STATUS OF THE STEREO EXPERIMENT,
A SEARCH FOR STERILE NEUTRINOS AT THE ILL

A. BONHOMME on behalf of the STEREO collaboration
aurelie.bonhomme@cea.fr
Irfu, CEA, Universite Paris-Saclay, 91191 Gif-Sur-Yvette, France

The standard three-family model describing the neutrino oscillations is challenged by several experimental anomalies, such as the Reactor Antineutrino Anomaly (RAA), that can be solved by introducing a light sterile neutrino at the eV mass scale. STEREO is designed to probe the oscillation parameter space region indicated by the RAA, by placing a gadolinium-doped liquid scintillator neutrino target at a 10 meters average distance from the core of the ILL research reactor, in Grenoble (France). An oscillation pattern - if any - will be measured both in energy and in distance thanks to a segmented detector consisting of six identical cells. The main challenge of such a measurement arises from the experimental location; consequently, the shielding design was optimized on the basis of detailed background measurements. The building of the detector was completed in 2016, and four months of data are under analysis.

1 Introduction

Although our current understanding of neutrino physics succeeds to accommodate most of the data into a three neutrino mixing framework, there are still experimental anomalies that need to be explained. The Reactor Antineutrino Anomaly (RAA) was highlighted in 2011, when a new spectral prediction of reactor antineutrinos fluxes showed a 6% deficit in the global rate of previous experiments located at a few tens of meters from reactors [1]. A possible explanation for this phenomenon consists in introducing sterile neutrinos at the eV mass scale into which antineutrinos would oscillate. In the simplest model with one sterile neutrino, the probability of disappearance of $\bar{\nu_e}$ at very short baseline would be described by an additional parameter Δm^2_{14}. Neglecting the impact of the known oscillations driven by Δm^2_{12} and Δm^2_{23} that develop at larger baselines, this probability is given by Eq. 1:

$$\mathrm{P}_{\bar{\nu_e}\to\bar{\nu_e}}(\mathrm{L},\mathrm{E}_{\bar{\nu_e}}) \approx 1 - \sin^2(2\theta_{ee})\sin^2\left(\frac{1.27\ \Delta m^2_{14}\ \mathrm{L}}{\mathrm{E}_{\bar{\nu_e}}}\right) \tag{1}$$

where $\mathrm{E}_{\bar{\nu_e}}$ is the $\bar{\nu_e}$ energy in MeV (few MeV for a reactor neutrino), L is the distance between the neutrino production and its detection in meters, and θ_{ee} and Δm^2_{14} are the mixing angle and the mass squared difference introduced by the additional sterile neutrino.

2 The Stereo experiment

2.1 The detector

The detector - consisting of six identical target cells - covers the distance from 9 to 11 meters from the ILL compact reactor core in Grenoble, allowing for the measurement of a relative distortion of the $\bar{\nu_e}$ spectrum with distance. Antineutrinos are dominantly produced by fission products of the ^{235}U isotope in the 93 percents-enriched uranium fuel of the nuclear core and are detected via the inverse beta decay (IBD) process in the liquid scintillator filling the detector:

$$\bar{\nu_e} + p \rightarrow e^+ + n. \tag{2}$$

The signature of this reaction is a coincidence in time between the prompt energy deposit and annihilation of the positron and the delayed γ cascade coming from the neutron capture after its thermalisation and diffusion in the medium. Neutron detection efficiency is enhanced by loading the liquid with Gadolinium, thanks to the high neutron capture cross-section and energy release ($\sim$8 MeV) of this element. The optical separation of the cells is ensured by multi-layers walls consisting of acrylic plates and reflective foils of VM2000. Light from scintillation produced in the liquid is collected by four 8-inch photomultipliers tubes (PMT) on the top of each cell, placed inside an acrylic buffer and immerged into mineral oil for optical contact. The full energy reconstruction of a target event is enabled by an outer crown - filled with undoped liquid scintillator - retrieving potential escaping γ's from positron annihilation or the γ cascade from neutron capture.

2.2 Background mitigation

The surrounding environment in the reactor casemate and its location at ground level makes the measurement challenging: on top of natural radioactivity, Stereo is exposed to radiations coming from the core, from the neighbouring experiments, and from cosmic particles.

Background for an IBD candidate may be decomposed into two types: the *accidental background*, resulting from random coincidences of two uncorrelated signals in the coincidence time window and *the correlated background*, arising from two physically linked signals. The first one is mostly due to reactor activity, and is reduced with passive shielding: as illustrated in Fig. 2, the detector is inserted into a support structure holding magnetic shielding, polyethylene, lead and neutron absorbers. The remaining accidental component is measured online and subtracted statistically. The correlated background comes from cosmic-induced events that can mimic the IBD interaction. A Cherenkov μ-veto detector on the top of the Stereo vessel acts as active shielding against this background by tagging crossing muons. The discrimination is completed offline using *Pulse Shape Discrimination* (PSD) - based on the different scintillation decay time constants of the liquid depending on the nature of the energy deposit - and topological information, the remaining component being measured during reactor-off periods.

