PROCEEDINGS OF SCIENCE

STEREO search for a sterile neutrino at the ILL Grenoble reactor

Laura Bernard*
Univ. Grenoble Alpes, CNRS, Grenoble INP, LPSC-IN2P3, 38000 Grenoble, France
E-mail: lbernard@lpsc.in2p3.fr

In the recent years, many acomplishments for neutrino physics were made close to nuclear reactors. The smallest mixing angle, θ_{13} was determined with high precision and the emitted antineutrino spectra was measured with unprecedent resolution. However, two anomalies concerning the absolute flux (smaller than the prediction) and the spectral shape (presence of a "bump" at energies around 5 MeV) have yet to be solved. While they seem together to point towards a wrong prediction in the antineutrino spectra due to underestimated systematics in the measurementsof the beta spectra emitted after fission or in the conversion method, the first anomaly, known as the Reactor Antineutrino Anomaly, could also be solved by introducting a fourth neutrino mass eigenstate of the eV mass participating in the oscillation phenomenon. To finally solve this puzzle, the Stereo detector has been taking data since the end of 2016 at the Institut Laue Langevin research reactor, Grenoble, France. In this contribution, descriptions of the Stereo experiment as well as the pulse shape discrimination parameter based analysis method are given. Then, the results from 66 days of reactor turned on and 138 days of reactor turned off are reported. The resulting antineutrino rate is (396.3 $\pm$ 4.7) $\bar{\nu}_e$ /day and the signal to background ratio about 0.9. The test of a new oscillation toward a sterile neutrino is found to be compatible with the null oscillation hypothesis and the best fit of the reactor antineutrino anomaly is excluded at 97.5% C.L.

The 39th International Conference on High Energy Physics (ICHEP2018)
4-11 July, 2018
Seoul, Korea

*Speaker.

PoS(ICHEP2018)064

1 Introduction

The standard framework of 3ν mixing can be extended with the introduction of non-standard massive neutrinos only if their mixing with the active neutrinos is sufficiently small in order not to spoil the successful 3ν mixing explanation of solar, atmospheric and long-baseline neutrino oscillation measurements. In a two flavors scheme, the survival probability of reactor electronic antineutrinos depends on the antineutrino energy ($E_{\bar{\nu}_e}$) and its length of propagation (L) [1] and is written as: $P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2(2\theta_{ee})\sin^2(1.27\,\frac{\Delta m^2_{41}[\mathrm{eV}^2]\mathrm{L[m]}}{E_{\bar{\nu}_e}[\mathrm{MeV}]})$ where θ_{ee} is the mixing angle and Δm^2_{41} the difference of the mass squares of the mass eigenstates. By 2011, global fits of short baseline neutrino oscillation data from experiments all over the world agreed on a best fit oscillation parameter located around $\sin^2(2\theta) \simeq 0.1$ and $\Delta m^2 \simeq 1eV^2$ [2].

The RAA and the spectral shape anomaly can both be investigated with the Stereo experiment. This very short baseline reactor antineutrino experiment, running since end of 2016, is installed at the High Flux Reactor of the Institut Laue-Langevin. Its compact core of 80 cm high and 40 cm diameter operates with highly enriched ^{235}U (93%). Contributions from fission of other isotopes are thus negligible, allowing Stereo to soon provide a pure ^{235}U antineutrino spectrum measured at a 10 m baseline. For now, this contribution will focus on the sterile neutrino hypothesis, which triggered the birth of several experiments worldwide. Even though the first two experiments to publish results, DANSS and NEOS, have excluded significant parts of the allowed region [3], an oscillation involving a fourth neutrino state is still favored at the 3σ level when combining all reactor antineutrino disappearance experiments.

In Stereo, the detector segmentation into six identical cells along the neutrino propagation axis allows for measurements at multiple short baselines, where the neutrino propagation distance is of the order of the oscillation length ($\simeq$ 8 meters). Therefore, the presence of a sterile neutrino should be signed by a distortion of the energy spectra in the different cells.

