Developments in surface background removal for the DARWIN liquid xenon detector

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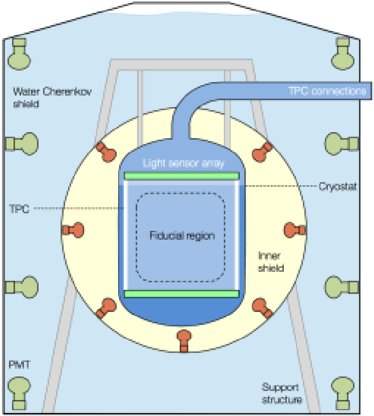
The DARWIN project



Design:

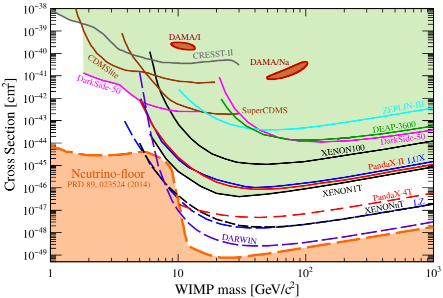
- 50t LXe in total, 40t active mass
- Drift length and diameter over 2.5 m
- Large purification flow necessary
- Enhanced light collection efficiency
- Optimized photosensors
- Low background (^{222}Rn and (α, n))

R&D ongoing:

- Xenoscope: 2.6m drift demonstrator
- ULTIMATE: Large electrode development
- Large cryogenic systems (storage, cooling, purification)

Physics case of DARWIN

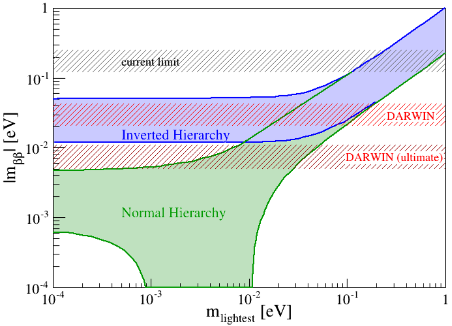
- Ultimate WIMP dark matter search
- Sensitivity to SI WIMP-nucleon σ: $\sigma_{SI} \simeq 10^{-49}$ cm^2 @ $m_\chi = 50$ GeV/c^2



Large potential for ν studies:

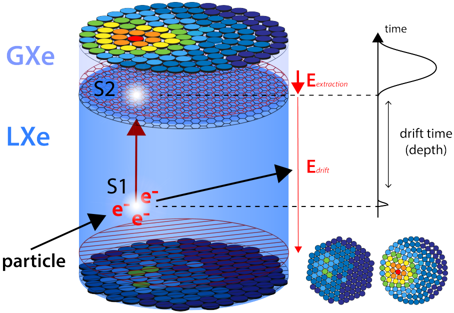
- Coherent ν Nucleus Scattering
- pp-ν from the Sun
- Supernova ν
- Search for $0\nu2\beta$ decay

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

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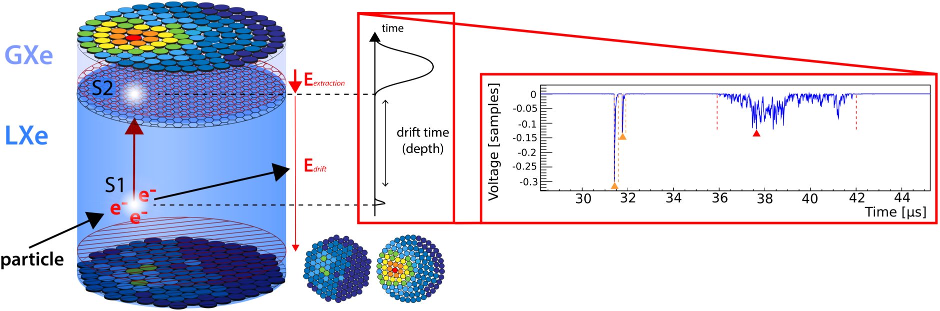
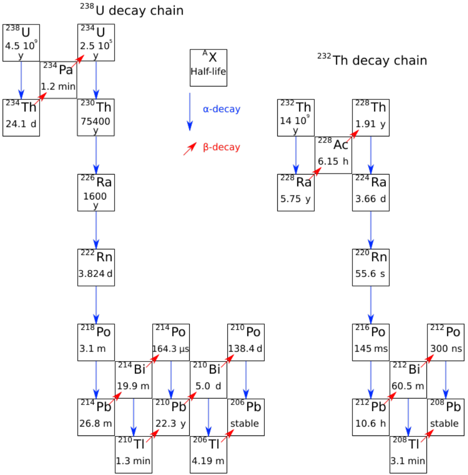


