I.

STEREO
Recherche de neutrinos stériles auprès du réacteur de l'ILL

Plan de Développement

23 septembre 2013
Révision 01

Référence : devSTEREO01

II. Page de contrôle du document

Titre:

STEREO
Plan de développement

Résumé:

L'objectif de ce document est de décrire les différentes solutions, les moyens à mettre en œuvre et les différentes étapes techniques pour la conception, la fabrication et la mise en œuvre d'un détecteur d'anti-neutrinos à courte distance du réacteur de recherche de l'ILL.
Il décrit la répartition des taches et des moyens entre les différents partenaires et précises les engagements des services techniques du LPSC.

Reference documentaire :	**Date :**	**Révision :**
devSTEREO01	23 septembre 2013	xx

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III. Page de suivi des modifications du document

Révision	Date	Modifié par :	Pages modifiées, explications…

IV. Acronymes utilisés

CEA	Commissariat à l'Energie Atomique
FPGA	Field Programmable Gate Array
IN2P3	Institut National de Physique Nucléaire et de Physique des Particules
LPSC	Laboratoire de Physique Subatomique et Cosmologie
PDF	Portable Document Format (Adobe Acrobat)
WBS	Work Breakdown Structure
WP	Work Package

V. TABLE DES MATIERES

1 GENERALITES

1.1 Objectif du document

L'objectif de ce document est de décrire les différentes solutions, les moyens à mettre en œuvre et les différentes étapes techniques pour la conception, la fabrication et la mise en œuvre d'un détecteur d'anti-neutrinos à courte distance du réacteur de recherche de l'ILL.
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1.2 Documents de réferences

DR1 Proposal of a search of sterile neutrino at ILL : the STEREO experiment
DR2 STEREO, Demande ANR 2013
DR3 STEREO, Analyse des risques projet

TDR. Proposal, dossiers ANR, plan de développement de niveau supérieur, etc…

2 OBJECTIFS DU PROJET

2.1 Scientific objectives

There are a number of experimental results that appear anomalous in the context of the standard 3 neutrino framework, and can be explained by a sterile neutrino with mass around 1 eV. Its discovery would be a major extension of the Standard Model of elementary particles with important impact on cosmological issues like big-bang nucleosynthesis, supernovae collapse and large-scale structures.

The reactor anomaly: The development of reactor neutrino experiments has followed a breakthrough in the prediction of the emitted spectra. In the 80's, the irradiation of foils of the fissile isotopes ^{235}U, ^{239}Pu and ^{241}Pu in the high flux reactor of ILL allowed an accurate measurement of the mean spectra per fission [Feil82, Schreck85, Hahn89]. Once converted into antineutrino spectra, they could serve as references to predict the spectrum of any reactors. Recently, a re-evaluation of these reference spectra has pointed out some biases in the conversion of the ILL electron data into neutrino spectra as well as in their application to year scale experiment [Mueller12]. The net effect is an increase of the reference neutrino spectra by about 4%, confirmed by a subsequent independent work [Huber11]. These results triggered a re-analysis of all past reactor experiments in the 10-100 m range of baseline [Mention11]. The comparison between expected and measured fluxes for 19 measurements at reactors was updated. It has led to a mean deficit of 7% with a 3 σ significance when taking into account all correlations. This is called the reactor anomaly.

A new neutrino: An interpretation of this deficit is the existence of a new neutrino state. From the measurement of the Z0 decay width only three neutrinos lighter than half the Z^0 mass can couple to the weak interaction. Therefore this new neutrino state has to be sterile. It doesn't couple to the weak vector bosons but still mixes with the others neutrino mass eigenstates during their propagation. In the case of reactor electron antineutrinos this would imply a new oscillation pattern when they propagate from a core to a detector. In the framework of a two flavor mixing scheme the survival probability of a reactor antineutrino writes

$$P_{\nu_e\to\nu_e}\left(E_{\nu_e},L\right)=1-\sin^2\left(2\theta\right)\sin^2\left(1.27\frac{\Delta m^2 L}{E_{\nu_e}}\right)$$

with θ the mixing angle driving the amplitude of the oscillation, Dm^2 the difference between the square masses of the two neutrino states in eV^2, E_{ne} the neutrino energy in MeV and L the baseline in m. A graph of the successive oscillation patterns taking place along the propagation path is displayed on *Figure 2*. The maximum of electron antineutrino disappearance due to oscillations in the solar and atmospheric sectors are clearly seen at 60 and 2 km respectively. To explain the reactor anomaly, mixing with a sterile neutrino should occur at shorter baselines (<10 m). The fact that all data at short baseline (< 100 m) are well aligned on the mean 7% deficit restricts Δm^2_{new} to higher values than the solar and atmospheric sectors ($\Delta m^2_{new} > 1$ eV^2) with a mixing angle centered around twice the mean deficit. When combining the rate only analysis with the spectral shape information of the Bugey and ILL experiments, the absence of significant deformation in the measured energy spectra further restricts the contours to the high mass domain.

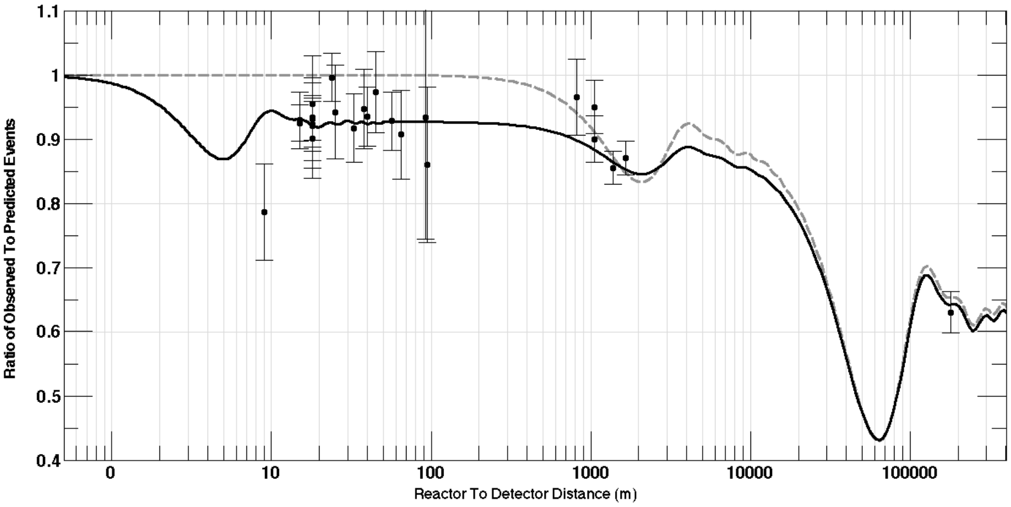

Figure 2: Ratio of observed over predicted reactor neutrinos versus the distance to the core. The predictions include the updated reference neutrino spectra related to the fission of U and Pu isotopes. For clarity the neutrino energy is fixed to a mean value of 4 MeV. The points correspond to published experimental values. The solid (dotted) line shows the expected rate evolution with (without) the mixing with a sterile neutrino at short baseline.

Another hint consistent with sterile neutrinos comes from the calibration data of radio-chemical solar neutrino experiments using gallium atoms as targets. These calibrations used very intense sources of ^{51}Cr and ^{37}Ar, which both decay via electron capture and emit mono-energetic electron neutrinos. The expected neutrino rate is accurately known from the determination of the source activity and the interaction cross-section. After inserting the sources in the Gallex [Gallex96] and Sage [Sage99, Sage06] detectors, a similar deficit of detected neutrinos was observed. This anomaly is even strengthened by new Gallium cross-section measurements [Giunti12]. Again, this result would find a natural explanation by a sterile neutrino with Dm$^{2}_{new}$>1 eV^{2}, which would allow some of the electron neutrinos from the source to "disappear" before they are absorbed by Ga atoms. The reactors and sources experiments combine nicely and lead to the global contours of *Figure* ***1***. The data are well fitted by the 3+1 neutrino hypothesis with best fit parameters Δm^2_{new}=2.3±0.1eV^2 and $\sin^2(2\theta_{new})$=0.17±0.04 while the no-oscillation hypothesis is disfavored at the 99.97% CL (3.6 s).

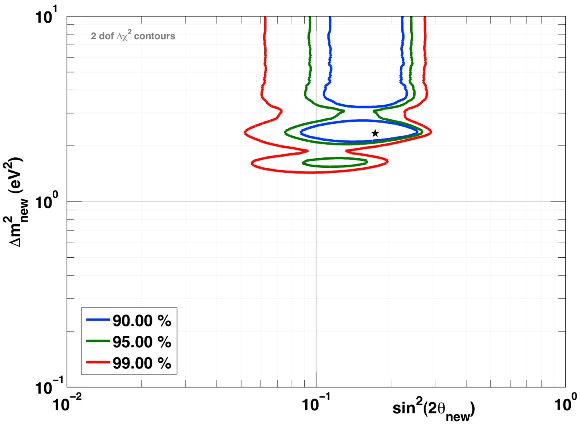

Figure 1 : Allowed regions in the [$\sin^2(2\theta_{new})$ - Δm^2_{new}] plane from the combination of reactor neutrino experiments, the Gallex and Sage calibration data, and the ILL and Bugey-3-energy spectra. The black star marker indicates the best fit parameters, the blue, green and red curves are the contours at 90, 95 and 99% C.L. respectively.

Independent data from observations of the cosmic microwave background and large scale structure also favor the existence of a fourth light degree-of-freedom which could be a sterile neutrino although the standard cosmological evolution model prefers this neutrino to be lighter than 1 eV [Cosmo13].

In the muon neutrino sector, the existence of a sterile neutrino could show up either via an anomalous disappearance or an anomalous appearance of electronic neutrinos with respect to the current three flavors framework. The most significant appearance of electron antineutrinos in a pure muon antineutrino beam is from the LSND experiment. However the agreement with the latest MiniBooNE results both with muon neutrino and muon antineutrino beams becomes marginal. Moreover the non-observation of muon neutrino disappearance by accelerator experiments like CDHSW or MINOS brings extra tension in any attempt of global fit.

Need of new measurements: While new measurements in the muon neutrino sector are required to clarify the situation, the combination of hints in the electron neutrino sector is very consistent and points with high significance toward a sterile neutrino around the 1 eV mass scale. So far all observed effects are purely in count rates. Stereo, the proposed measurement of an energy and distance-dependent new oscillation phenomenon is an unambiguous test of the existence of sterile neutrinos. Such a discovery would be a breakthrough in the exploration of physics beyond the Standard Model.

