Radon Monitoring and Reduction for the DRIFT dark matter experiments

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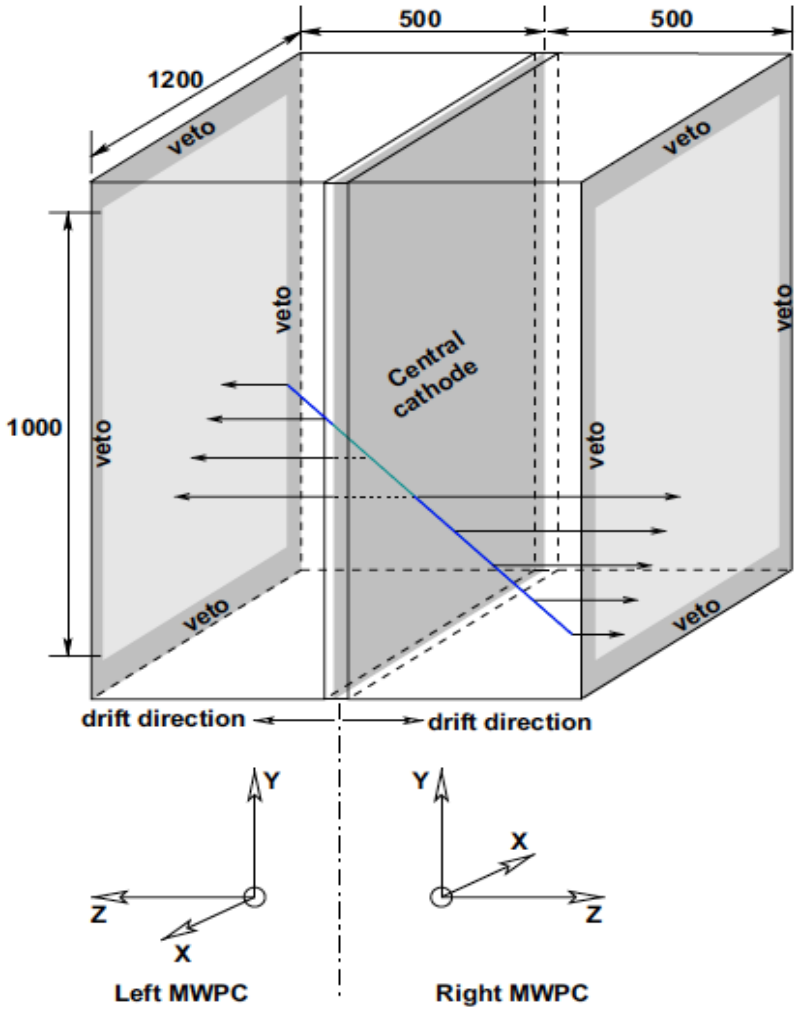
Contents

- DRIFT concept overview
- Radon background
- Measuring radon emanation using DRIFT data
- Measuring radon emanation using an alpha spectrometer
- Identifying and replacing the Rn contributing components
- Quantifying the improvement
- Have we eliminated the Rn problem?

DRIFT concept

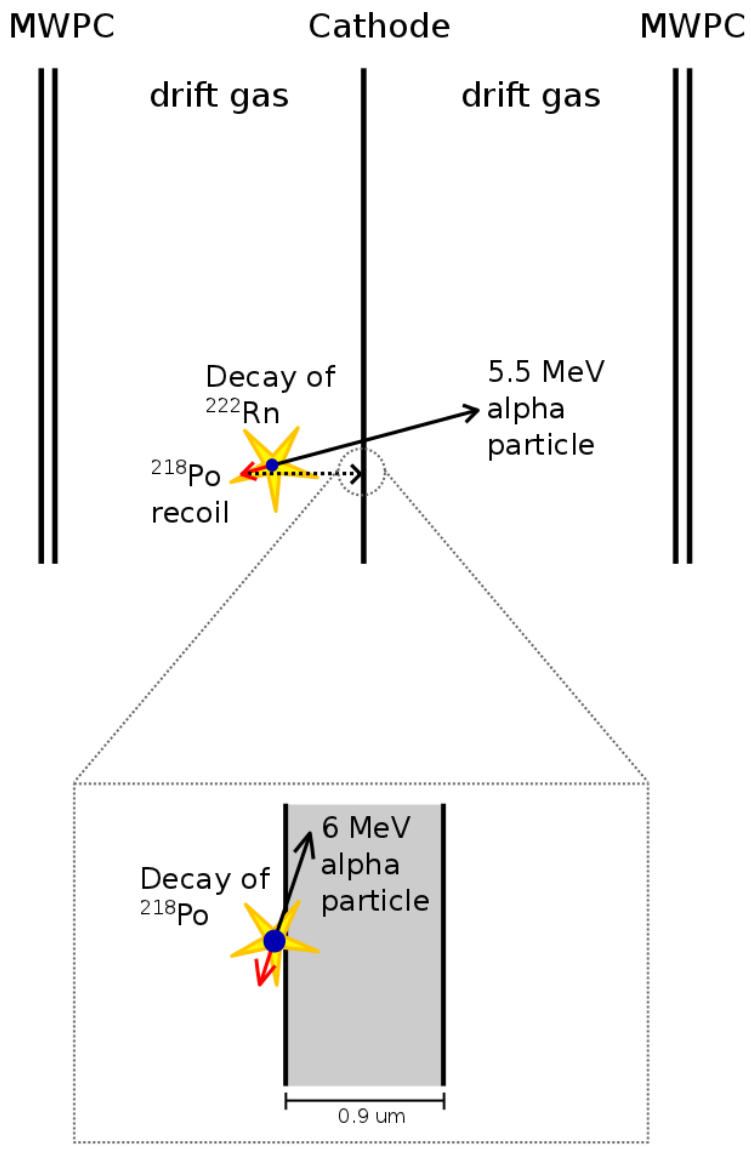
- 1.5 x 1.5 x 1.5 m vacuum vessel housing a 1 m^3 Negative ion TPC.
- Read out by two MWPCs.
- Electronegative drift gas (CS_2) to suppress diffusion.
- CF_4 target gas to provide J=1/2 ^{19}F nucleus => probe spin-dependent WIMP interactions.
- Shared 0.9 µm thin film central cathode defines two 624 V/cm drift regions.
- 512 wires on each of the orthogonal anode and grid planes. Every 8th wire joined to form 8 channels on each.
- DRIFT-IId is running at Boulby Mine in Cleveland, UK.
- > 67 cm polypropylene pellet neutron shielding on all sides.