Background from radon in rare-event searches

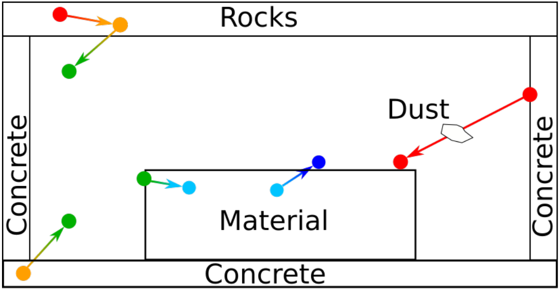
- Natural radioactivity chains: β, γ & α-emitters



- ^{222}Rn and ^{220}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 γ's from material
- $(\alpha$, n) reaction inside material

Surface background from long-lived ^{222}Rn daughters

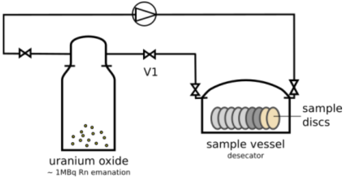
- Dust naturally contains ^{238}U and ^{232}Th
- ^{222}Rn emanated from material environment (concrete, rocks)
- Prolonged exposure to dust and ambient air containing ^{222}Rn:
  $\Rightarrow$ Surface contamination with long-lived ^{222}Rn daughters

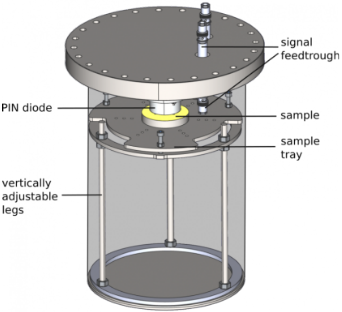


Motivation for surface treatments

- Radon-dominated background in XENON1T
  ⇒ mitigation necessary
- Clean room to prevent dust containing ^{238}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)

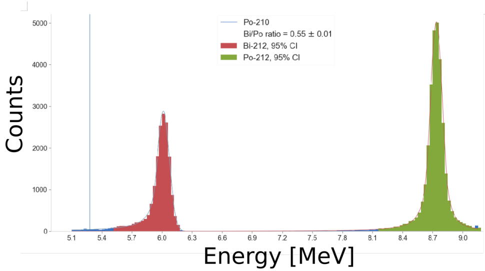
Preparation and measurement for surface cleaning



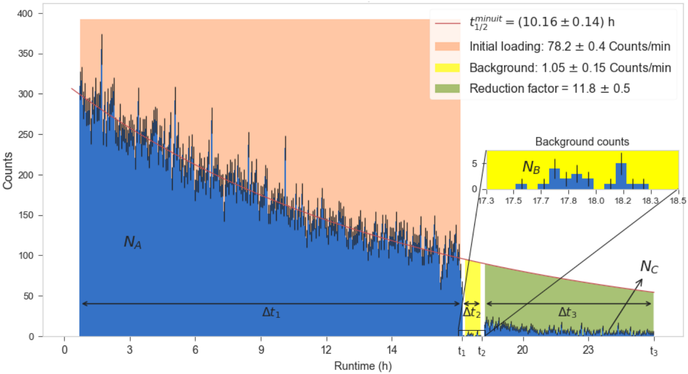


- Artificial loading of sample discs
- Uranium oxide and ^{228}Th sources
- Surface contamination in ^{222}Rn and ^{220}Rn daughters

- Measurement with α-spectrometer
- SiPIN diode identifying isotopes
- Operation under vacuum



