XenonFutures

R&D for a Global Rare Event Observatory

Henrique Araújo, Sergey Burdin, Jim Dobson, Henning Flaecher, Chamkaur Ghag, Maurits van der Grinten, Asher Kaboth, Hans Kraus (PI), Vitaly Kudryavtsev, Christopher McCabe, Pawel Majewski, Alex Murphy, Kimberley Palladino, Tim Sumner, Dan Tovey, Antonin Vacheret

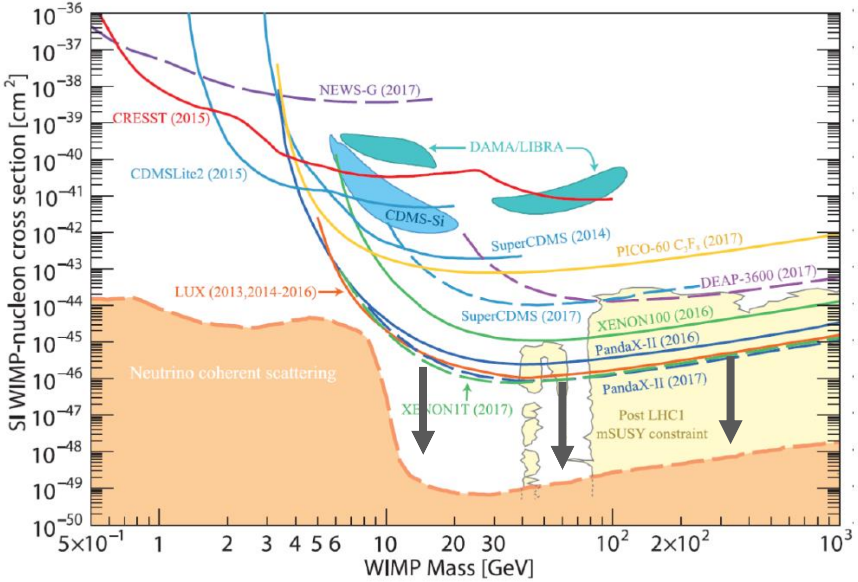
XenonFutures R&D: project aims

A portfolio of opportunities in a next-generation Liquid Xenon Rare Event Observatory as part of a wider global effort

This programme is aimed at:

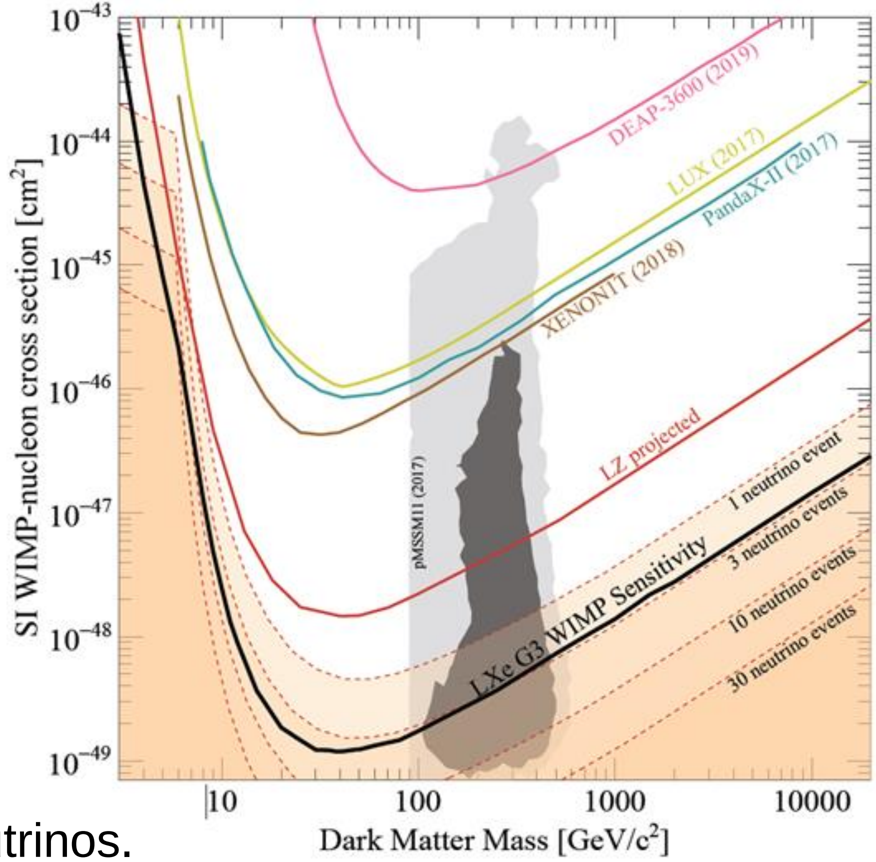
- Observation of Migdal effect from nuclear scattering
- Enhancing liquid xenon technology & readout
- Advanced radiopurity control techniques
- Design studies for a G3 experiment