The objective of the Stereo experiment is to address the question of the existence of a sterile neutrino with a mass in the eV range. Data taking and first results are expected in 2015. The proposed measurement takes place at short distance from the 58 MW research reactor of the "Institut Laue-Langevin" (ILL) in Grenoble, France. If a sterile neutrino exists then one should observe a distortion of the energy spectrum of the reactor electron antineutrinos induced by the mixing with the new sterile state. Therefore the analysis of the Stereo measurement is based on the comparison between the shape of the detected energy spectrum and a reference shape as predicted with no oscillation. This analysis is free of any normalization factor like the history of the reactor power. The reference shape is particularly under control in the case of the ILL reactor because the nuclear fuel is highly enriched in ^{235}U and no other isotope contributes significantly to the fission rate. The neutrino spectrum of the fission of ^{235}U is the most accurately known and is based on the associated beta spectrum measured at the same ILL reactor in the 80's. For an unambiguous interpretation of the results, the Stereo detector is designed to **exploit the expected evolution of the spectrum distortion both in energy and in distance**.

2.2 Technical objectives

The objective of the Stereo collaboration is the design and realization of the anti-neutrino detector described below and its operation at short distance from the ILL reactor.

Within the 2-8 MeV energy range of reactor antineutrinos, the expected oscillation length of the new oscillation pattern is a few meters only. To preserve a good sensitivity to the amplitude and the phase of the oscillations Stereo is designed to fulfill the following criteria:

- Close ($L \leq 10$m) to a **compact** (<1 m) **and intense source of neutrinos**
- **Good energy resolution:** $dE/E \leq 10\%$ (1 σ)
- **Good precision on the neutrino baseline:** $dL < 1$m
- **Efficient background rejection:** $S/B = 1.5$

The detection concept is based on the inverse beta-decay (IBD) $\overline{\nu_e} + p \to e^+ + n$. Here "p" is one proton of the hydrogen rich liquid scintillator (LS). The neutrinos interactions are tagged via the time correlation of the prompt and delayed signals induced by the final state of IBD. The light generated by the positron is proportional to its kinetic energy plus a 1.022 MeV offset coming from its annihilation with an electron. This prompt signal is related to the energy of the incident reactor neutrino. The LS is doped with Gd in order to tag the radiative neutron capture on Gd (8 MeV) in coincidence with the annihilation of the positron.

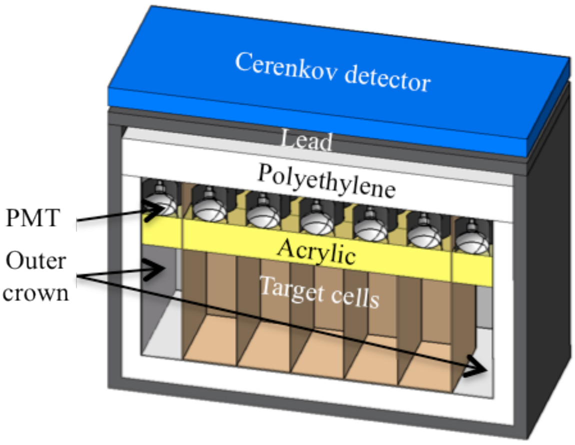

Figure 3: Cut view of the inner detector of Stereo

The detector concept: The Stereo detector consists in a 2 m^3 inner tank of liquid scintillator doped with gadolinium at about 0.2% in mass in order to tag the radiative neutron capture on Gd in coincidence with the annihilation of the positron. A 30 cm thick crown, filled with LS without gadolinium, surrounds this neutrino target and is optically decoupled from it. Photomultiplier tubes placed on top collect the light emitted in LS volumes. *Figure 3* represents a schematic view of the detector. The longest axis of the detector is pointing to the reactor core, so that neutrino oscillations may be spatially observed. In order to cover the relevant area of the contour of the sterile neutrino the target of Stereo is divided in six identical cells 0.4 m thick, 0.9 m high and 0.9 m wide. This setup provides a simple and passive determination of the vertex location with a binning of 40 cm in the direction of propagation. Such a position uncertainty is comparable to the size of the reactor core and small with respect to the expected oscillation length. The optical separation between the five cells is done with thin white Teflon plates fixed inside a single target vessel, itself coated with white Teflon. Five 8-inch photomultipliers are located above each cell and collect a total of 460 photo-electrons per MeV of deposited energy. A 20 cm thick acrylic buffer separates the LS from the photomultipliers. The main purpose of this buffer is to ensure a more homogeneous response across the whole volume of the cells. The bottom surface of the acrylic layer is on contact with the liquid surface and on the top of the buffer a few cm bath of mineral oil optically couple the photomultiplier tubes (PMTs) with the acrylic. All optical indexes being similar, the scintillation photons “see” a continuous medium from the vertex to the PMT photo-cathode. The same type of configuration is used for the outer crown. The target volume and the outer crown constitute the **inner detector**.

The inner detector is enclosed in a passive shielding of at least 15 cm of polyethylene and 10 cm of lead to isolate it from the external background. A water Cerenkov detector covers the top of the shielding to complete the veto of vertical muons.

The foreseen location to install Stereo is at level C of the reactor building, in front the exit of the H7 neutron tube (*Figure 4*). The rear wall of the room is the reactor pool wall, only 5 m from the core, providing a very short baseline and high neutrino flux. The main challenge of the experiment is the suppression of the neutron and gamma fluxes induced by the proximity to the reactor. These backgrounds have been characterized by on site measurements. Their suppression requires the implementation of heavy shielding between the detector and the reactor as well as all around the target volume.

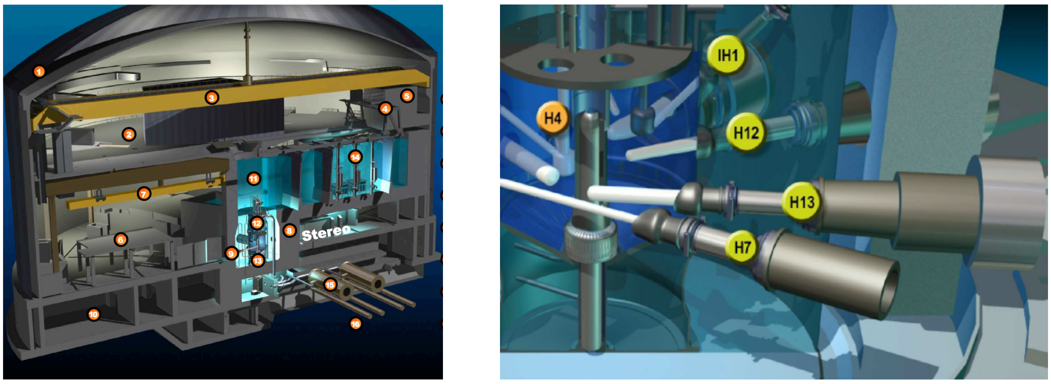

Figure 4: Cut view of the ILL reactor building (left). The foreseen site labeled "Stereo" is located underneath the water channel. The Stereo casemate is connected to the exit of the H7 tube (right). This tube traverses the pool but is not pointing to the core. A dedicated beam stopper will block gammas and neutrons inside the tube.

2.3 Expected performances

The expected performances of Stereo are summarized in *Table 1*. The quoted numbers rely on GEANT4 simulation, on-site measurements and results achieved in comparable detectors (Nucifer, Bugey, previous neutrino experiment at ILL).

Table 1: Summary of the expected performances of Stereo.

Energy resolution	**$\delta E/E = 10\%$ @ 2 MeV**
Threshold on visible E_{prompt}	2 MeV
Detection efficiency	$\varepsilon_{Det} \sim 50\%$
Evt by evt baseline uncertainty	$\delta L = 32$ cm
Uncertainty on energy scale	2%
Monitoring of detector response	At % level
Signal/Background	1.5
Detected neutrino /day	750
Sensitivity to best-fit oscill	$> 5\ \sigma$

2.4 Main stages of the project

The main stages of the project are summarized in *Figure* **5**.

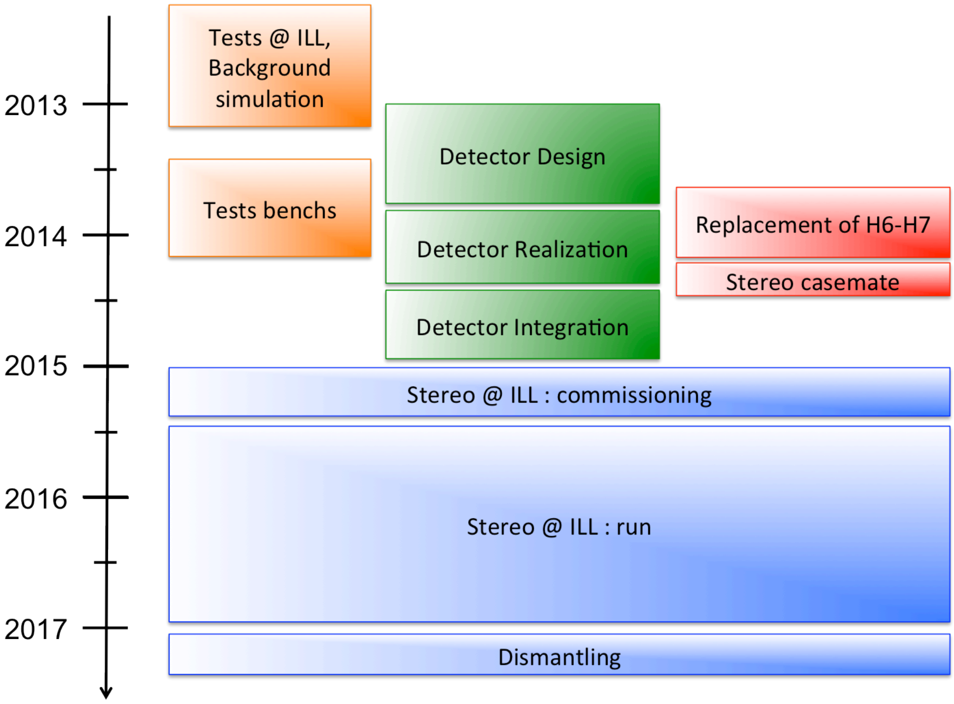

Figure 5 : Main stages of the Stereo project

3 PROJECT ORGANISATION

3.1 Roles of each partners

The installation on a reactor site brings specific constraints on the development of the project linked to the safety and the security of the setup and to the suppression of the external background. The following 8 main tasks are identified:

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- Task 1: Management and coordination
- Task 2: Security and Safety
- Task 3: Configuration of the casemate
- Task 4: Detector shielding
- Task 5: Liquid scintillators
- Task 6: Inner detector
- Task 7: Calibration and monitoring of the detector
- Task 8: Data acquisition system
-

David Lhuillier (Irfu) will coordinate the scientific aspects of the project in collaboration with the management team. Technical resources, engineers and technicians, for each of the hardware packages have been identified in the laboratories of the collaboration. The crucial technical coordination of Stereo will be done by Stéphane Fuard, permanent staff of ILL and experienced in project management.

Table 2 to *Table 4* summarize the contributions of the partners of the project.