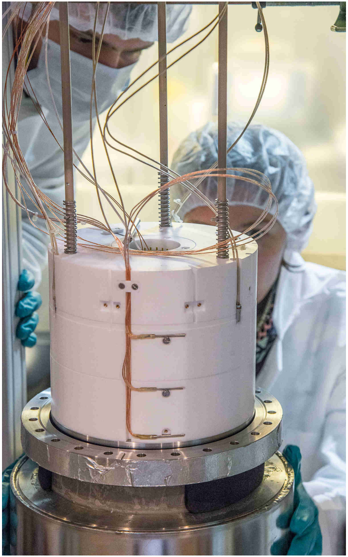
PTFE contamination reduction factors for ^{220}Rn daughters



Procedure	1st cleaning	2nd 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 ≃ 2 typically (HNO_3 and ethanol)

HeXe: dual-phase xenon TPC for purity measurements

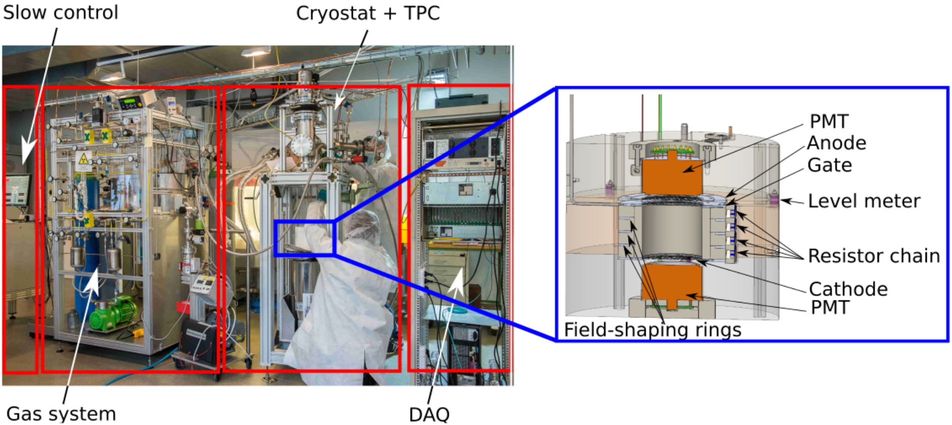


- Surface cleaning qualification setup for LXe TPCs
- Modular TPC with length increase possible (from 5 to 20 cm)
- Hot getter for xenon purification
- 3 ports for Xe recirculation: GXe in, GXe out and LXe out

- 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

HeXe: dual-phase xenon TPC for purity measurements

- Current system @ MPIK:



- TPC assembled in a nitrogen flushed glove bag
  $\Rightarrow$ Avoid dust, water and oxygen

Surface cleaning of PTFE

Preparation of the PTFE cylinder:

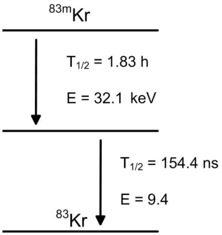
- Degreasing using detergent in an ultra-sonic bath (blank procedure)
- Acid treatment with e.g. HNO_3 (weakly or strongly concentrated)
- Rinsing in de-ionized water
- N_2 drying in an airtight vessel (50 mbar, 40 °C)

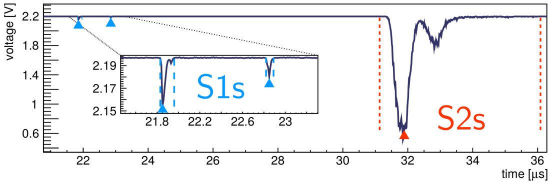
Installation in HeXe and measurement

- Minimised air exposure (less than 1 minute)
- Installation in glove bag

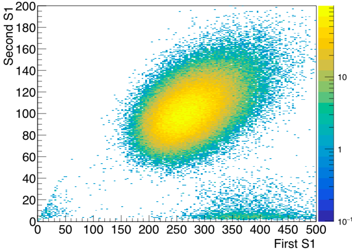
Measurement with the HeXe detector

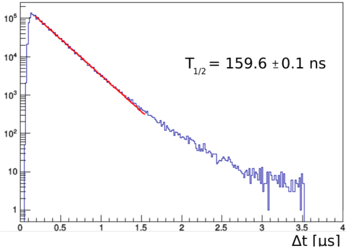
- Dual-phase operation with drift field of up to 1.2 kV/cm





