



Sean Paling
STFC Boulby Underground Science Facility

Astroparticle physics & ultra low background studies



The search for Dark Matter & beyond



Earth and environmental science, Astrobiology and planetary exploration

Boulby Underground Laboratory:
The UK's deep underground science facility. Status, plans and opportunities for growth



Underground lab @ Boulby

Boulby Underground Laboratory:

Status and plans for the UK's deep underground science facility

- About the facility
- Current science programme:
 - Astroparticle physics and Low Background science
 - Earth & Environmental Science
 - Astrobiology & Planetary Exploration Studies
- Future plans:
 - Small, medium & large (Expansion for Future DM/0vBB)

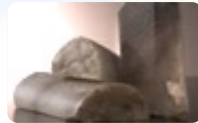
Boulby Underground Laboratory



The UK's deep underground science facility operating in a working polyhalite & salt mine.

1.1km depth (2805 mwe). With low background surrounding rock-salt

Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL

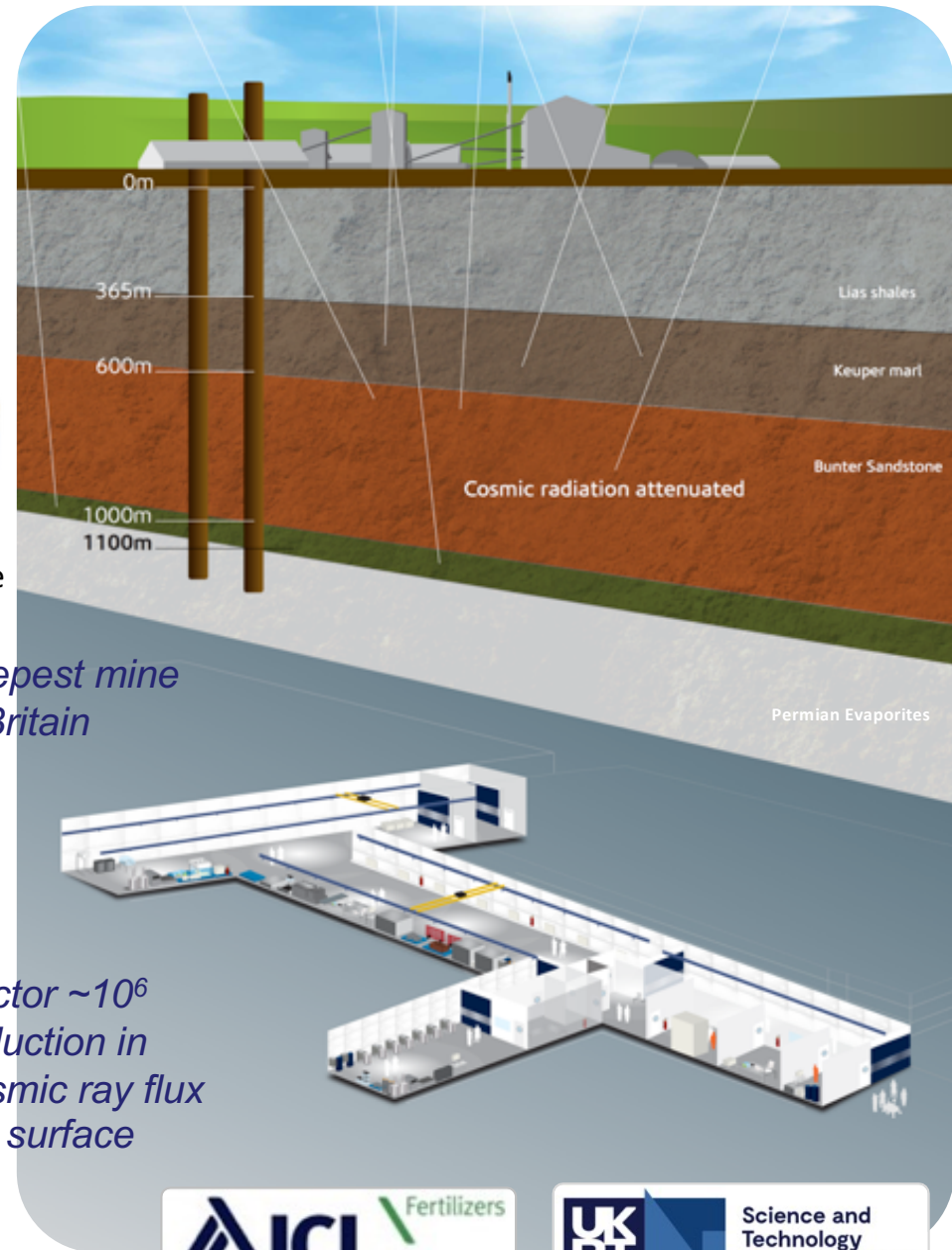


Polyhalite



Deepest mine in Britain

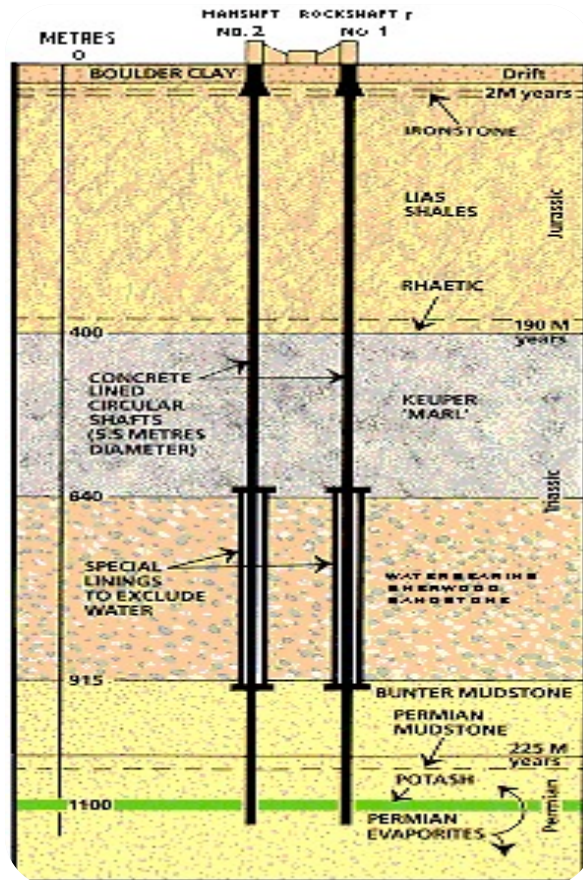
Factor $\sim 10^6$ reduction in cosmic ray flux vs. surface



A **QUIET** place in the Universe

Boulby Geology & Mining

Major local employer. Open since 1968.
Originally mining potash (KCl) for fertiliser.
Now first and only producers of polyhalite
Excavations are in Salt (NaCl) & Potash (KCl) Permian evaporite layers left over from the Zechstein Sea.