Table 2: Summary of the contributions of each Stereo partner

ANR Partners	**Contributions**
CEA/Irfu	Project coordination Design and realization of the inner detector Prediction of neutrino spectrum
IN2P3/LPSC	Muon veto Data acquisition & slow control Light injection system Fabrication and mounting of the shielding
IN2P3/LAPP	Calibration system Design of the shielding Fabrication and mounting of the shielding
Associate members	
MPIK-Heidelberg	Liquid scintillators and filling system PMT's
ILL	Design and realization of beam stopper Safety studies Infrastructure of experimental area, on-site installation
Casablanca Univ.	Fabrication of the additional lead walls of the casemate

Table 3: Summary of the tasks and the involved parteners

Task #	Partners
1 - Management	ILL
2 - Safety	ILL
3 - Casemate config.	ILL
	LPSC
	Casablanca Univ.
4 - Detector shielding	LPSC
	LAPP
	ILL (installation)
5 - Liquids	MPIK
6 - Inner Detector	Irfu
7 - Calibration	LAPP
	LPSC
8 – DAQ	LPSC

Table 4: Summary of the tasks in which each Stereo partner is involved

	Task
ANR partners	
Irfu	1,2,3,6
LPSC	1,3,4,7,8
LAPP	1,4,7
Associates	
MPIK	1,5
ILL	1,2,3,4
Casablanca/CNESTEN	1,3

3.1.1 *Distribution of financial costs*

As can be seen from *Table* 5, 85% of the needed budget is already available.
Potential budget savings can come from a reduction of the operating costs (travels …), extra funding for a postdoc in discussion with IN2P3, re-using lead available at IN2P3, CERN or ILL, discussion with ILL concerning the reinforcement of the casemate.
A balanced budget will be prepared for the End of Feasibility review to be held on 14 November 2013 at ILL.

Table 5: Budget estimation and summary of the available ressources

BUDGET ESTIMATION		K€
Detector		**1000**
	Tank	200
	Liquid scintillator + filling system	320
	PMT	125
	Data acquisition	175
	Calibration system	130
	Prototype	50
Detector Shielding		**305**
	Pb	140
	PEHD	50
	Structures	70
	Veto µ	45
Shielding reinforcement (casemate)		**240**
	H7 plug	35
	Pb (25T)	70
	Flexible B_4C ($100m^2$)	25
	Structures	30
	Concrete ($6m^3$)	30
	Masonery	50
Other		**350**
	Post-doc	215
	Operating costs	95
	Safety studies	20
	H7 front wall studies	20
TOTAL		**1895**

AVAILABLE RESOURCES	K€
ANR	990
ILL (excl. Reactor cycles + waste reprocessing)	55
MPIK	445
CEA-IRFU	50
AGIR/UJF/INP	10
Univ. Casablanca- CNESTEN	20
TOTAL	**1570**

85% of the needed budget

LPSC's contributions are funded by ANR and UJF/INP. An extra funding is requested to IN2P3.

ANR funding: Resources are used for the procurement of task 4 and task 8 which are under the responsibility of LPSC and for valorization of the scientific results, **234.5 k€**.

AGIR/UJF/INPG funding: Preliminary studies **10 k€.**

Request to IN2P3: Light injection system **10 k€.** Lead not funded by ANR in case re-using lead is not enough, **175 k€.**

4 LE DECOUPAGE DU PROJET (GLOBAL)

4.1 Découpage des taches (WBS)

The following 8 main tasks are identified and are described below:

- Task 1: Management and coordination
- Task 2: Security and Safety
- Task 3: Configuration of the casemate
- Task 4: Detector shielding
- Task 5: Liquid scintillators
- Task 6: Inner detector
- Task 7: Calibration and monitoring of the detector
- Task 8: Data acquisition system

TASK 1 - Management and coordination: A management team of Stereo will be formed with representatives of the partners of the project: David Lhuillier (CEA/Irfu) , coordinator of Stereo and in charge of the inner detector; Anne Stutz (IN2P3/LPSC), coordinator of the detector shielding; P. Del Amo Sanchez (IN2P3/LAPP), coordinator of the detector calibration and monitoring; M. Lindner (MPIK-Heidelberg), head of the Max Plank Institute in Heidelberg; T. Soldner (ILL), contact physicist on site; S. Fuard (ILL), technical coordinator of the project; A. Hoummada (Univ. Casablanca), leader of the Moroccan partners.

TASK 2 – Security and Safety:
Objectives: Interaction with the reactor security and safety teams to review and address any hazards of the stereo setup. Find the required resources to provide a complete file to reactor and national authorities by the end of 2013, well before the installation in the casemate.
Responsibilities: The task supervisor is Stéphane Fuard (ILL), in collaboration with David Lhuillier (CEA/Irfu), Torsten Soldner (ILL) and Véronique Caillot (ILL).

TASK 3 – Configuration of the casemate:
Objectives: The site of the Stereo experiment is currently occupied by a γ-spectrometry experiment, GAMS5. This setup will be dismantled during the long shut down of the ILL reactor scheduled from August 2013 to June 2014. The objective of task #3 is to suppress the γ and neutron leakages from the core by designing and installing a dedicated shielding external to the stereo detector. This shielding comprises a beam stopper in the H7 tube and additional lead walls. The installation should proceed as soon as the casemate is available, expected on February 2014.
Responsibilities: The task supervisor is Torsten Soldner (ILL) in collaboration with David Lhuillier (CEA/Irfu) and Abdeslam Hommada (Univ. Casablanca).

TASK 4 – Detector Shielding:
Objectives: Define, design, produce and install the shielding surrounding the inner detector. This task is split into two independent deliverables:

- 4.a: an active muon veto detector that protects the inner detector from cosmic muon induced background
- 4.b: an hermetic passive shielding made of ~15 cm of polyethylene and a ~10 cm of lead outer layer.

Responsibilities: The task supervisor is Anne Stutz (LPSC). Task 4.a will be led by the LPSC group in Grenoble in collaboration with Murielle Heusch (LPSC). Pablo Del Amo Sanchez (LAPP) will supervise the design of the passive shielding because of its important interface with the calibration system, which he has in charge (see below). The contact person at ILL for safety and installation issues will be Stéphane Fuard. The fabrication will be shared as much as possible between LPSC and LAPP and possibly subcontracted.

TASK 5 – Liquid Scintillator:

Objectives: Produce 2 m^3 of liquid scintillator doped with Gd at 0.2% in mass for the target volume; 1.7 m^3 of liquid scintillator with identical light yield but no Gd for the outer crown volume. The attenuation length at the maximum sensitivity of the PMTs (about 420 nm) must be ≥ 4 m and stable for the duration of the experiment.

Responsibilities: Christian Buck (MPIK-Heidelberg) will supervise the production and delivery of all liquids.

Work program: The foreseen composition of the liquid scintillator is a mix of mineral oil,

TASK 6 – Inner Detector:

Objectives: Build the inner part of the detector. Validate the energy response using simulation and a prototype detector cell.

Responsibilities: The task supervisor is David Lhuillier (CEA/Irfu) in collaboration with the physicists' team and the technical services of CEA/Irfu.

TASK 7 – Calibration and detector monitoring:

Objectives: Define, design, test, then build and exploit the radioactive source-based calibration system as well as the LED-based monitoring system.

Responsibilities: Task supervised by Pablo del Amo Sanchez (LAPP). The LAPP is responsible for the calibration system and its interplay with the detector shielding, whereas the LPSC will be in charge of the LED-based monitoring system.

TASK 8 - Data acquisition system

Objectives: Design, test, produce and install the electronics, triggers and data acquisition system for the Stereo detector. There are several sub-tasks that this task will undertake: processing signals from the detector and distributing them to the acquisition system, forming low-level triggers, and monitoring the stability and performance of the detector. They will be implemented with a mix of commercial and custom electronics.

Responsibilities: This task will be lead by the LPSC group in Grenoble. The task supervisor is Christophe Vescovi (LPSC).

5 DESCRIPTION DES SOLUTIONS TECHNIQUES

5.1 Présentation des solutions envisagées

TASK 1 - Management and coordination:
The goal of the management team is to guarantee the smooth progress of the scientific program and discuss the use of the resources. Special care will be taken to establish strong link with the ILL reactor to prepare the installation and to coordinate the work on site. The team will meet biweekly by phone or videoconference. Global collaboration meetings will be organized 2 or 3 times per year with the presentation of all activities and results.
The management team will also organize the data taking and analysis with the designation of an analysis coordinator. Most of the analysis work will be done by the collaboration students (1 ANR postdoc, 1 postdoc from the ENIGMASS LabEx, 1 IN2P3 postdoc request and several PhDs). Once data taking has started, the progress of the analysis will be discussed in weekly analysis phone meetings. On-call experts and automatic control systems will assist the on-site shifters.

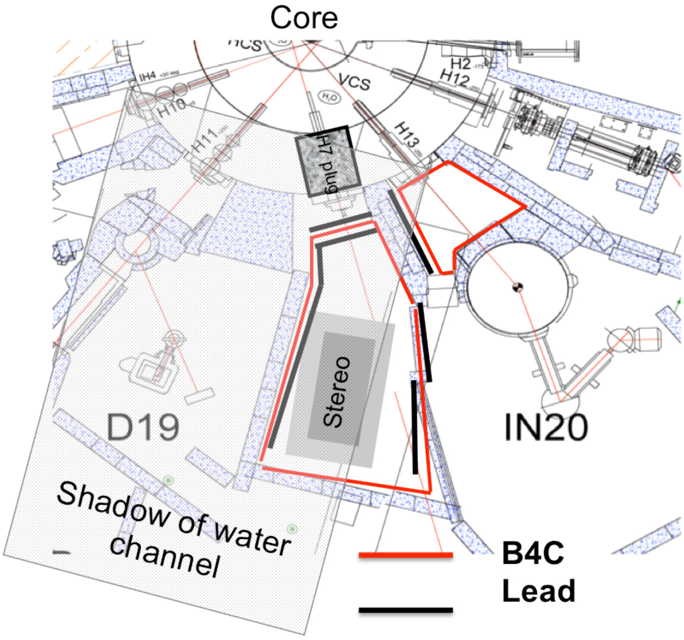
TASK 2 – Security and Safety:
Work program: An important aspect of the activity will be to coordinate the design of the various packages of the detector with the security and safety specifications involved by the work on a nuclear reactor site. Given his position at the Projects Office of ILL Stéphane Fuard will have easy contacts with the local security engineers and design office. As the local coordinator of the technical aspects of the Stereo installation he will also be well aware of the specifications and progress status of the detector. We expect the treatment and prevention of the risks of Stereo to be very similar to the Nucifer case. The Nucifer detector is currently operating at 7 m from the research reactor of Osiris in Saclay, with ~1m^3 of liquid scintillator and mineral oil inside a lead and polyethylene shielding. The Nucifer safety and security documents have already been transmitted to the ILL security engineer, Véronique Caillot. The experience from the Nucifer project combined with the current design of the Stereo detector already allows a good estimate of the required studies. The work was organized very early in the project with a first meeting in January 2013 at ILL. The ILL team will perform most of the risk analysis. Some specific calculations regarding the fire hazard will be sub-contracted by ILL.
The treatment of the installation of the shielding is standard to most experiments at ILL. Our target is to get the approval for the installation of the beam stopper, front wall and detector shielding by early 2014 in order to be ready for the installation as soon as the casemate is available. The treatment of the mechanics of the detector will be decoupled from the liquid handling and filling, presenting the extra risk of fire. We expect that this liquid part of the file will require a review by the ASN (Autorité de Sureté Nucléaire) with an extra mean delay of 4 to 6 months. Therefore our goal is to submit the file related to liquids before the end of 2013.
Risks and back-up solutions: The main risk is a delay in the approval due to late submission or interactions (questions – answers) between the ILL and ASN. We minimize this risk by an as early as possible submission of the file providing margin with respect to the installation schedule. The decoupling of the shielding and liquid review allows proceeding with most of the installation procedure. Once we receive the approval for filling the detector can be operational within one month.

