Acronyme / Acronym	**STEREO**		
Titre du projet	Recherche de neutrino stérile auprès du réacteur de l'ILL.		
Proposal title	Search for sterile neutrino at the ILL reactor.		
Comité d'évaluation / Evaluation panel	**SIMI5** – Physique subatomique et théories associées, astrophysique, astronomie et planétologie.		
Type de recherche / Type of research	x Recherche Fondamentale / Basic Research ☐ Recherche Industrielle / Industrial Research ☐ Développement Expérimental / Experimental Development		
Coopération internationale / International cooperation	x Oui, en dehors d'un accord bilatéral / Yes, outside of a bilateral agreement ☐ Non / No		
Aide totale demandée / Grant requested	1 168 087 €	**Durée du projet / Projet duration**	36 mois
Partenaire coordinateur / Coordinator partner	Identité du coordinateur: LHUILLIER David. Identification de l'établissement: CEA Saclay		
Lien avec un projet du programme *Investissements d'Avenir* (IA) / Link with a project of the *Investment for the Future* programme	x Oui ☐ Non si oui, préciser : LPSC et LAPP sont membres du LabEx ENIGMASS, une demande de postdoc sera soumise. L'Irfu est member du LabEx P2IO.		

People involved in the project:

Organisation	Last name	First name	Current position	Field of research*	Involvement in the project (PM)**	Contribution to the project *4 lines maximum*
Partner 1 CEA Saclay	*LHUILLIER*	*David*	*Physicist*	*Reactor neutrinos*	*22*	*Coordinator of the project Inner detector Safety file.*
	LETOURNEAU	*Alain*	*Physicist*	*Fission, reactor neutrinos*	*14*	*Responsible for reactor calculations Responsible for Inner detector and prototype*
	MATERNA	*Thomas*	*Physicist*	*Fission*	*11*	*Inner detector Electronics*
	MENTION	*Guillaume*	*Physicist*	*Reactor neutrinos*	*10*	*Inner detector Analysis software*
	TBA		*Engineer*	*Design office*	*12*	*Responsible for design of inner detector*
	TBA		*Engineer*	*Instrumentation*	*12*	*Responsible for fabrication of inner det.*
Partner 2 LPSC Grenoble	*STUTZ*	*Anne*	*Physicist*	*UHECR - Neutrino*	*12*	*Coordinator of LPSC group Shielding Muon veto*
	KOX	*Serge*	*Physicist*	*Hadronic physics*	*4*	*Coordination Shielding*
	REAL	*Jean-Sebastien*	*Physicist*	*Hadronic physics*	*9*	*Responsible for design and test of muon veto*
	MONTANET	*François*	*Professor*	*UHECR - Neutrinos*	*8*	*Responsible for DAQ tests and commissioning*
	VESCOVI	*Christophe*	*Research Engineer*	*IR1 Electronics*	*9*	*Responsible for DAQ production*
	HEUSCH	*Murielle*	*Engineer*	*IE2 Instrumentation*	*8*	*Responsible for fabrication of muon veto*
Partner 3 LAPP Annecy	*DEL AMO SANCHEZ*	*Pablo*	*Physicist*	*Neutrinos*	*10*	*Responsible for calibration system Detector shielding*
	PESSARD	Henri	Physicist	*Neutrinos*	8	*Calibration system Detector shielding*
	TBA		Research Engineer		10.5	*Mechanics team leader: calibration system and shielding support structure*
	TBA		Research Engineer		8	*Responsible for the calibration system automatism*
Associates						
ILL Grenoble	FUARD	Stéphane	Project engineer	*Reactor simulations*	8	*Technical coordination of the project Safety file*
	SOLDNER	Torsten	Physicist	*Neutron particle physics*	6	*Responsible of casemate configuration Safety file*
MPIK Heidelberg	LINDNER	Manfred	Physicist	*Neutrinos, dark matter*	2	Coordinator of MPIK group
	BUCK	Christian	Physicist	*Neutrinos, Liquid*	6	Responsible for the liquid scintillator

				scintillators		
	TBA		Postdoc	*Particle physics*	12	Responsible for PMT tests
Casablanca/CNESTEN	HOUMMADA	Abdeslam	Physicist	Neutrinos, ATLAS	12	Coordination of the Moroccan group Calibration Simulation
	Ouardi	Afaf	Physicist	Neutron physics	8	Responsible for shielding simulation
	Benchekroun	Driss	Physicist	Neutrinos, ATLAS	8	Detector response simulation
	Gouighri	Mohamed	Physicist	Neutrinos, ATLAS	8	Responsible for light injection system
	Ghazlane	Hamid	engineer	Electronics	8	Responsible for light injection electronics

* à renseigner uniquement pour les Sciences Humaines et Sociales

** à renseigner par rapport à la durée totale du projet

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1. EXECUTIVE SUMMARY OF THE PROPOSAL

The discovery of neutrino oscillations is a major achievement in the recent history of elementary particles. It implies that the most abundant matter particles in the universe are massive and that the three neutrino states alternately change from one type to another as they travel. A large experimental program is ongoing to measure accurately the parameters of the neutrino-mixing matrix.

A recent work published by CEA-Irfu has triggered a worldwide renaissance in the search of sterile neutrinos. In this work 19 published neutrino measurements at short distance (10-100 m) from reactors have been reanalyzed after a re-evaluation of the predicted reactor neutrino flux had revealed a bias in the previous calculations. The result is a mean deficit of 7% of detected neutrinos with respect to predictions, with a statistical significance of 3 σ. This is called the reactor neutrino anomaly and it combines nicely with another (long-standing) anomaly in the detection of electronic neutrinos from intense beta-decay sources.

By analogy with the already measured deficits of reactor neutrinos induced by their oscillations in the solar and atmospheric sectors, this new deficit at short distance can be interpreted as the existence of a new neutrino state, a light sterile neutrino. Evidence of this new particle would be a major discovery, with deep impact in particle physics and cosmology.

This new neutrino with no ordinary weak interactions could only be ‘visible’ by its mixing with the three ordinary neutrinos. In a global study of reactor and source anomalies, the most probable mixing parameters are $\sin^2(2\theta_{new})=0.17\pm0.04$ and $\Delta m^2_{new}= 2.3\pm0.1$ eV^2. These parameters correspond to an oscillation length in the range of a few meters for the few MeV antineutrinos emitted by reactors. Therefore the associated new oscillation pattern is easily smeared out by extended core size or by energy resolution effects at too long baseline. It explains why only a global rate deficit has been observed so far.

The aim of the Stereo proposal is to confirm the existence of a sterile neutrino state by searching for an oscillation pattern at short distance with a high sensitive, segmented detection assembly placed few meters away from the core of the ILL research reactor (Grenoble, France). The originality of the project is to provide a clear signature of the possible new oscillation pattern by looking for the distortion of the energy spectrum and the dependency of that distortion along the detector axis. No reactor input is needed to first order, reducing systematic uncertainties.

The detection concept is based on the interaction of the electronic antineutrinos in a liquid scintillator (LS) via the inverse beta decay process $\overline{\nu_e} + p \rightarrow e^+ + n$. The target volume consists in 5 cells of 1.1 x 0.9 x 0.4 m^3, stacked along the direction of the core. They are filled with Gd-doped LS in order to tag the radiative neutron capture on Gd in coincidence with the annihilation of the positron. An outer crown, filled with LS without Gd, recovers part of the escaping gammas to improve the detection efficiency and the energy resolution.

The long reactor shutdown of the ILL reactor scheduled from mid-2013 to mid-2014 will allow a dedicated arrangement of the area “GAMS5” where the installation of Stereo is foreseen. This site combines the assets of a very compact core (<1m), a very short baseline (8 m from core to detector centers) and a nuclear fuel highly enriched in ^{235}U, suppressing all effects of evolution of the fuel composition in the determination of the spectrum shape. A large overburden of concrete and water reduces the flux of cosmic rays and a set of active and passive shielding suppresses the γ and neutron background. The required heavy structure, estimated to be 70 tons, is well within the floor load specifications of the GAMS5 area, the strongest in the reactor building.

The Stereo collaboration gathers a large experience in the field of reactor neutrino physics covering all crucial aspects of the experiments. The presented schedule of installation and the sensitivity of the measurement (the exclusion contour of Stereo fully covers the domain of existence of the sterile neutrino at 99% confidence level) provide a high discovery potential to Stereo.

2. CONTEXT, POSITION AND OBJECTIVES OF THE PROPOSAL

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

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

with θ the mixing angle driving the amplitude of the oscillation, Δm^2 the difference between the square masses of the two neutrino states in eV^2, $E_{\nu e}$ 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 1*. 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 (Δm^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.

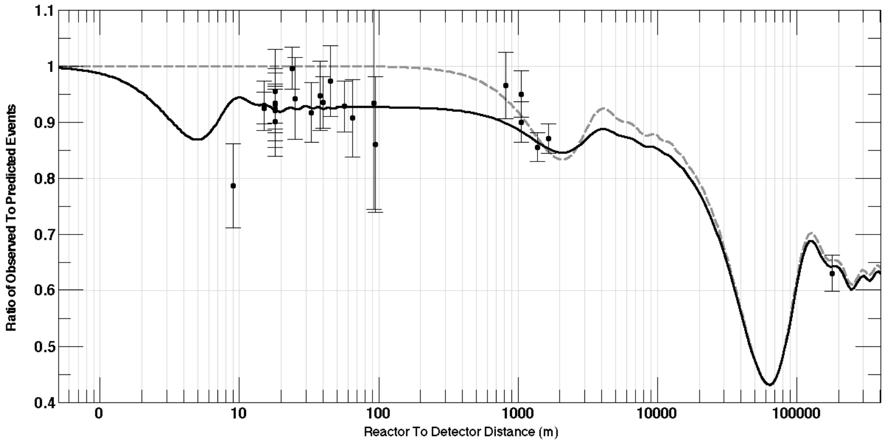

Figure 1: Ratio of observed over predicted reactor neutrinos versus the distance to the core. The predictions include the updated reference neutrino spectra related to the fission of U and Pu isotopes. For clarity the neutrino energy is fixed to a mean value of 4 MeV. The points correspond to published 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 $\Delta m^2_{new}>1$ 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 2*. The data are well fitted by the 3+1 neutrino hypothesis with best fit parameters $\Delta m^2_{new}=2.3\pm0.1$eV^2 and $\sin^2(2\theta_{new})=0.17\pm0.04$ while the no-oscillation hypothesis is disfavored at the 99.97% CL (3.6 σ).

