Observation of Radon Mitigation in MicroBooNE by a Liquid Argon Filtration System

Joseph Zennamo (Fermilab), on behalf of the MicroBooNE Collaboration

Low Radioactivity Techniques 2022
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Based on: “Observation of Radon Mitigation in MicroBooNE by a Liquid Argon Filtration System”, arxiv.org:2203.10147, submitted to JINST
MicroBooNE

89-ton active mass liquid argon TPC

Studied GeV-scale neutrino interactions in data from 2014-2020

(not primarily targeting low energy signals)

Experiment entered R&D period in 2021
Doping LAr with Radon

- 500-kBq 226-radium source used to perform a spike-test
- 222-radon is interesting for MicroBooNE:
  - 222-radon has a 3.8-day half-life
    - Mixes throughout cryostat
  - 214-polonium’s short 164 μs half-life
    - Tag the 214-bismuth $\beta$-signal with the trailing 214-polonium $\alpha$-signal

Source ($^{226}$Ra)

Injected $^{222}$Rn gas

BiPo Decays

J. Zennamo, Fermilab
MicroBooNE’s MeV-Scale Capability

- LArTPCs are capable of reconstructing low-energy signals
- MicroBooNE has shown the ability to reconstruct 100 keV β-decays

Simulated $^{214}\text{Bi}^{214}\text{Po}$ Event

$^{214}\text{Po}$ → $\alpha$ (7.7 MeV)
$T_{1/2} = 164 \mu$s

$^{214}\text{Bi}$ → $\beta$ ($Q = 3.3$ MeV)

Rn is identified by these coincident signals

$^{39}\text{Ar}$ Beta Decays at MicroBooNE
MicroBooNE Public Note 1050

MeV Physics in MicroBooNE
MicroBooNE Public Note 1076

Phys. Rev. D 99, 012002

Path Towards $0\nu\beta\beta$ with LArTPCs
A. Mastbaum, F. Psihas, J. Zennamo
arxiv:2203.14700
Two filters aim to remove electronegative contaminants from the liquid argon.

First, a 4Å Molecular Sieve with 1.6-2.6 mm beads removes water!

Second, a Copper Filter (Cu-0226 S) removes O₂!
MicroBooNE Cryogenic System

1. Flow LAr & GAr through the full-sized filter (Nominal mode)
2. Flow LAr & GAr through the 30%-sized filter
3. Recondensed GAr bypasses the filters (Reduces electron lifetimes)

System can be run in 3 modes
Selecting Radon Decays

Expected *hundreds* of signals per readout

- Selection takes overlapping small clusters where the cluster at higher-drift distance has less charge
- \((46^{+31}_{-29})\% ~ ^{214}\text{Bi}^{214}\text{Po}\) selection efficiency
  - The uncertainty comes from a data-driven comparison
  - Uncertainty covers source efficiency, simulation differences, reconstruction differences

Assumes cryostat comes into secular equilibrium with source and filter removes no radon
Radon Candidates in Different Modes

- Three modes we ran in:
  - **Full-sized filter:** recondensed GAr goes through 77 L mole sieve + 77 L copper
  - **30%-sized filter:** recondensed GAr goes through 25 L mole sieve + 24 L copper
  - **Filter-bypass:** recondensed GAr bypasses filters

- Only filter-bypass led to an increase in the $^{214}\text{Bi}^{214}\text{Po}$ rate
Radiological Survey

• Performed radiological survey of the complete cryogenic system

• Background rates (1-5 μrem/h) expect near the source and the copper filter (12-16 μrem/h)
  • Stratification stable over 8-months

• The mole sieve (first in line) has a larger surface area per gram compared to the copper filter but read at background levels
  • 900 m²/g compared to 200 m²/g
Radon Mitigation Models

**Trapping:** the filter captures and holds onto the radon, similar to electronegative contaminants

Measure **effective source strength**, compare that to 500-kBq injected

**Slowing:** the filter material slows the radon which then decays as it traverses the filter material

Measure **breakthrough time**, sets fraction of radon that decayed
Measured Radon Removal

**Trapping**

Fit for effective source strengths

No appreciable increase in BiPo rates

Correct selection efficiency and LAr mass

Compare to input source strength (500 kBq)

Fraction of radon removed:

- Full-sized filter: \((99.9997\pm0.0003)\%\)
- 30%-sized filter: \((99.9999\pm0.0001)\%\)

**Slowing**

Search for a delayed baseline shift

2% uncertainty on background level

Observed no baseline shift over 500 hrs

Places limit on fraction of \(^{222}\text{Rn}\) decayed

Lower limit of fraction of radon removed:

- 30%-sized filter: 97.7%

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**MicroBooNE Data**

**Fitted Effective Source Strengths**

- \(1.4 \pm 1.4\) Bq
- \(0.7 \pm 0.6\) Bq

**Breakthrough Time**

- DAQ Downtime
- Observed no significant BiPo rate increase

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**Correct selection efficiency and LAr mass**

Compare to input source strength (500 kBq)

Fractions of radon removed:

- Full-sized filter: \((99.9997\pm0.0003)\%\)
- 30%-sized filter: \((99.9999\pm0.0001)\%\)

**No appreciable increase in BiPo rates**

**Correct selection efficiency and LAr mass**

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**Fit for effective source strengths**

**Search for a delayed baseline shift**

2% uncertainty on background level

Observed no baseline shift over 500 hrs

Places limit on fraction of \(^{222}\text{Rn}\) decayed

Lower limit of fraction of radon removed:

- 30%-sized filter: 97.7%
Conclusions

• MicroBooNE has observed that its copper filter material is highly efficient at sequestering 222-radon from liquid argon
  • Analyses performed for radon being trapped or slowed by copper filter

• This work shows that 222-radon can be mitigated via liquid-phase filtration in liquid argon
  • Could enable scaling MeV-scale LAr detectors to very large masses

<table>
<thead>
<tr>
<th>Trapped Radon Removal Efficiency</th>
<th>Slowed Radon Removal Efficiency</th>
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<tbody>
<tr>
<td><strong>Full-sized filter:</strong> (99.9997±0.0003)%</td>
<td><strong>30%-sized filter:</strong> &gt;97.7%</td>
</tr>
<tr>
<td><strong>30%-sized filter:</strong> (99.9999±0.0001)%</td>
<td>No radon punch through observed for 500 hours</td>
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