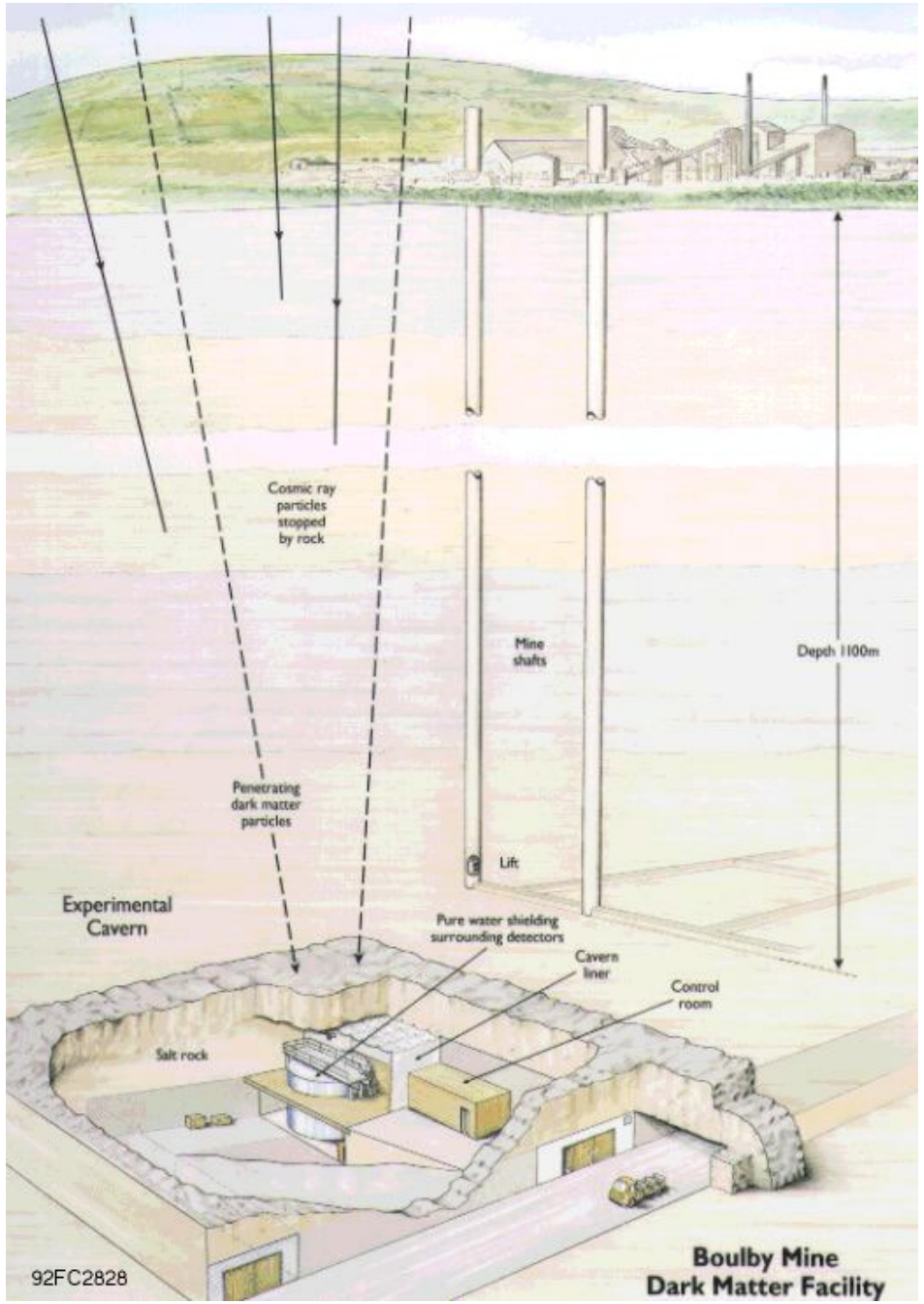


XLZD@BOULBY PROGRAMME

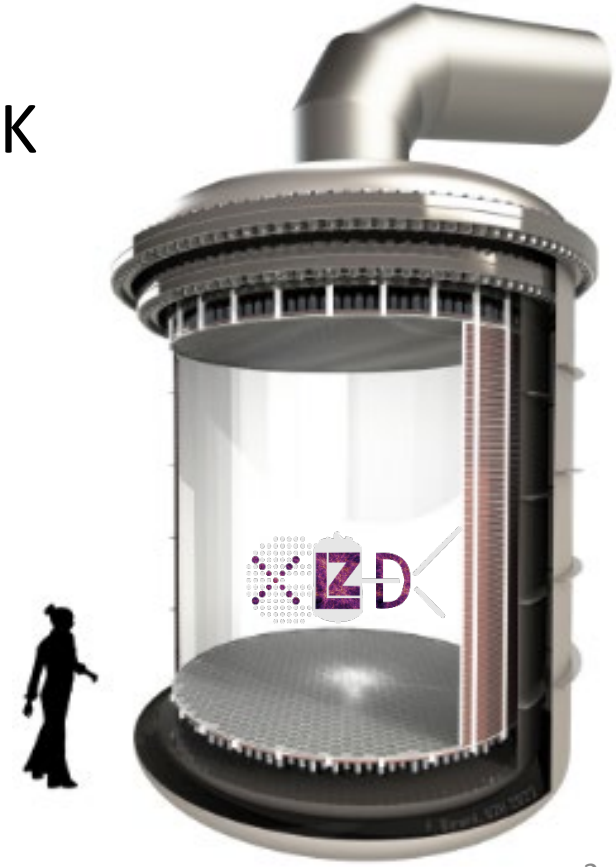
Henrique Araújo

4th July, 2023



OUTLINE

- A brief history, for context: the ‘Z’ and ‘LZ’ in XLZD
- XLZD@Boulby: the path to host in the UK

