Search for eV Sterile Neutrinos
The Stereo Experiment

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for the Stereo collaboration

Supported by:
Outline

- Experimental Setup
- Calibration and Energy Reconstruction
- Signal and Backgrounds
- Summary/Outlook

3 MeV reactor antineutrino flux worldwide:

Experimental Setup
Neutrino source:
- reactor at ILL Grenoble
- 58.3 MW
- Height: 80 cm
- Diameter: 40 cm
- Highly enriched in $^{235}\text{U}$ (93%)

Baseline: 9 - 11 m
Overburden: ~15 m.w.e.
• Target segmented in 6 cells
  → 1800 l of Gd-loaded liquid scintillator
• Surrounding outer crown to capture gammas
• 48 PMTs of 8 inch diameter
• Layers of acrylic and oil as buffer
• Water Cherenkov veto on top
• About 90 tons of shielding material
  → lead, polyethylene, B₄C, iron

Detector/Measurement Idea
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**Visible shape effects in energy**

- Sensitivity after 1 year

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**Figure:**
- Accessible parameter space
- Spectra (arbitrary normalization)
- Observed/expected events
- Reactor Anomaly contour @ 95% CL
- Best Fit
- Exp. contour @ 95% - Shape
  - Blue line
  - Red line
- Exp. contour @ 95% - Norm+Shape
- 100\textsuperscript{5} - 10\textsuperscript{2} (eV\textsuperscript{2})
- \(\Delta m^2\) new
- \(\sin^2(2\theta)_{\text{new}}\)
Inverse beta-decay (IBD):

$$\bar{\nu}_e + p^+ \rightarrow e^+ + n$$

Delay due to:
thermalisation of neutron before capture +
time constant of the capture process

$$E_{\text{vis}} = E_{e^+} + (m_n - m_p) + \mathcal{O}(E_{\bar{\nu}_e}/m_n)$$

$$E_{\text{prompt}} = E_{e^+} + m_{e^-}$$
Calibration and Energy Reconstruction
Homogeneity

→ three calibration systems
→ various γ+n sources

Mn-54 source at different heights in one cell shows:

→ low z-dependence

→ excellent MC to data agreement at current stage of analysis
Using $\gamma+n$ events of an AmBe source

$^{241}\text{Am} \rightarrow ^{237}\text{Np} + \alpha + \gamma$ (half life 432.7 yrs)

$^9\text{Be} + \alpha \rightarrow ^{13}\text{C}^*$

$^{13}\text{C}^* \rightarrow ^{12}\text{C} + n + \gamma$  

$E_\gamma = 4.438$ MeV

$E_n$ up to 7 MeV

→ study delayed event energy

→ study delay time

Source at centre of cell 6

$\Rightarrow$ n-Gd capture fraction $\sim$86%
Detection Efficiency

Using $\gamma+n$ events of an AmBe source

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Source at centre of cell 6

$\Rightarrow$ $n$-$\text{Gd}$ capture fraction $\sim 86\%$

Neutron capture time comparison

Capture time stability

Capture time spectra

$\tau_{\text{Am}} = 16.48 \pm 0.55 \mu$s

$\tau_{\text{AmBe}} = 16.24 \pm 0.15 \mu$s

at many points in time

stat. uncert. only
Energy Reconstruction

Collected charge in one target cell given by
- light produced in that cell and
- light cross-talking from neighbouring cells j:

\[ Q_i = \alpha_{i,\text{geom}} \sum_{j=\text{cells}} E_{j,\text{dep}} \times f_j \times L_{j\rightarrow i} \]

- Conversion factors obtained simultaneously and in-situ from calibration data

\[ Q_i = \sum_{j=\text{Cells}} E_{j,\text{dep}} C_j L_{j\rightarrow i} \]
Energy Reconstruction

Collected charge in one target cell given by
- light produced in that cell and
- light cross-talking from neighbouring cells $j$:

$$Q_i = \alpha_i \gamma_i \sum_{j=\text{cells}} E_j^{\text{dep}} \times f_j \times L_{j \rightarrow i}$$

→ Conversion factors obtained simultaneously and in-situ from calibration data

\[ Q_i = \sum_{j=\text{Cells}} E_j^{\text{dep}} C_j L_{j \rightarrow i} \]

Cell 1

Mn-54 source at centre of different cells:

→ Data-MC agreement goal: 2%

⇒ already achieved

Cell 6

Entries 100000
Mean 0.7393
RMS 0.1732
Energy Reconstruction

Energy response function
→ quenching curve
→ gamma sources
→ single gamma lines

→ expected behaviour of liquid scintillator ionisation quenching (Birk's law)

Energy stability from n-H captures of spallation neutrons
→ in good agreement with stable behaviour

Evolution of Target Energy Peak of H Capture

Evolution of Target Energy Width of H Capture
Signal and Backgrounds
Backgrounds

Muon induced

Examples:
- fast neutrons
- stopping muons

Counter measures:
- water pool
- active veto
- pulse shape discr.
- PMT cut

Reactor induced

Examples:
- neutrons
- $\gamma$-radiation via neutron capture

Counter measures:
- shielding
- pulse shape discr.
- event topology

Radioactive decays

Examples:
- thorium/uranium
- radon/argon
- potassium

Counter measures:
- shielding
- event topology
- precise measurement
Backgrounds

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Reactor induced

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Neutrino Candidate Search

Signal selection (proposal cuts):

<table>
<thead>
<tr>
<th>Cut 1</th>
<th>Cut 2</th>
<th>Cut 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_{\text{prompt}} )</td>
<td>( E_{G\text{C}} &lt; 1.1 \text{ MeV} )</td>
<td></td>
</tr>
<tr>
<td>( 1.5 \text{ MeV} &lt; E_{\text{tot}} &lt; 8 \text{ MeV} )</td>
<td>( 2.5 \sigma )</td>
<td></td>
</tr>
<tr>
<td>( E_{\text{delayed}} )</td>
<td>( E_{\text{TG}} &gt; 1 \text{ MeV} )</td>
<td></td>
</tr>
<tr>
<td>( 5 \text{ MeV} &lt; E_{\text{tot}} &lt; 10 \text{ MeV} )</td>
<td>( \tau_{\text{delay}} &lt; 70 \mu s )</td>
<td></td>
</tr>
</tbody>
</table>

+ after muon veto
+ additional cleaning cuts

Inverse beta-decay (IBD):

\[ \bar{\nu}_e + p^+ \rightarrow e^+ + n \]

Background rejection by Pulse Shape Discrimination (PSD)

IBD seen by detector:

\( \tau_{\text{cap}} \sim 16 \mu s \)

8 MeV

n-Gd
Neutrino candidate rate by comparing rates at reactor-on (75 days) vs. reactor-off (28 days):

~300/day
(with current proposal cuts)
Neutrino Candidate Rates

Neutrino candidate rate by comparing rates at reactor-on (75 days) vs. reactor-off (28 days):

~300/day (with current proposal cuts)

Comparison reactor-on vs. reactor-off via PSD
→ additional contribution only in signal region
→ shielding against reactor-induced background sufficient

Reactor on
Reactor off

Preliminary

Evolution of the IBD candidates rate in the Stereo detector
Summary/Outlook
Summary

→ first data taking phase completed (75 days reactor on + 28 days reactor off)
→ detector shows well-understood/stable response
→ first signal and background selections yield promising results

Outlook

→ cut optimisation

→ finalisation of energy reconstruction
  → for spectral shape oscillation analysis

→ studies of backgrounds + systematics

→ re-installation of detector (currently maintenance at reactor site)

→ further data taking
  → 2017: + 60 days reactor on
  → 2018: + ~150 days reactor on
The Stereo Collaboration

Supported by:

[Logos of various institutions]
Appendix
The Stereo Timeline

Spring-Autumn 2016:
Mounting and installation of the STEREO detector and its shielding

9th November 2016:
ASN approval
⇒ detector filled and commissioned (2 weeks)

Winter 2016-2017:
Data taking of
75 days reactor ON +
28 days reactor OFF

3rd March 2017:
Reactor shutdown
(up to October 2017)
⇒ End of the first data acquisition phase

March-August 2017:
STEREO retracted for reactor works, used for detector maintenance

Autumn 2016
Shielding types:

- 6 tons of borated polyethylene
- 65 tons of lead
- $B_4C$ sheets all around the detector
- Magnetic shielding (soft iron + $\mu$-metal)
- Casemate reinforcements (lead + borated polyethylene)