Developments in surface background removal for the DARWIN liquid xenon detector

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The DARWIN project

Design:
- 50t LXe in total, 40t active mass
- Drift length and diameter over 2.5 m
- Large purification flow necessary
- Enhanced light collection efficiency
- Optimized photosensors
- Low background ($^{222}\text{Rn}$ and $(\alpha, \text{n})$)

R&D ongoing:
- Xenoscope: 2.6m drift demonstrator
- ULTIMATE: Large electrode development
- Large cryogenic systems (storage, cooling, purification)
Physics case of DARWIN

- Ultimate WIMP dark matter search
- Sensitivity to SI WIMP-nucleon $\sigma$: $\sigma_{SI} \sim 10^{-49}$ cm$^2$ @ $m_\chi = 50$ GeV/c$^2$

Large potential for $\nu$ studies:
- Coherent $\nu$ Nucleus Scattering
- pp-$\nu$ from the Sun
- Supernova $\nu$
- Search for $0\nu 2\beta$ decay

JCAP (2016), 11, 017
Working principle of a dual phase Xenon TPC

- Energy deposits from interaction $\Rightarrow$ excitation and ionization of LXe

- Light signal (S1) from scintillation after deexcitation

- Ionization $e^-$’s drift upwards in E field

- $e^-$’s extracted at LXe/GXe interface to excite and ionize GXe atoms

- Secondary scintillation $\propto N_e^-$ extracted (S2)

- S2 observed by both PMT arrays, S1 mostly by bottom array

- Drift time and S2 pattern provide 3D position of the initial interaction
Working principle of a dual phase Xenon TPC

- Energy deposits from interaction $\Rightarrow$ excitation and ionization of LXe
- Light signal (S1) from scintillation after deexcitation

![Diagram showing the process of energy deposits, excitation, ionization, and the resulting light signal in a dual phase Xenon TPC.]
Background from radon in rare-event searches

- Natural radioactivity chains: $\beta$, $\gamma$ & $\alpha$-emitters

- $^{238}\text{U}$ decay chain
  - $^{238}\text{U} \rightarrow ^{234}\text{Pa} \rightarrow ^{234}\text{Th} \rightarrow ^{222}\text{Rn} 
  - $^{\beta}$, $^{\gamma}$, $^{\alpha}$-emitters

- $^{232}\text{Th}$ decay chain
  - $^{232}\text{Th} \rightarrow ^{228}\text{Ac} \rightarrow ^{224}\text{Ra} \rightarrow ^{224}\text{Ra} 
  - $^{\beta}$ and $^{\alpha}$-emitters

- $^{222}\text{Rn}$ and $^{220}\text{Rn}$: noble gases $\Rightarrow$ chemically inert

- Diffusion from environment or emanation from material

- Background from radon daughters: inside LXe plated-out on detector surface

- Background from high energy $\gamma$'s from material

- $(\alpha, n)$ reaction inside material
Surface background from long-lived $^{222}$Rn daughters

- Dust naturally contains $^{238}$U and $^{232}$Th
- $^{222}$Rn emanated from material environment (concrete, rocks)
- Prolonged exposure to dust and ambient air containing $^{222}$Rn:  
  ⇒ Surface contamination with long-lived $^{222}$Rn daughters
Motivation for surface treatments

- Radon-dominated background in XENON1T
  ⇒ mitigation necessary

- Clean room to prevent dust containing $^{238}\text{U}$ from depositing

- Background from radon daughters
  - Removal necessary and subsequent protection against new exposure to radon-containing air
  - Surface chemical treatment already in use
    ⇒ optimisable?

- Effect of chemical remnants on xenon purity
  ⇒ Heidelberg Xenon (HeXe) TPC

- Investigation of radon emanation mitigation
  ⇒ Surface coating (see F. Jörg’s talk)
Preparation and measurement for surface cleaning

- Artificial loading of sample discs
- Uranium oxide and $^{228}$Th sources
- Surface contamination in $^{222}$Rn and $^{220}$Rn daughters
- Measurement with $\alpha$-spectrometer
- SiPIN diode identifying isotopes
- Operation under vacuum
PTFE contamination reduction factors for $^{220}$Rn daughters

Procedure | 1$^{st}$ cleaning | 2$^{nd}$ cleaning |
--- | --- | --- |
Water | 3.8 ± 0.1 | - |
Citric acid | 12.3 ± 0.6 | 13.4 ± 0.7 |
Acetic acid | 11.8 ± 0.5 | - |
HNO$_3$ (5%) | 14.3 ± 1.9 | 14.0 ± 0.8 |
HNO$_3$ (32%) | 22.2 ± 2.3 | 32 ± 3 |

