Experimental review on neutrinoless double beta decay

GGI Neutrino and Invisibles meeting
June 26, 2012

Laura Baudis, Universität Zürich
Neutrinos and masses of elementary particles

- Neutrinos: much lighter than other known particles
  ➡ Why is their mass so small?
  ➡ What is their absolute mass scale?

\[ m^2_{\text{lightest}} = ? \]

1. family
[\[ \begin{array}{l}
\text{t} \\
\text{c} \\
\text{s} \\
\text{\mu} \\
\text{t}
\end{array} \] ]

2. family
[\[ \begin{array}{l}
\text{b} \\
\text{d} \\
\text{\mu} \\
\text{\nu}_\mu
\end{array} \] ]

3. family
[\[ \begin{array}{l}
\text{u} \\
\text{s} \\
\text{\nu}_e \\
\text{\nu}_\tau
\end{array} \] ]

\[ \Sigma_i m_i = 440 - 760 \text{ meV} \]
Double beta decay

- The decay with emission of 2 neutrinos was observed in more than 10 different nuclei: $^{48}$Ca, $^{76}$Ge, $^{82}$Se, $^{96}$Zr, $^{100}$Mo, $^{116}$Cd, $^{128}$Te, $^{130}$Te, $^{136}$Xe, $^{150}$Nd, $^{238}$U.

- The observed energy spectrum of the two electrons is continuous, up to the Q-value

$$\Gamma^{2\nu} = \frac{1}{T^{1/2}} = G^{2\nu}(Q, Z)|M^{2\nu}|^2$$

$$G^{2\nu} \propto (G_F \cos \theta_C)^4 Q^7 \left(1 + \frac{Q}{2} + \frac{Q^2}{9} + \frac{Q^3}{90} + \frac{Q^4}{1980}\right)$$

$$Q = E_{e1} + E_{e2} + E_{\nu 1} + E_{\nu 2} - 2m_e$$
Neutrinoless double beta decay

- More interesting: the decay mode without emission of neutrinos ("forbidden" in the SM, since $\Delta L = 2$)

$$\Gamma^{0\nu} = \frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}(Q, Z) |M^{0\nu}|^2 \frac{|m_{\beta\beta}|^2}{m_e^2}$$

$$G^{0\nu} \propto (G_F \cos \theta_C)^4 \cdot \left[ \frac{Q^5}{30} - \frac{2Q^2}{3} + Q - \frac{2}{5} \right] \propto (G_F \cos \theta_C)^4 \cdot Q^5$$

Energy [keV]

$$Q = E_{e1} + E_{e2} - 2m_e$$

expected: "peak" at the Q-value of the decay
Phase space

\[ \Gamma^{0\nu} = \frac{1}{T_{1/2}^{0\nu}} = \left| G^{0\nu}(Q, Z) \right| M^{0\nu} |2 \frac{m_{\beta\beta}}{m_e}|^2 \]

\[ G^{0\nu}(Q, Z) \propto (Z, Q^5) \]

<table>
<thead>
<tr>
<th>Transition</th>
<th>G [10^{-14} yr^{-1}]</th>
<th>Q [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{48}\text{Ca} \rightarrow ^{48}\text{Ti})</td>
<td>6.35</td>
<td>4373.7</td>
</tr>
<tr>
<td>(^{76}\text{Ge} \rightarrow ^{76}\text{Se})</td>
<td>0.63</td>
<td>2039.1</td>
</tr>
<tr>
<td>(^{82}\text{Se} \rightarrow ^{82}\text{Kr})</td>
<td>2.70</td>
<td>2995.5</td>
</tr>
<tr>
<td>(^{100}\text{Mo} \rightarrow ^{100}\text{Ru})</td>
<td>4.36</td>
<td>3035</td>
</tr>
<tr>
<td>(^{116}\text{Cd} \rightarrow ^{116}\text{Sn})</td>
<td>4.62</td>
<td>2809</td>
</tr>
<tr>
<td>(^{130}\text{Te} \rightarrow ^{130}\text{Xe})</td>
<td>4.09</td>
<td>2530.3</td>
</tr>
<tr>
<td>(^{136}\text{Xe} \rightarrow ^{136}\text{Ba})</td>
<td>4.31</td>
<td>2461.9</td>
</tr>
<tr>
<td>(^{150}\text{Nd} \rightarrow ^{150}\text{Sm})</td>
<td>19.2</td>
<td>3367.3</td>
</tr>
</tbody>
</table>
Matrix elements

$$\Gamma^{0\nu} = \frac{1}{T_{1/2}^{0\nu}} = G^{0\nu}(Q, Z) |M^{0\nu}|^2 \left( \frac{\left| m_{\beta\beta} \right|^2}{m_e^2} \right)$$

Fig. 3. Values of the NME calculated with the methods in Tab. 2.