TASK 3 – Configuration of the casemate:
Work program: The sources of reactor-induced background have been measured on site and are detailed in the Stereo proposal. During the first half of 2013 the simulations initiated at CEA/Irfu

to determine the neutron spectrum at the entrance of H7 were performed in collaboration with Stéphane Fuard (ILL). The results serve as input for the design of the dedicated beam stopper. A 1 m long portion of the H7 exit tube is available for an efficient blocking of the neutron and γ fluxes. A sandwich structure of Lead, Boron and Iron, similar to the current collimator is foreseen. This work was performed in full collaboration with the ILL experts in order to integrate the final choice of materials and geometry with the constraints of reactor safety. Also the GAMS6 experiment, located at the other end of the tube will continue taking data during the Stereo run. Therefore one has to make sure that the neutron absorption in the most upstream part of the beam stopper does not generate an overwhelming γ background. This constraint of low γ background along the axis of the H6-H7 tube motivated the use of Li as the first layer of the current collimator. We know from our on-site measurements that this material is an important source of secondary fast neutrons with energies extending above 10 MeV, which would constitute a critical background for Stereo. From preliminary study the replacement of the Lithium layer by Boron is a good compromise between low background in GAMS6 (the residual 477 keV line induced by neutron captures does not spoil the foreseen physics program) and complete absorption of the thermal neutron flux. Resources from the ILL design office are used for the technical design of the beam stopper and the safety review. The fabrication and the installation in the beam tube do not present major technical issues.

In parallel to the study of the beam stopper, simulations for the design of the front wall and casemate walls of Stereo were performed at LAPP and LPSC. The goal of this shielding is to suppress by at least a factor 100 the residual high-energy background coming from the core and the H13 primary casemate (γ flux above 2 MeV and neutrons above 3 MeV). The Stereo detector will be installed in the shadow of this shielding. The estimated total mass of 25 t will meet the floor load specifications of the area. The support mechanics must be designed strong enough to fulfill the earthquake specifications of the ILL. The University of Casablanca will subcontract the corresponding technical resources.

Standard B4C sheets, 5 mm thick, will complement this set of external shielding. They will cover the walls of the Stereo and H13 primary casemates. Such coating is commonly used for other experiments at ILL. They reduce the ambiance of thermal neutrons by 1 or 2 orders of magnitude with negligible generation of secondary particles. The γ rays associated with the neutron capture on Boron are far below the Stereo energy threshold. The rate of secondary fast neutrons induced by (α,n) reaction of Boron would already be acceptable with the current neutron ambiance, without dedicated beam stopper in H7.



Risks and back-up solutions: The risk is the presence of an unidentified source of background. This risk is minimized by the campaigns of on-site measurements already performed and by attenuation margins in the design of the shielding. Once the beam stopper and front wall are installed, the installation of Stereo will proceed simultaneously with reactor ON periods. The actual γ and n background will be re-measured at that time. In last resort extra shielding could be added in the space left available between Stereo and the walls.

TASK 4 – Detector Shielding:

Work program:
Active shielding: In the previous experiment at ILL, the primary background was induced by cosmic muons that produce high-energy neutrons. Most of these neutrons will be stopped in the polyethylene shielding around the detector, but a few of them can reach the target. The recoil proton generated by the thermalization process fakes the prompt signal and the same neutron provides the delayed signal when captured by the Gd nucleus. As the muon rate is measured to be around 70 Hz/m^2 at the ILL site, the detector has to be protected by an active muon veto that disables the acquisition after a muon or its associated shower passes in the target or close to it. The duration of the veto gate will be set to at least a few neutron capture time. With an expected muon rate of 500 Hz and a 100 µs veto time window, this will induce a 5% dead time. Obviously, the muon detector providing the veto gate has to cover the top part of the target. Note that the outer crown will also act as a muon veto since a crossing muon will deposit more than 60 MeV in the detector providing an unambiguous signal. In order not to increase the total calorific value of the Stereo setup, we plan to use a water Cherenkov detector. This kind of detector is widely used in particles physics experiment such as the Pierre Auger experiment or the Daya Bay reactor neutrino experiment. A 20 cm thick water tank would be placed above the Stereo detector outside the shielding, covering its entire surface. The total volume of water would amount to about 1.5 m^3. Muons crossing the water tank will emit Cherenkov light along their traces (about 500 photons per cm between 300 and 600 nm), whereas recoil electron induced by few MeV g-rays will be stopped within few mm. The Cherenkov light will be collected by photomultipliers. A simulation program based on GEANT4 is used to simulate the muon response and optimize the veto detector design. The overall goal is to provide a system with more than 95% efficiency. This requires good, uniform and stable optical propagation properties (large water absorption length, good tank reflectivity, uniform collection of photons). Before its deployment at the ILL site, the muon response of the veto detector will be validated with experimental data on muons crossing the detector at different incident angles and different locations. The electronics of the veto PMTs is very similar to that of the inner PMTs and will be addressed by Task 8. In the same way, a monitoring system will be provided to control the stability and efficiency of the veto detector to avoid systematic effects on the anti-neutrino signal. It will be based on trigger rate control and on dedicated runs to control the threshold.
Passive shielding: The γ background measured on site shows a rate and an energy spectrum similar to the Nucifer site. The same combination of a front wall and 10 cm lead shielding around the detector is used (15 cm on top side and 20 cm on bottom side). A strong structure, based on a girder frame anchored to the floor, will guarantee the mechanical stability of the shielding and fulfill the specifications of resistance to earthquake. The sidewalls will be built by assembling double V-shaped bricks. This geometry of lead brick ensures a good tightness of the shielding. A steel strapping inserted every 5 rows strengthens the mechanical stability. The inner layer of 15 cm polyethylene (30 cm on top and 20 cm on bottom) is light and can use anchor points on the lead walls. The root structure will both hold the lead layer and the muon veto. The design must also accommodate some space for the calibration system, cables and liquid handling tubes in the upper part of the shielding. This setup is quite similar to the Nucifer configuration illustrated in *Figure 6*.
The supervisors of this task will coordinate the design studies between the design offices of ILL, LPSC and LAPP. The total weight of this shielding is estimated to be 65 tons. Therefore the ILL

experts must validate the floor load of the final design. The installation in the casemate relies on technical manpower from LPSC and ILL.
Risks and back-up solutions: 4.a: The limited space in the ILL experiment casemate could constrain too much the design of the veto detector and this could result to a non-optimized light collection. If the specification of 95% efficiency cannot be reached a segmented design with extra PMTs will be considered. 4.b: all safety risks will be addressed in the related review. No other risk has been identified.

Figure 6: Nucifer shielding surrounding the inner detector (left) and support structure (right).

TASK 5 – Liquid Scintillator:
Work program: The foreseen composition of the liquid scintillator is a mix of mineral oil, purified dodecane, and phenyl-o-xylylethane, PXE. These components provide a flash point above 100 degrees Celsius that is an asset for the safety aspects. The light emission spectrum is shifted around the maximum sensitivity of the PMTs by the combination of two wavelength-shifters, PPO and Bis-MSB. The developments realized by the Heidelberg team for the Double Chooz and Nucifer experiments will serve for the procurement and mixing of all the liquid components and for the encapsulation of Gd atoms. Sample tests are foreseen for the optimization of the scintillator composition. Chemical compatibility with the materials of the inner detector will be validated by immersion of material samples in test cells of liquid and the transmission of the liquid measured regularly. The same validation procedure than double Chooz will be used, supervised by Guillaume Mention (CEA/Irfu). The liquid of the outer crown do not contain Gd. Its main constraints are to keep a density and a light yield similar to the target liquid. Use of a LAB based liquid, easy to obtain might be considered for the crown volume. Transport and storage can be done in standard Teflon coated barrels, filled under nitrogen atmosphere and sealed. The Heidelberg team will conceive a portable filling system similar to the setup used for Nucifer. It will be entirely made of Teflon, including the pumping system operated by pressurized nitrogen. The filling of both the target volume and the outer crown must happen simultaneously in order to avoid mechanical stress of the thin walls of the target vessel. Level sensors and infrared cameras will remotely control the liquid levels. The filling tubes remain accessible from outside during the data taking for liquid sampling.
Risks and back-up solutions: The team of MPIK-Heidelberg has demonstrated its expertise in the production, delivery and filling of stable and transparent liquids for the Double Chooz and

Nucifer experiments. The compatibility with all materials used for the inner detector will be tested. This central item of the detector is considered to be well under control.

TASK 6 – Inner Detector:

Work program: The inner detector is contained in a double walled steel vessel tightly closed by a rigid top lid. The vessel is about 1.5 m high with a footprint of 1.5 m x 3.0 m. The inner side will be coated with white Teflon for compatibility with the liquid scintillator and homogenous light collection. From past measurement for the Double Chooz and Nucifer experiments, standard steel is acceptable in terms of γ background induced by the vessel material. The 2 MeV threshold of deposited energy cuts most of the activity and only a few Hz are expected in the Stereo target volume, with the 2.6 MeV line of Thallium as the maximum energy. The radiopurity of each material will be measured with a dedicated Ge counter installed at CEA-Saclay and operated by Matthieu Vivier (CEA/Irfu) with the help of the LBA (Laboratoire de Basse Activité) platform at LPSC. The target vessel is embedded inside the steel vessel and anchored to the bottom of it. The choice of the material must find the best compromise between the mechanical strength of the structure, the efficient and homogenous light collection and the small perturbation of escaping γ rays before they enter in the outer crown. The current design is a thin (1 or 2 mm) aluminum box coated with VM2000. The target and outer crown liquid levels are only 90 cm and the outer double-walled vessel prevents any liquid leakage. Inside the target volume, vertical plates coated with VM2000 will define individual cells. These plates are mechanically held by few attach points on the vessel walls but small gaps will allow the liquid to circulate from one cell to another. This provides homogenous liquid properties in all cells and an easier filling process. The optical coupling with the acrylic buffer is simply ensured by a high enough level of liquid to stay in contact with the bottom surface of the buffer. The buffer itself is held from the top lid and centered by stops on the side. A few cm bath of mineral oil contained on top of the buffer provides the optical coupling with the PMT's.