Science Motivation



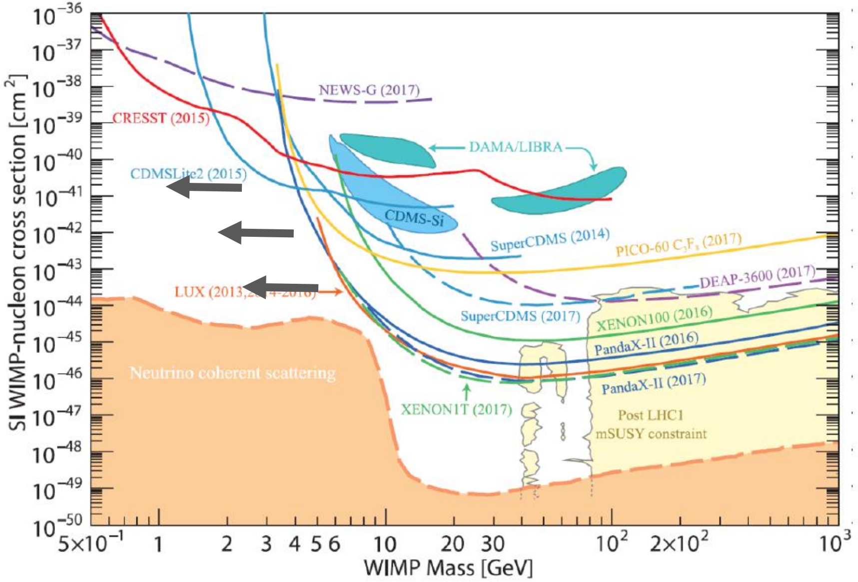
Exploring parameter space down-wards:

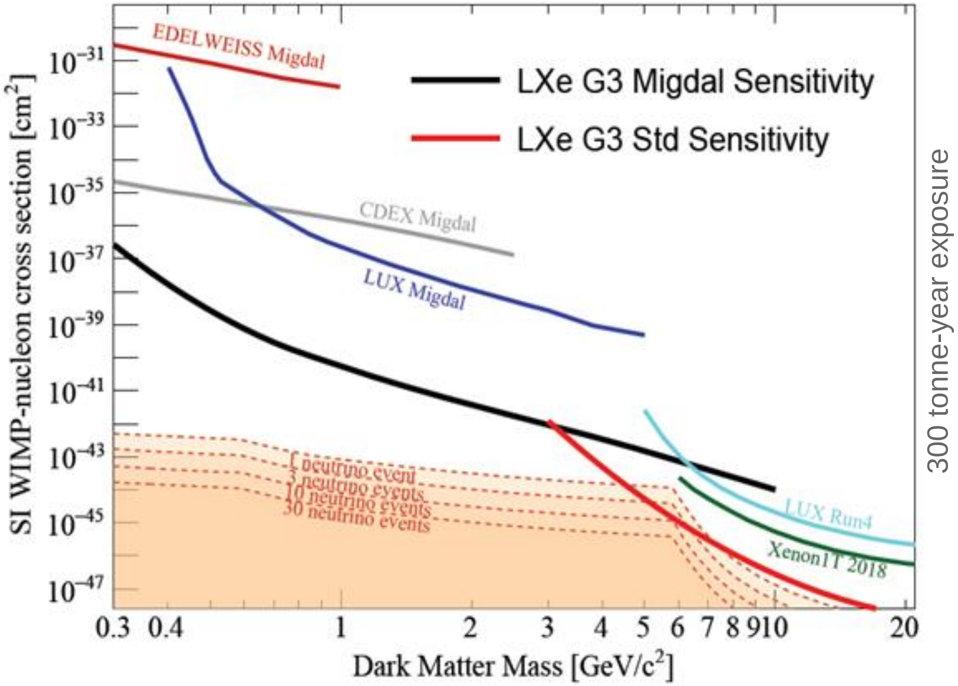
- LXe technology best placed for this.
- Into neutrino fog - as far as practicable.
- Exciting physics through sensitivity and flexibility: SI, SD, EFT, 0NBB, astro-neutrinos.