Sketch of the DRIFT-IId detector volume

Radon Background

- Radon background due to decay of charged daughters plated-out on central cathode – 'Radon Progeny Recoil (RPR)' events.
- RPRs are identified by alpha-tagging and rejected.
- Not 100% efficient!
- Possible second class of events due to alpha particles repeatedly entering and exiting the wrinkled cathode film.



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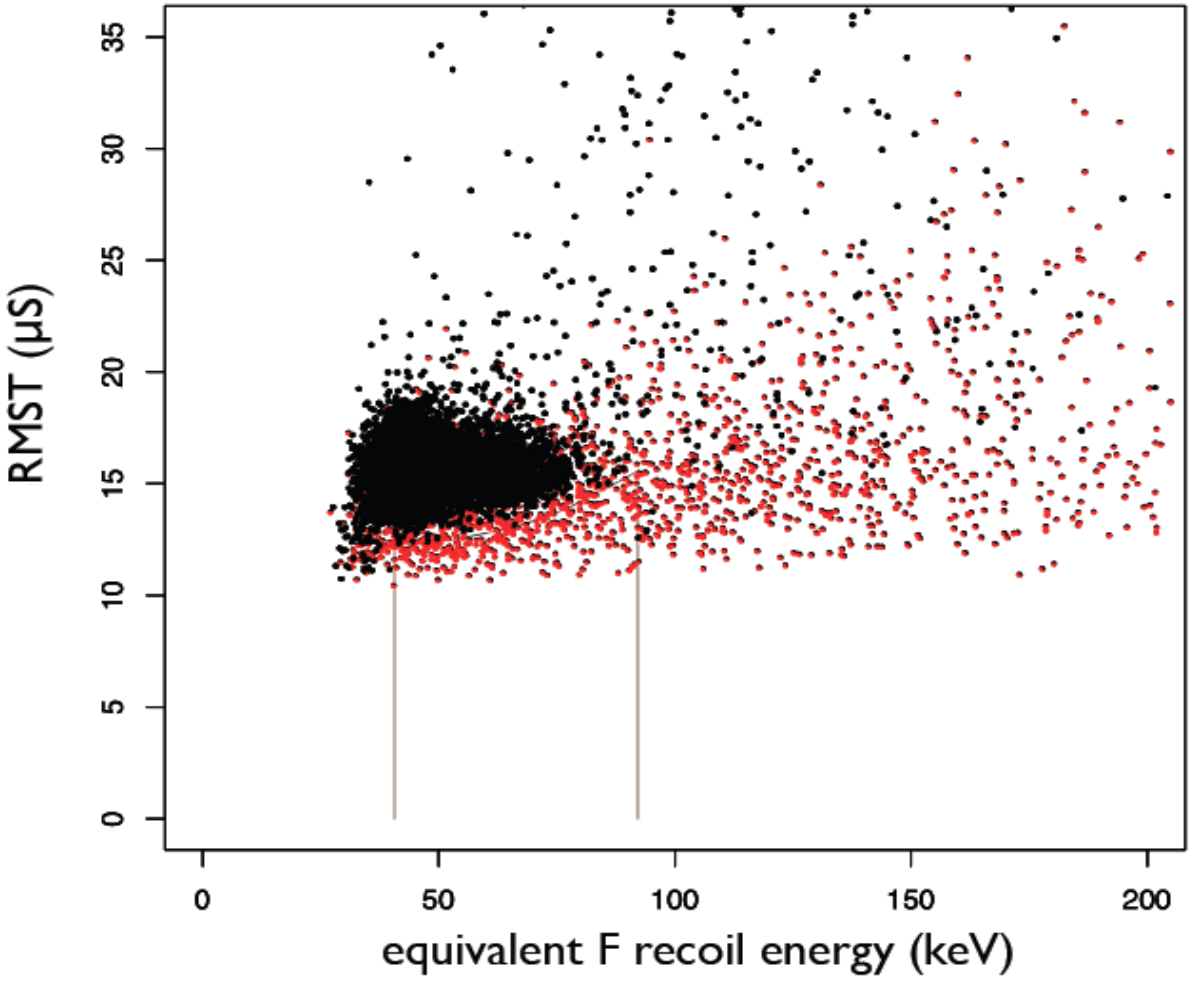
Signal Region