Boulby Geology

Potash



KCl

Rock-Salt



NaCl

Polyhalite



$K_2Ca_2Mg(SO_4)_4 \cdot 2H_2O$



Typical Boulby Salt Roadway



Zechstein Sea





Surface support and staging building

Office space, chemistry & clean prep lab, storage and staging space, IT room, conference room,

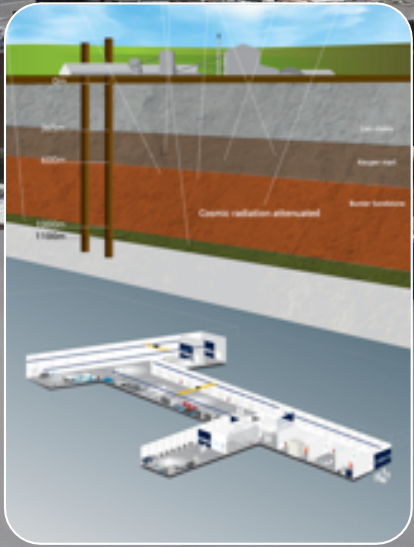


3000m³ Outside Experimentation Area



BUGS+ Material screening

Boulby Underground Lab Facilities 2020:
>4000m³ class 1k & 10k clean room lab space
100Mb Internet AC, Air filtration, 5T & 10T lifting, LN generation, fume hood & clean prep
3000m³ Outside Expt. Area. Power & internet



Underground Science @ Boulby Mine



- DRIFT/CYGNUS: Directional Dark Matter
- Spherical Proportional Counters (NEWS-G) R&D
- BUGS: Ultra-low background material screening
- AWE(Ge): Atmospheric gamma spectroscopy
- RESOURCE: Salt cavity energy storage study
- Deep Carbon: Muon tomography for CCS+
- AIT-NEO: Neutrino detection for nuclear security
- BISAL: Geo-microbiology / Astrobiology studies
- MINAR: Space Exploration Tech. Development
- Etc... (More to come).



ULB screening of LZ PMTs



Life in Boulby salt...



Astrobiology & planetary exploration

A busy & growing multi-disciplinary science programme:
Astrophysics and Low Background science, Earth and Environmental Science, Astrobiology and Planetary Exploration.



Boulby Facility Details...



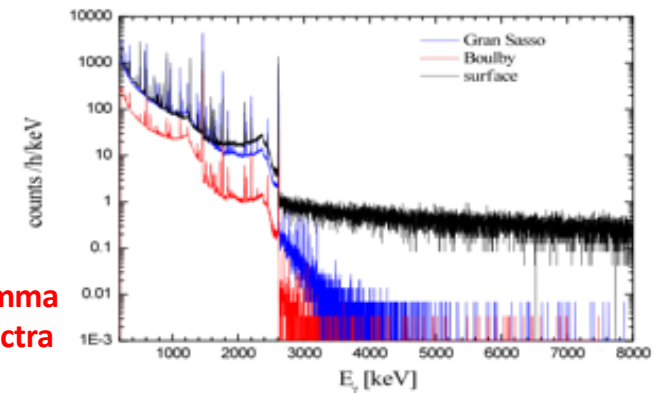
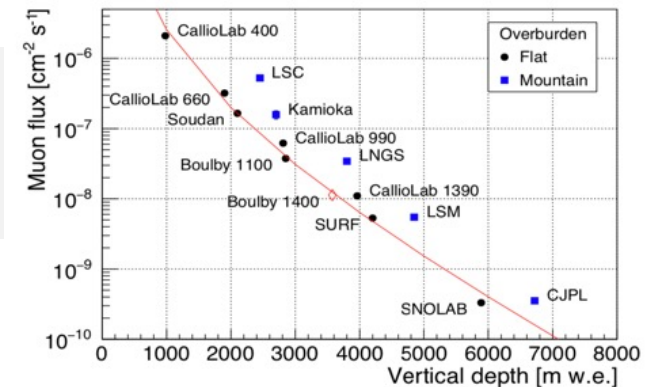
- The UK's deep underground science facility. One of 4 in Europe, <15 in the world.
- Supports work of >10 collaborative projects (astrophysics to climate, geology, environment etc), >40 institutions, >170 scientists & students.
- Facility funded and operated by the Science & Technology Facilities Council (STFC).



- Operations, H&S & science programme managed by 10 (+2) onsite staff and supported by Rutherford Appleton Lab (PPD).
- Mine operators ICL-UK provide wide-ranging operational & high level support.

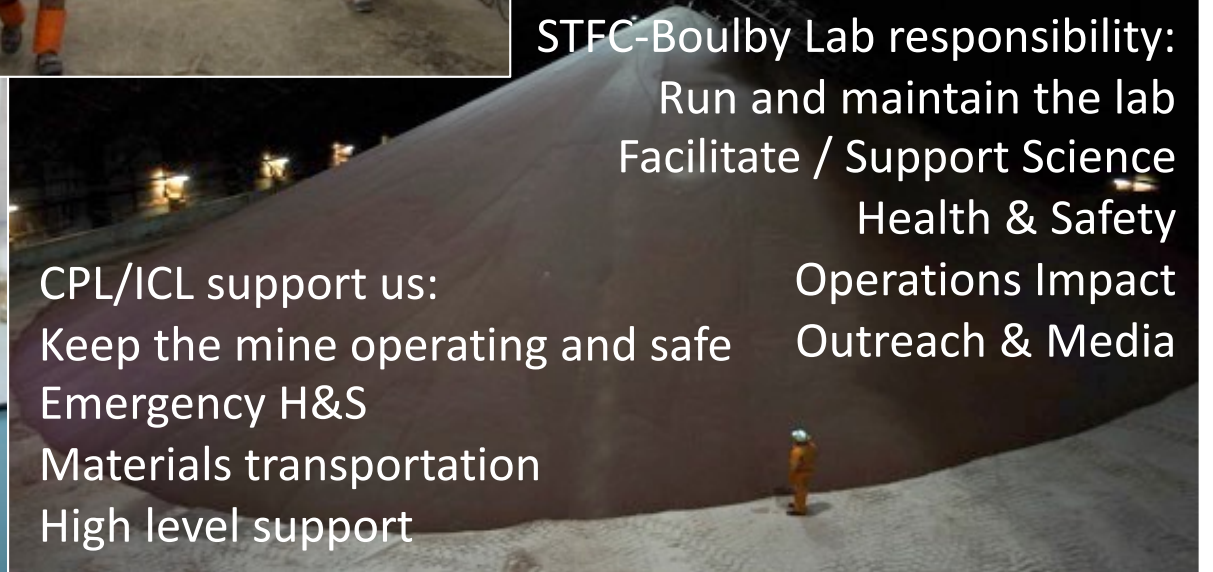
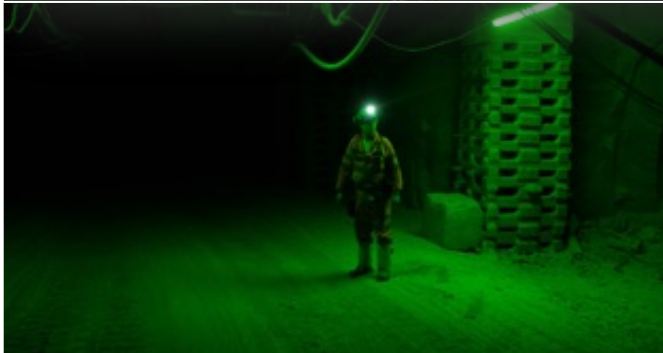
How does Boulby Compare?

- Low Radon levels (3 Bq/m³)
- Diverse science programme.
- Science and Industry partnership



Gamma Spectra

Working alongside mining at Boulby...