300 tonne-year, factor 10 reduction LZ Rn

Science Motivation





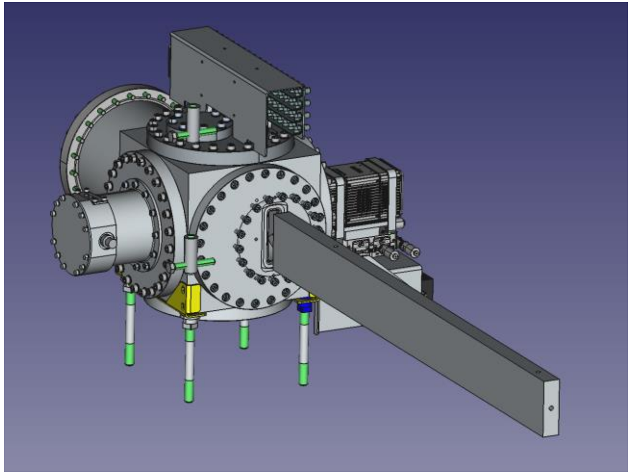
Exploring parameter space left-wards:

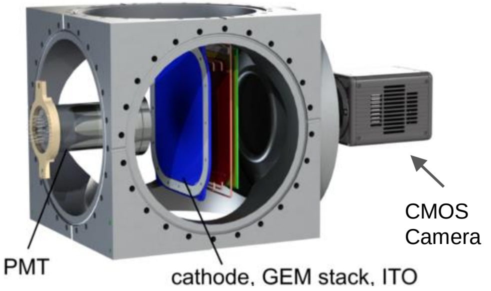
- Very large gains from self-shielding.
- Migdal, S2-only, doping (this R&D).
- New models for non-thermal, hidden-sector, asymmetric, freeze-in DM, Axion-like particles, hidden photons/WISPs, etc.
- Important to pursue DM-electron **and** DM-nuclear scattering capability.

Observation of Migdal effect from Nuclear Scattering

MIGDAL
Migdal In Galactic Dark mAtter expLoration

- Migdal effect should exist - but never verified experimentally in nuclear scattering
- Already used for setting limits at low WIMP mass by major DM experiments including LUX, LZ, XENON 1T, EDELWEISS, CDEX-1B, SENSEI, COSINE
- MIGDAL Collaboration : 40 participants from 11 institutions
- Experiment will use optical imaging w/ low-pressure TPCs filled with CF_4, charge redout by ITO strips and neutrons generators at NILE facility (more from talks by T. Marley and C. Cazzaniga).
- Observation will have impact on entire DM community, for present and future DM experiments.


Detector and front collimator



Optical TPC

University of Birmingham | GDD Gas Detectors Development Group | Helsinki Institute of Physics | Imperial College London | King's College London | LIP | The University of New Mexico | University of Oxford | Royal Holloway University of London | Science & Technology Facilities Council Rutherford Appleton Laboratory | The University Of Sheffield.

Enhancing Liquid Xenon Technology

Scintillation photons (S1)

$$E_{NR} = \frac{W}{\mathcal{L}}\left(n_\gamma + n_e\right) = \frac{W}{\mathcal{L}}\left(\frac{S1}{g_1} + \frac{S2}{g_2}\right)$$

Ionisation electrons (S2)

Pure xenon spectroscopy

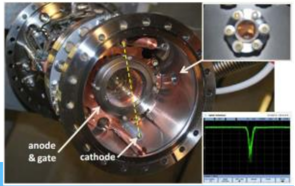
- S1 spectrum well measured, S2 not measured in cold vapour:
  have assumed identical, small systematic on energy reconstruction

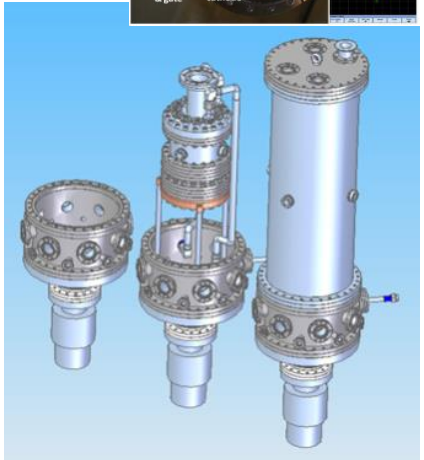
(H2-)doped xenon spectroscopy & transport properties

- Dissolve light elements (e.g. H_2) and exploit excellent response properties and self-shielding of backgrounds provided by host medium (LXe)
- Study S1 and S2 spectra, scintillation/ionisation yields, electron transport
- Imperial, with LIP-Coimbra, RAL + US HydroX groups: UCSB, LBNL, SLAC, ...