2 Description of the experiment

Detector design The detector consists of an antineutrino detector, several calibration devices and a muon veto on top, all illustrated on Figure 2. Its 2m^3 target volume, segmented into 6 optically separated cells, is filled with an organic liquid scintillator (LS) where the antineutrinos are detected via inverse beta decay (IBD) on hydrogen: $\bar{\nu}_e + p \rightarrow n + e^+$. The IBD signature is a coincidence of a prompt positron, from which the antineutrino energy is directly inferred as $E = E_{prompt} + 1.782$ MeV, and a delayed neutron capture event. We will refer to the IBD events as correlated pairs. To increase the neutrons capture rate, the LS has been loaded with gadolinium (Gd). This capture creates a gamma cascade with about 8 MeV total energy, that can interact in the target but also in a surrounding crown called the gamma-catcher. This crown is designed to contain γ-rays escaping from events in the target and also serves as an active veto against external background entering the target. The scintillation light is conveyed to the top of each cell by reflective walls, and read out by 48 Hammamatsu PMTs of 8 inch size. They are separated from the LS by acrylic buffers containing mineral oil, here to establish an homogeneous light collection as well as a good optical contact between LS and PMTs. Only the target LS is dopped with Gadolinium for efficiency neutron detection, confining the fiducial volume in this region. The 6 cells communicate in terms of liquid exchange, but are optically isolated to the few percent level, allowing for independent measurements of the neutrino spectrum. More details are given in [4].

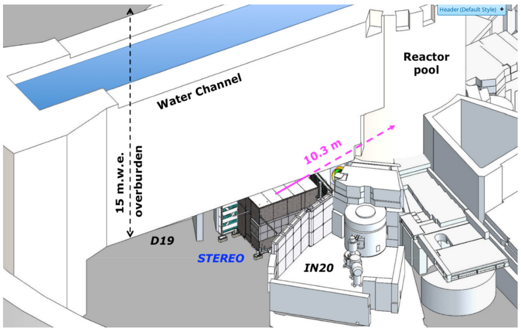

Figure 1: ILL reactor hall. The two neighboring experiments (D19 and IN20) are very close and provide a high rate of background.

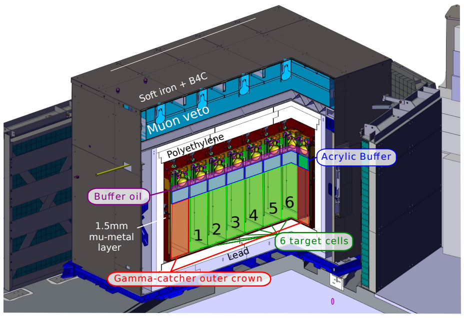

Figure 2: STEREO setup. 1-6(Green): target cells (baselines from core: 9.4-11.1 m); (Red): two of the four gamma catcher cells.

Backgrounds The accidental background is mainly discriminated by the 16 μs capture time constant of the neutron capture, and reduced by a passive shielding made of various materials of about 65 tons total mass. Selection cuts can be used to discriminate the cosmogenic background. The remaining backgrounds can then be measured during phases where the reactor is turned off.

Simulation and detector response A Geant4 (version 10.1) Monte Carlo model (MC) based on DCGLG4sim describes the detector geometry, the shielding, and the position to the reactor core. It also includes particle interactions including neutron moderation and capture; light production, transport taking into account cross talks between cells, detection, and signal conversion in the electronics. An automatic and daily monitoring of the electronic and liquid stability is done using light pulses from LED. On a weekly basis, a set of γ and neutron sources are regularly placed inside, below and around the detector to ensure the monitoring of the energy response. A good agreement between the data and the MC has been found.

3 Oscillation hypothesis testing

Pulse Shape Discrimination parameter (PSD) To select the neutrino candidates, a set of cuts corresponding to the best compromise between detection efficiency and background rejection is applied. The neutrino extraction is done using the PSD, which is defined as the ratio of the pulse tail over the total charge and shown for prompt events of one cell and energy bin on Figure 3. The figure is divided into electronic recoils at low PSD and proton recoils due to muon-induced fast neutrons at high PSD. From reactor off periods, a background model made of two gaussians can be extracted and reported to reactor on periods, assuming the presence of a third gaussian component describing the neutrinos. The only hypothesis assumes a constant ratio between the areas of electronic and proton recoils. Tests are described in [5].