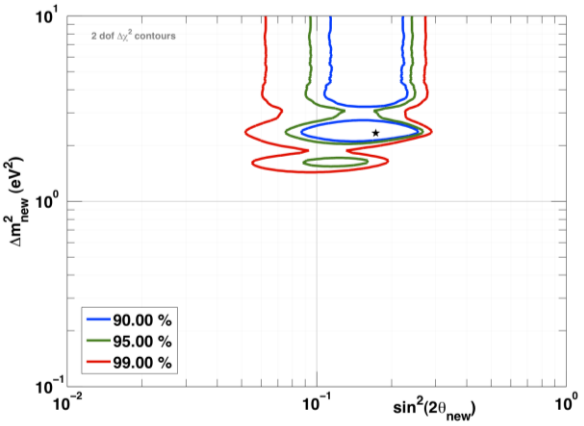

Figure 2 : Allowed regions in the [$\sin^2(2\theta_{new})$ - Δm^2_{new}] plane from the combination of reactor neutrino experiments, the Gallex and Sage calibration data, and the ILL and Bugey-3-energy spectra. The black star marker indicates the best fit parameters, the blue, green and red curves are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

2.1. OBJECTIVES, ORIGINALITY AND NOVELTY OF THE PROJECT

The objective of the Stereo experiment is to address the question of the existence of a lsterile 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. All related systematic errors and correlations are taken into account in the following sensitivity studies. 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. 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:** $\delta E/E \leq 10\%$ ($1\ \sigma$)
- **Good precision on the neutrino baseline:** $\delta L < 1$m
- **Efficient background rejection:** S/B = 1.5

The detector concept: The Stereo detector consists in a 2 m^3 inner tank of liquid scintillator (LS) doped with gadolinium at about 0.2% in mass. 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 five identical cells 0.4 m thick, 0.9 m high and 1.1 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. Four 10-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.

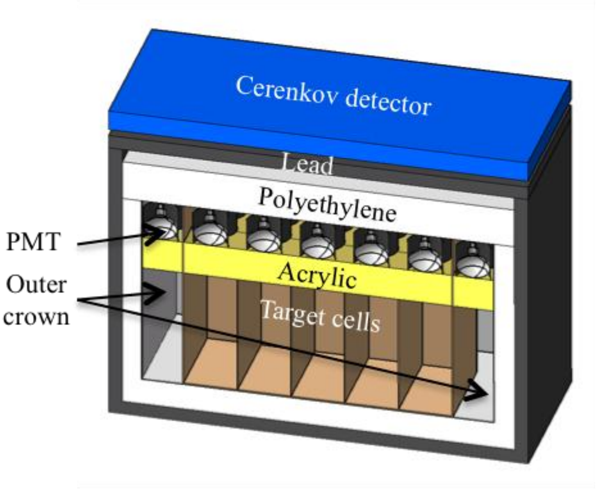

Figure 3: Cut view of the inner detector of Stereo

The target volume and the outer crown constitute the **inner detector**. The detection process used is the inverse beta-decay (IBD) $\overline{\nu_e} + p \rightarrow e^+ + n$. Here "p" is one proton of the hydrogen rich liquid scintillator. 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 via $E_\nu \approx E_{prompt} + 1.8 - 1.022$ MeV, where the 1.8 MeV offset is the threshold of the IBD reaction. For all our simulations and sensitivity studies, we have used a threshold of 2 MeV on the visible energy (i.e. E_ν>2.8 MeV). The choice of this value is justified because it is above most γ-ray lines of natural radioactivity and still preserves 81% of the detectable neutrino flux. The GEANT4 simulation packages of the Double Chooz [DChooz1,DChooz2] and Nucifer [Gaffiot12] experiments have been adapted to determine the response of the inner detector of Stereo. It includes a complete description of the emission of scintillation light and of optical properties of all materials. Simulations of the Stereo detector, with standard diffusion coefficients of white Teflon, show that with the addition of the outer crown, the responses of the five active cells (with LS and Gd) are quasi identical. This is illustrated in the left plot of **Figure 4** where the response of the middle cell and one side cell to 2 MeV positrons uniformly distributed in their volume is plotted. It shows as well that the detector meets the 10% energy resolution requirement. At low energy the width of the peak is dominated by the left shoulder due to the escape of one 511 keV annihilation gamma (sigma = 9%). At higher energy the resolution even improves because this shoulder is absorbed in the statistical width. In section 2.2, we show that this kind of simulation describes accurately the experimental response of the Nucifer detector, which configuration is close to the Stereo case.

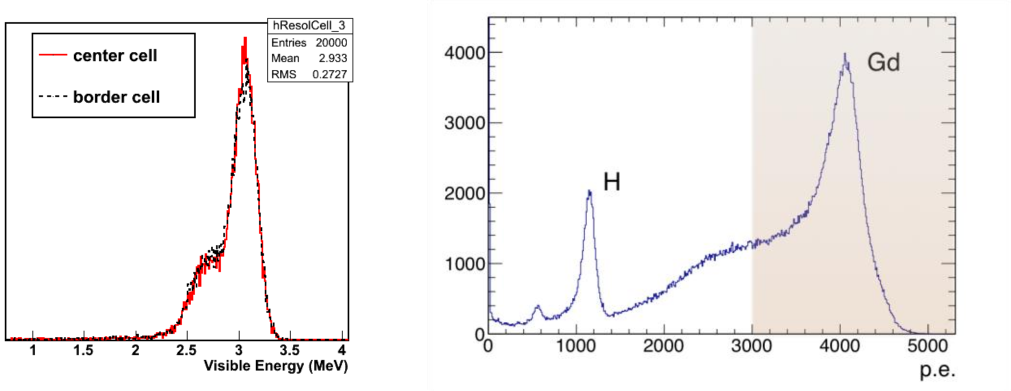

Figure 4: Left plot: response of the central and a border cells of the inner detector to uniformly distributed positrons of 2 MeV. Right plot: response to n captures uniformly distributed in the target volume. The shaded area illustrates a ~5 MeV energy cut to select captures on Gd. The quoted response is always the sum of target + outer crown signals.

Because of its heavy mass the neutron, second particle of the IBD final state, has few 10 keV kinetic energy only. It thermalizes in the liquid then diffuses around until it is captured. Thanks to their huge neutron capture cross-section, Gd atoms absorb most neutrons (~90%). For a 0.2% mass fraction, the mean capture time is reduced to about 15 μs instead of 200 μs for a capture on hydrogen. Another advantage of the neutron capture on Gd is its associated γ-cascade with 8 MeV total energy. This delayed neutron signal is higher in energy than most backgrounds. Combined with the time correlation with the prompt signal it provides a very selective signature of a neutrino interaction. However, while a few MeV positron deposits its energy in a LS within a cm, the interaction length of a few MeV γ-rays of the Gd cascade is about 30 cm. This induces significant energy leakage in a 1 m scale detector with limited neutron detection efficiency as direct consequence. The outer crown reduces these energy leakages and preserves the efficiency of neutron detection. The simulated response to neutron capture is shown on the right plot of **Figure 4** where one can see the 8 MeV peak of the Gd capture, the left tail due to energy leakage and the 2.2 MeV peak of the hydrogen capture. The neutron detection efficiency above 5 MeV is 63.5 %.

The outer crown also serves as an active shielding against external backgrounds. Firstly against muons: a muon crossing 30 cm of LS deposits about 60 MeV, saturating the light collection with a clear signal. Secondly against gammas: an external γ-ray entering the detector has good chance to deposit more energy in the outer crown than in the target volume. Finally, the 30 cm liquid scintillator provides an additional shielding against neutrons, produced by the reactor or induced by cosmic rays. Residual neutrons having traveled through the shielding will be further absorbed in the hydrogen rich liquid scintillator of the outer crown, preventing a capture on Gd in the target volume.

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

ILL site: The characteristics of the high flux reactor of ILL are very favorable to a neutrino experiment at short baseline. The 58 MW core, a cylinder of 40 cm diameter and 80 cm height, is very compact. Combining this core size with the size of a detector cell, the overall uncertainty on the neutrino baseline is only 32 cm at one σ. This number is small compared to the expected oscillation length of a sterile neutrino with the best-fit parameters of *Figure 2*. For instance the distance between two oscillation maxima is 3.2 meters for 3 MeV antineutrinos. The foreseen location to install Stereo is at level C of the reactor building, in front the exit of the H7 neutron tube (*Figure* **5**). 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 discussed in section 2.2. Their suppression requires the implementation of heavy shielding between the detector and the reactor as well as all around the target volume. The H7 location can accommodate heavy structure since the maximum floor load of the area is 10 t/m^2, the strongest in the reactor building. The other important source of background is induced by cosmic rays. Again the ILL site is quite favorable since the roof of the experimental room consists of a large water channel providing a significant overburden. The flux of vertical cosmic muons is reduced by a factor 4 with respect to the surface and the hadronic component of the cosmic showers is well absorbed.

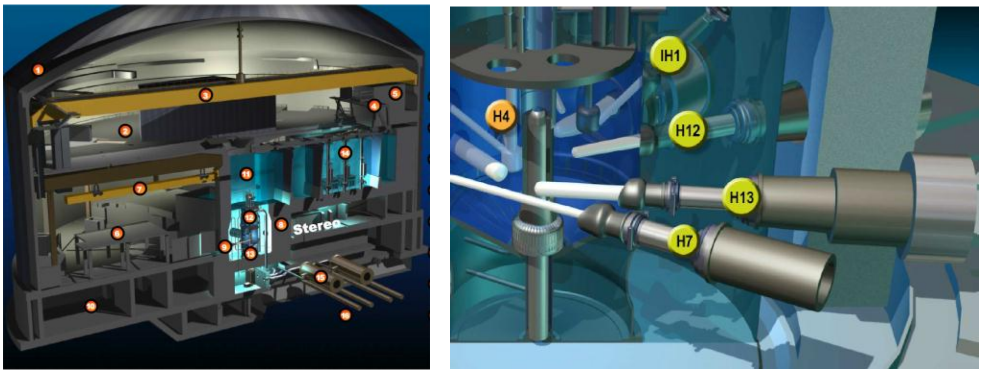

Figure 5: Cut view of the ILL reactor building (left). The foreseen site labeled "Stereo"is located underneath the water channel. The Stereo casemate is connected to the exit of the H7 tube (right). This tube traverses the pool but is not pointing to the core. Gammas and neutrons inside the tube will be blocked by a dedicated beam stopper.

Background rejection: The goal is to achieve a signal over background ratio S/B≥1.5, similar to what was achieved for the previous neutrino experiment performed at ILL in the 80's. To mimic a neutrino event, a background event has to produce a prompt signal above the 2 MeV energy threshold, followed within a few 10 μs by a high energy n-capture like signal, typically in the 5-10 MeV energy range. The main sources of background are:

- **Accidental coincidence** between a γ-rays (reactor leakage, natural radioactivity) and a neutron capture (reactor leakage, muon-induced neutron). Both single rates must be reduced to an acceptable level by passive shielding and by control of the radiopurity of detector materials. The specifications on the background reaching the Stereo target are: γ rate above 2 MeV ≤350 Bq; accidental neutron capture rate on Gd ≤1 Bq. The residual prompt spectrum of accidental background is measured on line by associating several randomly distributed delayed time windows with each prompt trigger. Then it is subtracted from the global (signal+background) prompt spectrum.
- **Fast neutrons** produced by spallation of cosmic rays close to the detector or via (γ,n) and neutron capture reactions. Fast neutrons can enter the target volume and induce prompt proton recoils correlated with the delayed capture of the same neutron once it is thermalized. This kind of reaction is a **correlated background** and can perfectly fake a neutrino event. It is reduced by a set of technics: the muon flux is partly absorbed by the overburden and vetoed by the Cerenkov detector and the outer crown when passing through them; since all non-vetoed sources are external to the detector, the fast neutrons have to traverse the thick polyethylene shielding and outer crown inside which they are efficiently slowed down; the prompt proton recoils induced by the remaining fast neutrons reaching the target are further reduced by about one order of magnitude using the pulse shape discrimination (PSD) capability of the liquid scintillator.