The top lid of the inner detector ensures the tightness of the setup. The target and outer crown volumes will be flushed with nitrogen before filling and a slight over pressure of nitrogen will always be maintained inside.

The GEANT4 simulation shows that the quoted 1optical properties of Teflon are good enough for the sensitivity of Stereo. A prototype single cell will be built under the responsibility of Thomas Materna using the CEA/Irfu own funds to validate the light collection with the real geometry. This setup can be operated rapidly using PMT's available from the MPIK group and left over of liquid from the Nucifer experiment. Contacts with the relevant companies for the acrylics and vessel materials established for the Double Chooz and Nucifer experiments will serve for the procurement.

Risks and back-up solutions: This technology is already validated by the Nucifer and Double Chooz experiments. The quality of the wall coating is an important parameter to reduce the dependence on the vertex location. The prototype cell will test it. If the specification of 90% reflection cannot be reached an extra vertex correction could be implemented by adding two 3" PMTs at the bottom of each cell. They would be inserted in the thickness of polyethylene shielding underneath the target volume with no impact on neutron shielding. In this case the second wall for liquid containment would include the polyethylene layer.

TASK 7 – Calibration and detector monitoring:

Work program: Calibration is necessary to reduce detection inefficiency systematics, and to determine the energy scale at the few percent level. Radioactive sources will be employed regularly to map the detector response as a function of gamma energy (between 2 and 8 MeV), and of location of the energy deposition. The sources considered include ^{22}Na, ^{60}Co and ^{68}Ge.

They are sealed and in the range of the kBq activity. Additional calibration points are provided by neutron capture on H and Gd. Furthermore, a MBq Am-Be source is needed to test the IBD signal detection efficiency, thanks to its correlated gamma-neutron emission. Since the Stereo detector is divided in 10 optically independent volumes, an ensemble of (closed) guiding tubes will be used to circulate the sources within the liquid scintillator-filled volumes in a way that prevents radio-contamination. The sources will be pulled along the tubes by a wire or a chain, controlled by an automated system. The advantage of an automated system over manual displacement of the sources is the reproducibility of the measurements that will be compared to the detailed GEANT4 simulation. The position of the sources in the detector during the calibration phase is to be known up to 1 cm. Monitoring of the energy scale in between calibration runs will be performed online using special trigger lines.

The work foreseen is divided in three main phases:

1. The conception phase will optimize a number of parameters using simulations as well as input from the engineers. Mechanical constraints from the passage of a finite-sized source through the tubes determine the diameter of the tubes as well as their bending radii. On the other hand, the shadowing and the light absorption due to the guiding tubes should be minimized, which implies carefully choosing the size, location and length of the tubes. The impact of the tubes positions and angles on the tightness of the shielding is to be studied and reduced. The tubes in contact with the liquid scintillator will be Teflon coated.
2. During the testing phase, a prototype will be built. The correct passage of the sources through the bendings and the precision of the sources location will be verified.
3. Construction and installation on site.

The second goal of the task concerns the monitoring of the detector conditions. PMT gain and light transport stability will be followed frequently by means of light pulses generated by LED emitters. Light will be guided to a diffuser at the bottom of each of the 10 optically independent volumes by means of optic fibers. A specific diffuser will provide single photo-electron triggers and two other fibers with different light output, fired separately or in coincidence, will monitor the detector stability and its linearity.

An additional work item of this task is the development of the calibration and monitoring software of the experiment.

Risks and back-up solutions: The technologies involved are well established as similar calibration and monitoring systems have been developed in the past for other experiments (Bugey, Double Chooz, Nucifer). The technological risks are therefore considered negligible. The tight schedule envisaged for the project could be an issue. The solution proposed to overcome this possible hurdle is to start preliminary studies before T0.

TASK 8 - Data acquisition system

Work program: The Stereo detector is divided into seven optically independent sub-detectors: the five inner cells, the outer crown and the outer veto. The readout is based on large PMTs and waveform-FADC based electronics allowing for pulse shape discrimination of the signal. The light produced in each cell of the detector is collected by five 8-inch PMTs viewing the scintillator from the top. The same type of configuration is used for the outer crown with 24 additional 10-inchs PMTs, leading to a total of 54 PMTs. The collected light is about 460 photoelectrons per MeV of deposited energy and the dynamic range extends up to 8 MeV for both the prompt (positron) and delayed (neutron capture) signals.

These large PMTs, already used in the Double Chooz experiment, were designed to run at very high gain (~10^7) for single photo counting. A new custom design of the PMT base will be developed to satisfy the Stereo specifications; in particular the dynode voltage divider will be reconfigured to operate these PMTs at lower gain to achieve good linearity up to large anode currents. This is necessary to achieve this large dynamic range from single photo-electron level (per PMT) up to 8 MeV for the whole detector (800 p.e. per PMT) because the signature of the oscillation exploits the distortion of the energy spectrum in each cell. If such large dynamic cannot be achieved, an additional amplification stage can be provided for calibration runs at the photo-electron level. The foreseen electronics of the base is very similar to that used for years in large neutrino detectors and proven to be very safe and stable.

A high voltage system will be specified to provide stable power for the PMTs. One HV channel will control each PMT. Because of the proximity of mineral oil, PMTs are supplied with a positive high voltage, with the photocathode being grounded. This requires some +1.5 kV at 1 mA per PMT. Control and monitoring of the HV system is required as well as electrical protection means.

Each Front End Board will consist of five channels of analogue Front End Electronics (FEE) feeding a Fast Analog to Digital Conversion (FADC) system. The FEE will perform amplification and shaping of the base output signal in order to match the signal dynamics to the input of the FADC. The FEE will also have to ensure baseline stability to avoid baseline shifts caused by large muon signals.

If needed, analogue pulse summations per sub-detector will be produce for triggering purposes. The FEE may also provide an integrated charge measurement that could be used for triggering and/or an attenuated signal to fulfill calibration with muon crossing signals.

The FADC system will be developed, based on 250 MHz/12bit analog to digital converters and a modern FPGA providing fast online processing. The data stream will be continuously written in a circular memory buffer, allowing holding samples up to few microseconds per trigger and per channel. The system will have constant fraction auto-triggering capabilities. When a trigger occurs, the FPGA writes the event arrival time and freezes the buffer that can be processed to provide the pulse charge and pulse-tail charge measurements. The acquisition can continue without dead time in a new buffer.

A customized trigger system will be developed. It will rely on the estimation of the energy deposited in the *sub*-detectors, triggering the readout upon an energy threshold condition (>0.5 MeV in the inner cells or >5MeV in the inner cells and outer crown). The trigger system will also handle the FEE discriminator outputs and will check the multiplicity and the detector hit pattern. The trigger logic will be fully programmable and will accommodate any required input signals, such as the outer veto muon, the LED calibration signal or random signal.

The trigger system will not only provide the neutrino trigger but also other triggers to allow the study of backgrounds. If some trigger rates are too high a reduction of the rates will be applied by accepting only a programmable fraction of the triggers. The output of the trigger logic has to be stored and read out in case of event. The trigger system will provide a common clock for the whole detector and the time information has to be stored and read out in case of event. The overall systems are expected to sustain a rate of about 1 kHz.

The anti-neutrino signature relies on the coincidence of the energy released by the positron and the delayed neutron capture within a few 15 ms. The principle of the Stereo acquisition will be to perform as much online processing as possible in order to reduce the amount of data to be stored. However, in order to debug and check the performance of the online processing, the recorded pulse samples (100 samples or 200ns) will be transferred to the central DAQ along with the processed outputs only for a fraction of events.

A monitoring system will be provided to control systematic effects that could impact the experiment and send alarms to the operators. The quantities to be controlled include pressures, liquid levels, temperatures, PMT high voltages.

Risks and backup solutions:

There are no high technical risks identified for this task. This kind of data acquisition system is well known in high energy physics experiments and the main risk is probably the compatibility

of the PMTs available to Stereo requirements and will be mitigated by an early phase study of a dedicated PMT base.
The schedule for this task is however very tight and in order to be ready for prototyping at T0, all preliminary studies and design were performed before funding, in the beginning of year 2013.

5.2 Intégration et déploiement sur site

Il est prévu que l'ensemble des sous systèmes soient validés avant leur déploiement sur site.

Les contraintes liées au déploiement sur site tels que les dimensions et le poids des pièces à manipuler, sont pris en compte dés la phase de conception de chaque sous-système.

Le déploiement sur site est fortement contraint par les cycles de fonctionnement du réacteur et la disponibilité des moyens de manutention. Le déploiement sur site sera coordonné par Stéphane Fuard (ILL), responsable technique du projet, et intégré au planning général du grand-arrêt du réacteur.

5.3 Logistique, administration, transports, locaux

Une partie du matériel pourra être stocké au LPSC dans le hall Ariane avant son déploiement sur site.
Les ingénieurs sécurité de l'ILL devront être prévenus avant toute livraison sur le site afin de mettre en place un protocole permettant un déchargement respectant les règles de sécurité de l'ILL.
Pour permettre l'entrée et la sortie du matériel du site de l'ILL, celui-ci ne doit pas être contaminé. Chaque élément devrait donc être contrôlé individuellement à l'entrée et à la sortie. Dans notre cas (briques de plomb) cette opération est difficile à mettre en place et nous procéderons, en accord avec le service de radioprotection de l'ILL, par un échantillonnage parmi des lots représentatifs. Un marquage des différents lots devra être fait.

5.4 Aspects de sécurité

En plus des aspects classiques de sécurité de ce type d'expérience, le projet Stereo doit prendre en compte les spécificités du travail sur le site d'un réacteur nucléaire.

La sécurité des matériels sera gérée par la tache 1 et en particulier par les ingénieurs sécurité de l'ILL.

La sécurité des personnes devant intervenir sur le site de l'ILL est soumise à la réglementation des personnes travaillant sous rayonnement ionisant. Le personnel est donc soumis à une surveillance médicale particulière et à une évaluation individuelle de l'exposition dés qu'il opère en zone contrôlée. L'accès au site est également conditionné par la validation de la formation à la radioprotection prodiguée en ligne par l'ILL.

Les aspects de sécurité liés à la manipulation de quantités importantes de plomb seront pris en compte dés la phase de conception du blindage et validés par les ingénieurs sécurité de l'ILL.

6 RISQUES

Une analyse des risques projet a été réalisée en utilisant la liste des risques type proposée par l'IN2P3.