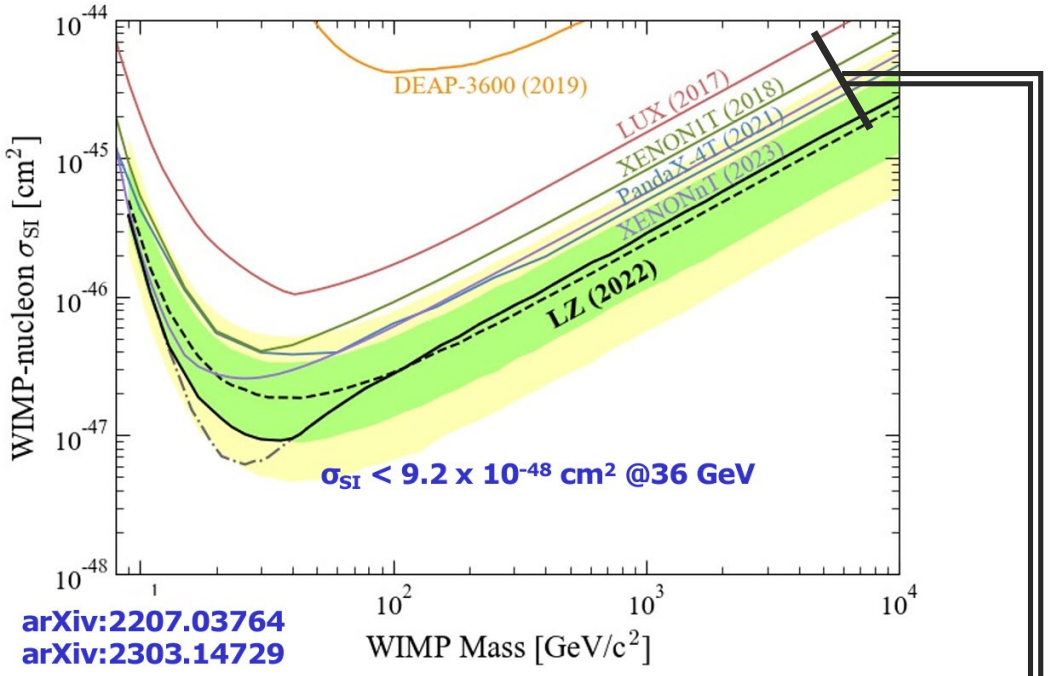


← *Boulby lab in the 1990s*

LXe-TPC TECHNOLOGY

A success story,
with the UK in a central role

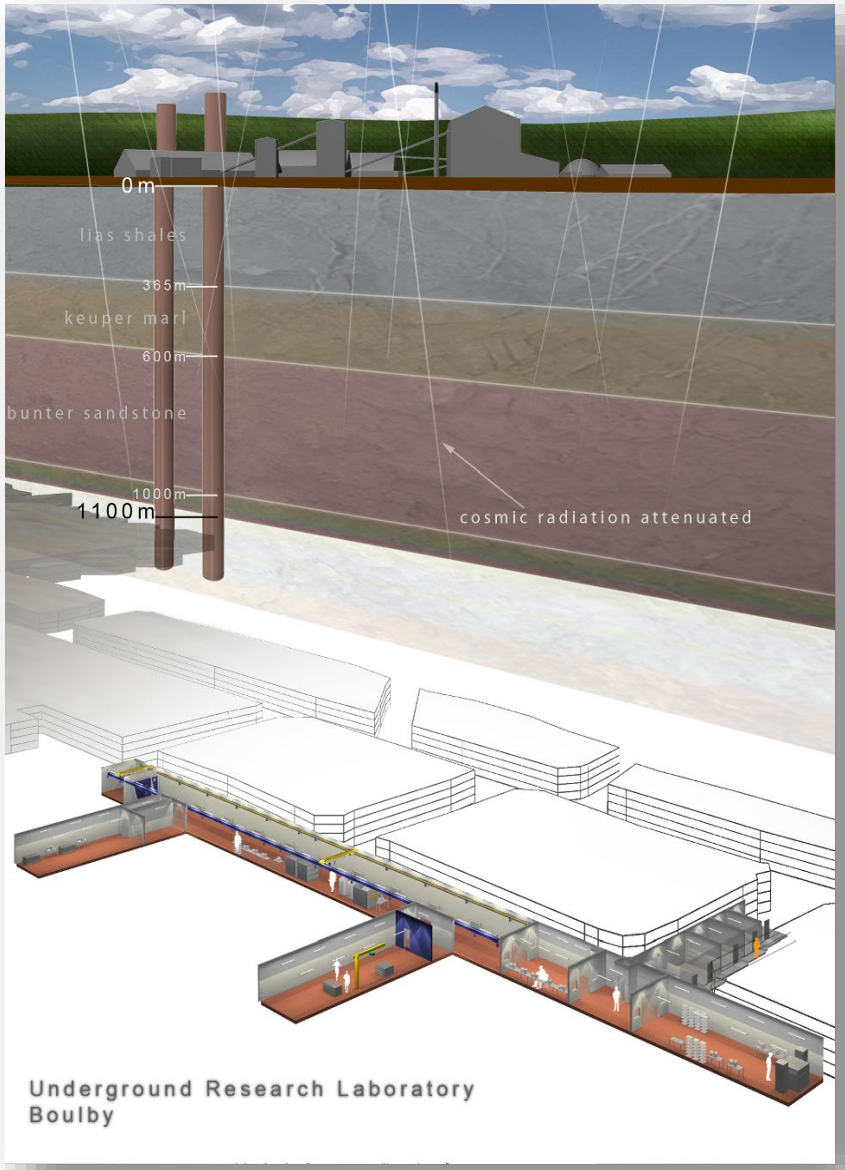
- ZEPLIN-I/-II/-III
- LUX
- LUX-ZEPLIN (LZ)
- XLZD