Matrix elements: vary by a factor of 2-3 for a given $A$.
Effective Majorana neutrino mass

- $|m_{\beta\beta}|$ is a mixture of $m_1$, $m_2$, $m_3$, proportional to the $U_{ei}^2$, where $U_{ei}$ are complex entries

$$|m_{\beta\beta}| = |m_1|U_{e1}|^2 + m_2|U_{e2}|^2e^{i(\alpha_1-\alpha_2)} + m_3|U_{e3}|^2e^{i(-\alpha_1-2\delta)}$$

- where $U =$ neutrino mixing matrix, $c_{ij} = \cos \theta_{ij}$, $s_{ij} = \sin \theta_{ij}$, $\alpha_1, \alpha_2 =$ Majorana phases

**Remark:** here the exchange of a light neutrinos is considered; many other contributions are possible (Majoron, heavy Majorana neutrino exchange, right-handed currents, SUSY, etc)

For a recent review, see: http://xxx.lanl.gov/pdf/1205.0649.pdf
Experimental sensitivity

- Experiments observe:

\[ N_{\beta\beta}^{0\nu} = \frac{a \cdot M \cdot N_A \ln 2}{A} \cdot \frac{T_{1/2}^{0\nu}}{T_{1/2}^{0\nu}} \cdot \epsilon \cdot t \]

- with a non-zero number of background events:

\[ N_{bg} = M \cdot t \cdot B \cdot \Delta E \]

- The experimental sensitivity is thus:

\[ T_{1/2}^{0\nu}(n_{\sigma}) = \frac{N_A \ln 2}{\sqrt{2n_{\sigma}}} \cdot \frac{a \cdot \epsilon}{A} \cdot \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} \]

\( a = \) enrichment
\( \epsilon = \) detector efficiency
\( M = \) total mass
\( t = \) measuring time
\( \Delta E = \) energy resolution
\( B = \) background index
\( n_{\sigma} = \) confidence level in units of sigma
Experimental requirements

- Experiments thus measure the half life of the decay, $T_{1/2}^{0\nu}$

\[ T_{1/2}^{0\nu} \propto a \cdot \epsilon \cdot \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} \]

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

Minimal requirements:
- Large detector masses
- Enriched materials
- Ultra-low background noise
- Excellent energy resolution

Additional tools to distinguish signal from background:
- Angular distribution
- Decay to excited states (gamma-rays)
- Identification of daughter nucleus
Backgrounds for double beta experiments

- primordial radionuclides (\(^{238}\)U, \(^{232}\)Th, \(^{40}\)K) in the detector materials, in the shielding and the concrete/rock (alpha, beta, gamma and neutrons)
- cosmic activation of detector materials (\(^{60}\)Co, \(^{54}\)Mn, \(^{65}\)Zn,...)
- cosmic rays - muons - and secondary particles
- radon in air, radon emanation of materials,....
- anthropogens (\(^{85}\)Kr, \(^{137}\)Cs, \(^{207}\)Bi,...)

2\(\nu\)\(\beta\beta\)-events: irreducible background
an excellent energy resolution of the detector is crucial

transition energy \(Q_{\beta\beta}\)

\begin{align*}
E_{\text{MeV}} & \\
208\text{Tl (and thoron)} & \\
214\text{Bi (and radon)} & \\
208\text{Tl (2.6 MeV \(\gamma\))} & \\
40\text{K}, 60\text{Co},... & \\
\end{align*}

F. Piquemal, Neutrino2012, Kyoto
### Experiments: Main Approaches

**Source ≠ Detector**

- Source as thin foil
- Electrons detected with: scintillator, TPC, drift chamber, semiconductor detectors
- Event topology
- Low energy resolution and detection efficiency

