Background identification for neutrinoless double beta decay detection with the DARWIN experiment

Yanina Biondi on behalf of the DARWIN collaboration,
Universität Zürich
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www.darwin-observatory.org
The highest sensitivity to WIMPs above 5GeV/C^2 comes from experiments using liquid noble gases as target (Xe,Ar).

Lower cross sections will require much larger detectors. DARWIN with 40t aims to increase 100-fold the current sensitivity.
XENON EVOLUTION

2008
10 kg

2012
100 kg

2017
2 t

2019
5.9 t

XENON10

XENON100

XENON1T

XENONnT
XENON EVOLUTION

XENON10

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10 kg

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2017

XENON1T

2019
5.9 t

DARWIN

2025
40 t

XENONnT

2025

DARWIN
DARWIN DESIGN: AMBITIOUS 50 TONS LXE TPC OBSERVATORY

- Dual-phase Time Projection Chamber (TPC).
- 50t total (40 t active) of liquid xenon (LXe).
- Dimensions: 2.6 m diameter and 2.6 m height.
- Two arrays of photosensors (top and bottom).
- PMTs, SiPM and other technologies are being considered.
- Drift field ~0.5 kV/cm.
- Low-background double-wall cryostat.
- PTFE reflector panels & copper shaping rings.
- Outer shield filled with water (14 m diameter)
- Neutron veto

For more details see Carla Macolino General talk at 16:10 room 202
Given its projected low background and large mass, DARWIN will be sensitive to other rare physics processes such as:

- Solar Axions and Axion Like Particles
- Low energy Solar Neutrinos: pp, $^7$Be
- Neutrinoless Double Beta Decay
- Coherent Neutrino Nucleus Scattering
- Supernova Neutrinos
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Exchange of a Majorana neutrino

$$\mathcal{L}(x) = -\frac{1}{2} \sum_{\nu, l} \bar{\nu}_{\nu l}(x) M_{\nu l}^2 (\nu_{l L})^c(x) + h.c.$$
DARWIN provides the opportunity to study this process for free

\[ Q = (2457.83 \pm 0.37)\text{keV} \]

\(^{136}\text{Xe}\) has a natural abundance of 8.9% in natural Xe, ~3.5 t in 40t

Above the region of interest for WIMPs

- Expected Energy resolution of ~0.8% at 2.5 MeV
- Ultra-low background environment achieved via xenon purification and screening campaigns

Signal coverage ~ 0.76 for FWHM
Natural abundance 8.9%  Efficiency 90%
The XENON1T Collaboration reached an unprecedented energy resolution, below 1% at Q-value, in a dual phase TPC.

- Improvements for high-energies:
  - Saturation Correction
  - Peak clustering
  - After-pulse removal

Energy resolution fit:

\[
\frac{\sigma}{E} = \frac{a}{\sqrt{E[keV]}} + b
\]
BACKGROUND CONTRIBUTIONS AROUND $^{136}$XE Q-VALUE

- Materials
- Contaminants in LXe
- $2\nu\beta\beta$
- Cosmogenic
- Solar neutrinos
Mostly gammas from detector components with low attenuation in LXe due to their energy
Materials

Contaminants in LXe

$2\nu\beta\beta$

Cosmogenic

Solar neutrinos

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$^{222}\text{Rn}$ in the LXe

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$$T_{1/2} = (2.165 \pm 0.075) \times 10^{21} \text{y}$$


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$^{137}$Xe from cosmogenic activation underground

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$^{137}$Xe from cosmogenic activation underground

Irreducible $^8$B solar neutrinos

Critical components for the background are fully simulated in detail

Elements under consideration: Photosensors (PMT, SiPM,...)

### Materials

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<th>Mass [kg]</th>
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<th>$^{228}$Th*</th>
<th>$^{60}$Co*</th>
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<tr>
<td>Ti</td>
<td>5717.7</td>
<td>&lt;0.09</td>
<td>0.23</td>
<td>&lt;0.03</td>
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<tr>
<td>PTFE</td>
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<td>Cirlex</td>
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<td>SiPM(^1)</td>
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<tr>
<td>PMT(^2)</td>
<td>378.8</td>
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\(^1\) per cm\(^2\)  
\(^2\) per unit mBq/kg

Study performed by the engineering group to optimise size and materials for the cryostat
Critical components for the background are fully simulated in detail. Elements under consideration: Photosensors (PMT, SiPM,...)