L'échelle des valeurs de risques utilisée est la suivante :

Tableau 6 : Echelle des risques utilisée

Impact sur :	Valeur	Critères
Délais	1	Sans effet
	2	Faible retard (1 à 3 mois)
	3	Retard significatif (3 à 6 mois)
	4	Gros retard (> 6 mois)
Ressources	1	Sans effet
	2	Faible surcoût (1 à 10%)
	3	Surcoût significatif (10 à 30%)
	4	Fort surcoût (> 30%)
Performances	1	Conformes aux exigences techniques
	2	Exigences pas tout à fait satisfaites
	3	Certaines exigences non satisfaites
	4	Non conformes aux exigences techniques

L'échelle permettant de quantifier la probabilité d'apparition de chaque risque est la suivante :

Tableau 7 : Echelle des occurrences

	Valeur	Critères
Probabilité d'apparition	1	Aucune occurrence (jamais)
	2	Extrêmement rare (pratiquement jamais)
	3	Rare ou peu fréquente (peut-être)
	4	Fréquent ou systématique (sûrement)

Un indice de gravité global (G) a été defini pour chacun des risques, comme étant égal à la somme pondérée des gravités « Délais » (D), « Ressources » (R) et « performances » (P), soit :

$$G = (D+R+P)/3.$$

La criticité des risques est alors étudiée dans une matrice combinant la probabilité d'apparition et la gravité globale.

6.1 Analyse des risques majeurs

Les activités du projet STEREO sont reparties entre les différents partenaires du projet. Les risques projets ont été analysés sur l'ensemble des activités mais plus particulièrement sur les activités dont le LPSC a la responsabilité

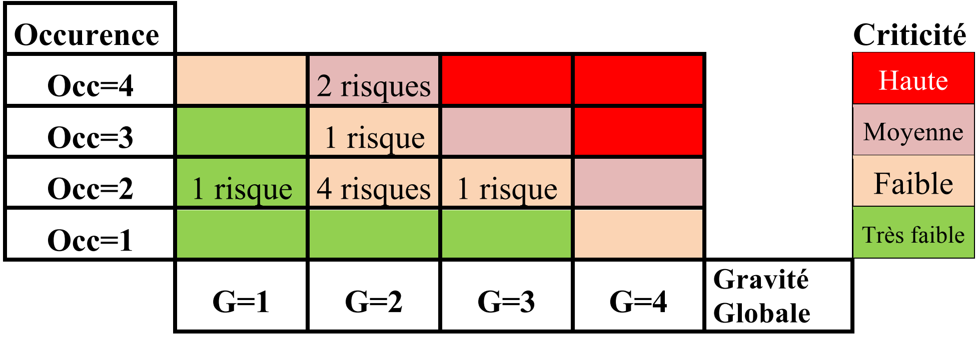
Le *Tableau **8***, montre la liste des risques identifiés avec les probabilités d'apparition ainsi que les indices de gravités.

Le *Tableau **9*** montre la distribution des différents risques identifiés en fonction de la criticité. Aucun risque n'est à un niveau de criticité élevé.

Tableau 8 : Identification et évaluation des risques

N#	Description du risque	Occurrence	Impact sur délais	Impact sur ressources	Impact sur performance	Gravité globale
1	Risque de difficultés liées aux partenaires du projet (abandon, projet non prioritaire, réglementation et normes différentes, situation économique et sociale difficile, instabilité politique, instabilité budgétaire).	**3**	2	2	1	**1.6 (2)**
2	Risque de manque de financement pour l'acquisition d'une partie du blindage passif nécessaire (plomb).	**4**	2	1	3	**2**
3	Risque de spécifications manquantes, incomplètes, insuffisamment précises.	**2**	2	2	1	**1.6 (2)**
4	Risque de fluctuation des spécifications après le démarrage du projet..	**2**	2	2	1	**1.6 (2)**
5	Risque de nouvelles exigences de sûreté (ex. sûreté nucléaire) avec remise en cause d'une solution technique, en raison de manque de dialogue ou d'implication tardive des autorités de contrôle et sécurité (ASN).	**2**	2	2	1	**1.6 (2)**
6	Risque d'accident technique (origine mécanique, origine thermique, origine chimique, origine électrique, incendie) en raison d'utilisation de matériaux nécessitants des dispositifs de sécurité adaptés.	**2**	4	3	1	**2.6 (3)**
7	Risque de fourniture d'équipements non conformes par les industriels sollicités	**2**	2	1	1	**1.3 (1)**
8	Risques liés aux difficultés de livraison de la part des partenaires du projet.	**2**	3	2	1	**2**
9	Risque de marges insuffisantes pour le délai global annoncé.	**4**	2	2	1	**1.6 (2)**

Tableau 9 : Matrice des risques et criticité



Occurence					
Occ=4		2 risques			
Occ=3		1 risque			
Occ=2	1 risque	4 risques	1 risque		
Occ=1					
	G=1	**G=2**	**G=3**	**G=4**	**Gravité Globale**

Criticité
Haute
Moyenne
Faible
Très faible

6.2 Actions de réduction des risques et vérifications

La table montre les solutions envisagées pour la réduction des risques ainsi que les critères qui permettent de vérifier ces réductions.

Tableau 10 : Table de réduction des risques et de vérification

N#	Description du risque	Action de réduction	Critère de vérification de la réduction
1	Risque de difficultés liées aux partenaires du projet (abandon, projet non prioritaire, réglementation et normes différentes, situation économique et sociale difficile, instabilité politique, instabilité budgétaire).	Etudes des possibilités de prise en charge de certaines activités critiques par d'autres partenaires	Rapports d'activités conformes aux attentes
2	Risque de manque de financement pour l'acquisition d'une partie du blindage passif nécessaire (plomb).	- Demande de financement IN2P3 - Recherche de stock dans la collaboration et au-delà	Approvisionnement et stock adapté au besoin
3	Risque de spécifications manquantes, incomplètes, insuffisamment précises.	- Mise en place de réunions de définitions régulières - échanges de documentations claires et précises	Documentation de définition peu révisée, ECR en diminutions
4	Risque de fluctuation des spécifications après le démarrage du projet..	- Mise en place de réunions de définitions régulières - échanges de documentations claires et précises	Documentation de définition peu révisée, ECR en diminutions
5	Risque de nouvelles exigences de sûreté (ex. sûreté nucléaire) avec remise en cause d'une solution technique, en raison de manque de dialogue ou d'implication tardive des autorités de contrôle et sécurité (ASN).	- Dossier ASN élaboré par des experts (ILL) -Transmission complètes des informations techniques	Délais de traitement du dossier réduit
6	Risque d'accident technique (origine mécanique, origine thermique, origine chimique, origine électrique, incendie) en raison d'utilisation de matériaux nécessitants des dispositifs de sécurité adaptés.	- Mise en œuvre de dispositifs de sécurité adaptés en collaboration avec l'ILL -Mise en place de procédures d'installation et d'exploitation adaptees	Approbation par les services de sécurité de l'ILL
7	Risque de fourniture d'équipements non conformes par les industriels sollicités	Vérification de la certification des industriels sous-traitants.	Bonne qualité de la prestation
8	Risques liés aux difficultés de livraison de la part des partenaires du projet.	-Coordination et gestion de projet claire et éventuellement renforcée pour certain partenaires - Organisation de revues d'activités	Délais conformes aux prévisions
9	Risque de marges insuffisantes pour le délai global annoncé.	- Anticipation des délais d'approvisionnement longs - Définition des priorités par rapport a la criticité des activités	Planning conforme aux prévisions

7 PLAN DE VERIFICATION

Le plan de vérification présenté porte uniquement sur les activités dont le LPSC a la responsabilité.

Tache 4a, Réalisation du veto muon.
Le plan de vérification du détecteur véto est constitué des étapes suivantes :

1. Estimation des performances à l'aide d'une simulation GEANT4 dans laquelle les paramètres optiques sont introduits.
2. Validation de l'effet de l'utilisation du shifter de longueur d'onde en utilisant la cuve Cerenkov du TP muon (cuve d'eau de dimensions 50 cm x 50 cm x 50 cm vue par le dessus par un photomultiplicateur).
3. Test des performances de collection de lumière (définition du diffuseur optique recouvrant les faces de la cuve, définition du nombre et de l'emplacement des photomultiplicateurs, validation du système de purification de l'eau), avec un prototype de dimensions proches des dimensions finales.
4. Validation du dispositif de contrôle de la stabilité du détecteur.

Le prototype est constitué d'une cuve rectangulaire en PMMA de dimensions 3.0 m x 2.5 m et 20 cm d'épaisseur et d'un couvercle. Les surfaces de la cuve et du couvercle seront recouvertes d'un diffuseur optique de type tyvek. Plusieurs diffuseurs pourront être testés. La cuve sera remplie d'eau purifiée et une circulation associée à un dispositif de purification UV est également prévue. La lumière sera collectée par plusieurs photomultiplicateurs de 5'' à photocathode plate (origine JLAB) placés sur les faces latérales de la cuve.
Le prototype sera installé dans une chambre noire à ossature bois de 5.0 m x 4.0 m x 2.5 m installée dans le hall Ariane. Des plaques de scintillateur (2.0 m x 20 cm) vues par 2 PMT (origine Alice) seront disposées au dessus de la chambre noire et sous le prototype afin de permettre une cartographie de l'efficacité du détecteur de muon.

Tache 4b, Blindages passifs
Les blindages ont été validés par des simulations GEANT4, leur efficacité vis à vis du bruit de fond gamma et neutron sera validée à chacune des étapes de l'installation par des mesures sur site avec des détecteurs Ge et ^{3}He. Plusieurs campagnes de mesure sont ainsi prévues dés le redémarrage du réacteur pour valider et optimiser les blindages avant l'installation du détecteur. La structure mécanique sera prévue de telle sorte que des épaisseurs supplémentaires de plomb ou de PEHD pourront être ajoutées si les spécifications de niveau de bruit de fond ne sont pas atteintes.

La structure du blindage sera validée du point de vue mécanique par un montage à blanc de l'ensemble de la structure avant l'installation sur site.

Tache 7, Système d'injection de lumière
Le système d'injection de lumière avec LED sera testé sur le prototype du détecteur véto.

Tache 8, Electronique et acquisition de données
La linéarité des bases sera testée avec un PMT de 10'' prêté par la collaboration Double Chooz et un système de génération de lumière à LED et filtres.

Un démonstrateur de la carte Front End est en cours de réalisation et sera testé avant de lancer la production des cartes finales. Ce démonstrateur intègre les ressources matérielles nécessaires à la simulation d'un seizième de la future carte trigger/centralisation. Ceci nous permettra, avec une seule carte électronique, de valider le protocole d'échange des données entre les différentes électroniques et de disposer d'un système d'acquisition autonome de test.

Un prototype constitué d'un faible volume de liquide scintillateur (40 cm x 40 cm x 40 cm) et d'un PMT de 10'' pourra être réalisé afin de permettre le test de l'électronique avec un véritable signal de PMT. Il permettra entre autre de mettre au point les algorithmes de DFC et de PSD qui seront implantés dans le FPGA et de tester la carte électronique du système de déclenchement des LED.

Des tests seront également réalisés avec un prototype correspondant à une demi cellule du détecteur et disposant d'au moins 2 voies de PMT. Ce prototype est en cours de réalisation à l'Irfu, et pourra être déplacé au LPSC.

8 BUDGET

Cette partie du document détaille le budget nécessaire à la réalisation des taches 4a (veto muon), 7b (système d'injection de lumière) et 8 (électronique et acquisition de données) qui sont sous la responsabilité du LPSC.