We have performed two campaigns of **background measurements on the ILL site**. Because of the proximity to the core a large γ activity develops in the casemate when the reactor turns on. Using a germanium detector we have identified high-energy γ-rays, between 6 and 9 MeV, coming from neutron captures on various metals (nickel, iron, aluminum, molybdenum…). Below 6 MeV the spectrum is dominated by the related Compton events. As expected directionality tests point the source of background toward the direction of the core. The total γ flux above 2 MeV is found to be comparable (2 times lower) than at the Nucifer site. The same approach than for the Nucifer configuration is chosen, with 10 cm of lead as the most external layer of shielding around the detector and a front wall inserted between the reactor and the detector to further attenuate the main source of background. Simulation with the Tripoli4 software performed in collaboration with the CEA/DEN/SERMA shows that an equivalent of 10 cm of lead in the front wall is enough to meet the Stereo specifications. Preliminary results of Nucifer also confirm this configuration (see section 2.2).

The neutron spectrum in the casemate was also studied using a ^{3}He counter enclosed in variable thicknesses of B4C and polyethylene. Each configuration was simulated with MCNPX to compare with the data and determine the flux and spectral shape of the neutron background. The results show that the shielding foreseen for Stereo blocks very efficiently the thermal component of the neutron background. However a more annoying fast neutron component is seen, pointing to the reactor. The required reduction of this fast neutron flux is 2 orders of magnitude. Combining data from different shielding thicknesses and simulation results, we found that the neutron spectrum extends to 10 MeV or more and that the evolution of the rate goes approximately like the inverse of the energy. This result is not compatible with fast neutrons produced by the core. The expected fast fission spectrum is a Maxwellian distribution centered at 1.3 MeV, corresponding to a lot stepper spectrum than measured. This points to the generation of secondary fast neutrons induced by the capture of thermal neutrons on specific materials. A very likely candidate is a lithium collimator currently installed upstream in the H7 tube, where the thermal neutron flux from the core is the highest (10^{10} n/s/cm^2). It is known in the literature [Lone80] that neutron capture in Lithium compounds can induce fast neutrons up to 15 MeV with an energy spectrum compatible with our observation. The simple replacement by a Boron compound would reduce this fast neutron source by a factor ~200. For Stereo all Lithium will be removed and a specific beam stopper, about 1m thick, will be installed inside H7. The current one consists of 5 cm of high-density polyethylene and 20 cm of lead. It is optimized to stop γ-rays for the currently running γ-spectroscopy experiment but it is almost transparent to fast neutrons. The foreseen insertion of a dedicated beam stopper, and the addition of polyethylene in the front wall will further reduce the fast neutron flux by several orders of magnitude, providing confortable margin with respect to the factor 100 of suppression currently required for a signal over background ratio S/B = 1.5 in Stereo.

The configuration of the Stereo setup is summarized in *Figure 6***.** The shielding structure is three fold: a dedicated strong beam stopper to block the thermal neutrons in the H7 tube; a front wall between the detector and the wall of the reactor; active and passive shielding around the detector target (muon veto, lead, boron doped polyethylene and outer crown). This combination of shielding is designed to zero the fast neutron component from the reactor. The fast neutron component induced by cosmic ray cannot be totally suppressed. Its residual contribution after the shielding and the PSD cut will be measured during the regular reactor shutdowns (about 100 days per year) and subtracted from the global spectrum. Finally, we will consider coating the walls of the casemate with standard B4C sheets. From measurements in other rooms on level C, such coating reduces the ambiance of thermal neutron by an order of magnitude. This reduction of the neutron ambiance would reduce the capture γ-lines as well.

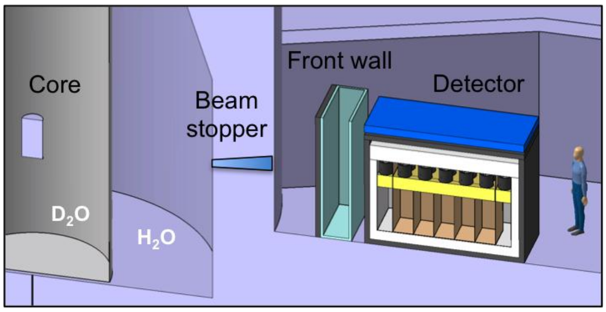

Figure 6: Illustration of the Stereo configuration.

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	δE/E = 10% @ 2 MeV
Threshold on visible E_{prompt}	2 MeV
Detection efficiency	ε_{Det}~ 50%

Evt by evt baseline uncertainty	δL = 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 σ

The expected distortion of the neutrino spectra in Stereo is illustrated in **Figure 7** with all the detection effects included. The change of spectrum shape induced by an oscillation with the best-fit parameters is shown in the left plot for the central cell only. In the right plot one clearly sees the phase shift of the oscillation energy pattern between the first and the last detector cell. This phase shift provides extra robustness to the analysis. In particular, a spurious bump or deep coming from an imperfect background subtraction would have hard time to fake this displacement of the minima and maxima along the detector axis.

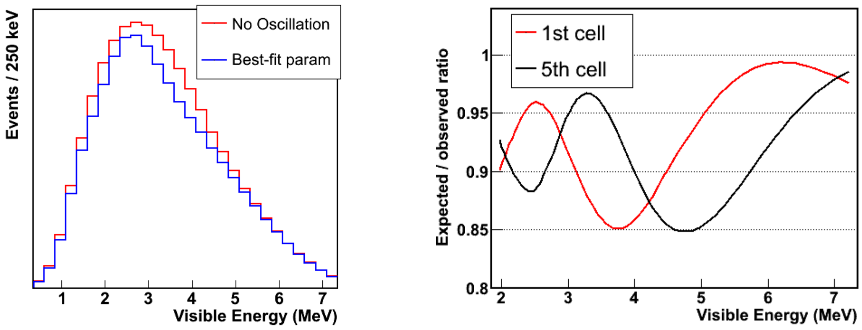

Figure 7: Expected distorsions of the neutrino spectra measured in the Stereo cells.

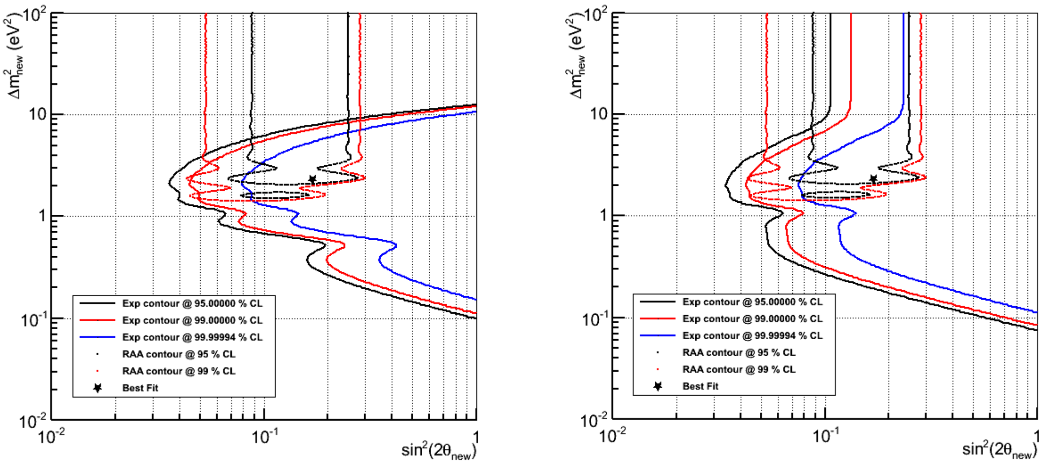

Figure 8: Sensitivity contours computed for a shape only analysis (left plot) and with a ±3.5% absolute normalization added (right plot).

The data taking is foreseen to start late 2014. More than 200,000 neutrinos should be collected within 300 days at full reactor power. This corresponds to 6 reactor cycles over 1.5 years. The associated sensitivity is show in **Figure 8**. The contour of the reactor anomaly at 99% CL is covered with the same confidence level by the Stereo measurement. The Stereo high sensitivity and the foreseen start of data taking on late 2014 provides a unique discovery potential

2.2. STATE OF THE ART

Since the first re-evaluation of neutrino spectra emitted by nuclear reactors on early 2011 [Mueller11] and the subsequent reanalysis of reactor neutrino experiments at short baseline [Mention11], the revealed reactor anomaly has been the subject of a growing interest in the neutrino community. The re-evaluation of the neutrino fission spectra has been crosschecked by an independent work [Huber11] and confirmed. The hypothesis of a sterile neutrino state of mass around 1 eV has been discussed in many papers and conferences. Following the “Sterile Neutrinos at the CrossRoads” conference [Snac11] neutrino physicists decided to write a white paper presenting a theoretical and experimental status on sterile neutrinos [WhiteP12]. This paper also collects all proposals of experiments aiming at testing the existence of a sterile neutrino via the observation of new oscillation patterns. The number and variety of projects reflects the intense activity of the field. In the electron neutrino sector, the proposed measurements can be sorted in two classes: the reactor experiments and the source experiments.

Table 2: Summary table of reactor projects.

Reactor Projets	Configuration	Sensit. to best fit	Collaboration	Data taking	Comments References
Nucifer	7m Osiris, 1m^3, 70 MW, 10 mwe	~ 2-3 σ	CEA, Subatech-Nantes, MPIK	2013	[Gaffiot12]
DANSS	11m VVR, 1m^3 3 GW, 50 mwe	?	Russia	2013	Extended core and limited E resol.
Stéréo	8 m ILL, 2m^3, 57 MW, 15 mwe	5 σ	CEA, LAPP,LPSC, MPIK, Univ. Casablanca, CNESTEN	2014-15	This proposal
SCRAAM	25m SONGS, 2m^3, 3 GW, 25 mwe	~ 3 σ	LLNL, Sandia	?	Extended core and longer baseline
Neutrino-4	6-12m SM-3, 7m^3, 100 MW	5 σ	Russia	?	[Nu4-12]
Poseidon	5-8m PIC, 4m^3, 100 MW	5 σ	Russia	?	[Poseid12]
SOLID	8m ILL, 2m^3, 57 MW, 15 mwe	?	UK	?	Patented technology

The list of reactor experiments is presented in *Table* **2**. By default we refer the reader to the white paper for more details on the proposed setups and we provide dedicated references in the last column when available. The Nucifer experiment [Gaffiot12] is currently installed at the Osiris research reactor at CEA Saclay and should take data in nominal conditions in April after completion of the last part of its shielding. It consists of a simple cylindrical vessel filled with 850 l of liquid scintillator read out by PMTs at the top through an acrylic buffer. The design was guided by compactness, simplicity, robustness and cost specifications from the International Atomic Energy Agency (IAEA), with application of antineutrinos to non-proliferation as a primary motivation. It turns out that the Nucifer configuration (very compact Osiris core and 7 m baseline) is quite favorable to search for the new oscillation pattern due to sterile neutrinos. However the sensitivity is limited by design and the required upgrades are in conflict with the available space and floor load capacity. Still, the leading contributions from CEA/Irfu and the Max Plank Institut für Kerphysik (MPIK- Heidelberg) to Nucifer bring crucial experience on detection, background rejection and safety aspects for the preparation of the Stereo project. This is discussed in more details below. Among the other reactor projects DANSS is also likely to start taking data before Stereo. This detector, based on a 1-m^3 stack of plastic scintillator strips read out by fibers, was also designed for non-proliferation studies and is therefore more suited for rate measurements rather than spectral measurements. Its sensibility will be strongly limited by the size of the core (commercial reactor), the modest energy resolution and the longer baseline. The Scraam, Neutrino-4 and Poseidon projects propose liquid scintillator based detectors dedicated to the search of sterile neutrinos. The SOLID experiment proposes to adapt a patented technic of neutron detection, based on segmented plastic scintillators read out by fibers and interleaved with ^{6}LiF:ZnS layers, to the detection of reactor neutrinos. A proposal should be submitted soon to the ILL. These projects are direct competitors of Stereo and the high discovery potential of this topic combined with reasonable budget and time scale make it very attractive for number of research teams in the world. Stereo has taken the lead these last few months via important progresses in terms of formation of the collaboration, identification of resources, characterization of the reactor site and design of the detector. Experienced work teams cover all crucial aspects of the experiment and great care is brought to the organization of resources in close collaboration with the reactor staff for a timely development of the experiment.