STFC-Boulby Lab responsibility:

- Run and maintain the lab
- Facilitate / Support Science
- Health & Safety
- Operations Impact
- Outreach & Media

CPL/ICL support us:

- Keep the mine operating and safe
- Emergency H&S
- Materials transportation
- High level support

Boulby Underground Laboratory:

Status and plans for the UK's deep underground science facility

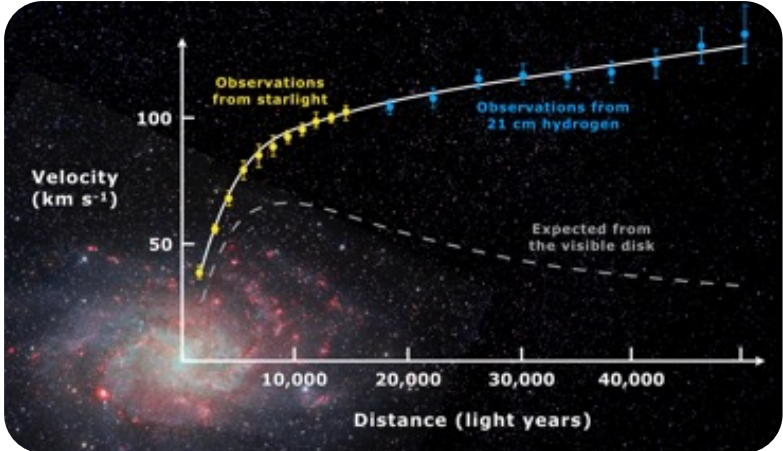
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Boulby Dark Matter Studies...

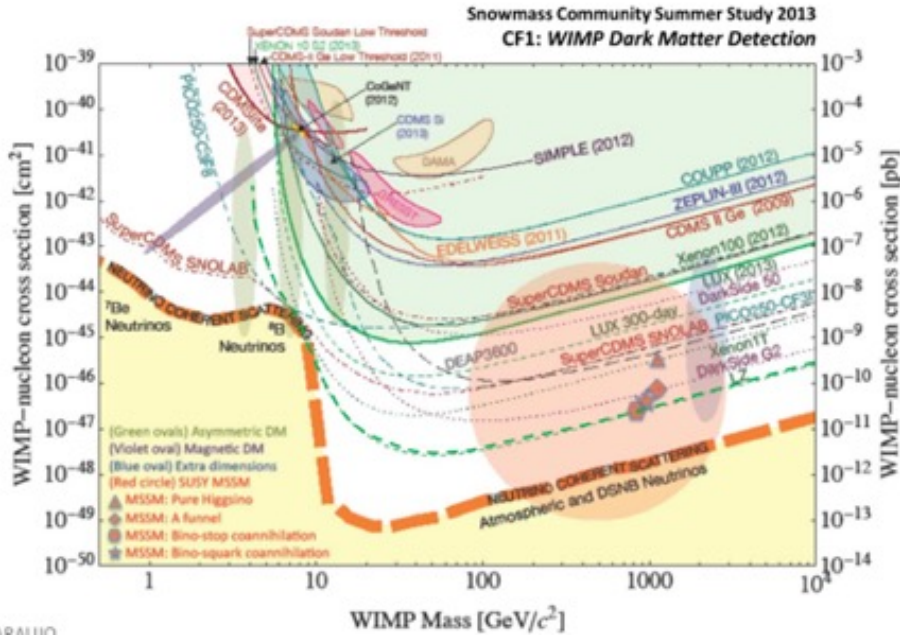


Boulby has hosted **Dark Matter search** studies for over two decades. Including the **NAIAD**, **DRIFT & ZEPLIN** experiment programmes.

Boulby now hosts CYGNUS directional DM programme, NEWS-G/Dark-Sphere R&D and providing ULB material screening for other studies, inc **LUX-ZEPLIN (LZ)**



Galactic rotation curves



ZEPLIN-II & III:
The world's first 2-phase Xenon dark matter detectors (Finished 2011)



World DM particle search limits and future projections

ZEPLIN-III @ Boulby



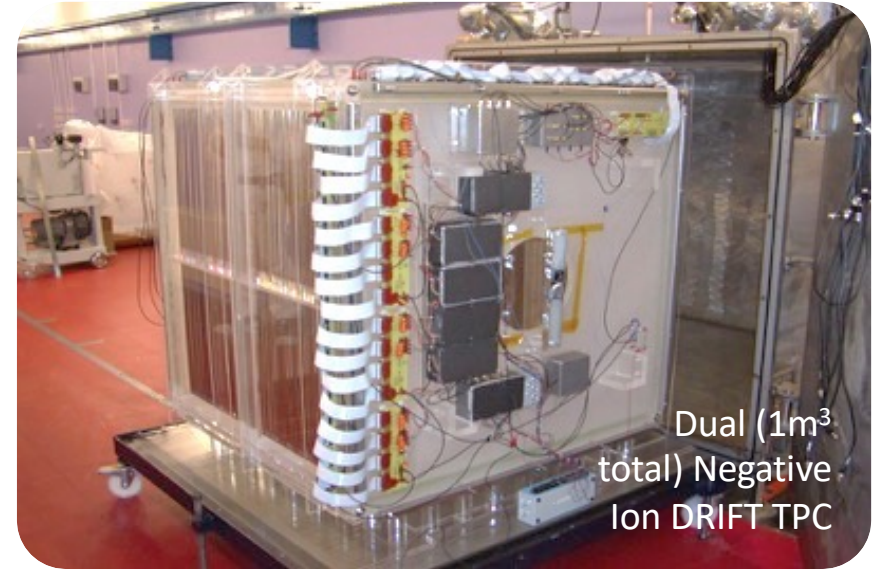
Dark Matter Studies @ Boulby.

DRIFT/CYGNUS: R&D for DIRECTIONAL Dark Matter detection.

STATUS: Programme operating at Boulby since 2001. Limit-setting and conducting system performance & scale-up R&D. Plans for further R&D & expansion / collaboration (**CYGNUS**).



Status: CYGNUS detector R&D, exploring issues and technologies for future scale-up

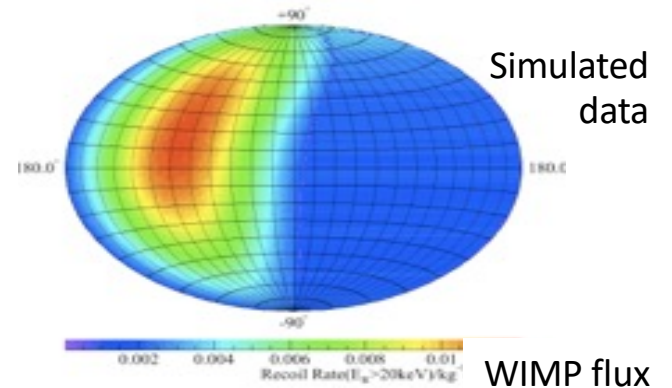


DRIFT-11d @ Boulby

Dual (1m³ total) Negative Ion DRIFT TPC

Directional detection

Occidental College,
New Mexico,
Colorado State,
Hawaii, Wellesley,
Sheffield,
Edinburgh, Boulby

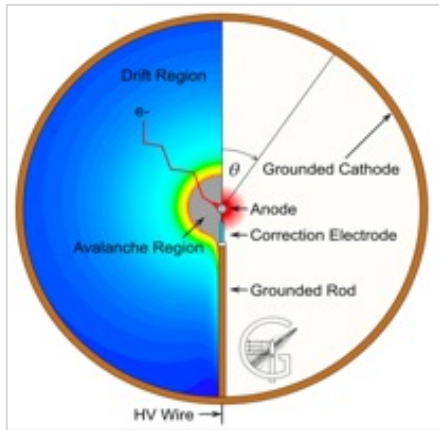


Directional DM detection – providing the most powerful direct detection signature