**Source = Detector (calorimeters)**

- The sum of the energy of the two electrons is measured
- Signature: peak at the Q-value of the decay
- Scintillators, semiconductors, bolometers
- High resolution + detection efficiency
- No event topology (unless pixellized)

**Source = Detector = Tracker**

- Source is - for example - the (high-pressure) gas of a TPC
- Charge and light detected with electron multipliers and/or photosensors
- Good energy and position resolution, high efficiency
- Event topology very helpful in reducing the background and in identifying the potential signal
Existing experimental limits on $T_{1/2}$ and the effective Majorana neutrino mass

Current best sensitivities are around a few 100 meV

Table 1. A list of recent $0\nu\beta\beta$ experiments and their 90% confidence level (except as noted) limits on $T_{1/2}^{0\nu}$. The $\langle m_{\beta\beta} \rangle$ limits are those quoted by the authors using the $M_{0\nu}$ of their choice.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Technique</th>
<th>$T_{1/2}^{0\nu}$</th>
<th>$\langle m_{\beta\beta} \rangle$ (eV)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{48}$Ca</td>
<td>CaF$_2$ scint. crystals</td>
<td>$1.4 \times 10^{22}$ y</td>
<td>$&lt;7.2-44.7$</td>
<td>14</td>
</tr>
<tr>
<td>$^{76}$Ge</td>
<td>enr Ge det.</td>
<td>$1.9 \times 10^{25}$ y</td>
<td>$&lt;0.35$</td>
<td>15</td>
</tr>
<tr>
<td>$^{76}$Ge</td>
<td>enr Ge det.</td>
<td>$(1.19^{+2.99}_{-0.50}) \times 10^{25}$ y (3σ)</td>
<td>0.24-0.58</td>
<td>16</td>
</tr>
<tr>
<td>$^{82}$Se</td>
<td>Thin metal foils and tracking</td>
<td>$1.57 \times 10^{25}$ y</td>
<td>$&lt;(0.33-1.35)$</td>
<td>17</td>
</tr>
<tr>
<td>$^{96}$Zr</td>
<td>Thin metal foils and tracking</td>
<td>$3.6 \times 10^{23}$ y</td>
<td>$&lt;(0.89-2.54)$</td>
<td>18</td>
</tr>
<tr>
<td>$^{100}$Mo</td>
<td>Thin metal foils and tracking</td>
<td>$9.2 \times 10^{21}$ y</td>
<td>$&lt;(7.2-19.5)$</td>
<td>19</td>
</tr>
<tr>
<td>$^{116}$Cd</td>
<td>$^{116}$CdWO$_4$ scint. crystals</td>
<td>$1.1 \times 10^{24}$ y</td>
<td>$&lt;(0.45-0.93)$</td>
<td>18</td>
</tr>
<tr>
<td>$^{128}$Te</td>
<td>geochemical</td>
<td>$1.7 \times 10^{23}$ y</td>
<td>$&lt;1.7$</td>
<td>20</td>
</tr>
<tr>
<td>$^{130}$Te</td>
<td>TeO$_2$ bolometers</td>
<td>$7.7 \times 10^{24}$ y</td>
<td>$&lt;(1.1-1.5)$</td>
<td>21</td>
</tr>
<tr>
<td>$^{136}$Xe</td>
<td>Xe dissolved in liq. scint.</td>
<td>$2.8 \times 10^{24}$ y</td>
<td>$&lt;(0.3-0.7)$</td>
<td>22</td>
</tr>
<tr>
<td>$^{150}$Ne</td>
<td>Thin metal foil within TPC</td>
<td>$5.7 \times 10^{24}$ y</td>
<td>$&lt;(0.3-0.6)$</td>
<td>23</td>
</tr>
</tbody>
</table>

Current, near-future, future experiments
Current, near-future, future experiments
Existing and proposed experiments

