Improved Sterile Neutrino Constraints from the STEREO Experiment with 179 Days of Reactor-On Data

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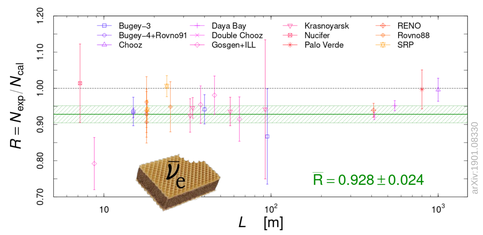
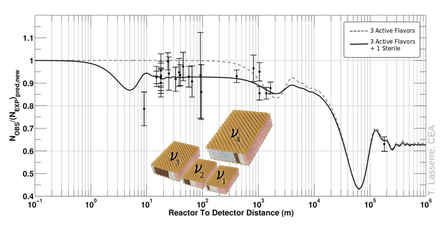
on behalf of the STEREO collaboration

Motivation – The Reactor Antineutrino Anomaly and Sterile Neutrinos





→ updated reactor flux prediction yields a deficit of ~6% [arXiv:1101.2755]
→ also deficits in calibration runs of gallium experiments were found
→ hypothesis: caused by an additional sterile neutrino state, which mixes with active neutrinos via oscillation, having a squared mass difference in the eV-range

Systematics

→ cell-to-cell correlated normalisation systematics irrelevant for our type oscillation analysis

Type	Relat. uncert.
Normalisation (uncorrelated)	
Cell volume	0.83 %
Neutron efficiency correction	0.84 %
Energy scale (uncorrelated)	
Mn anchor point	0.2 %
Cell-to-cell deviations	1.0 %
Energy scale (correlated)	
Time stability	0.3 %

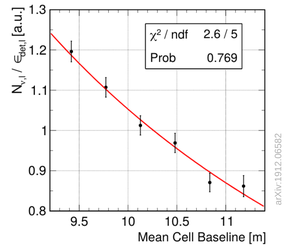
→ for more details on systematics see poster #142

Oscillation Analysis

→ event rates of each cell and energy bin taken from the PSD fits
→ absolute events rates in the six Target cells agree with an $1/L^2$ decrease due to solid angle
→ fit performed independent of absolute reactor flux model
→ free flux factors ϕ_i decouple energy bins, but are common to all cells
→ fit insensitive to cell-to-cell correlated normalisation effects
→ energy scale systematics and cell-to-cell uncorrelated normalisation systematics included as pull terms

$$\chi^2 = \sum_{l=1}^{N_{\text{cells}}} \sum_{i=1}^{N_{\text{Ebins}}} \left(\frac{A_{l,i} - \phi_i M_{l,i}}{\sigma_{l,i}} \right)^2 + \sum_{l=1}^{N_{\text{cells}}} \left(\frac{\alpha_l^{\text{EscaleU}}}{\sigma_l^{\text{EscaleU}}} \right)^2 + \left(\frac{\alpha^{\text{EscaleC}}}{\sigma^{\text{EscaleC}}} \right)^2 + \sum_{l=1}^{N_{\text{cells}}} \left(\frac{\alpha_l^{\text{NormU}}}{\sigma_l^{\text{NormU}}} \right)^2$$

$$M_{l,i} \equiv M_{l,i}\left(\sin^2(2\theta_{ee}), \Delta m^2_{41}, \vec{\alpha}\right) = \mathcal{M}_{l,i}\left(\sin^2(2\theta_{ee}), \Delta m^2_{41}\right) \cdot \left[1 + \alpha_l^{\text{NormU}} + S_{l,i}^{\text{Escale}} \cdot \left(\alpha_l^{\text{EscaleU}} + \alpha^{\text{EscaleC}}\right)\right].$$

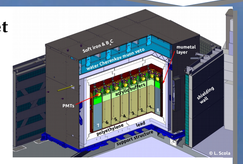


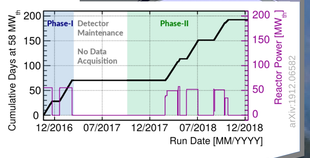
→ fit performed with two free oscillation parameters Δm^2_{41} and $\sin^2(2\theta_{ee})$
→ phases combined by summation of fit functions
→ additional free global flux factor accounts for different reactor power between phases

$$\chi^2_{\text{PI+PII}} = \chi^2_{\text{PI}}\left(\sin^2(2\theta_{ee}), \Delta m^2_{41}, \vec{\alpha}_{\text{PI}}, \phi_i, \Phi_{\text{PI}}\right) + \chi^2_{\text{PII}}\left(\sin^2(2\theta_{ee}), \Delta m^2_{41}, \vec{\alpha}_{\text{PII}}, \phi_i\right).$$