NEWS-G

Spherical Proportional Counter (SPC) studies @ Boulby

*k. Nikolopoulos
I. Katsioulas, P. Knights, T. Need, R. Ward
University of Birmingham
And wider NEWS-G Collab.*



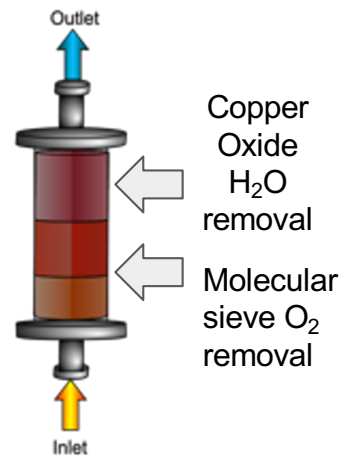
SPC concept: Variable target
Low E_{th} , Low mass sensitivity

Simulation study of neutron interactions in the S30 at Boulby



AI-S30 R&D Detector

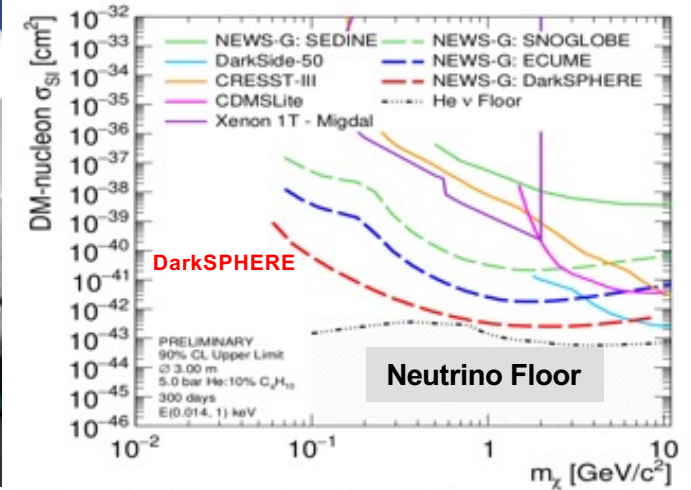
Purpose-made gas filter



11-anode sensor



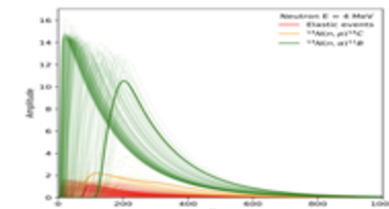
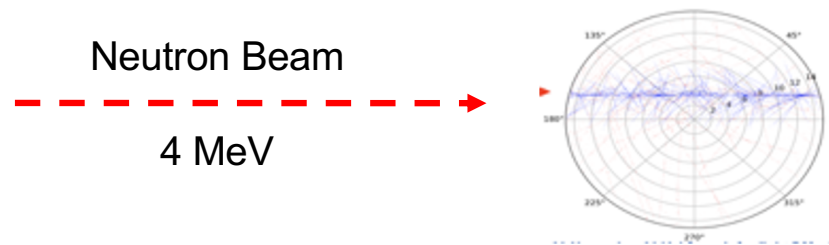
SPC Sensitivities

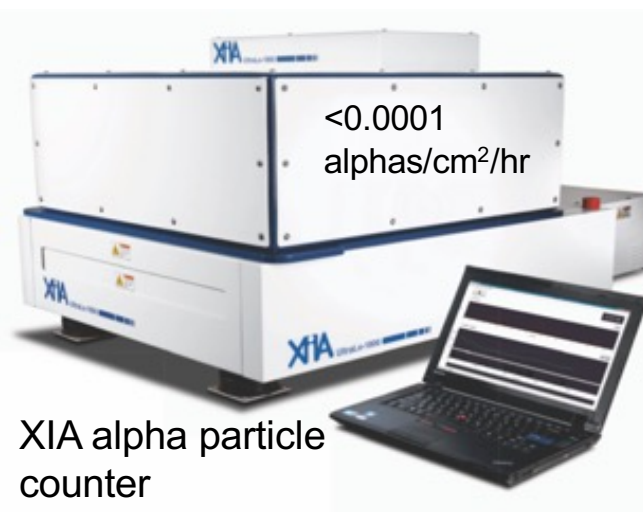


Direction of R&D at Boulby

- Instrumentation development alongside NEWS-G at SNOLAB
 - Multi-anode sensor
 - Gas mixtures & filtration
- Working towards scaled-up detector at Boulby, 3m diam. **DarkSPHERE**
- Establishing **Electro-forming Capability** at Boulby for Dark SPHERE and beyond

(*I. Katsioulas, This conf.*)

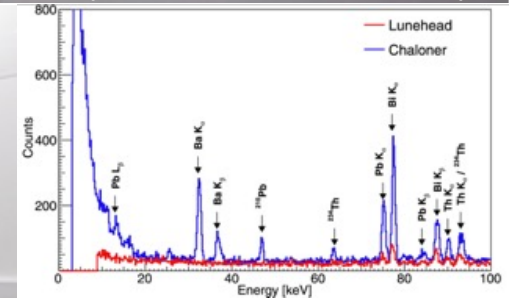




(XinRan Liu, this conf).



8 ULB Ge detector systems, 2 XIA alpha counters, Rn emanation, ICPMS to come



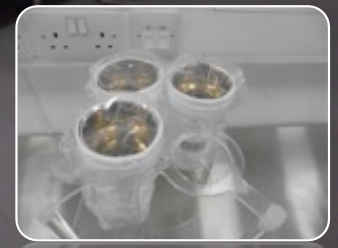
BUGS (Boulby UnderGround Screening). World-class material screening for current and future ULB experiments. Towards PPT sensitivity for G3 DM and Neutrino experiments



LZ PMTs



Aiming for **ALL** key ULB screening systems under one (1.1km) roof.



Multi-Disciplinary Studies

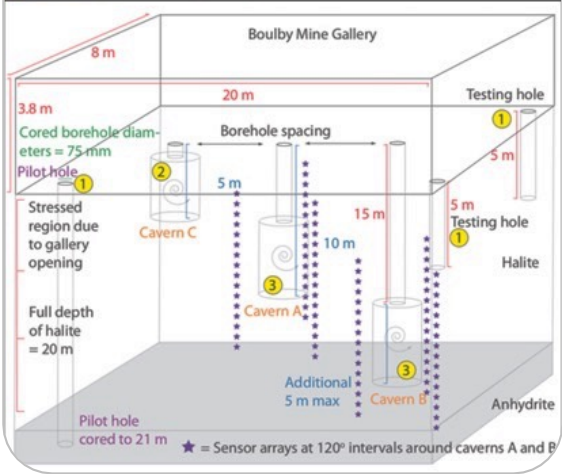


ERSaB: Gamma spectroscopy & low background counting environmental radioactivity studies

Boulby, Scottish Universities Env. Research Ctr (SUERC), Atomic Weapons Estab. (AWE)

RESOURCE: Rock engineering feasibility study of salt cavity compressed gas sustainable energy storage

Boulby, British Geology Survey (BGS), Cambridge, Manchester.