LIQUID XENON TIME PROJECTION CHAMBERS SEARCHING FOR DARK MATTER



ZEPLIN PROGRAMME – THE BOULBY YEARS





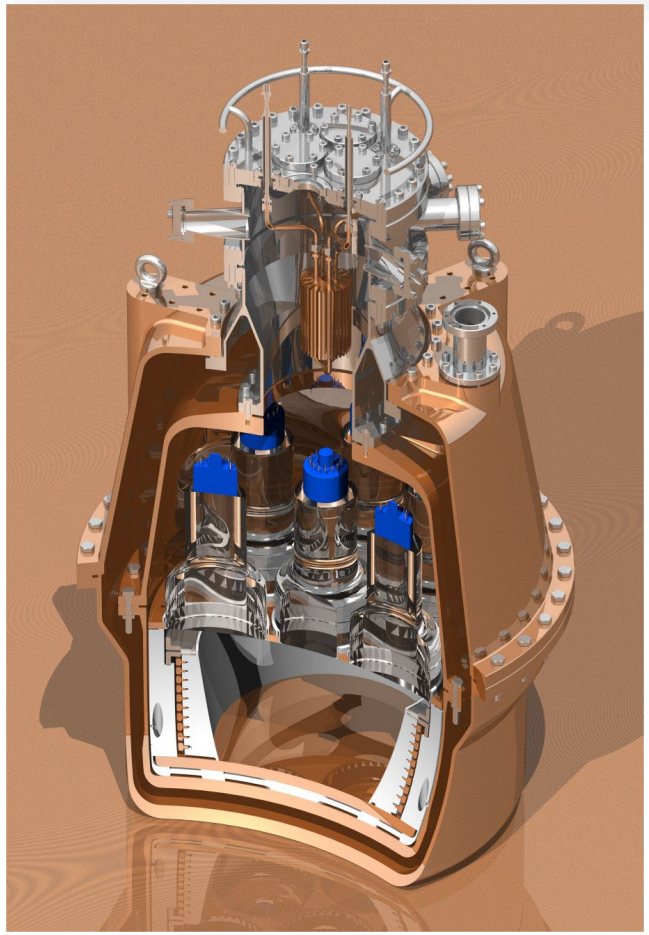




ZEPLIN-II

2002-2007

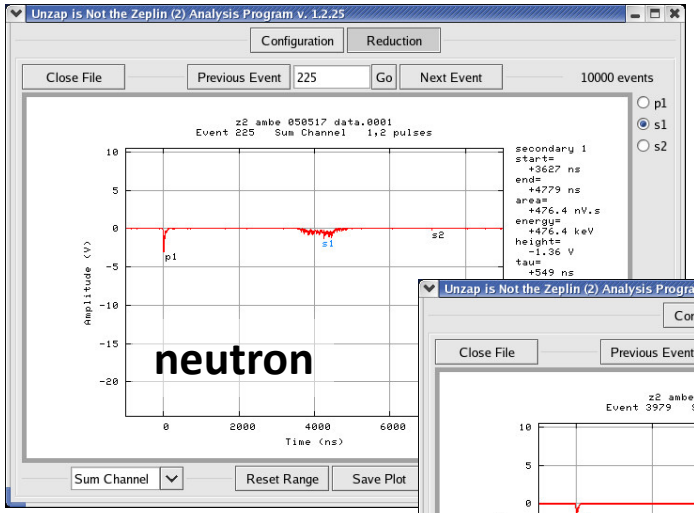
Whitby



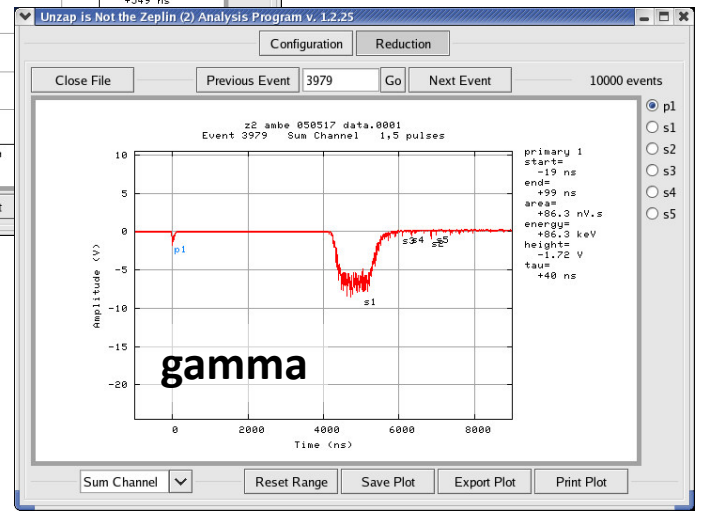




The first two-phase xenon detector for dark matter searches



~2005



Science & Technology Facilities Council
Rutherford Appleton Laboratory

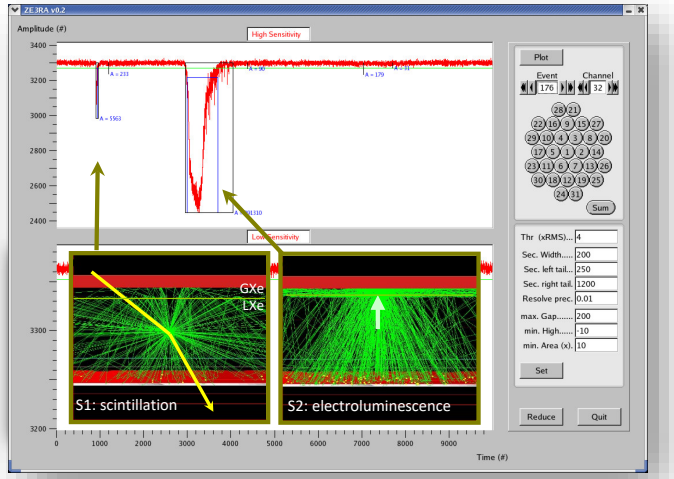
ZEPLIN-III

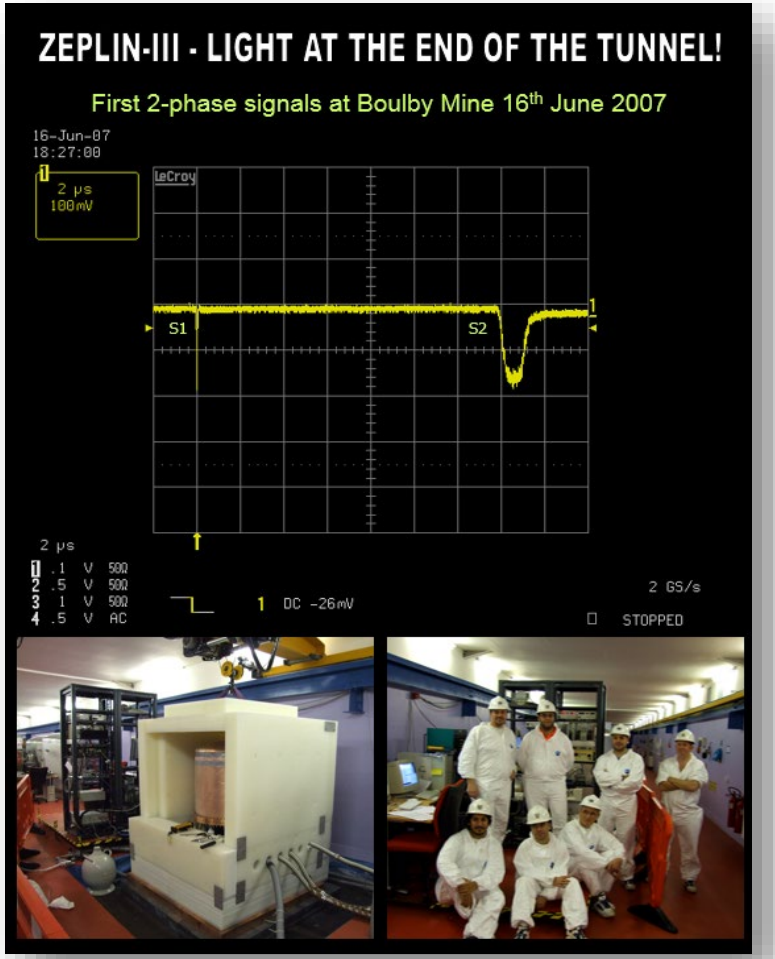
2002-2012



Imperial College London

First (and only…) high-field two-phase xenon detector

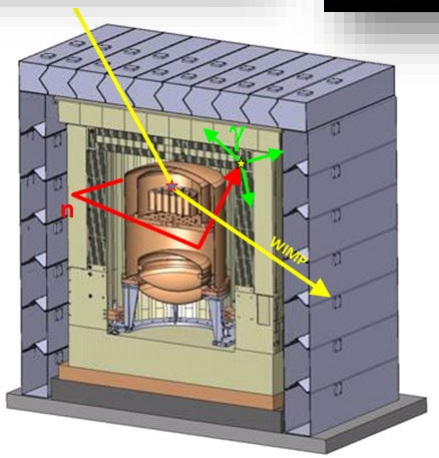






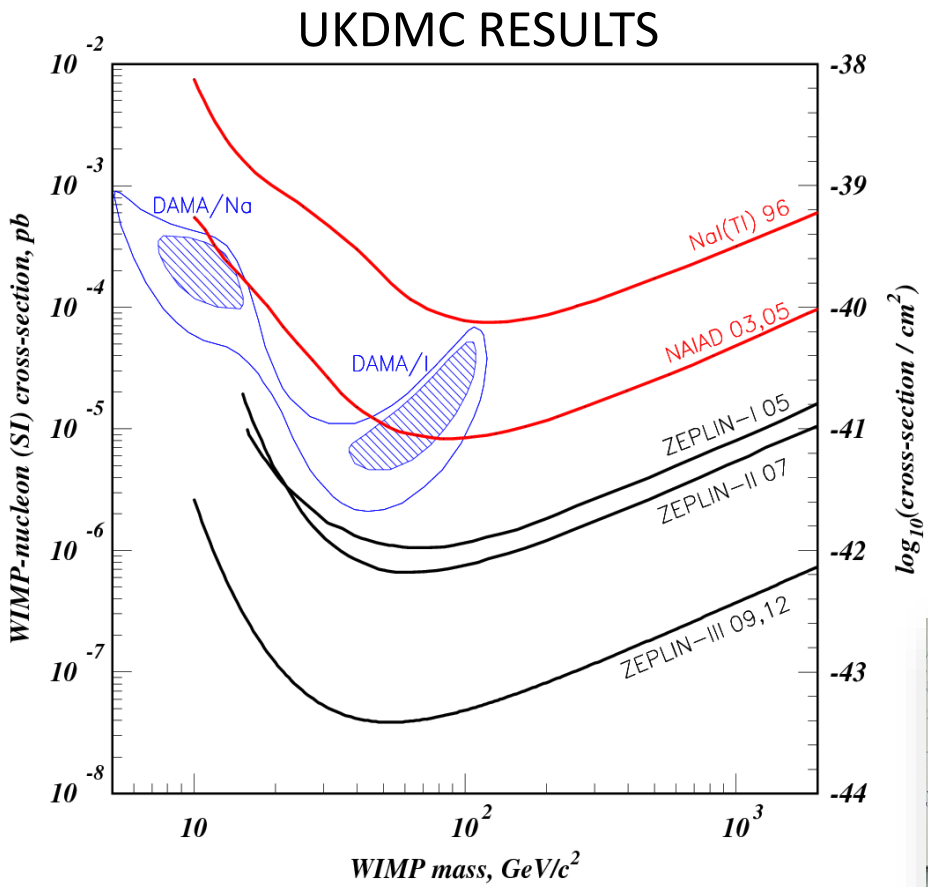








UK DARK MATTER COLLABORATION



UKDMC programme
1987 – 2012

JETP LETTERS VOLUME 11, NUMBER 11 5 JUNE 1970

NEW METHOD OF REGISTRATION OF IONIZING-PARTICLE TRACKS IN CONDENSED MATTER[1)]

B.A. Dolgoshein, V.N. Lebedenko, and B.U. Rodionov
Moscow Engineering Physics Institute
Submitted 14 April 1970
ZhETF Pis. Red. 11, No. 11, 513 - 516 (5 June 1970)



Vadim N. Lebedenko
1939 – 2008





ZEPLIN → LUX → LUX-ZEPLIN (LZ)

