Molecular sieve vacuum swing adsorption for gaseous dark matter and rare-event detectors

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R.R. Marcelo Gregorio, N.J.C. Spooner, F. Dastgiri, A. C. Ezeribe, G. Lane, A.G. McLean, K. Miuchi, H. Ogawa

Queen Mary University of London
University of Sheffield

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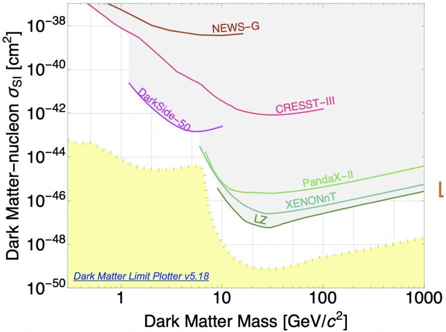
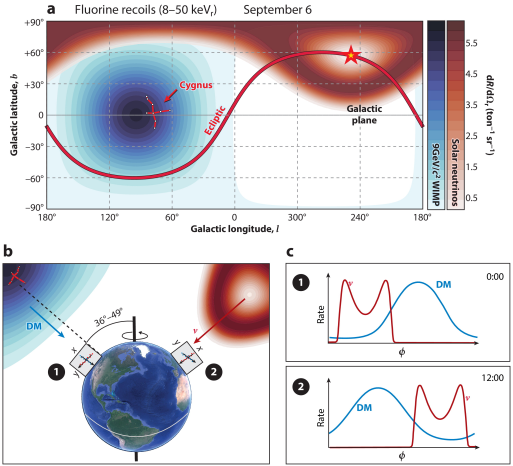
Introduction



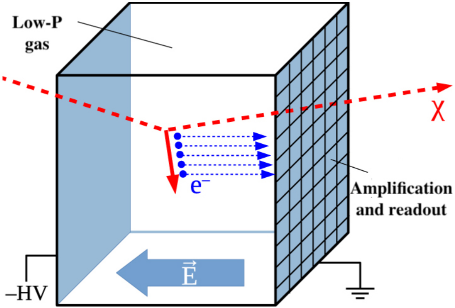
- Next-generation direct detection dark matter experiments increase in sensitivity, they approach an irreducible neutrino background
- If no dark matter signals are detected, this background establishes an ultimate discovery limit for these experiments
- Directional detectors offer a way to mitigate this issue



Vahsen SE, et al. 2021
Annu. Rev. Nucl. Part. Sci. 71:189–224

Directional Detectors

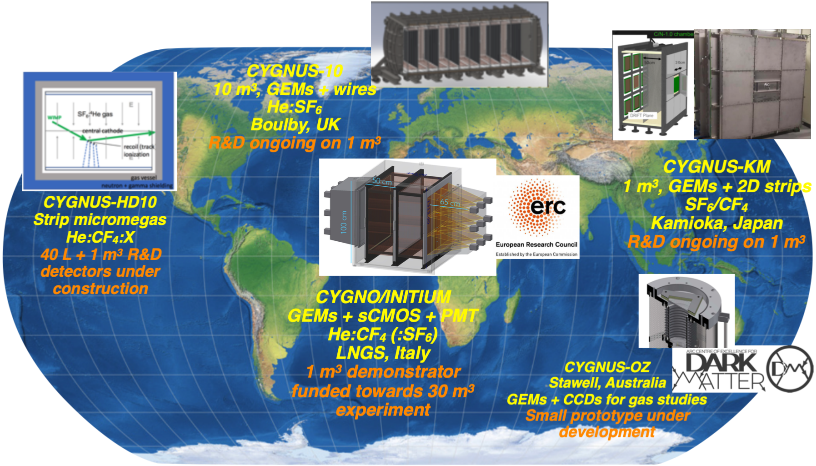
Gas TPCs



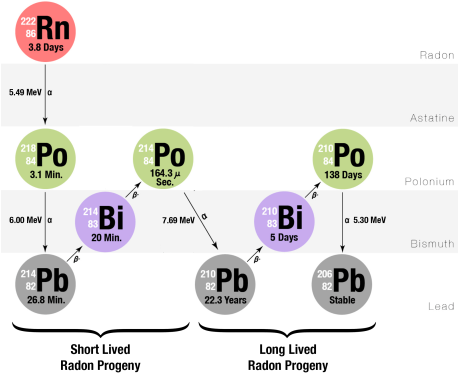
- Gas-based Time Projection Chambers (TPCs) are the most commonly employed for directional searches
- These detectors use low-pressure gas targets to produce long nuclear recoil tracks
- SF_6 has gained popularity in gas-based directional detectors due to its novel properties [a]

