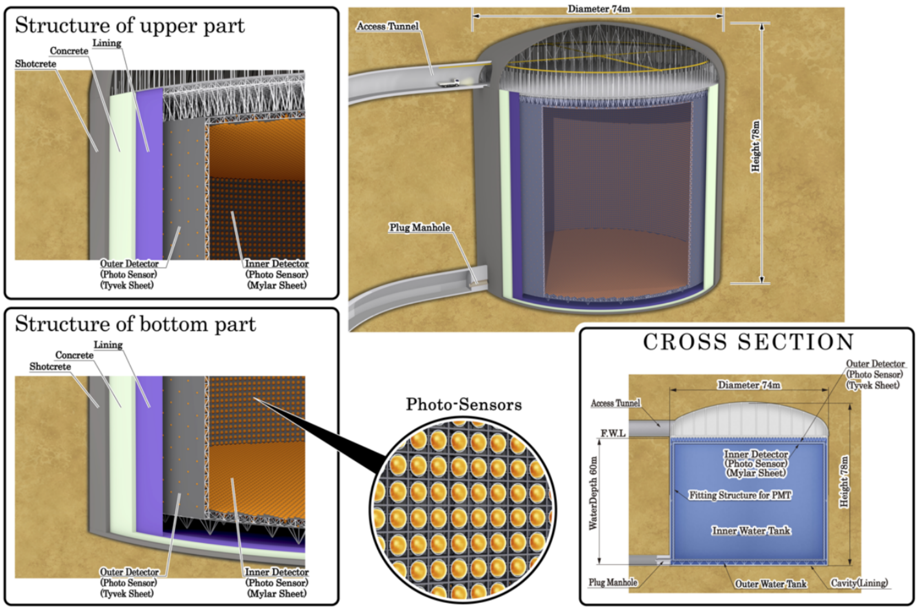


Figure 3: Scheme of the Hyper-Kamiokande far detector.

this far detector should about 4,200 ν_e events and about 23,000 ν_μ events, thus increasing statistics by a factor 40 compared with T2K.

IWCD and mpmt A dominant source of uncertainty in the determination of the mass hierarchy using atmospheric neutrinos are related to the neutrino and antineutrino cross section ratios on water. Also the possibility to better constraint intrinsic backgrounds and measure neutrinos spectra with different energies seems attractive. For these reasons, an Intermediate Water Cherenkov Detector (IWCD)

Thanks to this very large statistics and the constraints on the systematic parameters (cross-sections and flux) obtained with the near and intermediate detectors, a combined analysis using disappearance and appearance samples will provide exquisite sentivity to the δ_{CP} phase. Indeed, as depicted on figure 4, depending on the value of δ_{CP}, Hyper-Kamiokande will obtain a measurement with an error between 10° and 23°. Any more clever comments on δ_{CP} and the other oscillation parameters?

Expected physics program (OA, SN, solar upturn...?) The rich Hyper-Kamiokande physics program goes well beyond the measurements of neutrino oscillation parameters and neutrino cross-sections measurements. For example, thanks to its gigantic mass, Hyper-Kamiokande will detect thousands of electron antineutrinos (via inverse beta-decay) and electron neutrinos (via elastic scattering) from SN bursts in the galactic center. Using the elastic scattering events, it will be possible to reconstruct the direction towards a SN at a distance of 10 kpc with an accuracy of about 1 degree. The events observed in Hyper-Kamiokande will allow to provide detailed information about the time profile and the energy spectrum to further inspect SN explosion mechanism. In addition, it will be possible to detect neutrinos also from extra-galactic SN explosions. Even for distances of 4 Mpc, we will observe few tenths of neutrinos in Hyper-Kamiokande and, at such distances, one SN is expected every three years. Hyper-Kamiokande will also be able to detect the SN relic neutrinos (SRN) that are neutrinos produced by all SN explosions since the beginning of the universe. Such neutrinos fill the present universe and have a flux of few tens/cm^2/s. The observation of SRN would allow understanding how heavy elements have been synthesized in stellar formation.