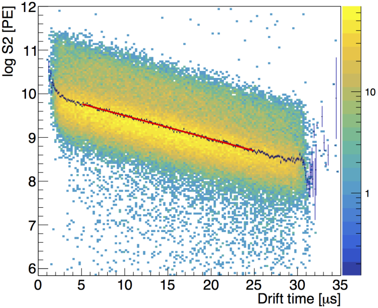
- ^{83m}Kr source emitting 2 IC e$^-$'s at 32.1 keV and 9.4 keV

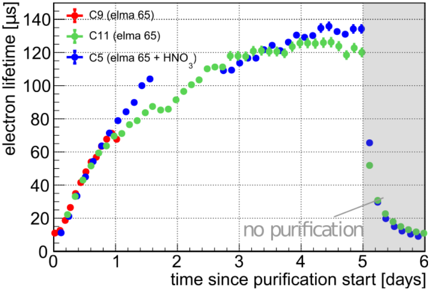




HeXe: Purity measurements

- 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





Summary

- 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

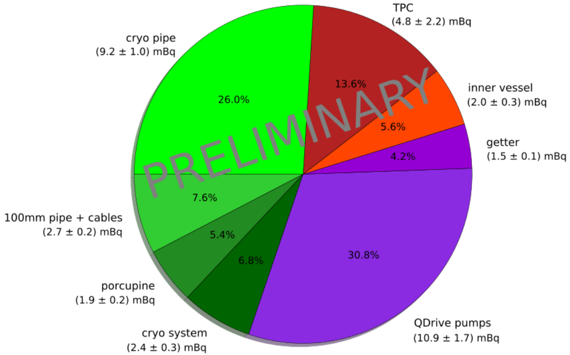
Surface ^{222}Rn daughters contamination reduction

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

Procedure	Sample 1	Sample 2	Sample 3	Sample 4
1^{st} ethanol wiping	1.57 ± 0.08	-	1.61 ± 0.07	1.82 ± 0.04
2^{nd} ethanol wiping	-	-	1.22 ± 0.12	1.07 ± 0.04
HNO_3 (5 %)	1.24 ± 0.06	1.40 ± 0.15	-	-
HNO_3 (6 mol/L)	1.16 ± 0.05	1.09 ± 0.15	1.12 ± 0.11	1.10 ± 0.06
HNO_3 (60 C)	1.06 ± 0.02	0.94 ± 0.09	-	-
Total reduction	2.4 ± 0.01	1.44 ± 0.08	2.15 ± 0.31	2.26 ± 0.14

Background from radon in the XENON1T detector

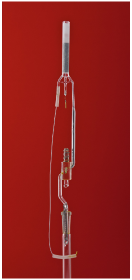
- ^{222}Rn: current most critical background source in XENON1T.
- Total radon budget: $\sim 10\mu$Bq/kg.



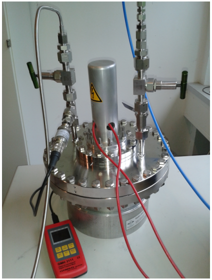
- Individual radon sources identified by emanation measurement.
- Fighting strategies: material selection (HPGE, ICPMS, emanation measurements), surface cleaning.

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



Proportional counter



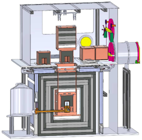
Radon monitor

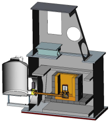
Auto-Ema

Background reduction strategies for XENONnT

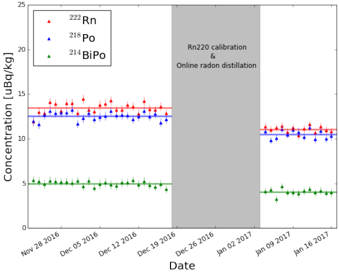
- Radon is the dominating background in XENON1T
- Material screening and selection with γ-spectrometry

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