Low Background Science, Earth & Environment Science, Astrobiology & Planetary Exploration...



STFC Boulby April 2022

MINAR: Space Technology Development

Boulby, Edinburgh, NASA, York, ICL etc.

Plus Misc. Geology & Geoscience (& more to come)...



BISAL: Astrobiology / Geo-microbiology. Studies of life in salt, life on Earth & beyond



MINAR V. 9th to 20th October 2017

MINAR 5

Overall objectives:

- To test instruments and methods for the subsurface exploration of the Moon and Mars.
- To develop new educational material.

MINAR – Pac Man, HABIT & many more

Main accomplishments:

- Testing of life detection equipment and planetary exploration instruments from: NASA JPL, NASA Ames, University of Leicester, Space-X Institution, University of Newcastle, University of Edinburgh, Luleå University of Technology.
- Development of education materials on planetary exploration at primary and secondary school level.
- Training of ESA Astronaut, Matthias Maurer.
- Life links from Boulby with up to 38,000 views.
- Live link with Kalam Centre, India



MINAR - SPLIT



MINAR - Pancam



 Boulby Underground Laboratory shared UK Centre for Astrobiology's live video. Published by Emma Meehan [?] · 17 October ·



14,955 Views

UK Centre for Astrobiology was live.



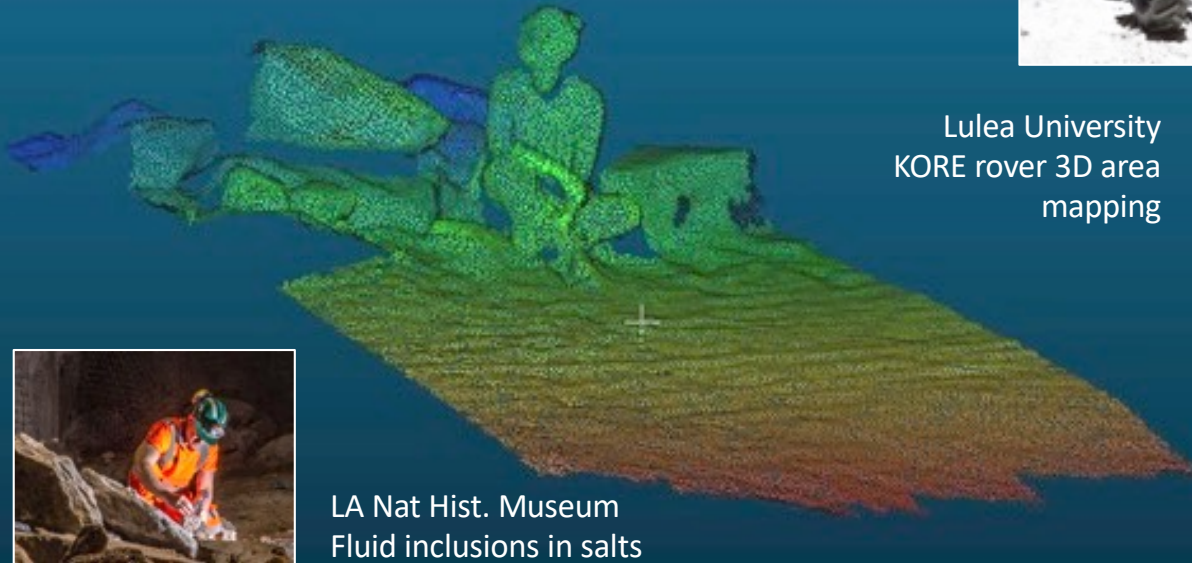
MINAR VII & VIII. 2018 - 2020



NASA-JPL
Signatures of life studies



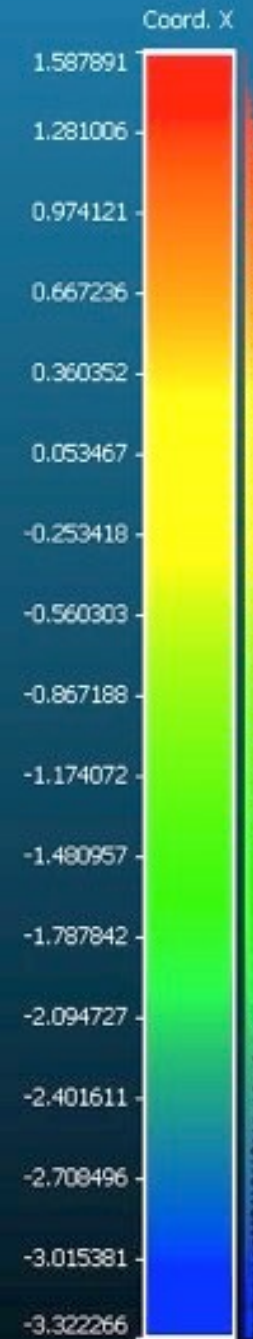
Lulea University
KORE rover 3D area
mapping



LA Nat Hist. Museum
Fluid inclusions in salts



Edinburgh University
MUFFHINS water activity
monitoring payload



Boulby Growth Potential & Plans....



Develop as a truly internationally-important centre for astro-particle physics and pure and applied multi-disciplinary science.

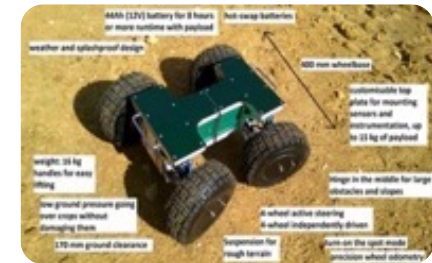
- **Expand in all current science theme areas:**
 - Astro-particle Physics & Low Background Science
 - Earth & Environmental Science
 - Astrobiology & Planetary Exploration Studies
- **For Astro-particle Physics & Low Background Science:**
 - Develop BUGS to give world's best support for future ULB projects
 - Host/support new medium-scale projects: (BOLEYN, DarkSPHERE+)
 - **EXPAND** to host Next Generation Dark Matter & Rare Event Studies & more.

Find out more:
@BoulbyLab
www.stfc.ac.uk/boulby

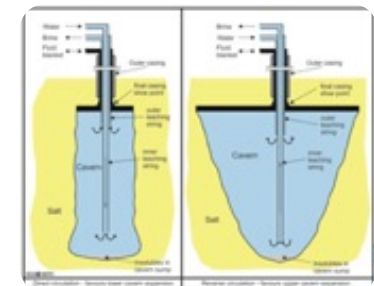
Future Science...

Continue current studies, PLUS...