[a] N.S. Phan et al 2017 JINST 12 P02012

Directional Detectors
CYGNUS Collaboration

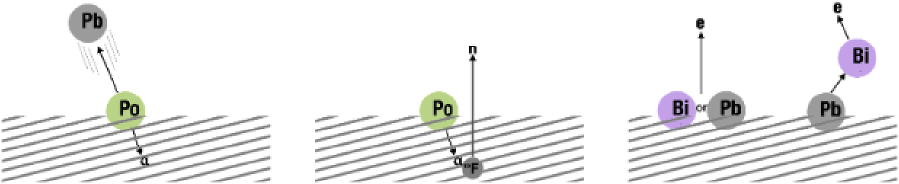


Radon
Contamination



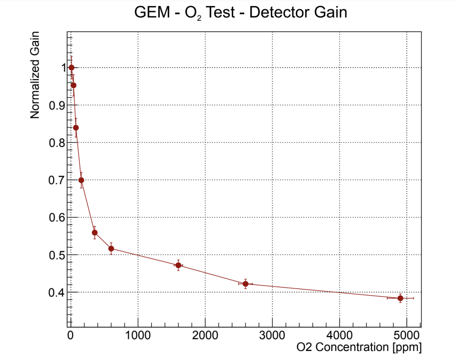
- Radon is a naturally occurring radioactive noble gas
- Contamination in detectors originate intrinsically from detector material or plate out from atmospheric radon
- Radon contamination can act as a source of unwanted background noise from its decay and progeny decay

Radon
Backgrounds



(a) Nuclear recoil (b) Neutron emission (c) Electron recoil

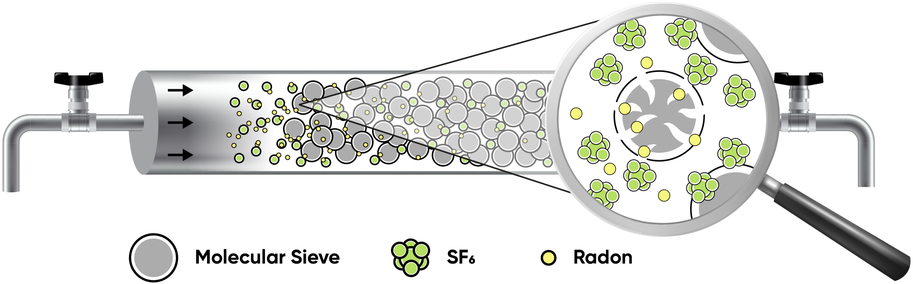
Common Pollutants



- Common pollutants (O_2, N_2 and H_2O) can reduce the detector's amplification capabilities (Gain) by capturing electrons produced during interactions[a]
- SF_6 is the most potent greenhouse gas, making the method of continuous flow and disposal problematic
- In industry gas filters are readily available to remove common pollutants

[a] R Guida et al 2020 J. Phys.: Conf. Ser. 1498 012036

Molecular Sieves
Radon Removal



- The Molecular Sieve was able to reduce the initial radon of ~ 4 kBq/m^3 in SF_6 gas by 87% [1]

[1] R.R. Marcelo Gregorio et al., *Demonstration of radon removal from SF6 using molecular sieves*, JINST 12 P09025 (2017)

Commercial Molecular Sieves are DIRTY!

- We want **High** Radon Filtration but **Low** Radon Emanation
- Commercial MS 5.4 $\times 10^{-3}$ Radon emanated per captured

Table 1. Radon filtration, intrinsic MS emanation and comparison parameter results for the NU-developed MS in granule and powdered form and NU-developed MS V2.

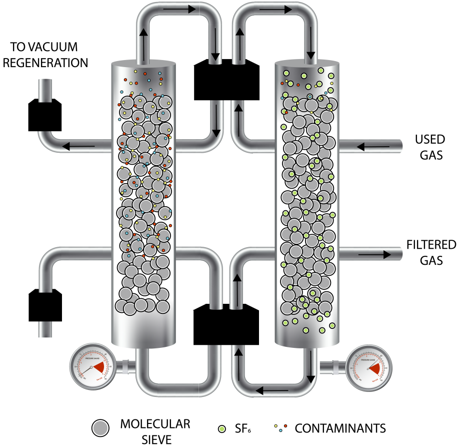
NU-developed MS	^{222}Rn Captured per kg (Bq kg^{-1})	^{222}Rn Emanated per kg (mBq kg^{-1})	^{222}Rn Emanated per ^{222}Rn Captured ($\times 10^{-3}$)
V1 (Granules)	35 ± 2	99 ± 23	2.8 ± 0.7
V1 (Powder)	330 ± 3	680 ± 30	2.1 ± 0.1
V2 (Powder)	254 ± 3	< 14.4	$< 5.7 \times 10^{-2}$

- Nihon University MS V2 emanates **99%** less per captured compared to commercial [2]

[2] R.R. Marcelo Gregorio et al., *Test of low radioactive molecular sieves for radon filtration in SF6 gas-based rare-event physics experiments*, JINST 16 P06024 (2021)

Gas System
Design

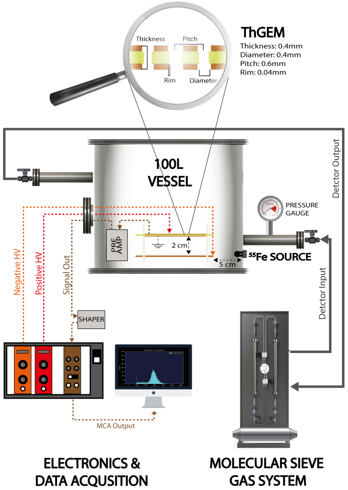
The dual MS column configuration ensures an MS filter is always available by allowing simultaneous filtration and regeneration