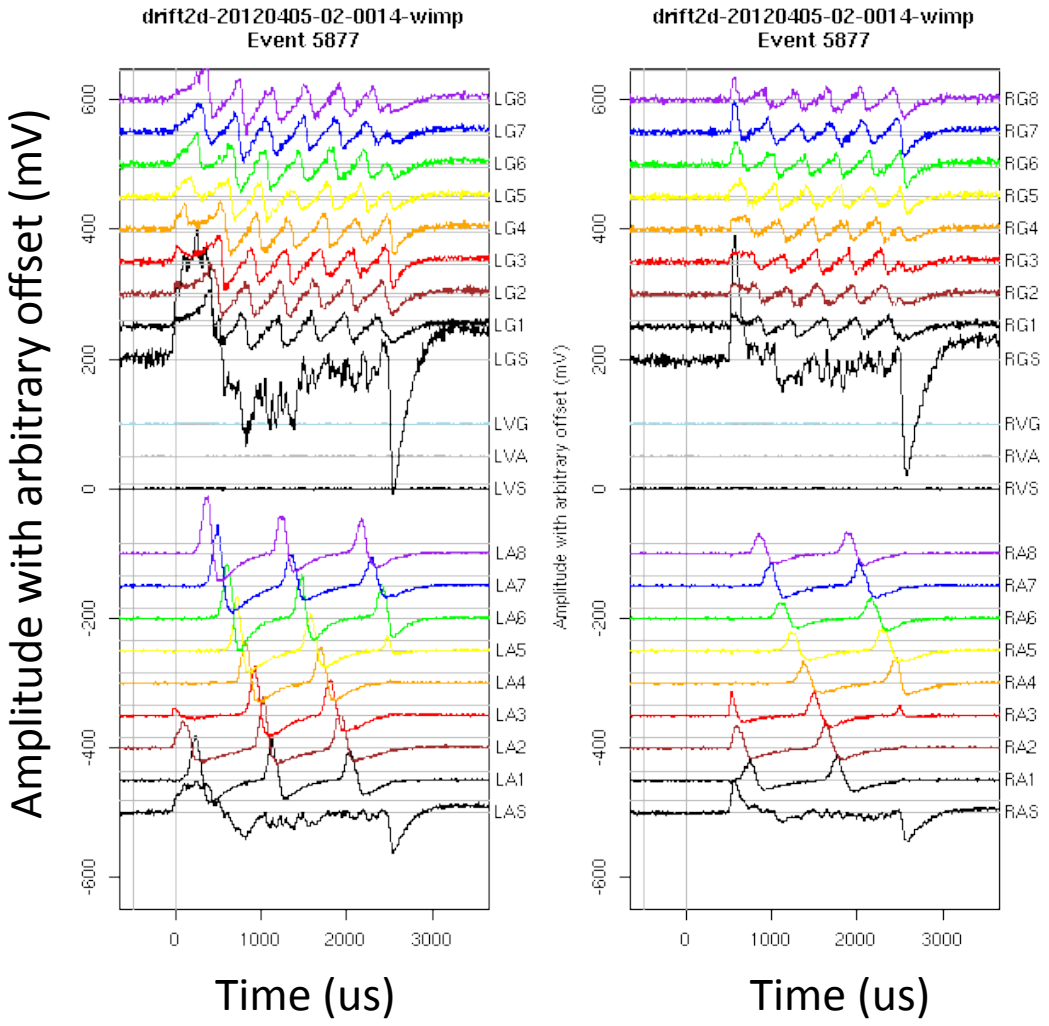


Final stage analysis cut in energy-RMST space

- Final stage cut: define signal region in RMST-Energy space.
- RMST: Root mean square time of the pulse. Pulse shape parameter similar to FWHM, but takes better account of wings.
- Crude measure of diffusion => z-position
- **Red**: neutron calibrations (simulated signal + BG)
- **Black:** background

Cathode-crossing alpha events (GPCCs)

- ‘Golden’ signature of radon inside the vacuum vessel.
- Alpha particle crosses the central cathode.
- No veto activity.
- Only one possible source: alpha decay of a neutral, radioactive species in the gas.
- ^{222}Rn, or uncharged daughters.
- Events satisfying the above dubbed **‘Gold-plated cathode crossers’ (GPCCs)**.
- A dataset of 6.6 days’ livetime from April 2012 was chosen to investigate the GPCC rate.