On top of that, Hyper-Kamiokande will collect a large sample of atmospheric high-energy neutrinos. Such measurements will complement the long-baseline program since joint analyses between beam and

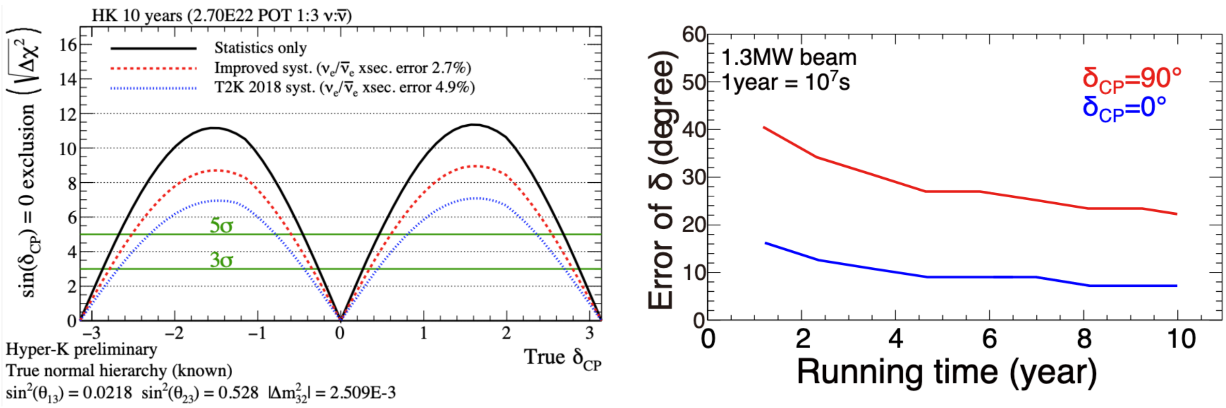


Figure 4: Left: Hyper-Kamiokande sensitivity on the exclusion of CP conservation after 10 years of data taking. Right: precision on the δ_{CP} measurement as a function of time for $\delta_{CP} = 0$ (blue) and $\delta_{CP} = \pi/2$ (red).

atmospheric neutrinos can improve the sensitivity to neutrino mass ordering and thus onto CP violation in neutrino oscillations. Indeed, the matter effects are rather small for the 295 km baseline of Tokai to Hyper-Kamiokande making the sensitivity to the mass ordering limited, while atmospheric neutrinos emitted on the other side of the Earth and measured at the Hyper-Kamiokande detector have crossed the Earth's core and experienced strong matter effects. Therefore, the Hyper-Kamiokande detector as part of the Japanese long-baseline neutrino program will be extremely useful to further constrain neutrino oscillation parameters.

Need for a great synchronization system both locally and global The success of this experiment relies on the excellent reconstruction of incoming neutrino energies and directions using the PMTs. The detection of SN events strongly depends on the reconstruction of the associated low-energy events and on the synchronisation of Hyper-Kamiokande PMTs and other experiments around the world. Moreover, reconstruction of neutrino interaction vertices in the detector requires an accurate timing determination of the event occurrence. It is therefore essential that an excellent distribution system is built for distributing clocks among all the detectors. Preliminary studies indicate that the timing precision should be lower than 1 ns with a maximum jitter of 100ps rms along with the capability of sending slow control data using this link thanks to a sufficient bandwidth.

World-wide, several detectors currently running or nearing completion are sensitive to a core-collapse supernova neutrino signal in the Milky Way using the so-called SNEWS (SuperNova Early Warning System) network. The neutrino burst signal emerges promptly from a supernova's core, whereas it may take hours for the first photons to be visible. Therefore, the detection of the neutrino burst from the next Galactic supernova can provide an early warning for astronomers. Requiring a coincident signal from several detectors will provide the astronomical community with a very high confidence early warning of the supernova's occurrence. Being able to properly time an neutrino event in the Hyper-Kamiokande detector is essential when studying time profile of these astrophical events or when comparing with other experiments. write somehow the keyword "multimessenger".

2.2 Originality and relevance in relation to the state of the art

Technological challenges related to the clock characterisation

Need to test mPMT on test beam

Need to properly characterize cherenkov light modelling before Hyper-Kamiokande

2.3 Work packages and deliverables

Here we present the different work packages and associated deliverables

2.3.1 Work package 1: Project coordination and outreach

Task responsible: Mathieu Guigue

The BERTHA project will be coordinated by Mathieu Guigue. This responsibility includes the definition and tracking of the various work packages, their schedule and all the actions required for producing the associated deliverables. The coordinator will also oversee the hiring process of the postdoc. He will organize bi-weekly meetings with the project members to follow on the evolution of the work packages and coordinate the commun efforts between tasks 2 and 3. Given the international nature of the project, regular workshops involving people of interest (in IN2P3 and internationnally) in the work packages will be organized. The responsability also includes the writing of reviews and reports both for the internal project and for the Hyper-Kamiokande collaboration and the overseeing of the papers publication and data release process. Finally, he will make sure that all the members of the team gain in visibility inside and outside the Hyper-Kamiokande collaboration by attending to collaboration meetings and workshops and at international conferences.

Deliverables: project organization, project and collaboration reviews and reports.