- Expanded **MINAR & Planetary exploration technology** development. Links to mining / industry, **Robotics**.
- **RESOURCE+**: Advanced salt cavity test facility for studies of compressed gas energy storage.
- Misc. Geoscience R&D: **geological repositories / waste containment, geothermal energy** and more.
- **BUGS+**: Expanding ultra low background material screening and environmental gamma spectroscopy.
- Misc. applied low background studies: **AWE-Ge/RECON, Muon Tomography, QCLB** (Quantum Computing)
- Misc: medium scale astro-particle studies: **DarkSPHERE, AION, LEGEND, AIT-NEO / BOLEYN,**
- Large scale EXPANSION: **Next Gen DM / $0\nu\beta\beta$ decay +**



Robotics



RESOURCE: Salt cavity energy storage



Develop as a truly multi-disciplinary facility for **Astrophysics and Low Background science, Earth and Environmental Science, Astrobiology and Planetary Exploration Technology Development.**



AIT-NEO (WATCHMAN)

World
antineutrino
flux levels



A WATER Cherenkov Monitor of ANtineutrinos

Design,
excavation,
installation &
operation 2019
to 2027(+)

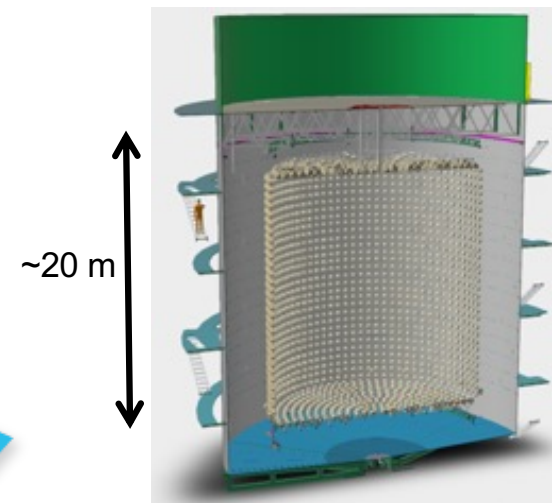
HARTLEPOOL REACTORS



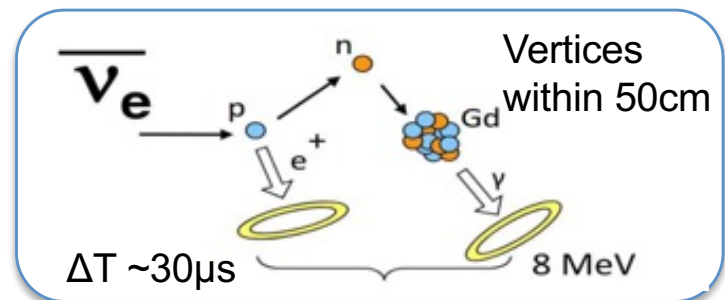
- 2 cores
- 1570 MWt per core
- 25 km standoff



WATCHMAN detector at the Boulby mine

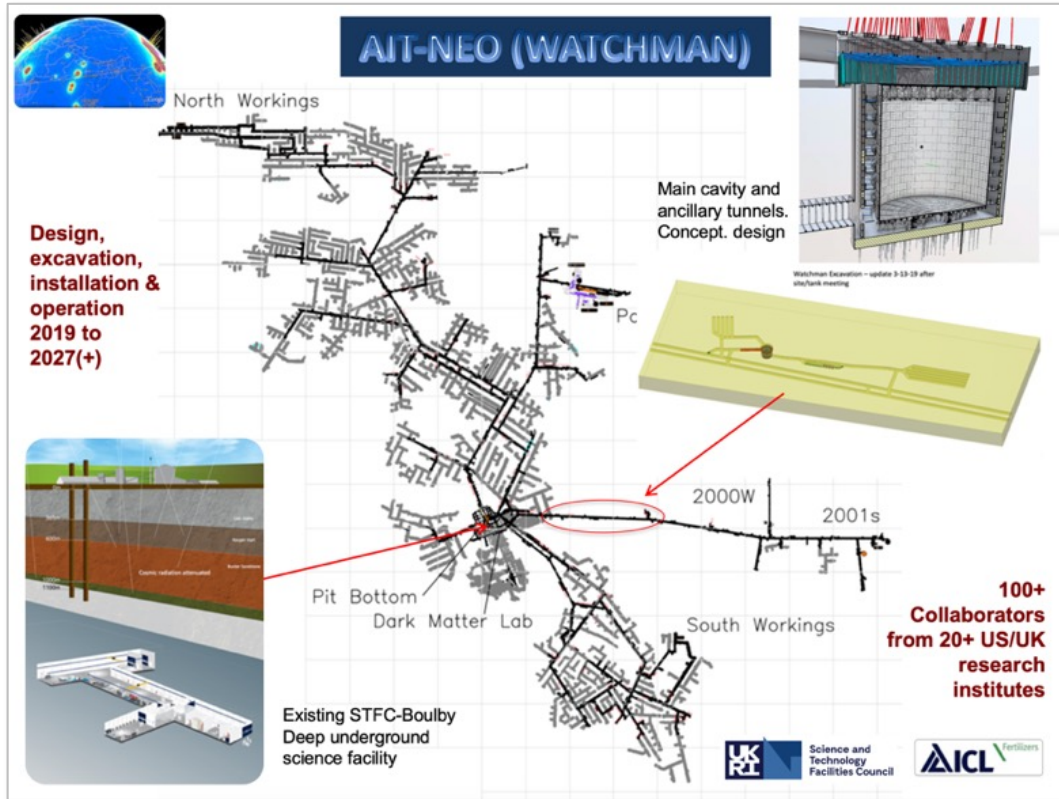


A ~6kT Gd-loaded water (& WBLs) detector looking at anti-neutrinos from nearby nuclear reactors



NEW ~6kT prototype detector: R&D for anti-neutrino monitoring of nuclear reactors for global nuclear non-proliferation purposes & more

AIT-NEO (WATCHMAN) Status...



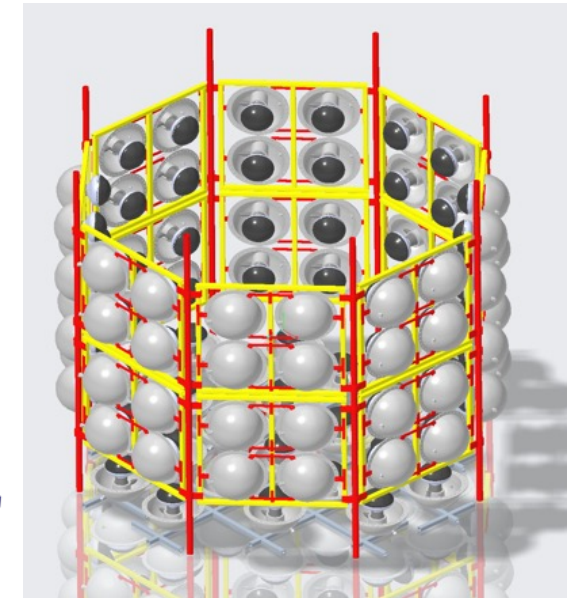
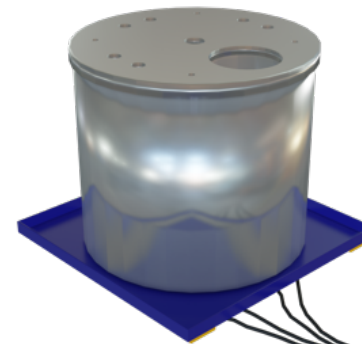
AIT-NEO recent happenings:

- **2018-Present:** Detector design and performance studies. (L. Kneale, C. Toth, S. Wilson, Y Schellback). Studies of new site location, geology, designs, costs and schedule
- **June 2021:** NEW news from EDF of **Hartlepool closure in 2024** due to new understanding of aging rates.
- **December 2021:** News of **early closure (2028) of next nearest power stations** (Heysham 2 and Torness).