ZEPLIN-I



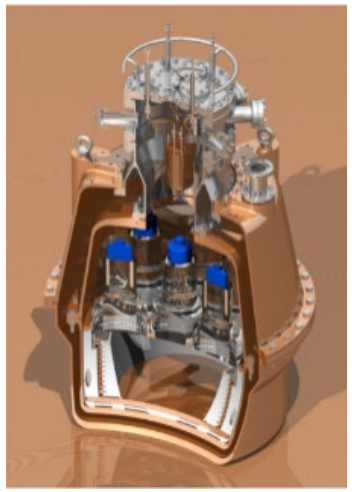


LUX
250 kg LXe

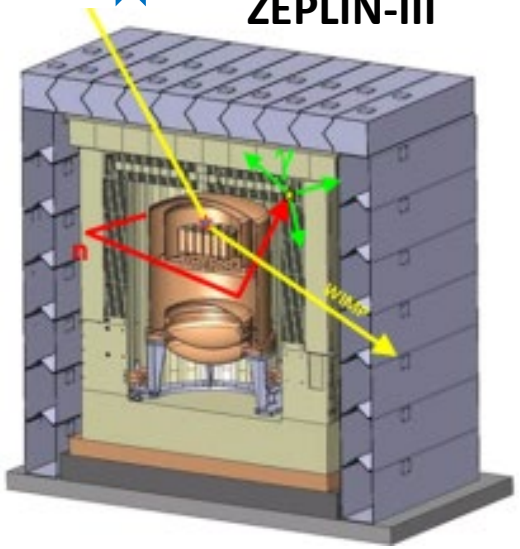
7,000 kg LXe

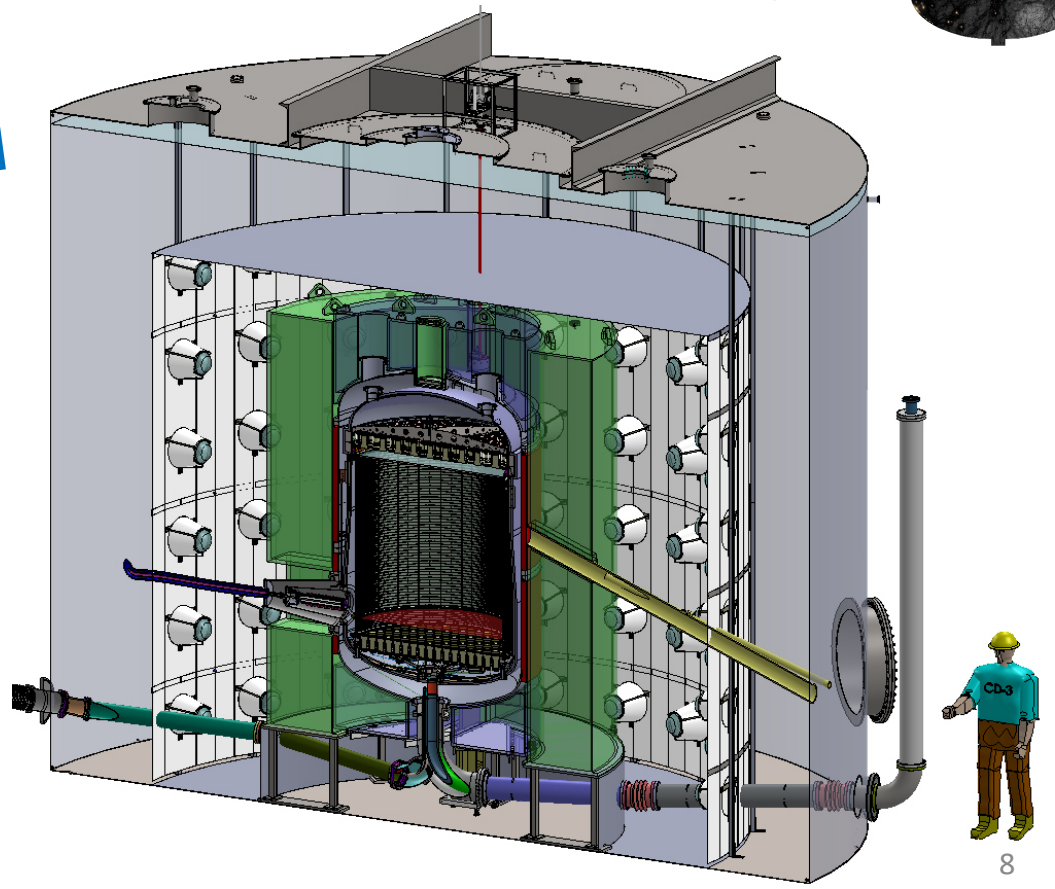


ZEPLIN-II



ZEPLIN-III

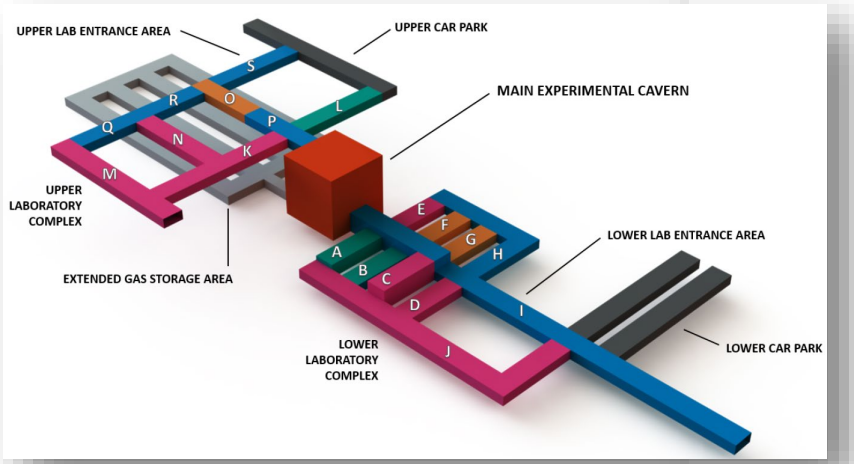




BOULBY DEVELOPMENT

- Facility and experiment requirements first detailed in 2019-21 Boulby Feasibility Study (BFS):
  u/g and surface facilities, outfitting, services, etc.
- STFC plans for Boulby have expanded, now aspiring to host multiple experiments, with XLZD probably the largest;
  STFC-led Boulby Development Project ongoing (£2.8M)
- New laboratory location identified at 1,300 m depth (existing one at 1,100 m)





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 Araújo[1], J Dobson[2], C Ghag[2], S Greenwood[3], V A Kudryavtsev[4], P Majewski[3], S M Paling[5], V Pěč[4], R Saakyan[2], P R Scovell[5], N Smith[6], and T J Sumner[1,*]

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

June 25, 2021

Issue v1.0

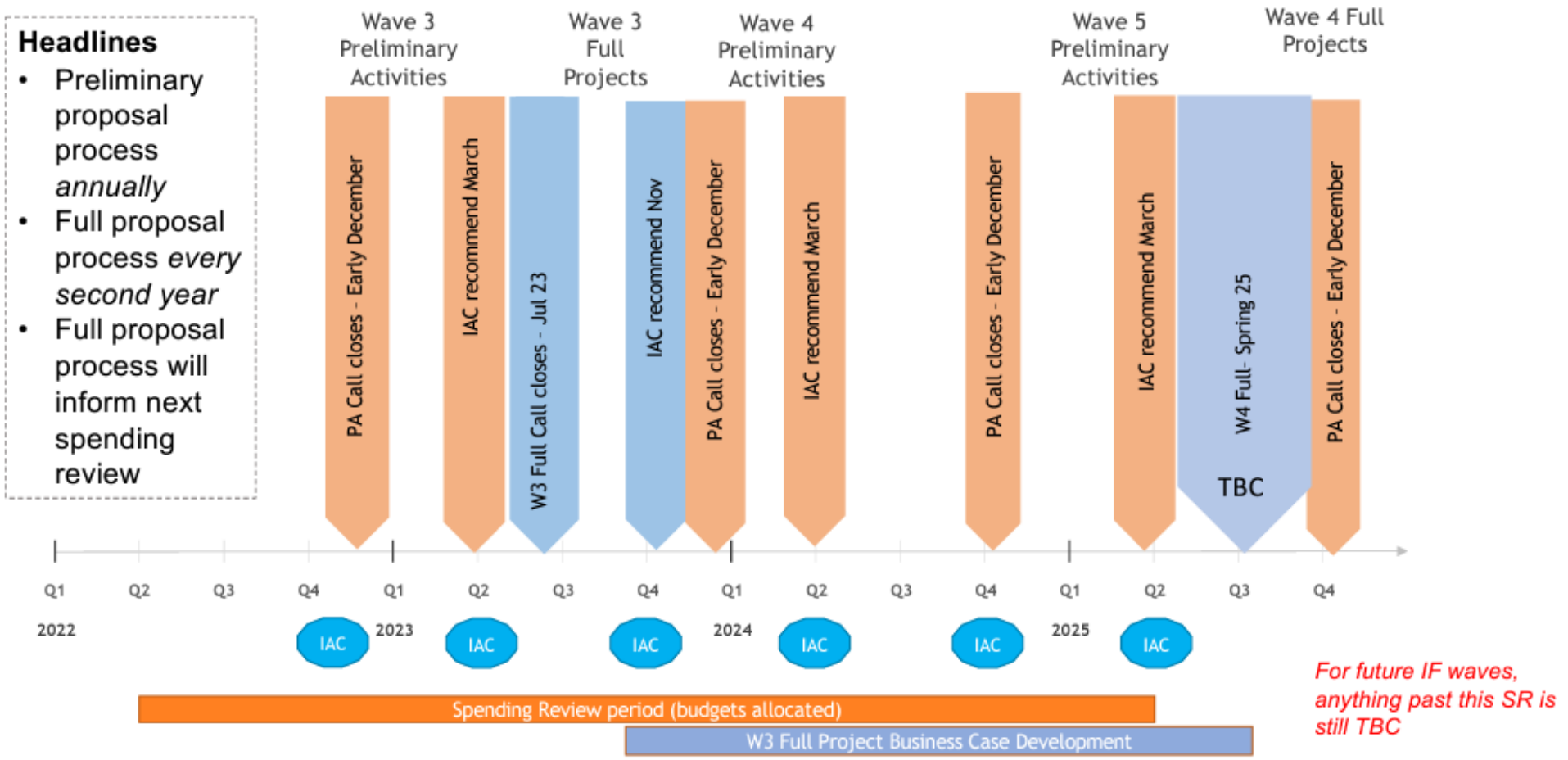
OFFICIAL-SENSITIVE [COMMERCIAL]

THE UKRI INFRASTRUCTURE FUND

Future Waves of the Infrastructure Fund

Headlines

- Preliminary proposal process *annually*
- Full proposal process *every second year*
- Full proposal process will inform next spending review

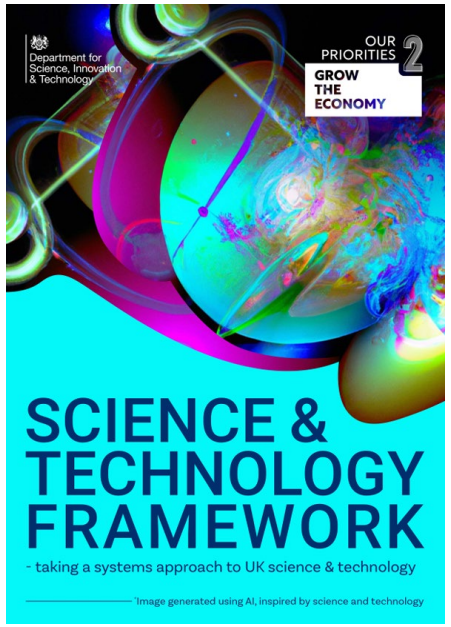


For future IF waves, anything past this SR is still TBC

K. Clifford Sep 2022

STRATEGIC ALIGNMENT

Hosting in the UK is credible and possible, and perfectly aligned with:



- The Government's plan to cement the UK as a "science and technology superpower" by 2030: *"Increased infrastructure capacity to deliver science and technology ambitions by using a portfolio approach across all Technology Readiness Levels."*
- The Government's Levelling-Up Agenda White Paper, including investment in Science, Skills & Infrastructure away from the South East.