Status

- Simple LXe-TPC (gate-anode only) ready to commission (spectroscopy)
- VUV spectrometer coupled through MgF_2 viewports, new calibration sources
- Designed H_2-delivery capability to existing xenon gas handling system
- In parallel, developing more complex small chamber (Xenia)



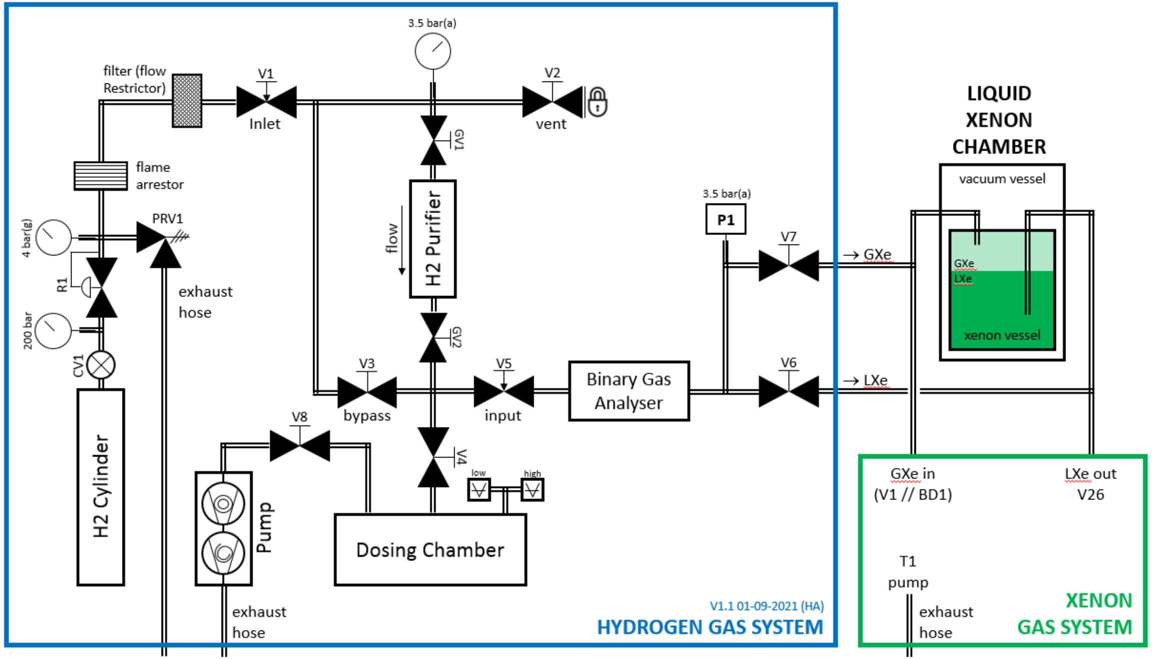


Redesign of
Imperial LXe chamber

Enhancing Liquid Xenon Technology

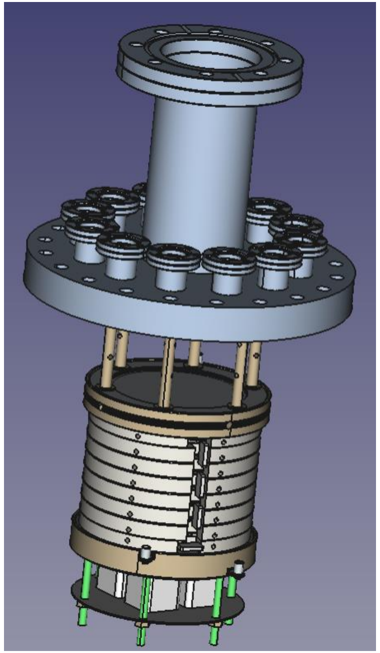
H2 gas system

- Design essentially complete, starting construction
- Preliminary safety approval obtained - the hardest part...