Status & Next Steps

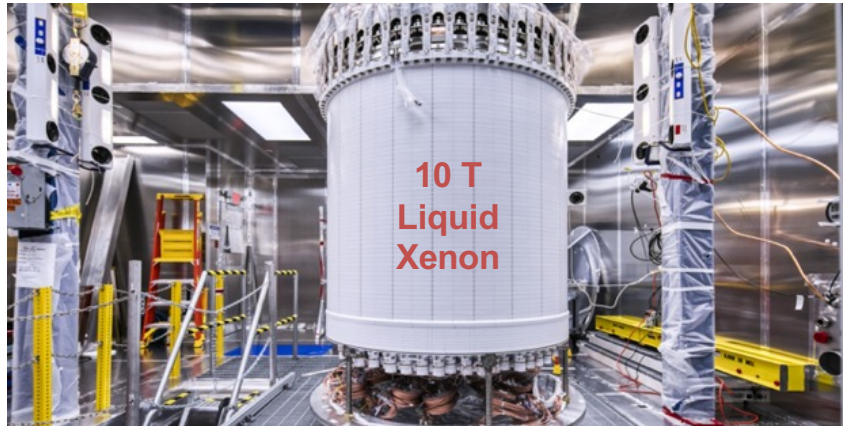
- Full AIT-NEO now not likely to go ahead at Boulby
- Continued collaborative (US/UK) work undertaken on technology demonstrators – inc 30T system @ Boulby
- **‘BOLEYN’:** Boulby antineutrino detection technology testbed. Engineering, operation, technology, fill medium and low-background studies.
- Installation → operation @ Boulby: 2022-2024

BOLEYN.
~30T antineutrino
technology
testbed.
. (A Scarff, this
conference)



Next Generation Rare Event Studies @ Boulby

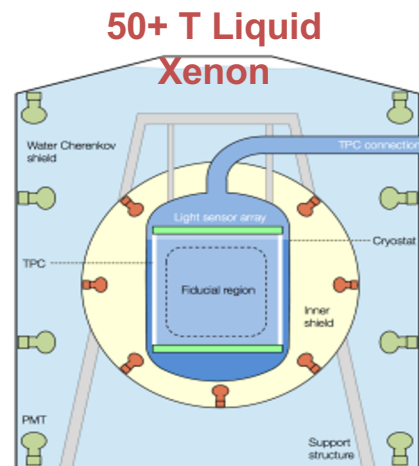
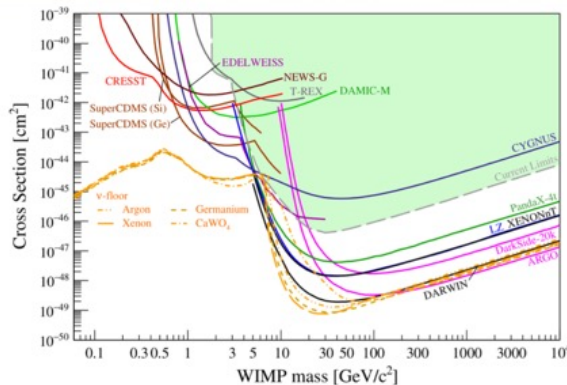
Towards EXPANDING Boulby to host MAJOR international Dark Matter, neutrino & fundamental science projects from 2028+



LZ, SURF, USA



Boulby-FS study:
Infrastructure design, feasibility & costing studies for next generation Dark Matter and/or 0νββ detectors
Study undertaken 2020-2021



E.g. LZ / XENON / DARWIN / G3

Next generation DM and/or 0νββ at Boulby?

Expansion bringing to the UK:

- HIGH-impact, world-leading science
- BIG fundamental science questions
- LARGE multi-national collaborations
- MAJOR local & national investment, impact and visibility

Boulby Feasibility Study (Boulby-FS)

Submitted to STFC June 2021

FINAL REPORT

FEASIBILITY STUDY
FOR DEVELOPING THE BOULBY UNDERGROUND LABORATORY
INTO A FACILITY FOR FUTURE MAJOR
INTERNATIONAL PROJECTS

Supported by the STFC Opportunities Call 2019

H M Araújo¹, J Dobson², C Ghag², S Greenwood³, V A Kudryavtsev⁴, P Majewski³, S M Paling⁵, V Péc⁴, R Saakyan², P R Scovell⁵, N Smith⁶, and T J Sumner^{1*}

¹Imperial College London, UK
²University College London, UK
³STFC Rutherford Appleton Laboratory, UK
⁴University of Sheffield, UK
⁵STFC Boulby Underground Laboratory, UK
⁶SNOLAB, CA
*Corresponding author (t.sumner@imperial.ac.uk)

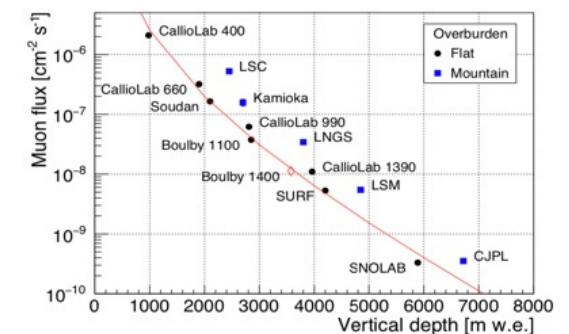
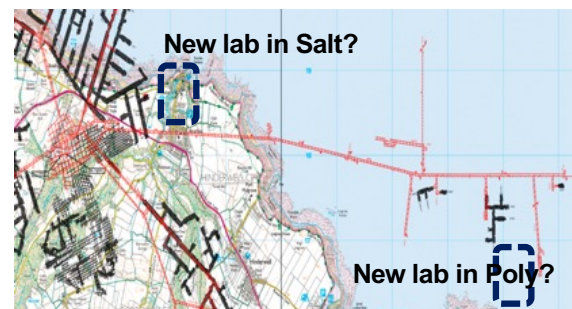
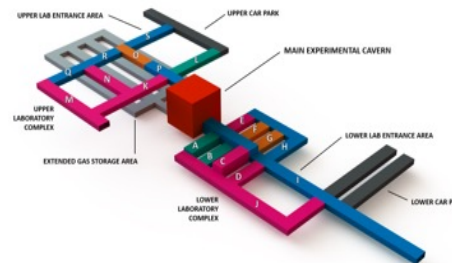
June 25, 2021

Issue v1.0

OFFICIAL-SENSITIVE [COMMERCIAL]

Boulby-FS Study Overview:

- Context and need: Dark Matter (DM), Neutrinoless Double Beta Decay (0νBB)
- Infrastructure specifications for potential projects (LXe & LAr DM, Ge 0νBB, and more)).
- Conceptual designs for excavations and outfitted labs – in 1.1km (Salt) and 1.4km (Polyhalite) layers
- Staffing and surface facility needs.
- Detailed costs and schedules.



Government 'fit': Levelling Up, Strength in Places, Build Back Better

Results: It IS feasible, well motivated and timely.
Outfitted facility: £100m+ (Inc contingency, VAT)

Next Generation Dark Matter(+) @ Boulby?