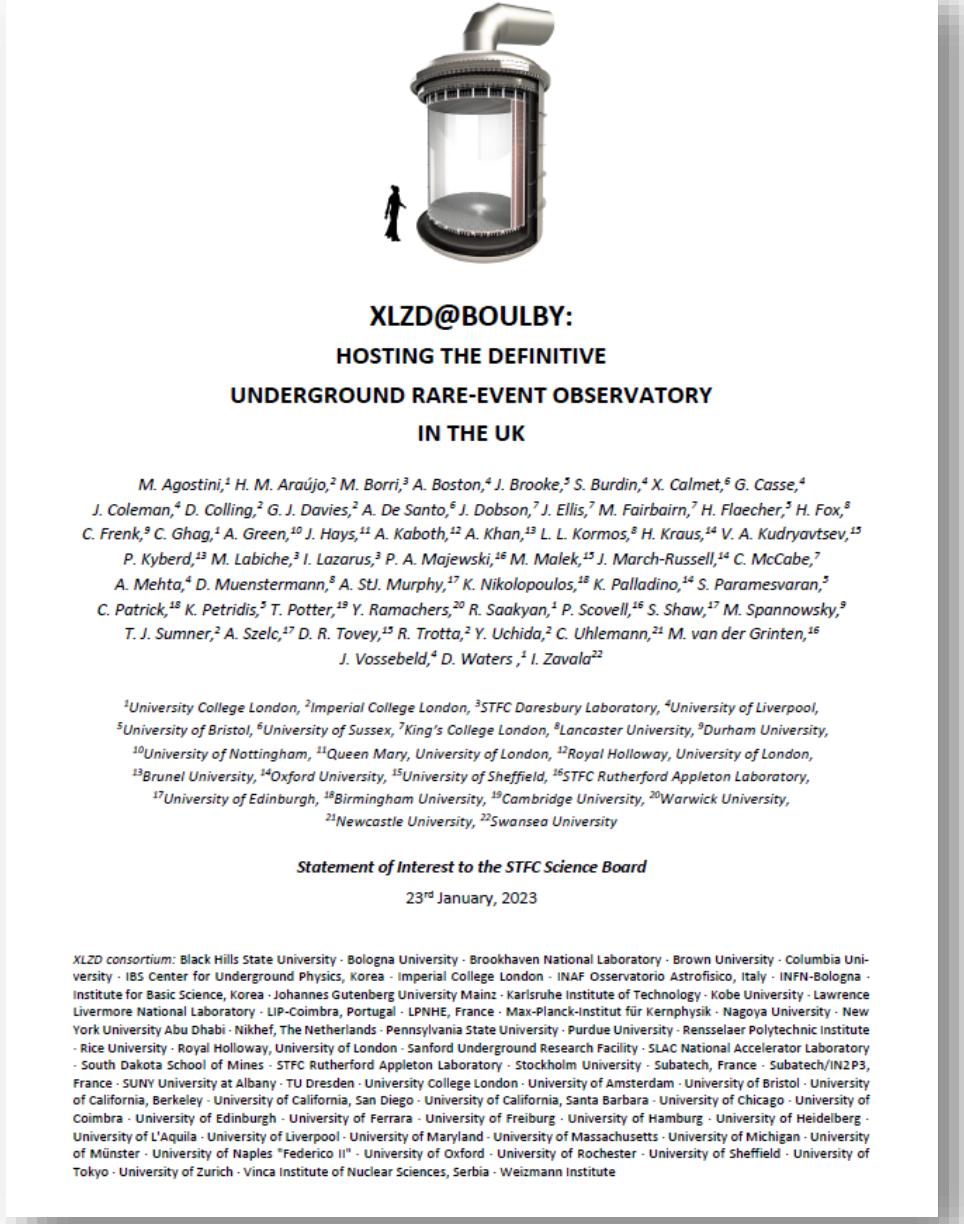
- The STFC Strategic Delivery Plan 2022-25:
  "To deliver our vision we will: Provide high-quality strategic leadership for UK frontier research in particle physics, nuclear physics, astronomy, space science and particle astrophysics."

Objective 2: World-class places: *"We will: […] Complete the design study for a greatly expanded underground science facility in the North East, with the potential to host a major international science infrastructure, such as a next generation dark matter experiment (with £2.8 million from the Infrastructure Fund).*



UK PROGRAMME

- SoI submitted to STFC Science Board & STFC Visions, signed by 57 academics from 22 UK institutes
- Substantial support from the wider community
  - 0NBB, AIT/NEO, Theory/Pheno, …
  - Forging partnerships with industry (engineering)
- UK proposes to contribute around 1/3 of the O(£500M) total project cost of XLZD
  - Major systems naturally suited to host nation, including: Outer Detector, Cryostat, elements of Xenon Detector,
  - Xenon stock (1/3)
  - Centres based at Boulby focused on skills, to deliver: Engineering & technical effort; (radio-)clean manufacture & underground science; data centre & on-site computing; societal and economic impact in a sustainable way



XLZD@BOULBY:

HOSTING THE DEFINITIVE

UNDERGROUND RARE-EVENT OBSERVATORY

IN THE UK

M. Agostini,[1] H. M. Araújo,[2] M. Borri,[3] A. Boston,[4] J. Brooke,[5] S. Burdin,[4] X. Calmet,[6] G. Casse,[4] J. Coleman,[4] D. Colling,[2] G. J. Davies,[2] A. De Santo,[6] J. Dobson,[7] J. Ellis,[7] M. Fairbairn,[7] H. Flaecher,[5] H. Fox,[8] C. Frenk,[9] C. Ghag,[1] A. Green,[10] J. Hays,[11] A. Kaboth,[12] A. Khan,[13] L. L. Kormos,[8] H. Kraus,[14] V. A. Kudryavtsev,[15] P. Kyberd,[13] M. Labiche,[3] I. Lazarus,[3] P. A. Majewski,[16] M. Malek,[15] J. March-Russell,[14] C. McCabe,[7] A. Mehta,[4] D. Muenstermann,[8] A. StJ. Murphy,[17] K. Nikolopoulos,[18] K. Palladino,[14] S. Paramesvaran,[5] C. Patrick,[18] K. Petridis,[5] T. Potter,[19] Y. Ramachers,[20] R. Saakyan,[1] P. Scovell,[16] S. Shaw,[17] M. Spannowsky,[9] T. J. Sumner,[2] A. Szelc,[17] D. R. Tovey,[15] R. Trotta,[2] Y. Uchida,[2] C. Uhlemann,[21] M. van der Grinten,[16] J. Vossebeld,[4] D. Waters ,[1] I. Zavala[22]

[1]University College London, [2]Imperial College London, [3]STFC Daresbury Laboratory, [4]University of Liverpool, [5]University of Bristol, [6]University of Sussex, [7]King's College London, [8]Lancaster University, [9]Durham University, [10]University of Nottingham, [11]Queen Mary, University of London, [12]Royal Holloway, University of London, [13]Brunel University, [14]Oxford University, [15]University of Sheffield, [16]STFC Rutherford Appleton Laboratory, [17]University of Edinburgh, [18]Birmingham University, [19]Cambridge University, [20]Warwick University, [21]Newcastle University, [22]Swansea University