Setup and Dataset

→ target of six cells of liquid scintillator
→ 9 – 11 m baselines
→ heavy shielding against ambient radiation
→ research reactor of almost pure uranium-235 (99.3% of fissions)
→ 15 m.w.e. overburden
→ 65.5k neutrino candidates
→ better background understanding due to increased reactor-off dataset



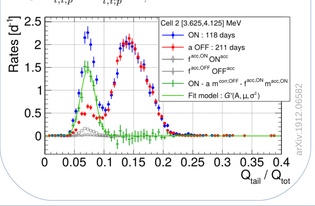


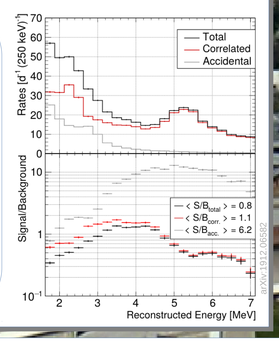
Neutrino Extraction

→ 1st: cuts aiming for inverse beta decay signature and background rejection
→ 2nd: online extraction of accidental backgrounds by off-time method
→ 3rd: cosmic background measured during reactor-off periods
→ 4th: fit all spectra based on pulse shapes (PSD, Q_{tail}/Q_{tot}) of backgrounds, scaling reactor-on to reactor-off spectra by assuming a constant shape over time
→ difference between spectra gives neutrino rate

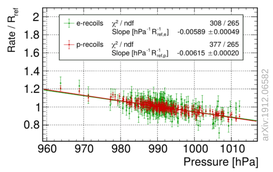
Type	#	Requirement for passing cut
Energy	1	$1.625\,\text{MeV} < E^{\text{detector}}_{\text{prompt}} < 8.125\,\text{MeV}$
	2	$4.5\,\text{MeV} < E^{\text{detector}}_{\text{delayed}} < 10.0\,\text{MeV}$
Coincidence	3	$2\,\mu\text{s} < \Delta T_{\text{prompt-delayed}} < 70\,\mu\text{s}$
	4	$\Delta X_{\text{prompt-delayed}} < 600\,\text{mm}$
Topology	5	$E^{\text{cell}}_{\text{prompt}} < \begin{cases} 1.0\,\text{MeV, neighbour cell} \\ 0.4\,\text{MeV, other cell} \end{cases}$
	6	
	7	$E^{\text{Target}}_{\text{delayed}} > 1.0\,\text{MeV}$
Rejection of muon-induced background	8	$\Delta T^{\text{veto}}_{\text{muon-prompt}} > 100\,\mu\text{s}$
	9	$\Delta T^{\text{detector}}_{\text{muon-prompt}} > 200\,\mu\text{s}$
	10	$\Delta T_{\text{before prompt}} > 100\,\mu\text{s}$ and $\Delta T_{\text{after delayed}} > 100\,\mu\text{s}$ for all events with $E^{\text{detector}}_{\text{event}} > 1.5\,\text{MeV}$
	11	$\frac{Q_{\text{PMT max, prompt}}}{Q_{\text{cell, prompt}}} < 0.5$

$$\begin{aligned}
\text{ON}_{l,i;p} &= a_{l,i}\, m^{\text{corr,OFF}}_{l,i;p} + f^{\text{acc,ON}}\, m^{\text{acc,ON}}_{l,i;p} + G^{\nu}_{p}(A_{l,i}, \mu_{l,i}, \sigma^2_{l,i}), \\
\text{OFF}_{l,i;p} &= m^{\text{corr,OFF}}_{l,i;p} + f^{\text{acc,OFF}}\, m^{\text{acc,OFF}}_{l,i;p}, \\
\text{ON}^{\text{acc}}_{l,i;p} &= m^{\text{acc,ON}}_{l,i;p}, \\
\text{OFF}^{\text{acc}}_{l,i;p} &= m^{\text{acc,OFF}}_{l,i;p},
\end{aligned}$$