2.3.2 Work package 2: Development and characterisation of clock distribution and time synchronisation system for Hyper-Kamiokande

Task responsible: Stefano Russo Responsible: SR

Parler de l'open source et du développement de compétences pour tout le laboratoire

Integration du slow control dans la solution de distribution d'horloges

Papers on arXiv (open access)

2.3.3 Work package 3: Cherenkov light studies with Water Cherenkov Test Experiment

Responsible: BP

Papers on arXiv (open access)

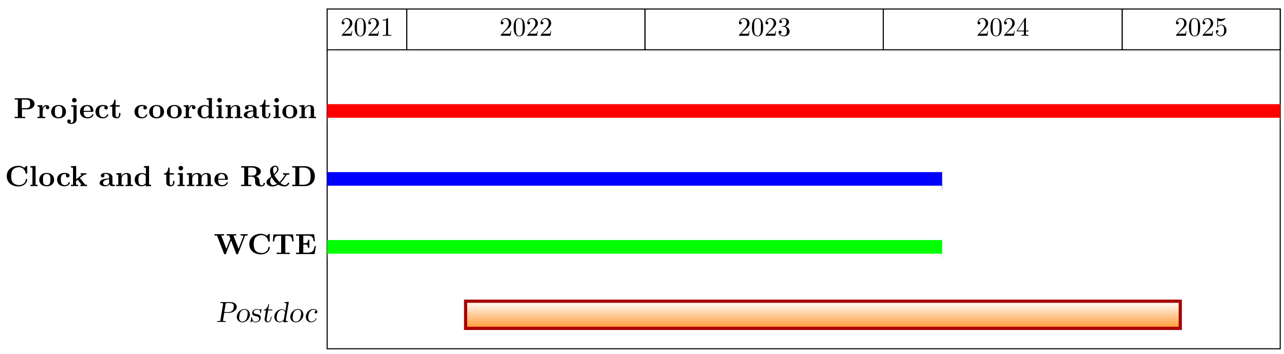
2.3.4 Work package 4: Computing developments and integration

Responsible: MG

Deliverables:

- data management plan
- global computing
- Collaboration with Jennifer-II and Belle-II

2.4 Project schedule



2.5 Risks management

Liste des risques à propos du projet

1. Project funding

2. Scientific challenges of Hyper-Kamiokande
3. Need for clock distribution system
4. Technological challenges of clock distribution
5. Technological challenges of mPMT and WCTE
6. Covid

3 Organisation and implementation of the project

The BERTHA project is structured around three tasks with a responsible designated in the permanent members of the LPNHE Neutrino group. The whole team, including the hired postdoc, will contribute to the tasks 2 and 3, while the first one, concerning the project coordination, will be managed by the project leader.

3.1 Scientific coordinator and team

The project will include Mathieu Guigue, Jacques Dumarchez, Claudio Giganti, Boris Popov, Stefano Russo and Marco Zito, permanent staff in the neutrino group at LPNHE, and Lucile Mellet, Sorbonne Université PhD student working on the Hyper-Kamiokande experiment.

The funding will cover the postdoc salary and travel expenses to conferences and the Hyper-Kamiokande meetings and workshops related to this project. In addition, the equipment necessary to the success of this project will be funded with this ANR.

The project coordinator Mathieu Guigue earned in 2015 his PhD in particle physics from Université de Grenoble-Alpes and was employed as a Postdoctoral Research Associate by Pacific NorthWest National Laboratory (Washington, USA) from 2016 until 2018. During this period, he had leading roles on the Project 8 experiment at the University of Washington being the Experiment Coordinator and Analysis Convenor from 2016 until 2019 and has been the primary author of two pee-reviewed papers of the collaboration. In addition, he strongly contributed the development of slow control and DAQ system for this experiment in order to produce a reliable monitoring system during all of the Phase II data taking period (2016-2020). He has then been hired by Sorbonne Université in Paris as Maître de Conférences since September 2018 and joined the T2K activities of the Neutrino group at LPNHE. Since 2019 he is co-convenor of the T2K Simulation and Reconstruction working group. As such, he is coordinating the simulation and reconstruction efforts for the upgrade of ND280. He is also contributing to the T2K Oscillation Analysis effort, in particular on the combined analysis with SK atmospheric neutrinos. In addition to his activities in T2K, he is working on the Hyper-Kamiokande experiment, primarly on the test of mPMTs at the Memphyno setup, on the R&D for the clock distribution and time synchronisation system. Finally, he is pushing for a global long-term plan to provide computing and long-term storage resources to both the T2K and Hyper-Kamiokande collaborations which should last at least until the middle of the century Mention Data Management Plan? Was told it was important, maybe keep it for the benefits?. Table 2 summarises the implication of the scientific coordinator in on-going projects. Mathieu Guigue will be responsible of the overall coordination of the BERTHA project (task 1) and of the studies at Water Cherenkov Test Experiment (task 3), but he will also contribute to the clock distribution and time synchronisation system (task 2).

