Status of the STEREO experiment: search for a light sterile neutrino at ILL

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Abstract. The search for a light sterile neutrino started to be a popular topic in neutrino physics, since the observation of the "gallium anomaly" and "reactor anomaly" in which a deficit of neutrinos was observed relative to the prediction. Such anomalies could be explained by short distance oscillations towards a sterile state with $\Delta m^2 \sim 1 \text{eV}^2$. In a highly competitive context, several projects were started to search for a light sterile neutrino. This paper will focus on the STEREO experiment for which a detector has been designed to observe the electron antineutrino energy spectrum distortion from 3 to 8 MeV due to such a new L/E oscillation, and should therefore confirm or reject the light sterile neutrino hypothesis. Electron anti-neutrinos produced by the compact reactor core of the Institut Laue-Langevin will be detected in a 6-cell segmented volume of Gd-loaded liquid scintillator through the inverse $\beta$-decay process. The STEREO detector was completed in November 2016 and was commissioned right away, STEREO is currently taking data. In this paper we will present the final design of the detector and the first results of the commissioning.

1. Introduction
The STEREO experiment was initiated in 2012, after the rise of the "reactor antineutrino anomaly". This anomaly which corresponds to a deficit of detected neutrinos, relative to the predictions of the emitted fluxes, was observed by many experiments at short distance of nuclear reactors [1]. Such an anomaly could be explained by an error on the flux prediction or by the existence of a neutrino oscillation to a hypothetical flavour, the sterile neutrino, which does not interact by weak interaction. The last hypothesis is reinforced by the observation of a similar deficit with electron neutrinos coming from calibration sources deployed in detectors of two neutrino solar experiments, GALLEX and SAGE, the so-called "gallium anomaly" [2]. In the case of a sterile neutrino hypothesis, the survival probability of anti-neutrinos with an energy $E_{\nu e}$ and after propagating over a distance $L$ can be approximated as:

$$P(E_{\nu e}, L) = \sin^2(2\theta_{\text{st}}) \sin^2 \left(1.27 \frac{\Delta m^2_{\text{st}} \text{[eV}^2\text{]} L \text{[m]}}{E_{\nu e} \text{[MeV]}}\right)$$

(1)

A common analysis of the "reactor antineutrino" and the "gallium" anomalies [1], favours a $\Delta m^2_{\text{st}} \gtrsim 1 \text{eV}^2$ and $\sin^2(2\theta_{\text{st}}) \sim 0.1$.

The main goal of the STEREO experiment is to confirm or reject the hypothesis of an oscillation at short distance using antineutrinos emitted by the reactor of the Institut Laue-Langevin (ILL). In order to test this hypothesis without ambiguity, it is necessary to be independent from the...
antineutrinos flux prediction, since this prediction is possibly biased [3]. The STEREO detector was designed to measure relative deformations of the antineutrino spectrum at different distances from the reactor core. These relative deformations should follow Eq.1, providing a hint on the existence of a sterile neutrino without requirement of a precise prediction of the antineutrino flux. The STEREO detector has already started taking data, after few days of commissioning, in November 2016.

2. The STEREO detector

The STEREO detector covers a range of [8.9 - 11.1] m from the ILL reactor core. The reactor has a nominal power of about 57 MW\text{th} and the fuel is highly enriched in $^{235}$U which will decrease systematic uncertainties related to the fuel burnup effect. This core also has the advantage to be very compact with a diameter of 37 cm preventing the potential oscillation signal to be washed-out.

The STEREO detector presented in Fig. 1 is segmented in six cells containing liquid scintillator loaded with gadolinium for neutron capture. This volume is the ”target” of inverse beta decay (IBD) reactions used to detect antineutrinos ($\overline{\nu}_e + p \rightarrow e^+ + n$), in which the neutron signal is delayed by a few $\mu$s to the positron signal. The measured energy of the positron signal is used to estimate the neutrino energy. The ”target” is surrounded by an outer crown, called ”gamma-catcher”. The latter is subdivided in four cells filled with liquid scintillator without gadolinium to collect escaping gamma energy improving both the energy resolution and the neutron detection efficiency. It is also used as a veto for external background. A total of 48 photo-multipliers (PMTs) at the top of the cells are coupled to the liquid scintillator via mineral oil contained in acrylic buffers to increase light collection. The detector was mounted in spring 2016 and was tested without liquid and with the full dedicated electronics [4][5] during summer.