The second class of concurrent projects, the source experiments, is presented in **Table 3.** The principle is to introduce an intense beta source inside or close to already existing large neutrino detectors like Borexino or Kamland and look for a new oscillation pattern in the detected rates and energy spectra. One option is a 3-10 MCi neutrino source of ^{51}Cr similar to the sources developed for SAGE [Sage99, Sage06] and Gallex [Gallex96]. A new idea proposed by the CeLand project [CeLand12] is to produce an antineutrino source by isolating few grams of ^{144}Ce from spent fuel. The IBD interaction of antineutrinos provides a virtually background free measurement in a deep underground detector. The CeLand project is funded by an ERC starting grant and a technical solution is identified for the production of a 50-75 kCi source. The foreseen start of data taking with the source at the Kamland detector is similar to the Stereo timeline.

Table 3: Summary table of source projects.

Source Projects	Activity/ isotope	Sensitivity to best fit	Collaboration	Data taking	Comments References
CeLAND	50-75 kCi ^{144}Ce	5σ	CEA+KamLAND (Russia / Japan)	2014-15	ERC Starting grant [CeLand12]
SOX-Cr	10 MCi ^{51}Cr	2-3σ	Borexino (Italy)	2014-15	ERC advanced grant. ^{50}Cr available from Gallex
SOX -Ce	50 kCi ^{144}Ce	5σ		>2015	
SNO+Cr, LENS	10 MCi ^{51}Cr	3σ	SNO& VT (US / Canada)	?	R&D
Baksan-Cr	3 MCi ^{51}Cr	3σ	Sage2 (Russia)	?	

We do not discuss here the projects in the muon neutrino sector. These measurements will be complementary to the above mentioned. They are based on neutrino beams with typical time scale in the 5-10 years range.

The technical choices of Stereo were guided by the experience of our collaborators on reactor neutrino detection with liquid scintillators. This includes participation to the previous neutrino experiment at ILL [ILL81], Bugey measurements [Bugey95], Double Chooz [DChooz1, Dchooz2] and Nucifer. Members of the Irfu and MPIK teams are involved in these last two experiments in synergy with the Stereo project. In particular the detection concept of the Nucifer detector is similar to Stereo. Although Nucifer hasn't seen neutrinos yet because of its incomplete shielding, preliminary results can help validating the Stereo setup. We review below main Nucifer's achievements with direct impact on Stereo:

Safety file: Prior its installation at the Osiris reactor, the Nucifer setup has been reviewed by safety committees internal to CEA Saclay. The fire hazard induced by the presence of liquid scintillator has required a review by the French national authority (ASN). The approval was obtained to fill the detector with a commercial liquid from the Eljen company with a flash point of 57° C (EJ-335). This liquid turned out to have a too large absorption of light. MPIK-Heidelberg promptly delivered a new liquid based on a PXE-Dodecane mixture and meeting the specifications. Its significantly higher flash point (110° C) provides a safety margin to the foreseen Stereo liquid. Also the total calorific charge remains comparable (1.7 times the Nucifer charge). Documents of the Nucifer file have already been transmitted to ILL experts for an early preparation of all the required studies.

Detection of reactor neutrinos in liquid scintillators: The detection of few MeV antineutrinos in liquid scintillators is a mature technic. The use of the inverse beta process, the large light yield and pulse shape discrimination capabilities allow combining an efficient background rejection with a good energy resolution. For the new generation of reactor experiments a breakthrough in the liquid chemistry was achieved. In the Stereo collaboration we will benefit from the developments performed for the Double Chooz liquid with leading

contribution from the Max Plank Institut für Kerphysik (MPIK) in Heidelberg [Aberle11]. Gd-doped liquid have been proven to remain stable over 5 years with negligible attenuation effects for a 1 m scale detector.
The GEANT4 software of Nucifer and Stereo is inspired from the Double Chooz code. Accurate simulation of the detector response can be achieved, validated by calibration runs with radioactive sources inserted at different locations in the target volume (see left plot of *Figure* **9**). The Nucifer liquid provided by the MPIK group is enriched in PXE with respect to the Double Chooz liquid for enhanced PSD capability. The separation between recoil protons induced by fast neutrons and recoil electrons induced by γ-rays is illustrated in the central plot of *Figure* **9**. A good background rejection is seen although the plotted results correspond to specific prompt-delayed pairs from a calibration run with an Am-Be radioactive source. Therefore the selected candidate recoil protons are around 2 MeV while the gammas from n-capture correspond to the 8 MeV cascade. Evolving the gamma signal down to 2 MeV (by accounting for the statistical width) the expected figure of merit, defined as $\Delta\text{Mean}/\Sigma(\text{FWHM}_i)$, is 0.8. This is equivalent to a rejection of the correlated background at the 90 % level with a cut of 1% of the neutrino signal only.

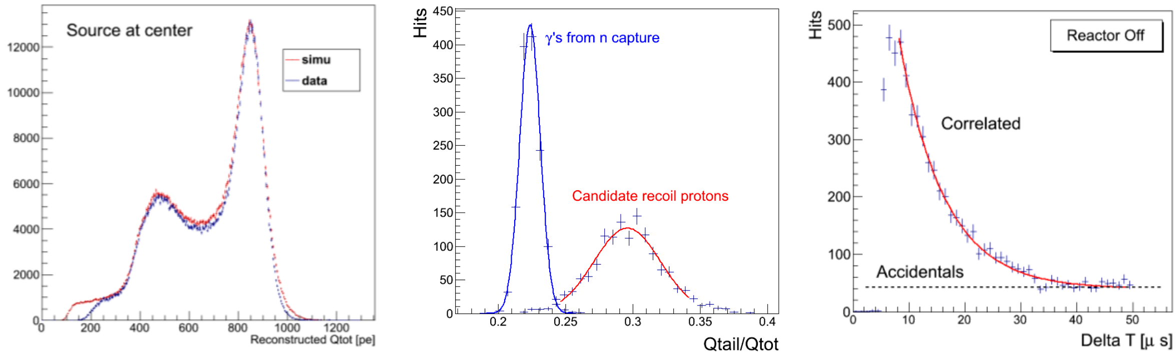

Figure 9: Illustration of Nucifer results. Left plot: comparison of simulation and data in the case of a ^{60}Co source in the center of the detector. The same quality of agreement is achieved for different elevations of the source. The position of the threshold is not tuned in the simulation. Middle plot: example of PSD using Am-Be event (see text for details). Right plot: distribution of time correlated pairs of event with reactor off.

Detector shielding: The missing part of Nucifer shielding is a sidewall. The extension of the PMTs ring on top of the target vessel provides some sensitivity to vertex location allowing selecting the opposite side of the Nucifer vessel, less sensitive to the side background contamination. In this area of the detector the measured counting rate with reactor at full power is found to be compatible with the expected total rate of 300 Hz above 2 MeV. This is a first validation of the shielding configuration (front wall + around the detector). In April, new data with the complete shielding will allow to study the energy distribution of the residual spectrum. Meanwhile data collected with the Osiris reactor off have been analyzed to quantify the amount of cosmic ray induced correlated background. On the right plot of *Figure* **9** a clear exponential shape is seen with a time constant in agreement with the neutron capture time in the liquid scintillator. The accidental pairs show up as a flat distribution. After muon veto and PSD cuts, the residual background is about 2 times smaller than the expected neutrino rate. This is a favorable situation for Stereo since the ILL site is better protected by a large overburden. Moreover the ILL reactor is off about 30% of the time allowing accurate measurements for the final subtraction of the residual background. Finally simulations developed in collaboration with the CEA-DEN/SERMA (Service d'Etude des Réacteurs et de Mathématiques Appliquées) have shown that γ-n conversion in the 20 cm thick lead shielding is not dangerous for the experiment. The induced neutron spectrum is too soft to generate a correlated background. The total induced neutron flux is small and will be further absorbed by the polyethylene shielding.

Reactor calculations: Although the configuration of Stereo at ILL suppresses the dependence on the reactor evolution to first order, the thermal power information will be used for a final shape+norm analysis. In the Double Chooz and Nucifer experiments the power history is routinely retrieved from a database of the reactor and/or inserted on line in the data stream and the Irfu group has performed detailed studies of the power uncertainties. A dedicated survey will be performed to determine the distance between the center of the core and the center of the detector. At ILL the nuclear fuel is enriched at 93% in ^{235}U, reducing the fission rate of the other isotopes to negligible level. The main effect we'd like to control is the displacement of the barycenter of the fissions induced by the displacement of the central control rod over a cycle. The movement occurs along the vertical axis only, perpendicular to the axis of the Stereo detector. Hence solid angle effects cancel out to first order. Still we plan on monitoring the evolution of the fission barycenter based on a collaboration with the "Bureau Projets et Calculs" of ILL and possibly the CEA-DEN/SERMA, already involved in calculations for Double Chooz and Nucifer.

3. SCIENTIFIC AND TECHNICAL PROGRAMME, PROJECT ORGANISATION

3.1. SCIENTIFIC PROGRAMME AND PROJECT STRUCTURE

The scientific program of Stereo is the design and realization of the neutrino detector described previously and its operation at short distance from the ILL reactor. Publication of the first results is foreseen within the 3 years of the project. 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 and described in the next section:

- 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 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 and are summarized in **Tables 5** to **7** of section 5.1. The crucial technical coordination of Stereo will be done by Stéphane Fuard, permanent staff of ILL and experienced in project management. In order to meet the milestones presented below the direction of ILL agreed on allocating this resource now (January 2013) to start working on the safety studies and the preparation of the casemate. The combination of ILL resources with those of LPSC-Grenoble and LAPP-Annecy provides a very strong local support to the project.

3.2. DESCRIPTION BY TASK

All tasks are presented below. The deliverables are summarized in *Table*.

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 LPSC activities (muon veto, shielding and electronics); 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.
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 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 (2 ANR postdocs requested for Irfu and LAPP, 1 foreseen postdoc resquest to the ENIGMASS LabEx for LPSC, 1 Postdoc at MPIK 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 and alarm reports will assist the on-site shifters.

TASK 2 – Security and Safety:

Objectives: Interaction with the reactor security and safety teams to review and address any hazards of the stereo setup. Organize resources and progress of detector design to provide a complete file to reactor and national authorities before 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).

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 will be organized very early in the project with a first meeting on January 28, 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 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:

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 a front wall. The installation should proceed as soon as the casemate is available, expected on March 2014.

Responsibilities: The task supervisor is Torsten Soldner (ILL) in collaboration with David Lhuillier (CEA/Irfu) and Abdeslam Hommada (Univ. Casablanca).