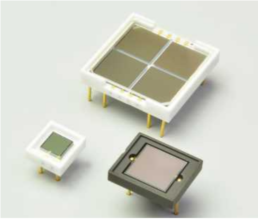


Xenia, “the hospitable”

- Transport properties in H2-doped LXe
- SiPM-array readout
- Design complete, started construction



Development of high-resolution SiPM tile



VUV testing
of Hamamatsu
and FBK devices

Technology

VUV SiPMs behind in development; advancing, but significant task ahead

- PDE at 175 nm, correlated noise, dark noise, thermal cycling, backgrounds, ...
- Full array integration with front-end electronics
- Integrated/scalable designs, assessment in real LXe conditions

Physics

- High spatial resolution at high (MeV) energies - 0NBB, LXe Cherenkov, Migdal in LXe
- Imperial, with RAL, LIP-Coimbra, Oxford, Liverpool, Bristol, UCL

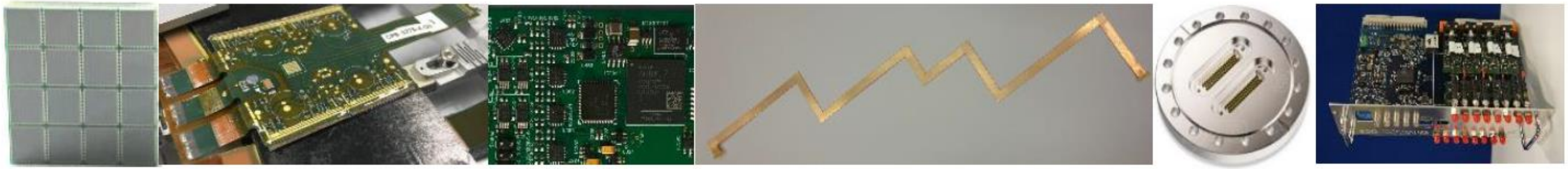
Liquid Xenon Laboratory @Imperial

Xenon handling system

VUV cryostat

Connectors and Interconnects (Liverpool, Oxford)

SiPM | Interconnect | Front-end | Interconnect (15m long) | Feedthrough | Back-end

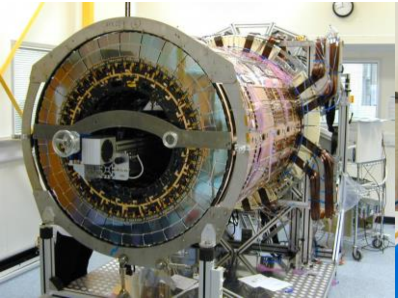


External | WP2.1 / WP4.1 | WP4.2 | WP4.3 | Commercial | WP4.4

Developing end-to-end solution through integrated electronics / interconnect design

- A programme to identify suitable and reliably low-background materials
    - Engaged with tape production companies, material screening in progress
- Development of clean assembly and qualifying procedures
- Focus on delivering low-background multi-pin interconnects

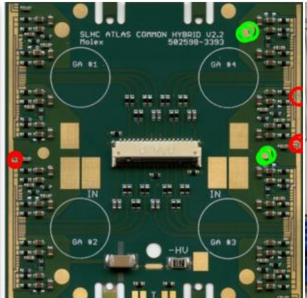
ATLAS SCT EndCap



Modern Workshop

Cleanroom

ATLAS Flex



Adv. Mat. Lab

Cold and Warm Electronics (Oxford, Bristol)

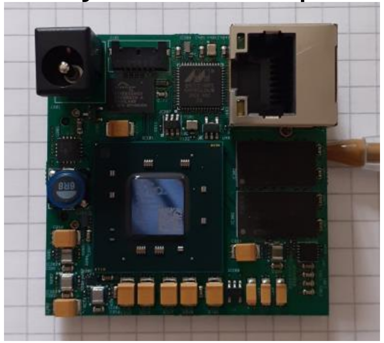
Providing low-background, integrated readout solutions that work reliably

- Standard components
- Liquid xenon temperature not far from mil-spec range
- Providing mature solutions in time for G3