The ratio method A ratio formalism is used in order to rely only on the difference between cells and being insensitive to the model of the reactor spectrum. It consists of dividing the spectrum of cells 2 to 6 by the spectrum of cell 1, serving as a reference. The ratios are then compared between data and MC within a $\Delta\chi^2$ method, with:

$$\chi^2 = \sum_{i=1}^{N_{\text{ebin}}} \left(\overrightarrow{R_i^{\text{data}}} - \overrightarrow{R_i^{\text{MC}}(\alpha)}\right)^t V_i^{-1} \left(\overrightarrow{R_i^{\text{data}}} - \overrightarrow{R_i^{\text{MC}}(\alpha)}\right) + \sum_{l=1}^{N_{\text{cells}}} \left(\frac{\alpha_l^{\text{norm}}}{\sigma_l^{\text{norm}}}\right)^2 + \sum_{l=0}^{N_{\text{cells}}} \left(\frac{\alpha_l^{\text{escale}}}{\sigma_l^{\text{escale}}}\right)^2 \tag{3.1}$$

where $\overrightarrow{R_i^{\text{data}}}$ and $\overrightarrow{R_i^{\text{MC}}(\alpha)}$ are five-dimensional vectors for cells 2 to 6 corresponding to the measured and MC ratios for the ith energy bin. Covariance matrices V_i have been introduced since cell 1

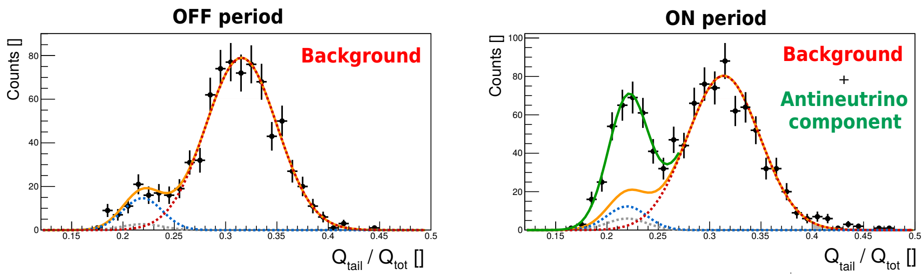

Figure 3: PSD distribution for cell 1 with energy [3.125,3.625] MeV for 23 days of acquisition in off and on periods. The bleu(red) dashed lines model the gamma(proton) PSD. The yellow is the total OFF-model, reported in the on period. The green line is the total ON-model, including the neutrino component.

is used as a common denominator for all ratios. Moreover, nuisance parameters α have been added to take into account systematic uncertainties such as volume and detection efficiencies, energy response and energy scale bias, precisely described in [5]. The null hypothesis can not be rejected since the test gives a $\Delta\chi^2$ of 9.1 corresponding to a p value of 0.34.

Exclusion contours An exclusion contour in the oscillation parameter space has been produced using a raster scan method [6]. The sensitivity contour matches the exclusion contour, with oscillations due to the statistical fluctuations. Figure 4 excludes the original RAA best fit at 97.5% C.L. These first results have demonstrated the ability of the Stereo experiment to discriminate between antineutrinos and residual cosmic-ray induced background. The accumulation of statistics in more stable conditions during the Phase-II of data acquisition has already lead to a better understanding of the background, and should allow the experiment to reach its 300 days of data taking before the end of 2019.

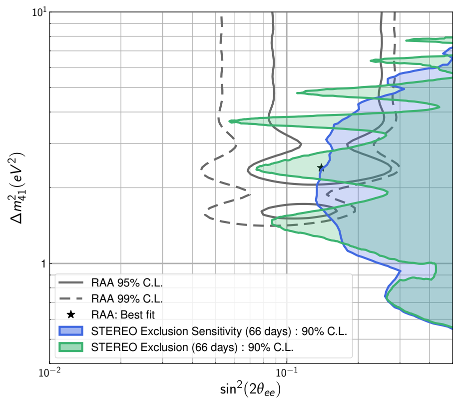

Figure 4: Exclusion contour of the oscillation parameter space.

References

[1] Kayser Boris, "Neutrino Mass, Mixing, and Flavor Change", 2008 arXiv 0804.1497

[2] J. Kopp, P. A. N. Machado, M. Maltoni and T. Schwetz, "Sterile Neutrino Oscillations: The Global Picture," JHEP

[3] G. Mention, M. Fechner, T. Lasserre, T. A. Mueller, D. Lhuillier, M. Cribier, and A. Letourneau, Phys. Rev. D **83**, 073006 (2011).

[4] N. Allemandou *et al.* [STEREO Collaboration], JINST **13**, no. 07, 07 (2018) doi:10.1088/1748-0221/13/07/P07009 [arXiv:1804.09052 [physics.ins-det]].

[5] H. Almazan *et al.* [STEREO Collaboration], Phys. Rev. Lett. **121**, no. 16, 161801 (2018) doi:10.1103/PhysRevLett.121.161801 [arXiv:1806.02096 [hep-ex]].

[6] G. J. Feldman and R. D. Cousins, Phys. Rev. D **57**, 3873 (1998).