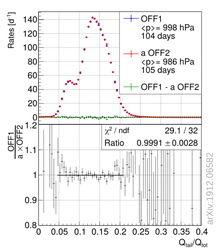
PSD Stability and Cross-Checks



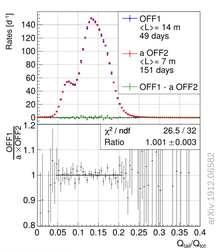
→ event rates corrected from atmospheric pressure and temperature effects

→ Extreme bins in pressure or water level in the reactor pool confirm a stable PSD shape

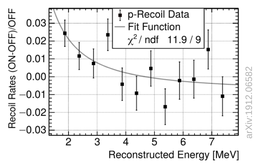
Pressure



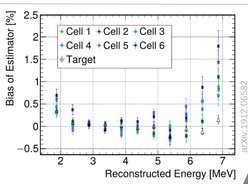
Water Level



→ reactor background in lower energy bins corrected
→ conservative 100% uncertainty assigned for it

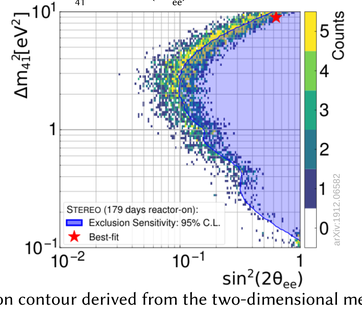


→ bias in PSD fit due to little statistics at high energies corrected

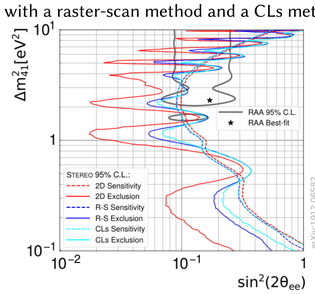


Oscillation Analysis Cross-Checks

→ oscillatory structure of contour fluctuates in pseudo-experiments – statistical effect
→ best-fit point falls into the expected region – fit function allows to describe statistical fluctuations of the data by converging on high values of Δm^2_{41} and $\sin^2(2\theta_{ee})$



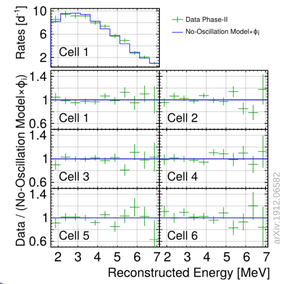
→ exclusion contour derived from the two-dimensional method is confirmed with a raster-scan method and a CLs method

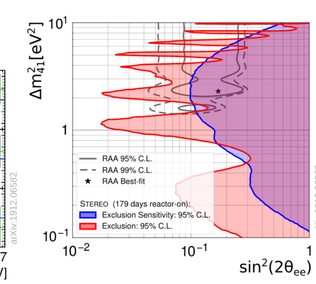


→ by using pseudo-experiments, the shift of the exclusion contour to lower values of $\sin^2(2\theta_{ee})$ with respect to sensitivity contour is found to be typical in the presence of a small p-value of the no-oscillation hypothesis

The Results

→ data in agreement with no-oscillation hypothesis
→ p-value: 9%
→ nuisance parameters α contained within their uncertainties
→ global flux factor in agreement with difference of reactor power between phases
→ large fraction of RAA-conformal parameter space for sterile neutrinos excluded at 95% C.L.
→ RAA best-fit point excluded at more than 99.9% C.L.

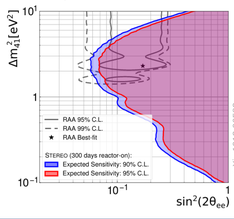




Outlook and Final Sensitivity

→ more data currently acquired
→ final dataset (>300 days reactor-on) until end of 2020

→ final sensitivity expected to fully cover most relevant parameter space at 95% C.L.



Take-away Message

Stereo excludes a large fraction of the allowed parameter space of RAA-conformal sterile neutrinos

References and Further Reading

→ posters #104, #140,# 142
→ arXiv:1912.06582
→ arXiv:1804.09052
→ www.stereo-experiment.org