Status & Next Steps

- Next steps funding request submitted to UKRI in 2021.
- Future (3 year) work includes:
 - Next step facility conceptual designs (1.1km & 1.4km)
 - Scoping, networking, community engagement.
 - Business case, economic impact studies, risks → **Submission to BEIS**

Preliminary details and descriptions	
Name of project (and acronym or short name if relevant)	Boulby Underground Laboratory – Dark Matter and Beyond
Type of infrastructure project	Significant change to existing capability (e.g. major upgrade, new wave of a survey or other data collection activity)
Submitting Council(s)/UKRI team(s)	<input type="checkbox"/> AMRC <input type="checkbox"/> BBSRC <input type="checkbox"/> EPSRC <input type="checkbox"/> ESRC <input type="checkbox"/> Innovate UK <input type="checkbox"/> MRC <input type="checkbox"/> NERC <input type="checkbox"/> Research England <input type="checkbox"/> STFC <input type="checkbox"/> Infrastructure Team <input type="checkbox"/> Large multidisciplinary facilities (STFC managed)
Name(s)	Prof. Sean Paling (WG contact – Alish Woodcock)
UKRI Contact(s) Email address(es)	sean.paling@stfc.ac.uk
Phone number(s)	01287 546300
One-line description of the preliminary activity for use in summary tables to IAC, ExCo, etc. (22 words)	Essential design work, engineering studies and business case preparation for a major uplift in capability of the Boulby Underground Laboratory from 2026.
Long description of the preliminary activity (800 words, please continue to the next box when full – for IAC)	This proposal describes preliminary work required for a major uplift in science infrastructure at Boulby Underground Laboratory from 2026, enabling the UK to host a major new international Dark Matter (DM) detector in the coming decade. The uplift will offer a step-change increase in UK capability and prominence in particle physics and wider underground science and bring the UK truly to the forefront of one of the most important studies in science at a critical time in the field. Boulby is the UK's deep underground science laboratory, 1.1 km deep in a working polyhalite and salt mine in NE England. Boulby is a unique and important national scientific asset, offering vastly reduced levels of cosmic ray and radiological backgrounds necessary for sensitive experiments across disciplines, including DM detection, neutrino and atomic physics, and quantum technologies. The facility also enables access to the unique deep underground environment for wider studies of earth and environmental science and more. Boulby is one of only a few such facilities in the world, including laboratories in USA, Canada and Japan. Although not the deepest or largest amongst these, Boulby has key advantages: it is readily accessible nationally and internationally, the geology is favourable for background levels and construction, and the commercial mining activity enables safe and efficient operation at relatively low cost. Confirming the existence of DM through direct detection is arguably the highest priority question in both particle physics and astronomy. The UK has invested in DM detection for over three decades, with sustained intellectual lead. Current experiments aim to confirm or rule out the hypothesis that DM comprises heavy particles (WIMPs) not included in the Standard Model of particle physics. The key detection technique – dual-phase liquid xenon (LUXe) – was invented by UK scientists and developed at Boulby. This has enabled ground-breaking experiments in other countries, but it is over fifty years since any major experiment in fundamental physics took place on UK soil. Within five years, the current-generation experiments (operating in the USA and Italy) will report on the latest searches for DM – a positive detection would be an epochal event comparable to the discovery of the Higgs boson. Whatever these results, the essential next step will be a larger and more advanced detector – to confirm and broadly expand on early detections, or to continue the search to the ultimate limit imposed by neutrino backgrounds. Cost and complexity will mandate a single 'third-generation Dark Matter detector' (3GDM), with worldwide participation and investment.

Boulby Future: UKRI Bid

Boulby Facilities. The UK's deep underground science facility operating in a working mine in a unique and important national scientific asset giving access to the deep and low environment for studies of astro-particle physics and multi-disciplinary science.

2020 2025 2030

Boulby current science and medium-scale project development

- Astro-particle & Low background Science
- Earth & Environmental Science
- Astrobiology & Planetary Exploration

Boulby Infrastructure development for 3GDM+

Feasibility (Boulby-FS) → Design & Preparation (Infrastructure proposal) → Construction & Outfitting → Site Beneficial Occupancy

Detector development for 3GDM (Rare-event community)

Collaboration / strategy development → Design & Pre-install Construction → Construction & Operate

2025 2030

Boulby current science and medium-scale project development

Infrastructure development for 3GDM+ (Feasibility, Design & Prep, Construction & Outfitting, Site Beneficial Occupancy)

AIT-NEO Development (AIT Conceptual then Final Design, AIT Construction, NEO Installation, NEO Operation)

b) Towards a Major Uplift in Capability. Preliminary work proposed for a major expansion of infrastructure at Boulby, enabling the facility to host a 3rd Generation Dark Matter (3GDM) project and giving a step-change uplift in capabilities for multidisciplinary science, innovation and outreach.

Now seeking community:

- Attention / understanding
- Support..
- Collaboration & involvement...



Thank You....



Sean Paling
STFC Boulby Underground Laboratory

Facebook: [Boulby Underground Laboratory](https://www.facebook.com/BoulbyUndergroundLaboratory)
You Tube: [Boulby Underground Laboratory](https://www.youtube.com/BoulbyUndergroundLaboratory)

Please Contact us...

Email: Boulby@stfc.ac.uk

Web: www.stfc.ac.uk/boulby



Boulby Underground Lab Backgrounds

Cosmic ray muon backgrounds:

Measured as $(3.79 \pm 0.04(\text{stat}) \pm 0.11(\text{sys})) \times 10^{-8} \text{ cm}^{-2} \cdot \text{s}^{-1}$ (2850 \pm 20 mwe)

H. Araujo, et al., Astroparticle Physics 29 (2008) 471–481.

Radon:

Measured as $2.5 \pm 1.6 \text{ Bq}\cdot\text{m}^{-3}$ (year round)

Internal reports (JIF Lab 2015)

Neutrons:

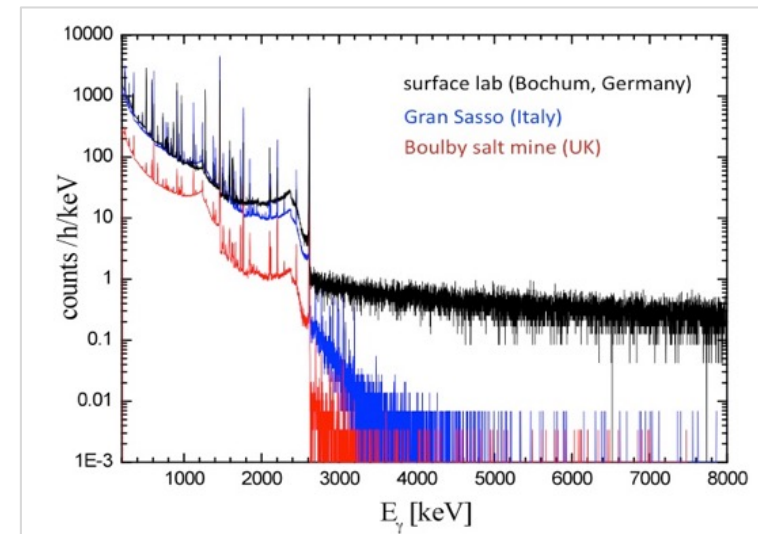
Simulations based on U/Th content:

$1.2 \times 10^{-6} \text{ neutrons}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$ (>500keV @rock/cavern bndry).

M.J. Carson et al., Astrop. Phys 21 (2004) 667.

Measured as: $(1.72 \pm 0.61(\text{stat}) \pm 0.38(\text{sys})) \times 10^{-6} \text{ cm}^{-2}\cdot\text{s}^{-1}$

M.J. Tziaferi et al., Astrop. Phys 27 (2007) 326-338.



Gammas:

Germanium detector survey of Boulby JIF Lab Area

Flux = $0.128 \text{ cm}^{-2}\cdot\text{s}^{-1}$

D. Malczewski et al. J. Radioanal. Nucl. Chem. 298 (2013) 1483-1489.