Gas System
Prototype Demonstration

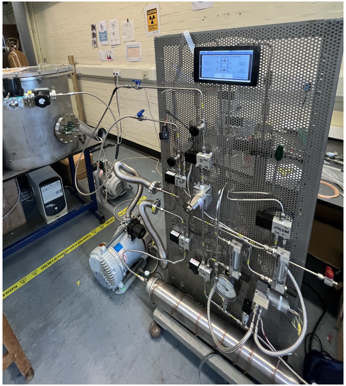
To assess the performance of MS, a gas system prototype was constructed and applied to a lab-based TPC detector with Thick Gas Electron Multiplier (ThGEM)

- Radon reduction test
- Gas gain conservation test

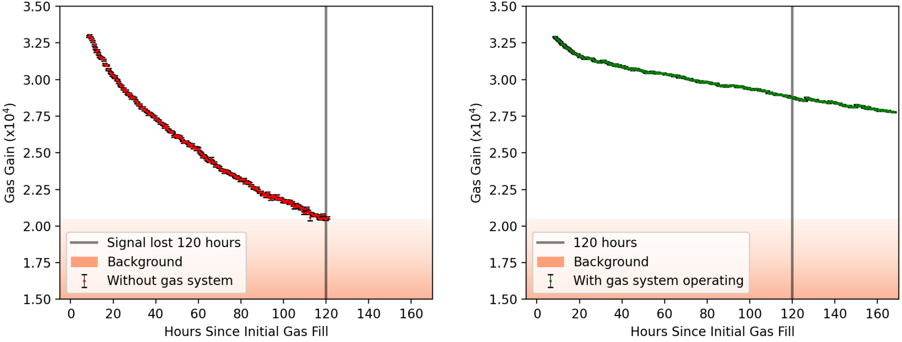


Gas System
Radon Reduction

- The gas system prototype resulted in suppressing the radon activity to 0.8 ± 6.4 mBq
- The large error margin can be attributed to the background limits of radon measurement apparatus
- The intrinsic radon activity in the ThGEM-based TPC detector setup to **less than 7.2 mBq** at a 95% C.L

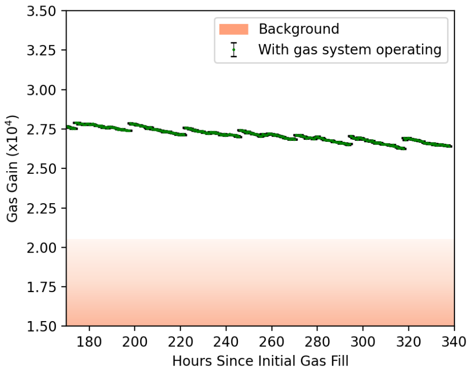


Gas System
Gain Conservation



Gas System
Gain Conservation

- Gain stayed above background until detector operation was terminated
- Appears to approach a steady state gain
- ~ 3 times less gas compared to conventional fresh gas flush systems

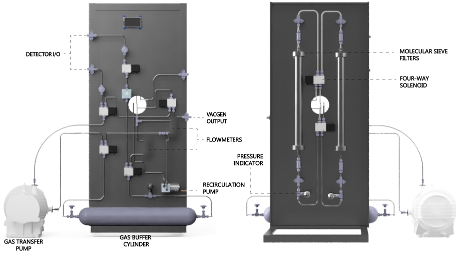


Further Work

- Gas System and MS are currently being implemented to directional dark matter experiments (NEWAGE, Japan, CYGNO, Italy and CYGNUS-OZ, Australia)
- Awarded a Grant to build a Radon Emanation Facility in Australia (DREAMR)
- Next generation filters Metal Organic Framework (MOFs) research
- Investigation to filter application to other target material such as Xenon and Argon

Summary

- Two independent problems arise in gas-based DM detectors due to contaminant gases
- Radon contamination can mimic genuine signals
- Common pollutants can reduce gain capabilities
- These are two separate issues can be addressed with appropriate low radioactive MS filters
- A prototype gas system was constructed and applied to a ThGEM-based TPC detector, demonstrating reduction of intrinsic radon contamination and conservation of detector gain



MS VSA for Gas-Based DM detectors

Introduction

Directional Detectors

Radon

Common Pollutants

Molecular Sieves

Gas System

Further Work

Summary

Thank You! Any Questions?

Dr. Robert Renz Marcelo Gregorio, CPhys

robert.gregorio@cern.ch

linkedin.com/in/rrmg

@renzmarcelo

List of Relevant Papers in This Work:

- R.R. Marcelo Gregorio et al., JINST 12 P09025
- R.R. Marcelo Gregorio et al., JINST 16 P06024
- R.R. Marcelo Gregorio et al., JINST 19 P03012

University of Sheffield

EPSRC Engineering and Physical Sciences Research Council

DURRIDGE Radon Capture & Analytics

Direction-Sensitive WIMP-search NEWAGE

CYGNO Experiment

ARC Centre of Excellence for Dark Matter Particle Physics