Work program: The sources of reactor-induced background have been measured on site. During the first half of 2013 the simulations initiated at CEA/Irfu to determine the neutron spectrum at the entrance of H7 will continue in collaboration with Stéphane Fuard (ILL). The results will 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 will be 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 seems to be 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 will be 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 of Stereo will be performed under the supervision of Afaf Ouardi (CNESTEN). The goal of this shielding is to suppress by at least a factor 100 the residual high-energy background coming from the core (γ flux above 2 MeV and neutrons above 3 MeV). A sandwich of iron and polyethylene might be the best configuration since it will efficiently degrade and absorb the fast neutron flux and fulfill the γ absorption for the equivalent of 30 cm of iron. The Stereo detector will be installed in the shadow of this shielding of approximate section 2 m x 2.5 m. The estimated total mass of 11 t will be spread out across a 1.6 m^2 footprint, meeting 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 should cover the walls of the casemate. 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 particle. 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. A complementary survey of all lithium compounds in the neighboring casemates will happen during the reactor shutdown of January, for replacement by boron or polyethylene. 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 front wall.

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 between LPSC and LAPP.

***Work program*:**

<u>Active shielding</u>: 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 γ-rays will be stopped within few mm. The Cherenkov light will be collected by photomultipliers. A simulation program based on GEANT4 will be 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.

Figure 10: Nucifer shielding surrounding the inner detector (left) and support structure (right).

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 a 10 cm lead shielding around the detector is used. A strong structure, based on a girder frame anchored to the floor, will guarantee the mechanical stability of the shielding and fulfil the specifications of resistance to earthquake. The side walls 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 polyethylene 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* **10**.
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.

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, 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. The total cost of this task will be covered by the MPIK-Heidelberg funds. It is estimated at 310 k€ divided between the liquid production (250 k€), the filling system (35 k€) and the transport (25 k€).
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:

Objectives: Build the inner part of the detector. Validate the energy response using simulation and a prototype detector cell.
Responsibilities: The task supervisor is Alain Letourneau (CEA/Irfu) in collaboration with Thomas Materna.
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 1.7 m x 2.7 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 Teflon. Inside the target volume, individual cells will be defined by vertical Teflon plates. 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 (~90 cm) 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 optical properties of Teflon are good enough for the sensitivity of Stereo. A prototype single cell will be built under the responsibility of Alain Letourneau early in 2013 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 (possibly recycled from NEMO3 experiments). 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. The Teflon coating specifications will be tested early enough with the prototype to not impact the progress of the design studies in the second half of 2013.

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 University of Casablanca will be in charge of the LED-based monitoring system.

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 6 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 6 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 as well as the analysis of the resulting data.

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

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).

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 four 10-inch PMTs viewing the scintillator from the top. The same type of configuration is used for the outer crown with 24 additional PMTs, leading to a total of 44 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, the PMT base will be redesigned to provide two outputs (anode and dynode) and 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 four 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 500MHz/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 μs. 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 will be performed before funding, in the beginning of year 2013.

3.3. TASKS SCHEDULE

The Stereo proposal has been reviewed by the ILL scientific council and has been ranked to high priority. We quote below the official statement of the scientific director of ILL, H. Schober:
“ 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.”

The task schedule of Stereo is presented in the Gantt diagram in **Figure 11**. It is optimized to match the long shutdown of the ILL reactor from August 2013 to June 2014. The June 2014 reactor cycle will be followed by a summer shutdown. Then 50 days long standard cycles will take it up in autumn 2014. The start of the Stereo installation follows the end of the reactor work to change the H6-H7 tube, scheduled for March 2013. The first pieces to come in are the beam stopper and the front wall. Once this shielding is in place we can proceed with the installation work in the casemate even with the reactor operating at full power. The goal is to start taking data in Nov. 2014. Data taking will last for 6 cycles, i.e. about 1.5 years (not fully represented in the Gantt diagram for legibility of the earliest part of the schedule.
To fulfill this deadline the partners agreed on allocating some resources (mostly man power) before the ANR response expected in June. These resources will be used to run complementary simulations studies and to set up prototypes for the detector cells and the electronics. Also to anticipate potential delays in the safety studies and reviews, ILL experts and the coordinator of Stereo have already started to collaborate and will have regular meetings in the first half of 2013. The major objective of the schedule is to keep the concomitance between the long reactor shut down and the installation of the first pieces of shielding in the casemate. **Table 4** reports the deliverables for each task with the associated supervisor.

Table4: List of deliverables of Stereo.

Task	Date	Deliverable	Supervisor
Management			
1.a	Every 4 months	Organization of collaboration meetings	D. Lhuillier (Irfu)
1.b	11/2014	Operational Stereo detector	D. Lhuillier (Irfu)
1.c	07/2015	Publication of first results	D. Lhuillier (Irfu)
Safety			
2.a	01/2014	Agreement for the installation of the shielding	S. Fuard (ILL)
2.b	07/2014	Agreement for the filling of the detector	S. Fuard (ILL)
Configuration of casemate			
3.a	03/2014	New beam stopper for H7 delivered on site	T. Soldner (ILL)

3.b	04/2014	Front wall shielding delivered on site	T. Soldner (ILL)
Detector shielding			
4.a	06/2014	Muon veto delivered on site	A. Stutz (LPSC)
4.b	05/2014	Support structure and lead and CH2 shielding	A. Stutz (LPSC)
Liquid Scintillator			
5.a	11/2013	Final choice of liquid component and filling system	C. Buck (MPIK-Heidelberg)
5.b	09/2014	Delivery on site and filling	C. Buck (MPIK-Heidelberg)
Inner detector			
6.a	07/2013	Operational prototype cell	A. Letourneau (Irfu)
6.b	08/2014	Inner detector inside double walled vessel	A. Letourneau (Irfu)
Calibration System			
7.a	08/2014	Radioactive source-based calibration system	P. del Amo Sanchez (LAPP)
7.b	08/2014	Light injection monitoring system	A. Hoummada (Univ. Casablanca)
Data acquisition			
8.a	09/2013	First results from prototype channel	C. Vescovi (LPSC)
8.b	09/2014	Complete DAQ	C. Vescovi (LPSC)

4. DISSEMINATION AND EXPLOITATION OF RESULTS, INTELLECTUAL PROPERTY

Since the publication of the reactor anomaly paper, there has been a growing activity in the neutrino community on sterile neutrinos and several projects are in preparation in the world. The Stereo time scale provides a potential revelation of a new particle with large impact in the community. Sterile neutrinos are naturally present in many theories beyond the standard model, in particular in several manifestations of the seesaw mechanism. In principle they can have any mass. Relatively light sterile neutrinos that mix significantly with ordinary neutrinos are relevant to neutrino oscillation experiments, astrophysics and cosmology. Starting from other neutrino related experiments, the evidence of such particles will impact deeply on absolute neutrino mass measurements for β-decays and neutrinoless double β-decays. As new, never yet observed particles, sterile neutrinos might be messengers of New Physics beyond the standard model of particle physics. With the eV mass scale, their abundances make them play a significant role in the description of the Universe content and evolution. Discovery of eV mass scale sterile neutrinos might also help to understand fundamental mechanisms for the explanation of core collapse in supernovæ.

The results of Stereo will be made available to the scientific community via the publication of the results in refereed journals and presentations at conferences and workshops but also to non-experts. All publications related to Stereo and making use of the Stereo installation and/or its data will be submitted to a collaboration publication committee established by the management team.

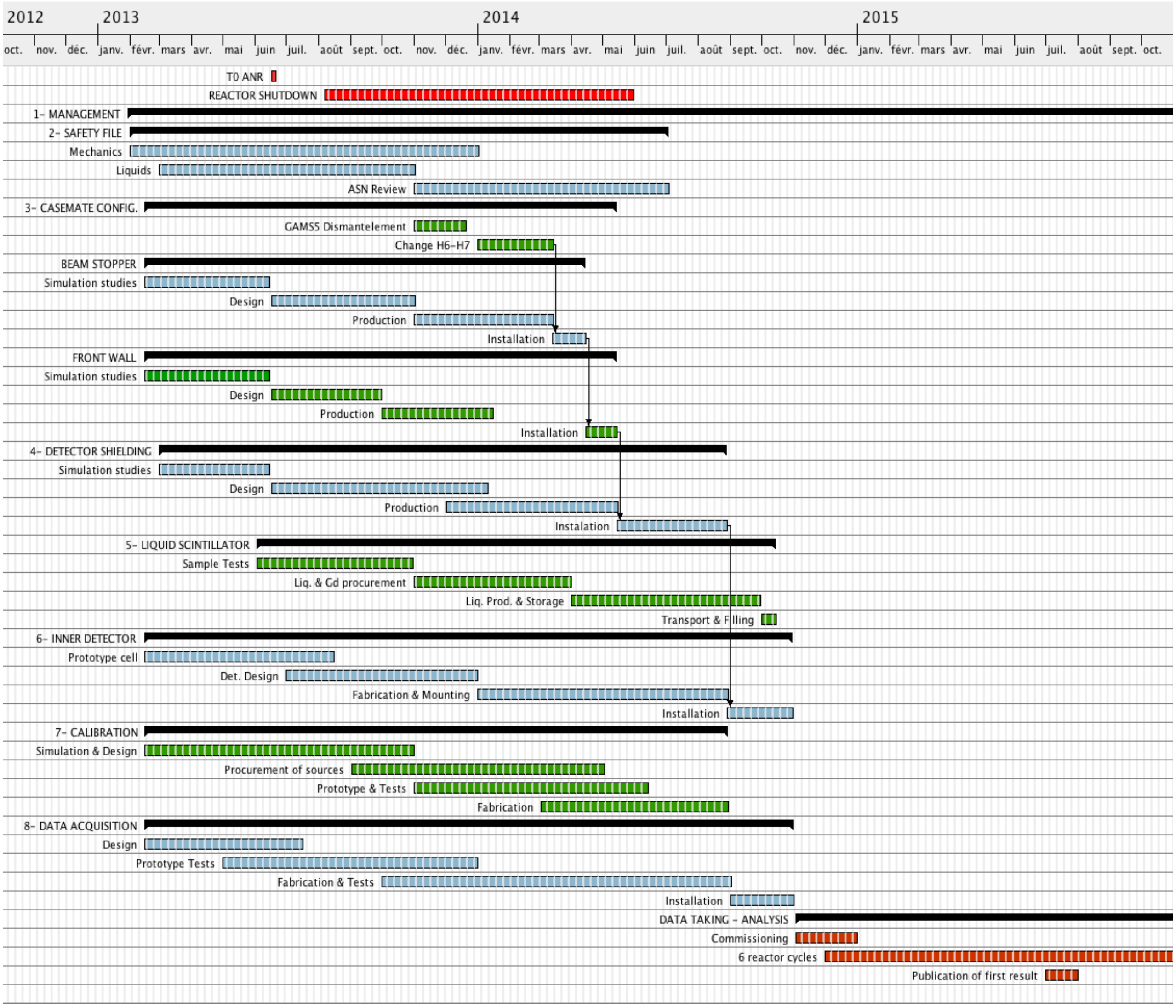

Figure 11: Gantt diagram for Stereo.