DRIFT event display for a candidate GPCC event

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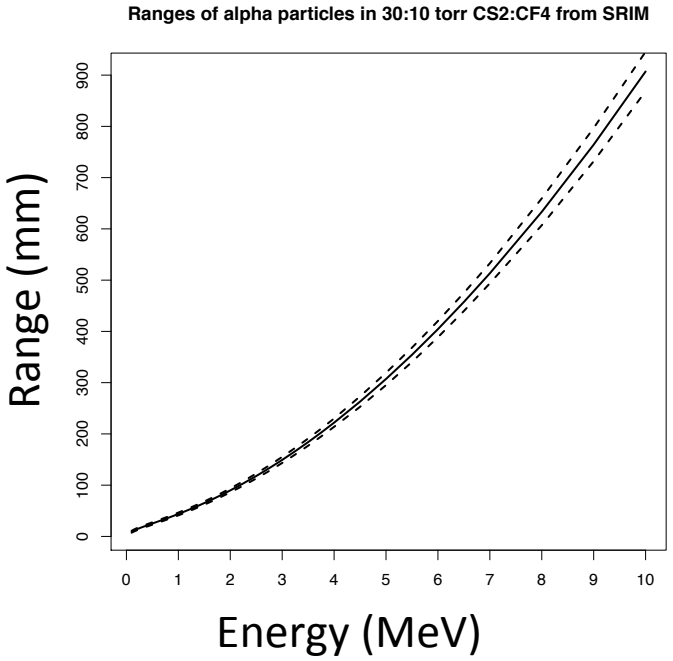
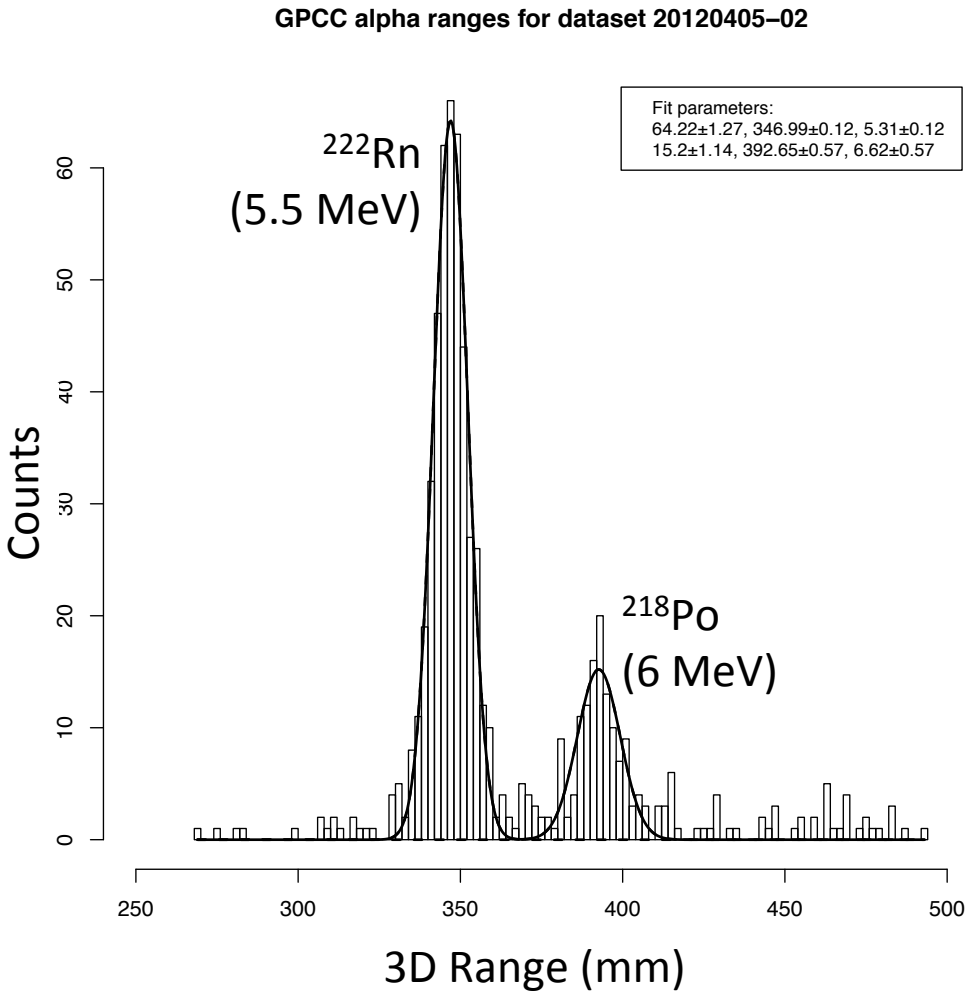
Alpha particle ranges

- x (y) ranges reconstructed based on counting peaks on the anode (grid).
- Each crossing = 2mm, the wire pitch.
- z range = v.drift * Δt



Alpha particle energy vs range from SRIM 2011



Histogram of ^{222}Rn GPCC alpha particles

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Efficiency factor Monte-Carlo simulation

- Use geometrical MC to convert measured radon GPCC rate into the 'true' rate of decay inside the vacuum vessel.
- Generate a population of alpha particle tracks in the 1.5 x 1.5 x 1.5 m vessel.
- Random position, random orientation.

- Calculate fraction of events that satisfy the following criteria:

✓ Fully contained within 896 x 896 x 1000 mm fiducial volume in the centre.

✓ Crossed the cathode plane bisecting the fiducial volume.

✓ $\Delta x > 16$ mm. Corresponds to all anode wires hit.

✓ $\Delta z > 50$ mm. Ensures track is long enough in time to be well-measured.

✓ Track length within 3σ of the radon range peak on the previous slide.