Statement of Interest to the STFC Science Board

23rd January, 2023

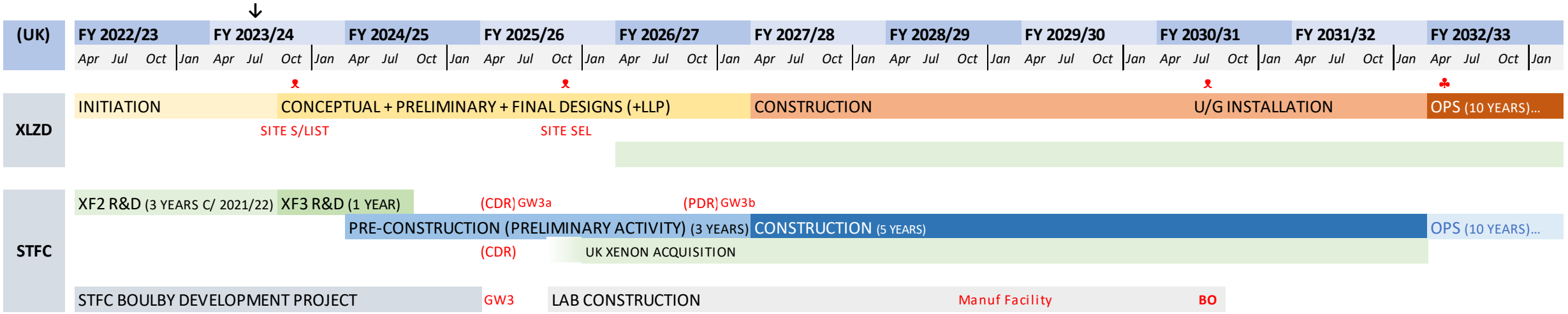
XLZD consortium: Black Hills State University · Bologna University · Brookhaven National Laboratory · Brown University · Columbia University · IBS Center for Underground Physics, Korea · Imperial College London · INAF Osservatorio Astrofisico, Italy · INFN-Bologna · Institute for Basic Science, Korea · Johannes Gutenberg University Mainz · Karlsruhe Institute of Technology · Kobe University · Lawrence Livermore National Laboratory · LIP-Coimbra, Portugal · LPNHE, France · Max-Planck-Institut für Kernphysik · Nagoya University · New York University Abu Dhabi · Nikhef, The Netherlands · Pennsylvania State University · Purdue University · Rensselaer Polytechnic Institute · Rice University · Royal Holloway, University of London · Sanford Underground Research Facility · SLAC National Accelerator Laboratory · South Dakota School of Mines · STFC Rutherford Appleton Laboratory · Stockholm University · Subatech, France · Subatech/IN2P3, France · SUNY University at Albany · TU Dresden · University College London · University of Amsterdam · University of Bristol · University of California, Berkeley · University of California, San Diego · University of California, Santa Barbara · University of Chicago · University of Coimbra · University of Edinburgh · University of Ferrara · University of Freiburg · University of Hamburg · University of Heidelberg · University of L'Aquila · University of Liverpool · University of Maryland · University of Massachusetts · University of Michigan · University of Münster · University of Naples "Federico II" · University of Oxford · University of Rochester · University of Sheffield · University of Tokyo · University of Zurich · Vinca Institute of Nuclear Sciences, Serbia · Weizmann Institute

UK PROGRAMME: ‘CREDIBLE TIMELINE’

1-year R&D: pre-conceptual design study activities, Boulby interactions, industry interactions

3-year pre-construction (IF Preliminary Activity): conceptual & preliminary designs, business case

5-year construction project (IF Full Project): final design, procurements, construction



2023: Agency strategies; inter-agency discussions; site shortlisting; R&D repositioning; IF application (PA)

2025: Investment decisions for Boulby and XLZD@Boulby; site selection; IF application (FP)

2027: Start of construction project

2028: Pilot space for clean underground manufacture

2030: Beneficial occupancy of outfitted facility

2032: Start of XLZD operations

EARLY DEVELOPMENT

Xenon Futures R&D Project (2019-)

- Initially not focused on Design Study, only technology R&D and Migdal studies
- Proposing 1-year extension for **design study activities** (outcome expected soon)

Aim

- To position the XLZD-UK team to put forward a credible bid to host the experiment at Boulby, by addressing concerns related to underground manufacture and to increase technical readiness.

Objectives

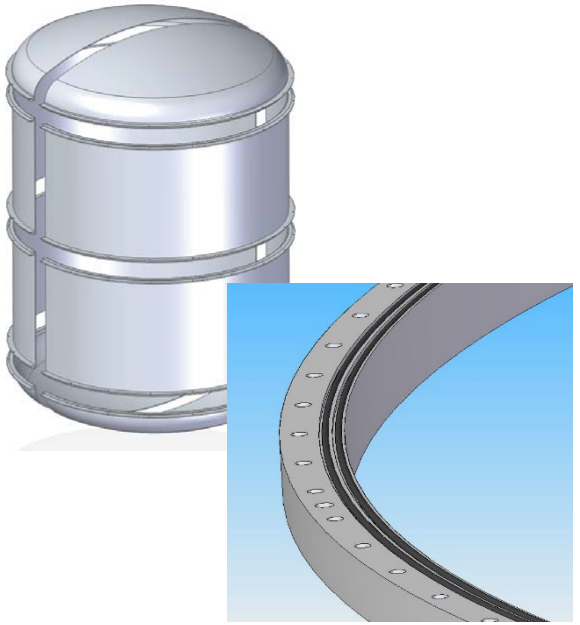
i) Demonstrate the viability of manufacturing key hardware elements underground; ensure that concerns related to vertical access can be overcome, and that the cost and schedule implications are understood.

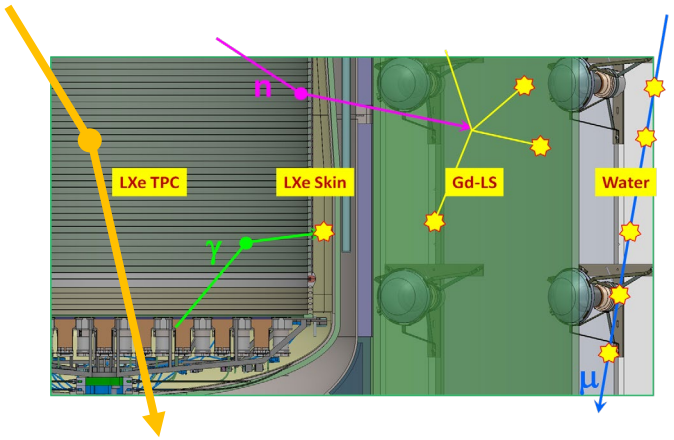
ii) Conduct pre-conceptual design studies of subsystem configuration to define the experimental strategy for the large experimental subsystems, determining the basic geometry of the larger hardware items which must work in concert to meet our scientific requirements; this will inform the UK proposal and ensure that viable design solutions are identified ahead of a preconstruction project.

Interaction with Boulby Development Project (outcome expected soon)

- **XLZD Infrastructure** (liaising with facility design team)
- **XLZD Industrial Engagement** (building links with Industry)

ALL OF THE ABOVE: WORK COLLABORATIVELY ACROSS XLZD





Pre-conceptual designs
Subsystem interactions
Some technology R&D

THE INFRASTRUCTURE FUND PROJECT – STATUS

This is the beginning of a long & winding road – even to arrive at the starting block

- **Science**: STFC Science Board feedback on our SoI: "Science Board recommended that the proposal should progress through the Visions or UKRI Infrastructure Fund processes" [Strategic Review of Dark Matter expected, tbc]
- **Infrastructure:** STFC Visions process initiated (proforma & panel assessment); very positive feedback for concept "…*we are pleased to let you know that your concept was given an overall rating of* ***High****. This indicates that this concept is of a high standard and should progress to the next stage of development without significant further iteration.*"
- In parallel, STFC are progressing the "**Boulby Development Project**" to design and prepare a business case to government for a new international underground facility (£200-300M) – talk by Jon Burns & Sean Paling next
- The next step is to propose the 3-year Preliminary Activity that prepares the project

IF PRELIMINARY ACTIVITY: AIMS & PROCESS

Application to Wave 4 of the UKRI Infrastructure Fund

- Deliver the Conceptual Design of the UK scope by 2025, including determination that the selected options meet the needs and definition of a cost range. This is associated with the application to the Wave 4 Full Project and development of a Business Case, with the ensuing investment decision feeding into the XLZD site selection process.
- Deliver the Preliminary Design of the UK scope by late 2026/27, to define the baseline scope, cost and schedule, including procurement plans for the main deliverables.