Beside journal publications we will also promote a strong scientific communication by means of international conferences, workshops and seminars. All partners of the present project will contribute to this dissemination with special care taken to promote the work and the visibility of our younger colleagues. An Internet web site dedicated to the experiment will be created with a public part for dissemination of the non-confidential reports and results. Popularizing Stereo science will be done by communications in non-experts journal such as La Recherche, Science, Science & Vie, internal journals of CEA and CNRS and by a dedicated public part in the Stereo web site. Several members of the collaboration are used to participate in popular scientific seminars and have published in various popular science media (see for instance [Science07], [Monde11], [Science11], [S&Vie12]).

Each partners of the present project will do valorization of the scientific results in terms of patents and industrial partnership. This valorization is carried out within the "local valorization cell" of each laboratory under the guidance and rules of IN2P3 and CEA.

5. CONSORTIUM DESCRIPTION

5.1. PARTNERS DESCRIPTION, RELEVANCE AND COMPLEMENTARITY

The Stereo collaboration has a strong experience in reactor neutrino physics. All partners have been or are currently involved in reactor experiments involving γ and neutron background suppression and detection systems based on liquid scintillators. In particular the collaboration will benefit from developments performed for the previous ILL neutrino experiment as well as for the Bugey, Nucifer and Double Chooz experiments.

Tables 5 to 7 summarize the contributions of the partners of the project and the manpower allocated by the institutes to fulfill their commitments. The internationally recognized expertise of each team covers all the important aspects of the project in a very complementary way. The close collaboration with the reactor staff is strengthened by the involvement of ILL physicists, engineers and technicians in Stereo, by the proximity of the LPSC laboratory to the reactor and by the participation of several physicists of the Stereo collaboration in other ILL experiments. The technical coordination of the project will be done by an ILL engineer, S. Fuard.

Table 5: Summary of the contribution 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 Fabrication and mounting of the shielding
IN2P3/LAPP	Calibration system Design of the shielding Fabrication of the shielding support structures
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. CNESTEN	Light injection system Simulation of front wall

Table 6: summary of physicists manpower.

	Task	Physicists (pers.month)	Postdocs & PhDs (pers.month)
ANR partners			
Irfu	1,2,3,6	60,6	53
LPSC	1,4,8	33	48
LAPP	1,4,7	18	48
Associates			
MPIK	1,5	8	27
ILL	1,2,3,4	12	48
Casablanca/CNESTEN	1,3,7	36	

Table 7:summary of technical manpower.

Task #	Partners	Engineers (pers.month)	Technicians (pers.month)
1 - Management	ILL	1	
2 - Safety	ILL	3	
3 - Casemate config.	ILL	3	6
	Casablanca/CNESTEN	1	
4 - Detector shielding	LPSC	9	21
	LAPP	8	6
	ILL (installation)	1	6
5 - Liquids	MPIK		18
6 - Inner Detector	Irfu	24	18
7 - Calibration	LAPP	22,5	10
	Casablanca/CNESTEN	8	
8 - DAQ	LPSC	34	5

Partner 1 - CEA/Irfu - Saclay:
The Irfu, Institut de Recherche sur les Lois Fondamentales de l'Univers, comprises about 610 people divided in basic science divisions covering nuclear, particles and astrophysics and technical divisions with expertise in detector design, instrumentation and electronic, data handling, cryogenics and magnets, and integration systems. The institute has long track record in neutrino physics with continuous participation in beam and reactor experiments over the last 25 years. The CEA team of the project is composed by nuclear and particle physicists and by engineers and technicians from the technical divisions. Our group of physicists is at the origin of the Double Chooz and Nucifer experiments. From strong involvement in these projects and the close collaboration with the technical services we have developed skills in many aspects of the neutrino detection: simulation and tests of liquid scintillators, validation of the detector materials in terms of chemical compatibility with the liquid and radiopurity, fabrication of acrylic and Teflon coated vessels, rejection of gamma and neutron backgrounds by passive and active shielding and pulse shape discrimination, reactor calculations, data handling and analysis, safety aspects related with the installation on a reactor site. We'll take advantage of a large synergy between these developments and the Stereo project. Simulation software, test labs and experience with specialized companies will serve the fabrication of the Stereo inner detector.

Partner 2 – LPSC - Grenoble:

Laboratory for Subatomic Physics and Cosmology of Grenoble (LPSC) is a joint research unit affiliated to the IN2P3 institute of CNRS and the Joseph Fourier University of Grenoble and the Institut National Polytechnique de Grenoble, with a workforce of about 230 people. It is one of the pioneering group in neutrino physics in France. During the last two decade he has acquired a solid know-how on detection techniques of reactor anti-neutrinos. In the end of the seventies the LPSC (formerly called ISN) team was largely involve in the very first oscillation experiment that took place near the ILL research reactor. This team was also one of the leading groups in a series of successive neutrino experiments at the Bugey nuclear reactors. In particular, intermediate oscillation baseline experiments (15, 40 and 95 m) where performed in the nineties followed by an experiment dedicated to the search for the neutrino magnetic moment. The ISN/LPSC team initiated the detection of anti-neutrinos with doped liquid scintillator for the Bugey-3 experiment and was responsible for designing and setting-up the shielding (active and passive) and part of the electronics of these experiments. Part of the group is now member of the Auger collaboration since 2006 and is involved in particular in the surface detector array, which uses the water Cherenkov technique.

The laboratory is currently involved in multiple national and international projects with strong technical support in electronics in most of them such as GUINEVERE, PLANCK, ALICE… The laboratory also has a technical expertise in developing detector mechanics as well as in computing and has acquired a high expertise in working near reactors (ILL, VENUS facility at Mol). The LPSC team will benefit from this technical support with the advantage of been located only at a few hundred meters from the ILL.

Partner 3 – LAPP - Annecy:

The Laboratoire d'Annecy-le-Vieux de Physique des Particules (LAPP) is a CNRS and Université de Savoie research unit. The laboratory is very actively involved in several large international collaborations working on accelerators (ATLAS and LHCb on the LHC at CERN, OPERA in Gran Sasso) and astroparticle experiments (VIRGO, AMS, HESS, CTA). A strong R&D program on machine and detector development for future linear colliders is ongoing. The laboratory benefits from important technical expertise from engineering teams in mechanical, electronic and computing departments.

The laboratory has a long tradition on neutrino physics and has participated starting in 1980 to the design, construction and running of pioneering experiments (Bugey, NOMAD, CHOOZ) allowing to build the current neutrino picture. The LAPP research team involved in this neutrino project is presently participating actively on the CNGS/OPERA program. It has a well-established expertise in neutrino experiments covering detector conception, construction and exploitation as well as physics analysis.

The developments done at LAPP for the previous Bugey liquid scintillator neutrino experiment are well adapted in the context of this project since it included the design, development and construction of a similar calibration system with radioactive sources.

The mechanical design work for the passive shielding will benefit from the expertise acquired in designing the shielding for the SEDINE spherical TPC installed in the Modane Underground Laboratory in 2012.

Associate partner MPIK – Heidelberg:

The Max Planck Institut fuer Kernphysik (MPIK) in Heidelberg, Germany, is worldwide one of the leading institutes in the field of neutrino physics. In the past the institute was leading or significantly contributing to several neutrino projects. Over more than 20 years expertise was built up in well-known neutrino experiments like Gallex/GNO, Borexino or LENS. The focus of the experimental activities in this field is also on projects in neutrino physics and in the search for Dark Matter particles. The relevant group is currently strongly involved or even leading the neutrino experiments GERDA and Double Chooz. MPIK is also involved in the NUCIFER project, which is a predecessor of the proposed Stereo project. The group is in addition one of the leading partners of the XENON100 dark matter experiment and in the future XENON1T project.

Over the last decades the institute built up unique knowledge in low level techniques which are essential for background identification and reduction in neutrino and dark matter experiments. The institute has also excellent expertise in the field of metal loaded scintillators, as required for Stereo, including the detection of its scintillation light with dedicated photomultiplier tubes. The infrastructure for the production of scintillators on the ton scale, as well as to do the detailed scintillator characterizations is available.

In addition MPIK has the equipment ready to test and calibrate multiple photomultipliers simultaneously. MPIK has also good internal mechanical and electronics workshopsand technicians to support the experimental activities. In addition to the researchers there are several technicians with special know-how for work in this field of research. Members of the group work also on data analysis, perform simulation studies for the experiments and perform phenomenological studies. The Stereo project could therefore benefit in many ways from the skills and expertise at MPIK.

“The Max Planck Institut fuer Kernphysik (MPIK) is interested to participate in the Stereo project and it's potential contribution is already fully funded. The scientific merit of the project is, however, very time critical and the commitment of MPIK is therefore tied to the fact that all partners obtain their funding latest by summer 2013, such that the schedule can be met.”

- Manfred Lindner, head of MPIK, **lindner@mpi-hd.mpg.de**

Associate partner ILL – Grenoble:

The Institut Laue Langevin (ILL) in Grenoble, France, is the leading neutron user facility in the world. It operates a 58 MW compact core high-flux research reactor and about 40 instruments for neutron scattering, nuclear and particle physics. The ILL has vast expertise in instrument design, construction and installation including the related project management; instrument control and data acquisition; shielding; reactor calculations; reactor safety and security. In the field of nuclear and particle physics, the ILL is involved in measurements of fission yields and the structure of fission products, studies of neutron decay and weak interaction, measurements of the neutron electric dipole moment, investigation of quantum states of neutrons in the gravitational field, and developments of experimental techniques. The first reactor neutrino oscillation experiment was performed at the ILL about 30 years ago. This result is still the shortest-baseline experiment performed so far.

Several physicists from the Nuclear and Particle Physics group and engineers from the reactor calculation group have expressed strong interest to participate in a sterile neutrino oscillation experiment or the related simulations. The ILL disposes of all technical services needed to evaluate the safety of instruments, prepare the infrastructure and install an instrument.

The direction of ILL confirms it abides by the commitments exposed above in the description of tasks in terms of infrastructure and man power.

- Helmut Schober, Scientific Director of ILL, **schober(@ill.fr**

Associate partner University of Casablanca / CNESTEN:

The Casablanca and CNESTEN group have been working together for more than 15 years, on many projects such as:

- Neutron simulation for reactor beam lines
- Neutron simulation and construction of shielding for the reactor of the CNESTEN
- Simulation of shielding for the neutron irradiation station constructed at SARA accelerator and simulation of shielding for the low radioactivity laboratory at the LPSC in Grenoble

This team has a vast expertise in simulation codes like Geant4, FLUKA and MCNP.

We are involved in ATLAS experiment with contribution to the construction of the presampler of the electromagnetic calorimeter and also the preamplifier of the Front End Board of the Calorimeter.

One of our major tasks will be the simulation and the design of the front wall separating the detector and the reactor. The other task is the design and the production of the light injection system for calibration and monitoring of the inner detector. The Moroccan team has a long experience in conducting detector calibration, in neutrino oscillations experiment at Bugey and also calibration of the electromagnetic calorimeter in ATLAS experiment.

The amount of our contribution for the next two years is around 20 k€, 10 k€ are already available and can be used this year.

- Abdeslam Hoummada, coordinator of the Moroccan group, **a.hoummada@academiesciences.ma**

5.2. QUALIFICATION AND CONTRIBUTION OF EACH PARTNER

Fournir les éléments permettant de juger la capacité du coordinateur à coordonner le projet. (0,5 page maximum)

David Lhuillier, Stereo coordinator: I'm working in the nuclear division of the CEA/Irfu. Over the past 15 years I have acquired a solid experience in experimental physics both at the operational and coordination level. My first interest was in experiments with polarized electron beams looking for tiny parity violating asymmetries. The associated Z0 exchange was used as a new probe of matter and electroweak interaction at low transfer ($Q^2 \leq 0.1$ GeV/c^2). I was co-spokesperson of the Happex2 experiment at Jefferson Lab (Virginia). I had leading contributions in the apparatus by taking the responsibility for the electron detectors and the Compton polarimeter developed by CEA/Irfu. I achieved a record accuracy of 1% on the polarization of a 3 GeV beam.

