Analyzing Gas Diffusion in LXe-TPCs for Upcoming Hydrogen Doping Studies
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Introduction

Liquid xenon time projection chambers (LXe-TPCs) currently lead the direct-detection search for dark matter (DM) in the form of weakly interacting massive particles (WIMPs). However, sensitivity is currently limited to DM with masses above 5 GeV/c². Hydrogen doping in LXe-TPCs would allow for better kinematic matching between light DM particles and target nuclei, expanding sensitivity to DM masses down to 200 MeV/c². Additionally, this method would introduce sensitivity to spin-dependent DM. So far, no major experiments have explored this parameter space [1].

Plans are underway to dope an existing small-scale LXe-TPC (XELDA) with H₂ to study behavior and mixing properties in LXe. This will include measuring the Henry coefficient and characterizing the charge-to-light spectrum of H₂ recoils in LXe. Prior to this, it is important to determine an expected time scale of H₂ diffusion and saturation in our TPC.

Methodology

Tritiated methane (CH₃) is a radioactive gas with mixing properties similar to H₂. In this project, CH₃ is used to understand diffusion and equilibration of non-condensable gases in the XELDA detector.

Detector Operations

- Injected CH₃ into source panel, then switched detector into forced circulation mode to encourage Xe-CH₃ mixing.
- Returned to data acquisition after four hours of circulation and collected 12 ten-minute data sets.

Data Analysis

- Processed and analyzed raw data using ROOT.
- Calculated overall trigger rate for each ten-minute data set to track CH₃ activity in the LXe.
- Used S₁ pulse area to discriminate between tritium beta decay and ‘other’ events, then analyzed rate trends separately.

Rate Analysis Results

Fig 4. Overall trigger rate following four hours of circulation. The rate falls from 22.7 Hz to 16.4 Hz over a two-hour period, with stabilization beginning approx. one hour after exiting circulation.

H₂ Afterpulsing Calculation

Light gases can permeate PMT window materials over time, causing detrimental afterpulsing effects.

\[
P_{\text{after}} = C \times \text{Pext} \times (1 + C \times t)
\]

(1)

\[
P = R \times T \times K \times (V / d)
\]

(2)

\[
P_{\text{H₂}} = P_{\text{He}} \times (T + 1) + P_{\text{after}} + 1\text{ atm}
\]

(3)

Conclusions

- Using our circulation methods, the CH₃ saturated the LXe on a reasonable experimental time scale and remained in solution after circulation. We expect H₂ to display similar mixing behavior, presenting encouraging results for future operations.
- It is projected that H₂ will not cause significant afterpulsing in our PMTs until at least 26 years of exposure. Based on this analysis, it is unlikely that detrimental effects will occur within the time frame of our hydrogen operations.

References