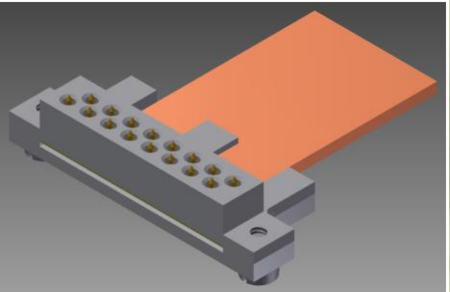
Technical solutions, that are based on an integrated approach

- Radon barrier approach to encapsulate front-end electronics
- Low-background, adaptable connectors - synergy with LAr+others

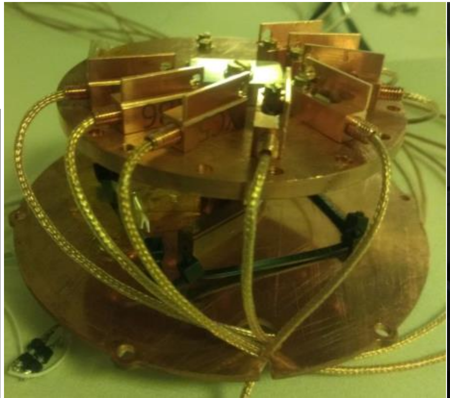
System on Chip



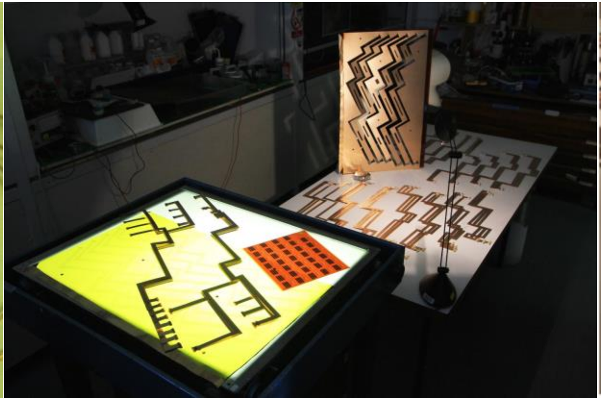
Low-background connector design example



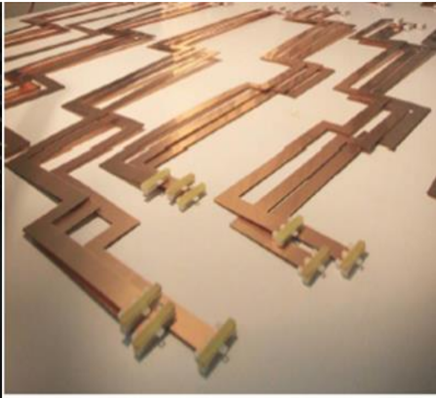
LN2 Cryogenic Test Facility



Laminated Interconnect Manufacturing



EDELWEISS cable



Advanced Radiopurity Control Techniques

Radon levels at G3 must be reduced to **~0.2 μBq/kg**

Requires high sensitivity (<0.1 mBq ^{222}Rn) assay capability and at low temperatures.

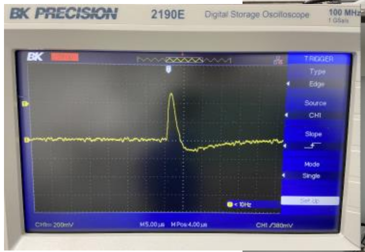
R&D with Cold Radon Emanation Facility (CREF) at RAL to deliver high-sensitivity cryogenic Rn emanation assays

- Material screening
- Mitigation strategies/testing (epoxies, plating, …)
- Radon transport modelling

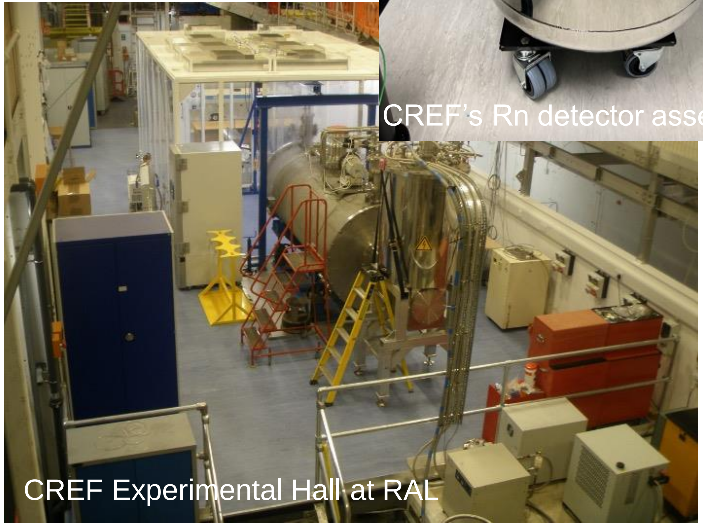
All subsystems (radon concentration line, vessels, cryogenics, detector) are ready for integration