In 2006, I took the opportunity of the development of the Double Chooz experiment at Irfu to switch to reactor neutrino physics. At that time nuclear physicists were marginally involved in neutrino physics for specific issues. I developed a complete research activity on neutrinos in the nuclear division of CEA/Irfu, in close collaboration with the neutrino group of the particle physics division. This transverse collaboration inside our institute has been quite prolific since then. For the Double Chooz experiment I am co-head of the reactor group, in charge of the prediction of the neutrino spectrum emitted by the two reactors of the Chooz power plant. To address the important issue of absolute normalization of the first phase of the experiment (with the far detector only) I established contacts with EDF experts to provide a detailed error budget with a total uncertainty of 0.5% at one sigma. In the same framework of accurate predictions for Double Chooz I'm at the origin of the re-evaluation of the neutrino spectra emitted by the reactors. This work led to the re-analysis of past reactor experiments and to the related reactor anomaly.

In parallel to the development of Double Chooz, I'm strongly involved in the Nucifer experiment. The main motivation of this 1 m^3 detector is an application of neutrinos to the remote surveillance of reactors in the context of non-proliferation of atomic weapons. In 2008 the International Agency for Atomic energy (IAEA) recognized that neutrino detectors have unique abilities to non intrusively monitor the power and fissile content of a nuclear reactor, in real-time and from outside the reactor containment. I'm a member of a group of neutrino experts meeting regularly with the IAEA to exchange on our progress in neutrino detection and on the needs of the agency. I played a leading role in the conception of the detector and its shielding as well as in the current phase of commissioning and coordination of the analysis.

From my recent research activities, I'm deeply connected to the revelation of the reactor anomaly as well as the experimental technics to look for it. This motivated my initiative on the Stereo project, very positively received by the ILL scientific council. This project has a unique opportunity in terms reactor site availability and sensitivity of the measurement. Combined the strong commitments of the external partners this ANR grant covers the needs of a high-potential search for the sterile neutrino within a 3 years experiment.

DEL AMO SANCHEZ Pablo
31 years old

Curriculum:

- **2007** Ph.D. in Experimental Particle Physics, « Time dependent Dalitz-plot Analysis of the Charmless Decay $B^0 \to K^0_S \pi^+ \pi^-$ at BaBar » , University of Birmingham, UK
- **2004** M.Sc. Physics, University of Salamanca, Spain

Present position: Lecturer (permanent position) at the University of Savoie, research on neutrino oscillations (OPERA experiment) within the neutrino group of the LAPP-IN2P3-CNRS (Laboratoire d'Annecy-le-Vieux de Physique des Particules).

Professional experience:

- **2009-2012** Search for $\nu_\mu \to \nu_\tau$ oscillations in the τ to three prongs channel at the OPERA experiment. Vertexing studies.
- **2004-2009** Measurements of CP violation in charmless decays of the B meson; test of the V-A structure of the weak interaction in loop, radiative decays of the B meson, both at the BaBar experiment. Reconstruction efficiency studies for K^0_S and π^0 particles.

Five significant publications over the past five years*:*

- *Search for $\nu_\mu \to \nu_\tau$ oscillations with the OPERA experiment in the CNGS beam*, OPERA collaboration, New Journal of Physics **14** (2012) 033017.
- *Study of neutrino interactions with the electronic detectors of the OPERA experiment,* OPERA collaboration, New Journal of Physics **13** (2011) 053051.
- *Observation of a first ν_τ candidate in the OPERA experiment in the CNGS beam*, OPERA collaboration, Physics Letters B**691** (2010) 138.
- *Time-dependent amplitude analysis of $B^0 \to K^0_S \pi^+ \pi^-$*, BaBar collaboration, Physical Review D**80** (2009) 112001.

- *Observation of the decay* $B^+ \to K^+ K^- \pi^+$, BaBar collaboration, Physical Review Letters **99** (2007) 221801.

LETOURNEAU Alain
40 years old.

Curriculum:

- **2011** Habilitation Thesis, « Réactions nucléaires induites par nucléons et applications dérivées », Université Paris Sud.
- **2000** Ph.D in Physics, « Etudes de la réaction de spallation p+Au à 2.5 GeV et de la production neutronique en cibles épaisses par protons de 0.4 à 2.5 GeV», Université de Caen.
- **1995** Master (Diplôme d'Etude Approfondie) in Physics, speciality Particle and Nuclear physics, Université de Strasbourg.

Present position: Permanent position of physicist at "Service de Physique Nucléaire" – CEA Saclay. Nuclear measurement and modelisation group leader. Research on neutron and neutrino physics.

Professional experience:

- **2005-2012** Reactor neutrino experiments: Double Chooz: measurement of θ_{13} mixing angle, Nucifer: application to non-proliferation.
- **2003-2009** Megapie experiment: characterization of a spallation target. Responsible for the inner neutron flux measurement.
- **2001-2009** Mini-Inca project: measurement of neutron-induced reactions on actinides with thermal neutrons at the ILL reactor. Responsible of the project.

Five significant publications over the past five years*:*

- *Reactor electron antineutrino disappearance in the Double Chooz experiment*, Double Chooz collaboration, Physical Review D86 (2012) 052008
- *Indication for the disappearance of reactor electron antineutrinos in the Double Chooz experiment.* Double Chooz collaboration, Physical Review Letters 108 (2012) 131801.
- *The Reactor Antineutrino Anomaly*, G. Mention et al., Physial Review D83 (2011) 073006.
- *Improved Predictions of Reactor Antineutrino Spectra*, Th. A. Mueller et al., Phys.Rev. C83 (2011) 054615.
- *Isotopic yield measurement in the heavy mass region for the 239Pu thermal neutron induced fission*, A. Bail et al., Phys. Rev. C84 (2011) 034605.

LHUILLIER David
42 years old

Curriculum:

- **2007** Habilitation Thesis, « Violation de parité en diffusion d'électrons», Université de Caen.
- **1997** Ph.D in Physics, « Diffusion Compton virtuelle à basse énergie », Université de Caen.
- **1993** Master in Physics (Diplôme d'Etude Approfondie "Matière et Rayonnement"), specialty nuclear physics, Université de Caen.
- **1993** Engineering Degree from IRMRA, Caen, option Instrumentation.
-

Present position: Permanent position of physicist at "Service de Physique Nucléaire" – CEA Saclay. Research on reactor neutrinos.

Professional experience:

- **2006-2012** Reactor neutrino experiments. Double Chooz: measurement of θ_{13} mixing angle, responsible of neutrino spectrum prediction and analysis contributions. Leading contribution on the re-evaluation of the reactor neutrino spectra. Nucifer: application of reactor neutrinos to non-proliferation, responsible of the detector electronics, coordination of detector tests and analysis.

- **2001-2004** E158 experiment at SLAC, California. Low energy test of the electroweak interaction via parity violation in Moller scattering. Responsible of the pion detector.
- **1997-2005** Experiments at Jefferson Lab, Virginia on parity violation in elastic e-p and e-^{4}He scattering. Co-spokesperson of the Happex2 experiment. Responsible of beam polarimetry and electron detectors.

Five significant publications over the past five years*:*

- *Reactor electron antineutrino disappearance in the Double Chooz experiment*, Double Chooz collaboration, Physical Review D86 (2012) 052008 – 19 citations.
- *Indication for the disappearance of reactor electron antineutrinos in the Double Chooz experiment.* Double Chooz collaboration, Physical Review Letters 108 (2012) 131801 – 210 citations.
- *The Reactor Antineutrino Anomaly*, G. Mention et al., Physial Review D83 (2011) 073006 – 153 citations.
- *Improved Predictions of Reactor Antineutrino Spectra*, Th. A. Mueller et al., Phys.Rev. C83 (2011) 054615 – 109 citations.
- *Precision Measurements of the Nucleon Strange Form Factors at $Q^2 \sim 0.1$ GeV^2*, Happex collaboration, Physical Review Letters 98, 032301 (2007) – 128 citations.
-

Prices: Joliot-Curie 2010 price of the French Physical Society.

MATERNA Thomas
40 ans

Curriculum:

- **1995** Engineering degree in physics. Faculté des Sciences Appliquées, Université Libre de Bruxelles, Belgique.
- **2000** Ph.D. in experimental radiation physics in the Atomic and Nuclear Physics Group of the University of Fribourg, Switzerland

Present position: Permanent position of physicist at “Service de Physique Nucléaire”, CEA Saclay since December 2010. Research on nuclear fission.

Professional experience:

- **2001-2006** Post-doctoral position in experimental nuclear physics at the Nuclear Physics Institute of the University of Cologne, Germany. Research activity in applied nuclear physics and in nuclear structure: design and setup-up of a PIXE/PIGE station at the Cologne accelerator, development of an imaging station by neutron tomography and prompt-gamma activation at the Munich reactor, local responsible of the European project ‘Ancient Charm’ dedicated to the development of non-destructive techniques with neutrons and its use in the field of cultural heritage, reconstruction and first tests of a double orange electron spectrometer at the Cologne accelerator.
- **2006-2010** Instrument responsible at the Institut Laue-Langevin, Grenoble, France, co-responsible of the Lohengrin fission product spectrometer. Research activity at Lohengrin in nuclear structure and in nuclear fission. Development of new imaging techniques using cold neutrons at the reactors of Budapest and FRM-II and using pulsed epithermal neutrons at ISIS within the Ancient Charm project.
- **2011-2012** Development of a new fission fragment spectrometer (FALSTAFF) at NFS (GANIL) for the study of fission in the energy range 0.5-40 MeV.

Five significant publications over the past five years*:*

- *Novel Neutron Imaging Techniques for Cultural Heritage Objects*. C. Andreani, G. Gorini and T. Materna. Chapter 13 of *Neutron Imaging and Applications*, Neutron Scatterings Applications and Techniques, I.S. Anderson et al. (eds) Springer Science, 2009.

- *Sub-nanosecond lifetime measurements using the Double Orange Spectrometer at the Cologne 10 MV Tandem accelerator.* J.-M. Regis et al., Nucl. Instr. and Meth. A 606, 466-474 (2009)
- *Near-yrast structure of ^{142}Cs and ^{144}Cs.* T. Rzaca-Urban et al., Phys. Rev. C 80, 064317 (2009).
- *Isotopic yield measurement in the heavy mass region for ^{239}Pu thermal neutron induced fission,* A. Bail et al., Phys. Rev. C **84**, 034605 (2011)
- *New neutron long-counter for delayed neutron investigations with the LOHENGRIN fission fragment separator.* L. Mathieu et al., JINST 7 P08029 (2012)

MENTION Guillaume
34 years old.

Curriculum:
- **2005** Ph.D in Particle Physics, "Étude des sensibilités et bruits de fond de l'expérience Double Chooz pour la recherche du paramètre de mélange leptonique θ_{13}", Université Claude BERNARD, Lyon I.
- **2002** Master in Theoretical Physics (Diplôme d'Études Approfondies de Physique Théorique Rhône-Alpin), École Normale Supérieure de Lyon.
- **2002** École Normale Supérieure de Lyon, Diplôme de Magistère, Département des Sciences de la Matière.

