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Radon removal system for the LZ Dark Matter experiment

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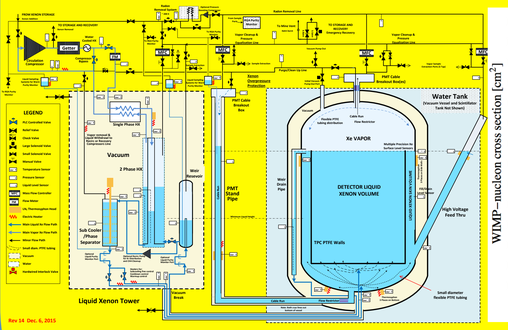
on behalf of the LZ collaboration

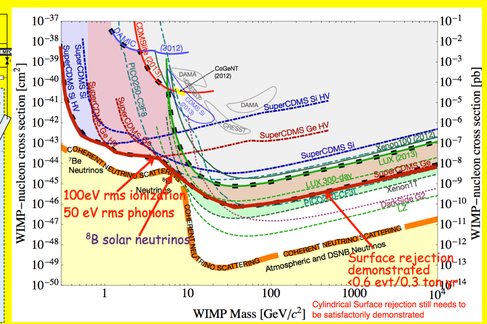
Introduction

Dark Matter is a hypothetical substance that is believed to constitute 80% of the matter in the Universe. Although it has not been directly observed and confirmed, its existence and properties have been inferred from various gravitational effects such as gravitational lensing and the cosmic microwave background. The most attractive candidate for Dark Matter is Weakly Interactive Massive Particles (WIMPs). Since WIMPs only interact through gravitational and weak forces, they are extremely difficult to detect. Relying on an active detector mass of 7 tons heavily shielded in a deep mine, LZ is the next generation of a dual phase Time Projection Chamber (TPC) based on liquid xenon (LXe). To be located at the Sanford Underground Research Facility (SURF) in South Dakota, the LZ detector is designed to reach the ultimate sensitivity of 2×10^{-48} cm^2 in three years of operation for a WIMP mass of 50 GeV. The LZ detector is a dual TPC which utilizes liquid xenon medium with a gaseous interface. When a charged particle interacts with the xenon, it produces scintillation light with a wavelength of 175 nm and liberates electrons. Electric fields applied across the liquid and gaseous xenon separate electrons from positive ions. When the electrons drift to the anode, they are extracted into the gaseous phase and produce electroluminescence light. Both primary scintillation light and electroluminescence signals are detected by photomultiplier tubes (PMTs) arrays on both the top and the bottom of the TPC. This allows for a full 3-D localization within the detector that can discriminate a Dark Matter signal from radioactive background.

The LZ experiment



Flow block diagram with the LXe detector in the cryostat and gas system

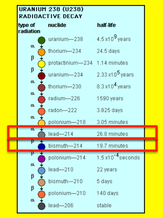


Spin independent WIMP elastic cross section sensitivity (solid curves), hints for WIMP signals (shaded closed contours), and projections (dashed curves) for future direct detection experiments

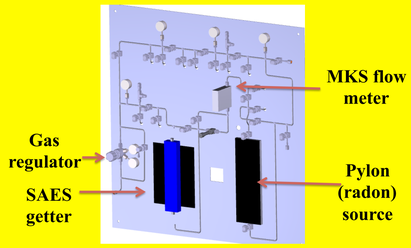
Motivation

Radon is a radioactive, colorless, odorless noble gas. Its most stable isotope, ^{222}Rn, has a half-life of 3.8 days and is an intermediate of the uranium, ^{238}U, decay chain. A daughter nucleus, ^{214}Pb, has 11% beta - branching fraction to the ground state of ^{214}Bi whose signal can end up in the dark matter search window and survive S2/S1 nuclear recoil discrimination cut. The sources of radon include signal cables, feedthrough cables, and stainless steel conduits at an estimated level of 30 mBq to 85 mBq and demand an active radon removal system to reach the LZ detection sensitivity goals.

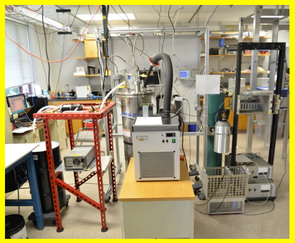
Prototype radon removal system



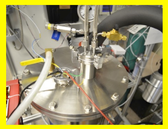
^{222}Rn decay chain



3-D rendering of radon removal system

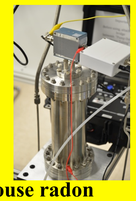


Prototype radon removal system



Cryostat with cryo fluid (HFE7100)

RAD-7 radon detector



In-house radon detector based on Si PIN

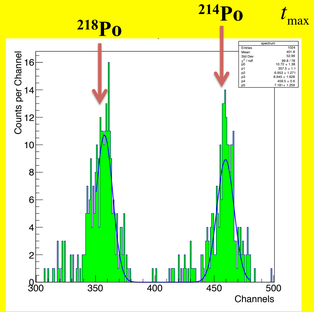
Analysis and experimental results

Elution curves were fitted with a function based on the chromotographic plate model [1] for the case of radon "spike" (δ-function) method:

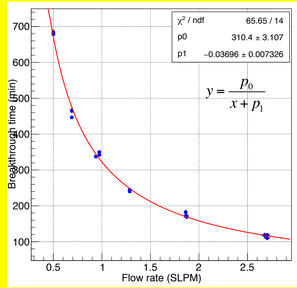
$$y(\frac{t}{\tau}) = \frac{\alpha n^n}{(n-1)!}(\frac{t}{\tau})^{n-1}\exp(-\frac{nt}{\tau}) \qquad (1)$$

Where τ - average radon breakthrough time through the carbon trap, n – number of equivalent theoretical stages, and α-the amplitude of the input δ-function. The maximum of the elution curve is at:

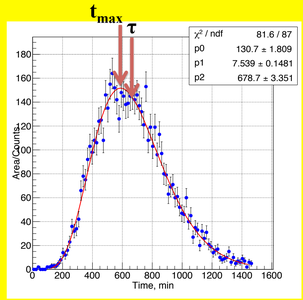
$$t_{max} = \frac{n-1}{n}\tau \qquad (2)$$



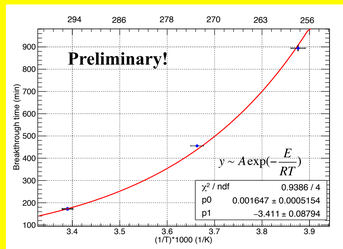
Radon spectrum



^{222}Rn breakthrough time in N_2 carrier gas vs flow rate (data were taken at 294 K)



Elution curve of ^{222}Rn in N_2 at a gas flow rate of 0.5 L/min



^{222}Rn breakthrough time in N_2 carrier gas vs temperature of carbon trap at 2 L/min

Summary

- We have finished the design and construction of the prototype radon removal system and are currently taking data.
- Currently, we are taking radon breakthrough time data in N_2 carrier gas in a broad range of flow rates at various temperatures of the carbon trap.
- We plan to take data with Ar and Xe gases in the broad range of flow rates (0.5-3) slpm and at different carbon trap temperatures (293 to 188) K.

ACKNOWLEDGEMENTS

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REFERENCES

1. A. Pocar, PhD thesis, "Low Background Techniques and Experimental Challenges for Borexino and its Nylon Vessels", 2003, p.98.