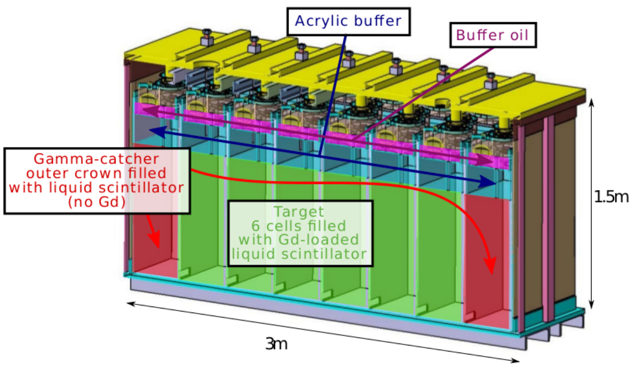

Figure 1 – Six identical *target* cells (green) are surrounded by the *gamma catcher* (red). Acrylics buffers - holding photomultipliers - are placed on top of the volumes (blue).

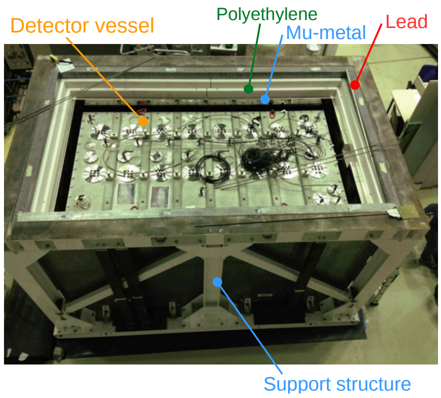

Figure 2 – Detector vessel inside the support structure holding shielding layers (before the installation of the roof, the soft iron magnetic shielding and the boron thermal neutron shielding).

3 Status of STEREO

The STEREO detector was moved into its final position during autumn 2016 and the data taking started in November 2016. Single events and muon veto signals were recorded during a 89-days period of reactor on and a 32-days reactor off period, commissioning phase included.[a]

3.1 Running conditions

Signals from the 68 photomultipliers (48 from the inner detector and 20 from the muon veto) are continuously digitised at 250 MSamples/s by the electronic system - designed for this experiment - embedded in a μTCA crate.[2] With a trigger threshold at $\sim$ 250 keV for physics, corresponding to a few kHz of trigger rate, the acquisition dead time is below the percent.

Detector response and stability are continuously monitored. A light injection system allows hourly specific acquisitions used for PMTs calibration, measurements of the linearity of the electronics and studies of the liquid's properties. Time-evolving optical light leaks through cell walls induced a larger cross-talk than expected. The total light collected remained constant. Values of these leaks and their evolution were monitored online and are corrected offline.

A set of radioactive gamma sources (covering the energy range from 0.5 to 4.4 MeV) is regularly deployed inside and all around the detector ensuring a precise calibration of the energy response. Fig. 3 shows the reconstructed energy spectrum obtained for the ^{54}Mn calibration source. The expected light yield of 300 photoelectrons at 1 MeV was confirmed by calibration data and will guarantee the aimed energy resolution of 10% (FWHM).

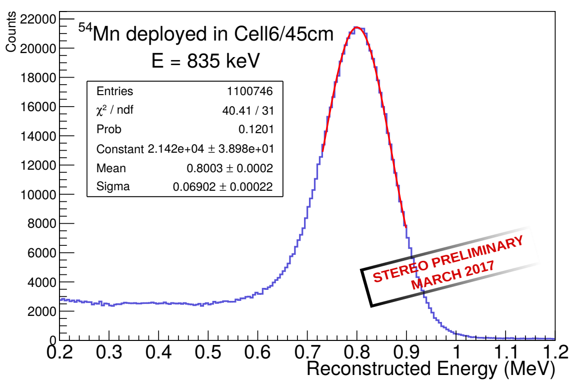

Figure 3 – Reconstructed energy spectrum for a ^{54}Mn source deployed in cell 6.

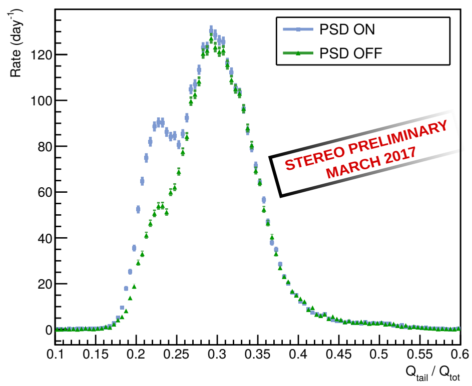

Figure 4 – PSD distributions for reactor-on period (blue) and reactor-off period (green). The low Q_{tail}/Q_{tot} region corresponds to electron recoils (as in the case of IBD events) whereas the high Q_{tail}/Q_{tot} region corresponds to proton recoils due to energetic neutrons.