Les taches 4a et 8 sont entièrement financées par l'ANR, ainsi que le budget mission et conférences. Le montant total alloué par l'ANR au LPSC est de 234,5 k€.
Un financement complémentaire de 10 k€ a été demandé à l'IN2P3 pour la tache 7b, ainsi que 175 k€ pour l'achat d'une partie du plomb manquant. Des taches 3 et 4b.

Suivant les disponibilités du SERM et en fonction des délais, la réalisation de la cuve du détecteur veto muon pourra être sous-traitée ainsi qu'une partie de la fabrication des pièces de la structure du blindage.
Le câblage de l'électronique sera sous traité.

Tâche 4, Réalisation du veto muon : 45 000 €

Ce budget représente le coût total pour la réalisation du veto muon, incluant la matière première pour la structure et la collection de lumière, les photomultiplicateurs et le système de purification de l'eau.

Item	**Comment**	**Price (k€)**
Fabrication		20
Teflon coating		10
Water purification		9
PMT		6
Total		**45**

Tâche 8, Electronique et acquisition de données : 176 000 €

Ce budget représente tout ce qui est nécessaire à la fabrication de l'électronique et de la chaîne d'acquisition dont le LPSC a la responsabilité.

Item	**Comment**	**Price (k€)**
HV and LV power supply		30
PMT bases	For 50 PMT	10
FEB Prototype	4 channels	5
FEB Production	64 channels	48
Trigger board		10
Electronics housing, mechanics		30
Harness, Connectors		20
Central DAQ	2 PCs	3
Slow Control	Sensors and acquisition modules	20
Total		**176**

Tâche 7, Système d'injection de lumière **: 10 k€**

Ce budget représente ce qui est nécessaire à l'achat des fibres optiques et de leur connecteur ainsi que des diffuseurs de lumière.

Item	Comment	Price (k€)
External optical fibers	40 channels	6
Internal optical fibers	40 channels	4
Total		10

Tâches 3 et 4b : Achat de 27 tonnes de plomb à 32 euros la brique de 11 kg: **175 k€**

Missions: 13,6 k€
Participation à 3 conférences internationales : 4,5 k€
Missions pour reunions de collaboration, 6 personnes concernées: 9 k€

9 SEQUENCEMENT DES ACTIVITES

Le projet STEREO a été évalué par le conseil scientifique de l'ILL, qui a donné son accord pour une installation au niveau C pour la durée demandée de l'expérience, à savoir 3 ans. La réponse officiel du directeur scientifique de l'ILL est présentée ci-dessous :

" We are pleased to inform you that your proposal for a short baseline neutrino oscillation experiment at the ILL reactor has received an extremely favorable response from the ILL Scientific Council.
In addition, the ILL has been urged by its Steering Committee to pursue efforts to conduct an experiment of this kind at the ILL as soon as possible in view of the currently high level of interest in this topic. Experimental areas close to the reactor core at the H7 and B42 positions can be made available in the time period from 2013 to 2017."

Le projet Stereo tire également profit du grand arrêt réacteur d'aout 2013 à juin 2014. Un aménagement dédié de la casemate est prévu durant cette période.

Le calendrier général proposé s'articule autour du planning de ce grand arrêt et des cycles de fonctionnement du réacteur :

- **Aout 2013- mi juin 2014** : Grand arrêt réacteur de 10 mois
  - Remplacement du bouchon-collimateur de H7
  - Couverture B4C des casemates primaires PN3 et IN20
  - Montage des murs de plomb supplémentaires

- **Juin 2014** : 1 cycle court réacteur ON de 1 mois
  - Test de bruit de fond dans la casemate aménagée

- **Juillet 2014 à fin 2014** : 2 cycles réacteur de 50 jours
  - Installation des blindages et du détecteur
  - Tests de bruit de fond à chaque étape

- **Début 2015** : 2 cycles pour commissionning.

- **Avril 2105 à fin 2016** : Prise de données effective durant 6 cycles

- **Janvier 2017** : changement du tube H6-H7, Stereo devra être démonté

9.1 Planning général d'installation

Le planning d'installation est fortement lié au planning du grand arrêt de l'ILL. L'objectif est de construire la protection primaire de la casemate Stereo durant cet arrêt afin de pouvoir faire des mesures de bruit de fond dés le premier cycle de fonctionnement du réacteur et de pouvoir continuer l'installation lorsque le réacteur est en marche.

Le montage de Stereo dans la casemate PN3 à l'ILL se décomposera en 6 étapes principales :

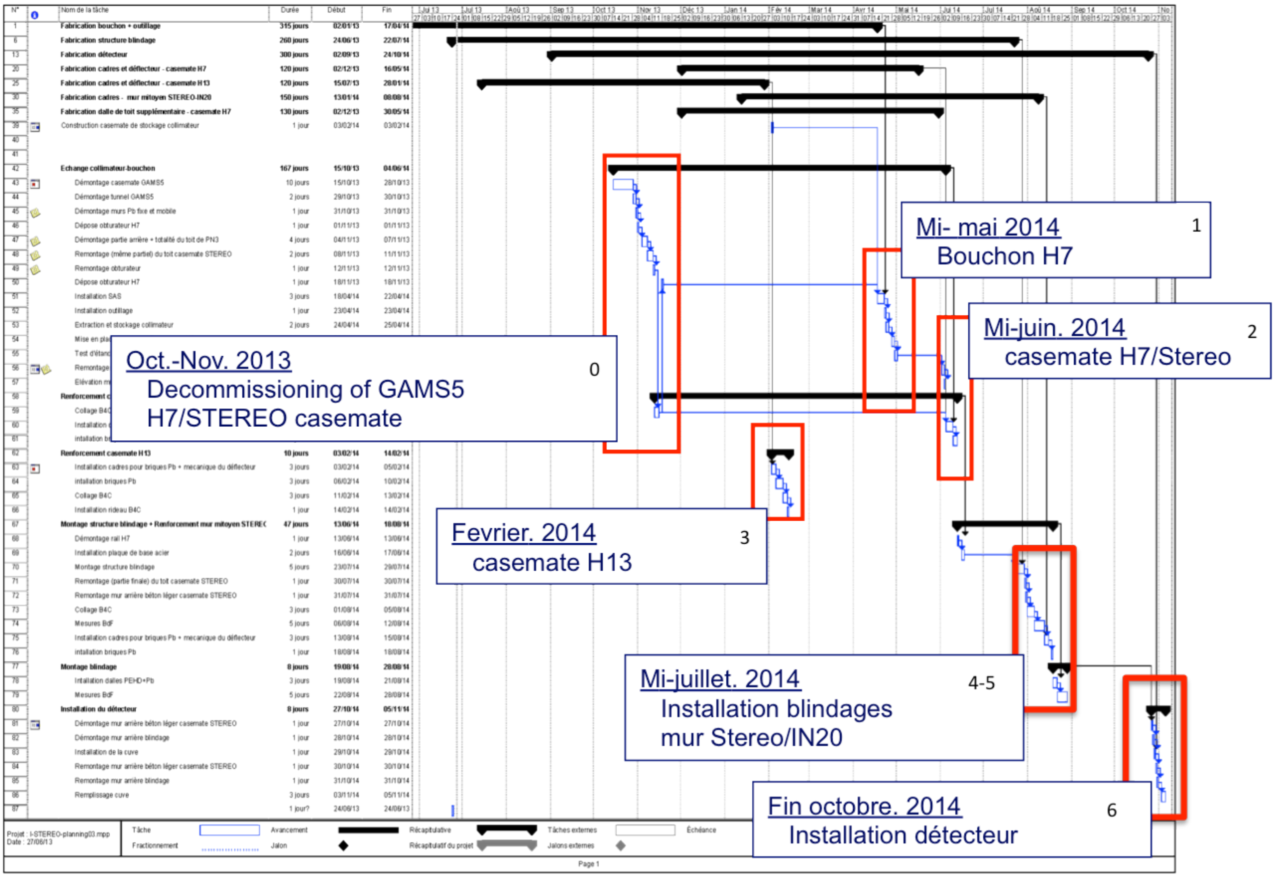
1. Remplacement du collimateur de H7 par un bouchon plein
2. Renforcement radiologique de la casemate primaire de H7
3. Renforcement radiologique de la casemate primaire de H13
4. Montage de la casemate béton de Stereo et renforcement radiologique du mur mitoyen
5. Montage des blindages de Stereo
6. Installation du détecteur de Stereo

Les contraintes d'installation liées aux autres chantiers ont été intégrées dans le planning d'installation de Stereo présenté à l'ILL. Il en est de même des contraintes liées à l'ouverture de la porte d'accès au bâtiment réacteur, à l'utilisation du pont ou du chariot élévateur.

Le planning proposé est présenté sur le diagramme de Gantt des *Figure 7* et *Figure **8***. Les étapes clés ont été annotées. Une vue synthétique est également donnée dans la *Figure **9***

La structure du blindage devra être prête pour mi-juillet 2014 et on ne pourra entrer la cuve du détecteur que fin d'octobre 2014. L'électronique, la DAQ et le système de calibration devront être prêts pour novembre 2014.