Stefano Russo is Fill with great things about Stefano, that he is convenor of the Electronic WG...

Boris Popov is Fill with great things about Boris, that he is convenor for NA61 and leading the upgrade effort for the electronics at LPNHE...

The strength of this project resides in the strong expertise of the group in neutrino physics and in the electronic design in various experiments and the close collaboration established with other groups.

Name of the researcher	Person. month	Call, funding agency, grant allocated	Project's title	Name of the scientific coordinator	Start-End
M. Guigue	6	SU Emergence	MULTIPLY	M. Guigue	2019 - 2021
M. Guigue	20	ANR JCJC	SUNCORE	C. Giganti	2019 - 2023

Table 1: Implication of the scientific coordinator in on-going projects.

Partner	Name	First name	Current position	Role & responsibilities in the project	Involvment in person.month
Sorbonne Université	Guigue	Mathieu	Maitre de Conférences	Coordinator Responsible of task 1 and 3	
LPNHE	Russo	Stefano	Ingénieur de Recherche HDR	Responsible of task 2	
LPNHE	Giganti	Claudio	Chargé de Recherche HDR	Scientific partner on task 3	
LPNHE	Popov	Boris	Directeur de Recherche HDR	Scientific partner on task 2 and 3	

Table 2: Implication of the scientific coordinator in on-going projects.

The LPNHE is well integrated in the laboratories network in the Paris area. First of all, LPNHE is part of the "Paris federation" which gathers IN2P3 laboratories, namely AstroPhysique et Cosmologie (APC) and the Laboratoire Leprince Riguet (LLR) on the Ecole Polytechnique campus, along with the Institut de Recherches des lois Fondamentales de l'Univers (IRFU) at CEA Saclay. LLR, IRFU and LPNHE have been collaborating for the last 10 years on the T2K experiment on which the three labs are providing major hardware and software contributions. In particular, the ND280 upgrade design and construction have been led by Marco Zito and are now under the supervision of Claudio Giganti. In collaboration with CEA, the LPNHE has developed and produced the front-end electronics that will equip the High-Angle TPCs in the upgraded ND280 Other significant contributions?. Such collaboration continues in the development and integration of the detector responses and performances in the T2K official simulation, reconstruction and analysis tools.

Collaboration within the Paris federation are also very active in the context of Hyper-Kamiokande. Indeed the test of the mPMTs is a collaboration between the APC that provides the water tank and overall infrastructure, the LLR that provides scientific context and integration in the Hyper-Kamiokande simulation and the LPNHE that provides the logistic and resources for the tests. This strong collaboration will continue during the construction and exploitation of the WCTE at CERN (task 3). For the development of the time synchronisation system for Hyper-Kamiokande (task 2), the Neutrino group is working closely with the SYstèmes de Référence Temps-Espace (SYRTE) laboratory at the Observatoire de Paris. Indeed Michel Abgrall's team has strong expertise in the design and the characterisation of stable and accurate time references; this project aims at providing the LPNHE group the necessary financial and human resources to complete this R&D and propose a complete solution suitable for the Hyper-Kamiokande experiment. Collaboration with IRFU on the development of a clock distribution system has also emerged recently given their interest in this topic. Moreover, the solution developed by LPNHE will be integrated with the other parts of the far detector front-end electronics for the 20-inch PMTs developped by LLR, Omega and CEA.

The funding of this ANR project would allow the scientific coordinator to secure the LPNHE group contribution to the Hyper-Kamiokande experiment, strengthen his team dedicated to the clock distribution system and improve the group's visibility within the collaboration (see section 4).

3.2 Implemented and requested resources to reach the objectives

4 Impact and benefits of the project

4.1 Positionning LPNHE and IN2P3 in the Hyper-Kamiokande collaboration

Strenghten involvment in WG4

Clock solution will be integrated with LLR/CEA electronics -¿ stronger proposal to the collaboration

4.2 Developing national and international synergies and expertise

Collaborative work with SYRTE

- Development of close relationship with SYRTE
- Knowledge transfer to LPNHE
- Connect with other synchronisation projects (V Voisin?)

Collaborations in Europe

- Colllaboration with INFN colleagues on mpmt
- Collaboration with CERN

Talk about the benefits of a close collaboration of Japan-France

- Collaboration with the UoT (joint PhD programs, exchange progams, joint lab)
- Synergies with Belle-II
- Creation d'une école France-Japon

4.3 Impact on society

Proposition de stages et de thèses

Parler de l'open source et du développement de compétences pour tout le laboratoire

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