Table 2. A summary list of the $0\nu2\beta$ proposals and experiments.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Isotope</th>
<th>Mass</th>
<th>Technique</th>
<th>Present Status</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMoRE$^{89,90}$</td>
<td>$^{100}$Mo</td>
<td>50 kg</td>
<td>CaMoO$_4$ scint. bolometer crystals</td>
<td>Development</td>
<td>Yangyang</td>
</tr>
<tr>
<td>CANDLES$^{91}$</td>
<td>$^{48}$Ca</td>
<td>0.35 kg</td>
<td>CaF$_2$ scint. crystals</td>
<td>Prototype</td>
<td>Kamioka</td>
</tr>
<tr>
<td>CARVEL$^{92}$</td>
<td>$^{48}$Ca</td>
<td>1 ton</td>
<td>CaF$_2$ scint. crystals</td>
<td>Development</td>
<td>Solotvina</td>
</tr>
<tr>
<td>COBRA$^{93}$</td>
<td>$^{116}$Cd</td>
<td>183 kg</td>
<td>$^{enr}$Cd CZT semicond. det.</td>
<td>Prototype</td>
<td>Gran Sasso</td>
</tr>
<tr>
<td>CUORE-0$^{69}$</td>
<td>$^{130}$Te</td>
<td>11 kg</td>
<td>TeO$_2$ bolometers</td>
<td>Construction - 2012</td>
<td>Gran Sasso</td>
</tr>
<tr>
<td>CUORE$^{94}$</td>
<td>$^{130}$Te</td>
<td>203 kg</td>
<td>TeO$_2$ bolometers</td>
<td>Construction - 2013</td>
<td>Gran Sasso</td>
</tr>
<tr>
<td>DCBA$^{94}$</td>
<td>$^{150}$Ne</td>
<td>20 kg</td>
<td>$^{enr}$ Nd foils and tracking</td>
<td>Development</td>
<td>Kamioka</td>
</tr>
<tr>
<td>EXO-200$^{57}$</td>
<td>$^{136}$Xe</td>
<td>160 kg</td>
<td>Liq. $^{enr}$ Xe TPC/scint.</td>
<td>Operating - 2011</td>
<td>WIPP</td>
</tr>
<tr>
<td>EXO$^{70}$</td>
<td>$^{136}$Xe</td>
<td>1-10 t</td>
<td>Liq. $^{enr}$ Xe TPC/scint.</td>
<td>Proposal</td>
<td>SURF</td>
</tr>
<tr>
<td>GERDA$^{71}$</td>
<td>$^{76}$Ge</td>
<td>$\approx$35 kg</td>
<td>$^{enr}$ Ge semicond. det.</td>
<td>Operating - 2011</td>
<td>Gran Sasso</td>
</tr>
<tr>
<td>GSO$^{95}$</td>
<td>$^{160}$Gd</td>
<td>2 ton</td>
<td>Gd$_2$SiO$_4$:Ce crys. scint. in liq. scint.</td>
<td>Development</td>
<td>Kamioka</td>
</tr>
<tr>
<td>KamLAND-Zen$^{96}$</td>
<td>$^{136}$Xe</td>
<td>400 kg</td>
<td>$^{enr}$ Xe dissolved in liq. scint.</td>
<td>Operating - 2011</td>
<td>Kamioka</td>
</tr>
<tr>
<td>LUCIFER$^{97,98}$</td>
<td>$^{82}$Se</td>
<td>18 kg</td>
<td>ZnSe scint. bolometer crystals</td>
<td>Development</td>
<td>Gran Sasso</td>
</tr>
<tr>
<td>MAJORANA$^{77,78,79}$</td>
<td>$^{76}$Ge</td>
<td>26 kg</td>
<td>$^{enr}$ Ge semicond. det.</td>
<td>Construction - 2013</td>
<td>SURF</td>
</tr>
<tr>
<td>MOON$^{99}$</td>
<td>$^{100}$Mo</td>
<td>1 t</td>
<td>$^{enr}$ Mofoils/scint.</td>
<td>Development</td>
<td>Fréjus</td>
</tr>
<tr>
<td>SuperNEMO-Dem$^{87}$</td>
<td>$^{82}$Se</td>
<td>7 kg</td>
<td>$^{enr}$ Se foils/tracking</td>
<td>Construction - 2014</td>
<td>Fréjus</td>
</tr>
<tr>
<td>SuperNEMO$^{87}$</td>
<td>$^{82}$Se</td>
<td>100 kg</td>
<td>$^{enr}$ Se foils/tracking</td>
<td>Proposal - 2019</td>
<td>Fréjus</td>
</tr>
<tr>
<td>NEXT$^{82,83}$</td>
<td>$^{136}$Xe</td>
<td>100 kg</td>
<td>gas TPC</td>
<td>Development - 2014</td>
<td>Canfranc</td>
</tr>
<tr>
<td>SNO+$^{84,85}$</td>
<td>$^{150}$Nd</td>
<td>55 kg</td>
<td>Nd loaded liq. scint.</td>
<td>Construction - 2013</td>
<td>SNOLab</td>
</tr>
</tbody>
</table>