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1 per cm$^2$
2 per unit mBq/kg
Background contributions around $^{136}$Xe Q-value

Materials

- Cryostat was optimised with Ti material and stiffeners for low mass
- Different photosensors: SiPM, PMTs (shown below)
- Superellipsoid fiducial volume cut

40 tonnes, no fiducial cut
Single Scatter ~ 15 mm resolution (very conservative)
~99% of signal events end in SS spectra

Preliminary
**137Xe from cosmogenic activation underground**

- 137Xe beta decays with a Q-value of **4173 keV**
- **Uniform** background inside the detector
- Primary background from betas

- Neutrons from natural radioactivity in the rock/concrete
- Neutron from natural radioactivity in detector’s materials
- Muon induced neutrons in the rock and concrete
- Muon induced neutrons in the materials of the detector

137Xe is mainly produced when muon-induced neutrons are captured by 136Xe

**Production rate for 137Xe in LNGS: 6.7 atoms/t/y**
Contaminants in LXe

The noble gas $^{222}\text{Rn}$ ($T_{1/2} \approx 3.8$ days) from $^{226}\text{Ra}$ ($T_{1/2} \approx 1600$ years), mixes with the xenon with beta decays from this chain.

$^{214}\text{Pb}$ and daughters adhere to material surfaces (plate-out) and can lead to $(\alpha, n)$ reactions.

Contamination assumption $0.1\mu\text{Bq/kg}$

**Bi-Po**: 99.8% tagging efficiency and suppression

Removal by cryo-distillation columns

More info in Michael Murra’s Poster
Double beta decay of two neutrons:

\[(Z, A) \rightarrow (Z + 2, A) + e^-_1 + e^-_2 + \nu_e^1 + \nu_e^2\]

\[\nu + e \rightarrow \nu + e\]

Neutrino electron scattering with the target LXe

\[\phi_{ve} = 5.82 \times 10^6 \text{ cm}^{-2} \text{ s}^{-1}\]

\[P_e = 0.534\]

\[\sigma_{ve}(\sigma_{\nu\mu}) = 59.4 \times 10^{-45} (10.6 \times 10^{-45}) \text{ cm}^2\]

 Astrophys. J. 621: L85–L88

Sensitivity estimate sweep through different fiducial masses

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

Contributions in ROI 2435-2481 keV* SS spectra:

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* FWHM with energy resolution 0.8%, PMT for both arrays scenario ~15 mm resolution x-y-z

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~15 mm resolution x-y-z

Sensitivity estimate sweep through different fiducial masses
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\[ T_{1/2}^{0}\nu \propto f \cdot a \cdot e \cdot \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} \]

\( \sim 6-7 \) tonne

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\( f(M_{\text{fiducial}}) \)

* FWHM with energy resolution 0.8%, PMT for both arrays scenario

~15 mm resolution x-y-z
DARWIN'S BACKGROUND BUDGET

6 tonne fiducial mass

Preliminary

Currently performing a profile likelihood test to calculate the sensitivity with the optimal mass

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**CONCLUSIONS**

- Full assessment of background contribution for the neutrino-less double beta decay channel successfully performed.
- $^{137}$Xe was calculated and simulated for the first time as a background in Laboratori Nazionali del Gran Sasso, one of the potential locations of DARWIN.
- SiPM are strong alternative candidates for photosensors that imply less background.
- The study will continue performing simulations for SiPM (and/or other lower activity photosensors) scenario.
- Statistical tests for the sensitivity are being performed.
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Thanks for your attention!
BACK UP SLIDES
TOPOLOGY OF NEUTRINOLESS DOUBLE BETA DECAY IN LXE

Energy per electron and angle between the two depends on the yet unknown decay mechanism.

Model assuming mixing mechanism and emission back to back

In liquid xenon the electrons thermalise within O(mm) resulting in a single-site (SS) signal topology

Bremsstrahlung photons emitted during electron thermalisation. Infrequently photons with energies above a few 100 keV can cross O(cm) distances before interacting
The biggest contributions in the region of interest come from the cryostats and the PMTs. 40 tonnes (Total sensitive volume)
Why do we fiducialize our volume?

Gamma rays (ER background contribution from materials) have different penetration depth in LXe