**Note:** for $^{210}$Po factor $\simeq 2$ typically (HNO$_3$ and ethanol)
HeXe: dual-phase xenon TPC for purity measurements

- Surface cleaning qualification setup for LXe TPCs
- Modular TPC with length increase possible (from 5 to 20 cm)
- Hot getter for xenon purification
- 3 ports for Xe recirculation: GXe in, GXe out and LXe out

- Two methods for purity investigation after material cleaning:
  - Study of purity increase over time w/ recirculation
  - Study of purity decrease over time w/out recirculation
Current system @ MPIK:

- TPC assembled in a nitrogen flushed glove bag
  ⇒ Avoid dust, water and oxygen
Surface cleaning of PTFE

Preparation of the PTFE cylinder:

▶ Degreasing using detergent in an ultra-sonic bath (blank procedure)
▶ Acid treatment with e.g. HNO₃ (weakly or strongly concentrated)
▶ Rinsing in de-ionized water
▶ N₂ drying in an airtight vessel (50 mbar, 40 °C)

Installation in HeXe and measurement

▶ Minimised air exposure (less than 1 minute)
▶ Installation in glove bag
Measurement with the HeXe detector

- Dual-phase operation with drift field of up to 1.2 kV/cm

\[ ^{83}\text{mKr} \]

- \( T_{1/2} = 1.83 \text{ h} \)
- \( E = 32.1 \text{ keV} \)

\[ ^{83}\text{Kr} \]

- \( T_{1/2} = 154.4 \text{ ns} \)
- \( E = 9.4 \text{ keV} \)

- \(^{83}\text{mKr} \) source emitting 2 IC e\(^-\)'s at 32.1 keV and 9.4 keV

\( T_{1/2} = 159.6 \pm 0.1 \text{ ns} \)
HeXe: Purity measurements

- Electronegative impurities can capture free electrons
  $\Rightarrow$ S2 signal size depends on xenon purity

- *Electron lifetime* defined as $e^-$ survival time before recombination

- No significant outgassing from chemical treatment

- Achievable electron lifetime: 0.5 ms
DARWIN: ultimate dark matter detector additionally providing numerous neutrino physics channels

Radon dominates background level for rare-event searches in several experiments

Several origins for background requires various strategies

Potential for surface contamination from radon daughters removal

Chemical treatment characterized for compatibility with liquid xenon TPC operation
Surface $^{222}\text{Rn}$ daughters contamination reduction

- $^{210}\text{Po}$ measurement with $\alpha$-spectrometer
- Nitric acid and various treatment time and temperature
- Reduction factors around 2

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1^{st}$ ethanol wiping</td>
<td>1.57 ± 0.08</td>
<td>-</td>
<td>1.61 ± 0.07</td>
<td>1.82 ± 0.04</td>
</tr>
<tr>
<td>$2^{nd}$ ethanol wiping</td>
<td>-</td>
<td>-</td>
<td>1.22 ± 0.12</td>
<td>1.07 ± 0.04</td>
</tr>
<tr>
<td>HNO$_3$ (5 %)</td>
<td>1.24 ± 0.06</td>
<td>1.40 ± 0.15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HNO$_3$ (6 mol/L)</td>
<td>1.16 ± 0.05</td>
<td>1.09 ± 0.15</td>
<td>1.12 ± 0.11</td>
<td>1.10 ± 0.06</td>
</tr>
<tr>
<td>HNO$_3$ (60 C)</td>
<td>1.06 ± 0.02</td>
<td>0.94 ± 0.09</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total reduction</td>
<td>2.4 ± 0.01</td>
<td>1.44 ± 0.08</td>
<td>2.15 ± 0.31</td>
<td>2.26 ± 0.14</td>
</tr>
</tbody>
</table>
Background from radon in the XENON1T detector

- $^{222}$Rn: current most critical background source in XENON1T.
- Total radon budget: $\sim 10\mu$Bq/kg.

Individual radon sources identified by emanation measurement.

- Fighting strategies: material selection (HPGE, ICPMS, emanation measurements), surface cleaning.
Radon emanation measurement strategies

- Proportional counters for sensitive radon emanation measurement
- Electrostatic radon monitors
- Parallel measurements available for high sample throughput
- Automatized emanation measurements with Auto-Ema setup for reproducibility
Background reduction strategies for XENONnT

- Radon is the dominating background in XENON1T
- Material screening and selection with $\gamma$-spectrometry

EPJ C (2017), 77, 890

- Online reduction using cryogenic distillation,
- Proofs of principle EPJ. C (2017), 77, 143 and XENON100 EPJ C (2017), 77, 358

- Expected reduction factor for the column: 100