F. Piquemal, talk at Neutrino2012, Kyoto
Recent results
EXO-200

- Liquid xenon TPC: 175 kg LXe, 80.6% enriched in 136Xe
- Charge and light readout (triplet wire channels and large area avalanche photodiodes)
- Drift field: 376 V/cm

Copper vessel 1.37 mm thick 175 kg LXe, 80.6% enr. in $^{136}$Xe
Copper conduits (6) for:
- APD bias and readout cables
- U+V wires bias and readout
- LXe supply and return
Epoxy feedthroughs at cold and warm doors
Dedicated HV bias line
EXO-200

- So far, 2 data taking phases
- First measurement of $^{136}$Xe 2-neutrino half life; limit on the 0-neutrino mode

<table>
<thead>
<tr>
<th></th>
<th>Run I</th>
<th>Run 2 (this analysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>May 21, 11 – Jul 9, 11</td>
<td>Sep 22, 11 – Apr 15, 12</td>
</tr>
<tr>
<td>Live Time</td>
<td>752.7 hr</td>
<td>2,896.6 hr</td>
</tr>
<tr>
<td>Exposure ($^{136}$Xe)</td>
<td>4.4 kg-yr</td>
<td>26.3 kg-yr</td>
</tr>
</tbody>
</table>

**Run I Results:**

$$T_{1/2}^{2
\nu\beta}\left(^{136}\text{Xe}\right) = (2.11 \pm 0.04 \text{ stat } \pm 0.21 \text{ sys}) \cdot 10^{21} \text{ yr}$$

In disagreement with previously reported limits by


This was also a measurement of a nuclear matrix element of 0.019 MeV$^{-1}$, the smallest measured among the $2\nu\beta\beta$ emitters.
EXO-200: resolution and calibration

- Good energy resolution by linear combination of scintillation and charge signals

Properties of xenon cause increased scintillation to be associated with decreased ionization (and vice-versa)


Use projection onto a rotated axis to determine event energy

Rotation angle chosen to optimize energy resolution at 2615 keV

At $Q_{\beta\beta}$ (2458 keV):

- $\sigma/E = 1.67\%$ (SS)
- $\sigma/E = 1.84\%$ (MS)

Scintillation: 6.8\%
Ionization: 3.4\%
Rotated: 1.6\%
(at 2615 keV gamma line)
EXO-200: low-background spectrum

- Observed 22,000 2-neutrino events in 32.5 kg yr exposure
- Background PDFs fitted along with 2-neutrino and 0-neutrino PDFs

\[ T_{1/2}^{2\nu\beta\beta}(^{136}\text{Xe}) = (2.23 \pm 0.017 \text{ stat} \pm 0.22 \text{ sys}) \times 10^{21} \text{ yr} \]

In agreement with previously reported value by
and
EXO-200: low-background spectrum

- No 0-neutrino signal observed => lower limit on $T_{1/2}$

From profile likelihood:

$$T_{1/2}^{0\nu\beta\beta} > 1.6 \cdot 10^{25} \text{ yr}$$

$$\langle m_{\beta\beta} \rangle < 140 - 380 \text{ meV}$$

(90% C.L.)

arXiv:1205.5608 – Subm. to PRL
KAMLAND-Zen

- Scintillator loaded with xenon
- 320 kg 90% enriched $^{136}$Xe so far (more than 600 kg in the Kamioka mine)
- Advantages: huge and clean (U: 3.5e-18 g/g, Th: 5.2e-17 g/g) running detector
- Xe-LS can be purified, and is highly scalable
- No escape or invisible energy from gammas and beta: good background identification
- Disadvantage: relatively poor energy resolution
- no beta/gamma discrimination
- limited LS composition

Zero Neutrino double beta decay search

enr Xe loaded LS in a mini-balloon
KamLAND-Zen: installation

Installation in a class 10~100 clean room built at the top of KamLAND.