- Resulting MC geometrical efficiency factor for Rn alphas: **0.0267±0.0016**

Effect of gas flow

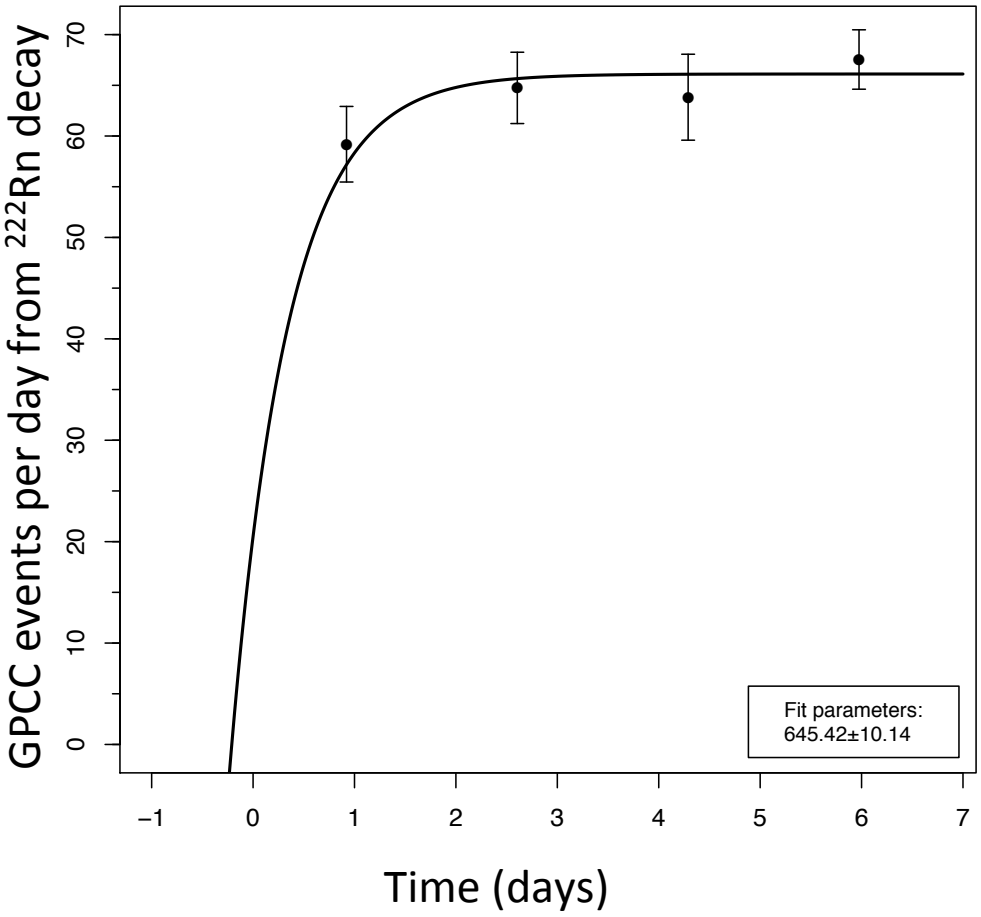
- Under conditions of secular equilibrium with no gas flow:
- $A_{Rn} = D_{Rn}$.
- We have a constant flow rate, and have not yet reached equilibrium:

$$D_x = A_x \frac{1}{1+\frac{\tau_e}{\rho}} \left(1 - \exp\left(\frac{-(t-t_0)}{\tau}\right) \exp\left(\frac{-(t-t_0)}{\rho}\right)\right)^*$$

- t_0= last time vessel was evacuated (-0.21 days)
- τ_e = decay time (5.52 days)
- ρ = flush time (0.63 days)

Fitting this function to the data on the right, we find:

- A_{Rn} = 645±10 x MC efficiency factor
- **A_{rn} = 0.277±0.017 atoms/second**



^{222}Rn GPCC rate as a function of time for the April 2012 dataset

* Burgos et al. 2008

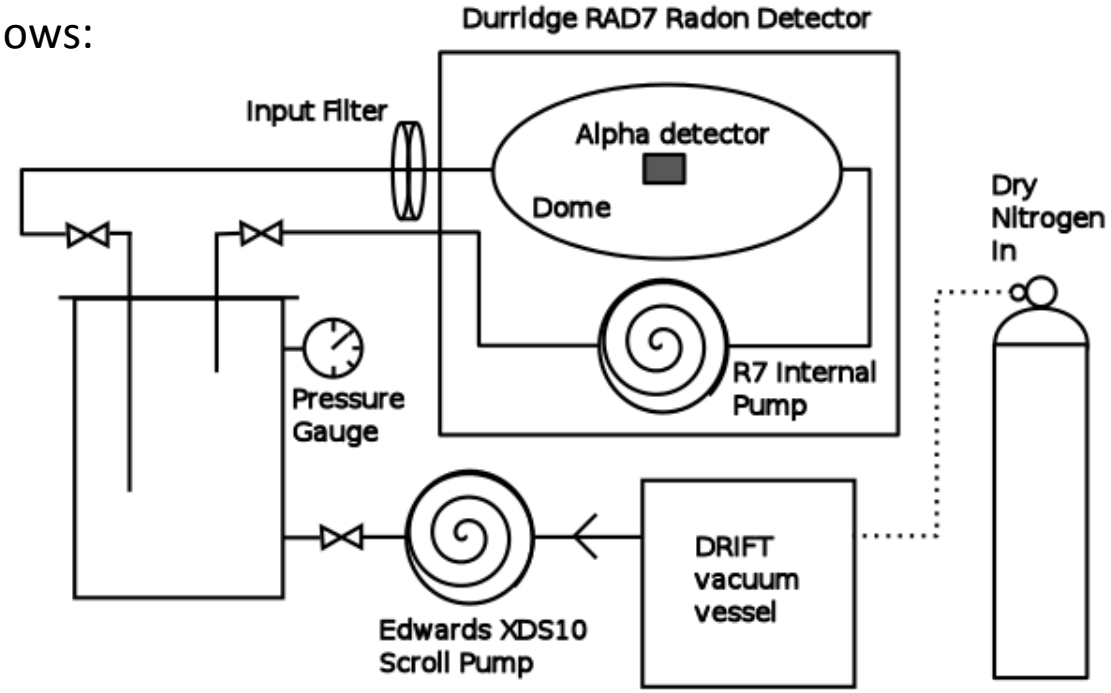
Measuring Rn emanation using an alpha spectrometer

- DRIFT vacuum vessel pumped out and sealed for 1 week to allow radon to emanate.
- Vessel backfilled to 8 torr with dry N2.
- Gas compressed into a smaller volume using a scroll pump.
- Increasing radon concentration increases sensitivity by factor equal to ratio of vessel volumes, or x 100.
- Gas sampled in 12 x 4 hour tests by a Durridge RAD7 radon detector.
- RAD7 uses alpha spectrometry to calculate radon decay rate inside its sensitive volume.