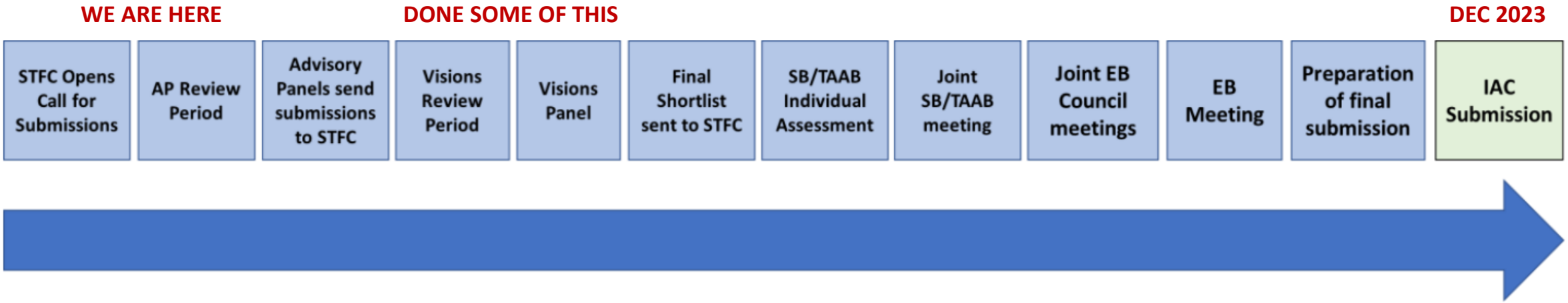


Figure 2: STFC Infrastructure Prioritisation Process flow, leading up to submission to the IAC

IF PRELIMINARY ACTIVITY: M&Ds (PRELIMINARY)

- M1 Project Management Plan approved [WP0]: Q2-FY24/25
- M2 Draft Delivery Plan – Skills Pipeline [WP7]: Q4-FY24/25
- M3 Draft Delivery Plan – Impact & Sustainability [WP8]: Q4-FY24/25
- D1 Xenon procurement plan [WP1]: Q1-FY25/26
- D2 Conceptual Design Report & Review [WP1-6,8]: Q1-FY25/26
- D3 Proposal for peer review + IAC submission [WP0]: Q2-FY25/26
- D4 Sample prep & radioassay facility (existing lab) [WP6]: Q2-FY25/26
- M4 Site selection milestone (external) Q3-FY25/26
- M5 Change request for alternative UK scope [WP0] (if not Boulby selected) Q3-FY25/26
- D5 Delivery Plan for Skills Pipeline [WP7]: Q2-FY26/27
- D6 Delivery Plan for Impact Realisation [WP8]: Q2-FY26/27
- D7 Preliminary Design Report & Review [WP1-6]: Q3-FY26/27
- D8 Business Case for XLZD-UK (GW3) [WP0] Q4-FY26/27

IF FULL PROJECT

The UK deliverables would focus on systems naturally suited to the host nation, including:

i) Those requiring substantial engineering and having major interfaces to laboratory infrastructure

ii) Ecosystem of skills needed to deliver the project (with major links to other projects and to the facility)

iii) Procurement of up to 1/3 of the xenon stock required by the experiment

WP1	Xenon acquisition & storage	WP5	Data Centre & Onsite Computing
WP2	Outer Detector	WP6	Radioassay & Clean Manufacture
WP3	Cryostat	WP7	Engineering & Skills
WP4	Xenon Detector Elements	WP8	Impact and Environment

See presentations this afternoon

These are proposals for the UK scope, predicated on the UK hosting plus a substantial investment in XLZD; necessarily, they represent a compromise: two major collaborations of 30+ institutes each have the expertise and firepower to deliver the full experiment; in all cases we will work closely with other XLZD partners.

IF FULL PROJECT

In this model the UK would fund 1/3 of total project cost (1/3 of ~£500M), with the remainder from:

- 1/3 USA (DOE, NSF)
- 1/3 Europe + Japan (MPG, BMBF, Helmholtz, SNSF, INFN, NWO; JSPS, MEXT; …)

If Boulby is not selected in 2025:

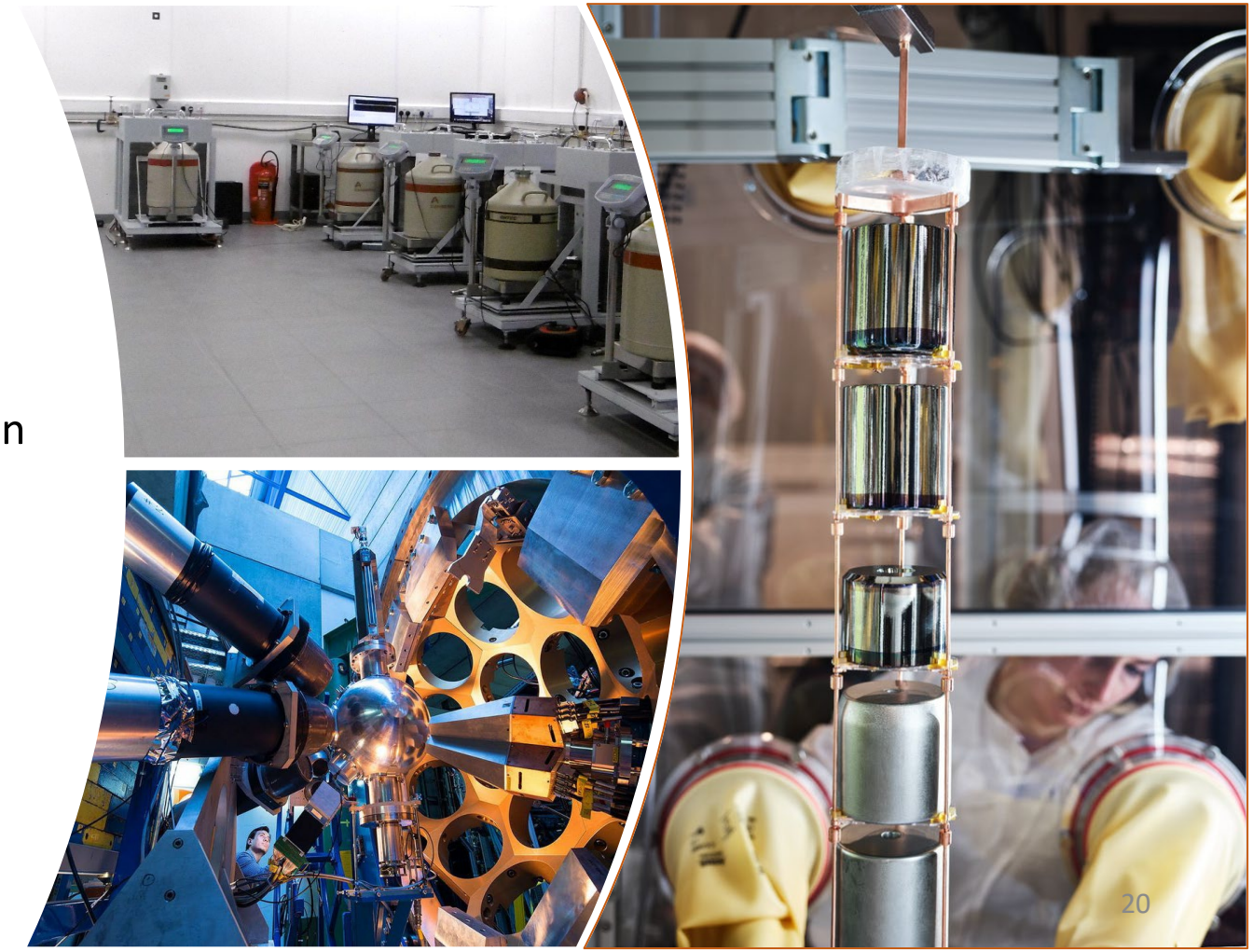
- The UK would contribute a smaller fraction of the experiment (~10%), with scope to be agreed
- We would re-direct the preconstruction project (Preliminary Activity) to prepare the new scope

The take-home message: XLZD will be a larger and better experiment if it comes to the UK

SYNERGIES & COMPLEMENTARITY – DATUM

DATUM – Detector Assembly, Testing and Underground Manufacturing

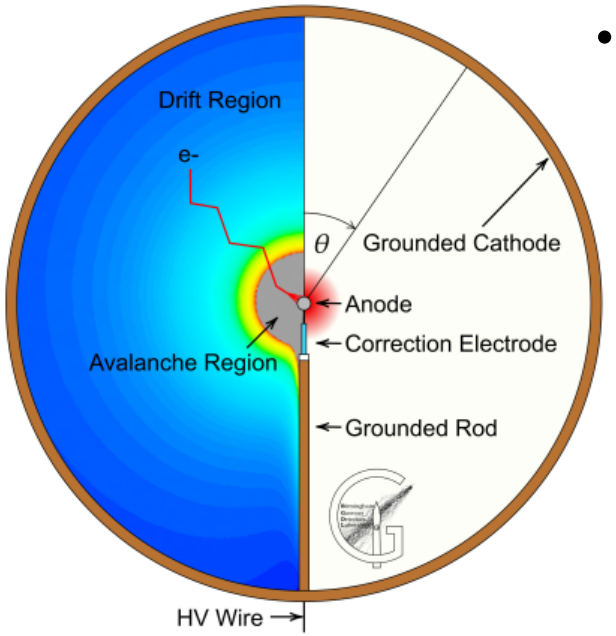
- Particle and Nuclear Physics communities brought together by HPGe technology
- Initially driven by LEGEND $0\nu\beta\beta$ and AGATA nuclear structure experiments
- Plan to use existing Boulby lab space to design and prototype an underground facility for detector production, assembly and characterisation
- Complementarity of science, major synergies in clean construction and radioassay [WP6]