balloon and corrugated tube deployment

balloon went through the black sheet

installation completed

mini-balloon inflated with dummy LS and then replaced with Xe-loaded LS density tuning finished and tubes to be extracted.
KamLAND-Zen
KamLAND-Zen: energy calibration and low-background spectrum

- Resolution at 2.6 MeV: \( \sigma \approx 4.1\% \)

\[
\sigma = \frac{6.6\pm0.3\%}{\sqrt{E[\text{MeV}]}}
\]

\( \sigma \approx 4.1\% \)

KamLAND-Zen (2012) Xe loaded liquid scintillator

\[
T^{2\nu}_{1/2} = 2.38\pm0.02(\text{stat})\pm0.14(\text{syst}) \times 10^{21} \text{ years}
\]


update

\[
T^{2\nu}_{1/2} = 2.30\pm0.02(\text{stat})\pm0.12(\text{syst}) \times 10^{21} \text{ years}
\]

arXiv:1205.6372
KamLAND-Zen: low-background spectrum

- Peak around the Q-value; however, peak position is different

\[ T^{0\nu/2} > 5.7 \times 10^{24} \text{ years at 90\% C.L. (78 days)} \]

\[ T^{0\nu/2} > 6.2 \times 10^{24} \text{ years (KL-Zen 112 days)} \]

(ref. current best is $16 \times 10^{24}$ years from EXO-200)

\(\langle m_{\beta\beta} \rangle < 0.26 \text{ to } 0.54 \text{ eV} \) @ 90\% C.L.
• HPGe detectors in liquid argon (U/Th in LAr < 7x10^{-4} \mu Bq/kg)

• Physics run started on November 9, 2011
GERDA Calibration

- Energy resolution: ~ 4.5 - 5 keV (FWHM) at 2.6 MeV
• Background goal of ~ $10^{-2}$ events/(kg yr keV) was reached
• Phase II (BEGe) detectors in production and testing
• LAr instrumentation (PMTs or SiPM & scintillating fibers) in development
• End of phase I and start of phase II: spring 2013
GERDA low-background spectrum

- Analysis of 2-neutrino decay mode is in progress

\[ \text{T}_{1/2}^{2\nu}(^{76}\text{Ge}) = (1.88 \pm 0.10) \times 10^{21} \text{ yr} \]
Summary

- Two-neutrino decay mode was measured for the first time in $^{136}$Xe
- Xenon experiments provide competitive limits to germanium for the neutrinoless mode
- Several experiments are taking data, new results are expected soon
- Experiments under construction (or phase II of existing experiments) should achieve a sensitivity of 50 - 100 meV
- To go beyond, much lower backgrounds and larger masses are needed
- Tracking will be important to confirm a potential signal
Let us hope that...

- this prediction is true - it could be probed with future double beta experiments!

Tsutomu Yanagida
(Kavli IPMU)

Conclusion

The seesaw with Occam’s razor

Frampton, Glashow, Yanagida

CP violation in neutrino oscillation

The normal hierarchy is excluded and it is consistent with the inverted hierarchy !!!

|\delta_{CP}| = \frac{\pi}{2} \pm 0.02

It predicts

\( m_{ee} = (47 \pm 1) \text{ meV} \)

NEUTRINO 2012 at Kyoto

Bilenky, Giunti: http://xxx.lanl.gov/abs/1203.5250

Current Bound

Cosmological Limit

Universe’s baryon asymmetry

\( m_{\text{min}} \) [eV]

\( \text{Im}(\rho) \) [eV]
End
Double beta decay

- If simple $\beta^-$ or $\beta^+$-decay is forbidden on energetic grounds a nucleus can decay through a double beta mode:

$$^{106}_{48}Cd \rightarrow ^{106}_{46}Pd + 2e^+ + 2\nu_e$$

- The probability for a decay is very small, the mean lifetime of a nucleus is much larger than the age of the universe ($\tau_U \sim 1.4 \times 10^{10}$ a)

$$\tau_{2\nu} \approx 10^{20} a$$

- This is indeed a very rare process (as for instance proton decay, which was not yet observed)

- Nonetheless - if one uses a large amount of nuclei, the process can be observed experimentally