3.2 Preliminary set of IBD candidates

A preliminary IBD selection was performed on a first set of data, looking for coincidences between prompt [2-8 MeV] and delayed [5-10 MeV] signals within a 70 μs time window. In addition to a 100 μs muon-veto, we require no events within 100 μs window before and after pair candidates. The latter criteria allows to get rid of multi-neutron cascades created by cosmic radiations.

Non-tagged muons that stop and decay in the top layer of the detector may be mistaken as IBD candidates. Their asymmetry of charge deposition in the PMTs of the vertex cell is higher than that of events in the detector bulk and was used to remove these stopping muons events. Note that muons stopping deeper inside the detector are rejected due to their high energy deposit before the stop.

[a]Data taking durations updated with respect to those given at the Moriond conference. May 2017 status.

The PSD allows to discriminate electron recoil (IBD signal) from proton recoil (background signal). PSD of reactor-on periods shows an excess of electronic recoils with respect to the one of reactor off, corresponding to $\bar{\nu}_e$ detection. There is no significant excess of proton recoils, allowing to set limits on reactor-related correlated background. A PSD energy-dependent cut was applied on prompt candidates to discriminate between the two populations.

Neutrinos are obtained statistically through the subtraction of reactor-off IBD candidate set from the reactor-on IBD candidate set. Since cosmic background is subject to fluctuations depending on atmospheric conditions, rates have to be corrected before subtraction. A linear correlation between rates and atmospheric pressure is used to renormalise the reactor-off and reactor-on periods to the same reference pressure value.

Fig. 5 shows the evolution of the IBD rate satisfying the cited cuts as a function of time, after the pressure correction mentioned above. The measured accidental rate, highly sensitive to the activity of neighbouring experiments, is plotted on the same figure; it contributes to less than 10% to the signal. Rates are stable (within the statistical fluctuations) and the neutrinos contribution derived from the difference between reactor-on and reactor-off period corresponds to a signal over background ratio of ~ 0.7 for this preliminary analysis.

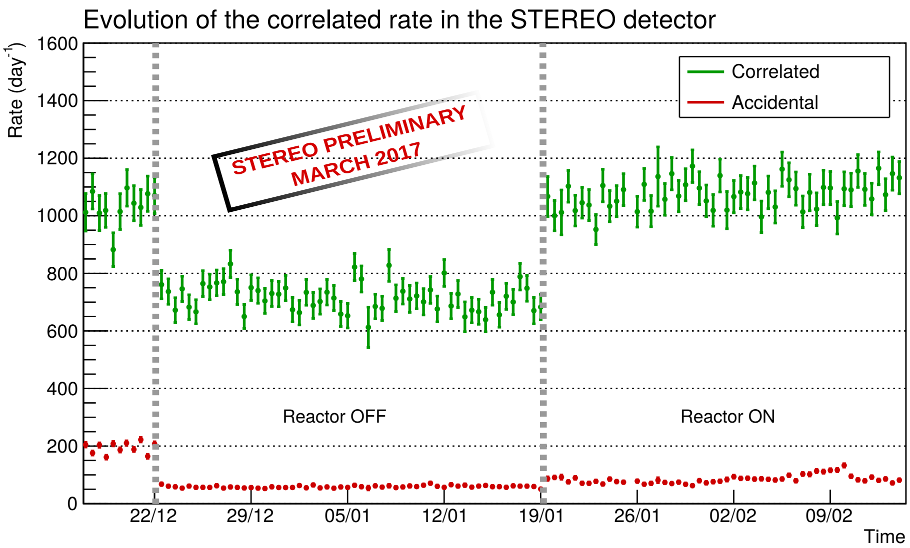

Figure 5 – In green (in red): evolution of the correlated (accidental) rate as a function of time for IBD candidates satisfying time, energy, asymmetry and PSD cuts.

4 Perspectives

Analysis work is on-going to reduce the correlated background in order to reach the expected signal over background ratio of 1.5. Further rejection focuses on promising topological informations, such as the multiplicity of lightened cells or the distance between prompt and delayed candidate energy deposition signals. With the full energy reconstruction based on calibration data and quenching curves, a relative comparison of $\bar{\nu}_e$ spectra between cells will be possible.

A new data taking period starting September 2017 will supplement the already existing set of IBD candidates, providing the nominal 300 days of statistics required for Stereo to cover the contours of the Reactor Antineutrino Anomaly.

References

1. G. Mention et al., *Phys. Rev.* D **83**, 073006 (2011).
2. V. Helaine et al., in Proceedings of the Neutrino-2016 conference, arXiv:1610.00003