- Raw measured rate/m^3 adjusted as follows:

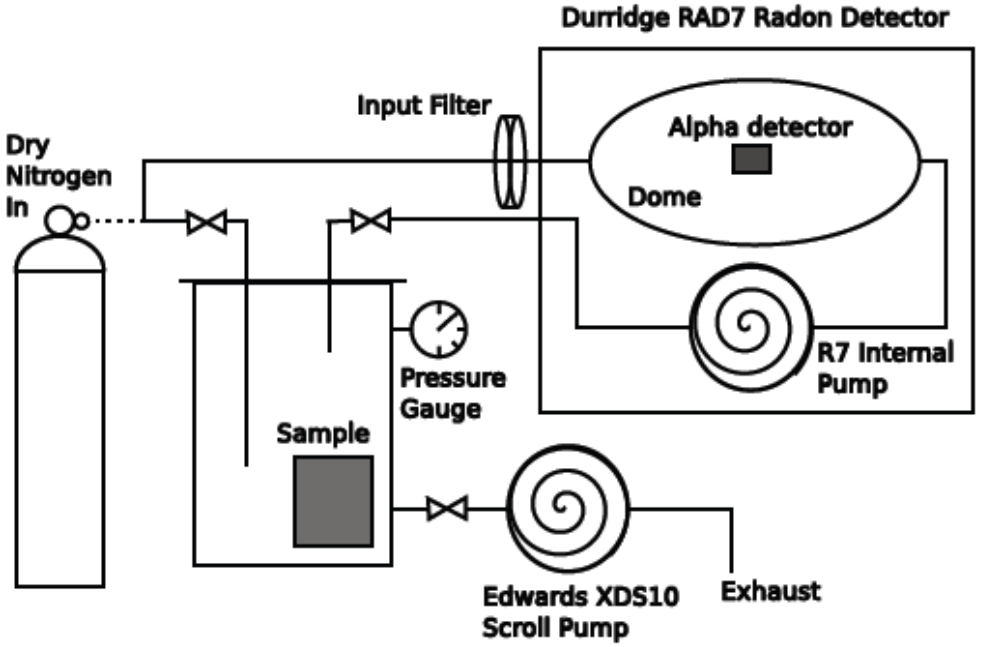
  - Volume correction
  - Emanation time-independent BG sub
  - Humidity correction
  - Emanation time adjustment
  - Decay after concentration adjustment
  - Emanation time dependent BG sub
  - Subtract zero emanation time control

- **A_{rn} = 0.257±0.022 atoms/second**



Identifying the main offenders

- Similar apparatus was used to screen current and proposed DRIFT detector materials for Rn emanation.
- Sample placed into vessel and left to emanate for one week.



Radon emanation screening apparatus

- Same set of corrections applied, excepting the ‘decay after concentration adjustment’.

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Results

Sample	Rn emanation (atoms/s)	Scaling & notes
Nitrile O-ring	0.0602 ± 0.0068	$\times 0.5$.
Black HV cables	0.1069 ± 0.0134	None, full set tested.
Rubber bungs (old)	0.0333 ± 0.0027	$\times 2$ and $\times 0.718$. $\frac{1}{2}$ number of bungs.
Aluminized Mylar	0.0076 ± 0.0046	$\times 2$. Sample was $\frac{1}{2}$ cathode area.
Electronics boxes [1]	0.05 ± 0.01	None
FEP ribbon cables [1]	0.00 ± 0.02	None
PTFE signal cables [1]	0.00 ± 0.02	None
Total	0.258 ± 0.034	GPCC implied rate: 0.277 ± 0.017

Detector materials present during April 2012 run

Sample	Rn emanation (atoms/s)	Scaling & notes
Nitrile O-ring	0.0602 ± 0.0068	$\times 0.5$.
White HV cables	0.0053 ± 0.0019	None, full set tested.
20 silicone bungs	0.0129 ± 0.0015	$\times 0.718 \pm 0.028$.
Aluminized Mylar	0.0076 ± 0.0046	$\times 2$. Sample was $\frac{1}{2}$ cathode area.
Electronics boxes [1]	0.05 ± 0.01	None
FEP ribbon cables [1]	0.00 ± 0.02	None
PTFE signal cables [1]	0.00 ± 0.02	None
Total	0.136 ± 0.031	GPCC implied rate: 0.151 ± 0.013