Since the detector is located close to the reactor, the gamma and neutron background level is one of the main concern. Lead, polyethylene and $B_4C$ walls were deployed around the detector position to shield the area against fast and thermal neutrons coming from the reactor but also against neutrons and gammas produced by neighbouring experiments. In addition, the detector is enclosed in a shielding made of layers of lead (48 tons) and borated polyethylene (6 tons). Extra layers of soft iron and $\mu$-metal are also used to decrease the variable magnetic field produced by neighbouring magnets to below the Earth magnetic field level to avoid any induced PMT gain variation. The top of the detector is covered by a muon Cerenkov-detector, called the $\mu$-veto, filled with pure water. It helps to tag cosmic muons which can produce fast neutrons, by

![Figure 1: Cut view of the detector, along the antineutrino propagation axis.](image_url)
spallation on high-Z material, which induce the main contribution of the correlated background. The $\mu$-veto allows to reject off-line correlated events after a muon which potentially produced events similar to neutrino events. The shielding was assembled with the detector in August and it was moved to the data taking position in September 2016.

3. Commissioning and data taking
On 10th November 2016, the detector was filled with liquid scintillator and mineral oil and the experiment entered the commissioning period.

Two event displays are depicted in Fig. 2, showing photo-electron (PE) distributions over the PMTs in the detector filled with liquid scintillator. They illustrate the good containment of the light in one cell for a positron-like event (2a) and in the gamma-catcher for an external-background-like event (2b), demonstrating the capability of the STEREO detector to easily determine the cell of the event vertex.

First calibrations were performed with a radioactive $^{54}$Mn source, emitting 835 keV gammas. PE spectra of such calibrations are shown in Fig. 3 where the $^{54}$Mn source was deployed in a "target" cell at several heights. A total of $\sim 280$ PEs per MeV is collected which is in agreement with the STEREO simulation based on Geant4. The relative difference of the collected light between the bottom, the center and the top of the cell is only about $\sim 2\%$, in the specifications.

Right after the detector filling, light collection decreases have been spotted in one "target" cell and in one short "gamma-catcher" cell. These decreases have been explained by leaks in the buffers of problematic cells which was confirmed visually thanks to a camera in the inner

![Figure 2: Map of photo-electrons measured on the detector PMTs, for two events around $\sim 3$ MeV, in the detector filled with liquid scintillator. The first displayed event (a) is a positron like event well contained in one cell with small light leaks to the neighbouring cells. The second displayed event (b) is a background like event contained in the gamma-catcher.](image-url)
detector. After all the mineral oil leaked into the liquid scintillator, the light collection of the two cells stabilized at a factor of light collection of $\sim 2.5$ less than the ones of others cells because of the light coupling losses. The liquid scintillator performance is not impacted since it is chemically compatible with the mineral oil. All possible systematics from the buffer leaks are currently under investigation since the detector will not be opened before March 2017 to fix the leaks.

Finally after a few days of commissioning, the STEREO experiment started taking data during a reactor ON period. Internal source calibrations are performed three times a week to monitor the detector performance and each week external calibrations are performed with several sources (neutron and gamma sources) deployed aside and underneath the detector. A full set of gammas sources is regularly used to monitor the non-linearity of the energy response. The ”Neutrino” runs exhibit a trigger rate of about 2 kHz with less than 1% dead time using a 250 keV threshold. Single events in the neutrino energy window $[2\text{ MeV} < E_{\text{vis}} < 8\text{ MeV}]$ exhibit a rate of $\sim 14\text{ Hz}$, in the specifications intended to probe the sterile neutrino hypothesis.

4. Conclusion
The STEREO experiment is now taking data, until a break in March 2017. The first period of data taking will regroup around 80 days of reactor ON and 30 days of reactor OFF. Currently, the STEREO collaboration concentrates its efforts on the energy reconstruction and the background identification to extract correlated events related to neutrinos. First results and publication are expected in 2017.

References
[1] The Reactor Antineutrino Anomaly - Mention, G. et al. Phys.Rev. D83 (2011) 073006 arXiv:1101.2755 [hep-ex]
[2] Statistical Significance of the Gallium Anomaly - Giunti, C. et al. Phys.Rev. C83 (2011) 065504 arXiv:1006.3244 [hep-ph]
[3] Systematic Uncertainties in the Analysis of the Reactor Neutrino Anomaly - Hayes, A.C. et al. Phys.Rev.Lett. 112 (2014) 202501 arXiv:1309.4146 [nucl-th] LA-UR-13-27154
[4] Trigger and readout electronics for the STEREO experiment - Bourrion, O. et al. JINST 11 (2016) no.02, C02078 arXiv:1510.08238 [physics.ins-det]
[5] Electronics for the STEREO experiment - STEREO Collaboration (H´ elaine, V. for the collaboration) arXiv:1610.00003 [physics.ins-det]