Integration and commissioning of subsystems now

Ops in 2022 for world's first low-T Rn emanation assays



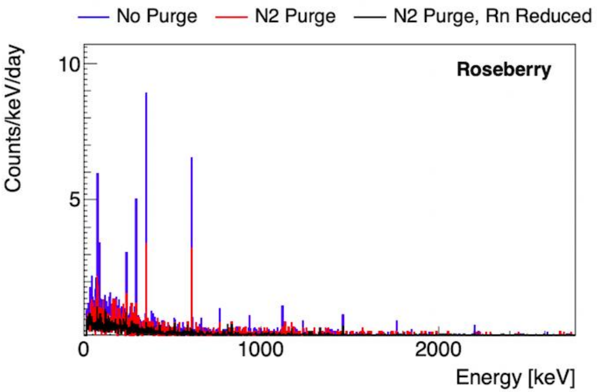

CREF's Rn detector assembly

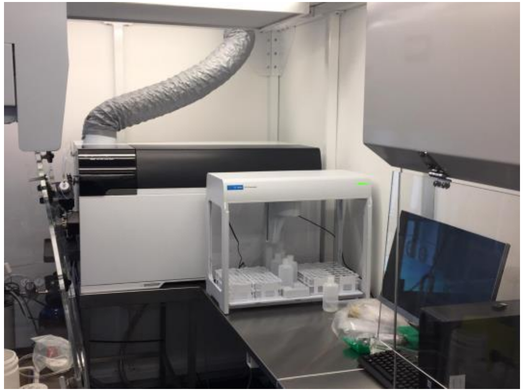

CREF Experimental Hall at RAL

Advanced Radiopurity Control Techniques

5-10x improvement in sensitivity of gamma spectroscopy and mass spectrometry is needed

R&D with BUGS & ICP-MS will deliver world-leading facilities for G3





BUGS detectors after Rn-reduction system installed: will deliver <10 ppt (g/g) sensitivity to ^{238}U & ^{232}Th daughters, complementing already world-leading early ^{238}U and direct ^{210}Pb sensitivity.

World's first SAGe well-type instrument with high resolution and ultra-low background construction, required for mid-late chain ^{238}U & ^{232}Th assays of small materials now being commissioned at Boulby.

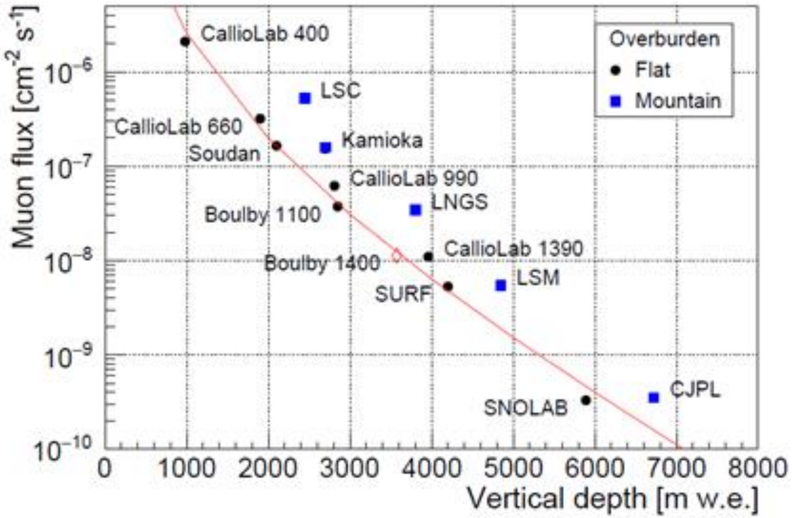
New Agilent 8900 triple-quad ICP-MS system commissioned at UCL with direct sensitivity to <1 ppt (g/g) ^{238}U & ^{232}Th.