Detector materials present during December 2012 run

[1] Measurements made by another member of the DRIFT collaboration in 2006

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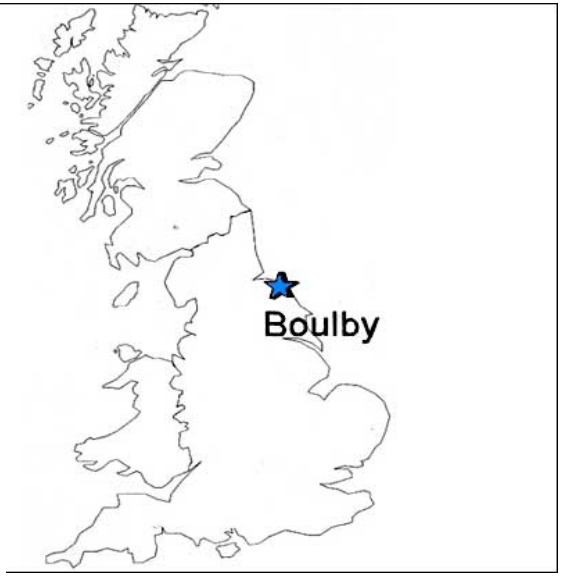
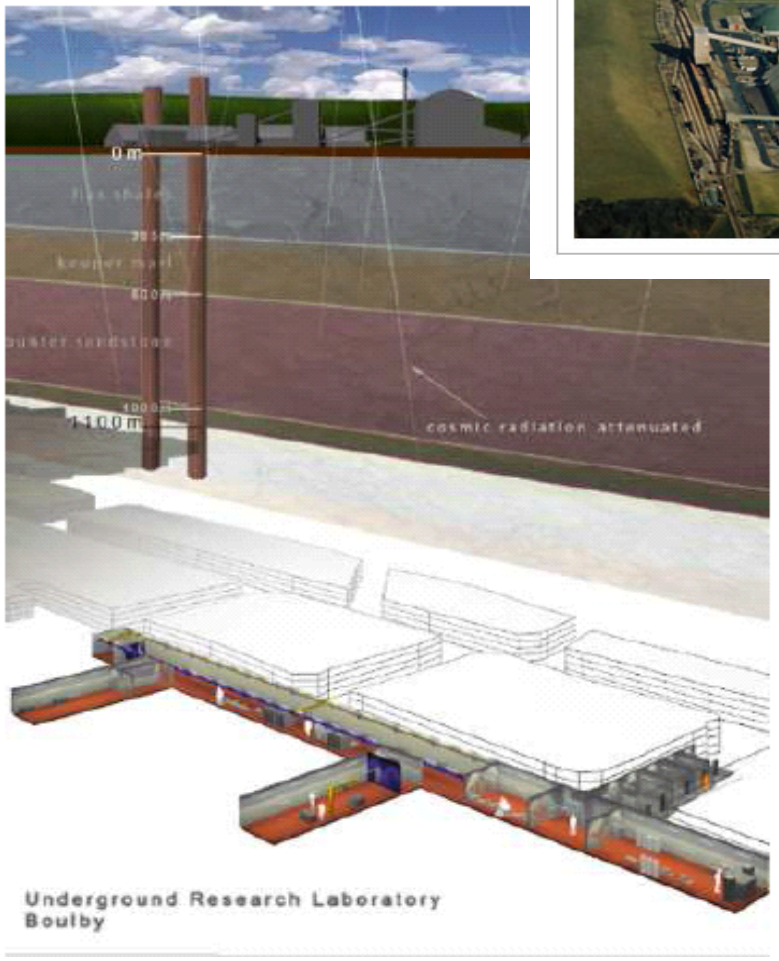
Summary

- Radon emanation rate in DRIFT measured with two completely different techniques.
- Results are in very good agreement.
- Major radon emanators identified. Sum of their emanation rates is in agreement with total. Suggests we have found all the major sources of radon in DRIFT!
- Several radon-hot components replaced (rubber bungs, HV distribution cables).
- New rate agrees with expectation from sum of emanation rates from new materials present in the detector.
- Rate reduced by a factor ~ 2 after some component substitution.
- Results of individual component tests suggest the rate can be reduced by another factor of two with further materials substitution.

Backup - Boulby Mine





- 1.1 km rock overburden (2800 m.w.e).
- Cosmic ray muon flux reduced to 4.1 x 10^{-8} cm^{-2} s^{-1} (Robinson et al., NIM A **511** (2003)).
- Continuing strong support from Cleveland Potash Ltd. going forward towards DRIFT-III.1

