How to improve the sensitivity of future neutrino mass experiments with thermal calorimeters

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While the existence of a non-vanishing neutrino mass is definitely proved by the evidence for neutrino flavour oscillations, the absolute value of this mass is still unknown.

Experiments using spectrometers have set a limit on the electron anti-neutrino mass of about 2 eV, while experiments using thermal microcalorimeters have reached sensitivities of about 10 eV. A new experiment to measure the neutrino mass with a sensitivity of about 0.25 eV using a large electrostatic retardation spectrometer (KATRIN) is planned to start taking data in 2007.

In this paper we discuss the perspectives for a new generation of neutrino mass experiments using thermal detectors to reach scientifically interesting sensitivities before and after the KATRIN experiment. By scaling the performance of the present Milano neutrino mass experiment with Monte Carlo simulations, we show how a new experiment can validate the present limit of few eV set by spectrometers before the KATRIN experiment starts. We also show how such a result can be used to design a very large thermal detector experiment to reach sensitivities beyond the KATRIN expected one.

1. Montecarlo simulation

- generate 1000 simulated experiments
- calculate total β spectrum
- \( R(E) (\text{Si}) = \sum \left( N(E) + \text{pile-up} N(E) + \text{bkg} N(E) + b(E) \right) \text{d}E \)
- \( N(E) \) total β statistics
- \( e^{-T_\text{pile-up}} \) fraction of unresolved β pile-up events
- \( b(E) \) background (usually constant)
- \( g(E) \) detector energy resolution function (usually gaussian)
- \( \text{generate 1000 spectra} \)
- \( \text{see Montecarlo input} \)

2. Montecarlo experimental parameters

- relationships between Montecarlo input parameters and real experiment parameters
- \( N_{\text{det}} = N_{\text{det}} \times N_{\text{eff}} \times \beta \)
- \( \beta \) fraction of resolved β events
- \( A \) activity of single detector
- \( \Delta t \) measuring time
- \( \Delta E \) gaussian energy resolution function
- \( \Delta E \) FWHM detector energy resolution

3. Comparison with the Milano experiment

- \( N_{\text{eff}} \) sensitivity
- \( A \) activity of single detector
- \( \beta \) background scale with the detector mass
- \( \Delta t \) time resolution for pile-up identification
- \( \Delta E \) FWHM detector energy resolution

4. \( m_\nu \) sensitivity

- from pure statistical considerations
- \( m_\nu \) from Montecarlo simulations

5. A new Milano neutrino mass search: first phase

- aim: reach a sensitivity of about 2 eV before the KATRIN experiment ends
- possible experimental configurations \( b = 0 \)

<table>
<thead>
<tr>
<th>Montecarlo input parameters</th>
<th>90% CL sensitivity</th>
<th>Possible experimental configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{\text{det}} ) ( [x10^3] )</td>
<td>( \Delta E ) [eV]</td>
<td>( N_{\text{det}} ) [y]</td>
</tr>
<tr>
<td>1.4</td>
<td>2.0</td>
<td>10</td>
</tr>
<tr>
<td>3.2</td>
<td>2.5</td>
<td>10</td>
</tr>
<tr>
<td>4.7</td>
<td>2.5</td>
<td>10</td>
</tr>
</tbody>
</table>

- microwave amorphised layers of implanted silicon thermistors or Ge-NTDs
- experimental technical challenges:
  - improve energy resolution \( \Delta E \) from 30 eV to 10 + 15 eV
  - improve time resolution \( \Delta t \) from 1 ms to 100 / 200 μs
  - reduce background at least a factor 10

6. Second phase: a next generation experiment

- aim: be an alternative to the KATRIN experiment
- first phase must succeed:
  - no unexpected source of systematics
  - a very large collaboration is needed
  - really innovative technical solutions are required
- results would come much later than the KATRIN experiment
- it could be really interesting in case KATRIN fails the target

- Montecarlo simulations show a feasible way to reach sensitivities similar or better than present spectrometers limits
- Further improvements maybe unrealistic