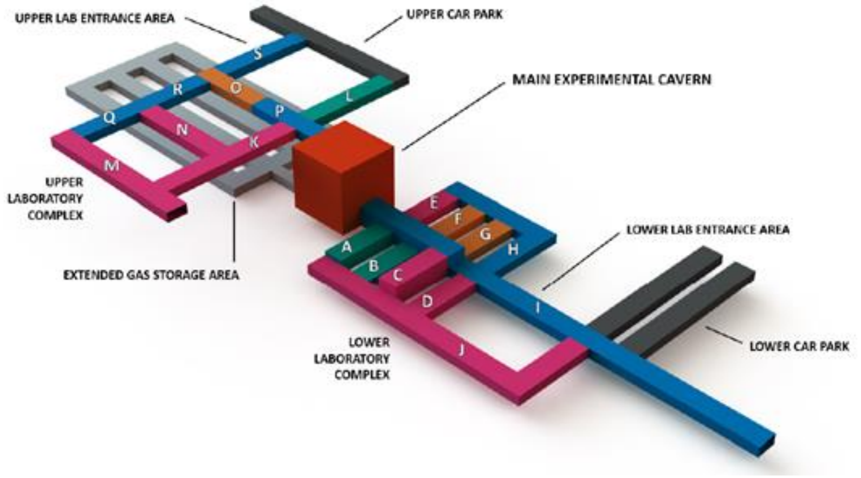
XIA Ultra-Lo, two detectors at Boulby, sensitivity to Rn plate out down to 0.00013 alphas/cm^2/hr already and improving with continuous R&D.

R&D needed to further develop clean sample preparation routines for all key construction materials.

Boulby Underground Laboratory

- Feasibility Study completed and submitted to STFC
- Two underground locations identified as suitable for significant (30,000 m3) development for next generation rare event search experiments
- STFC developing DM roadmap with Boulby as possible focus facility





Label	Use	Level	Length (m)	Width (m)	Height (m)	Area (m^2)	Volume (m^3)	Comments
	Main cavern (cubic)		25	25	25	625	15,625	ODH, ISO7/RR, crane
	Gas recovery/storage	Lower (Sump)	476	8	3.8	3,808	14,470	ODH
	Lower car park	Lower	120	8	3.8	960	3,648	
	Upper car park	Upper	60	8	3.8	480	1,824	
A	Clean manufacture facility	Lower	24	8	5.5	192	1,056	ISO6, RR, crane
B	Precision cleaning facility	Lower	24	8	3.8	192	730	ISO6, RR,
C	Test/staging Facility	Lower	24	8	8.0	192	1,536	ISO7, RR, crane
D	Clean workshop	Lower	24	8	3.8	192	730	ISO7, RR, crane
E	Radon reduction plant	Lower	24	8	3.8	192	730	ISO7
F	Control room	Lower	24	8	3.8	192	730	Sound-proofing
G	Messroom/restrooms	Lower	24	8	3.8	192	730	Sound-proofing
H	Storeroom	Lower	24	8	3.8	192	730	Crane
I	Lower entrance/loading bay	Lower	20	8	3.8	160	608	Crane
J	Noble gas storage	Lower	80	8	3.8	640	2,432	ODH, ISO7, crane
K	Water treatment plant	Upper	56	8	3.8	448	1,702	ISO7
L	Scintillator plant	Upper	30	8	3.8	240	912	ISO6, RRS
M	Radioassay facility	Upper	30	8	3.8	240	912	ISO7
N	Electronics room	Upper	24	8	3.8	192	730	ISO7
O	Messroom/restrooms	Upper	12	8	3.8	96	365	Sound-proofing
P	Upper gowning area	Upper	12	8	3.8	96	365	
Q	Workshop	Upper	30	8	3.8	240	912	
R	Storeroom/LN2 store	Upper	26	8	3.8	208	790	ODH
S	Upper entrance/loading bay	Upper	30	8	3.8	240	912	Crane
	Total for outfitted spaces[†]							
	With cubic main cavern		542			4,961	33,235	
	With cylindrical main cavern		542			4,827	29,881	

[†] Excluding car parks and extended gas recovery/storage caverns.

Global Liquid Xenon Observatory Collaboration

- Joint workshop XENON/DARWIN and LUX-ZEPLIN (LZ) in April, 200+ attendees
- July 2021: MOU signed by senior researchers from 15 countries and over 70 institutes
- Strong UK representation on newly established Steering Committee

Memorandum of Understanding between members of the XENON/DARWIN and LUX-ZEPLIN Collaborations towards a Next-Generation liquid Xenon Experiment