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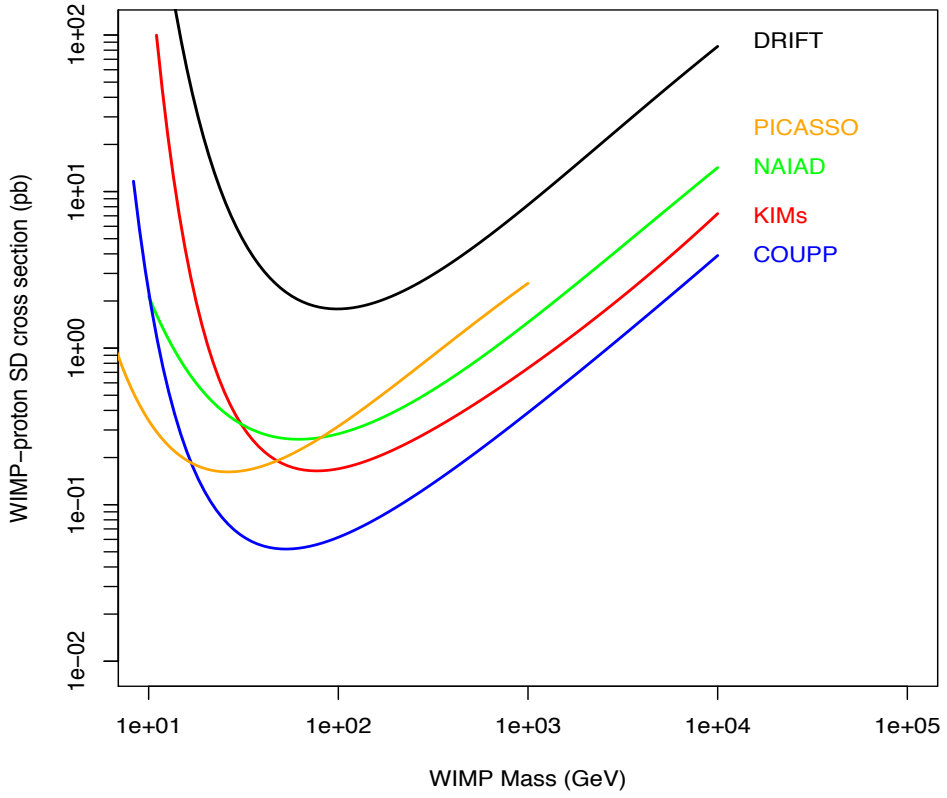
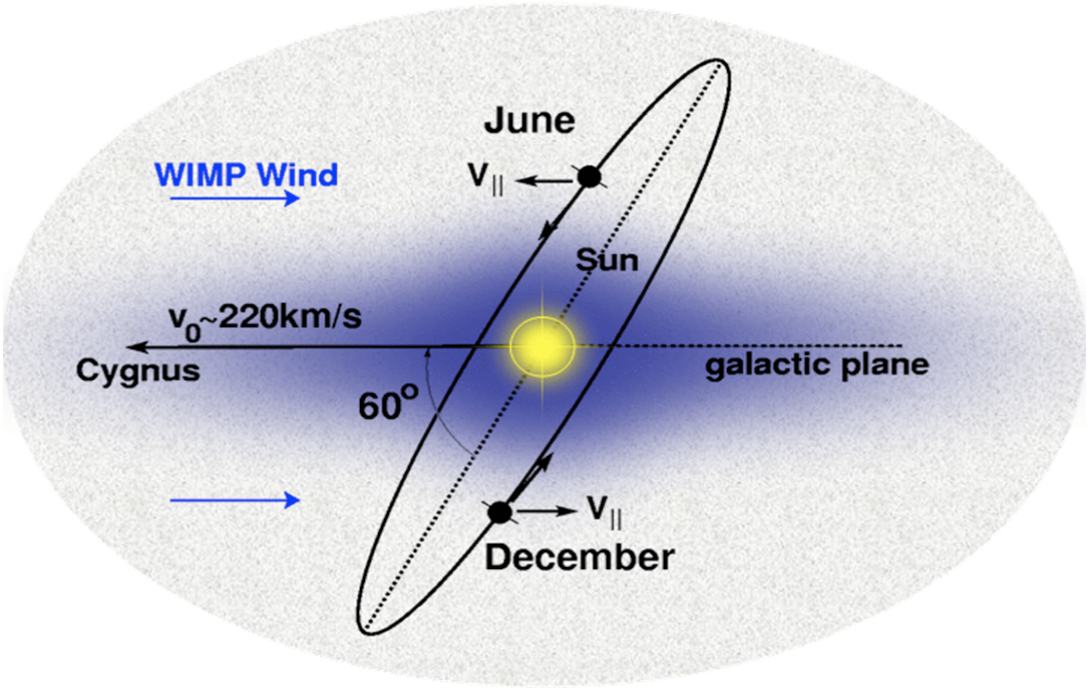
Backup - Current limits

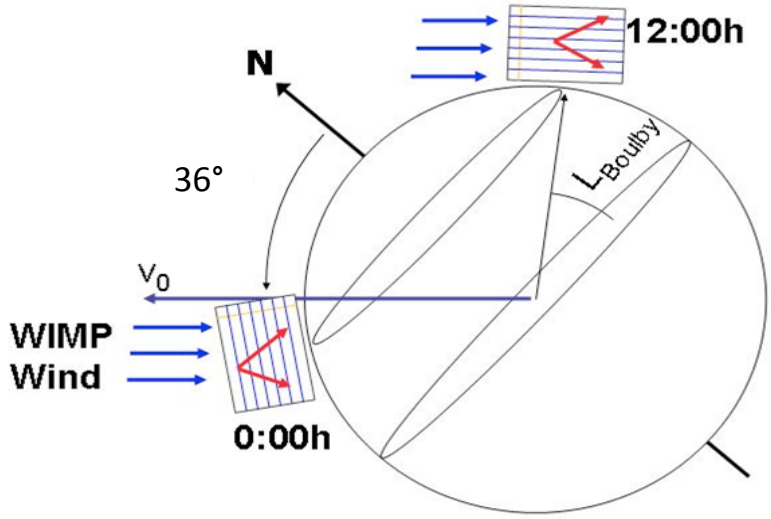
- SD limits from an unblind analysis of 47.4 days of livetime published last year (Daw et al., Astropart. Phys. **35** (2011) 397).
- Plot is from the paper: other experiments' limits may be out of date.



Backup: Directional dark matter detection

- WIMP wind caused by motion of Earth through stationary halo.
- Mean speed ~ 220 km s^{-1} coming from the direction of Cygnus





- Mean direction changes by ~ 90° every 12 hours due to Earth's rotation.
- Order 10 events needed to reject isotropy (Green & Morgan, Astropart. Phys. **27** (2007) 142).