EXO experiment

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Double beta decay

EXO collaboration searches for neutrino-less double beta decay using enriched $^{136}$Xe

- Rare nuclear transition between same mass nuclei
  - Energetically allowed for even-even nuclei
  - Usually from ground state to ground state
  - $(Z,A) \rightarrow (Z+2,A) + e^-_1 + \nu_1 + e^-_2 + \nu_2$
  - $(Z,A) \rightarrow (Z+2,A) + e^-_1 + e^-_2$
  - $(Z,A) \rightarrow (Z+2,A) + e^-_1 + e^-_2 + \chi$

Observation of neutrino-less double beta decay would provide information about the nature of the neutrino and help to determine the mass pattern
- $m_\nu \neq 0$ (required)
- $\nu = \nu$ (required)
- $\Delta L = 2$ (conserved in S.M.)
- $<m_\nu>$, “effective mass” is the average over neutrino masses

Combined with data from neutrino oscillation experiments
- $m_\nu \neq 0$ (already determined)
- $\Delta m^2_{ij}$ only defines a lower limit on neutrino mass scale
- $\Delta m^2_{atm} \approx 3 \times 10^{-3}$ eV$^2$
- $\sin^2 2\theta_{atm} \approx 1.0$
- $\Delta m^2_{sol} \approx 5 \times 10^{-5}$ eV$^2$
- $\sin^2 2\theta_{sol} \approx 0.8$

Computations for $^{136}$Xe

$T_{1/2}$: 48.4, 13.2, 8.8, 21.2, 7.2 $\times 10^{26}$ years for $<m_\nu> = 50$ meV

$Q = 2479$ keV

8.9% natural abundance

EXO collaboration

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EXO-200 project

200 kg of 80% enriched Xe available (A = 136)

Light & charge readout!
Installation at WIPP

Waste Isolation Pilot Plant
Carlsbad, New Mexico
300 m deep salt mine dedicated to nuclear wasted disposal;
remote experimental area available!
Expected performance

- Very low radioactive background expected
  - Careful selection of materials
  - Optimized custom design
  - Manufacturing, handling and installation in clean rooms
- Very good energy resolution

The ultimate background is the $\beta\beta_{2\nu}$

Physics runs starting in April 2009
Targeted run time: about two years

Good energy resolution is essential!

Note: $\beta\beta_{2\nu}$ not yet observed for $^{136}$Xe, limit at $T_{1/2} > 1.2 \times 10^{24}$ years (90% CL)

<table>
<thead>
<tr>
<th>Case</th>
<th>Mass (ton)</th>
<th>Eff. (%)</th>
<th>Run Time (yr)</th>
<th>$\sigma_E/E$ @ 2.5 MeV (%)</th>
<th>Radioactive Background (events)</th>
<th>$T_{1/2}^{0\nu}$ (yr, 90% CL)</th>
<th>Majorana mass (meV)</th>
<th>QRPA</th>
<th>NSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXO-200</td>
<td>0.2</td>
<td>70</td>
<td>2</td>
<td>1.6</td>
<td>40</td>
<td>$6.4 \times 10^{25}$</td>
<td>133</td>
<td>186</td>
<td></td>
</tr>
</tbody>
</table>

2) Caurier, et. al., arXiv:0709.2137v1
Ba\(^+\) tagging R&D

**Easy Ba\(^{++}\) → Ba\(^+\) conversion expected**

- Xe and Ba ionization potentials
- Xe\(^+\) = 12.13 eV / Ba\(^+\) = 5.21 eV
- Xe\(^{++}\) = 21.21 eV / Ba\(^{++}\) = 10.00 eV
- \(E_G = 9.22 \pm 0.01\) eV
- 9.28 to 9.49 eV range
- Use of additives for gas based detectors

\[
\langle m_v \rangle \propto 1 / \sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1 / (Nt)^{1/4}
\]

\[
\langle m_v \rangle \propto 1 / \sqrt{T_{1/2}^{0\nu\beta\beta}} \propto 1 / \sqrt{Nt}
\]

Measurement **without background**

- Observed in a RF cage
- 5 sec. integration
- \(p = 10^{-3}\) torr He

- Fluorescence (counts/sec)
Future plans …

Gas TPC with in-situ $\text{Ba}^+$ tagging

**Targeted performance:** $T_{1/2}$ better than $10^{27}$ years

- Large active mass
- Operation at high pressure
- No ion fishing and transport
- Deeper location
- Very high energy resolution
- Tracking and background ID
Swiss group activities

- Material qualification using the Ge detector installed in the "Vue des Alpes" tunnel
- R&D for the liquid and gas phase detectors
  - Cryostat development
  - Micromegas TPC operation at high pressure
  - Light readout using fibers
- Design and manufacturing of EXO-200 cryostat (completed)
- Installation and operation underground shifts
"Vue des Alpes" setup

- 400 cc low background Ge detector
- High purity copper and lead shield
- Radon tight container and nitrogen purging

100 pg/g sensitivity for $^{232}\text{Th}$ and $^{238}\text{U}$ chains
1 $\mu$g/g sensitivity for K concentration
Cryostat development

LN₂ cooling and electrical heating
100 kg of LXe maximum capacity
Operation at high pressure possible
Quartz windows for optical access
Micromegas TPC

Objectives:
- operation at high pressure
- energy resolution optimization
- additives selection

Multiple amplification gaps tried:
- 70, 100 and 250 µm

Drift voltages:
- 200 to 300 V/cm/bar range
Xe + CF₄, Xe + isobutene
CF₄ advantageous:
- increased drift velocity, reduced diffusion, does not absorb light (required for t₀)

Studies done by Leila Ounalii
Future Micromegas TPC R&D

Reuse the available infrastructure, mini-TPC (10 cm) and Gothar TPC (50 cm), with improved Micromegas detectors!

The Gothar TPC available
Already used with a 50 cm Micromegas detector (P10 gas)

Pressure sealed segmented anodes now available for very large surfaces

TPC (60X70cm)
Conclusion

- EXO-200 detector soon operational
  - Should allow $\beta\beta 2\nu$ observation with Xe
  - Improved limits on $\beta\beta 0\nu$ expected
- Swiss group R&D work performed on both liquid and gas options
- Continuous operation of a low background Ge detector for material qualification