SYNERGIES & COMPLEMENTARITY – DARKSPHERE

DARKSPHERE – Exploring light dark matter with a spherical proportional counter

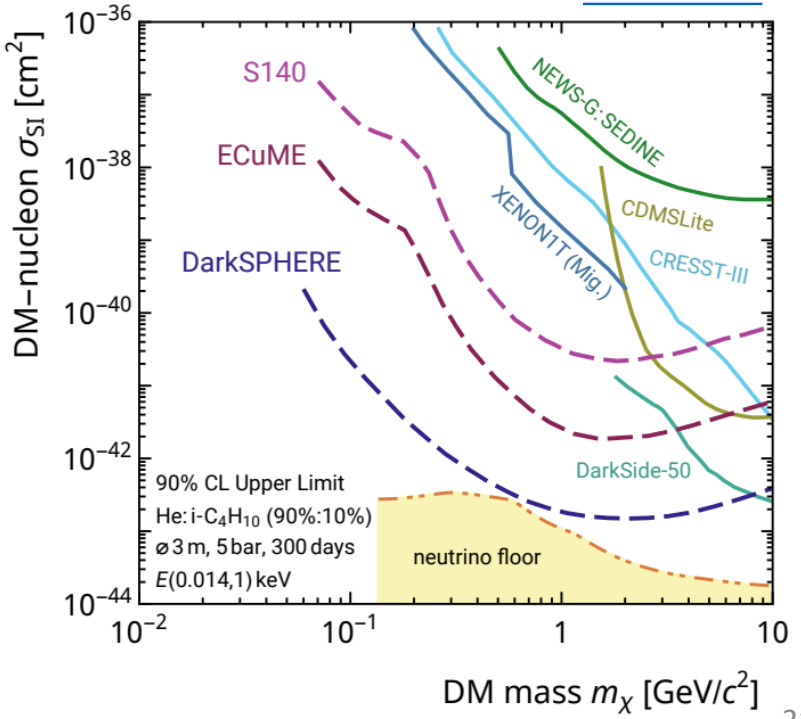
- Primarily designed to search for nuclear recoils from light dark matter in the 0.05–10 GeV mass range
- 3-m diameter spherical proportional counter electroformed underground at Boulby
- Builds on R&D and experience acquired by the NEWS-G collaboration



- Complementary physics (LDM)
- Technological synergy [WP6]: electrochemistry
  - Electroforming
  - Electroplating
  - Electropolishing

Key to achieving ultra-low backgrounds, esp. radon emanation from detector components, gas system, cryostat

2301.05183



SYNERGIES & COMPLEMENTARITY – BUTTON

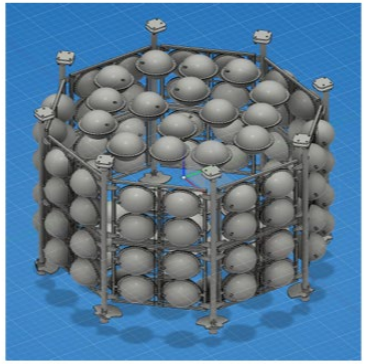
BUTTON – A technology testbed for future (anti)neutrino detection

- Develop the innovative technology (scintillator, photosensors) required for a remote reactor monitor prototype, including Gadolinium-doped Water-based Liquid Scintillator (Gd-WbLS), with BNL, LLNL, LBNL, UC Davis, …
  - BUTTON-30: UK involvement with WbLS, first tonne-scale demonstration
  - BUTTON-100: potential for a follow-up 100-tonne experiment; at-scale demonstrator for a remote reactor monitoring experiment
  - Great synergy with XZLD Outer Detector and Water Tank [WP2]

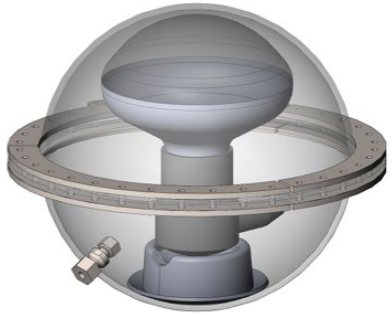


WATCHMAN* scientific collaboration: a water-based detector for remote non-proliferation monitoring.

*WATer CHerenkov Monitor for ANtineutrinos



Kneale 2023

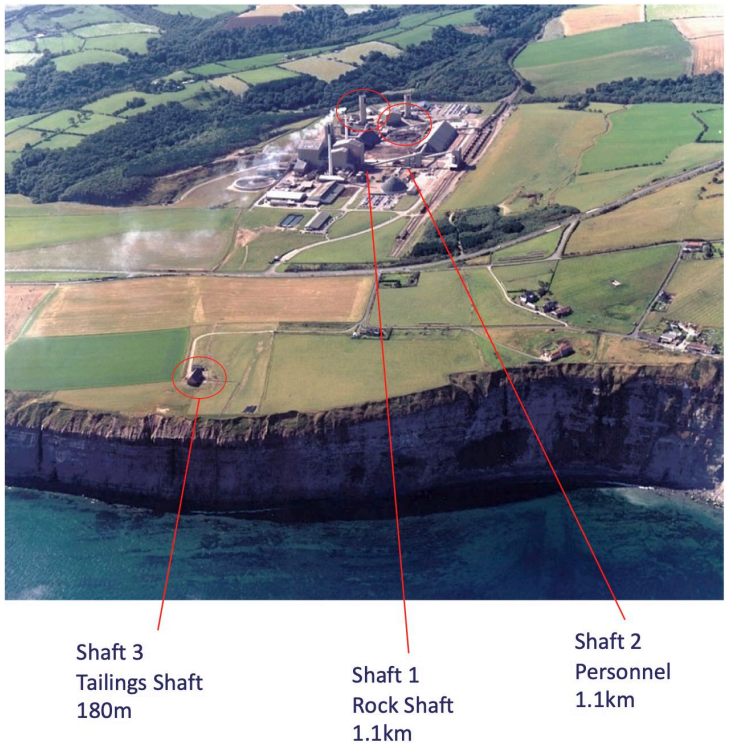




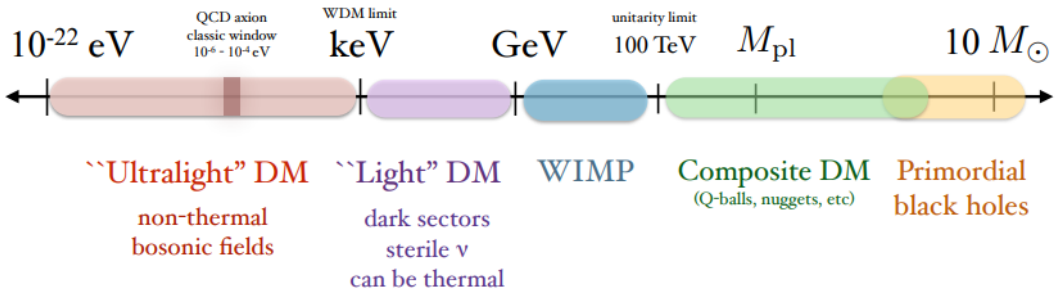
SYNERGIES & COMPLEMENTARITY – AION

AION – Atom Interferometer Observatory and Network

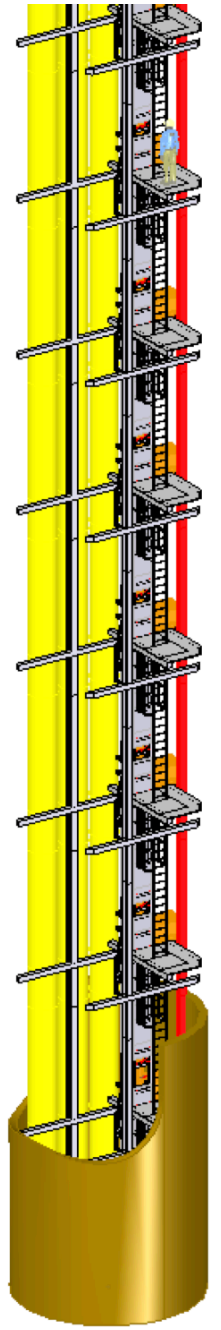
1. Explore well-motivated ultra-light dark matter candidates well beyond current bounds
2. New generation of generic precision searches for new particles and their fields
3. Explore mid-frequency band gravitational waves from astrophysical sources and very early Universe



- AION proposes a complementary programme:
  - Science: wave DM vs particle DM
  - Infrastructure: vertical shaft vs cavern lab
  - Community



← wave-like (bosons) | particle-like (mostly fermions) →



CONCLUSION

- XLZD will be the definitive experiment for WIMP dark matter and offer other exciting physics too – based on the world-leading LXe technology first deployed u/g in the UK
- The XLZD consortium brings together the top collaborations in the field, who will continue to operate the best experiments in the field
- XLZD@Boulby is an excellent fit to UKRI and UK Government strategic priorities, and it seems ideally suited to the UKRI Infrastructure Fund
- Boulby Development Project ongoing: our fate is tightly coupled to their success…
- We are setting off on the road to establish a UK “preconstruction” project to design and plan the hosting of XLZD@Boulby
- Speak to us if you want to get involved!