Figure 7 : Diagramme de Gantt de l'installation de l'expérience Stereo à l'ILL



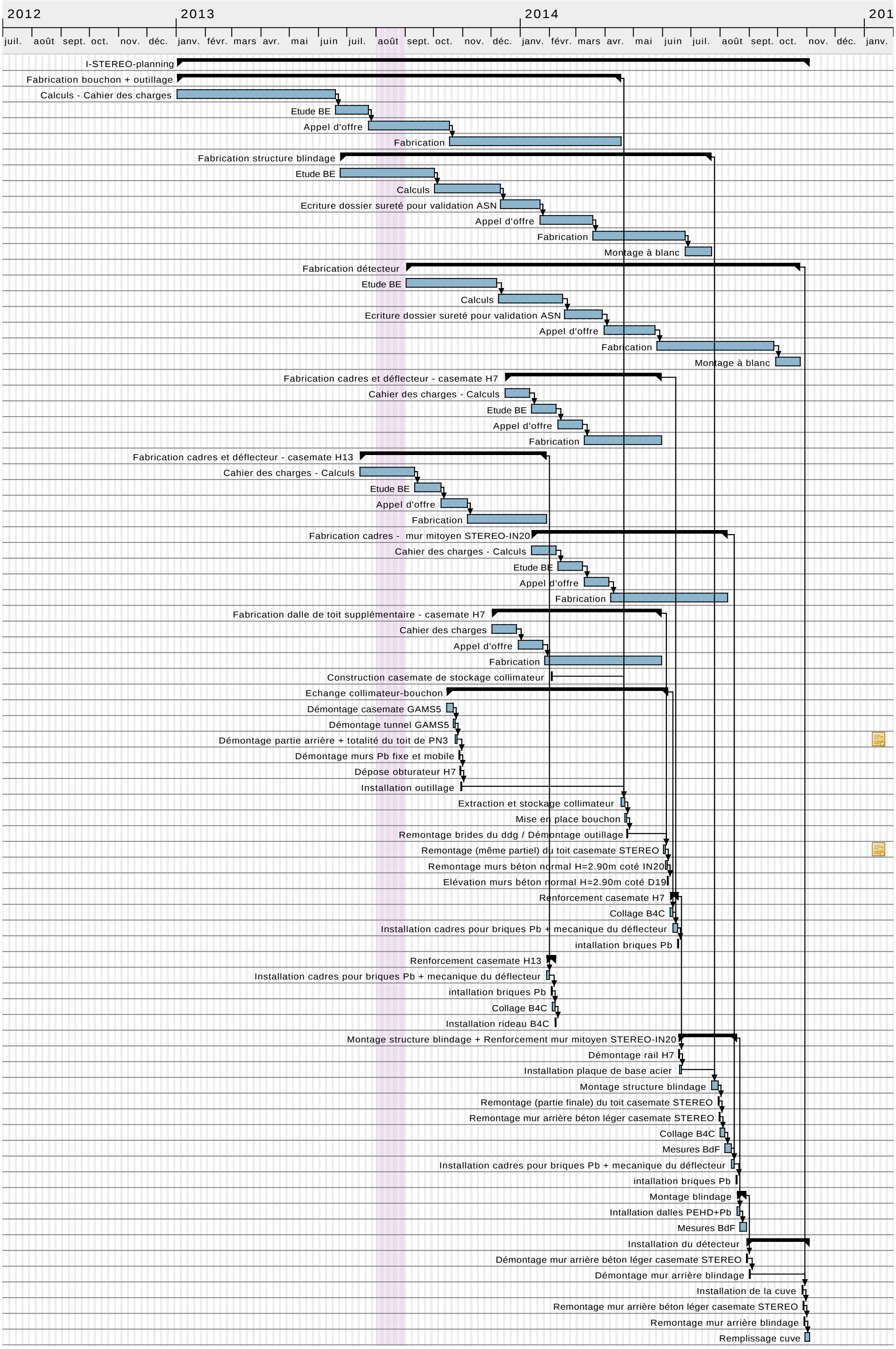


Figure 8 : Planning d'installation à l'ILL

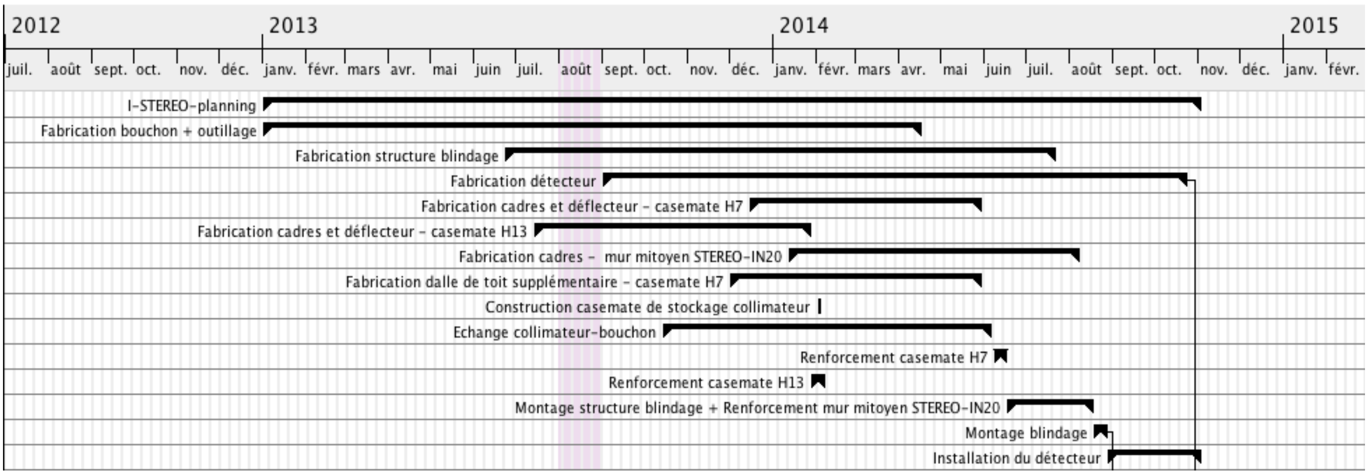
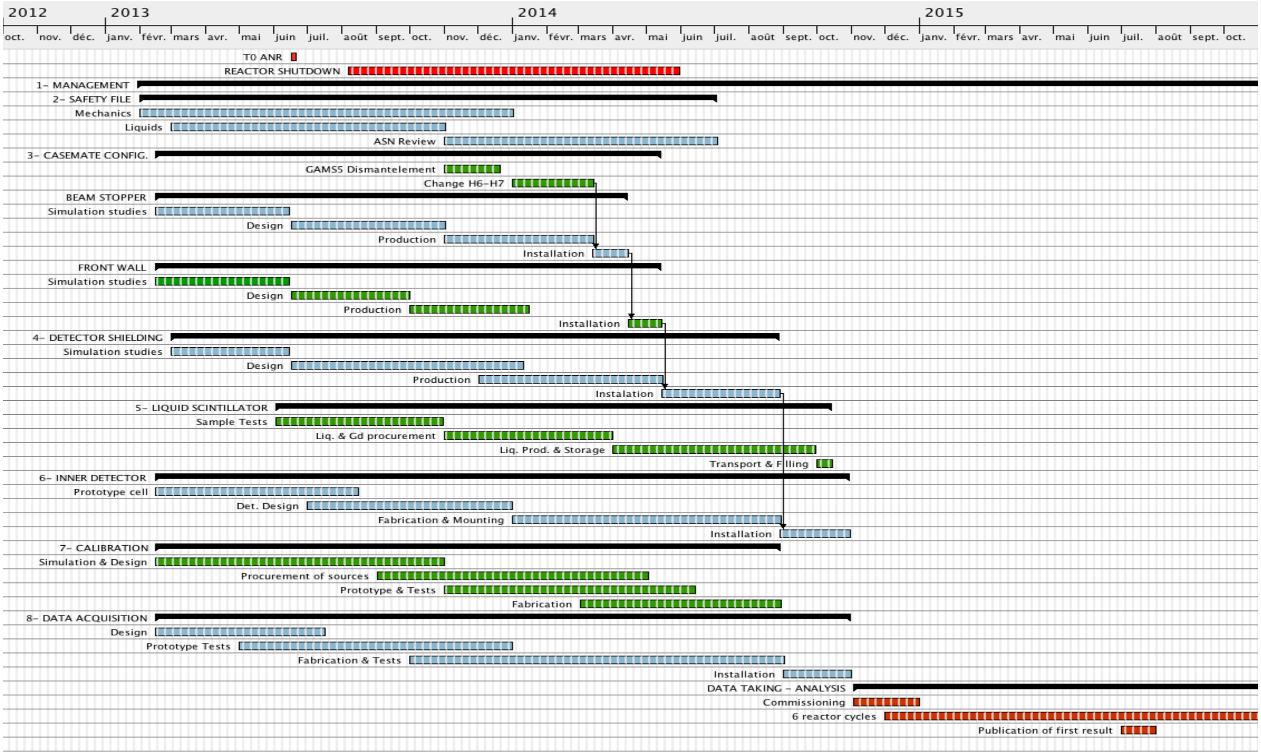


Figure 9 : Diagramme de Gantt de l'installation de l'expérience Stereo à l'ILL

9.2 Planning par lot de travaux et ressources humaines

Le planning de chaque tâche, tel qu'il a été présenté dans le dossier ANR est présenté dans le diagramme de Gantt de la *Figure* ***10***. Un léger glissement dans le démarrage du design et du prototypage de plusieurs tâches a eu lieu du fait de la difficulté de mobiliser les services techniques dans l'attente de l'assurance du financement par l'ANR. Ce retard ne remet pas en cause le planning prévu initialement.

Figure 10 : Planning des taches



Les activités techniques concernent plusieurs services du laboratoire. Elles seront coordonnées par **Murielle Heusch**.

Outre les taches décrites précédemment dans le document, un support a été demandé aux :

- **service informatique** pour la gestion d'un ELOG, d'un WIKI et pour faciliter les échanges avec le CCIN2P3 ou seront hébergées les données et les programmes de la collaboration.
- **service communication** pour l'organisation des réunions de collaboration qui se tiendront préférentiellement au LPSC
- **service administratif** pour le suivi financier du projet.

Les chercheurs du projet (S. Kox, J. Lamblin, F. Montanet, J.S Réal et A. Stutz) sont également impliqués dans les activités techniques du projet.

Les ressources humaines des services techniques du LPSC impliqués dans le projet Stereo sont présentées dans le **Erreur ! Source du renvoi introuvable.***Tableau **11***, leur répartition par tâche dans le *Tableau **12***.

Le séquencement des activités pour 2013 et 2014 est présenté dans le T*ableau **13***.

Tableau 11 : Ressources humaines du LPSC impliquées dans le projet Stereo

Nom		**Service**	**% 2013-2014**
Ch Bernard	CHB	SDI	20
M. Chala	MC	SDI	15
F. Collovati	FV	SDI	10
M. Heusch	MH	SDI	20
J.L Bouly	JLB	Electronique	15
O. Bourrion	OB	Electronique	10
G. Marcotte	GM	Electronique	20
J.P Scordilis	JPS	Electronique	15
D. Tourres	DT	Electronique	30
C. Vescovi	CV	Electronique	25
J.C Malacour	JCM	SERM	20
S. Roni	SR	SERM	10
S. Roudier	SeR	SERM	5
C. Gondrand	CG	Informatique	5
C. Biscarat	CB	Informatique	5
F. Melot	FM	Informatique	5
J.Riffault	JR	Communication	5
F. Petiot	FP	Administration	5

Tableau 12 : Répartition des ressources humaines du LPSC par tâche

ID Tache	**Définition de la tache**	**Intervenants**	**ETP**
Tache 3	Configuration de la casemate	CHB, MC	0.1
Tache 4a	Veto muon	CHB, MC, MH	0.2
Tache 4b	Fabrication du blindage Installation du blindage	JCM, SR, SeR, CHB, MC	0.35 0.15
Tache 7	Système d'injection de lumière	MH, FV	0.2
Tache 8	Electronique et DAQ	JLB, OB, GM, JPS, DT, CV	1.15
	Support informatique	CG, CB, FM	0.15
	Support événementiel	JR	0.5
	Support administratif	FP	0.5

Tableau 13 : Séquencement des activités techniques au LPSC

Tâches	**2013**				**2014**			
Config casemates			🟦		🟦	🟦		
Veto muon			🟦	🟦	🟦	🟦	🟦	
Fabrication blindage					🟦	🟦		
Installation blindage							🟦	
Injection de lumière				🟦	🟦	🟦	🟦	
Electronique et DAQ			🟦	🟦	🟦	🟦	🟦	🟦
Support info		🟦	🟦	🟦	🟦	🟦	🟦	🟦
Support com. et adm.		🟦	🟦	🟦	🟦	🟦	🟦	🟦