Present position: Permanent position of physicist at "Service de Physique des Particules" since 2007 – CEA Saclay. Research on reactor neutrinos.

Professional experience:
- **2007-2012** Reactor neutrino experiments. Double Chooz: measurement of θ_{13} mixing angle. One of the 3 people in charge of θ_{13} determination from data. Expertise in statistics. Responsible of material compatibility certification between liquids and solid materials exposed in the detector. Nucifer: in charge of material compatibility expertise and filling operations of the detector. Contributions to analysis and uncertainties propagation for model prediction.
- **2005-2007** Post-doctorate position in Double Chooz: development of protocols and tests for chemical material compatibility of Double Chooz. Participation to the Double Chooz proposal. Performed the Double Chooz physics studies and sensitivity studies on θ_{13} determination.
- **2002-2005** Double Chooz: development of statistical software packages for reactor experiment studies. Performed estimation of sensitivities and main Double Chooz parameters (distances, sizes and detector physics parameters) to optimize the performances for θ_{13} determination. Borexino: phenomenological simulations of neutrino propagation in matter (Sun and Earth) searched for in Borexino experiment.

Five significant publications over the past five years*:*
- *Reactor electron antineutrino disappearance in the Double Chooz experiment*, Double Chooz collaboration, Physical Review D86 (2012) 052008 – 19 citations.
- *Indication for the disappearance of reactor electron antineutrinos in the Double Chooz experiment.* Double Chooz collaboration, Physical Review Letters 108 (2012) 131801 – 210 citations.
- *The Reactor Antineutrino Anomaly*, G. Mention *et al.*, Physial Review D83 (2011) 073006 – 153 citations.
- *Improved Predictions of Reactor Antineutrino Spectra*, Th. A. Mueller *et al.*, Physical Review C83 (2011) 054615 – 109 citations.
- *A unified analysis of the reactor neutrino program towards the measurement of the θ_{13} mixing angle,* G. Mention, Th. Lasserre, D. Motta, J.Phys.Conf.Ser. 110 (2008) 082013. – 17 citations.

STUTZ Anne
49 years old

Curriculum:

- **1989** Ph.D in Physics, Université Joseph Fourier, Grenoble « Conception by simulation and Realisation of an antineutrinos detector ».
- **1986** Master (Diplôme d'Etude Approfondie) in Physics specialty Measurements and Instrumentation, Université Joseph Fourier, Grenoble.
- **1986** Engineering Degree from ENSIEG (INPG), Grenoble, option Nuclear and Energy Engineering.

Present position: Researcher permanent position at 'Laboratoire de Physique Subatomique et de Cosmologie' - CNRS Grenoble, in the Auger (UHECR) team ».

Professional experience:

- **2005-2012** Pierre Auger Experiment: Study of cosmic rays at ultra high energy. R&D CODALEMA: Radio detection of cosmic rays at ultra high energy.
- **2002-2005** EUSO Project: Study of cosmic rays at ultra high energy with a space-based detector.
- **1993-2002** MUNU Experiment: Measurement of the neutrino magnetic moment at the Bugey Nuclear Reactor. R&D Solar Neutrinos: LENS, Super-Munu, Indium.
- **1990-1996** BUGEY 3 Experiment: Search for neutrino oscillation at the Bugey Nuclear Reactor.
-

List of publications*:* Number of journal publications and conference proceedings with referees: 56.
Five significant publications over the past five years:

- *Ultra-High Energy neutrinos at the Pierre Auger Observatory*, Abreu P. et al , Advances in High Energy Physics, in press 2012
- *Measurement of the proton-air cross-section at* $\sqrt{s}=57$ *TeV with the Pierre Auger Observatory*, Abreu P. et al , Physical Review Letters, 109 (2012) 062002
- *Measurement of the Depth of Maximum of Extensive Air Shower above* 10^{18}*eV*, Abraham J. et al, Physical Review Letters, 104 (2010) 091101
- *Full Simulation of Space-Based Extensive Air Showers Detectors with ESAF*, Bérat C. et al., Astroparticle Physics, 33 (2010) 221-247
- *Observation of the suppression of the flux of cosmic rays above* 4.10^{19}*eV*, Abraham J. et al, Physical Review Letters, 101 (2008) 061101

VESCOVI Christophe
42 years old

Curriculum:

- **1996** Ph.D in Electronics, Grenoble INP, « Inversion d'un modèle des cordes vocals pour un robot parlant ».
- **1993** Engineering Degree from ENSERG (INPG), Grenoble, option Signal Processing.

Present position: Engineer permanent position at 'Laboratoire de Physique Subatomique et de Cosmologie' - CNRS Grenoble, Electronics group leader.

Professional experience:

- **2008-2012** Technical project manager of the LSST (Large Synoptic Survey Telescope) French team.
- **2004-2010** Analog electronics development for the nEDM experiment.
- **2001-2008** System engineer of the Dilution Cooler Electronics for the HFI Planck Instrument (ESA / CNES).
- **2001-2008** Analog electronics developments of the Sorption Cooler Electronics for HFI and LFI Planck Instrument (ESA / NASA).
- **2004–2008** Development of the Low Level RF for the CNAO synchrotron.
-

List of publications*:*

Significant publications over the past five years:

- *Development of a multifunction module for the neutron electric dipole moment experiment at PSI*, Bourrion O. et al , NIM-A **701** (2013) 278-284.
- *NIKEL: Electronics and data acquisition for kilopixels kinetic inductance camera*. Bourrion O. et al, *Journal of Instrumentation* **7** (2012) 07-014.
- *A dual-band millimeter-wave kinetic inductance camera for the IRAM 30-meter telescope*, Monfardini A. et al, *The Astrophysical Journal Supplement Series* **194** (2011) 24

Participation of Stereo partners in other national projects is summarized in **Table 7**. The organization of human resources among the different projects has been presented to internal committees in each institute. The allocation of the Stereo resources (physicists and technical staff) has been validated according to the planning presented in section 3.

Table 7:participation to other national projects.

Partner	Name of involved people	Project name, financing institution, grant allocated	Start and end dates
CEA	T. Lasserre, A. Letourneau, D. Lhuillier, G. Mention, M. Vivier	Double Chooz, CEA/Irfu, Region Champ- Ard. 2.15 M€, FEDER 1.5 M€,Conseil Général Ard. 250 k€, C.C. Ardennes RdM 150 k€	2003-2018
CEA	T. Lasserre, A. Letourneau, D. Lhuillier, G. Mention, M. Vivier	CeLand, ERC starting grant T. Lasserre, 1.5 M€	2012-2017
LPSC	A. Stutz, F. Montanet	GIGAS / ANR / 130 k€	2012-2016
LAPP	H. Pessard	LAGUNA/LBNO, FP7 4.9 M€	2011-2014

6. SCIENTIFIC JUSTIFICATION OF REQUESTED RESOURCES

The description of all hardware components of the Stereo detector is presented in section 3. The following price estimates are based on recent purchases or bids made in the different laboratories for same or similar items.
The associate partners of Stereo provide a significant fraction of resources summarized in **Table 8**. The 50 k€ of own funds from Irfu are also mentioned. All MPIK funds are already available as stated by the head of the institute (section 5.1). The requested ILL budget is comparable to the yearly budget allocated to the GAMS5 installation. Complementary funds might be requested depending on the final amount of subcontracted safety studies (depends on the availability of the local design office, difficult to estimate now). Half of the Casablanca/CNESTEN budget is available. The second half will be available in 2014 from the CNRST (Moroccan public research).

Table 8: Associate funding of the Stereo project.

Associate Partner	**Equipment / Subcontracting**	**Budget (k€)**
MPIK-Heidelberg	Liquid Scintillator	250
	Filling system	70
	PMTs	125
ILL	Beam Stopper	35
	Safety studies / infrastructure	20
Univ. Casablanca CNESTEN	Design of front wall	10
	Light injection system	10
Irfu own funds	Prototype detector cell	50
Total		**580**

6.1. PARTNER 1 : CEA/IRFU

- *Equipment 201,1 k€*

The equipment requested below covers the need of materials and machining for the fabrication of the inner detector as described in **task 6**.

Item	**Comment**	**Price (k€)**
Target vessel	Fabrication	25
	Teflon coating	10
Outer crown vessel	Fabrication (double walled)	40
	Teflon coating	10
Top lid	Fabrication	25
Acrylic buffer	Raw material	40
(1 central + 4 lateral plates)	Machining and gutter gluing	45
Total		**195**

The total request is 201.1 k€ including non recoverable TVA taxes.

- *Staff 107,0 k€*

A two years Postdoc position under the responsibility of David Lhuillier. The requested budget is 107 k€.
The candidate will have a leading role in the inner detector work package. The first year will be dedicated to the fabrication, installation on site of the detector and preparation of the analysis software. The second year will focus on data taking and analysis.

- *Operating costs 48,5 k€*

- Participation to 3 international conferences : 4,5 k€
- Missions to Grenoble for technical meetings and installation of the experiment: 8 people concerned, 20 person.week (20 k€).
- Missions for collaboration meetings and data taking: 8 people concerned, 24 person.week (24 k€).

6.2. PARTNER 2 : IN2P3/LPSC

- *Operating costs 234,5 k€*

Equipment resources are used for the procurement of tasks 4 and 8, which are under the responsibility of LPSC, and for valorization of the scientific results.

Task 4, muon veto realization: 45 000 €
This budget represents the total cost of the active shielding realization, including raw materials for the structure and light collection, photo sensors and water purification system.

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

Task 8, data acquisition: 176 000 €

This budget represents all what is needed to realize the data acquisition system.

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**

Missions :
Participation to 3 international conferences: 4,5 k€
Missions for collaboration meetings, 6 people concerned: 9 k€

6.3. PARTNER 3 : IN2P3/LAPP

- *Equipment 260,0 k€*

The funds requested below will be used for the detector shielding, designed by the LAPP partner. The price for the lead wall is based on the current unit price (32 €) of double chevron brick with size: 10 cm x 10 cm x 10 cm. The root can be made of 2 layers of flat, cheaper, bricks. ILL will take in charge the calculations for the earthquake-proof validation of the support structure.

Item	**Comment**	**Price (k€)**
Lead shielding		140
Polyethylene shielding		50
Support structures		70
Total		**260**

- *Staff 108,4 k€*

A two years Postdoc position under the responsibility of Pablo del Amo Sanchez. The requested budget is 108,4 k€. During his first year, the candidate will finalize the optimization of the calibration system, and will develop the calibration and monitoring software. The second year he will focus on the commissioning of the detector setup, including the calibration system, and data analysis.

- *Operating costs 163,6 k€*

Task 7: Calibration system: 131 k€

Item	**Comment**	**Price (k€)**
Radioactive sources		11
Automatism	Engine, sensors, electric rack, etc	40
External mechanics and support structure		20
Internal mechanics	Tubes, wires, source container, etc	50
Prototype		10
Total		**131**

Participation to 3 international conferences : 4,5 k€
Missions to Grenoble for the installation of the experiment: 6 people concerned, 18 person.week (12,6 k€).
Missions for technical meetings and data taking: 4 people concerned, 17 person.week (13.5 k€).
Costs of hosting the ANR postdoc (PC, desktop) : 2 k€.

7. REFERENCES

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